Accelerator developments for ISOL facilities

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Accelerators and Radioactive Ion Beams

- At the cutting edge of accelerator technology, RIBs allow to reach the frontier in experimental nuclear physics
  - New beam species
  - Finely tunable energy
  - High beam quality in re-accelerated RIBs
  - Unique nuclear reactions achievable for high precision measurements
- Specially Required:
  - Driver accelerators (*p, d, HI, e*)
  - RI production target systems
  - RIB sources, charge breeders
  - High resolution mass separators
  - High sensitivity beam diagnostics
  - Post-accelerators (*HI*)
    - From keV to hundreds of MeV/u

Recent RIB facilities worldwide

In-flight facilities	Driver	MeV/u	I (pps)	Separator	Exp.
RIBF (RIKEN, Japan/2006 –)	SRC	345	6×10^{12}	BigRIPS	ZDS etc.
HIRFL (IMP, China/2006 –)	CSRm	500	10^{9}	RIBLL2	CSRe etc.
FRIB (USA/2017+)	SC linac	200	5×10^{13}	A1900	ReA12 etc.
FAIR (2018+)	SIS100	1500	2×10^{11}	SuperFRS	CR etc.
Catcher-reacc. facilities	**Driver (Beam)**	**MeV/u**	**Breeder**	**Post acc.**	**MeV/u**
ReA3 (MSU, USA/2011 –)	K1200 (HI)	170 - 80	EBIT	SC linac	3 - 6
CARIBU (ANL, USA/2011 –)	(^{252}Cf)	–	ECR	ATLAS	15
ISOL facilities	**Driver (Beam)**	**MeV**	**kW**	**Post acc.**	**MeV/u**
BRIF (CIAE, China/2013)	Cyclotron (*p*)	100	20	SC linac	2
ARIEL (TRIUMF, Canada/	Cyclotron (*p*)	500	50	ISAC	18
2013)	SC linac (*e*)	50	500	ISAC	18
Spiral2 (GANIL, France/2014)	SC linac (*d*)	40	200	CIME	2 - 25
SPES (INFN, Italy/2014)	Cyclotron (*p*)	40	8	ALPI	10
HIE-ISOLDE (CERN/2015)	PSB (*p*)	2000	10	REX upgrade	5.5 - 10

RIB facilities recently commissioned or under construction for facility upgrade (from O. Kamigaito, IPAC 2013)

New facility under construction:

RISP (Korea/2023?)	SC linac	200	5×10^{13}	A1900	SC linac etc.

RIB production methods reminder [1]

- **ISOL (Isotope Separation On-Line)**: the primary <u>hadron beam</u> (proton in most cases) induces nuclear reactions (*either <u>directly</u> or <u>through secondary neutrons</u> produced by a neutron converter target*) in the RIB production target. The reaction products are stopped in the target material, which is kept at a very high temperature, and thermally drift in it until they reach its surface and are delivered in a vacuum chamber; a vacuum duct leads them to an ion source where they are ionized and extracted as a radioactive ion beam $\Rightarrow$ high beam quality

- **Photo-fission**: a primary <u>electron beam</u> hits a target and produces high energy photons by bremsstrahlung; the <u>secondary γ-rays are sent to a RIB production target</u>, enclosed in an ion source, where radioactive ions are produced by photo-fission and extracted as in the ISOL case. $\Rightarrow$ high beam quality

ISOL example

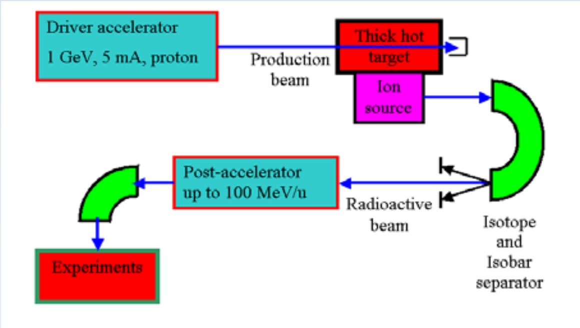
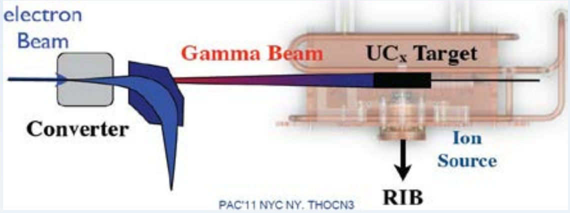


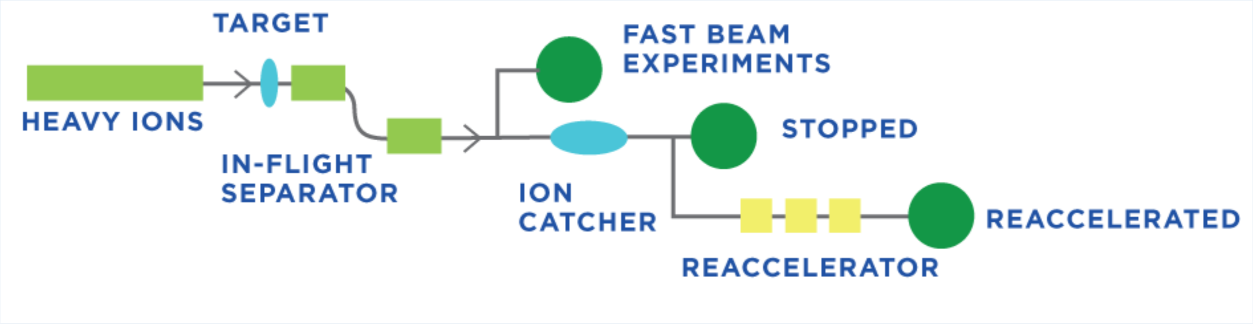
Photo-fission example



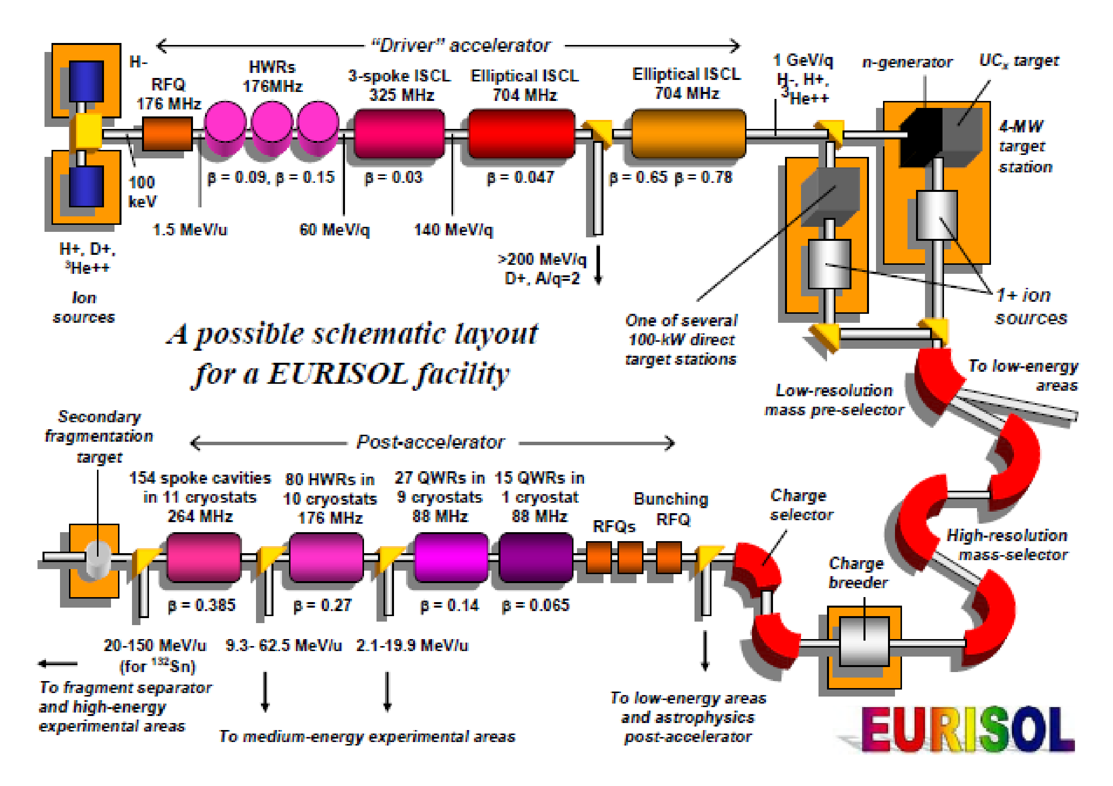
RIB production methods reminder [2]

- **In-Flight**: a heavy ion primary beam hits a target, and the nuclear reactions products – typically fragments of the incoming ions - leave the target thanks to the kinetic energy of the primary beam $\Rightarrow$ low beam quality but fast
- **In-Flight-IGISOL**: The in-flight produced RIB is slowed down and stopped, charge bred and re-accelerated $\Rightarrow$ high beam quality

In-flight + IGISOL example



"Great EURISOL" the dream ISOL facility

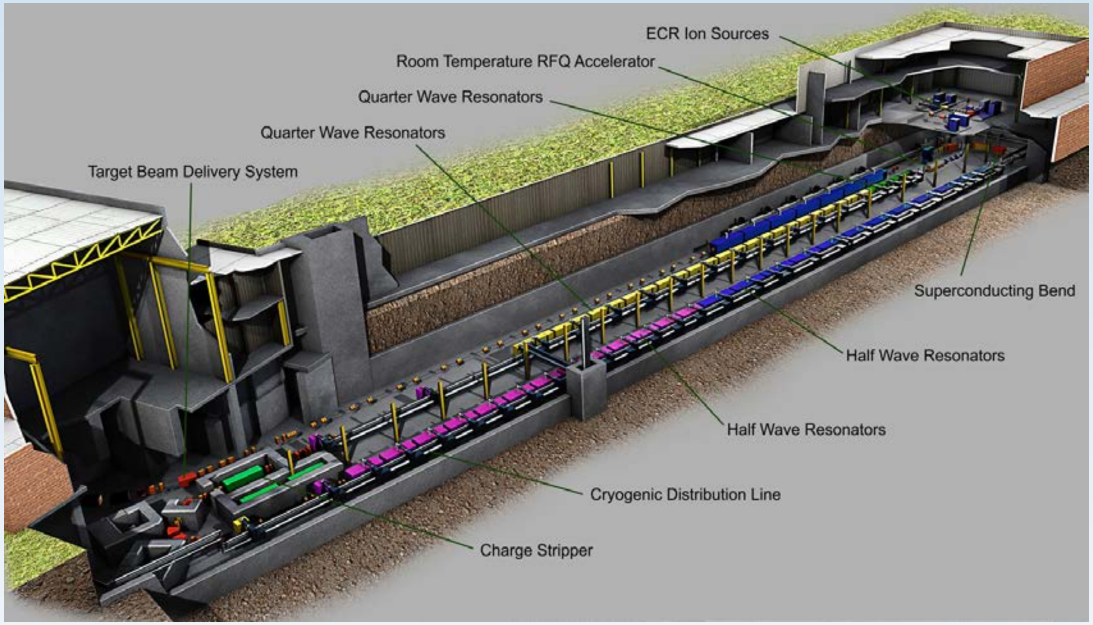


- High power driver proton accelerator
- 4 MW target with neutron converter + several ≤100kW direct targets run in parallel
- Post-accelerator up to 150 MeV/u, finely tunable
- High beam quality of RIBs
- High beam current of RIBs
- Design sudy completed

Still a dream, but some of the EURISOL DS ideas are being developed and pursued in other facilities and laboratories

Accelerator challenges in RIB facilities
(in addition to ion sources, targets, mass selection etc.)

