eRD16: Forward/Backward Tracking at EIC using MAPS Detectors

E. Biermann, A. Collu, X. Dong, L. Greiner, B.V. Jacak, P.M. Jacobs, S.R. Klein,
Y.S. Lai, Y. Mei, G. Odyniec, M. Ploskon, R.J. Porter, E.P. Sichtermann, N. Xu.

Nuclear Science Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley, California 94720

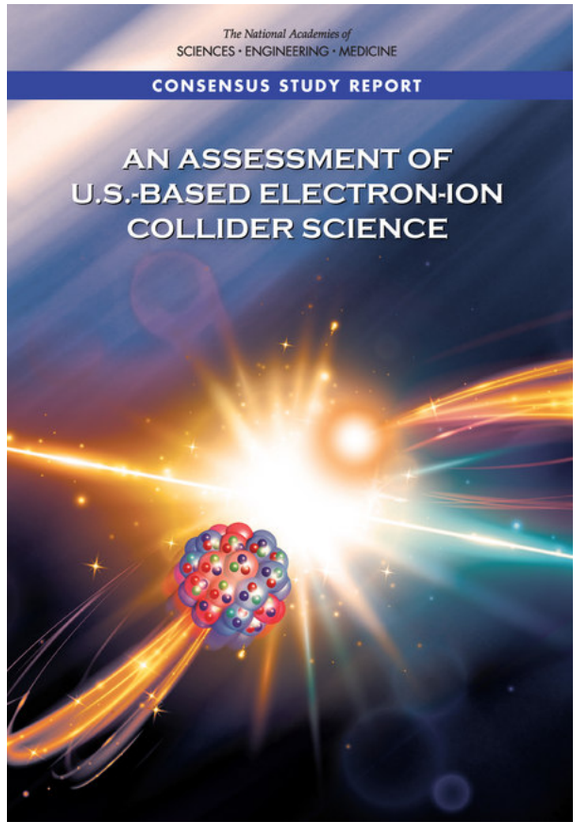
Abstract

We report on and propose continued 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 EIC beams. The focus is on disks with thinned-silicon sensors with the overall goal to arrive at science-driven sensor specifications, optimized geometrical configuration of the forward/backward disks, disk layout, conceptual arrangement of services, and integration with tracking subsystems covering the central barrel region. Part of this work is being pursued in collaboration with eRD18, which focuses on mid-rapidity (vertex) tracking and sensor development.

Outline

- Introduction / reminder
- Simulation tools used,
- Progress report
  - Comparisons of fast and slow simulations
  - All-silicon configuration
- Proposed work

Forward/backward Tracking - Why?



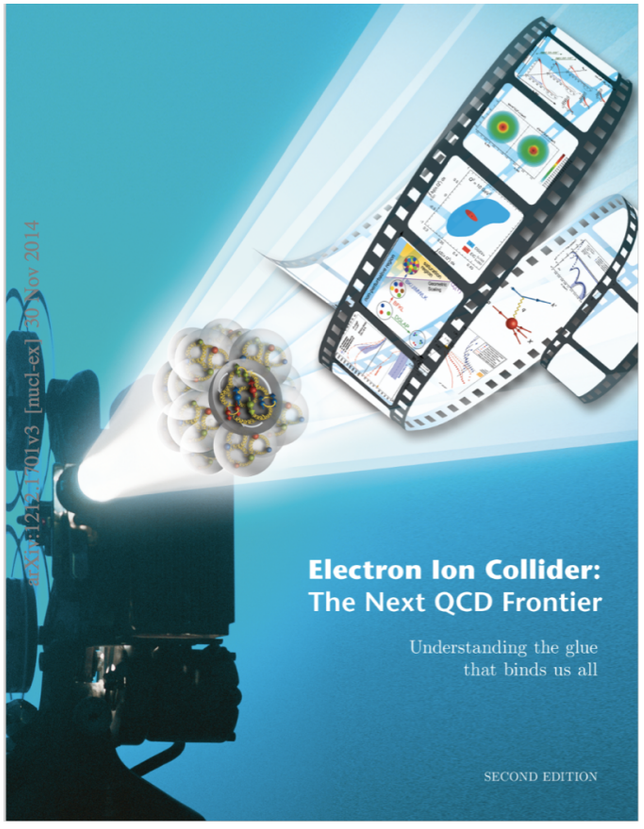
Endorsed science case,

Four nuclear-physics themes:
- nucleon spin,
- imaging in nucleon and nuclei,
- gluon-dense matter / saturation,
- hadronization and fragmentation

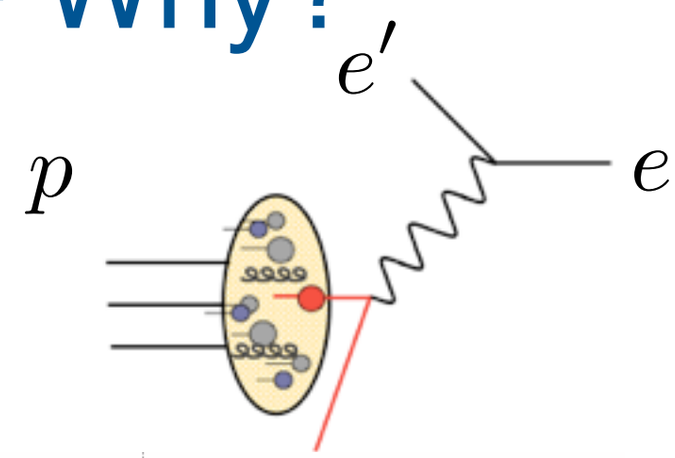
Most/all measurements *require* large acceptance,

High resolution is a must in the solenoidal fields of current general purpose detector designs,

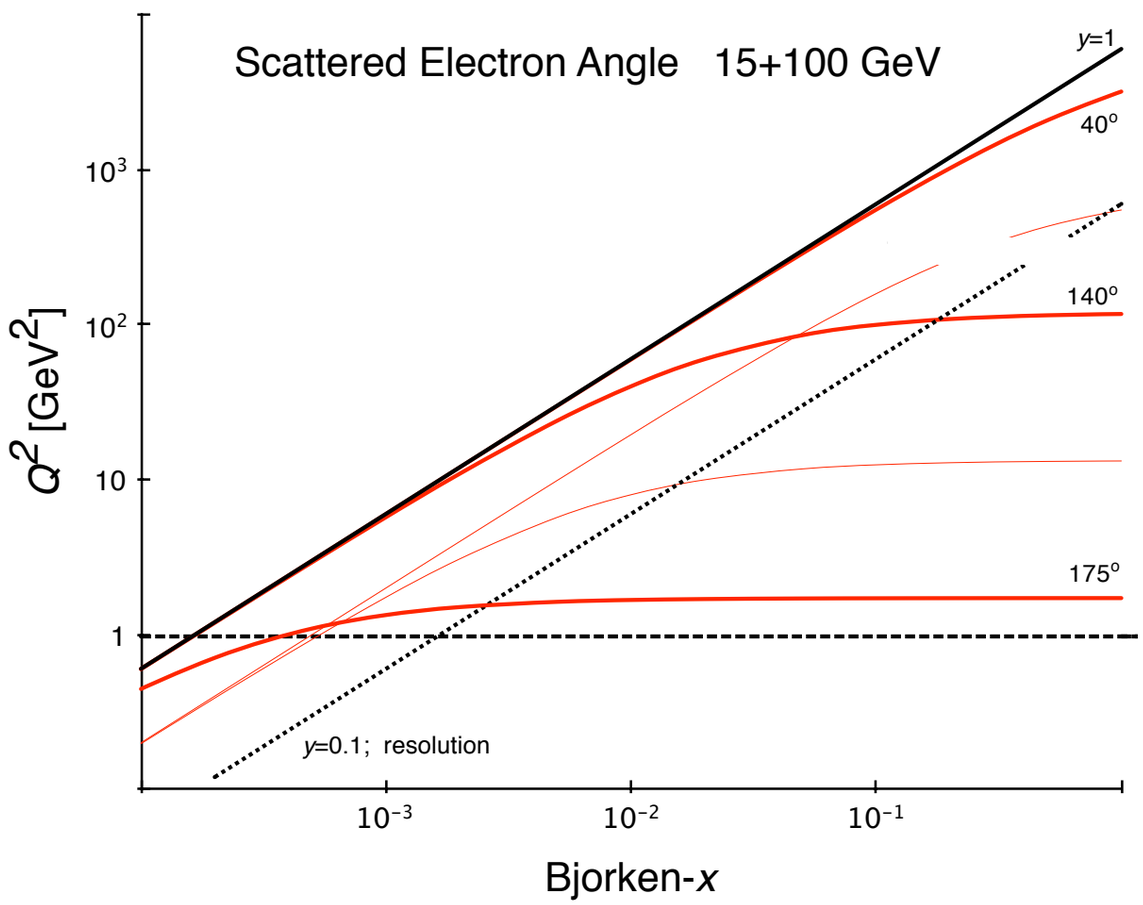
Traversed material will need to be kept in check, especially in the electron direction.

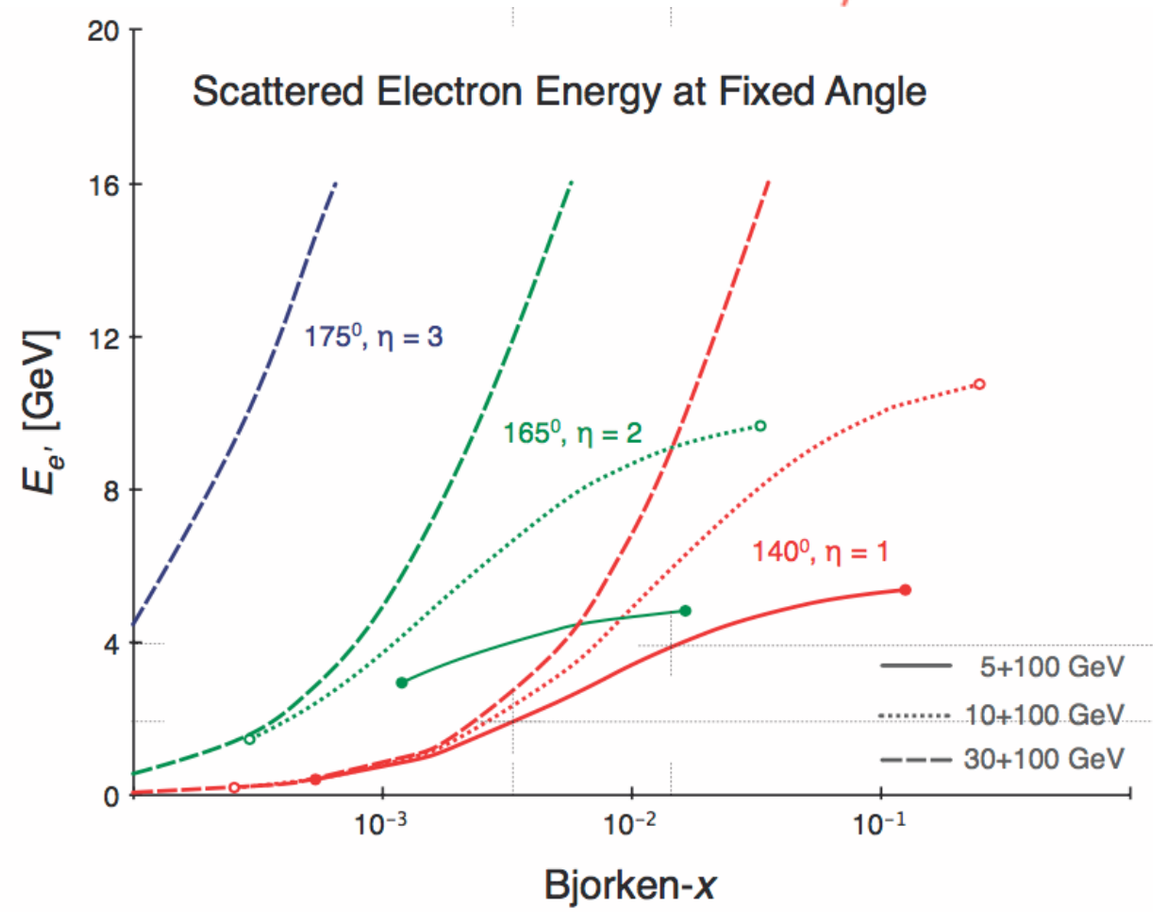


Forward/backward Tracking - Why?



The scattered electron, for example,

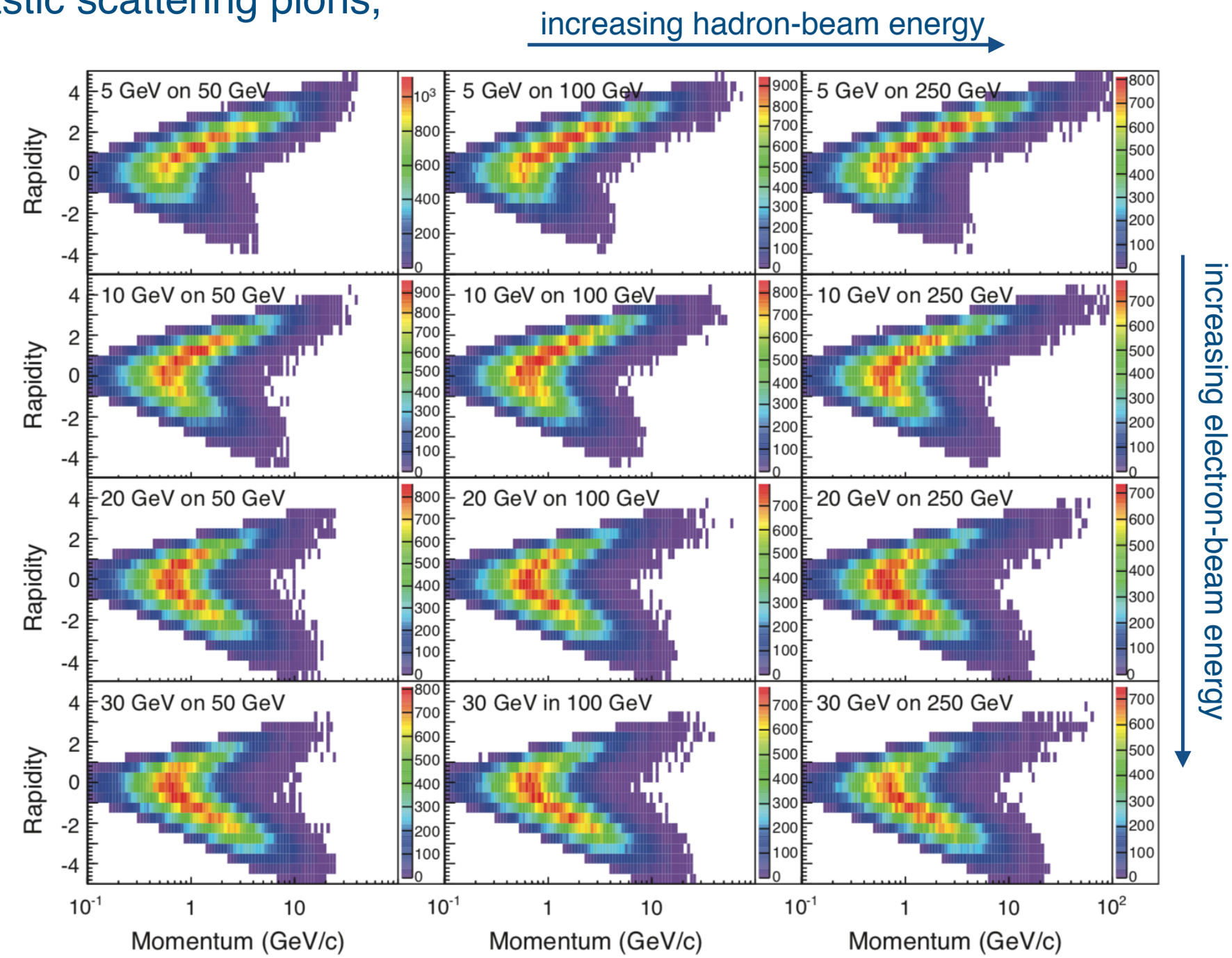




will in many cases need to be observed at large *backward* angles with respect to the hadron beam (HERA angle convention).

Forward/backward Tracking - Why?

Deep-inelastic scattering pions,



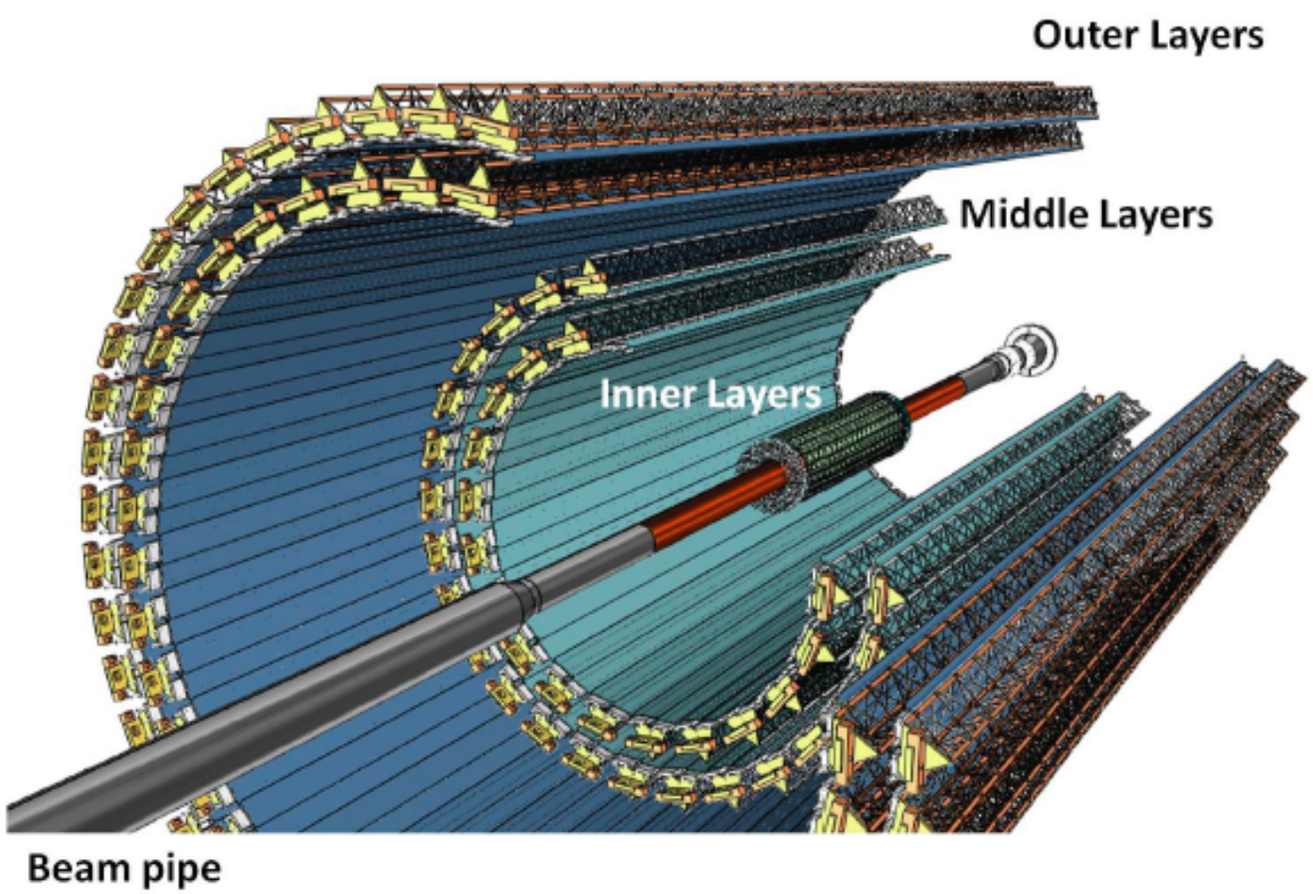
likewise require large (tracking) acceptance.

