The Electron-Ion Collider (EIC)

and the ePIC experiment

S. Dalla Torre
INFN - TRIESTE

OUTLOOK

- **The EIC project**
- **The EIC scientific scope**
- **The Collider**
- **ePIC – The project detector**

BREAKING NEWS, January 2020

Department of Energy

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will smash electrons into protons and heavier atomic nuclei in an effort to penetrate the mysteries of the "strong force" that binds the atomic nucleus together.

Secretary Brouillette approved Critical Decision-0, "Approve Mission Need," for the EIC on December 19, 2019.

https://www.energy.gov/articles/us-department-energy-selects-brookhaven-national-laboratory-host-major-new-nuclear-physics

BREAKING NEWS, January 2020

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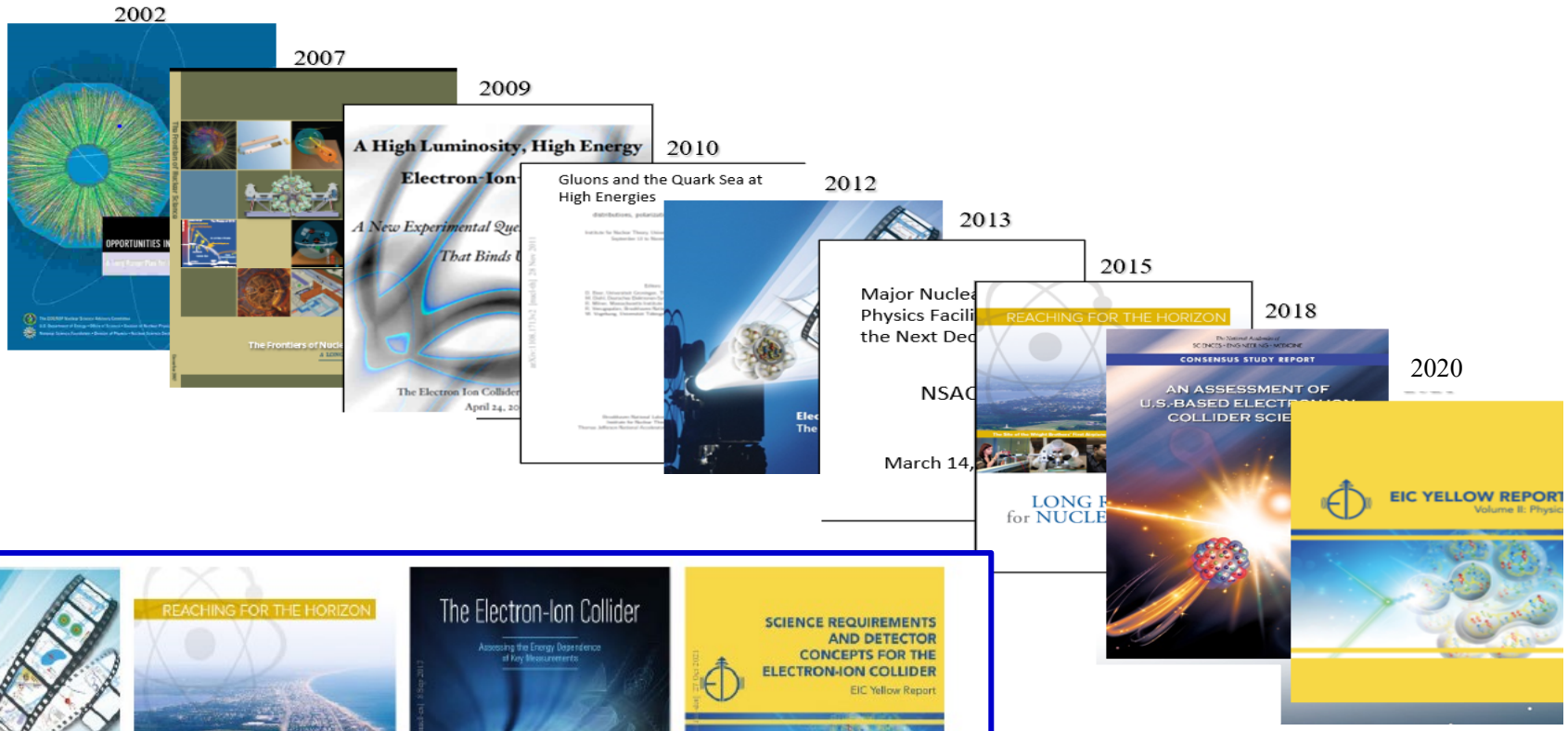
THE PATH TO THE EIC PROJECT



NAS report

EIC projet is compelling, fundamental and timely

THE INTERNATIONAL COMMUNITY

The EIC User Group:
https://eicug.github.io/

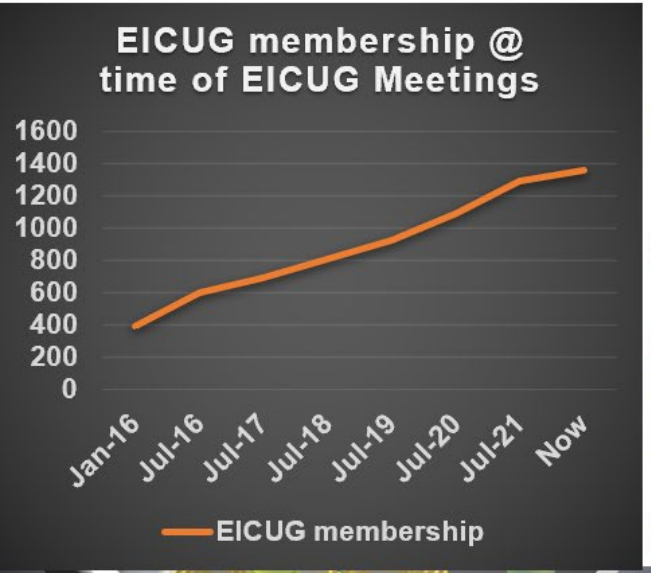
Formed 2016 –

- **1383 members**
- **36 countries**
- **274 institutions**

As of May 31, 2023

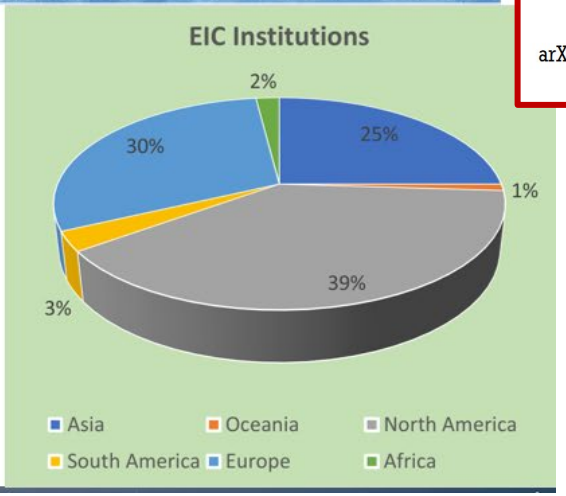
Strong and Growing International Participation.

Among the main Achievements: The Yellow Report

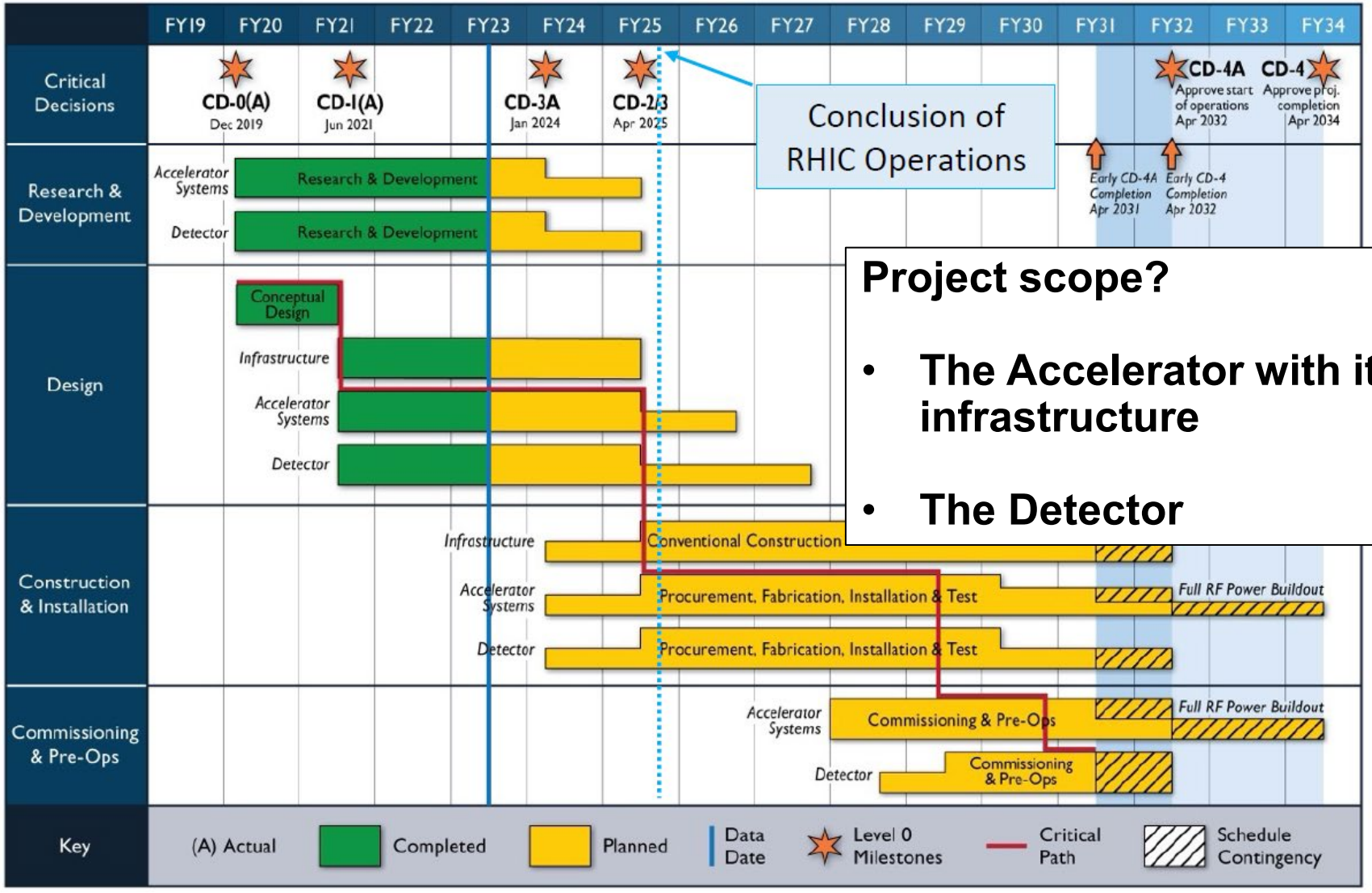


Annual EICUG meeting

2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 CUA, Washington, DC
2019 Paris, France
2020 Miami, FL
2021 VUU, VA & UCR, CA
2022 Stony Brook U, NY
2023 Warsaw, Poland



