Industrial Opportunities at Future Nuclear Physics Machines Worldwide

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EUROPEAN COMMISSION
DIRECTORATE-GENERAL FOR RESEARCH & INNOVATION
Research infrastructure

Overview

- In high energy physics, most proposals have very long timescales

- In nuclear physics, there is a lot of activity and the timescales are shorter
  - China: HIAF
  - Europe: FAIR
  - Korea: KOMAC, RAON
  - Russia: C-Tau, NICA
  - United States: e-RHIC, FRIB, JLEIC

Note: order is alphabetic, no priority is implied and no bribes were accepted (or even offered)!

- In most cases, I received more information than I can pack into this talk
  - The online version has all of the information I received, including some detailed information regarding upcoming orders

High-Intensity Heavy Ion Accelerator Facility-HIAF

HIAF: One of 16 large-scale research facilities proposed in China in order to boost basic science, next-generation high intensity facility for advances in nuclear physics and related research fields.

The HIAF project:

- Proposed by IMP in 2009.
- Approved in principle by the central government in the end of the 2012.
- The final approval was in the December of 2015
- **Construction started in the end of 2018, early completion in 2025.**
- **The total budget of facility is about $400 million, including $160 million of local government**

Science motivations:

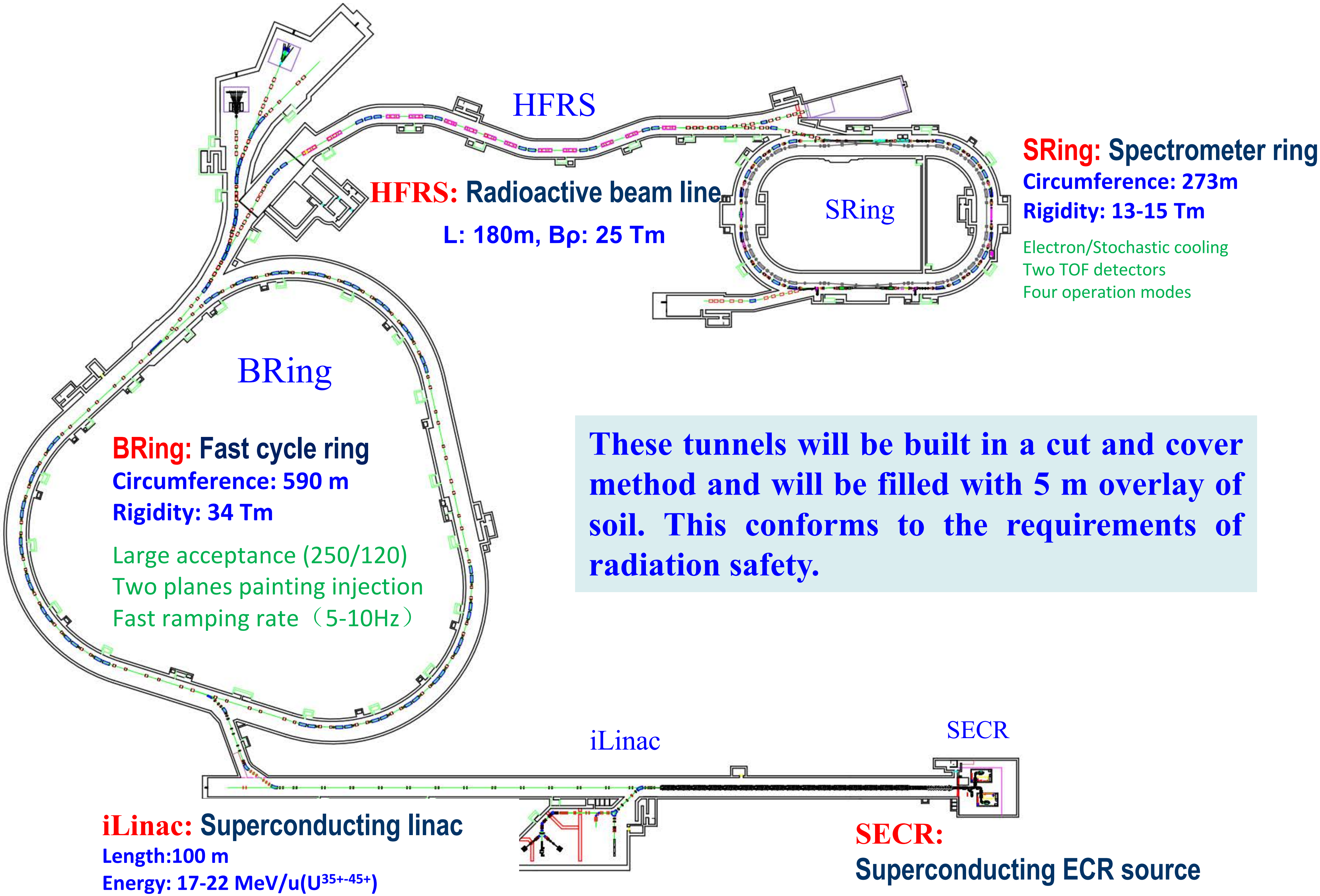
※ High intensity radioactive beams to investigate the structure of exotic nuclei, nuclear reactions of astrophysics and to measure the mass of nuclei with high precision.

※ High charge state ions for a series of atomic physics programs.

※ Quasi-continuous beam with wide energy range for applied science.

※ High energy and intensity ultra-short bunched ion beams for high energy and density matter research.

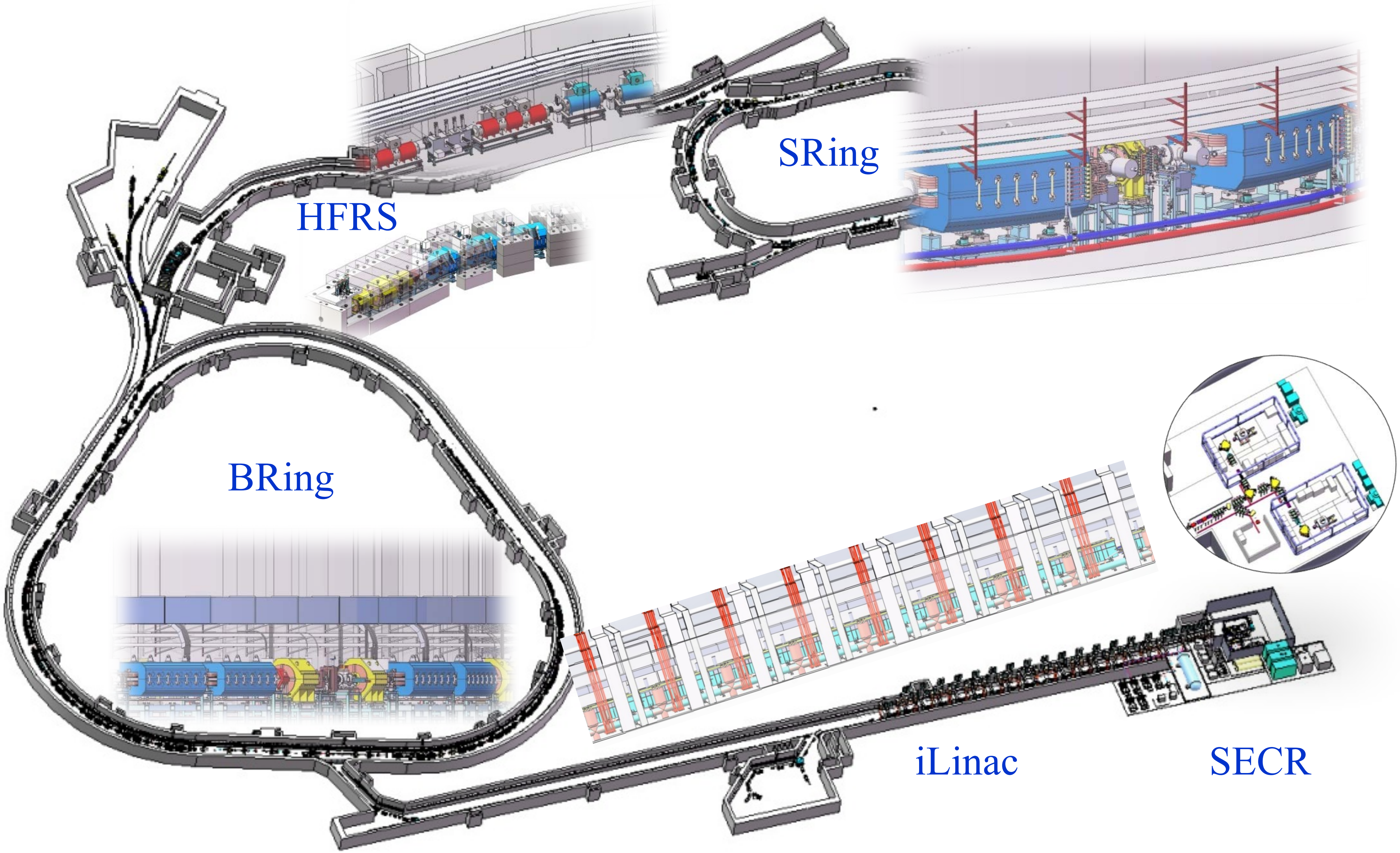
HIAF: Main accelerator components



These tunnels will be built in a cut and cover method and will be filled with 5 m overlay of soil. This conforms to the requirements of radiation safety.

HIAF: Present status

Details of technical design has been finished and most of hardware systems are under production.



HIAF: Present status

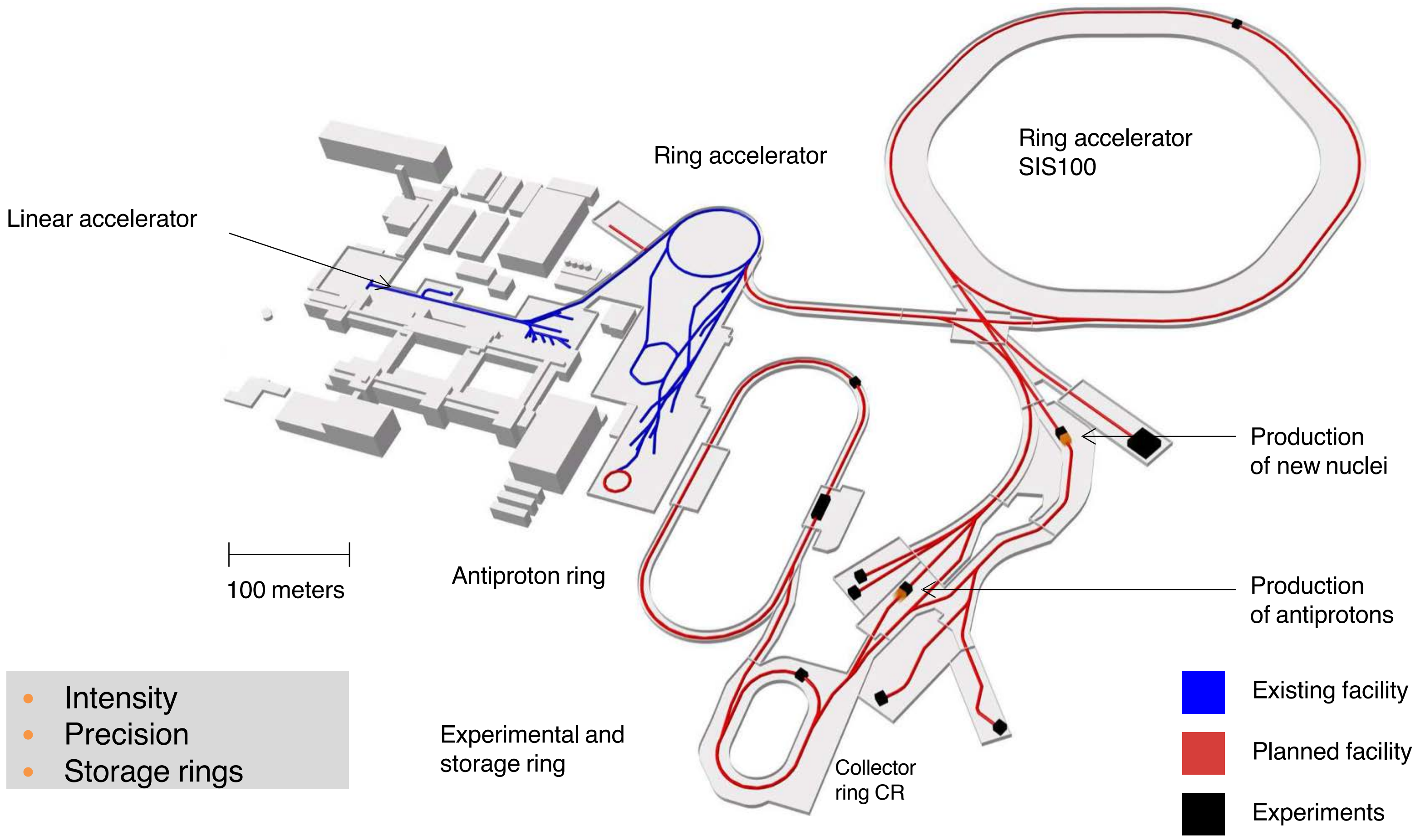
The planed construction period is about 7 years, and the early completion is expected in the end of 2025

The FAIR Project

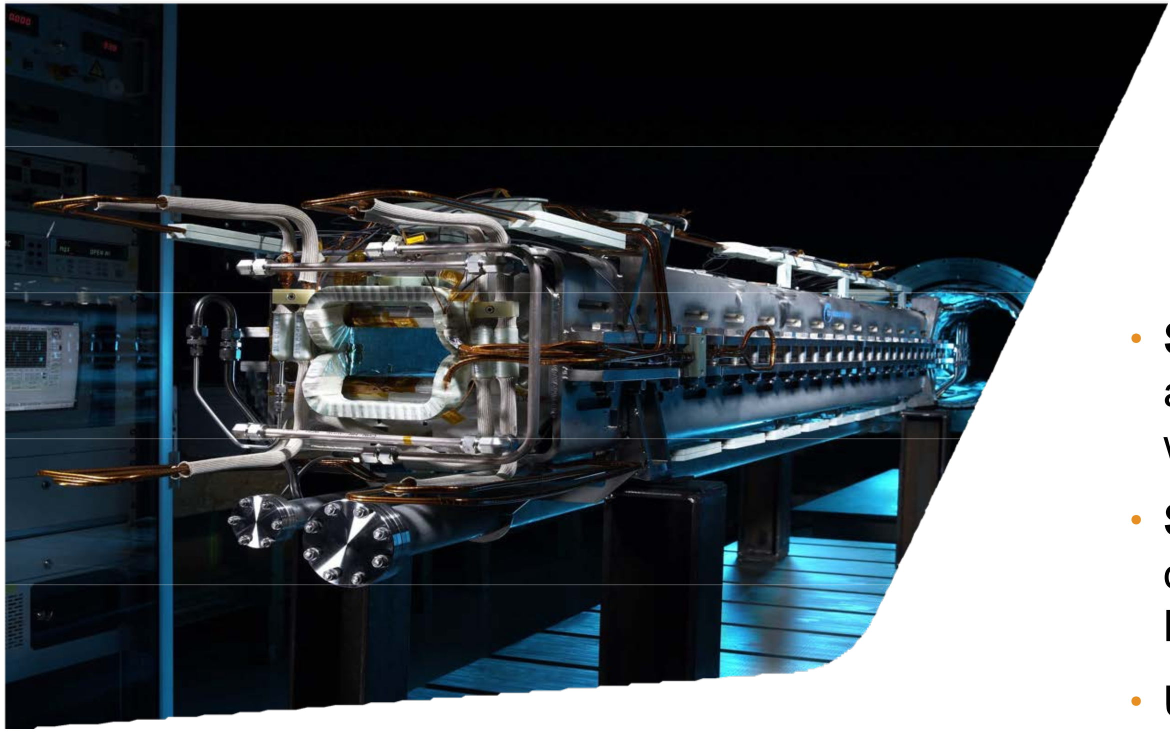
Realization of the world's unique particle accelerator facility in Darmstadt

September 2019

FAIR – The facility



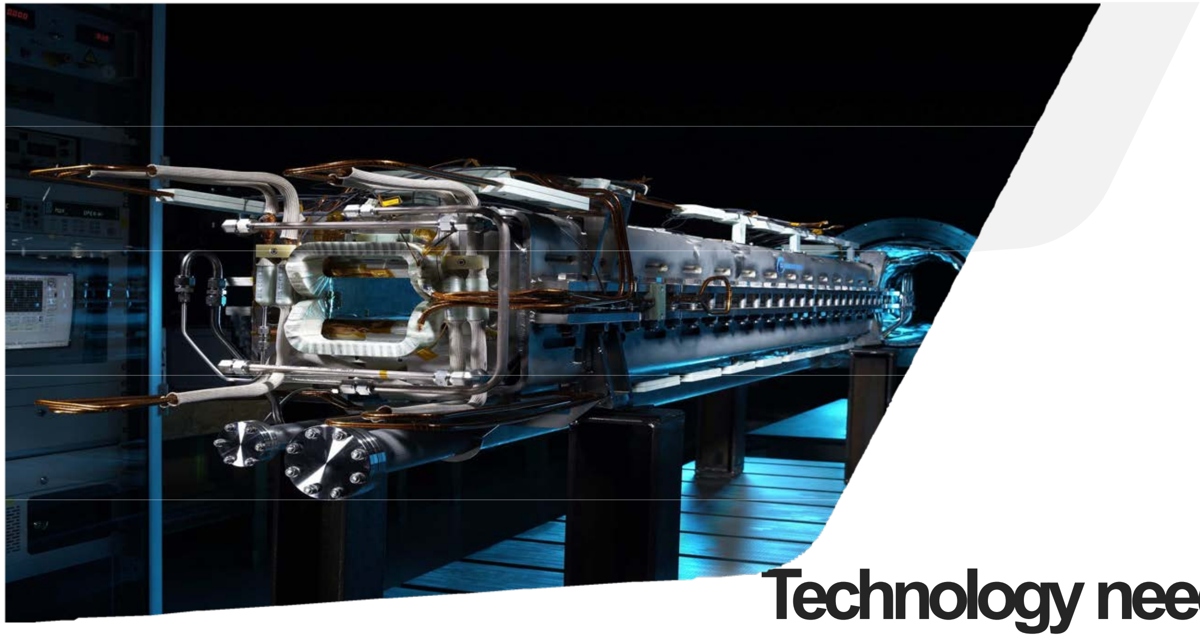
- Intensity
- Precision
- Storage rings



Overview of technology

- **Superconducting magnets**: for strong and rapidly changing magnetic fields with maximum field precision
- **Sophisticated cryotechnology**: Use of liquid helium to cool down to 4 Kelvin (-269°C)
- **Ultra-high vacuum**: 10^{15} times below the earth's air pressure
- **Development and construction** of cryo-collimators with special coatings

Credit: Babcock Noell



Technology needs

1500	1000	1500
magnets	**power supplies**	**vacuum chambers**
Worth 200 M€	worth 30 M€	worth 20 M€

Of which 600 are superconducting

Please visit our procurement website:
www.gsi.de/start/wirtschaft_industrie.htm

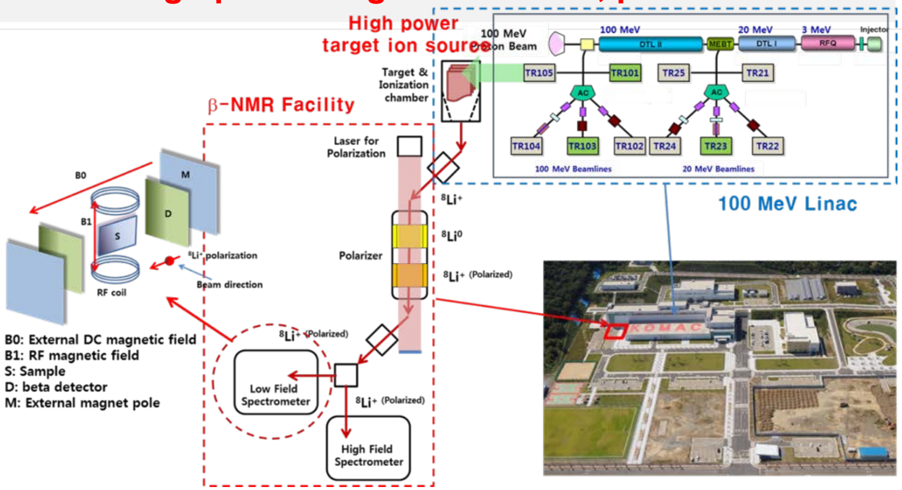
Additional slides are attached with detailed requirements and contract signing dates

Korea Multi-purpose Accelerator Complex (KOMAC)

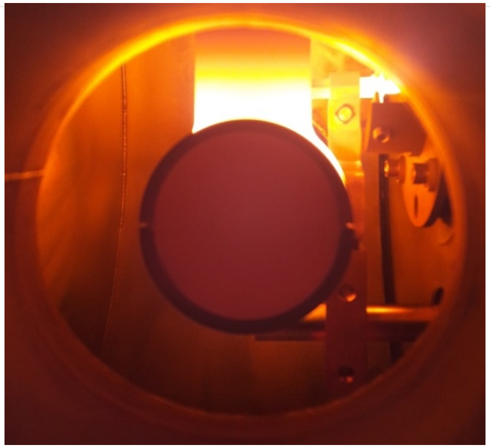
- National User Facility: Intense Proton & Ion Source for Basic & Applied Research
  - High-Power Proton Linac (100MeV, 20mA, Proton Source) under operation
  - 1 GeV, 2MW Upgrade (Spallation Neutron Source) under R&D study
- 100MeV Linac developed through Proton Engineering Frontier Project (2002 – 2012)
- Funding: 300M USD (Government (57%), Local Gov. (39%), & Industry (4%))
- Lead Institute : Korea Atomic Reseaech Institute (KAERI)
- KOMAC Operation as one of branches of KAERI (2013~)

❖ Li-8 Beamline: 100-MeV Proton

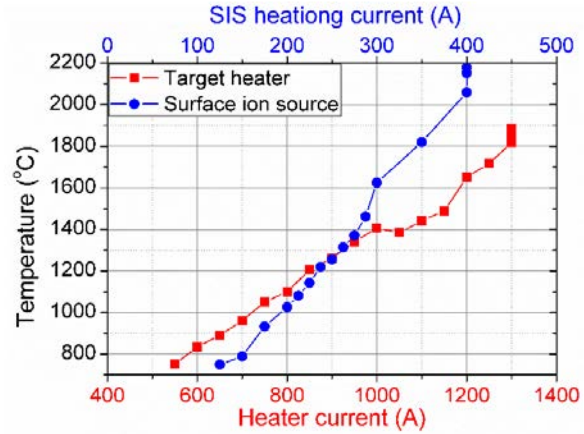
- **Application : Li-8 based β-NMR**
- **Proton beam**
  - **Energy: 100 MeV**
  - **Beam Power: 1 kW @ 100 MeV**
  - **Li-8 Ion Production: 1x10^6 pps**
  - **Target: BeO**
- **Status : Prototype development (2017~)**
- **Plan : High power target ion source, β-NMR facilities**



Layout plan for β-NMR facility



Prototype target ion source heating test

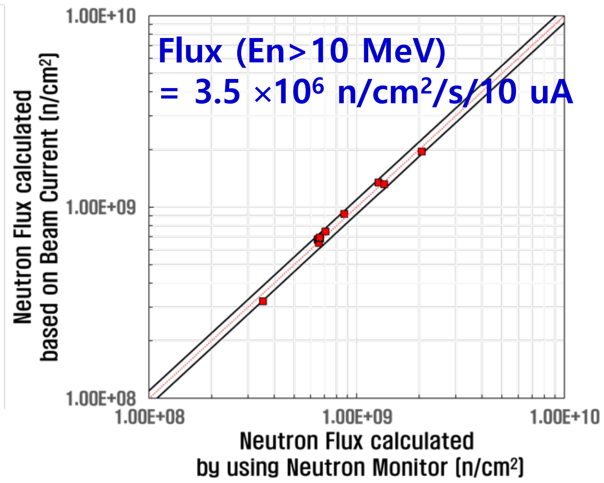


Heating current vs. temperature

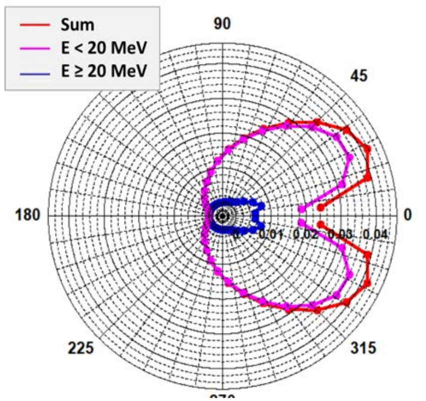
Near Future Plan 2

❖ Pulse Neutron Beamline: 100-MeV Proton

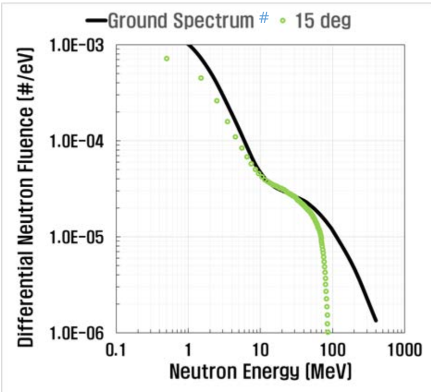
- **Application : Fast neutron production**
- **Proton beam**
  - **Energy: 100 MeV**
  - **Beam Power: 1 kW @ 100 MeV (upgrade 160 MeV)**
  - **Target: Copper (plan to change to W)**
- **Status : Neutron utilization @ 100 MeV, 1kW (2018~)**
- **Plan : Accelerator energy upgrade, target improvement, neutron facility**



Measurement results



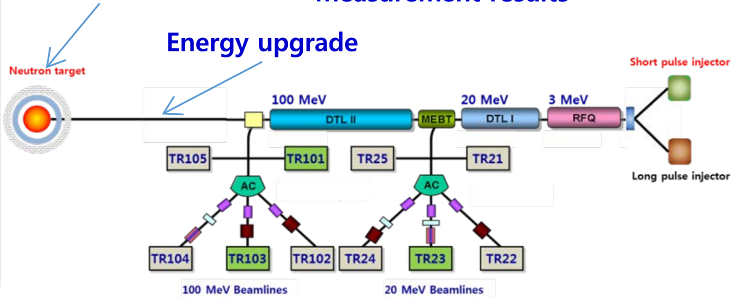
Angular distribution of the neutron



Gordon et al, IEEE Trans. Nucl. Sci. 51 (2004)

Neutron spectrum compared with the ground spectrum

Neutron target

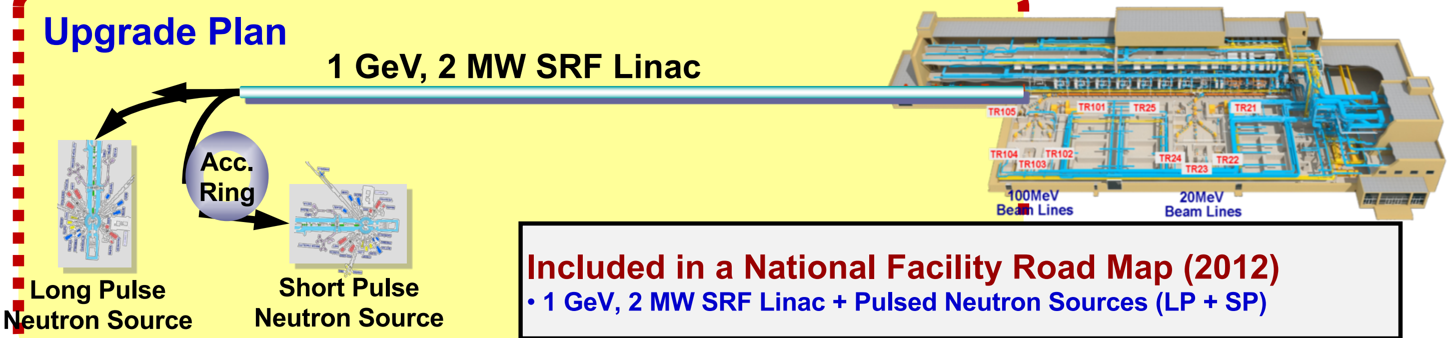


Layout plan of the pulse neutron source

Future Plan

❖ **Upgrade to 1GeV, 2MW proton linac, two pulsed neutron sources**
- **Reflected in National Large Research Facility Road Map (2010 & 2012)**

Upgrade Plan



Included in a National Facility Road Map (2012)
- **1 GeV, 2 MW SRF Linac + Pulsed Neutron Sources (LP + SP)**

- **Neutron Sources:** Materials, Bio-life, Energy, Environment, etc.
  - **Long Pulse (1.3 ms):** Spatial resolution: μm~nm, Temporal resolution: μs~ns
    - SANS, Holography, Phase shift interferometry, Static & Dynamic tomography, Spin echo, etc.
  - **Short Pulse (~μs):** Spatial resolution: 0.01~10 nm, Temporal resolution: ns~fs
    - Elastic scattering, Diffraction, PGAA, Neutron resonance transmission, Neutron resonance capture analysis, Neutron spectroscopy, Neutron stimulated emission CT, etc.

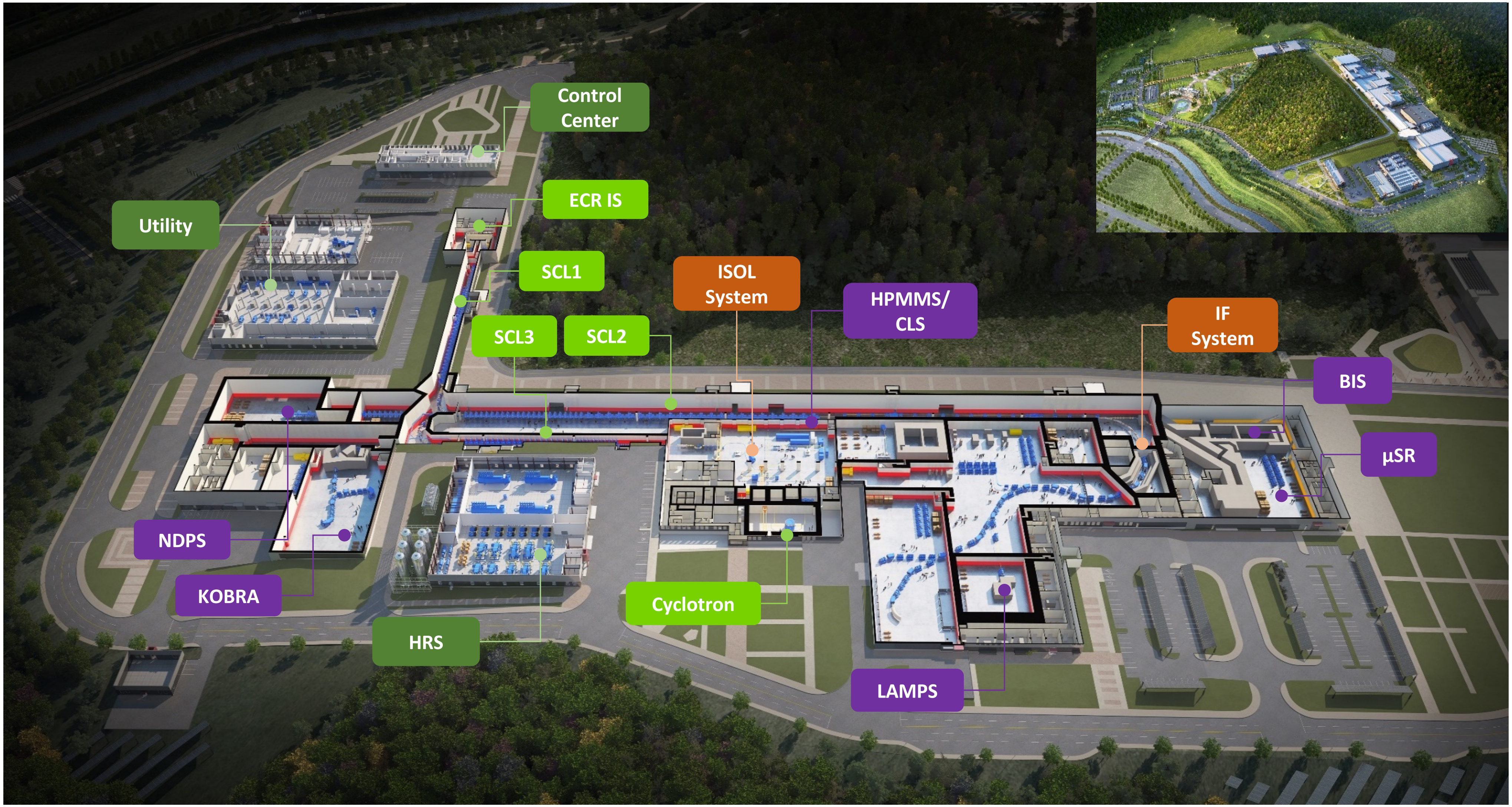
Rare isotope
Accelerator complex for
ON-line experiments

Overview of The Rare Isotope Science Project (RISP)

기초과학연구원
Institute for Basic Science

중이온가속기건설구축사업단
Rare Isotope Science Project

RAON Layout



- **SCL1 has been decided to be pended**

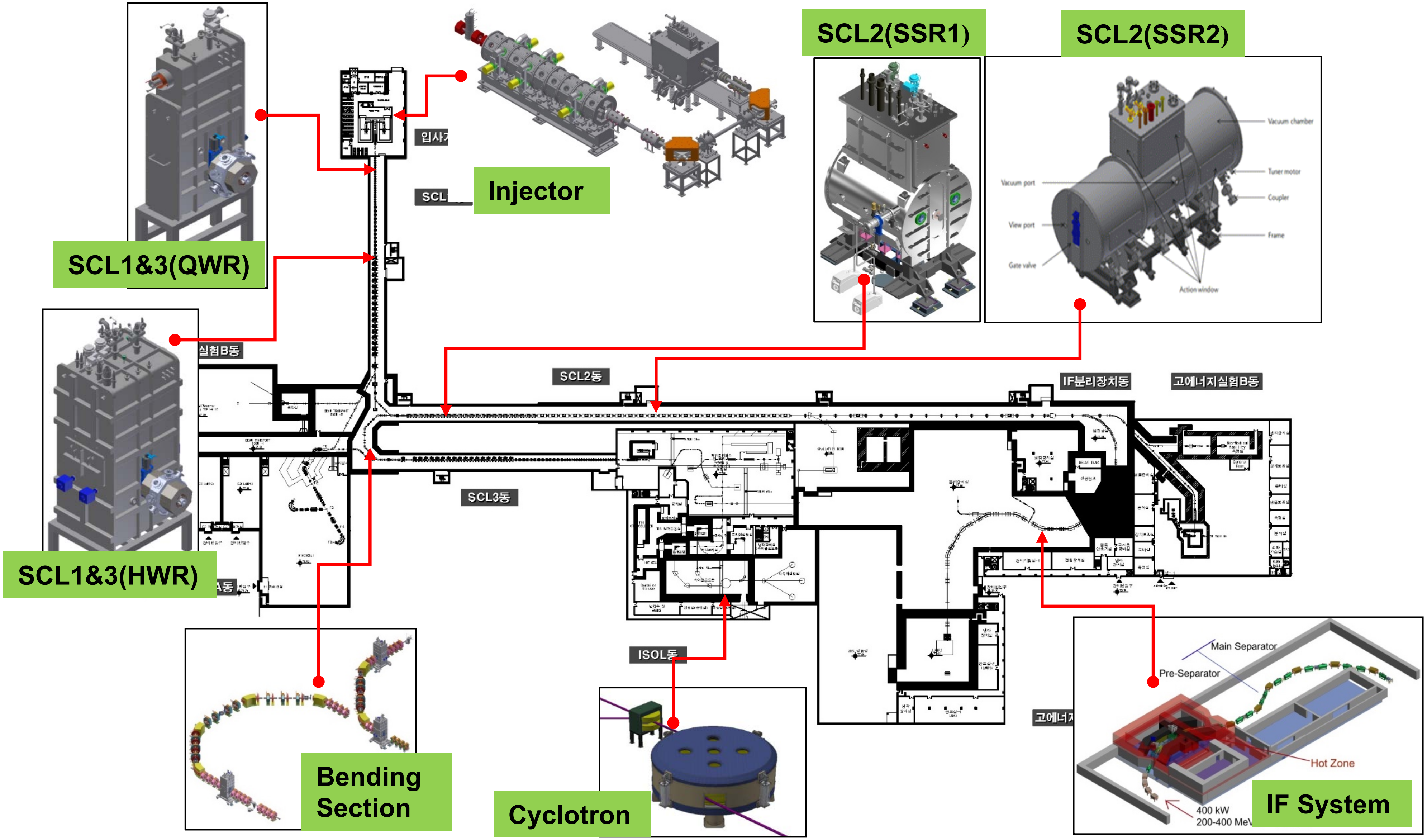
  : SCL3 is going to be taking a role of SCL1 in the early operation

Building Layout

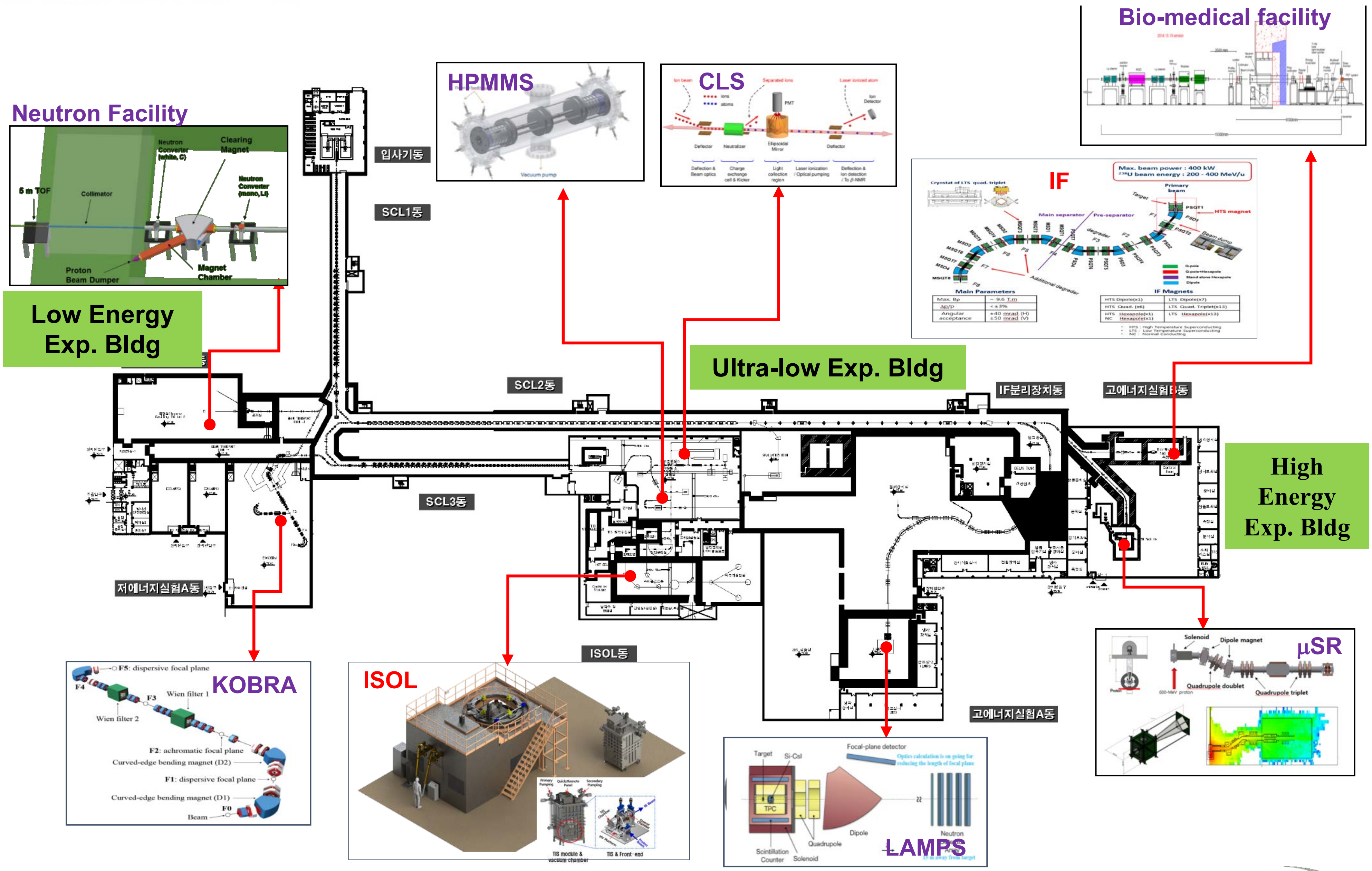
Building Layout

- Campus Area : **952,066**㎡ (including the reservation area of **144,640**㎡)
- Period : **2014** ~ **2021**(8 years)
- Cost : 972 billion won (incl. 357 billion won for land)
- Building Area : **76,259**㎡(**11** Bds)
- Total Bd. Area : **116,252**㎡
- Constructor : POSCO Consortium(11 companies)

Accelerator System



RI & Experimental System



기초과학연구원 Institute for Basic Science

Rare Isotope Science Project

Summary & Outlook

▪ Accelerator

- Mass production for SCL3 is under way
- SCL2 is under pre-production phase
- **From April, 2019, installation for SCL will start from SCL3**
- Test facility for cavities and cryomodules will operate from next Jan.

▪ By the end of 2021, we will achieve

- **SI beams:** Stable ion beams (^{16}O, ^{40}Ar) from ECRIS → SCL3 → low E exp hall
- **RI beams:** RIBs extraction from ISOL → re-acceleration through SLC3 → low E exp hall
- Stable / RI beams will be delivered to low-E experimental hall
- **Early phase experiments are going to be performed using KOBRA**
  → RIBs production at KOBRA (A<~50, beam energy < 20 MeV/u) using SI beams from SCL3

- Beam commissioning starts for SCL2

- Installation and commissioning for IF, LAMPS, Neutron, bio-medical and muSR
  → Collaborative works with RUA (RAON Users Association) via RULC (RAON Users Liason Center)

▪ Post RISP (2021 ~)

- Beam acceleration for ISOL → SCL3 → SCL2 → IF **(ISOL+IF)**
- Beam commissioning and experiments for IF, LAMPS, Neutron, bio-medical and muSR
- **Ramping-up to get the 400kW beams (more 5 yrs)**
- Energy upgrade to 400MeV/u (require budget)

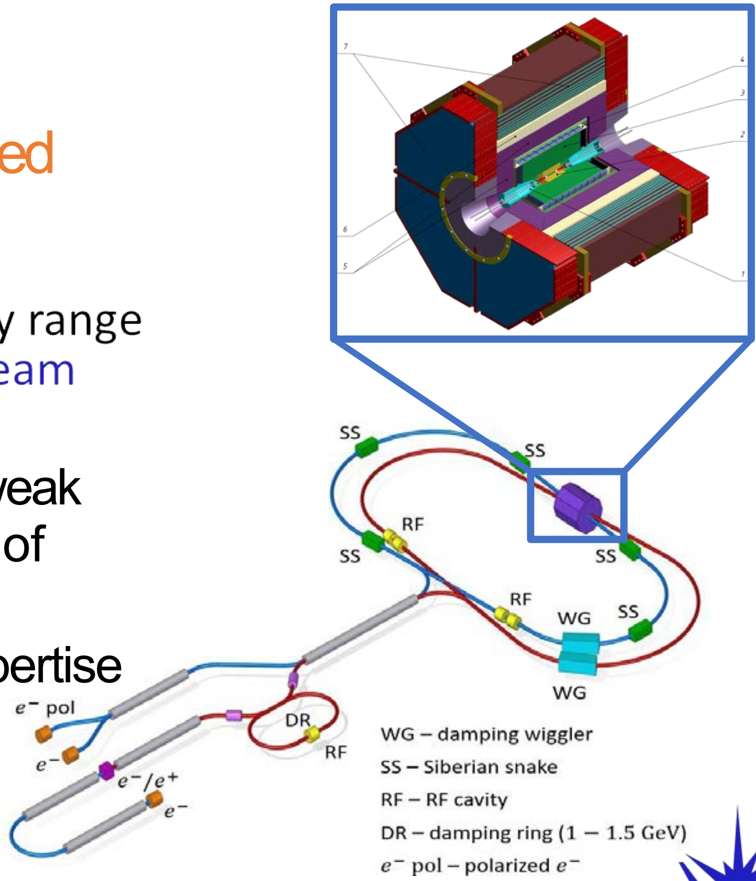
SCT Project Overview

Pavel Logachev

What is SCT?

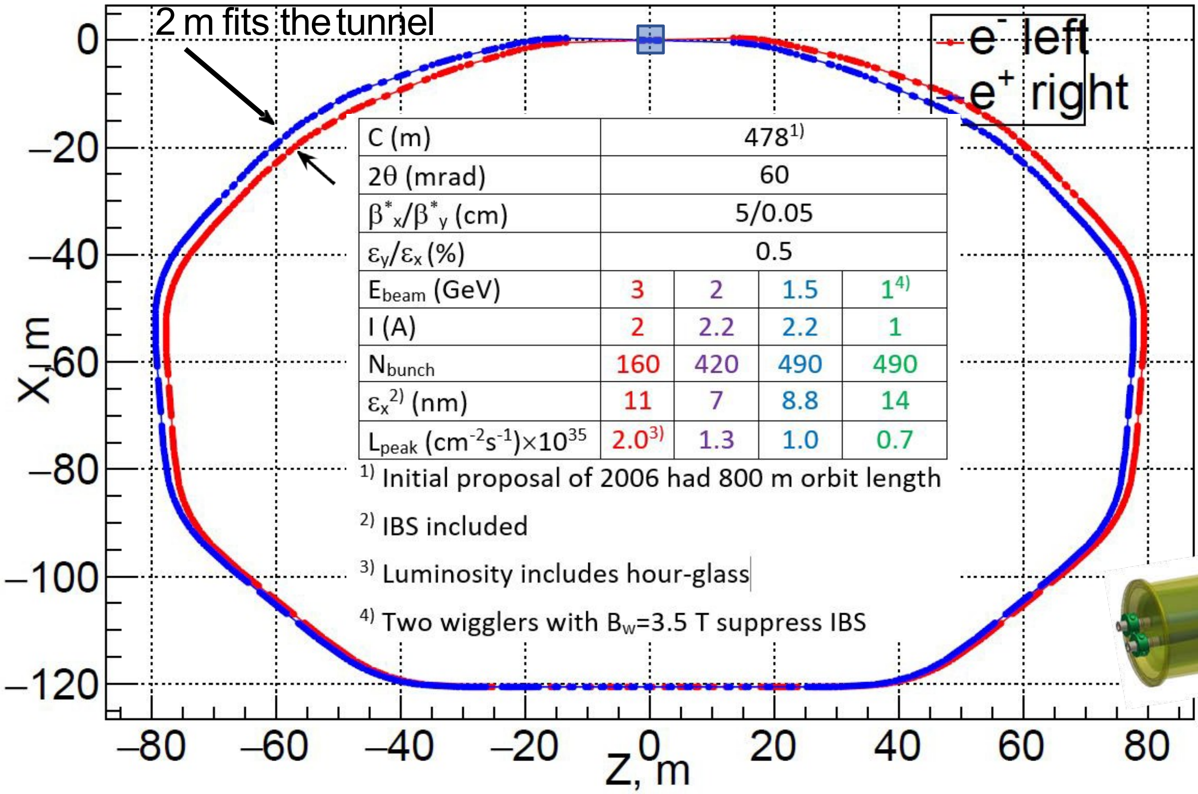
Super Charm-Tau factory is a BINP-based electron-positron collider project

- ➢ World-best luminosity $10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ in the energy range between 2 and 6 GeV with longitudinal electron beam polarization
- ☐ Rich program of high precision measurements of weak and strong fundamental interactions in the region of charm quark and tau lepton
- ☐ Provides solid ground for development of BINPexpertise in particle accelerators and colliders technologies
- ☐ Based on replacing and upgrade of existing BINP facilities: VEPP-2000 and VEPP-4M colliders, and electron and positron injection complex



BINP

SCTConfiguration and Parameters



C (m)	478[1]			
2θ (mrad)	60			
β^*_x/β^*_y (cm)	5/0.05			
$\varepsilon_y/\varepsilon_x$ (%)	0.5			
E_{beam} (GeV)	3	2	1.5	1[4]
I (A)	2	2.2	2.2	1
N_{bunch}	160	420	490	490
ε_x[2] (nm)	11	7	8.8	14
L_{peak} ($cm^{-2}s^{-1}$)$\times 10^{35}$	2.0[3]	1.3	1.0	0.7

[1] Initial proposal of 2006 had 800 m orbit length

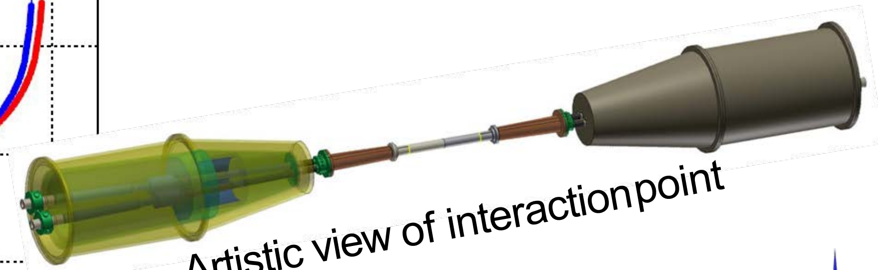
[2] IBS included

[3] Luminosity includes hour-glass

[4] Two wigglers with B_w=3.5 T suppress IBS

2019 Status

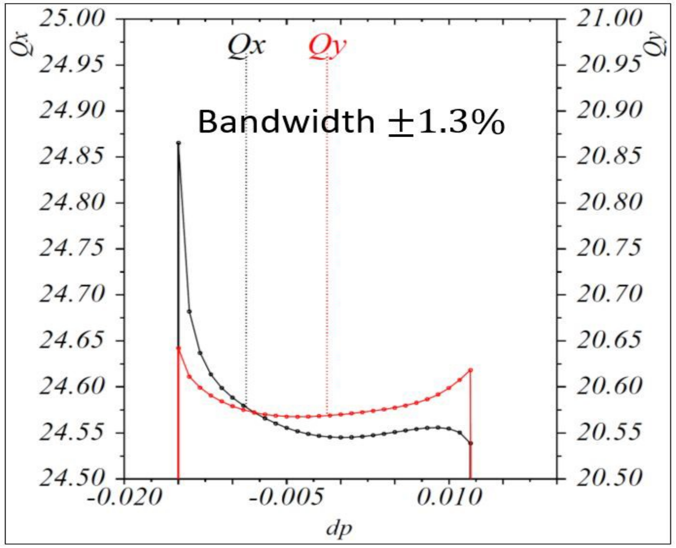
- ☐ Double-ring collider
- ☐ Max beam energy 3 GeV
- ☐ Crab Waist collision
- ☐ longitudinally polarized electrons
  - Three Siberian Snakes

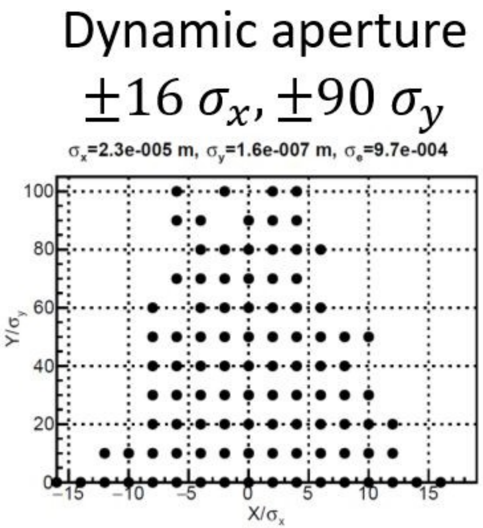


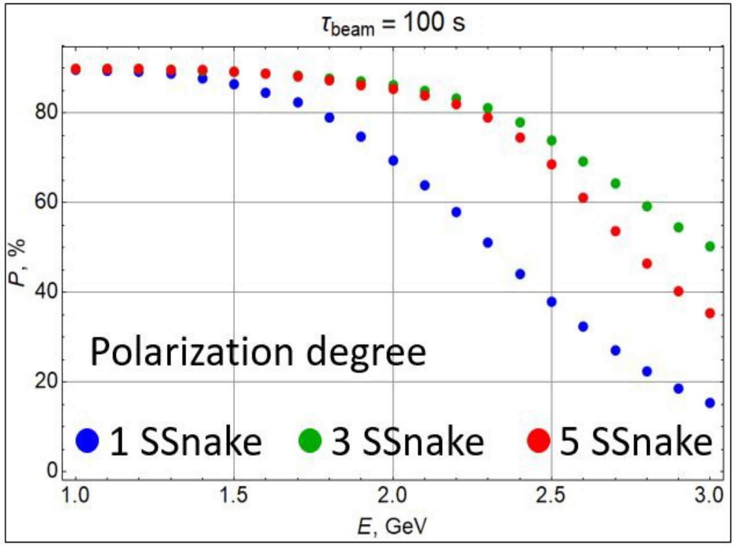
Artistic view of interactionpoint

BINP

Beam dynamics and polarization







- ✔ All essential beam physics issues are considered
  - optics, nonlinear beam dynamics, longitudinal polarization, IBS, etc.
- ✔ No showstoppers revealed

BINP

Project Status

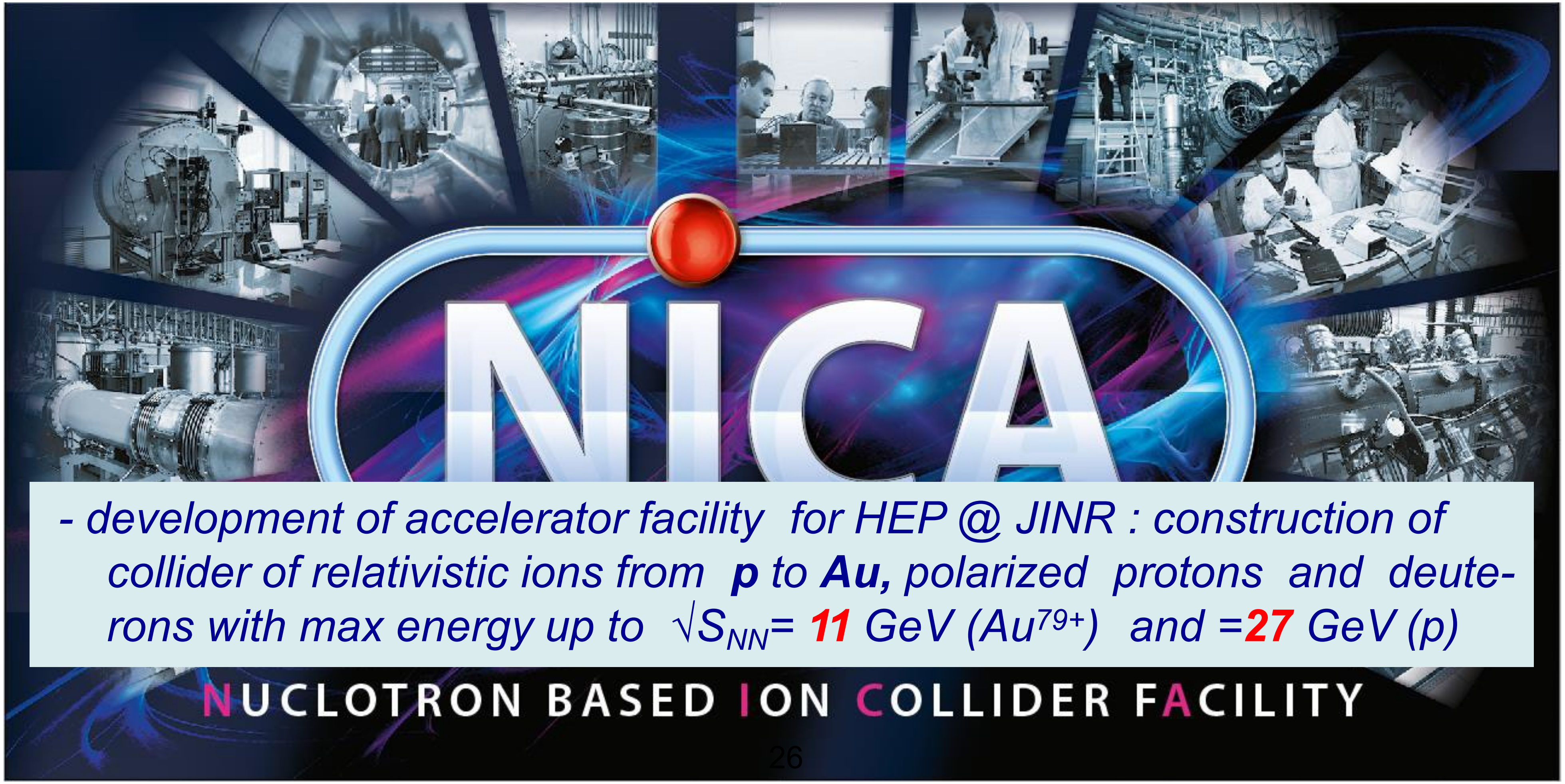
- Draft Conceptual Design Report is available at ctd.inp.nsk.su
  - Cost estimate: 37B RUB (about $560M)
  - Construction period: 6 years
- Approval status
  - SCT is one of six mega-sciences projects selected by Russian Government
  - SCT project is included in the plan for the implementation of the first phase of the Strategy for Scientific and Technological Development of the Russian Federation
  - Officially supported by ECFA
- R&D for accelerator and detector underway
- International collaboration around the SCT experiment is being formed
  - MoUs with CERN, KEK, INFN, JINR, John Adams Institute, etc. are signed
  - Annual international workshops are being held
  - HORIZON 2020 project CREMLINplus in collaboration with CERN, INFN, LAL, and Giessen U.
  - SCT has been well-recognized at the Open Symposium on the Update of European Strategy for Particle Physics (Granada, Spain)

BINP

NICA (Nuclotron based Ion Colider fAcility

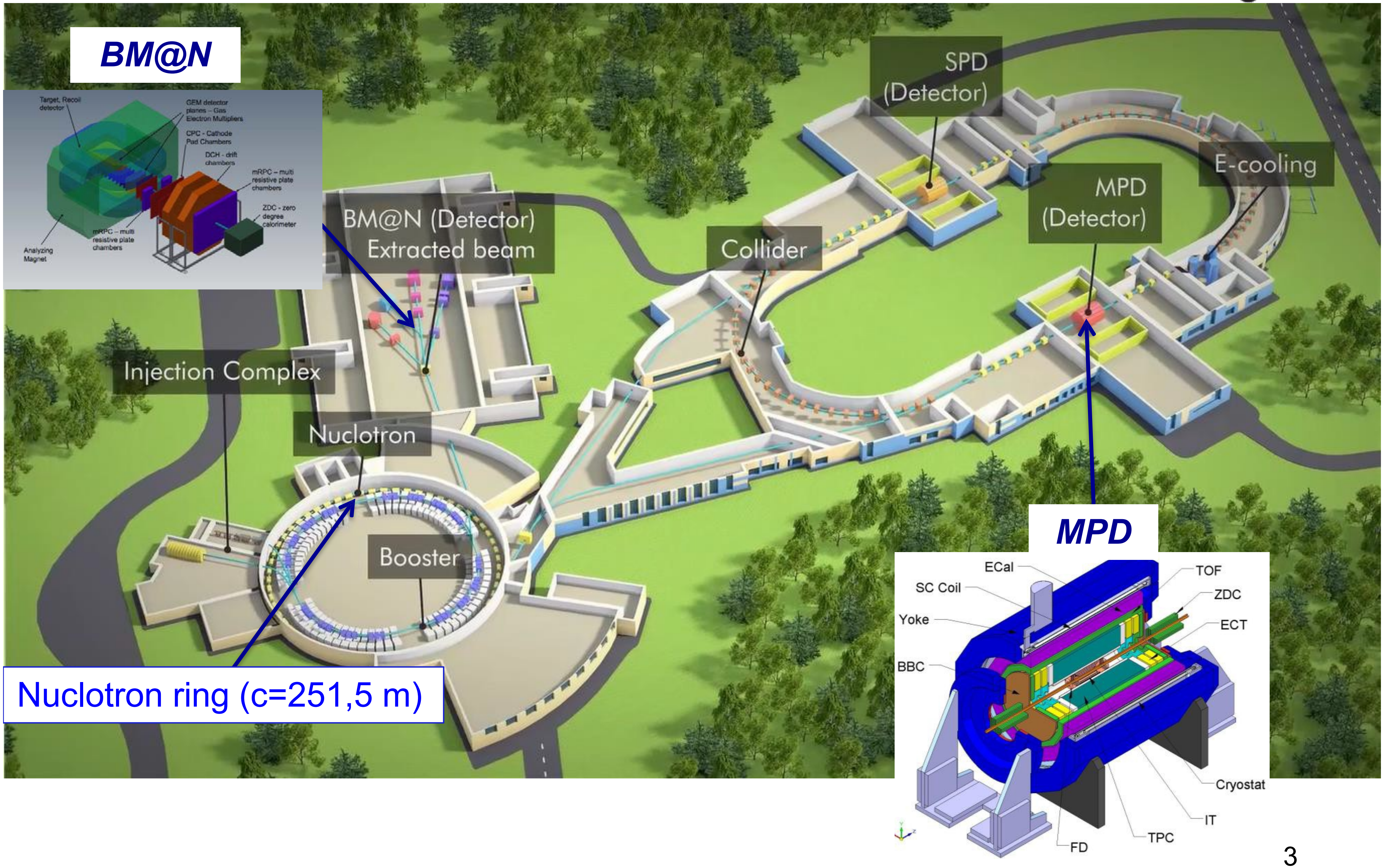
Main targets:

