EIC Detector

HUGS2022

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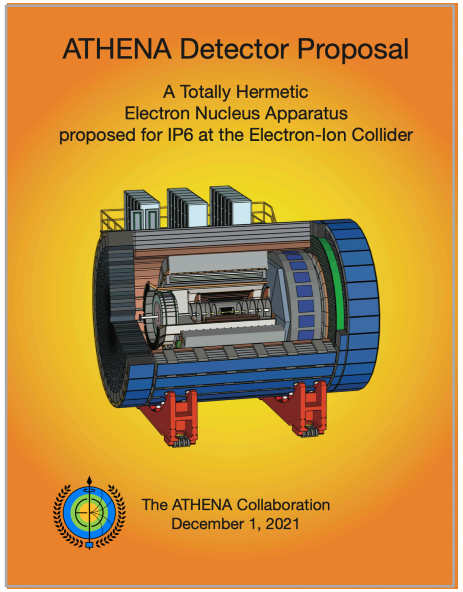
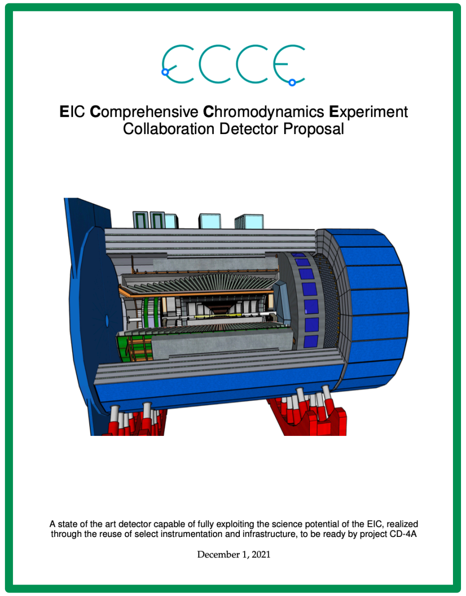
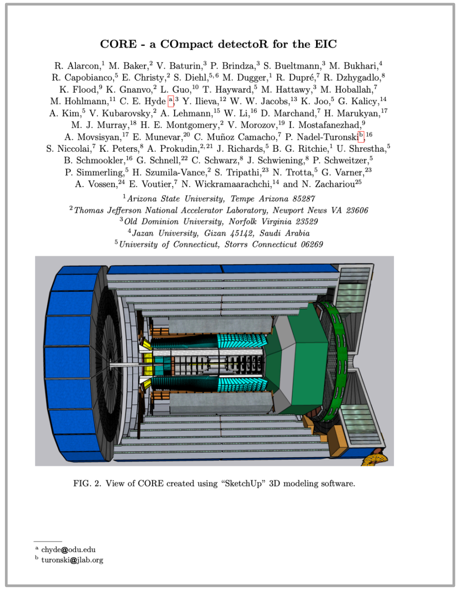
Outline

- Detector acceptance, location, size , global integration
- Central detector:
  - Tracking detectors, PID, Calorimeter …
- Far-forward/backward detectors
- Background

Materials for slides come from multiple EIC community efforts (Yellow Report, EIC Project, ECCE/ ATHENA proposals, etc)







Number of events

$$\boxed{N = \sigma \cdot L \cdot \epsilon \cdot a}$$

Where L is a luminosity

σ is a cross section

a is an acceptance,

ε is a detector efficiency

Statistical uncertainties: $\sim \dfrac{1}{\sqrt{N}}$

$$(d\sigma^{tot}_{measured} = \sqrt{N_{obs}}\frac{\sigma^{tot}_{measured}}{N_{obs}})$$

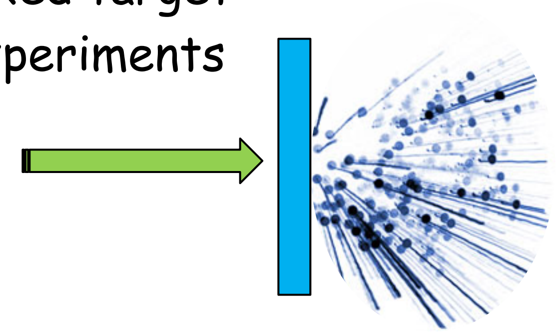
✓ As high luminosity as possible

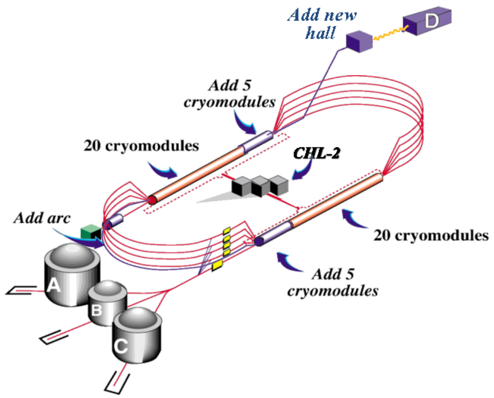
✓ detector efficiency at 100% => no dead-time for detectors

✓ full acceptance (100%) => detect all particles

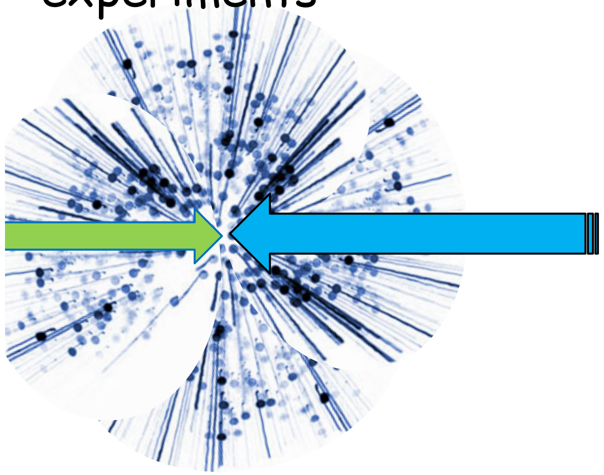
Acceptance and event kinematics :
fixed target vs collider ?

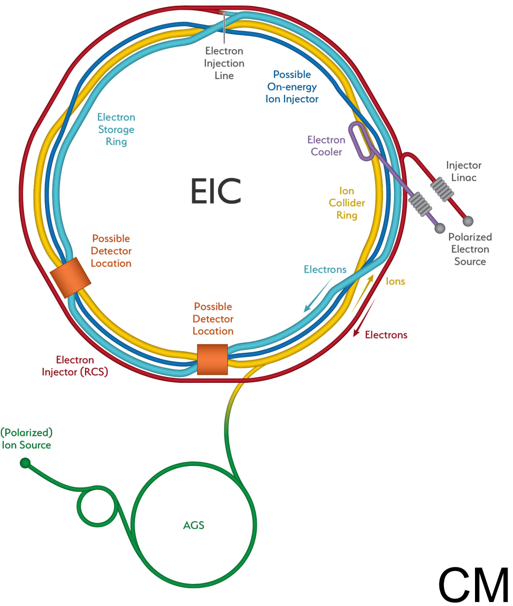
Fixed target
experiments





Collider
experiments



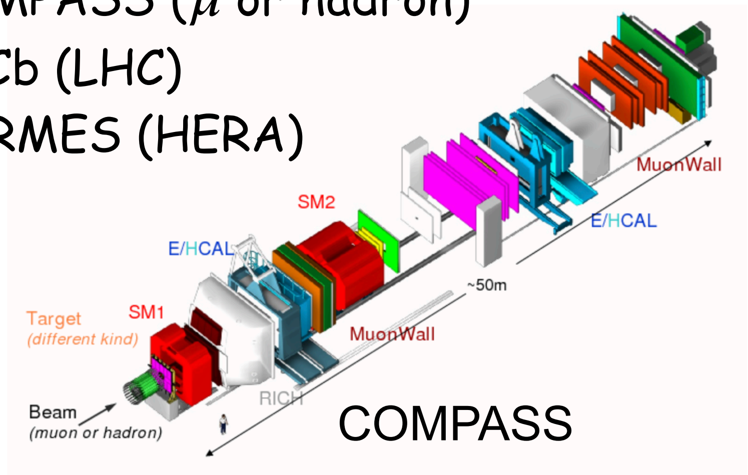


CEBAF/JLAB (e)

COMPASS (μ or hadron)

LHCb (LHC)

HERMES (HERA)

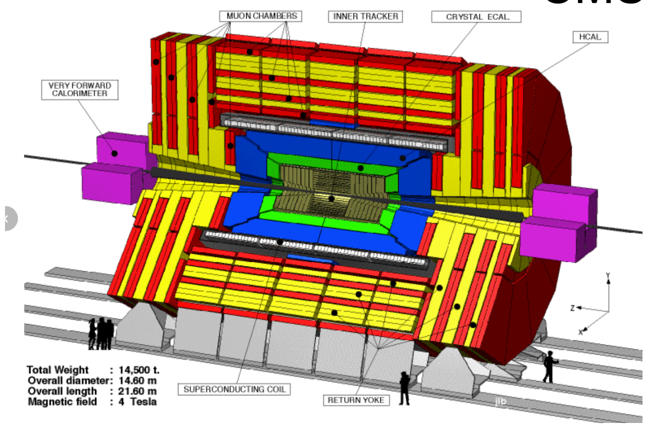


(pp) - ATLAS, CMS (LHC)

(e+e-) - KEK (Belle-II)

(e- p/A) - H1,ZEUS (HERA) , EIC

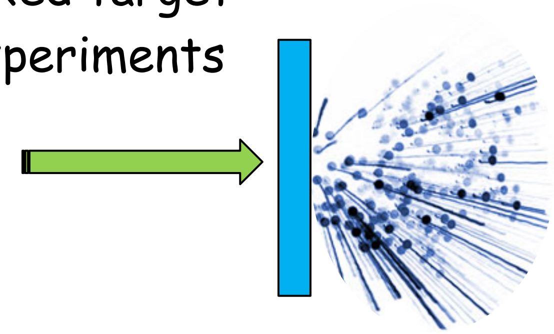
CMS



Homework question:

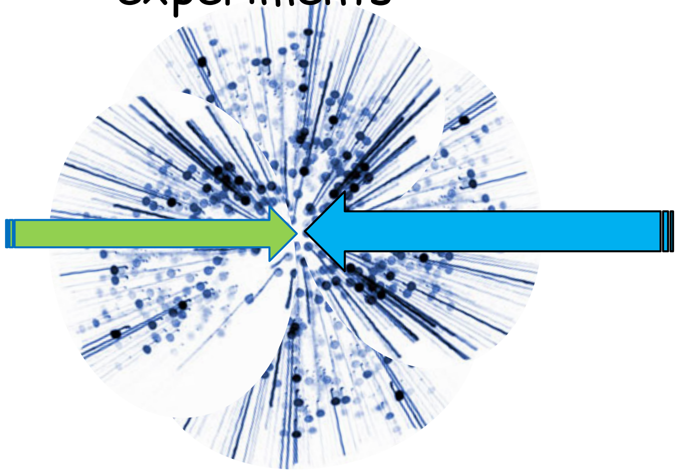
At EIC, electrons with energy of 18 GeV will collide with protons with energy of 275 GeV . Calculate the center-of-mass energy of this accelerator.
Consider an experiment, where protons are at rest (fixed target). What electron energy would be needed to obtain the same center-of-mass energy as at EIC collider ?

Fixed target experiments



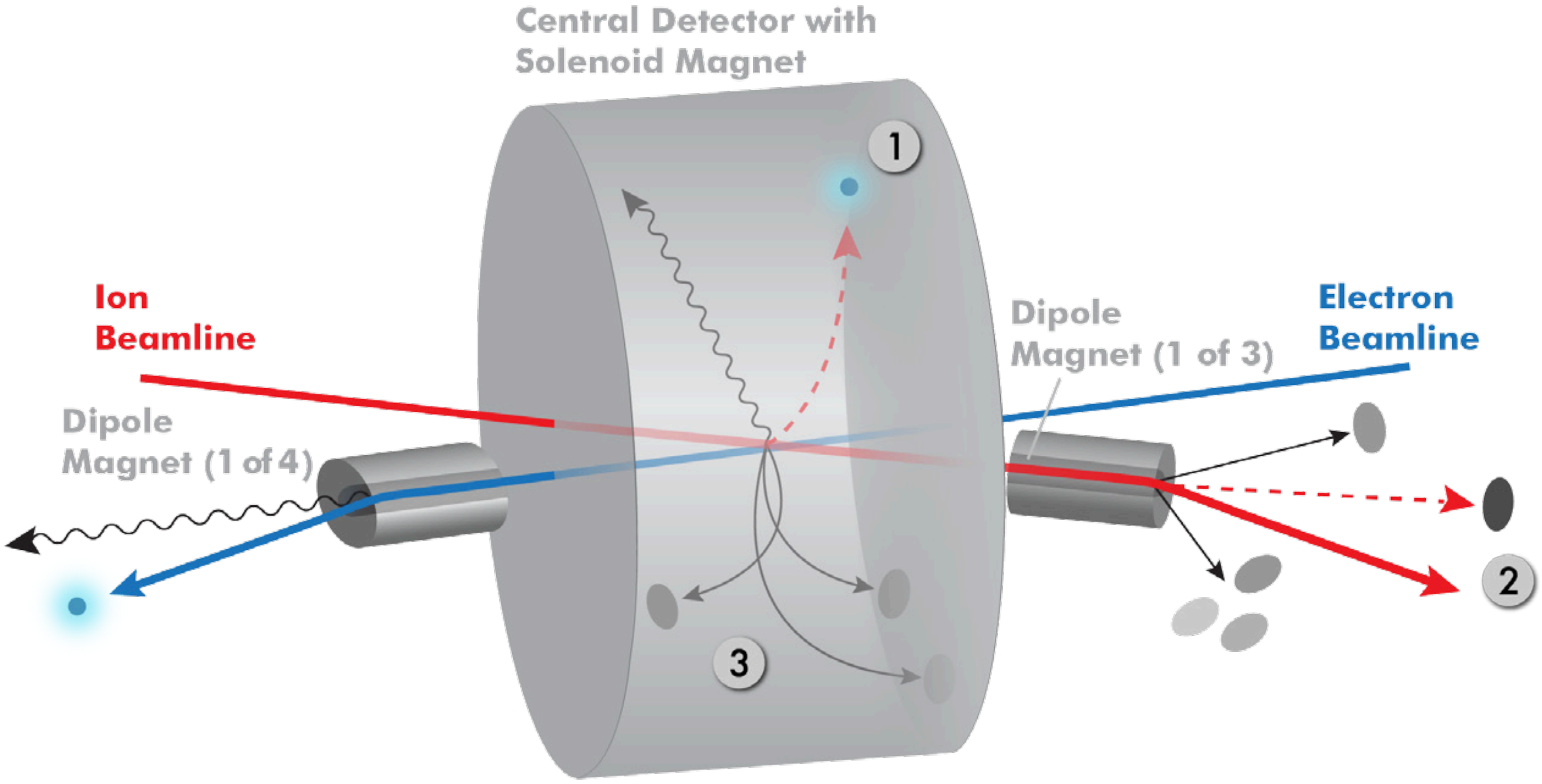
vs

Collider experiments



Collider: Total acceptance detector

- In ideal case – we want to have 4π coverage for the detector.



But, beam elements **limit a forward acceptance**

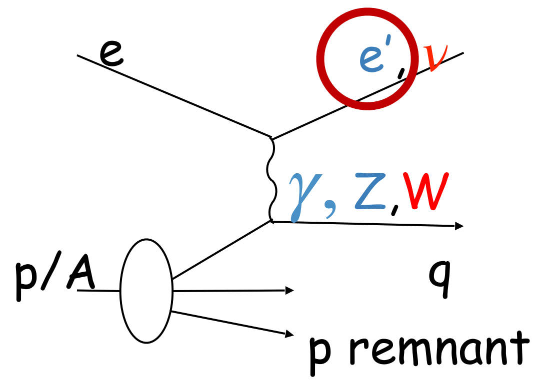
Detection of forward going particles are particularly challenging

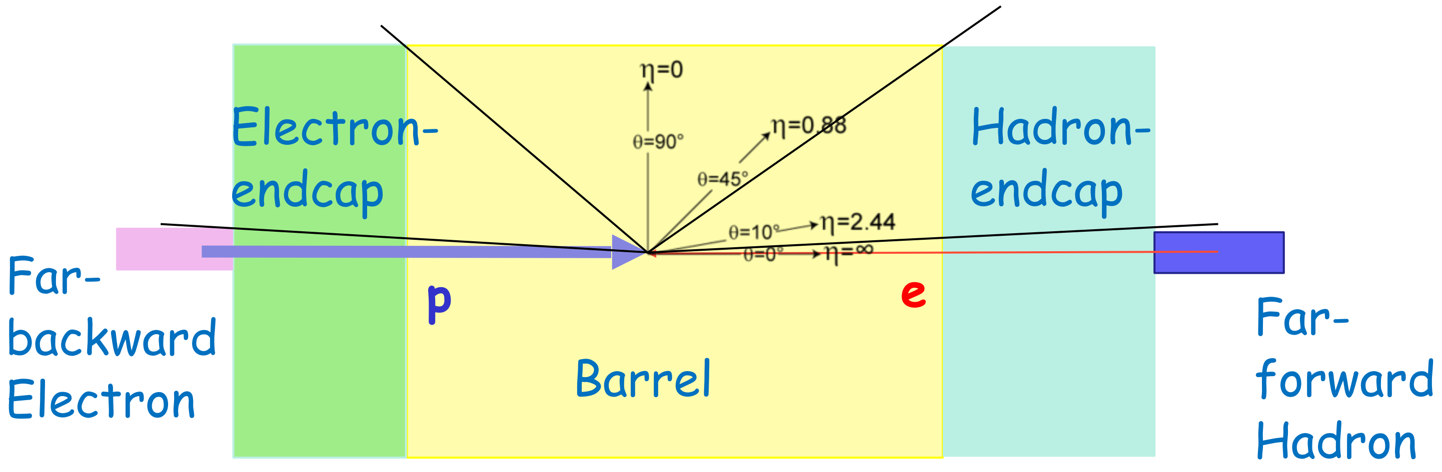
- not usual concern at colliders
- Higher the Ion Beam energy, more difficult to achieve.

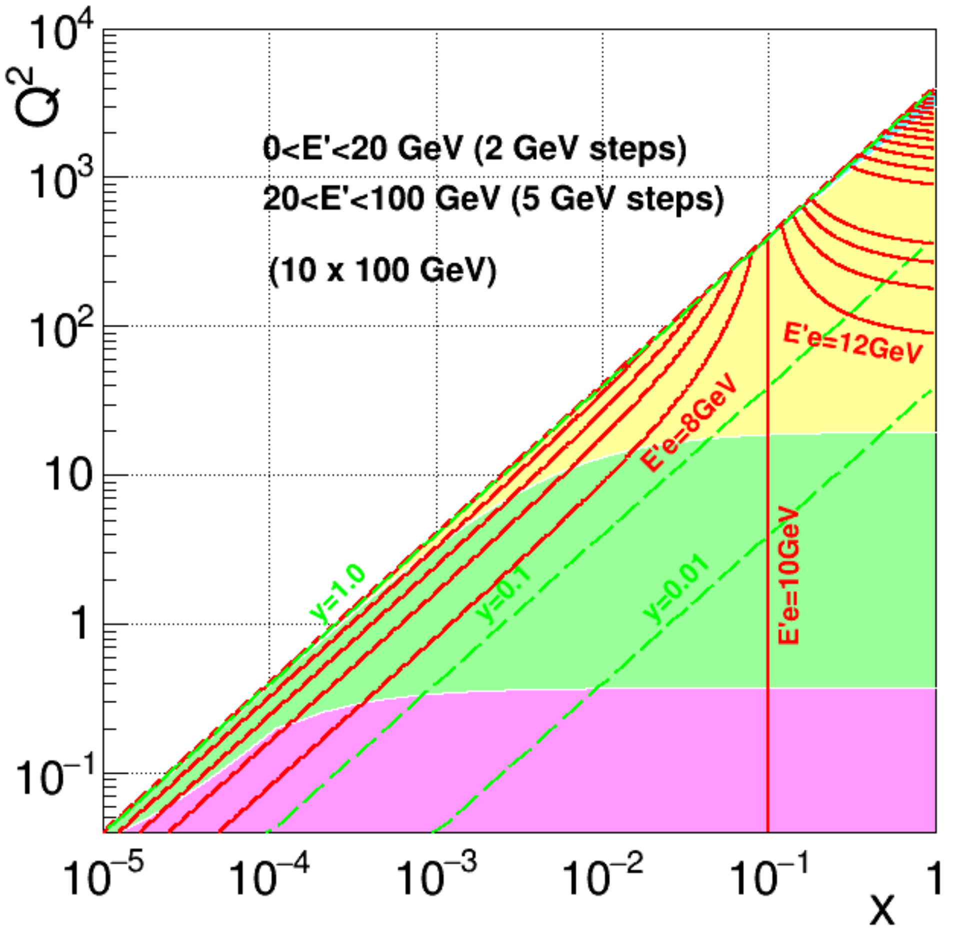
=> Integration with accelerator is very important

=> eP collider=> forward and backward directions have different functions.

Why endcaps and forward areas are important at EIC?





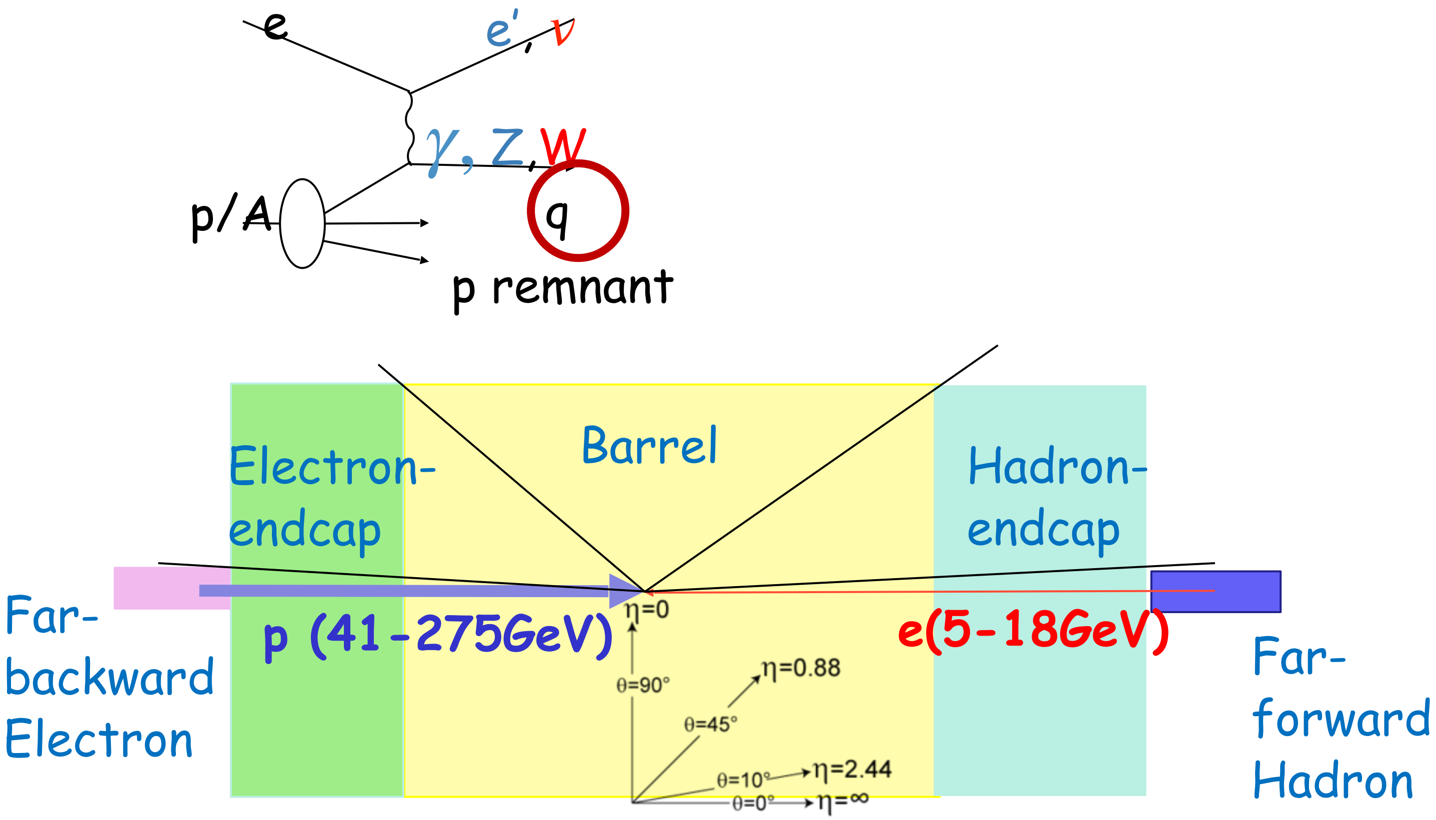


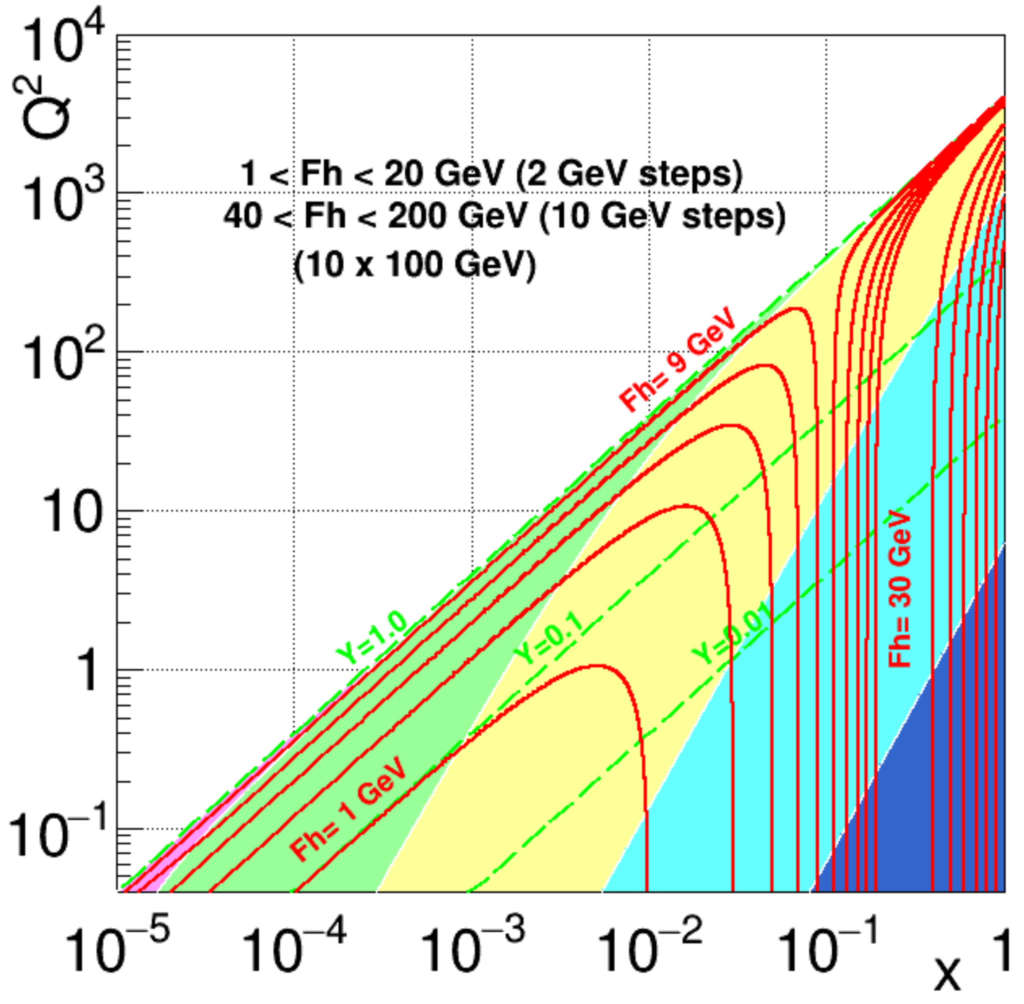
Transition area from DIS to Photoproduction (Q^2<5GeV)

Pseudorapidity:

$$\eta = -\ln(\tan(\theta/2))$$

Why endcaps and forward areas are important at EIC?





- All hadrons are boosted towards hadron-endcap due to asymmetric beam energies
- Proton/Ion Remnant
- Diffractive/exclusive physics in the Far-forward area

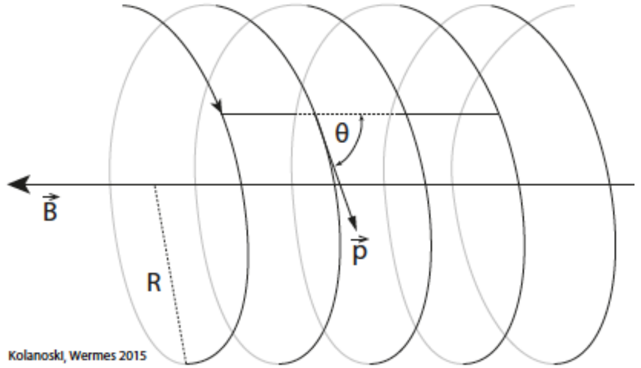
Why do we need a magnetic field?

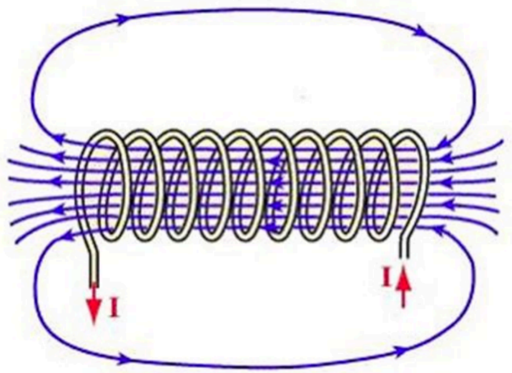
Magnetic field to measure momentum and charge

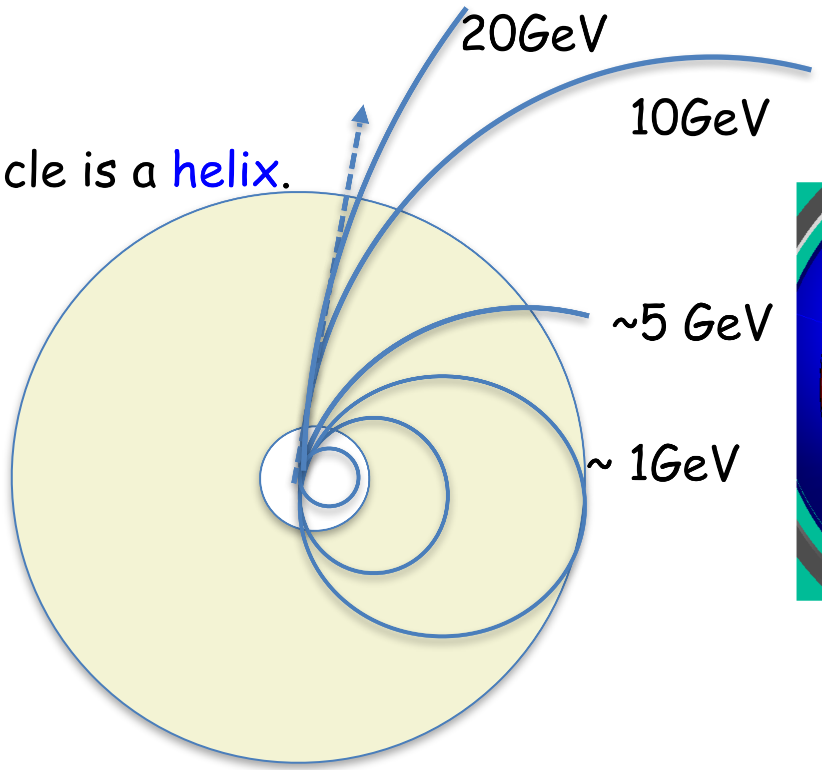
Solenoid:

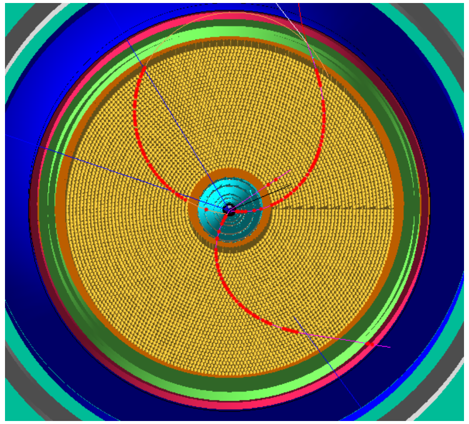
In a homogeneous B-field the motion of a charged particle is a helix.

$$\boxed{p_T[\mathrm{GeV}] = 0.3 \cdot B\,[\mathrm{T}] \cdot R\,[\mathrm{m}]}$$







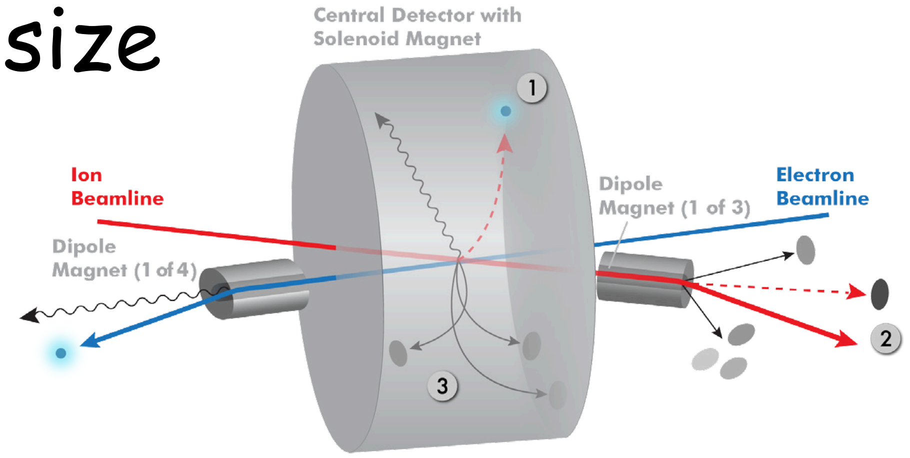


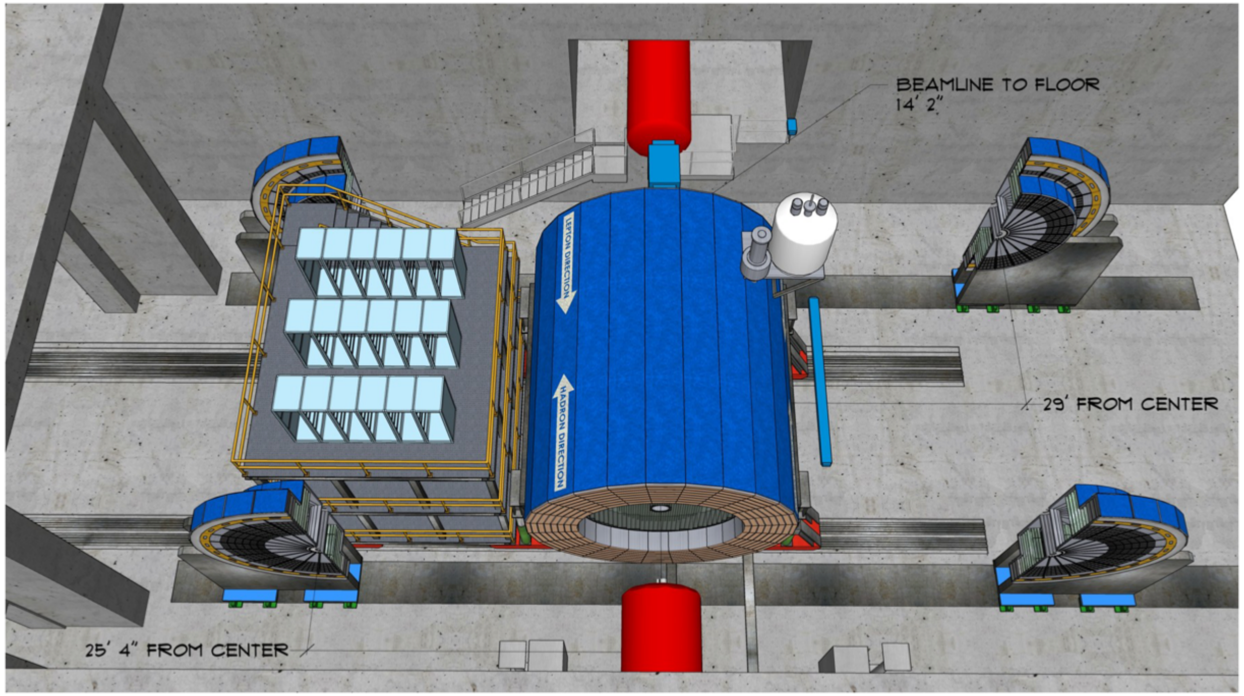
- Need high magnetic field to reconstruct bending radius: for high momentum particles, otherwise straight segment (no momentum measurements, no charge) – depends on resolution of tracker.
- Also we need higher magnetic field for particles going at the shallow angle (along a beampipe)
- **BUT** Too high magnetic field: low momentum particles could bend/fly inside a beampipe without detection

Total acceptance detector: Detector size

Detector needs a **Solenoid** to measure particle momenta =>

- We need it only for our detector system ! The accelerator could function without it! => Solenoid field **needs to be compensated by accelerator**
- Optimize/change a magnetic field - depending on the beam energy configuration we use ?
- **limitation in size:** for the central detector (in R and Z) due to the radius/length of solenoid magnet =>
  - how it fits into the HALL?
  - how to do assembly, installation, maintenance ?





