JLEIC central detector

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on behalf of JLEIC detector group

Overview

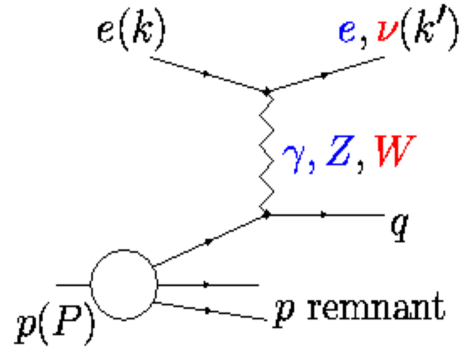
- Introduction
- Main Components of Central Detector
- Accelerator related aspects
- Conclusions

Examples of EIC physics goals

JLEIC full-acceptance detector has to be designed to support the physics program outlined for a generic EIC

It has to provide detection and identification of a complete final state, including low-Q2 photoproduction (PhP) electrons, as well as a proton/ion remnant

PhP and DIS

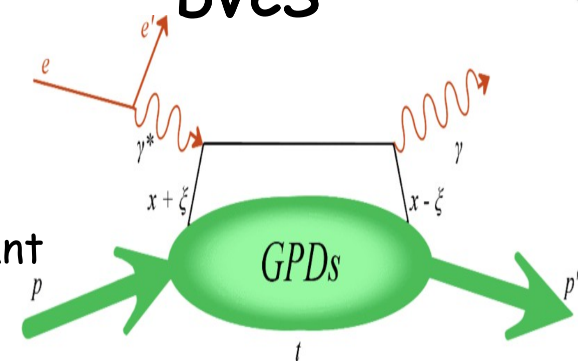


$$Q^2 = -(k-k')^2$$

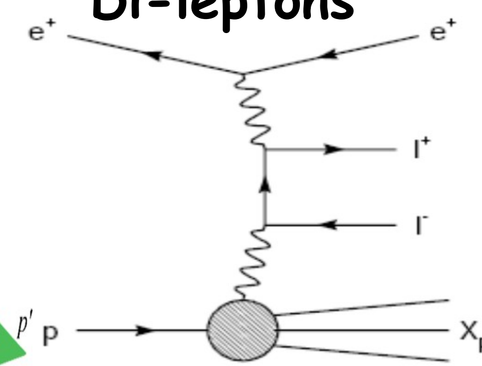
$$x = \frac{Q^2}{2P\cdot(k-k')}$$

$$y = \frac{P\cdot(k-k')}{P\cdot k}$$

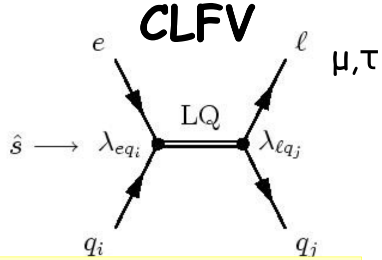
DVCS



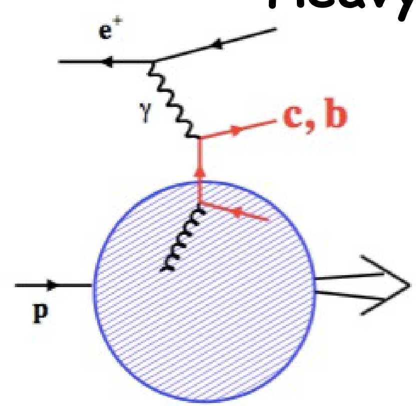
Di-leptons

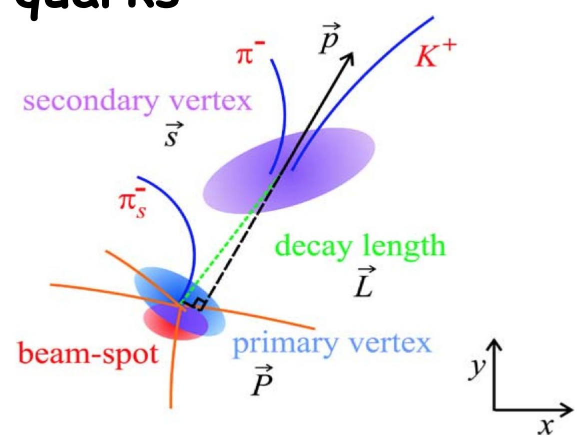


CLFV



Heavy quarks



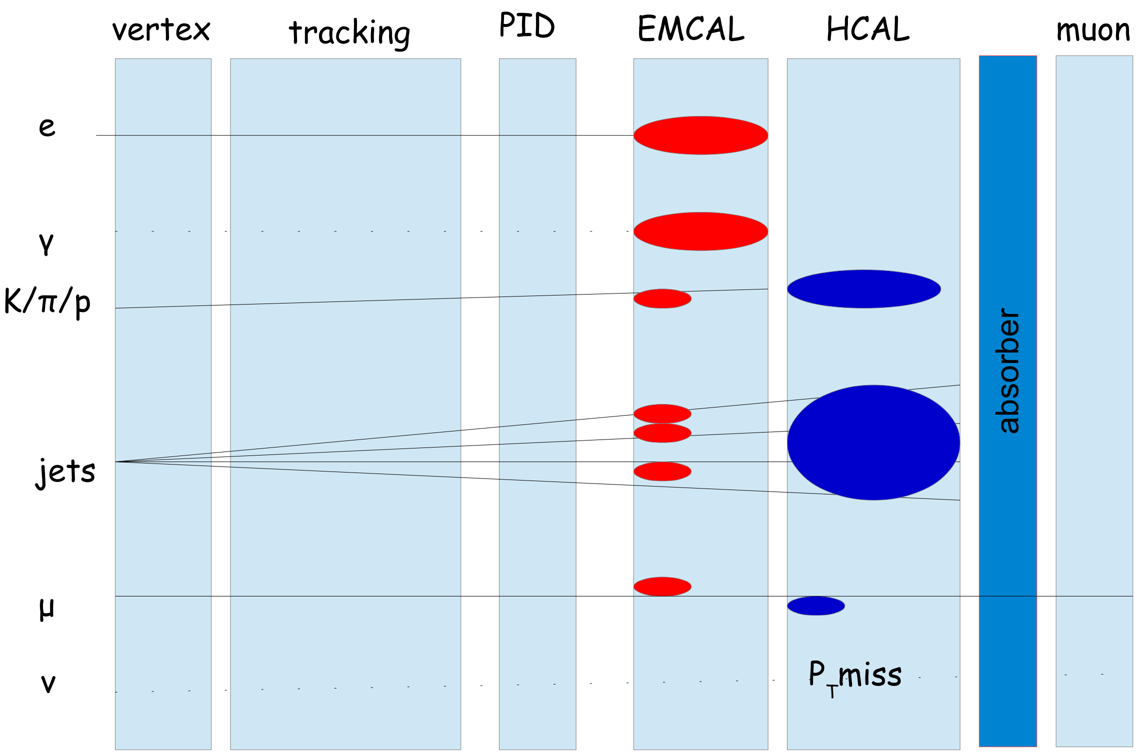


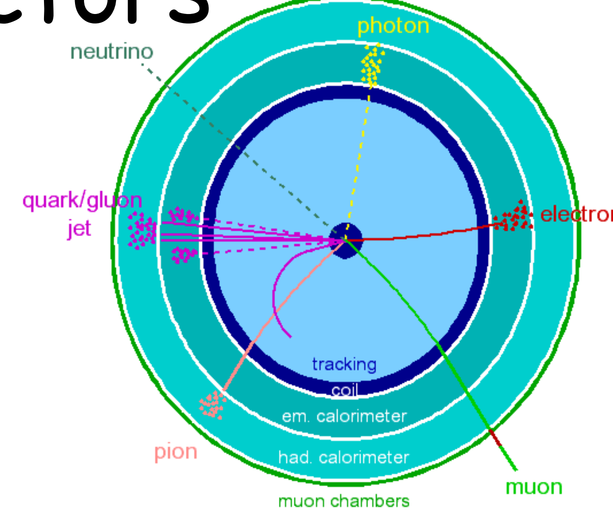
Detection of complete final state.
General purpose detector,
covering a full acceptance (4π).

General structure of detectors

Stable particles (e,μ,π,K,p, jets(q,g), gamma, ν):

Momentum/Energy, Type(ID), Direction, vertex





Particle identification methods:

-tracking, CAL , muon det.

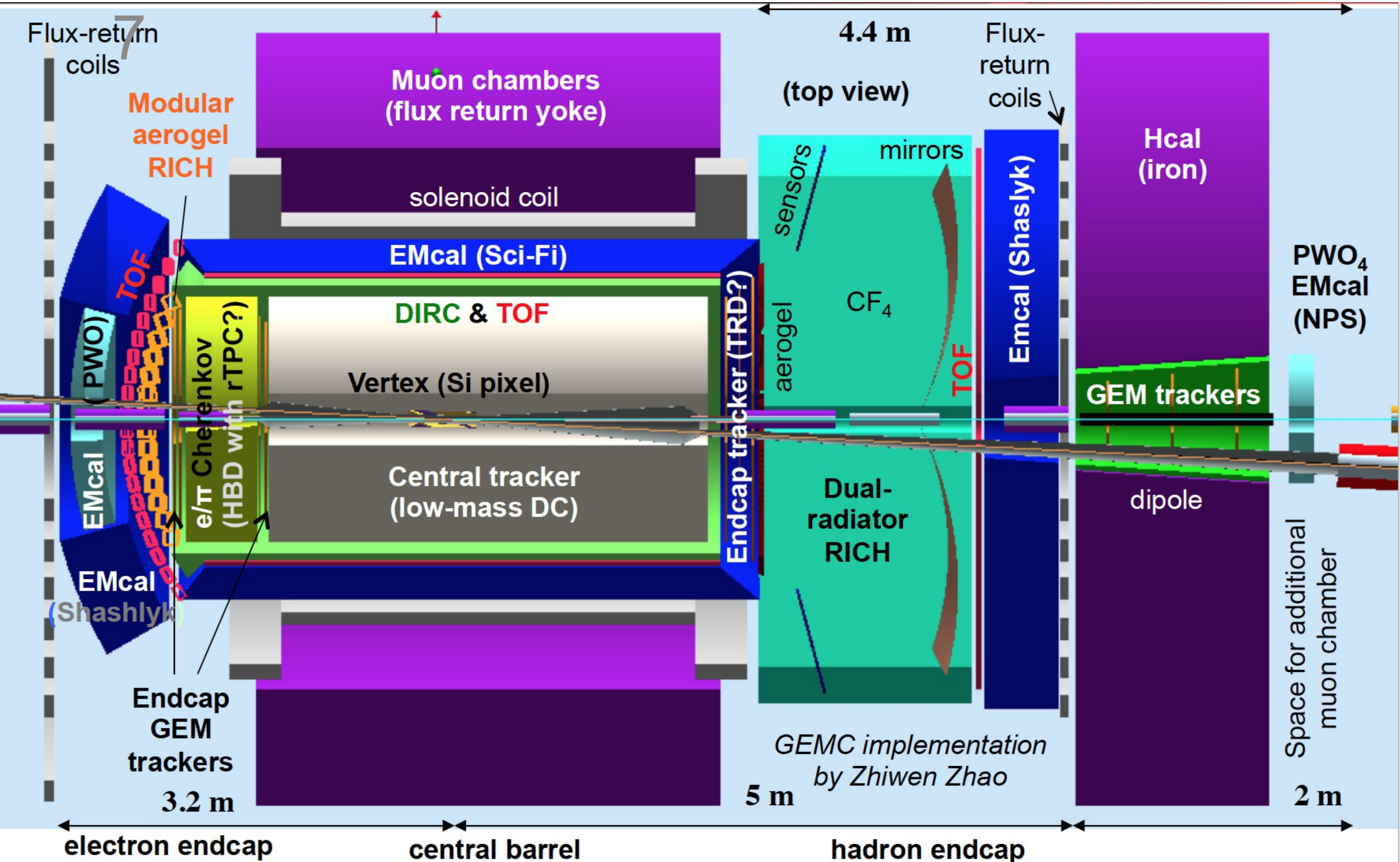
-Time of Flight (TOF)
-Energy Loss (dE/dx)
-Cherenkov light (DIRC,RICH)
-Transition radiation (TRD)

Pythia Minbias EIC (Q2> 10^{-6}) σ ~ 200 μb (HERA ~165 μb)
N events = σ•L ~ 2· 10^6 ev. per sec (2MHz) ~ 2 events / μs

ZEUS/HERA(ep)= 165 •10^{-30} •2 •10^{31} ~ 3.3· 10^3 per sec (~3kHz)

Challenging in terms of detector technologies

Central detector overview



Modular design of the central detector

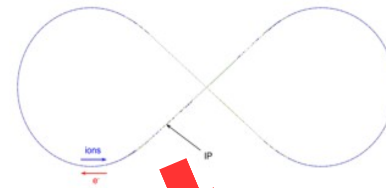
Size and placement of the IP1 detector

- IP placement
  (to reduce a background IP1 detector)
  -Far from electron arc exit (synchrotron)
  -close to ion arc exit (hadron background)

- Total size ~80m
  -Forward hadron spectrometer ~40m
  -Low Q2 electron detection ~30m
  -Central detector ~10m

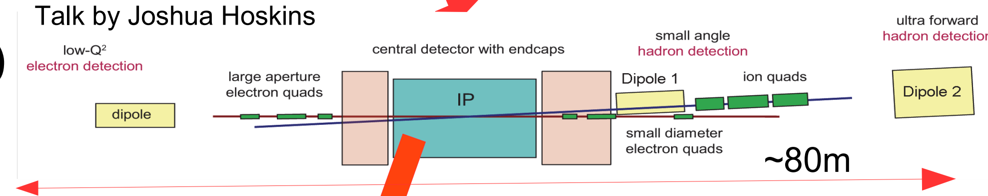
- Limitation in size:
  -in R – size of magnet
  -in L - Luminosity is inverse proportional to a distance between ion quadrupoles

This talk - focus on the IP1 central detector

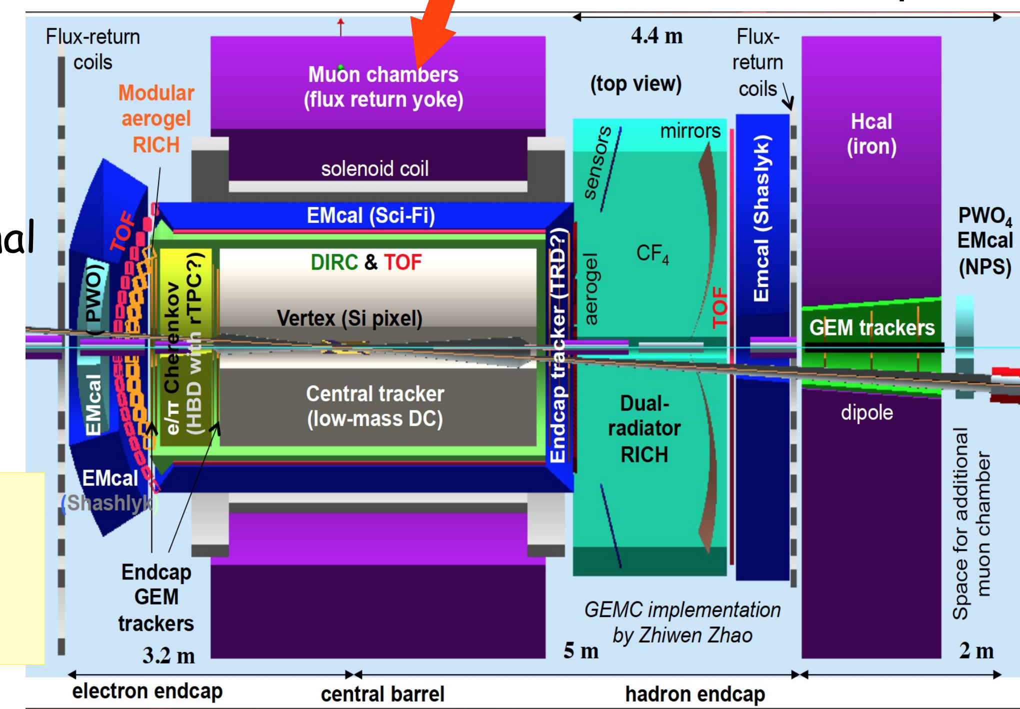


Talk by Charles Hyde

Talk by Joshua Hoskins



Central detector Top view

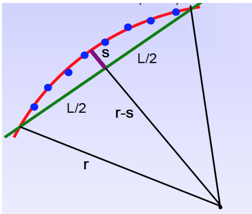


Magnet

The solenoid has been integrated with the accelerator such that it can operate at any required field independent of the beam energies and optics.

