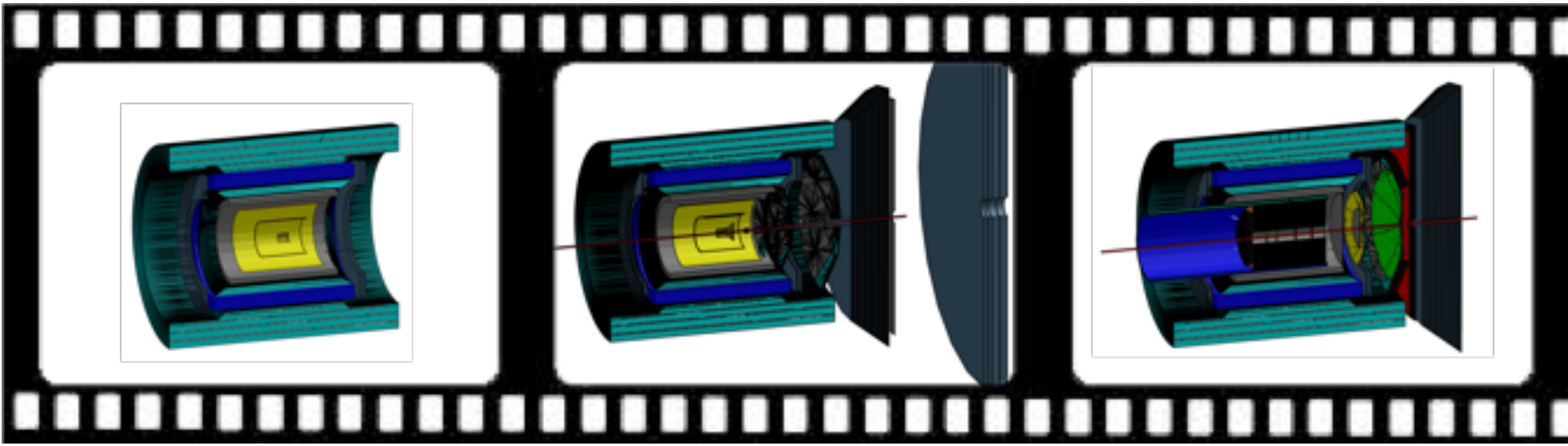
Evolution of PHENIX into a Day-1 EIC Detector

Kenneth N. Barish

UC Riverside



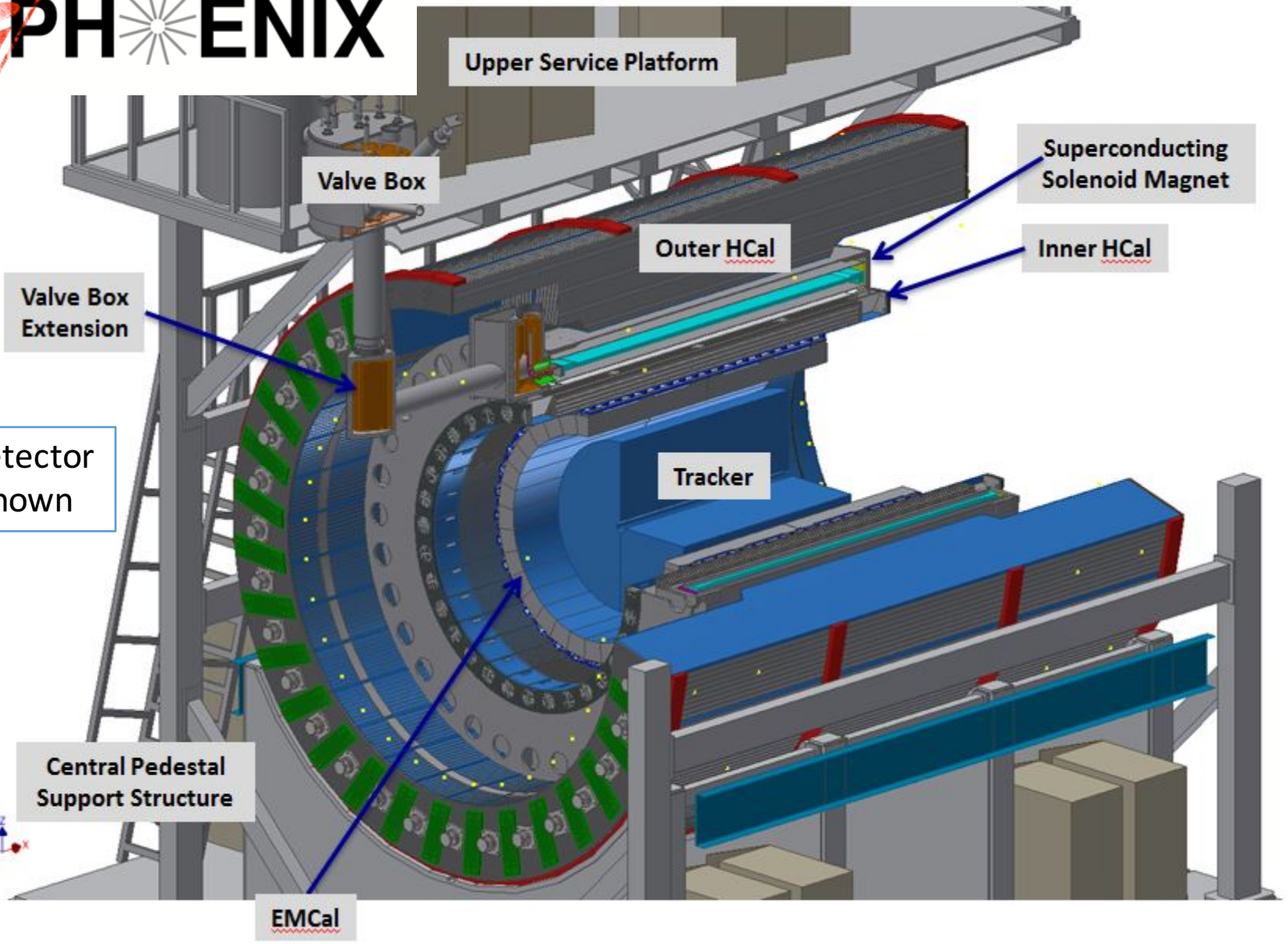
sPHENIX → **fsPHENIX** ⇄ **EIC Day-1 Detector**

PHENIX @RHIC

- **Motivation:** Study strongly coupled Quark Gluon Plasma in heavy-ion collisions via jet structure, heavy-flavor tagged jets, and Upsilon spectroscopy.
- **New Detector at PHENIX IP**
- **New Collaboration** (formed Dec 2015)
  - **Cold QCD topical group being formed.**
- **Reference design** (good foundation for EIC detector)**:**
  - **Magnet:** 1.5T BaBar superconducting solenoid
    - Uniform acceptance $|\eta|<1.1$ and $0<\phi<2\pi$
    - **Space for forward instrumentation** (fsPHENIX, EIC detector).
  - **Calorimetry** (common readout electronics)**:**
    - Compact fine segmentation electromagnetic calorimeter.
    - Hadronic calorimeter doubling as flux return
  - **High resolution tracking** (in magnetic field within 80cm radius)**:**
    - MAPS inner tracker
    - TPC outer tracker