- Driver accelerators:
  - High power
  - Low losses
  - High reliability
- Post-accelerators:
  - High transmission
  - High operational stability
  - Capability to accelerate very low current beams
  - Capability to accelerate a large range of A/q
- Special features sometimes required
  - CW operation
  - Multi-charge beam transport
  - Extremely high reliability

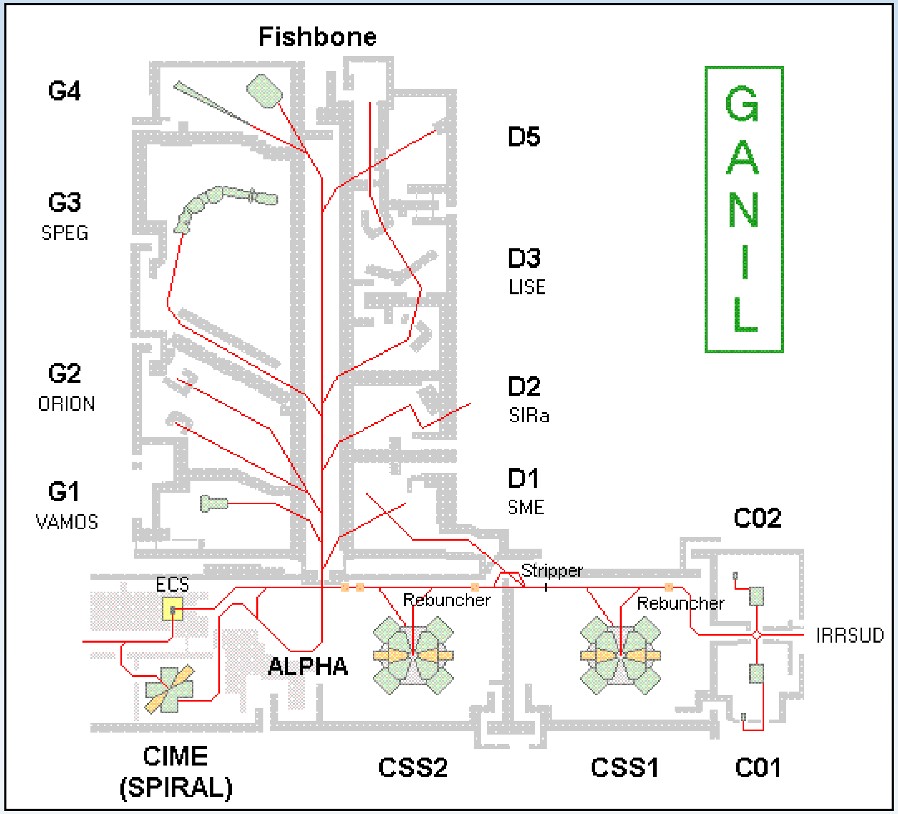


Artist view of the FRIB SC linac driver

European ISOL facilities with dedicated accelerator development: EURISOL-DF partners

- GANIL
  - cyclotron complex (operating; with RIB post-accelerator)
  - SPIRAL2 (under commissioning, RIB production in the long term)
- REX/HIE-ISOLDE
  - (operating; with RIB post-accelerator)
- SPES (under construction; with RIB post-accelerator)
- ALTO
  - (operating, low energy RIBs)
- MYRRHA
  - (Phase 1 driver accelerator construction starting)
  - ISOL production planned in the long term
  - SC linac compatible with EURISOL-DS driver requirements

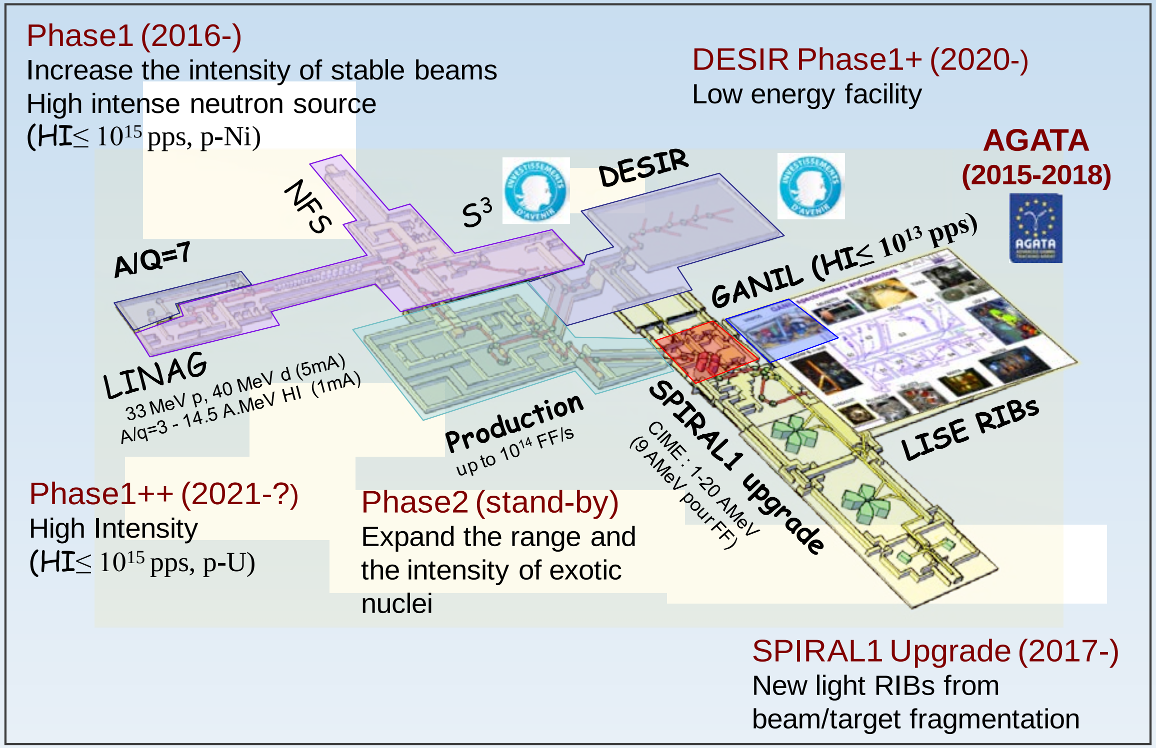
Accelerator developments in GANIL



Present RIB facility

- Driver accelerator: GANIL cyclotrons
  - from ^{12}C (24MeV/u) to ^{238}U (95MeV/u)
  - Beam current in the ~10 μA range
- ISOL method:
  - primary heavy ion beams into a thick carbon target.
  - fragments produced are ionized (ECR)
- Post-accelerator: cyclotron CIME (K=265) from 1.2 to 25MeV/u
- "In Flight" method:
  - Fragmentation of 2kW primary beam in a high power, 2000 rpm rotating target system.
  - exotic cocktail beam purified with a fragment separator spectrometer.
- Since end 2014, due to the SPIRAL1 upgrade, the acceleration of radioactive beams with the cyclotron CIME is suspended

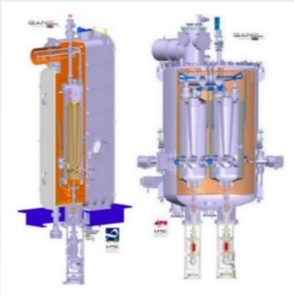
Upgrade plan

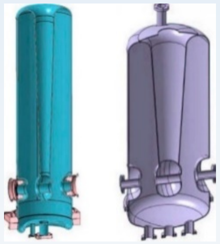


- Phase1: SPIRAL2 accelerator, the Neutron-based research area (NFS) and the Separator Spectrometer (S3)
- Phase2 (long term): RIB production process and building, and the low energy RIB experimental hall called DESIR
- Due to *budget restrictions*, the RIB production part has been postponed, and DESIR low energy RIB facility included as a continuation of the first phase.

