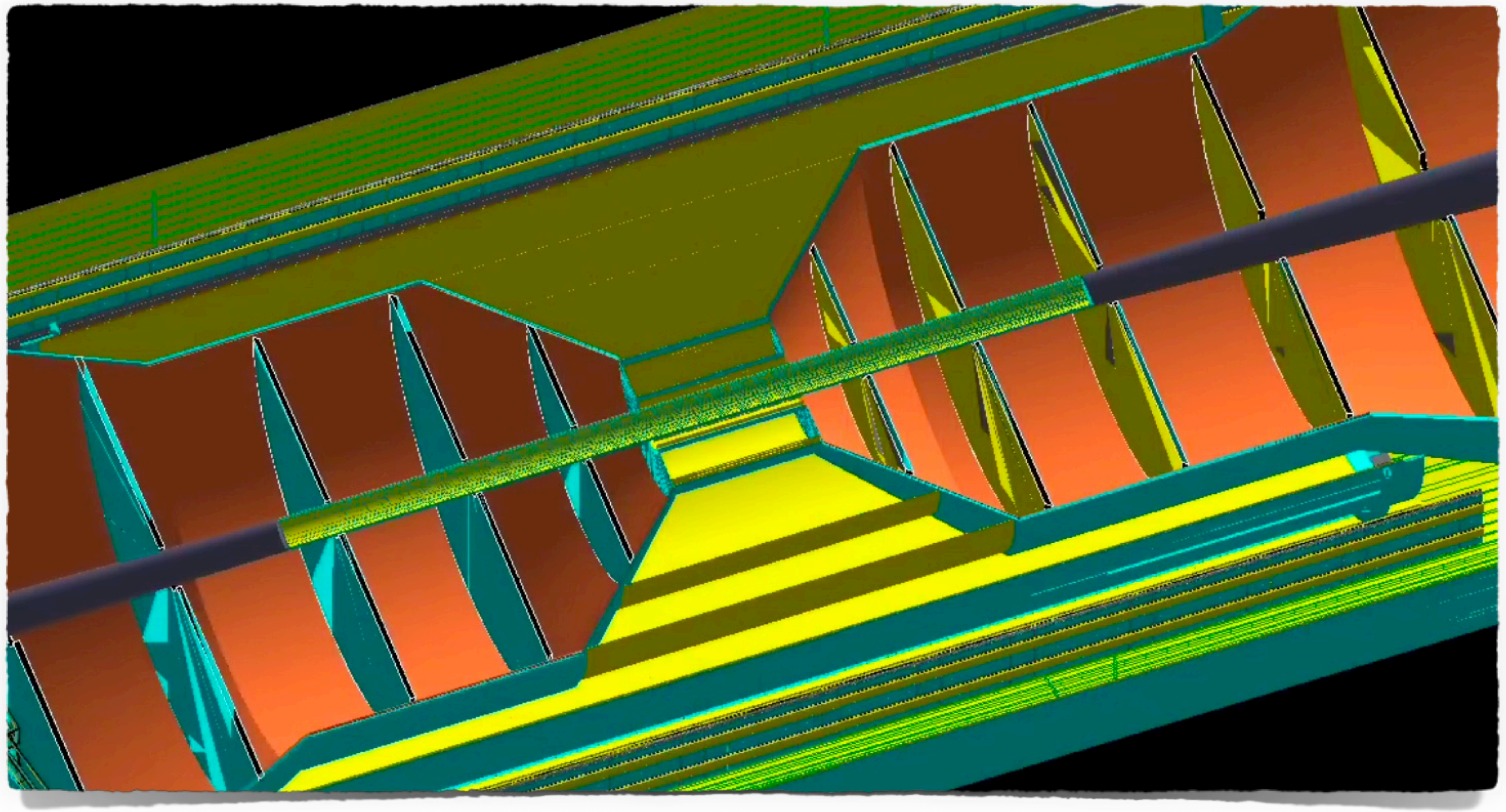
MC studies to optimize pixel tracker



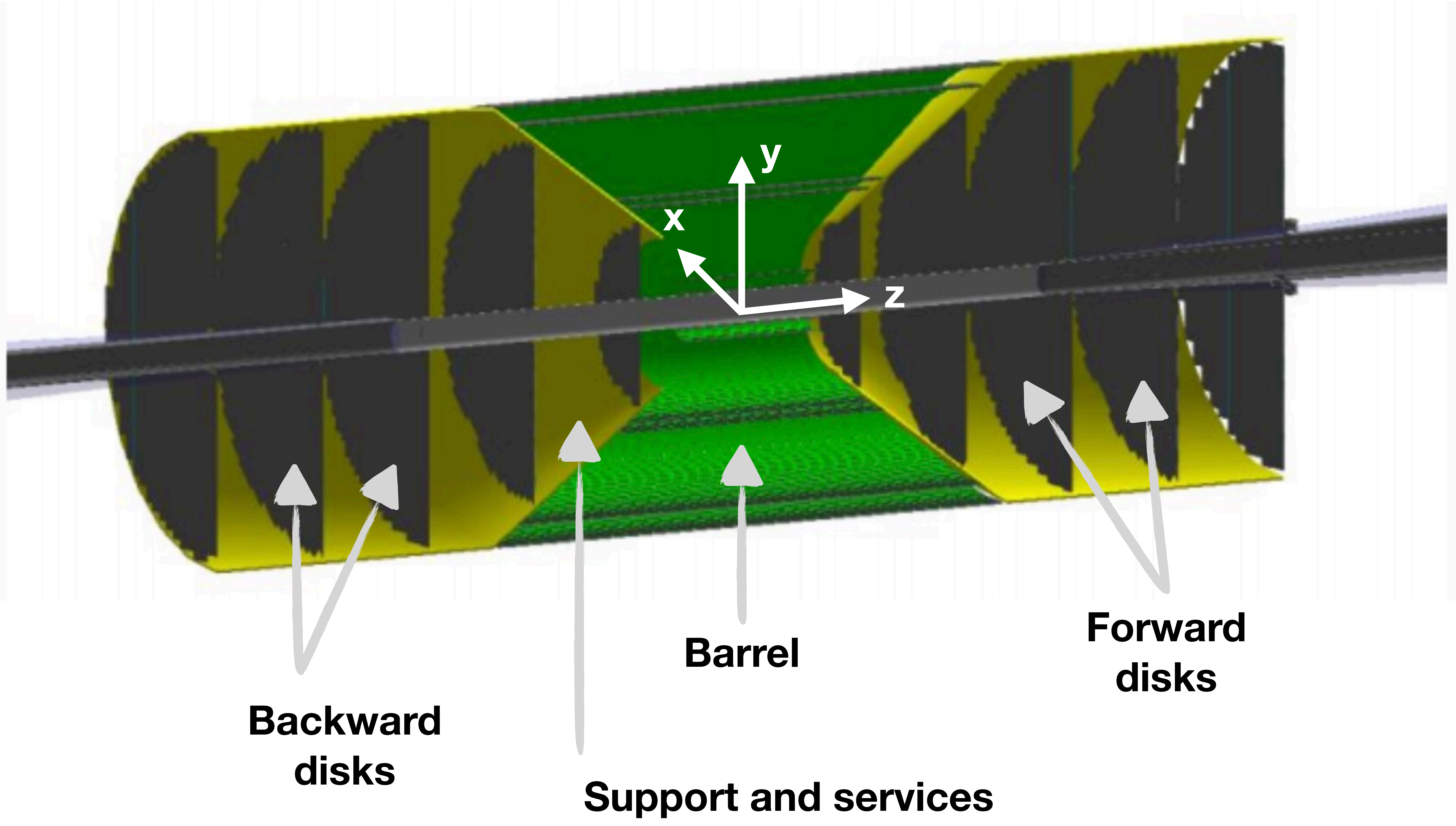
Reynier Cruz-Torres
July 19th, 2022

California EIC Consortium Meeting
UCDAVIS

EIC tracker

- measures:
  - charged-particle momentum and direction
  - primary and secondary vertices
- aids in PID

Original LBNL MAPS-based all-silicon tracker concept designed and implemented in Geant by **Y.S. Lai** and **E. Sichtermann** (circa 2019)



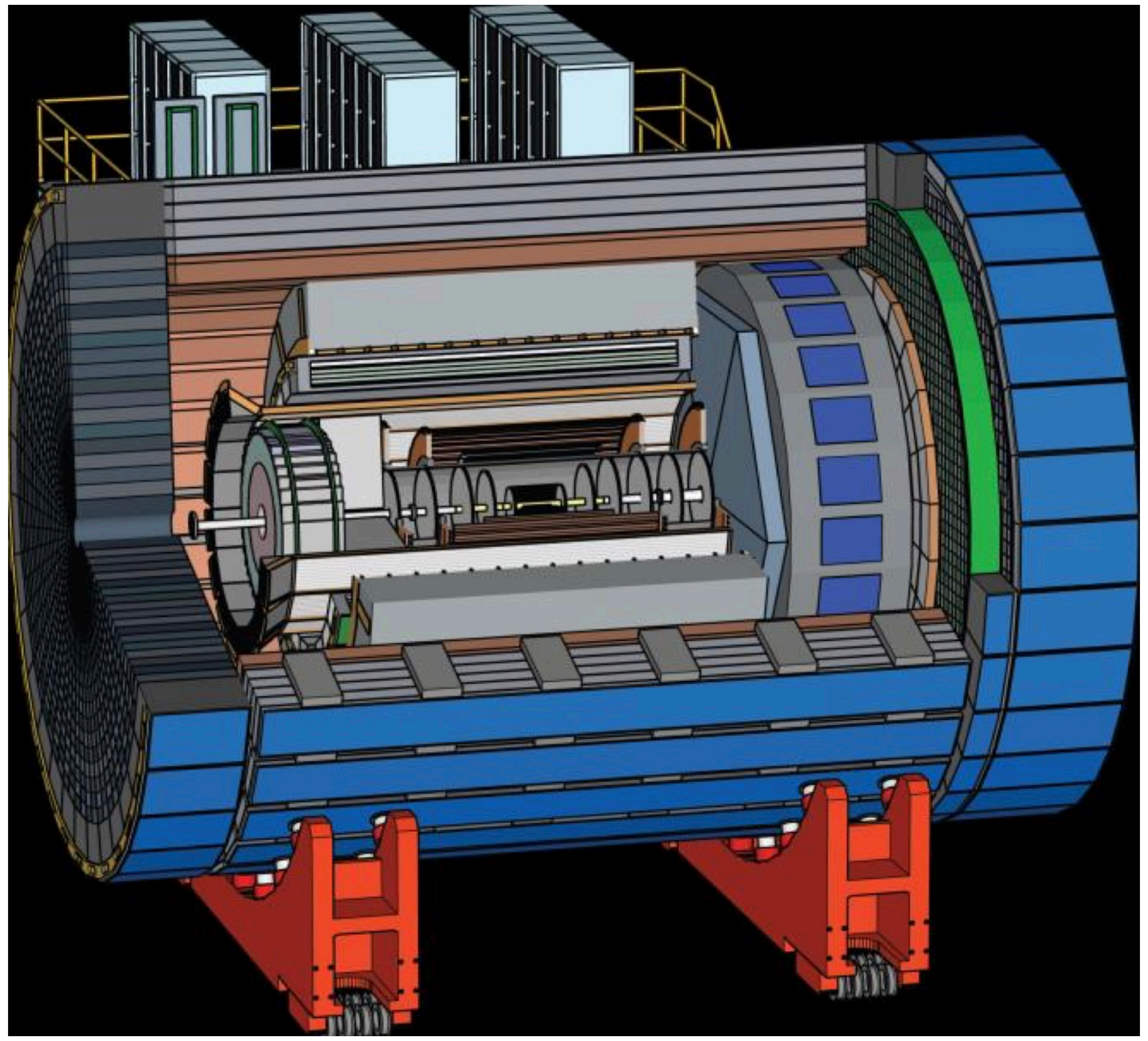
requirements for an EIC tracker:

- hermetic
- compact
- low-material budget
- excellent performance

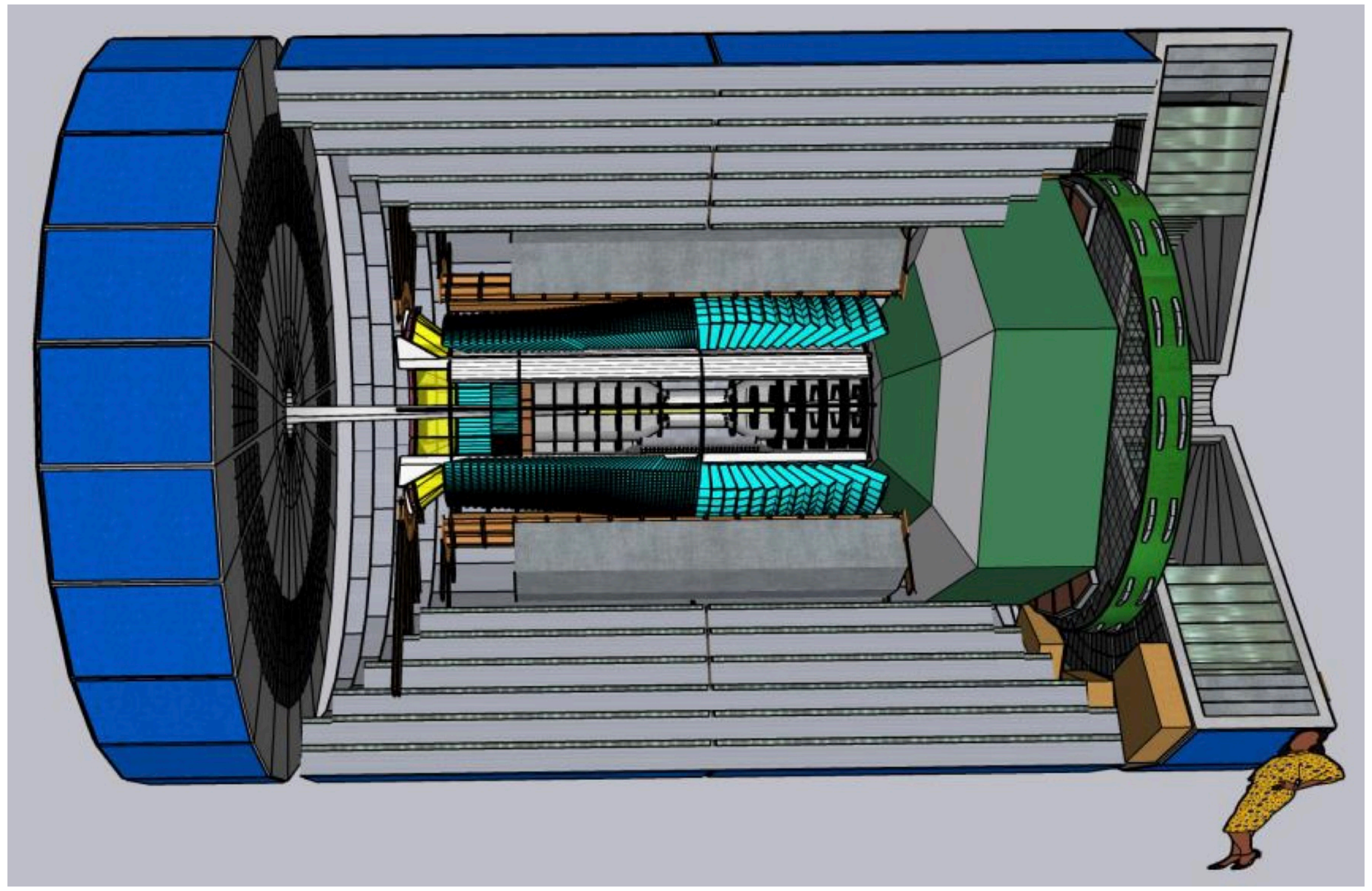
Forward $\equiv +\hat{z}$ $\equiv$ hadron direction
Backward $\equiv -\hat{z}$ $\equiv$ electron direction

MAPS-based trackers are at the center of all EIC detector concepts...

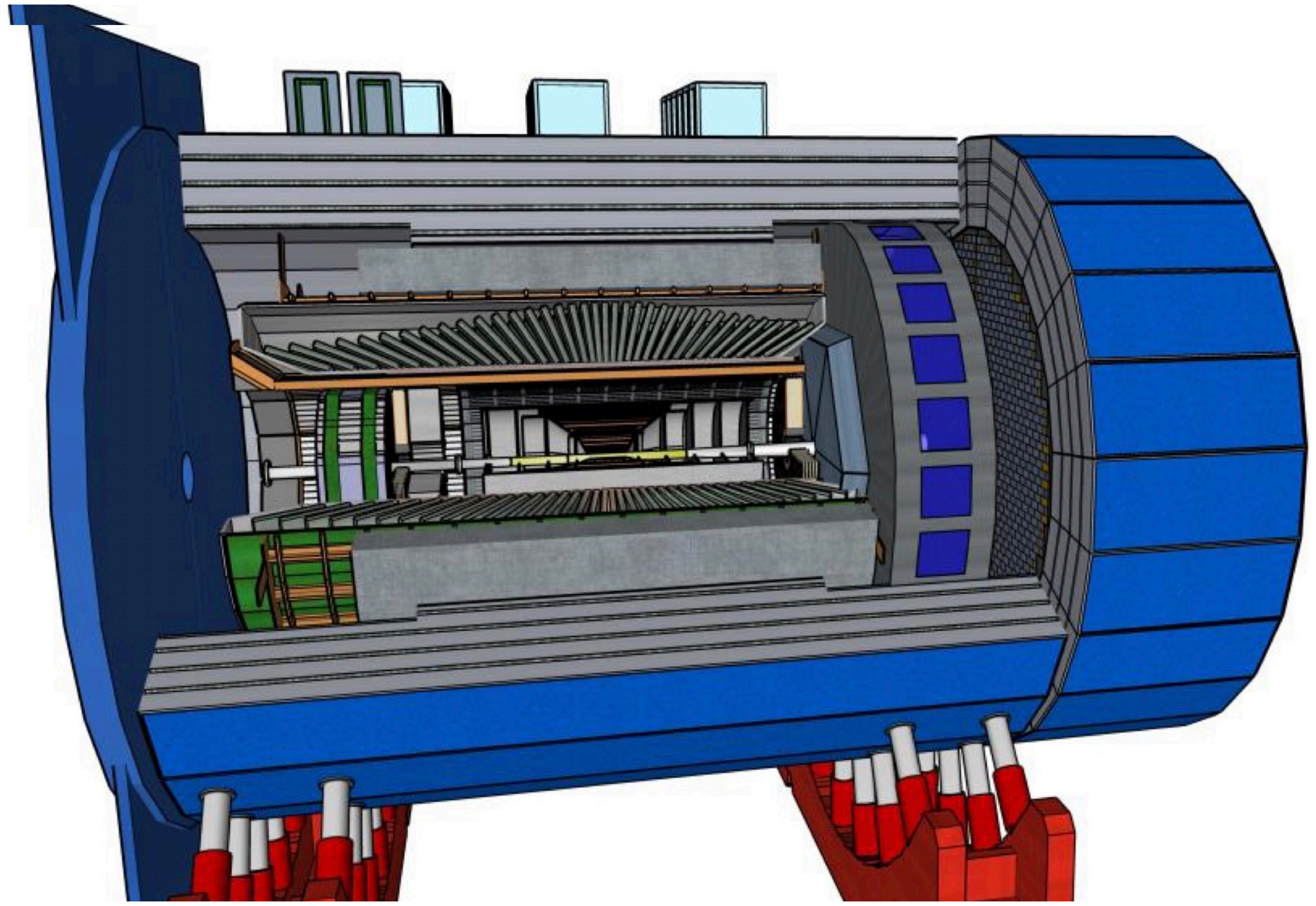
ATHENA



CORE

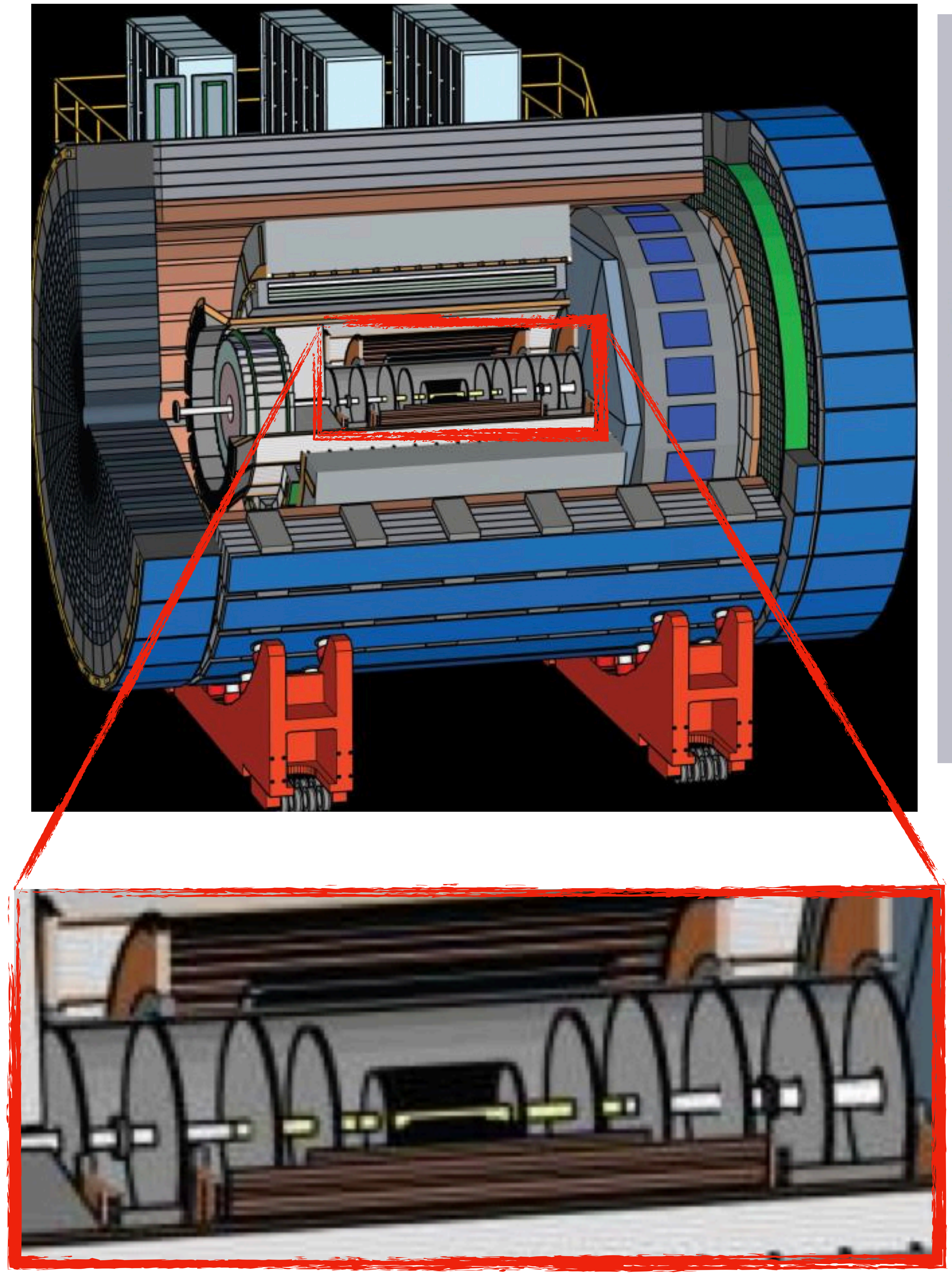


ECCE



MAPS-based trackers are at the center of all EIC detector concepts… literally

ATHENA



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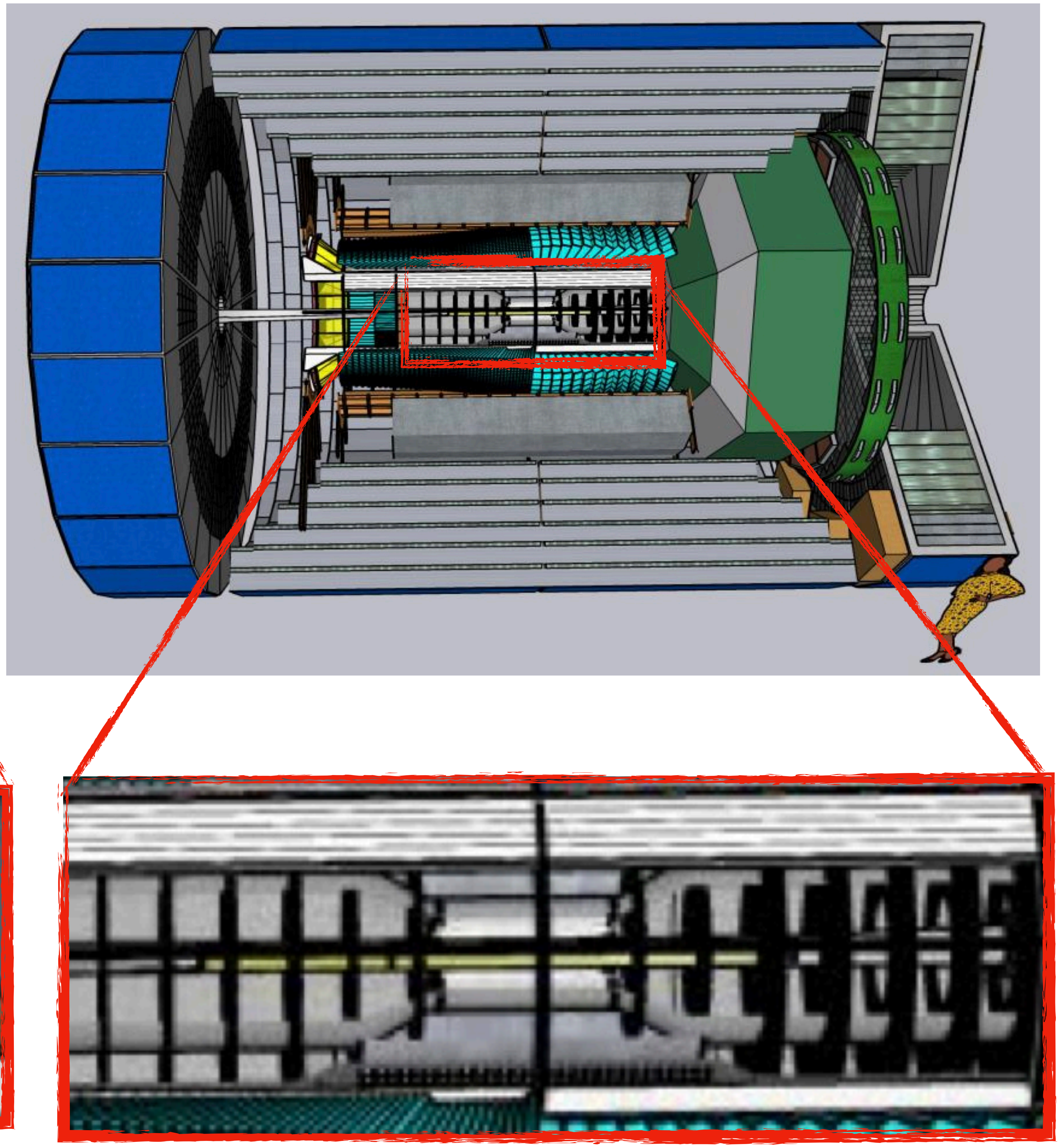