- *study of hot and dense baryonic matter at the energy range of max baryonic density*
- *investigation of nucleon spin structure, polarization phenomena*



- *development of accelerator facility for HEP @ JINR : construction of collider of relativistic ions from* ***p*** *to* ***Au,*** *polarized protons and deuterons with max energy up to* $\sqrt{S_{NN}}$= ***11*** *GeV* (Au^{79+}) *and =**27** GeV (p)*

experiments at **NICA**



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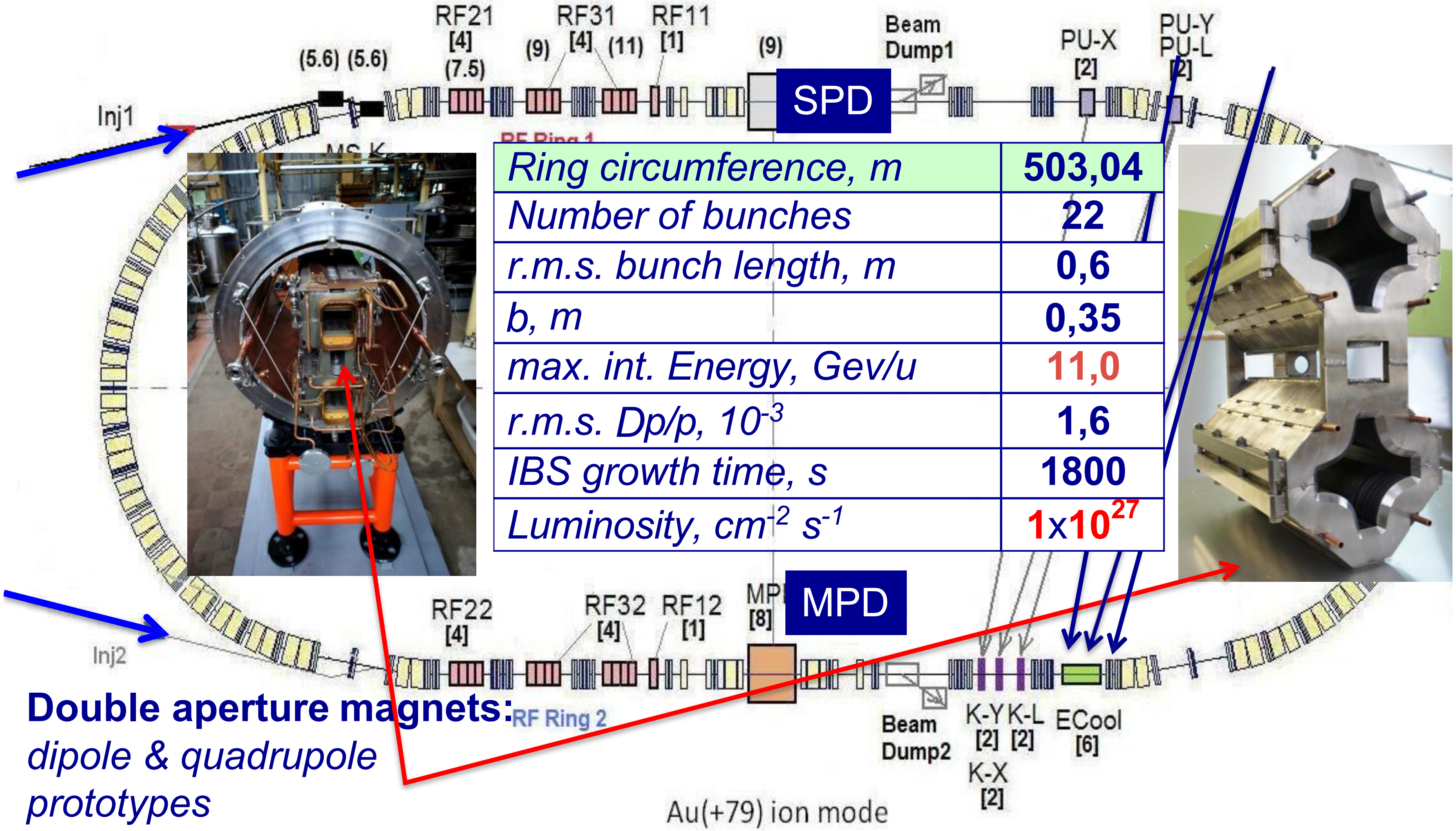
The Collider

45 T*m, *4.5 GeV/u for* ***Au^{79+}***



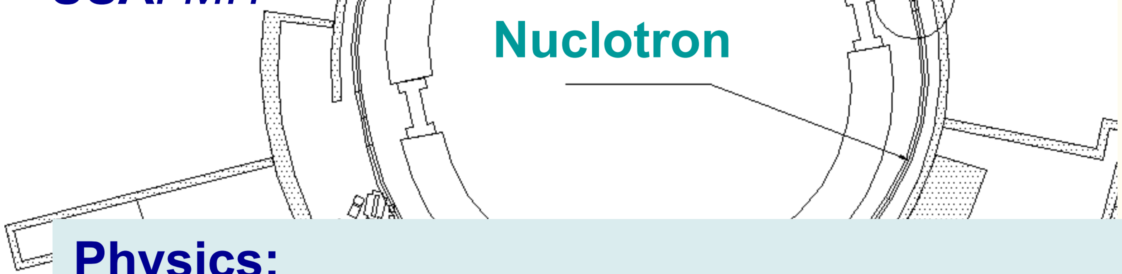
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
b, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. Dp/p, 10^{-3}	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**$1x10^{27}$**

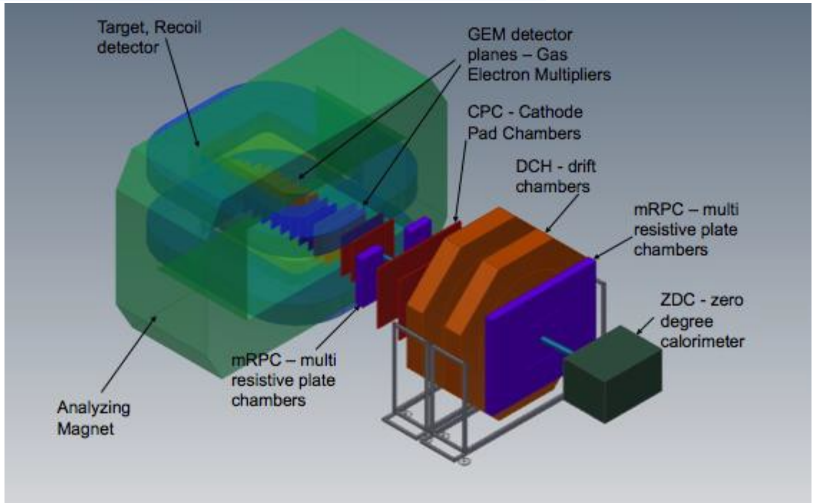
Double aperture magnets:
dipole & quadrupole prototypes

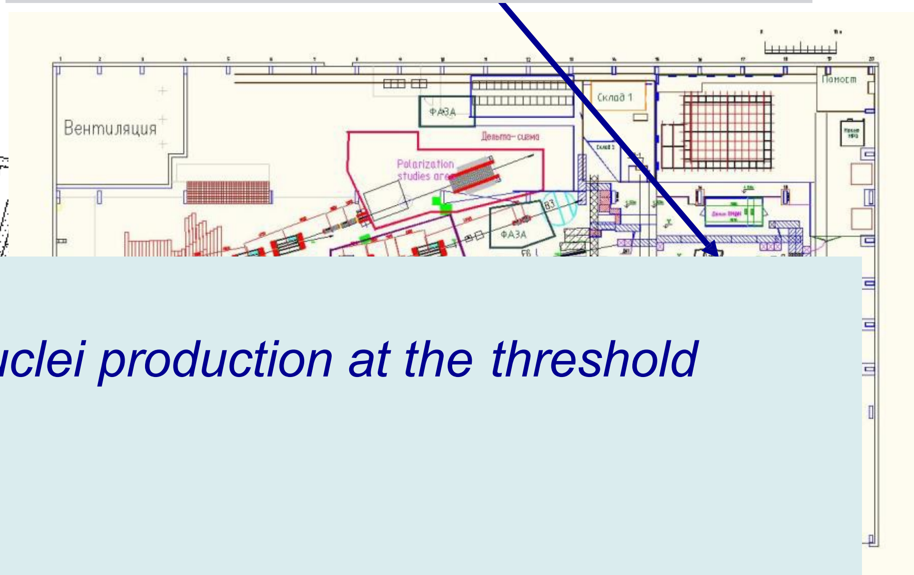
Baryonic Matter at Nuclotron (BM@N)

experiment at Nuclotron extracted beams

BM@N Collaboration:
Russia: *INR, MEPhi, SINP, MSU, IHEP, S-Ptr Radium Inst.*
Bulgaria: *Plovdiv University;*
China: *Tsinghua University, Beijin;*
Poland: *Warsaw Tech.Uni.*
Israel: *Tel Aviv Uni., Weitzman Inst.*
Germany: *Frankfurt Uni.; eoi GSI*
USA: *MIT*







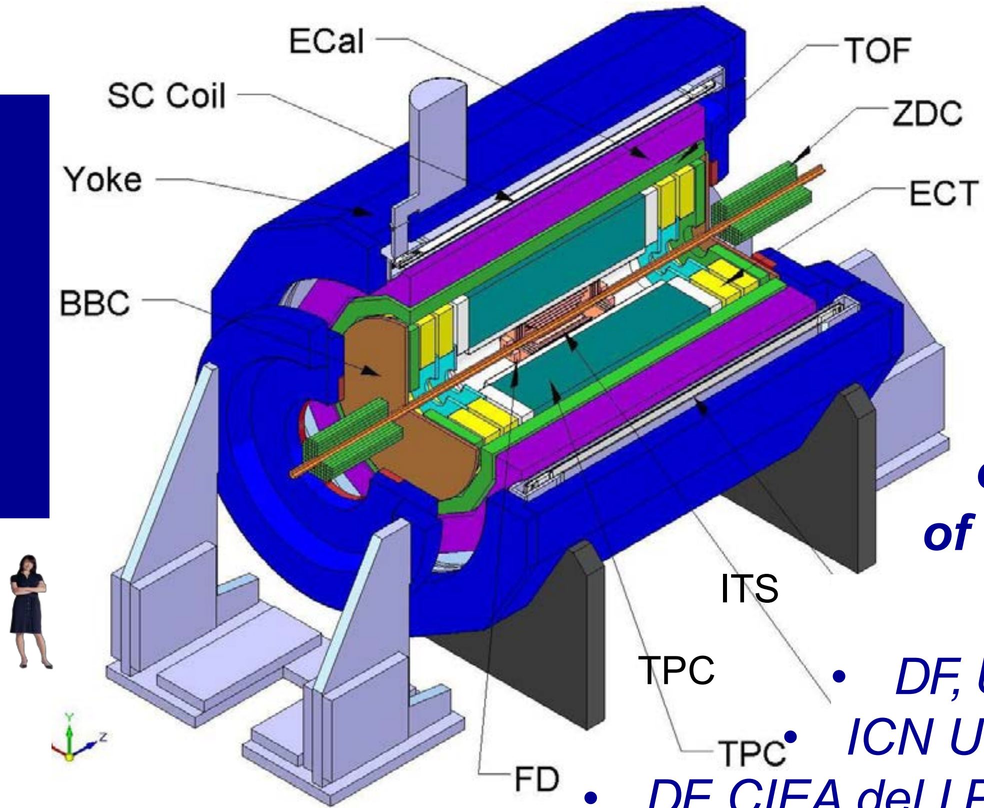
<u>Physics:</u>

- ✓ *strange / multi-strange hyperon and hypernuclei production at the threshold*
- ✓ *hadron femtoscopy*
- ✓ *short range correlations*
- ✓ *event-by event fluctuations*
- ✓ *in-medium modifications of strange & vector mesons in dense nuclear matter*
- ✓ *electromagnetic probes, states decaying into γ, e (with ECAL)*

MultiPurpose Detector (MPD)

Main target:

- *study of hot and dense baryonic matter at the energy range of max net baryonic density*



MPD Collaboration:

- *JINR, Dubna;*
- *Tsinghua University, Beijing, China;*
- *MEPhI, Moscow, Russia.*
- *INR, RAS, Russia;*
- *PPC BSU, Minsk, Belarus;*
- *WUT, Warsaw, Poland;*

expression of interest by:

- *CERN;*
- *DF, US, Mexico;*
- *ICN UNA; Mexico;*
- *DF, CIEA del I.P.N, Mexico;*
- *FCF-M UAS, Sinaloa, Mexico;*
- *FCF-MB UAP, Puebla, Mexico;*
- *PI Az.AS, Baku, Azerbaijan;*
- *ITEP, NC KI, Moscow, Russia;*
- *PNPI NC KI, Saint Petersburg, Russia;*
- *CPPT USTC, Hefei, China;*
- *SS, HU, Huzhou, Republic of South Africa.*

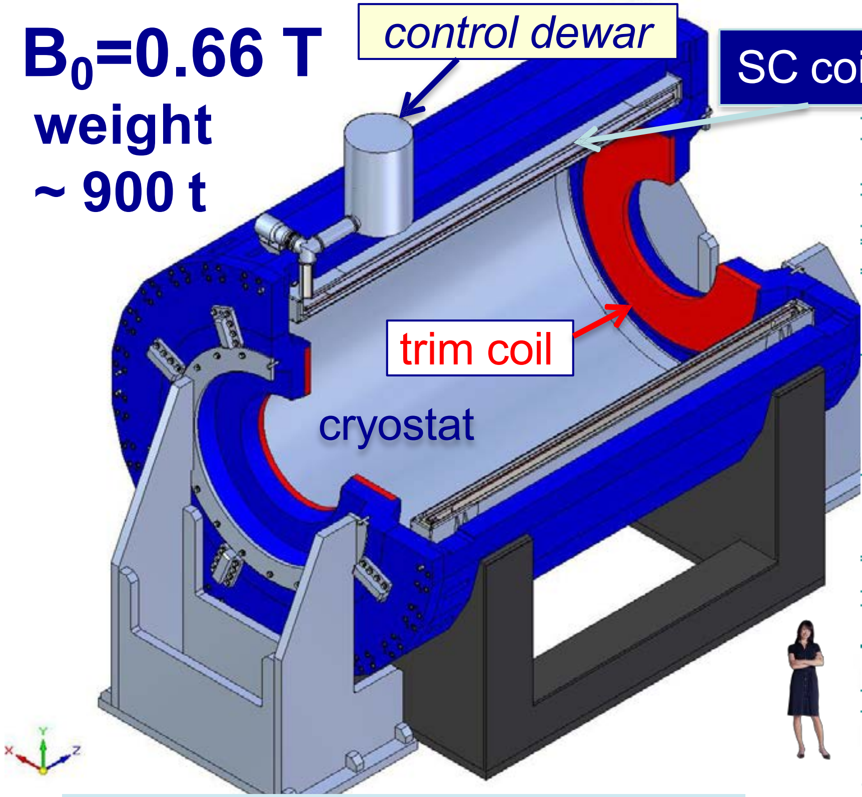
MPD detector for Heavy-Ion Collisions @ NICA

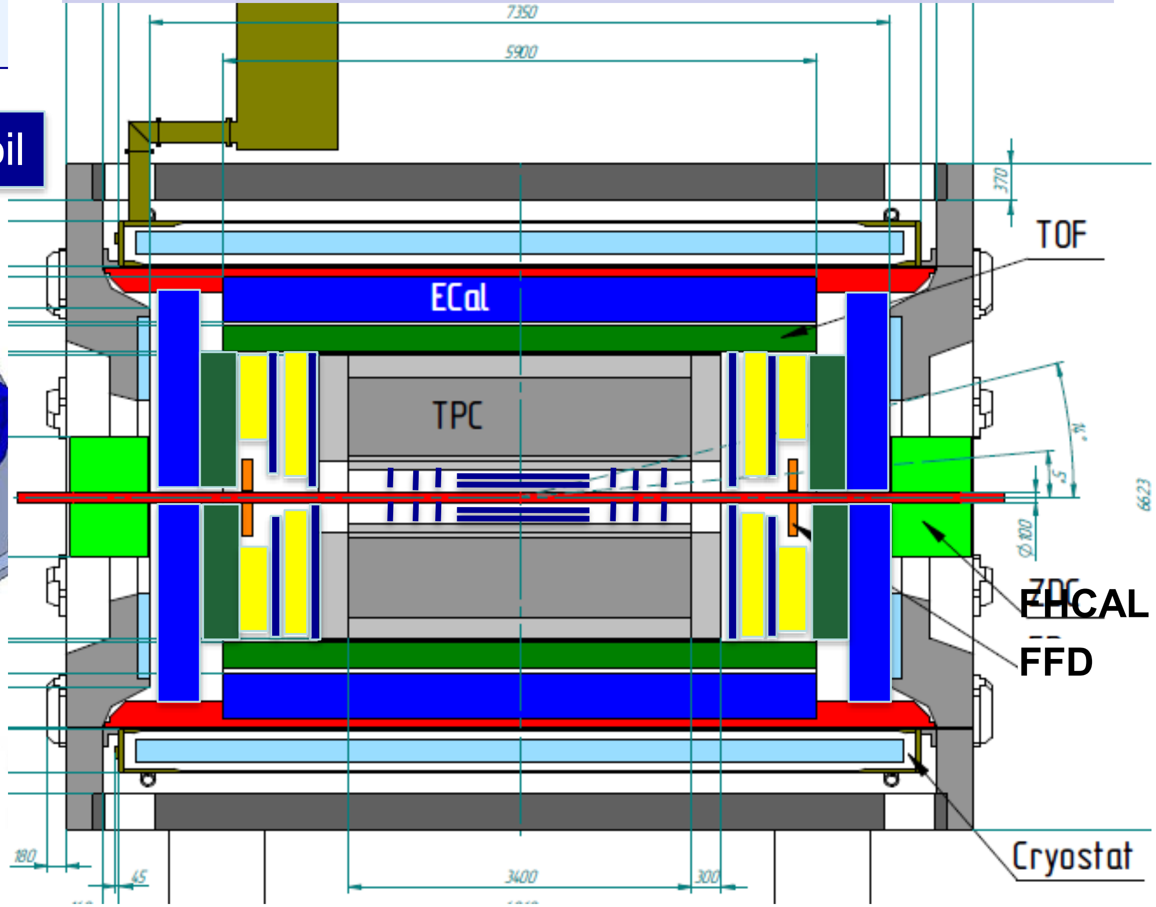
Tracking: up to |h|<1.8 (TPC)
PID: hadrons, e, g(TOF, TPC, ECAL)
Event characterization:
centrality & event plane (FHCAL)

Stage 1: TPC, TOF, ECAL, FHCAL, FFD

Stage 2: ITs + Endcaps (tracker, TOF, ECAL)

B_0=0.66 T
weight
~ 900 t

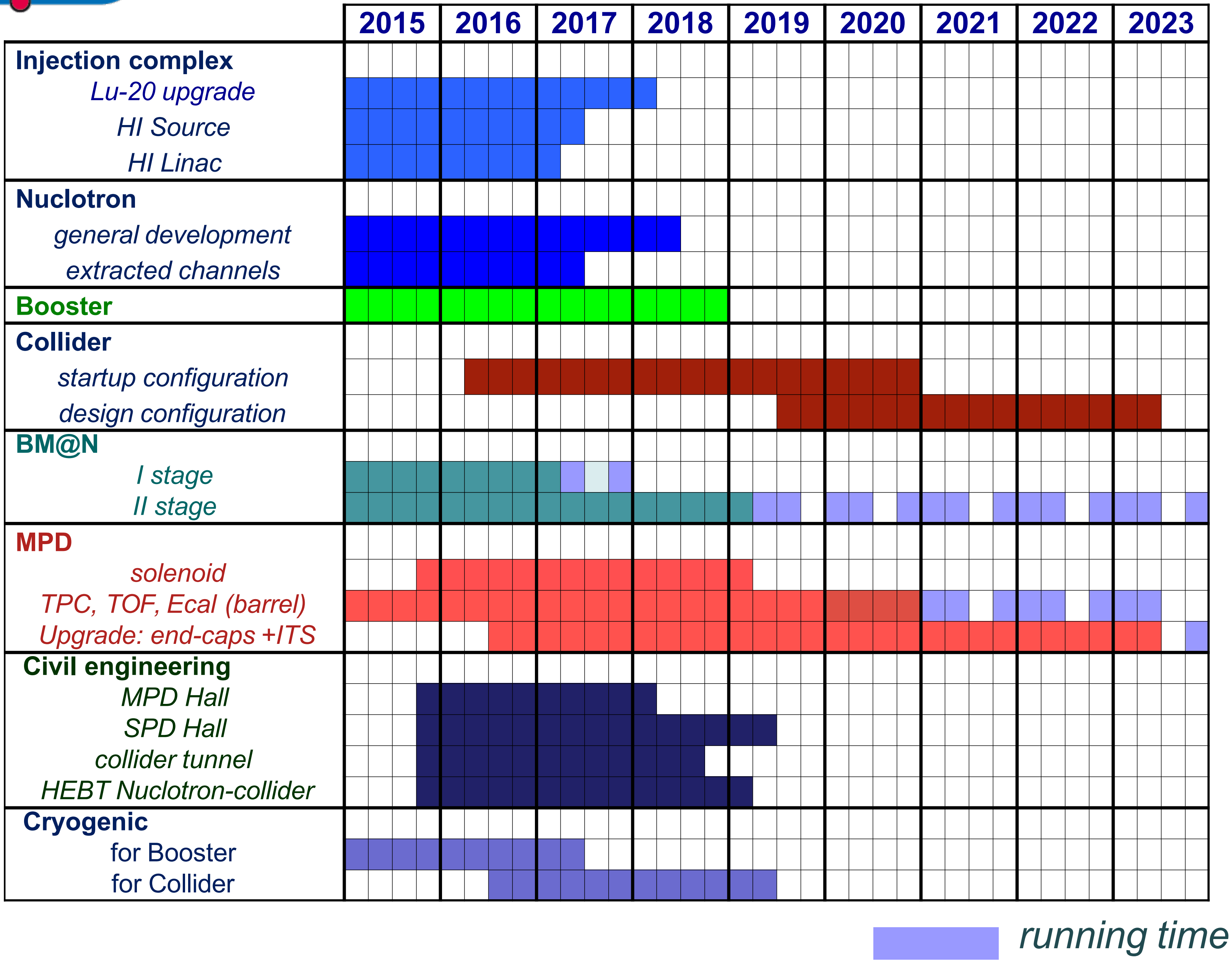




General contractor:
ASG Superconductors,
Genova, Italy

Status: *technical design – completed / close to completion; preparation for the mass production*

NICA schedule



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EIC Accelerator Overview and R&D

Ferdinand Willeke, BNL

EICUG Annual Meeting, Paris 2019

Electron Ion Collider

U.S. DEPARTMENT OF ENERGY | Office of Science

Requirements on EIC Performance

The EIC is designed to meet the requirements set forth in NSAC Long Range Plan, which was emphasized by the NAS report:

Highly polarized (~70%) electron and nucleon beams
Ion beams from deuterons to the heaviest nuclei (uranium or lead)
Variable center of mass energies from ~20 - ~100 GeV, upgradable to ~140 GeV
High collision luminosity ~10^{33} – 10^{34} $cm^{-2}s^{-1}$
Possibilities of having more than one interaction region

There are two proposals:

JLEIC to be constructed at Jefferson Lab
eRHIC to be constructed at Brookhaven National Lab

Both design benefit from existing Nuclear Physics infrastructure and are based on the same accelerator principles:

Electron Storage Rings with frequent injection of fresh polarized beams
Hadron storage rings with strong cooling or alternatively frequent injections

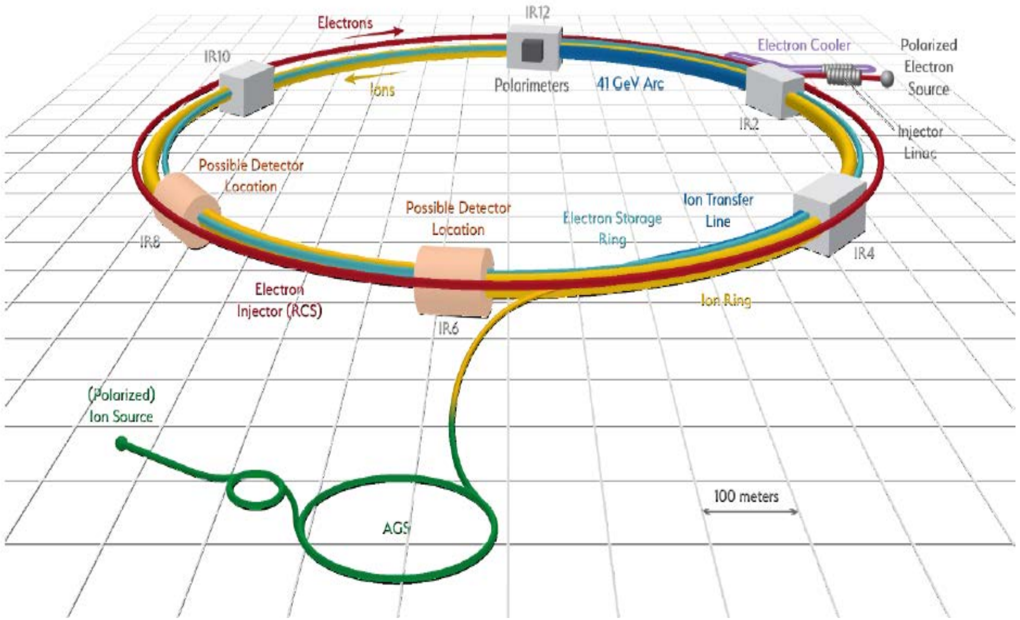
eRHIC

Hadrons up to 275 GeV

eRHIC is using the existing RHIC complex: Storage ring (Yellow Ring), injectors, ion sources, infrastructure,

Need only few modifications for eRHIC

Todays RHIC beam parameters are close to what is required for eRHIC



Electrons up to 18 GeV

Electron storage ring with up to 18GeV ➔ E_{cm} = 20 GeV -141 GeV installed in RHIC tunnel. Beam current are limited by the choice of installed RF power 10 MW.

Electron beams with a variable spin pattern accelerated in the on-energy, spin transparent injector: Rapid Cycling Synchrotron with 1-2 Hz cycle frequency in the RHIC tunnel

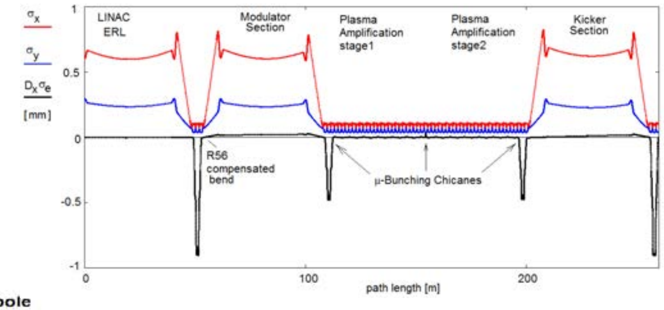
Polarized electron source and 400 MeV s-band injector linac in existing tunnel

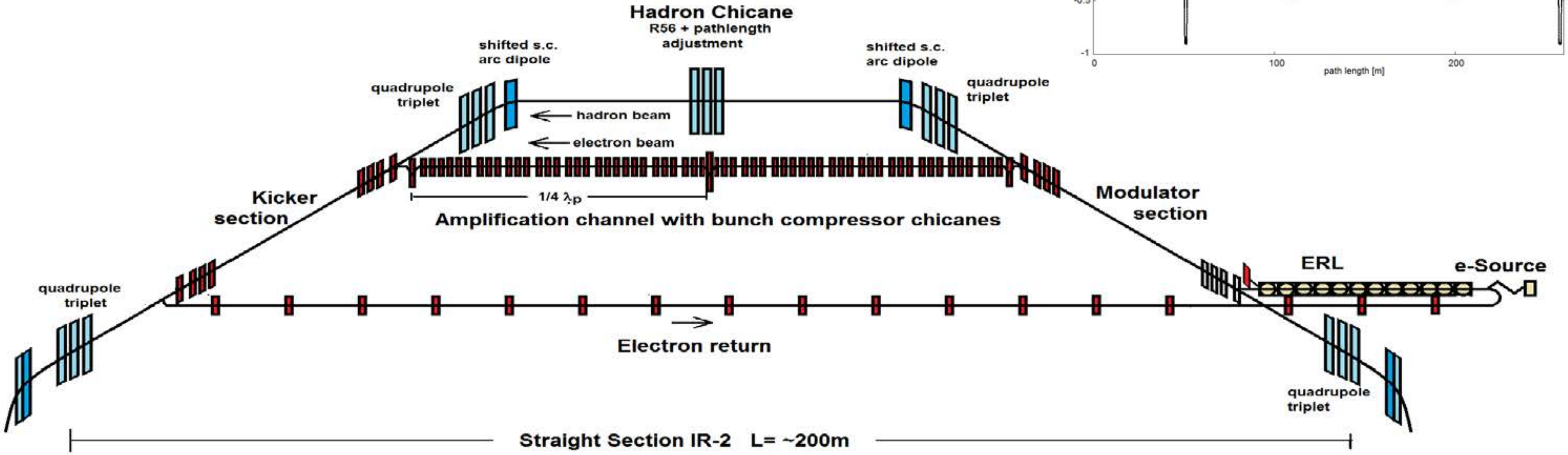
Design meets the high luminosity goal of **$L = 10^{34} cm^{-2} s^{-1}$**

eRHIC Strong Hadron Cooling

Coherent Electron Cooling with μ-bunching amplification

Electron Beam Optics

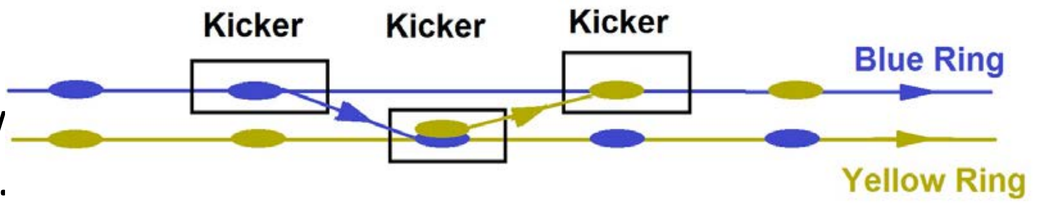




- Micro-bunched cooling is a novel scheme based on available technology
- For eRHIC, strong cooling as desirable but not necessary for high luminosity (especially high average luminosity) as the hadron beam could be replaced frequently on-energy using the existing second ring of present RHIC. As the JLEIC scheme, this option requires electron cooling at low energy.

Alternative to Strong Hadron Cooling in eRHIC

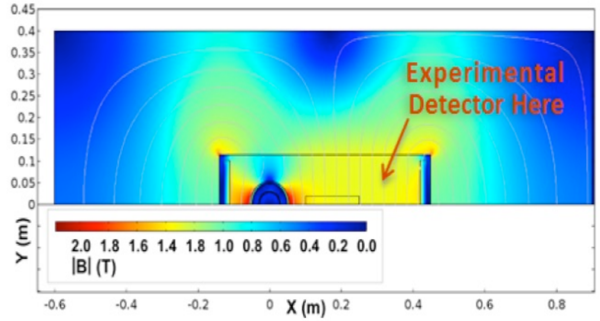
eRHIC maximum luminosity of $1 \cdot 10^{34}\ cm^{-2}s^{-1}$ does not depend on the feasibility of strong hadron cooling.
Since RHIC has a second superconducting ring, the Blue Ring, on-energy injections into the collider ring, the Yellow Ring will replace the hadron bunches after one hour of storage.
Transfer takes 13 μs and will preserve the total charge in both machines, no transient injection effect.



The emittance grow … uminosity of **$0.9 \cdot 10^{34}\ cm^{-2}s^{-1}$** will be achieved.

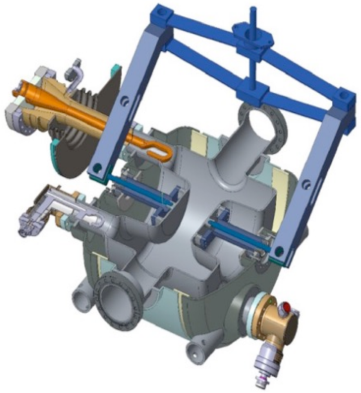
The required small vertical emittance ε_{Ny} = 0.5 μm will be achieved with standard DC electron beam cooling in the AGS.
No new hardware for spin transparency is required

On-Going EIC R&D Effort

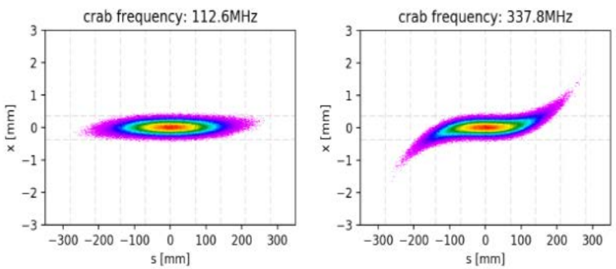


Instrumented accelerator magnet

Component Development
Crab Cavity design development and prototyping
IR magnet development and prototyping
HOM damping for RF structure development
Variable coupling high power forward power couplers development
Effective in situ Cu coating of the beam pipe (BNL hadron only)
High average current electron gun development
Polarized ^3He source
Bunch by bunch polarimetry


Crab cavity

Accelerator Physics R&D
Strong hadron cooling CeC, cooling development (simulation and experim
Strong hadron cooling bunches electron beam cooling (simulation and ex
ERL development for strong hadron cooling
Test of suppression of intrinsic depolarizing resonances
Study of collisions with different revolution frequencies (JLAB only)
Experimental verification of figure-8 configuration
Study of residual crab cavity effect on beam emittance



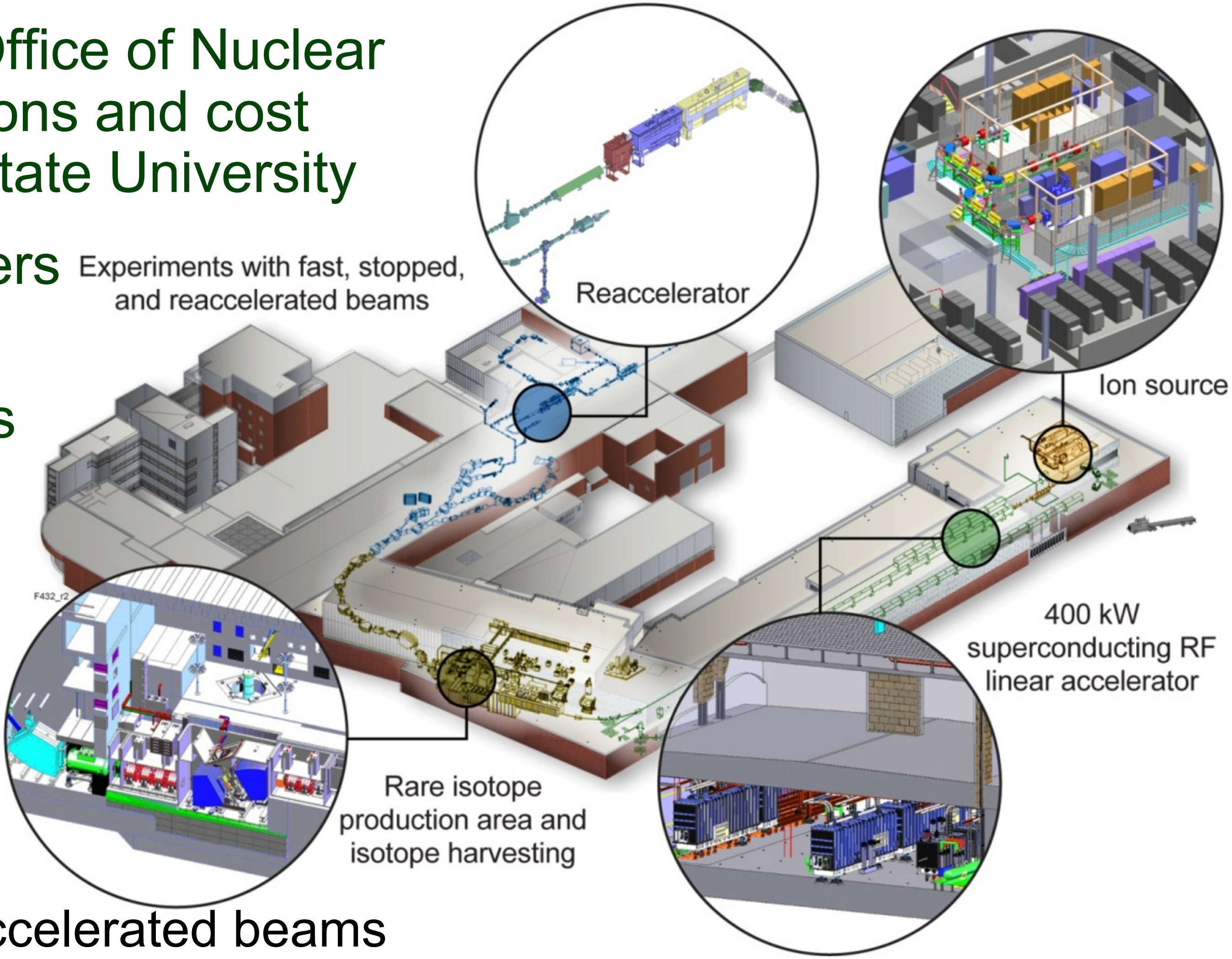
Crabbed beam dynamics

FRIB Project Overview

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Facility for Rare Isotope Beams
A Future DOE-SC National User Facility

- Funded by DOE–SC Office of Nuclear Physics with contributions and cost share from Michigan State University
- Serving over 1,400 users
- Key feature is 400 kW beam power for all ions (e.g. 5×10^{13} ^{238}U/s)
- Separation of isotopes in-flight provides
  - Fast development time for any isotope
  - All elements and short half-lives
  - Fast, stopped, and reaccelerated beams



Civil and Technical Construction on Track

FRIB Project 92% complete

- June 2009 – DOE-SC and MSU sign Cooperative Agreement
- September 2010 – CD-1 approved, DOE issues NEPA FONSI
- August 2013 – CD-2 approved (baseline), CD-3a approved
- March 2014 – Start civil construction
- August 2014 – CD-3b approved (technical construction)
- December 2021 – Early completion
- June 2022 – CD-4 (project completion)
- Recent milestones
  - October 2018 – First superconducting magnets installed in target facility
  - December 2018 – Cryoplant 2 K coldbox commissioned
  - April 2019 – Ar and Kr beams accelerated above 20 MeV/nucleon

- $730M Total Project Cost (TPC)
  - $635.5M DOE outlay
  - $94.5M MSU cost share
- $306.6M contributions
  - Outside of project baseline
  - Monitored for schedule and performance, all critical items complete

Successfully Delivering Technical Scope

Major technical procurements progressing well:

	Accelerator Systems	Experimental Systems
Major technical procurements	286	111
Cost	$113.7M	$24.2M
% Costed/committed	95%	82%

Beta=0.041 cryomodule

Beam dump module

Accelerator Systems:

- Linac cryomodules (4 types) – 46 + 3 spares
  - Cavities – 324 + 16 spares
  - Solenoids – 69 + 5 spares
- Room temperature magnets – 151
- Superconducting dipole magnets – 4
- Solid-state RF amplifiers (5 types) – 220
- Cryogenic transfer lines – 49
- Network switches – 164
- Room temperature magnet power supplies – 314
- Superconducting magnet power supplies – 278
- High voltage power supplies – 74
- Diagnostics – 608 total devices
  - Beam position monitors – 150
  - Fast thermometry for beam loss - 240
- 4 K and 2 K Cryogenic plants
- Radio Frequency Quadrupole
- Charge state stripper
- Low- and high-level controls

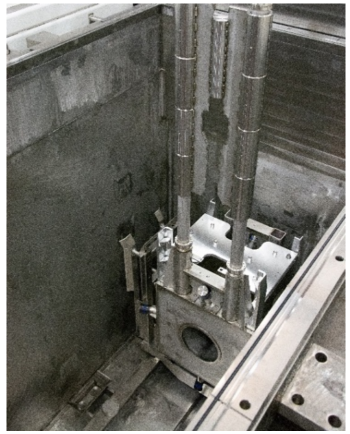
Experimental Systems:

- Preseparator magnets
  - Superconducting dipoles – 4
  - Superconducting cold iron quads – 4
  - Superconducting warm iron quads – 5
  - Room temperature magnets – 1
- Large vacuum vessels – 3
- Remote handling gallery
- Target, beam dump, and wedge
- Cooling water processing loops – 2

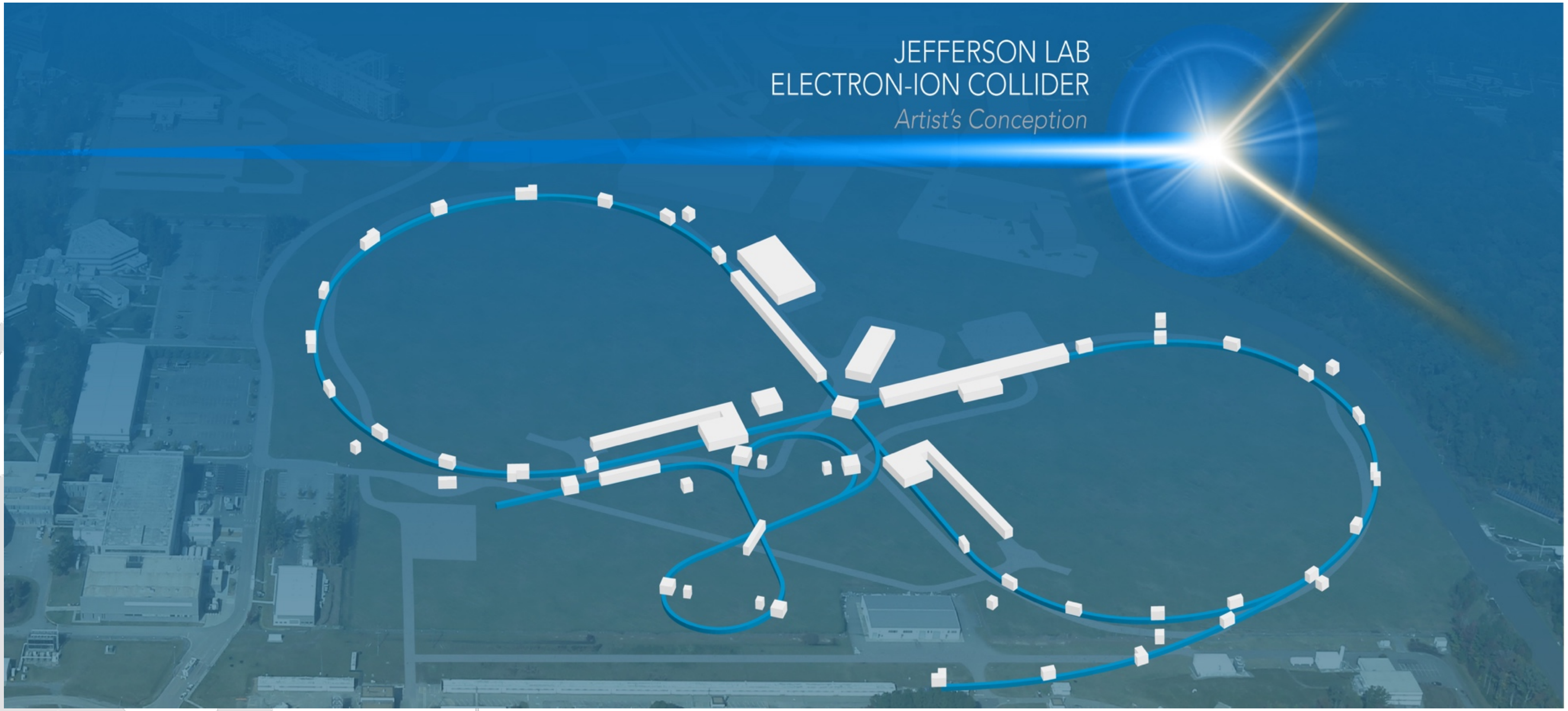
4K cold box

SC dipole magnet

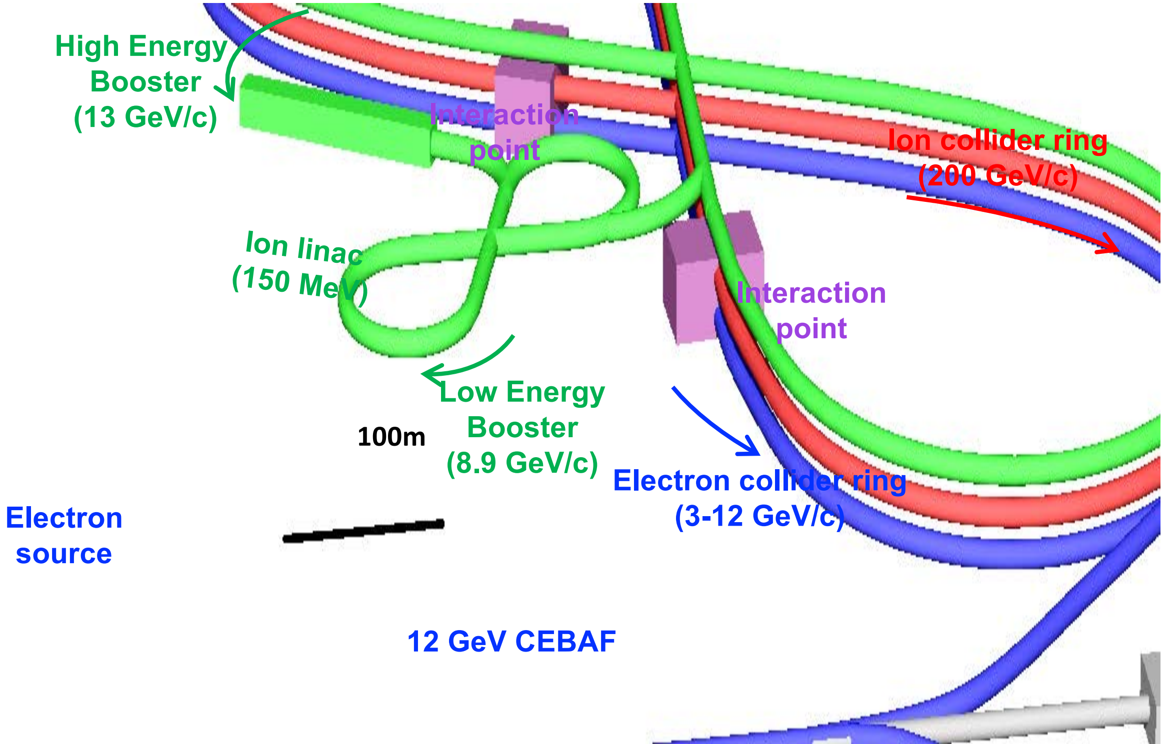
Warm iron quadrupole magnet



Overview of JLEIC – The EIC at Jefferson Lab



JLEIC Overview



- **Electron complex**
  - CEBAF as a full energy injector
  - Electron collider ring (ECR): 3-12 GeV/c
- **Ion complex**
  - Ion source, SRF linac: 150 MeV for proton s
  - Low Energy Booster (LEB): 8.9 GeV/c
  - High Energy Booster (HEB): 13 GeV/c
  - Ion collider ring (ICR): 200 GeV/c
- **Up to two detectors** at minimum background l ocations
- **20-100 GeV CM, Upgradable to 140 GeV CM**

45

Magnets, Kickers, BPMs - Summary

Element	Type	Electron Complex	Ion Complex
Length of Beamline		2,669 m	5,416 m
Dipole Magnets	Normal-Conducting	369	252
	Superconducting	-	258
Quadrupole Magnets	Normal-Conducting	515	394
	Superconducting	6	196
Sextupole Magnets	Normal-Conducting	148	48
	Superconducting	-	56
Correctors Magnets	Normal-Conducting	321	164
	Superconducting	-	55
Solenoids Magnets	Superconducting	10	6
Kickers	Normal-Conducting	2	6
BPMs		321	337

Accelerating and Bunching – Summary

		# Cavitie s	Cavities per unit	Fwd Pwr per cavity (kW)
Electron Collider Ring	Acceleration – Normal Conducting	16**	1	500**
	Acceleration – SRF	12	4	600
	Crab Cavities – SRF	6	3	40
Low Energy Booster	Acceleration/Bunch Control	3	1	50
High Energy Booster	Acceleration/Bunch Control	7	1	100
Ion Collider Ring	Acceleration/Bunch Control – Normal Conducting	3	1	120
	Bunch Control – SRF	26	4	120
	Crab Cavities – SRF	24	6	30
Electron Cooling	DC Cooler (LEB)	1	4	50
	DC Cooler (HEB)	1	1	50
	Bunched Beam (ICR) – ERL	15	2	50

** - PEP-II Cavities and HPAs

Thanks

All the information presented was provided by my generous collaborators

- Sonia Utermann, GSI, Germany
- Pavel Logachev, BINP, Russia
- Hongwei Zhao, IMP, China
- Won Namkung, PAL, Korea
- Alexander Kovalenko, Dubna, Russia
- Paul Mantica, NCLS, USA
- Ferdi Willeke, BNL, USA
- Tim Michalski, Jefferson Lab, USA

Thanks to all of you!

Additional Slides

Here is all the information sent by my collaborators

High-Intensity Heavy Ion Accelerator Facility-HIAF

HIAF: One of 16 large-scale research facilities proposed in China in order to boost basic science, next-generation high intensity facility for advances in nuclear physics and related research fields.

The HIAF project:

- Proposed by IMP in 2009.
- Approved in principle by the central government in the end of the 2012.
- The final approval was in the December of 2015
- **Construction started in the end of 2018, early completion in 2025.**
- **The total budget of facility is about $400 million, including $160 million of local government**

Science motivations:

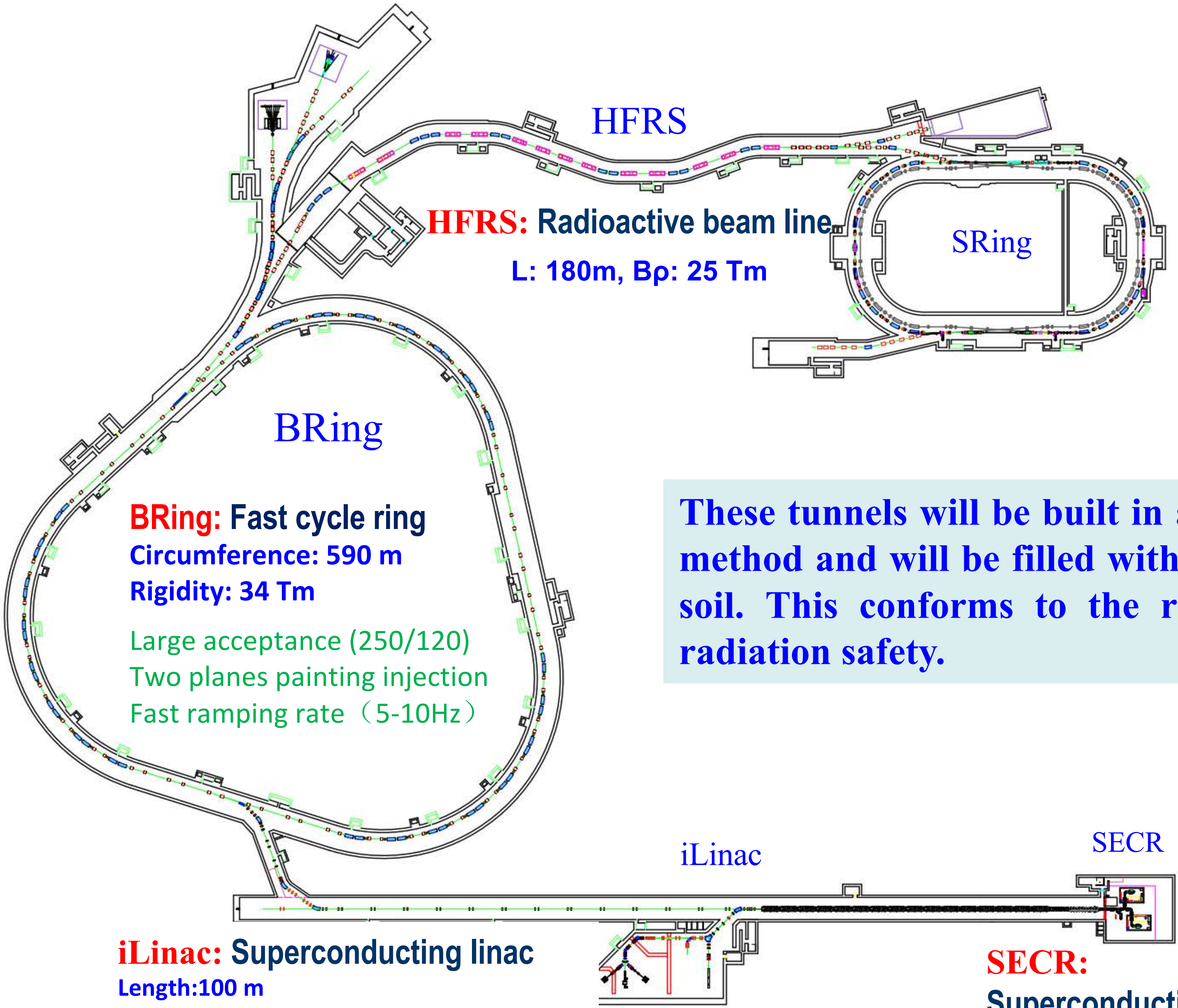
※ High intensity radioactive beams to investigate the structure of exotic nuclei, nuclear reactions of astrophysics and to measure the mass of nuclei with high precision.

※ High charge state ions for a series of atomic physics programs.

※ Quasi-continuous beam with wide energy range for applied science.

※ High energy and intensity ultra-short bunched ion beams for high energy and density matter research.

HIAF: Main accelerator components



HFRS: Radioactive beam line

L: 180m, Bρ: 25 Tm

SRing: Spectrometer ring

Circumference: 273m

Rigidity: 13-15 Tm

Electron/Stochastic cooling
Two TOF detectors
Four operation modes

BRing: Fast cycle ring

Circumference: 590 m

Rigidity: 34 Tm

Large acceptance (250/120)
Two planes painting injection
Fast ramping rate（5-10Hz）

These tunnels will be built in a cut and cover method and will be filled with 5 m overlay of soil. This conforms to the requirements of radiation safety.

iLinac: Superconducting linac

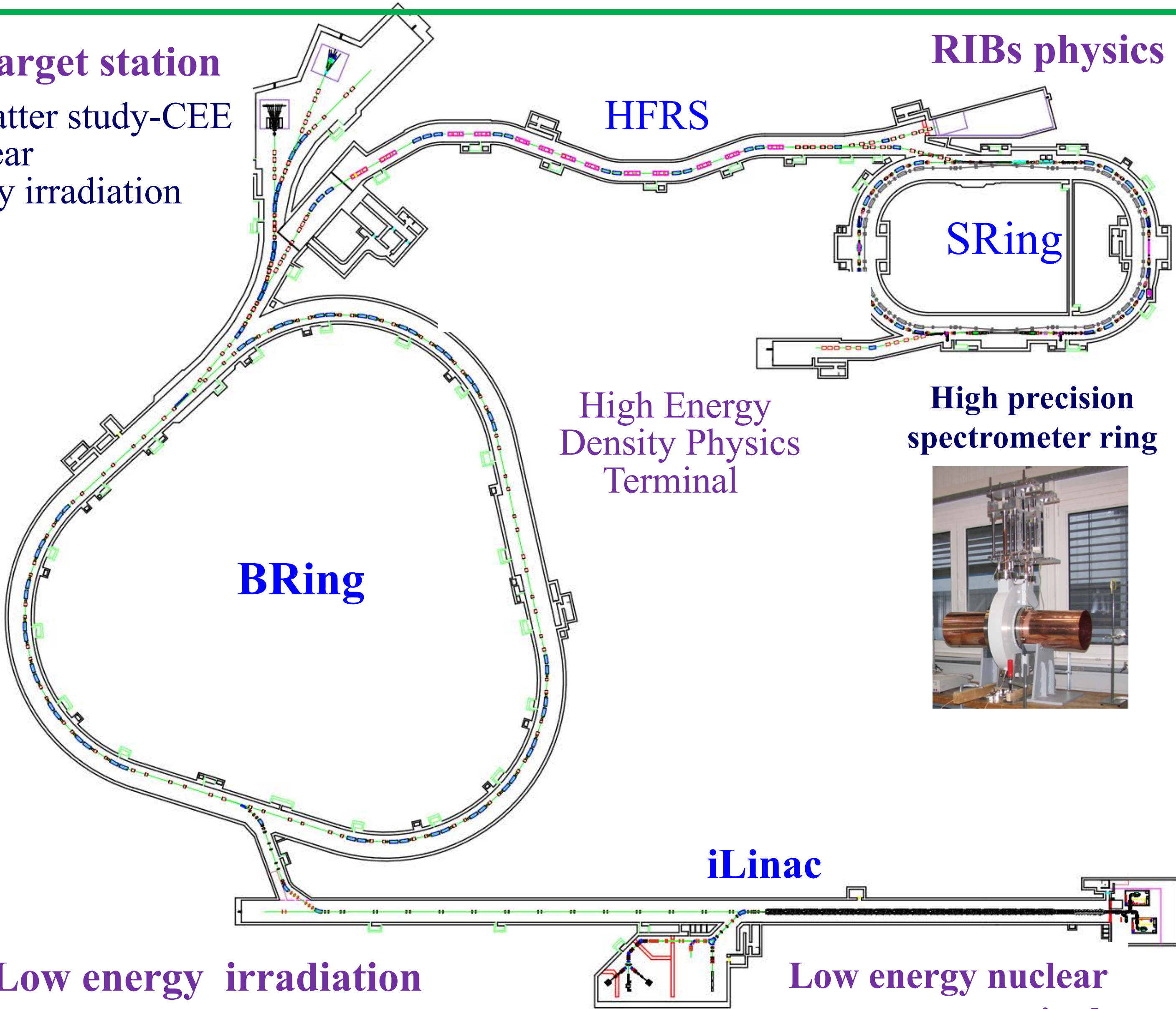
Length:100 m

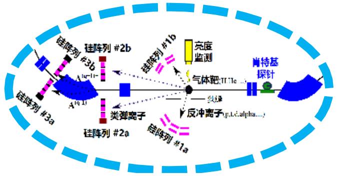
Energy: 17-22 MeV/u($U^{35+\text{-}45+}$)

SECR:

Superconducting ECR source

HIAF: Experiment terminals





High precision spectrometer ring

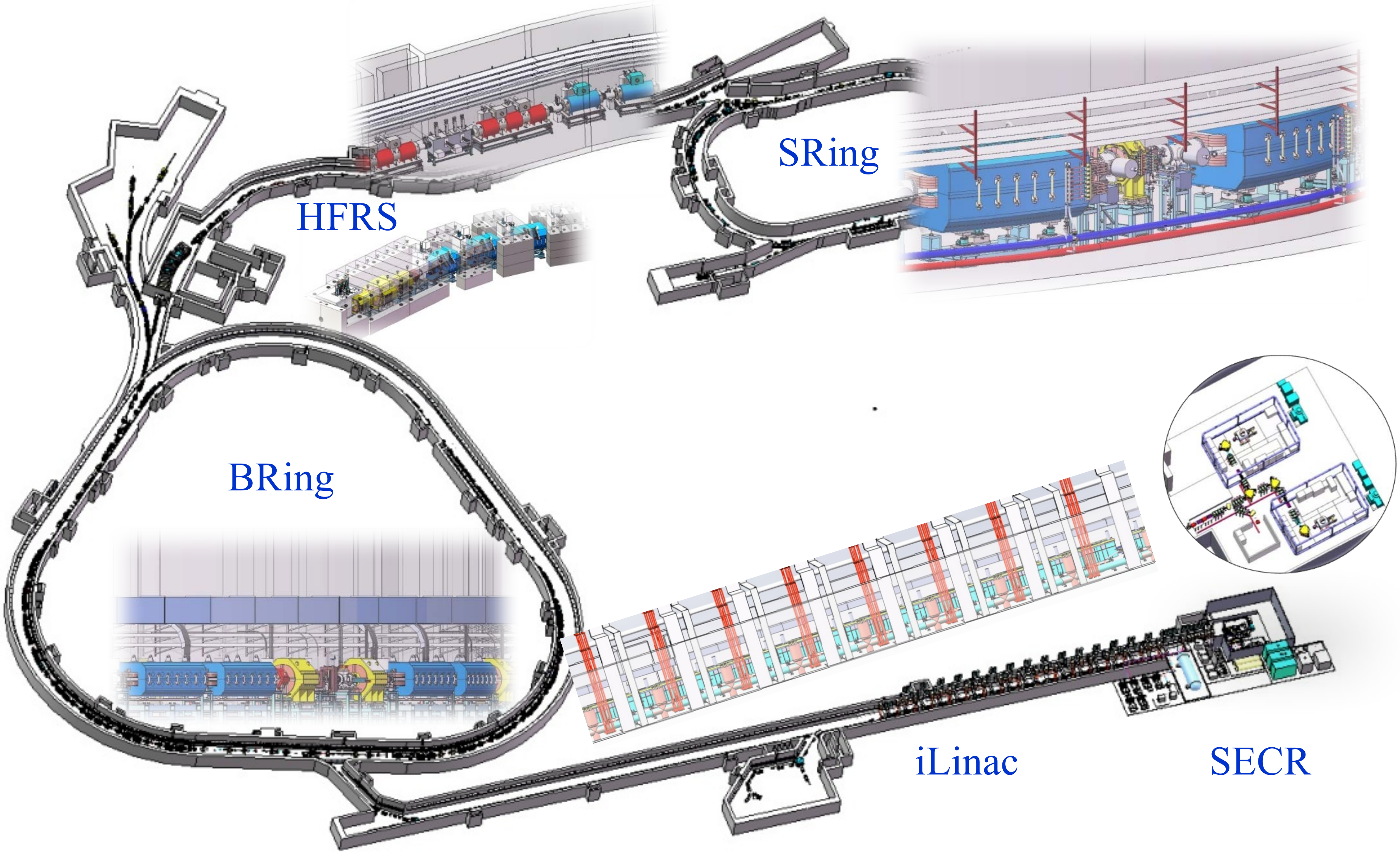
Around the whole facility, there are a series of experiments terminals

HIAF: Basic beam parameters

	Ions	Energy	Intensity
SECR	$^{238}U^{35+}$	14 keV/u	0.05-0.1 pmA
iLinac	$^{238}U^{35+}$	17-22 MeV/u	0.028-0.05 pmA
BRing	$^{238}U^{35+}$	0.8 GeV/u	$\sim 2.0\times10^{11}$ppp
	$^{238}U^{76+}$	2.45 GeV/u	$\sim 5.0\times10^{10}$ ppp
SRing	RIBs: neutron-rich, proton-rich	0.84 GeV/u(A/q=3)	$\sim 10^{9-10}$ ppp
	Fully stripped heavy ions H-like, He-like heavy ions	0.8 GeV/u($^{238}U^{92+}$)	$\sim 10^{11-12}$ ppp

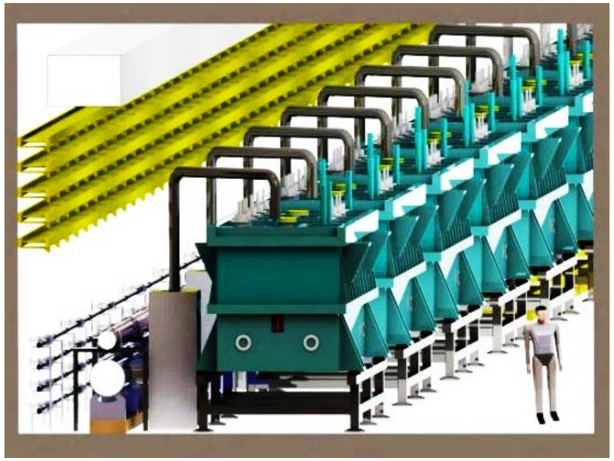
HIAF: Present status

Details of technical design has been finished and most of hardware systems are under production.

