Benjamin Audurier - Rencontres QGP France - Tours, 4 mai 2022

Prospectives LHCb

« I wish there were less experimental talks » - a rookie PhD student in theory.

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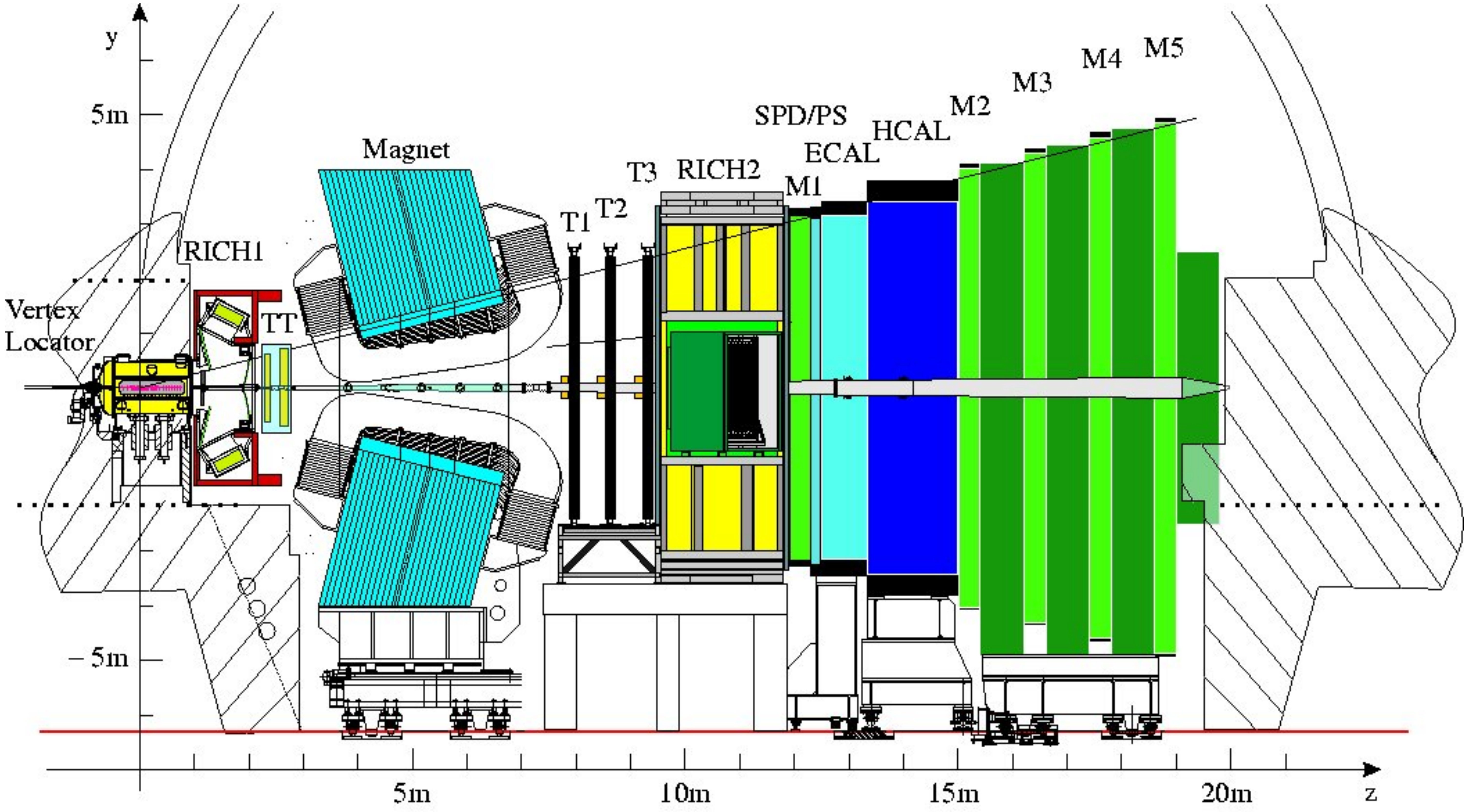
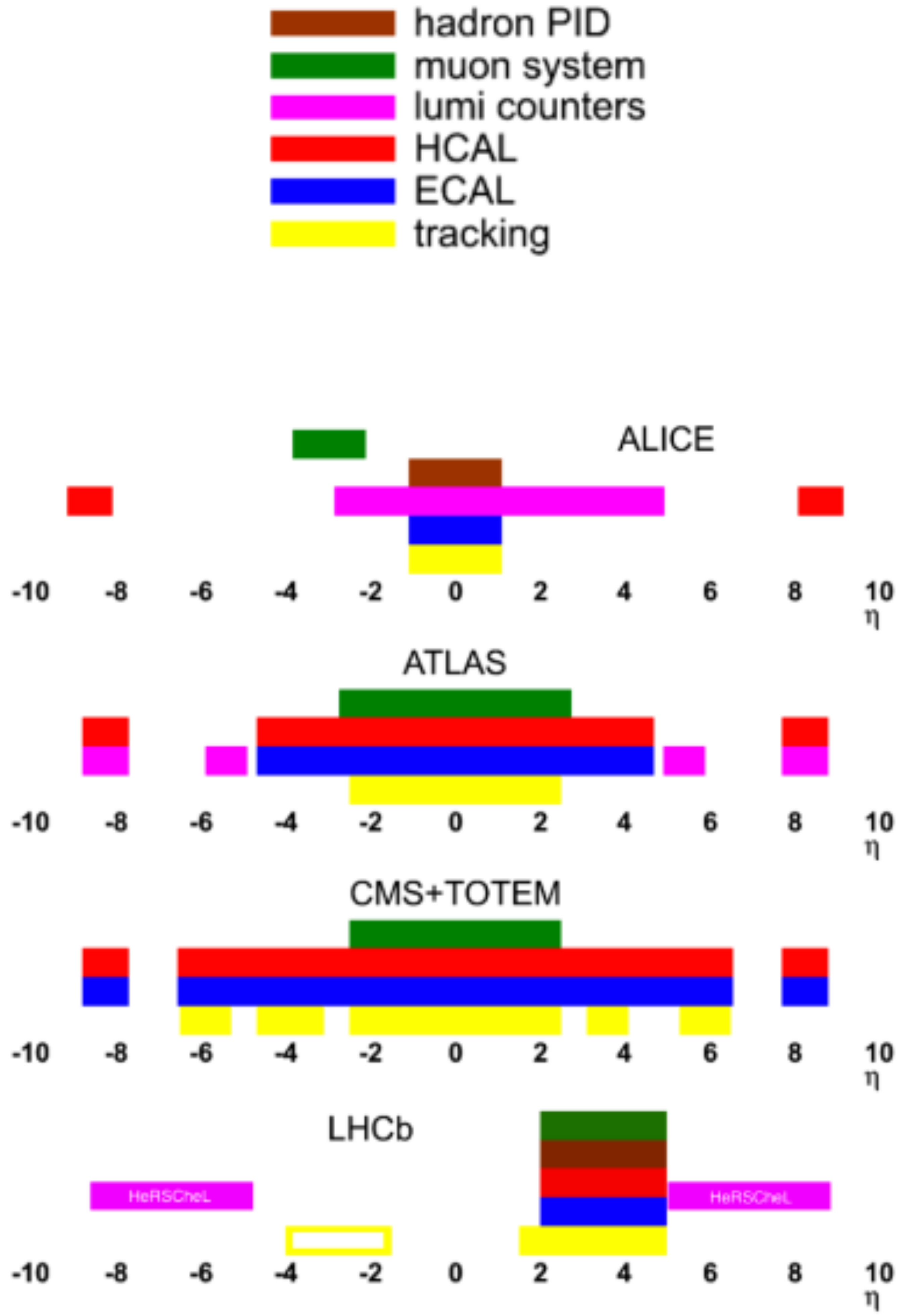
The past

The LHCb detector

10.1142/S0217751X15300227

LHCb : **single arm spectrometer fully instrumented** in pseudo-rapidity range **2 < η < 5**

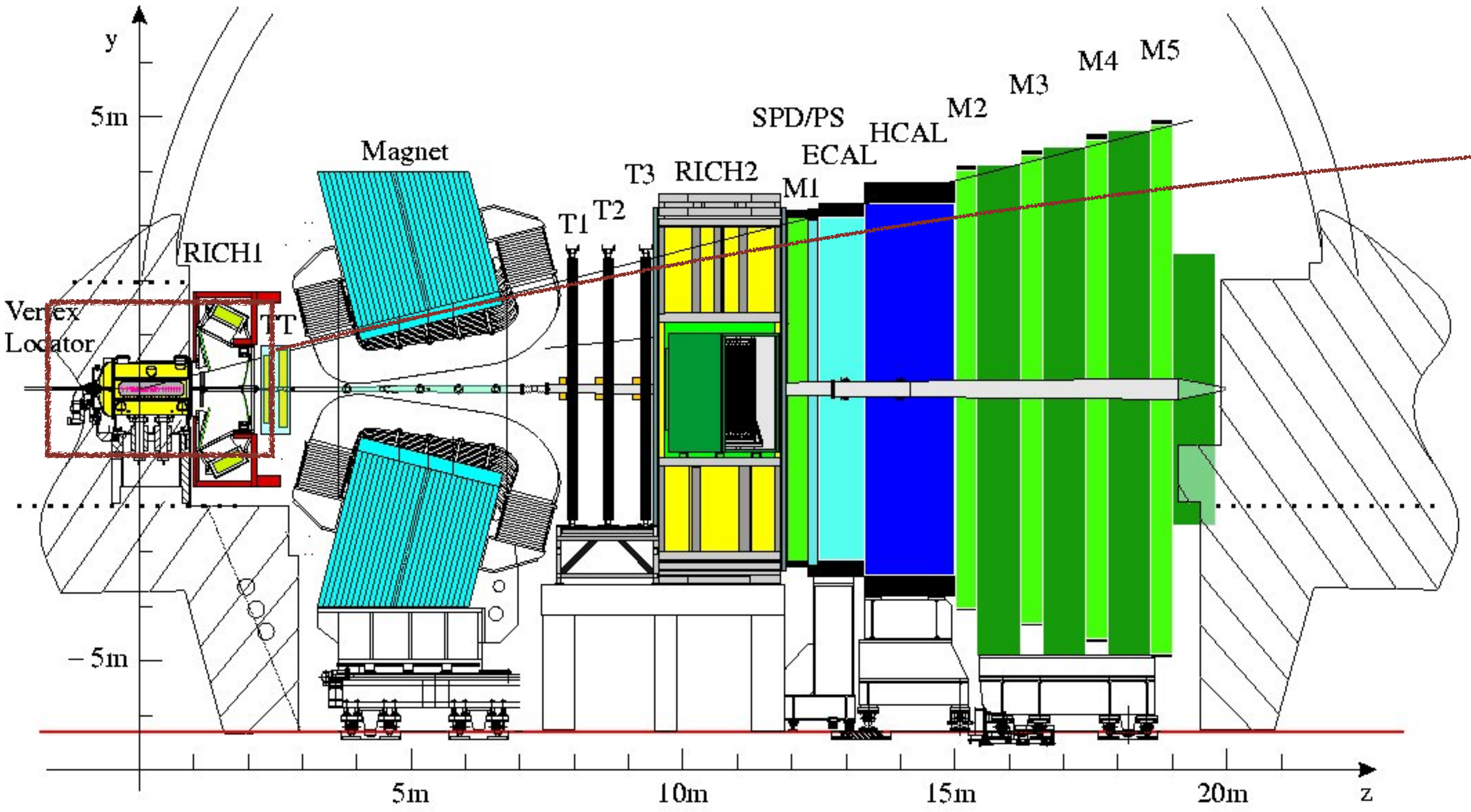


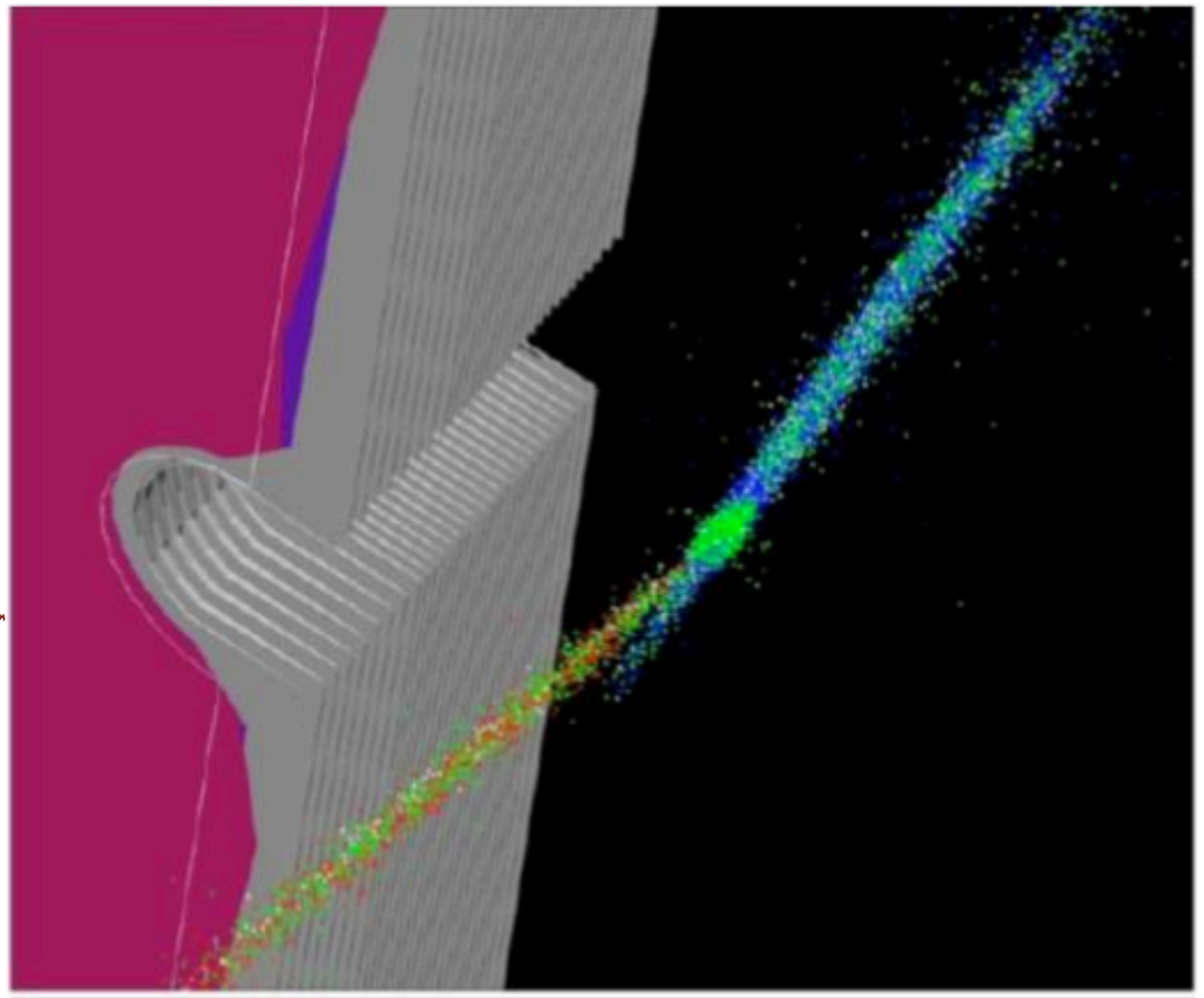


The LHCb detector

10.1142/S0217751X15300227

Can operate both in Pb-Pb/p-Pb and fixed-target !





Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

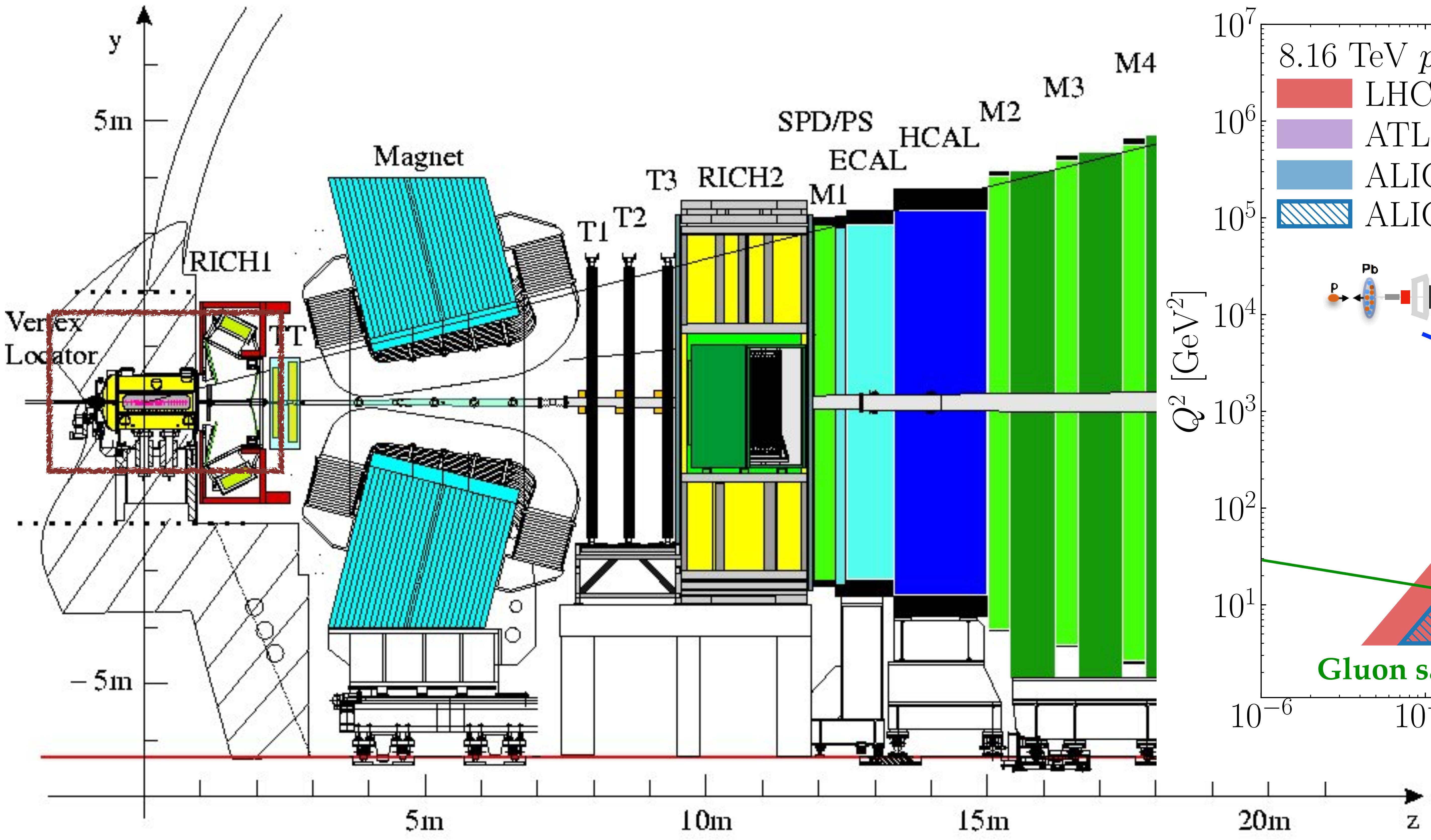
Fixed-target mode: **unique at LHC !**

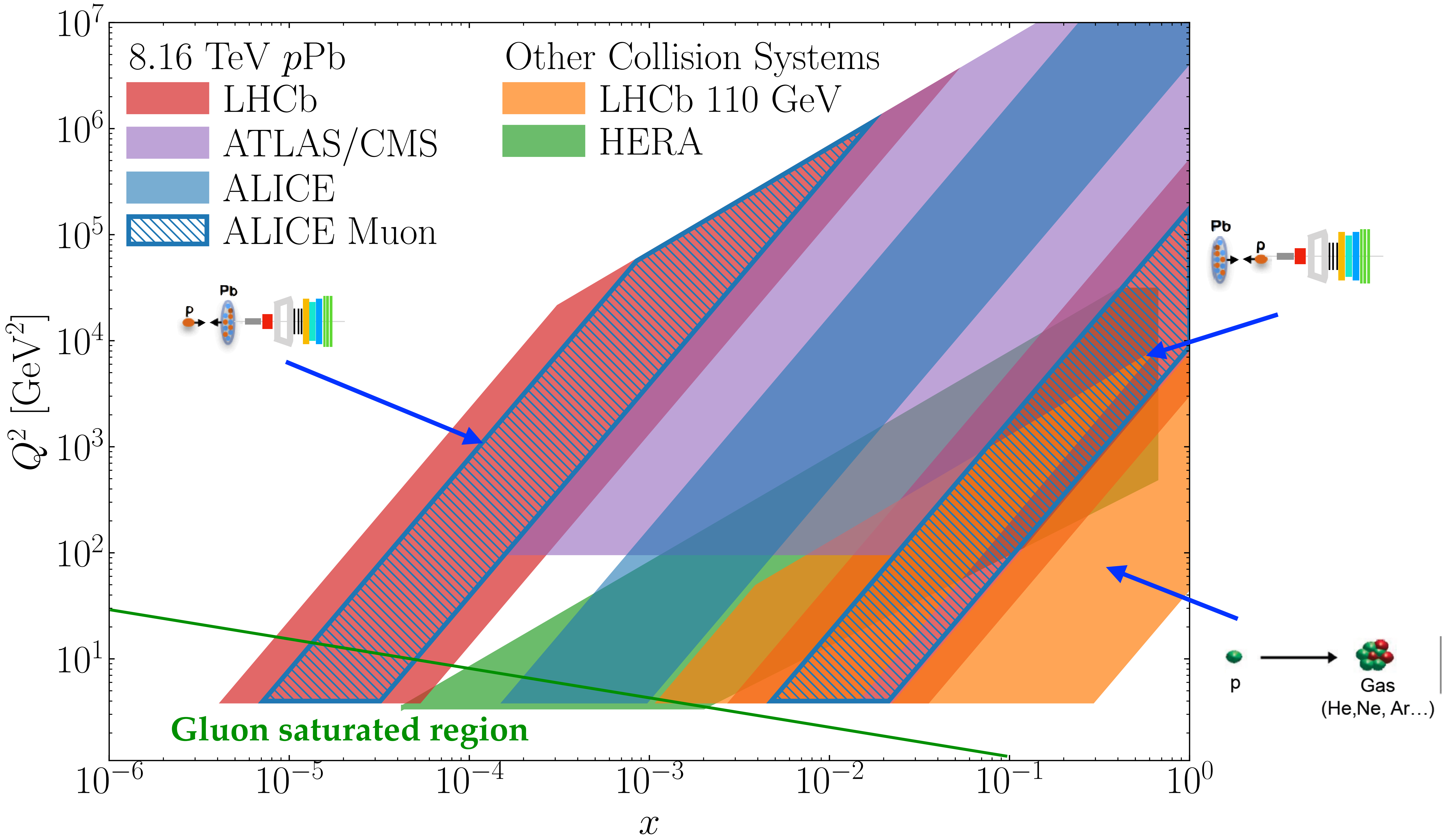
- Injecting gas in the LHCb VErtex LOcator (VELO) tank
- **Noble gas only** : He, Ne, Ar, Kr, Xe
- Gas pressure : 10^{-7} to 10^{-6} mbar

The LHCb detector

10.1142/S0217751X15300227

Can operate both in Pb-Pb/p-Pb and fixed-target !