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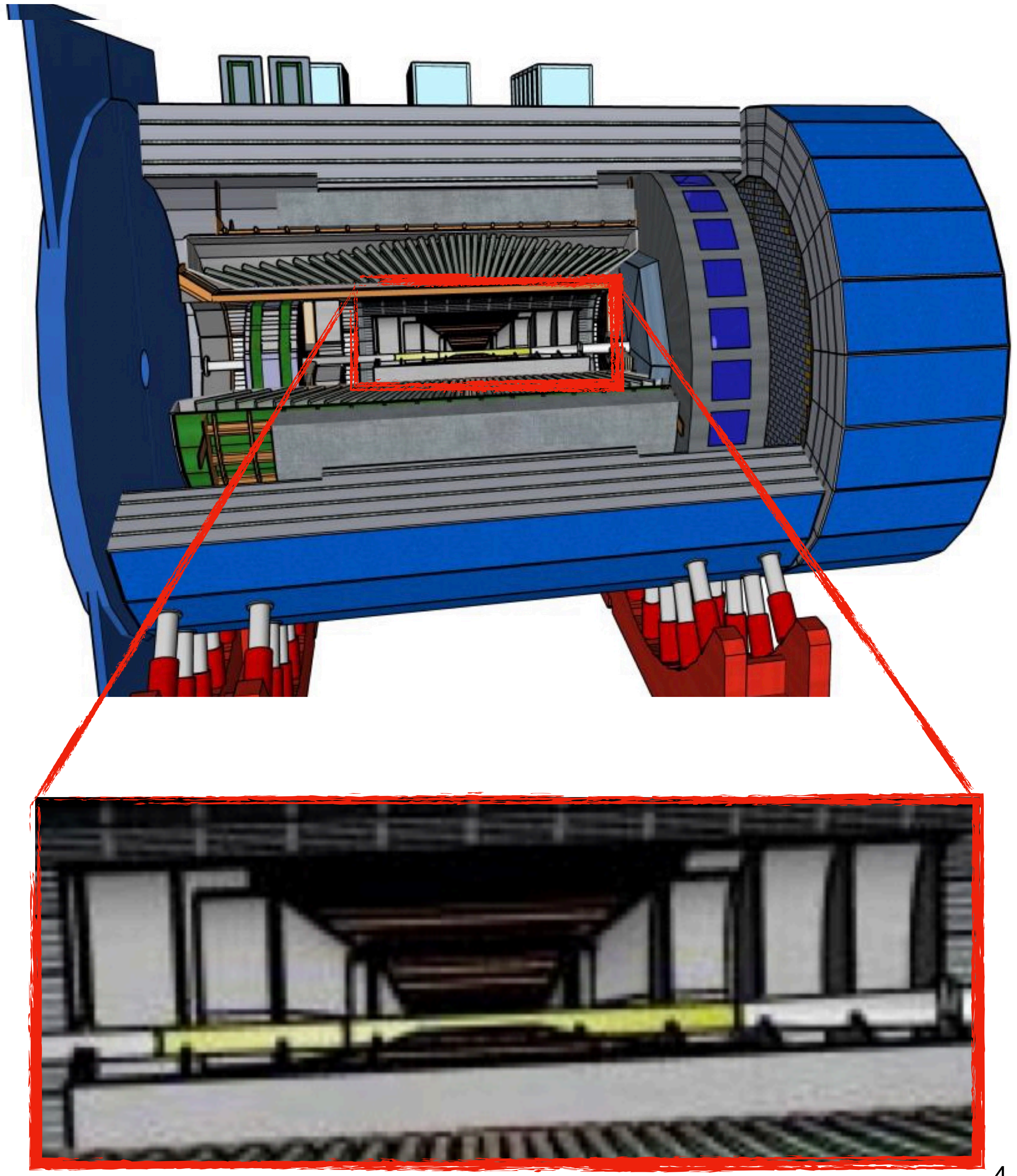

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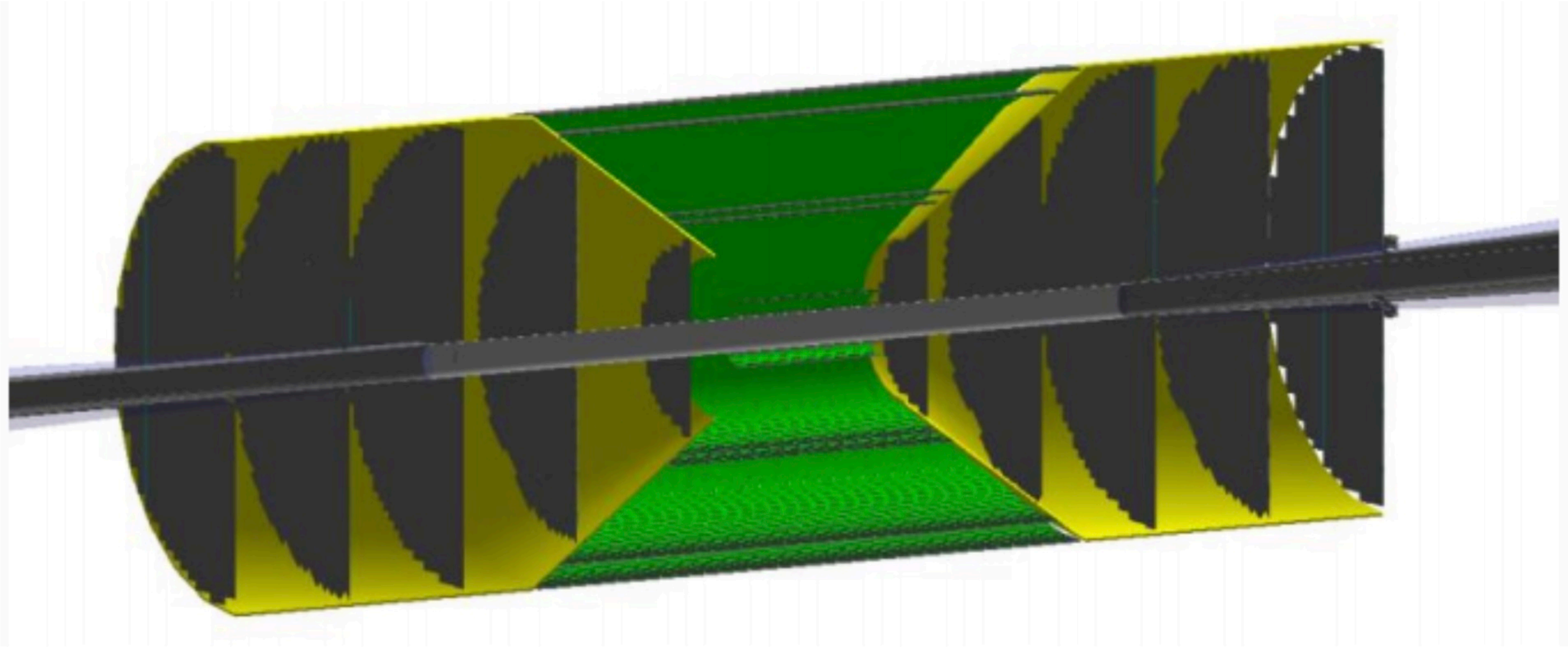

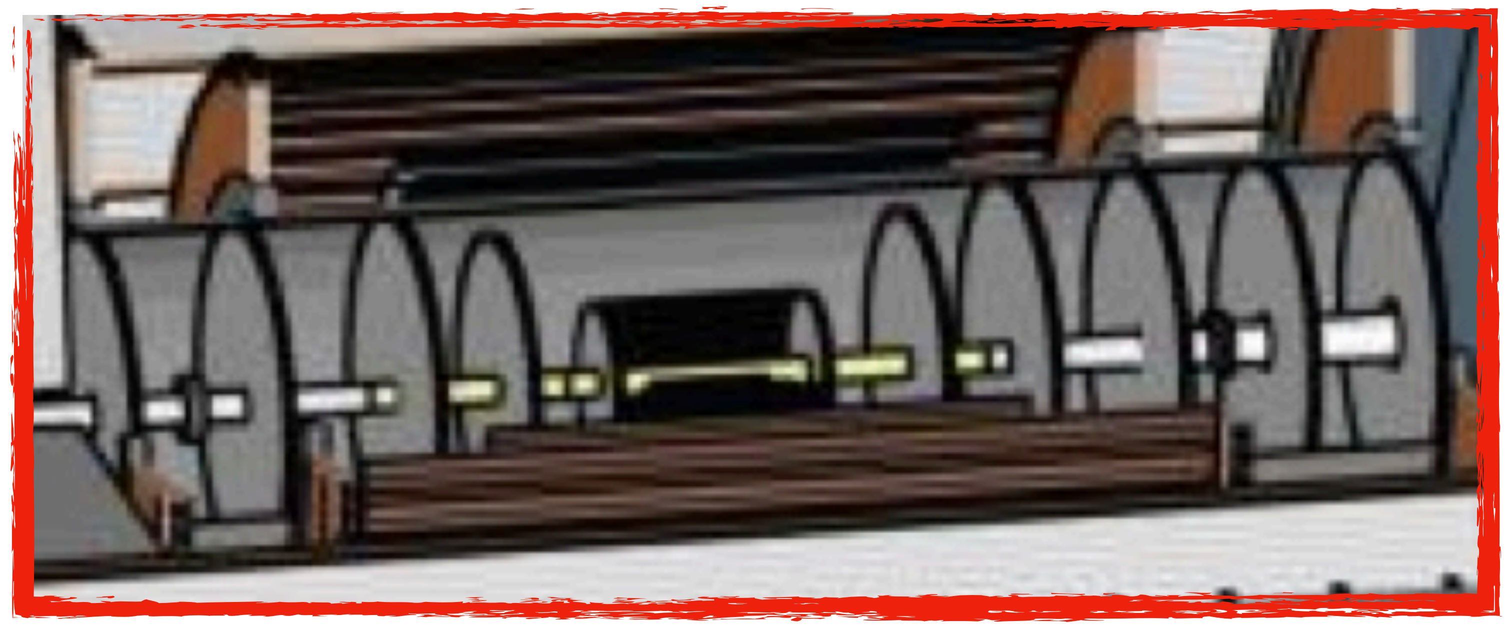

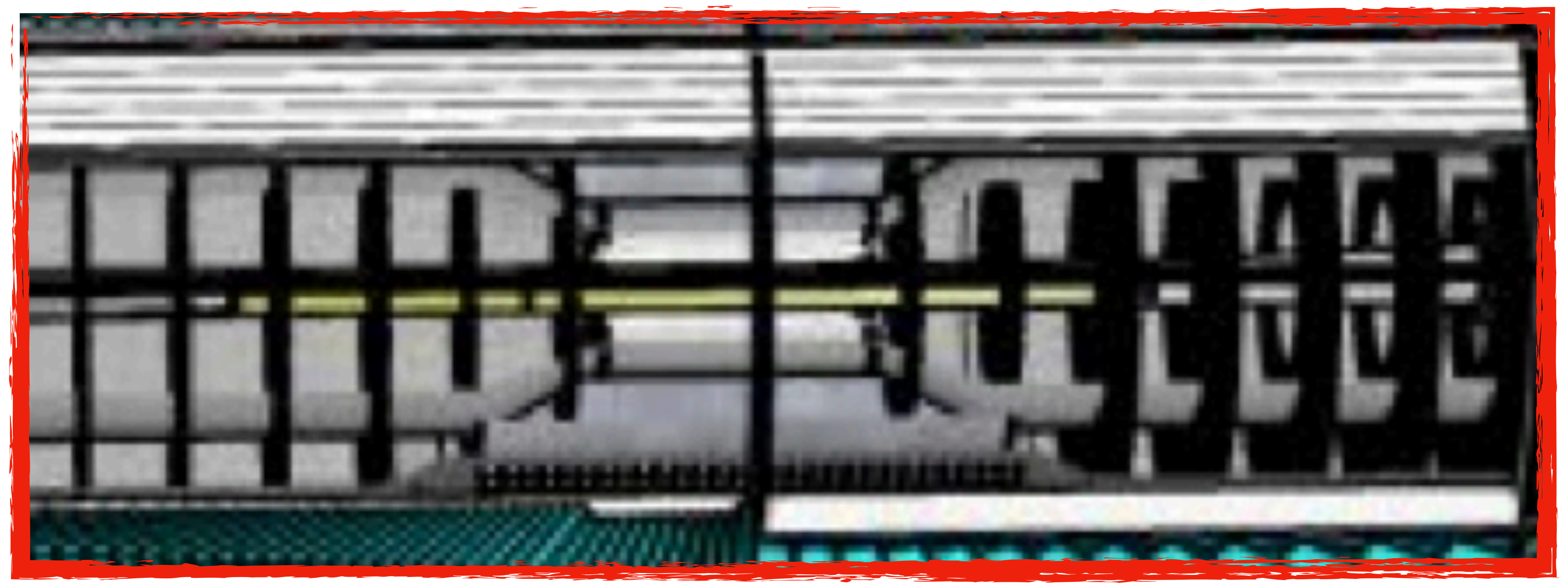

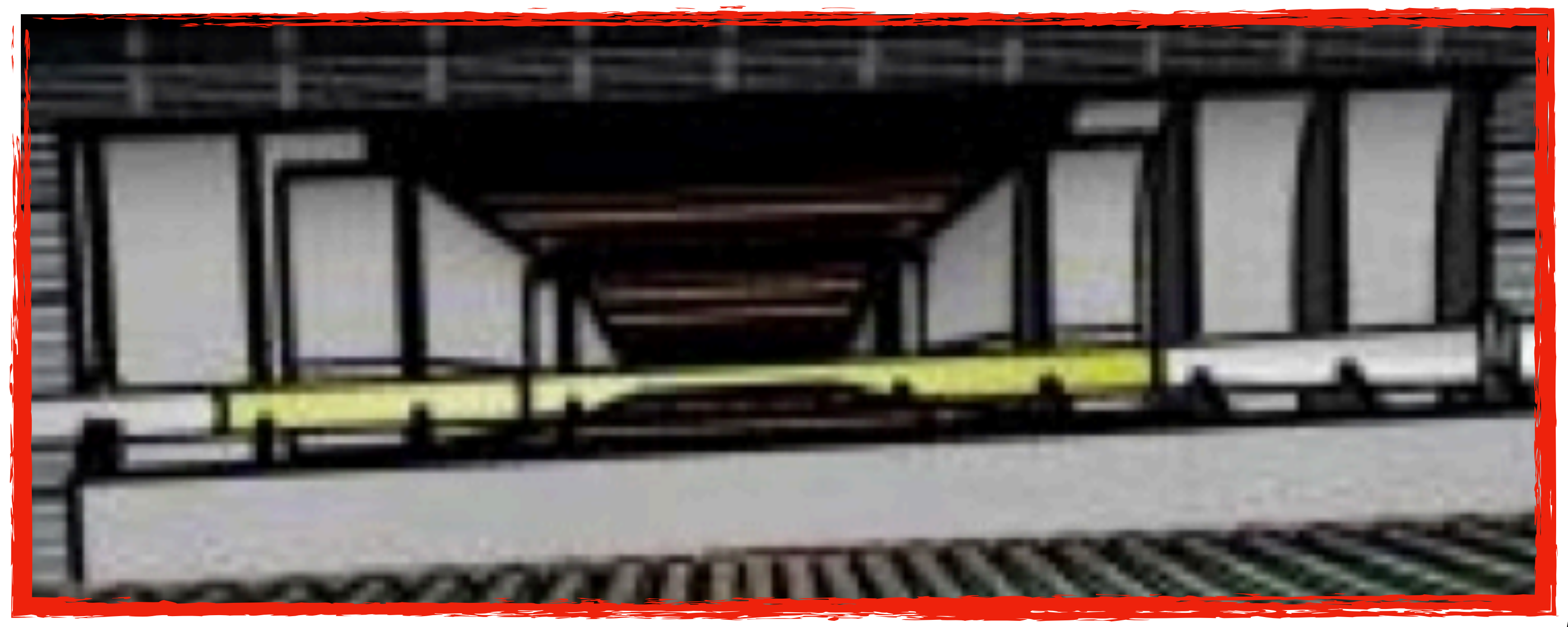

Some of Berkeley's tracking work since 2020

- Geometry implementation in EICroot (Y.S. Lai, E. Sichtermann)
- Geometry implementation in Fun4All (D. Dixit)
- Characterization of concept performance (both fast and full simulations) (E. Sichtermann, Y. Song, W. DeGraw)
  - Momentum resolution
  - Angular resolution (at vertex and at PID detectors)
  - Distance of closest approach (DCA) and vertexing resolution
  - Studies carried out with different particle species and jets (F. Torales Acosta)
  - Pixel-size scan
- Geometry optimization
  - Barrel, disks, support and services
  - Overall detector length and radius
- Study of crossing-angle effects
- Material-budget parametrization (L. Greiner)
- Exploration of hybrid concepts
  - Large r/|z| MPGDs
- Characterization of material budget and material impact on detector performance
- Comparison with different magnet concepts
- Comparison to fast simulations and benchmarks of DD4HEP-based simulations (W. Fan, S. Li, E. Sichtermann)
- Contributions to YR
  - Performance parametrizations
  - All-silicon tracker section
- arXiv:2102.08337
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- Optimizing detector-1 tracker

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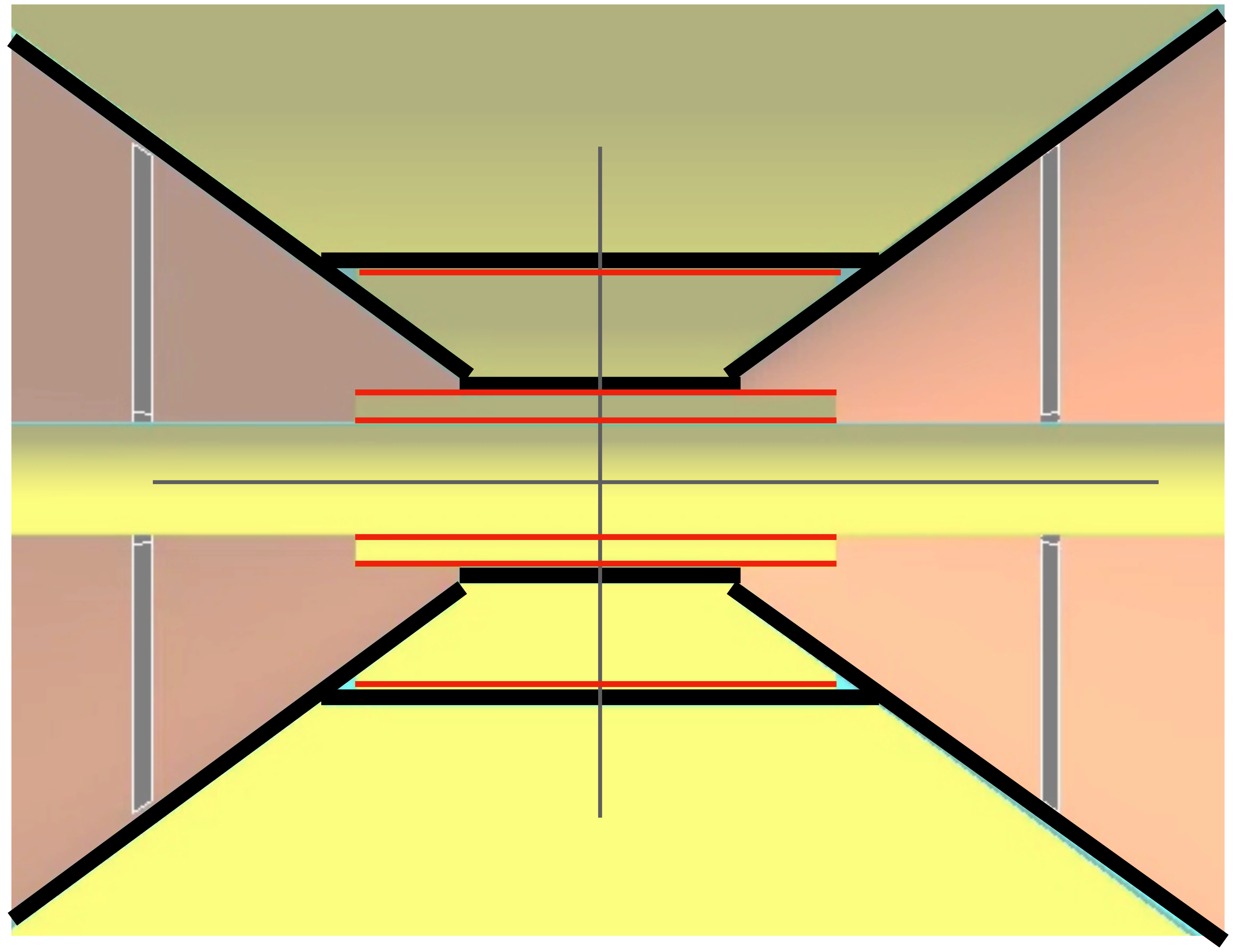
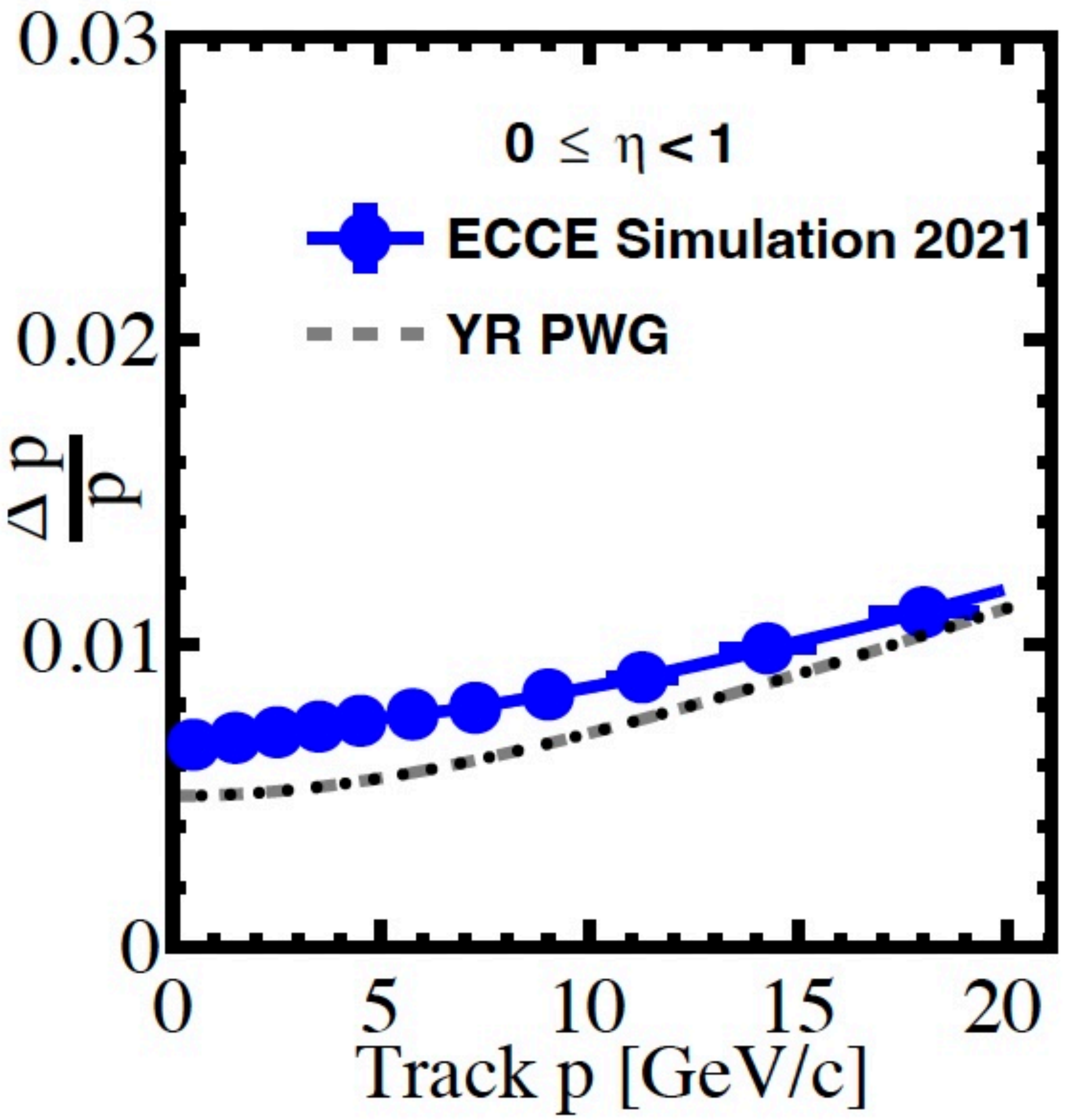
- **Optimizing detector-1 tracker**

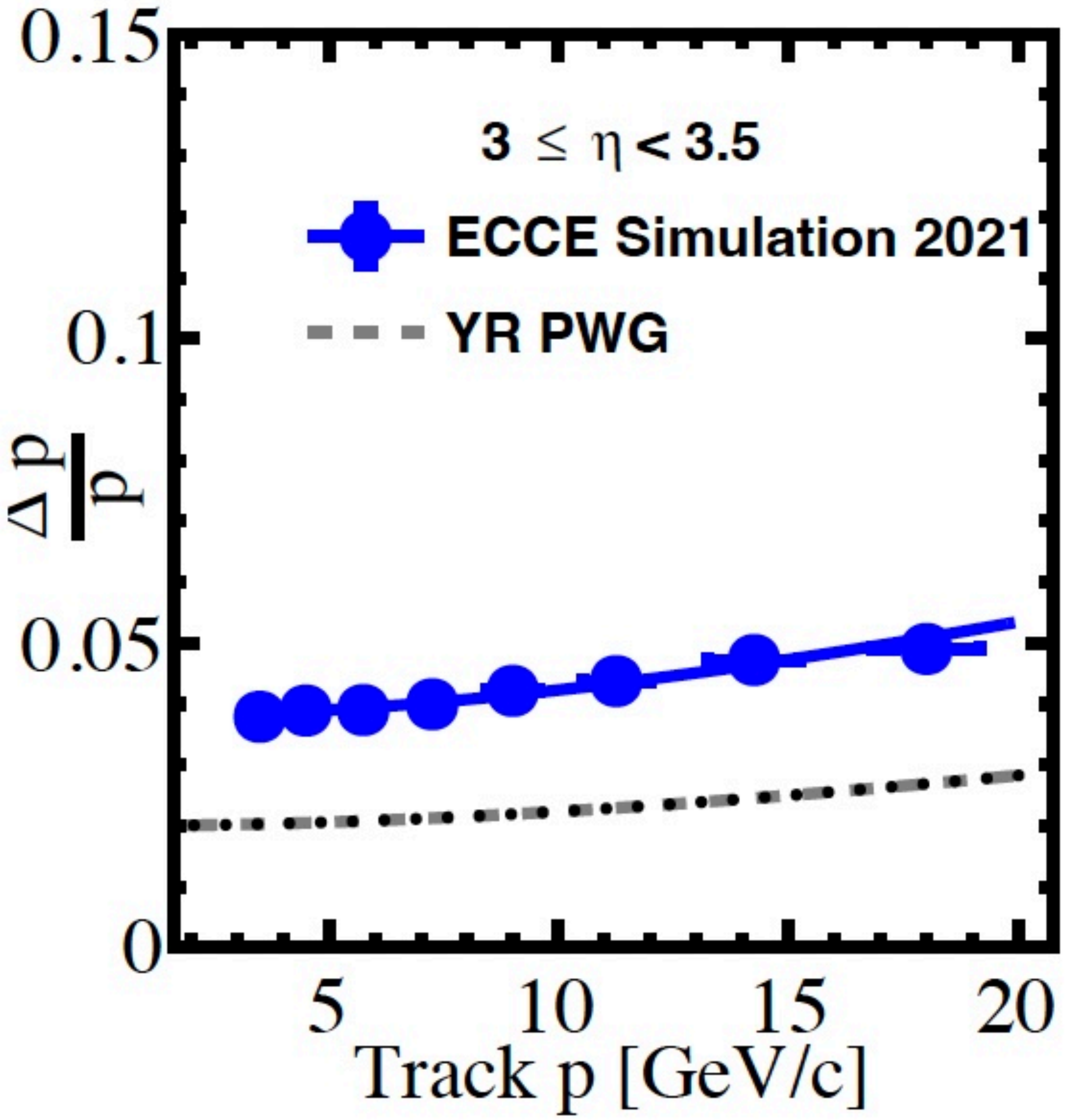
Motivation

Several aspects need to be revisited:

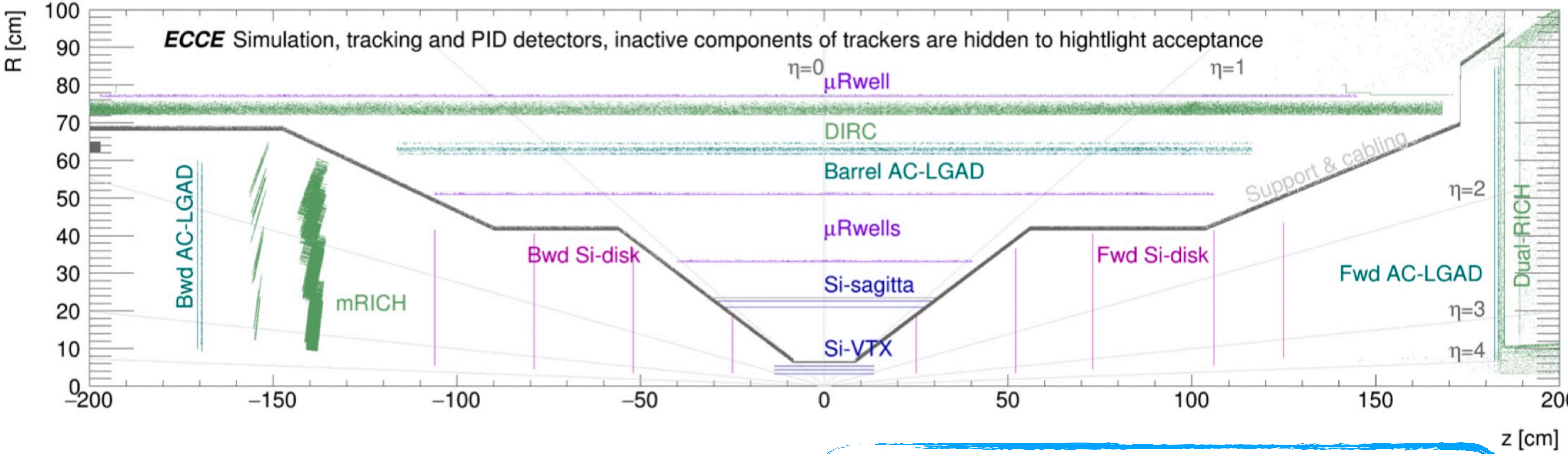
- new developments (e.g. beampipe bake-out radius)
- material budget near sagitta
- details of support structure
- YR performance requirements







