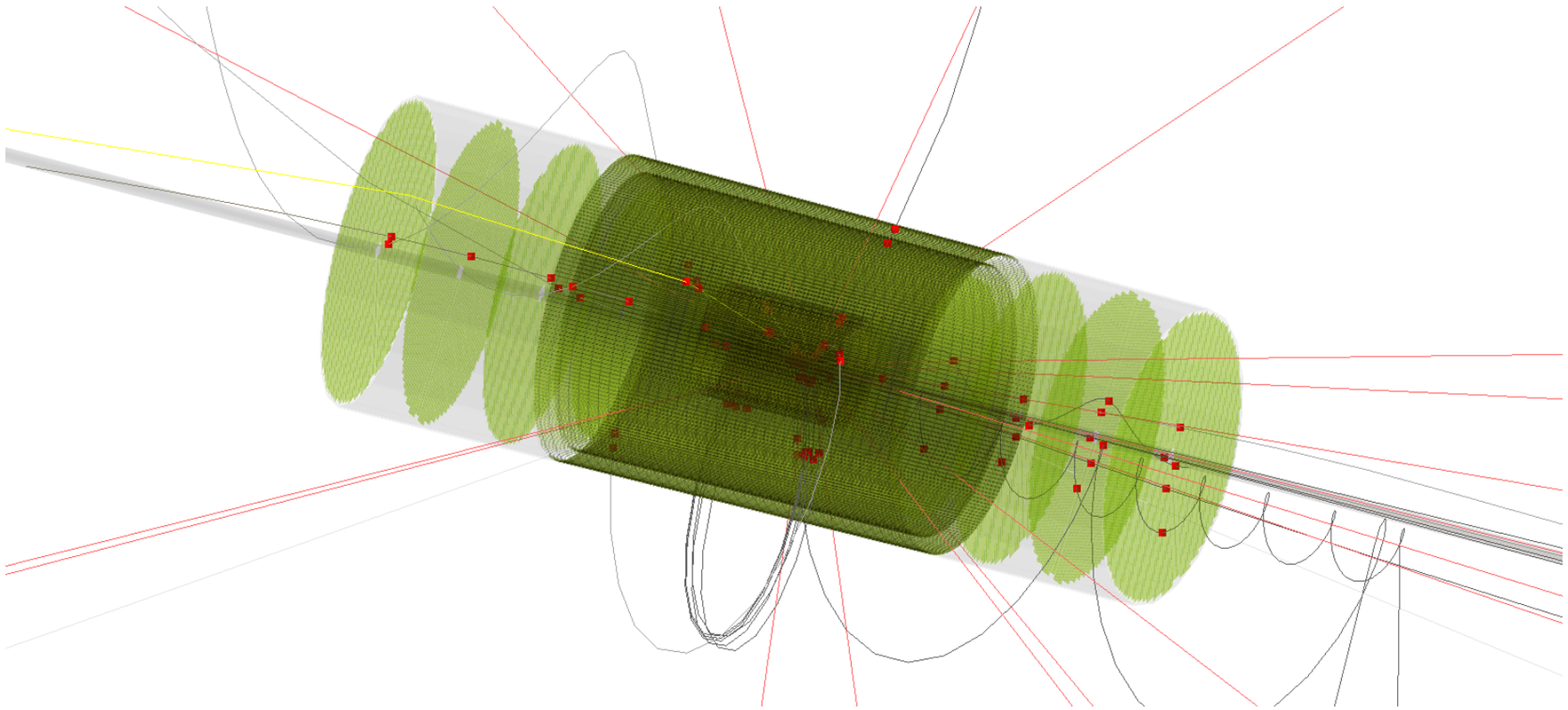
A compact all-silicon tracker concept for the future Electron-Ion Collider

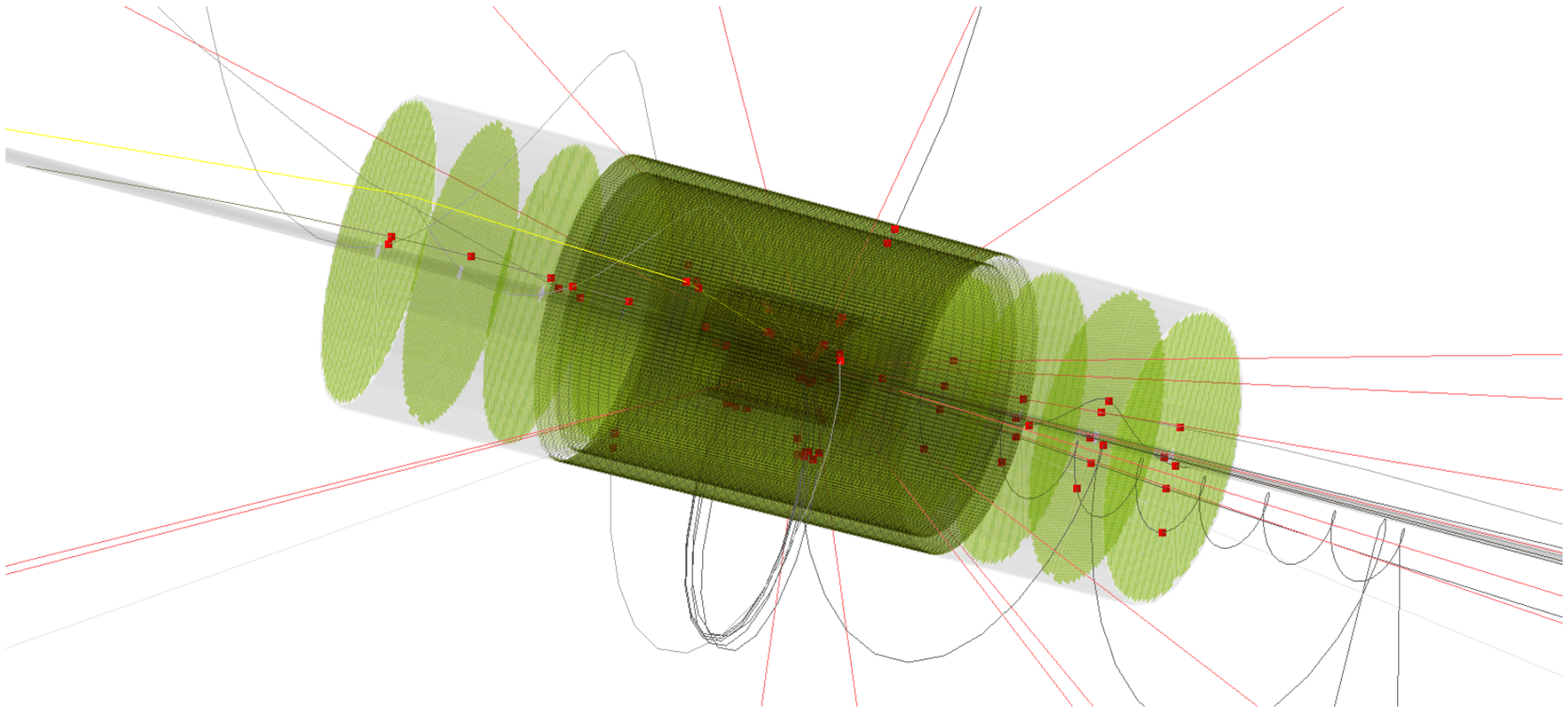


Ernst Sichtermann (Lawrence Berkeley National Laboratory)

Ad-hoc: CORE workshop
March 29, 2021

In part supported by:
U.S. DEPARTMENT OF ENERGY | Office of Science

A compact all-silicon tracker concept for the future Electron-Ion Collider



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Special thanks to eRD25

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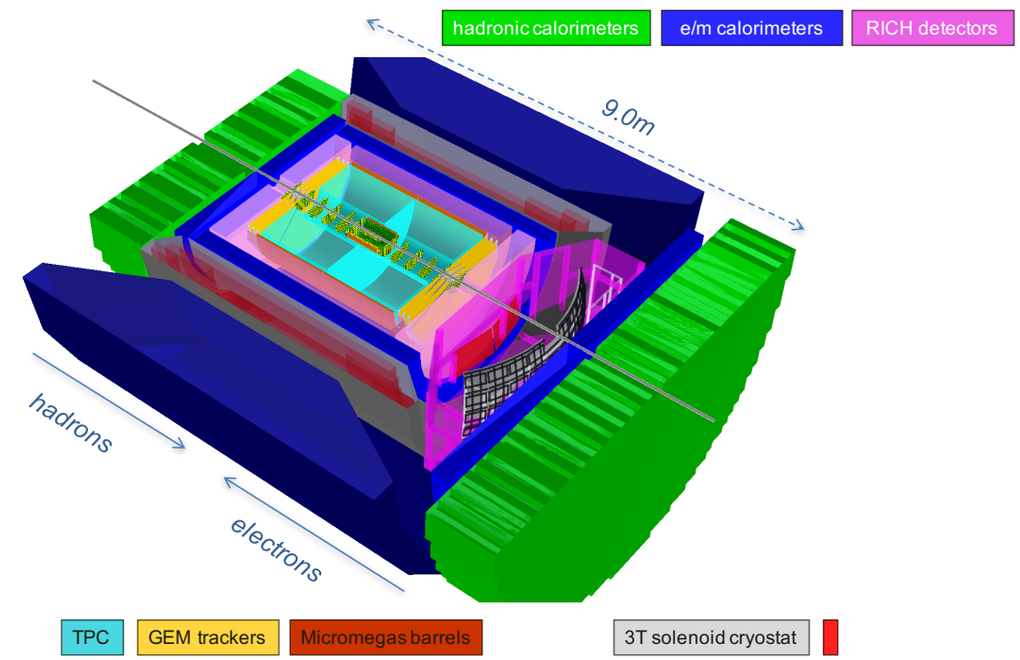
Motivation