EIC-WP, figure 5.2

Recent Group Instrumentation Projects

STAR HFT-pixel is complete,

ALICE ITS upgrade is ongoing,



- 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)

Makes 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

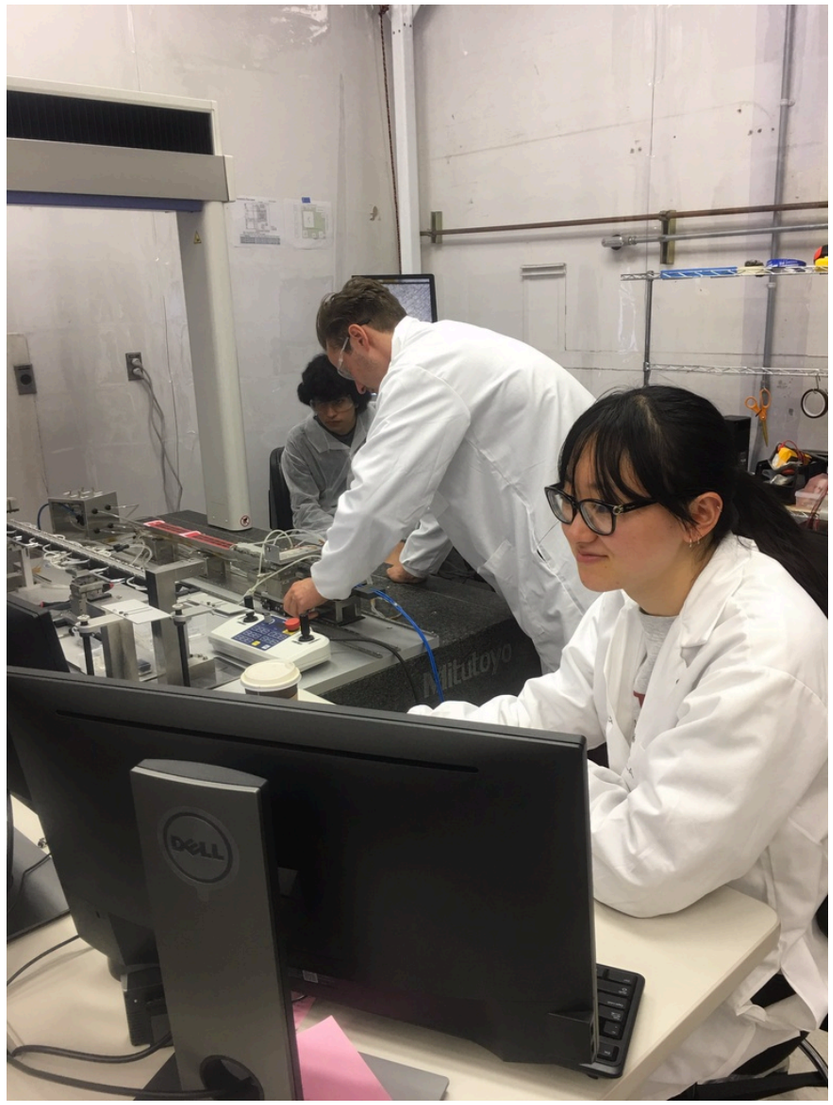
TDR: http://iopscience.iop.org/0954-3899/41/8/087002/

Vertex tracker for sPHENIX being pursued.

Recent Group Instrumentation Projects

STAR HFT-pixel is complete,

ALICE ITS upgrade is ongoing,



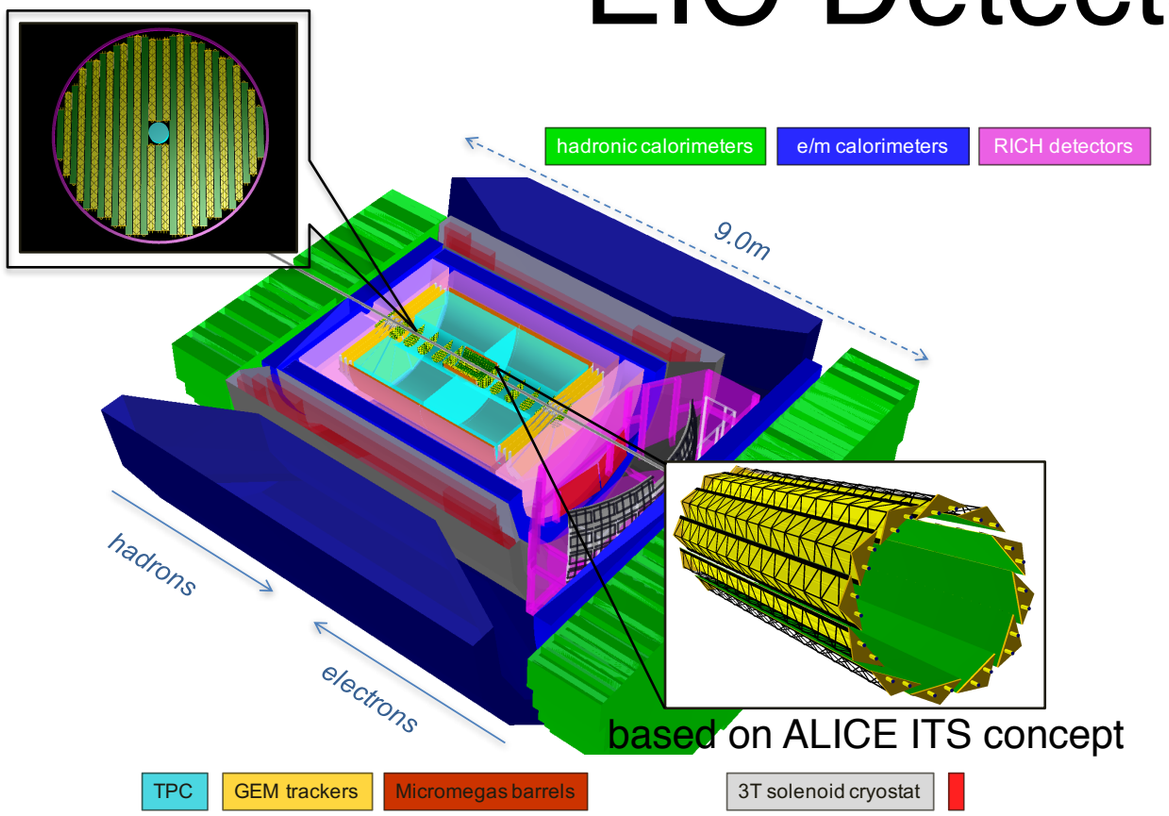
- 7 layers
- 10 m^2 of silicon
- Installation in early 2019
- X/X_0 ~ 0.3% (inner layers)
- X/X_0 ~ 0.8% (outer layers)

Makes use of CERN-developed MAPS sensors, ALPIDE:

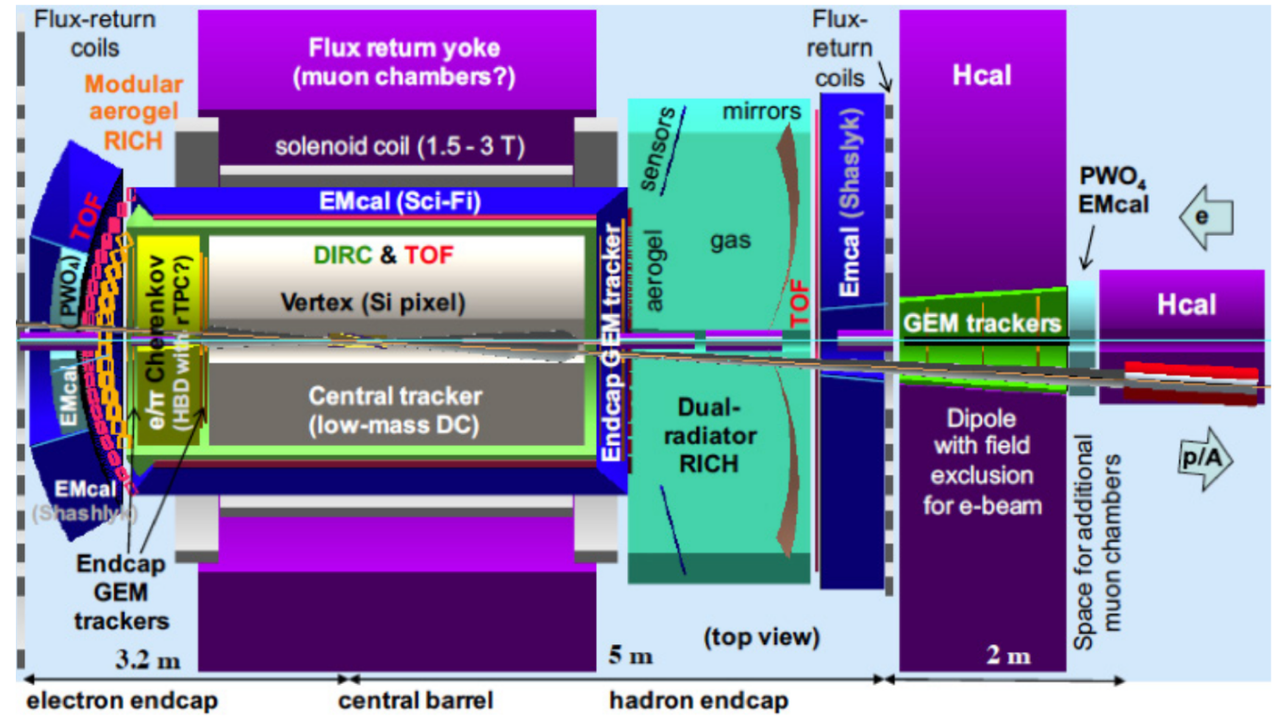
Dimensions:	15mm x 30mm
Pixel pitch:	28µm x 28µm
Integration time:	approx. 4 µs
Power consumption:	39mW/cm^2

Vertex tracker for sPHENIX being pursued.

EIC Detector Concepts*



BeAST concept



JLEIC detector concept

Si-based *inner* tracking and vertex detectors*, covering central and forward regions, for eRHIC as well as JLEIC detector concepts,

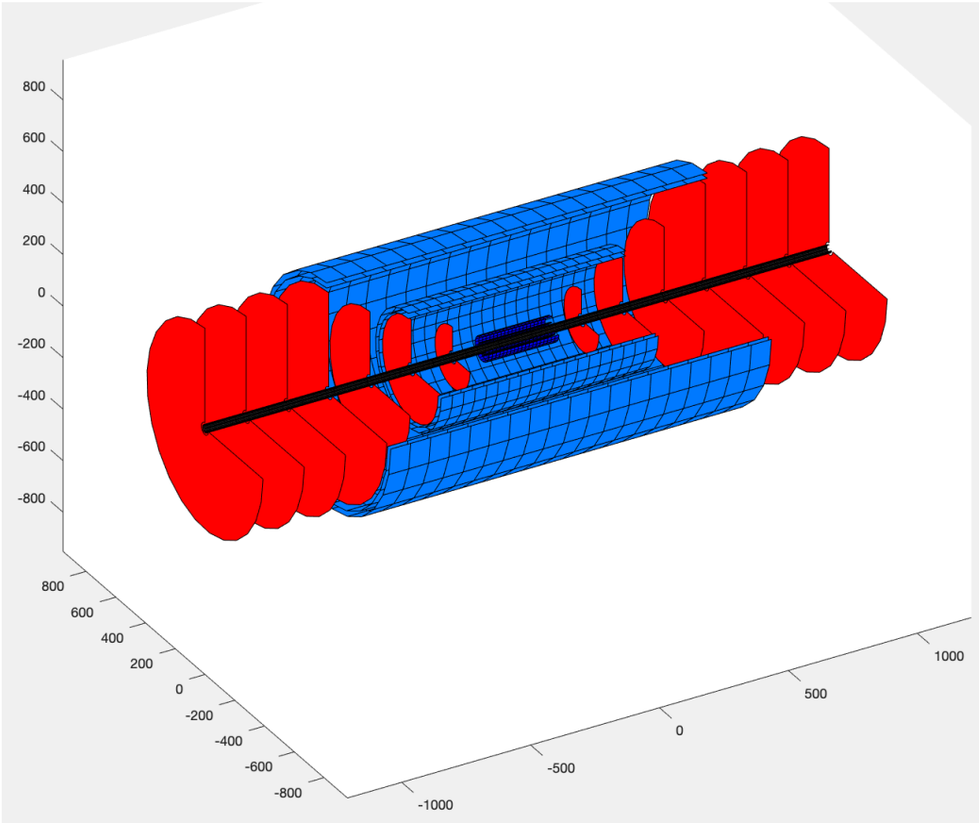
EIC needs: large acceptance, low mass, and high resolution.

All-Si detector concepts were until this cycle mostly outside the scope of our R&D; made a start following a committee suggestion.

*Other concepts exist; e.g. J. Repond et al. have put forward an all-Si tracker sPHENIX transition to a day-1 EIC detector.

eRD16 - Simulation Tools

- 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
  - Documented and published.



Hypothetical all-Si tracker in a 3T Solenoidal field.

- Rapid studies of number of layers, disks, geometrical layout, etc.
- Work done mostly with (former) undergraduate students.

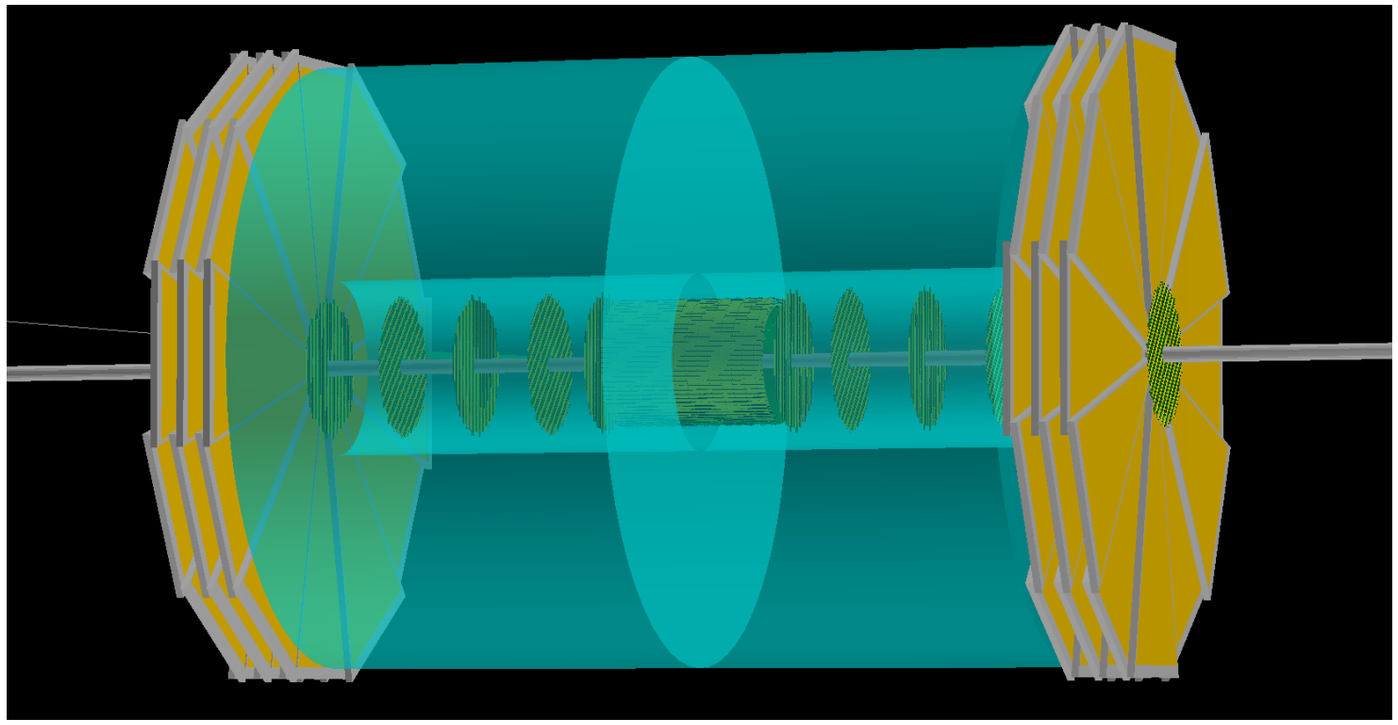
eRD16 - Simulation Tools

- 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

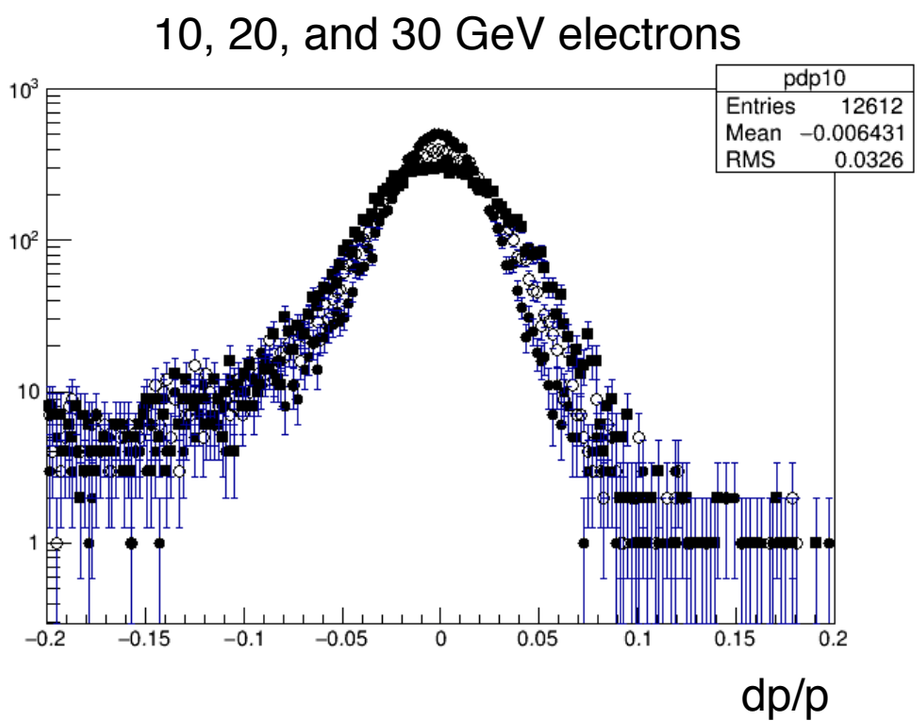
- Ongoing work with/by Y.S. Lai, with the aim to
  confirm/refute key findings from fast simulations and v.v.,
  changes to improve geometry and infrastructure,