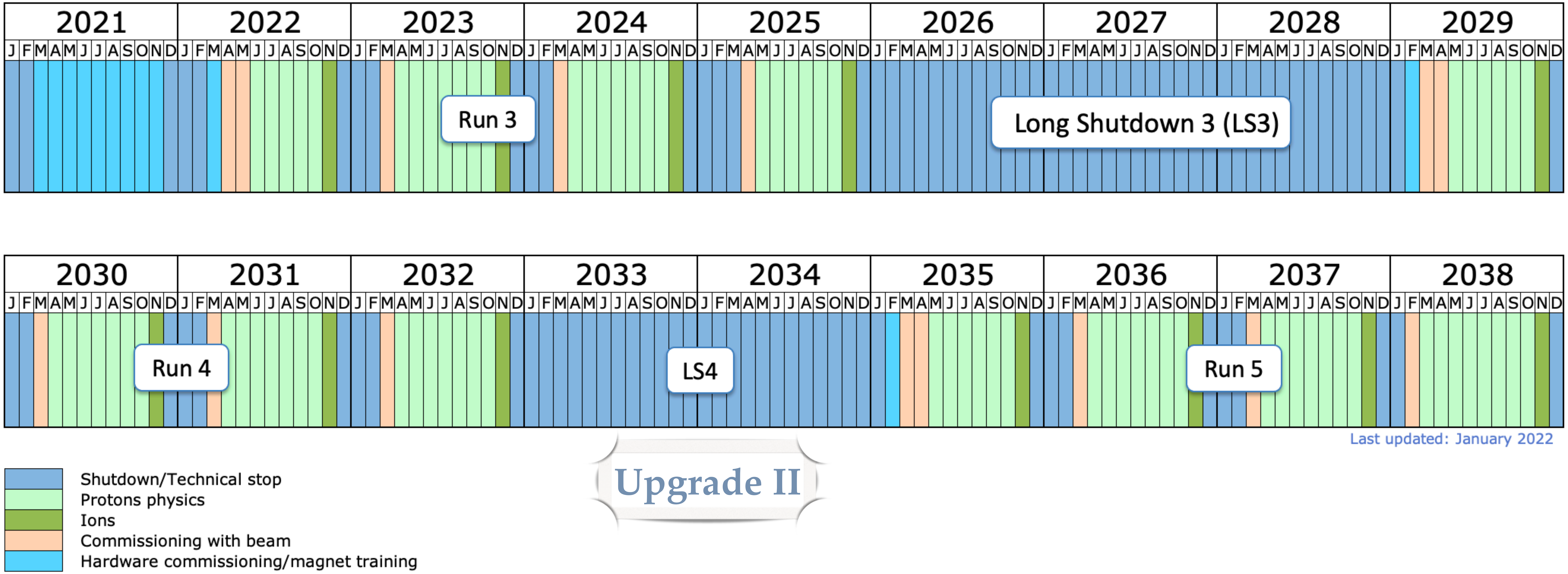




The futur planed by the LHC

Upgrade Ia

Upgrade Ib

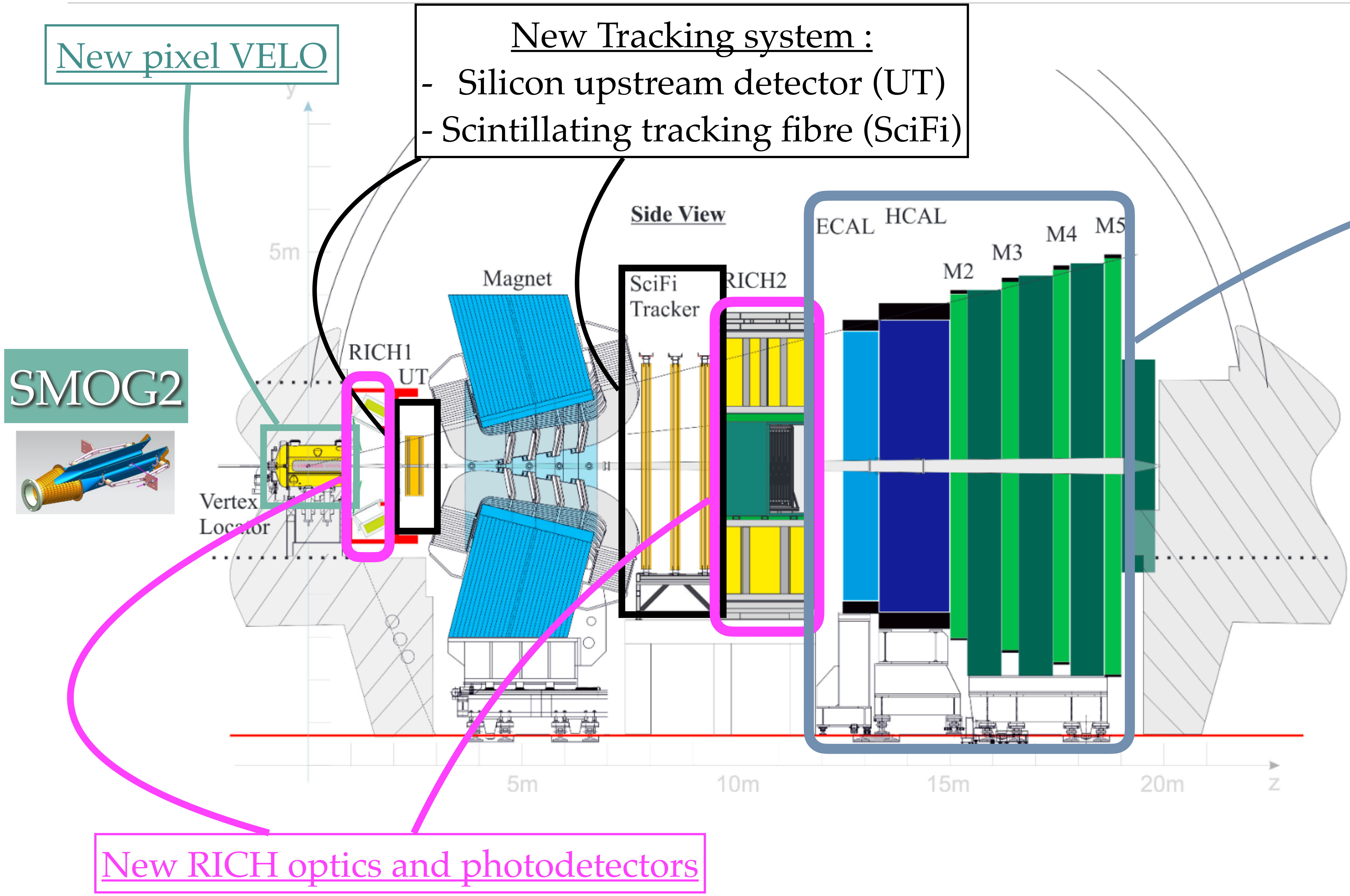


Upgrade II

The present

Requirements for Run 3 - Run 4

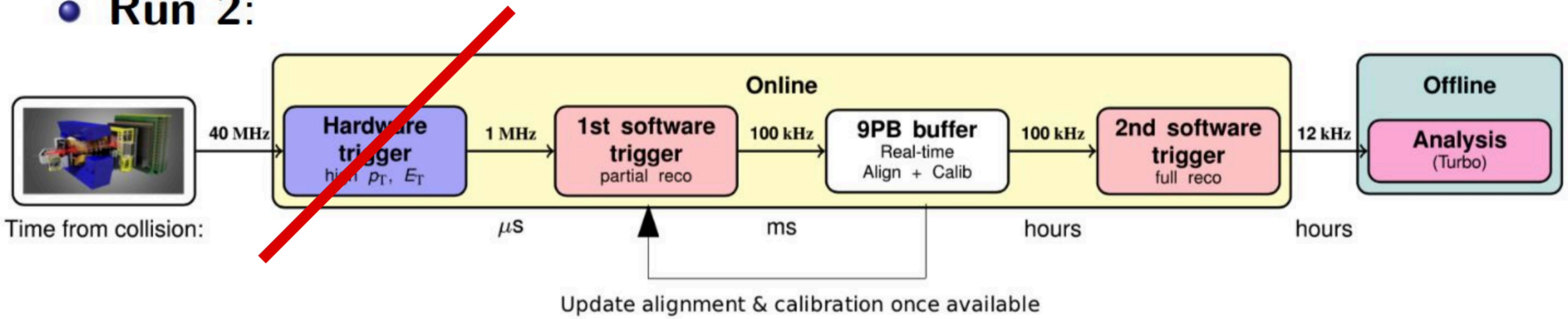
[CERN-LHCC-2012-007]



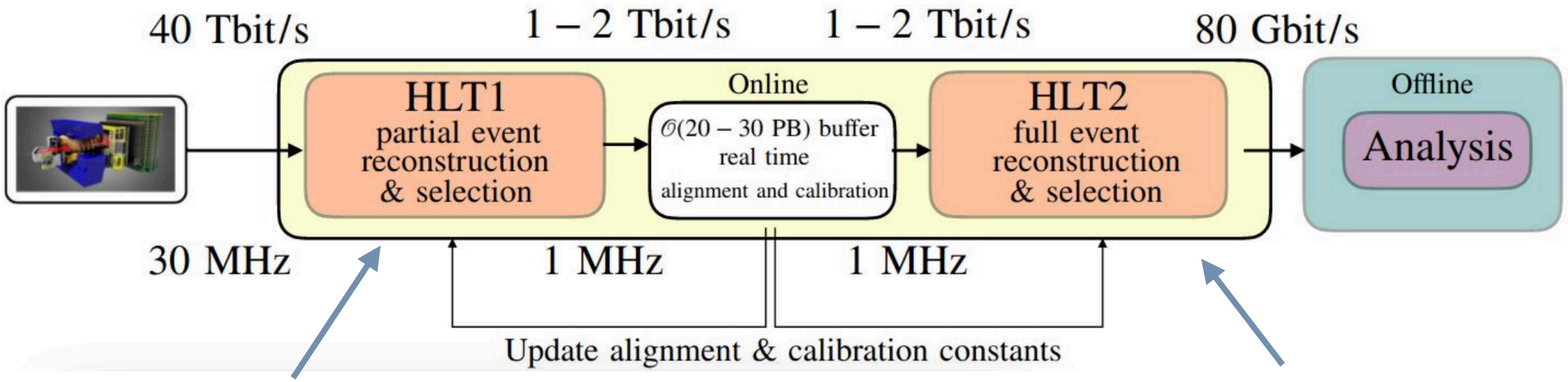
- Upgrade based on pp collision requirements :
  - Collision rate at 40 MHz.
  - Pile-up factor $\mu \approx 5$
- Full **software trigger.**
  - Remove L0 triggers.
  - Read out the full detector at 40 MHz.
  - Replace the entire tracking system.

Trigger scheme

- Run 2:



- Run 3:

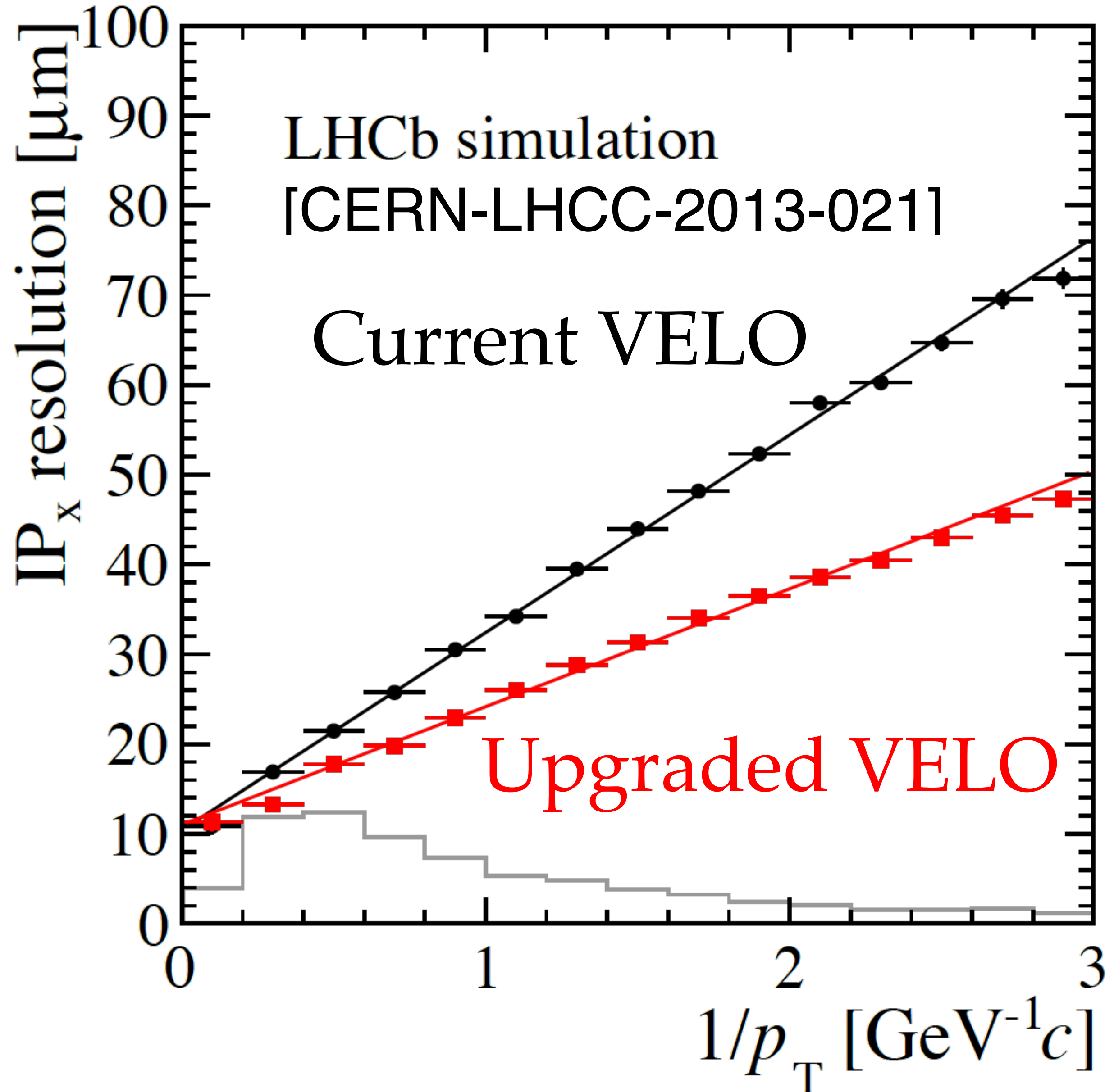


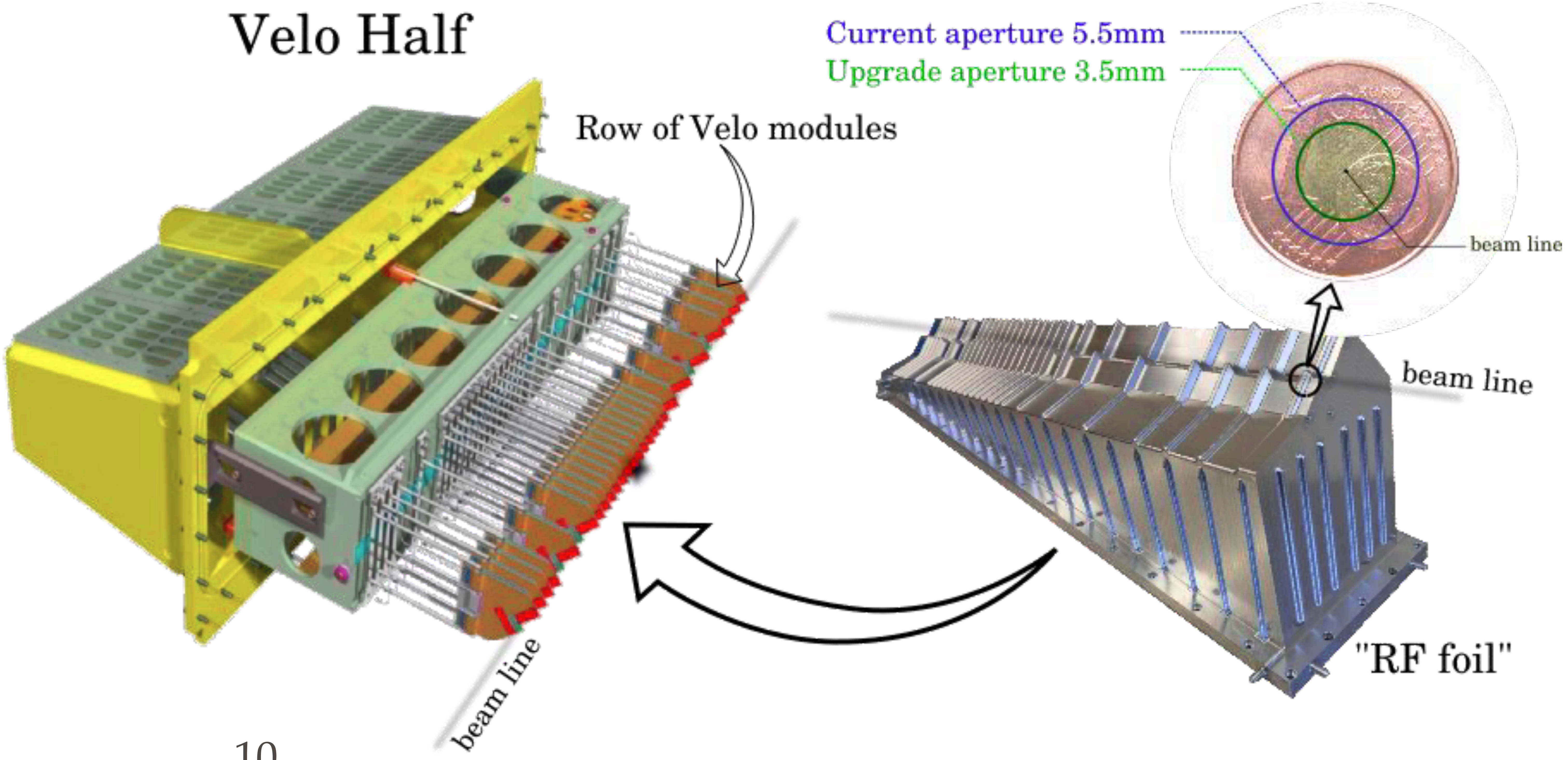
- Tracking only on GPUs.
- First trigger selections based on tracking only.