SPIRAL2 superconducting linac

beam	P+	D+	ions	ions
A/Q	1	2	<3	<6 or 7
Max. I (mA)	5	5	1	1
Min. output E (MeV/A)	2	2	2	2
Max. output E (MeV/A)	33	20	14.5	8.5
Max. beam power (kW)	165	200	44	48

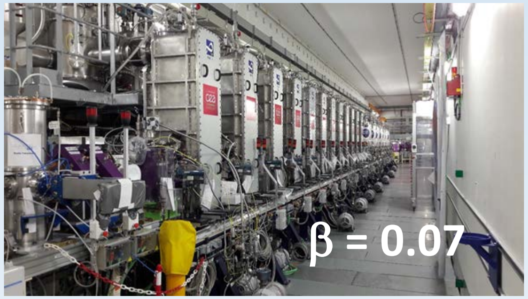




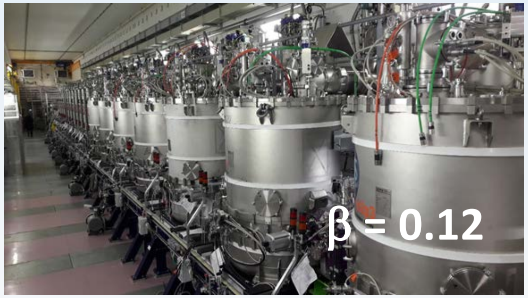
- High intensity HI SC linac (up to 40 MeV, 5mA, 200 kW)
- SRF development undertaken by **IPN Orsay** and **CEA Saclay**
    - 2 types of Bulk-Nb QWRs. Excellent cavity performance
    - Unique linac design with 1 and 2 cavity cryostats and NC quadrupole magnets
- Long term plan: new q/A=1/7 injector under study
    - increase the intensity of ions beyond Argon
    - production of very- and super-heavy elements for S3.
- SPIRAL2 in the long term will be used as driver for high intensity RIB production, which can be post-accelerated by the CIME cyclotron
    - SPIRAL2 could be also an excellent RIB post-accelerator

SPIRAL2 status

- **Sources and LEBT:** operational, beam commissioning performed in LEBT up to the RFQ, with the 2 ions sources (except for D^+)
- **RFQ:** Nominal specifications reached for H^+ (A/Q=1 at 50kV)), $^4He^{2+}$ (A/Q=2 at 80kV) and $^{16}O^{6+}$ (A/Q=2.7 at 105kV) in CW operation (with transmission close to 100%. RF conditionning of the RFQ at nominal value for A/Q = 3 (113.5 kV) is in smooth progress



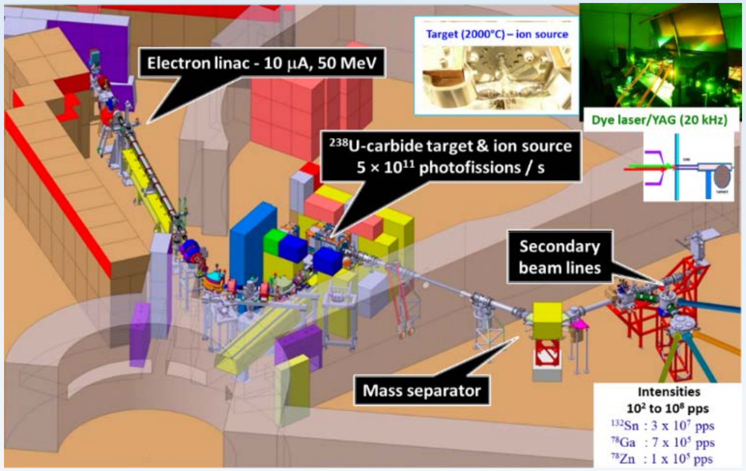
- **Linac:** 01/2017 installation completed, 1st cooldown successfully performed
- **HEBT**: Installation ongoing, to be completed by the end of this year
- **Safety**: The full authorization is expected beginning of next year. First experiment with NFS in year 2020.
- **Next year**: RF commissioning of all superconducting cavities of the LINAC, and then to the commissioning of the accelerator up to the beam dump with protons beam.



ALTO

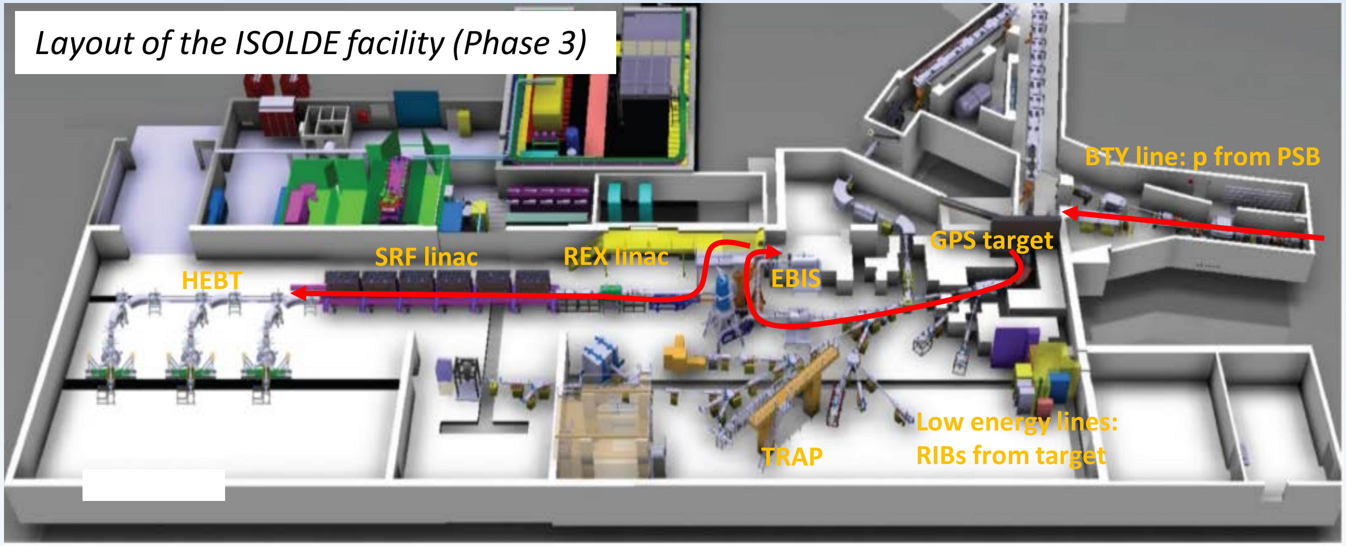
- electron LINAC dedicated to the production of RIBs
  - 50 MeV, 10 μA, pulsed
  - 3 GHz, TW linac from CERN
  - Operating since 2013
- photofission in a thick UCx target (heated up to 2000°C) with a 10 μA electron beam. RIB production rate is 5 10^{11} fissions/s
- No post-accelerator planned yet due to lack of space
- **Accelerator R&D for ALTO focused on efficiency and reliability**
- **IPNO major center in SRF development, contributing in numerous SC linac projects in Europe (SPIRAL2, MYRRHA, ESS, etc.)**

- The ALTO facility
  - Tandem accelerator dedicated to stable (ions and cluster) beam physics,
  - Linear electron accelerator (NC) dedicated to the production of radioactive beams
- Before the construction of the electron Linac, the tandem has been used as a driver accelerator to produce RIBs with a 1 μA, 26 MeV deuterons beam hitting a Uranium target. The fast neutrons produced in the converter led to a rate of 10^9 fissions/s.

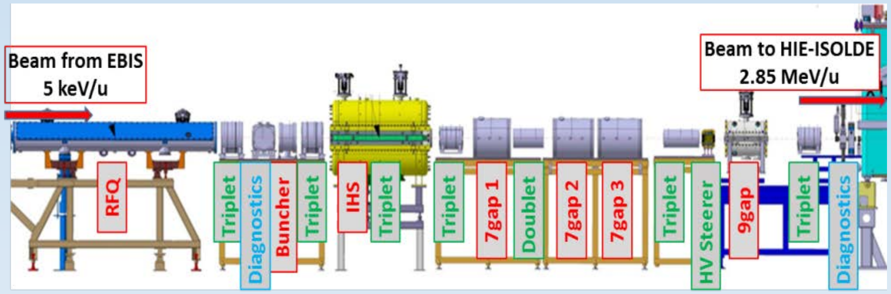


Accelerator developments at ISOLDE at CERN

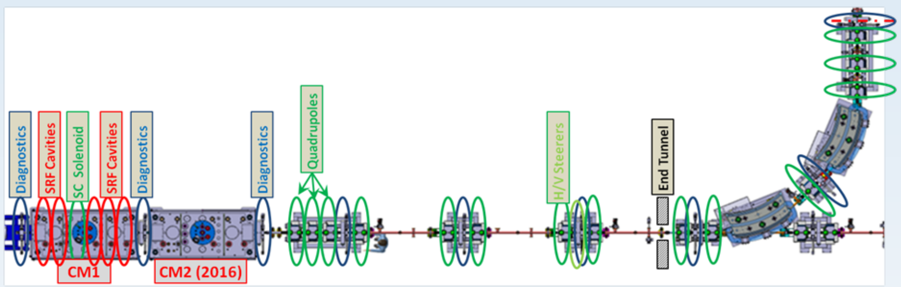
- Driver: Proton-Synchrotron Booster (PSB) - 1.4 GeV protons
  - LHC injector parasitically used for RIB production
- RIBs produced at the ISOLDE targets, accumulated and cooled in the REX-TRAP
- RIBs used either at low energy, or charge bred in the REX-EBIS and post-accelerated in the REX/HIE linac