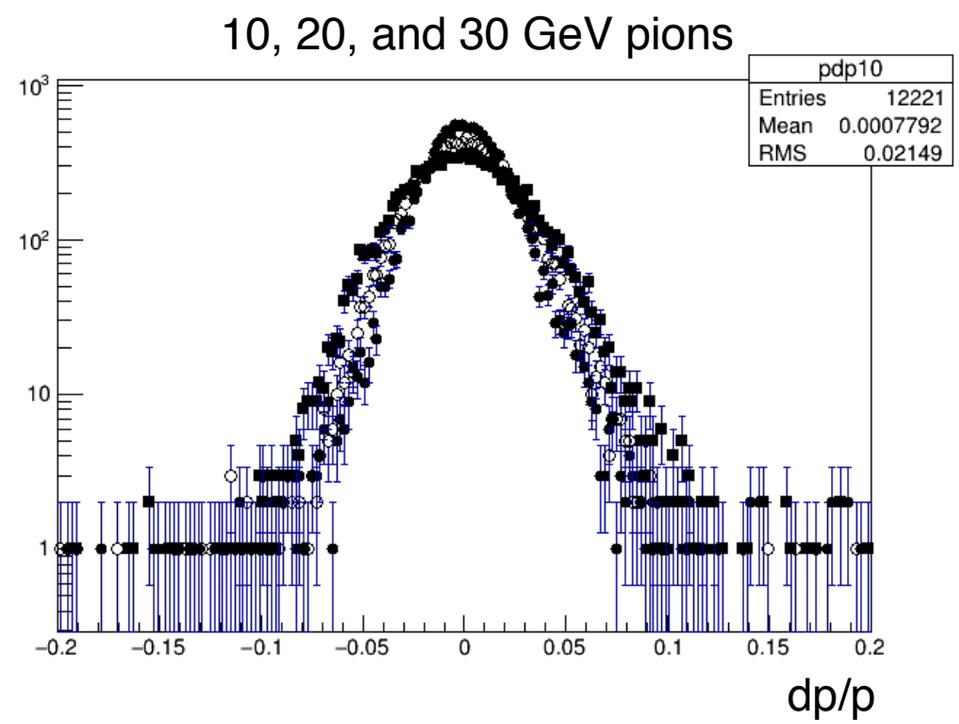
- Preferred toolset in the near-term future; seek increasingly realistic answers, integration with eRD18 barrel tracker,

- Following eRD20 (software consortium) effort.

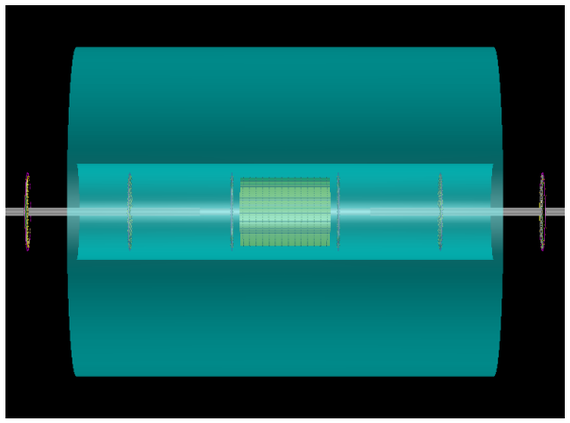
eRD16 - Simulation Tools

- For example,





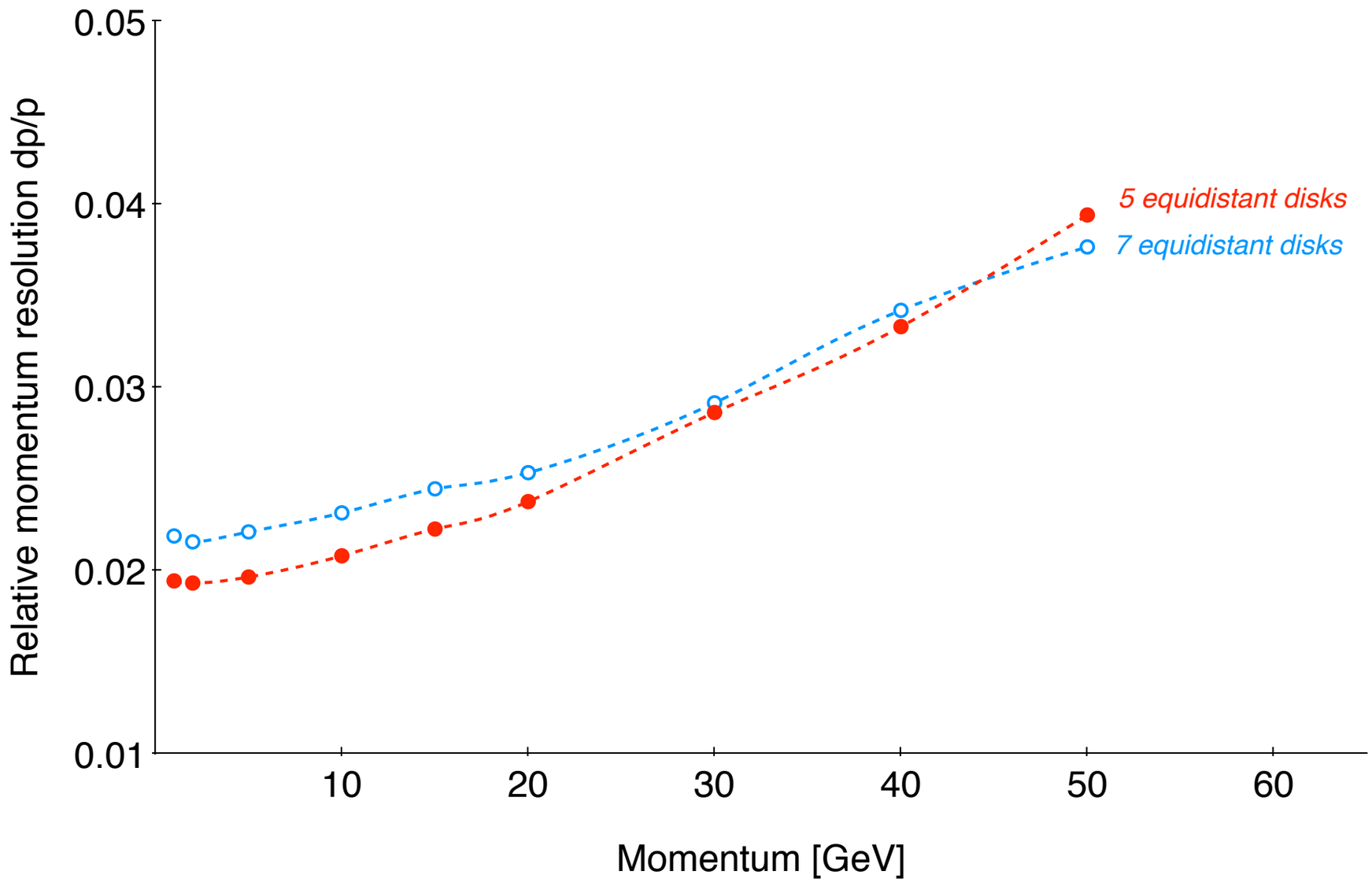
Tails (can/do) matter, even in a 3-disk simulation.



Tails handled in what follows by focusing on the central 2-3 sigma,

eRD16 - January Progress Report

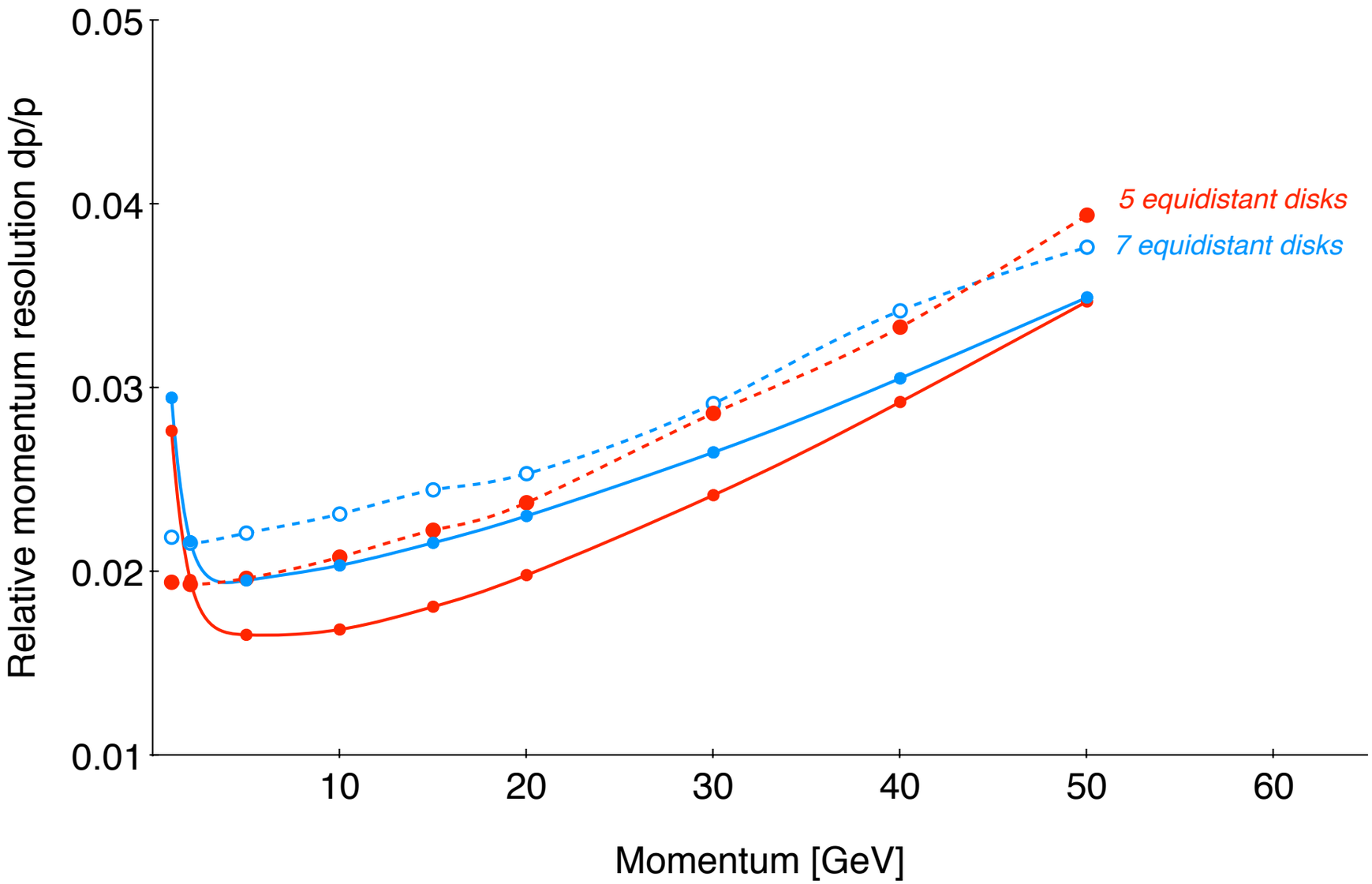
- E.g. disk-scan from EICroot,



Equidistant disks with 20μm² pixels, 3T field, 0.25 < z < 1.21m

eRD16 - January Progress Report

- E.g. disk-scan from EICroot compared to LDT fast-simulations,

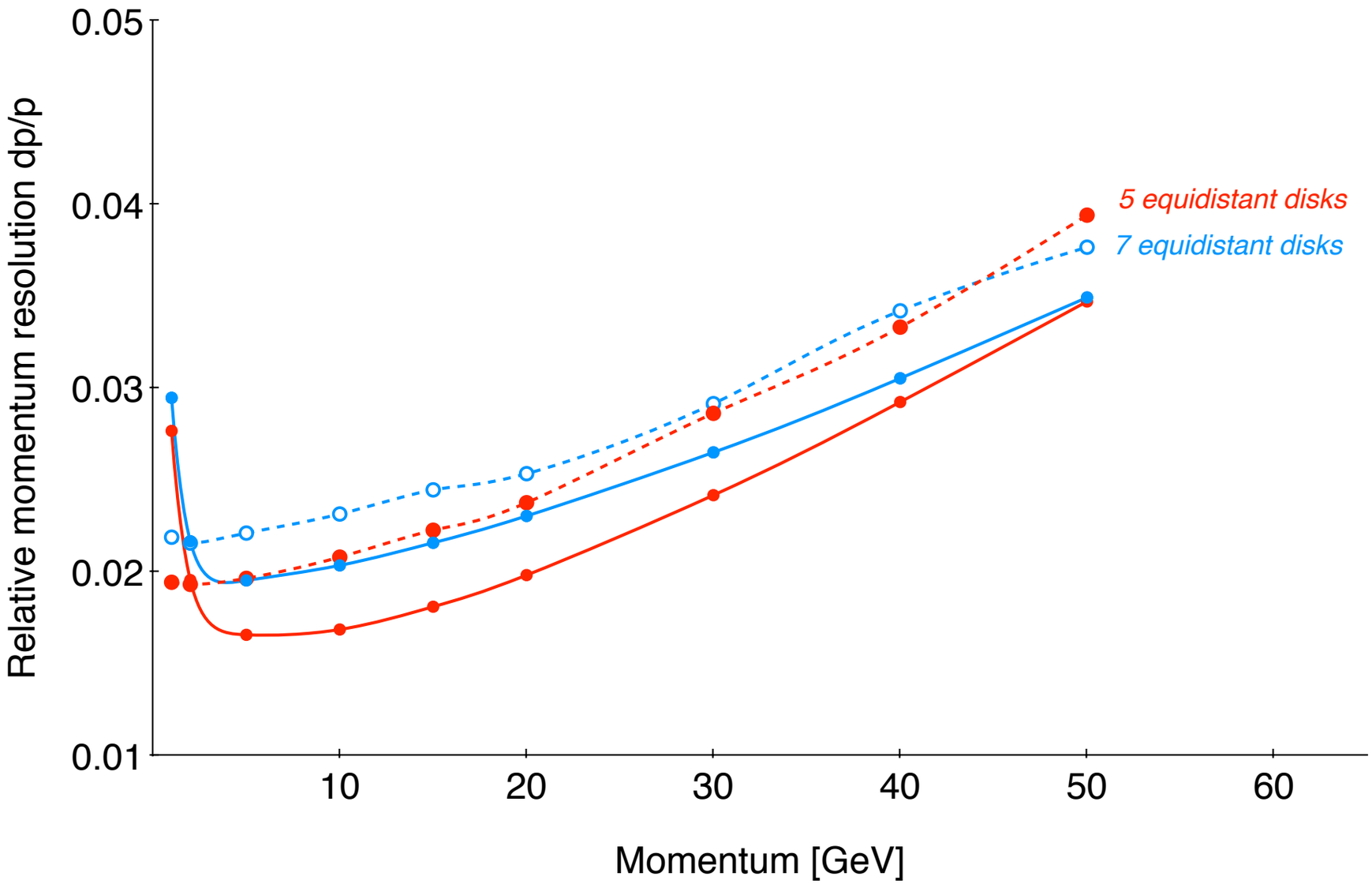


Continuous curves from LDT fast-simulations - c.f. June 2017 writeup, corrected for 20μm^2 pixel size (28μm^2 in writeup).

- Committee recommended to better understand the differences.

