EIC simulation under PHENIX Geant4 framework

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Overview

Overview

- PHENIX software framework (Fun4All)
  - Compact C++/STL framework, driving the analysis cycles
  - Same framework to handle simulation and real data analysis
  - Allow save/readback data object at any given breakpoint of analysis flow through formatted ROOT TTree files (DST)
  - Software packages and expertise available in PHENIX internal repository
- PHENIX Geant4 framework was systematically introduced around 2010 to drive Geant4 under PHENIX software framework
  - PHENIX upgrade project has been heavily using this framework (sPHENIX proposal, "ePHENIX" concept and fsPHENIX concept)
  - Large scale simulation production >6TB data for sPHENIX DOE scientific review alone
- Beyond PHENIX
  - Decision to relocate the framework and Geant4 part to GitHub for wider access/collaboration
  - Continue evolving the framework
  - Merge features from EICROOT or GEMC? Suggestions? Comments?

# Three major detector proposal/concept currently developed under PHENIX Geant4

- sPHENIX proposal submitted to DOE
- An EIC detector concept on top of sPHENIX
- forward sPHENIX to bridge these two concepts

PH ENIX

The sPHENIX detector

- sPHENIX: major upgrade to the PHENIX experiment aim for data @ 2020
- Physics Goals: detailed study QGP using jets and heavy quarks at RHIC energy region
- Baseline consists of new large acceptance EMCal+HCal built around recently acquired BaBar magnet. Additional tracking also planned
- Successful DOE scientific review last month
- A good foundation for future detector upgrades

Baseline detectors for sPHENIX
sPHENIX MIE, http://www.phenix.bnl.gov/plans.html

An EIC detector concept

arXiv:1402.1209

- -1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC
- -4<η<-1 (e-going) :
  Crystal calorimeter + GEM trackers
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH
  - 1<η<2 : Aerogel RICH
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots
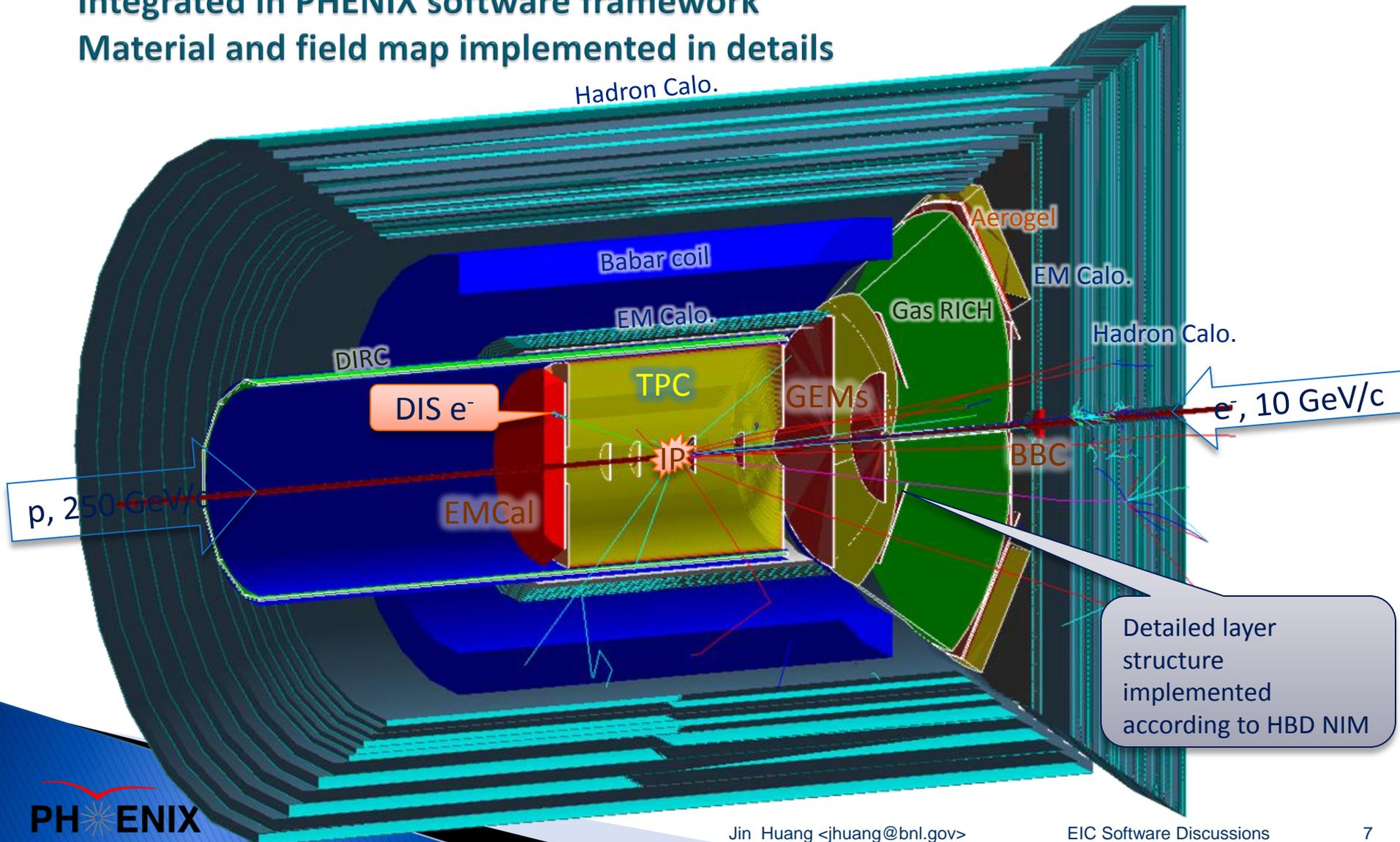- Cost: sPHENIX MIE + 75M$ (including overhead + contingency)

