LHCb U-II baseline layouts

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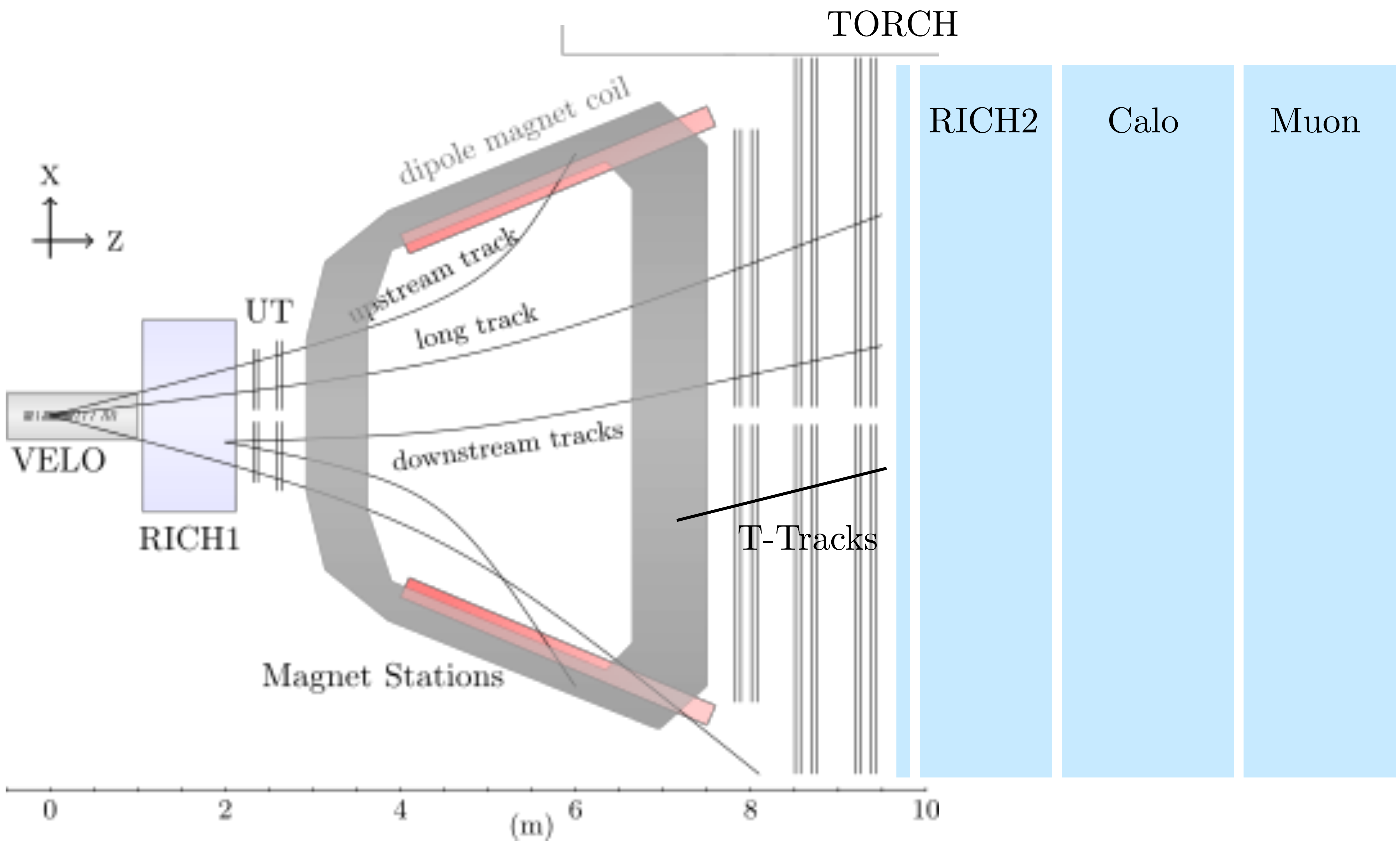
Disclaimer : for illustration purposes the U2 MC sample for tests from Mark has been used as well as a 1.5 week ago geometry dump of the run5 branch in Detector.

Disclaimer : several material cherry picked from previous presentations

Introduction

- **U2 design**: aim to operate and deliver a vast physics program output at an ultimate instantaneous luminosity $O(10^{34}\text{cm}^{-2}s^{-1})$, maintaining or surpassing the Run3 performance.
  - Ensure detectors can operate efficiently until their end of life



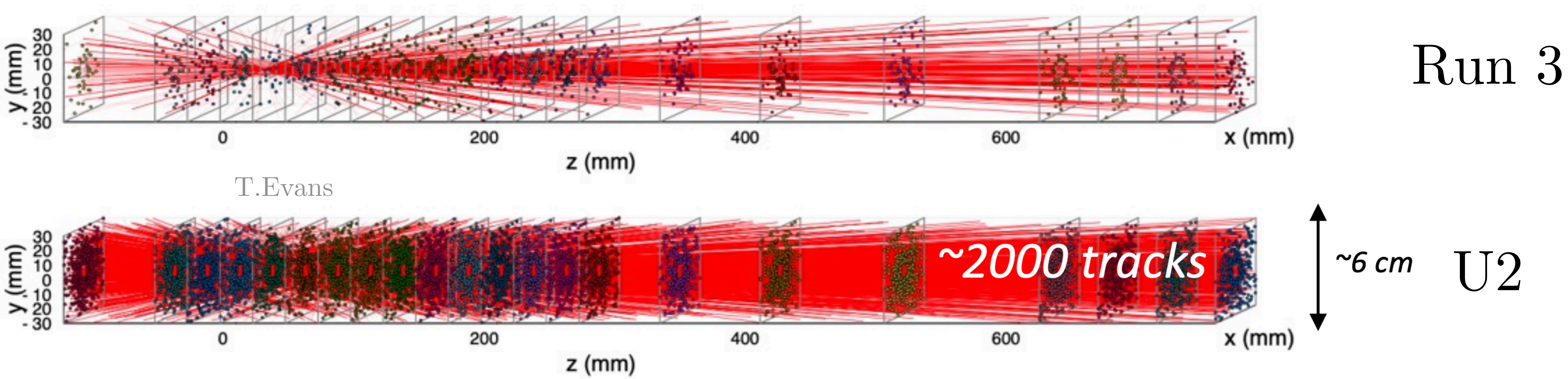
- Magnet Stations dedicated talk this afternoon/evening.
- Not covering other detector than trackers in this talk.

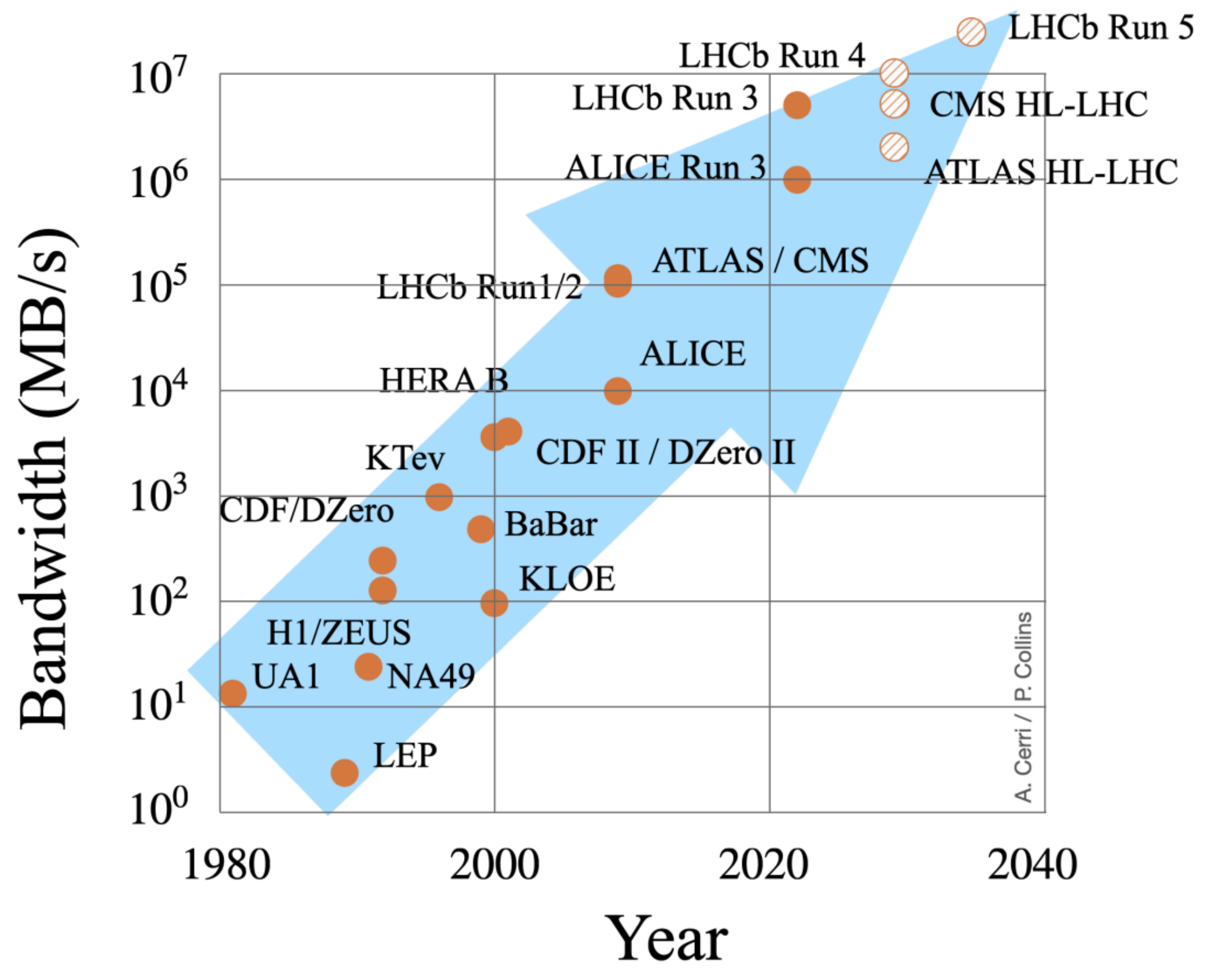
- **How to operate efficiently at the increased pile-up of 40?**
- **Deal with O(200) Tb/s produced?**

- **Detectors should be**
  - **Light, highly granular, radiation resistant and provide timing resolutions of O(20ps). Velo/ Calo/RICH/TORCH.**
  - **Pile-up mitigation with precise timing information**

Introduction

- Same or better performance than expected ones in Run3, but at pile-up of O(40)



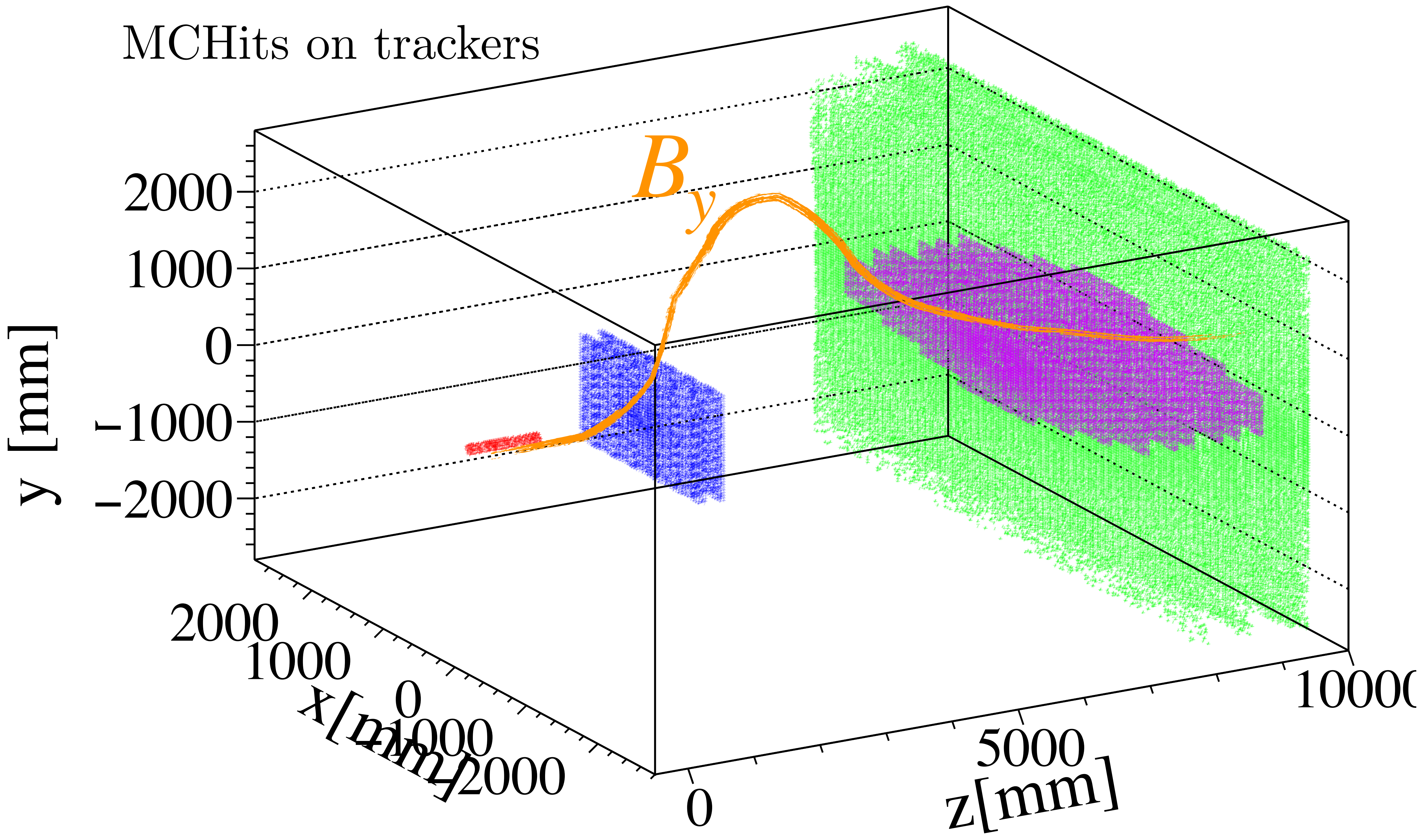


- Find tracks and reconstruct events having a complexity scaling up by more than 2 orders of magnitude while keeping high momentum resolution and PID performance
- Fast timing O(20ps) required in few sub-system.

What we are simulating in U2 from Tracking Point of View

25 events "energy deposits" in active regions of tracker system with latest U2 simulation from Mark

(* overlap region in MP/FT to masked by hand for illustration, simulation to fix)



(Illustration purpose)

TV : pixel detector, with timing

- (x,y,z,t) with pitch$_{x,y}$ $\sim 40-55\ \mu m$, $\sigma_t \sim 40$ ns

UP : pixel detector, no timing

- 4 layers (x,y,z) with pitch$_{x,y}$ $\sim 30\ \mu m$ or 50x150 μm

MP : pixel detector, no timing

- 6 layers (x,y,z) with pitch$_{x,y}$ $\sim 50 \times 150\ \mu m$

FT : Sci-Fi detector, no timing (?)

- 12 layers (x,z) with pitch$_x$ $\sim 250 \mu m$, y-info from x-u-v-x layout

Velo (TV) detector: 4-D tracking

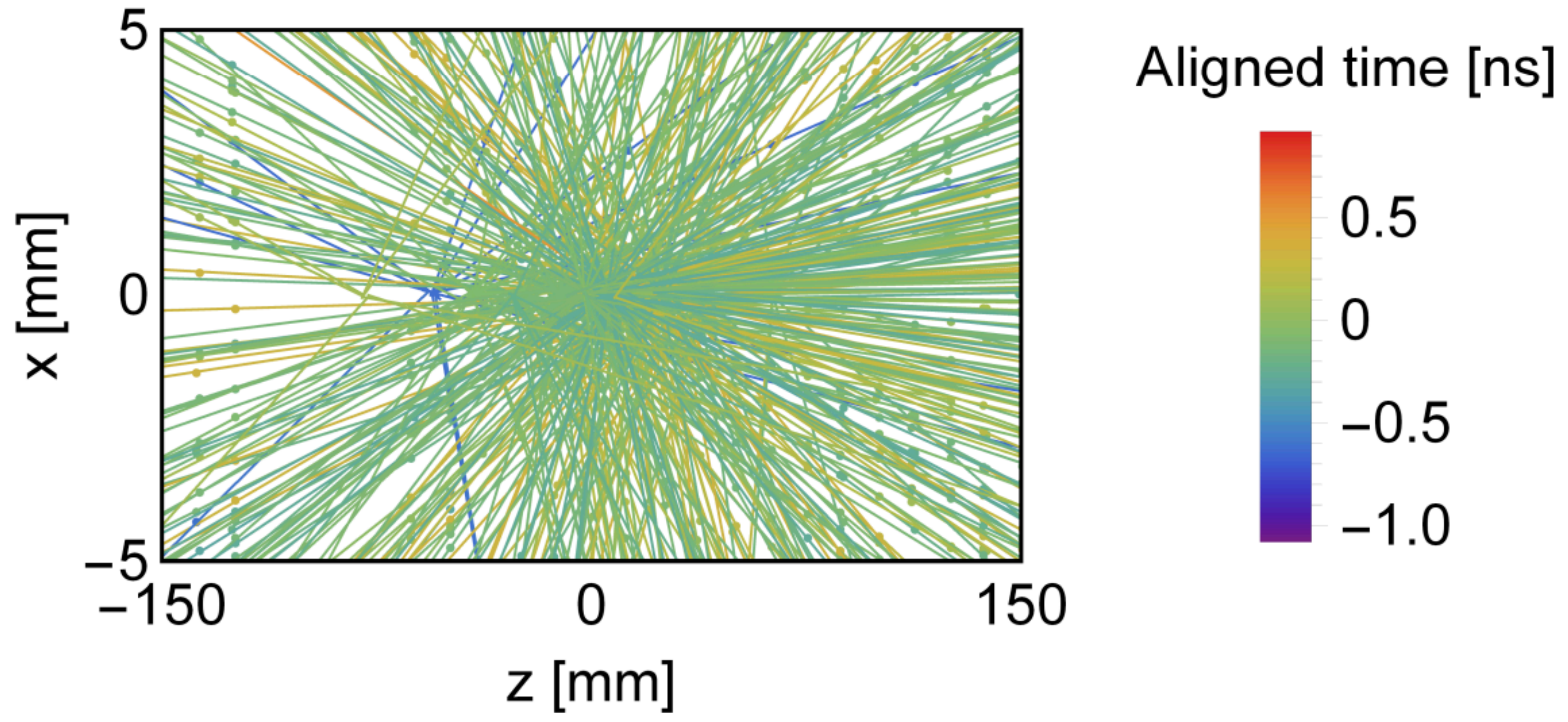
$$\text{charged particle density} = 39 \times \left(\frac{R}{\text{cm}}\right)^{-1.9} \text{tracks per cm}^2 \text{ per event,}$$

At 10 mm distance, we have 1.2 THz/cm^2 rate of tracks. Prohibitive to place the Velo very close to PV as in Run3

