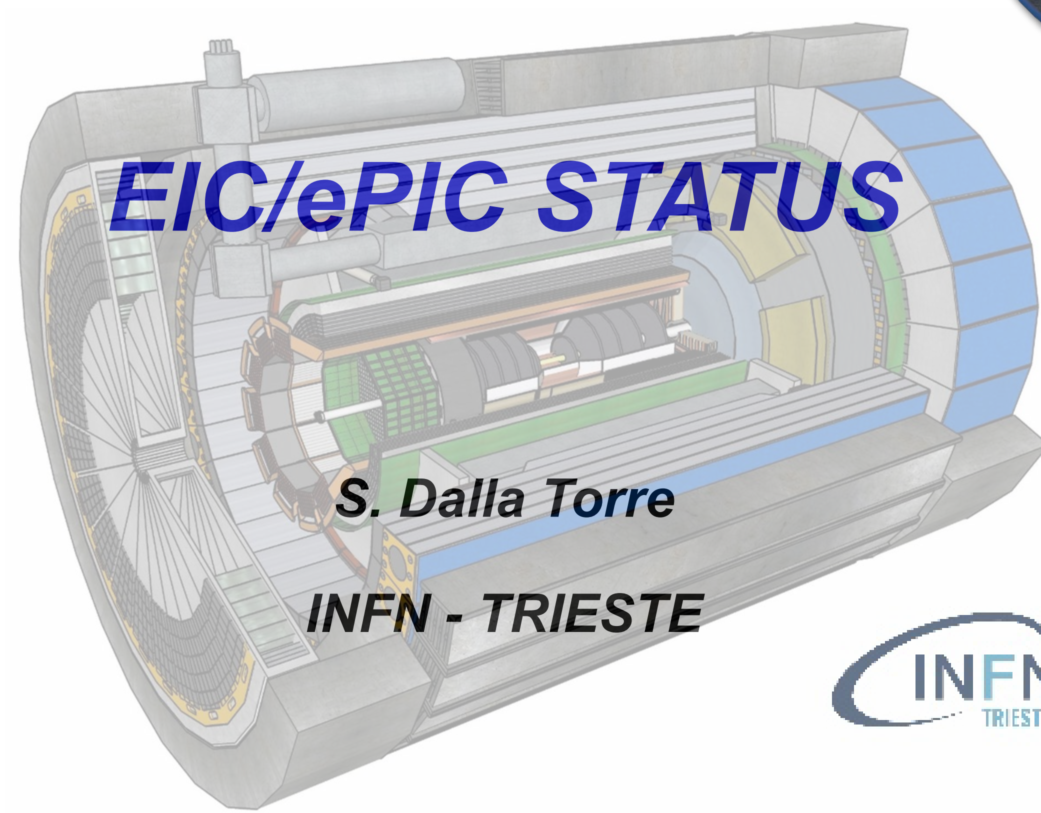


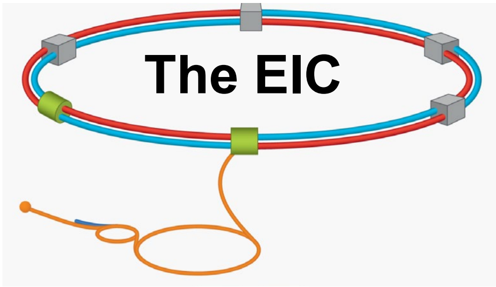
EIC/ePIC STATUS

S. Dalla Torre

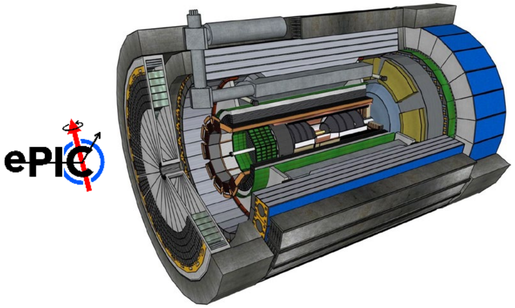
INFN - TRIESTE

EIC and ePIC in a nutshell

- **Enable the ultimate QCD exploration**



  - **By a high-luminosity polarized electron-ion collider: the EIC**



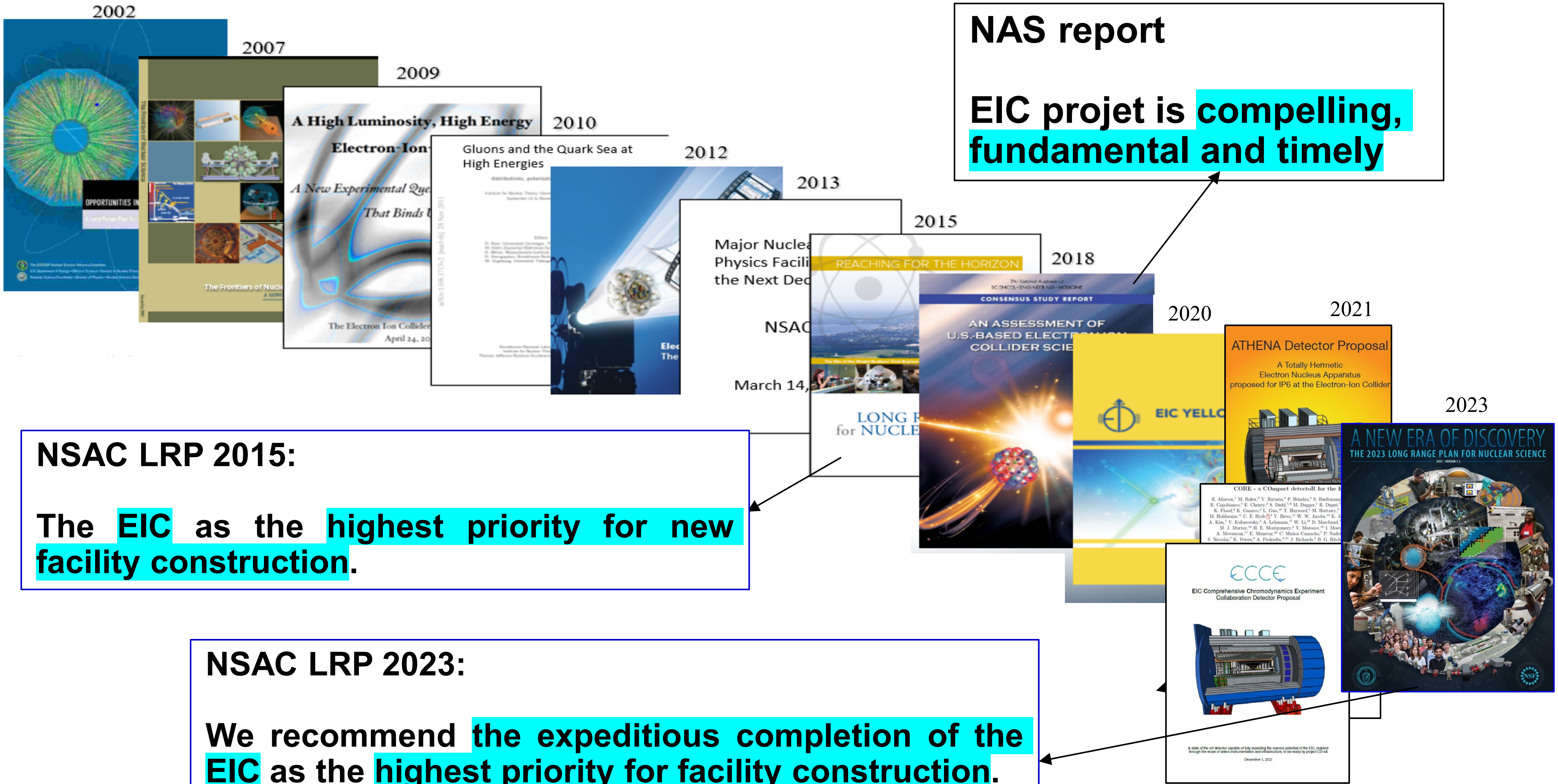
  - **By a detector highly integrated with the collider and capable to cope with the overall EIC physics scope, ePIC**

- **Status :**
  - **EIC is an approved project progressing towards its realization at BNL in cooperation with JLab**
  - **ePIC Collaboration established with > 1000 members and high international character**

OUTLOOK

- The path to the present status
- The EIC project and its physics scope
- The ePIC detector

THE PATH TO THE EIC PROJECT



NAS report

EIC projet is compelling, fundamental and timely

NSAC LRP 2015:

The EIC as the highest priority for new facility construction.

NSAC LRP 2023:

We recommend the expeditious completion of the EIC as the highest priority for facility construction.

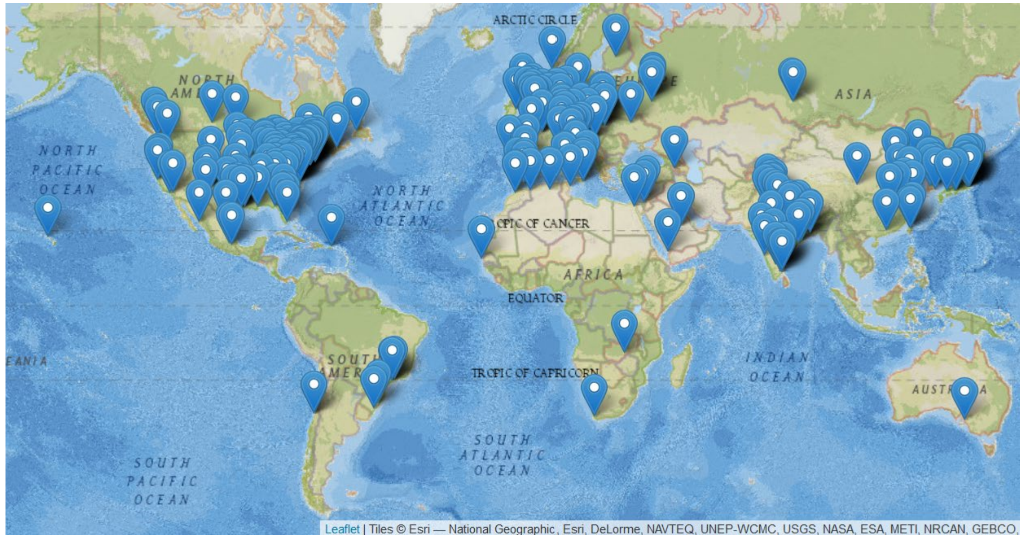
THE INTERNATIONAL COMMUNITY: the EIC-User Group

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

Formed in 2016 –

- **1550 members**
- **40 countries**
- **6 world regions**
- **303 institutions**

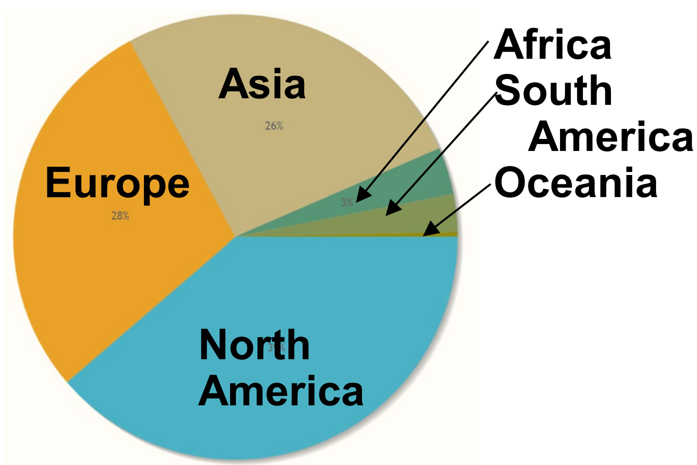
As of March 11th, 2025



Among the main Achievements:
The Yellow Report (2020)

Nucl. Phys. A 1026 (2022) 122447

Institutions



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 U., PA
2025 JLab, VA

The ePIC Collaboration

The community dedicated to the EIC science mission by the realization of the ePIC detector

JLab, Jan. 2023

Warsaw, July 2023

Lehigh, July 2024

ANL, Jan. 2024

Frascati, Jan 2025

The ePIC Collaboration

ePIC Institutions
177

ePIC countries
25

ePIC World Regions
4

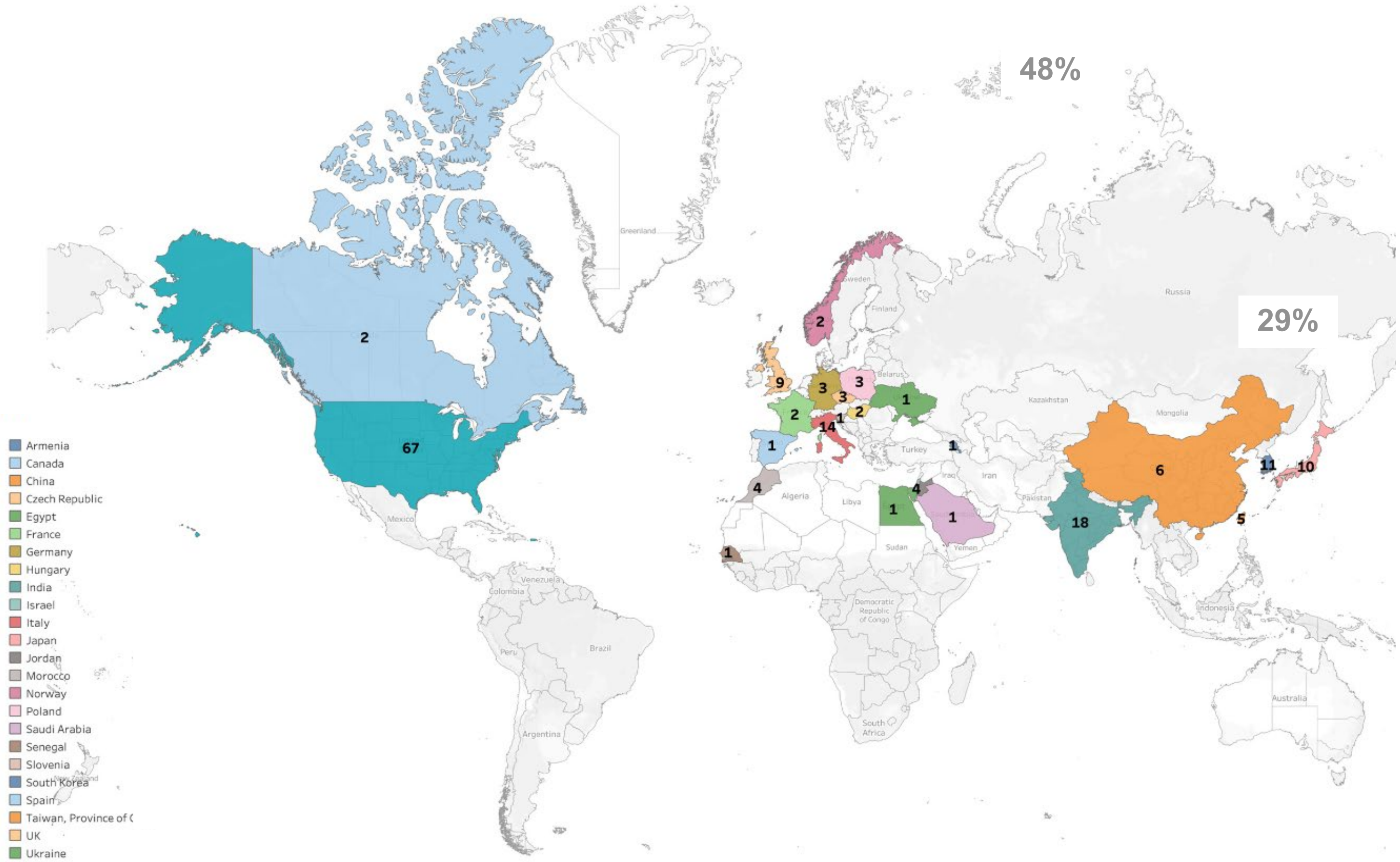
ePIC initiated
in July 2022

Currently:

1030 collaborators

USA: 48%

Europe: 29%



OUTLOOK

- The path to the present status
- The EIC project and its physics scope
- The ePIC detector

EIC PHYSICS: ultimate QCD exploration

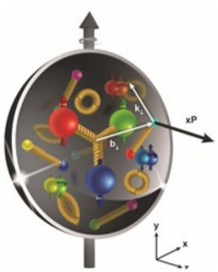
In short words:

Investigate with precision the universal dynamics of gluons to understand the emergence of hadronic and nuclear matter and their properties

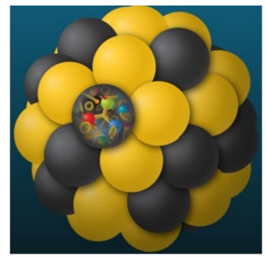
In terms of major open questions:

How does the **spin** of the nucleon arise?