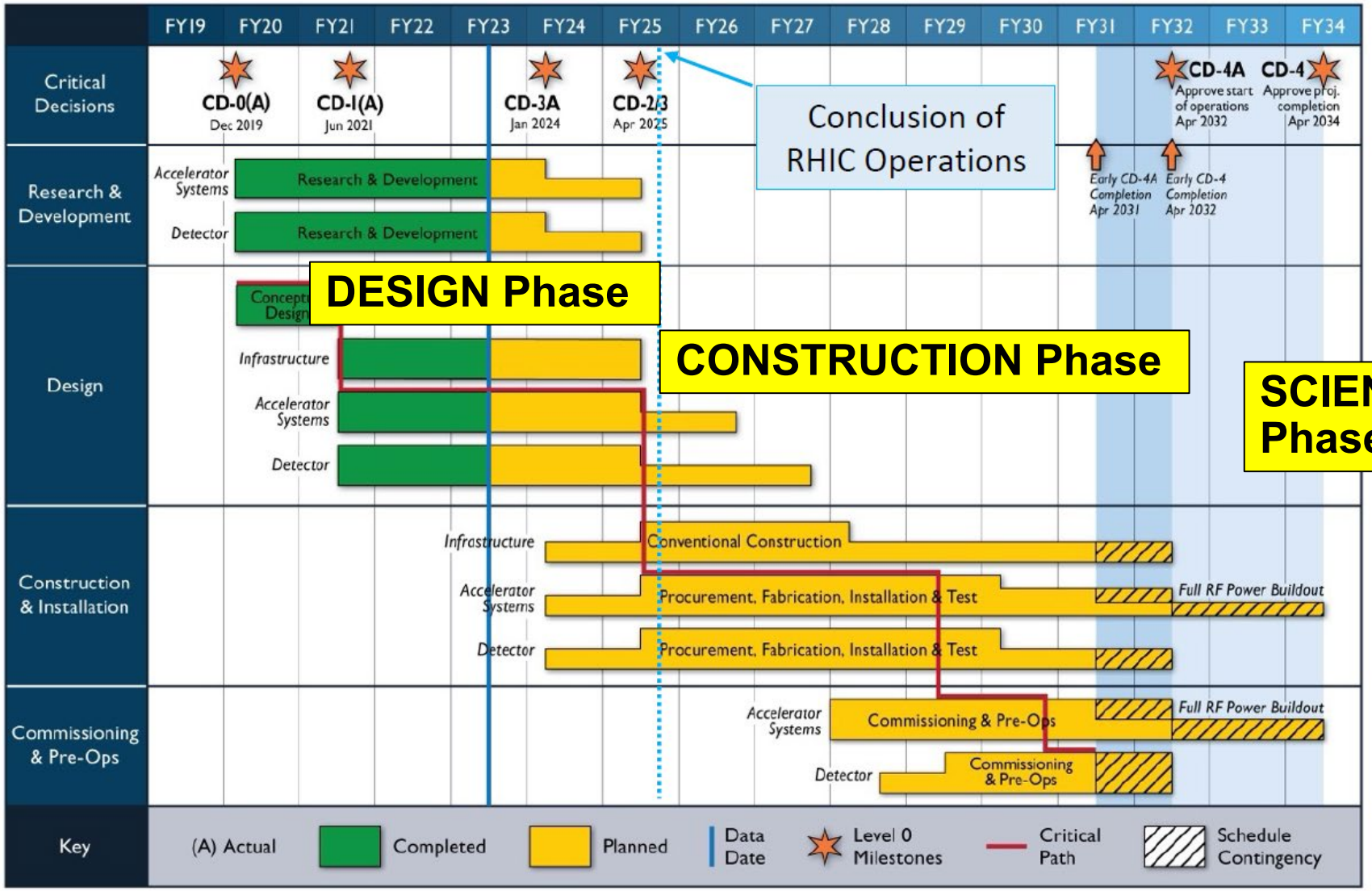
The EIC schedule



Project scope?

- **The Accelerator with its infrastructure**
- **The Detector**

The EIC schedule



OUTLOOK

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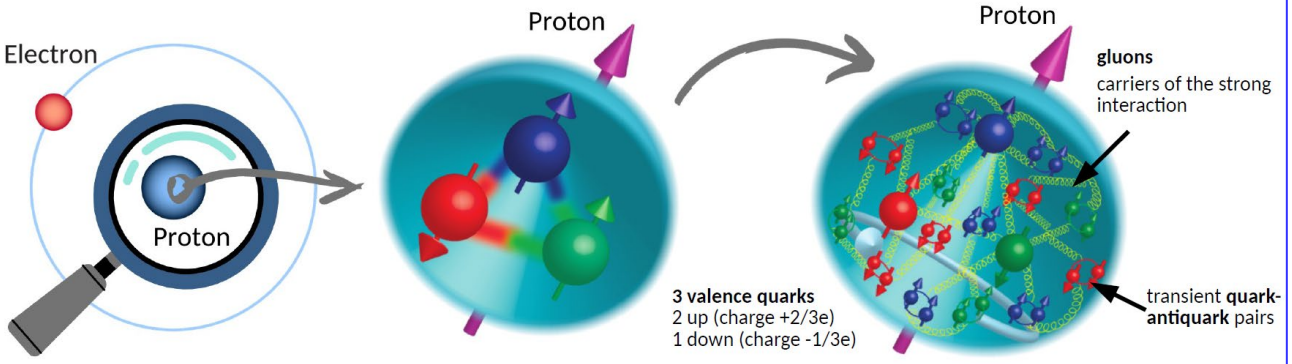
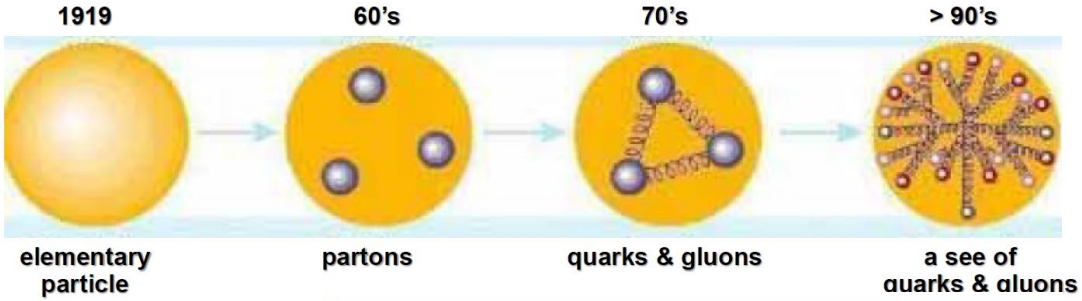
- **ePIC – The project detector**

THE SCIENTIFIC SCOPE

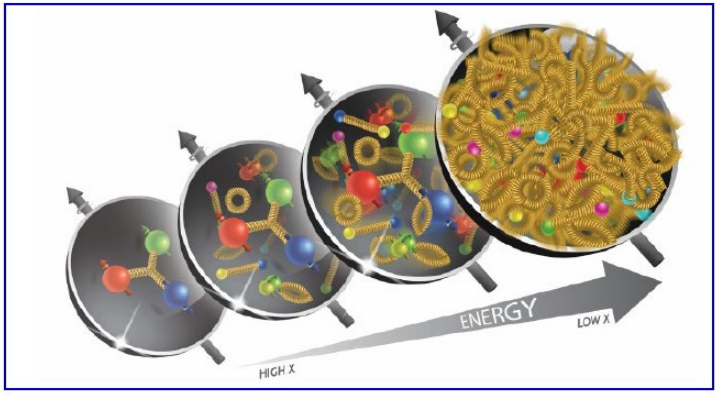
The Evolving Understanding of the Structure of the Nucleon





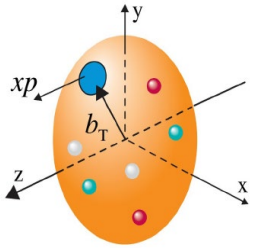
An evolution that has required time and increasing "microscope" energies
The golden microscope is DIS:

$$e + p \rightarrow e' + X$$



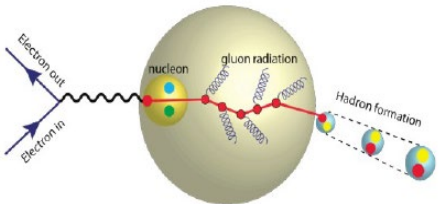
THE SCIENTIFIC SCOPE

The physics quest for the EIC ↔ the QCD open questions



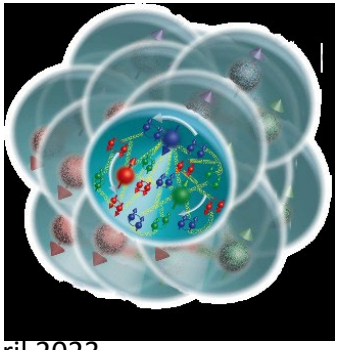
- How do the **nucleon properties like mass and spin emerge** from them and their interactions?