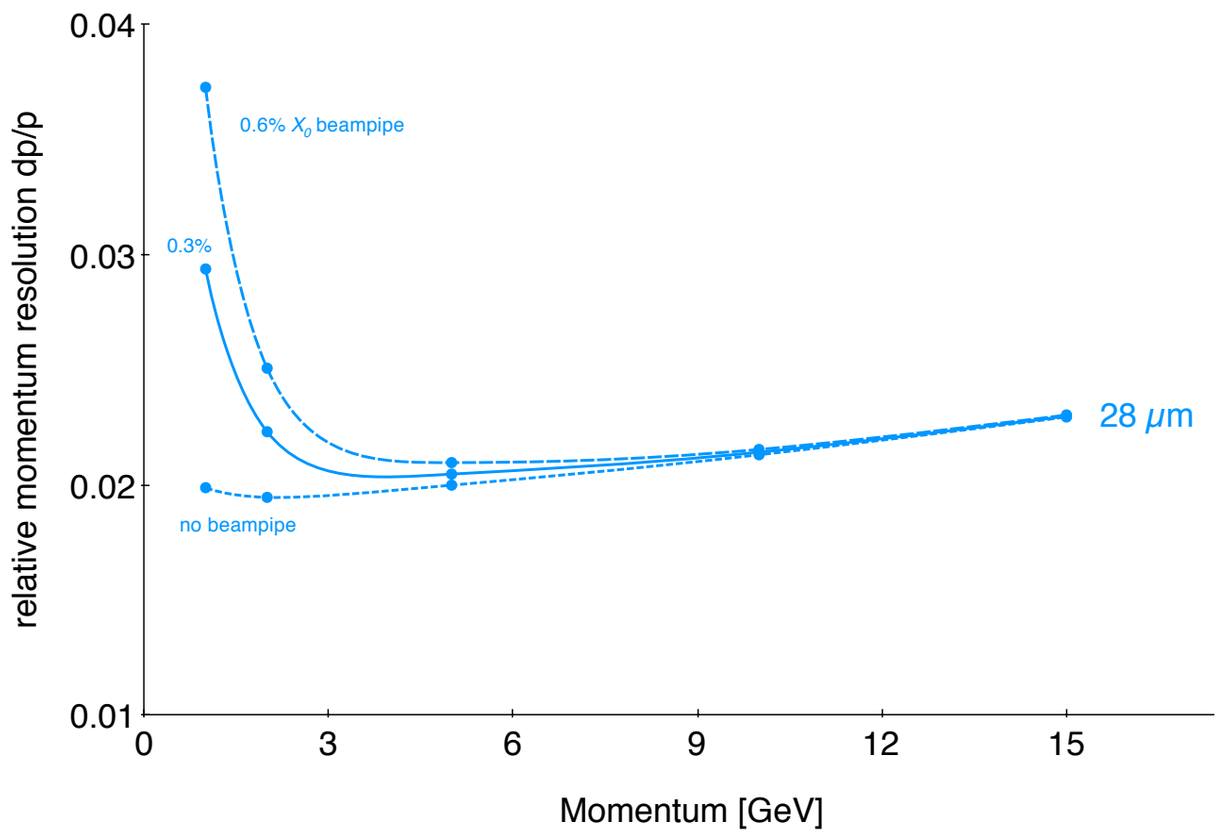
eRD16 - Simulations

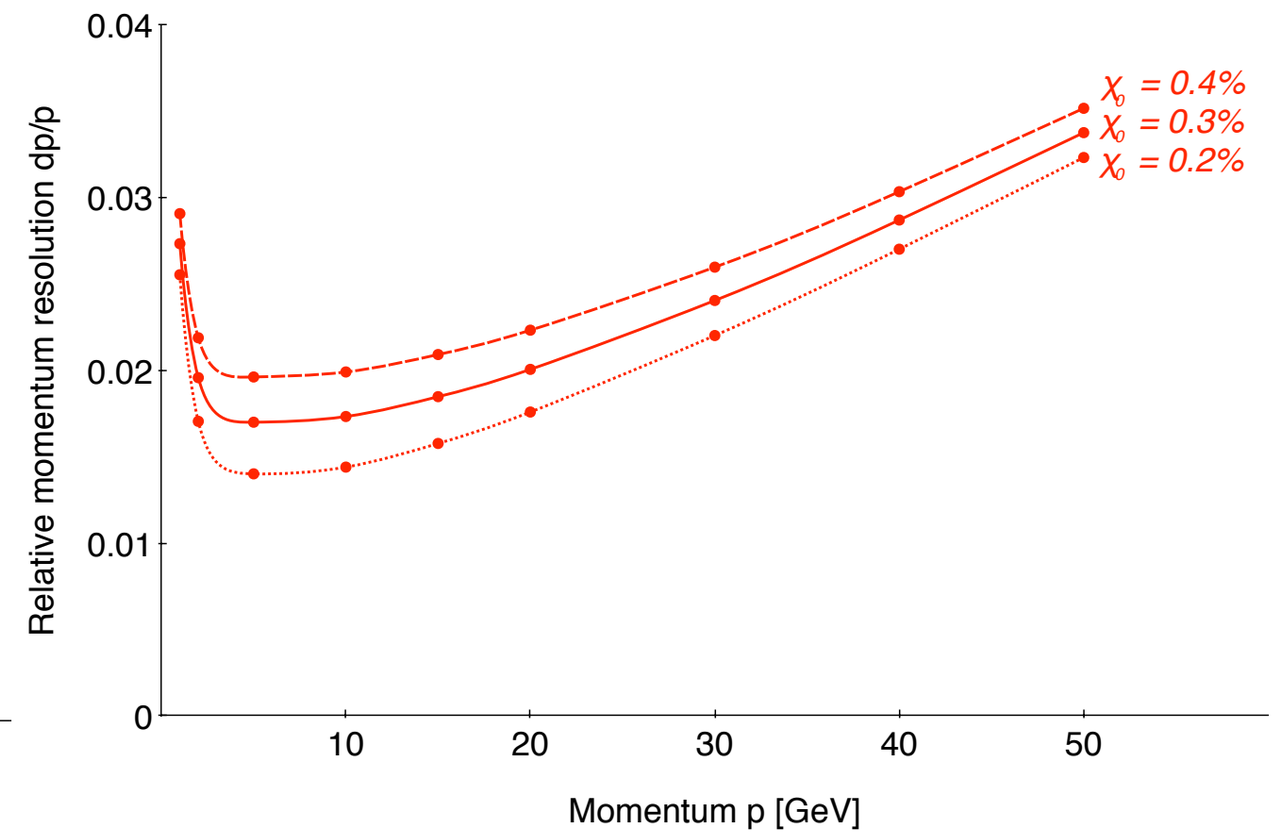
- Two main features, offset at higher *p* and LDT rise at small *p*



eRD16 - Simulations

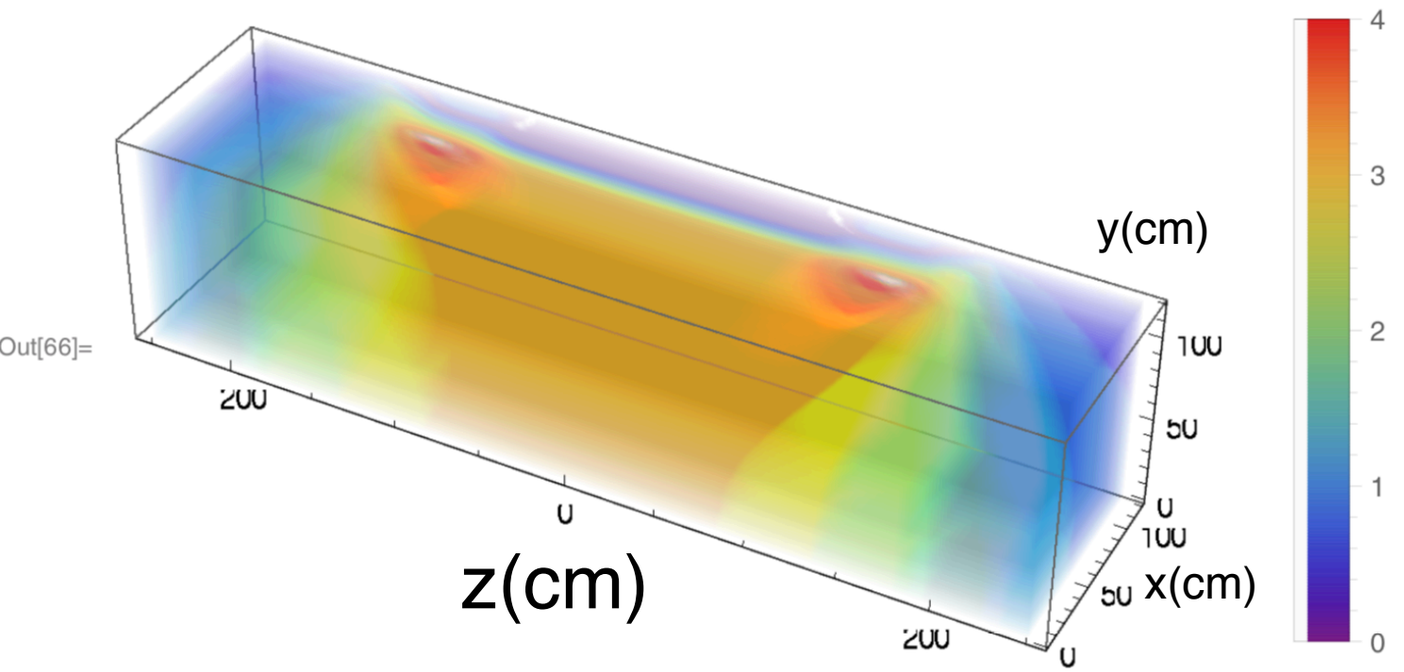
- Two main features, offset at higher *p* and LDT rise at small *p*,
- Two precursory figures (c.f. July 2018 report) to set some scales,

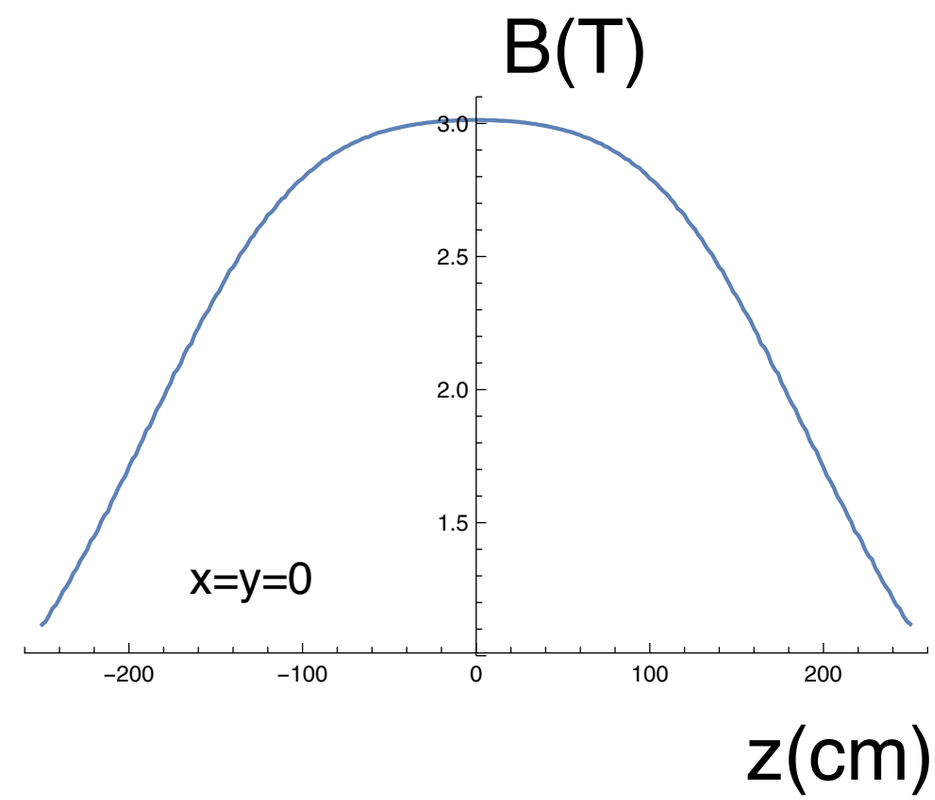




eRD16 - Simulations

- Two main features, offset at higher *p* and LDT rise at small *p,*
- Two precursory figures (c.f. July 2018 report) to set some scales,
- Labor intensive, two main outcomes:

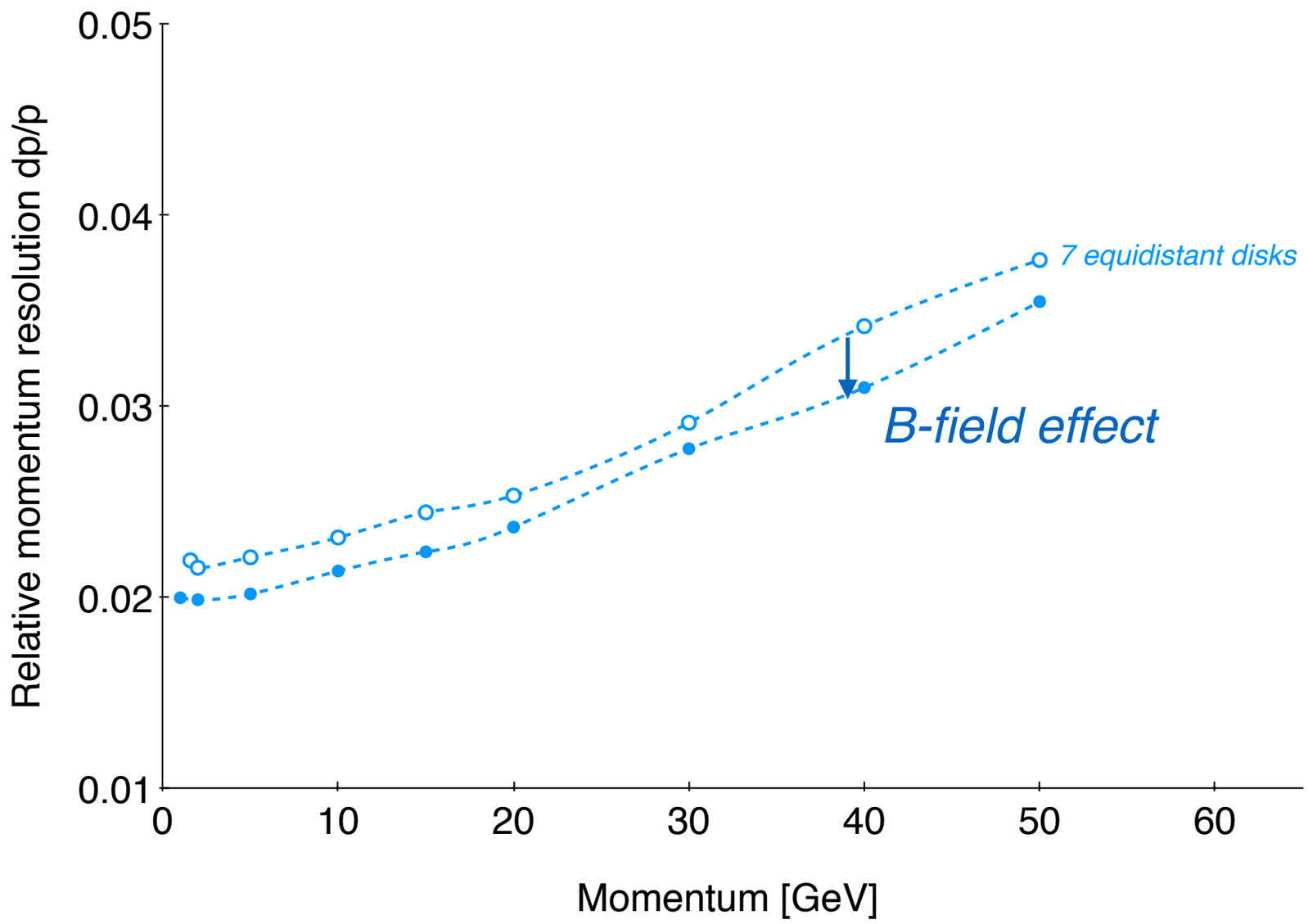




- Magnetic field in our ElCroot simulations was *not* a uniform 3T.

