eRD16: Forward/Backward Tracking at EIC using MAPS Detectors

N. Apadula, A. Collu, W. DeGraw, X. Dong, L. Greiner, B.V. Jacak (project leader), P. Jacobs, S. Klein, Y.S. Lai, M. Lomnitz, G. Odyniec, M. Ploskon, E.P. Sichtermann (contact person), J. Thomas, I. Velkovsky, N. Xu
Nuclear Science Division Lawrence Berkeley National Laboratory 1 Cyclotron Road Berkeley, California 94720

Abstract:

This report describes progress towards the conceptual development of tracking stations with silicon-sensors near the collision vertex to detect the scattered electron and produced secondary hadrons at forward and backward angles with respect to the beam directions in the period between July and December 2017. The main focus is on disks with thinned-silicon sensors (MAPS) with the goal to arrive at physics-driven sensor specifications, the overall geometrical arrangement of the forward/backward disks, disk layout, conceptual arrangement of services, and integration with central barrel tracking subsystems. Part of this work is being pursued in collaboration with eRD18, which focuses on mid-rapidity tracking and sensor development.

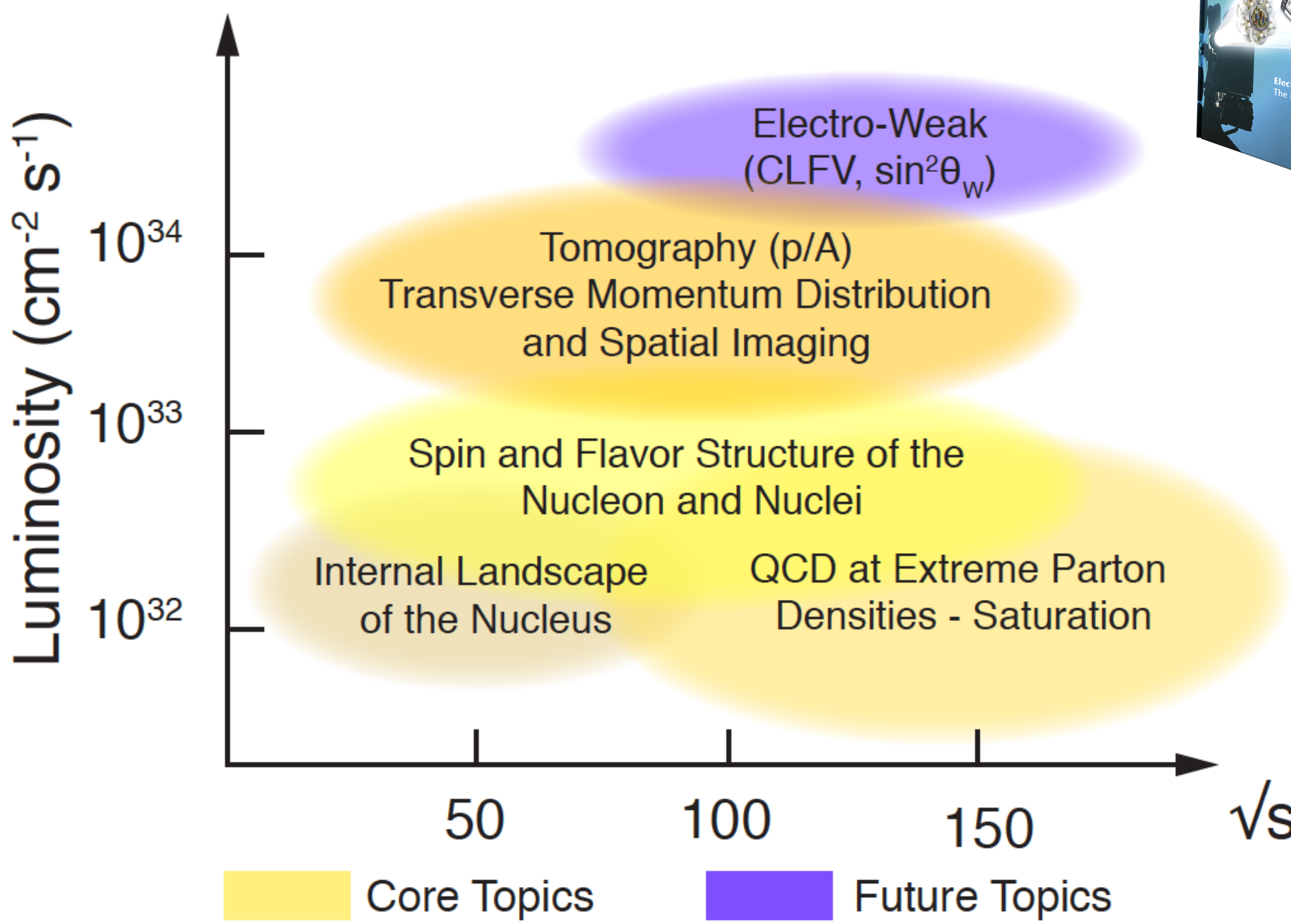
EIC Generic Detector R&D
Advisory Committee Mtg.
BNL, January 18, 2018

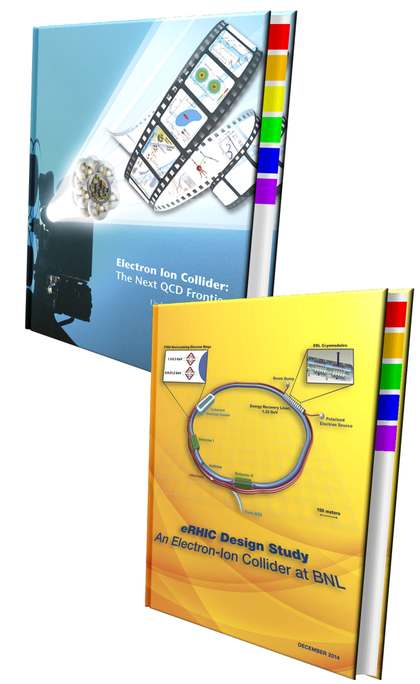
Outline

- Introduction
    - RNC physics interests in EIC
    - Instrumentation efforts in relation to EIC
- Simulation progress,
    - Tools used,
    - Selected topics and results
- Progress
    - Simulation development and studies

RNC - EIC Physics Interests

Interest in *gluon-dense matter:*



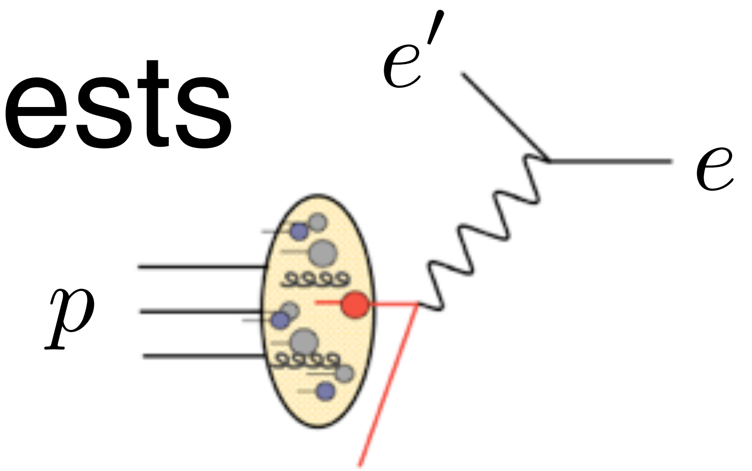


implies a need for *high*-√s,

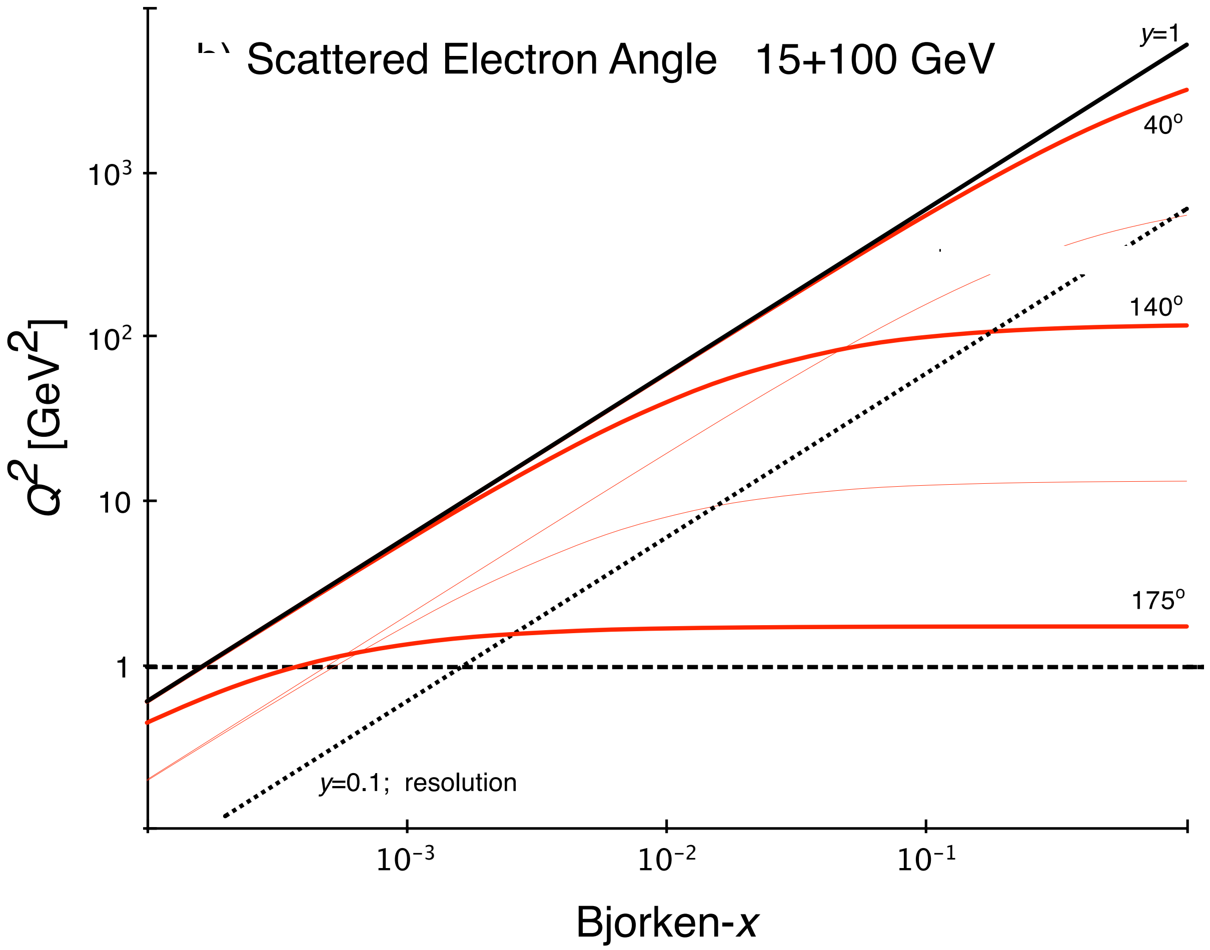
observables $F_2(x,Q^2)$, $F_L(x,Q^2)$, $g_1(x,Q^2)$ at *low*-x

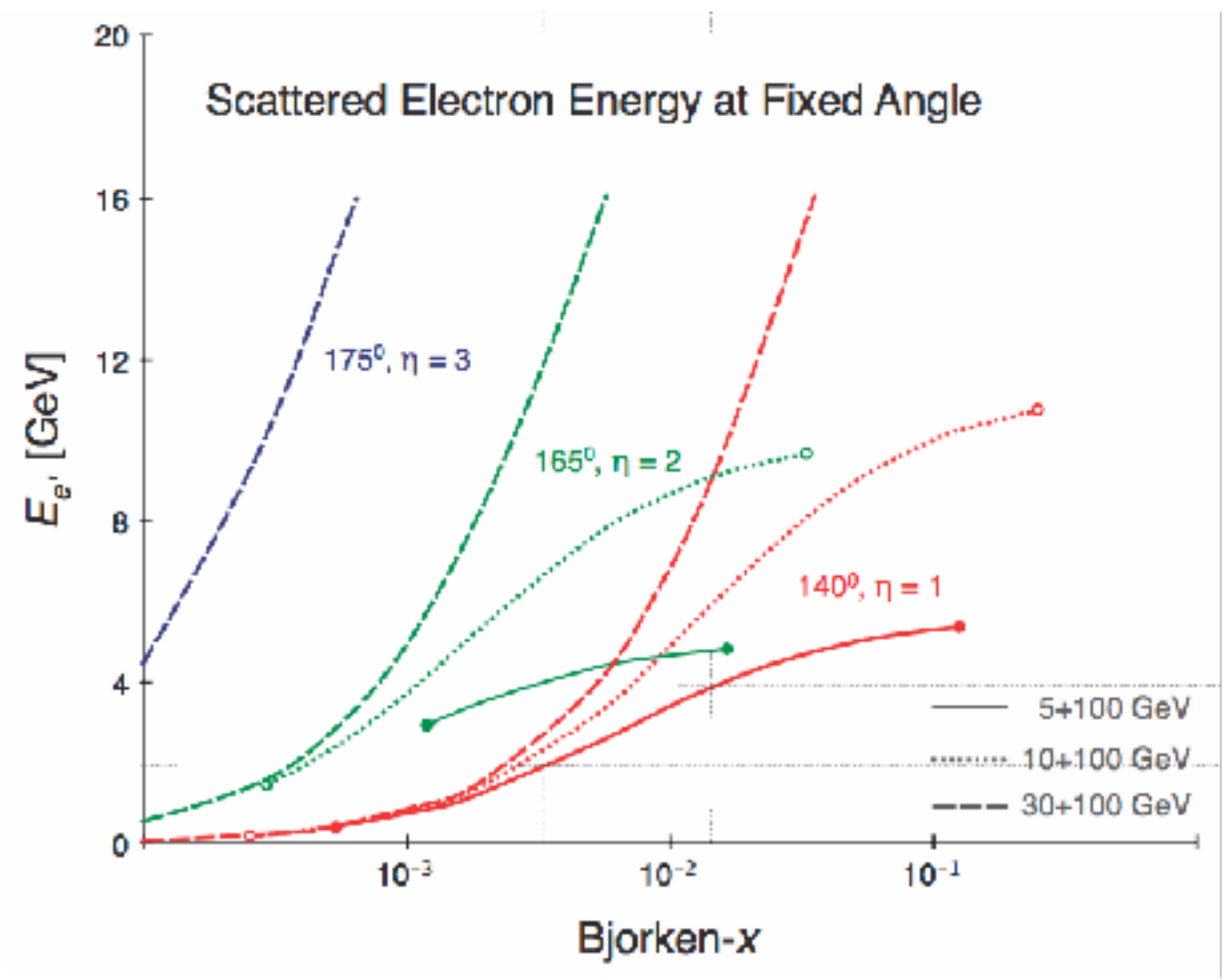
+ diffraction, dijets, heavy flavor, …

RNC - EIC Physics Interests



Interest in gluon-dense matter:





necessitates instrumentation at *backward* angles w.r.t. the hadron beam (HERA convention),

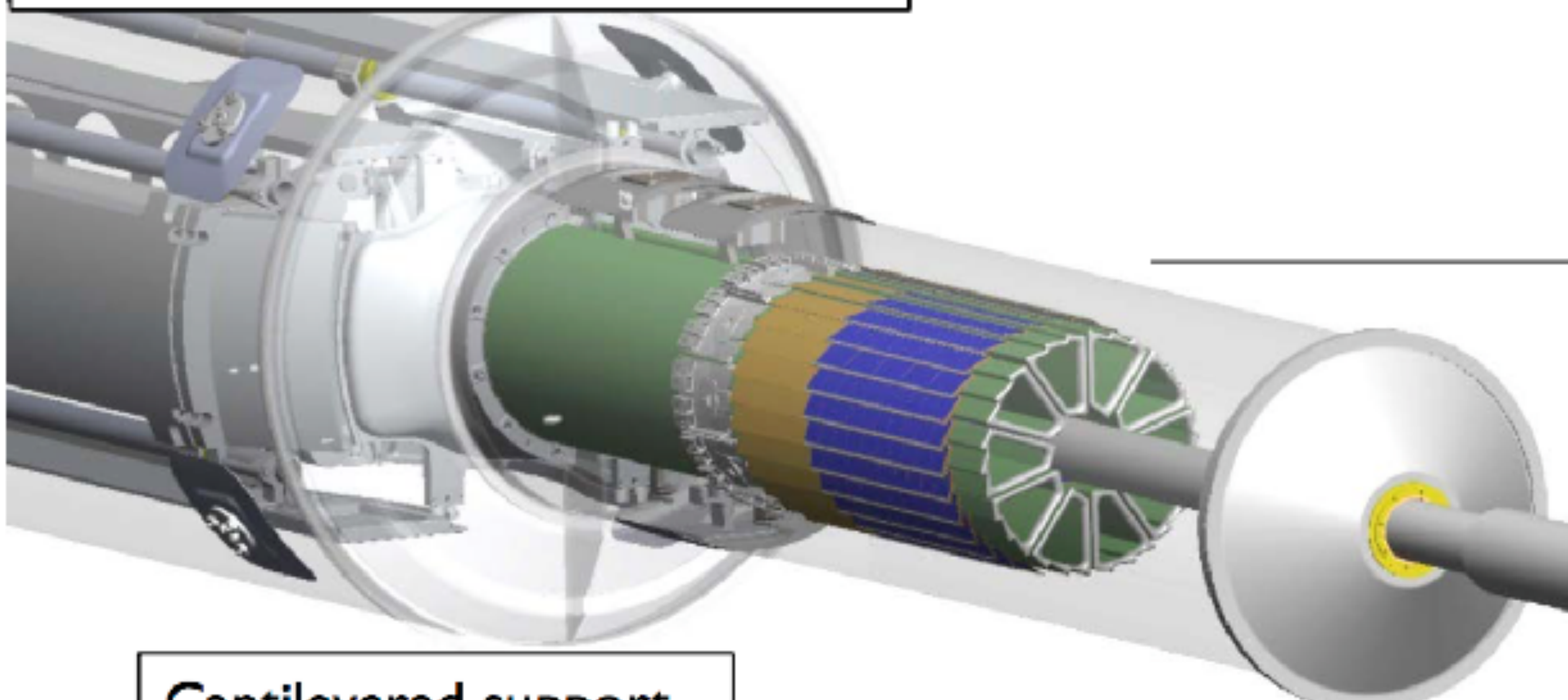
semi-inclusive observables do so at *forward* angles.