Figure courtesy A.Kiselev, BNL EIC Task Force



1. Space is really at a premium at the EIC and the baseline general purpose detector(s) will need to be compact and tightly integrated,

2. EIC candidate baseline detector concepts feature graded charged-particle tracking resolution; track points are measured with better point resolution closer and closer to the IP,

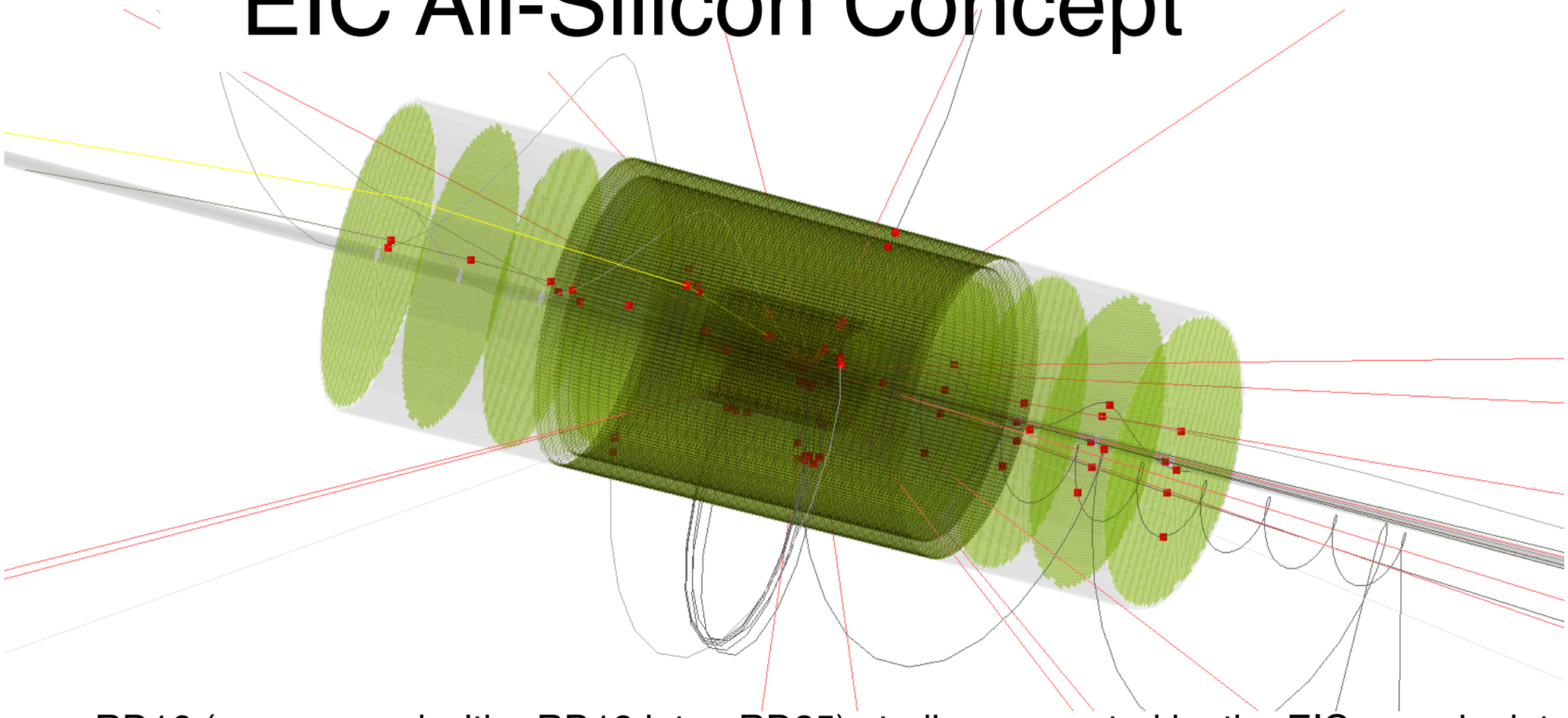
3. Closest to the IP one typically has barrel layers and disks with silicon-sensors; in the BeAST greenfield detector concept, for example, these are monolithic-active pixel sensors (MAPS),

We formed eRD25 to study charged-particle tracking and MAPS silicon-sensor technology with the aim to address EIC low-mass vertexing and momentum-measurement needs,

MAPS technology in HENP has come of age in recent years; the ALICE collaboration, for example, has construction a ~10m^2 MAPS-based upgrade, and is actively pursuing the next generation of technologies. Strong synergy with EIC, so we are teaming up.

➡ *What if EIC could benefit from superior position and pointing resolution along the full track trajectory?*

EIC All-Silicon Concept



Originated from eRD16 (now merged with eRD18 into eRD25) studies supported by the EIC generic detector R&D program,

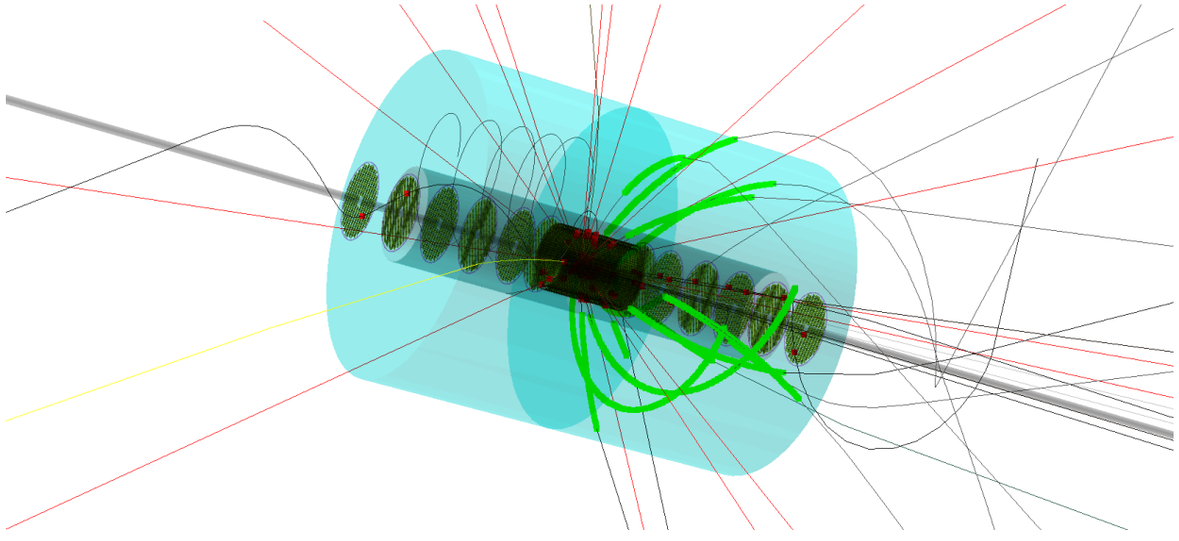
Initially as 20×20 μm MAPS sensors; 2–3 inner-most barrel layers *originally* between 23mm and 46mm drive vertexing performance, surrounded by two barrel layers at 14.0 and 15.7cm, and two at 39.3 and 43.2 cm, complemented with 5–7 forward and backward disks spanning z ~ 1m on both the electron and hadron side of the collision point,

p_T (resolution) steps at ~0.2 (0.1) GeV in 3.0 (1.5) T in barrel region,

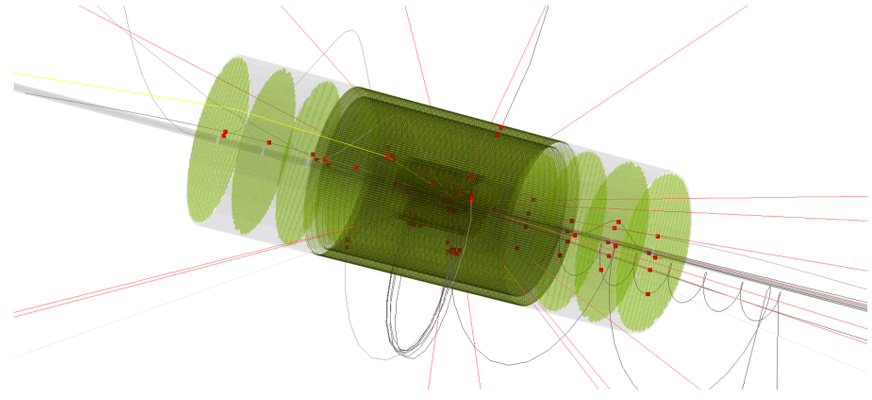
Evolved to a similar configuration with 10×10 μm MAPS sensors; detailed stave structures and initial modeling of support and services along tapered cones,

One of two baseline tracking concepts in the recently released EIC “Yellow Report”, arXiv:2103.05419

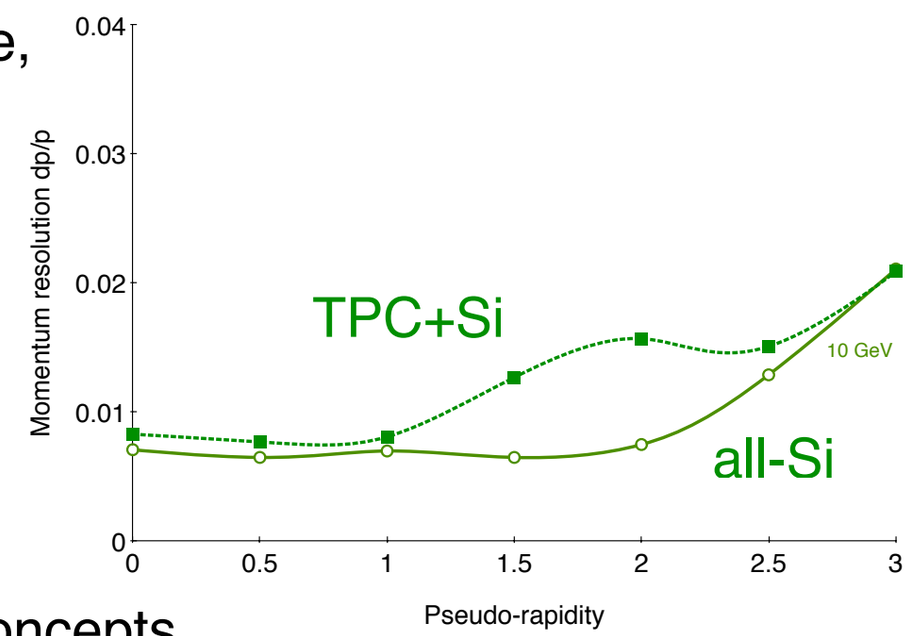
EIC All-Silicon Concept



3T BeAST with ~80 cm outer radius TPC,
MAPS inner barrels & disks



~45 cm outer radius MAPS barrels and disks,
identical in length, $-1.2 < z < 1.2$ m
MAPS area ~15 m^2