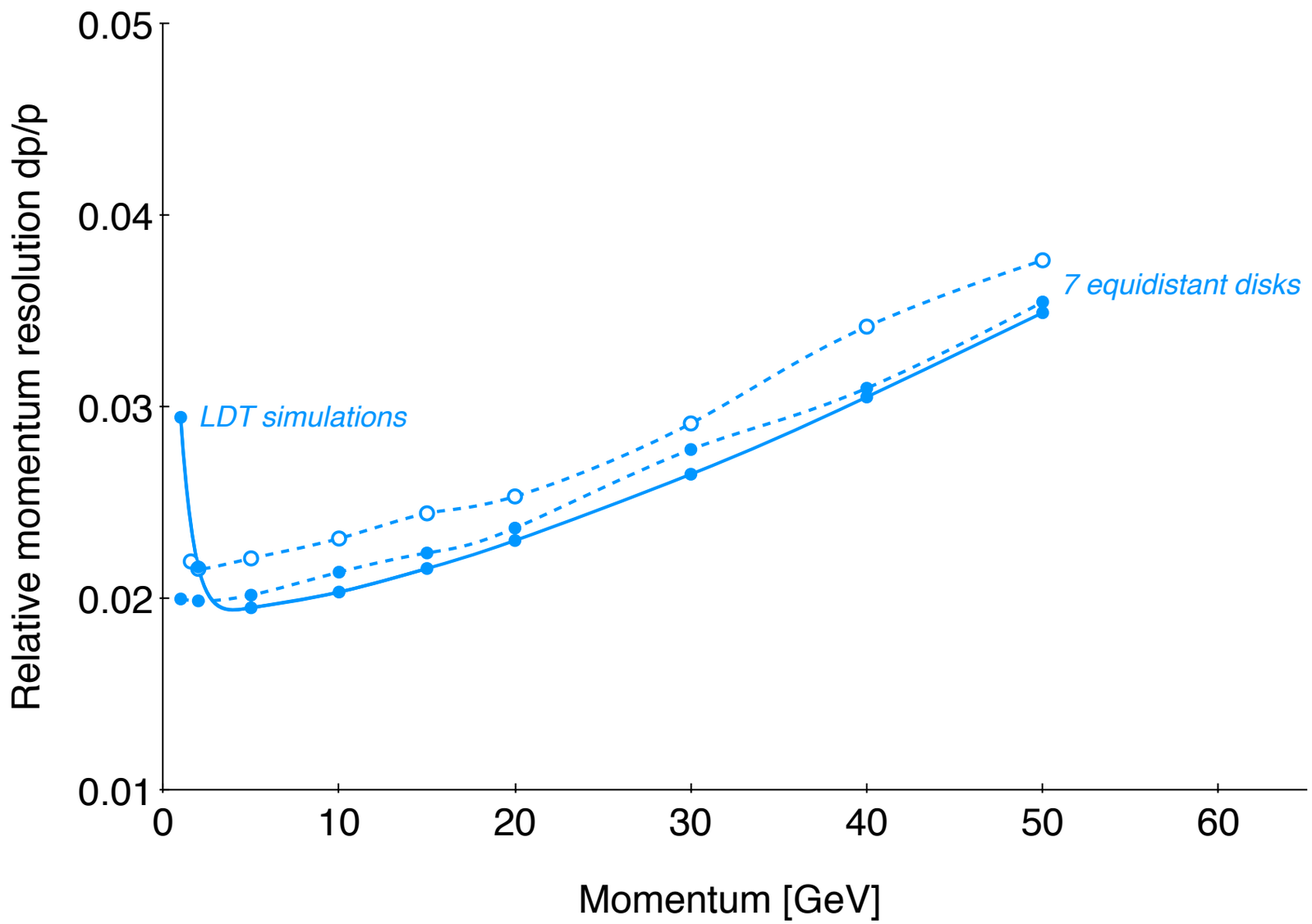
eRD16 - Simulations

- Offset at higher p — B = 3T,



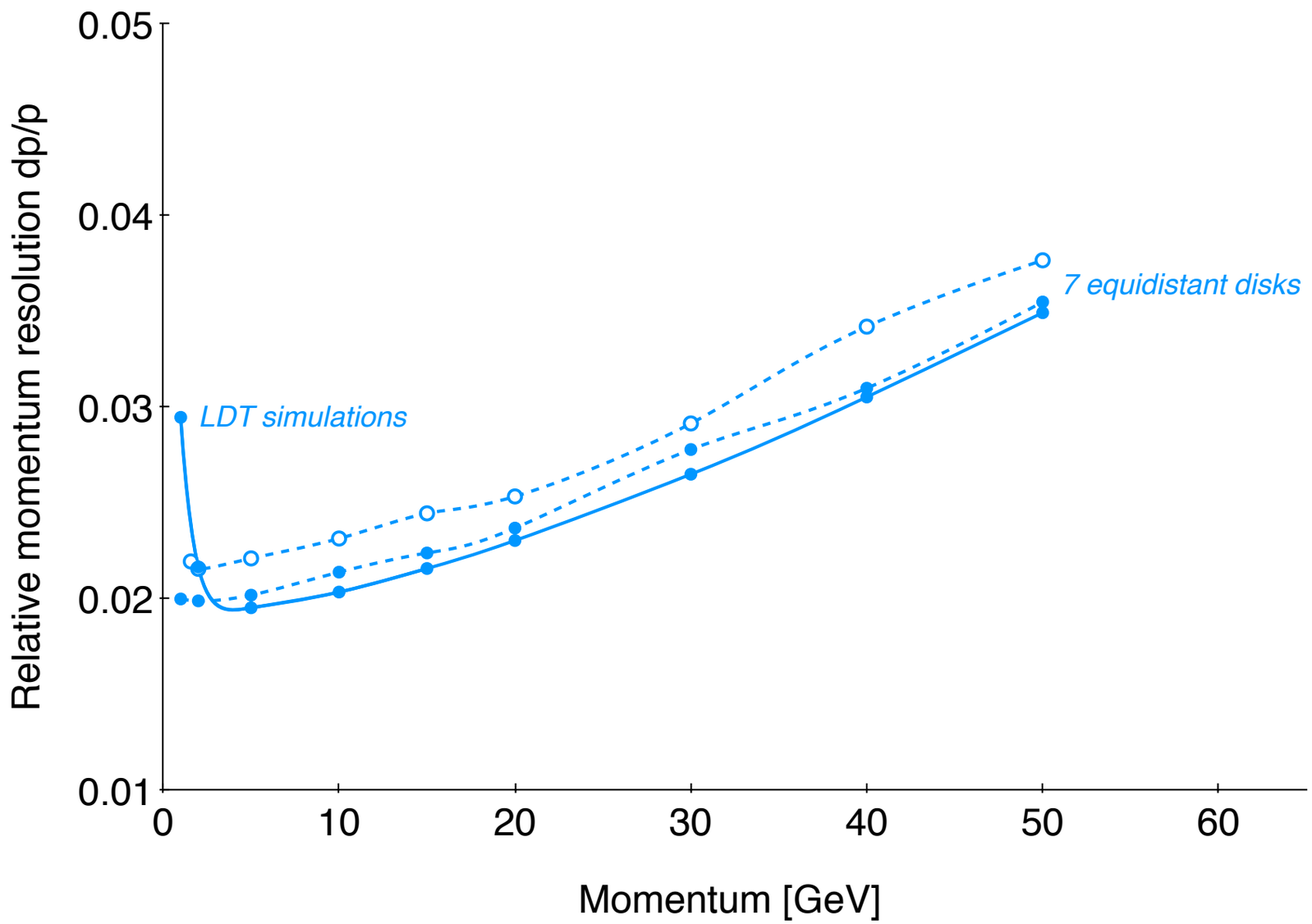
eRD16 - Simulations

- Offset at higher *p* — B = 3T,



eRD16 - Simulations

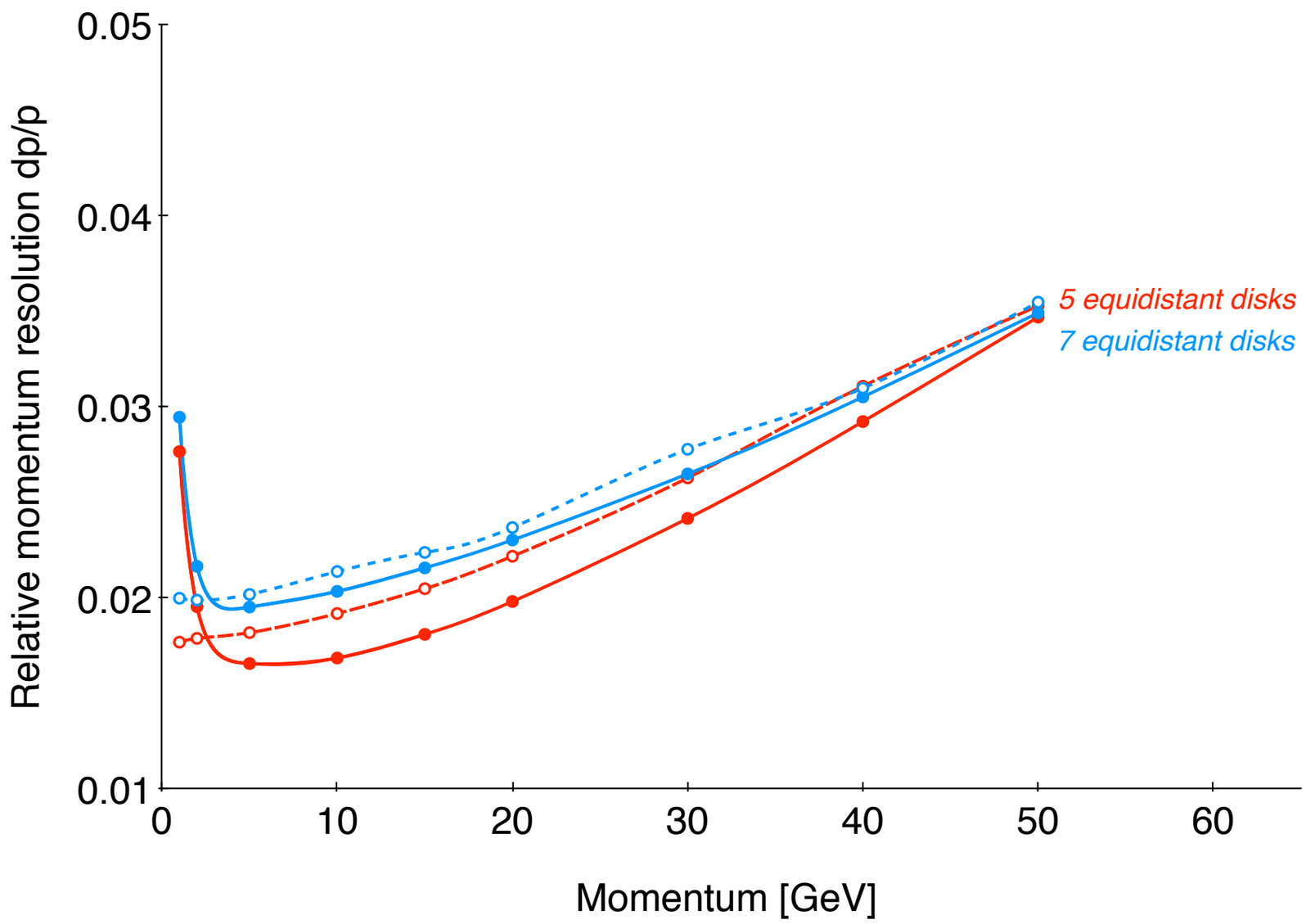
- Offset at higher p — B = 3T,



5-disk agreement is somewhat worse.

eRD16 - Simulations

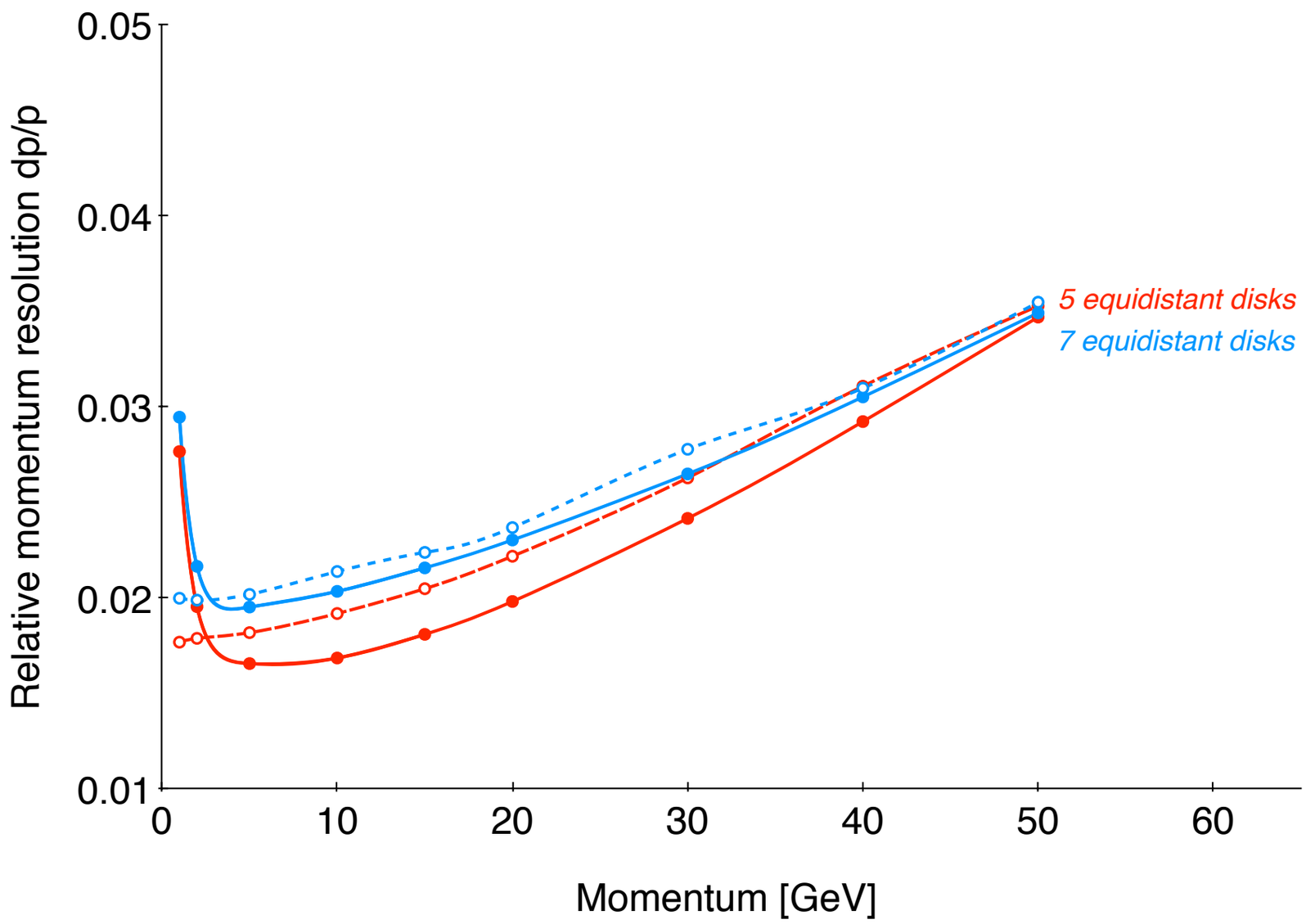
- Offset at higher p — B = 3T,



5-disk agreement is somewhat worse.

eRD16 - Simulations

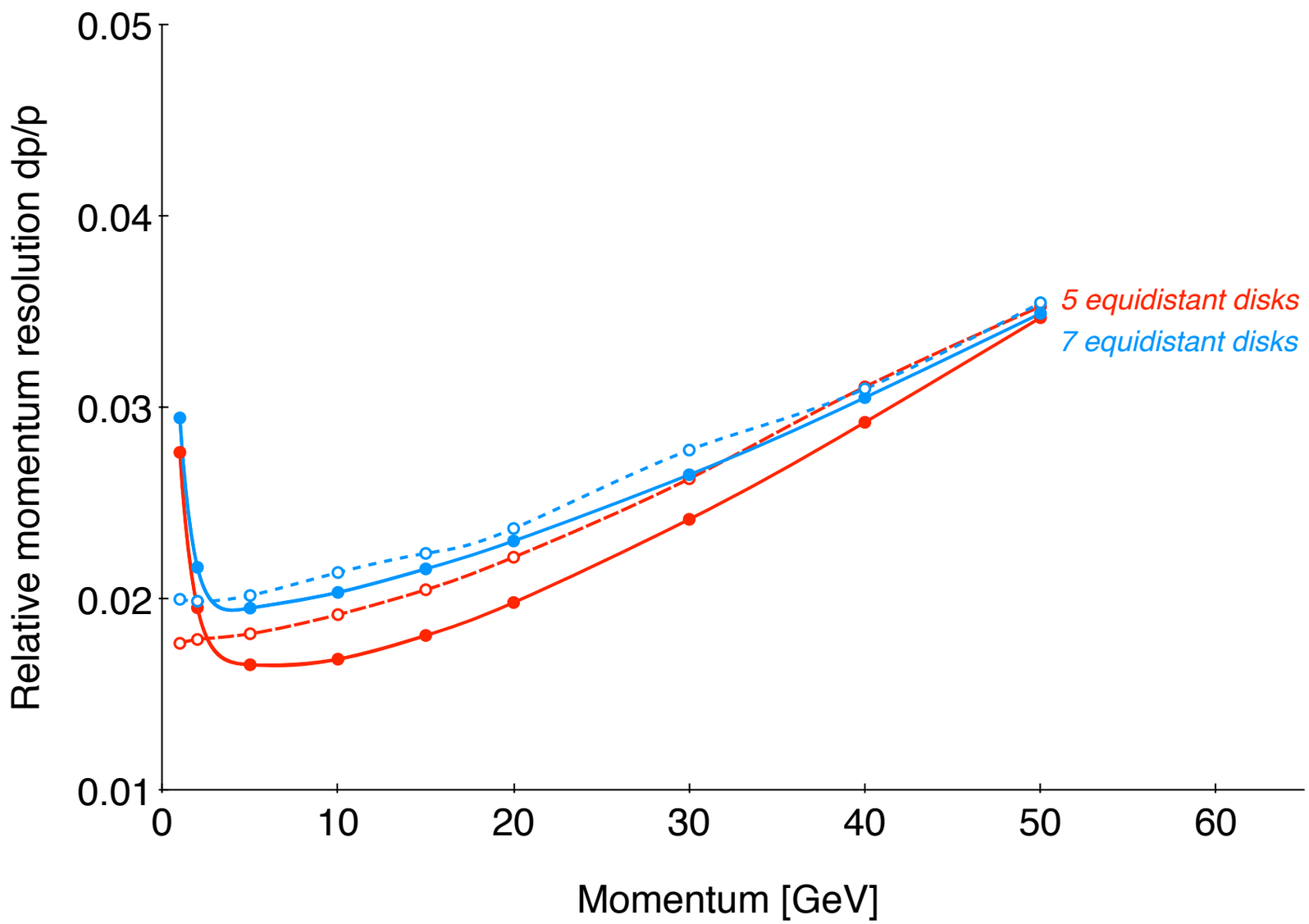
- Offset at higher p — B = 3T,



5-disk agreement is somewhat worse.