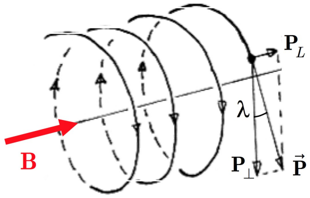
1. Strong magnetic field (3T)
for high momentum particles
at the highest center-of-mass energy

$$\frac{\sigma(p_T)}{p_T} = \frac{\sigma(x)\cdot p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$



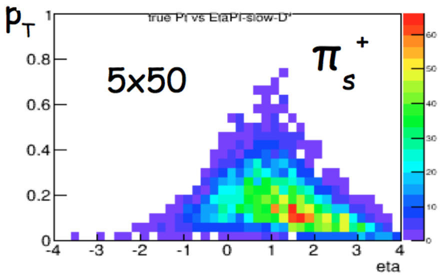
ATLAS: (2Tesla, σx~200μm, pt= 100GeV 3.8%)
EIC: (3 Tesla σx~100μm pt=100 GeV 3%)

2. Low magnetic field (1.5T)
for low momentum particles
at the lowest center of mass energy



$$R(m) = \frac{P_T(GeV)}{0.3\cdot B(T)}$$

$$D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$$



Keep solenoid field independent from beam optics
(compensating solenoids)

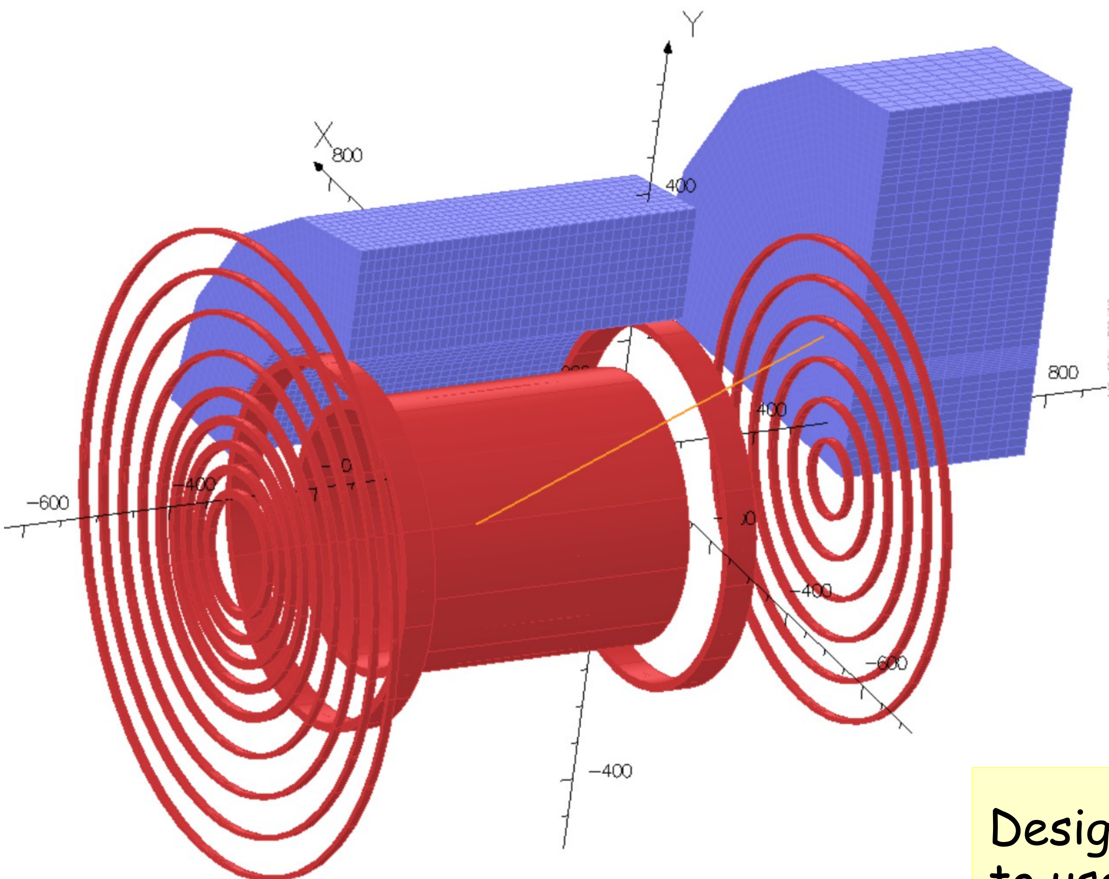
By Paul

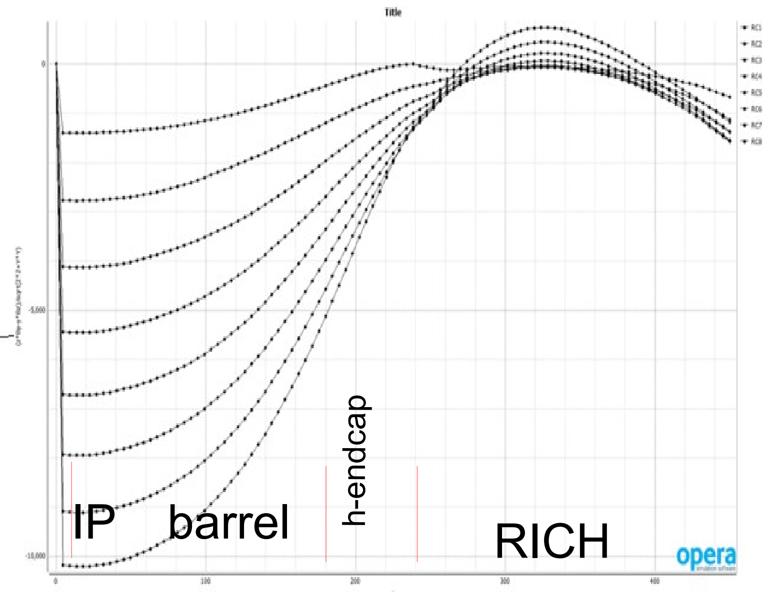
Magnet

1. Reuse 1.5 T magnet from CLEO or BaBar

2. New design 3(1.5)T solenoid

minimize the magnetic field at hadron-endcap (dual-radiator RICH region)





Design of a new solenoid could allow to use dual-radiator RICH in endcap.

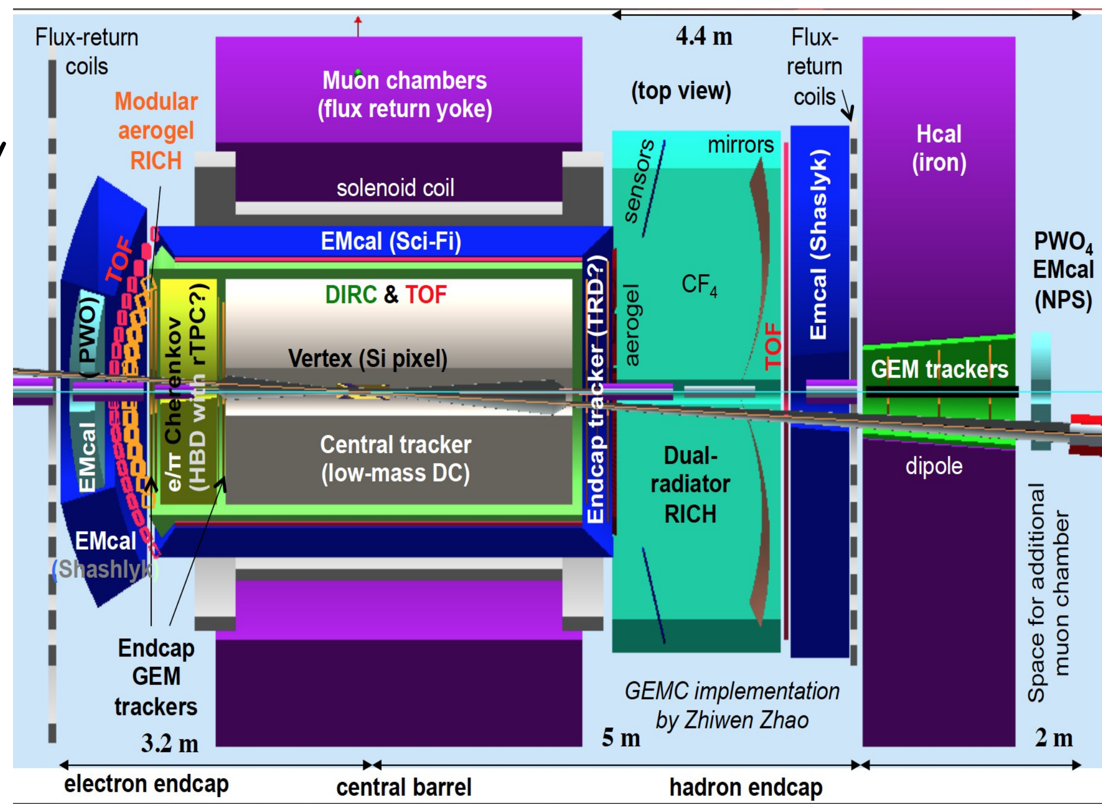
Tracking

Main purpose of tracking:

-reconstruct charged tracks and measure their momenta precisely (~few %)

-dE/dx (PID) for low momentum tracks.

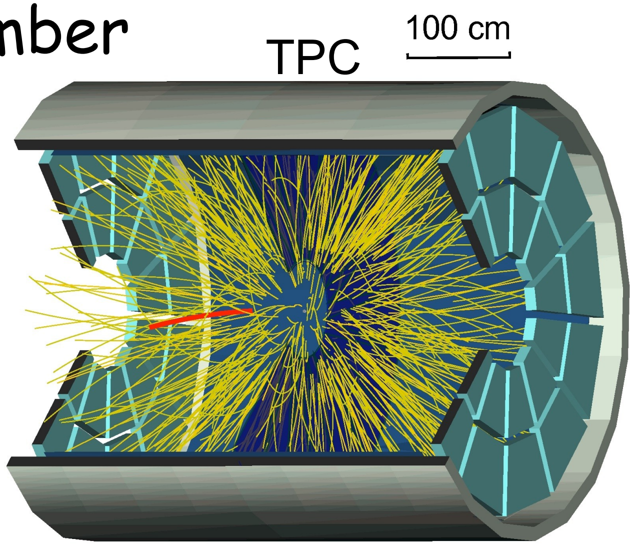
Parameters:
-Single hit resolution and efficiency
-Momentum resolution
-Readout time and occupancy
-dE/dx measurements for PID

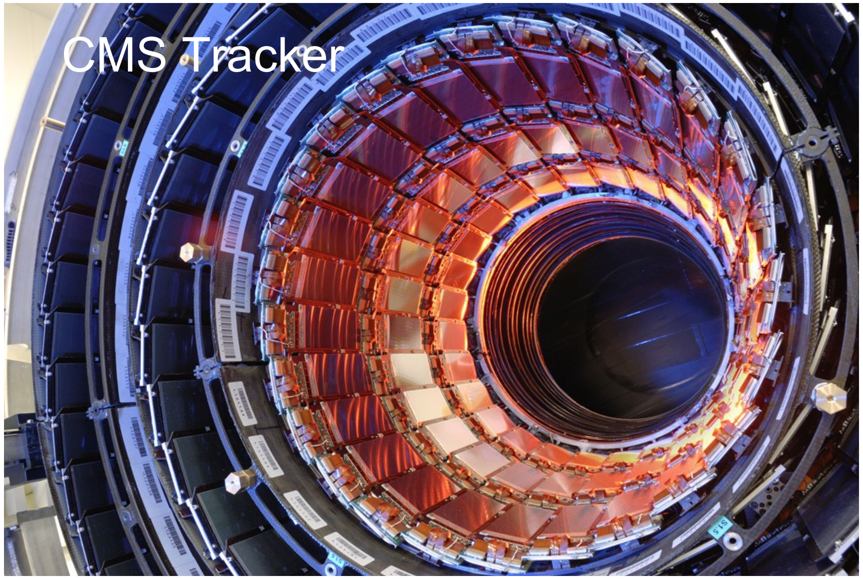


Different Tracker technology

Time projection chamber (TPC at ALICE/LHC)

- EIC R&D
- 3D trajectories
- Gas: Ne-CO2-N2
- Total drift time: 92μs
- space point resolution in rφ 300 – 800 μm
- momentum: Δ(p)/p = 1% p
- material budget 3.5% X_0





Silicon Tracker (CMS/LHC)

Largest silicon tracker ever built
~200m^2 Silicon Sensors
(9.3 million strips, 66 million pixels)

- single hit resolution 15 -30 μm
- Readout time 25 ns
- Material budget : 10 % X0 ?

Selection of tracker technology is based on luminosity, occupancy and material budget

Tracking at JLEIC

Barrel: Low mass drift chamber

KLOE LMDC (ILC, alternative to TPC)

- good momentum resolution $\Delta pt / pt \sim 3 \cdot 10^{-4}\, pt$
- Drift cells 2x2 cm2, 3x3 cm2
- Drift cells - carbon fiber composite (<0.1 %X0) -minimal multiple scattering
- Gas : 90% helium, 10% isobutane mixture
- Drift velocity 17-23 mm/μs
- Resolution for 3x3 cells ~250 μm
- Limited Hadron separation by dE/dx or using cluster counting method

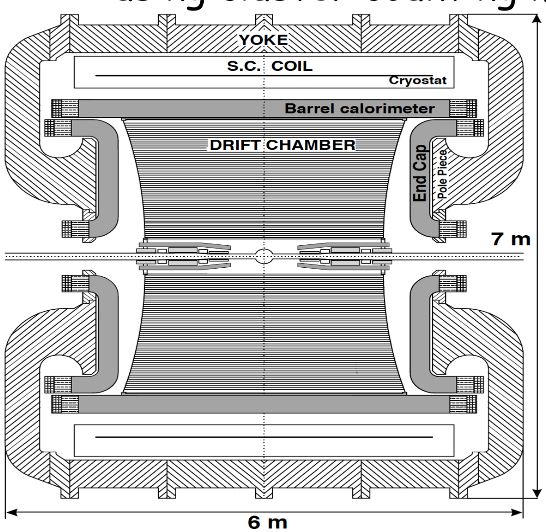


Fig. 1. Cross-section of the KLOE detector, along the beam line.

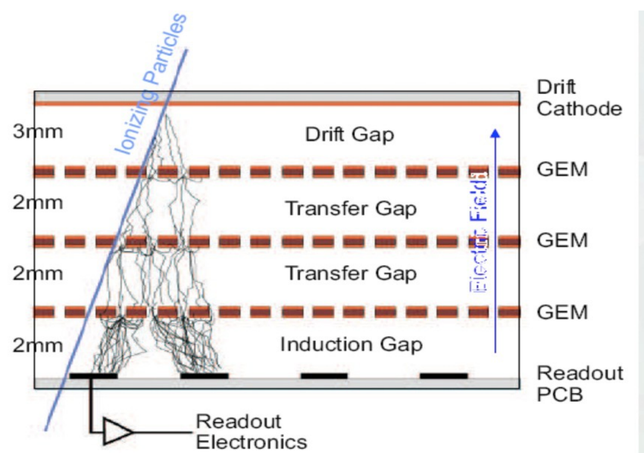
Endcaps: GEM

-High multiplicity in forward region – need High granularity tracker

-drift time ~300ns

-resolution ~50 μm.