RNC - STAR HFT-PXL

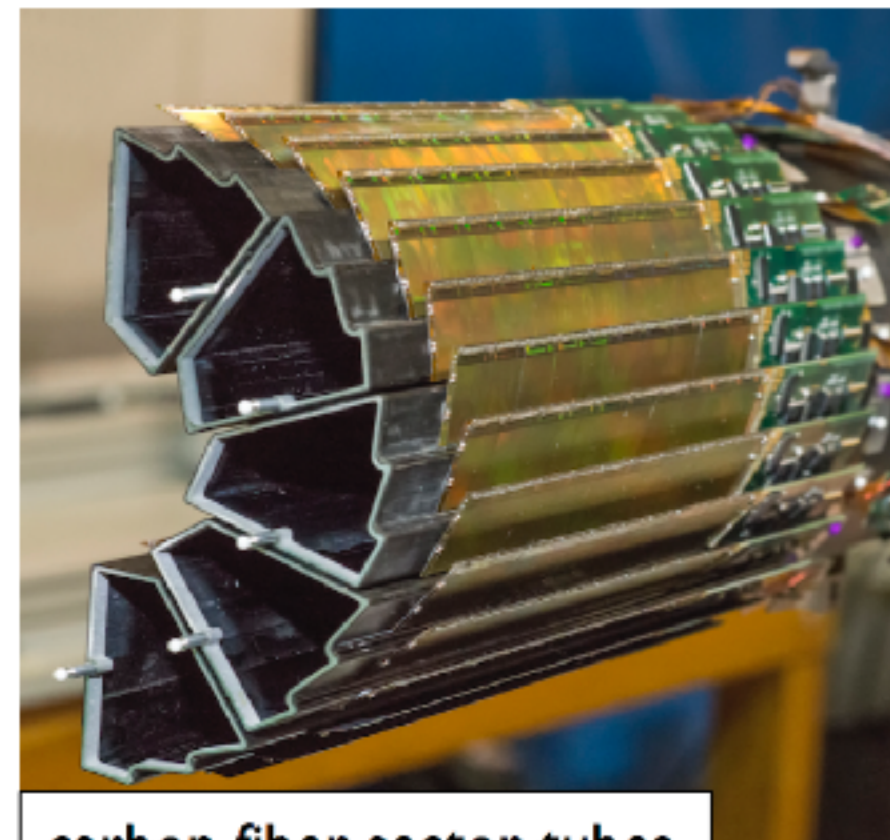
10 sectors total
5 sectors / half
4 ladders / sector
10 sensors / ladder

Highly parallel system

Mechanical support with kinematic mounts (insertion side)



Cantilevered support

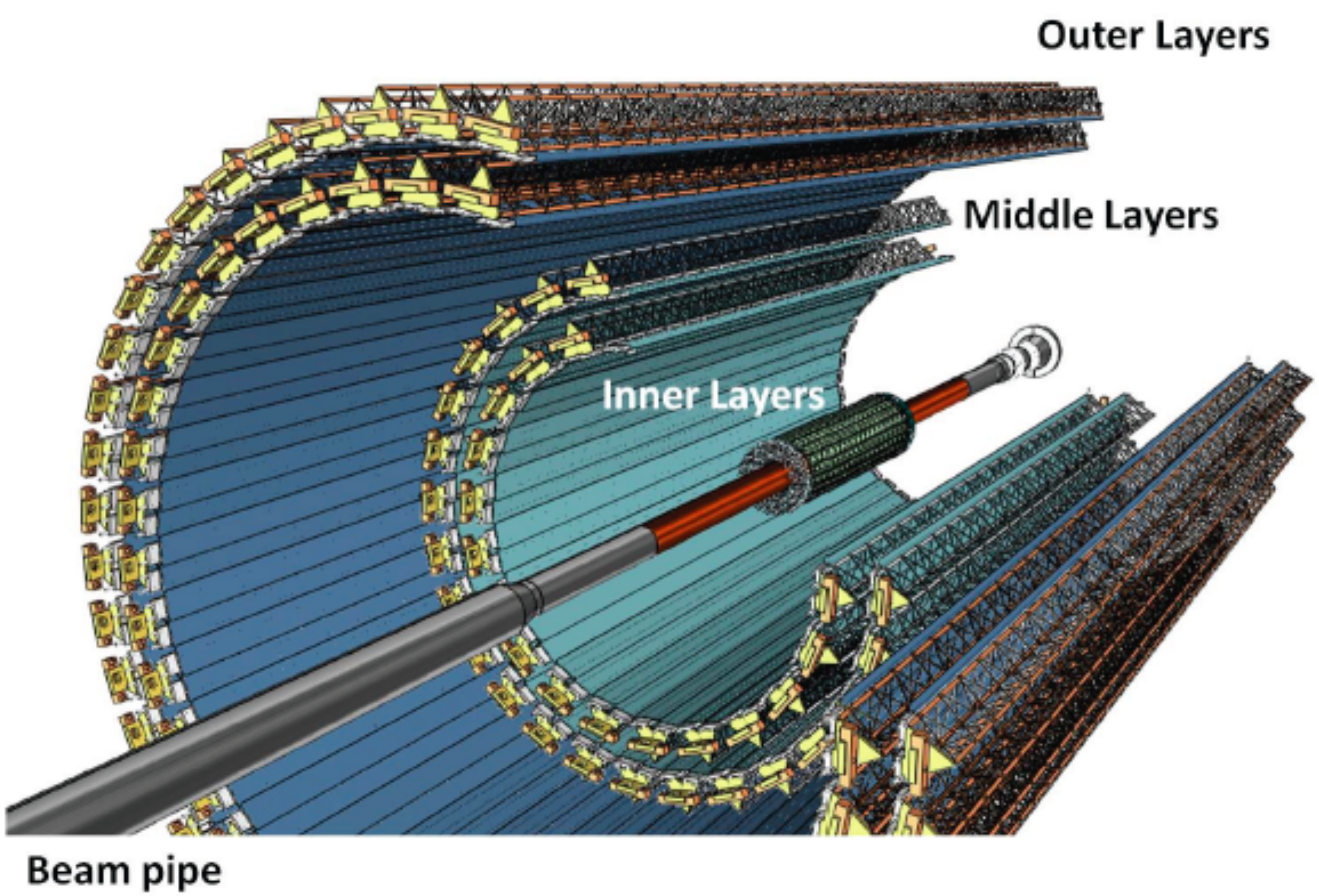


carbon fiber sector tubes (~ 200 μm thick)

Ladder with 10 MAPS sensors (~ 2×2 cm each)

Courtesy G. Contin (LBL-RNC), for the STAR collaboration, QM2015

RNC - ALICE ITS Upgrade



- 7 layers
- 10 m^2 of silicon
- Installation in early 2019
- X/X_0 ~ 0.3% (inner layers)
- X/X_0 ~ 0.8% (outer layers)

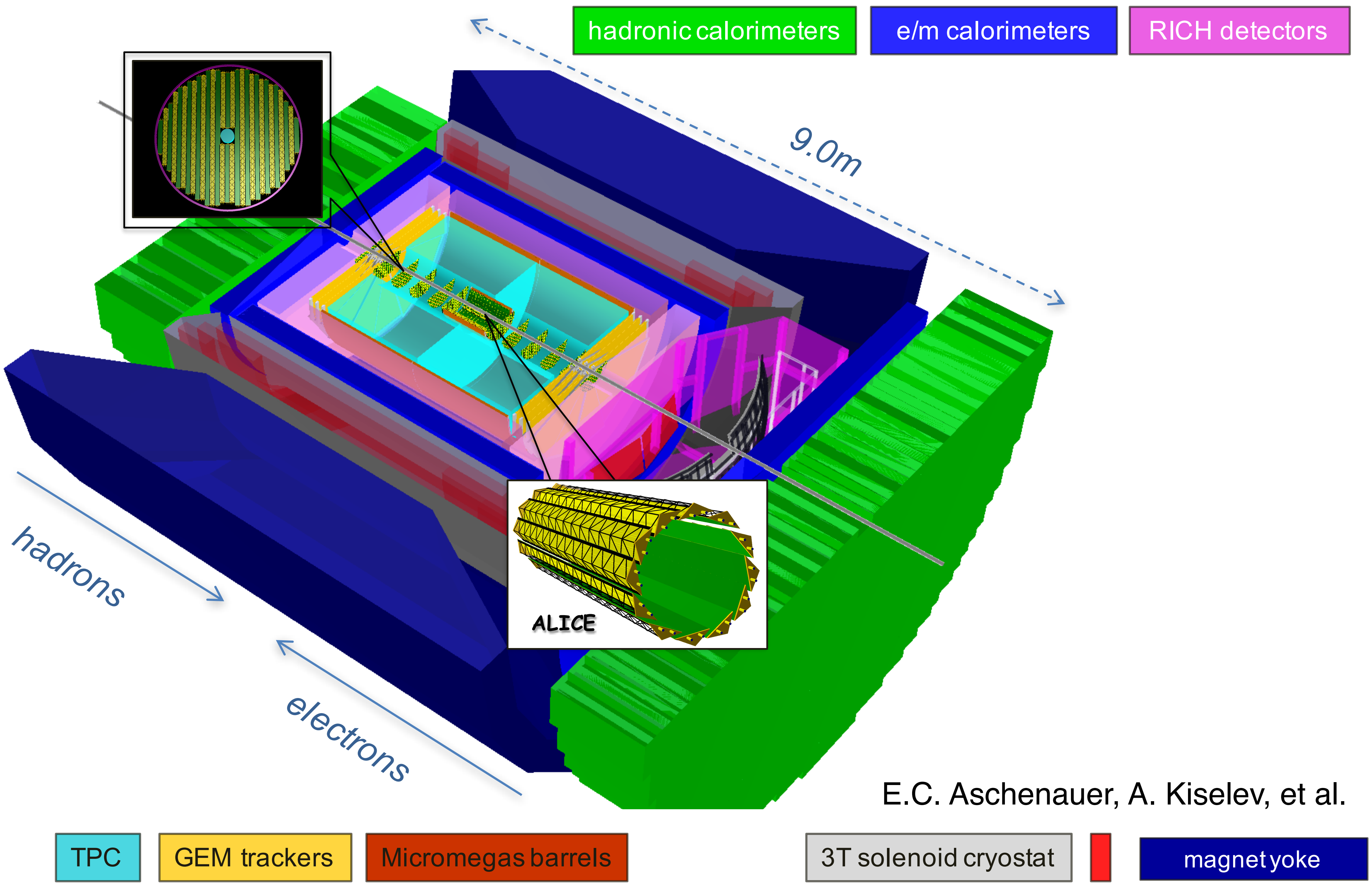
Anticipated use of CERN-developed MAPS sensors, ALPIDE:

Dimensions:	15mm x 30mm
Pixel pitch:	28µm x 28µm
Integration time:	approx. 4 µs
Power consumption:	39mW/cm^2

TDR: http://iopscience.iop.org/0954-3899/41/8/087002/

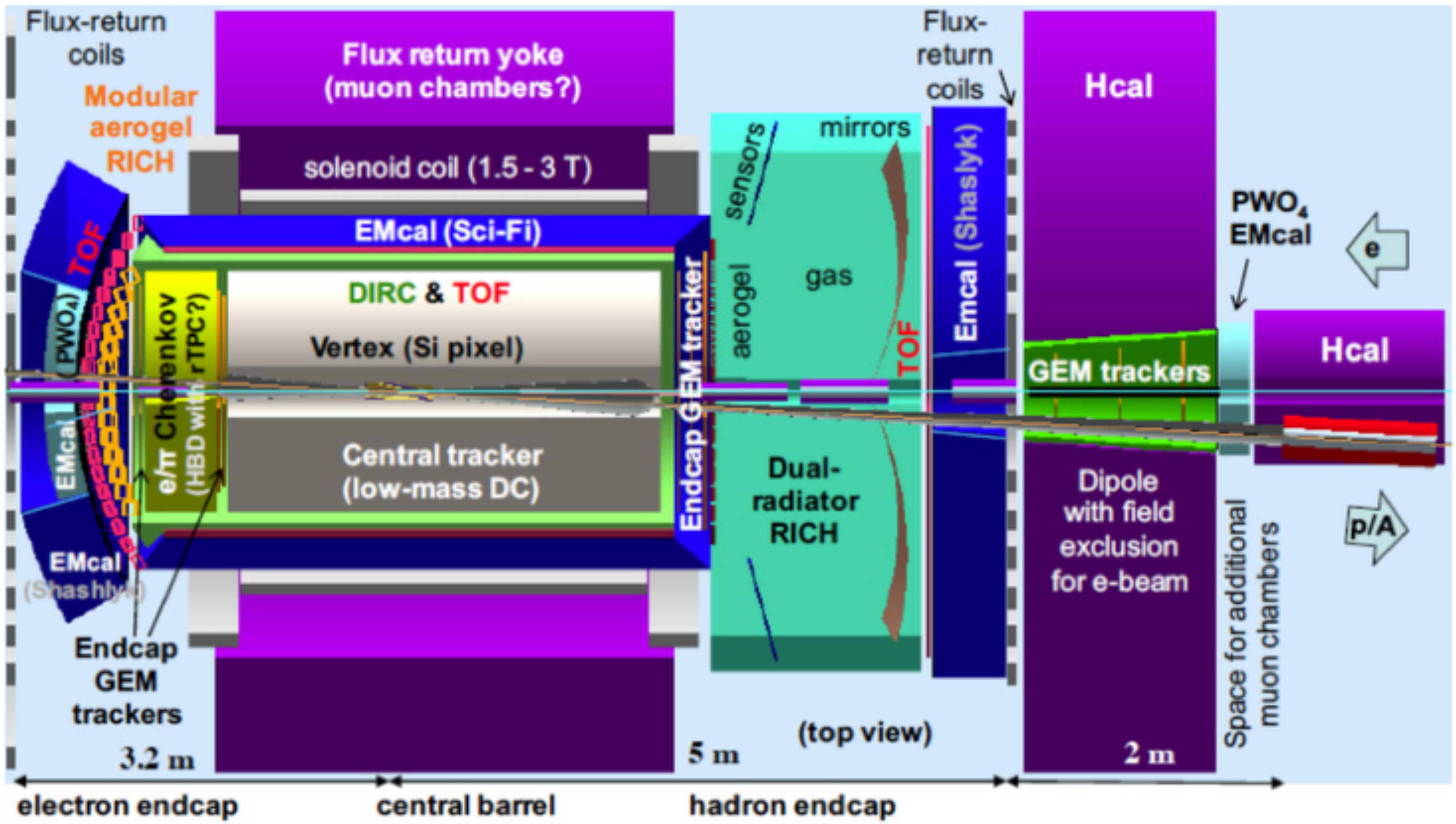
Vertex tracker for sPHENIX being proposed (MVTX).

EIC - eRHIC Model Detector (BeAST)



MAPS-based Si; optimize resolutions, provide vertexing, minimize Bremsstrahlung.

EIC - JLEIC Model Detector



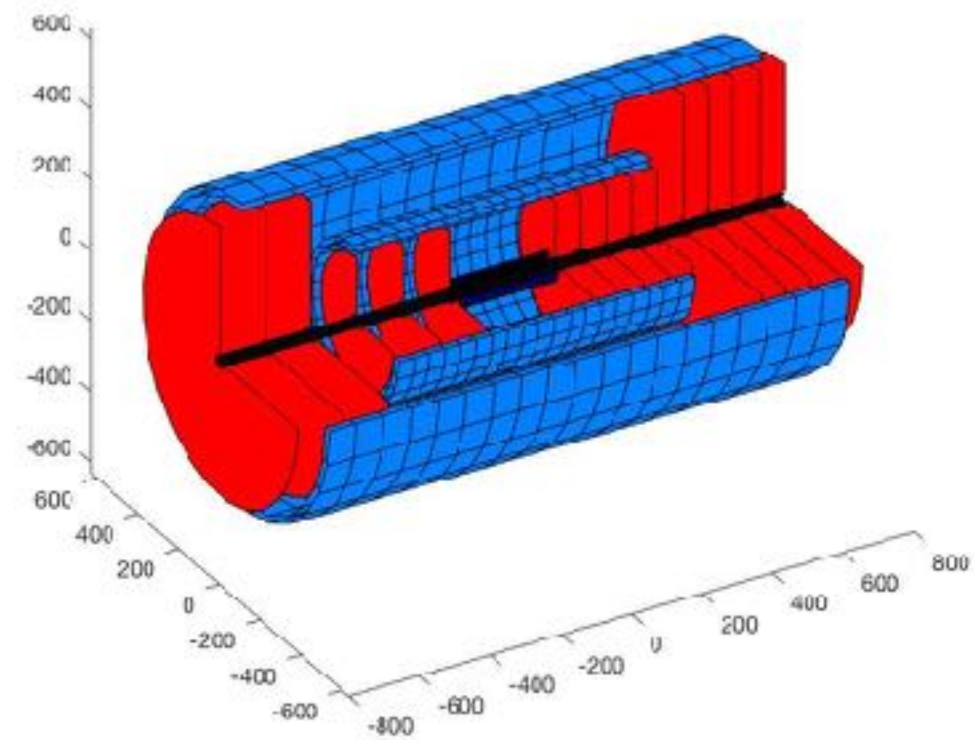
JLEIC Detector and Interaction Region Study Group

Si pixel detectors covering central and forward rapidities.

Aim for *high resolution* and *low mass* solutions.

RNC - EIC R&D Simulations

- Charged-particle tracking toolset originally developed for ILC studies by the Vienna group, M. Regler, M. Valentan, and R. Frühwirth (2008):
  - Helix track model,
  - Multiple scattering,
  - Full track reconstruction from digitized hits using a Kalman filter.



Hypothetical all-Si tracker in a 1.5T Solenoidal field.

- Rapid studies of number of layers, disks, geometrical layout, etc.
- Work done with UCB undergraduate students, previously mostly Ivan Velkovsky, this period Winston DeGraw (c.f. earlier reports).

