The next nucleon microscope: the ePIC detector at EIC

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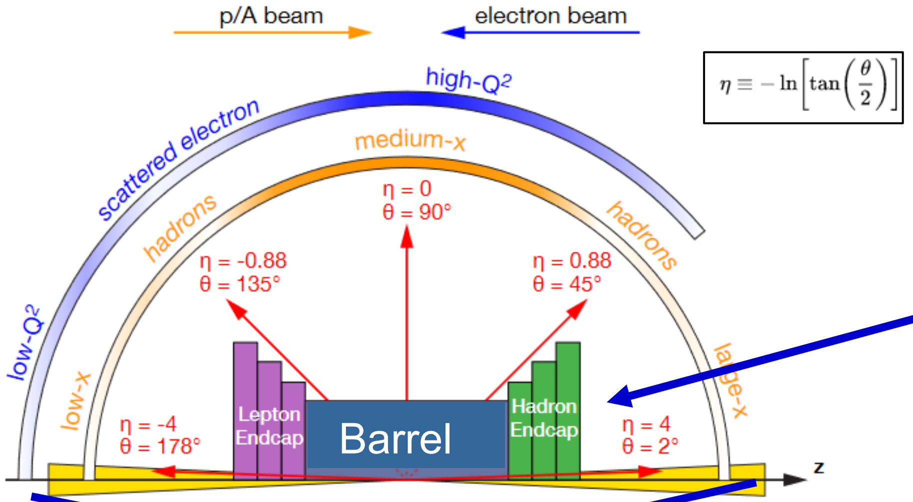
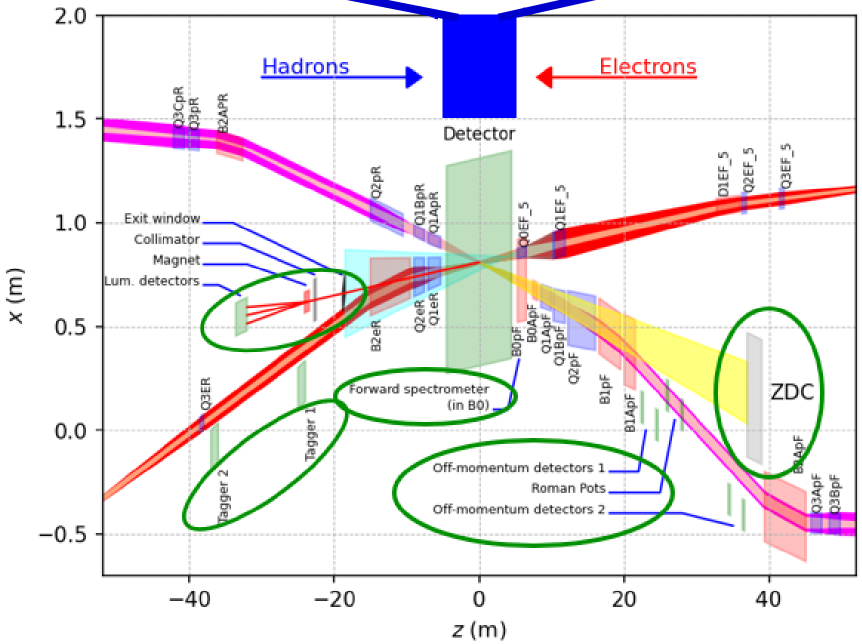
INFN TRIESTE

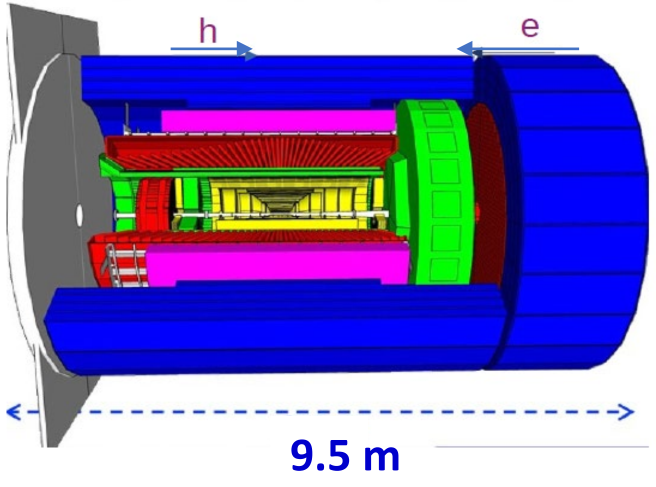
The ePIC Detector at EIC

- The ePIC Detector challenges
- The subsystems of the ePIC Detector
- DAQ and streaming read-out
- Take-away messages

ePIC: an extended detector







Central Detector (CD)

Total size detector: ~75m

Central detector: ~10m

Far Backward electron detection: ~35m

Far Forward hadron spectrometer: ~40m

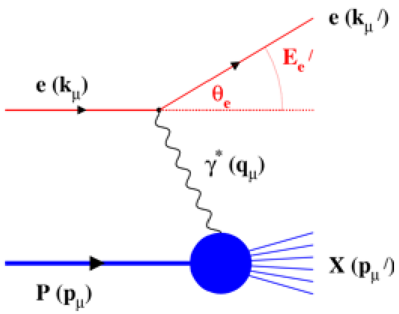
Auxiliary detectors needed to tag particles with very small scattering angles both in the outgoing lepton and hadron beam direction (B0-Taggers, Off-momentum taggers, Roman Pots, Zero-degree Calorimeter and low Q2-tagger).

What is needed experimentally?

The detector challenges – from physics

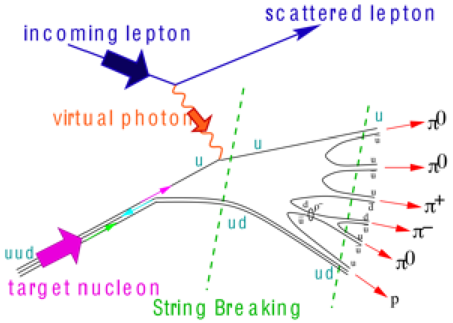
experimental measurements categories to address EIC physics:

Parton Distributions in nucleons and nuclei | QCD at Extreme Parton Densities - Saturation | Spin and Flavor structure of nucleons and nuclei | Tomography Transverse Momentum Dist. | QCD at Extreme Parton Densities - Saturation | Tomography Spatial Imaging



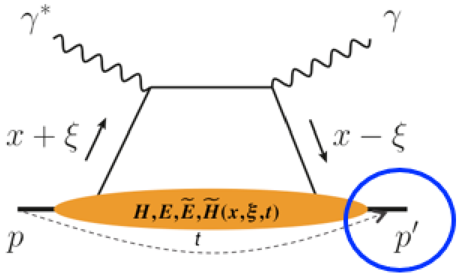
inclusive DIS

- measure scattered lepton
- → event kinematics
  - → e-ID: e/h separation
  - → reach to lowest x, Q^2 impacts Interaction Region design



semi-inclusive DIS

- measure scattered lepton and hadrons in coincidence
- multi-dimensional binning: x, Q^2, z, p_T, Θ
  - → particle identification over entire kinematic region is critical
  - → Jets: excellent E_T, jet-energy scale



exclusive processes

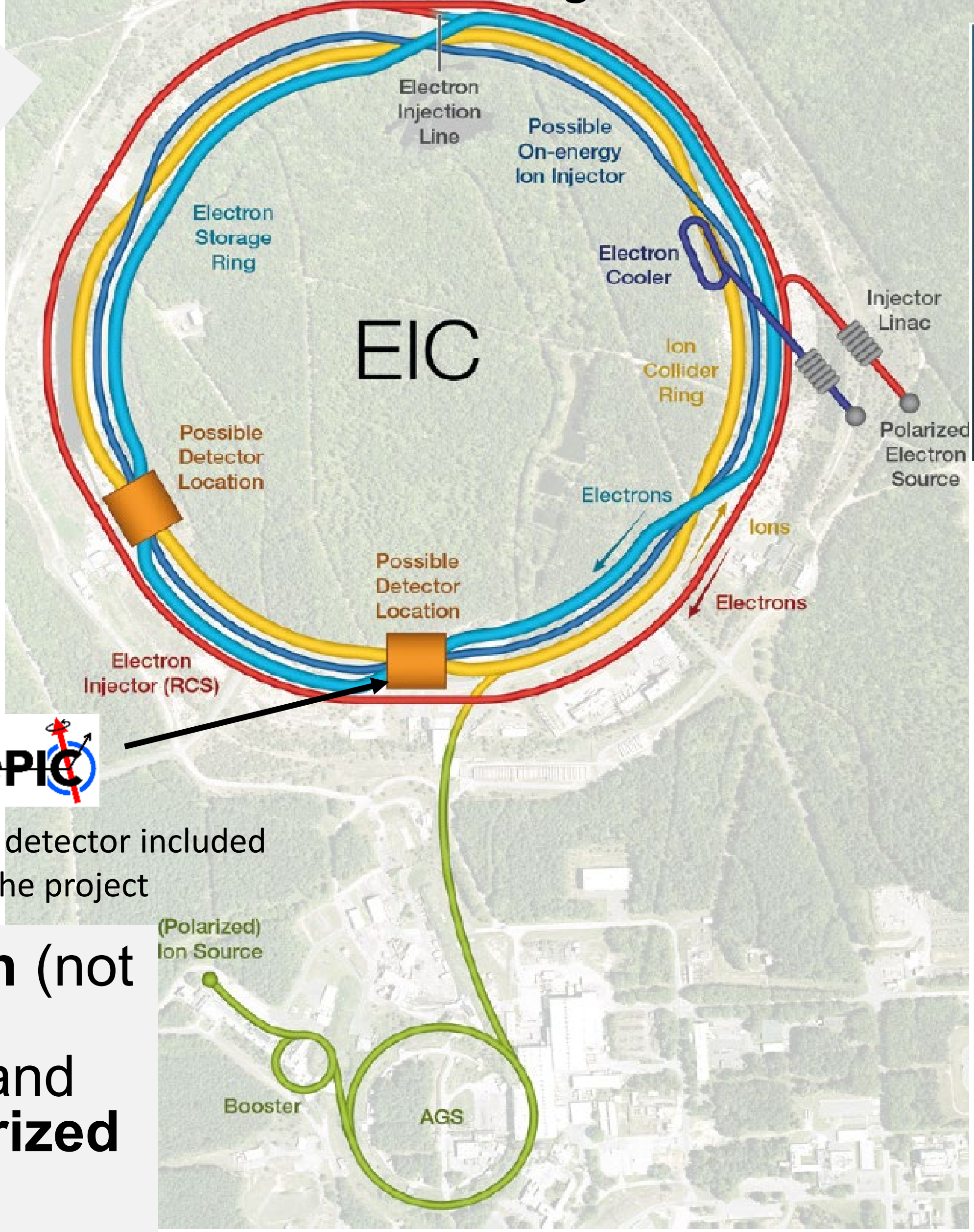
- measure all particles in event
- multi-dimensional binning: x, Q^2, t, Θ
- proton p_t: 0.2 - 1.3 GeV
  - → cannot be detected in main detector
  - → strong impact on Interaction Region design

$\int Ldt$: 1 fb^{-1} | 10 fb^{-1} | 10 - 100 fb^{-1}

machine & detector requirements

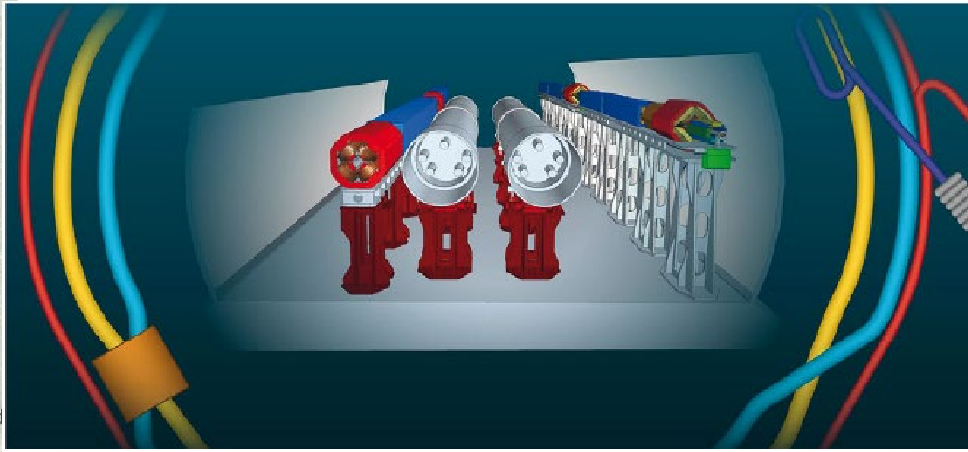
The EIC collider, in a nutshell

Usage of RHIC tunnel and RHIC p/ion complex



ePIC

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**

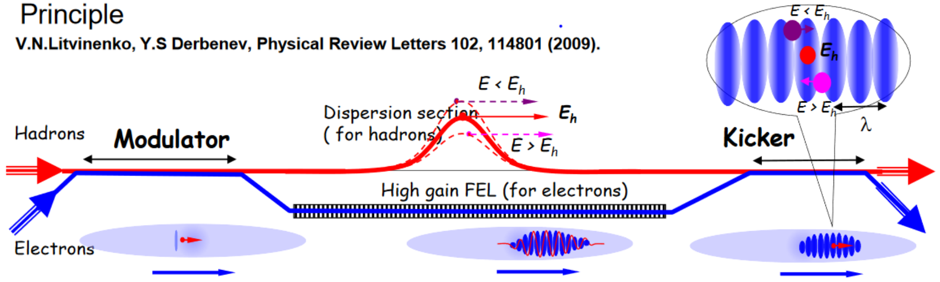
- First **electron-ion** (not only p!) collider
- First electron-p (and light nuclei) **polarized collider**

The EIC collider, in a nutshell

Coherent Cooling with FEL amplifier

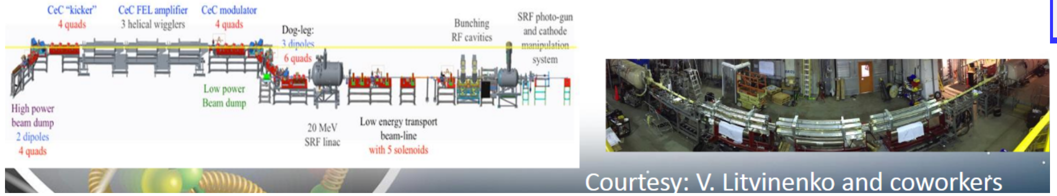
Principle

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



Courtesy: V. Litvinenko and coworkers

CRAB CROSSING ANGLE (25 mrad)

For the first time a sizable crab crossing angle

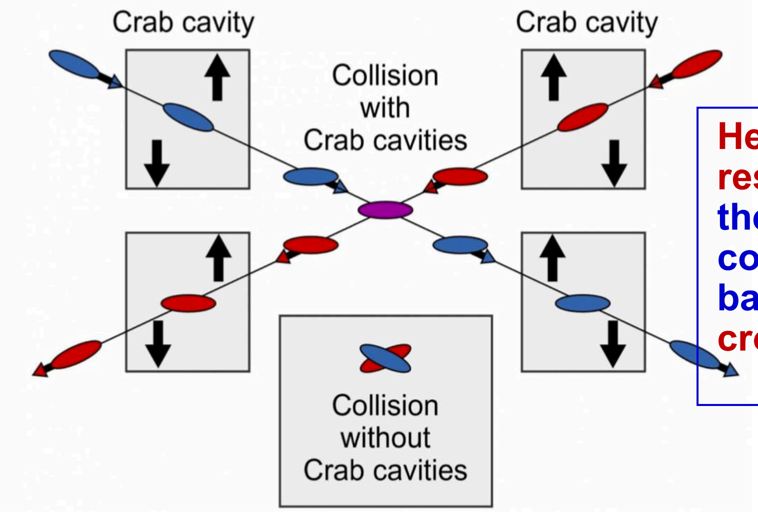
3 critical ingredients for HIGH LUMINOSITY

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 IP every 10ns, with a max collision rate of ~0.5 MHz (1 event every ~200 bunch crossing)



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

The EIC collider, in a nutshell

ION SPECIES

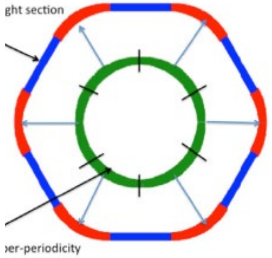
The existing RHIC ion sources & ion acceleration chain provides already today all ions needed at EIC

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

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

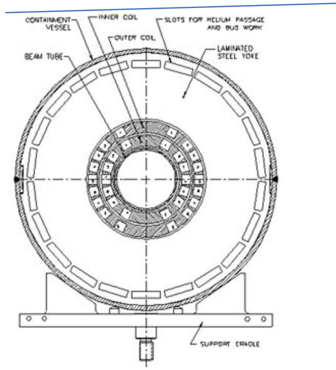
➔ expect 80% in Polarization in RHIC and eRHIC

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

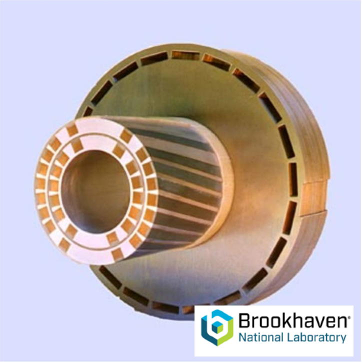
Handling and measuring the beam polarization

p (D, ^{3}He) capitalizing on RHIC experience and expertise

- In the acceleration/storage ring : **vertical polarization** (the "ring" is the horizontal plane!)
- Intrinsic and imperfection resonances tend to **depolarized the beams**
- **Siberian snakes** : to preserve beam polarization during acceleration and storage (2/ring in RHIC → 6 for EIC ion ring)
- **Spin Rotators** : to provide longitudinal polarization at the IP
- **Polarized D, ^{3}He beams** – NEW

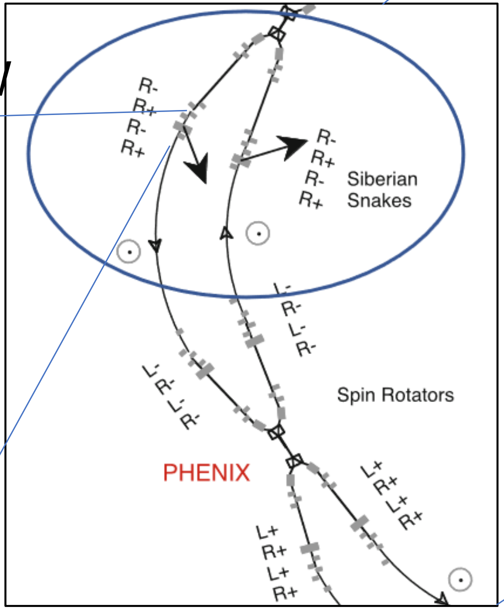


Cross section drawing of a helical magnet for RHIC. The inner coil diameter is 80 mm.



Photograph of a section cut from a prototype RHIC helical dipole magnet.

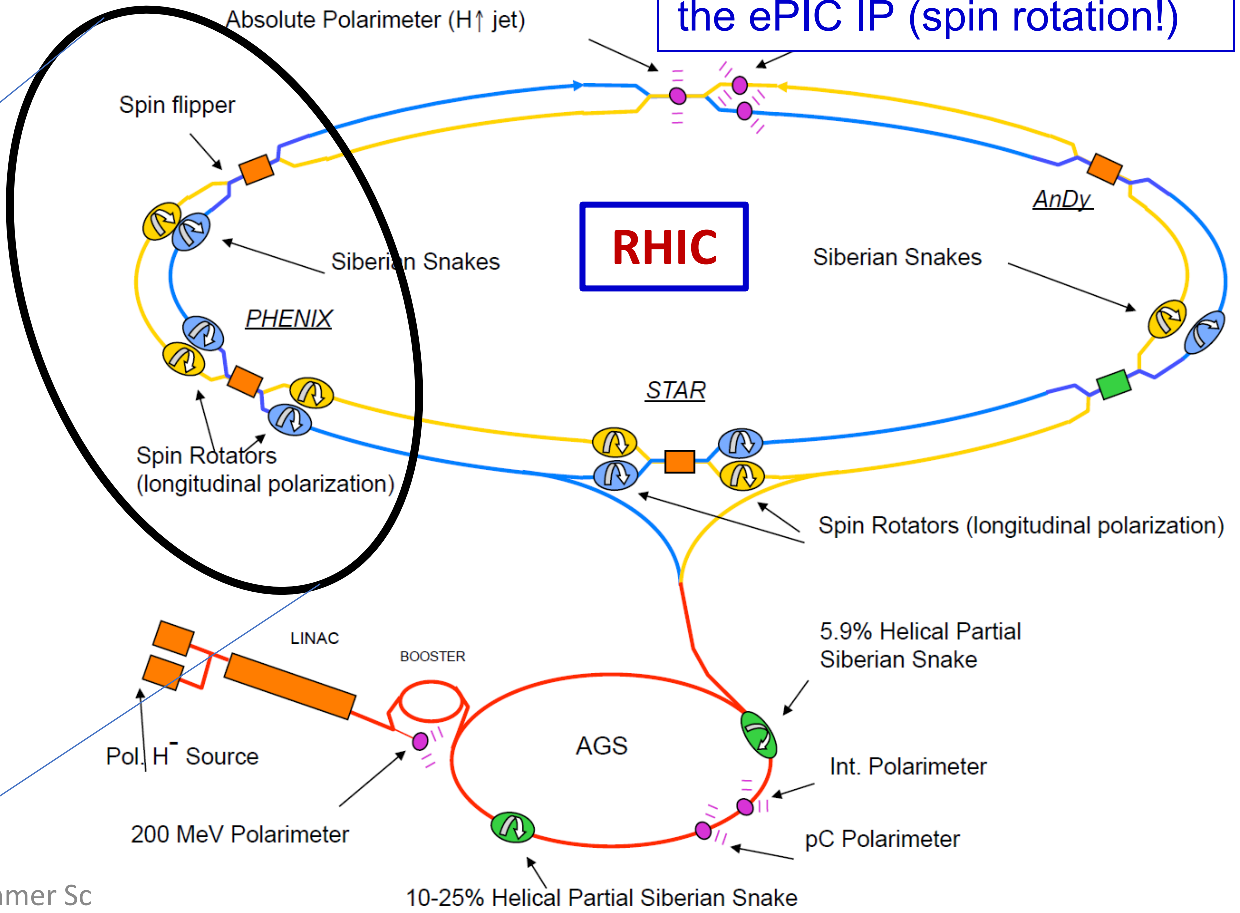
Helicoidal superconducting dipole, 2.4 m long



Absolute measurement of the p beam polarization : Internal polarized H jet target

Fast (spill by spill) relative measurement of the p beam polarization : on a thin C internal target;

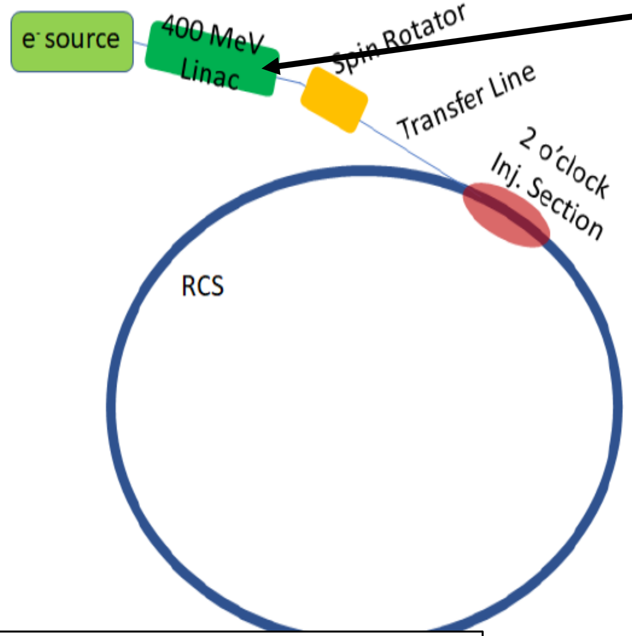
A similar "monitor" also near the ePIC IP (spin rotation!)