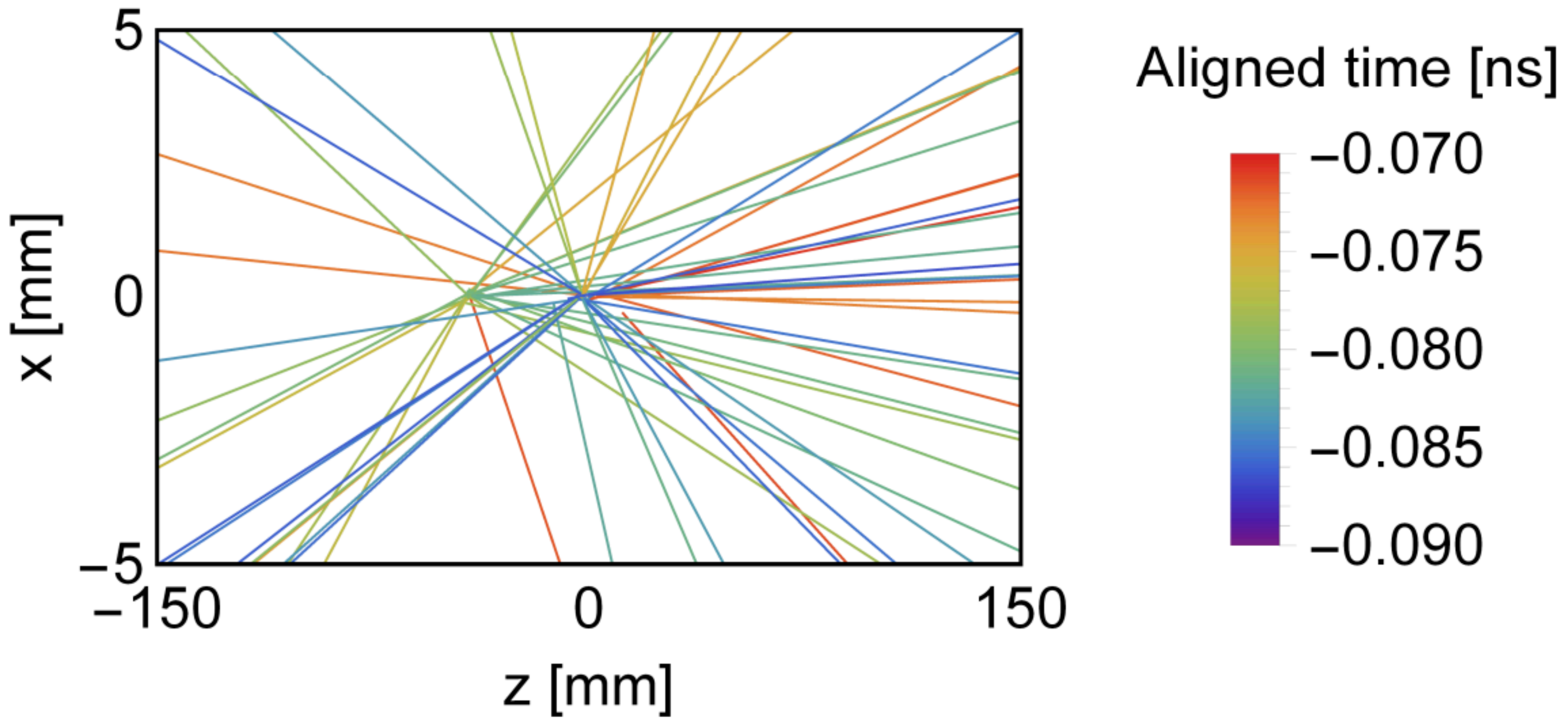
Extrapolation term for IP would deteriorate, but material budget, RF material reduction and $\sigma_{x,y}$ can compensate [partly]

In any case, timing is absolutely need. Requirements evaluated checking key performances such as PV efficiency and IP resolution

Within a 2 *ns* window

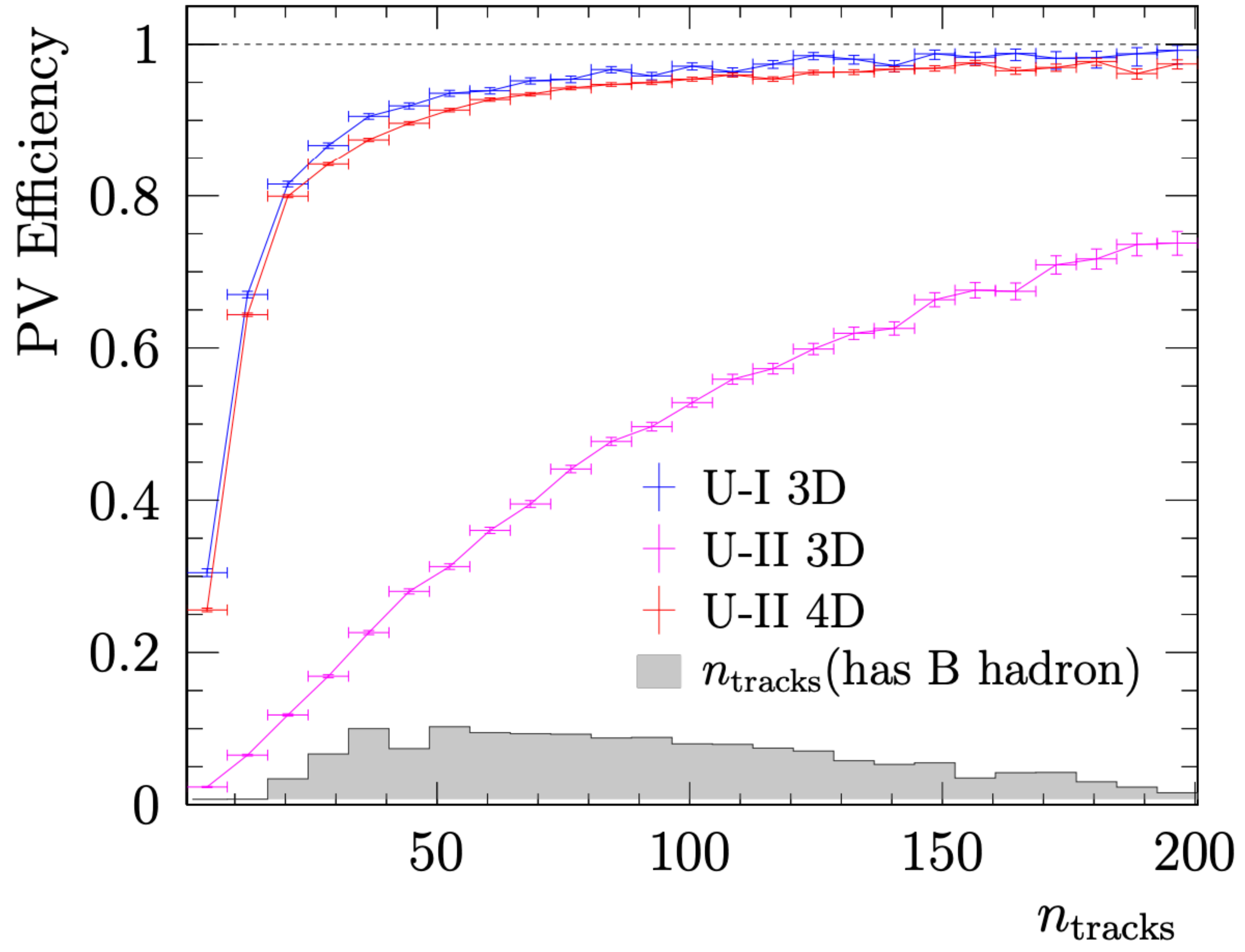


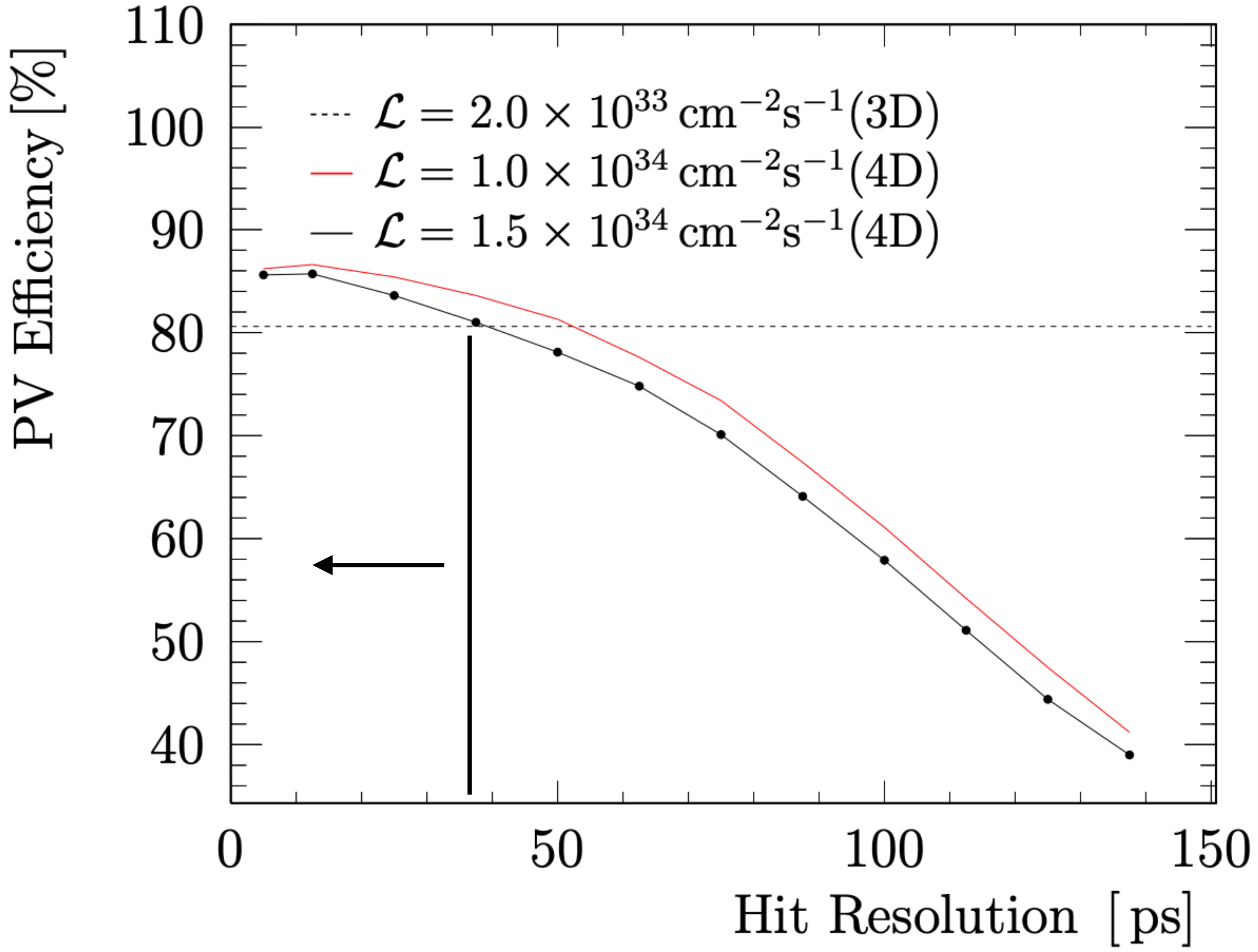
Within a 20 *ps* window



Tracking in Velo has to be O(100%) efficient across all η range we want to cover for PV finding, SV finding and forming the Velo-segments for (almost) all tracks we use in data analysis

TV detector: 4-D tracking





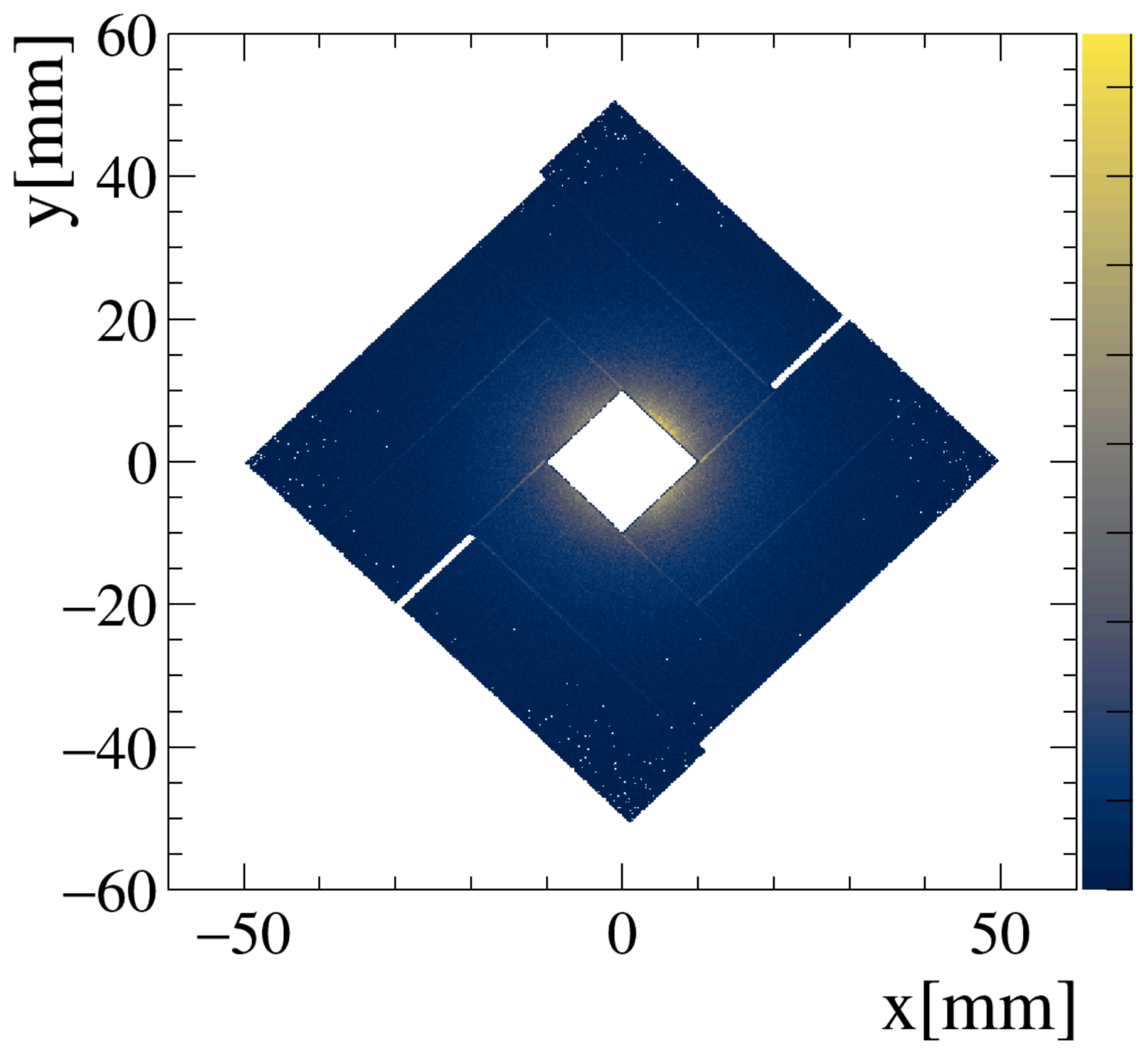
Has to be better than O(40ps)

$$\sigma_{IP} = \sigma_{Extrapolation} \oplus \sigma_{Scat}/p_T$$

- σ_{IP} depends on hit resolution, distance from origin of first measurement on track, the material budget in Velo and material between first measurement and the track vertex.
- Extensive R&D and evaluation of different technologies to meet timing resolution, radiation hardness low material budget and performance requirements

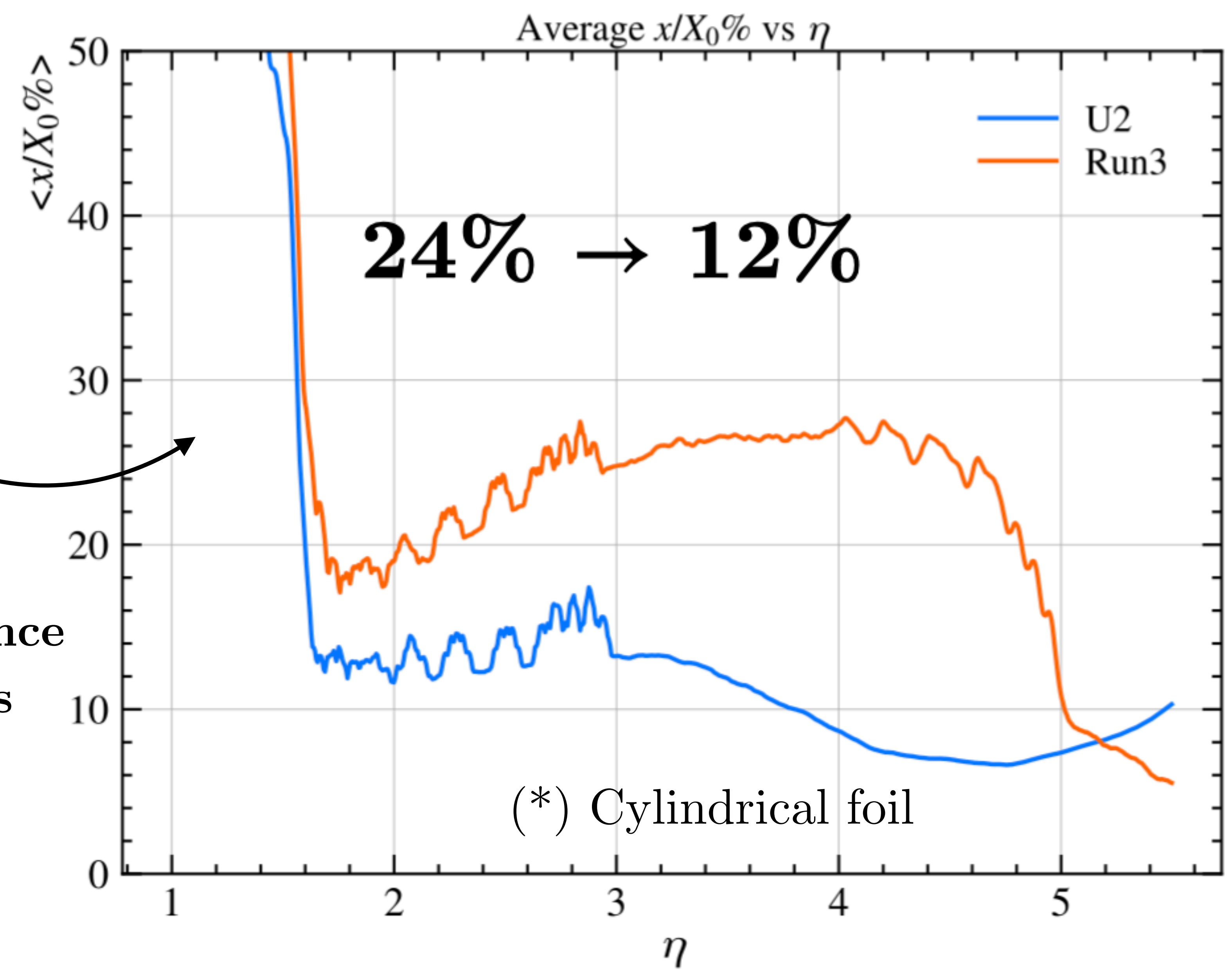
TV detector

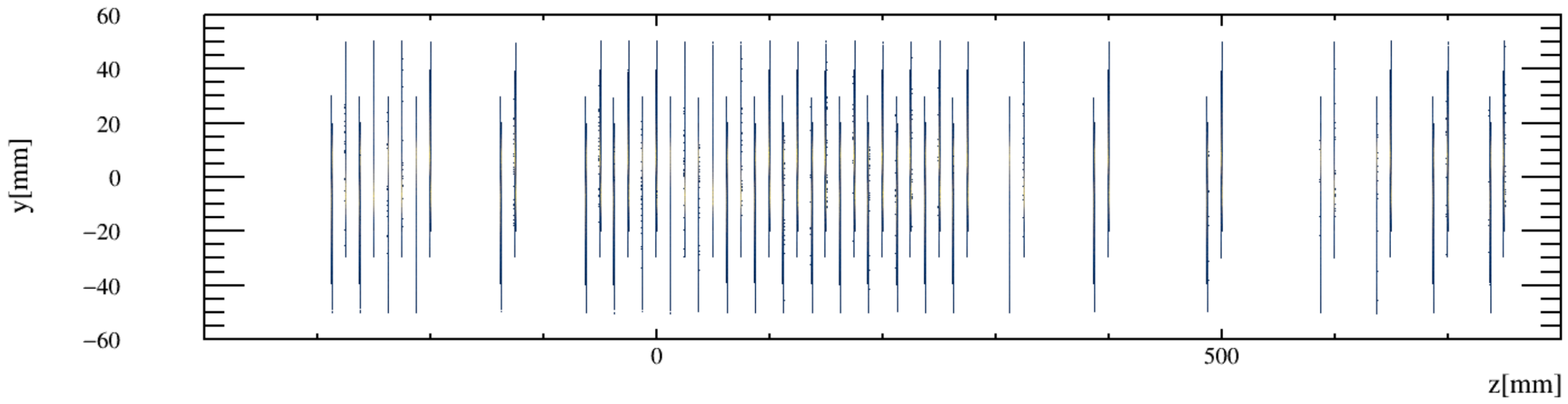
- Strong R&D and technological considerations to meet requirements. See 3.1.4 in FTDR
- Timing is absolutely necessary here
- Obtaining higher hit efficiency might require more layers : more material.



