Towards Transitioning Tracking and Vertexing for Detector 1 from Reference to Baseline

Ernst Sichtermann - LBNL

Proposed ECCE Tracker – now reference for Detector 1

(ECCE proposal)

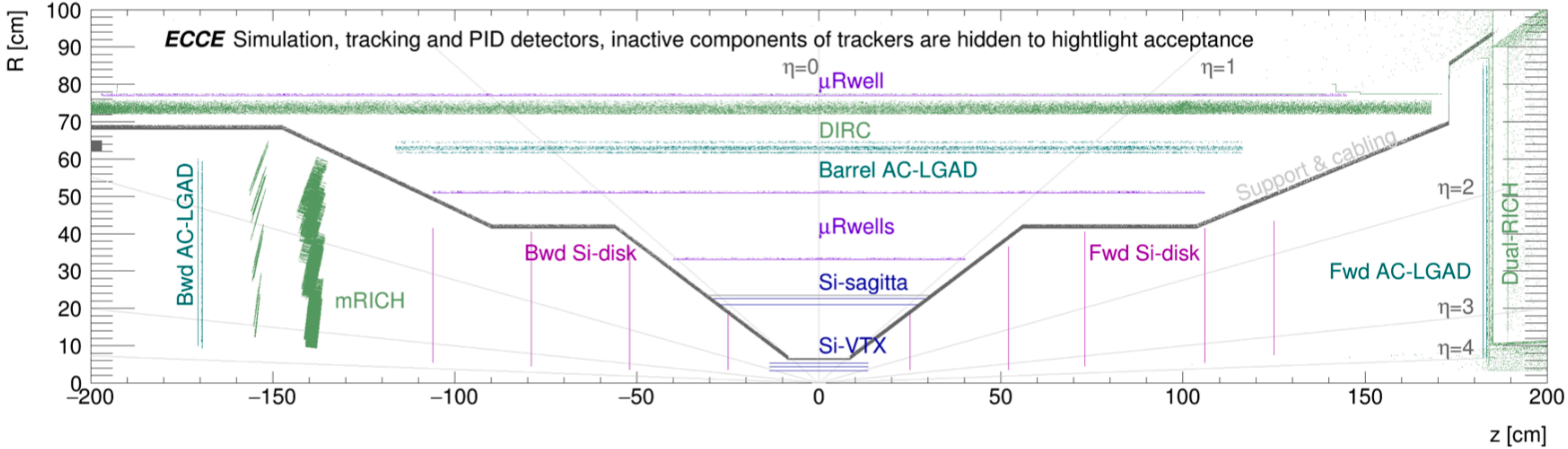

Figure 2.5: Schematic view of the ECCE tracker, including silicon, μRWELL, AC-LGAD, DIRC, mRICH and dRICH detector systems.

Transition from reference to baseline will entail, if not require, refinement / revision of the tracker configuration and layout,
Let's consider the ~1.4 T solenoidal field fixed,
My main focus for today will be about resolutions, in particular those at mid-rapidity.

Proposed ECCE Tracker – now reference for Detector 1

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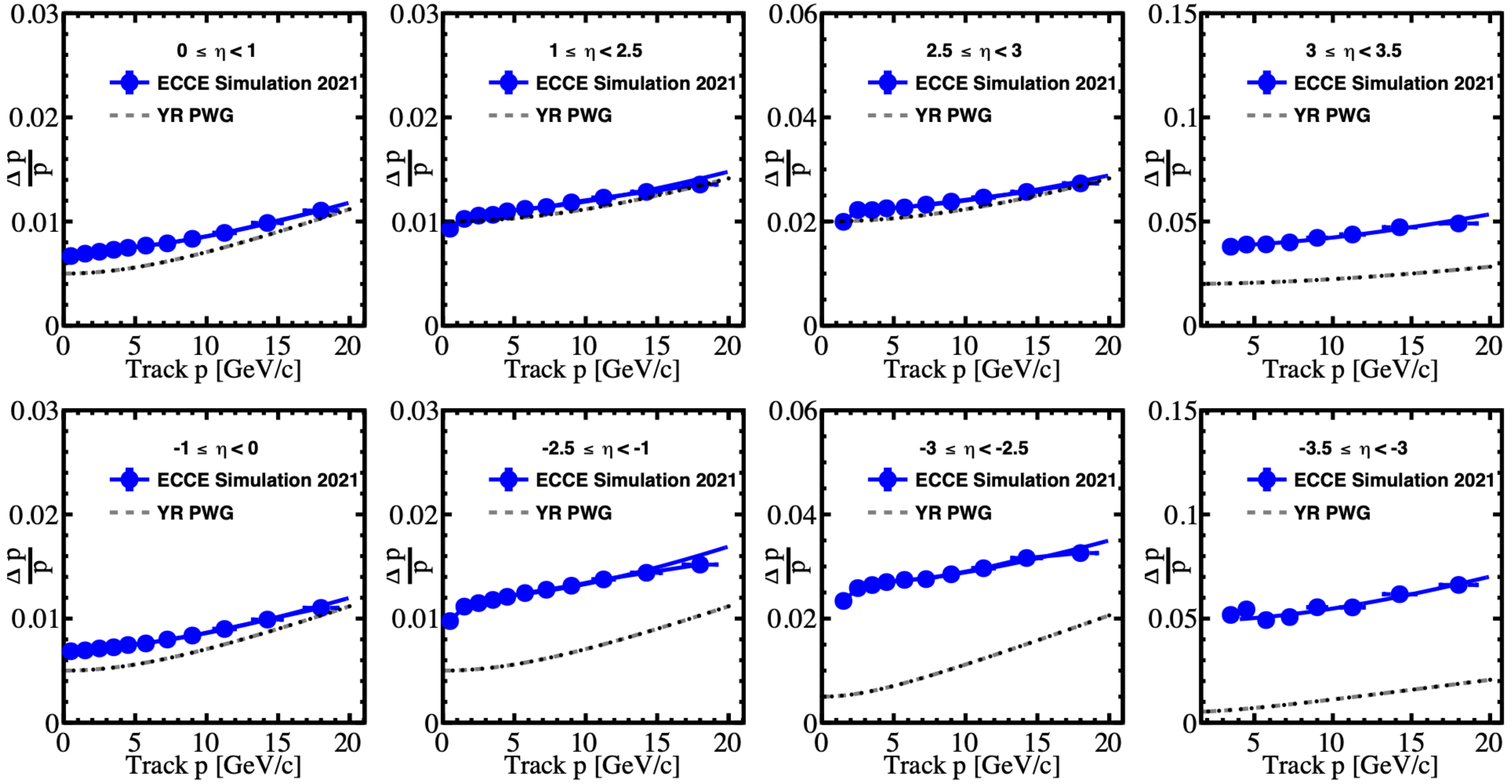


Figure 2.7: ECCE pion track momentum resolution (data points) with the EIC YR PWG requirements for the tracker indicated by the dashed lines. Note that the ECCE performance simulations take into account materials for readout and services. The impact of these can be observed most clearly in the bins covering the barrel/barrel endcap transition regions. As an integrated EIC detector with all subsystems operating in a complementary way, ECCE achieves the EIC physics goals as described in Chapter 3.

(Too) much ado about unrealistic assumptions about traversed material that degrade projected mid-central performance, YR backward dp/p is a tall order within the constraints; note, however, the ECCE-projected forward performance is better i.e. disk configuration will need revisiting — not for today though.

A reminder of Yellow Report Table 11.2

Table 11.2: Requirements for the tracking system from the physics groups.

Tracking requirements from PWGs						
			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
η						
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 0.5%	~5% X0 or less	100-150 MeV/c	
-3.0 to -2.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5		Barrel	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					100-150 MeV/c	
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 60 µm

The requirements for the tracking in an EIC detector are derived from the physics simulations and are represented by the detector requirements table shown in Table 11.2. The ranges in pseudorapidity are accompanied with requirements for relative momentum resolution, allowed material budget in terms of radiation length, minimum p_T cutoff, transverse and longitudinal pointing resolutions. These requirements form the basis of the designs and concepts that are presented.