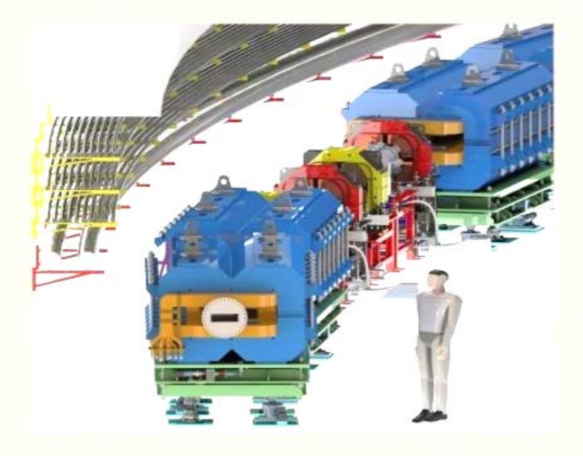


HIAF: Present status

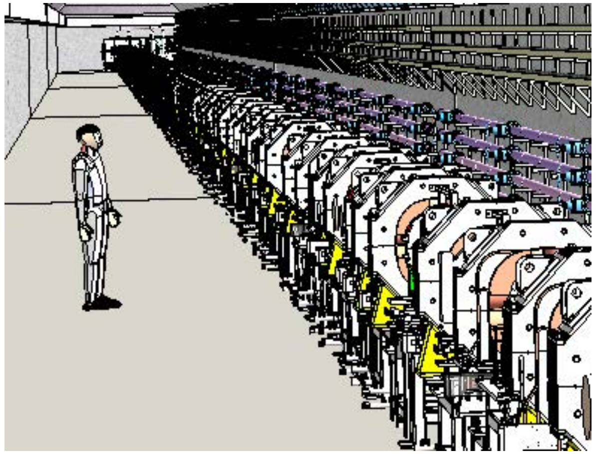
The civil construction and common system are going smoothly



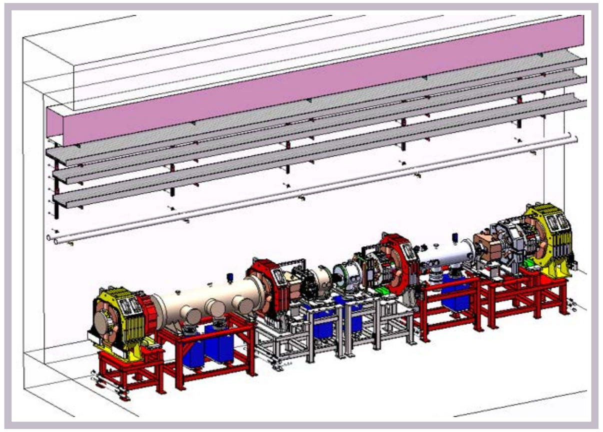
iLinac section



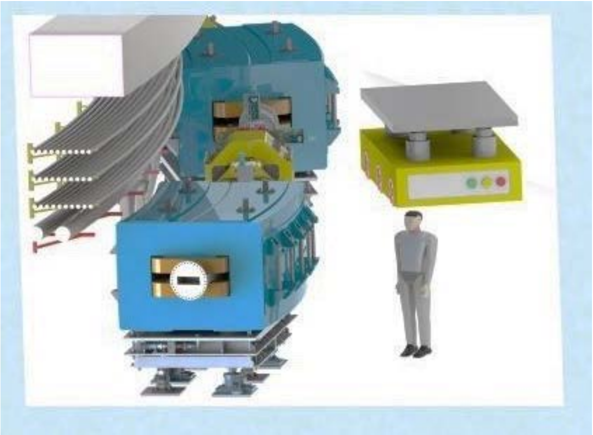
BRing arc section



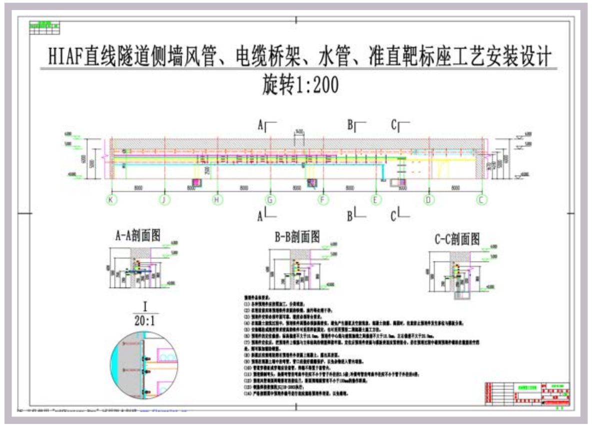
BRing straight section



Beam transfer line



SRing arc section



Tunnel mechanical installation

HIAF: Present status

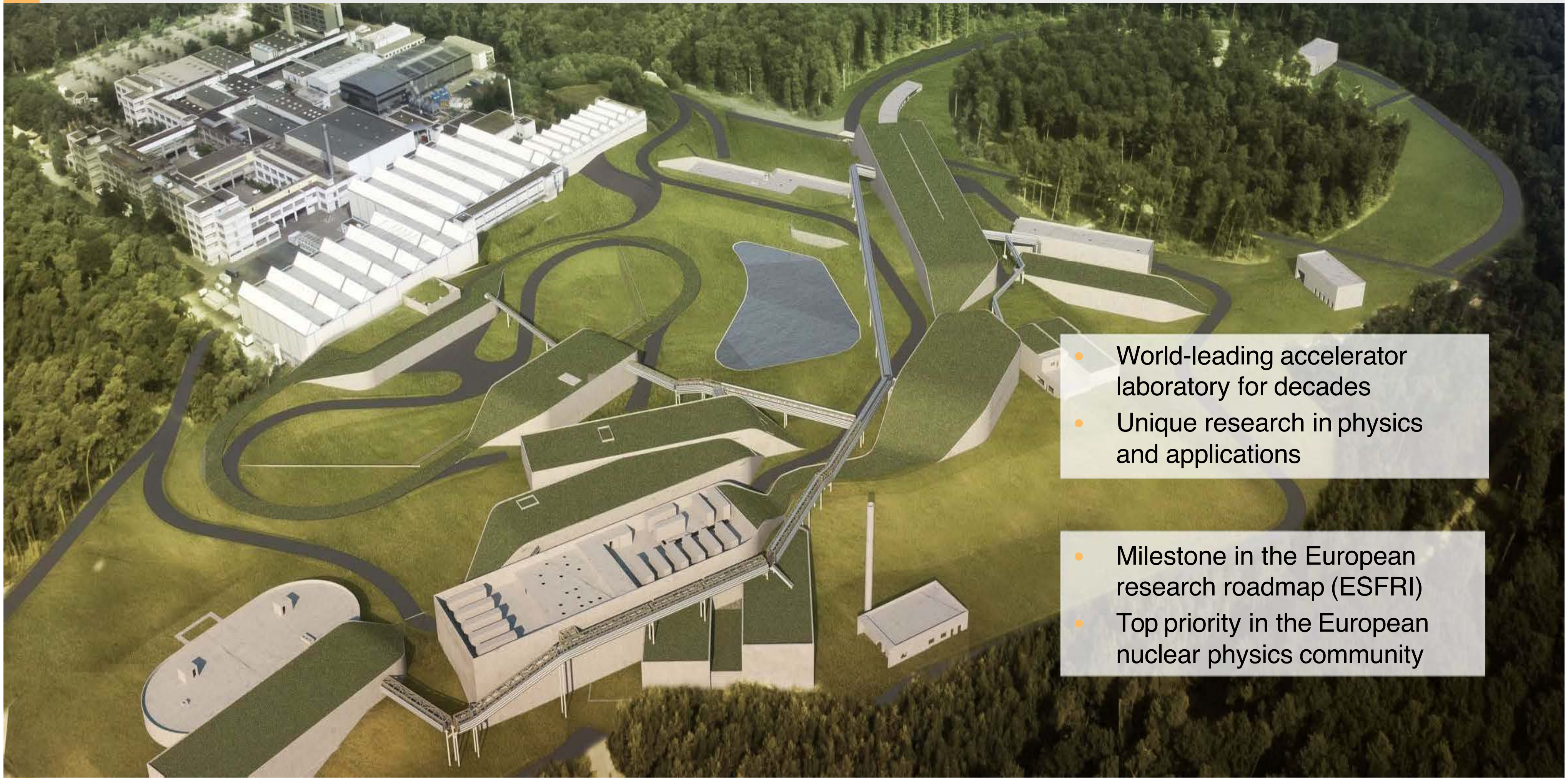
The planed construction period is about 7 years, and the early completion is expected in the end of 2025

The FAIR Project

Realization of the world's unique particle accelerator facility in Darmstadt

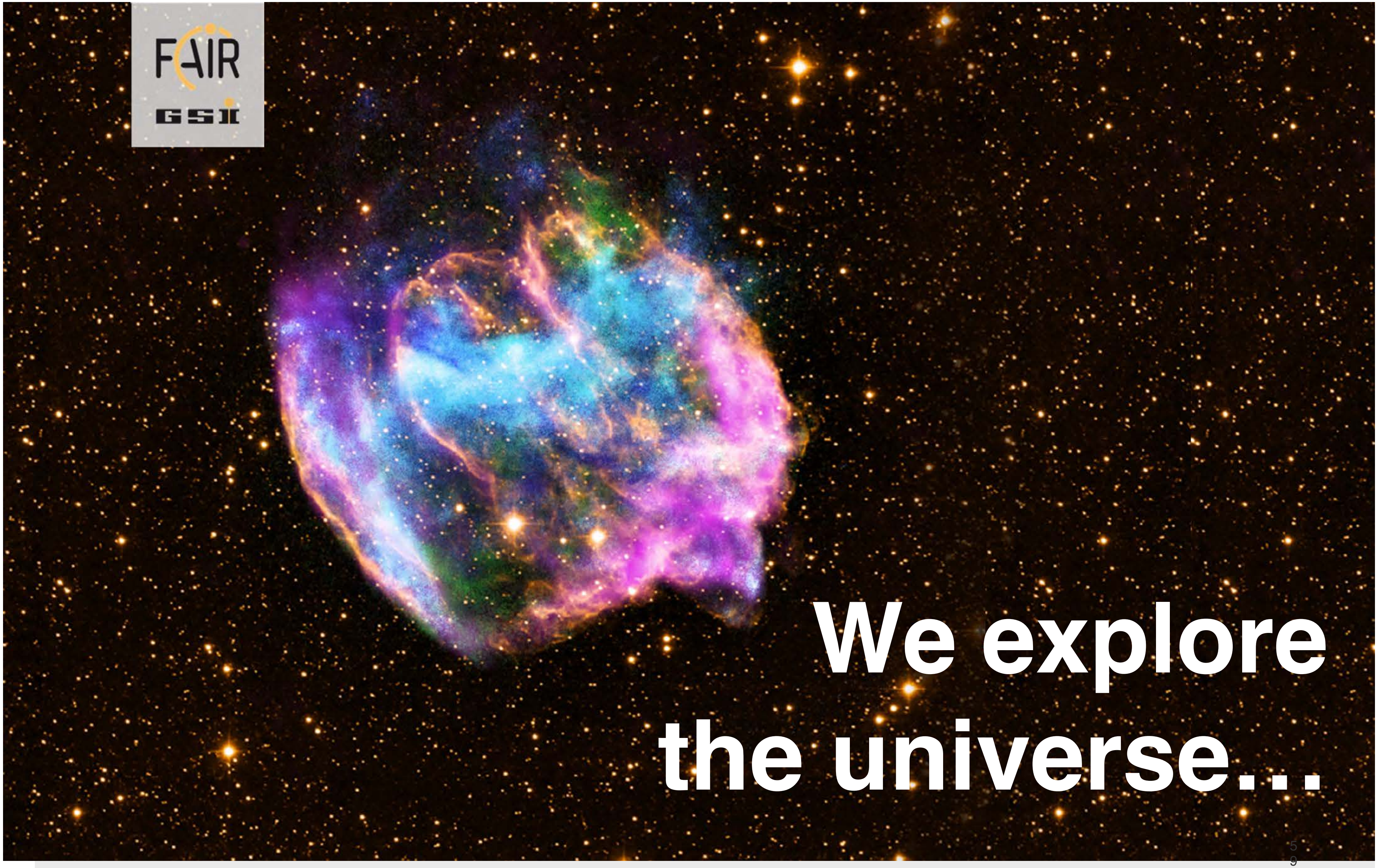
September 2019

Accelerator facilities GSI and FAIR

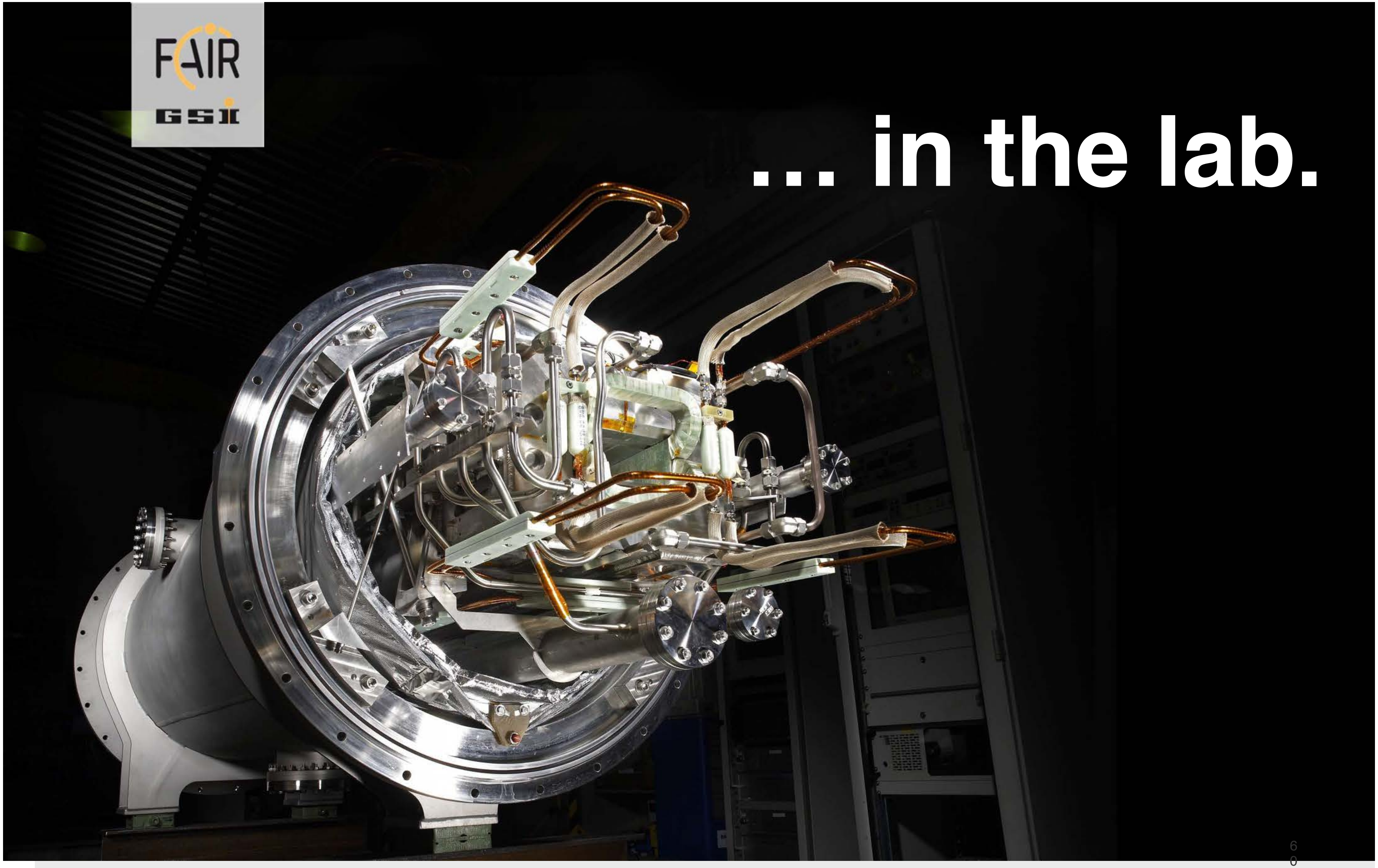


- World-leading accelerator laboratory for decades
- Unique research in physics and applications

- Milestone in the European research roadmap (ESFRI)
- Top priority in the European nuclear physics community

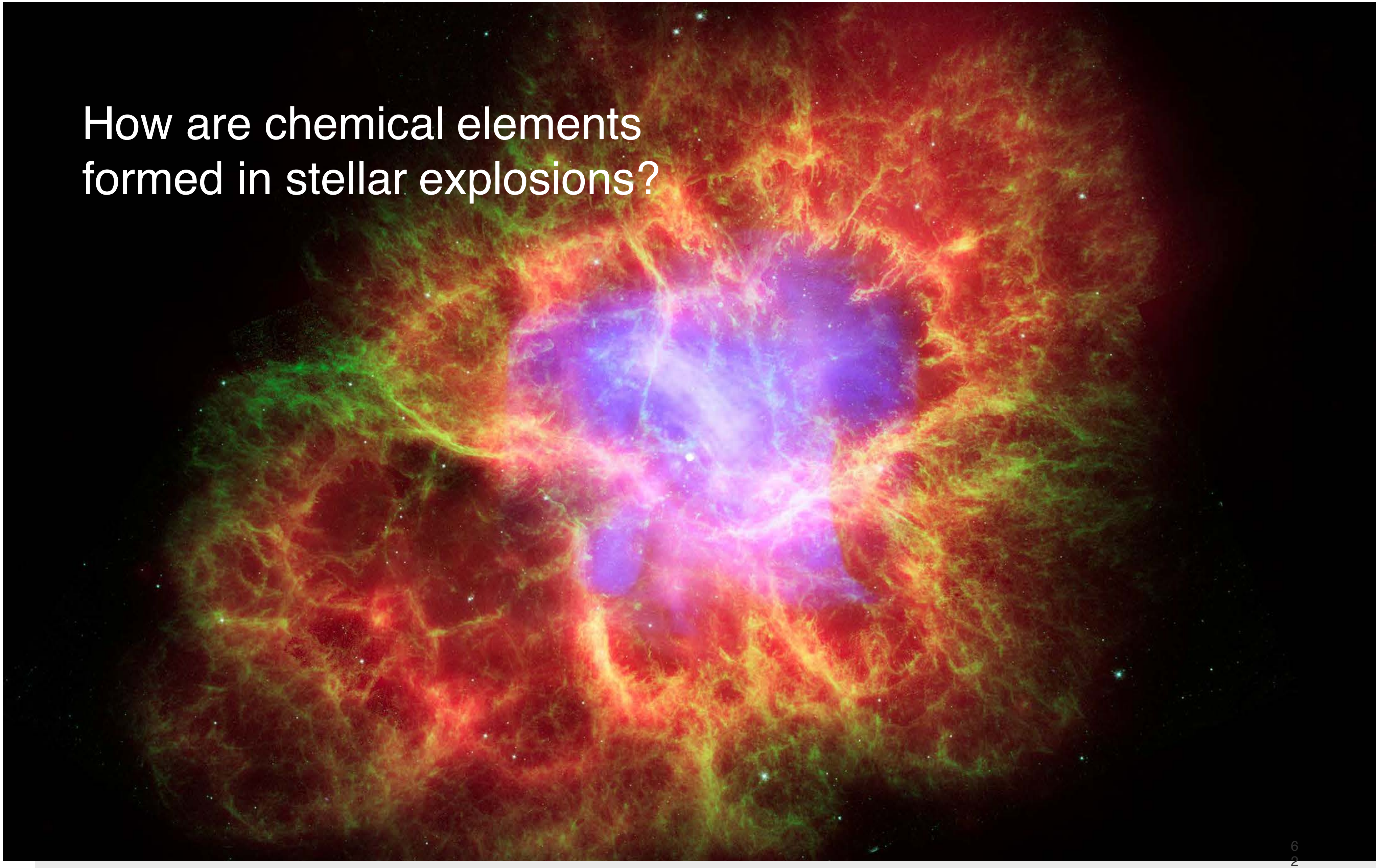

FAIR
GSI
We explore
the universe…

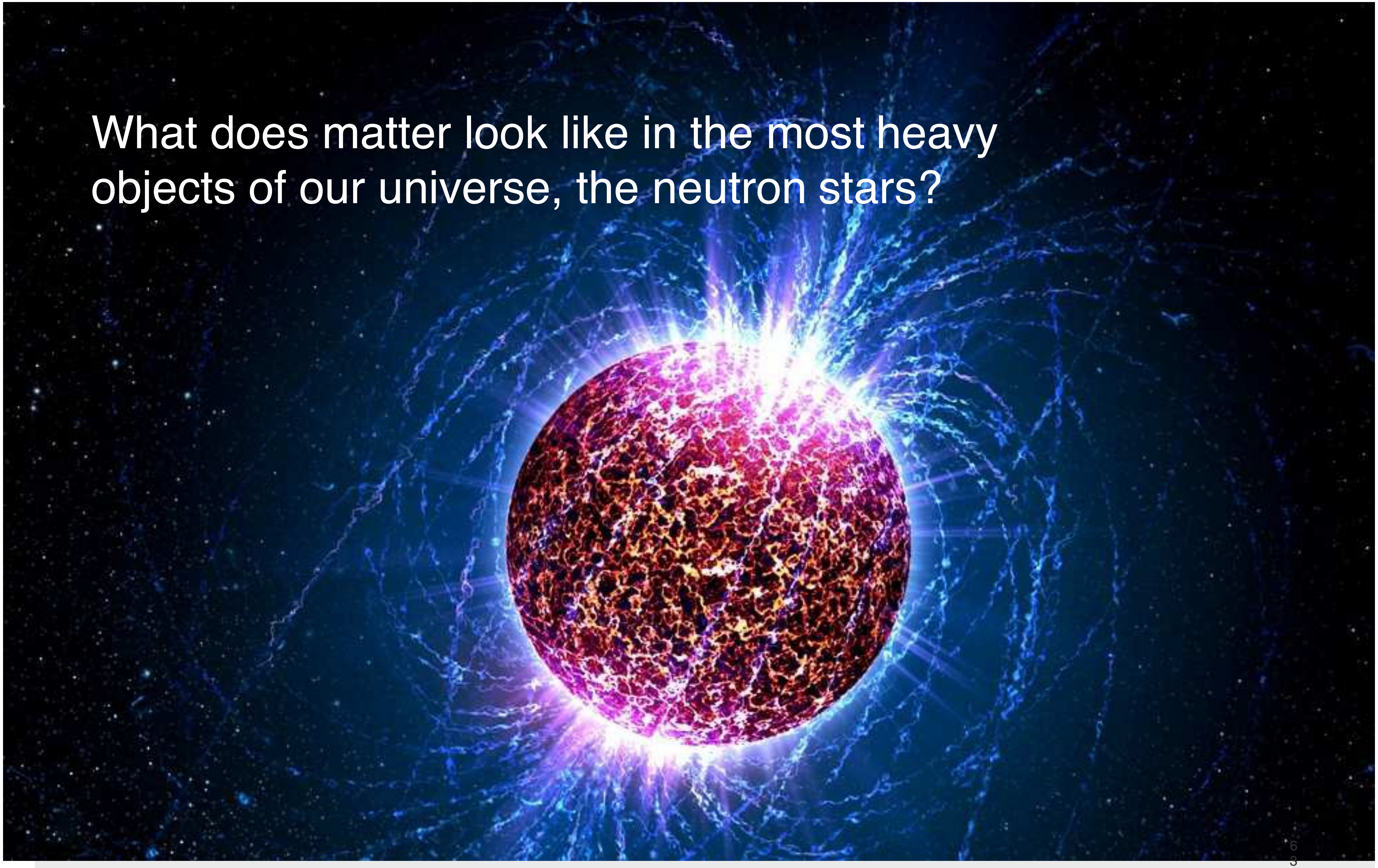
… in the lab.



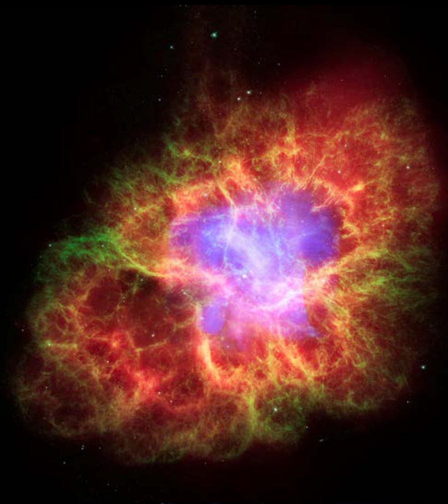
What are the smallest
building blocks
of our matter?

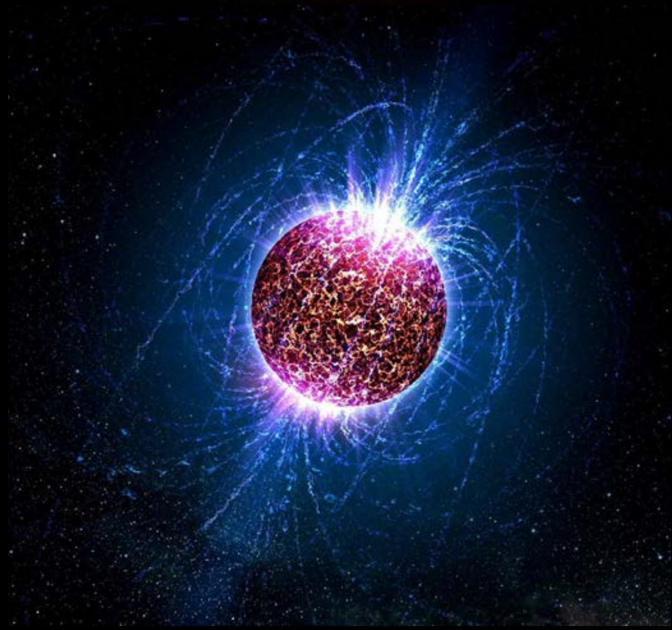
How, when and
where did they
come into being?


How are chemical elements
formed in stellar explosions?

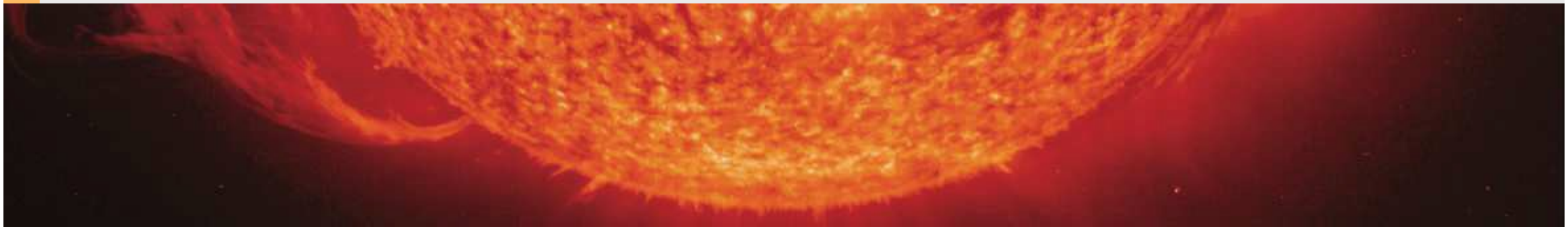

What does matter look like in the most heavy objects of our universe, the neutron stars?

Cosmic matter can be produced with particle accelerators in the lab.





The four scientific pillars at FAIR



NUSTAR
Nuclear Structure, Astrophysics and Reactions: Stars and nuclei
(850 scientists)

CBM
Compressed Baryonic Matter: Inside a neutron star
(500 scientists)

PANDA
Antiproton-Annihilation at Darmstadt: Antimatter research
(500 scientists)

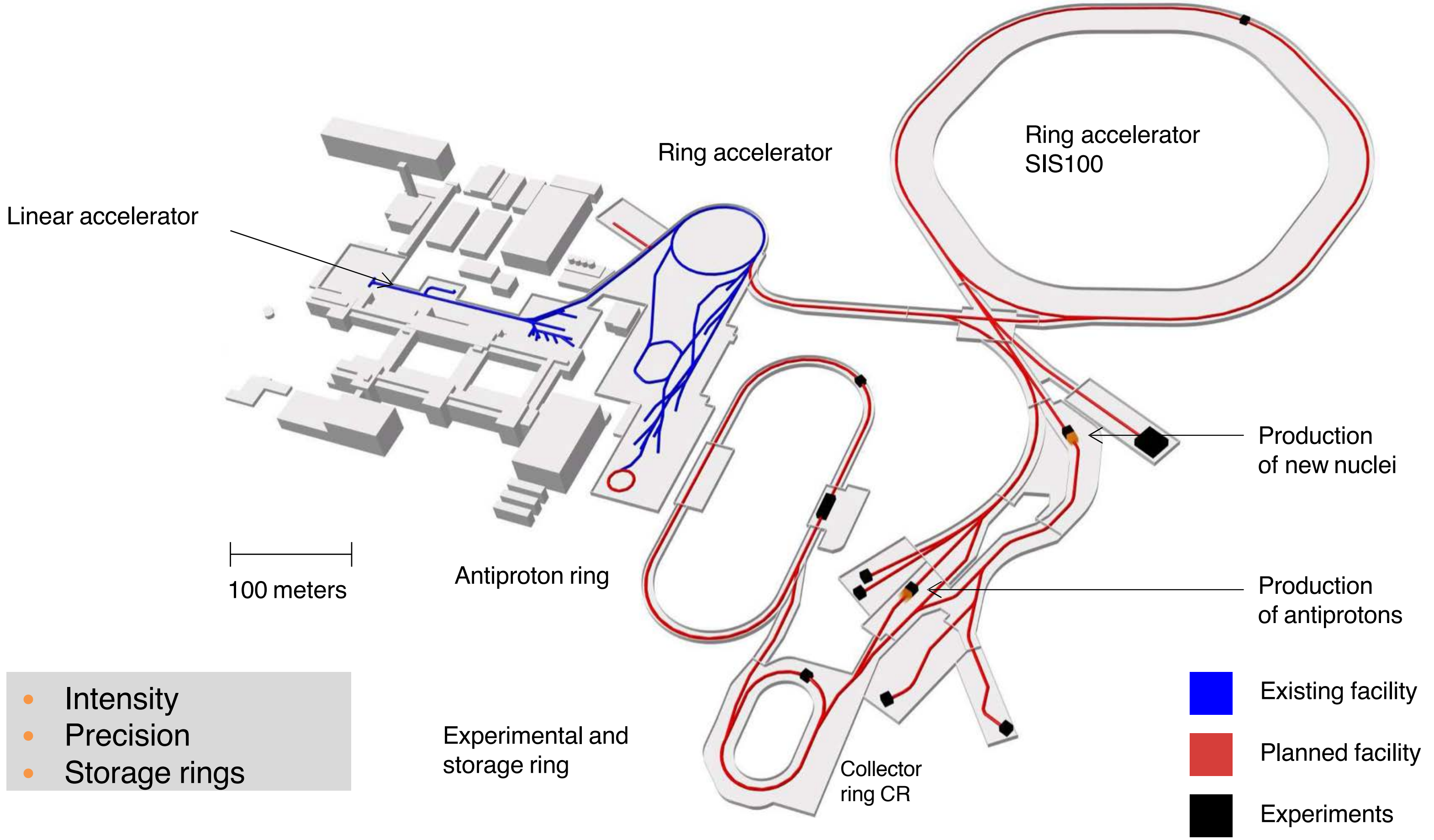
APPA
Atomic, Plasma Physics and Applications: From atoms to planets to cancer research
(720 scientists)

FAIR—Facility for Antiproton and Ion Research

In addition to the existing linac and ring accelerator and storage ring at GSI, FAIR is building:

- A ring accelerator, 1.1 km in circumference
- 3 storage rings
- 1 linac
- 2 major target stations
- 1 super fragment separator with extra-large acceptance

FAIR – The facility



- Intensity
- Precision
- Storage rings

FAIR — key figures

Completion until

2025

Investments

> €1 billion

70% of this amount will be provided by the German federal government and the State of Hesse

Area covered by the land-use plan

686,373 m²

Construction volumes

2 million m³

of earth

to be moved

As much as for 5,000 single-family homes

600,000 m³

of concrete

to be used

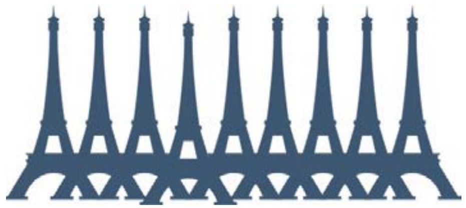
As much as eight Frankfurt soccer stadiums

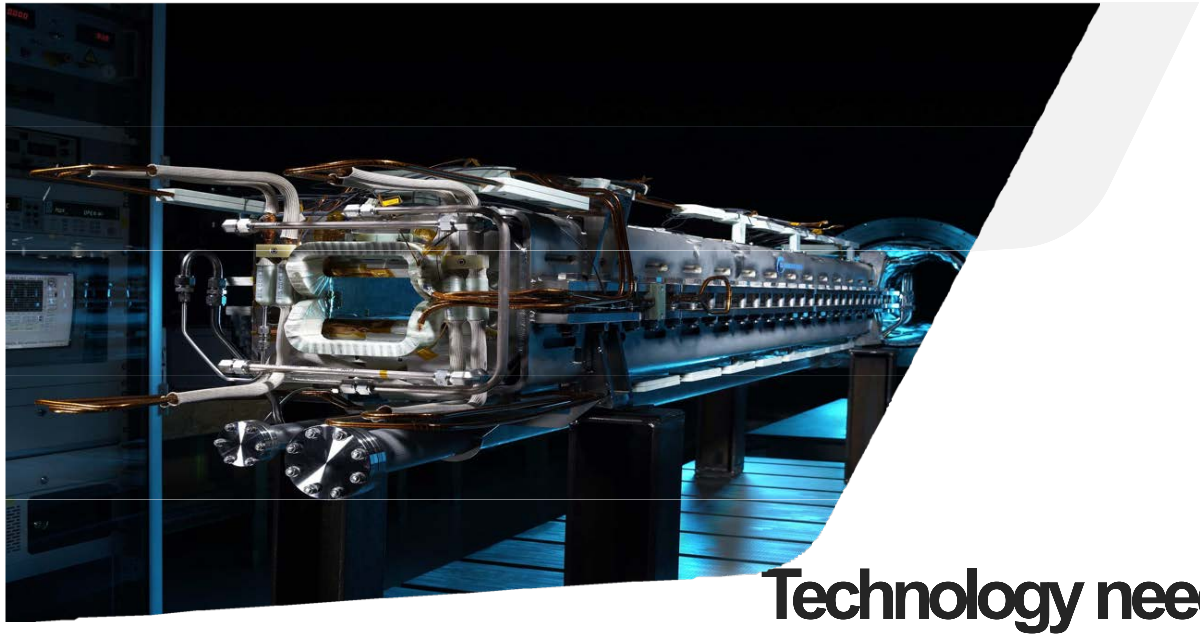
65,000 tons

of steel

to be utilized

As much as nine Eiffel Towers





Technology needs

1500

magnets

Worth 200 M€

1000

power supplies

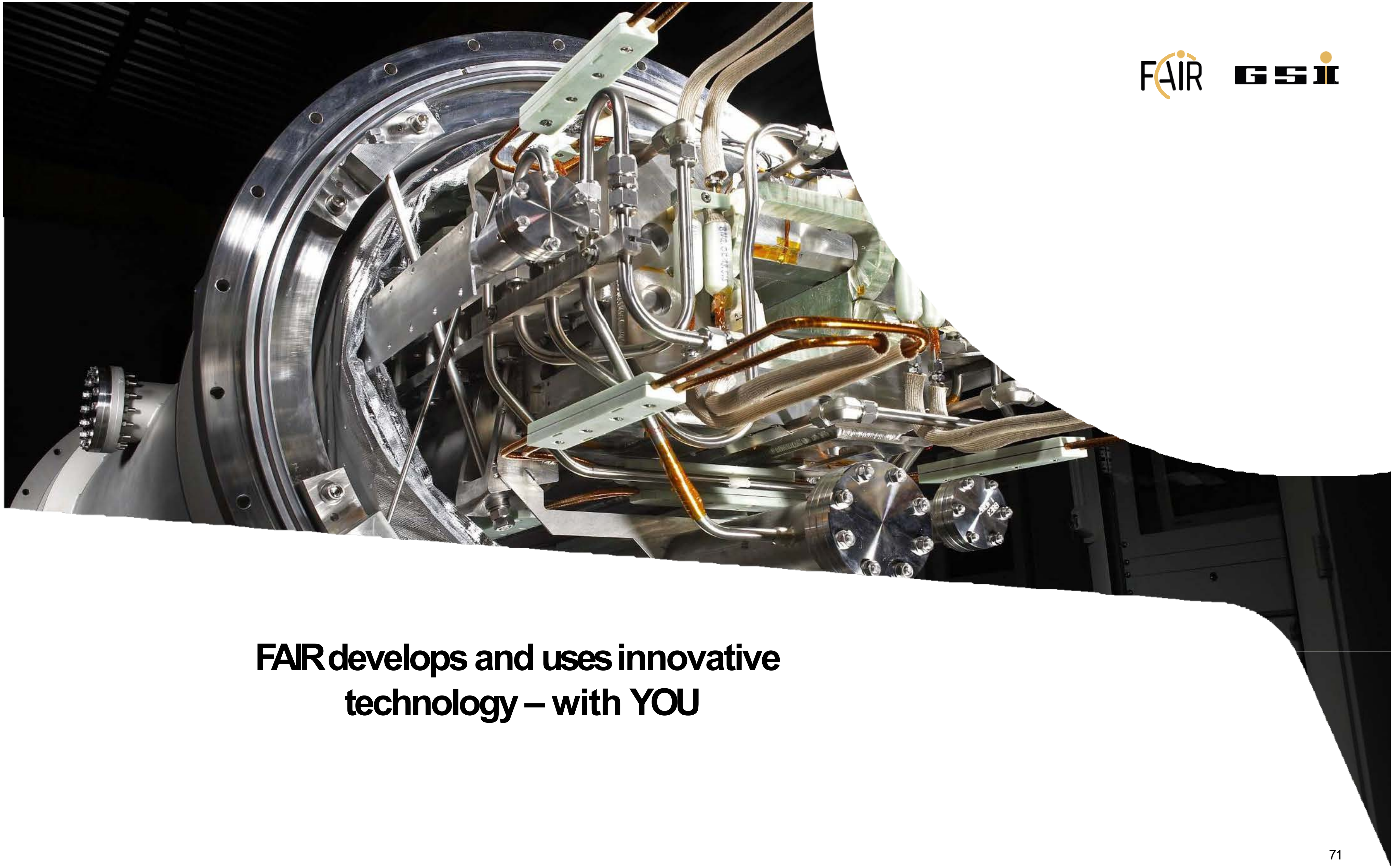
worth 30 M€

1500

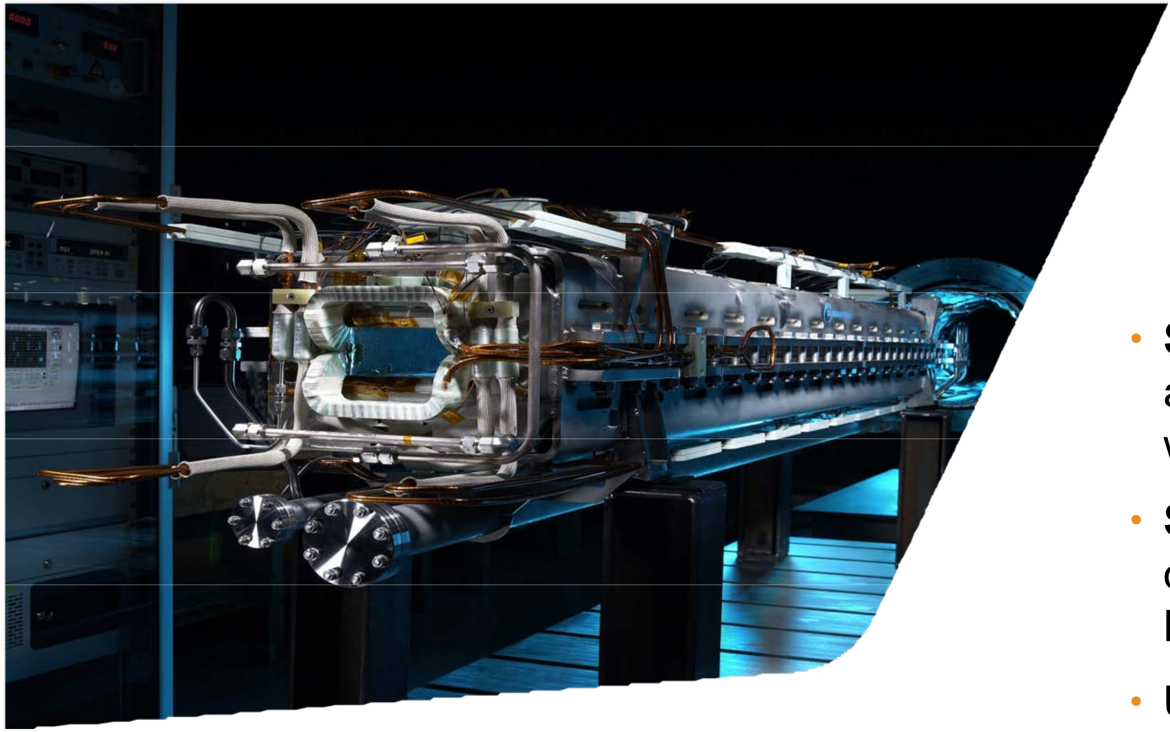
vacuum chambers

worth 20 M€

Of which 600 are superconducting



FAIR develops and uses innovative technology – with YOU



Overview of technology

- **Superconducting magnets**: for strong and rapidly changing magnetic fields with maximum field precision
- **Sophisticated cryotechnology**: Use of liquid helium to cool down to 4 Kelvin (-269°C)
- **Ultra-high vacuum**: 10^{15} times below the earth's air pressure
- **Development and construction** of cryo-collimators with special coatings

Credit: Babcock Noell

Current technical needs

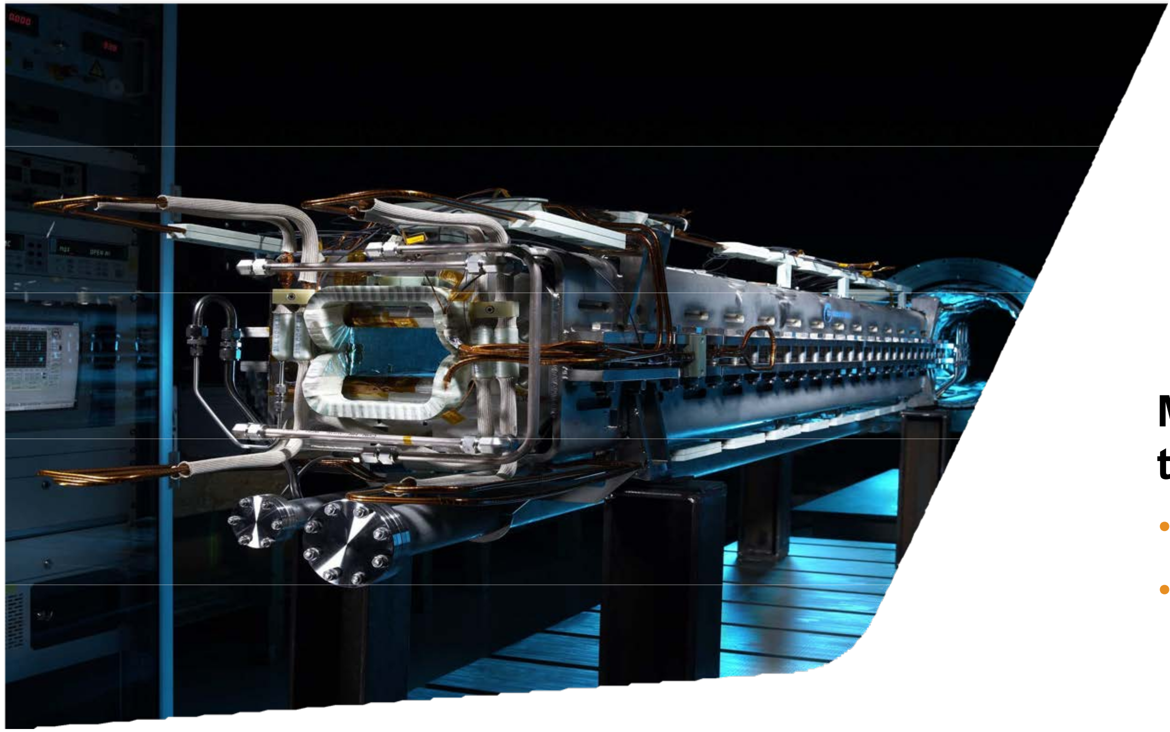
For the Proton Linac

- 3 crossbar H-Mode cavities (CH) and 3 coupled crossbar H-Mode cavities (CCH)
- Stainless steel
- Operating resonance frequency 325 MHz
- Duty cycle 0.5 ‰
- CALL TO TENDER NOW OPEN

Current technical needs

GHE tanks

- 26 standing helium tanks
- each 100 cubic metres
- for storing helium gas at ambient temperature at a maximum pressure of 20 bar.
- Pipe class PN25



Current technical needs

Modular stands for high-energy beam transport

- 317 stands of six different types
- For mounting magnets and diagnostic chambers

Power parts

- Various parts with various power and ramping specifications

3 Local cryogenic plants

Current technical needs

Sup ent separator shielding of the target area

- Cast iron grade GJL150 - 250 or GJS with
- ^{60}Co content less than 50 ppm
- nickel content below 0.5%.

Pbar target station (for antiprotons)

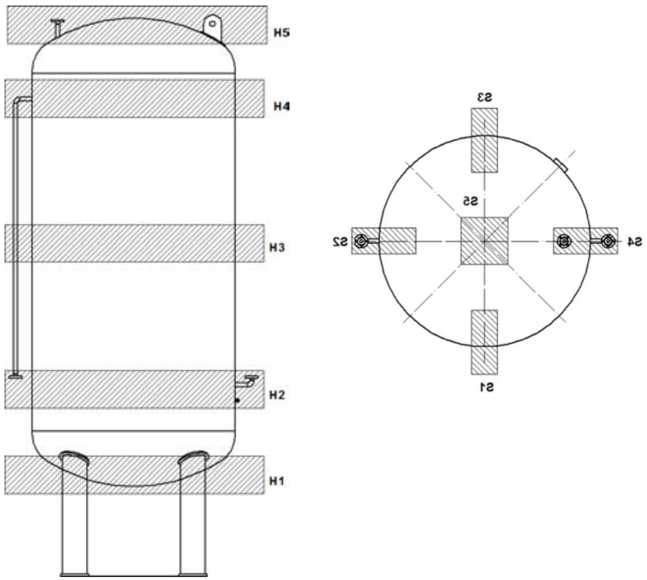
- main shielding block (150t)
- 1st (24t) and 2nd (8.5t) sliding doors
- sliding doors support and 2 sliding door motor
- graphite collimator
- copper and iron collimators stack
- adjustment table

Various UHV components

Various diagnostics

Please visit our procurement website:
www.gsi.de/start/wirtschaft_industrie.htm

Current technical needs



GHE Storage Tanks (PSP 2.14.8.1.7)

Content of delivery:

- 26 Storage vessels.
- One storage vessel in one unit, finally mounted, tested and packed.
- specification completed as required, including all performance descriptions and drawings.

Dimensions:

- positioning Vertical
- geometric volume 100 m³
- outside diameter Max- 2800 mm

FAIR

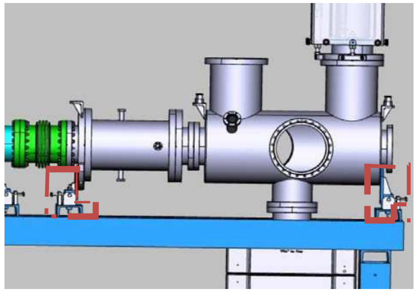
Facility for Antiproton and
Ion Research in Europe GmbH
Planckstraße 1
64291 Darmstadt
www.fair-center.eu

Necessary technological capabilities:

- detailed 3D design
- billets cutting
- welding work
- anticorrosion processing and painting
- tests and inspections according codes and standards

Contract signing date (Milestone M4) 02/2020

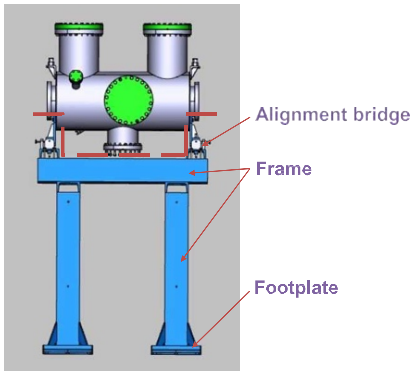
Frames for HEBT (PSP: 2.3.11.13.2 and 2.3.11.13.3) (indicated in blue and red)



Frames category I

Scope of delivery:
- dimensioning, design
- production for all parts
- weight – 500 kg

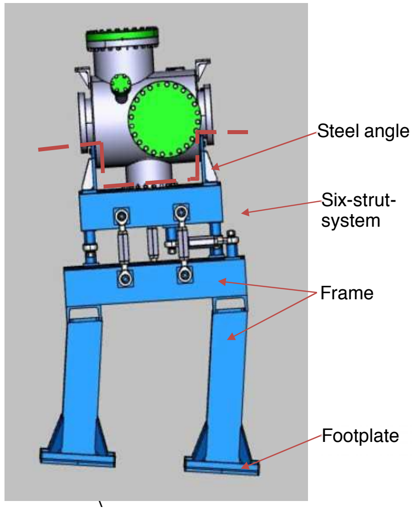
Necessary technological capabilities:
- detailed 3D design
- billets cutting
- welding work
- electrolytic galvanizing and painting



Frames category II

Scope of delivery:
- dimensioning, design
- production for all parts
- weight – 500 kg

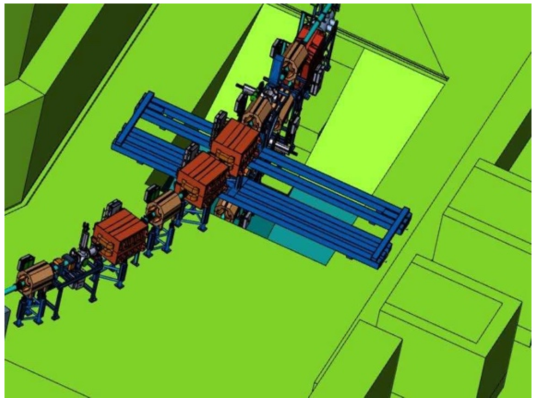
Necessary technological capabilities:
- detailed 3D design
- billets cutting
- welding work
- electrolytic galvanizing and painting



Frames category III

Scope of delivery:
- dimensioning, design
- design for six-strut-system
- production for all parts
- weight – 500 kg

Necessary technological capabilities:
- detailed 3D design
- billets cutting
- welding work
- electrolytic galvanizing and painting



Frames category IV

Scope of delivery:
- dimensioning, design
- production for all parts
- Frame load– 12000 kg

Necessary technological capabilities:
- detailed 3D design
- billets cutting
- welding work
- painting

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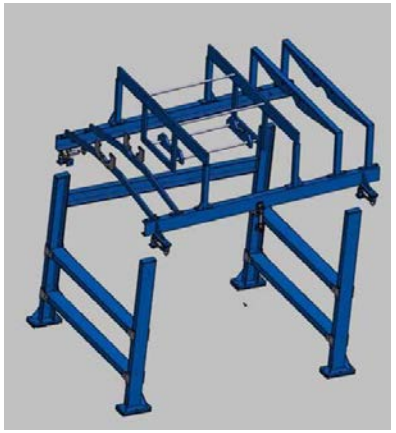
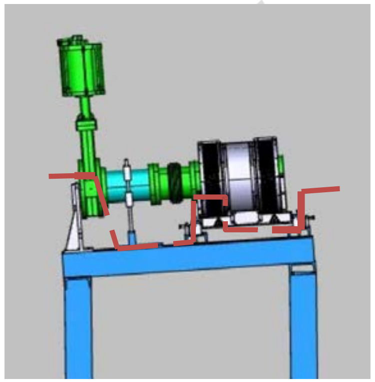


Frames category V
Scope of delivery:
- dimensioning, design
- design for the six strut system
- the development of an compensation for enlargement of components because of the baking process for vacuum
- production for all parts
- weight– 500 kg

Necessary technological capabilities:
- detailed 3D design
- billets cutting
- welding work
- baking process for vacuum to 300°C.
- painting



Frames category VI
Scope of delivery:
- dimensioning, design
- design for the six strut system
- production for all parts
- weight– 500 kg

Necessary technological capabilities:
- detailed 3D design
- billets cutting
- welding work
- electrolytic
- galvanizing painting

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Amount of frames per category

Category	I	II	III	IV	V	VI
Amount	16	61	15	1	1	1

Contract signing date (Milestone M4) 03/2020

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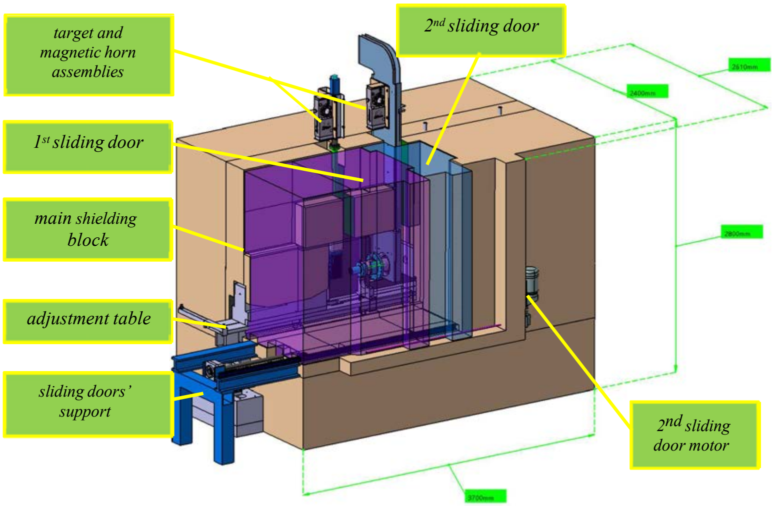

Shielding of the pbar target station (PSP 2.9.11.6.1)

The antiprotons are generated by a primary proton beam that is interacting with a nickel rod. The main purpose of the target station is the suppression of secondary particles originating from the target. The shielding of the target station is pre-designed to have 1.6 m of iron behind the target area and 1 m in each other direction from the target area. The approximate weight of the main shielding block (brown) is 150 t. The 1st door (purple) is 24 t and the 2nd one (light blue) is about 8.5 t. Both doors are sliding on the support frame (blue) and get pushed individually by the motors.

Content of delivery:

- main shielding block (150t)
- 1st (24t) and 2nd (8.5t) sliding doors
- sliding doors support and 2 sliding door motor
- graphite collimator
- copper and iron collimators stack
- adjustment table

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Necessary technological capabilities

- detailed 3D design
- casting steel billets
- billets cutting
- milling the required shape
- welding work
- anticorrosion processing and painting

Contract signing date (Milestone M4) 04/2020

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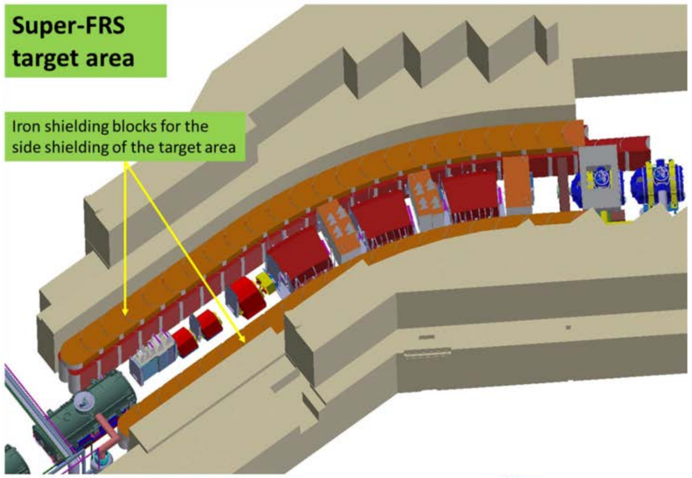
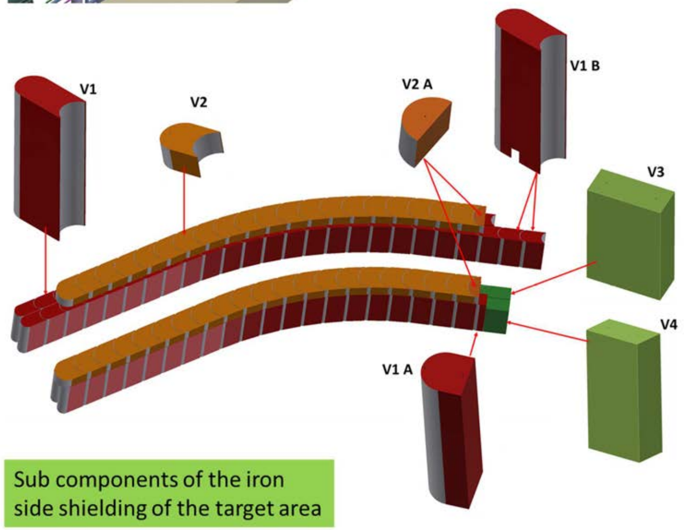
Shielding of the SFRS target area (PSP 2.4.11.4.1)





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Super-FRS target area will require a large amount of iron shielding for radiation protection reasons. The overall work package consists of three parts with an independent PSP for each sub-work package. These three sub-work packages are the side shielding of the target area, the roof shielding, and dedicated inner shielding to balance dimension differences of the various components installed in the target area. The iron shielding serves as an inner shielding and all beamline components are installed within this iron shielding. Those components will never be directly accessible during facility operation but maintenance shall be performed from above by a so-called working platform. The side shielding must be installed in a very early phase of the project, namely during the shell construction of the target building of Super-FRS. The shielding blocks shall be made of Cast Iron Grade GJL 150 - 250 or GJS with ^{60}Co content less than 50 ppm (parts per million) and nickel content below 0.5%. The chemical composition of the material needs to be proven using mass spectroscopic analysis.

