Benjamin Audurier - U2 Tracking workshop - Dec. 15th 2020

U2 Occupancy and tracking studies

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II. Study 1: occupancies in MC PbPb.
III. Study 2: track matching in MC PbPb.
IV. Study 3: downstream tracking.

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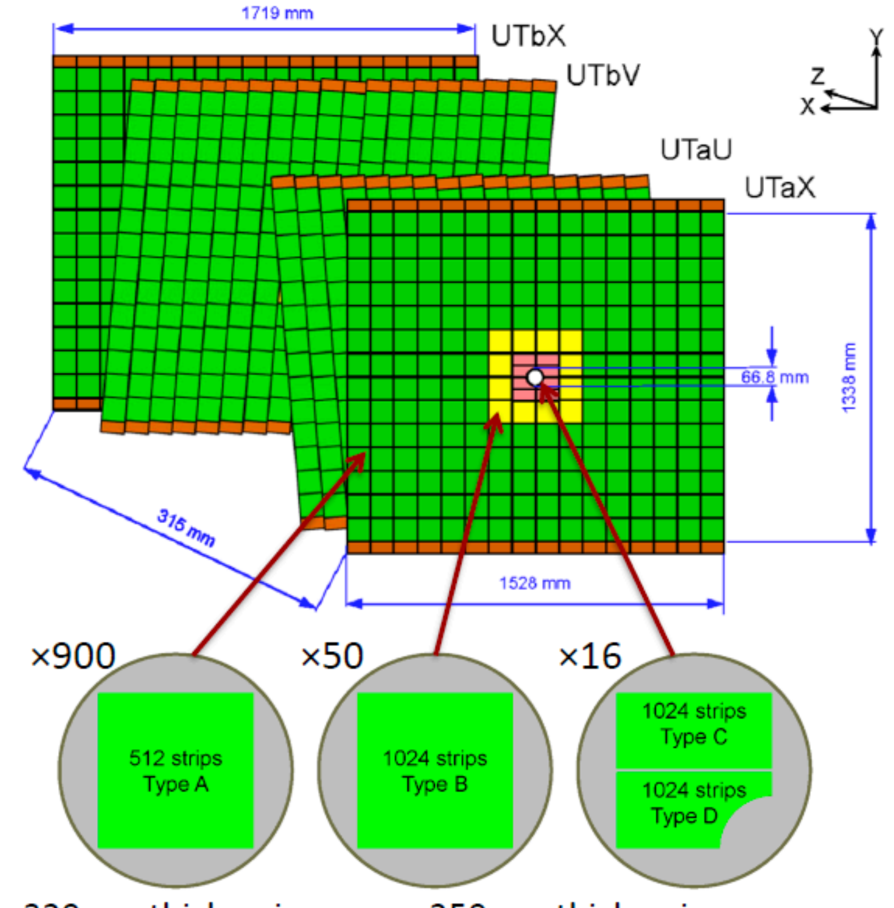
General consideration



320 µm thick, p-in-n, 190 µm pitch

250 µm thick, n-in-p, 80 µm pitch

Current UT design won't cope with U2 conditions.

Number of e-ports needed (<95% busy)

3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	4	4
3	3	3	3	3	4	4	4	4
3	3	4	4	4	4	5	5	5
4	4	4	4	5	5	6	7	8
4	4	5	5	6	6	8	8	10
5	5	5	6	6	8	10	14	12 / 18

Not sufficient active e-ports

Channel occupancy [%]

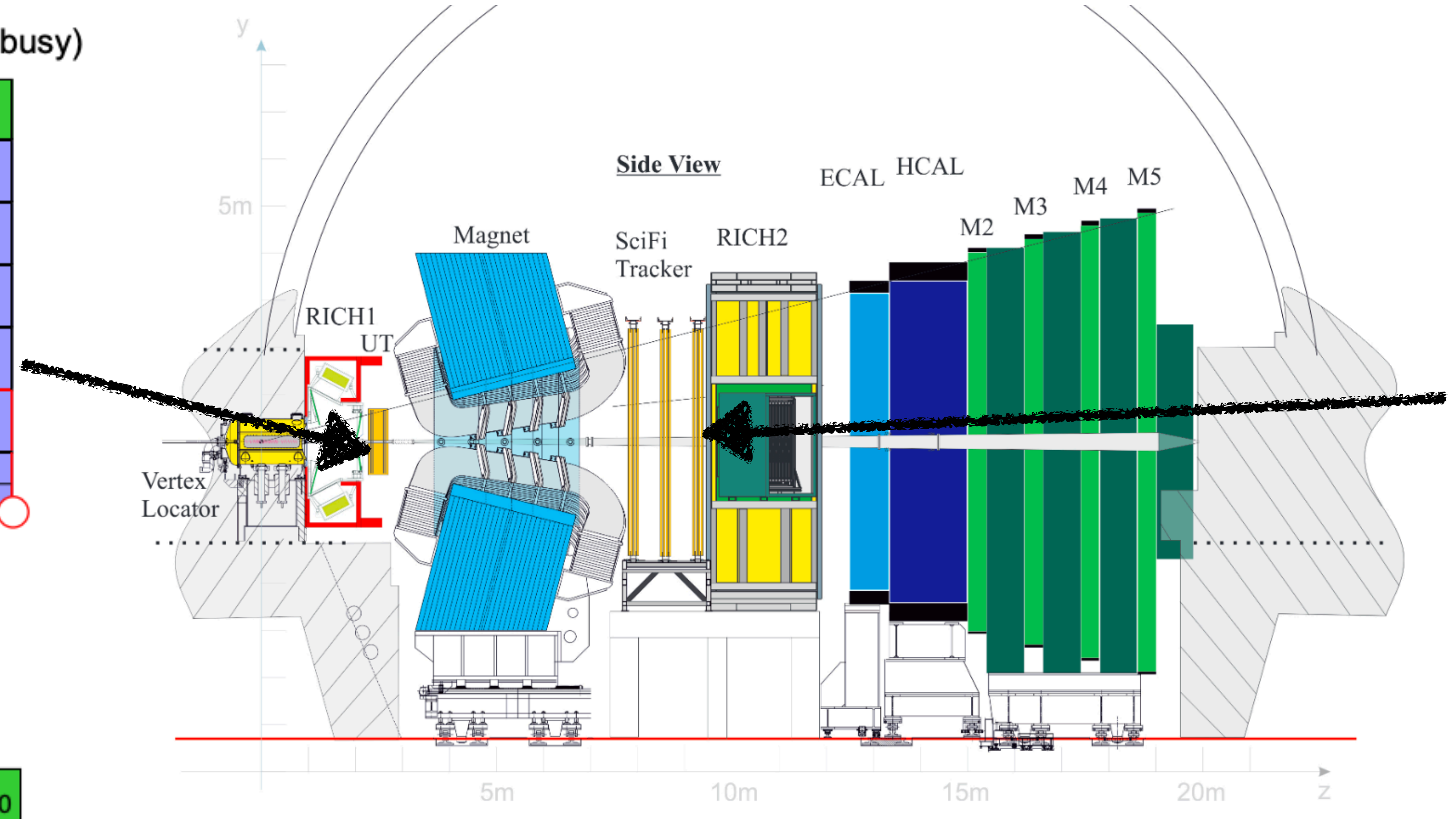
0.42	0.45	0.47	0.49	0.52	0.54	0.57	0.60	0.60
0.46	0.49	0.52	0.56	0.59	0.63	0.68	0.74	0.77
0.53	0.58	0.62	0.68	0.73	0.83	0.89	1.00	1.06
0.64	0.70	0.77	0.86	0.96	1.10	1.26	1.48	1.63
0.78	0.88	0.97	1.13	1.27	1.54	1.81	2.34	2.72
0.96	1.10	1.23	1.45	1.68	2.05	2.63	2.84	3.87
1.28	1.45	1.54	1.81	2.04	2.57	3.42	4.48	3.95 / 5.13