- R&D is ongoing: Florida Institute of Technology (FIT), Temple University (TU), University of Virgina (Uva)....

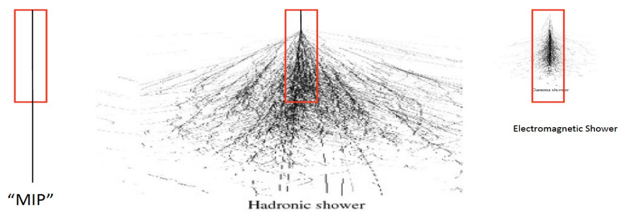


Barrel : relatively fast detector, minimal multiple scattering, limited PID

Endcaps: occupancy/ high granularity and radiation hardness are important

Electromagnetic Calorimeters

- Electromagnetic Calorimeters measure EM showers and early hadron showers:
  Energy, position, time
- Typical EM calorimeter resolution
  $\sigma E/E = a/\sqrt{(E)} + b/E + c$
  sampling, noise and constant terms
- Combination with HCAL(?)

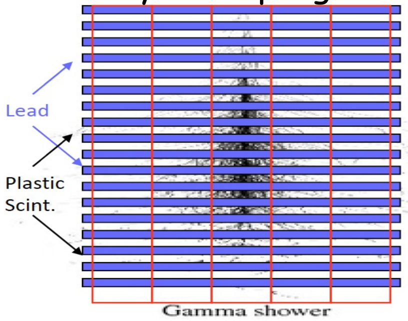


Types of EM calorimeters:

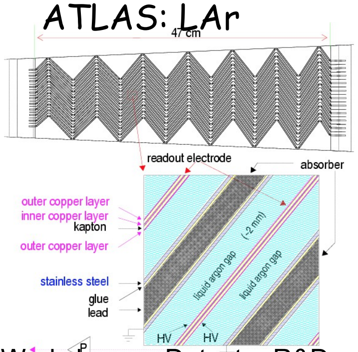
- Crystal :
  - -CsI (CLEO-II, Belle, BaBar) ,
  - Tungsten glass "PWO" $PbWO_4$ (CMS, ALICE, PANDA)
- Sampling :
  - -Scintillator sampling - Shashlyk: HeraB, PHENIX, LHCb, ALICE
  - Silicon sampling: OPAL, DELPHI
  - -Liquid Lar, Lkr,LXe: LAr: D0, SLD, H1, ATLAS
- Particle flow Calorimeter (ILC)

Crystal

Shashlyk: sampling scint.



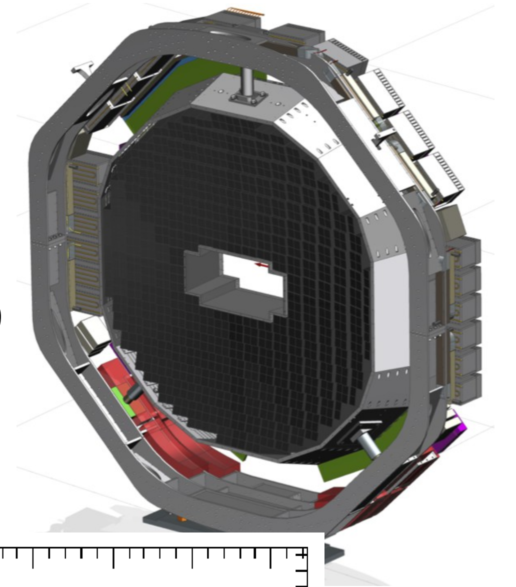
ATLAS: LAr



Selection of EM calorimeter based on energy resolution and radiation hardness

$PbWO_4$ EM Calorimeter

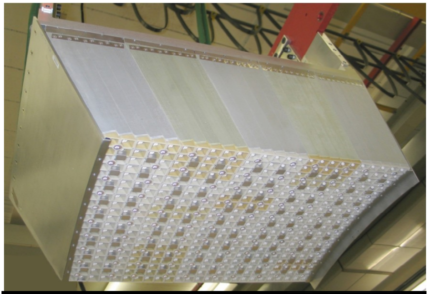
PANDA PWO endcap CAL

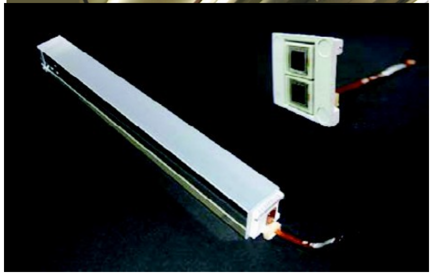


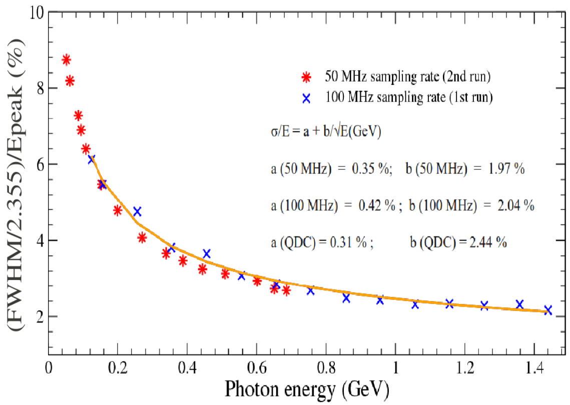
CMS
-Tungsten glass (PbWO4)
-76000 crystals
-Took 10 years to grow all crystals !!!

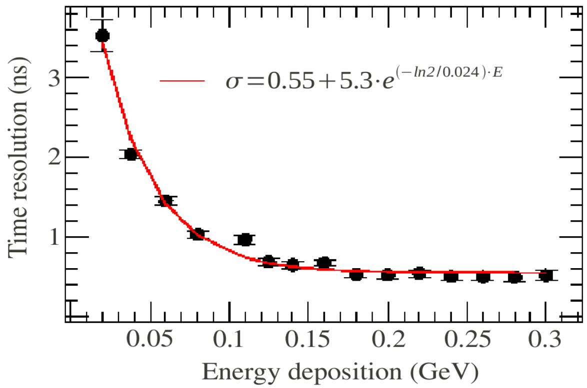
$\sigma_E/E = \mathbf{5.7\%}/\sqrt{E} \oplus \mathbf{0.55\%} \oplus 0.77/E$

PANDA
- Scintillation material:
  Lead tungstate (PbWO4)
- Length corresponds to ~ 22 X0
- Produced at two places (China, Russia)
- Time resolution: <2 ns
- Energy resolution: <2%/√E(GeV) + 1%
- Cluster threshold: 10 MeV









PWO crystal calorimeter has good energy and time resolution.
PWO has less photon output compared to CsI,
But CsI is less rad hard
BaBar CsI-endcap showed 15% loss after 1.5 krad
LYSO crystals 10-15% after 1Mrad γ – more radiation hard

Sampling EM Calorimeter

- **Shashlyk** (scintillators + absorber)

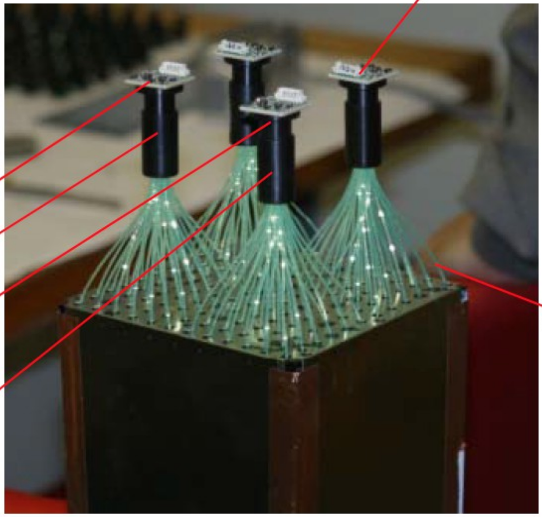
-WLS fibers for readout (radiation hardness?)

-KOPIO(Pb): $\sigma_E/E = 2.74\ \% / \sqrt{E} + 1.96\%$

-LHCB(Lead): $\sigma_E/E = 10\% / \sqrt{E} + 1.5\%$

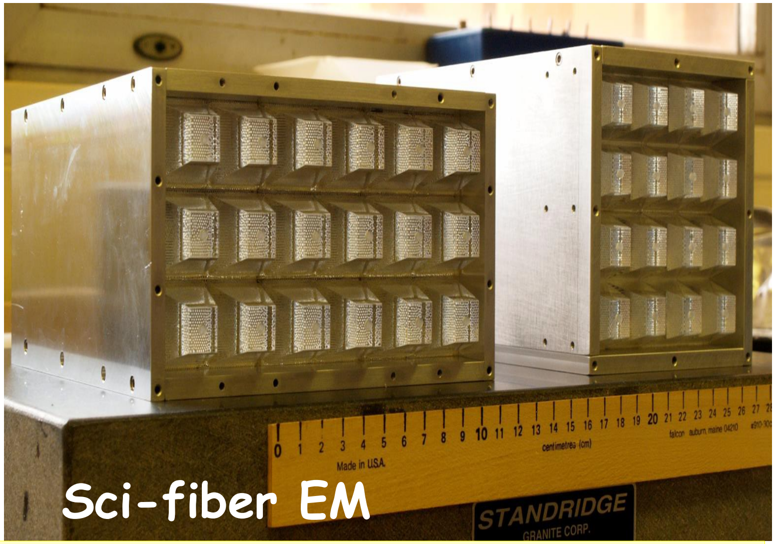
- **Liquid Ar** (ATLAS):
  - long drift time ~ 400-500 ns
  - But excellent timing resolution 83ps at 245GeV
  - $\sigma_E/E = 10.1\ \% / \sqrt{E} + 0.17\%$
  - radiation hardness – perfect!
- **Liquid Kr** (NA48) $-\sigma_E/E = 3.2\ \% / \sqrt{E} + 9\%E + 0.4$
- **Liquid Xe** - 58MeV photons

ALICE EMCAL



Sci-fiber EM(SPACAL) R&D for EIC

- Compact W-scificalorimeter, developed at UCLA
- Sc. Fibers -SCSF78 Ø 0.47 mm, Spacing 1 mm center-to-center
- Resolution ~12%/√E
- On-going EIC R&D