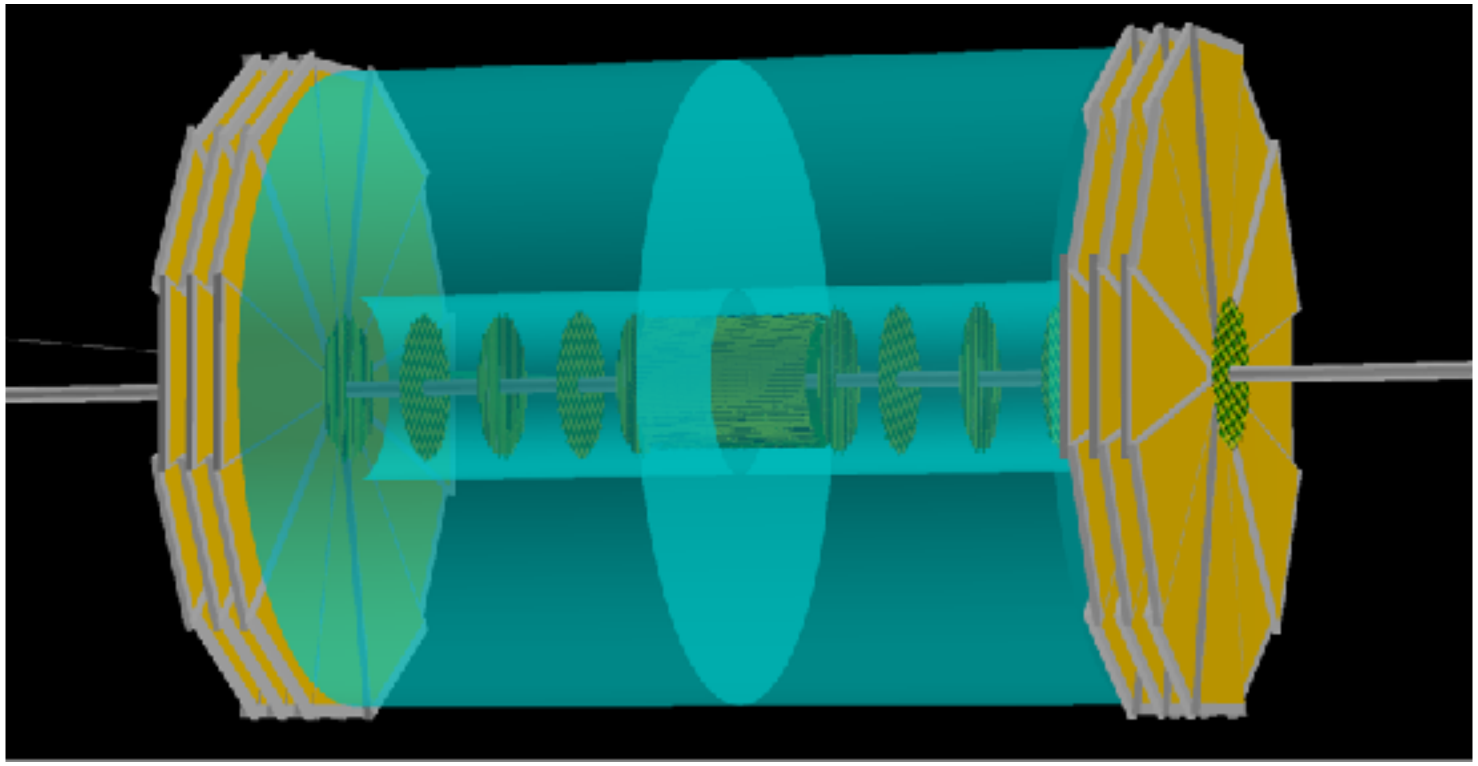
RNC - EIC R&D Simulations

- Toolset(s) developed by EIC task-force at BNL;

  EICRoot; GEANT-based simulations

  Pythia-eRHIC,

  (EIC-smear)



BeAST; seen are the TPC, Si-barrel and disks, and large-area GEMs

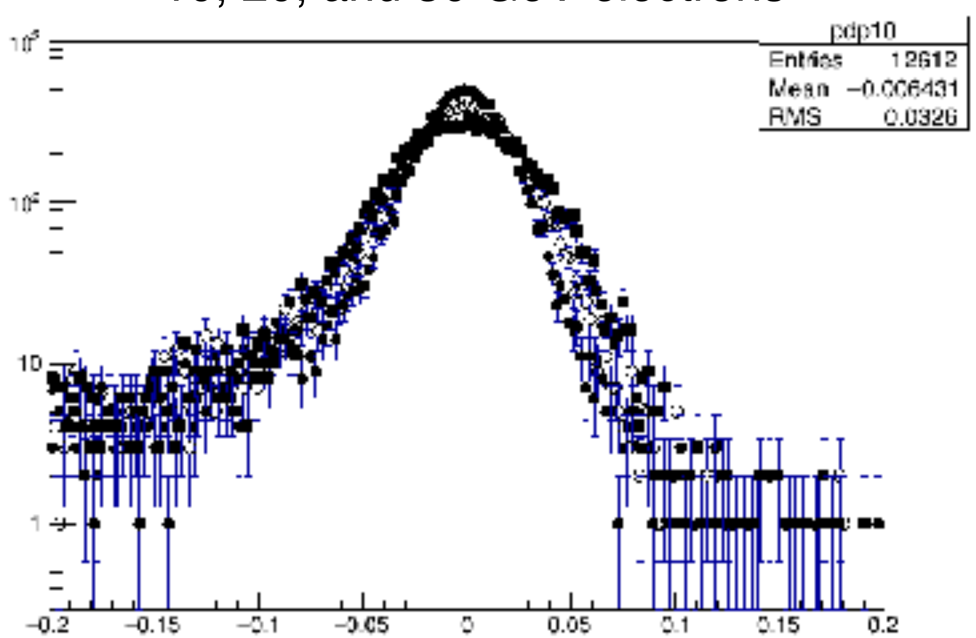
- Work done by Yue Shi Lai, and ongoing to
  confirm/refute key findings from fast simulations,
  changes to improve geometry and infrastructure.

- Preferred toolset going forward, as the issues need more realistic answers, and for collaboration with eRD18.

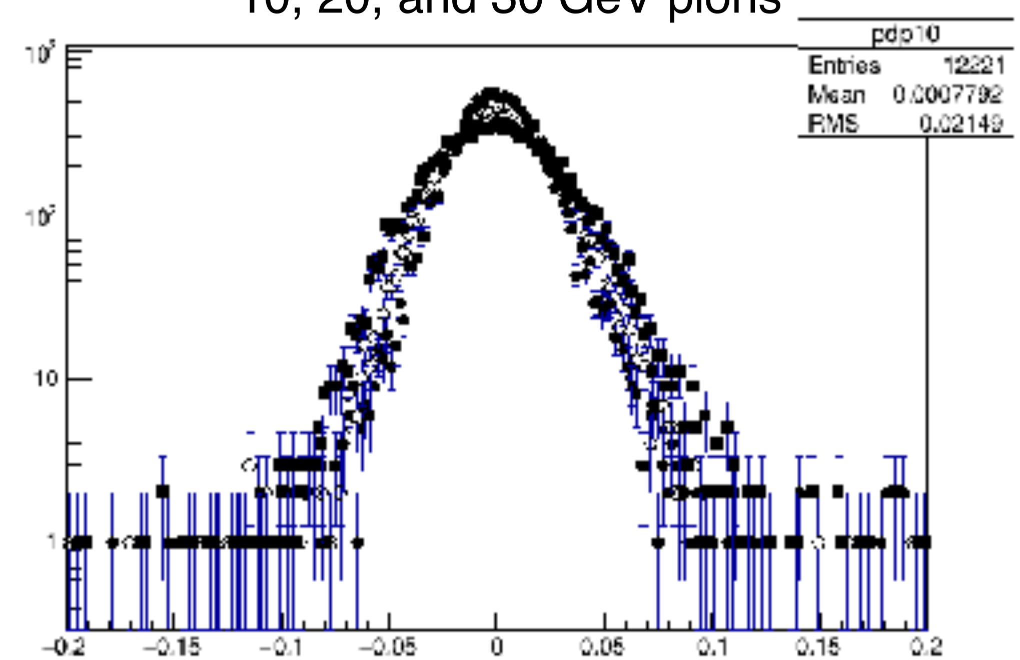
RNC - EIC R&D Simulations

- For example,

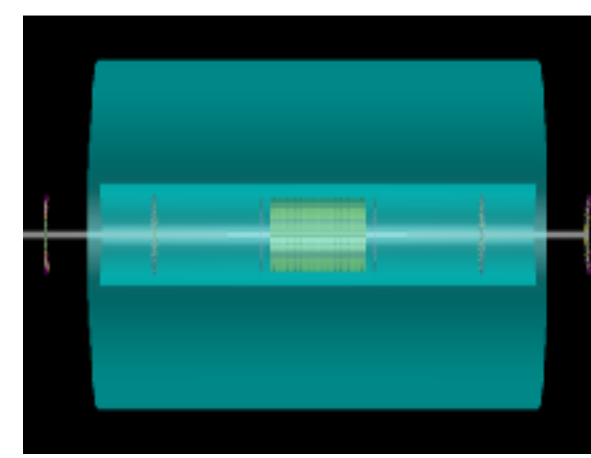
10, 20, and 30 GeV electrons



10, 20, and 30 GeV pions



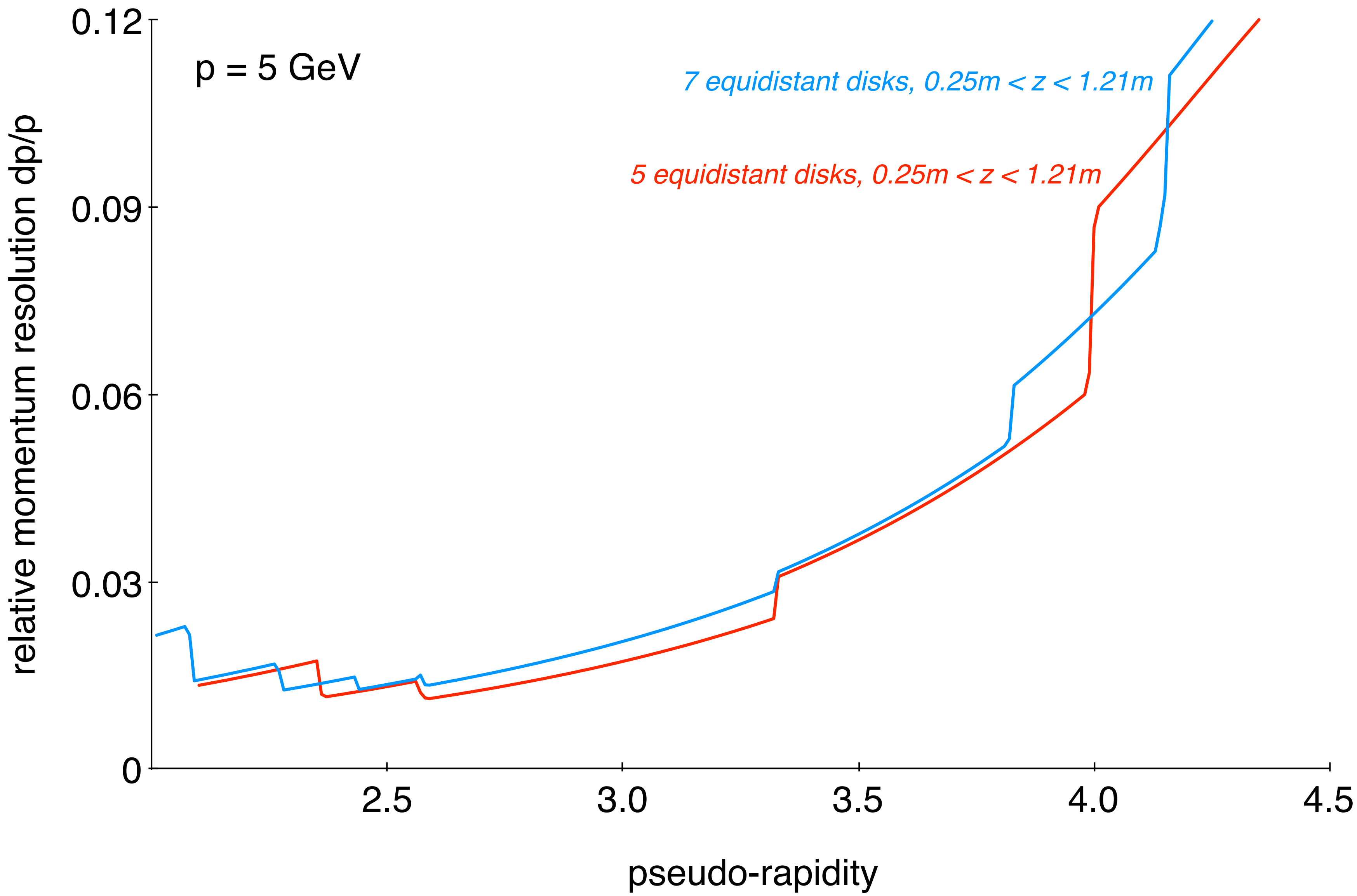
Tails and energy losses (can/do) matter,
even in a 3-disk simulation.



- Supports and infrastructure.

RNC - EIC R&D Simulations

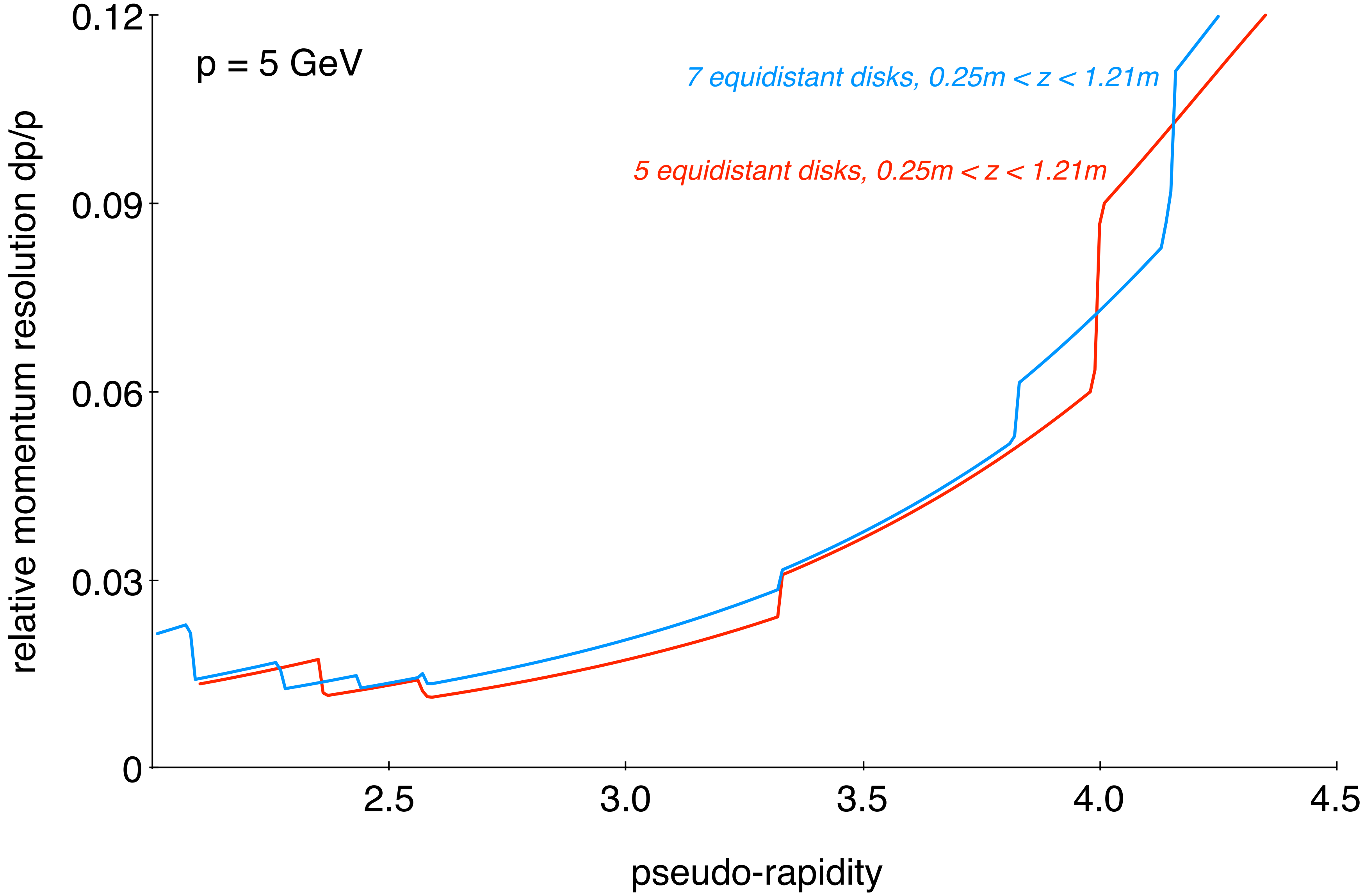
Fine-binned LDT results for disks in a 3T field (BeAST):



Affected by dip-angle and curvature measurement (20μm pixels),
acceptance (18mm inner radii and 185mm out radii),
positions (disks are equidistant in *z*; nominal collision vertex),
traversed material (0.3% beam-pipe, 0.3% for each disk).