The BaBar solenoid

The BaBar superconducting solenoid will be repurposed for the EIC detector

The warm bore diameter of 2.84m and coil length of 3.512 m

Provides the 1.4 T field

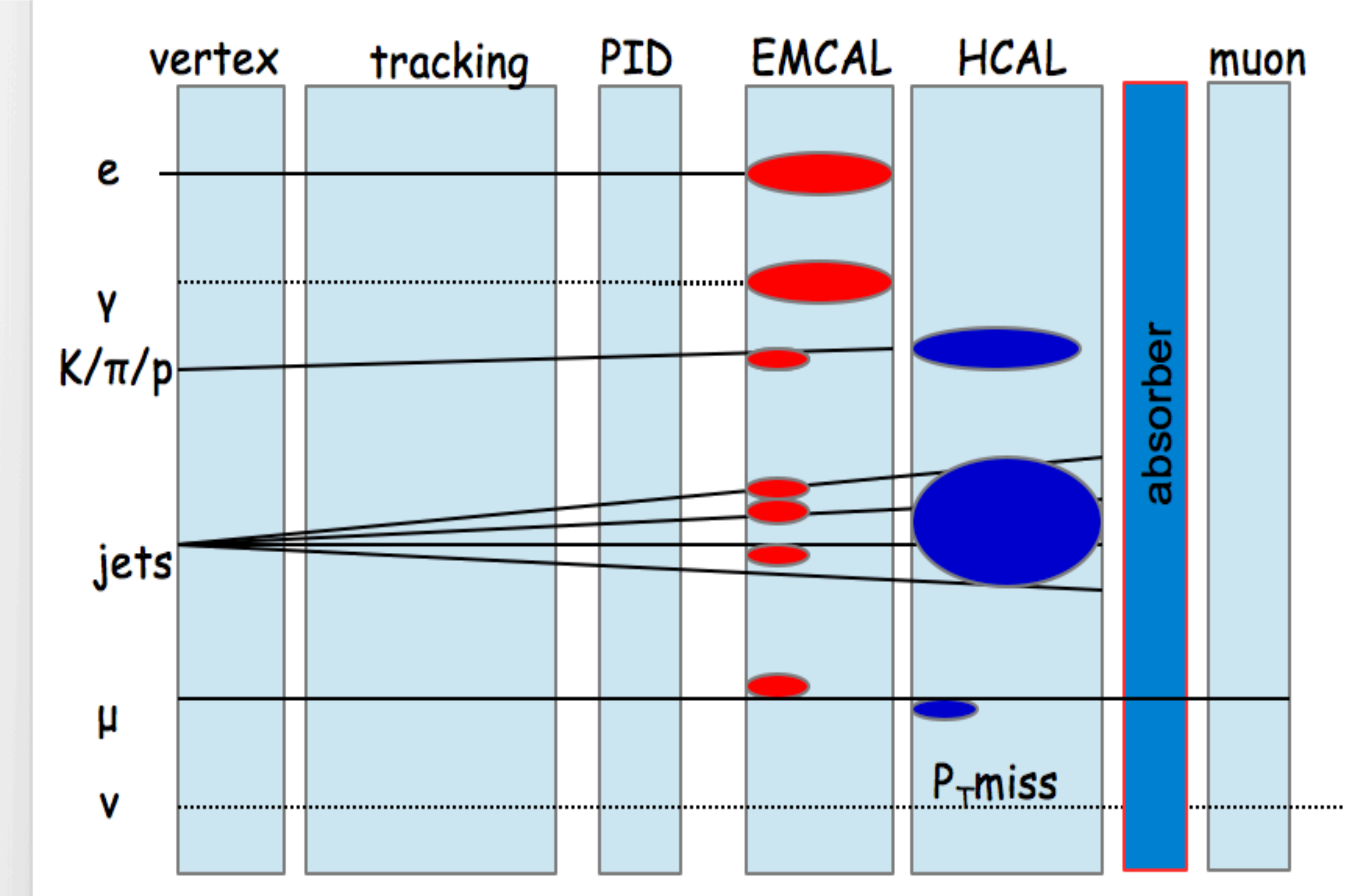
Central Induction	1.5 T* (1.4 T in ECCE flux return)
Conductor Peak Field	2.3 T
Winding structure	Two layers, graded current density
Uniformity in tracking region	±3%
Winding Length	3512 mm *at R.T.*
Winding mean radius	1530 mm *at R.T.*
Operating Current	4596 A (4650 A*)
Inductance	2.57 H (2.56 H*)
Stored Energy	27 MJ
Total Turns	1067
Total Length of Conductor	10,300 m

* Design Value

Table 2.3: Design parameters of the BaBar superconducting solenoid.

planing to reuse the surrounding combined hadronic calorimeter and flux containment system for this magnet

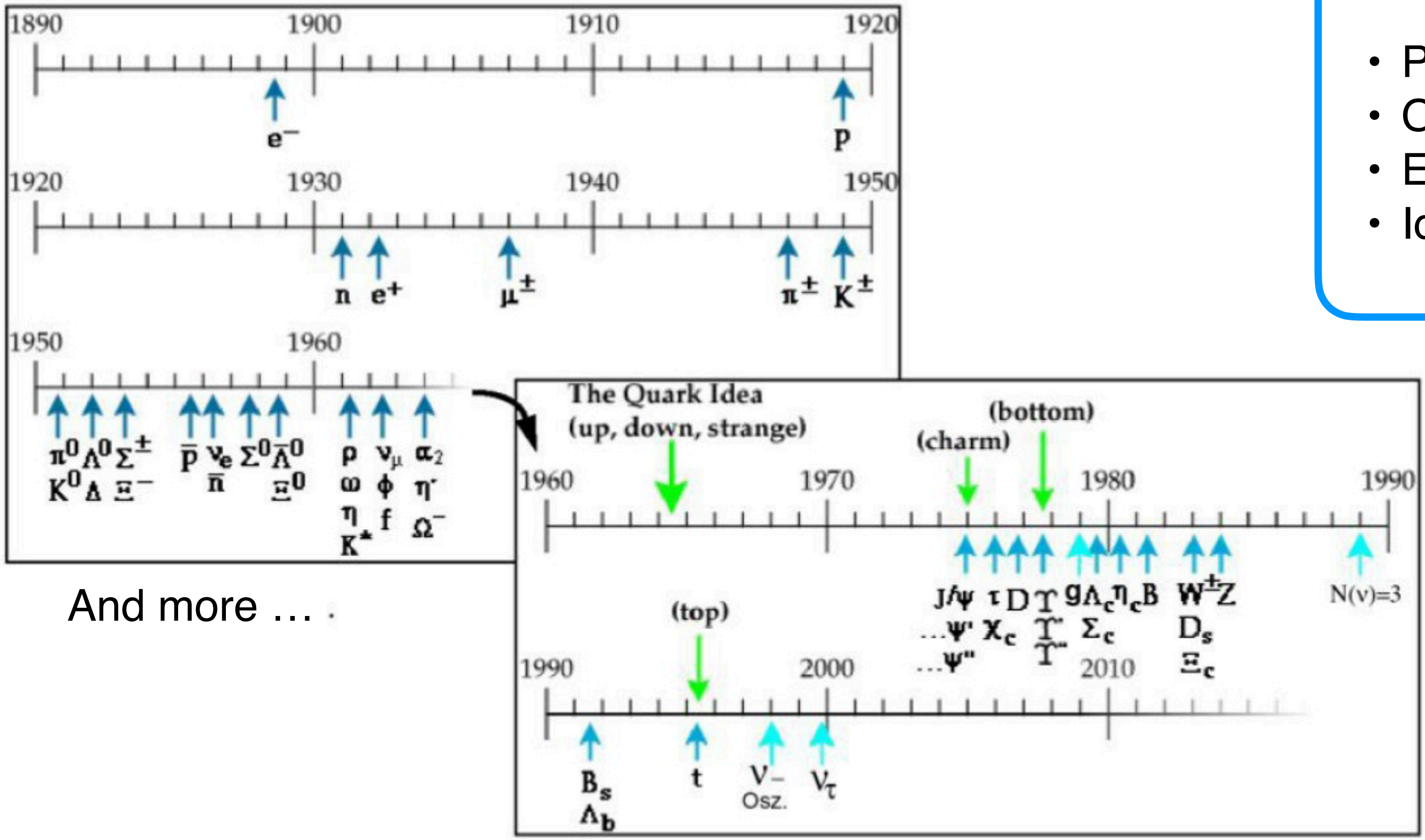
Central detector layout (General purpose detector)



Particles

Today more then 200 particles listed in Particle Data Group (PDG)

But only 27 have cτ > 1μm
and only 13 have cτ > 500μm



And more … .

For all particles we want to measure:

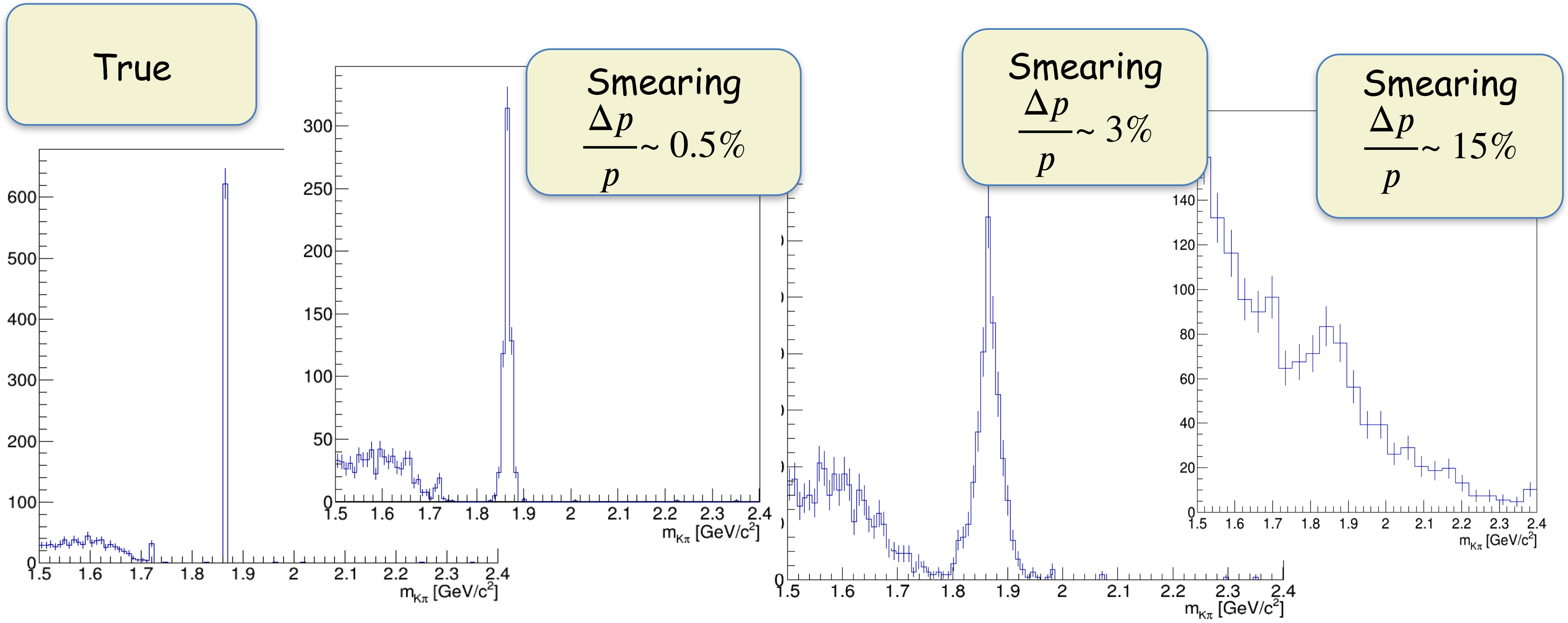
- Particle momentum
- Origination (vertex)
- Energy
- Identification (Mass) : type of the particle

Why do we need precision measurements of particle momentum?

For all particles we want to measure:

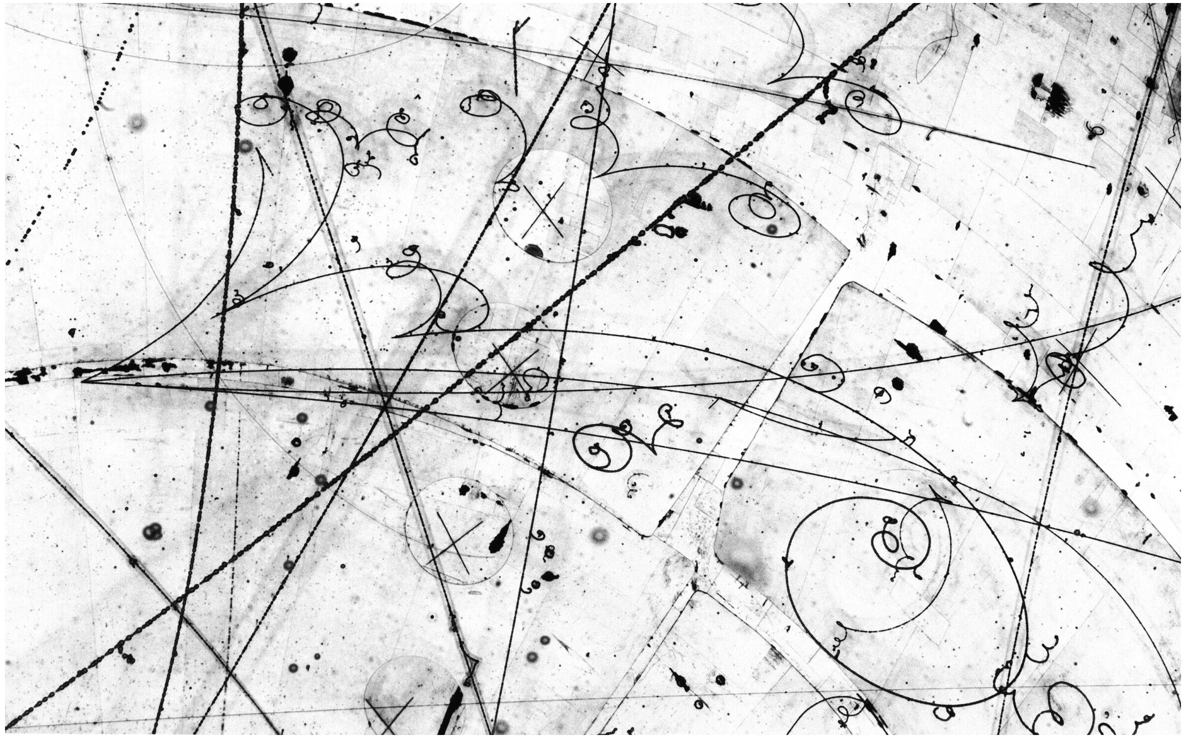
- Particle momentum
- Origination (vertex)
- Energy
- Identification (Mass) : type of the particle

For example, $D^0 \rightarrow \pi^- K^+ (\pi^+ K^-)$



Tracks

Tracks in particle physics

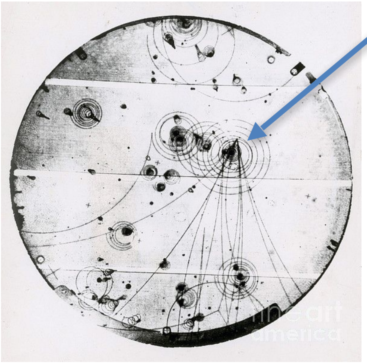


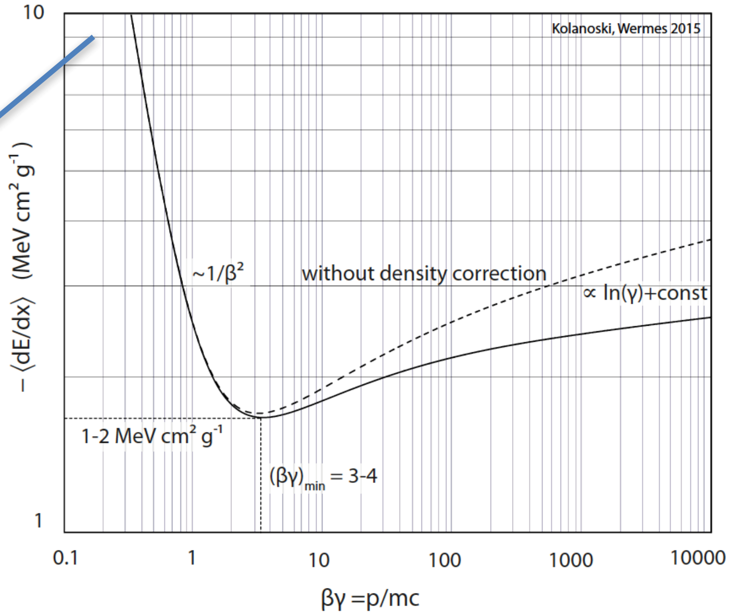
- Particles have to interact with material of detector

Tracking detectors (position sensitive detectors)

➢ Particles have to interact with material of detector

➢ Electronically recordable hits/tracks
➢ Provide precise space point coordinates/trajectory of charged particles
➢ Provide momentum measurements in magnetic (B) field
➢ Provide angle measurements
➢ Provide measurements of primary and secondary vertices
➢ Provide a multitrack separation
➢ Provide a particle identification (if possible)
➢ Keep a minimum of material along the path of particles to minimize scattering and secondary interactions.





Bethe-Bloch formula:

$$-\left\langle \frac{dE}{dx} \right\rangle = K \boxed{\frac{Z}{A}} \rho \boxed{\frac{z^2}{\beta^2}} \left[\frac{1}{2} \ln \frac{2\, m_e\, c^2\, \beta^2\, \gamma^2\, T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} - \frac{C(\beta\gamma,\, I)}{Z} \right]$$

- Almost does NOT depend on material (Z/A ~ ½)
- Proportional to z^2
- Depends on $\beta\gamma$ = p/E *E/m = p/m
- The same curve for all z=1 particles when plotted as a function of $\beta\gamma$)
- Have a minimum at $\beta\gamma$ =3-4
- Plateau at high $\beta\gamma$

Momentum resolution

$$\frac{\sigma_{p_T}}{p_T} = \sqrt{\left(\frac{\sigma_{p_T}}{p_T}\right)^2_{\text{meas}} + \left(\frac{\sigma_{p_T}}{p_T}\right)^2_{\text{MS}}}$$

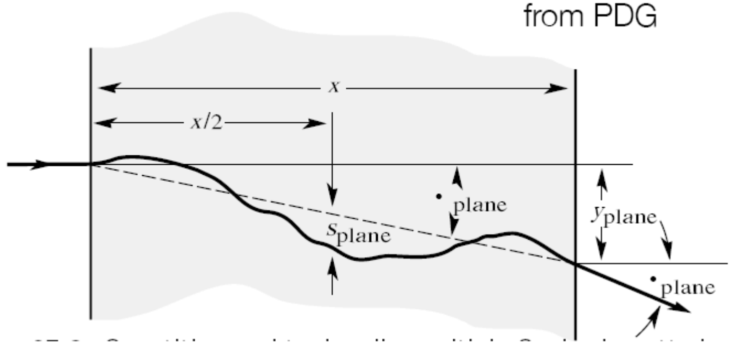
Position resolution (N>10) :

$$\left.\frac{\sigma(p_T)}{p_T}\right|_{\text{meas}} = \frac{\sigma(x)\cdot p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$

Multiple scattering:

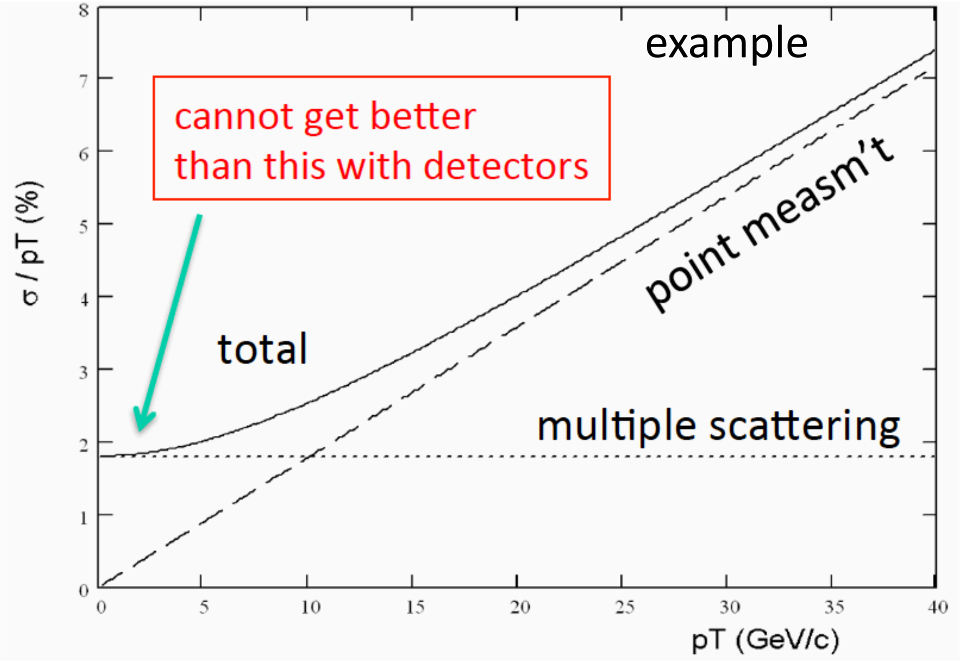
$$\frac{\sigma(pT)\text{MS}}{pT} \approx \frac{1}{\sqrt{LX0B}}$$

from PDG



At small momenta this limits resolution of momentum measurement ...

$$\boxed{p_T\,[\text{GeV}] = 0.3 \bullet B\,[\text{T}] \bullet R\,[\text{m}]}$$



-Optimize material effects (multiple scattering)
optimize amount of material along particle track (sensitive area (Si), support structure, cables..)

-Place first plane as near as possible to IP

-P_T is linearly better with B-field, but…

-Increase N (but only as $1/\sqrt{N}$)

-Improve hit point resolution (σmeas)

Tracking detectors/Vertex

For example,

$D^{+} \rightarrow \pi^{-}K^{+}\pi^{+}$

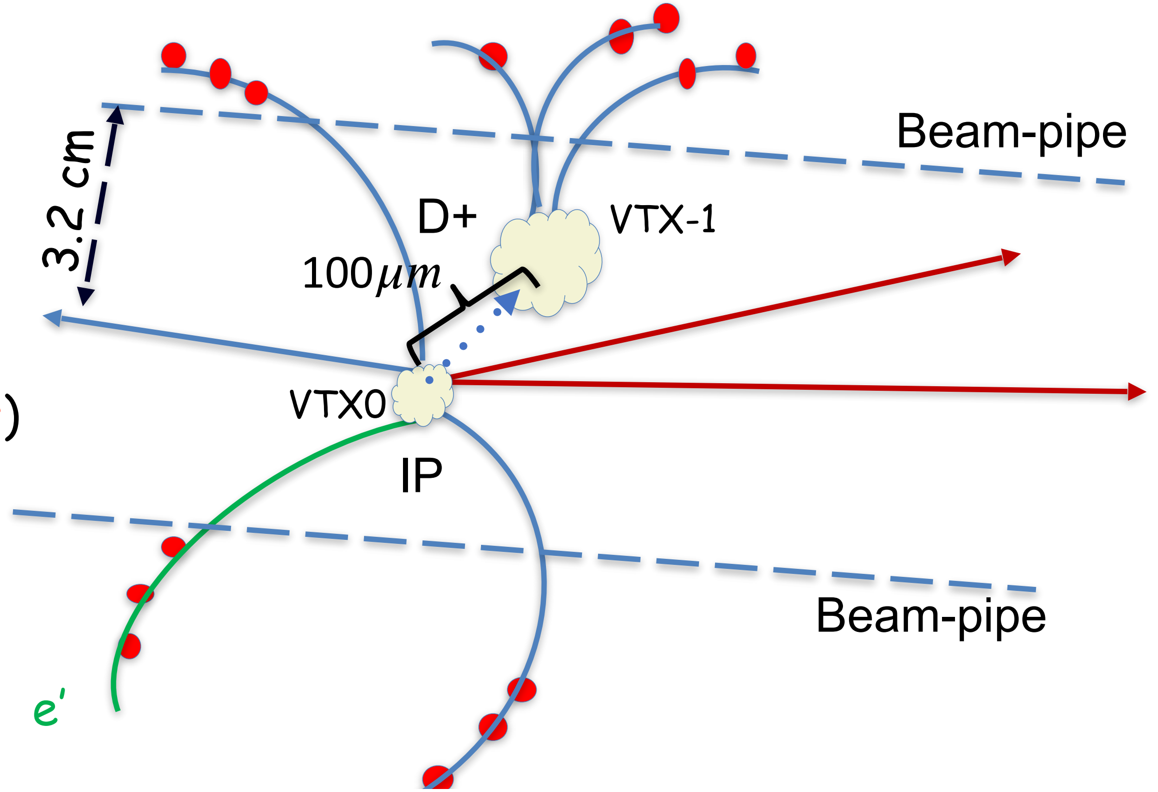
Challenge: How to measure a displaced vertex ?!

-Secondary vertices: D-mesons (lifetime) ca 100-300μm

(our hair 50-150 μm)

=> Need to place high granularity and precision detector as close as possible to IP (to beam-pipe)

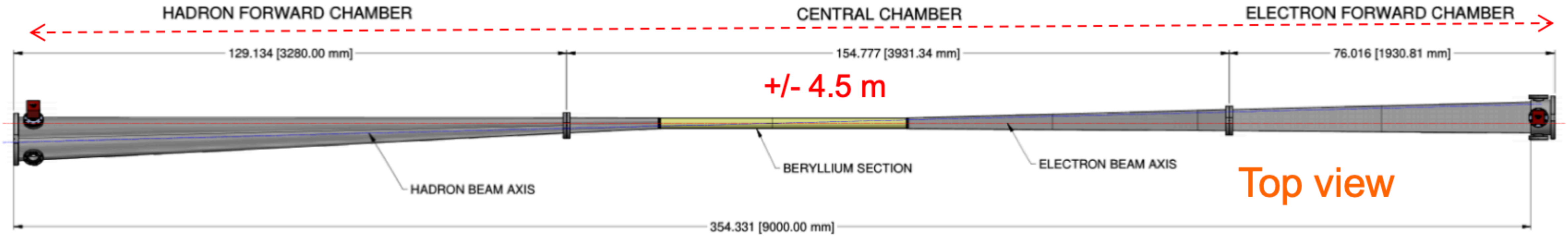
BUT a beam pipe needs to be large enough to allow beam (with beam halo) to path through (depends on bunch sizes)



EIC central beam-pipe

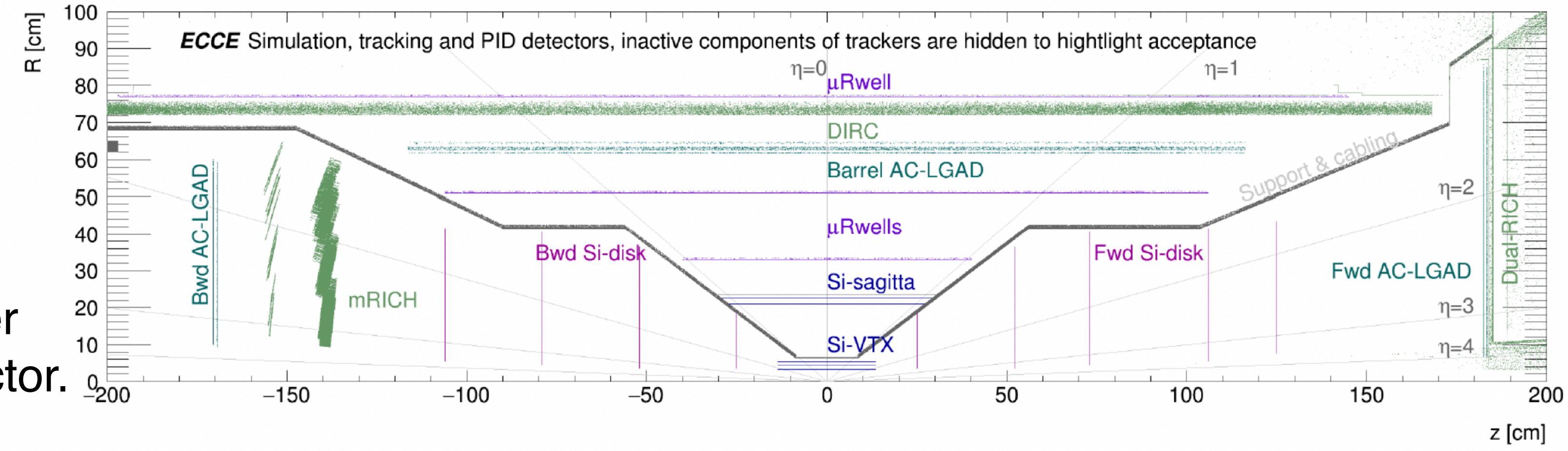
-Inner section: 1.5 m Beryllium to minimize multiple scattering

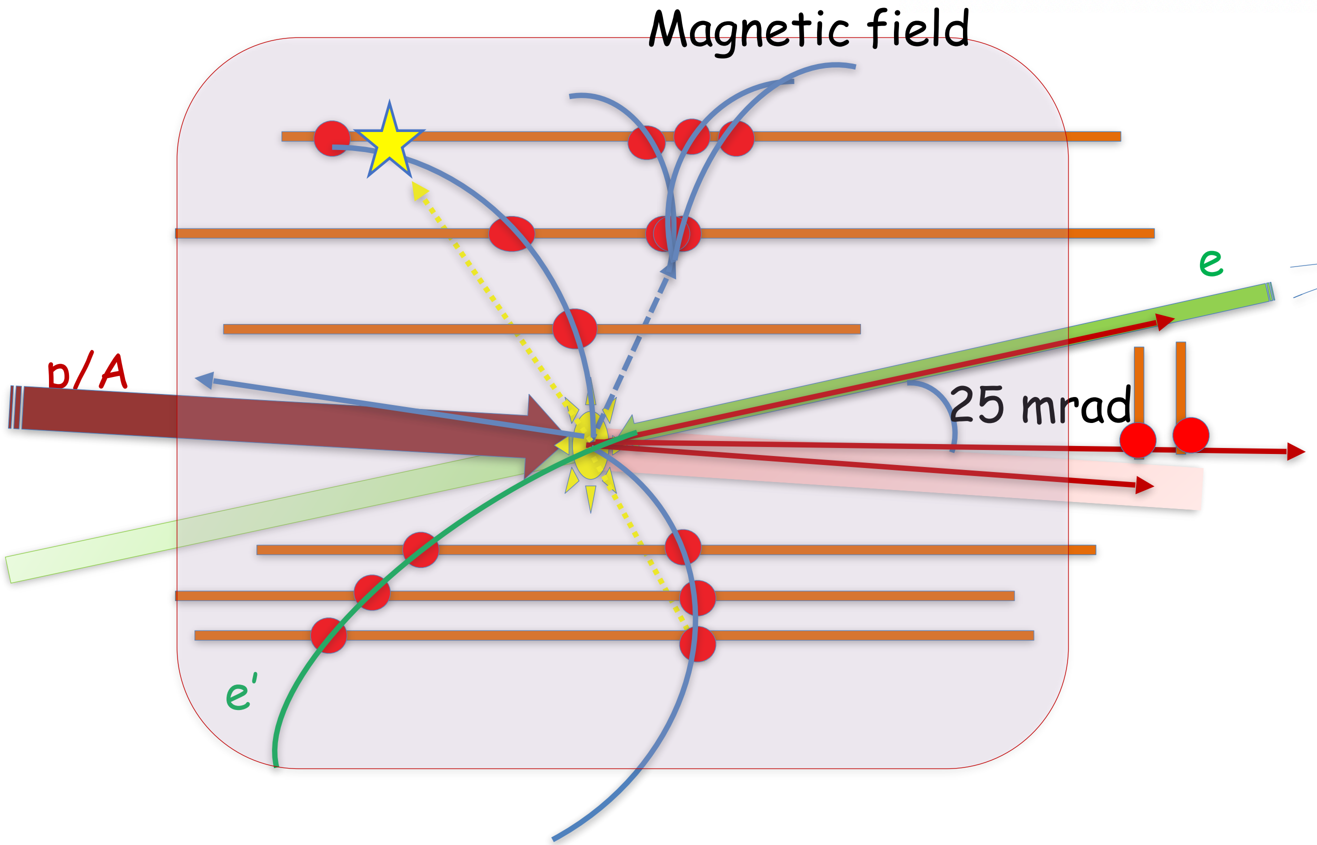
-2um Gold coating to absorb soft photons from synchrotron radiation



Tracking at EIC

Hybrid tracking detector design: Monolithic Active Pixel Sensor (MAPS) based silicon vertex/tracking subsystem, the muRWELL tracking subsystem and the AC-LGAD outer tracker, which also serves as the ToF detector.