Currently in U2 simulation Vs Run3

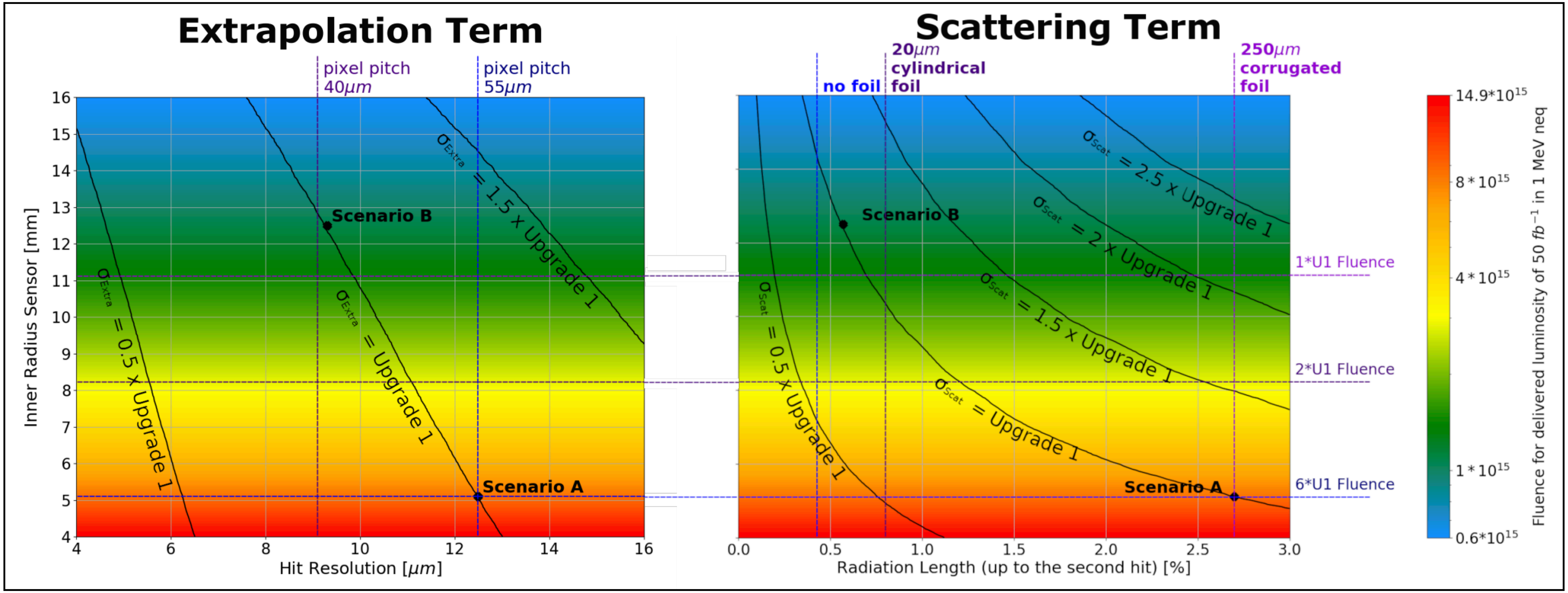
More on performance and IP next days





Scenarios from FTDR abandoned

- In **FTDR** :



"Original scenarios"

S_A: inner radius = 5.1 mm, operationally tricky and implications on mechanics

S_B: inner radius = 12.5 mm, same IP as U1 if reduction in material [thinner Foil] and $\sigma_{pitch} \sim 40\mu m$, but ruled out as achievable [see last year Kazu talk]

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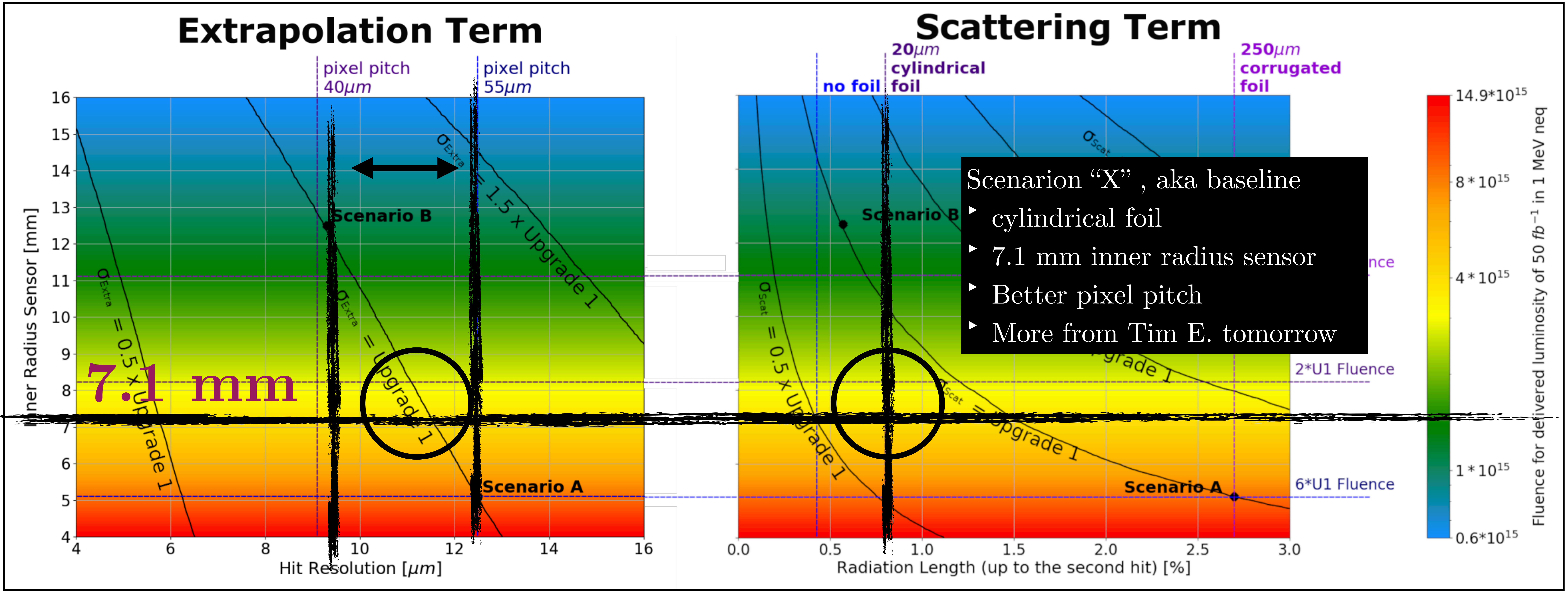
- In FTDR :



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U2 UT Geometric Configuration

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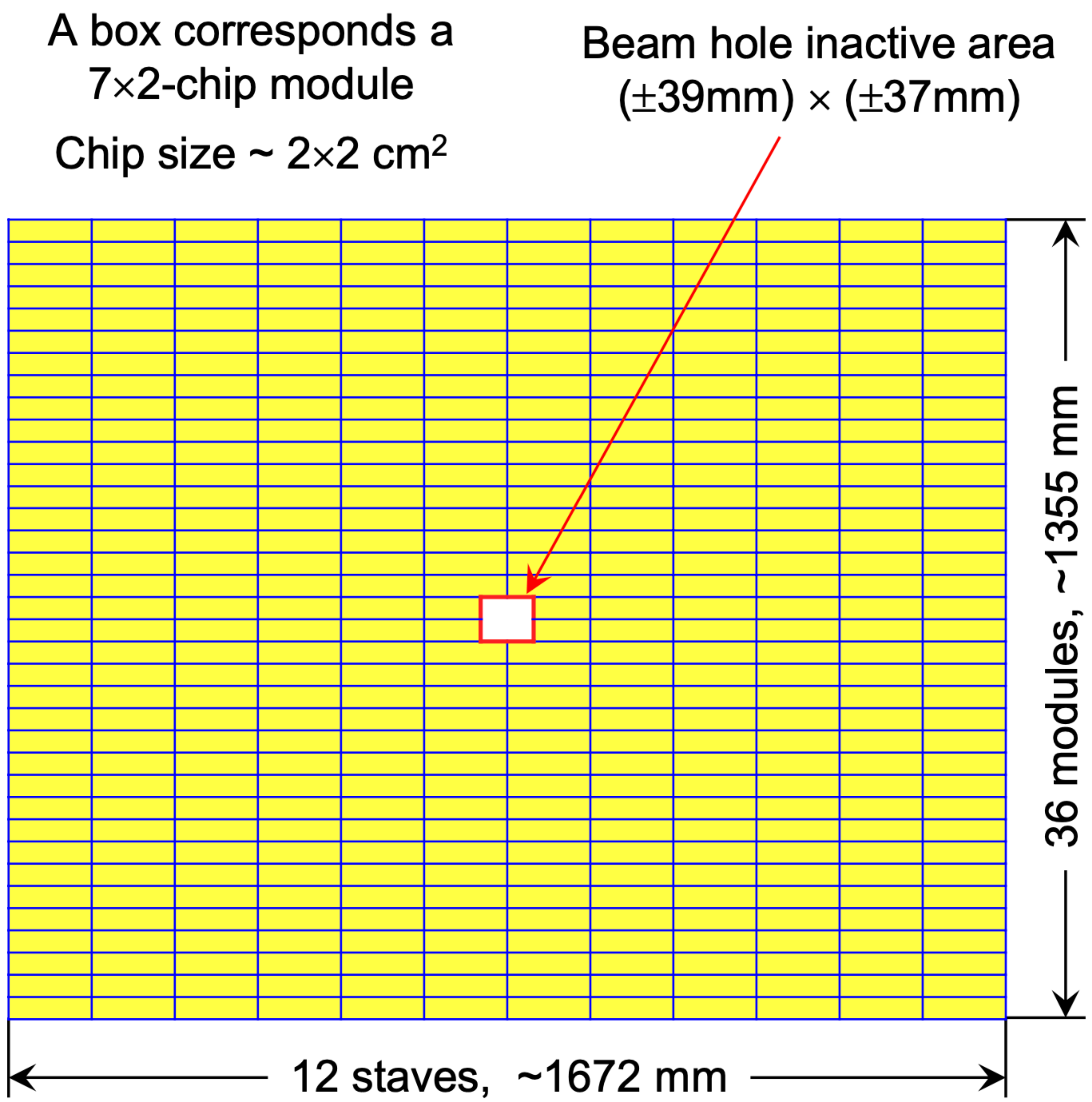

- The U2 UT has 4 detector planes, at Z similar to the current UT. The number of planes may be reduced to 3, pending further studies.
- A plane has 12 staves, covers ~1672 mm in the X direction, with 2 mm overlaps.
- A stave has 36 modules, covers ~1355 mm in the Y direction.
- A module consists of 7×2 sensor chip. In the outer regions of each plane dual-modules are used for efficient lpGBT.
- The central 4×4 chips are removed for beam pipe, covers (±39mm)×(±37mm).
- In total: 4 layers, 48 staves, 1728 modules, 24128 chips.

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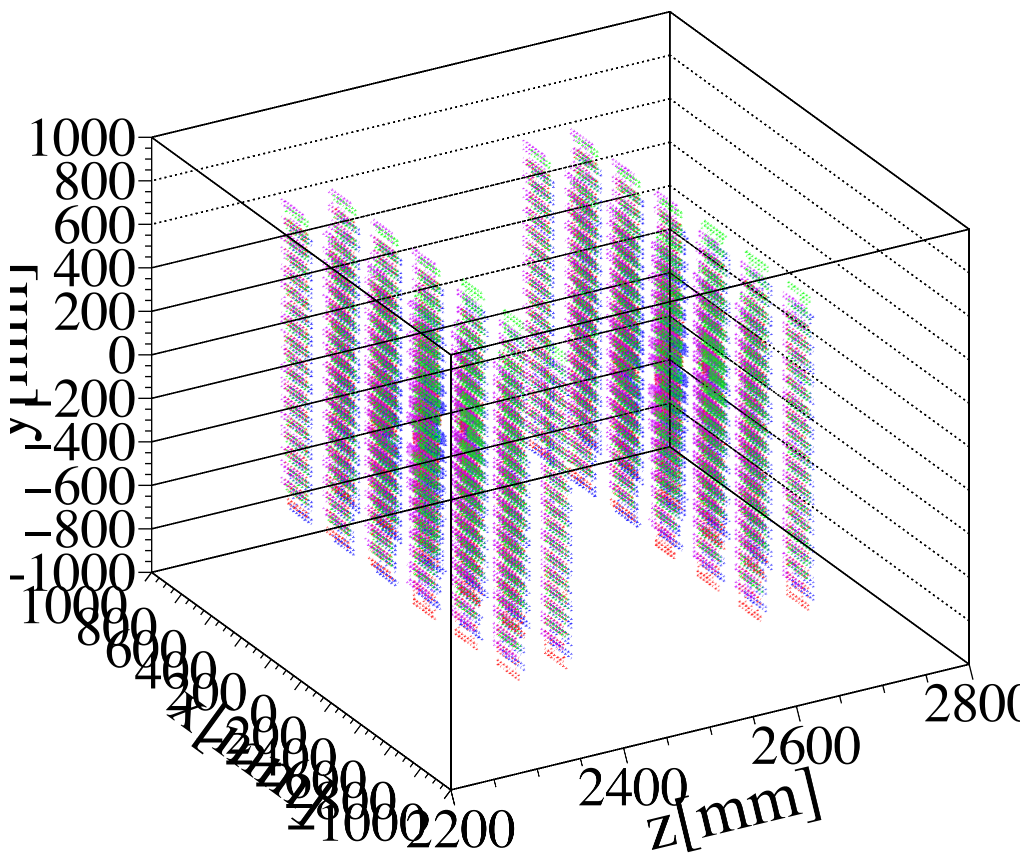
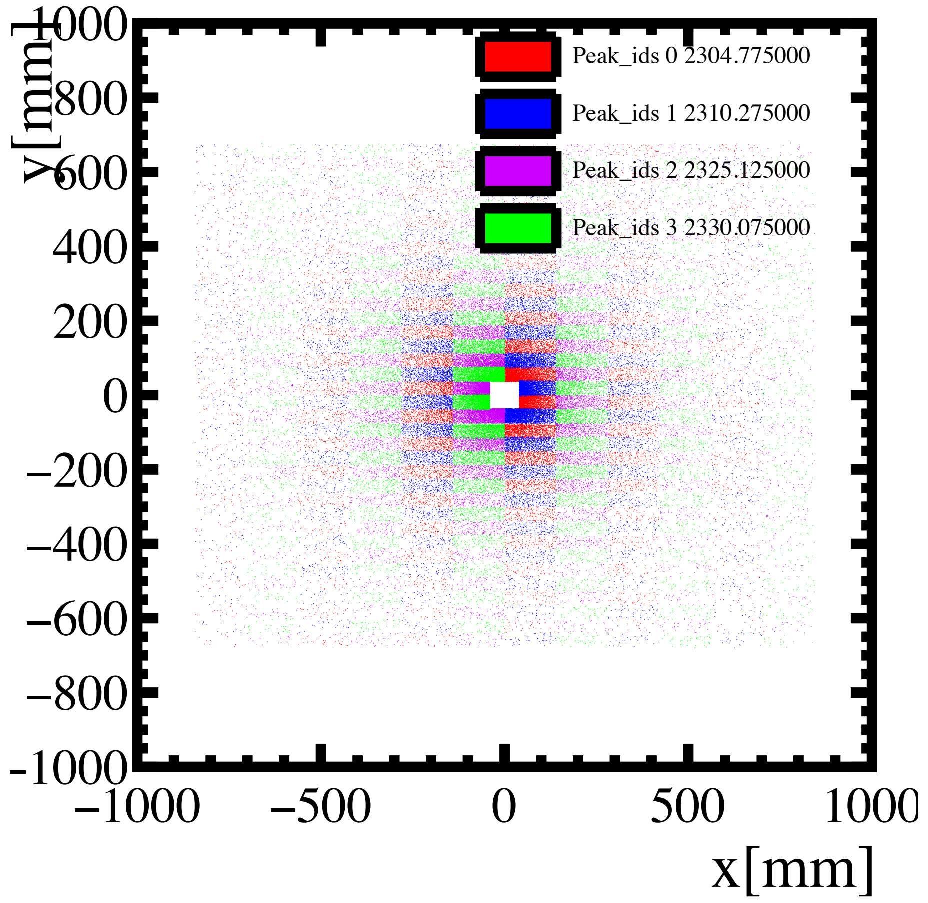
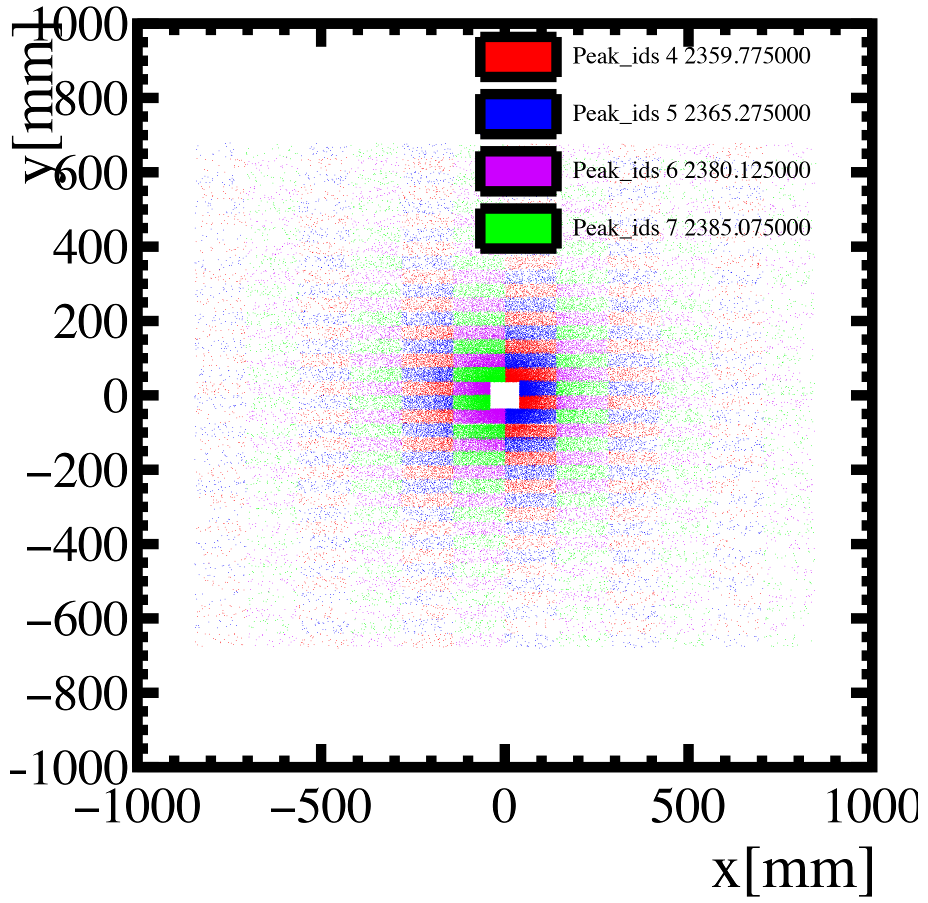
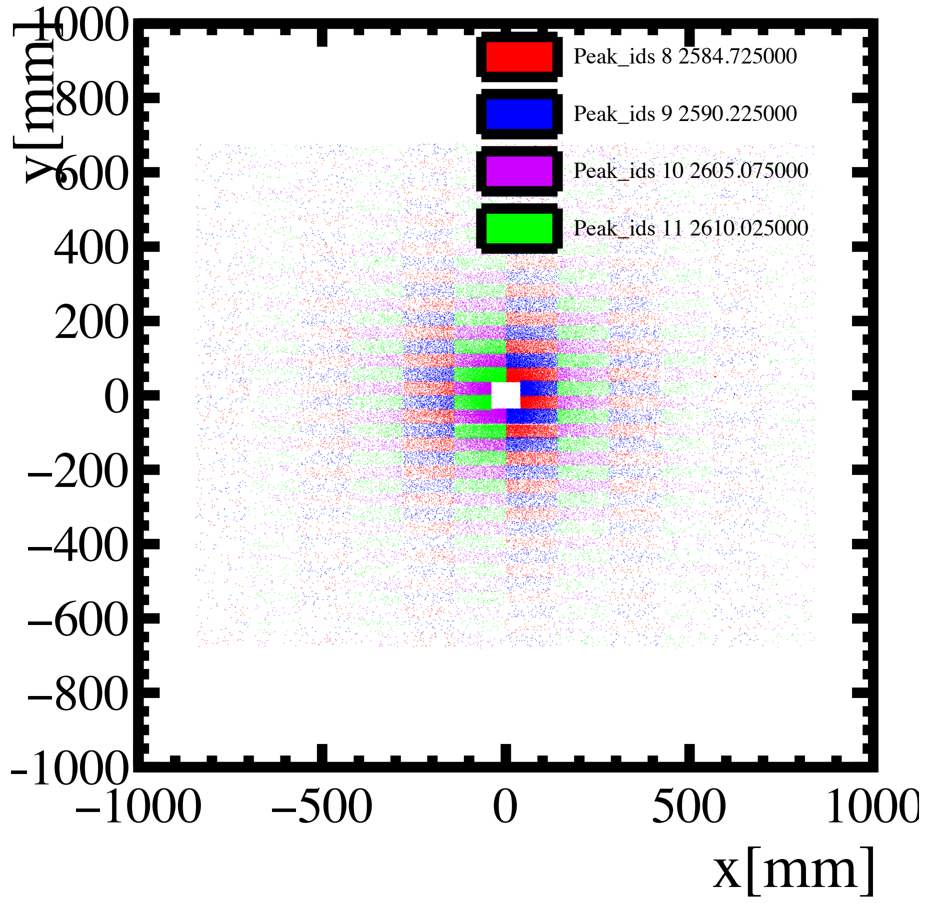
A sketch view [UP]