RNC - EIC R&D Simulations

Fine-binned LDT results for disks in a 3T field (BeAST):



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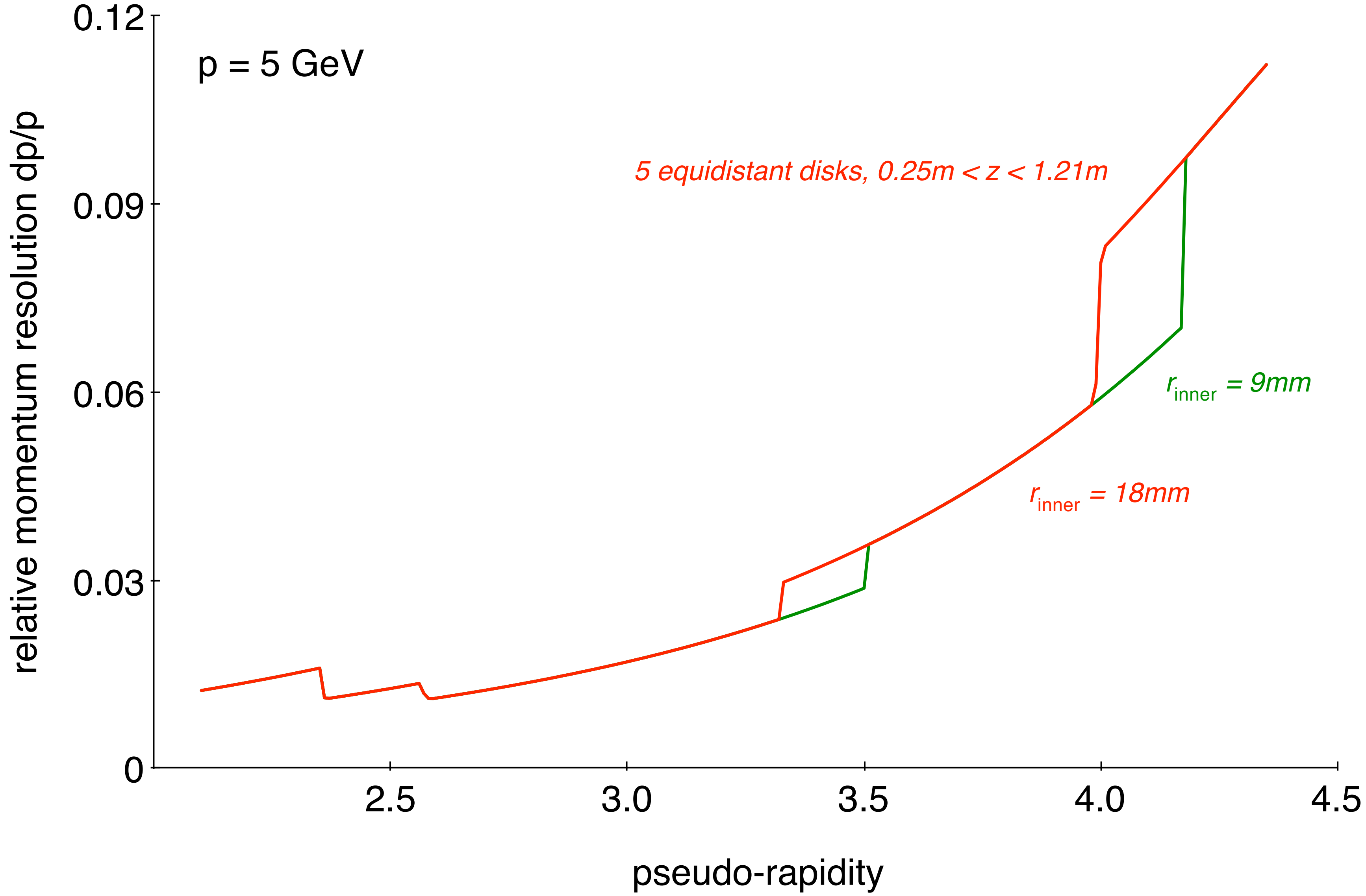

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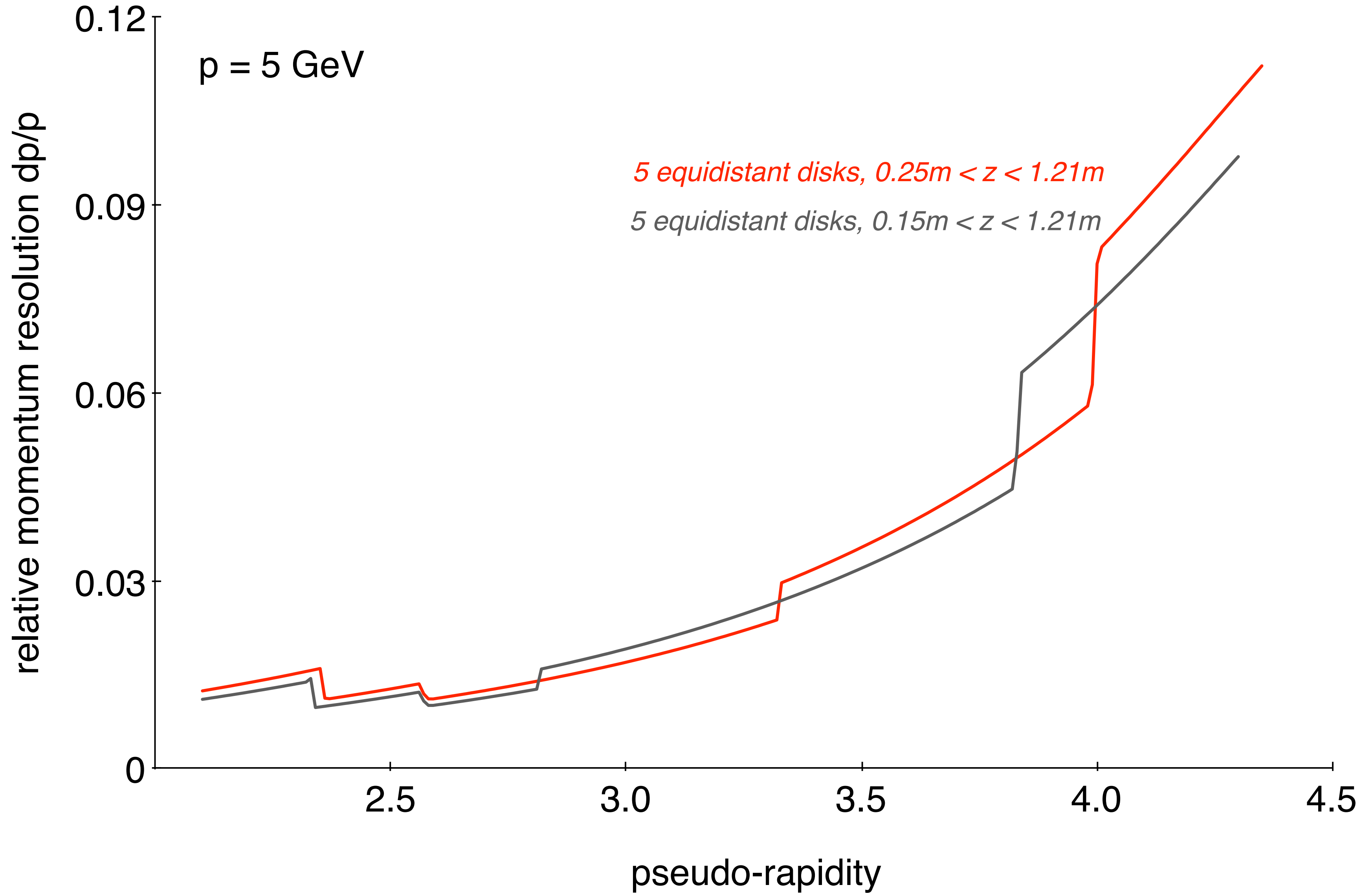
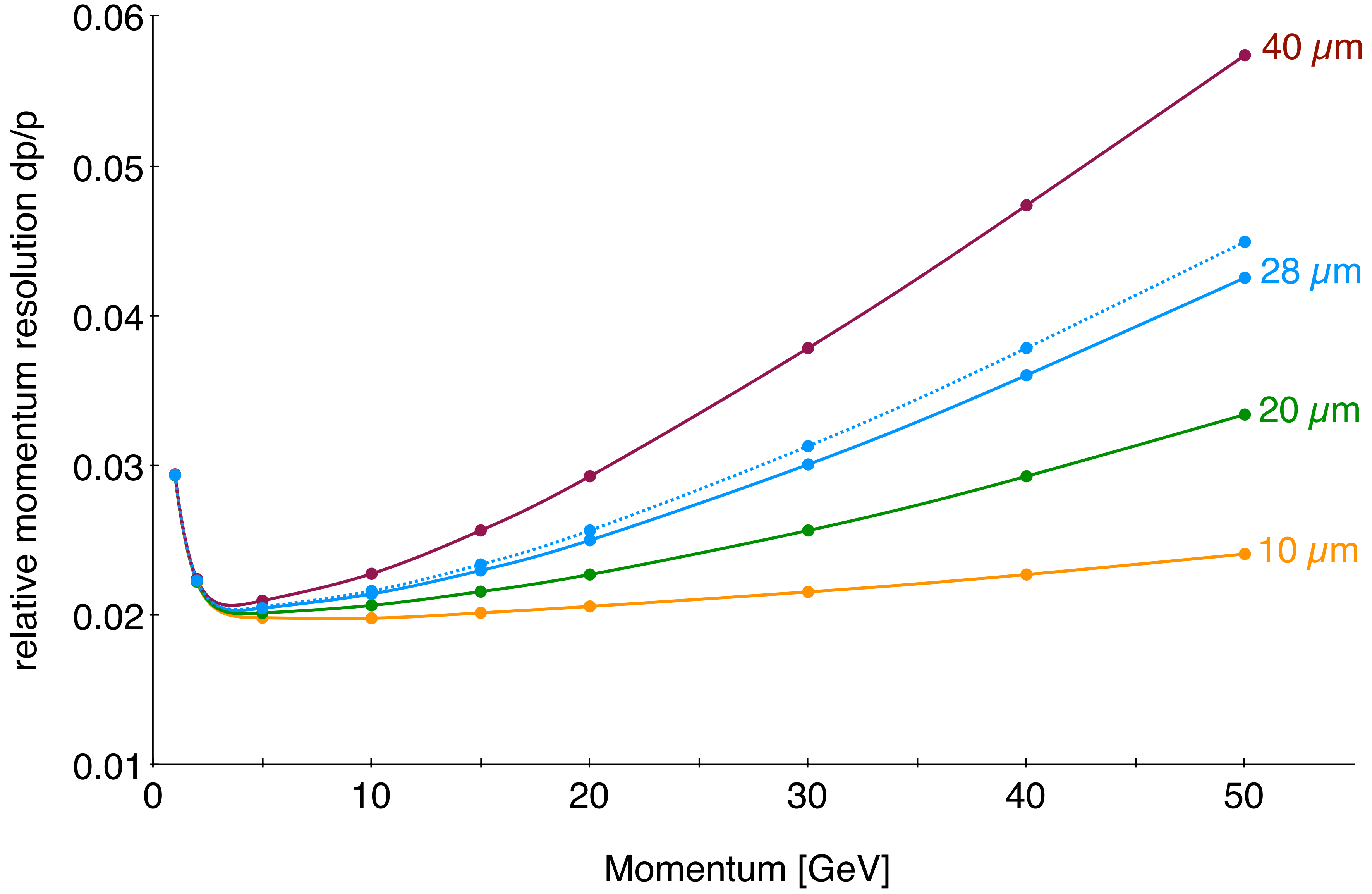
Fine-binned LDT results for disks in a 3T field (BeAST):



Affected by dip-angle and curvature measurement (20μm pixels),
acceptance (18mm inner radii and 185mm out radii),
positions (disks are equidistant [revisit] in *z*; nominal collision vertex),
traversed material (0.3% beam-pipe, 0.3% for each disk).

RNC - EIC R&D Simulations

LDT scan of pixel-size; 7 equidistant disks in a 3T field (BeAST):

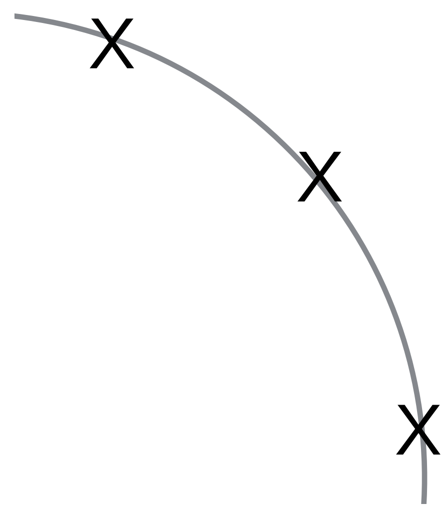


Pseudo-rapidity is 3 here; measurements from all disks.

Momentum is *inside* the beam-pipe here; upturn at low (absolute) momentum originates mostly with uncertainty in the dip-angle.

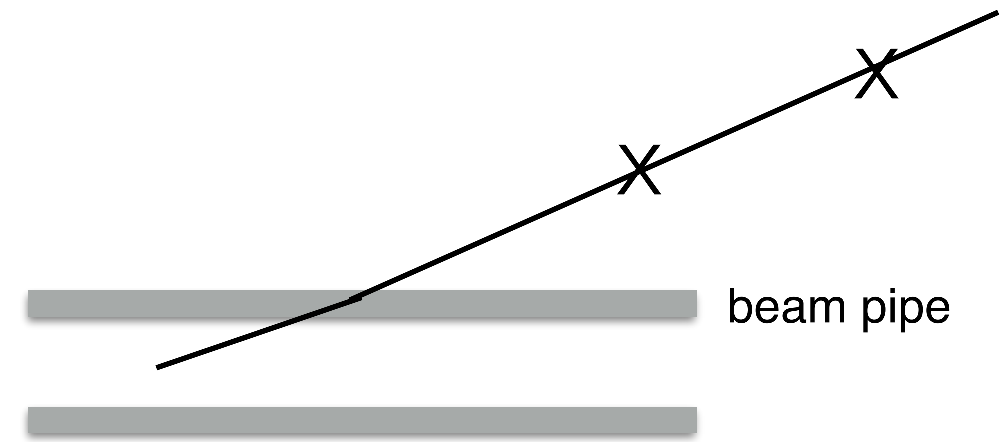
RNC - EIC R&D Simulations

Two main effects in total momentum determination:



view orthogonal to B

curvature measurement



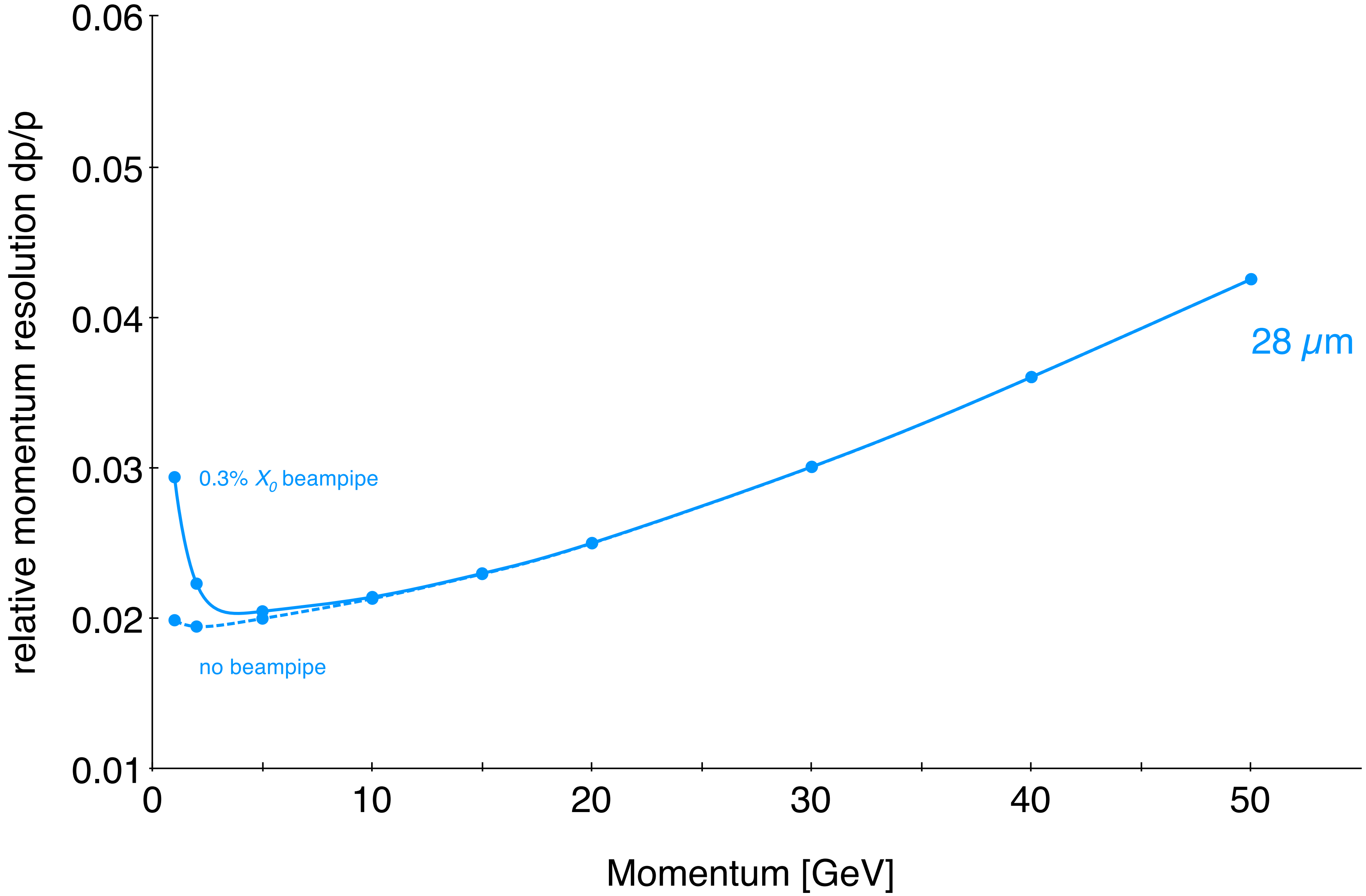
sideview along beam line

dip angle

Momentum is *inside* the beam-pipe here; upturn at low (absolute) momentum originates mostly with uncertainty in the dip-angle.

