# Tracking in LHCb in high multiplicity events and LHCb Phase II

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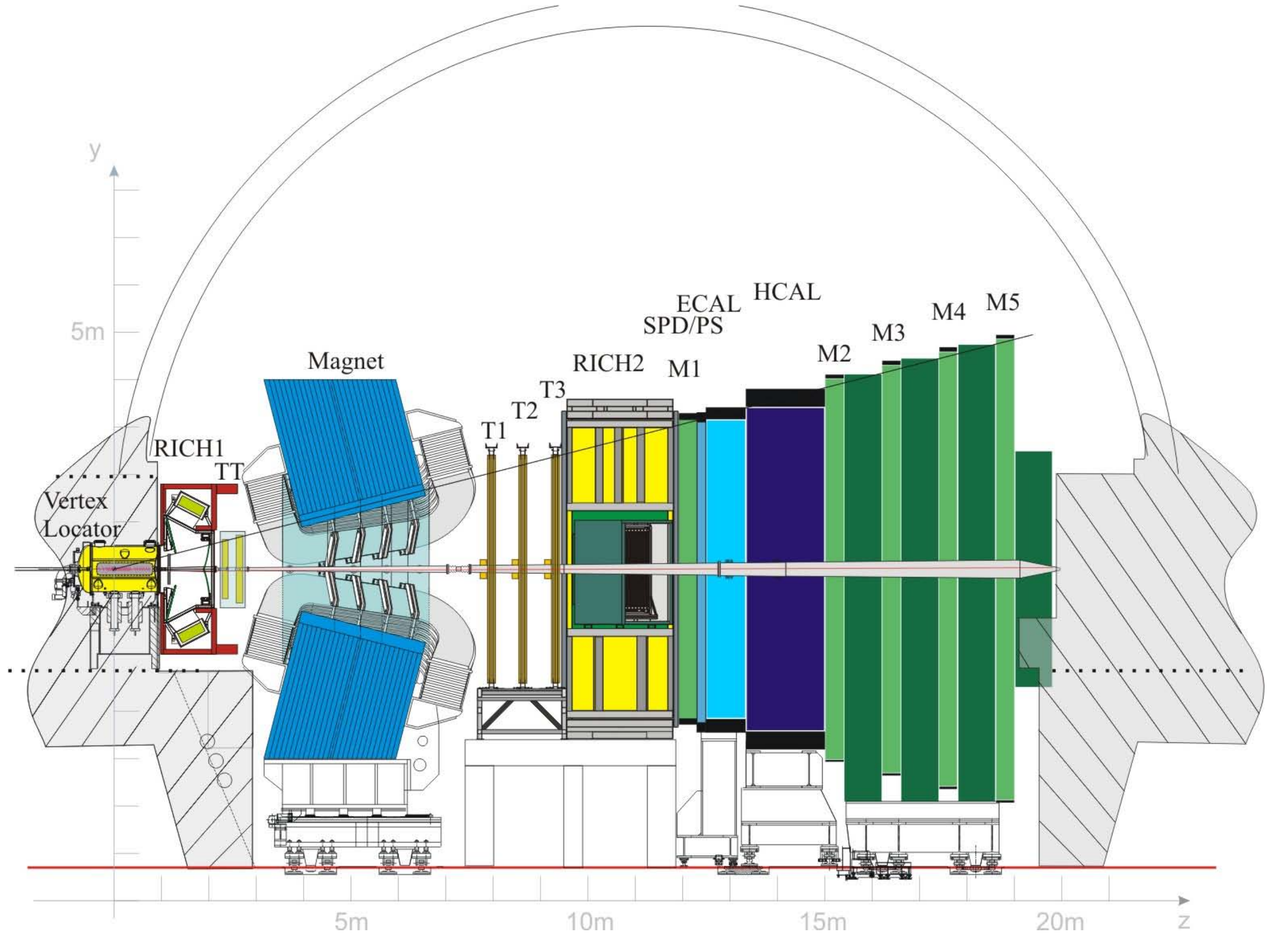
# LHCb so far




- Forward single arm spectrometer.
- Designed to study heavy flavour physics in *pp* collisions.
- Only LHC experiment fully instrumented in the region $2 < \eta < 5$.
- Some nice features:
  - ✦ Excellent vertex, IP and decay time resolution thanks to VELO.

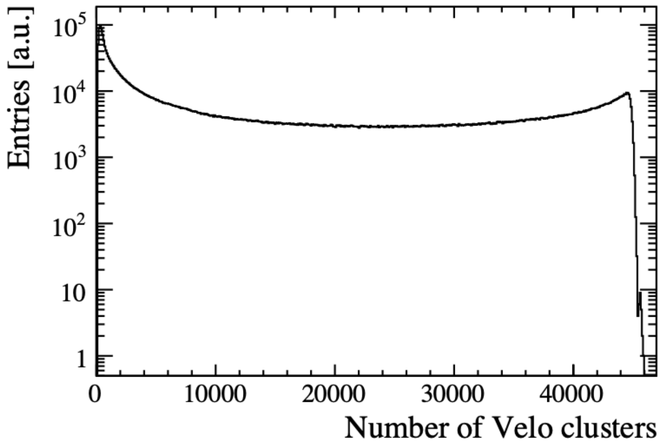
    $\Rightarrow \sigma(\text{IP}) \approx 20\,\mu\text{m}$.
  - ✦ Very good momentum resolution.

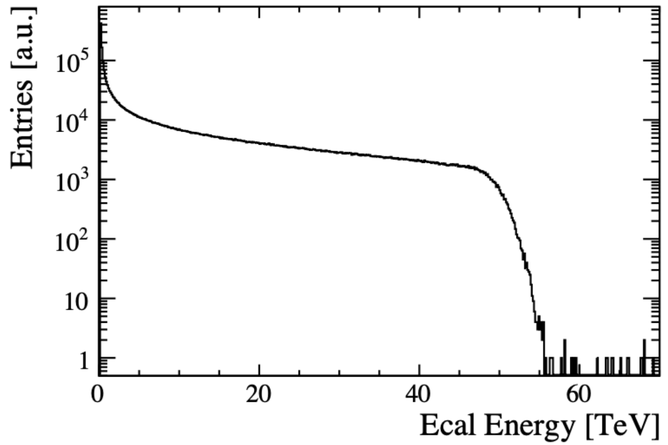
    $\Rightarrow \delta p/p \approx 0.5 - 1.0\,\%$ for $0 < p < 200$ GeV/$c$.
  - ✦ Particle identification.