- dp/p is a combination of the constant and proportional term,
- Both matter over most of the EIC range, but the trade-offs can be different,
- E.g. in the central barrel, the terms are balanced for p = 10 GeV/c; in the (very) forward region this is for p = 20 GeV/c, and in the backward region for p = 5 GeV/c.
- Transitions are, of course, not as hard as suggested by the table; little if any EIC physics is about achieving "5σ" (i.e. more about measurement qualities than discovery probabilities),

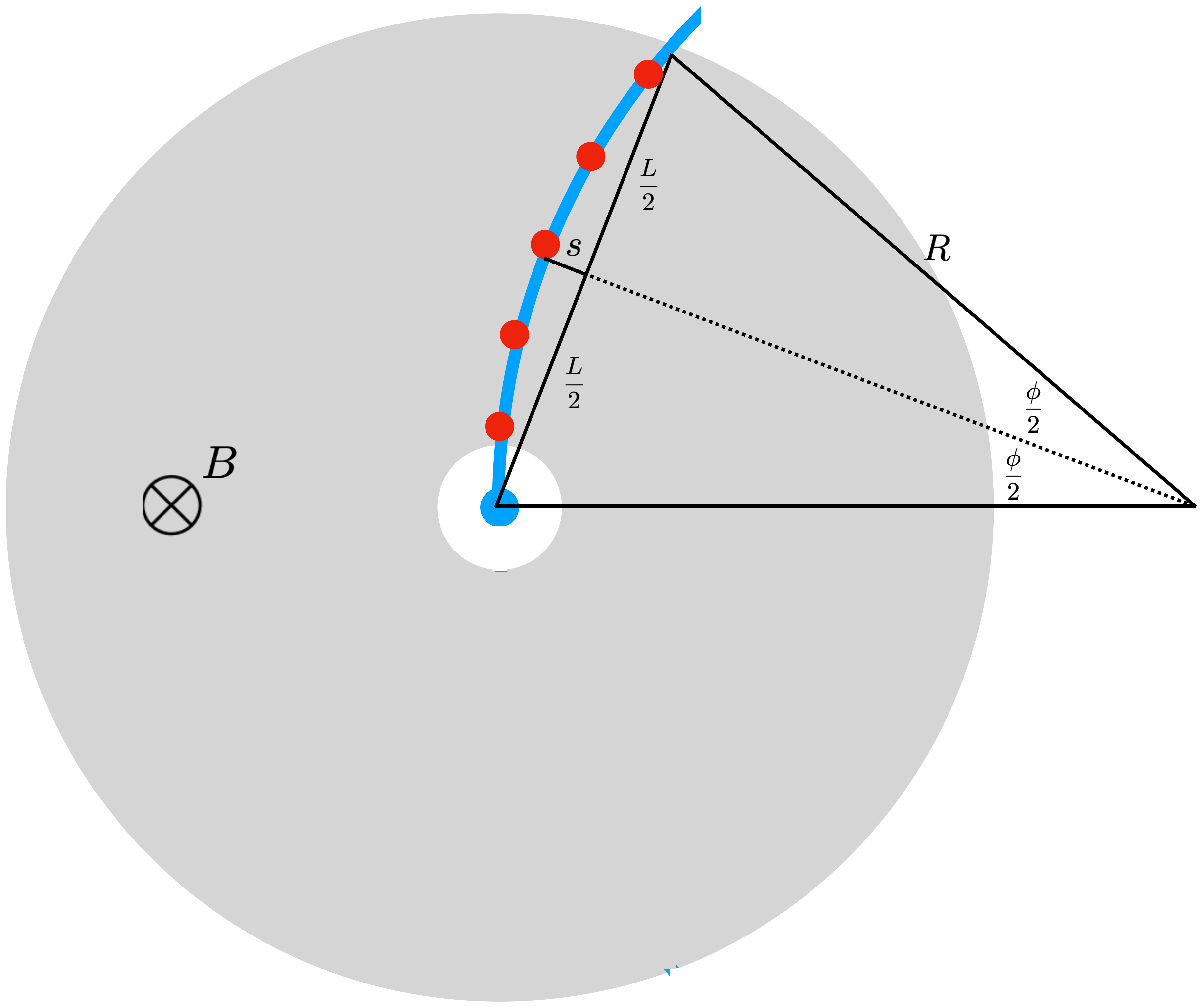
YR tracking requirements do not strictly specify a range, other than the implied phase-space (kinematic) limits.

That said, it would seem ill-advised to do anything other than accept the YR as a snapshot of community best knowledge.

I will thus take the requirement as meeting the constant term and the slope and, while DIS cross-sections typically fall as Q^{-4}, note that physics exists also at high-Q^2. That is, I will show a wider range in momenta than what is often shown.

A recap of Tracking

Momentum resolutions can be captured with straightforward considerations - imagine a view along the beam and a helical track model inside a solenoidal field (for either disks or barrel). Then,



$$p_{\mathrm{T}}\,[\mathrm{GeV}] = 0.3B\,[T]\;\,R\,[m]$$

$$s = R - R\cos\frac{\phi}{2} \approx R\frac{\phi^2}{8} \qquad \phi = \frac{L}{R}$$

Hence,

$$\frac{\Delta p_{\mathrm{T}}}{p_{\mathrm{T}}} = \frac{\Delta R}{R} = \frac{\Delta\phi}{\phi} \approx \frac{\Delta s}{L^2}\cdot\frac{8p_{\mathrm{T}}}{B}$$

In other words, a good (transverse) momentum resolution requires:

- a large path length *L* (scales as L^2)
- a large magnetic field (scales as *B*)
- good Sagitta measurement.

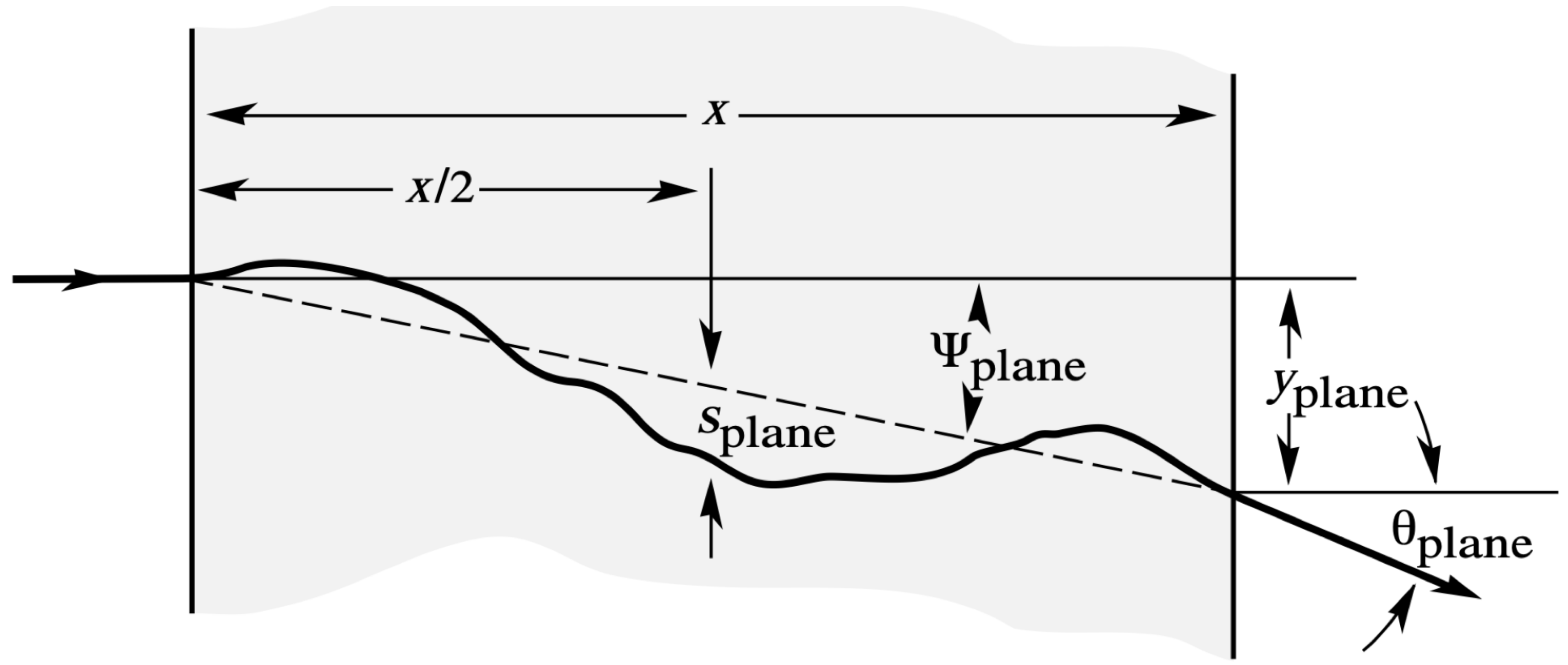
$$\Delta s = \frac{\Delta_{r\phi}}{8}\sqrt{\frac{720}{N+5}}$$ (Glückstern, 1963)

Note, however, that multiple scattering through the material of the detector matters.