- Tracking + PID on CPUs.
- More complexe trigger selection possible.

Tracking system: Vertex Locator (VELO)

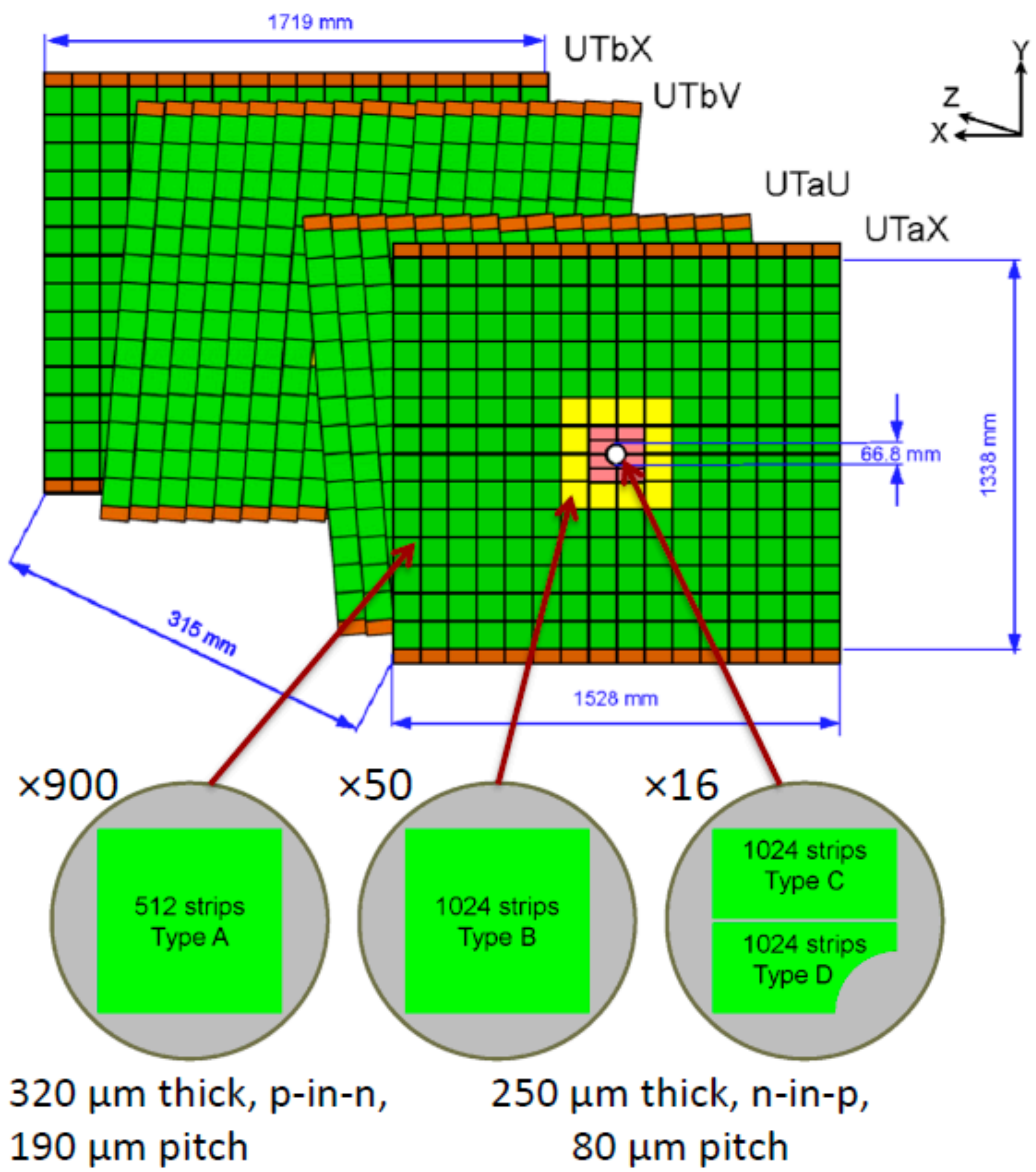
- Silicon pixel detector, **41 M 55 x 55 μm² pixels.**
- Closest pixels at 5.1 mm from the beam line.
- Aluminium foil to protect the Velo without interfering with the beam.
- Sensors to be kept < -20°C
- **Total data rate** : 2.8 Tb/s





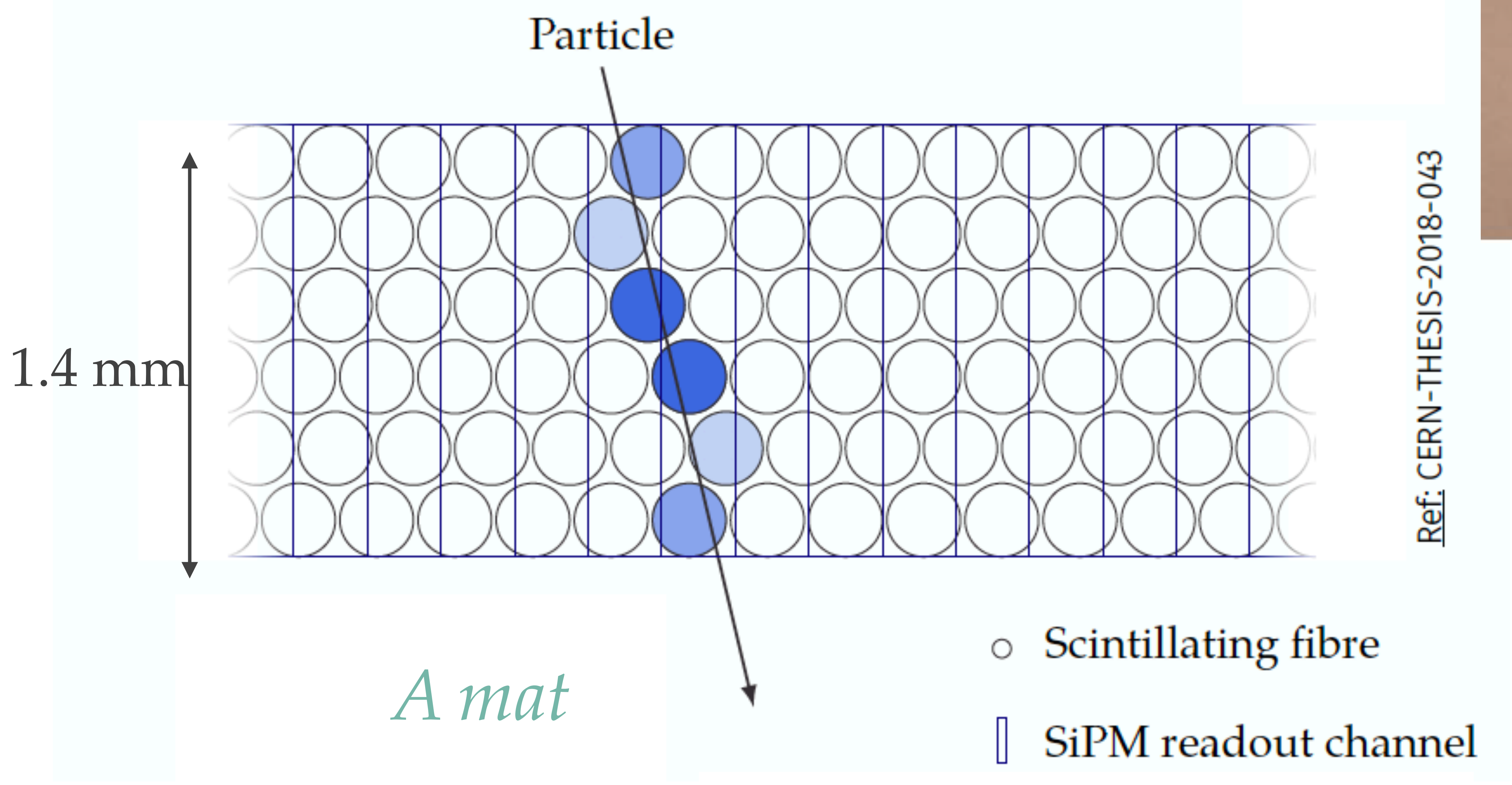
Tracking system: Upstream Tracker (UT)

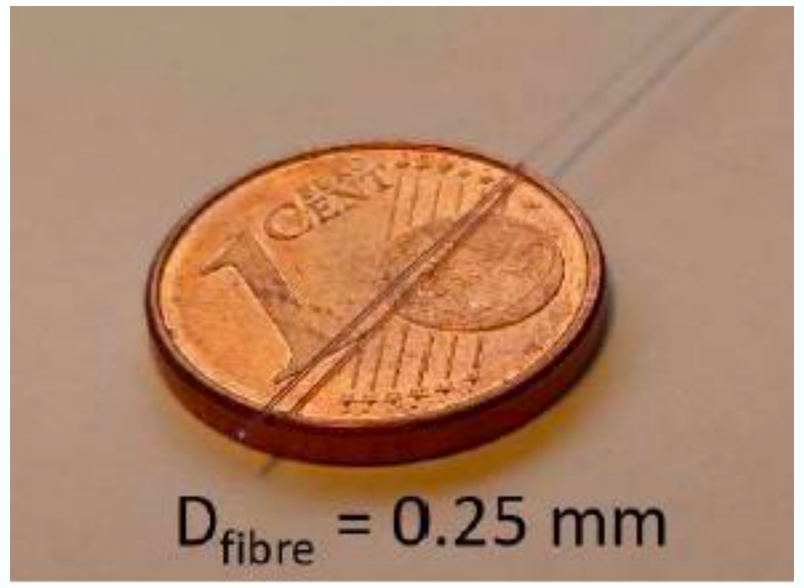
- 4 stations with x-u-v-x layers of silicon micro strip detectors.
  - Sensors with 512 or 1024 strips (4 different types).
  - 68 staves / 968 sensors.
- **Replace the TT system.**

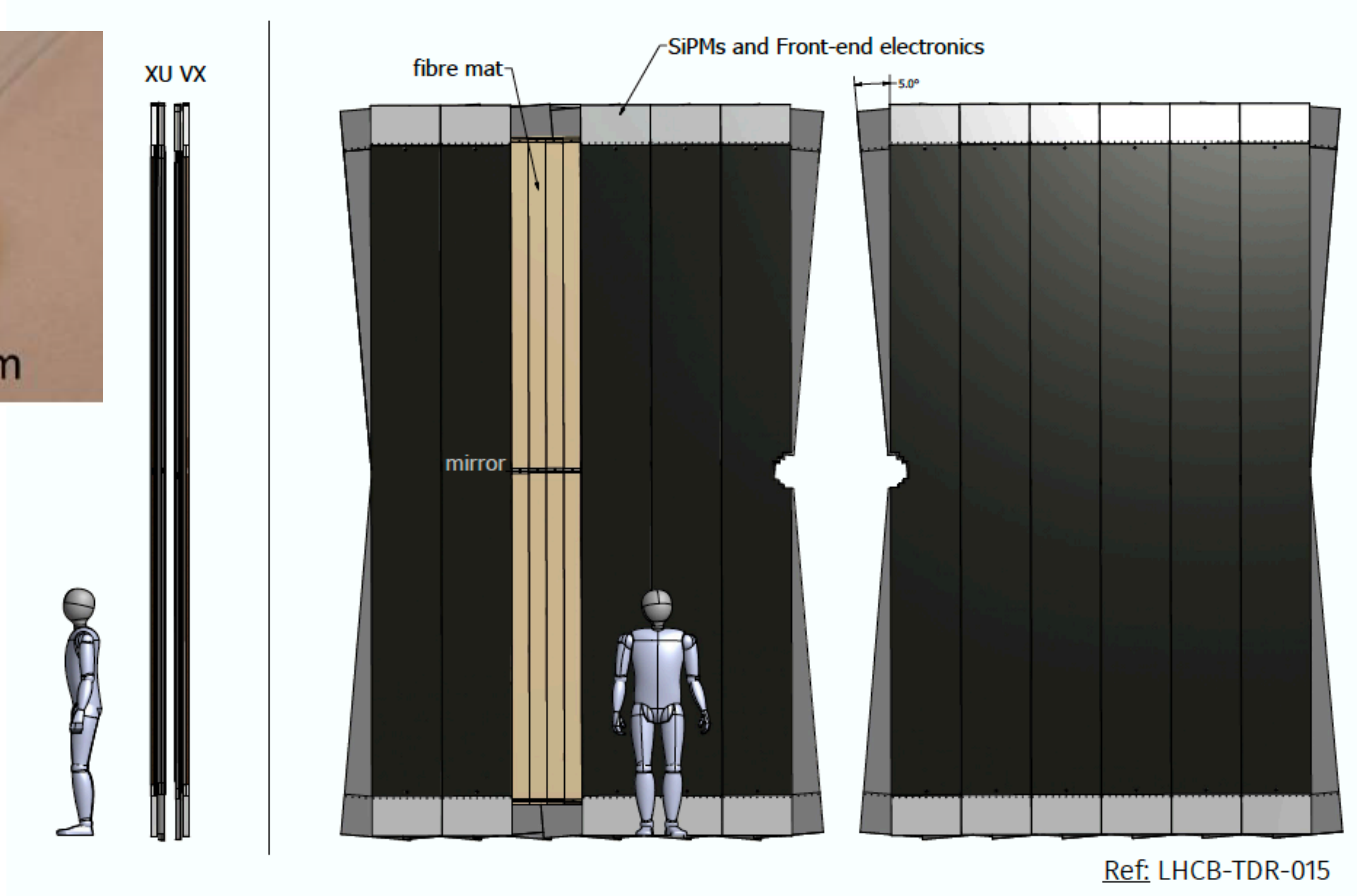


Tracking system: Scintillating fibre tracker (SciFi)

- ~10000 km of scintillating fibres arranged in 6 layers with silicon photo-multipliers (SiPM) readout.
  - 3 stations.
  - 4 detection layers per station arranges in x-u-v-x configuration per stations.
  - 10 modules of 2x4 mats.