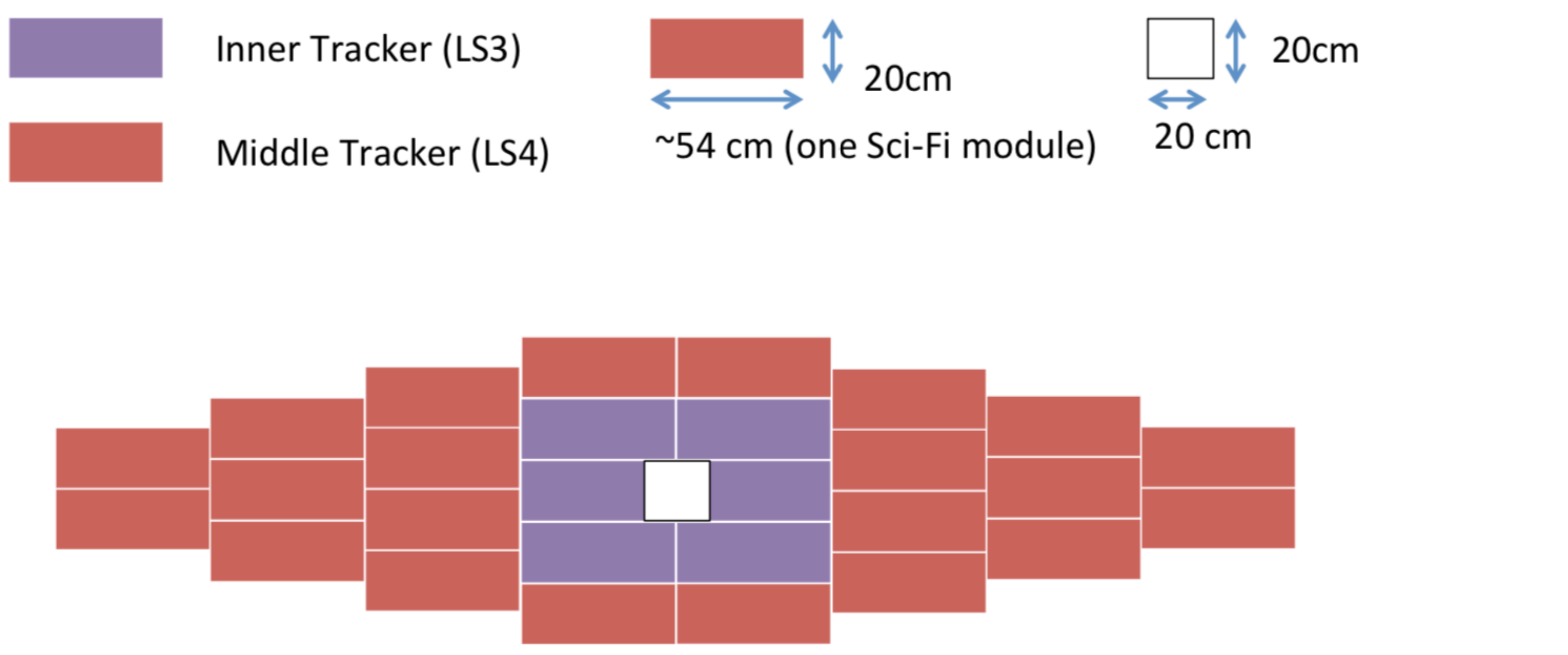
Data rate = (12 + 12 <nHits>) × 40 MHz, i.e 1.5 e-ports for header, and 1.5 per hit.

An ASIC can have up to 6 active e-ports, thus can handle up to <nHits> = 2.8, or 2.2% channel occupancy rate, for e-ports to be < 95% busy.

Due to constraints of the flex cable, not all e-ports were connected. Each UT stave would have some modules fail this data rate. None of them can be kept in U2.

(See JC's presentation)



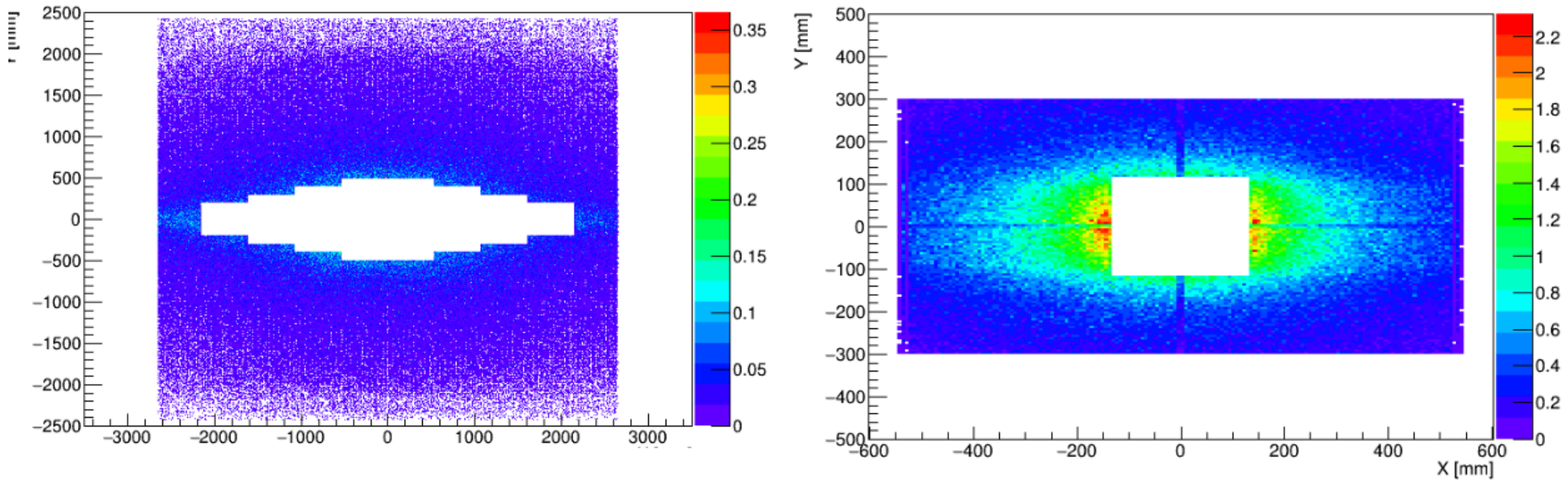


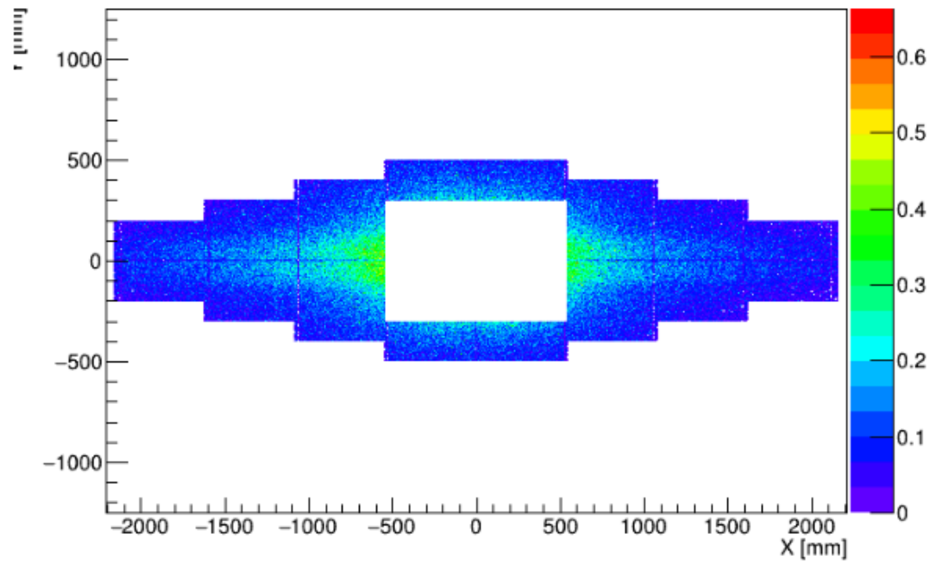
- Baseline for inner part: HV-CMOS pixels 100x300 µm.
- 6 layers of silicon, 0.7 m² per layer giving 18 m² in total.