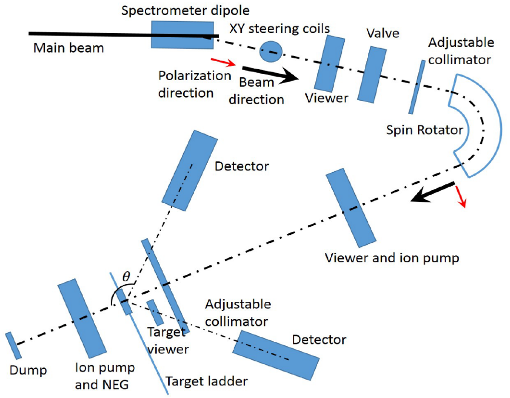
Handling and measuring the beam polarization

e-beam: large polarimeter experience at HERA and JLab

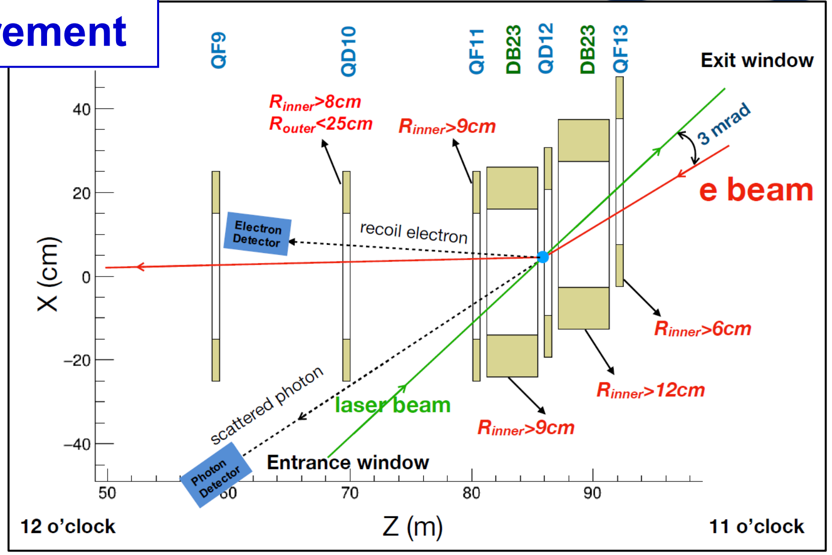
- Polarized electrons produced in the source with **85% longitudinal polarization, rotated after LINAC acceleration**
- Two new rings
  - a **rapid cycling synchrotron** (RCS) for electron beam **acceleration**; design resonance-free
  - an **electron storage ring** (ESR)
  - In ERS, e- polarization affected by stochastic depolarization and the Sokolov-Ternov self-polarization process



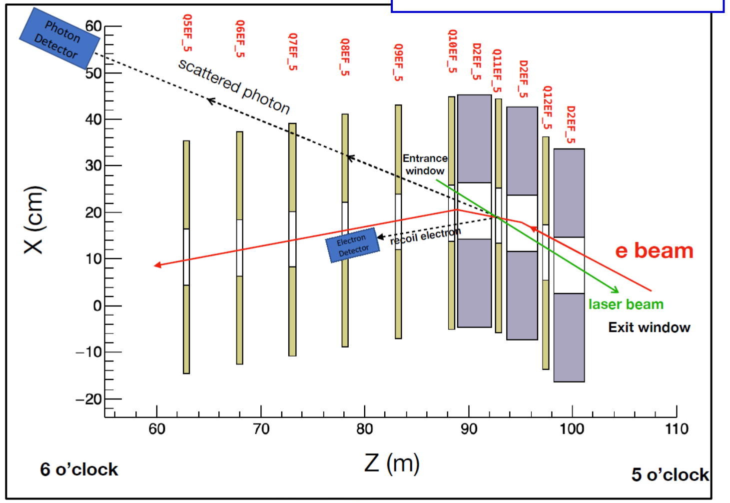
MOTT polarimeter at 400 MeV



ESR measurement



Near ePIC IP



In the ESR: precise polarization measurements with **COMPTON polarimeter with circularly polarized laser light ,** sensitive to both longitudinal and transversal polarization

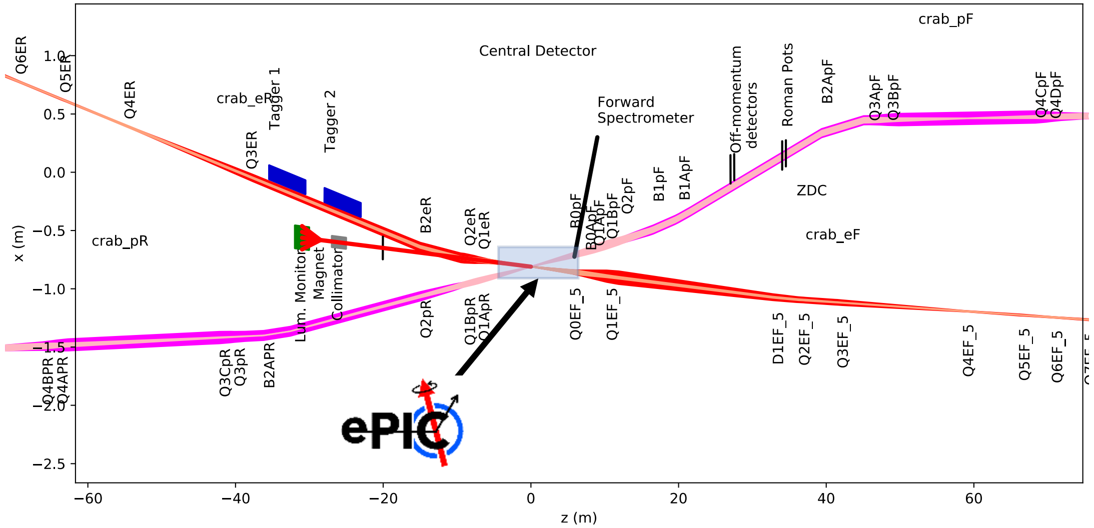
The detector challenges – from IR design

- Why a large (25 mrad) crossing angle ?

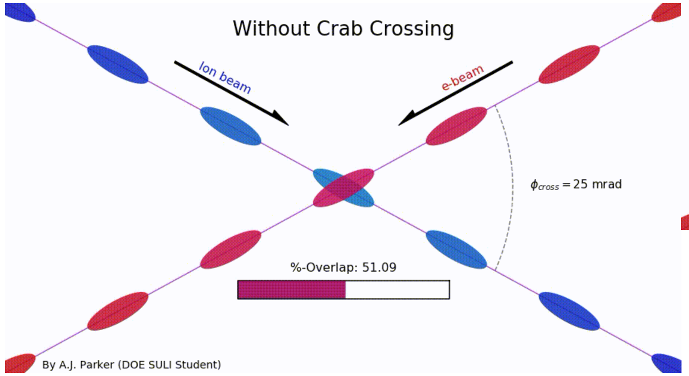
- **Crossing angle of 25 mrad**
  - bring focusing magnets close to IP
  - no separator dipole
    - → reduce detector background
      - → reduced SR
      - → beams less in one common beam pipe
  - Multi-staged separation → separate beam from particles needed for physics
    - → space for forward equipment along beam line
- **However**, crossing angle causes
  - Low luminosity
  - more challenging Beam dynamics
  - → **avoided by Crab Crossing**

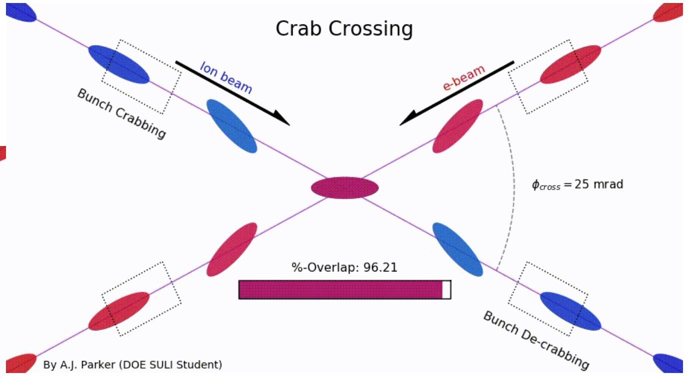
→ e and ion beam axis at IP are DIFFERENT

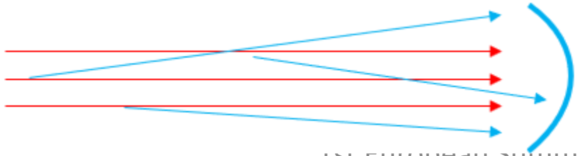
- Detector solenoid aligned with e-beam
  - To reduce synchrotron radiation
  - To avoid a too large e-beam size after IR (difficult to handle)
- Beam ions do not travel straight in the solenoid region !



E.C. Aschenauer







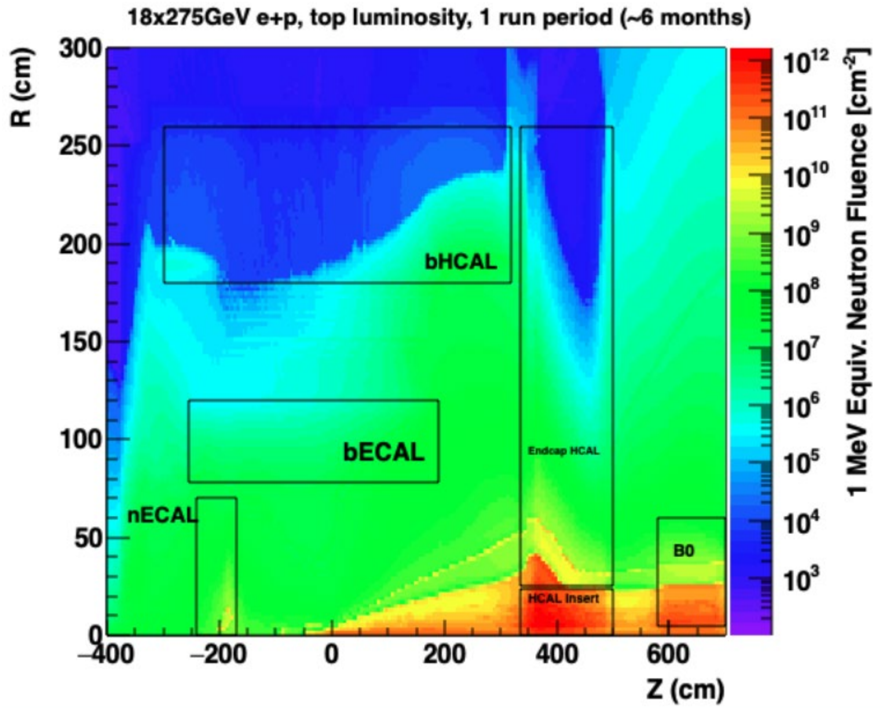
Crab Crossing →

- **Angular beam divergence**
  - Angular "spread" of the beam away from the central trajectory.
  - Gives some small initial transverse momentum to the beam particles
  - → impact on p_T resolution
- **Bunch length**
  - both beams have a longitudinal extension hadron beam < 10 cm & electron beam ~1cm

Radiation rates

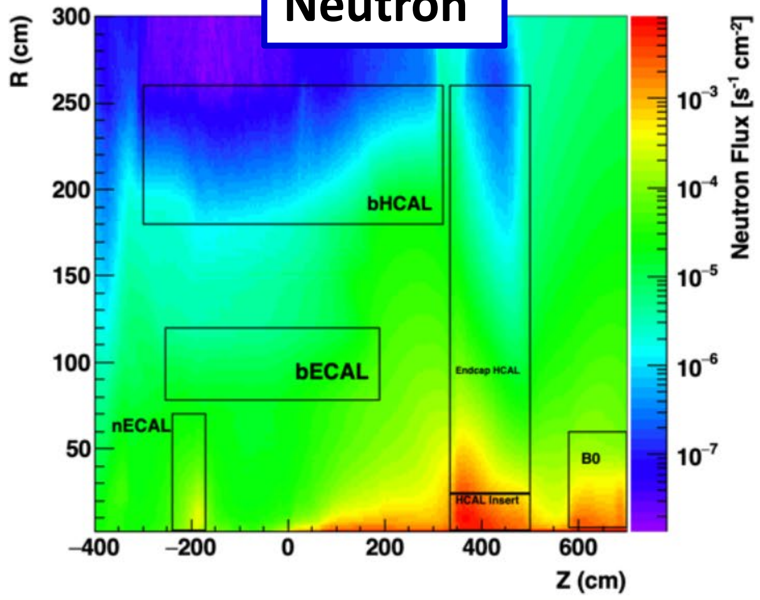
Moderate respect to hadron colliders
Evaluated to estimate damages and ageing of sensors (f.i.: SiPMs) and electronics (f.i.: FPGAs)

Neutron fluence (1 MeV eq.)

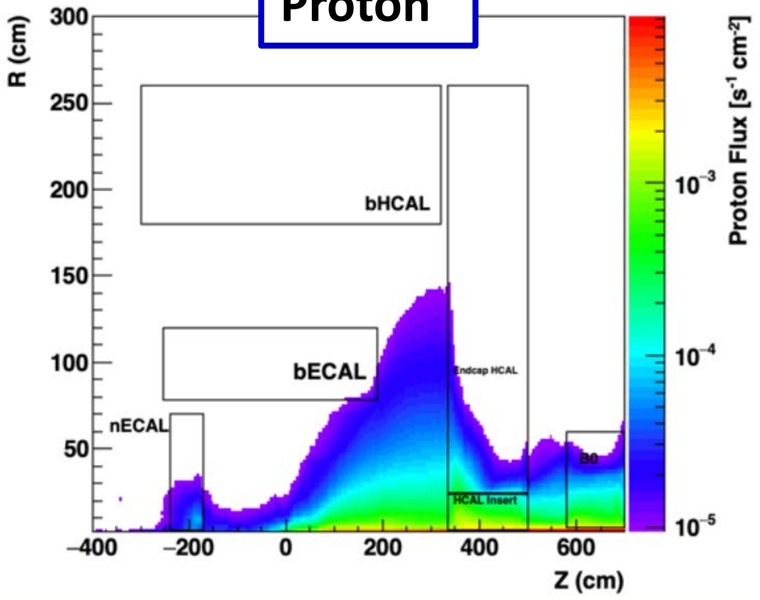


E_{kin} > 20 MeV, fluxes Hz to determine risk for single event upsets

Neutron



Proton



Alex Jentsch, ePIC wiki pages

Background sources

Background sources

- **Beam-gas induced**
  - Hadron-gas interaction
  - Electron-gas interaction
  - *Depend on the vacuum in the machine*
- **Synchrotron radiation**
  - *Origin: quads and bending magnet upstream of IP*
  - *Tails in electron bunches: can produce hard radiation*

IMPORTANT TO NOTE:

- No pileup from collisions 500 kHz @10^{34} cm $^{-2}$ s^{-1} → 1 coll. every 200 beam crossings

The rates of background hits in the detector depend on:

- Time properties
- Threshold setting

Sub-detector	Threshold	Integration time	Sub-detector	Threshold	Integration time
VertexBarrel	0.65 keV	2 µs	EcalEndcapP	3.0 MeV	5 ns
SiBarrel	0.65 keV	2 µs	TOFBarrel	0.5 keV	50 ps
EcalEndcapN	5.0 MeV	5 ns	TrackerEndcap	0.65 keV	50 ps
MPGDBarrel	0.25 keV	20 ns	DIRCBar	0.2 p.e.	50 ps
EcalEndcapPInsert	3.0 MeV	5 ns	TOFEndcap	0.5 keV	50 ps
LFHCAL	500 keV	25 ns	PFRICH	0.5 p.e.	50 ps
HcalEndcapPInsert	500 keV	25 ns	DRICH	0.5 p.e.	50 ps
HcalBarrel	75 keV	25 ns	EcalBarrelScFi	2.5 MeV	5 ns
B0ECal	1 MeV	5 ns	HcalEndcapN	170 keV	25 ns
B0Tracker	1.0 keV	40 ps	ZDCEcal	1 MeV	5 ns
ForwardOffMTracker	1.0 keV	40 ps	ZDCHcal	100 MeV	25 ns
TaggerTracker	1.0 keV	5 ns	ForwardRomanPot	1.0 keV	40 ps

Zhengqiao Zhang, ePIC General Meeting, May 26, 2023

Background sources

Background sources

- **Beam-gas induced**
  - Hadron-gas interaction
  - Electron-gas interaction

- **Synchrotron radiation**

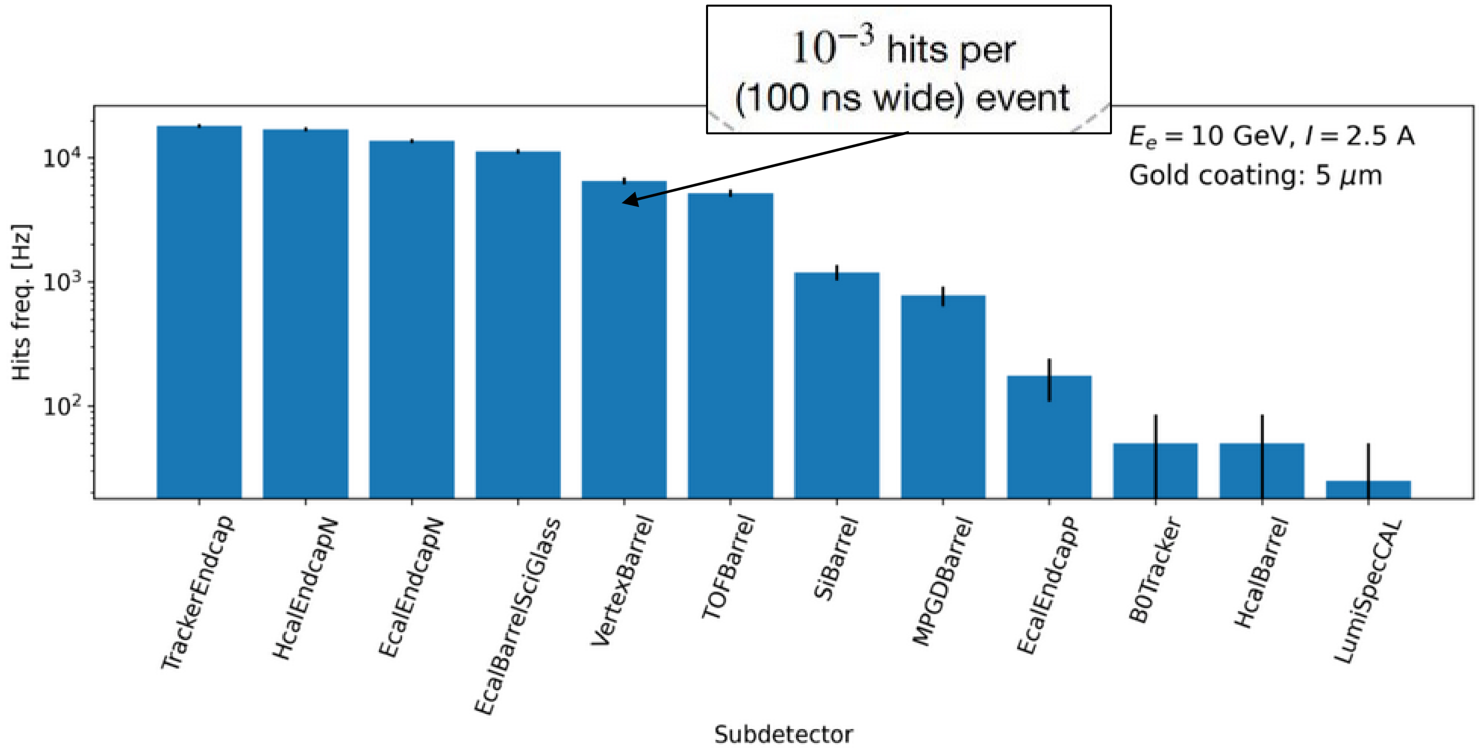
Zhengqiao Zhang,
ePIC General Meeting,
May 26, 2023

Electron Beam-Gas interactions

rates in kHz	5x41 GeV	5x100 GeV	10x100 GeV	10x275 GeV	18x275 GeV
DIS ep	12.5 kHz	129 kHz	184 kHz	500 kHz	83 kHz
hadron beam gas	12.2kHz	22.0kHz	31.9kHz	32.6kHz	22.5kHz
electron beam gas	kHz	kHz	3177.25 kHz	3177.25 kHz	kHz

Main contribution to detector background are from Bethe-Heitler process:

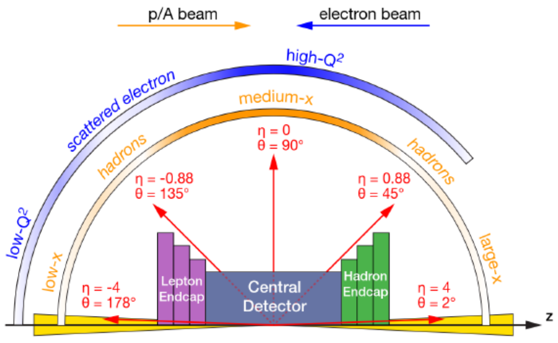
$$e_{beam} + H^2_{rest\ gas} \rightarrow e' + \gamma + H^2_{rest\ gas}$$