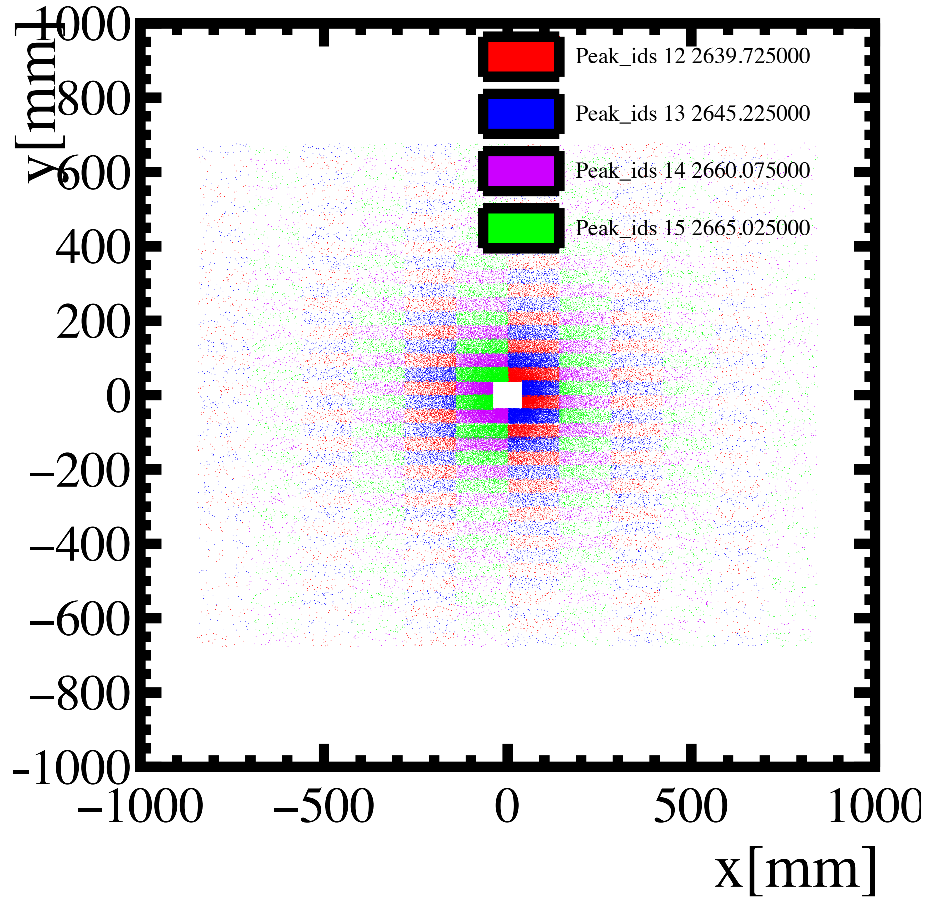
(Only active areas where possible clusters are formed)

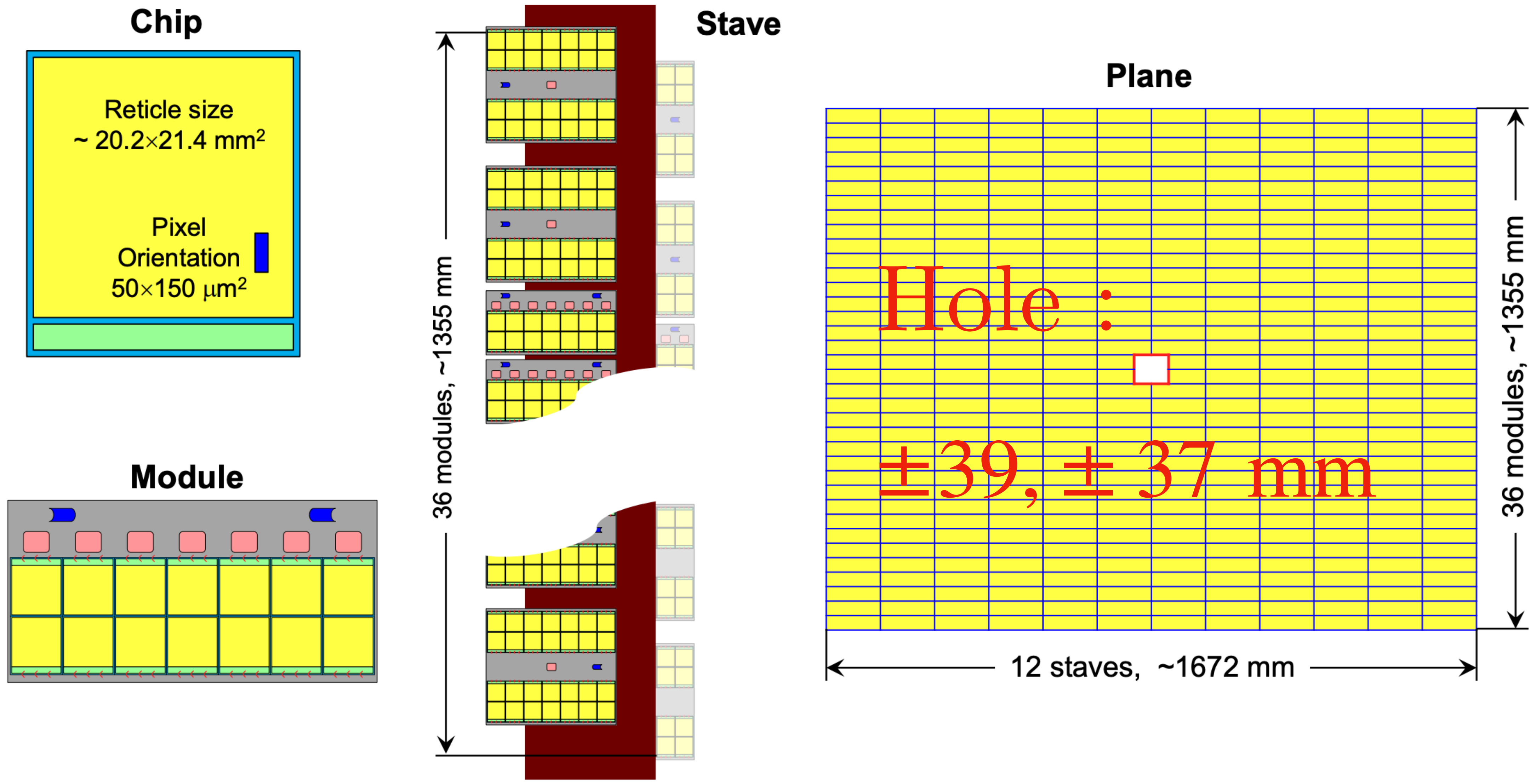






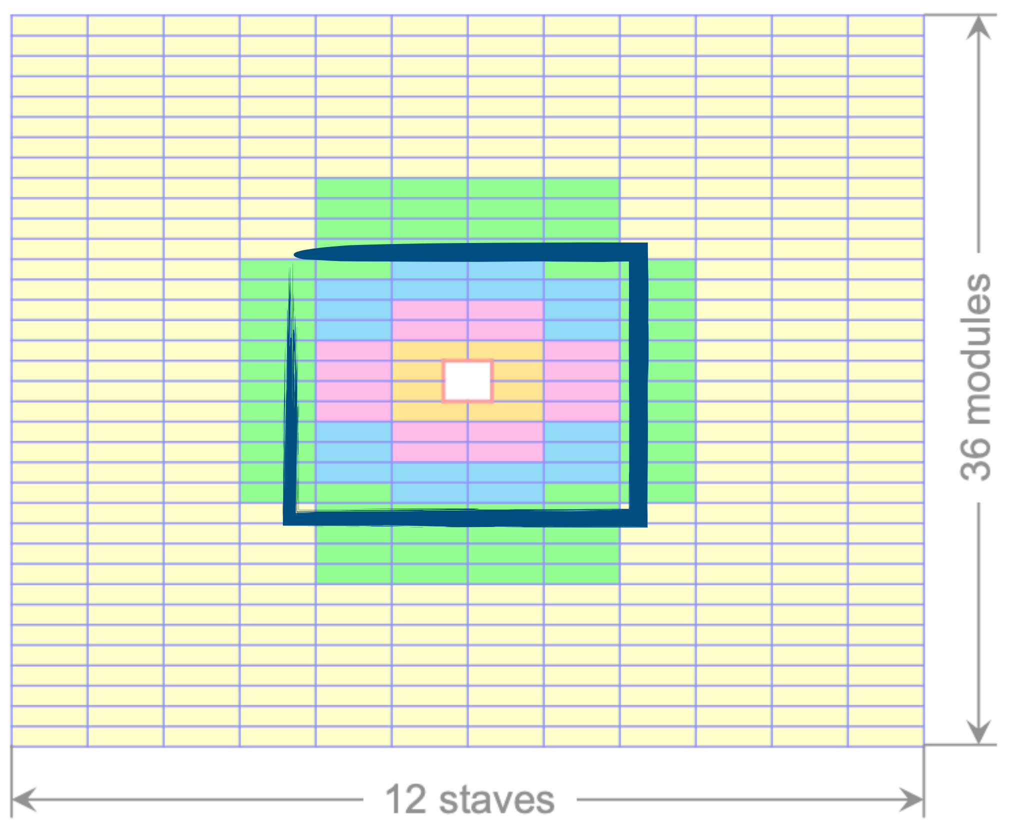






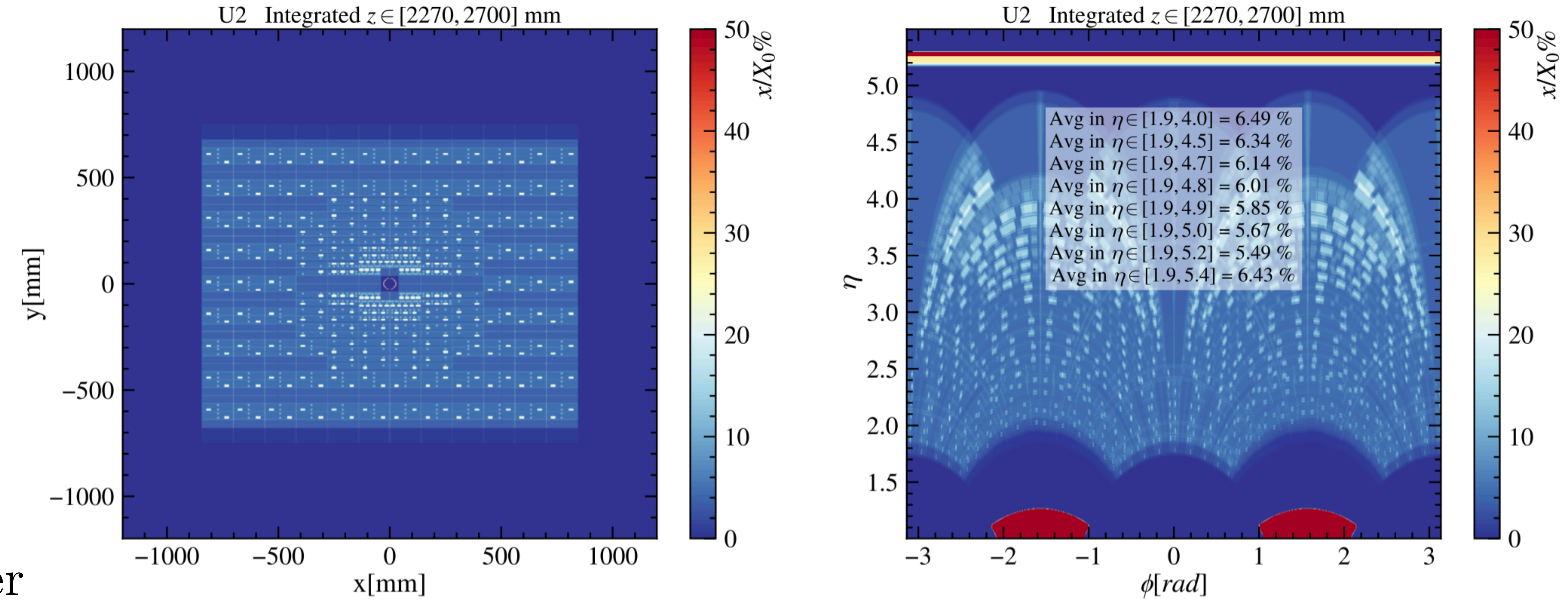
- Material budget aimed to be kept below or around 1% per detection layer.
- UT in Run3 main driver of fake rejection
- UT in Run3 plays also a critical role in trigger strategy
- 3/4 layers from performance not yet determined, see tomorrow
- UT/UP is and will be crucial for downstream physics with K_s, Λ
- Critical for *p-p* and *Pb-Pb* physics programme

Material budget in UP region



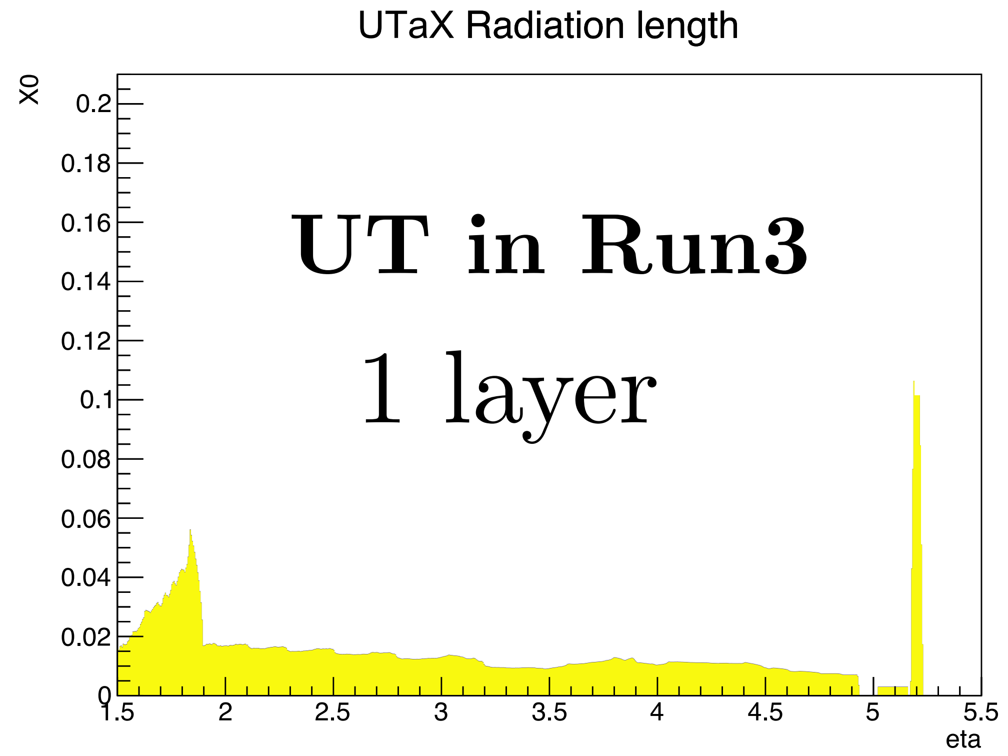
Ring	5	4	3	2	1
e-links / chip	1	1	1	1-3	2-7
Gbps / e-link	0.32	0.64	1.28	1.28	1.28
lpGBT / module	0.5	1	2	7	14/10
Num of modules	1312	240	80	64	32
Num of lpGPTs	656	240	160	448	384