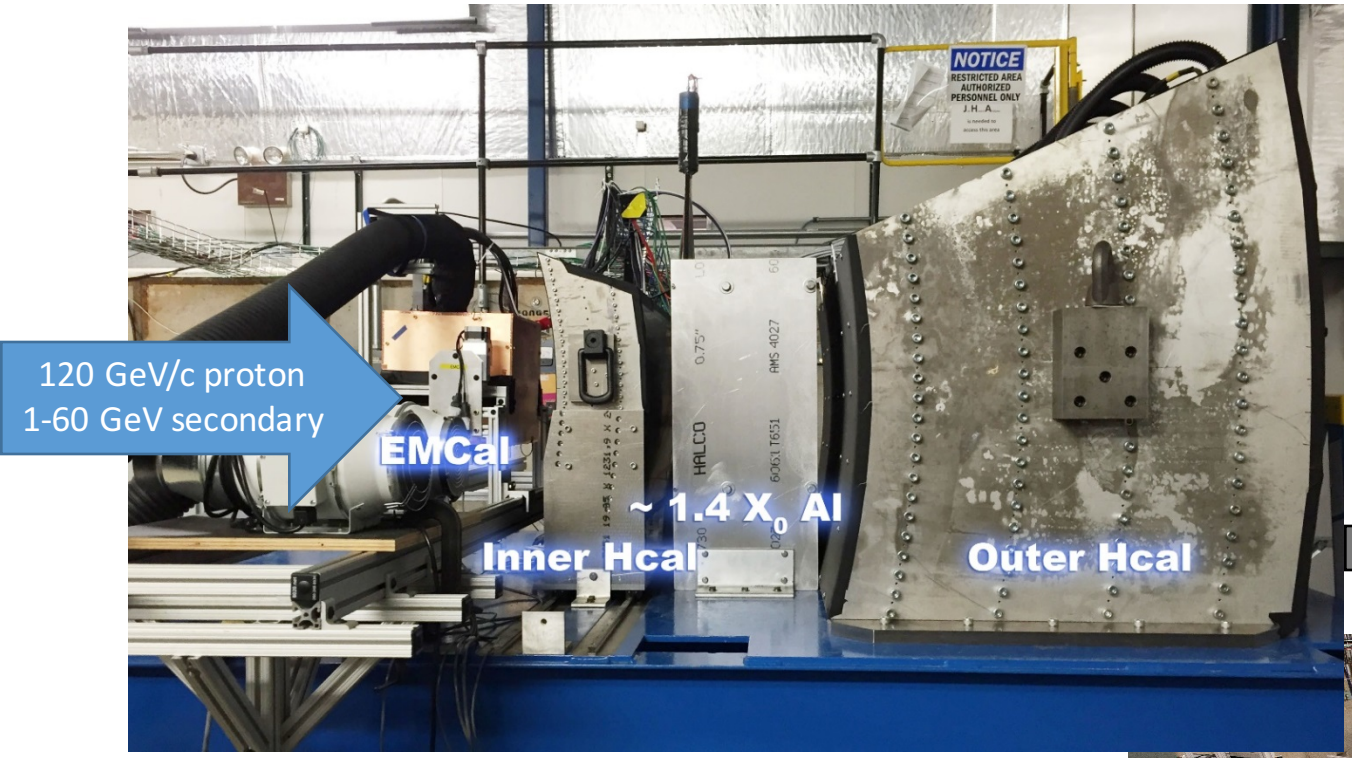
@ BNL Passed cold test

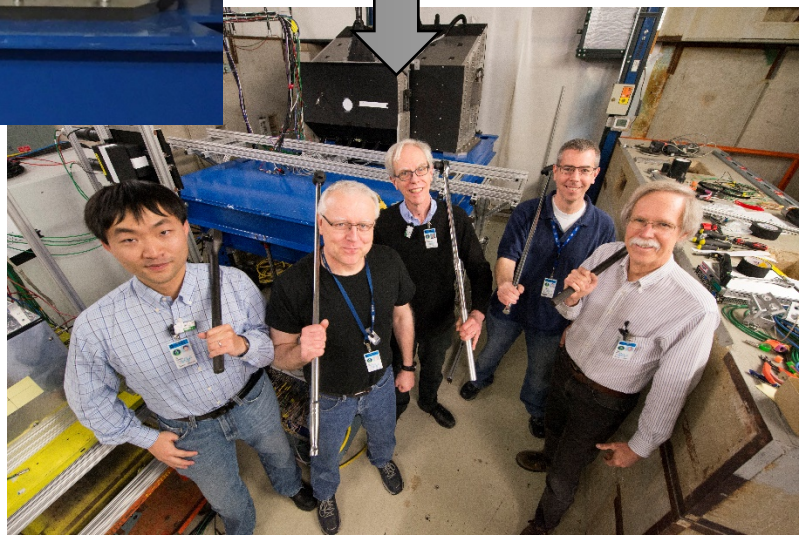
PHENIX



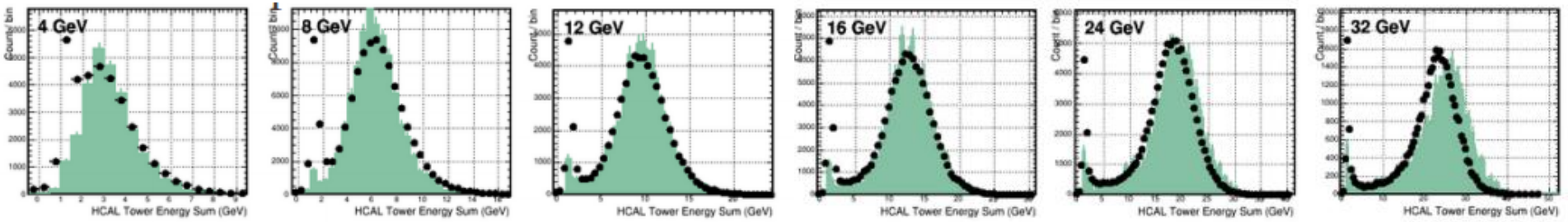
BBC Detector not shown

sPHENIX news – Beam Test

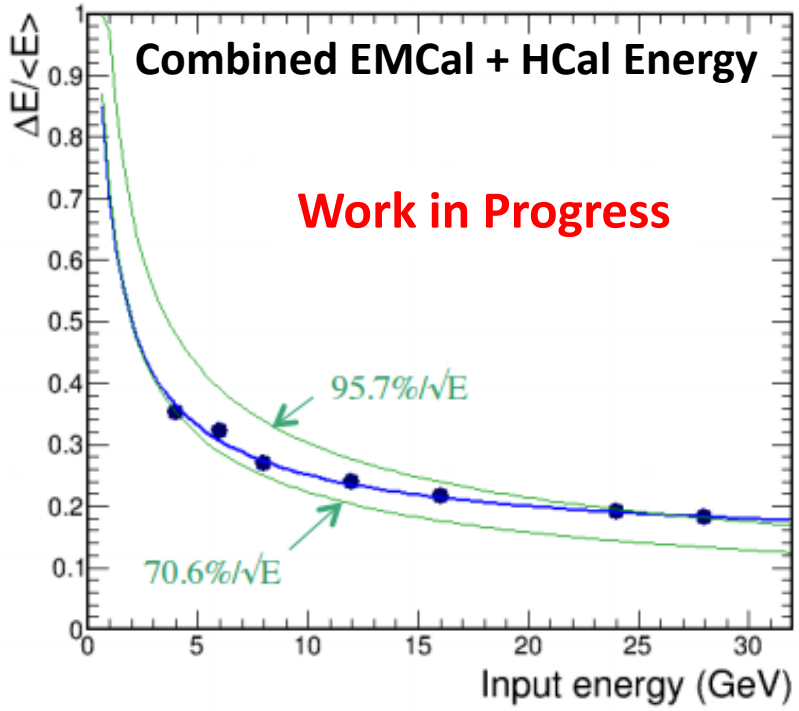




Beam Test Preliminary results

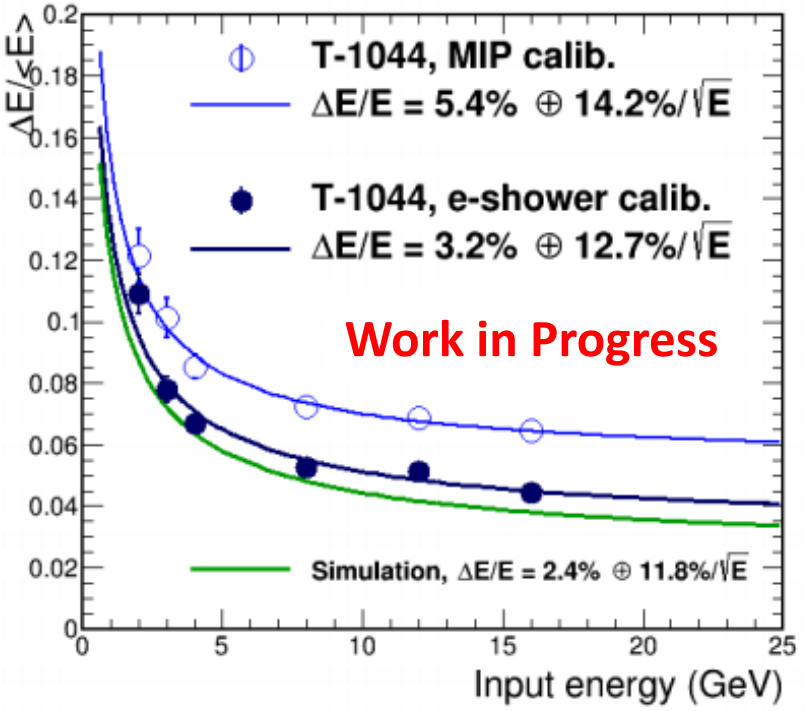


$\Delta E/E = [70.6\% - 95.7\%]/\sqrt{E}$



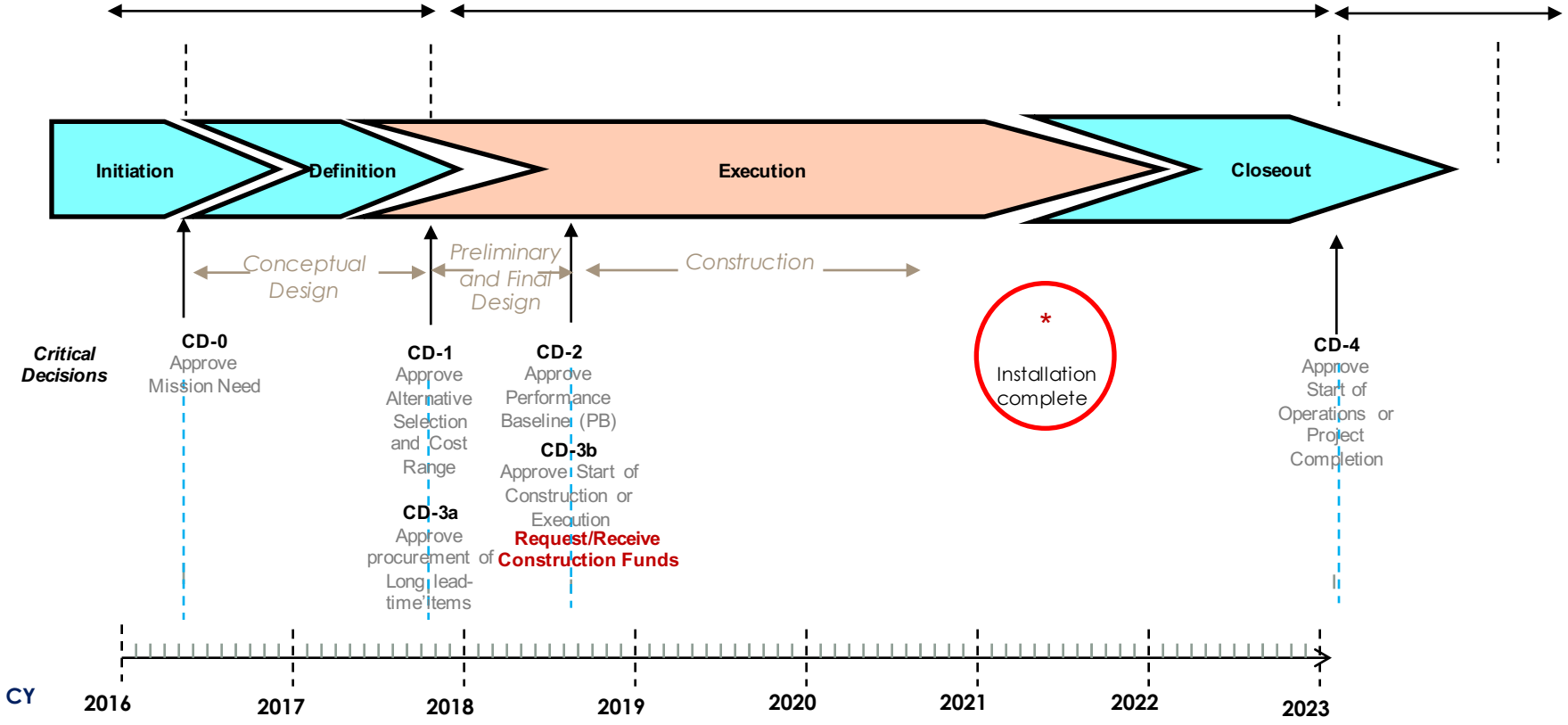
Final calibrations ongoing!

Electron Resolution in EMCal



- Simulation shows good agreement with early **data** results
- Expect to achieve required resolution of 12%/√E

sPHENIX Timeline

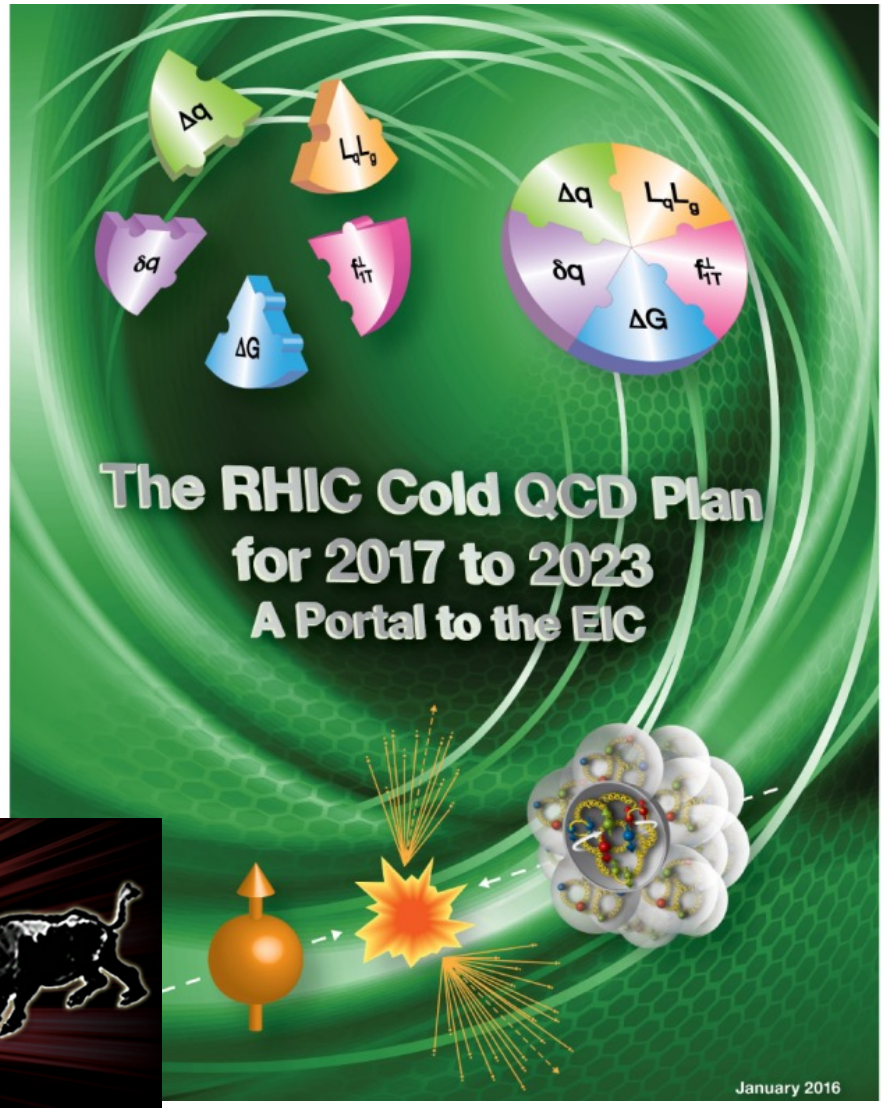


CD-0	**2016**
CD-1/CD-3a	**Nov 2017**
CD-2/3	**Jul 2018**
Installation complete	**Jun 2021**
Ready for Beam	**Jan 2022**
CD-4	**Jan 2023**

- Passed March 2015 physics review
- reConceptual Design Report
  - http://tinyurl.com/sPHENIX-PreCDR
  - November 2015 review went very well

RHIC Cold QCD Plan

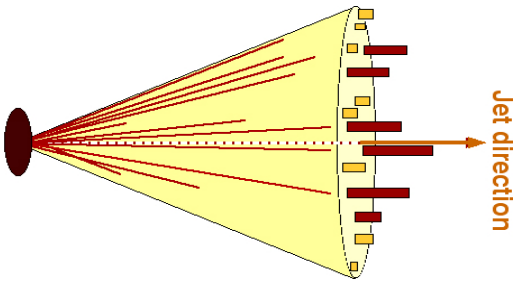
- Requested by DOE, submitted Feb 2016
  - Subject of RBRC workshop
- Lays out a comprehensive set of important measurements to be made on the road to an EIC

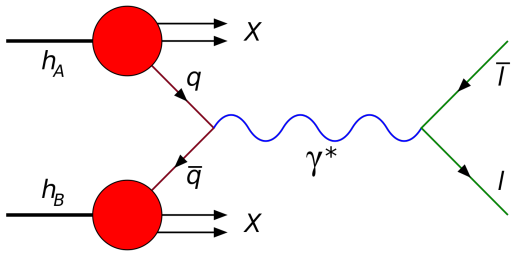


http://arxiv.org/abs/1602.03922

Physics Goals From Cold QCD Plan

- **Key Physics Measurements:**
  - Jets in polarized p+p (510 GeV)
  - nFF's in p+A
  - DY and Direct Photons in p+A
  - Diffraction in polarized p+p (200 GeV)
  - Ultraperipheral Collisions in p+Au



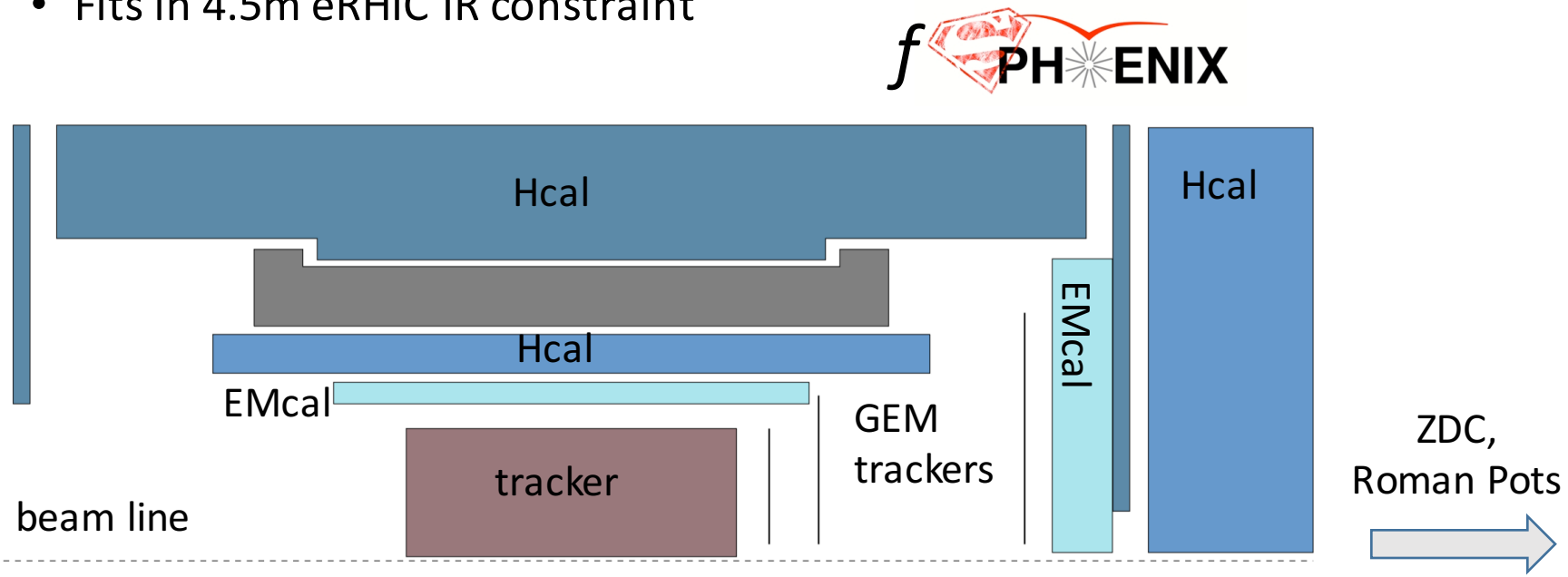


For many of these measurements RHIC offers *unique* capabilities with unique kinematic coverage