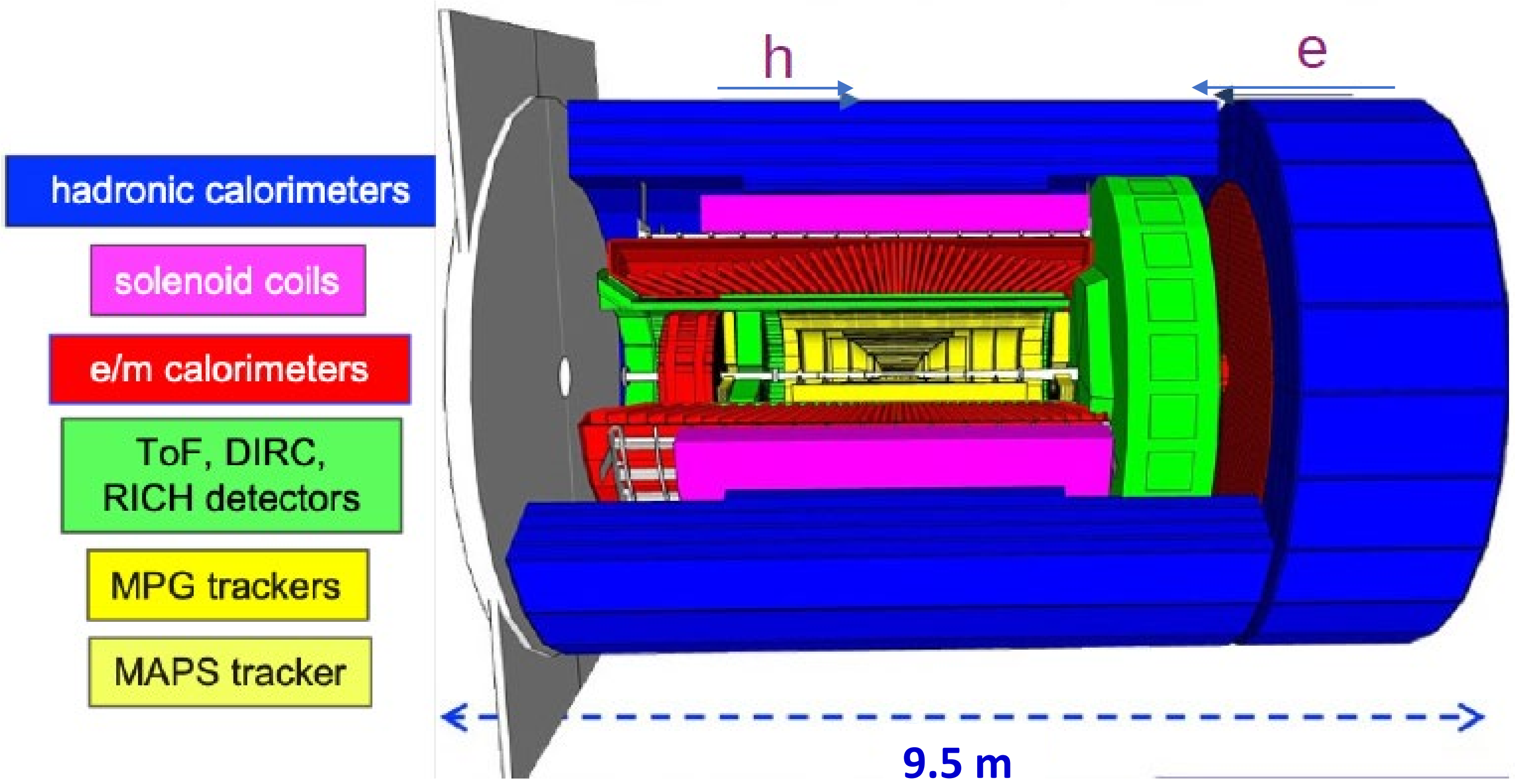


The ePIC Detector at EIC

- The ePIC Detector challenges
- The subsystems of the ePIC Detector
- DAQ and streaming read-out
- Take-away messages

The ePIC Central Detector, overview

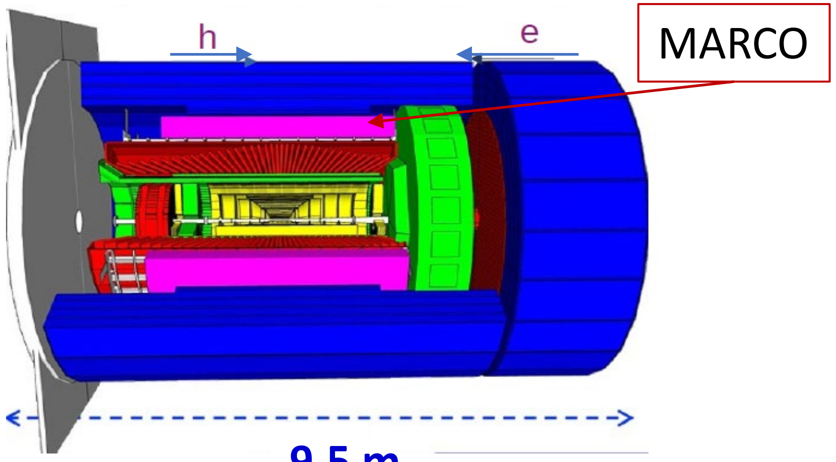


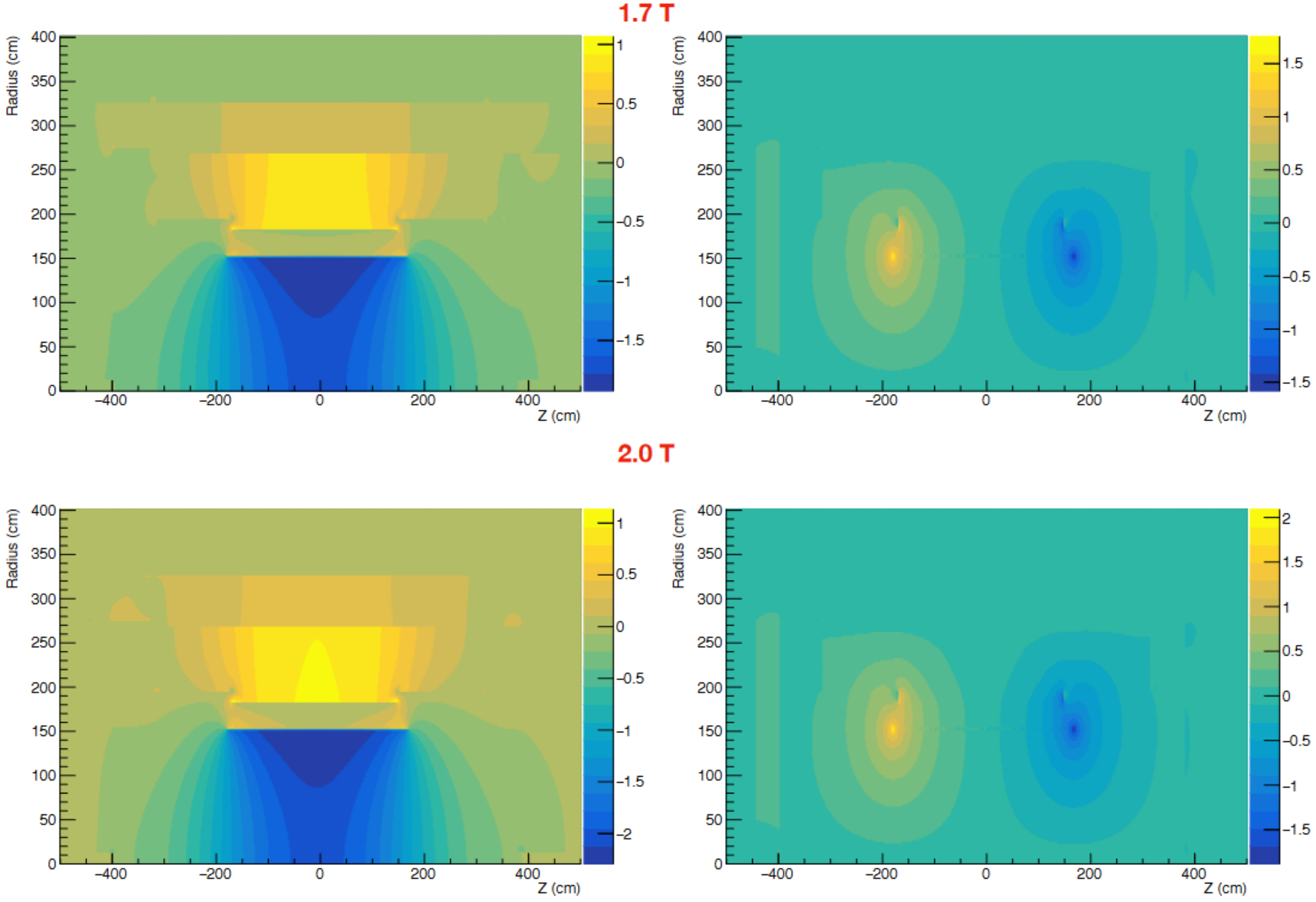


including:

- Backward endcap
- Barrel
- Forward endcap

The ePIC experimental SOLENOID "MARCO"





- Design to operate at 1.7 T
- It can provide up to 2 T

ePIC Tracking (for trajectories, angles, vertex, momentum)

CHALLENGES

- Efficient pattern recognition
- Very low material budget for the central tracking region not exceeding 5% X/X_0 (p resolution!)
- Solenoidal magnetic field
  - Fine $\int B \cdot dl$ in the barrel
  - Limited $\int B \cdot dl$ in the endcaps
- Limited lever arm
  - Solenoid and overall detector design constrains in the barrel
  - IR design in the endcaps
- "low" interaction rate (< 0.5 GHz), but background !

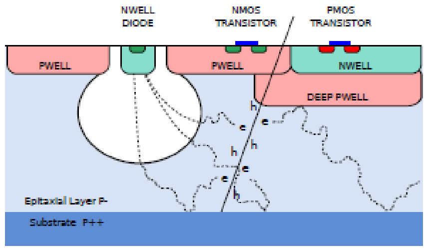
STATEGIES

- Redundancy of the measured space point coordinates
- Monolithic Active Pixel Silicon (MAPS)
  - Guiding example: the inner tracking in ALICE (ALPIDE chip, also used in sPHENIX)
- Fine space resolution – fine granularity Si sensors
- Synergies among detector components (backward ECal, barrel ECal, RICH counters, …)
- Good time resolution to disentangle signal and background: this cannot be provided by MAPS, use additional MicroPattern Gaseous Detector layers

ePIC Tracking: a few words about technologies

Monolithic Active Pixel Silicon (MAPS)

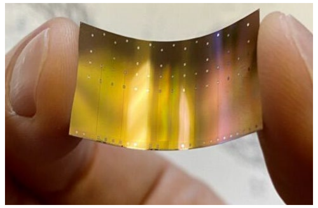
- **ALPIDE**, CMOS 180 nm technology

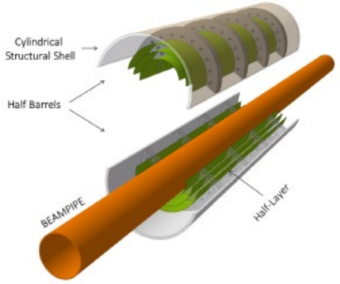


- Novelty:
  - Partial depleted substrate ↔ collect part of the charge by drift
  - integrate both PMOS and NMOS transistors. These features have improved

→ charge collection properties, radiation hardness, and signal processing capabilities

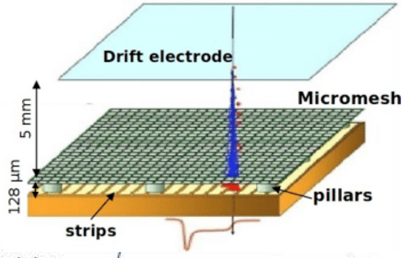
- Being developed **ITS3 sensors** (for ALICE): MAPS derived from ALPIDE in CMOS 65 nm technology
  - Lower power consumption
  - Lower material budget
  - Flexible: minimum support material for moderate-size layers (VERTEX)



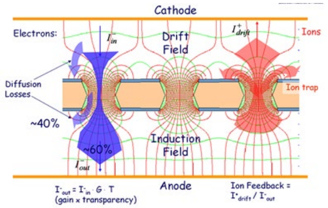


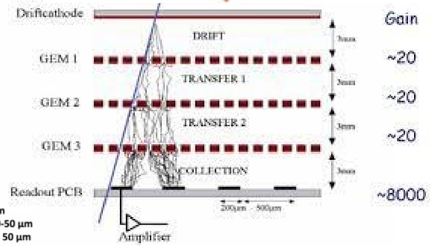
MicroPattern Gaseous Detector (MPGD)

- A family of gaseous detectors technologies
- Main common characteristics:
  - Built upon advanced PCB technologies
  - Fine space resolution: O(100 μm)
  - Fine time resolution: O(10 ns)
  - High-rate capabilities: up to 10 MHz/cm^2
- Considered for ePIC
  - **MICROMEGAS**

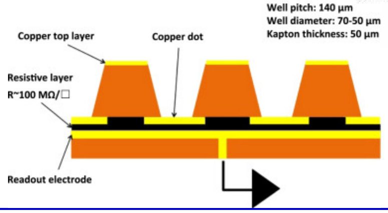


- **GEM**





- **microRWELL**

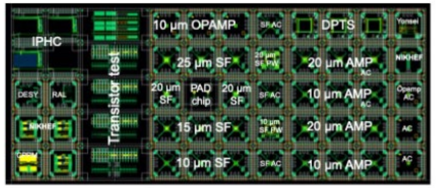


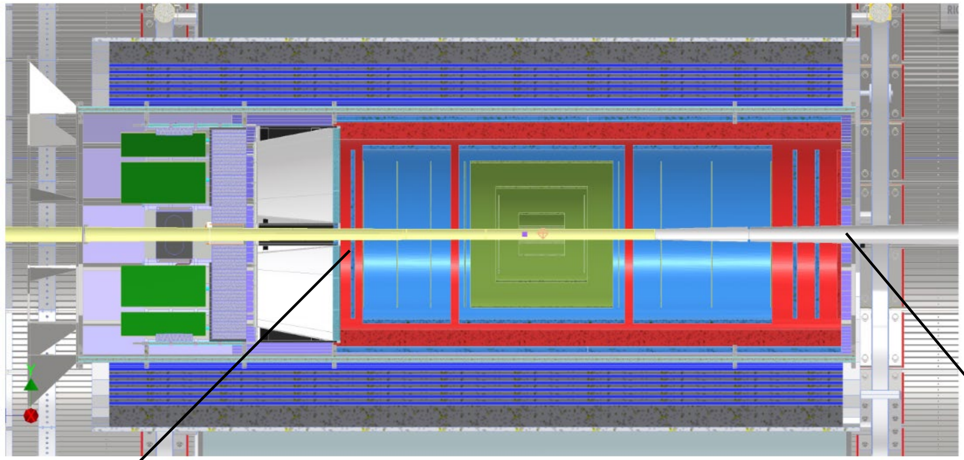
ePIC Tracking (for trajectories, angles, vertex)

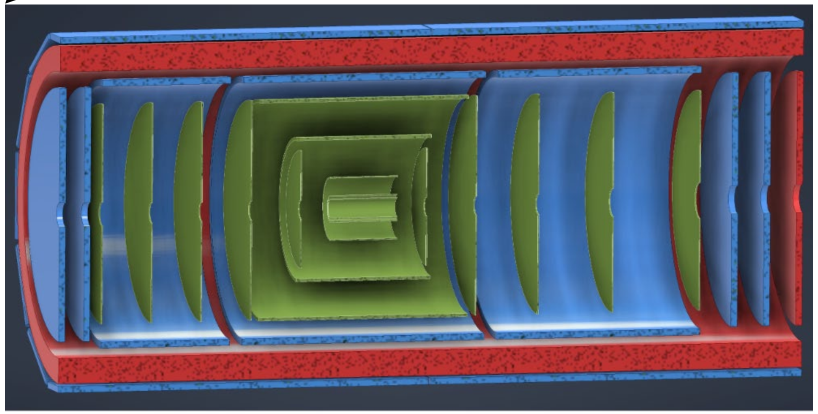
Ongoing layout optimization

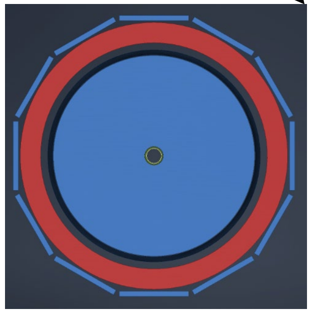
Monolithic Active Pixel Silicon (MAPS) Tracker:

- 1 single technology: 65-nm MAPS
  - O(20 μm) pitch, <20 mW/cm^2
  - No fine time resolution: signal length O(~5 μs)
  - Developed for ALICE ITS3
- Silicon VERTEX (3 layers)
  - First layer @ R ~ 4 cm
  - Material: 0.05% X/X_0 / layer
- Silicon BARREL (2 layers)
  - Material: 0.55% X/X_0 / layer
- F & B Silicon DISKs (5 in Front and Back)
  - Material: 0.24% X/X_0 / layer









SVT MPGDs ToF (fiducial volume)

Multi Pattern Gas DetectorS (MPGD):

2 technologies being considered

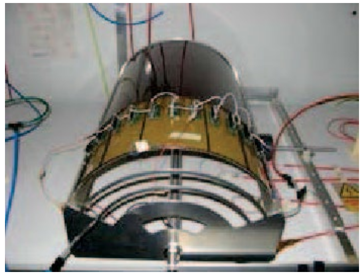
- MicroMEGAS
- µRWELL
- Time resolution < 10 ns

2 geometrical implementations

→ cylindrical (established for MM, R&D for µRWELL)
→ planar

Role of the MPGDs

→ Additional space points for pattern recognition / redundancy
→ time information

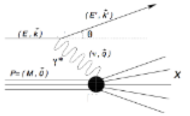


ELECTROMAGNETIC CALORIMETRY for ePIC

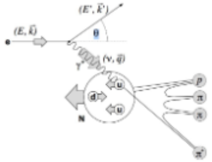
Electron/photon PID, energy, angle/position:

Coverage (in rapidity and energy), resolution, e/π, granularity, projectivity

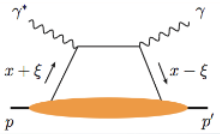
Inclusive DIS: scattered electron



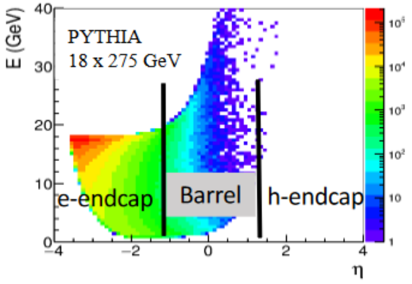
Semi-Inclusive DIS: $\pi 0 \rightarrow \gamma\gamma$, HF $\rightarrow$ e



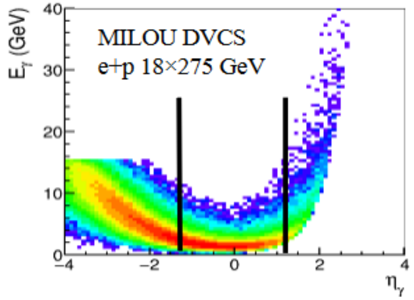
Exclusive DIS: DVCS photons, J/ψ→ee etc.



DIS e

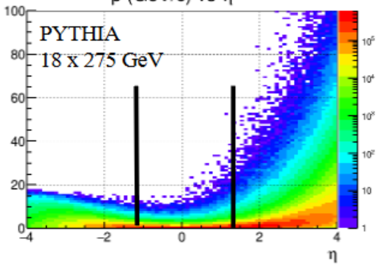


DVCS photons



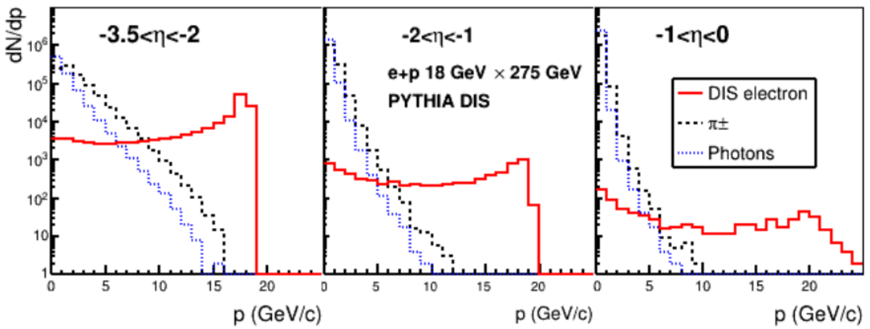
SIDIS π0

p (GeV/c) vs η



Alexander Bazilevsky,
Calorimetry Review, 2022

DIS kinematics: ePID

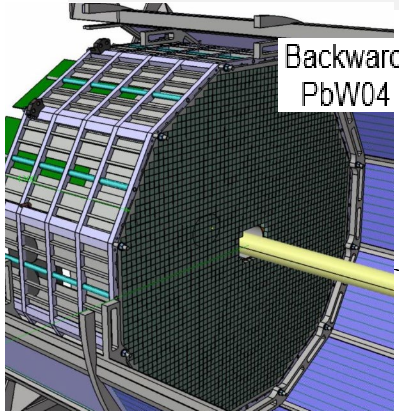


Detector Requirements: Summary

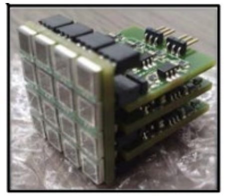
	σ_E/E	E range, GeV	$\pi^{\pm}$ suppression (In combination with other subsystems)	$\pi 0/\gamma$ discr.
e-endcap	$\frac{(2-3)\%}{\sqrt{E}} \oplus (1-2)\%$	0.05–18 GeV	Up to 10^4	Up to 7 GeV/c
Barrel	$\frac{(7-10)\%}{\sqrt{E}} \oplus (1-3)\%$	0.05–50 GeV	Up to 10^4	Up to 10 GeV/c
h-endcap	$\frac{(10-12)\%}{\sqrt{E}} \oplus (1-3)\%$	0.1–100 GeV	Up to 10^4	Up to 50 GeV/c

- Continuous acceptance (particularly from e-endcap to barrel)
- Photosensors and FEE tolerate magnetic field
- Operate at full luminosity and expected background conditions (rad. dose, neutron flux)
- Minimal material budget on the way from the vertex (particularly for e-endcap to barrel)

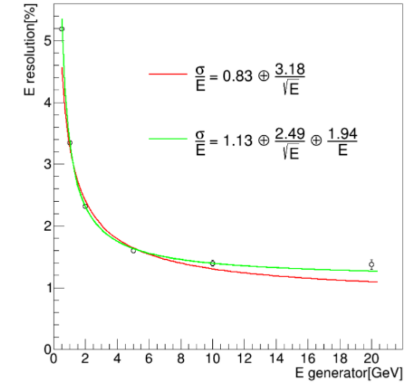
ELECTROMAGNETIC CALORIMETRY for ePIC

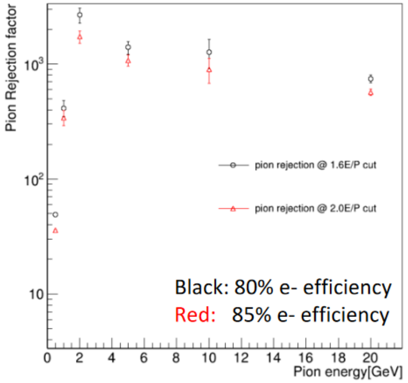


Concept based on a recent PWO calorimeter at JLab



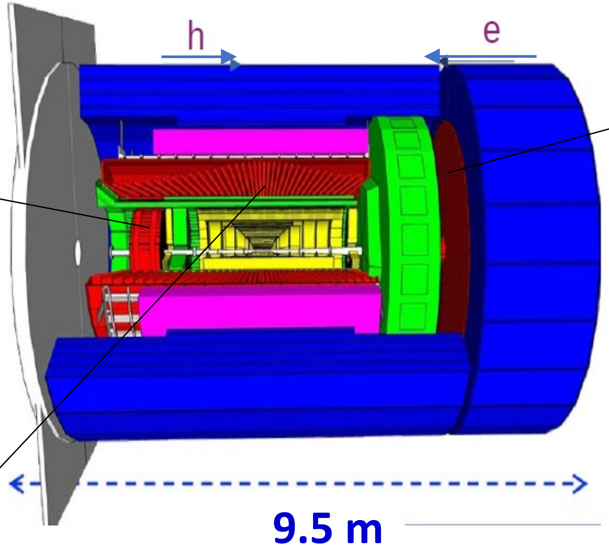
SiPM 4x4 per crystal

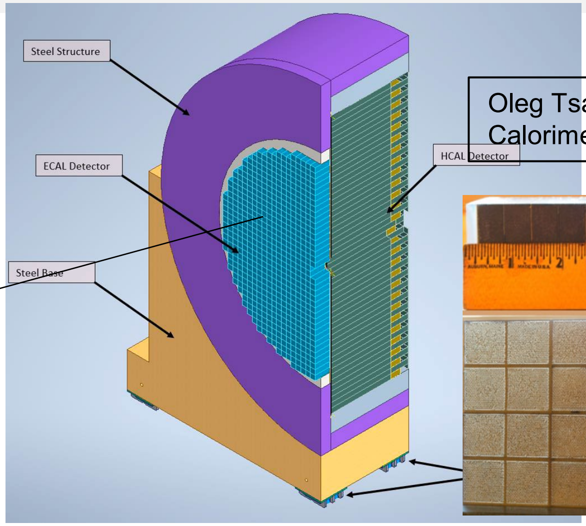




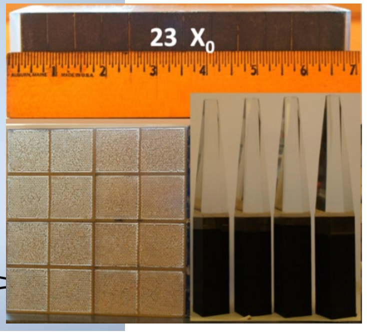
Carlos Muñoz Camacho, Calorimetry Review, 2022