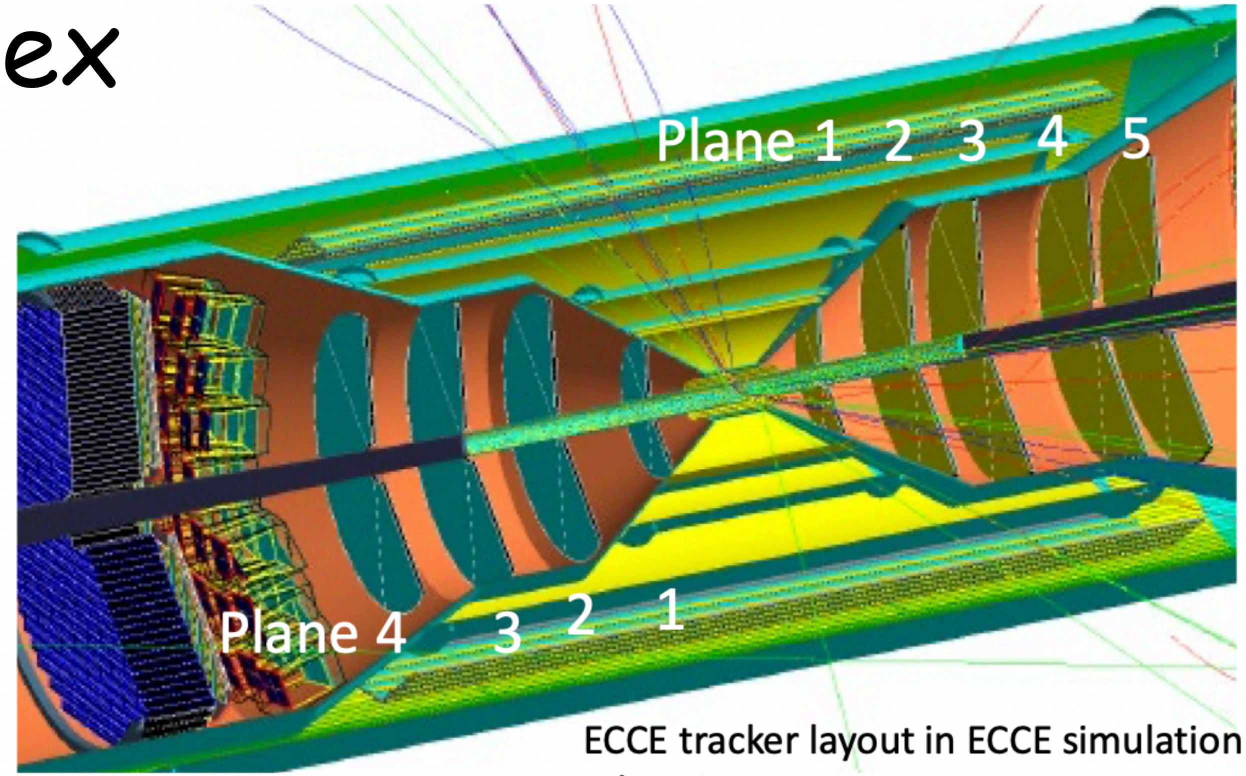
Magnetic field to measure momentum and charge (bended curves)

Particles have to interact with material of detector:

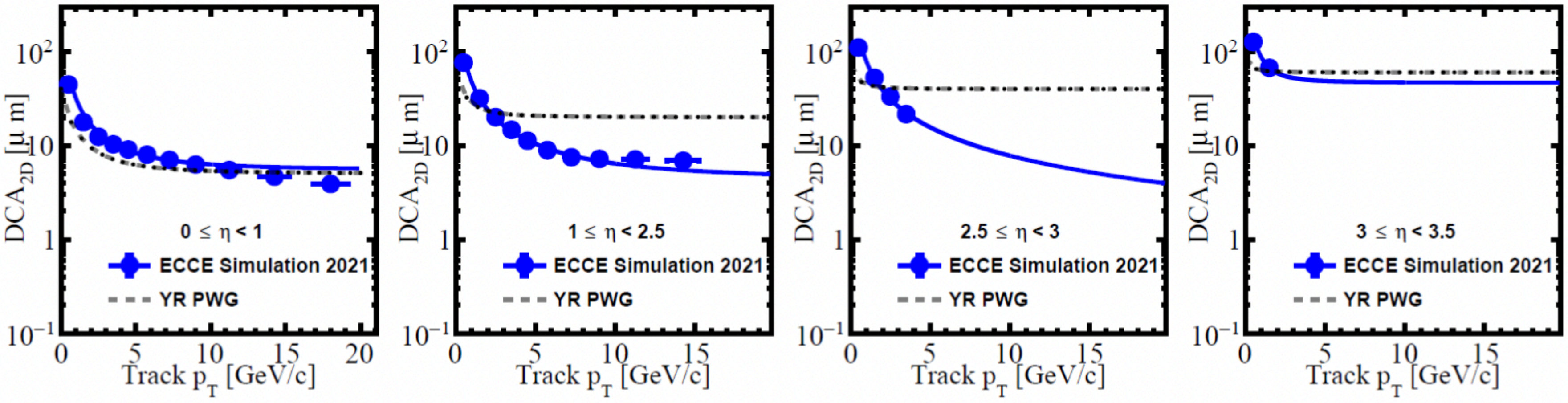
- ✓ Charged particles: leave energy along the track (hits) (dE/dx)
- ✓ Photons/Gammas- depending on energy (*): no tracks (no hits or just a single hit)

Tracking detectors/Vertex

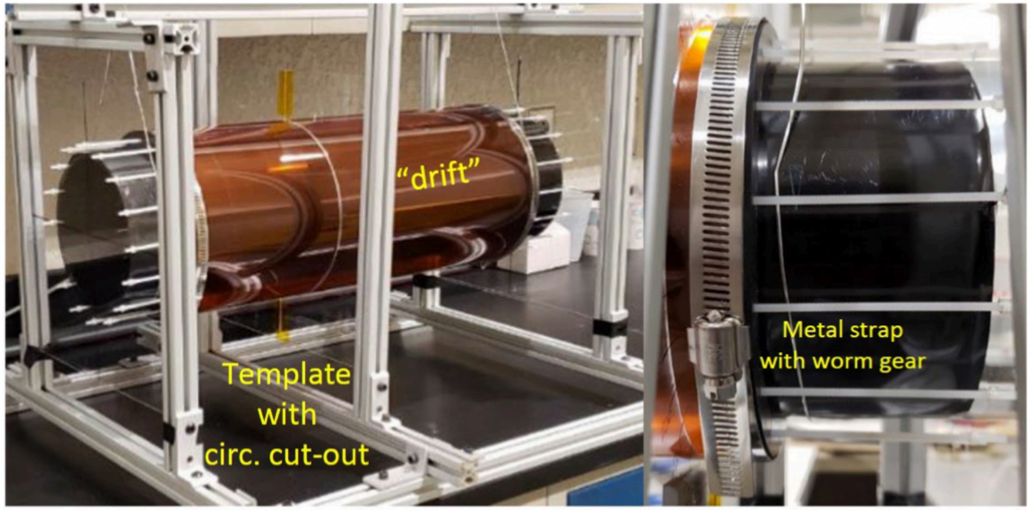
- Low material budget: 0.05% X/X0 per layer
- High spatial resolution: 10 µm pitch MAPS (Alice ITS3)
- TowerJazz 65nm technology (ongoing R&D Si Consortium)
- Configuration: Barrel + Disks for endcaps
- Iηl<3.5 with full azimuth coverage



ECCE tracker layout in ECCE simulation taking into account support structures

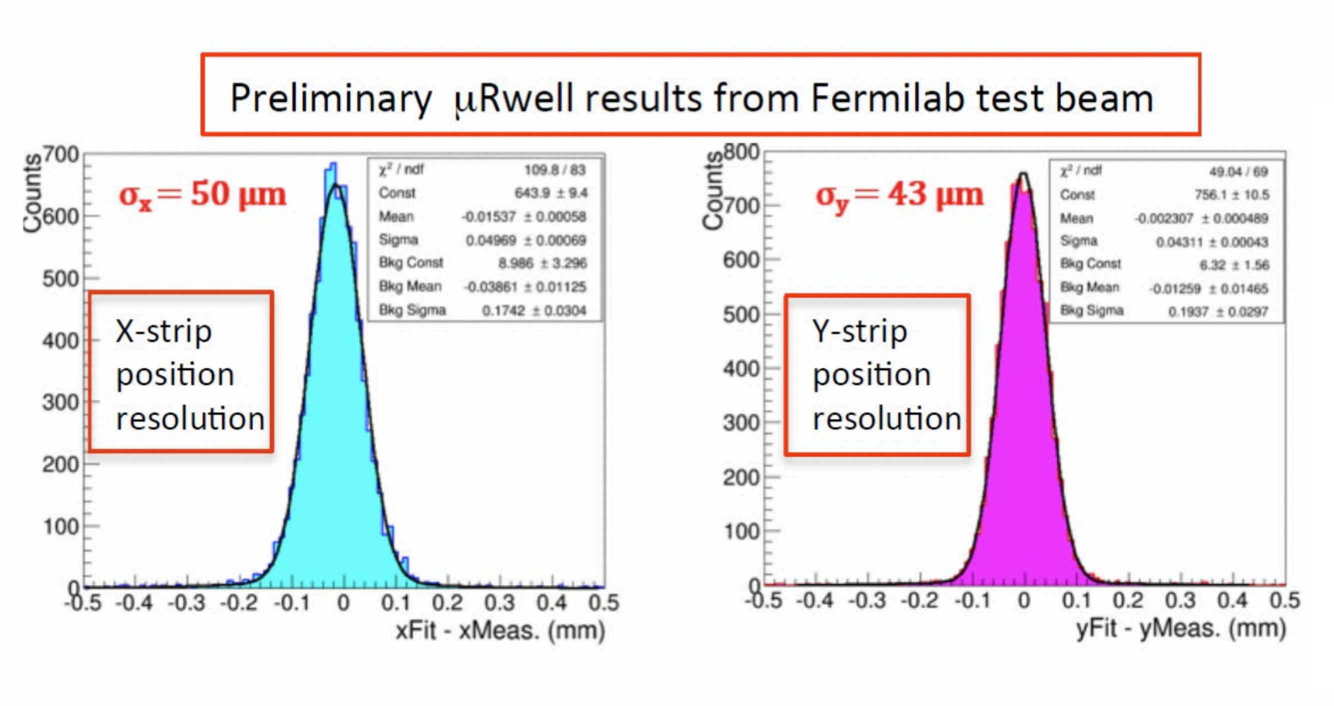


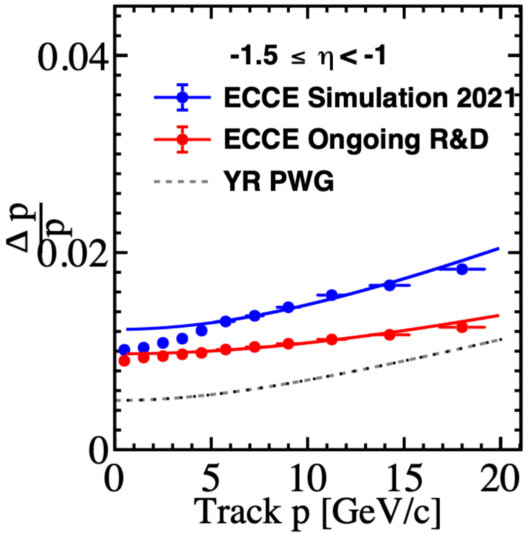
Tracking detectors/Vertex

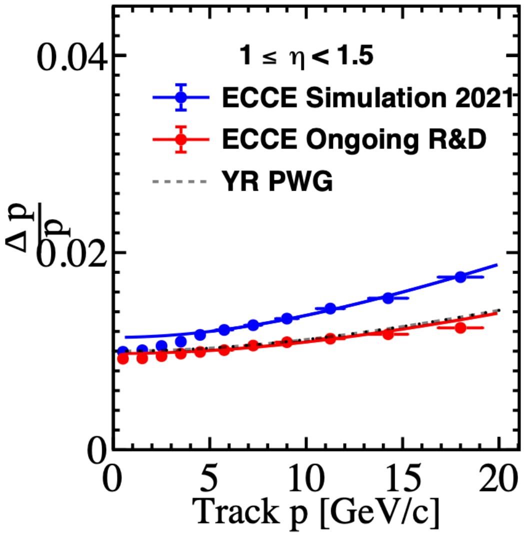


For the larger/outer layers :

- muRWell technology is based on the outcome of the EIC generic R&D (eRD6)
- spatial resolution well below 100 um for curved geometry
- Large-area detectors possible - cost efficient compared to silicon large surface detectors







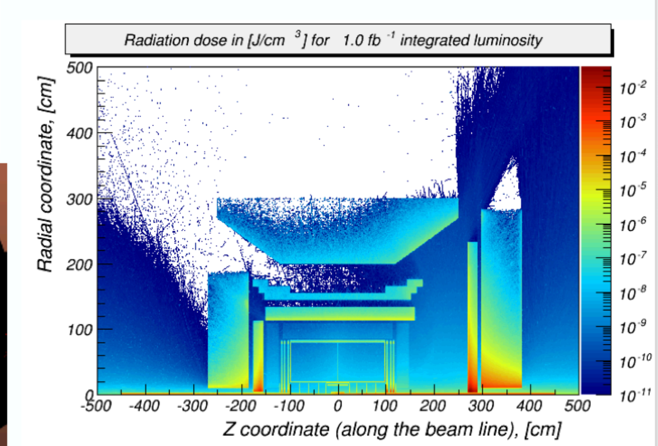
Background/radiation

- ➢ The HERA and KEK experience show that having backgrounds under control is crucial for the EIC detector performance

- ➢ There are main background/radiation sources :
  - ❖ primary collisions
  - ❖ beam-gas induced
  - ❖ synchrotron radiation

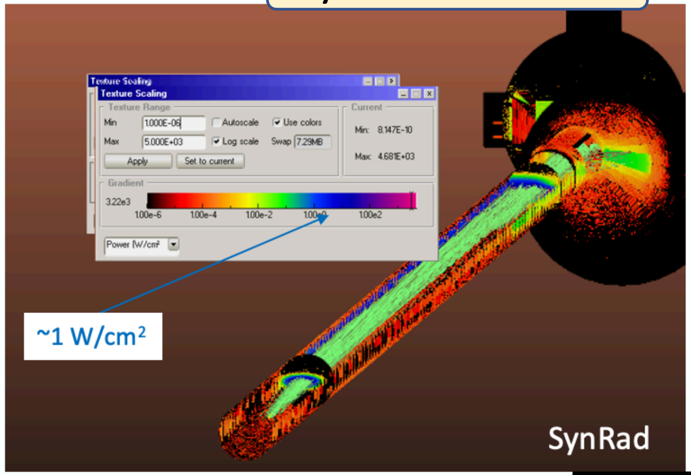
- ➢ The design of absorbers and masks must be modeled thoroughly

Primary collisions/ionizing radiation

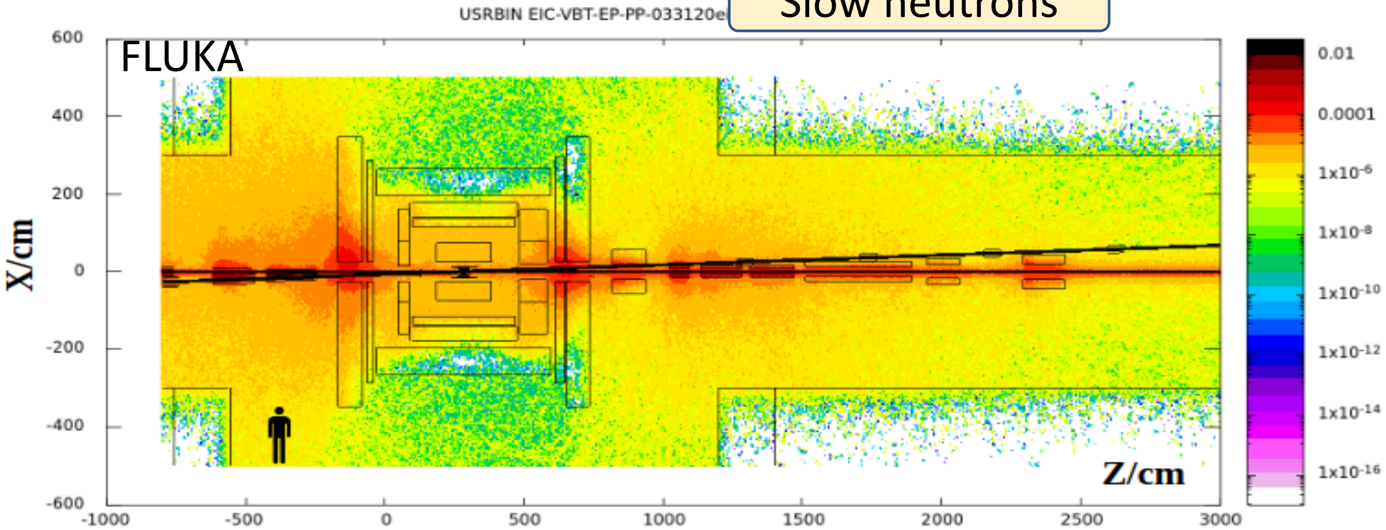


-> backward EmCal: ~250 rad/year (at a "nominal" luminosity ~10^{33} cm^{-2} s^{-1})

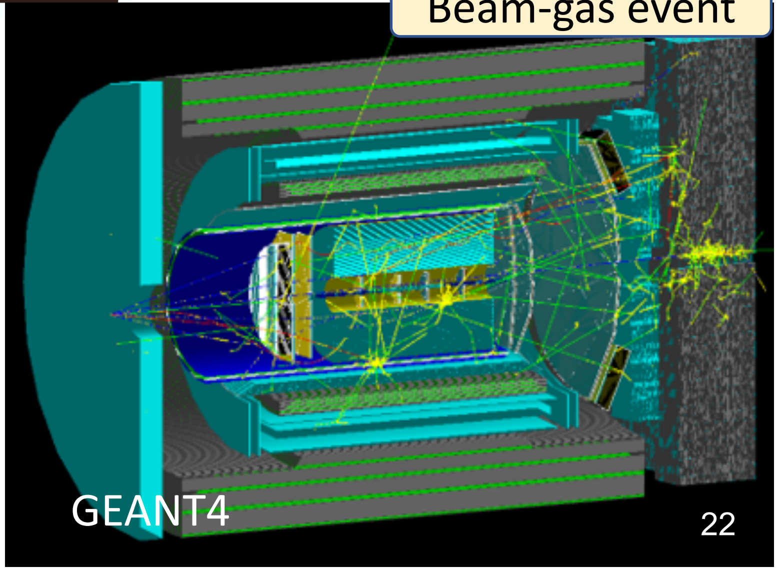
Synchrotron rad.



Slow neutrons



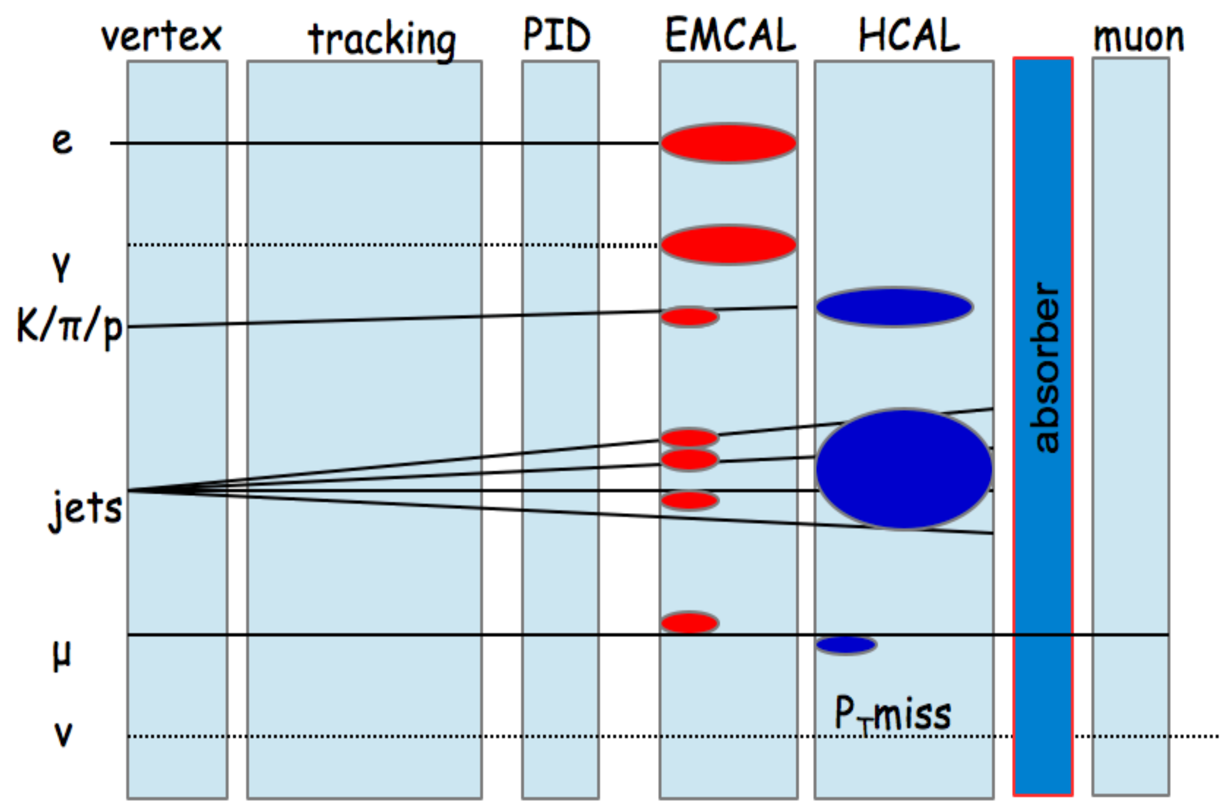
Beam-gas event



Particle Identification

Limited number of “stable” final state particles: only 13 have cτ > 500μm

- Electrons /positrons
- Gammas
- Jet/Jets
- Individual hadrons ($\pi\pm$, K±,p)
- Muons (absorber and muon chamber)
- Neutrinos (missing PT in EM+HCAL)
- Neutral hadrons (n,K^0_L) (HCAL)

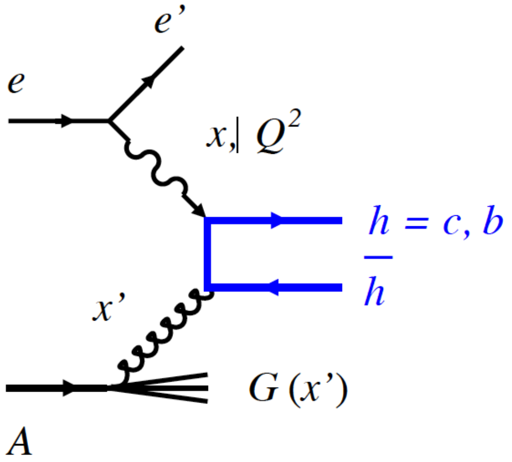


- Electrons: EMCAL cluster + track pointing to cluster
- Gammas (γ): EMCAL cluster, no track pointing to cluster
- Neutrinos (ν): missing P_T
- Muons: track, min. energy in EMCAL, min. energy in HCAL, track in muon det.
- Charged pions, kaons and protons from each other -> **Cherenkov detectors**

Short lived particles: hadron identification

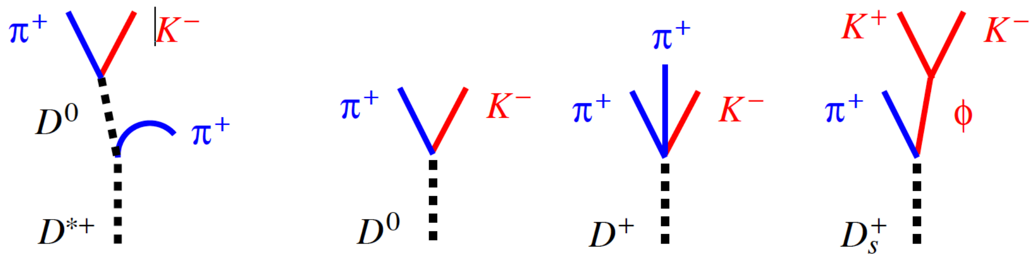
Example: charm -> (fragmentation)-> D-mesons ->(decay) -> hadrons,leptons…

Invariant mass reconstruction



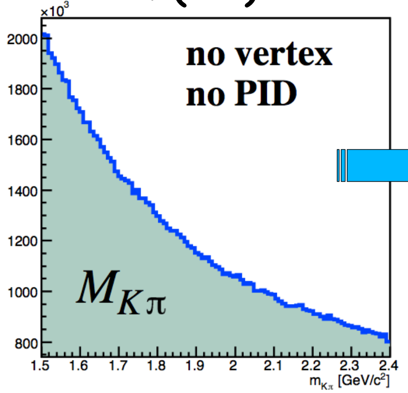
$D^{-*} \rightarrow \pi^-_s D^0$

$\quad\quad \llcorner \pi^- K^+$

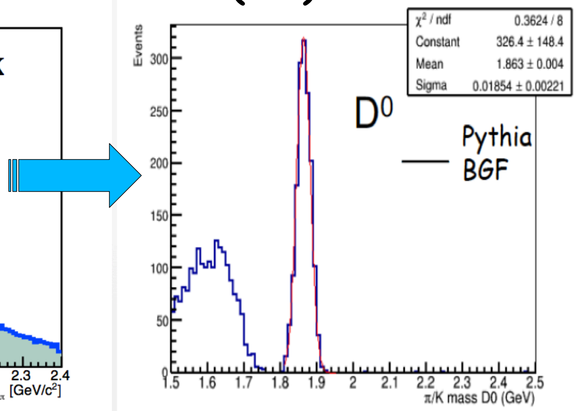


- high combinatorial background without PID

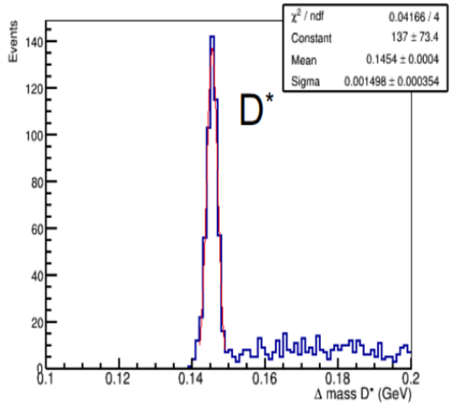
m(D^0)



m(D^0)

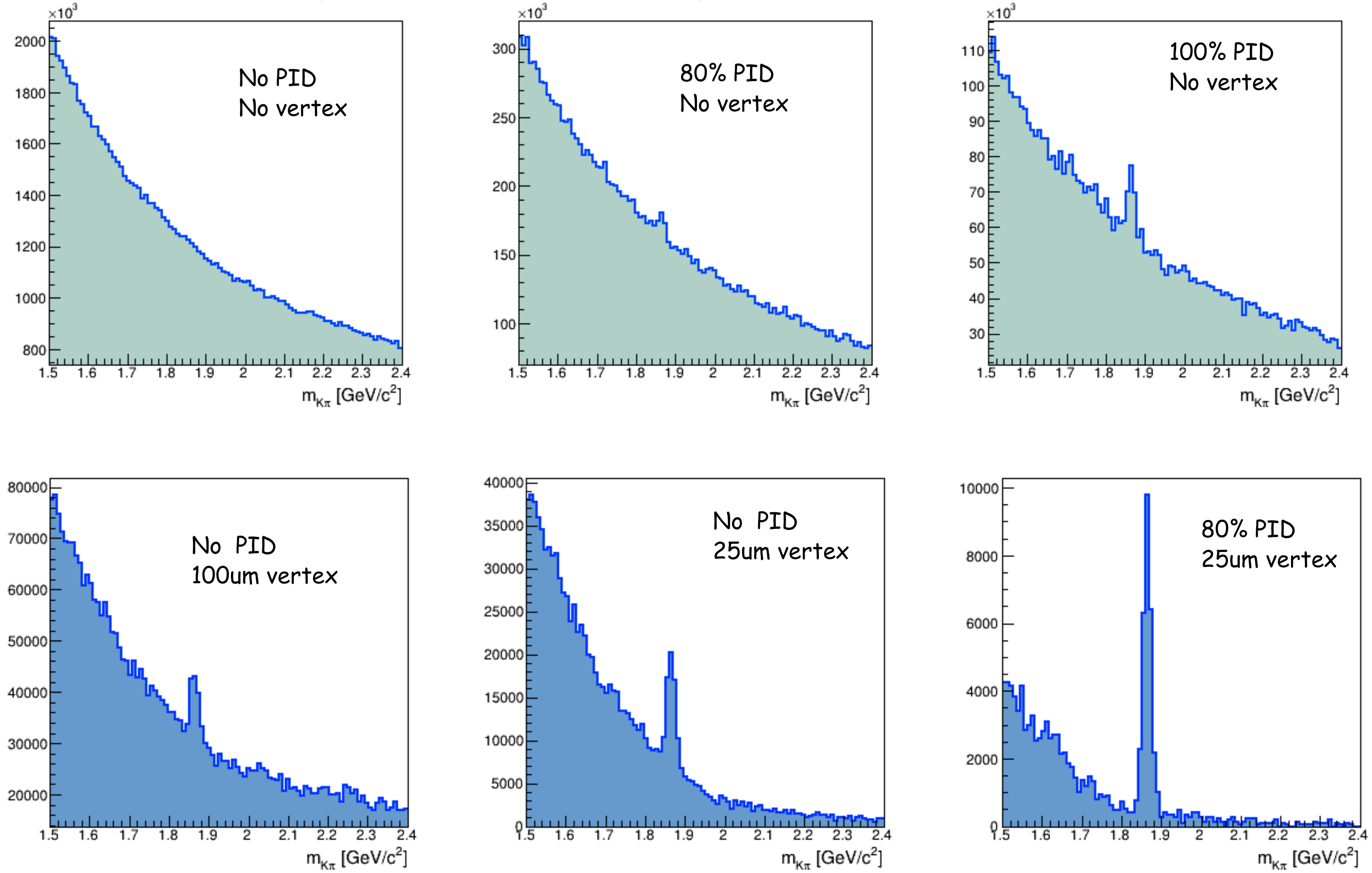


m(D*) – m(D^0)= m (π^-_s)



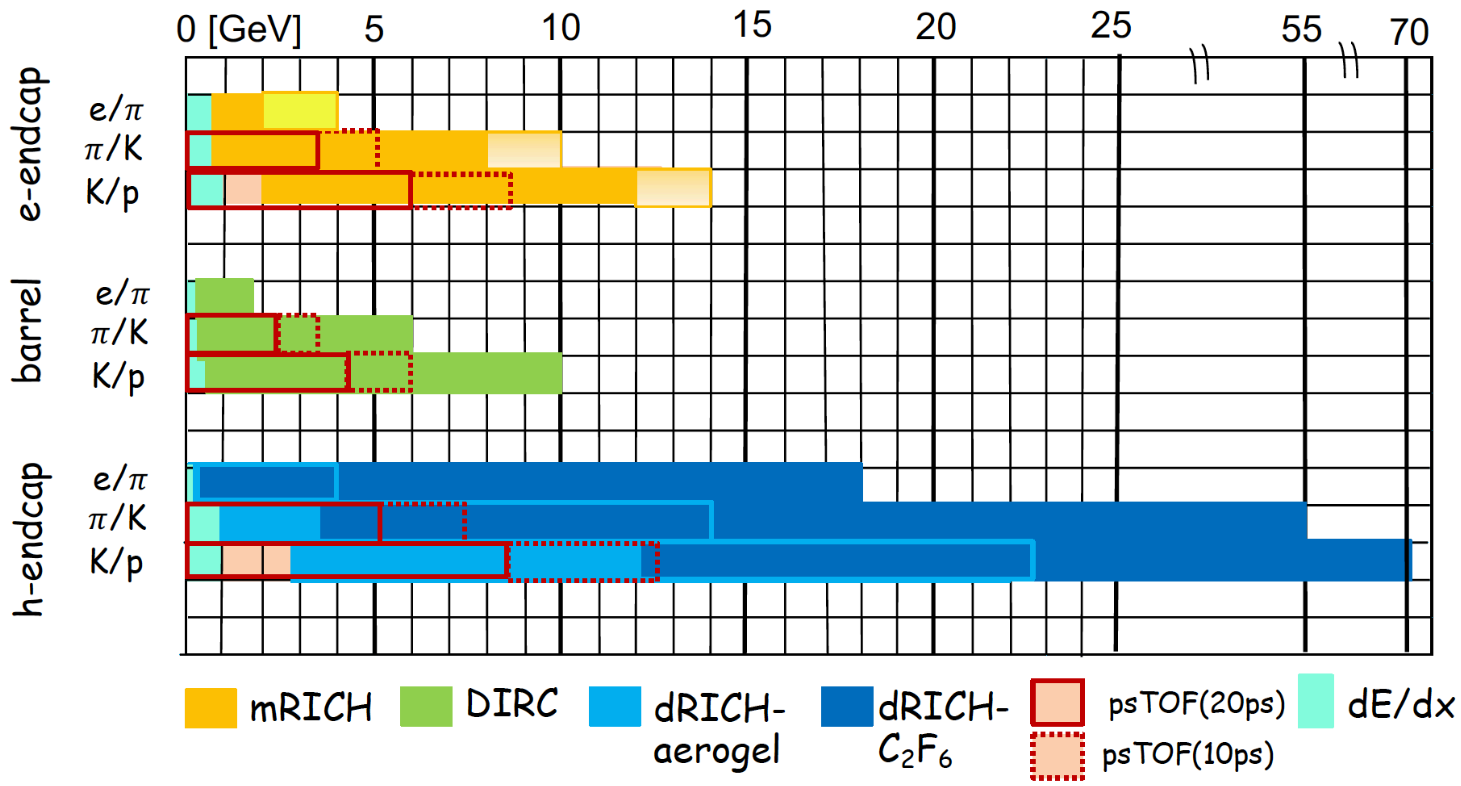
Individual charged hadrons(π, K, p)

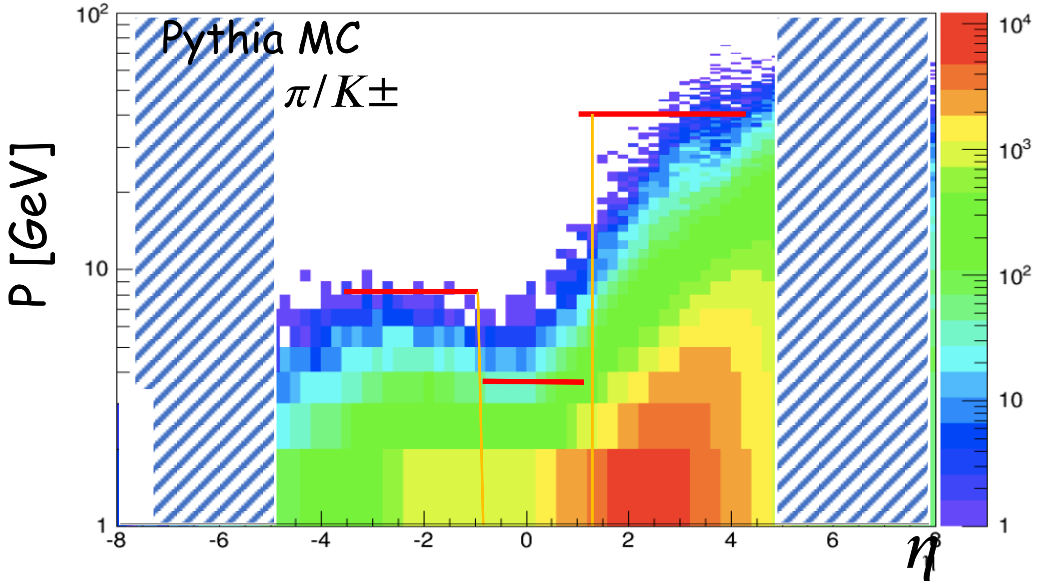
$D^0 \rightarrow \pi K$ mass spectrum, on the top of DIS background



In order to select/identify specific reaction (for example, D0 production) one need to apply certain criteria/cuts to extract such events from the minbias events (DIS background).