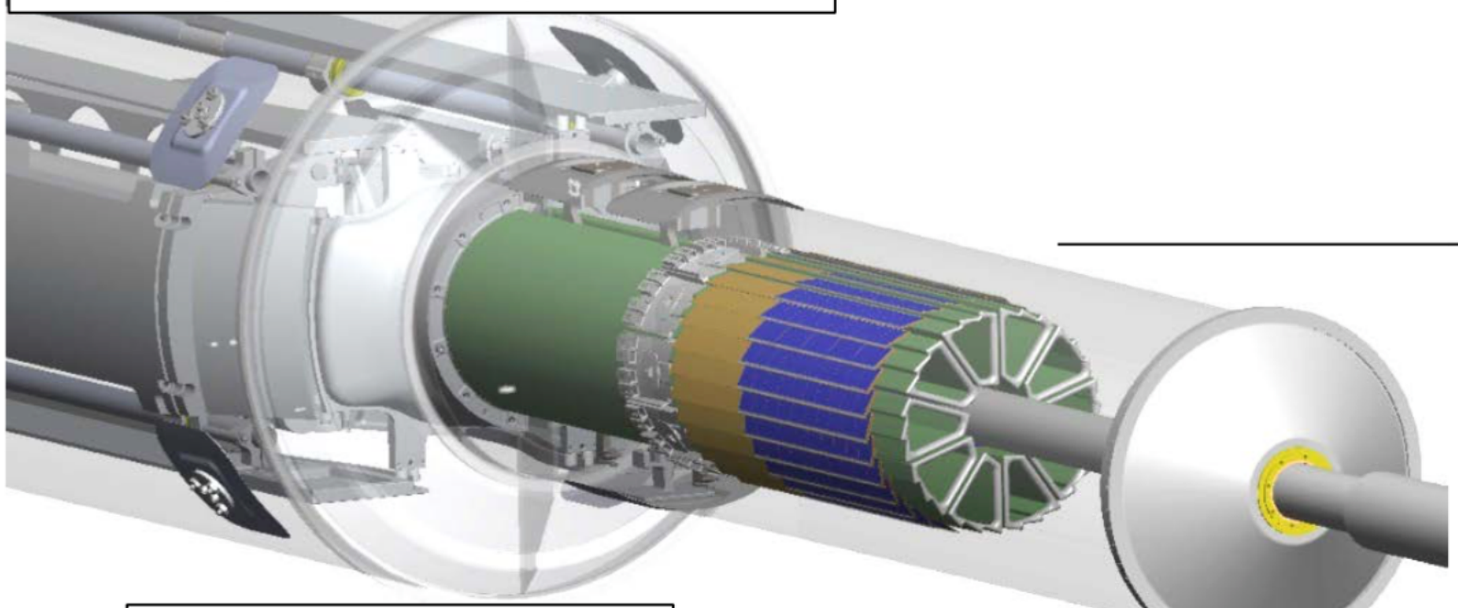
- Similar or better momentum and angular performance,
- Identical vertexing performance,
- Radially more compact, ~80 → ~45 cm,
- Thereby freeing ~35 cm that could be used for alternate purposes such as PID,
- Opportunities for complementary baseline detector concepts,
- Note: the different choices for the number of vertexing layers and disks in the two YR baseline concepts serve to cover the parameter space, not to advocate one over the other.

STAR HFT - first MAPS system at a Collider

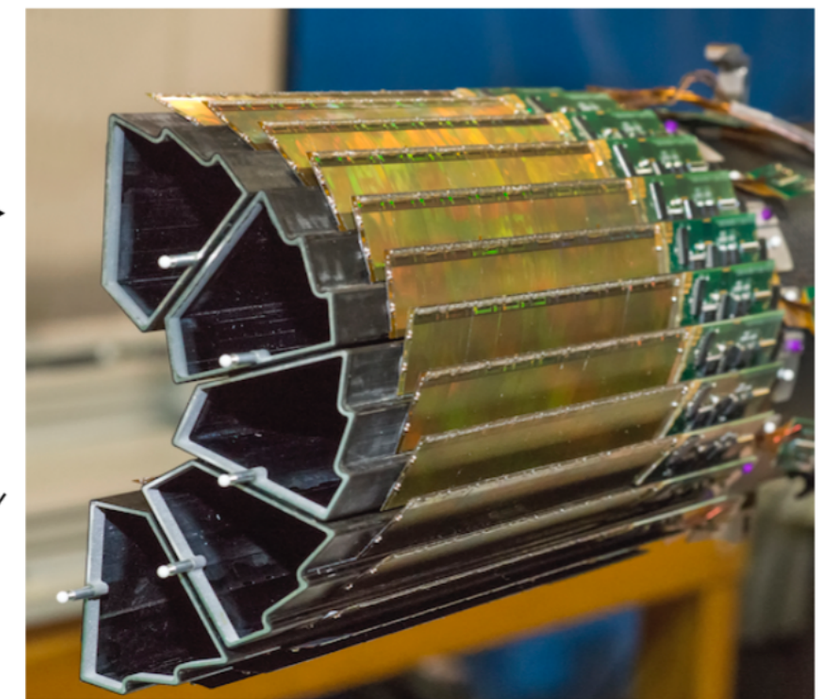
10 sectors total
5 sectors / half
4 ladders / sector
10 sensors / ladder

Highly parallel system

Mechanical support with kinematic mounts (insertion side)



Cantilevered support



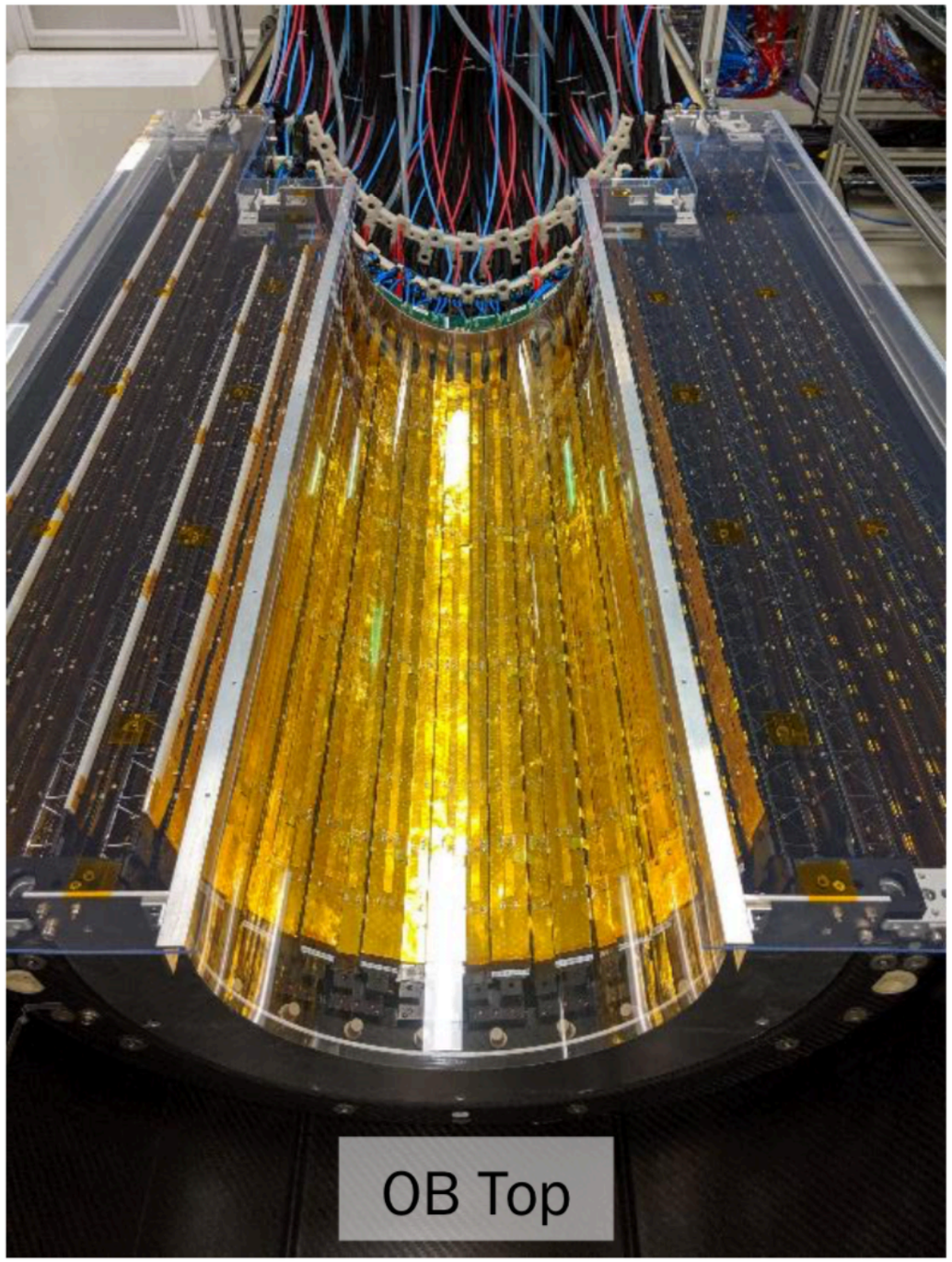
carbon fiber sector tubes (~ 200 μm thick)

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

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

Note - development timeline was/is about 10^{+} years; e.g. sensor development must start now.