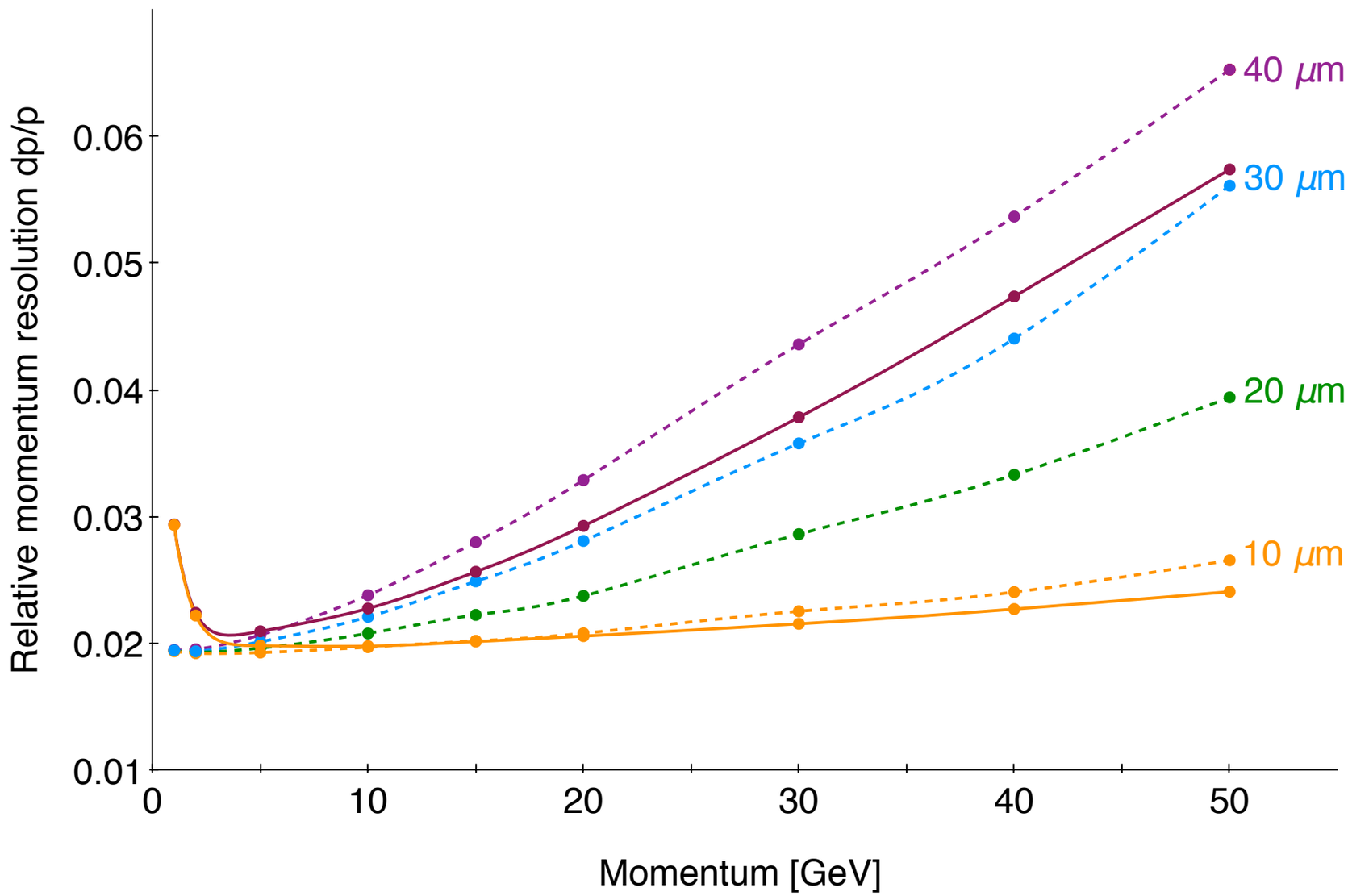
eRD16 - Simulations

- Offset at higher p — B = 3T,



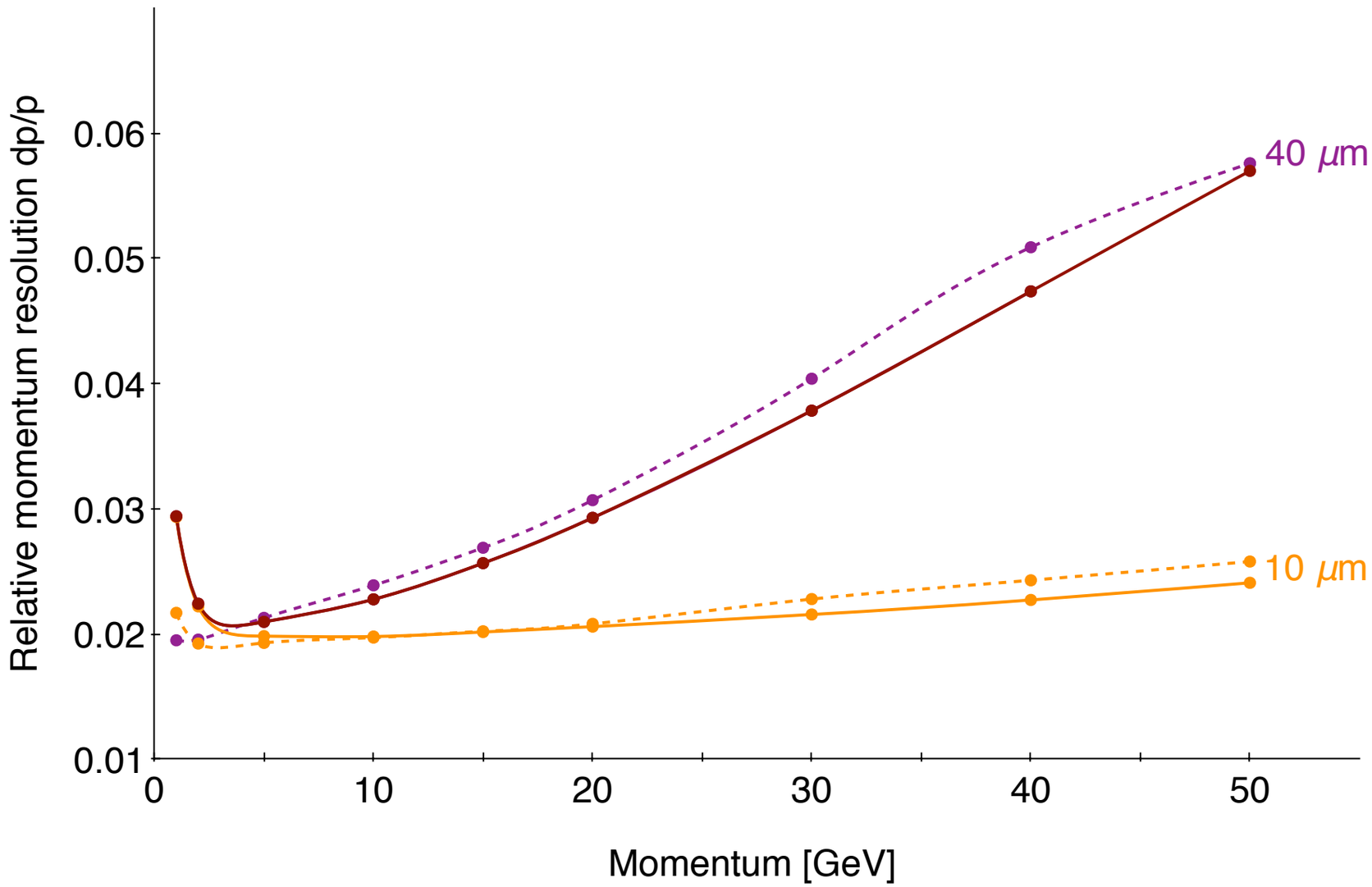
eRD16 - January Progress Report

- Offset at higher p — B = 3T,



eRD16 - Simulations

- Offset at higher p — B = 3T with updated B-field,



eRD16 - Simulations

- Offset at higher p — B = 3T,

eRD16 - Simulations

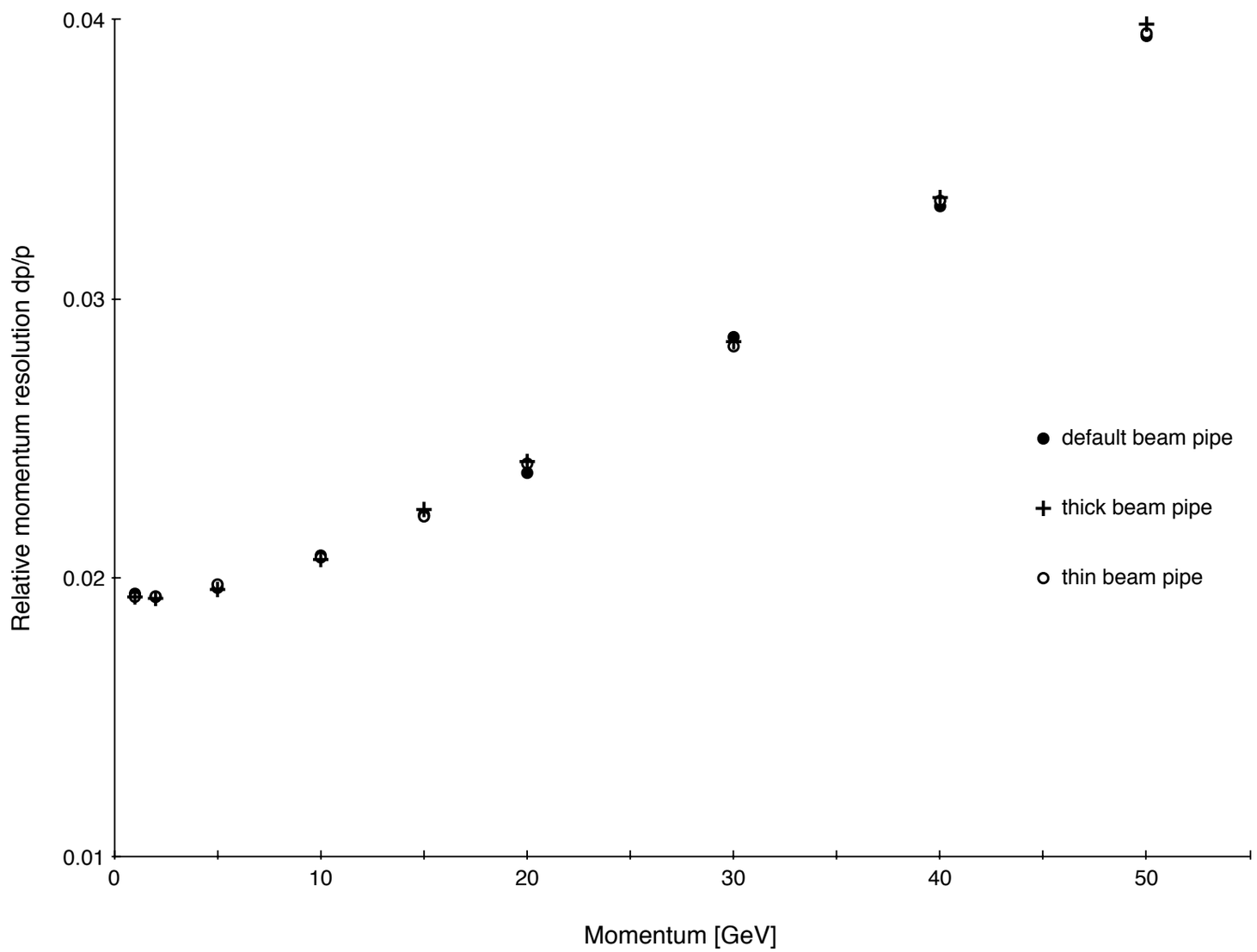
- Offset at higher *p* — B = 3T,
- Rise at small *p* — $\left\langle \left(p^{\mathrm{reco}} - p^{\mathrm{true}}\right)^2 \right\rangle \not\propto \left\langle \left(p_T^{\mathrm{reco}} - p_T^{\mathrm{true}}\right)^2 \right\rangle$

when multiple scattering is sizable, but energy “loss” is small,
+ a few other considerations

This is the case in the forward region; the effective thickness of the beam-pipe can reach multiple % of radiation length.

eRD16 - Simulations

- Offset at higher *p* — B = 3T,
- Rise at small *p* — $\left\langle \left(p^{\mathrm{reco}} - p^{\mathrm{true}}\right)^2 \right\rangle \not\propto \left\langle \left(p_T^{\mathrm{reco}} - p_T^{\mathrm{true}}\right)^2 \right\rangle$



EICroot simulations for *vastly* different geometric beam-pipe thicknesses, *with* the analysis cuts of tails.

eRD16 - Simulations

- Offset at higher *p* — B = 3T,
- Rise at small *p* — $\left\langle \left(p^{\mathrm{reco}} - p^{\mathrm{true}}\right)^2 \right\rangle \not\propto \left\langle \left(p_T^{\mathrm{reco}} - p_T^{\mathrm{true}}\right)^2 \right\rangle$

when multiple scattering is sizable, but energy "loss" is small,
+ a few other considerations

This is the case in the forward region; the effective thickness of the beam-pipe can reach multiple % of radiation length.

LDT: approximately $\left\langle \left(p^{\mathrm{reco}} - p^{\mathrm{true}}\right)^2 \right\rangle \propto \left\langle \left(p_T^{\mathrm{reco}} - p_T^{\mathrm{true}}\right)^2 \right\rangle$

i.e. a (the) correlation with θ is lost.

This said, beam-pipe thickness *does* matter,
just not for *p* when *E* is preserved.

eRD16 - Simulations

- Offset at higher *p* — B = 3T,
- Rise at small *p* — $\left\langle \left(p^{\mathrm{reco}} - p^{\mathrm{true}}\right)^2 \right\rangle \not\propto \left\langle \left(p_T^{\mathrm{reco}} - p_T^{\mathrm{true}}\right)^2 \right\rangle$

when multiple scattering is sizable, but energy "loss" is small,
+ a few other considerations

This is the case in the forward region; the effective thickness of the beam-pipe can reach multiple % of radiation length.

LDT: approximately $\left\langle \left(p^{\mathrm{reco}} - p^{\mathrm{true}}\right)^2 \right\rangle \propto \left\langle \left(p_T^{\mathrm{reco}} - p_T^{\mathrm{true}}\right)^2 \right\rangle$

i.e. a (the) correlation with θ is lost.

This said, beam-pipe thickness *does* matter,
just not for *p* when *E* is preserved.

Overall considerations, pixel size, layers, etc. unchanged.

Writeup, joint with eRD18, is (now) a priority.

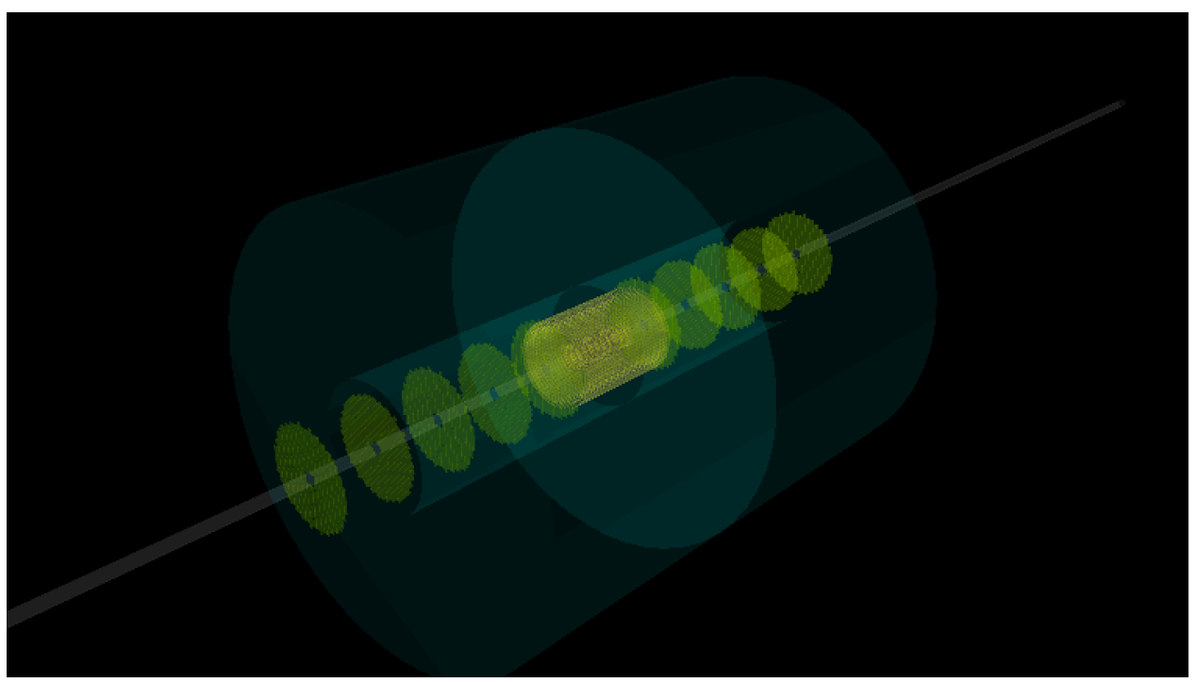
eRD16 - Simulations

- Past January, we reported our results from initial studies based on LDT fast simulations on an all-silicon tracker concept;

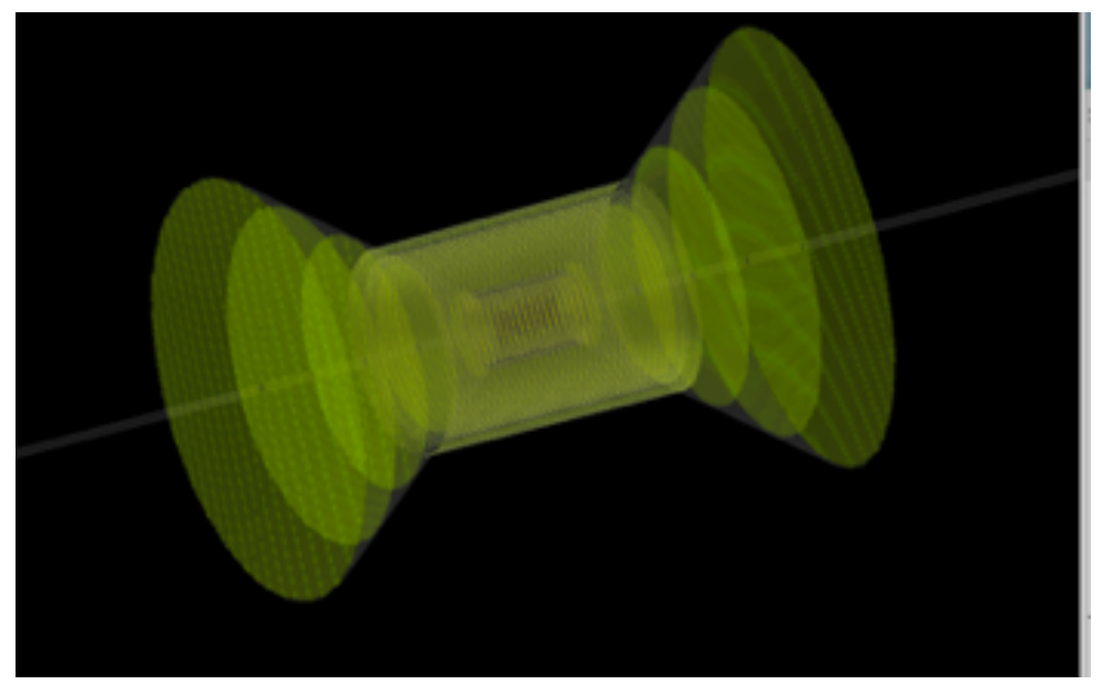
  The main outcome was that such a concept has potential to achieve similar momentum resolution and have smaller radius;

  This may be attractive: space for PID, non-uniform B-field, etc.

  We have now made a start in EICroot simulations of such a configuration, starting by reproducing the TPC+Si performance.



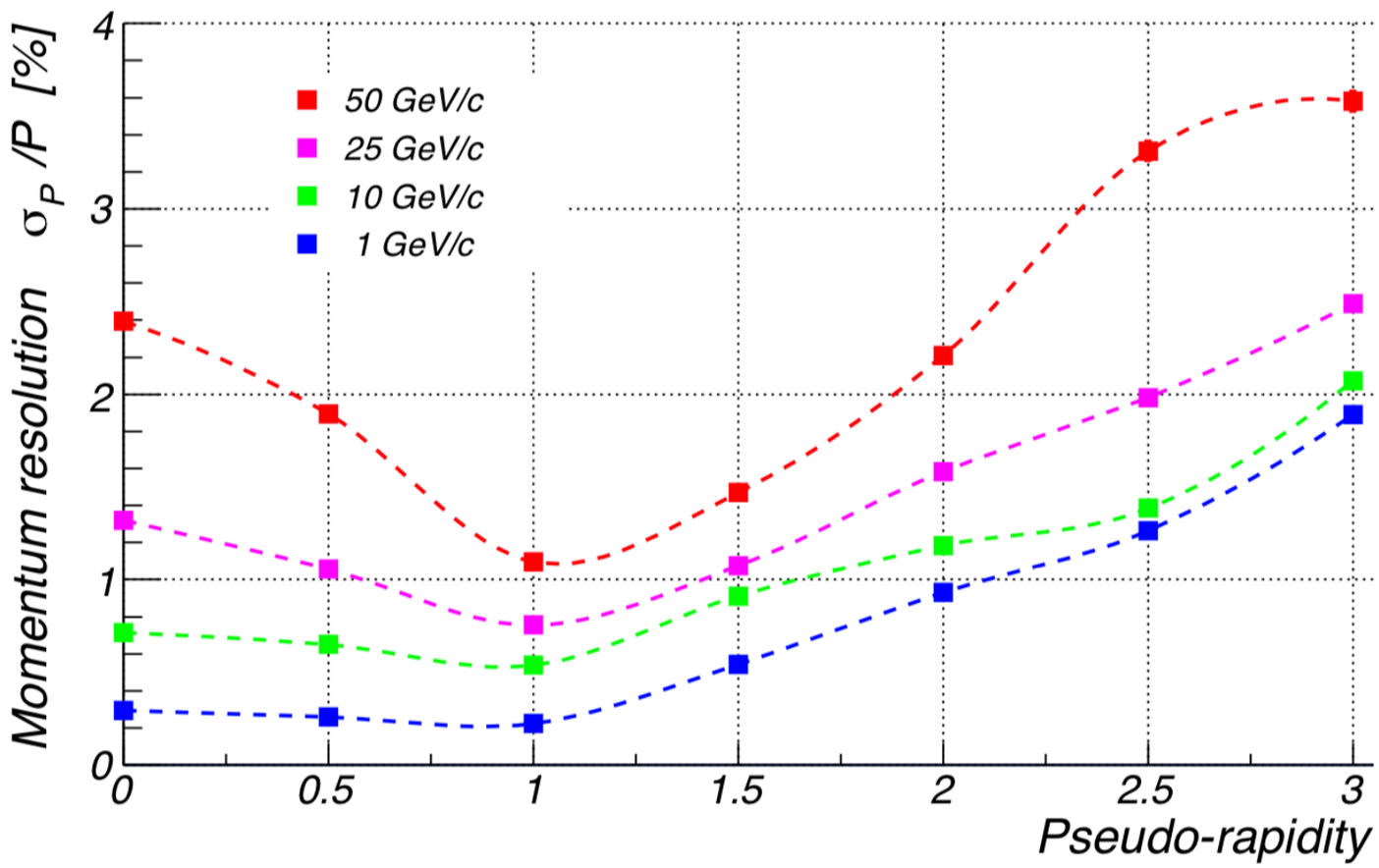
Beast(-like) TPC+Si configuration



All Si configuration, same z-extent smaller barrel radius of ~43 cm.