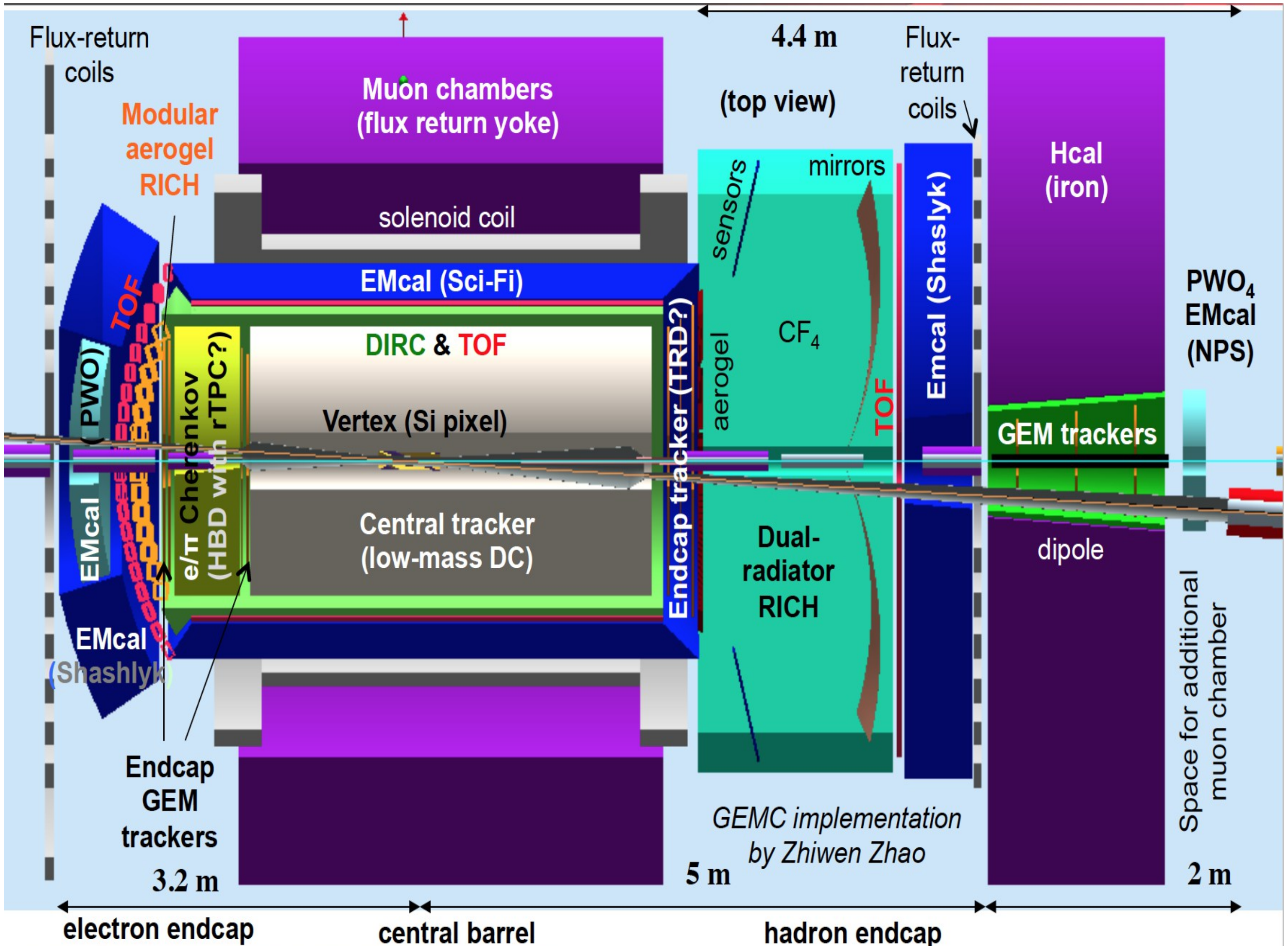


Shashlyk radiation hardness of WLS/Sci-fibers has to be investigated

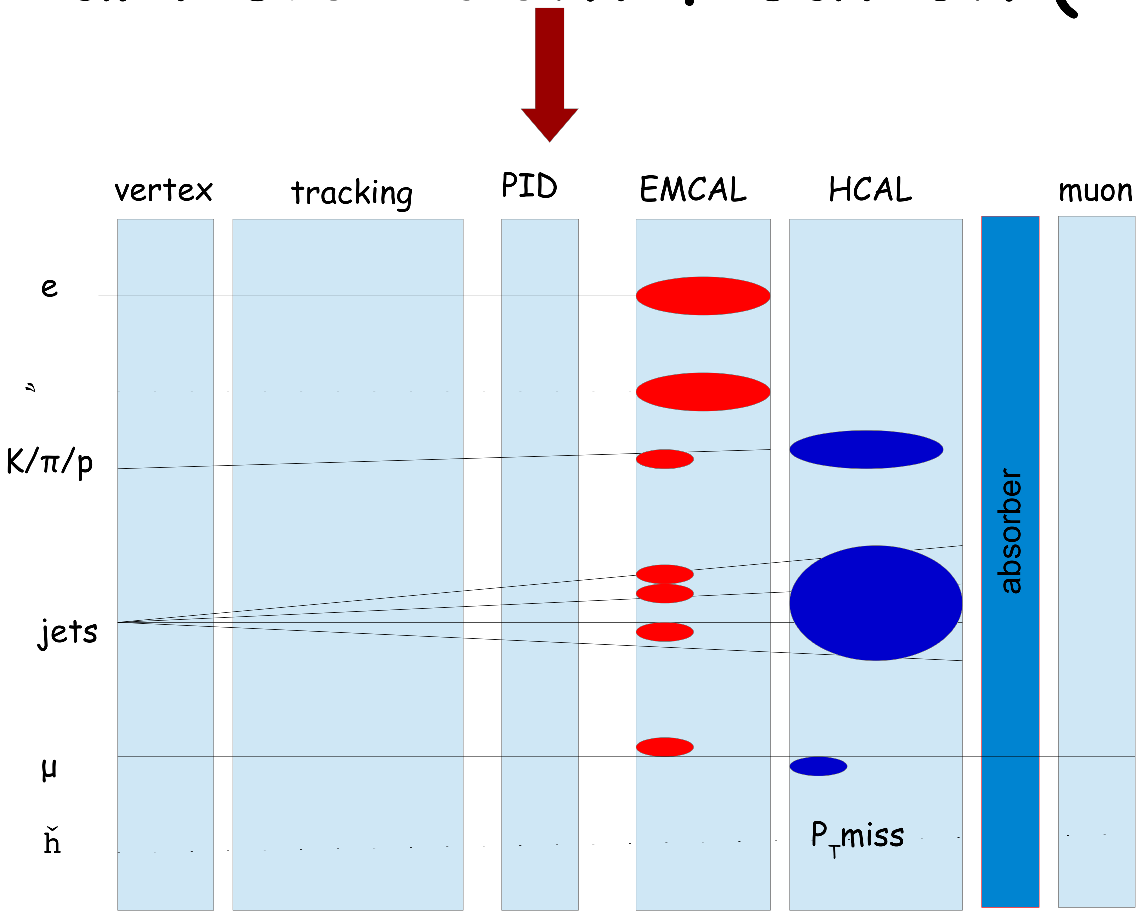
Electromagnetic Calorimeters

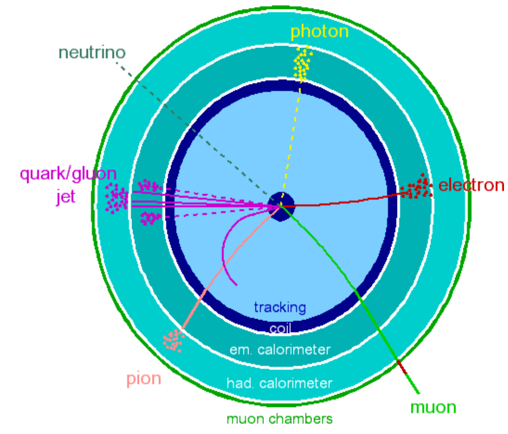
PWO | Close to the beam – more precise and more radiation hard. calorimeter

Shashlyk | Barrel and endcaps – less expensive



Particle Identification (PID)

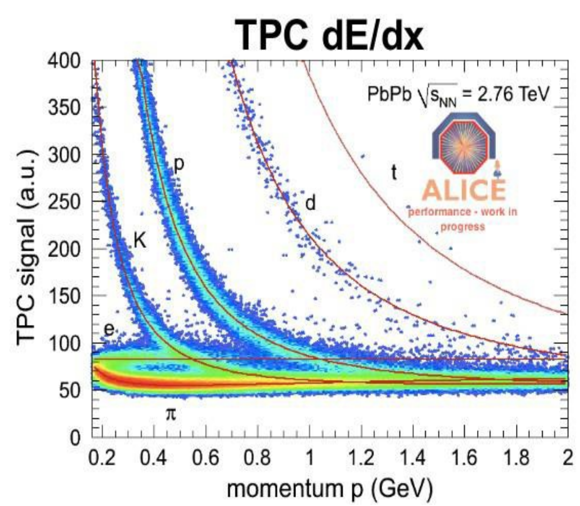




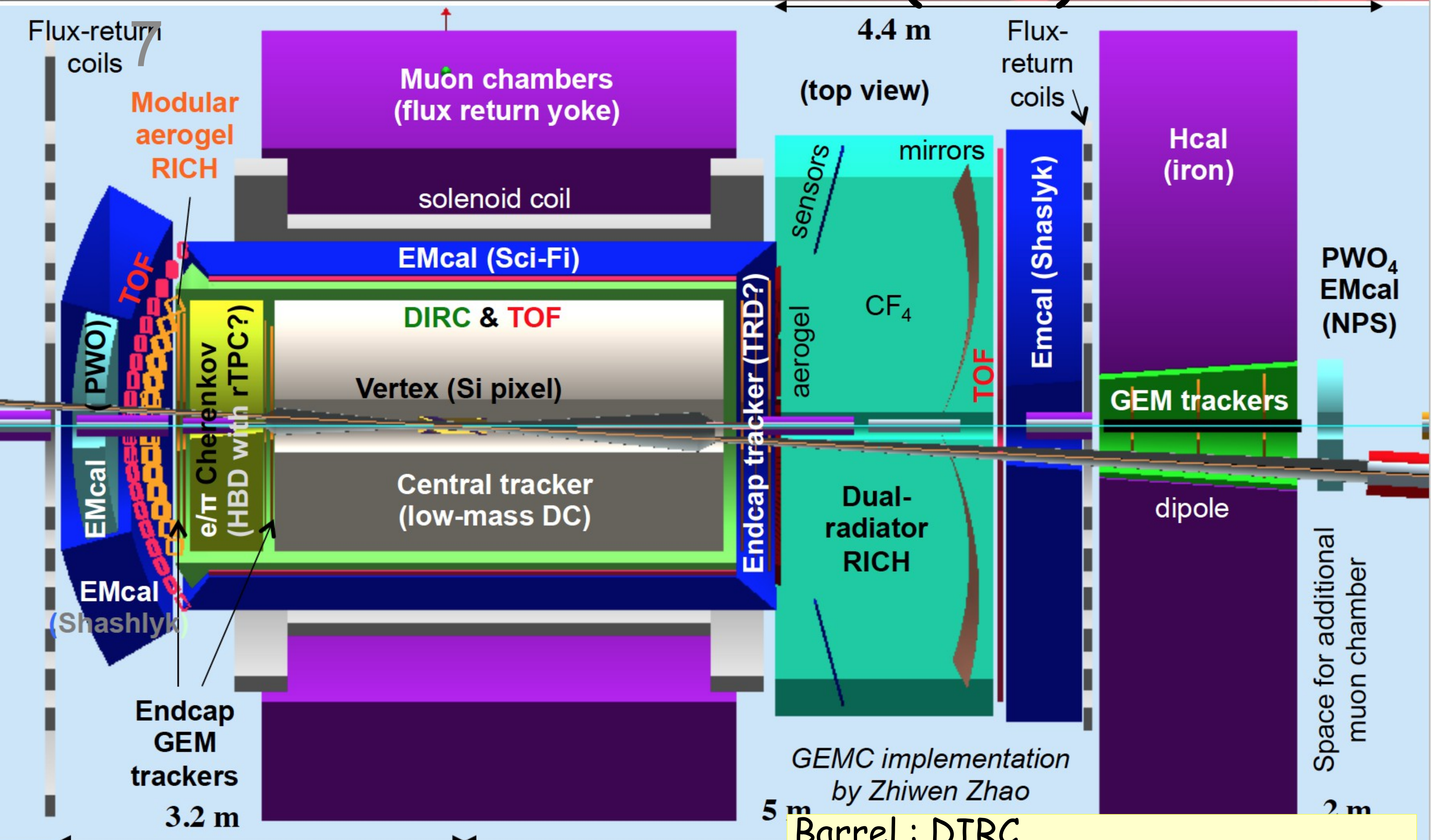
Tracking devices could provide limited PID
via dE/dx or cluster counting method

Particle identification methods:

- Energy Loss (dE/dx)- tracking
- Time of Flight (TOF)
- Cherenkov light (DIRC,RICH)
- Transition radiation (TRD)



Particle Identification (PID)

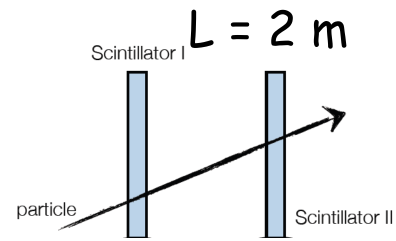


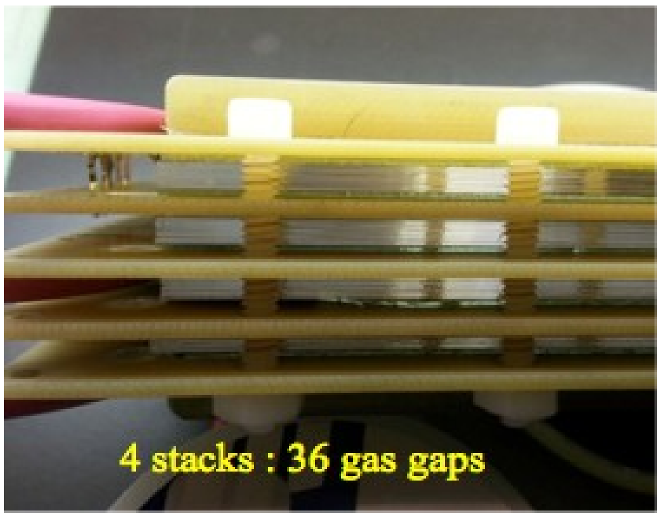
TOF- 4π coverage
TRD at hadron-endcap?

Barrel : DIRC
Electron endcap: Modular RICH
Hadron endcap: Dual-radiator RICH

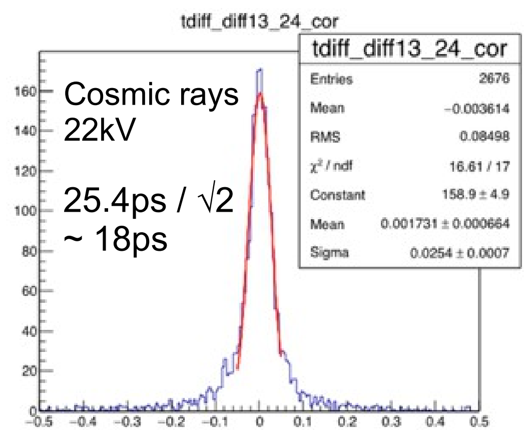
Time of Flight (TOF): MRPC

Measure signal time difference between two detectors with good time resolution (can use time of beam crossing as start signal)

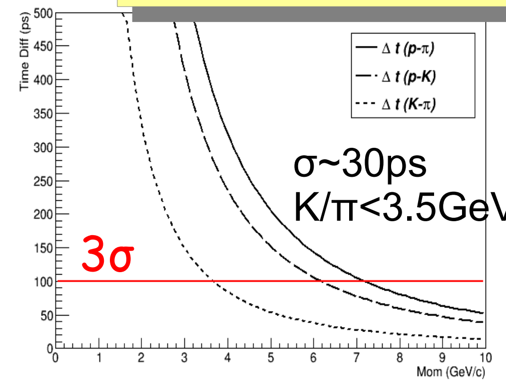




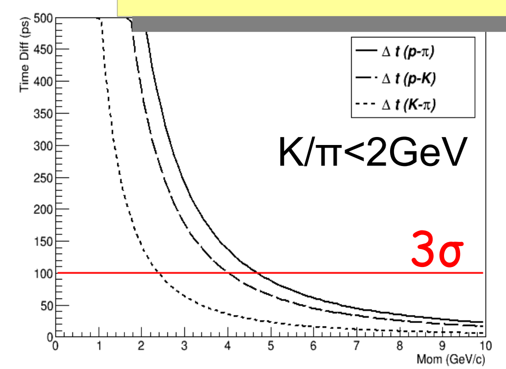
Multi-gap Resistive Plate Chamber (MRPC) R&D: achieved ~18 ps resolution with 36-105 μm gap glass MRPC



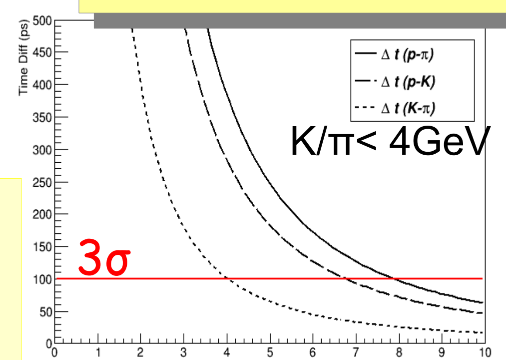
TOF e-side 362 cm



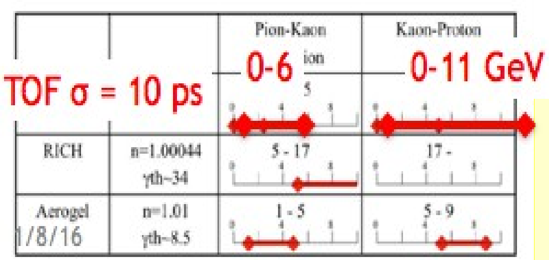
TOF Barrel 155 cm



TOF Ion-side 435 cm



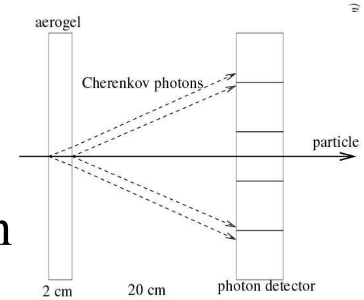
Mickey Chiu

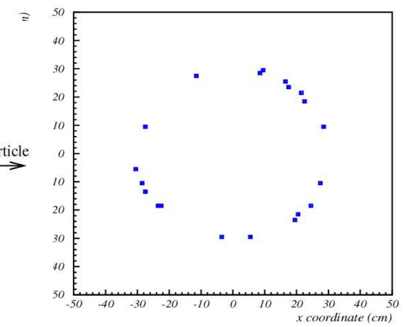


TOF should provide fast signal. Important for bunch identification and for hadron separation

Cherenkov detectors

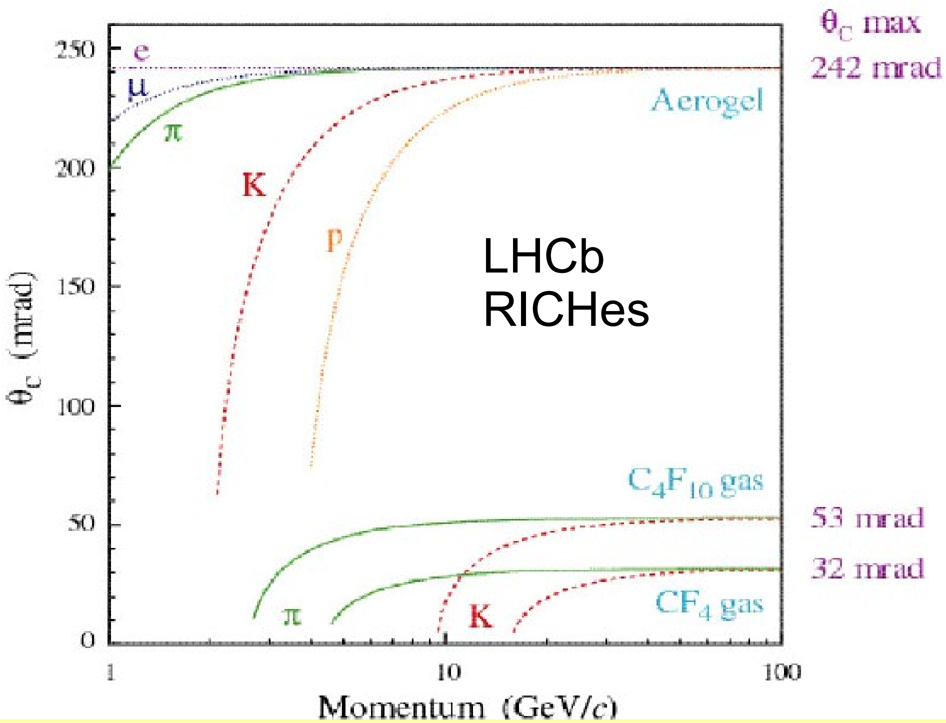
A charged track with velocity v=βc exceeding the speed of light c/n in a medium with refractive index n emits **polarized light** at a characteristic (Cherenkov) angle, $\mathbf{\cos\theta = c_0/nv = 1/\beta n}$