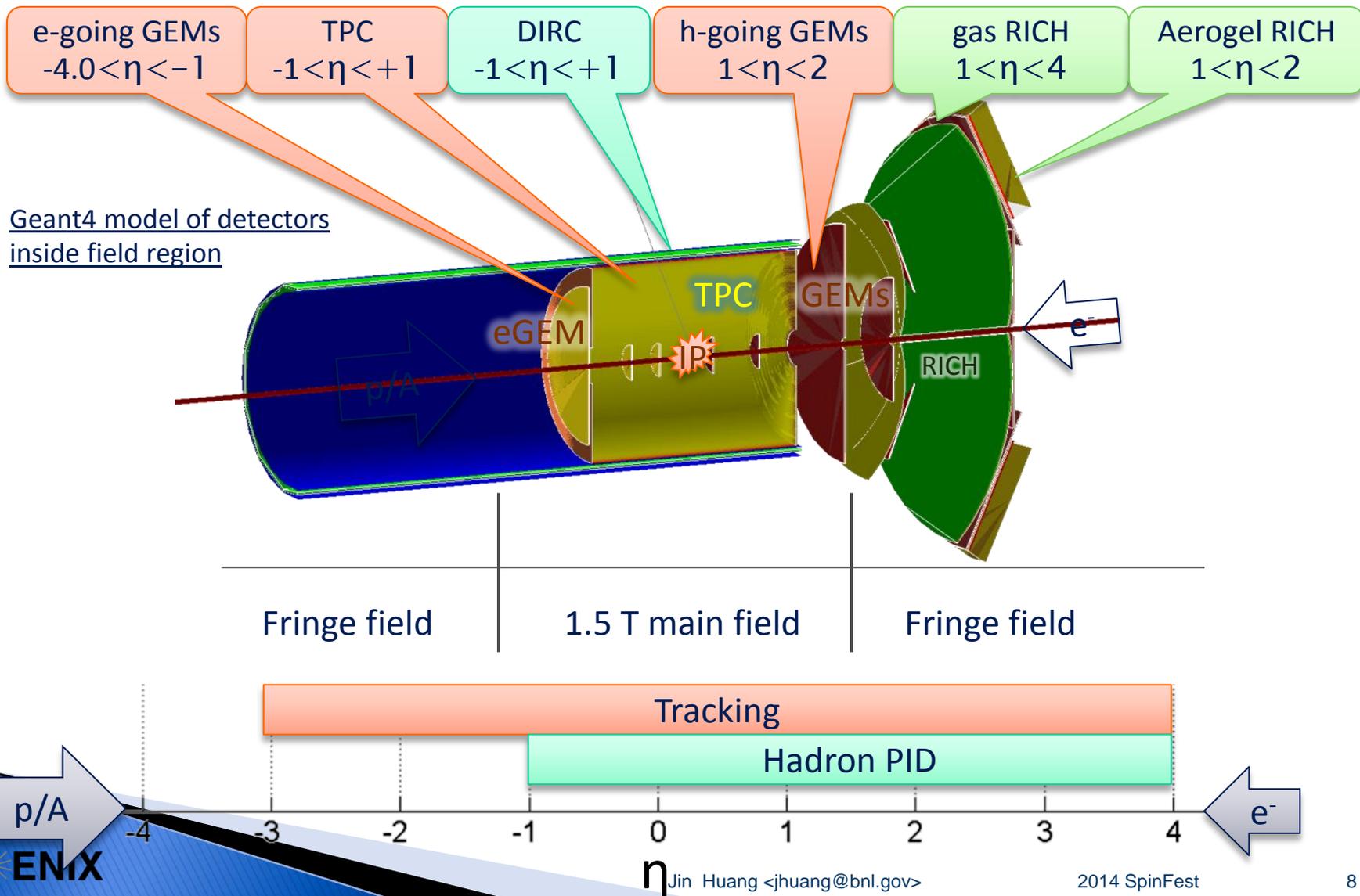ePHENIX Δg projection
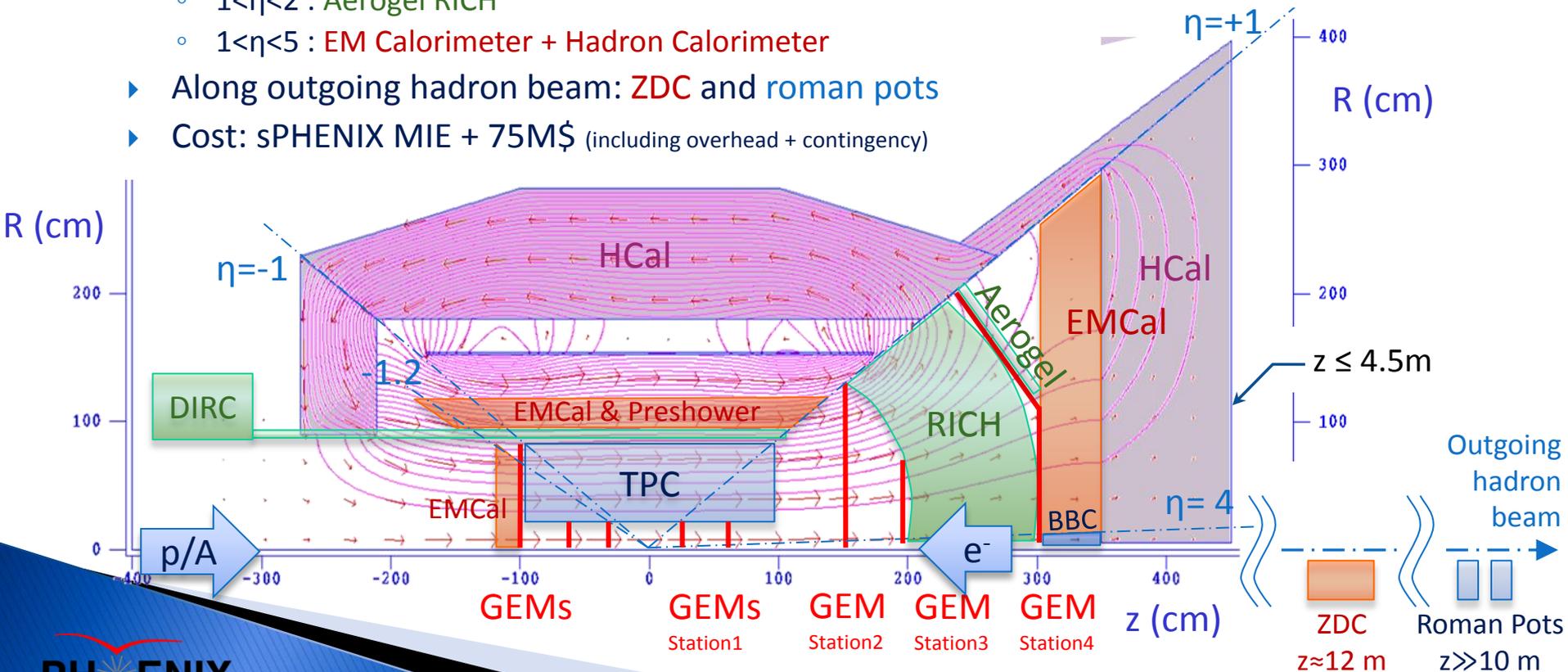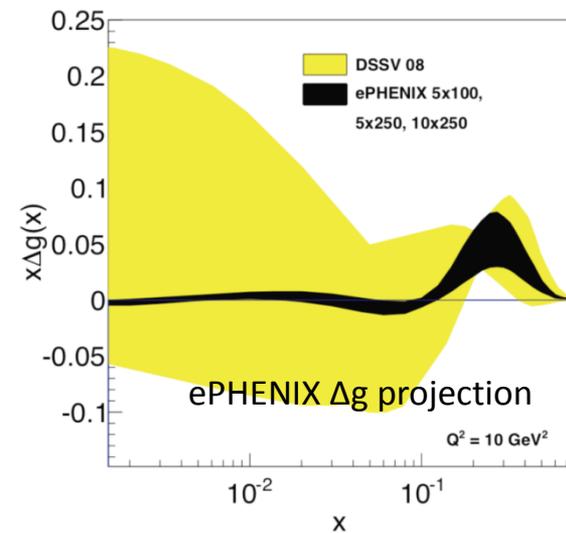
Implementation in sPHENIX Geant4