ALICE ITS2 - 10m² MAPS at a Collider



Both half-barrels are complete,

Commissioning ongoing,

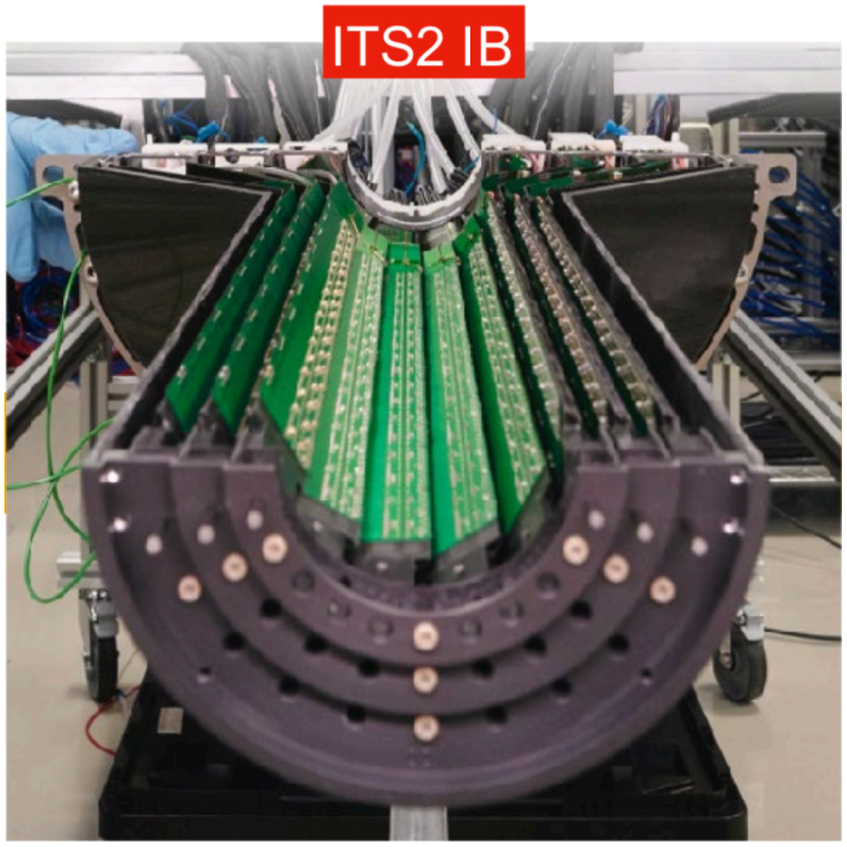
Installation planned for January 2021,

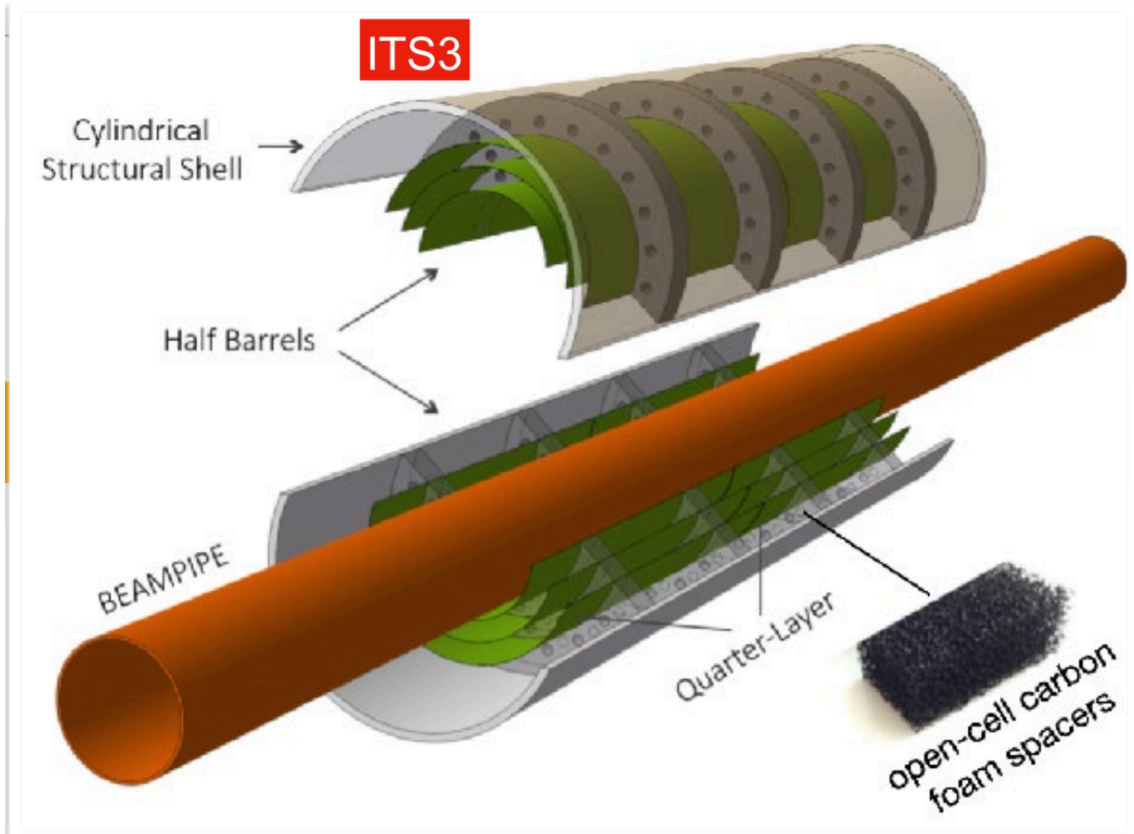
On the cusp of 10m² (!) MAPS deployment in experiment

Courtesy N. Appadula (LBL), EIC-SVT workshop, 2020

ALICE ITS3 - EIC

ALICE collaboration at CERN is looking forward:





Courtesy G. Contin (INFN), EIC-SVT workshop, 2020

Aims to replace the inner-most vertexing layers with a next-generation MAPS instrument based on:

- wafer-scale, up to ~28 × 10 cm (stitched sensors),
- ultra-thin, 20-40 μm, X/X_0 below 0.1%
- curved/bent - r ~18-30mm - MAPS sensors

Strong synergies with EIC goals and a natural branching for EIC (see e.g. L. Greiner YR kick-off mtg),

eRD25 has teamed up with this sensor R&D effort to make a state-of-the-art happen for EIC,

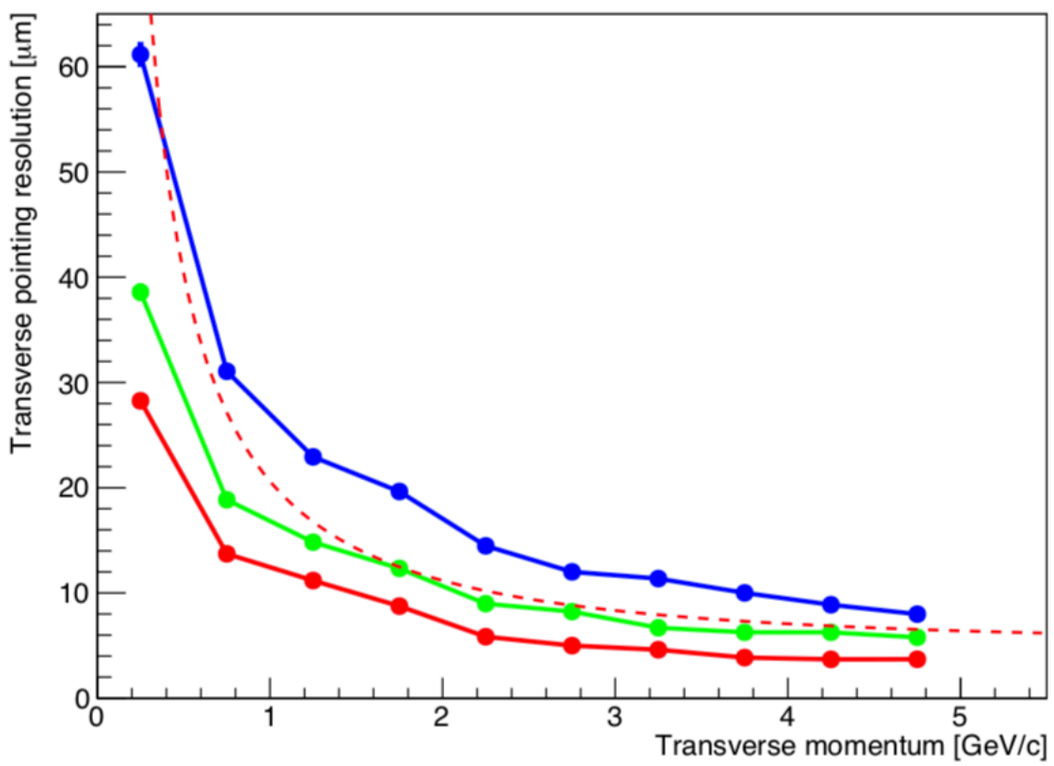
eRD25 is transitioning into an/the EIC-Si consortium, open to new (to this effort) collaborators.