Content of delivery:

Component	Weight /component [Ton]	Total number
Shielding block type V1	23.5	86
Shielding block type V1 A	13	2
Shielding block type V1 B	23	2
Shielding block type V2	11.7	40
Shielding block type V2 A	5.2	2
Shielding block type V3	30.1	1
Shielding block type V4	23	1

Necessary technological capabilities:

- Detail 3D design
- Casting steel billets
- Billets cutting
- Milling the required shape
- Anticorrosion processing and painting
- Material quality inspection and certification

Contract signing date (Milestone M4) 04/2020

p-Linac: Bellows

Call for tender shall start in Q4/2019, end of delivery Q2/2021

- ~20 pieces (3 different types)
- Geometry: round, length ~10 cm, diameter DN40, DN100
- flanges: CF

Vacuum Properties

- Integral Leak rate ≤ 1 · 10^{-10} mbar l/s
- Outgassing rate: ≤ 5 · 10^{-10} mbar l/ s cm^2
- Chamber material according DIN EN 10088: 1.4404 or 1.4571
- Flange material according DIN EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- UHV suitable cleaning required

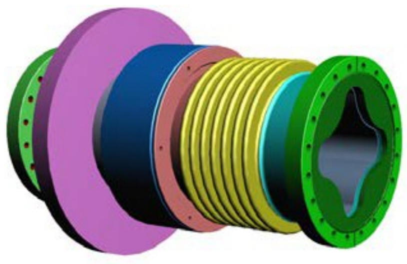
Mechanical requirements:

- Check of welding seam according to DIN EN ISO 9712, quality class DIN EN ISO 5817 B
- Surface quality Rz=25

SIS100: Beam Vacuum Cold Warm Transitions (BV-CWTs)

Call for tender shall start in Q2/2019, delivery until Q4/2020

- ~50 pieces
- 6 types
- Length: ~0.5 m
- Elliptically/star-shaped aperture of inner tube: 133 x 65 mm^2
- Chamber material according to EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- Corrugated (hydroformed) round bellows, material according to EN 10088: 1.4404 or 1.4571
- Flanges DN160CF, material according to EN 10088: 1.4429 ESR
- Additional Helicoflex type seal
- Bake-out jackets (on warm side) part of delivery



BV-CWT with
star-shaped inner tube

BV-CWT with
elliptically shaped inner tube

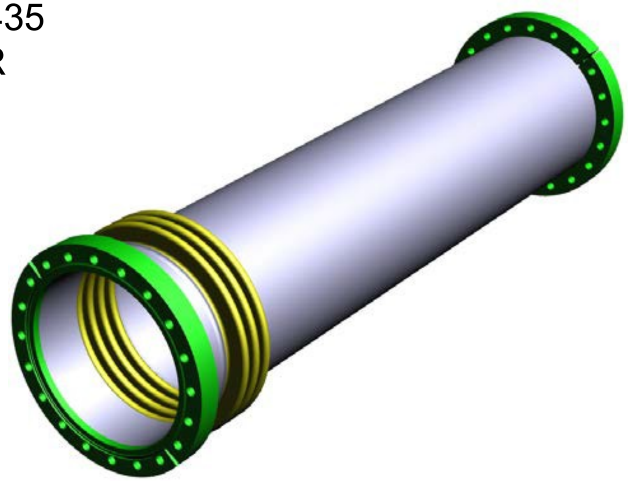
Vacuum requirements:
- Integral leak rate ≤ $1x10^{-10}$ mbar l/s
- Outgassing rate (after bake-out) ≤ $1x10^{-12}$ mbar l/(s cm^2)
- Operational temperature (on cold side) < 20 K
- UHV suitable cleaning
- Bakeable up to 300°C
- Bake-out cycle for acceptance test required

Mechanical requirements:
- Check of welding seams according to ISO 9712, quality class ISO 5817 B
- Surface quality Rz=25

SIS100:
Chamber for Resonance Sextupoles

Call for tender shall start in Q4/2019 , delivery until Q2/2020

- 6 pieces
- Round tube, diameter DN160, with integrated corrugated (hydroformed) bellow
- Chamber length: 730 mm
- Chamber/bellow material according to EN 10088: 1.4429 or 1.4435
- Flanges DN160CF, material according to EN 10088: 1.4429 ESR
- Magnetic permeability $\mu_r \leq 1.01$
- Bake-out jackets part of delivery



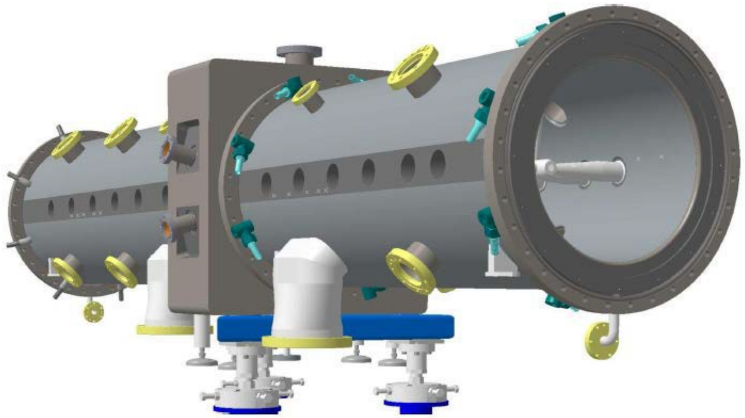
Vacuum requirements:
- Integral leak rate ≤ 1×10^{-10} mbar l/s
- Outgassing rate (after bake-out) ≤ 1×10^{-12} mbar l/(s cm^2)
- UHV suitable cleaning
- Bakeable up to 300°C
- Bake-out cycle for acceptance test required

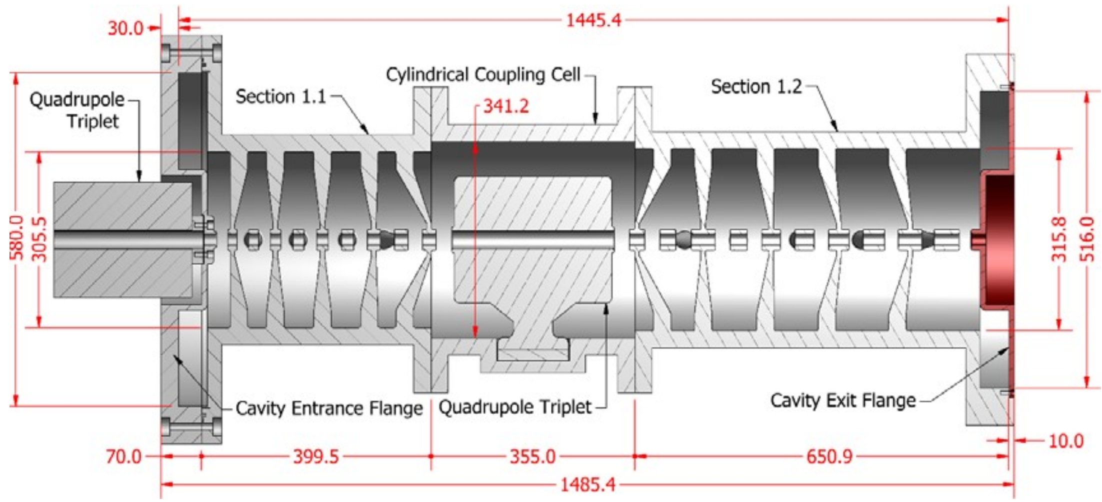
Mechanical requirements:
- Check of welding seams according to ISO 9712, quality class ISO 5817 B
- Surface quality Rz=25

p-Linac: CH & CCH structures

Call for tender shall start in Q4/2019, delivery until Q4/2021

6 pieces (2 types)
Geometry: diameter ~300 to 400mm, length 1.4m to 3.7m, wall thickness ~10 mm





Vacuum Properties

- Integral Leak rate ≤ 1 · 10^{-10} mbar l/s
- Outgassing rate: ≤ 5 · 10^{-10} mbar l/ s cm²
- Chamber material according DIN EN 10088: 1.4301
- Flange material according DIN EN 10088:
- UHV suitable cleaning required

Mechanical requirements:

- Check of welding seam according to DIN EN ISO 9712, quality class DIN EN ISO 5817 B
- Surface quality Rz= 4 - 6.3 (structures will be copper plated at GSI)
- High mechanical accuracy and tolerances for electron beam welding and complex RF structures

SIS100: Cryogenic Bellows

Call for tender shall start in Q1/2020, delivery until Q4/2021

- ~120 pieces
- ~3 types
- Length: ~0.1 m ... ~0.3 m
- Corrugated (hydroformed) round bellows
- Chamber/bellow material according to EN 10088: 1.4404 or 1.4571
- Flanges DN160CF, material according to EN 10088: 1.4429 ESR

<u>Vacuum requirements:</u>

- Integral leak rate ≤ 1x 10^{-10} mbar l/s
- Outgassing rate (after bake-out) ≤ 1x 10^{-12} mbar l/(s cm^2)
- Operational temperature < 20 K
- UHV suitable cleaning
- Bake-out cycle for acceptance test required

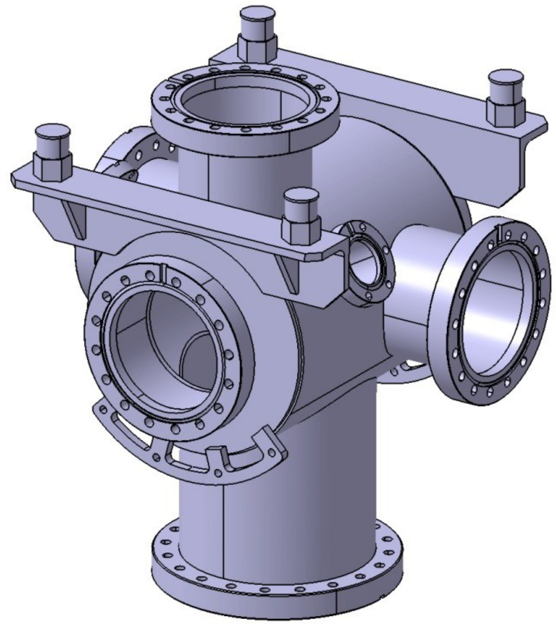
<u>Mechanical requirements:</u>

- Check of welding seams according to ISO 9712, quality class ISO 5817 B
- Surface quality Rz=25

p-Linac: Beam diagnostic chambers

Call for tender shall start end of Q4/2020, delivery Q1/2021

- ~5 pieces (4 different types)
- Geometry: round, length ~250 mm, diameter ~250mm
- with DN100CF flanges



Vacuum Properties

- Integral Leak rate ≤ 1 · 10^{-10} mbar l/s
- Outgassing rate: ≤ 5 · 10^{-10} mbar l/ s cm²
- Chamber material according DIN EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- Flange material according DIN EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- UHV suitable cleaning required

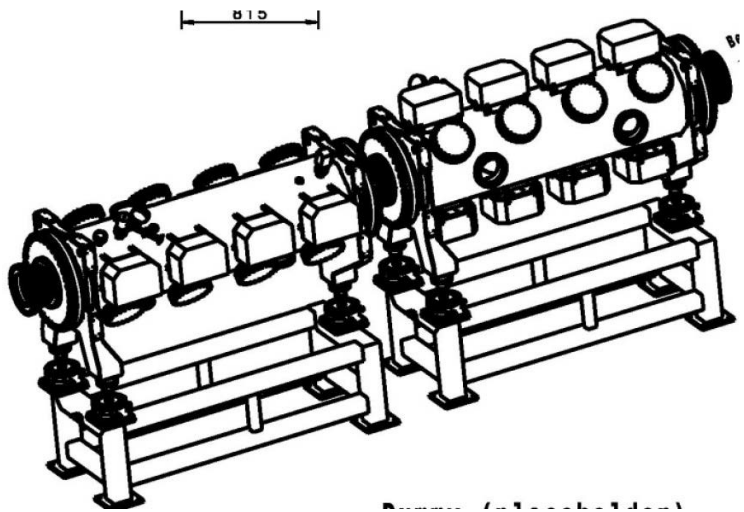
Mechanical requirements:

- Check of welding seam according to DIN EN ISO 9712, quality class DIN EN ISO 5817 B
- Surface quality Rz=25
- High accuracy of orientation of flanges towards beam axis

CR: Double Kicker Tank

Call for tender shall start in Q2/2020, delivery Q4/2020

Two tanks (one double tank)
Geometry: diameter ~500mm, total length of two tanks ~4.7m
Flanges per tank: 2x DN500COF, 8x DN200CF, 2x DN160CF, 8x DN100CF, 8x DN40CF, 2x DN200CF with bellow DN200



Vacuum Properties

- Integral Leak rate ≤ 1 · 10^{-10} mbar l/s
- Outgassing rate: ≤ 5 · 10^{-10} mbar l/s cm²
- Material within the UHV range DIN EN 10088: 1.4306
- Material outside the UHV range DIN EN 10088: 1.4301
- Material for COF Flange according DIN EN 10088: 1.4429 ESR
- UHV suitable cleaning required

Mechanical requirements:

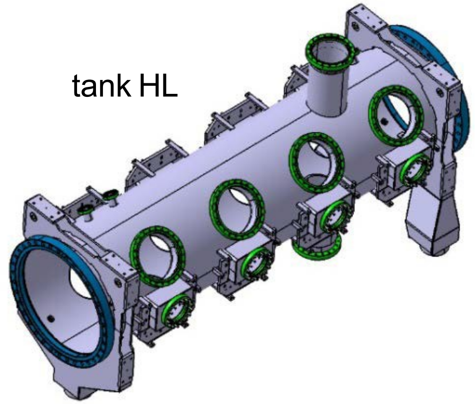
- Check of welding seam according to DIN EN ISO 9712
- Quality class DIN EN ISO 5817 B of vacuum tight welds
- Quality class DIN EN ISO 5817 C from all other welds
- Surface quality DIN ISO 1302
- Mechanical tolerances: DIN ISO 2768-mK & EN ISO 13920-BF

CR: Double Pick-Up Tanks

Call for tender shall start in Q1/2020, delivery Q1/2021

Two tanks (one double tank)

Geometry: diameter ~500mm, total length of two tanks ~4.7m
Flanges per tank: 2x DN500COF, 8x DN200CF, 2x DN160CF. 8x DN100CF, 8x DN40CF, 2x DN200CF with bellow DN200

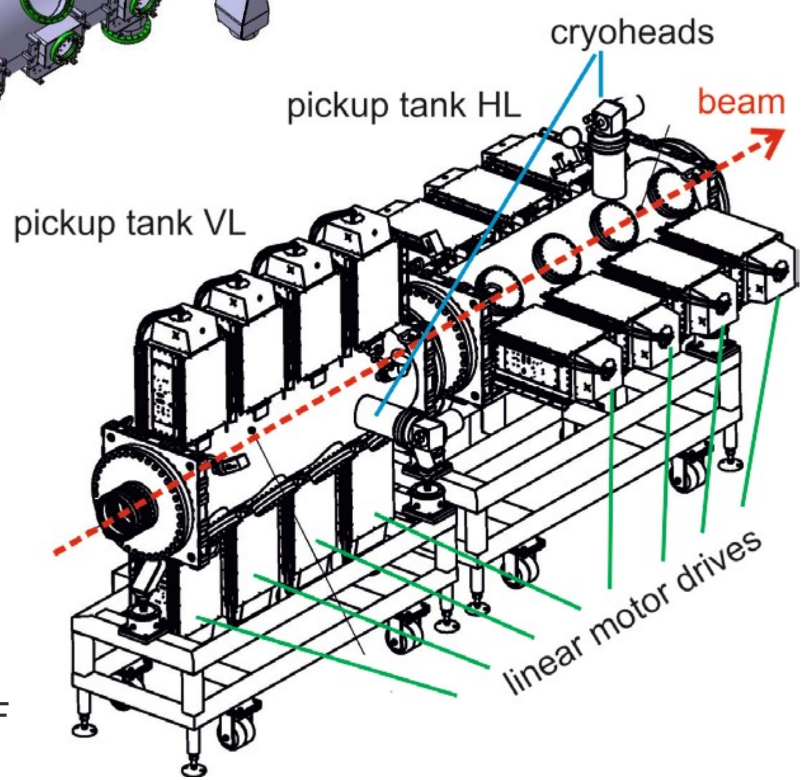


Vacuum Properties

- Integral Leak rate ≤ 1 · 10^{-10} mbarl/s
- Outgassing rate: ≤ 5 · 10^{-10} mbar l/scm²
- Material within the UHV range DIN EN 10088: 1.4306
- Material outside the UHV range DIN EN 10088: 1.4301
- Material COF Flange according DIN EN 10088: 1.4429 ESR
- UHV suitable cleaning required

Mechanical requirements:

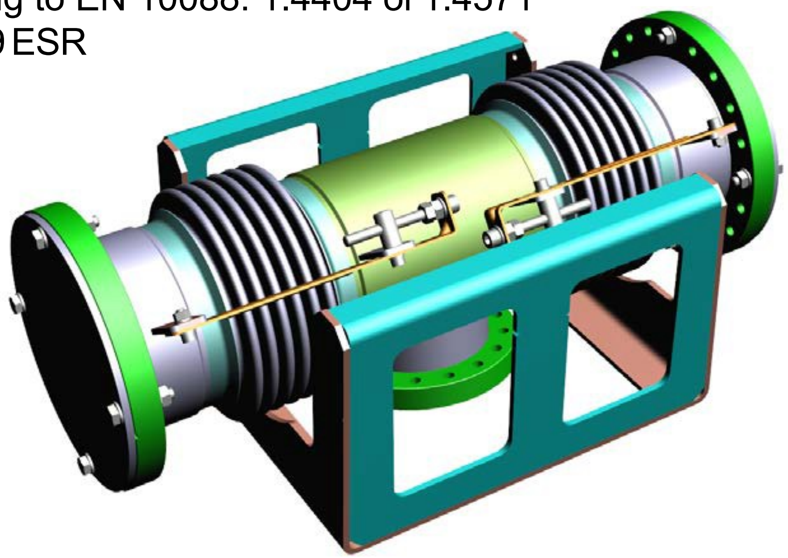
- Check of welding seam according to DIN EN ISO 9712
- Quality class DIN EN ISO 5817 B of vacuum tight welds
- Quality class DIN EN ISO 5817 C from all other welds
- Surface quality DIN ISO 1302
- Mechanical tolerances: DIN ISO 2768-mK & EN ISO 13920-BF



SIS100: Drift Tubes

Call for tender shall start in Q3/2019, delivery until Q4/2021

- ~60 pieces
- ~5 types
- Length: ~0.5 m
- T-type round chambers with two integrated bellows
- Support structure for pumps as shown part of delivery
- Chamber material according to EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- Corrugated (hydroformed) round bellows, material according to EN 10088: 1.4404 or 1.4571
- Flanges DN160CF, material according to EN 10088: 1.4429 ESR



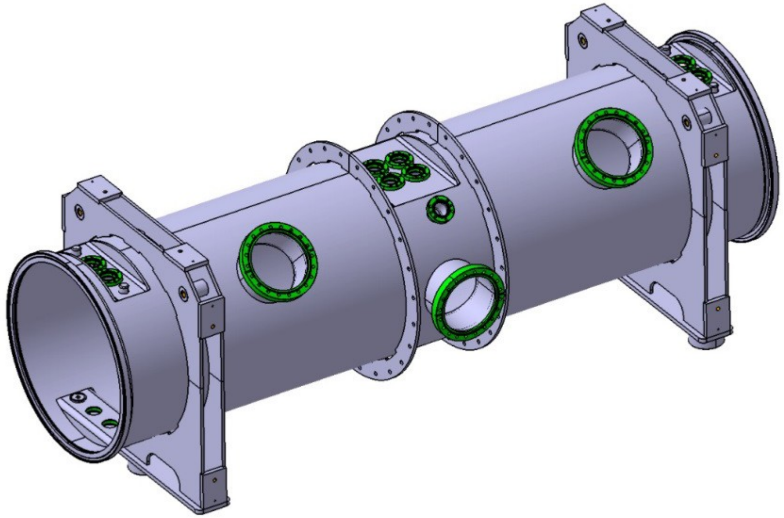
Vacuum requirements:
- Integral leak rate ≤ $1x10^{-10}$ mbar l/s
- Outgassing rate (after bake-out) ≤ $1x10^{-12}$ mbar l/(s cm^2)
- Operational temperature < 20 K
- UHV suitable cleaning
- Bake-out cycle for acceptance test required

Mechanical requirements:
- Check of welding seams according to ISO 9712, quality class ISO 5817 B
- Surface quality Rz=25

CR: Palmer Pick-Up Tank

Call for tender shall start in Q1/2019, delivery Q4/2019

Geometry: diameter ~500mm, length ~2000m
Flanges: 2x ISO-K DN500, 3x DN160CF, 17x DN40CF



Vacuum Properties

- Integral Leak rate ≤ 1 · 10^{-10} mbar l/s
- Outgassing rate: ≤ 5 · 10^{-10} mbar l/s cm²
- Material within the UHV range DIN EN 10088: 1.4306
- Material outside the UHV range DIN EN 10088: 1.4301
- UHV suitable cleaning required

Mechanical requirements:

- Check of welding seam according to DIN EN ISO 9712
- Quality class DIN EN ISO 5817 B of vacuum tight welds
- Quality class DIN EN ISO 5817 C from all other welds
- Surface quality DIN ISO 1302
- Mechanical tolerances: DIN ISO 2768-mK & EN ISO 13920-BF

SIS100: Radiation-resistant warm quadrupole chambers

Call for tender shall start in Q3/2019, delivery until Q3/2020

- 2 piecss
- length: ~ 2 m
- star-shaped aperture: 135 x 135 mm^2
- chamber material according DIN EN 10088: 1.4429 or 1.4435
- Flanges DN160CF & DN300CF, material according DIN EN10088: 1.4429 ESR
- Magnetic permeability: $\mu_r \leq 1.01$
- Heating jacket part of delivery

Vacuum Properties:

- Integral leak rate ≤ 1x 10^{-10} mbar l/s
- Outgassing rate ≤ 1x 10^{-12} mbar l/(s cm^2)
- UHV suitable cleaning
- Fully bakeable up to 250°C
- Bake-out cycle for acceptance test required

Mechanical requirements:

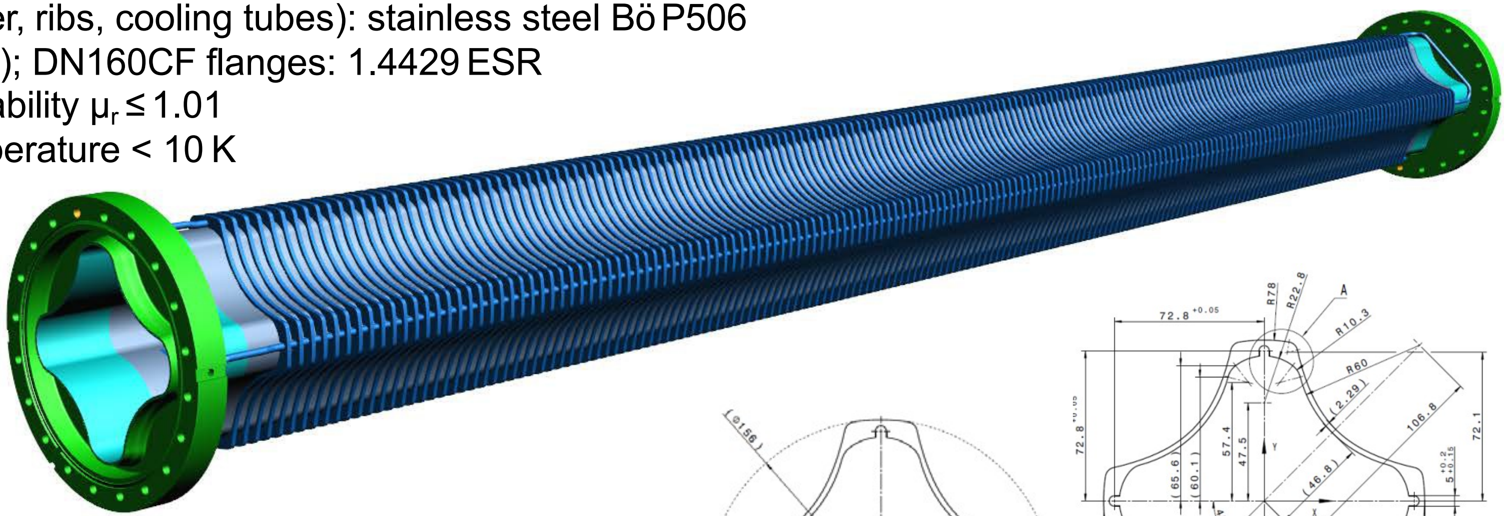
- Check of welding seam according to DIN EN ISO 9712, quality class DIN EN ISO 5817 B
- Surface quality Rz=25

SIS100: Cryogenic quadrupole chambers with star-shaped cross section

FAIR GSI

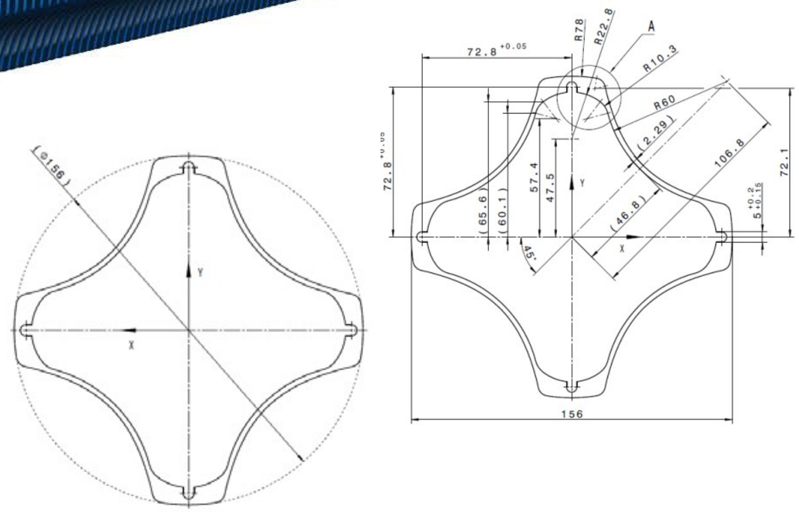
Call for tender shall start in Q3/2019, delivery until Q4/2020

- 8 pieces
- 2 types
- Chamber length: 1.4 m & 1.9 m
- Star-shaped aperture: 135 x 135 mm^2
- Wall thickness: 0.3 mm
- Stabilizing transversal ribs
- Four LHe cooling tubes Ø 5 mm, wall thickness 0.5 mm
- Material (chamber, ribs, cooling tubes): stainless steel Bö P506 (provided by GSI); DN160CF flanges: 1.4429 ESR
- Magnetic permeability $\mu_r \leq 1.01$
- Operational temperature < 10 K



<u>Vacuum requirements:</u>

- Integral leak rate ≤ 1x 10^{-10} mbar l/s
- Outgassing rate (after bake-out) ≤ 1x 10^{-12} mbar l/(s cm^2)
- UHV suitable cleaning
- Bake-out cycle for acceptance test required



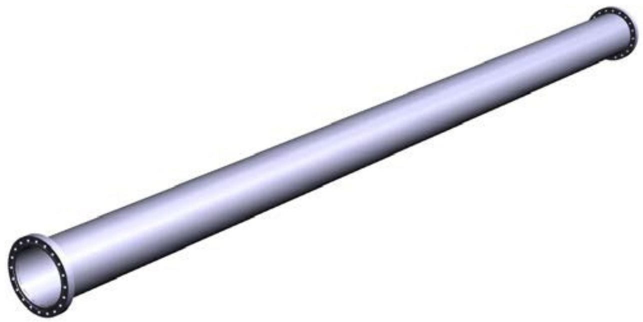
SIS100: Straight Beam Pipe

Call for tender shall start in Q4/2020, delivery until Q4/2021

- 11 pieces
- 2 types
- Round tube, diameter DN160
- Chamber length: ~1.3 m & ~3 m
- Chamber material according to EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- Flanges DN160CF, material according to EN 10088: 1.4429 ESR
- Bake-out jackets and chamber support stands part of delivery

<u>Vacuum requirements:</u>

- Integral leak rate ≤ $1x10^{-10}$ mbar l/s
- Outgassing rate (after bake-out) ≤ $1x10^{-12}$ mbar l/(s cm^2)
- UHV suitable cleaning
- Bakeable up to 300°C
- Bake-out cycle for acceptance test required



<u>Mechanical requirements:</u>

- Check of welding seams according to ISO 9712, quality class ISO 5817 B
- Surface quality Rz=25

p-Linac: Straight Beam Pipes

Call for tender shall start in Q4/2019 , delivery until end Q3/2020

- ~10 pieces (3 to 4 different types)
- Geometry: round, length ~50cm, diameter DN40, DN63, DN100
- flanges: CF

Vacuum Properties

- Integral Leak rate ≤ $1 \cdot 10^{-10}$ mbar l/s
- Outgassing rate: ≤ $5 \cdot 10^{-10}$ mbar l/ s cm²
- Chamber material according DIN EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- Flange material according DIN EN 10088: 1.4306, 1.4307, 1.4404, 1.4429 or 1.4435
- UHV suitable cleaning required

Mechanical requirements:

- Check of welding seam according to DIN EN ISO 9712, quality class DIN EN ISO 5817 B
- Surface quality Rz=25

Rare Isotope Science Project (RISP)

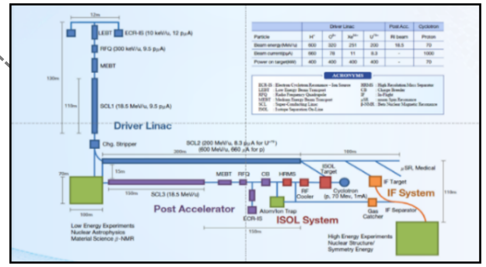
- **Goal:** To build **a heavy ion accelerator complex RAON,**
  for **rare isotope science** research in Korea.

  * RAON - Rare isotope Accelerator complex for ON-line experiments

- **Budget: KRW 1,432 billion (US$ 1.26 billion, 1$=1,135krw)**
  - accelerators and experimental apparatus : 460.2 billion won
  - civil engineering & conventional facilities : 972 billion won (incl. site 357 billion won)
- **Period: 2011.12 ~ 2021.12**

System Installation Project

Development, installation, and commissioning of the accelerator systems that provides high-energy (200MeV/u) and high-power (400kW) heavy-ion beam



Facility Construction Project

Construction of research and support facility to ensure the stable operation of the heavy-ion accelerator, experiment systems, and to establish a comfortable research environment

※ Accelerator and experiment buildings, support facility, administrative buildings, and guest house, etc.

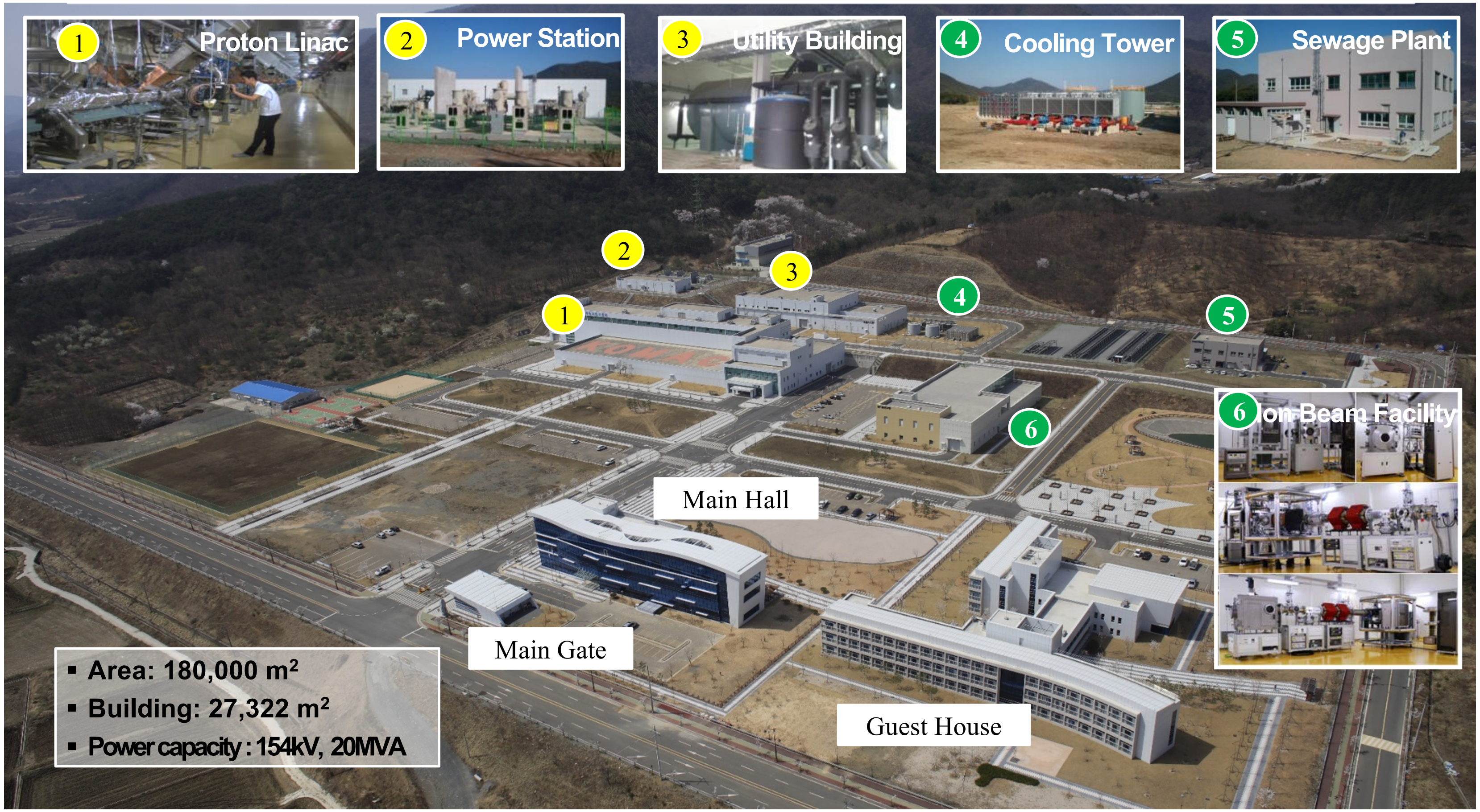
- Providing high intensity RI beams by ISOL and IF
  ISOL: direct fission of ^{238}U by 70 MeV proton
  IF: 200 MeV/u ^{238}U (intensity: 8.3 pμA)
- Providing high quality neutron-rich beams
  e.g., ^{132}Sn with up to 250 MeV/u,
  up to 10^9 particles per second
- Providing More exotic RI beam
  production by combination of ISOL and IF

Korea Multi-purpose Accelerator Complex (KOMAC)

- ■ National User Facility: Intense Proton & Ion Source for Basic & Applied Research
  - High-Power Proton Linac (100MeV, 20mA, Proton Source) under operation
  - 1 GeV, 2MW Upgrade (Spallation Neutron Source) under R&D study
- ■ 100MeV Linac developed through Proton Engineering Frontier Project (2002 – 2012)
- ■ Funding: 300M USD (Government (57%), Local Gov. (39%), & Industry (4%))
- ■ Lead Institute : Korea Atomic Reseaech Institute (KAERI)
- ■ KOMAC Operation as one of branches of KAERI (2013~)

Main Facilities

❖ Building layout at KOMAC



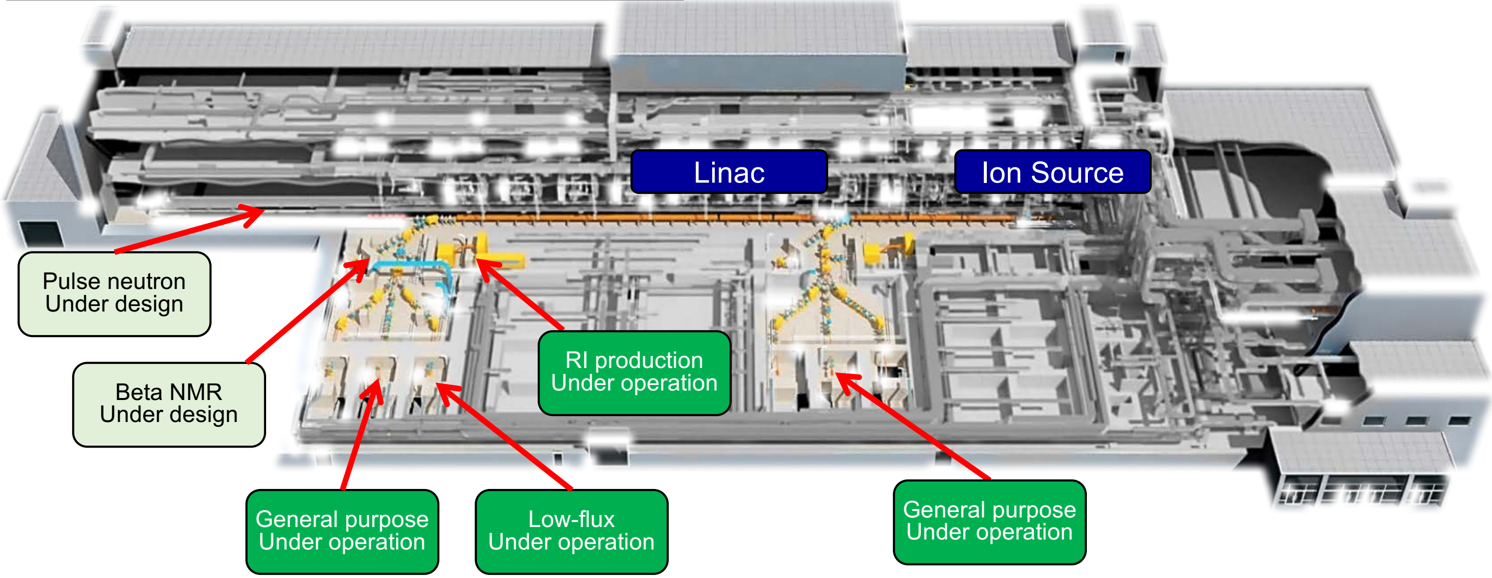
100 MeV Linac and Beamlines

❖ 100 MeV linac and beamline specification and layout

Features of KOMAC 100MeV linac

- 50-keV Injector (Ion source + LEBT)
- 3-MeV RFQ (4-vane type)
- 20 & 100-MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV

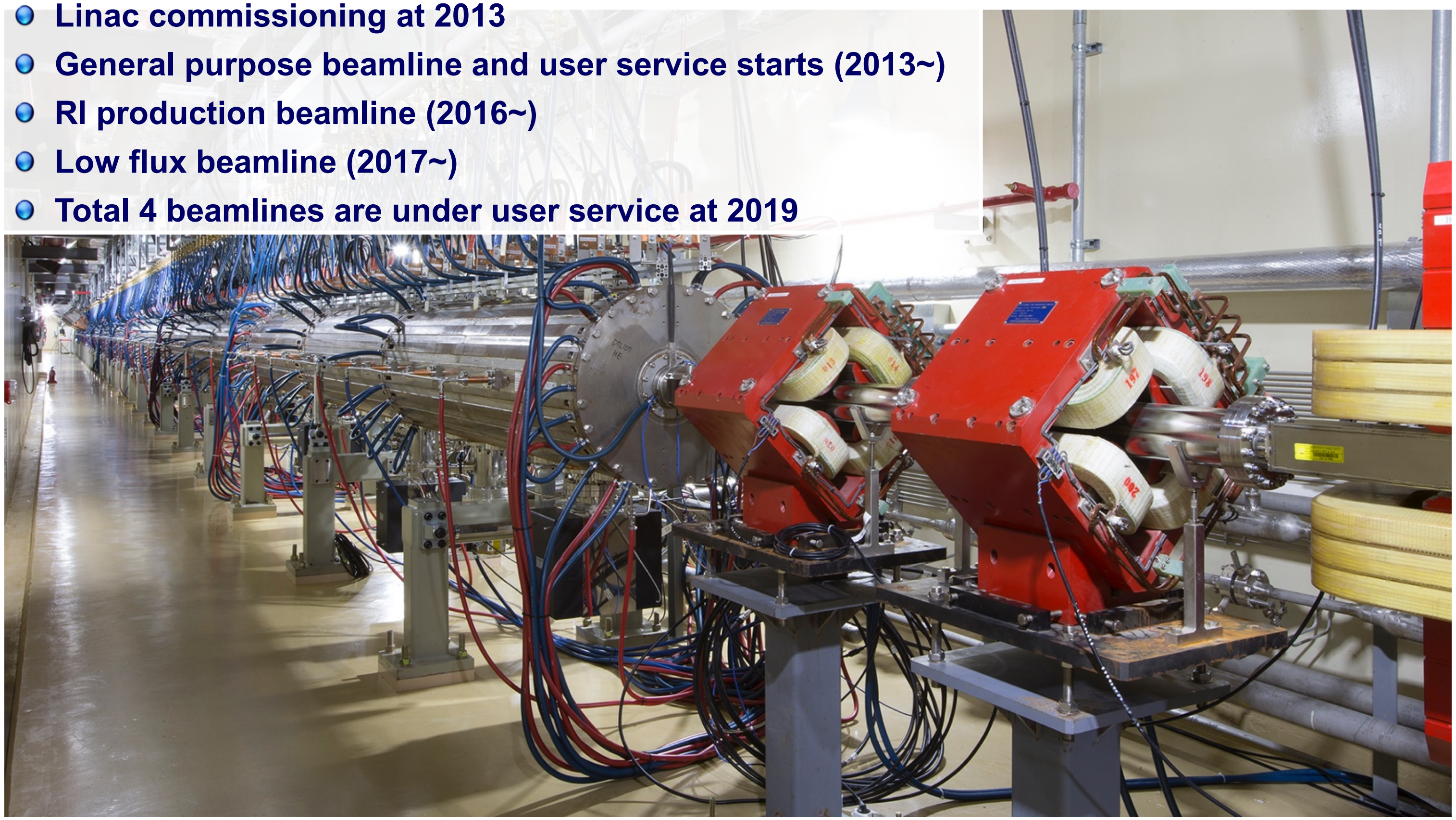
Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	1 ~ 20	1 ~ 20
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
Pulse Length (ms)	0.1 ~ 2	0.1 ~ 1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160



100 MeV Proton Linac

❖ 100 MeV linac / beamline development and operation

- **Linac commissioning at 2013**
- **General purpose beamline and user service starts (2013~)**
- **RI production beamline (2016~)**
- **Low flux beamline (2017~)**
- **Total 4 beamlines are under user service at 2019**

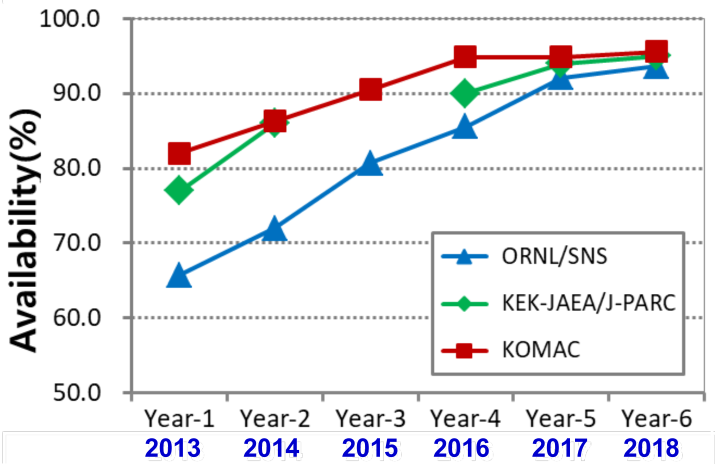


100 MeV Proton Linac Operation Statistics

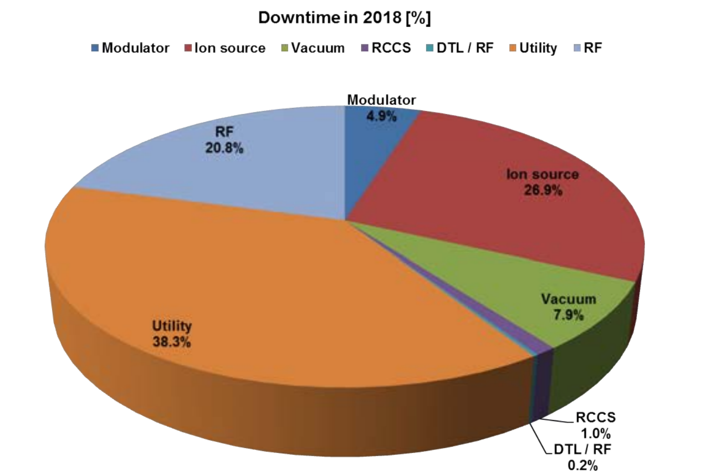
❖ Machine availability and main failure components

Year	2013	2014	2015	2016	2017	2018	Sum
Operation hours	2,290	2,863	2,948	2,961	3,231	3,038	17,331
Unplanned Downtime	412	392	280	151	164	134	1,534
Machine Availability	82.0%	86.3 %	90.5%	94.9%	94.9%	95.6%	91.1%

Availability: improved to ~95%

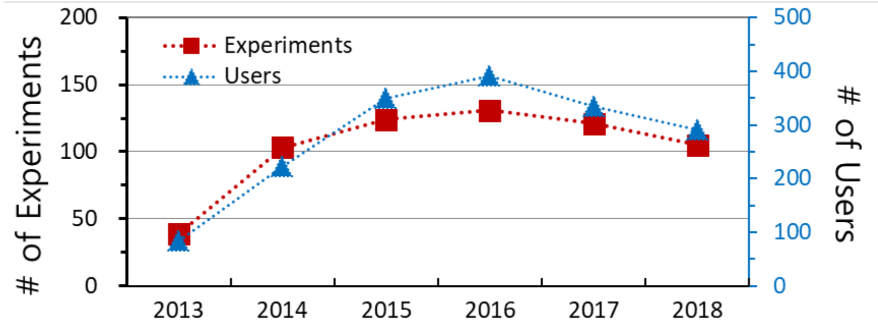


Downtime: Utility, IS, RF, Vacuum fails

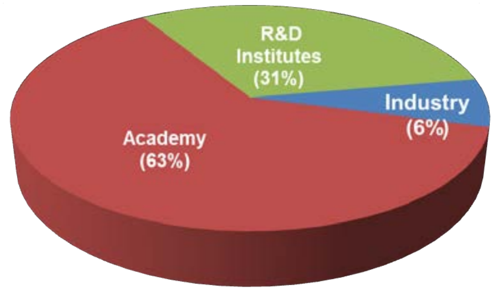


100 MeV Proton Linac User Service Statistics

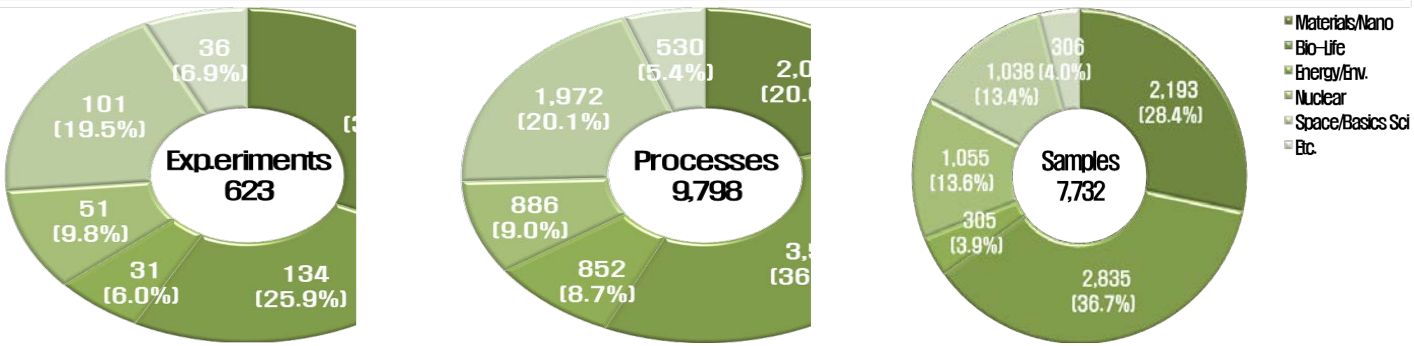
❖ Users and main R&D fields



User's Institution



R&D Fields: Materials(31.9%), Bio-Life(25.9%), Space/Basic Sci.(19.5%) etc.

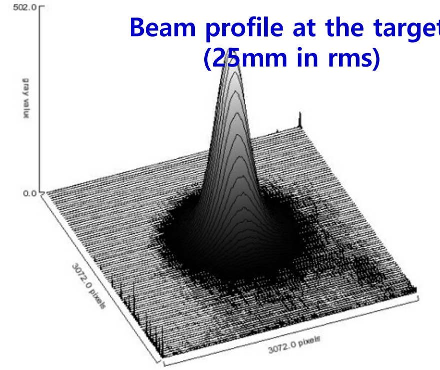


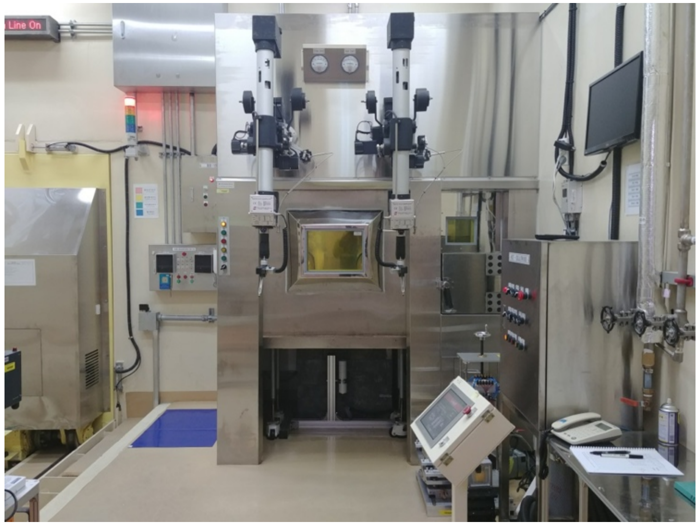
- KOPUA: Korea Proton Beam User Association (Self-organized user network)
  - PAC(Program Advisory Committee): Review proposals & Allocate beamtime

100 MeV Proton Linac Beamline 1

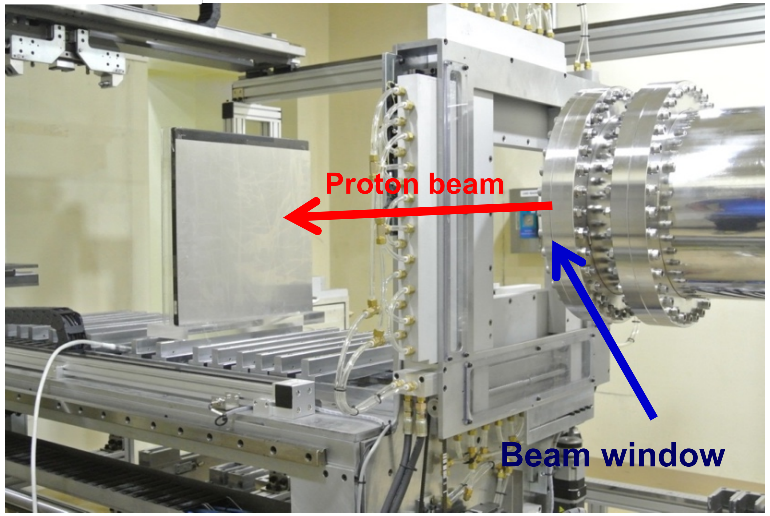
❖ General Purpose Beamline: 20-MeV / 100-MeV Proton

- **Application :** Proton beam irradiation for general purpose (material / nano-science, semiconductor etc.)
- **Proton beam**
  - Energy: 20 MeV / 33 ~ 100 MeV
  - Beam power: 10 kW @ 100 MeV
- **Status :** Under operation (2013~)





Hot cell for sample manipulation



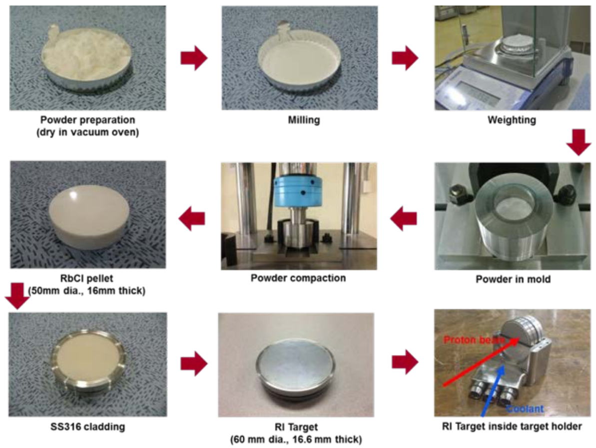
Beam irradiation station

100 MeV Proton Linac Beamline 2

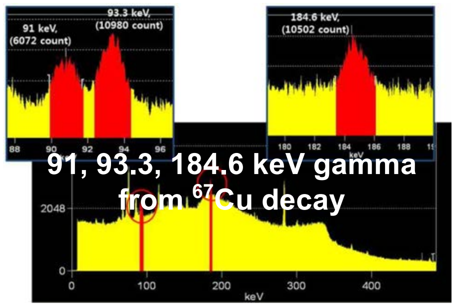
❖ RI Production Beamline: 100-MeV Proton

- **Application**
  - RI production: Cu-67, Sr-82, etc.
- **Proton beam**
  - Energy: 33 ~ 100 MeV
  - Beam power: 30 kW @ 100MeV
- **Status**
  - Completed installation: Dec. 2015
  - Status: Under operation (2016~)

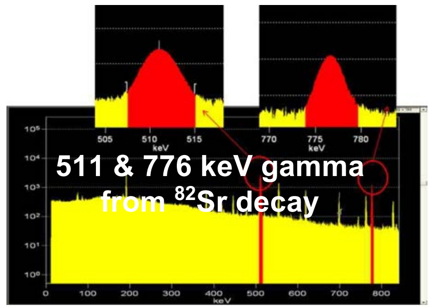
Target Preparation



$^{68}Zn(p,2p)^{67}Cu$



$^{nat}Rb(p,x)^{82}Sr$

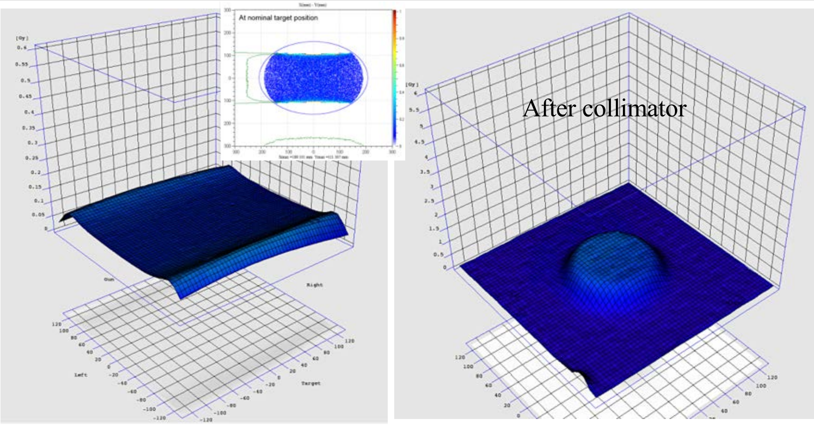


100 MeV Proton Linac Beamline 3

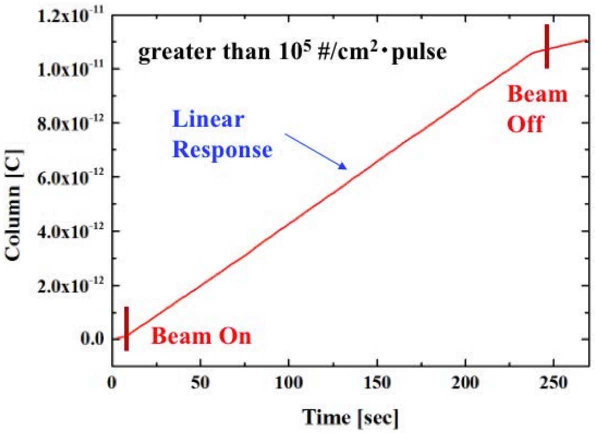
❖ Low-flux Beamline: 100-MeV Proton

- **Application :** **Space radiation, Detector R&D, Bio etc.**
- **Proton beam**
  - **Energy: 100 MeV**
  - **Avg. Current : 0.13 nA (1.6 nA peak, duty 8%, 60 Hz)**
  - **Uniformity: < 10%, 100 mm X 100 mm**
  - **Flux: $1\times10^5 \sim 1\times10^8$/cm^2 @ peak**
- **Status : Under operation (2017~)**

Target room



Beam uniformity < 5% @ 100mm X 100mm

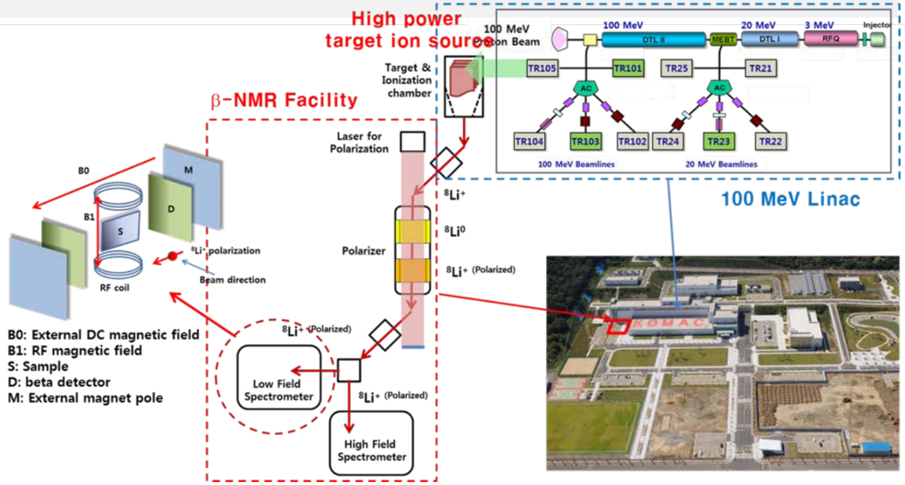


Accumulated dose during irradiation on sample

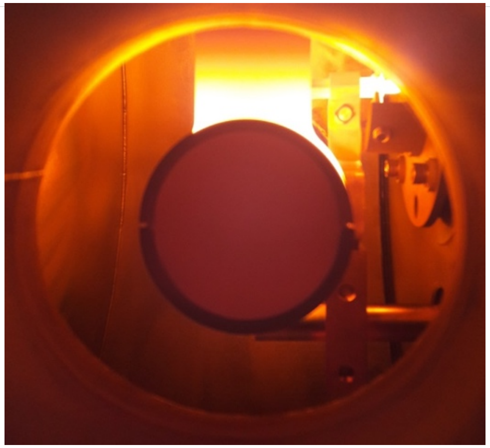
Near Future Plan 1

❖ Li-8 Beamline: 100-MeV Proton

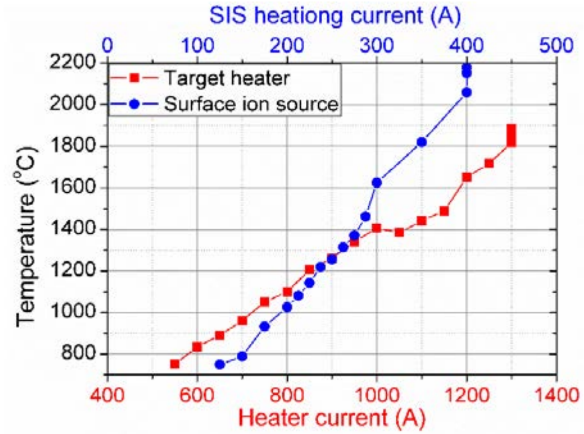
- **Application : Li-8 based β-NMR**
- **Proton beam**
  - **Energy: 100 MeV**
  - **Beam Power: 1 kW @ 100 MeV**
  - **Li-8 Ion Production: 1x10^{6} pps**
  - **Target: BeO**
- **Status : Prototype development (2017~)**
- **Plan : High power target ion source, β-NMR facilities**



Layout plan for β-NMR facility



Prototype target ion source heating test

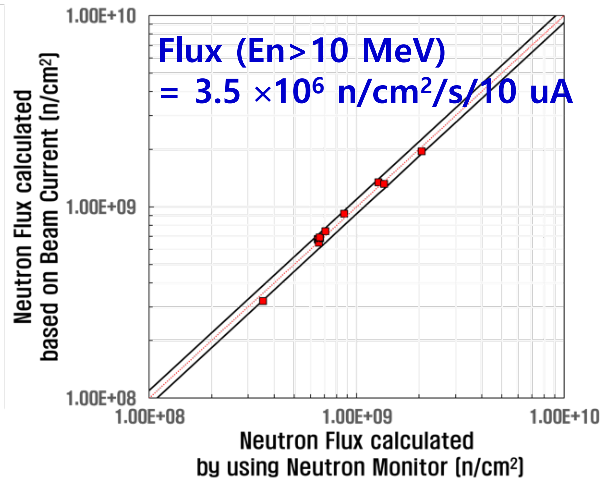


Heating current vs. temperature

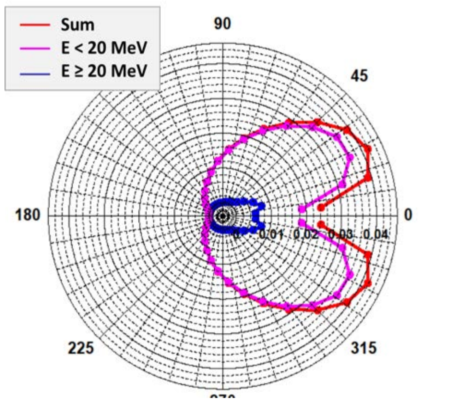
Near Future Plan 2

❖ Pulse Neutron Beamline: 100-MeV Proton

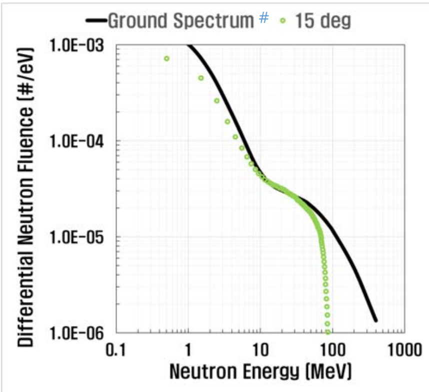
- **Application : Fast neutron production**
- **Proton beam**
  - **Energy: 100 MeV**
  - **Beam Power: 1 kW @ 100 MeV (upgrade 160 MeV)**
  - **Target: Copper (plan to change to W)**
- **Status : Neutron utilization @ 100 MeV, 1kW (2018~)**
- **Plan : Accelerator energy upgrade, target improvement, neutron facility**



Measurement results

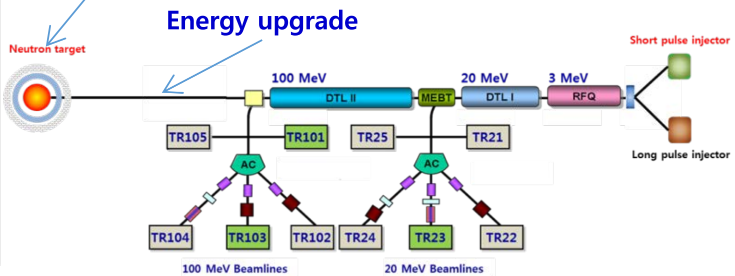


Angular distribution of the neutron



Gordon et al, IEEE Trans. Nucl. Sci. 51 (2004)

Neutron spectrum compared with the ground spectrum



Layout plan of the pulse neutron source

Future Plan

❖ **Upgrade to 1GeV, 2MW proton linac, two pulsed neutron sources**
- **Reflected in National Large Research Facility Road Map (2010 & 2012)**

- **Neutron Sources:** Materials, Bio-life, Energy, Environment, etc.
  - **Long Pulse (1.3 ms):** Spatial resolution: μm~nm, Temporal resolution: μs~ns
    - SANS, Holography, Phase shift interferometry, Static & Dynamic tomography, Spin echo, etc.
  - **Short Pulse (~μs):** Spatial resolution: 0.01~10 nm, Temporal resolution: ns~fs
    - Elastic scattering, Diffraction, PGAA, Neutron resonance transmission, Neutron resonance capture analysis, Neutron spectroscopy, Neutron stimulated emission CT, etc.

