The Electron-Ion Collider (EIC)

and the ePIC experiment

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INFN - TRIESTE

OUTLOOK

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

BREAKING NEWS, January 2020

Department of Energy

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

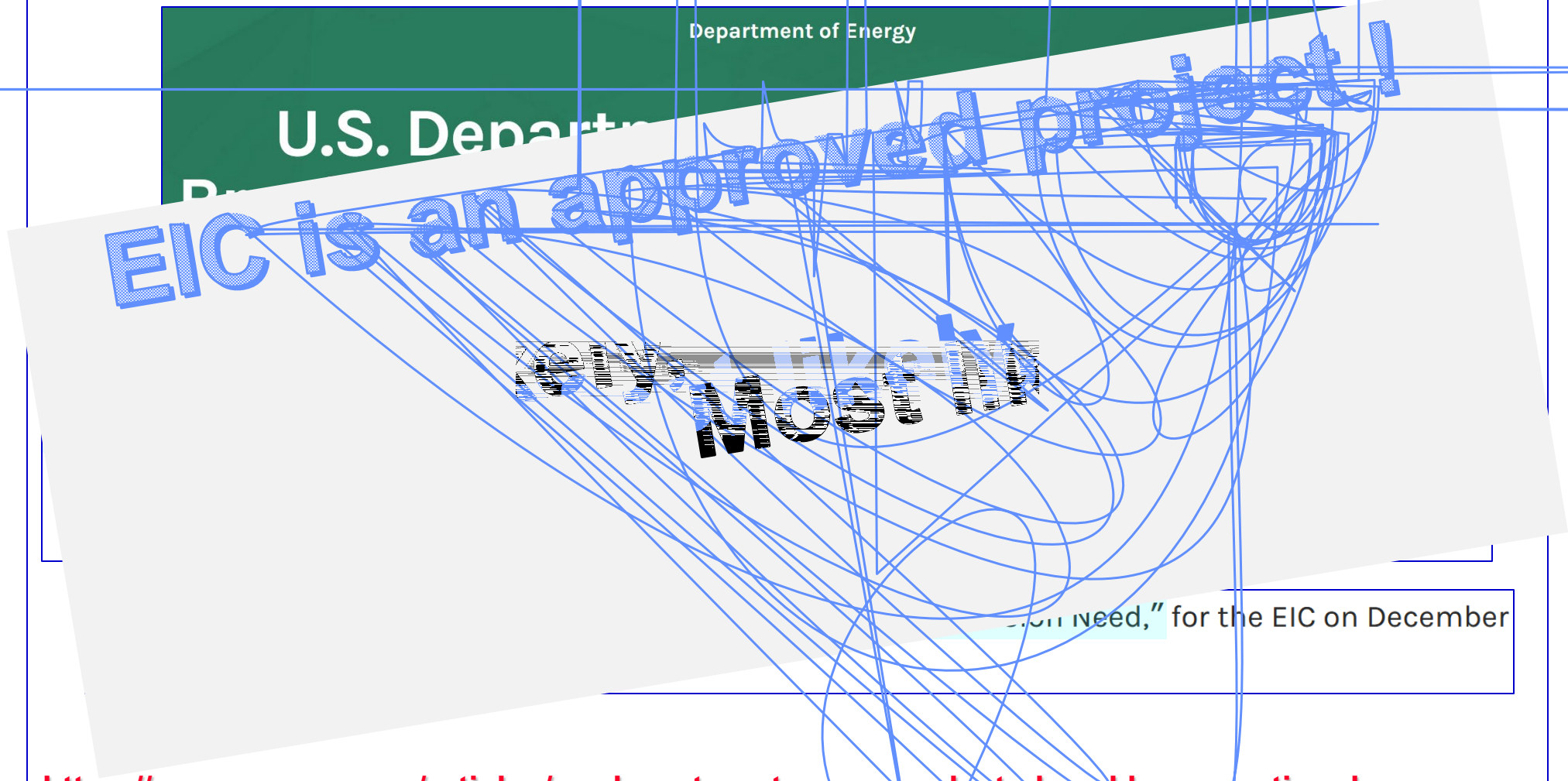
JANUARY 9, 2020

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



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

THE INTERNATIONAL COMMUNITY

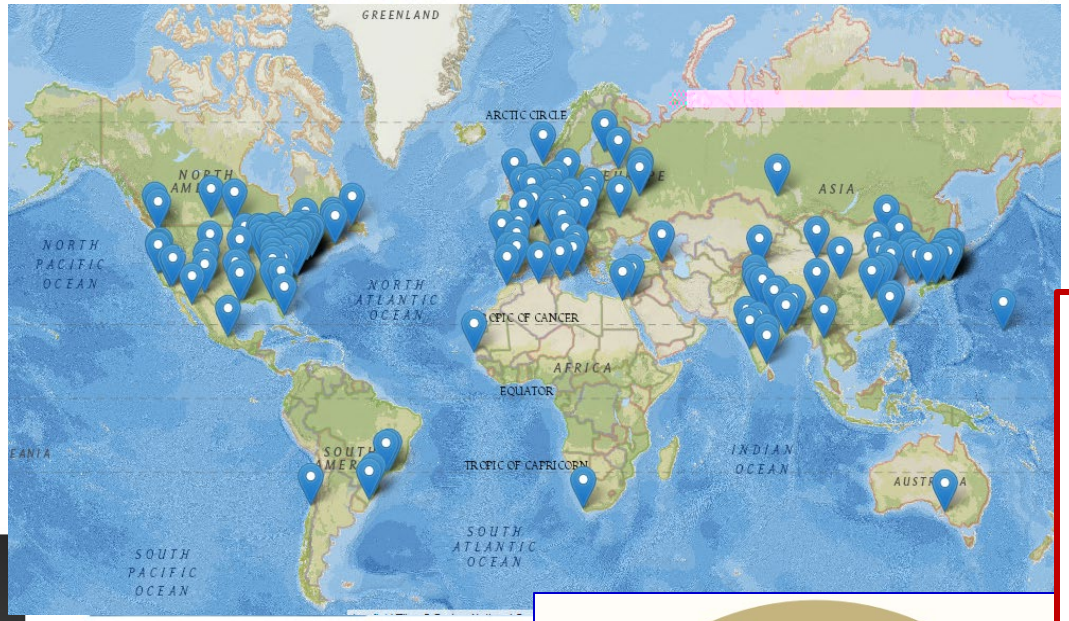
The EIC User Group:
https://eicug.github.io/

Formed 2016 –

- **1440 members**
- **40 countries**
- **295 institutions**

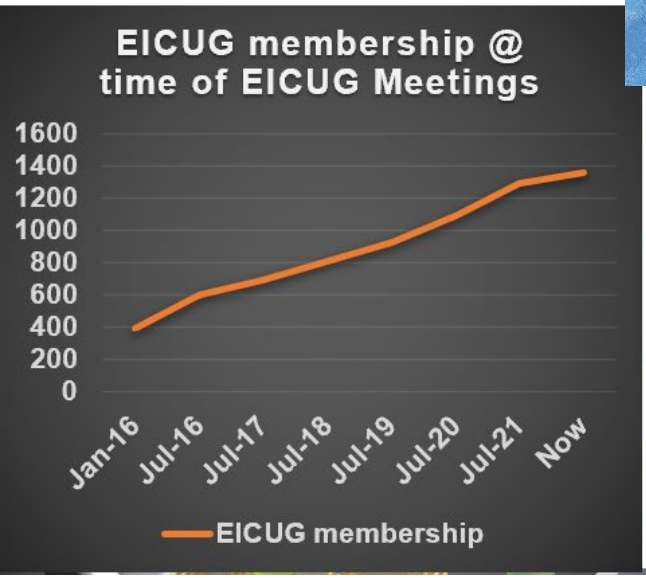
As of January 26, 2024

Strong and Growing International Participation.