- How are the **quarks and gluons**, and their spins, **distributed in space and momentum** inside the nucleon?



- In what manner do **color-charged quarks and gluons**, along with **colorless jets, interact with the nuclear medium**? And how do the **confined hadronic states** emerge from these quarks and gluons?

- What is the mechanism through which quark-gluon interactions give rise to **nuclear binding**?



- What impact does a **high-density nuclear environment** have on the **interactions, correlations, and behaviors of quarks and gluons**?

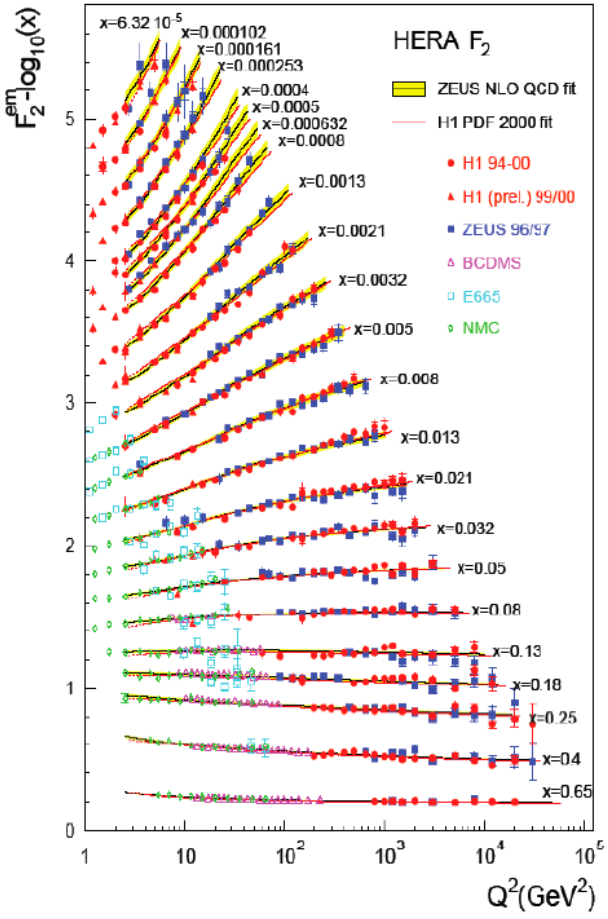
- Is there a **saturation point** for the density of gluons in nuclei at high energies, and does this lead to the **formation of gluonic matter** with universal properties across all nuclei, including the proton?

Maria Żurek, EIC RRB, April 2023

THE SCIENTIFIC SCOPE

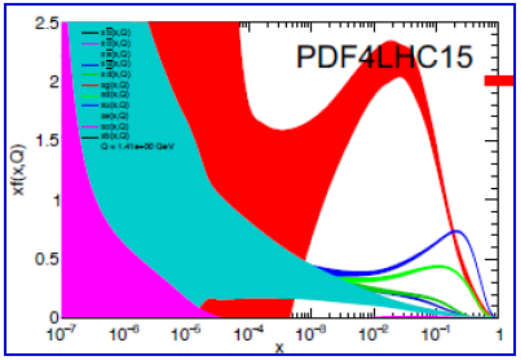
Exploring new territories

$F_2(x, Q^2)$ largely studied

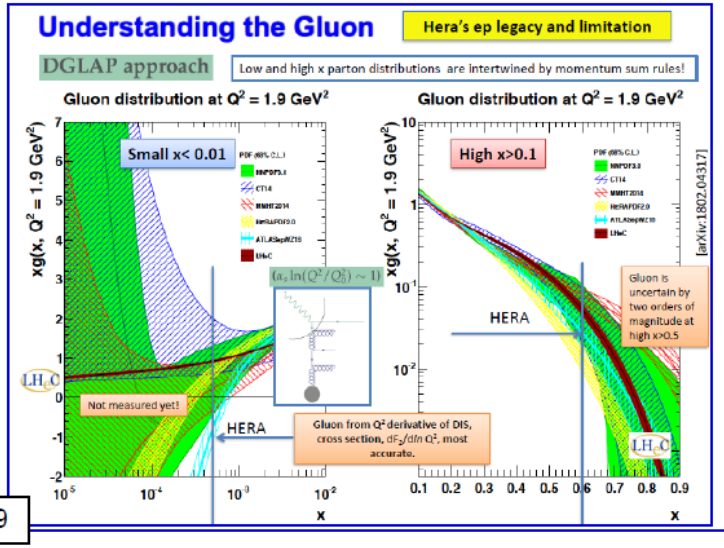


Nevertheless, specific kinematic regions not deeply explored

Quark distribution functions functions poorly known at very small x



Gluon distribution Functions need further exploration at small and large x



C. Gwenlan, DIS2019

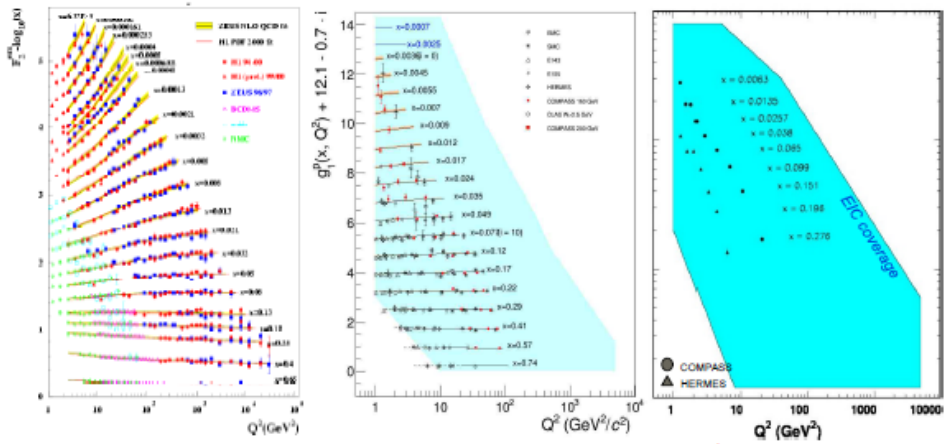
THE SCIENTIFIC SCOPE

TMDs and SPIN

The 8 leading-twist quark TMD PDF

TMD - Transverse-Momentum–Dependent

N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1 $h_{1T}^\perp$



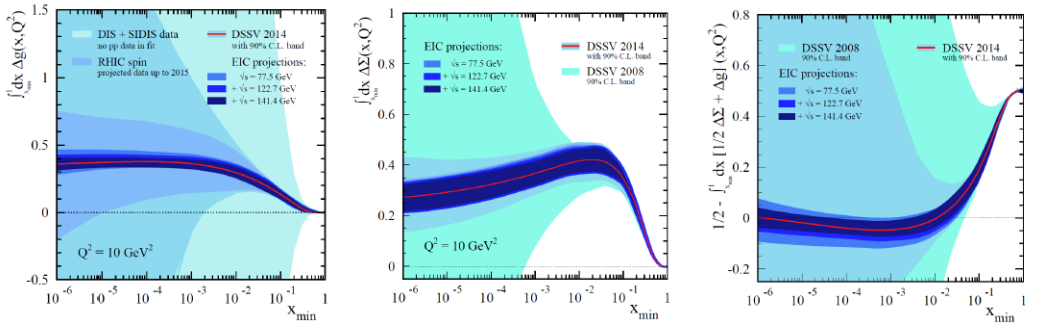
momentum | spin | transverse spin ~ angular momentum

A. Bressan, "Prospettive per fisica adronica e collisionatori adronici"

A. Bressan, "Prospettive per fisica adronica e collisionatori adronici"

What do we know:

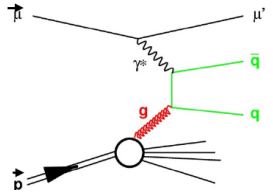
$$\frac{1}{2}\hbar = \left\langle P,\frac{1}{2}\left|J^z_{QCD}\right|P,\frac{1}{2}\right\rangle = \overbrace{\frac{1}{2}\int_0^1 dx\Delta\Sigma(x,Q^2)}^{\text{total quark spin}} + \overbrace{\int_0^1 dx\Delta G(x,Q^2)}^{\text{gluon spin}} + \overbrace{\int_0^1 dx\left(\sum_q L^z_q + L^z_g\right)}^{\text{angular momentum}}$$