An event display for SIDIS @ $x \approx 5 \times 10^{-3}$ and $Q^2 = 10$ (GeV/c)^2
Integrated in PHENIX software framework
Material and field map implemented in details

Hadron Calo.

Aerogel

Babar coil

EM Calo.

EM Calo.

Gas RICH

DIRC

TPC

GEMs

Hadron Calo.

DIS e$^-$

e$^-$, 10 GeV/c

BBC

p, 250 GeV/c

EMCal

Detailed layer structure implemented according to HBD NIM

Or you can turn on/move a subset of detector on the macro level

e-going GEMs
$-4.0 < \eta < -1$

TPC
$-1 < \eta < +1$

DIRC
$-1 < \eta < +1$

h-going GEMs
$1 < \eta < 2$

gas RICH
$1 < \eta < 4$

Aerogel RICH
$1 < \eta < 2$

Geant4 model of detectors inside field region

TPC   GEMs

eGEM

p/A

IP

e⁻

RICH

Fringe field   1.5 T main field   Fringe field

Tracking

Hadron PID

p/A

e⁻

-4 -3 -2 -1 0 1 2 3 4

η

PH☆ENIX

Physics before the EIC era:

▸ The ePHENIX forward detector can be constructed earlier
→ a unique forward program with RHIC's pp/pA collision

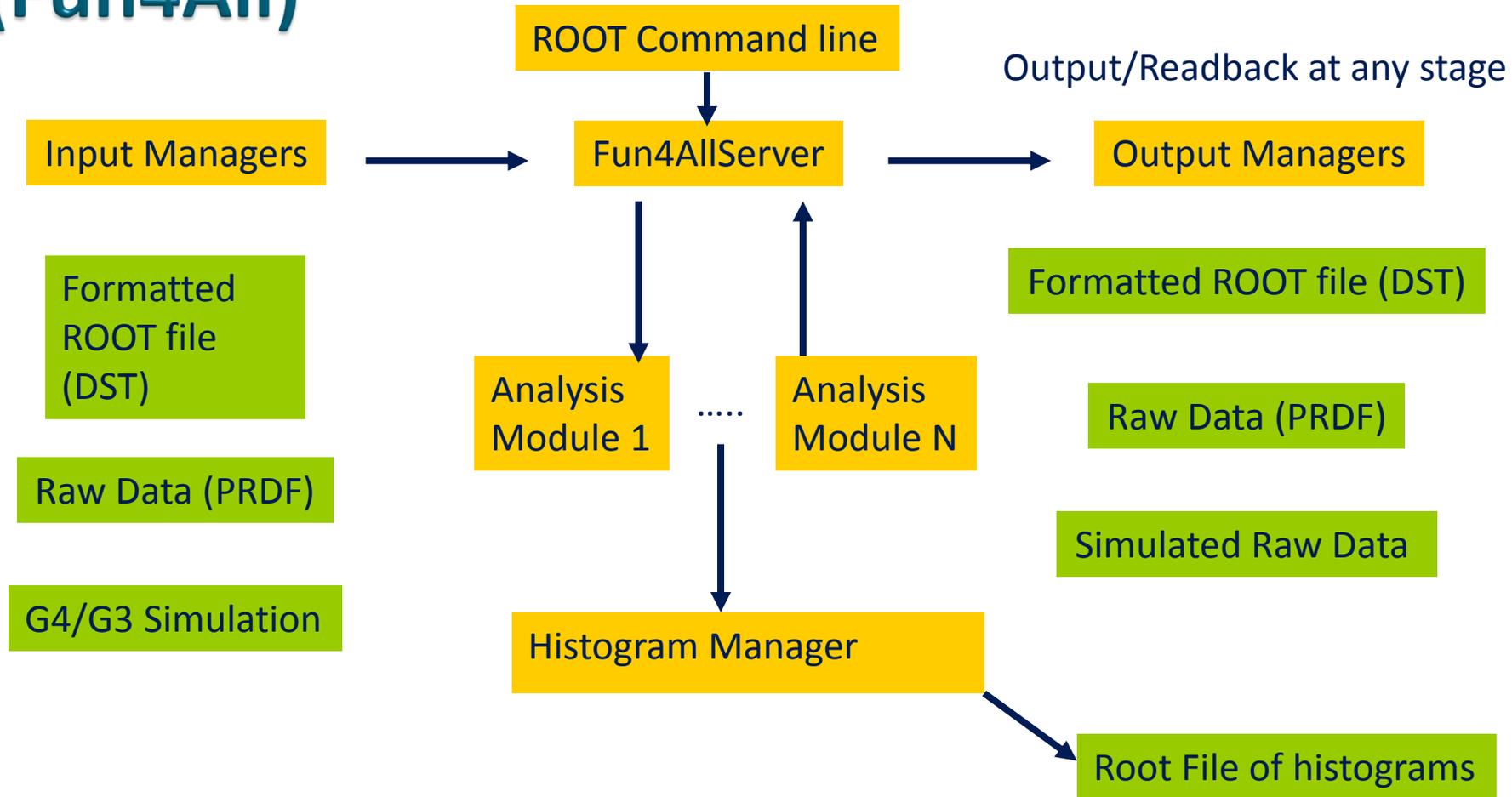▸ White paper submitted to BNL in Apr 2014

ePHENIX GEM + H-Cal
→ Forward jet with charge sign tagging
→ Unlock secrets of large A_N in hadron collisions
+ reuse current silicon tracker & Muon ID detector
→ polarized Drell-Yan with muons
→ Critical test of TMD framework
+ central detector (sPHENIX)
→ Forward-central correlations
→ Study cold nuclear matter in pA