ECCE tracking configuration



Barrel:
- 5 Si layers ($\sigma = 10/\sqrt{12}\ \mu$m, 0.05% X0)
- 2 μRwells ($\sigma = 55\ \mu$m)
- 1 ACLGAD ($\sigma = 30\ \mu$m)
- 1 uRwell ($\sigma = 55\ \mu$m) behind DIRC

Forward:
- 5 Si layers ($\sigma = 10/\sqrt{12}\ \mu$m, 0.48% X0)
- 1 ACLGAD ($\sigma = 30\ \mu$m)

Backward:
- 4 Si layers ($\sigma = 10/\sqrt{12}\ \mu$m, 0.48% X0)
- 1 ACLGAD ($\sigma = 30\ \mu$m) behind mRICH

From ECCE proposal to new configuration

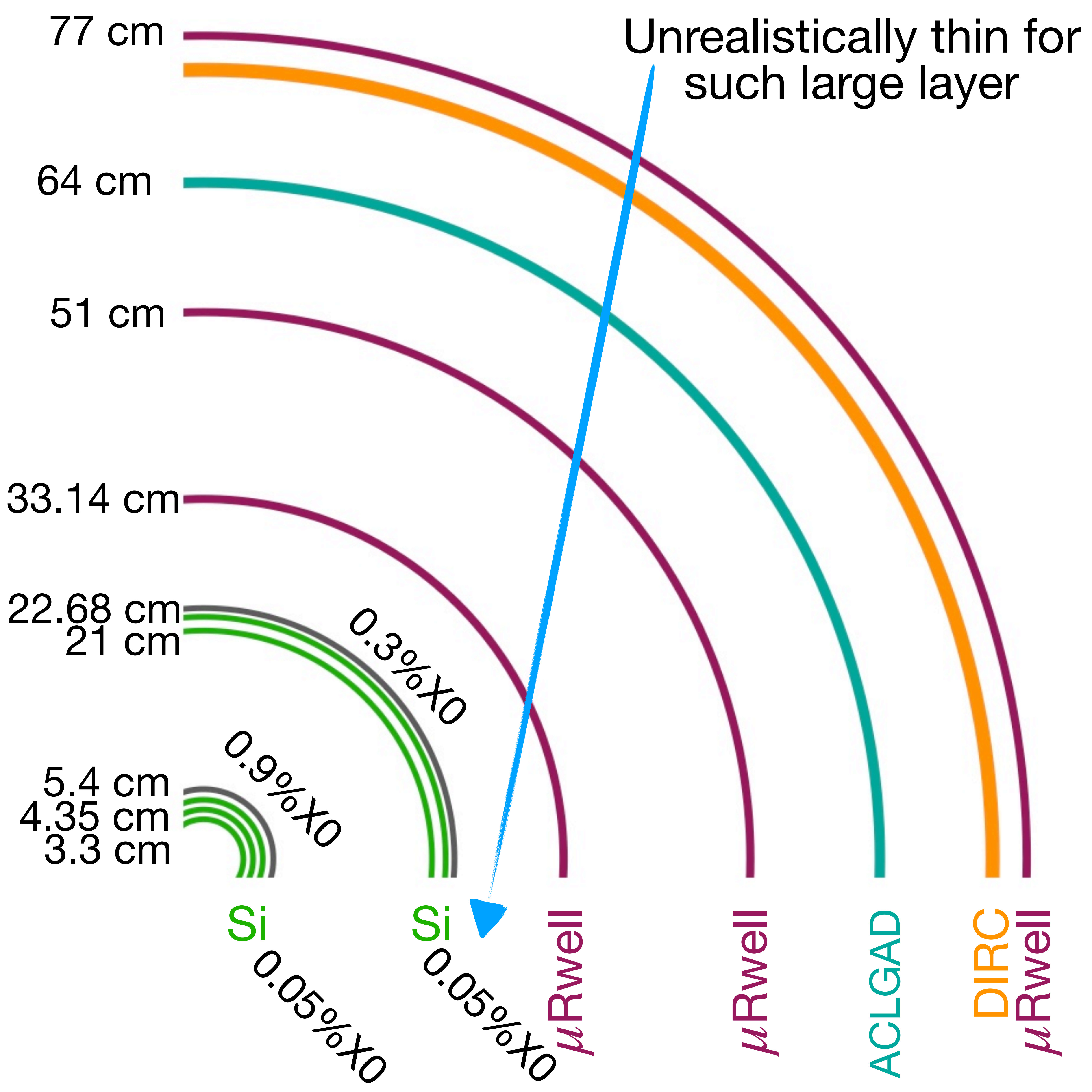
Outline

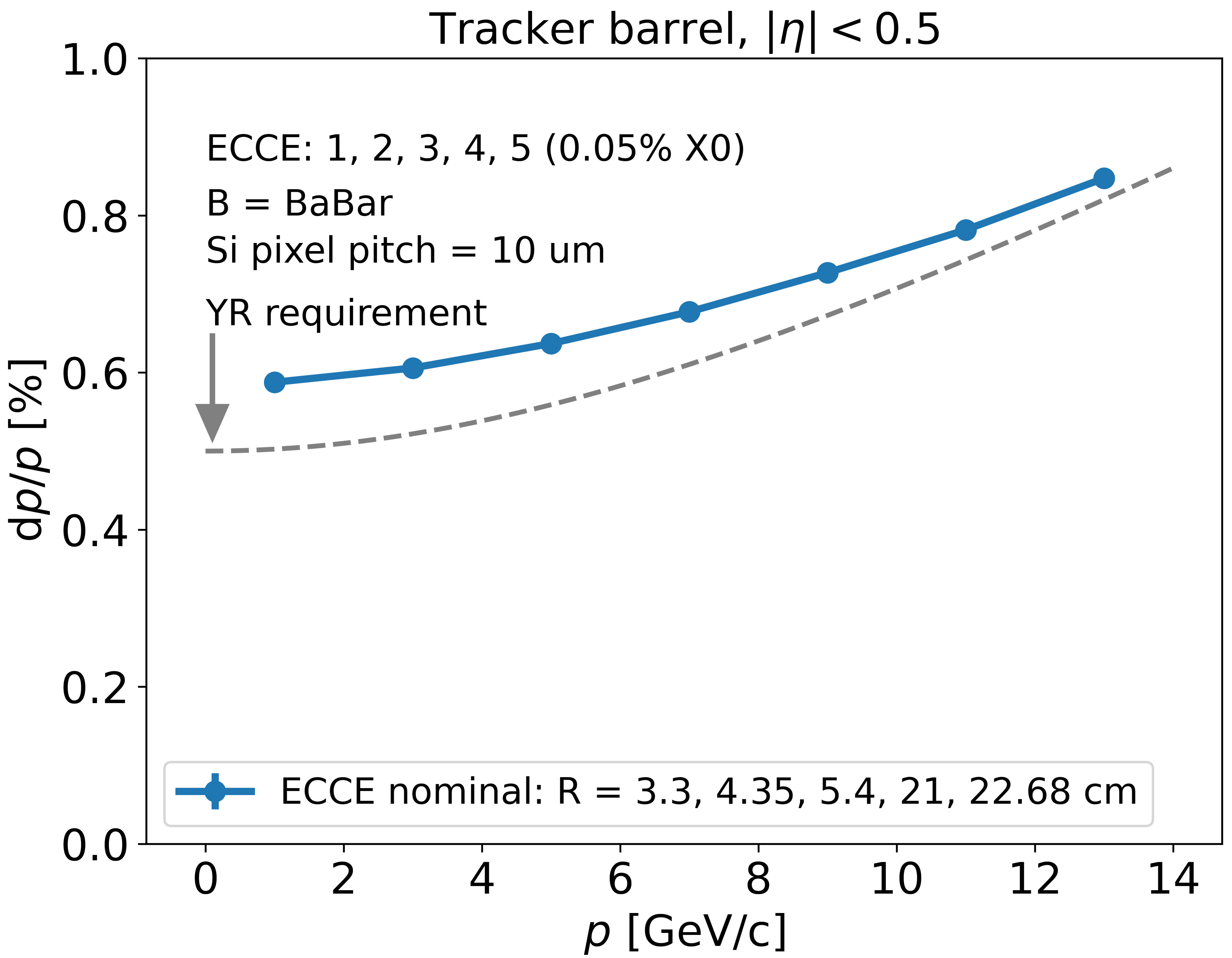
- barrel studies
- disk studies
- support updates

Outline

- barrel studies
- disk studies
- support updates

Momentum resolution performance of ECCE Barrel

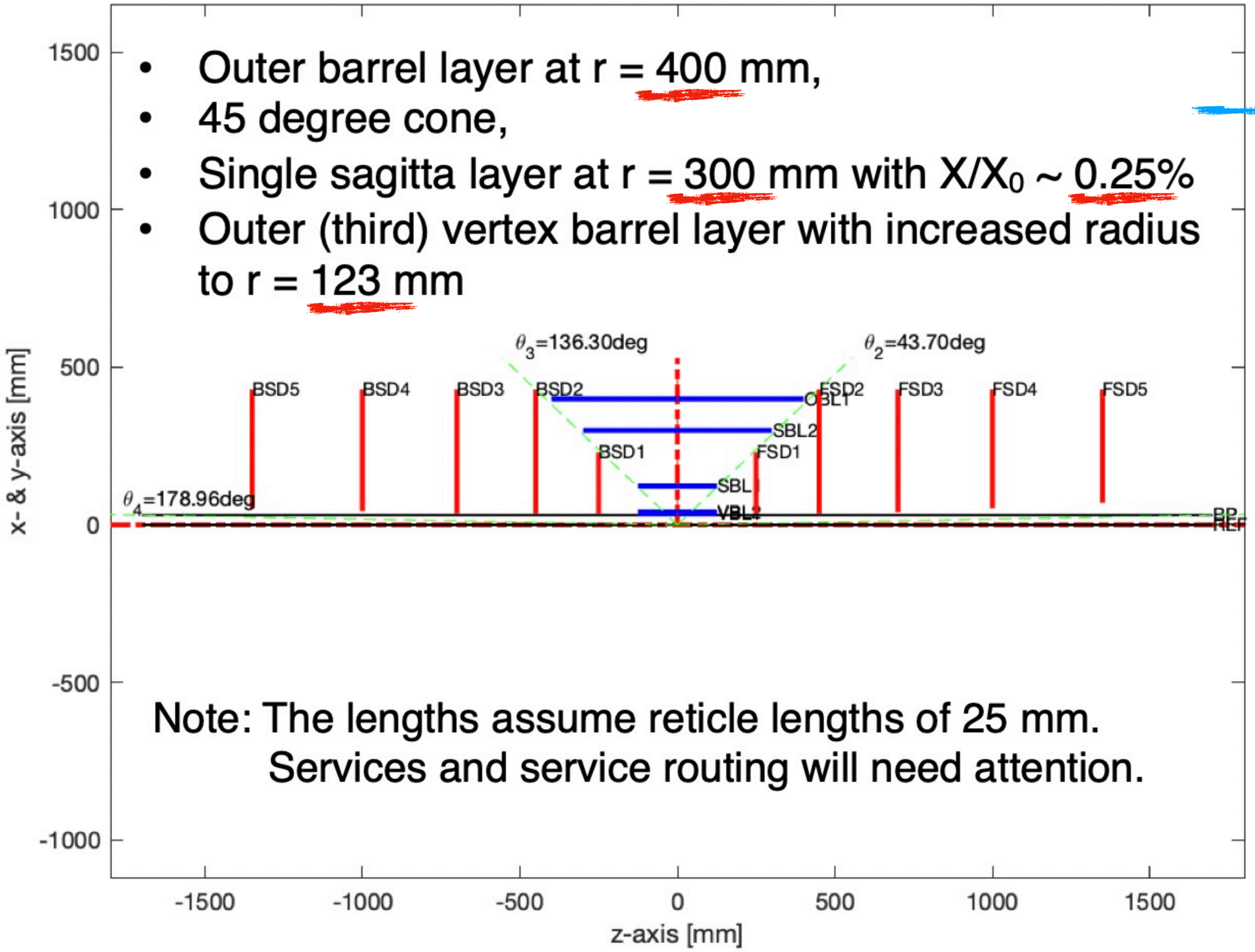




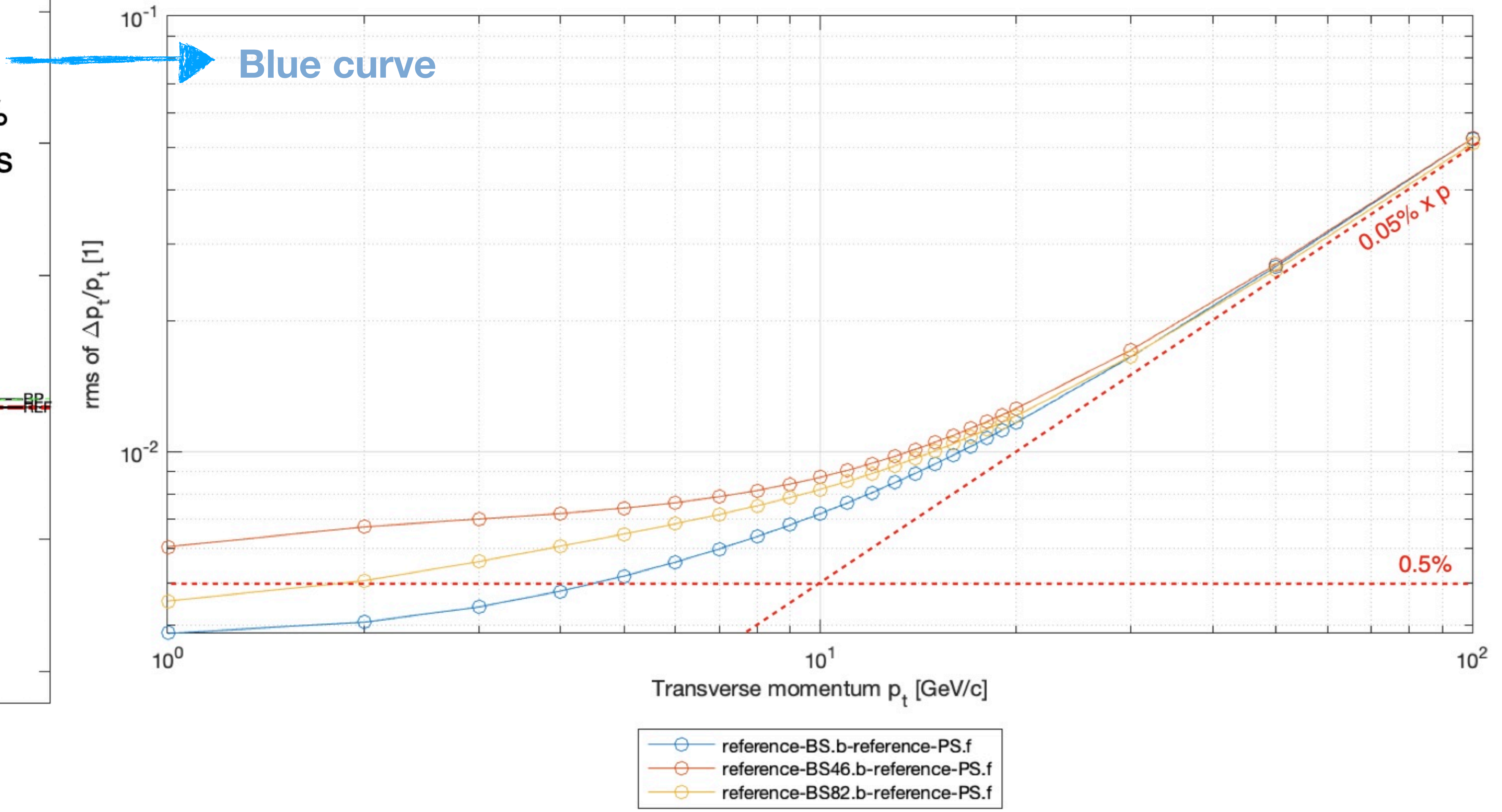
Barrel optimization with fast simulations

Configuration proposed and studied in fast simulations by **E. Sichtermann**

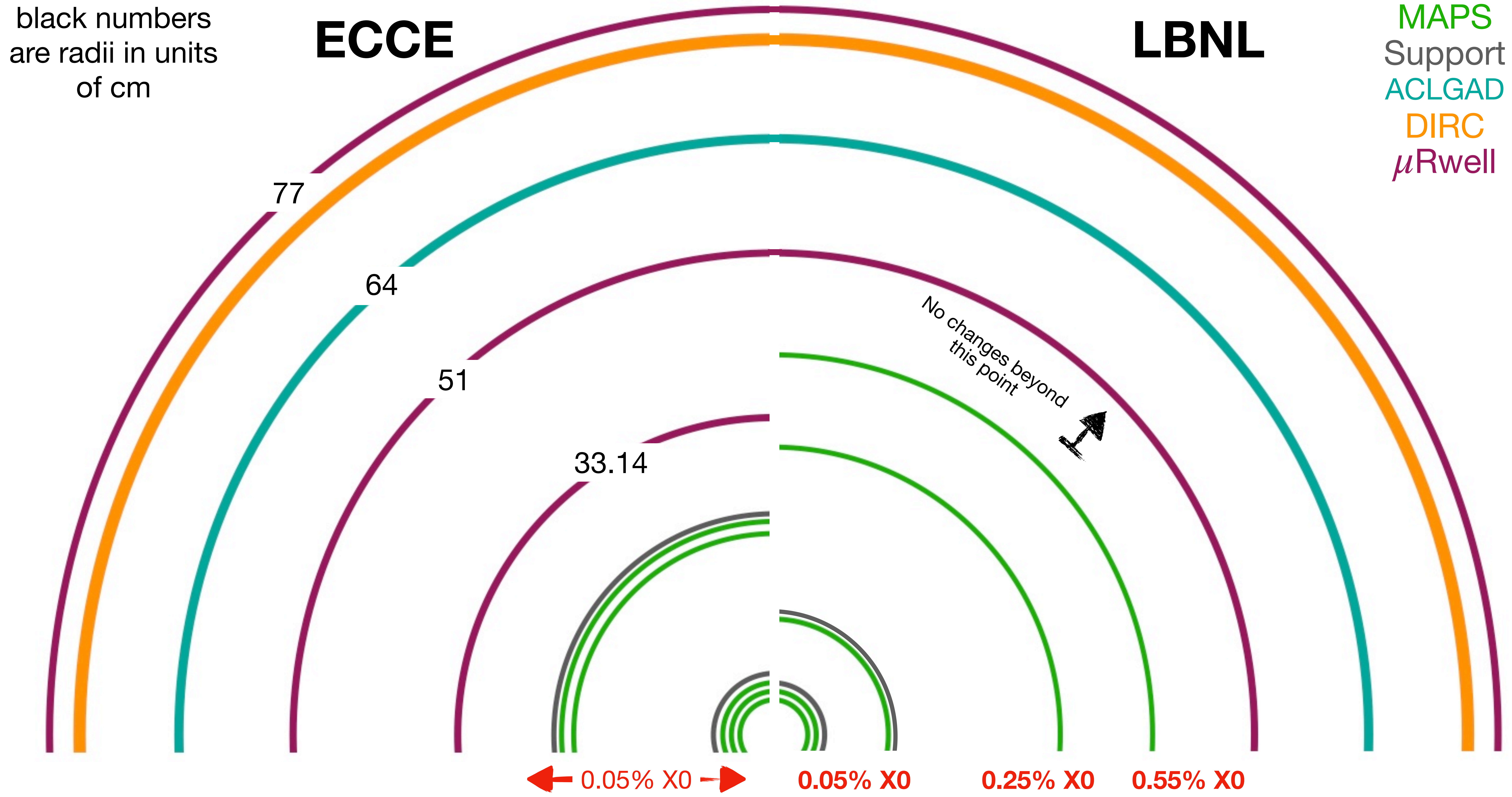
- Outer barrel layer at r = 400 mm,
- 45 degree cone,
- Single sagitta layer at r = 300 mm with $X/X_0 \sim 0.25\%$
- Outer (third) vertex barrel layer with increased radius to r = 123 mm



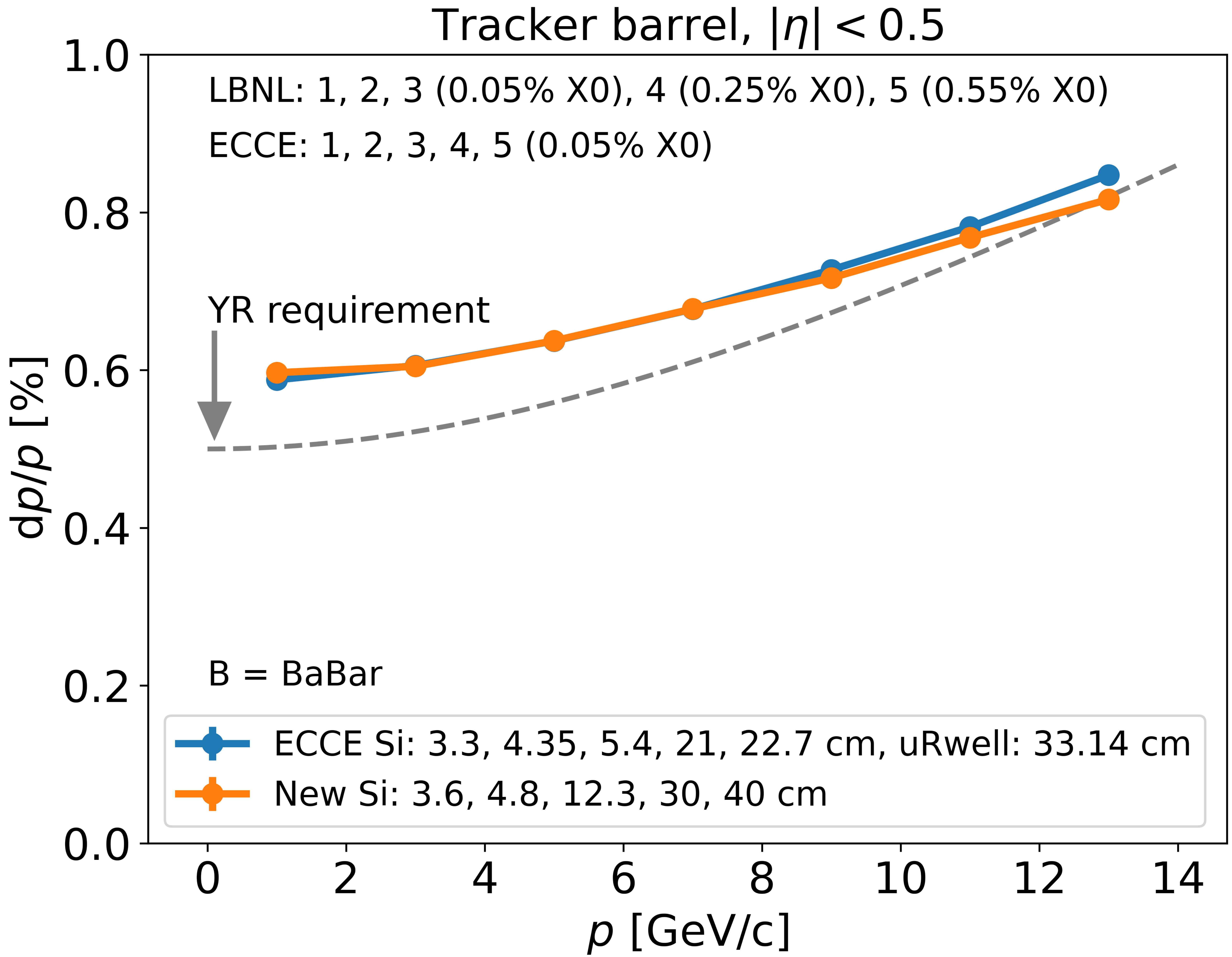
Note: The lengths assume reticle lengths of 25 mm.
Services and service routing will need attention.



New proposed barrel configuration



New proposed barrel configuration



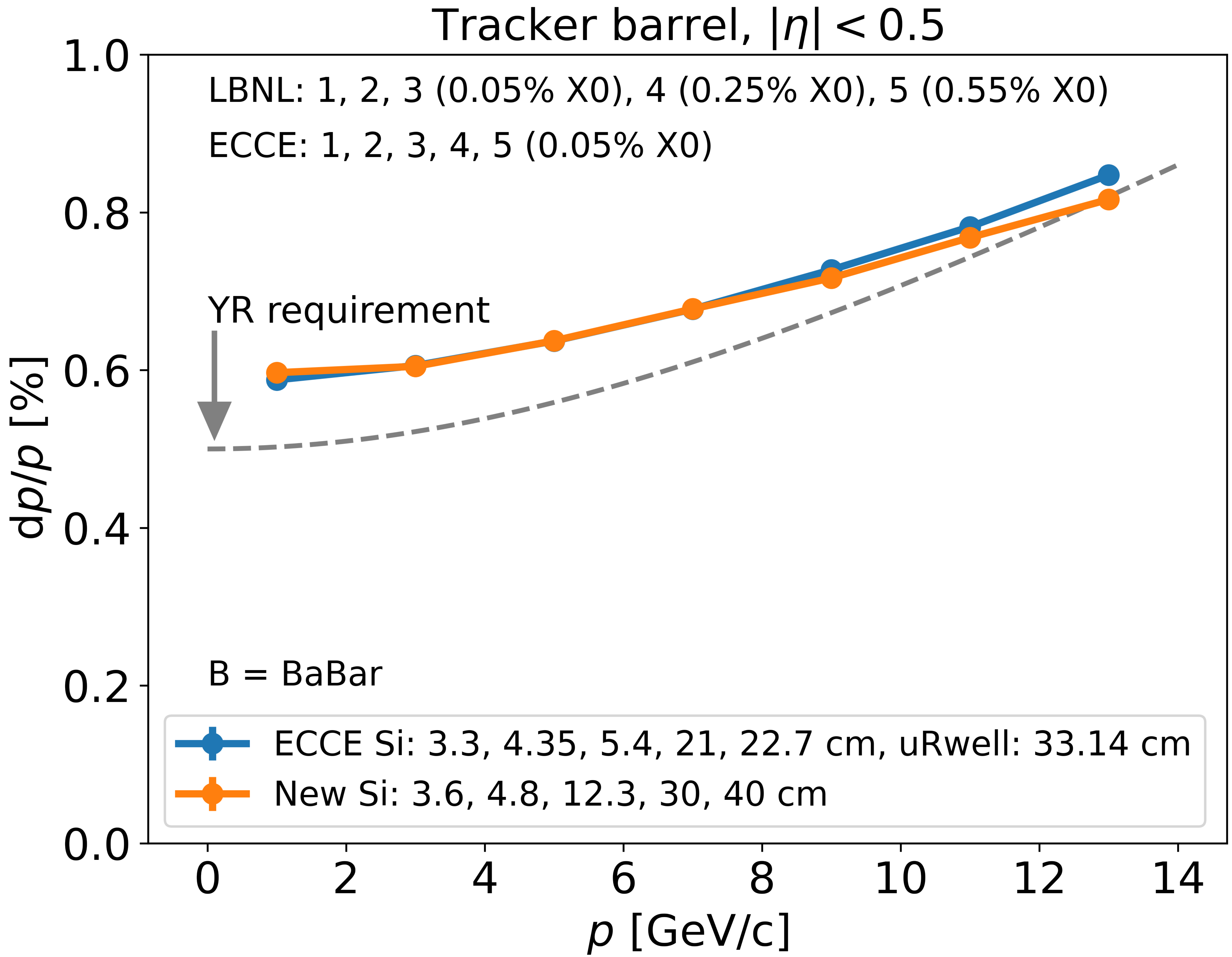
Both settings have:
uRwell R = 51, 77 cm
ACLGAD R = 64 cm

ECCE has support layer:
R = 6.3 (0.9%), 23.5 cm (0.3%X0)

New has support layer:
R = 5.7 (0.1%), 12.6 cm (0.1%X0)

MAPS $\sigma = 10/\sqrt{12}\ \mu m$
μRwells $\sigma = 55\ \mu m$
ACLGAD $\sigma = 30\ \mu m$

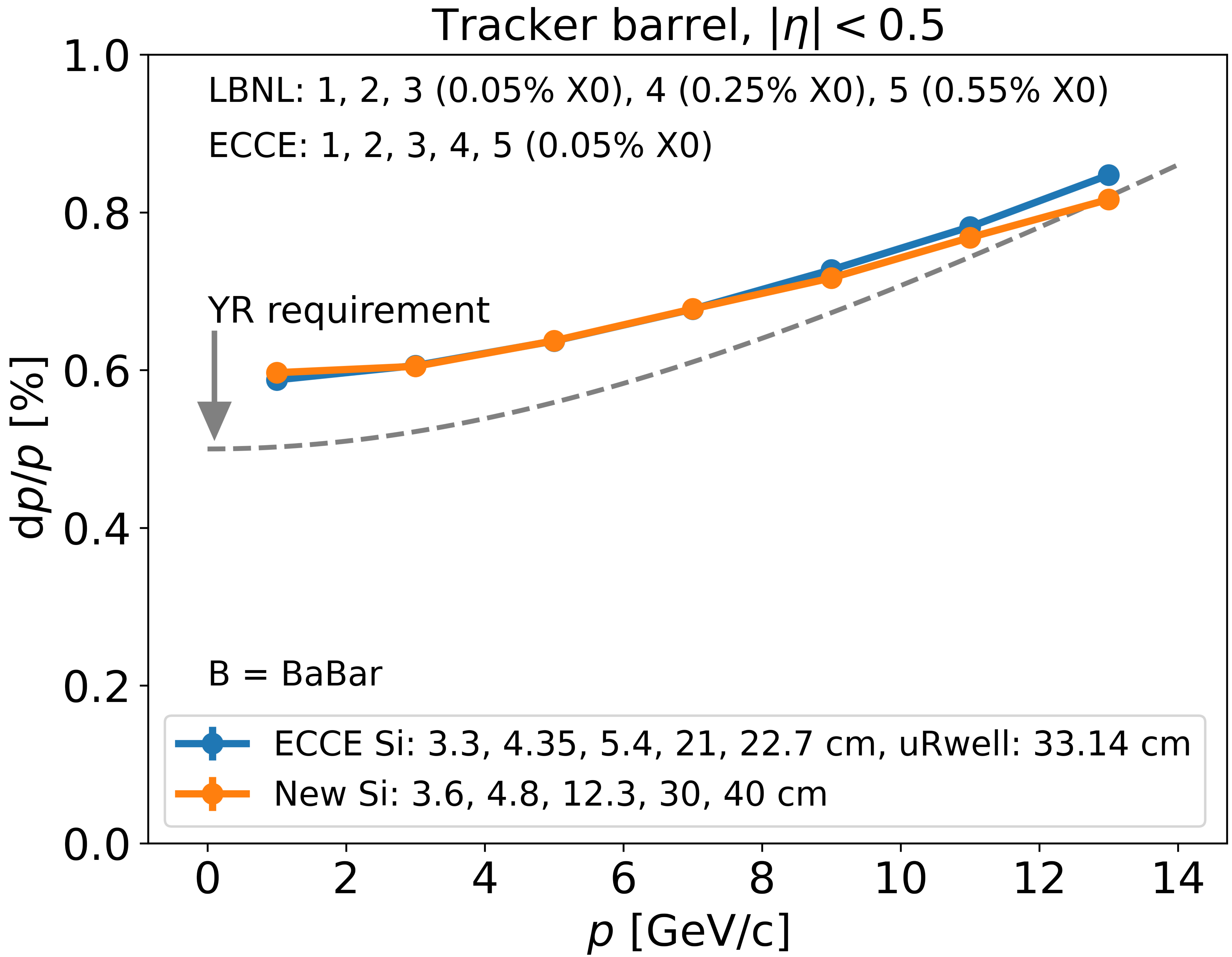
New proposed barrel configuration



Did we go through this redesign to just end up with the same performance?