REX/HIE



Schematics of the REX normal conducting linac



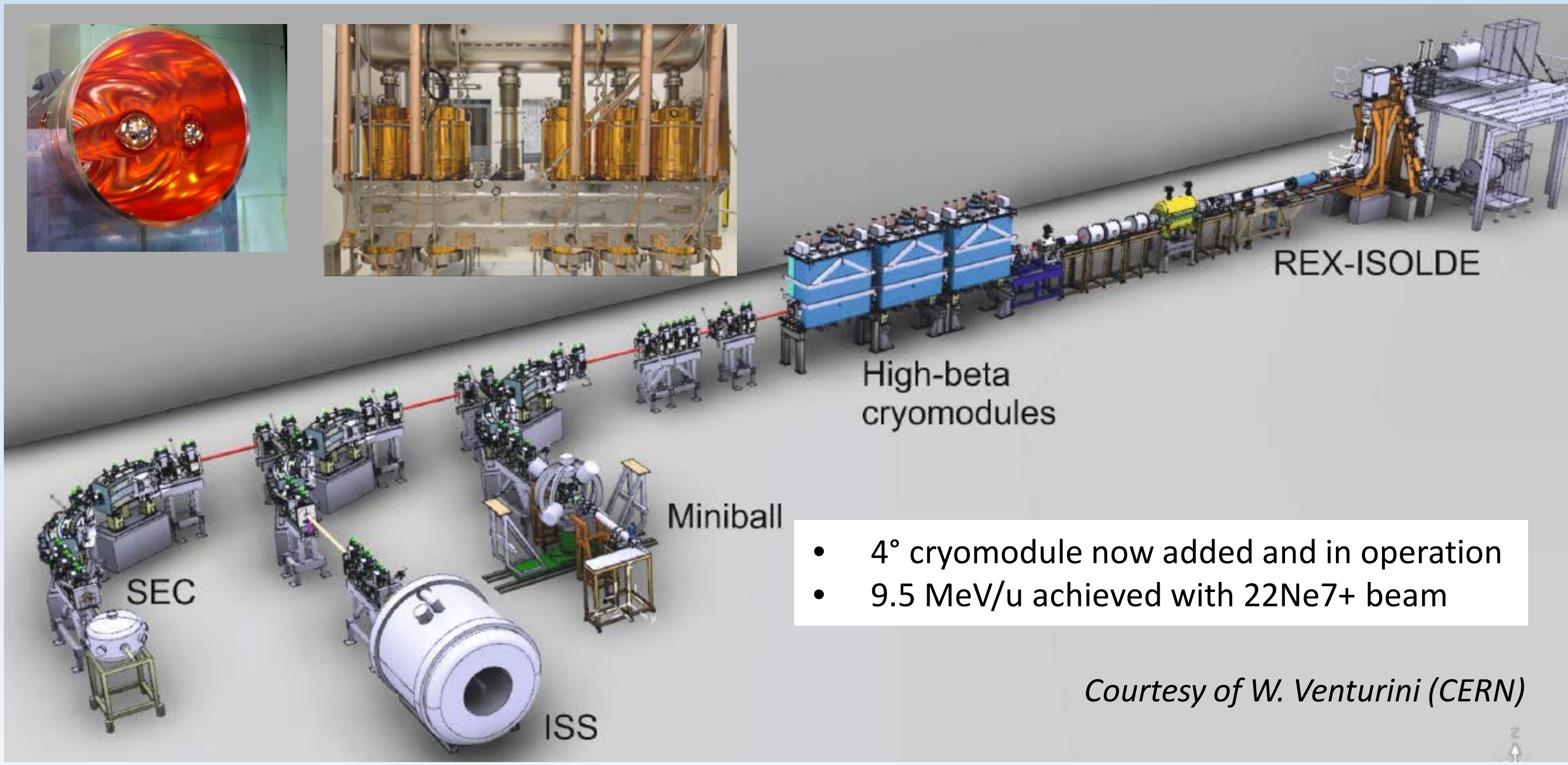
Phase 1b of superconducting HIE-ISOLDE

Maximum beam energy in MeV/u for beams with different A/Q after completion of each phase

	Phase 1a	Phase 1b	Phase 2a	Phase 2b
A/Q=2.5	5.9	8.9	11.8	14.5
A/Q=4.5	4.3	6.0	7.7	9.3

- NC linac: IH and CH structures
- SC linac now: 4 cryomodules, each including 5×101.28 MHz, β=0.103 QWRs+ 1 SC solenoid
- Phase 3 future upgrade: Replacing a fraction of the REX NC linac by 2, β=0.063 SC Cryomodules, each hosting 2 SC solenoids and 6 SC QWRs
- final RIB energy after Phase 3:
    - 16.8 MeV/u (with A/q = 2.5)
    - 10.2 MeV/u (with A/q = 4.5)

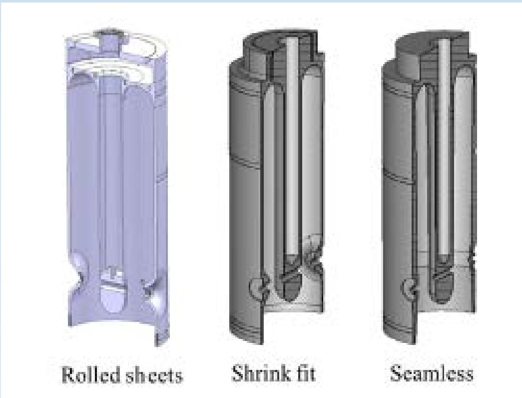
HIE ISOLDE Linac in 2017

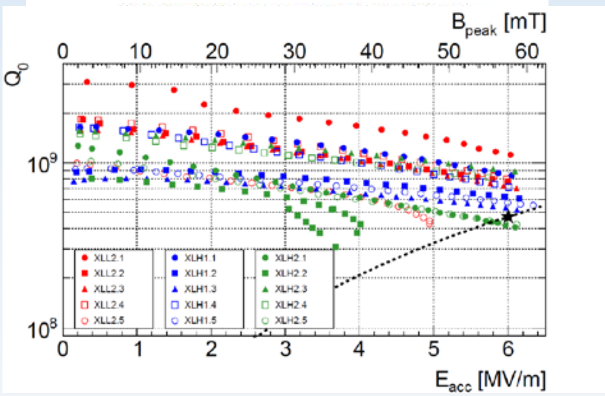


- 4° cryomodule now added and in operation
- 9.5 MeV/u achieved with 22Ne7+ beam

Courtesy of W. Venturini (CERN)

Major R&D : Nb sputtered SC QWRs

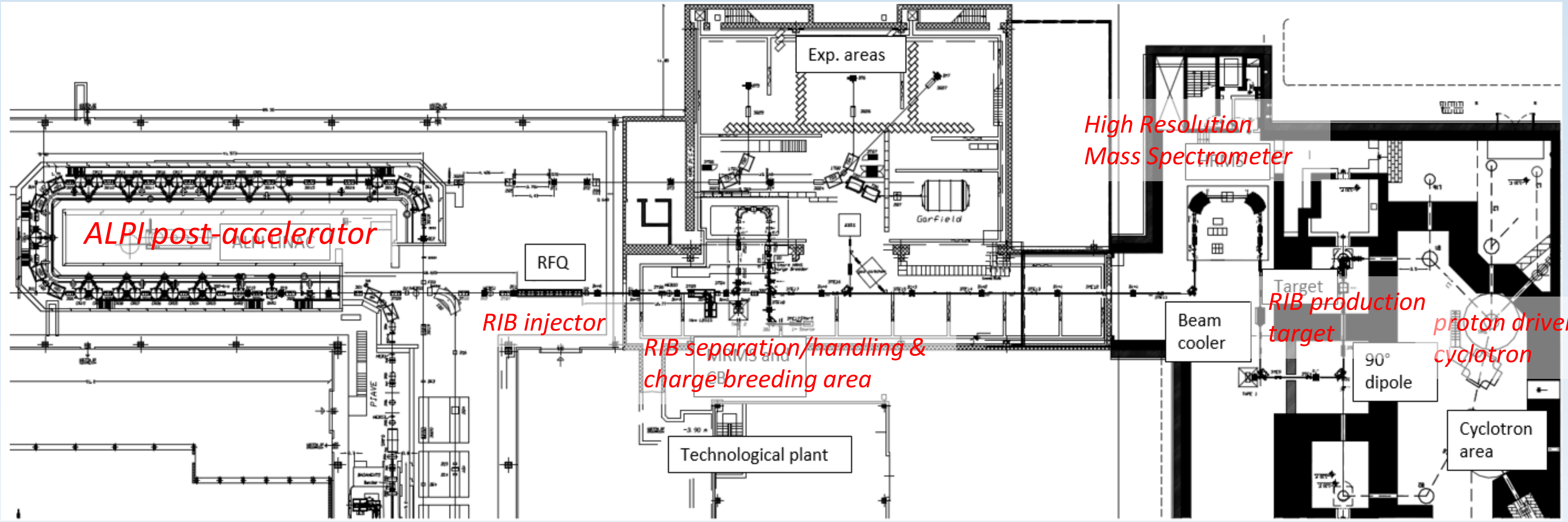




Sputtered QWRs on-line performance

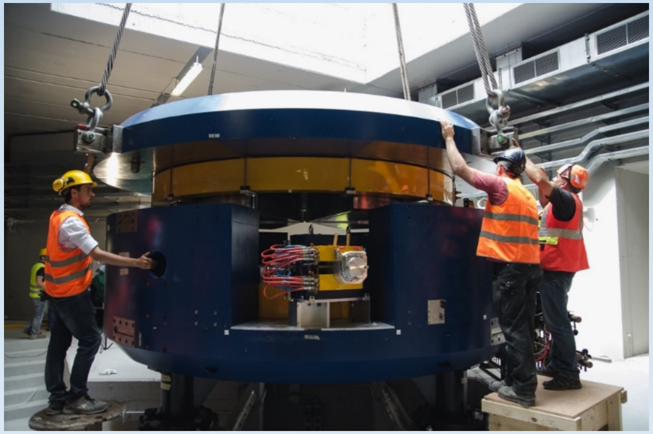
- Nb sputtered on Cu resonator technology - evolution of INFN-LNL technology developed in ’90es
- ISOLDE became the second low-β SC linac worldwide based on sputtered Nb on Cu cavities
- Main developments:
  - Cavity design modified to fit ISOLDE needs
  - Cu substrate preparation
  - sputtering technique
- **Excellent on-line performance**
  - 15 cavities are running at 4.5 K requiring in total ~ 100 W RF power
  - Cavity dissipation in the linac < 10 W at 6 MV/m
  - Cavity V_{acc} ~ 1.8 MV
  - No magnetic shielding required
  - No interference from neighbouring superconducting solenoids
- CERN/ISOLDE becaming world leader in low-β Cu/Nb sputtered resonators

Accelerator developments in SPES at INFN-LNL



The SPES complex, including (from right to left): the cyclotron proton driver and RIB production target area, the RIB beam handling/separation/charge breeding area, the RIB injector, the ALPI post-accelerator.

