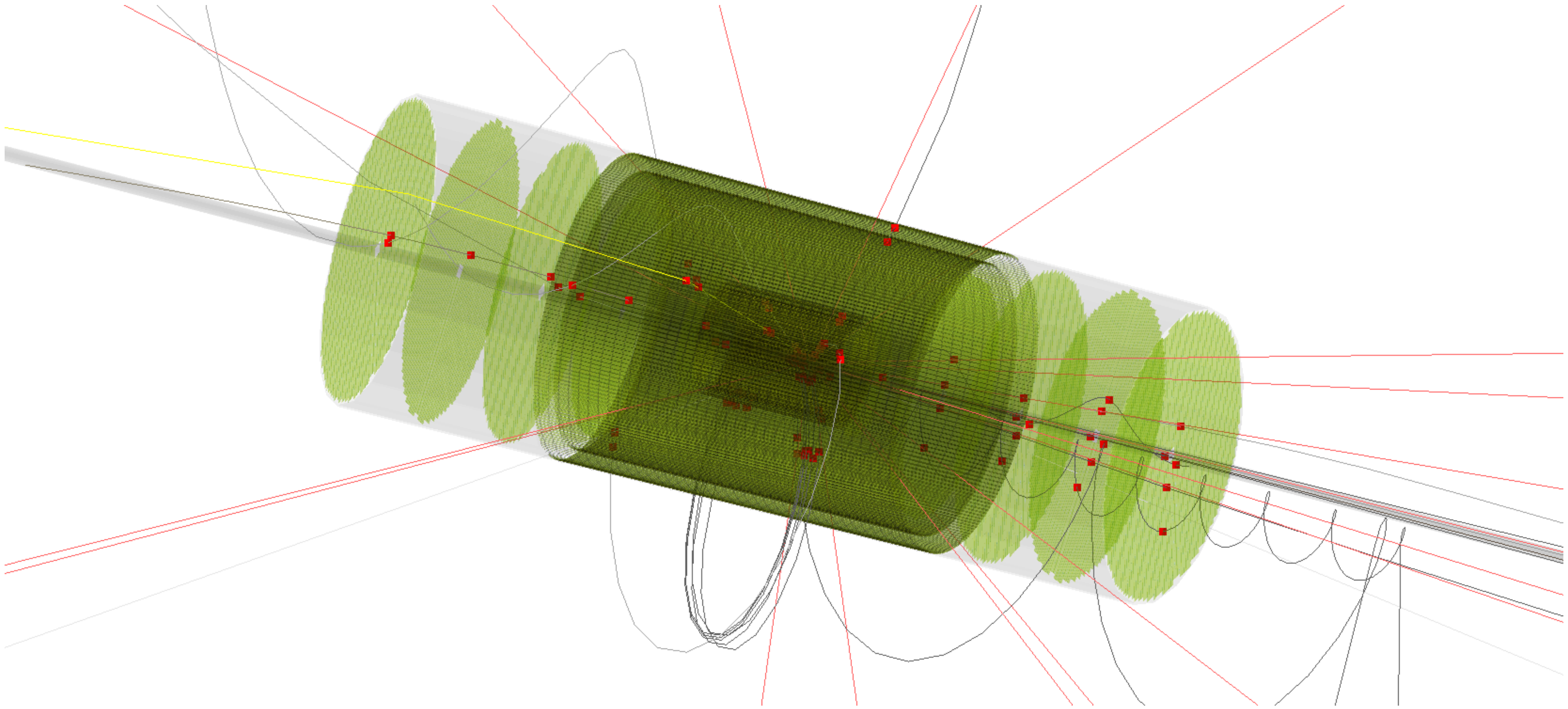
Integration of Barrel and Endcaps into a Full Silicon-tracker



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Input and/or inspiration from many; eRD16,18,25 collaborators and others
Errors are my own, of course

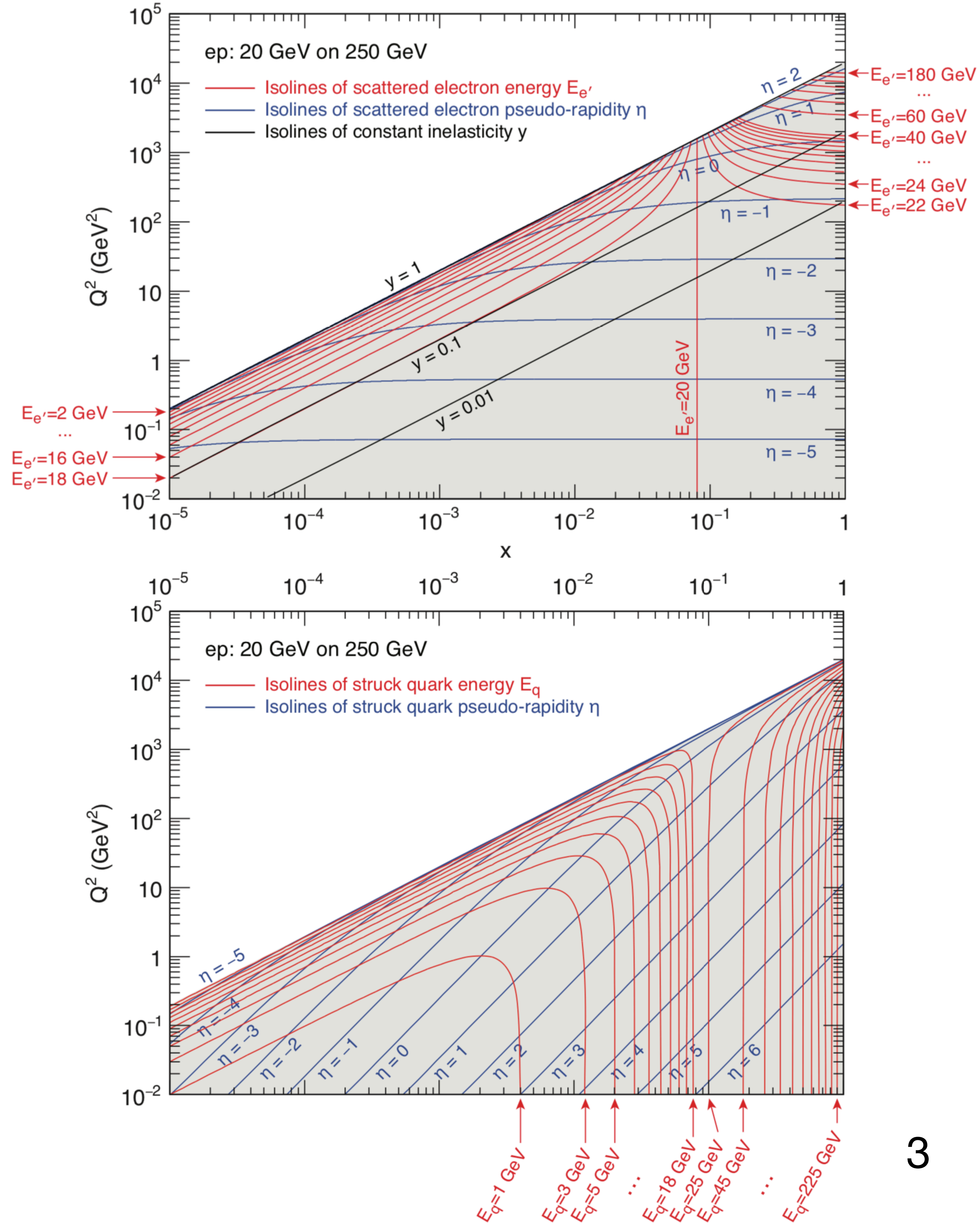
EIC SVT workshop
September 4, 2020

Outline

- Motivation
- Simulation tools
- All-Silicon concept
    - Introduction
    - Disks; number, positioning, resolution, material
    - Barrels; vertexing
    - Arranging barrels and disks; trade-offs
    - Towards integrating services and supports
- Closing comments

Motivation

source: EIC Detector Handbook - DIS process



Challenges for any general purpose detector concept for the EIC include:

- need for large acceptance,
- need to be compact,
- need to be precise.

All general purpose concepts are equipped with inner subsystems to measure charged particles and to determine primary and secondary interaction vertices,

These subsystems need to have large acceptance, low-mass, and high-granularity, and be well-integrated.

Thus far, typically

$-1.25 < z < 1.25$ m and $r < 0.85$ m

Simulation Tools

1. Event generator(s); pythia-eRHIC, eSTARlight, …
   pythia-eRHIC e.g. for event-overlap (pile-up) and open-charm

2. EIC-smear - event smearing,
   here, EIC-smear as an I/O library,

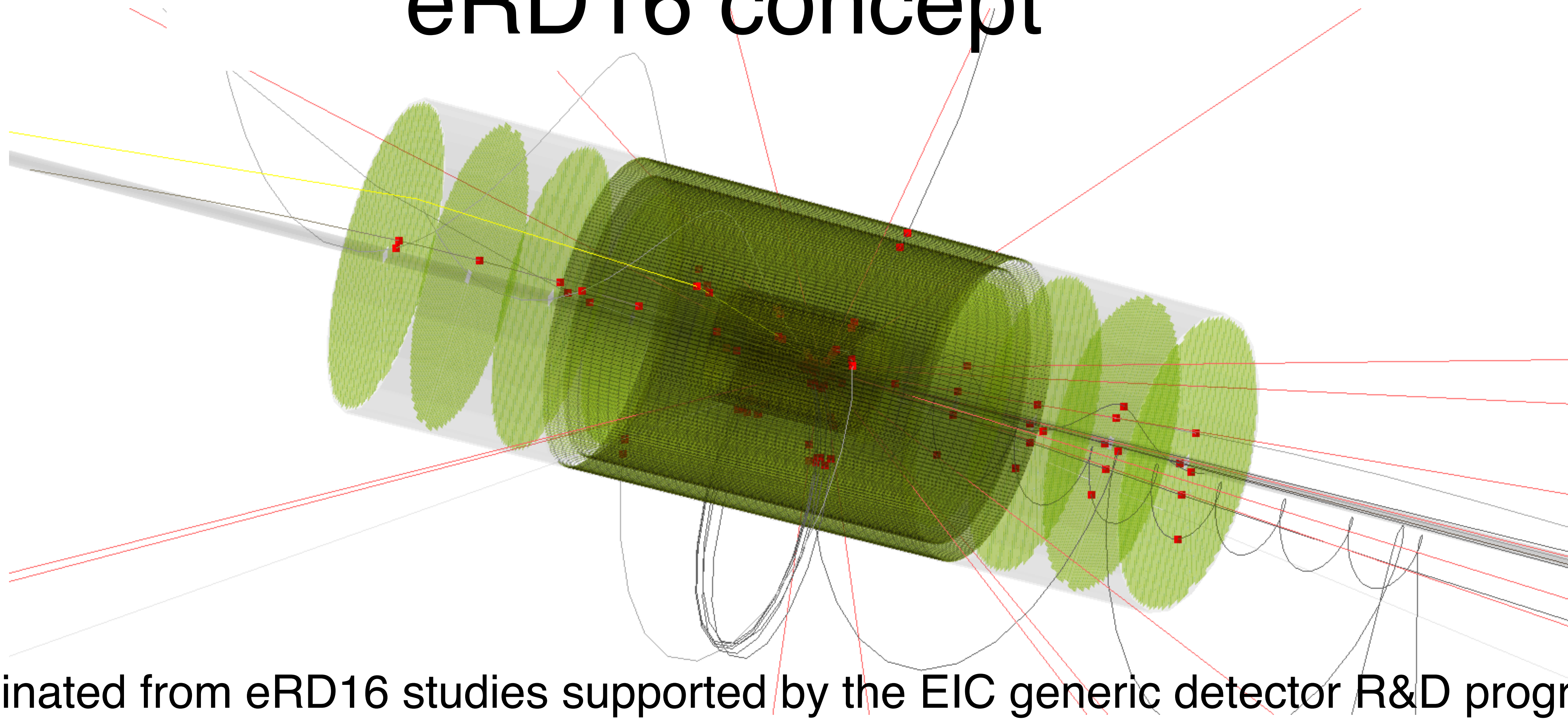
3. LDT - fast simulation,
   Originally developed by the Vienna group (Regler et al.),
   Use-cases include ILC and LHeC detector concept studies,
   MC with analytical track propagation through cylindrical barrels
      and disks including multiple-scattering in ideal solenoidal fields,
      parametrized digitization, Kalman track-reconstruction.
   Not GEANT-based; no energy-loss, for example.