Can we do anything to improve this performance further?

New proposed barrel configuration



Did we go through this redesign to just end up with the same performance?

↓

NO

Can we do anything to improve this performance further?

↓

YES

Further improving barrel performance

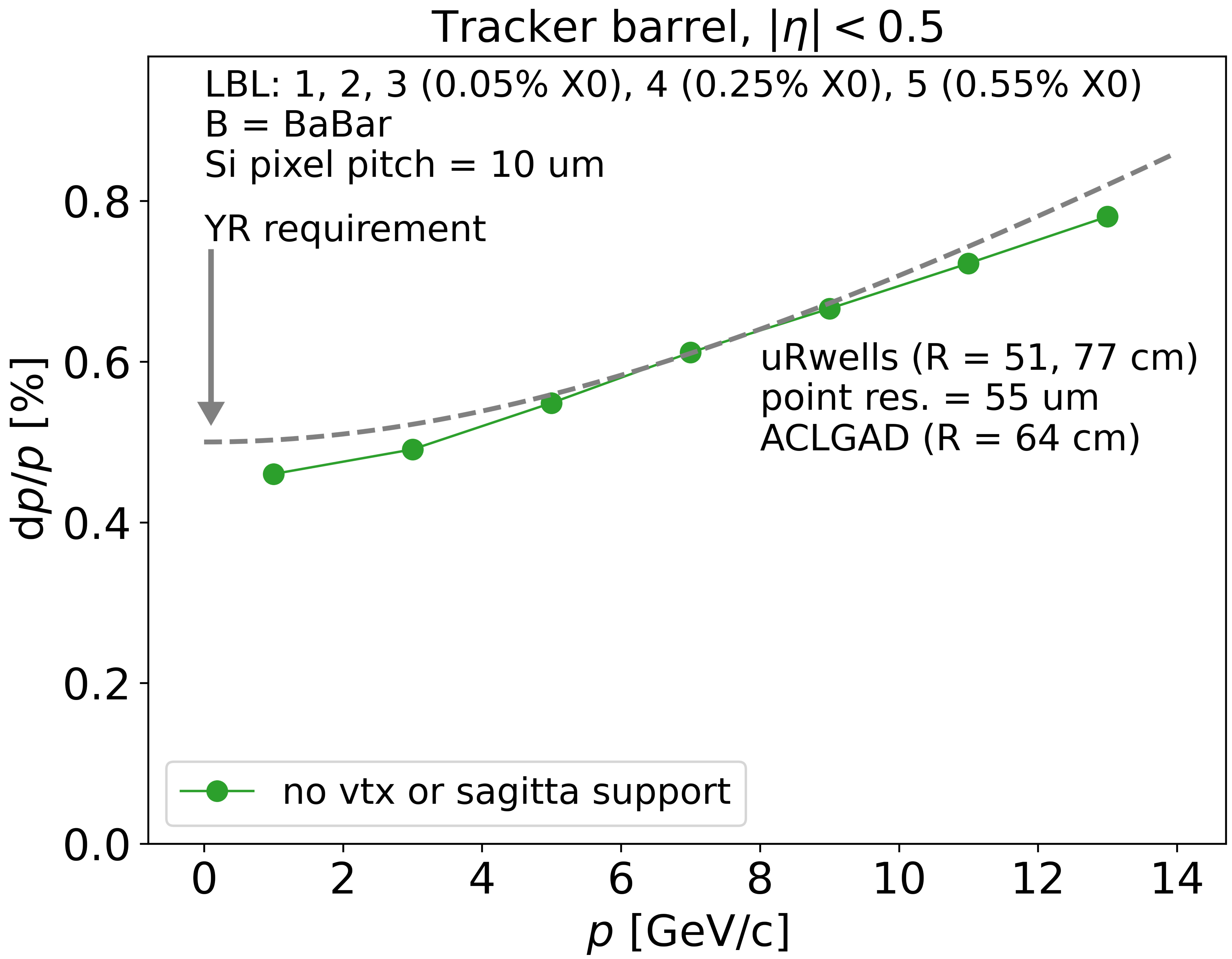
Reduction of material budget near sagitta

Targeting the constant term

Expansion of highest-R silicon layer

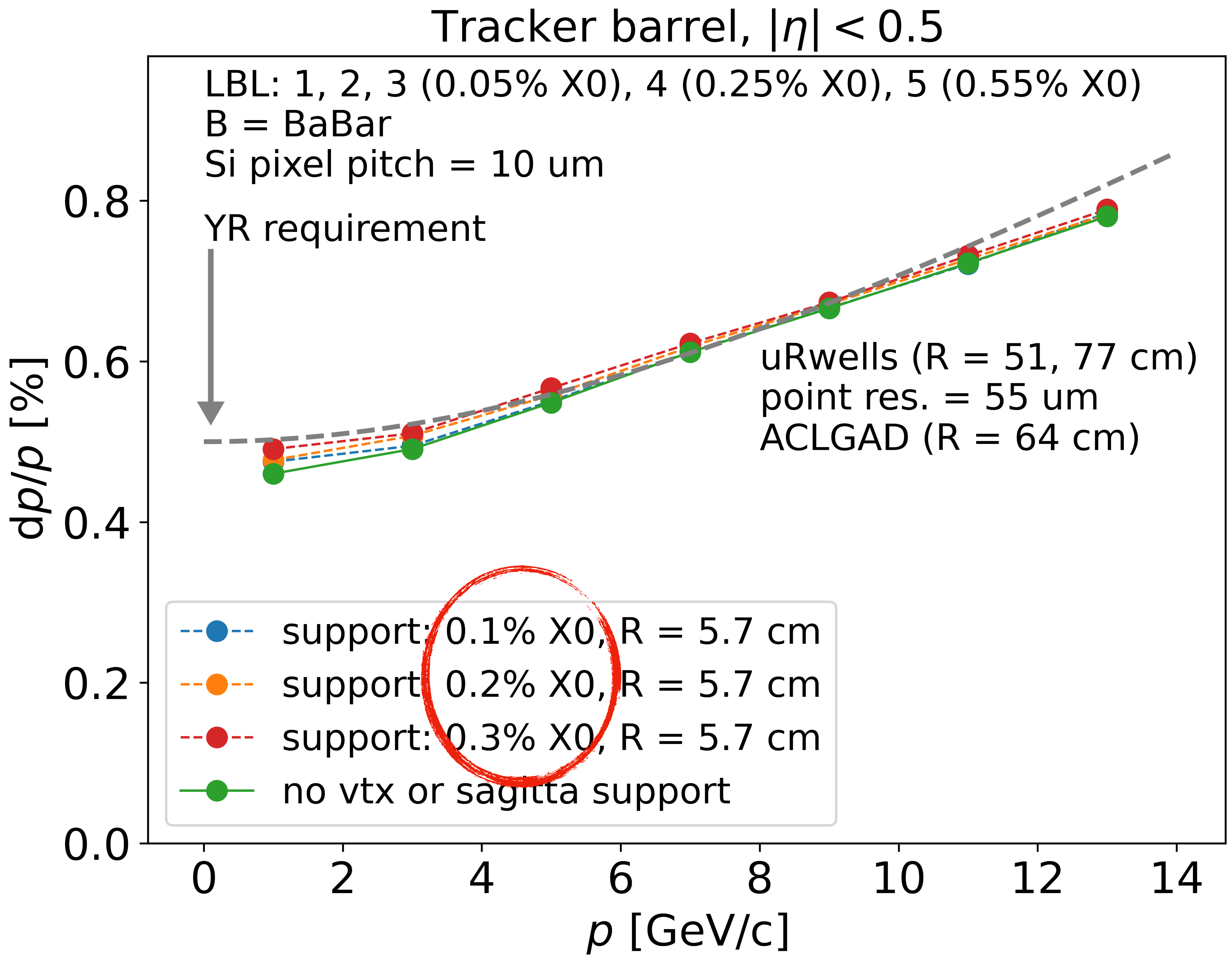
$$dp/p = Ap \oplus B$$

Momentum Resolution Performance

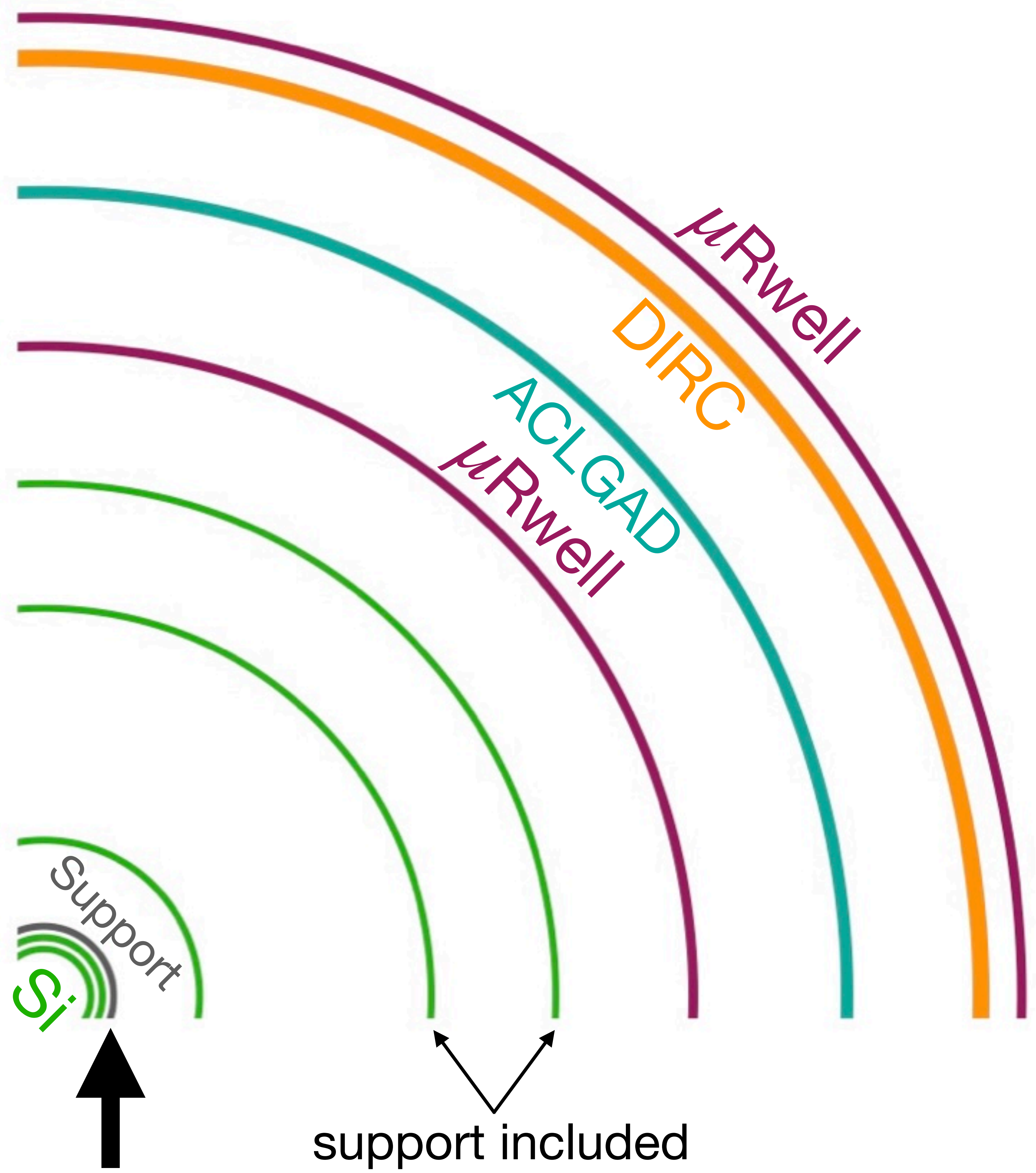


Performance below requirement when innermost three layers are not supported

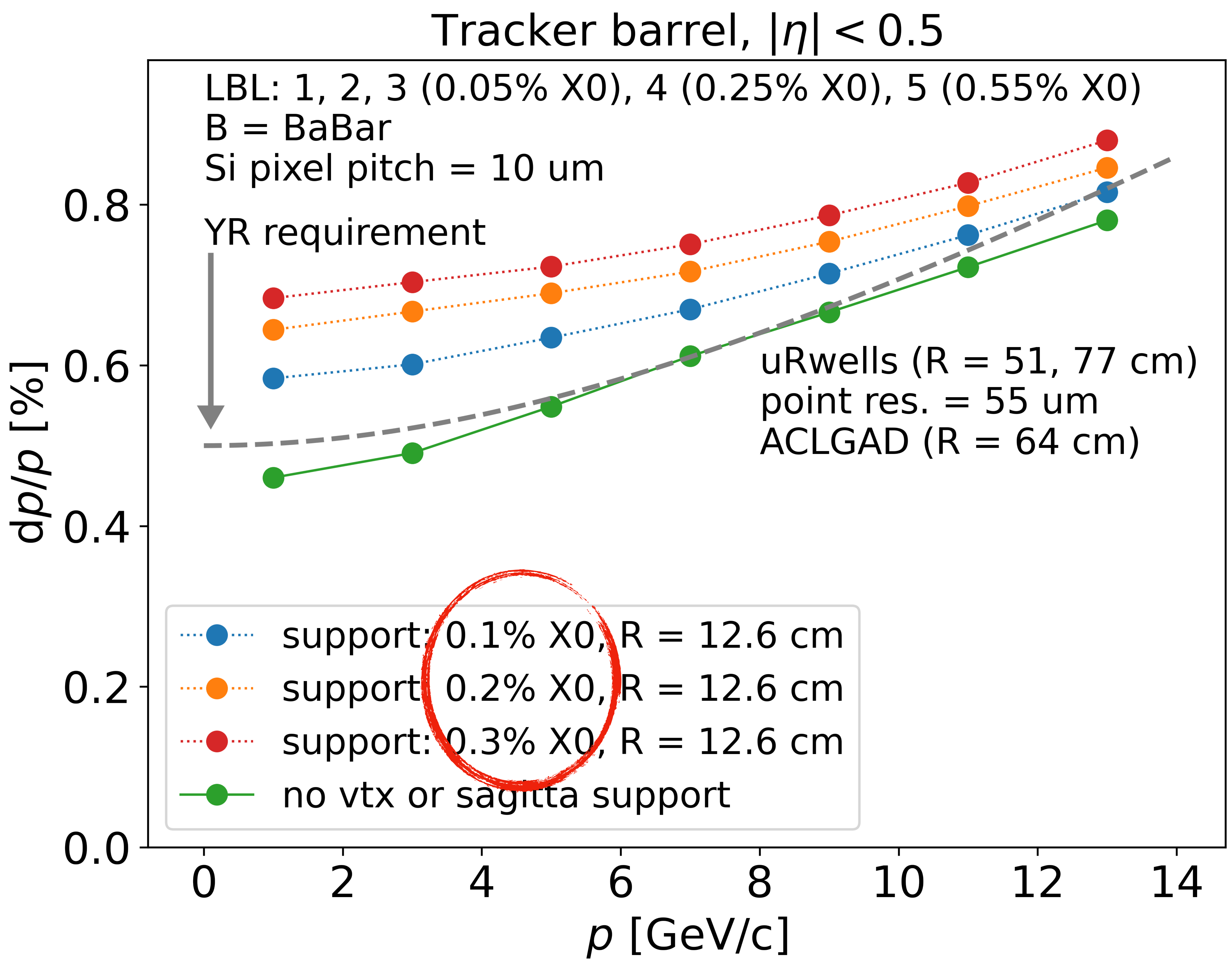
Momentum Resolution Performance



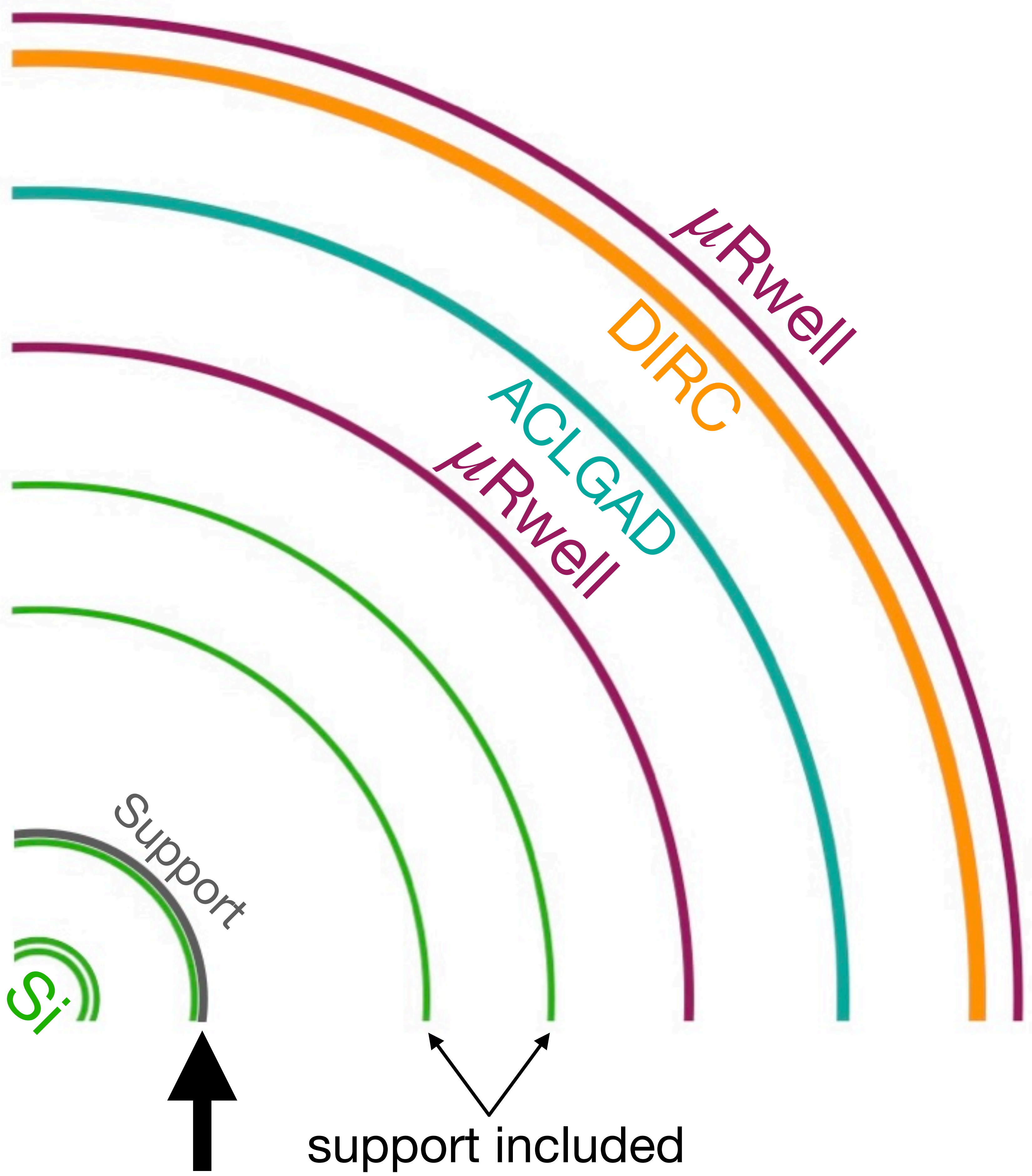
Material near innermost two layers doesn't significantly degrade dp/p



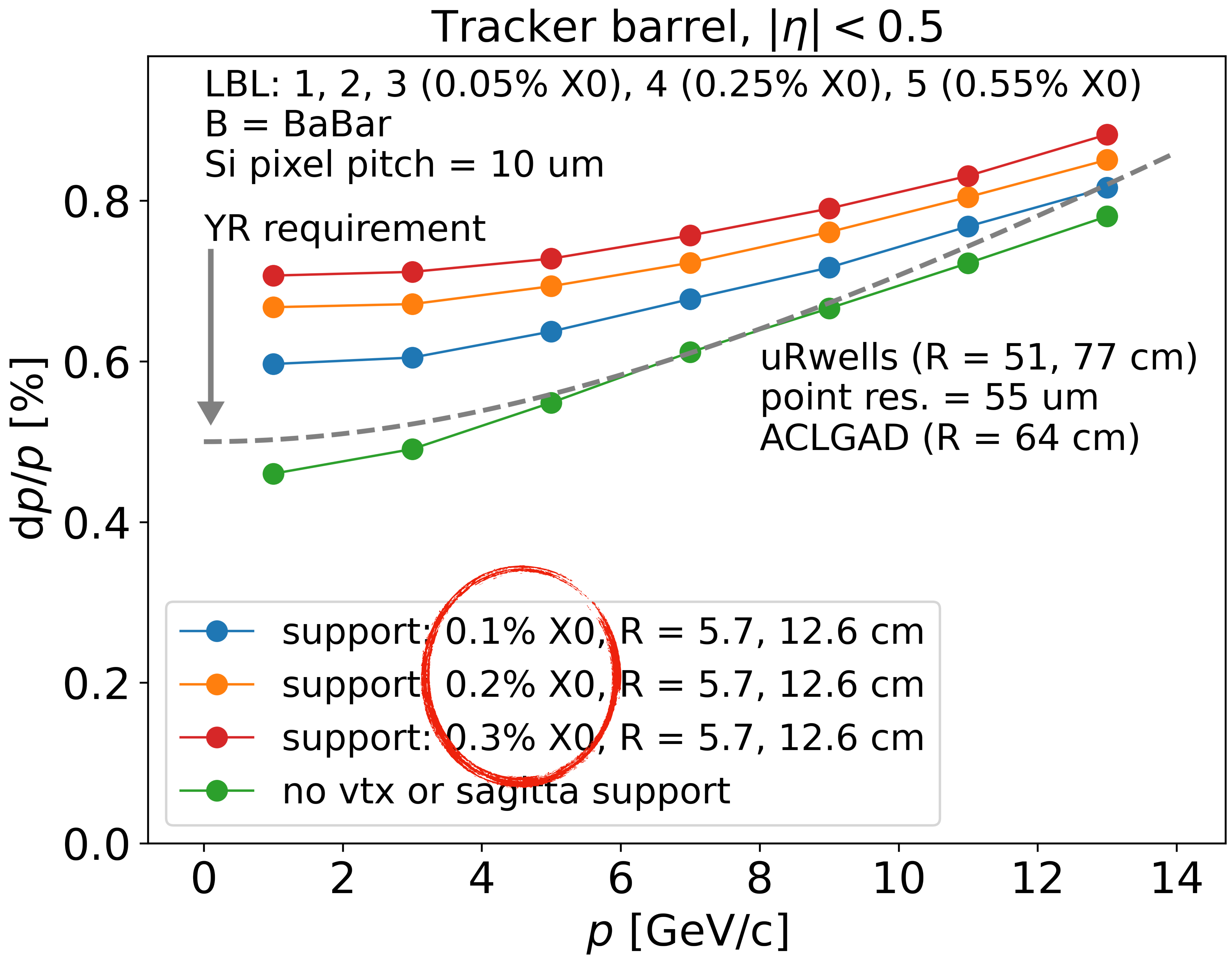
Momentum Resolution Performance



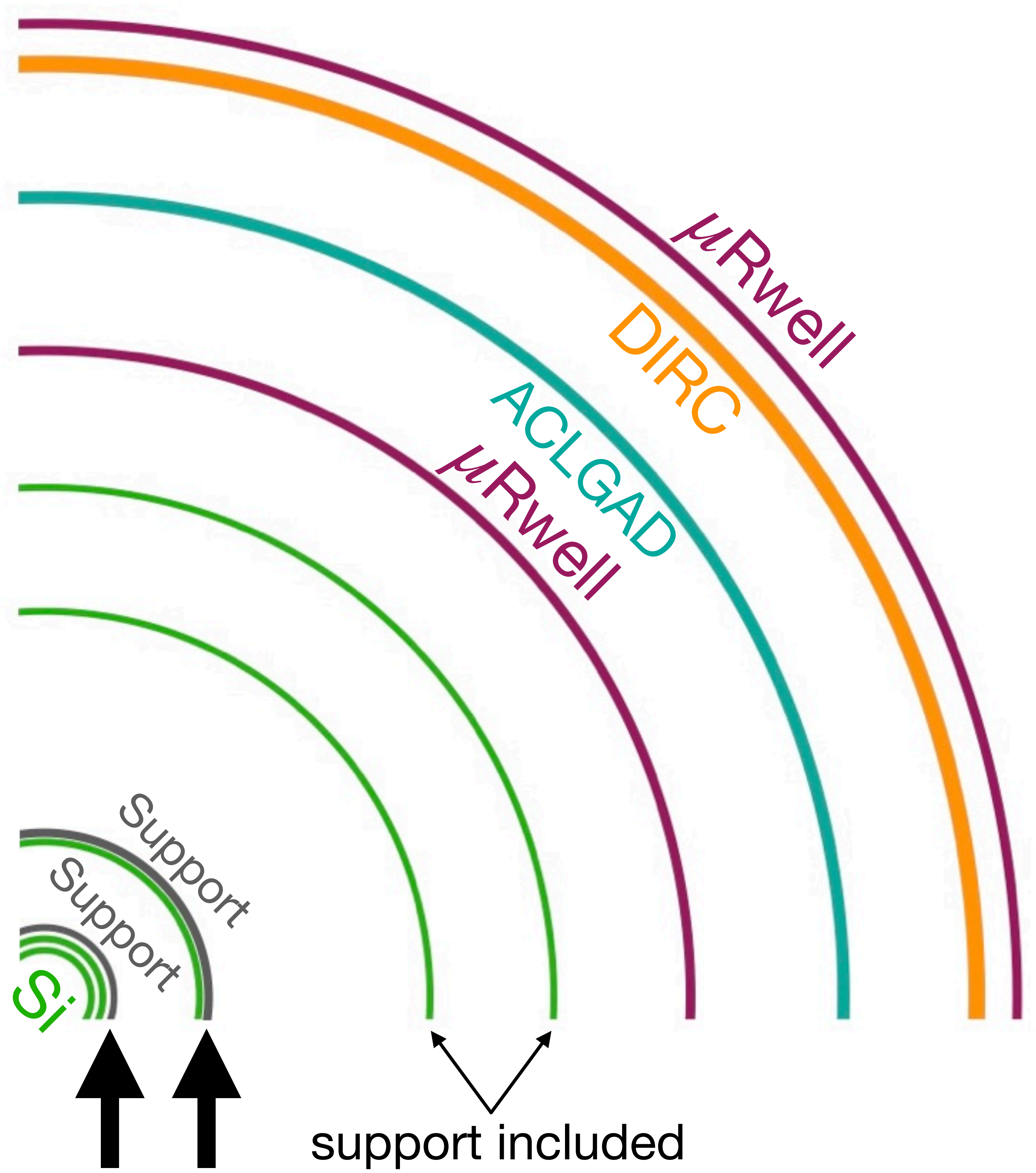
Material near sagitta significantly degrades dp/p