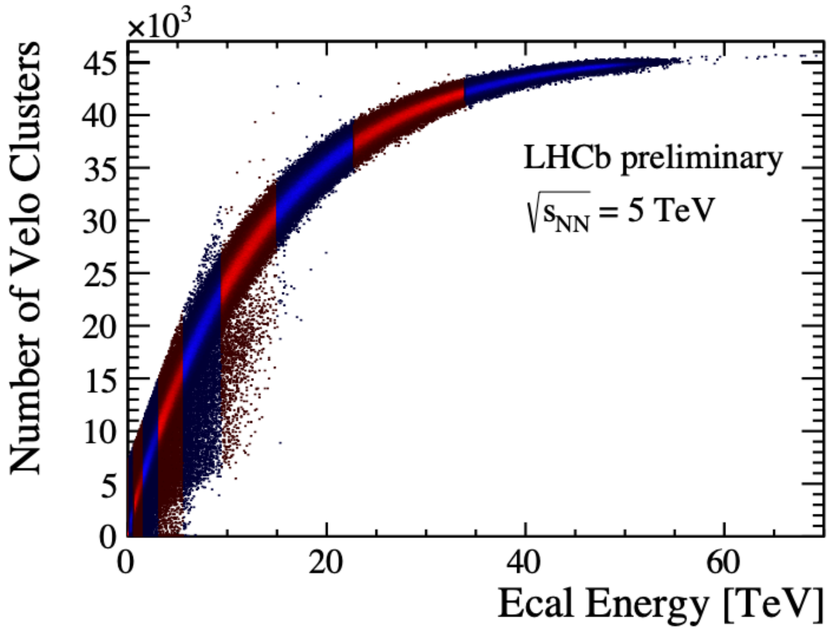
    $\Rightarrow \varepsilon_{K\to K} \approx 95\,\%$ for $\varepsilon_{\pi\to K} \approx 5\,\%$ up to 100 GeV/$c$.
    $\Rightarrow \varepsilon_{\mu\to\mu} \approx 97\,\%$ for $\varepsilon_{\pi\to\mu} \approx 1 - 3\,\%$.
- LHCb can also operate in *p*-Pb, Pb-Pb collisions and fixed target thanks to the SMOG system.

# Tracking performance in PbPb

- The reach in centrality is limited by the tracking capabilities.
- This includes both hardware and software.
  - The VELO saturates in a high multiplicity environment.
  - This impacts the overall performance.
  - In the 10% most central collisions there are about 5000 charged particles within LHCb acceptance.
  - In the future the occupation will likely be similar and LHCb needs some adjustments to cope.



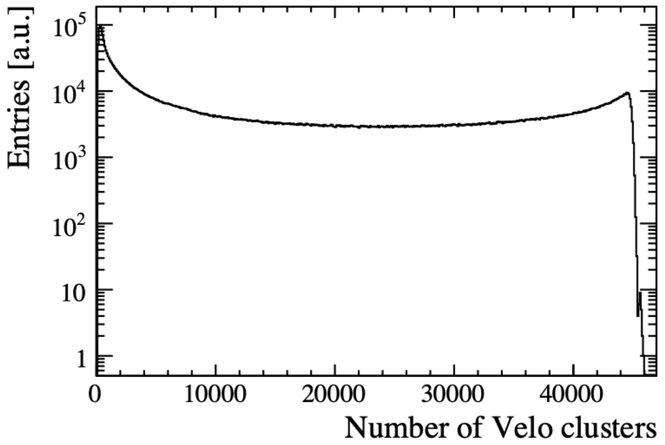



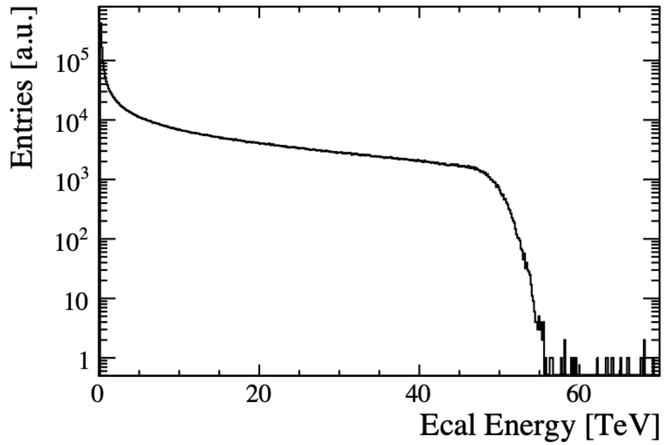



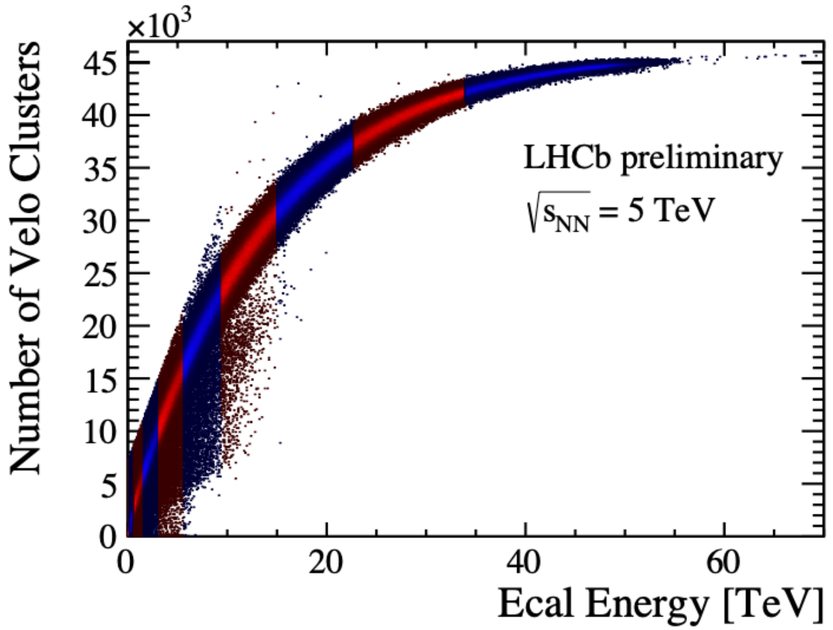
# Tracking performance in PbPb

❖ On the software side:

- Room for improvement in the track reconstruction algorithm.
- The track reconstruction is affected much before the saturation regime.
- This limited the analysis of PbPb to centralities of roughly 60%.

