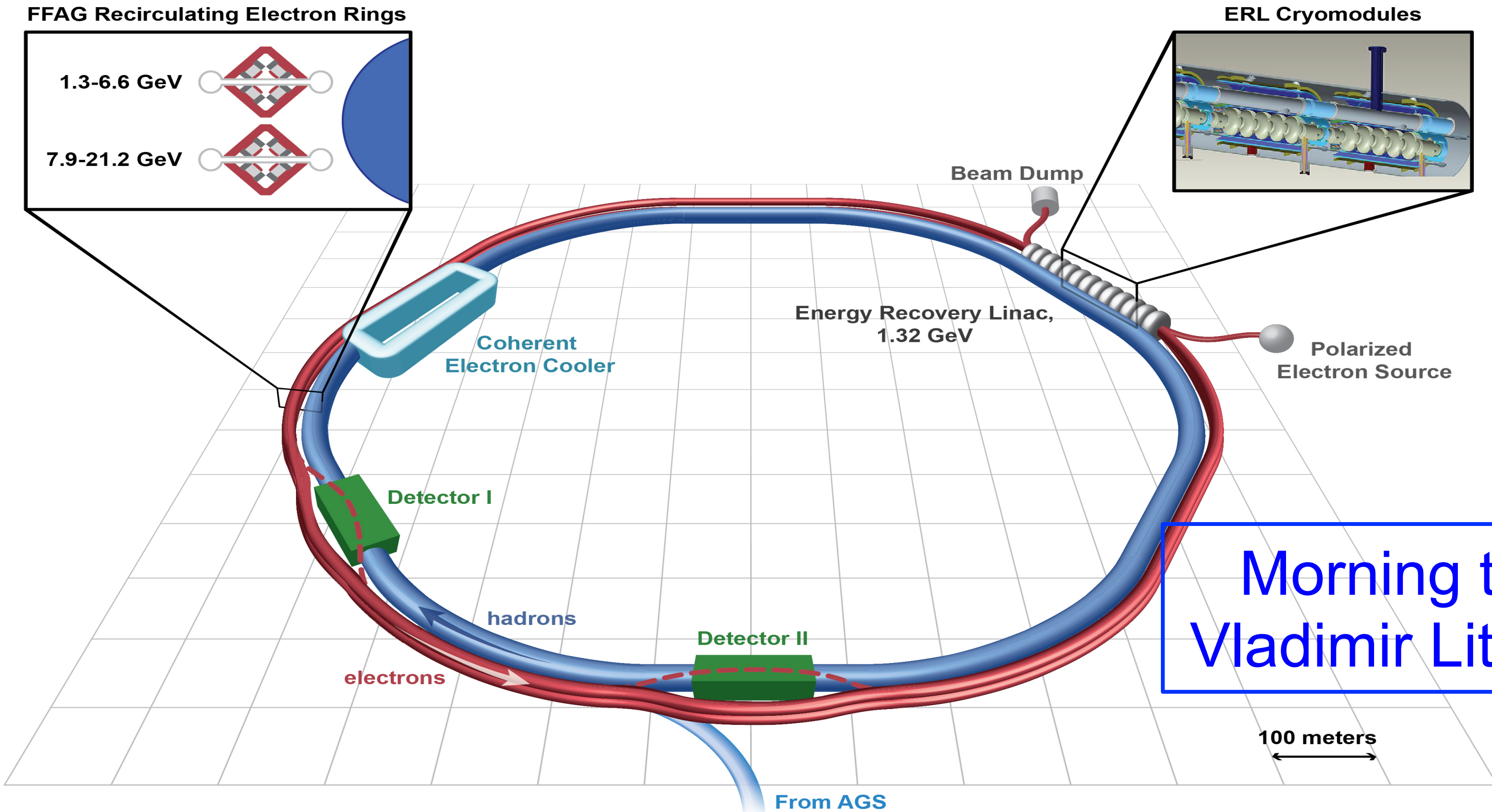
A dedicated eRHIC Detector Design

Alexander Kiselev for the BNL EIC taskforce

DIS 2016 Workshop DESY Hamburg

RHIC -> eRHIC upgrade proposal

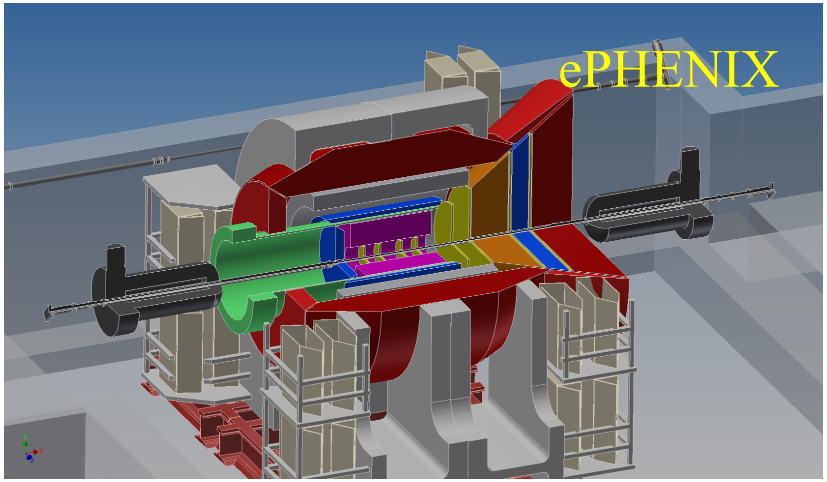


Morning talk by
Vladimir Litvinenko

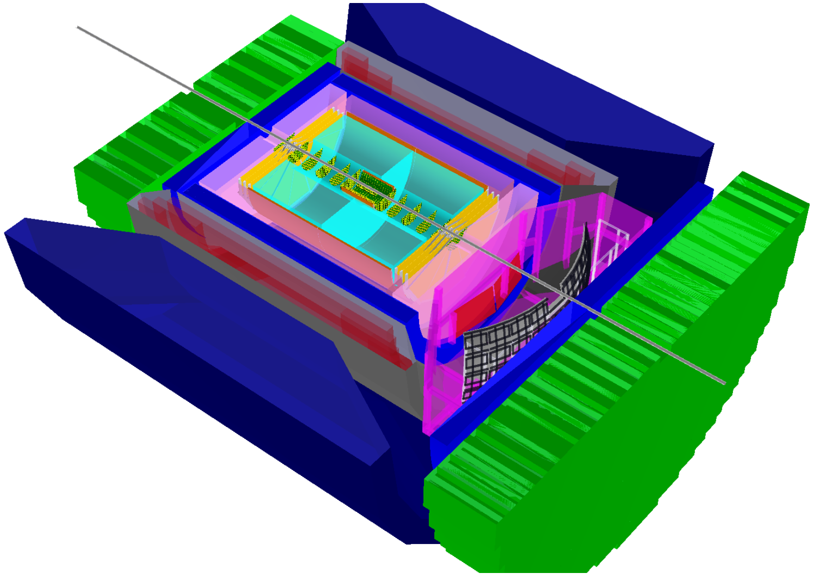
by 2025 convert RHIC to an electron-ion collider by adding ~21 GeV electrons to the existing hadron ring facility (arXiv 1409.1633)

Two viable eRHIC detector options

- Upgrade sPHENIX to ePHENIX



- Build a new detector: BeAST (Brookhaven eA Solenoidal Tracker)

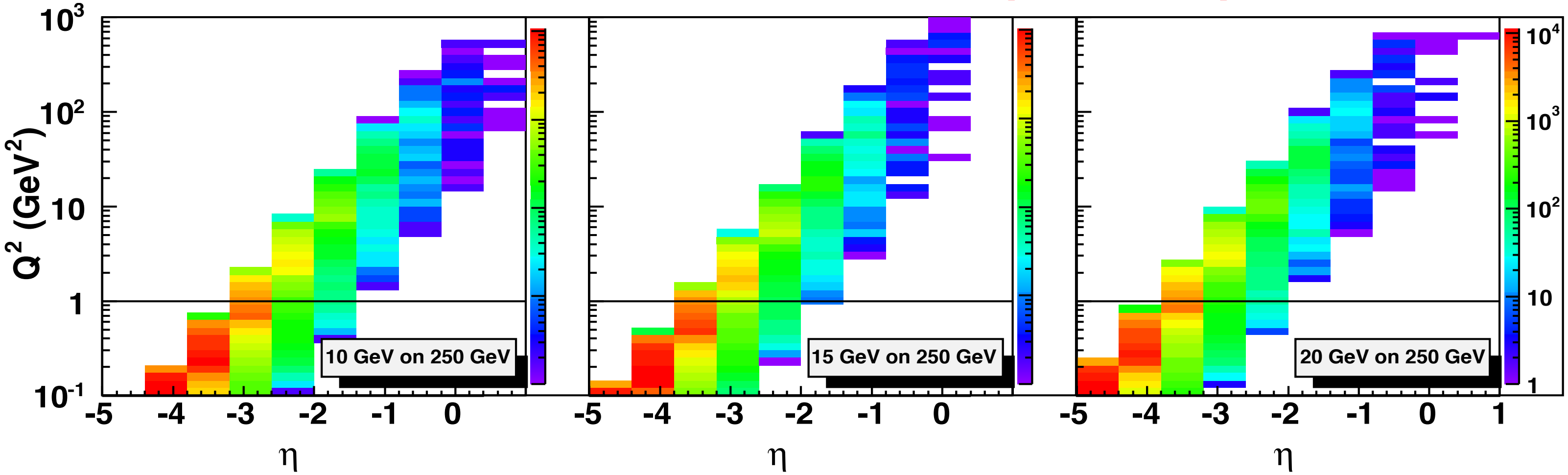


A “perfect” DIS detector requirements

- The more close to 4π acceptance the better
- Reach in kinematic variables
- Reliable electron identification
- Good hadron PID
- High spatial resolution of primary vertex
- Low material budget

- Luminosity and polarization measurement
- Close-to-beam-line acceptance add-on detectors in order to register:
  - recoil protons
  - low Q^2 electrons
  - neutrons in hadron going direction

Lepton kinematics and (x,Q^2) coverage



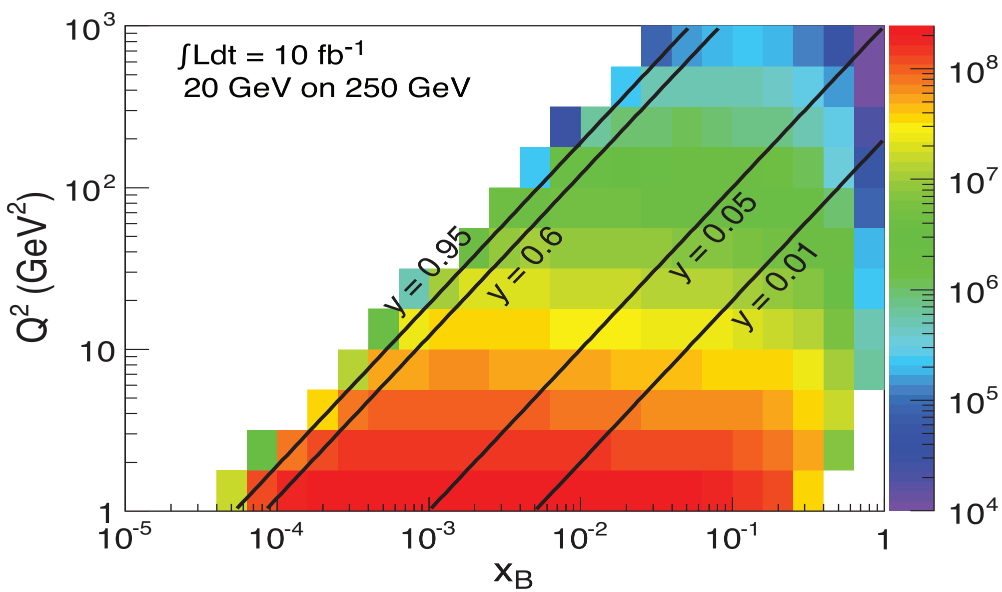
→ $Q^2 > 1.0$ GeV^2: rapidity coverage $-4 < \eta < 1$ is sufficient