1/2 - Gluon $_{40\%}$ - Quarks $_{30\%}$ = orbital angular momentum

- **Gluon contribution needs a deeper exploration**

Photon Gluon Fusion: $\gamma g \rightarrow q\bar{q}$



High p_T hadron pair $q\bar{q}$ -> hh

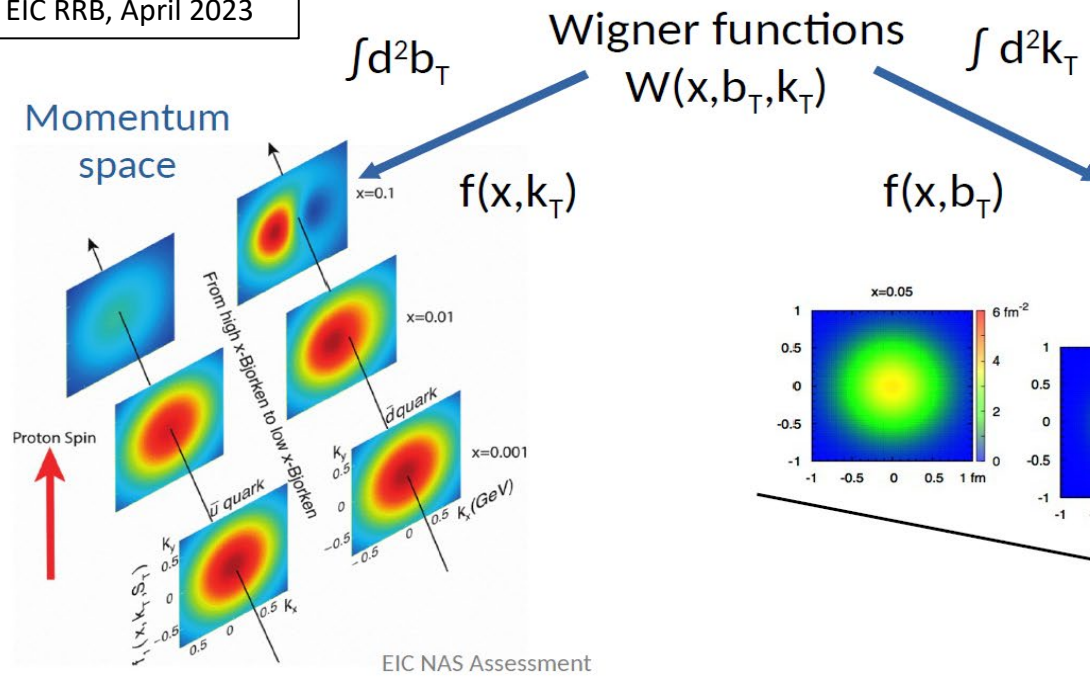
of course, by a SI-DIS measurement

- **Orbital momentum to be extracted from TMDs**

THE SCIENTIFIC SCOPE

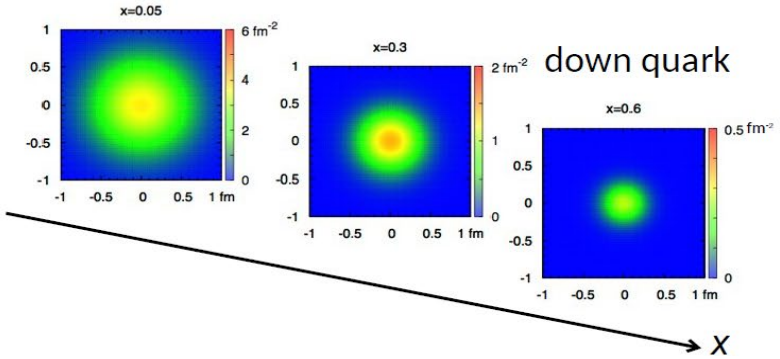
Spatial and Momentun structure of the N in 3D

Maria Żurek, EIC RRB, April 2023



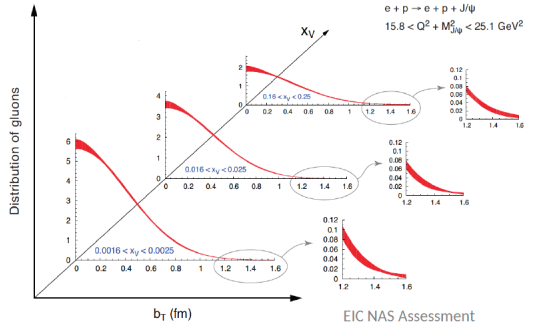
COORDINATE SPACE

Spin-dependent 2+1D coordinates space images from exclusive scattering



Nucleon tomography

- Deeply Virtual Photon scattering – real photon is produced
- Deeply Virtual Meson production – quark-antiquark bound state is produced



MOMENTUM SPACE

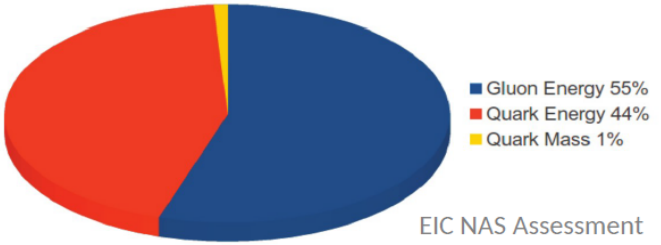
Access to spin-orbit correlation (TMDs) via SIDIS

THE SCIENTIFIC SCOPE

HOW DO NUCLEONS ACQUIRE MASS ?

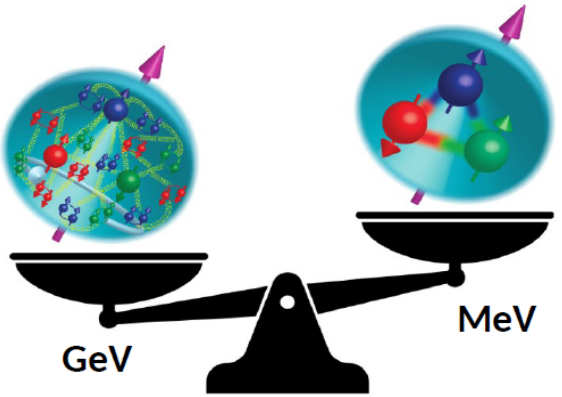
- **Gluons have no mass** and **quarks are nearly massless**, but nucleons and nuclei are heavy, making up most of the visible mass of the universe
- Visible world mostly made out of light quarks: **masses emerge form quark-gluon interactions**

Contributions to the total mass of the nucleon



EIC NAS Assessment

Proton (valence content *uud*) - mass ~940 MeV
- The mass is dominated by the energy of the highly relativistic gluonic fields
- EIC will allow determination of an important term contributing to the proton mass, the so-called "QCD trace anomaly" → accessible in exclusive reactions



What about the mass of light mesons?

Pions (valence content *ud*) mass ~140 MeV
- Cleanest expression of the emergent mechanism
- Empty or full of gluons?

Kaons (valence content *us* – strange content!) mass ~ 490 MeV
- Probing boundary between emergent and Higgs-mass mechanisms
- More or less gluons than in pion?

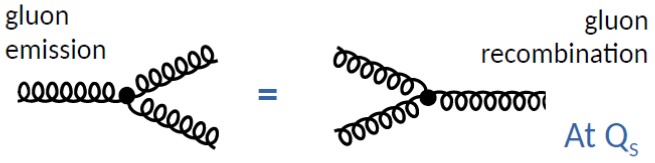
Maria Żurek, EIC RRB, April 2023

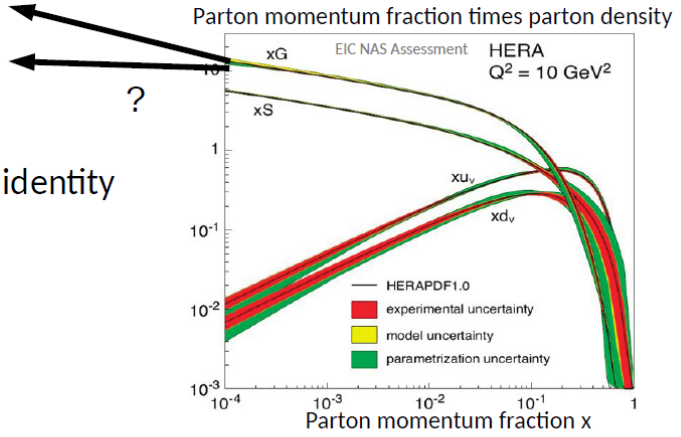
THE SCIENTIFIC SCOPE

ACCESS TO A NEW STATE OF THE GLUONIC MATTER

What happens to the gluon density in nuclei?

- Number of gluon **grows in the low-x limit**
- At some point the **density becomes so large** that gluons lose their individual identity and are **strongly overlapping**

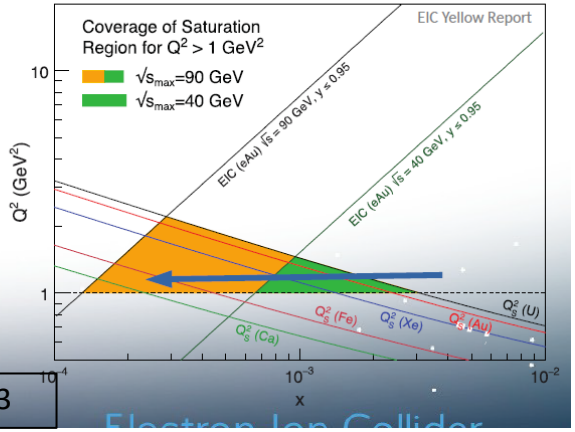




Q_s - resolution scale at which the number density so large that gluons are no longer independent → **saturated gluon matter**

EIC provides a unique opportunity to have very high gluon densities
electron – heavy nuclei (e.g., Pb) collisions
Combined with an unambiguous observables, e.g., **di-jets in ep and eA, diffractive processes**

EIC will allow to unambiguously map the transition from a non-saturated to saturated regime