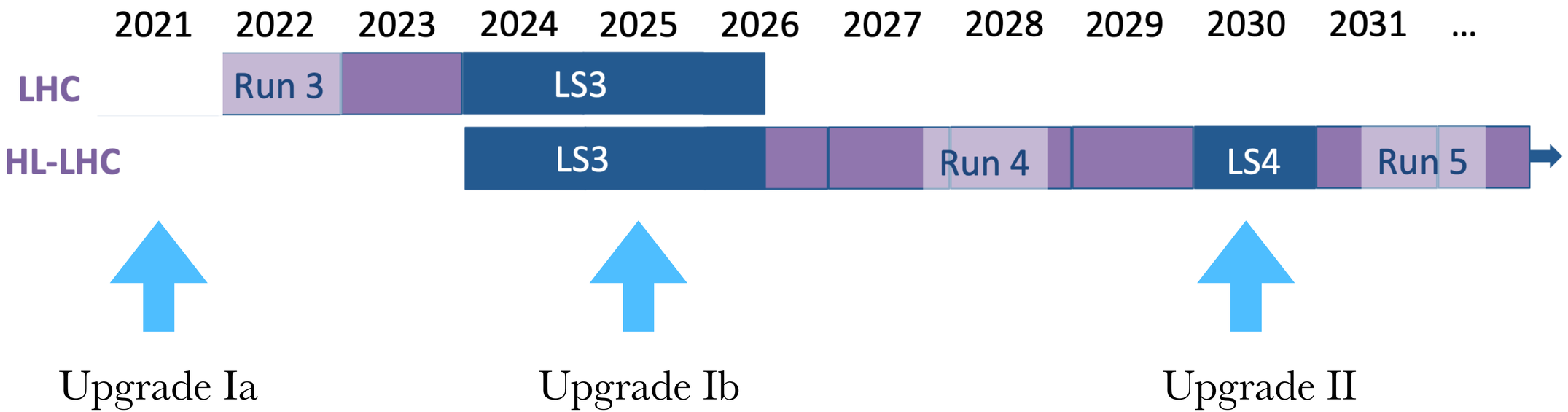


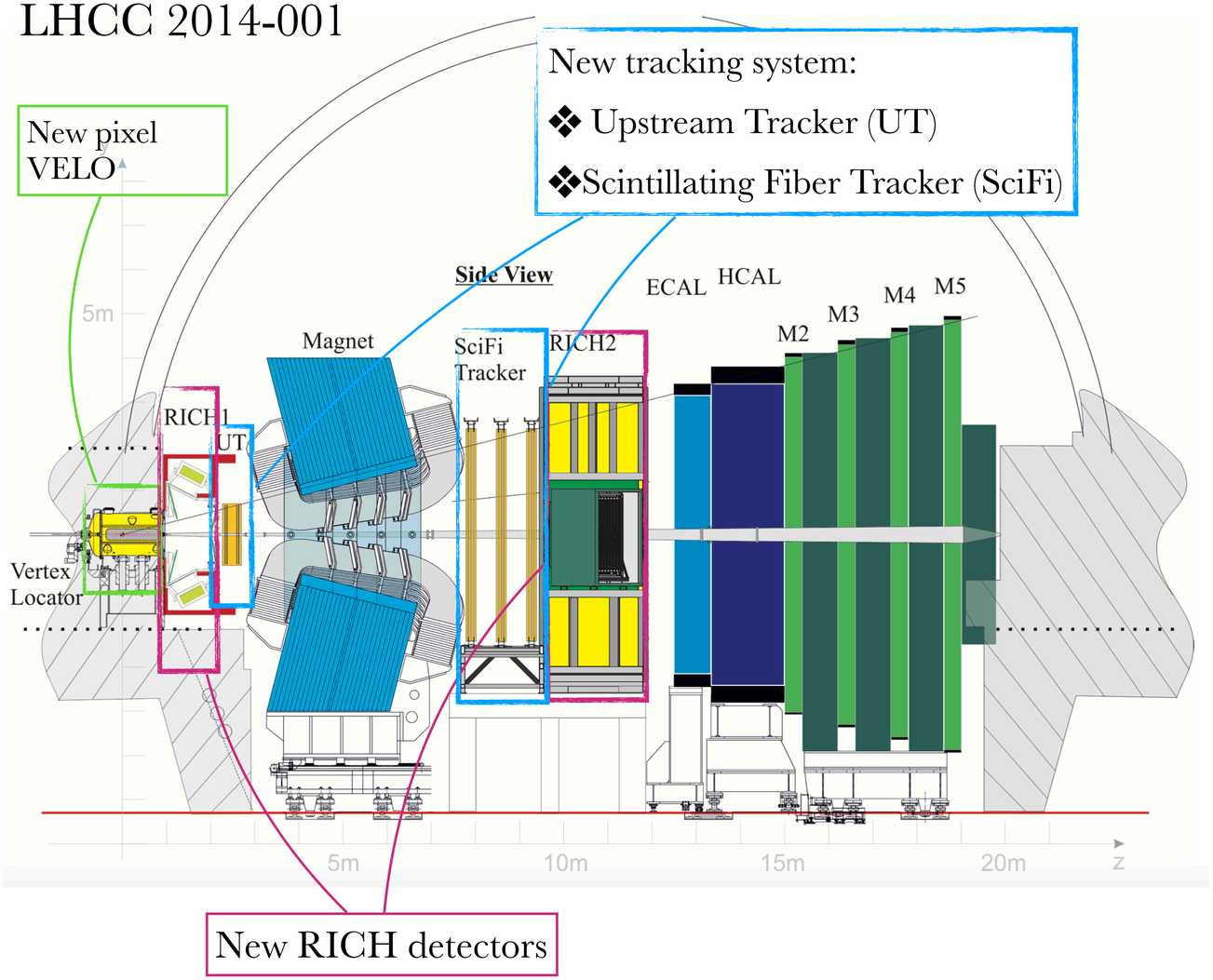
# For the future

- The objective is to be able to push the centrality reach down to 0%.
- How?