SiPMs of all Calorimeters





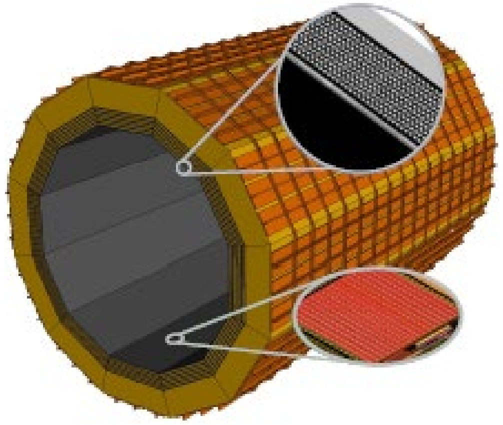
Oleg Tsai, Calorimetry Review, 2022

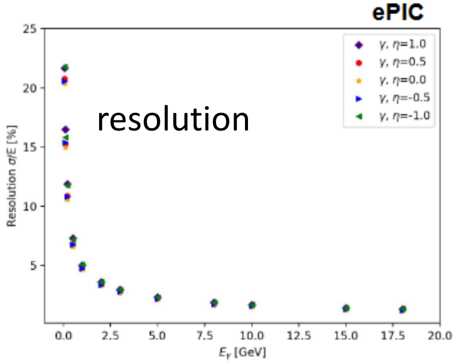


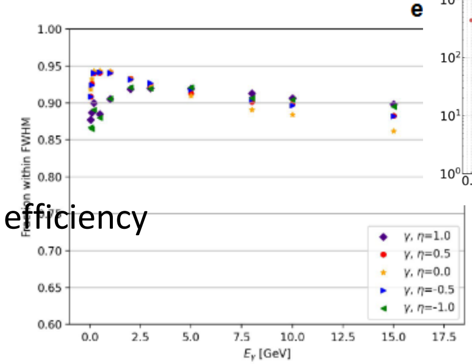
WScFi is a unique technology allowing to achieve e/h ~1 (response to hadrons) and at the same time keep em energy resolution at ~10%/√ E + 2%

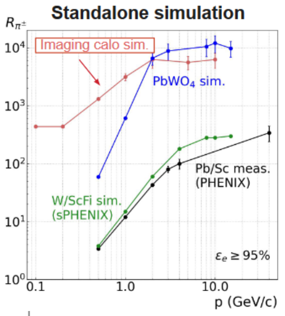
4 (6) layers of imaging calorimetry by Astropix MAPS, and sampling calorimetry by Pb/SciFi

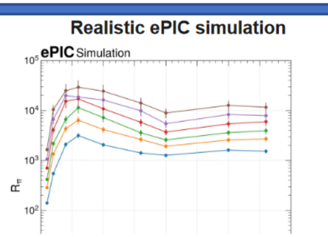
Maria Zurek, GD/I Review, 2023



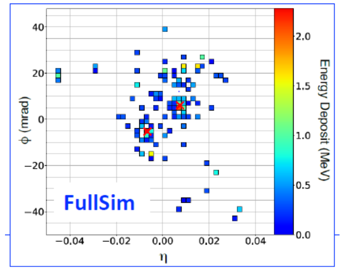




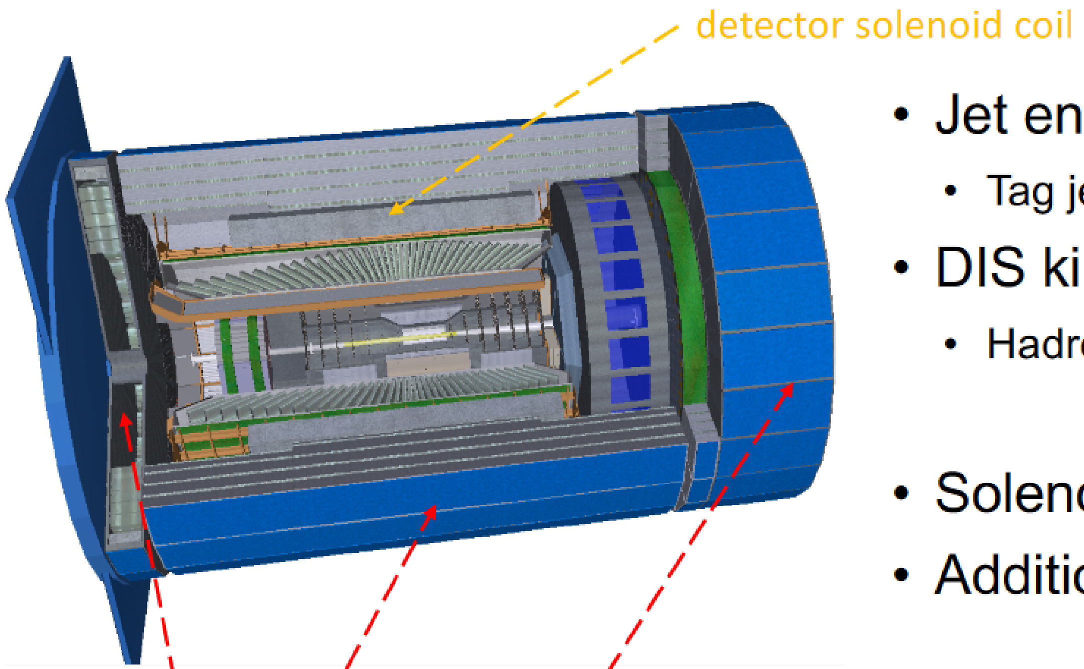




γ's from 15 GeV/c π^0 decay



HADRON CALORIMETRY for ePIC



- Jet energy measurement
  - Tag jets with a neutral component
- DIS kinematics reconstruction
  - Hadronic method
- Solenoid flux return
- Additional capability: muon ID

Requirements

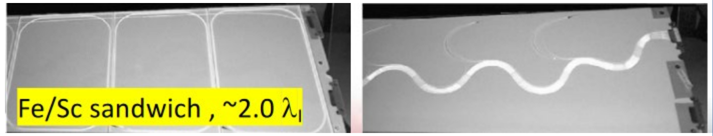
η	σ_E/E, %	E_{min}, MeV
-3.5 to -1.0	$50/\sqrt{E}+10$	500
-1.0 to +1.0	$100/\sqrt{E}+10$	500
+1.0 to +3.5	$50/\sqrt{E}+10$	500

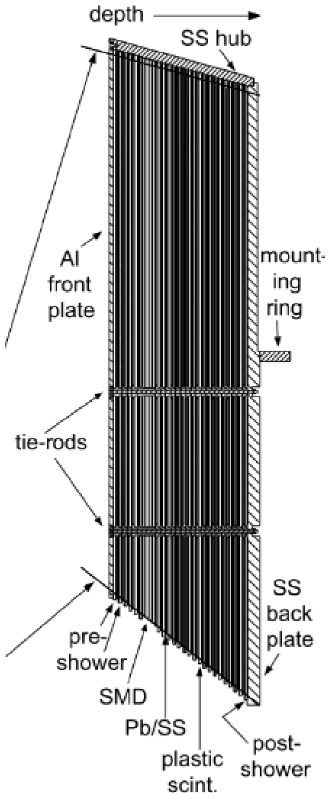
Barrel HCal	Refurbished sPHENIX barrel calorimeter
Backward HCal	Scintillator recycled from STAR endcap EmCal
Forward HCal	Brand new design

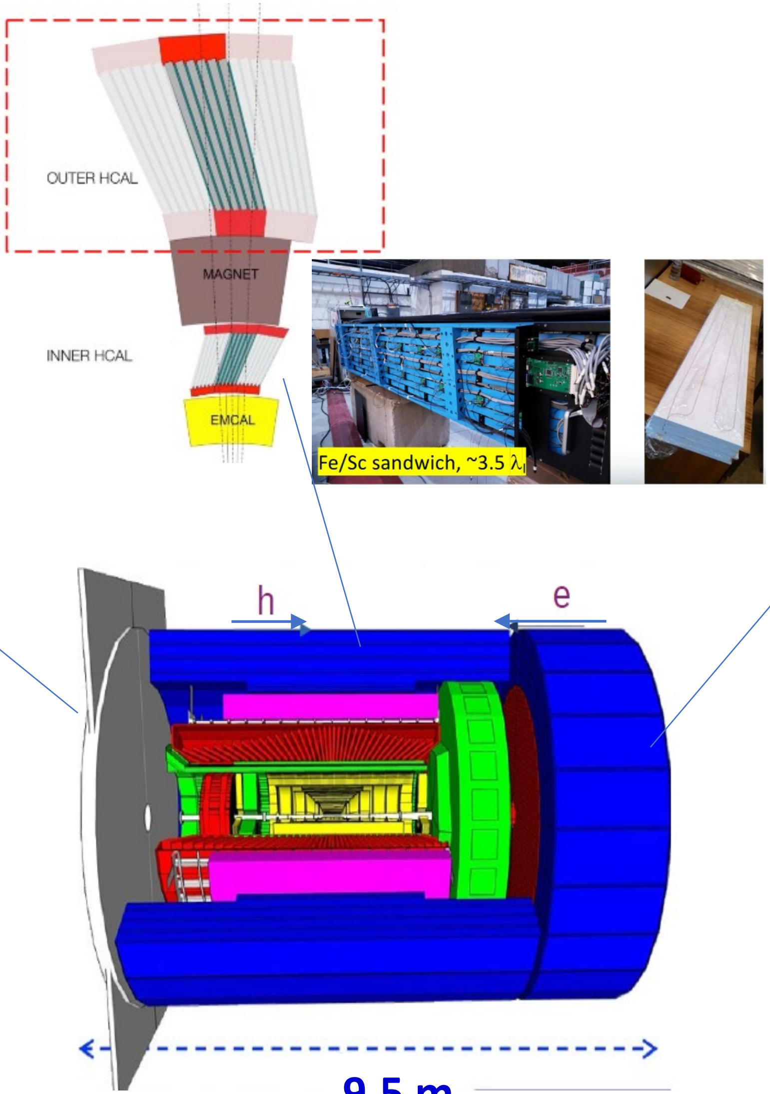
All: sampling sandwich design with WLS fibers & SiPM readout

Alexander Kiselev, Calorimetry Review, 2022

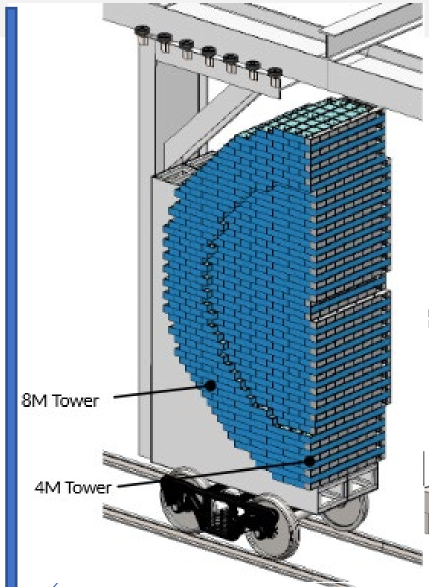
HADRON CALORIMETRY for ePIC





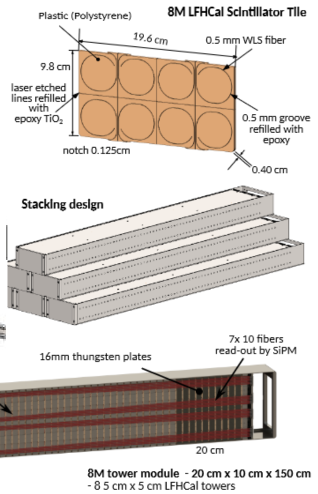


Alexander Kiselev,
Calorimetry Review, 2022

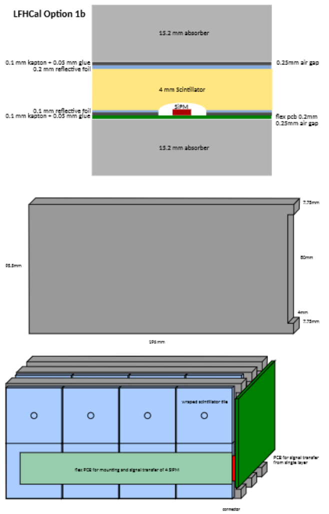


Fredericke Bloch,
Calorimetry weekly, 2023

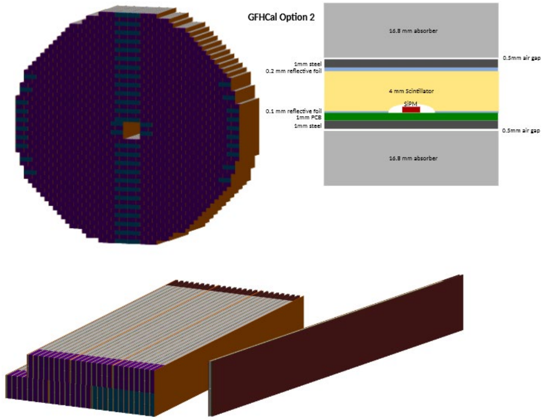
Option 1 (WLS fibers)



Option 1b (Buried SiPM)

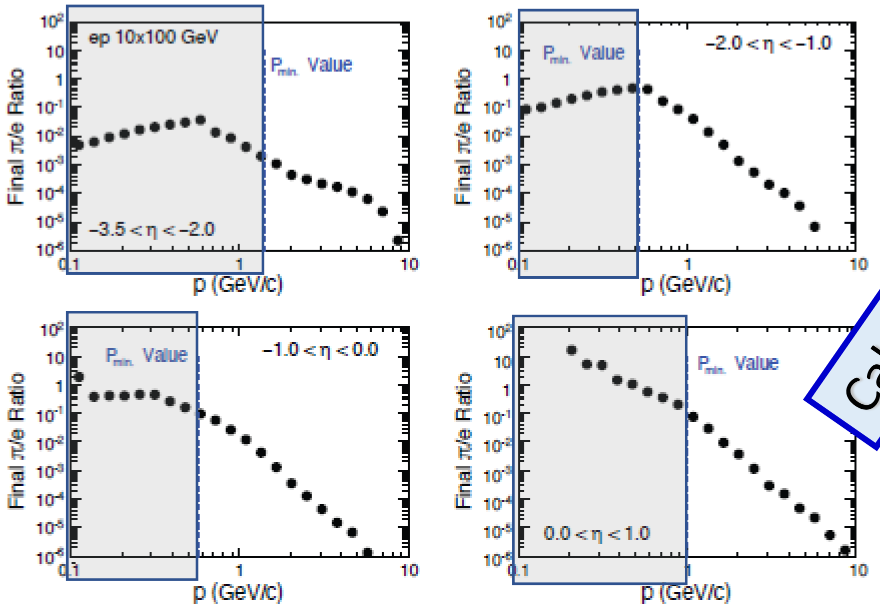


Option 2 - GFHCal



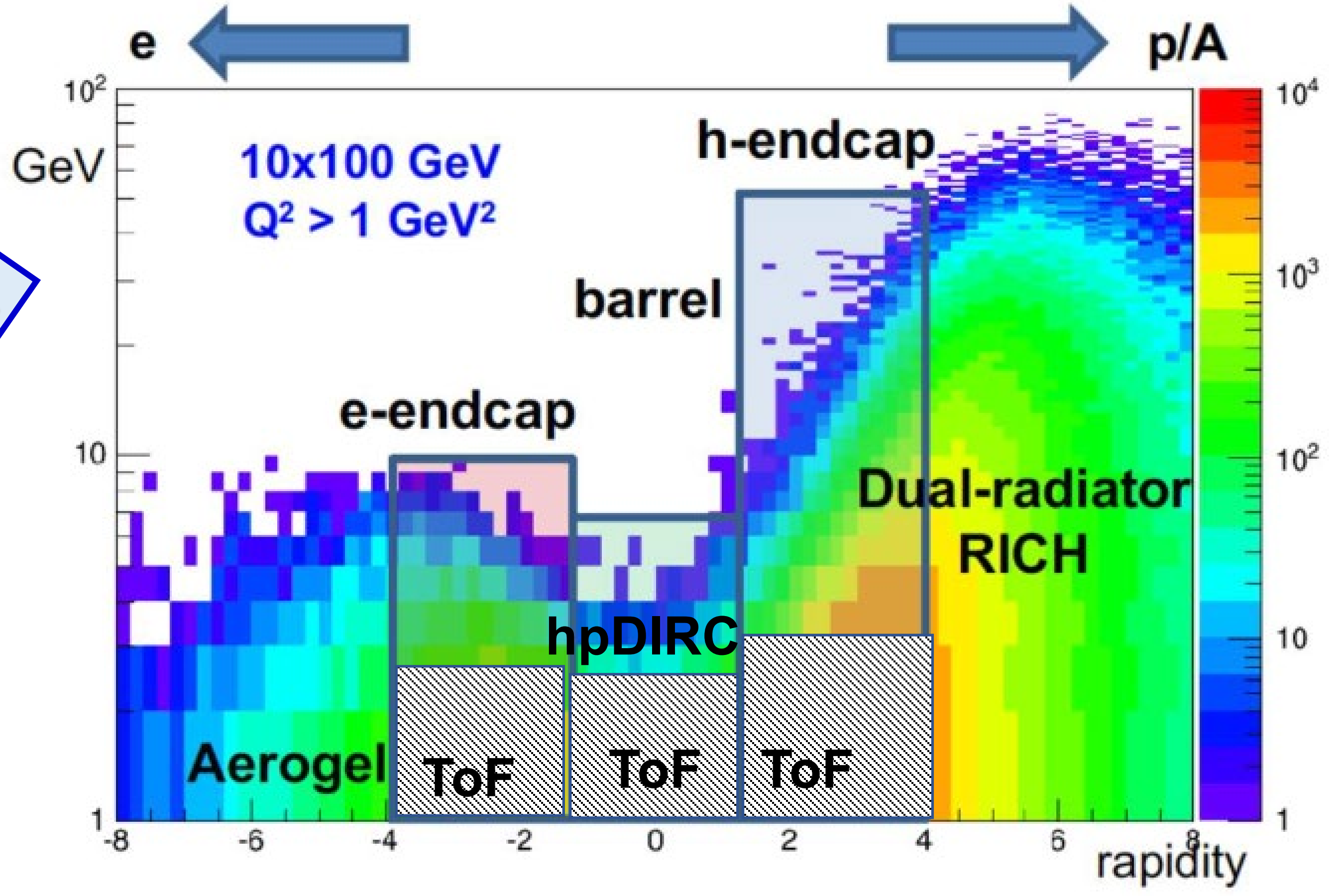
ePIC PID system – the double mission

e-π separation:
Cherenkov imaging support the Ecal effort, in particular needed at low momenta
(the whole EIC physics scope)



Calorimeters only

h-PID: **Cherenkov imaging complemented with ToF**
(SIDIS, heavy flavour, …)

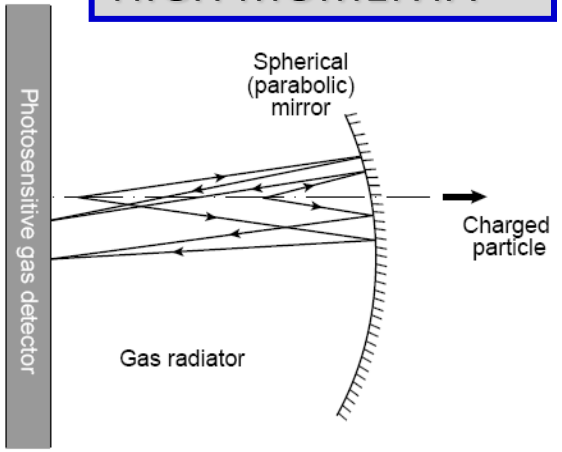


PID by Cherenkov imaging techniques

HIGH MOMENTA

With focalization

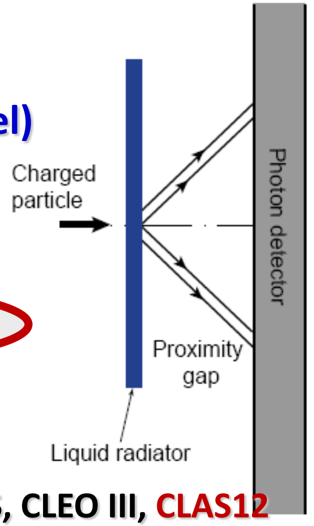
- Extended radiator (gas)
- the only approach at high momenta (p > 3-4 GeV/c)



- EXAMPLES: SELEX, OMEGA, DELPHI, SLD-CRID, HeraB, HERMES, COMPASS, LHCb, NA62, EIC

Proximity focusing

- thin radiator (liquid, solid, areogel)
- Effective at low momenta (p < 5-8 GeV/c)

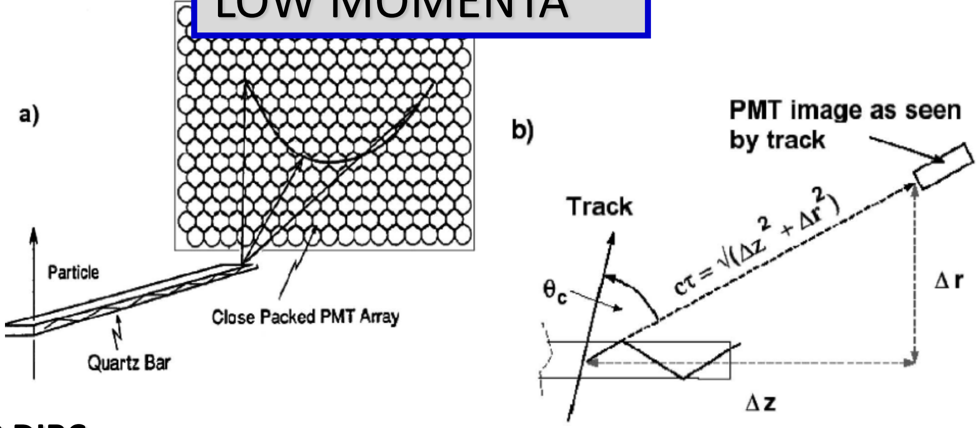


- EXAMPLES: STAR, ALICE HMPID, HERMES, CLEO III, CLAS12

LOW MOMENTA

DIRC

- Quartz as radiator and as light guide
- Effective at low momenta (p < 5-6 GeV/c)



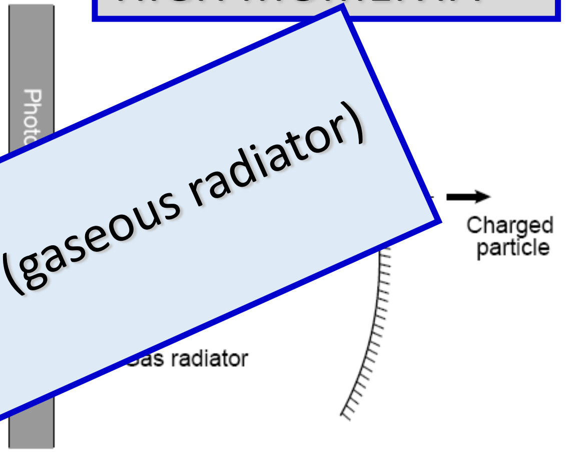
- The only existing DIRC operated in an experiment: BABAR DIRC
- NEW: DIRC-derived architectures in BELLE II (TOP), Panda (focusing DIRC)