How does the **mass** of the nucleon arise?



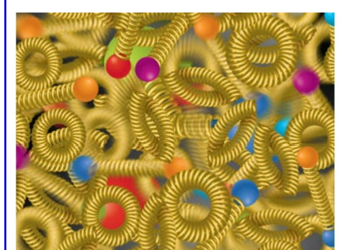
How are the **quarks and gluon distributed in space and momentum** inside the nucleon and nuclei?



How do quarks and gluons **interact with a nuclear medium**?

How do the **confined hadronic states** emerge?

How do the quark-gluon interactions create **nuclear binding**?



What are the emergent properties of **dense system of gluons**?

Ultimate QCD exploration

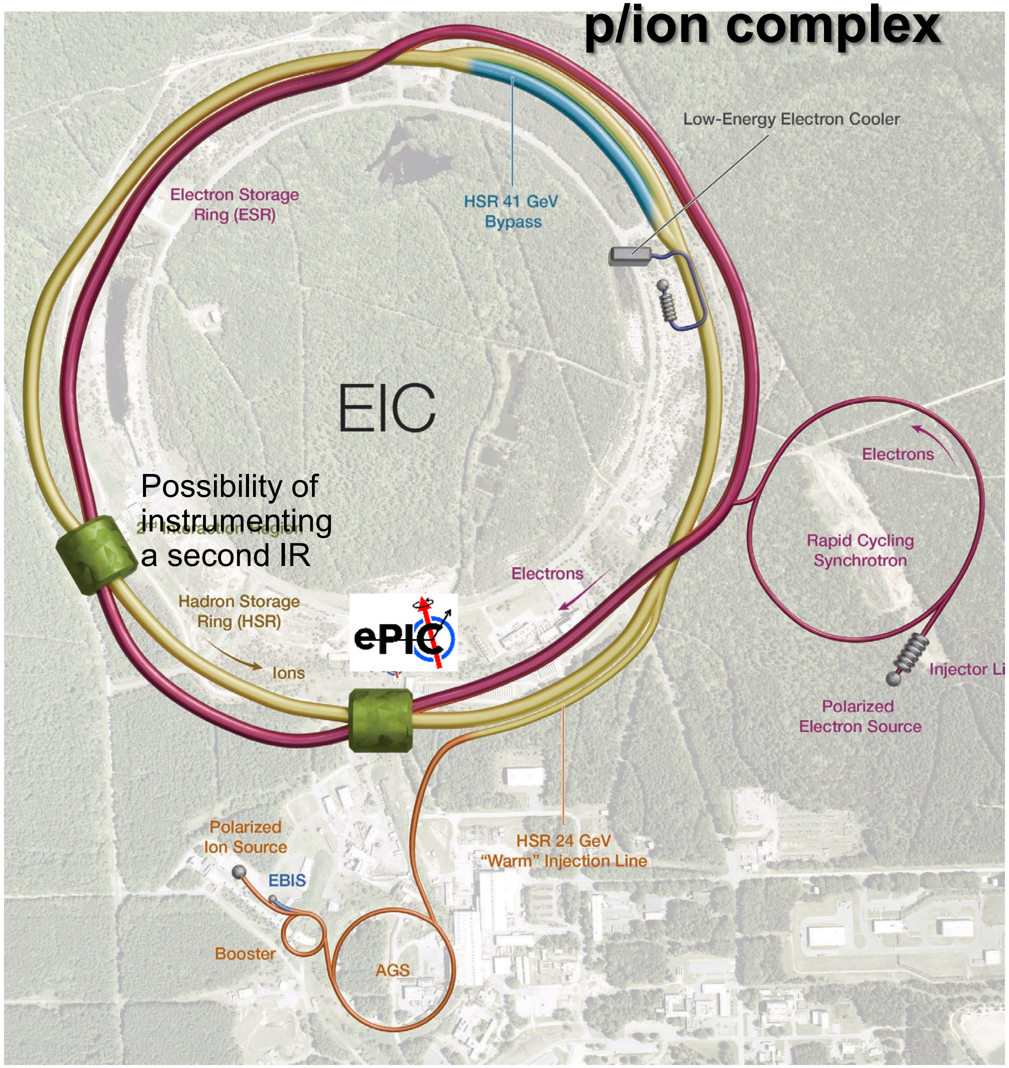
REQUIREMENTS

- Access to gluon dominated region and wide kinematic range in x and Q^2
- Access to spin structure and 3D spatial and momentum structure
- Accessing the highest gluon densities ($(Q_s^A)^2 \sim c Q_0^2 \left(\frac{A}{x}\right)^{1/3}$)
- Studying observables as a function of x, Q^2, A, hadronic flavour, …

THE EIC COLLIDER PROVIDES

- *Large center-of-mass energy range:*
  $\sqrt{s}$ = 28 -140 GeV
- *Polarized electron, proton and light nuclear beams ≥ 70%*
- *Nuclear beams, the heavier the better (from H to U)*
- *High luminosity (100 x HERA): $10^{33\text{-}34}$ cm^{-2} s^{-1}*

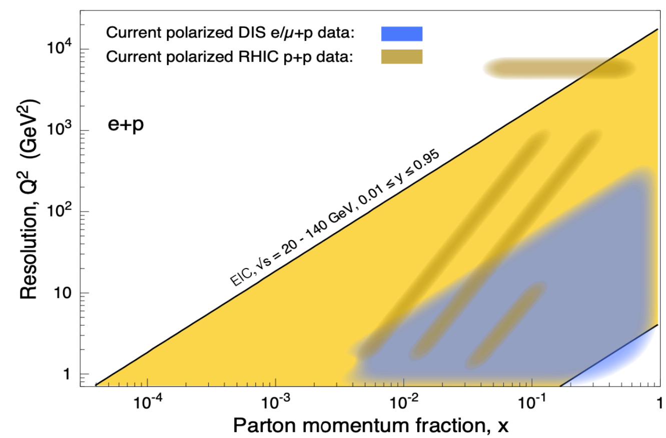
Usage of RHIC tunnel and RHIC p/ion complex



Design parameters

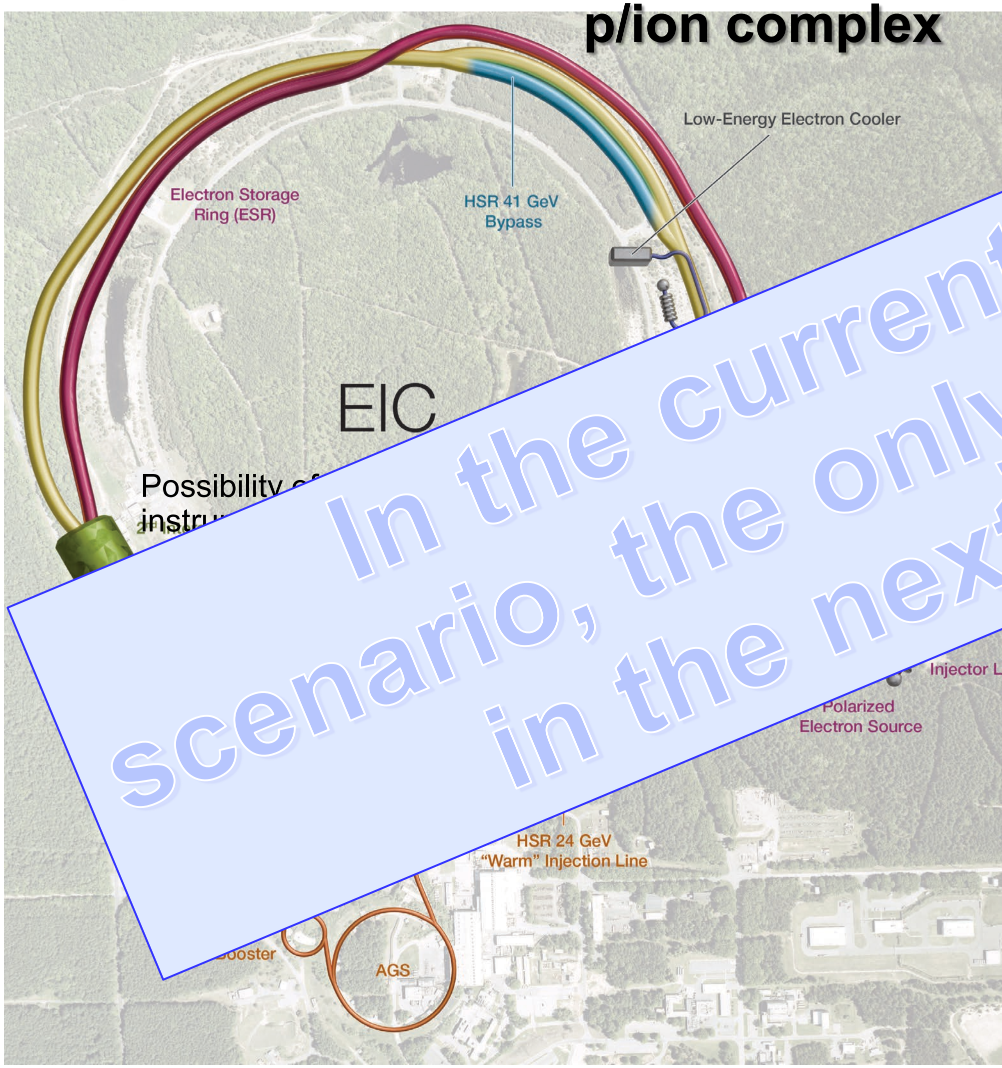
- **ep ECM: 28-140 GeV**
  - 2 decades increase in kinematic coverage in x and Q^2 respect to fix target
- **ep/eA luminosity up to 10^{33}-10^{34} cm^{-2} s^{-1}**
  - > 100 time higher luminosity as HERA
- **e, p beam polarization : 70%** → unique opportunity
  - Polarization of light nuclei
- **Ions from H to U** → ample variety
  - Up to the highest density gluon systems

Polarized e-p DIS



The EIC Collider

Usage of RHIC tunnel and RHIC p/ion complex

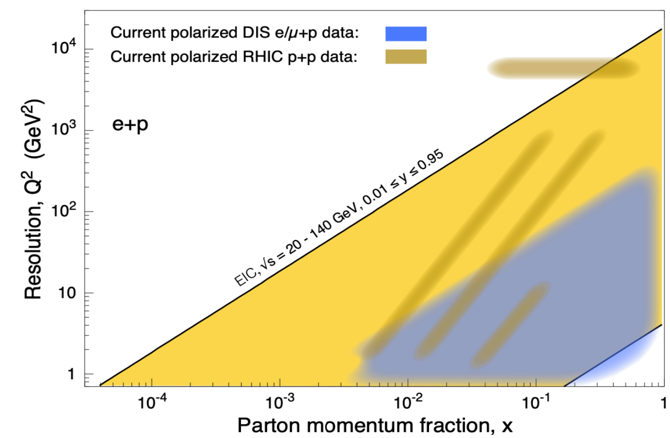


In the current worldwide scenario, the only novel HE collider in the next 10-20 years

Design parameters

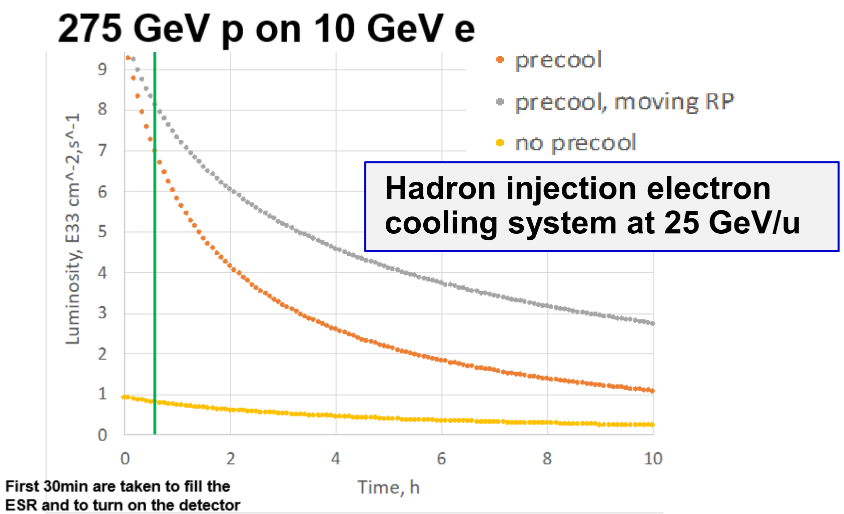
- **ep ECM: 28-14**
  - 2 d
- ERA
- **%** → unique opportunity
- n of light nuclei
- **from H to U** → ample variety
  - Up to the highest density gluon systems

Polarized e-p DIS



The EIC Collider

4 critical ingredients for HIGH LUMINOSITY



Bunches and beam crossing rates

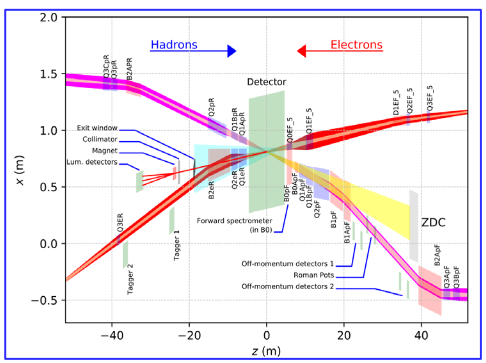
Species	p	e	p	e	p	e	p	e	p	e
Beam energy [GeV]	275	18	275	10	100	10	100	5	41	5
$\sqrt{s}$ [GeV]	140.7		104.9		63.2		44.7		28.6	
No. of bunches	290		1160		1160		1160		1160	

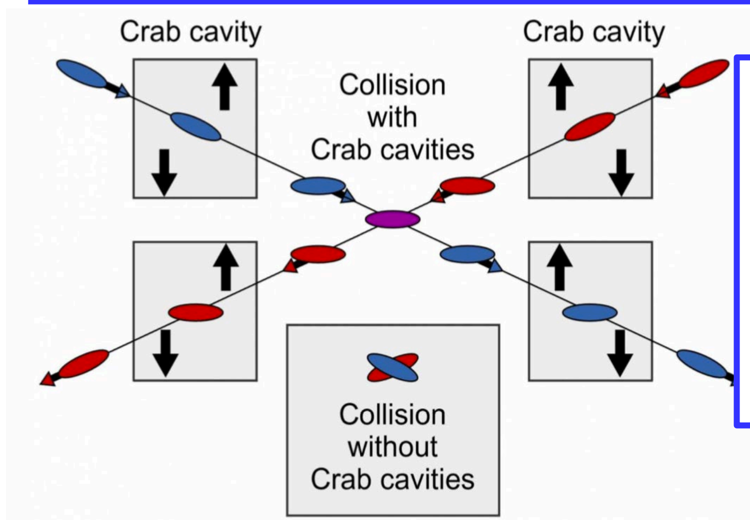
Species	Au	e	Au	e	Au	e	Au	e
Beam energy [GeV]	110	18	110	10	110	5	41	5
$\sqrt{s}$ [GeV]	89.0		66.3		46.9		28.6	
No. of bunches	290		1160		1160		1160	

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

a challenge for the collider and the experiment !