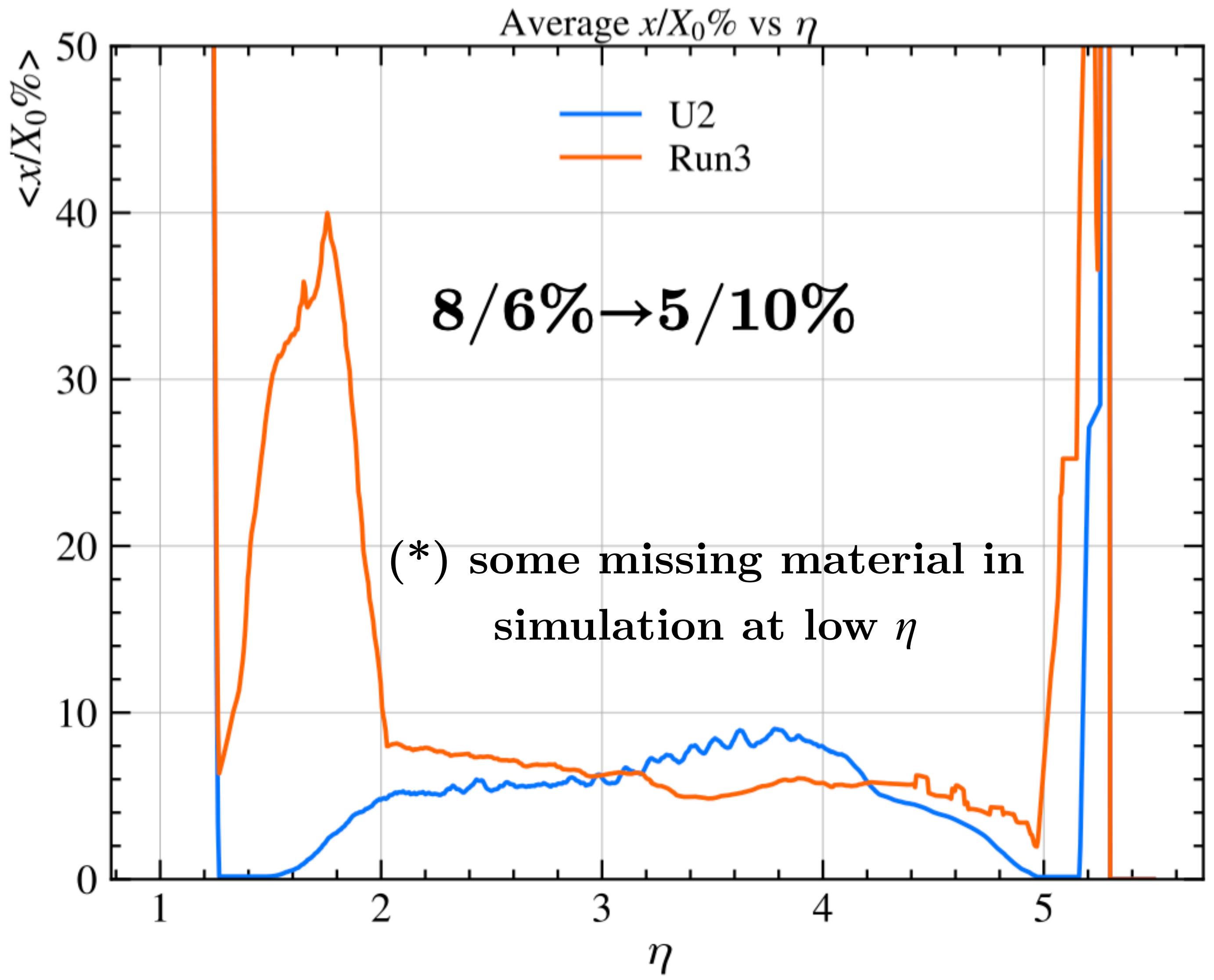
UP in U2 simulation ~1.5 weeks ago



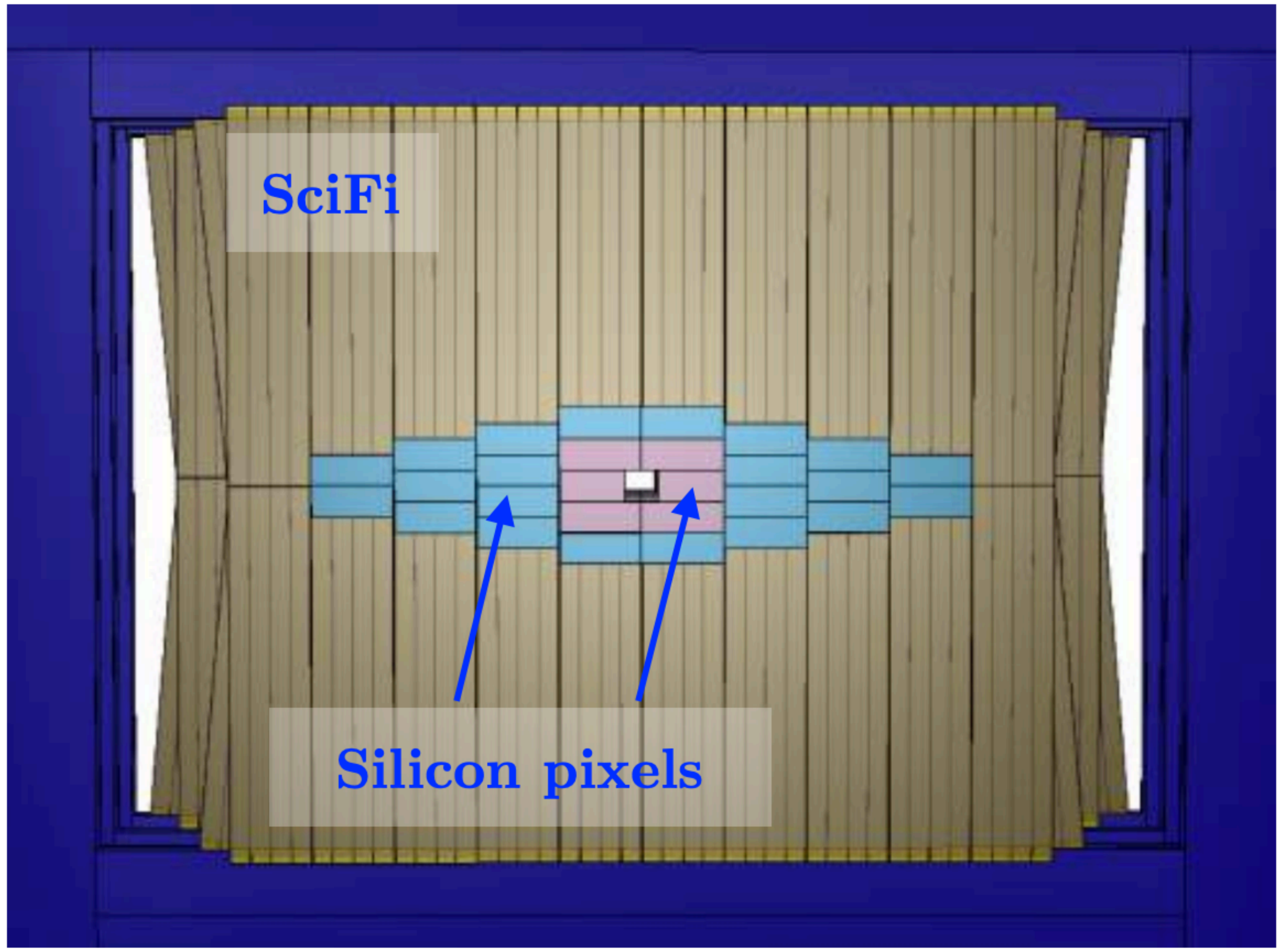
(Passing through all volume)

- Due to higher data rate more electronics in the inner part leading to more material.
- Technological choice depends on radiation hardness
- We know from various studies, that σ_p/p is very sensitive to material in UT. Depends on technology it might go up.



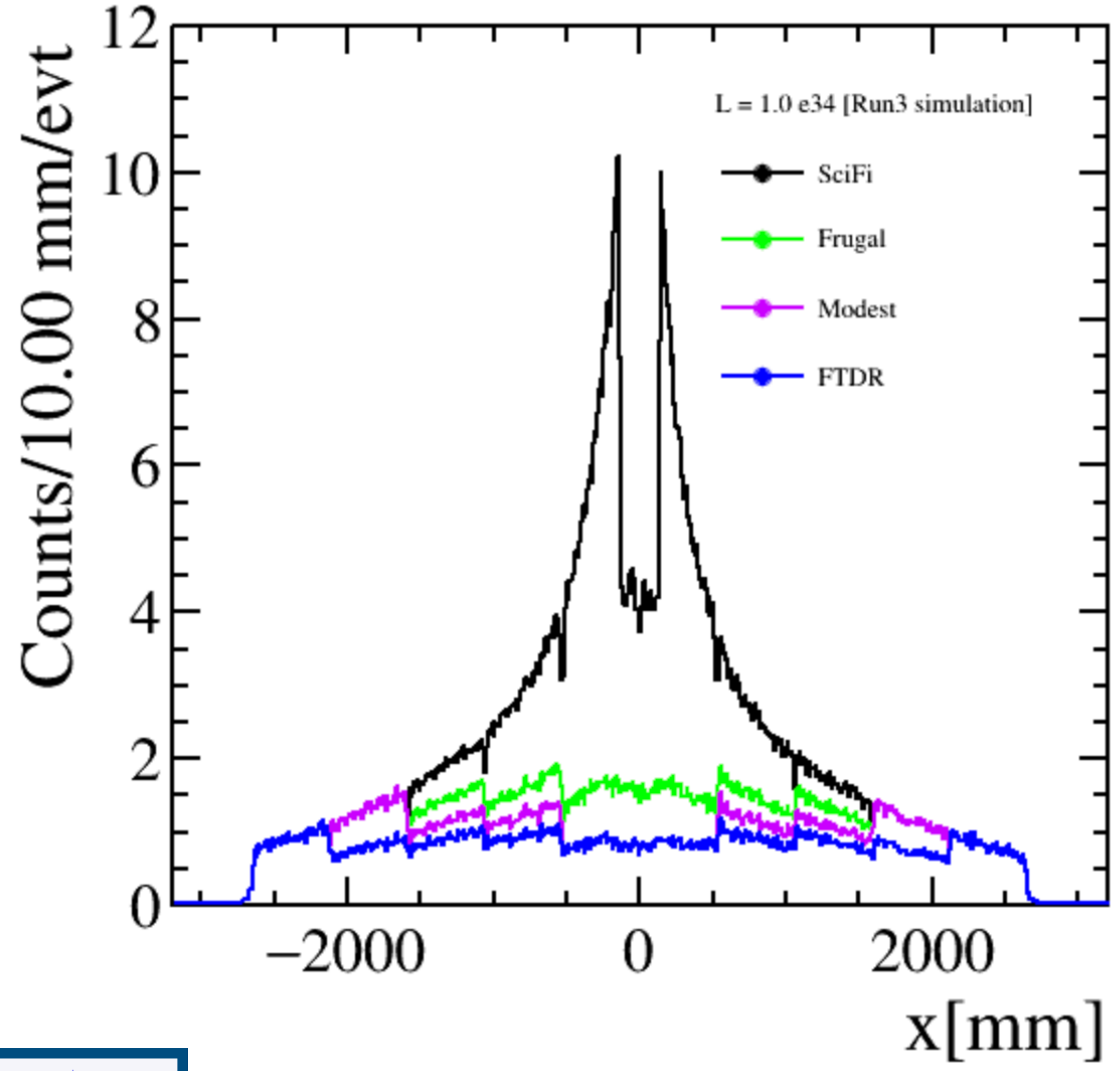


MT detector

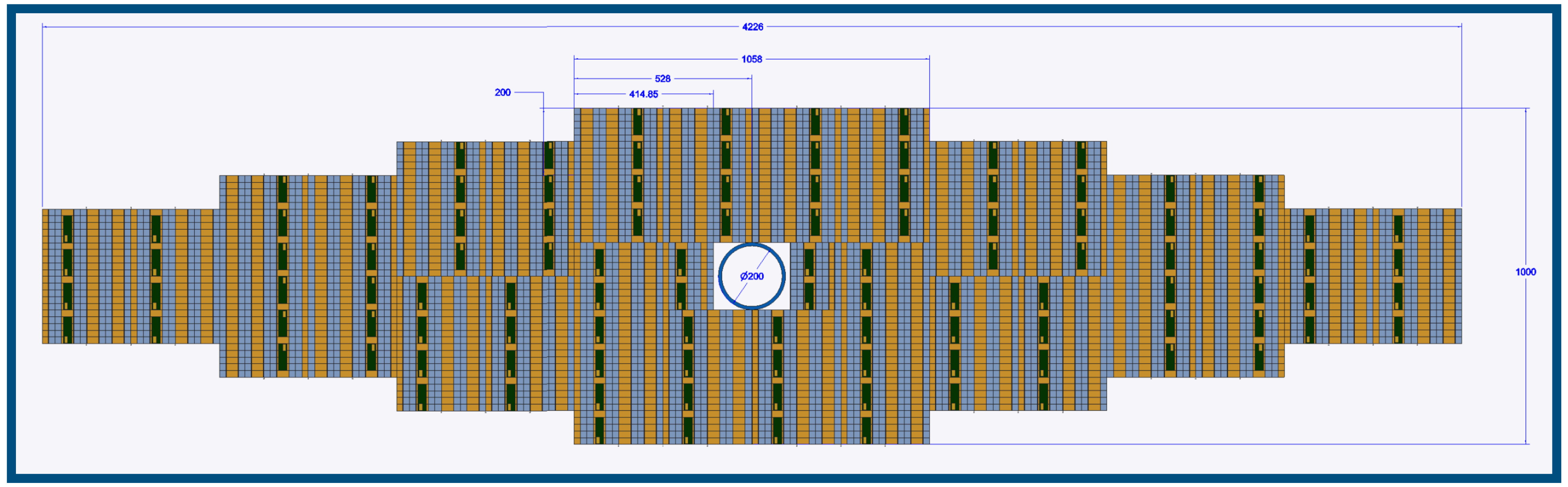


Why a split in inner/outer acceptance?

Scaling Run3 detector at higher Lumi value (1e34) & cutting by hand Pixel acceptance by hand



Design of the shape of MT defined by irradiation of fibers to expect at different Lumi and hit efficiency in fibres/occupancy impact on tracking performance

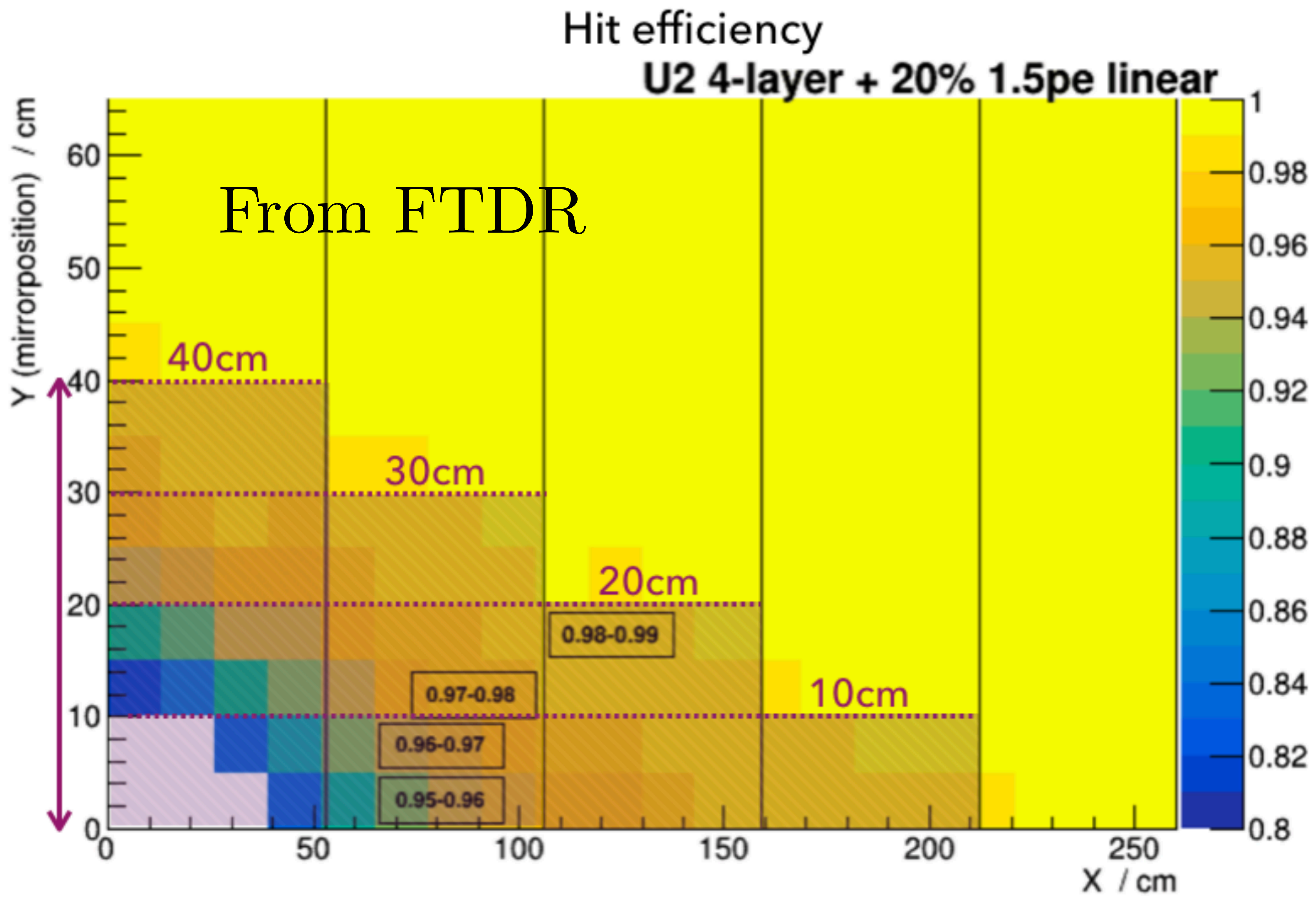


Hole-updated since FTDR to be 260 mm

Design driven by SciFi occupancies and radiation damage assuming SciFi as in U1 [no better SiPM and Cryo cooling].

MT detector

How is the split for acceptance obtained?