PID by Cherenkov imaging techniques

HIGH MOMENTA

With focalization

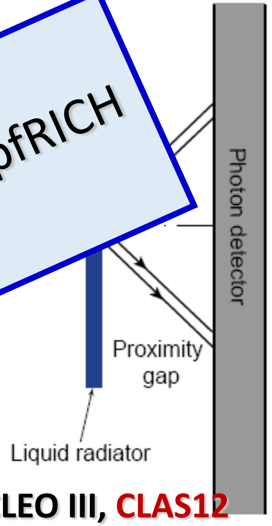
- Extended radiator (gas)
- the only approach at high mom
  (p > 2
- EXA
  OME , SLD-CRID, HeraB, HERMES, COMPASS, LHCb, NA62,



@ePIC: the dRICH (gaseous radiator)

Proximity focusing

- thin radiator (liquid, soli
- Effe at low m
  (p < 5-8
- EXAMPLES: STAR, ALICE HMPID, HERMES, CLEO III, CLAS12

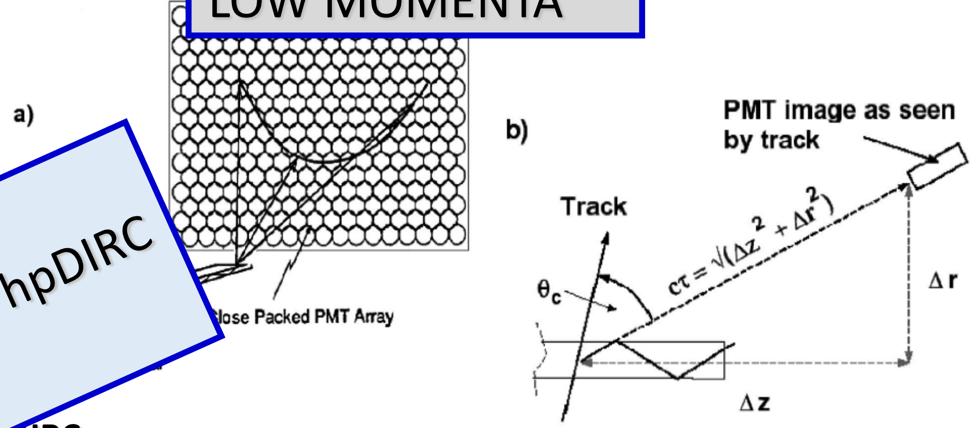


@ePIC: the pfRICH

LOW MOMENTA

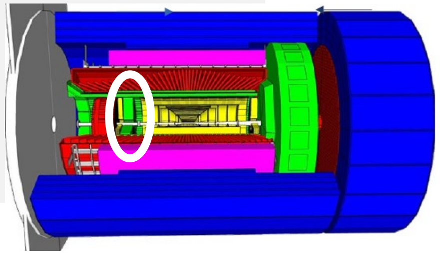
DIRC

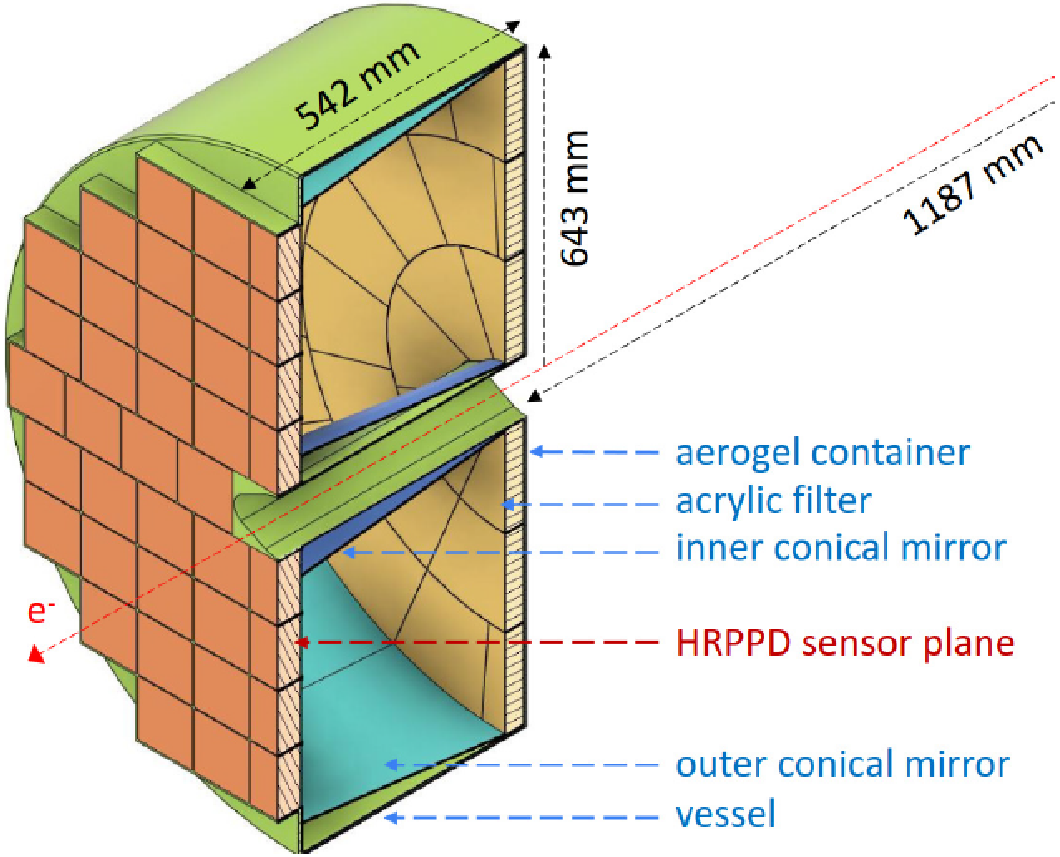
- Quartz as radiator and as light guide
- Effective at low momenta
  (p < 5-6 GeV/c)
- The only existing DIRC operated in an exp DIRC
- NEW: DIRC-derived architectures in BELLE I), Panda (focusing DIRC), [LHCb (TORCH)]



@ePIC: the hpDIRC

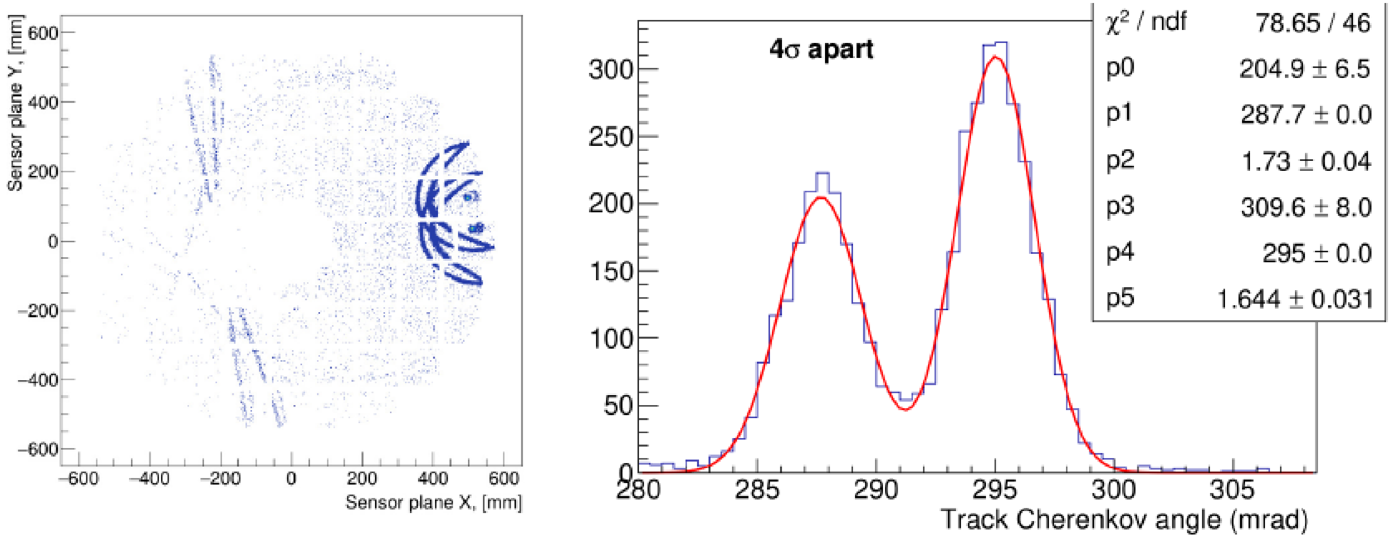
The ePIC backward RICH – pfRICH





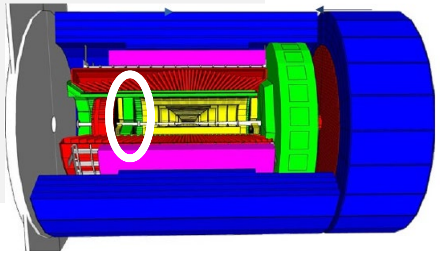
e-endcap RICH for ePIC detector

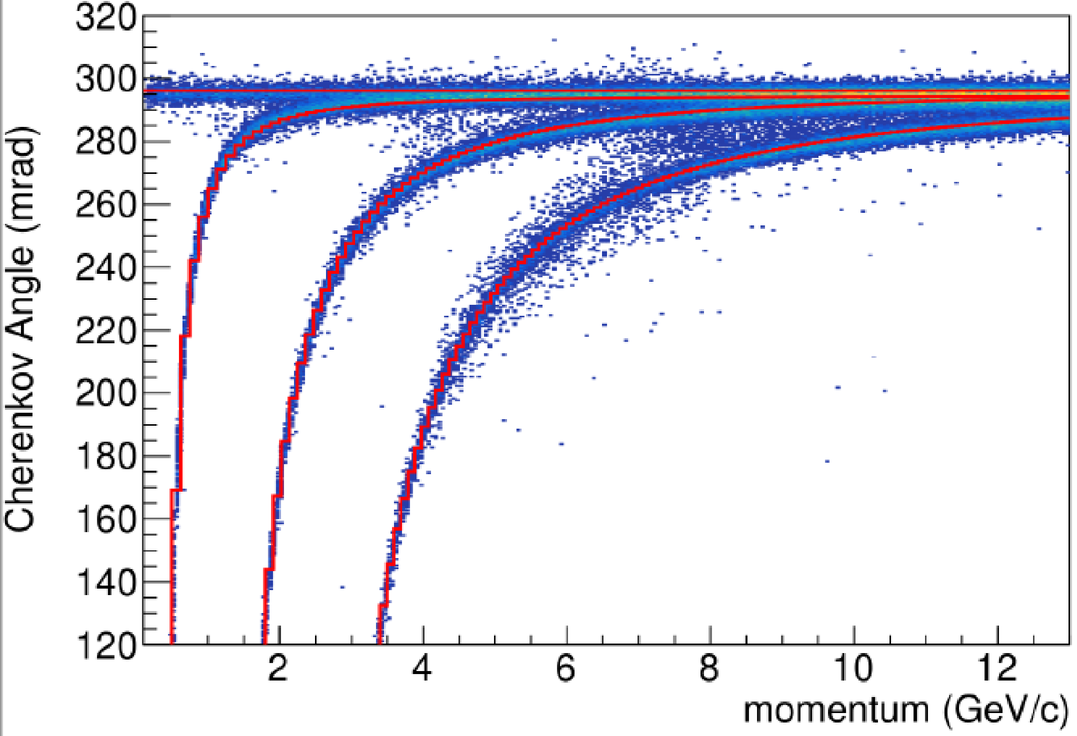
- A classical proximity focusing RICH
- Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- Uniform performance in the whole $\{\eta,\phi\}$ range
- π/K separation above 3σ up to ~ 9.0 GeV/c and ~10-20ps t_0 reference with a ~100% geometric efficiency in one detector



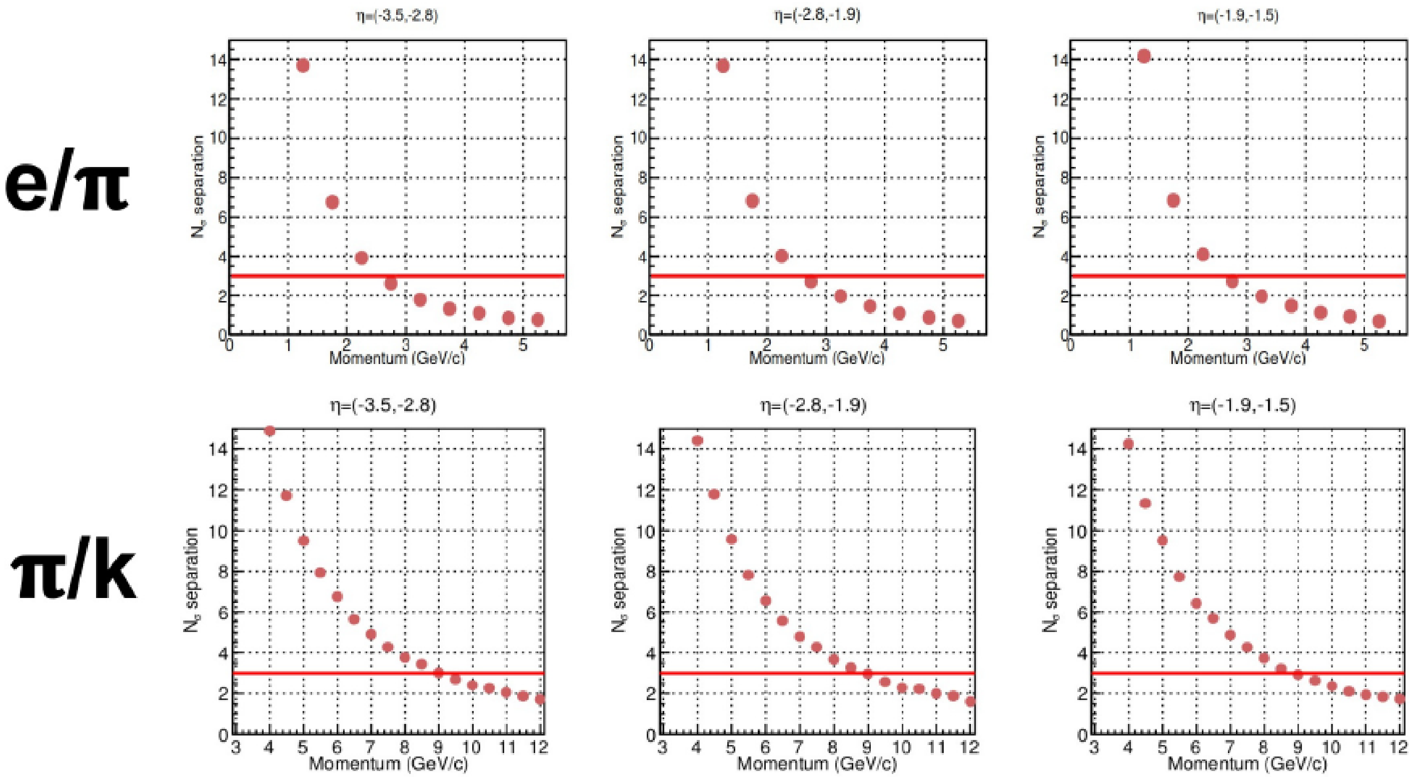
Sophisticated chi-squared analysis capable of performing efficient pid with complicated event topologies.

The ePIC backward RICH – pfRICH

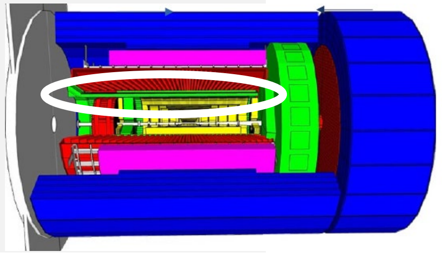


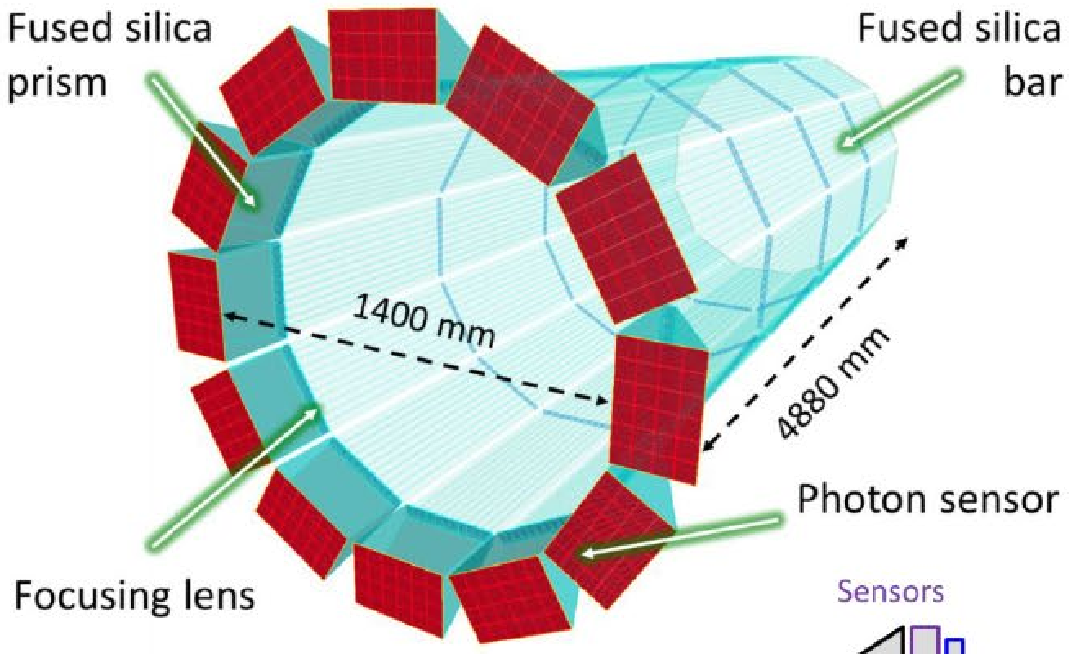


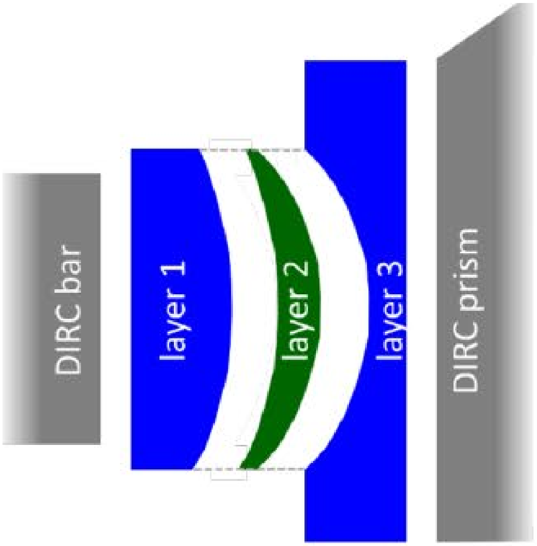
Performance: e/π & π/k separation



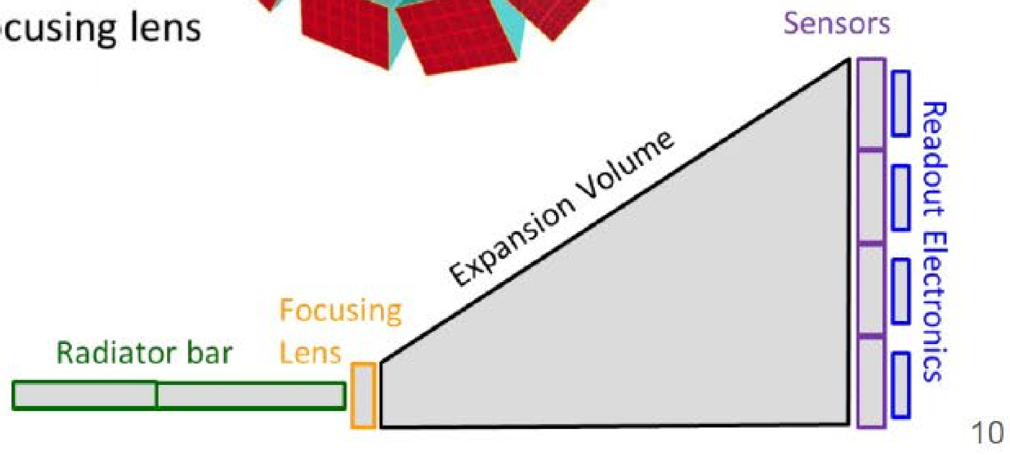
The ePIC barrel RICH – hpDIRC

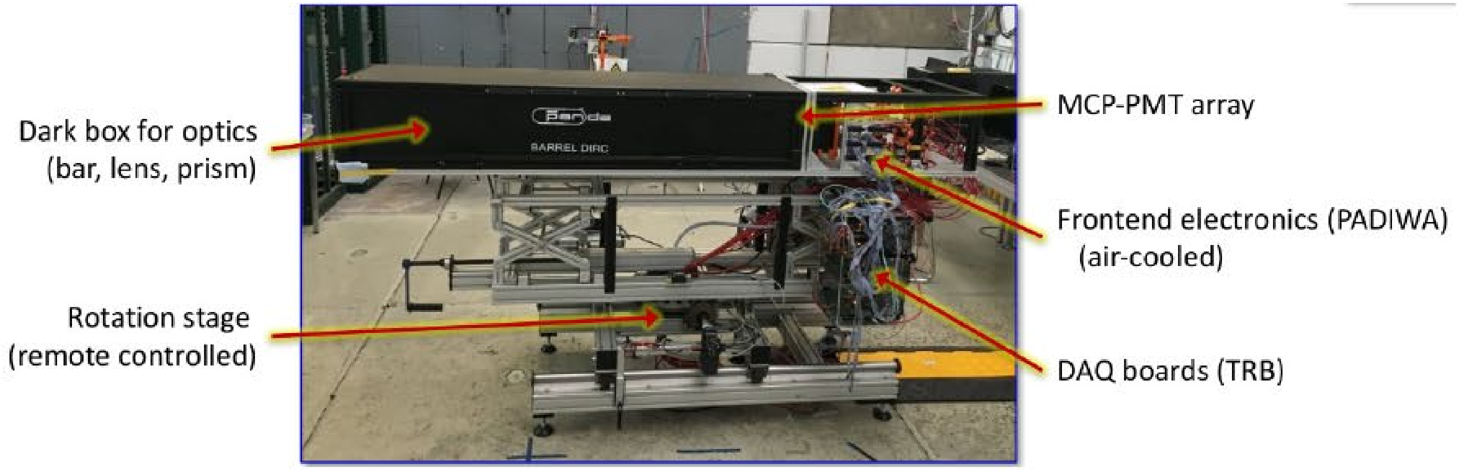




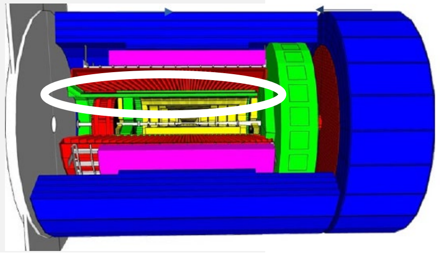


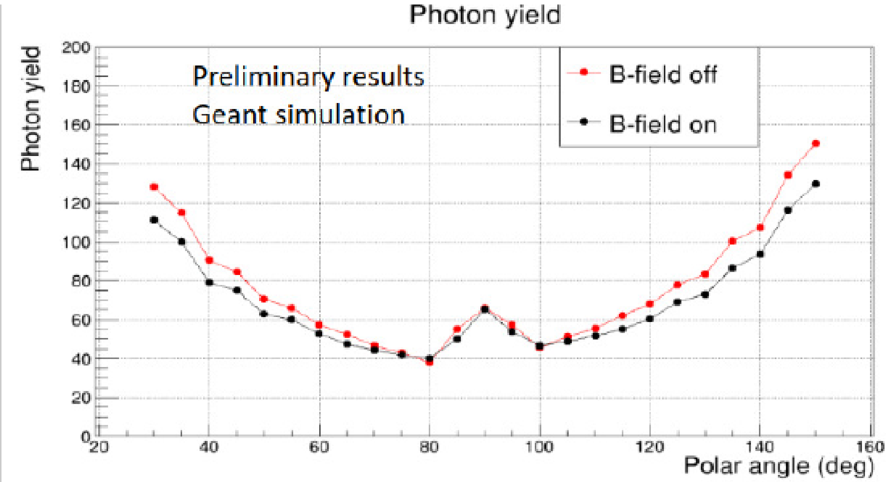
- Improved resolution.
- Key components:
  - Innovative focusing lens
  - Compact fused silica expansion.
  - Fast photon detection.