Among the main Achievements: The Yellow Report

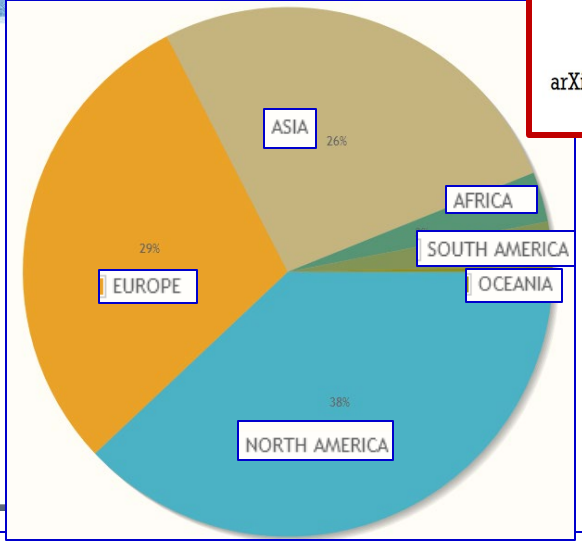
Nucl. Phys. A 1026 (2022) 122447



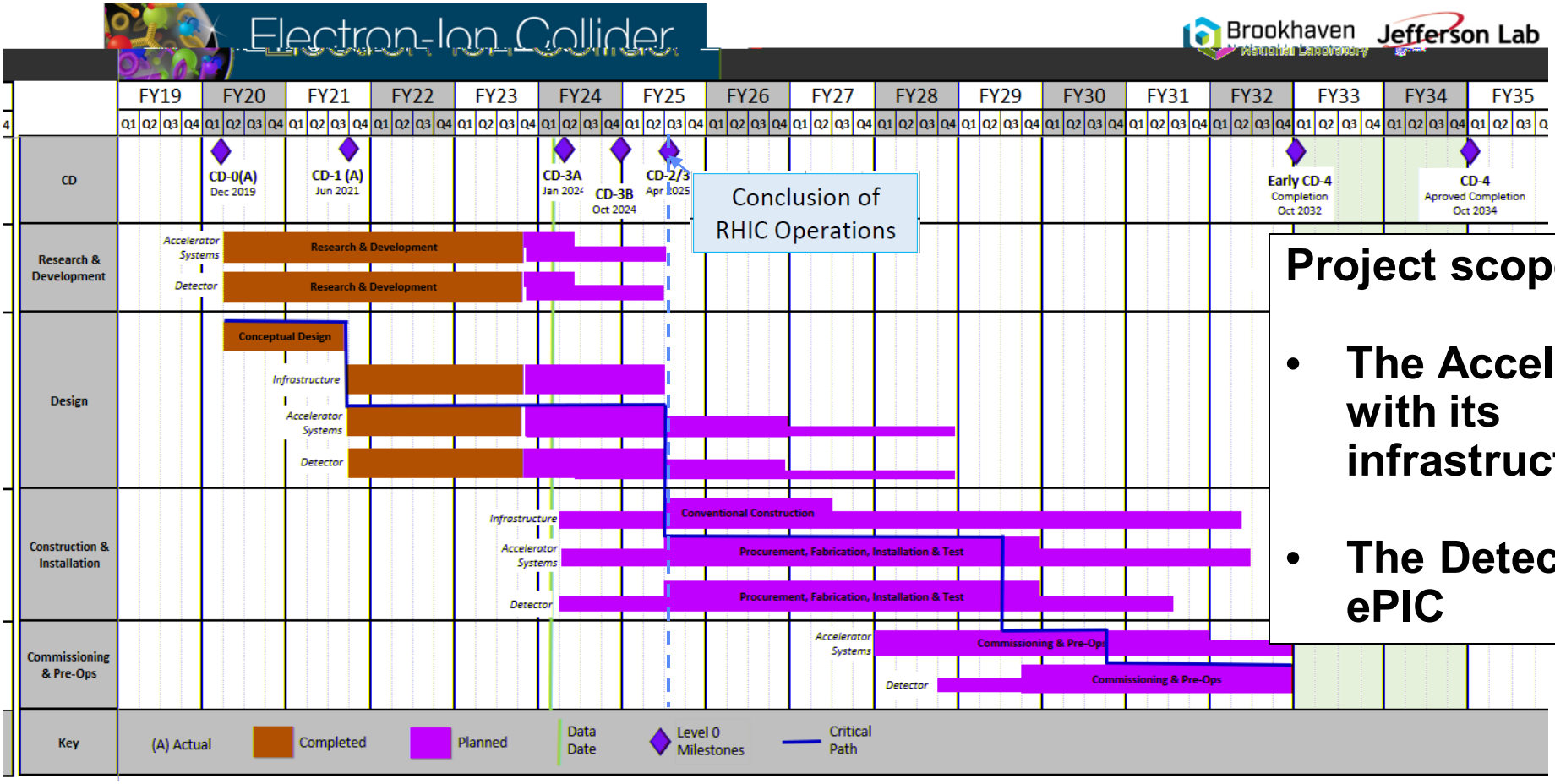
Annual EICUG meeting

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

2024 Lehigh, USA



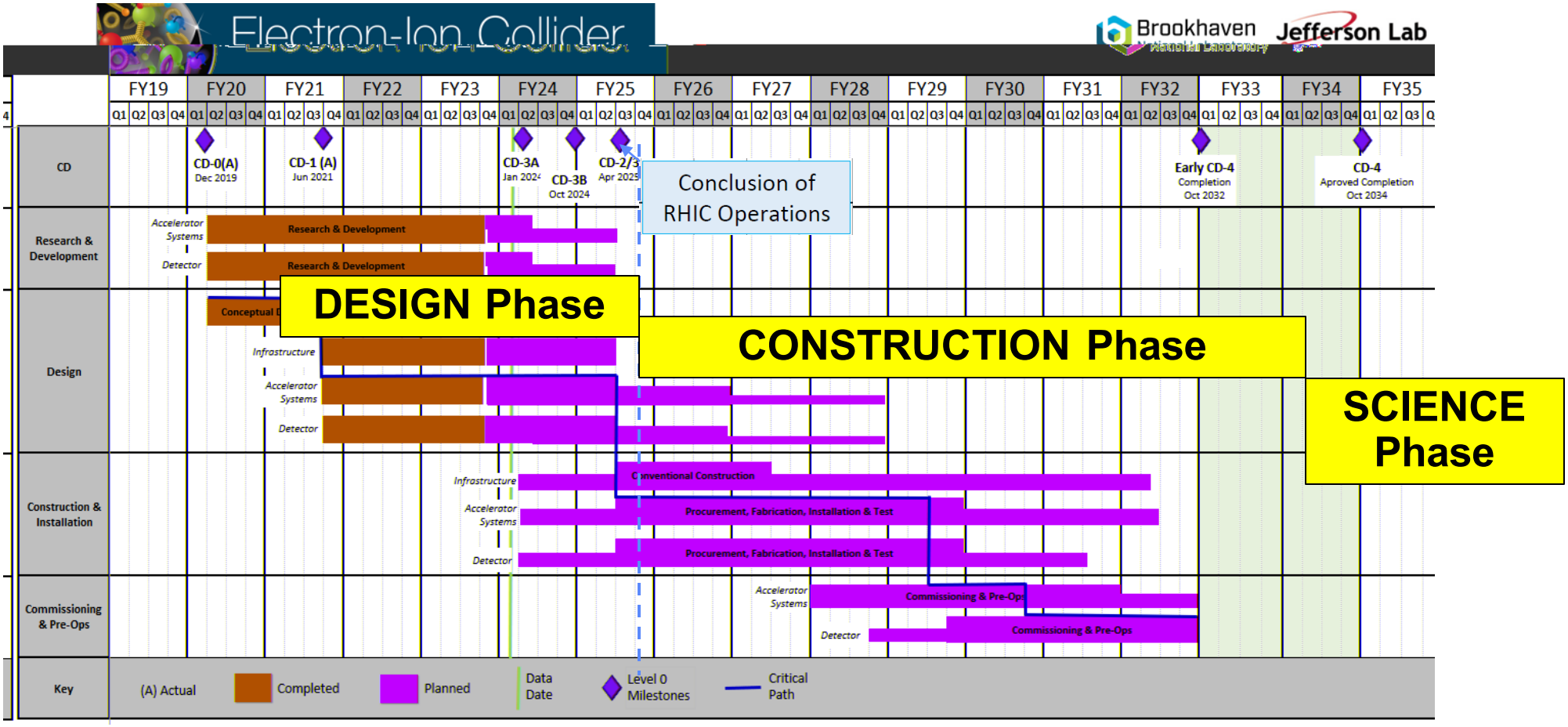
The EIC schedule



Project scope?

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

The EIC schedule



A TRULY INTERNATIONAL PROJECT

From EIC Resource Review Board (RRB) charter

The purpose of the Electron-Ion Collider Resources Review Board (EIC-RRB) is to provide coordination among the different funding partners during both the detector development and construction phase of the project and during the operations of the experiments that follow. In its early years, the RRB will focus on the construction, commissioning, and initial operations. T

Calendar:

- 1st meeting, April 3-4, 2023, Stonybrook, USA
- 2nd meeting, December 6-7, 2023, Washington, USA
- 3rd meeting, May 6-7, 2024, Rome, Italy

Hosts, participants and invited (2nd meeting)

- From the hosting labs (BNL, TJNAF)
- From U.S. Department of Energy
- From EIC Project
- RRB co-chairs
- From ePIC management

- From the international Institutions:
  - Czech Technical University in Prague, Czech Republic
  - INFN, Italy
  - UKRI-STFC, UK
  - CEA Saclay, France
  - IN2P3/CNRS, France
  - University of Manitoba, Canada
  - RIKEN, Japan
  - University of Tokyo, Japan
  - Office of Science for Nuclear Physics, DOE, USA
  - University of Birmingham, UK
  - University of Connecticut, South Korea
  - Cheikh Anta Diop University, Senegal
  - National Central University, Taiwan
  - Canada Foundation for Innovation, Canada
  - AGH University of Krakow, Poland
  - University Mohammed V in Rabat, Morocco

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THE SCIENTIFIC SCOPE

Open questions in QCD and nuclear matter

The study of Nuclear Physics is the quest to understand the origin, evolution, and structure of the matter of the universe

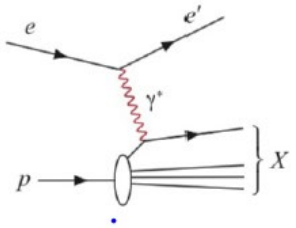
- How do the **properties of the proton** such as **mass** and **spin** emerge from the sea of quarks, gluons, and their underlying interactions?
- What is the **configuration and motion** of quarks and gluons located within the nucleon?
- What happens to the **gluon density** in nucleons and nuclei at small x?
- How do **quarks and gluons interact** with a nuclear medium?
- How do the **confined hadronic states** emerge from quarks and gluons?