Single jet in GEANT4
p_T = 4.1 GeV/c, eta = 3

IP

p↑

p/A

GEMs

Hadron Calo.
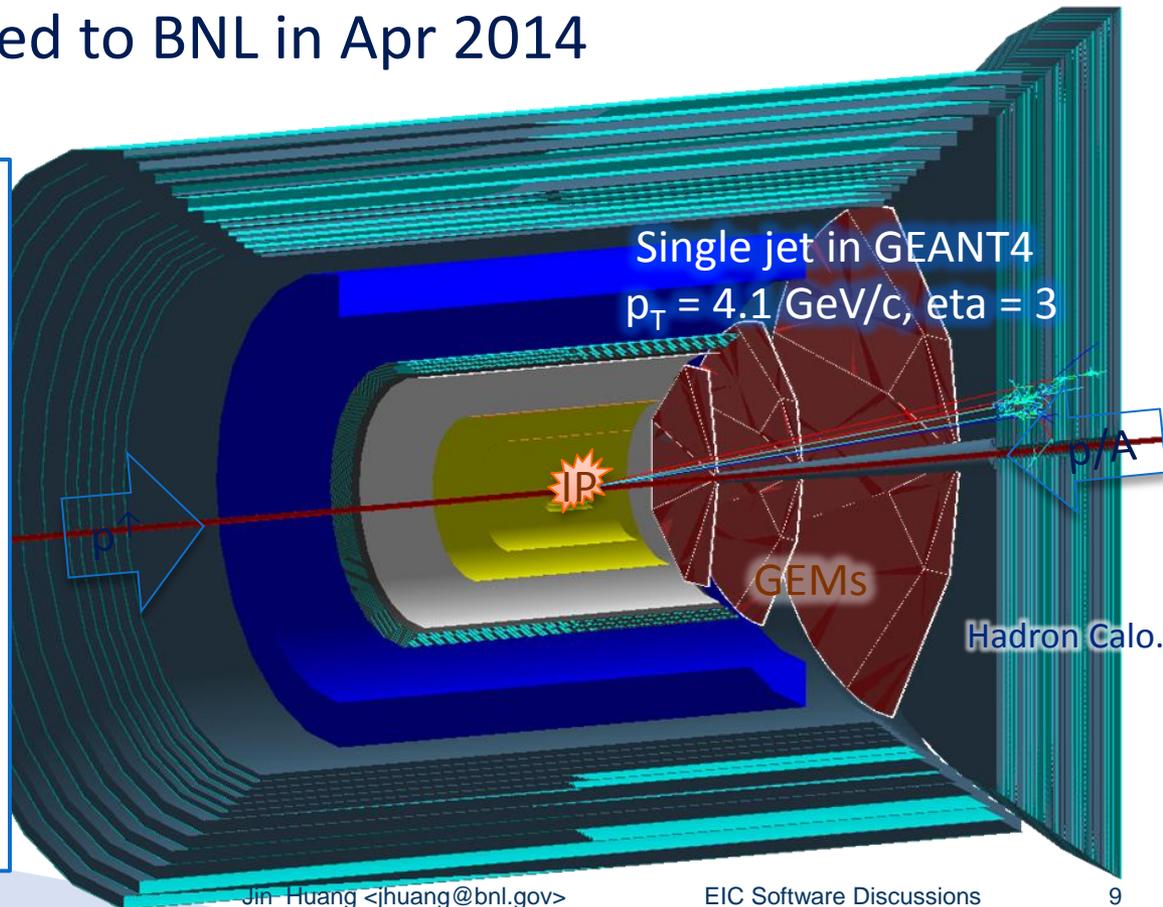
PH*ENIX

More features

»

Structure of PHENIX analysis framework (Fun4All)

ROOT Command line

Input Managers → Fun4AllServer → Output Managers

Output/Readback at any stage

Formatted ROOT file (DST)

Raw Data (PRDF)

G4/G3 Simulation

Analysis Module 1 ..... Analysis Module N

Formatted ROOT file (DST)

Raw Data (PRDF)

Simulated Raw Data

Histogram Manager

Root File of histograms

From Dr. Chris Pinkenburg (BNL)

Implementation of Geant4

- PHENIX framework link and use Geant4 like many other external packages (e.g. DB, fast jet, etc.)
- Detector configurable from ROOT macros
- Detector choose how to import data from Geant4 to data nodes (integrated G4Steps out-of-box)
- Easy configure for different input formats, Geant4 physics list, etc.
- Run Geant4 event display and control through ROOT command lines. A GUI will be nice