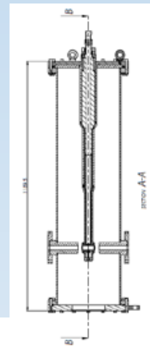
SPES Cyclotron Proton Driver

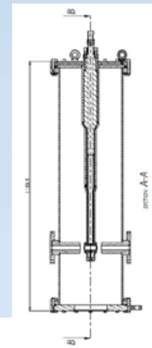


Main Parameters	
Accelerator Type	Cyclotron AVF 4 sectors
Particle	Protons (H- accelerated)
Energy	Variable within 30-70 MeV
Max Current	750 µA (52 kW max beam power)
Available Beams	2 beams (upgradeable to different energies)
Max Magnetic Field	1.6 Tesla
RF frequency	56 MHz, 4th harmonic mode
Ion Source	Multicusp H- I=15 mA, Axial Injection
Dimensions	Φ=4.5 m, h=1.5 m
Weight	150 tons

- Made by Best Cyclotron Systems Inc.
- Now operating (presently on a beam dump)
- 2 beams, 2 targets:
  1) radiopharmaceutical research (design stage)
  2) RIB production (2023)
     - Primary beam: 40 MeV, 0.2 mA, 8 kW
     - Production rate: 10^{13} f/s
- Planned upgrades (beyond 2023)
  - ISOL2: second RIB production chamber for target development.
    - Primary beam: 70 MeV, 0.15÷0.3 mA, 10 ÷20 kW
    - Goal: ×4 increase of fissions/s

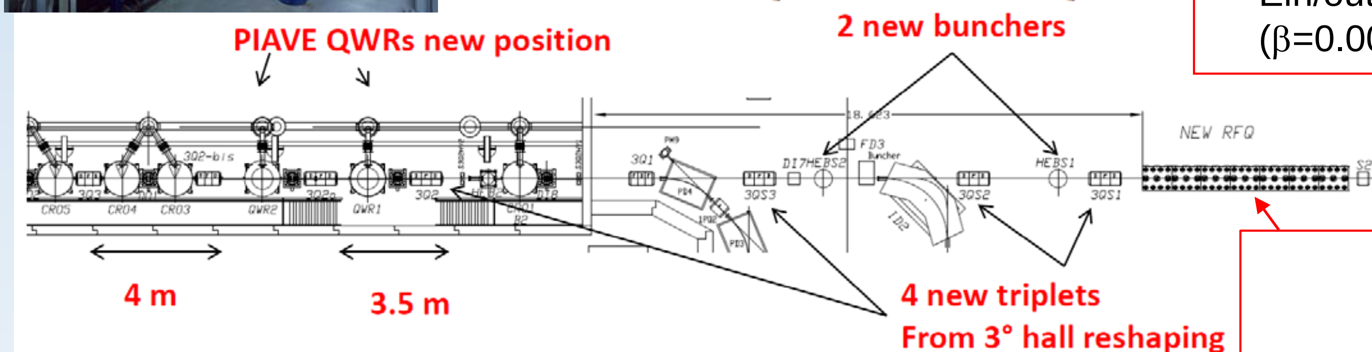
SPES RIB injector

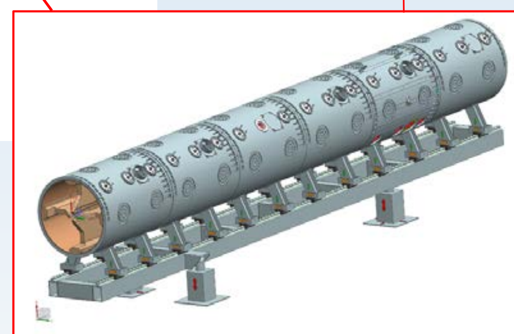




SPES RFQ is designed in order to accelerate beams in CW with A/q ratios from 3 to 7

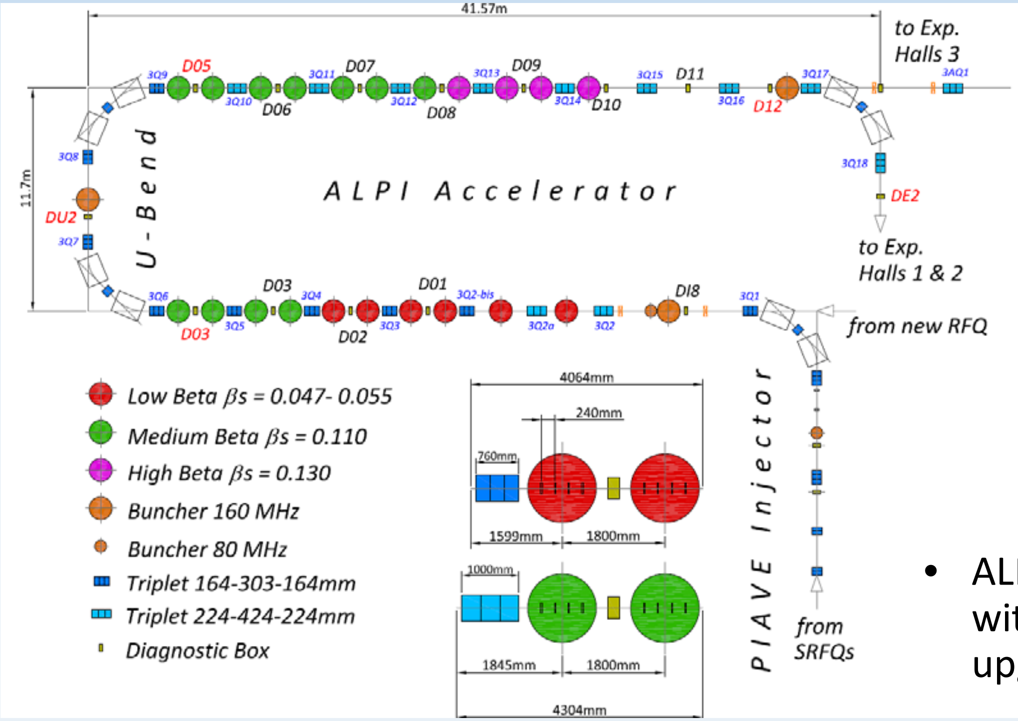
- 4-vane type, composed of 6 modules
- Length: 7.2 m
- 80 MHz CW
- RF power dissipation: 115 kW
- Ein/out =5.7/727 keV/u (β=0.0035÷0.036)





- SPES injector includes 5 MHz buncher, 80 MHz CW RFQ, two 80 MHz rebunchers and new focusing triplets.
- SPES injector resently under construction. Operation (with stable beams) foreseen in 2020
- Operation with RIBS after completion of SPES beyond 2023

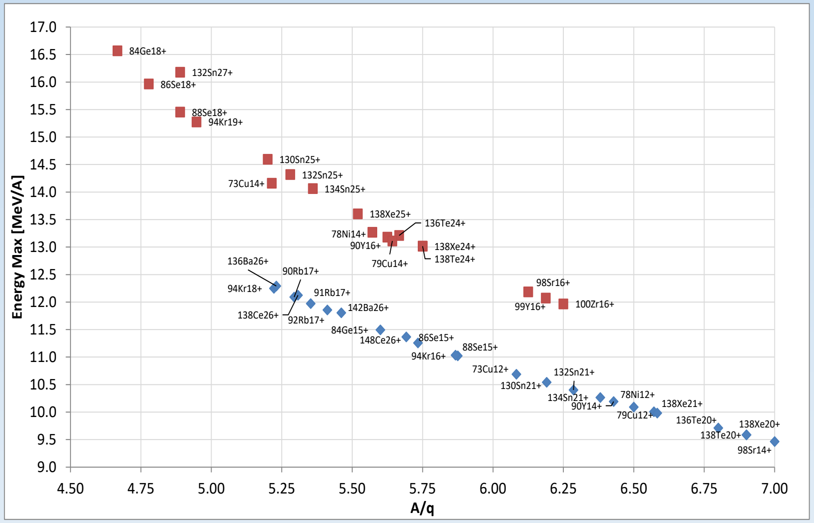
SPES post-accelerator



	SPES/ALPI SC QWRs				SPES/ALPI SC QWRs Upgraded			
beta	n.	E_a	L_{eff}	V_g (MV)	n.	E_a	L_{eff}	V_g (MV)
0.047	8	5	0.18	7.20	8	5	0.18	7.20
0.055	16	5	0.18	14.40	16	5	0.18	14.40
0.11	44	4.3	0.18	34.06	44	5.5	0.18	43.56
0.13	8	5.5	0.18	7.92	16	5.5	0.18	15.84
0.11	4	4.3	0.18	0	4	4.3	0.18	0
Total	80			63.6	88			81.0 (71)

- ALPI: SC linac in operation since 1992, coupled with the SC Positive Ion injector PIAVE and upgraded several times.
- Cavities: SC QWRs, made of bulk Nb and sputtered Nb on Cu (LNL development)
- Eq. Voltage gain: ~64 MV ÷ 81 (depending on future funding)
- Upgraded to become the SPES post-accelerator

SPES performance after upgrade



The expected beam energy and A/q from SPES, before (blue) and after SPES and ALPI upgrades (including a new EBIS charge breeder)

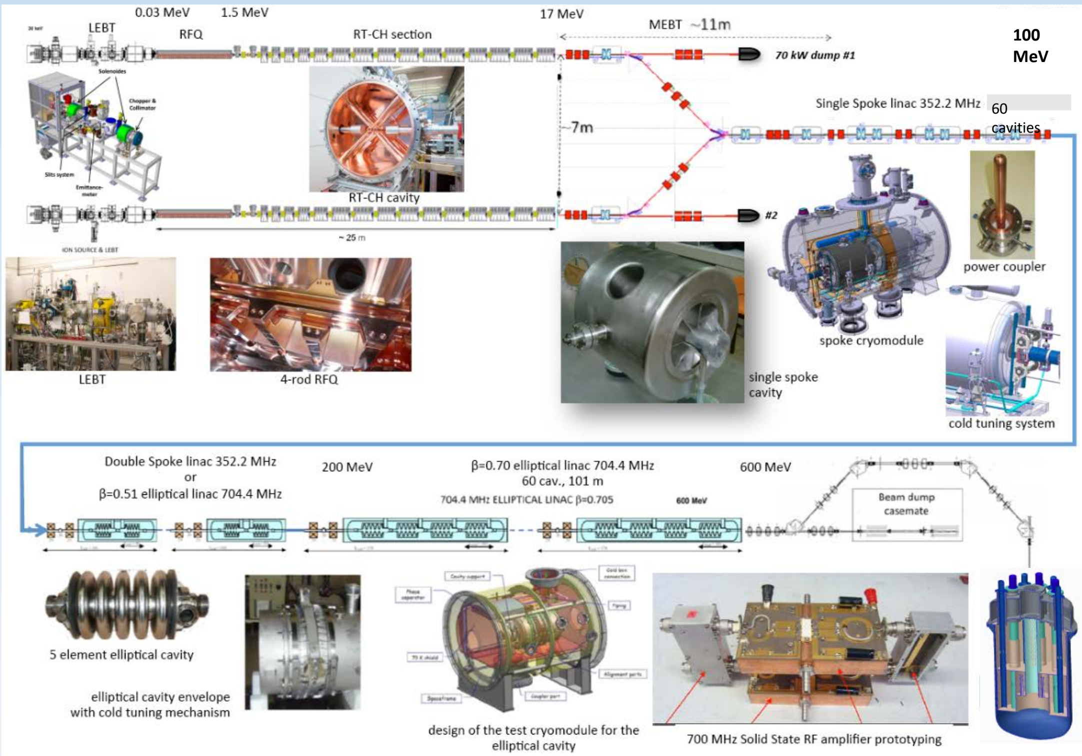
- **Low-β upgrade (ongoing):** both β=0.047 cryostats operating in PIAVE are being moved to the front end of the ALPI low-β section, increasing the linac voltage gain for all beams, including RIBs, by about 7.2 MV.
- **Improved transmission (ongoing):** Replacement of 10 magnetic quadruple triplets with increased gradient ones (from 20 to 30 T/m); replacement of all resonator controllers with digital ones. These measures, together with a precise component alignment ensured by laser tracking, are expected to at least double beam transmission along ALPI (from present 40% to 80%), by means of better transverse focusing (new quads) and more precise definition and stability of the resonators'phase (digital controllers).
- **Improved reliability (almost completed):** Refurbishment of ALPI cryogenic plant both on the compressors/recovery side (new purifiers, automated recovery system) and on the cold-box side (new valve boxes with external actuators, new control system for both cryogenic plants and cryomodules).
- **High-β upgrade (not yet funded):**
    - Addition of 2 more β=0.13 cryostats (8 NbCu, 160 MHz cavities with β=0.13) at the end of the high-β section
    - replacement all the 44 existing β=0.11 NbCu cavities with new ones capable of higher gradient. This upgraded ALPI will then further increase its output voltage gain by about 18 MV.
- In total, the upgraded ALPI linac will increase its beam output energy by about 25 MV, reaching a final accelerating voltage of 71 MeV up to 81 MV (not yet funded).