A recap of Tracking

Regarding the multiple scattering contribution,

PDG:



$$\Delta\phi \approx \frac{14\,\text{MeV}}{p}\sqrt{L/X_0}$$

$$p = \frac{p_\text{T}}{\tan\theta}$$

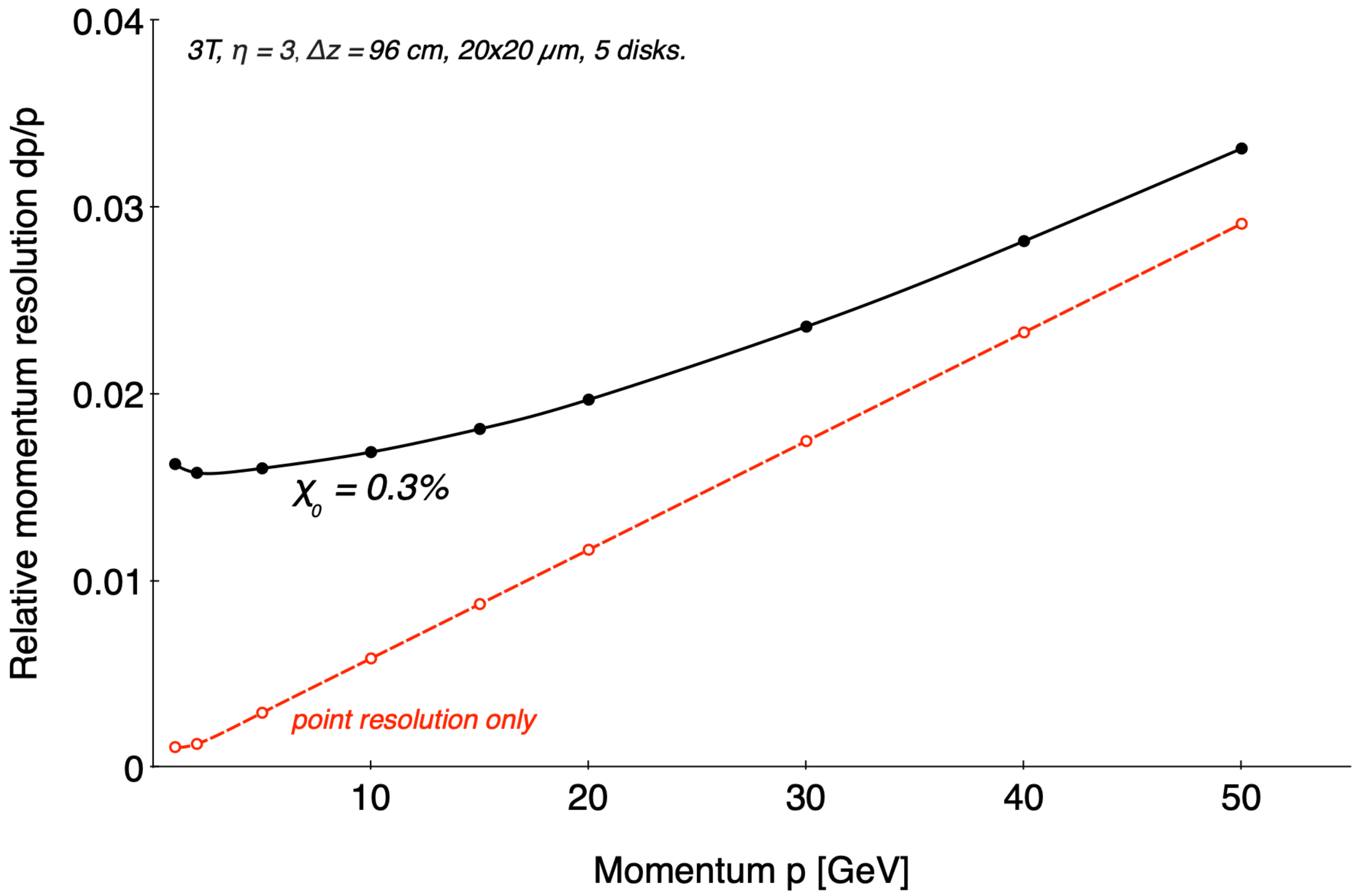
$$\left.\frac{\Delta p_\text{T}}{p_\text{T}}\right|_{\text{m.s.}} \approx \frac{14\,\text{MeV}}{p}\sqrt{\frac{L}{X_0}}\cdot\frac{R}{L} = \frac{14\,\text{MeV}}{p}\sqrt{\frac{1}{LX_0}}\frac{p_T}{eB}$$

Hence, the m.s. contribution depends on the dip-angle *θ* in this approximation, though *not* on *p* or p_T, and

$$\frac{\Delta p_\text{T}}{p_\text{T}} = a\cdot\frac{p_\text{T}}{BL^2} \;\oplus\; b(\theta)\cdot\frac{1}{B\sqrt{LX_0}}$$

For forward angles, m.s. is actually the limiting component in d*p/p for much of the p range.*

There is, indeed, a subtle correlation of m.s. and the dip angle measurement (not explicitly considered in the arguments presented here).



Proposed ECCE Tracker – now reference for Detector 1

(ECCE proposal)

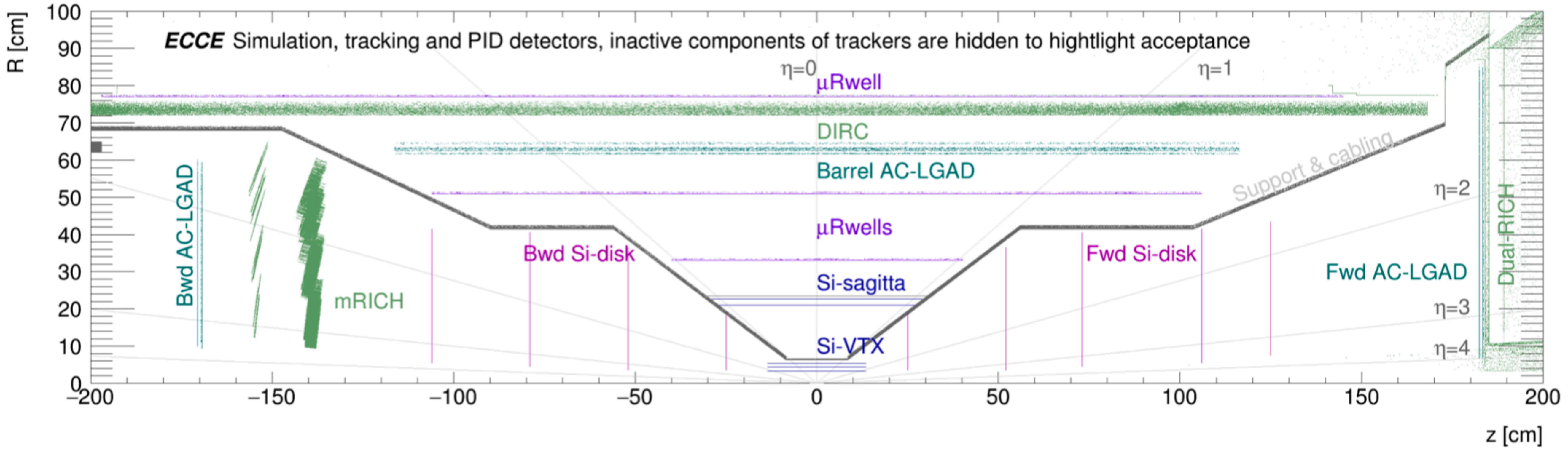


Figure 2.5: Schematic view of the ECCE tracker, including silicon, μRWELL, AC-LGAD, DIRC, mRICH and dRICH detector systems.

Points of discussion most will have heard:

- Material budget for sagitta layers,
- Resolutions or μRwells, AC-LGADs,

Not the main topics I want to pursue here and now.