Particle identification: charged hadrons(π, K, p)



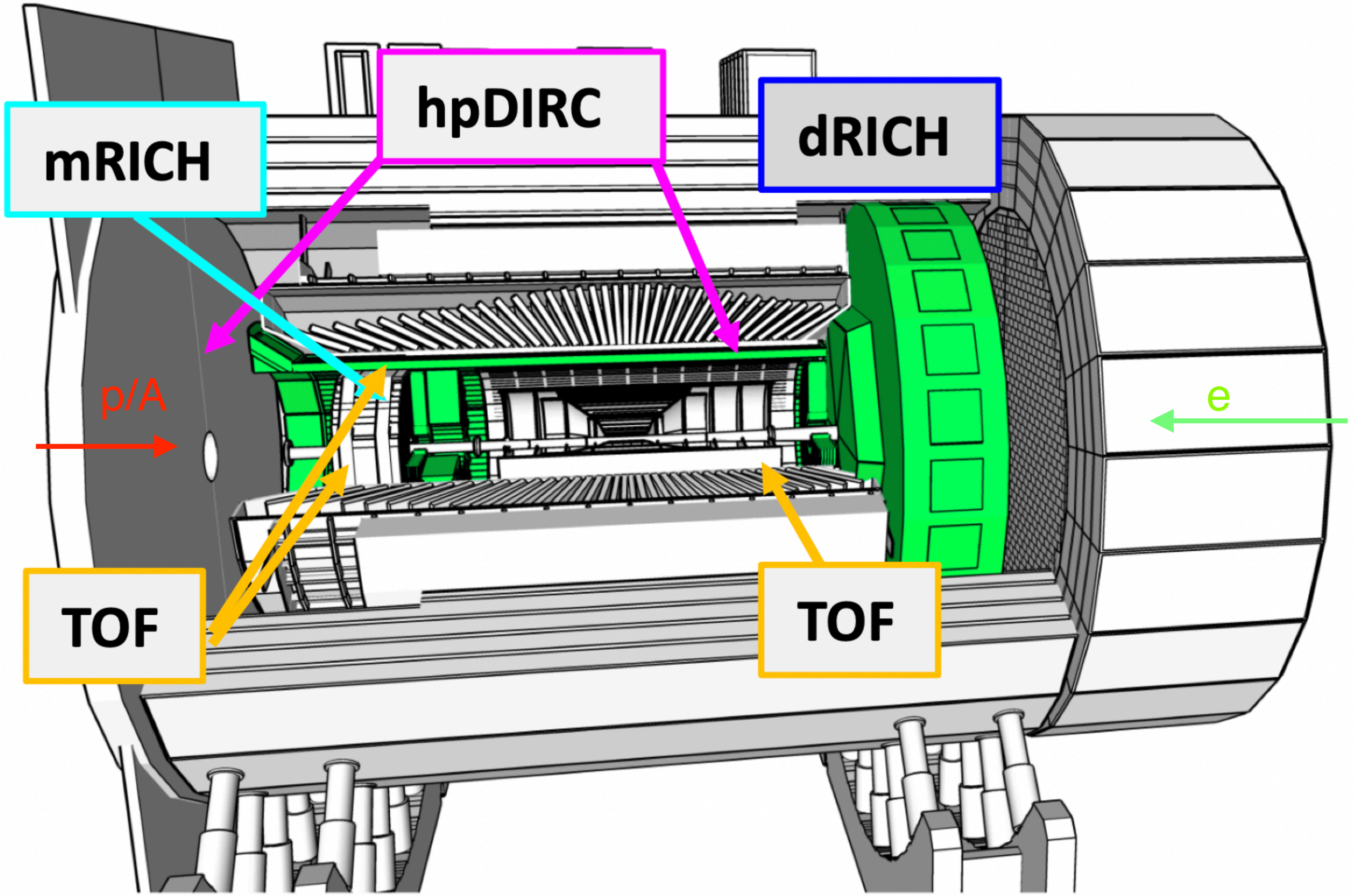


Cherenkov detectors, complemented by other technologies at lower momenta (TOF)
Need 4π coverage

Particle Identification detectors

PID technologies are based on the outcome of the EIC generic R&D (eRD14)

- Backward: Short, modular RICH **(mRICH)**
- Barrel: Radially compact with flexible design high-performance DIRC **(hpDIRC)**
- Forward: Double-radiator RICH **(dRICH)**
- TOF (*) AC-LGAD based time-of-flight (TOF) system for hadronic PID in momentum range below the thresholds of the Cherenkov detectors



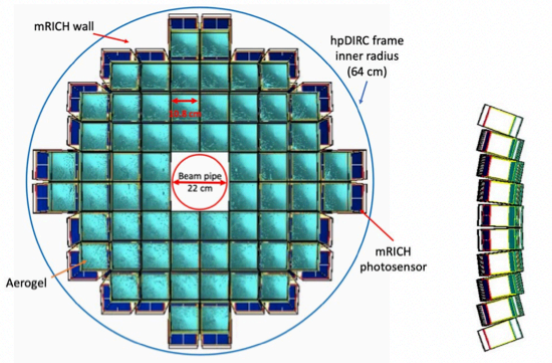
Particle Identification detectors

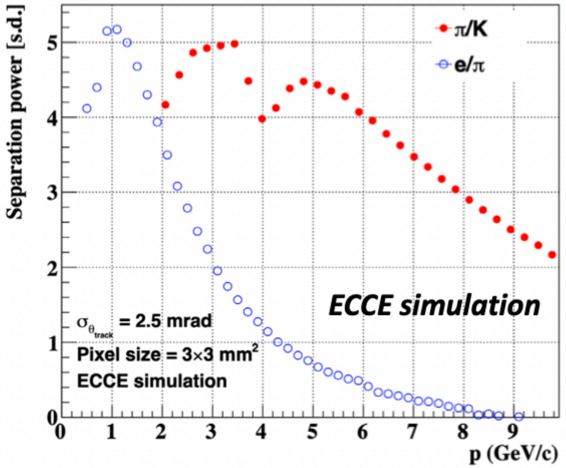
T. Horn (DPAP meeting)

Backward PID

Compact version of a conventional aerogel-based proximity focusing RICH

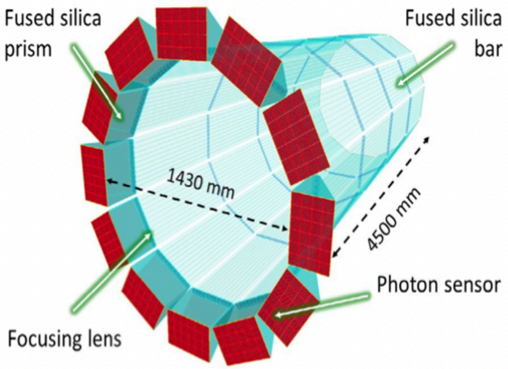
π/K up to 10 GeV

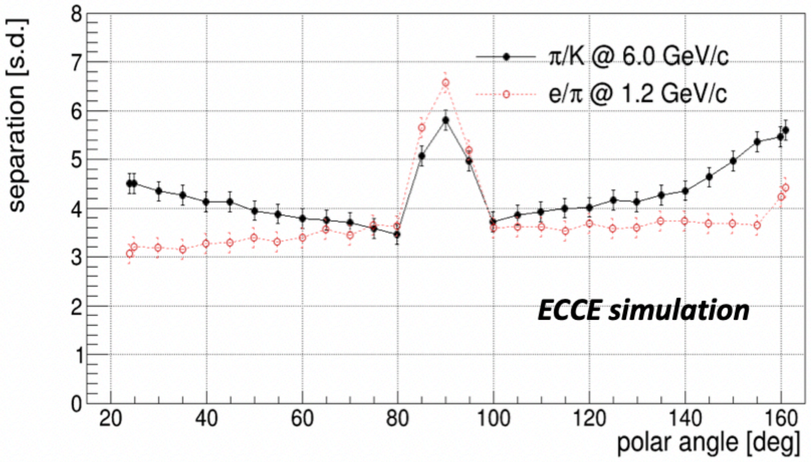




Barrel PID

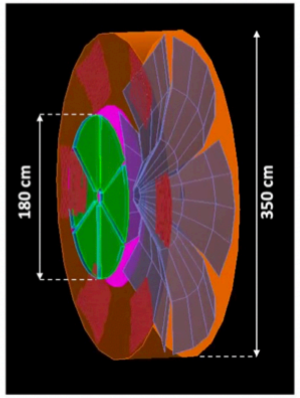
- Radially compact (~ 5cm)
- hpDIRC with better optics and <100 ps timing (π/K up to ~6 GeV/c)



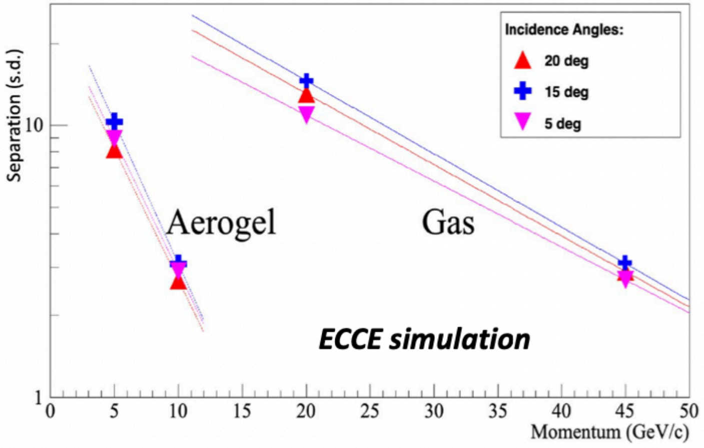


Forward PID

Use a combination of aerogel and C_mF_n with indices of refraction matching EIC momentum range in the forward endcap. Similar to LHC-b, HERMES, JLAB/Hall-B, …

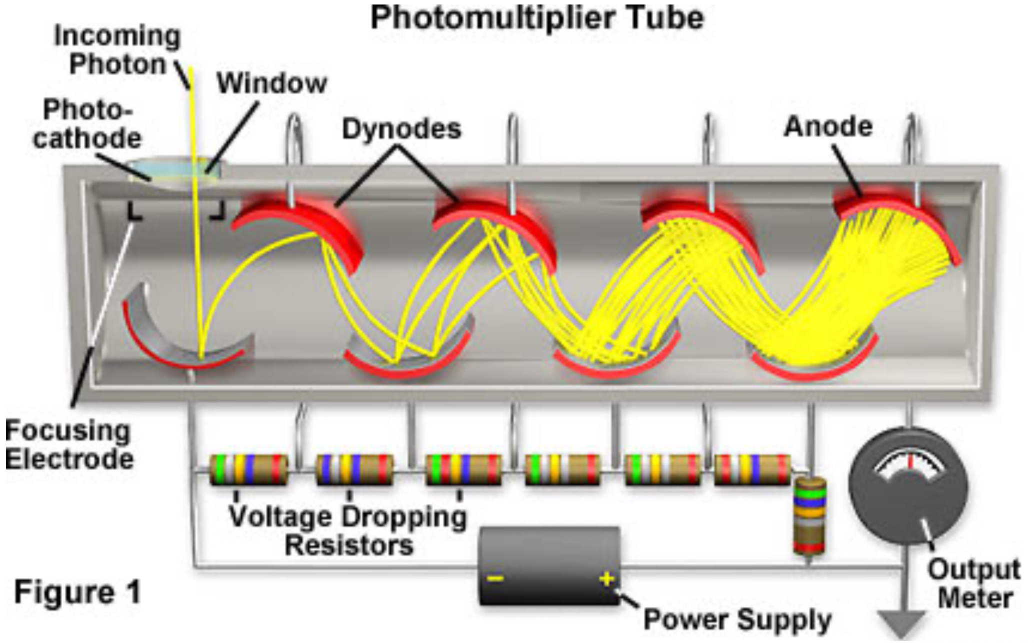


π/K up to 50 GeV



Readout: PMT vs SiPM

PMT

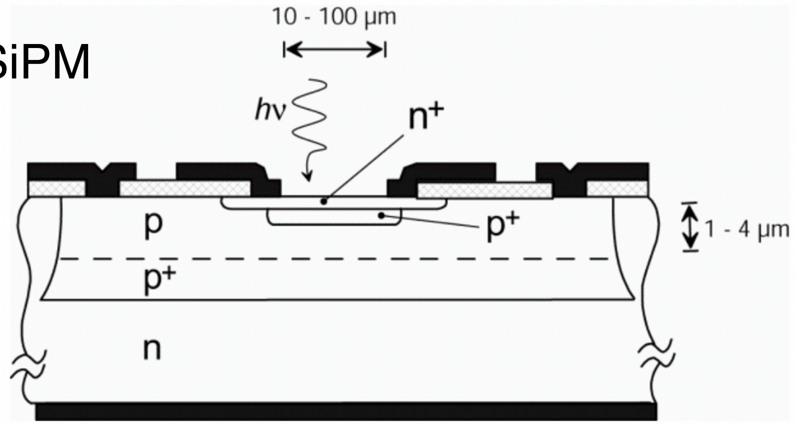


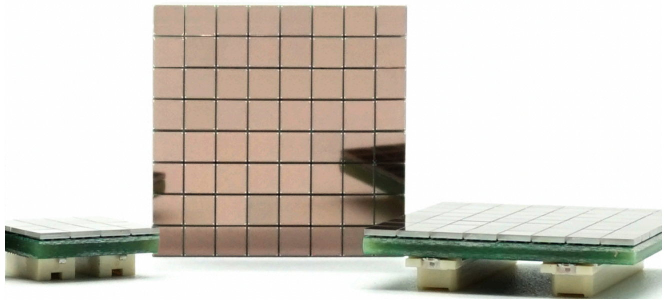
Good linearity in large dynamic range

Very sensitive to the magnetic field

Typical Gain $=10^4 - 10^7$

SiPM





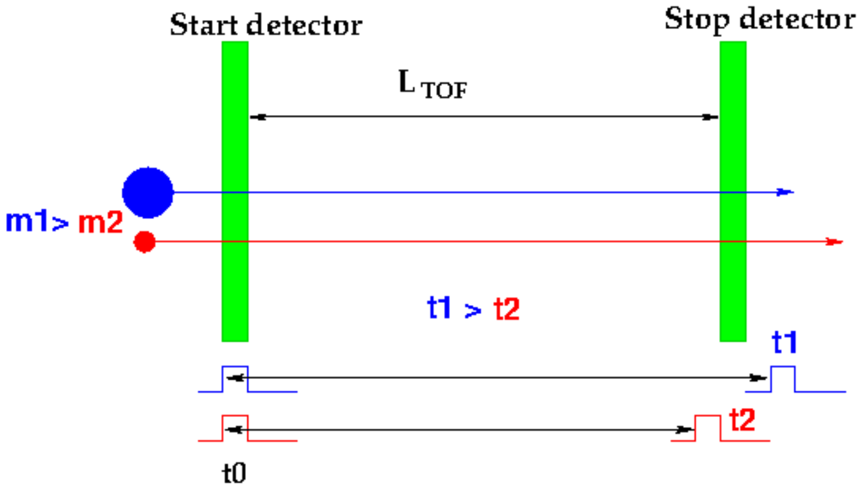
Compactness

Single photon sensitive

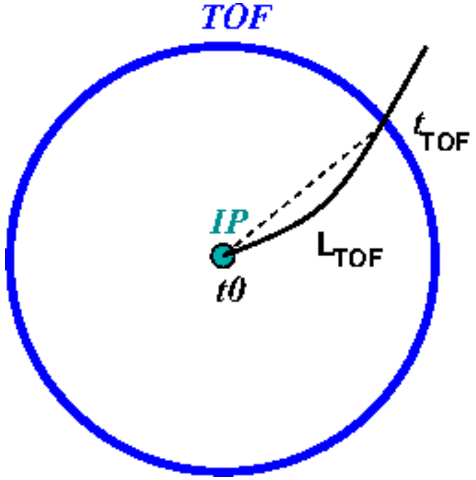
Huge dark noise rate (temperature dependent)

> 100kHz/mm2 @ 25C

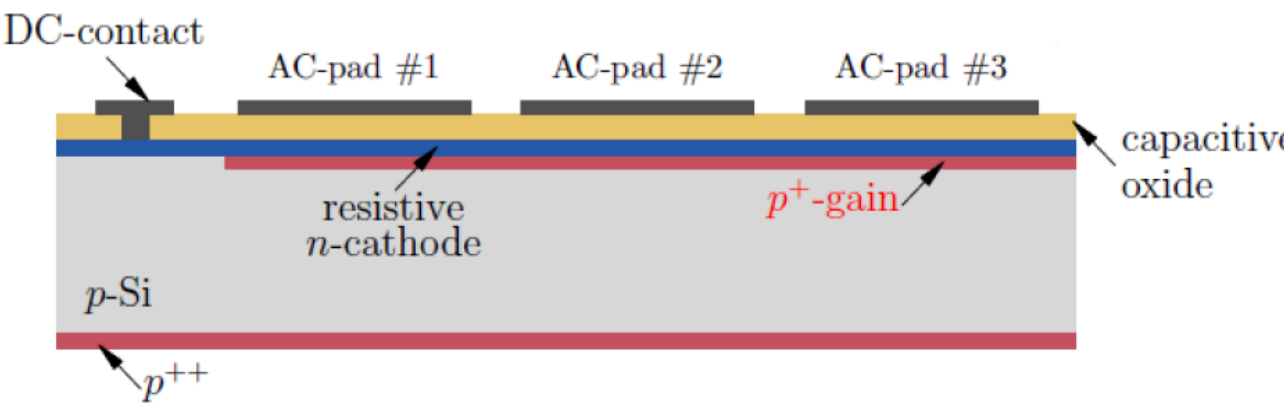
Timing detectors: AC-LGAD



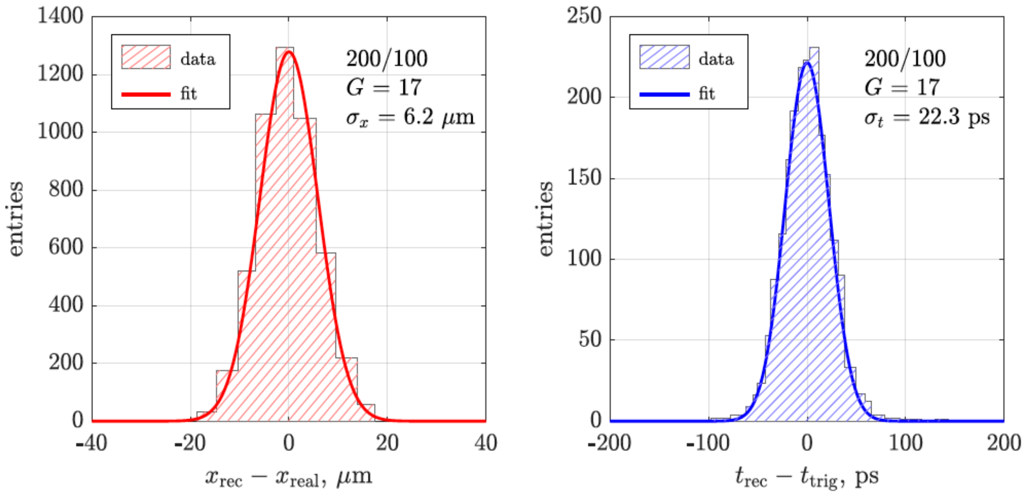
$$\Delta t_{TOF} = \frac{cL_{TOF}}{2p^2}(m_1^2 - m_2^2) \qquad \frac{dm}{m} = \frac{dp}{p} + \gamma^2\left(\frac{dt}{t} + \frac{dL}{L}\right).$$



- ➢ In barrel - limited space L_{TOF} < 1 m
- ➢ No space for "Start detector" - t0
- ➢ Need to know **vertex position** more precisely to **measure L_TOF** precise (total particle length/curvature)
- ➢ high timing resolution of TOF detector (10-20 ps)

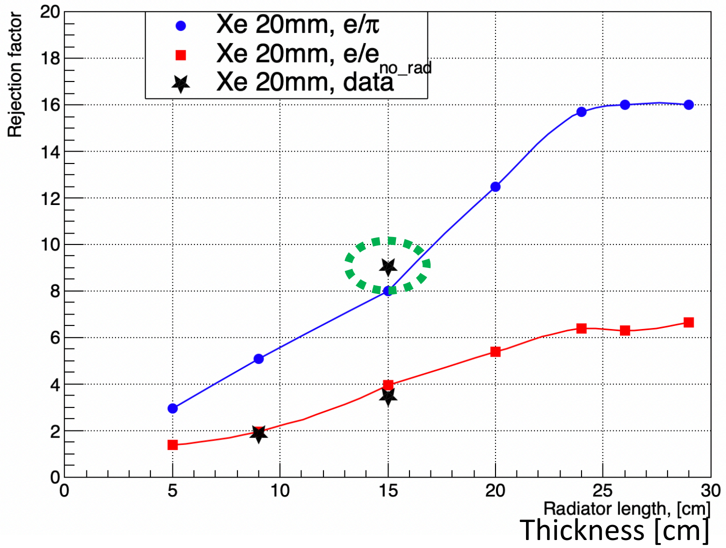


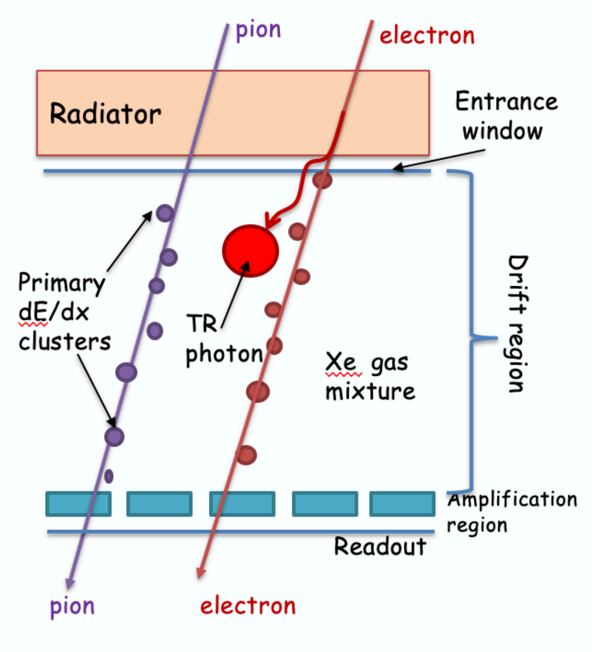
- For TOF or Far-Forward/Backward area
- Detectors can provide <20ps / layer
- AC-coupled variety gives 100% fill factor and potentially a high spatial resolution (dozens of microns) with >1mm large pixels

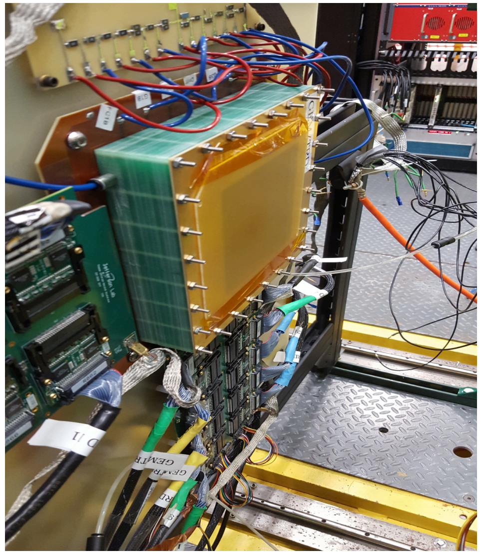


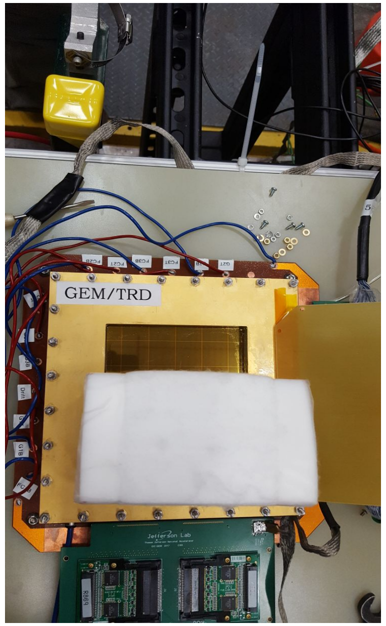
Additional e- ID L GEM based TRD

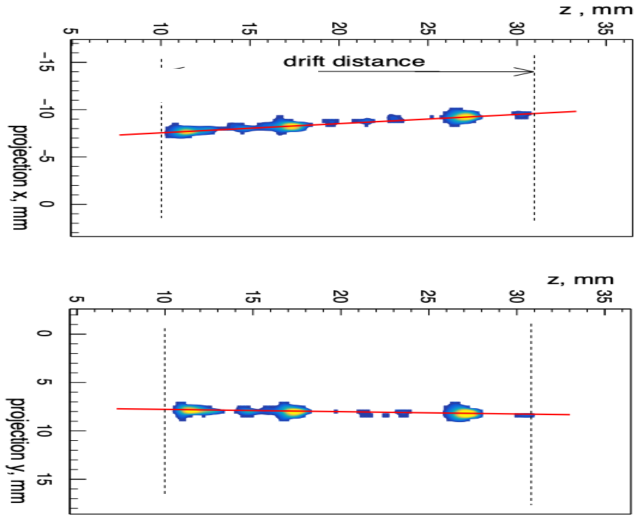
- To improve e-identification for leptonic/semi-leptonic decays.
- In addition to Calorimeters and Cherenkov detectors in the hadron-endcap considering TRD.
- GEM -TRD/Tracker :
  - e/π rejection factor ~10 for momenta between 2-100 GeV/c from a single ~15cm thick module.











- Very precise Tracking segment behind dRICH.
- Could be used as the EIC detector upgrade

Why do we need a calorimeter ?

✓ Use momentum measurements for charged particles: $E^2 = (p^2+m^2)$

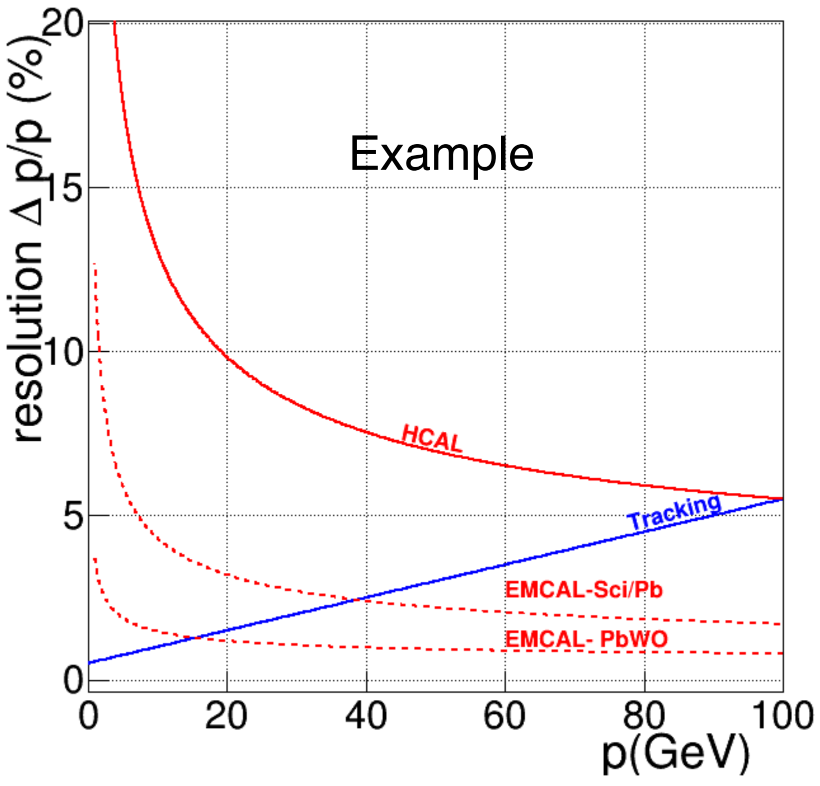
➢ Need to identify a particle (or mass): not always possible.

➢ Need to measure momentum precise: not always possible.

❖ Momentum measurements are getting worse with increase of particle momenta ($\frac{\Delta p}{p} \sim p$)

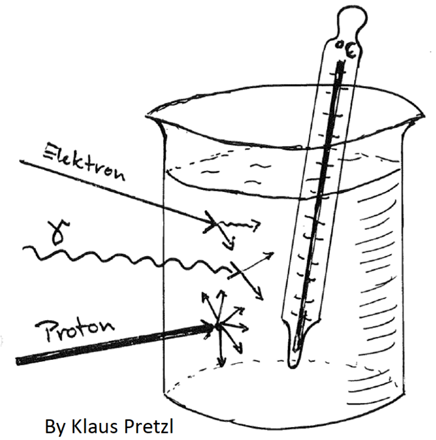
❖ BUT, Calorimeter measurements are getting better with increase of the energy ($\frac{\Delta E}{E} \sim \frac{1}{\sqrt{E}}$)

✓ Need to measure neutral particles! Calorimeter is the ONLY detector for them.



Calorimetry

- ✓ In nuclear and particle physics calorimeter refers to energy measurements of particles.



By Klaus Pretzl

We need 1kCal to change a temperature on 1 ℃ for 1 liter of water

1kCal ~ 1000•2.61•10^{19} eV
~ 2.61 • 10^{10} TeV

- ✓ In calorimeters the process of energy measurements is destructive:
  we must completely stop the particle in our detectors to measure its full energy :

  Unlike, for example, tracking chambers (silicon, gaseous, etc) , the particles are no longer available for detection once they path through a calorimeter.

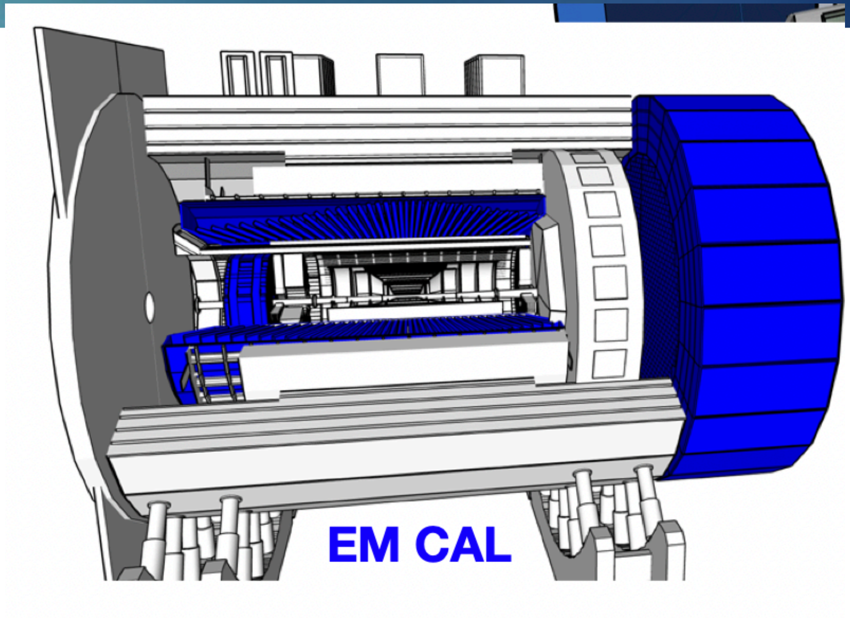
  With just few exceptions: muons and neutrinos penetrate through with a minimal interactions

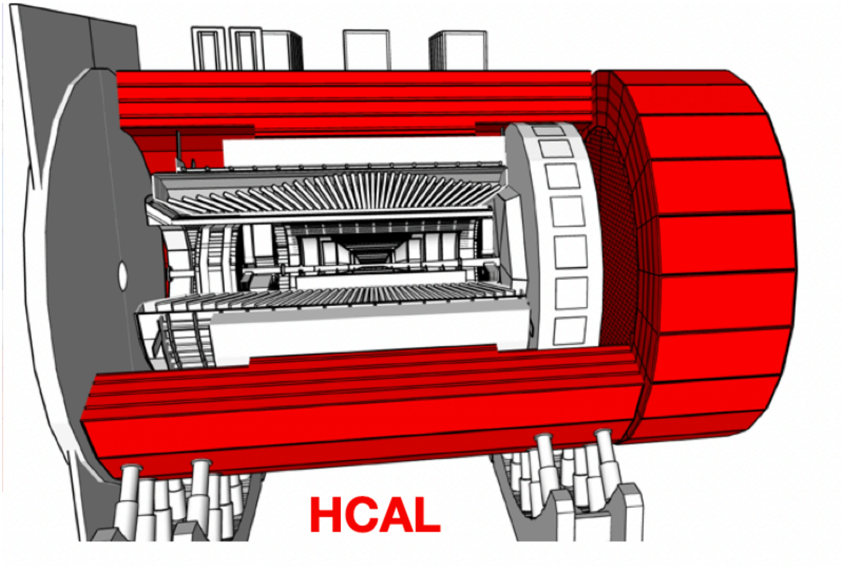
  ⇒ Calorimeter is the **outermost detector**
- ✓ Calorimeter measure charged + neutral particles

Calorimetry at EIC

Close to 4π coverage
calorimeters need to perform
- Scattered electron kinematics measurement
- Photon detection and energy measurement
- e/h separation (via E/p & cluster topology)
- π0/γ separation

EMCAL technologies are based on the outcome of the EIC generic R&D (eRD1)





Electromagnetic calorimeter

T. Horn (DPAP meeting)

Backward ECAL (EEMC)

Homogeneous calorimeter based on high-resolution $PbWO_4$ crystals

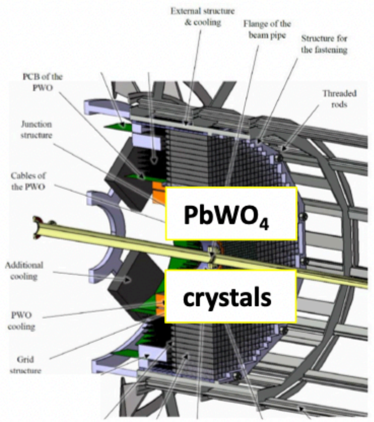


Figure from the EIC EEEMCAL Consortium design report

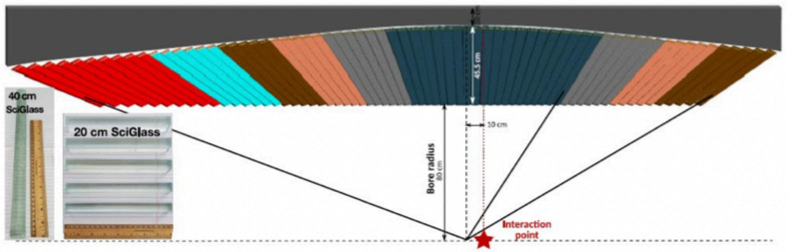
Backward ECAL

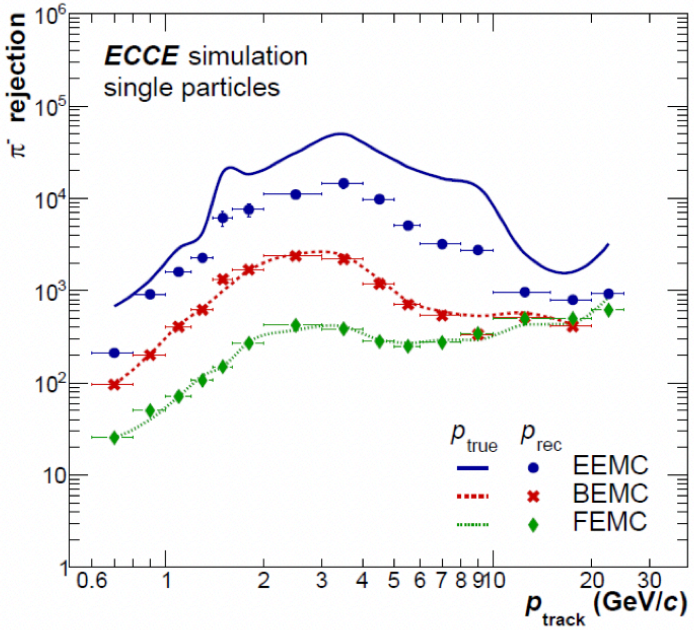
η	[-4 .. -1.8]
σ_E/E	2%/√E+1%*

*Based on prototype beam tests and earlier experiments

Barrel ECAL (BEMC)