- UT upgrade is mandatory for pp and heavy-ion physics.
- Several laboratories (LLR, IRFU, LPNHE, SUBATECH …) have already started to work on occupancies and tracking efficiency with pp/PbPb simulations.

Study 1: occupancies from PbPb simulations

MIGHTY hit density: 0-5% PbPb centrality

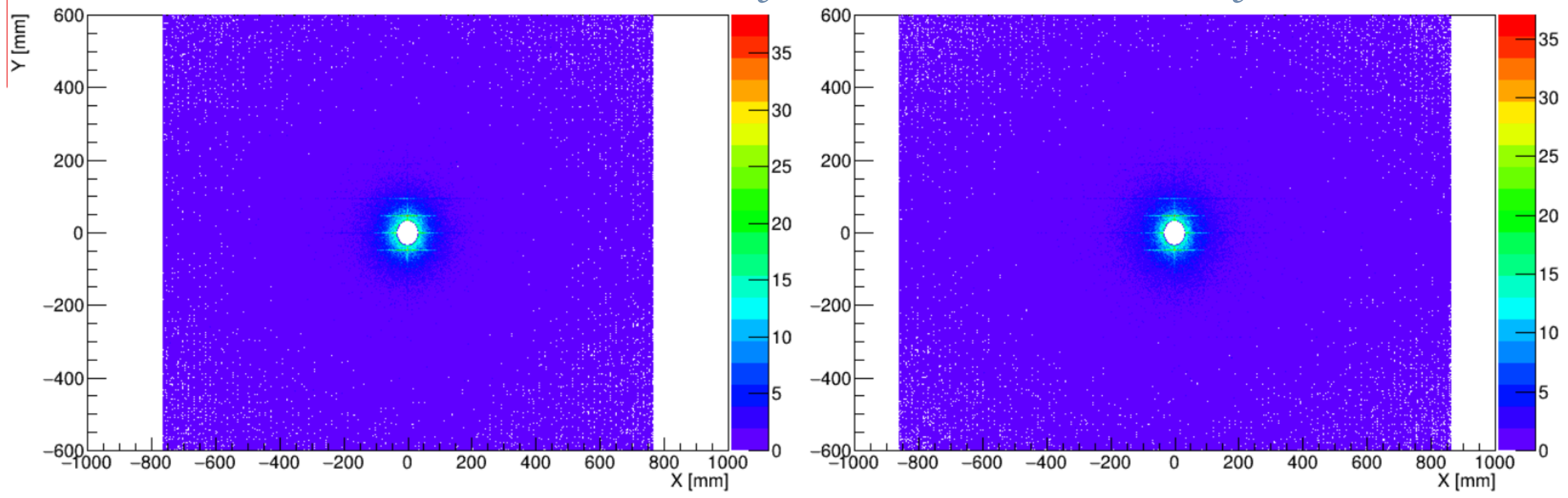




Max hit density T1 [hit/cm² event] :
- OT : 0.36
- IT : 2.32
- MT : 0.66

(Previous estimates, w/ eta cut) :
- *OT : 0.19*
- *IT : 1.18*
- *MT : 0.39*

UT hit density: 0-5% PbPb centrality



Occupancy histograms [hit/cm² event] for **PbPb** in UT first detection plane (left) and last detection plane (right)

Detection plane	Max hit density [hit/cm^2 event]	Corresponding η	Corrected max hit density [hit/cm^2 event]
UT 1	38.33	4.575	52.49
UT 4	37	4.682	50.67

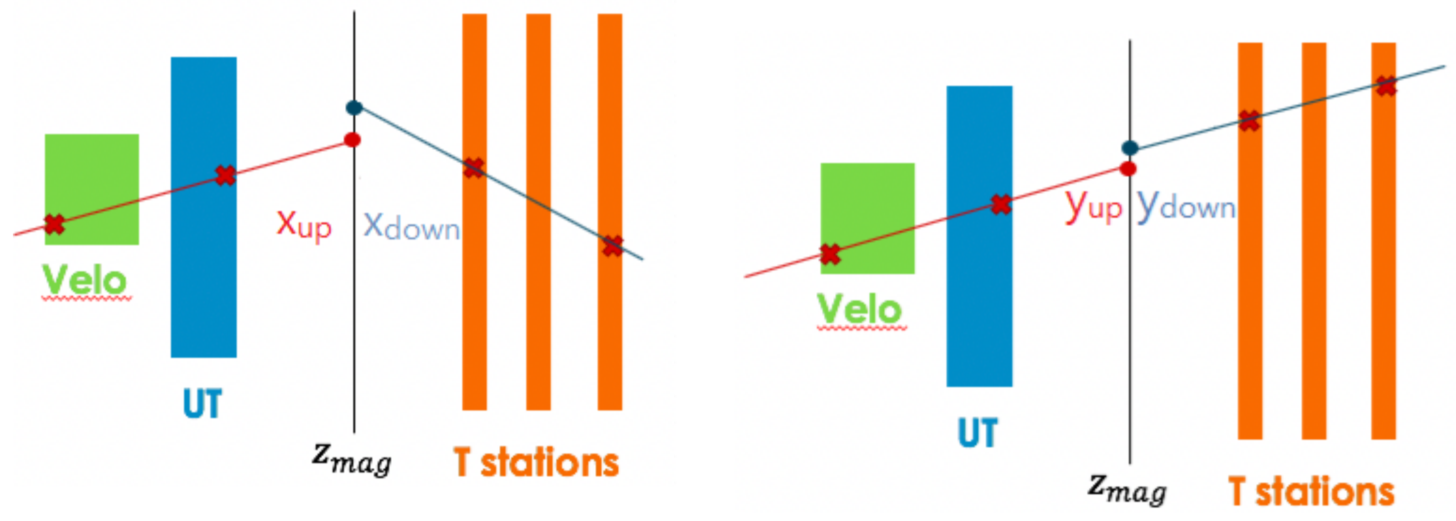
Hit density for 0-5% PbPb centrality

Detection plane	Max hit density [hit/cm^2 event]	Corresponding η	Corrected max hit density [hit/cm^2 event]
T1 OT	0.365714	2.910	0.443297
T2 OT	0.434286	3.145	0.53279
T3 OT	0.502857	3.154	0.616910
T1 IT	2.32	4.687	3.17715
T2 IT	2.36571	4.773	3.461176
T3 IT	2.16	4.852	3.160210
T1 MT	0.662857	3.314	0.840151
T2 MT	0.708571	3.427	0.899361
T3 MT	0.685714	3.474	0.869122

- Similar to pp studies (see Vadym's talk) but for PbPb collisions, both for UT and MIGHTY.
- Waiting for new MC sample to finalise the study.