- **fsPHENIX studying to cover as many topics as possible:**
  - **Jets and Drell-Yan ✔**
  - Considering Roman Pots to cover additional topics

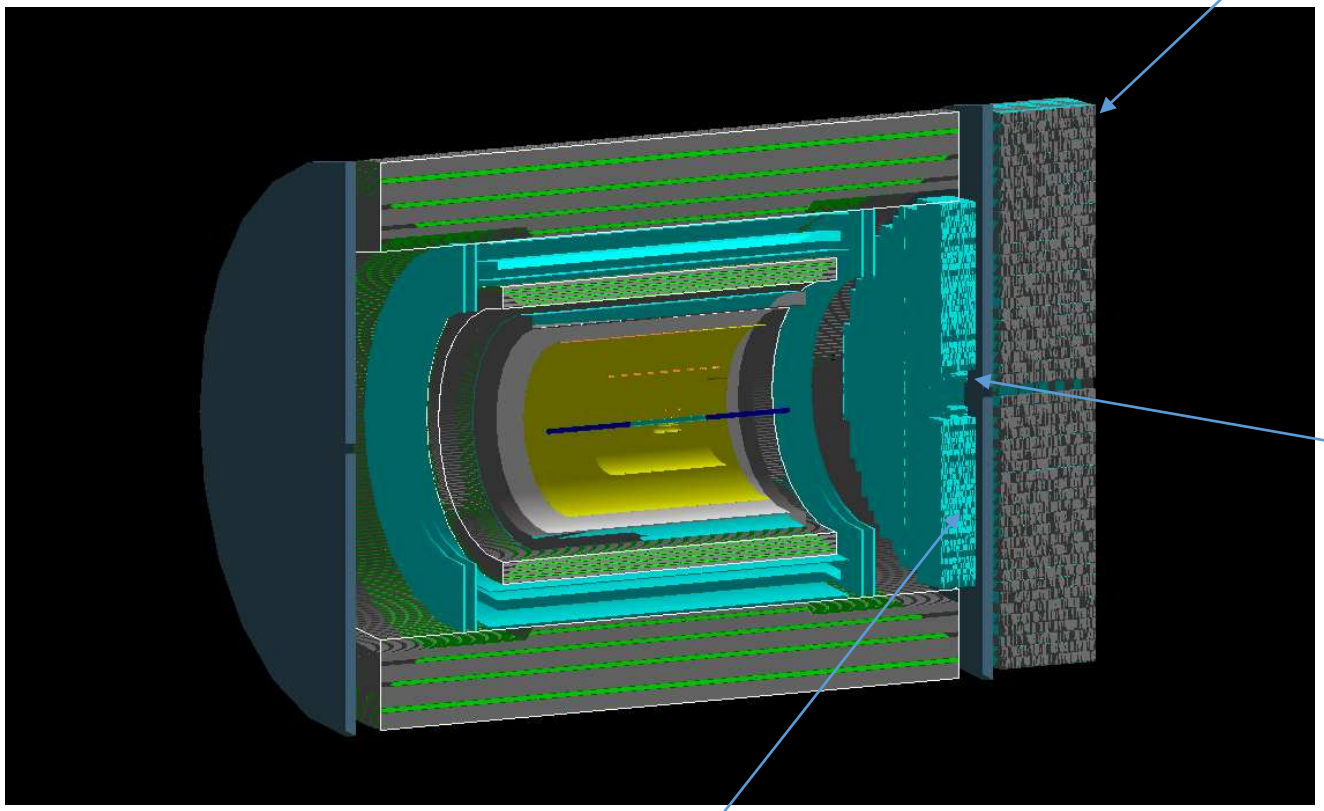
Forward instrumentation in sPHENIX

- sPHENIX plug door is compatible with a forward detector suite.
  - Plug door could be as thin as ~10cm
- Implement “forward sPHENIX”:
  - GEM trackers and forward EMCal in magnetic field volume
  - Forward Hcal outside plug door
  - Magnetic field shaper piston
  - Roman Pots in beamline
  - Fits in 4.5m eRHIC IR constraint



Forward Calorimeters

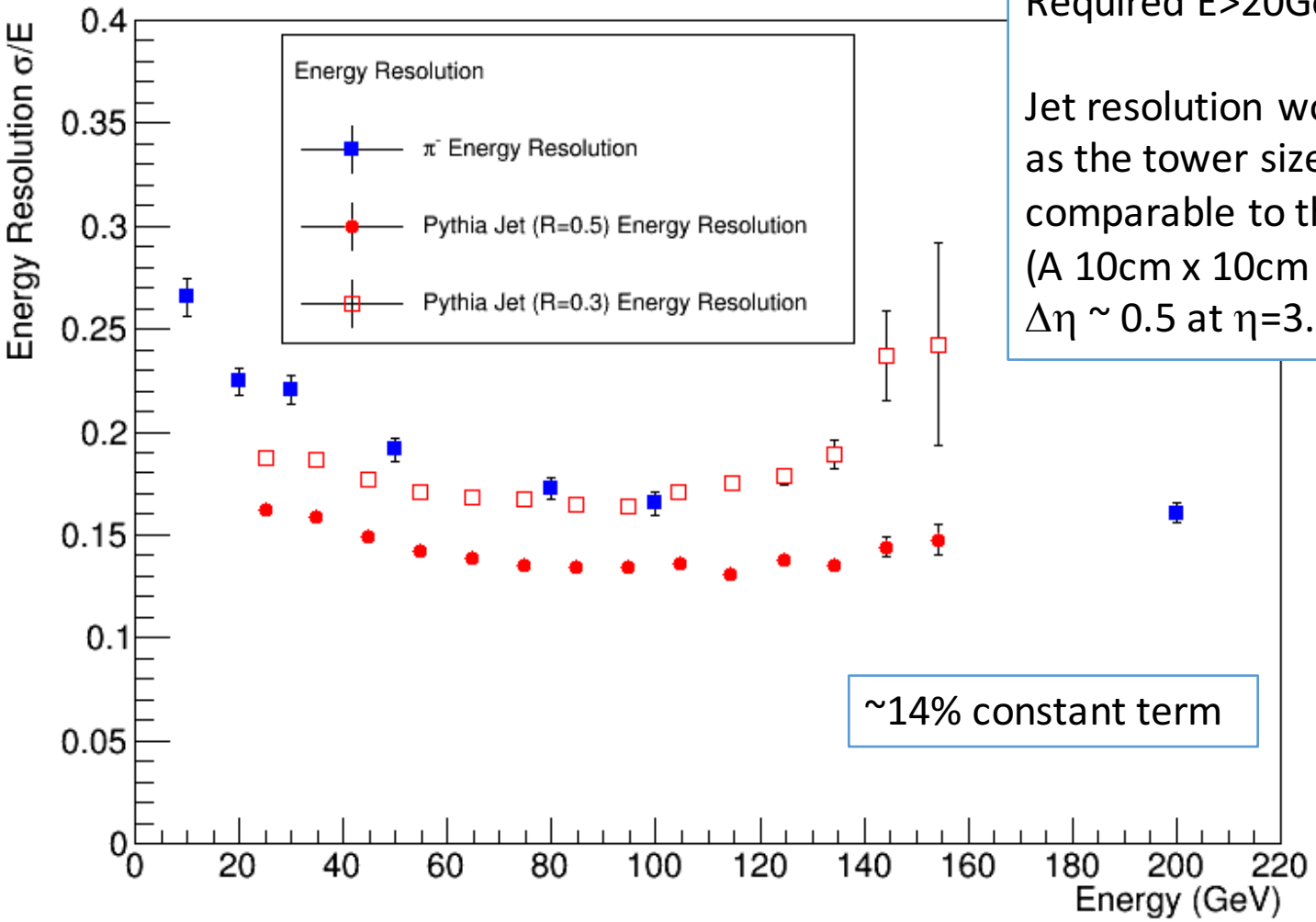
Pb/Sc sandwich HCAL (NEW)
10 x 10 x 100 cm^3 towers
$(1.2 < \eta < 4.0)$



20x20 array of
2.2 x 2.2 x 18 cm^3
PbW (PHENIX MPC) EMCal Crystals with 10x10 square hole (300 crystals total)
$3.0\text{-}3.3 < \eta < 4.0$

PHENIX PbSc EMCAL modules (5.5 x 5.5 x 33 cm^3) organized in groups of four modules (3152 modules or 788 groups of 4) $(1.4 < \eta < 3.0\text{-}3.3)$

Jet Energy Resolution



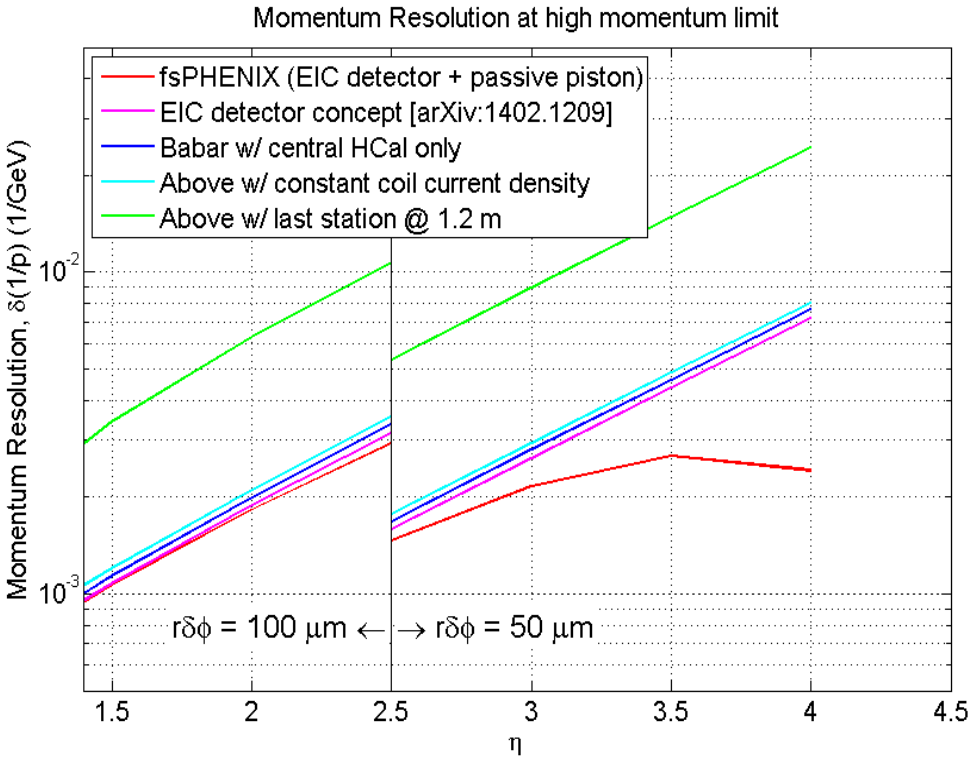
Jets from 510 GeV Pythia8, using jet trigger, jet energy is correlated with pseudorapidity. Required E>20GeV, p_T>5GeV.

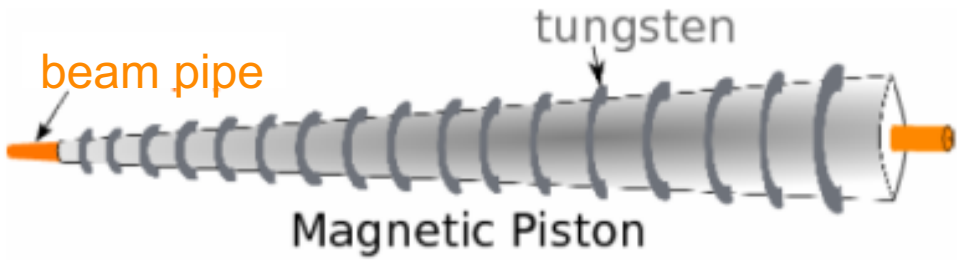
Jet resolution worsens at high η as the tower size gets comparable to the cone size. (A 10cm x 10cm FHCAL tower is $\Delta\eta \sim 0.5$ at η=3.5.)

~14% constant term

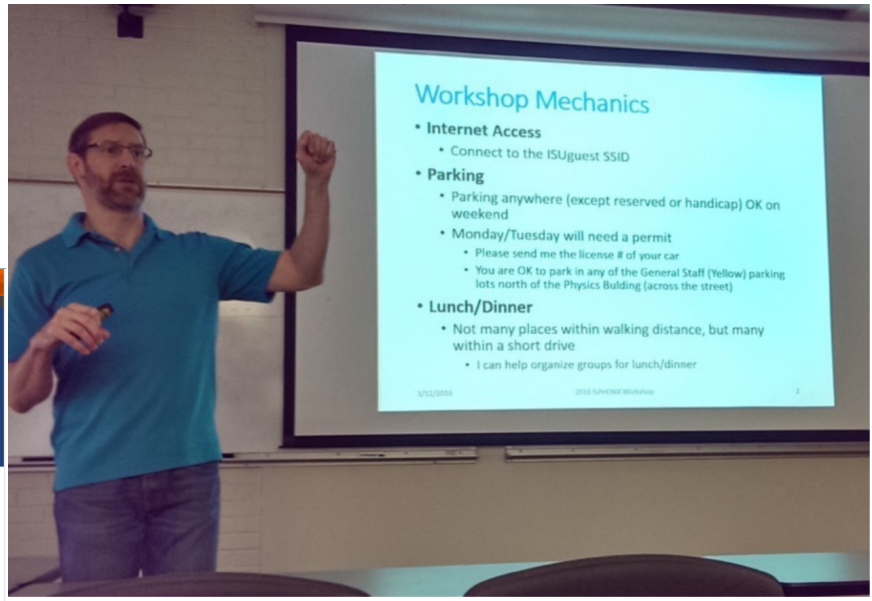
Forward Tracking

- Large area GEM tracking stations at z=120, 150, 275cm ($1.45 < \eta < 4.0$)
  - Space left between ST1 and 2 for future PID
  - ***Strong tie-ins with existing EIC R&D efforts!***
- Additional passive field shaper piston to enhance field shape for improved momentum resolution at high η.