PHENIX Analysis Framework
w/ interface to configuration macro in ROOT

Geant4 libs
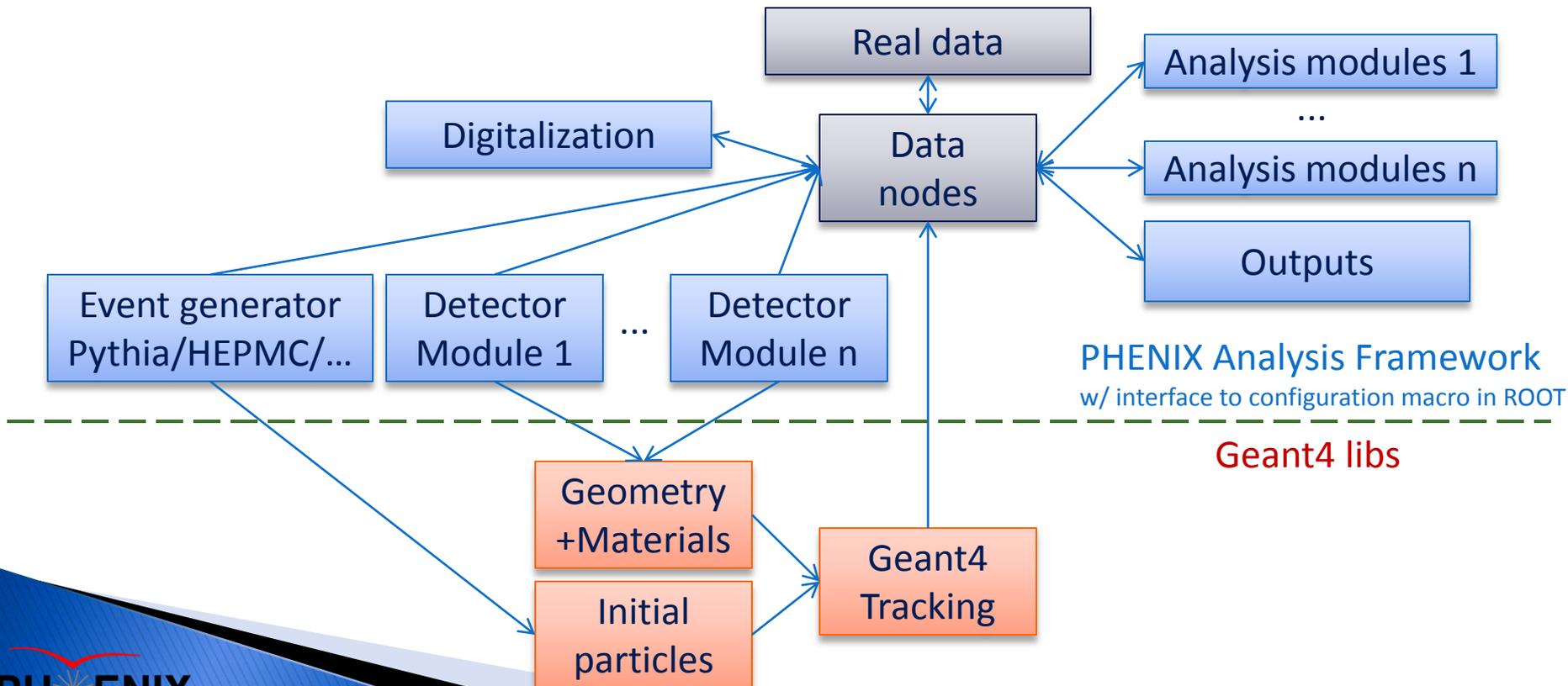
SPACAL simulation

- SPACAL implemented in sPHENIX simulation framework, in reference to Alexander Kiselev's work in EICROOT for EIC RD1 and BeAST simulation
- Covered full azimuthal and |η|<1.1 in s/ePHENIX
- Large scale (TBs) simulation run with full Geant model of 20M fibers

Side view 2 cm
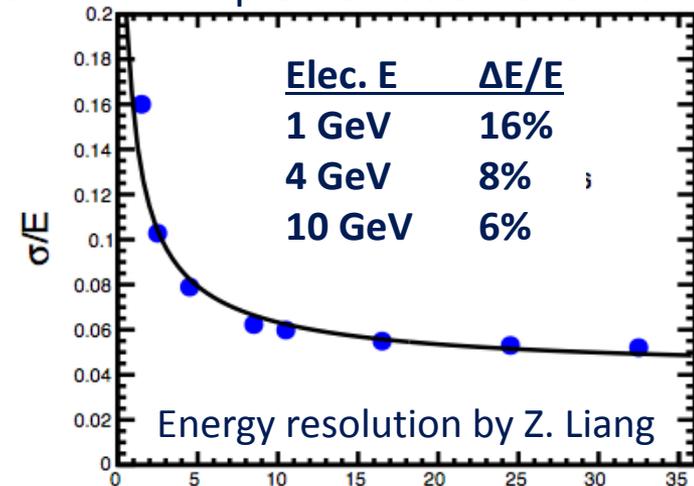
Fibers :
diameter of 0.5mm
Spacing of 1mm

10GeV, e+

s/ePHENIX implementation of SPACAL
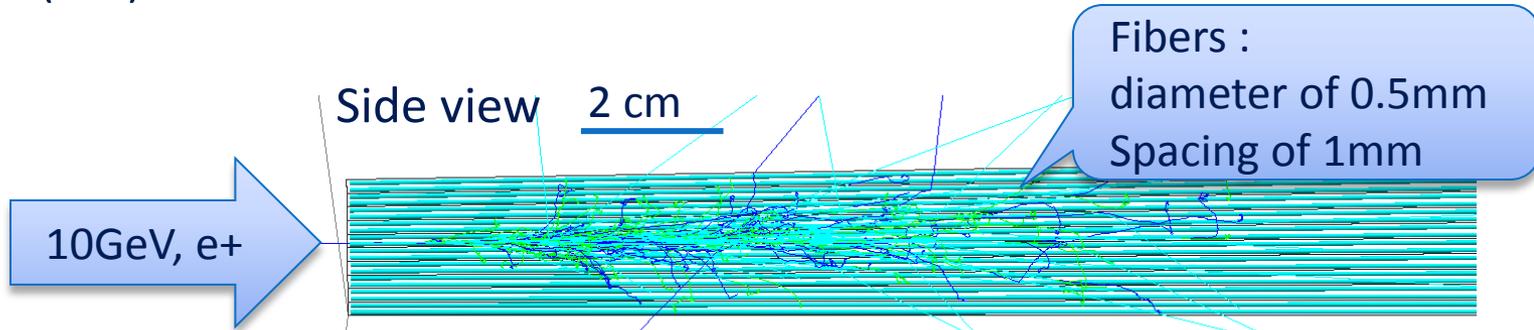
Hermetic and projective design in progress