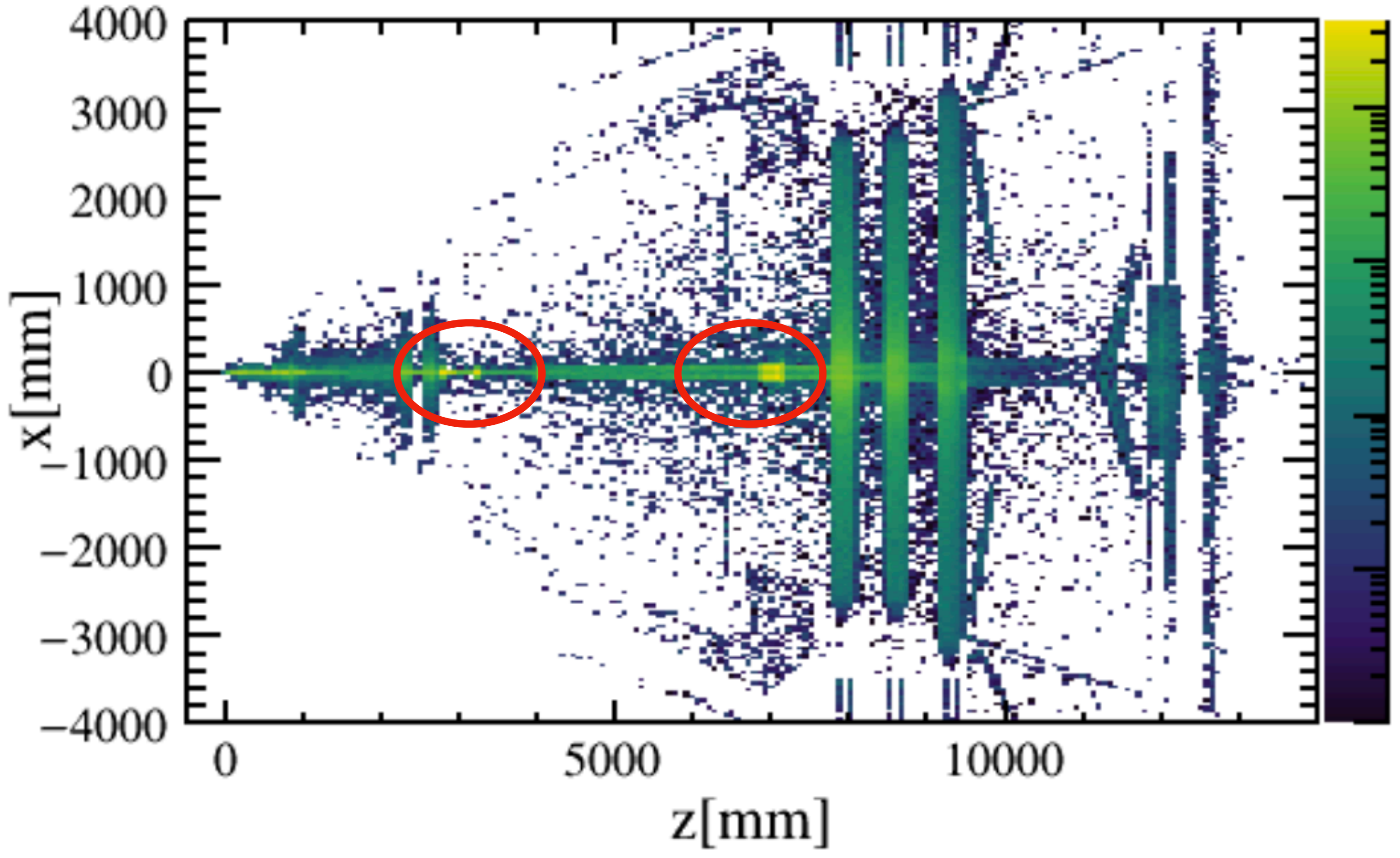
- How much can we make the fibre modules leaking into the inner region until they maintain high (99%) hit efficiency?

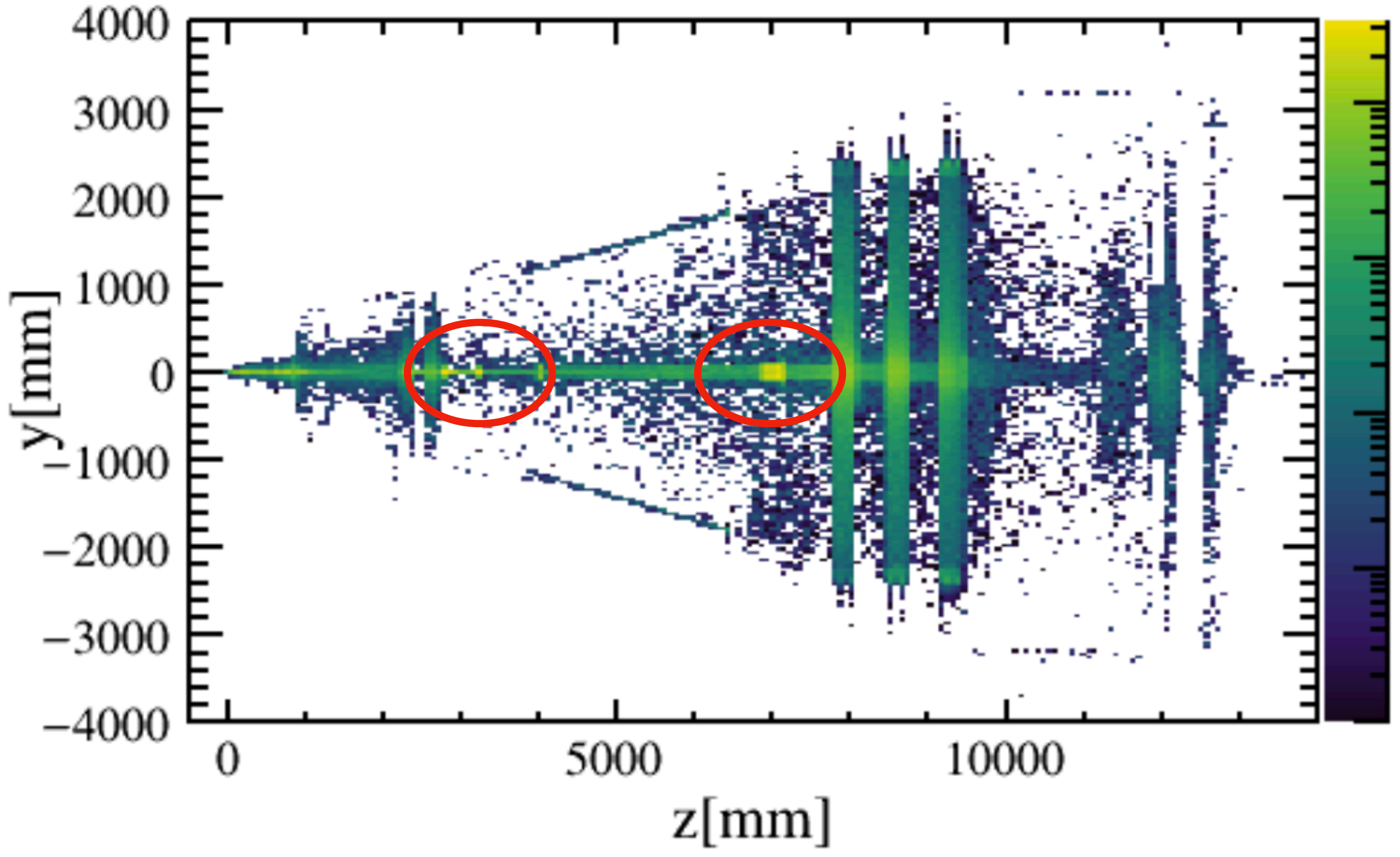
Figure 3.30: Hit efficiency map for a quadrant of a scintillating fibre detector, assuming cryogenic cooling, resulting in a consistent noise reduction and the possibility of using 1.5 photo-electrons signal thresholds, four-layer fibre mats and a 20% light yield gain. Hit efficiency is required to be above 99%, and this defines the minimum area to be covered with silicon pixels.

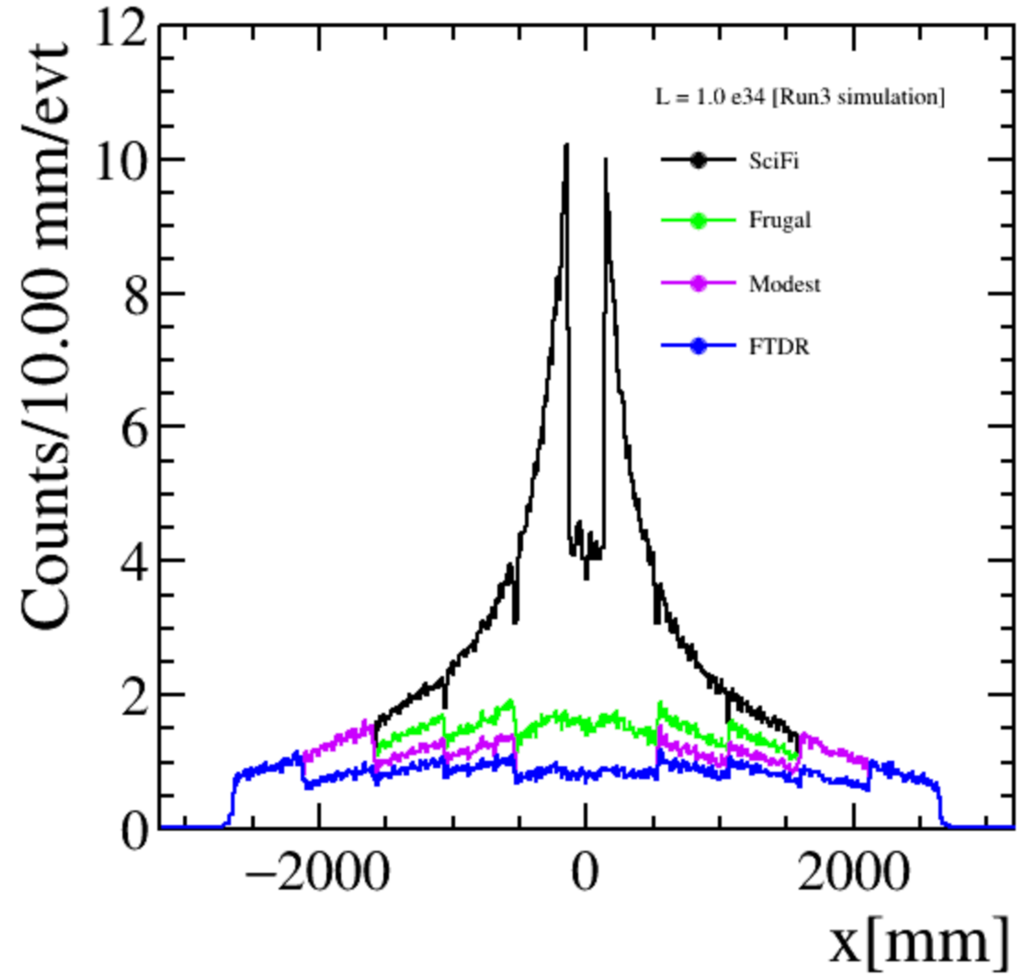
Secondary tracks for MT

- Comparing to same lumi a run3 vs U2 geometry production at U2 lumi
- O(2x) increase in occupancy in FT due to beam pipe elements supports