LEPTONS as HADRON PROBES @ HIGH ENERGY

Deep Inelastic Scattering – DIS

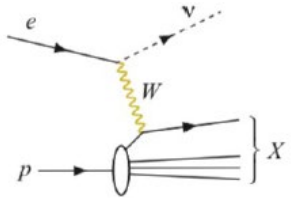
Much more information can come when :

- Access to a **wider phase space** domain is made possible
- **polarized** particle scattering
- part of the final state is measured: **SIDIS** (Semi-Inclusive DIS)
- The whole final state is measured: **exclusive reactions**



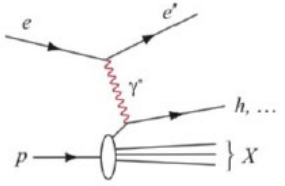
NC inclusive DIS

essential measurement: scattered electron

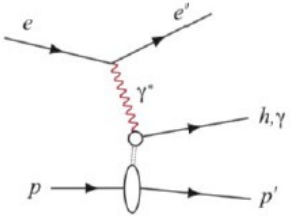


CC inclusive DIS

kinematics reconstructed via final state particles



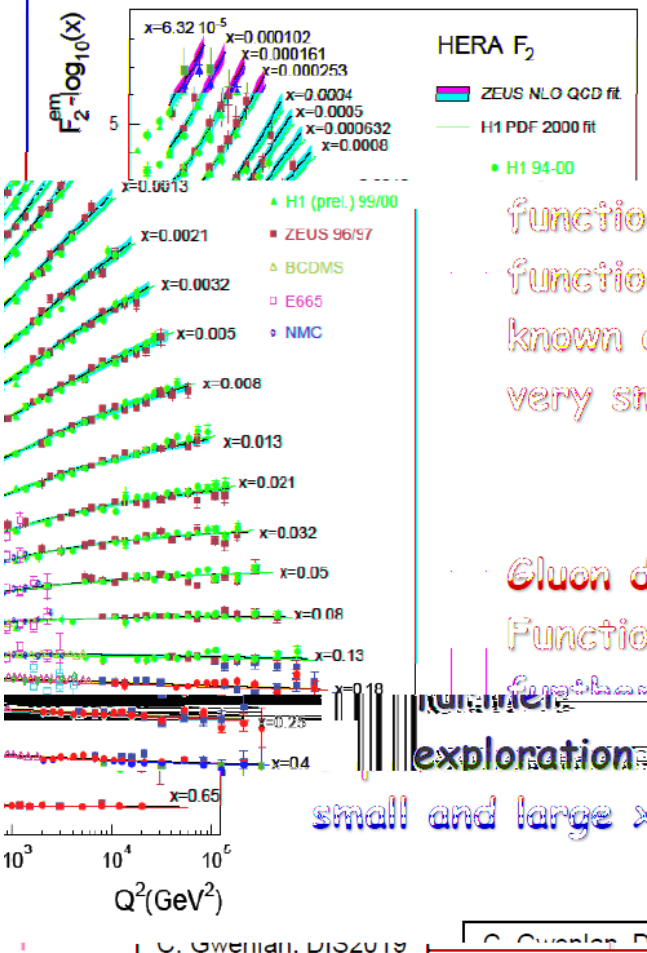
Semi-Inclusive DIS



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

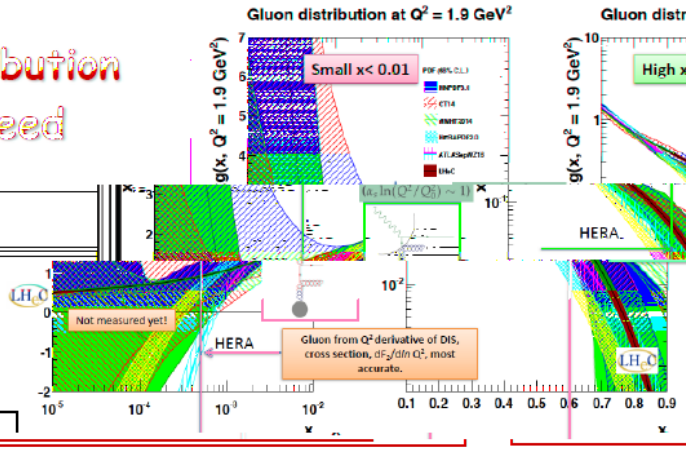
exploration at small and large x

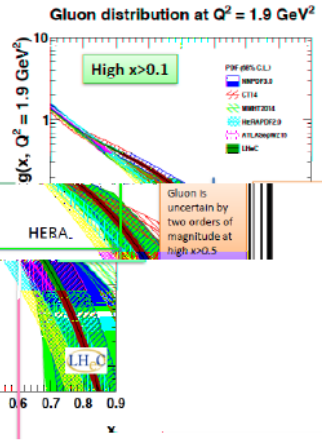
Understanding the Gluon

Hera's ep legacy and limitation

DGLAP approach

Low and high x parton distributions are intertwined by momentum sum rules!





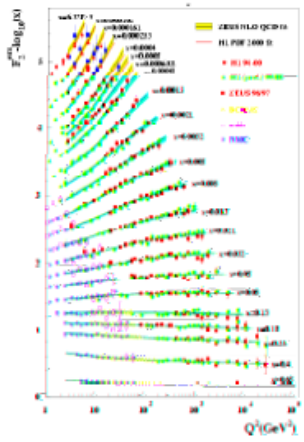
THE SCIENTIFIC SCOPE

TMDs and SPIN

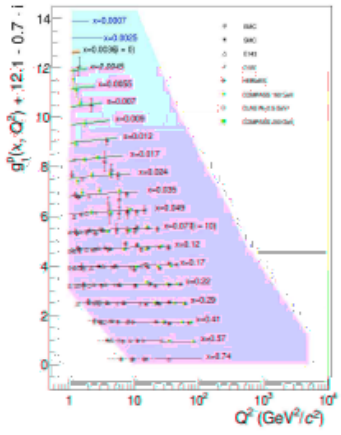
The 8 leading-twist quark TMD PDF

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



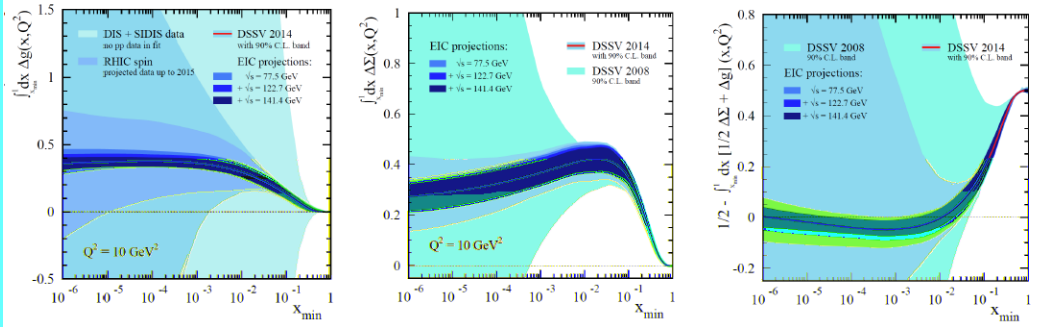
spin

transverse spin ~ angular momentum

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

What do we know:

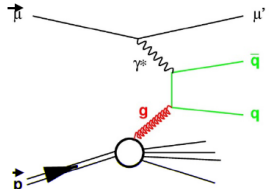
$$\frac{1}{2}\hbar = \left\langle P,\frac{1}{2}\left| J^z_{QCD} \right| P,\frac{1}{2}\right\rangle = \overbrace{\frac{1}{2}\int_0^1 dx \Delta\Sigma(x,Q^2)}^{\text{total quark spin}} + \overbrace{\int_0^1 dx \Delta G(x,Q^2)}^{\text{gluon spin}} + \overbrace{\int_0^1 dx \left(\sum_q L_q^z + L_g^z\right)}^{\text{angular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



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

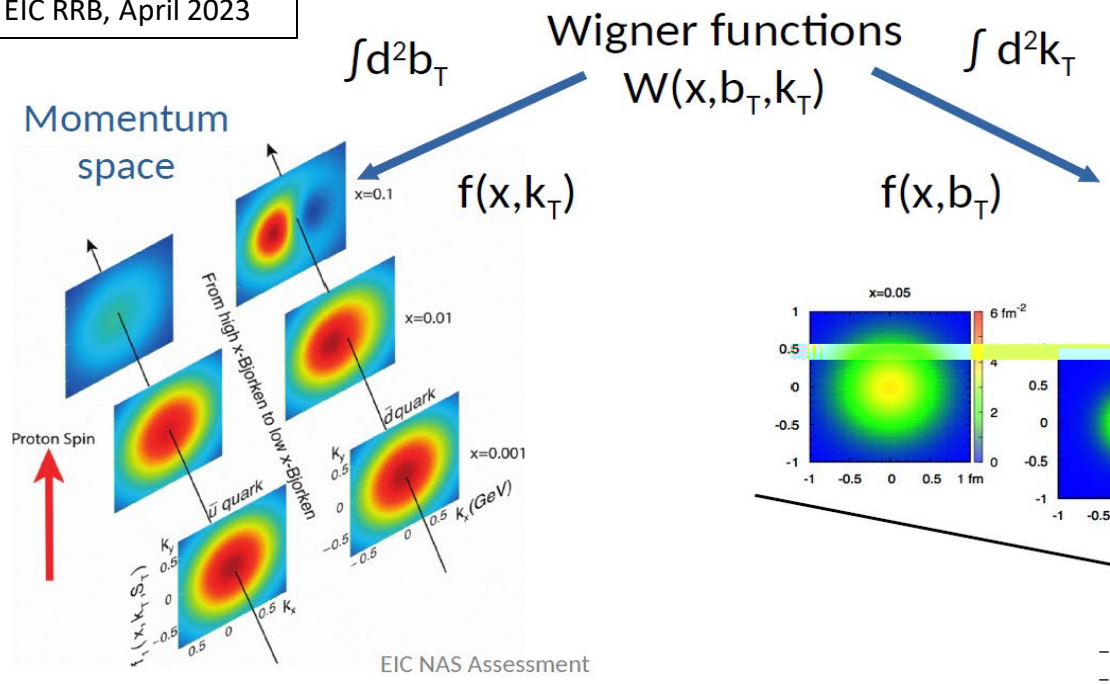
of course, by a SI-DIS measurement

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

THE SCIENTIFIC SCOPE

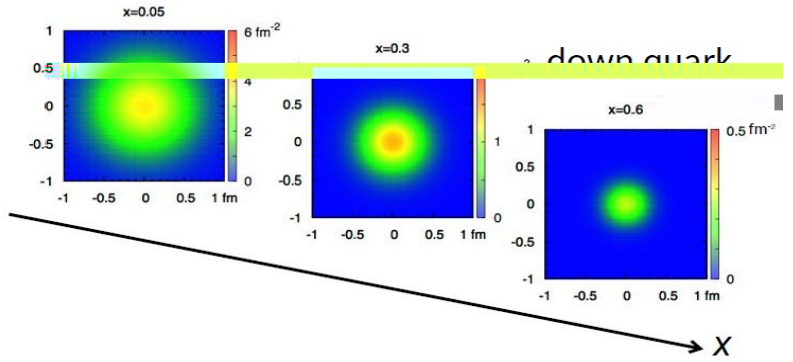
Spatial and Momentun structure of the N in 3D