R = 95cm

1-D projective
SPACAL towers

Elec. E	ΔE/E
1 GeV	16%
4 GeV	8%
10 GeV	6%

σ/E

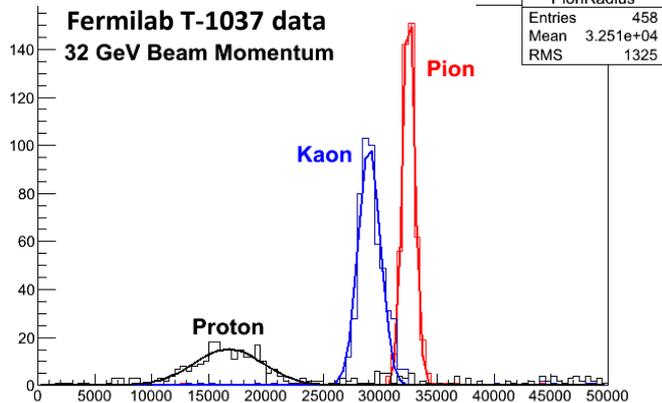Energy resolution by Z. Liang

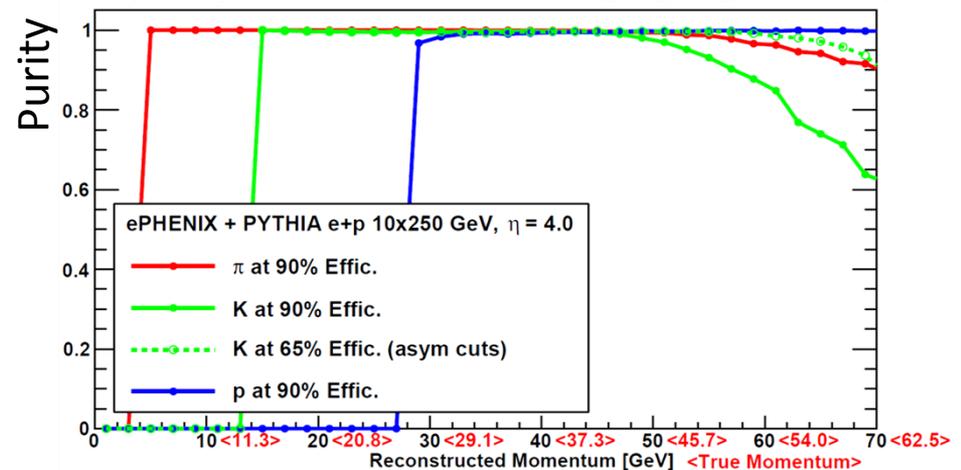Incident Energy (GeV)

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ePHENIX Gas RICH

- High momentum hadron ID require gas Cherenkov
  ◦ CF_4 gas used, similar to LHC_b RICH
- **Beautiful optics** using spherical mirrors
- **Photon detection** using CsI–coated GEM in hadron blind mode
- **Magnetic field line most along track** within the RICH volume → minor ring smearing due to track bending
- **Active R&D**: recent beam test by the stony brook group
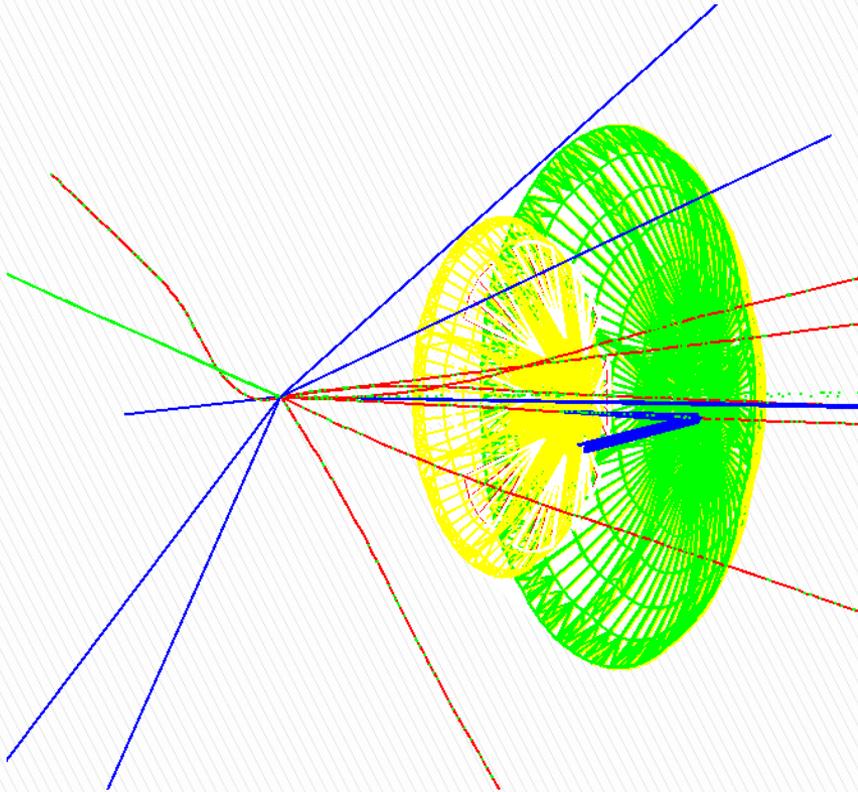
Courtesy: Stonybook group

Fermilab T-1037 data
32 GeV Beam Momentum

PionRadius	
Entries	458
Mean	3.251e+04
RMS	1325

Pion
Kaon
Proton

Ring size (A.U.)

Beam test data
StonyBrook group

Pion

RICH Mirror

η=1

RICH Gas Volume (CF_4)

η=2

Focal plane HBD detector

spherical mirror center

η=3

Entrance Window

η=4

IP

R (cm)
Z (cm)
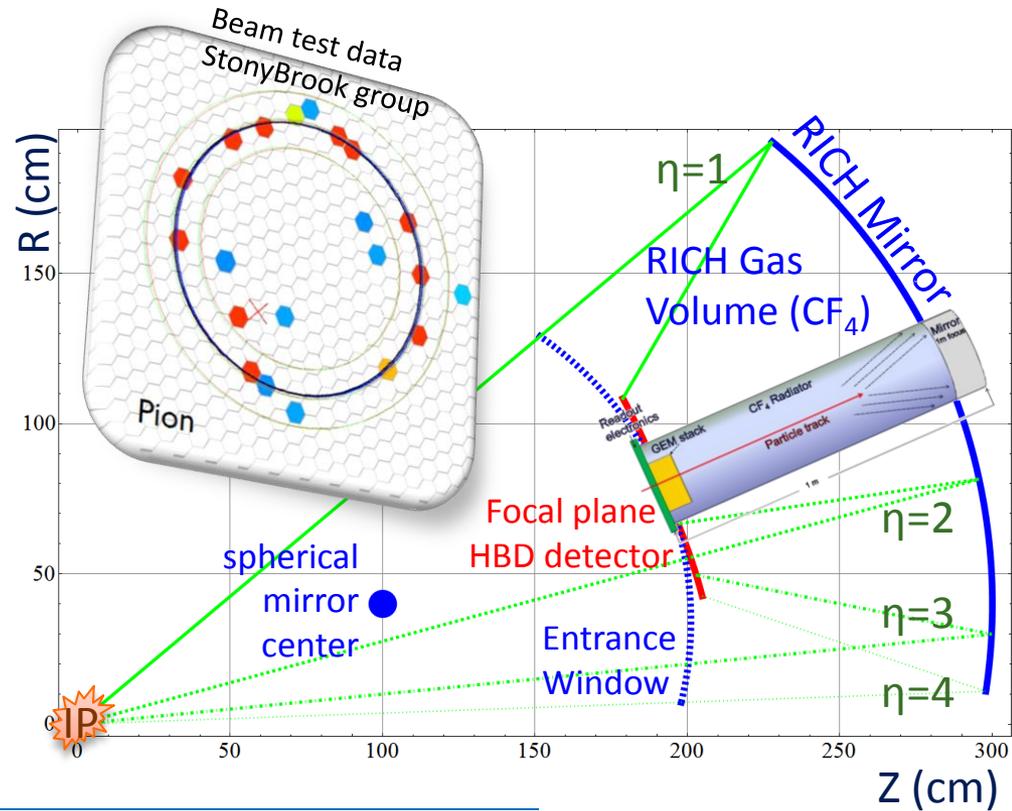
PID purity at η=4 (most challenging region w/ δp)

Purity

ePHENIX + PYTHIA e+p 10x250 GeV, η = 4.0

— π at 90% Effic.
— K at 90% Effic.
--- K at 65% Effic. (asym cuts)
— p at 90% Effic.