Small β^*_y → quads close to IP leaving ~10 m for the detector





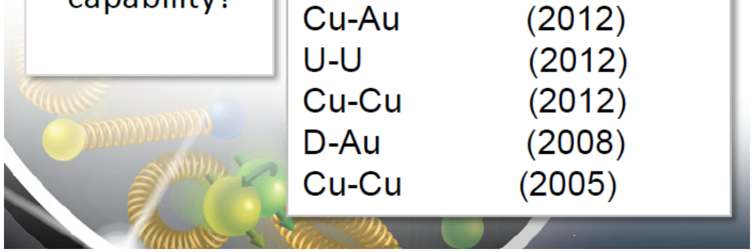
CRAB CROSSING ANGLE (25 mrad) to restore head-on collisions

The EIC Collider

MORE unique aspects

ION SPECIES

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

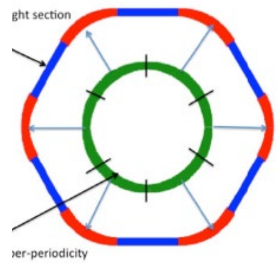


Ion Pairs in the RHIC Complex	
Zr-Zr, Ru-Ru	(2018)
Au-Au	(2016)
d-Au	(2016)
p-Al	(2015)
h-Au	(2015)
p-Au	(2015)
Cu-Au	(2012)
U-U	(2012)
Cu-Cu	(2012)
D-Au	(2008)
Cu-Cu	(2005)

Enormous versatility! is a unique capability!

BEAM POLARIZATION

ABOUT e POLARIZATION



➔ resonance free acceleration up >18 GeV

on average, every bunch refilled in 2.2 min

ABOUT p/ light ion POLARIZATION

presently

<u>Measured RHIC Results:</u>

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

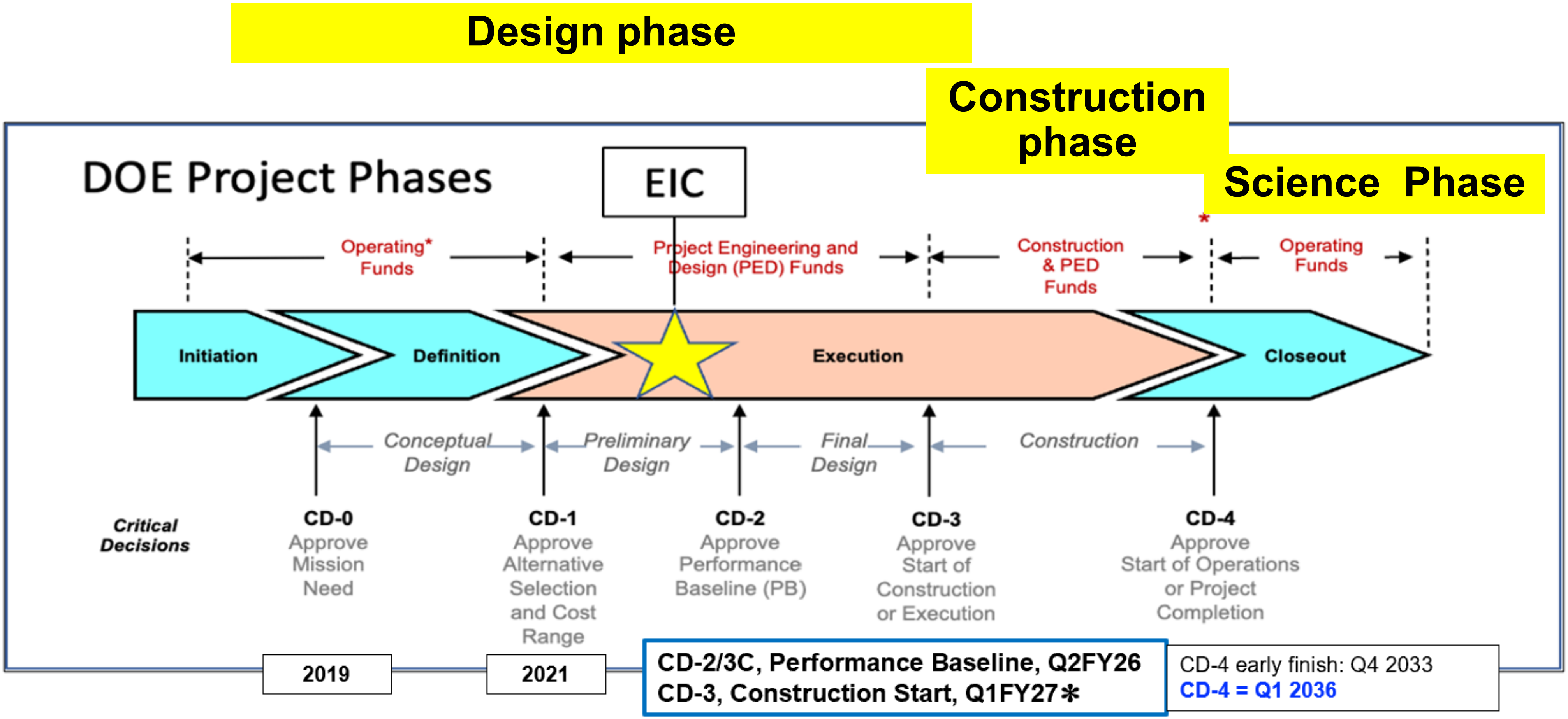
empowerment

<u>Planned near term improvements:</u>

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

The EIC schedule



- CD-3A, Long Lead Procurement, approved March 2024. Excellent use of IRA funding.
- CD-3B, Long Lead Procurement, approval planned for March 2025.
- CD-2, Project Performance Baseline, requires a more certain annual funding profile.

✻ FY25 and FY26 funding will impact CD-2 and CD-3 milestone dates.

OUTLOOK

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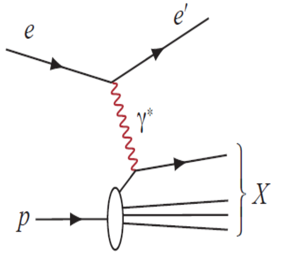
- The ePIC detector

Ultimate QCD exploration

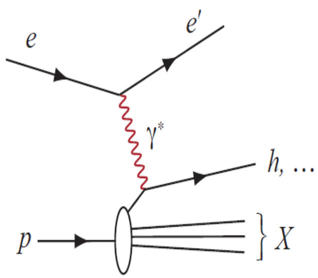
REQUIREMENTS → ePIC detector

Measurement categories to address EIC physics:



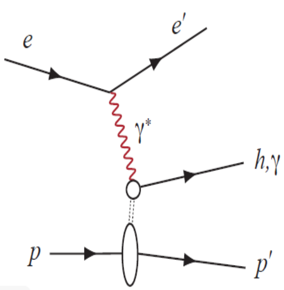
- Inclusive DIS
  - fine multi-dimensional binning in x, Q^2

- ***Large coverage ($-3.5 < \eta < 3.5$) for wide phase-space reach***
- ***Excellent EM-calorimetry with PID support for e/π separation***
- ***Fine resolution tracking by low mass detectors***



- Semi-inclusive DIS
  - 5-dimensional binning in x, Q^2, z, p_T, θ

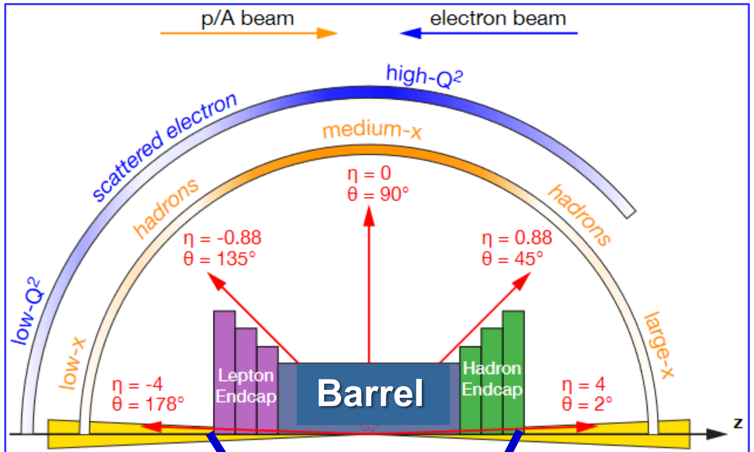
- ***Fine p_T resolution***
- ***Extended PID systems for hadron identification***
- ***H-calorimetry to attempt TMD assessment with jets (new world-wide), as tail catcher, for μ identification***

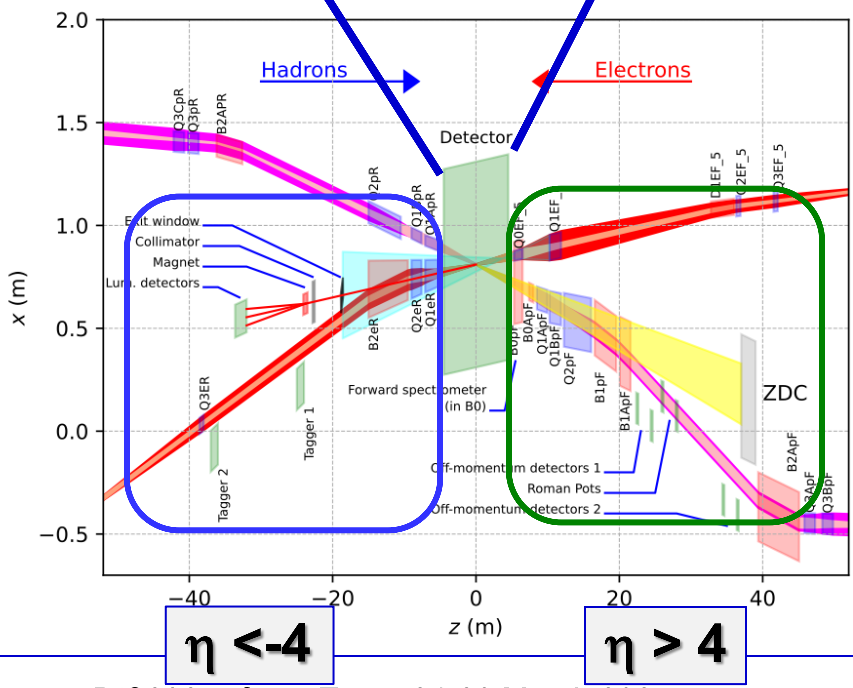


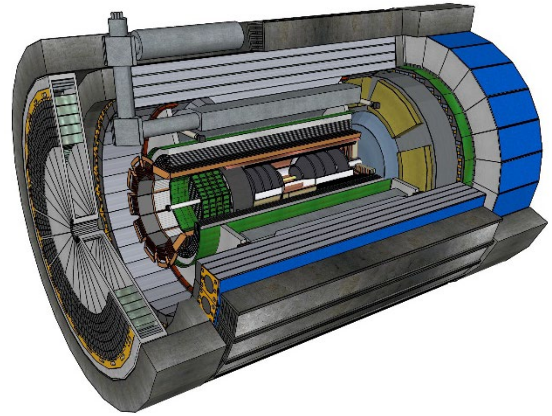
- Exclusive processes
  - 4-dimensional binning in x, Q^2, t, θ to reach |t| > 1 GeV2

- ***Extend acceptance at extremely small scattering angles***
- ***Fine vertex resolution by tracking***