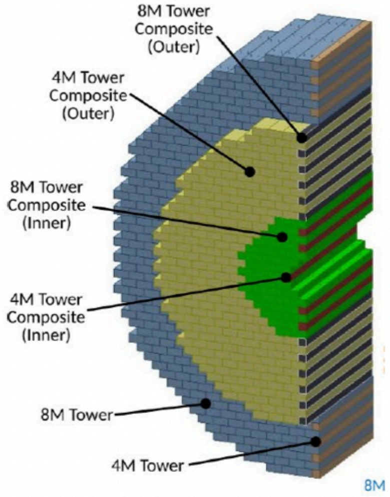
Homogeneous, projective calorimeter based on SciGlass, cost-effective alternative to crystals





Forward ECAL (FEMC)

Highly-granular shashlik sampling calorimeter based on Pb/SC



	Barrel ECAL	Forward ECAL
η	[-1.7 .. 1.3]	[1.3 .. 4]
σ_E/E	2.5%/√E+1.6%*	7.1%/√E+0.3%

*Based on prototype beam tests and earlier experiments

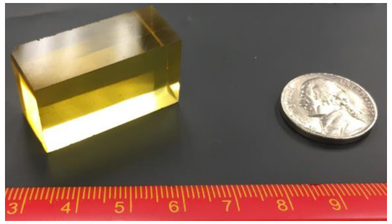
ECCE EM calorimeters provide the required coverage, meet the physics energy resolution, and pion suppression in all three regions (endcaps, barrel)

Crystals/Glass

- High-resolution $PbWO_4$ (PWO) crystals are available from two vendors
- SciGlass 20cm has been produced reliably; We tested a 3x3 20 cm SciGlass prototype detector in beam and measured its performance as per simulation (ongoing R&D EEEMCAL consortium, eRD105)
- Received the first polished 40 cm SciGlass with more on the way
- We have an SBIR phase-II to start large-scale production (40+ cm, rectangular and projective shapes)

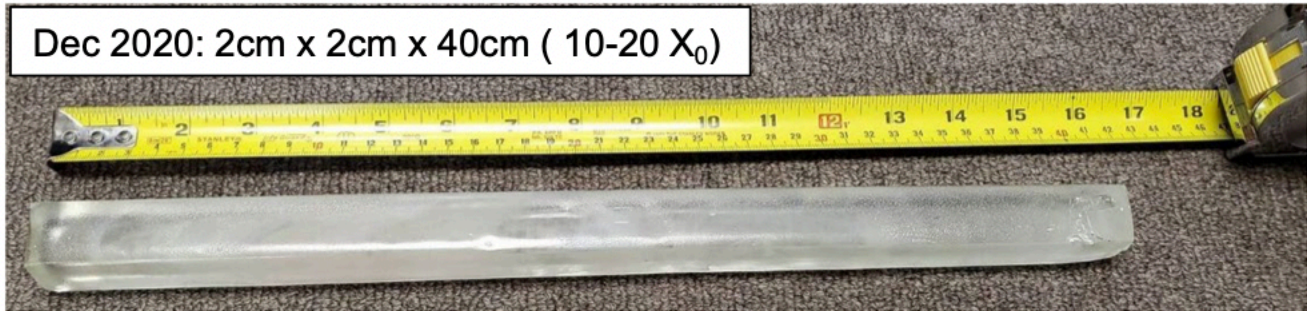
Example: SC1 glass

2018: 1cm x 1cm x 1cm



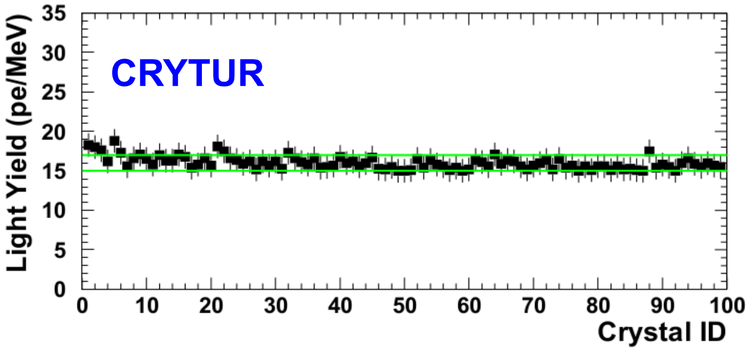
2019: 2cm x 2cm x 4cm

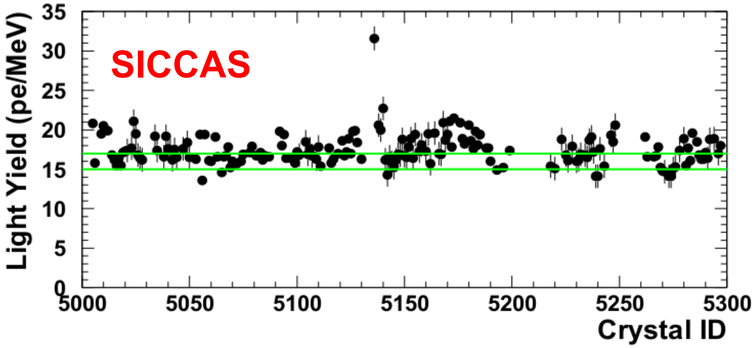
2020: 2cm x 2cm x 20cm



Dec 2020: 2cm x 2cm x 40cm (10-20 X_0)

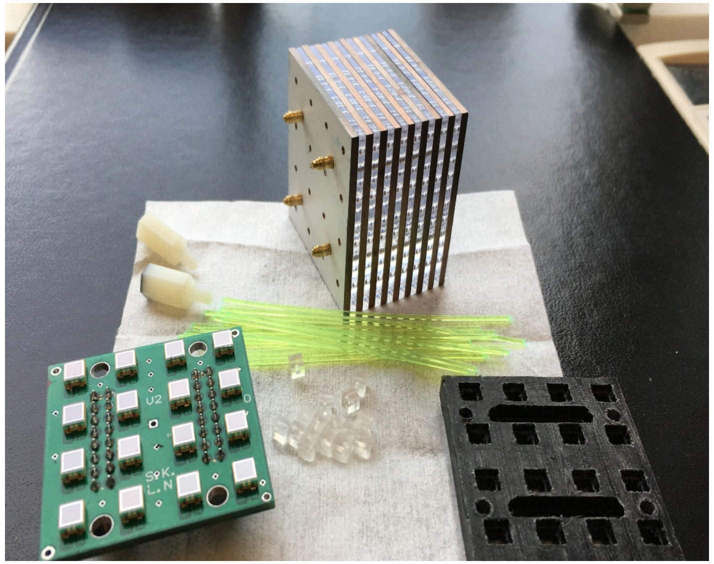
PWO: vendor characterization

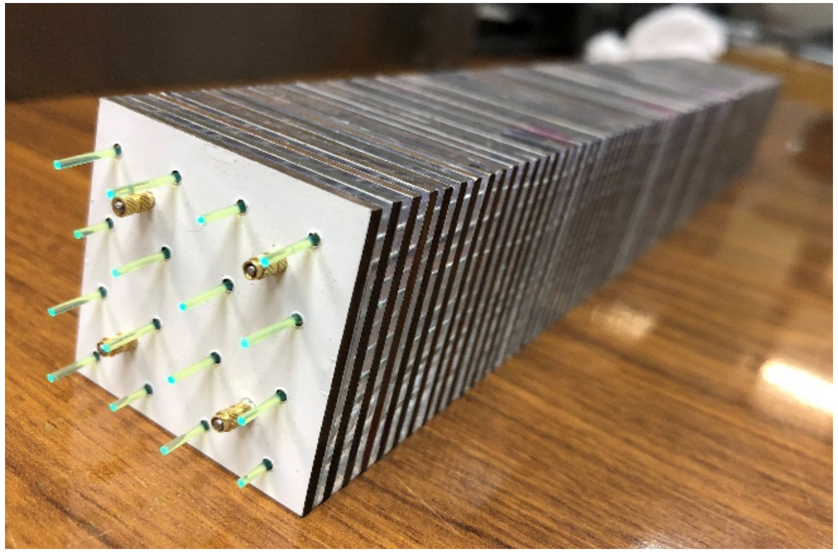


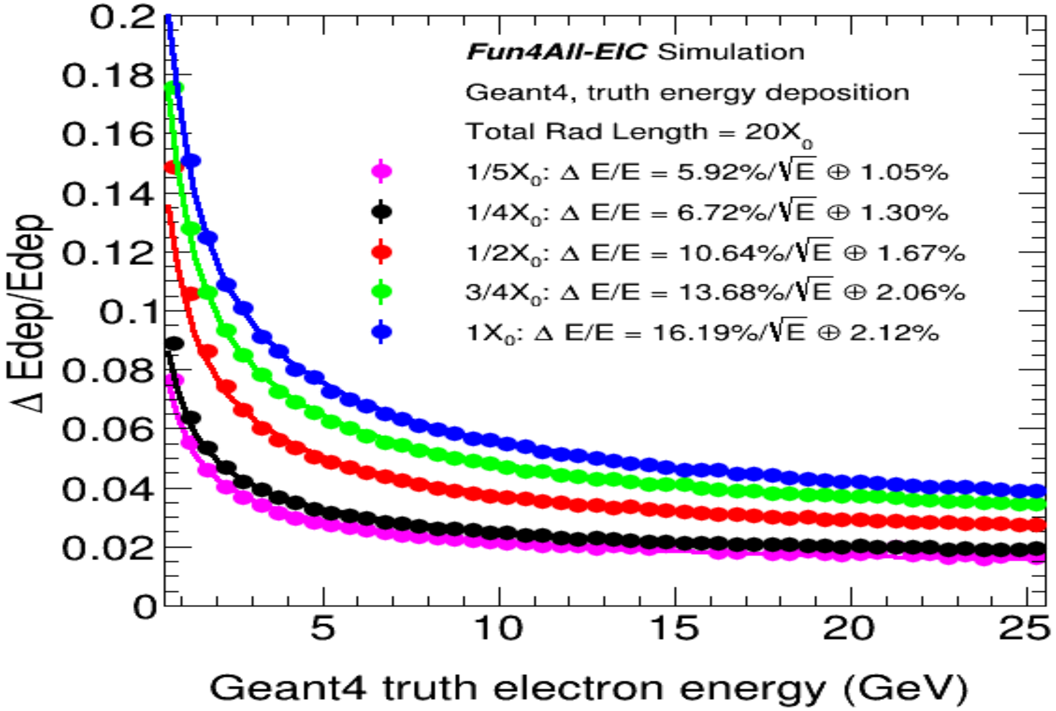


Sampling calorimeter: EMCAL

- Well established technology
  - HERA-B, ALICE, PHENIX, PANDA, …
- Medium energy resolution ~7..13%/√E
- Compact (X_0 ~7mm or less), cost efficient
- Pb/Sc shashlyk

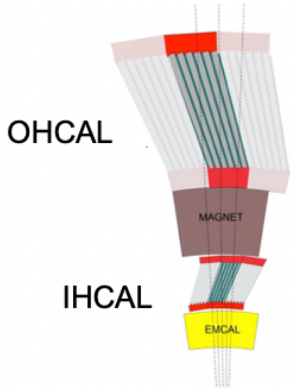




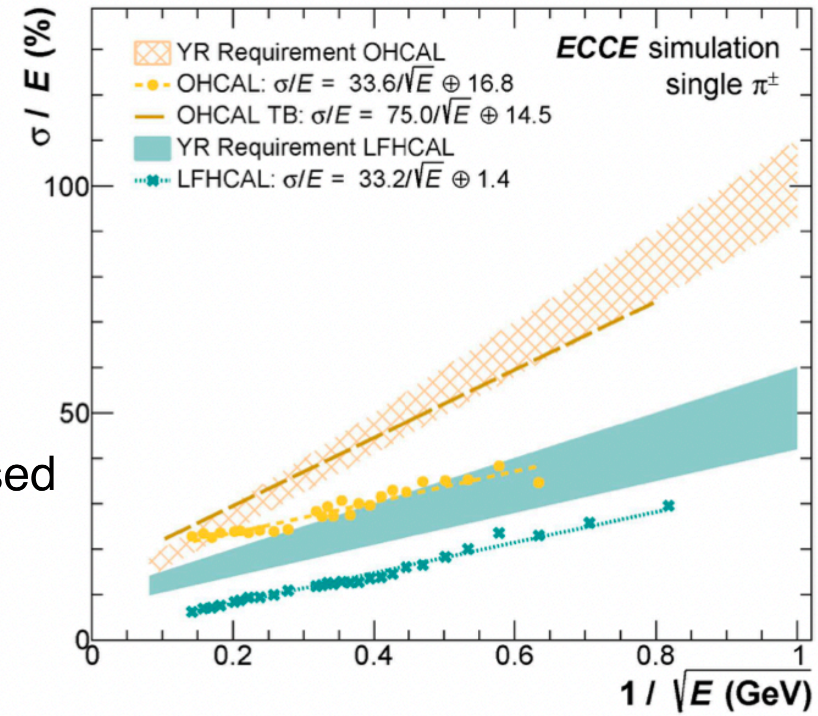


Sampling calorimeter: HCAL

Barrel HCAL (OHCAL+IHCAL)

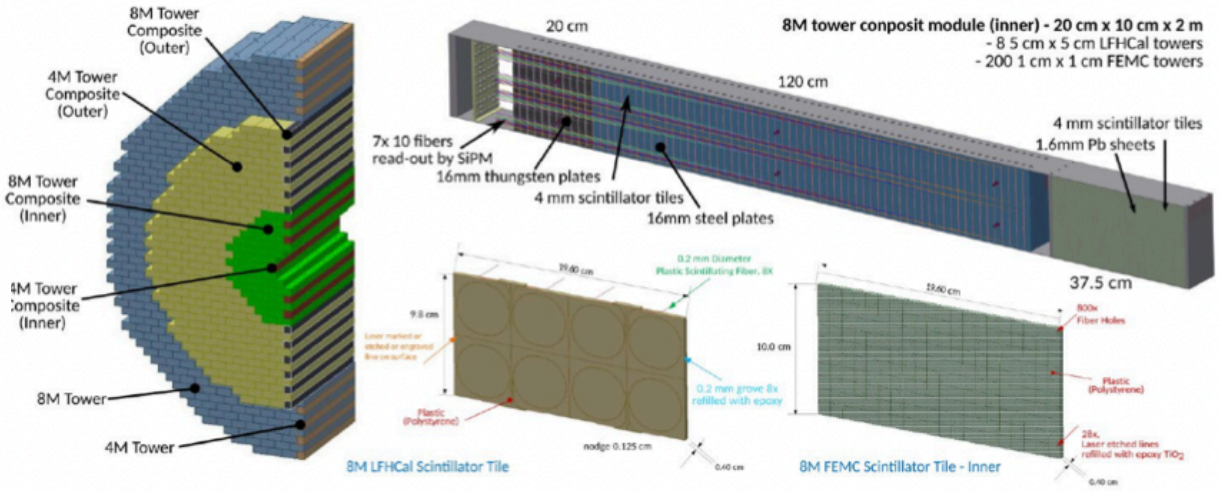


Sampling calorimeter based on Fe/SC tiles



Forward HCAL (LFHCAL)

Integrated ECAL+HCAL longitudinally segmented sampling calorimeter based on Fe/SC, W/Sc and last segment W (tailcatcher)

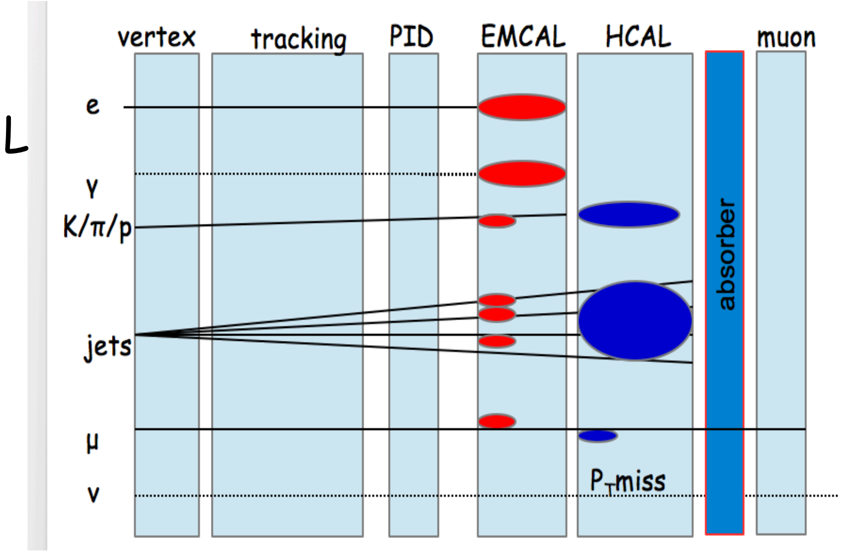


	Barrel HCAL	Forward HCAL
η	[-1 .. 1]	[1 .. 4]
σ_E/E	~75%/√E + 15%*	~33%/√E + 1.4%
depth	~4-5 λ_I	~7-8 λ_I

*Based on prototype beam tests and earlier experiments

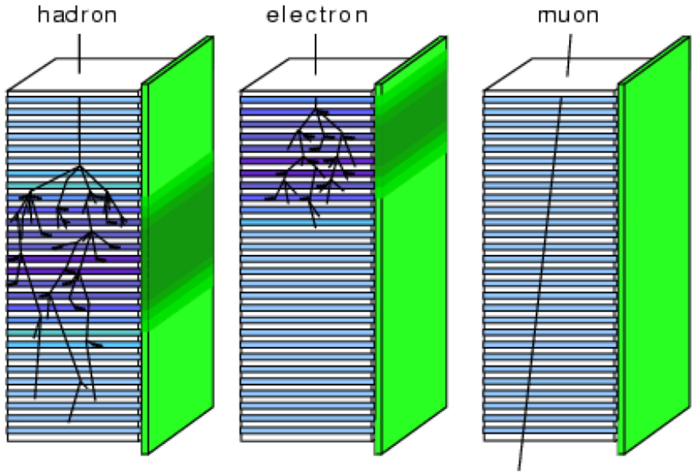
Calorimeter for particle identification

Electrons: track pointing to cluster in EMCAL
Gammas: no track but cluster in EMCAL
Neutral hadrons: no tracks, energy in HCAL
Neutrino: missing energy (E_T, p_T)
Muon: track, minimum energy in CAL
Charged hadrons: track+ energy in HCAL (ratio EMCAL/HCAL)



Problems (misidentification):

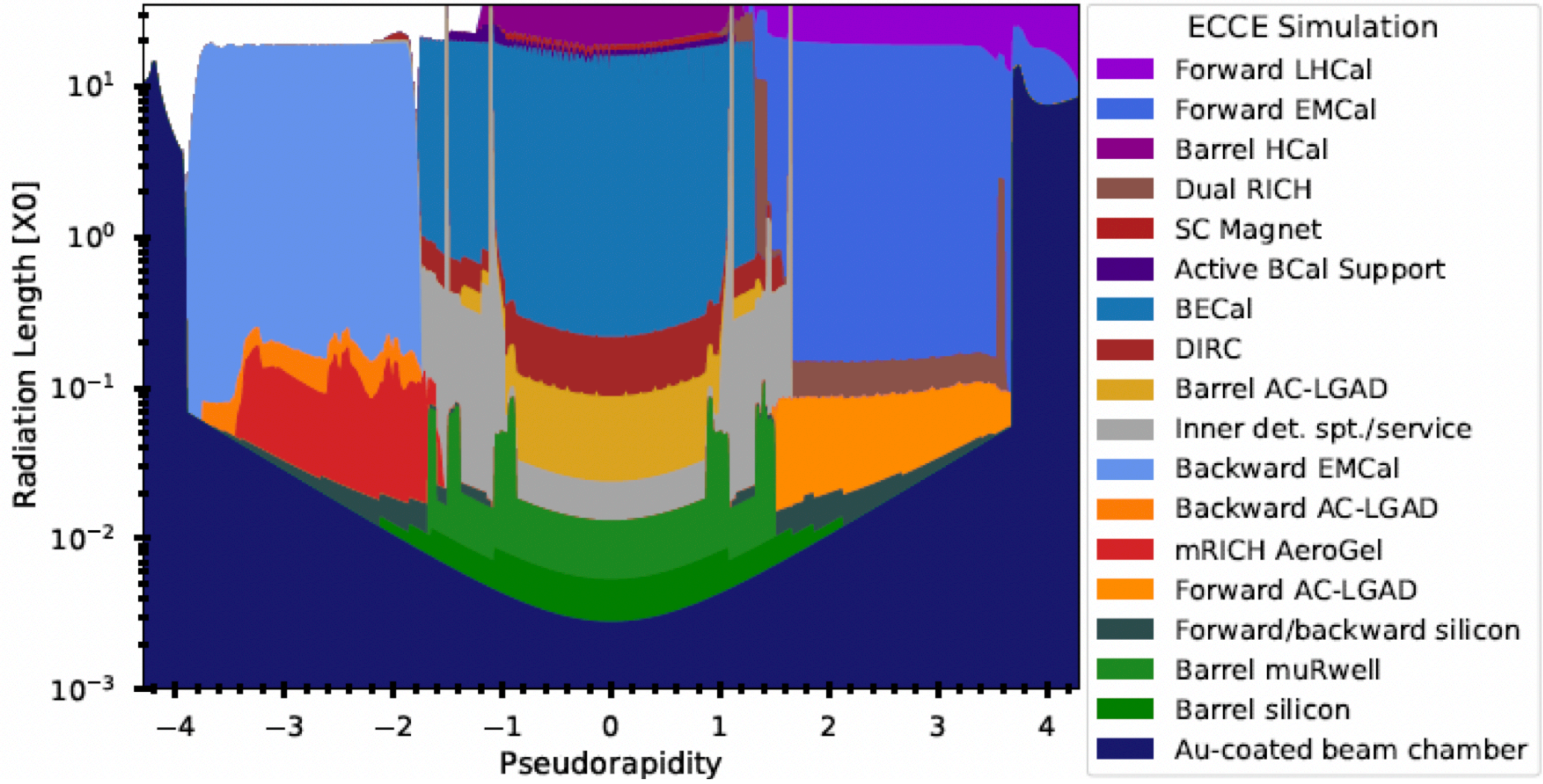
e/hadron separation:
hadrons could develop shower in EMCAL
$\pi 0 \rightarrow \gamma\gamma$: cluster in EMCAL
Not possible to separate charged hadrons (π,K,p)



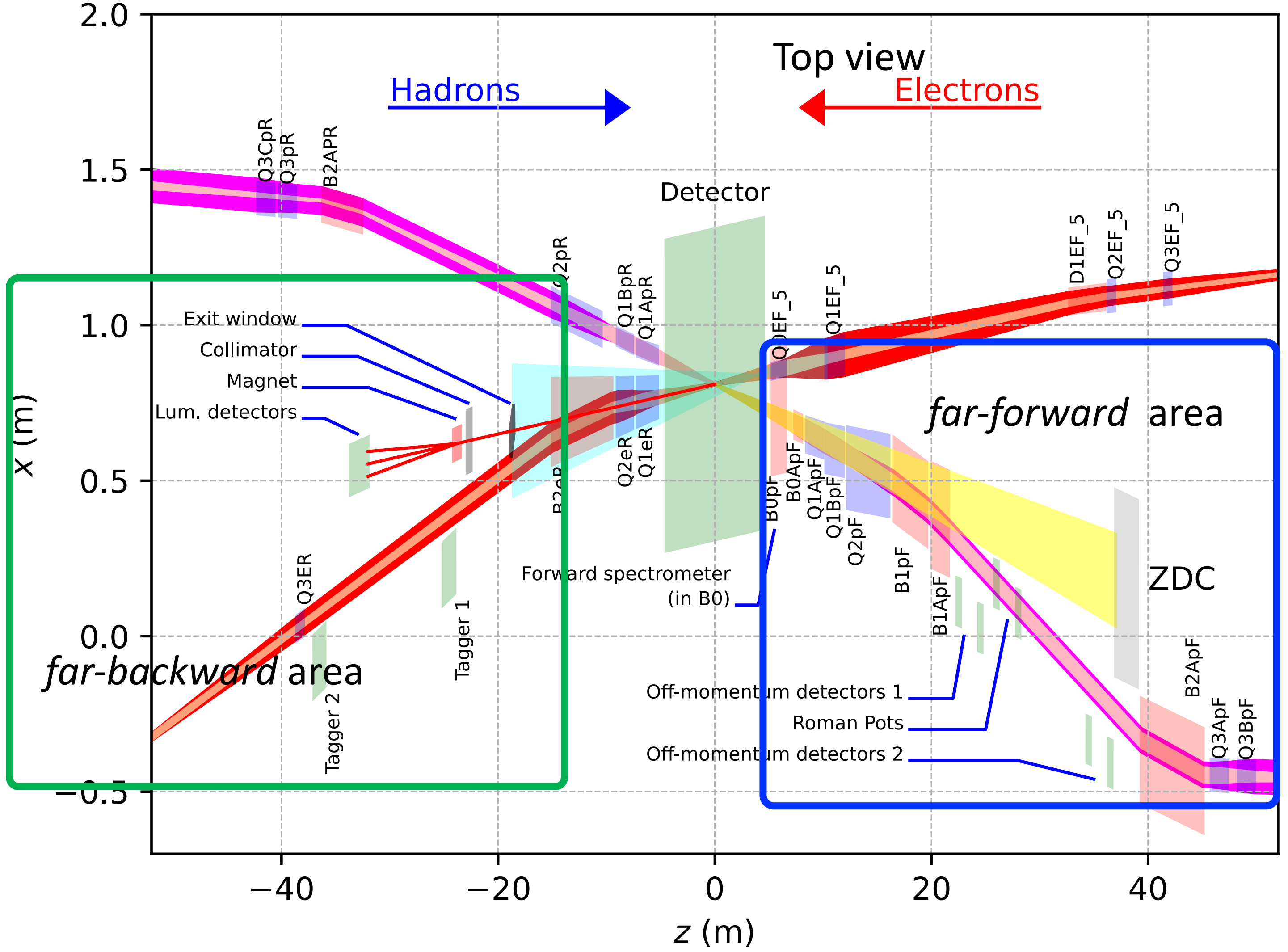
Erik Maddox

Material budget

- Low material budget
  - Minimize bremsstrahlung and conversions for primary particles
  - Improve tracking performance at large $|\eta|$ by minimizing multiple Coulomb scattering
  - Minimize the dead material in front of the high-resolution EM calorimeters



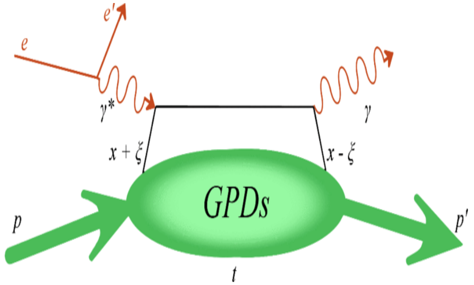
EIC interaction region layout (IP6)



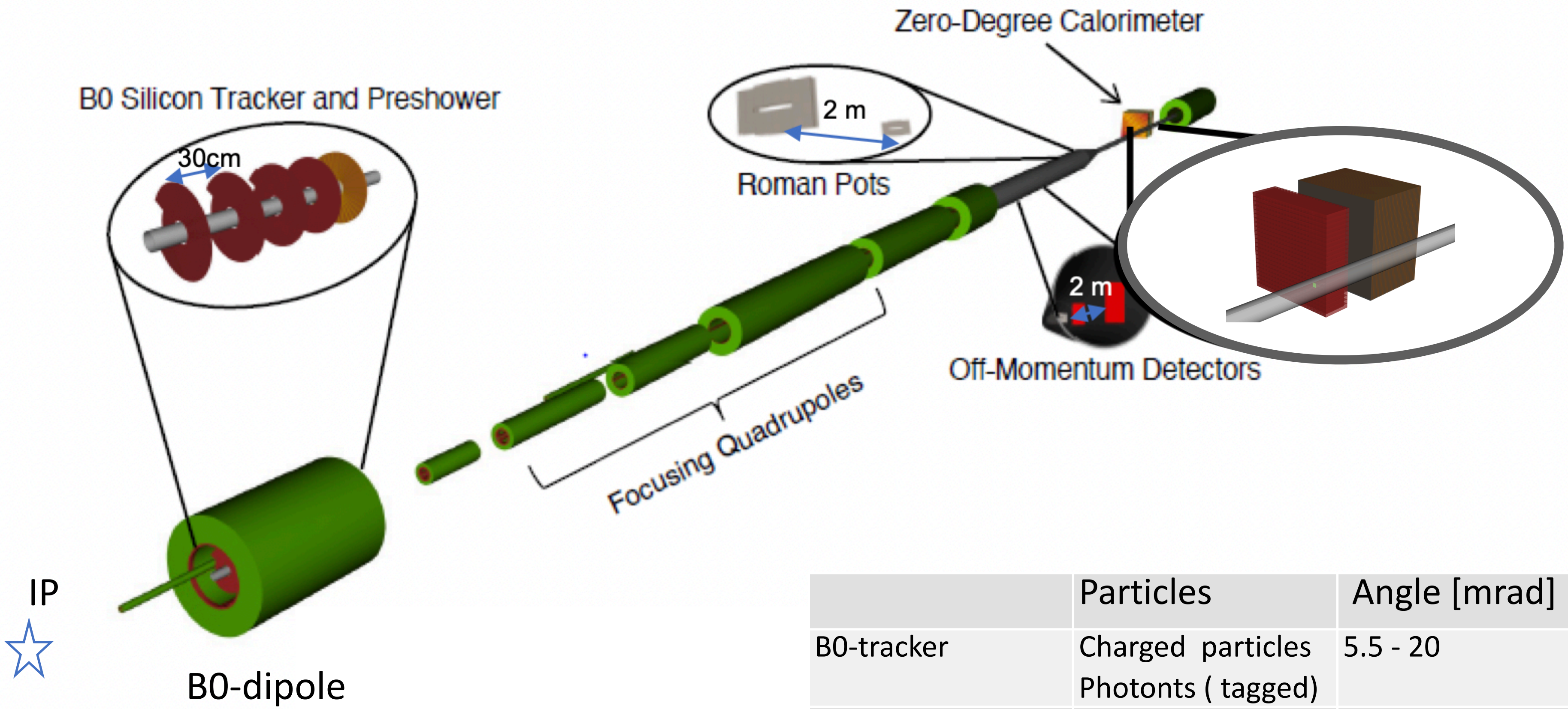
- ~9.5 m around the IP is reserved for the *central* detector
- Crossing angle provides beam separation and space for detector placements
- Apertures of FFQs and dipoles are designed to allow forward going particles to go through

- *Far forward* and *far backward* detector components are distributed along the beam line within ±40 m
- Design should be able to operate **with different beam energy and high luminosity**
- We are keeping a full detector integration in sync with the accelerator design from the early stages on

Far-forward detectors (hadron-going)

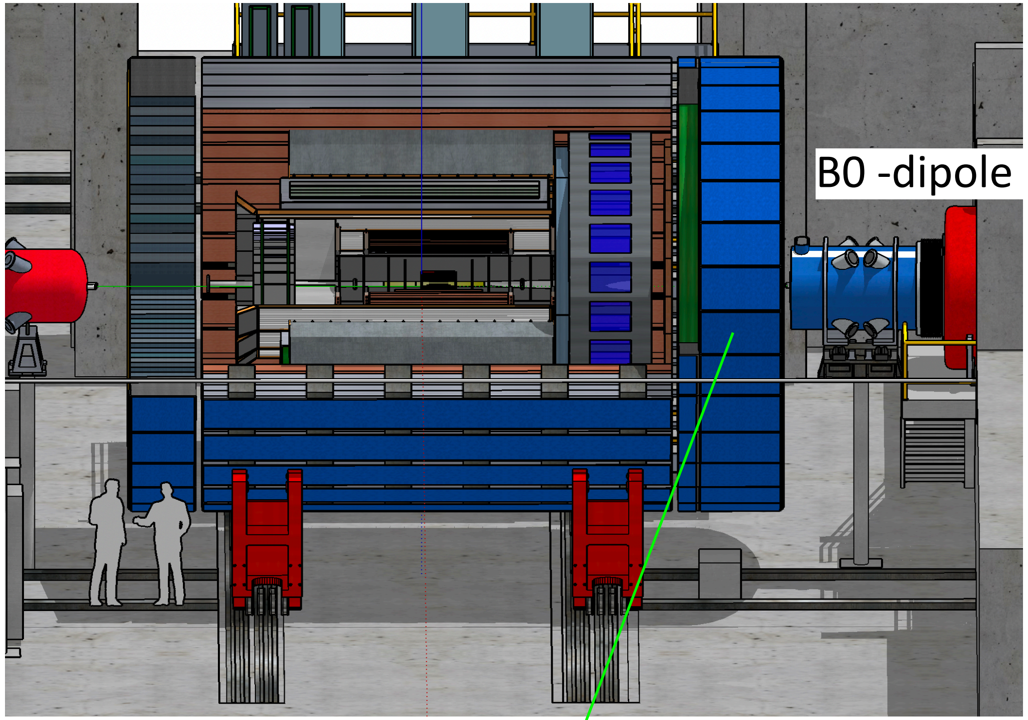


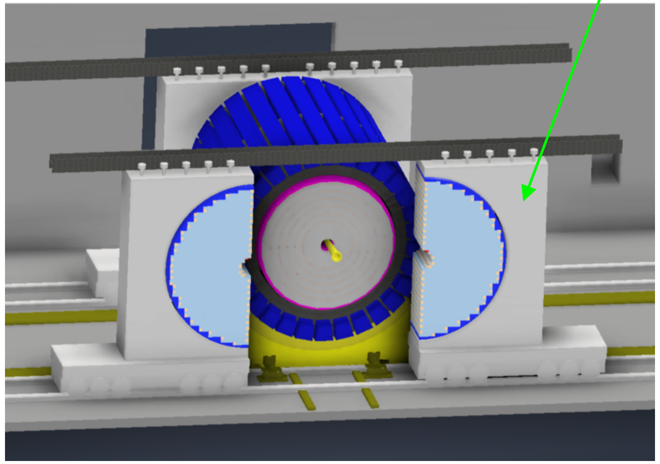
Geant4 implementation of IP6 Far-forward area



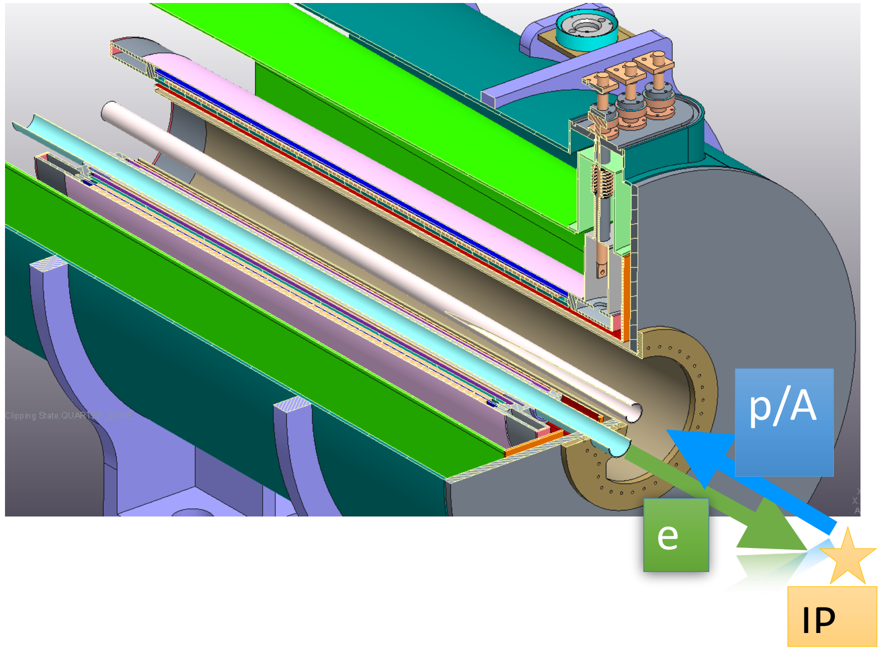
	Particles	Angle [mrad]	$p/p_{beam}(x_L)$
B0-tracker	Charged particles Photonts (tagged)	5.5 - 20	
Off-momentum	Charged particles	0-5.0	0.4< xL< 0.65
Roman Pots	Protons Light nuclei	0 * - 5.0 $(*)10\sigma\ cut$	0.6 < xL< 0.95
ZDC	Neutrons Photons	0-4.0 (5.5)	