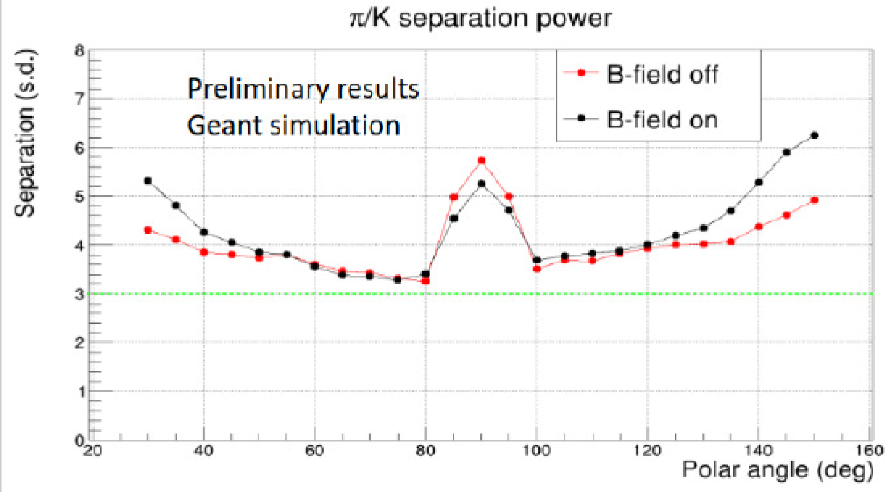


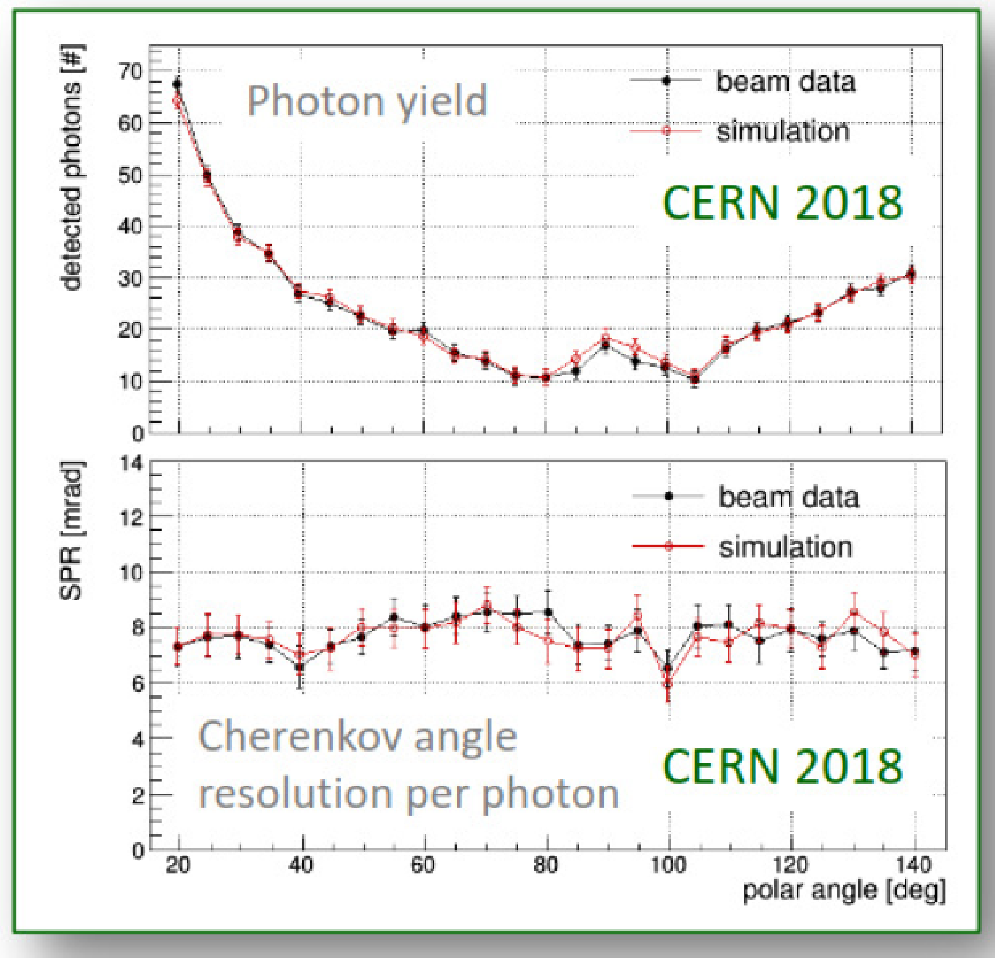


The ePIC barrel RICH – hpDIRC





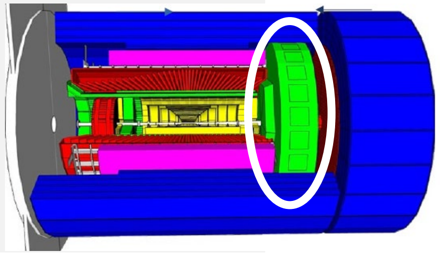


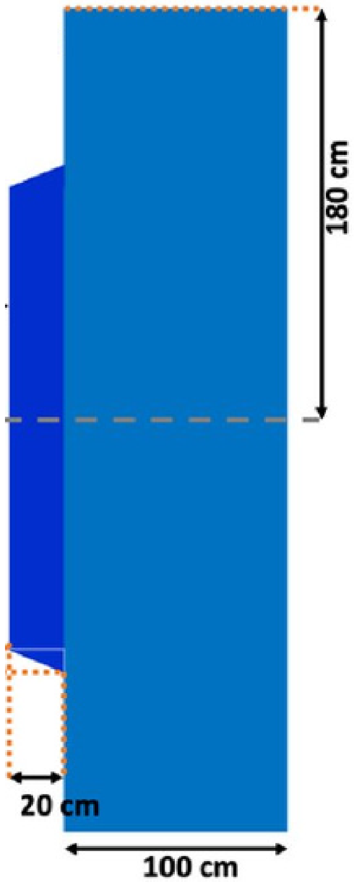


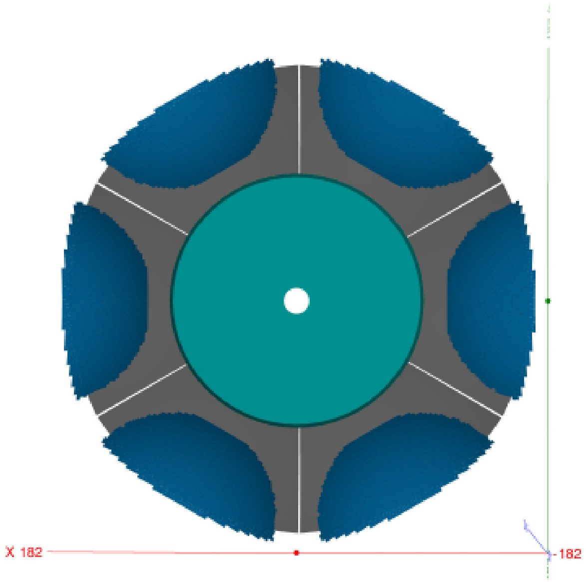
3D (X,Y,t) reconstruction thanks to fast photon detection sensor. Potential commonality with pfRICH for using HRPPD.

Excellent agreement between simulation and beam test results. 3 sigma pi/K separation up to 6 GeV/c (covering -1.73<eta<1.73).

The ePIC forward RICH – dRICH

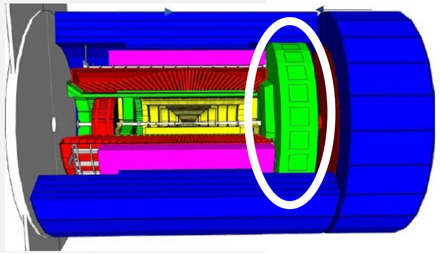


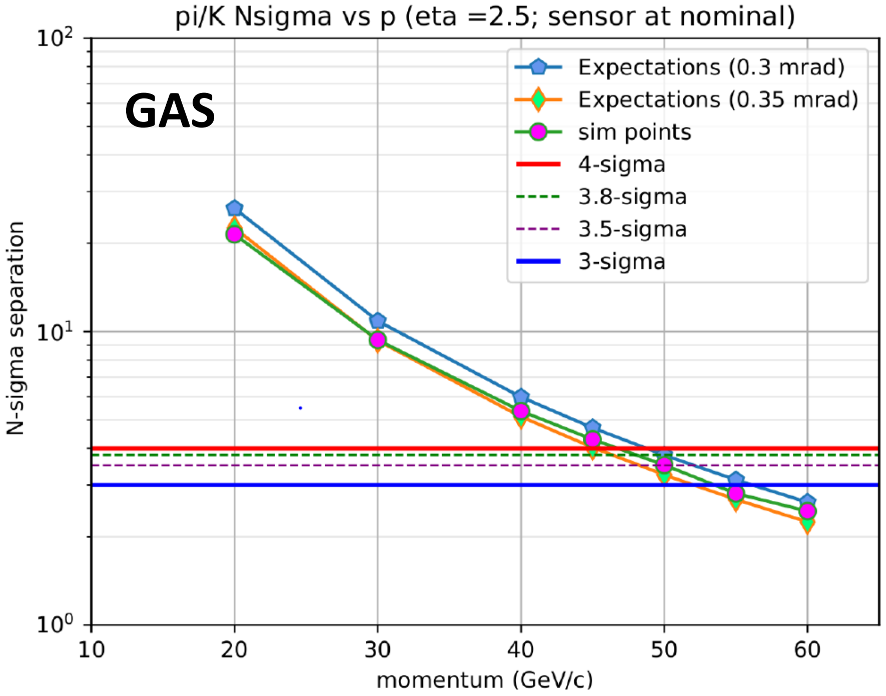


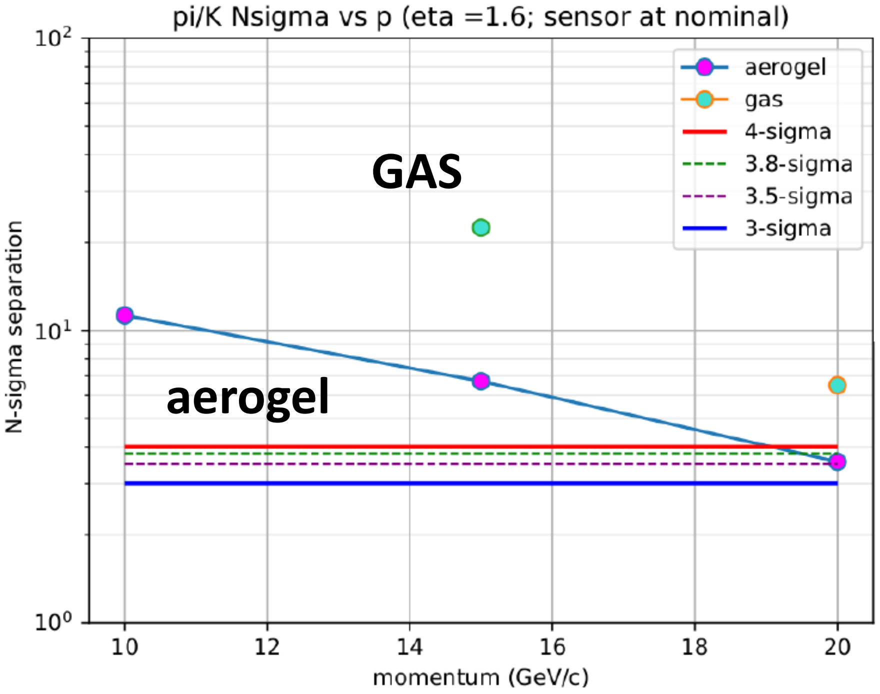


- Requirements:
  - Wide acceptance (+- 300 mrad/ 1.5<η≤3.5)
  - High momentum coverage up to 50GeV/c pi-K
    - Dual radiator (aerogel (n ~1.02)+ C2F6 gas (n~1.0008))
- Short radiator space available
  - Smaller number of detected photons → Critical optical tuning and control over background hits.
- Large sensor surface to be covered in magnetic field.
  - Limited choice of photon-sensor(SiPM as a cheap solution)
- Simulation contains: 6 identical sectors composing.
  - Spherical mirror with radius 220 cm
  - SiPM sensors with realistic PDE and additional 70% safety factor.

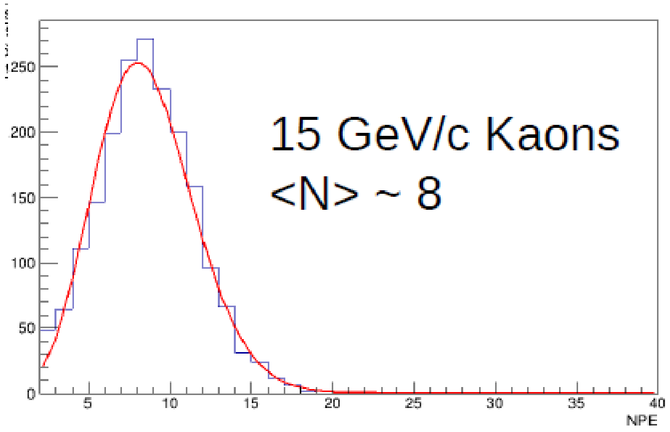
The ePIC forward RICH – dRICH



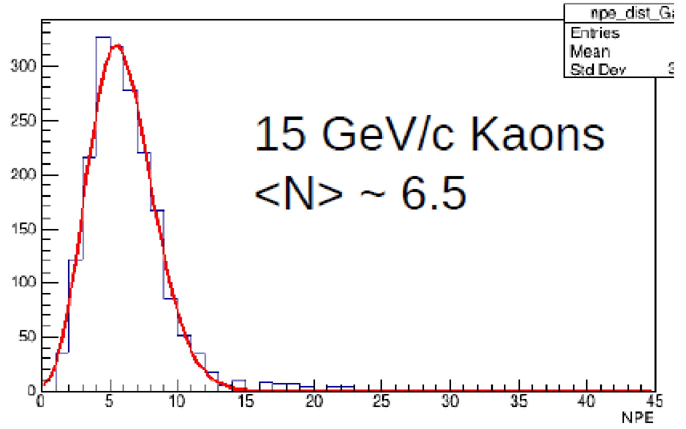




Aerogel



GAS



GAS: W/ conservative 70% safety factor 18 photoelectrons are detected at saturation

Sensors for Cherenkov imaging detectors

3 families (grouping by technologies)

Vacuum based PDs

- **PMTS (SELEX, Hermes, BaBar DIRC, NA62)**
- **MAPMTs (HeraB, COMPASS RICH-1 forward region, LHCb upgrade, GlueX, CLASS12, Panda forward-RICH)**
- **Hybride PMTs (LHCb)**
- **HAPD (BELLE II aerogel-RICH)**
- **MCP-PMT (BELLE II barrel: TOP detector)**
- **LAPPDs – large size MCP-PMTs (under development, not used so far in experiments)**

Gaseous PDs

- **Organic vapours - in practice only TMAE and TEA (Delphi, OMEGA, SLD CRID, CLEO III, …)**
- **CsI and open geometry (HADES, COMPASS, ALICE, STAR, JLAB-HALL A)**
- **CsI and MPGDs (PHENIX HBD, no imaging, COMPASS RICH-1 2016-17 upgrade**

SiPMs

- **Silicon PMs (not used so far in any experiment)**
  - **radiation hardness , intrinsic noise**
  - **cooling to moderate**

Time resolution (s)

- **PMTs, MAPMTs >/~ 0.3 ns**
- **MCP-PMT << 100 ps**
- **SiPM <100 ps**
- **MWPCs >/~ 20 - 400 ns**
  - **FE dependent, ballistic deficit implications (*)**
- **MPGDs ~ 7-10 ns (INTRINSIC)**

Operation in magnetic field

- **PMTs, MAPMTs, HPMTs NO**
- **MCP-PMT YES**
- **MWPCs, MPGDs YES**
- **SiPM YES**

Effective QE range

- **Vacuum-based devices:**

  λ > 300, 250, 200 nm [also solar-blind]
- **Gaseous devices (CsI):**

  λ < 205 nm
- **SiPM:**

  visible and near UV

Detection of single photons !

Sensors for Cherenkov imaging detectors

3 families (grouping by technologies)

Vacuum based PDs

- **PMTS (SELEX, Hermes, BaBar DIRC, NA62)**
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SiPMs

- **Silicon PMs (not used so far in any experiment)**
  - **radiation hardness , intrinsic noise**
  - **cooling to moderate**

hpDIRC

pfRICH (hpDIRC)

dRICH

Time resolution (s)

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- **MCP-PMT <100 ps**
- **SiPM <100 ps**
- **MWPCs >/~ 20 - 400 ns**
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- **Gaseous devices (CsI):**

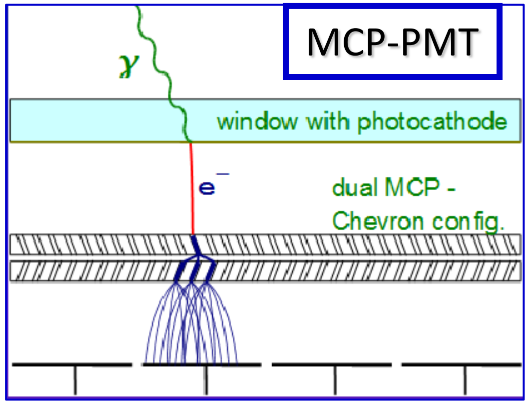
  λ < 205 nm
- **SiPM:**

  visible and near UV

Detection of single photons !

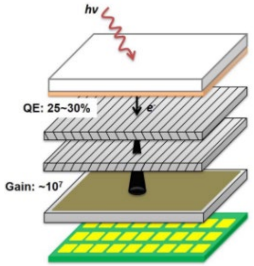
INFN TRIESTE

LAPPDs/HRPPDs for pfRICH (and hpDIRC)

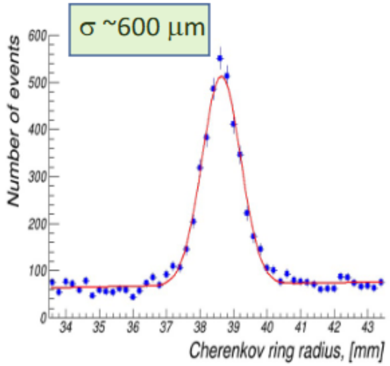


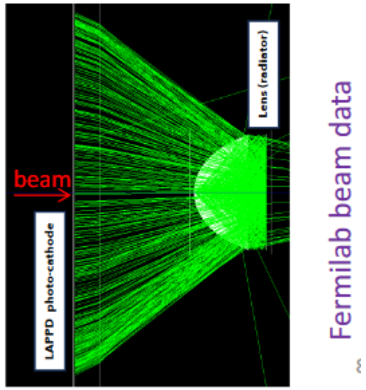
LAPPD/HRPPD, large-size detectors of the MCP-PMT family

LAPPD
(20 x 20 cm^2, 20 μm pore)

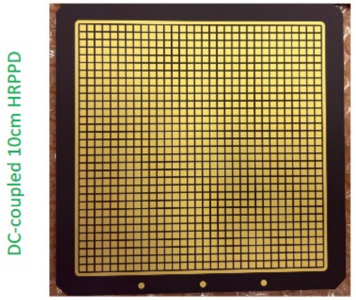


Gen II variety

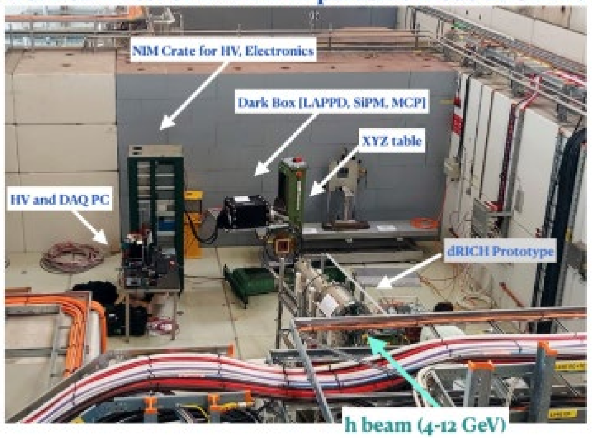




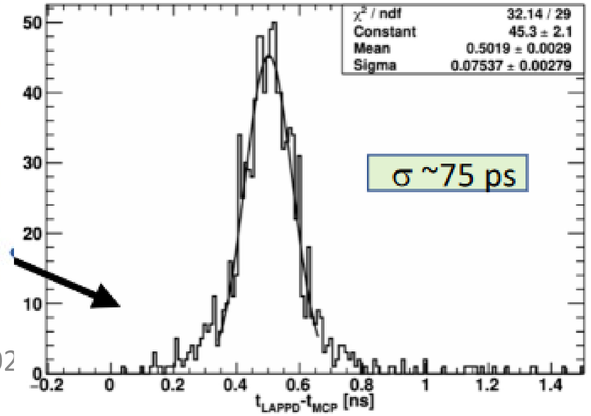
HRPPD (10 x 10 cm^2 , 10 μm pore)