Study 2: track matching in MC PbPb

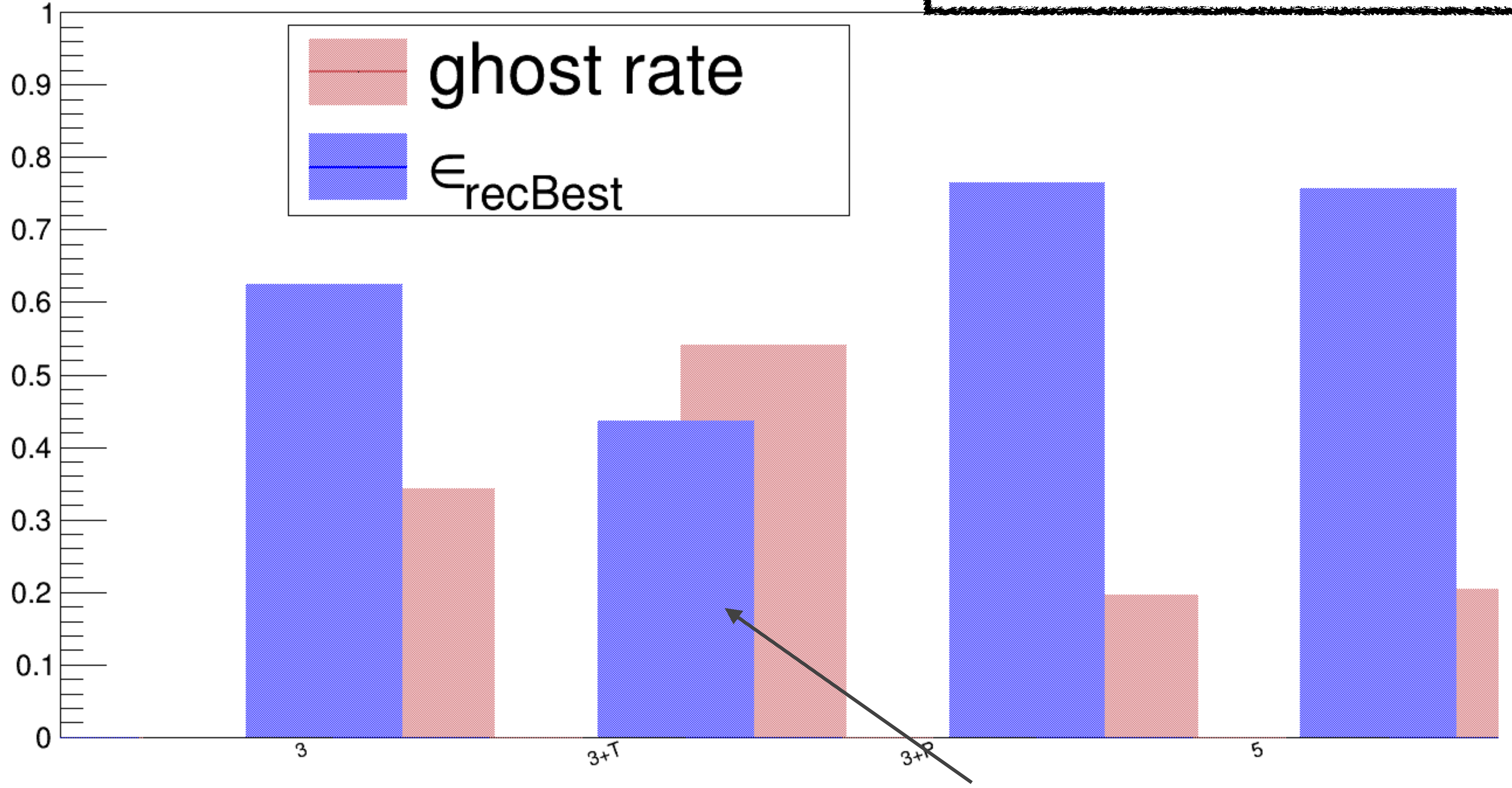
- Similar to Zak's studies (with the same baseline) but in MC PbPb. Thanks to him for the code !



- Results are compatible with pp data.