Maria Żurek, EIC RRB, April 2023



COORDINATE SPACE

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

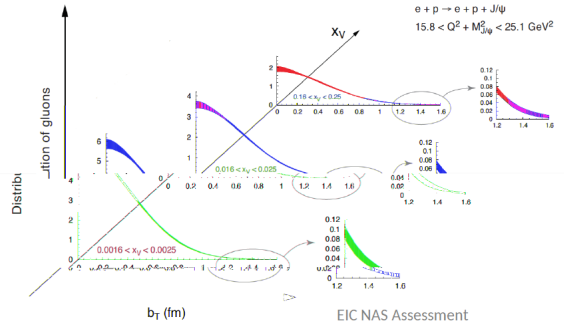


Nucleon tomography

- 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

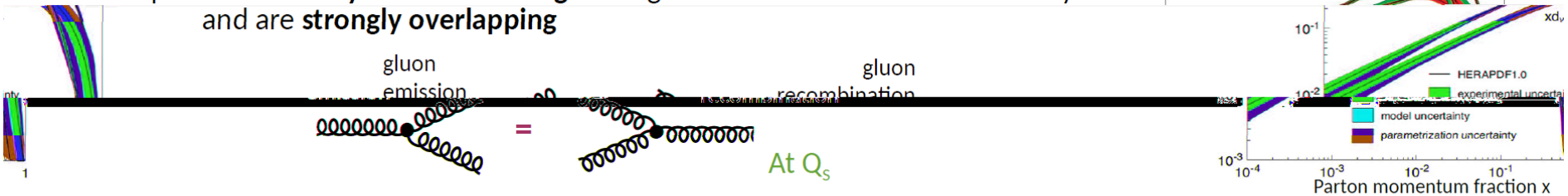


THE SCIENTIFIC SCOPE

ACCESS TO A NEW STATE OF THE GLUONIC MATTER

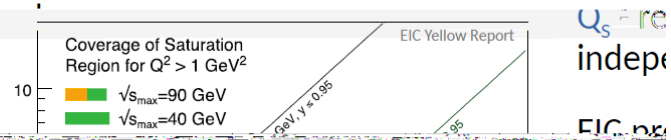
What happens to the gluon density in nuclei?

- 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**



solution scale at which the number density so large that gluons are no longer
endent → **saturated gluon matter**

ovides a unique opportunity to have very high gluon densities



Q_s re
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EIC pr

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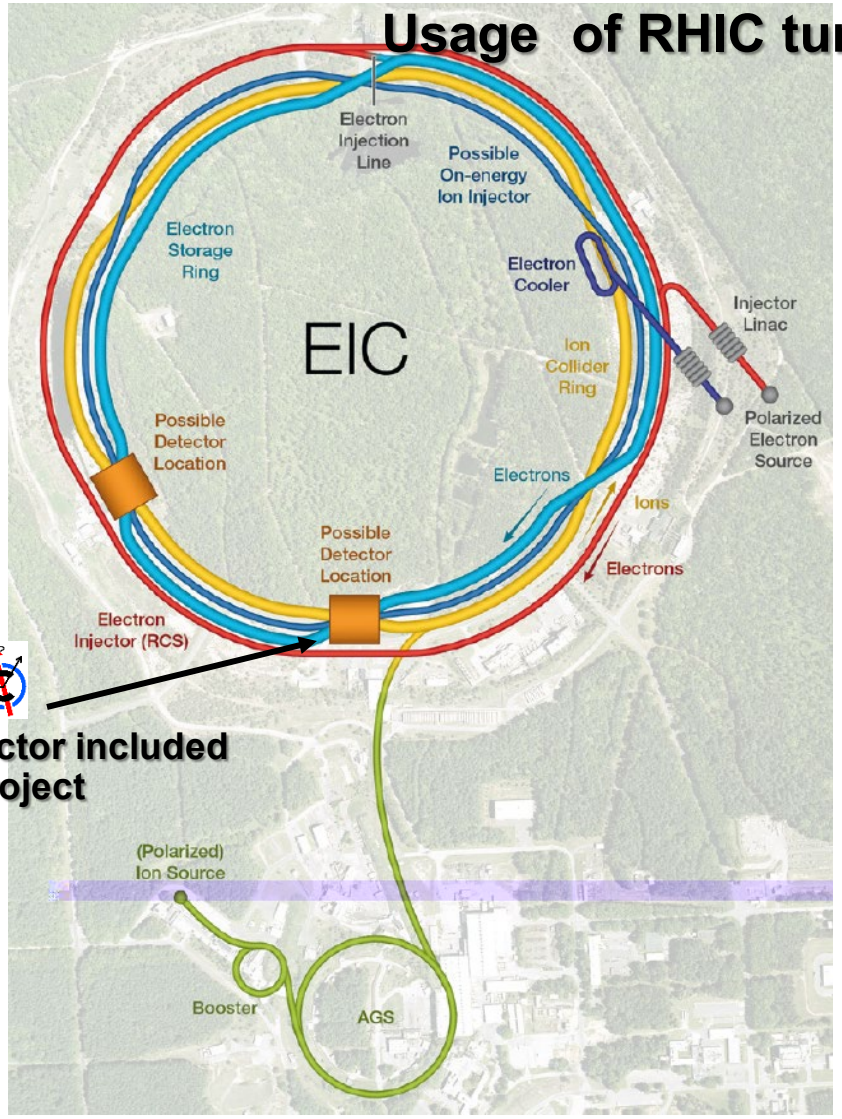
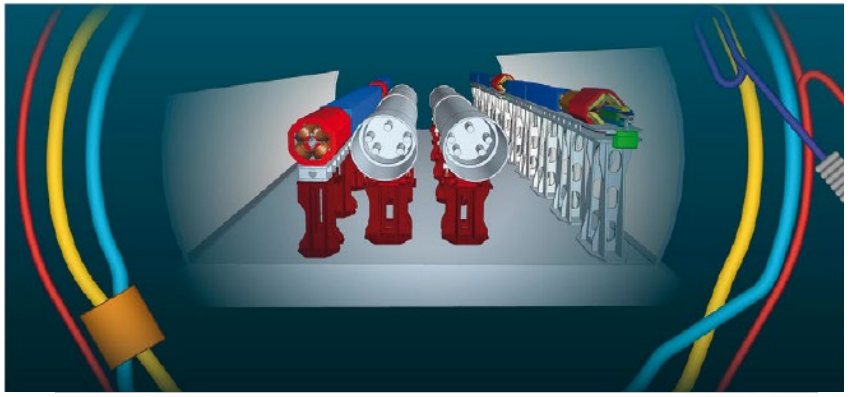
The EIC Collider

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**

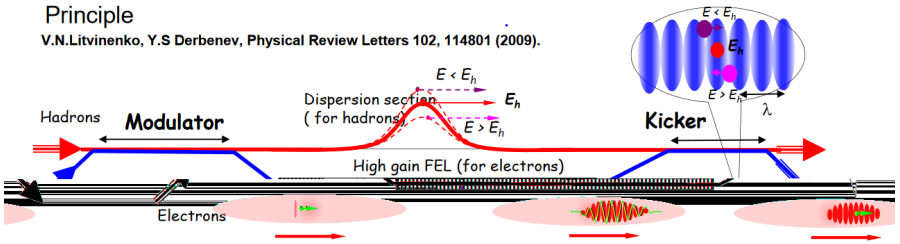
The EIC Collider

3 critical ingredients for HIGH LUMINOSITY

Coherent Cooling with FEL amplifier

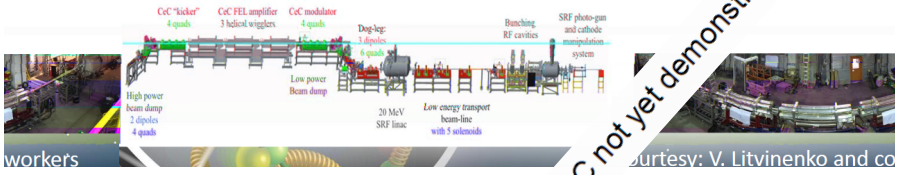
Principle

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, ongo



workers

Courtesy: V. Litvinenko and co

CeC not yet demonstrated

Bunches and beam crossing rates

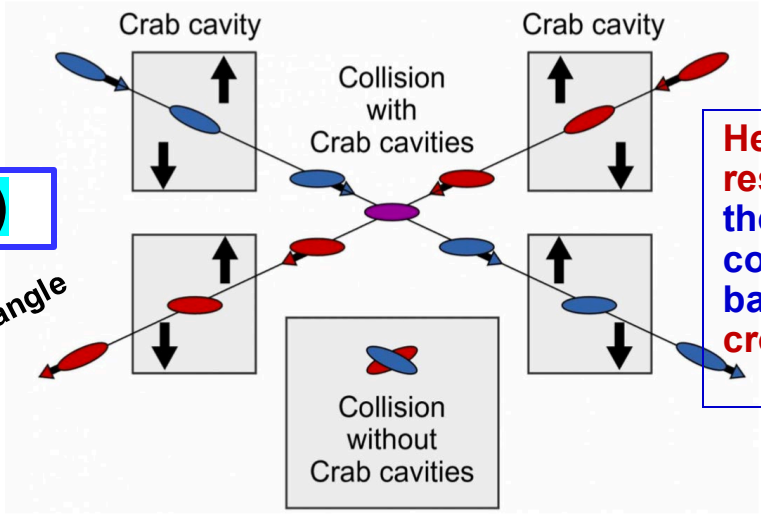
Species	p	e	p	e	p	e	p	e	p	e
Beam energy [GeV]	275	18	275	10	100	10	100	5	41	5
$\sqrt{s}$ [GeV]	140.7		104.9		63.2		44.7		28.6	
No. of bunches	290		1160		1160		1160		1160	
Species	Au	e	Au	e	Au	e	Au	e		
Beam energy [GeV]	110	18	110	10	110	5	41	5		
$\sqrt{s}$ [GeV]	89.0		66.3		46.9		28.6			
No. of bunches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

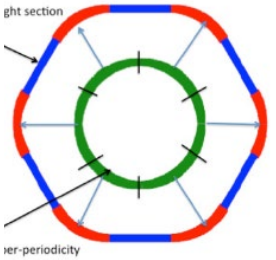
The existing RHIC ion sources & ion acceleration chain provides already **today** all ions needed at EIC