Let's instead simply agree:

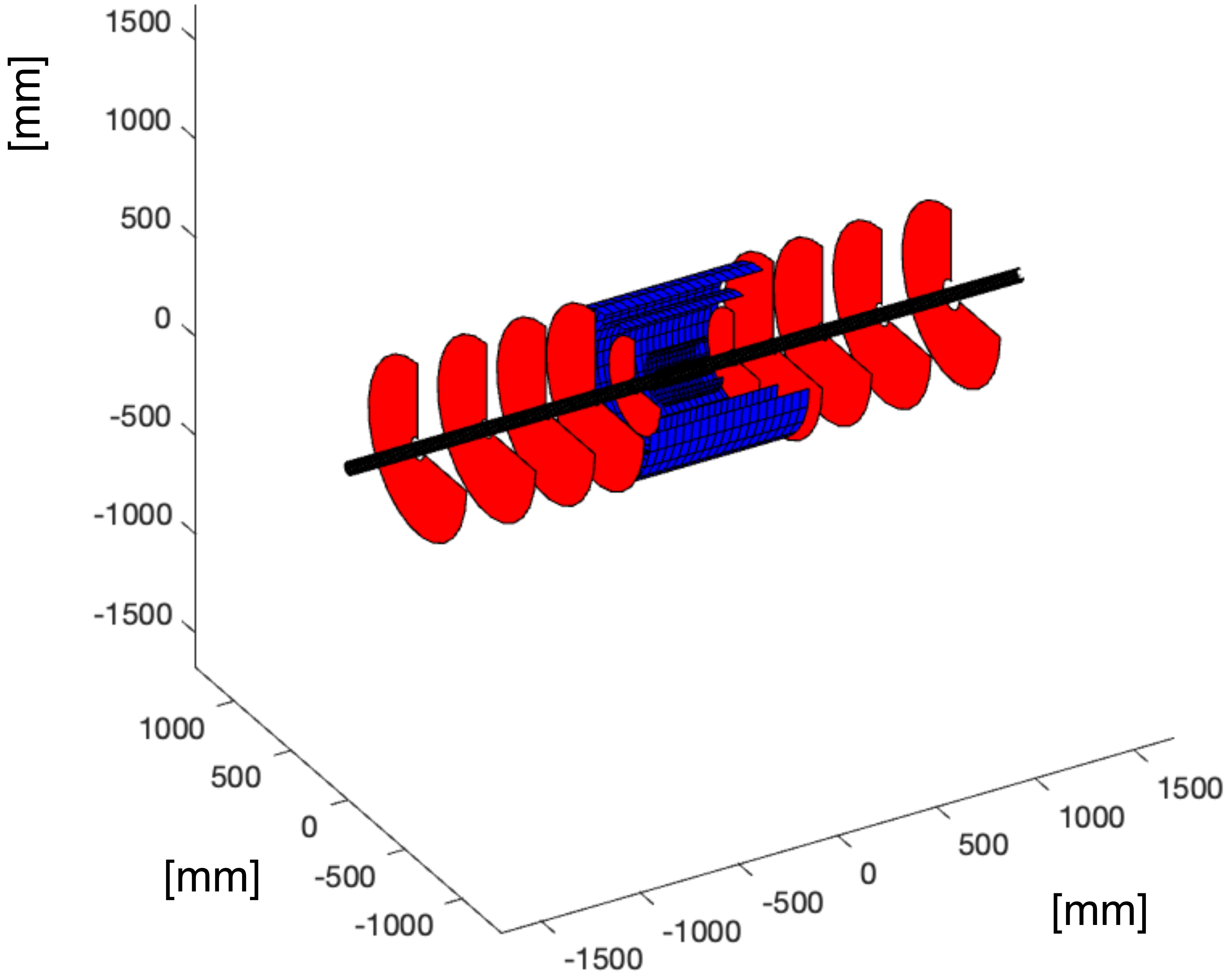
MAPS point resolution is about an order of magnitude better than for μRwells or AC-LGAD,
that is, it is far from obvious that having two closely spaced groups of MAPS layers results in optimal resolutions,

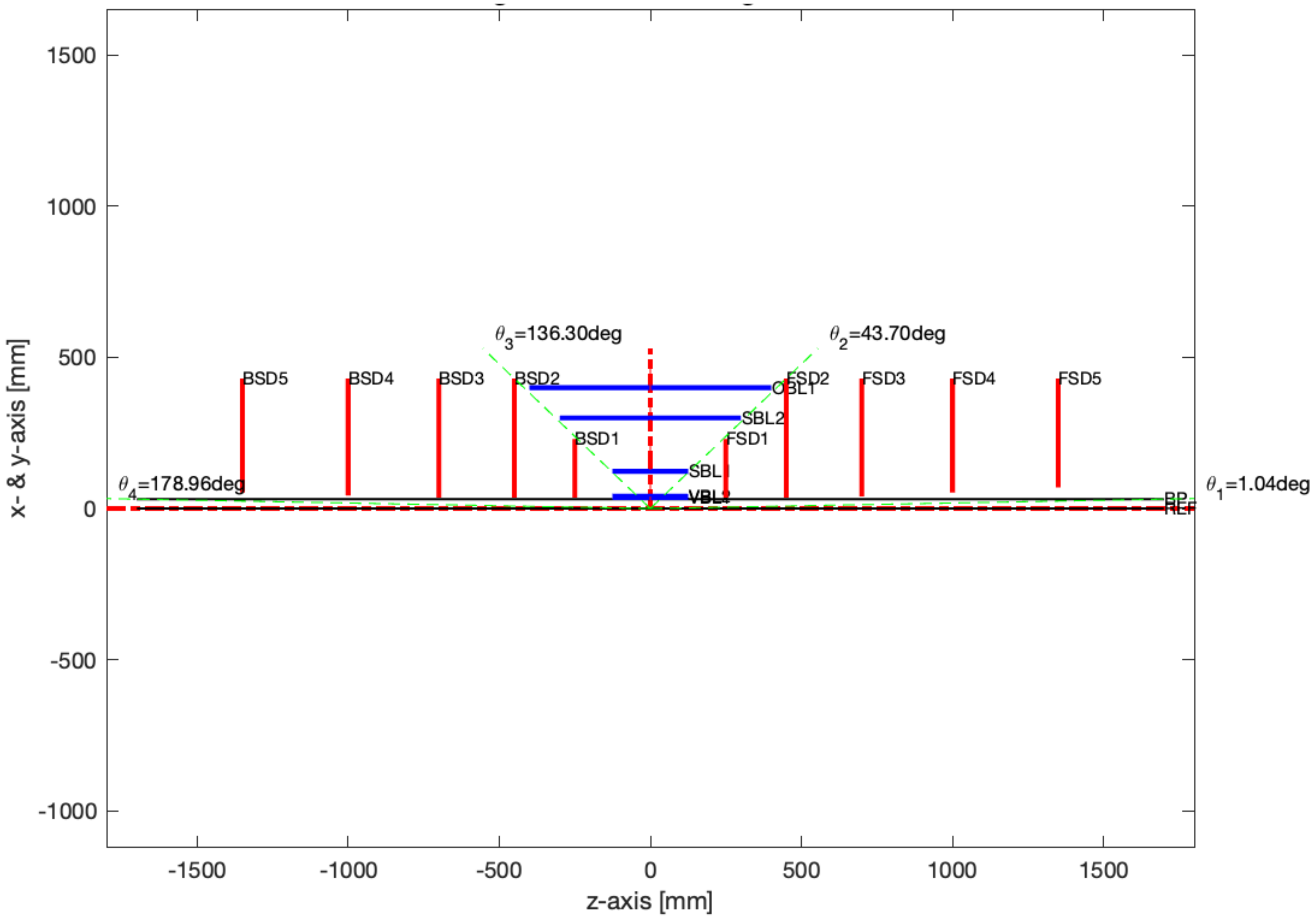
The radiation length in (dry, atmospheric) air is about 300 m;
that is, 15 cm of air corresponds to $X/X_0 \sim 0.05\%$ and will similar
if the material in the sagitta layers is all important, then *also* consider e.g. helium

My main question for today will be about resolutions, in particular those at mid-rapidity; is there a viable re-configuration of the five MAPS barrel layers in the reference design that could bring detector-1 to YR performance at mid-central rapidities?

Is the YR mid-rapidity performance recoverable in 1.4T?