Reconstructed Momentum [GeV]   <True Momentum>

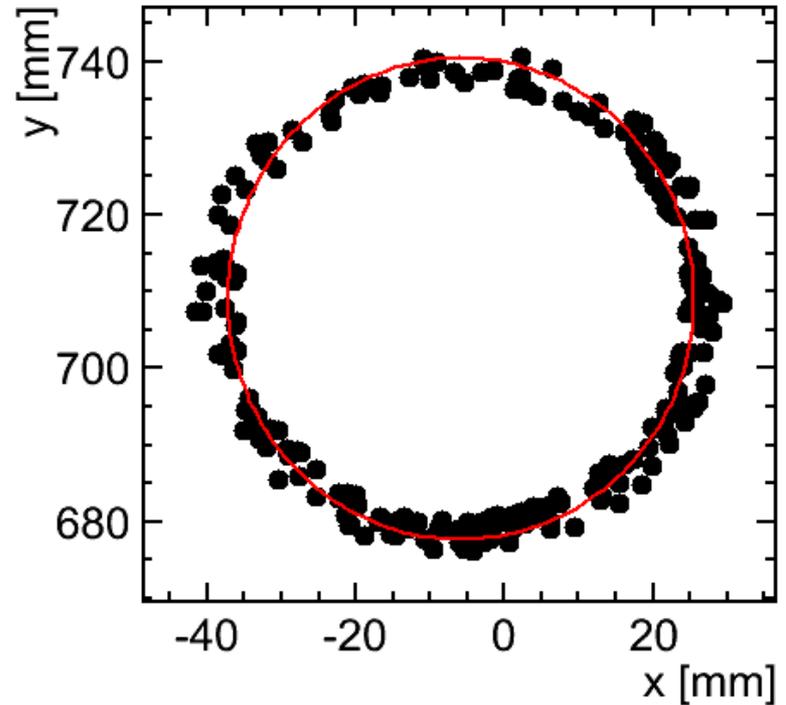# Some RICH event display
Courtesy: Nils Feege <nils.feege@stonybrook.edu>

photon tracking in full event


RICH Ring @ focal plane

PH✳ENIX

Final words

▸ PHENIX analysis framework adopted Geant4 simulation around ~2010

▸ All detector/analysis configuration are scriptable (through ROOT interface)

▸ Three full detector proposal/concepts developed, large scale multi-TB simulation run

▸ Framework is evolving, looking forward to adopting new features, new ideas and welcoming new users

▸ Looking forward to a forum for discussing simulation issues in EIC community

Backup

Summary

▸ Plan: PHENIX → sPHENIX → ePHENIX

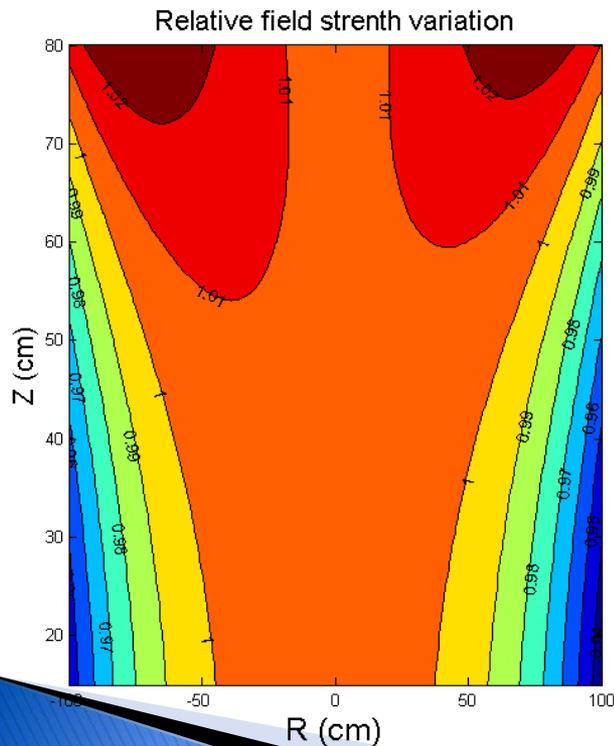▸ ePHENIX : a comprehensive detector concept for 10x250 GeV EIC
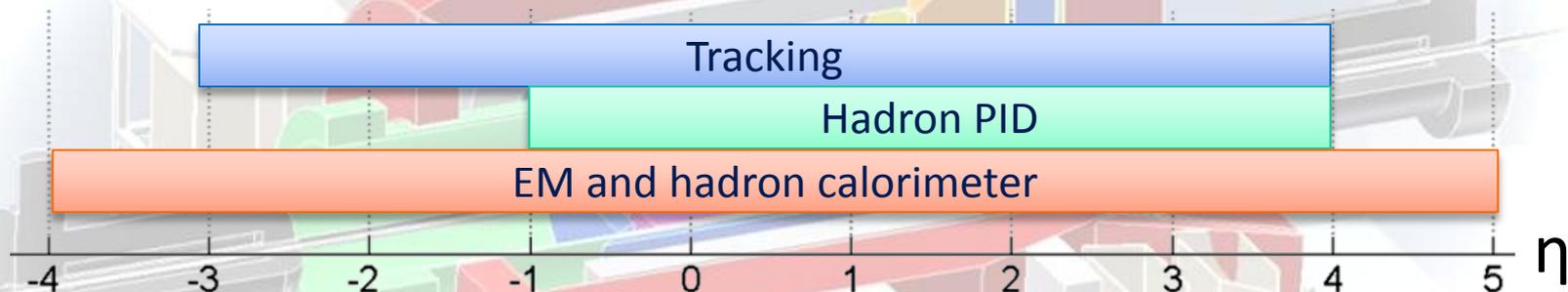
▸ h-going arm of ePHENIX perfect for forward pp/pA measurement (fsPHENIX), if constructed earlier
  ◦ Talk: CG.00003 Cesar da Silva