# For the future

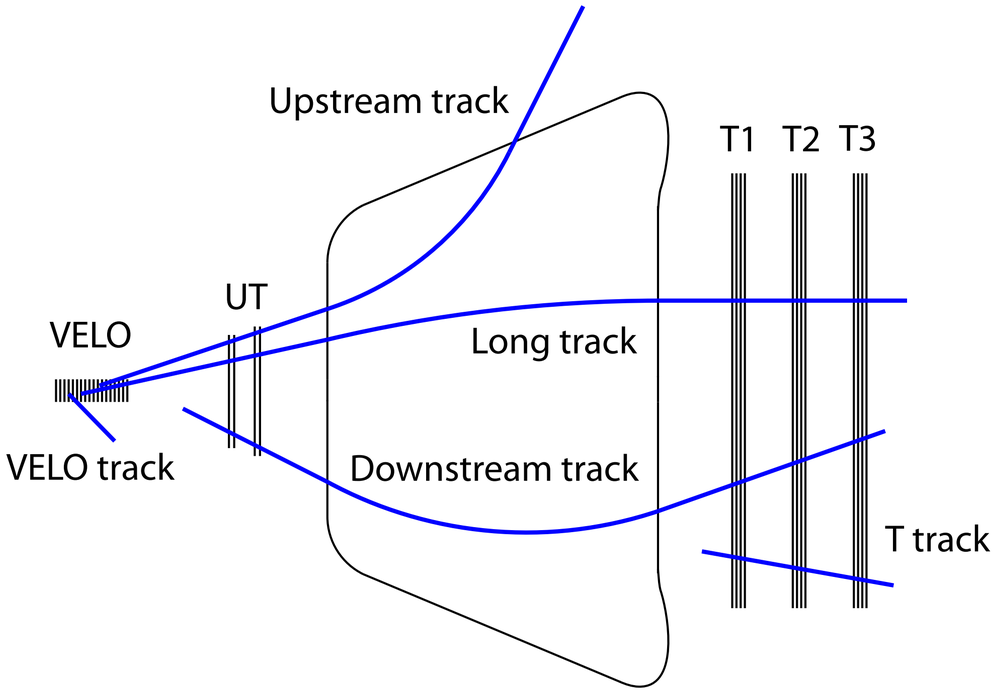
LHCC 2014-001




- ❖ LHCb will undergo major changes in the following upgrades:
  - Upgrade Ia (currently taking place).
  - Upgrade Ib (LS3).
  - Upgrade II (LS4).
- ❖ Upgrades to cope with pp requirements for Run 3 and 4:
  - Collision rate increased with the increased LHC luminosity.
  - Pile-up increased ~ 5 (about 40 for Run 5).
  - Full software trigger:
    - Remove the Level-0 triggers.
    - Detector to be read-out in real time.
  - Replace entire tracking system.

# LHCb in Run 3

- LHCb will have the SciFi and UT installed.
- The main track types of use:
  - VELO: at least 3 pixels sensors with at least 1 digit each.
  - Upstream track: VELO + at least 1 UT cluster in station 1/2 and at least 1 UT cluster in station 3/4.
  - Long track: VELO + at least 1 cluster and 1 stereo cluster in each station.
- A track is reconstructed if at least 70% of the hits used come from a MC generated particle.
- If no MC particle can be associated to a track → Ghost track!



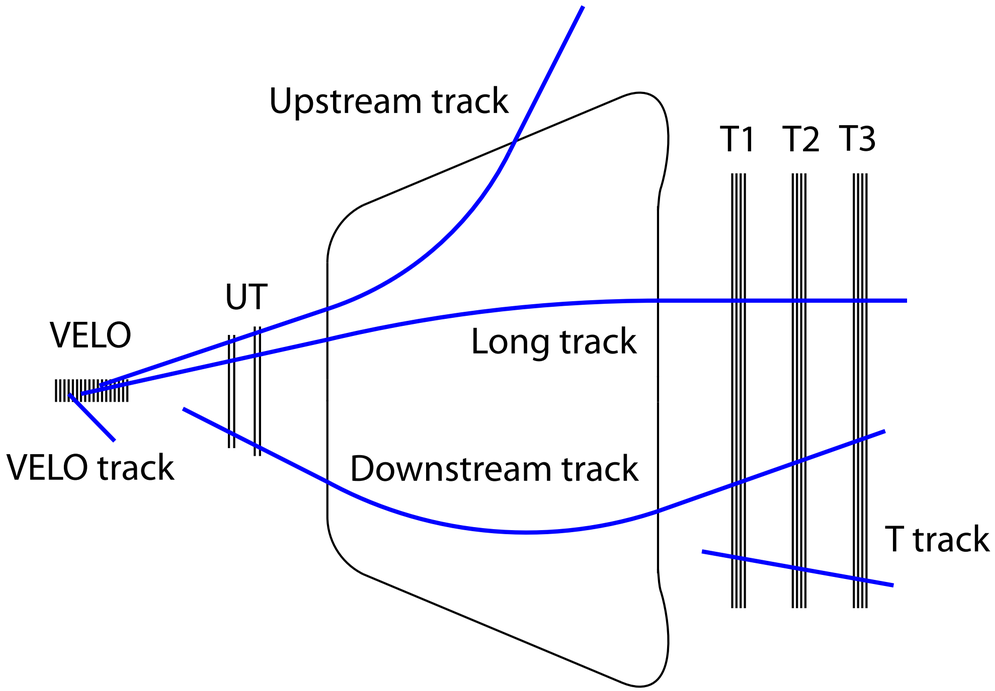
# LHCb in Run 3

❖ Simulations show that in high occupancy conditions:

- The new VELO presents a low ghost track rate → ~0.3 at 30% centrality.
- The Long tracks (SciFi) shows a ghost track rate close to 1 at 50% centrality.

❖ There is possible improvement within the track reconstruction algorithm and there are big efforts being made on this front.

❖ A reduction in the Long track seed ghost rate (information from the VELO and UT) would also improve performance at the SciFi stage.