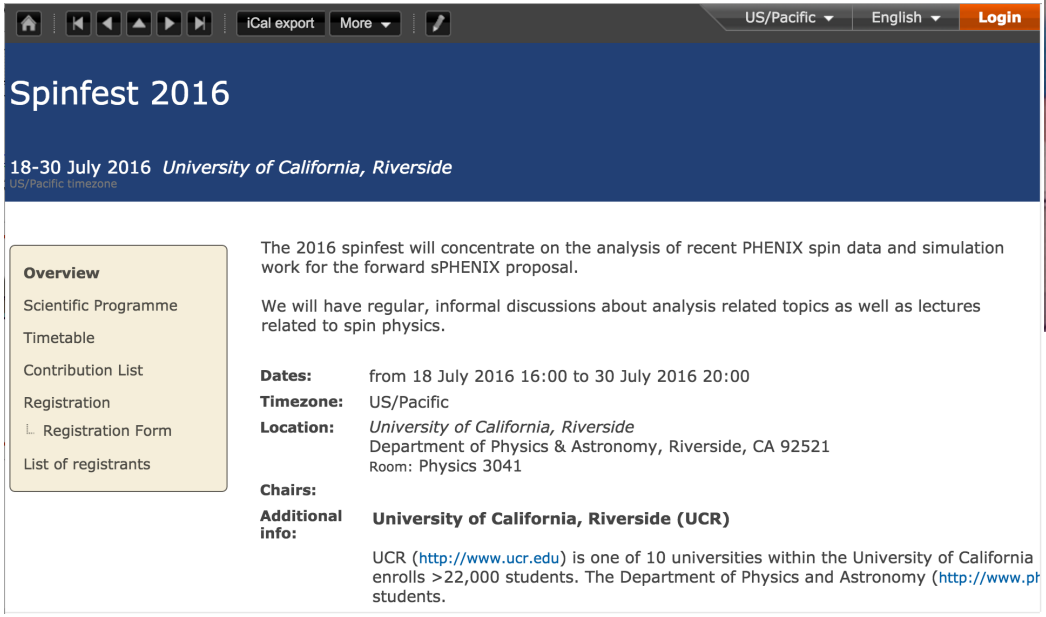




fsPHENIX Workfests



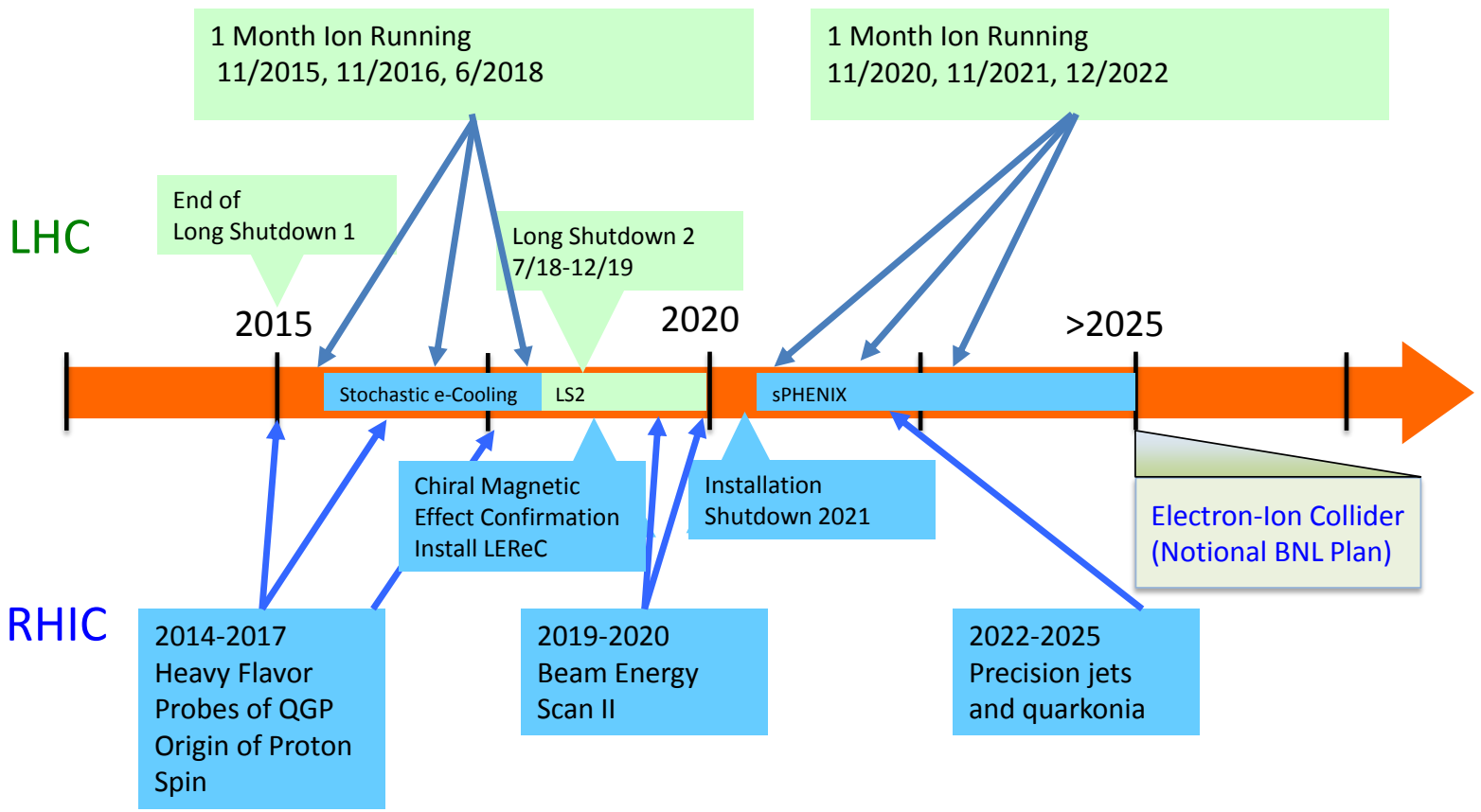
3rd fsPHENIX Workfest:
Iowa State University, March 2016



4th fsPHENIX Workfest: UC Riverside, July 2016

- Activity: Workfests + bi-weekly phone meetings
- Working toward a LOI by the end of 2016
- **fsPHENIX is at the beginning stages, participation of new collaborators are welcomed!**

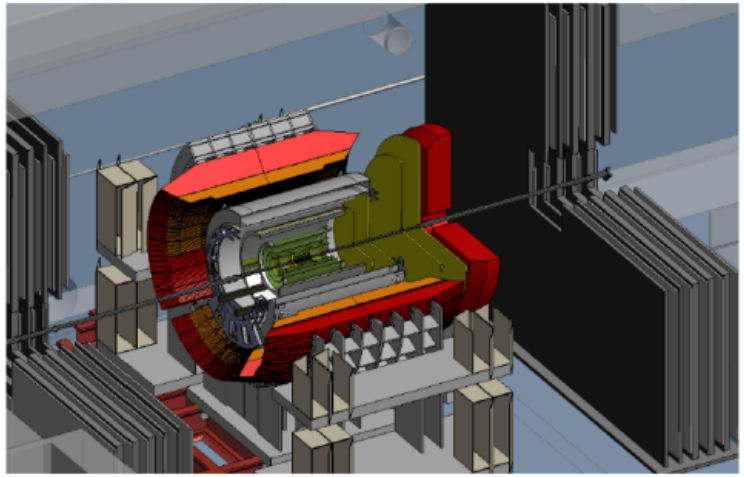
RHIC / LHC Timeline



Slide from Tim Hallman's talk at RHIC Users' Meeting, June 2016

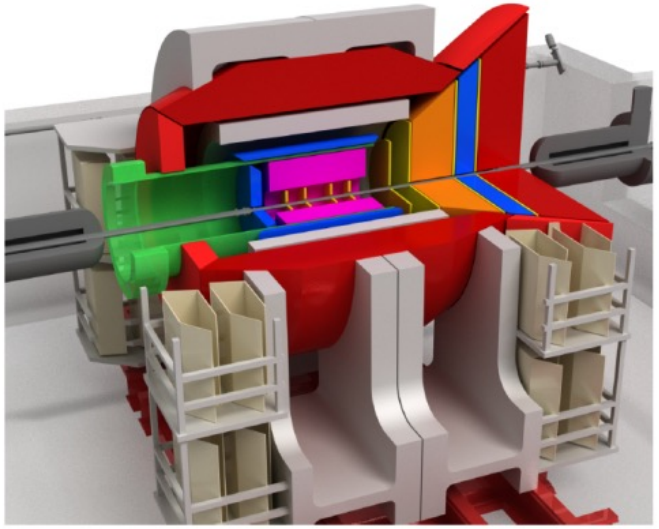
On to the EIC…

Future Opportunities in $p+p$ and $p+A$ Collisions at RHIC with the Forward sPHENIX Detector



The PHENIX Collaboration
April 29, 2014

Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid

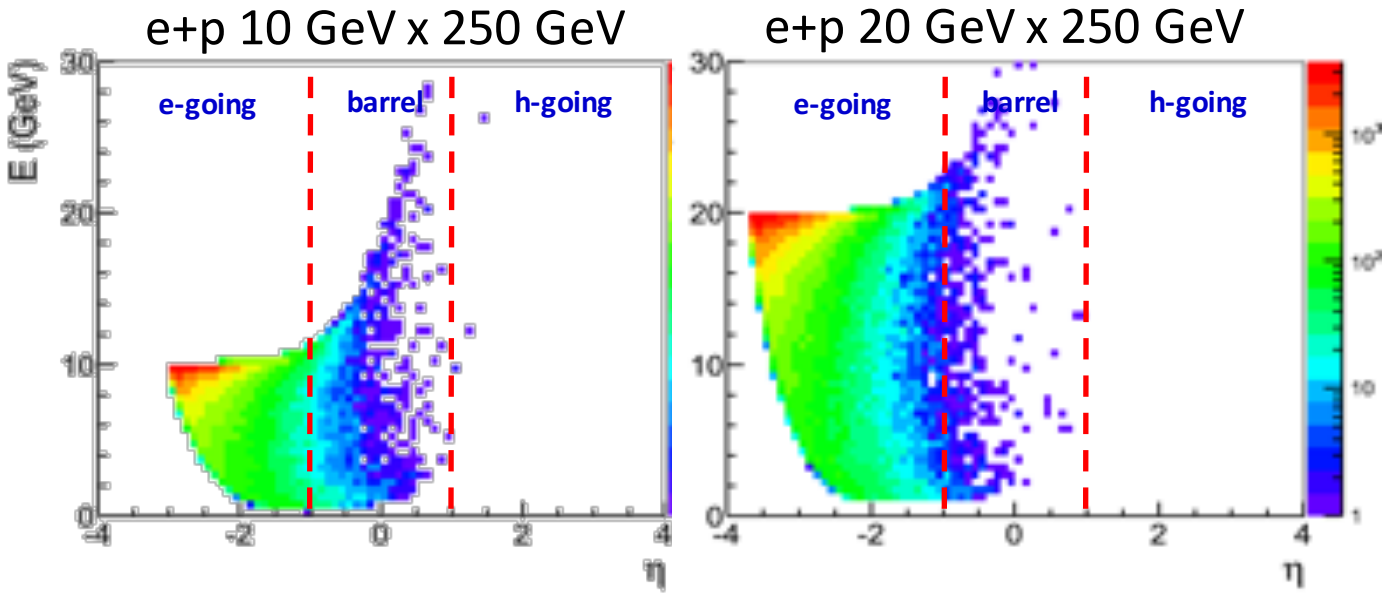


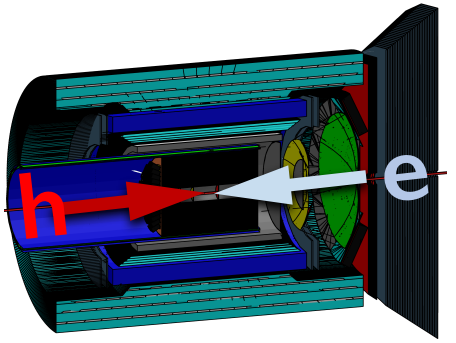
The PHENIX Collaboration
February 3, 2014

arXiv:1402.1209v1

The forward detectors for fsPHENIX could potentially be re-used for an EIC detector!