THE COMPLETE ePIC DETECTOR

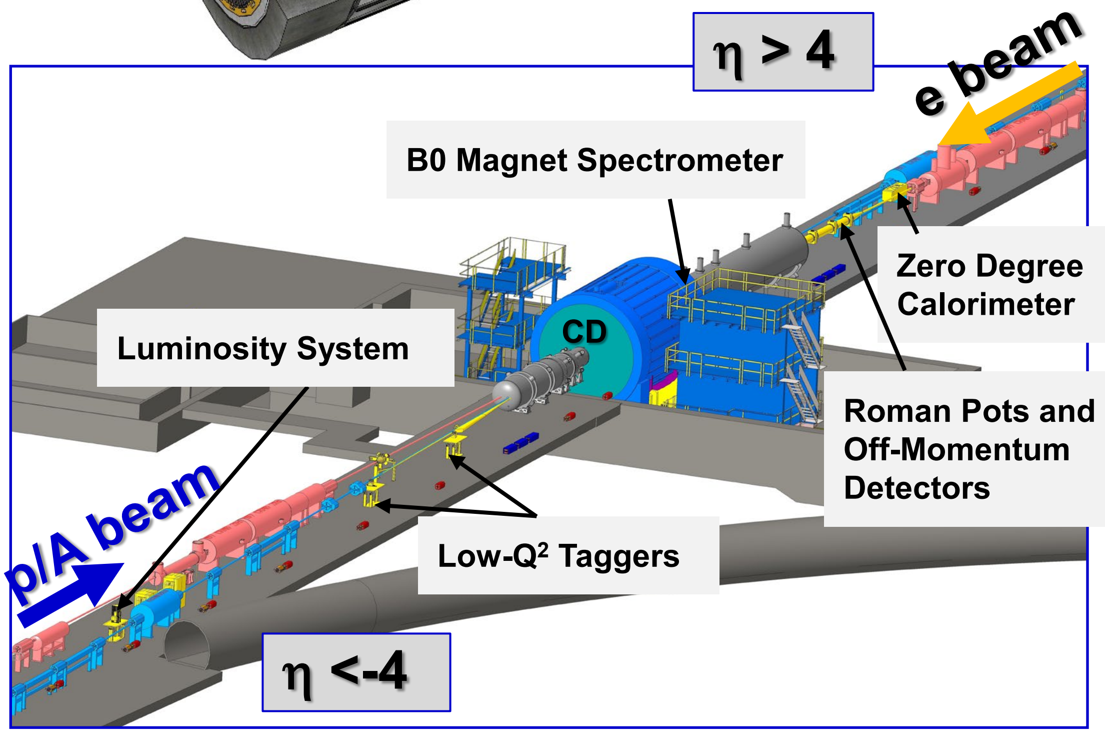




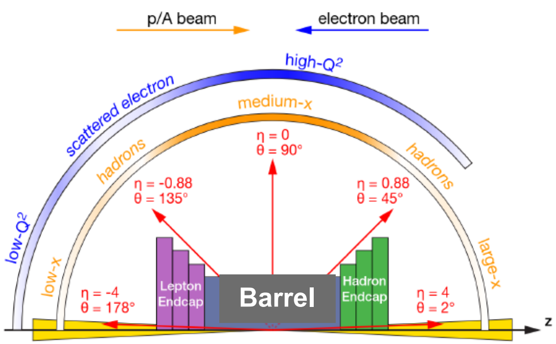


Central Detector (CD)

-4 < η < +4



ePIC Central Detector (CD)



Very naturally organized in:

- Backward endcap
- Barrel
- Forward endcap subsystems

hadronic calorimeters

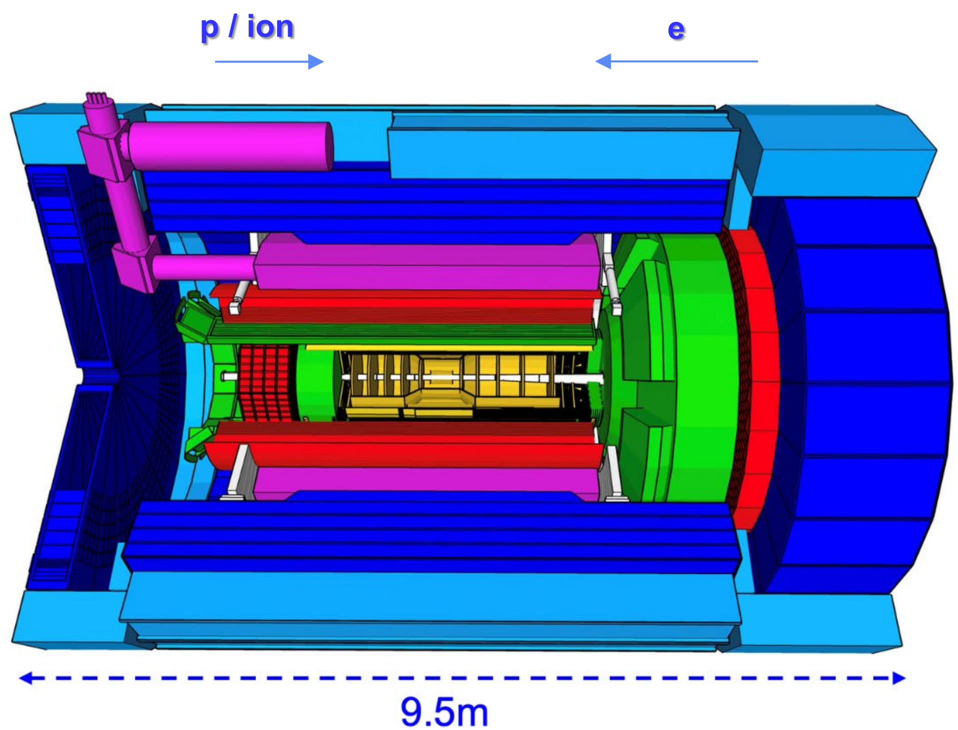
Solenoidal Magnet

e/m calorimeters (ECal)

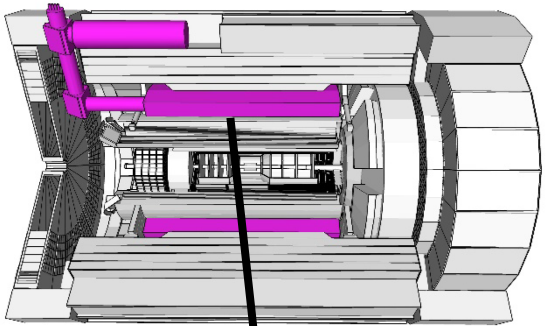
Time.of.Flight, DIRC, RICH detectors

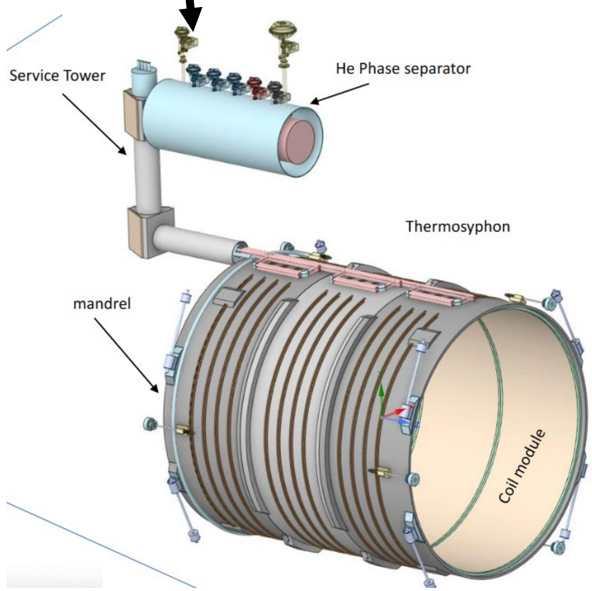
MPGD trackers

MAPS tracker



The ePIC solenoid



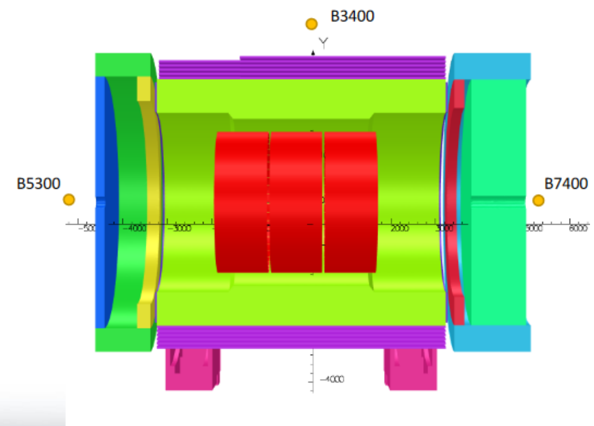


Parameter	Value
Coil length	3512 mm
Warm bore diameter	2840 mm
Cryostat length	< 3850 mm
Cryostat outer diameter	< 3540 mm

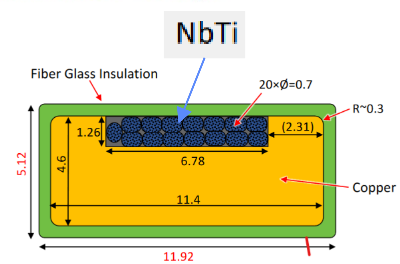
Parameter	Value	Comment
Central Field B_0	2.0 T	
Lowest operating field	0.5 T	
Field Uniformity in FFA	12.5 % ± 100 cm around center 80 cm radius	Magnetic Field Properties
Projectivity in RICH Area	< 0.1 (mrad@30GeV/c) < 10 T/A/mm² From Z = 180 cm to 280 cm	

Reference field value: 1.7 T

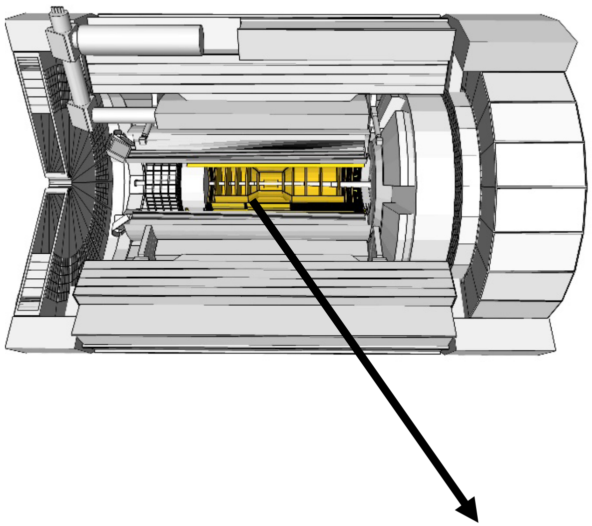
Parameter	Value	Comment
B5300 (B @ Z= -5300 mm)	< 10 G	Stray field requirement is based on IR magnet location
B7400 (B @ Z= 7400 mm)	< 10 G	
B3400 (B @ R= 3400 mm)	< 10 G	



Conductor Design



TRACKING IN ePIC CD

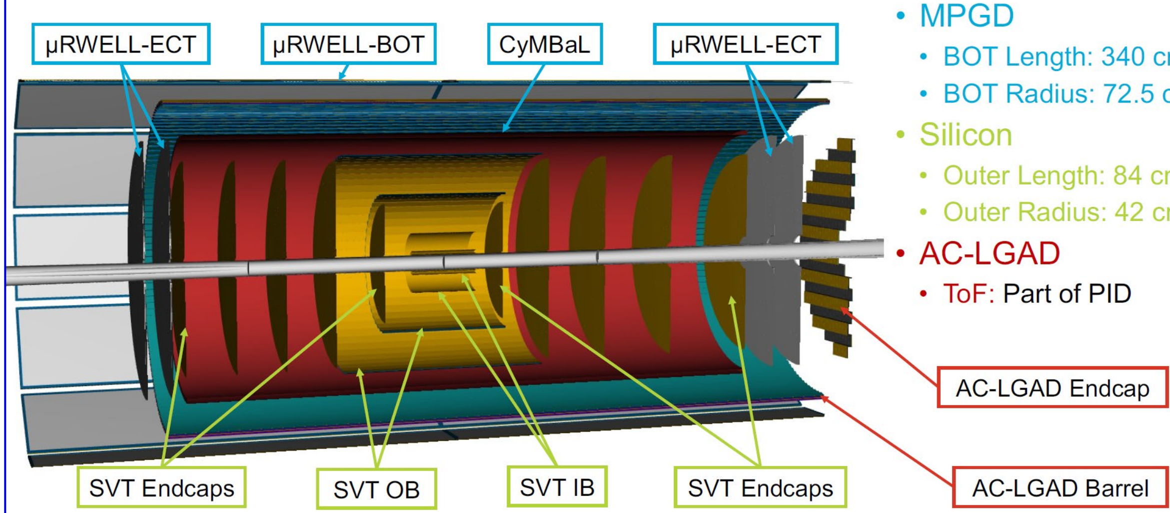


Complementary tracking technologies characterized by light materials

SVT: Si trackers based on ALICE ITS3 65 nm MAPS sensors
- **Fine space resolution < 5 μm**
- **Five cylindrical layers in the barrel and five disks in each endcap**

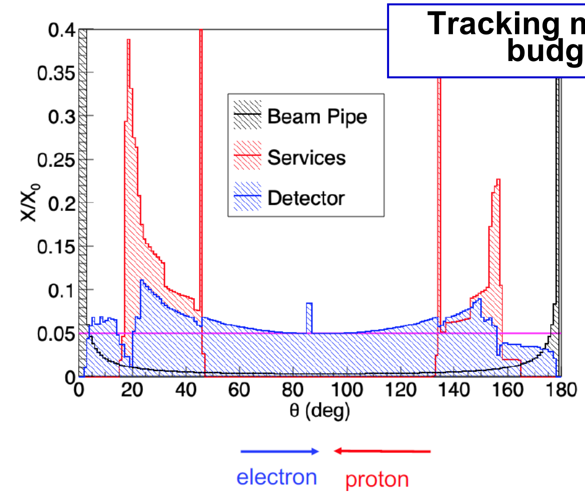
MPGD trackers
- **Good time resolution $\mathcal{O}$ (10 ns)**
- **Cylindrical MICROMEGAS**
- **Planar μR-WELL with GEM pre-amplification**

Additional information
- AC-LGADs for ToF (PID) - very fine time resolution: 20/30 ps
- First layer of the barrel imaging EM calorimeter – fine space resolution (150 μm), good time resolution (~ 2 ns)



- MPGD
  - BOT Length: 340 cm
  - BOT Radius: 72.5 cm
- Silicon
  - Outer Length: 84 cm
  - Outer Radius: 42 cm
- AC-LGAD
  - ToF: Part of PID

Tracking material budget



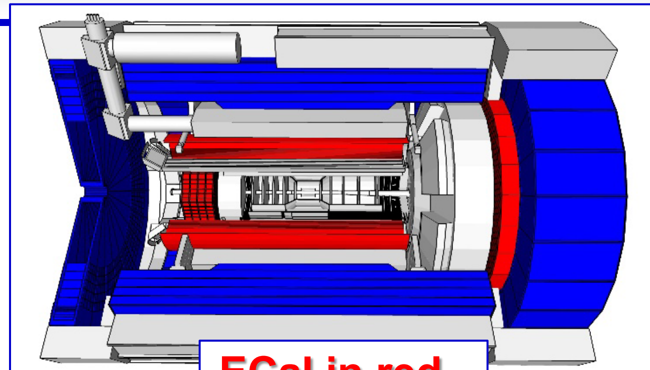
SENSORS FOR CALORIMETRY IN ePIC

SiPM sensors for all Calorimeters in ePIC

- **SiPMs recently introduced in calorimetry**
- direct experience is coming from the applications in GlueX, STAR and sPHENIX
- these colleagues now at work for ePIC calorimetry

Relevant SiPM features for ePIC calorimetry

- **Cost-effective** technology
- Operation in **magnetic field**
- Wide **dynamic range** with tuned parameters for the different calorimeters
- Low **noise** with appropriate thresholding
- Effect of the radiation
  - Not new, already addressed for STAR and sPHENIX
  - Further irradiation campaigns on-going