→ $Q^2 < 0.1$ GeV^2: a dedicated low-Q^2 tagger is required

Increasing lepton beam energy: scattered lepton is boosted to negative η

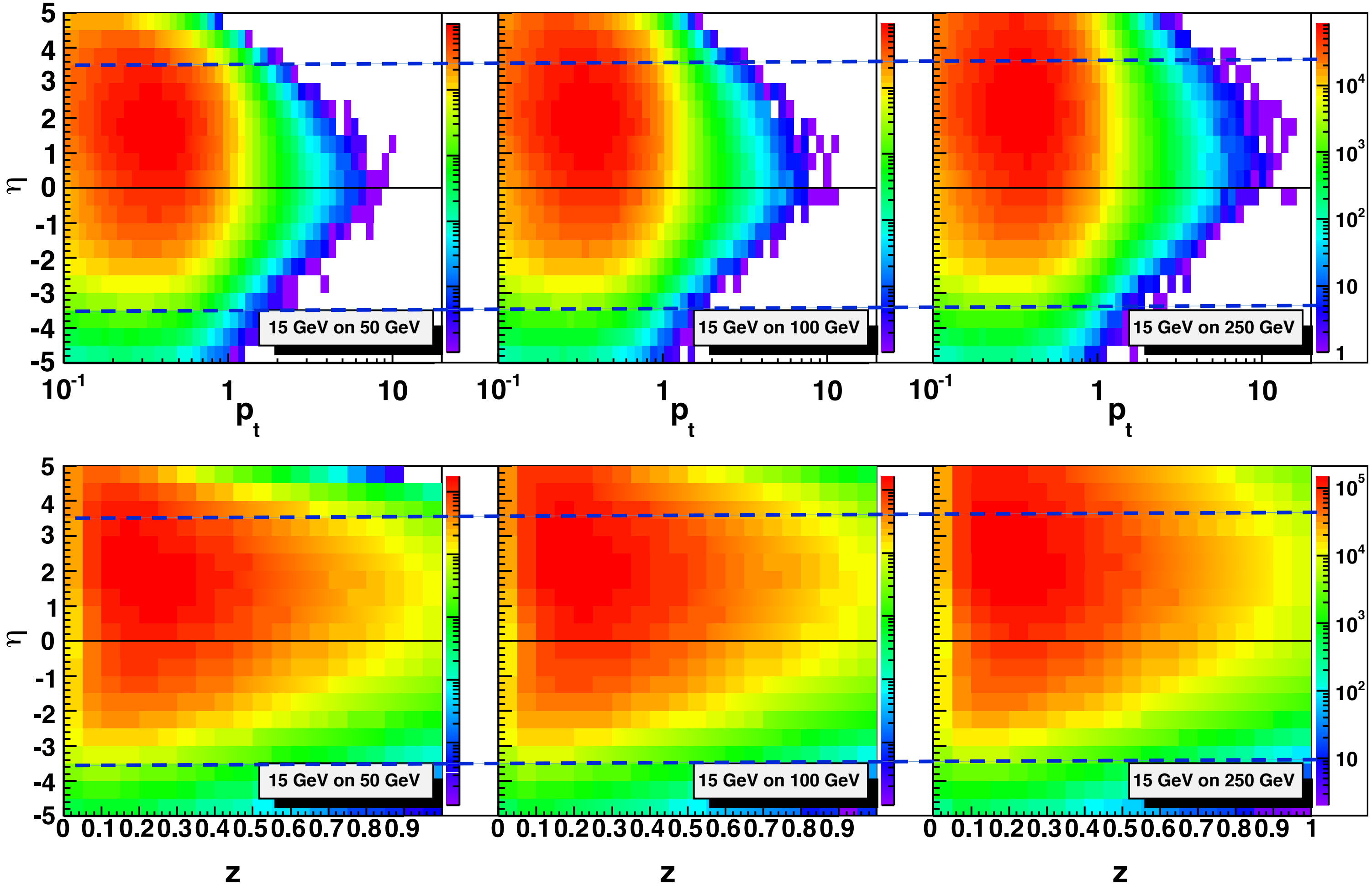
low y-coverage limited by E'_e resolution

-> use hadron or double angle method to reconstruct event kinematics



SIDIS: kinematic coverage for pions

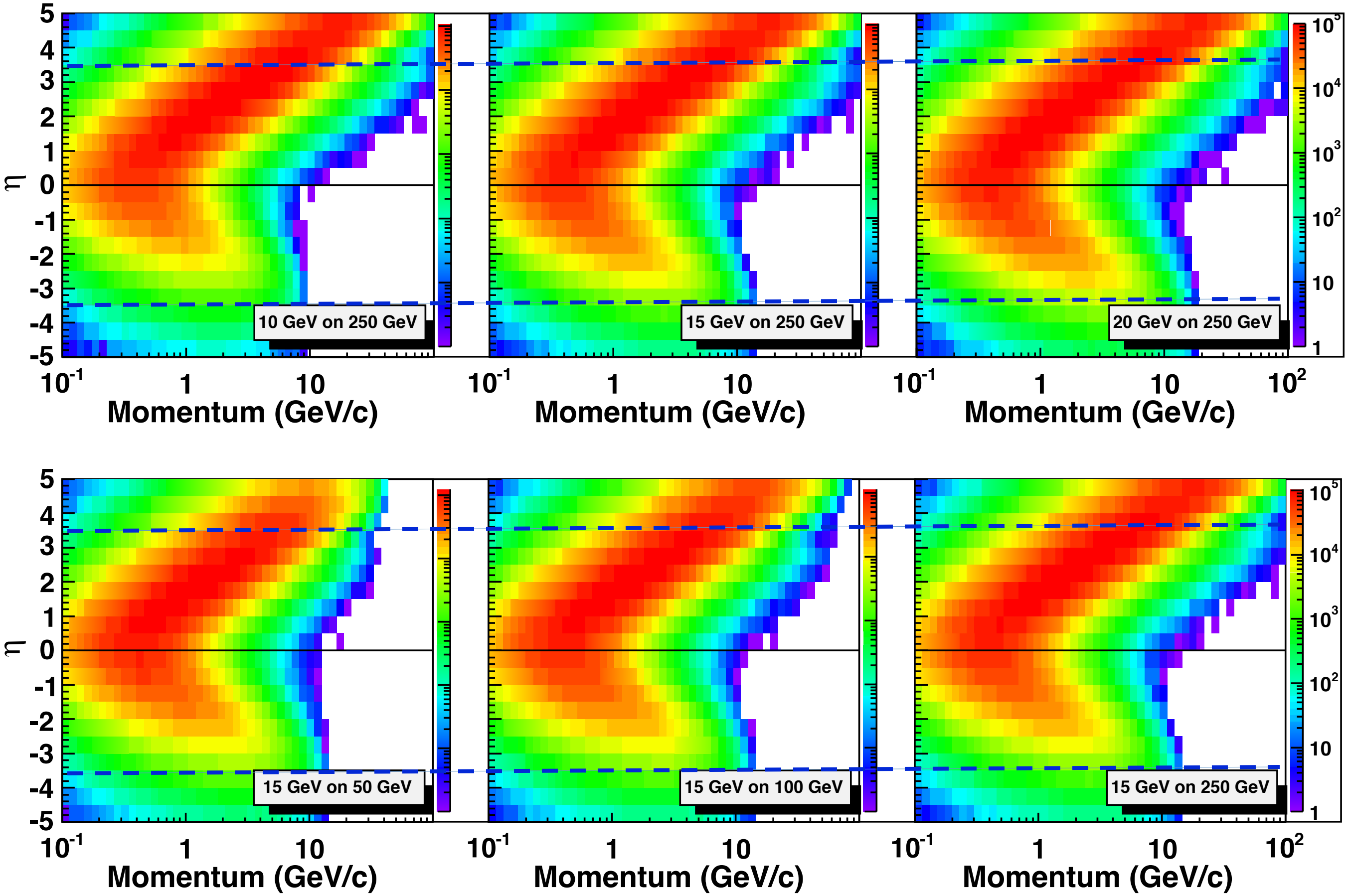
Cuts: $Q^2>1$ GeV^2, $0.01<y<0.95$, $p>1$GeV (no difference between $\pi^\pm$, $K^\pm$, $p^\pm$)



-> $-3.5 < \eta < 3.5$ covers entire kinematic region in p_t & z important for physics

SIDIS: kinematic coverage for pions

Cuts: $Q^2>1$ GeV^2, $0.01<y<0.95$, $z>0.1$ ($\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ look similar)



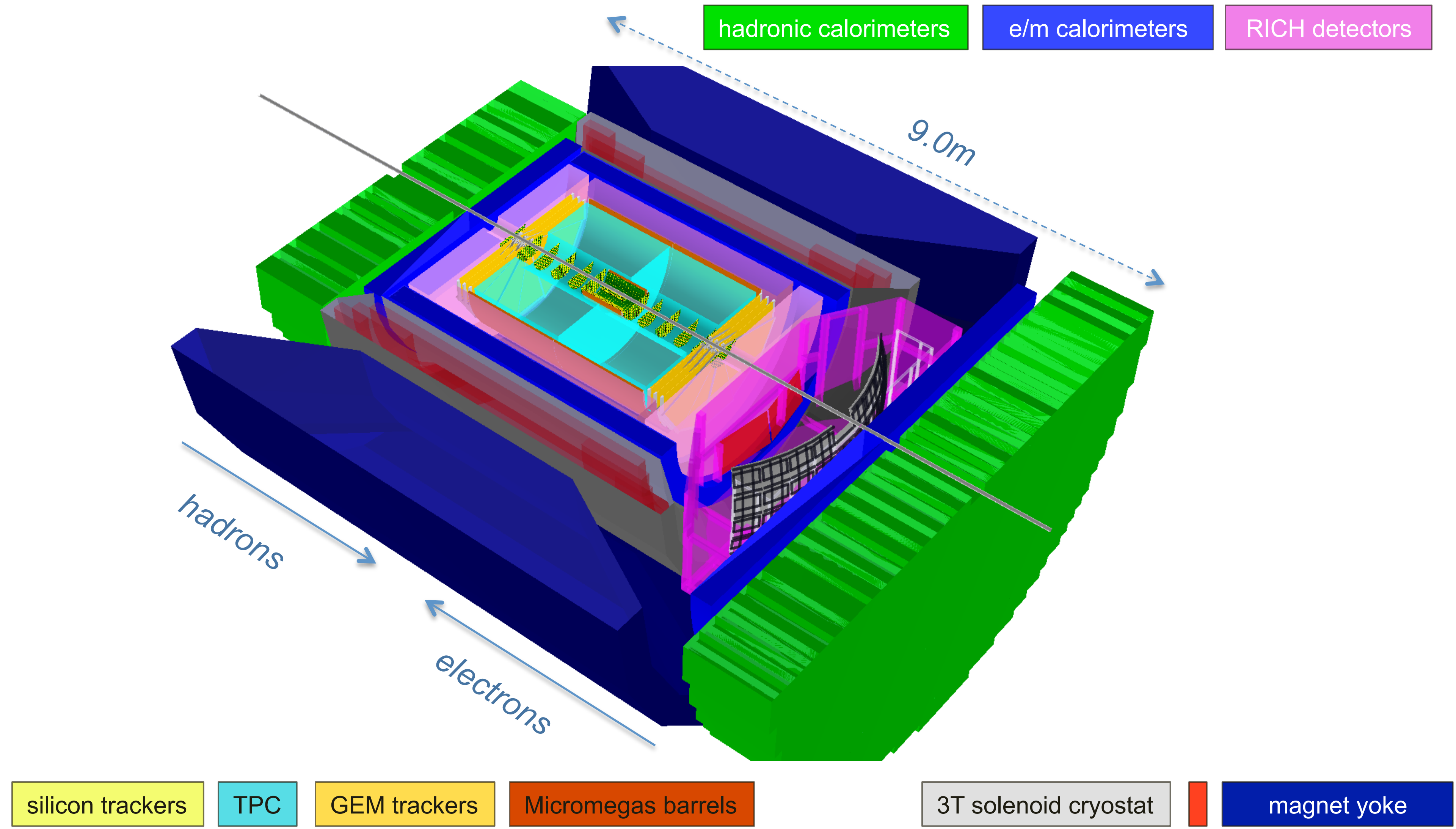
Increasing lepton beam energy boosts hadrons more to negative rapidity