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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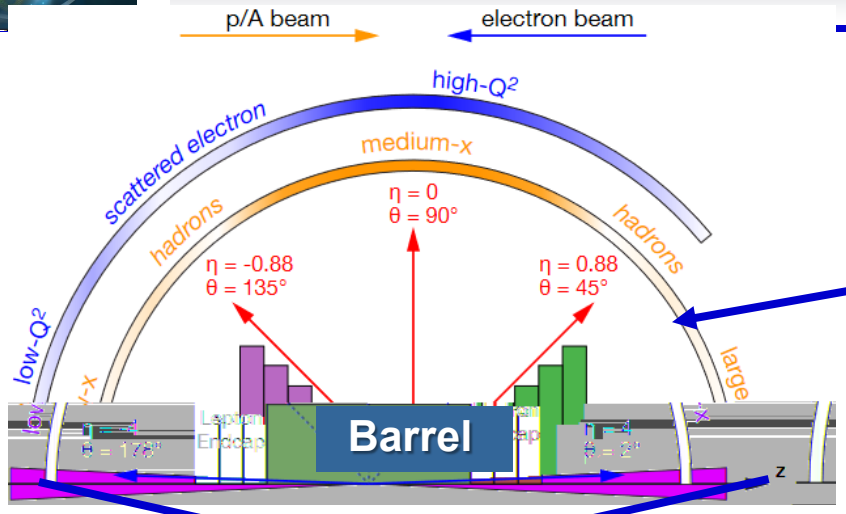
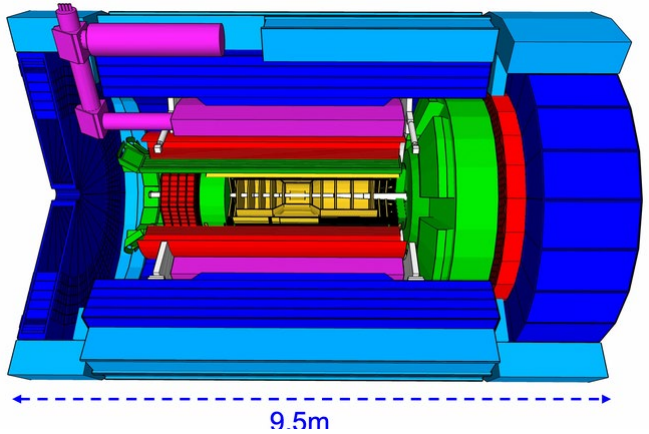
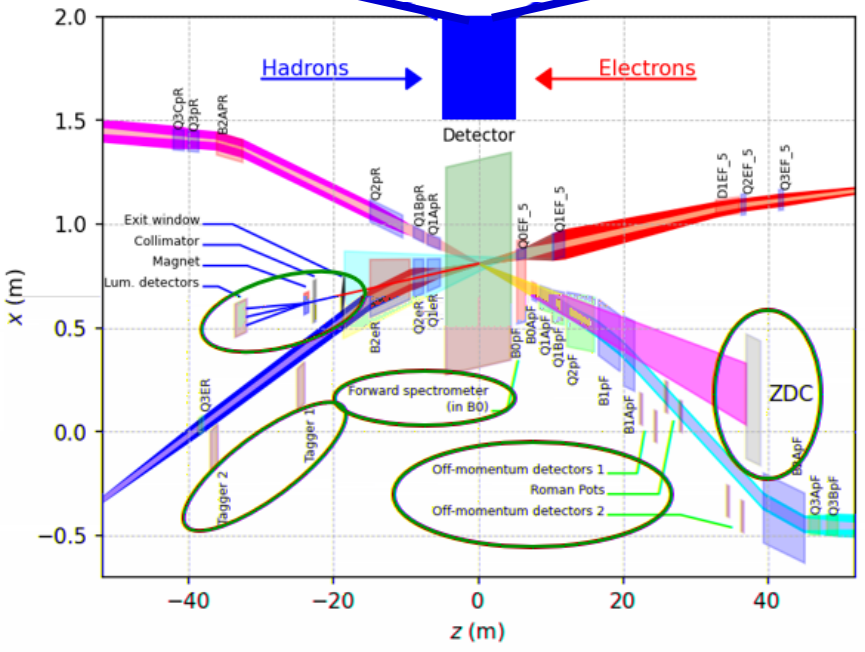
THE COMPLETE ePIC DETECTOR





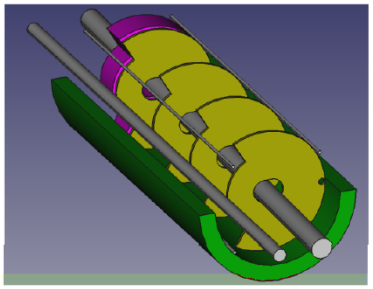
Central Detector (CD)

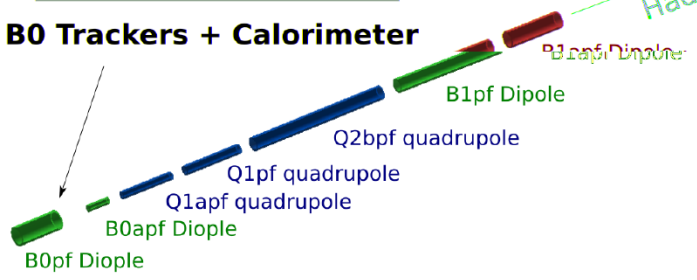


Total size detector: ~75m
Central detector: ~10m
Backward electron detection: ~35m
Forward hadron spectrometer: ~40m

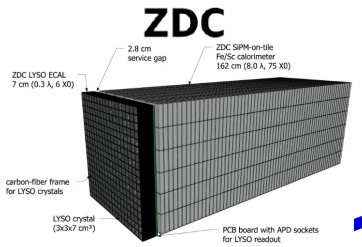
Auxiliary detectors needed to tag particles with very small scattering angles both in the outgoing lepton and hadron beam direction (B0-Taggers, Off-momentum taggers, Roman Pots, Zero-degree Calorimeter and low Q2-tagger).

Far forward and backward





Far Forward



Far Backward

Figure: Luminosity detector

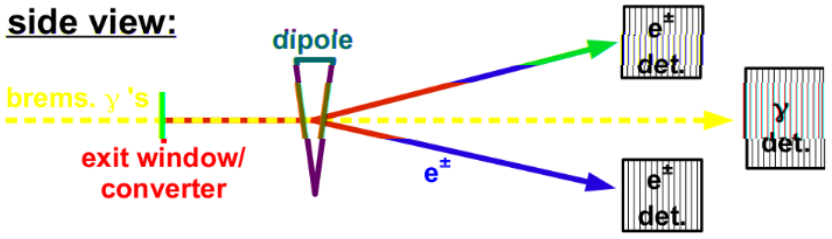
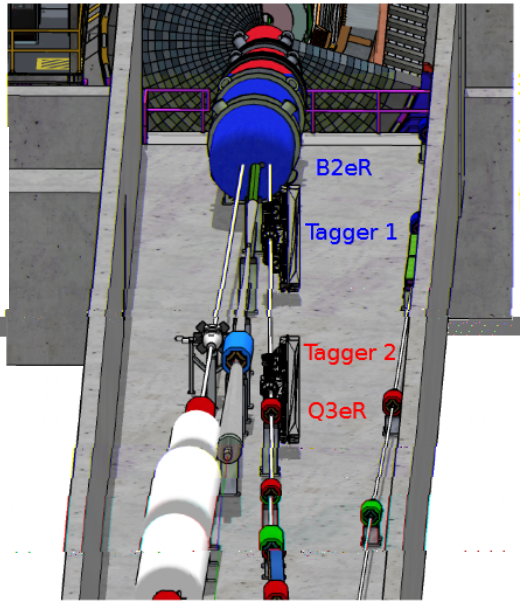
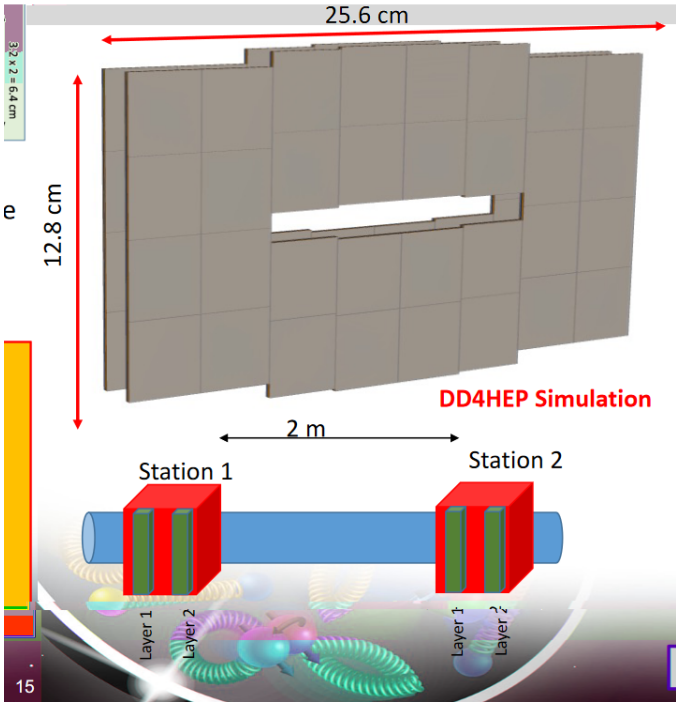


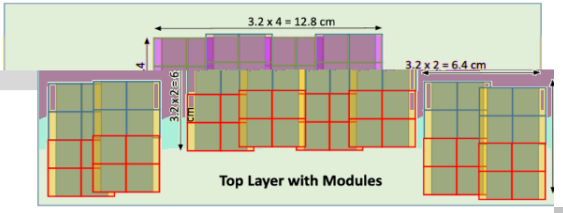
Figure: Low-Q^2 taggers



Roman Pots

Roman "Pots" @ the EIC

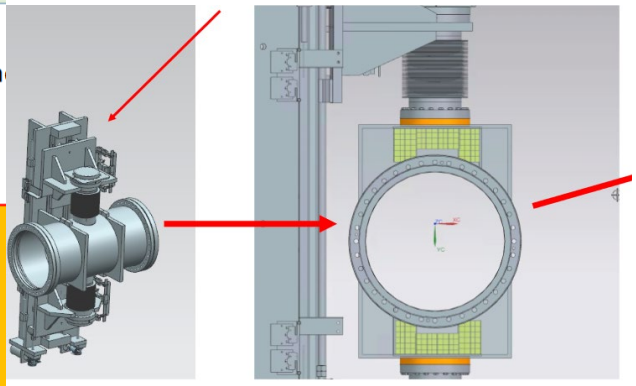




- **Technology**
  - 500um, pixilated AC-LGAD sensor provides both fin pixilation.
  - "Potless" design concept with thin RF foils surrounding detector components.