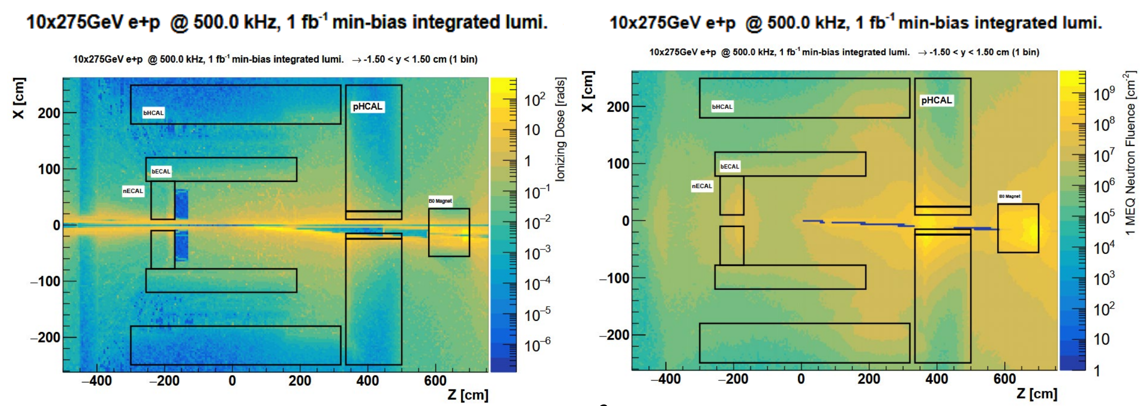


ECal in red
HCal in blue

SiPM requirements for HCals

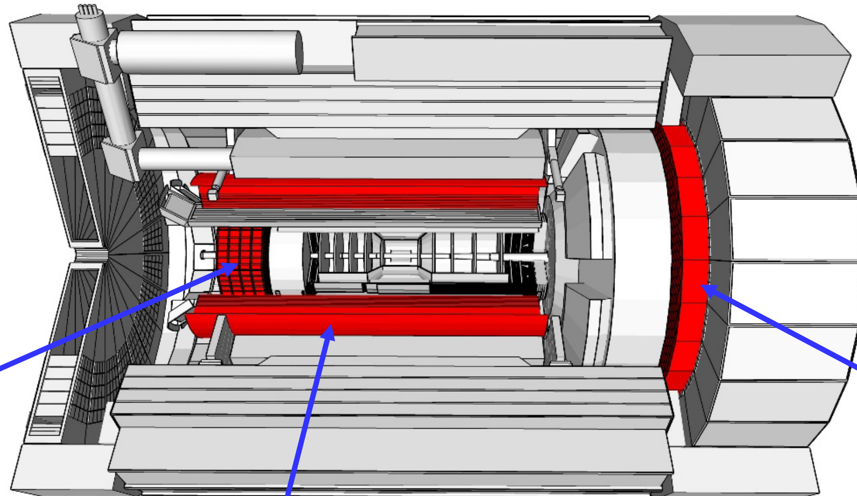
Parameter	Value
Size	1.3mm x 1.3mm
Pixel size	15 µm
Photon Detection Efficiency (PDE)	>25%
Dark Count Rate (DCR)	<400 kHz
Gain	> 5*10^5
Fill factor	>40%
Peak sensitivity	~450 nm

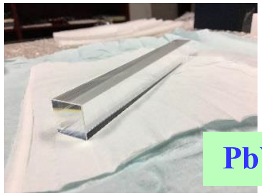
Rad Dose and Neutron Flux



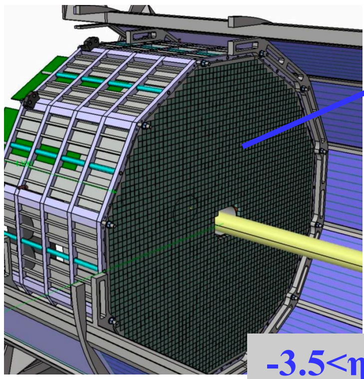
Doses and fluxes ~ 10^{-3} compared to HL-LHC

ELECTROMAGNETIC CALORIMETRY IN ePIC CD

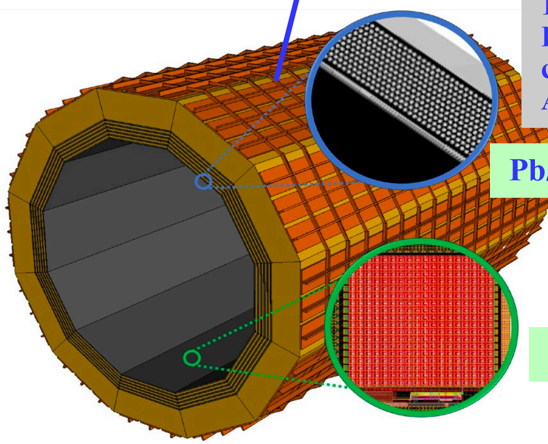




PbWO4



$-3.5<\eta<-1.7$
$22X_0$
~3k crystals
R_{outer}=64cm

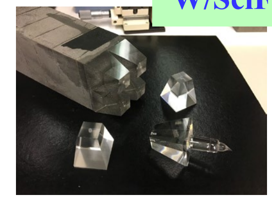


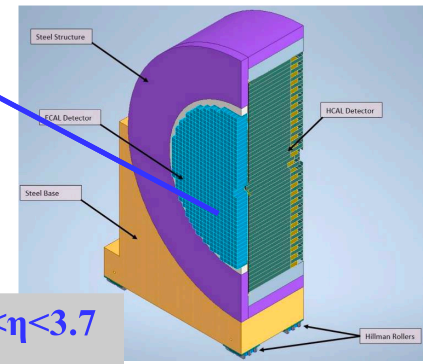
$-1.7<\eta<1.4$
$17X_0$
Pb/SciFi: 5760 readout ch.s
AstroPix: ~0.5B pixels

Pb/SciFi

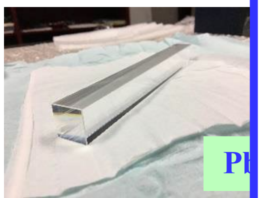
AstroPix

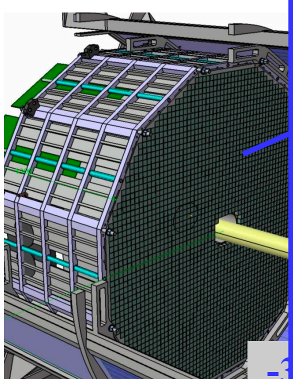
W/SciFi

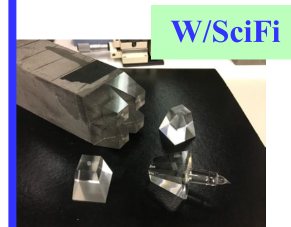


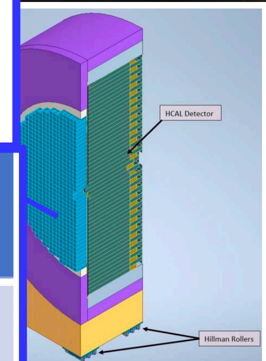


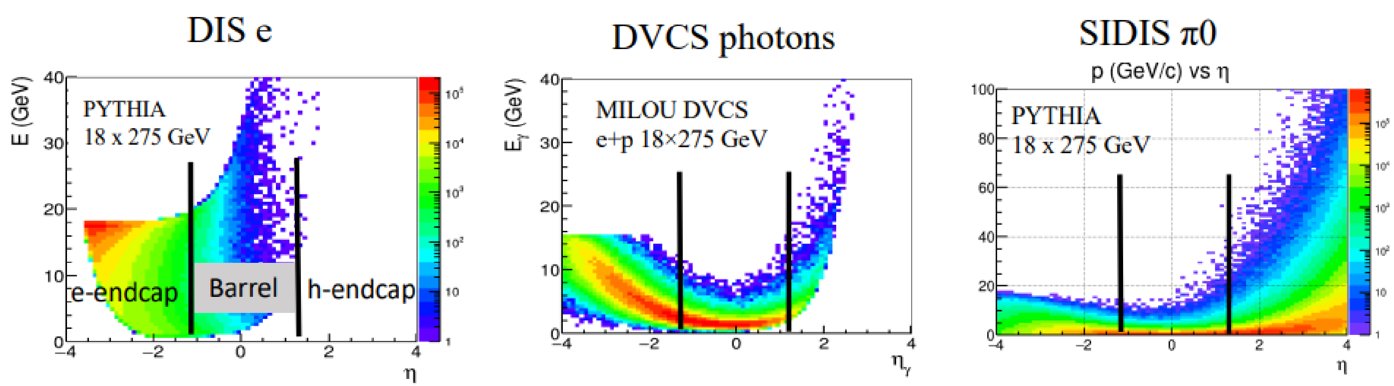
$1.4<\eta<3.7$
$23X_0$
~16k towers
R_{outer}=160cm



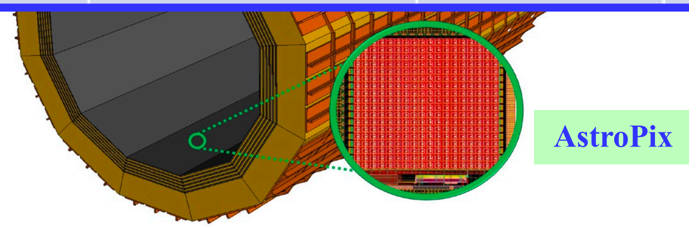








	σ_E/E	E range, GeV	$\pi^{\pm}$ suppression (In combination with other subsystems)	$\pi0/\gamma$ discr.
e-endcap	$\frac{(2-3)\%}{\sqrt{E}} \oplus (1-2)\%$	0.05–18 GeV	Up to 10^4	Up to 7 GeV/c
Barrel	$\frac{(7-10)\%}{\sqrt{E}} \oplus (1-3)\%$	0.05–50 GeV	Up to 10^4	Up to 10 GeV/c
h-endcap	$\frac{(10-12)\%}{\sqrt{E}} \oplus (1-3)\%$	0.1–100 GeV	Up to 10^4	Up to 50 GeV/c

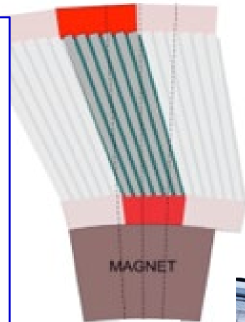


HADRON CALORIMETRY IN ePIC CD

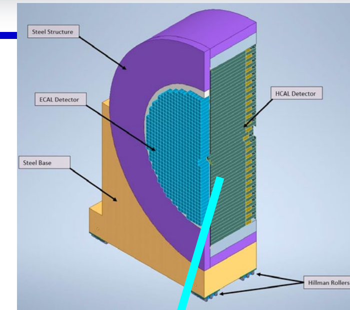
Backward and barrel:

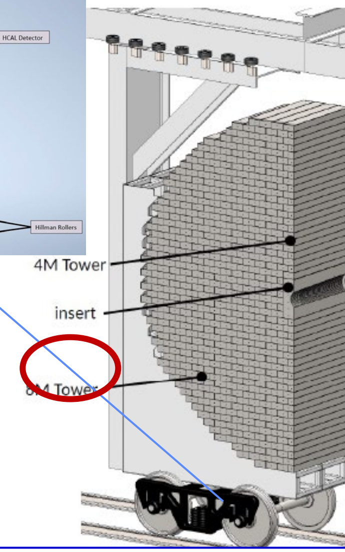
Steel/scintillator sampling calorimetry - CONSOLIDATED TECHNOLOGY

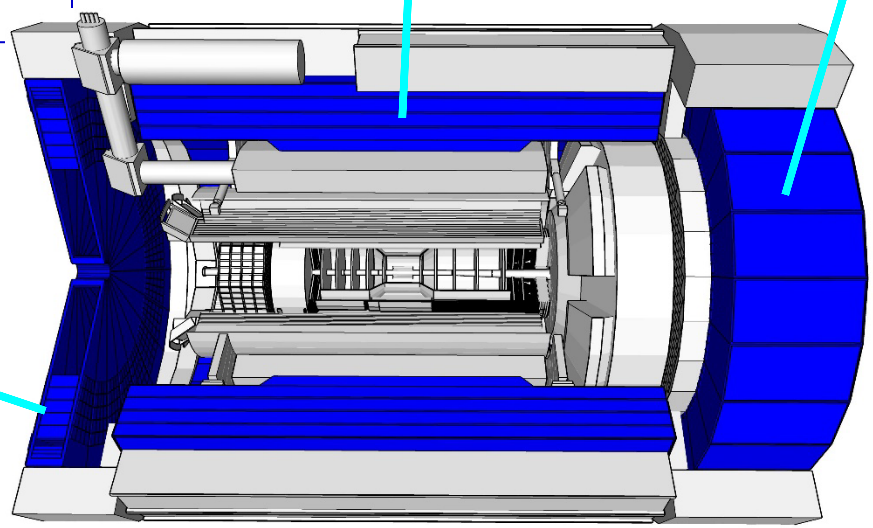
- Identification of neutral hadron jets, especially at low x
- Tail catcher for e/m calorimeter
- μ identification

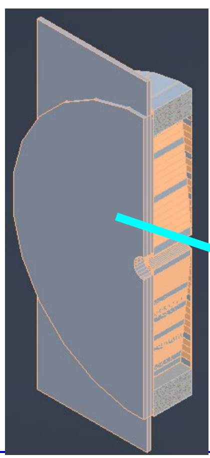


Barrel Hcal
(re-use from sPHENIX)