Increasing hadron beam energy influences max. hadron energy at fixed η

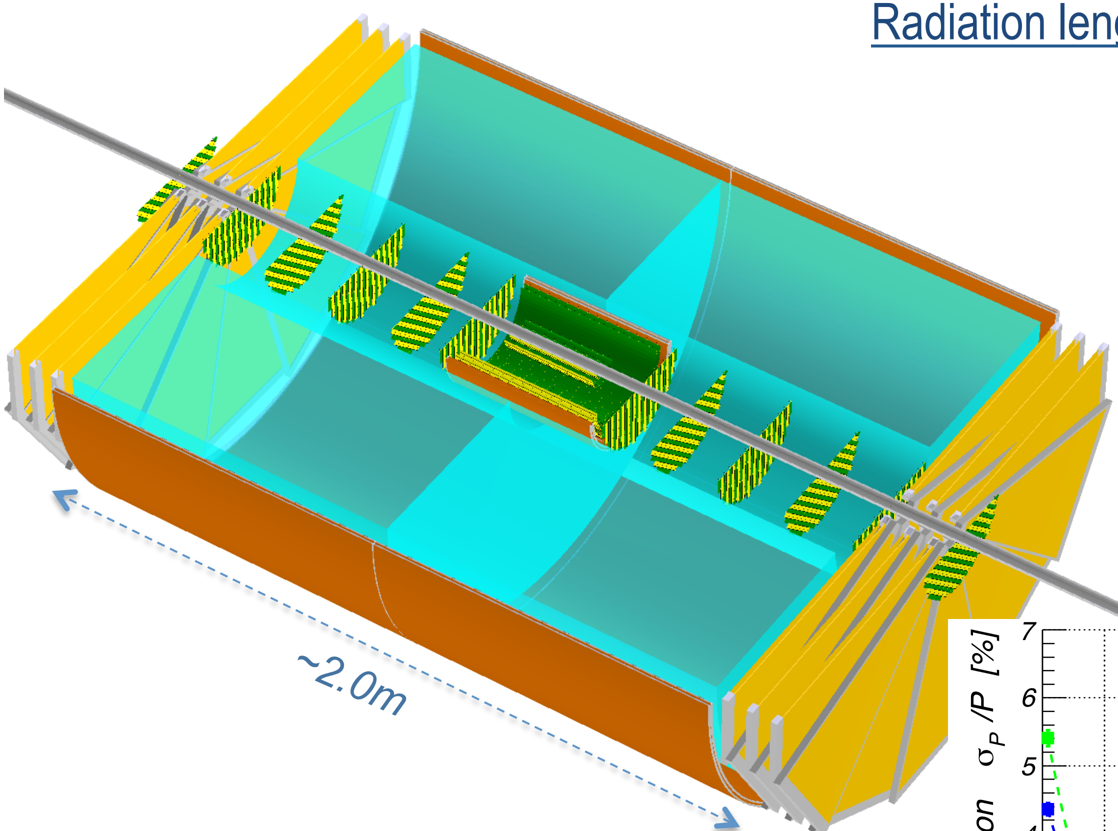
-> except for the highest η values ($1.5 < \eta < 3.5$ range) hadron PID below ~5 GeV/c is sufficient

BeAST detector layout

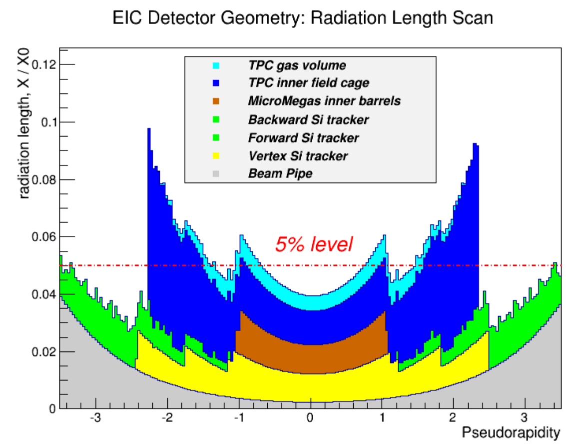
-3.5 < η < 3.5: Tracking & e/m Calorimetry (hermetic coverage)



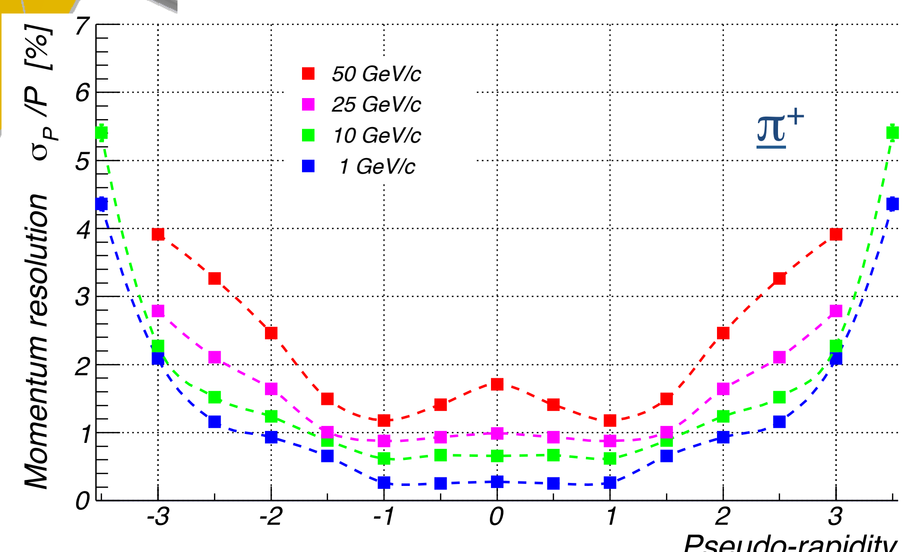
Tracker performance & properties



Radiation length scan (inner tracking elements only)



Momentum resolution

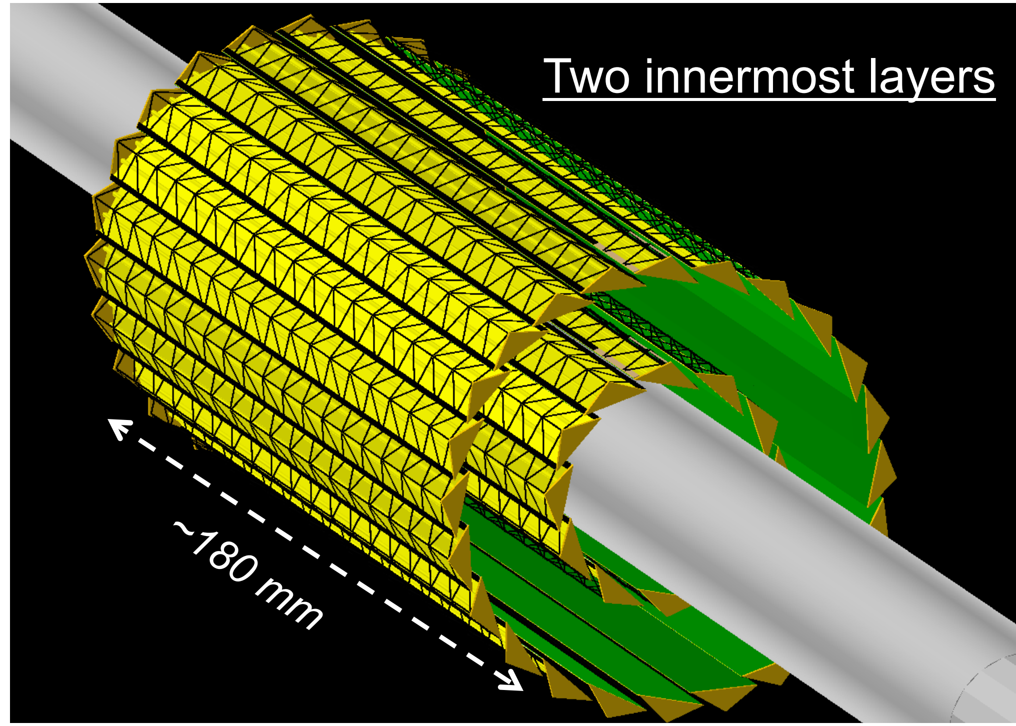


- High redundancy
- Low material budget
- High resolution up to (at least) $|\eta|$~3

Silicon Vertex Tracker

ALICE ITS design

- 2x2 barrel layers with high resolution MAPS
- assume discrete 20x20 μm^2 pixels and ~0.3% X_0 per layer



The prototype (ALICE ITS TDR page)

J. Phys. G: Nucl. Part. Phys. **41** (2014) 087002 The ALICE Collaboration

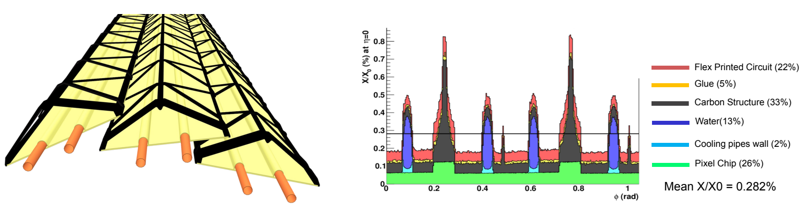
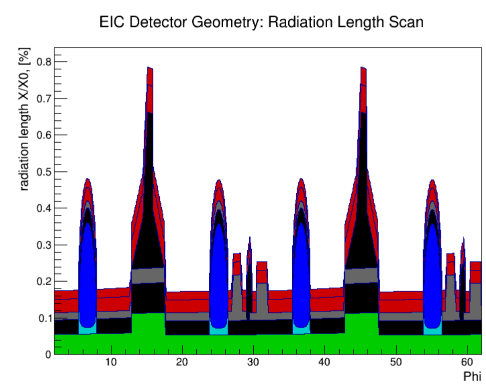


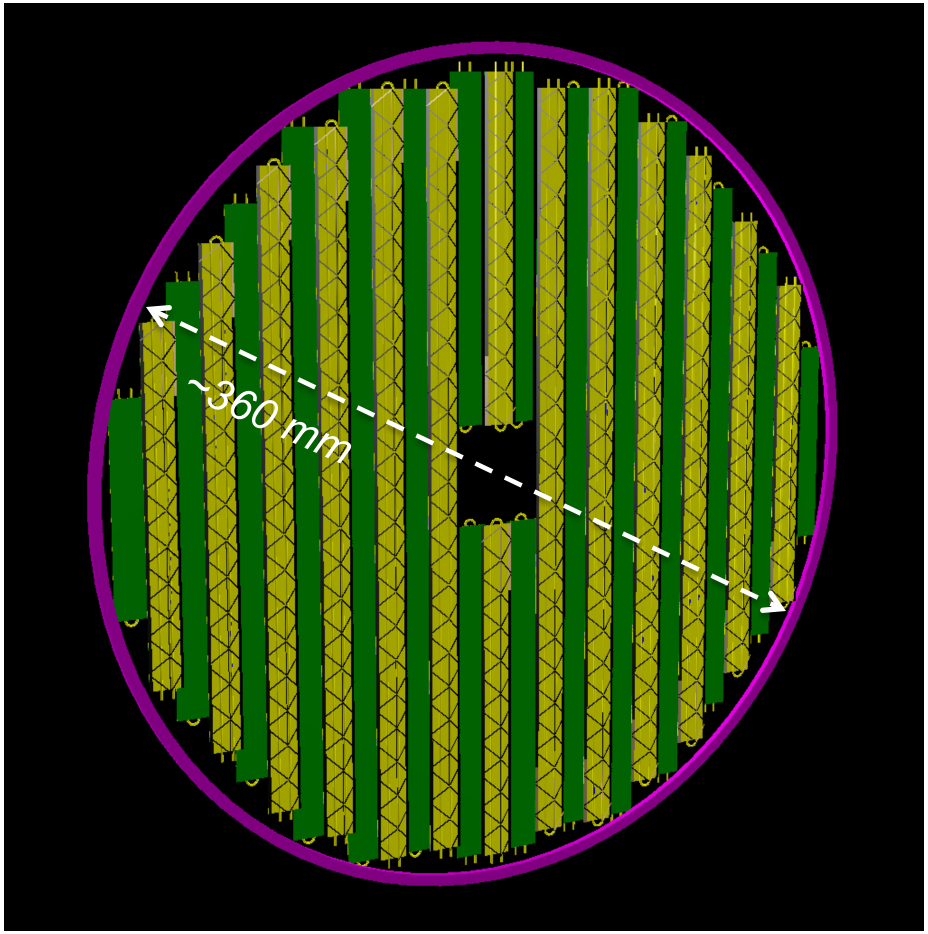
Figure 4.3: A detail of the Stave overlaps of the Inner Layers (left) and the corresponding material budget distribution (right). The highest peaks correspond to the overlap of the reinforced structures at the edges of the Space Frame, while the narrow spikes to the reinforcement at the upper vertex. The peaks around 0.5 % X_0 are due to the polyimide cooling pipes fully filled of water.