RNC - EIC R&D Simulations

LDT scan of pixel-size; 7 equidistant disks in a 3T field (BeAST):



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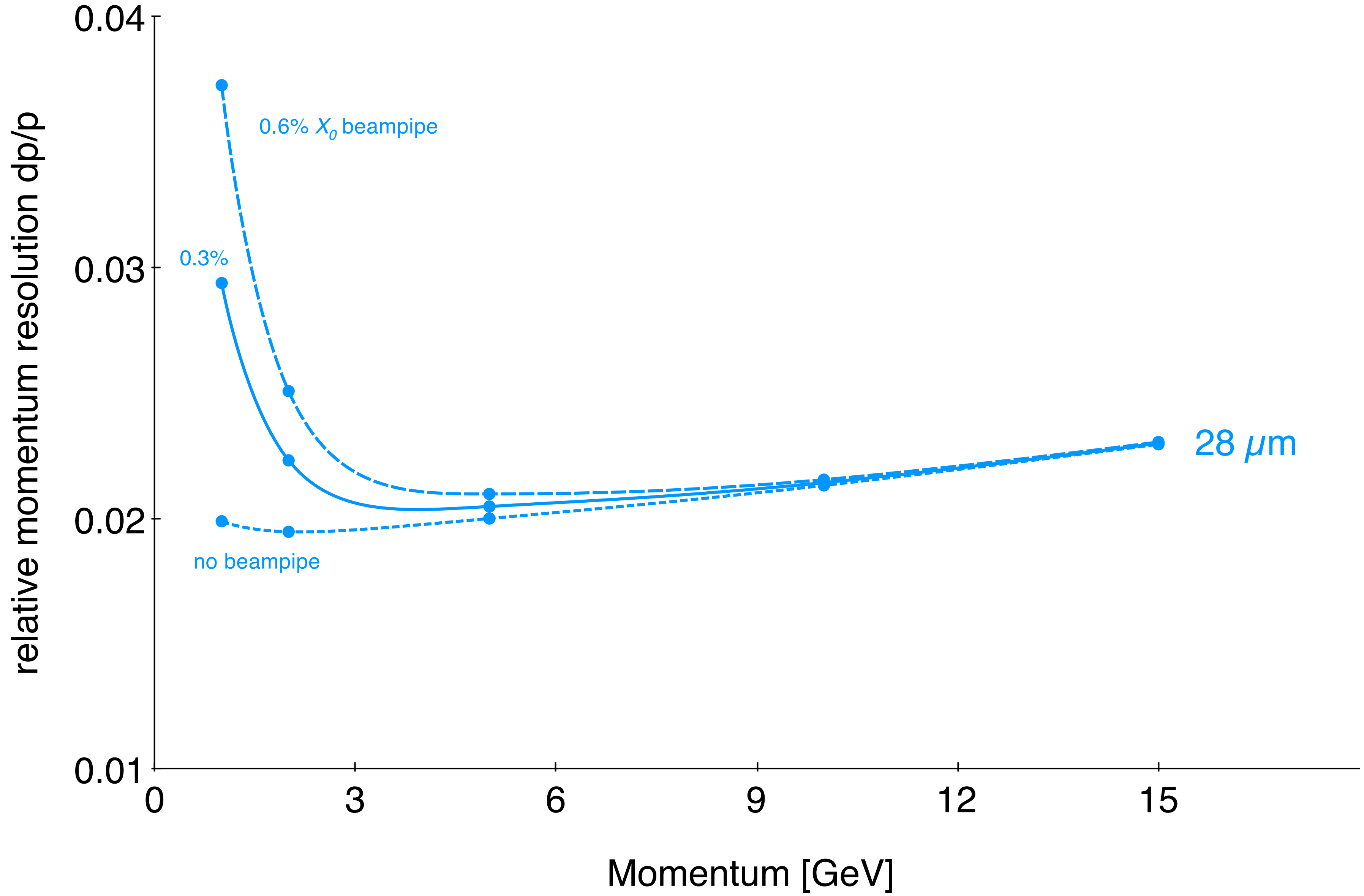


Pseudo-rapidity is 3 here; measurements from all disks.

Momentum is *inside* the beam-pipe here; upturn at low (absolute) momentum originates mostly with uncertainty in the dip-angle.

RNC - EIC R&D Simulations

Initial considerations of timing and rates,

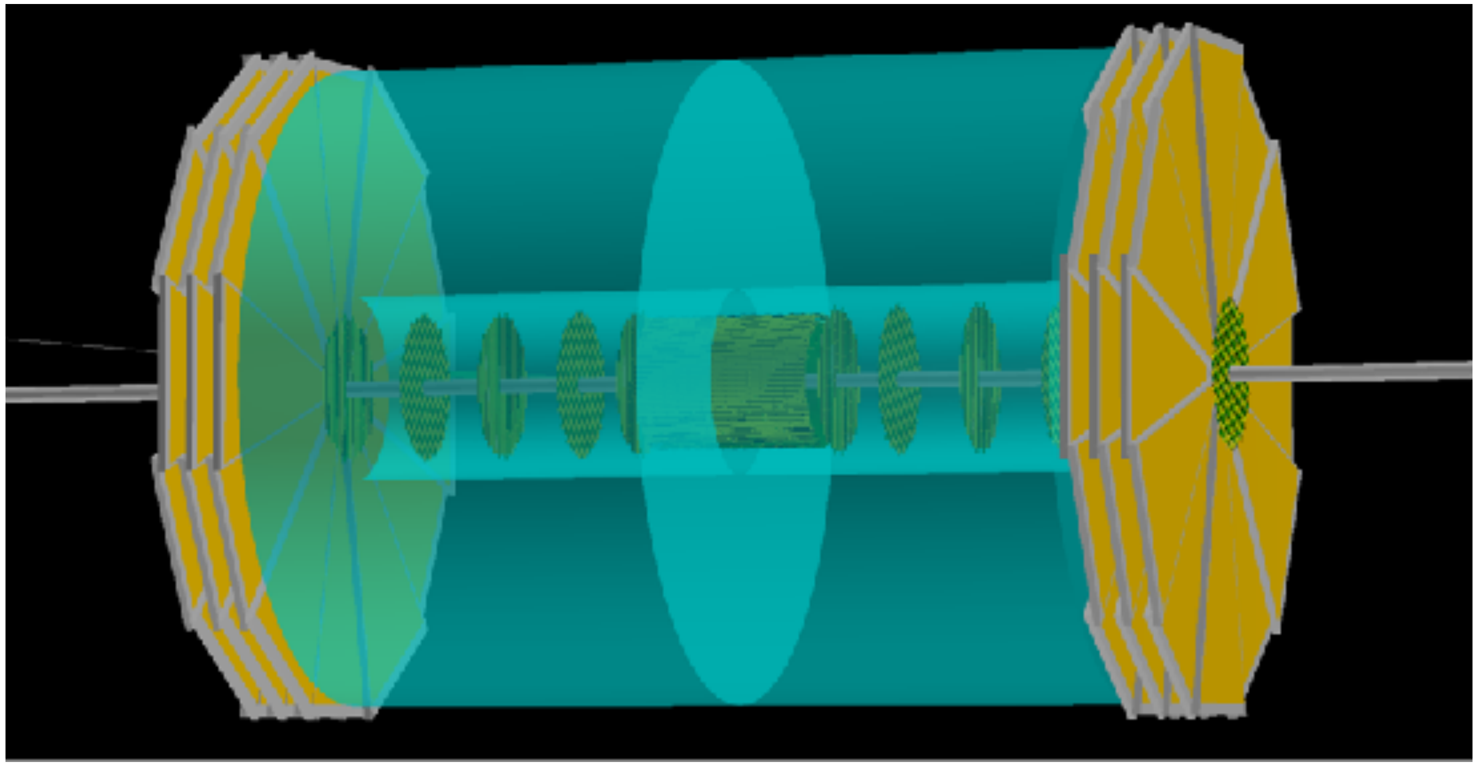
- eRHIC: 10 MHz beam bunch repetition rate, or higher (100ns separation, or less),
  JLEIC: 476 MHz (2.1ns),
- Not every bunch crossing produces a collision,
- The track density in a typical collision is modest; few tracks are produced,
- The Si-sensors considered *so far* (effectively) integrate over multiple beam-crossings,
  ~4μs for ALPIDE,
- Tracks and events need to be associated with each other and
  with the beam-crossing (spin config.)
- Implications for optimal EIC Si sensors?

RNC - EIC R&D Simulations

Initial considerations of timing and rates,

- Several possible approaches to handle the issues. We start here with `anchoring' tracks to one or more faster detection layers.

- The large area GEMs in the BeAST design, for example, might serve this purpose.



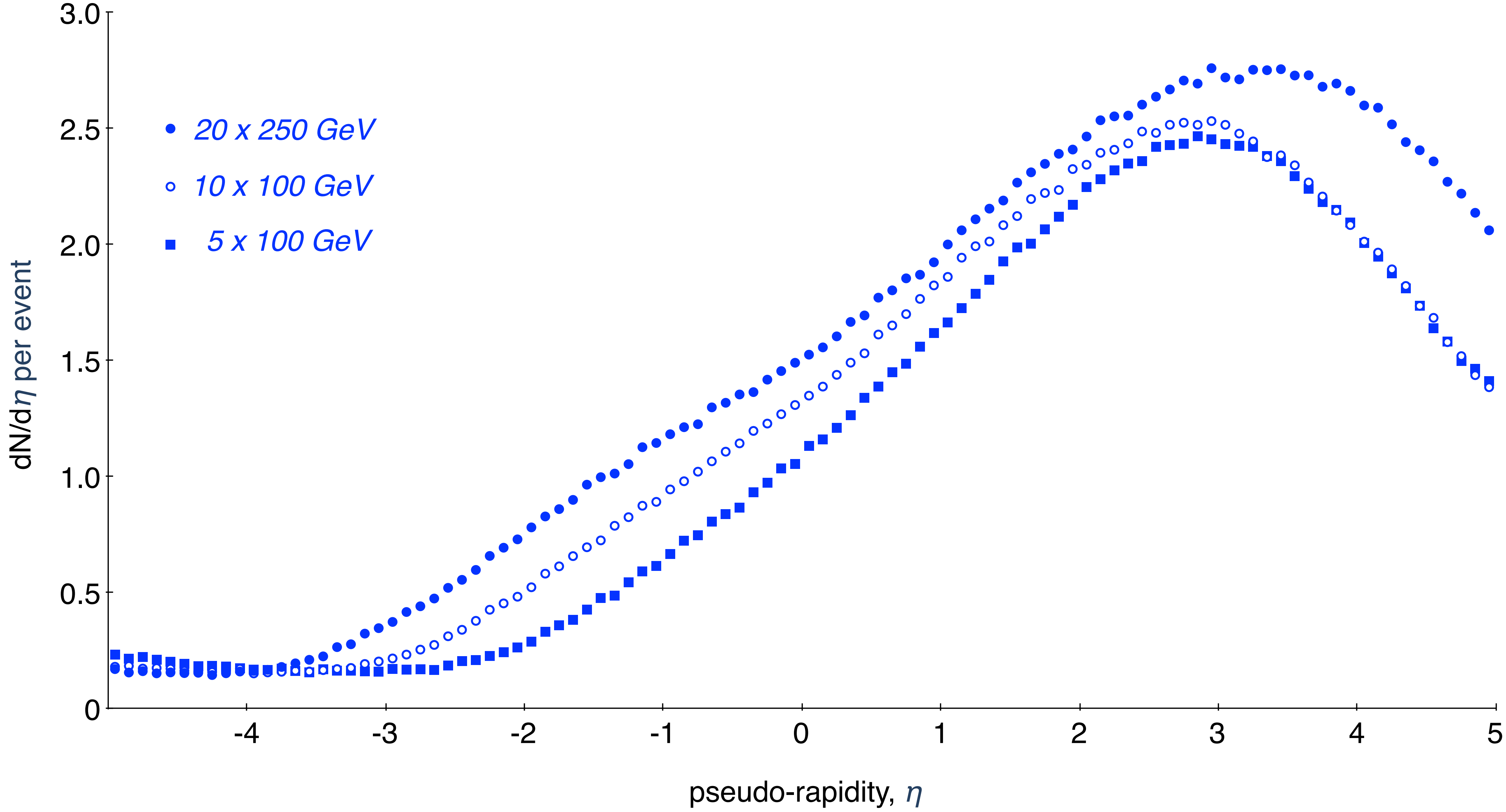
BeAST; seen are the TPC, Si-barrel and disks, and large-area GEMs

- Alternatives could include one or more fast Silicon disks or barrel layers, or …

RNC - EIC R&D Simulations

Initial considerations of timing and rates,

PythiaeRHIC simulations of track-densities for different beam-energy configurations

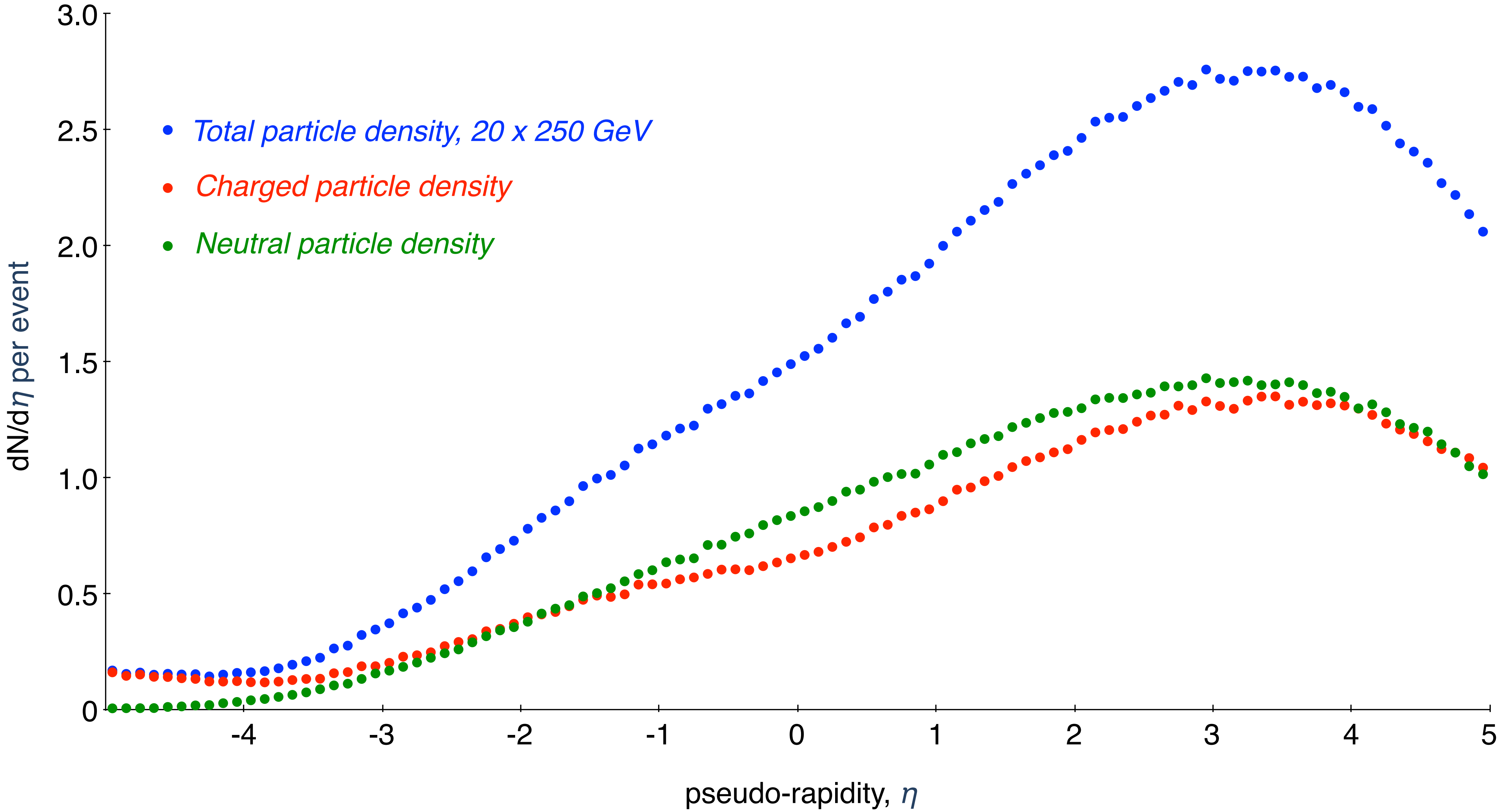


Here, consider the forward hadron direction and 20x250 GeV as a driving case.

RNC - EIC R&D Simulations

Initial considerations of timing and rates,

PythiaeRHIC simulations of track-densities for *charged* particles



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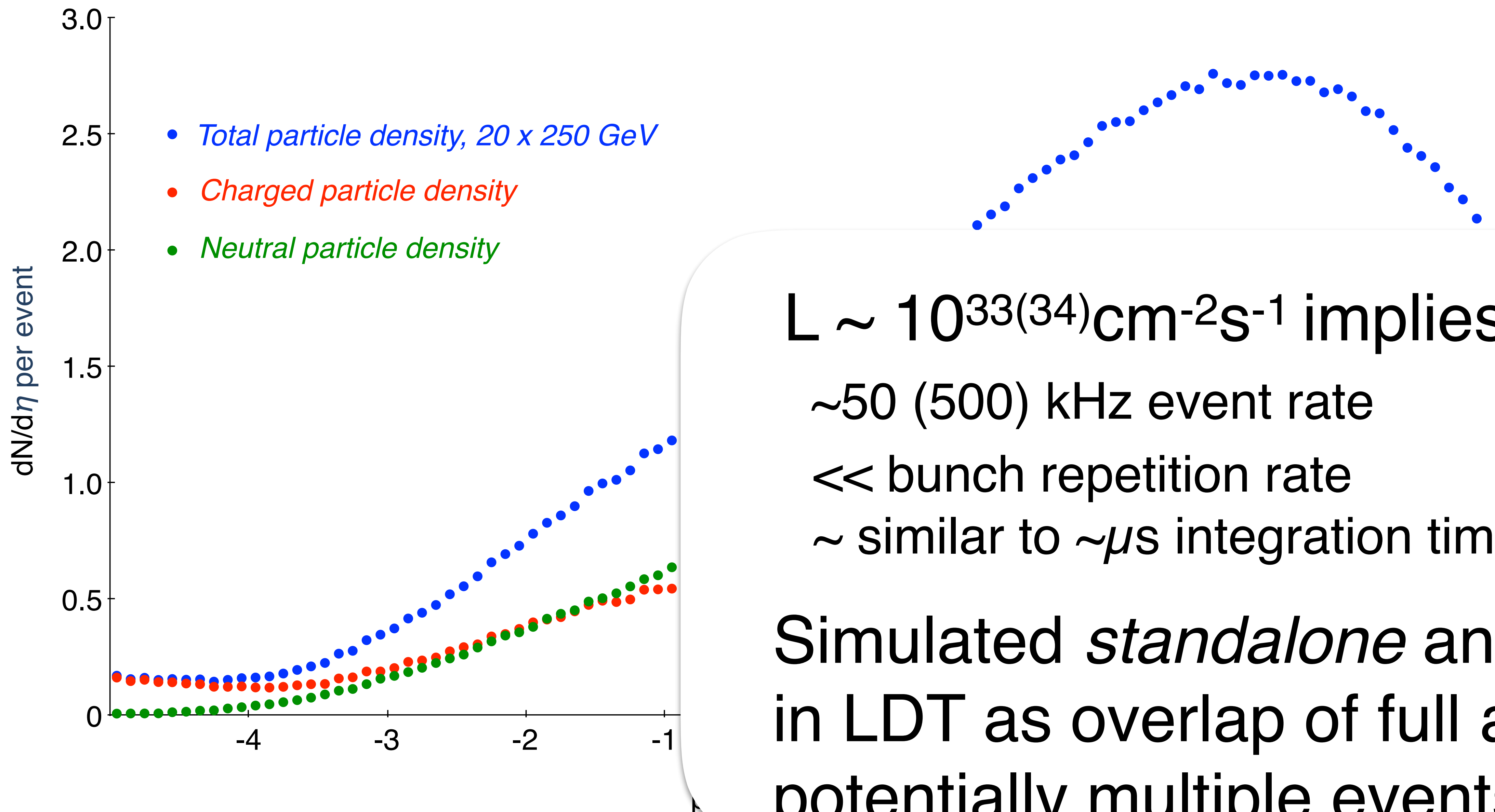