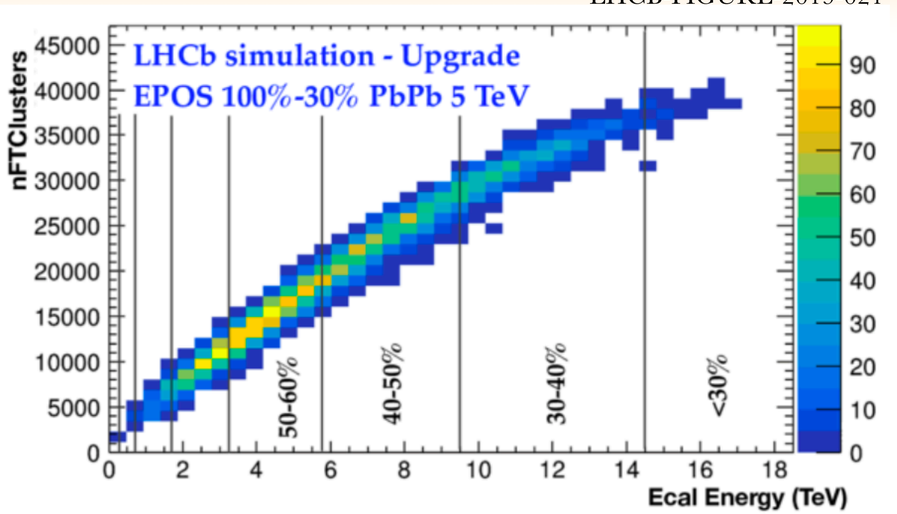
# LHCb in Run 3

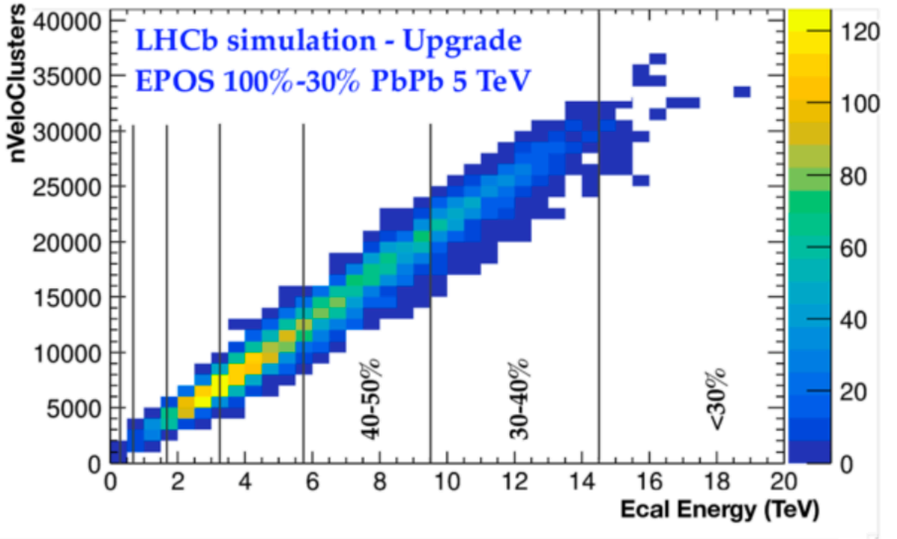
❖ On the front of actual detector occupancy:

- The VELO does not saturate up to 30% centrality.
- The SciFi begins to saturate at around 30% centrality.
- This is already an improvement from the Run 2 scenario.

❖ At 30-40% centrality there are about ~1000 particles in the LHCb acceptance.