Momentum Resolution Performance



The performance with both layers is dominated by the support near the sagitta



Further improving barrel performance

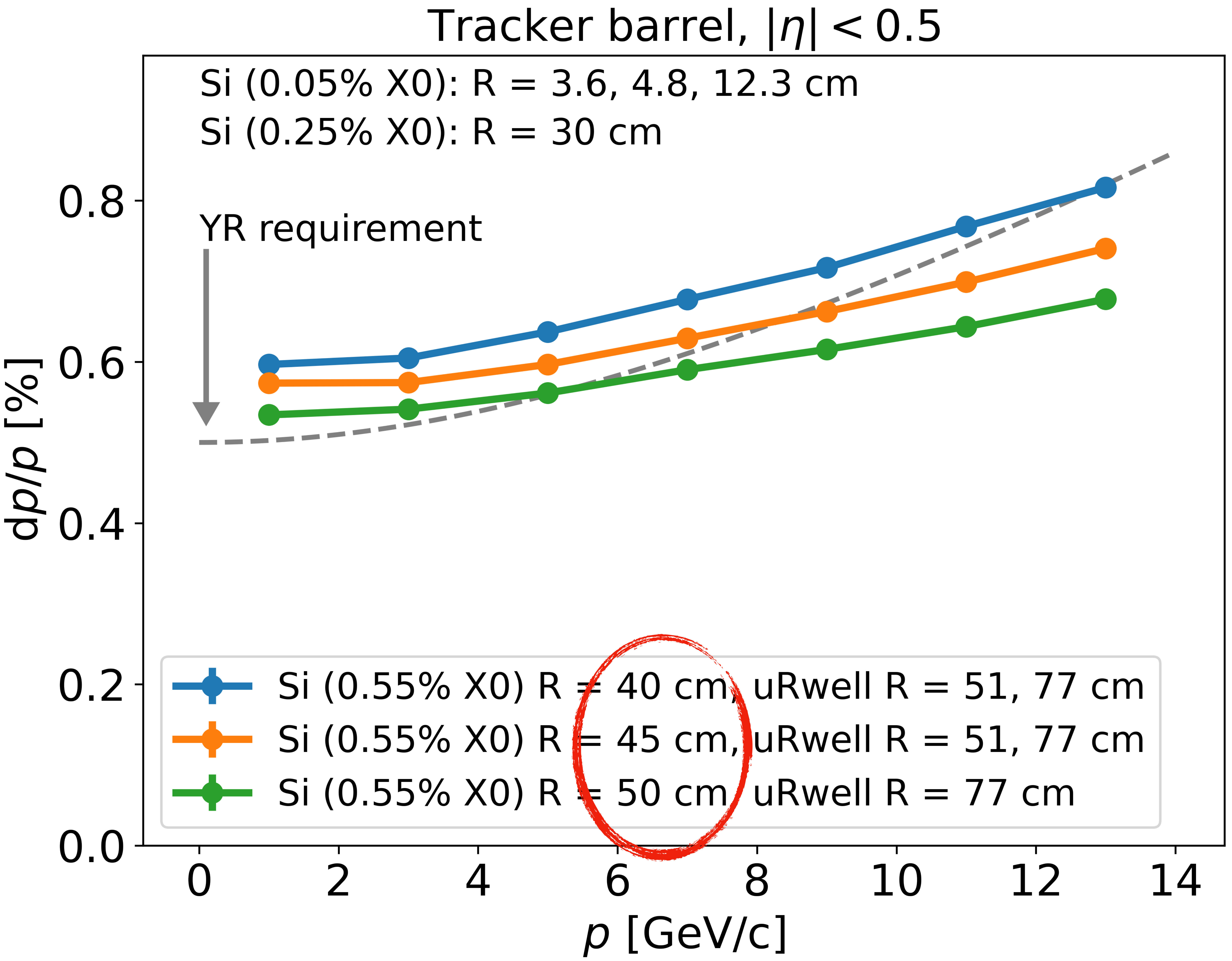
Reduction of material budget near sagitta

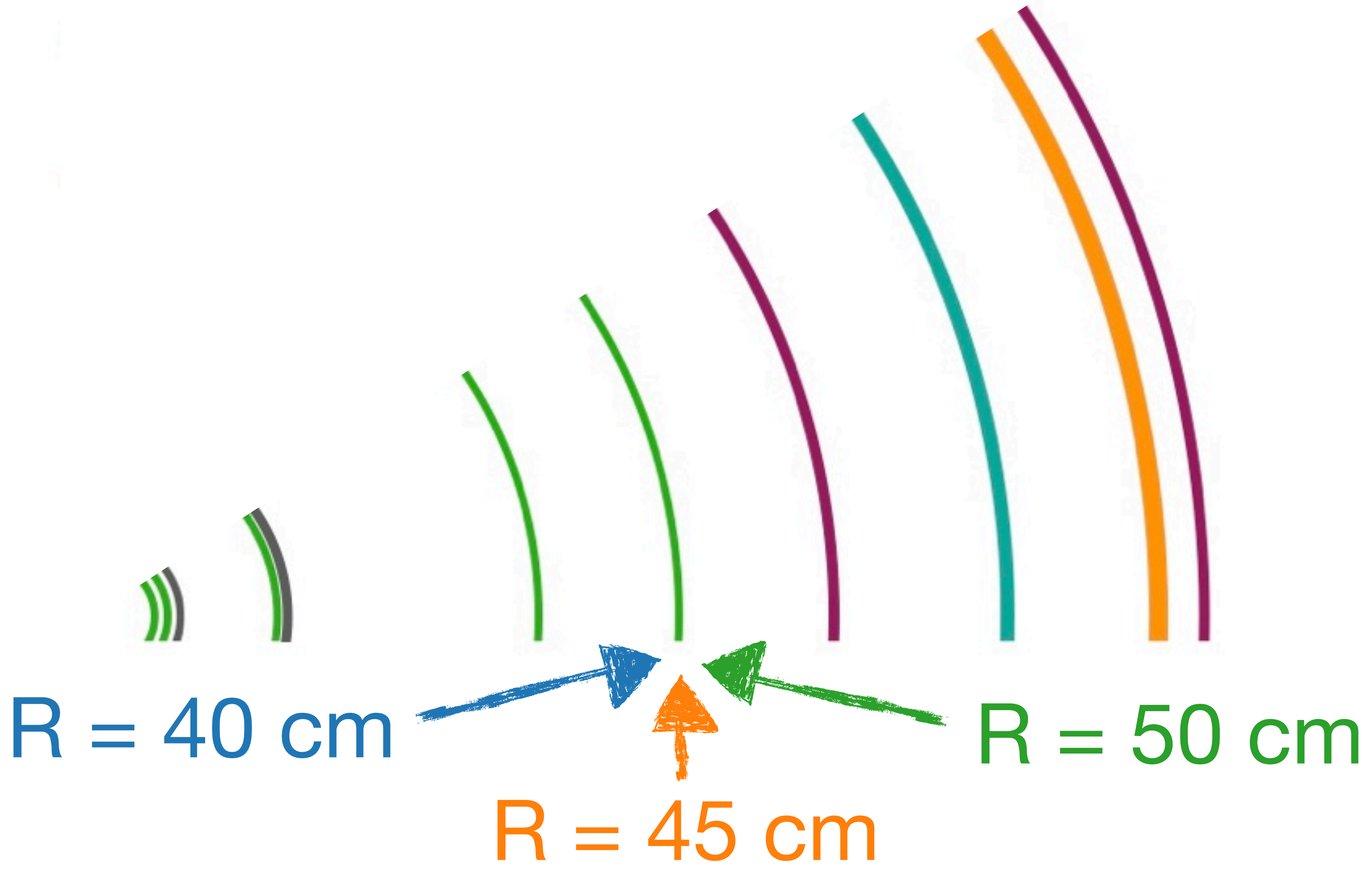
Expansion of highest-R silicon layer

Targeting the linear term

$$dp/p = Ap \oplus B$$

Impact from expanding radius of outermost silicon layer





The larger the radius the better the dp/p performance (and the larger the area)

MAPS $\sigma = 10/\sqrt{12}\ \mu m$
μRwells $\sigma = 55\ \mu m$
ACLGAD $\sigma = 30\ \mu m$

B = BaBar

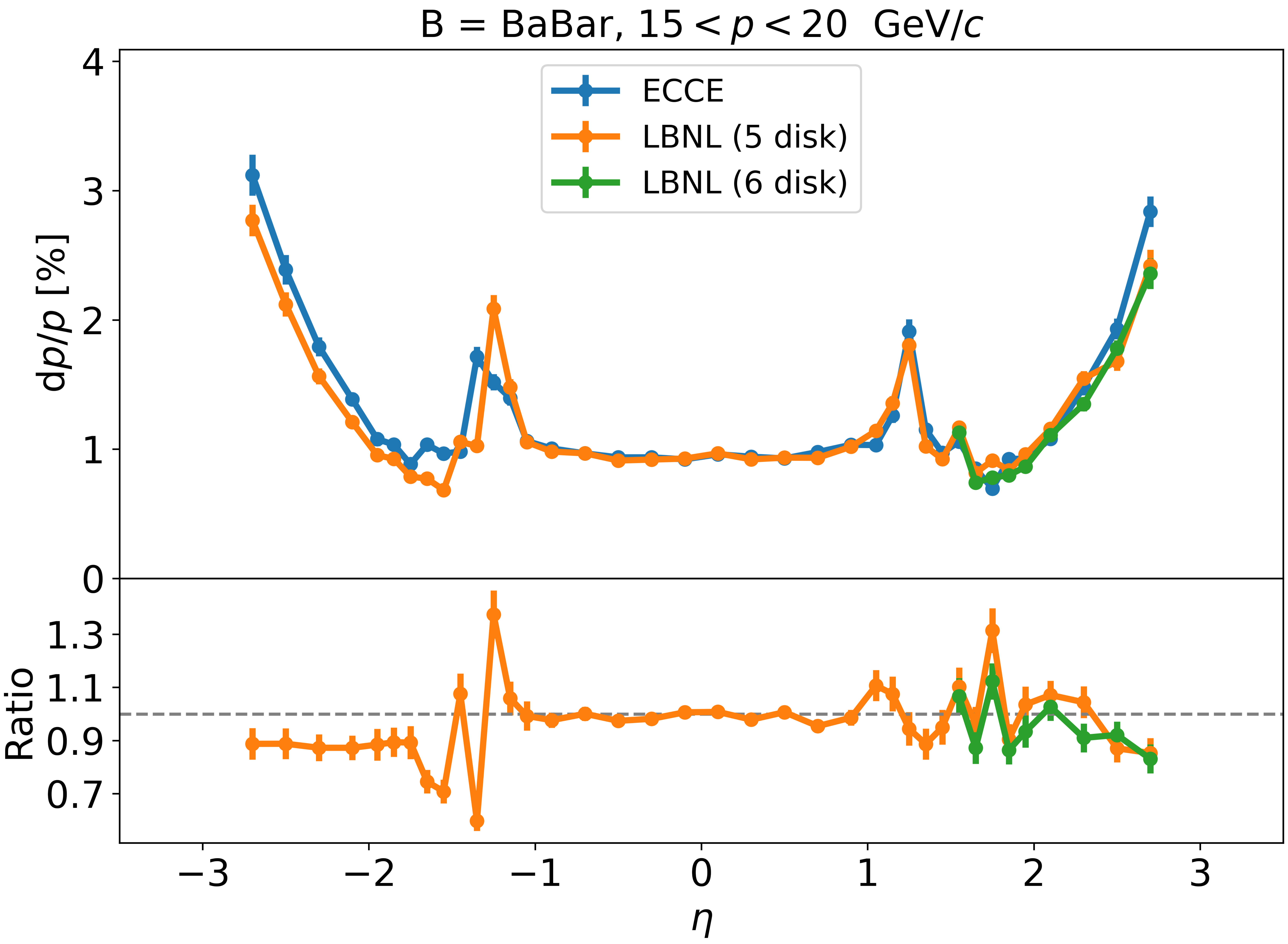
Outline

- barrel studies
- disk studies
- support updates

Disk layout

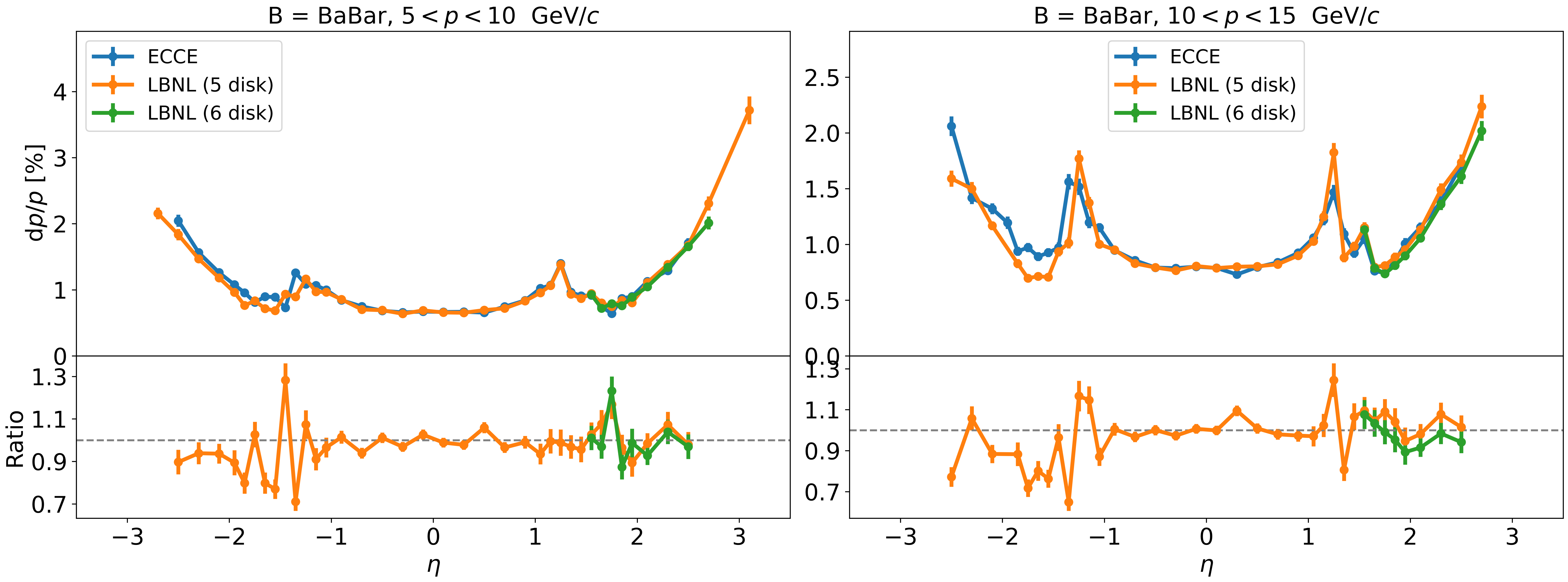
Insertion of a disk in each side + rearrangement of disks

Momentum resolution results



Forward and backward regions are challenging primarily because of solenoidal B-field and beampipe

Momentum resolution results



Outline

- barrel studies
- disk studies
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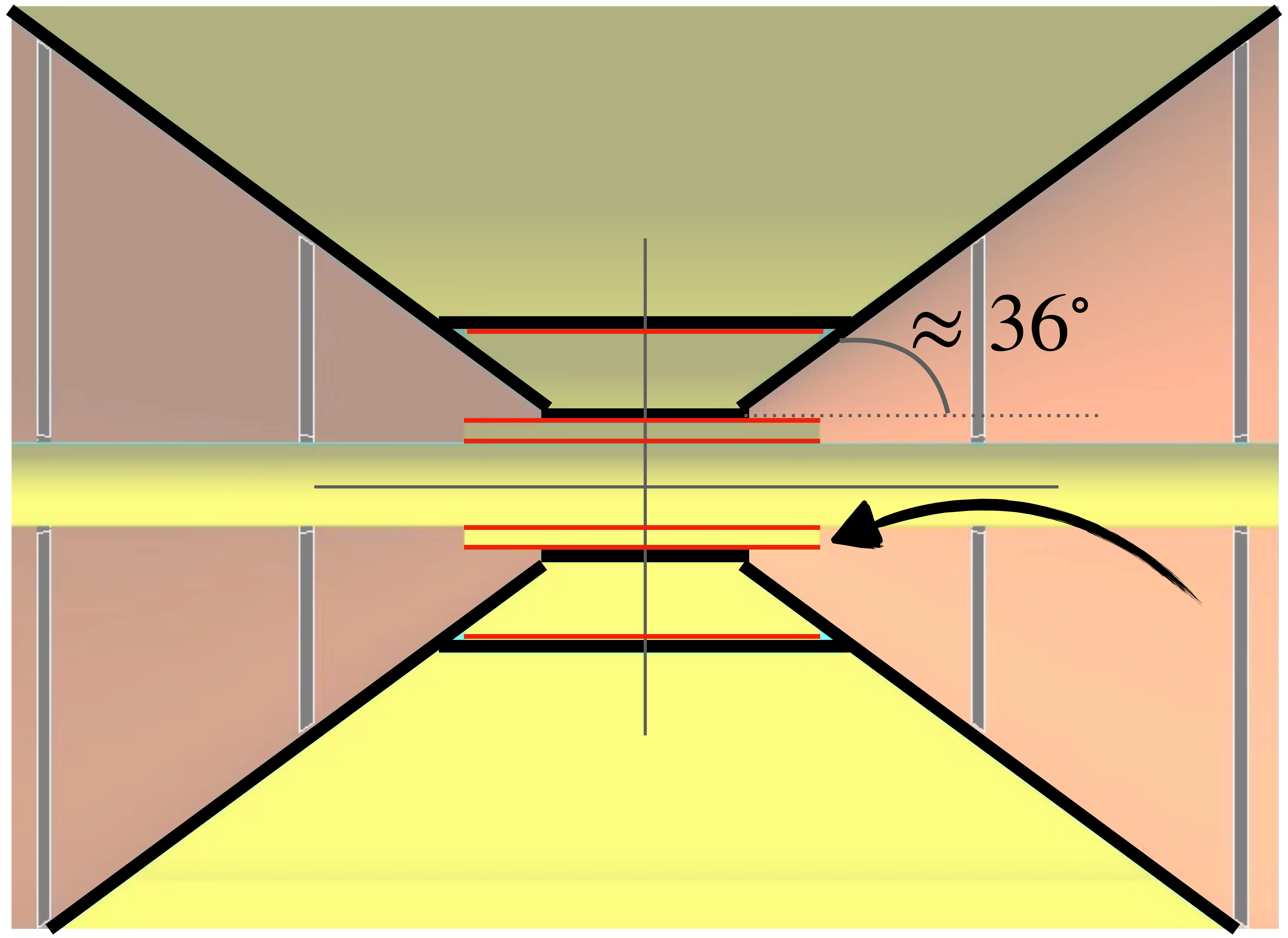
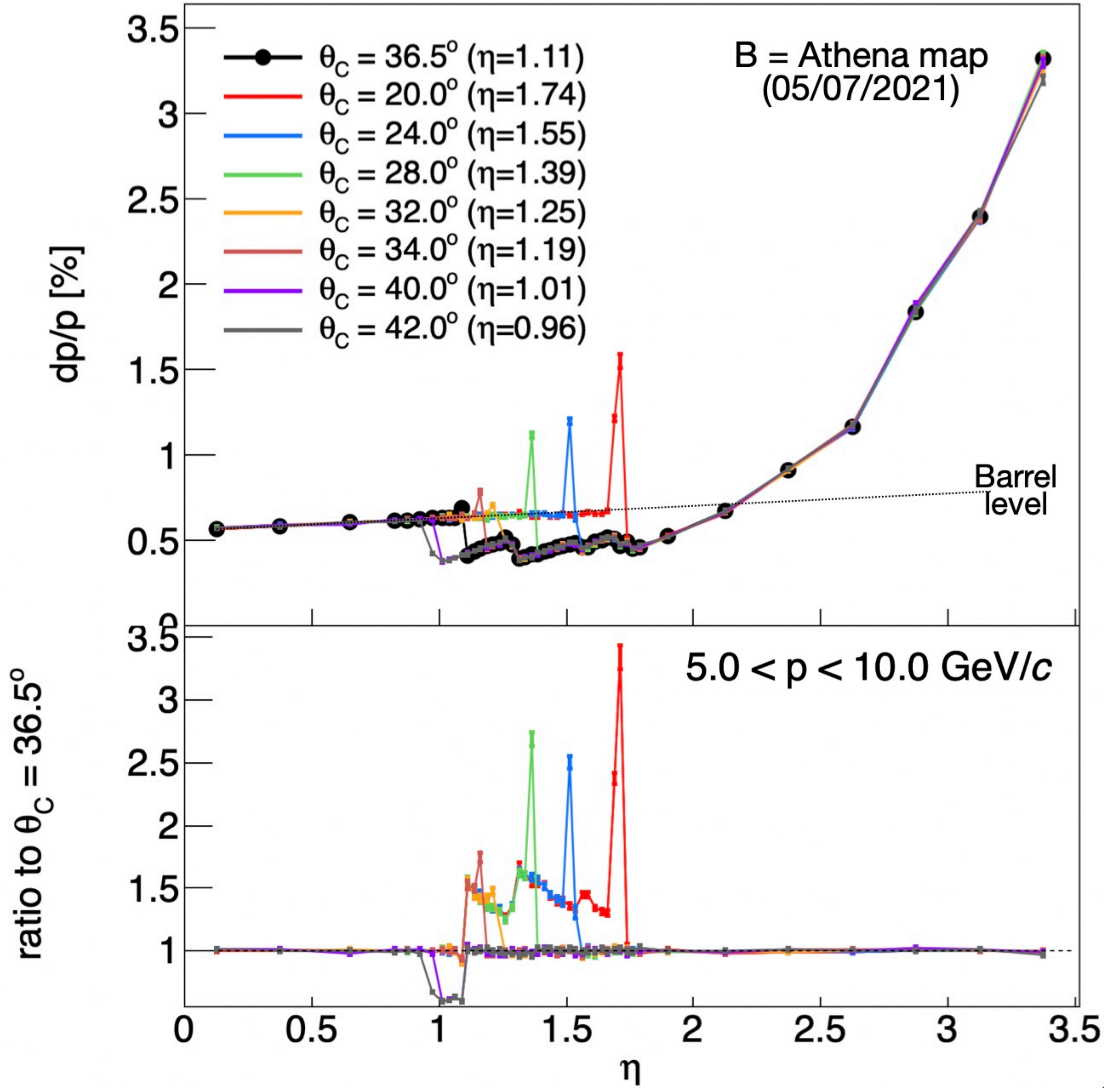
Updating support/service structure

ECCE support



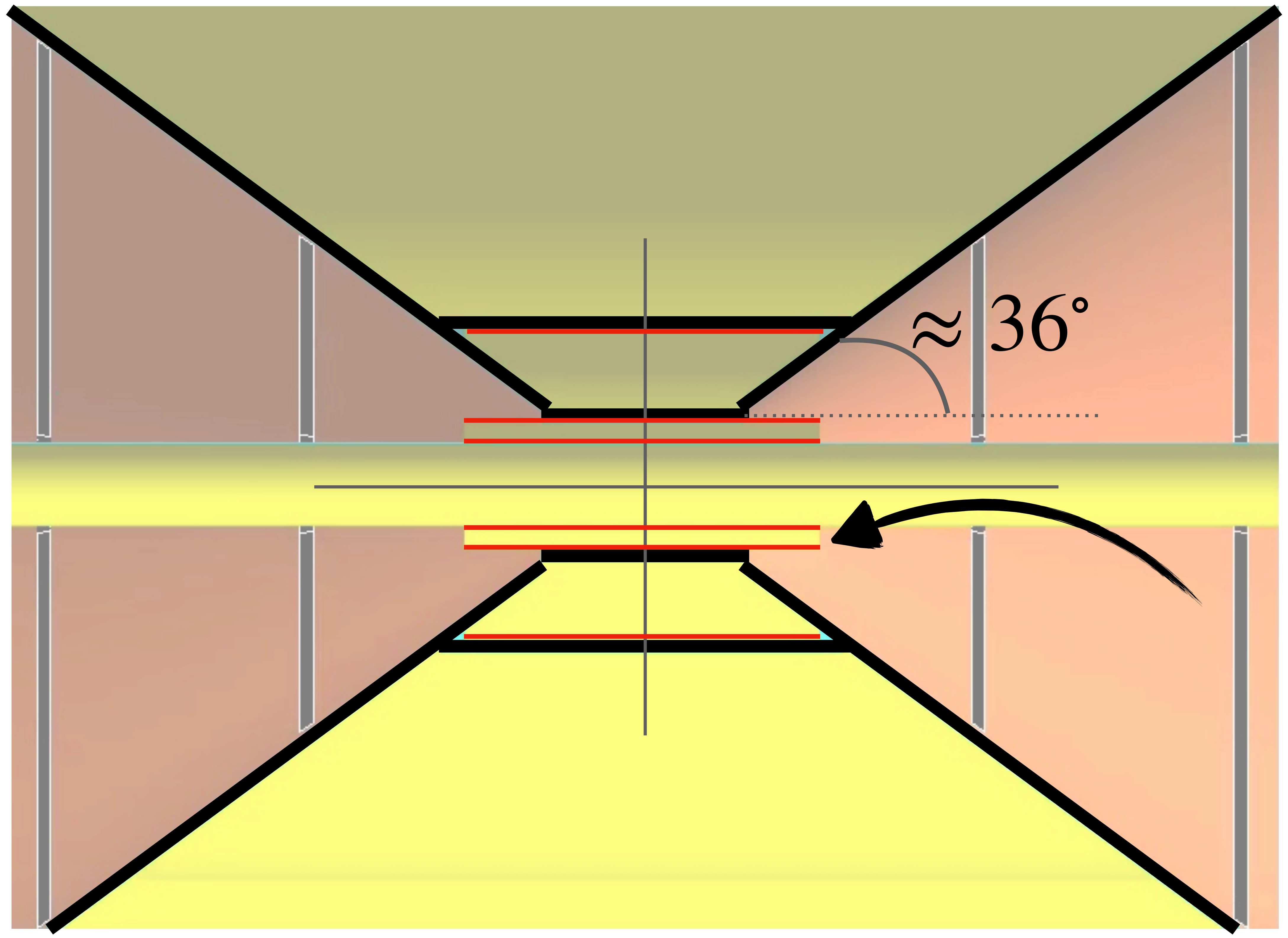
Services need to come out of the end-points of vtx layers