Maria Żurek, EIC RRB, April 2023

OUTLOOK

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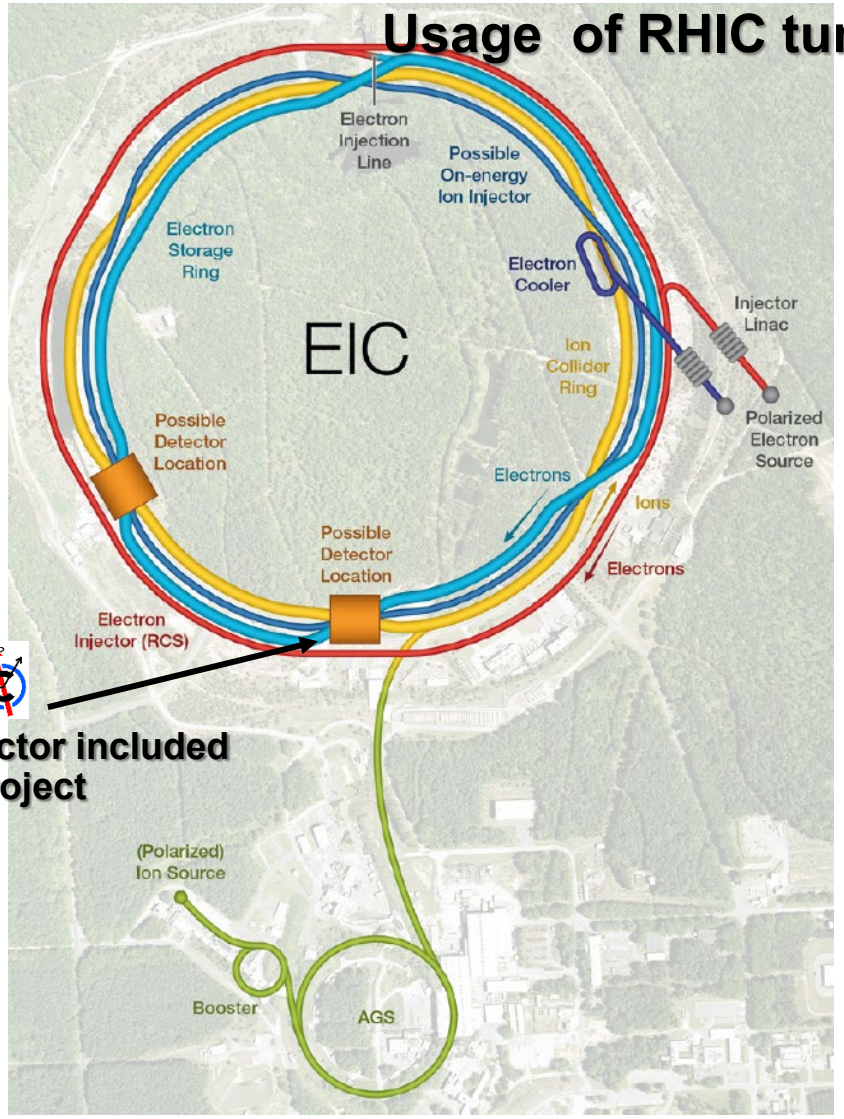
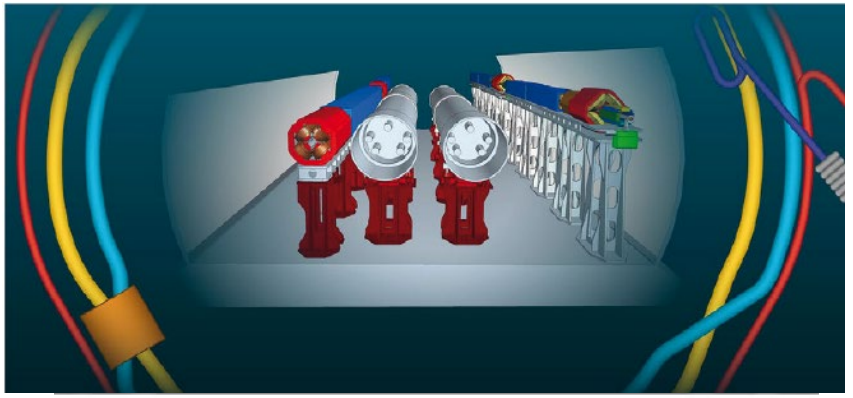
- **The Collider**
- **ePIC – The project detector**

The EIC Collider

Usage of RHIC tunnel and RHIC p/ion complex



IP6 detector included in the project



- spanning a wide kinematical range
  - **ECM: 20 – 141 GeV**
- High luminosity
  - up to 10^{34} cm^{-2} s^{-1}
- **highly polarized e (~ 70%) beams**
- highly polarized light A (~70%) beams
- wide variety of ions: **from H to U**
- **Number of interaction regions: up to 2**

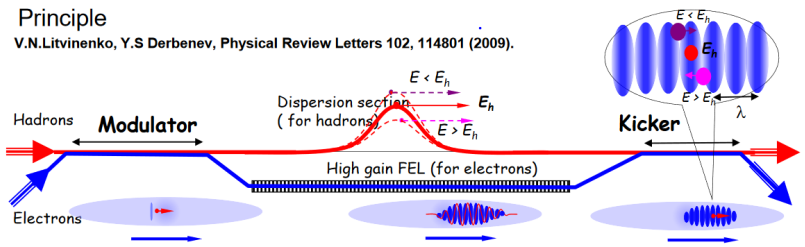
The EIC Collider

3 critical ingredients for HIGH LUMINOSITY

Coherent Cooling with FEL amplifier

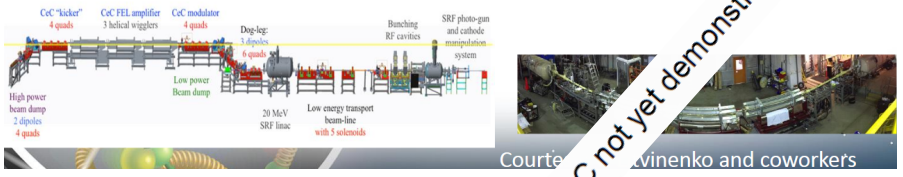
Principle

V.N.Litvinenko, Y.S Derbenev, Physical Review Letters 102, 114801 (2009).



➔ cooling of high energy Hadron beams with high band-width; BW: **1THz**
short cooling times to balance strong **IBS**

Proof of Principle Experiment at BNL, ongoing



CeC not yet demonstrated

Courte… …vinenko and coworkers

Bunches and beam crossing rates

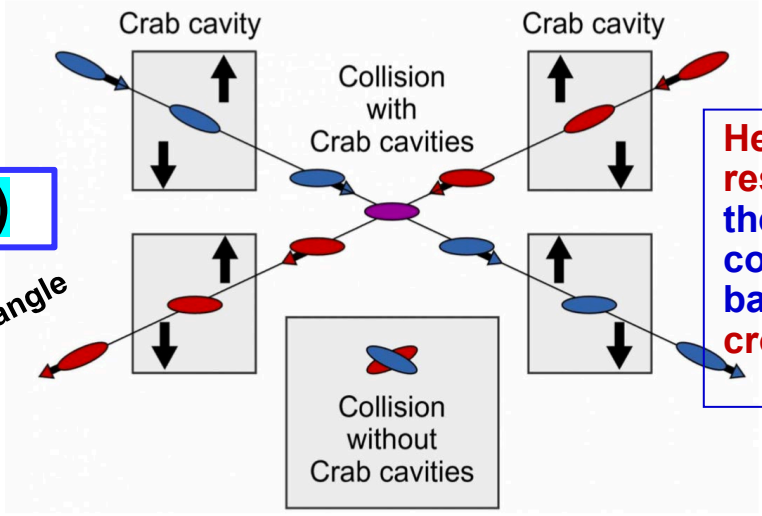
Species	p	e	p	e	p	e	p	e	p	e
Beam energy [GeV]	275	18	275	10	100	10	100	5	41	5
$\sqrt{s}$ [GeV]	140.7		104.9		63.2		44.7		28.6	
No. of bunches	290		1160		1160		1160		1160	
Species	Au	e	Au	e	Au	e	Au	e		
Beam energy [GeV]	110	18	110	10	110	5	41	5		
$\sqrt{s}$ [GeV]	89.0		66.3		46.9		28.6			
No. of bunches	290		1160		1160		1160			

Up to a beam crossing rate at the IR every 10ns

a challenge for the collider and the experiment !

CRAB CROSSING ANGLE (25 mrad)

For the first time a sizable crab crossing angle



Head-on collision is restored by rotating the bunches before colliding and, then, back ("crab crossing")

The EIC Collider

MORE unique aspects

BEAM POLARIZATION

ION SPECIES

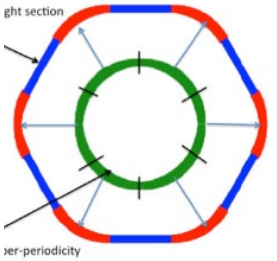
The existing RHIC ion sources & ion acceleration chain provides already **today** all ions needed at EIC

Enormous versatility! is a unique capability!