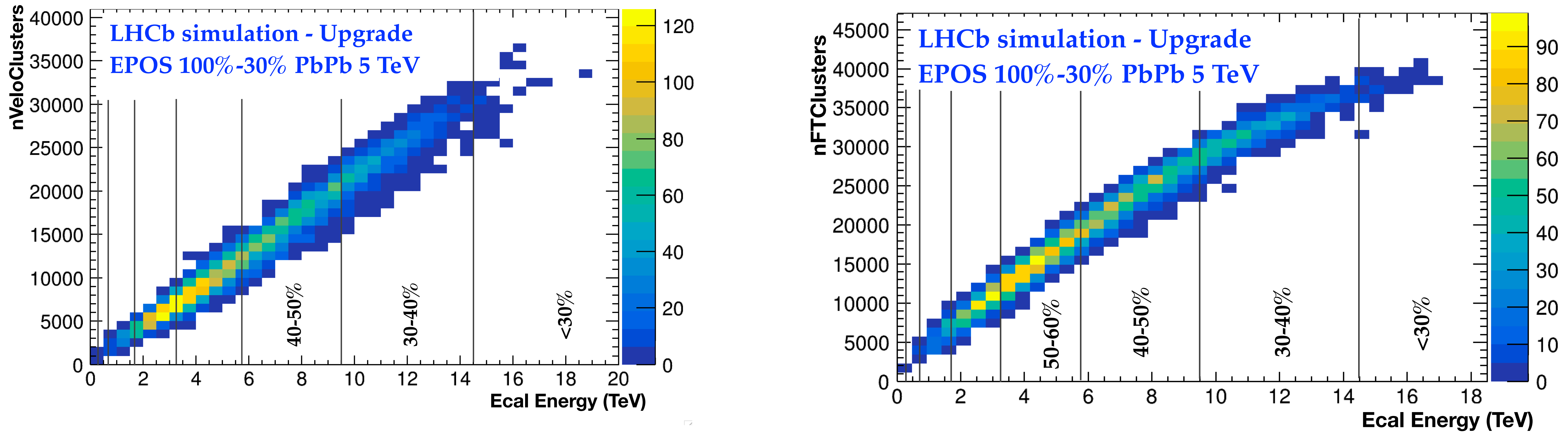


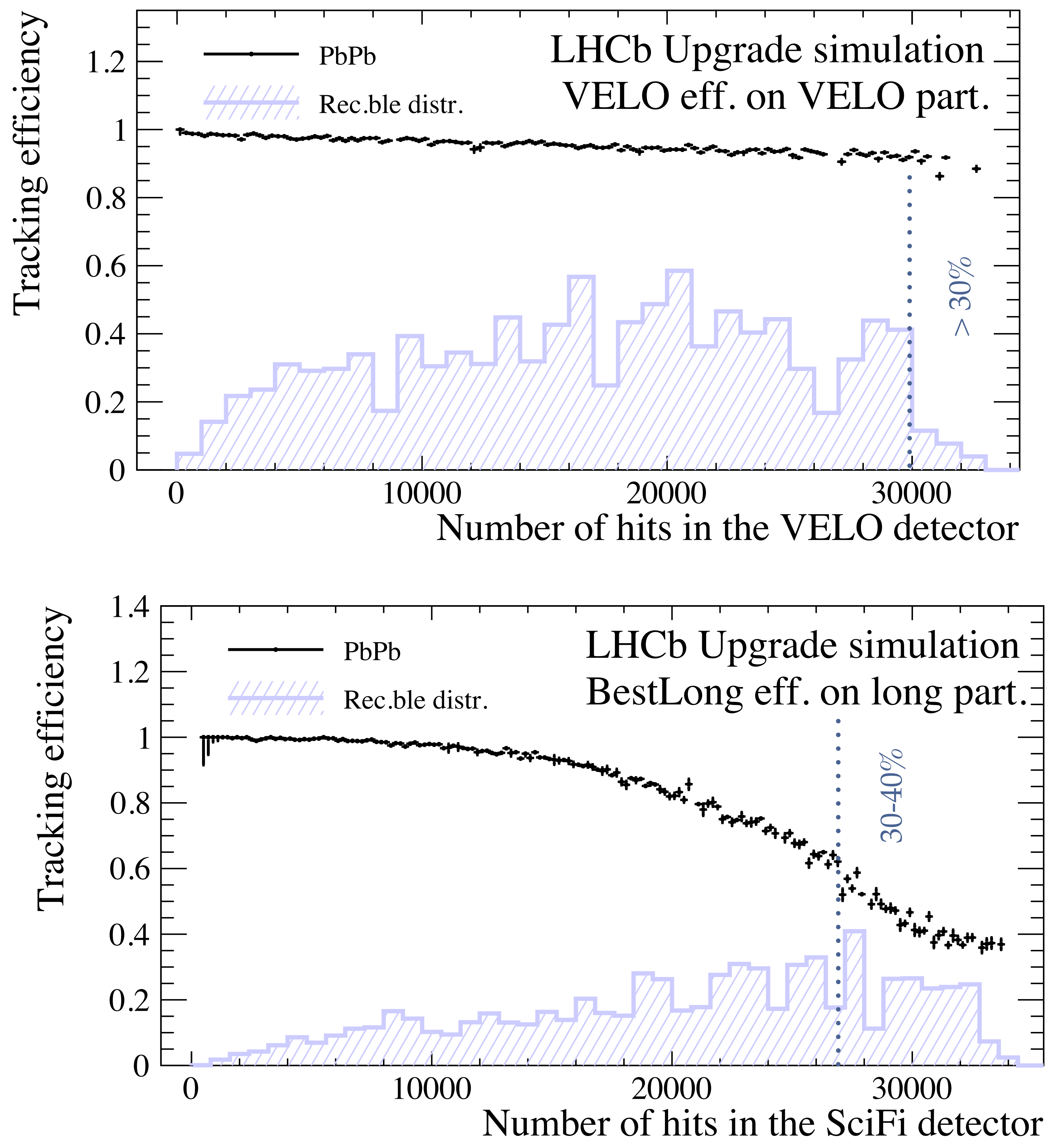




Run 3 and Run 4 prospects for heavy-ion physics with LHCb

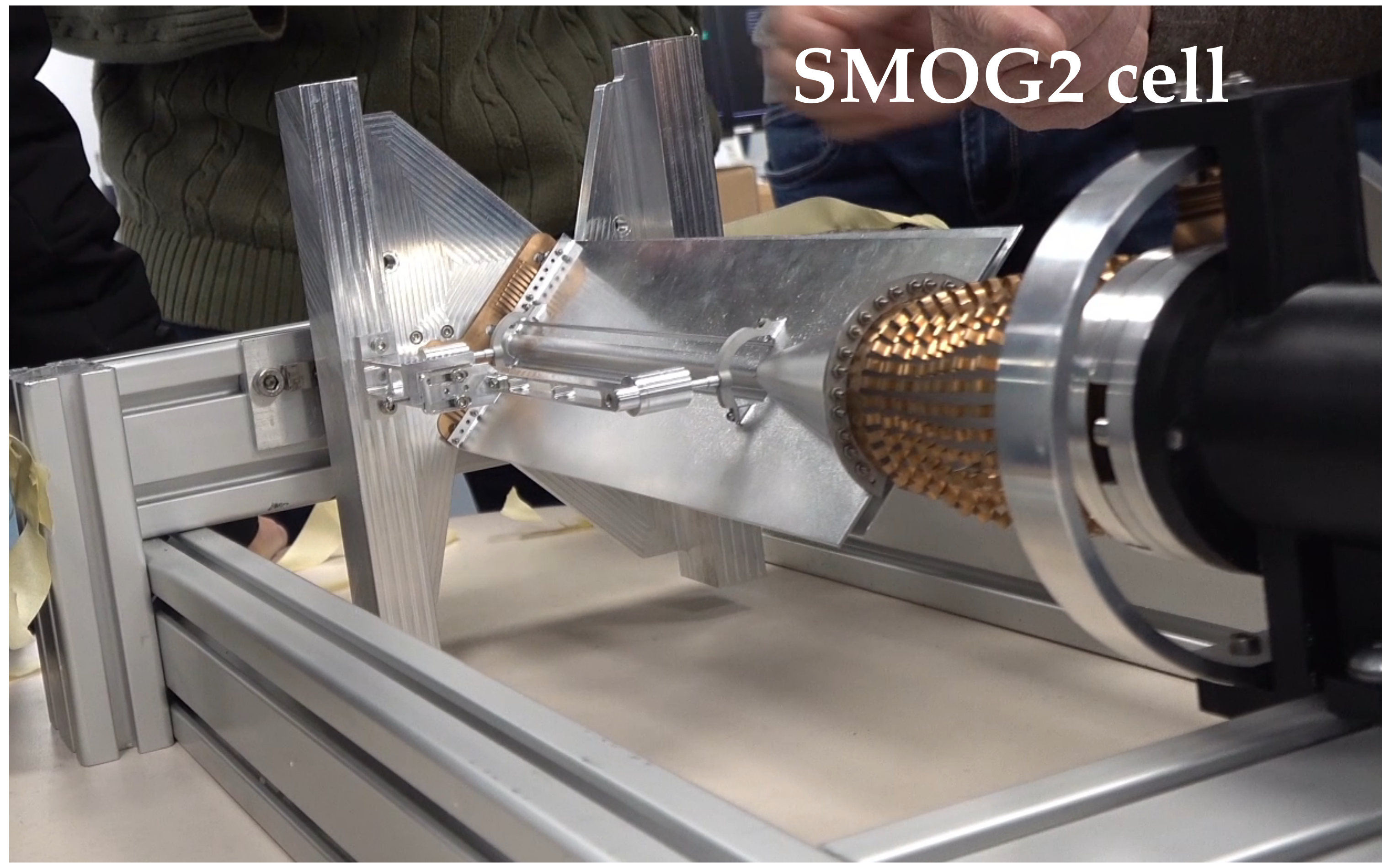
PbPb collisions at LHCb





- No significant saturation of the new LHCb detectors **up to 30%!**
- Two proposals for a new tracker :
  - in 2024 → **reach event more central collisions !**
  - In 2030 → **no more limitations !**

SMOG2 versus SMOG1



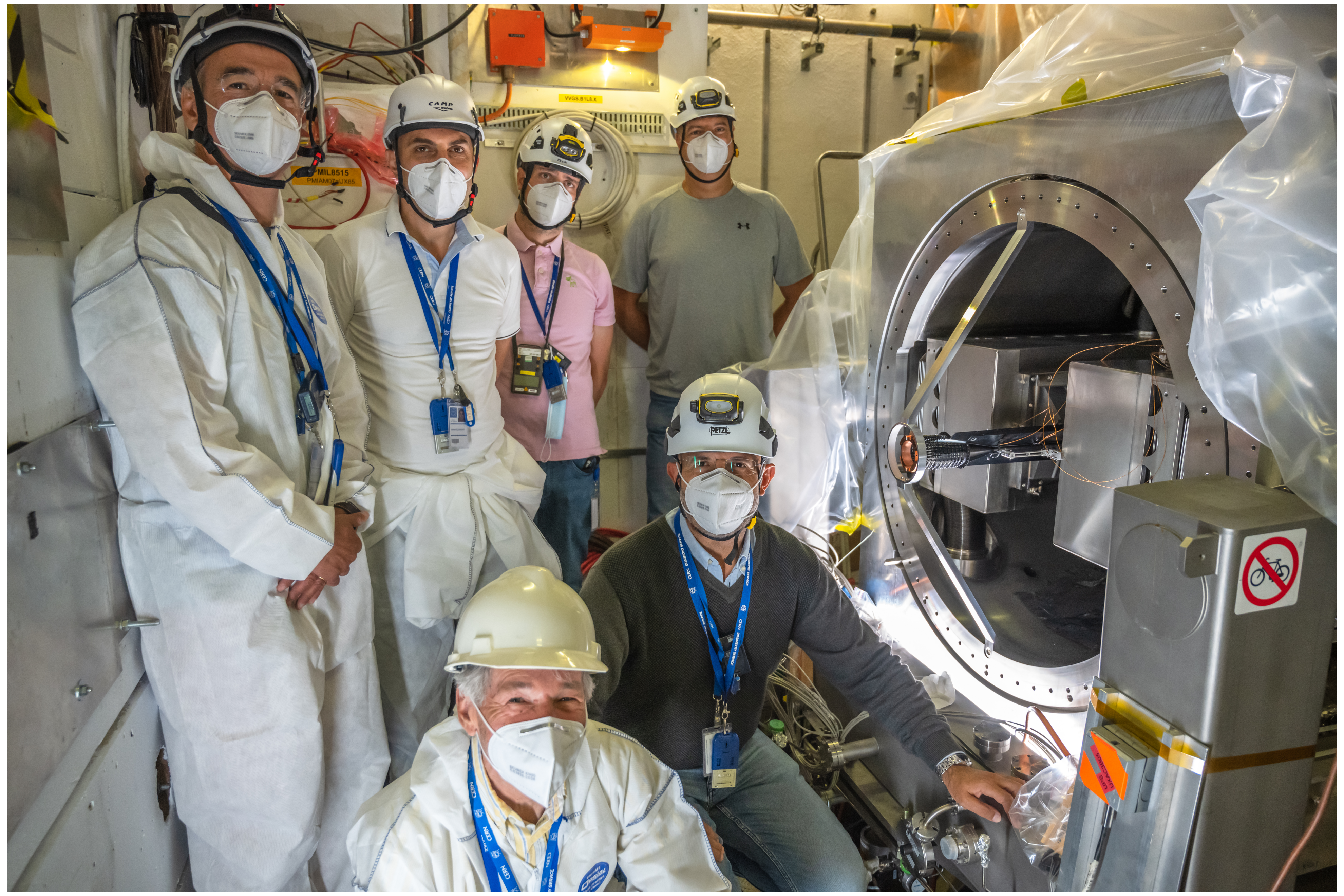
Int. Lumi.		80 pb^{-1}
Sys.error of J/Ψ xsection		~3%
J/Ψ	yield	28 M
D^0	yield	280 M
Λ_c	yield	2.8 M
Ψ'	yield	280 k
$\Upsilon(1S)$	yield	24 k
$DY\ \mu^+\mu^-$	yield	24 k

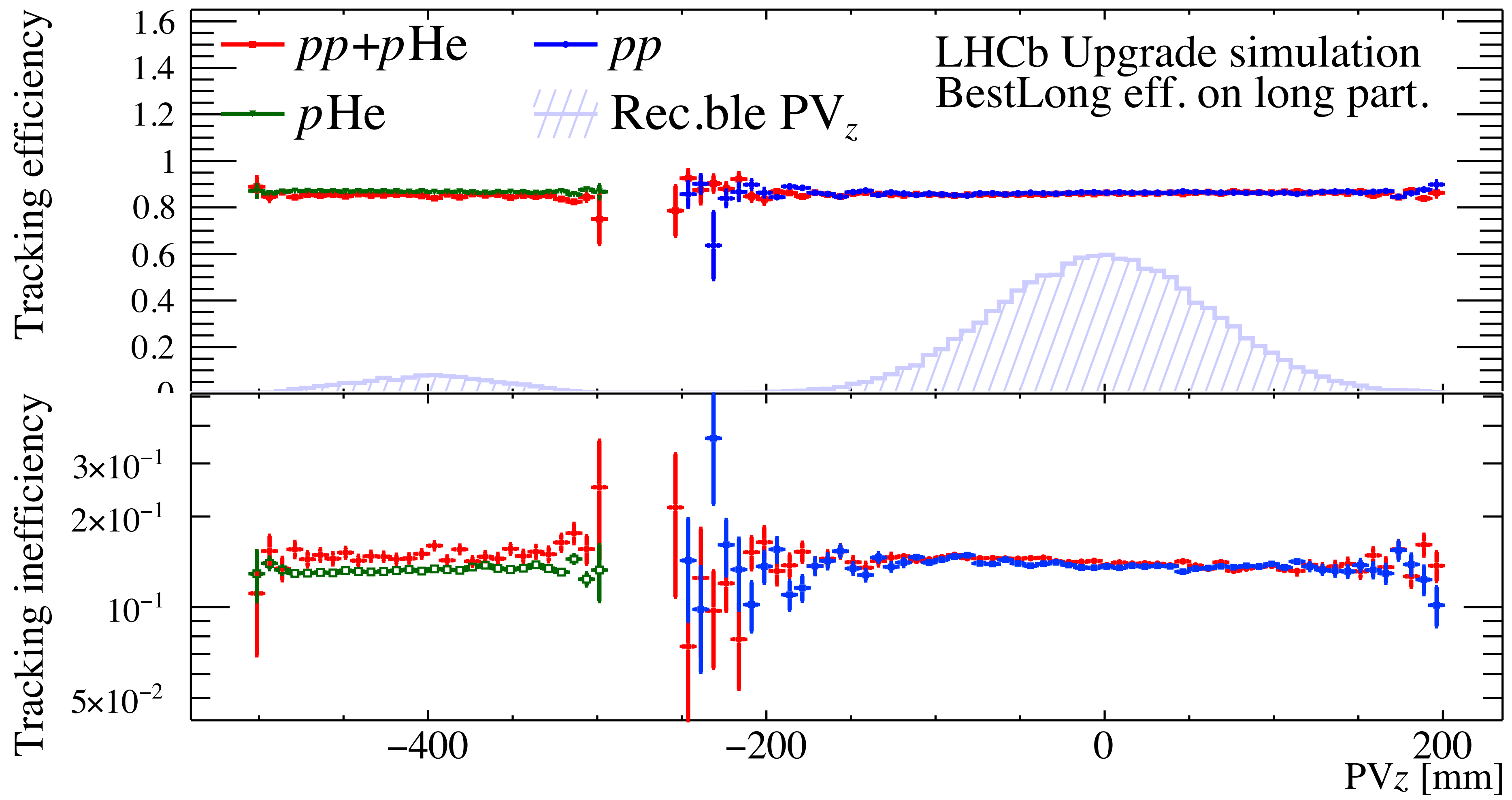
Projection of ~1 year data taking in parallel mode.

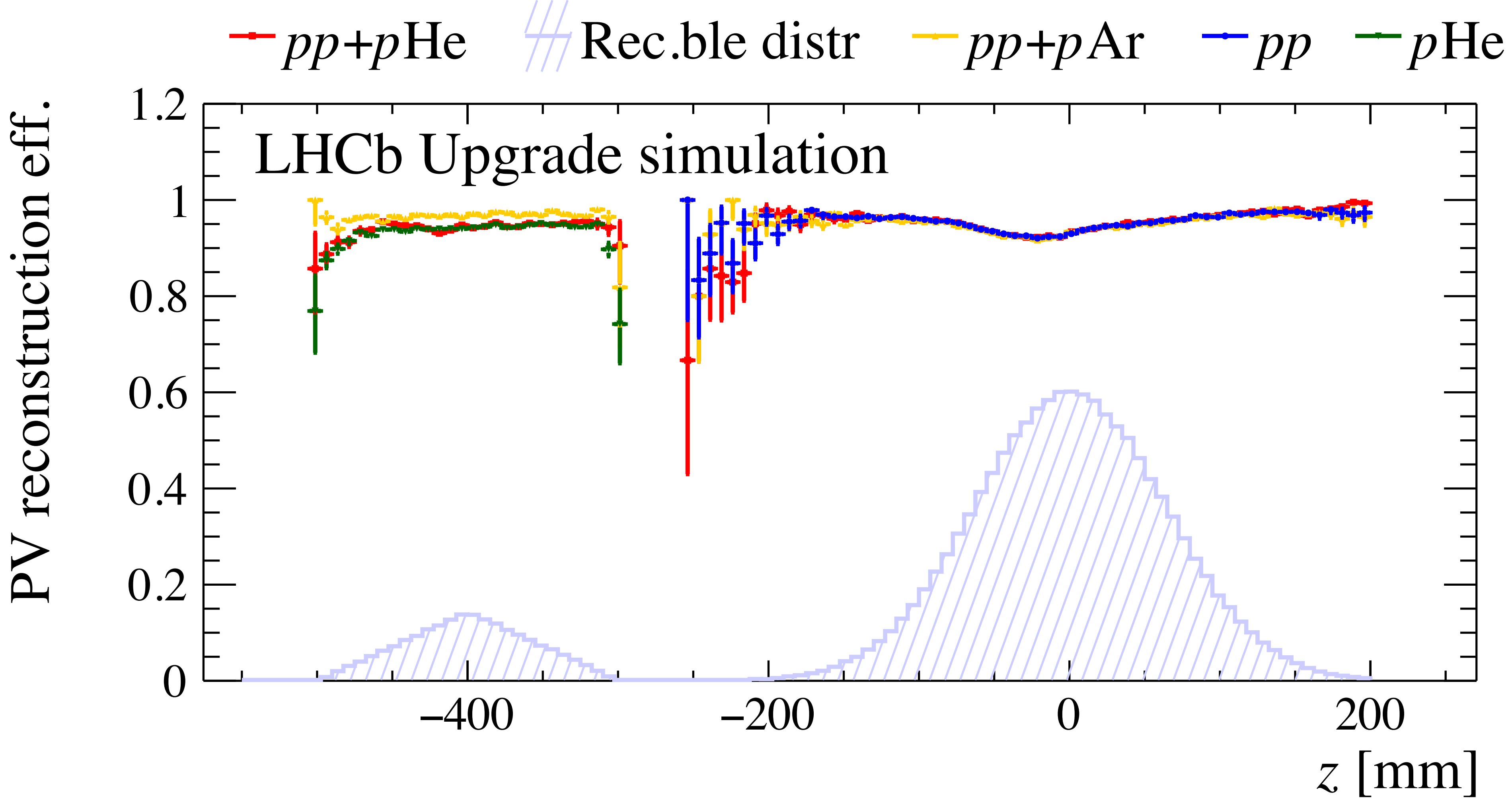
- **SMOG2** (TDR) : Standalone gas storage cell covering z ϵ [-500;-300] mm :
  - Well defined interaction region.
  - **Increase of target density (luminosity)** by up to 2 orders of magnitude using the same gas load of SMOG.
  - Gas feed system measures the **gas density with few % accuracy**.
  - Possibility to inject more gas species: H, D, He, N, O… (SMOG: He, Ne, Ar).
  - **More sophisticated Gas Feed System**: will allow to measure the target density (and luminosity) with much higher precision.
  - **Possibility to run in parallel of pp collisions and inject non noble Gaz.**

Status of SMOG2

The cell is in place and ready for commissioning !



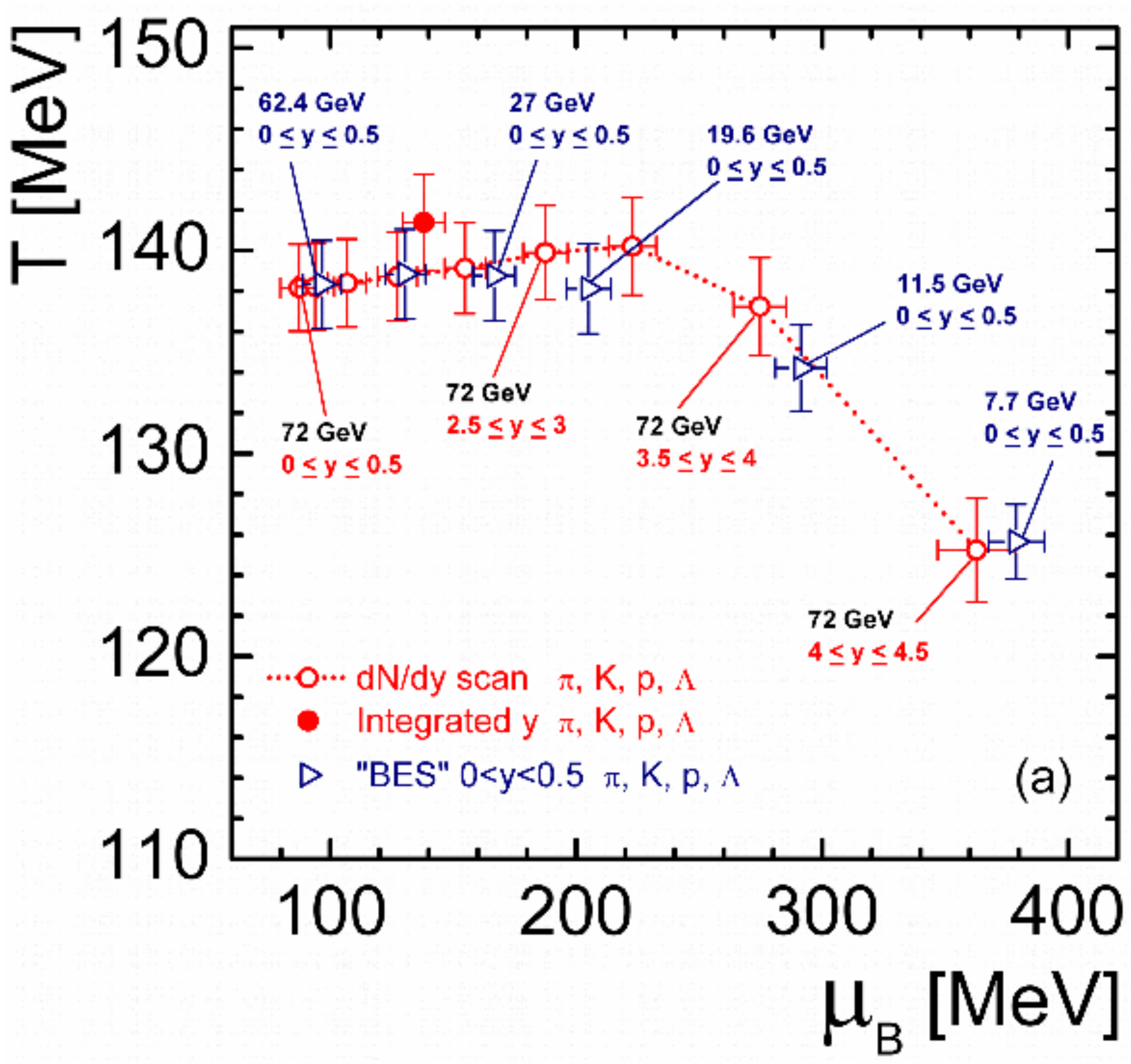




Run 3 prospects for SMOG2 with LHCb

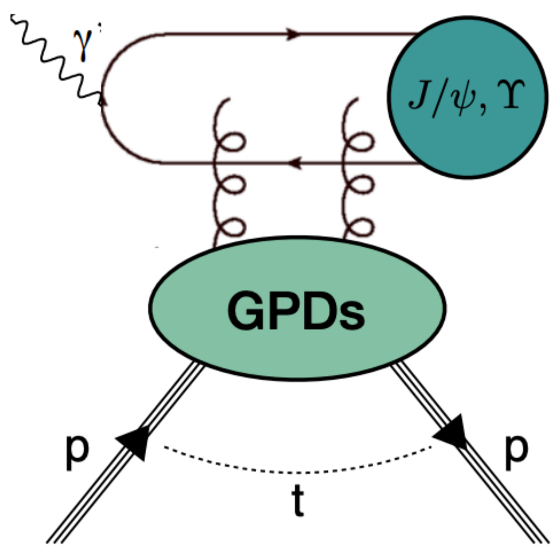
Rapidity scan

Phys. Rev. C98 (2018) 034905

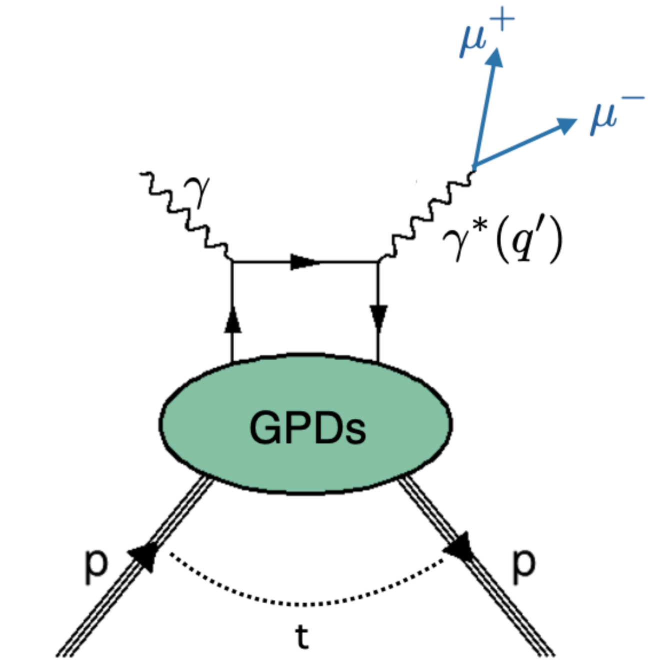


- **Rapidity scan** at $\sqrt{s_{NN}} = 72$ GeV with FT@LHCb **could complement the RHIC beam energy scan.**