Accelerator developments in MYRRHA

Multipurpose h**Y**brid **R**esearch **R**eactor for **H**igh-tech **A**pplications

- Main goals of the MYRRHA-Project: Construction of an Accelerator Driven System for
  - ADS concept demonstration
  - Transmutation of nuclear High-Level-Waste (HLW) demonstration
  - multipurpose and flexible fast irradiation facility, including ISOL system
- Major requirement: High power proton linac with unprecedented beam stability and reliability to avoid damaging the ADS reactor
- Phased approach to reduce risk
  - Phase 1: 100 MeV linac (2018-2024)
    - to develop and validate technology, reliabilty, fault tolerance
    - To use the beam for science and technology applications, including RIBs

Superconducting proton linac driver

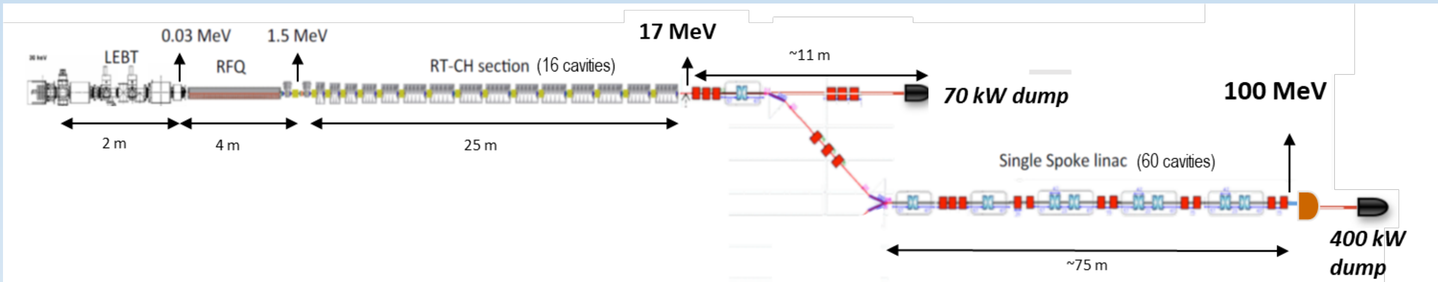


- Proton energy: 600 MeV
- Beam current: 0.1 to 4.0 mA
- Repetition rate: CW, 10 to 250 Hz
- Beam duty cycle: 10^{-4} to 1
- Beam power: up to **2.4 MW**
- Beam power stability: < ± 2% on a time scale of 100ms
- **<10 beam trips longer than 3 sec. per 3-month operation**

This linac, with some energy upgrade, would be a suitable driver for the ''Great EURISOL''

personal communication. By courtesy of SCK•CEN

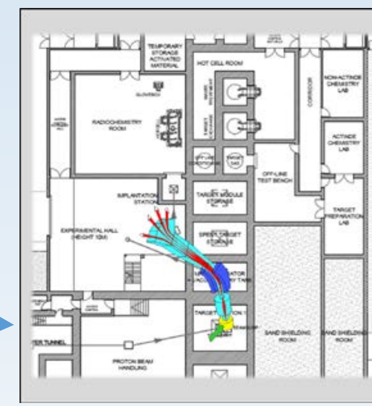
Phase 1 : 100 MeV linac
+ISOL target + material irradiation target



MINERVA project

- 100 MeV linac coupled to a Proton Target Facility (PTF)
- Applications
  - Production of medical radioisotopes for targeted cancer therapy
  - Fundamental physics: high-precision, high-statistics experiments (nuclear, atomic & solid state physics, condensed matter, biology…)
  - Material irradiation for Fusion studies

- A fraction of the beam will be redirected to the PTF
- PTF design ongoing, will include an ISOL System and various related facilities
  - target pit and shielding
  - spent-targets storage
  - isotopes collector station
  - off-line conditioning station
  - laser laboratory

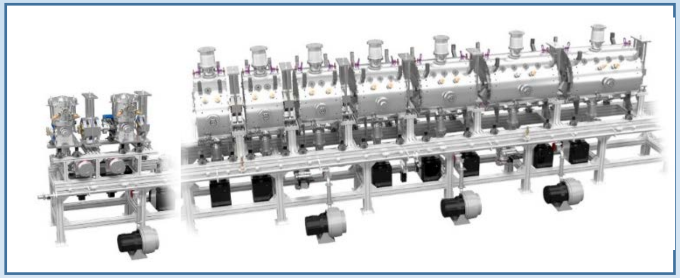


personal communication. By courtesy of SCK•CEN

Accelerator developments for Phase 1 (2018-2024)

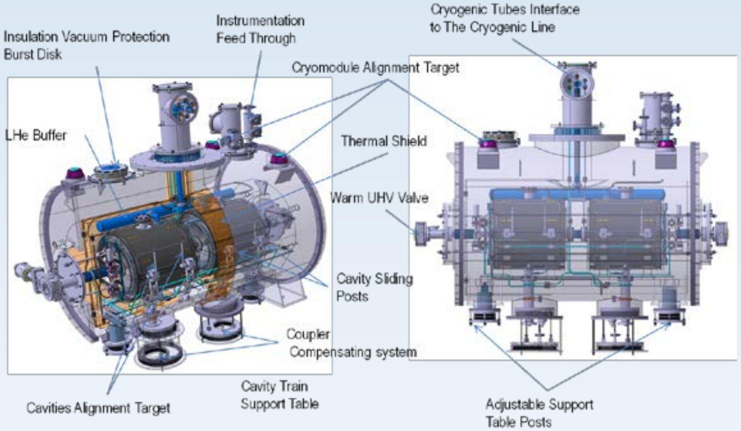
ECR source: Pantechnik
LEBT: coll. LPSC Grenoble, IPHC Strasbourg

RFQ: Designed by IAP Frankfurt, constructed by NTG



MEBT and CH: Bevatech GmbH (contract). Construction phase.

Single Spoke SC cavities: IPNO.
Collaboration agreement with French CNRS/IN2P3.
Prototyping phase near conclusion.
Required for MYRRHA Phase 1: 60



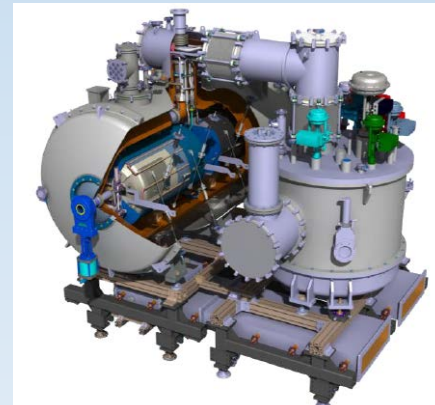
Single Spoke Cryomodule: Prototyping phase started for design validation and testing. Preparation phase of industrialisation / series production.
Required for MYRRHA Phase1 : 30

personal communication. By courtesy of SCK•CEN

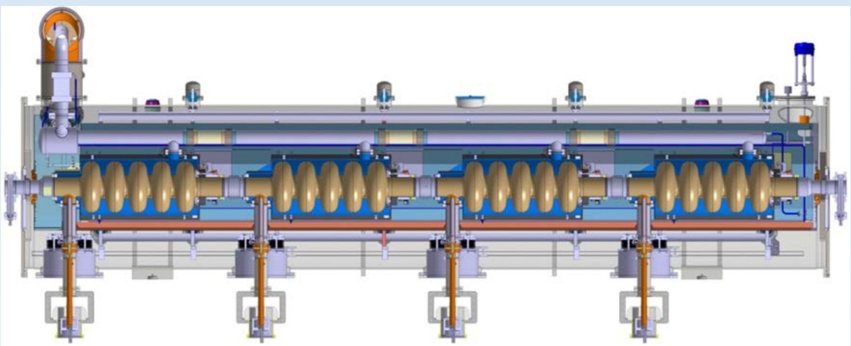
Accelerator development for Phase 2 (2020-2030)

Section from 100 MeV to 600 MeV: Superconducting RF structures based on ESS design experience (CEA Saclay, IPNO, INFN Milan)

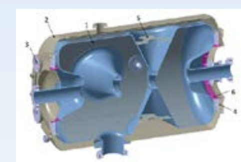
- Section 4, 100 – 200 MeV: either double spoke (352.2 MHz), or elliptical cavities (704.4MHz)
- Section 5, 200 – 600 MeV: elliptical cavities (704.4MHz). Required: 15 cryomodules, 60 cavities