- Radiation length scan (single layer)

Forward & backward Silicon Trackers

- 2x7 disks with 30 .. 180 mm radius
- for now assume the same building blocks (complete staves) as in the vertex tracker
- Final configuration can be a combination of ALICE ITS and MFT upgrades

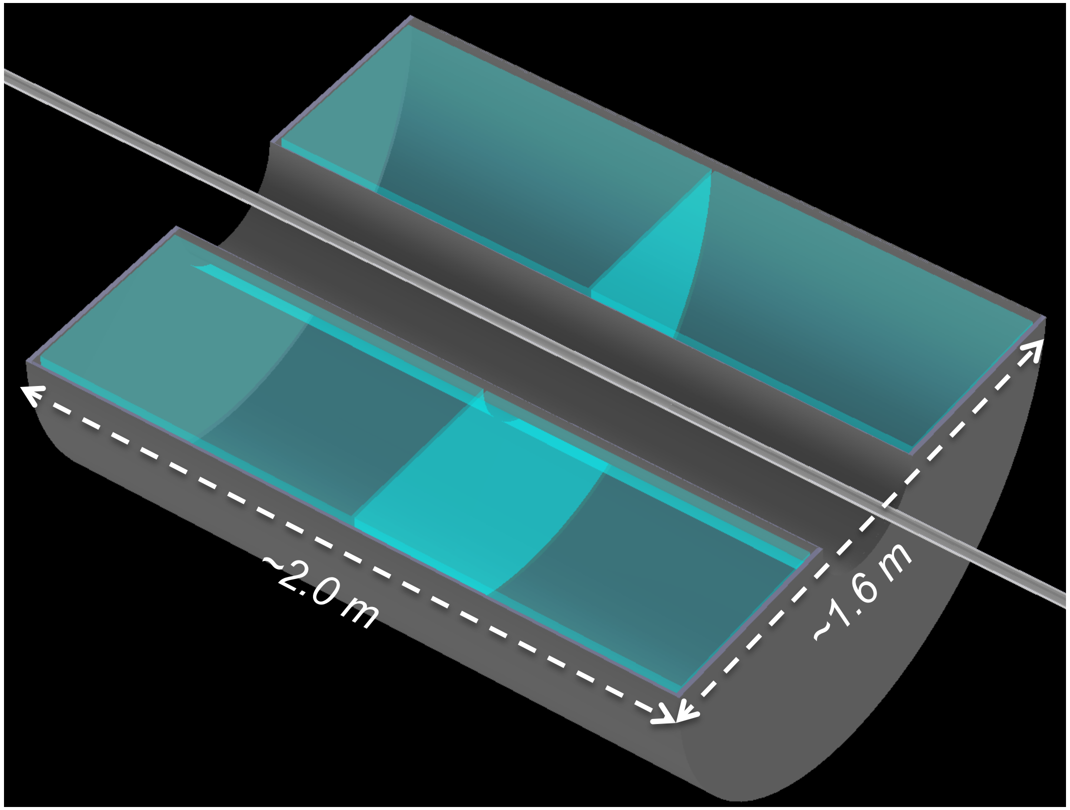


Design of this subsystem will likely become a topic for a separate R&D effort soon

TPC

Ongoing EIC R&D project

- ~2m long; gas volume radius [225..775] mm
- 1.2% X/X_0 IFC, 4.0% X/X_0 OFC; 15.0% X/X_0 end-caps
- assume 5 mm long GEM pads and ~250 μm single point $\{r\phi\}$ resolution for the max. drift distance of ~1m
- A gas mixture like T2K at ~250 V/cm (very small transverse dispersion in 3T field) will do the job

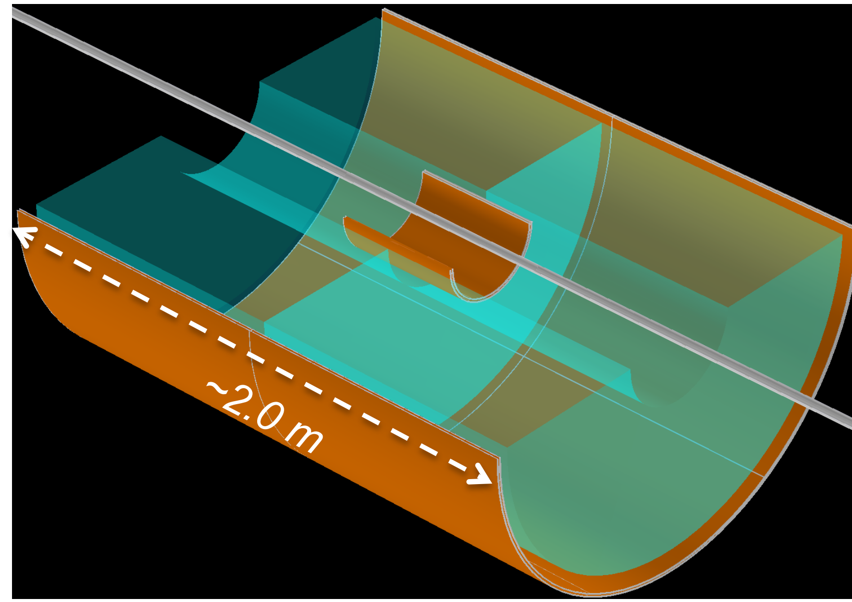


A medium size and medium resolution TPC, having in mind current status of the ILD R&D work

Micromegas barrel tracker

- 4 layers; technologically driven azimuthal and longitudinal segmentation
- 2D readout; assume ~100 μm spatial resolution

CLAS12 upgrade project

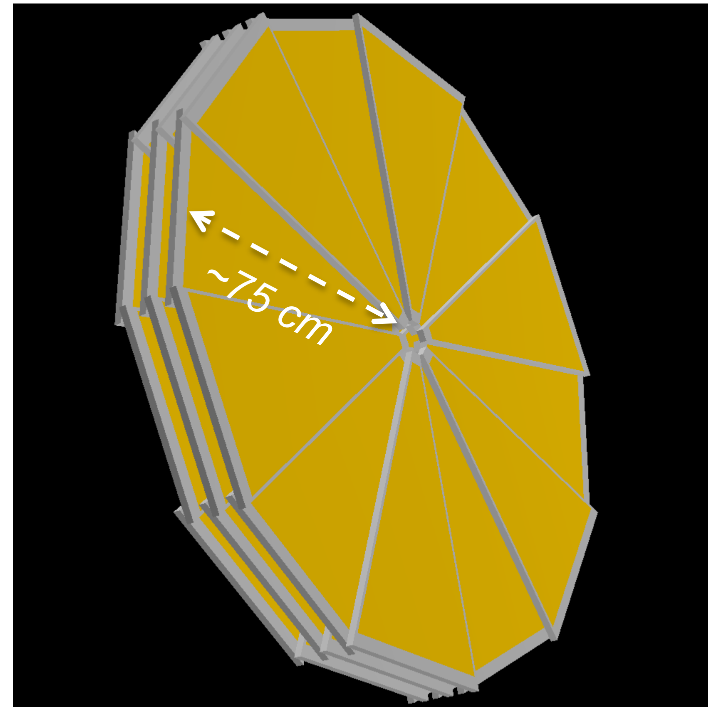


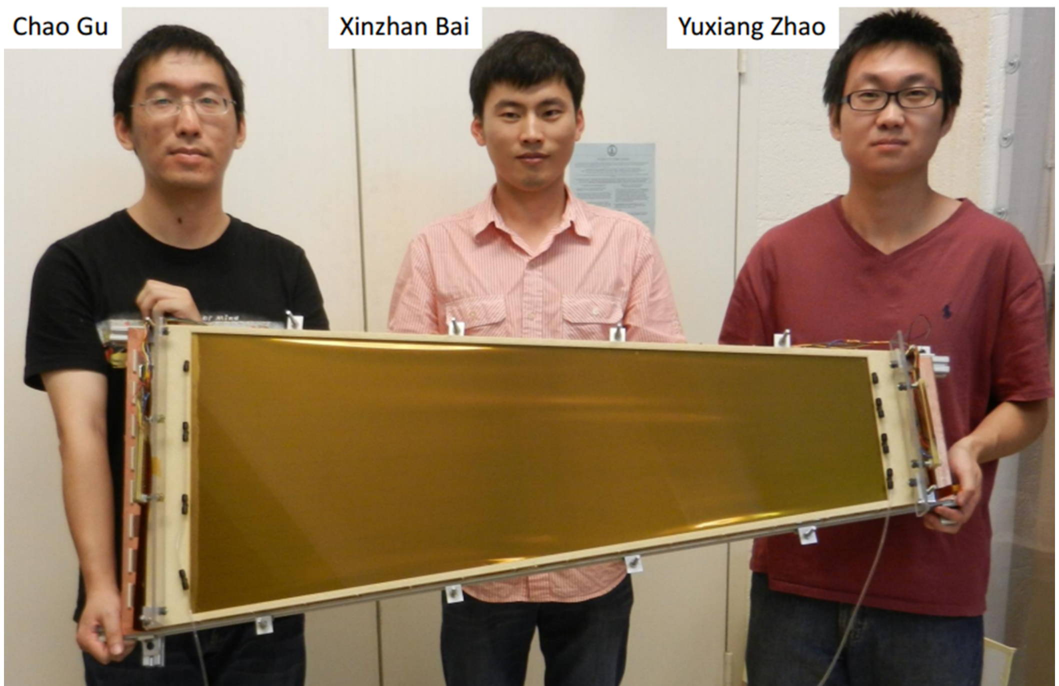
- Internal structure modeled according to the real-life prototypes
- ~0.5% X/X_0 per layer

GEM endcap trackers

- 3 disks behind the TPC end-caps; SBS internal design for now
- assume 50 μm {rϕ} spatial resolution can be achieved

Ongoing EIC R&D project





- Well advanced R&D program
- A couple of groups have their own large area GEM designs