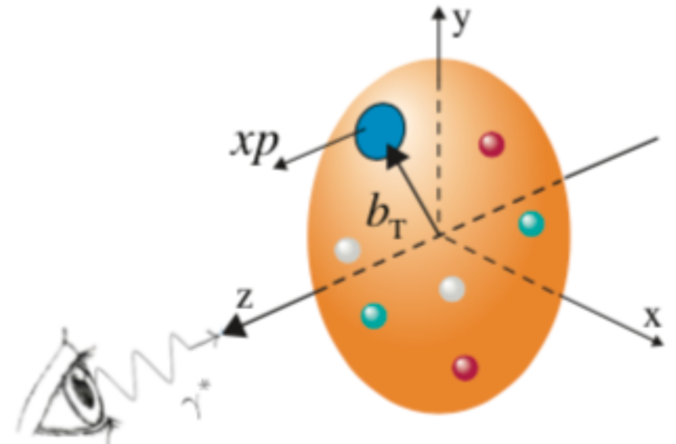
Deep in the hadronic structure



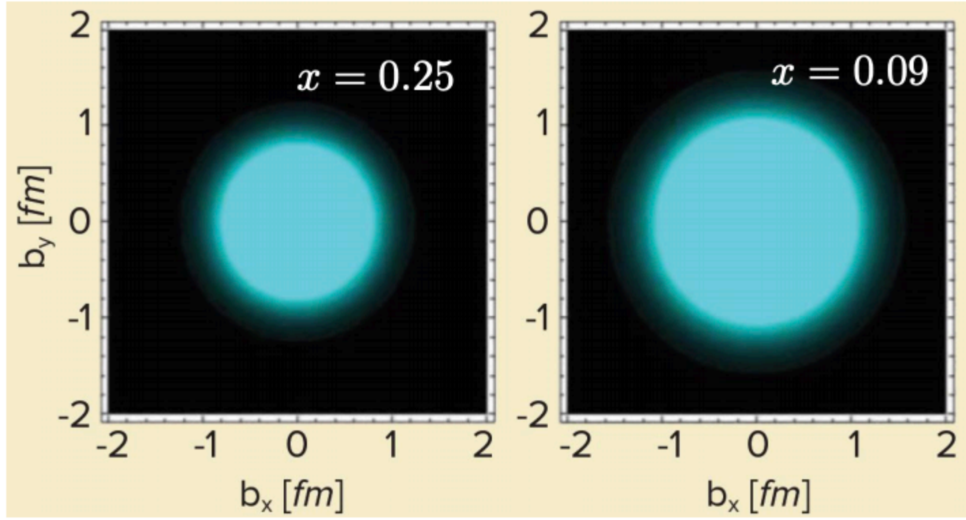
Exclusive meson production



Timelike Compton scattering (TCS)
(access via angular modulation)



2015 Long Range Plan for Nuclear Science



One of the objectives : 3D pictures in impact parameter space

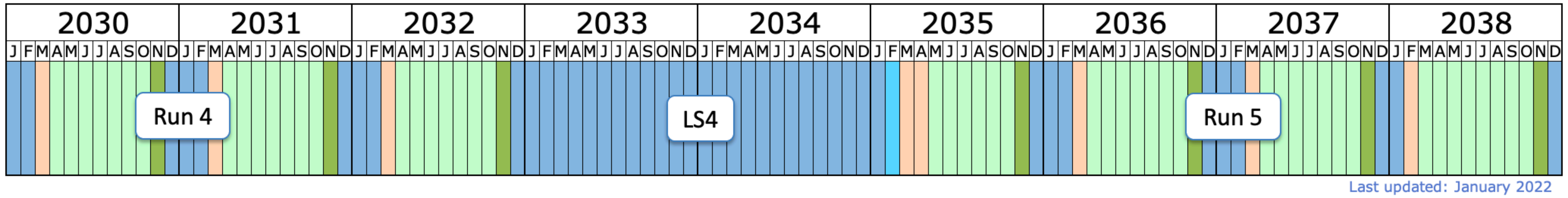
- SMOG2@LHCb could probs **nuclear PDFs, TMDs, GPDs at large Bjorken-x.**

The future

Objectives: same performance as in Run 3!

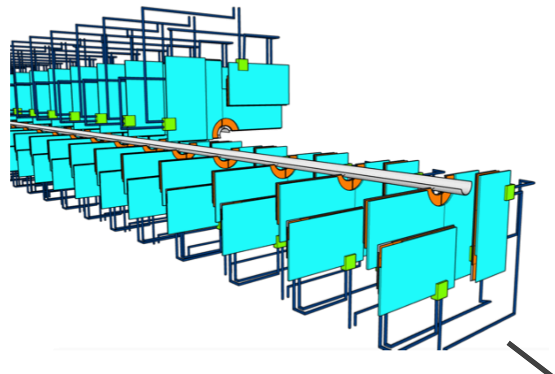
187 pages long, I will only present the main challenges faced by some detector ….

Phase II in a nutshell

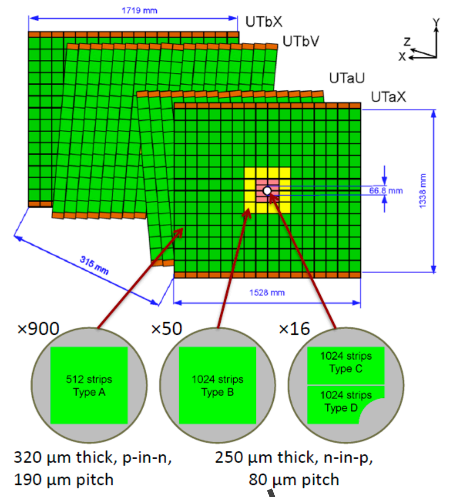


<u>Upgrade II:</u>
- $2\times10^{34}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- **Pile-up = 42 in pp collisions**