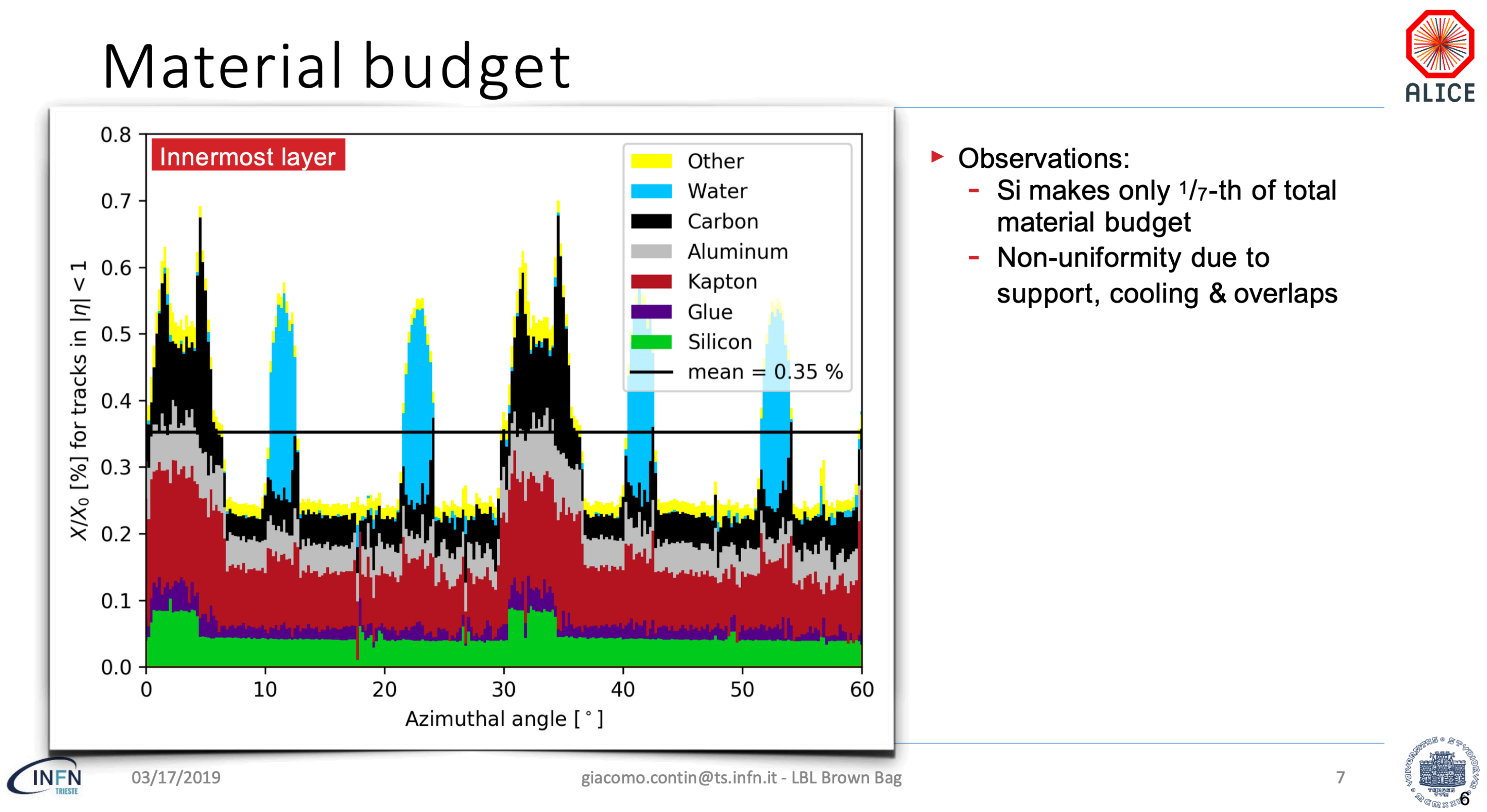
- Inner cone angle of ~45^{o}, at least for now — c.f. Rey Cruz-Torres's studies https://indico.bnl.gov/event/12595/
- Consider increasing the radius of the outermost vertexing layer while preserving its length of approximately 27 cm; the starting point is the r_{vtx} = 36, 48, 60 mm configuration discussed by Stephen earlier in this meeting - the goal is to have it contribute more/better to the momentum measurement,
- Replace the two sagitta layers with a more conventional stave-based design of one layer two half-lengths of $X/X_0 \sim 0.25\%$ (or less, if feasible) at a radius of approximately r ~ 0.2 m, and optimize this radius,
- Complement with a large-radius, $r_{out} \sim 0.4$ m, conventional stave-based design, with an overall length of about 0.8 m — this radius follows from the basic considerations (and YR requirements) presented earlier.

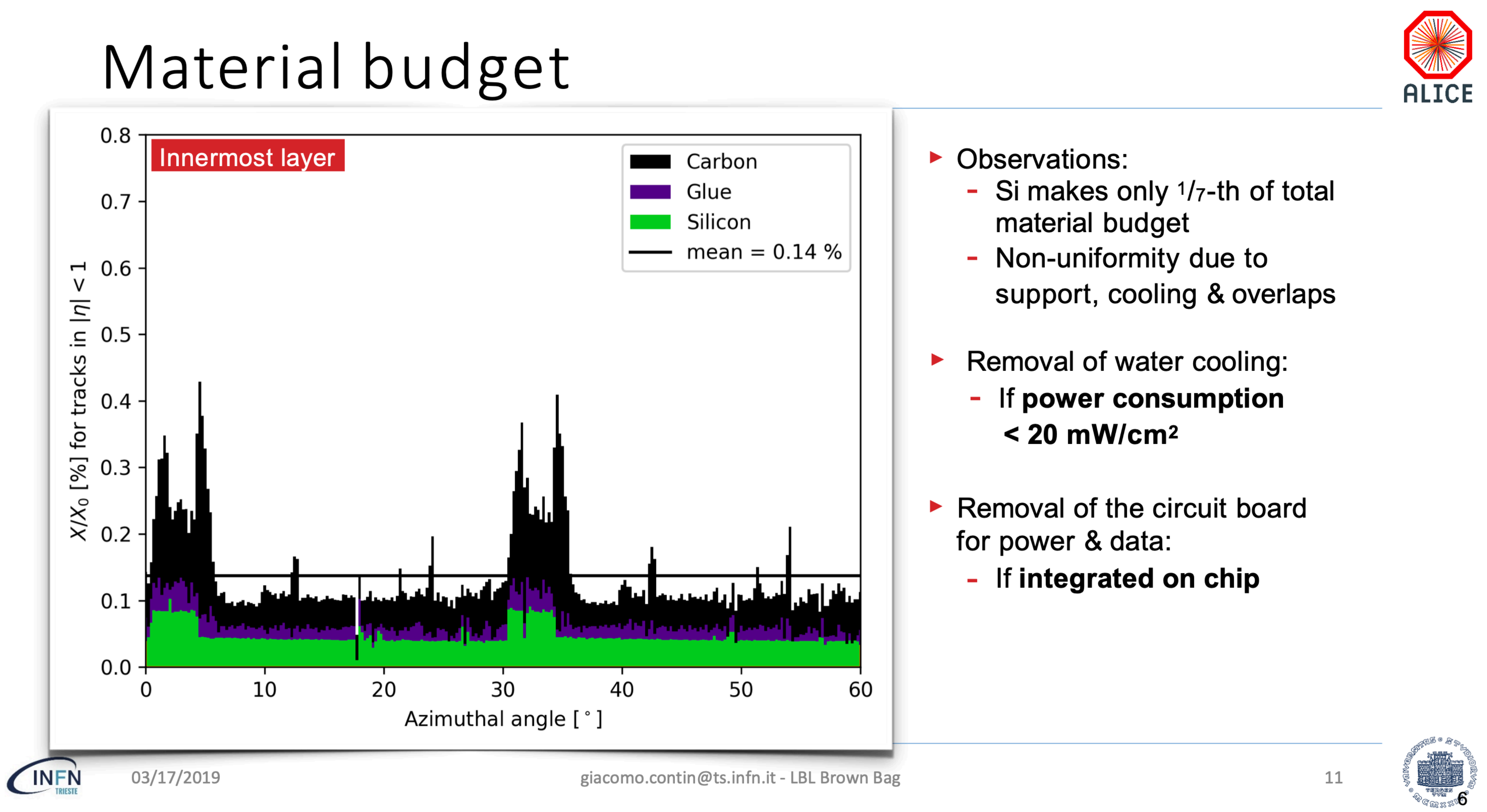




Brief Intermezzo

- $X/X_0 \sim 0.25\%$ for the sagitta layer in this study is *not* some "random" number
- Existing ALICE ITS2 innermost vertex layers have a sensitive length of 270 mm and $X/X_0 \sim 0.35\%$, c.f TDR.
- Borrowing from an excellent seminar talk by Giacomo Contin on R&D from the existing ITS2 to ITS3,