Ion Pairs in the RHIC Complex

Zr-Zr, Ru-Ru	(2018)
Au-Au	(2016)
d-Au	(2016)
p-Al	(2015)
h-Au	(2015)
p-Au	(2015)
Cu-Au	(2012)
U-U	(2012)
Cu-Cu	(2012)
D-Au	(2008)
Cu-Cu	(2005)

ABOUT e POLARIZATION



➔ resonance free acceleration up >18 GeV

on average, every bunch refilled in 2.2 min

ABOUT p/ light ion POLARIZATION

presently

Measured RHIC Results:

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

empowerment

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

High polarization ^{3}He and D beams also possible

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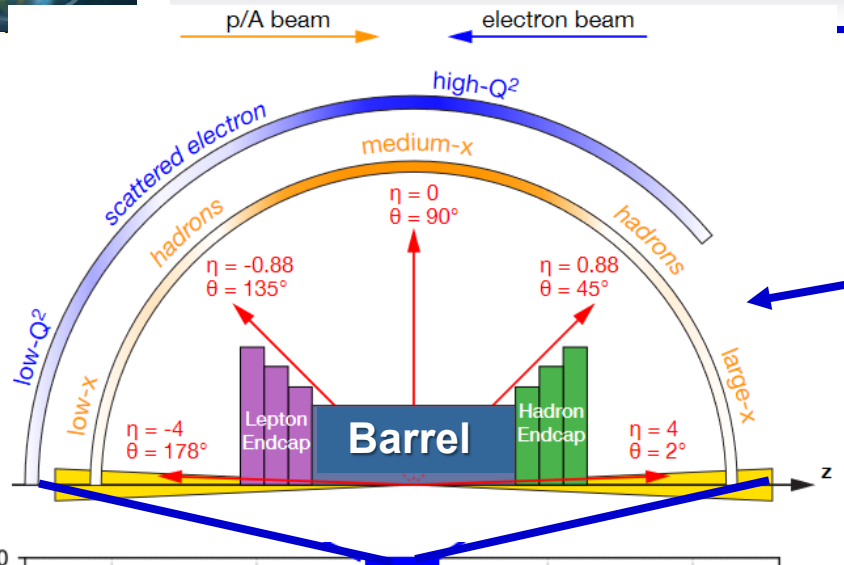
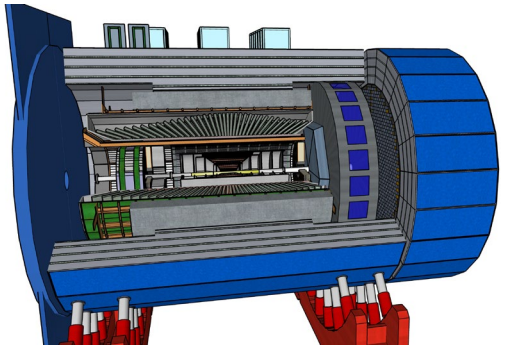
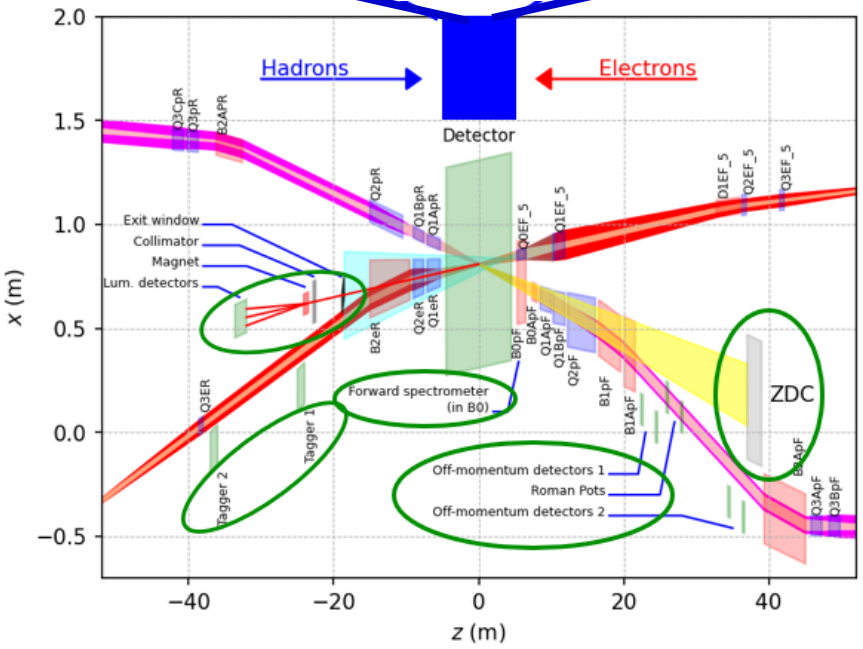
THE COMPLETE ePIC DETECTOR





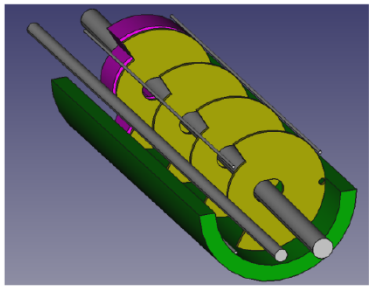
Central Detector (CD)



Total size detector: ~75m
Central detector: ~10m
Backward electron detection: ~35m
Forward hadron spectrometer: ~40m

Auxiliary detectors needed to tag particles with very small scattering angles both in the outgoing lepton and hadron beam direction (B0-Taggers, Off-momentum taggers, Roman Pots, Zero-degree Calorimeter and low Q2-tagger).

Far forward and backward



B0 Trackers + Calorimeter

Roman Pots

ZDC

Hadron Beam after IP

Off Momentum

B1apf Dipole

B1pf Dipole

Q2bpf quadrupole

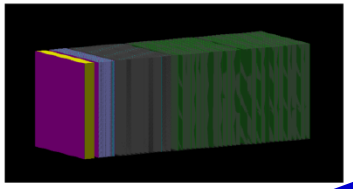
Q1pf quadrupole

Q1apf quadrupole

B0apf Diople

B0pf Diople

ZDC



Far Forward

Far Backward

Figure: Low-Q^2 taggers

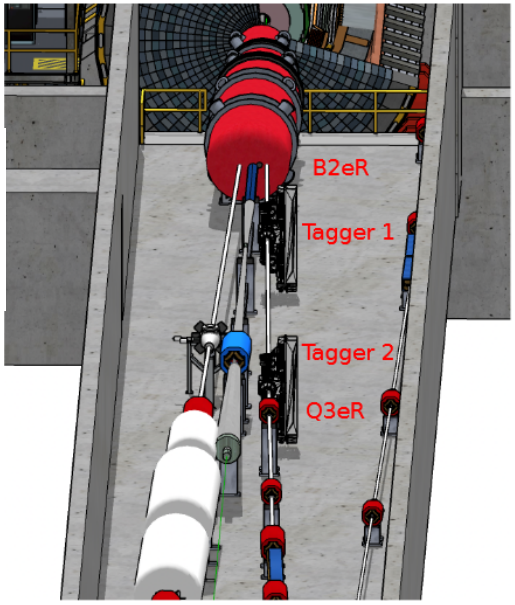
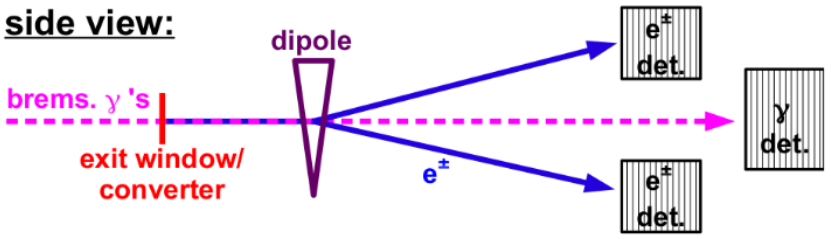
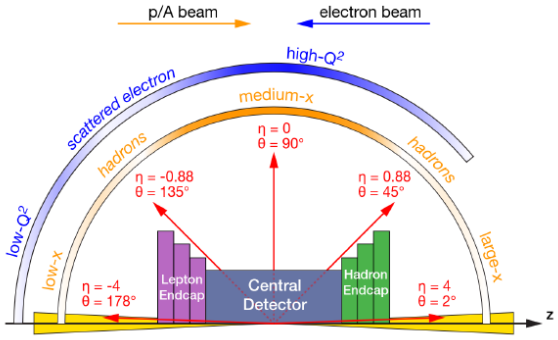


Figure: Luminosity detector



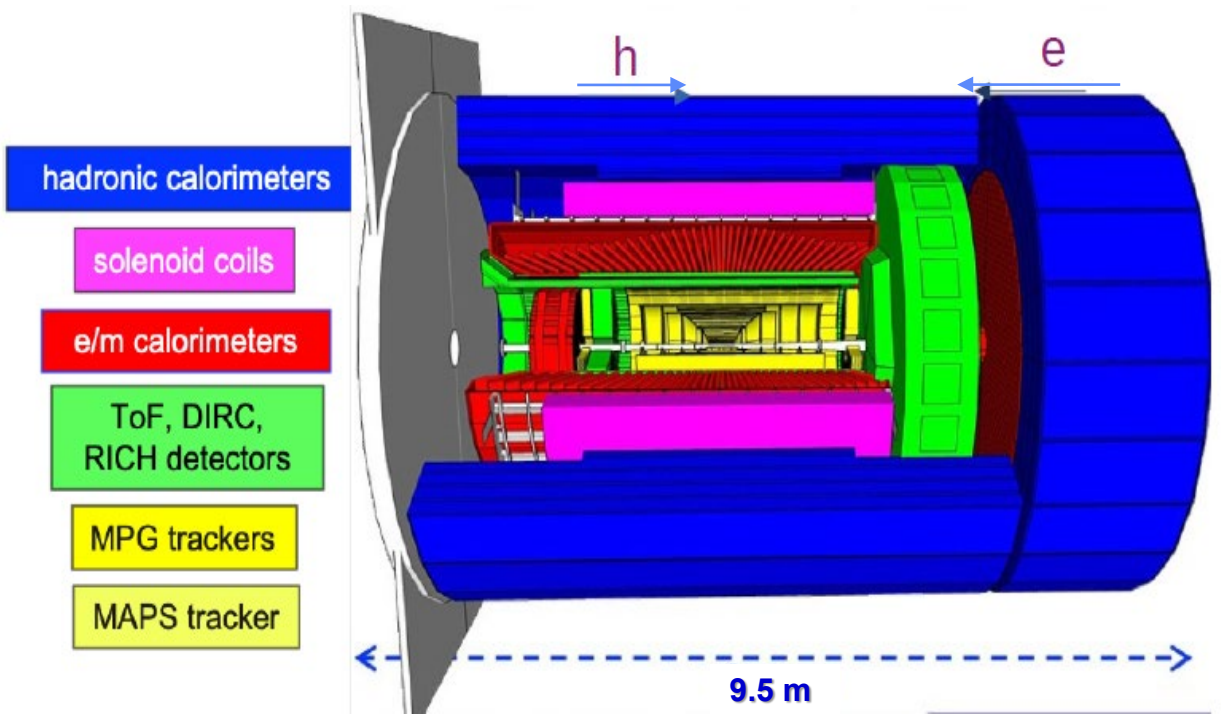
ePIC Central Detector



Very naturally formed by:

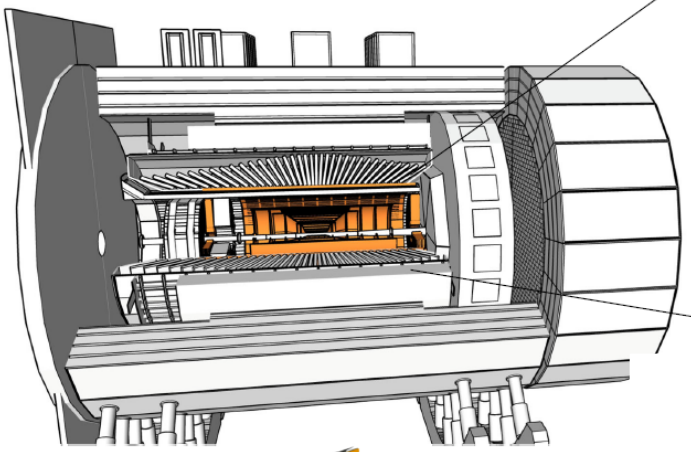
- **Backward endcap**
- **Barrel**
- **Forward endcap**

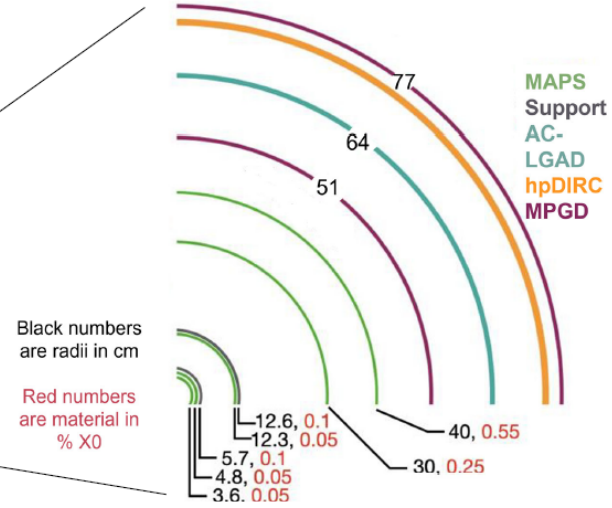
components



TRACKING IN ePIC CD

Tracking

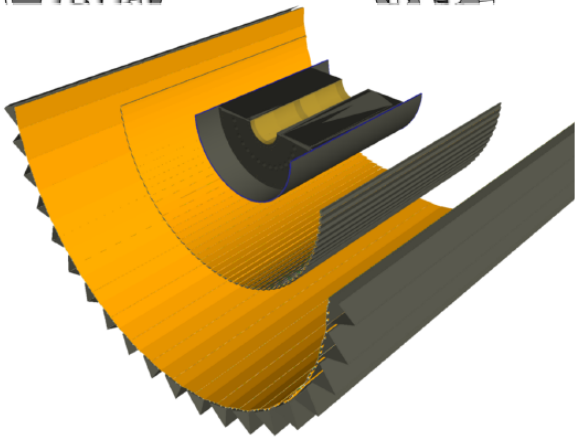


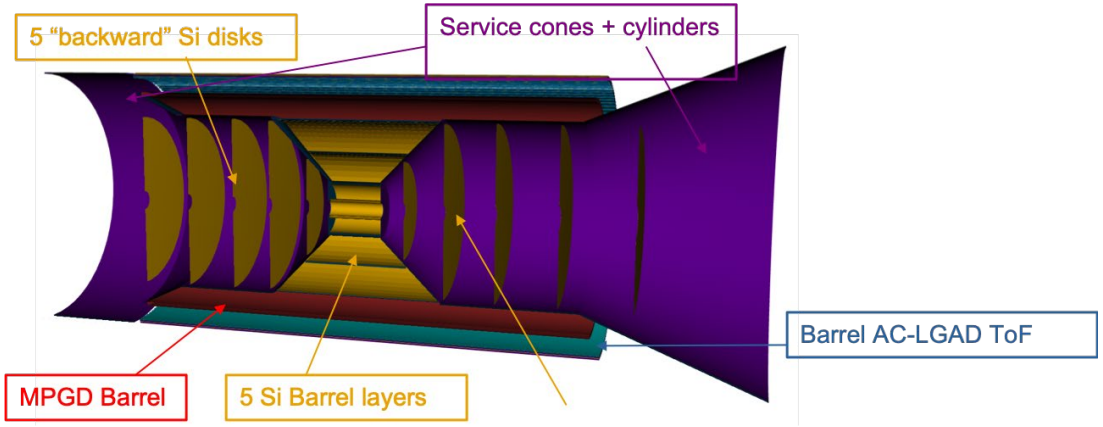


Si trackers based on ALICE ITS3 65 nm MAPS sensors

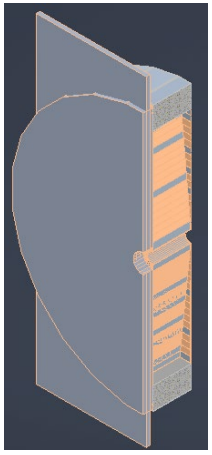
Five (six) layers in the barrel in backward (forward)

Supplemented by MPGD trackers



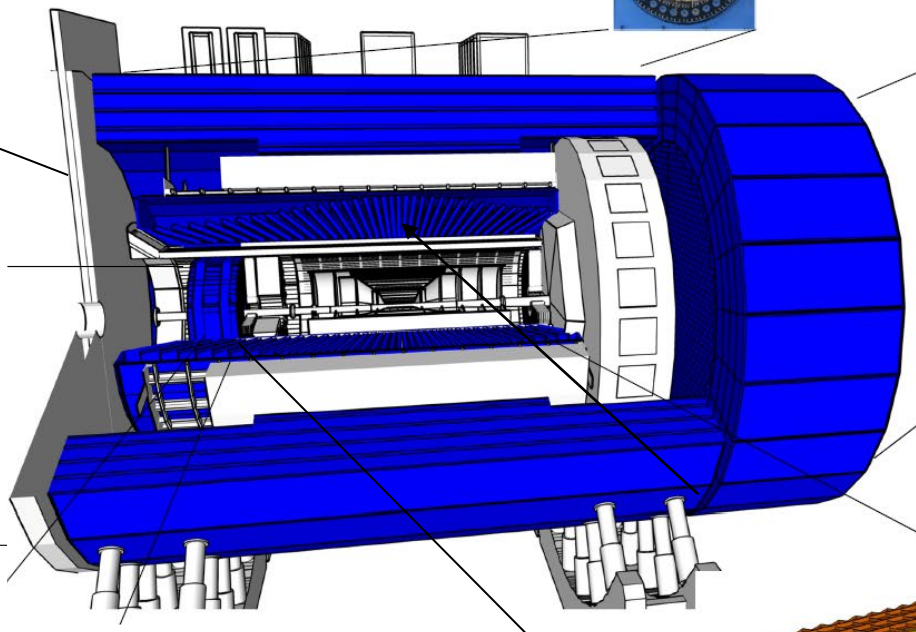


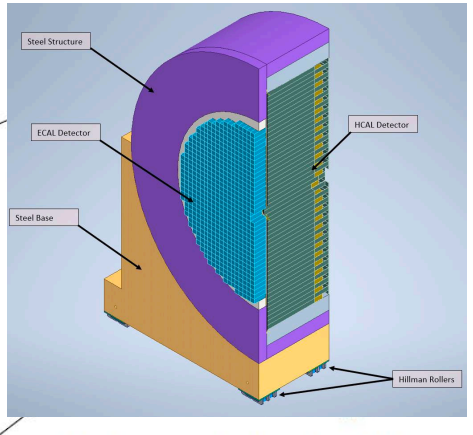
CALORIMETRY IN ePIC CD



Backwards HCal
Steel/Sc Sandwich
tail catcher

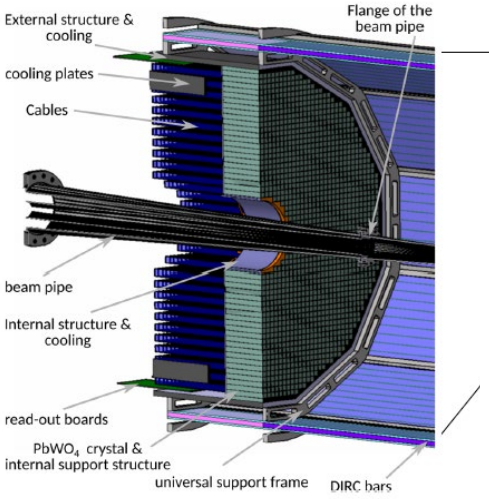
Barrel HCAL
(sPHENIX re-use)

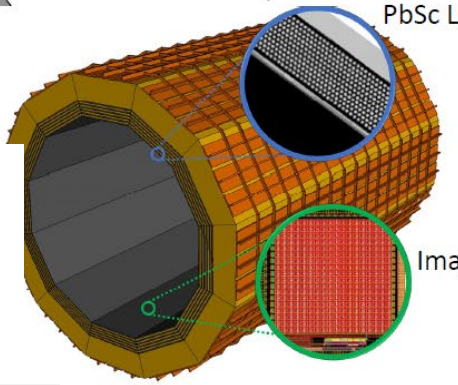




High granularity shashlik
W/SciFi EMCal
Longitudinally separated
HCAL with high-η insert
Steel/Sc & W/Sc sandwich