L ~ $10^{33(34)}$cm^{-2}s^{-1} implies:

~50 (500) kHz event rate

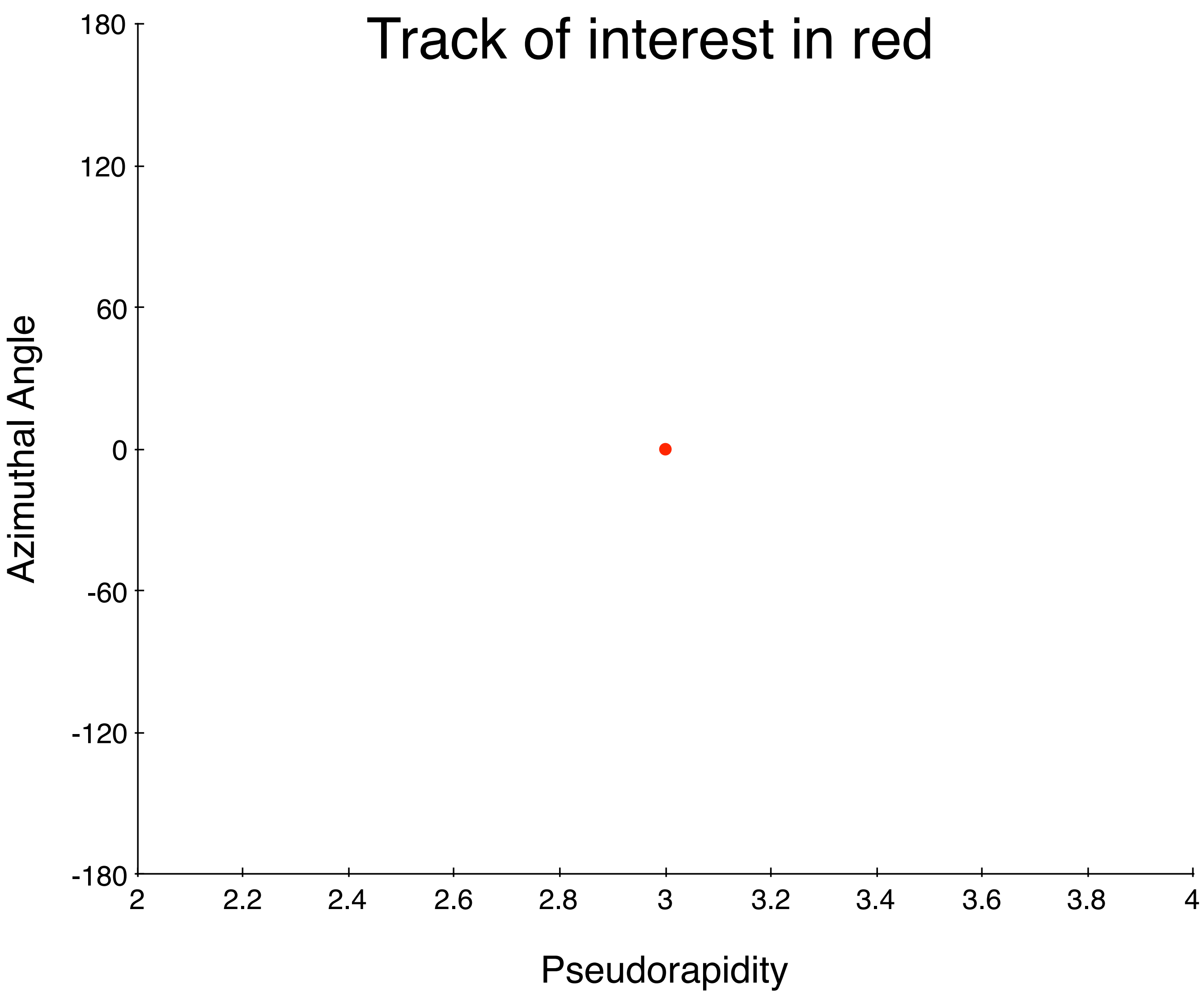
<< bunch repetition rate

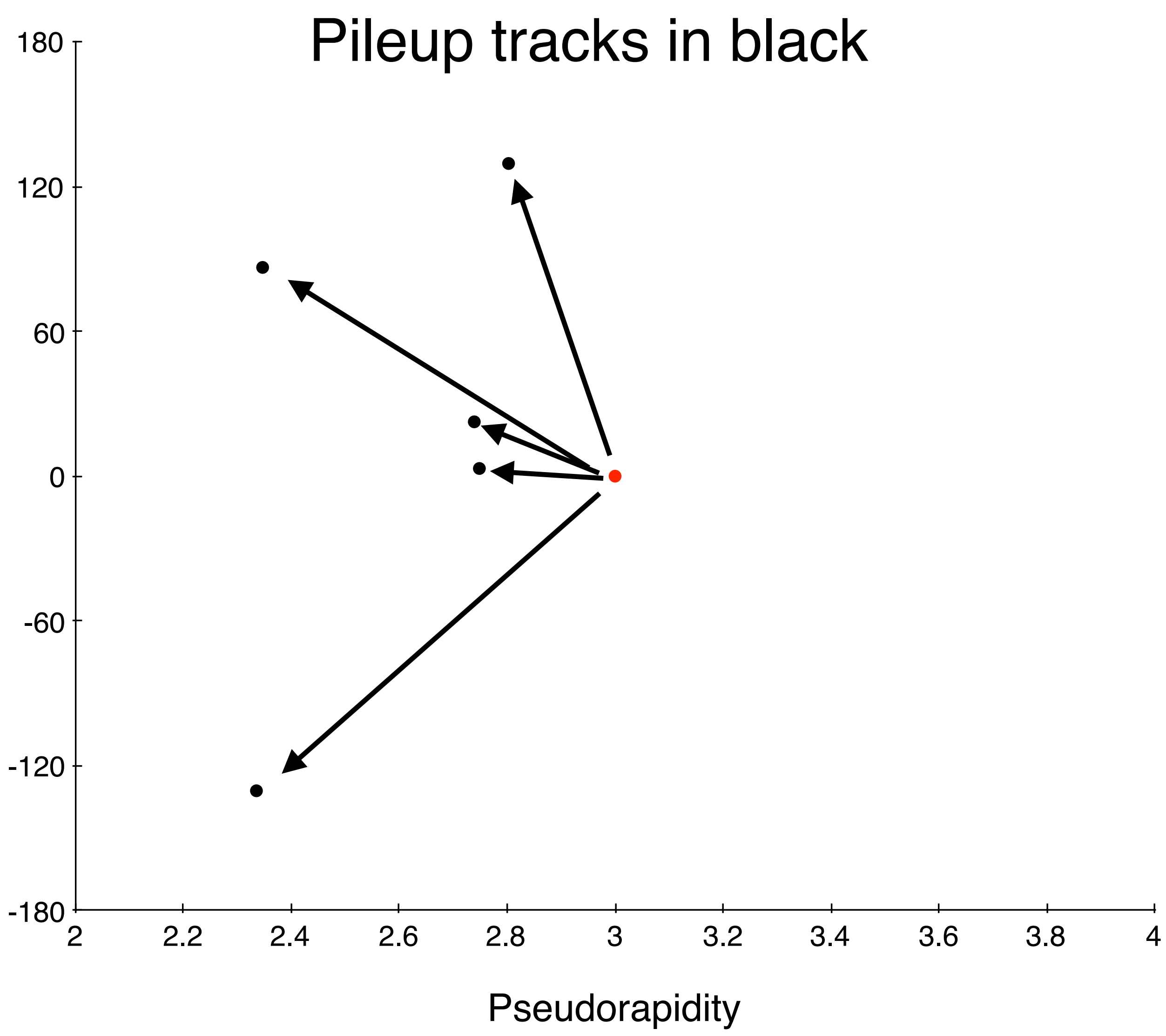
~ similar to ~μs integration times

Simulated *standalone* and in LDT as overlap of full and potentially multiple events.

RNC - EIC R&D Simulations

Initial considerations of track/event pileup in Si-sensors

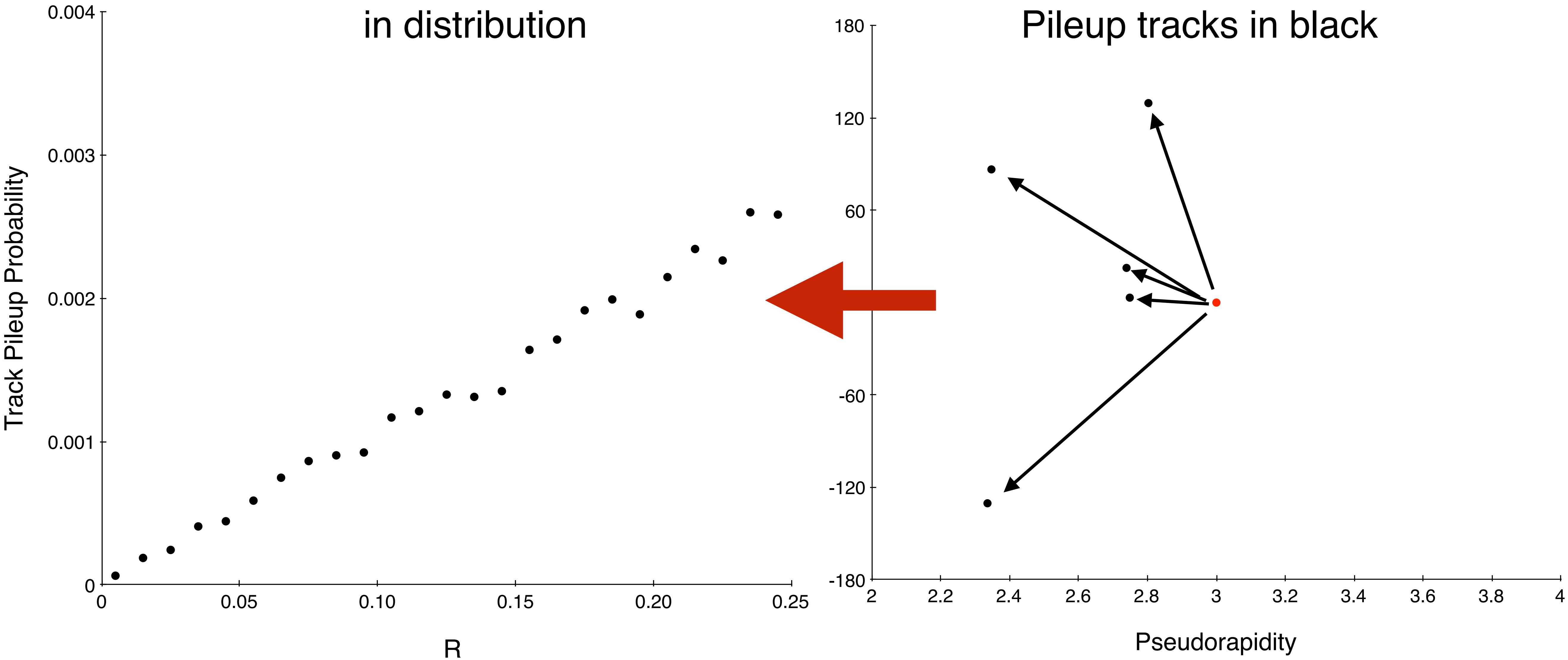




L ~ 10^{33}cm^{-2}s^{-1}, event pileup probability 0.04/μs, 10μs integration.

RNC - EIC R&D Simulations

Initial considerations of track/event pileup in Si-sensors



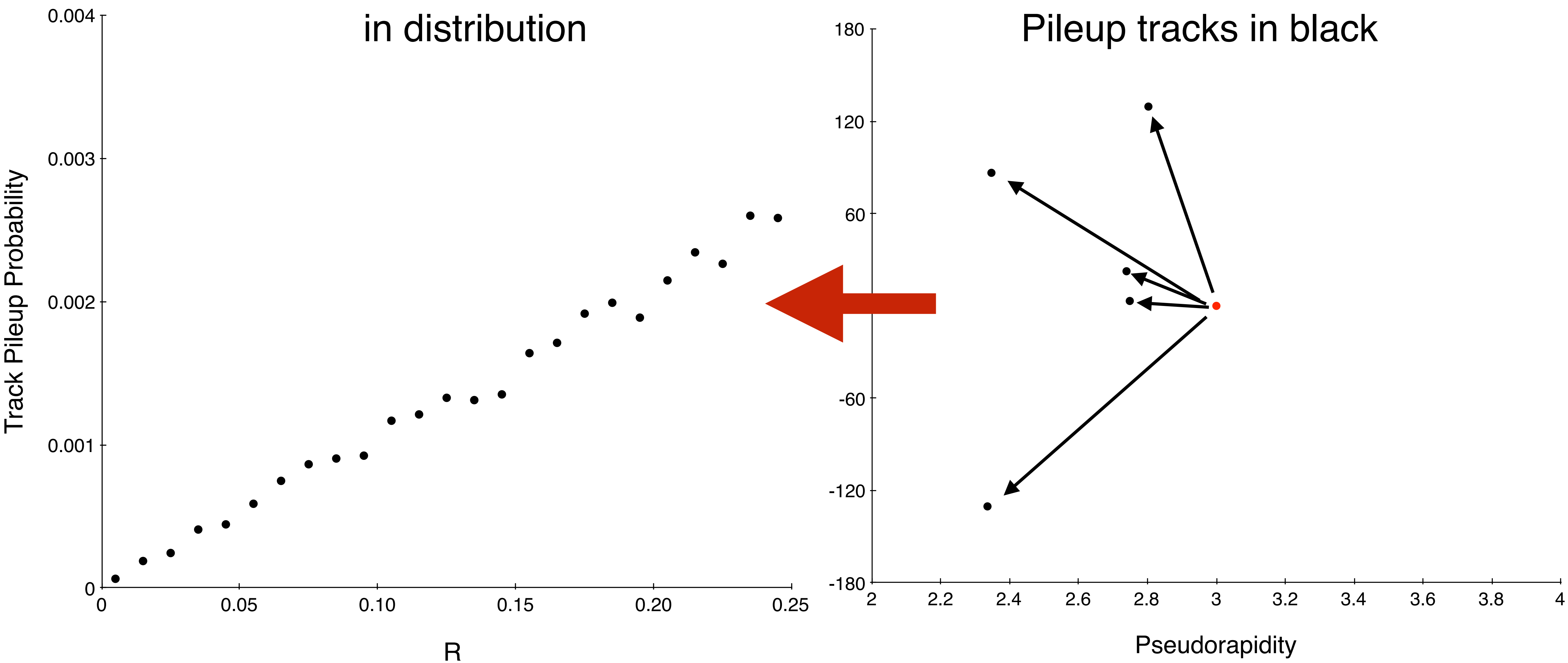
L ~ 10^{33}cm^{-2}s^{-1}, event pileup probability 0.04 per μs, 10μs integration,

1mm resolution at 1m corresponds to ~0.01 in R for eta~3,

➔ Within capability of BeAST large area forward GEMs.

RNC - EIC R&D Simulations

Initial considerations of track/event pileup in Si-sensors



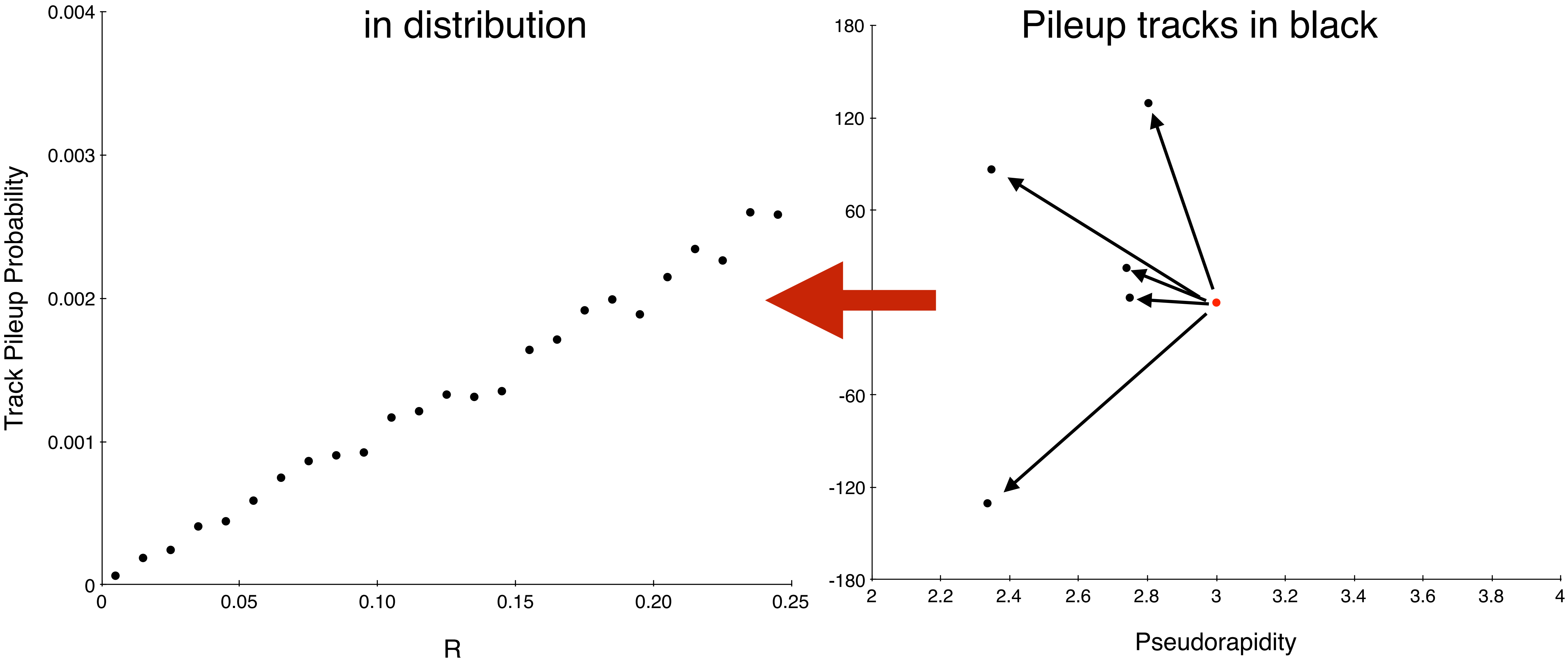
L ~ $10^{33}cm^{-2}s^{-1}$, event pileup probability 0.04 per μs, 10μs integration,

1mm resolution at 1m corresponds to ~0.01 in R for eta~3,

→ Noise in the pixel sensors workable; anchoring plane to be studied.