- **Status**
  - ✓ **Acceptance: 0.0* < θ < 5.0 mrad (lower bound depends on optics).**
  - ✓ **Detector directly in-vacuum a challenge for both detector and beam → impedance studies underway.**
  - ✓ **Approved generic R&D to develop more-adaptive reconstruction code!**

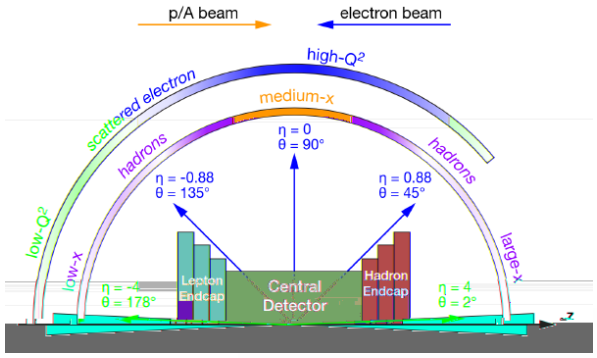
ML + Roman Pots: See talk by D. Ruth WG6; Tuesday @ 2pm



The pixelized **AC-LGADs** will be read-out with **EICROC**.

The same read-out ASIC is considered for the AC-LGAD ToF layer in the forward endcap of the central detector

ePIC Central Detector



Formed by:

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

hadronic calorimeters

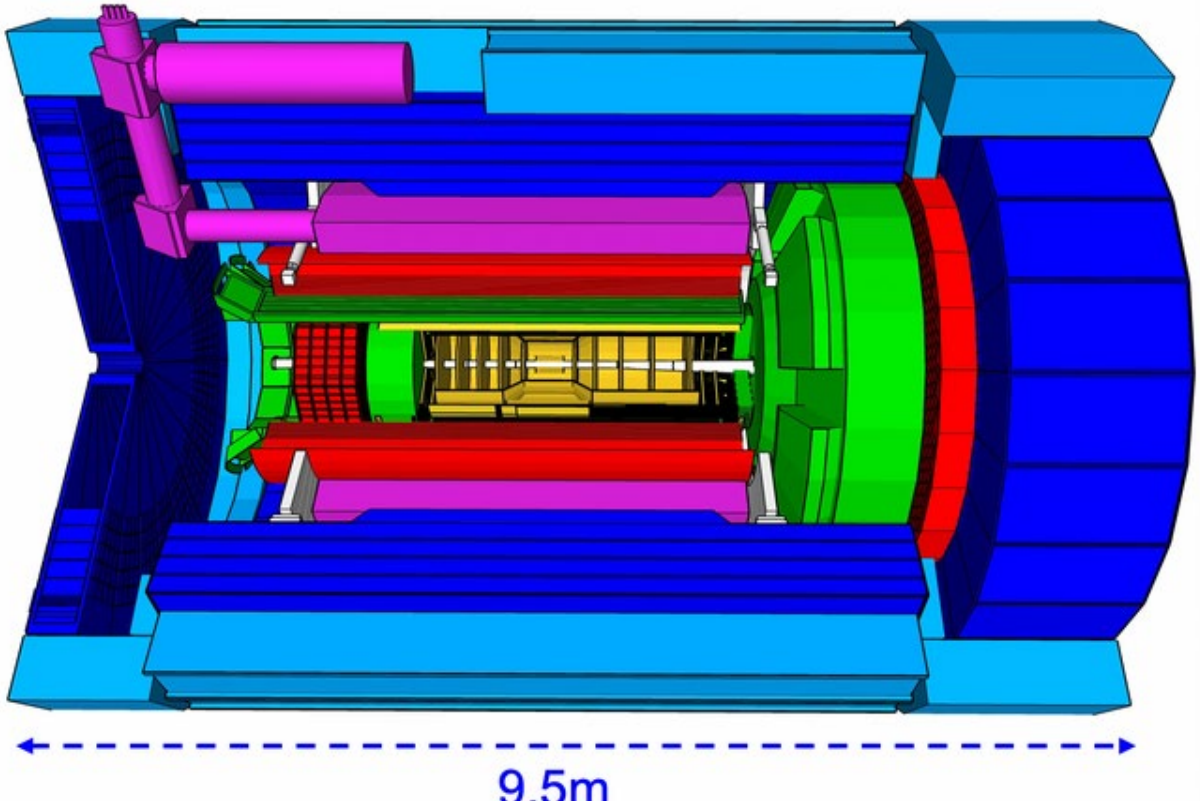
Solenoidal Magnet

e/m calorimeters (ECal)

Time.of.Flight, DIRC, RICH detectors

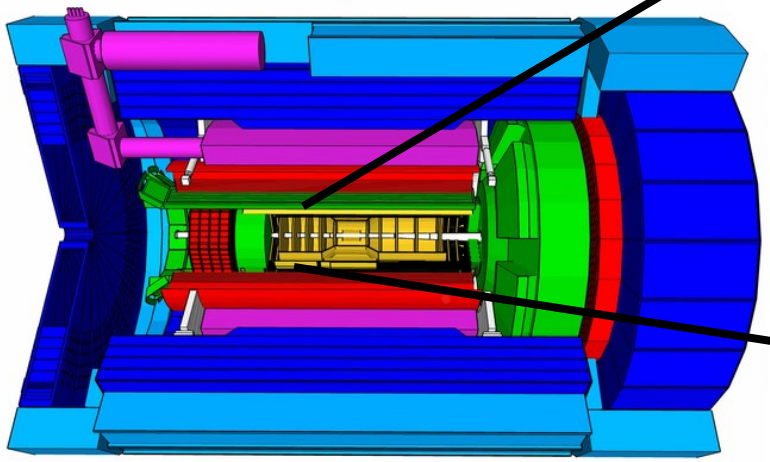
MPGD trackers

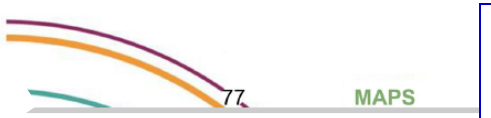
MAPS tracker



TRACKING IN ePIC CD

Tracking





Five layers in barrel, supplemented by MPGDs for pattern recognition.

IRC
MPGD

ive discs in forward/backward
irections (+MPGD in forward)

Meets EICUG Yellow Report design
equirements.

Si trackers based on ALICE ITS3 65 nm MAPS sensors

- Five layers in the barrel and in the endcaps

Supplemented by MPGD trackers

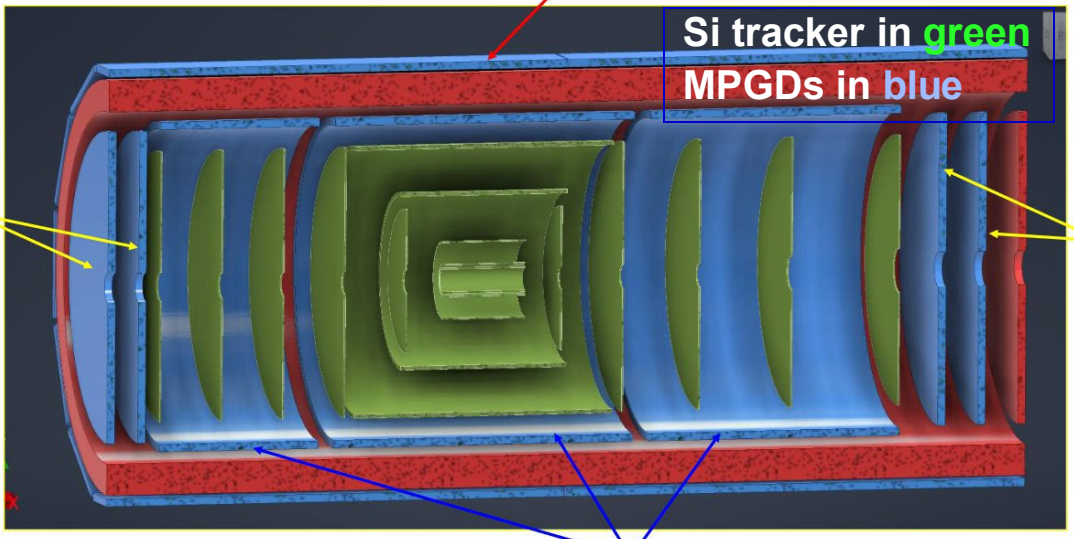
- Cylindrical MICROMEGAS
- Planar μR-WELL

The 3 most internal layers are support-less !