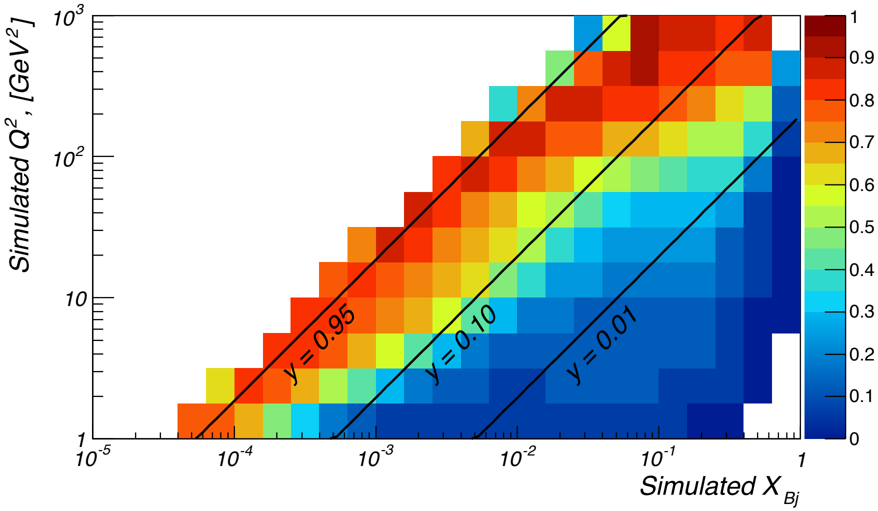
"Purity" in (x,Q^2) kinematic bins

$$Purity = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$$

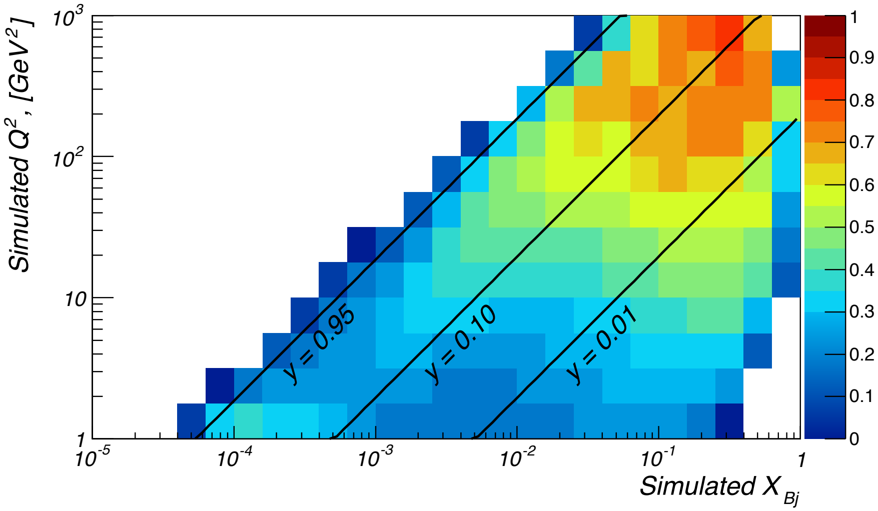
- Describes migration between kinematic bins
- Important to keep it close to 1.0 for successful unfolding

- {PYTHIA 20x250 GeV} -> {GEANT} -> {Kalman filter track fit}
- Bremsstrahlung turned on here (and it matters even for detector with ~5% X/X_0!)

Lepton tracking only



Double-angle method

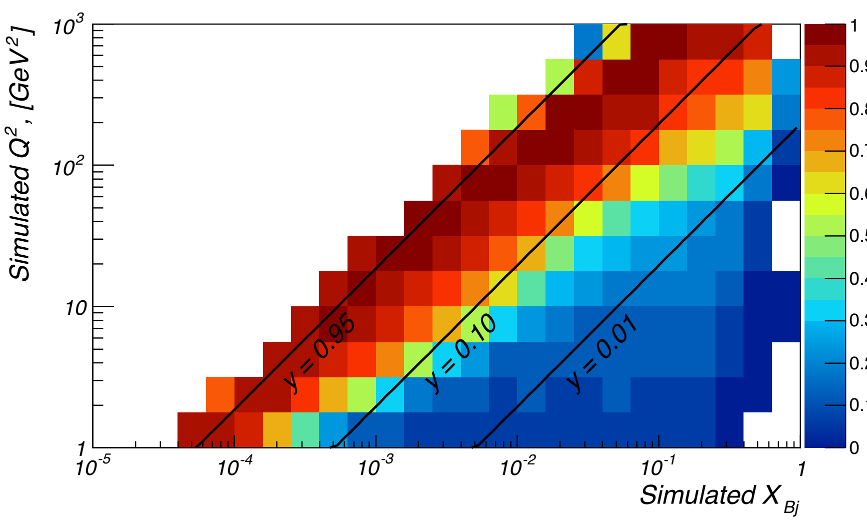


- "Straightforward" lepton tracking can hardly help at Y<0.1
- Hadronic final state accounting allows to recover part of the high Q^2 range

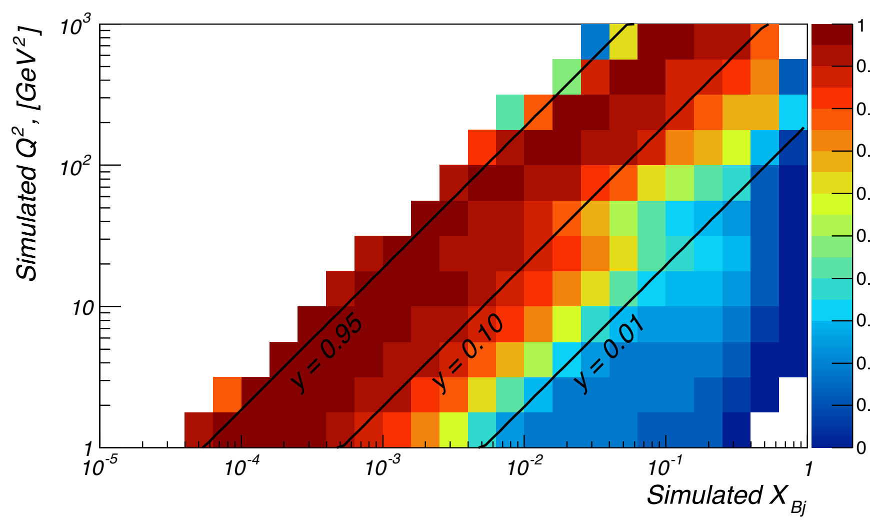
"Purity" in (x,Q^2) kinematic bins, cont'd

- Assume e/m calorimeter is used in addition to tracking
  - ~2%/√E energy resolution for $\eta > 2$ (PWO crystals)
  - ~7%/√E energy resolution for $1 < \eta < 2$ (tungsten powder scint. fiber sampling towers)
- Consider "bremsstrahlung off " case here for simplicity

Lepton tracking only



Lepton tracking + EmCal



- High-resolution e/m calorimeter allows to noticeably increase available Y range

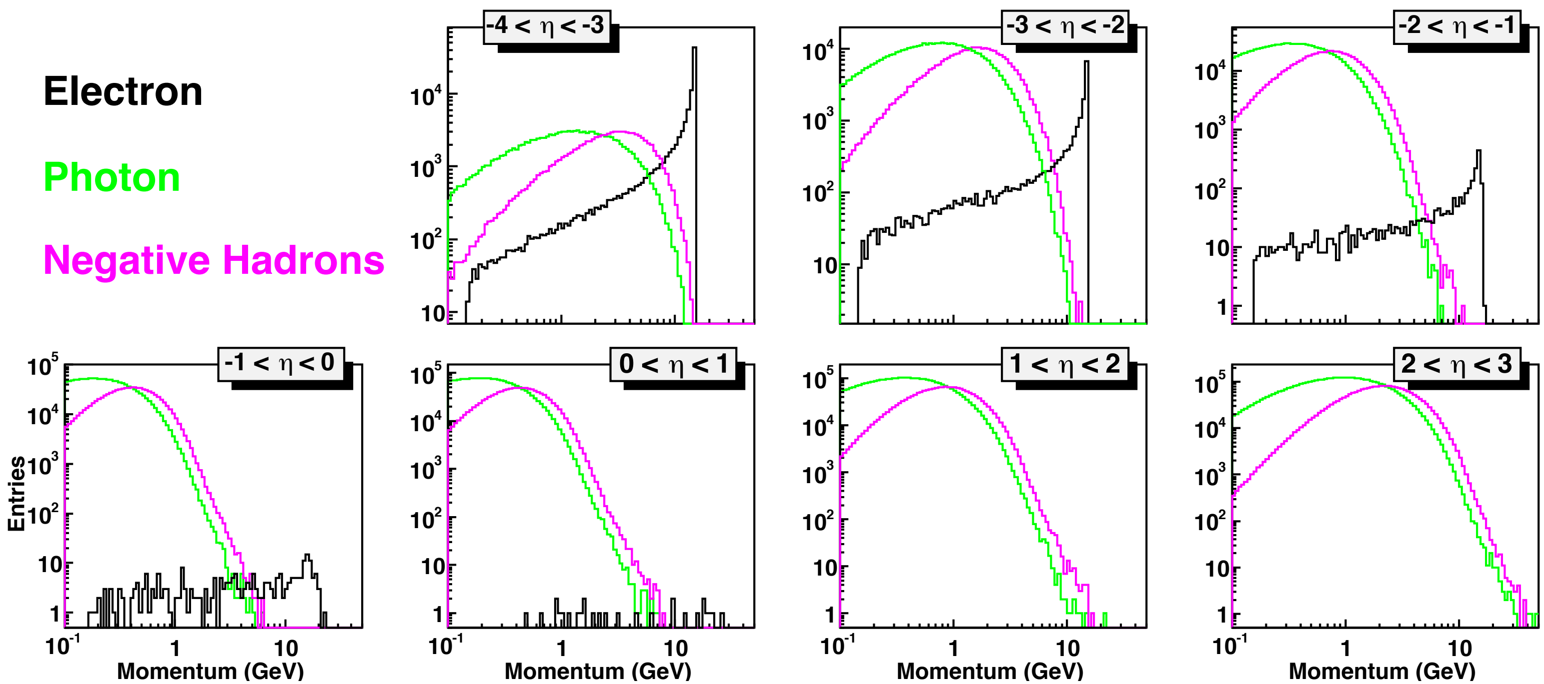
Electron ID

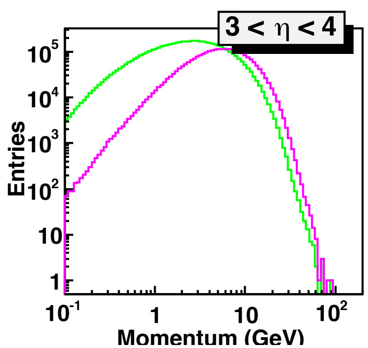
15x250 GeV configuration; particle yields versus momentum in the 4 < η < 4 range:

Electron

Photon

Negative Hadrons





γ suppression:
the same η coverage for tracking & Ecal

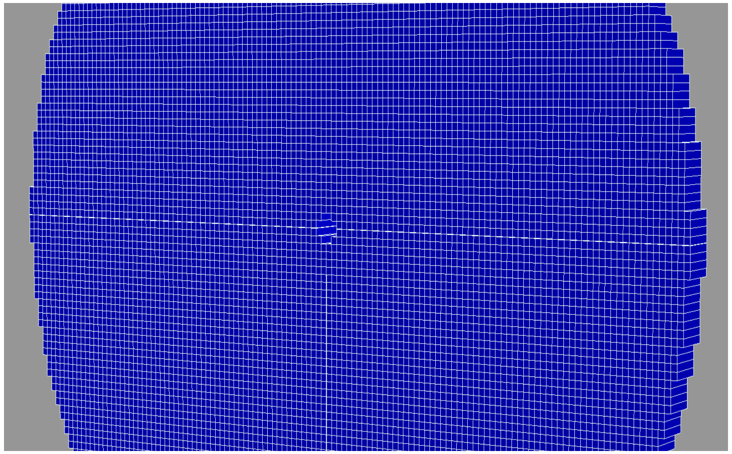
h^- suppression through E/p
-3.5<η<-1: 10:1 to 10^3:1
−1<η <1: 10^4:1