RNC - EIC R&D Simulations

Initial considerations of track/event pileup in Si-sensors



L ~ 10^{33}cm^{-2}s^{-1}, event pileup probability 0.04 per μs, 10μs integration,

1mm resolution at 1m corresponds to ~0.01 in R for eta~3,

➜ Is eta~3 actually realistic? Depends if the problem is track- or hit-like.

RNC - EIC R&D Simulations

Initial considerations of track/event pileup in Si-sensors

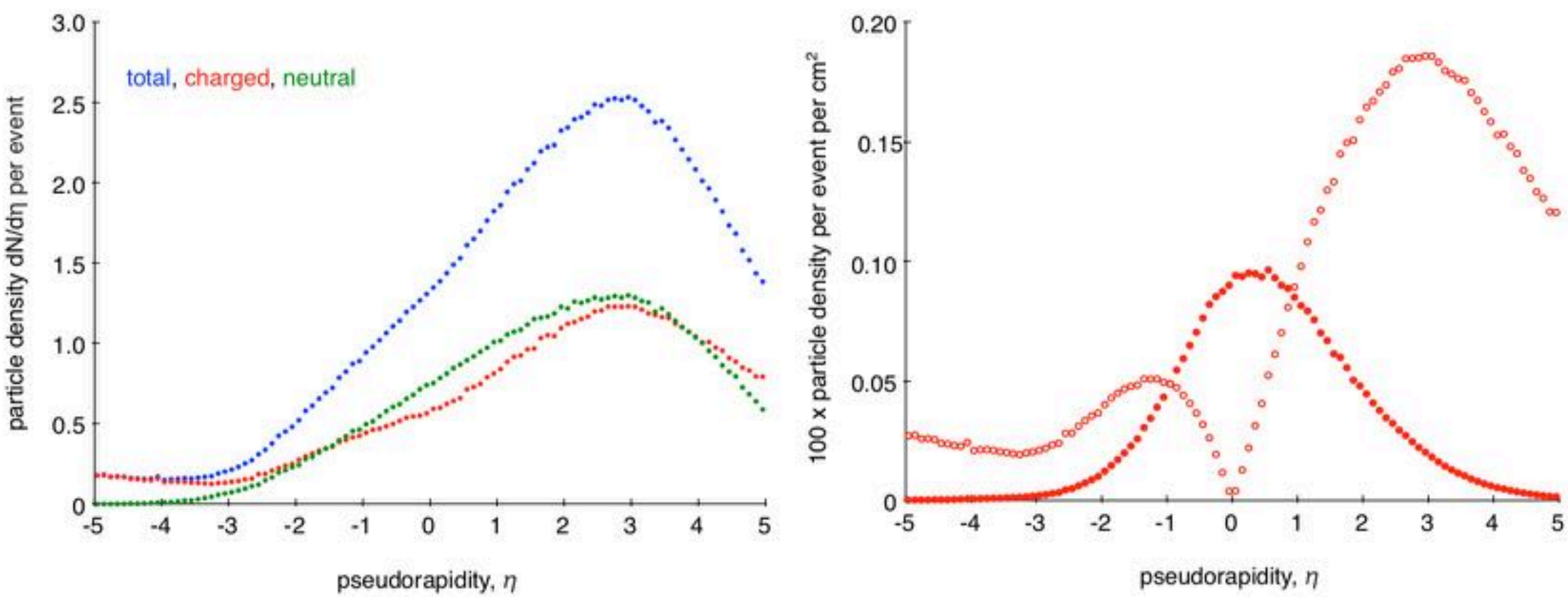


Figure 2: (left) Particle densities dN/dη versus η per collision event for 10 GeV electrons and 100 GeV protons for $Q^2 > 0.1$ GeV^2. (right) The corresponding charged particle densities along (filled symbols) and orthogonal (open symbols) to the beam axis at a distance of 10cm.

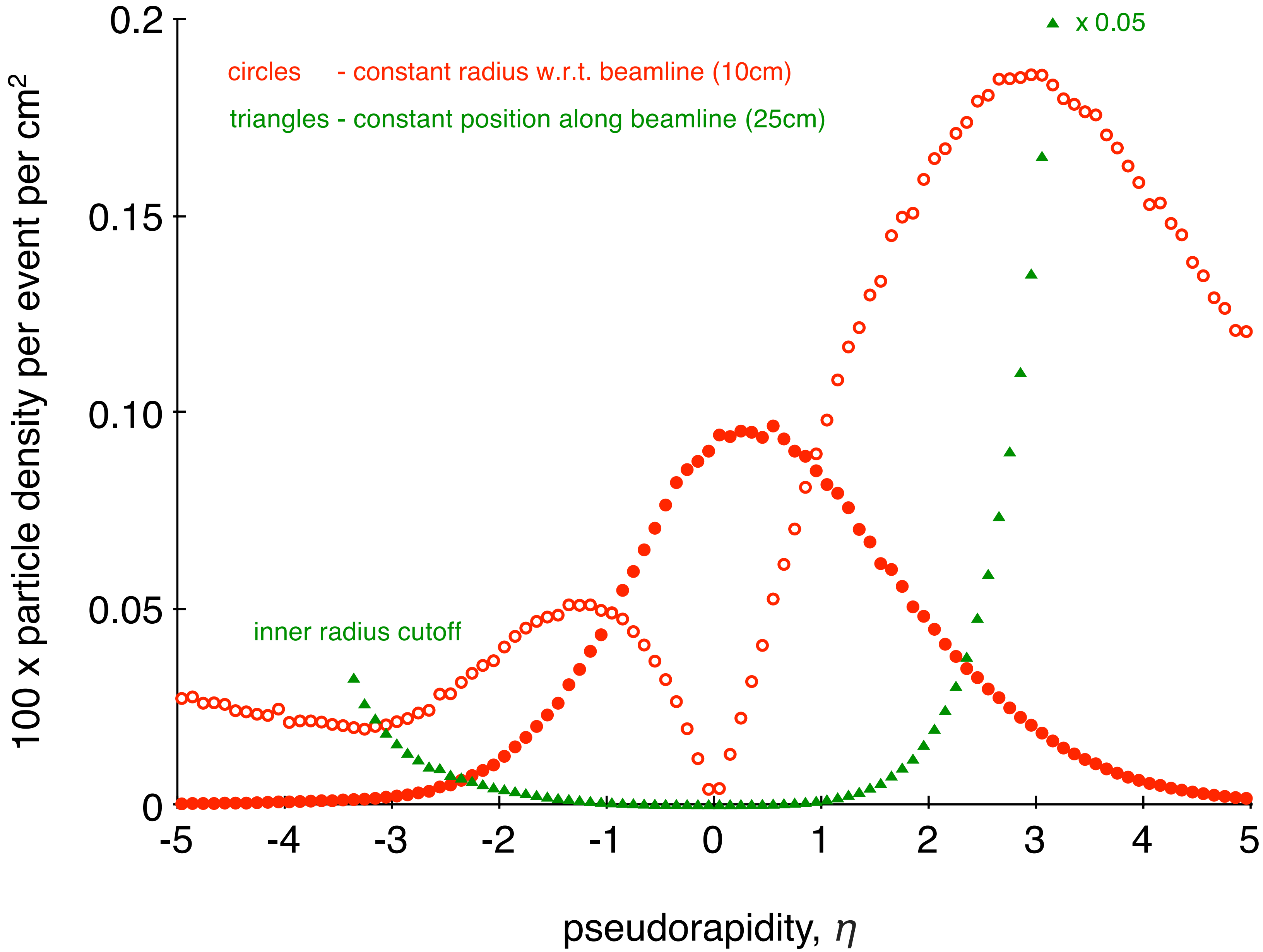
L ~ 10^{33}cm^{-2}s^{-1}, event pileup probability 0.04 per μs, 10μs integration,

1mm resolution at 1m corresponds to ~0.01 in R for eta~3,

→ Is eta~3 actually realistic/conservative? Particle flux incident on detector.

RNC - EIC R&D Simulations

Initial considerations of track/event pileup in Si-sensors



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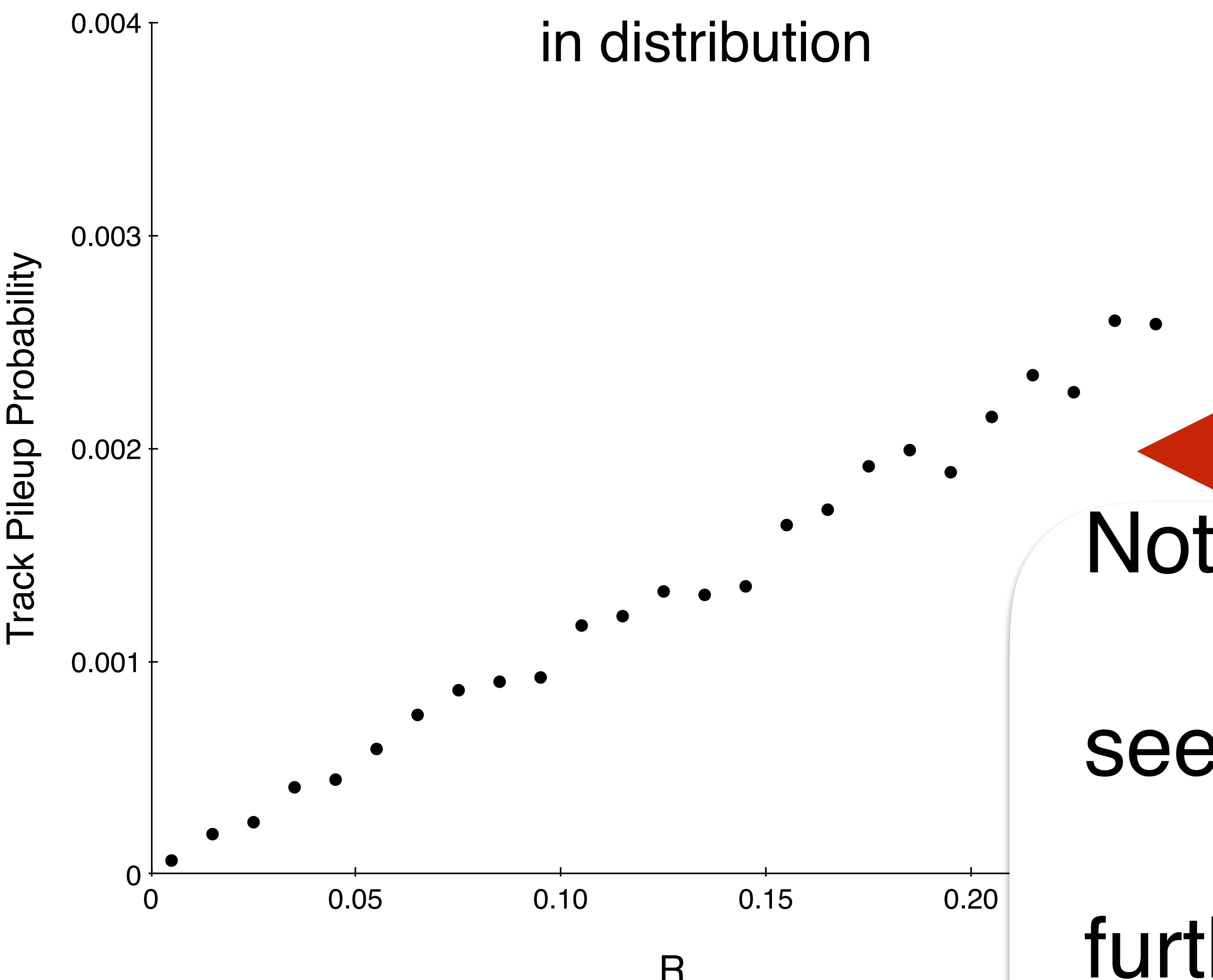
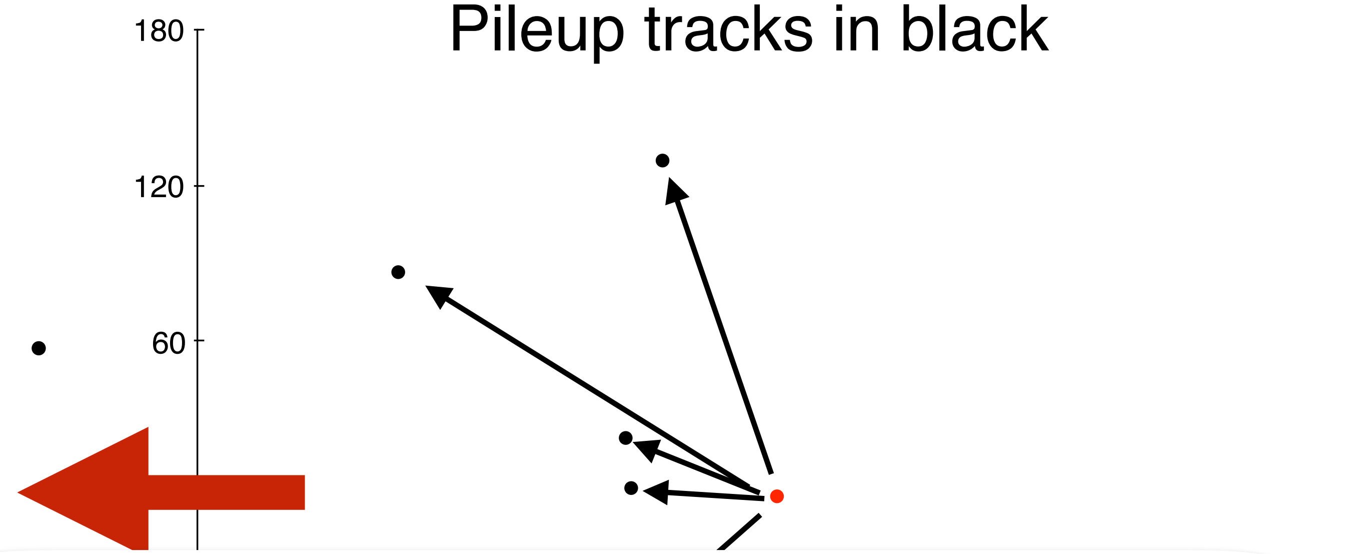
RNC - EIC R&D Simulations

Initial considerations of track/event pileup in Si-sensors





Not the last word, obviously:

seek to incorporate in EICRoot,

further study noise,

study background(s).

$L \sim 10^{33} cm^{-2} s^{-1}$, event pileup p

1mm resolution at 1m correspo

➜Within capability of BeAST large area forward GEMs; JLab to be studied.

RNC - LDRD-funded mid-rap. simulations

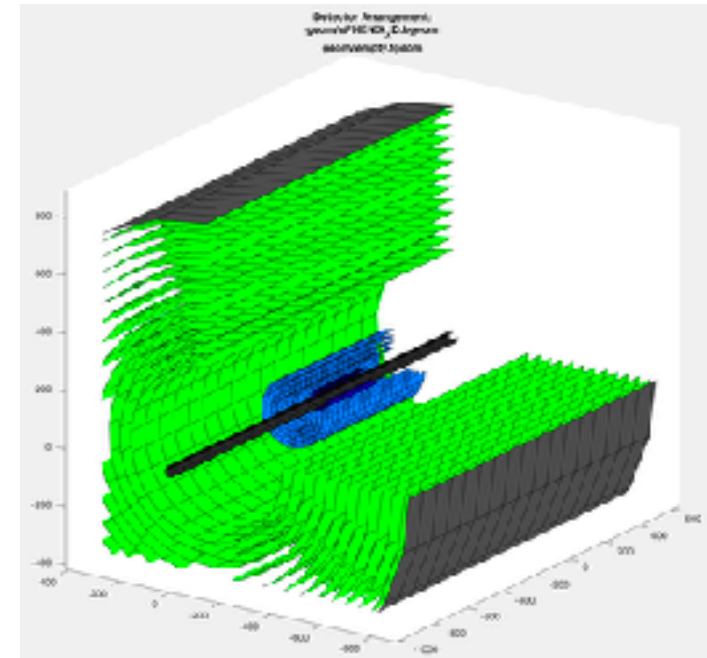
Work done by Michael Lomnitz

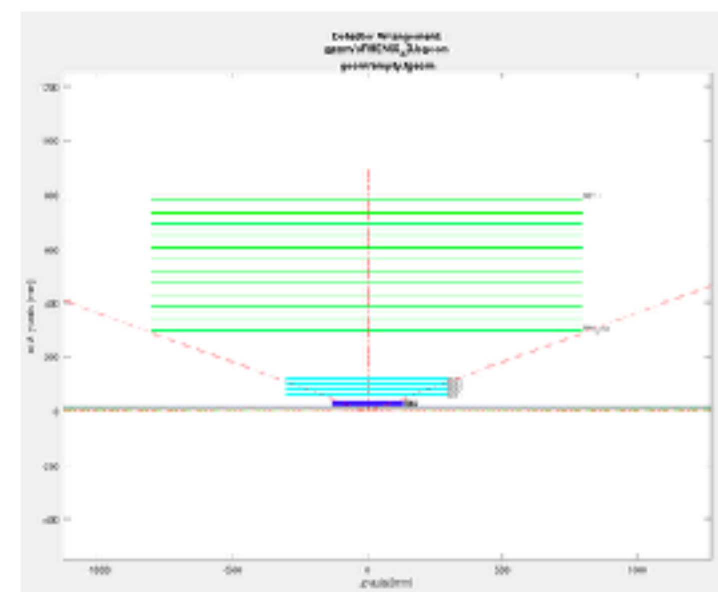
- LiC[1] Detector simulation tool:
  - Simple toy simulation for detector design.
  - Easy to implement, useful for quick studies of different detector geometries, material budget, etc.
  - Includes multiple scattering based on the material budget of detector elements.
  - Can be used to simulate forward detectors (disks) and central detectors (concentric cylinders). Current studies only include barrel geometry.
  - Generates charged particle tracks and fits based on Kalman Filter.
  - Can include in-active elements.
  - No energy loss is included in model → especially important for low momentum
- RAVE[2] Generic vertex toolkit:
  - Based on CMS vertex reconstruction algorithms.
  - Toolkit takes reconstructed tracks as input and reconstructs interaction vertices.
  - Pattern recognition + statistical estimation to find vertices.
- 1.5k events with tracks ($\pi^{+/-}$) used for initial studies.
- That is, indeed, heavy-ion minded; valuable for a making contact to EIC single-track results.