EIC YR – All-Silicon Tracking and Vertexing Concept

Regarding the evolution of the *initial* all-silicon concept to the current YR baseline:

Pre-CD0 simulations by eRD16 and eRD18 based on BeAST assumed

- A beam pipe radius of 18 mm
- An ITS2-derived detector concept with 0.3/0.8% X/X0 in vertex/tracking layers and a 20 um pixel pitch
- Note that a pixel pitch of 20 um is NOT the ALPIDE, ALPIDE has ~28um pitch.
- With the post-CD0 beam pipe radius of 31 mm, initial simulations highlighted the need for ITS3 like spatial resolution and material budget to reach required vertex resolution



	Green	Blue	Red (ITS3-derived EIC SVT)
Beam pipe radius [mm]	18	31	31
x/X0 vertex	0.3%	0.3%	0.05%
x/X0 tracking layers	0.8%	0.8%	0.8%
Pixel pitch [um]	20	20	10

Pions, momentum range up to 5 GeV/c
$-0.5 < \eta < 0.5$
Uniform 1.5T magnetic field

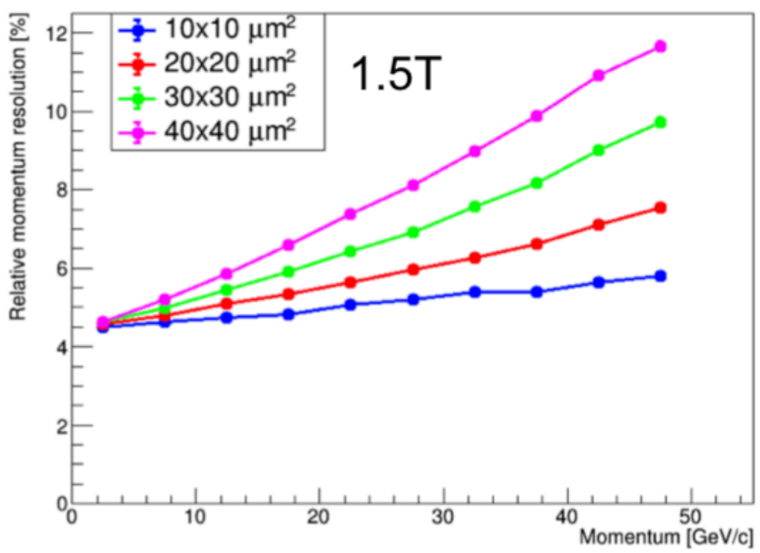
--- YR PWG requirement

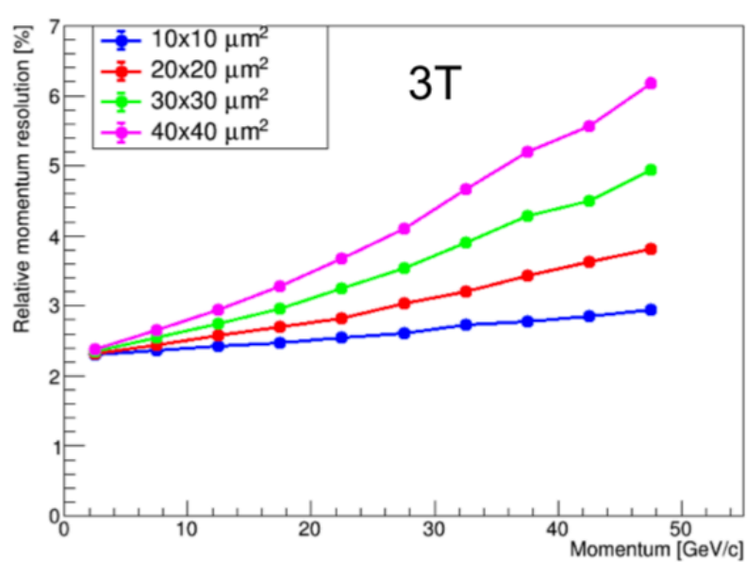
Motivation for 10μm pixel pitch (reduced from 20μm in the initial concept).

EIC YR – All-Silicon Tracking and Vertexing Concept

Regarding the evolution of the *initial* all-silicon concept to the current YR baseline:

- GEANT-based simulations demonstrate that dp/p at high p can be materially improved with 10μm pixel pitch,





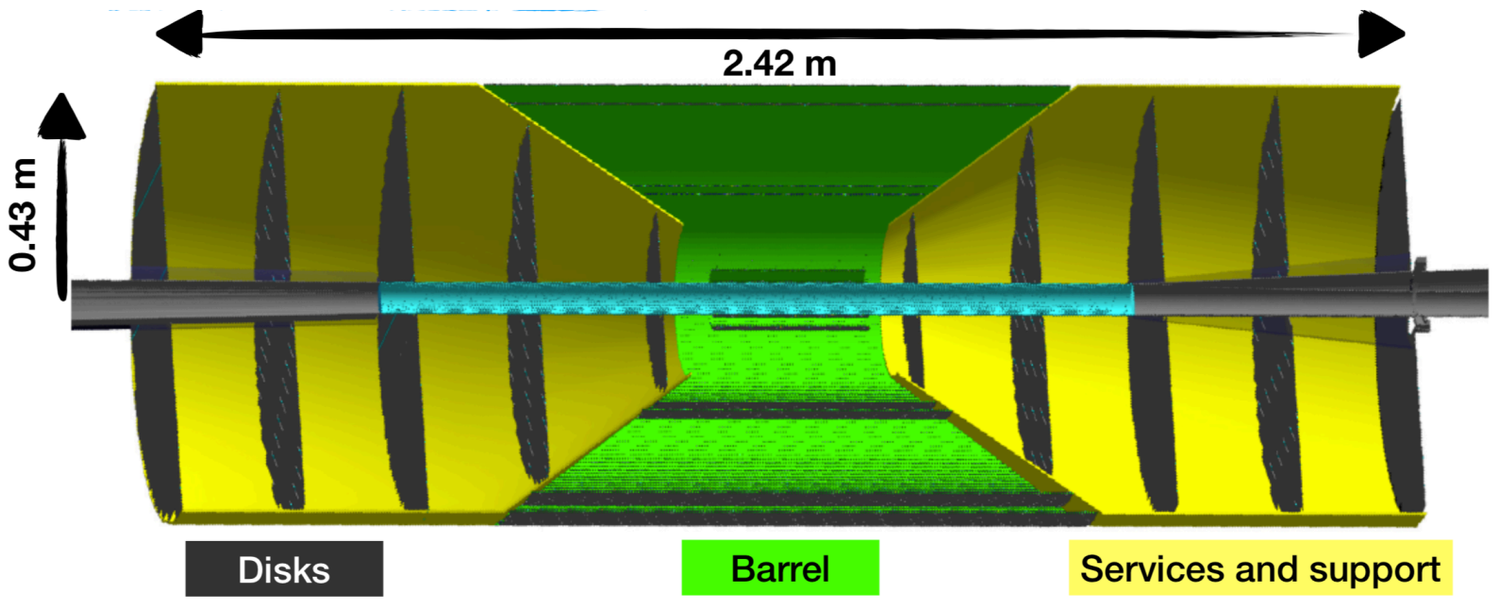
Forward region; η = 3
Single electrons fired from centre
Magnetic field: uniform 1.5 T and 3 T
Vertex layers and disks: 0.3% x/X0
Tracking layers: 0.8% x/X0
All disks hit

See H. Wennlöf at
https://indico.jlab.org/event/400/contributions/6529/ and
http://cern.ch/go/xKk6

Motivation for 10μm pixel pitch driven by more stringent YR physics requirements,

Note the “floor” in dp/p is driven by traversed material budget (!).

EIC YR – All-Silicon Tracking and Vertexing Concept



Barrel layer	radius [cm]	length along z [cm]
1	3.30	30
2	5.70	30
3	21.00	54
4	22.68	60
5	39.30	105
6	43.23	114

Disk number	z position [cm]	outer radius [cm]	inner radius [cm]
-5	-121	43.23	4.41
-4	-97	43.23	3.70
-3	-73	43.23	3.18
-2	-49	36.26	3.18
-1	-25	18.50	3.18
1	25	18.50	3.18
2	49	36.26	3.18
3	73	43.23	3.50
4	97	43.23	4.70
5	121	43.23	5.91

10 μm pixel pitch, $x/X_0 = 0.3\%$ per layer, disk

~15 m^2 MAPS in this configuration (ALICE ITS2 has ~10 m^2)

Note,

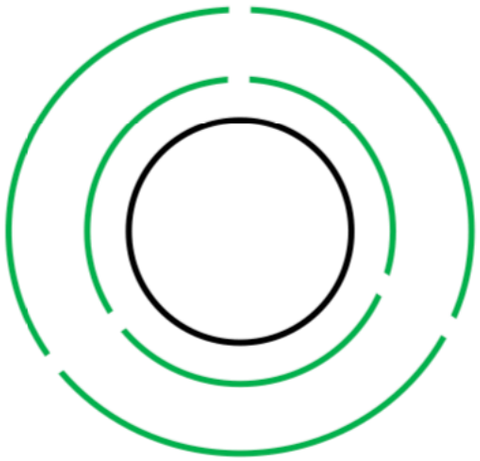
- the hybrid concept has 3 vertexing layers, whereas the all-silicon concept has 2; vertexing resolution is near-identical, however, differences exist in threshold and redundancy,
- the all-silicon concept has 2 x 5 disks, whereas the hybrid has 2 x 7, again spanning the range from prior eRD16 and eRD18 work,
- the outer radius was originally chosen such that dp/p for ***20*** µm pixel pitch is similar to dp/p of the hybrid concept for $-1 < \eta < \sim 1$

Rey Cruz-Torres et al., https://indico.bnl.gov/category/276 and Yellow Report Ch 11.