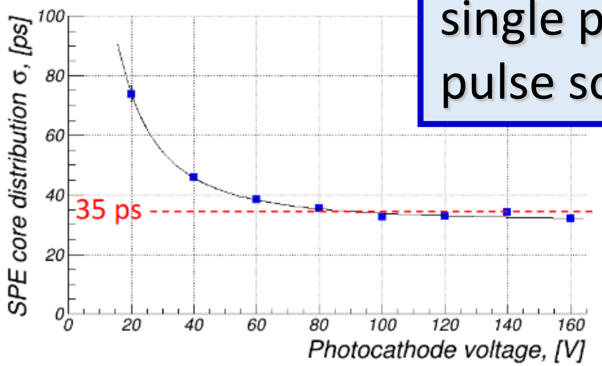
First Beam Test of LAPPD in parasitic mode at CERN-PS



single photon, Cherenkov light

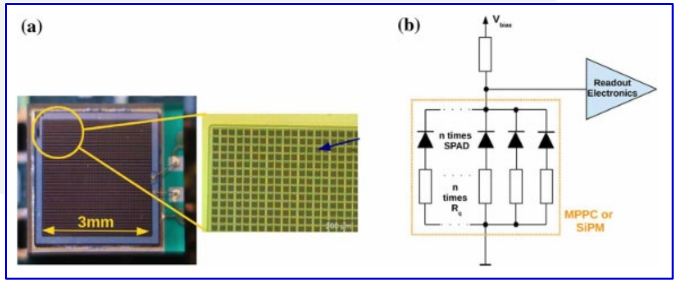


single photon, pulse sourse light



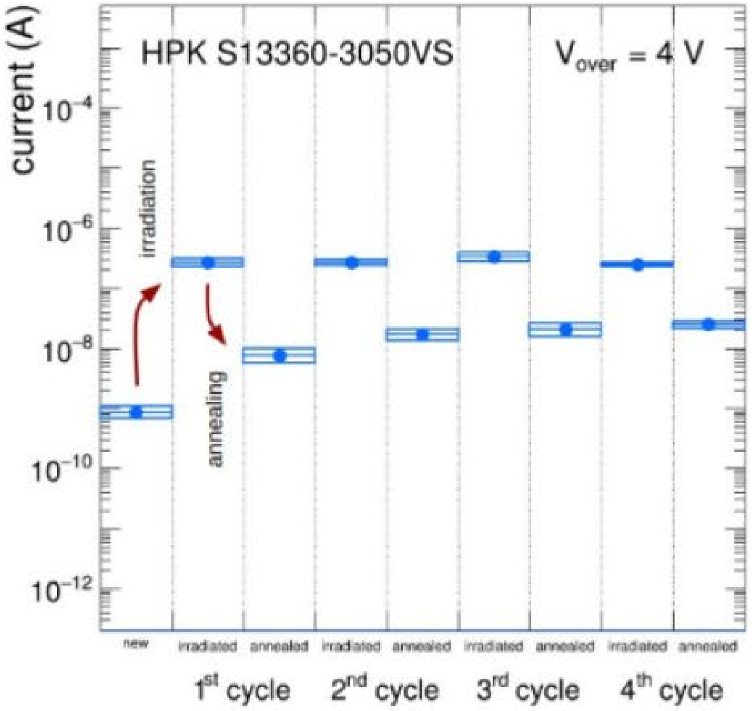
Alexander Kiselev, FAST 2023

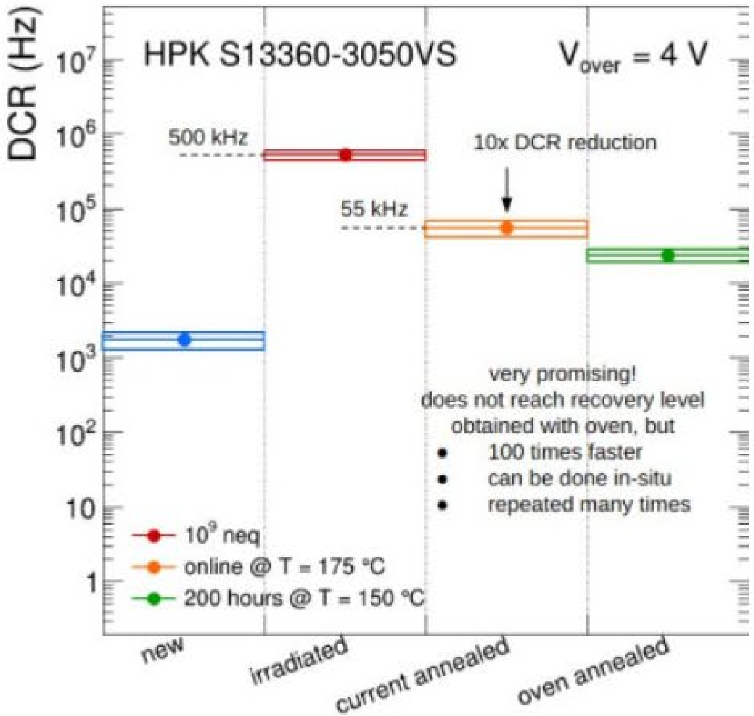
SiPMs for the dRICH



SiPM: An array of pixelized Avalanche Photodiodes operated in Geiger mode

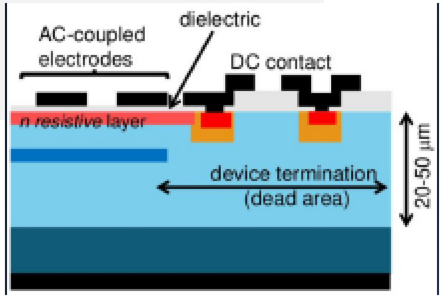
- **pros**
  - high photon efficiency
  - excellent time resolution
  - insensitive to B field
- **cons**
  - large DCR, ~ 50 kHz/mm^2 @ T = 24 °C
  - not radiation tolerant
    - moderate fluence < 10^{11} n_{eq}/cm^2
- **R&D on mitigation strategies**
  - reduce DCR at low temperature
    - operation at T = -30 °C (or lower)
  - recover radiation damage
    - in-situ high-temperature annealing
  - exploit timing capabilities
    - with ALCOR (INFN) front-end chip





Different types of SiPMs are understudy.

ToF for ePIC (barrel and forward endcap)

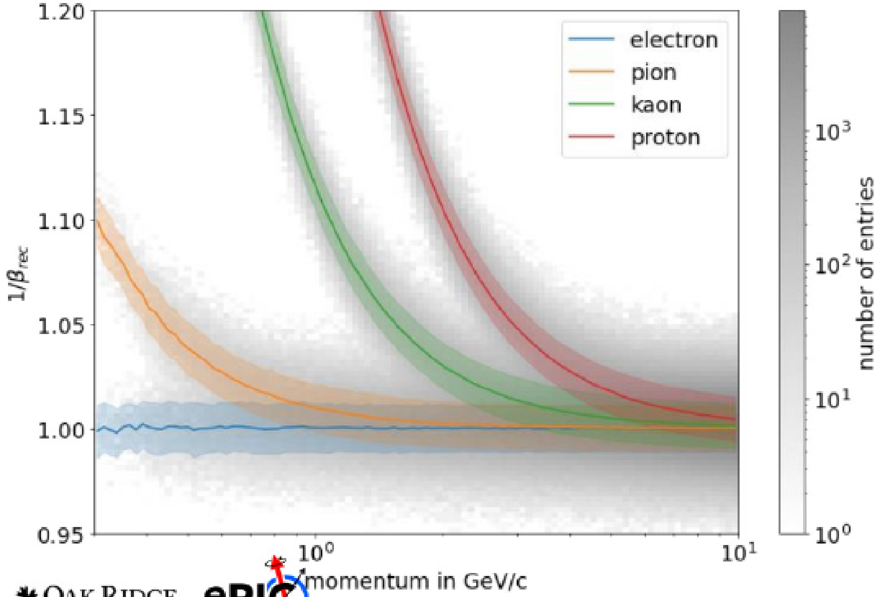


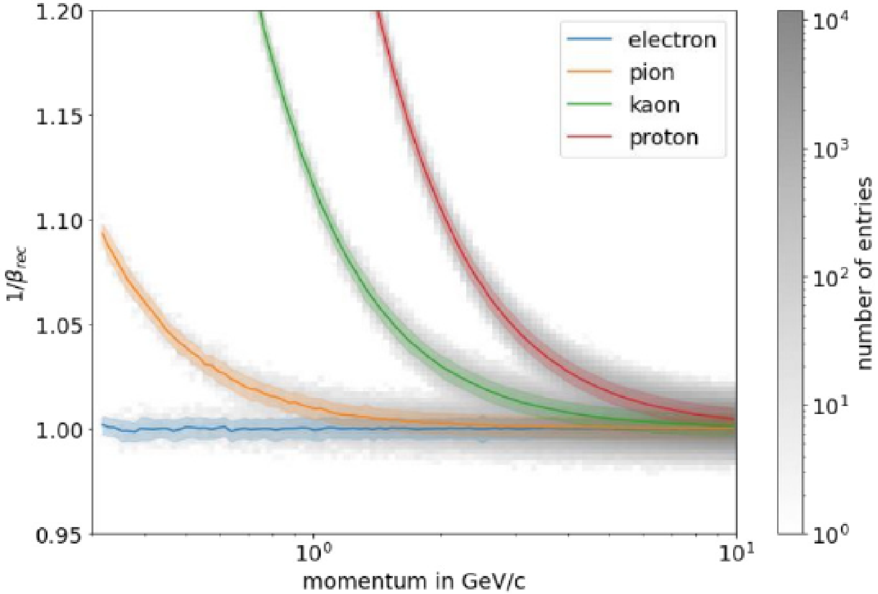
AC-LGAD - AC-coupled Low-Gain Avalanche Diode

TOF PID Performance – Single Particle Gun

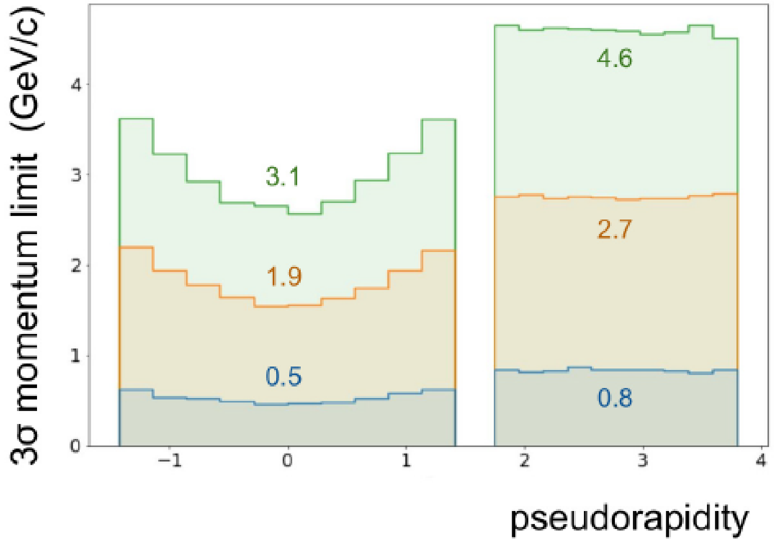
Assuming 30 ps time resolution

- Barrel Region
  - e/pi up to 0.5 GeV/c
  - pi/K up to 1.9 GeV/c
  - K/p up to 3.1 GeV/c
- Endcap Region
  - e/pi up to 0.8 GeV/c
  - pi/K up to 2.7 GeV/c
  - K/p up to 4.6 GeV/c





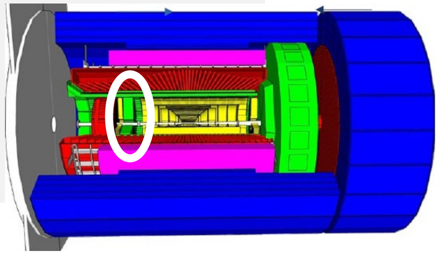
TOF Simulations in ePIC

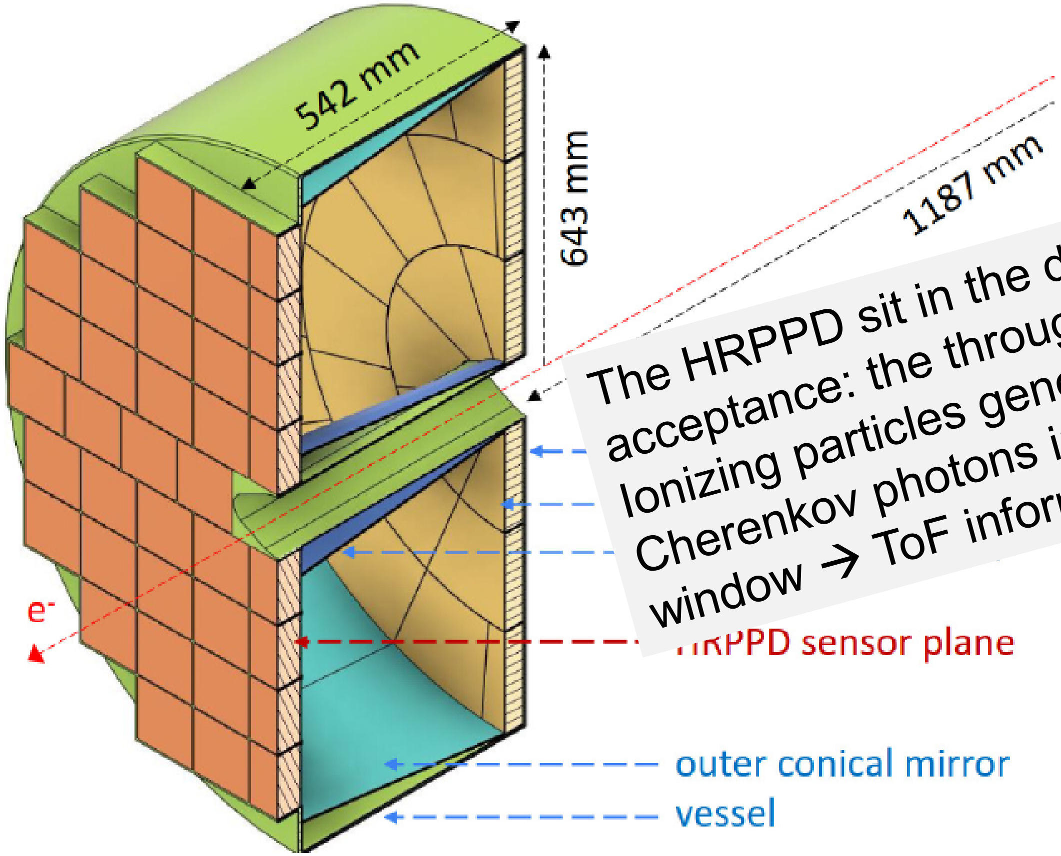


Advanced geometric description in simulation, Physics performance studies, dedicated R&D with photosensors and readout commonality with pfRICH in readout ASIC

OAK RIDGE National Laboratory ePIC

The ePIC backward RICH – pfRICH

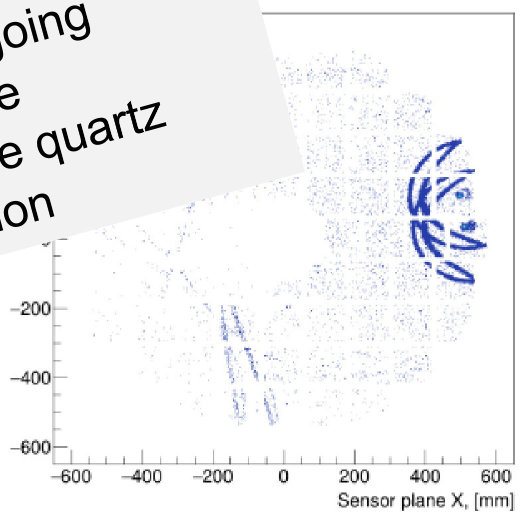


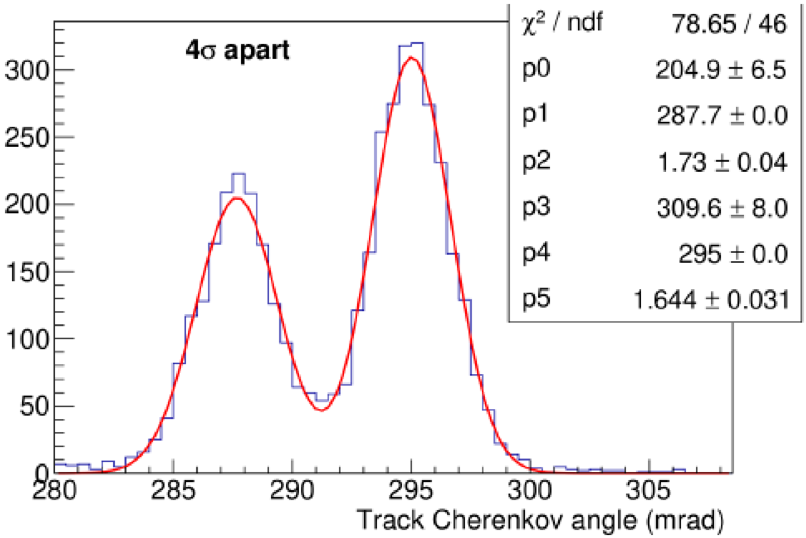


The HRPPD sit in the detector acceptance: the through-going Ionizing particles generate Cherenkov photons in the quartz window → ToF information

e-endcap RICH for ePIC detector

- A classical proximity focusing RICH
- Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- Uniform performance in the whole $\{\eta,\phi\}$ range
- π/K separation above 3σ up to ~ 9.0 GeV/c and ~10-20ps t_0
  ce with a ~100% geometric efficiency in one detector

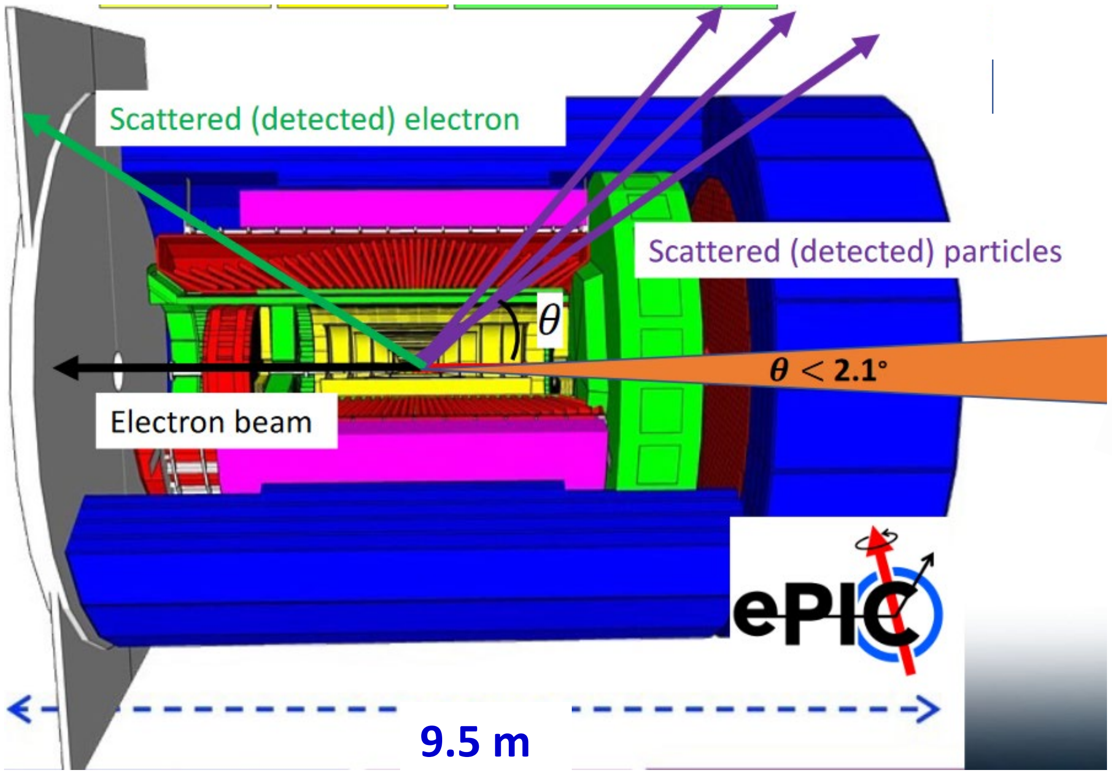


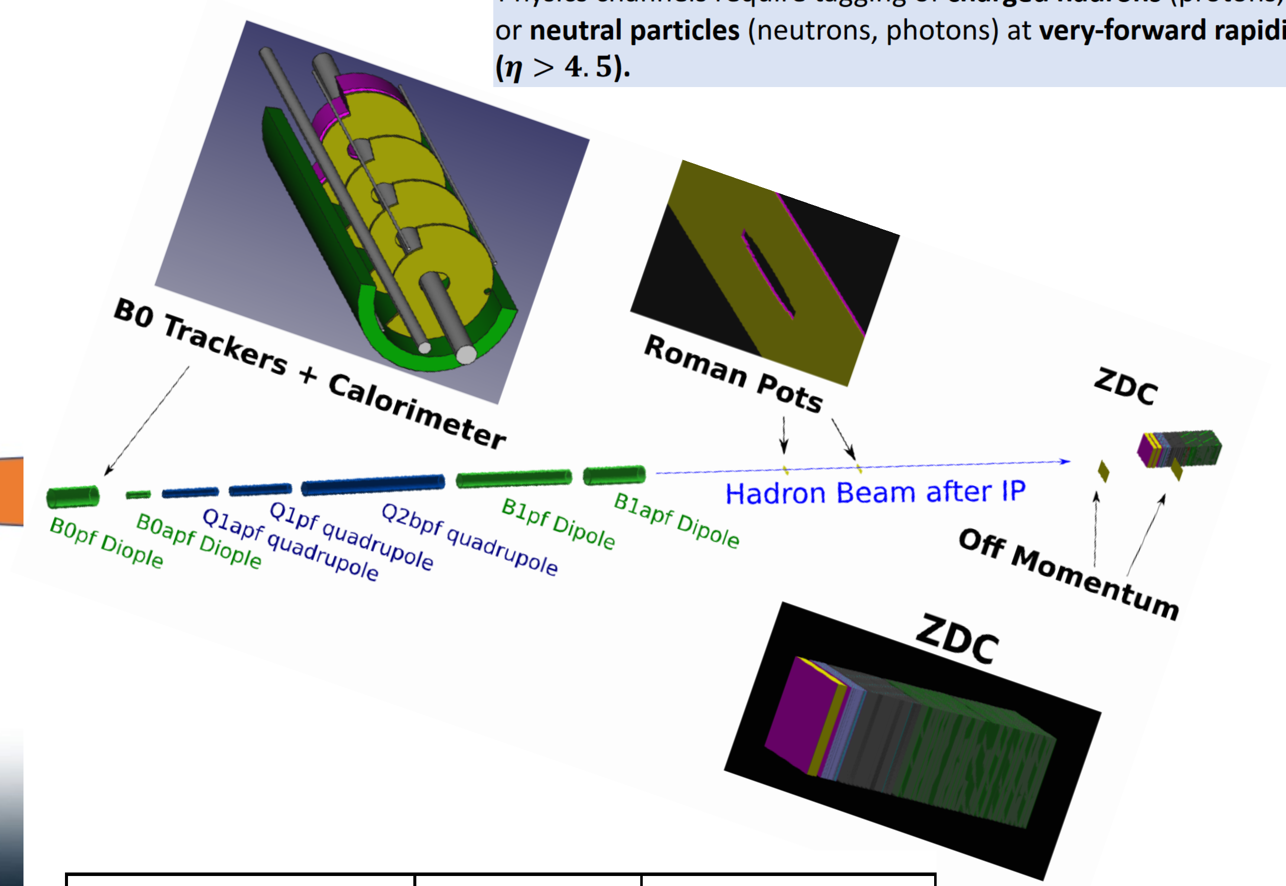


Sophisticated chi-squared analysis capable of performing efficient pid with complicated event topologies.