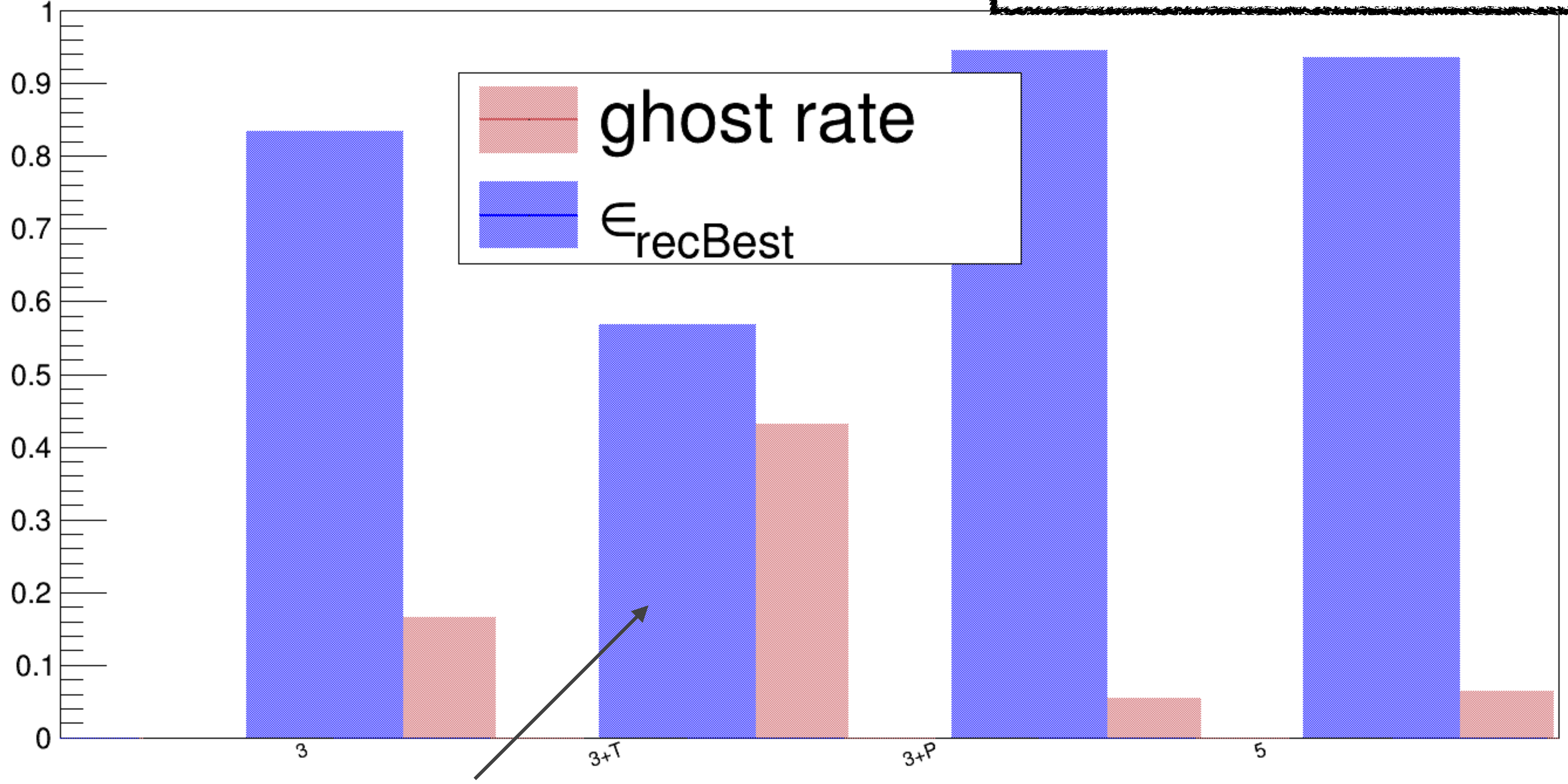
All LongTracks

- VELOUT-TT matching
- nFTHits > 60000



LongTracks with $p > 5$ GeV/c

- VELOUT-TT matching
- nFTHits > 60000



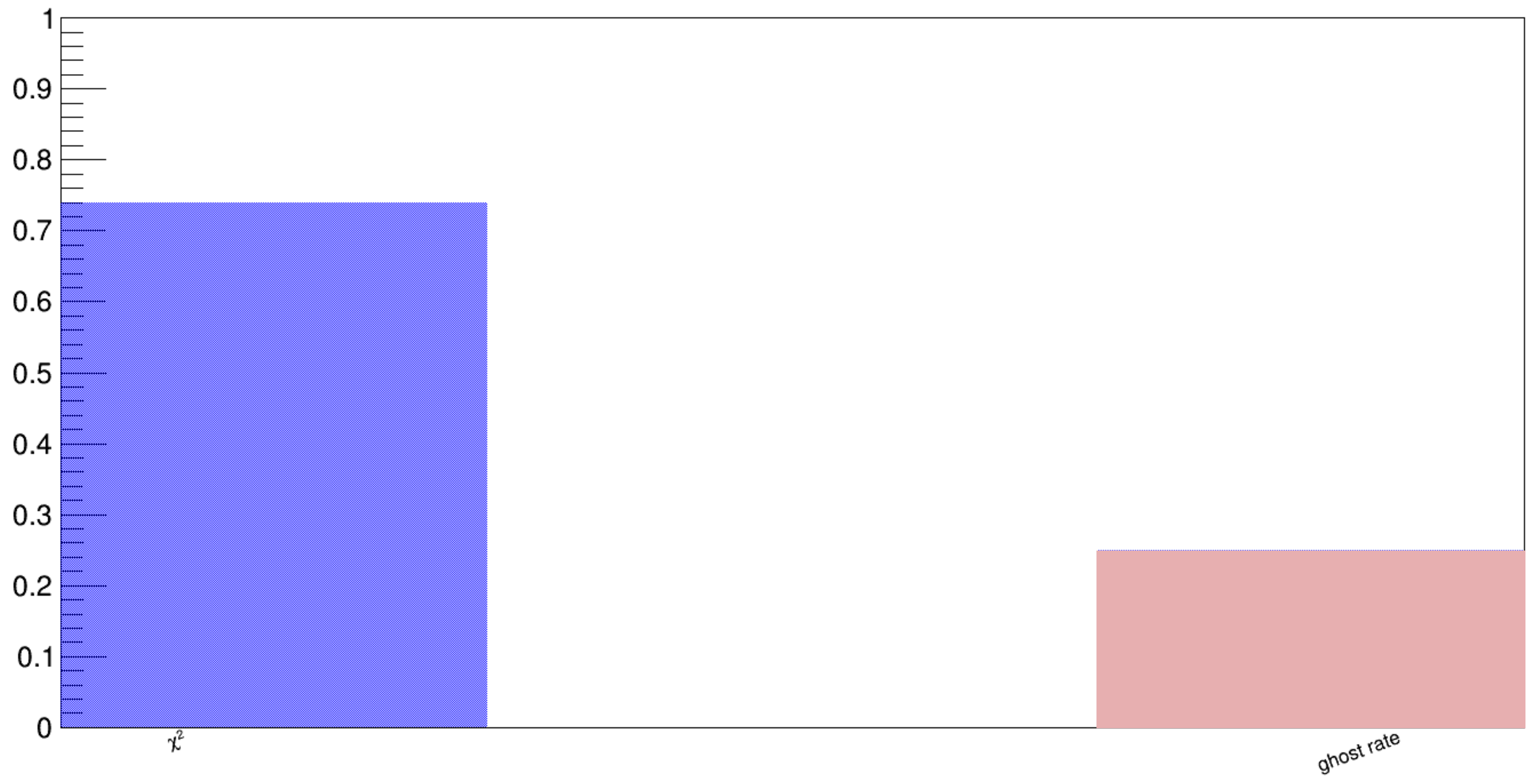
Strange results with timing info, probably due to MC PbPb configuration.

Study 2: track matching in MC PbPb

- Studies also done for VELO-UT matching.
- Can be extended to pp scenario.