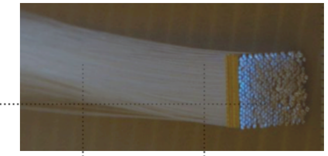
- Pseudo-rapidity range [-1.0 .. -3.5] is also covered by the hadronic calorimeter

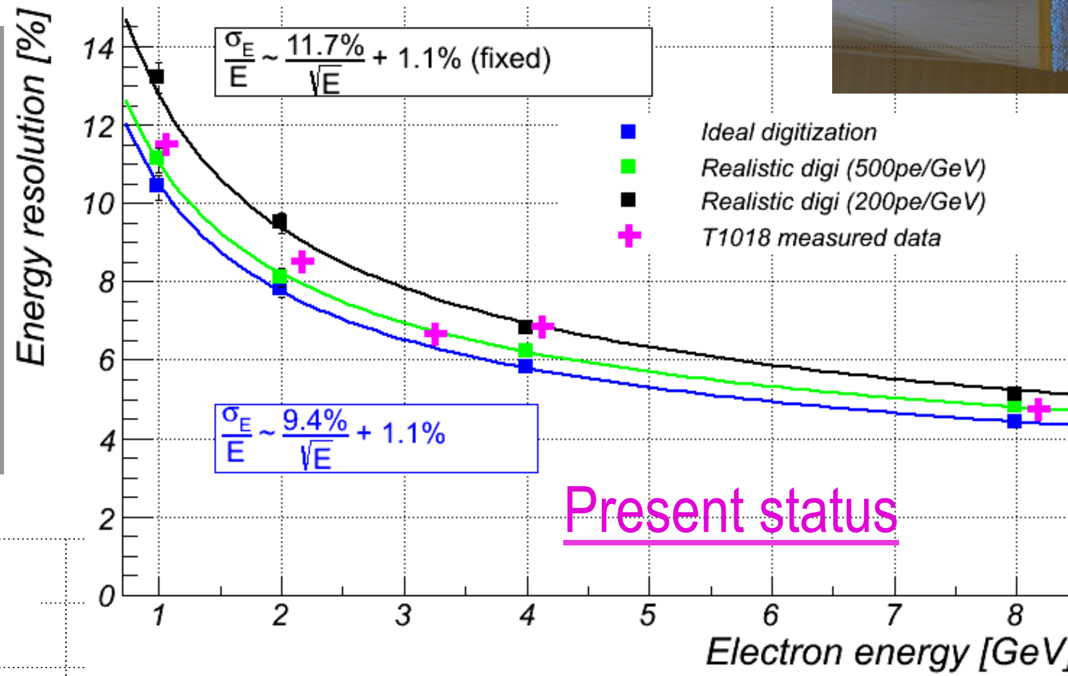
e/m calorimeters

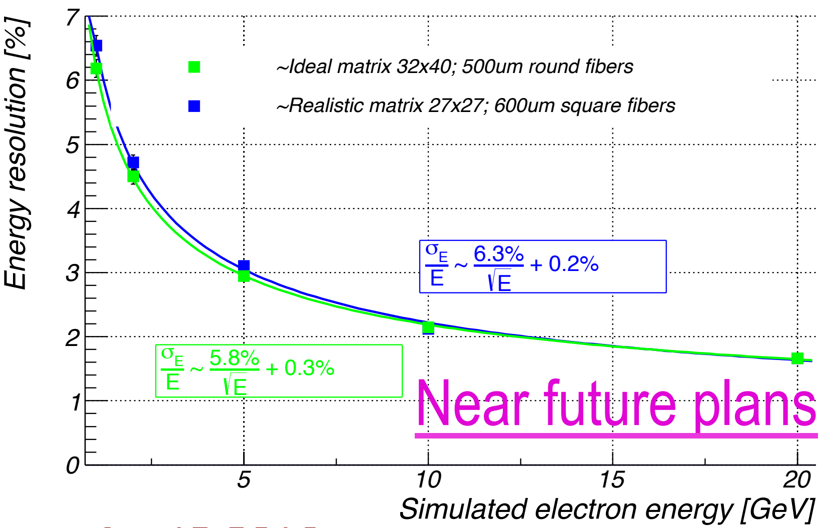
Tungsten powder scintillating fiber technology; straight (endcap) and tapered (barrel) geometry

Ongoing EIC R&D project







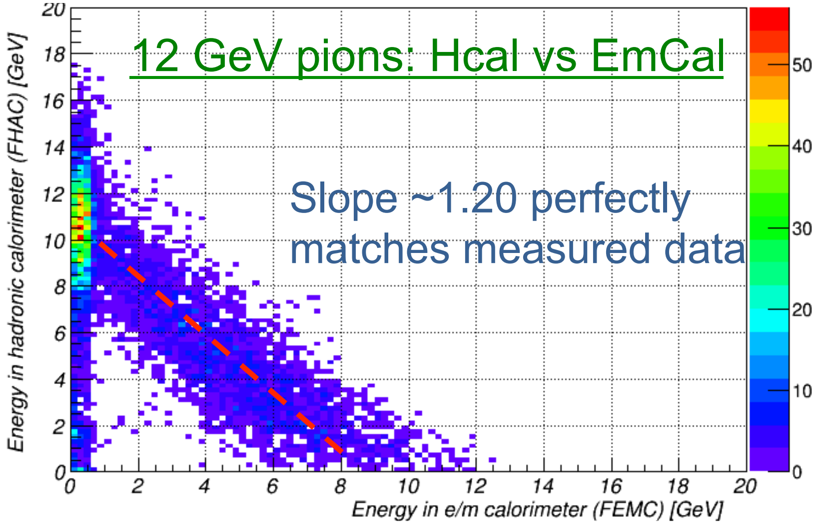


- Routinely obtain ~10%/√E energy resolution in various configurations
- Monte-Carlo simulations show one can push this technology as far as ~6-7%/√E
- The next test run is scheduled for May'2016