DIS: Electron measurement





PYTHIA DIS with
$Q^2 > 1$ GeV

Requirements (EIC task force):

- High purity electron ID (99%)
- Energy measurement
- Angle measurement
- High survival probability in each x,Q^2 bin (80%)
- e-going and barrel coverage

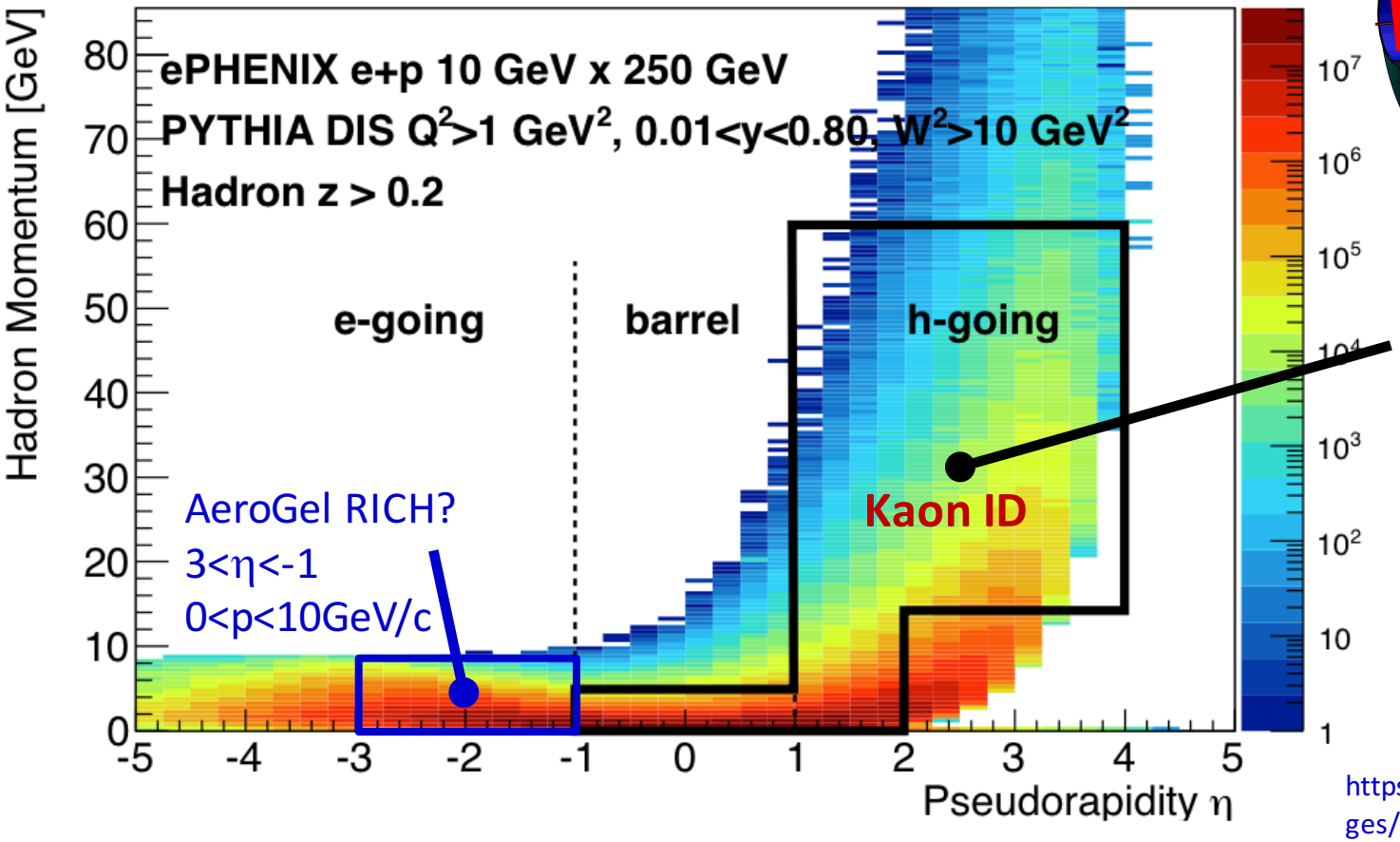
Solution (electron-going):

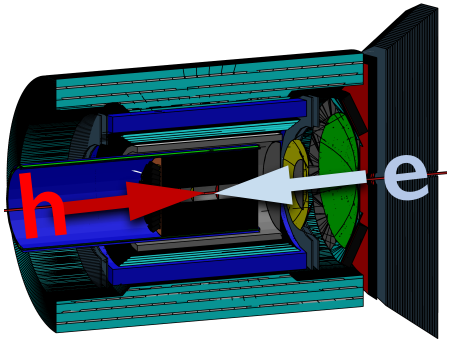
✓High resolution GEM Tracking
✓High resolution Crystal EMCal

Solution (barrel):

✓Compact-TPC
✓sPHENIX EMCal

SIDIS: Hadrons from DIS





Black outline: Identified Kaons in planned PID detectors

Considering e-going AeroGel modular RICH for 20GeV e-beam

Based on EIC eRD14

https://wiki.bnl.gov/conferences/images/8/8c/ERD14_FY17_proposal.pdf

Requirements:

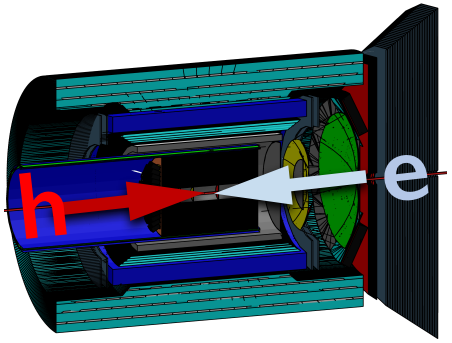
- Hadron ID
- 90% eff, 90% purity

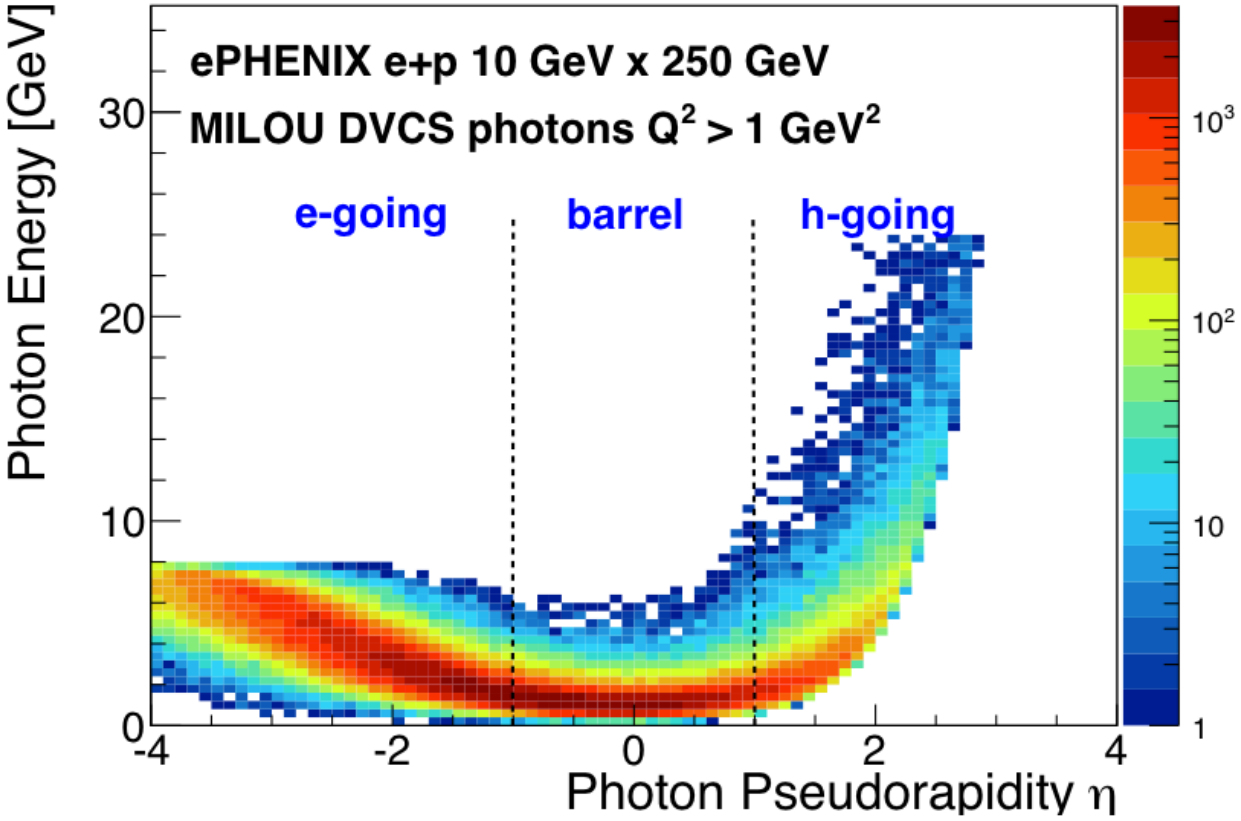
Solution: RICH

✓Barrel: DIRC (+TPC dE/dX for low p)

✓h-going: Gas RICH (high p)& Aerogel (low p)

Exclusive DIS: DVCS photons





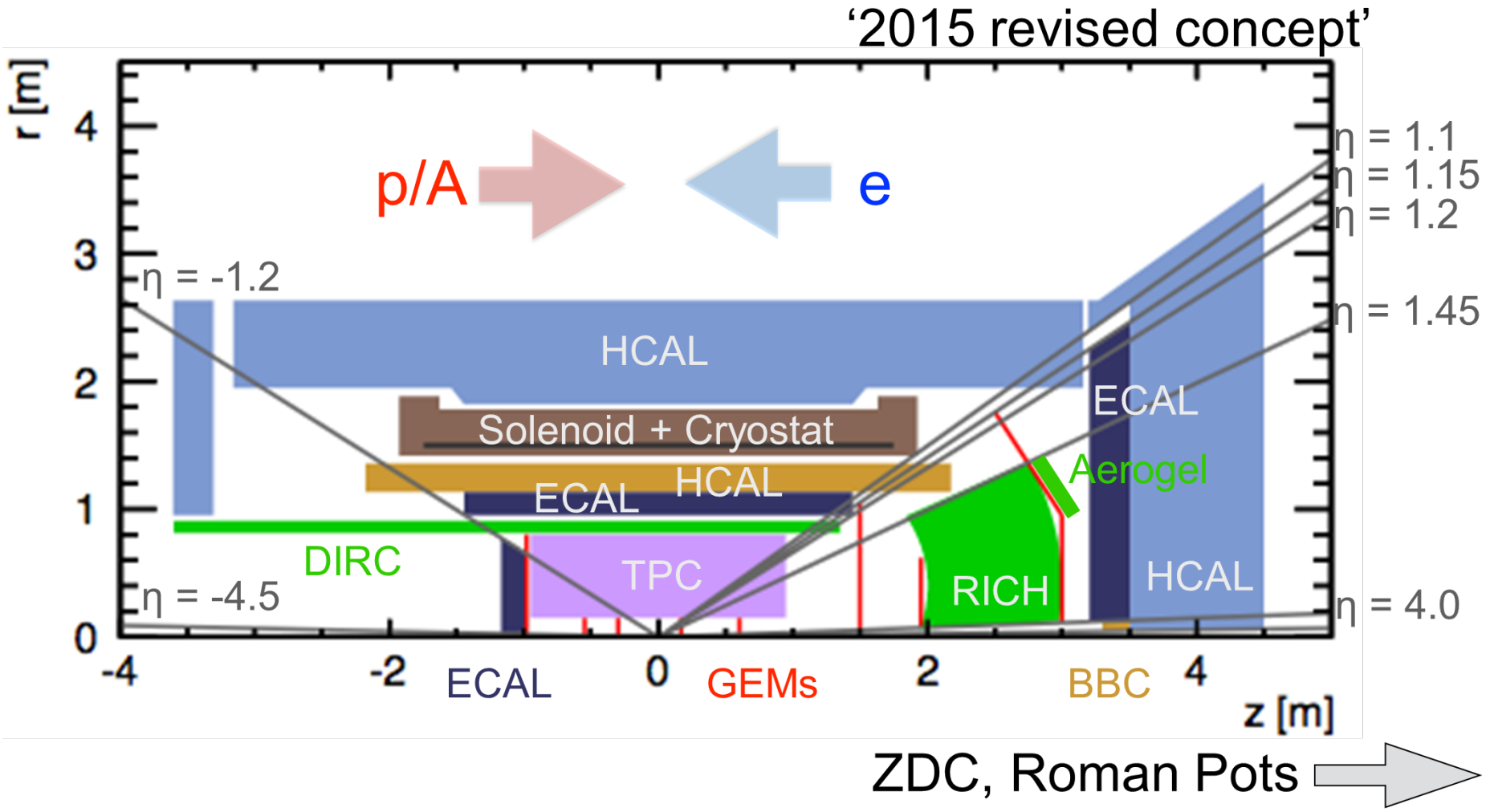
Requirements:

- e/γ separation over large x,Q^2,t range
- Confirm exclusiveness

Solution:

- ✓Granular EMCal and tracking from -4<η<4
- ✓Roman Pots

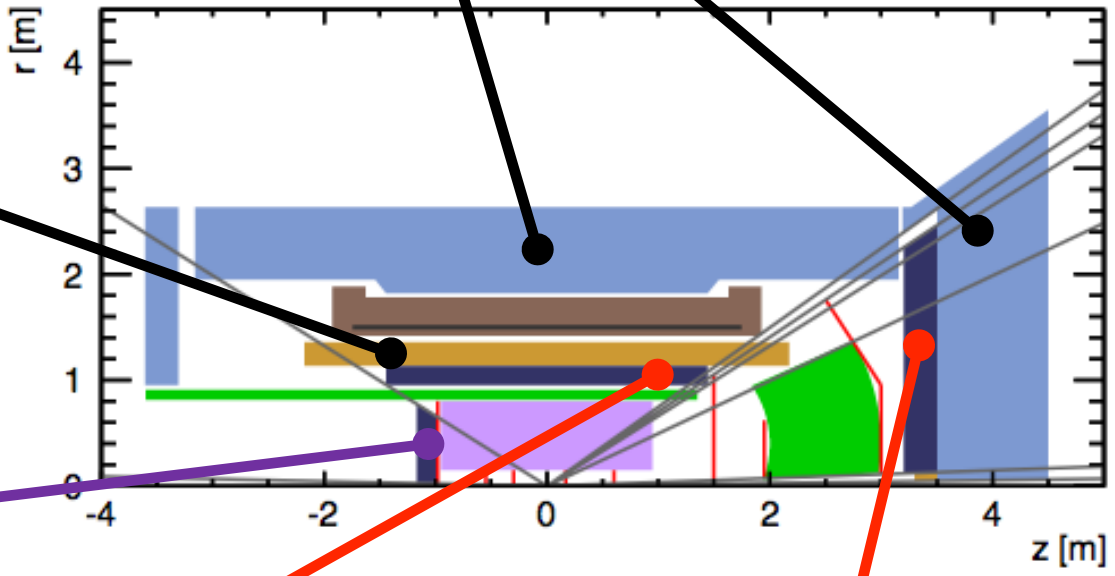
Day-1 EIC Detector



Calorimetry

HCAL: Steel-scintillator (5 λ_{int})
100%/√E energy resolution
~ 10 × 10 cm^2 segmentation