EIC YR – All-Silicon Tracking and Vertexing Concept

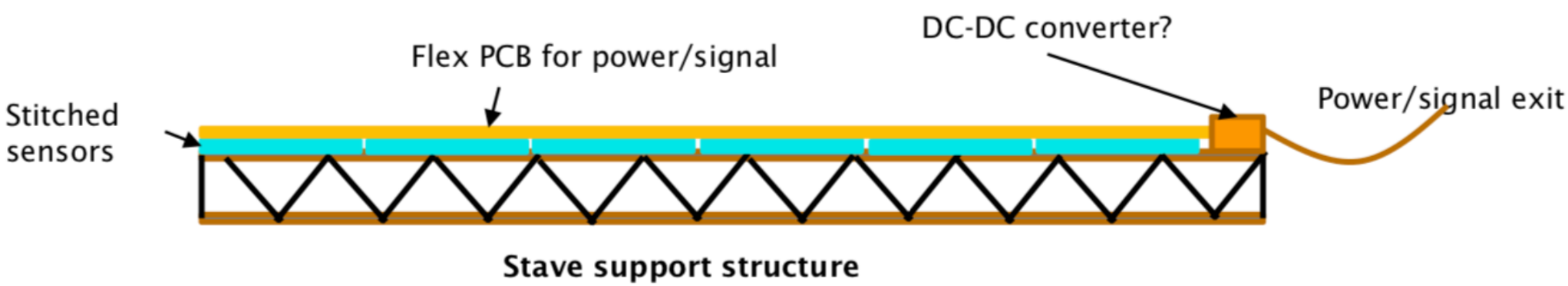
Vertexing inner layers:

- Use ITS3 sensor
- Adapt ITS3 detector concept to different length and radii of the EIC vertex layers

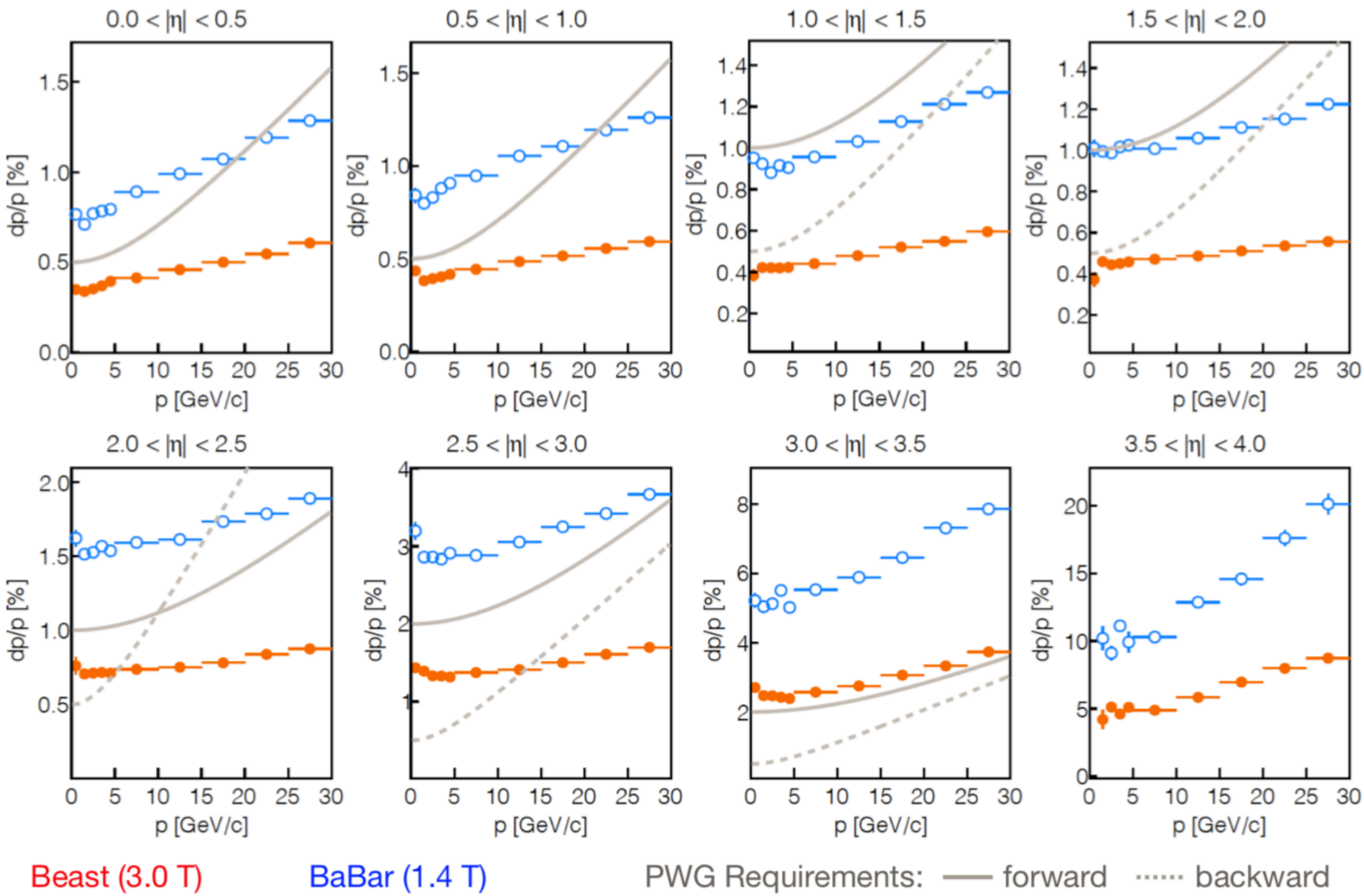


Tracking layers and disks:

- Staves and discs will be based on a forked EIC specific sensor design based on the ITS3 sensor,
- The primary concern is yield for long rows of stitched sensors. The eRD25 plan is to assess yield in the first engineering run and adjust the EIC sensors to optimize yield for the number of stitched sensors in a row,
- Staves and disks will need to optimize the stitched sensor layout on the wafers to provide the right number of stitched sensor lengths to give the proper needed lengths for each stave/disc. This will need further study and optimization.



EIC YR – All-Silicon Tracking and Vertexing Concept

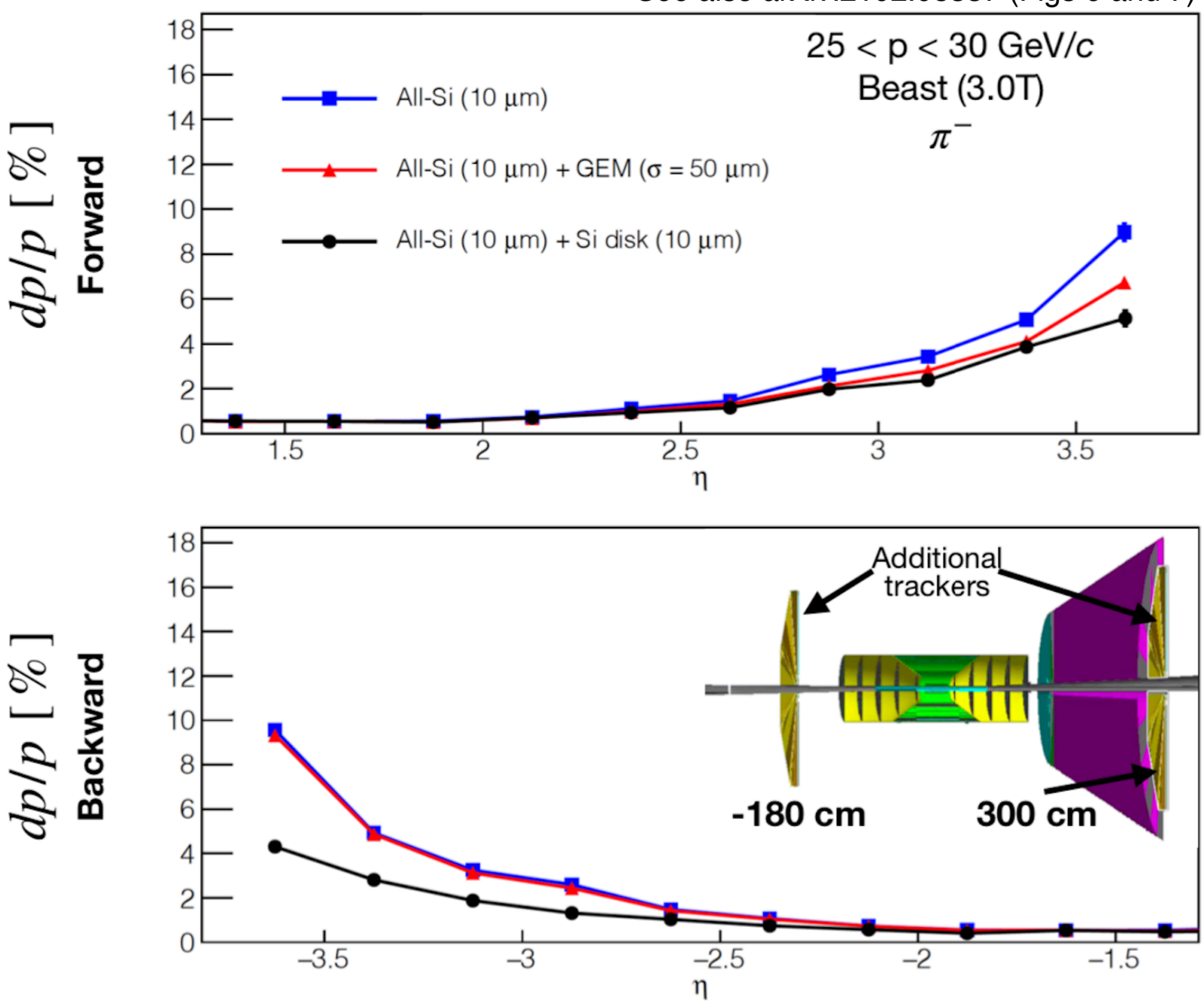


Physics requirements (YR table 10.6) present a challenge in the forward regions, despite the low traversed mass and 10μm pixel pitch.