LHCB-FIGURE-2019-021

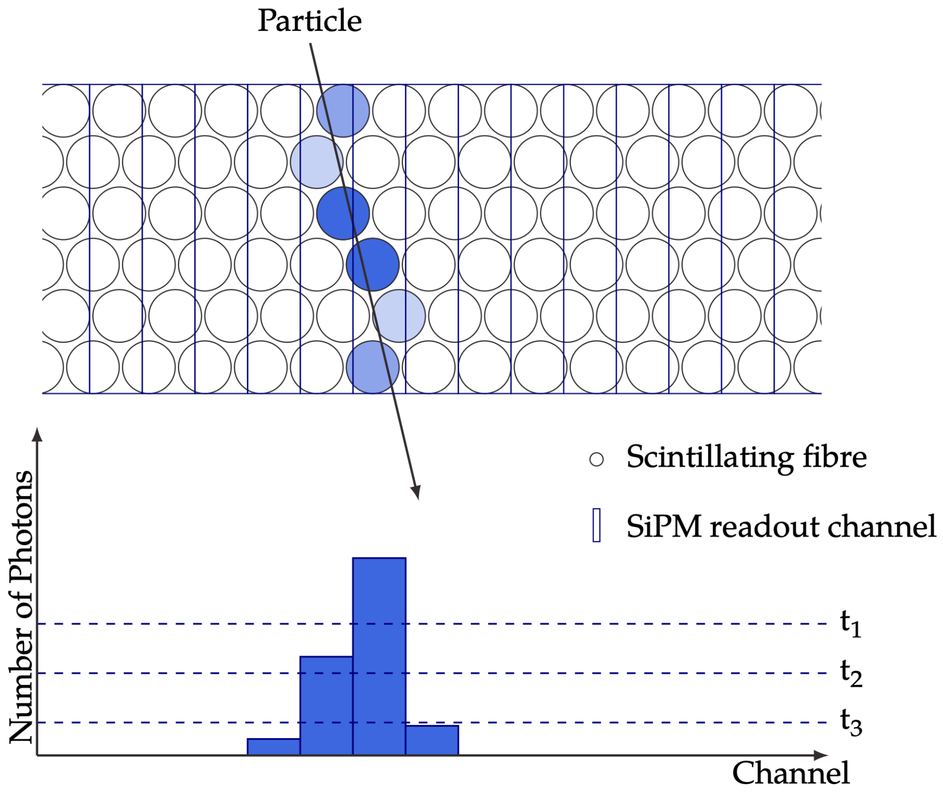


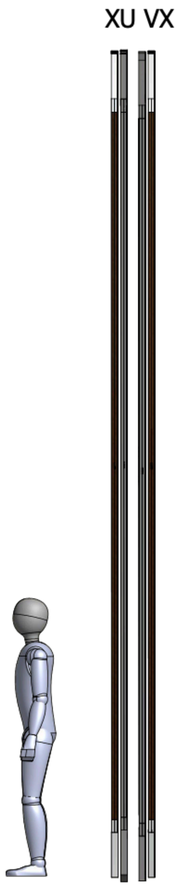



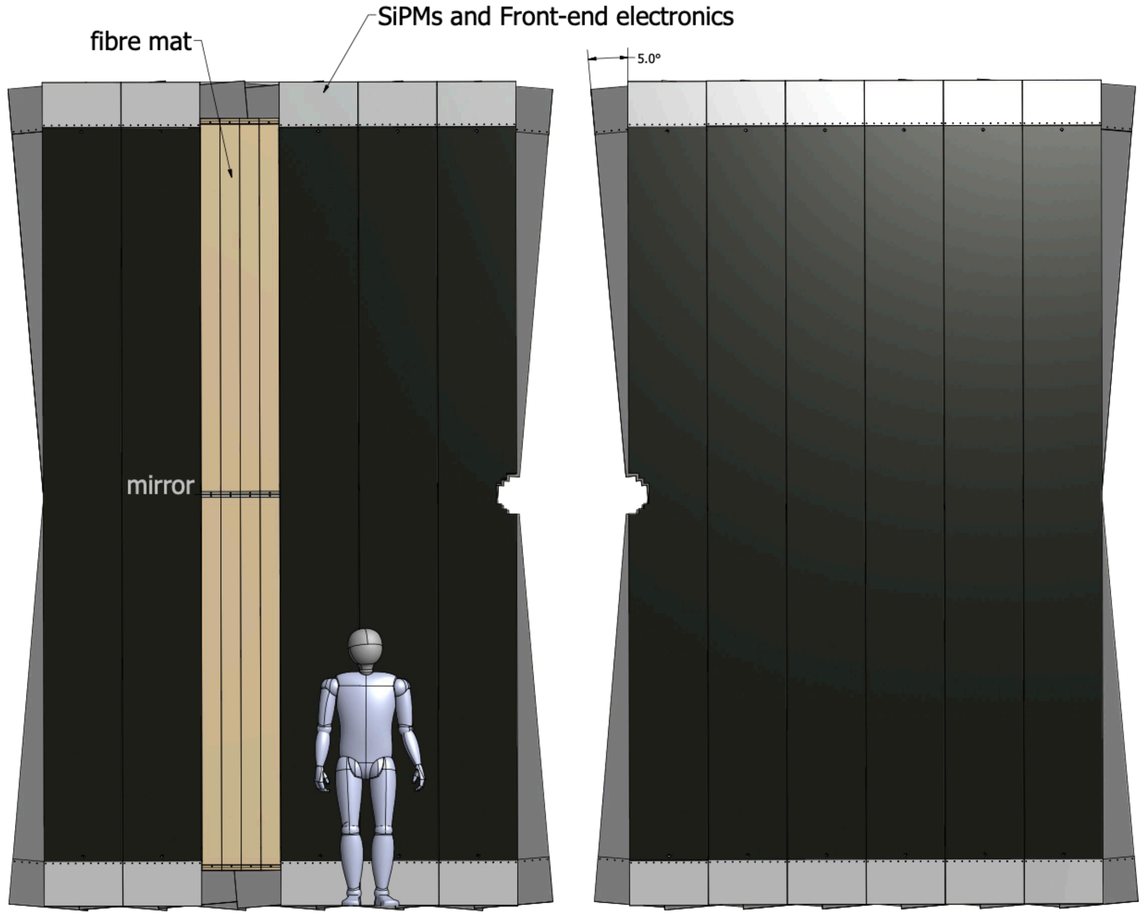
# The SciFi

❖~10000 km of scintillating fibres arranged in 6 layers with silicon photo-multipliers (SiPM) readout.

- 3 stations.
- 4 detection layers per station.