Cone angle impacts the performance

Support/service structure comparison

ECCE support



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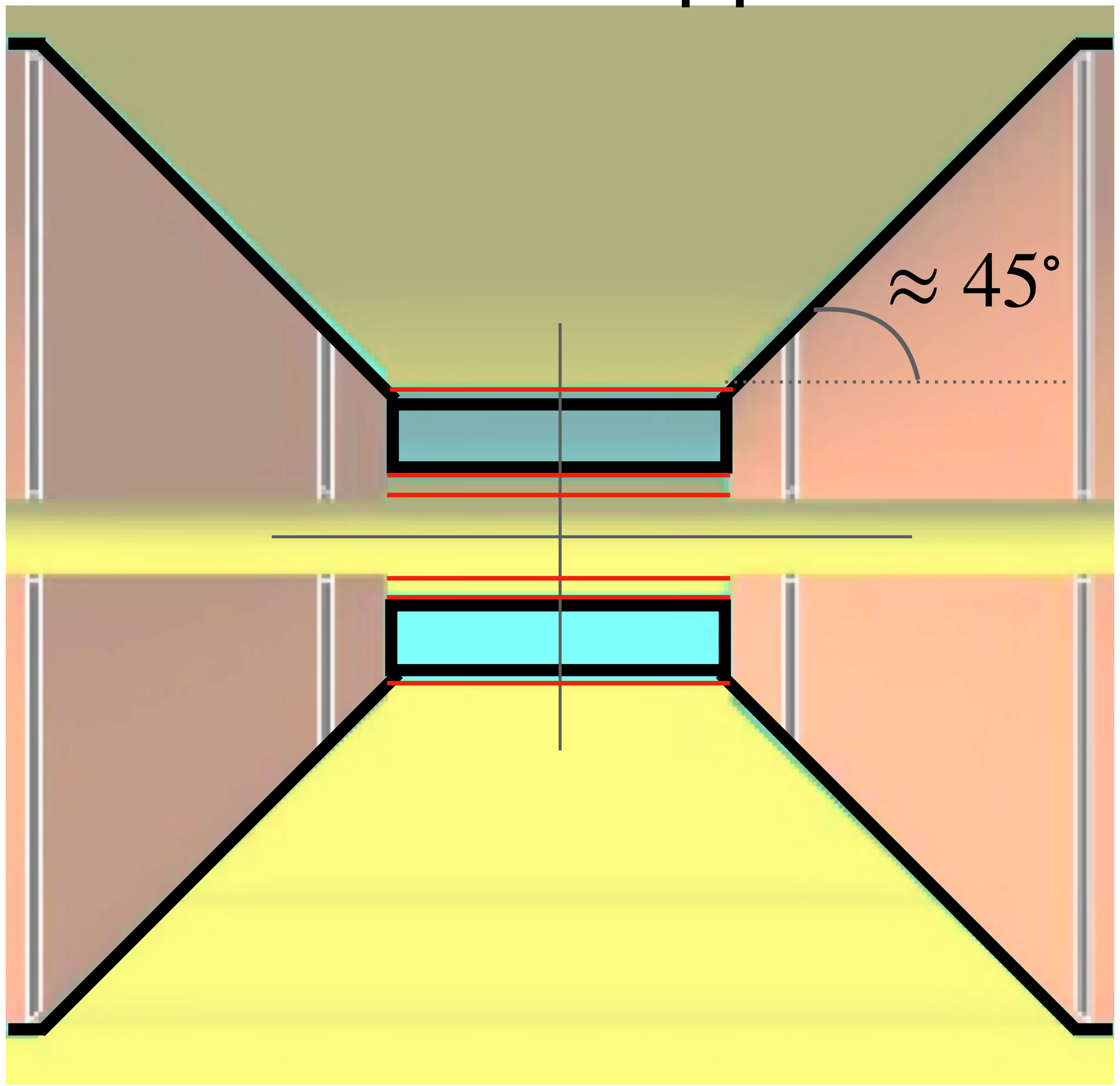
LBNL support



Support/service structure comparison

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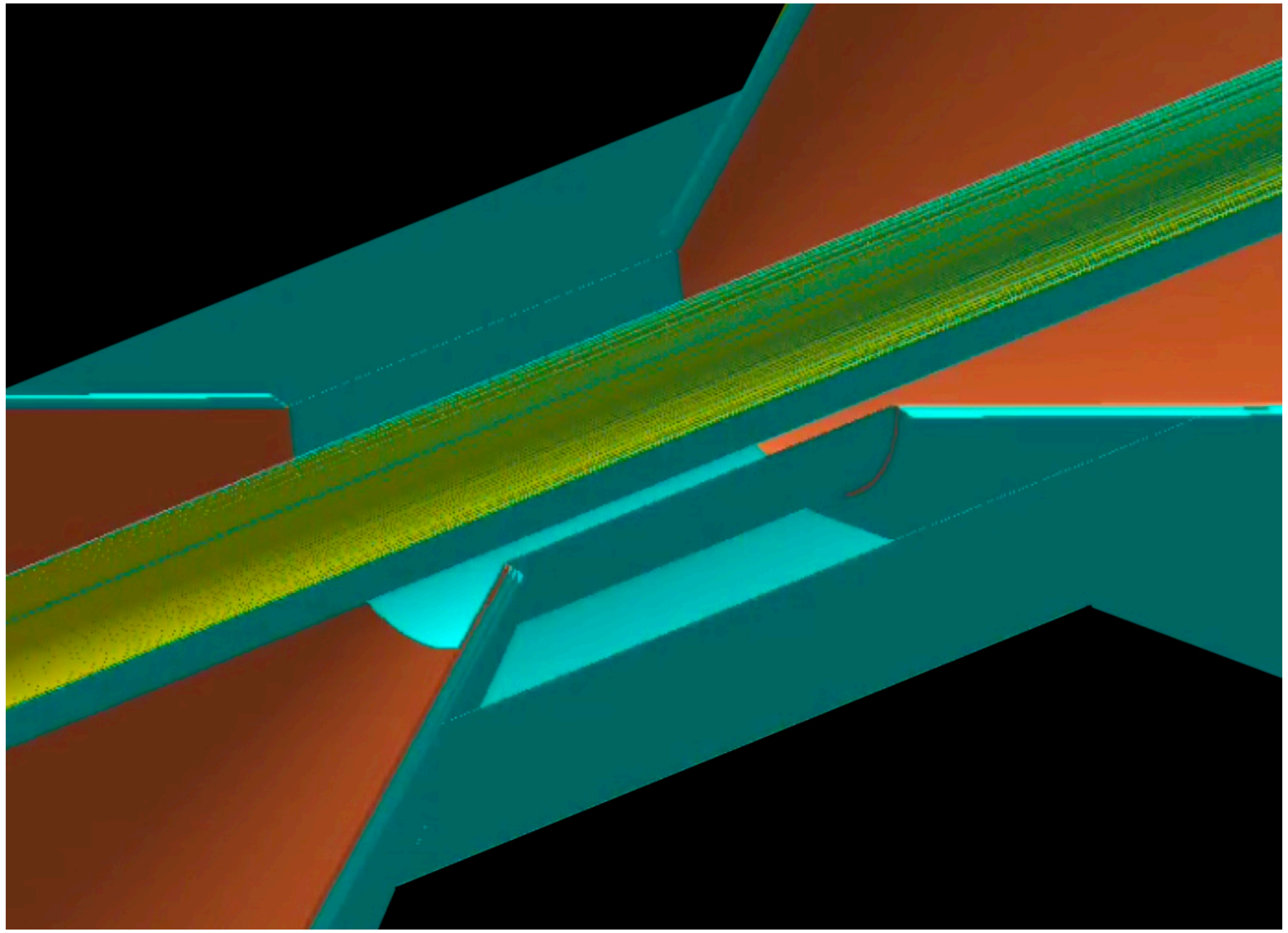

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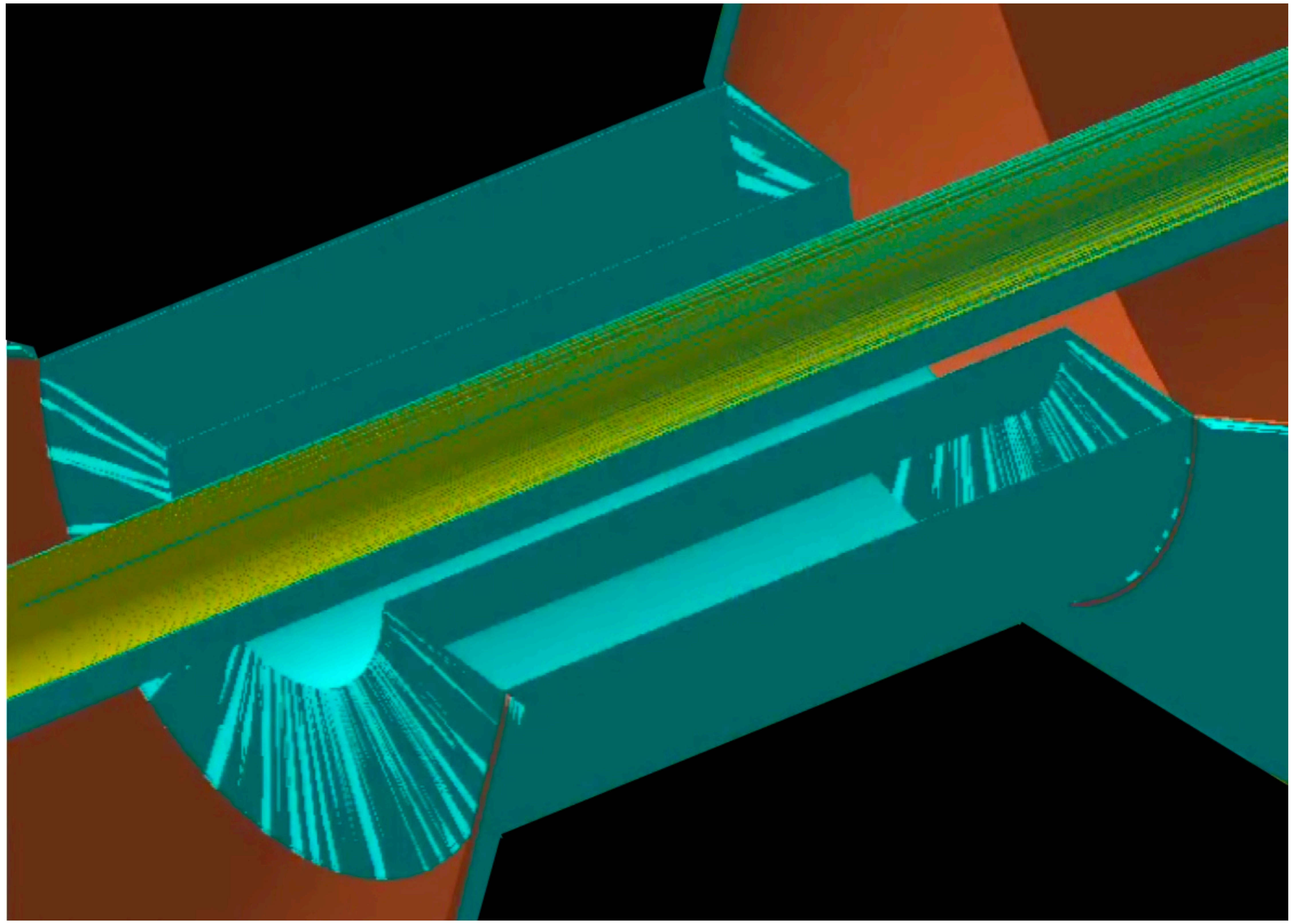
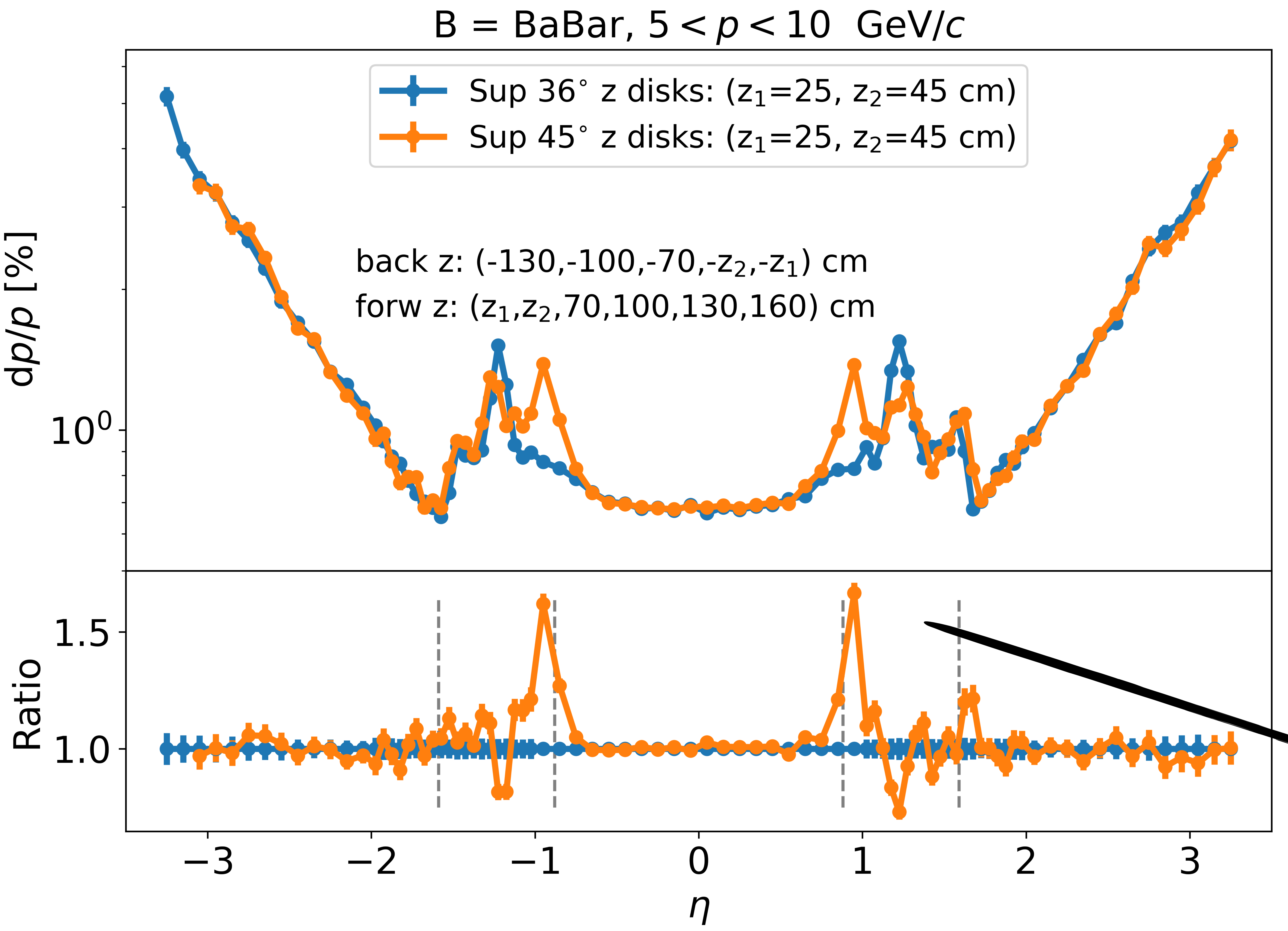


Geant4 rendering of these concepts

Support/service structure comparison

Support/service structure comparison



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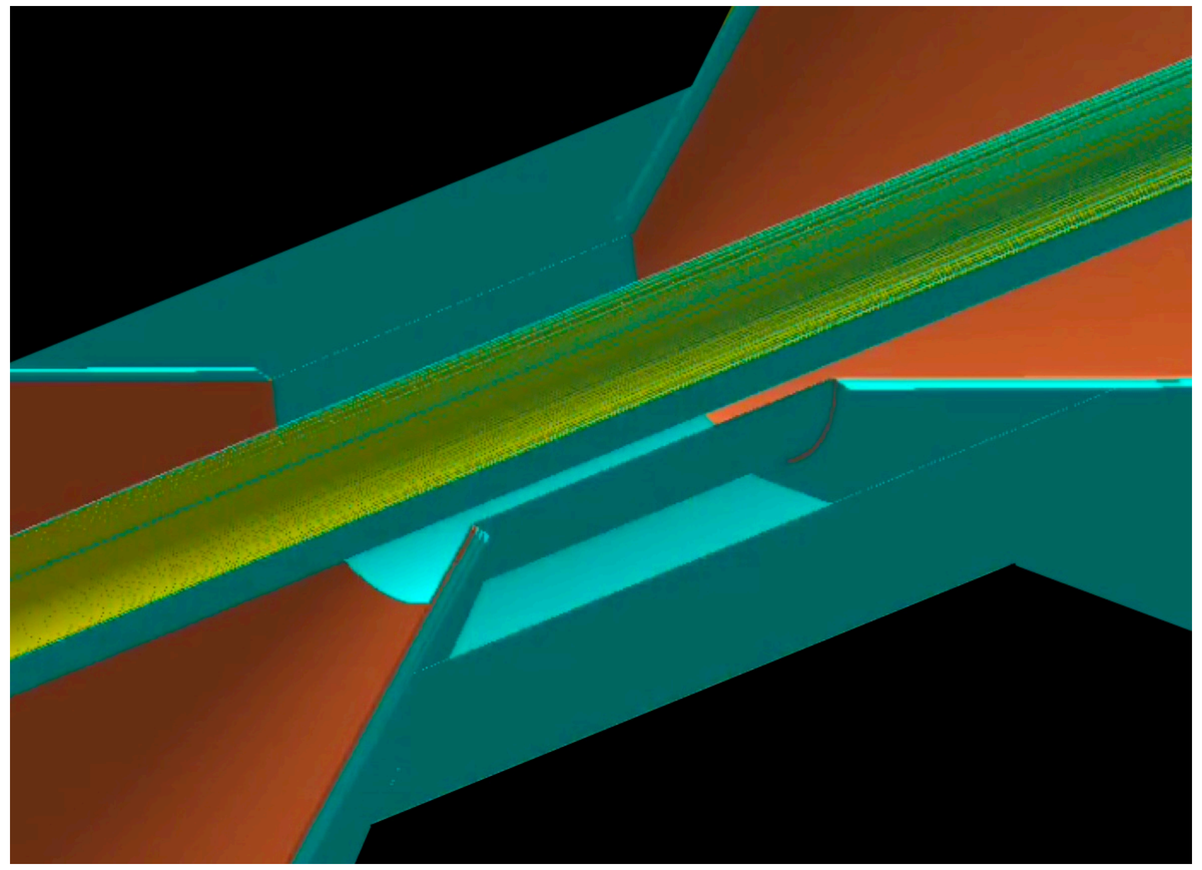

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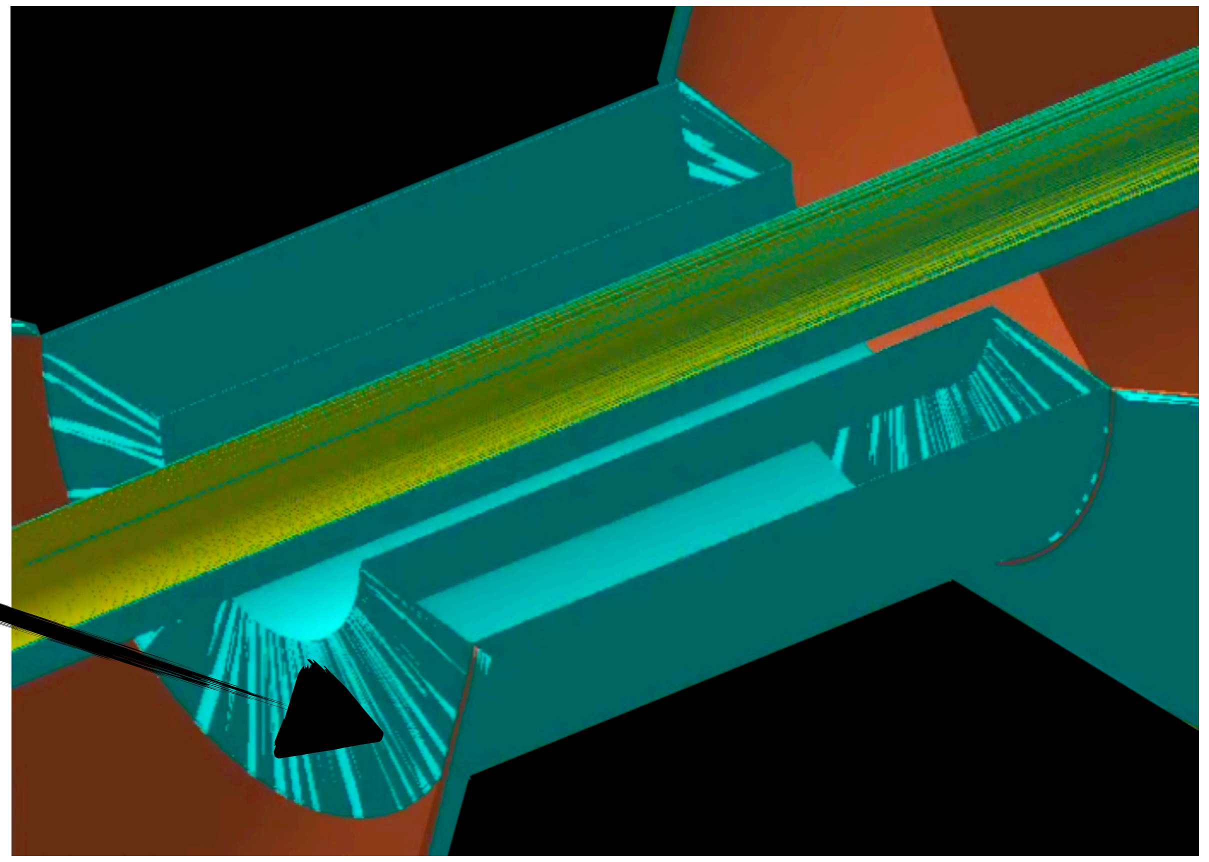
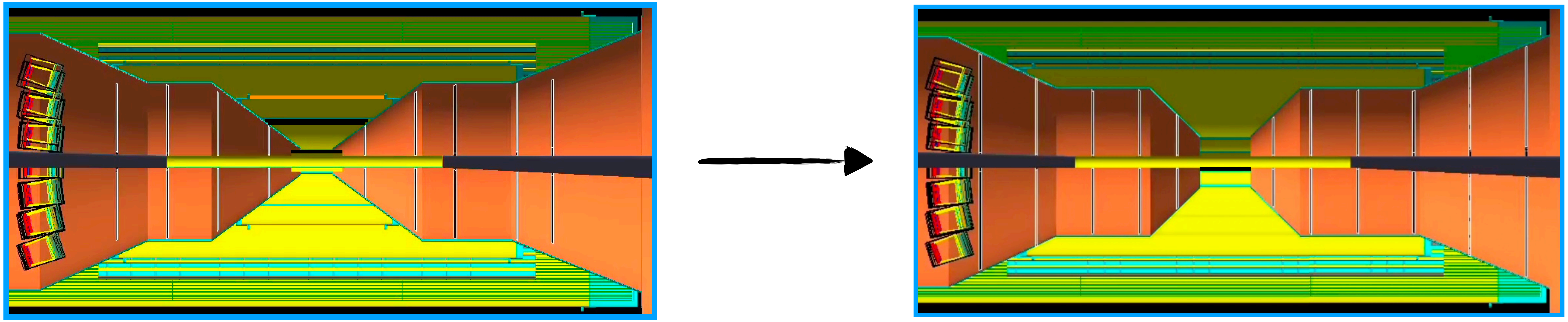


Summary

- Ongoing efforts to advance the EIC tracker design (fast+full simulations)



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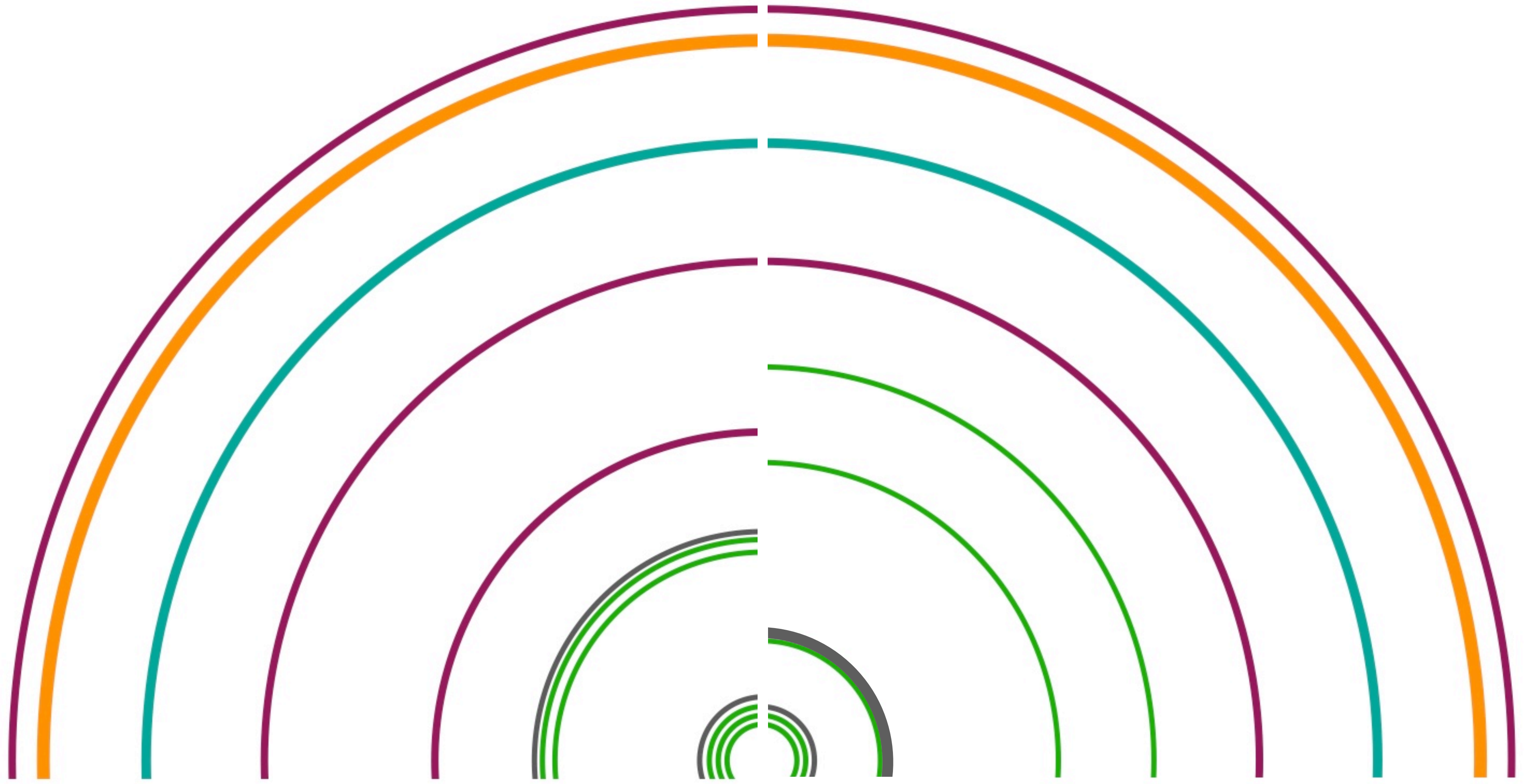
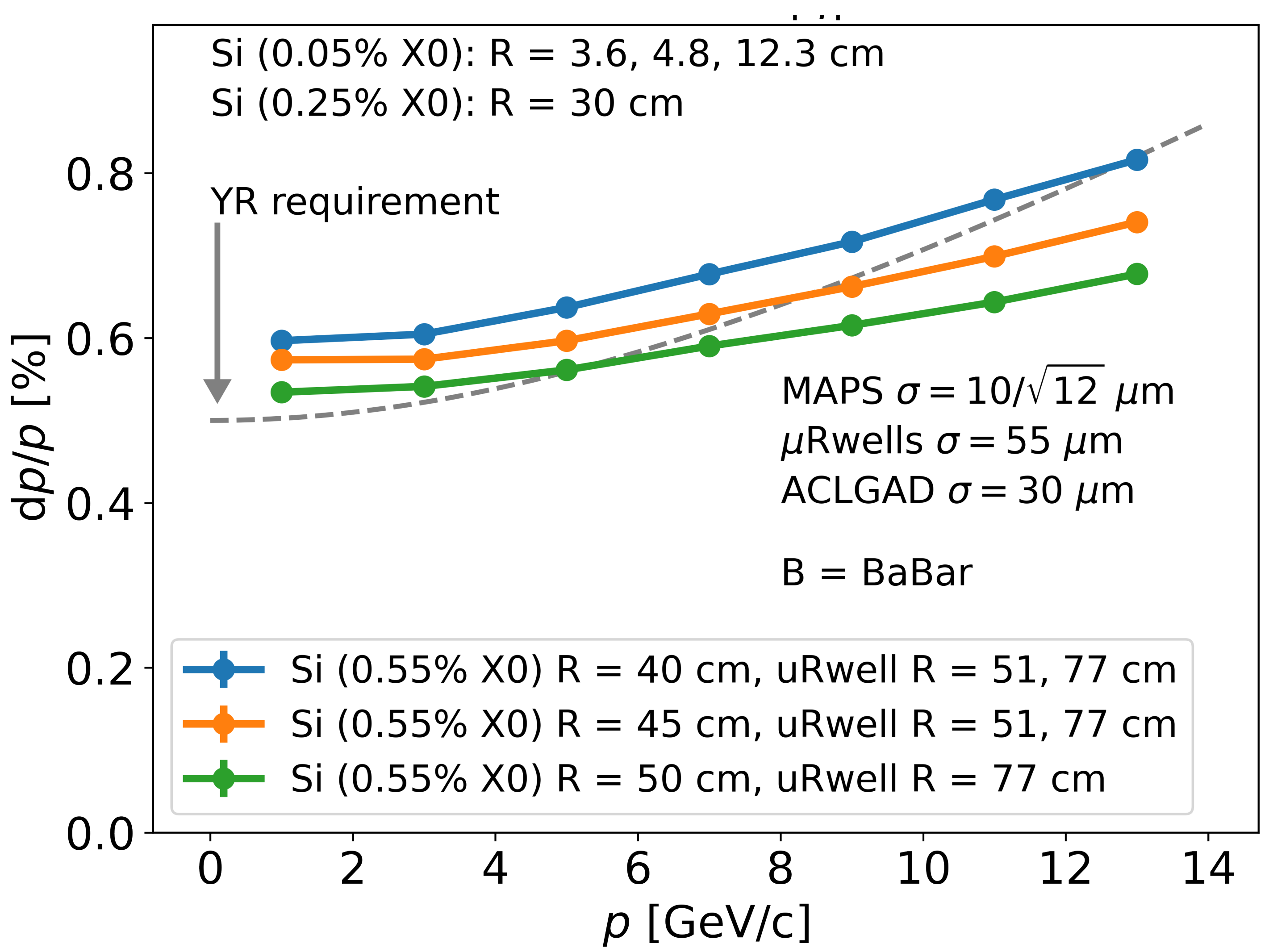
- Barrel:
    - vertex layer position updated to account for beampipe bake-out
    - new concept proposed / studied in fast simulations by E. Sichtermann
    - implemented in Fun4All and propagated to current simulation campaign
    - several clear avenues to further improve the barrel performance in a 1.4 T field