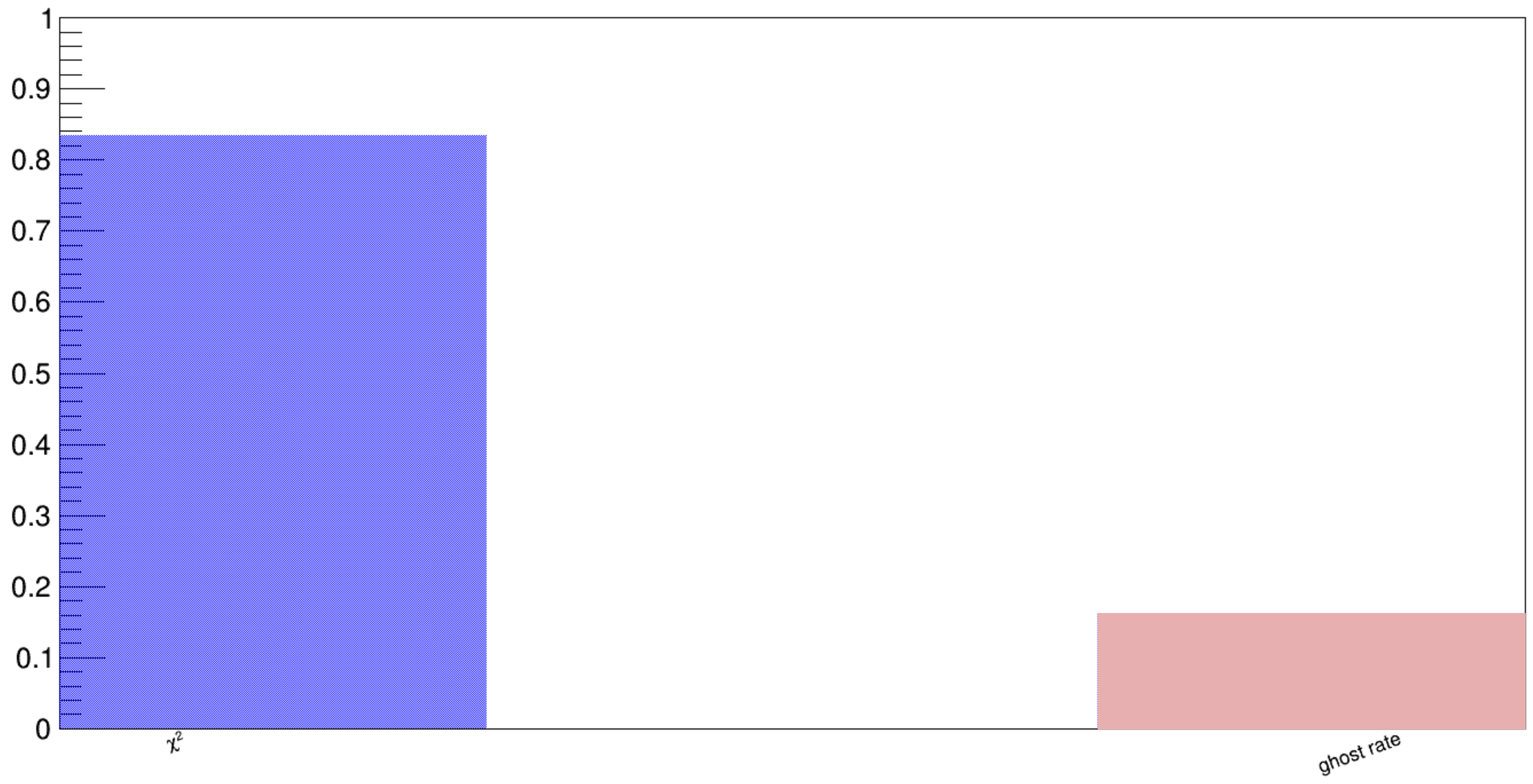
- VELO-UT matching
- nFTHits > 60000

All LongTracks



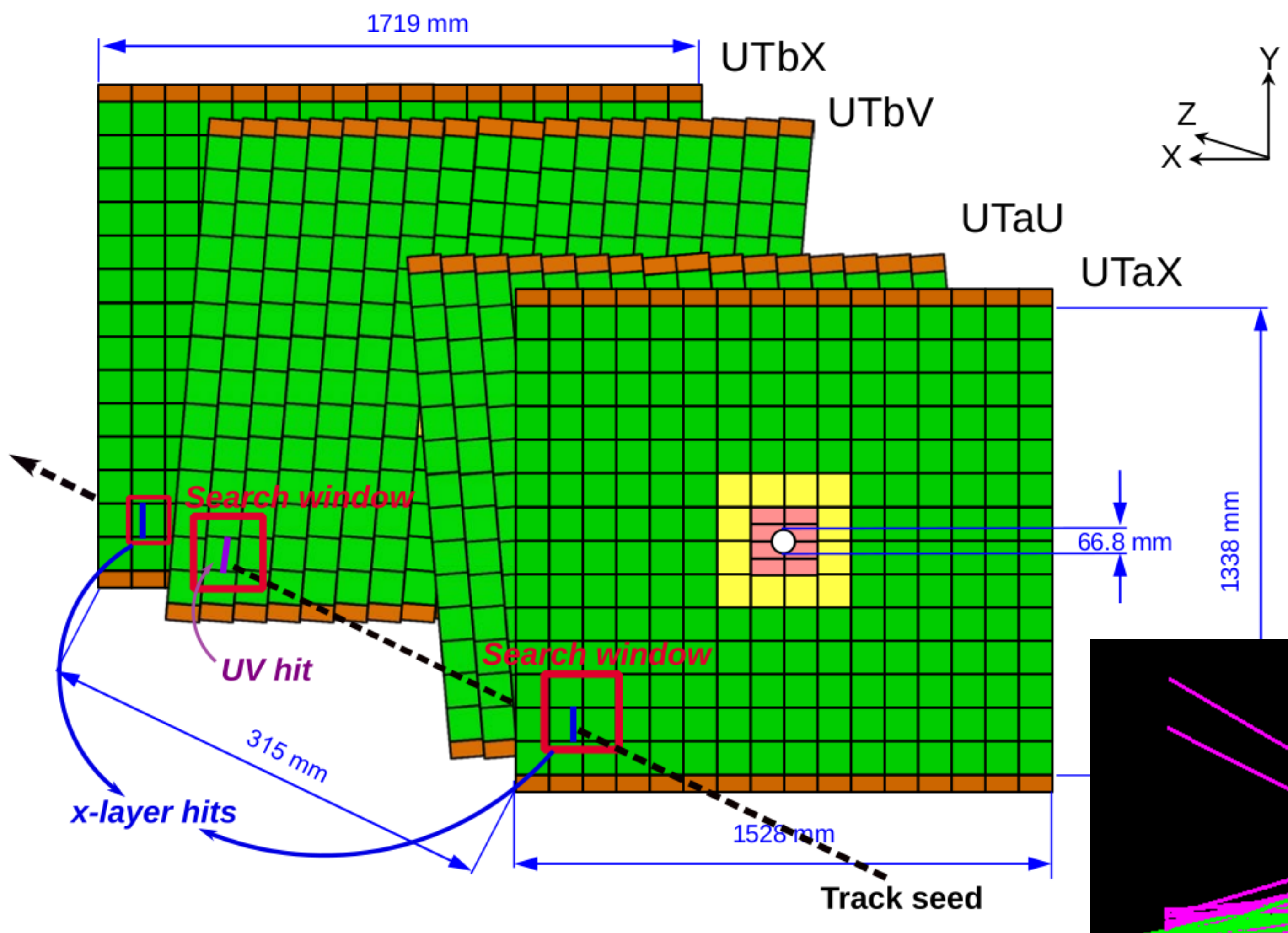
- VELO-UT matching
- nFTHits > 60000

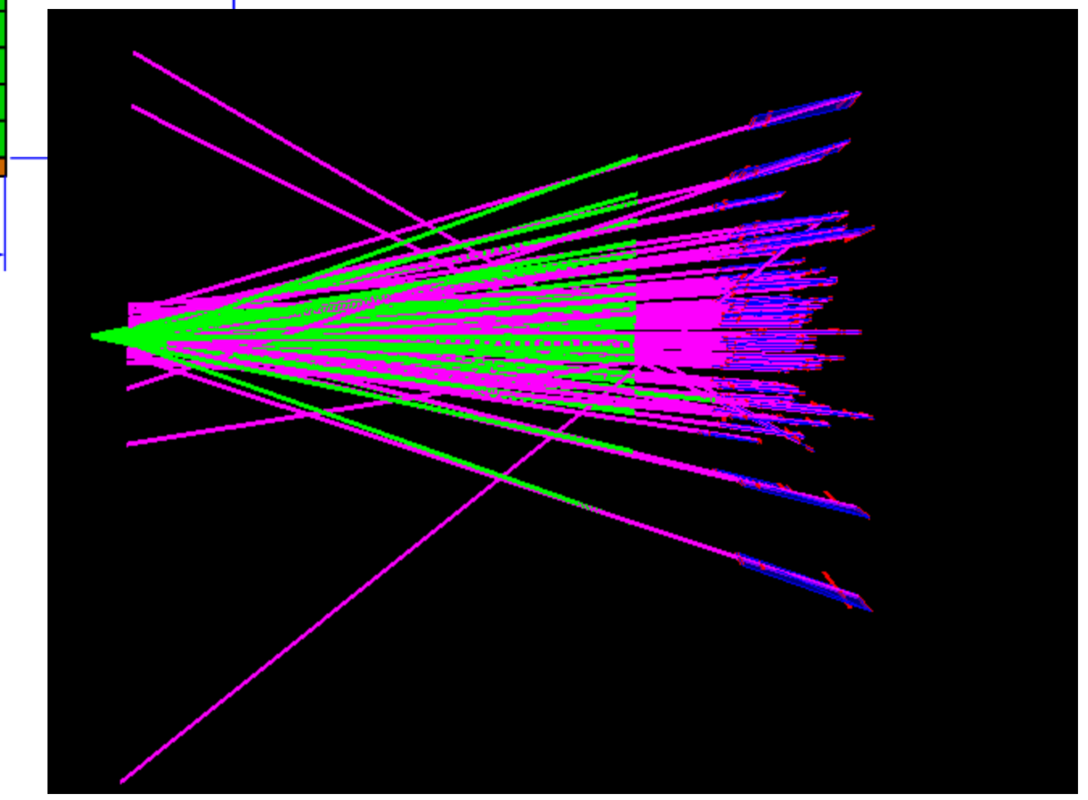
LongTracks with $p > 5$ GeV/c



Study 3: downstream tracking

- Downstream tracking with GPUs (HLT1): include long-lived particles at the first trigger level
- Strategy:
  - Standalone tracking ("seeding") individually from SciFi and UT.
  - Match track seeds from UT/SciFi to reconstruct downstream tracks.
- **Performance shows:**
  - Reasonable efficiency in most categories.
  - ~35% ghost rates (to be expected from a 4-layer detector without additional information).
  - Matching to SciFi/VELO should significantly decrease ghost rate.
- **Plan for U2: quantify and optimize!**
  - Use the feasibility of standalone UT reconstruction (reasonable eff vs ghosts) as a metric.
  - Additional targets are to study / optimize:
    - spatial resolution
    - improvements using timing information
    - spacing / position / number of layers (interplay with B-field).
  - Simulation samples in preparation to perform studies.