Run3



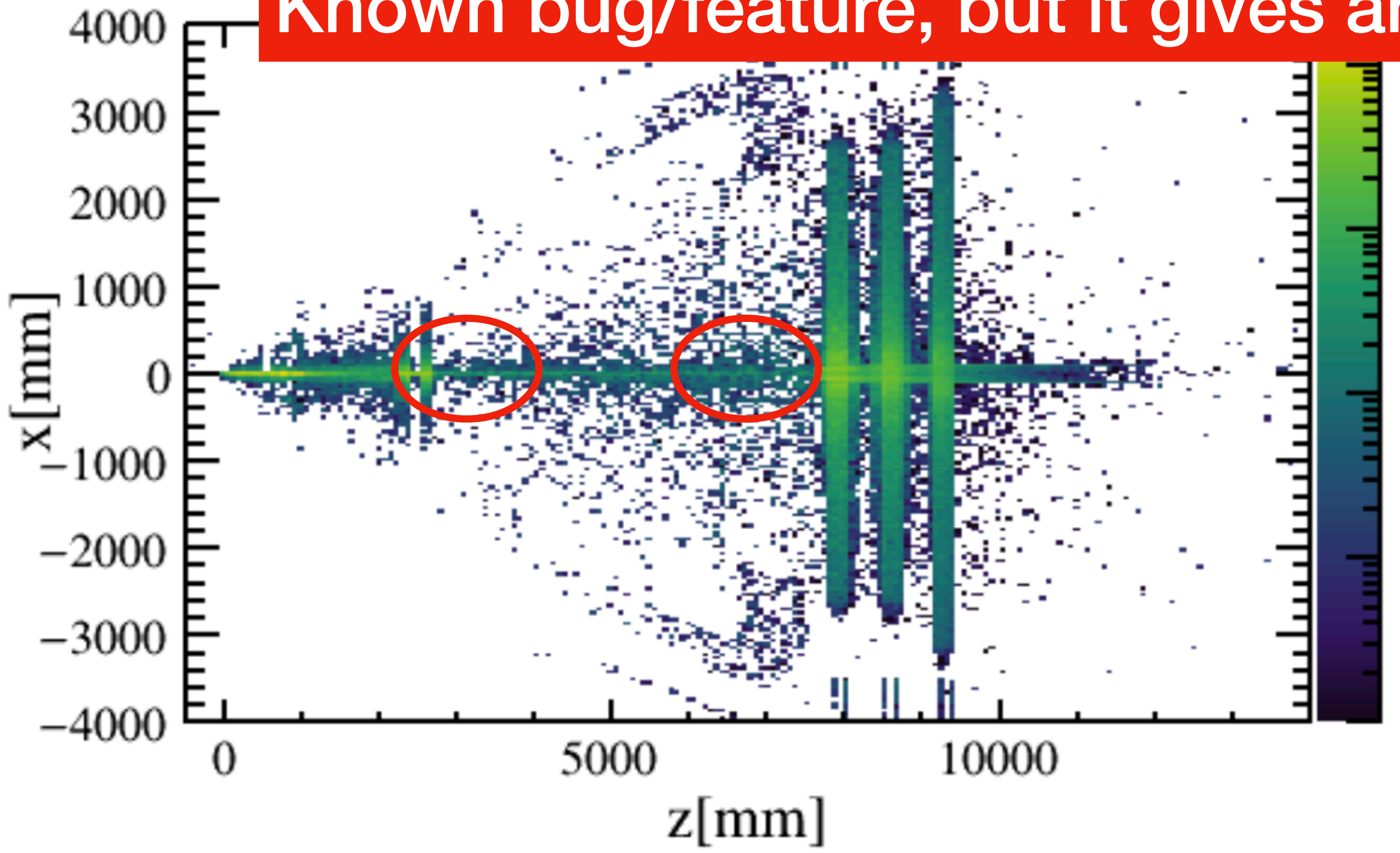


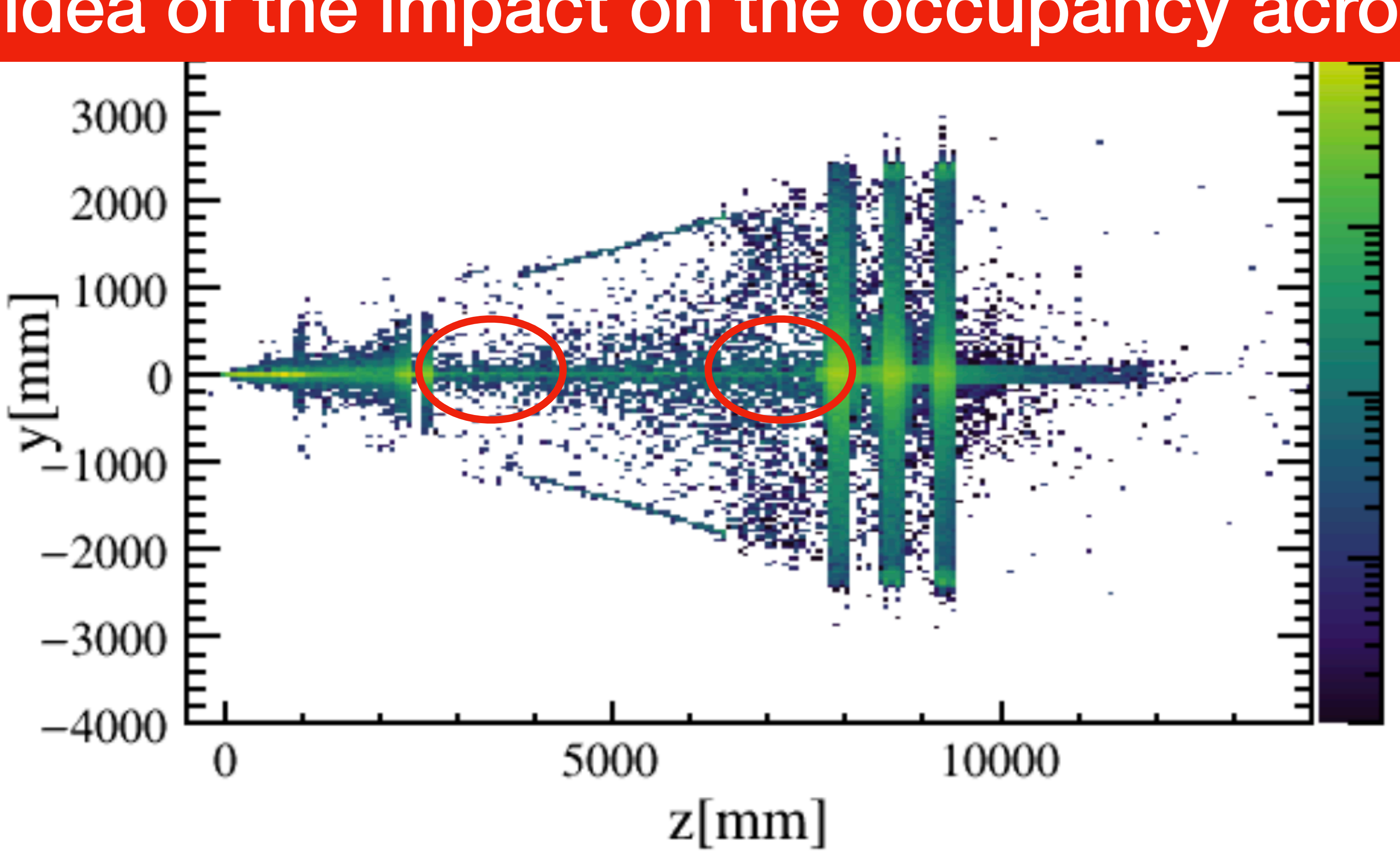


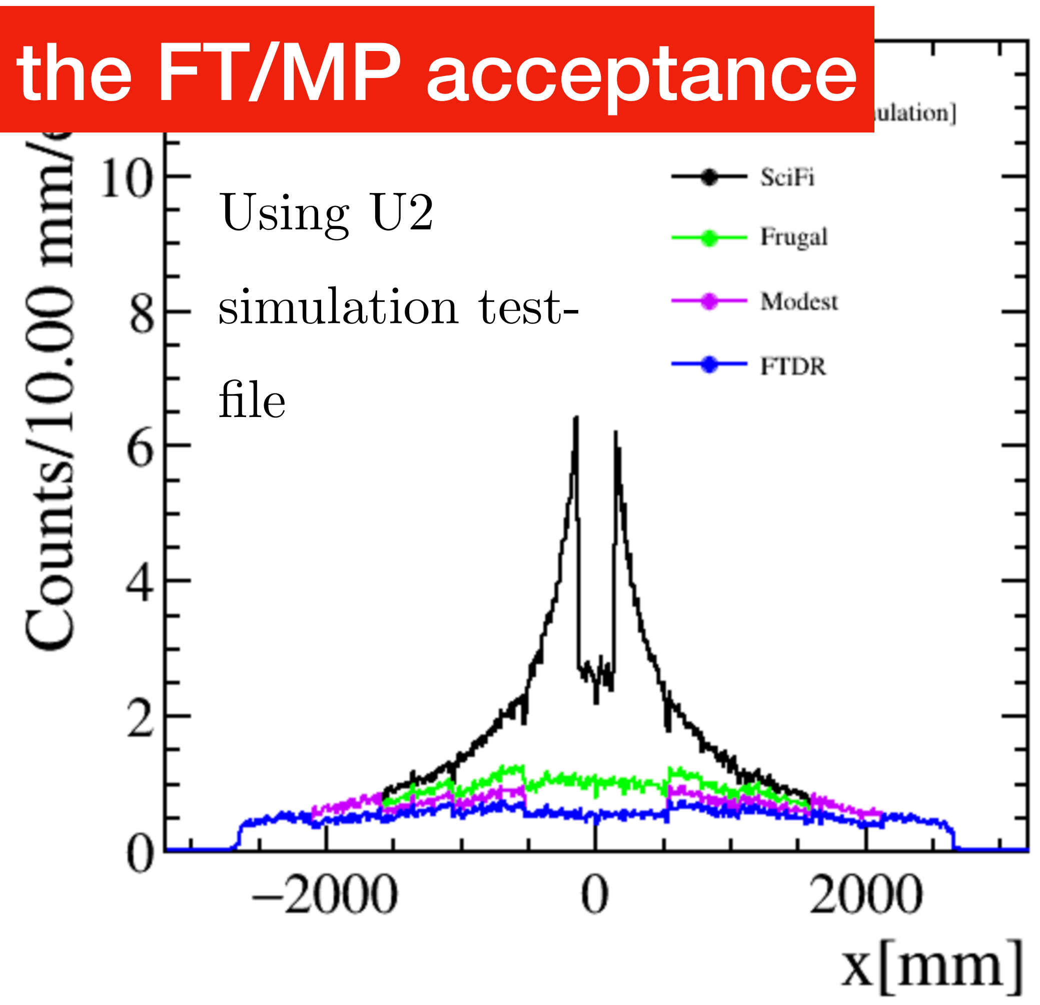
Both at L = 1.0E34

Known bug/feature, but it gives an idea of the impact on the occupancy across the FT/MP acceptance

U2 Samples



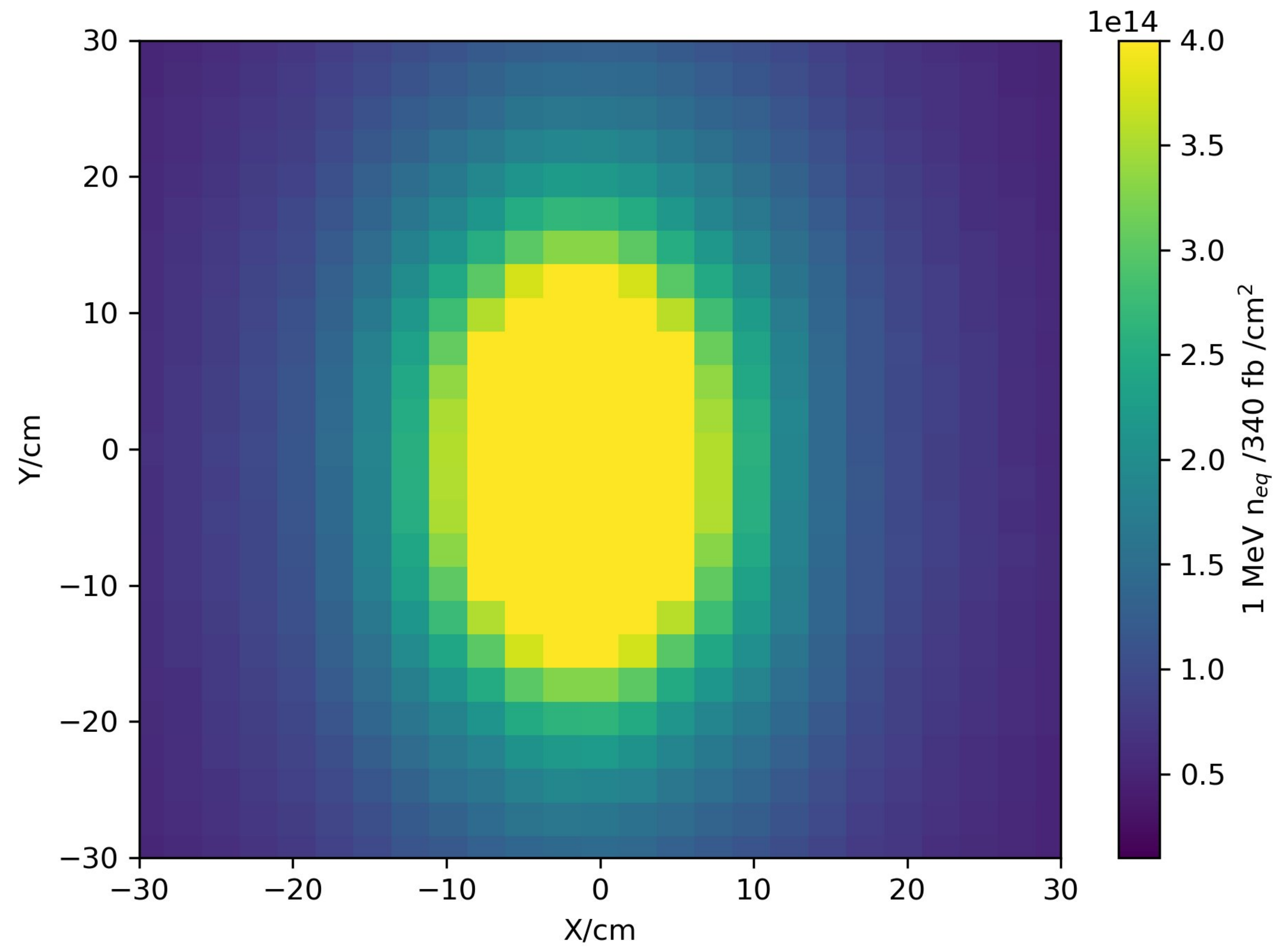




MT detector [radiation requirements]

- **For the fibre part, radiations impact**
  - **SiPMs**:
    - Neutron flux is estimated $\sim 3 \times 10^{12}$ neq/cm^2 with 350 fb^{-1}.
    - Can be reduced by a factor 3 at SiPM with neutron shielding.
    - SiPM degradation expected beyond $\times 10^{12}$neq/cm^2.
    - New radiation map to do to account for upgraded ECAL
  - **Fibres**
    - New maps ongoing, size of pixel will adjust accordingly
- **For the pixel part**
  - Study from Klaas <u>here</u> , from rad-damage point of view different lumi-scenarios don't make difference
  - According current understanding of MightyPix sensors, one may have to cool it to -10°C
    - If not cooling, first thing that will increase is number of hits to process

Radiation studies from Klaas in pixel



Full tracking system at work

- Simulation of U2 getting into shape to be usable for reliable performance estimation/checks of the complete tracking system. Good already for Velo.

- Lot of preparatory work carried on to understand how to best make use of new detectors in reconstruction with offline-standalone tools and to prepare the machinery in the LHCb software to do so.

- In those harsher environment, given the pile-up/occupancy/data-rates and expected performance, some considerations has to be made at some point about RTA and how to have efficient and fast algorithms running with those new detector.

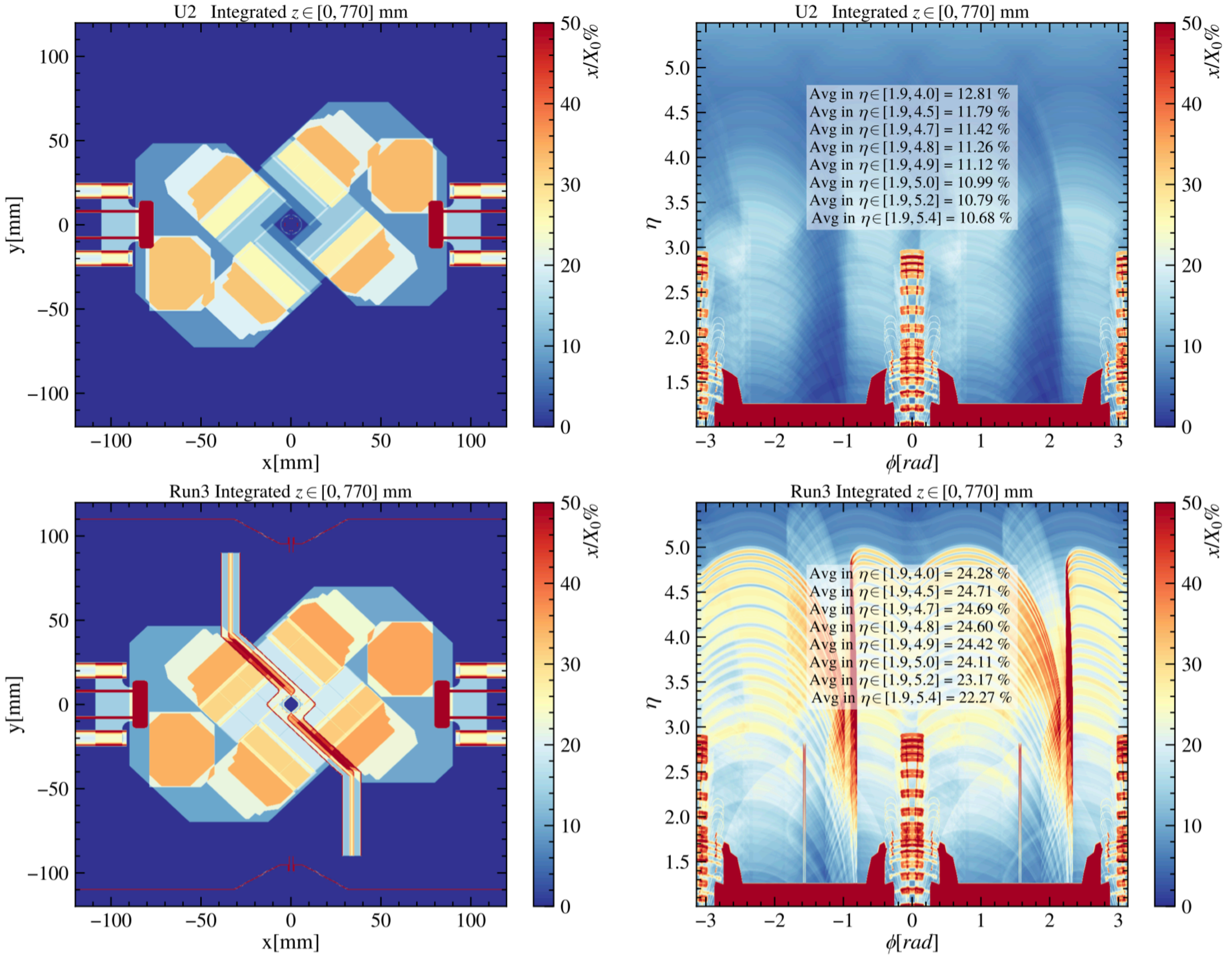
Conclusions

- Keep understanding technological boundaries and R&D ongoing and will continue for the next years. Probably we will hear more in next talks today/tomorrow
- Baseline tracker layout not dramatically changed since FTDR, several consideration/pro-and-cons to account for and studies done. Also HW capabilities evaluation done but not completely. Bigger change since FTDR in Velo moving away from Scenario A/B (both ruled out), migrated to Scenario X as baseline. More tomorrow on it.
- A large amount of work in simulation and developing standalone tools to evaluate key performance to get the detectors in a common stack in the recent months. We will hear more on results and status of studies in next talks.
- Of course, when we talk about trackers layout, we will then need to interplay it with the remaining part of the detector after among themselves, such as Muon,RICH, CALO. Talk aimed to cover only trackers.

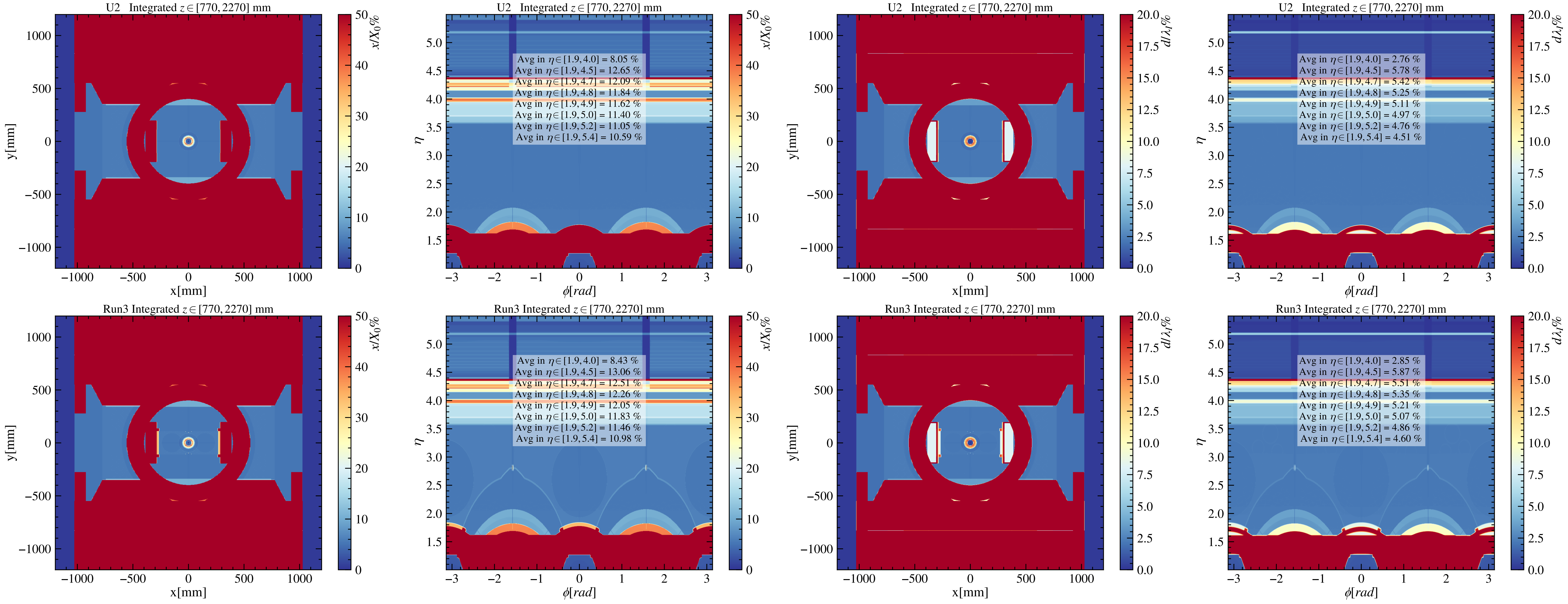
Backup

A jump into simulation

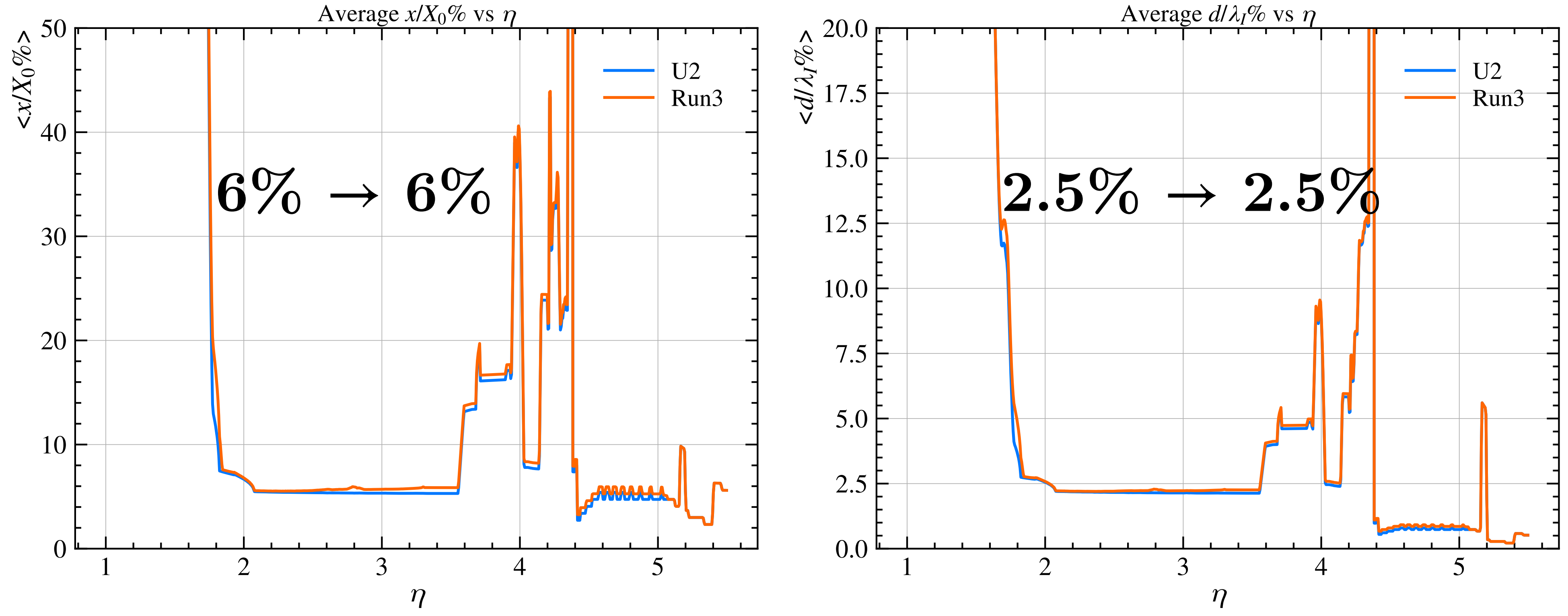
- End of december 2024, a first sample was produced for checks. Plots shown before in the slides are from that sample. Material budget comparison to Run3 performed.