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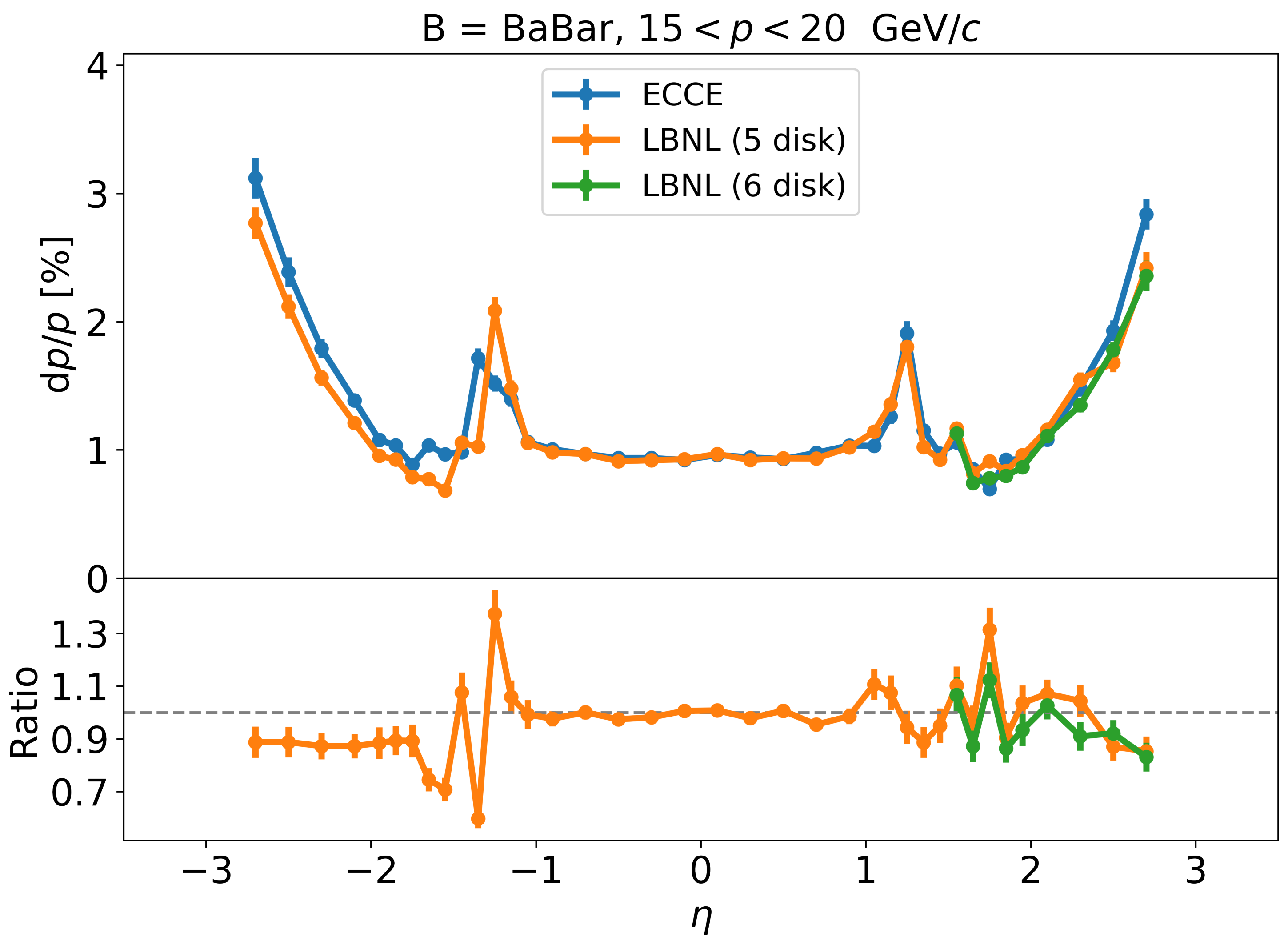
  - challenging region (B field, beampipe)



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  - several clear avenues to further improve the barrel performance in a 1.4 T field
- Disks:
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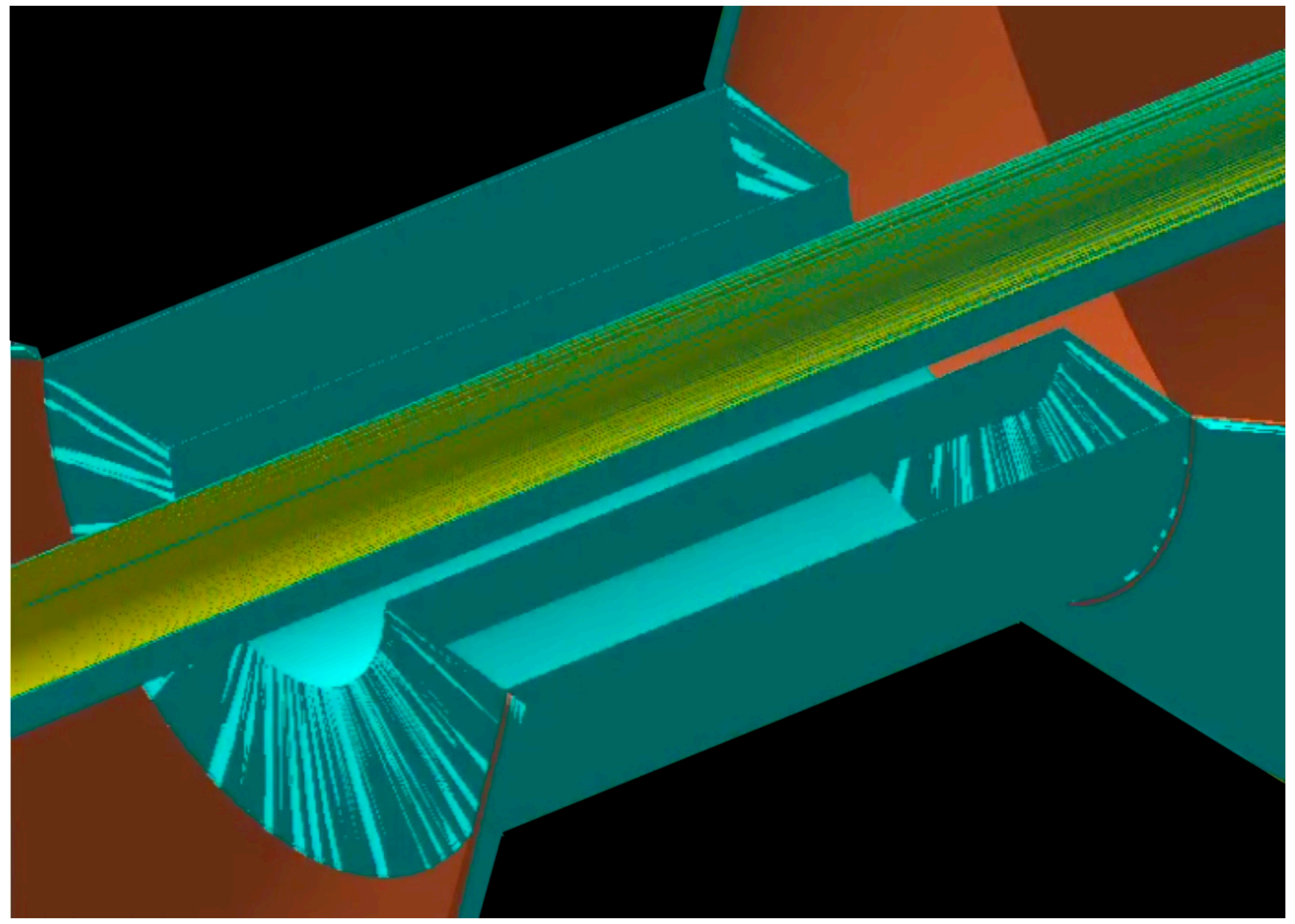
  - challenging region (B field, beampipe)
- Support structure:
  - implementing slightly more realistic support structure



Ongoing silicon tracker work

- Synchrotron radiation background (Cruz Torres, Sterwerf)
- Tracking pattern recognition (Lai, Fan)
- Optimization of tracker layout (Cruz Torres, Liang Gilman, Yeats, *with Sichermann, Li*)
- Quantify low p_T PID requirements for Detector 1 (Fan)
- Radiative corrections (Hwang, *with Barak Schmookler**)
- Study sensor cooling strategies (Liang Gilman, Yeats, Seddigh, Lew, *with Apadula, Li*)
- Model tracker mechanics (Yeats, Liang Gilman, *with Apadula*)

** UC EIC Fellow*

B.Jacak

Thank you!

Backup

Vertexing performance

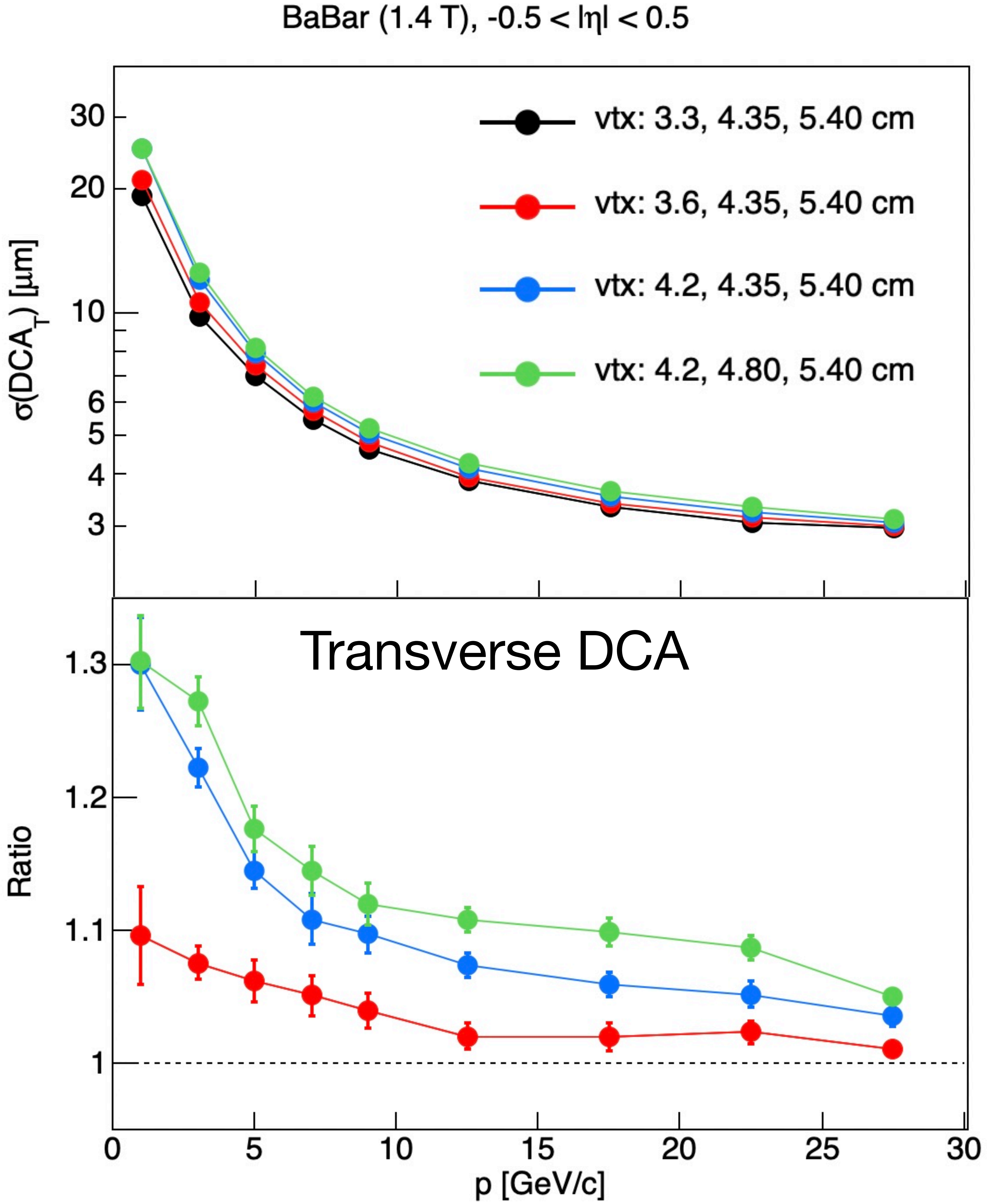
DCA ≡ Distance of Closest Approach

ECCE vertexing configuration

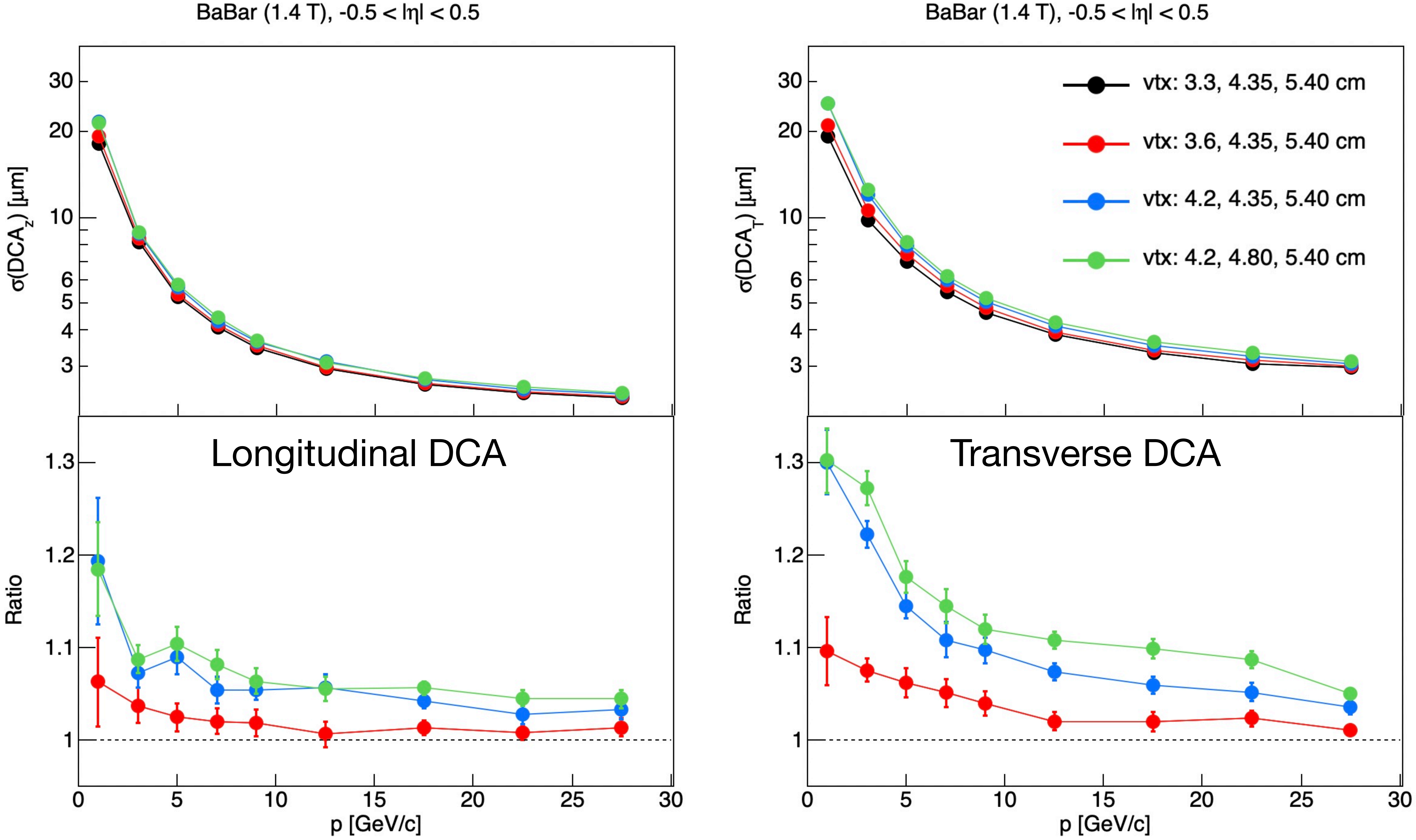
Barrel index	R (cm)	z_{min} (cm)	z_{max} (cm)
1	3.3	-13.5	13.5
2	4.35	-13.5	13.5
3	5.4	-13.5	13.5

Space needed for bake-out. Minimum radius cannot be < **3.6** cm

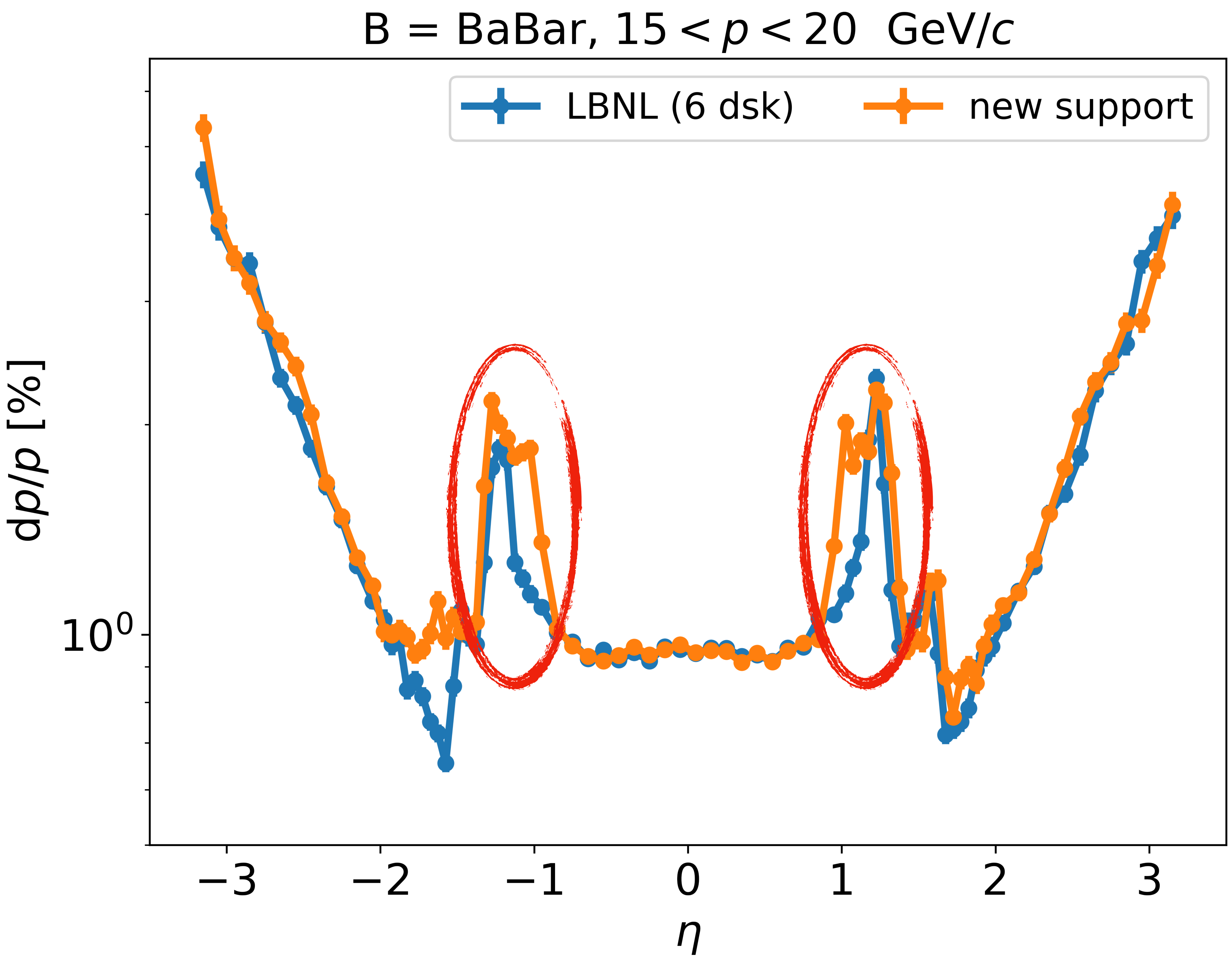
Need to understand DCA performance impact from a 36 mm inner radius, and potentially 42 mm



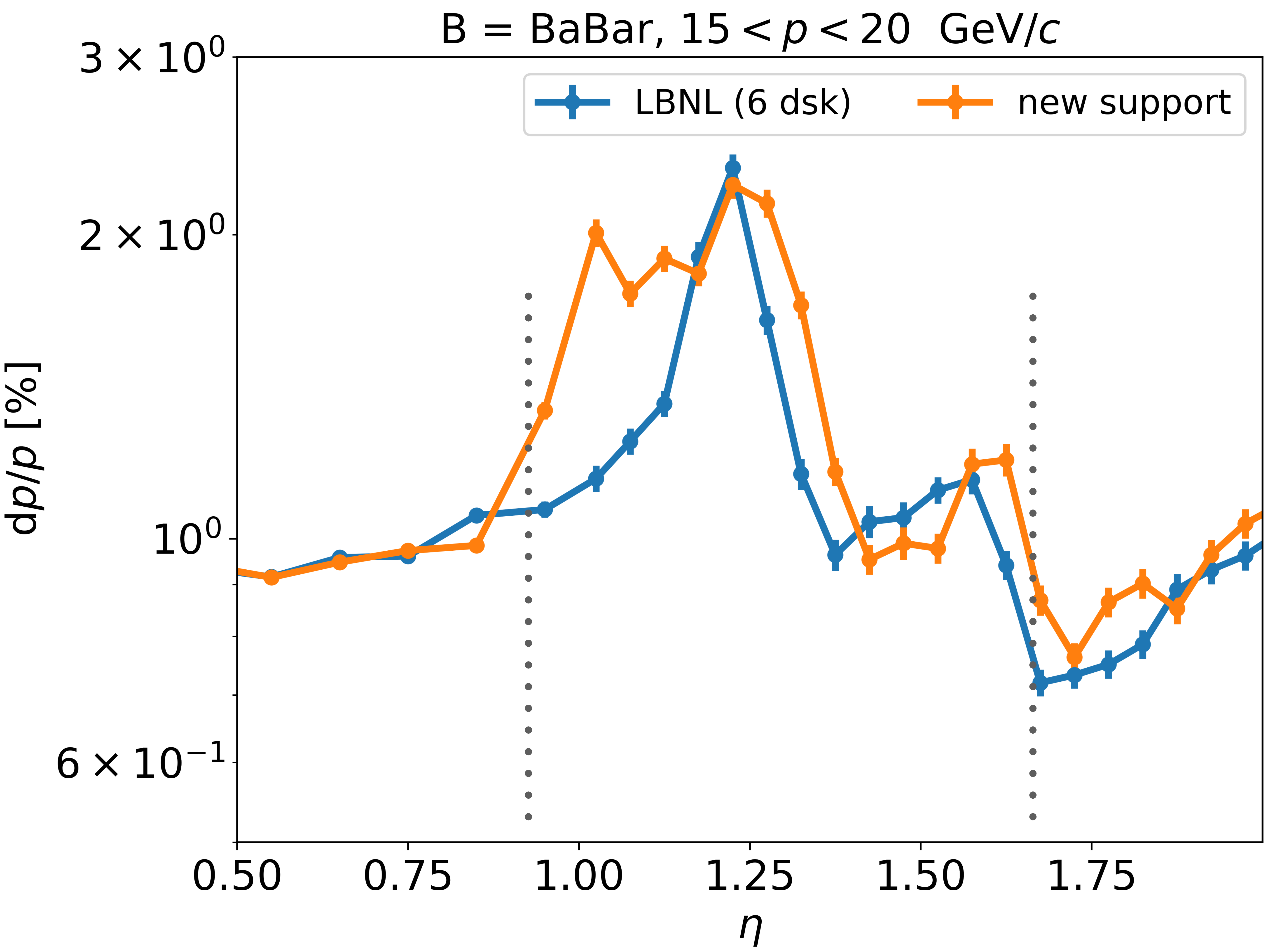
Vertexing performance

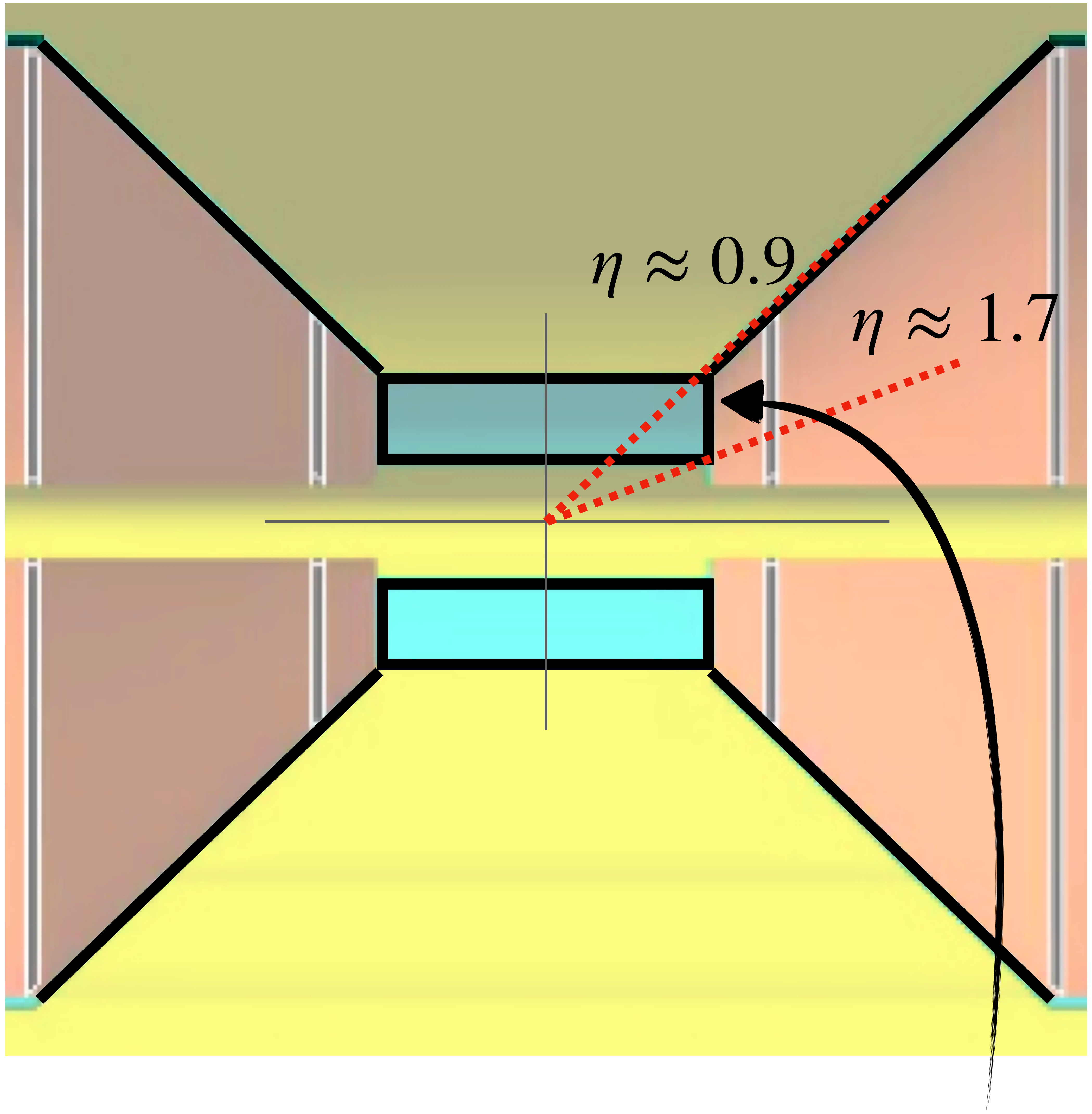


Momentum resolution results



Disk-shaped portion of support



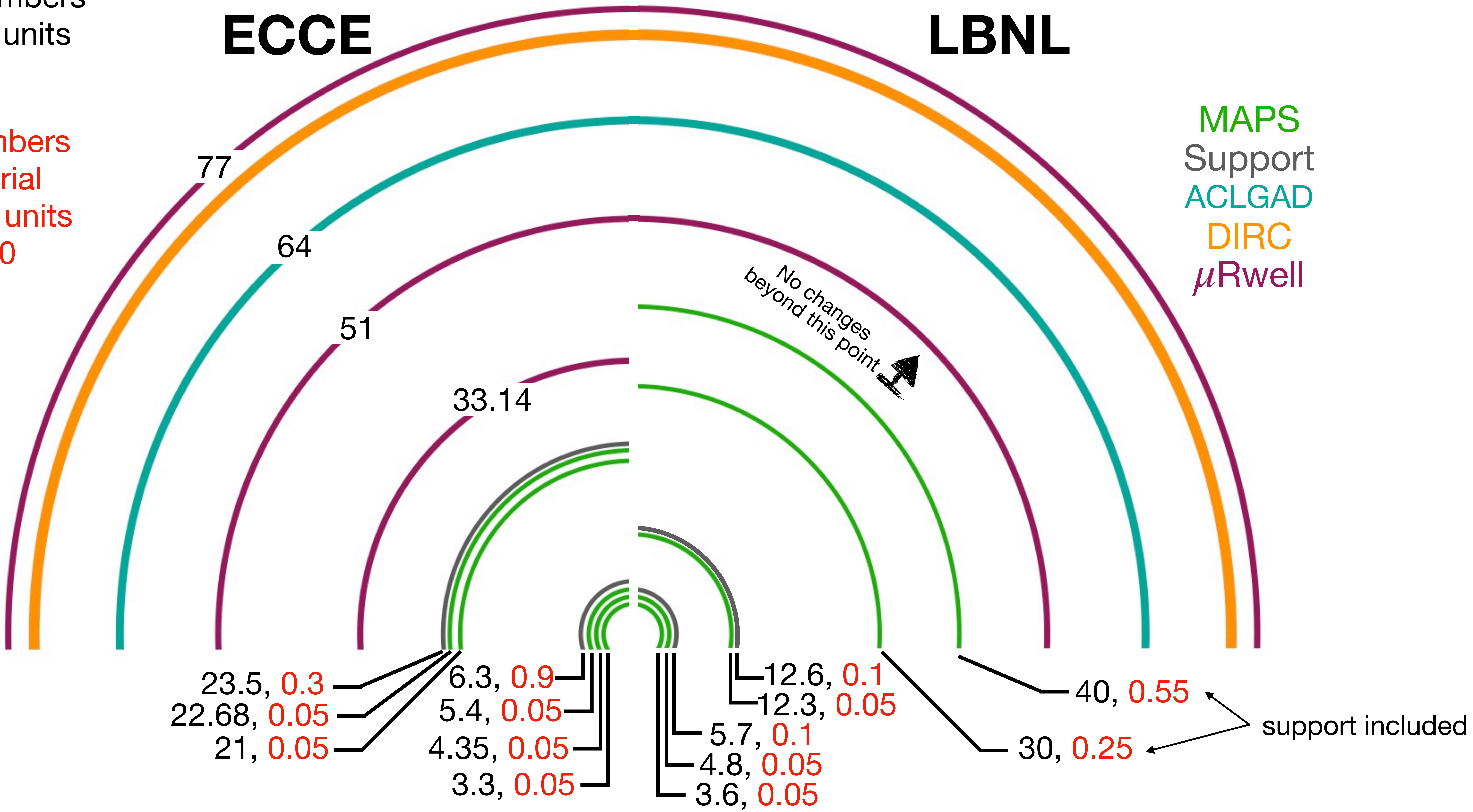


This structure did not exist in the previous geometry and thus is “new material” that tracks go through