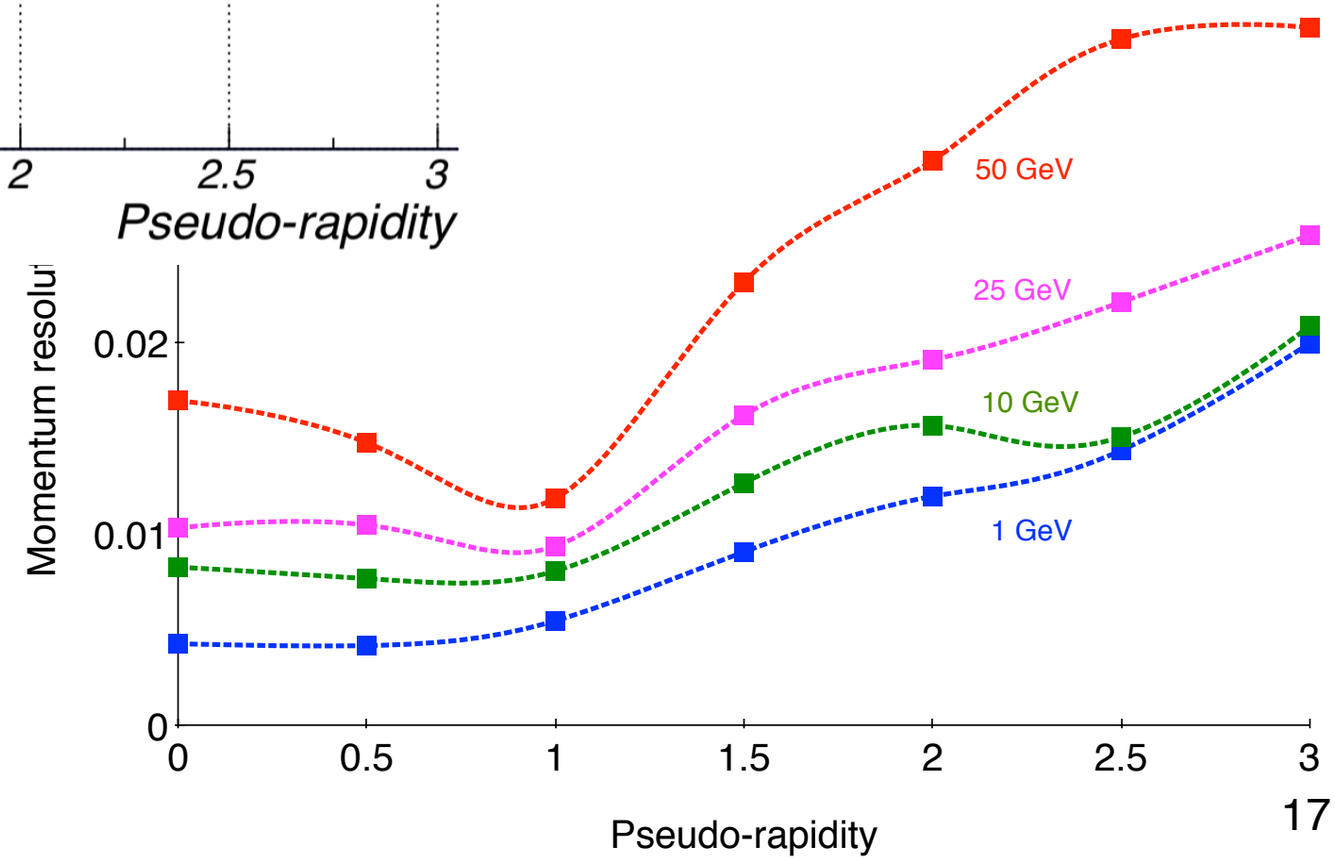
eRD16 - Simulations

- BeAST TPC+Si tracker



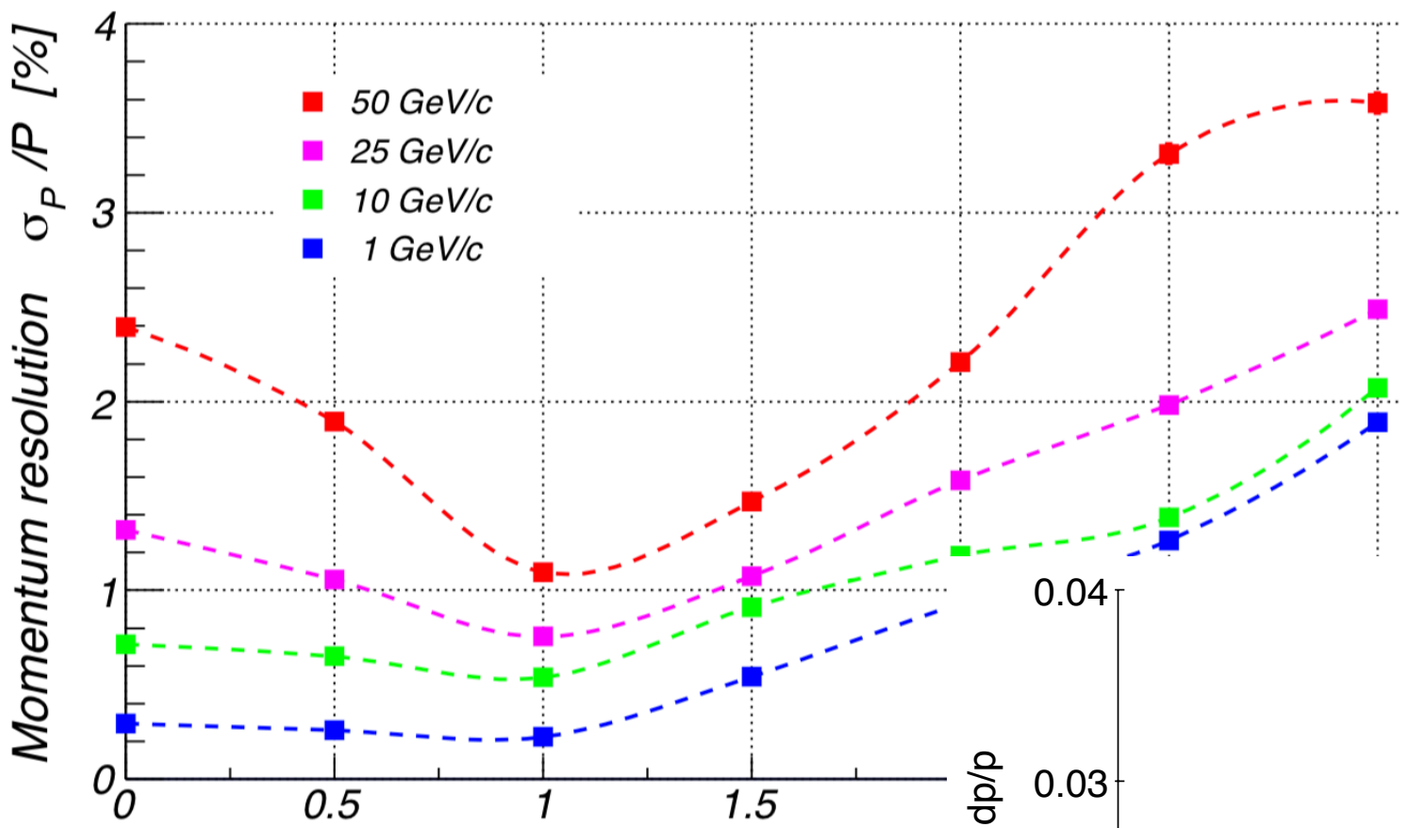
← E.C. Aschenauer et al, eRHIC design study, ArXiv:1409.1633, figure 4.8

eRD16 simulation →

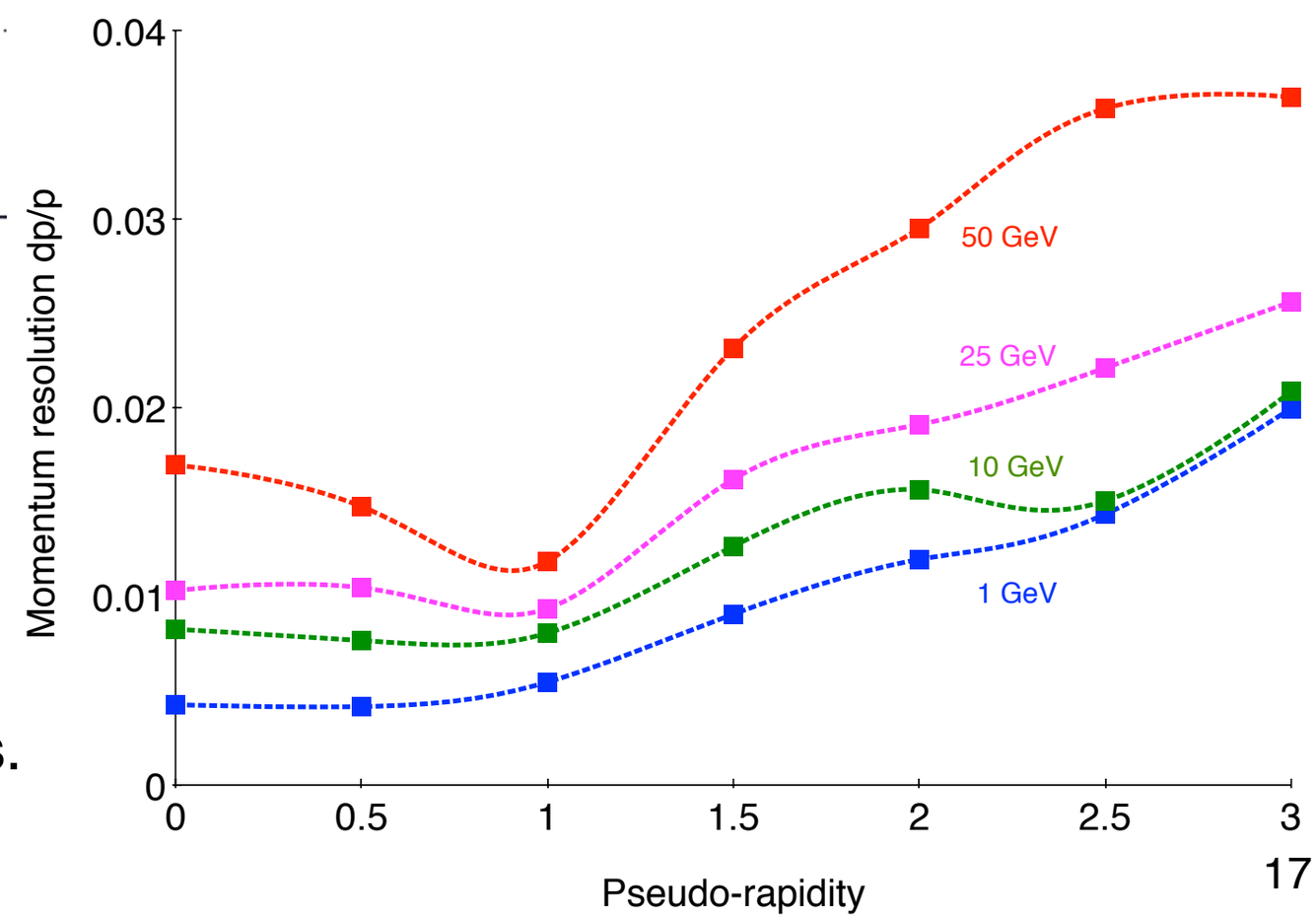


eRD16 - Simulations

- BeAST TPC+Si tracker



← E.C. Aschenauer et al, eRHIC design study, ArXiv:1409.1633, figure 4.8

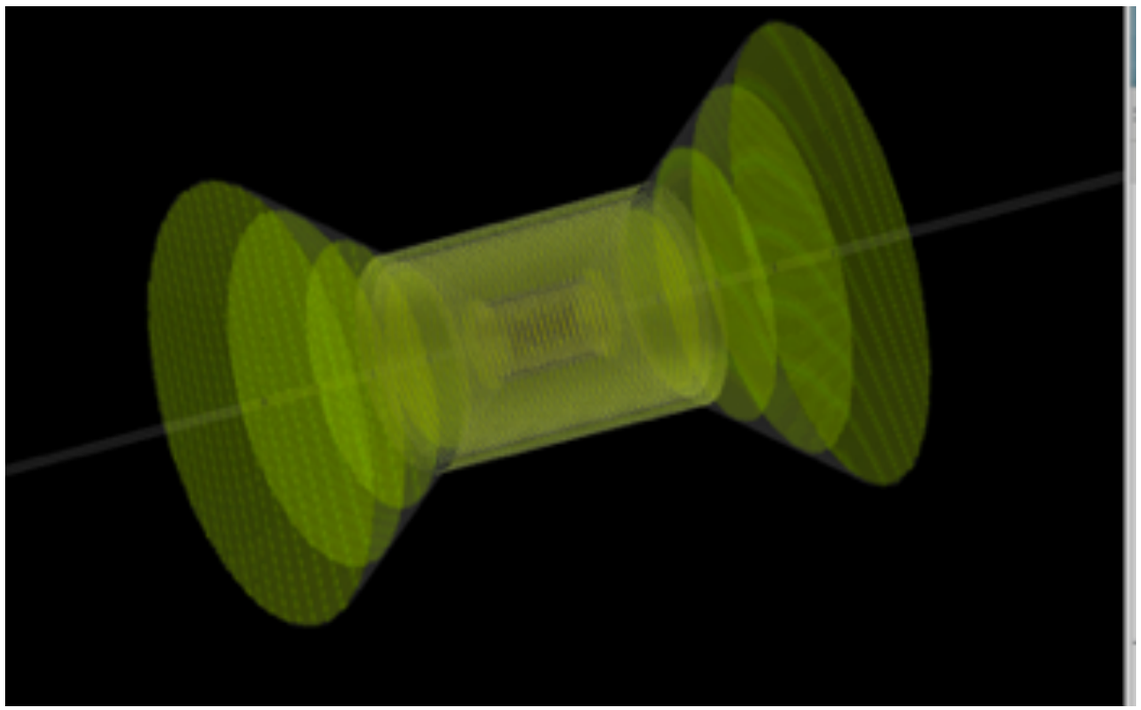


eRD16 simulation →

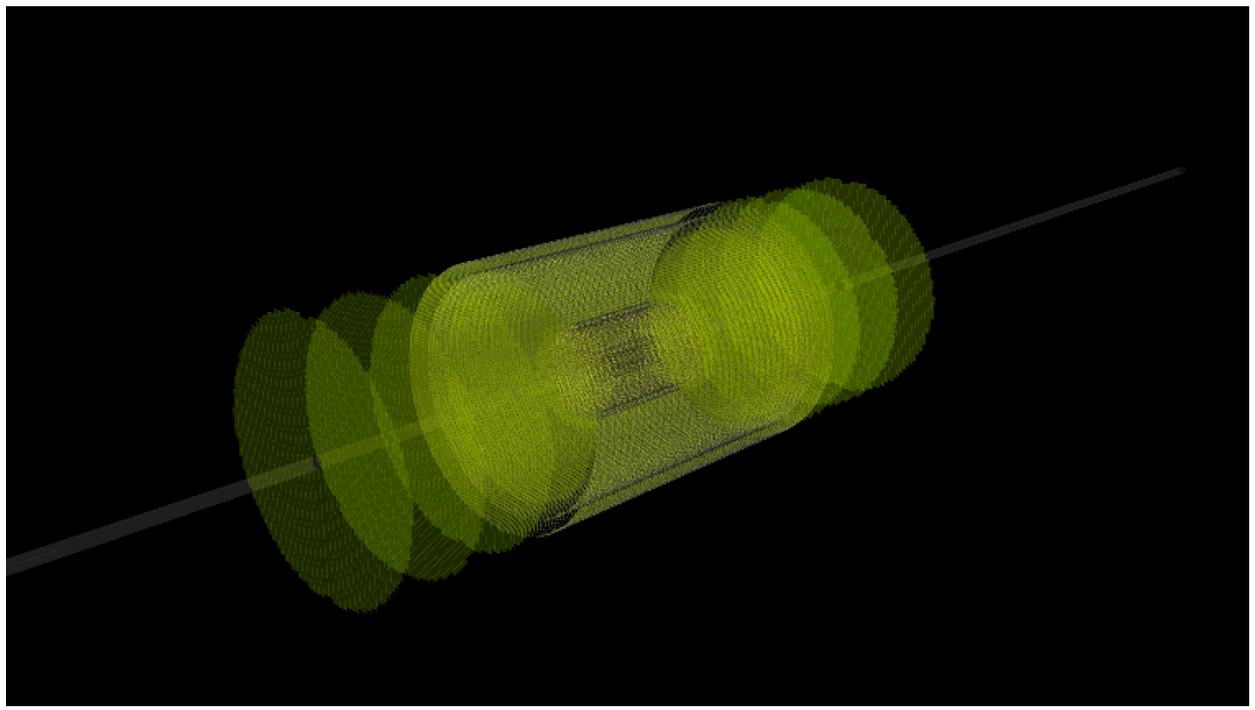
Baseline for what follows.

eRD16 - Simulations

- Since radial compactness is potentially attractive, we considered also a variant with restricted outer disk radii, similar to the fast-simulation configuration reported past January (20 x 20um MAPS).



all-Si configuration

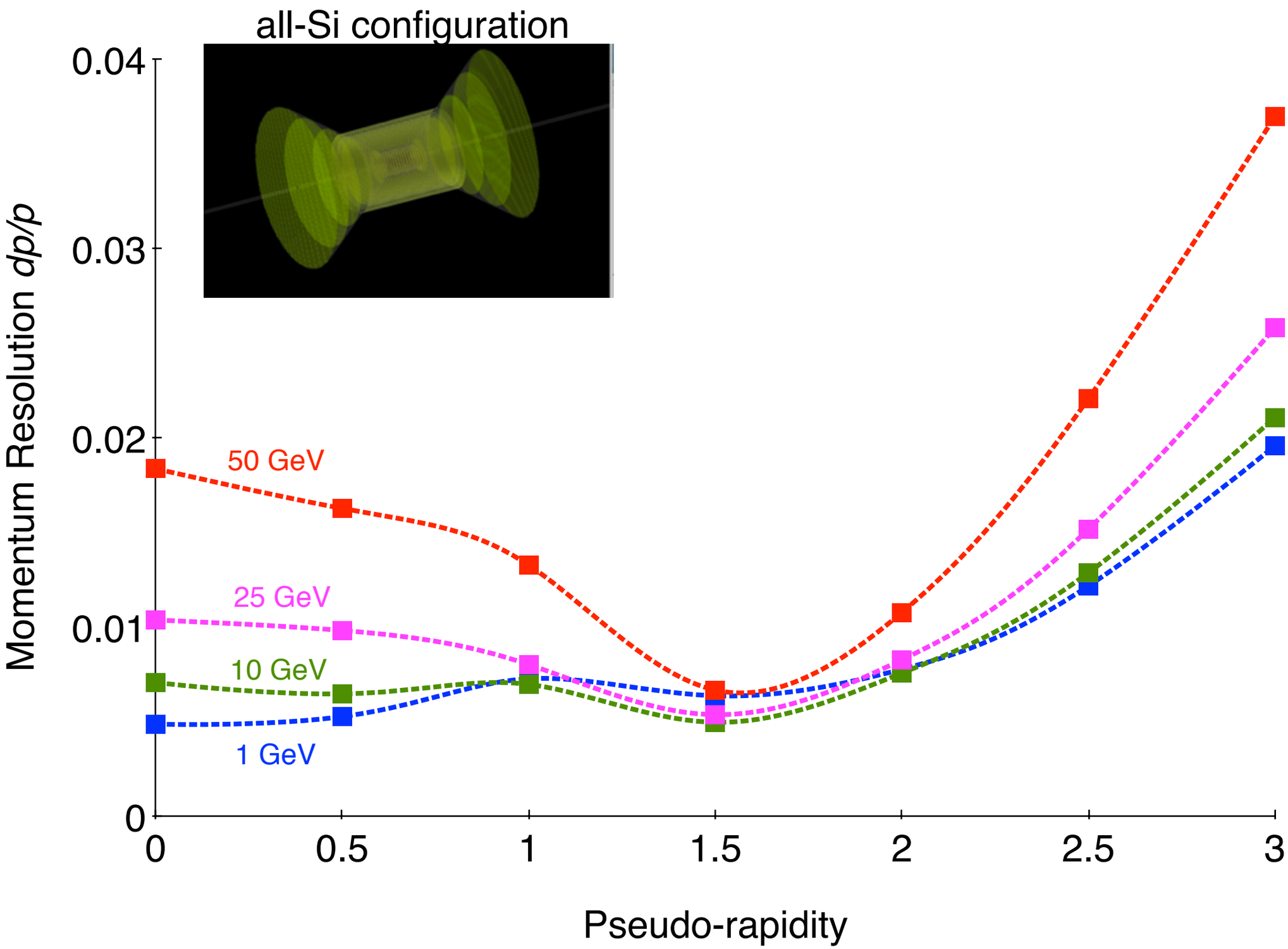


tapered all-Si configuration, r ~ 43cm

Identical barrel configurations, identical in length (*z*) to BeAST.