Backwards EMCal
PbW04 crystals





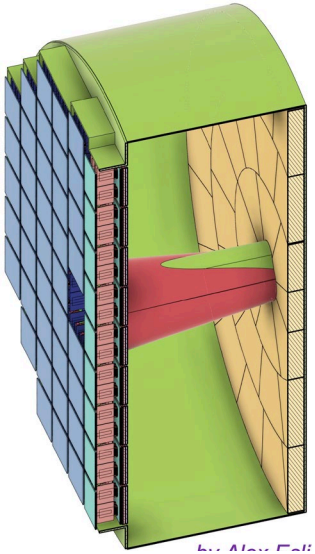
4 (6) layers of imaging calorimetry by Astropix MAPS, and sampling calorimetry by Pb/SciFi

SiPMs of all Calorimeters

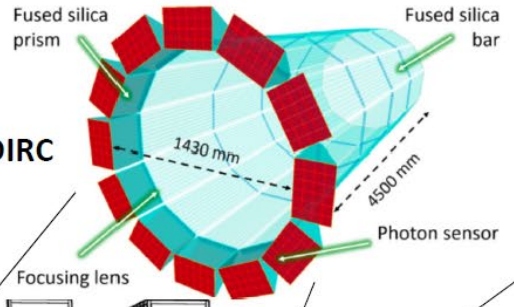
Particle ID

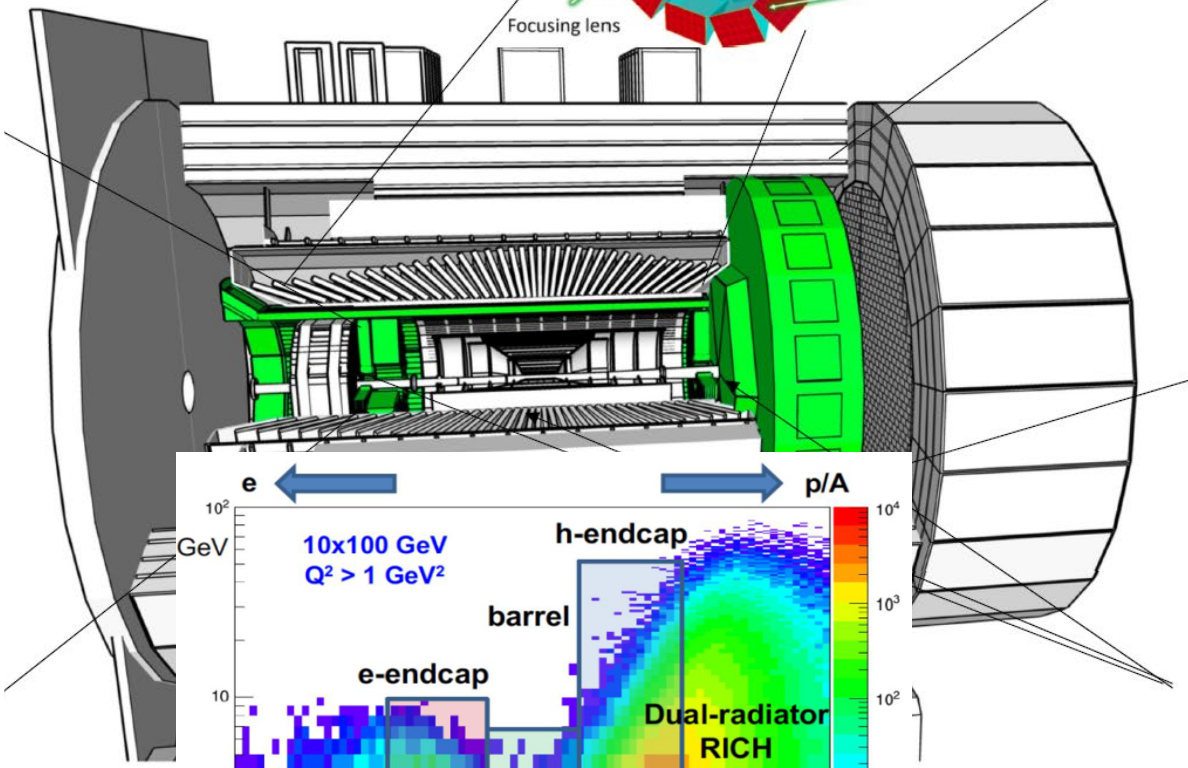
Single volume proximity focusing aerogel RICH with long proximity gap (~30-40 cm)

- **Sensor: <u>LAPPDs →</u> includeTOF**

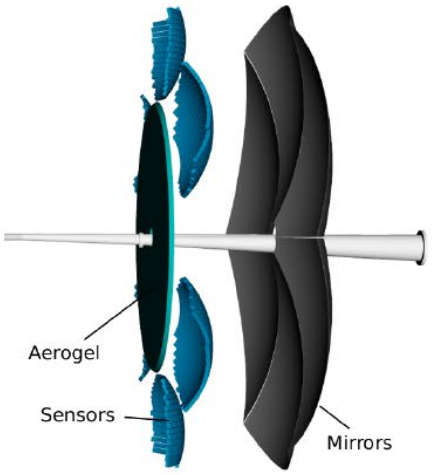


High-Performance DIRC

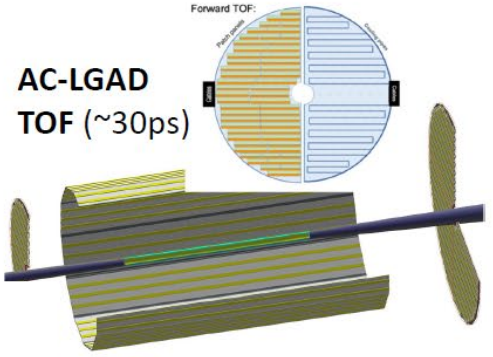




Dual-Radiator RICH (dRICH)



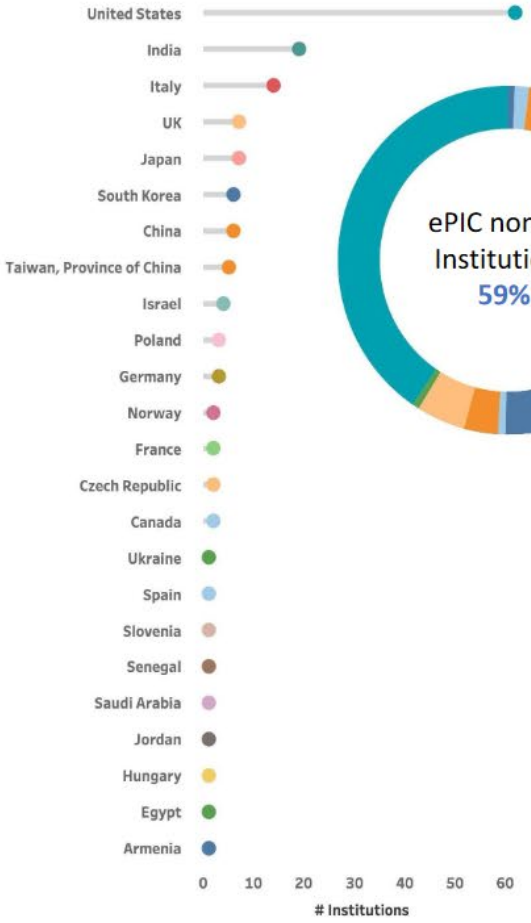
AC-LGAD TOF (~30ps)

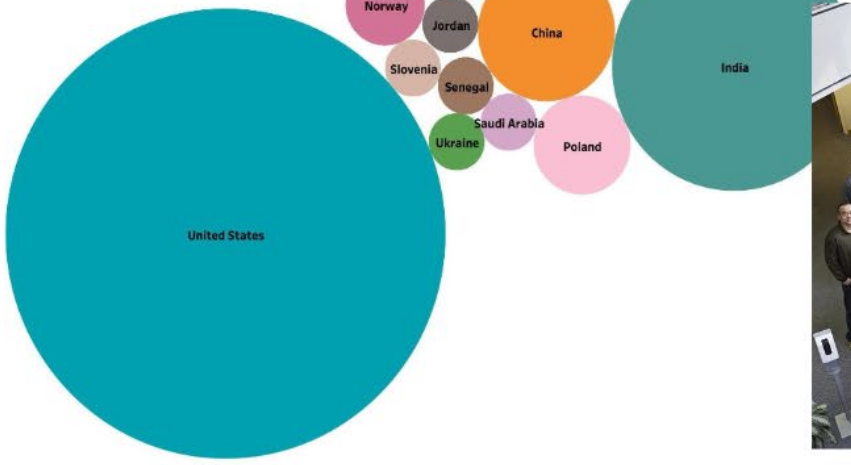


11

The ePIC Collaboration

The ePIC Collaboration





160+ institutions
24 countries

500+ participants

A truly global pursuit for a new experiment at the EIC!

CONCLUDING REMARKS

The EIC is a unique project, the only concrete one around the world for the ultimate understanding of QCD

The only novel collider in the next 15-20 years

- **The EIC project is approved and progressing according to schedule**
- **The ePIC Collaboration for the project detector effort has kicked-off**

  ePIC is designing the detector for the TDR (CD2&3)

  EIC detector is an enormous undertaking that will require participation and expertise from both the US (Labs and academia)communities, as well as the international contributions (60% of Institutions from abroad world-wide) !

  - **In parallel, the new Collaboration being formed and structured**

  - ***It is NOW the right time to join the effort and get involved !***
  - ***Have exciting perspectives with us designing, building, operating ePIC***