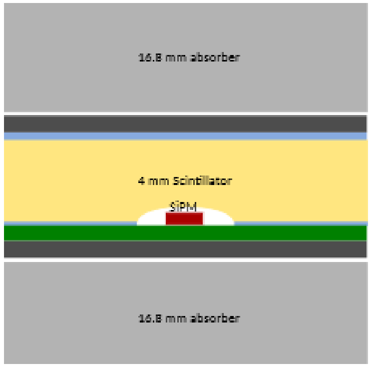






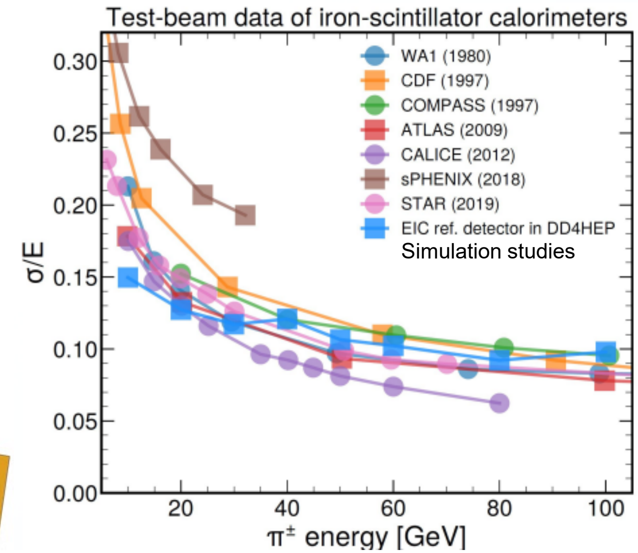
Forward endcap

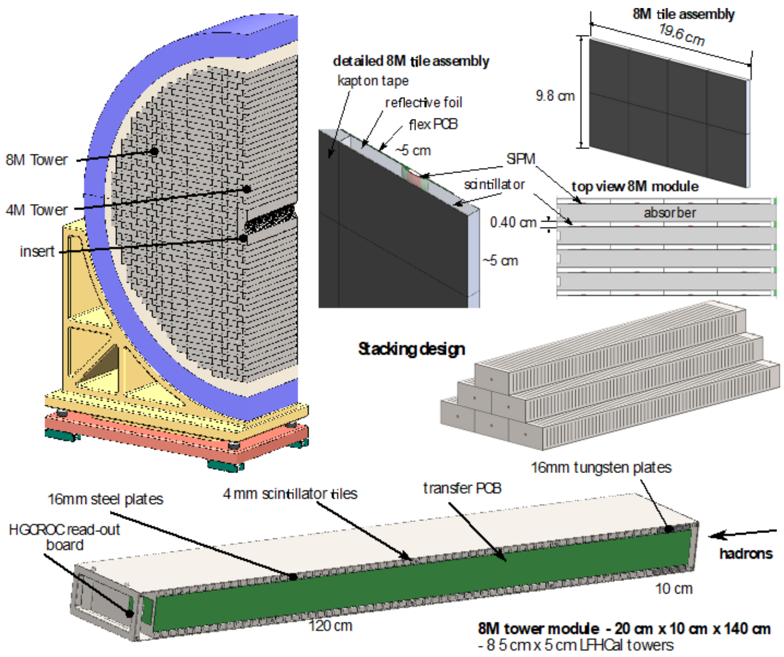
- Original design inspired by CALICE development:
- "SiPM on TILE"
- High granularity insert at high η
- Jet energy measurement
- DIS kinematics reconstruction "Hadronic method"
- muon ID



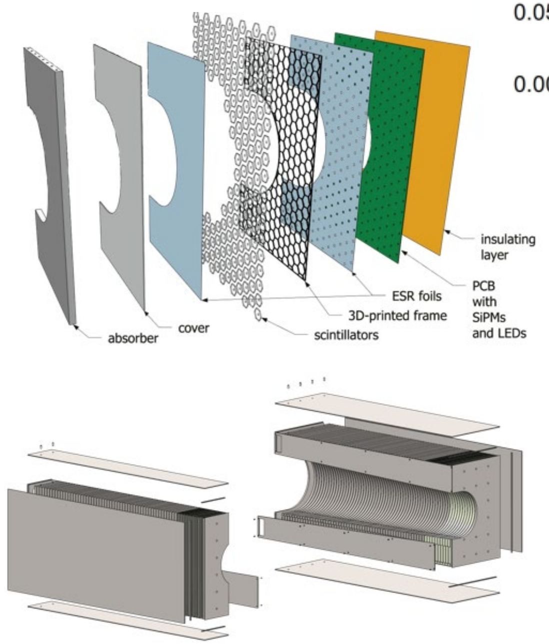
EHal in forward endcap: "SiPM on tile"

- **Sampling calorimetry with Fe absorber**
- **Derived by a development for CALICE**
- Tower structure with read-out at the rear face

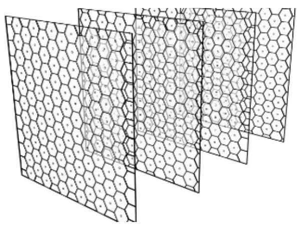




The Insert

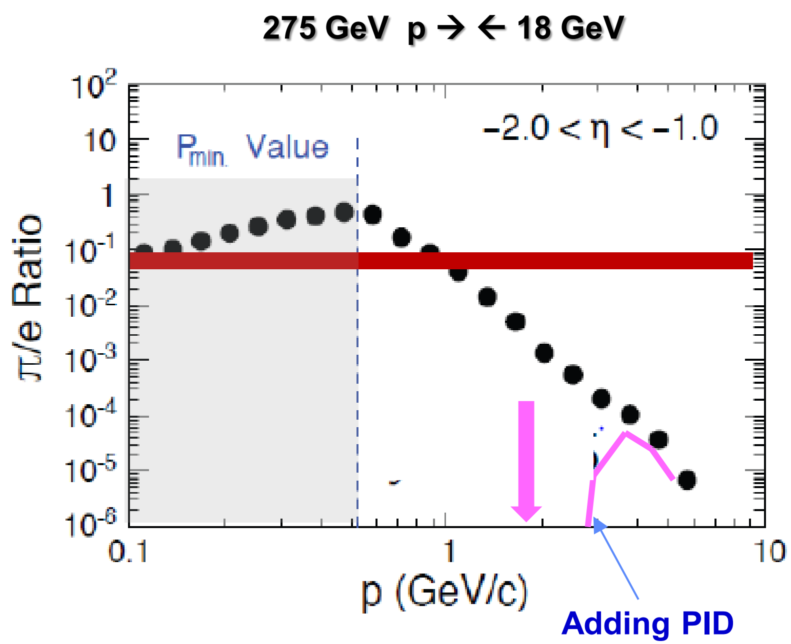


with staggered tiles for improved space resolution



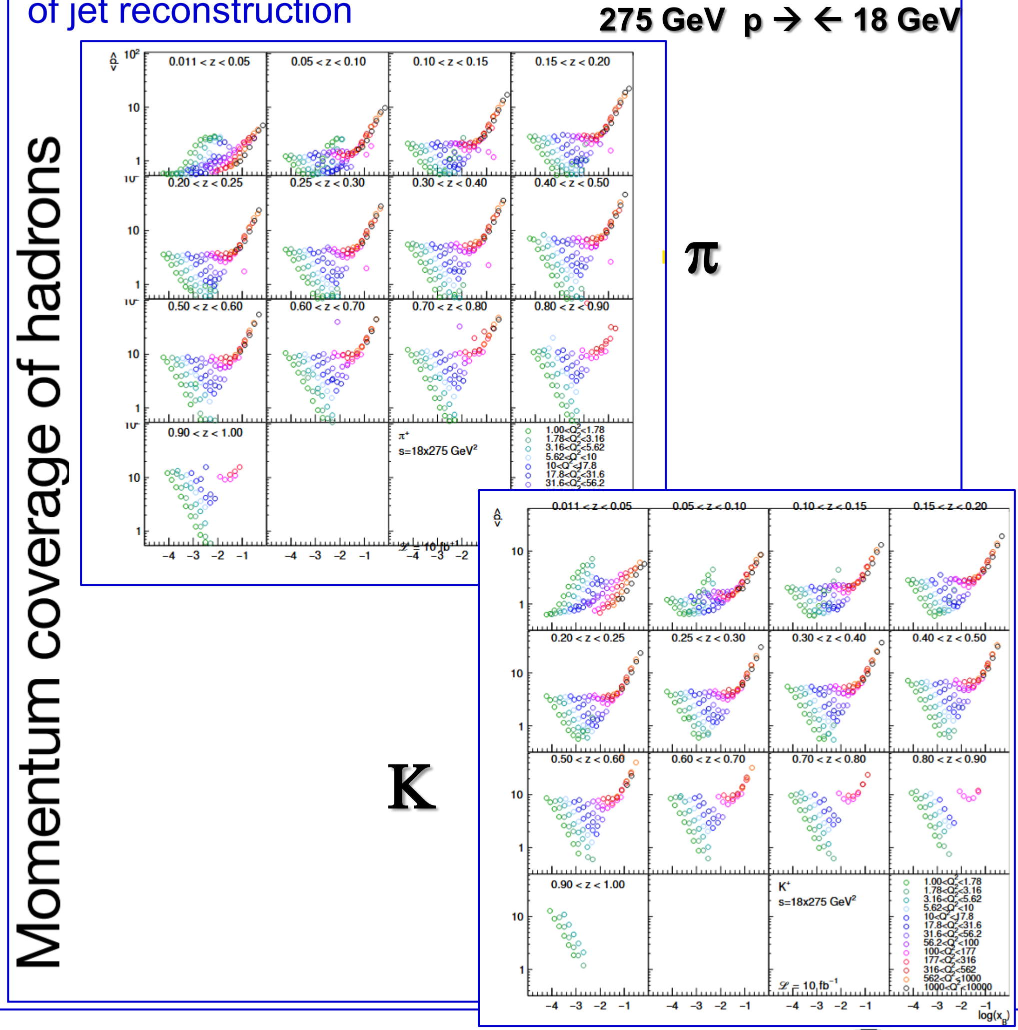
The double role of PID in ePIC CD

Support electron identification, which cannot be provided by ECals only in DIS experiments with electron beams (see HERMES, JLab)



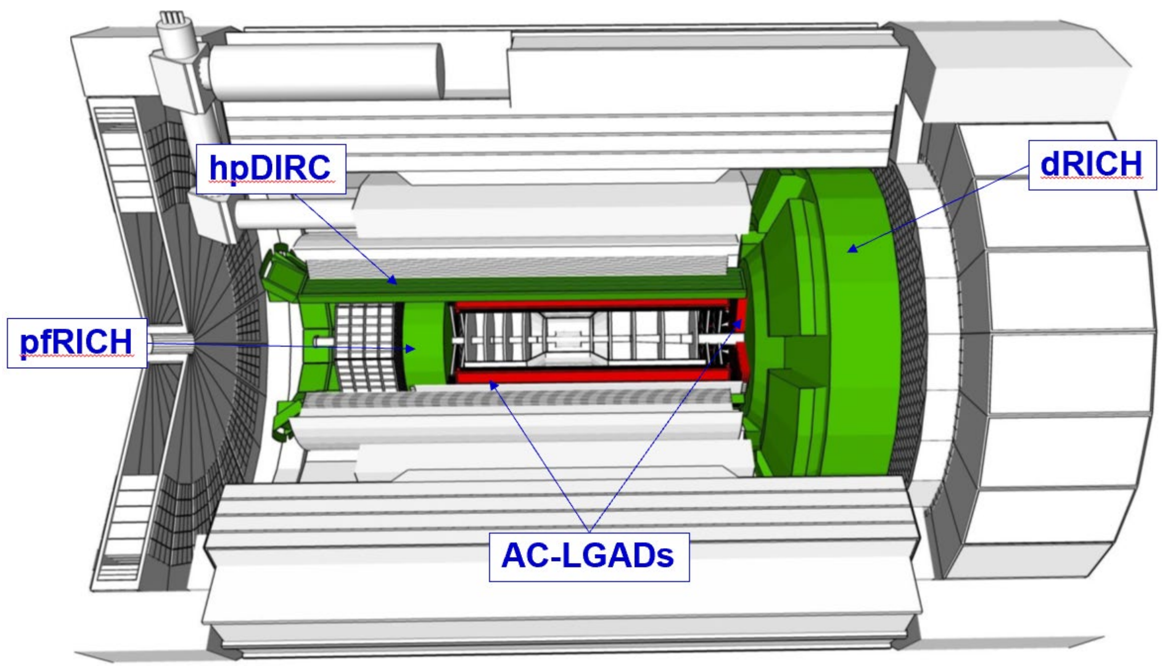
The different physics channels require π contamination in the electron sample down to 10^{-4}

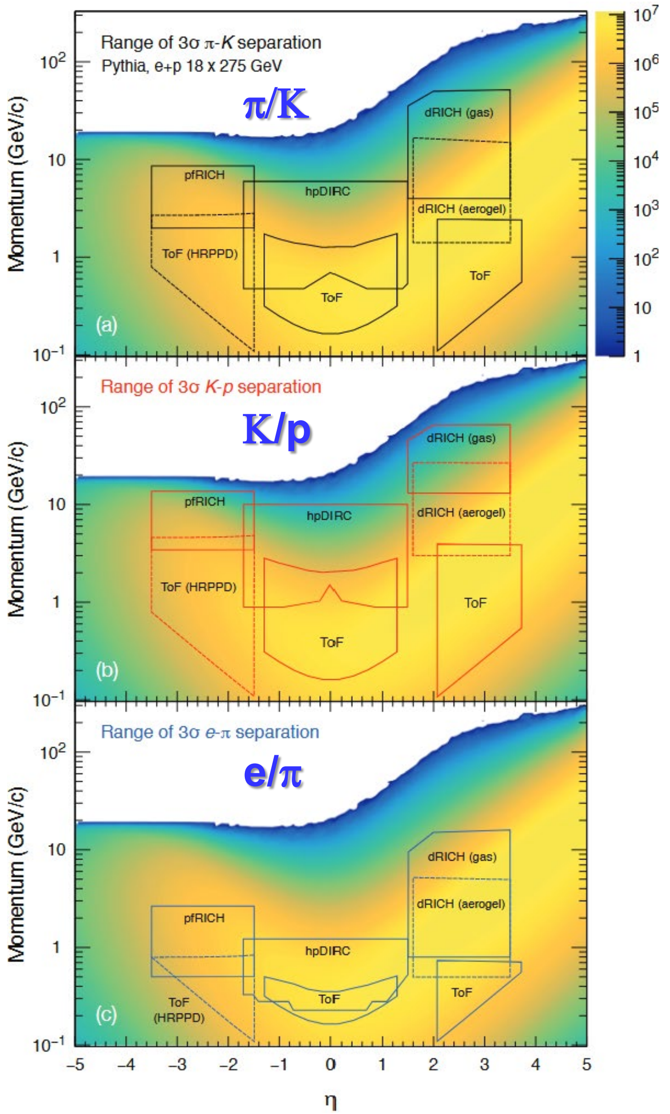
Hadron identification, a key ingredient for TMDs address by SIDIS and with the novel approach of jet reconstruction



DIS Pythia, e+p 18 x 275 GeV

3 σ separation areas



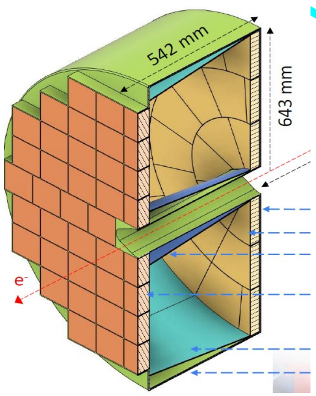


PID IN ePIC CD

Cherenkov imaging PID in backward endcap:

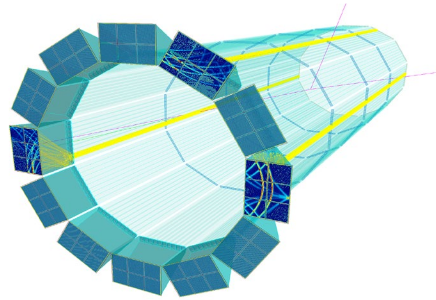
proximity focusing RICH (pfRICH)