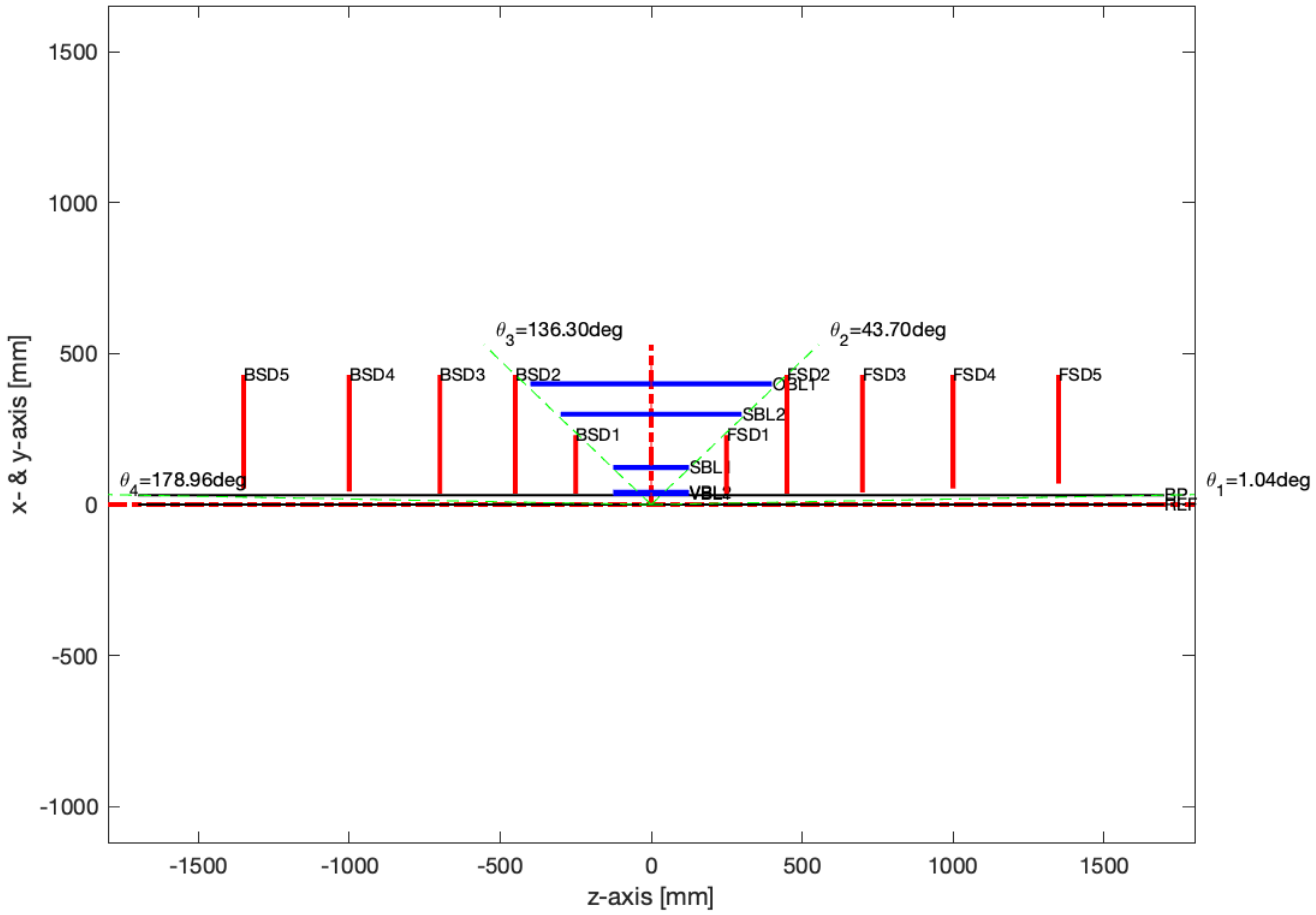


ITS2

Steps towards ITS3

- Removal of cooling by water, in view of the lower power consumption of the ITS3 sensor, results in ~0.31%
- Sensor yield considerations may make it impractical to *fully* forego circuit board for power and data beyond ITS3 scale (area),
- Foregoing *all* mechanical support would likewise be imaginary,
- $X/X_0 \sim 0.25\%$ is <u>instead</u> consistent with by Leo Greiner's estimates for the YR (ITS2 and ITS3 informed, and consistent with disks).

Is the YR mid-rapidity performance recoverable in 1.4T?



Following the previous steps, consider:

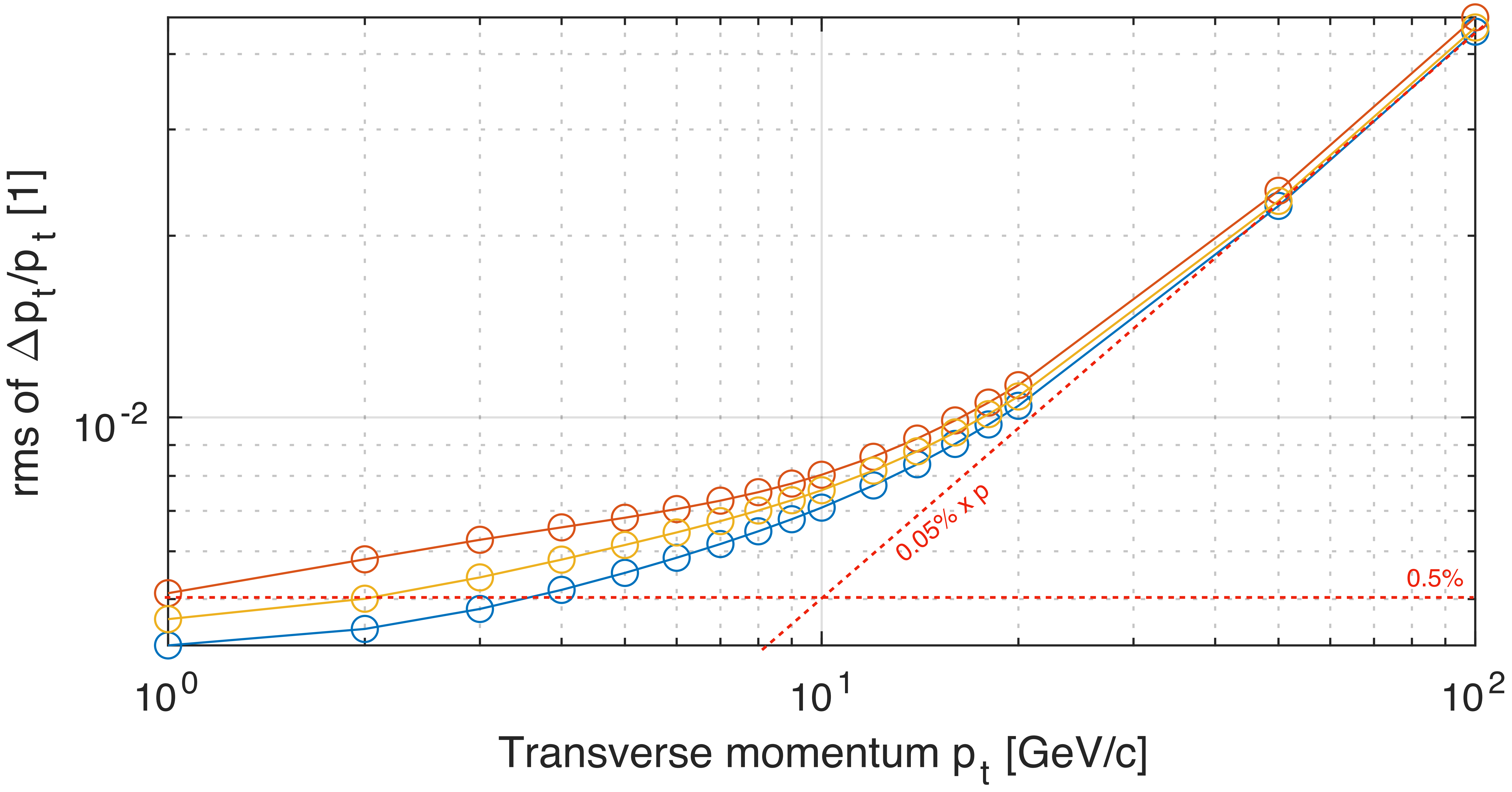
- Outer barrel layer at r = 420 mm,
- ~45 degree cone,
- Single sagitta layer with r <= 270 mm, X/X_0 ~ 0.25%
- Outer (third) vertex barrel layer with increased radius to r = 120 mm while preserving its length,

Notes:

The lengths assume reticle lengths of 30 mm.

Services and service routing will need further attention; it is not for today, but I have concerns over the “double-cone” and otherwise consider a single projection angle determined by the DIRC length impractically shallow. Not for today.