4. EIC-root - **full simulation**
   Parametrized sensor-response,
   GEANT-based, detailed stave/module descriptions; start towards services/supports

5. Fun4All, c.f. earlier talks by Håkan Wennlöf and Rey Cruz-Torres

6. (GenFit, RAVE, FastJet, …)

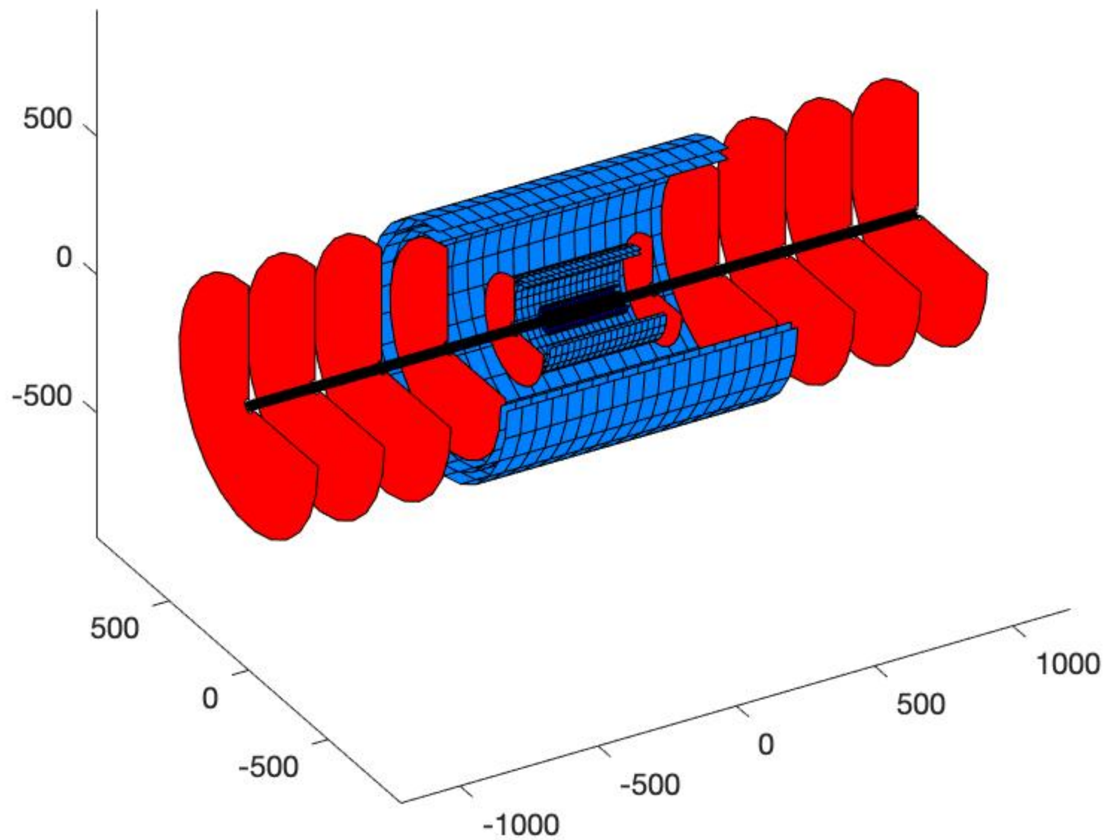
eRD16 concept



- Originated from eRD16 studies supported by the EIC generic detector R&D program,

  20 x 20um MAPS sensors; two inner-most barrel layers at 23mm and 46mm drive vertexing performance, surrounded by barrel layers at 14.0 and 15.7cm, and 39.3 and 43.2 cm, complemented with 5-7 forward and backward disks spanning z ~ 1m,
- p_T (resolution) steps at ~0.2 (0.1) GeV in 3.0 (1.5) T in barrel region,
- Initial modeling of support and services along tapered cones; now starting to be firmed-up (c.f. Leo Greiner's talk yesterday),
- Featured extensively in Rey Cruz-Torres's talk yesterday,
- Let me try to break some of it up, and provide some background and trade-offs next

eRD16 concept(s) - LDT model(s)



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

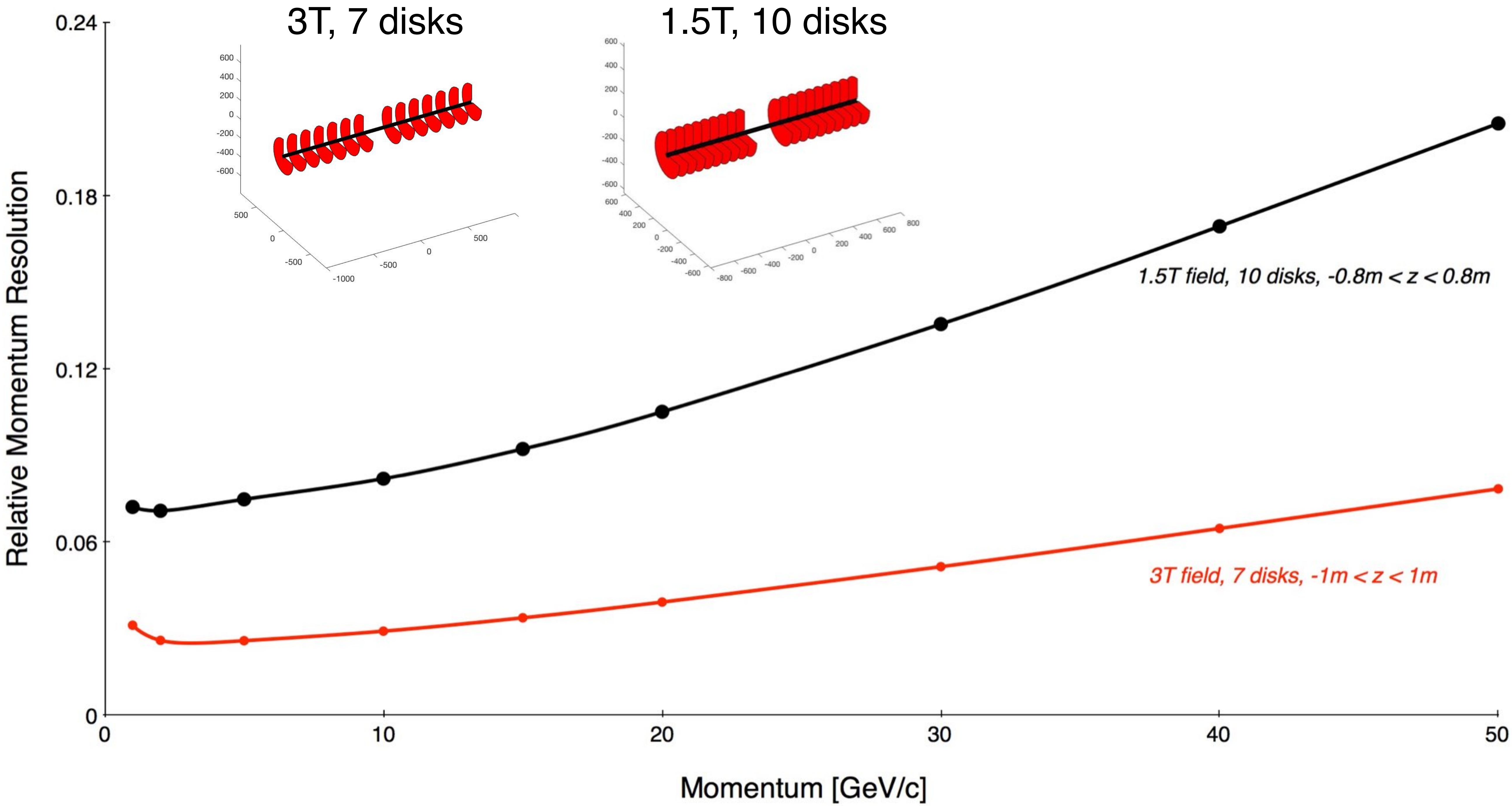
Incorporates:

- helix track model,
- multiple scattering,
- full track reconstruction from digitized hits using a Kalman filter,
- documented (and peer-reviewed)*

- Rapid studies of number of layers, disks, geometrical layout, etc.
- Let's next consider the number of disks and their positioning.

* Two (now) known issues: low-$p_{(T)}$ threshold (out-of-the-box, straightforward to overcome), correlation between dip-angle and p_T lost through beam-pipe in p-mode (not straightforward).