B0-detectors





B0 -dipole



➡Dipole field 1.3T: for momentum reconstruction. Design still ongoing (most likely B0 will be shorter 1.8m -> ~1.5m)

➡B0 placement - after HCAL

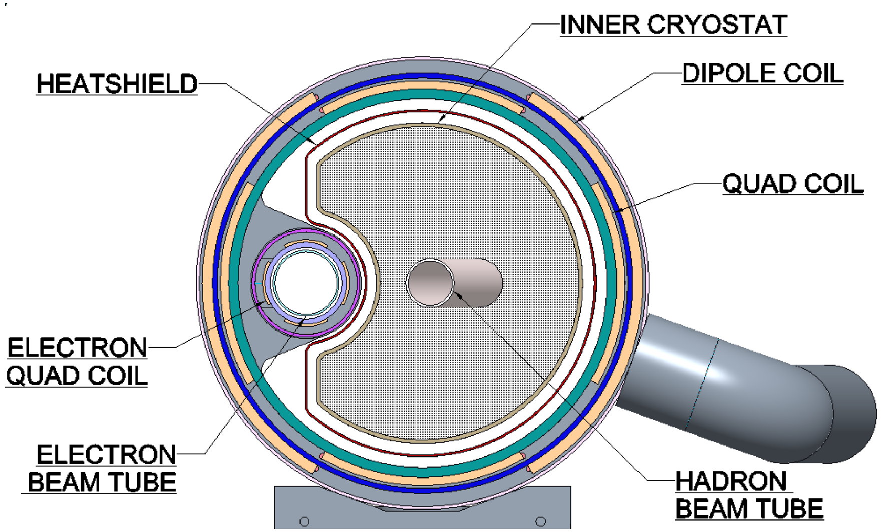
- ✦ Limited space
- ✦ Access to B0-detectors only from one side (after opening HCAL)
- ✦ Vacuum pumps
- ✦ Beam-pipes: crossing angle

➢ B0 placement: high background area => high granularity detectors needed in this area

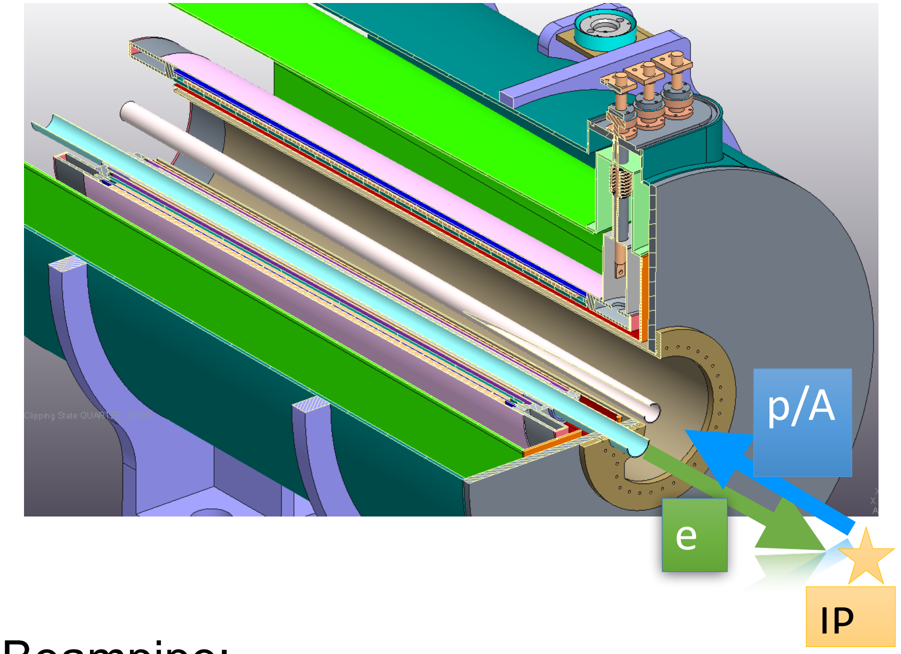
B0-detectors

(5.5 < θ < 20.0 mrad) (4.6 < η < 5.9) -- large |t| value

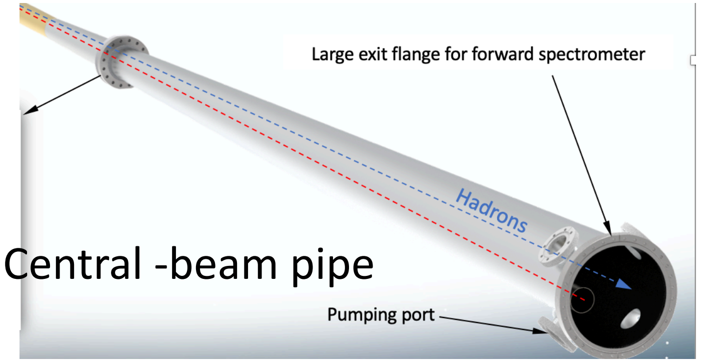
- Create zero field line at electron beam axis.
- Warm space for detector package insert located inside a vacuum vessel to isolate from insulating vacuum.



B0 -dipole



➢ Beampipe:
- ❖ Near IP - common beam pipe
- ❖ Beams are separation into two independent beam-pipes in front of B0
- ❖ Low-mass **exit window** for far-forward particles



Central -beam pipe

=> B0 detector mechanical integration

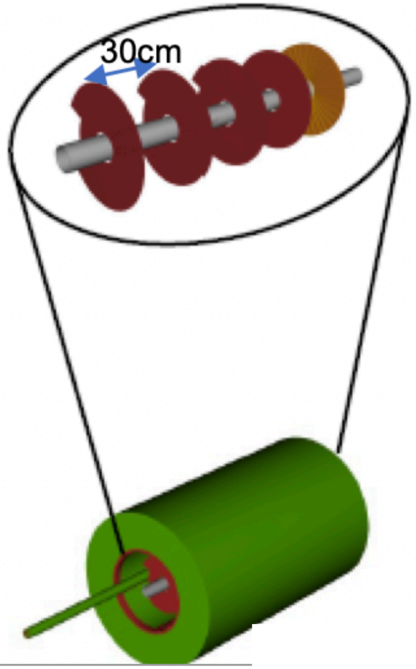
B0-detectors

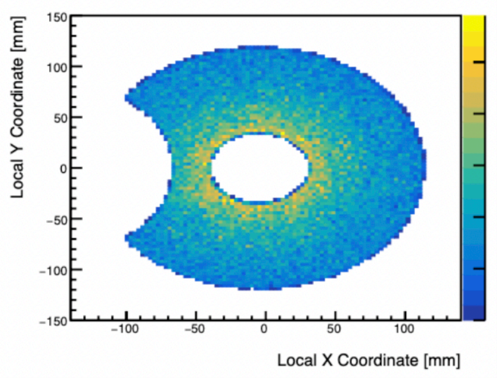
(5.5 < θ < 20.0 mrad)

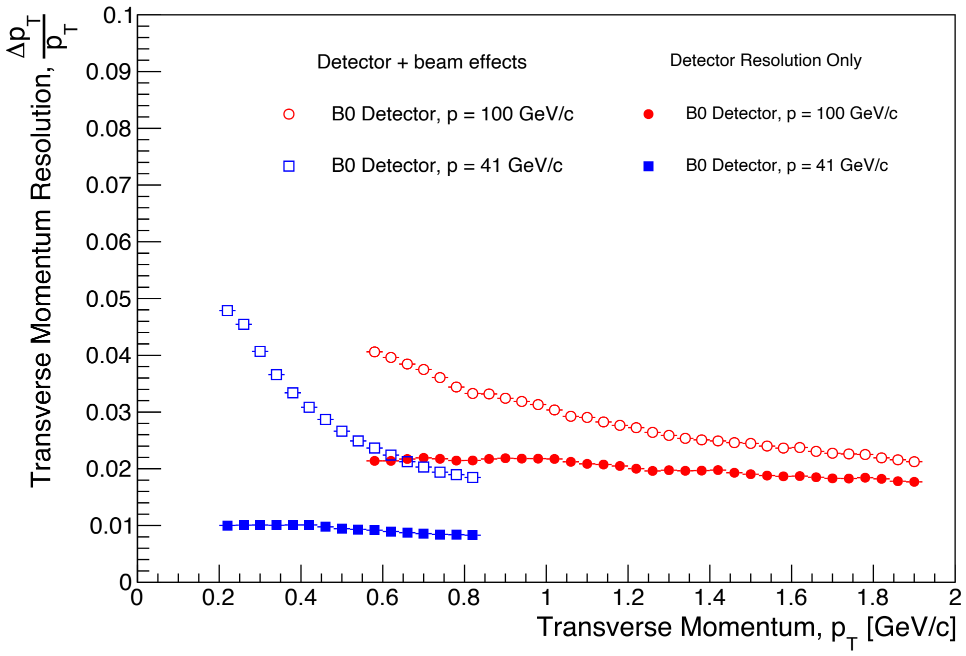
✓ **Tracker for charged particles**: High granularity detectors needed in this area with layers of fast-timing detectors due required p_T, beam effects, high background.

✓ B0-dipole length is ca 1.5m

✓ Combination of MAPS for spatial resolution and AC-LGADs for timing spaced evenly by 30cm inside (~20 cm in diameter)







For photon detection: A simple photon tagger or EMCAL (for energy measurements) will be needed. As an example: for $\gamma + \gamma$ from π^0 separation to clearly isolate u-channel DVCS

➡ $PbWO_4$ (11.2 r.l.) behind the tracking layers: each 10 cm long with a surface area of 2x2 cm^2 (ECCE)

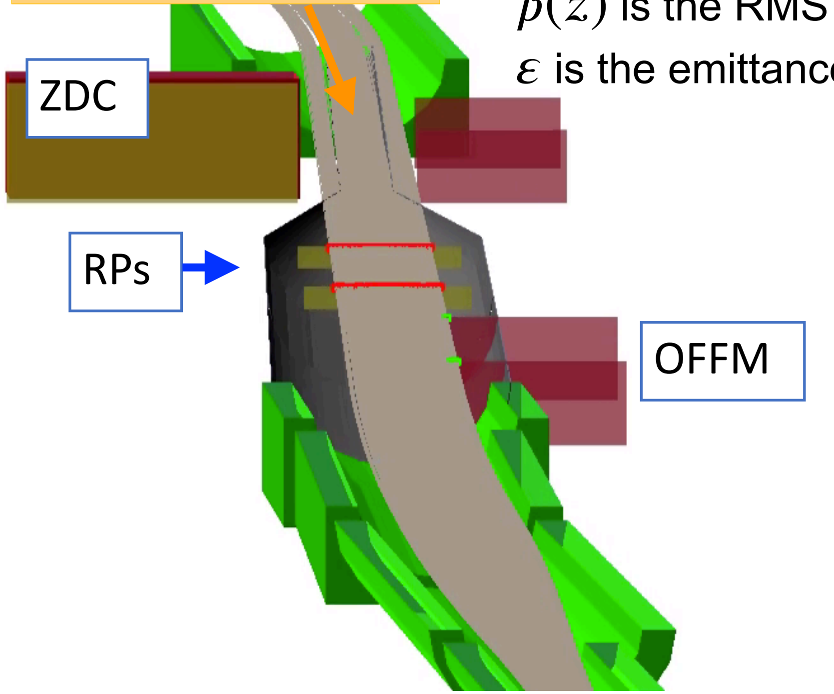
➡ or 2 radiations lengths of **Pb converter**, followed by a layer of **AC-LGADs** (ATHENA)

=> Work in progress

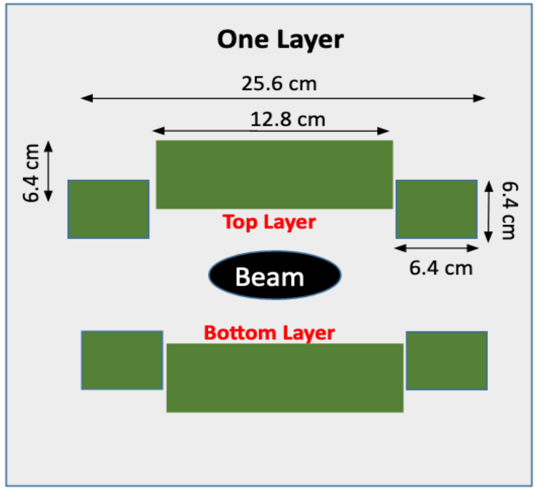
Roman-Pots

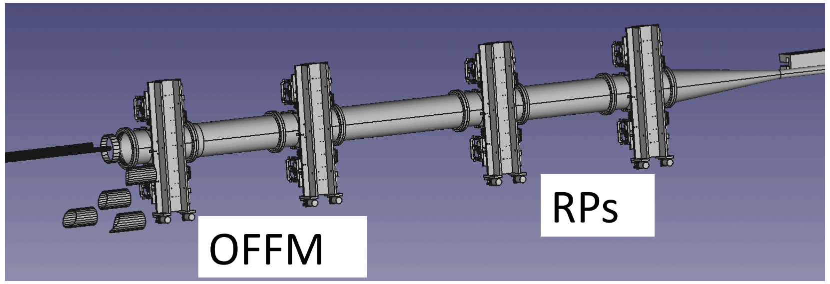
0.0* (10σ cut) < θ < 5.0 mrad $\quad \sigma(z) = \sqrt{\varepsilon \bullet \beta(z))}$

Geant4 setup:
5mrad particle cone



$\sigma(z)$ is the Gaussian width of the beam,
$\beta(z)$ is the RMS transverse beam size.
ε is the emittance.





- ✓**Movable** (as close as 10σ away from the beam (depends on beam energy and beam configuration: high divergence or high acceptance).
- ✓Move out during an injection.
- ✓RPs needs to be **integrated into the vacuum system**
- ✓Insertion from top and bottom - need to minimize space in front of ZDC.
- ✓Preliminary concept of a mechanical setup.
- ✓**Very close contact with accelerator** to avoid negative impacts on the machine operation

Roman-pots resolution

Alex Jentsch

- The various contributions add in quadrature (this was checked empirically, measuring each effect independently).

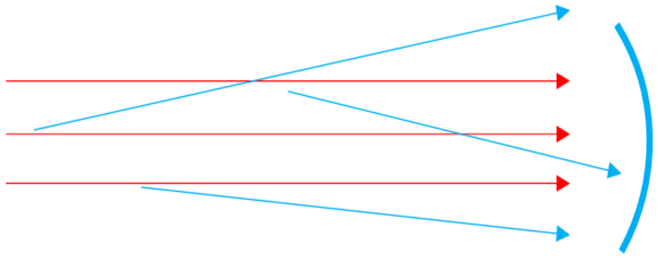
$$\Delta p_{t,total} = \sqrt{\underbrace{(\Delta p_{t,AD})^2}_{\text{Angular divergence}} + \underbrace{(\Delta p_{t,CC})^2}_{\text{Primary vertex smearing from crab cavity rotation.}} + \underbrace{(\Delta p_{t,pxl})^2}_{\text{Smearing from finite pixel size.}}}$$

These studies based on the "ultimate" machine performance with strong hadron cooling.

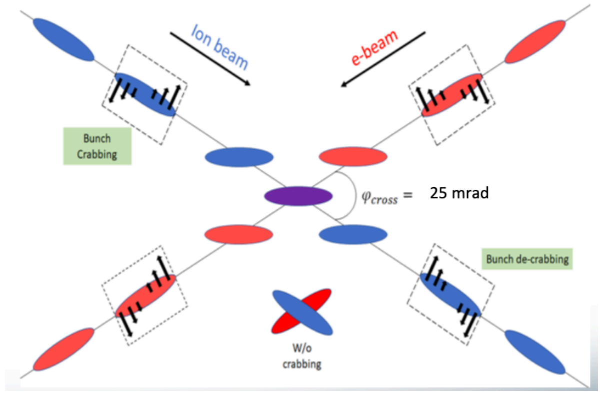
	Ang Div. (HD)	Ang Div. (HA)	Vtx Smear	250um pxl	500um pxl	1.3mm pxl
$\Delta p_{t,total}$ [MeV/c] - 275 GeV	40	28*	20	6	11	26
$\Delta p_{t,total}$ [MeV/c] - 100 GeV	22	11	9	9	11	16
$\Delta p_{t,total}$ [MeV/c] - 41 GeV	14	-	10	9	10	12

- **Beam angular divergence**
  - Beam property, can't correct for it – sets the lower bound of smearing.
  - Subject to change (i.e. get better) – beam parameters not yet set in stone
    - *using symmetric divergence parameters in x and y at 100urad.
- **Vertex smearing from crab rotation**
  - Correctable with good timing (~35ps).
  - With timing of ~70ps, effective bunch length is 2cm ->.25mm vertex smearing (~7 MeV/c)
- **Finite pixel size on sensor**
  - 500um seems like the best compromise between potential cost and smearing

Angular divergence

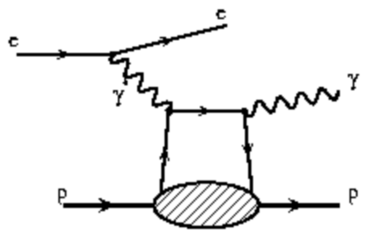


Primary vertex smearing from crab cavity rotation

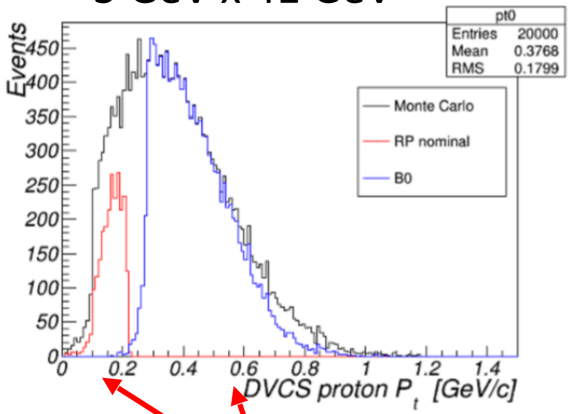


Forward proton acceptance

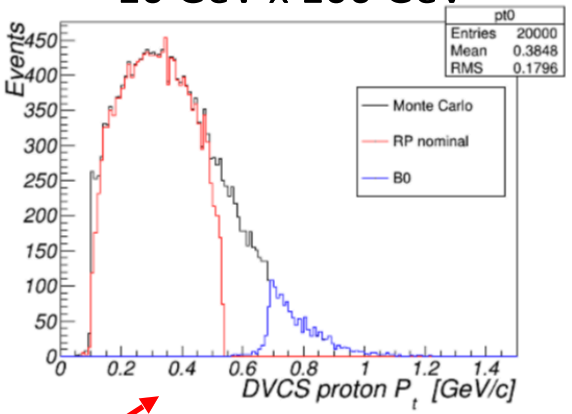
Alex Jentsch



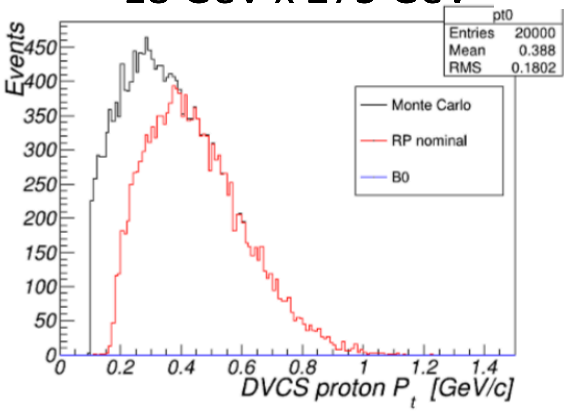
5 GeV x 41 GeV



10 GeV x 100 GeV



18 GeV x 275 GeV

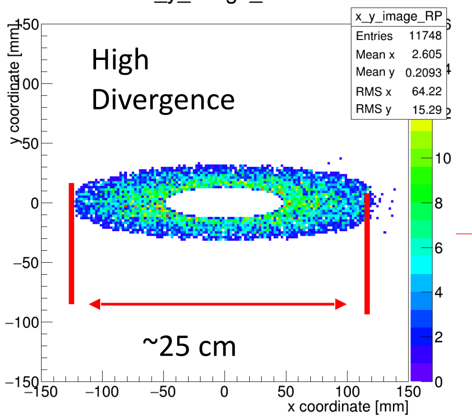


Need both detector systems together here!

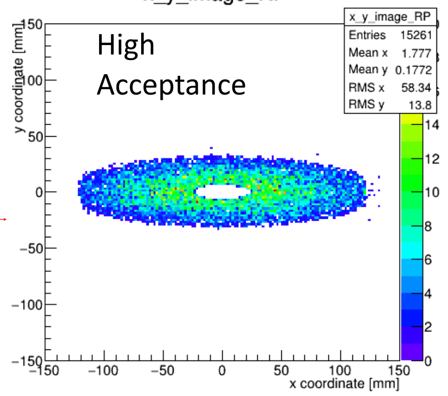
High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

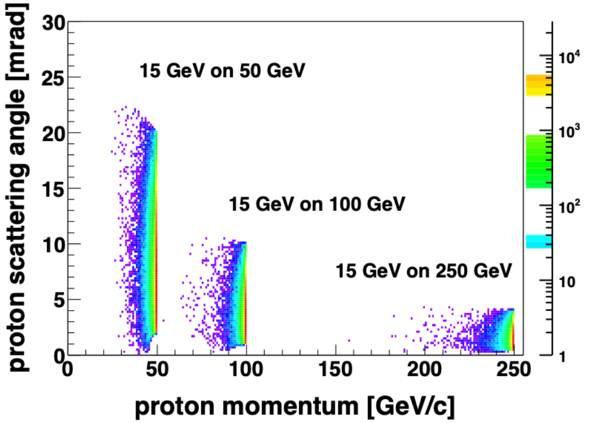
High Acceptance: larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

x_y_image_RP



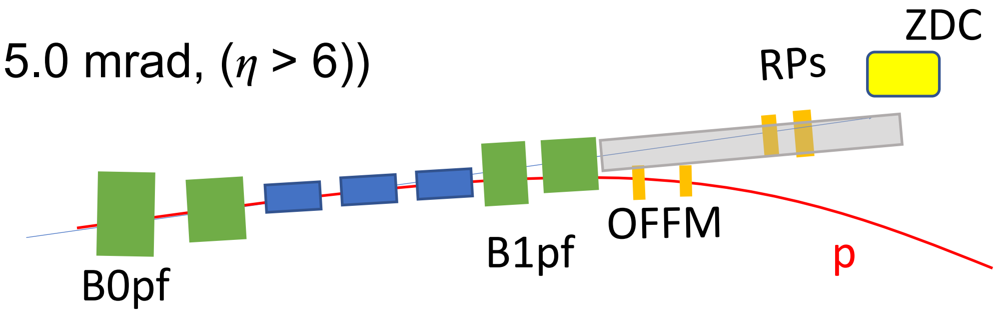
x_y_image_RP

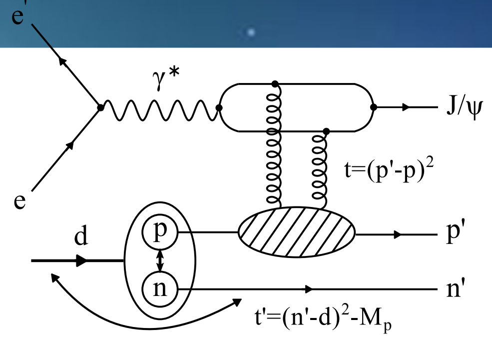




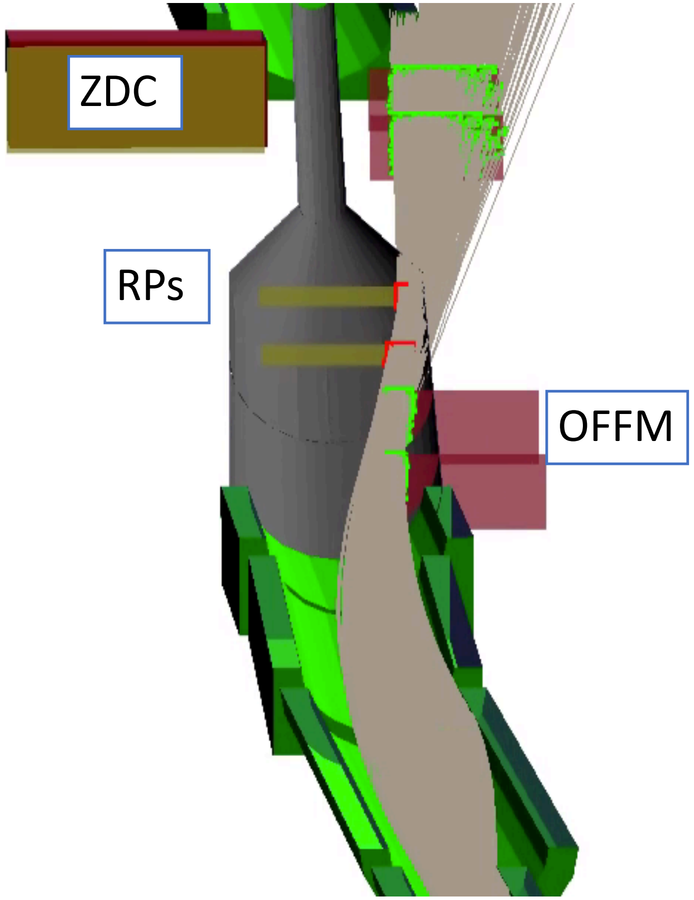
Off-momentum detectors

(0.0 < θ < 5.0 mrad, (η > 6))



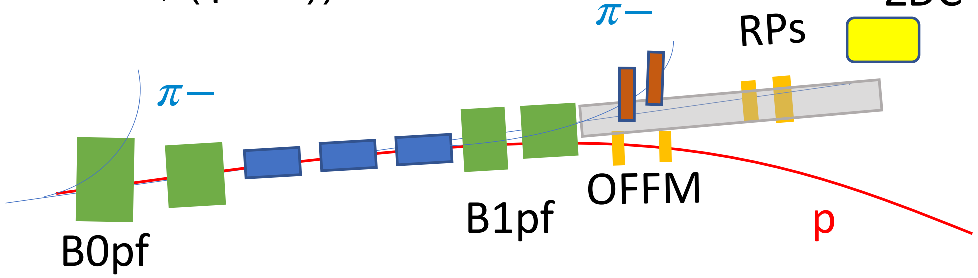


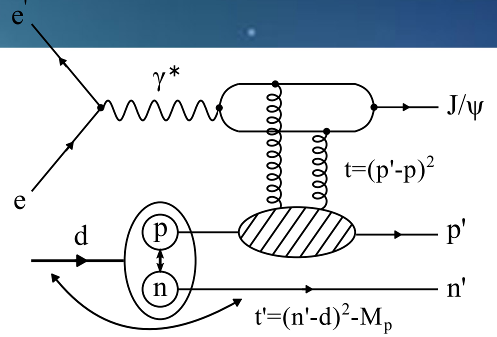
- Protons that come from nuclear breakup have a different magnetic rigidity than their respective nuclear beam (x_L<1)
- This means the protons experience more bending in the dipoles.
- As a result, small angle (Θ < 5mrad) protons from these events will not make it to the Roman Pots, and will instead exit the beam pipe after the last dipole.
- Detecting these requires "off-momentum detectors".
- Movable, beam pipe integration.



Off-momentum detectors

(0.0 < θ < 5.0 mrad, (η > 6))



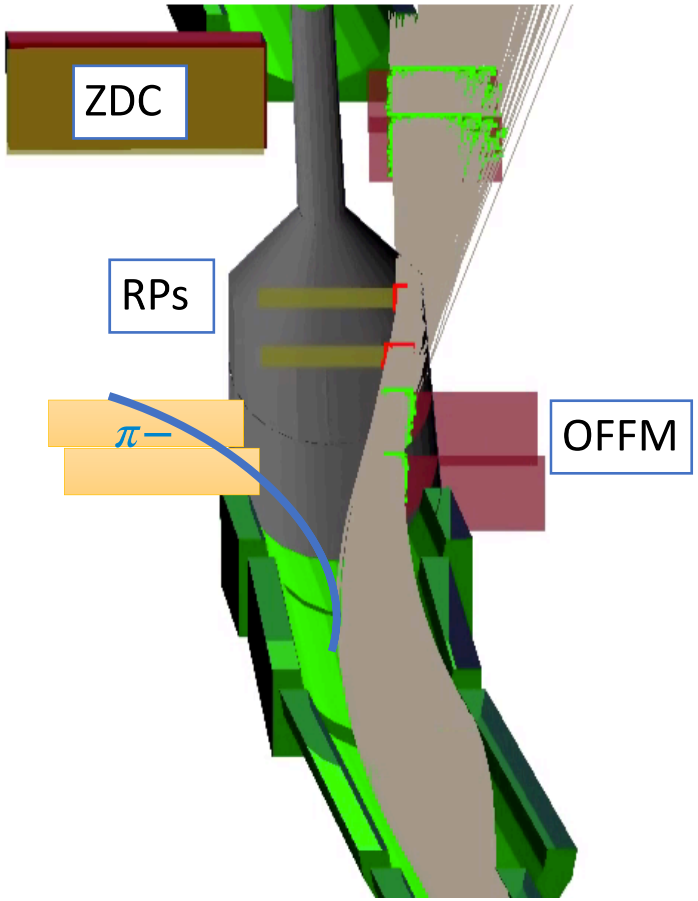


e p -> (K) -> e' + Λ + X

↳ p + $\pi-$(Br~64%)

➢ Detecting Lambda's decays in the target fragmentation area is very hard, due to a very large decay length (meters).

➢ Would require in addition detection of negative charged particles (pi-) at the OFF-momentum detector location



Zero Degree Calorimeter (ZDC)

For detection of neutrons and photons

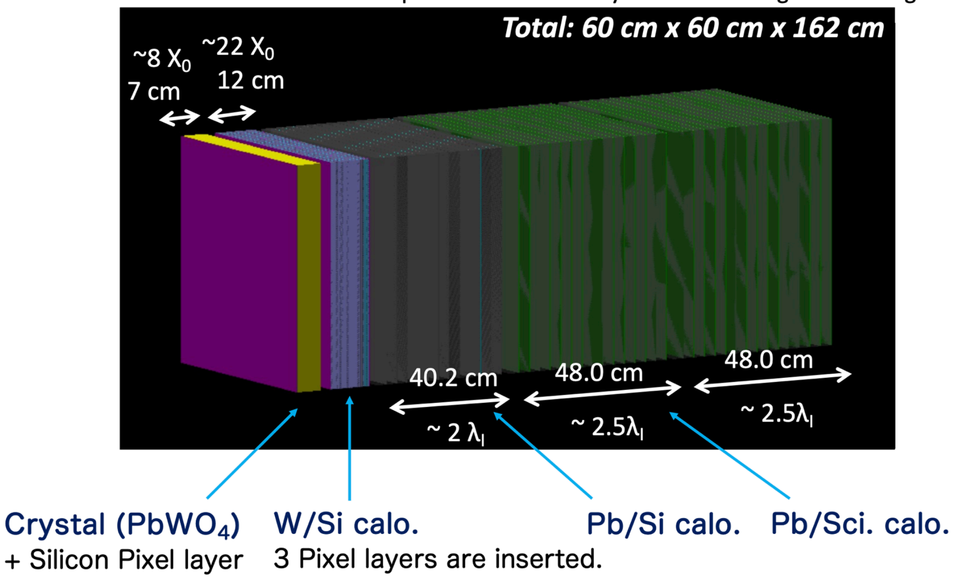
Acceptance:

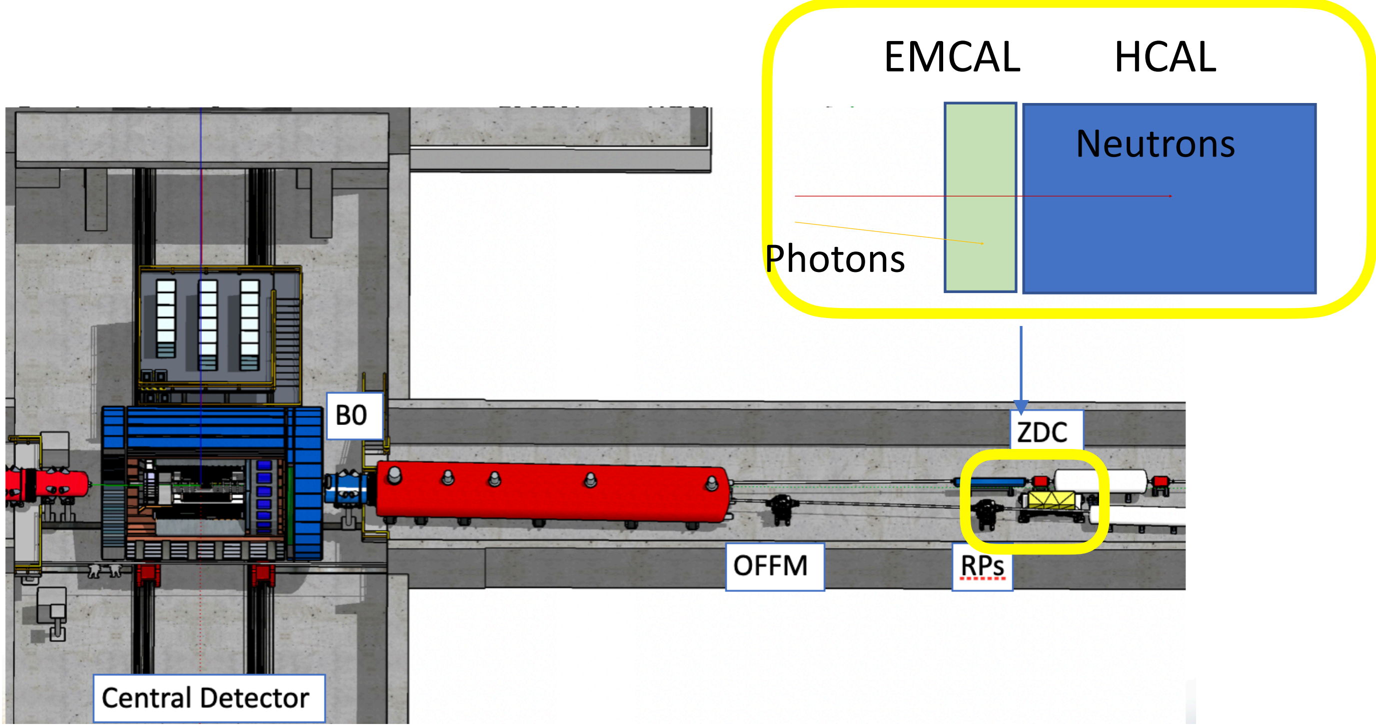
0<θ<5.5 mrad

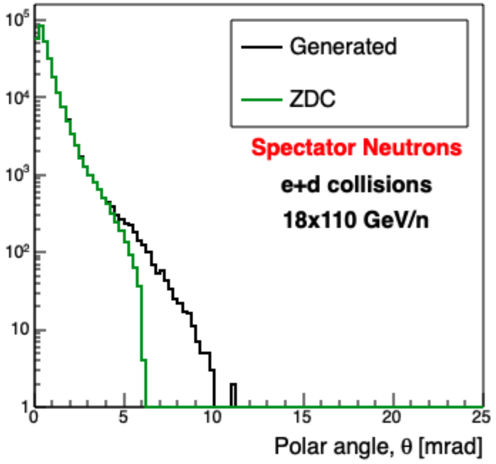
(Limited by bore of magnet where the neutron cone has to exit)

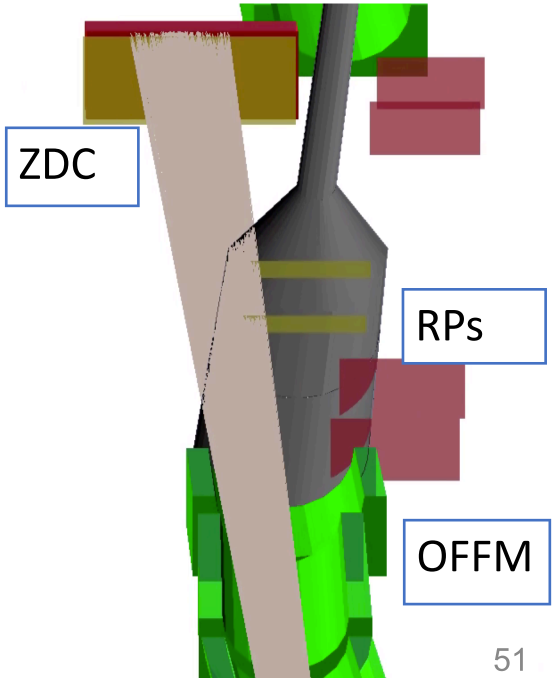
High resolution ZDC, based on ALICE FoCAL

*note: space for readout may extend the longitudinal length.