HCAL: Steel-scintillator (1 λ_{int})
100%/√E energy resolution
~ 10 × 10 cm^2 segmentation



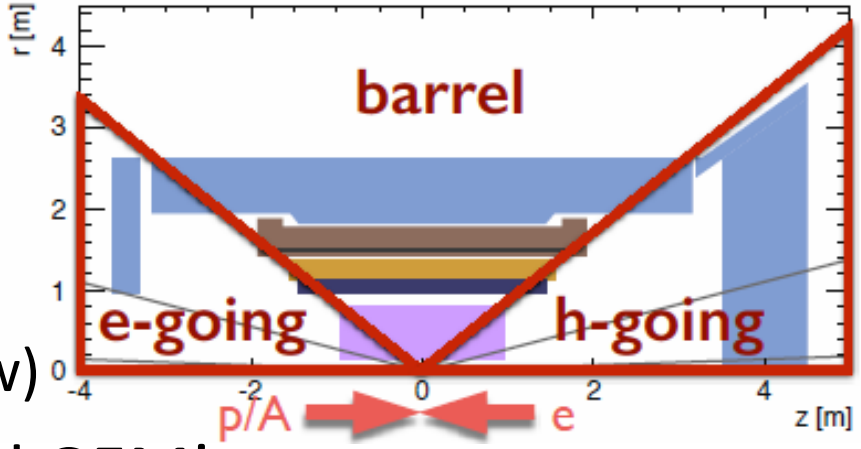
EMCal: Lead-tungstate (20 X_0)
2%/√E energy resolution
2x2 cm^2 segmentation
3mm/√E position resolution

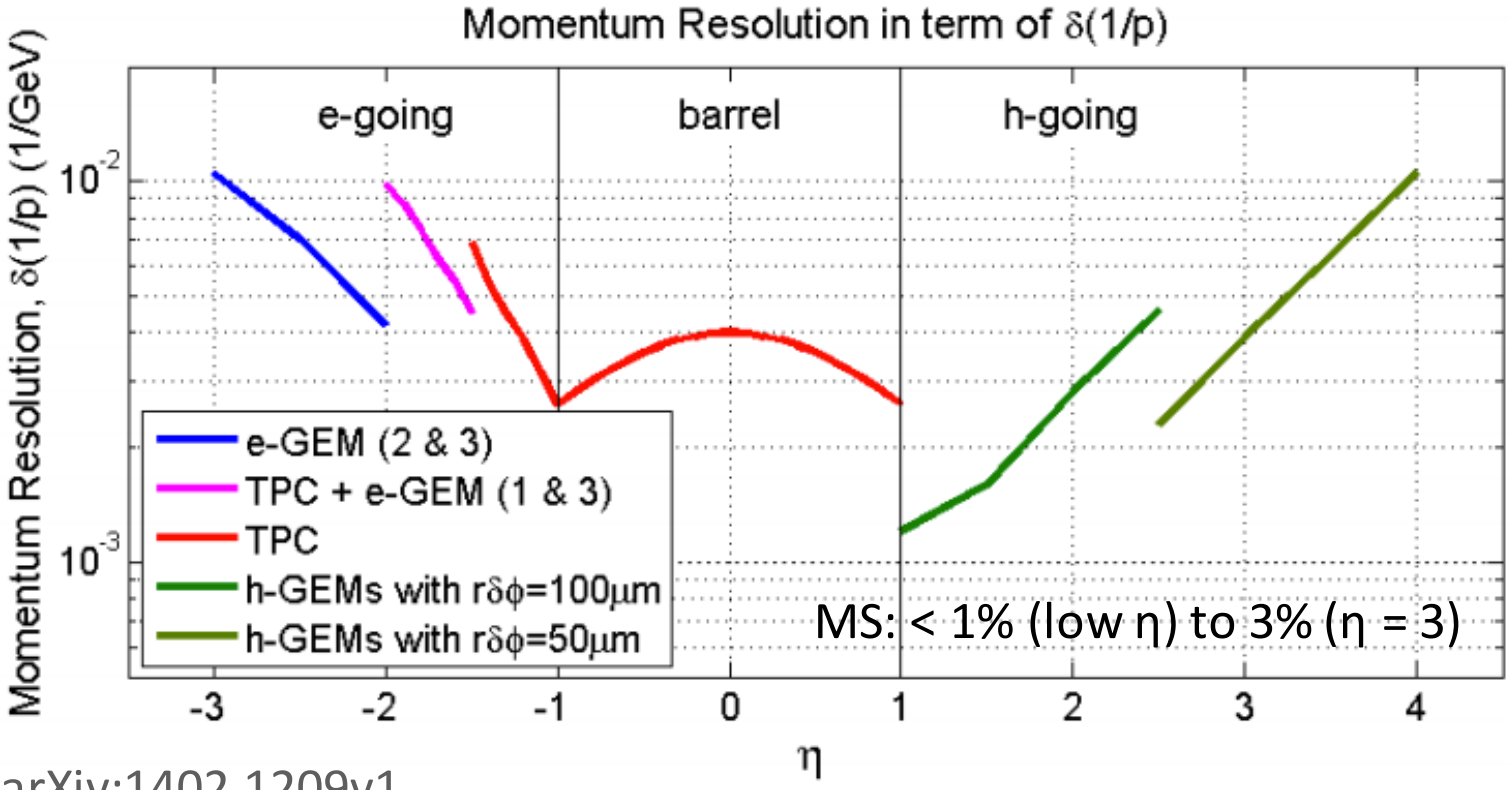
EMCal: Tungsten-fiber (18 X_0)
12%/√E energy resolution
~3x3 cm^2 segmentation

EMCal: Lead-scintillator (18 X_0)
12%/√E energy resolution
~3x3 cm^2 segmentation

Tracking

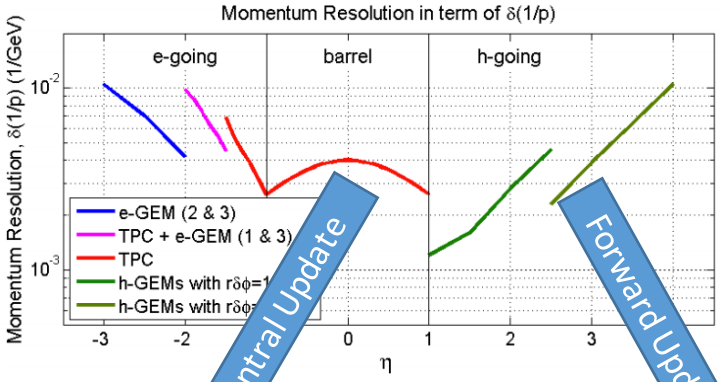
- Barrel: sPHENIX options
  - Silicon, MAPS, TPC (9/2016 review)
- EIC Detector: TPC (+MAPS?) and GEM's





arXiv:1402.1209v1

Tracking Updates



Analytical estimation of linear resolution term In 2012-concept [arXiv:1402.1209v1]

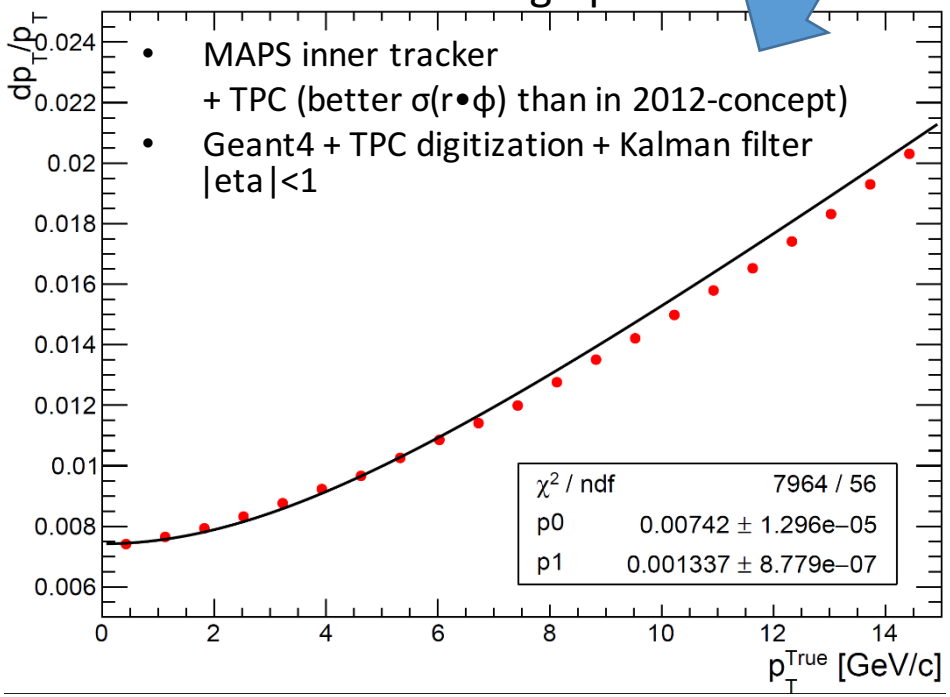
MS: < 1% (low η) to 3% (η = 3)

Central Update

Forward Update

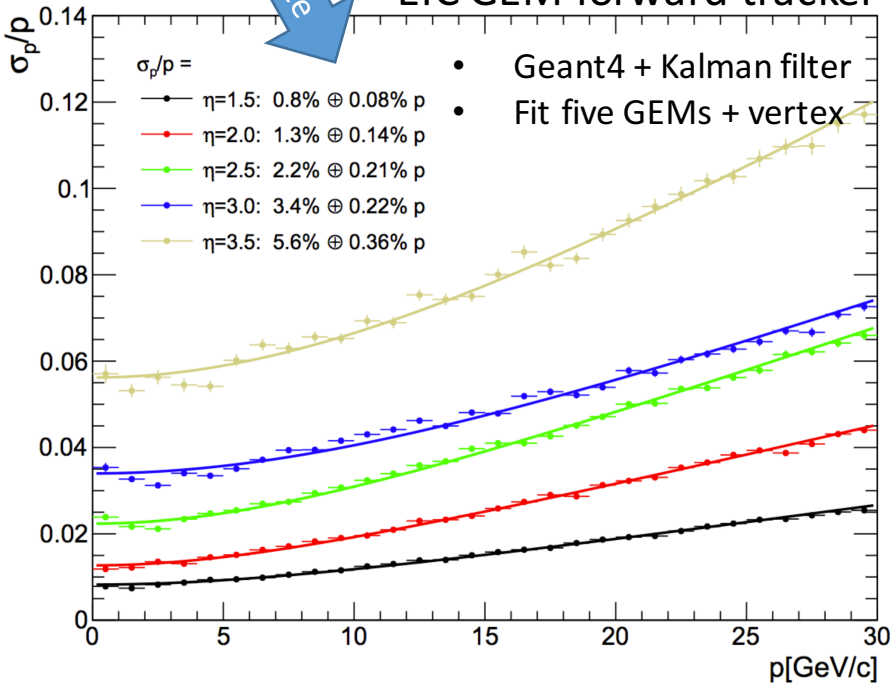
One sPHENIX tracking option

- MAPS inner tracker
  + TPC (better σ(r•ϕ) than in 2012-concept)
- Geant4 + TPC digitization + Kalman filter
  |eta|<1



EIC GEM forward tracker

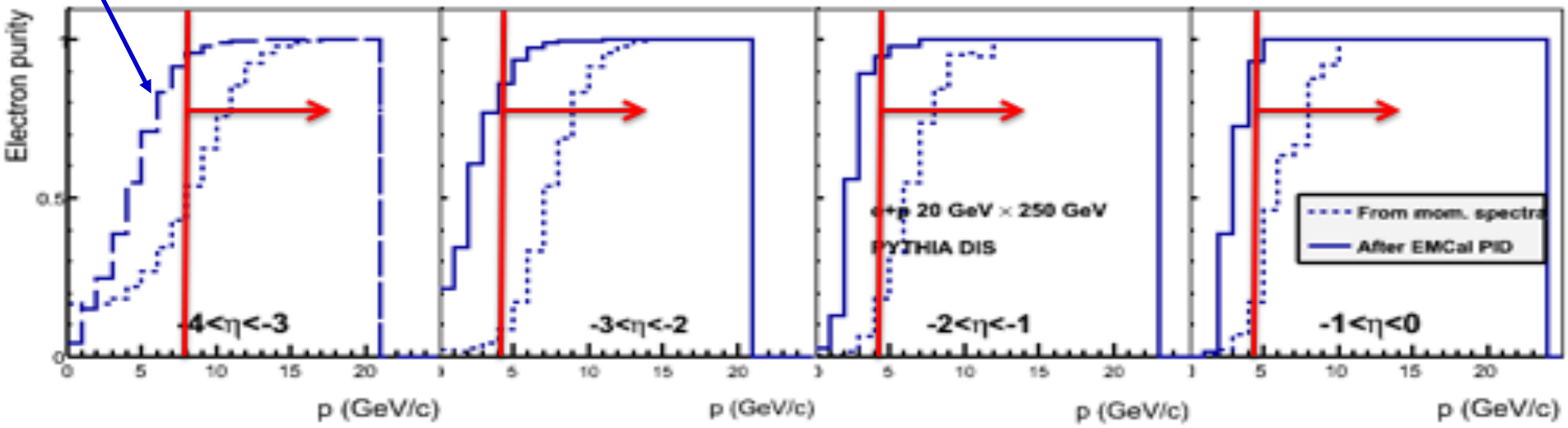
- Geant4 + Kalman filter
- Fit five GEMs + vertex