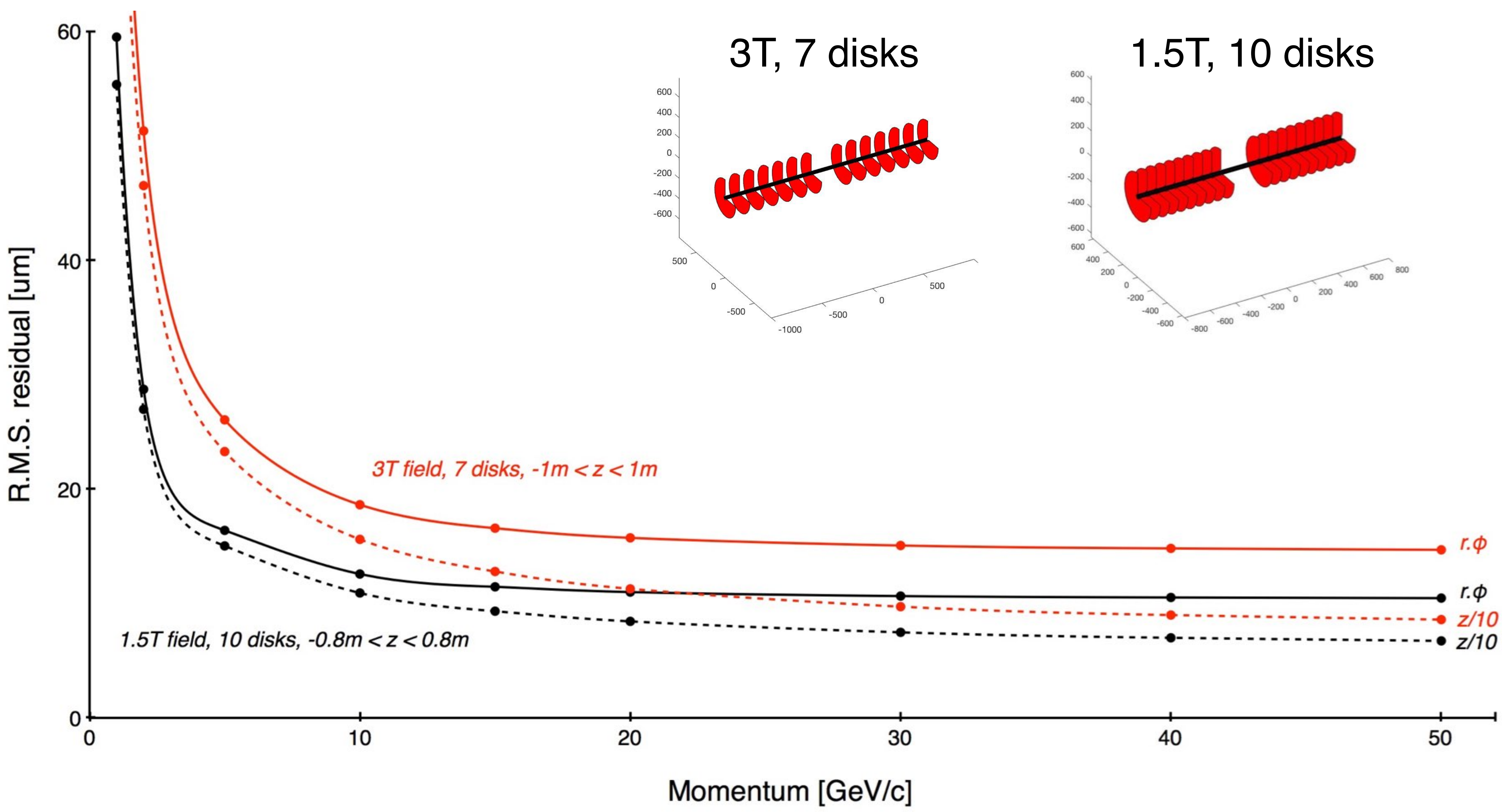
Disks and their positions - early/old illustrations



$\eta = 3$ ($\theta = 5.7^{o}$), 28μm pixels (28μm/$\sqrt{12}$ point resolution), $\chi_0 = 0.3\%$/disk

expected scaling with B.dl

Disks and their positions - early/old illustrations



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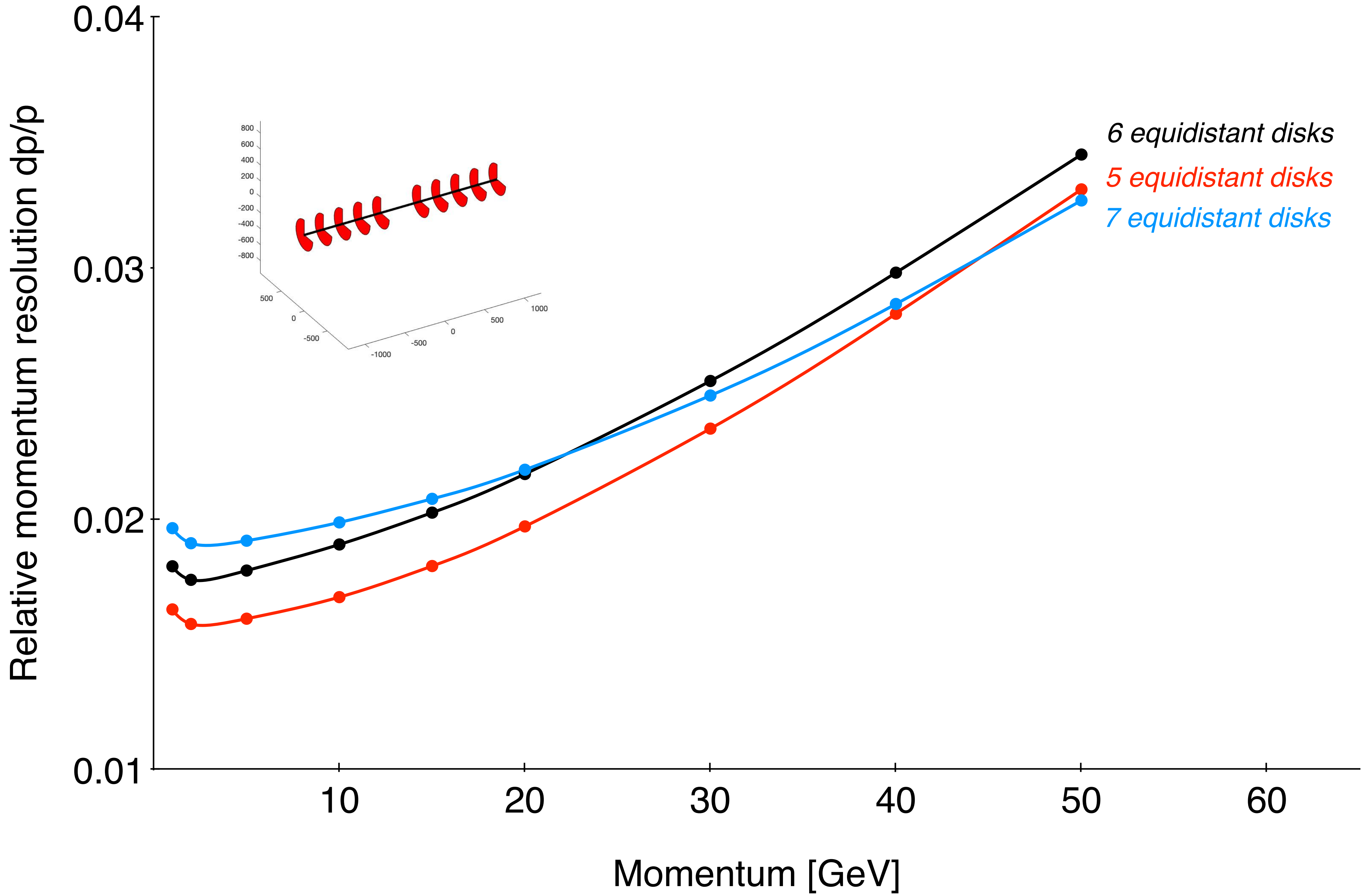
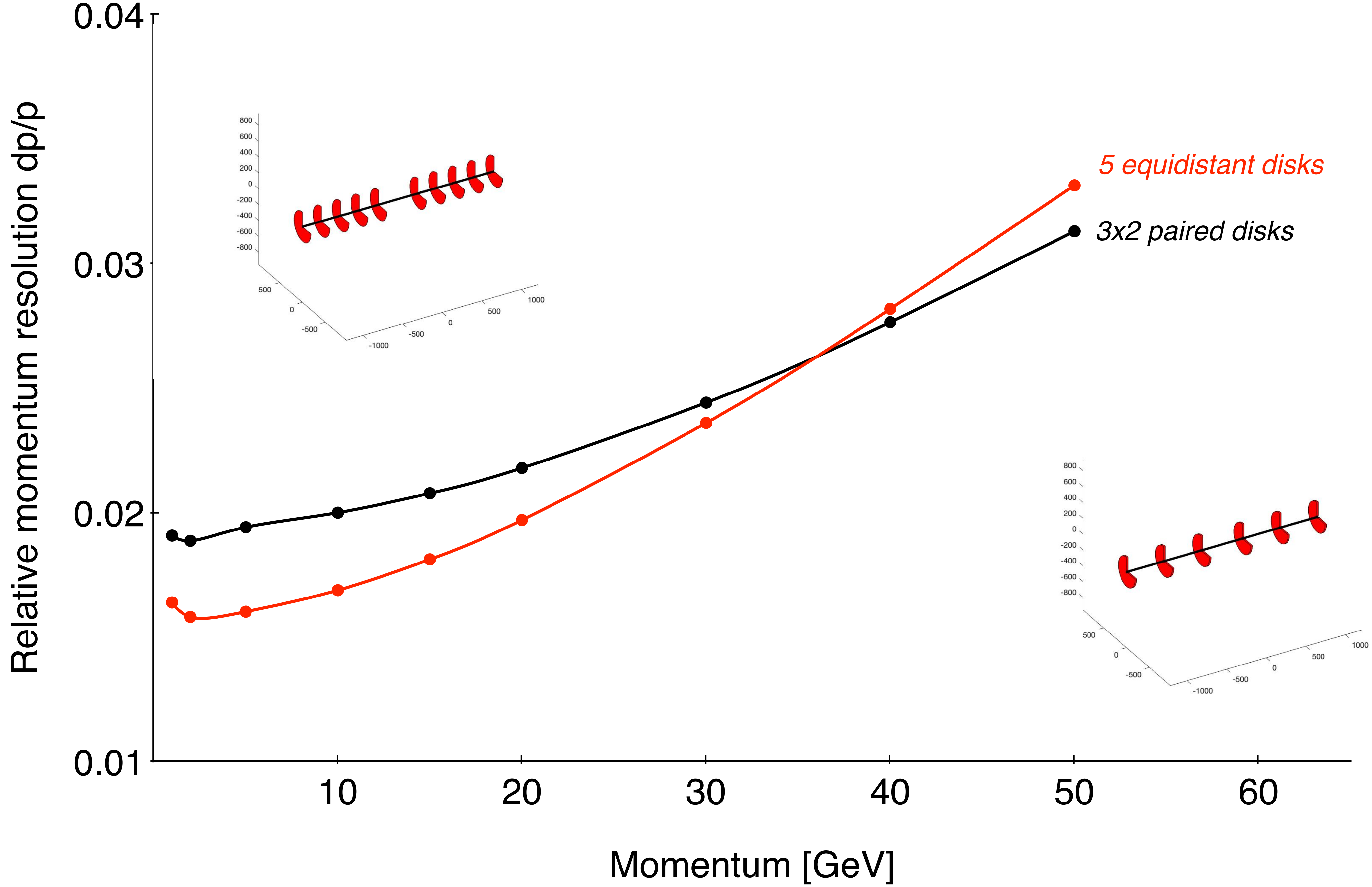
Disks and their positioning



Five, six, and seven equidistant disks, $0.25 < z < 1.21$m, $\chi_0 = 0.3\%$/disk

Fixed $\eta = 3$ ($\theta = 5.7^{o}$), 20μm pixels (20μm/$\sqrt{12}$ point resolution), 3T