[1]: http://www.hephy.at/project/ilc/lictoy/UserGuide_20.pdf
[2]: https://github.com/newtrino/rave

RNC - LDRD-funded mid-rap. simulations

sPHENIX





Geometry definition[1]:

- TPC
  - 30 < r (cm) < 80, 60 active layers
  - Coverage (cm): |z| < 80
  - Thickness (per layer): X/X_0 = 0.0082 %
  - Errors (normal) σ(rφ) x σ(z): 120 μm x 120 μm
- IST:
  - 4 layers, radius (cm): 6.0, 8.0, 10.0 & 12.0
  - Coverage (cm): |z| < 30.0
  - Thickness (per layer): X/X_0 = 3 %
  - Errors d(rφ) x dz: 22.5 μm x 3500 μm
- VTX:
  - 3 layers, radius (cm): r = 2.3, 3.2 & 3.9
  - coverage (cm): |z| < 13.5
  - Thickness (per layer): X/X_0 = 0.3 %
  - Errors d(rφ) x dz: 4 μm x 4 μm (ALICE LOI ~ 13 μm pixel pitch)
  - Actual ALICE chip will 28 μm pitch (errors ~ 8.1 μm)
- 1.5 T magnetic field

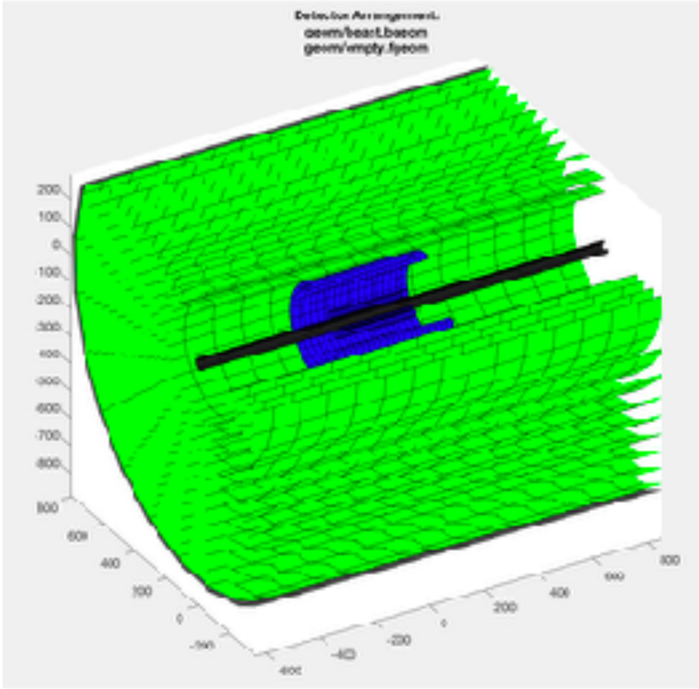
[1]: https://indico.bnl.gov/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=2865

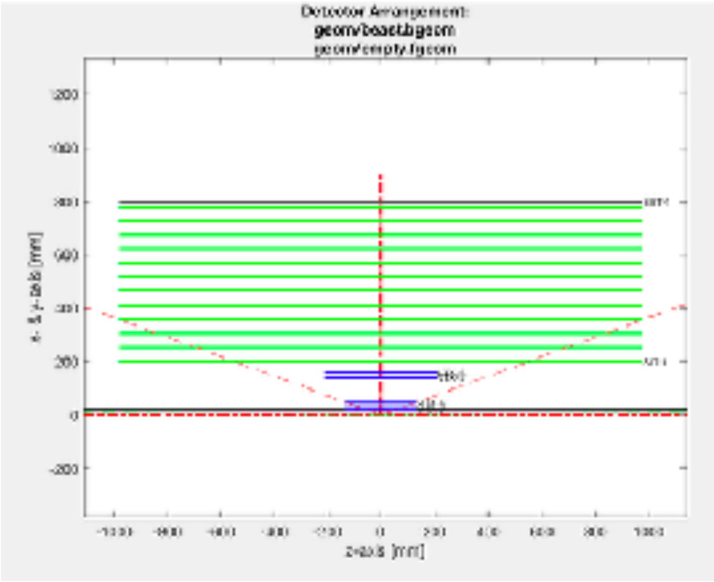
RNC - LDRD-funded mid-rap. simulations

BEAST

Geometry definition[1]:

- TPC
  - 20 < r (cm) < 80, 60 active layers
  - Coverage (cm): |z| < 80
  - Thickness (per layer): X/X_0 = 0.0082 %
  - Errors (normal) σ(rφ) x σ(z): 120 µm x 120 µm
- VTX:
  - 4 layers, radius (cm): r = 2.34, 4.68, 14.04 & 15.72
  - coverage (cm): |z| < 13.5 & 21.0
  - Thickness (per layer): X/X_0 = 0.3 %
  - Errors d(rφ) x dz: 4 µm x 4 µm (ALICE LOI ~ 13 µm pixel pitch)
  - Actual ALICE chip will 28 µm pitch (errors ~ 8.1 µm)
- 1.5 T magnetic field for comparisons w. sPHENIX





[1]: http://svn.racf.bnl.gov/svn/eic/eicroot/

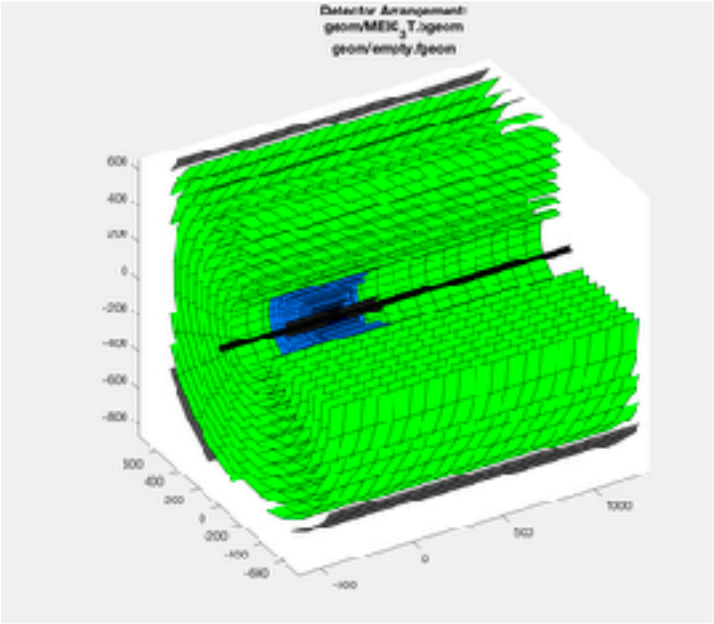
RNC - LDRD-funded mid-rap. simulations

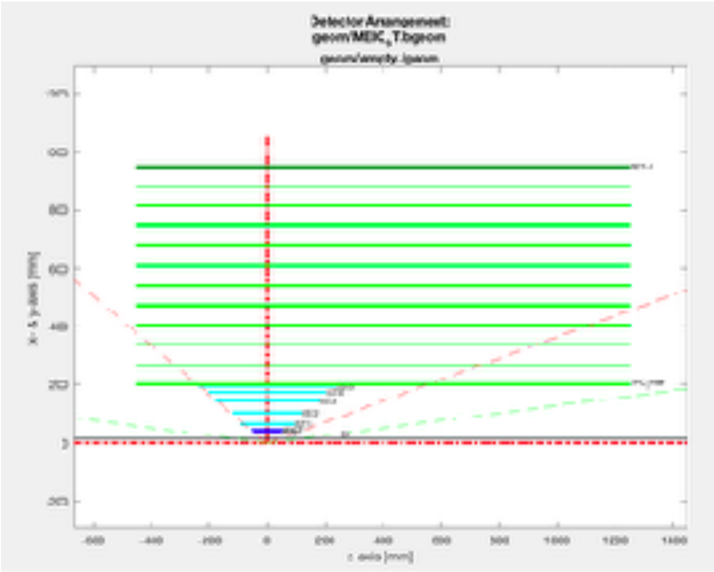
MEIC

Geometry definition[1]:

- TPC
  - 20 < r (cm) < 95, 60 active layers
  - Coverage (cm) shifted 40 cm relative IP : - 45< z < 125
  - Thickness (per layer): X/X_0 = 0.0082 %
  - Errors (normal) $\sigma(r\varphi)$ x $\sigma(z)$: 120 μm x 120 μm
- IST double sided Si:
  - 5 layers, radius (cm): 6.5, 10.5, 14.5, 17.5 & 19.5
  - Coverage (cm): |z| < 9, 12, 18, 20 & 24
  - Thickness (per layer): X/X_0 = 2 %
  - Errors d(rφ) x dz: 21.5 μm x 21.5 μm
- VTX:
  - 2 layers, radius (cm): r = 3.5, &4.5
  - coverage (cm): |z| < 5 & 5.5
  - Thickness (per layer): X/X_0 = 0.3 %
  - Errors d(rφ) x dz: 4 μm x 4 μm (ALICE LOI ~ 13 μm pixel pitch)
  - Actual ALICE chip will 28 μm pitch (errors ~ 8.1 μm)

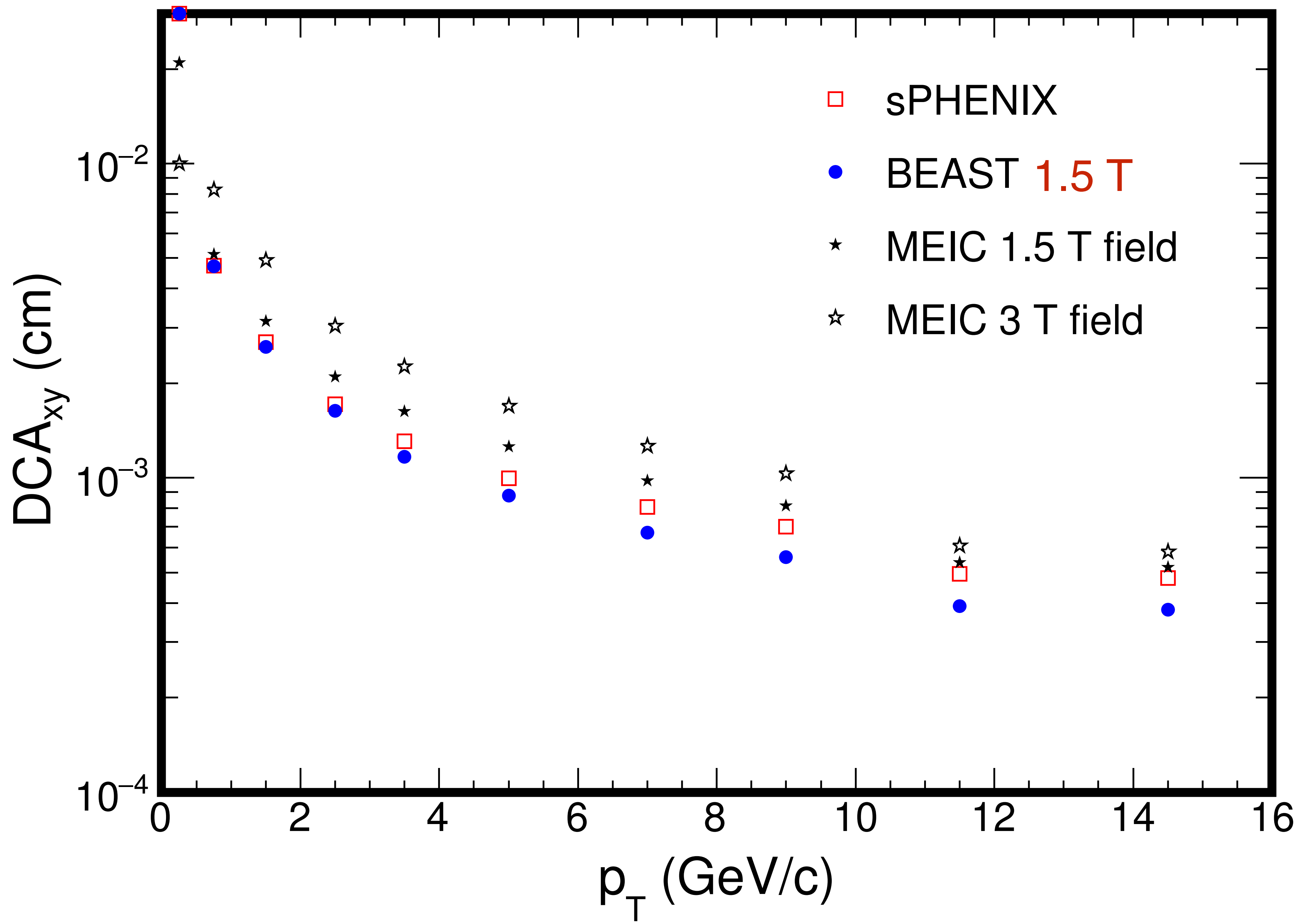
- 1.5 T & 3.0 T configurations tested magnetic field





[1]: Private communications Yulia Furletova

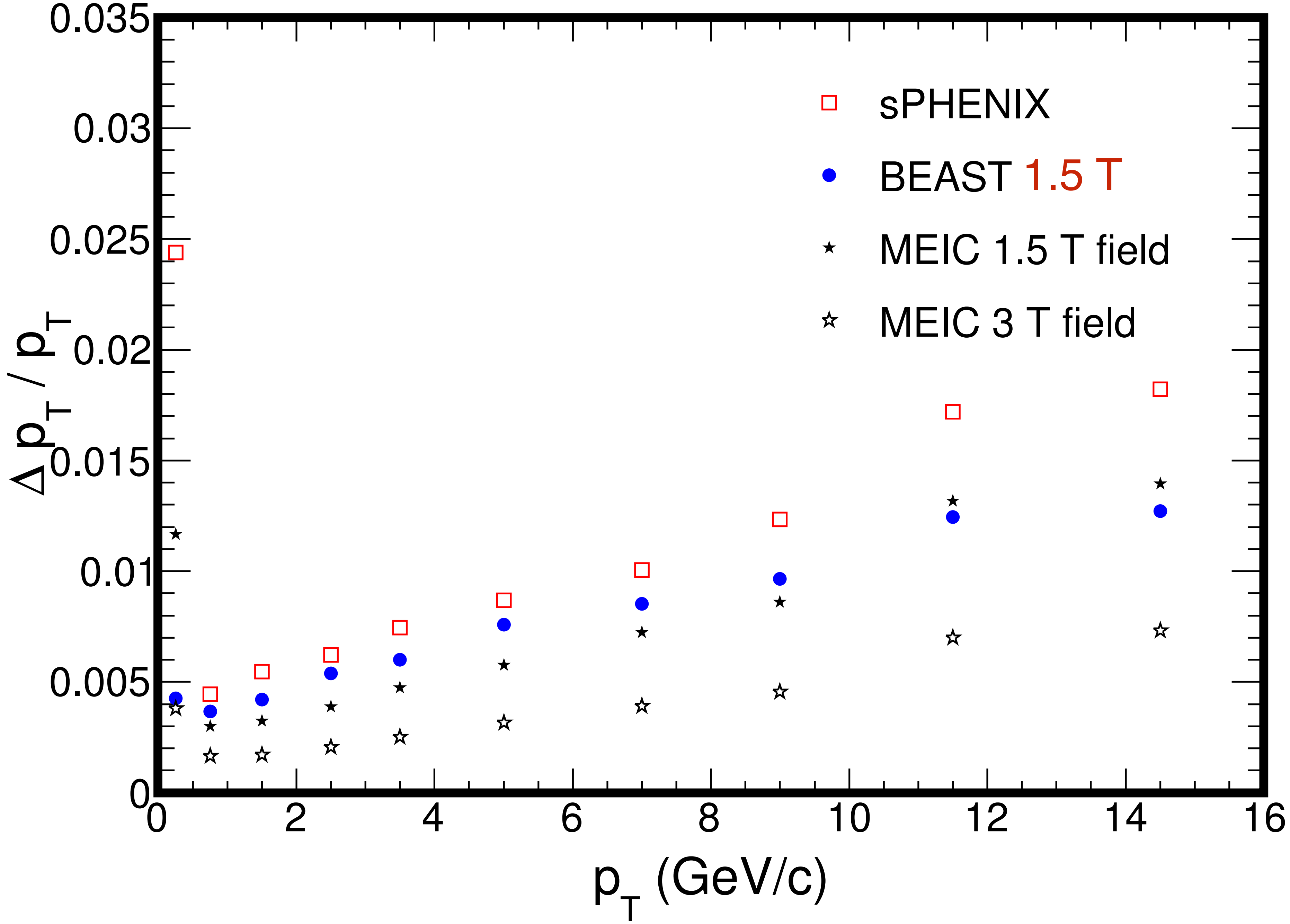
RNC - LDRD-funded mid-rap. simulations



Pre-prel. conlusion: vertex resolution primarily from innermost barrel layers

→ensure sufficient length; trade-off w. momentum resolution.

RNC - LDRD-funded mid-rap. simulations



Pre-prel. conlusion: use a modest number of intermediate barrel layers,

no substitute for field,

eRD16 and eRD18

- Started video conferencing to discuss ongoing work and plans;
  fell through late last year → new-year's resolution

- Made a start towards joint layout simulations, with a common toolset and detector descriptions; EICRoot,

- Initial division of effort along (main) physics interests,

- Aim for a set of optimized requirements for barrel and disks in FY18,

- Beyond FY18, aim for design, submission (and tests) of one or more EIC-specific sensor prototypes,

- Potential to form a consortium on that timeline.

Closing Comments

Sensor:
pixel size of approx. 28 x 28um appears adequate,
integration/rise time remains under study, 4us seems OK so far,

Configuration:
Optimization for momentum resolution slightly prefers a lower number of equidistant disks in the forward-going electron direction than in the forward-going hadron direction; this is a relatively small effect.

Vertexing appears driven primarily by the innermost barrel layers;
this presents a trade-off with momentum measurement
natural overlap between eRD16 and eRD18

Details matter, acceptance, beam-pipe, etc - we will document them in a note by June,

Generic EIC detector R&D and LBNL-LDRD funds have proven invaluable,

UCB students have proven a very productive avenue to advance simulations; will continue to pursue SULI program

Intend to re-integrate hardware aspects (conductors, cooling,) next round.