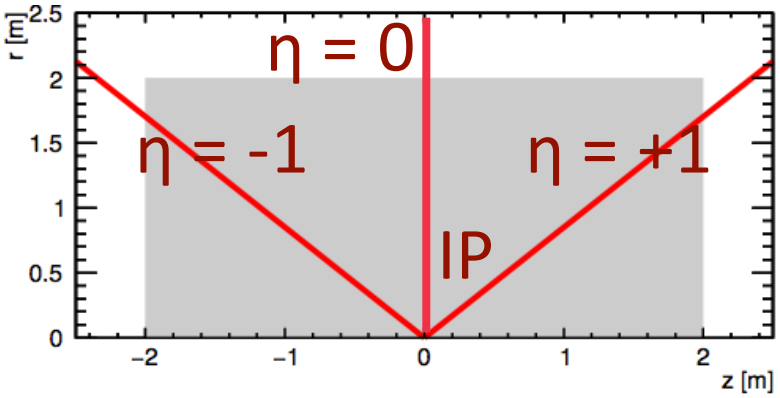


Electron Identification

No tracking or E/p

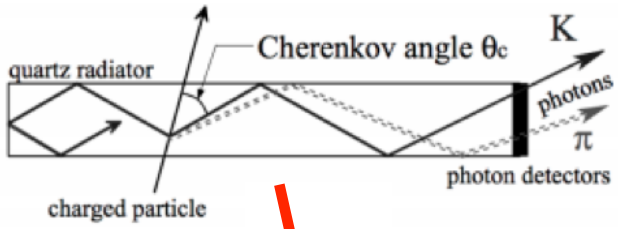
e+p 20 GeV x 250 GeV

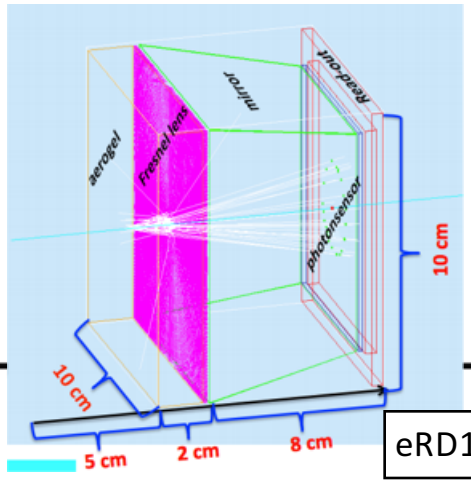




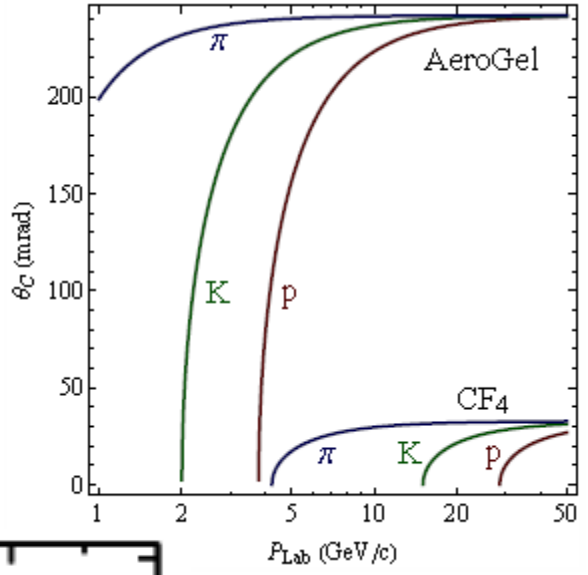
- Cut on electron energy only marginally reduces x-Q^2 coverage
- Working toward full simulation.

Particle ID: RICH/psTOF Detectors





eRD14

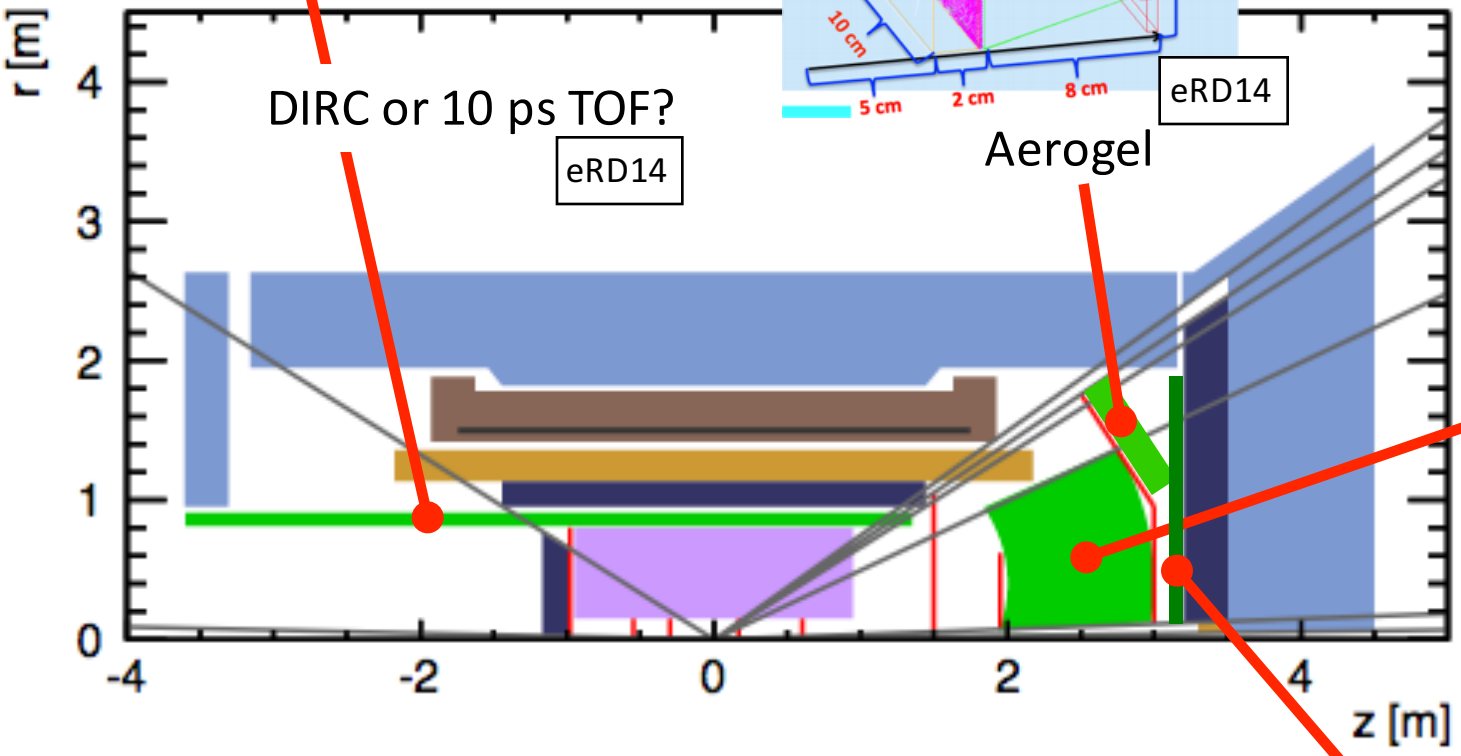


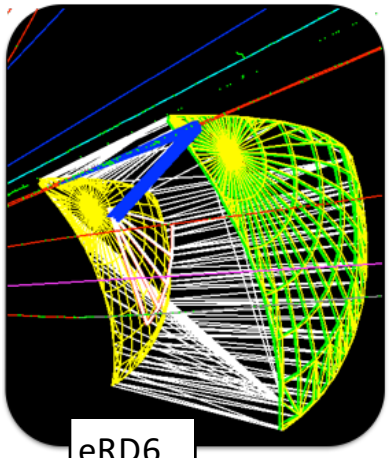
DIRC or 10 ps TOF?

eRD14

Aerogel

Gas (CF_4)

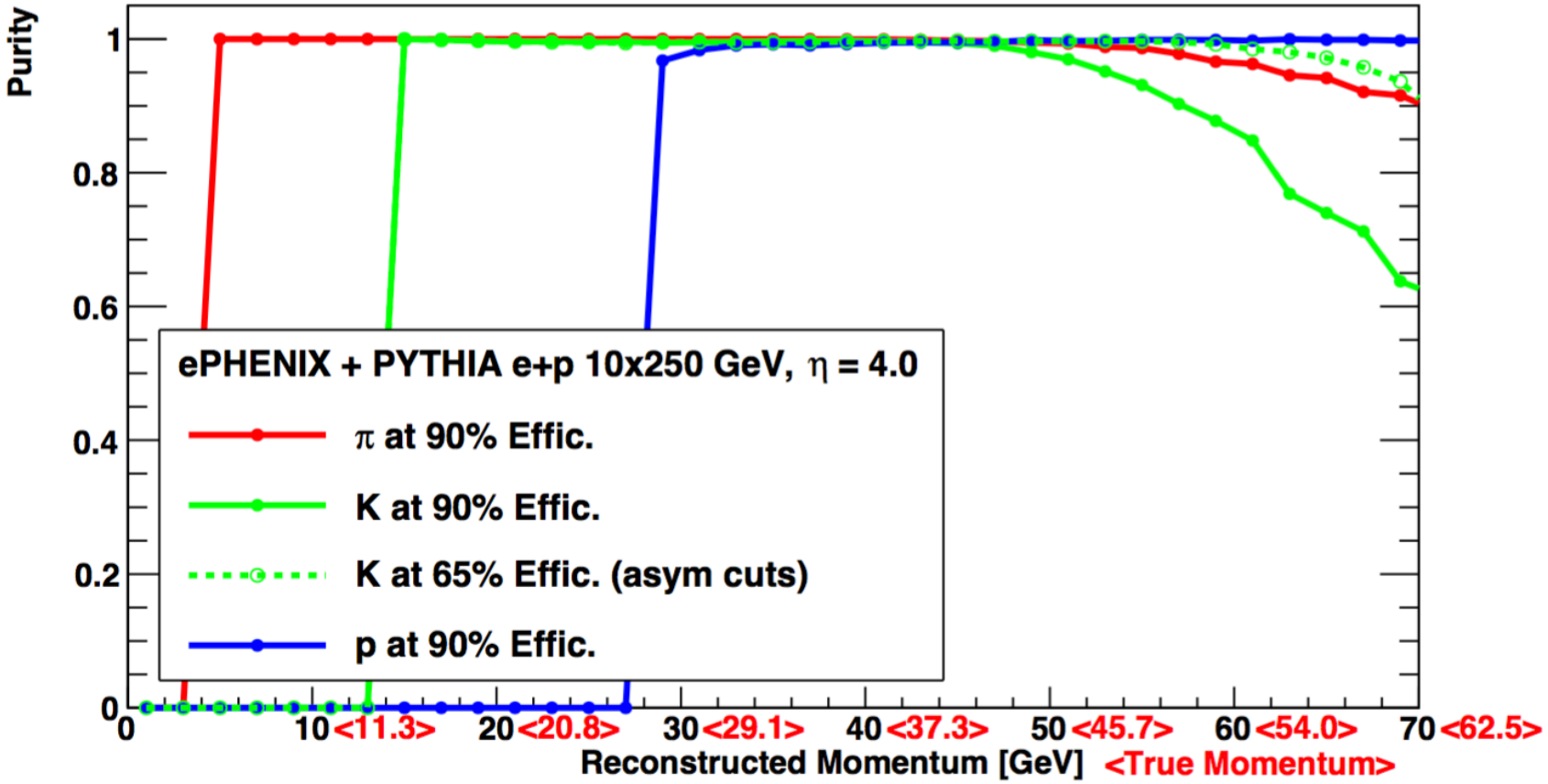




eRD6

10 psTOF?

Hadron Identification



- High purity for all particle species up to ~50 GeV with symmetric 90% efficiency cuts on mass distribution.
- Can be extended to higher momenta with asymmetric cuts.

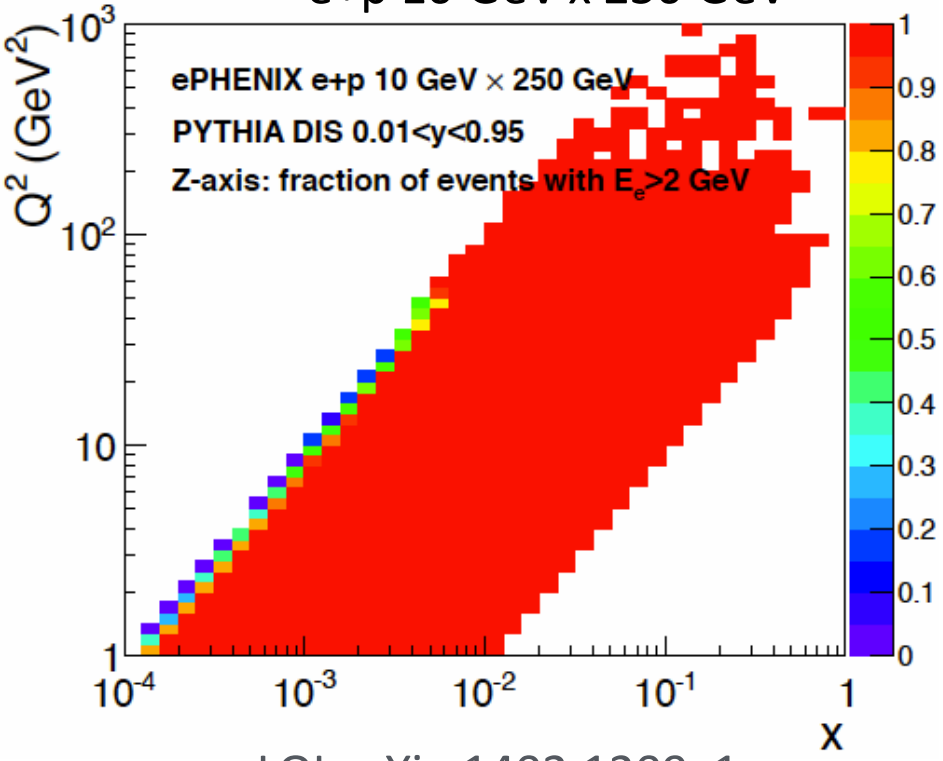
Summary

- sPHENIX is a major new project that will make available probes of the Quark Gluon Plasma with unprecedented precision.
- Additional forward instrumentation added to sPHENIX (fsPHENIX) is being actively explored.
    - Extend the sPHENIX physics program to include p+p/p+A as well as longitudinal dynamics in HI collisions
    - Substantial re-use of existing detector systems for calorimetry
    - Tie-ins with EIC R&D
    - Pushing towards a new fsPHENIX LOI end of 2016
- **Evolves naturally to a Day-1 EIC Detector**
    - Covers critical acceptances and physics
- Ongoing simulation and detector R&D activities.