Disks and their positioning

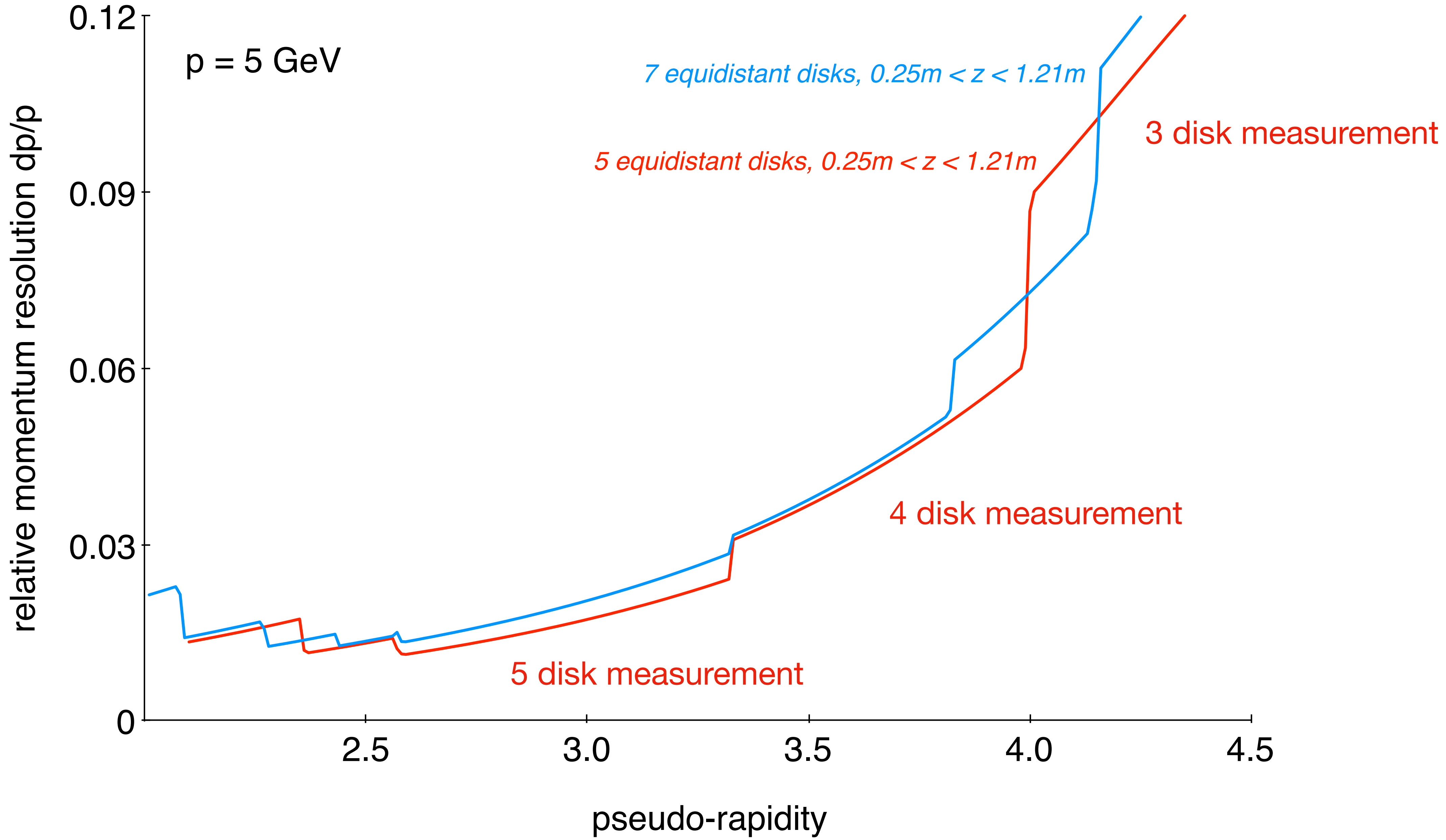


Five equidistant disks as before, six paired disks capturing the sagita

Similar holds in the *barrel* region; eRD16 barrel layers are indeed *paired*

Disk positioning

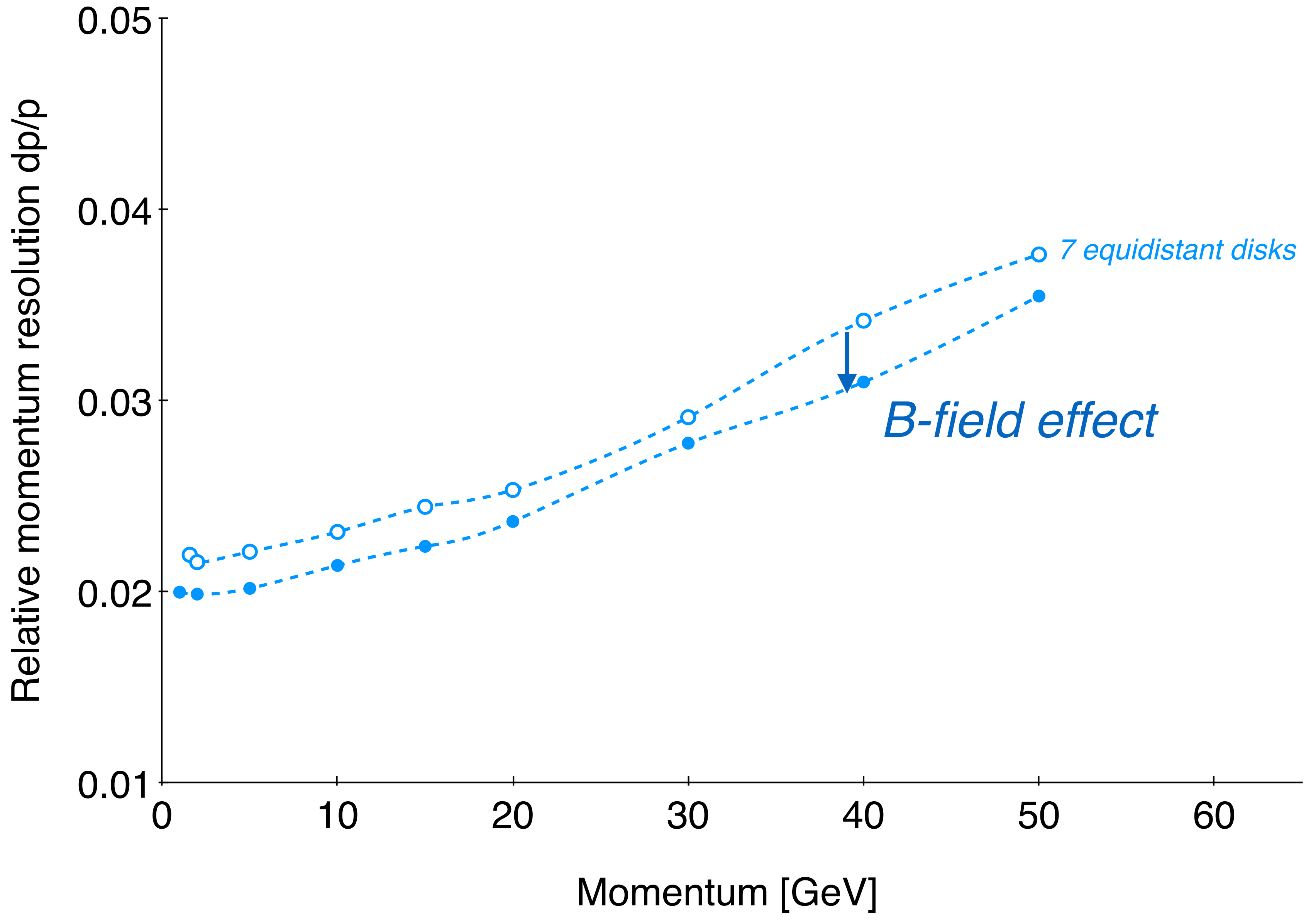
While eRD16 All-Si uses pair-wise barrel layers to (best) measure sagita, acceptance considerations near-exclude doing so for the disks,



The positions of the steps depend on inner and outer radius; the increased beampipe diameter again enters and impairs large |η|.

Fast and Full Forward Simulations

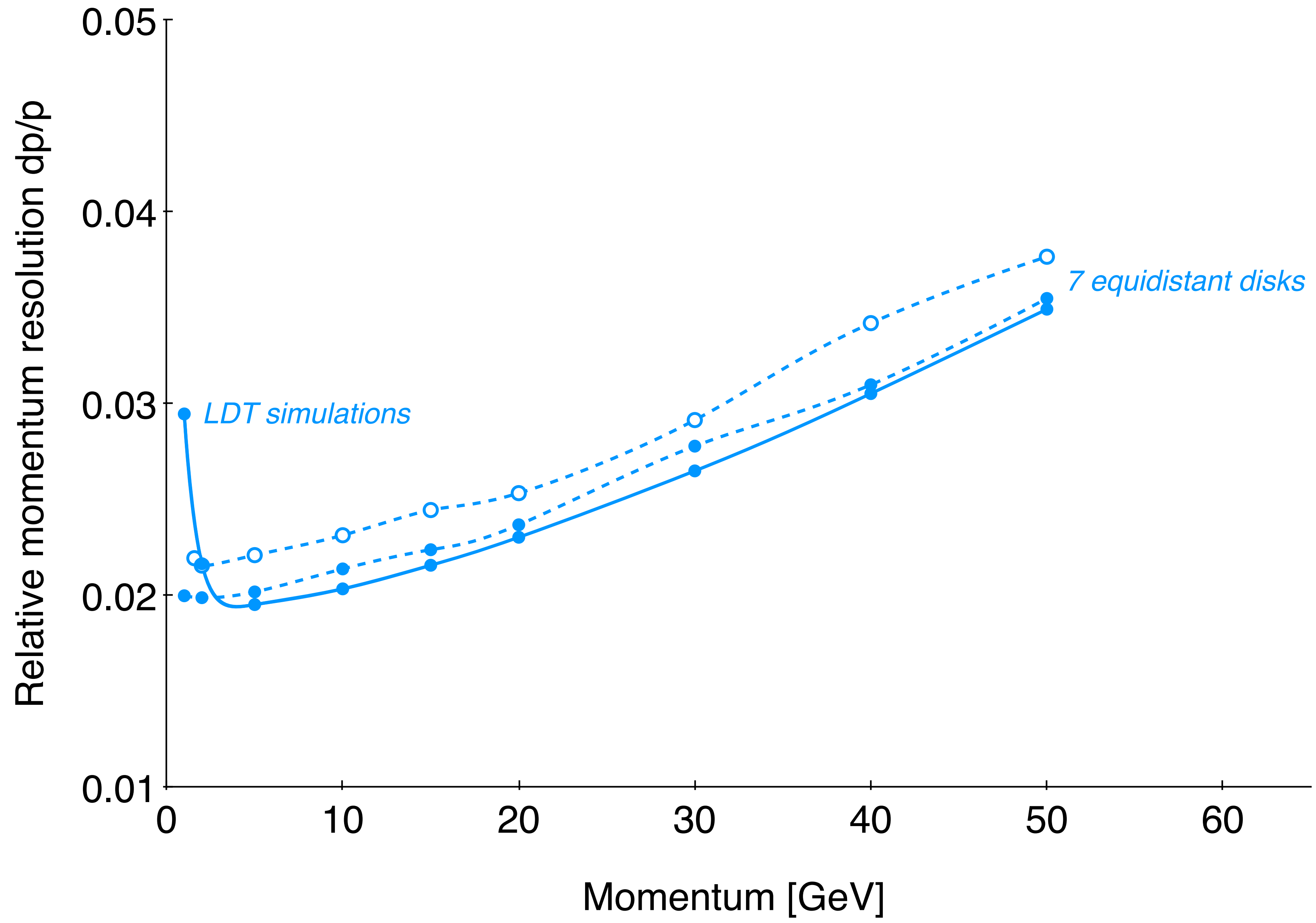
(Default) “open field” versus 3T box field in full simulations:



Fixed η = 3 (θ = 5.7°), 20μm pixels (20μm/√12 point resolution)

Fast and Full Forward Simulations

Comparing the 3T box field in full and fast simulations:

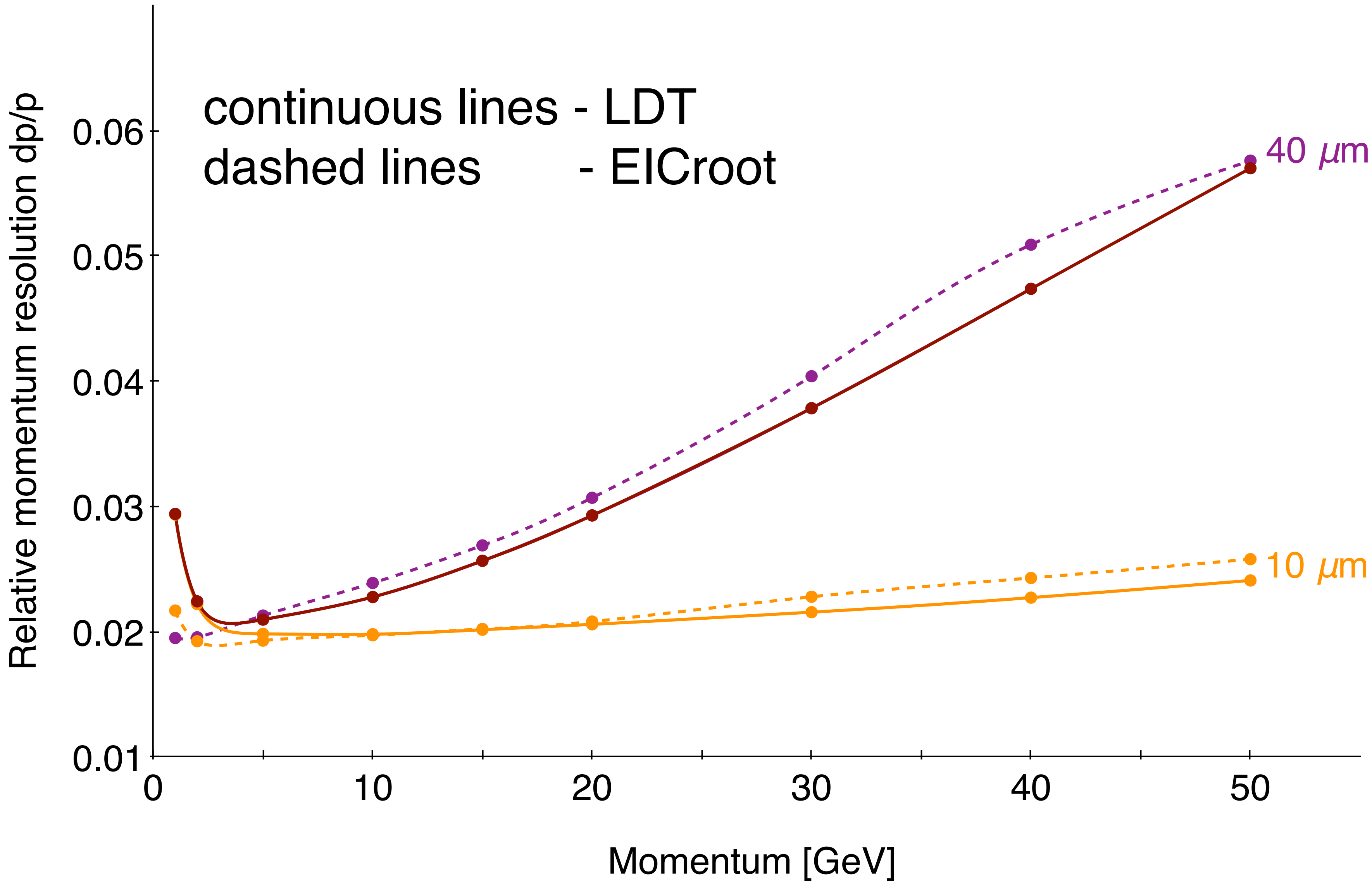


Up-turn at small-p is an LDT artifact (c.f. slide 6), otherwise good agreement,

Similar studies with 1.5T box field, # disks, pixel size, etc.

Fast and Full Forward Simulations

Performance compared for 10 and 40μm pixels (/√12 point resolution)



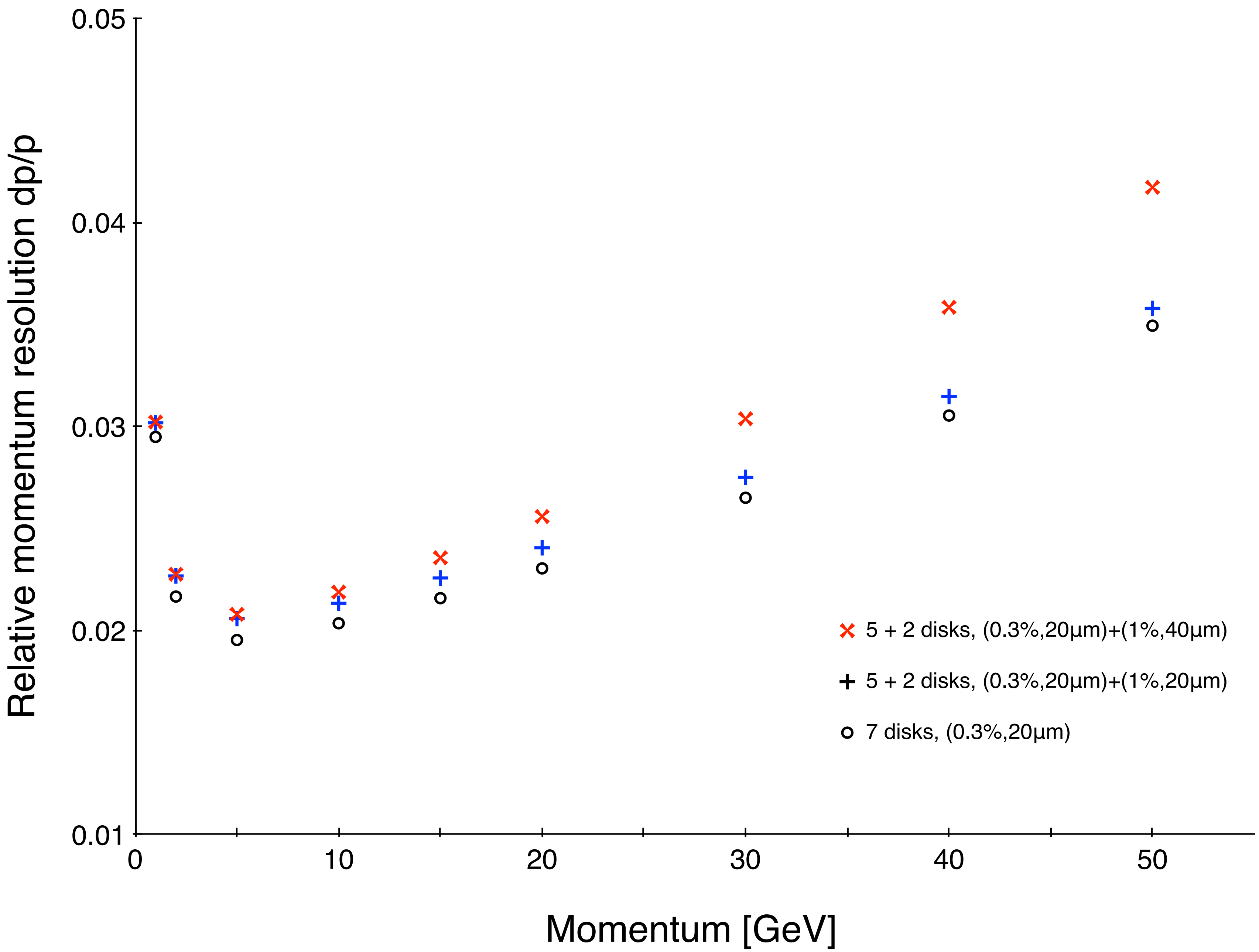
Fixed η = 3 (θ = 5.7°), 3T

Initial studies ~20μm; increased beampipe radius drives current 10μm

Disks - material budget and resolution

Outer instrumentation, possibly in the form of one or or more fast Si-disks or barrel layers, has come up previously as a *timing-layer* to anchor tracks to the crossing and possibly even for *ToF PID* in parts of the acceptance,

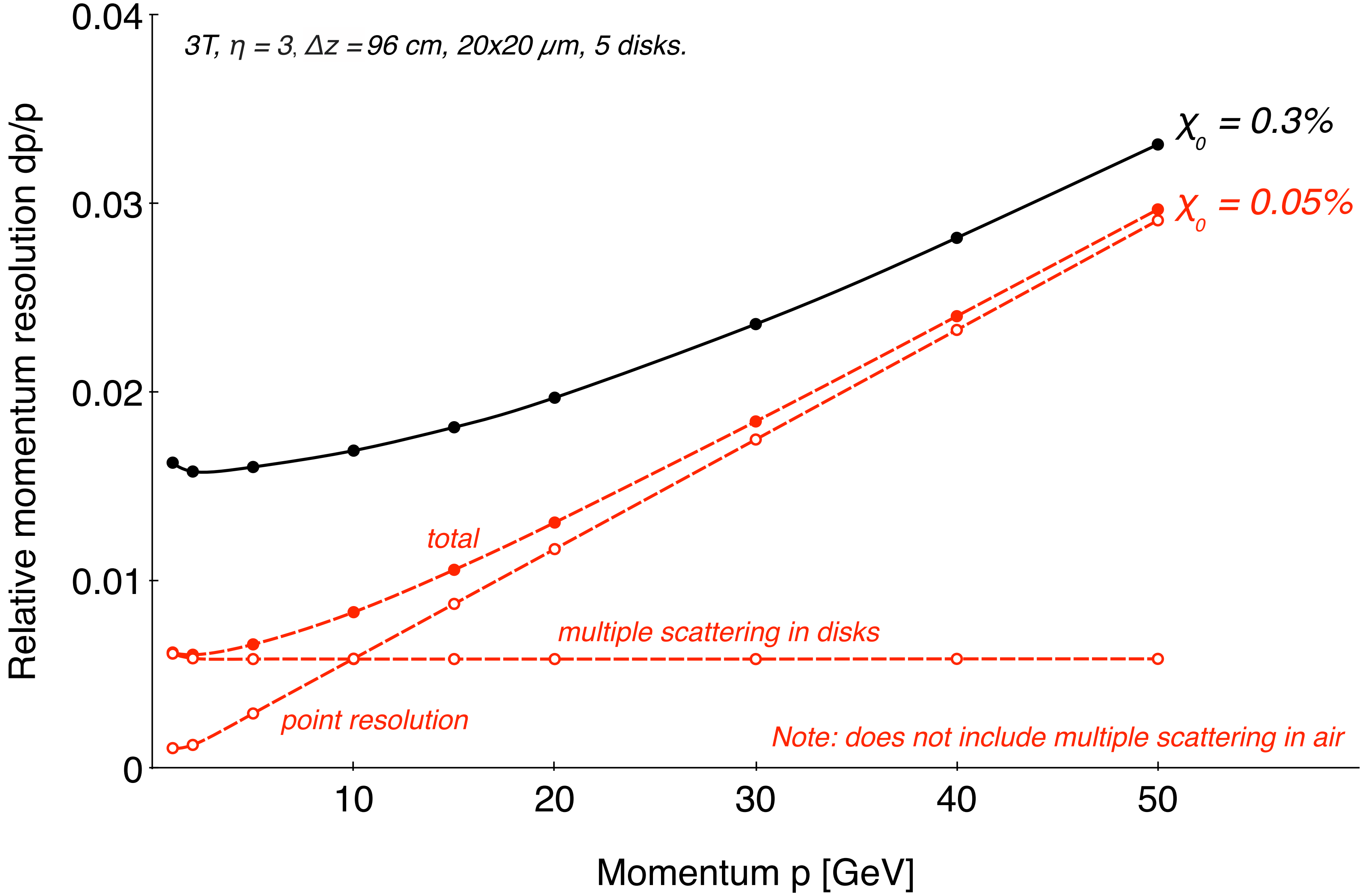
"What-if" such a timing layer were to take the form of the two disks furthest from the interaction-point, and were to be somewhat thicker/coarser:



- material *at this location* seems manageable,
- larger pixels (worse point resolution) for |*z*| < ~1m degrades performance, especially for large momenta in the forward hadron region (but see Rey's and Astrid's talks further out); similar holds for the barrel region
- motivates upfront attention to mechanical stability
- uptick at lowest p is an LDT artifact (c.f. slide 6)

Disks - material budget and resolution

B.dl, resolution, and material all enter:



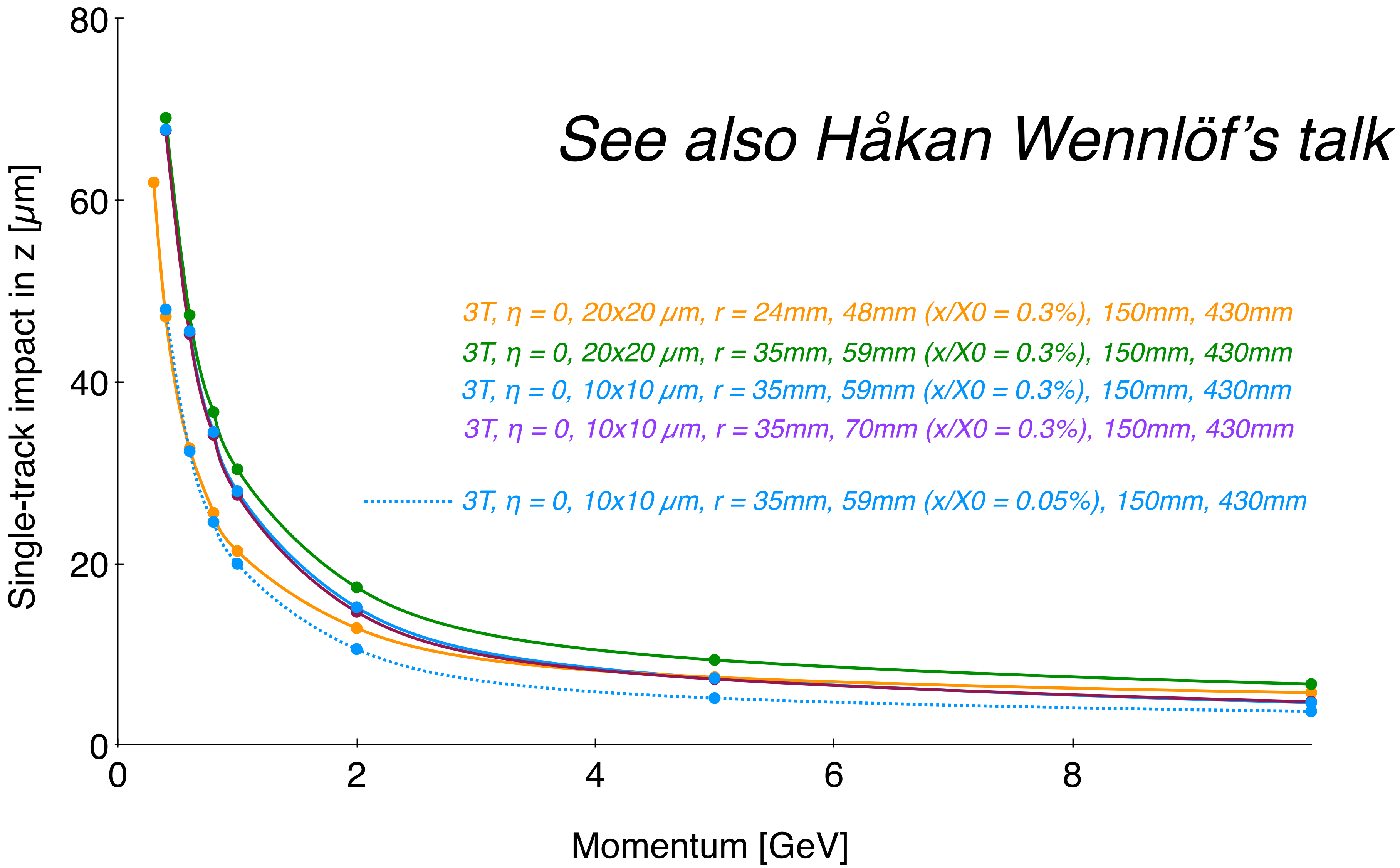
Traversed material generally needs to be kept low, even though it may need to be tolerated at specific locations,

Motivates transition from barrel to disks not too far from η ~ 1 or θ ~ 45°
set aside even that longer staves/modules generally have larger X_0

Motivates up-front consideration of supports and (routing of) services.

Vertexing

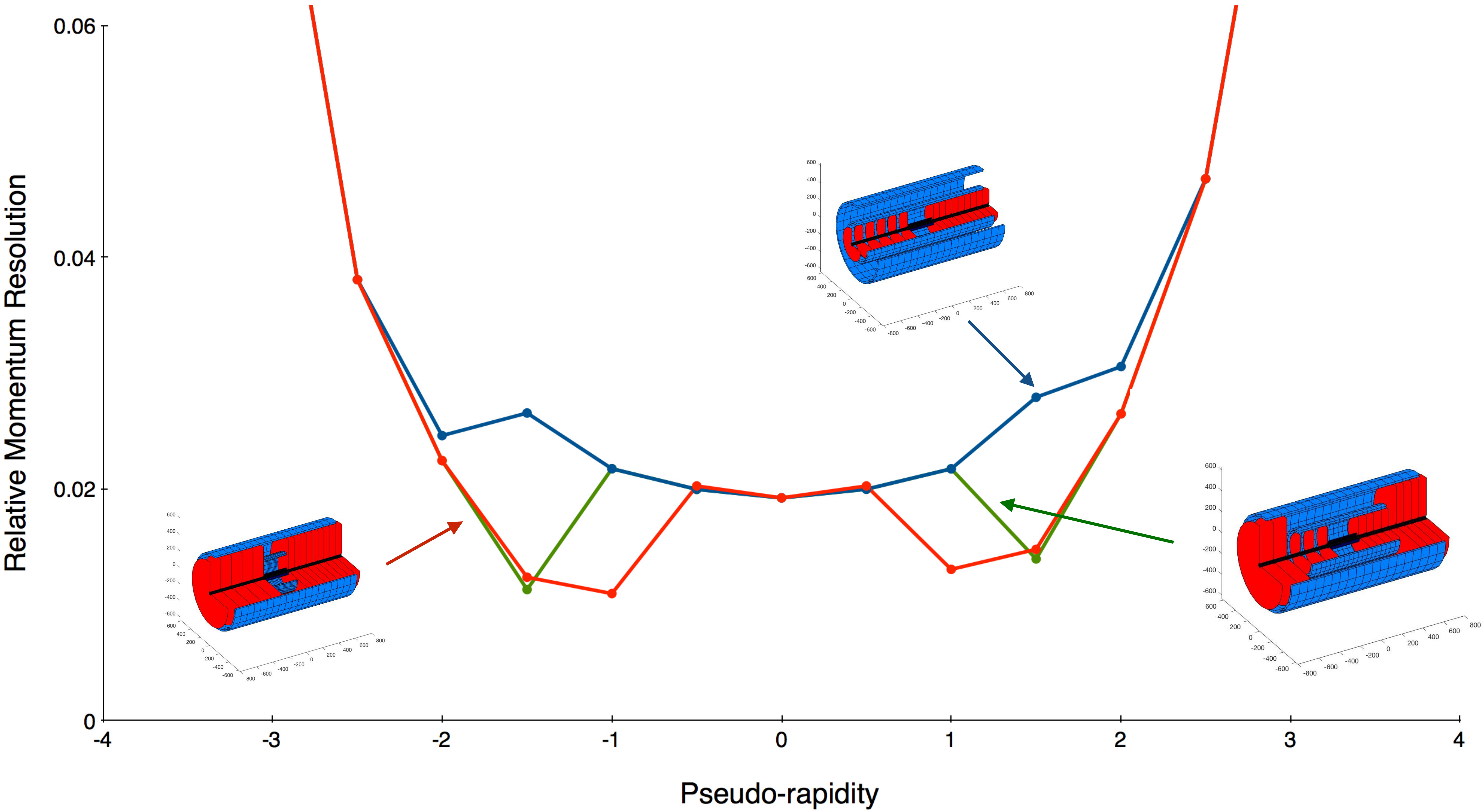
Vertexing entails different challenges than tracking, as illustrated here with considerations for different beampipe diameters,



Motivates capturing a *precise* point as close as possible to the collision and secondary vertices; direction and curvature enter as well, obviously, but pose fewer challenges,

Motivates innermost barrel layers extending (well) beyond |η| ~ 1 covering most of the physics phase-space - this presents a compromise with tracking.