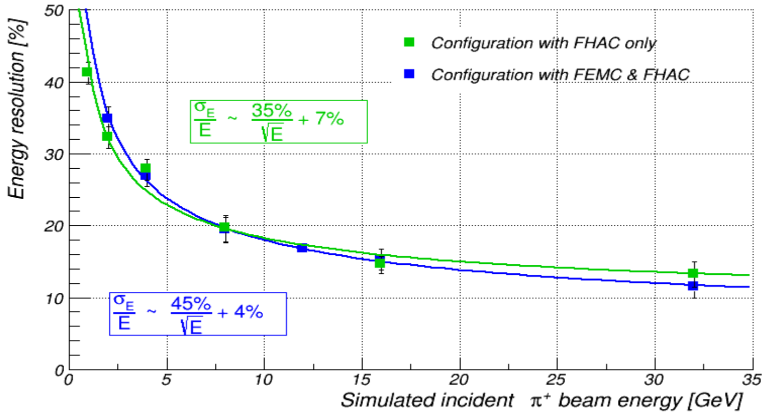
Hadronic calorimeters

Lead absorber scintillating plate sandwich technology

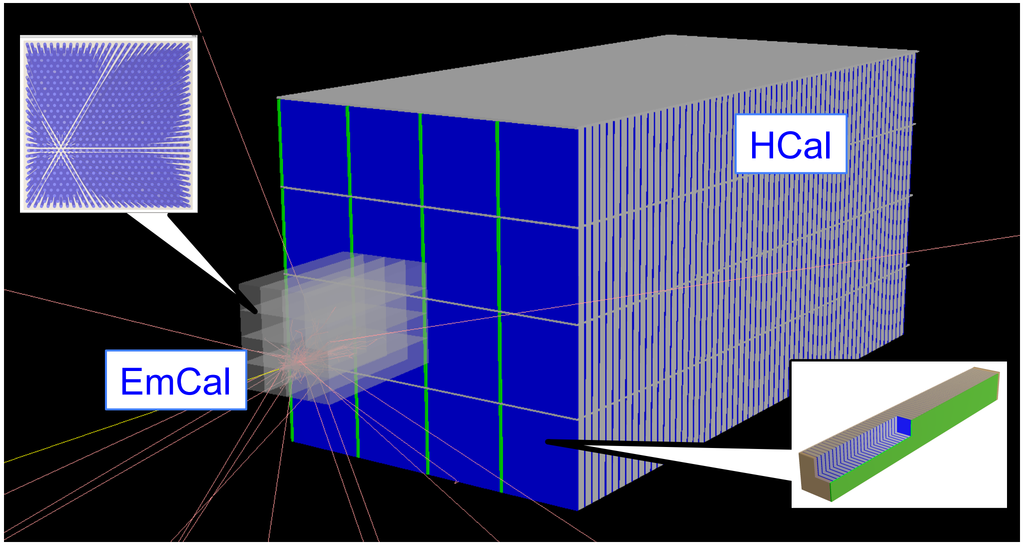
Ongoing EIC R&D project

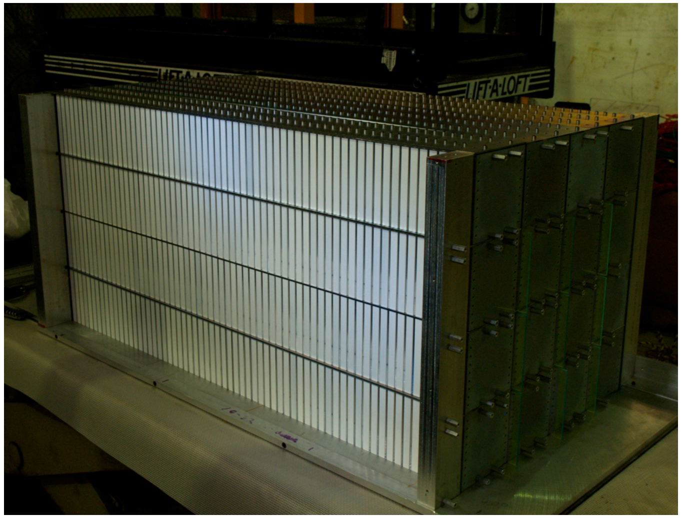


- Birk's correction accounted
- GEANT4, FTFP_BERT physics list



- energy resolution comparable to ZEUS 1987 paper

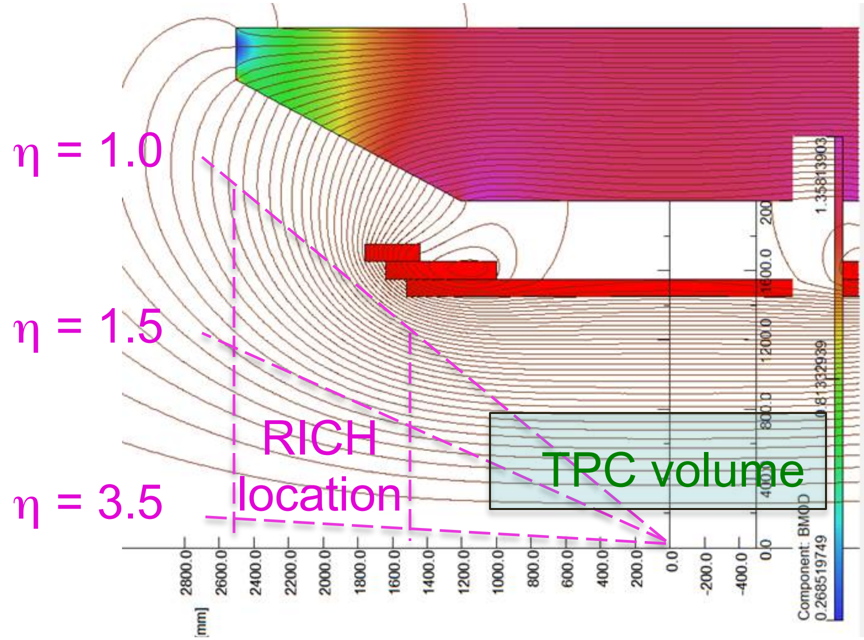


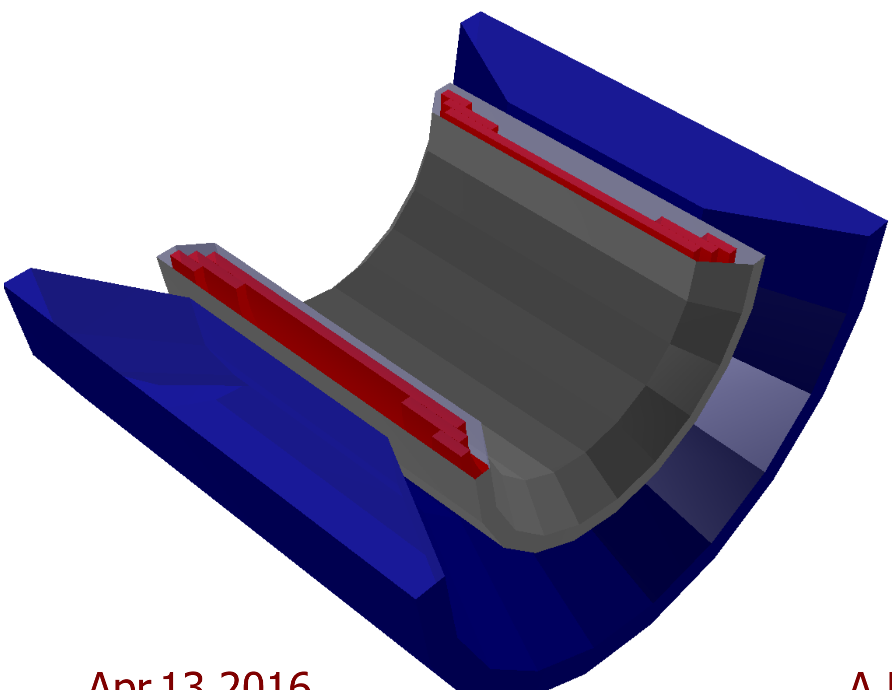


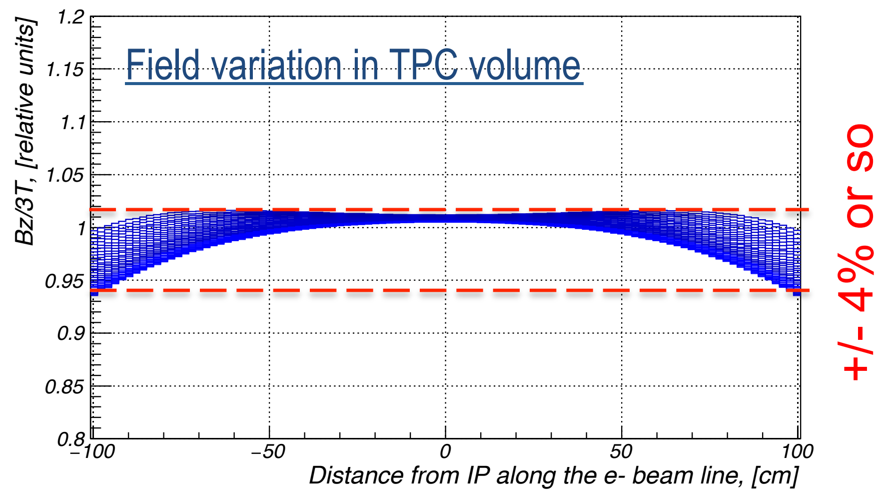
Superconducting solenoid

Goal:

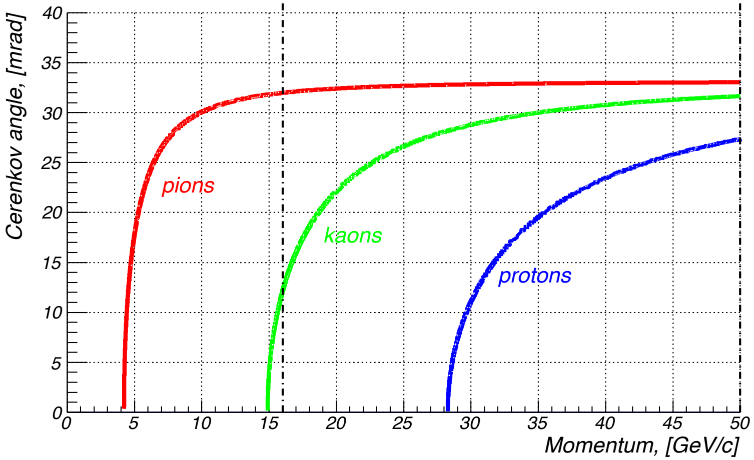
- Implement in the same compact design:
  - homogeneous ~3T field in the TPC
  - hadron-track-aligned field in the RICH
- Keep it simple (no dual solenoid configuration; no reversed current coils; no flux return through HCal; no warm coils between RICH and EmCal)







Will gas radiator RICH work in this field?



Consider configuration inspired by the RD6 test run:

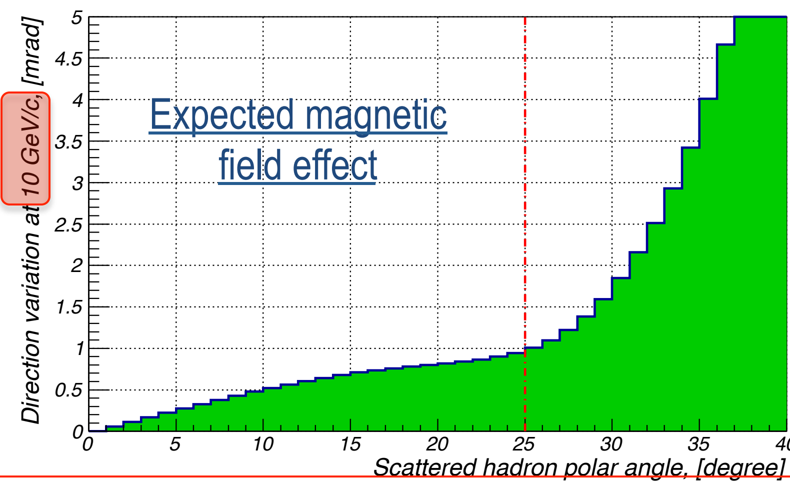
- 1m long CF_4 gas volume [1.5 .. 2.5]m from the IP
- 1m focal length; ~33mm ring radius at β ~ 1
- GEM readout; effective 2.5mm hexagonal pads
- Assume on average 12 photons per ring at β ~ 1
- Additional 300 μrad instrumental resolution

EIC R&D project

"Back-of-the-envelope" Monte-Carlo study:

- Realistic solenoid magnetic field
- Realistic tracker momentum resolution
- Cerenkov angle smearing in the field
- CsI quantum efficiency $\varepsilon(\lambda)$ dependence
- Refractive index $n(\lambda)$ variation
- Finite readout board "pixel" size

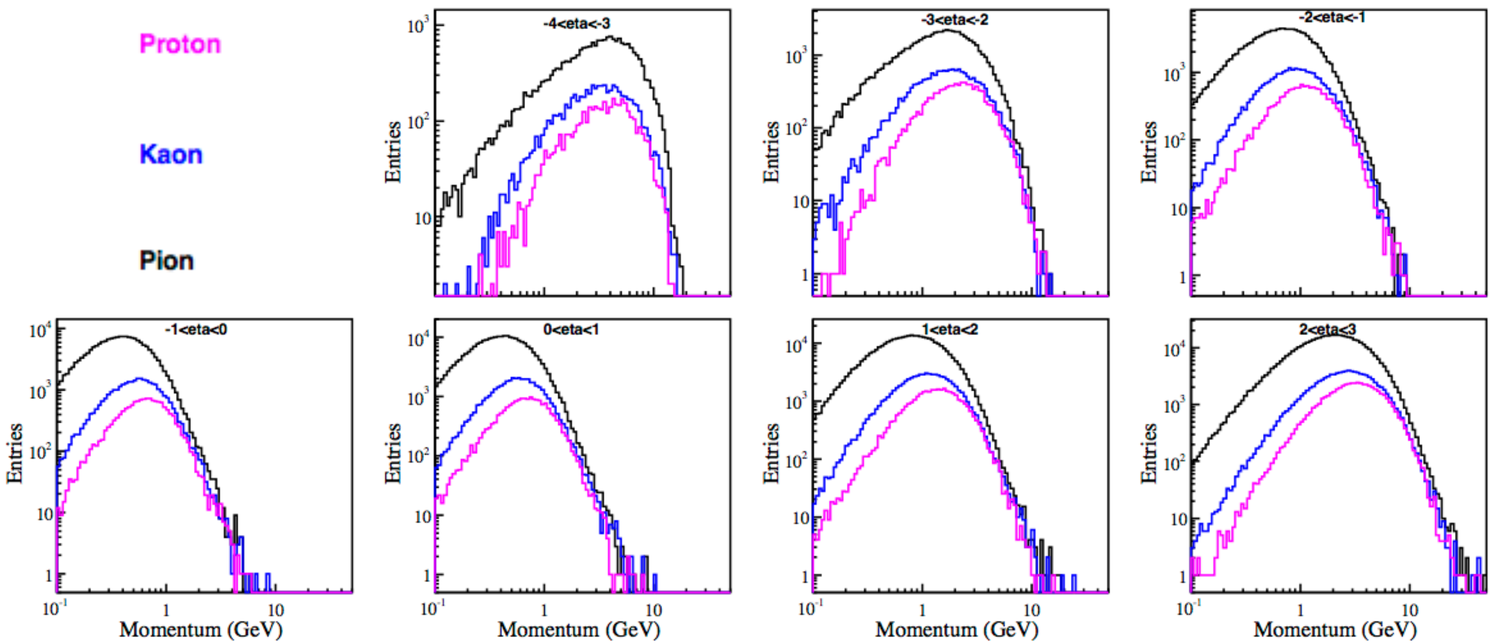
- ROOT TMVA-based output evaluation

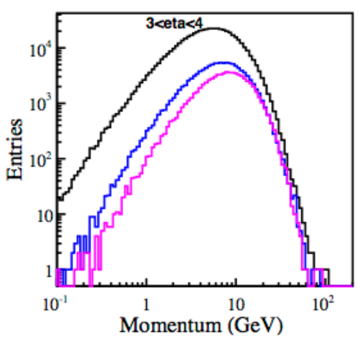


NB: this spread is in principle noticeable compared to the intrinsic single-photon angular resolution of ~1 mrad

Relative pion/kaon/proton yields

20x250 GeV configuration; yields versus momentum in the $4 < \eta < 4$ range:

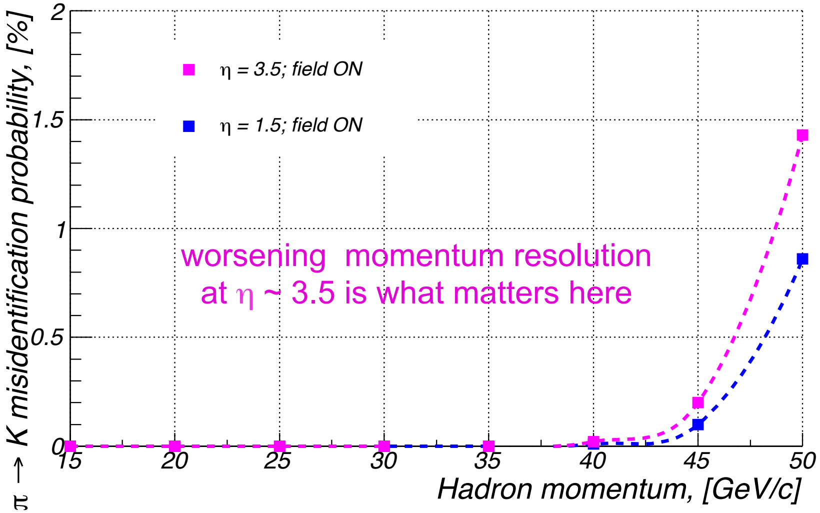


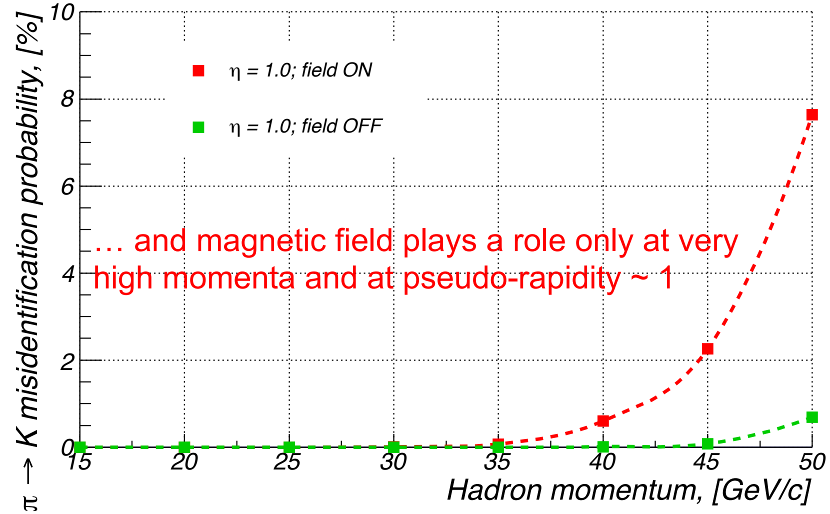


- π/K/p distributions at the same η look similar
- π/K ratio is about 3:1 -> depending on the desired efficiency and contamination this defines the required suppression factors