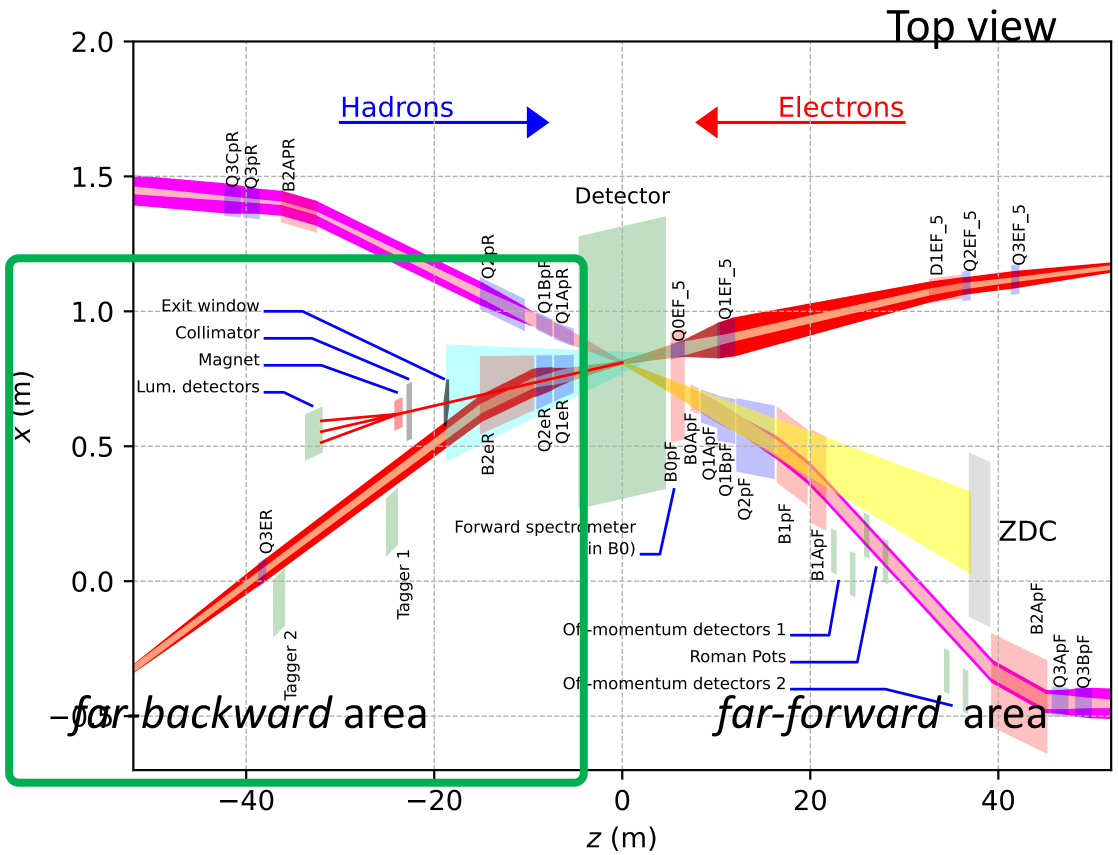








Far-backward (electron-going) region



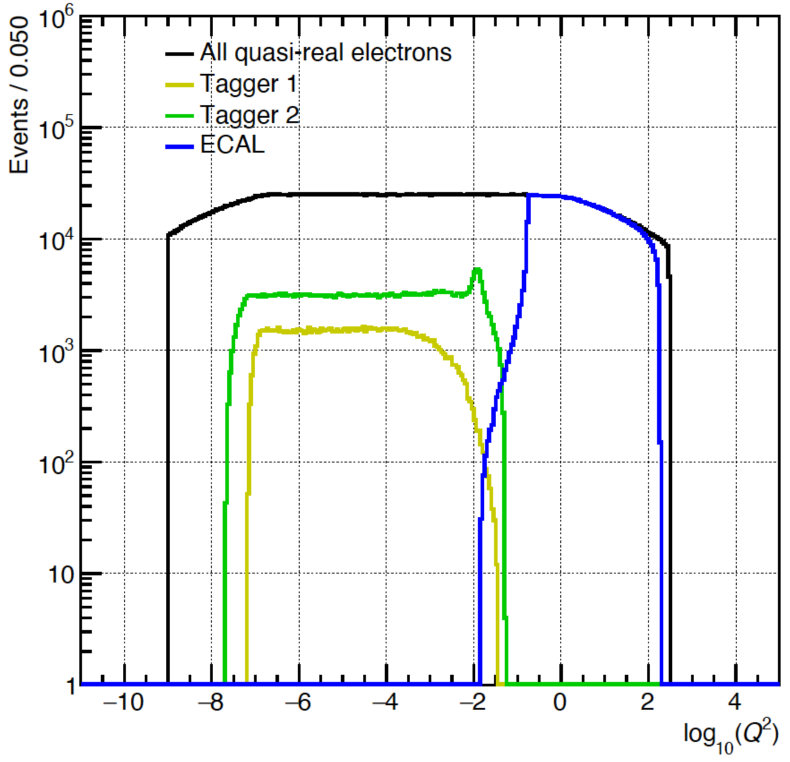
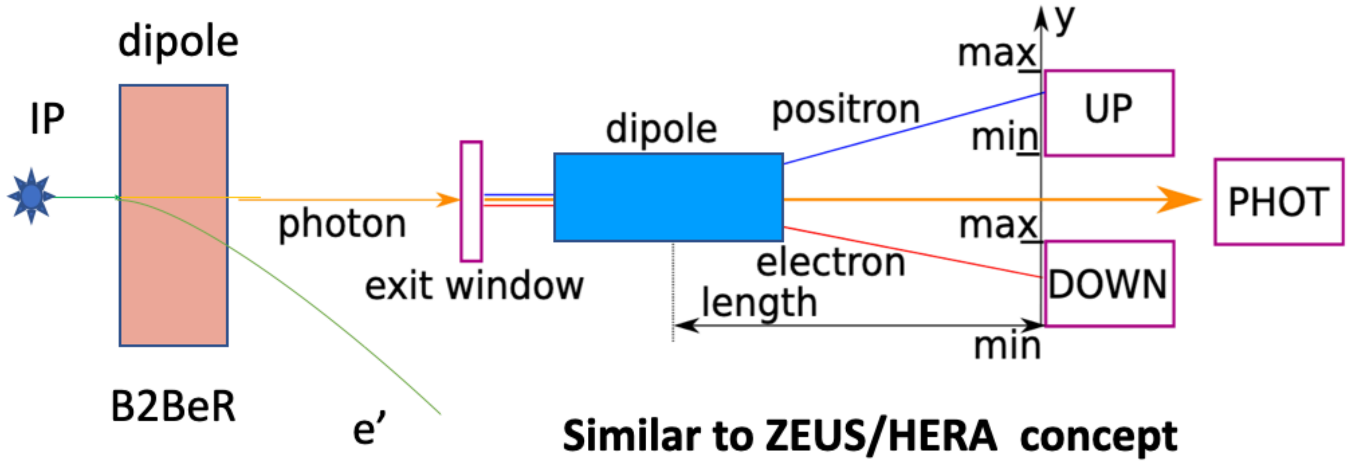
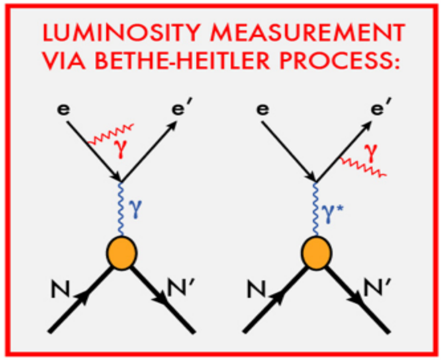


FIG. 16: Coverage in Q^2 for tagger detectors and ECAL.

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

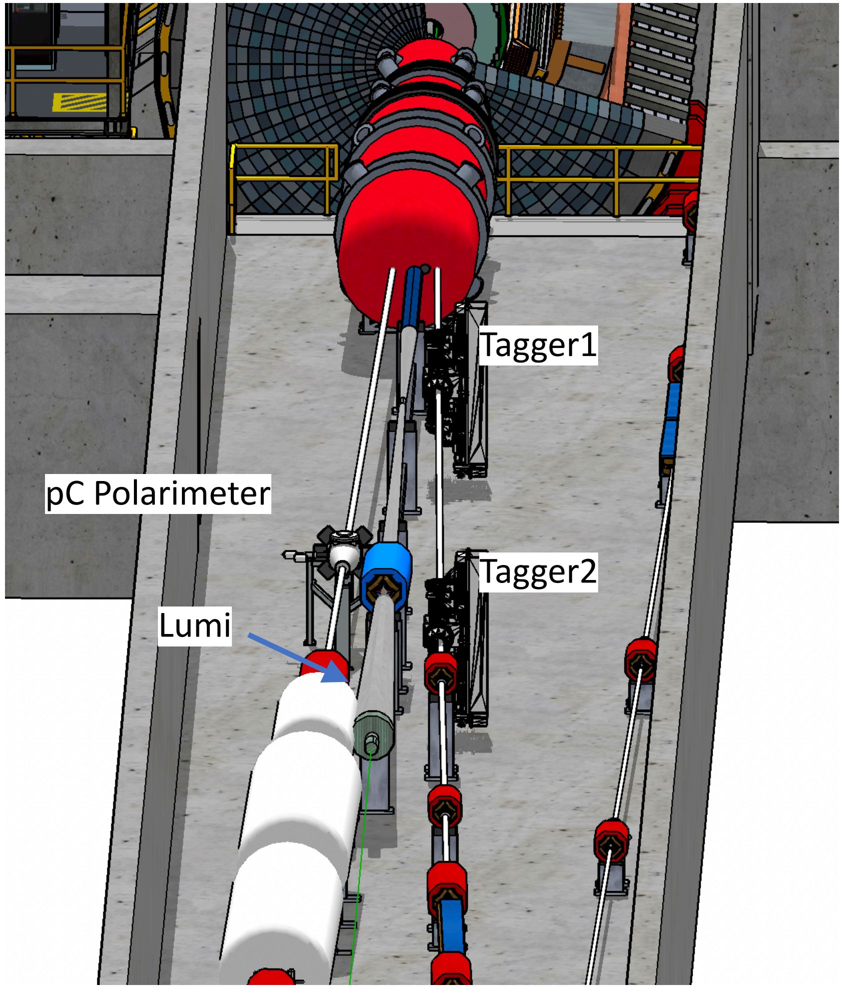
Luminosity monitor





Goals for Luminosity Measurement:
Integrated luminosity with precision δL/L< 1%

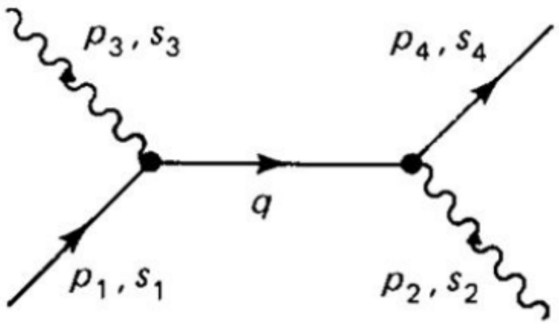
- ➢ Luminosity measurements via Bethe-Heitler process
- ➢ Photons from IP collinear to e-beam
- ➢ First dipole bends electrons
- ➢ Photon conversion to e-/e+ pair
- ➢ Pair-spectrometer
- ➢ Synchrotron photons collimation scheme needs to be further refined



Electron polarization measurements

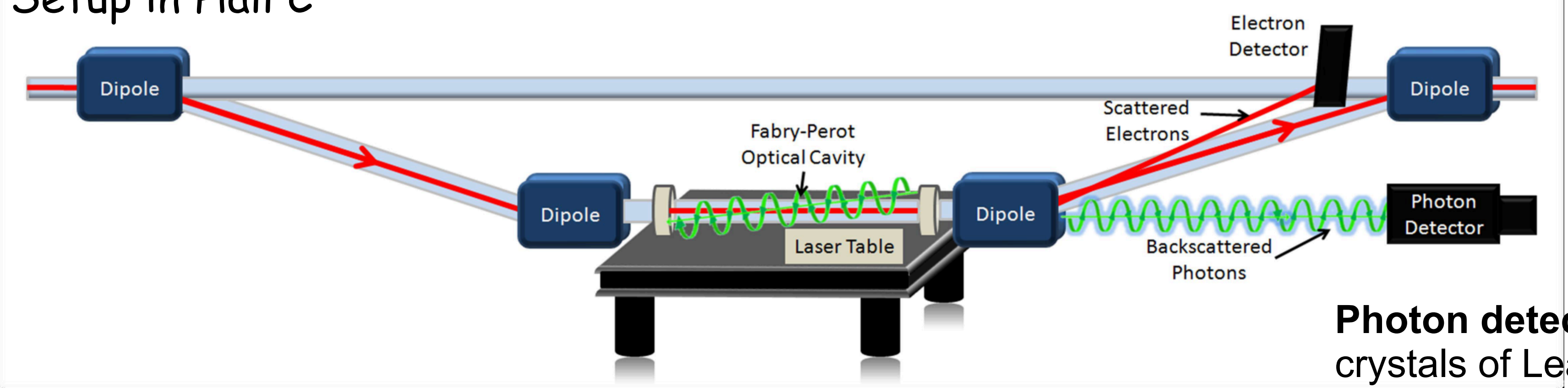
Compton polarimeter:

- Used to determine a polarization of electron beam
- Incoming photons scatters off electron



Compton Scattering

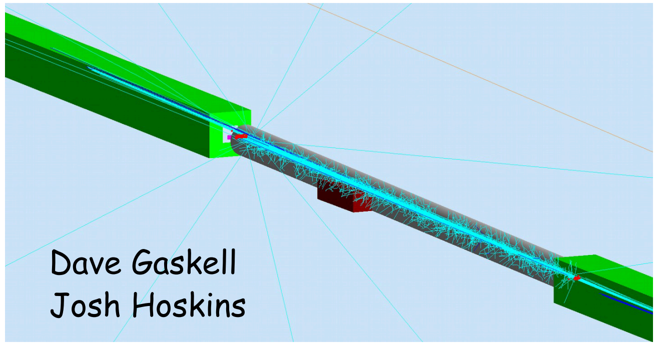
Setup in Hall C



Photon detector (calorimeter) a matrix of four crystals of Lead Tungstate (P bW O_4) scintillating crystals with dimensions of 3 × 3 × 20 cm to detect the backscattered photons.

~1% electron beam polarization measurements

Simulation for EIC is ongoing



Electron detector (Diamond micro-strip detector)

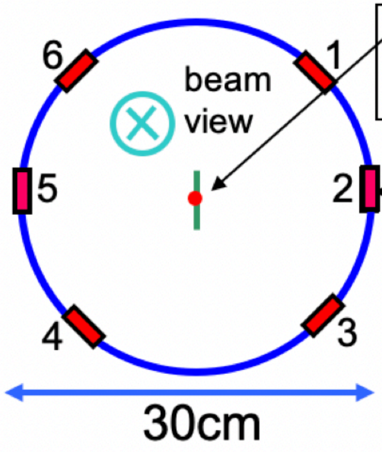
The detectors are made from 21 mm× 21 mm × 0.5 mm plates of Chemical Vapor Deposition (CVD) diamond . Each diamond plate has 96 horizontal metallized electrode strips with a pitch of 200 μm

Hadron Polarization (RHIC, EIC)

Elke Aschenauer
Vadim Ptitsyn

Existing p Polarization in RHIC achieved with “Siberian snakes”
• Near term improvements will increase proton polarization in RHIC from 60% to 80%

Polarimetry exploits left-right asymmetry in elastic scattering due to spin orbit interaction

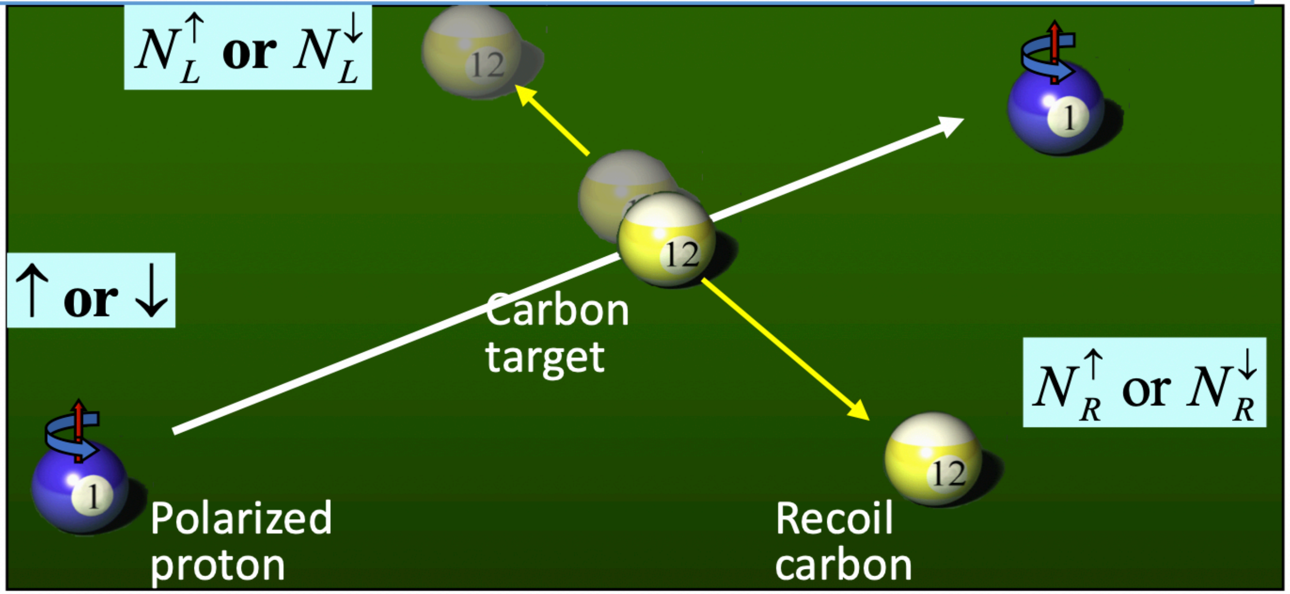


Ultra-thin carbon ribbon target ~ 100 mono-layers think, 10μm wide

Si strip detectors for recoil carbon (TOF, E_C)

$$p^{\uparrow}C \to p^{\uparrow}C$$

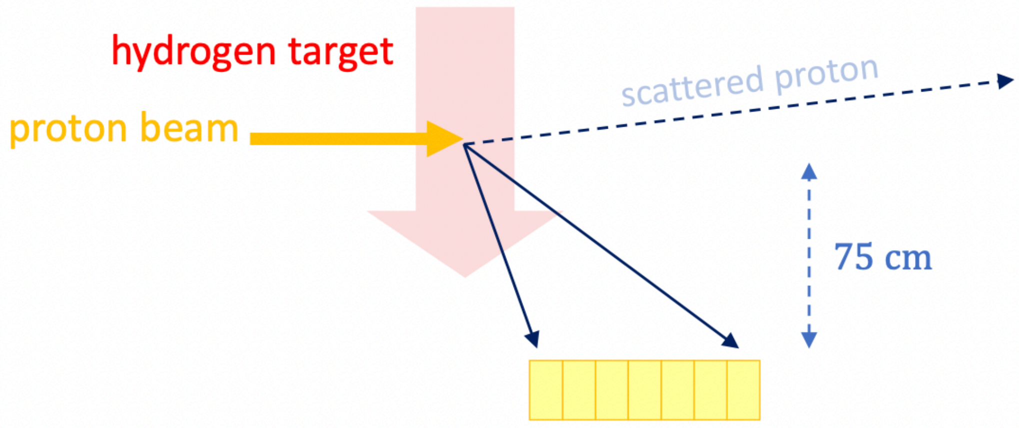
$$P_B = \frac{\varepsilon_{LR}}{A_N}, \quad \varepsilon_{LR} = \frac{N_L - N_R}{N_L + N_R}$$

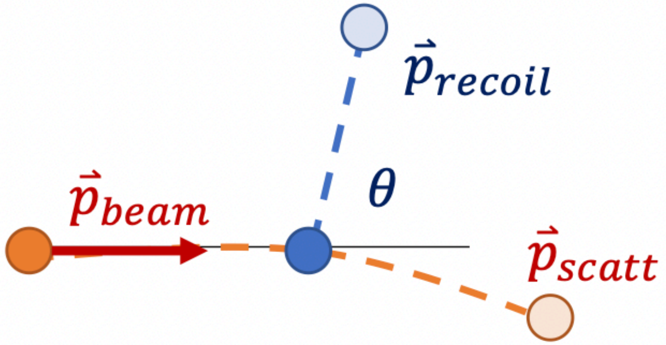


• Proton-Carbon Polarimeter (pC): very fast and high precision, but needs to be normalized

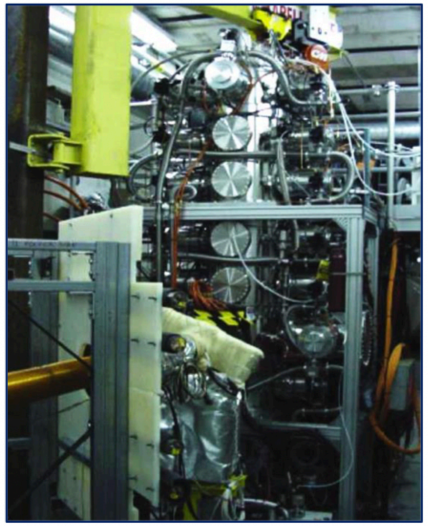
Hadron Polarization (RHIC, EIC)

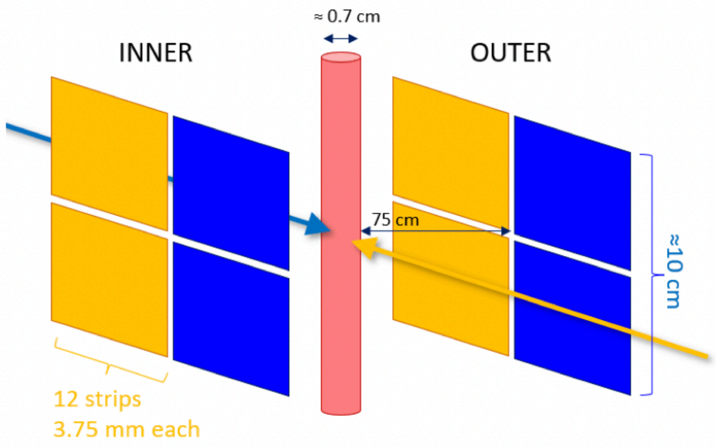
K. Oleg Eyser





HJET: Polarized atomic hydrogen jet target





- Polarized hydrogen Jet Polarimeter (HJet): absolute polarization, but slow.

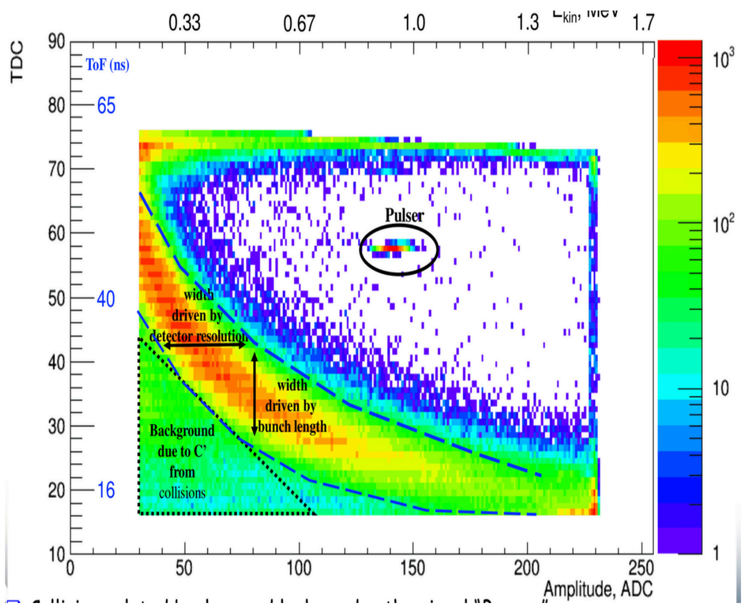
Hadron Polarization

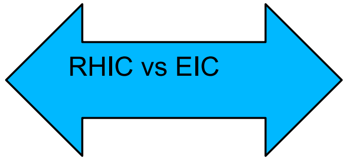
Elke Aschenauer

Hadron polarimetry at EIC

At RHIC:

- Polarized hydrogen Jet Polarimeter (HJet): absolute polarization, but slow.
- Proton-Carbon Polarimeter (pC): very fast and high precision, but needs to be normalized

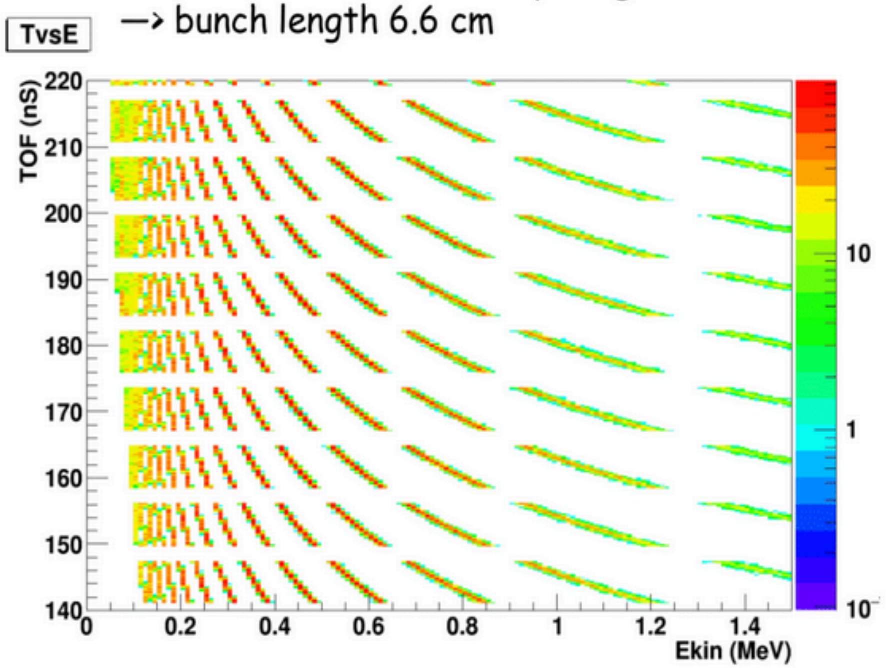




BUT EIC is not RHIC!

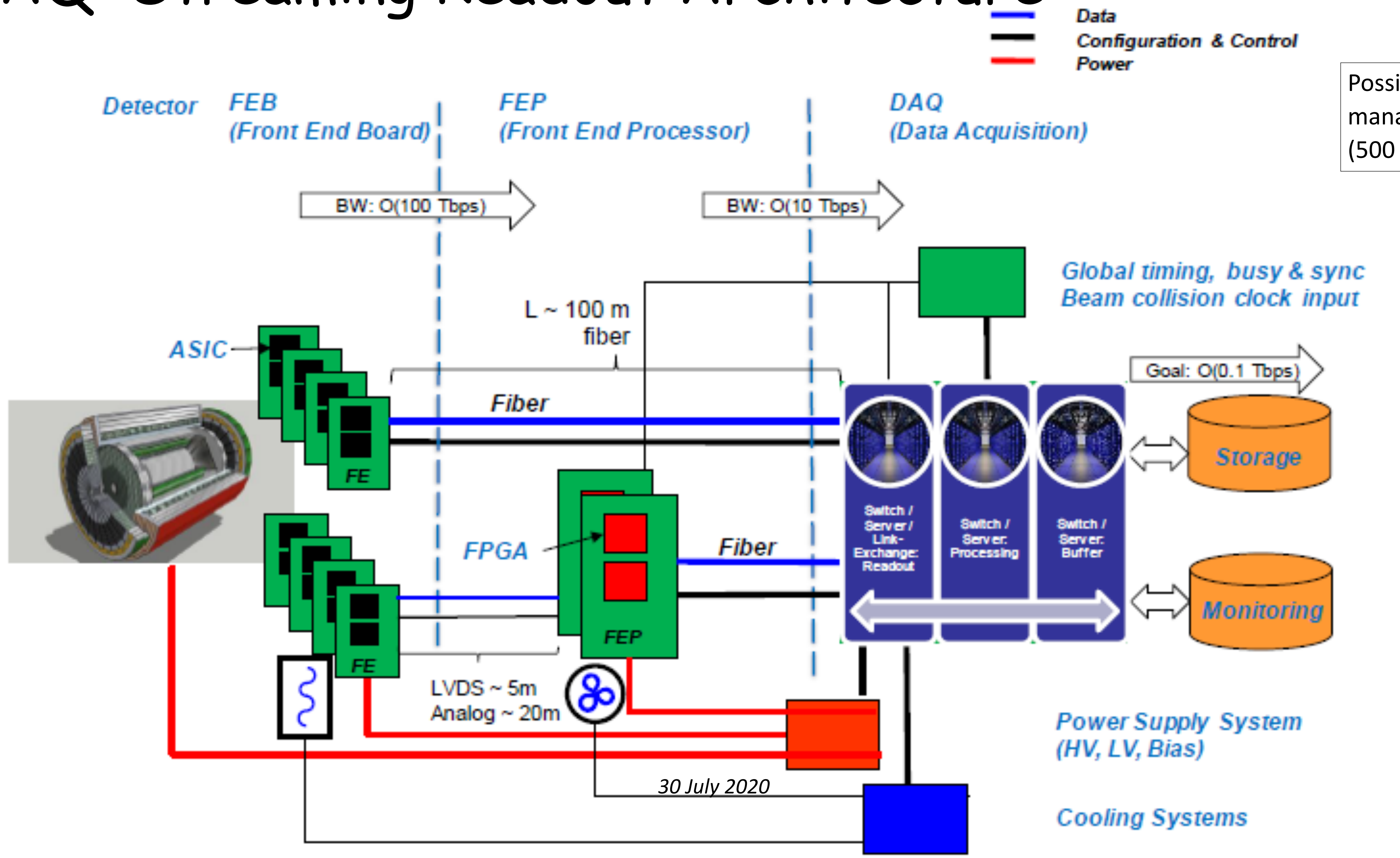
- Higher bunch frequency and current.
- Background?