Extra slides …

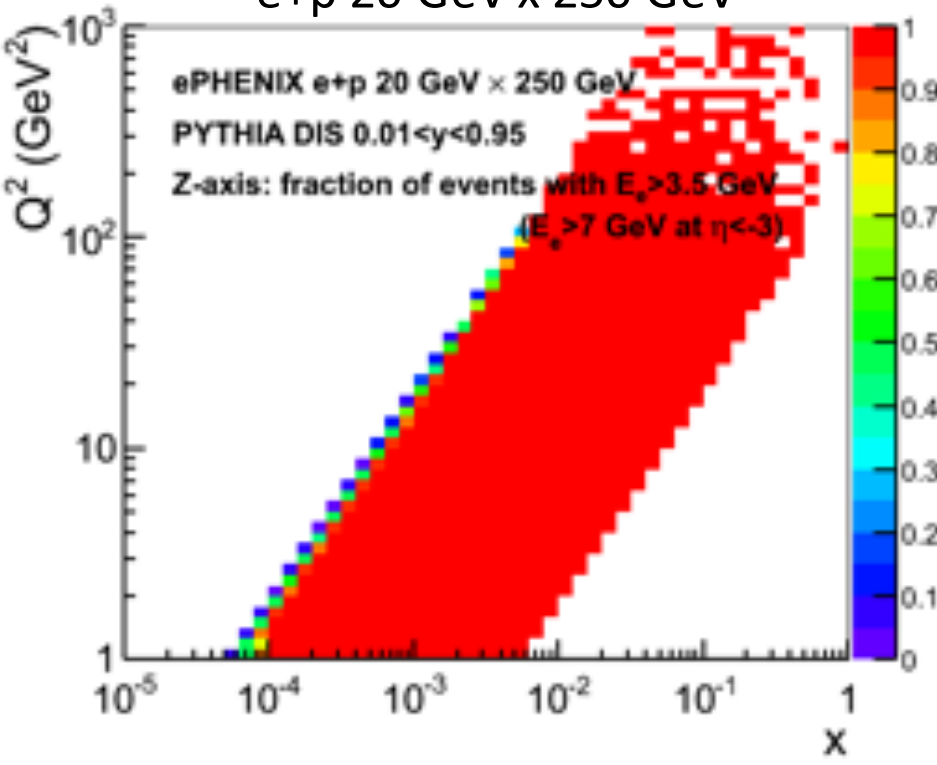
DIS: electron measurement

e+p 10 GeV x 250 GeV



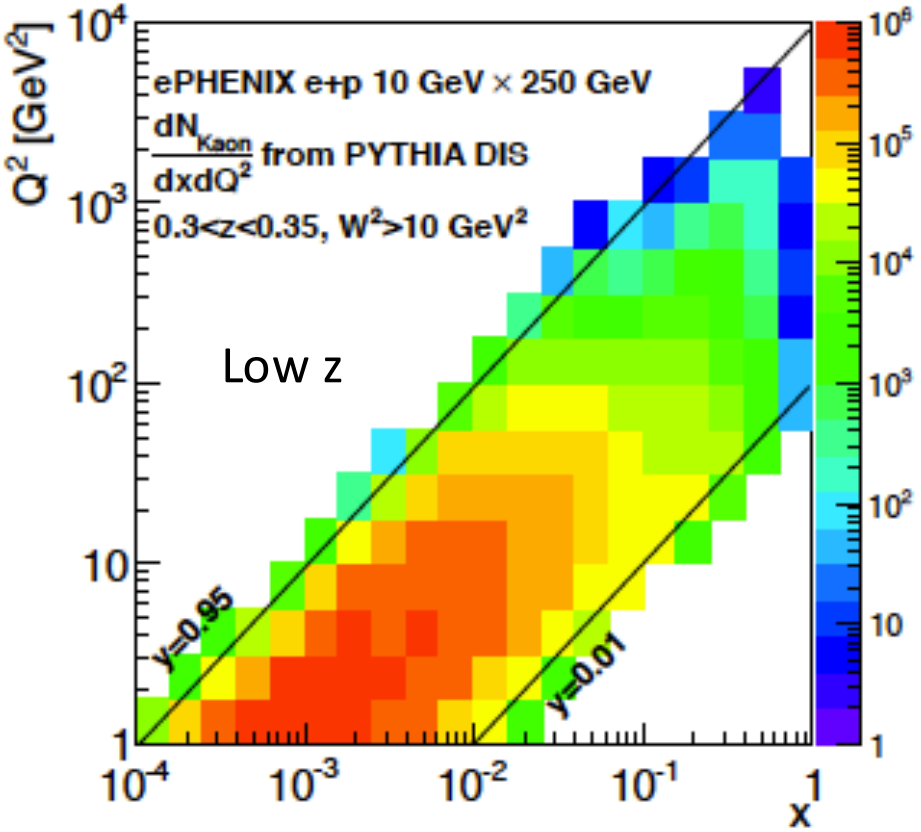
LOI arXiv:1402.1209v1

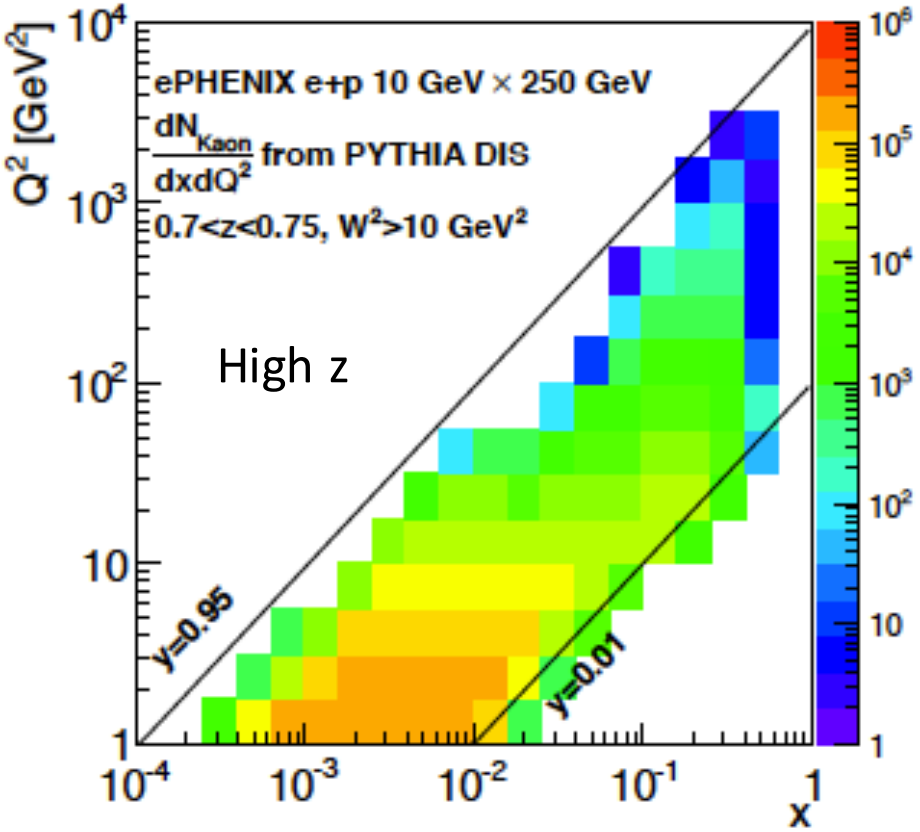
e+p 20 GeV x 250 GeV



- Cut on electron energy only marginally reduces x-Q^2 coverage

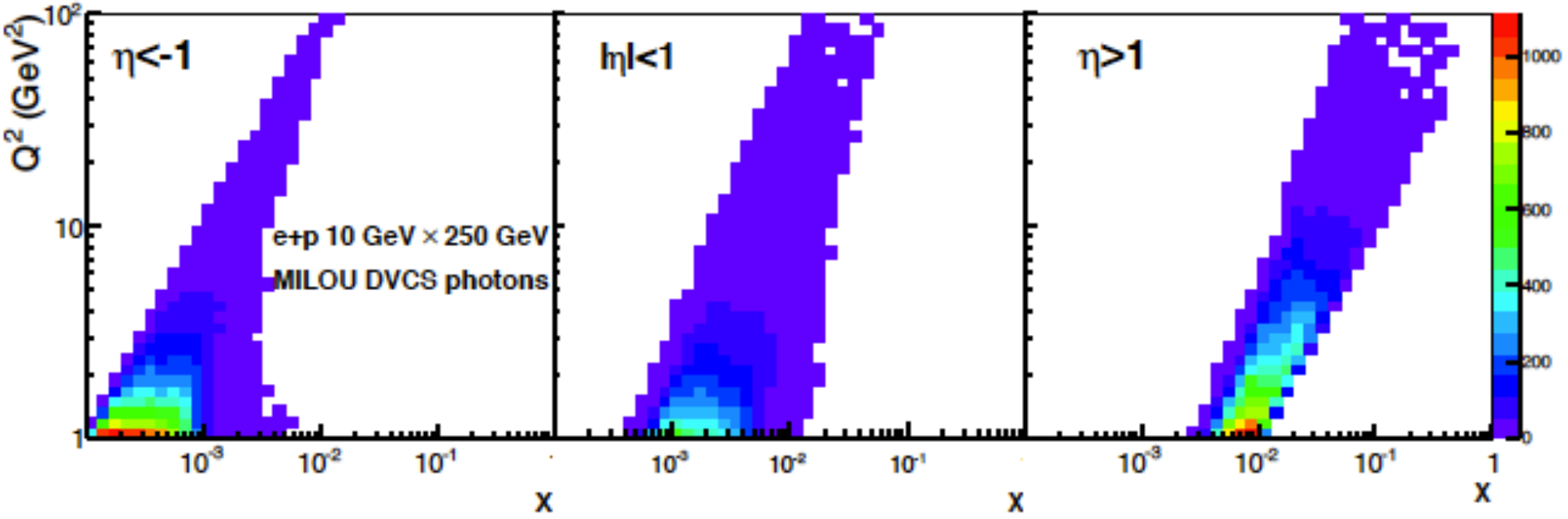
SIDIS: Hadrons from DIS





- Identified kaons kinematics coverage

Exclusive DIS: DVCS photons

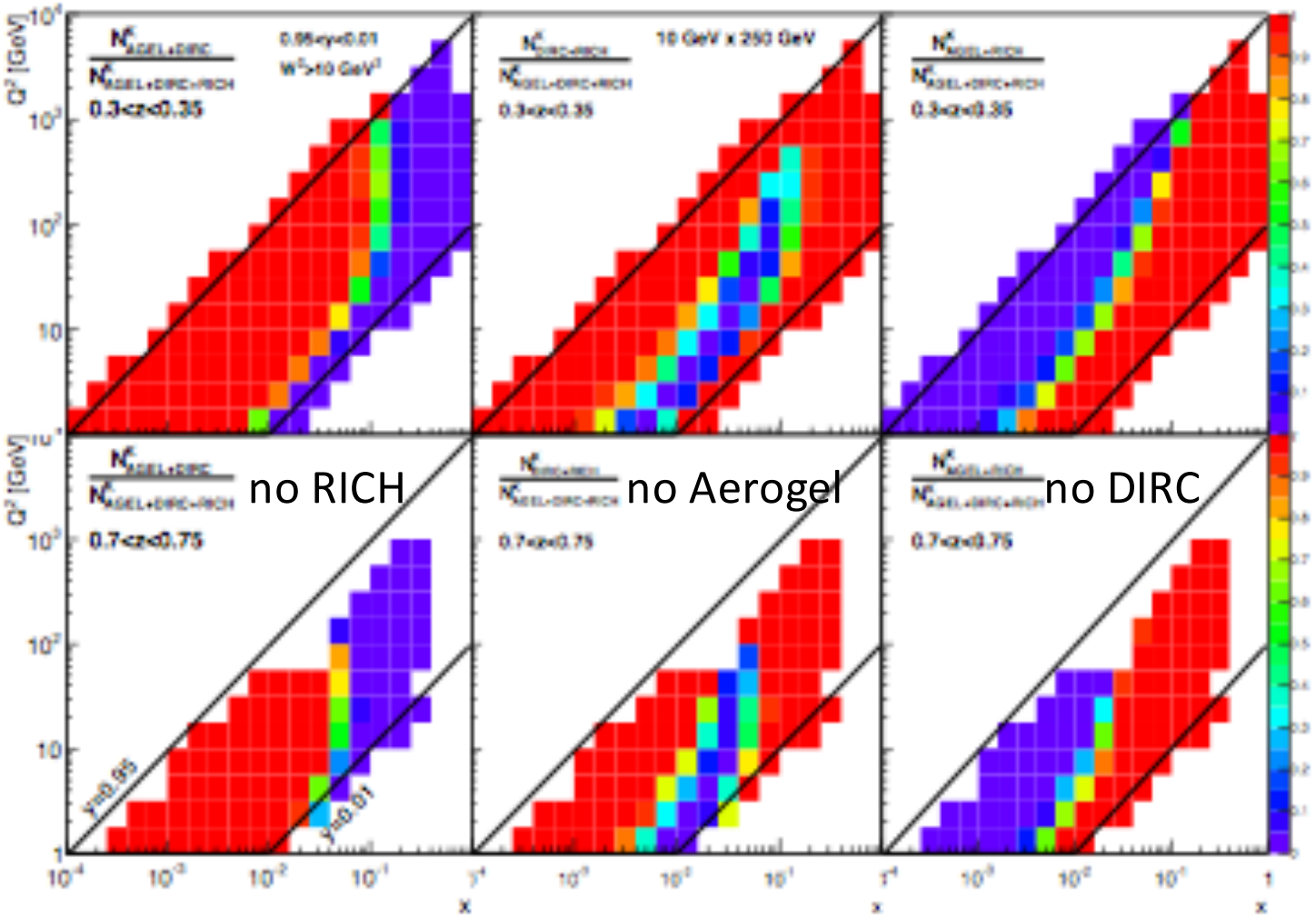


- Need to cover wide rapidity range

Hadron Identification

low z

high z



- All three RICH detectors are needed to cover full x-Q^2 range