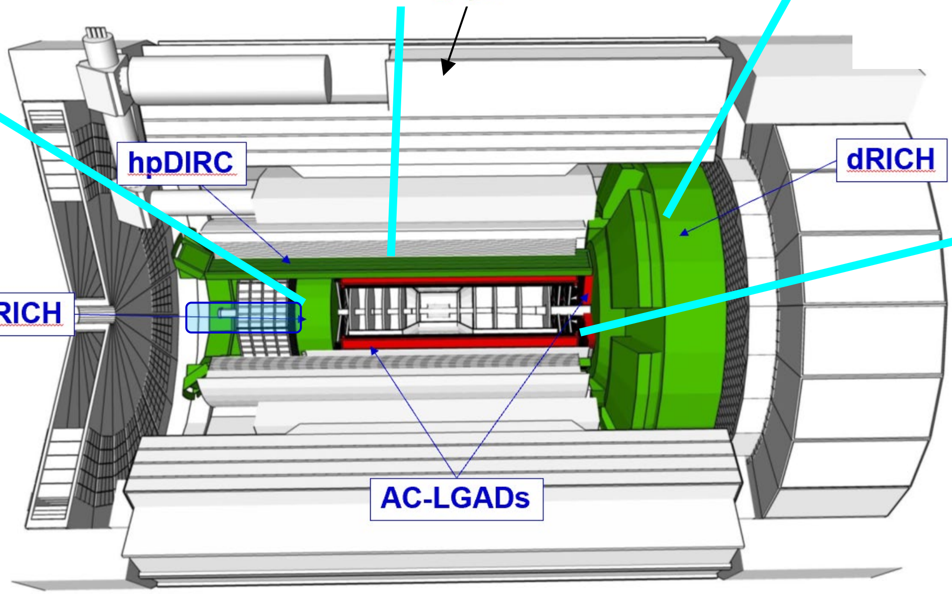
The long proximity gap (~ 35 cm) enhances the resolution



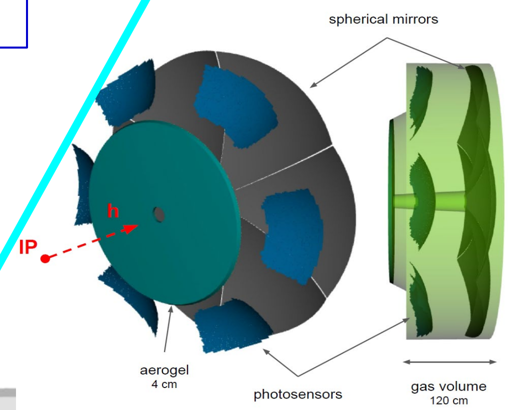
High performance DIRC (hpDIRC)

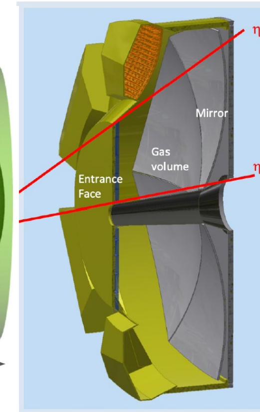
High performance thanks to **focalization** and **fine photosensor pizelization**

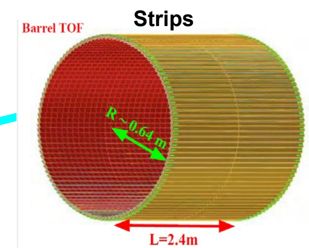


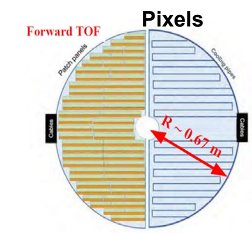


Dual radiator RICH (dRICH); Areogel and gas









ToF by AC-LGADs

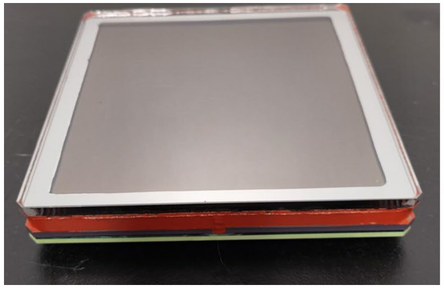
Goals for the application in ePIC:

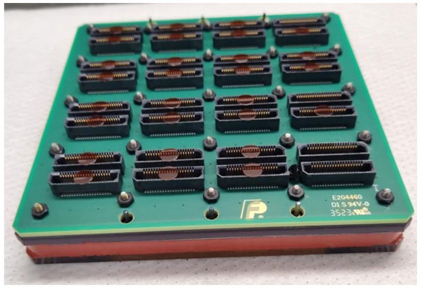
- **30 μm space resolution**
- **25-35 ps time resolution**

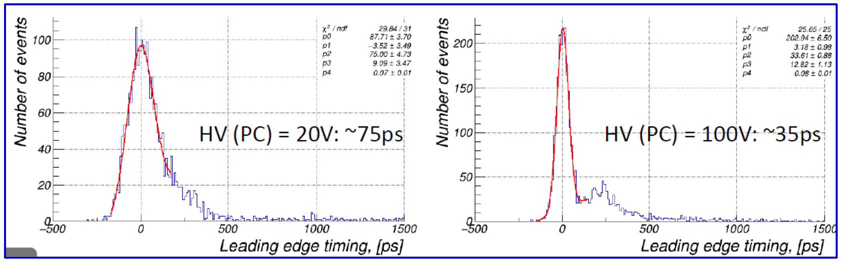
PHOTOSENSORS for CHERENKOV PID IN ePIC

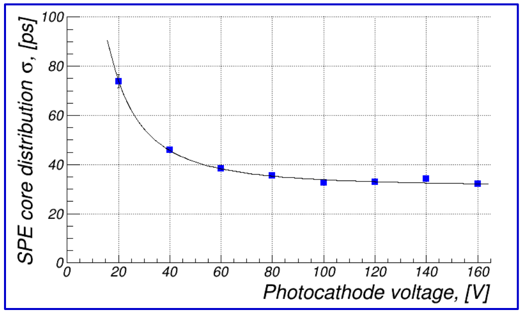
For pfRICH (option for hpDIRC) :
HRPPDs by INCOM

→ large-size (12 x 12 cm^2) MCP-PMTs, pixelized



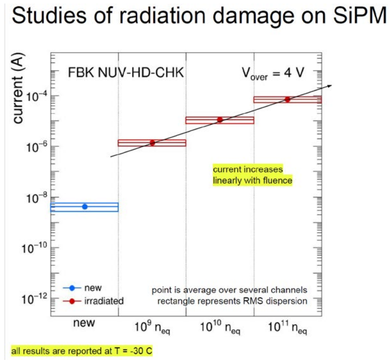


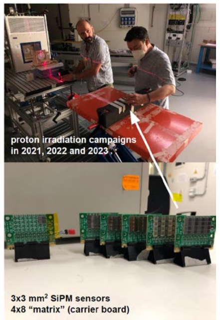


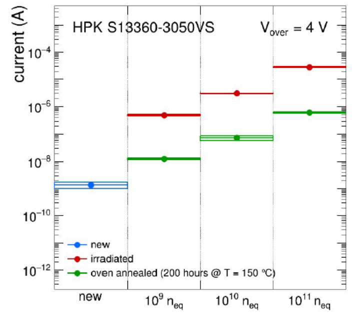


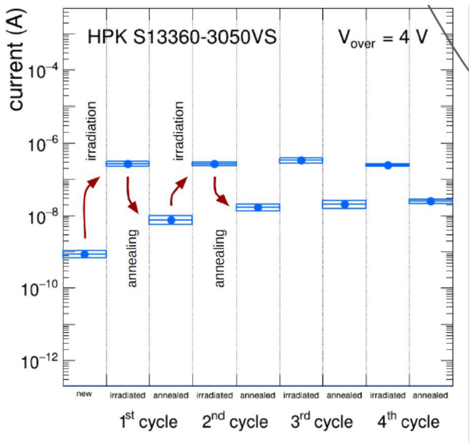
For dRICH : **SiPMs at -30°C**

→ Robust R&D for the validation

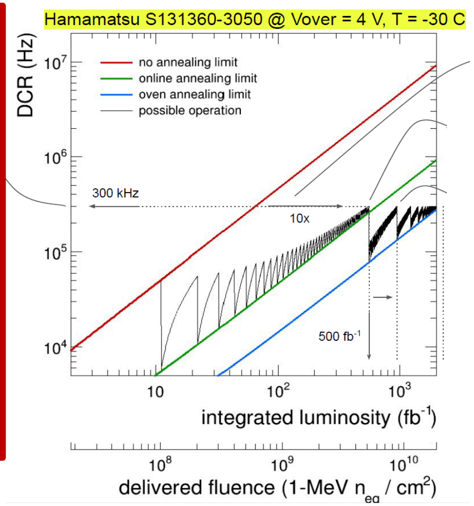








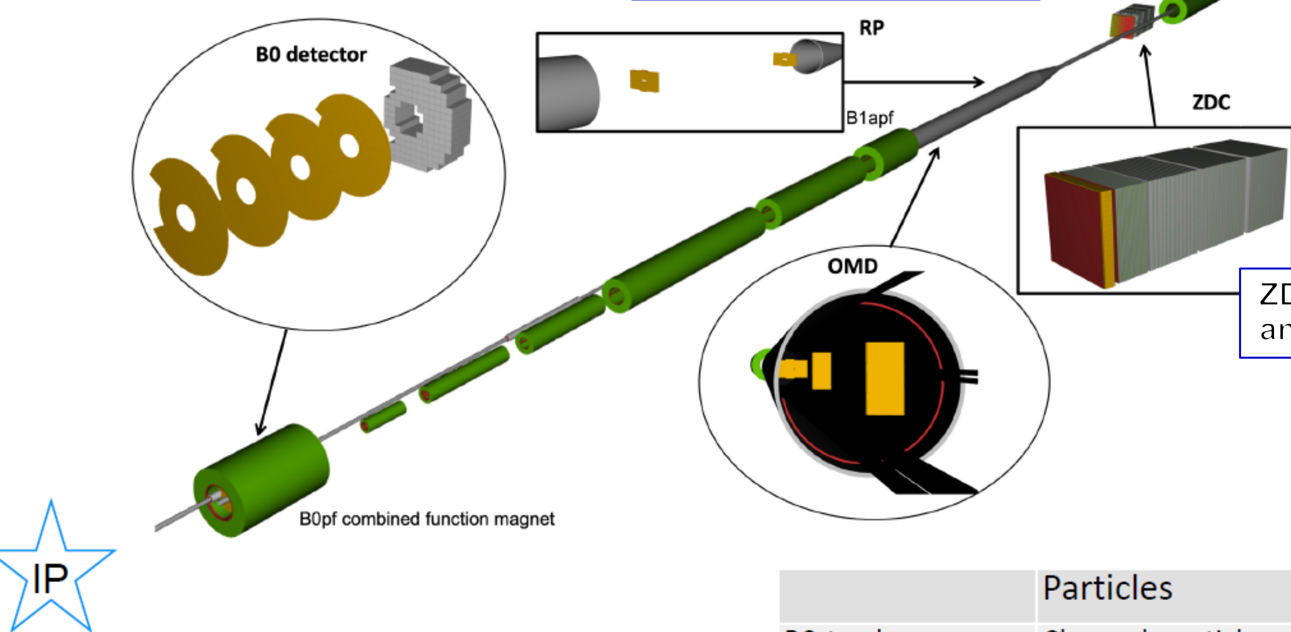
Ageing model



FAR FORWARD DETECTORS

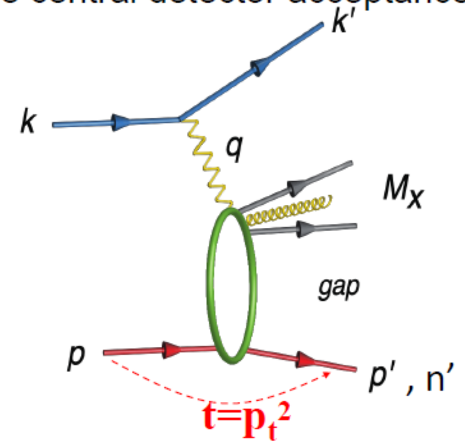
B0 trackers with AC-LGADS
B0 calorimetry by crystals

RPs and OMDs by
pixelized AC-LGADs



ZDC by crystals
and SiPM-on-tile

Exclusive /diffractive reactions driving the design of FF area -> reconstruction of particles outside of the central detector acceptance



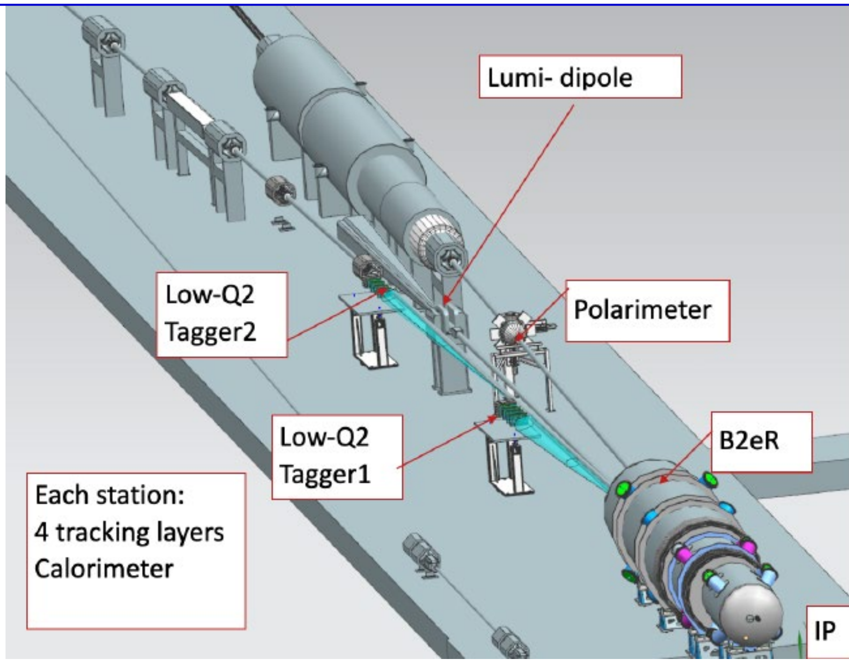
- ✓protons at wide range of p_T^2
- ✓protons with **different rigidity**
- ✓**neutrons and photons**

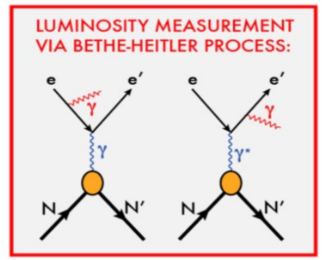
	Particles	Angle [mrad]		Distance from IP
B0-tracker	Charged particles Photons (tagged)	5.5 - 20		ca 6-7 m
Off-momentum	Charged particles	0-5.0	0.4< xL< 0.65	ca 23-25 m
Roman Pots	Protons Light nuclei	0*-5.0	0.6 < xL< 0.95	ca 27-30 m
ZDC	Neutrons Photons	0-4.0 (5.5)		ca 35 m