1320 bunches —> bunch spacing 8.7 ns
—> bunch length 6.6 cm



New detector technology (fast ~ 10ps Si?)
Reduce TOF ?
Polarized D and He-3

DAQ: Streaming Readout Architecture



Possible at EIC as data rates manageable
(500 kHz, O(100) Gbps)

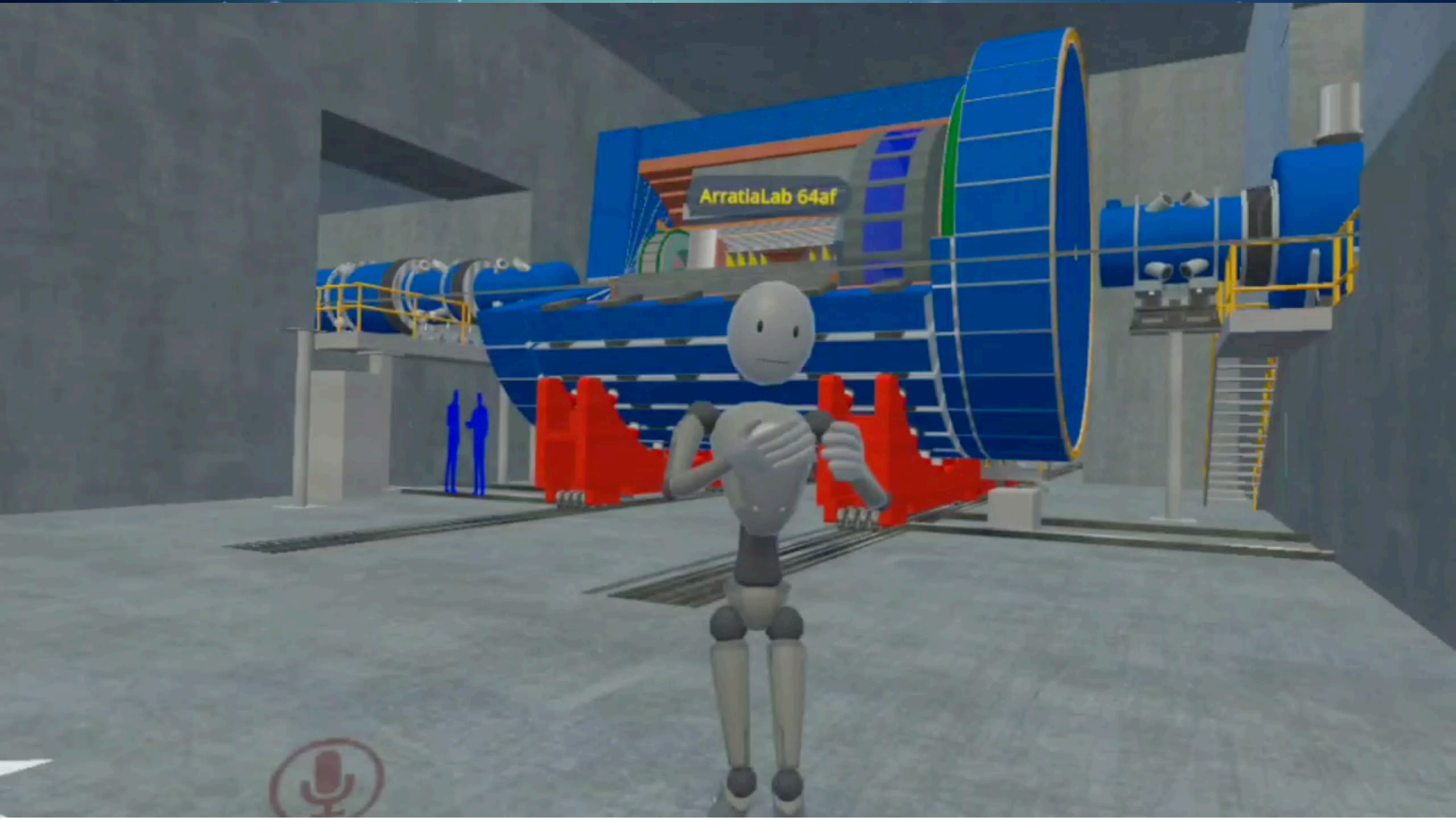
30 July 2020

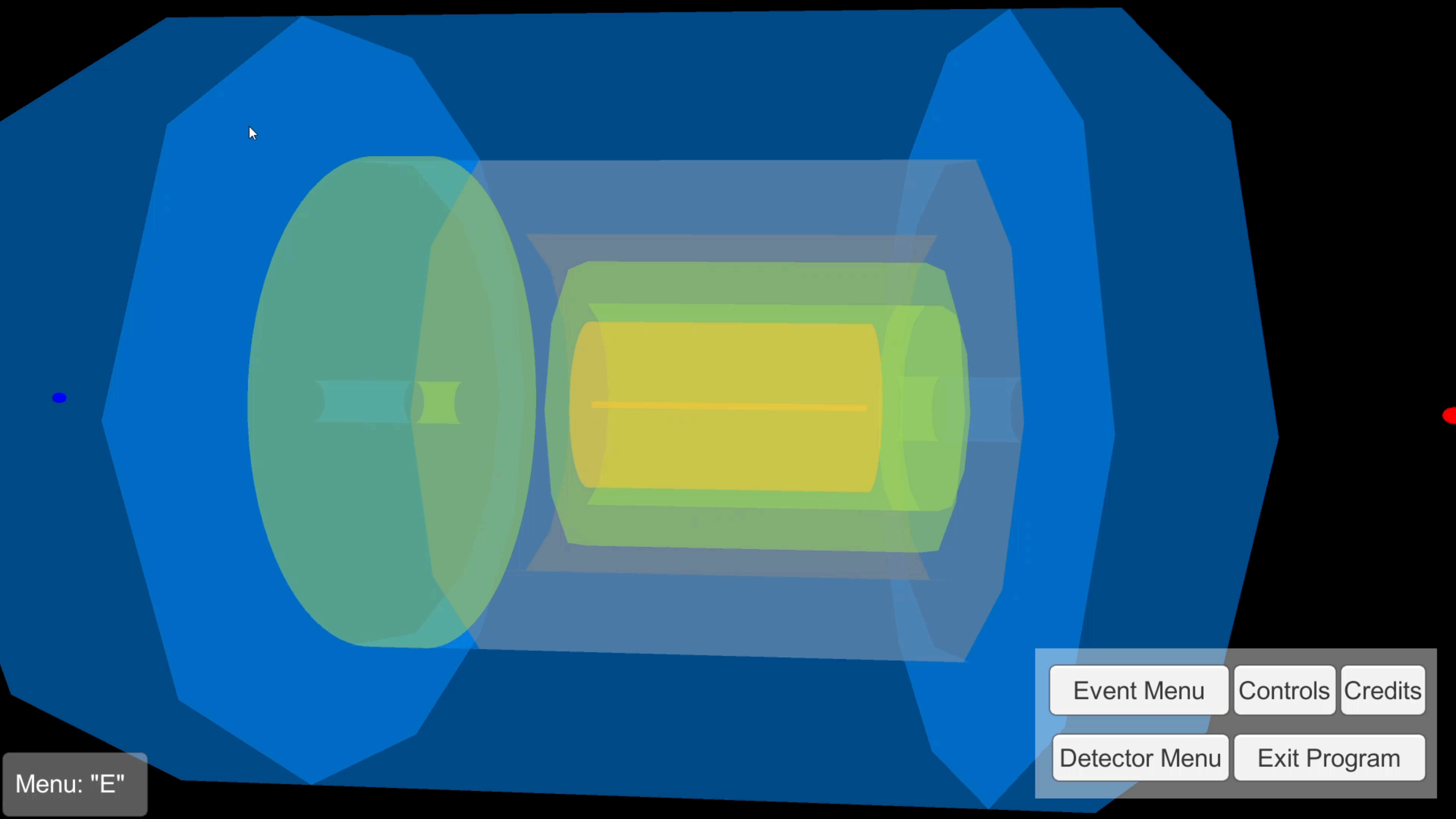
Summary

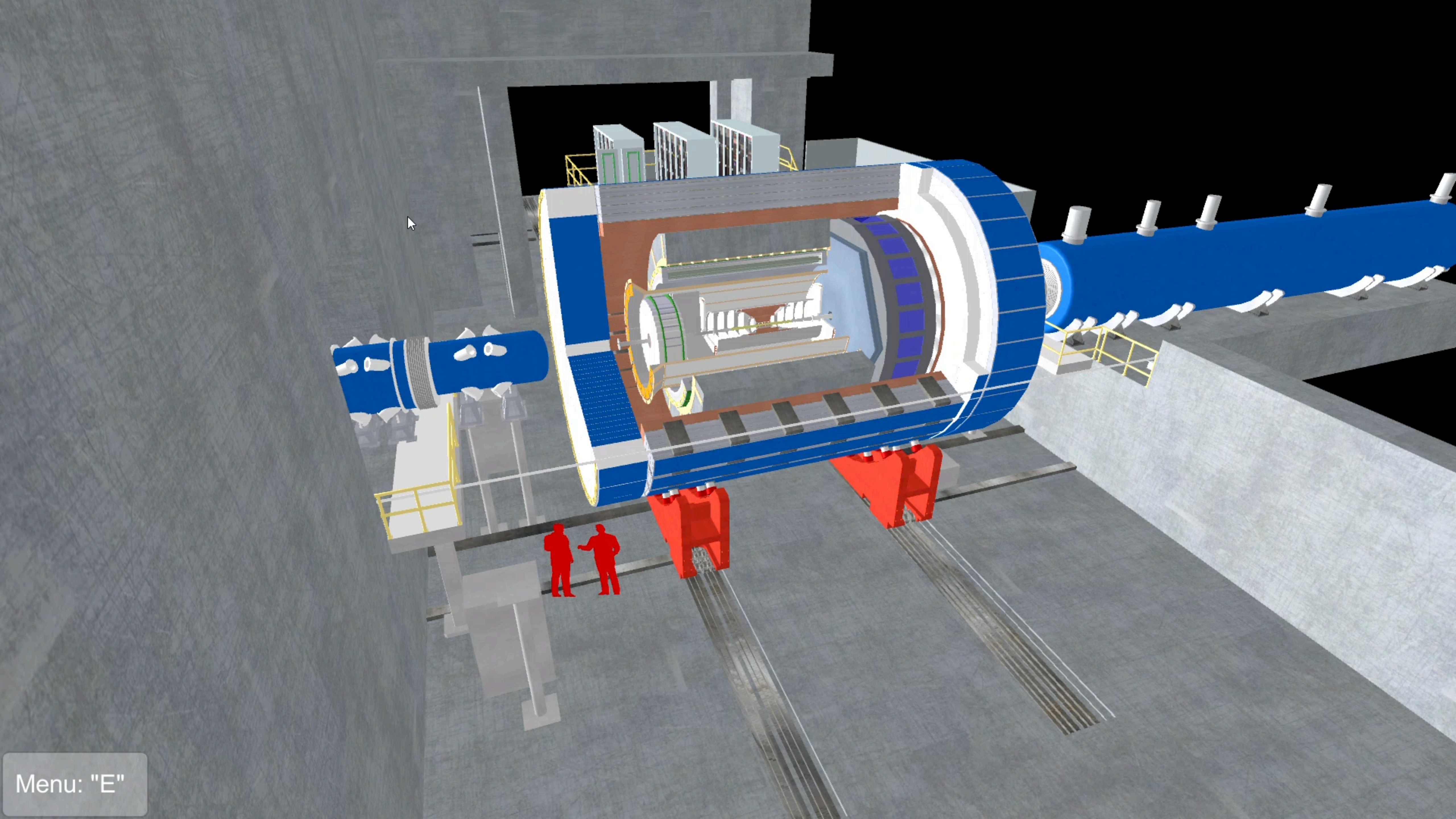
- The EIC detector had a physics-driven design
- It is a general purpose detector.
- It is also a balance between the reuse of equipment, the mature state of art technology and detector technologies that are at the near-end of an extensive R&D effort
- AI was used to optimize detector choices, locations, and materials.
- We are continue to improve the design on the way to CD2

Following movies are made by Miguel Arratia and **Sean Preins**

Backup


ArratiaLab 64af

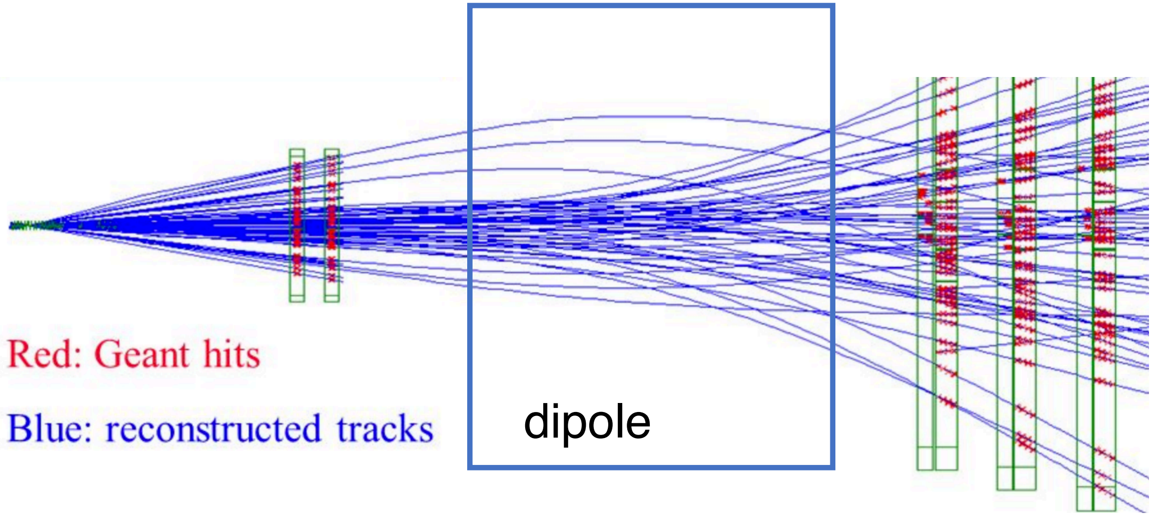

Event Menu
Controls
Credits
Detector Menu
Exit Program
Menu: "E"

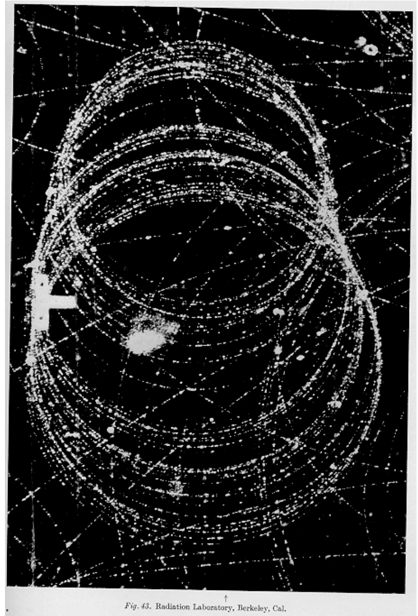

Menu: "E"

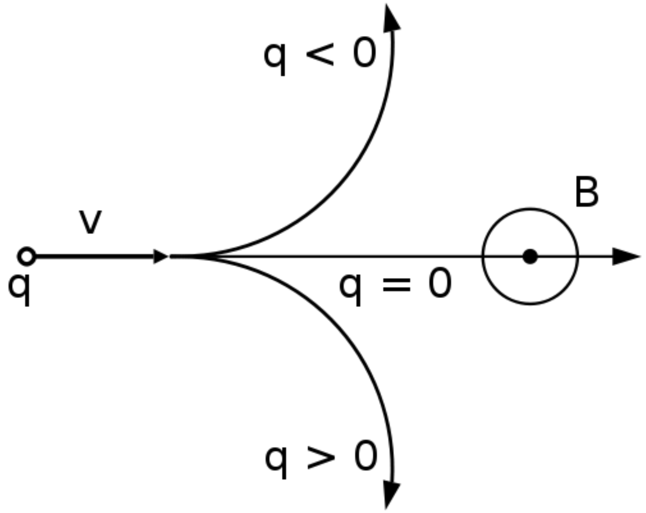
Why do we need a magnetic field?

-bending radius depends on a particle momentum
-charge (right, left)

$$\boxed{p[GeV] = 0.3 \cdot B\,[T] \cdot R\,[m]}$$







Electron in a magnetic field at the Bevatron, 1940

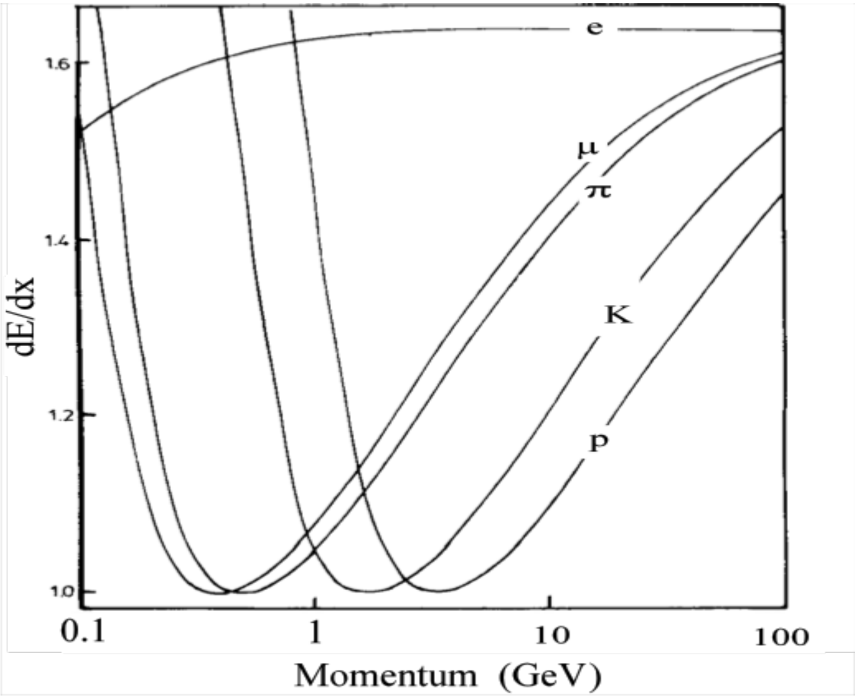
Yulia Furletova

Energy loss

Most tracking detectors are ionization detectors

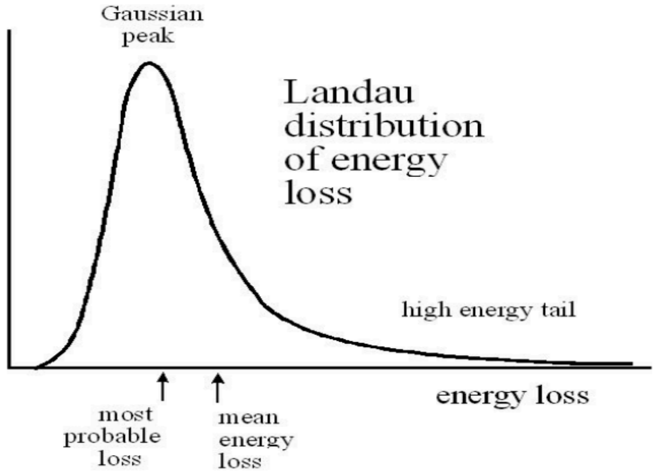
$$-\left\langle \frac{dE}{dx} \right\rangle = K \boxed{\frac{Z}{A}} \rho \boxed{\frac{z^2}{\beta^2}} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} - \frac{C(\beta\gamma, I)}{Z} \right]$$

same curve plotted vs. momentum for different particles => could be used for PID

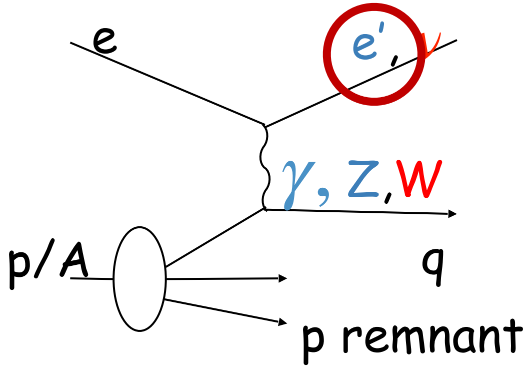


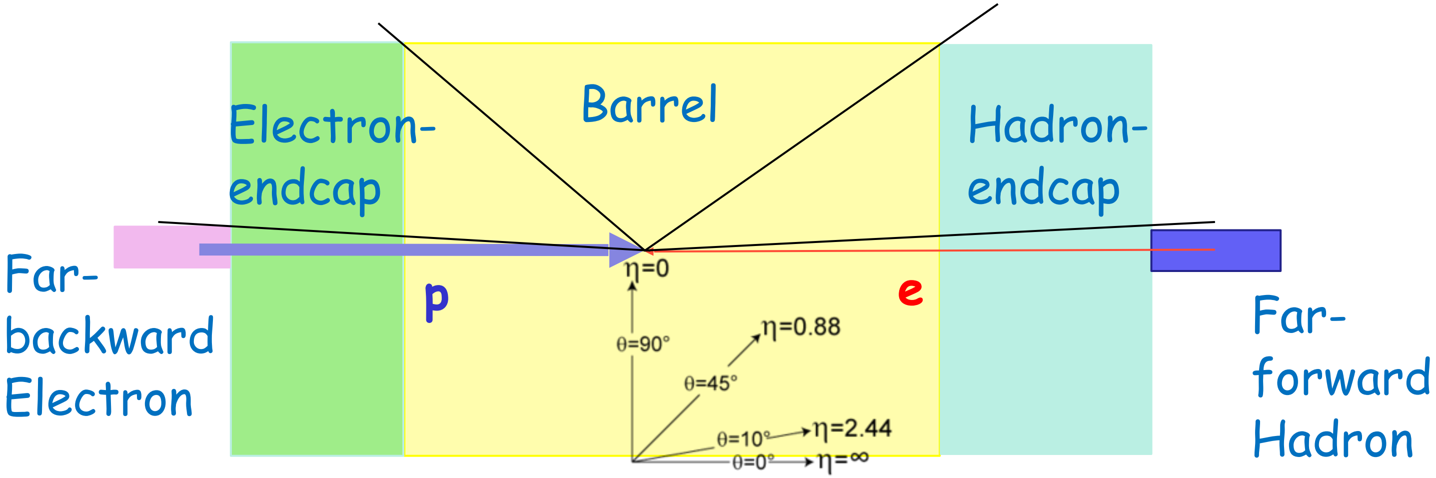
- Examples of typical energy loss at minimum ionizing:
  - ✓ 1 meter air: 0.22 MeV
  - ✓ 300μm Si: 0.12 MeV
  - ✓ 1mm iron: 1.1 MeV

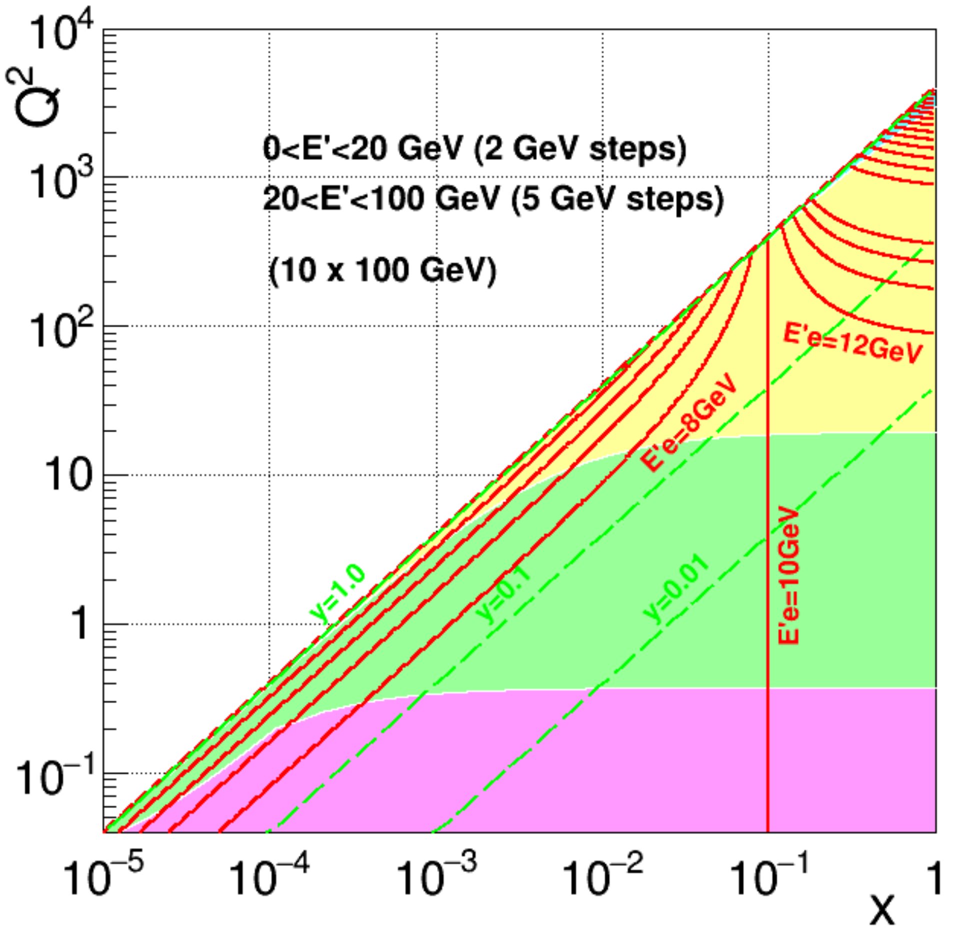
- Energy loss is a stochastic process (app described by Landay distribution) with infinitely" long tail.



Why endcaps and forward areas are important at EIC?





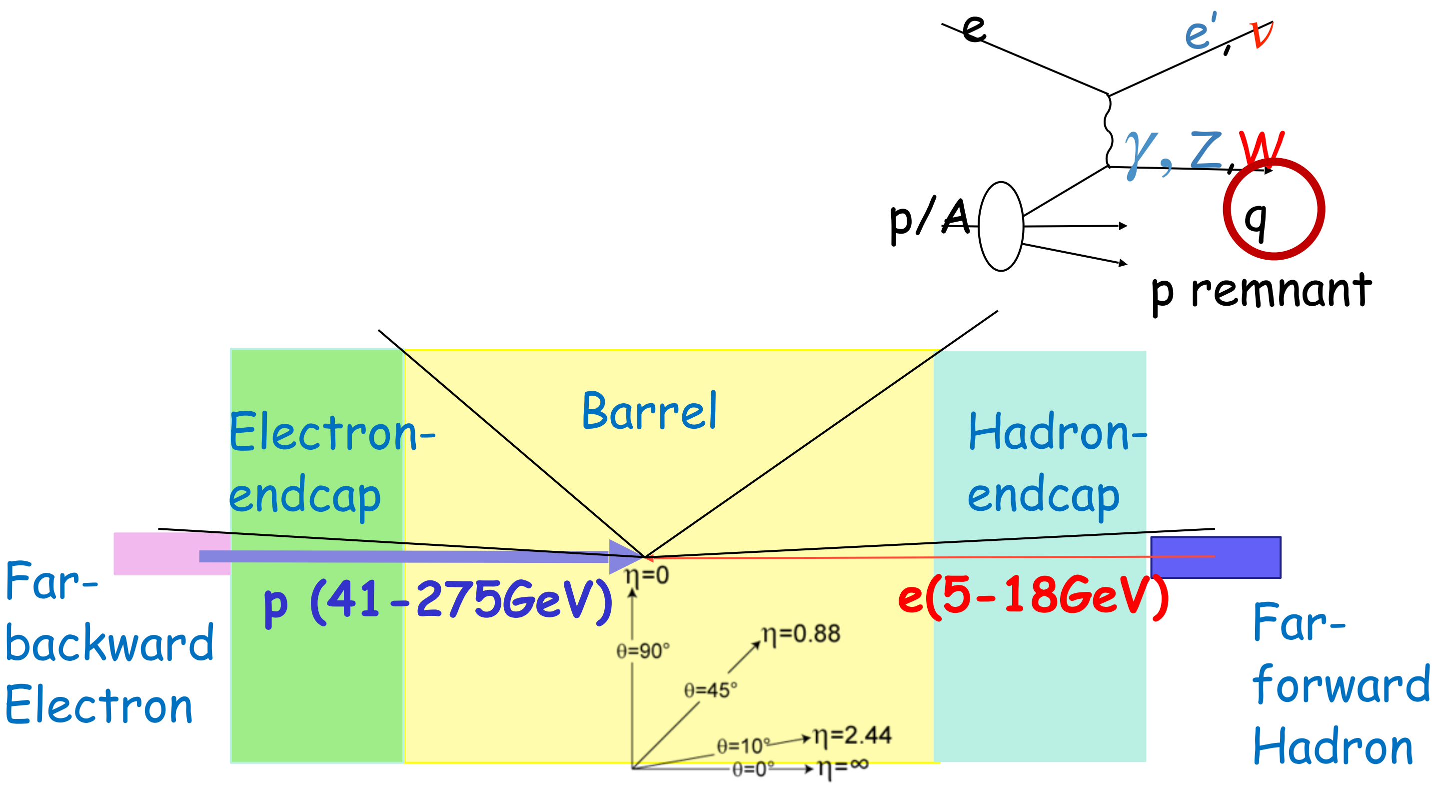


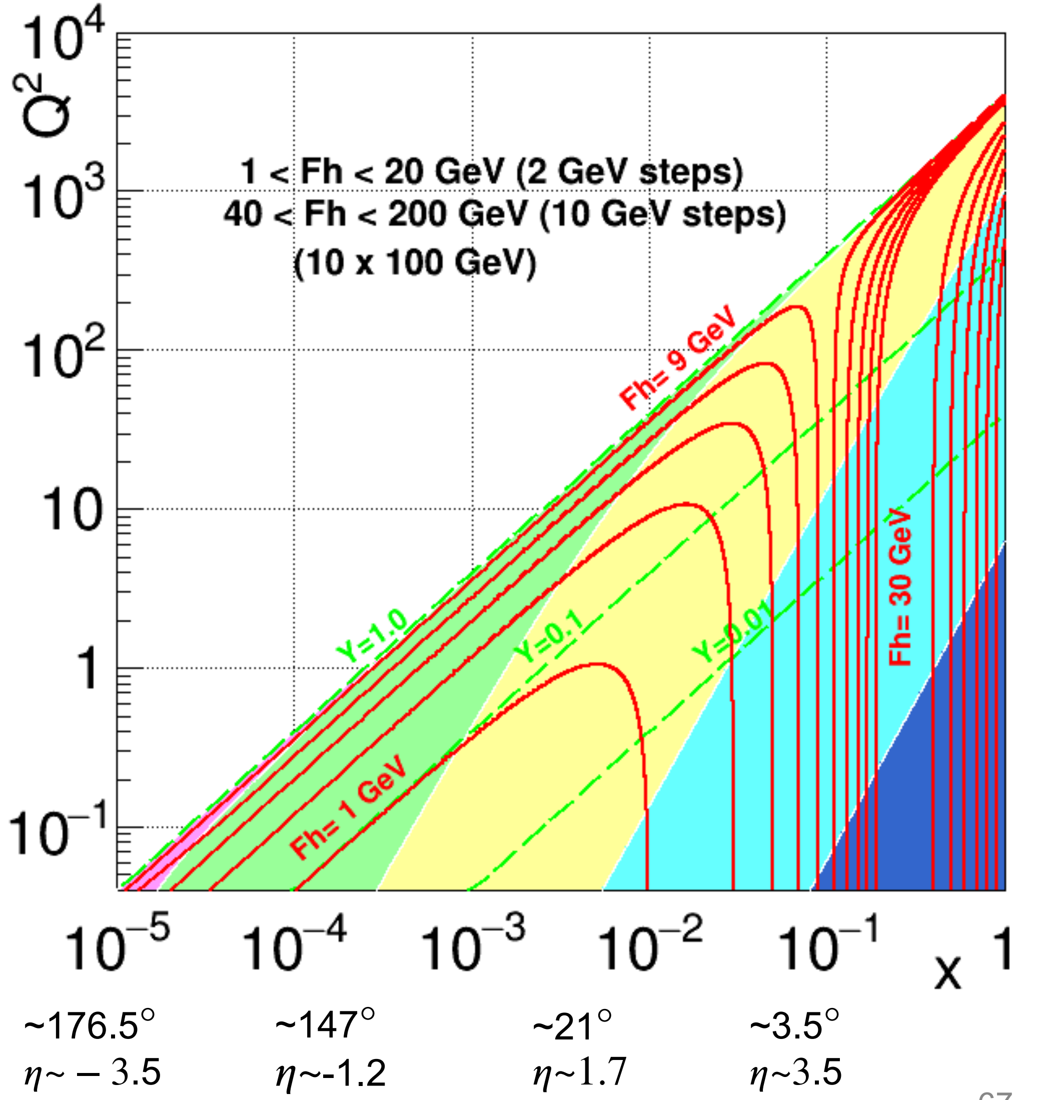
Pseudorapidity:

$$\eta = -\ln(\tan(\theta/2))$$

Transition area from DIS to Photoproduction (Q2<5GeV)

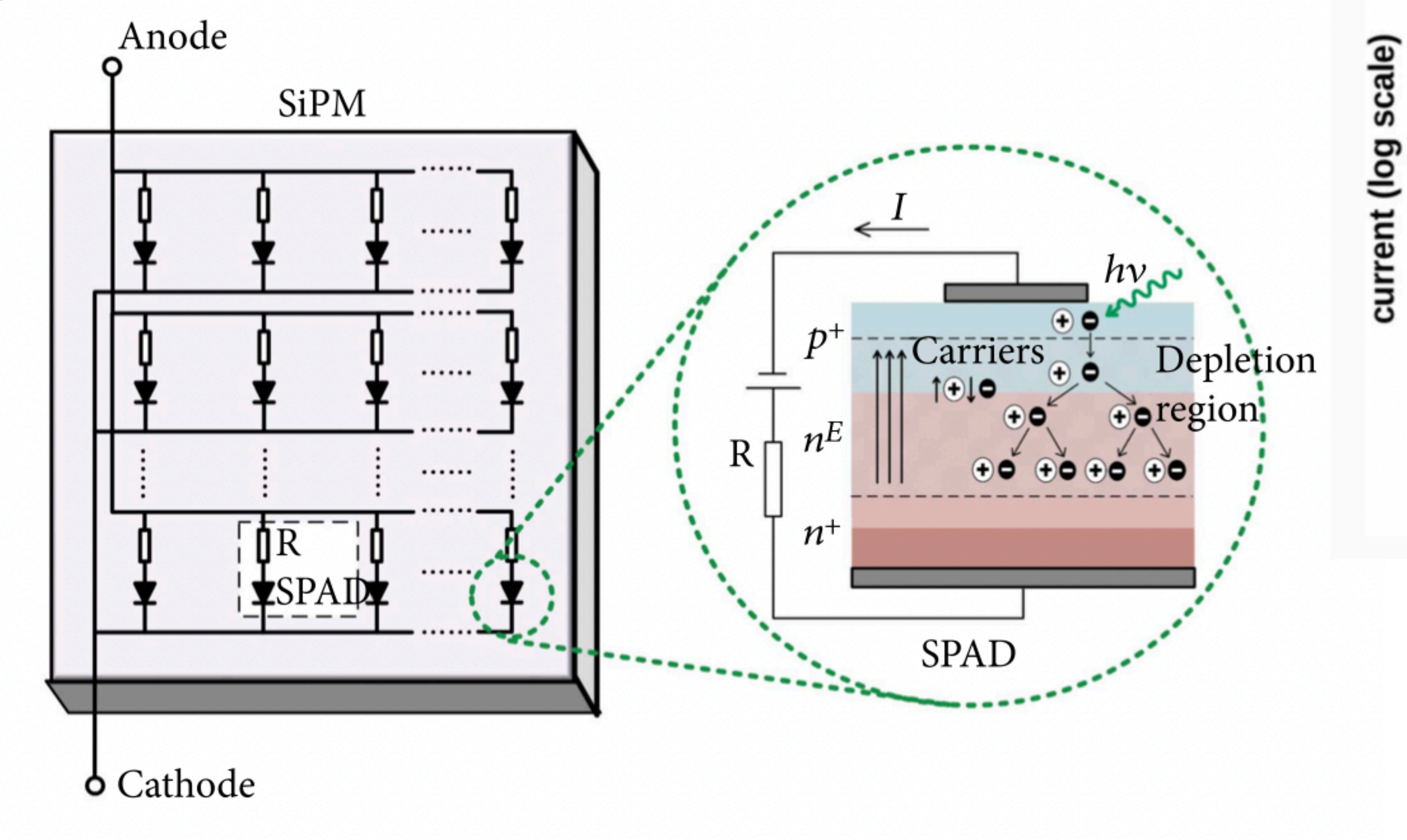
Why endcaps and forward areas are important at EIC?

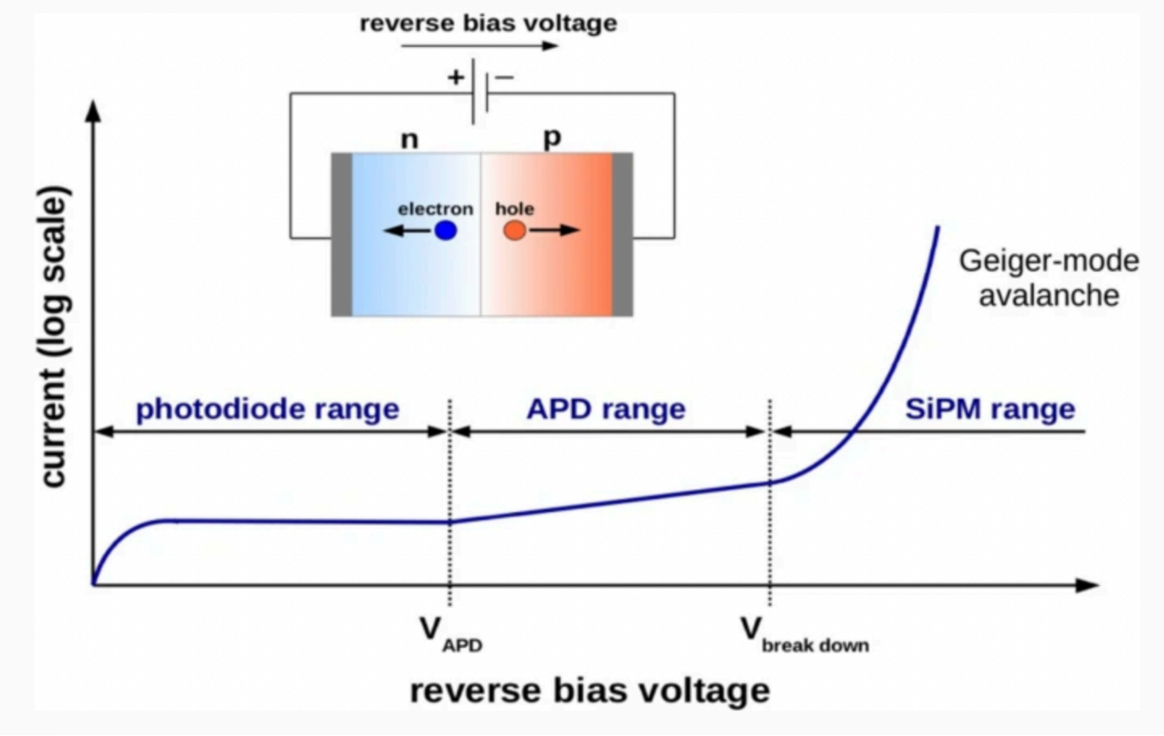




- All hadrons are boosted towards hadron endcap due to asymmetric beam energies
- Proton/Ion Remnant
- Diffractive/exclusive physics in the Far-forward area

Readout: SiPM





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