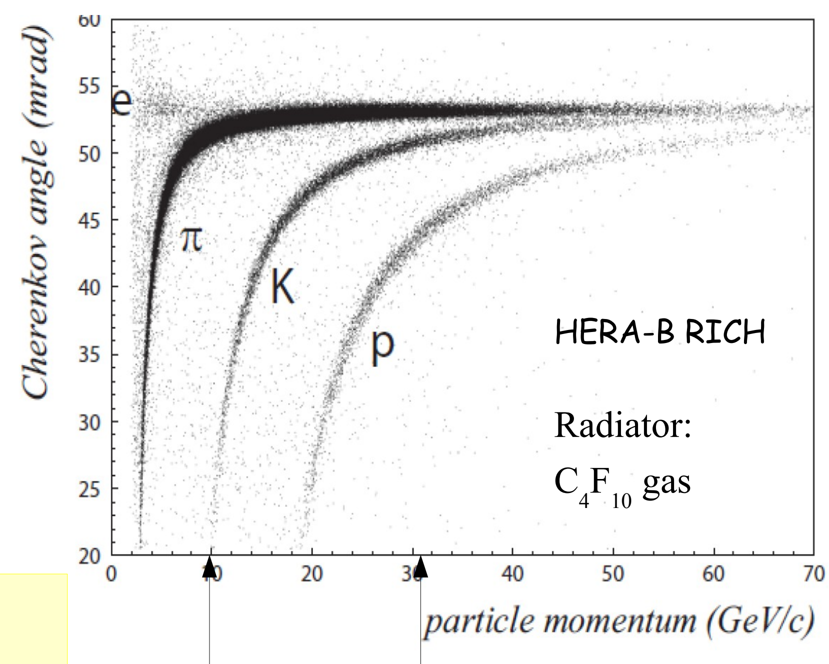




Limitations:

- p_{min} - p_{max} threshold
- magnetic field
- occupancy





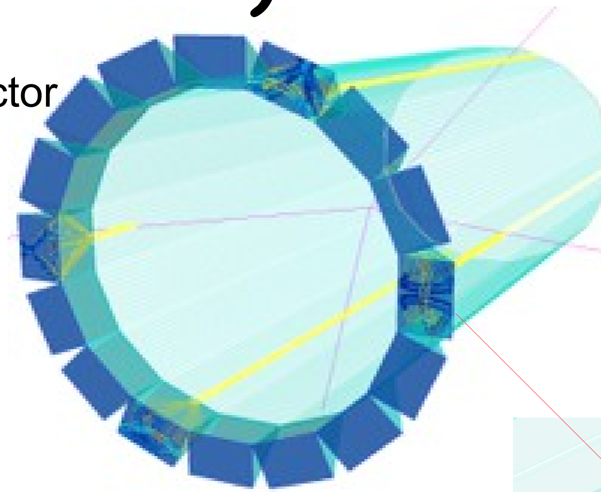
K/π p_{min}

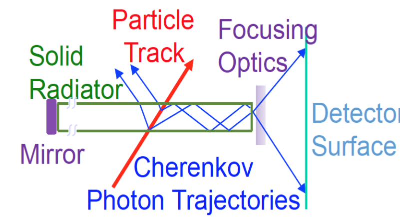
K/π p_{max} overlap

Cherenkov detectors are the main hadron (K/π/p) PID detectors for energies above TOF

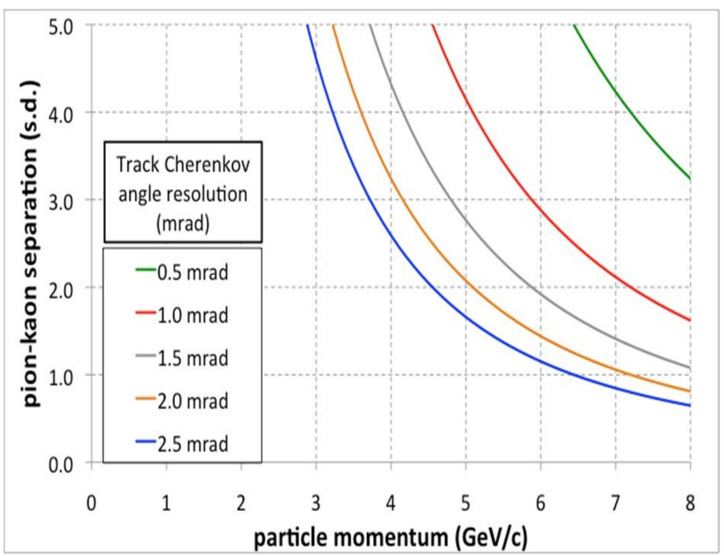
DIRC at JLEIC (barrel)

- radially compact (2 cm) Cherenkov detector
  (BaBar, Belle II, GlueX)
- eRD14 R&D program
- Test beam (together with PANDA),
radiation hardness test
- Particle identification:
  with 3σ separation capability:
- p/K: 10 GeV, π/K: 6 GeV, e/π: 1.8 GeV

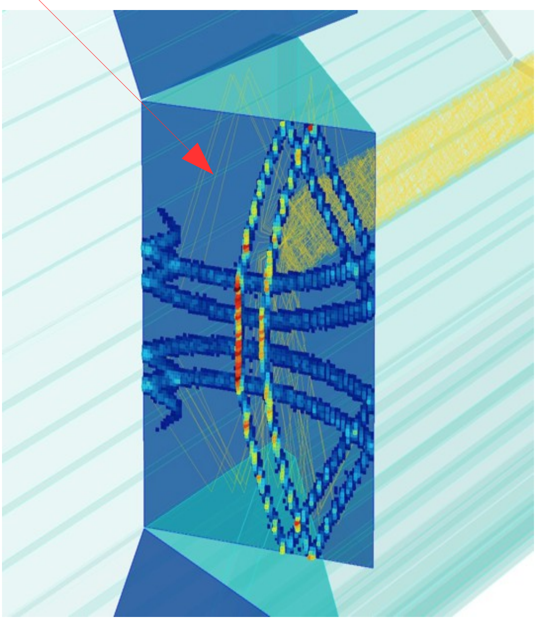




DIRC@EIC with 3-layer lens is capable of 1 mrad Cherenkov angular resolution per track



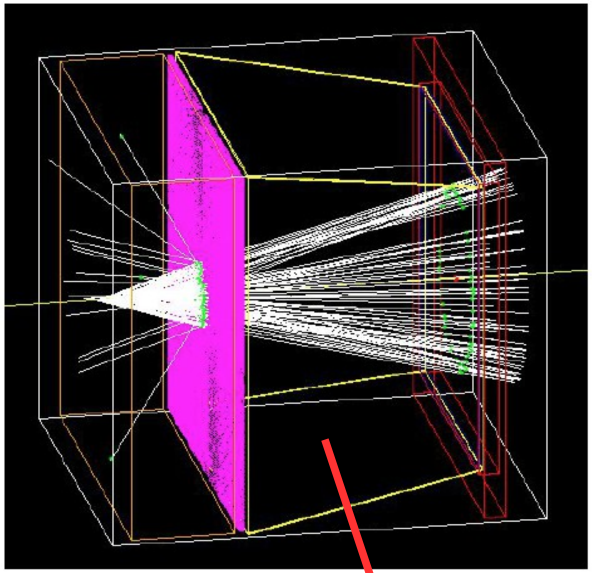
With a tracker angular resolution of 0.5-1.0 mrad and a sensor pixel size of 2-3 mm, the lens-based EIC DIRC will reach Cherenkov angle resolution close to 1 mrad corresponding to a 3σ π/K separation up to 6 GeV/c.

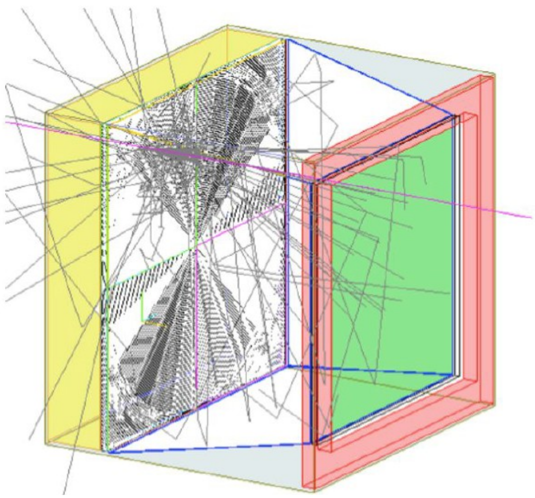


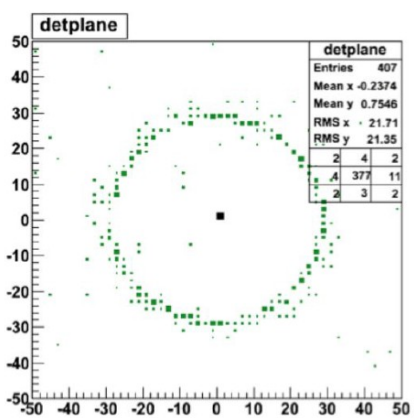
Barrel Cerenkov PID detector
DIRC covers energy for π/K up to 6GeV

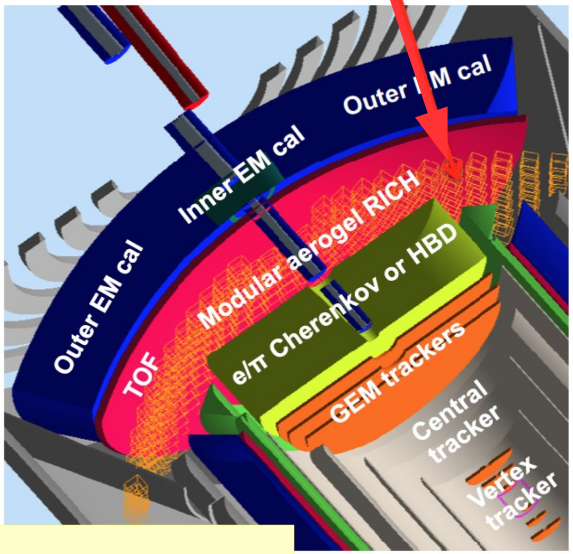
Modular RICH at JLEIC (electron side)

- Modular aerogel RICH (eRD14 detector R&D)
- π/K separation up to ~10 GeV
- A prototype of the modular aerogel RICH is under construction at Georgia State University
- The plan is to have a beam test in April of 2016 at Fermilab



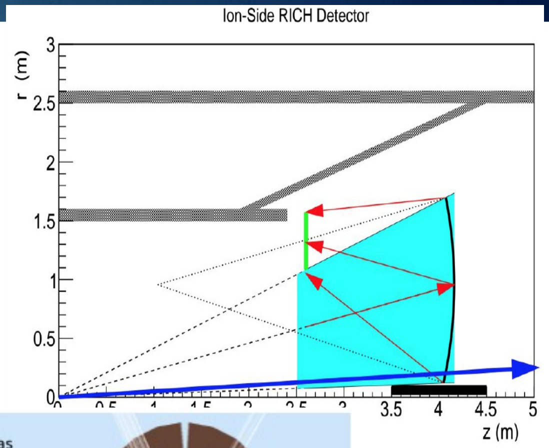




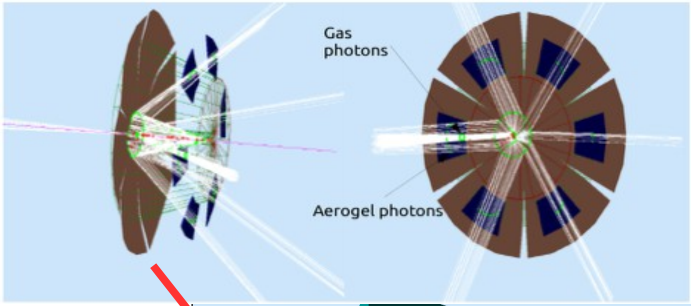


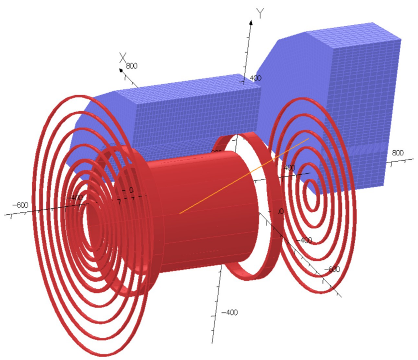
Electron -endcap Cerenkov PID detector
Modular RICH covers energy for π/K up to 10GeV

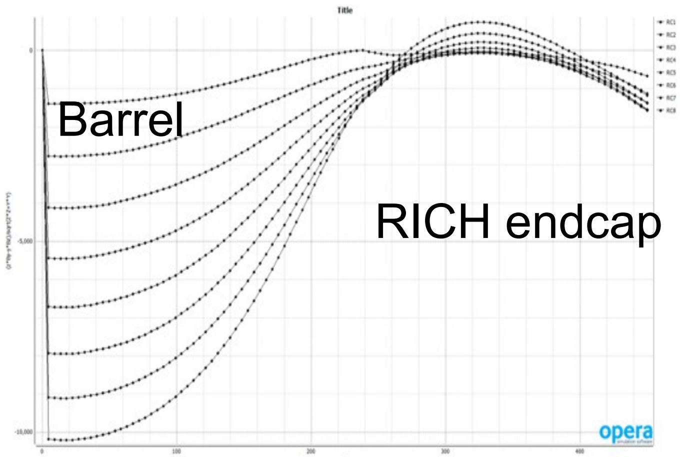
Dual-radiator RICH at JLEIC (forward,hadron side)

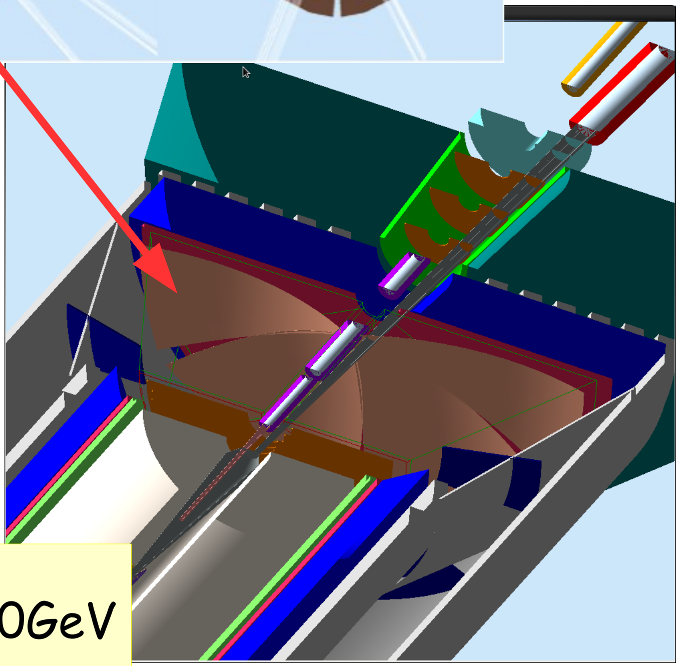


- JLEIC design geometry constraint:
  ~160 cm length
- Aerogel in front, followed by CF4
- Full momentum range (π/K up to ~50 GeV/c)
- eRD14 R&D program
- New 3T solenoid minimized a field
  in RICH region