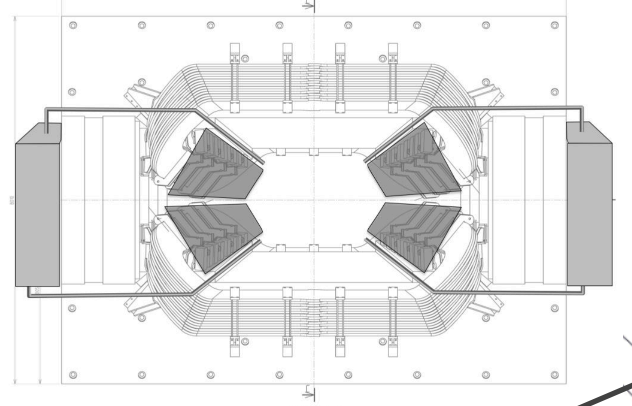
VELO



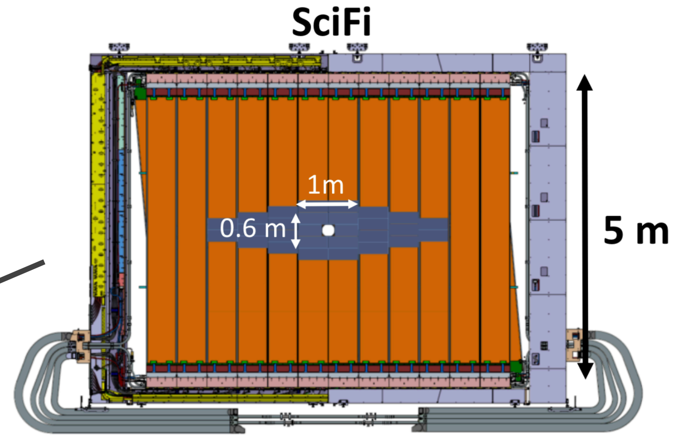
Upstream Tracker



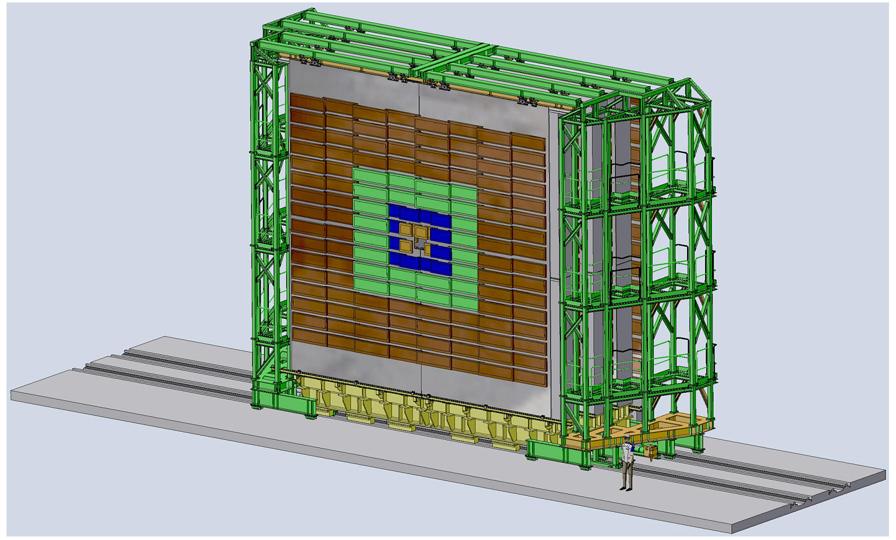
Magnet Station



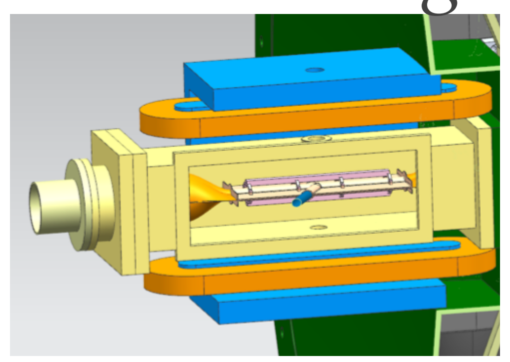
Mighty Tracker

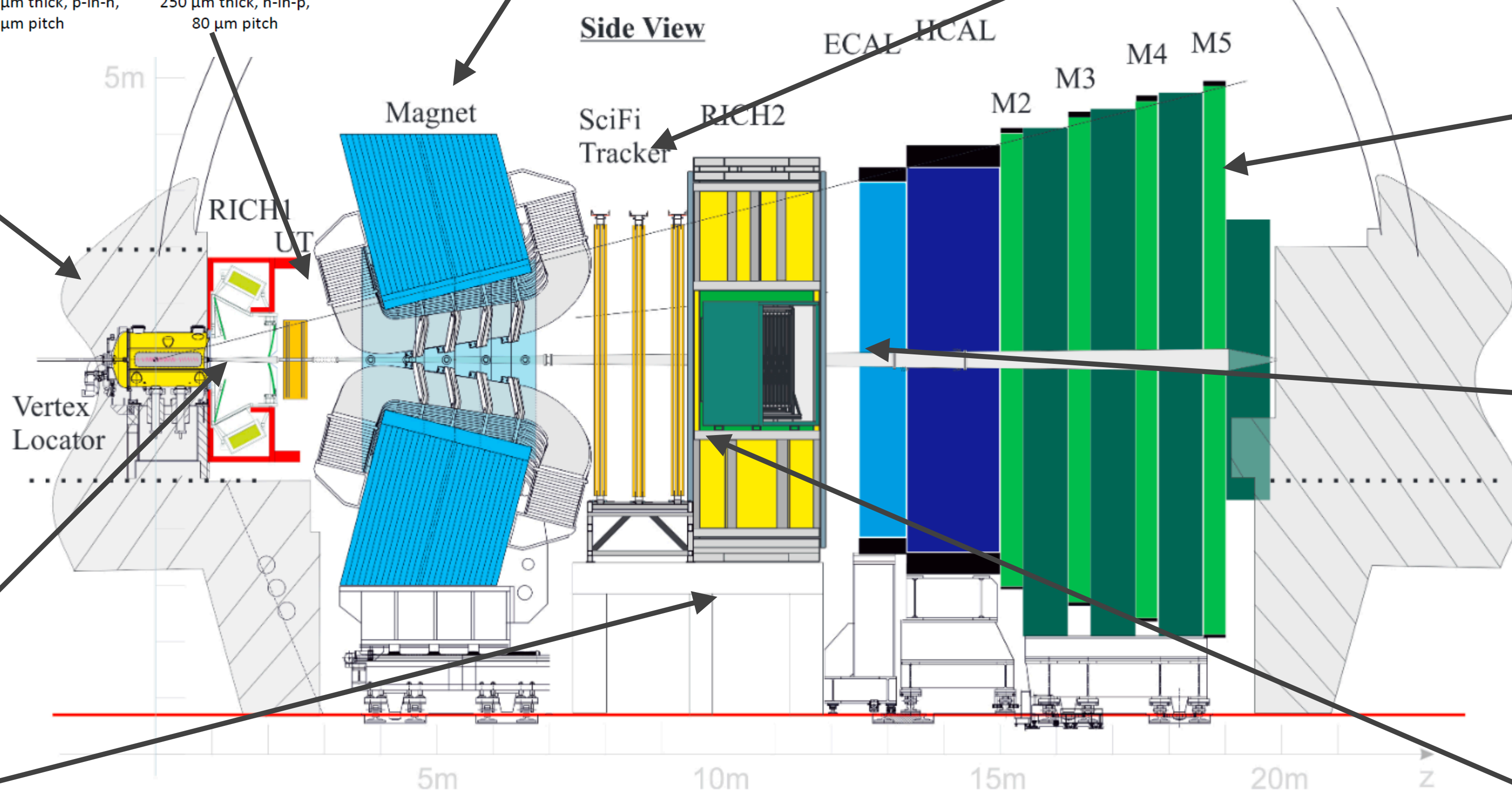


Muon station



Polarized target

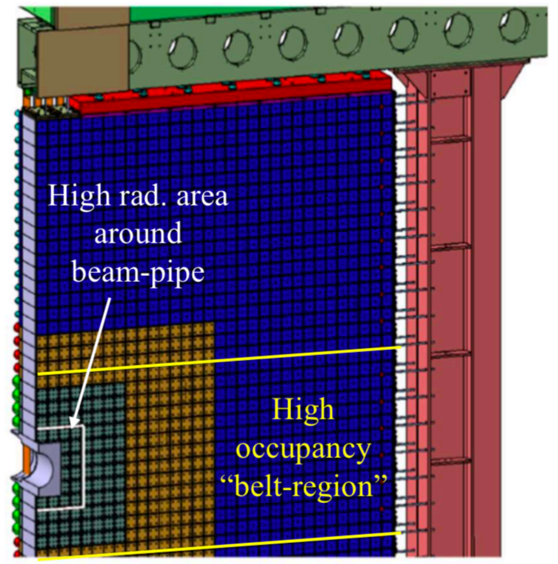




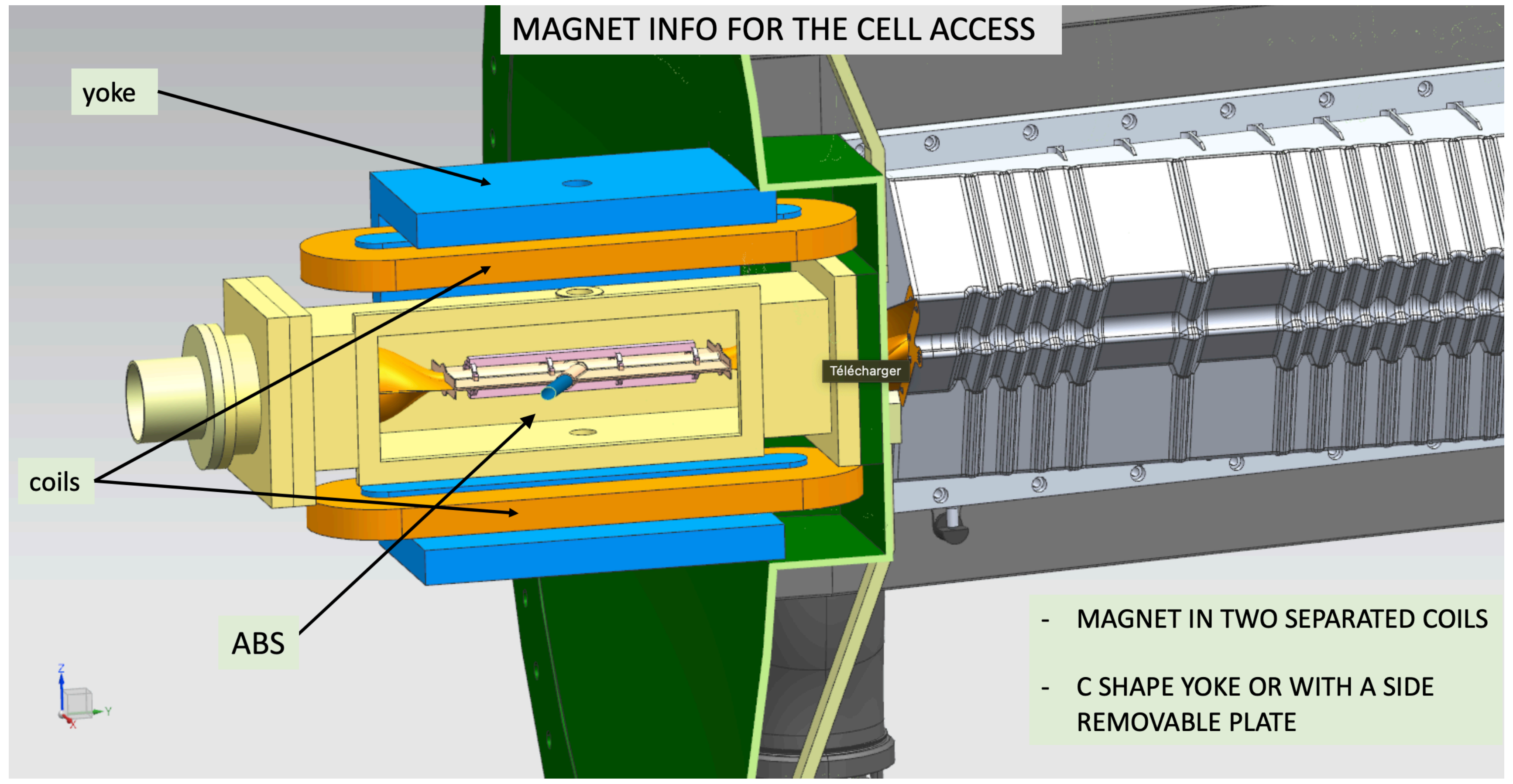
New RICHs

TORCH

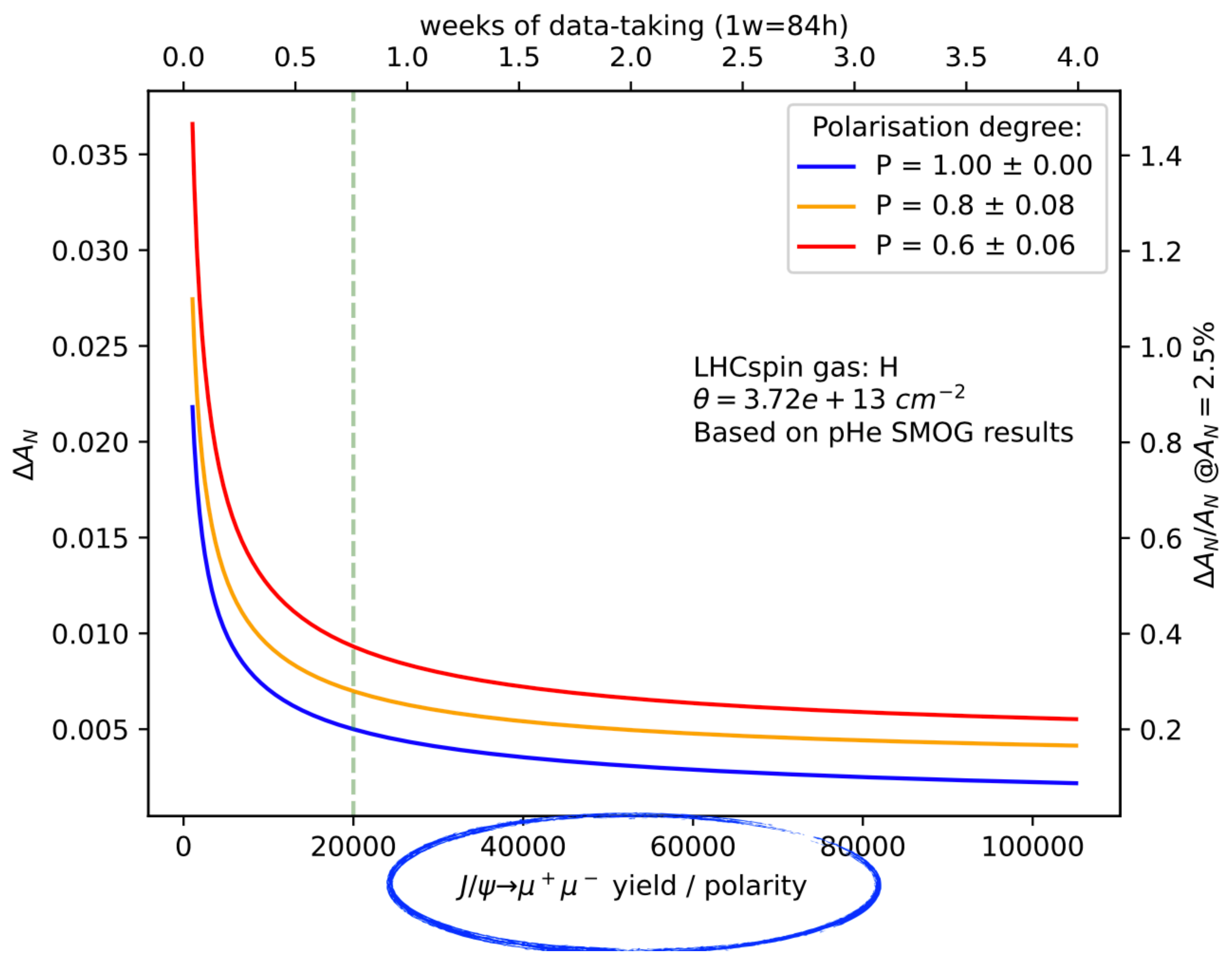
Ecal

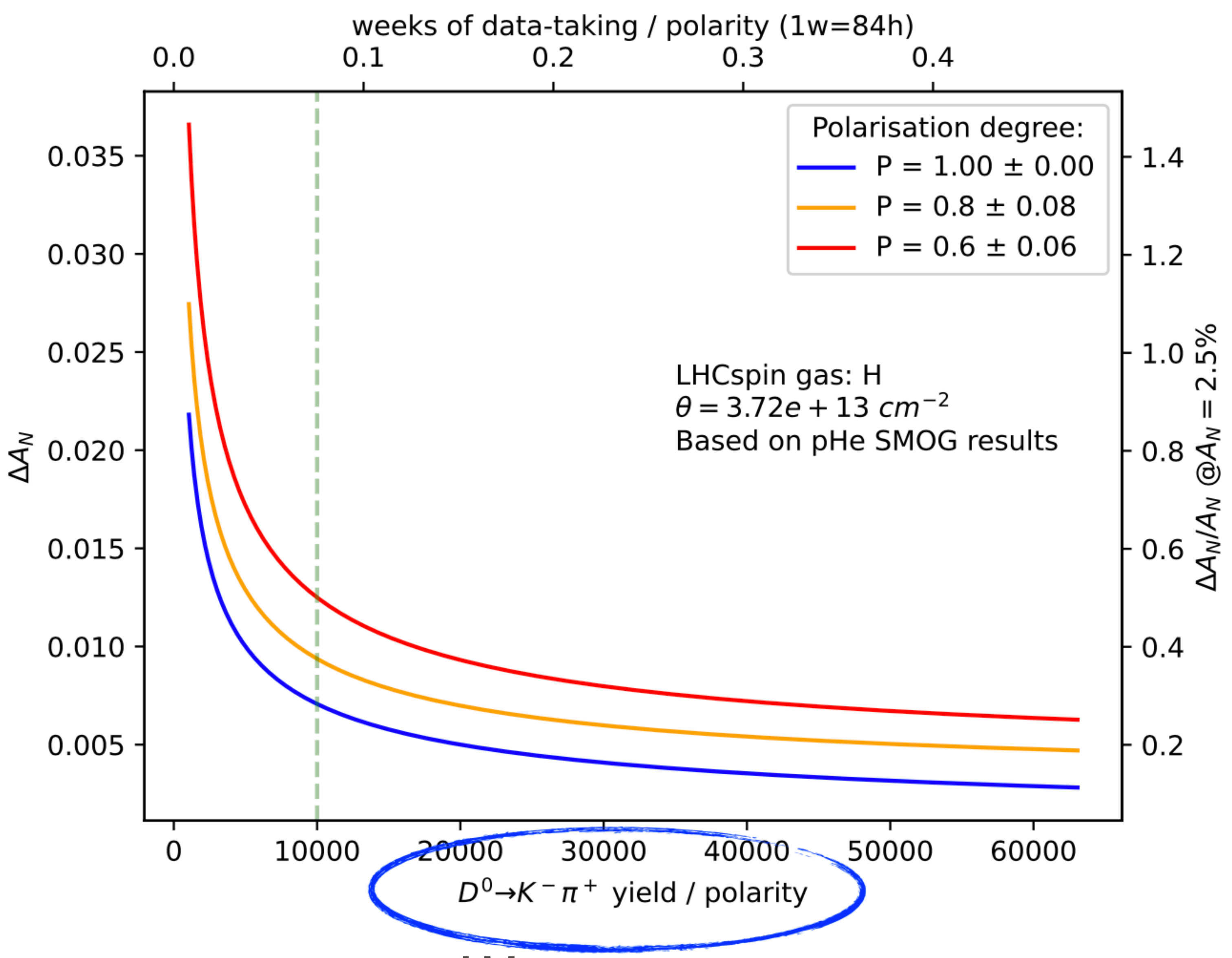


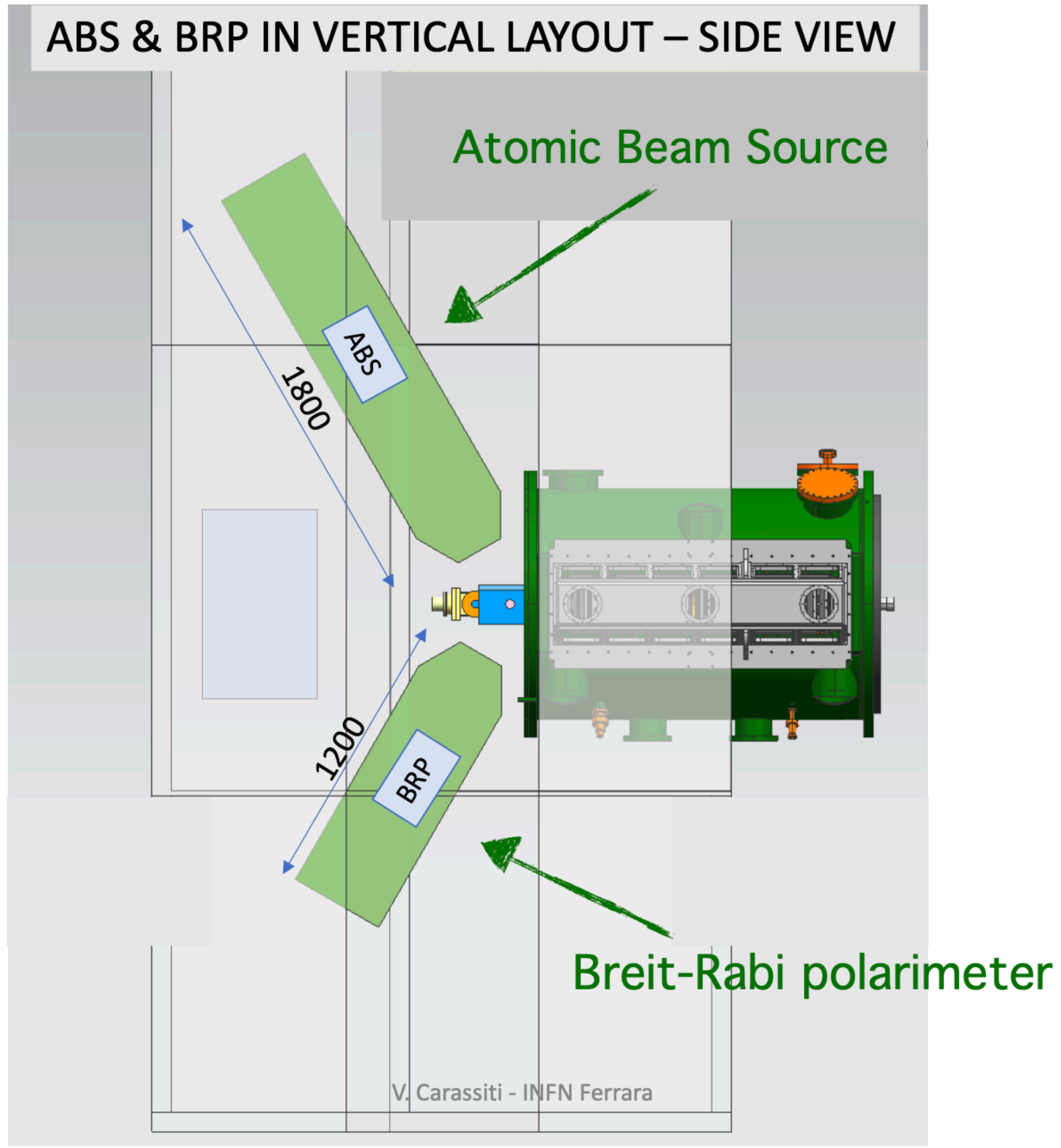
The Polarised Gas Target: LHCspin



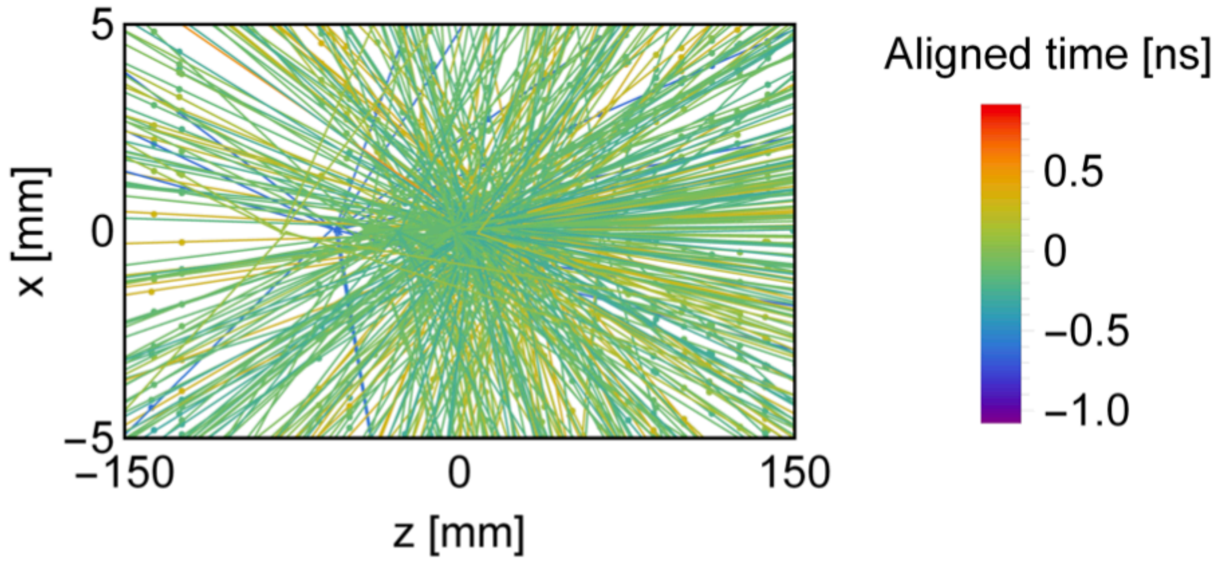
- R&D has started!
  - Compact dipole magnet static → transverse field.
  - Superconductive coils + iron yoke configuration fits the space constraints.
  - $B = 300$ mT, $\Delta B/B \simeq 10$ %, with polarity inversion.
- Achievable Luminosity (HL-LHC): $\sim 8 \times 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- Could be installed during LS3!