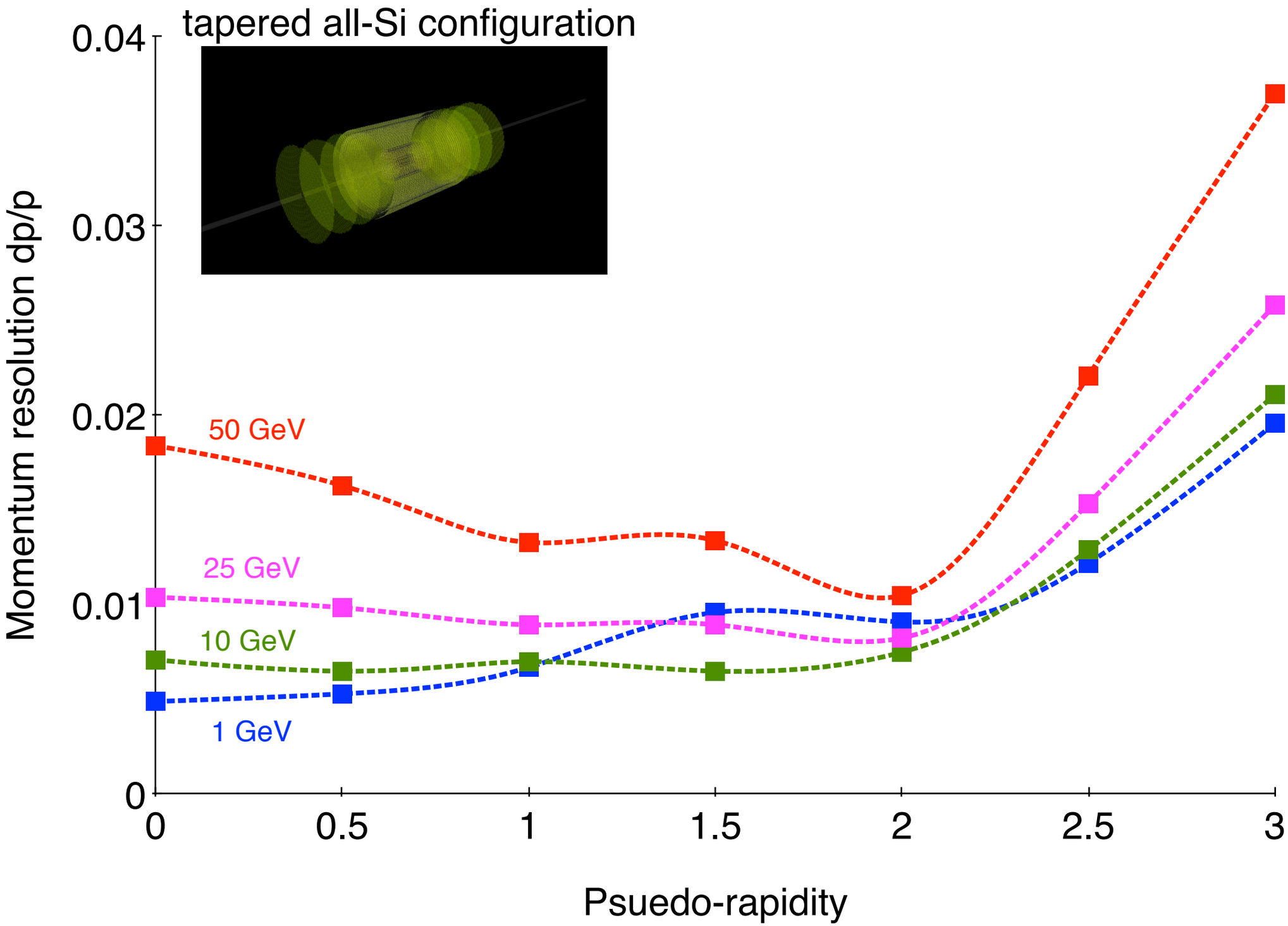
Material cones/cylinders surrounding the disks were implemented to make a start on the effects associated with support structures, read-out infrastructure, etc.; studies started/in progress.

eRD16 - Simulations



Resolution near ~1.5 results from large r disks; likely overkill.

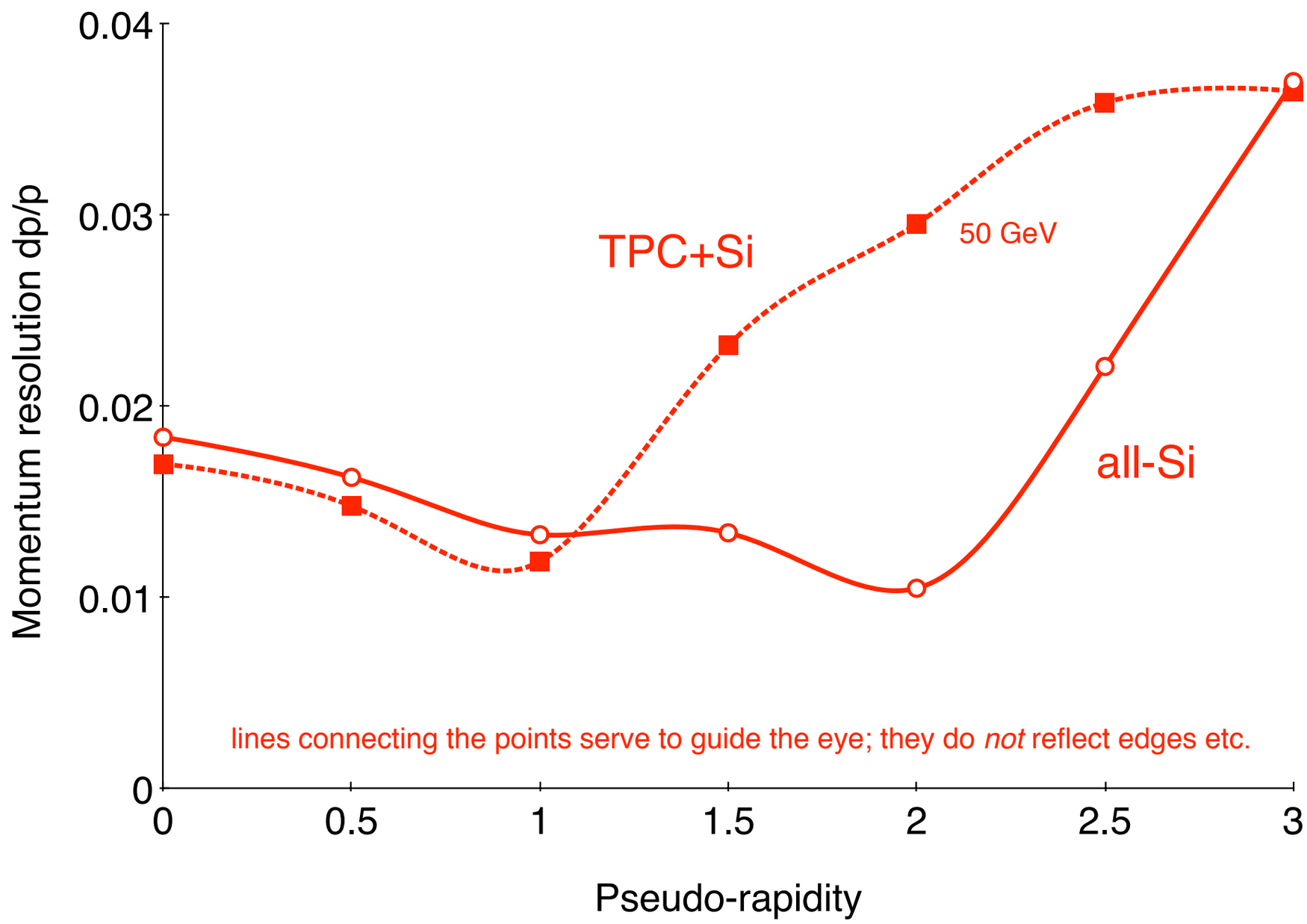
eRD16 - Simulations



There is a lot in these plots.

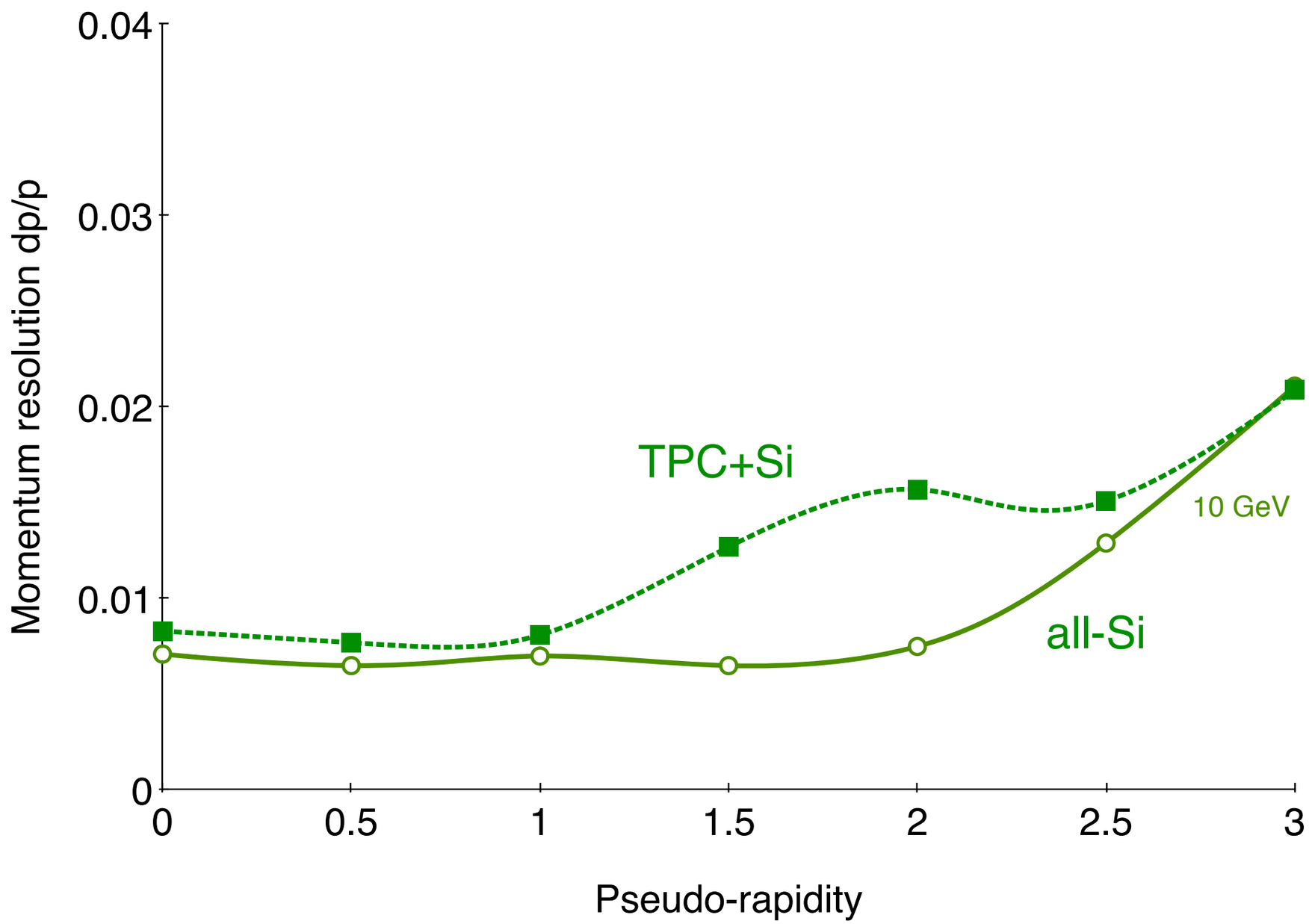
eRD16 - Simulations

- Resolution comparison with BeAST TPC+Si tracker



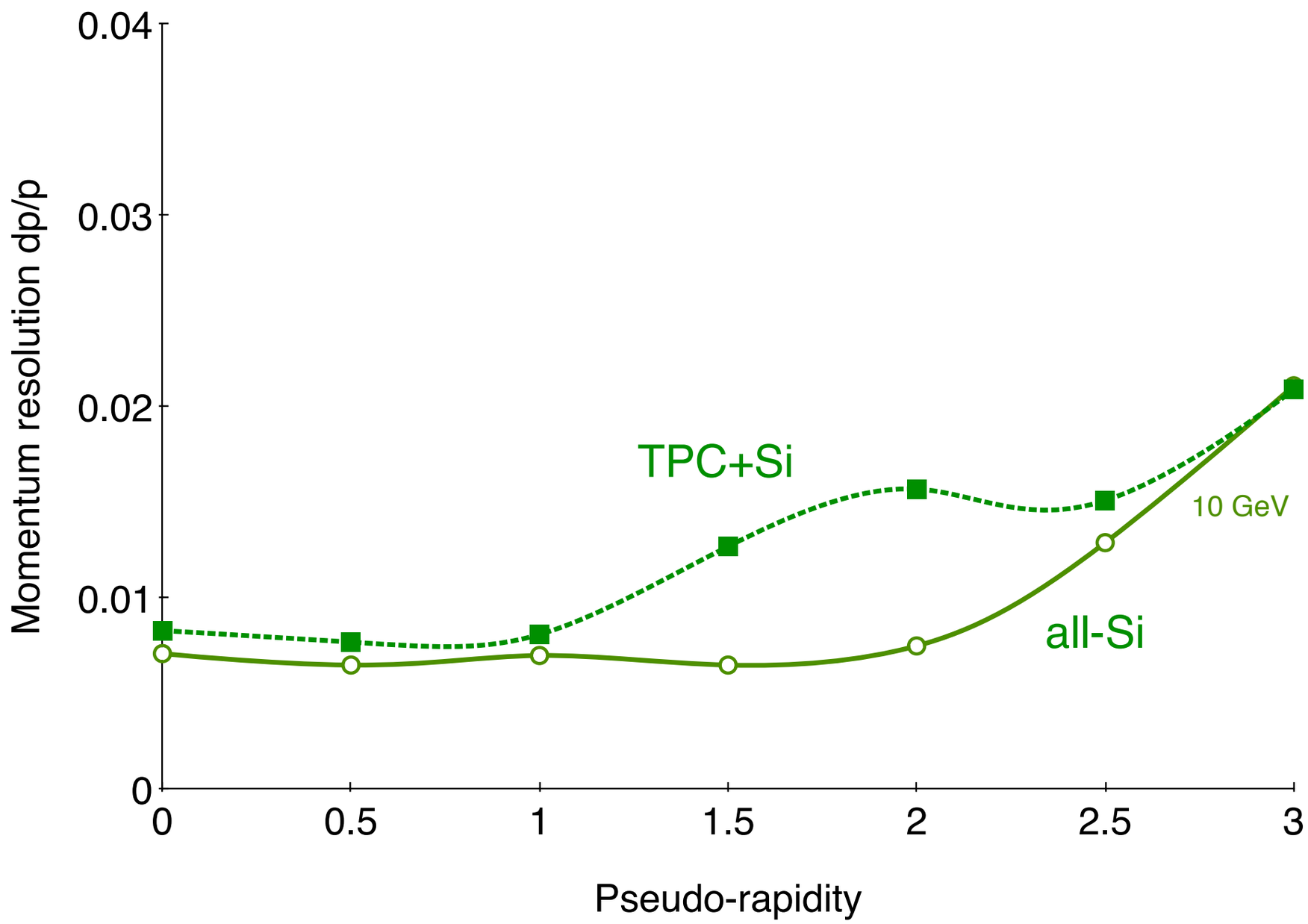
eRD16 - Simulations

- Resolution comparison with BeAST TPC+Si tracker



eRD16 - Simulations

- Resolution comparison with BeAST TPC+Si tracker



It seems worthwhile, to us, to investigate all-Si further.

eRD16 - Proposed work

During the remainder of the ongoing FY19 proposal cycle,

1. Assess impact of material associated with support and other infrastructure using material cones/cylinders in EICroot,
   Engage with engineering to assess feasibility, R&D needs.
2. A small set of fast (LDT) simulations to (further) refine all-Si concept,
3. Document considerations from simulations (joint with eRD18) to bring this initial R&D to a close, and prepare for a next phase,
4. Possibly, organize a small satellite meeting to POETIC-9 for:
   - (Si-) detectors
   - software/simulation

For the FY20 proposal cycle,

Extend response simulation to physics events (Pythia-eRHIC, SIDIS):
- kinematic reconstruction — go beyond *p,*
- correlated quantities — go beyond single particles,

for both the TPC+Si and an all-Si configuration (EICroot):
- study acceptance and edges.

eRD16 - Proposed work

FY19 Resource Summary:

- awarded $61,404 split between continued simulations and mech.eng.
- in use for remaining simulation work; mech.eng. will depend on outcome.

FY20 Resource Request including LBNL overheads etc.:

$17,954 — 1 month of Y.L. Lai (supervised by B. Jacak),
$23,642 — 2 months of P.D. (supervised by B. Jacak or E.S. or both)
$41,596 — total

In a -20% scenario, we will reduce the scope of the physics response studies.
In a -40% scenario, we will drop either the TPC+Si or all-Si response studies.

As reported in January, several University of California (-related) colleagues made a proposal to 2019 U.C. Multi-campus Research Funding Opportunity. This was awarded, P.I. B. Jacak. This will enable a small number of students at collaborating U.C. campuses to engage in EIC research. eRD16 may benefit from this engagement during upcoming proposal cycles.