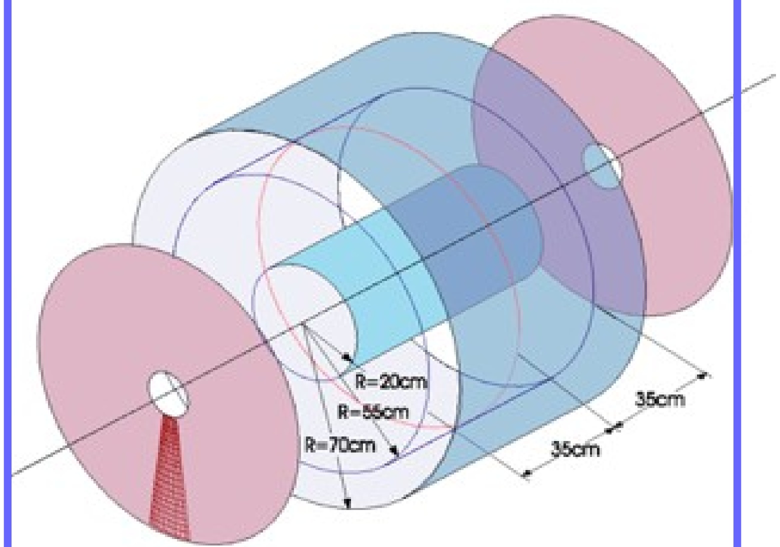


Hadron-endcap Cerenkov PID detector
dual-radiator RICH covers energy for π/K up to 50GeV
Sensitive to magnetic field.

e/π separation

Hadron-blind detector (Electron endcap)

- Cherenkov hadron-blind detector (HBD)
- TPC and HBD sharing gas volume (proposed for the PHENIX)
- e/π ID up to 4 GeV/c



Transition Radiation Detector (hadron endcap)

TRD -combined tracker and PID.
Cover energy range 1-100GeV.
Provide e/hadron rejection factor up to 1000.
R&D is needed

- GEM
  - proposal for R&D for EIC (Zhangbu Xu arXiv:1412.4769)
  - -drift time ~300ns
  - -resolution ~50 μm.
- MW chamber
  - -ALICE, ZEUS
  - - R&D for Hall D
  - -drift time 2μs , FADC readout
  - -resolution~ 400μm.
- Straws
  - -ATLAS
  - -4mm tubes with Xe-gas mixture
  - -drift time ~50ns
  - -resolution ~150 μm

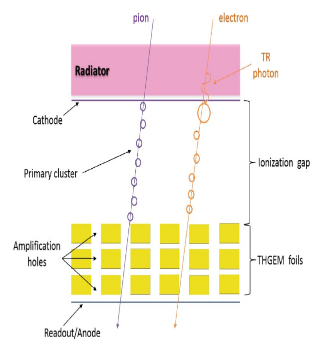
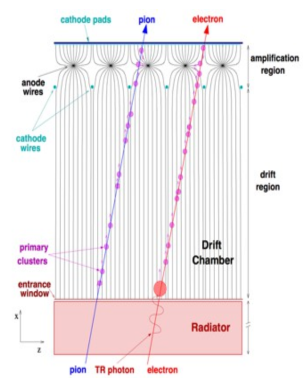
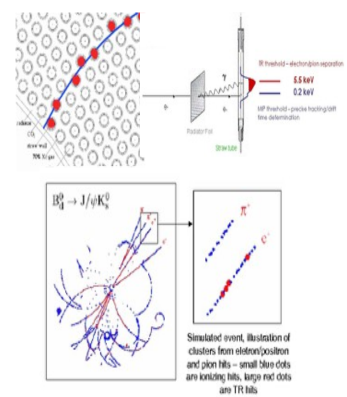


Figure 2: Schematic of the THGEM based TRD.



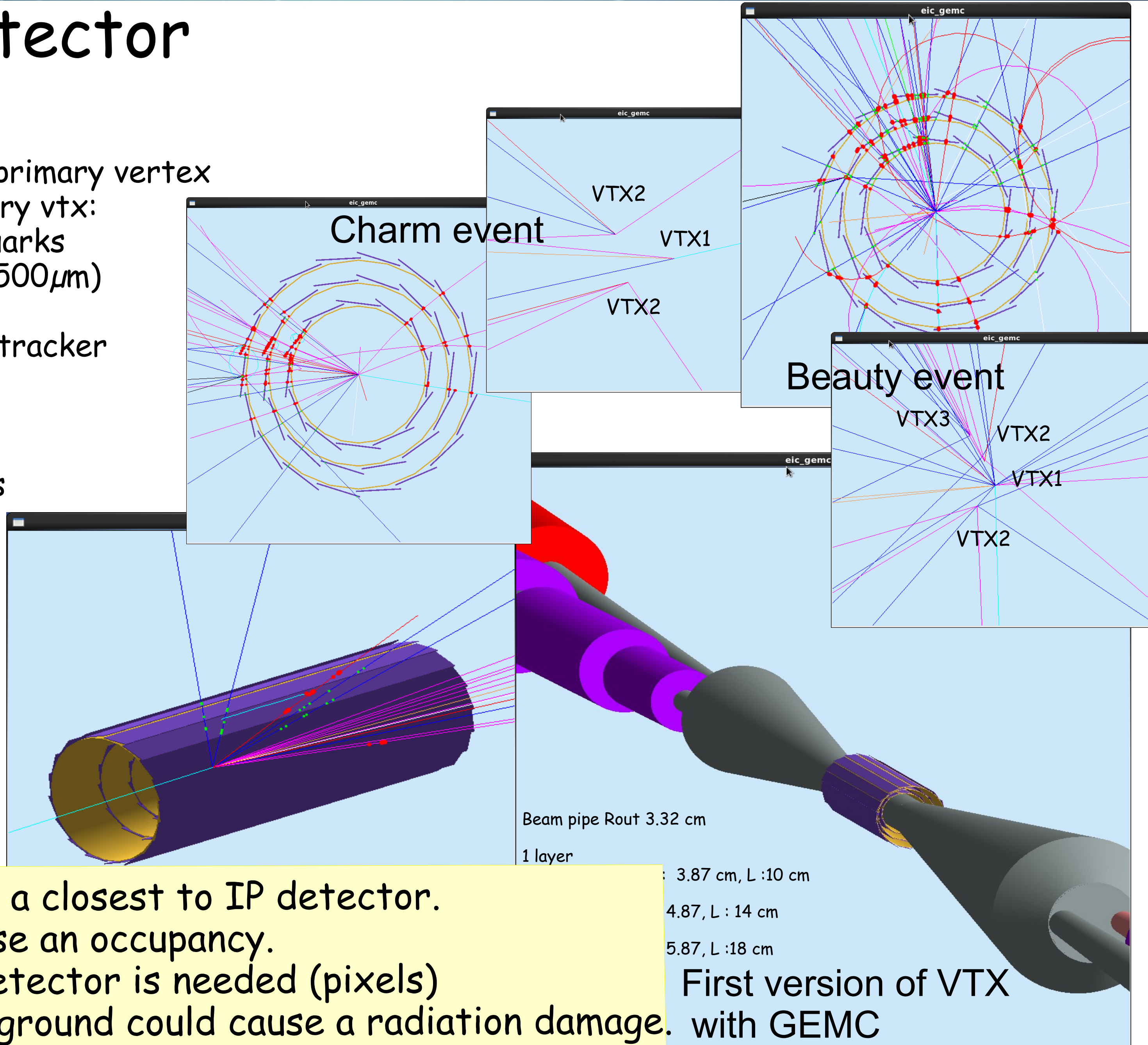


HBD and TRD combined with a tracker could improve e/hadron separation in endcaps. R&D is needed.

Vertex detector

Main purpose:

-Reconstruction of a primary vertex
-Reconstruct secondary vtx:
 Tagging of c and b quarks
 (decay length ~100-500μm)
-improve momentum
 resolution of outer tracker
-provide stand-alone
measurements
of low-Pt particles
-dE/dx measurements
for PID



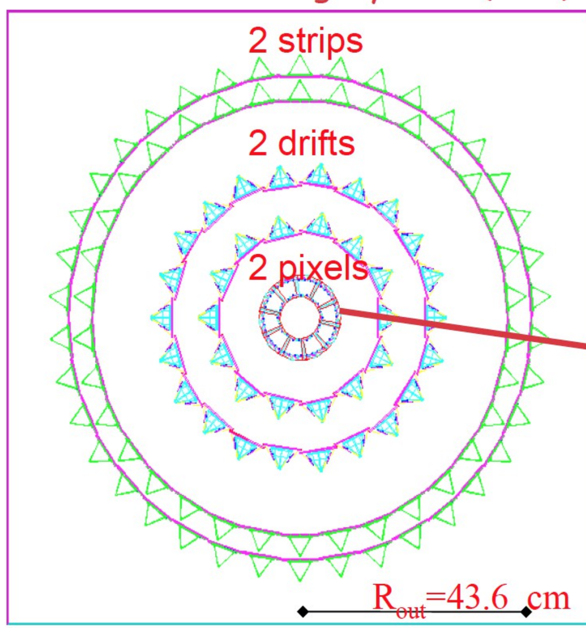
Vertex detector is a closest to IP detector.
Background increase an occupancy.
High granularity detector is needed (pixels)
Beam related background could cause a radiation damage.

Vertex detector technologies (MAPS)

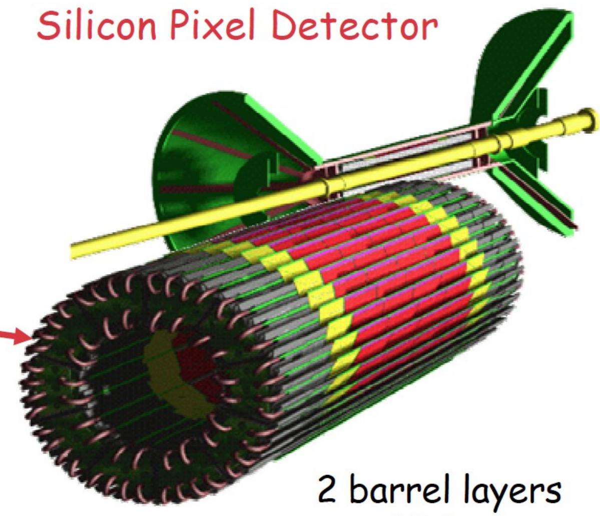
ALICE:
1 layers (with support)
≈ 1 % X/X_0
10 millions pixels
Integration time 30μs

STAR:
1 ladder 0.39% X/X_0
50μm thickness
Pixel size 20.7x20.7 μm^2
356 millions pixels
R1=2.8 cm, R2=8cm
Integration time 185.6 μs

The Inner Tracking System (ITS)



ALICE at LHC



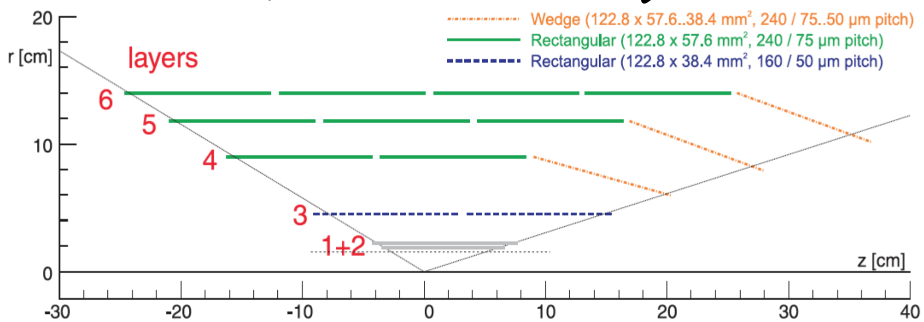
2 barrel layers
Δz= 28.3 cm
r= 3.9 cm & 7.6 cm

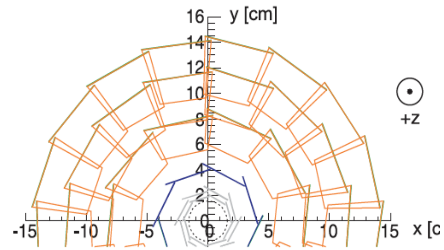
VERTEX 2003 Conference P. Riedler/ALICE SPD 3

Need to optimize material budget in order
to reduce a multiple scattering.
Optimize a readout time (occupancy)
Cooling for electronics is needed.
EIC R&D is ongoing

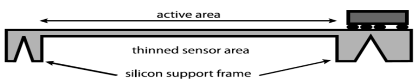
Example of vertex detector Technology (DEPFET, BELLE-II)

1-2 PXD: DEPFET pixel sensors
3-6 SVD: double-sided strip sensors



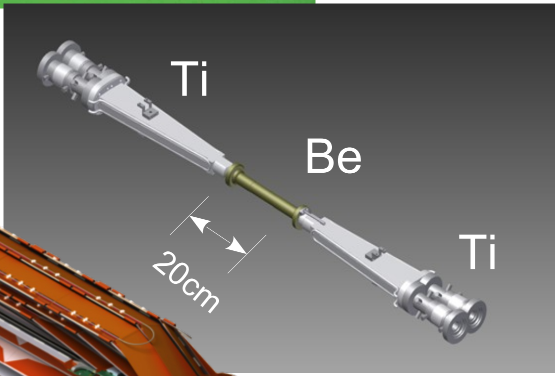


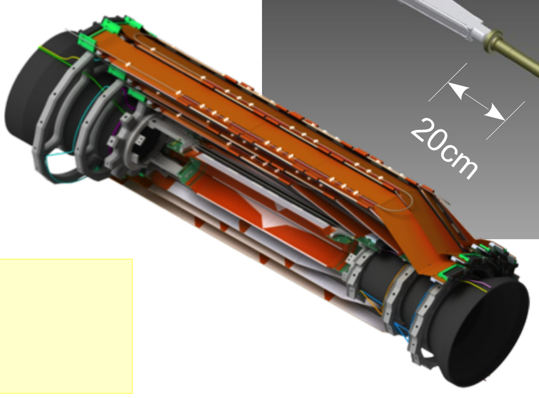
PXD:
-8 millions pixels
-1 ladder : 0.19 % X_0
-thickness 50µm

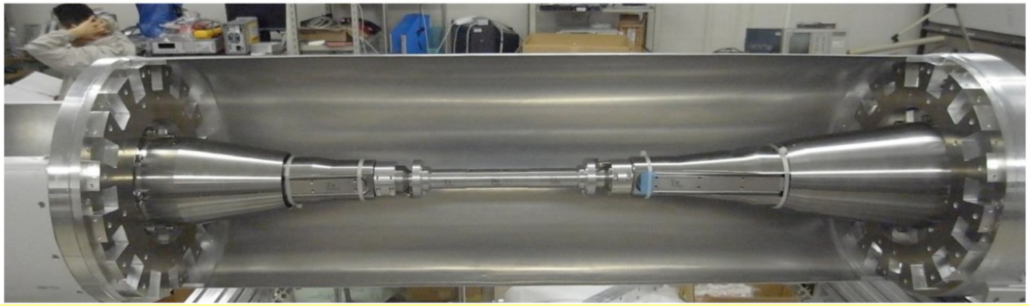


-Integration time ~10µs
-price for vertex ~R
(2.5 M$ for L ~12 cm R ~1 cm)

- Inner most layer: 2cm (Belle) -> 1.4cm (BelleII)
- Outer coverage: 8cm (Belle) -> 13.5cm (BelleII)