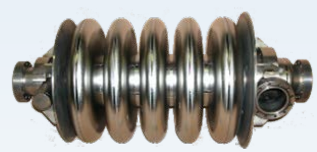
ESS β=0.5 Double Spoke cavity cryomodule



4-cavity cryomodule for β=0.7 elliptical cavities



ESS β=0.5 double Spoke cavity



β=0.5 elliptical cavity

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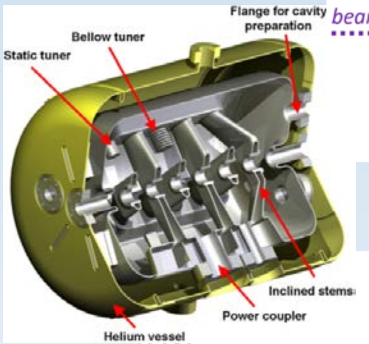
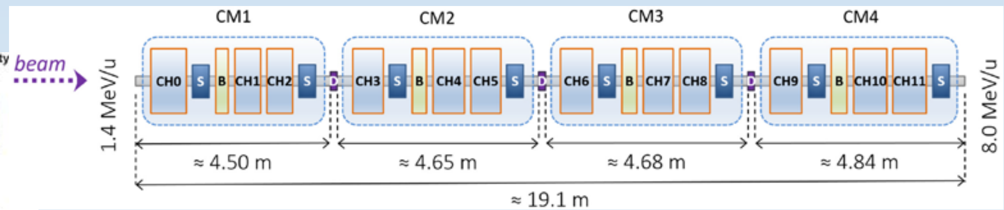
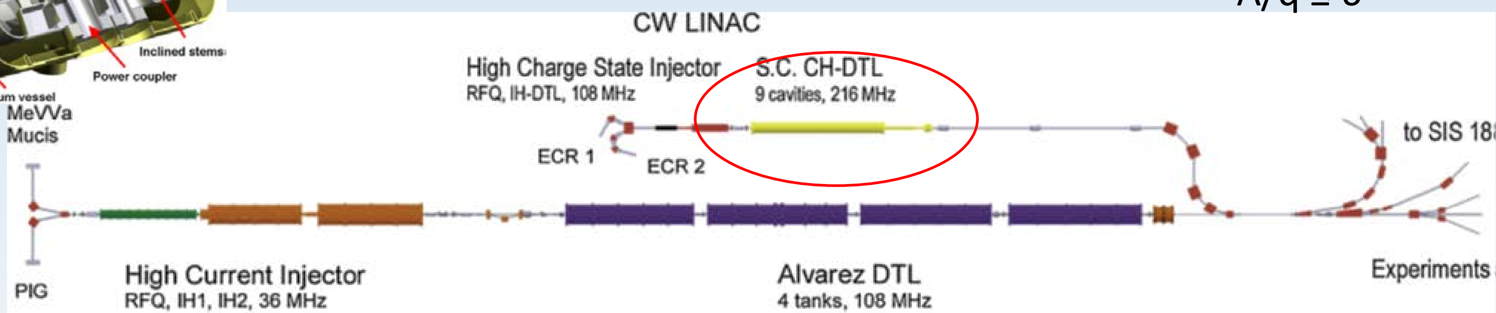
Other accelerator developments of interest for ISOL facilities: UNILAC upgrade at GSI





Win = 1.4 MeV/u)
Wout = 3.5–7.3 MeV/u
ΔWout = ±3 keV/u
I ≤ 1 mA
A/q ≤ 6



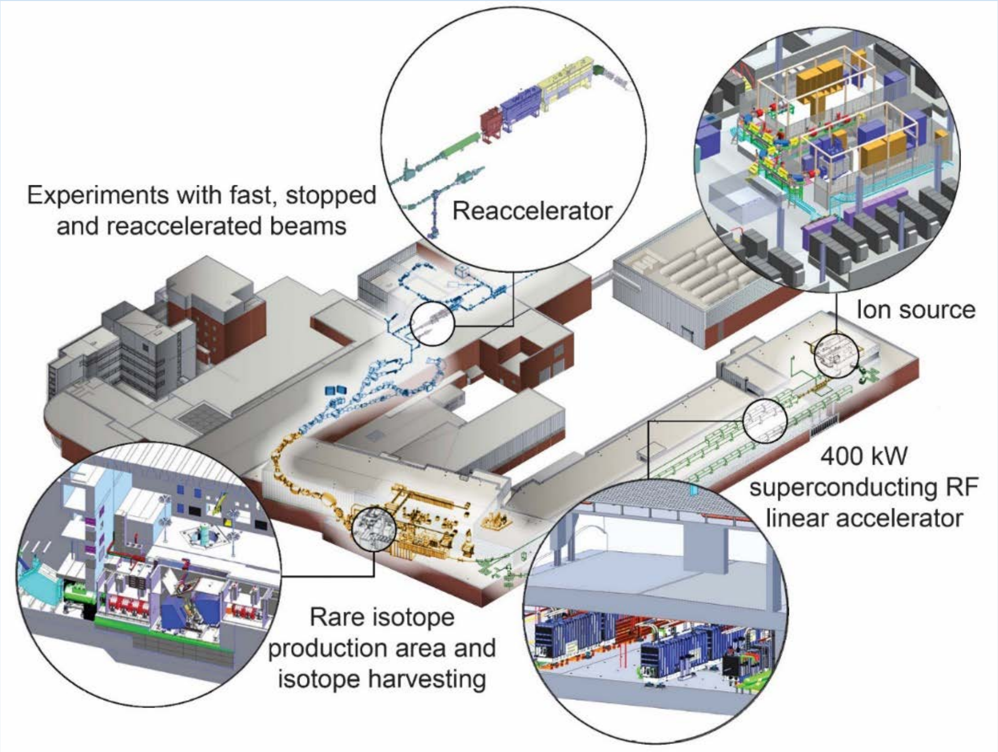
- SC linac based on CH cavities proposed to increase the HI beam intensity at GSI to 1 mA.
- 9 CH cavities working at 216 MHz + SC solenoids in 4 cryomodule
- Prototypes developed successfully exceeding 9 MV/m

Major accelerator development for RIB facilities outside Europe

- TRIUMF (ISOL operating; photo-fission under construction) - Canada
- MSU FRIB (IGISOL) under construction, operating in 2022 - USA
- RISP (ISOL; IGISOL) under construction – S. Korea

Noteworthy accelerator R&D in all of them, especially in Superconducting linac technology

The ”coming true dream” IGISOL facility: FRIB

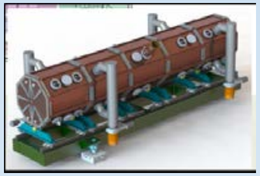


Not as powerful as the Great EURISOL, but soon becoming a reality

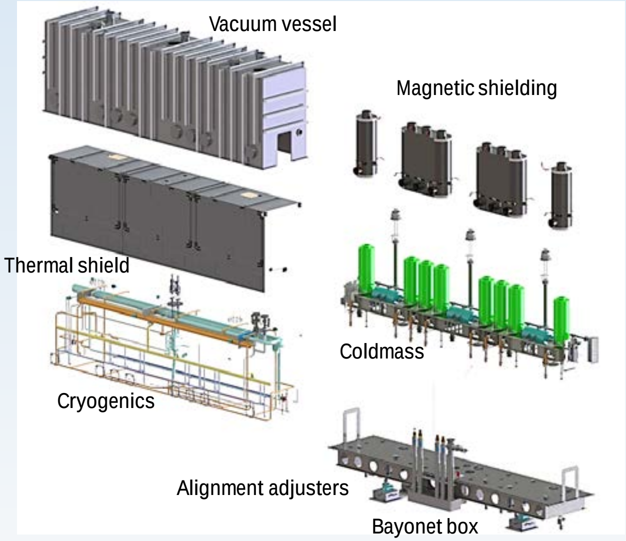
- High power ion SC linac driver (ready in 2019)
  - 330 SC cavities operating at 2K
  - **from *p* (600 MeV/u) to *U* (200 MeV/u)**
  - **0.5 mA, 400 kW**
- SC linac post-accelerator (under upgrade)
  - V_{eq}~60 MV, finely tunable
  - Operation at 4.5K
- 400 kW rotating target for in-flight RIB
- **In-flight and IGISOL (with 400kW ISOL target long term upgrade plan)**
- High beam quality of RIBs
- High beam current of RIBs
- Construction in an advanced stage, operating with RIBs in 2022

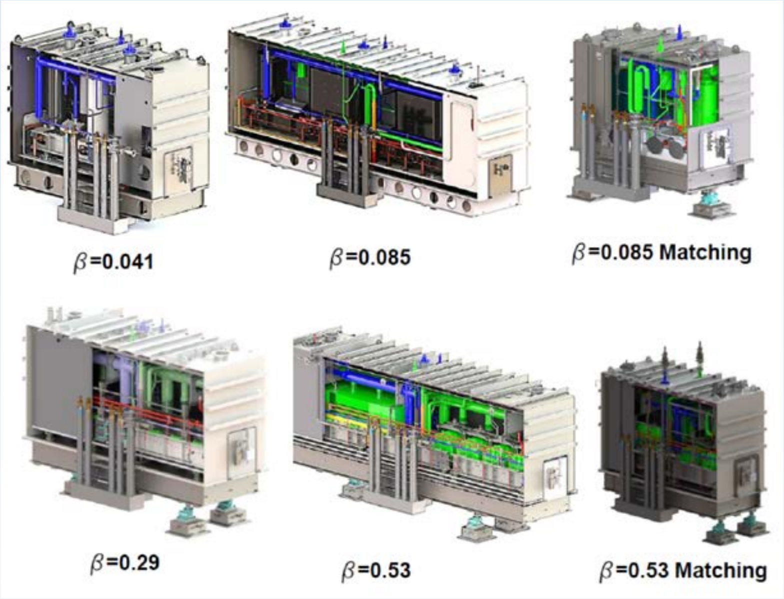
FRIB Accelerator R&D

- **SC linac technologies**: 2 QWR and 2 HWR types of bulk Nb resonators, and related cryomodules.
  - The large accelerator size, unique in low-β SC linacs worldwide, required new solutions for large industrial production and cost reduction.