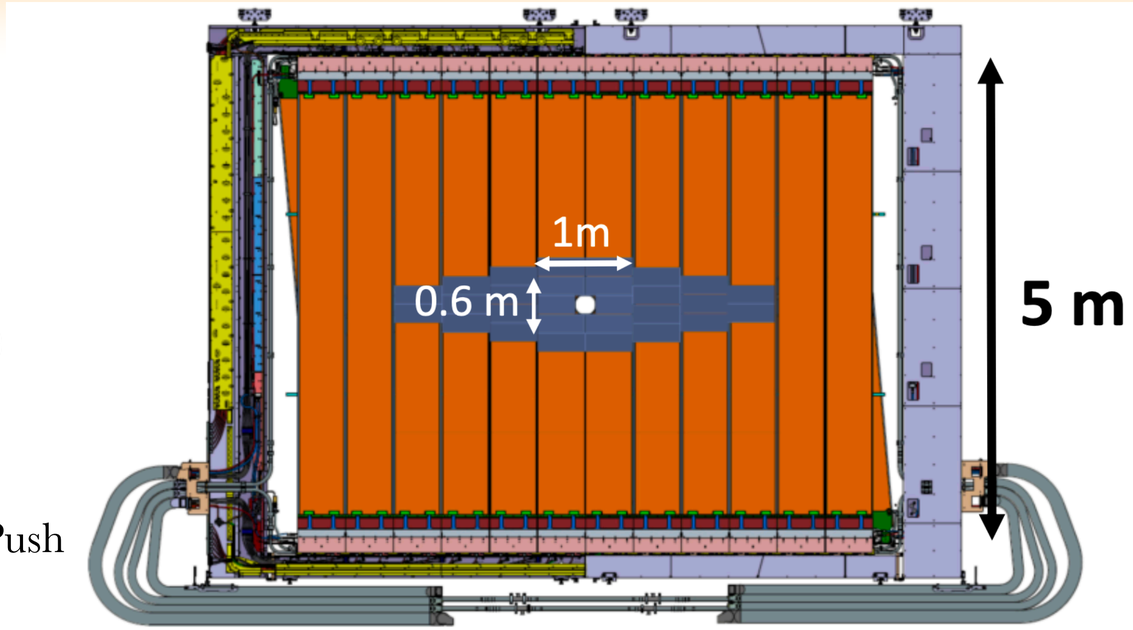


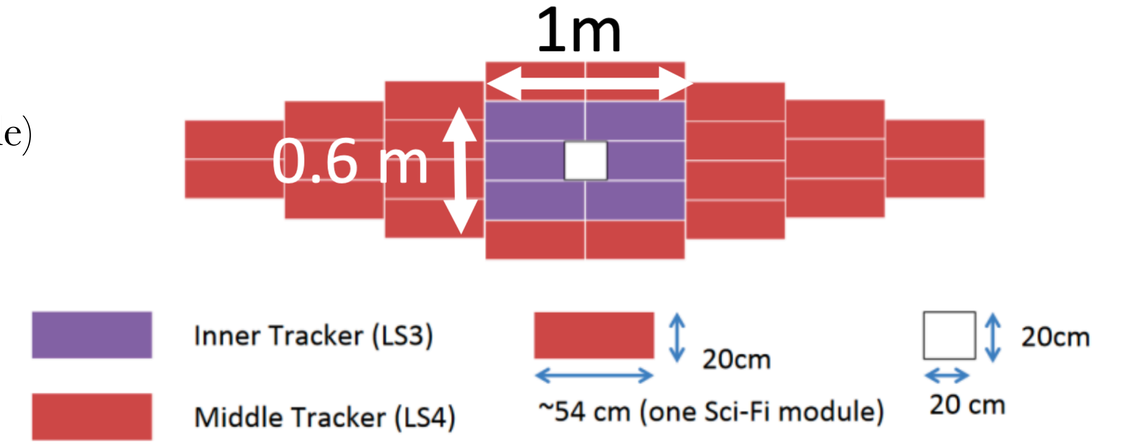



# LHCb in Runs 3 and 4

- SciFi upgrades in the future:
  - Upgrade 1B: Inner Tracker (IT) + SciFi → Push Pb-Pb to 10-20%.
    - DMAPs technology for silicon sensors.
    - Area per layer = 6 lots of 20x54 cm = 0.7 m2 (minus beam hole)
    - Total Area = 6 layers of 0.7 m2 = 3.9 m2 (minus beam hole)
  - Upgrade II: New MIGHTY silicon tracker covering larger area → Push Pb-Pb to 0%.
    - Rebuild of SciFi (SciFi + MT) + reuse IT.
    - Area per layer = 28 lots of 20x54 cm = 3.0 m2 (minus beam hole)
    - Total Area = 6 layers of 3.0 m2 = 18.1 m2 (minus beam hole)
- These changes will improve the track resolution after the magnet.
- IT (U1b) and IT+MT (U2) will greatly reduce the SciFi occupancy.



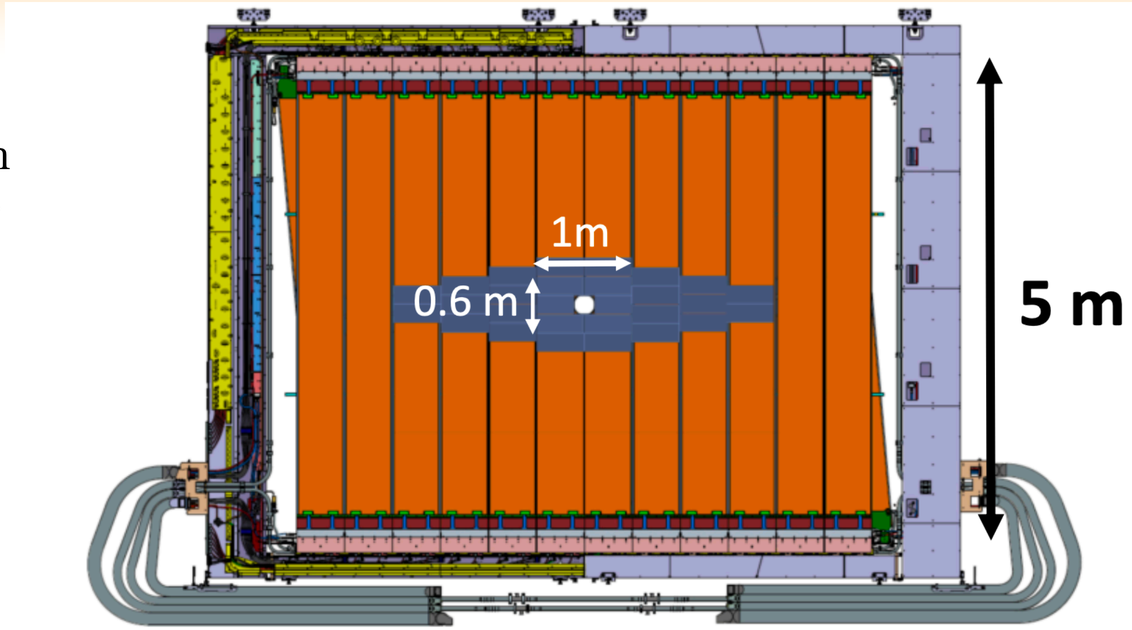



# LHCb in Runs 3 and 4

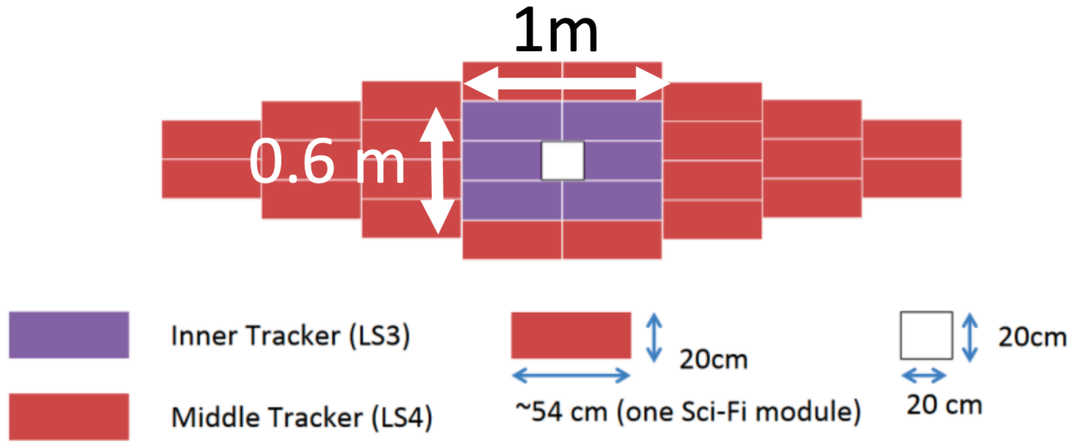
❖ What occupancies are we talking about?

- According to ALICE measurements (Phys. Lett. B 772 (2017)) in the centrality interval 5-0% the particle density grows by a factor 3.5 when compared to the 40-30%.