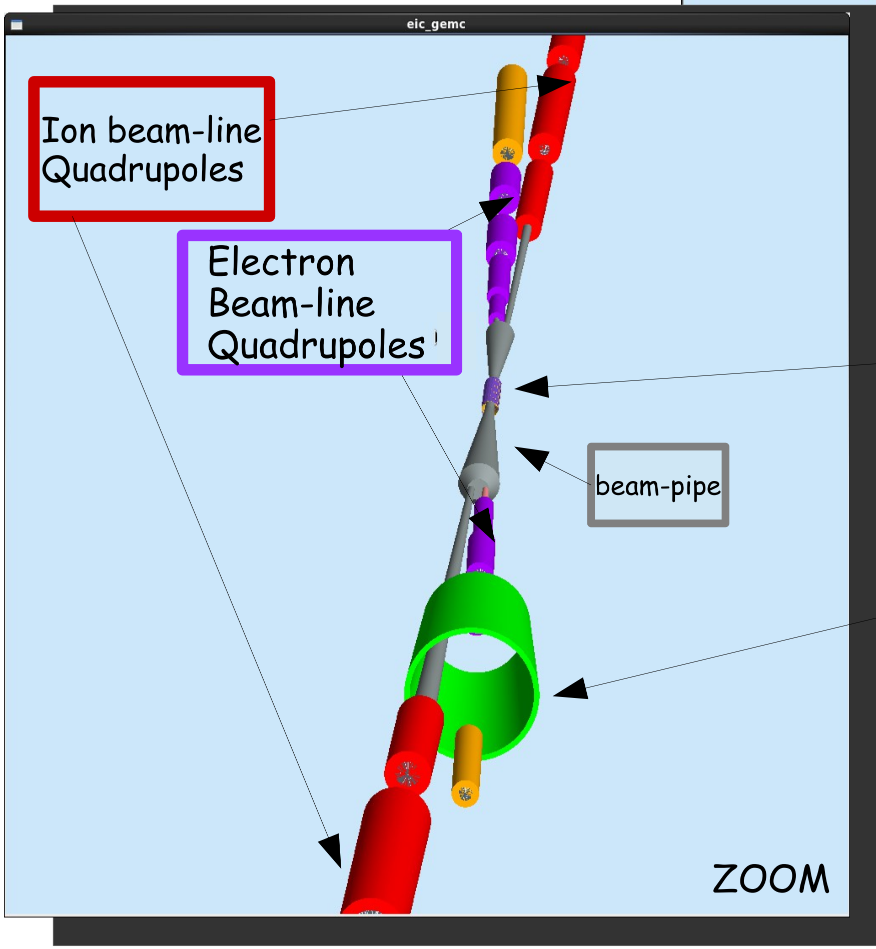


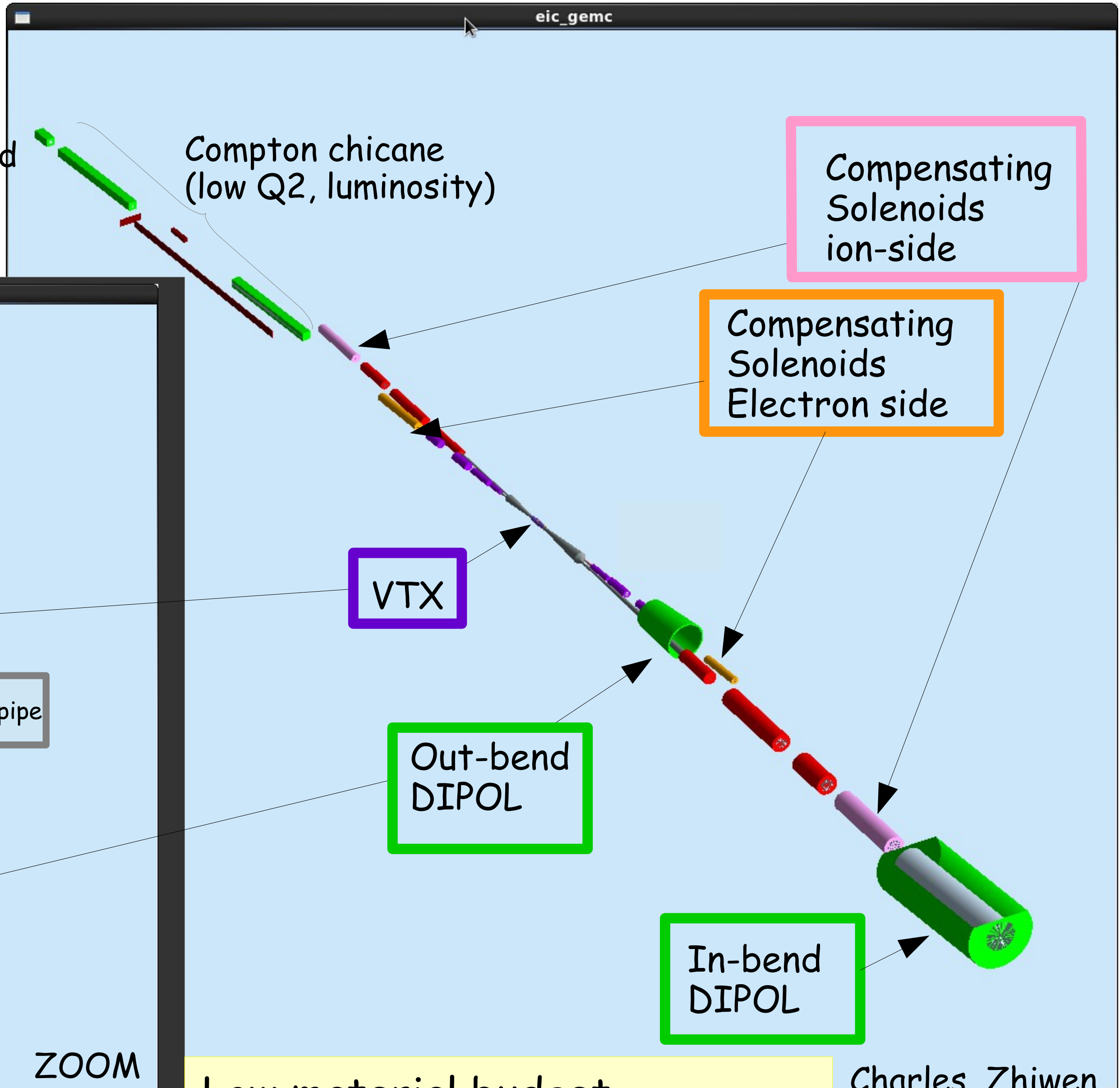


Low material budget device
Good integration of vertex with beam pipe.

Beam Line

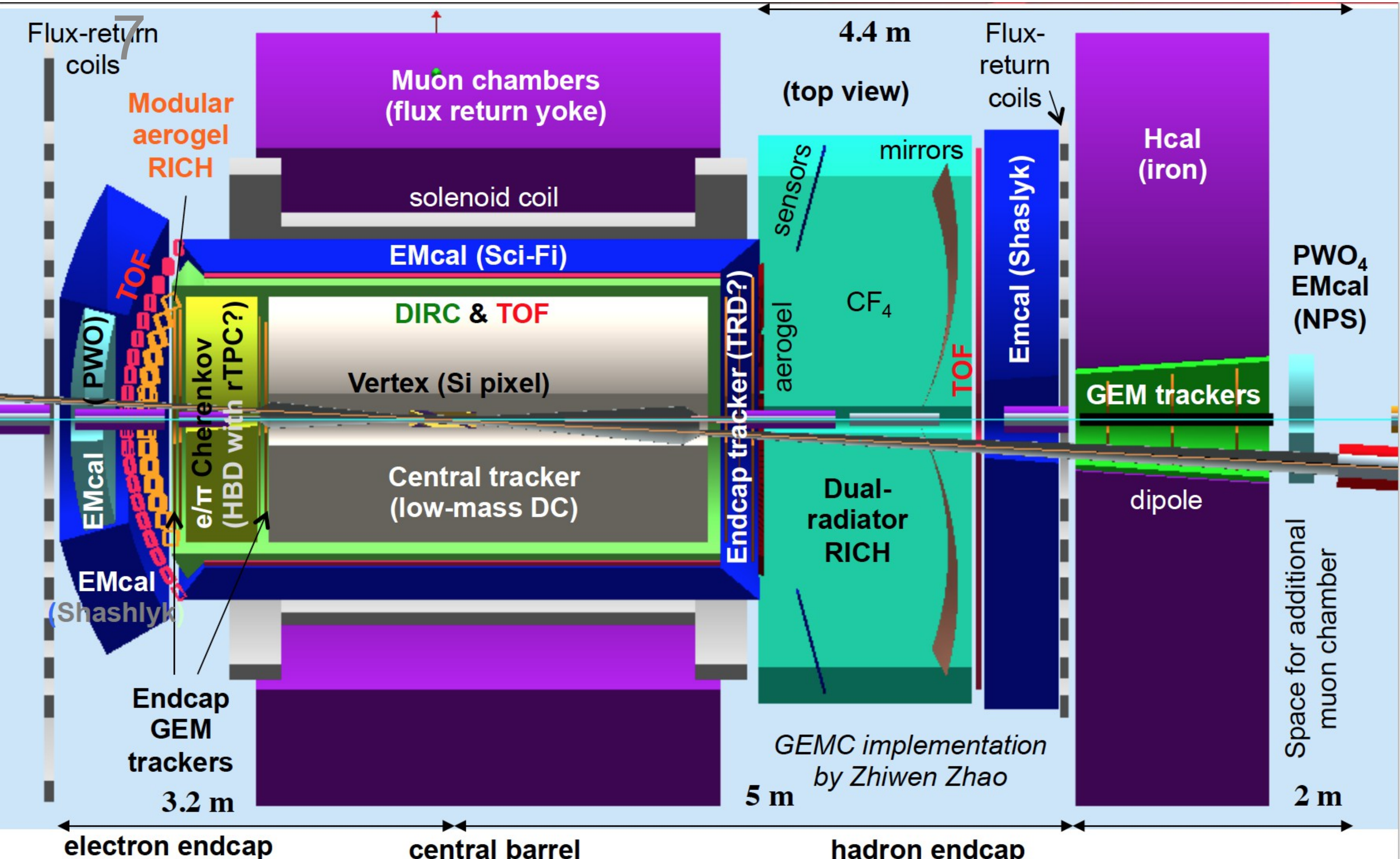
- Crossing angle 50mrad
- Beam-pipe symmetry axis at 25mrad





Low material budget
within an interaction region

Central detector overview



Modular design of the central detector

Accelerator related aspects

- **Beam pipe in interaction region:**
  - minimize multiple scattering (see talk by Charles Hyde)
- **Detector solenoid field:**
  -independent from beam optics
  -set detector field independent from accelerator settings
- **Background**
  -synchrotron radiation (see talk by Mike Sullivan)
  -vacuum/beam gas background
  -neutrons

Background Estimates

Pawel Nadel-Turonski

The signal-to-background ratio

HERA luminosity reached ~ 5×10^{31} $cm^{-2}s^{-1}$

The EIC (and the JLEIC in particular) aims to be close to 10^{34} $cm^{-2}s^{-1}$

The conditions at the JLEIC compare favorably with HERA

Typical values of *s* are 4,000 GeV^2 at the JLEIC and 100,000 GeV^2 at HERA

Distance from arc to detector: 65 m / 120 m = 0.54

p-p cross section ratio σ(100 GeV) / σ(920 GeV) < 0.8

Average hadron multiplicity per collision $(4000 / 100000)^{1/4} = 0.45$

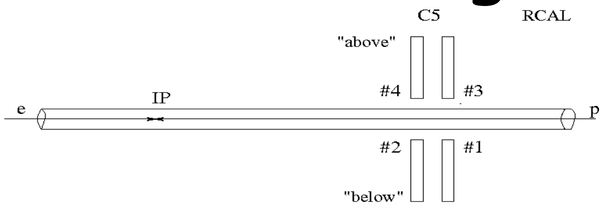
Proton beam current ratio: 0.5 A / 0.1 A= 5

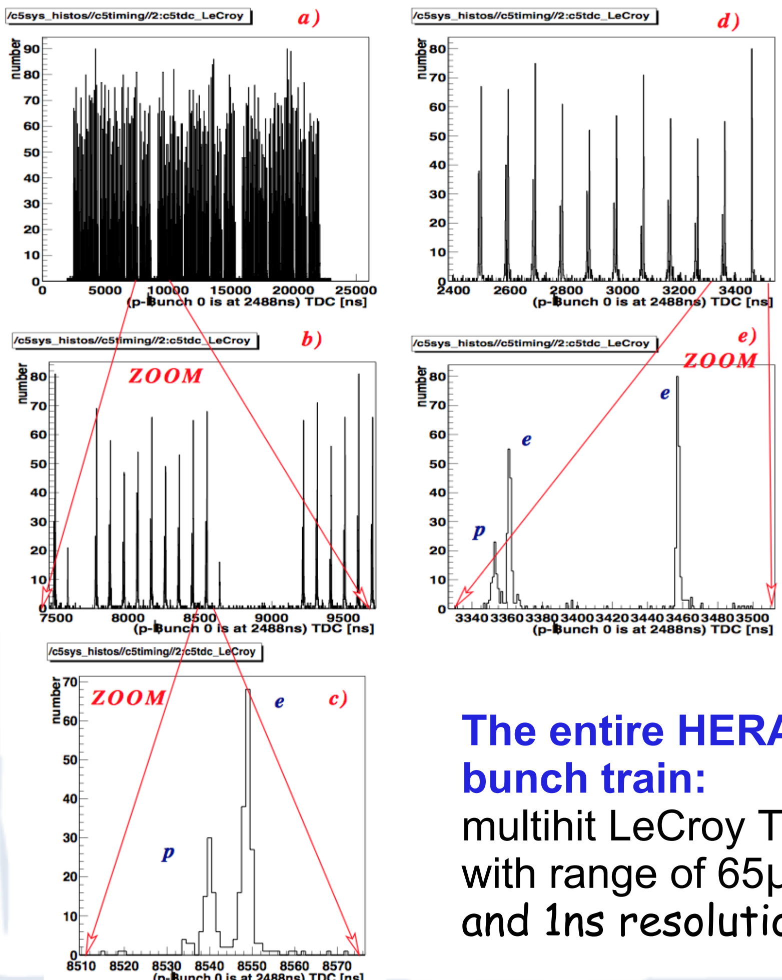
At the *same vacuum* the JLEIC background is 0.54*0.8*0.45*5 = 0.97 of HERA

But JLEIC vacuum should be closer to PEP-II (10^{-9} torr) than HERA (10^{-7} torr)

Need to estimate and monitor a background

C5 beam background monitor detector at ZEUS





Scintilators

- 3mm thick SCFN36, 20x20cm^2 octogon covered by tangsten , Hamamatsu (R647) photomulteplier s (PMTs), from IP Z= **-1.2m**

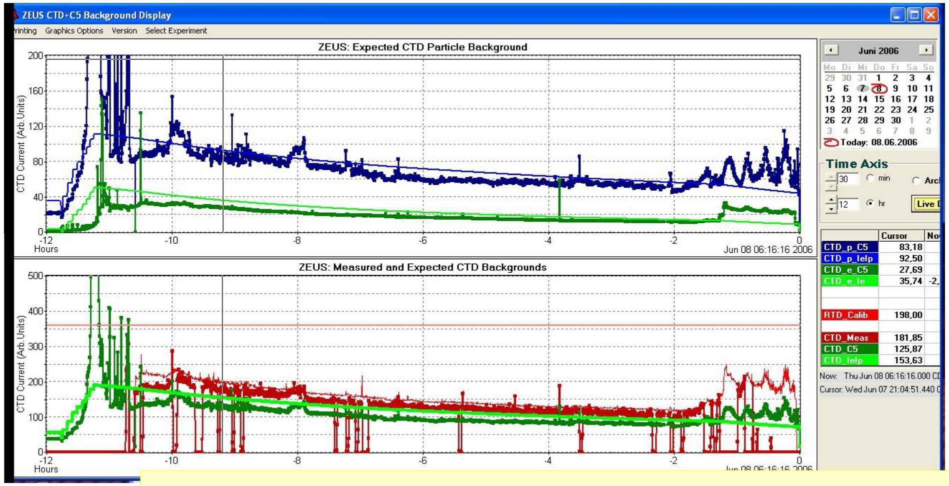
HERA 96ns bunch spacing

220 x 96 ns = 21.12 μs.

Primary use of the C5 detector are:

- ✔ Monitoring and controlling HERA beam conditions at ZEUS: bunch occupancy, satellite bunch intensity, etc.
- ✔ Background monitor
- ✔ Average Z-vertex position Z(IP)=(T(p)-T(e)) c/2 -Z(c5)
- ✔ VETO at the ZEUS GFLT to reduce background event rates

The entire HERA bunch train:
multihit LeCroy TDC with range of 65μs and 1ns resolution.