YR mid-rapidity performance in 1.4T



Single pion tracks, exactly vertical,

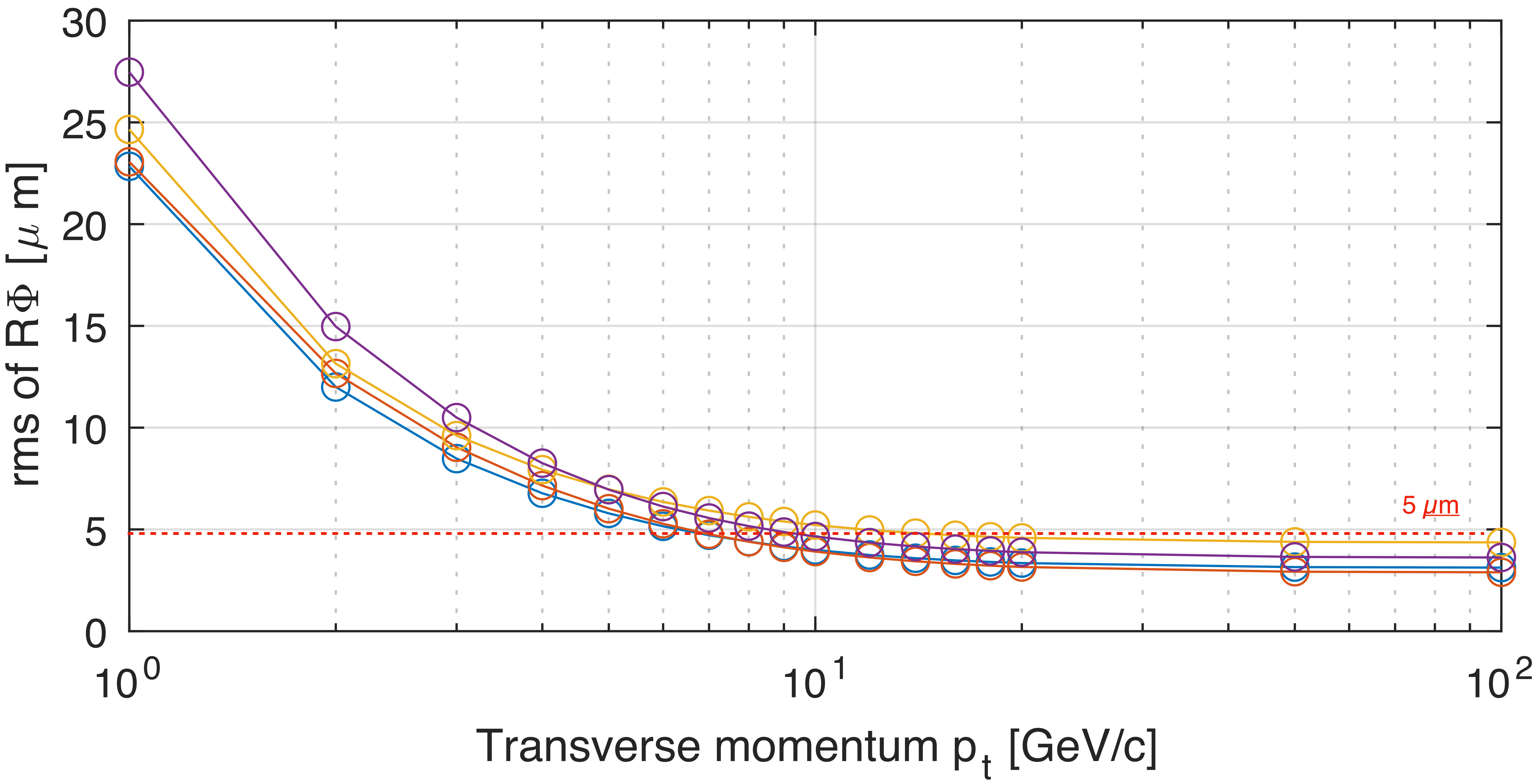
- Blue curve is the (outer) r_{vtx} = 120 mm and r_{sag} = 270 mm from the previous slide,
- Yellow has an outer r_{vtx} = 96 mm and r_{sag} = 240 mm,
- Red has an outer r_{vtx} = 60 mm and r_{sag} = 240 mm,

The different r_{sag} come from optimization, factoring in an assumed 30 mm reticle size,

The blue curve meets the YR requirements well within the all-silicon tracker silicon area with seemingly reasonable extensions of ongoing R&D plans/efforts.

There is likely to exist at least one path towards recovering YR mid-rapidity performance.

YR mid-rapidity performance in 1.4T



Potential concern could be "what if?" the innermost vertexing layer were inefficient. Or, put differently, would such a new configuration with in-effect two vertexing layers be "robust" against the change in pointing?

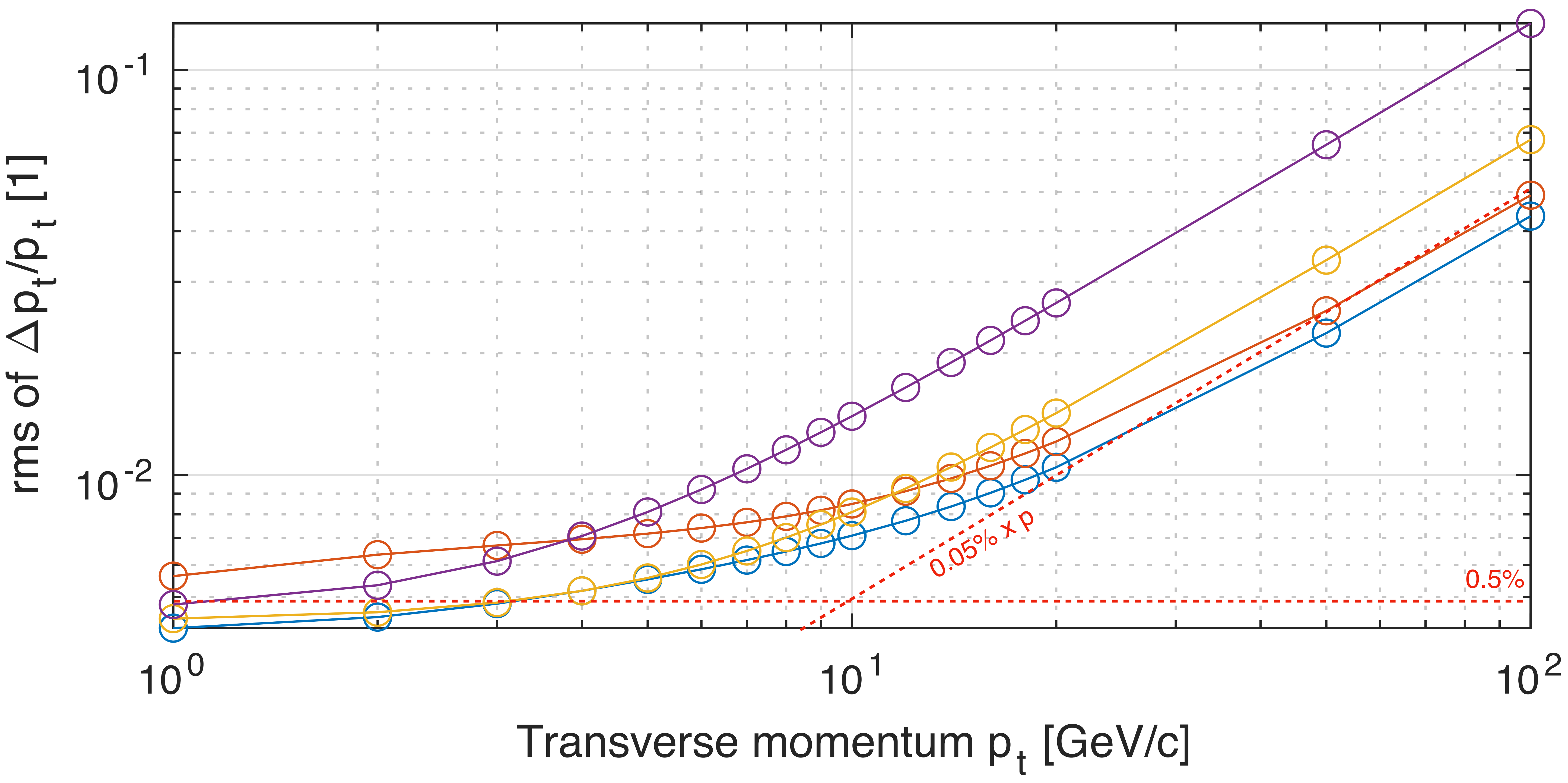
Red versus blue is the default 3-layer barrel versus a 2-layer barrel with r = 120 mm third (outer) layer,

Purple and yellow show results with an inefficient innermost vertex layer (i.e. material is kept, resolution lost) for these configurations,

Slight trade-offs; better low-p_T performance and somewhat worse at high-p_T (within 5 μm goal) for the r = 120 mm configuration,

For reference, YR: 20 μm/p_T $+^2$ 5 μm

YR mid-rapidity performance in 1.4T



Illustrative to consider also the "what ifs?" if MAPS layers outside of the innermost vertexing layers were inefficient,

The blue curve is again the (my) default r = 120 mm and r = 270 mm sagitta layer configuration with an outer barrel layer at r = 420 mm,