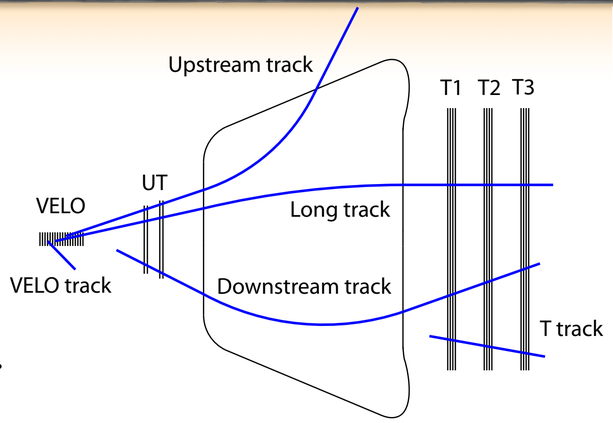
| centrality percentile | $2 < \eta < 4.5$ |
|---|---|
| 0%-5% | 4074 (× 3.5) |
| 5%-10% | 3366 (× 2.9) |
| 10%-20% | 2548 (× 2.2) |
| 20%-30% | 1736 (× 1.5) |
| 30%-40% | 1150 |



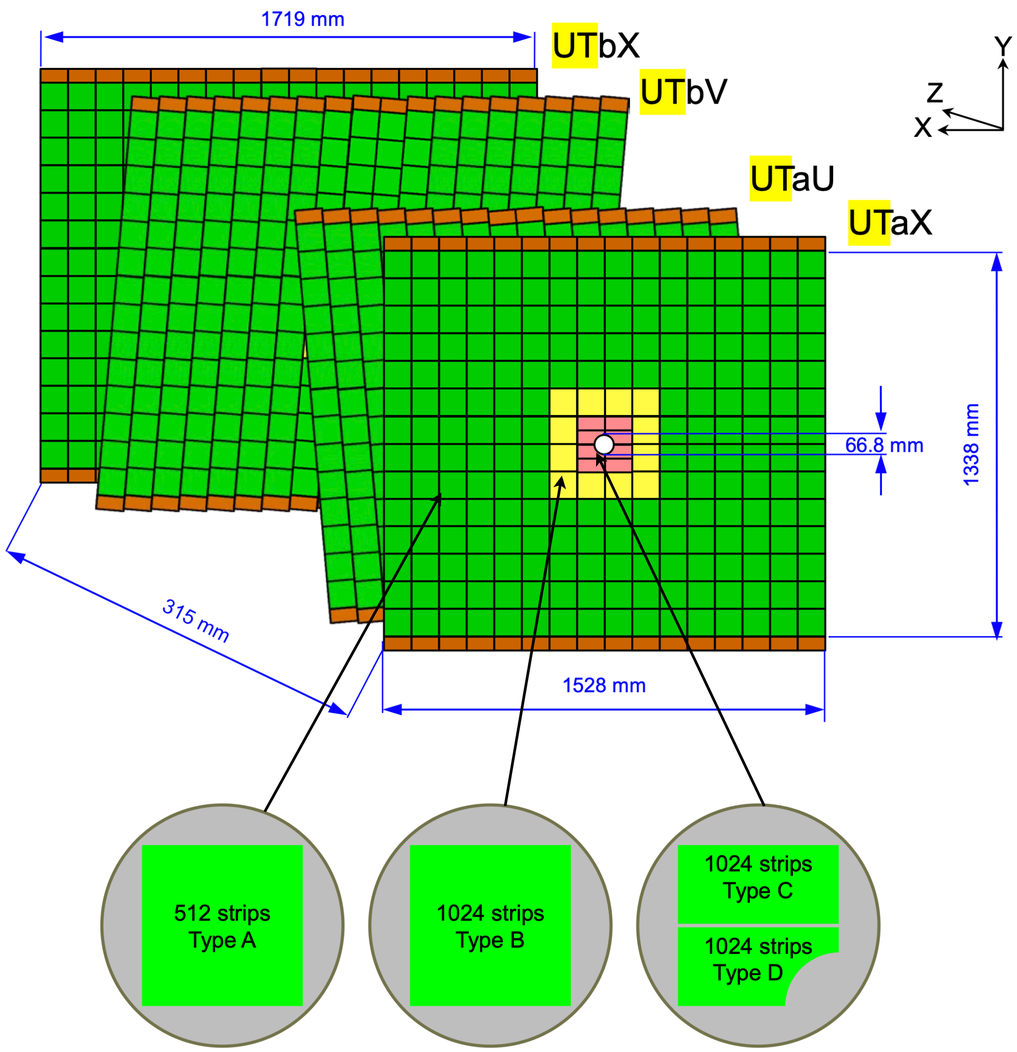

- According to some preliminary studies the addition of:
  - IT would reduce the occupancy by a factor 2.3.
    - Already allow to use the 10-20% centrality region.
  - IT+MT would reduce the occupancy by a factor 10.8.
    - Give access to 0% centrality region.



# LHCb in Runs 3 and 4




- Silicon micro-strip detector.
  - 968 silicon sensors.
  - 4 layers upstream of magnet.
- UT upgrade is necessary for Upgrade II.
  - Will provide opportunities to improve the tracking (both for pp and PbPb)
    - Improve VeloUT track finding.
    - Reduce ghost rate for LongTracks in central PbPb collisions.
    - It would cope with the increased pp collision rate (40 per crossing after upgrade II).
    - It could complement some proposed magnet tracking stations (aimed at low momentum particles, proposed for LS3).
  - Studies ongoing for the design, technology, and position of the UT for the upgrade.



# Conclusions

❖ Heavy-ion physics in Run 3-4: QGP studies accessible in LHCb with increasing centrality reach.

- Expecting great performances in pPb and in fixed-target.
- PbPb physics accessible up to 30% centrality in Run 3 and 20-10% in Run 4.

❖ In Run 5 expected full centrality coverage:

- MIGHTY tracker solves occupancy problem.
- UT upgrade would solve upstream occupancy, ghost rate in Long Tracks and cope with the data rate (40 pp collisions per bunch crossing).
- Studies still ongoing.

❖ The future of heavy-ion in LHCb is promising!

Thank you for your attention!

# Back up

# Magnet tracking station

❖Proposal for tracking station inside the magnet.

- Increase coverage of upstream tracks.
- Physics motivations : access to converted photons.

❖Technology:

- Triangular Extruded Scintillating Bars.
- SiPM readouts.
- Ongoing R&D in LANL.

❖Proposing the installation of a small prototype inside the magnet during LS3.