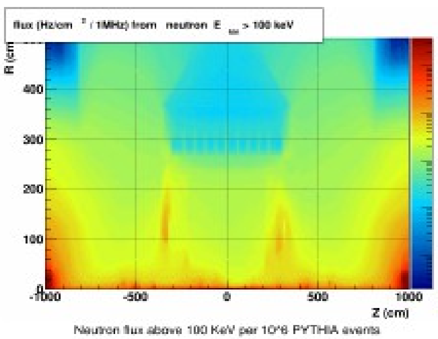
Important subdetector at HERA

Yulia Furletova

Neutron flux

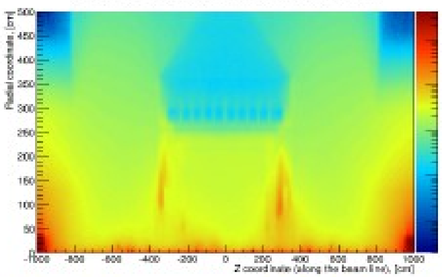
Radiation Damage in SiPMs

New calculation to estimate neutron fluences in BeAST Detector



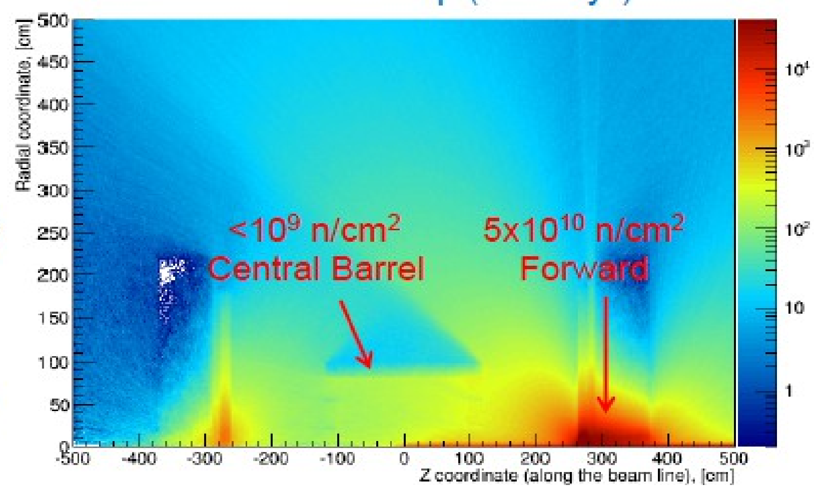
STAR
(Y.Fisyak)

100x100 GeV
pp



EICRoot
(A.Kiselev)

20x250 GeV ep (100 days)



Calculations verified for STAR 2014 detector configuration

Model of BeAST detector in STAR Hall w/o beam line elements and no return yolk

These ***very preliminary*** results indicate that the neutron fluences at EIC may be lower than those observed at RHIC

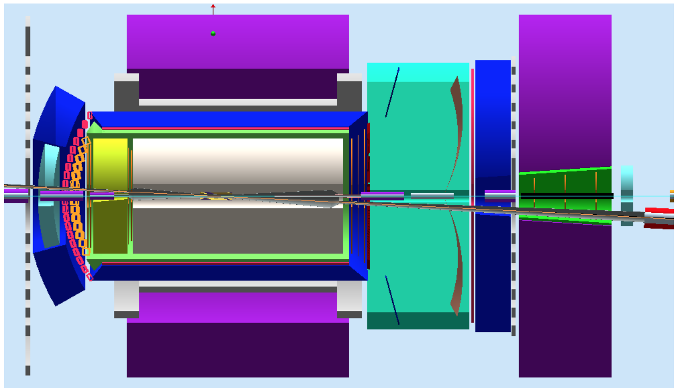
C.Woody, EIC R&D Comm

Important to know neutron flux, especially for vertex detector and for readout- electronics. Need to have similar estimates at JLEIC

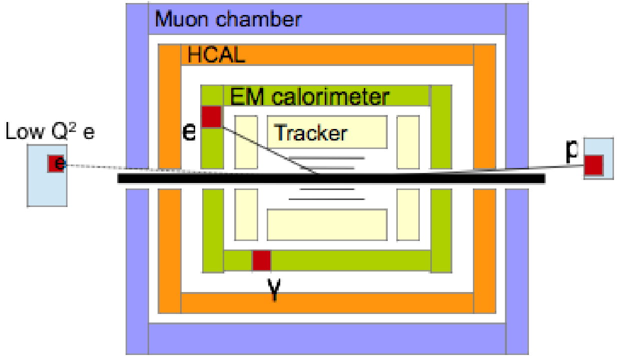
One detector or two?

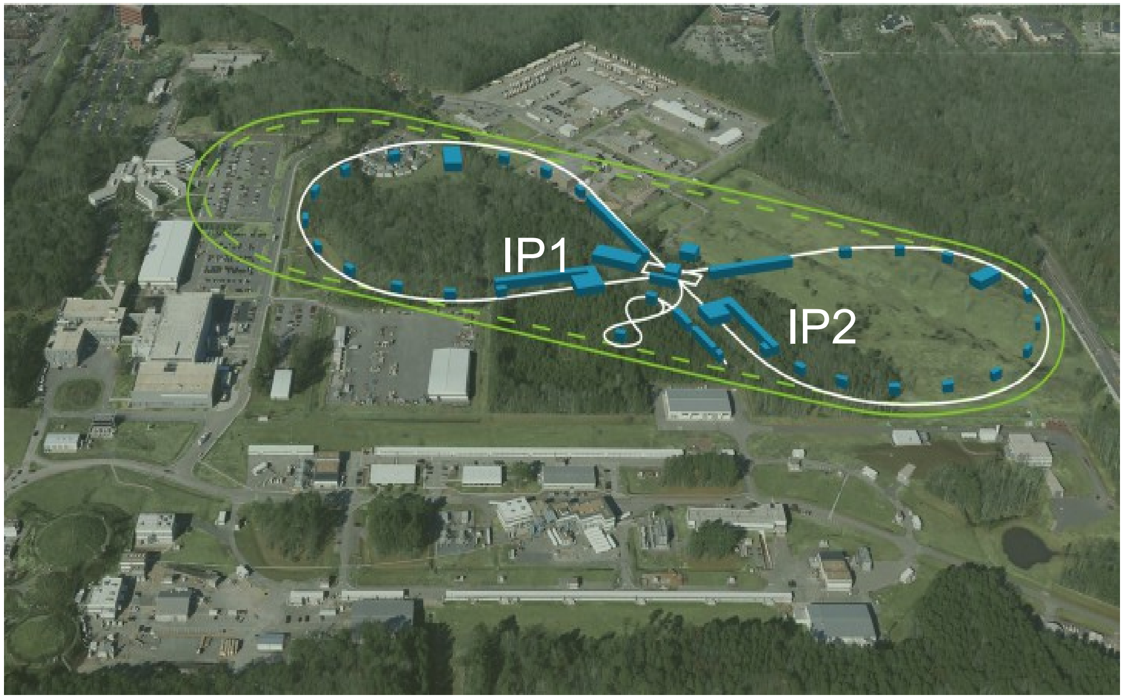
- 1^{st} IP (white paper): focuses on single particle reconstruction and identification
- 2^{nd} IP: compact and focuses on calorimetry- jets

1^{st} IP



2^{nd} IP





- Combine results for precision measurements
- Increase scientific productivity
- Cross-checks on discoveries and important physics results

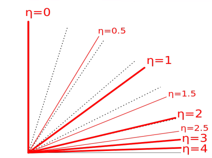
JLEIC accelerator design offers the second IP !

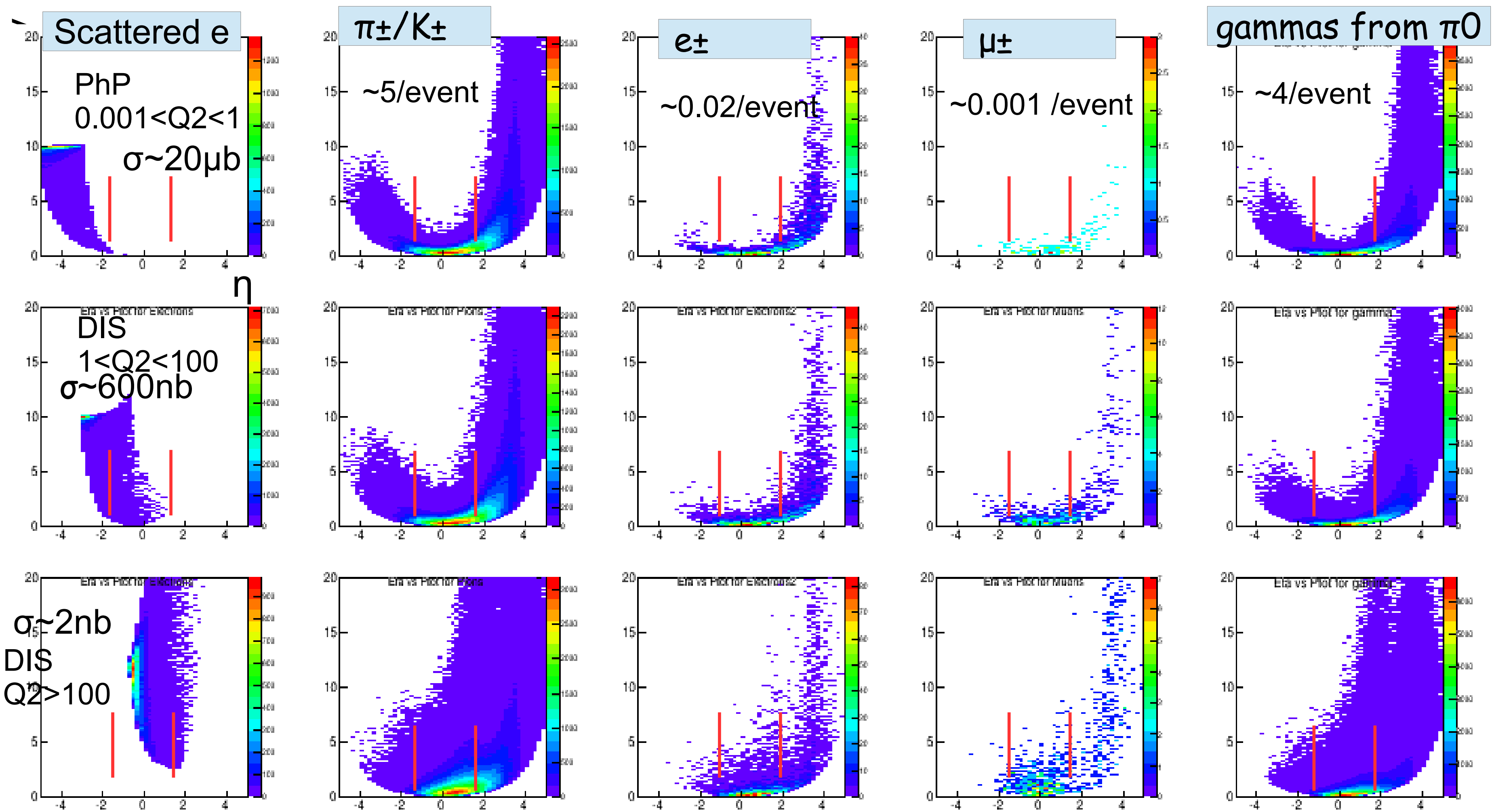
Summary

- Detector simulations and optimizations are in the progress
- R&D is ongoing for some of components
  (DIRC, RICH, TOF , CAL , Tracking-TPC, GEM)
- Need to extend R&D program (vertex, tracking, TRD, muons)
- Need to understand/estimate possible background

- Backup
-

e/π separation Minimum bias (e/p 10 GeV /100 GeV)

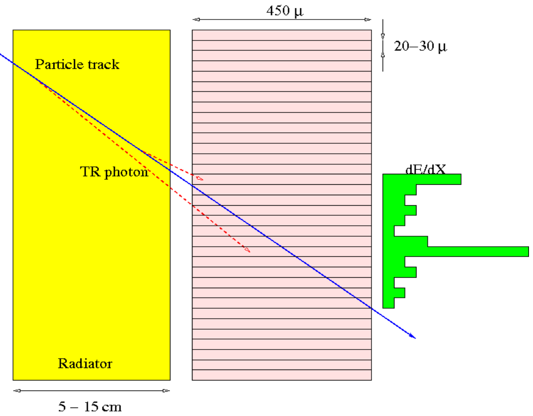


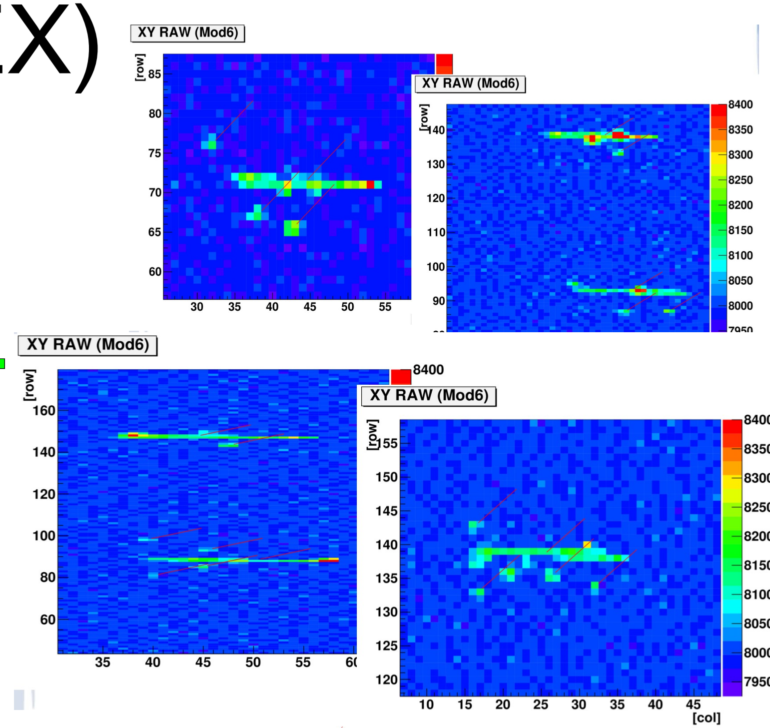


High pion background in forward region (hadron endcap)
EM calorimeter could provide rejection factor up to 100
Additional e/π identification is needed

Silicon pixel TRD (VERTEX)

Replacing the Xenon based gaseous detectors with modern silicon detectors is complicated by the huge dE/dX of particles in 300-700μm of silicon - about 100-300keV (TR photons 4-40 keV).



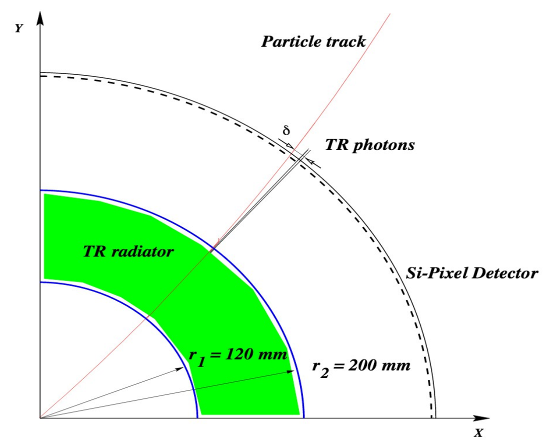


1. DEPFET based. measure dE/dX on track, and natural angular distribution.

- DEPFET silicon pixel detector with 450 μm thick fully depleted bulk(sensitive area), pixel size – 20x20μm^2 .
- Radiator - fleece 10cm.
- Test beam results with 5GeV electrons (DESY)
- TR photons are clearly visible and separated from track by a few pixels!

2. Separation of TR and dE/dX in different pixels in magnetic field

- Proposal for ILC VTX
- Large magnet needed- limitation on momentum of a charge particle.



Combined vertex and e/hadron identification
Additional R&D is needed.