▸ Active study on going : detector R&D, full simulation
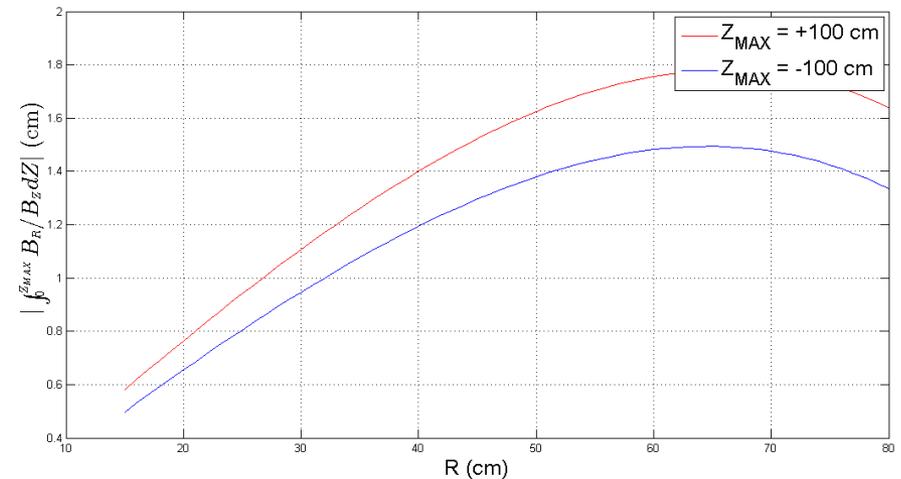
▸ Read more: https://www.phenix.bnl.gov/plans.html

TPC resolution:
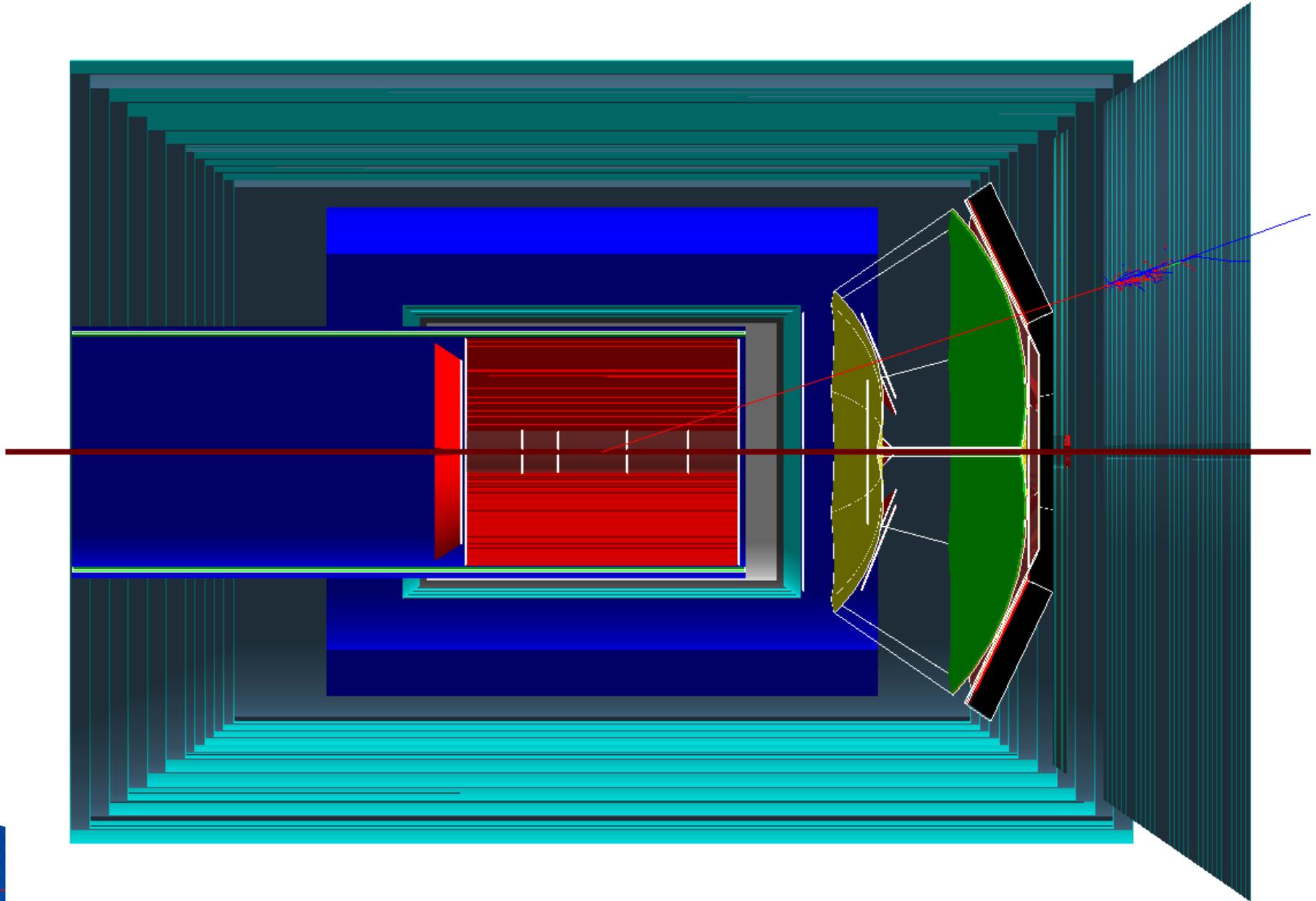## Caveat - Magnetic Field Effect and Correction

- Ideally, magnetic field along z axis for TPCs. $B_{X/Y}$ terms → corrections
- Field map can reach quoted uniformity for Babar (±3% for central tracking volume) by some tuning on the yoke
- But is it good enough for TPC? – Further optimization needed
  - Assumption in LOI: we can deal with it in the end

Relative field strenth variation

→ Field correction ~ few mm in Rφ

Implementing most complex geometry in current PHENIX G4 simulation

RICH Gas Container

TPC

Eight azimuthal sector

TPC

- RICH Windows
- spherical mirror

TPC

- Full HBD w/ readout
- RICH Windows
- spherical mirror

Six azimuthal sector

TPC

- RICH Windows
- spherical mirror