Efficiency study by A. Hennequin

Run 3 performances

```
DownstreamTrackChecker#1          INFO **** Downstream           187367 tracks including        65448 ghosts [34.93 %],
Event average 29.07 % ****
DownstreamTrackChecker#1          INFO   05_noVelo+UT+T_strange        :    1995 from    2349 [ 84.93 %]     261 clones [11.57 %],
purity: 96.41 %, hitEff: 94.35 %
DownstreamTrackChecker#1          INFO   06_noVelo+UT+T_strange_P>5GeV :    1187 from    1295 [ 91.66 %]     184 clones [13.42 %],
purity: 96.15 %, hitEff: 93.91 %
```

Conclusions

- Studies are still ongoing to finalise the numbers. The proposal UT design might be updated accordingly.
- Baseline for the FTDR is full a full CMOS UT.
- Lists of studies/contributions for the FTDR:
  - Occupancy studies
    - UT occupancies in pp and PbPb collisions.
    - MIGHTY tracker occupancies in PbPb collisions.
  - Track matching efficiency
    - VELOUT-MIGHTY in PbPb collisions.
    - VELO-UT in pp and PbPb collisions.
  - Downstream tracking
    - Downstream tracking studies.
    - Detector design optimisation studies (spacing / position / number of layers (interplay with B-field).

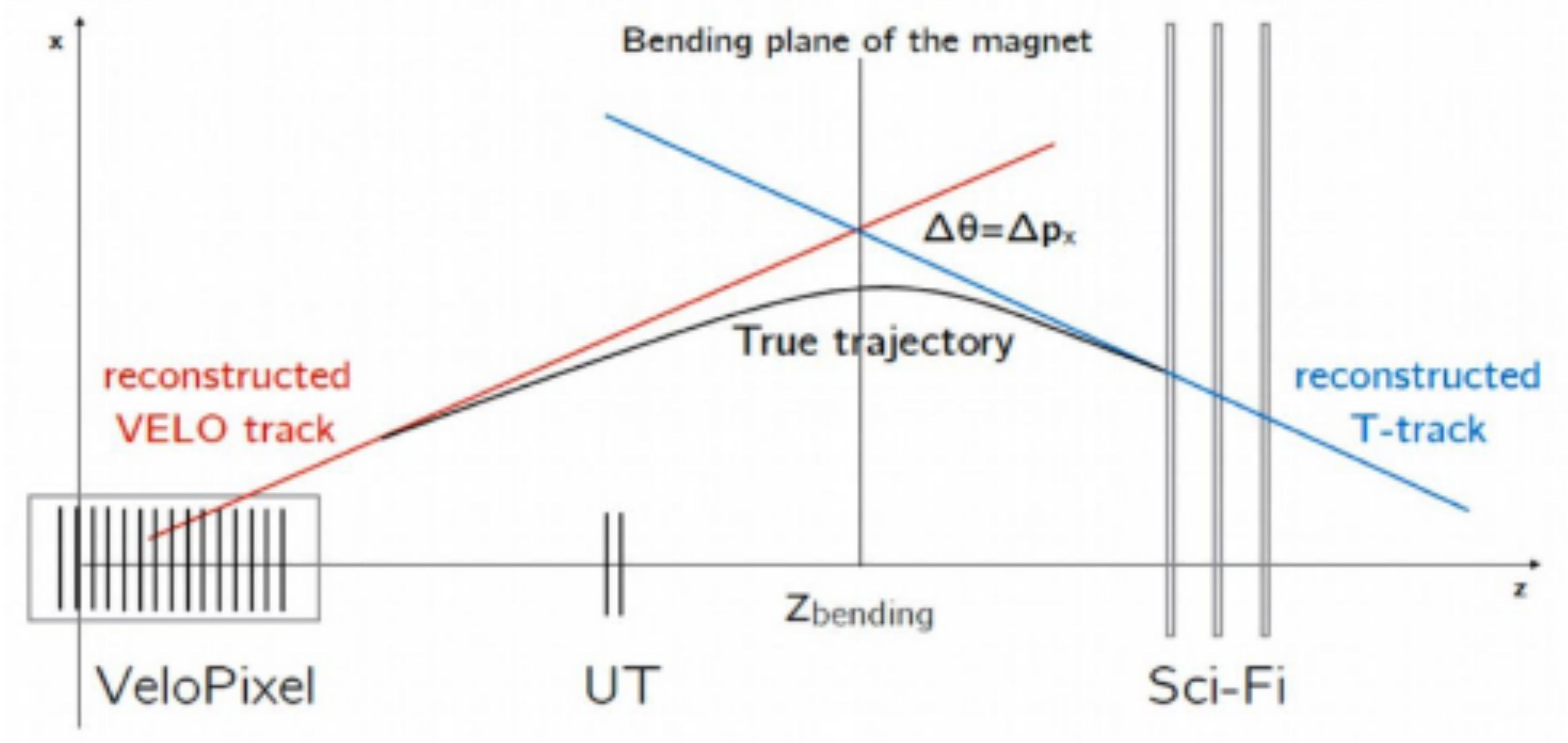
Back-up

Study 2: setting and definitions

- Next slides show results from similar studies in central PbPb collisions.
- The method in a nutshell:
  - Emulate a reconstructed Velo (Velo-UT) segment by smearing the MCHits of one MC track and extrapolate to the bending plane.
  - Emulate a T (UT) segment with the same strategy for all the other MC tracks in the event and extrapolate to the bending plane.
  - Compute the χ^2 for all the combinations.
- Settings for the toy model:

Detector	Resolution (x-y)	Resolution (p)	Resolution(t)
Velo	55x55 μm	-	30 ps
UT	100x100 μm	15 %	-
MIGHTY	80x80 μm	5 %	30 ps
SciFi	250x250 μm	5 %	30 ps

"Matching"



- Results with 500 tracks from MC PbPb simulations
- Assume full intrinsic detector efficiency
- Cut on tracks: $p_{track} > 5$ GeV/$c^2 < \eta_{track} < 4.5$

Study 2: setting and definitions

- Definition for the χ^2:

$$\chi^2_3 = \frac{(x_{up} - x_{down})^2}{\sigma_x^2} + \frac{(y_{up} - y_{down})^2}{\sigma_y^2} + \frac{(ty_{up} - ty_{down})^2}{\sigma_{ty}^2}$$

$$\chi^2_{4(p)} = \frac{(x_{up} - x_{down})^2}{\sigma_x^2} + \frac{(y_{up} - y_{down})^2}{\sigma_y^2} + \frac{(ty_{up} - ty_{down})^2}{\sigma_{ty}^2} + \frac{(p_{up} - p_{down})^2}{\sigma_p^2}$$

$$\chi^2_{4(t)} = \frac{(x_{up} - x_{down})^2}{\sigma_x^2} + \frac{(y_{up} - y_{down})^2}{\sigma_y^2} + \frac{(ty_{up} - ty_{down})^2}{\sigma_{ty}^2} + \frac{(t_{up} - t_{down})^2}{\sigma_t^2}$$

$$\chi^2_5 = \frac{(x_{up} - x_{down})^2}{\sigma_x^2} + \frac{(y_{up} - y_{down})^2}{\sigma_y^2} + \frac{(ty_{up} - ty_{down})^2}{\sigma_{ty}^2} + \frac{(p_{up} - p_{down})^2}{\sigma_p^2} + \frac{(t_{up} - t_{down})^2}{\sigma_t^2}$$