Barrel Outer μRWELL Layer

Si tracker in green
MPGDs in blue

Backward μRWELL Disks

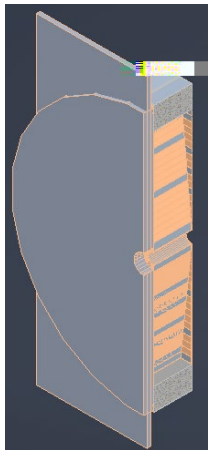


Forward μRWELL Disks

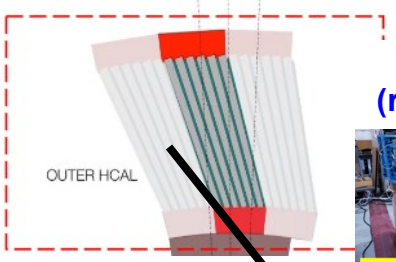
Inner Cyl Micromegas Barrel Layer CyMBaL

CALORIMETRY IN ePIC CD

SiPMs of all Calorimeters

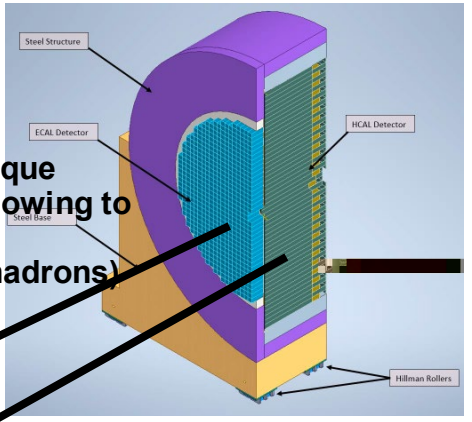


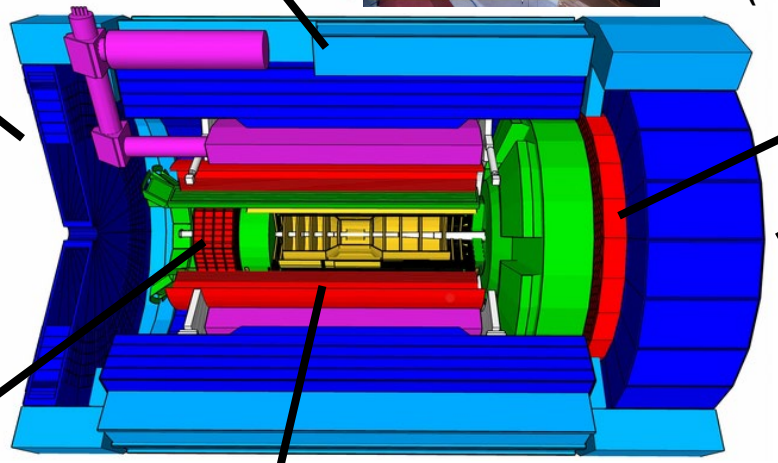
Backwards HCal
Steel/Sc Sandwich
tail catcher



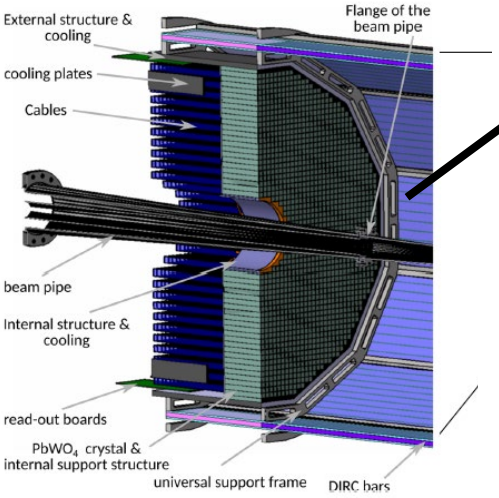
Barrel Hcal
(re-use from sPHENIX)

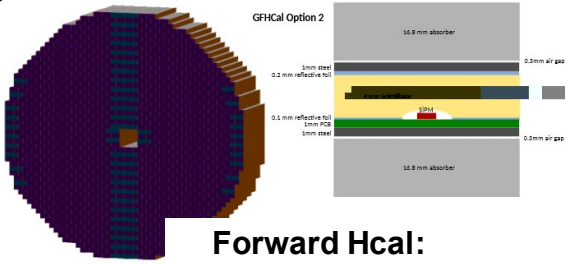
WScFi is a unique technology allowing to achieve e/h ~1 (response to hadrons)



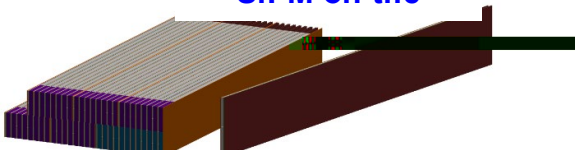


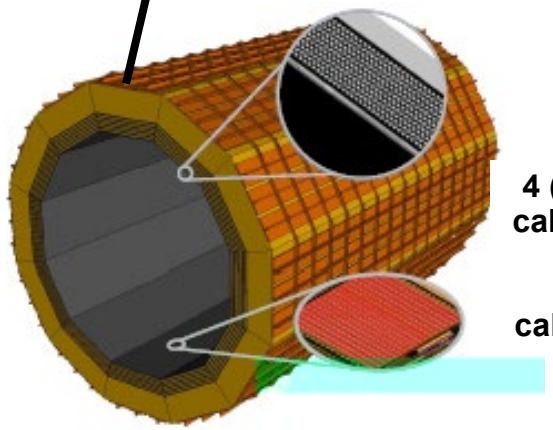
Backwards EMCal
PbW04 crystals





Forward Hcal:
SiPM on tile

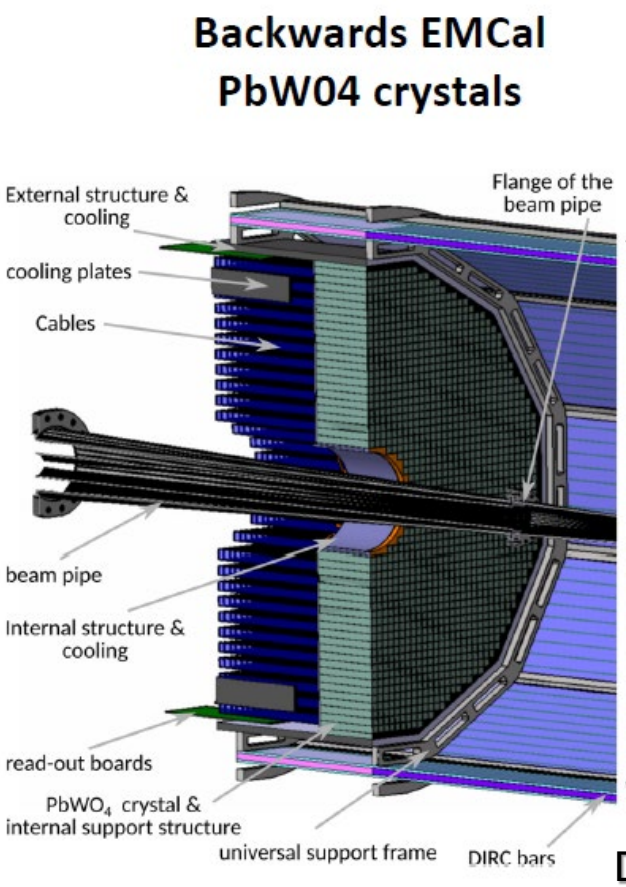


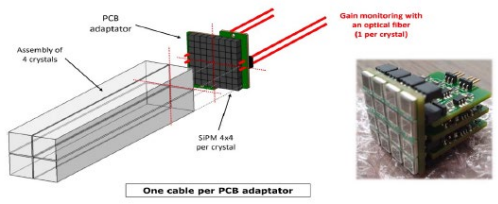


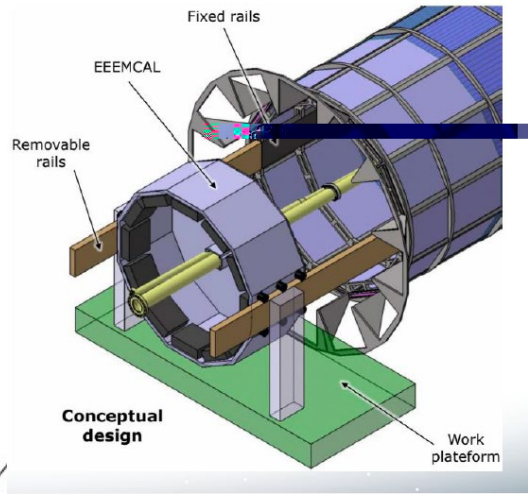
4 (6) layers of imaging calorimetry by Astropix MAPS, and sampling calorimetry by Pb/SciFi

BACKWORD ECAL

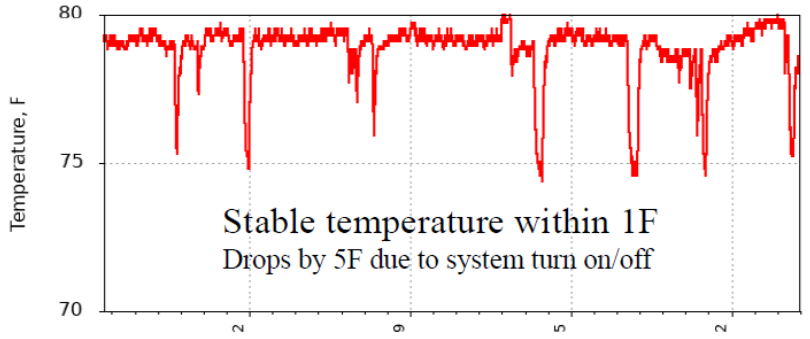
Mechanics and Integration

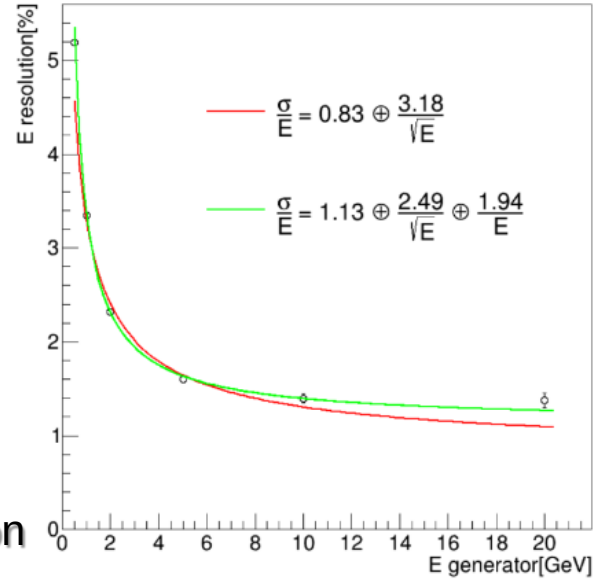






T^0 stabilization



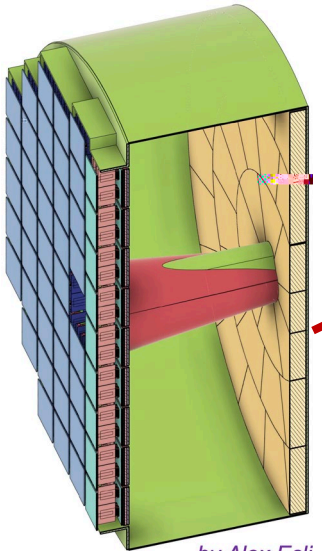


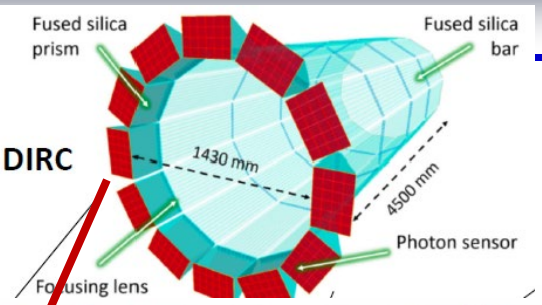
Demonstrate the adequateness of CALOROC for the required resolution is one of the present challenges