EIC YR – All-Silicon Tracking and Vertexing Concept

Initial studies were made to address this challenge:

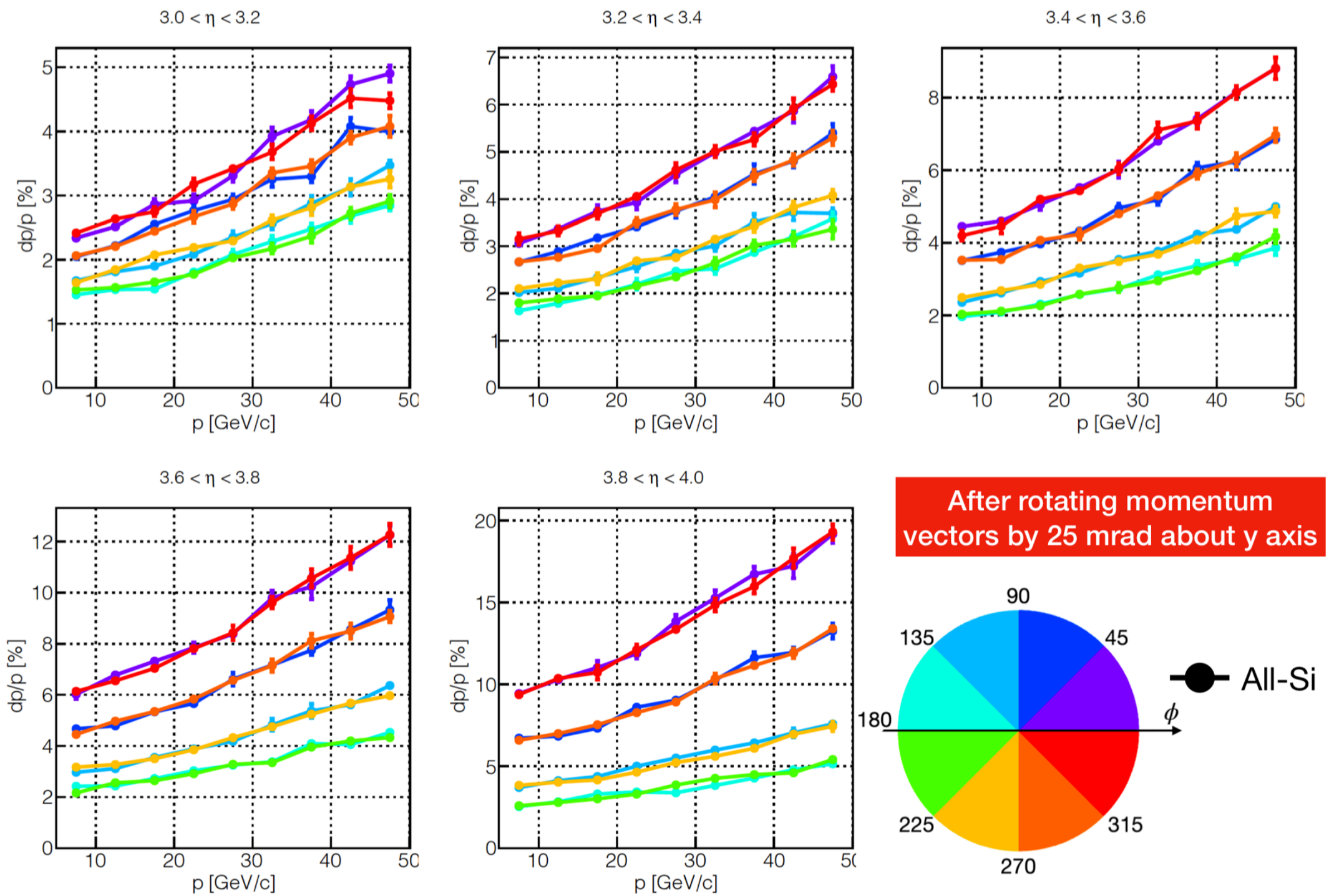
See also arXiv:2102.08337 (Figs 6 and 7)



An additional large-*z* detection layer would benefit PID with a forward RICH.

Note: this will materially depend on the shape of the magnetic field.

EIC YR – All-Silicon Tracking and Vertexing Concept

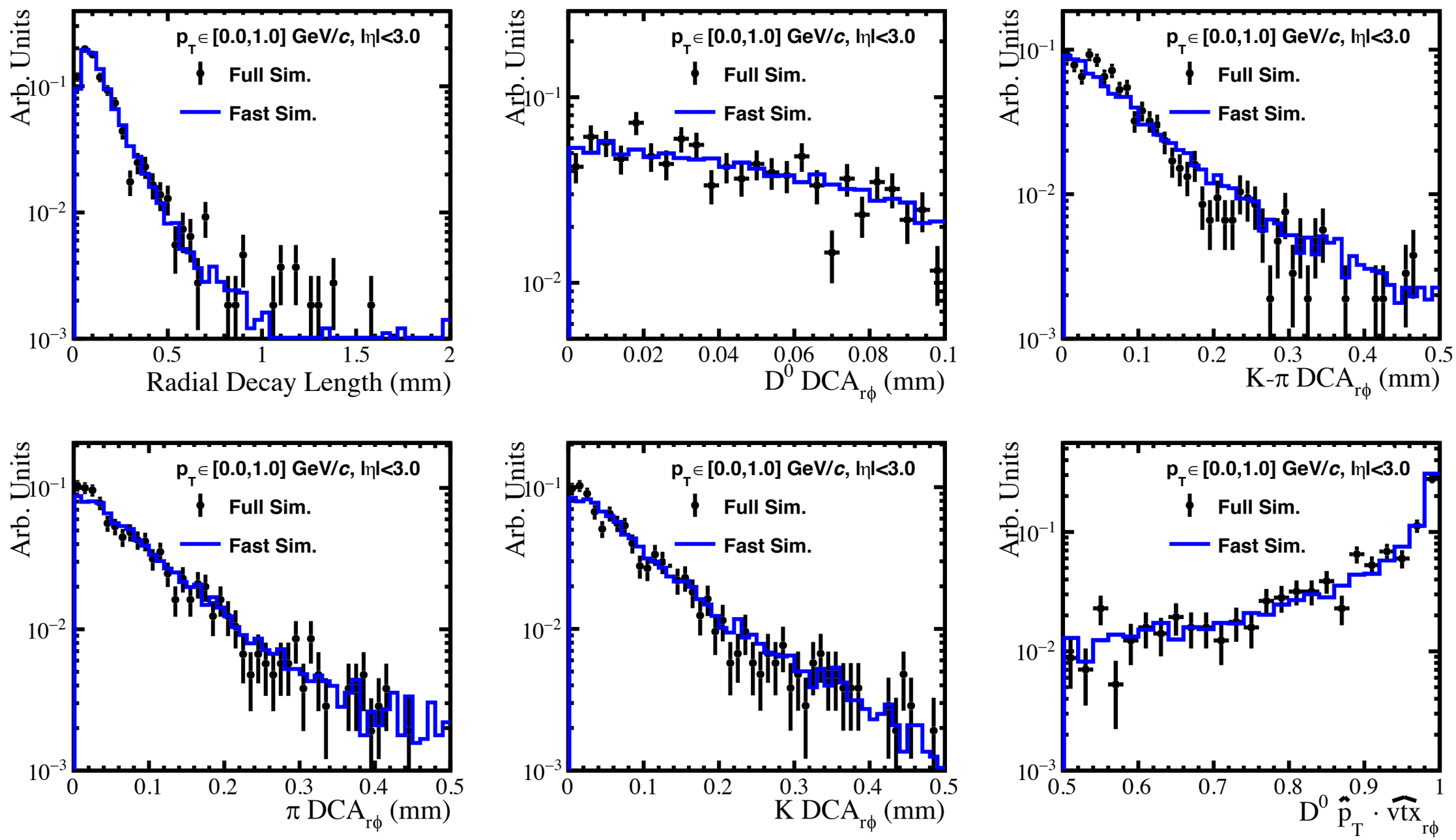


Note, 20 μm pixel pitch in these simulations corresponding to ~ 6 μm point resolution

Note, *not* part of *current* fast-simulation tools and *most* (*not* all) YR (physics) studies.