New proposed barrel configuration

All black numbers are radii in units of cm

All red numbers are material budgets in units of % X0



Disk layout

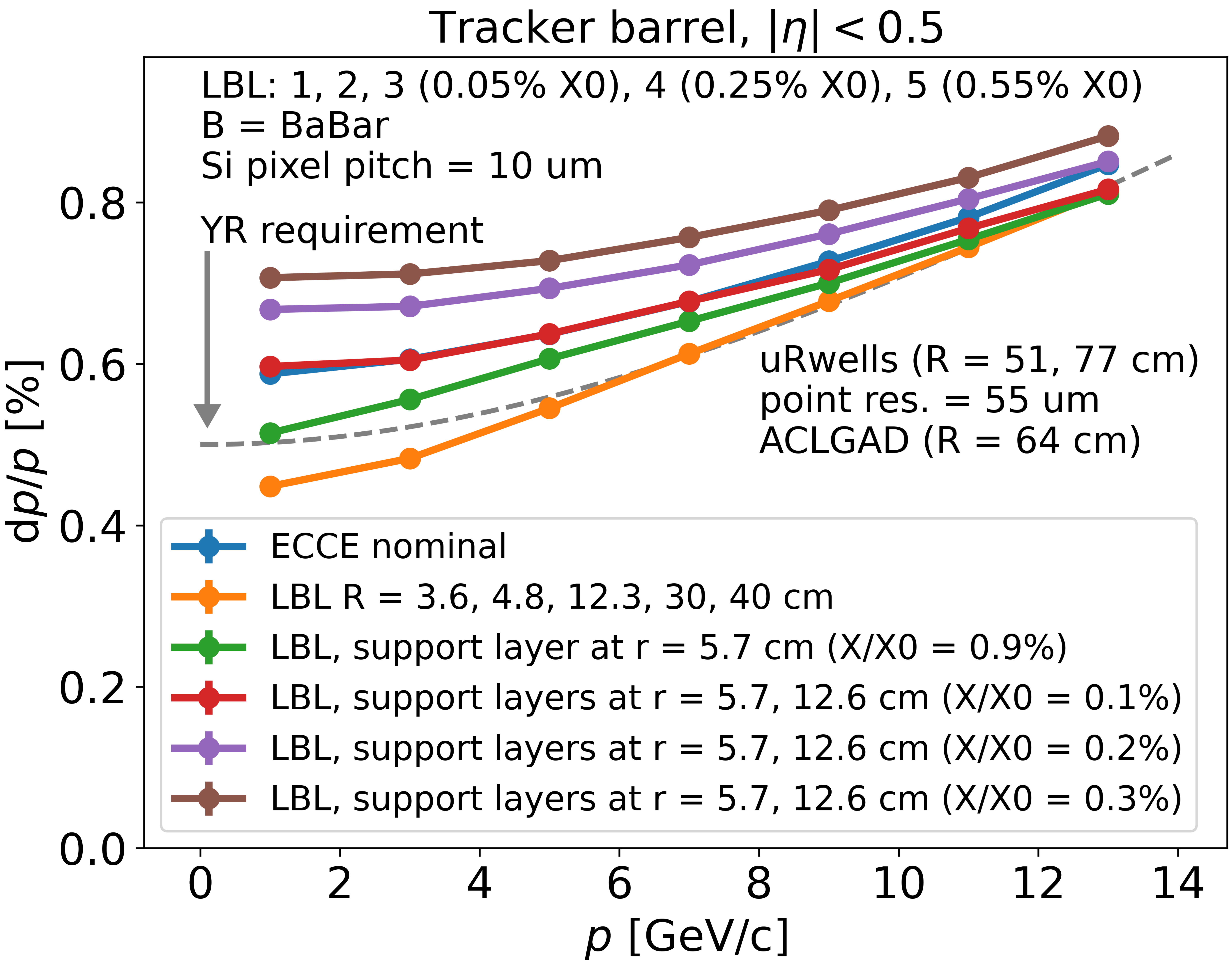
ECCE

	z (cm)	r_{min} (cm)	r_{max} (cm)
-4	-106	5.5	41.5
-3	-79	4.5	40.5
-2	-52	3.5	36.5
-1	-25	3.5	18.5
1	25	3.5	18.5
2	52	3.5	36.5
3	73	4.5	40.5
4	106	5.5	41.5
5	125	7.5	43.4

LBNL

	z (cm)	r_{min} (cm)	r_{max} (cm)
-5	-130	5.3	59.0
-4	-100	4.3	45.7
-3	-70	3.6	40.6
-2	-45	3.6	22.0
-1	-25	3.6	18.1
1	25	3.6	18.1
2	45	3.6	33.0
3	70	4.0	40.6
4	100	5.3	40.6
5	130	7.0	51.5
6	160	8.5	63.0

0.48% X0 per disk

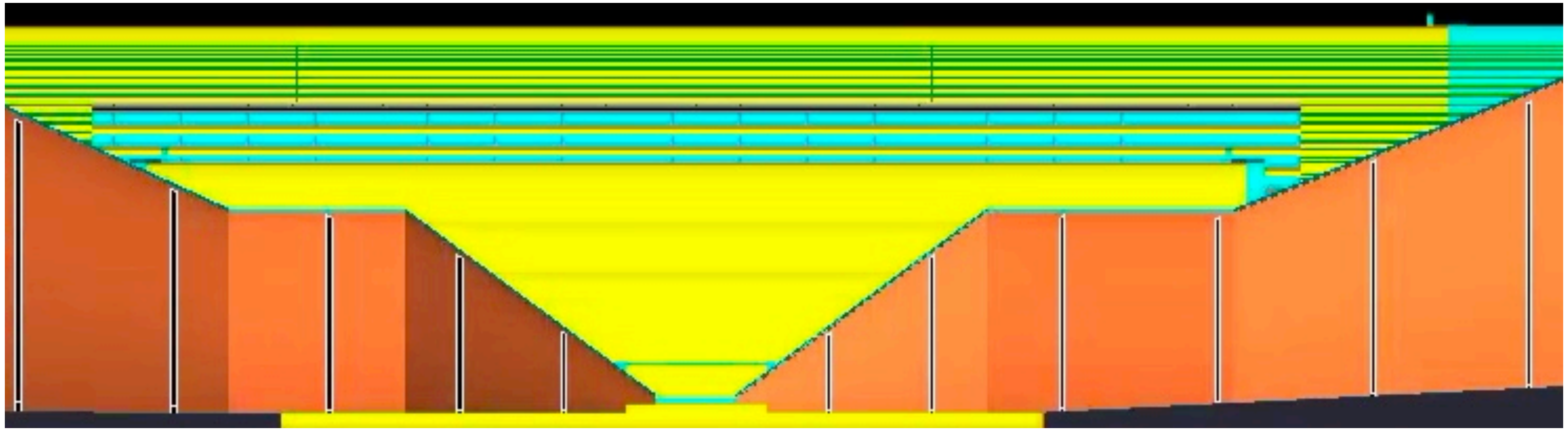


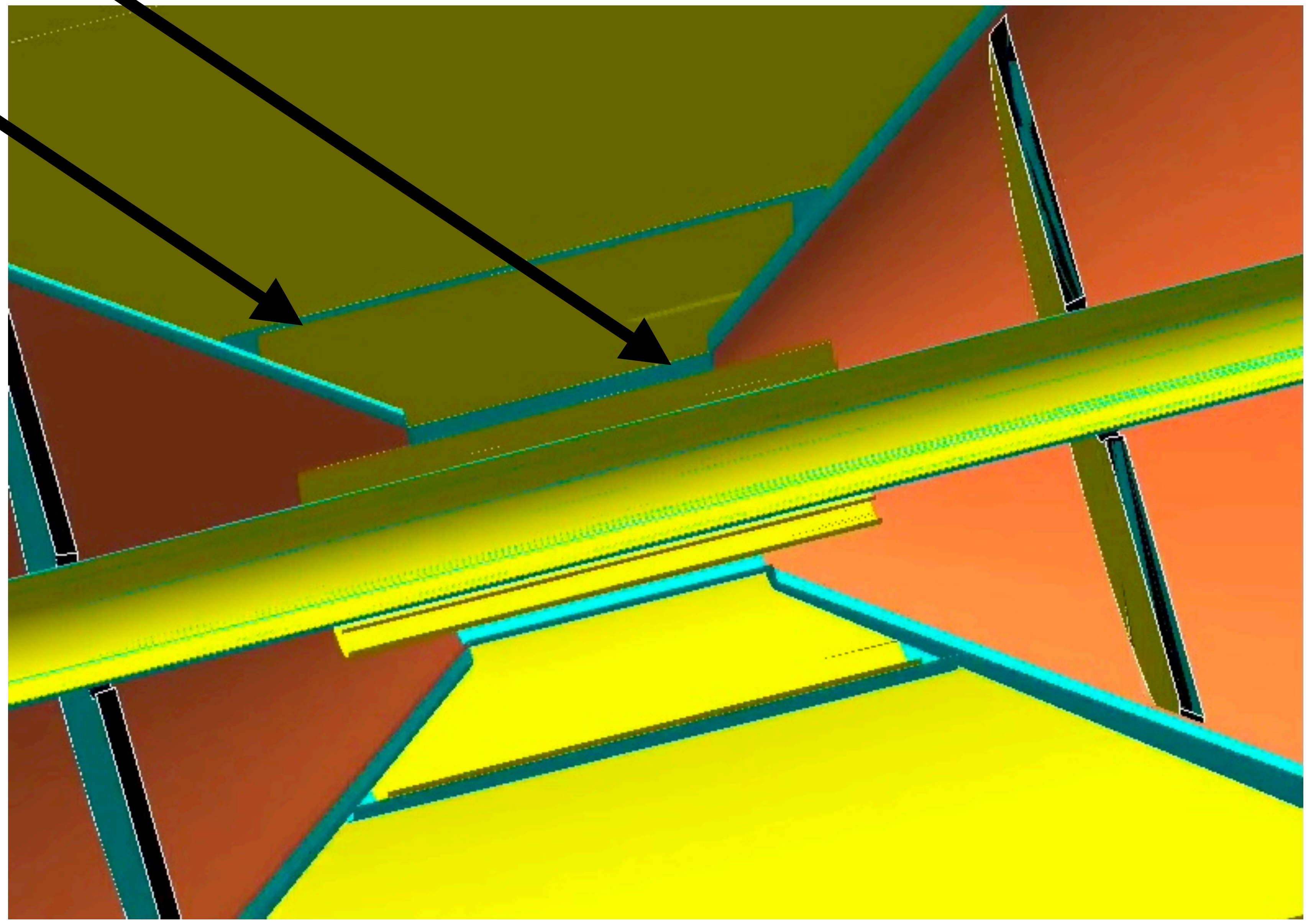
Tracker barrel, |η| < 0.5
LBL: 1, 2, 3 (0.05% X0), 4 (0.25% X0), 5 (0.55% X0)
B = BaBar
Si pixel pitch = 10 um
YR requirement
uRwells (R = 51, 77 cm)
point res. = 55 um
ACLGAD (R = 64 cm)
ECCE nominal
LBL R = 3.6, 4.8, 12.3, 30, 40 cm
LBL, support layer at r = 5.7 cm (X/X0 = 0.9%)
LBL, support layers at r = 5.7, 12.6 cm (X/X0 = 0.1%)
LBL, support layers at r = 5.7, 12.6 cm (X/X0 = 0.2%)
LBL, support layers at r = 5.7, 12.6 cm (X/X0 = 0.3%)
dp/p [%]
p [GeV/c]
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
12
14

New proposed barrel configuration

	r (cm)	length (cm)	X/X0	A (m²)
1	3.6	27	0.05%	0.061
2	4.8	27	0.05%	0.081
Support	5.7	15.4	0.1%	
3	12.3	27	0.05%	0.21
Support	12.6	30.6	0.1%	
4	30	77	0.25%	1.5
5	40	104	0.55%	2.6

	r (cm)	length (cm)	point res
uRwell2	51	212	55 um
ACLGAD	64	140	30 um
uRwell3	77.0175	342	55 um



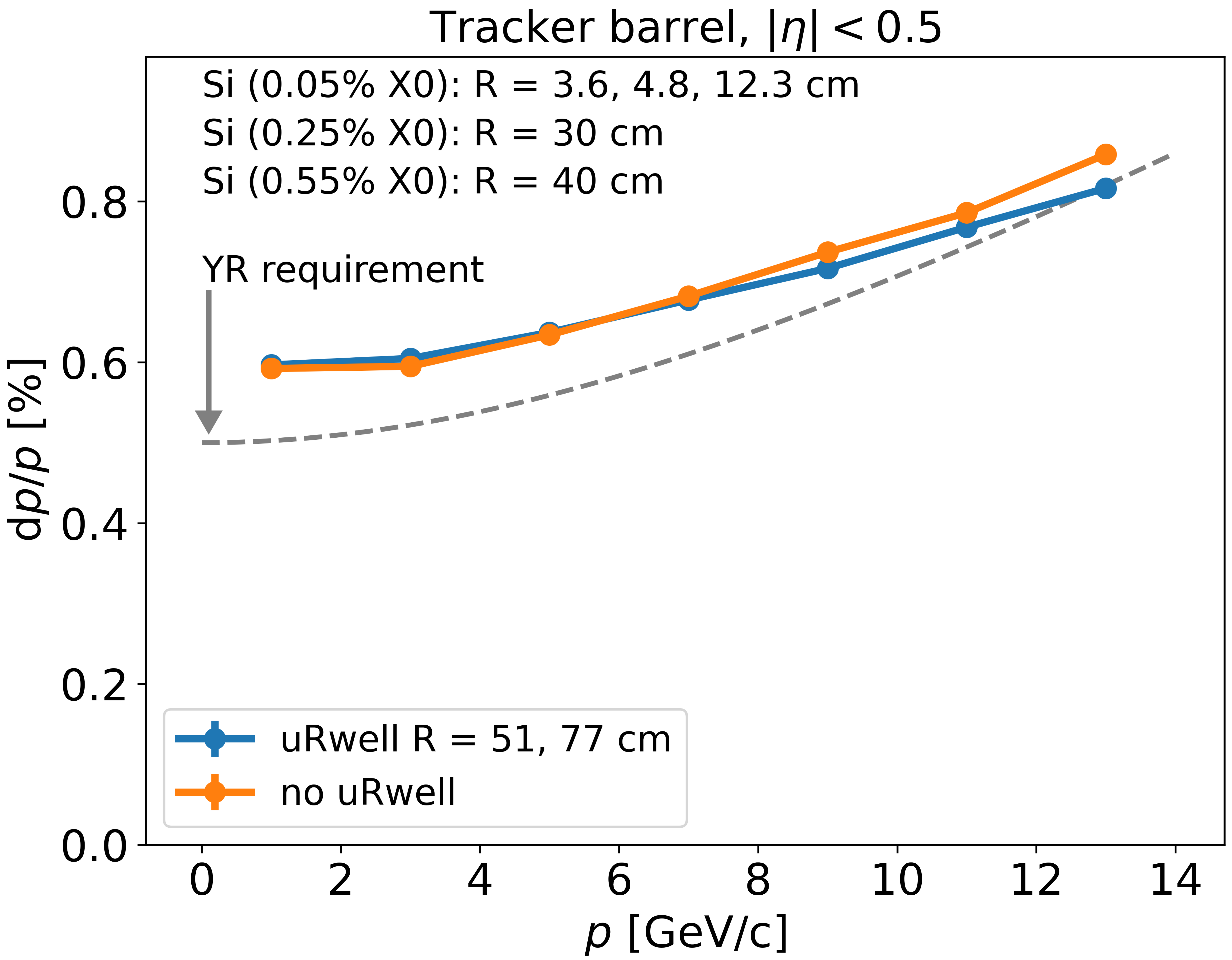


Disk Material budget

		X0 (cm)	X (cm)	X/X0
Si	Si	9.37	0.035	0.00373533
metal connection	Al	8.897	1.50E-03	0.0001686
HDI	kapton	28.57	2.00E-03	7.0004E-05
Cooling	Water	36.08	1.00E-02	0.00027716
Support	Graphite	19.32	5.00E-03	0.0002588
Support Gap	Air	3.04E+04	1	3.2906E-05
Support 2	Graphite	19.32	5.00E-03	0.0002588
			Tot	0.00480159

dp/p impact of MPGDs in the barrel

dp/p impact from barrel MPGDs



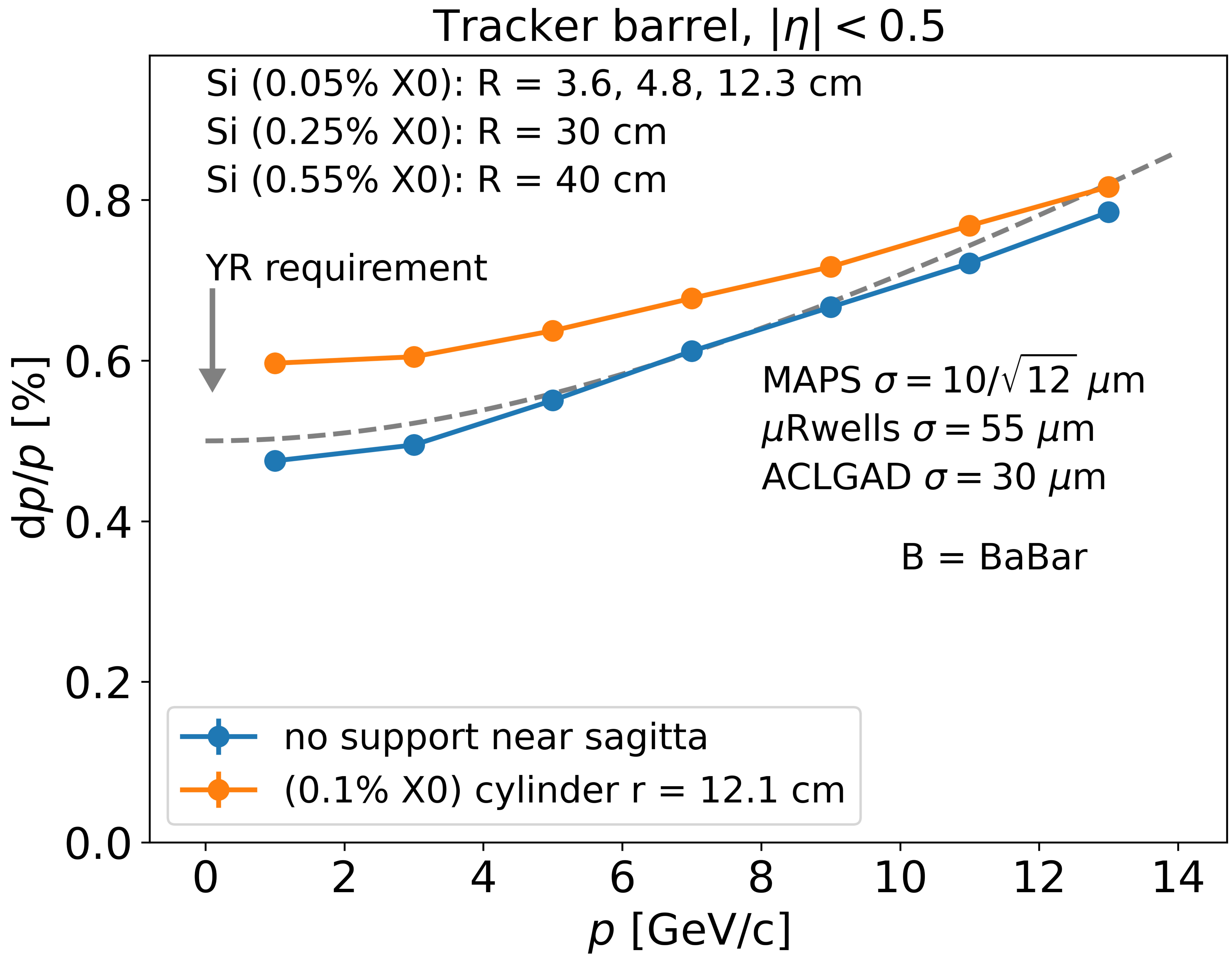
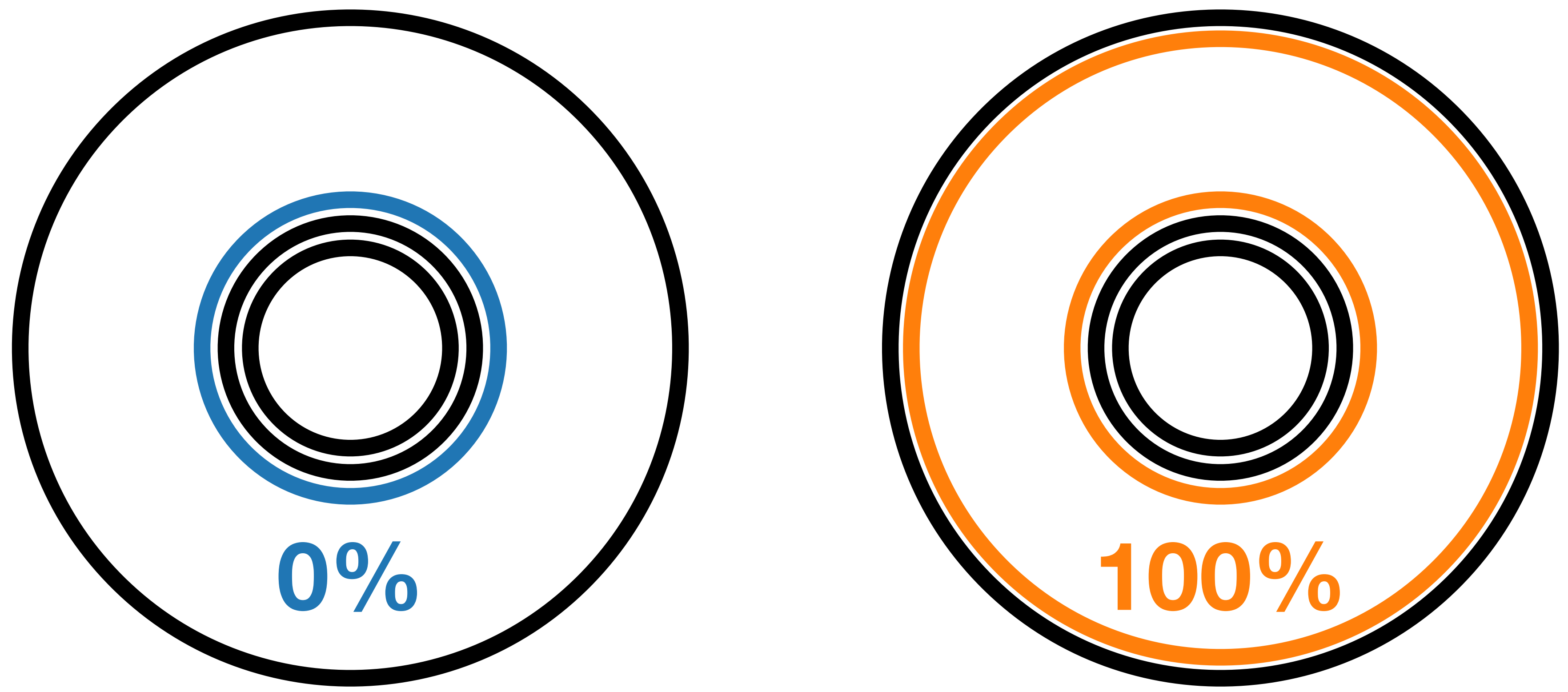
Barrel MPGDs (as specified in this configuration) only has some dp/p-resolution impact in the higher-momentum regime.

However, this is not the only figure of merit and, when simulations with backgrounds are carried out, these layers may have a larger impact

MAPS $\sigma = 10/\sqrt{12}\ \mu m$
μRwells $\sigma = 55\ \mu m$
ACLGAD $\sigma = 30\ \mu m$

B = BaBar

Support “concepts”


Tracker barrel, $|\eta| < 0.5$
Si (0.05% X0): R = 3.6, 4.8, 12.3 cm
Si (0.25% X0): R = 30 cm
Si (0.55% X0): R = 40 cm
YR requirement
MAPS $\sigma = 10/\sqrt{12}\ \mu m$
μRwells $\sigma = 55\ \mu m$
ACLGAD $\sigma = 30\ \mu m$
B = BaBar
no support near sagitta
(0.1% X0) cylinder r = 12.1 cm
dp/p [%]
p [GeV/c]
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
12
14

0%
100%


Tracker barrel, $|\eta| < 0.5$
Si (0.05% X0): R = 3.6, 4.8, 12.3 cm
Si (0.25% X0): R = 30 cm
Si (0.55% X0): R = 40 cm
YR requirement
MAPS $\sigma = 10/\sqrt{12}\ \mu m$
μRwells $\sigma = 55\ \mu m$
ACLGAD $\sigma = 30\ \mu m$
B = BaBar
no support near sagitta
(0.1% X0) cylinder r = 12.1 cm
25% ϕ coverage (0.1% X0)
50% ϕ coverage (0.1% X0)
75% ϕ coverage (0.1% X0)
dp/p [%]
p [GeV/c]
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
12
14
0%
100%
25%
50%
75%

Tracker barrel, |η| < 0.5
Si (0.05% X0): R = 3.6, 4.8, 12.3 cm
Si (0.25% X0): R = 30 cm
Si (0.55% X0): R = 40 cm
YR requirement
MAPS σ = 10/√12 μm
μRwells σ = 55 μm
ACLGAD σ = 30 μm
B = BaBar
no support near sagitta
(0.1% X0) cylinder r = 12.1 cm
25% φ coverage (0.1% X0)
50% φ coverage (0.1% X0)
75% φ coverage (0.1% X0)
dp/p [%]
p [GeV/c]
0%
100%
25%
50%
75%