THE ePIC FAR BACKWARD DETECTORS

- ➢ This area is designed to provide coverage for the low-Q2 events (photoproduction, $Q^2 < \sim 1 GeV^2$) . Need to measure a scattered electron position/angle and energy
- ➢ And luminosity detector (ep -> e'pγ bremsstrahlung photons)

<u>Low Q2 taggers</u>
- High rate capability, Fine tracking, pixelization
- Tracking – <u>Timepix4 Hybrid</u> (ASIC+Si tracker) – Calorimetry – W/SciFi

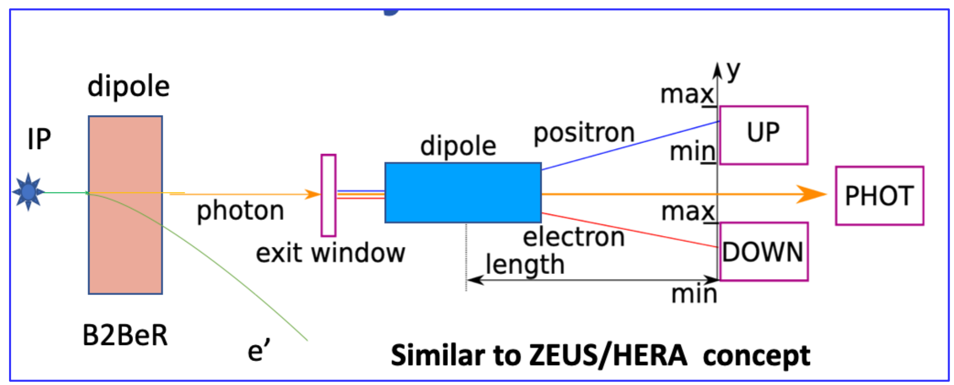




<u>Luminosity – high rate</u>
calorimeter - W-SCiFi

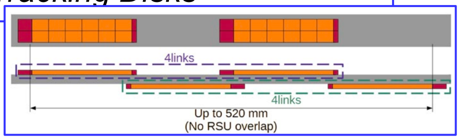
<u>LUMINOSITY – pair spectrometers</u>
- TRACKING – AC-LGAD strips
- CALORIMETRY – W-SciFi

Luminosity monitor and measurement

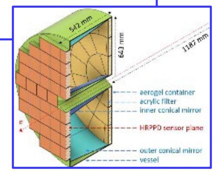


TECHNOLOGIES: WORLD FIRST AT ePIC

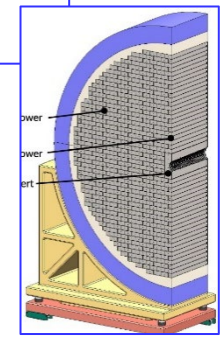
EIC Large Area Sensor (**LAS**), modification of ITS3 sensor with 5 or 6 RSU forming staves as the basic building elements *for the Outer Barrel and the Tracking Disks*

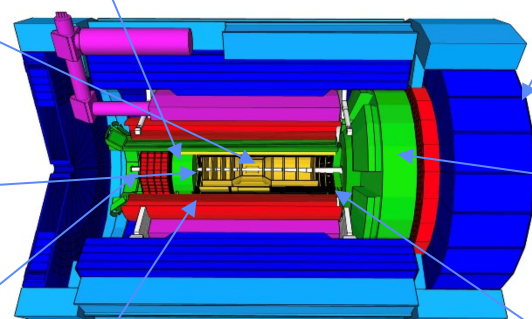


HRPPDs for Cherenkov imaging and Time-of-Flight *for pfRICH*

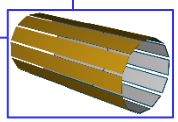


first-time **full-size CALICE-like calorimeter** in collider experiment *in the forward HCal*

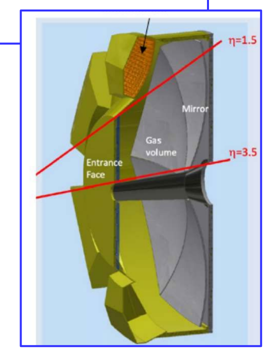




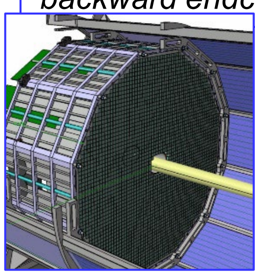
planar **double amplification (GEM & µRWELL)** modules & 2D-strip readout *for the MPGD outer trackers and disks*



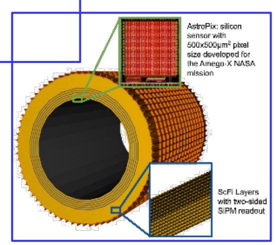
First use **of SiPMs as Photonsensors in a RICH** for the dRICH



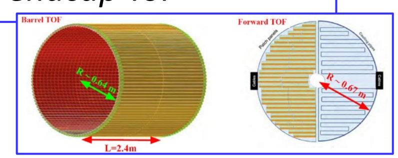
SiPM as Photonsensors in crystal calorimetry *for backward endcap ECal*



Use of **ASTROPIX in Calorimetry** *for the imaging barrel ECal*



First time use of **AC-LGAD** in a collider detector *for barrel and forward endcap ToF*



TAKEAWAY MESSAGES

The EIC is a unique project, the word only one approved for the ultimate understanding of QCD

Most likely, the only novel high energy collider in the next 15-20 years

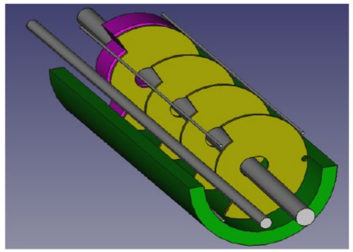
- **The EIC project is approved and progressing toward full realization**
- **The ePIC Collaboration for the project detector is working and highly committed to the detector and the physics scope**
- **The ePIC detector design is fully dictated by the physics scope**
  - **A number of established and novel technologies required to match this scope**
- ***Exciting perspectives in front of us designing, building, operating ePIC and progressing in physics with our detector***
  - ***The time to join us is now!***

THANK YOU

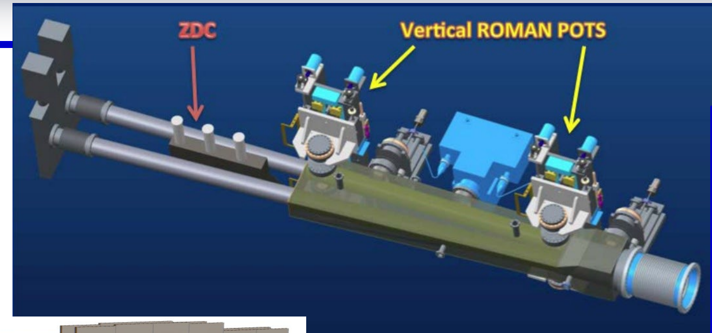
THE ePIC FAR FORFWARD DETECTORS

B0 trackers with AC-LGADS
B0 calorimetry by crystals

- TRACKING - *Synergies with forward ToF*
- CALORIMETRY - *Synergy with backward ECal and ZDC*

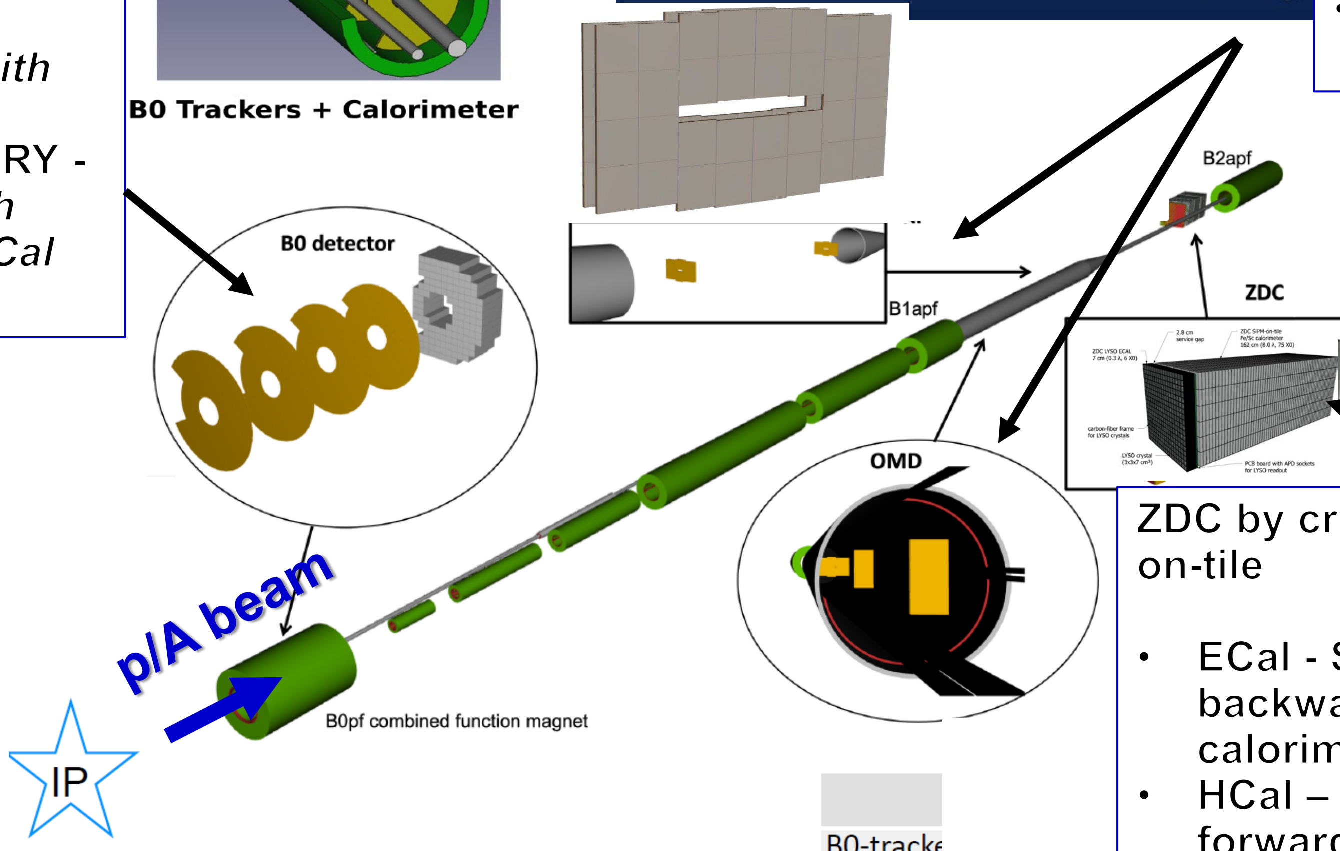


B0 Trackers + Calorimeter



RPs and OMDs by pixelized AC-LGADs

- *Synergies with forward ToF*



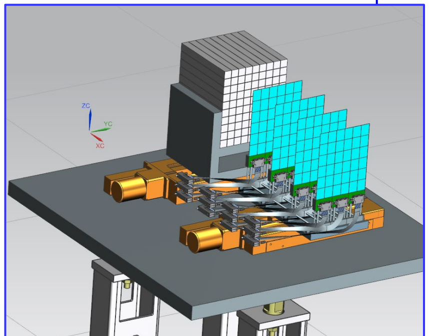
ZDC by crystals and SiPM-on-tile

- ECal - Synergy with backward ECal and B0 calorimetry
- HCal – Synergies with forward ECal insert

THE ePIC FAR BACKWARD DETECTORS

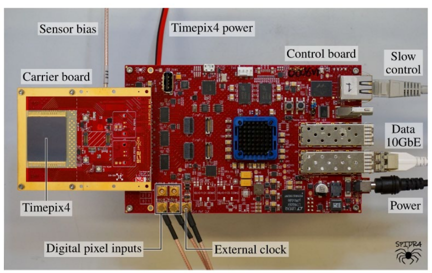
Low Q2 taggers

- High rate capability
- Fine tracking pixelization

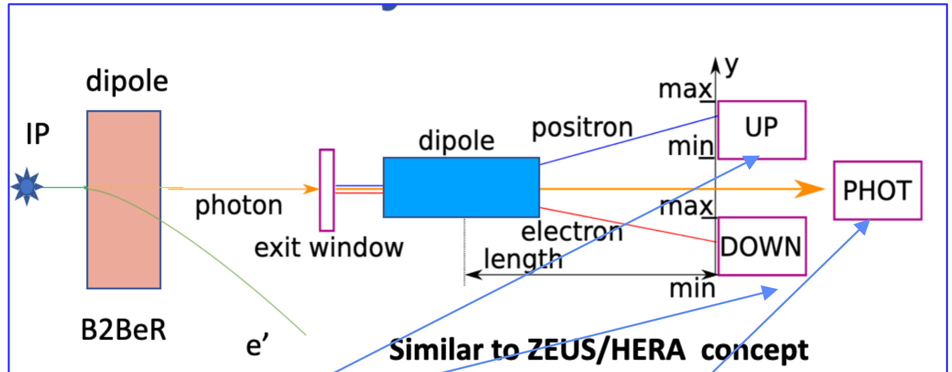


- Tracking – Timepix4 Hybrid (ASIC+Si tracker) – FRONTIER APPLICATION
- Calorimetry – SciFi's

- Timepix4 – wide experience accumulated with the different timepix versions



- CALORIMETRY - Synergy with forward ECal



LUMINOSITY – pair spectrometers

- TRACKING – AC-LGAD strips *Synergies with barrel ToF*

- CALORIMETRY – W-SciFi - *Synergy with farward ECal*

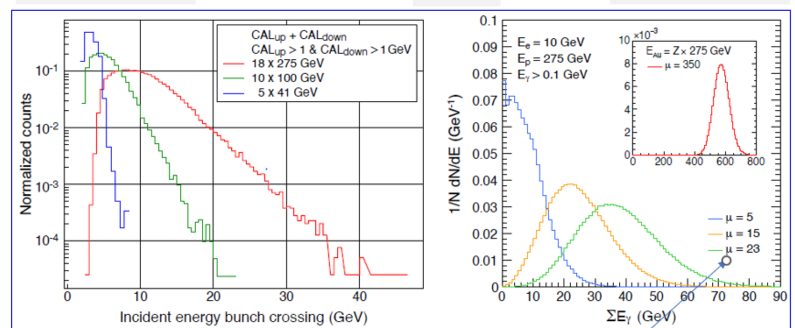
Luminosity – high rate calorimeter – CONSOLIDATED TECHNOLOGIES

- W-SCiFi – *synergies with forward ECal*
- Cu-QFi

different CM energy

PHOT

different Luminosity



$L = 2.2$, 6.5 and 10×10^{33} cm^{-2}s^{-1}, corresponding to the average photon multiplicity μ

27