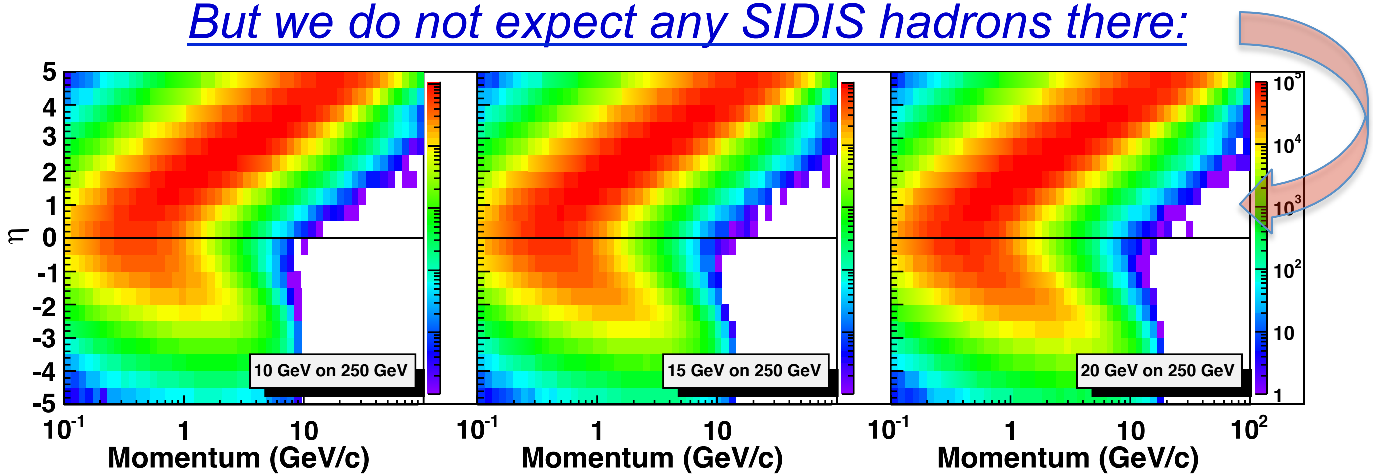
Gas radiator RICH in the magnetic field

Require 95% kaon positive identification efficiency





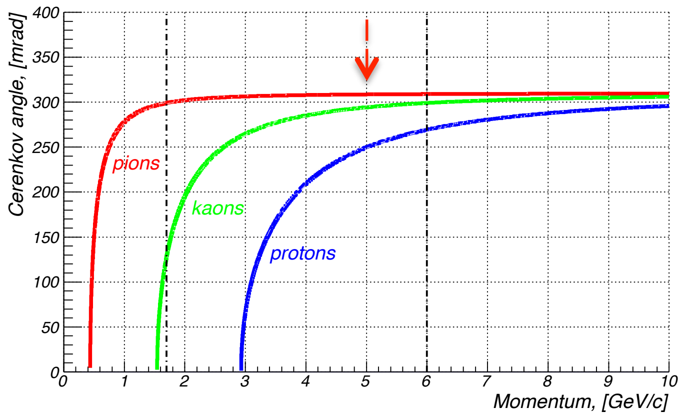
But we do not expect any SIDIS hadrons there:



So yes, RICH with a long enough gas radiator should work just fine in this solenoid stray field

Will aerogel RICH work in such a field?

NB: at 3T full track bending in aerogel volume is >5 mrad at 5 GeV/c!



Consider end-cap case in proximity-focusing configuration:

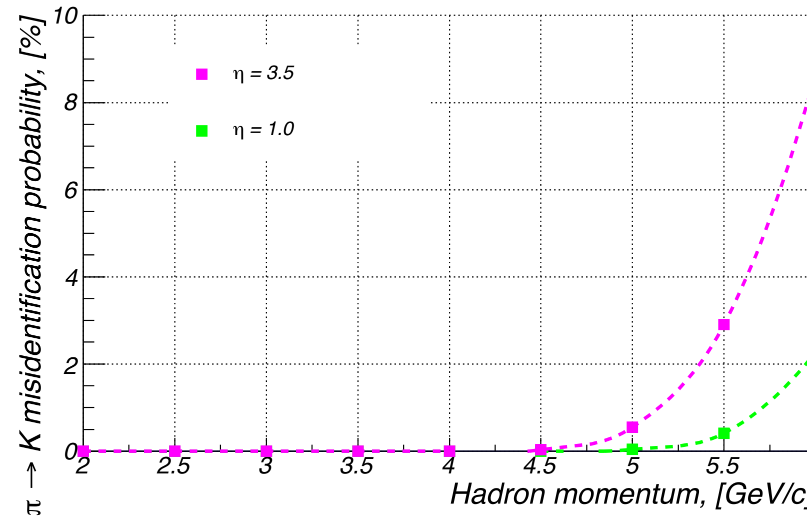
- 3cm thick aerogel; 20cm expansion volume
- $\langle n_0 \rangle = 1.05$
- ~5cm attenuation length
- SiPM array readout; 5mm^2 "pixel" size
- Assume on average 15 photons per ring at $\beta \sim 1$

Aerogel RICH R&D for Belle II upgrade

"Back-of-the-envelope" Monte-Carlo study:

- Constant $B_z \sim 3$T
- Asymmetric (ϕ-dependent) attenuation
- ϕ-dependent Cerenkov angle smearing in the field
- SiPM quantum efficiency $\varepsilon(\lambda)$ dependence
- Refractive index $n(\lambda)$ variation
- Emission point uncertainty (thick radiator)
- Finite readout board "pixel" size

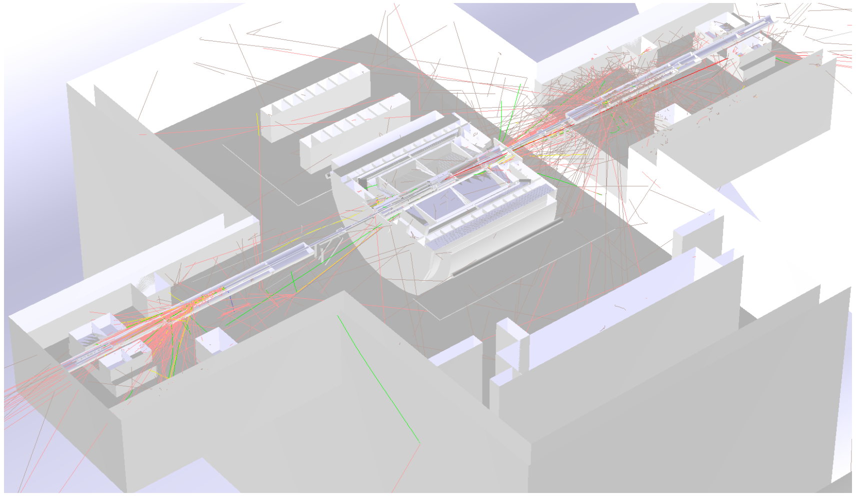
- TMVA-based output evaluation



Require 95% kaon positive identification efficiency

Neutron flux estimation

STAR geometry imported in EicRoot

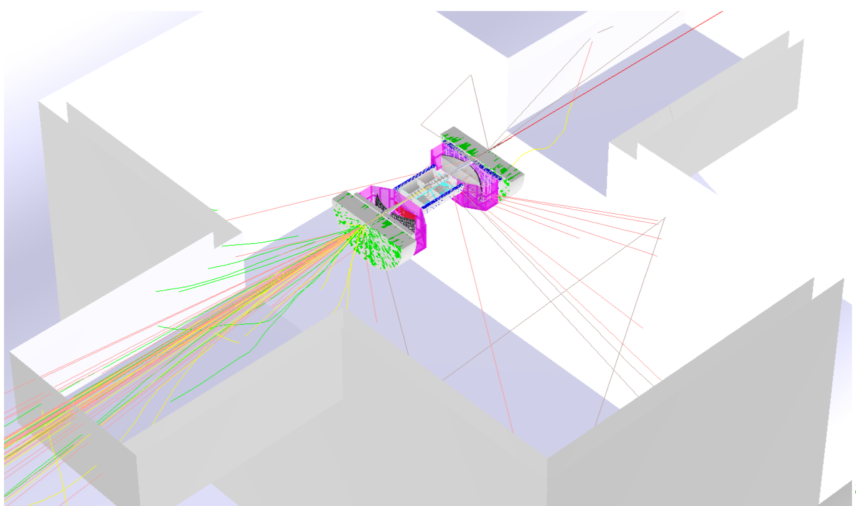


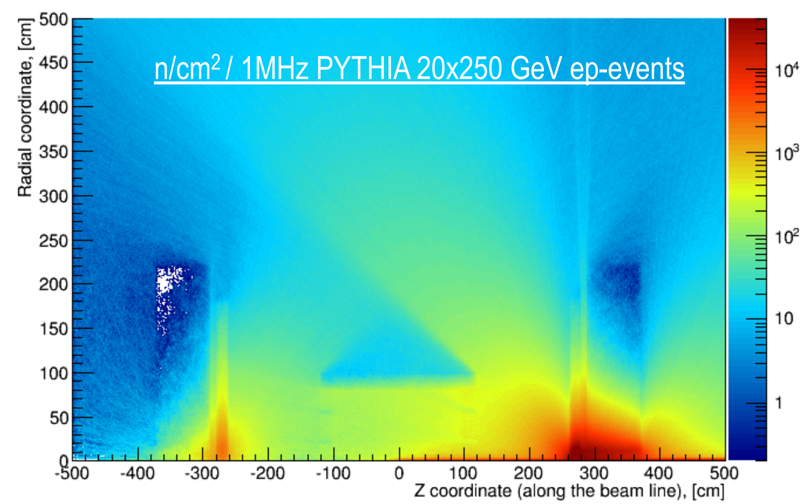
NB: very important topic since several detectors with SiPM type of readout are planned to be used

Strategy:

- Import STAR experiment geometry (including experimental hall)
- Run ep- and pp-PYTHIA simulations for STAR and BeAST setups
- Use direct STAR neutron flux measurements from 2013 as a reference

BeAST detector placed in STAR hall





At most ~10^{10} n/cm^2 per year of running at L=10^{33} cm^{-2}s^{-1}

Summary slide

- A flexible eRHIC detector configuration is put together
- It is based on either proven components or the ongoing R&D

- Current work is focused on:
  - Track finder algorithm for central rapidities
  - Realistic RICH detector implementation(s)
  - PID algorithm development

  - Further optimization of various detector technologies to meet the detector requirements imposed by physics