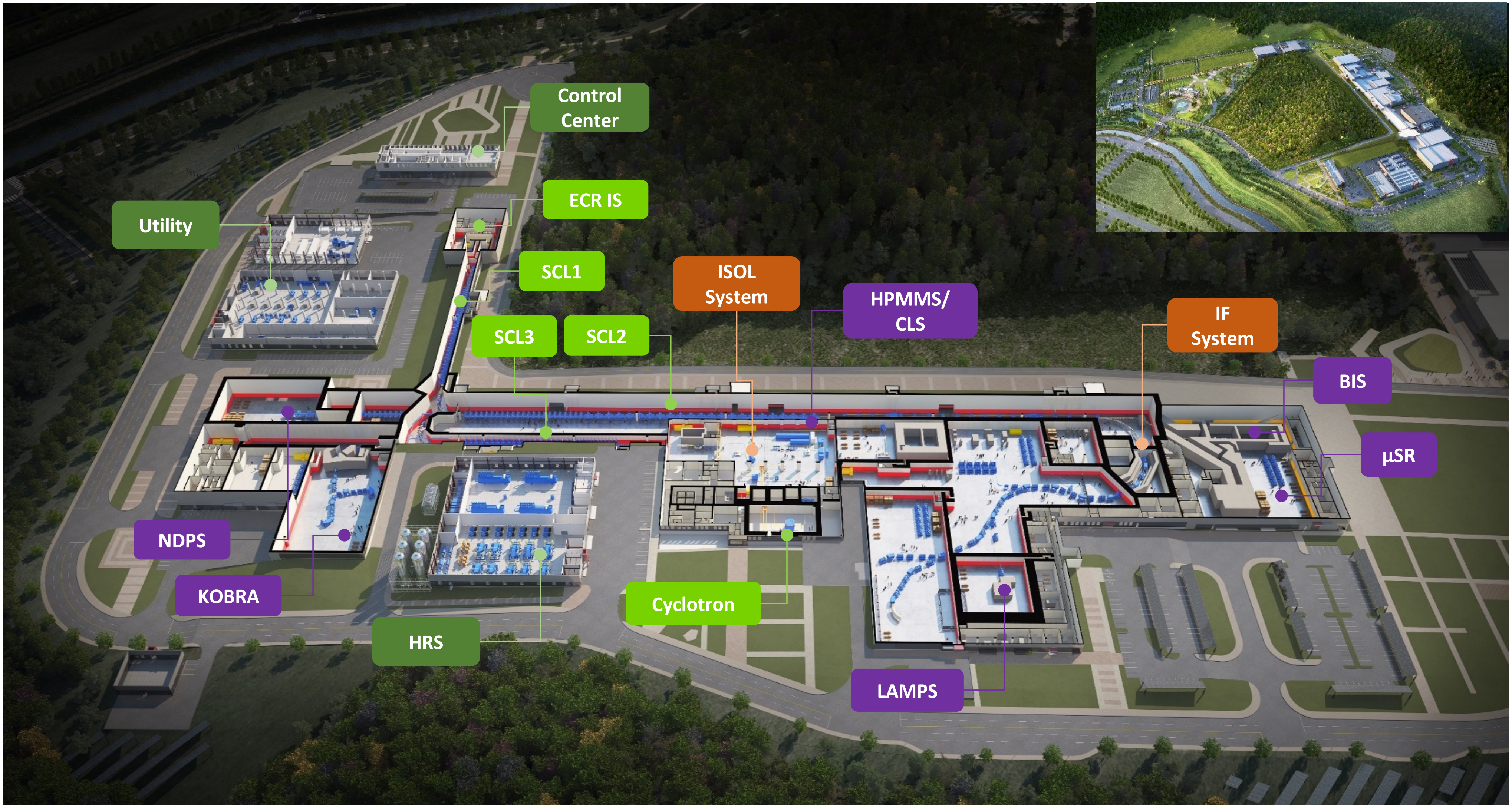
RAON Rare isotope Accelerator complex for ON-line experiments

Overview of The Rare Isotope Science Project (RISP)

기초과학연구원 Institute for Basic Science

중이온가속기건설구축사업단 Rare Isotope Science Project

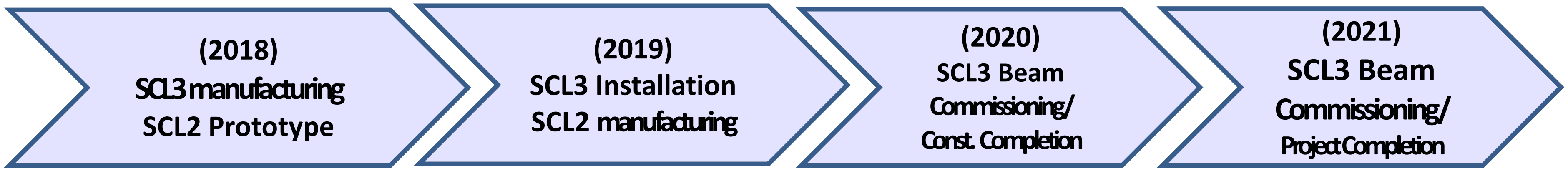
RAON Layout



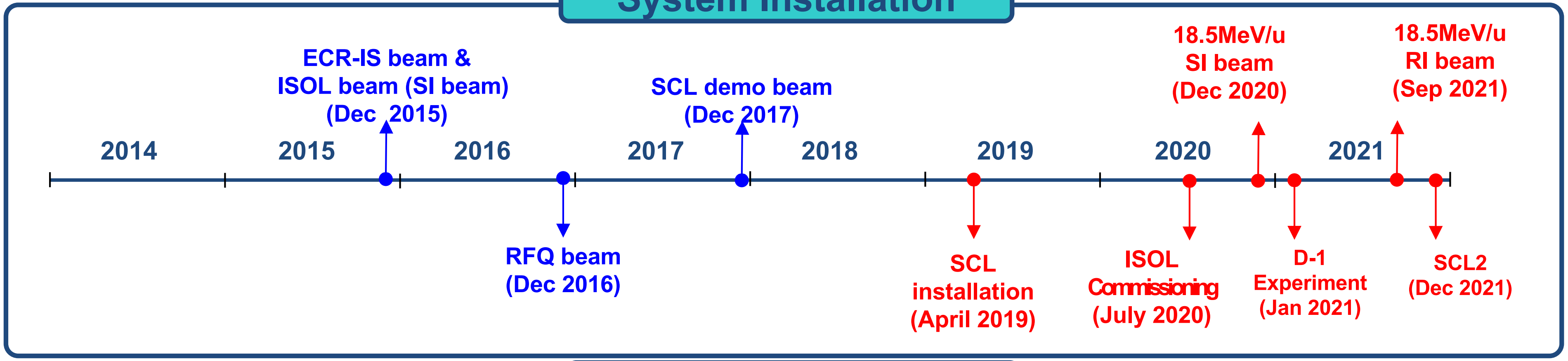
SCL1 has been decided to be pended

: SCL3 is going to be taking a role of SCL1 in the early operation

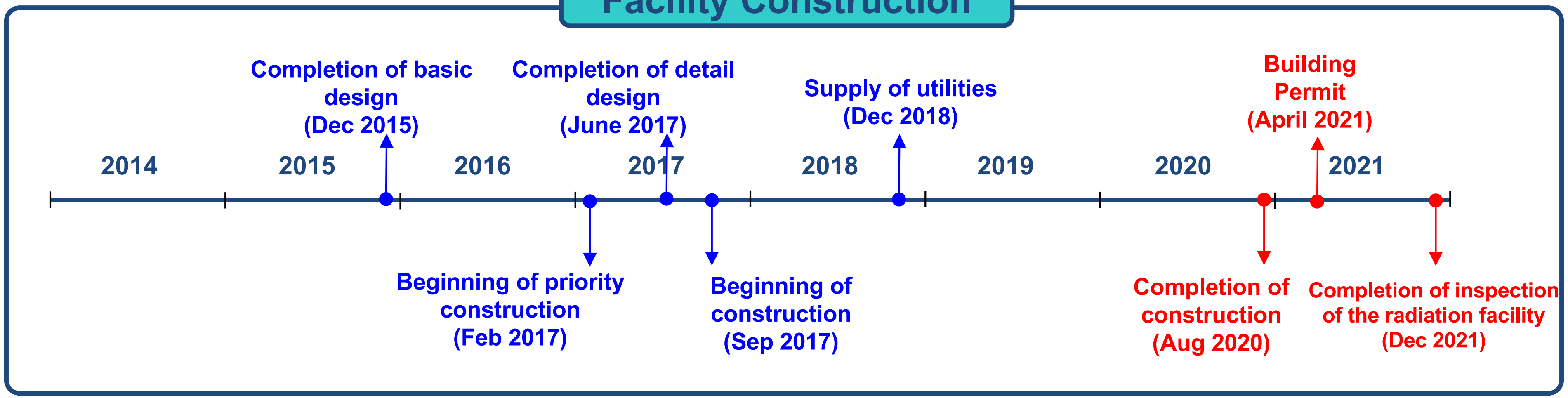
Project Milestone



System Installation



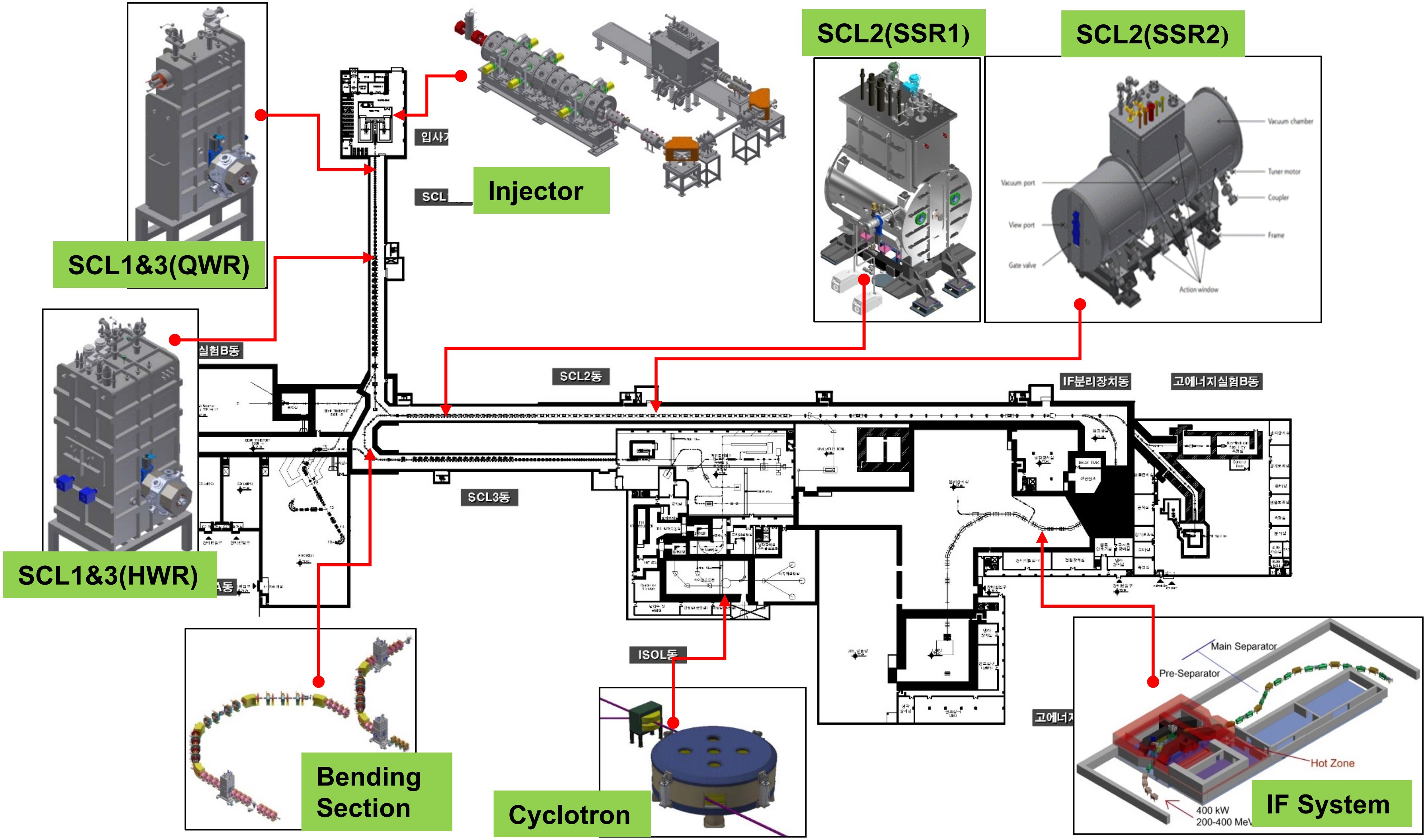
Facility Construction



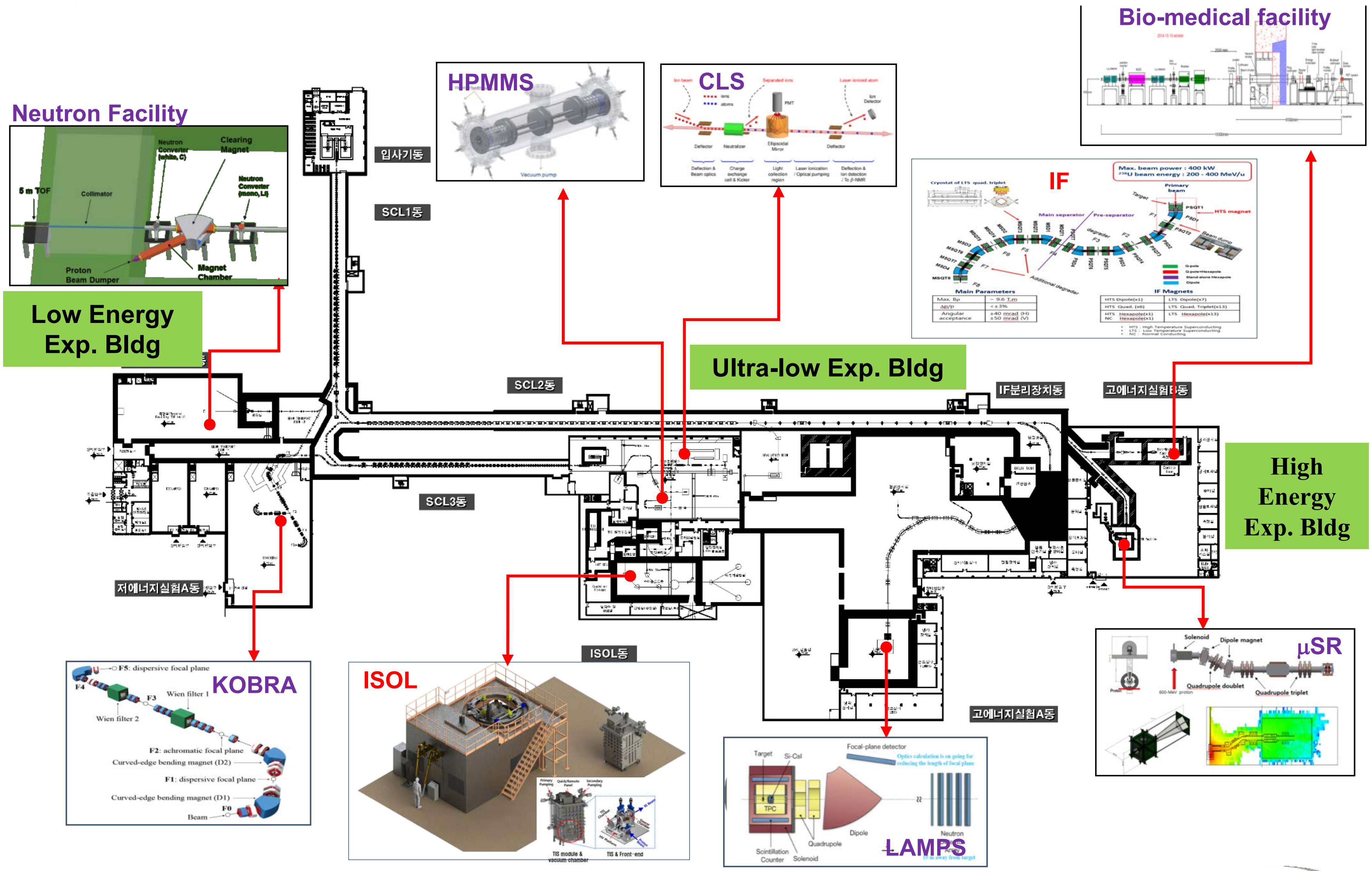
Building Layout

- Campus Area : **952,066**㎡ (including the reservation area of **144,640**㎡)
- Period : **2014** ~ **2021**(8 years)
- Cost : 972 billion won (incl. 357 billion won for land)
- Building Area : **76,259**㎡(**11** Bds)
- Total Bd. Area : **116,252**㎡
- Constructor : POSCO Consortium(11 companies)

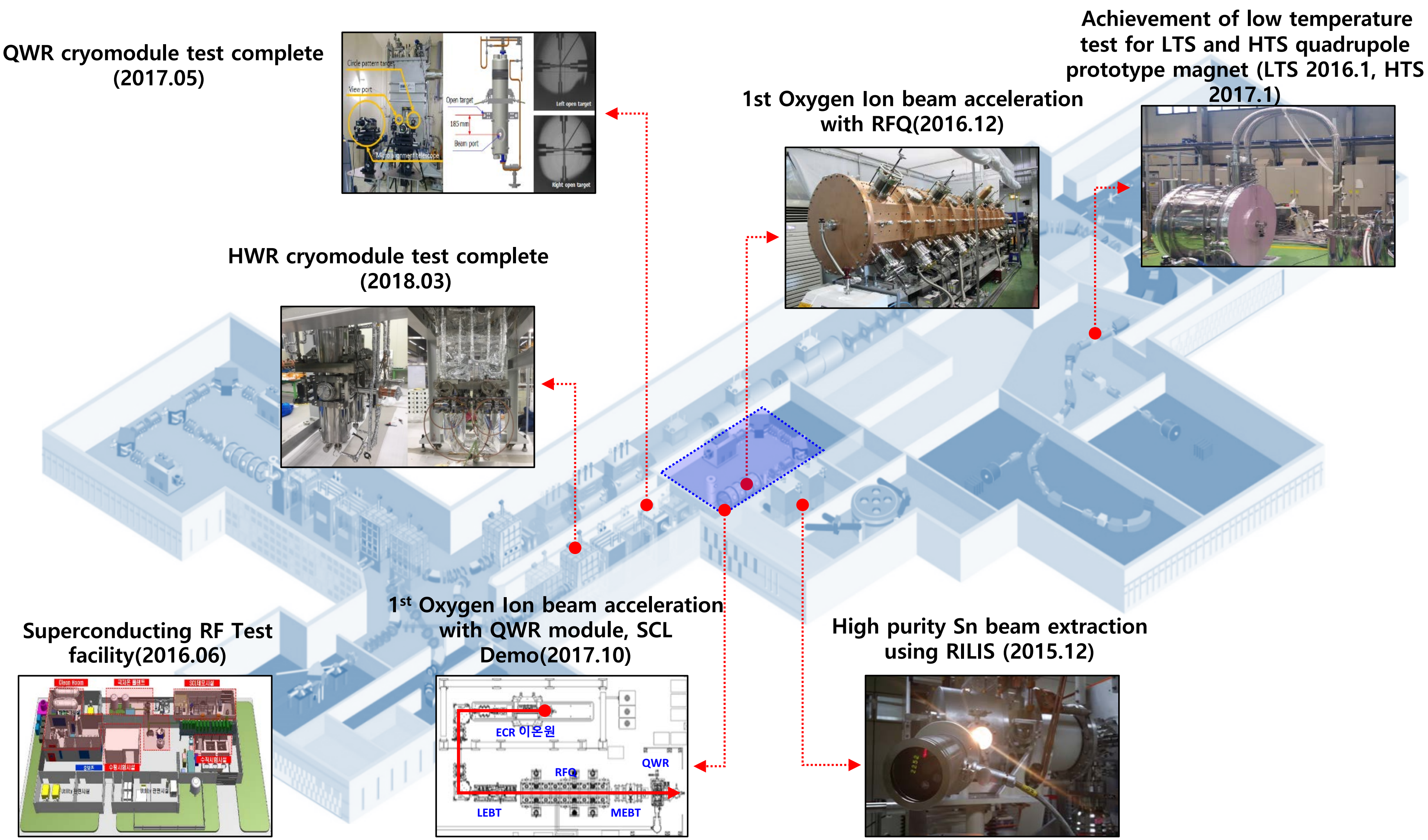
Accelerator System



RI & Experimental System



Major achievements



Summary & Outlook

Accelerator

- Mass production for SCL3 is under way
- SCL2 is under pre-production phase
- **From April, 2019, installation for SCL will start from SCL3**
- Test facility for cavities and cryomodules will operate from next Jan.

By the end of 2021, we will achieve

- **SI beams:** Stable ion beams (^{16}O, ^{40}Ar) from ECRIS → SCL3 → low E exp hall
- **RI beams:** RIBs extraction from ISOL → re-acceleration through SLC3 → low E exp hall
- Stable / RI beams will be delivered to low-E experimental hall
- **Early phase experiments are going to be performed using KOBRA**
  → RIBs production at KOBRA (A<~50, beam energy < 20 MeV/u) using SI beams from SCL3

- Beam commissioning starts for SCL2

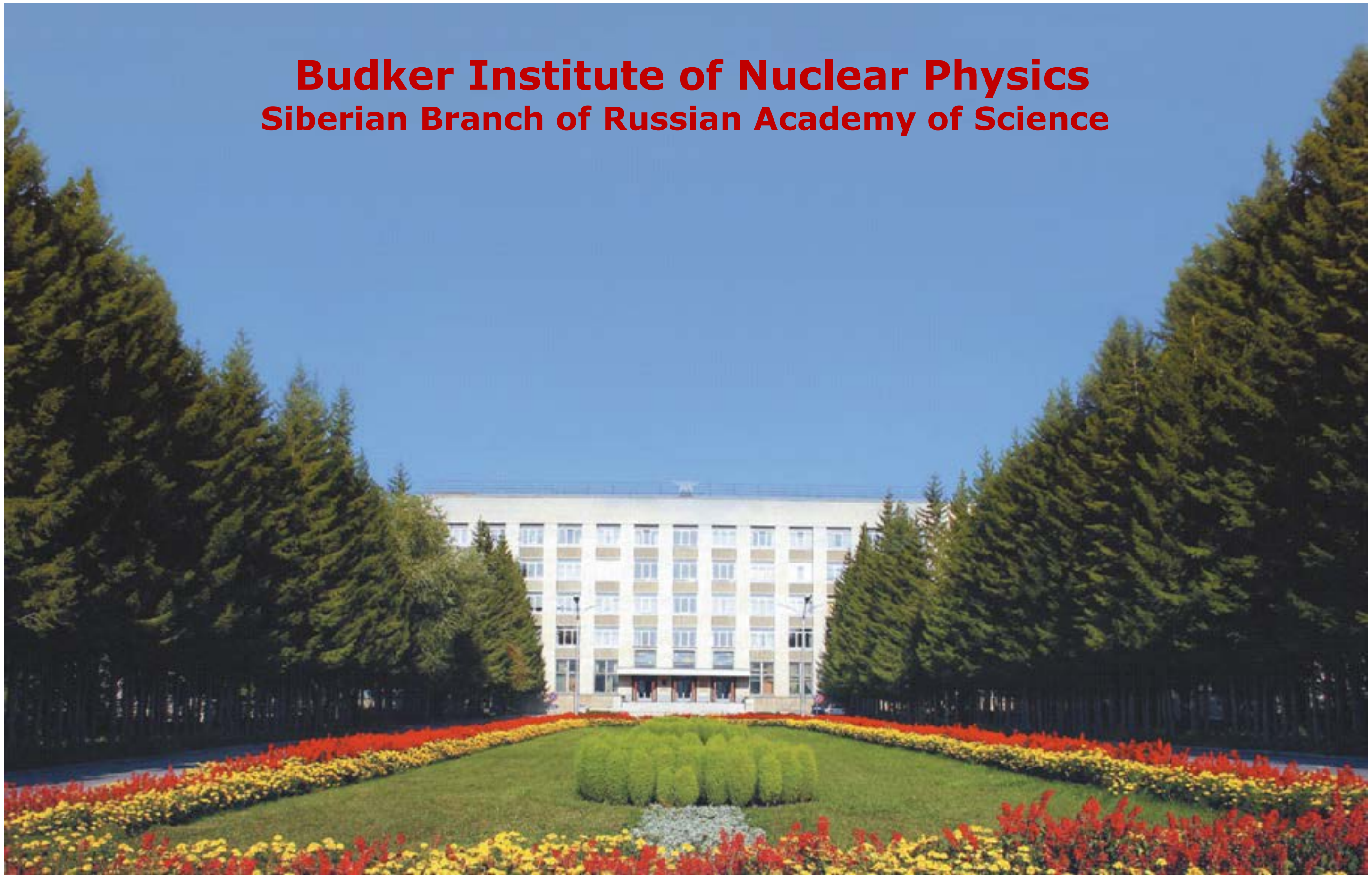
- Installation and commissioning for IF, LAMPS, Neutron, bio-medical and muSR
  → Collaborative works with RUA (RAON Users Association) via RULC (RAON Users Liason Center)

Post RISP (2021 ~)

- Beam acceleration for ISOL → SCL3 → SCL2 → IF **(ISOL+IF)**
- Beam commissioning and experiments for IF, LAMPS, Neutron, bio-medical and muSR
- **Ramping-up to get the 400kW beams (more 5 yrs)**
- Energy upgrade to 400MeV/u (require budget)

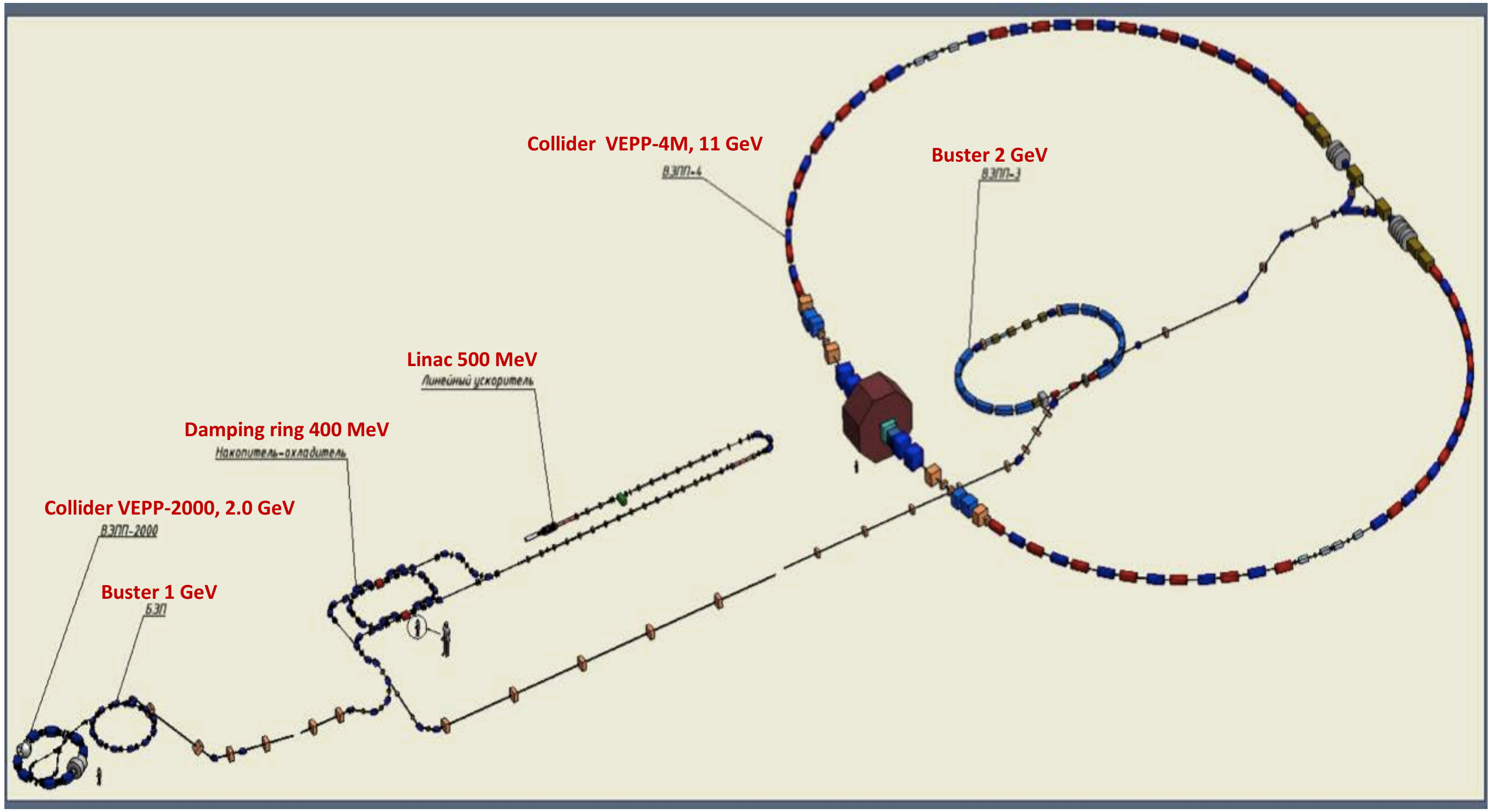
Super Charm-Tau factory: project status

P. Logachev



5+5 Meeting, CERN, April 15

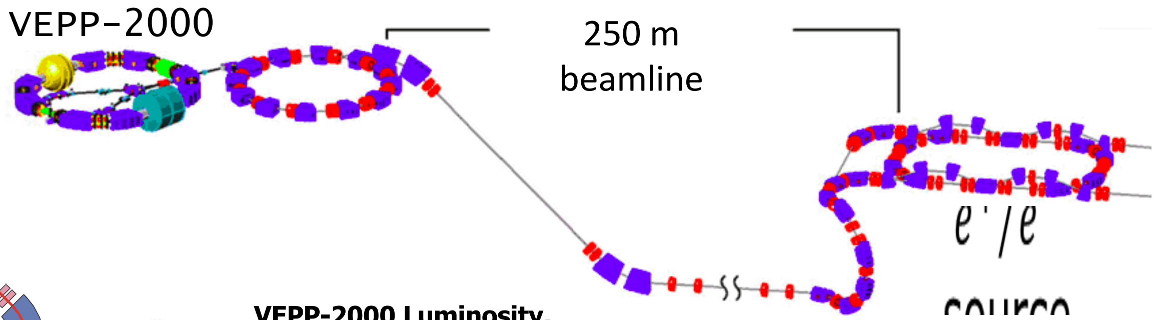
Two colliders VEPP-2000 and VEPP-4M at BINP operate with new injection complex (since 2017)

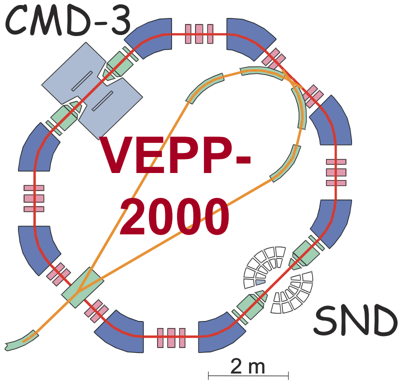


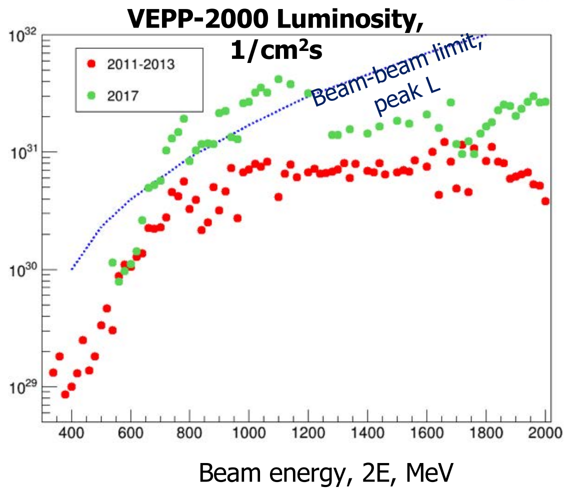
E = 400 MeV, N = 10^{11} e+-/s

VEPP-2000

☐ The world highest luminosity collider below 2 GeV (excl. phi1019 energy)





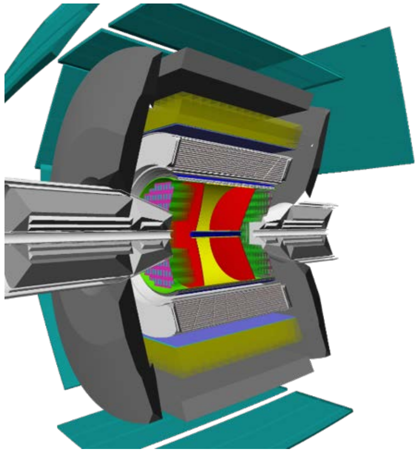


Luminosity
$(1-5)\times 10^{31}$ 1/cm²s

Two detectors

Physics at VEPP-2000

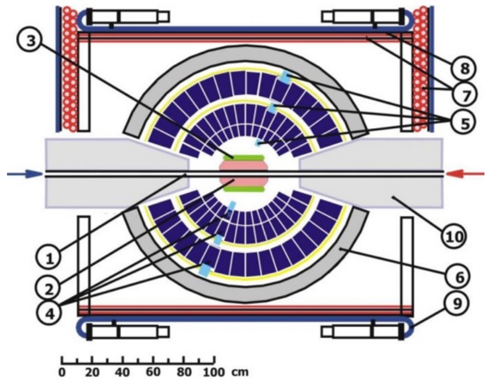
CMD-3 detector

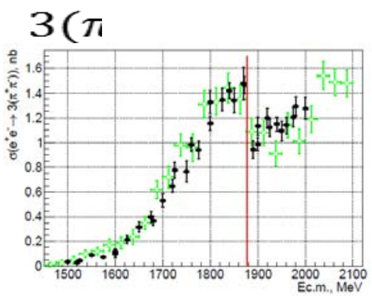


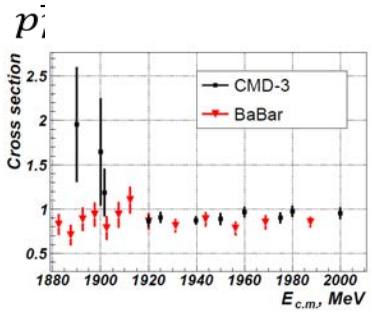
Main goal: study of $\gamma^* \rightarrow hadrons$ below 2 GeV, in particular

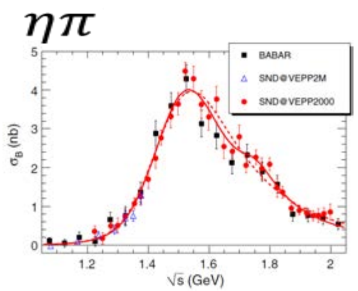
- $\sigma(e^+e^- \rightarrow hadrons)$ for muon (g-2)
- measurement of p and n formfactors

SND detector







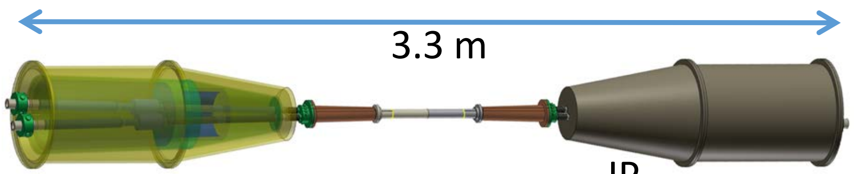


and many more…

SUPER CHARM- TAU FACTORY IN NOVOSIBIRSK

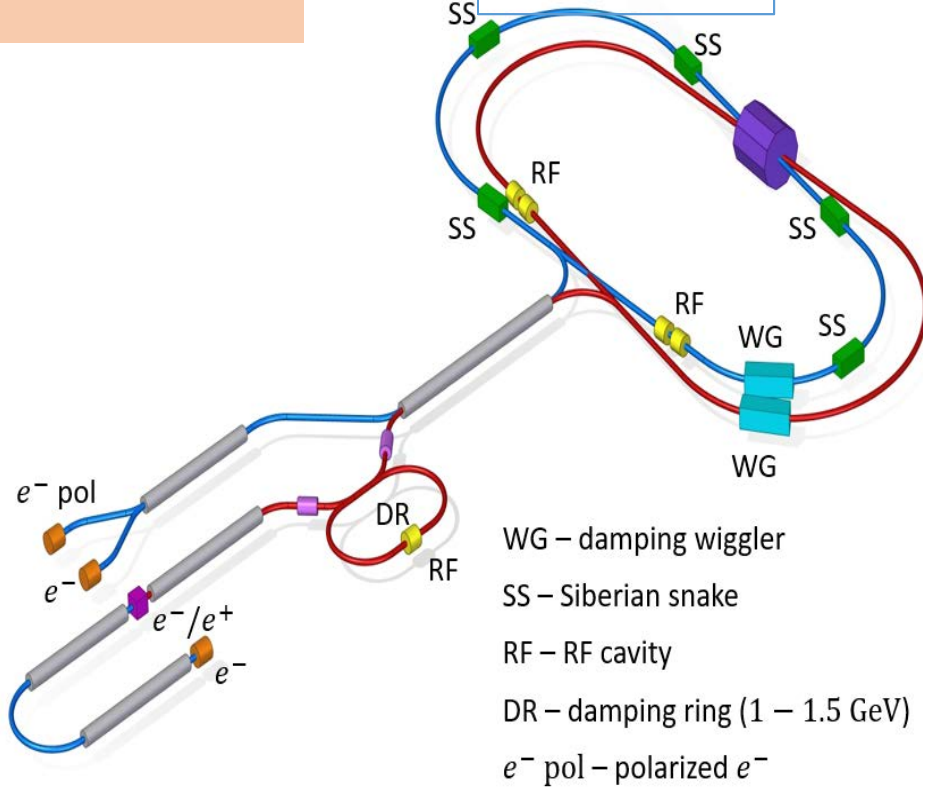
Super Charm-Tau (CT) Factory is a double ring e+e- collider to be operated in the center-of-mass energy range from 2 to 6 GeV, with a peak luminosity of about 10^{35} $cm^{-2}s^{-1}$ (Crab Waist collision) and with longitudinally polarized electrons at the IP.

Artistic view of interaction point



Cryostat with SC FF magnets

Novosibirsk SCTF schematic view

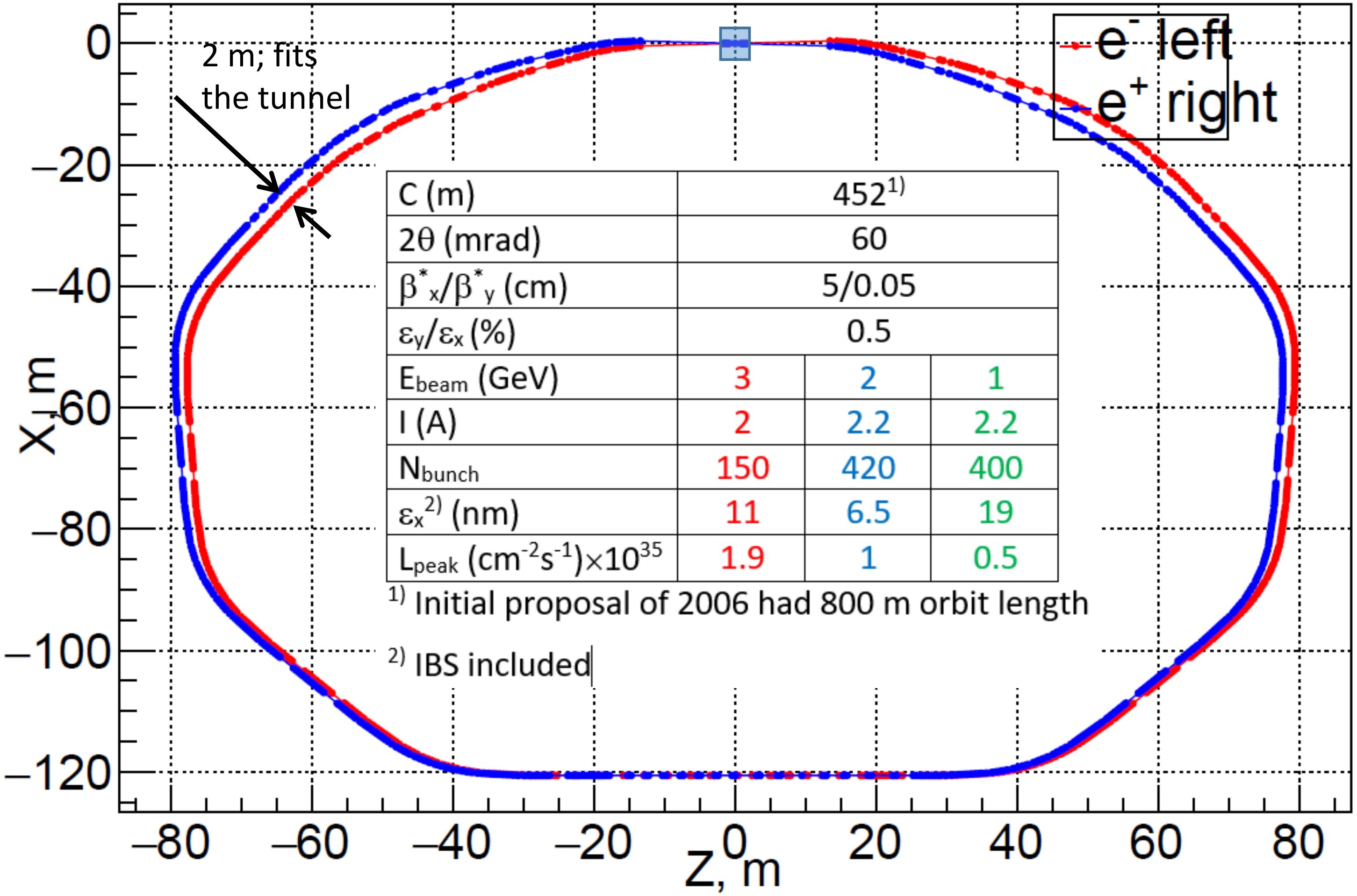


Accelerator present status

- Max beam energy increased from 2.5 GeV to 3 GeV
- Max peak luminosity at 3 (1) GeV is 1.9 (0.5)$\times 10^{35}$ $cm^{-2}s^{-1}$
- Three Siberian Snakes provide longitudinally polarized e-
- Collider conceptual design is completed; no showstoppers are found

CONFIGURATION AND PARAMETERS

(REVISED AFTER EXPERIENCE WITH FCC STUDY!)



C (m)	452[1)]		
2θ (mrad)	60		
β^*_x/β^*_y (cm)	5/0.05		
$\varepsilon_y/\varepsilon_x$ (%)	0.5		
E_{beam} (GeV)	3	2	1
I (A)	2	2.2	2.2
N_{bunch}	150	420	400
ε_x[2)] (nm)	11	6.5	19
L_{peak} ($cm^{-2}s^{-1}$)$\times 10^{35}$	1.9	1	0.5

1) Initial proposal of 2006 had 800 m orbit length

2) IBS included

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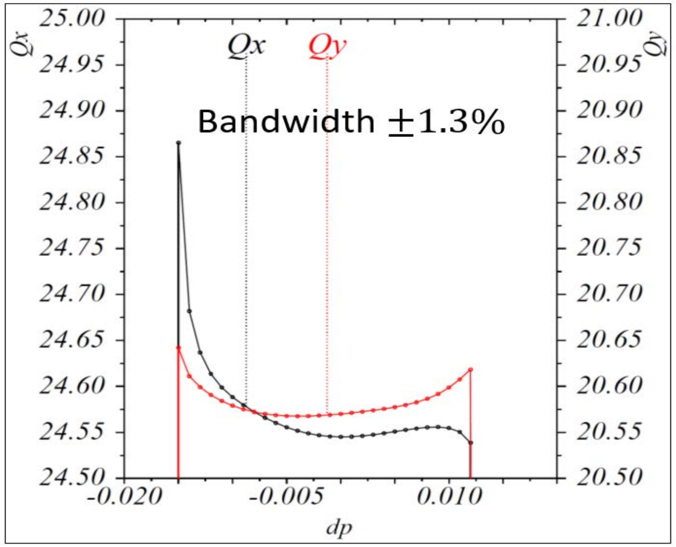
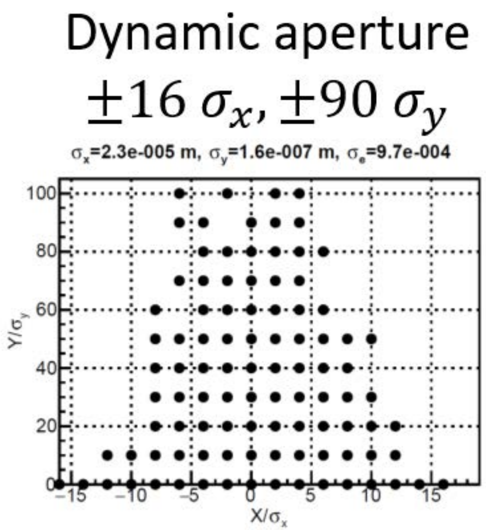
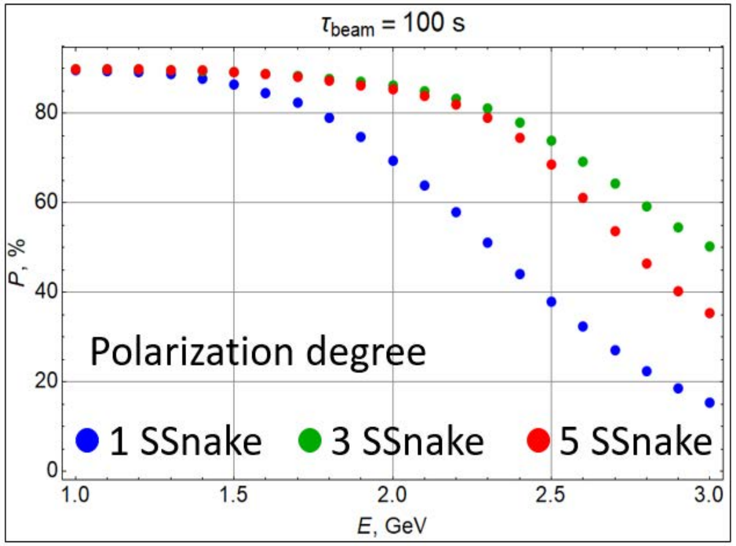
BEAM DYNAMICS AND POLARIZATION

All essential beam physics issues were considered (optics, nonlinear beam dynamics, longitudinal polarization, IBS, etc.). No showstoppers are revealed.







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Super C/tau Factory at Novosibirsk

(physics)

- Charm mixing
- CP violation in charm decays
- Rare and forbidden charm decays
- Standard Model tests in τ leptons decays
- Searches for lepton flavor violation $\tau \to \mu\gamma$
- CP/T violation searches in τ leptons decays

Requirements: $L > 10^{35}$ cm^{-2} s^{-1}, longitudinal polarization,
General Purpose Detector with best possible PID

If even one beam polarized, τ almost 100% longitudinally polarized near the threshold

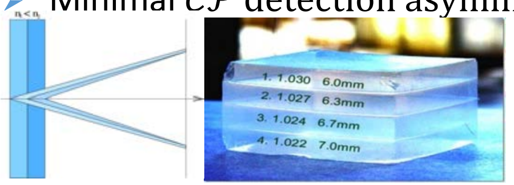
- Michel parameters
- CP-violation in τ-decays

Polarization may increase sensitivity by several times!

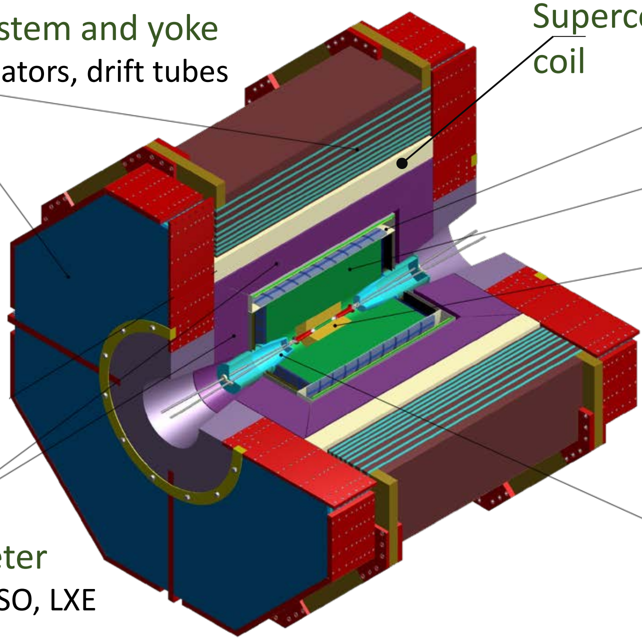
Detector concept

Requirements

- Occupancy 300 kHz
- Good energy and momentum resolution
- High detection efficiency of soft tracks
- Best possible π/K and π/μ separations
- Minimal $\mathcal{CP}$ detection asymmetry



FARICH: prototype tested.
Record K/π and π/μ separation achieved



SCT current status: expertise and partnership development

The conceptual design of the new facility, which had been developed at the BINP with the participation of Russian and foreign partners, was highly evaluated by Russian and foreign experts

Dedicated meeting of European Committee on Future Accelerators, ECFA in 2011 declared, in particular, that …Committee members are all convinced by the physics case of the SCT … Contribution of such a machine would further enhance the international role of Russia and attract a worldwide interest

In 2012, the SCT project got highest scores with specific recommendations of the Expert Group on the Assessment of EU Cooperation with Six Russian Federal Megascience Projects (European Commission, Directorate General for Research and Innovation): …this project would be an immensely appropriate project for Novosibirsk and it would give Russia a place at the table of a small club with world-class machines.

International scientific organizations (CERN, JINR) and authoritative and prominent scientists (among them – Atsuto Suzuki, Rolf Heuer, Tatsuya Nakada, and Nobel Prize Winner in Physics Martin Perl) have expressed their support for the SCT.

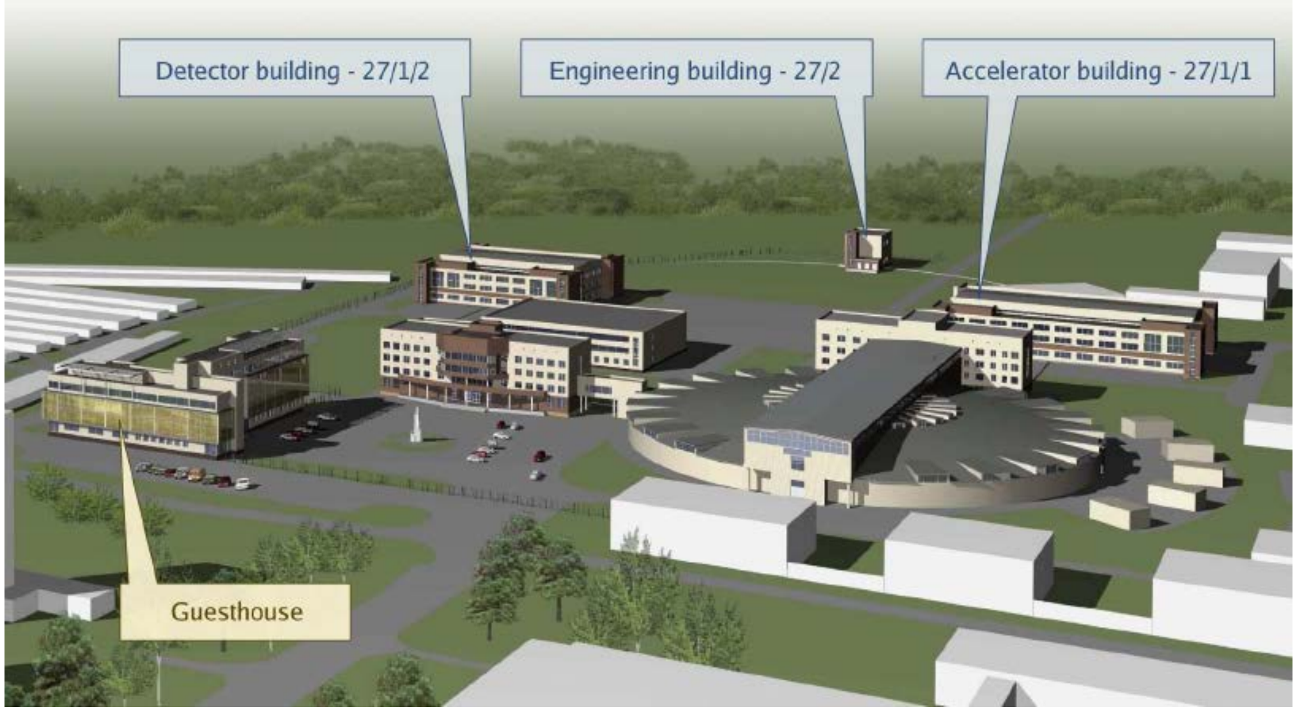
A number of countries and facilities have been formally involved in SCT to date (MoU/LoU, cooperation agreement etc.). These include:

- Switzerland (European Organization for Nuclear Research, CERN, Genève) – international organization
- China (Institute of High Energy Physics, IHEP, Bejing)
- Italy (Istituto Nazionale di Fisica Nucleare, Frascati – INFN-LNF)
- Japan (High Energy Accelerator Research Organization, KEK)
- UK (John Adams Institute for Accelerator Science, JAL)
- …

SCT current status: executive progress

- In 2011, the SCT project became one of the six mega-science class projects selected by a Governmental Commission for implementation on the territory of the Russian Federation.
- In June 2017, the SCT project is included in the plan for the implementation of the first phase of the Strategy for Scientific and Technological Development of the Russian Federation (activity: formation of international collaborations, completion of design, feasibility study – should be completed till October, 2019)
- A number of agreements between Russian research organizations for development and creation of new mega-science facilities on the territory of the Russian Federation are signed
- Support from EU – grant CREMLIN (Connecting Russian and European Measures for Large-scale Research Infrastructures), 2015-2018, in partnership with CERN (new project CREMLIN+ submitted in March, 2019 to EU)
- Preliminary road map and CDR are prepared, this work is go on with expanding participation of Russian and international community
- First international workshop on SCT factory – May, 25-27 (Novosibirsk)
- Second international workshop on SCT factory – Dec, 7-12 (Orsay)
- First Meeting of International Advisory Committee – May, 26-27, 2018

Образец заголовка



•	Accelerator Complex	207 MEuro
•	Detector	91 MEuro
•	Buildings infrastructure	100 MEuro

- BINP has already invested 37 MEuro in the capital construction and injection complex

129

Conclusion

- **Several generations of colliders and detectors successfully operated at Budker INP with world-wide recognized contributions to particle physics**

- **VEPP-4M and VEPP-2000 with 3 detectors are in operation at present → interesting physics in the coming years**

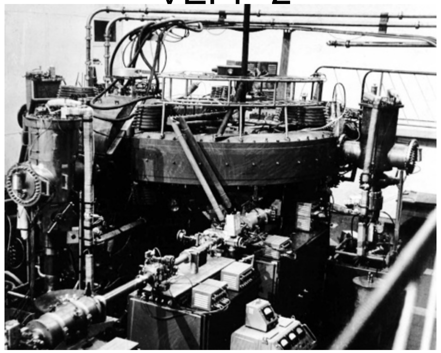
- **Budker INP successfully collaborates in a few outstanding experiments outside**

- **Super Tau-Charm Factory is the future!**

From VEP-1 to Tau-charm factory!