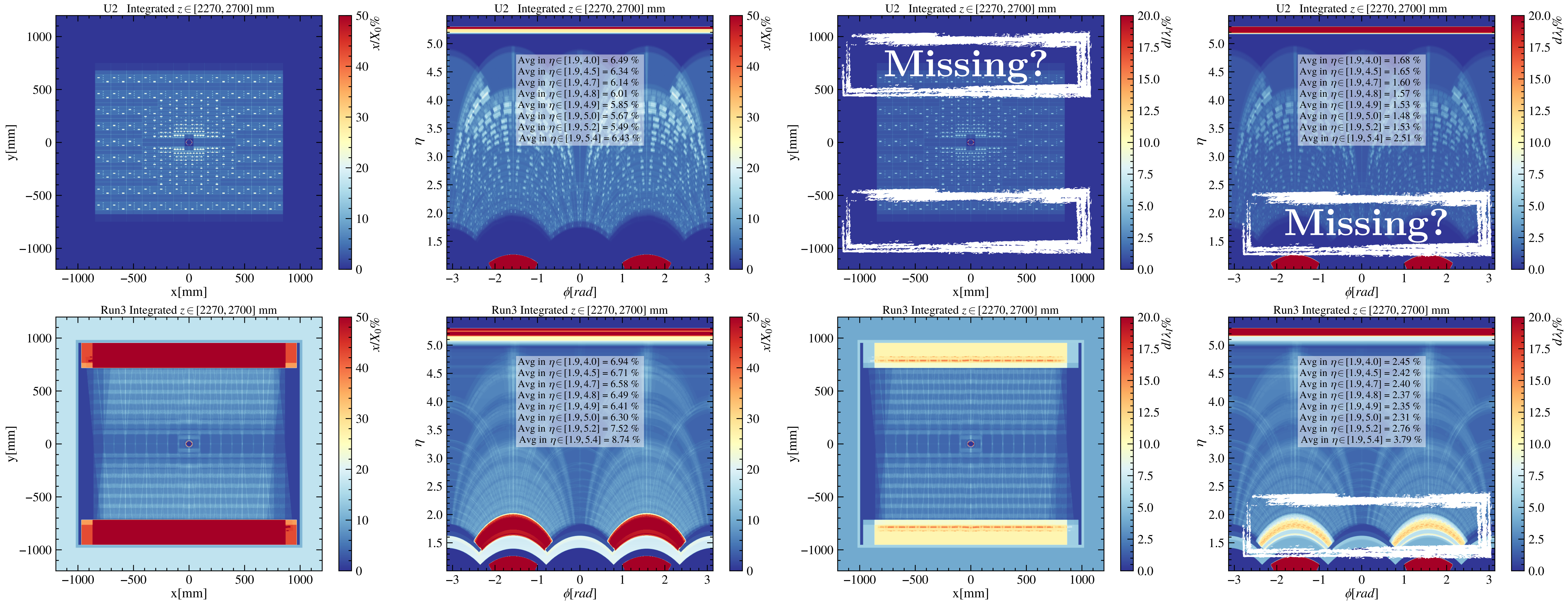
Summary z in [770,2270] Velo-To-UT [RICH1]



No difference in RICH1
Should we expect any change?
What type of changes?



Summary z in [2270,2700] UT

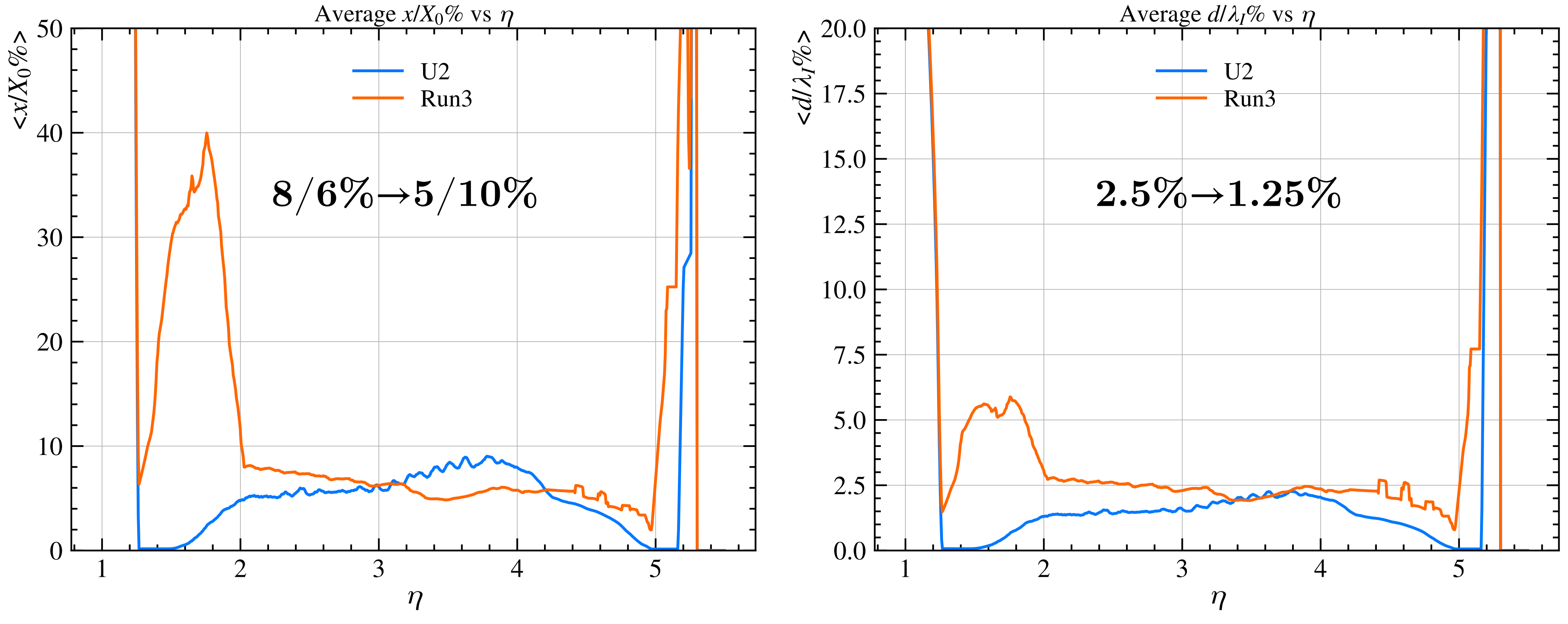


Lack of material in UP at y =800? [low η?]

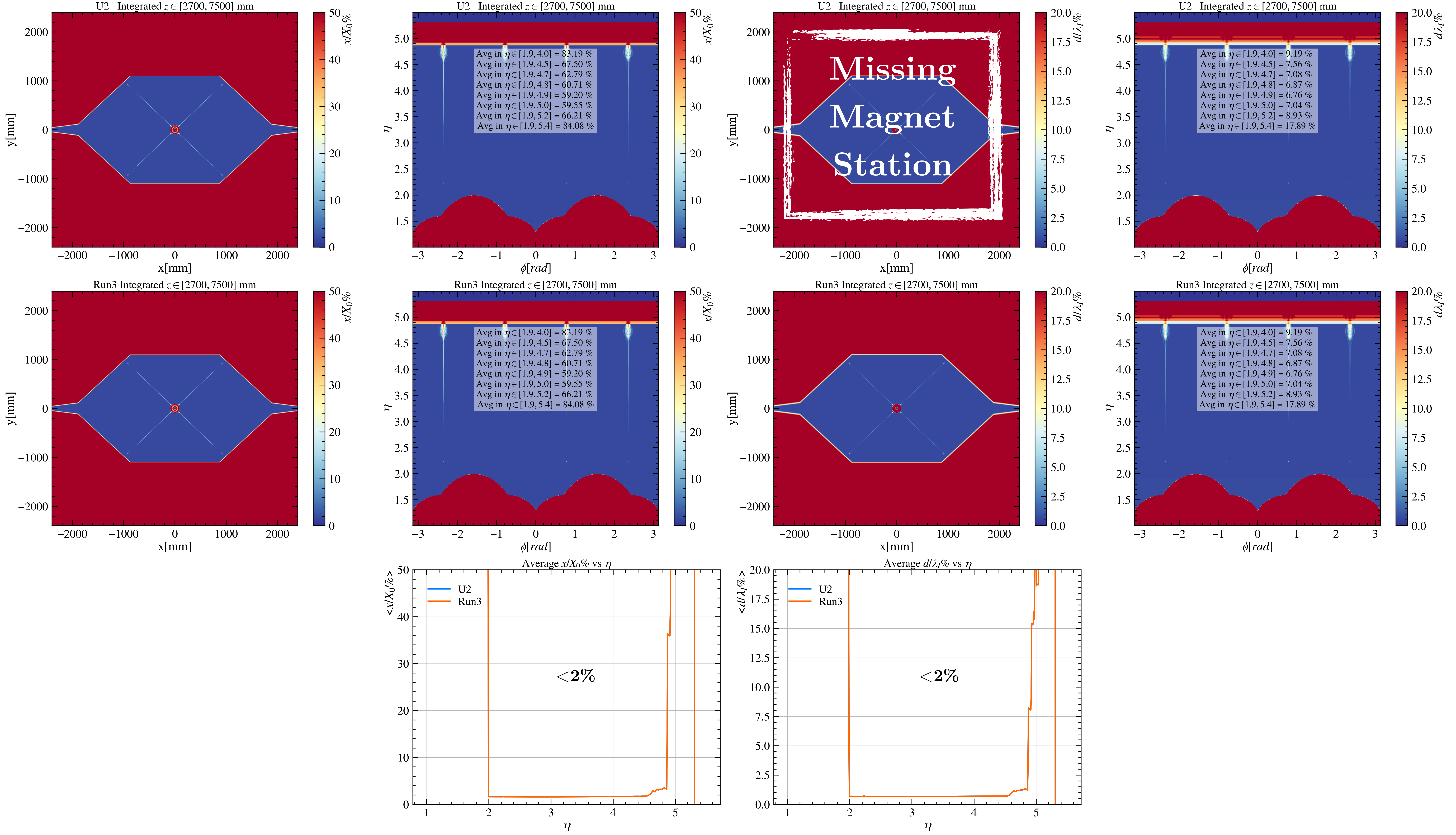
Reduced material in $\eta \in [2,3]$ but higher at higher η?

Makes sense?

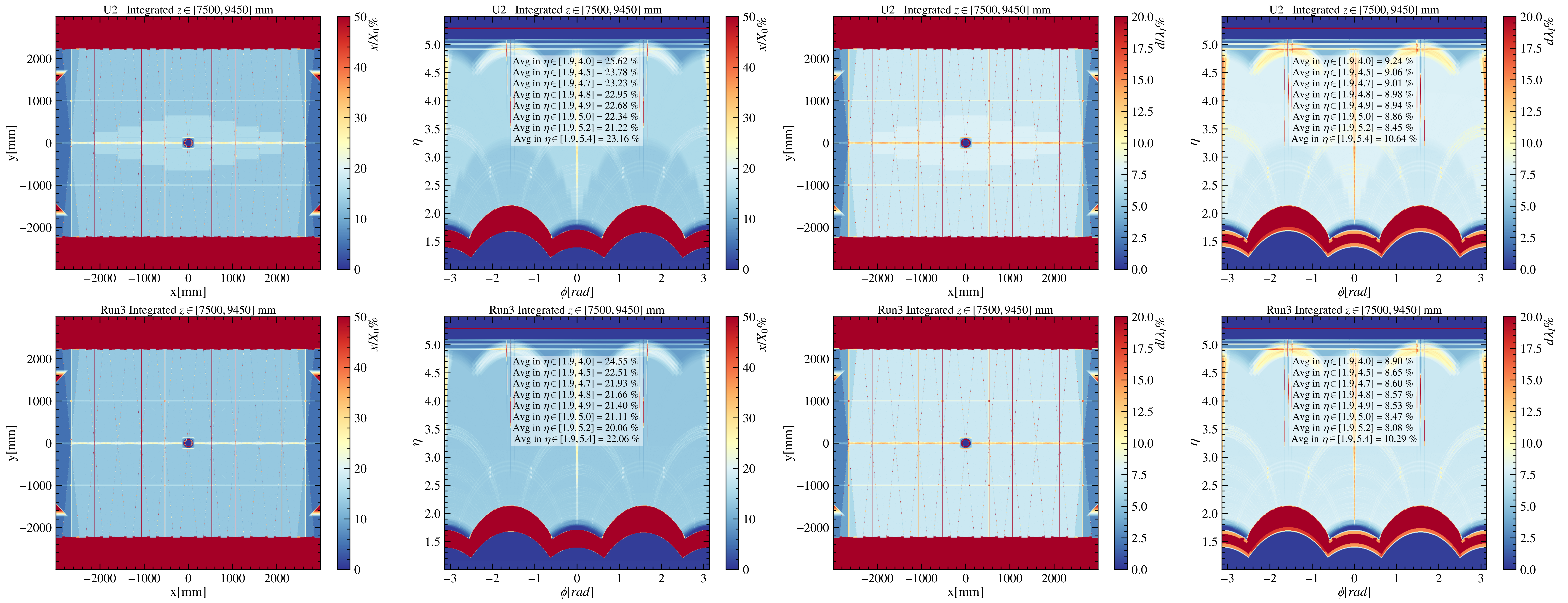
From dump there seems to be no Box material for UP as well



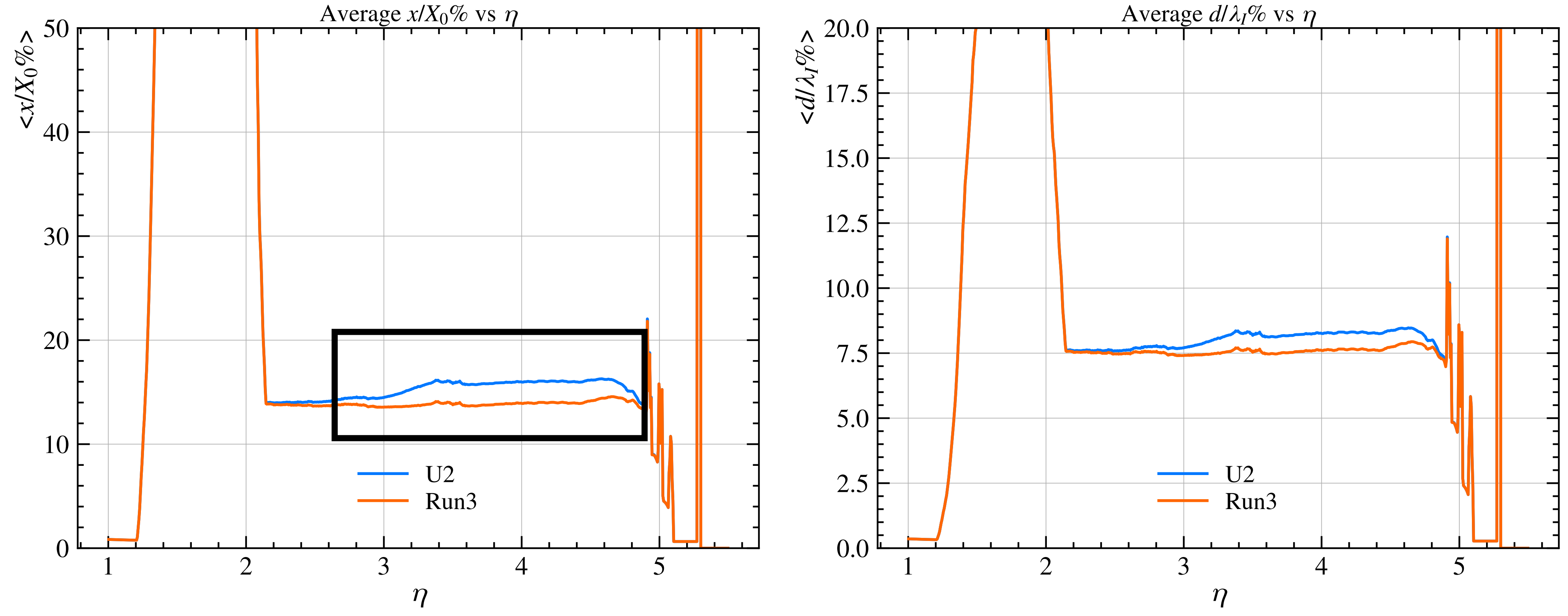
Summary z in [2700,7500] In Magnet



Summary z in [7500,9450] Downstream Tracker



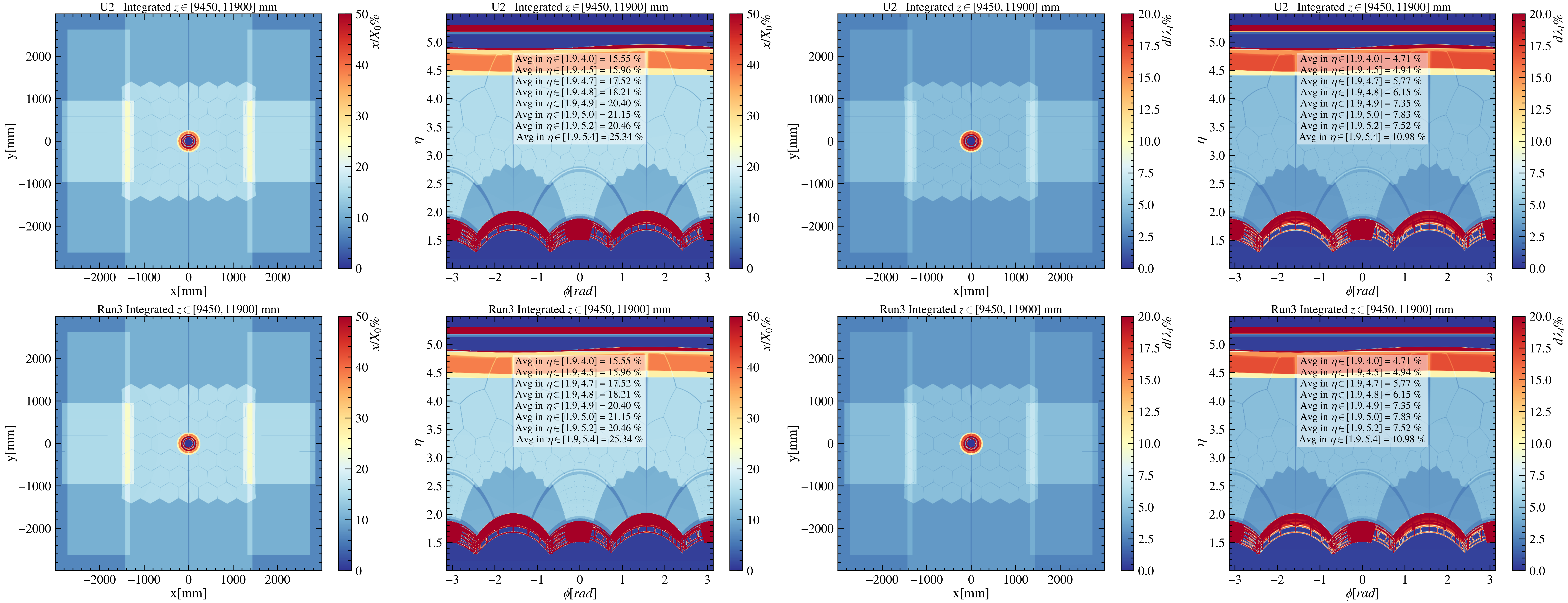
Over-estimation of material by having Fibres in all 12 layers leaking in acceptance of pixels. Tough the delta observed is a good representation of 6 MP layers?



We probably should subtract the fibre material with current samples. Fix on the hole TODO

Likely, less material after fix in the higher Eta region?

Summary z in [9450,11900] After Downstream Tracker



No diffs