Tracking and Vertexing

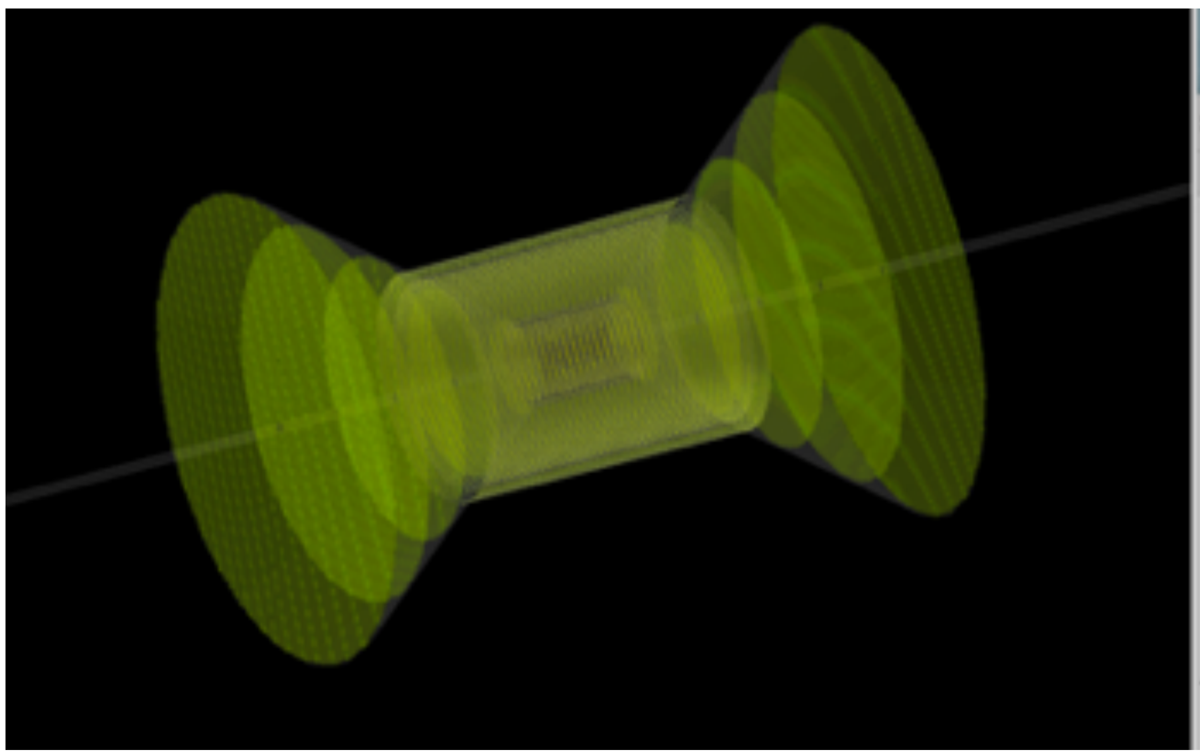


Multiple ways to bring tracking and vertexing together, compromises appear mostly in the transition region ~1 < |η| < ~2,

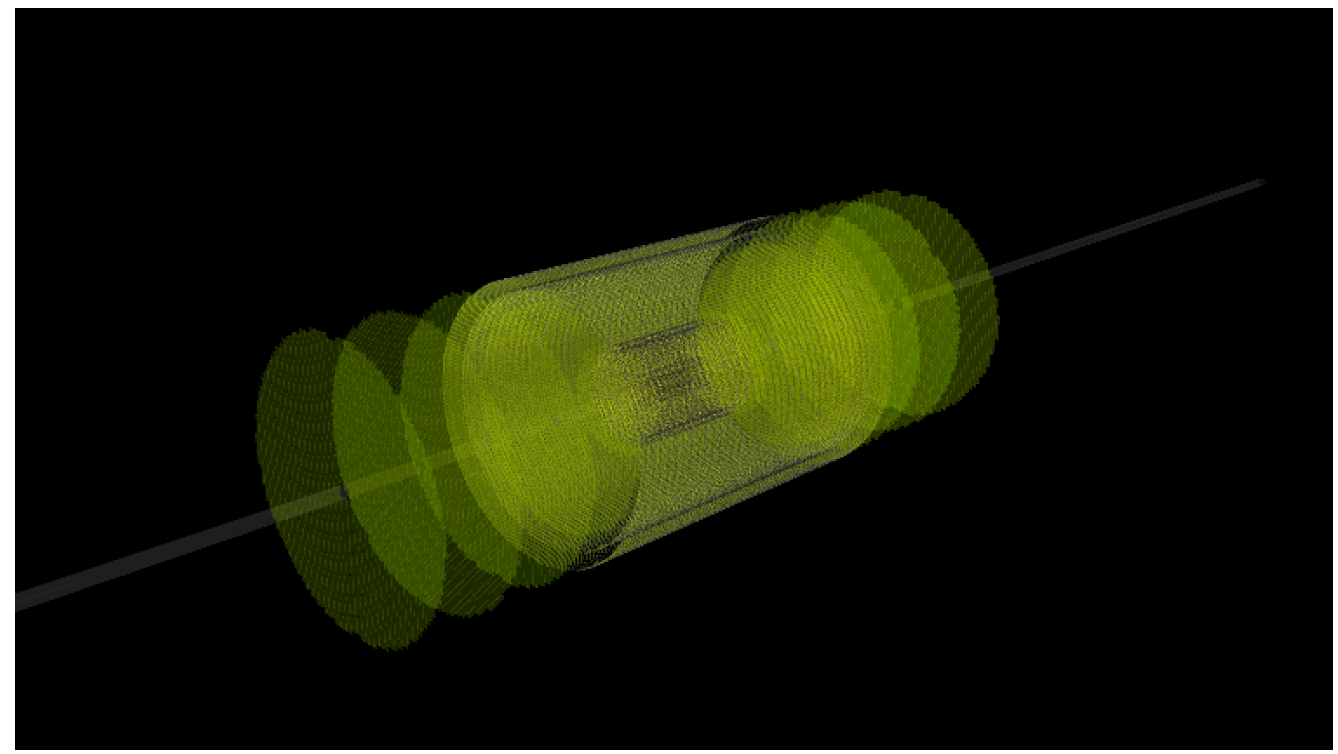
Beware of tracking across services and supports…

Tracking and Vertexing

The beam-collision region will be (just) several cm in z at EIC, so projective arrangements of barrel and disks can potentially avoid tracking across services and supports



all-Si configuration



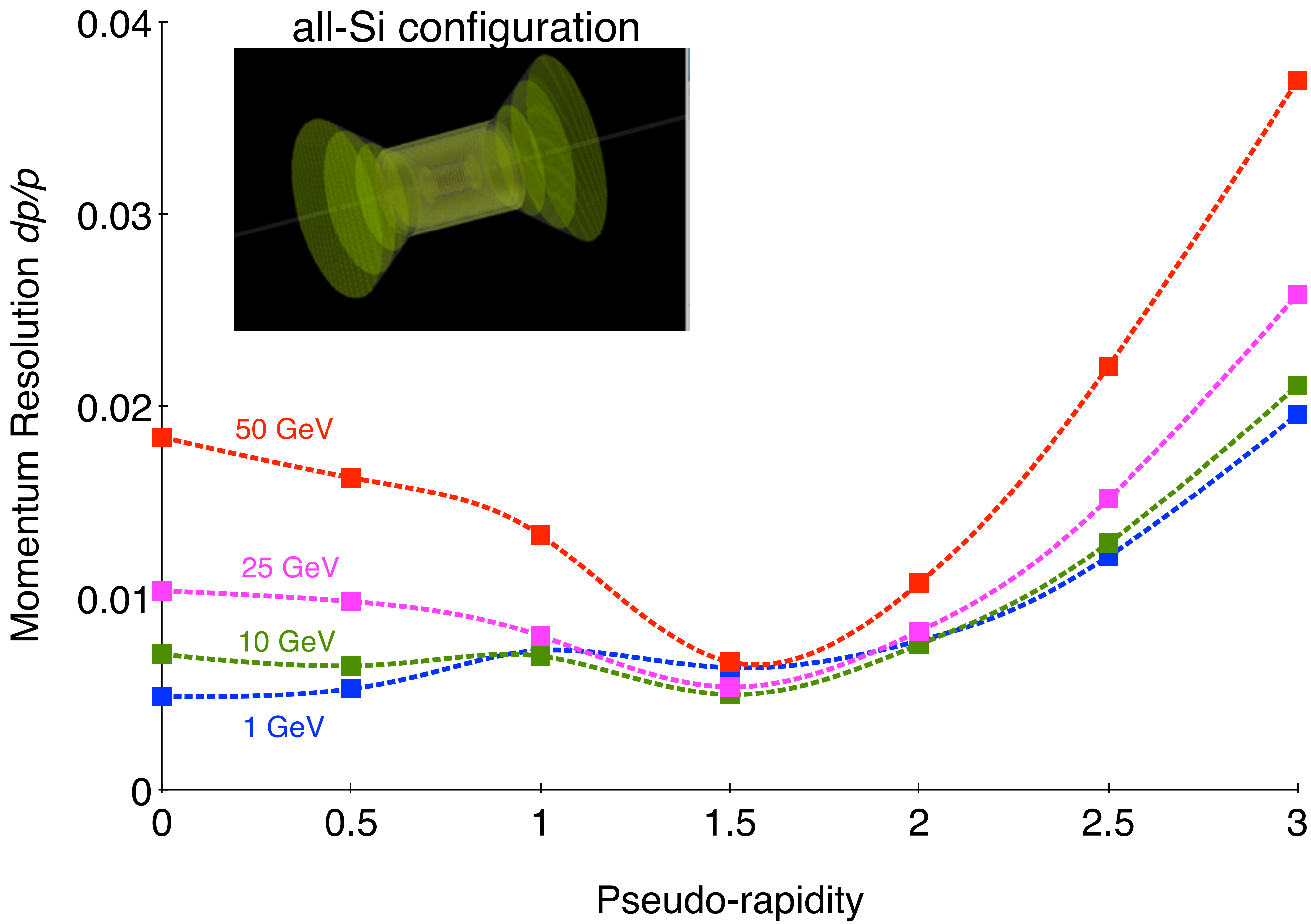
tapered all-Si configuration, r ~ 43cm

Identical barrel configurations, same length z as BeAST

Material cones/cylinders surrounding the disks to mock services and support structures,