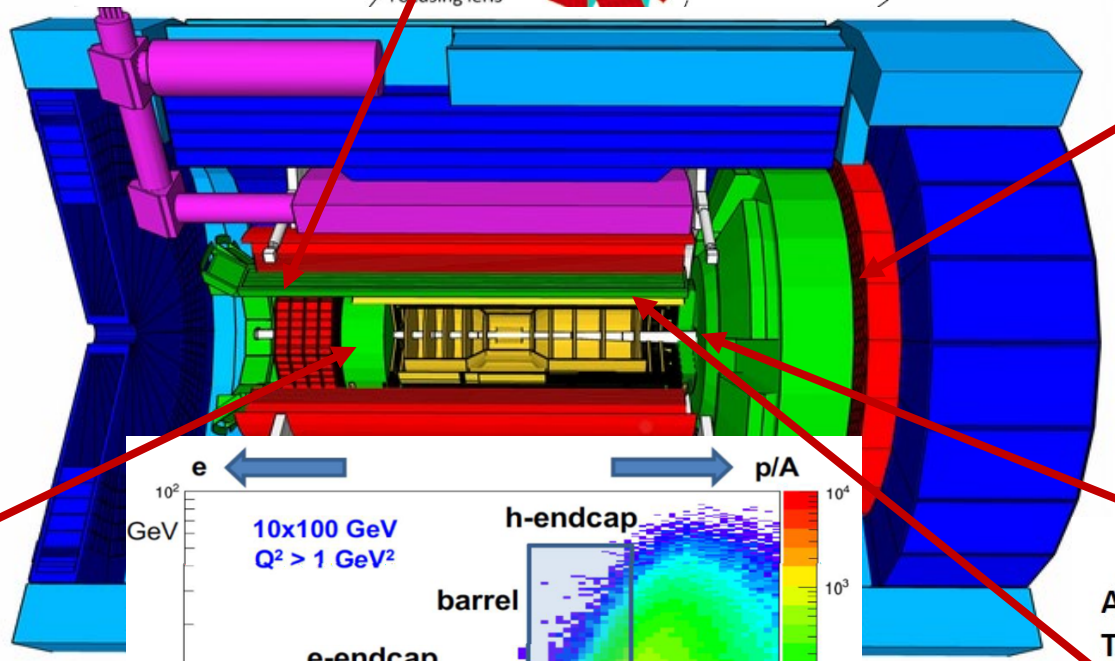
PID IN ePIC CD

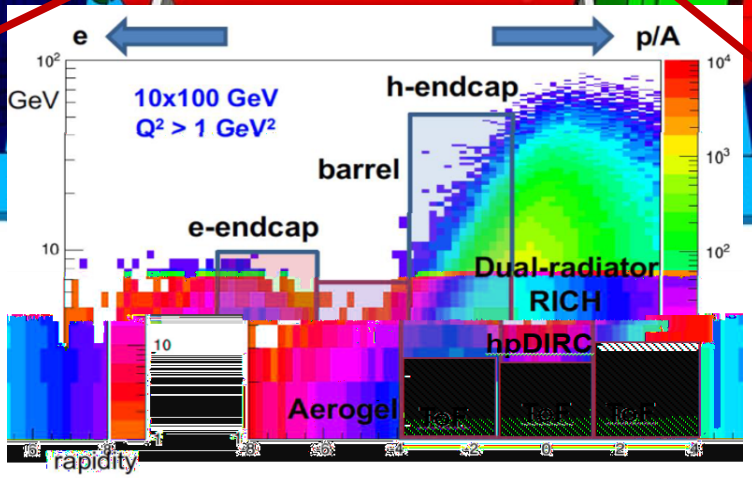
Single volume proximity focusing aerogel RICH with long proximity gap (~30-40 cm)

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

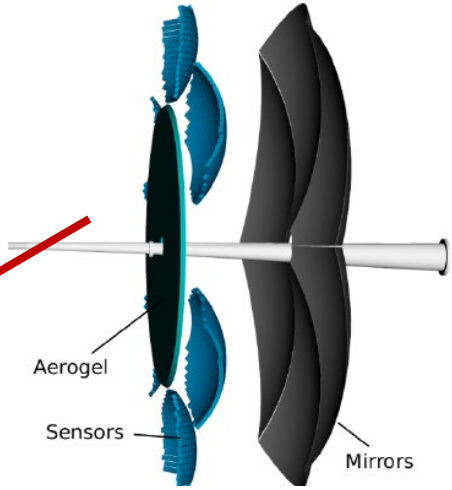






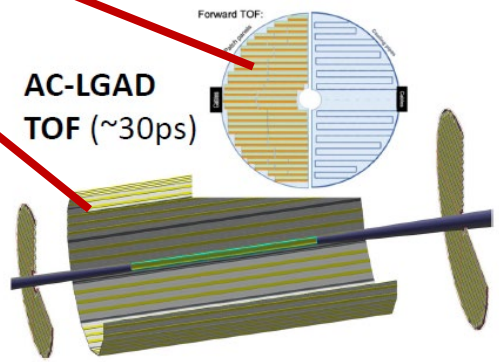


Dual-Radiator RICH (dRICH)



Single photon sensors: SiPMs

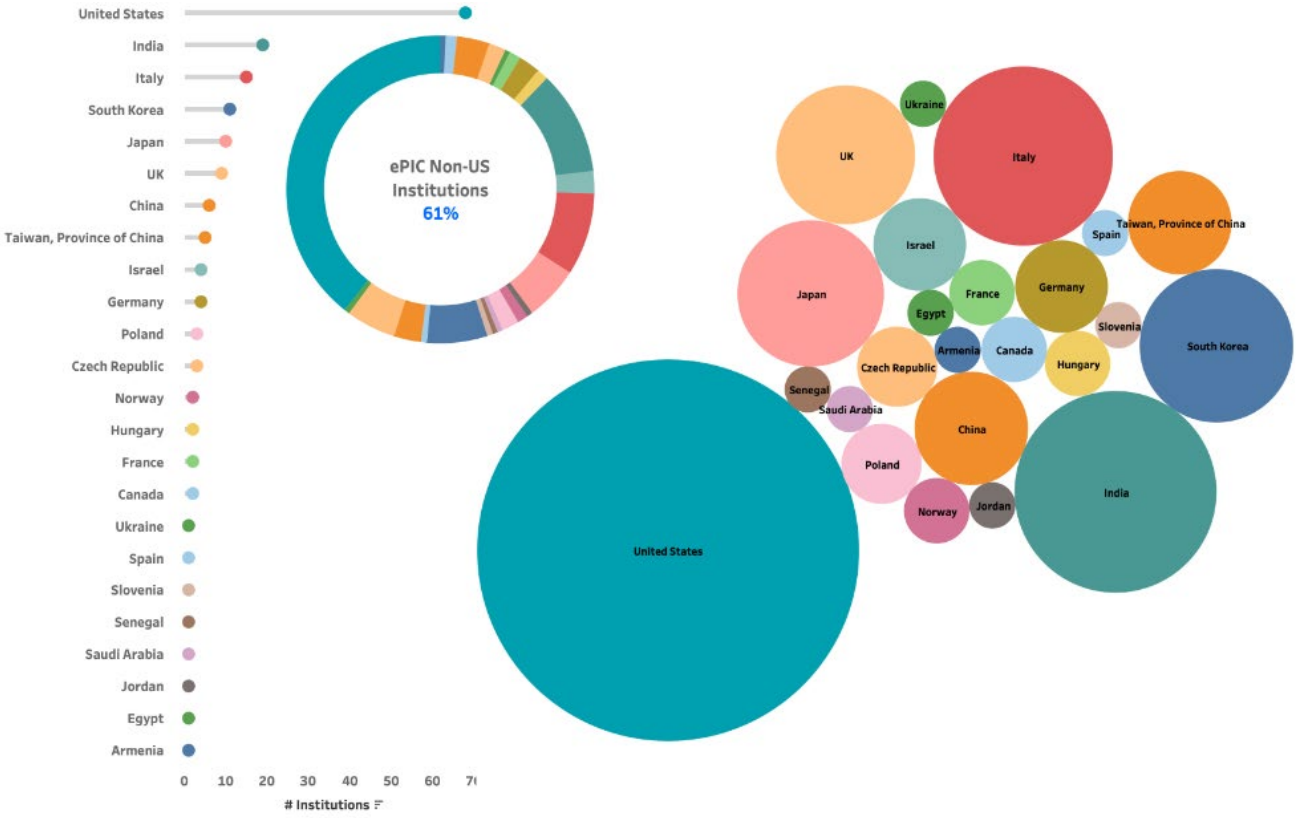
AC-LGAD TOF (~30ps)



OUTLOOK

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

The ePIC Collaboration



173 Institutions and increasing

24 countries

500 + participants

A truly global pursuit for a new experiment at 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 HE collider in the next 20-30 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

  The ePIC 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 has been formed and structured**

  - ***In front of us: exciting perspectives designing, building, producing science within ePIC at EIC***