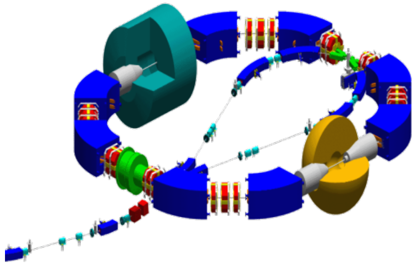
VEP-1

VEPP-2



VEPP-3

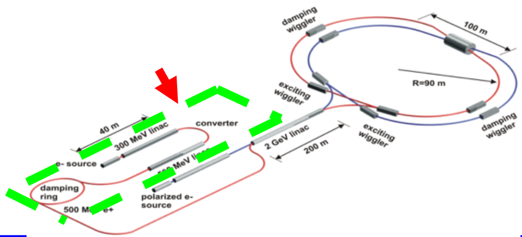
VEPP-2000



VEPP-4

VEPP-4M

Tau-charm



Status of NICA at JINR

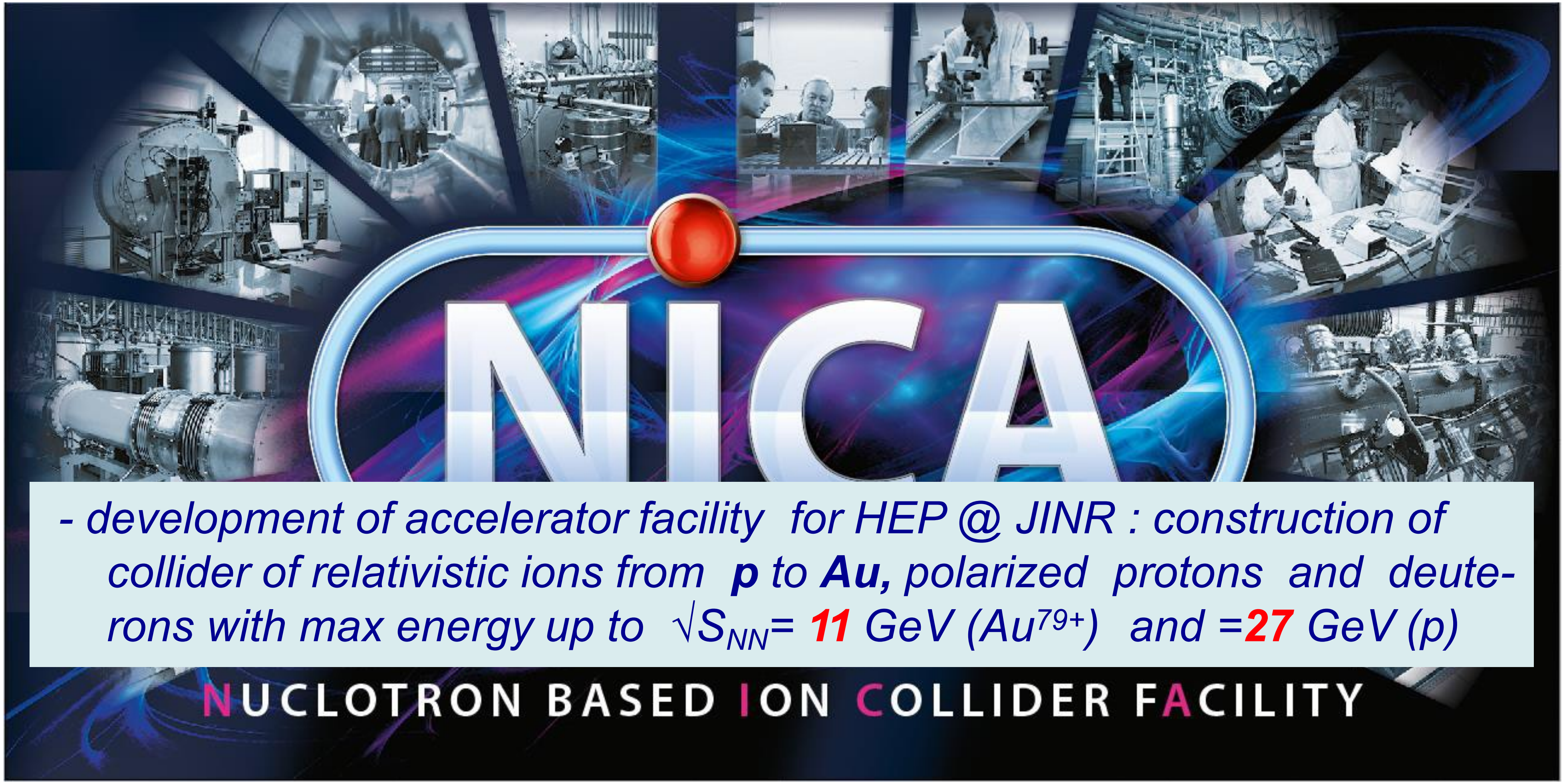
A.Kovalenko, V.Kekelidze, R.Lednicky, V.Matveev, I.Meshkov,,
A.Sorin, G.Trubnikov, R.Tsenov
Joint Institute for Nuclear Research, Dubna

QUARKS-2018
26 May-03 June 2018, Valday, Russia

NICA (Nuclotron based Ion Colider fAcility

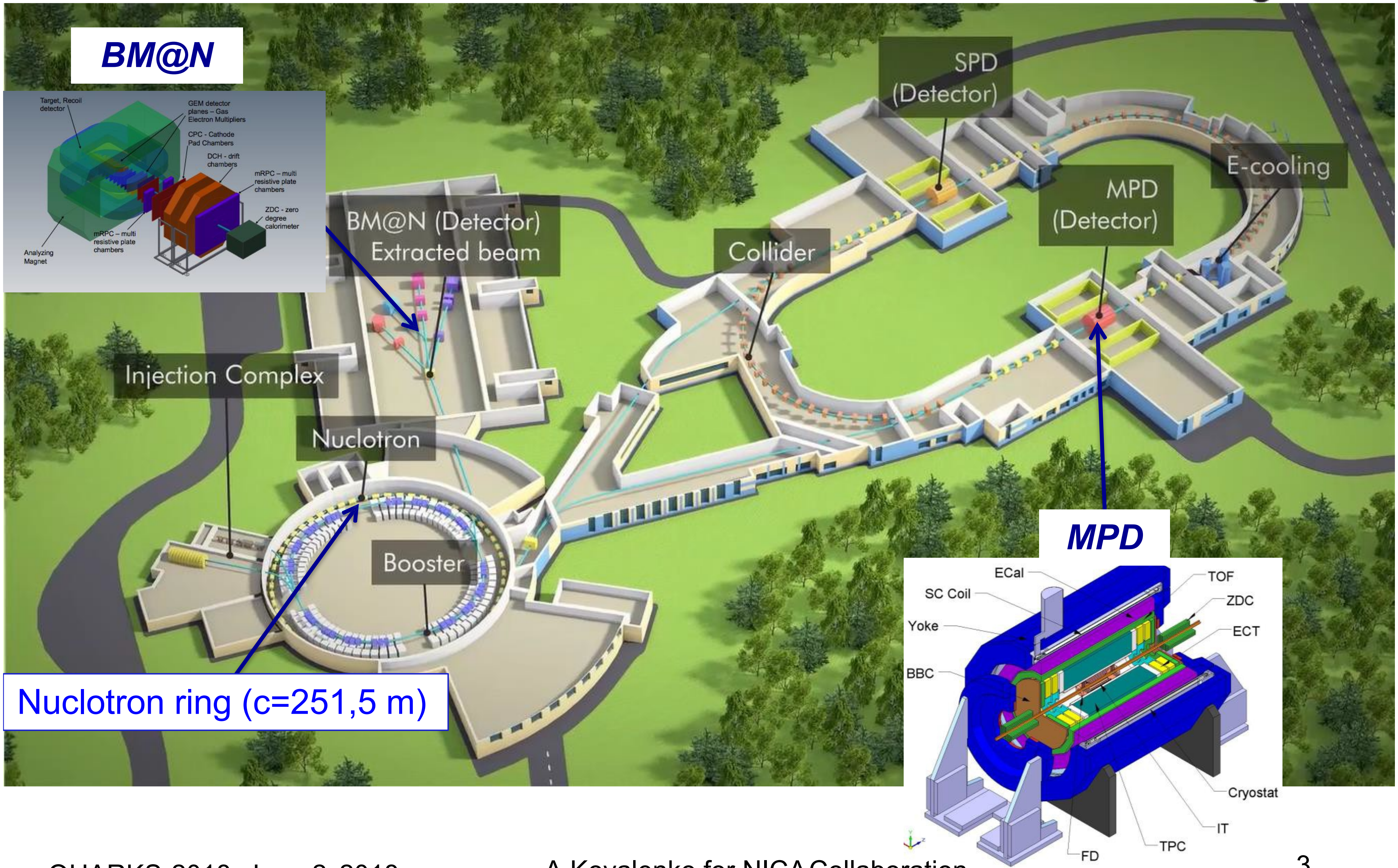
Main targets:

- *study of hot and dense baryonic matter at the energy range of max baryonic density*
- *investigation of nucleon spin structure, polarization phenomena*

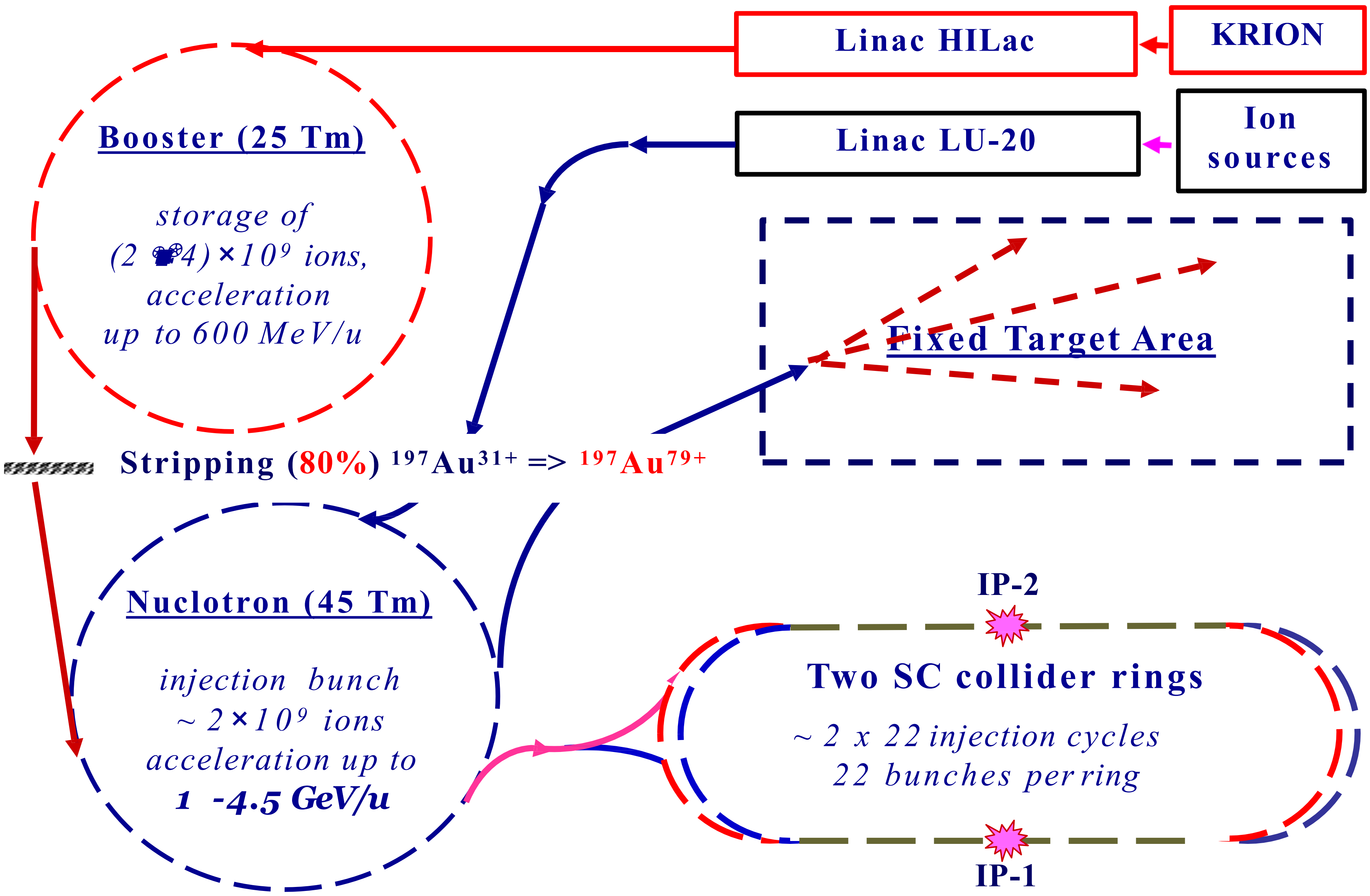


- *development of accelerator facility for HEP @ JINR : construction of collider of relativistic ions from **p** to **Au,** polarized protons and deuterons with max energy up to $\sqrt{S_{NN}}$= **11** GeV (Au^{79+}) and =**27** GeV (p)*

experiments at NICA



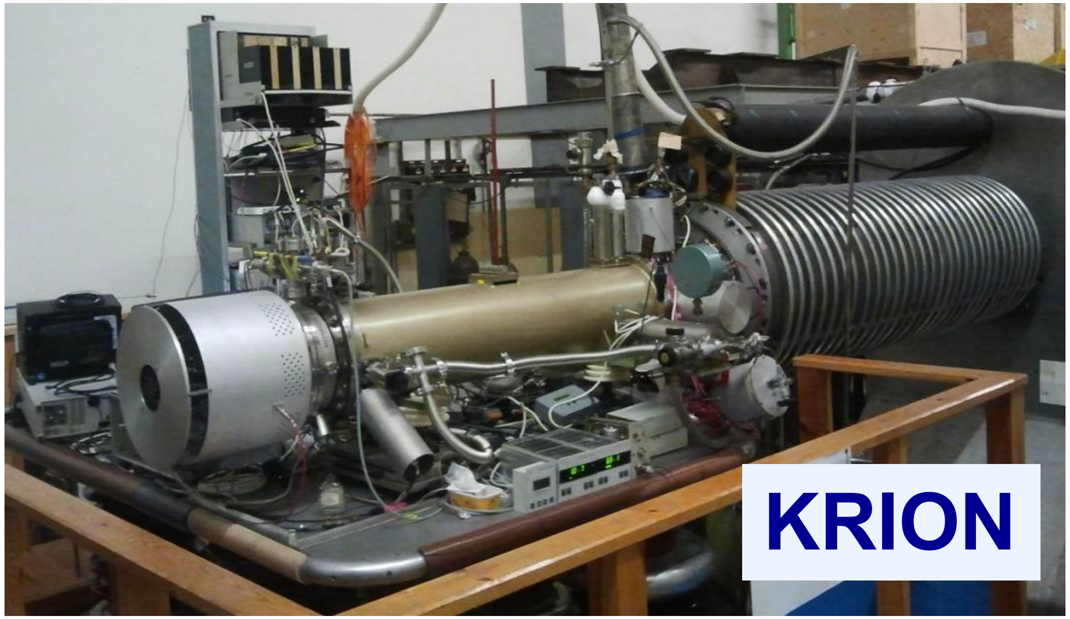
Structure and Operation Regimes



Injection complex: 4 ion sources

Source	KRION-6T	Laser	Douplasmatron	SPI new !
particles	Au^{31+}	up to Mg^{10+}	p, d, He^{2+}	↑p, ↑d
particle/cycle	~2.5 10^9	~10^{11}	p, d ~5 10^{12} He^{2+} ~10^{11}	5 10^{11}
repetition, Hz	10	0,5	1	0,2

to be commissioned



Injection complex: 2 Linacs

Linac	LU-20	HILAC **new !**
structure (section number)	RFQ + Alvarez type	RFQ + IH DTL(2)
mass to charge ratio A/Z	1-3	1-6
injection energy, keV/amu	150 for A/Z 1-3	17
extraction energy, MeV/amu	**5** (A/Z 1-3)	**3.24** (A/Z=6)
input current, mA	up to 20	up to 10

LU-20 – new fore-injector*:*
JINR, INR, ITEP, MEPHI

commissioned: May ‘16

HILAc: “BEVATECH OHG”

the first Linac with transistor RF amplifier

commissioned: Oct. ‘16

Machines: Nuclotron *(in operation since 1993)*

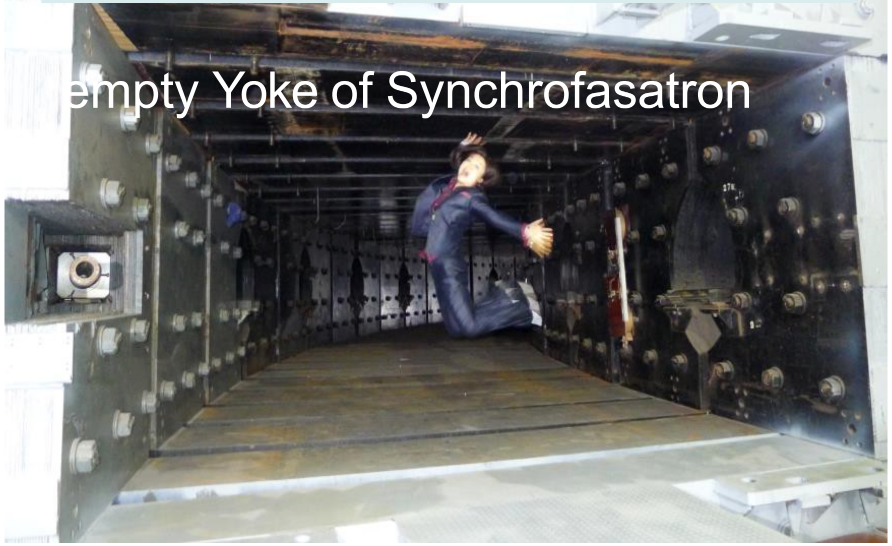
Parameters	Nuclotron
type	SC synchrotron
particles	p, d, (p, d polarized), nuclei
injection energy, MeV/u	5 (p, d) 570-685 (Au)
max. kin. energy, GeV/u	12.1 (p); 5.6 (d); 4.4 (Au)
magnetic rigidity, T m	25 – 43.25
circumference, m	251.52
cycle for collider mode, s	1.5-4.2 (active); 5.0 (total)
vacuum, Torr	10^{-9}
*intensity, **Au** ions/pulse*	$1\ 10^{9}$
transition energy, GeV/u	7.0
RF range, MHz	0.6 -6.9 (p,d) 0.947 – 1.147 (nuclei)
spill of slow extraction, s	up to 10

*modernized in **2010-2015***

Machine: Booster (*under construction*)

Parameter	**Booster**
type	SC synchrotron
particles	ions A/Z $\leq$ 3
injection energy, MeV/u	3.2
maximum energy, GeV/u	0.6
magnetic rigidity, T m	1.6 – 25.0
circumference, m	210.96
cycle for collider mode, s	4.02 (active); 5.0 (total)
vacuum, Torr	10^{-11}
*intensity, **Au** ions/pulse*	1.5 10^{9}
transition energy, GeV/u	3.25
RF range, MHz	0.5 -2.53
spill of slow extraction, s	up to 10

Li So Yon (South Korean Cosmonaut)
LHEP JINR, Dubna, 7 Sep., 2011



Commissioning in 2019

BINP contribution to the Booster

two RF stations

- *tested at JINR - Oct. '14*
- *commissioning - 2017*

electron cooling

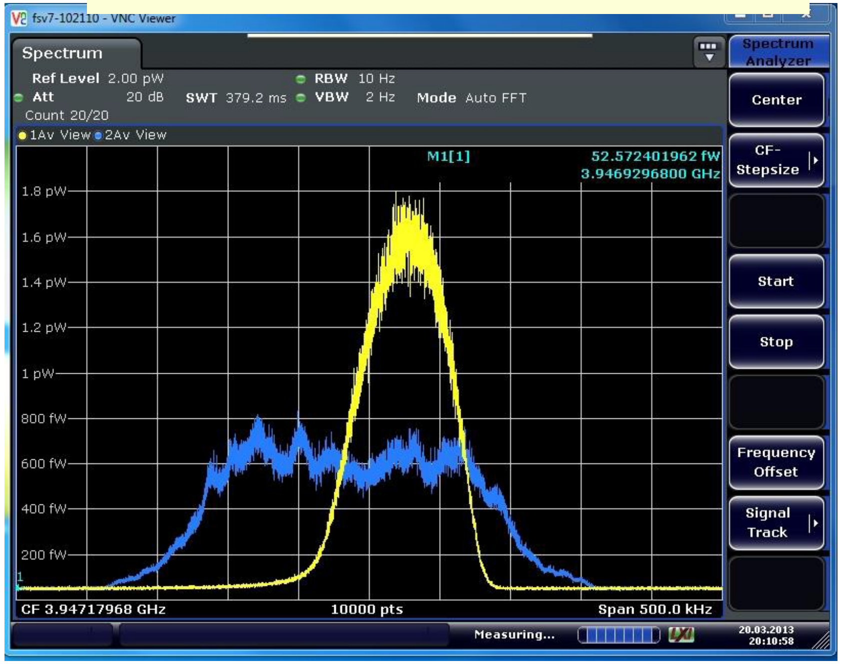
fabricated and tested at BINP in 2016
delivered to JINR in April 2017
*commissioned in **2017***

Project status: *on schedule*

Nuclotron development

- Stable and safe operation up to maximum design energy
- Beam time for users > 70%
- Time losses < 8%
- Development of cryogenic facility
- Modern automatic control system based on TANGO
- Test of stochastic cooling
- New RFQ fore-injector for LU-20

momentum spread of d beam

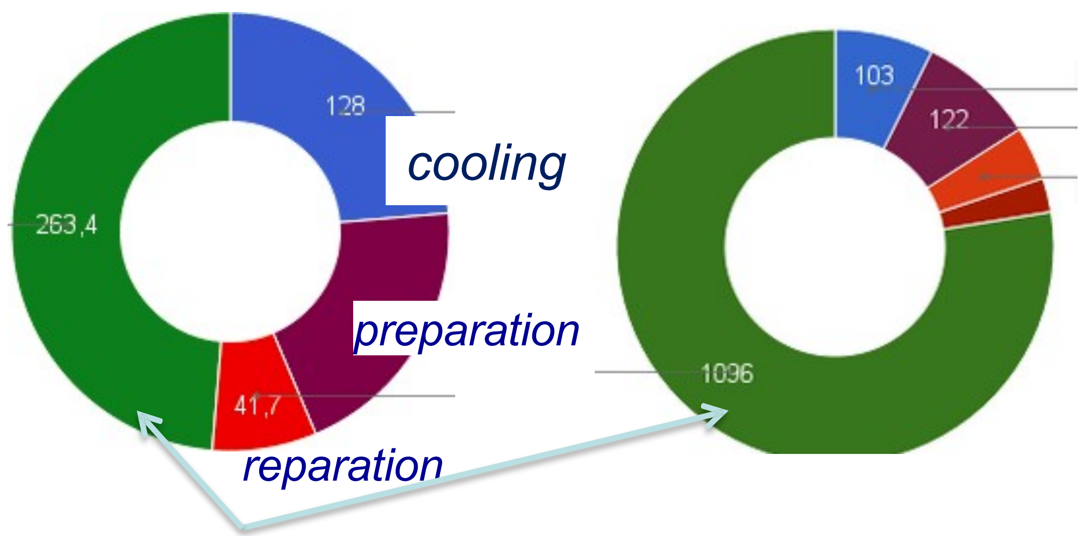


2 – 4 GHz bandwidth, the cooling of bunched and coasting deuteron and carbon beams was achieved

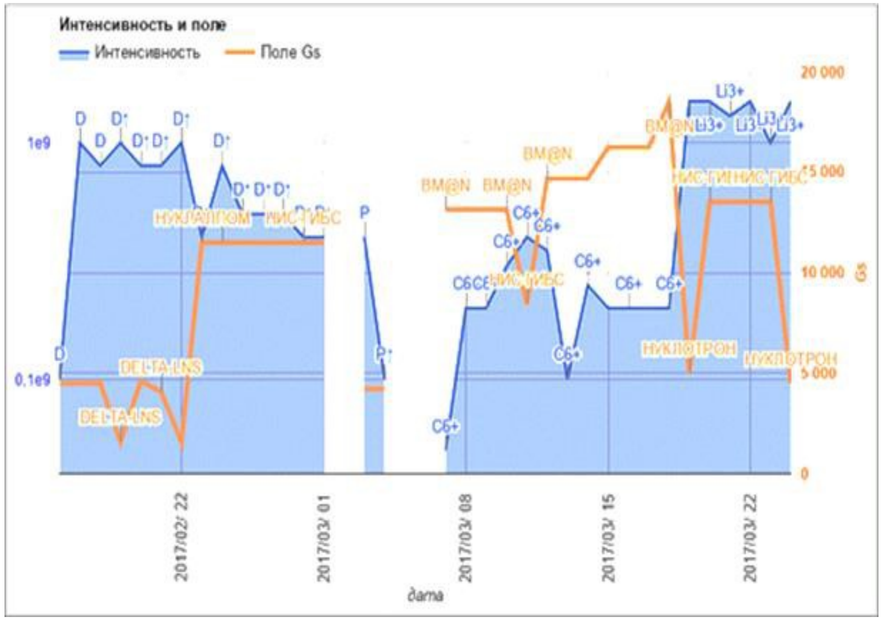
Nuclotron runs in 2015 -2018

- **Run – 51 (**d, Li, C) *26 Jan. - 26 Mar., **2015***
- **Run – 52 (** d...) ***Technical*** *June 2 –July 8, **2016***
- **Run – 53 (**d↑, Li) *Oct.19 – Dec. 25 , **2016***
- **Run – 54** (d↑,p↑), C *Feb. 1 – Mar. 24 , **2017***
- **Run – 55 (** C**,** Ar**,** Kr,) *Feb. **–** April **2018***

Run – 52 **Run – 53**

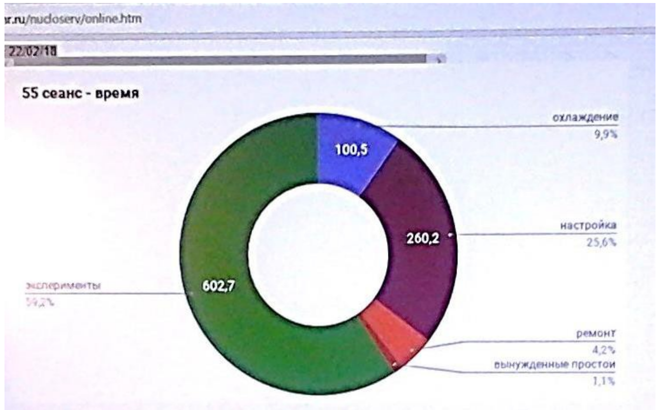


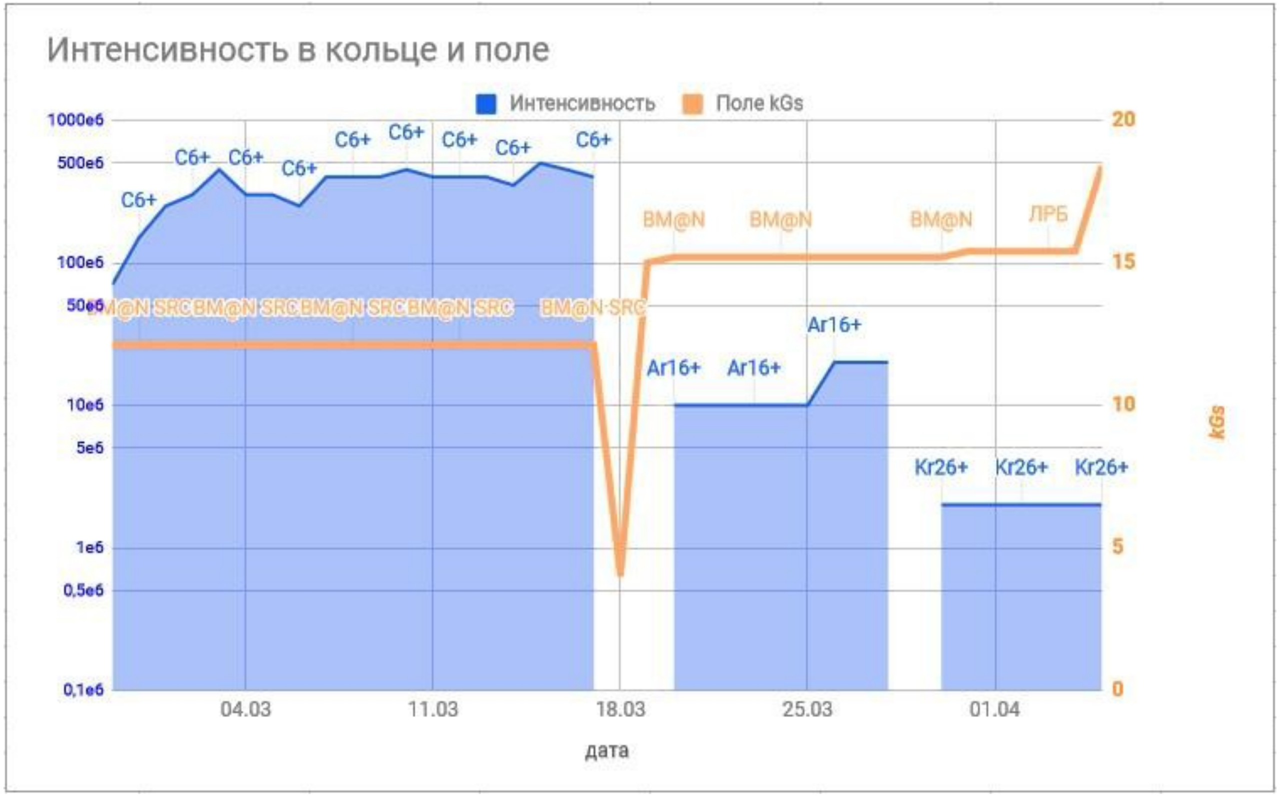
Run – 54



Nuclotron run in 2018

- **Run – 55 (** C, Ar, Kr,) *Feb. – April **2018***

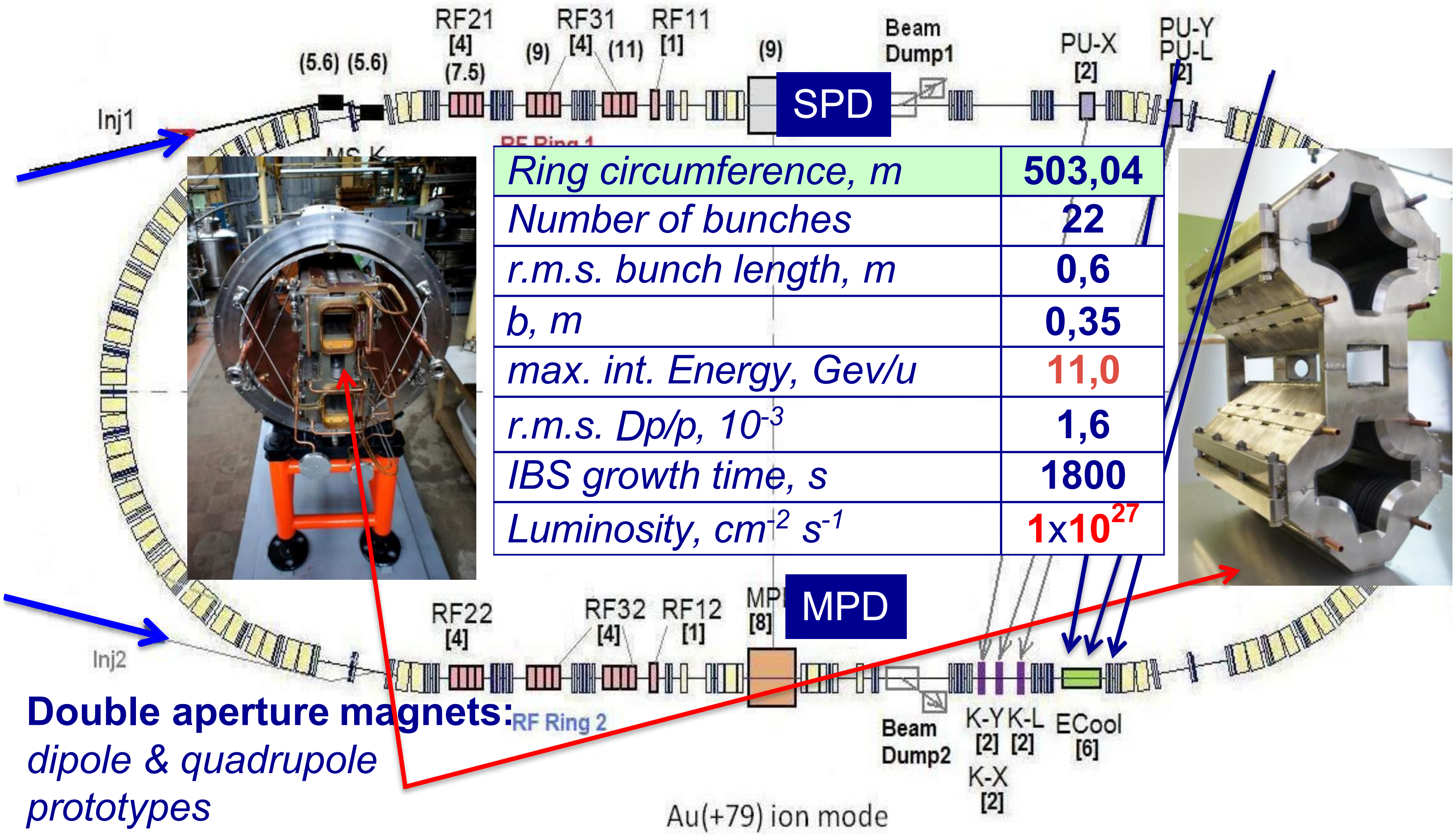




The run was completely devoted to data taken at BM@N setup

The Collider

45 T*m, *4.5 GeV/u for* ***Au^{79+}***

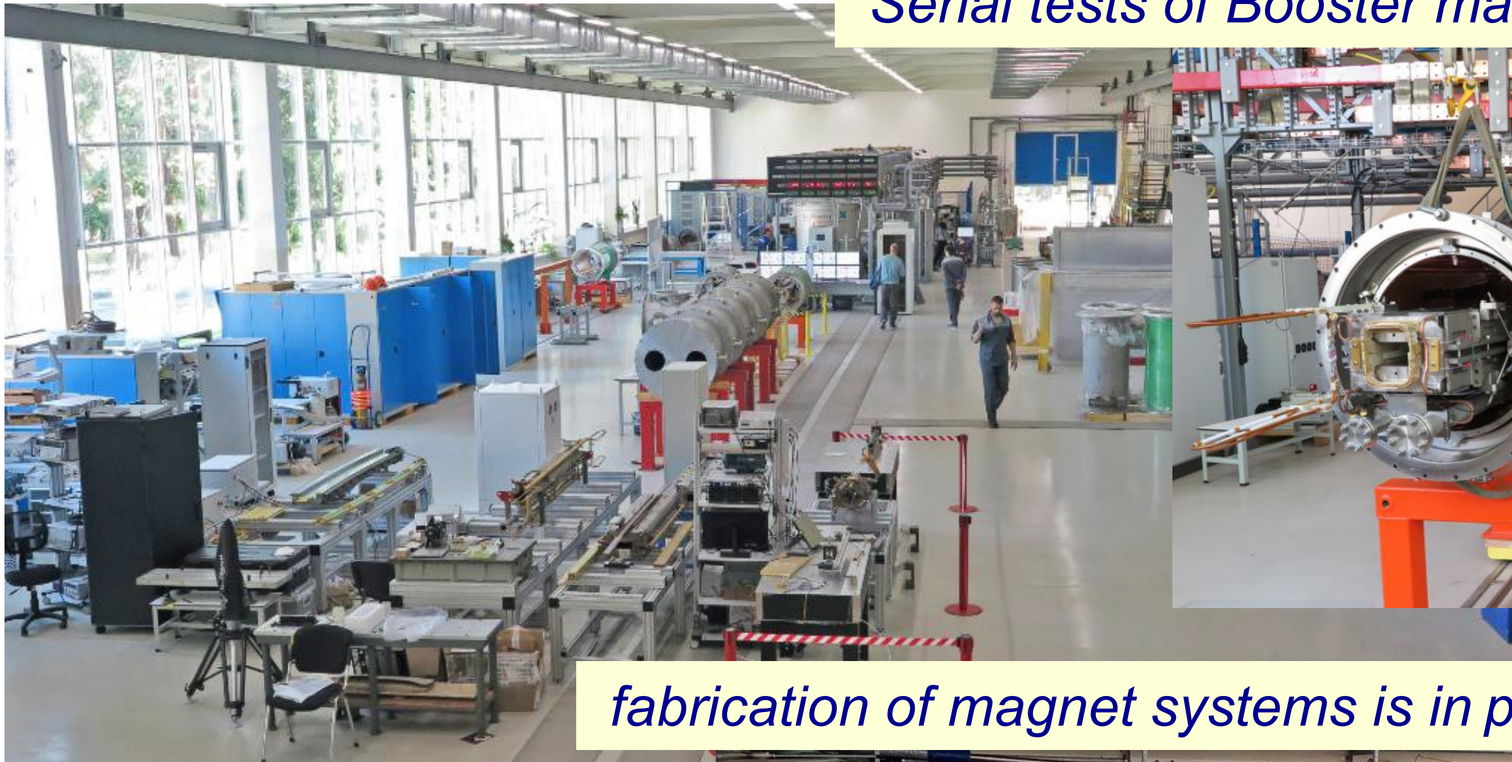


Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
b, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. Dp/p, 10^{-3}	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**$1x10^{27}$**

Double aperture magnets:
dipole & quadrupole prototypes

SC Magnets for Booster, Collider & SIS-100/FAIR workshop at VBLHEP JINR *(bld. 217)*

Serial tests of Booster magnets have started



fabrication of magnet systems is in progress

He liquefier has been put in operation, 1000 l/h

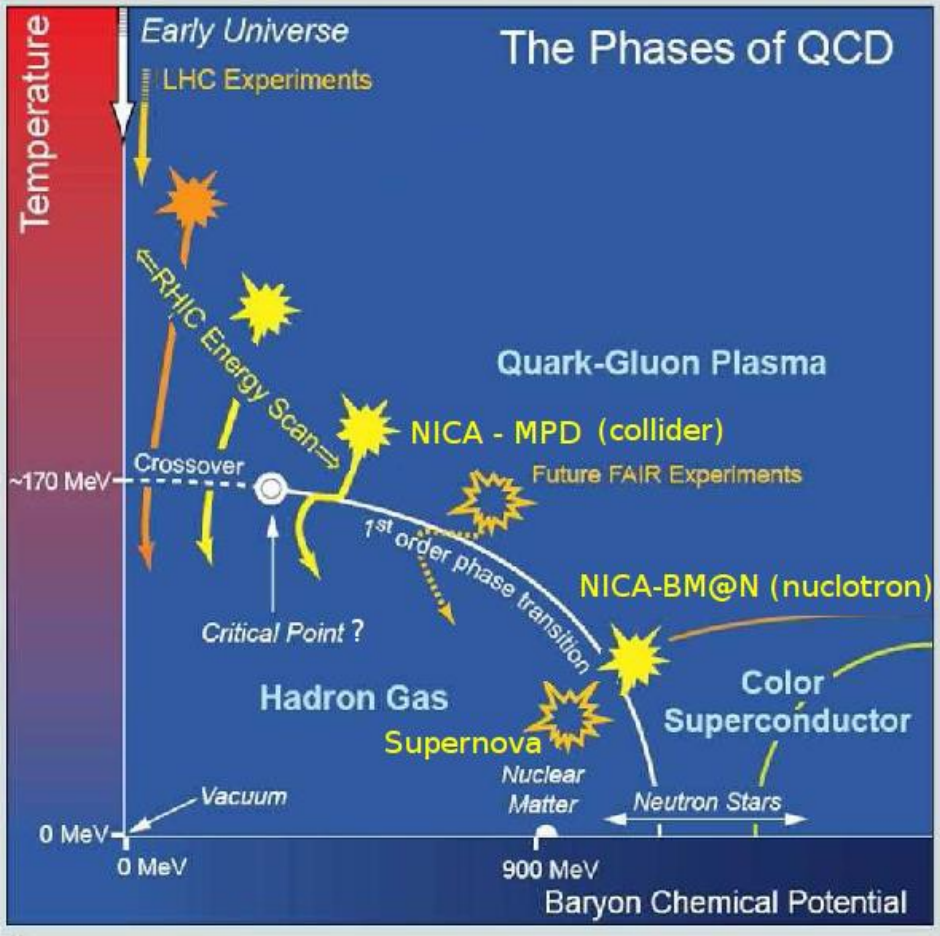
Largest in Russia

Finally the cooling power should be doubled from 4 kW to 8 kW @ 4.5K

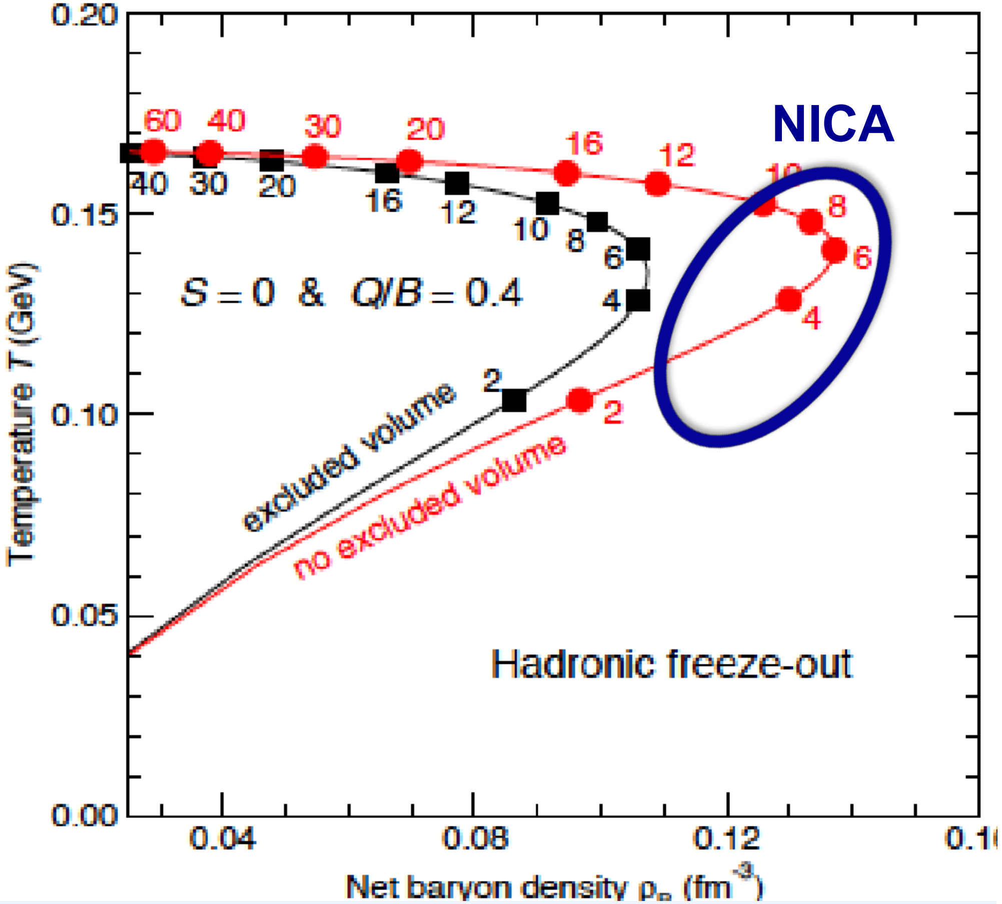
Physics program and the setups at NICA

Exploration of the QCD PD - Density Frontier

Exploring high-density baryonic matter: maximum freeze-out density



J. Randrup, J. Cleymans; White Paper



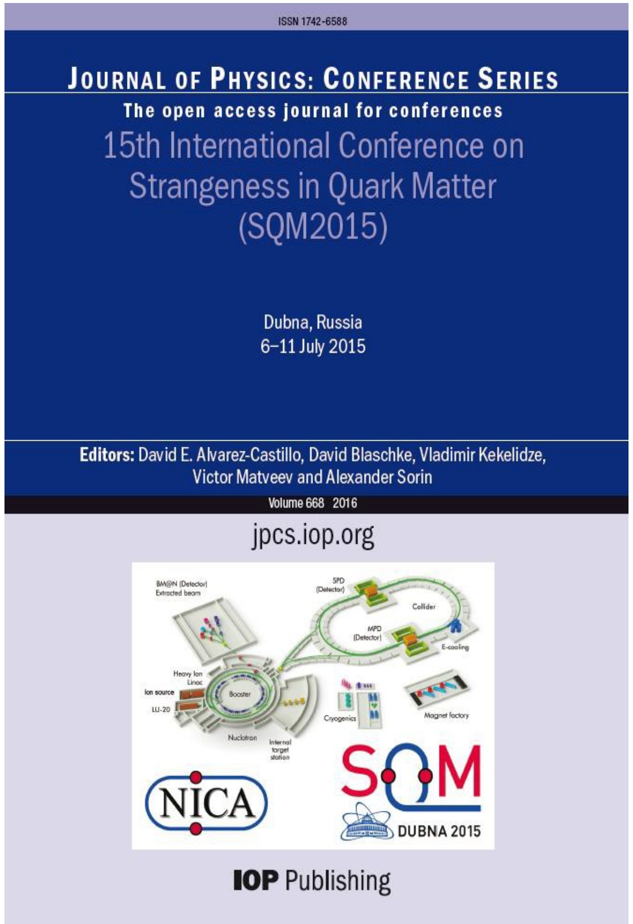
NICA is well suited for exploring the transition between the hadronic and q-g phases at the highest baryon density. This is the top priority of the NICA program.

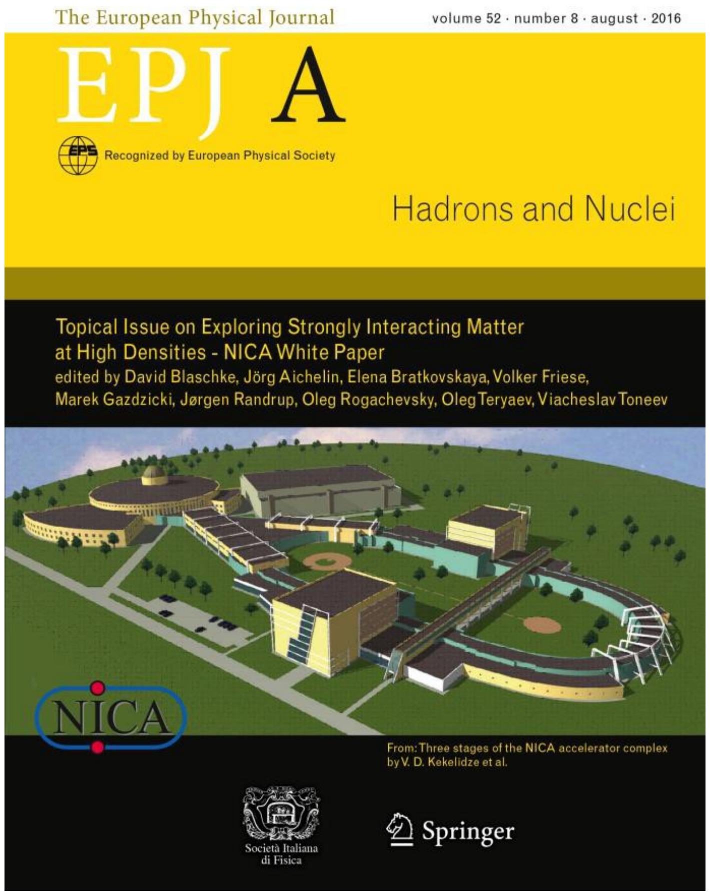
Physics objectives

- *Bulk properties, EOS*
  - particle yields & spectra, ratios, femtoscopy, flow
- *In-Medium modification of hadron properties*
  - onset of low-mass dilepton enhancement
- *Deconfinement (chiral) phase transition at high r_B*
  - enhanced strangeness production
- *QCD Critical Point*
  - event-by-event fluctuations & correlations
- *Chiral Magnetic (Vortical) effect, L polarization*
- *Hypernuclei*

New issues: NICA White Paper, SQM proceedings

Physics targets for the exploration of first order phase transitions in the region of the QCD phase diagram accessible to NICA & CBM and possible observable effects of a “mixed phase culminates this year in the release of the “NICA White Paper” as a Topical Issue of the ***EPJ A*** *(July 2016).*

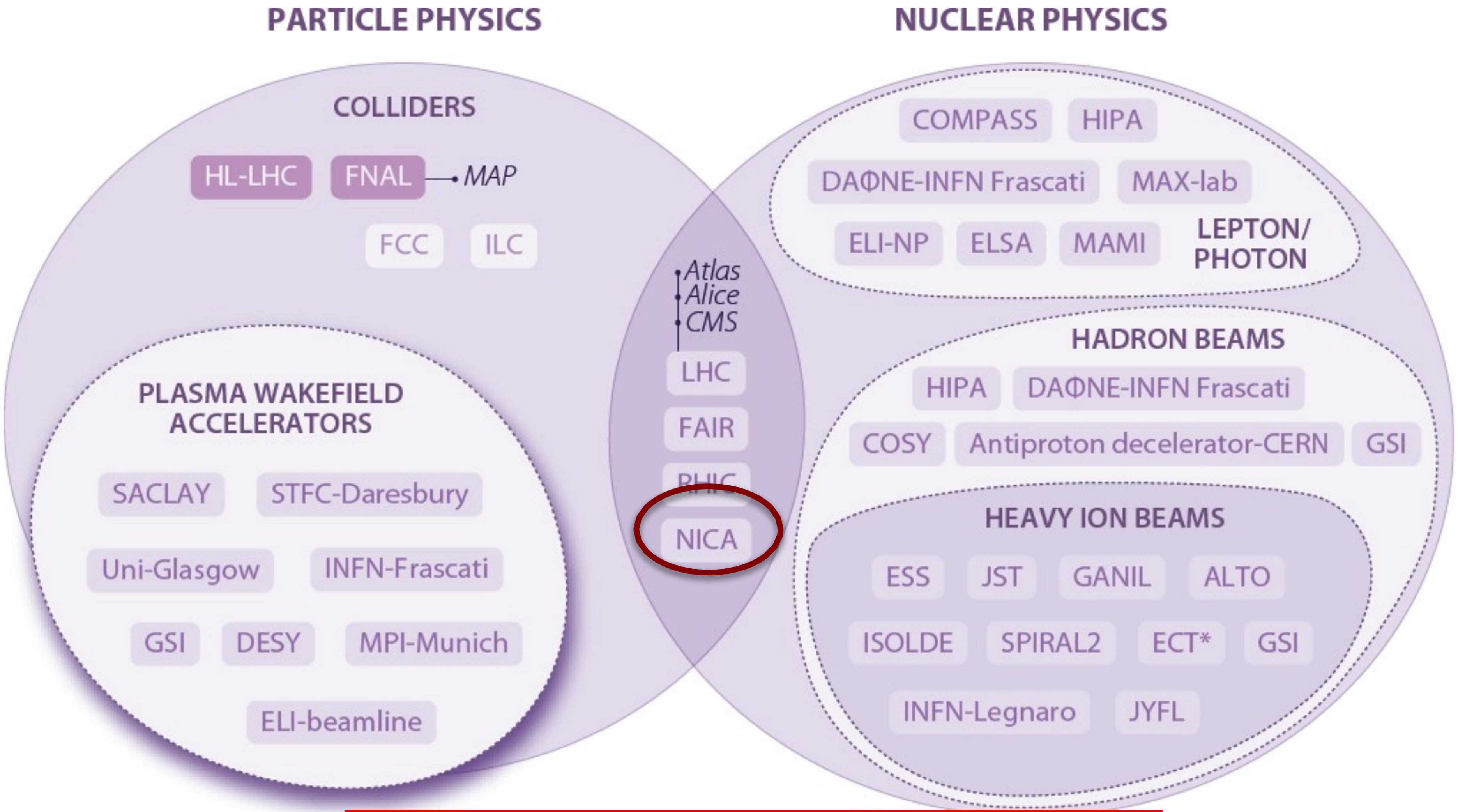




111 *contributions,*
188 *authors*
from **24** *countries*

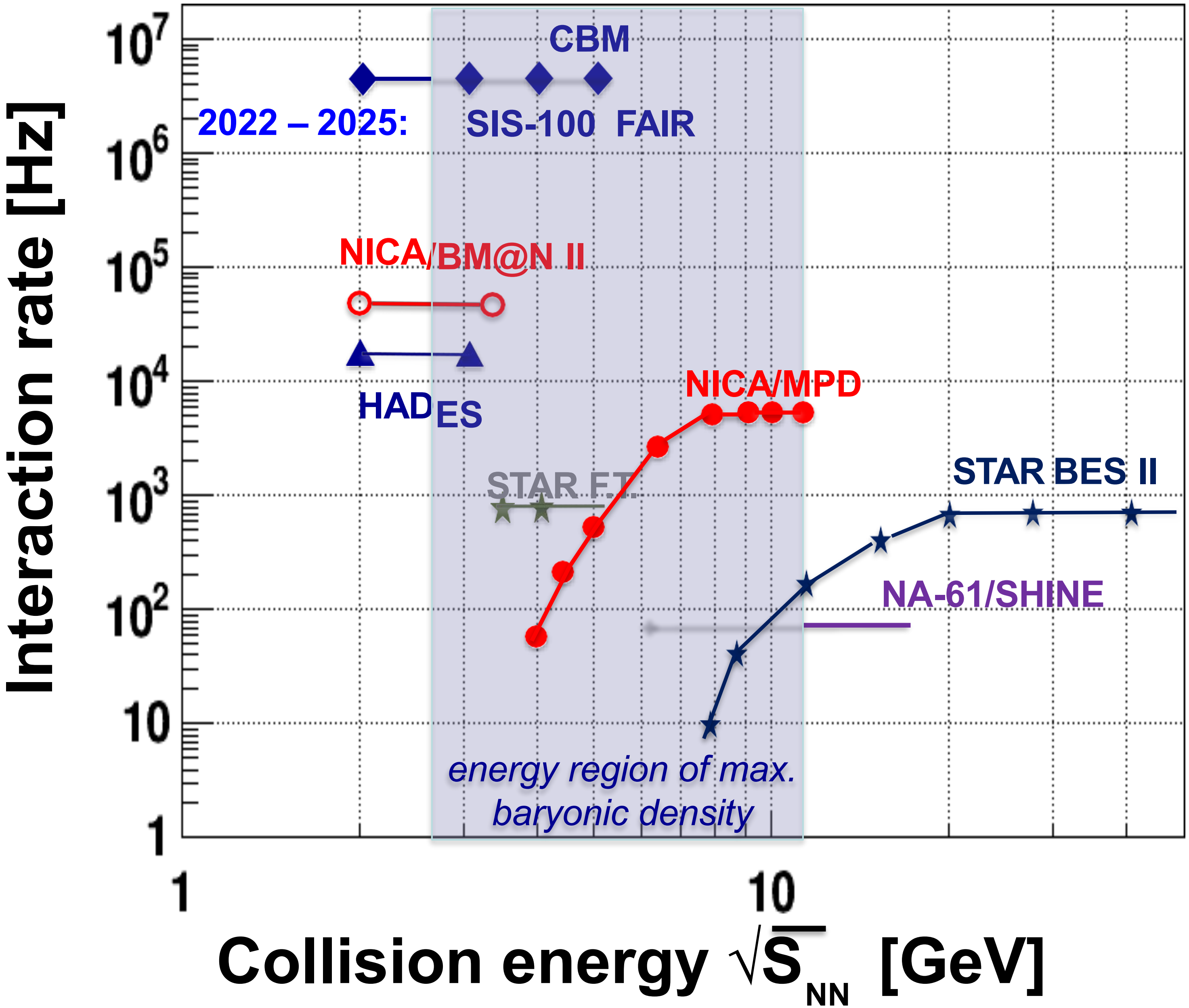
New issue of the ESFRI Roadmap

Main Research Infrastructure in Particle and Nuclear Physics

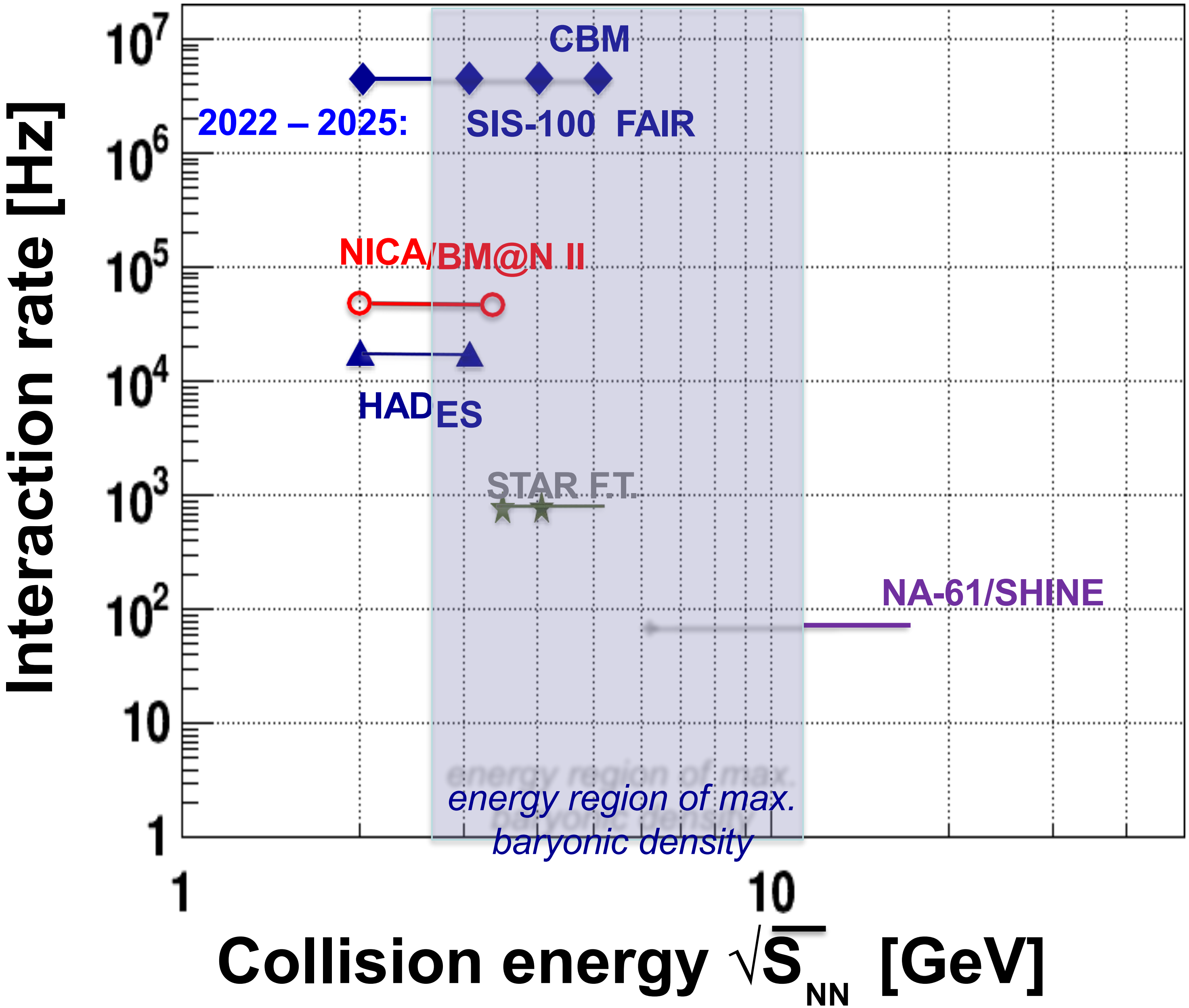


NICA – Complementary Project

Present and future HI experiments



Present and future HI F.T. experiments



Baryonic Matter at Nuclotron (BM@N)

experiment at Nuclotron extracted beams

BM@N Collaboration:

Russia: *INR, MEPhi, SINP, MSU, IHEP, S-Ptr Radium Inst.*

Bulgaria: *Plovdiv University;*

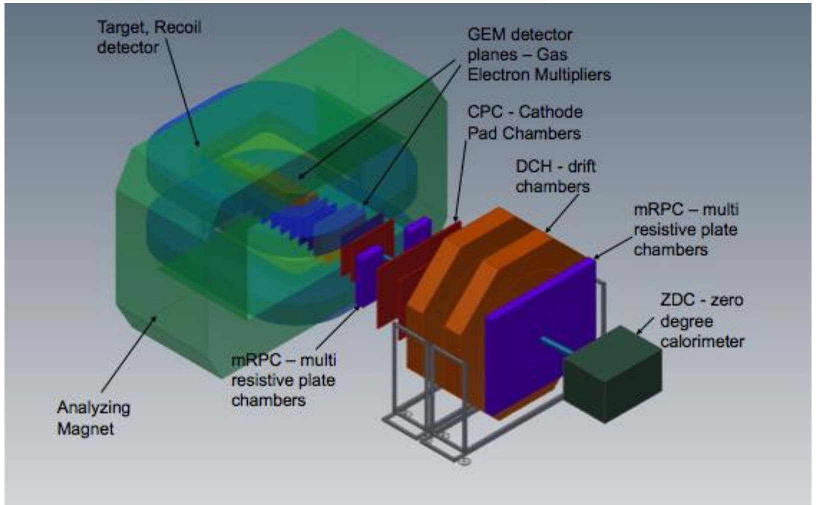
China: *Tsinghua University, Beijin;*

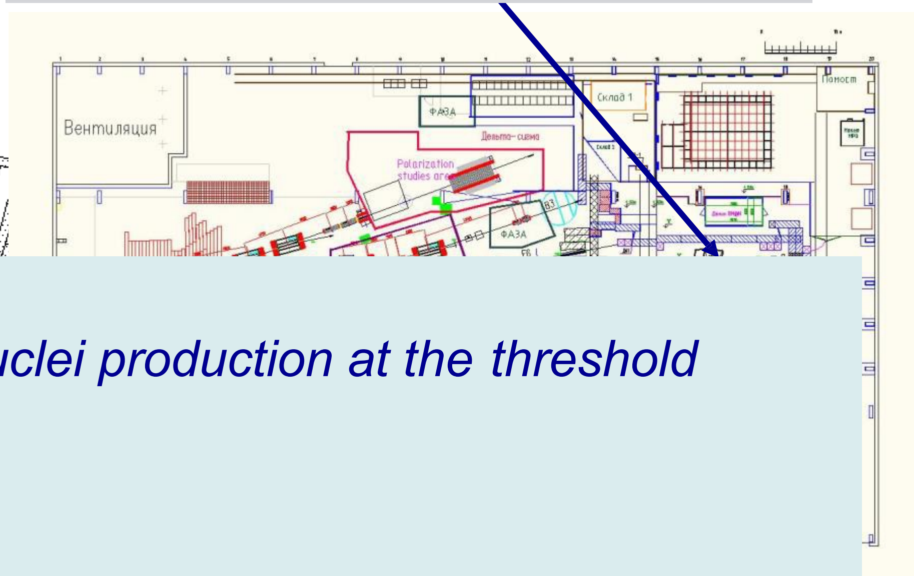
Poland: *Warsaw Tech.Uni.*

Israel: *Tel Aviv Uni., Weitzman Inst.*

Germany: *Frankfurt Uni.; eoi GSI*

USA*: MIT*





Physics:

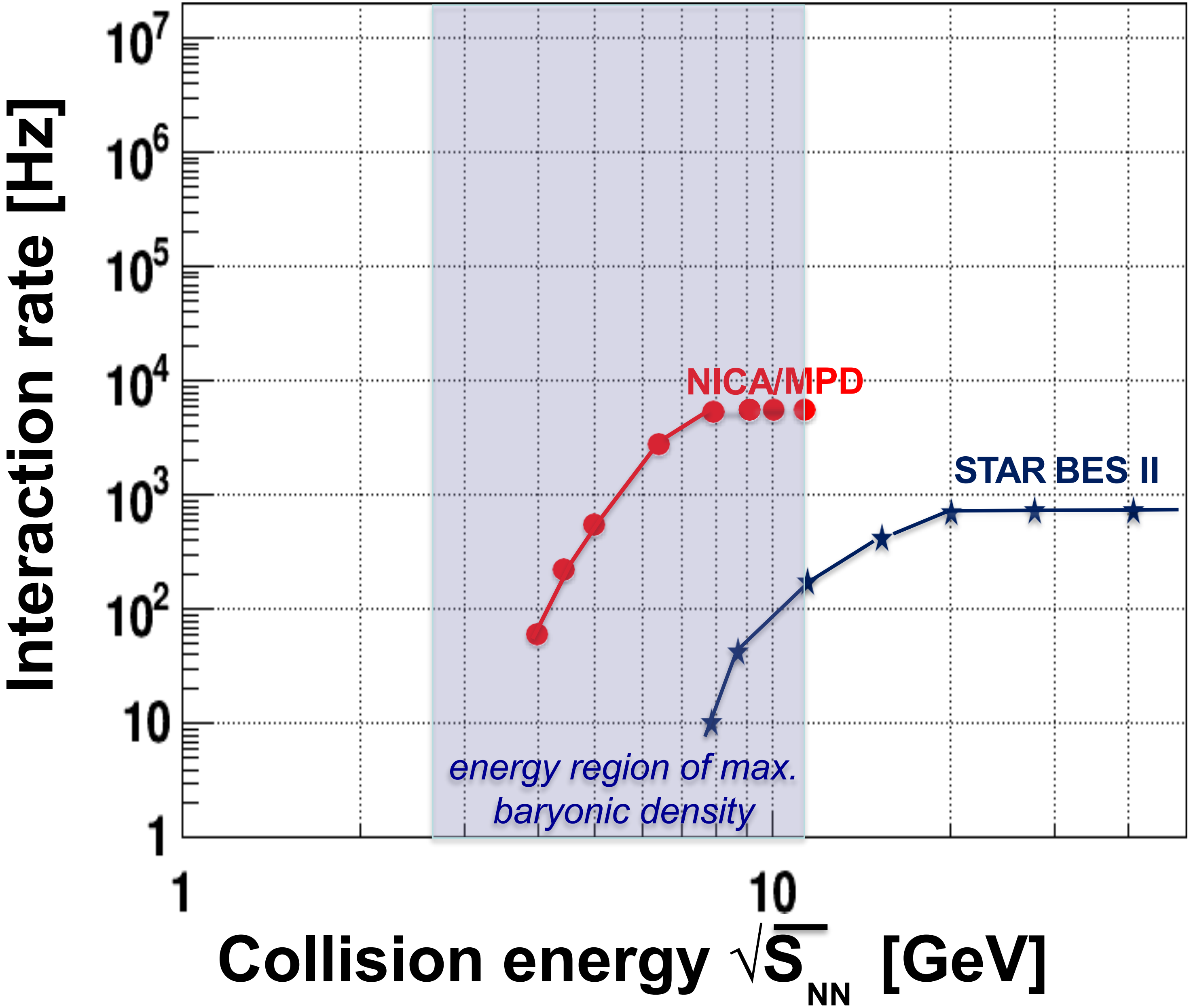
- ✓ *strange / multi-strange hyperon and hypernuclei production at the threshold*
- ✓ *hadron femtoscopy*
- ✓ *short range correlations*
- ✓ *event-by event fluctuations*
- ✓ *in-medium modifications of strange & vector mesons in dense nuclear matter*
- ✓ *electromagnetic probes, states decaying into γ, e (with ECAL)*

BM@N plans

year	2016	2017 Feb.-Mar.	2017 Nov.-Dec.	2019	2020 + ..
beam	**d (↑)**	**C, Ar**	**Kr**	**Au**	**Au, p**
maximum intensity, Hz	**1M**	**1M**	**1M**	**1M**	**10M**
trig. rate, Hz	**10k**	**10k**	**20k**	**20k**	**50k**
central tracker	**6 GEM half pl.**	**8 GEM half pl.**	**10 GEM half pl.**	**8 GEM full pl.**	**12 GEM or 8+2Si**
expiment status	**techn. run**	**techn. run**	**physics run**	**physics stage 1**	**physics stage 2**

beam: E_{kin} = 3.5, 4.0, 4.5AGeV

Present and future HI collider experiments

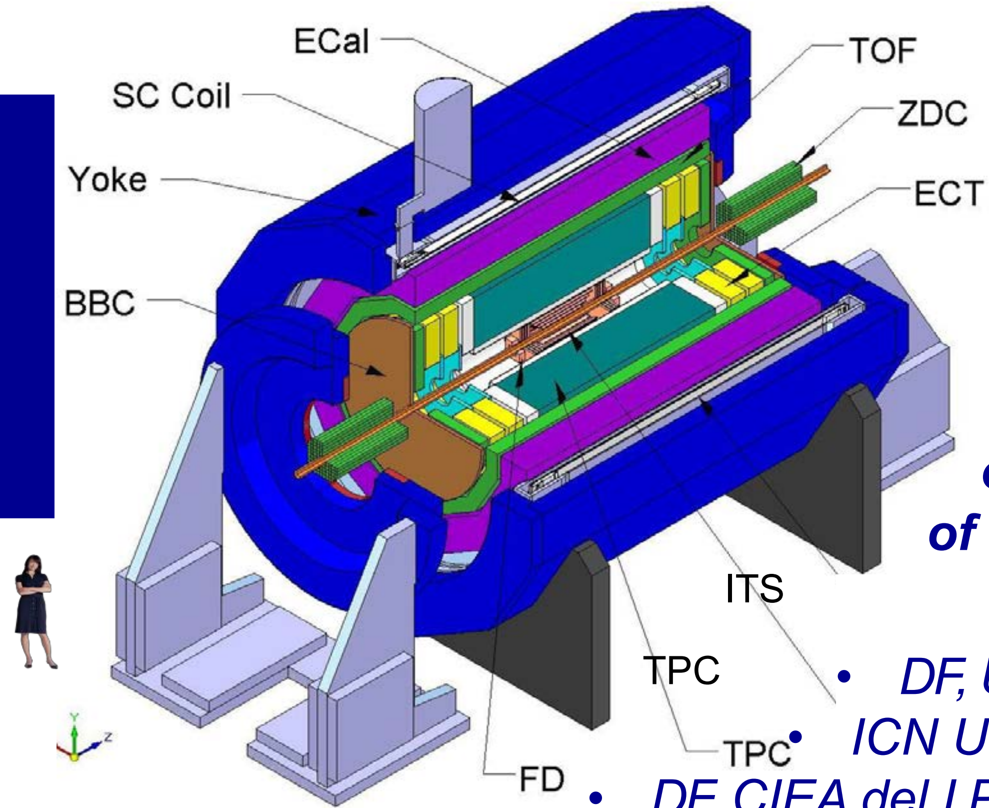


MultiPurpose Detector (MPD)

NICA

Main target:

- *study of hot and dense baryonic matter at the energy range of max net baryonic density*



expression of interest by:

- *CERN;*
- *DF, US, Mexico;*
- *ICN UNA; Mexico;*
- *DF, CIEA del I.P.N, Mexico;*
- *FCF-M UAS, Sinaloa, Mexico;*
- *FCF-MB UAP, Puebla, Mexico;*
- *PI Az.AS, Baku, Azerbaijan;*
- *ITEP, NC KI, Moscow, Russia;*
- *PNPI NC KI, Saint Petersburg, Russia;*
- *CPPT USTC, Hefei, China;*
- *SS, HU, Huzhou, Republic of South Africa.*

MPD Collaboration:

- *JINR, Dubna;*
- *Tsinghua University, Beijing, China;*
- *MEPhI, Moscow, Russia.*
- *INR, RAS, Russia;*
- *PPC BSU, Minsk, Belarus;*
- *WUT, Warsaw, Poland;*

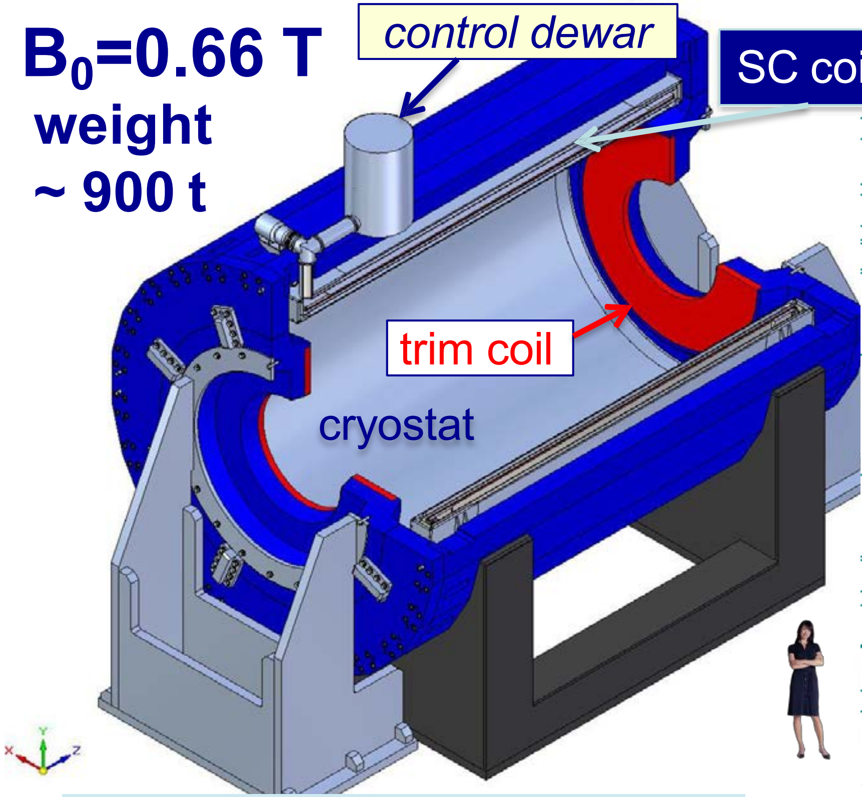
MPD detector for Heavy-Ion Collisions @ NICA

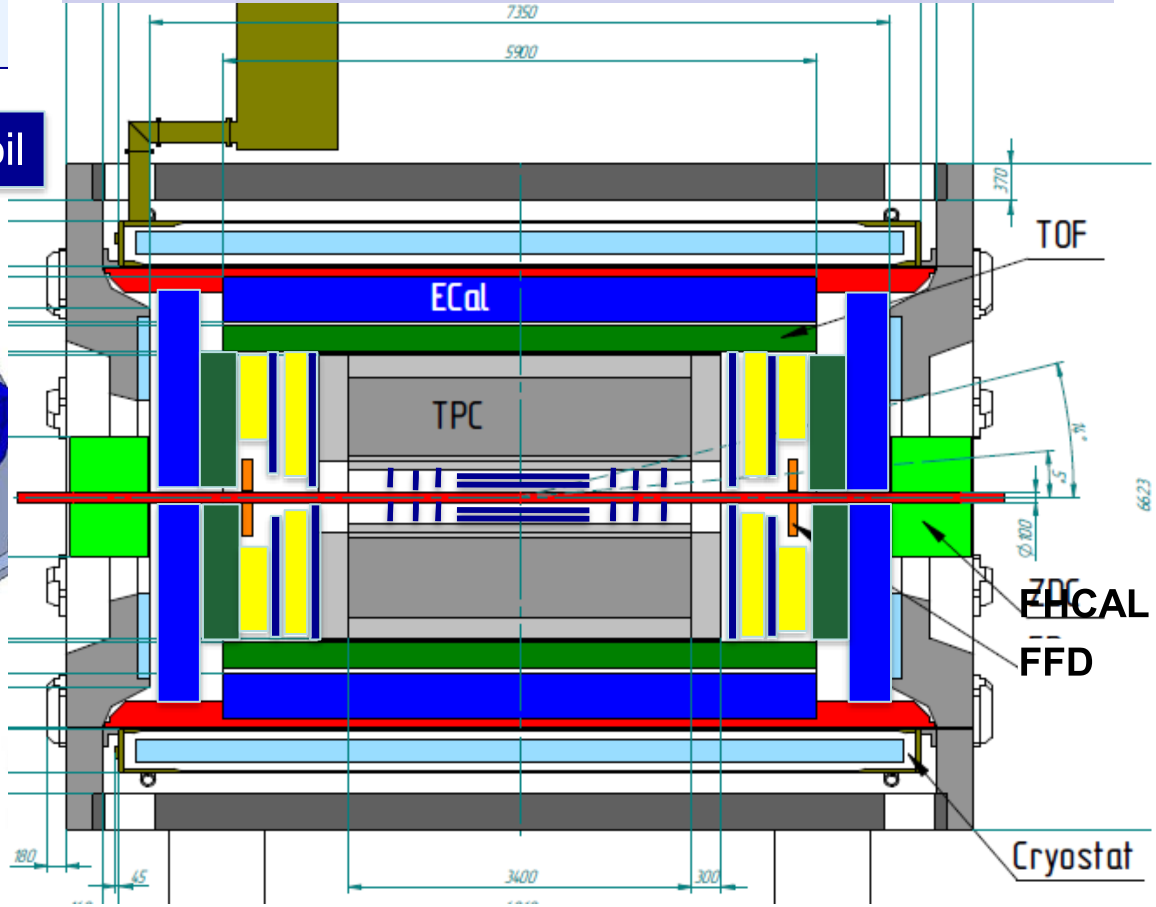
Tracking: up to |h|<1.8 (TPC)
PID: hadrons, e, g(TOF, TPC, ECAL)
Event characterization:
centrality & event plane (FHCAL)

Stage 1: **TPC, TOF, ECAL, FHCAL, FFD**

Stage 2: **ITs + Endcaps (tracker, TOF, ECAL)**

B_0=0.66 T
weight
~ 900 t





General contractor:
ASG Superconductors,
Genova, Italy

Status: *technical design – completed / close to completion; preparation for the mass production*

Vitkovice Heavy Machinery, Ostrava

Support rings: Ø 6.63 m, 43.7 tons each

need to have holes machining, sandblasting, painting

2 Poles: Ø 4.5 m, 47 tons each

28, February 2018

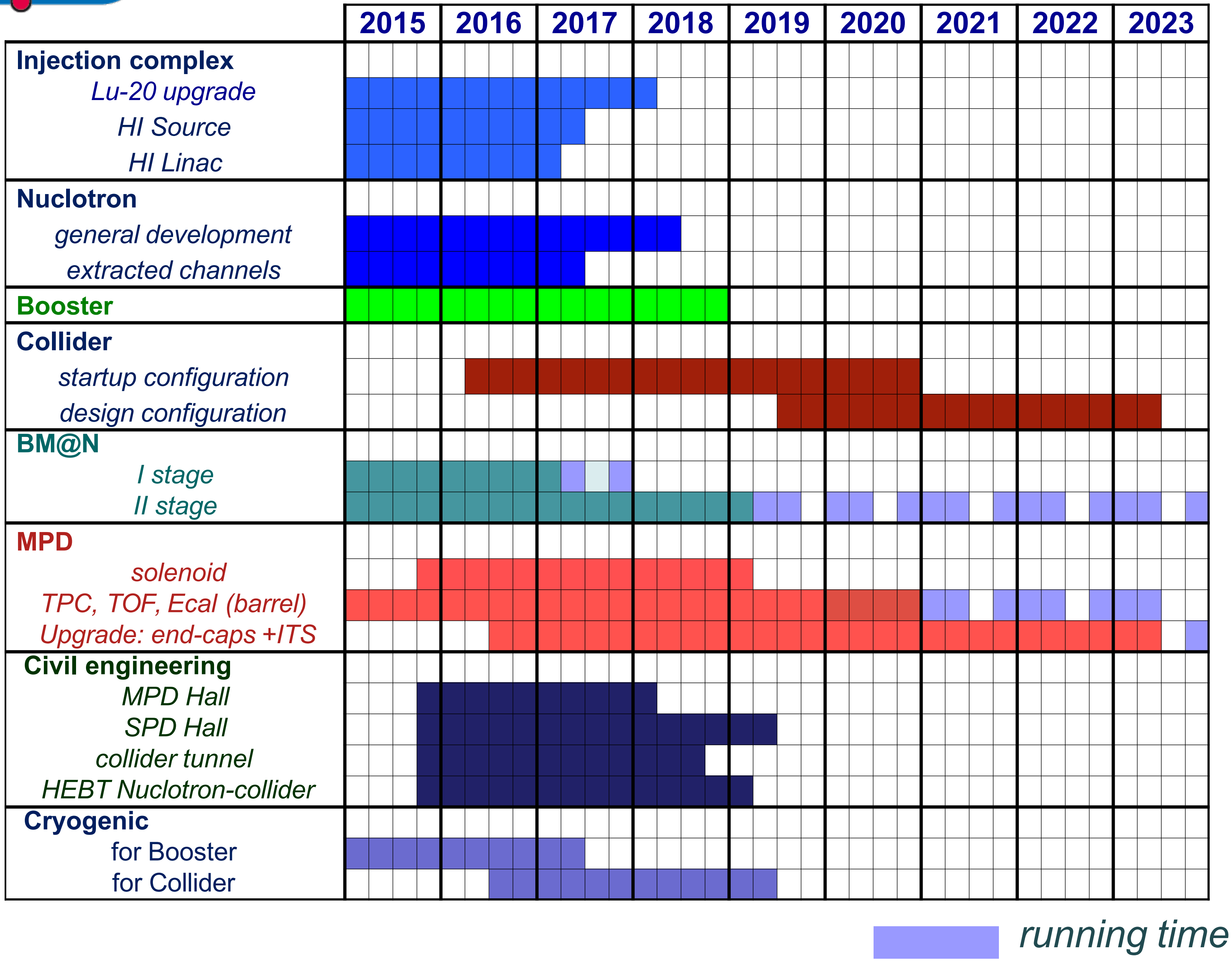
Cradles 2 main parts are in progress: 1.47x4.15x7.68, m; 34 tons in total

for

Two 80/20 tons Cranes by “URALKRAN” are ready

Appendix 2

NICA schedule



In the medium-term prospect the NICA complex will be
the only facility in Europe providing unique high intensity ion beams
(from ***p*** *to* ***Au****,* ***p***[illegible] *and* ***d***[illegible]*)*
in the energy range *from* ***2 – 27 GeV*** *(c.m.s.),*
which could be used for both fundamental and applied researches.

Researches at the NICA complex will contribute to

- *discovery and study of new forms of nuclear matter;*
- *comprehensive study of nucleon spin structure;*
- *applied researches, like irradiation of biological objects by heavy ion beams (space mission program) etc.*

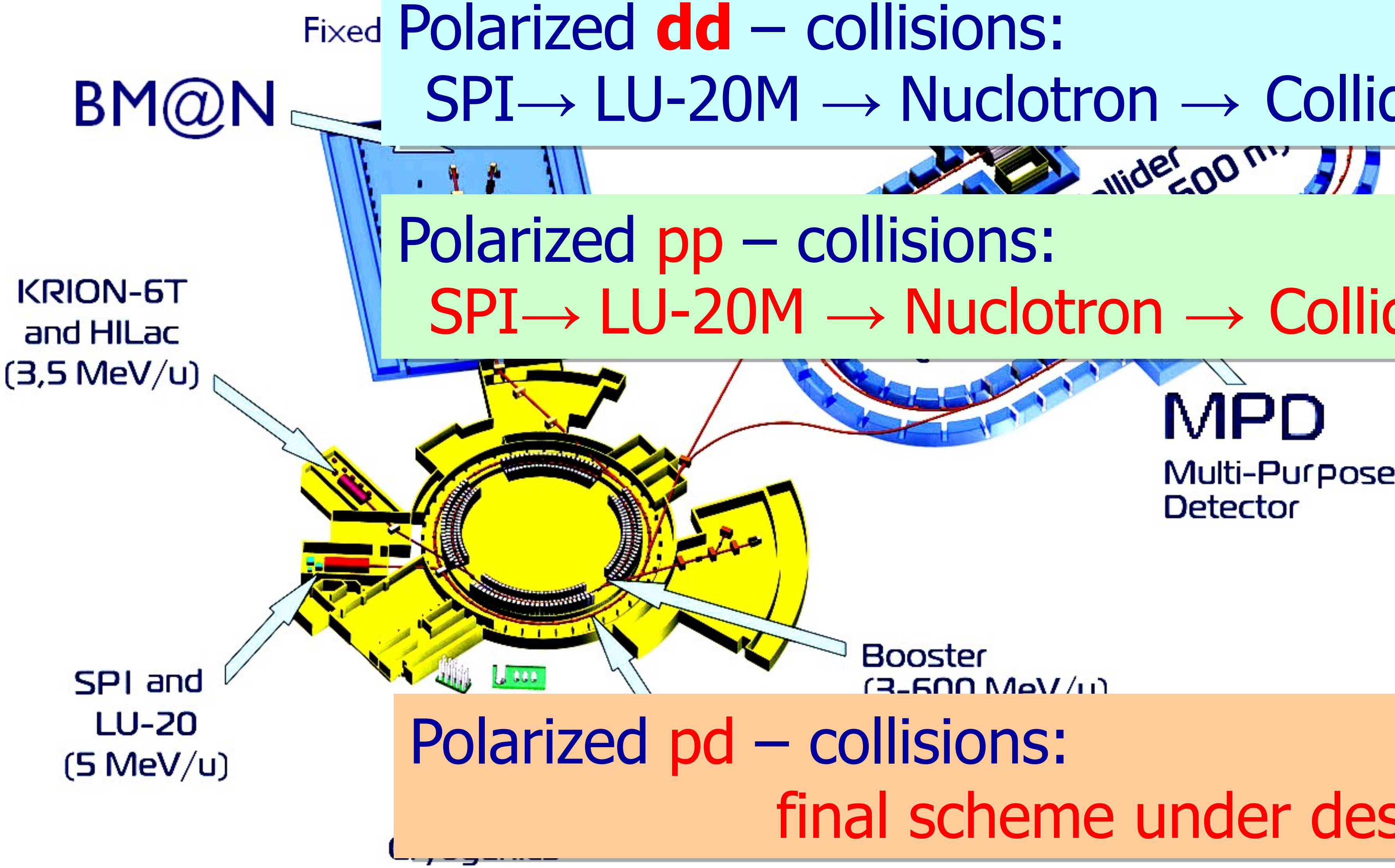
Civil Construction

Civil Construction

Civil Construction

Civil Construction

NICA operation in Polarized Mode (1)

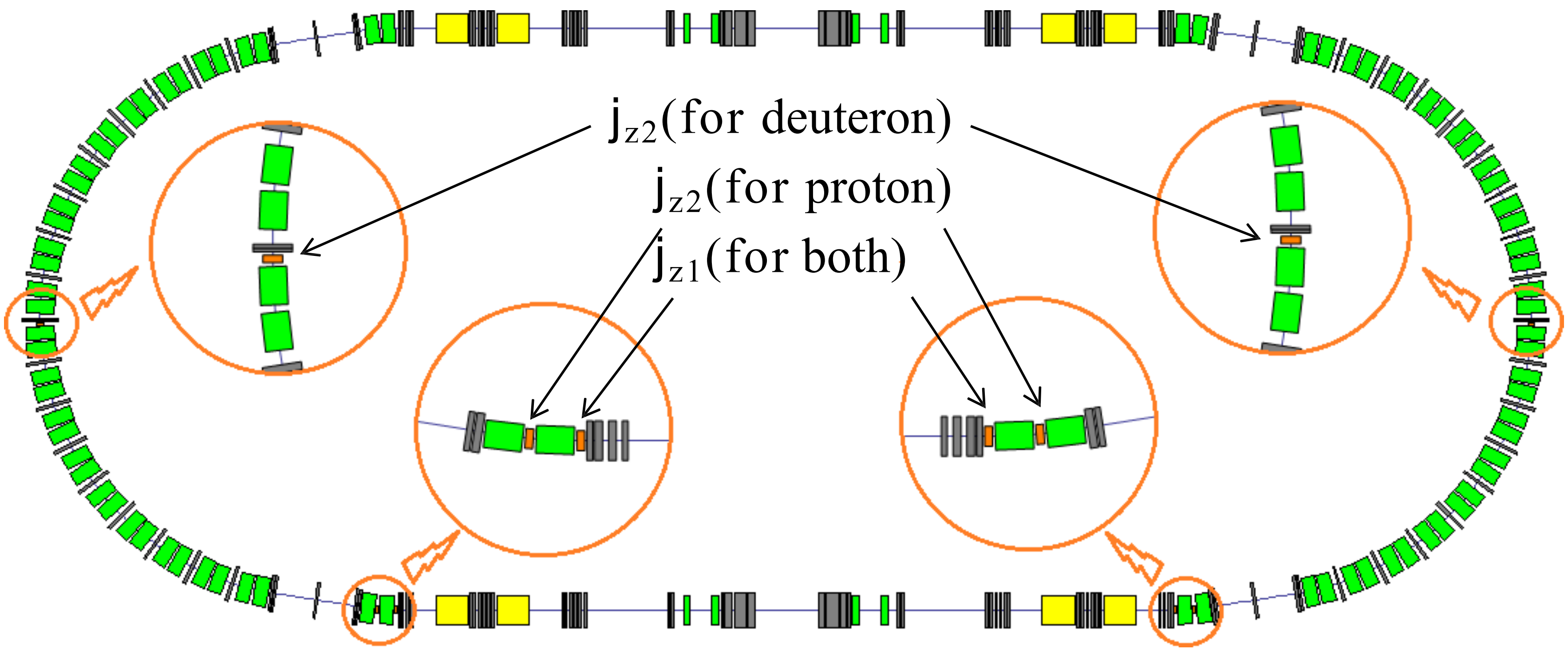


Polarized **dd** – collisions:
SPI→ LU-20M → Nuclotron → Collider

Polarized pp – collisions:
SPI→ LU-20M → Nuclotron → Collider

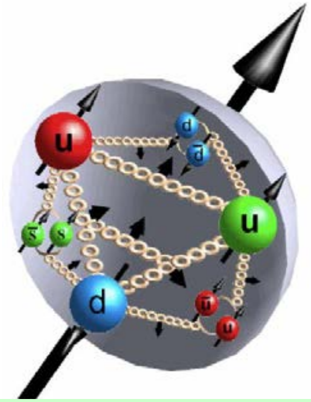
Polarized pd – collisions:
final scheme under design

Polarization control for p and d in NICA collider



	number	B_{max}, T	L, m	BL, T·m
Main tune shifts solenoid	8	7,3	5,5	0÷40
Weak solenoid for polarization control (red)	6	1,5	0,4	0÷0,6

Study of nucleon spin structure



must confirm

the sum rule: $$\frac{1}{2} = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g\,.$$

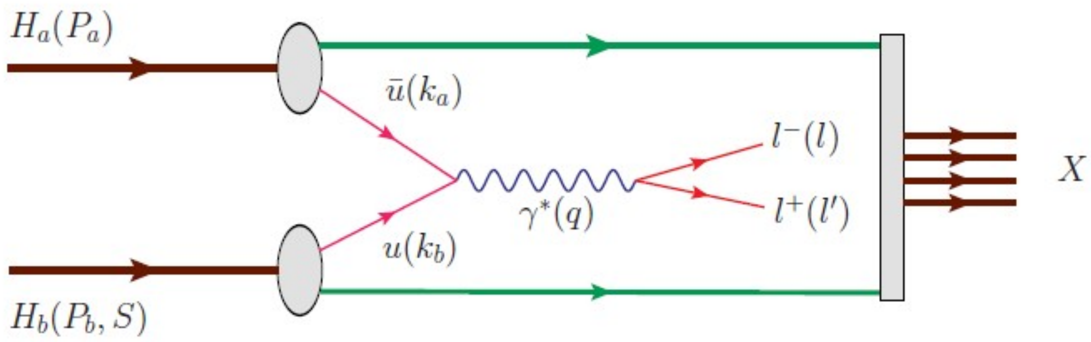
NICA collider will provide collisions of protons and deuterons with all combinations of polarization – *transversal and longitudinal*

*It will allow to measure all **8** intrinsic-transverse-momentum dependent **PDF**s (at leading twist)* ***in one experiment***

Matveev-Muradyan-Tavkhelidze-Drell-Yan mechanism and **SIDIS** processes **–** *are good tools for these measurements*

Direct photons production

(*gluon polarization***)**



RF Government disposal

ПРАВИТЕЛЬСТВО РОССИЙСКОЙ ФЕДЕРАЦИИ

РАСПОРЯЖЕНИЕ

от 27 апреля 2016 г. № 783-р

МОСКВА

**О подписании Соглашения между
Российской Федерации и международной
научно-исследовательской организацией О
ядерных исследований о создании и экс
сверхпроводящих колец на встречных пуч**

1. В соответствии с пунктом 1 стать
"О международных договорах Российской
представленный Минобрнауки России соглас
Минфином России, Минэкономразвития
межправительственной научно-исследова
Объединенным институтом ядерных исследо
между Правительством Российской Феде
межправительственной научно-исследова
Объединенным институтом ядерных ис
и эксплуатации комплекса сверхпроводящих
тяжелых ионов NICA (прилагается).

2. Поручить Минобрнауки России провести переговоры с международной межправительственной научно-исследовательской организацией Объединенным институтом ядерных исследований и по достижении договоренности подписать от имени Правительства Российской Федерации указанное в пункте 1 настоящего распоряжения Соглашение, разрешив вносить в прилагаемый проект изменения, не имеющие принципиального характера.

2947103

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3. Определить вклад Российской Федерации в создание базовой конфигурации комплекса сверхпроводящих колец на встречных пучках тяжелых ионов NICA до 2020 года в размере 8800 млн. рублей (в ценах 2013 года) за счет средств федерального бюджета.

4. Минобрнауки России выделить в 2016 году 4837,9 млн. рублей
в международную
скую организацию
в целях финансового
их колец на встречных
жетных ассигнований,
едеральным законом
м числе за 2016 год
ьеме 2340 млн. рублей,

ачиная с формирования
последующие периоды
джетные ассигнования
ов финансирования
ции "Развитие науки и
ния вклада Российской
лекса сверхпроводящих
колец на встречных пучках тяжелых ионов NICA до размера, указанного в пункте 3 настоящего распоряжения.

Председатель Правительства
Российской Федерации

Д.Медведев

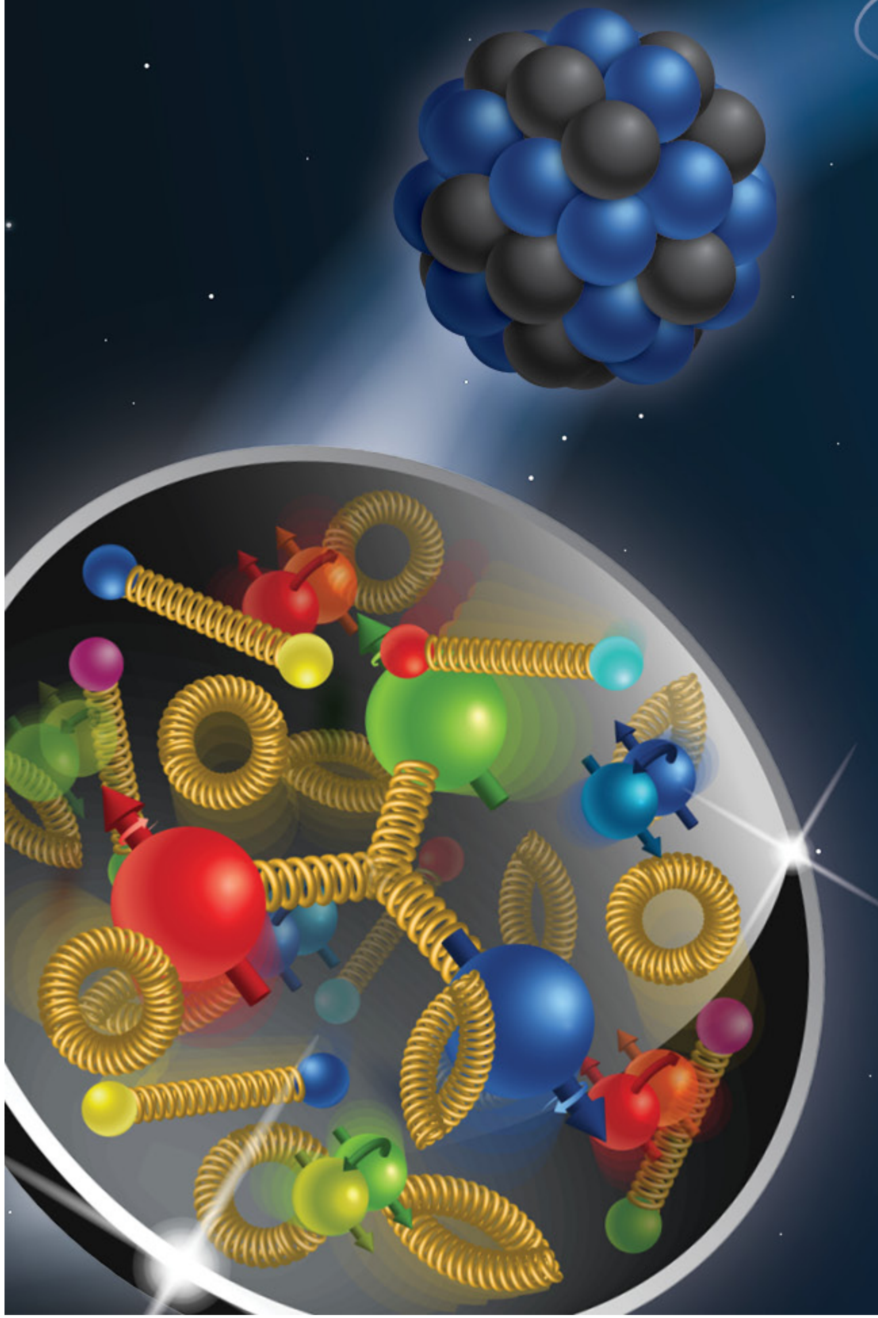
Agreement between the RF Government and the Joint Institute for Nuclear Research

has been signed on June 3-d

Concluding remarks

- **NICA complex has a potential for competitive research**
  in dense baryonic matter and spin physics
- **The construction of accelerator complex is going well**
  in close cooperation with many laboratories
- **The construction of both detectors BM@N & MPD *is going close to the schedule, SPD project and spin physics program are under preparation***
- **NICA recognized as a part of European research infr.**
- **NICA got a status of *mega-project developed at RF***
- **NICA is open for new participants**

Thank you!



EIC Accelerator Overview and R&D

Ferdinand Willeke, BNL

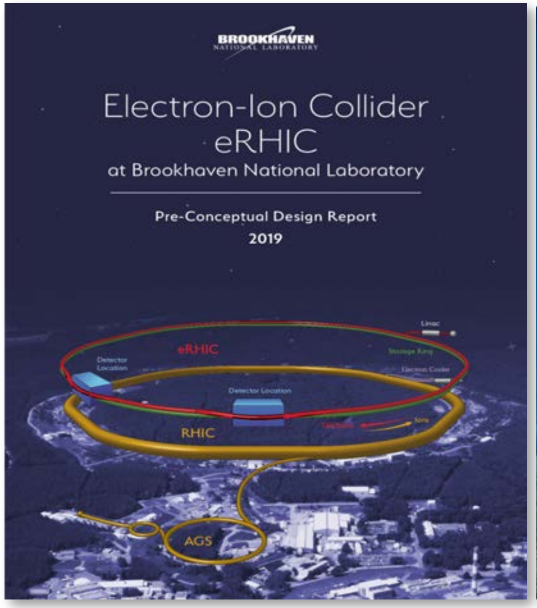
EICUG Annual Meeting, Paris 2019

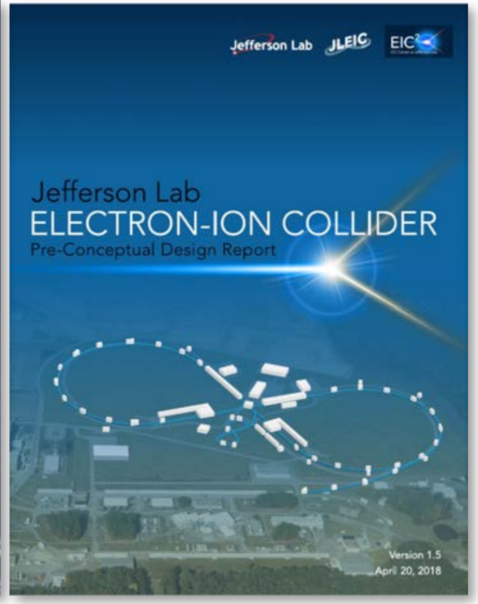
Electron Ion Collider

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Requirements
- Design concepts
- Luminosity
- Polarization
- Hadron Cooling
- Beam Dynamics Consideration
- R&D
- Summary





Electron Ion Collider (EIC) Physics Questions

Nuclear Physics Community compiled an EIC WHITE PAPER*) (2014/5):

- How are quarks, gluons & their spins distributed in space & momentum in nucleus?
- How do nucleon properties emerge from quarks and gluons and their interactions?
- How do color-charged quarks, gluons & colorless jets, interact with a nuclear medium
- How do confined hadronic states emerge from quarks & gluons
- How do the quark-gluon interactions create nuclear binding?
- How does dense nuclear environment affect the quarks-gluons correlations & interactions?
- Does gluon density in nuclei saturate @ high energy
  result in gluonic matter with universal properties?

*) A. Accardi et al, Eur. Phys. J. A529:268 (2016)

Requirements on EIC Performance

The EIC is designed to meet the requirements set forth in NSAC Long Range Plan, which was emphasized by the NAS report:

- Highly polarized (~70%) electron and nucleon beams
- Ion beams from deuterons to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from ~20 - ~100 GeV, upgradable to ~140 GeV
- High collision luminosity $\sim 10^{33} – 10^{34}\ cm^{-2}s^{-1}$
- Possibilities of having more than one interaction region

There are two proposals:

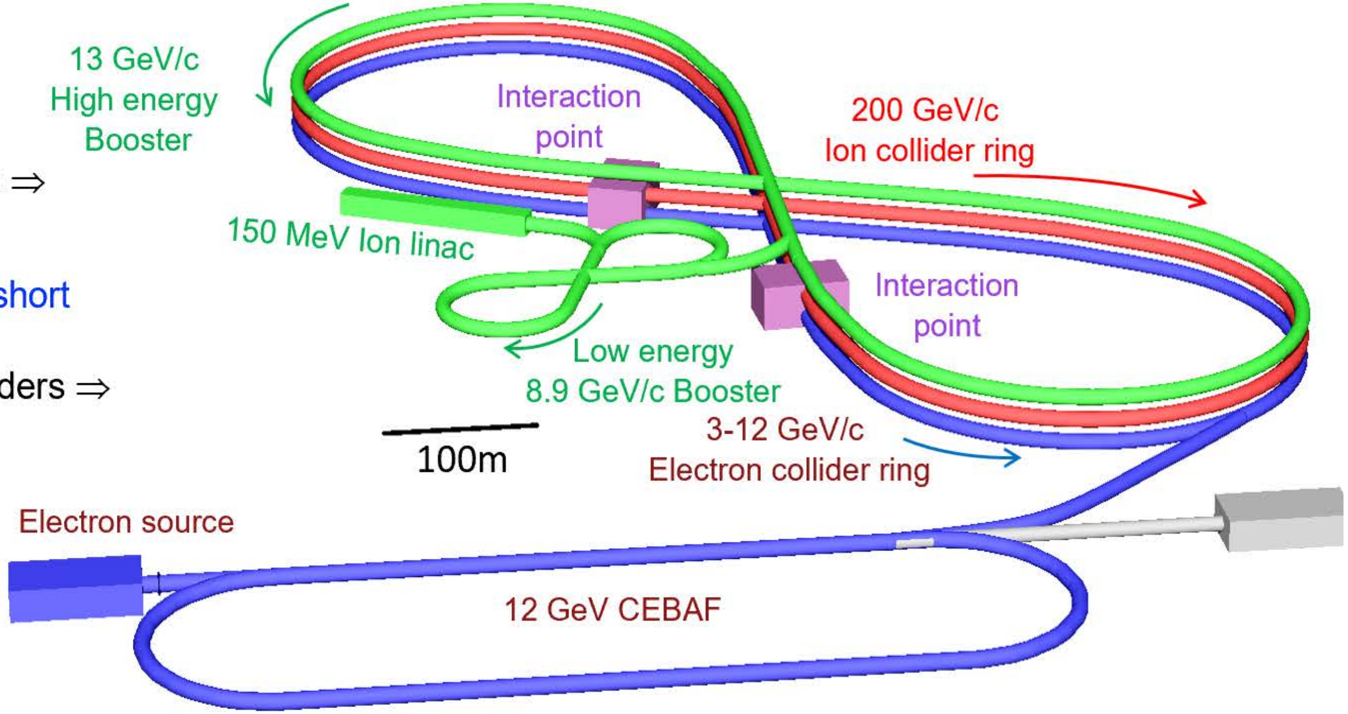
- **JLEIC** to be constructed at Jefferson Lab
- **eRHIC** to be constructed at Brookhaven National Lab

Both design benefit from existing Nuclear Physics infrastructure and are based on the same accelerator principles:

- **Electron Storage Rings** with frequent injection of fresh polarized beams
- **Hadron storage rings** with strong cooling or alternatively frequent injections

JLEIC Layout

- Full-energy top-up injection of highly polarized electrons from CEBAF ⇒
  High electron current and polarization
- Full-size high-energy booster ⇒
  Quick replacement of colliding ion beam ⇒
  High average luminosity
- High-rate collisions of strongly-focused short low-charge low-emittance bunches similarly to record-luminosity lepton colliders ⇒
  High luminosity
- Multi-stage electron cooling using demonstrated magnetized cooling mechanism ⇒
  Small ion emittance ⇒
  High luminosity



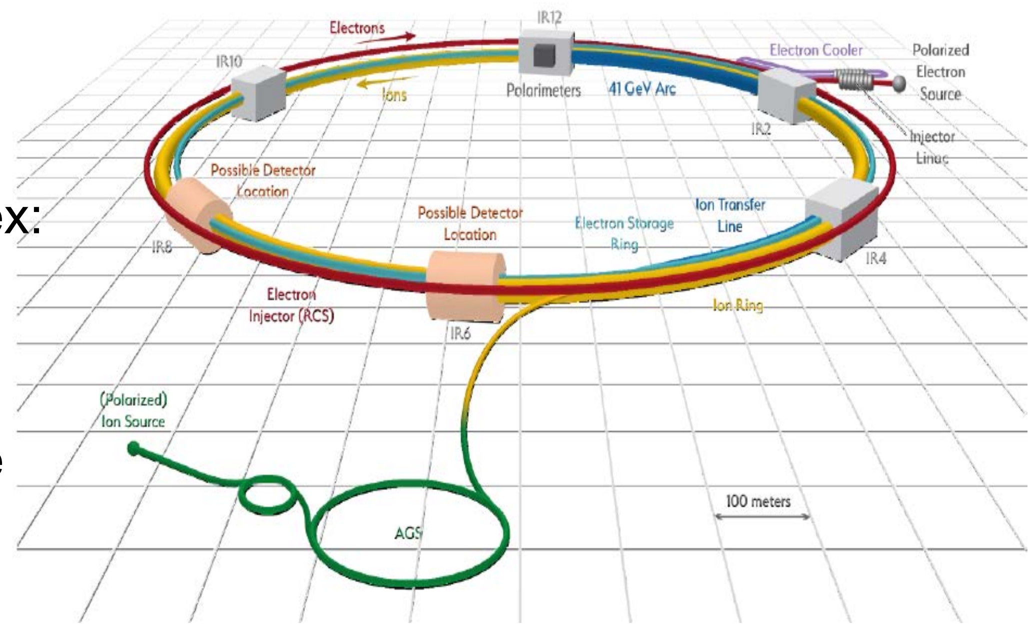
- Figure-8 ring design ⇒
  High electron and ion polarizations, polarization manipulation and spin flip
- Integrated full acceptance detector with far-forward detection sections being parts of both machine and detector
- Upgradable to 140 GeV CM by replacing the ion collider bending dipoles only with 12 T magnets

Courtesy: V Morozov, A Seryi

eRHIC

- **Hadrons up to 275 GeV**

  eRHIC is using the existing RHIC complex: Storage ring (Yellow Ring), injectors, ion sources, infrastructure,
- Need only few modifications for eRHIC
- Todays RHIC beam parameters are close to what is required for eRHIC



- **Electrons up to 18 GeV**

- Electron storage ring with up to 18GeV ➔ E_{cm} = 20 GeV -141 GeV installed in RHIC tunnel. Beam current are limited by the choice of installed RF power 10 MW.
- Electron beams with a variable spin pattern accelerated in the on-energy, spin transparent injector: Rapid Cycling Synchrotron with 1-2 Hz cycle frequency in the RHIC tunnel
- Polarized electron source and 400 MeV s-band injector linac in existing tunnel
- Design meets the high luminosity goal of **$L = 10^{34} cm^{-2} s^{-1}$**

Key EIC Machine Parameters

as required by the NSAC LRP & NAS

Parameter	Unit	JLEIC	eRHIC
Center of Mass Energies	[GeV]	20-100 a)	20-140
Ion Species		p to U	p to U
Number of Interaction Regions		2	2
Hadron Beam Polarization		85%	80%
Electron Beam Polarization		80%-85%	80%
Maximum Luminosity	[$10^{34}cm^{-2}s^{-1}$]	1.55	1.3

a) upgradable to 140 GeV

High Luminosity Implementation

As both designs, JLEIC and eRHIC are storage ring designs, the same ingredients are required for large luminosity

- **Large bunch charge**
- **Many bunches** ➔ large total beam currents

  ➔ crossing angle collision geometry
- **Small beam size** at collision point achieved by

  * **small emittance**

  ➔ Small hadron emittance requires strong hadron cooling (or frequent injection)

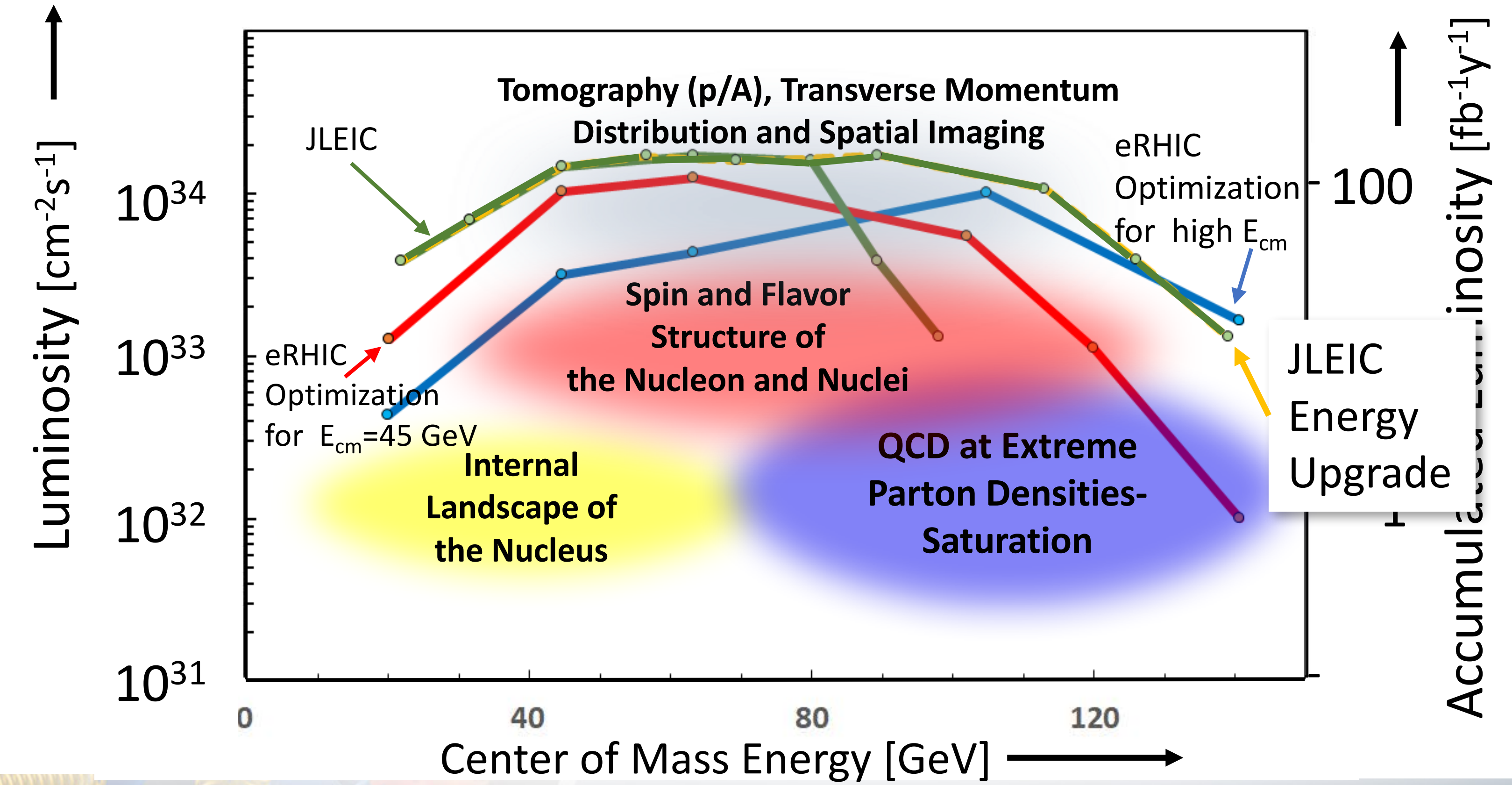
  * **and strong focusing at IR** (small β)

  ➔ required short bunches ➔ need strong cooling

Beam-Beam Limit: Transverse beam density at collision point limited by the detrimental effect of the corresponding nonlinear lens

EIC Luminosity

IR Designs can be adjusted to obtain peak luminosity at different center of mass energies. The curves below show luminosity vs E_{cm} with IRs optimized for high or low center of mass energy. With two IRs, in principle both optimization can coexist in the same machine



Note: For electron ion collisions, the E_{cm} scale needs to be reduced by a factor $(Z/A)^{1/2}$

Strong Hadron Cooling and High Luminosity

For high luminosity operation of the EIC strong hadron cooling is desirable if not necessary to avoid rapid decay of the luminosity caused by emittance blow-up due to intrabeam scattering

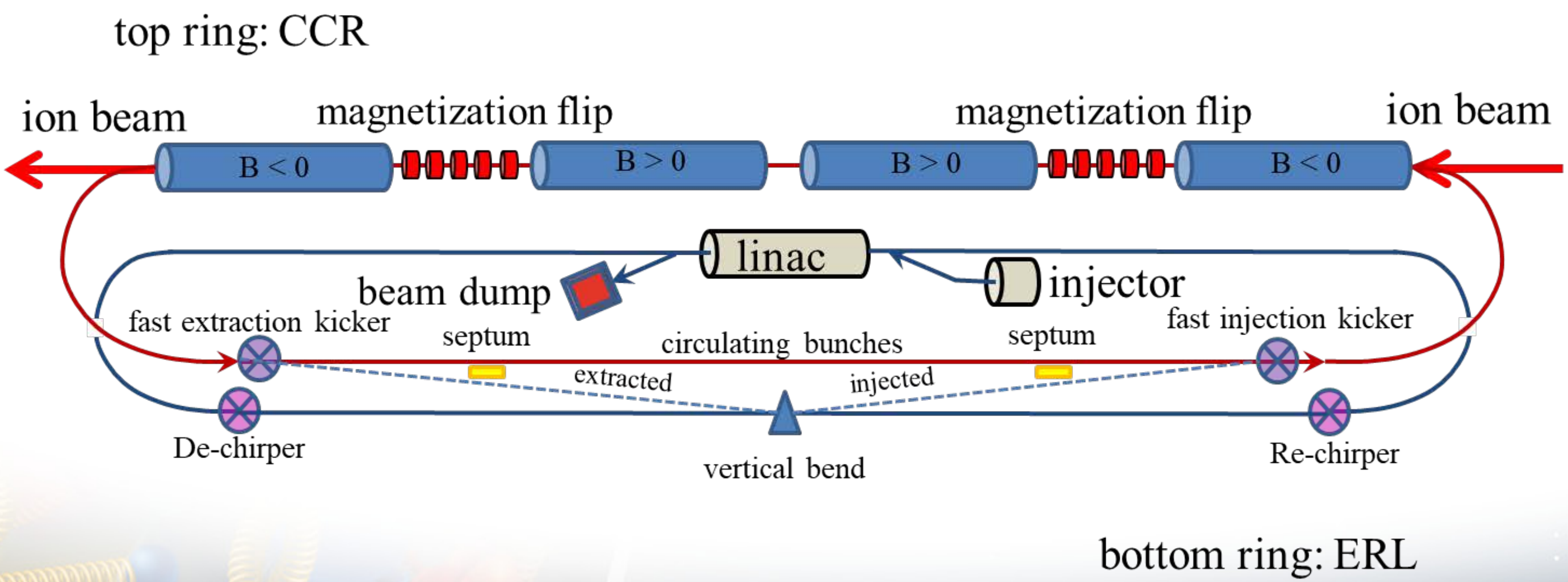
The two proposals operate at different ranges of hadron energy and the cooling systems are optimized accordingly.

- JLEIC uses a multi-turn magnetized bunched electron beam cooling ring fed by an energy recovery linac to balance IBS growth time between 15 and 40 minutes. This cooling increases the luminosity at lower energies, however JLEIC is not relying in this cooling for reaching NSAC goals, as it can use short fills with rapid turn arounds for achieving high average luminosity quoted as $1 \cdot 10^{34}$ $cm^{-2}s^{1}$.

- eRHIC has only modest IBS growth rates of t>2h for highest luminosity. It uses micro-bunched electron cooling as an option but does not rely on cooling to operate at highest luminosity as there is an on-energy for frequent injections available which results in an average luminosity which is still 90% of the peak luminosity.

Strong Hadron Cooling Scheme for JLEIC

- Magnetized electron beam for higher cooling efficiency
- Cooling electron beam is energy-recovered to minimize power consumption
- 11-turn circulator ring with 1 amp of beam current relaxes electron source requirements
- Fast harmonic kicker to kick electrons in and out of the circulator ring
- Pre-cooling a low energy is essential to achieve the anticipated performance

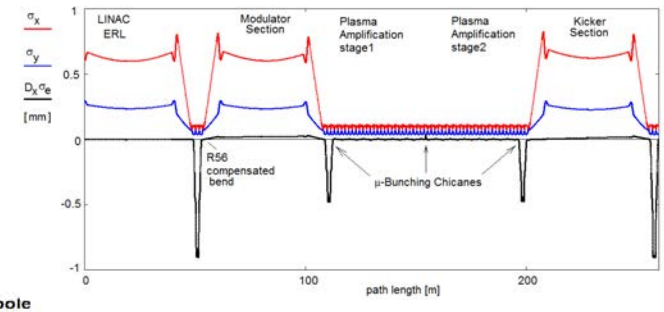


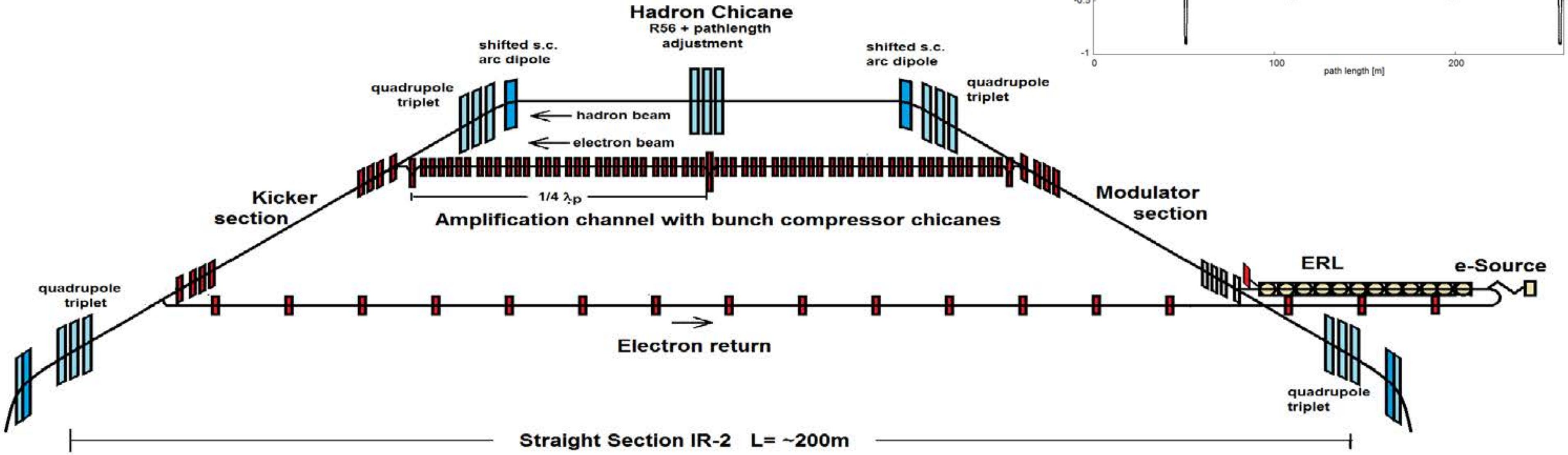
Courtesy: V Morozov, A Seryi

eRHIC Strong Hadron Cooling

Coherent Electron Cooling with μ-bunching amplification

Electron Beam Optics

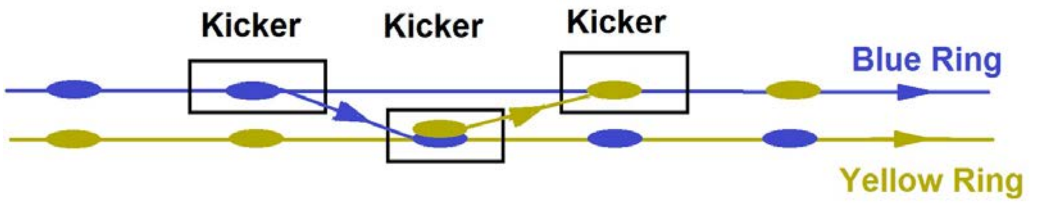




- Micro-bunched cooling is a novel scheme based on available technology
- For eRHIC, strong cooling as desirable but not necessary for high luminosity (especially high average luminosity) as the hadron beam could be replaced frequently on-energy using the existing second ring of present RHIC. As the JLEIC scheme, this option requires electron cooling at low energy.

Alternative to Strong Hadron Cooling in eRHIC

- eRHIC maximum luminosity of $1 \cdot 10^{34}$ $cm^{-2}s^{-1}$ does not depend on the feasibility of strong hadron cooling.
- Since RHIC has a second superconducting ring, the Blue Ring, on-energy injections into the collider ring, the Yellow Ring will replace the hadron bunches after one hour of storage.
- Transfer takes 13 μs and will preserve the total charge in both machines, no transient injection effect.