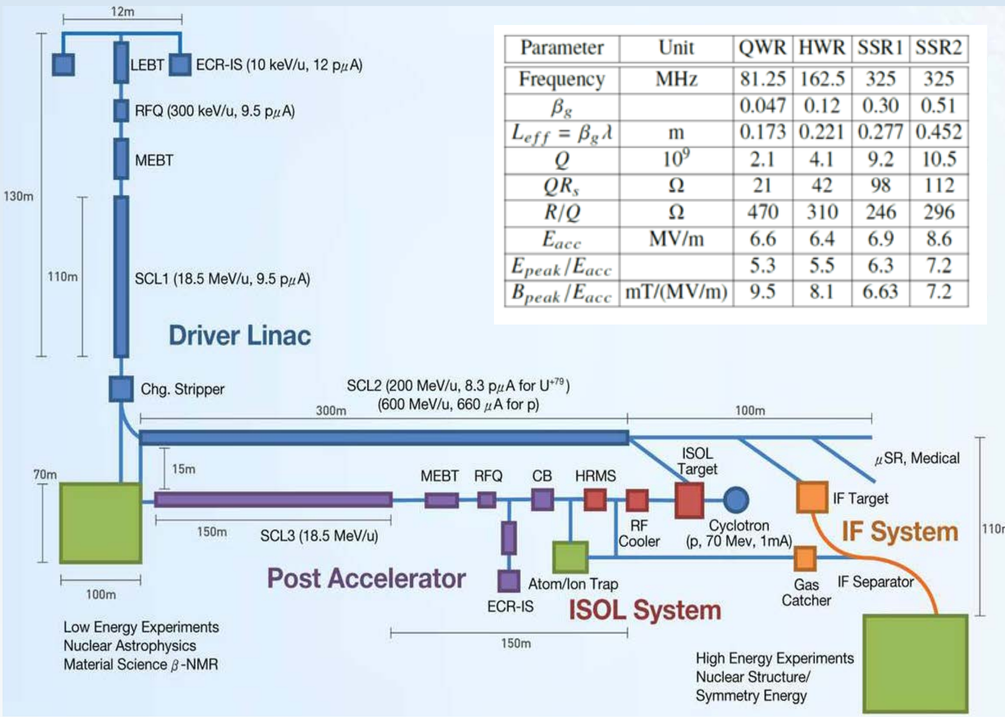


- **Heavy Ion RFQ** operating CW
- **Liquid Li stripper** for high current HI beam stripping at 20 MeV/u
- **Multi-charge beam transport** for high capture rate after ion source and stripper





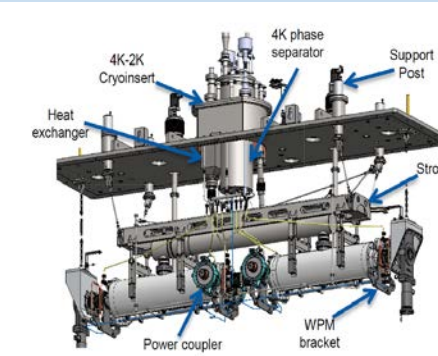
Accelerator developments at RISP RIB facility (Korea)



Parameter	Unit	QWR	HWR	SSR1	SSR2
Frequency	MHz	81.25	162.5	325	325
β_g		0.047	0.12	0.30	0.51
$L_{eff} = \beta_g \lambda$	m	0.173	0.221	0.277	0.452
Q	10^9	2.1	4.1	9.2	10.5
QR_s	Ω	21	42	98	112
R/Q	Ω	470	310	246	296
E_{acc}	MV/m	6.6	6.4	6.9	8.6
E_{peak}/E_{acc}		5.3	5.5	6.3	7.2
B_{peak}/E_{acc}	mT/(MV/m)	9.5	8.1	6.63	7.2

- RAON at RISP (Korea) HI SC linacs
  - RIB production: in-flight, ISOL
- very similar characteristics as for a combination of FRIB+SPES
- SC Linac Driver
  - **from *p* (600 MeV/u) to *U* (200 MeV/u)**
  - **Up to 400 kW HI beam power**
- Cyclotron driver: *p*, 70 MeV, 1 mA
- SC post-accelerator to ~20 MeV/u
- Huge R&D effort
- SC QWRs, HWRs and Single Spoke cavities and cryomodules prototyped
- The project was funded and it is now in its **initial construction phase**, with most of the accelerator components development completed

Accelerator developments at TRIUMF

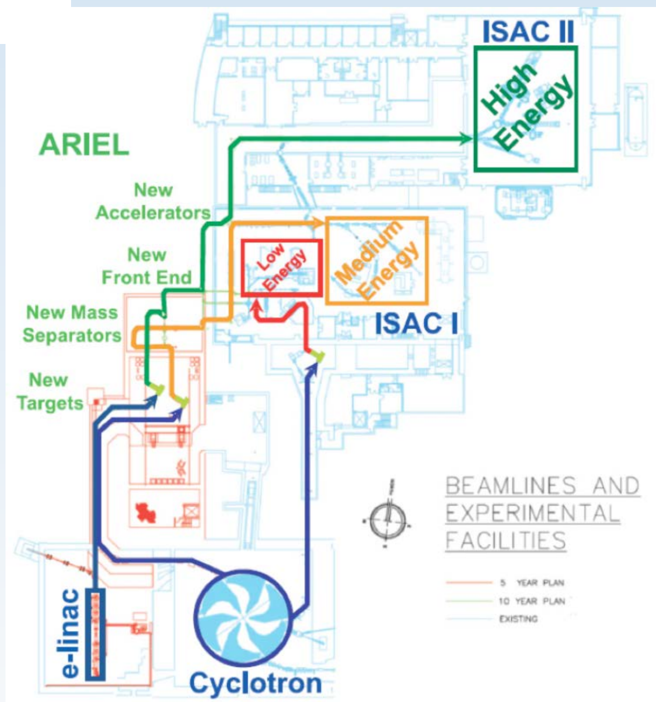


e-linac cryomodule

ISAC II cryomodule

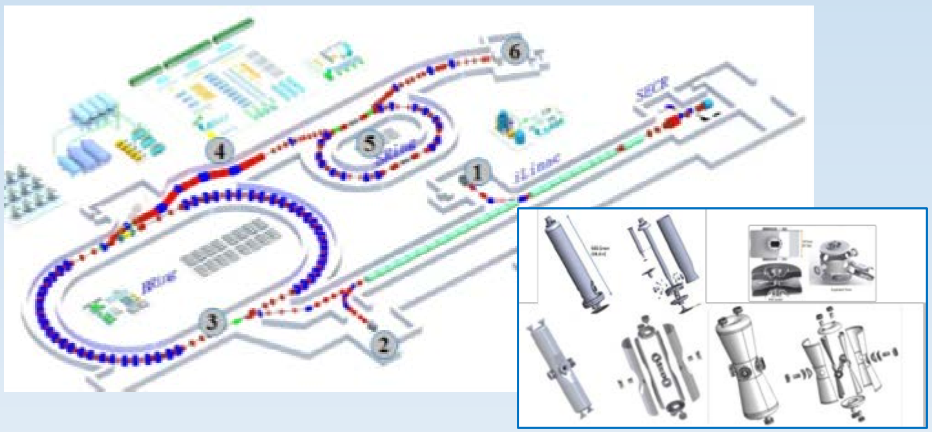
accelerating SRF cavity

deflecting SRF cavity

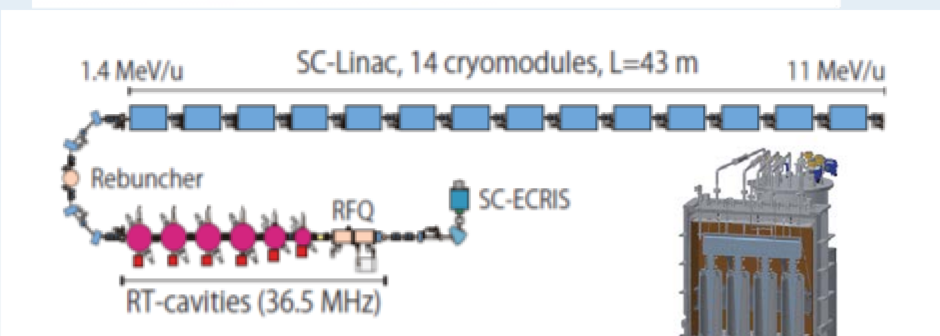


- TRIUMF is already a large ISOL RIB facility in operation
  - 500 MeV H^- cyclotron driver
  - 40 MV SC linac post-accelerator (ISAC II)
- **ARIEL: new ISOL facility based on photofission**
  - Complementary to the existing one
  - using the same post-accelerator
- New e-linac: final goal 50 MeV, 10 mA cw to reach 500 kW on target
- e-linac built up to 35 MeV, now under commissioning
- Beam on ARIEL RIB target planned in 2019
- ARIEL will further enrich the RIBs menu at TRIUMF

More accelerator developments of interest for ISOL facilities



The HIAF facility, 1st phase. 1) Nuclear structure spectrometer 2)Low energy irradiation target 3)Electron-ion recombination spectroscopy 4)RIBs beam line 5)High precision spectrometer ring 6) External target station.



SRILAC linac schematic layout.

ILINAC at HIAF ((High Intensity heavy-ion Accelerator Facility, China)

- New injector for synchrotron approved
- low-β SC HI linac: 120 MV, 120 kW, A/q≤7
- Construction of 100 SC cavities (QWR and HWR) and cryomodule prototypes started
- Start of operation for users is planned by 2023. HIAF shares the same SRF technology with the CADS project in China

SRILAC at RIKEN (Japan).

- SC low-β HI linac project at RIKEN to increase the primary Uranium beam intensity of the existing RIBF facility
  - New injector for a chain of three cyclotrons in cascade
  - all beam masses to 11 MeV/u with a maximum output beam power of 75 kW
- R&D and prototyping of SC QWR cavities and cryomodules ongoing

Summary and conclusions

- Impressive flowering of RIB facilities worldwide triggering new accelerator R&D
- Competition among RIB facilities is giving good fruits in the field of accelerators, especially in Superconducting low-β linacs
- EURISOL DF partner laboratories contributing significantly with new accelerators and facility upgrades
- Ambitious, large scale RIB projects in ASIA and North America are under construction to become operational in the next decade

…challenging EU labs: stay tuned!

Thank you