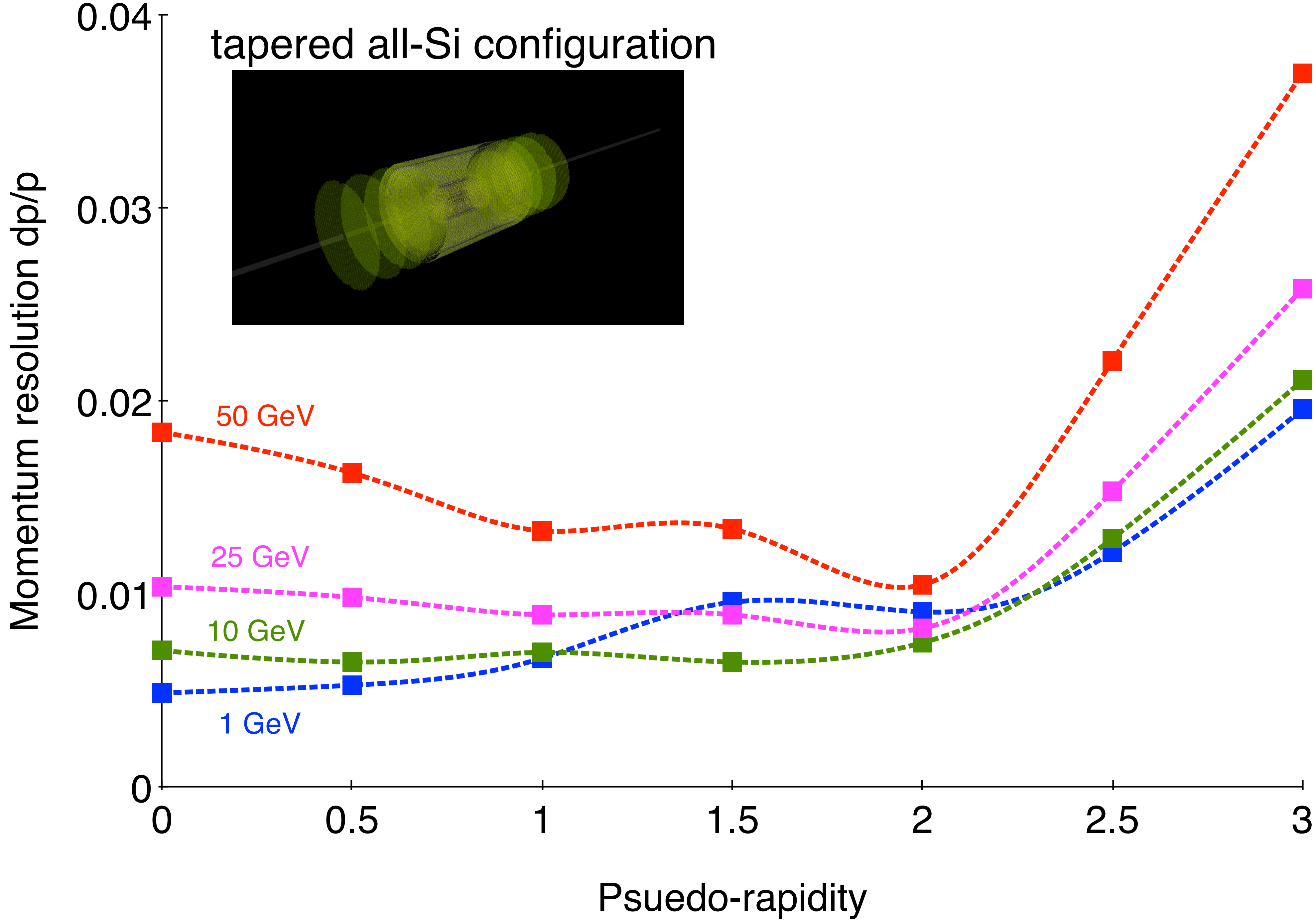
Investigate trade-off of tapering to gain radial compactness,

Tracking and Vertexing



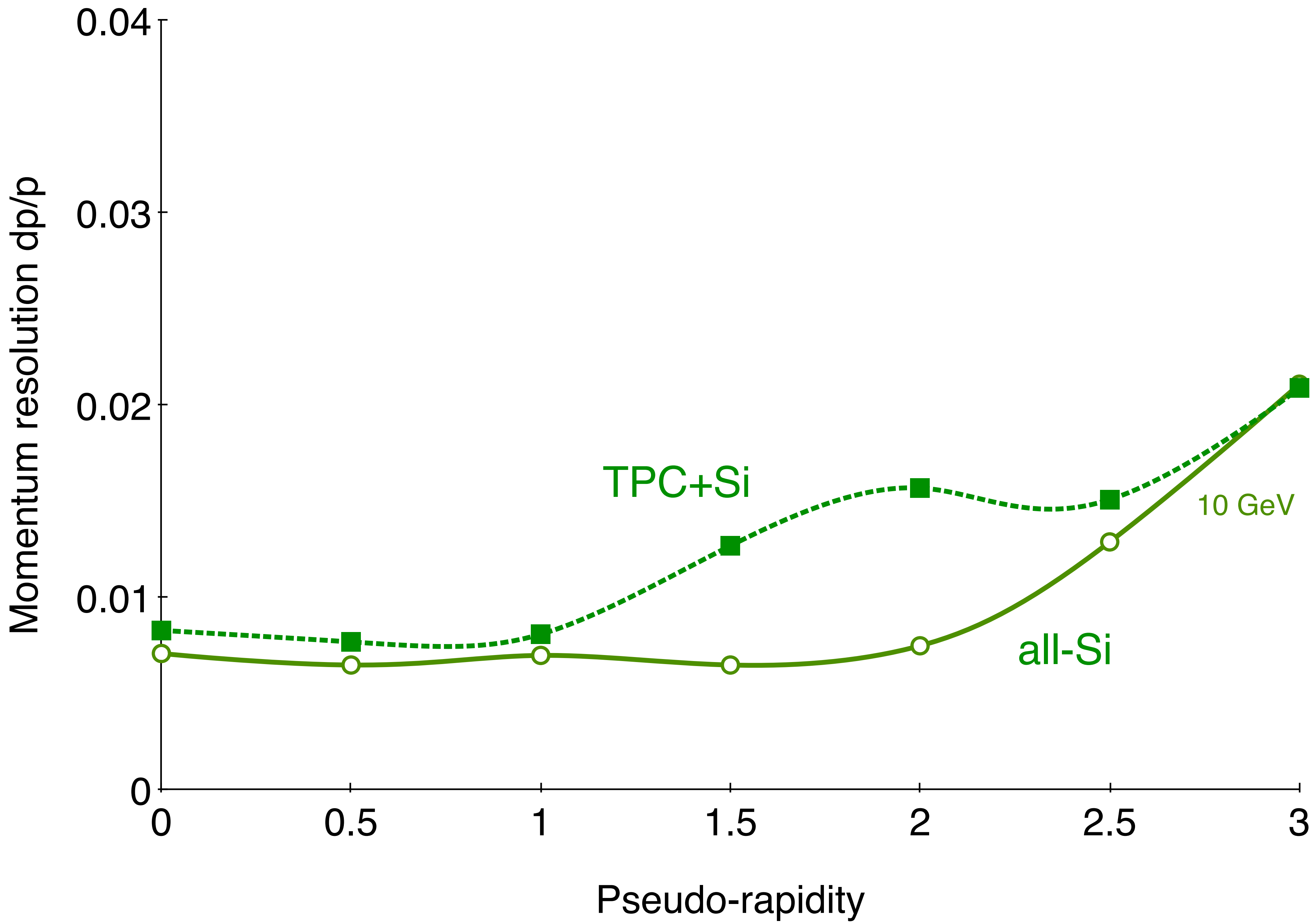
Resolution near ~1.5 results from large r disks; not likely necessitated by science.

Integrated All-silicon Concept



There is a lot in these plots.

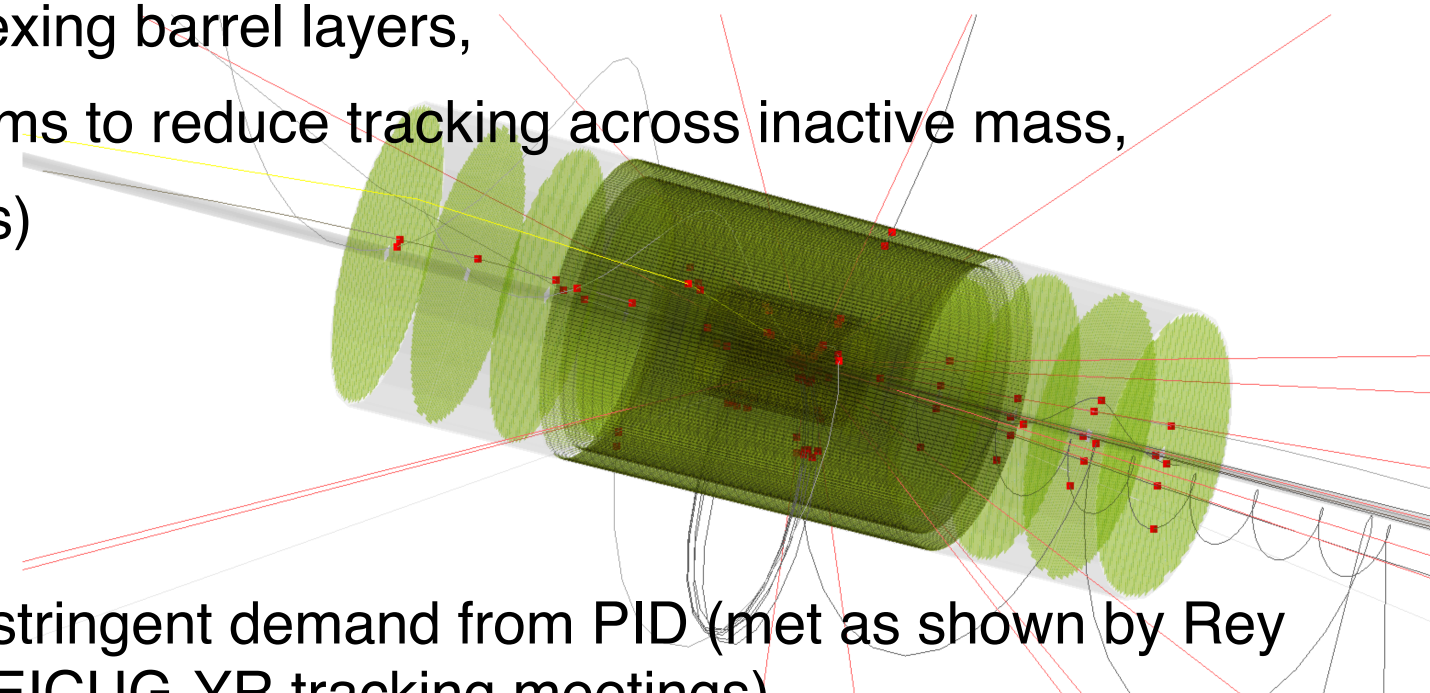
Integrated All-silicon Concept



A radially more compact all-silicon concept can outperform a TPC+Si hybrid,
All-Si concept is an ALICE-scale instrument: ~10m^2 (barrel) + ~5m^2 (disks).

Closing comments

- Discussed considerations for an all-silicon concept leading to:
  - 5 - 7 forward disks, low material, high granularity, $|z| < \sim 1.2$ m
  - 6 - 7 barrel layers, $r < \sim 0.45$ m
  - projective tracking geometry with transition near $|\eta| \sim 1$, $|\theta| \sim 45^{o}$
  - tapered disks,
  - comparatively longer innermost vertexing barrel layers,
  - start of services and supports that aims to reduce tracking across inactive mass,
  - scale $\sim 10\ m^2$ (barrels) + $\sim 5\ m^2$ (disks)



- Not discussed:
  - angular resolution at outer radius, a stringent demand from PID (met as shown by Rey Cruz-Torres discussed in one of the EICUG-YR tracking meetings),
  - crossing angle; $\sim 1^{o}$ effect, sizable in the forward region - both an advantage and a disadvantage and imo a motivation to consider radial polarization,
  - designs of different length in z in the hadron and electron direction,

Lots of work ahead, obviously - great to now be able to run in the Fun4All framework on HPC!

Thank you!