FAR FORWARD

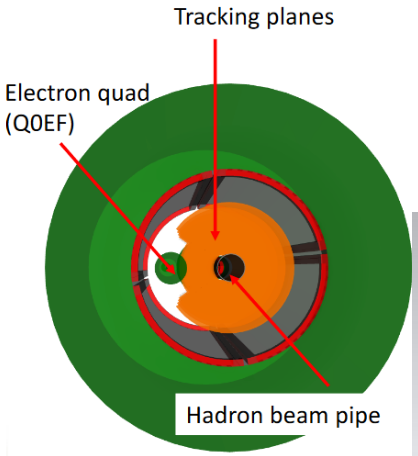
Physics channels require tagging of **charged hadrons** (protons, pions) or **neutral particles** (neutrons, photons) at **very-forward rapidities ($\eta > 4.5$).**

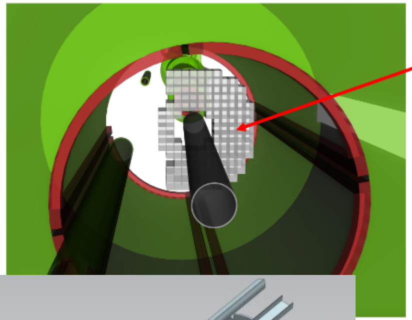


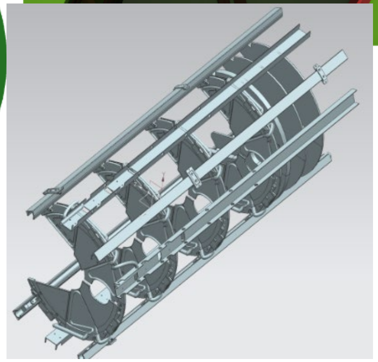


Detector	θ accep. [mrad	Particles
B0 tracker	5.5–20.0	Charged particles Tagged photons
Off-Momentum	0.0–5.0	Charged particles
Roman Pots	0.0–5.0	Protons Light nuclei
Zero-Degree Calorimeter	0.0–4.0	Neutrons Photons

B0 Tracking and EMCAL Detectors



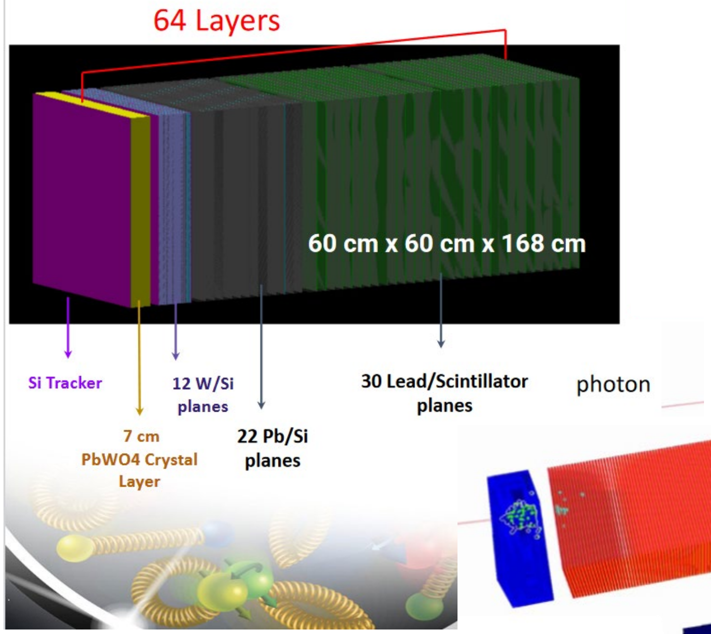


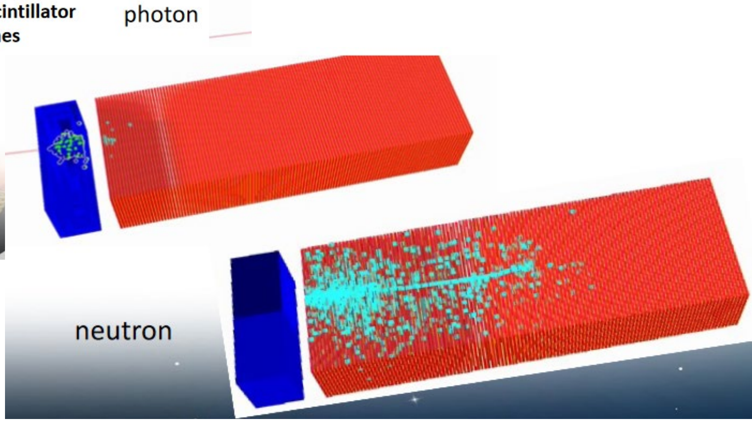


- **Technology choices:**
  - **Tracking: IT3 or ITS2 MAPS (3 layers) + AC-LGADs (1 layer; in middle)**
  - **PbWO4 EMCAL or silicon preshower, depending on available space in final B0pf magnet design (pending).**

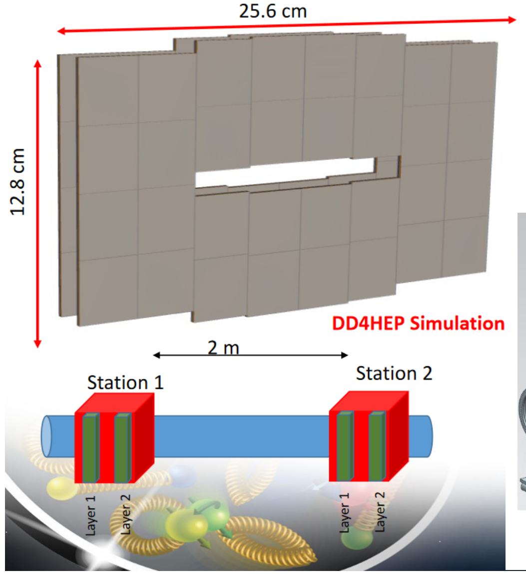
FAR FORWARD

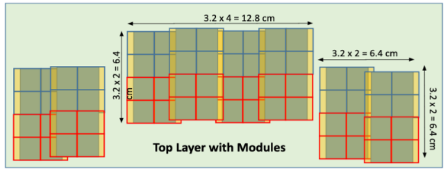
Zero-Degree Calorimeter



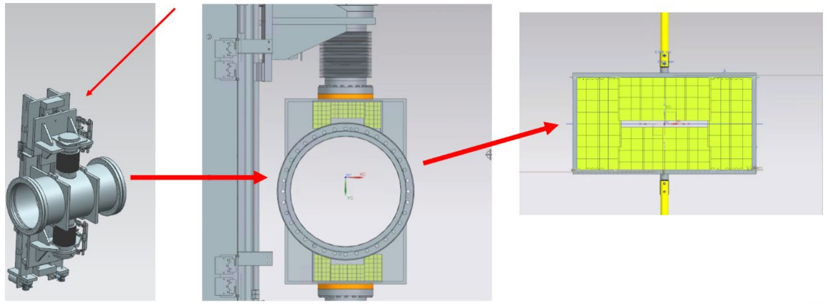


Roman "Pots" @ the EIC





- **Technology**
  - 500um, pixilated AC-LGAD sensor provides both fine pixilation.

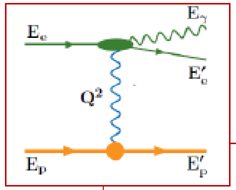


FAR BACKWARD

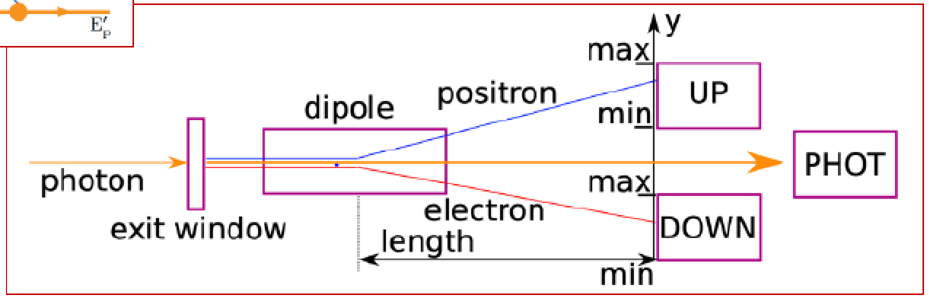
- measure IP6 luminosity with **an absolute precision better than 1% absolute and a relative precision better than 0.01%** using the electron-ion bremsstrahlung by three largely independent and complementary measurements

- electron detectors will also be used to tag low-Q^2 Events (photoproduction) in ATHENA

bremsstrahlung process



principle



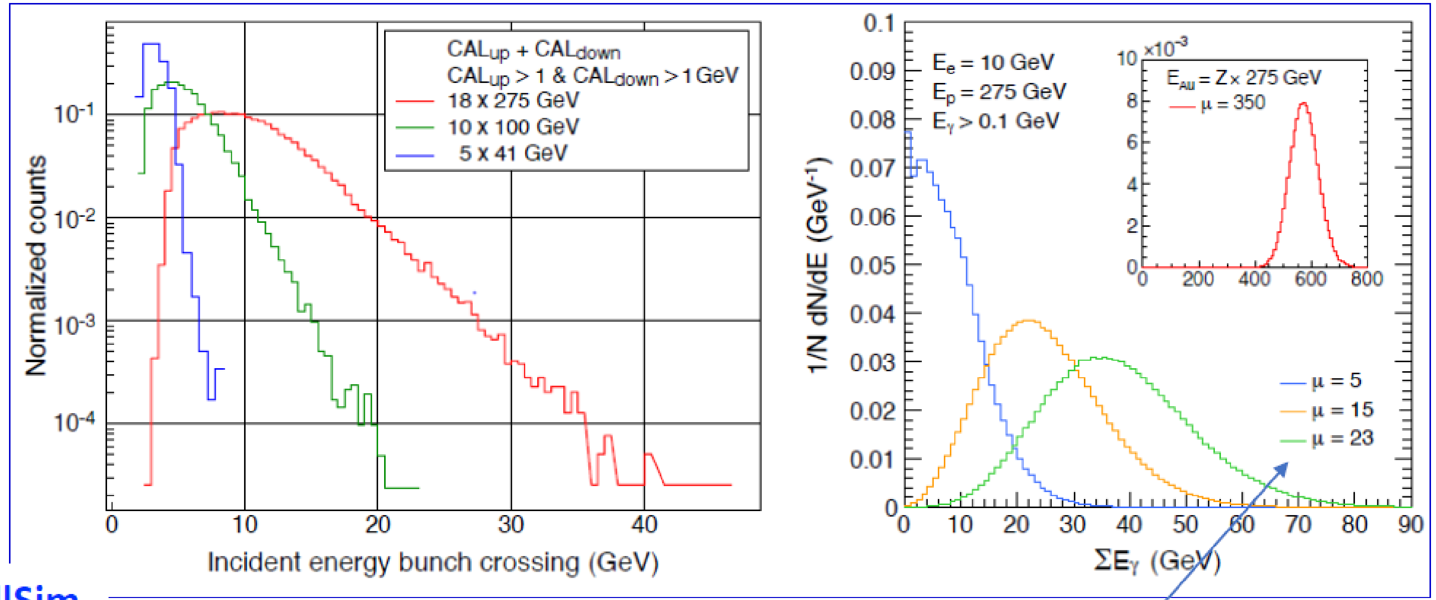
Technologies for the calorimetry:

- Spaghetti W-calorimeter with radiation-hard scintillating fiber, read out with fast PMTs
- Cherenkov-radiating quartz fibers read out by SiPMs

different CM energy

PHOT

different Luminosity



FullSim

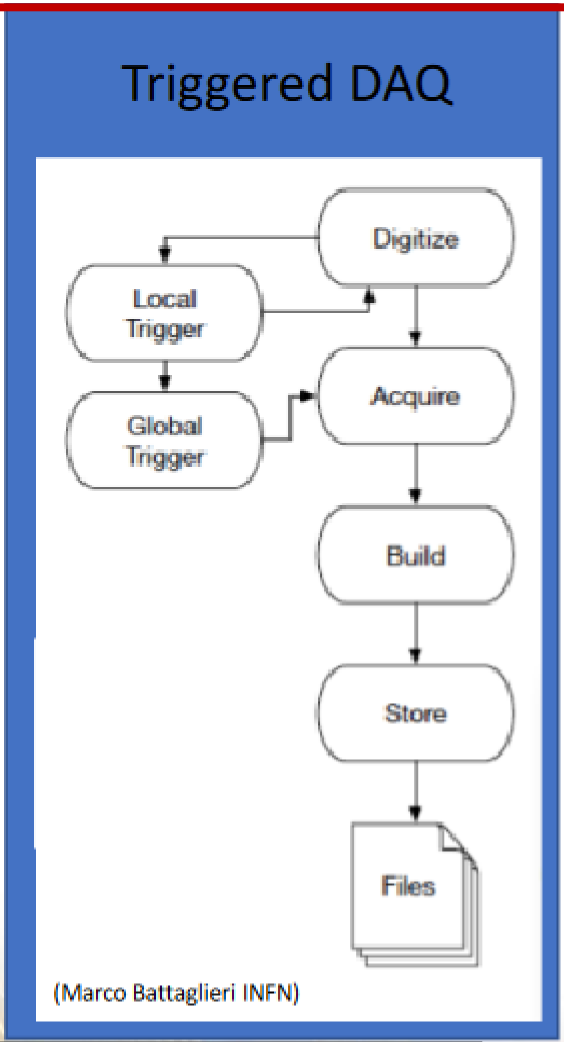
$L = 2.2$, 6.5 and 10×10^{33} cm^{-2}s^{-1}, corresponding to the average photon multiplicity μ

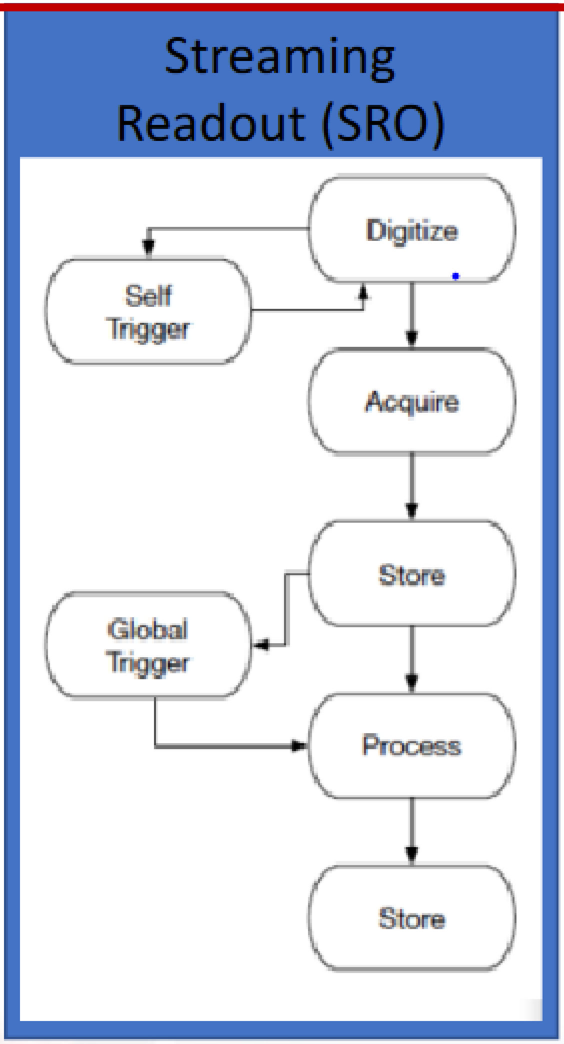
The ePIC Detector at EIC

- The ePIC Detector challenges
- The subsystems of the ePIC Detector
- DAQ and streaming read-out
- Take-away messages

ePIC – streaming readout

Triggerless streaming architecture gives much more flexibility to do physics



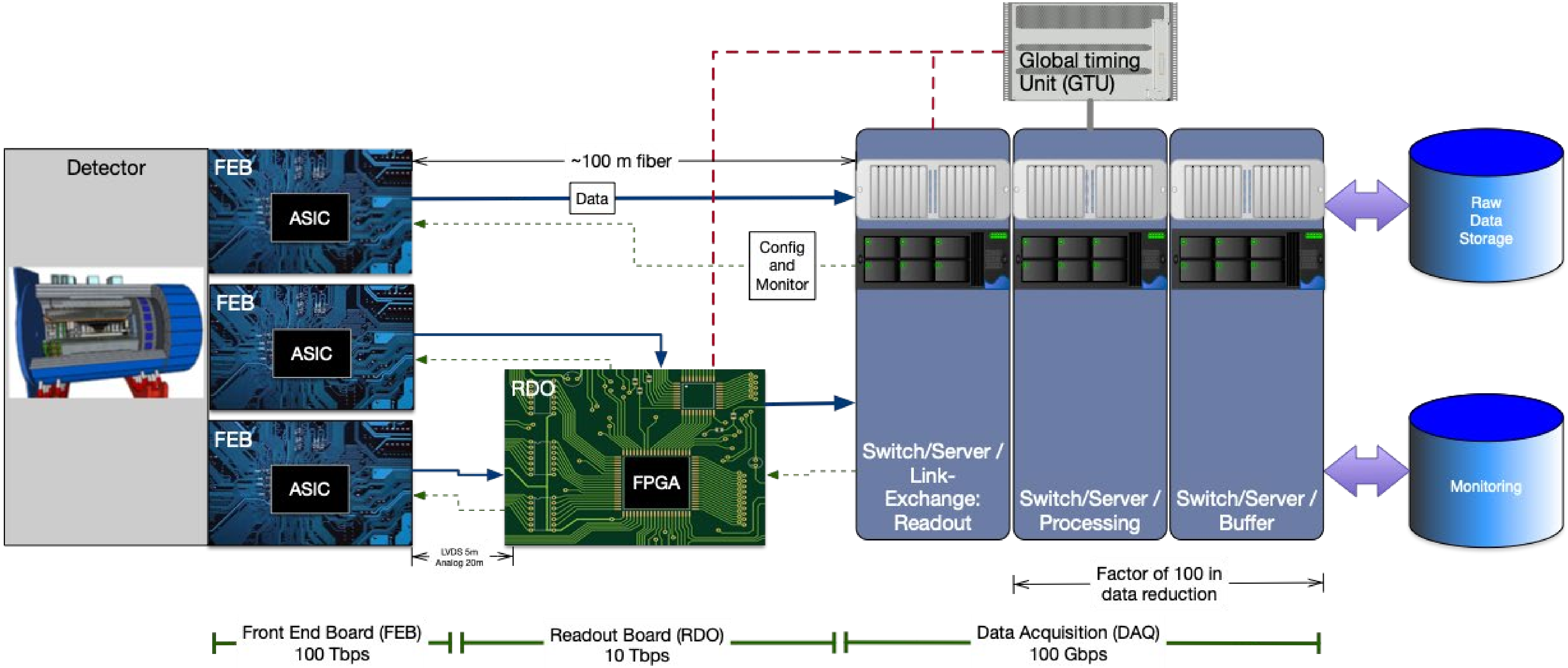


D. Abbott and J. Landgraf
Electronics/DAQ status Review, 2022

Features of ePIC SRO

- No global trigger
  - No global trigger electronics
  - Zero-suppress early (ASICs)
- Hits identified by time stamp rather than by event
- Flexibility in event selection
  - Can be performed in CPU, FPGA, or GPU
  - Can be performed with all channels available
  - Can be performed at different times, using different methods, for different purposes
- Cons
  - SRO has greater sensitivity to noise and background

ePIC Streaming readout/computer architecture



A key ingredient for streaming readout: the timing system

Main key aspects of the timing system

- The only handle for event reconstruction

- Beam crossing identification requires only 10 ns resolution
- Synchronization of far forward/backward detectors requires to integrate time differences up to ~ 150 ns

- Timing stability at 20 ps level needed to preserve the phase of the EIC to follow bunch structure and spin state
- Reference time for ToF measurements (resolution at 20-30 ps requested)

- Monitoring (and correcting) the time synchronization is needed

The ePIC Detector at EIC

- The ePIC Detector challenges
- The subsystems of the ePIC Detector
- DAQ and streaming read-out
- Take-away messages

Take-away messages

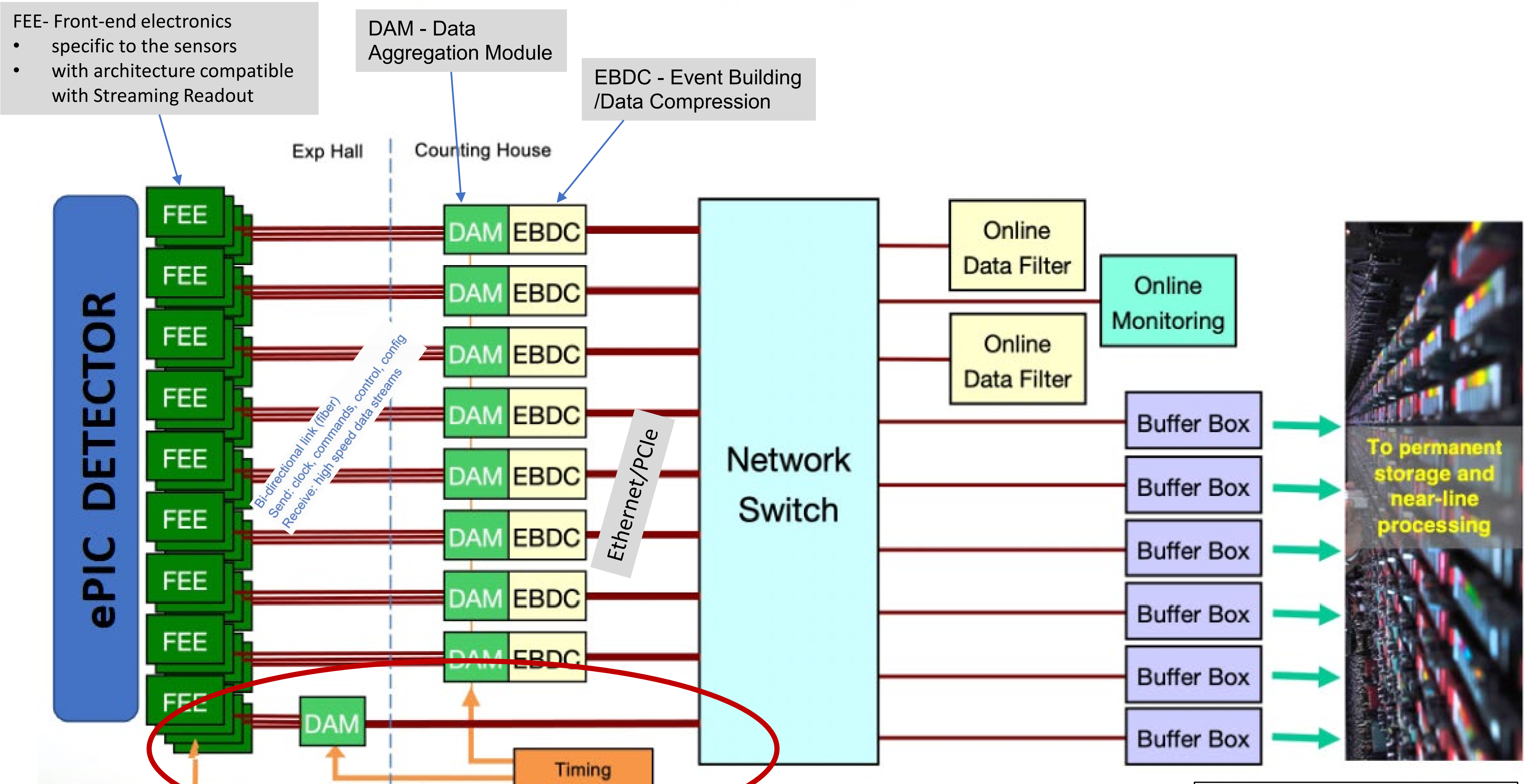
- The ePIC detector is the EIC project detector **designed to cover the whole EIC physics scope**
- The design copes with the **challenges** arising from
  - **the global physics scope**
  - **the machine and IR design**
  - **the background events**
- **Up-to-date technologies** are selected for all the detector subsystems

→ Together with the EIC collider, it truly represents the next nucleon microscope for the ultimate understanding of the **QCD**

THANK YOU

BACKUP SLIDES

EIC Streaming DAQ/Computing Architecture



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