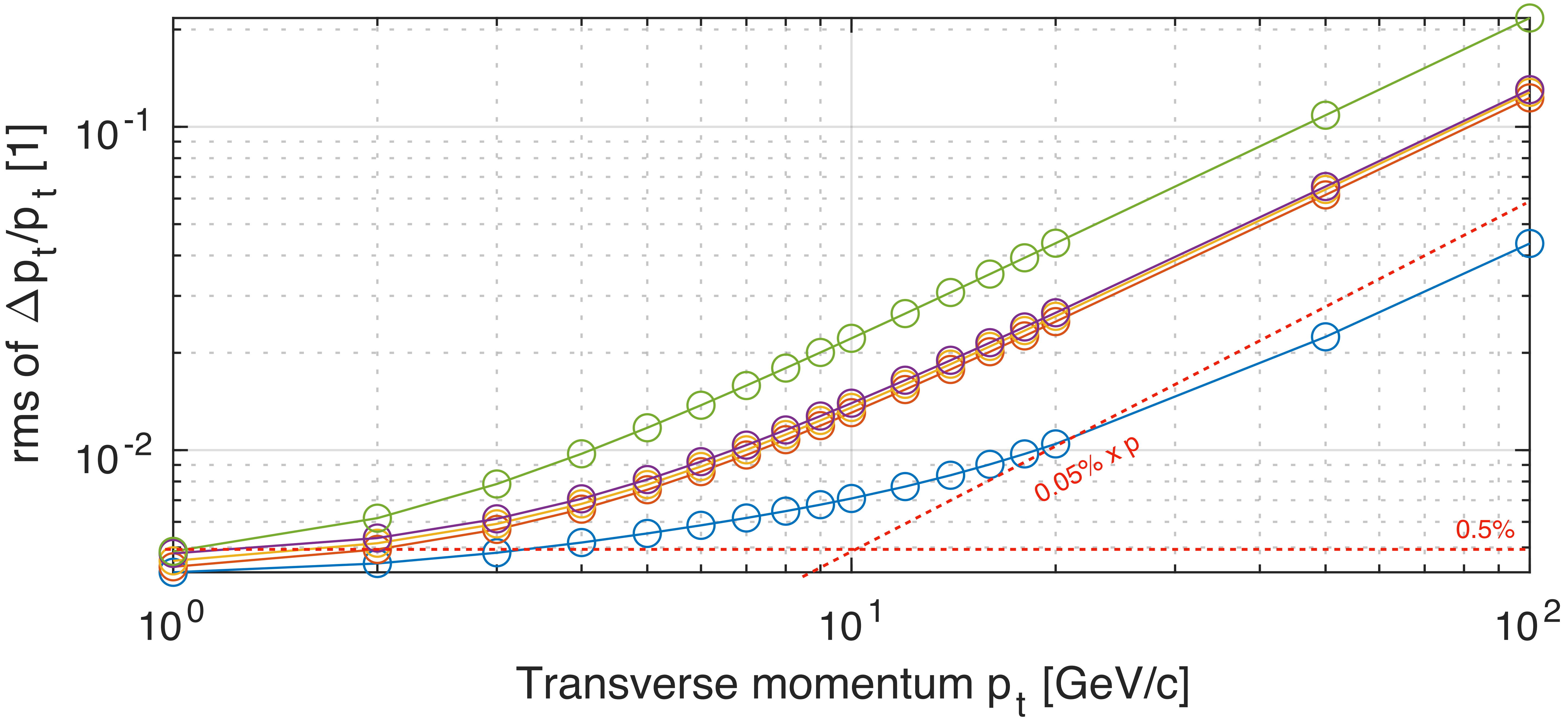
Red - layer at r = 120 mm inefficient,

Yellow - layer at r = 270 mm inefficient,

Purple - layer at r = 420 mm inefficient,

Fairly intuitive results; the outer barrel matters most for high-p_T, the inner r = 120 mm sagitta does so for low-p_T

YR mid-rapidity performance in 1.4T



Consider an alternative with an MPGD outer barrel with 50 — 100 μm Gaussian point resolution at r = 420 mm (instead of the MAPS outer barrel layer),

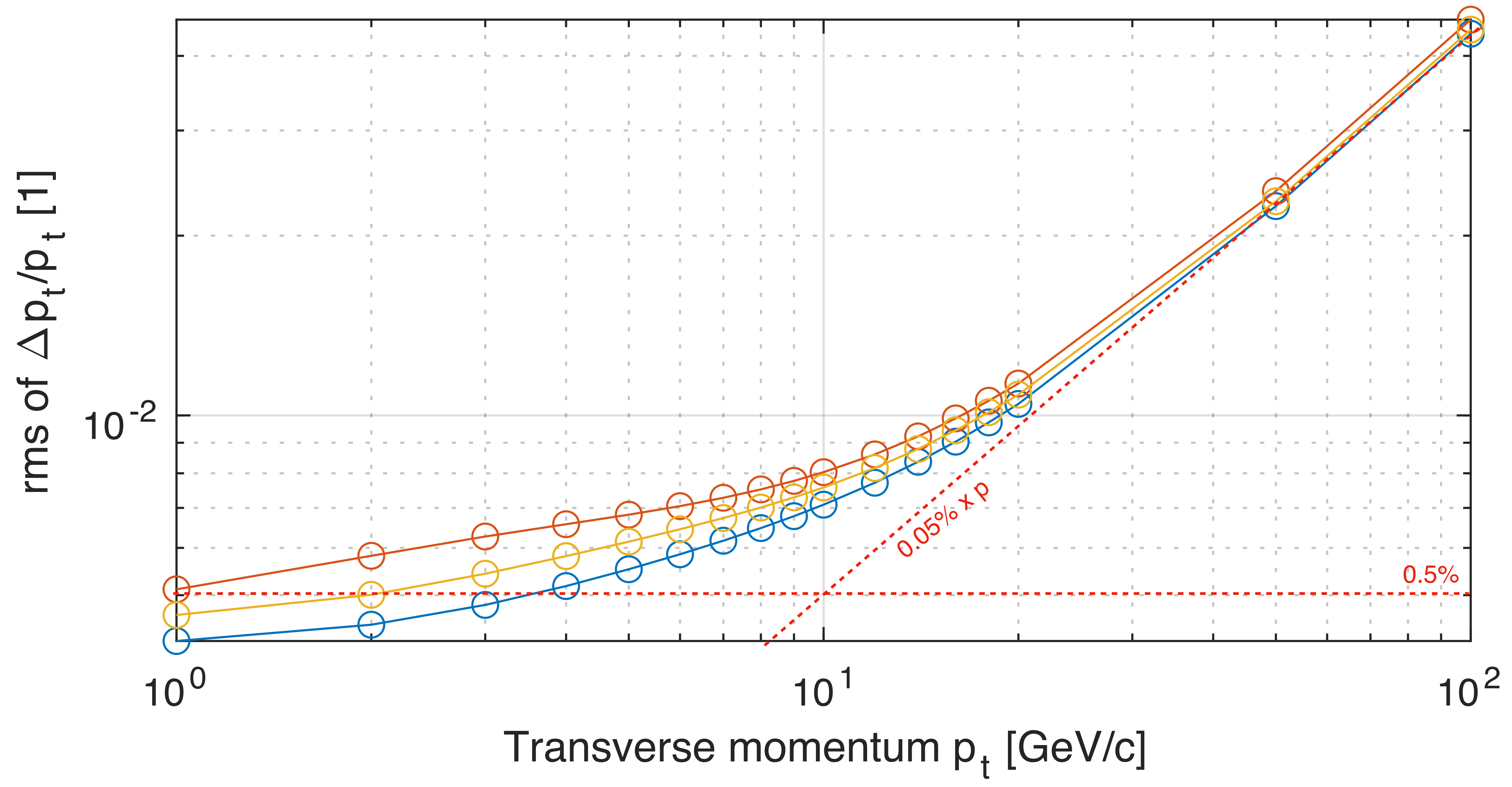
Results are not too surprising; in essence, dp/p is determined by MAPS in this case (c.f. overlapping curves),

Configuration not very “robust” to inefficiencies in the MAPS part of this configuration (c.f. green curve),

This conclusion carries over also if larger radii are considered up to r ~ 0.65 m (limited by the DIRC),

YR mid-rapidity performance in 1.4T

There is at least one path towards recovering YR mid-rapidity performance with five MAPS layers within r ~ 0.4 m, while preserving most of the rest of the reference design (track *finding* etc.)



Basically, "spread out" the five MAPS layers.

Key steps:

- ITS2 derived outer sagitta layer with ITS3 derived sensor, X/X_0 ~ 0.25%,
- Complement with a ~conventional outer barrel layer with r ~ 0.4 m using ITS3 derived sensor,
- Drive out the outermost ITS3 derived vertex layer, preferably to r_{vtx} ~ 120mm while preserving its length,
- Obviously requires additional R&D, but not "blue sky" development,
- Likewise, construction/cost seem likely to be more of an evolution rather than revolution.

Fun4all simulations of this configuration are starting up; anticipate reasonable consistency (prior experience),

As said, additional work will be needed on the disk arrays and services — not for today.