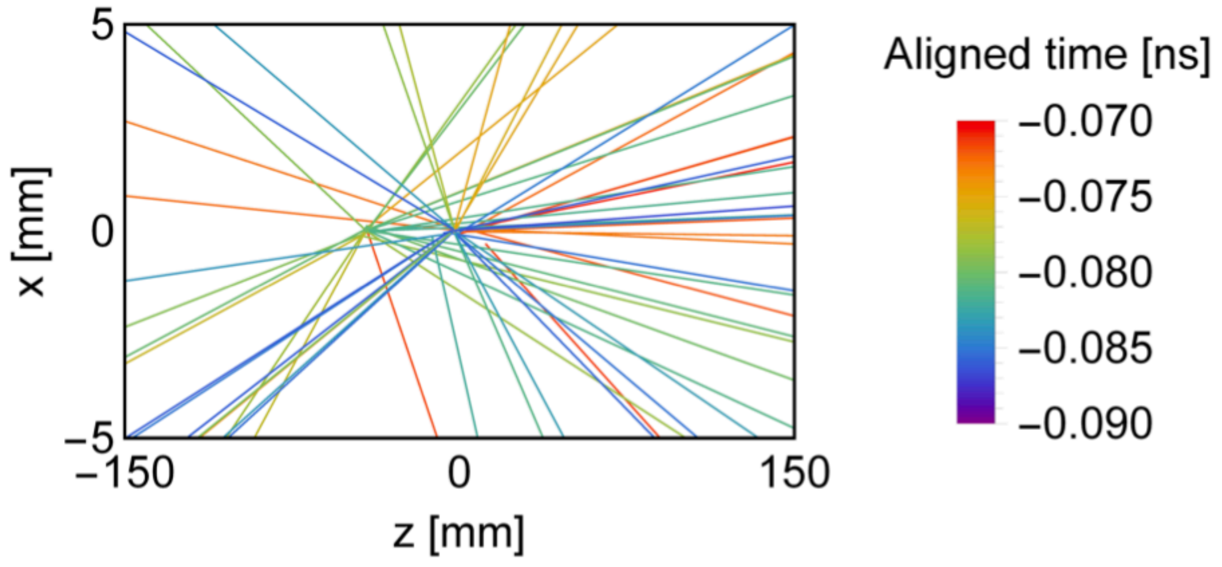




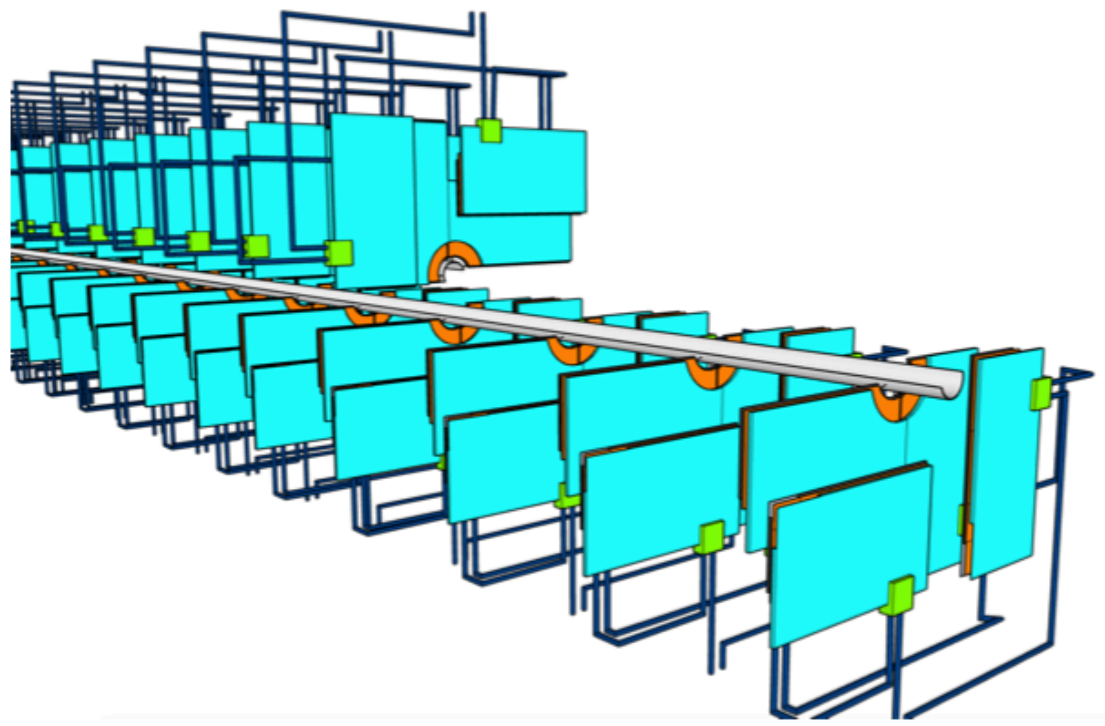
VELO upgrade



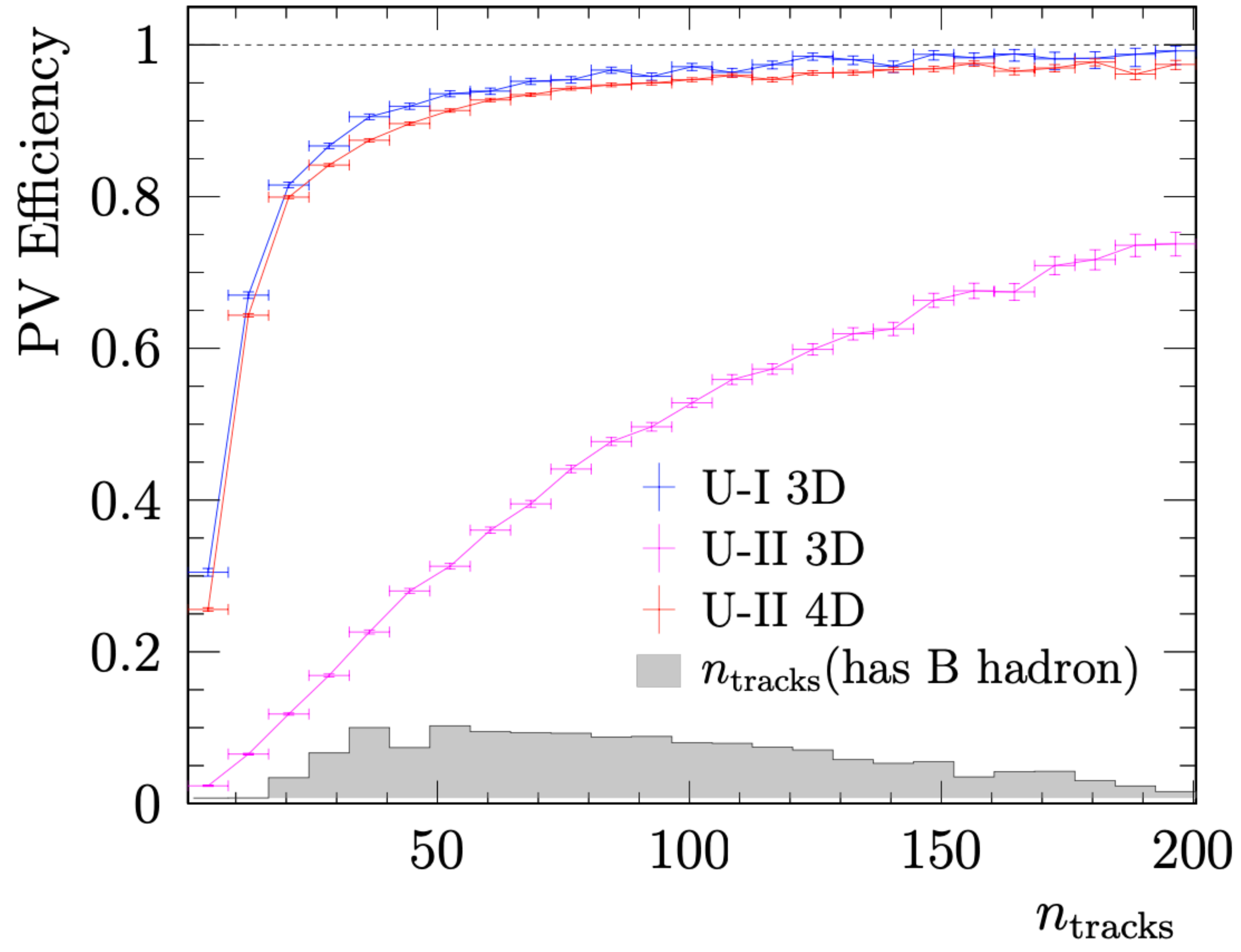
pp bunch-crossing



pp bunch-crossing + 20 ps resolution



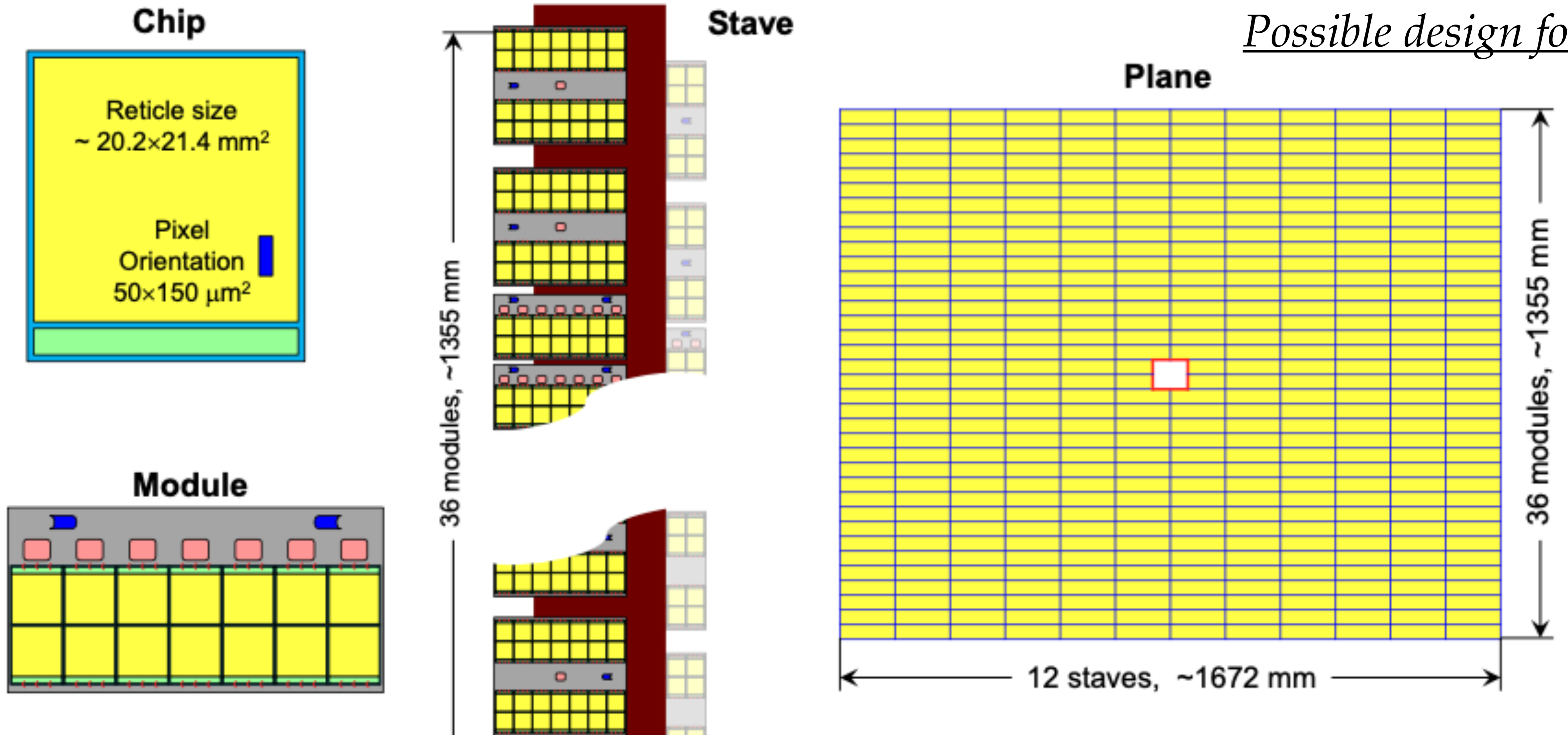
Possible design for the new VELO



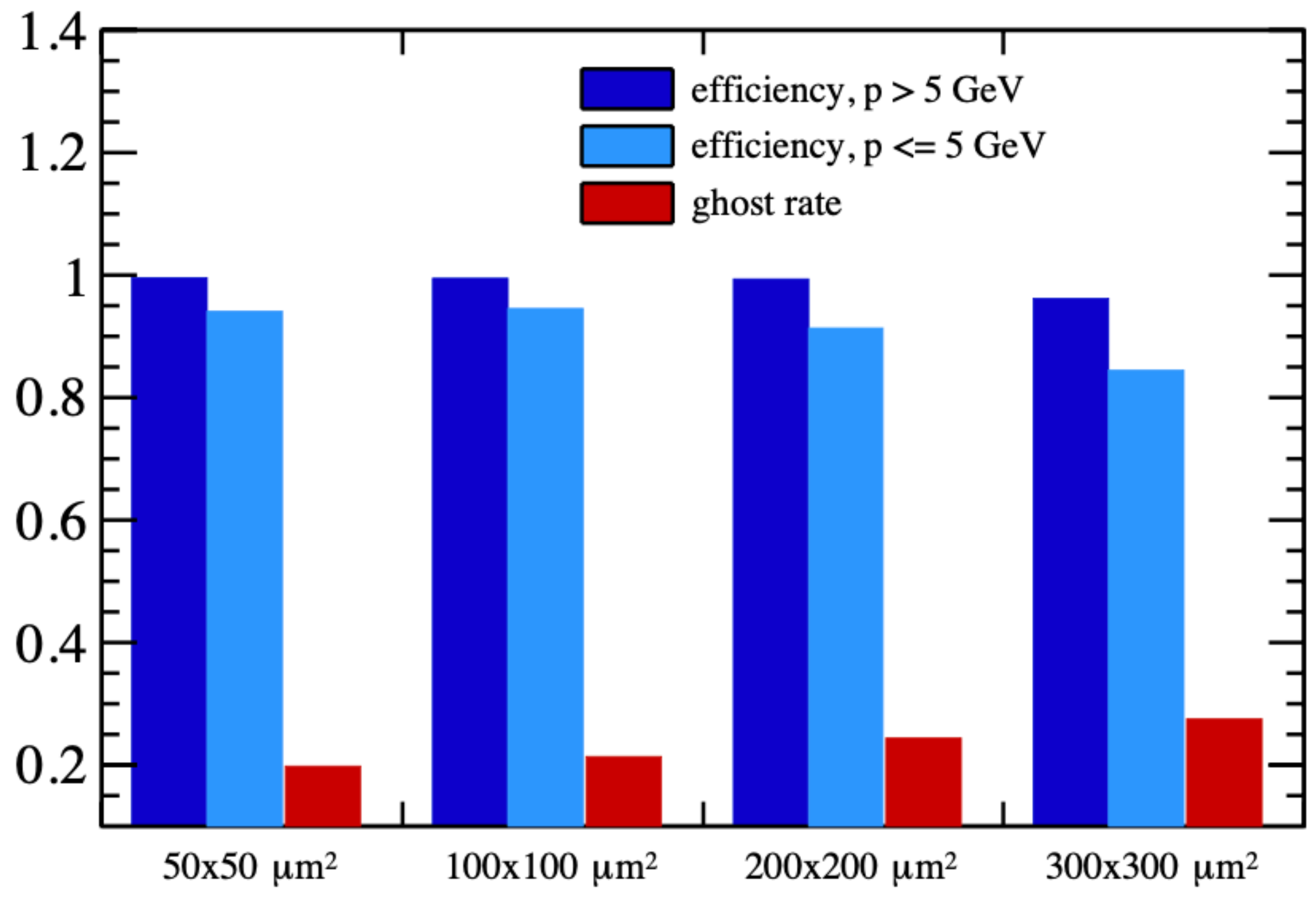
- Upgrade II VELO faces **significant mechanical challenges**
  - ➡ huge impact on the design and R&D.
- **Track timing will be crucial**
- Performance contrains:
  - ➡ 9-12 μm spatial resolution.
  - ➡ 4D tracking with 50 ps timestamp…
  - ➡ … and of course radiation hardness ($\sim 6 \times 10^{16}$ MeV n_{eq}/cm^2 for 350 fb^{-1})
- Pixel technology under developments, as well as alternative solutions.

Upstream Tracker

- UT in LHCb:
  - Ghost rate reduction.
  - Tracking efficiency.
- Design constrains:
  - pp data: data-rate → 9 Gbps.
  - PbPb data: maximum occupancy → 50 hits/cm^2.
- Paramètre d'optimisation :
  - Hardware :
    - Chip technology, module design …
  - Software :
    - Algorithms developments.



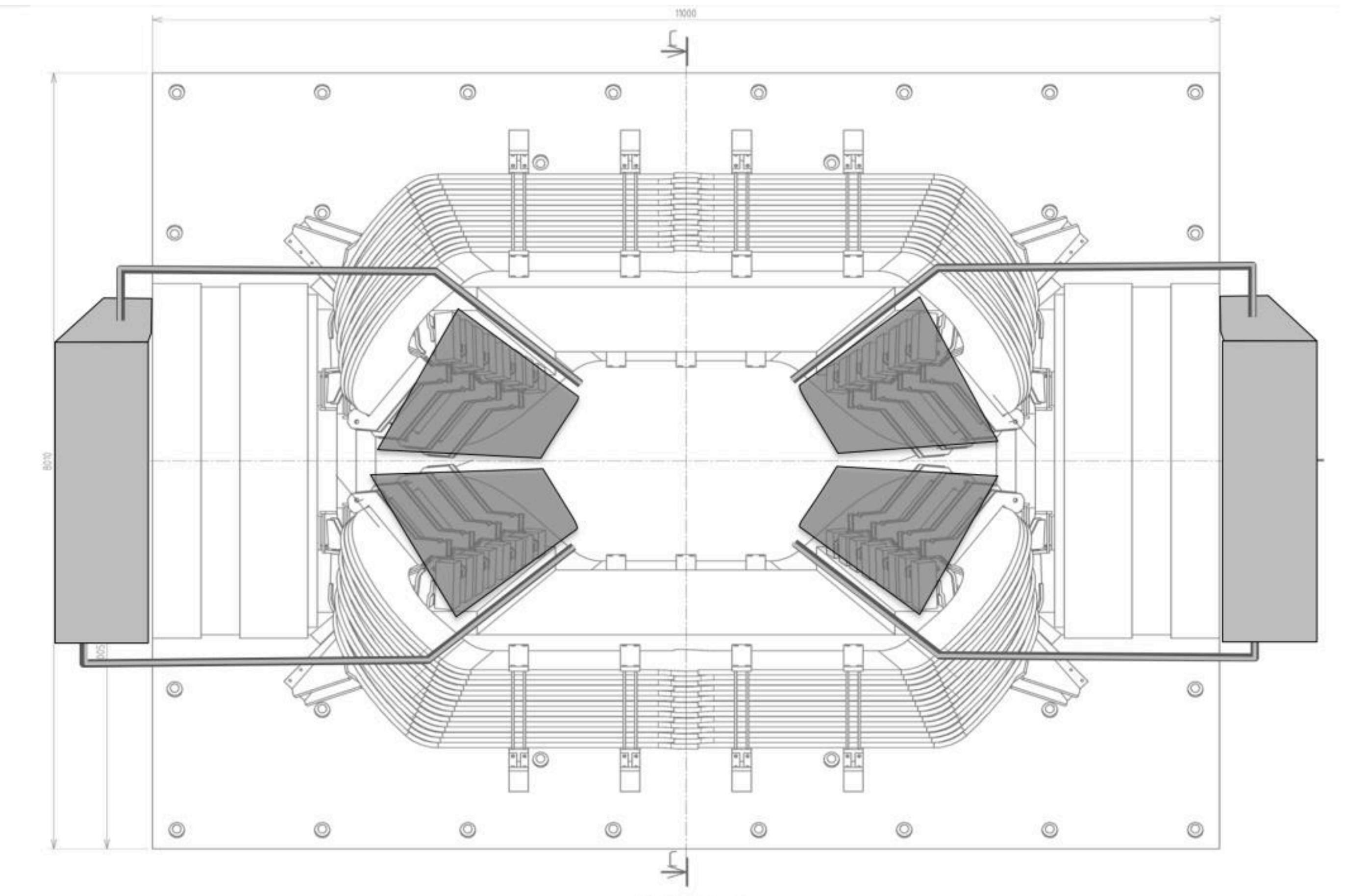
Possible design for the Run 5 UT

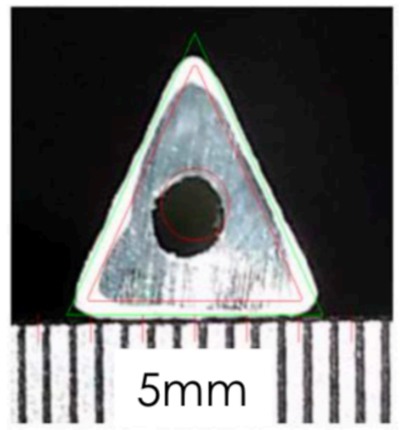


Standalone tracking efficiency studies

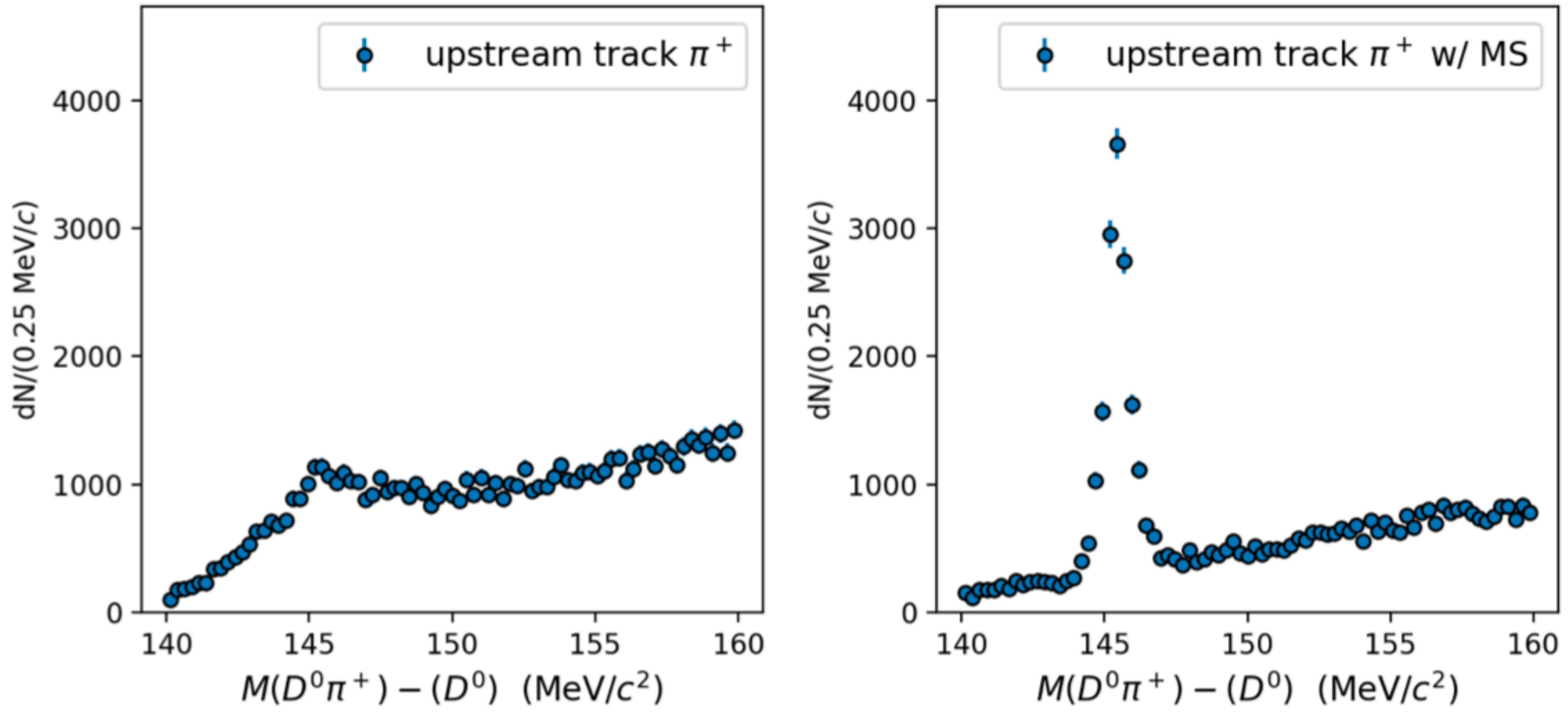
Magnet Tracking Station

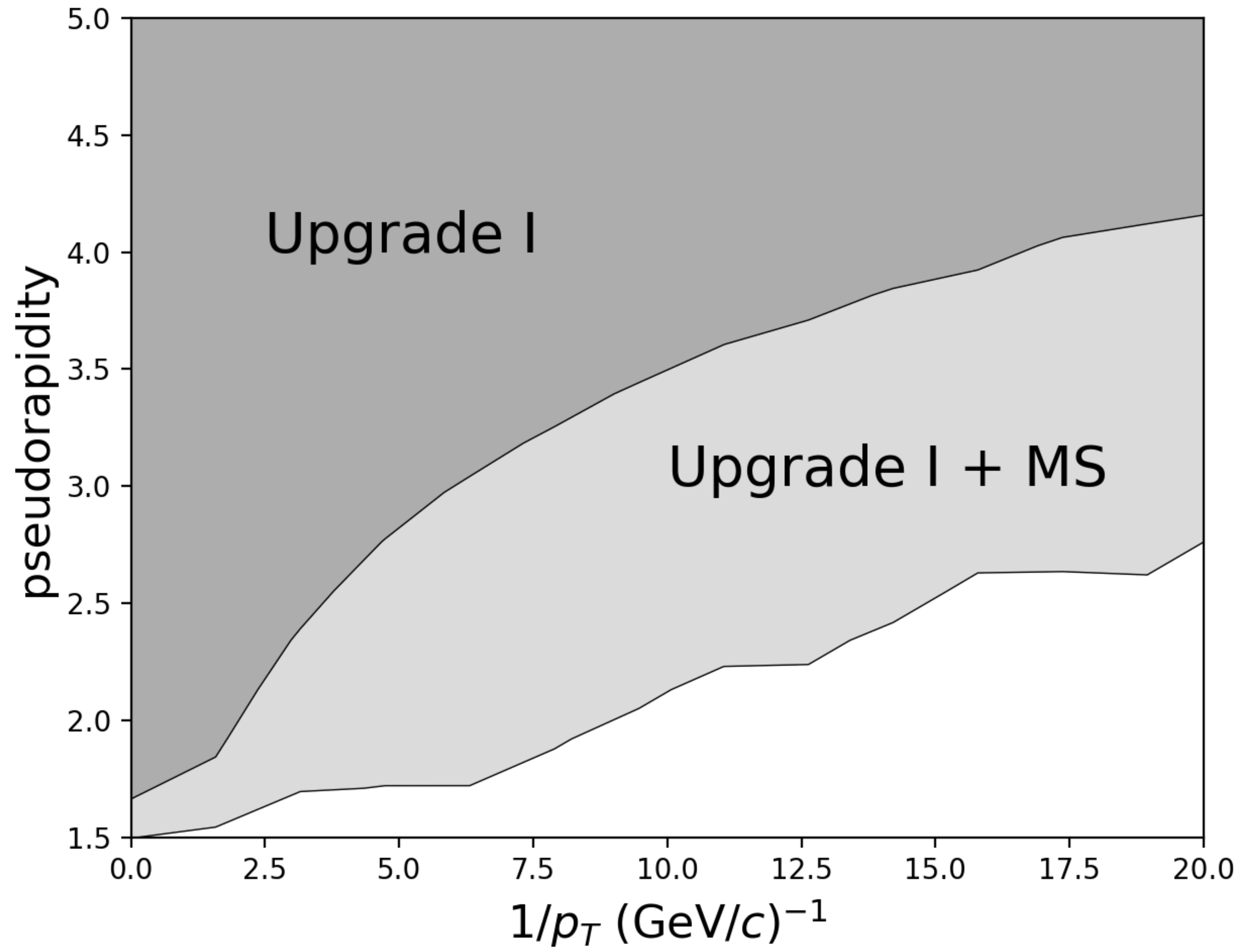
- Proposal for tracking station inside the magnet.
  - Increase coverage of Upstream tracks.
  - Physics motivations : **access to converted photons.**
- Technology:
  - Triangular Extruded Scintillating Bars (same as D0)
  - Ongoing R&D in LANL.
- **Proposing the installation of a small prototype** inside the magnet during LS3.