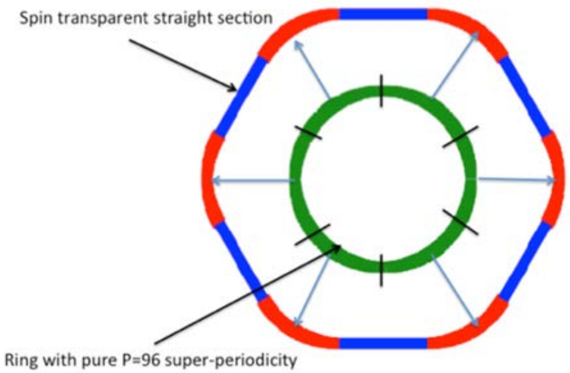
- The emittance growth between injections is so small that an average luminosity of **$0.9 \cdot 10^{34}$ $cm^{-2}s^{-1}$** will be achieved.
- The required small vertical emittance $\varepsilon_{Ny} = 0.5$ μm will be achieved with standard DC electron beam cooling in the AGS.
- No new hardware for spin transparency is required

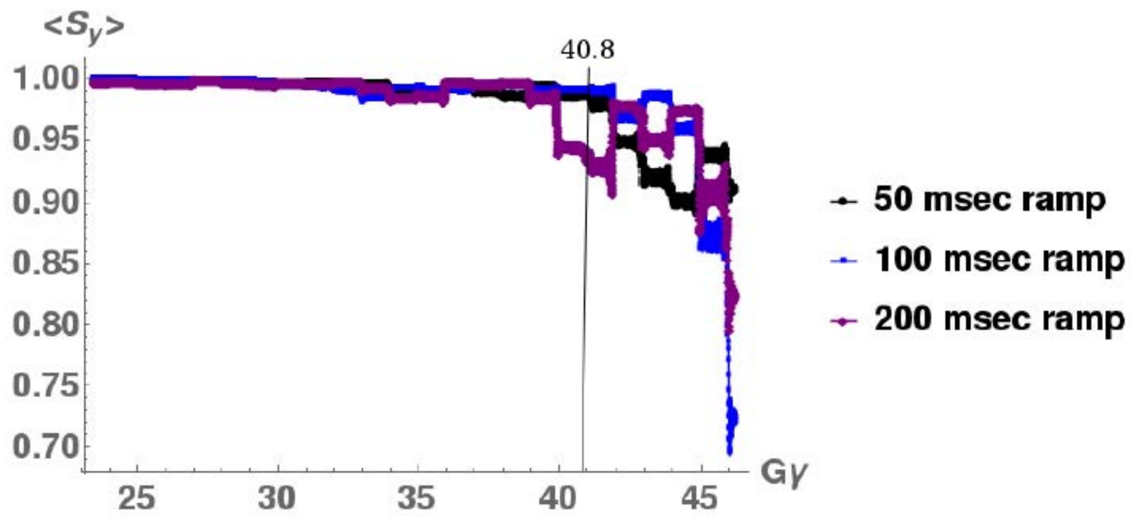
eRHIC Rapid Cycling Synchrotron Polarization

Ingenious optical design: High periodicity arcs and unity transformation in the straights suppresses all systematic depolarizing resonances up to Gγ =45

➔ **resonance free acceleration up >18 GeV**

➔ **no loss of polarization on the entire ramp up to 18 GeV (100 ms ramp time)**



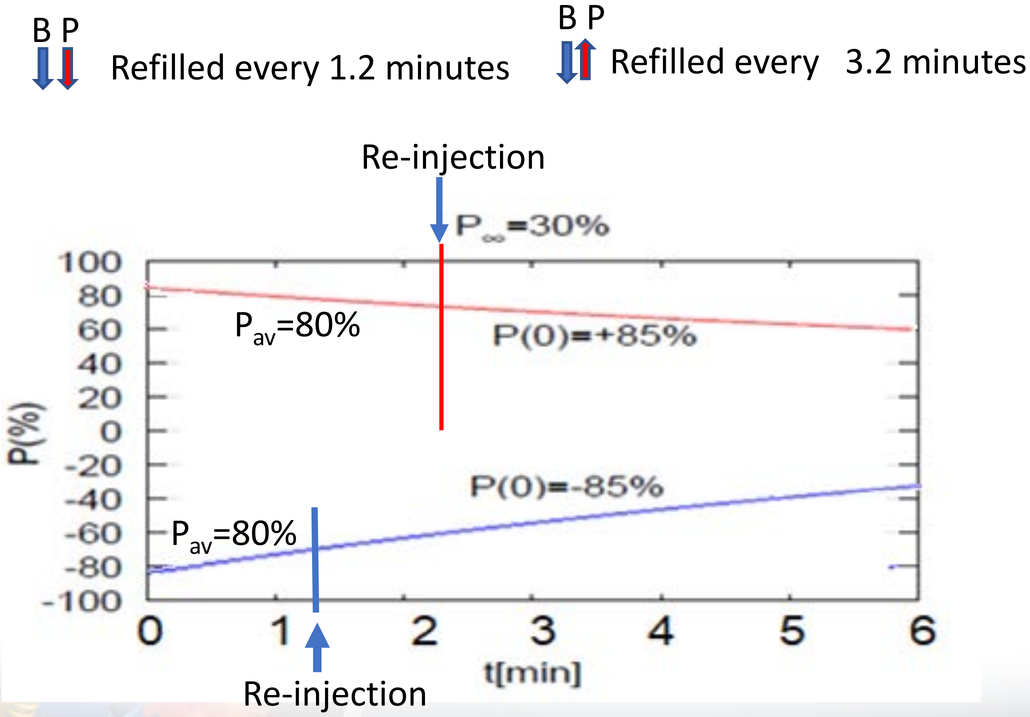


Need well aligned quadrupoles and rms orbit ≤ 0.5 mm and good reproducibility

➔ Well within the present state of the art of orbit control and achieved today by NSLS-II Booster synchrotron

Polarization in the electron storage ring

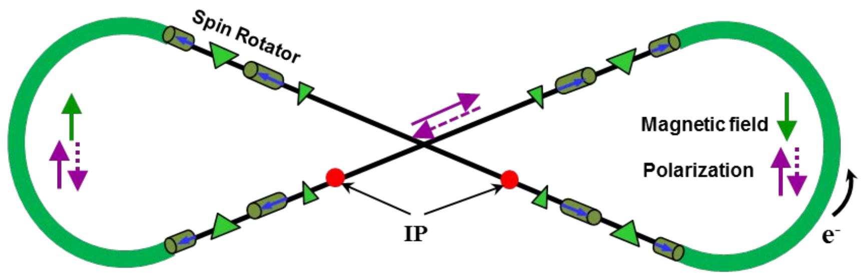
- Solenoid based Spin rotators ➔ longitudinal spin in collisions (arcs: vertical polarization)
- High initial polarization of 85% will decay towards equilibrium polarization $\mathbf{P_\infty}$ due to Sokolov-Ternov effect
- P_∞ of 40-50% achievable (HERA experience and eRHIC simulations)
- Time evolution of high polarization of bunches injected into the eSR at 18 GeV (worst case)
  RCS cycling rate = 2Hz ➔ on average, every bunch refilled in 2.2 min



Note: Calculation with P_∞=30% is conservative as P_∞= 50% was shown feasible

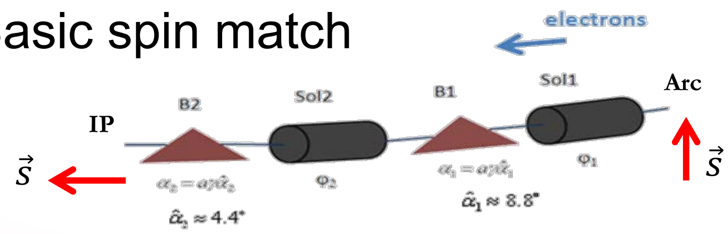
JLEIC High Electron Polarization

- Two highly polarized bunch trains maintained by top-off
- Universal spin rotator
  - Minimizes spin diffusion by switching polarization between vertical in arcs and longitudinal in straights
  - Sequence of solenoid and dipole sections
  - Geometry independent of energy
  - Two polarization states with equal lifetimes
  - Basic spin match



Energy (GeV)	3	5	7	9	10
Lifetime (hours)	66	8	2.2	0.9	0.3

E	Solenoid 1		Dipole set 1	Solenoid 2		Dipole set 2
	Spin Rotation	BDL	Spin Rotation	Spin Rotation	BDL	Spin Rotation
GeV	rad	T·m	rad	rad	T·m	rad
3	π/2	15.7	π/3	0	0	π/6
4.5	π/4	11.8	π/2	π/2	23.6	π/4
6	0.62	12.3	2π/3	1.91	38.2	π/3
9	π/6	15.7	π	2π/3	62.8	π/2
12	0.62	24.6	4π/3	1.91	76.4	2π/3

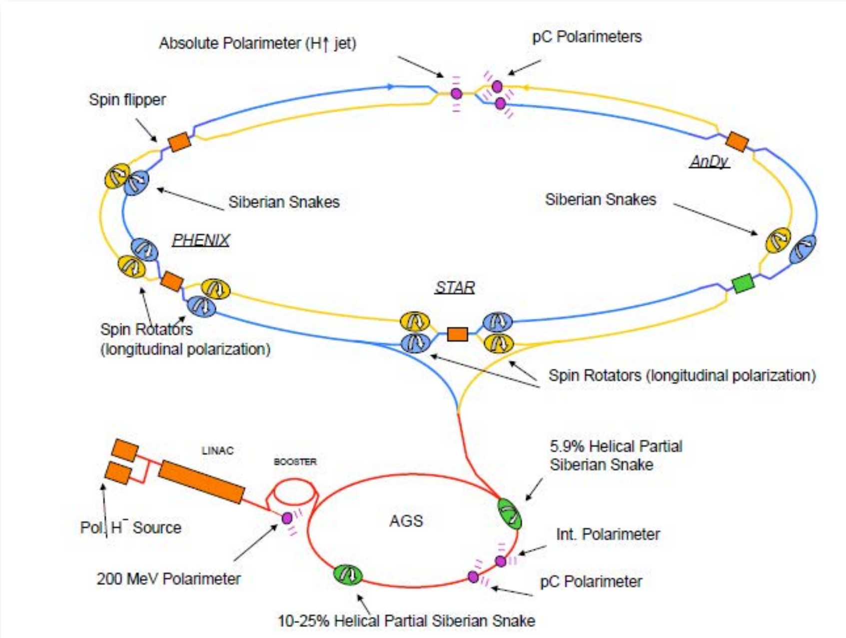


- Advantage of figure-8 geometry: negligible depolarization demonstrated by spin tracking

Courtesy: V Morozov, A Seryi

eRHIC Hadron Polarization

eRHIC will fully benefit from present RHIC polarization and near future upgrades



Measured RHIC Results:

- Proton Source Polarization 83 %
- Polarization at extraction from AGS 70%
- Polarization at RHIC collision energy 60%

Planned near term improvements:

AGS: Stronger snake, skew quadrupoles, increased injection energy

➔expect 80% at extraction of AGS

RHIC: Add 2 snakes to 4 existing no polarization loss

➔ expect 80% in Polarization in RHIC and eRHIC

Expected results obtained from simulations which are benchmarked by RHIC operations

^{3}He in eRHIC with six snakes

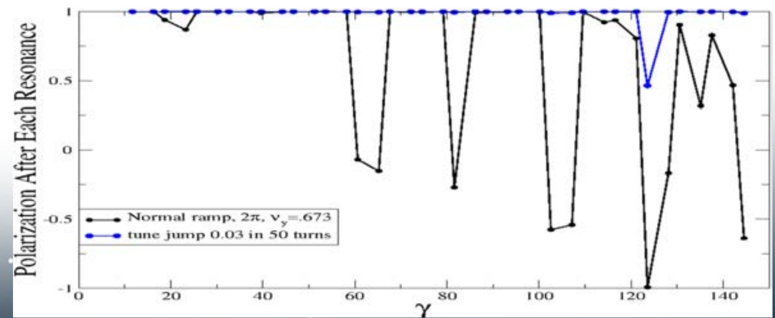
Achieved 85% polarization in 3He ion source

Polarization preserved with 6 snakes for up to twice the design emittance

Deuterons in eRHIC:

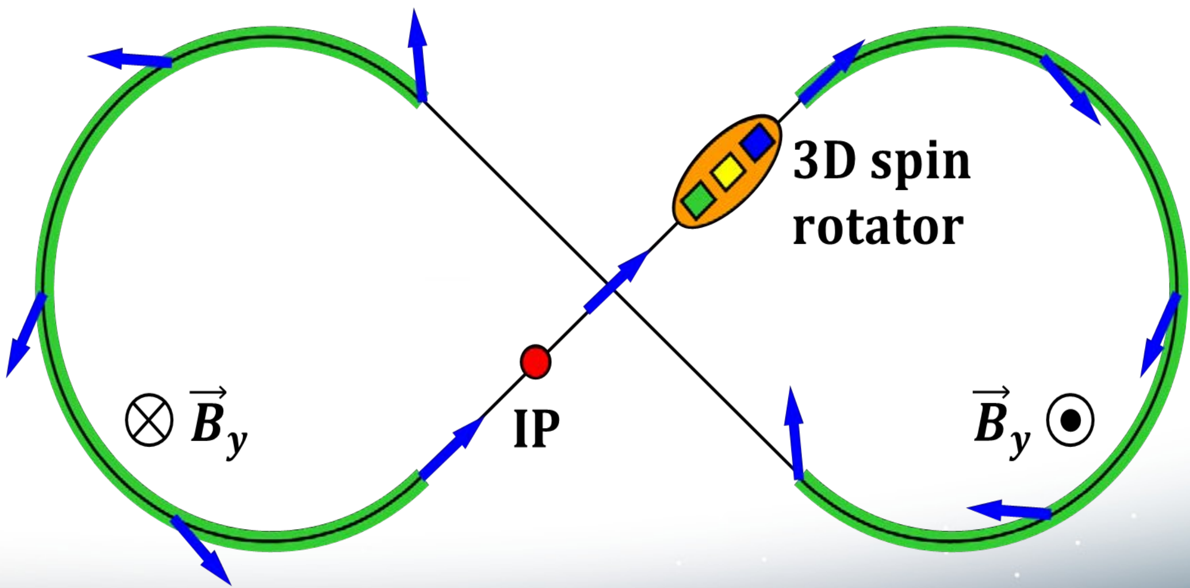
Requires tune jumps in the AGS, then benchmarked simulation show 100% Spin transparency

No polarization **loss** expected in the eRHIC hadron ring



Ion Polarization in JLEIC

- Figure-8 concept: Spin precession in one arc is exactly cancelled in the other
- Spin stabilization by small fields: ~3 Tm vs. < 400 Tm for deuterons at 100 GeV
  - Criterion: induced spin rotation >> spin rotation due to orbit errors
- 3D spin rotator: combination of small rotations about different axes provides any polarization orientation at any point in the collider ring
- No effect on the orbit
- Polarized deuterons
- Frequent adiabatic spin flips



Courtesy: V Morozov, A Seryi

Interaction Region Design

The interaction regions are the most challenging part of a EIC design.

- It needs to fit several essential components into a relatively small area
- Such as: Strong focusing, spin rotators, crab cavities, auxiliary detectors, mask and collimators, diagnostic equipment
- The accelerator components should not compromise the detector acceptance
- Design has to take into account that there are beam dynamics constraints:

IR chromaticity and related dynamic aperture issues, beam-beam tune shift, tight tolerances for magnet errors, residual crab cavity effects, …

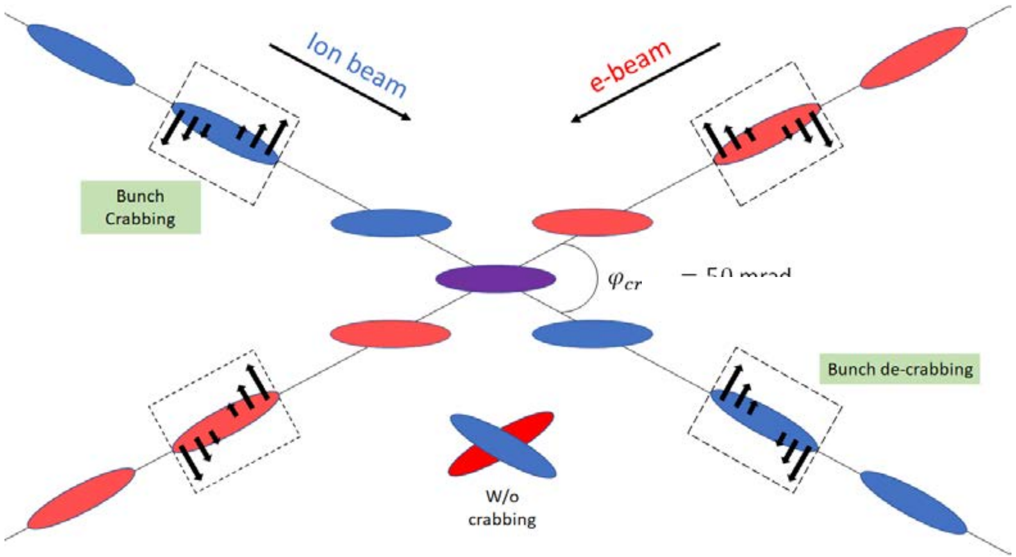
EIC High Luminosity with a Crossing Angle

crossing angle is necessary to avoid parasitic collisions due to short bunch spacing, make space for machine elements, improve detection and reduce detector background, q =50 mrad (JLEIC), 25mrad (eRHIC)

However, crossing angle causes

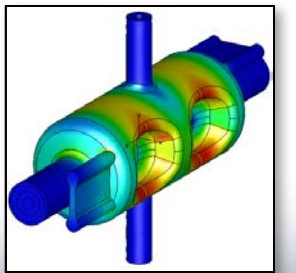
- Low luminosity
- Beam dynamics issues

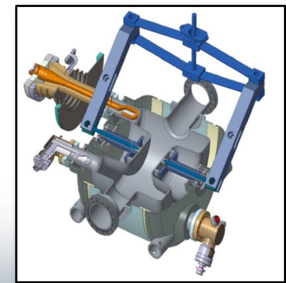
→ Crab Crossing



Effective head-on collision restored and most severe beam dynamic issue resolved

Both JLAB and BNL developed prototypes which have been tested with beam in the Cern-SpS

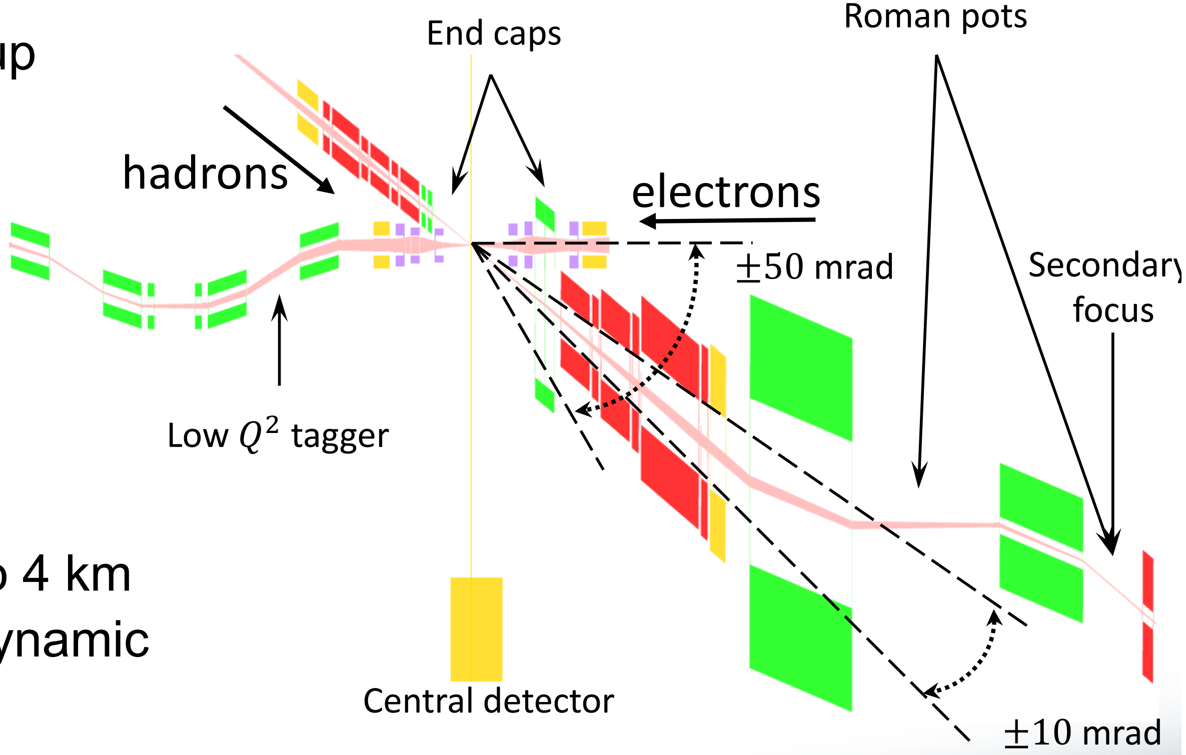




Courtesy V. Morozov and Andrei Seryi

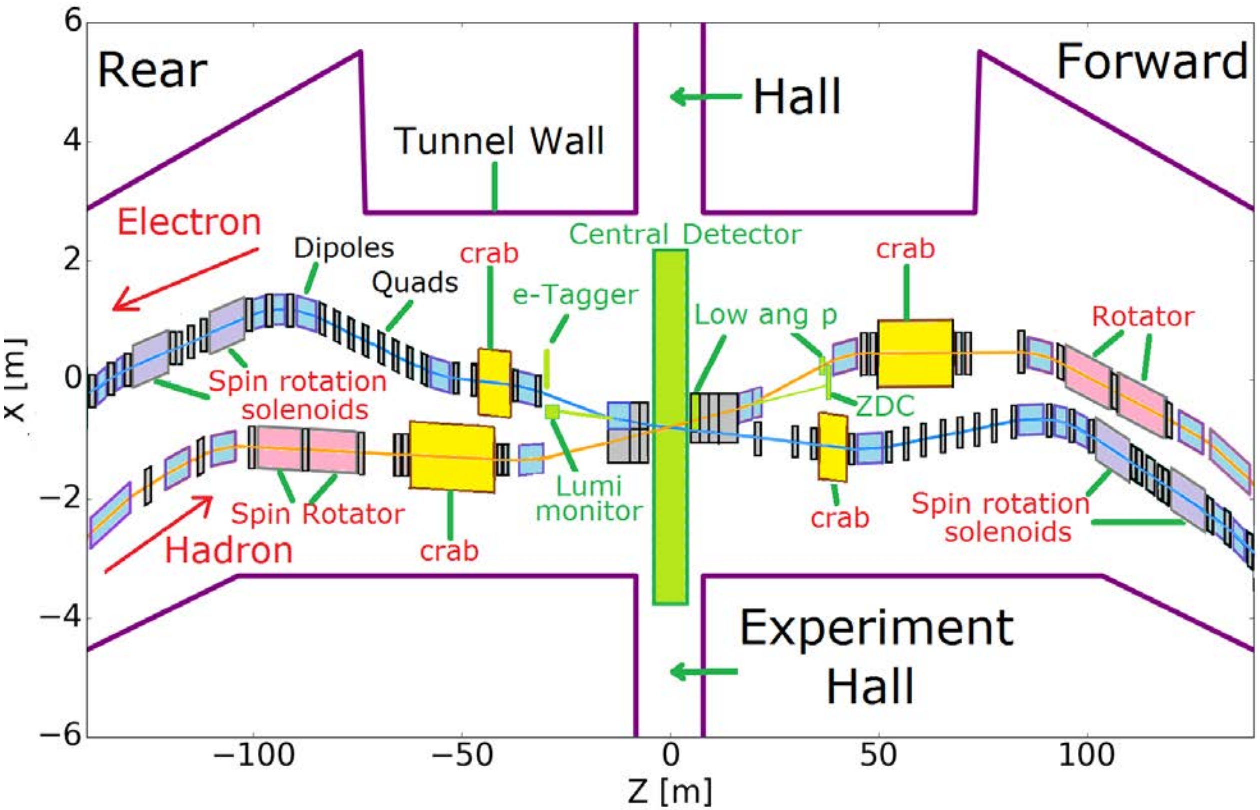
JLEIC Full Acceptance IR Layout

- 50 mrad crossing angle
- Forward hadron detection in three stages
  - Endcap
  - Small dipole covering angles up to ~3°
  - Far forward, ~10 mrad, for particles passing through accelerator quads
- Low-Q2 tagger
  - Small-angle electron detection
- Large beta functions in the IR up to 4 km but manageable chromatics and dynamic aperture



Courtesy V., Morozov, A. Seryi

Full Acceptance eRHIC IR Layout



<u>Design</u>

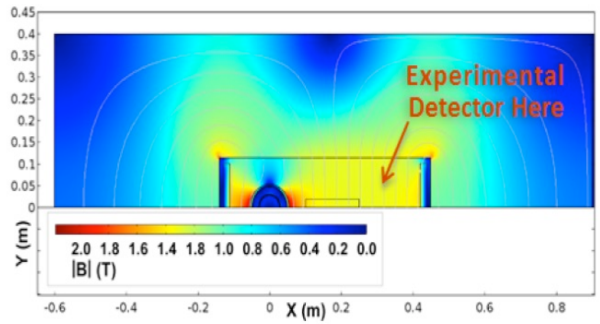
- All superconducting magnets
- Only 5 magnets need collared Nb-Ti coils
- All other magnets can be built with **direct wind** of Nb-Ti wire
- Full acceptance e.g.
  P_t =200 MeV/c-1.3 GeV/c
  Neutrons 4 mrad
- Large Aperture Dipole with instrumented gap
- Modest IR chromaticity
  Hadrons up to β<200m

➔ Manageable dynamic aperture optimization

EIC Beam Dynamics Challenges

- Proton Beam Stability (emittance growth, halo forming) in presence of strong, crab-enhanced beam-beam effects, strong chromatics
- Electron cloud in the hadron vacuum, suppression of secondary emission yield
- Fast Ion instability for the electron beam
- Multi-bunch stability and feedback: Feedback noise and hadron emittance growth
- Impedance optimization in the IR
- Dynamic aperture with extreme beta in the IR

On-Going EIC R&D Effort

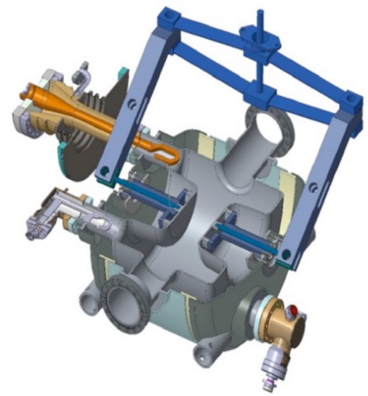


Instrumented accelerator magnet

Component Development

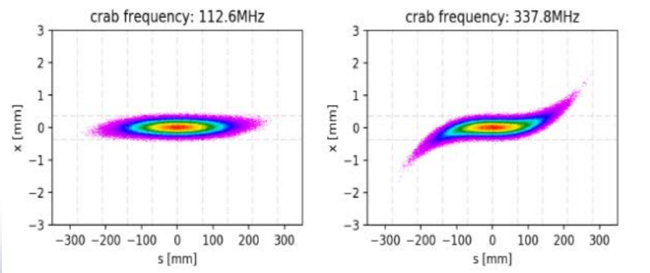
- Crab Cavity design development and prototyping
- IR magnet development and prototyping
- HOM damping for RF structure development
- Variable coupling high power forward power couplers development
- Effective in situ Cu coating of the beam pipe (BNL hadron only)
- High average current electron gun development
- Polarized ^3He source
- Bunch by bunch polarimetry

Crab cavity



Accelerator Physics R&D

- Strong hadron cooling CeC, cooling development (simulation and experimental)
- Strong hadron cooling bunches electron beam cooling (simulation and experimental)
- ERL development for strong hadron cooling
- Test of suppression of intrinsic depolarizing resonances
- Study of collisions with different revolution frequencies (JLAB only)
- Experimental verification of figure-8 configuration
- Study of residual crab cavity effect on beam emittance

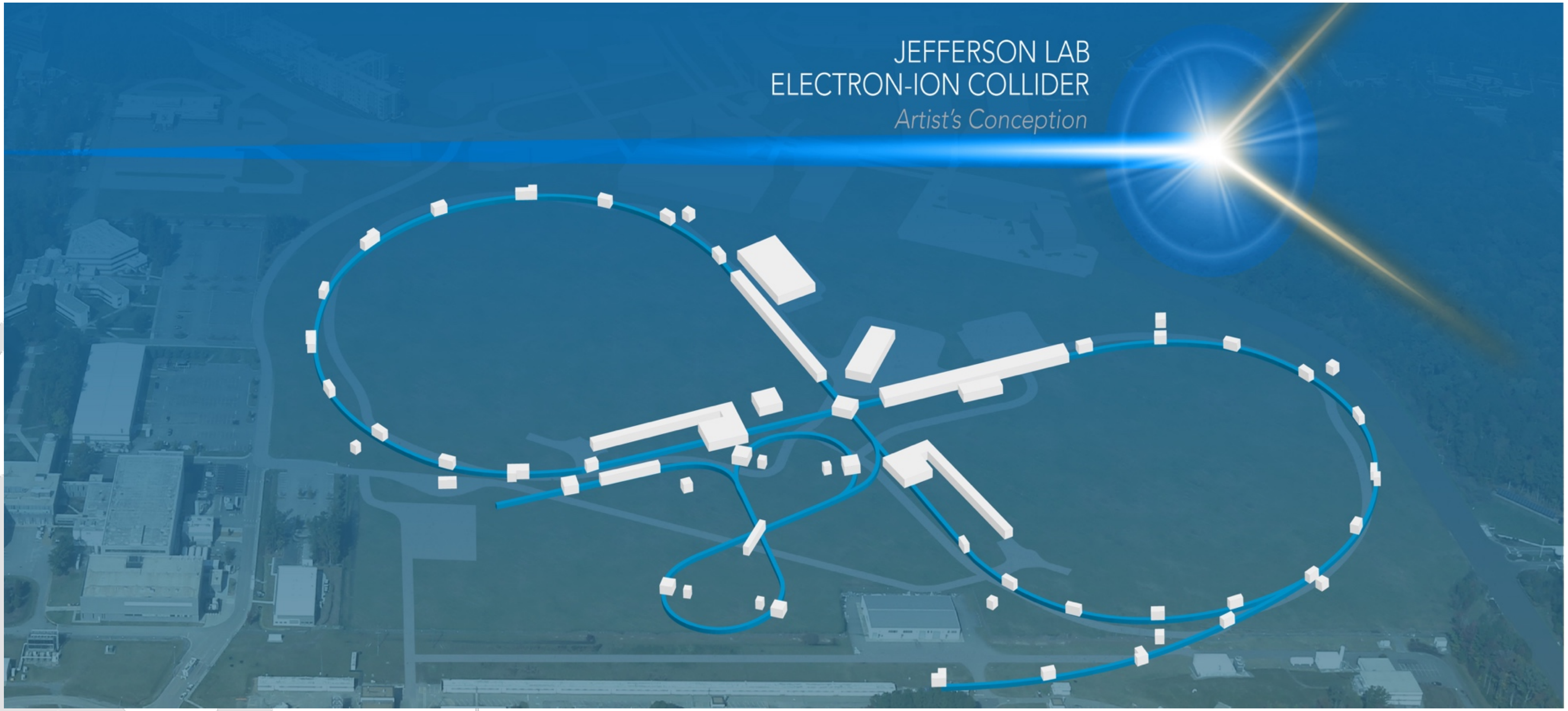


Crabbed beam dynamics

Conclusion

- Designs of EIC made significant progress since the last EICUG meeting
- There is good collaboration on accelerator physics and accelerator R&D between accelerator laboratories
- The two designs rely for the most part on established accelerator technology
- Crab cavity, IR magnets, and ERL are close to state of the art
  strong hadron cooling is beyond, but is well mitigated
- BNL and JLab are committed to working together and with the community to advance the EIC.
- We welcome further collaboration with our European colleagues

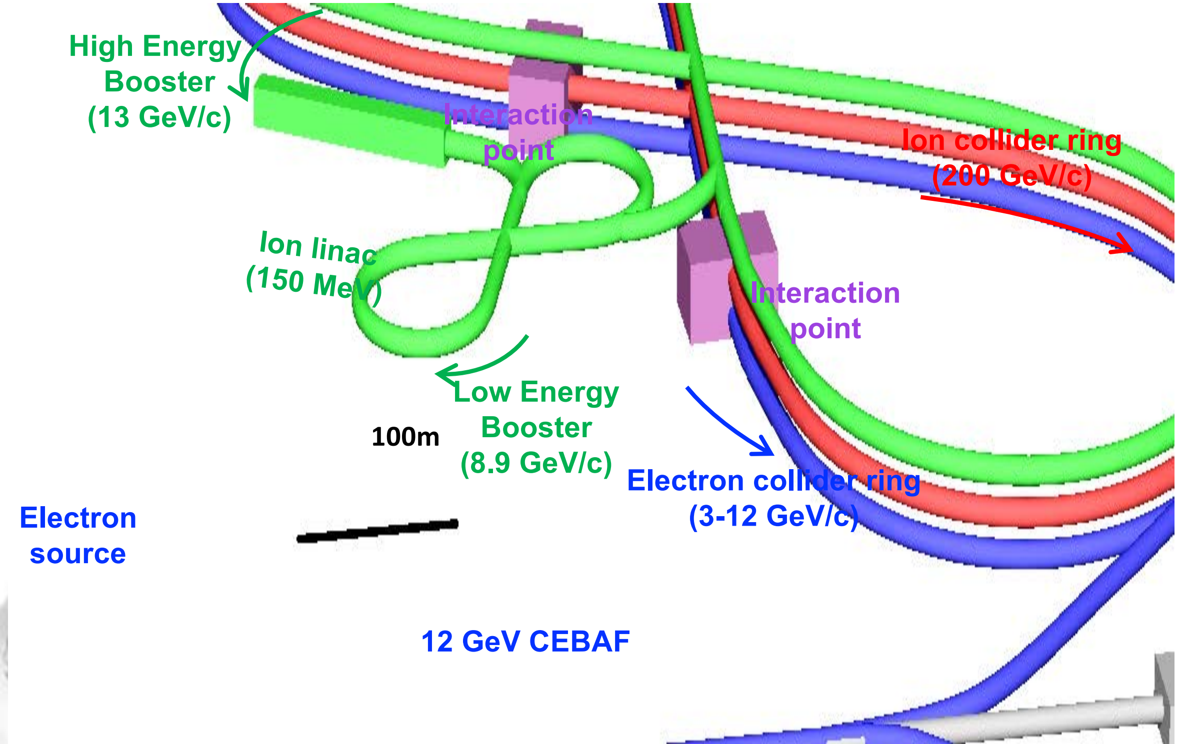
Overview of JLEIC – The EIC at Jefferson Lab



From the EIC White Paper:

- Highly polarized (~70%) electron and light ion beams
- Ion beams from protons, to deuterons, to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from ~20 - ~100 Gev, upgradable to ~140 GeV
- High collision luminosity of ~10^{34} $cm^{-2}s^{-1}$
- Possibilities of having more than one interaction region

JLEIC Overview



- **Electron complex**
  - CEBAF as a full energy injector
  - Electron collider ring (ECR): 3-12 GeV/c
- **Ion complex**
  - Ion source, SRF linac: 150 MeV for proton
    s
  - Low Energy Booster (LEB): 8.9 GeV/c
  - High Energy Booster (HEB): 13 GeV/c
  - Ion collider ring (ICR): 200 GeV/c
- **Up to two detectors** at minimum background l
  ocations
- **20-100 GeV CM, Upgradable to 140 GeV CM**

203

Jefferson Lab

Magnets, Kickers, BPMs - Summary

Element	Type	Electron Complex	Ion Complex
Length of Beamline		2,669 m	5,416 m
Dipole Magnets	Normal-Conducting	369	252
	Superconducting	-	258
Quadrupole Magnets	Normal-Conducting	515	394
	Superconducting	6	196
Sextupole Magnets	Normal-Conducting	148	48
	Superconducting	-	56
Correctors Magnets	Normal-Conducting	321	164
	Superconducting	-	55
Solenoids Magnets	Superconducting	10	6
Kickers	Normal-Conducting	2	6
BPMs		321	337

Accelerating and Bunching – Summary

		# Cavities	Cavities per unit	Fwd Pwr per cavity (kW)
Electron Collider Ring	Acceleration – Normal Conducting	16**	1	500**
	Acceleration – SRF	12	4	600
	Crab Cavities – SRF	6	3	40
Low Energy Booster	Acceleration/Bunch Control	3	1	50
High Energy Booster	Acceleration/Bunch Control	7	1	100
Ion Collider Ring	Acceleration/Bunch Control – Normal Conducting	3	1	120
	Bunch Control – SRF	26	4	120
	Crab Cavities – SRF	24	6	30
Electron Cooling	DC Cooler (LEB)	1	4	50
	DC Cooler (HEB)	1	1	50
	Bunched Beam (ICR) – ERL	15	2	50

** - PEP-II Cavities and HPAs

Technical Components – Electron Complex

- CEBAF – Full Energy Injector – no new elements
- Electron Collider Ring – 2,336m Length
  - Arcs – 167 Dipoles, 167 Quadrupoles, 148 Sextupoles, 167 Correctors
  - Straights – 46 Dipoles, 274 Quadrupoles, 154 Correctors, 8 superconductin g Spin Rotator solenoids
  - 321 BPMs, other instrumentation, and vacuum elements
  - 16 RF Cavities with associated HPA and PS – from PEP-II
  - 12 SRF Cavities (3 cryomodules) with associated HPA and PS (new)
  - 2 normal conducting kickers and beam dump
- *Many of the normal conducting magnets are expected to be PEP-II reuse*

Technical Components – Electron Complex

- Electron Transfer Line – 333m Length
  - 156 Dipoles, 68 Quadrupoles
  - Instrumentation and vacuum elements
- Interaction Region
  - 6 superconducting final focusing quadrupoles with nested skew quadrupoles
  - 2 superconducting solenoids (to counteract detector solenoid)
  - SRF Crab Cavities

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Technical Components – Ion Complex

- Ion Injector and SRF Linac – 150 MeV p, 40 MeV/u Pb^{67+}
  - SRF QWR and HWR – Based on FRIB linac design
  - IH-DTL with FODO
  - Separate heavy ion and light ion RFQs
- Low Energy Booster (LEB) – 604m Length, Figure-8 design
  - E_{kin} = 150 MeV – 8.9 GeV
  - 104 Dipoles, 144 Quadrupoles, 32 Sextupoles, 57 Correctors
  - 57 BPMs, other instrumentation, and vacuum elements
  - 2 Kickers for injection/extraction
  - 3 Normal-Conducting Cavities for acceleration and bunch control
  - DC Electron Cooling with 1 cooling solenoid for heavy ions
- High Energy Booster (LEB) – 2,336m Length, Figure-8 design
  - E_{kin} = 8.9 GeV – 13 GeV
  - 124 Dipoles, 202 Quadrupoles, 16 Sextupoles, 107 Correctors
  - 107 BPMs, other instrumentation, and vacuum elements
  - 2 Kickers for injection/extraction
  - 7 Normal-Conducting Cavities for acceleration and bunch control
  - DC Electron Cooling with 1 cooling solenoid

Technical Components – Ion Complex

- Ion Collider Ring – 2,336m Length
  - Arcs: 208 Dipoles, 112 Quadrupoles, 56 Sextupoles
  - Straights: 50 Dipoles, 74 Quadrupoles, 53 Correctors
  - 337 BPMs, other instrumentation, and vacuum elements
  - 2 Kickers for injection/extraction and beam dump
  - 26 SRF Cavities (7 cryomodules) for Bunch Control
  - 3 Normal-Conducting Cavities for Acceleration and Bunch Control
  - All magnets are superconducting
- Interaction Region
  - 6 Final Focusing Quadrupoles, 4 Skew Quadrupoles, 2 Anti-solenoids, 2 Co rrectors
  - 3 Spectrometer Dipoles (part of the detector system)
  - SRF Crab Cavities

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Technical Components – Ion Complex

- Transfer lines:
  - Linac→Low Energy Booster
  - Low Energy Booster→High Energy Booster
  - Total: 24 Dipoles, 48 Quadrupoles, all magnets are normal-conducting
- Bunched Beam Cooling with ERL
  - Magnetized Gun
  - 50 MeV Linac Cryomodule
  - 2 Fast Kickers
  - Chirper/Dechirper
  - Beam Dump
  - 10 Dipoles, 15 Quadrupoles, 2 x 180° Sector Bends
  - 4 x 15m superconducting solenoids (in the ion collider ring)

Other Systems

- Electrical Utilities: 67.5 MVA peak load
- Low Conductivity Water (LCW) for cooling of normal conducting magnets, power supplies, HPAs
- Cryogenics
  - 12.0kW @ 4.5K equivalent plant
  - 2.1K required for all SRF
  - 4.5K distribution with sub-atmospheric return from systems requiring 2.1K

Conventional Facilities

- 67 buildings with 110k sq ft
  - Service buildings (for accelerator components)
  - Access buildings (service buildings with a crane-serviced drop hatch to tunn el elevation)
  - Counting house
  - Cryogenics plant
- Tunnel
  - 3.5 km of shallow tunnel (30ft construction depth)
  - Vaults for two detectors
- Infrastructure
  - Power distribution
  - ICW and LCW
  - Roads

JLEIC Planning Overview

Now to CD0: Pre-project

- Pre-project R&D: **validation** of basic design technology and further **risk reduction** (JLEIC bas eline design minimizes project risk)
- Pre-project activities (site evaluation and environmental impacts, configuration management)
- Collaboration on EIC (National Labs: BNL, ANL, SLAC, LBL, Universities, International, EICUG)
- Preparation of a **pre-CDR (COMPLETE)**, to prepare for full CDR

CD0 to CD1: On-project

- On-project R&D (**value engineering** for performance optimization and cost reduction)
- Delivery of full **CDR**

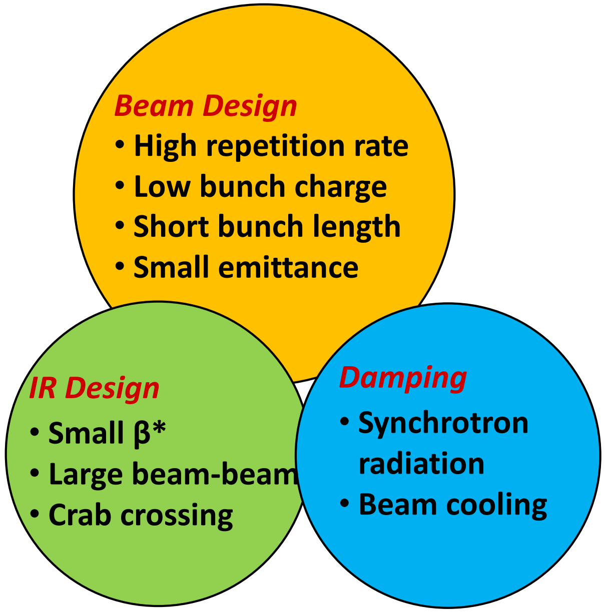
Backup Slides

Basic Design

- **High luminosity**: high collision rate of short low-charge low-emittance bunches
  - Small **beam size**
    - Small β* ⇒ Short bunch length
      Low bunch charge, high repetition rate
    - Small emittance ⇒ Cooling
  - Similar to **lepton colliders** such as KEK-B with $L > 2\times10^{34}$ $cm^{-2}s^{-1}$

$$L = f\frac{n_1 n_2}{4\pi\sigma_x^*\sigma_y^*} \sim f\frac{n_1 n_2}{\varepsilon\beta_y^*}$$

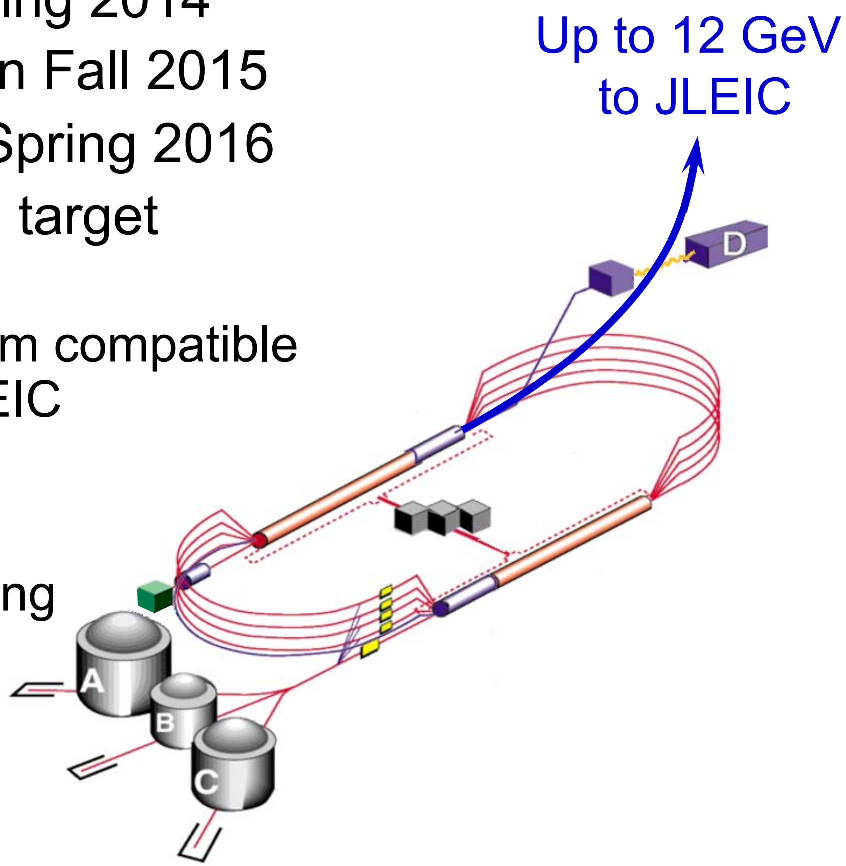
- **High polarization**: **Figure-8** rings
  - Net spin precession zero
  - Spin easily controlled by small magnetic fields for any particle species



- **Optimal integration IR and total acceptance detector** (including far-forward acceptance)
- **Technical risk minimization**
  adopt established technology where possible, focus technology demonstration in few selected areas

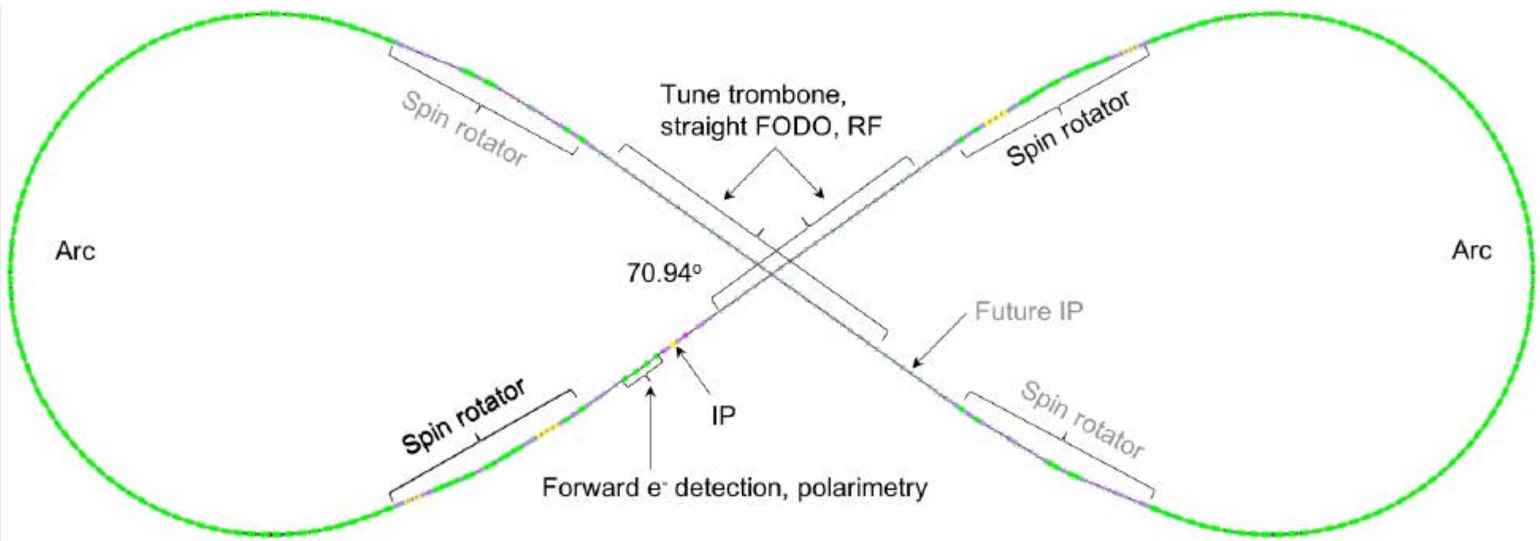
CEBAF as Injector

- Commissioned in Spring 2014
- Operated at 12 GeV in Fall 2015
- First Physics Run in Spring 2016
- Exciting science fixed target program
  - Fixed-target program compatible with concurrent JLEIC operations
- JLEIC injector
  - Fast fill of collider ring
  - Full energy
  - ~85% polarization
  - Enables top-off

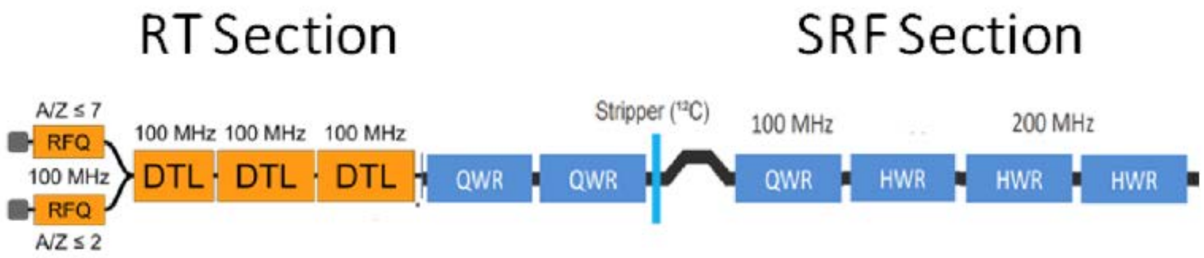


Electron Collider Ring

- Circumference of 2,336 m



Ion Linac: Layout and Highlights



- 150 MeV p, 40 MeV/u Pb^{67+}
- Separate light/heavy ion RFQs/LEBTs
- Improved NC FODO DTL with IH structure
- SRF based on ANL/FRIB QWR/HWR designs

- Active collaboration with ANL

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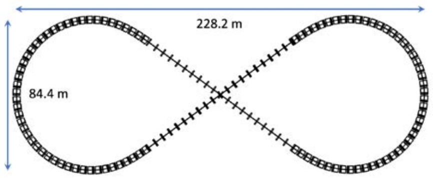
Ion Low Energy and High Energy Boosters: Layout and Parameters

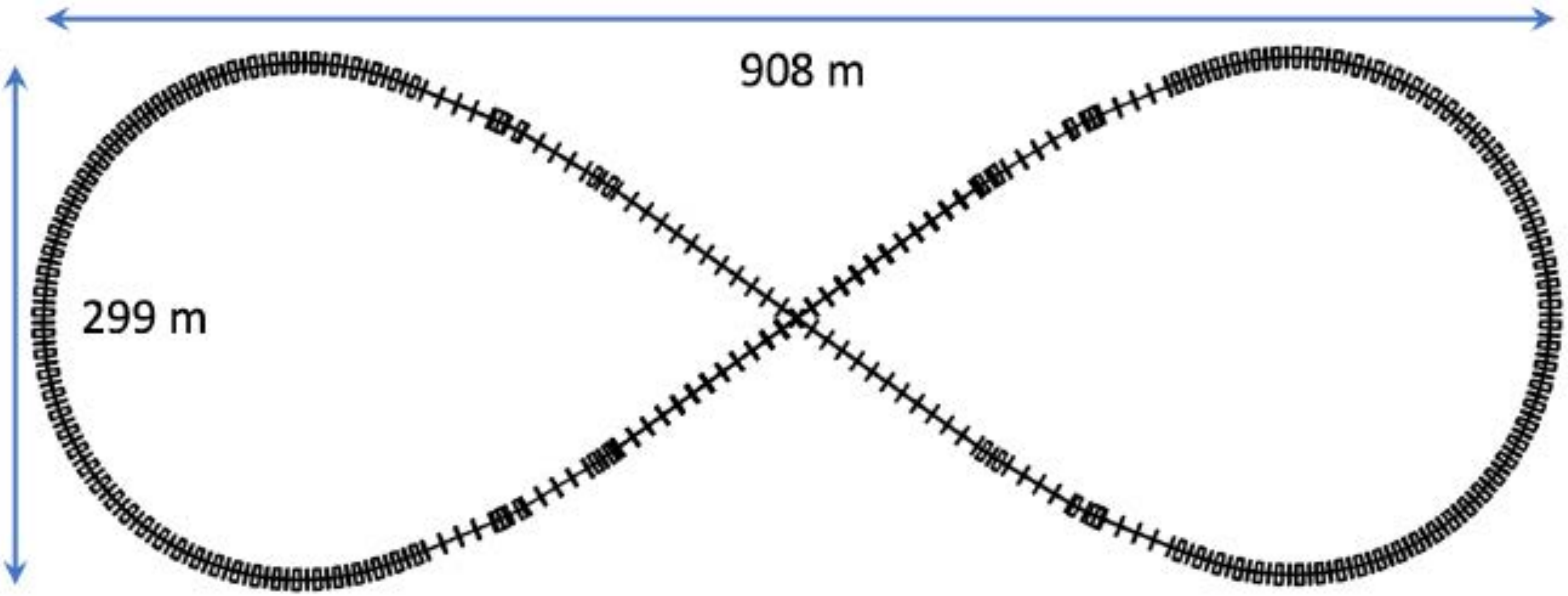


LEB: E_{kin} = 150 MeV – 8.9 GeV

Ring circumference: 604m

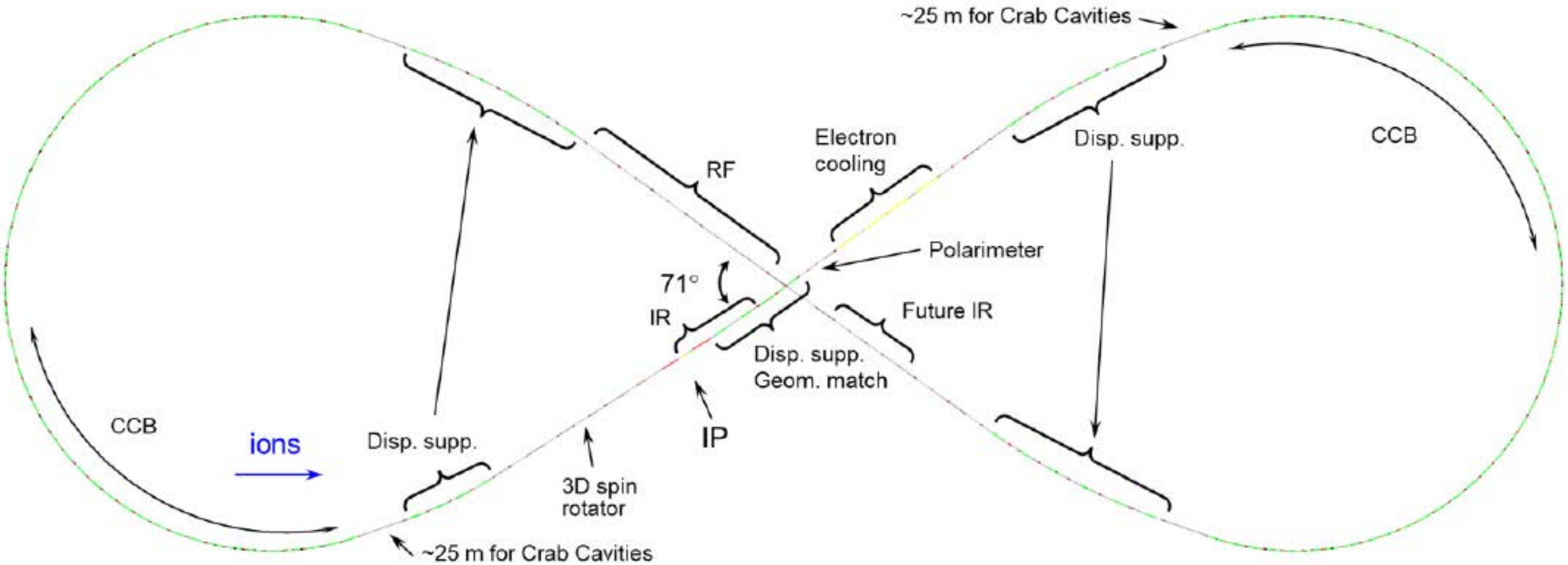
HEB: E_{kin} = 8.9 GeV – 13 GeV

Ring circumference: 2,336 m



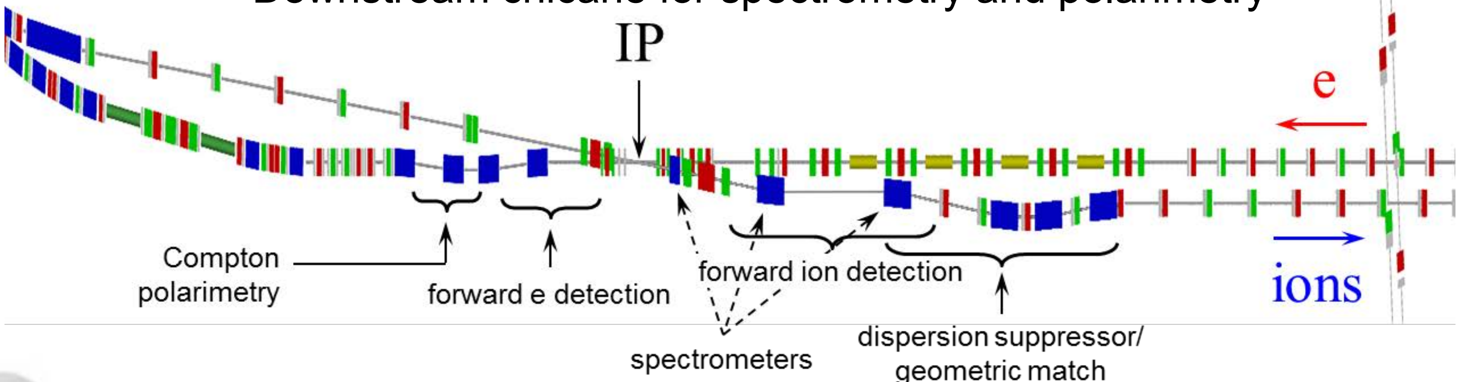
Ion Collider Ring

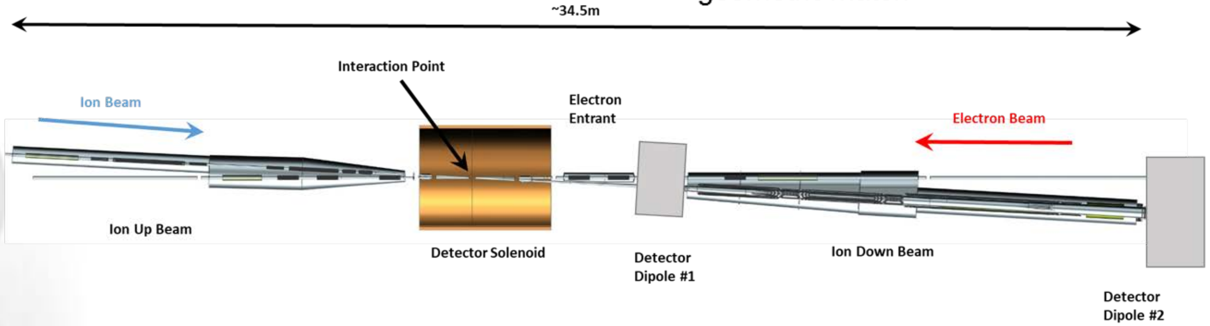
- Circumference of 2,336 m
- Superconducting Cosθ magnets
- SRF: bunching RF, electron cooler ERL, crabbing



Detector Region Layout

- 50 mrad crossing angle
  - Fast beam separation, no parasitic collisions, improved momentum resolution of the solenoid
- Electron beam on a straight line
  - Downstream chicane for spectrometry and polarimetry





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JLEIC Bunched Beam Electron Cooler

Parameter	Value	Units
Electron energy	20—109	[MeV]
Charge	1.6 (3.2)†	[nC]
CCR pulse frequency	476.3	[MHz]
Gun Frequency	43.3	[MHz]
Bunch length (top-hat)	4/23	[cm/°]
Thermal (Larmor) emittance	<19	[mm-mrad]
Cathode spot radius	3.1	[mm]
Cathode magnetic field	0.05	[T]
Normalized hor. Drift emittance	36	[mm-mrad]
rms Energy spread (uncorr)	3×10^{-4}	[—]
Energy spread (p-p corr.)	6×10^{-4}	[—]
Cooler solenoid field	1–2	[T]
Electron beta in cooler	36	[cm]
Solenoid length	4×15	[m]
Bunch shape	Beer can	[—]