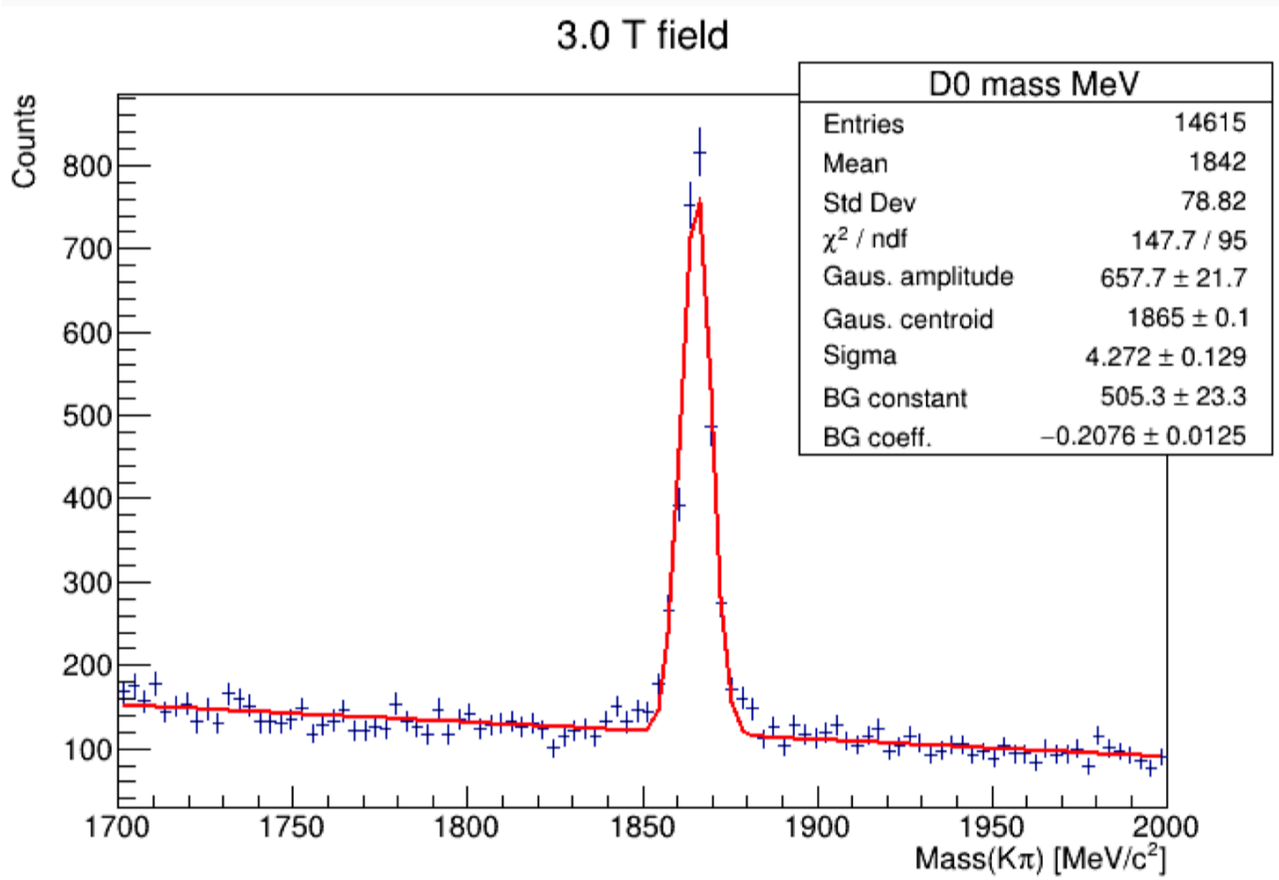
EIC YR – All-Silicon Tracking and Vertexing Concept

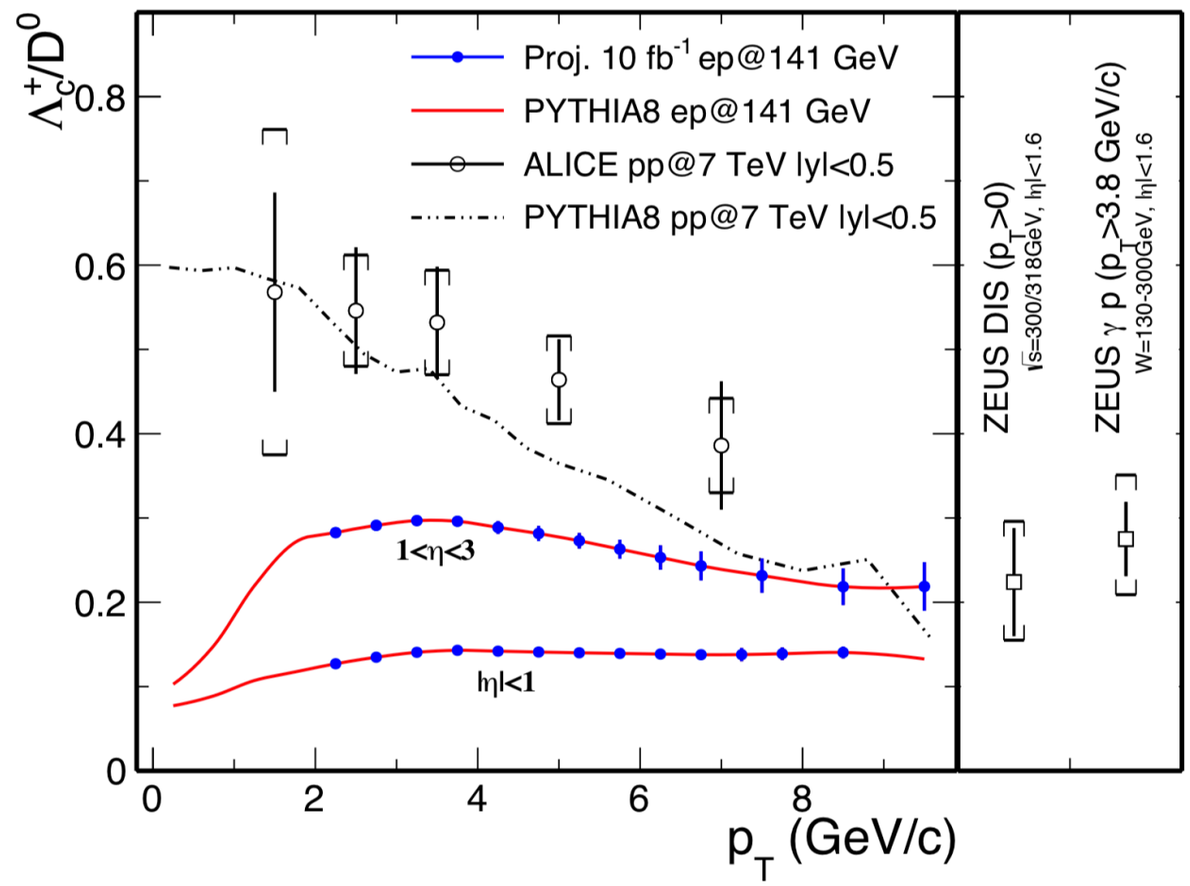
GEANT-based simulations were used to extend the “fast” simulation framework – used for most physics studies in the Yellow Report – with decay topological variables,



Not currently part of standard EICsmear, but part of fast-simulation studies in arXiv:2102.08337.

EIC – Physics studies with both tracking concepts





GEANT-based and “fast” simulations were both used to study a range of physics topics, including e.g. F_2-charm, the baryon to meson ratio, and others,

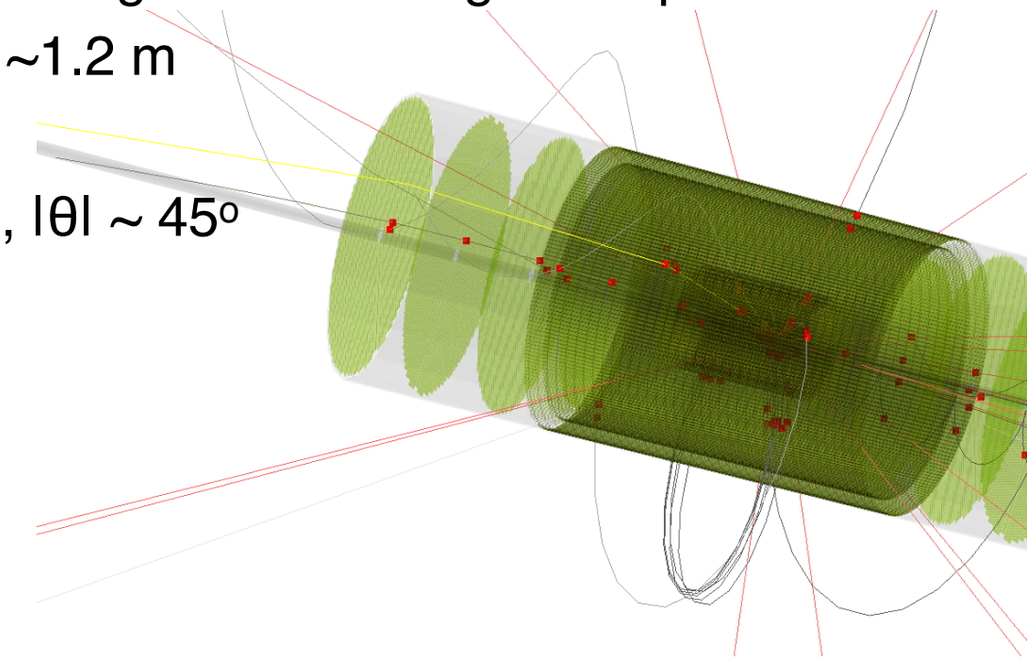
- EIC Yellow Report,
- John Arrington et al, arXiv:2102.08337,
- Håkan Wennlöf, Ph.D. thesis (in preparation).

A wealth of information on performance and R&D may be found also at:

- 1st – 4th EIC Yellow Report Workshop - https://indico.bnl.gov/category/220/
- Tracking Working Group - https://indico.bnl.gov/category/276/
- Jets and Heavy Quarks Working Group - https://indico.bnl.gov/category/290/

Closing Comments

- Physics-driven considerations for a viable EIC all-silicon tracking and vertexing concept:
  - 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,
  - scale ~10 m^2 (barrels) + ~5 m^2 (disks),



- R&D:
  - MAPS in high-energy nuclear physics collider experiment pioneered with STAR HFT-PXL,
  - 10m^2 second-generation MAPS instrument installed in ALICE,
  - R&D program for next MAPS generation based 65nm technology started for/with ALICE-ITS3,
  - Strong synergies with EIC goals and natural branching,
  - eRD25 and EIC silicon consortium initiated - IR-agnostic and open to new collaborators,
  - Aim for state-of-the-art and day-1,
  - Comprehensive overview: https://wiki.bnl.gov/conferences/images/3/36/ERD25-Mar20-final.pdf

- Simulations:
  - Fast simulations (event smearing) - successful for the YR, but a mixed bag going forward imho,
  - GEANT-based studies in EICroot, Fun4All for 1.4T and 3.0T fields with a start on infrastructure.