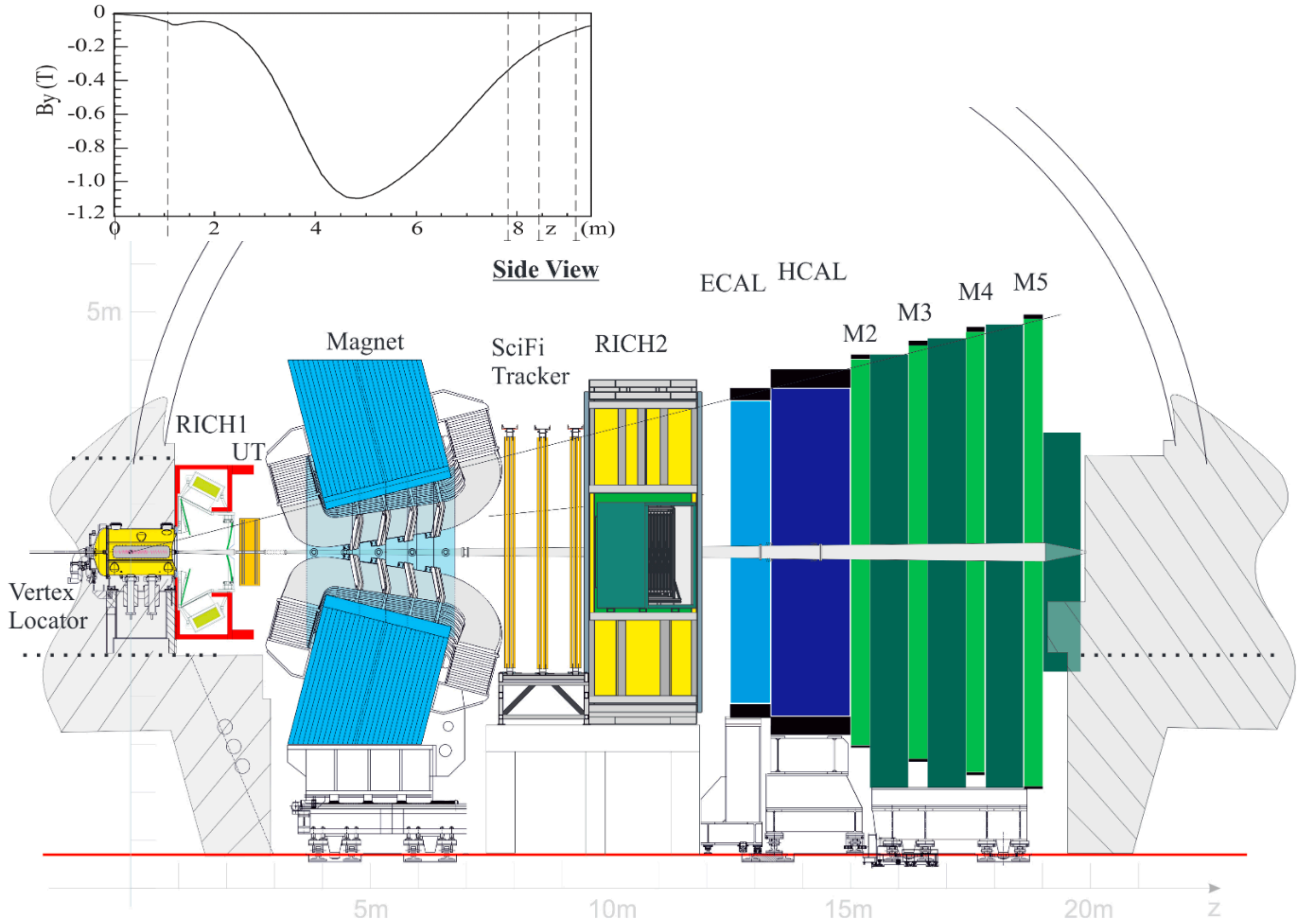
Momentum

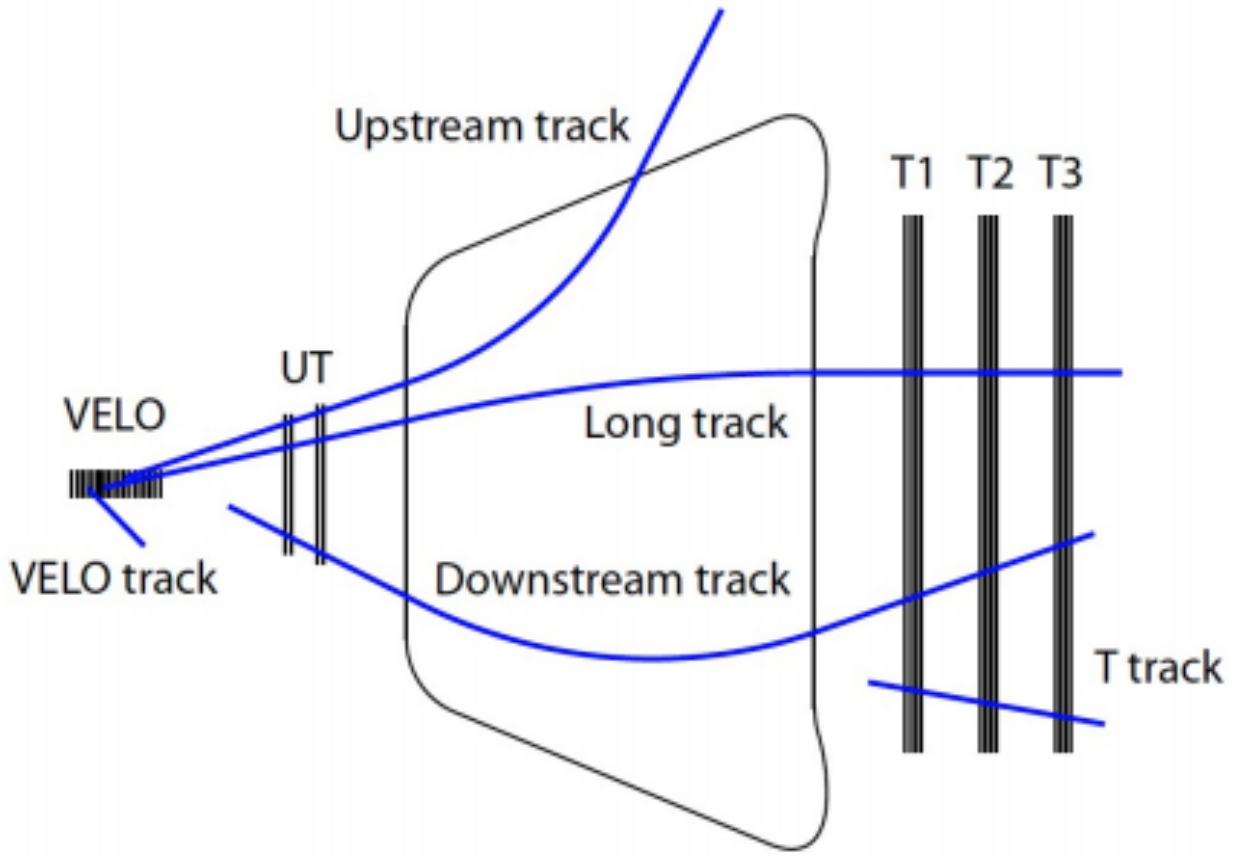
Time

Position

- **<u>Definition of reconstructed track</u>**: a pair of segments (upstream + downstream) for $\Delta x(z_{mag})<3\sigma_x$; $\Delta y(z_{mag}) < 3\sigma_y$…
- **<u>Definition of ghost</u>**: track reconstructed as Best from different segments than the true MC particle.
- **<u>MC truth match track</u>**: a « reconstructed » track candidate for which the two segments are from the same MC particle.
- **<u>Best track</u>**: the « reconstructed » track candidate with the lowest χ^2 from all the matching.
- **<u>Reconstruction efficience</u>** $\epsilon_{reco} = \dfrac{N^{rec}_{track}(\text{MCTruth \& Best})}{N^{MC}_{track}}$

Tracking challenges in U2





- Large pile-up in pp collisions → large occupancies !
- Order of magnitude:
  - 40 pp@13TeV ~ 40% most central PbPb collisions.
  - 5% most central collisions ~ 400 pp@13TeV
- Improving performances in central PbPb = improving performances in pp.
- Challenges coming along with high track density:
  - Hardware:
    - High local hit density, radiation dommage, data rate…
  - Software:
    - Matching and combinatorics for tracking algorithm…
- How UT upgrades will improve the tracking performances ?