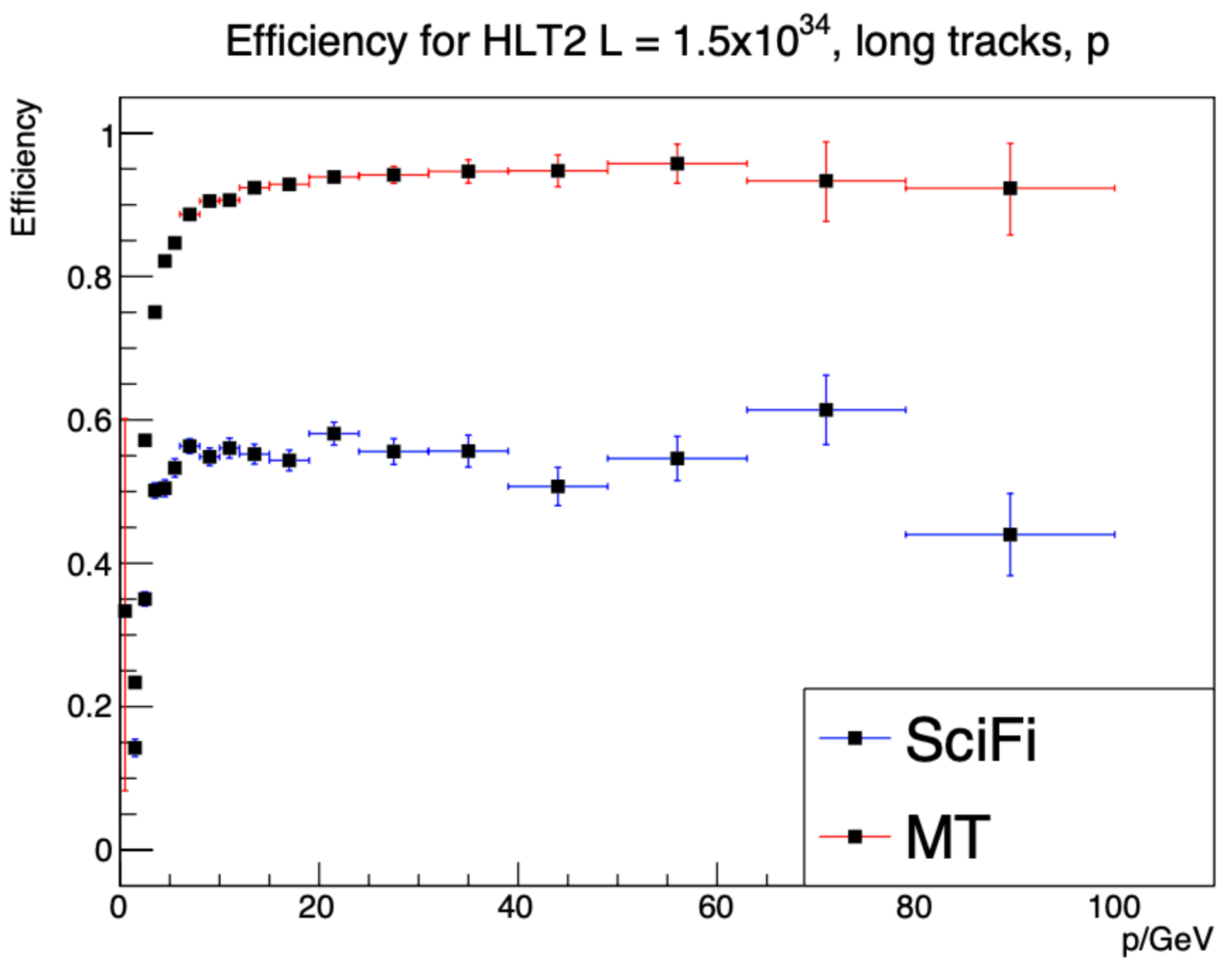
$p_{\mathrm{T}}\ (D^0\pi^+) < 1\ \mathrm{GeV}/c$

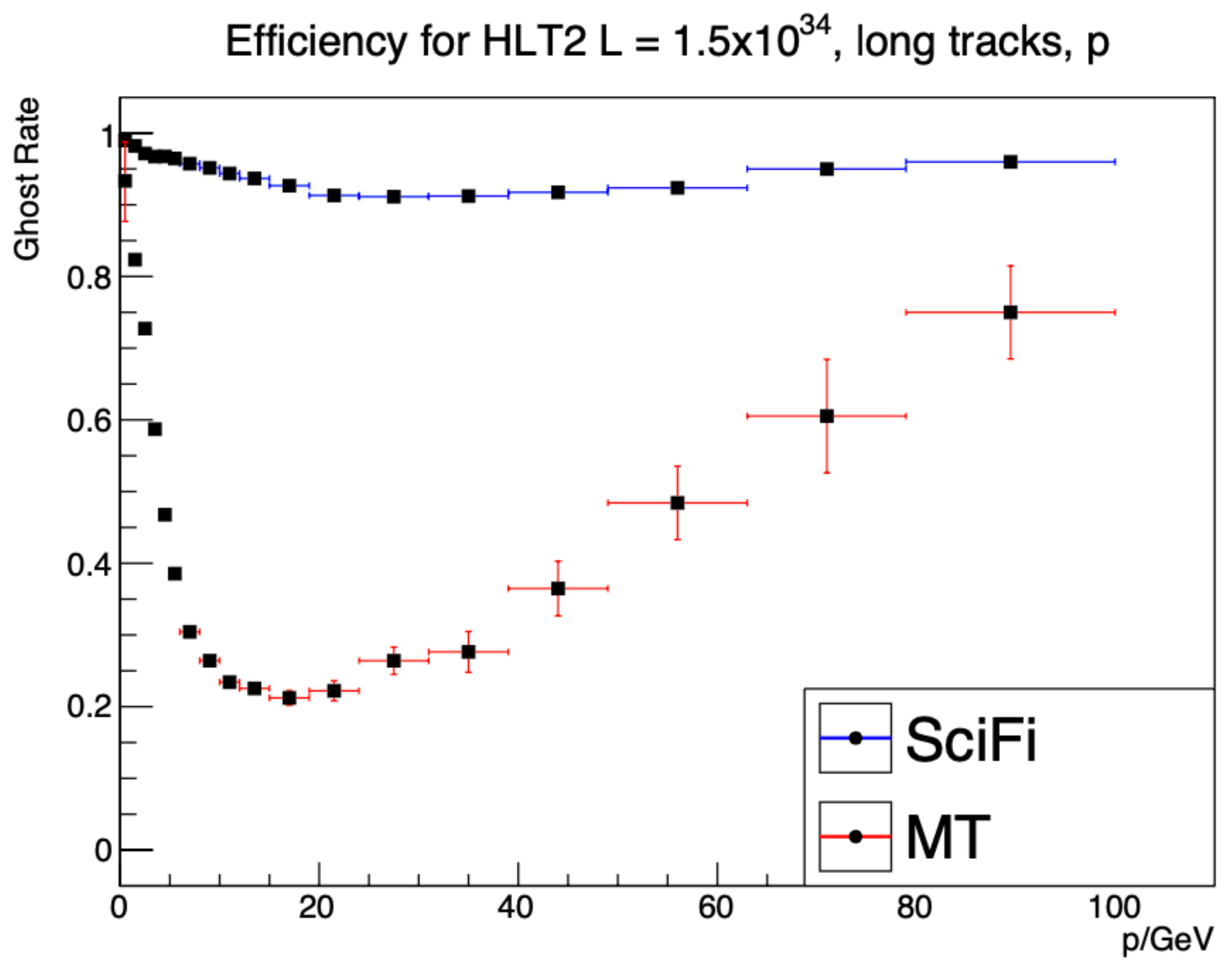


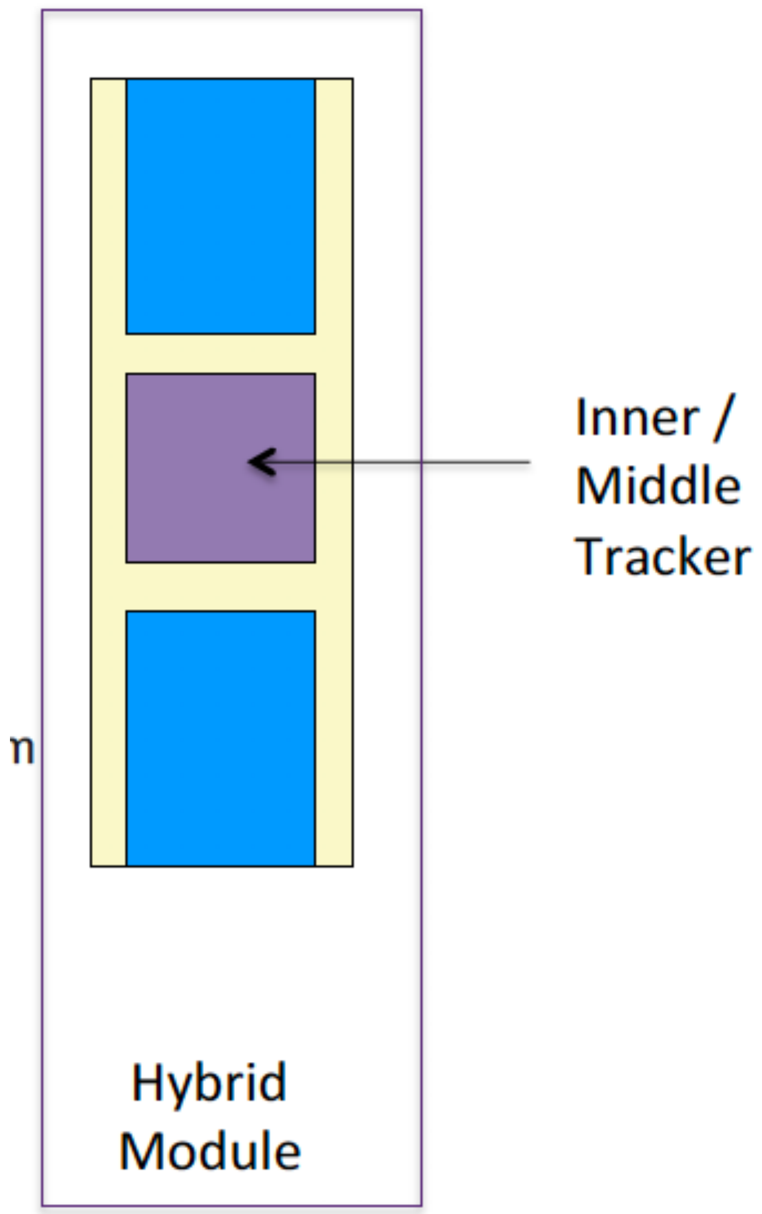


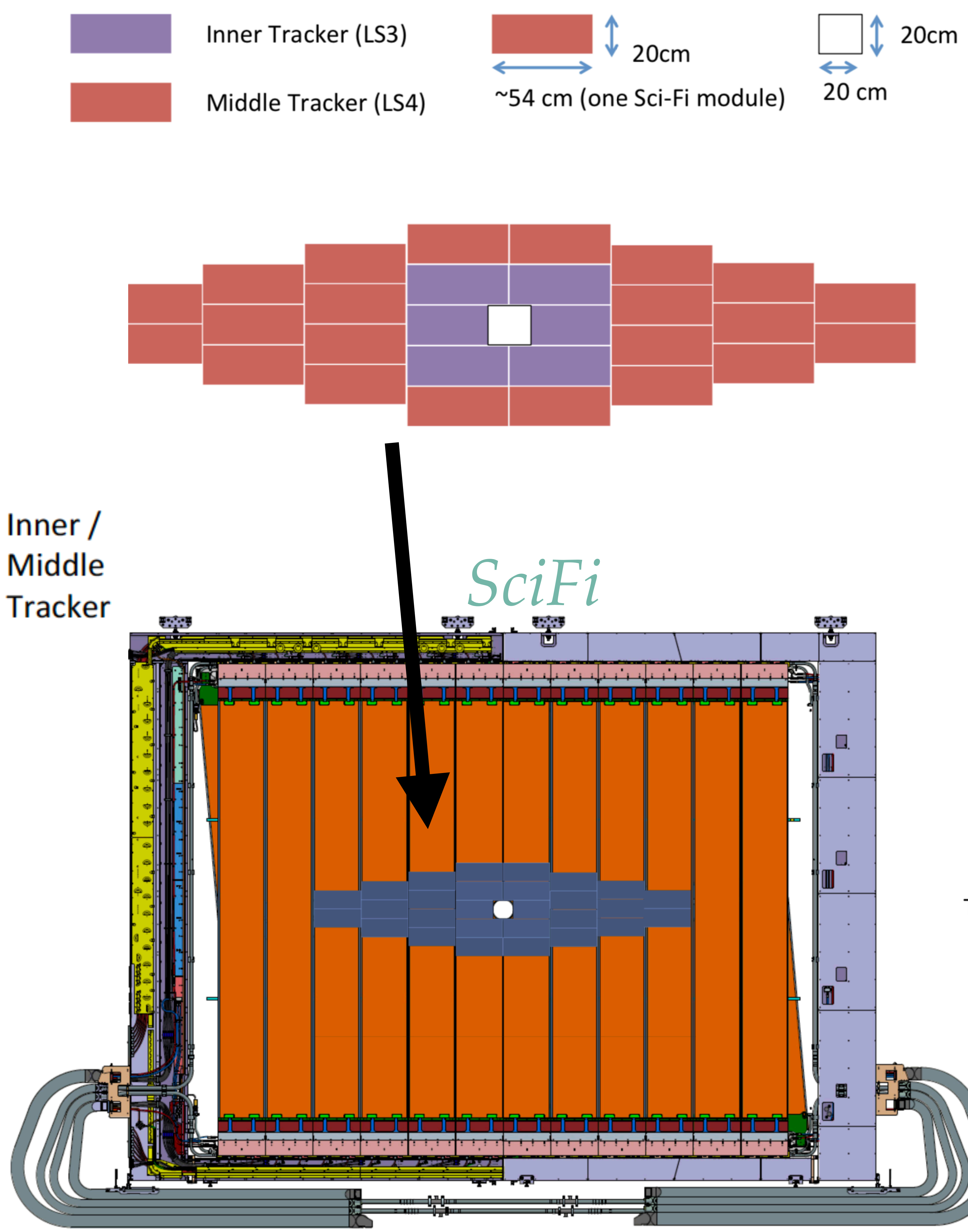
Mighty Tracker

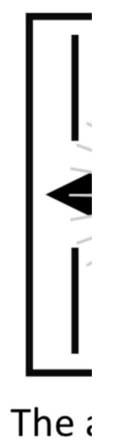
- Mighty tracker : biggest silicon tracker built by LHCb.
  - LS3: Inner Tracker + Scifi
    - Limited change to SciFi
  - LS4: New mighty silicon tracker covering larger area
    - Rebuild of SciFi + reuse IT
- Hybrid technology detector, many challenges !
  - Very similar to the UT -> joined development is likely.











Conclusion

- Lessons learned from run I - run II :
  - LHCb **fully performant** in peripheral HI collisions.
  - Main limitations : **tracking**
- Expectations for LHCb upgrade I :
  - **New tracking detectors + algorithms** benefit HI collisions !
  - LHCb **can reconstruct particles up to ~30% centrality** without specific tuning !
- LHCb Upgrade II (U2):
  - Brand new detector with **no hardware limitations foreseen for heavy-ion physics**.
  - **Expansion of the fixed-target program with polarised target!**

Cost of Upgrade 2

Detector	Baseline (kCHF)
VELO	14800
UT	8900
Magnet Stations	2300
MT-SciFi	22400
MT-CMOS	19500
RICH	15600
TORCH	9900
ECAL	34800
Muon	7100
RTA	17400
Online	8900
Infrastructure	13500
Total	175100

Back-up

PID detector system: RICH

- RICH requirements:
  - Occupancy bellow 30% in RICH1.
  - σ_θ>0.5 mrad.
  - Timing!
- RICH1 geometry:
  - **New photo-detectors and readout chain.**
  - Reducing the tilt of spherical mirror → place mirror inside LHCb's acceptance.
  - R&D ongoing to have light-weight carbon-fibre design

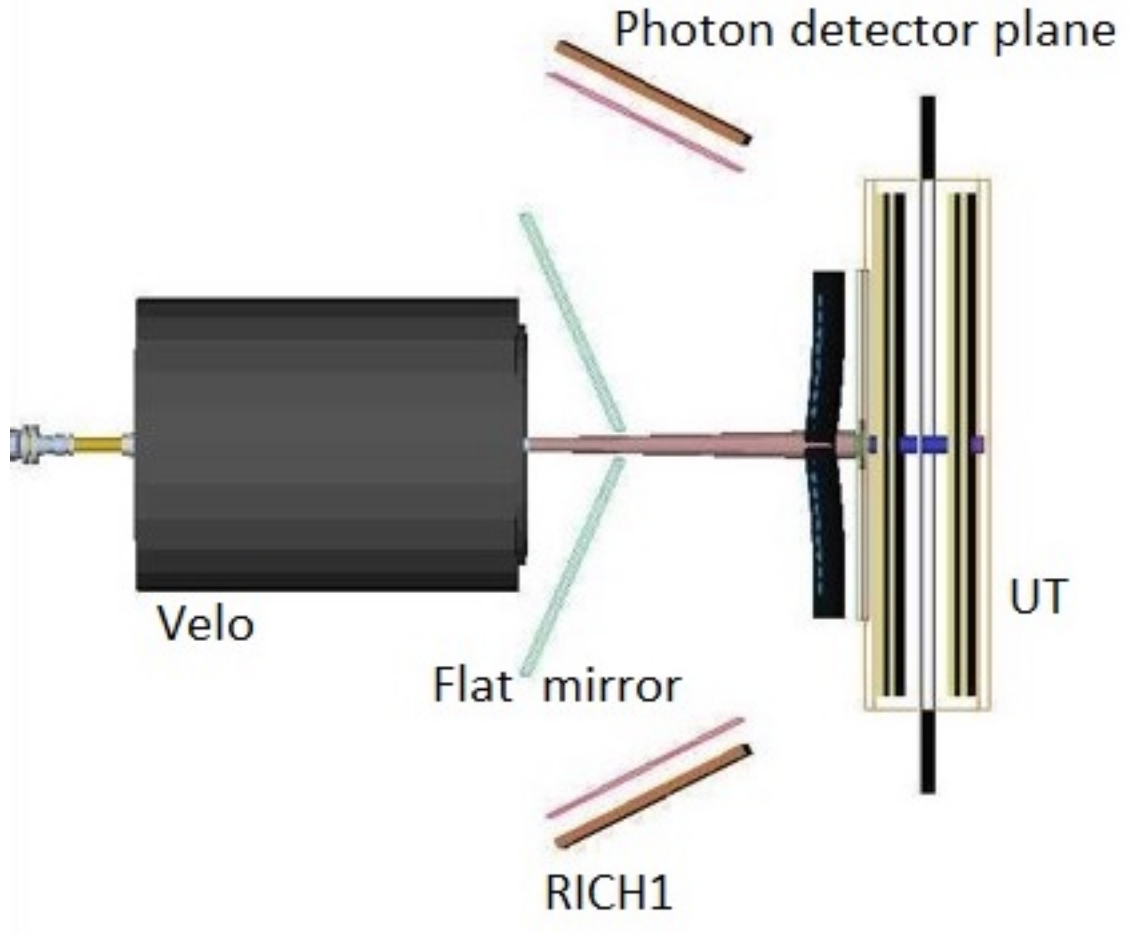
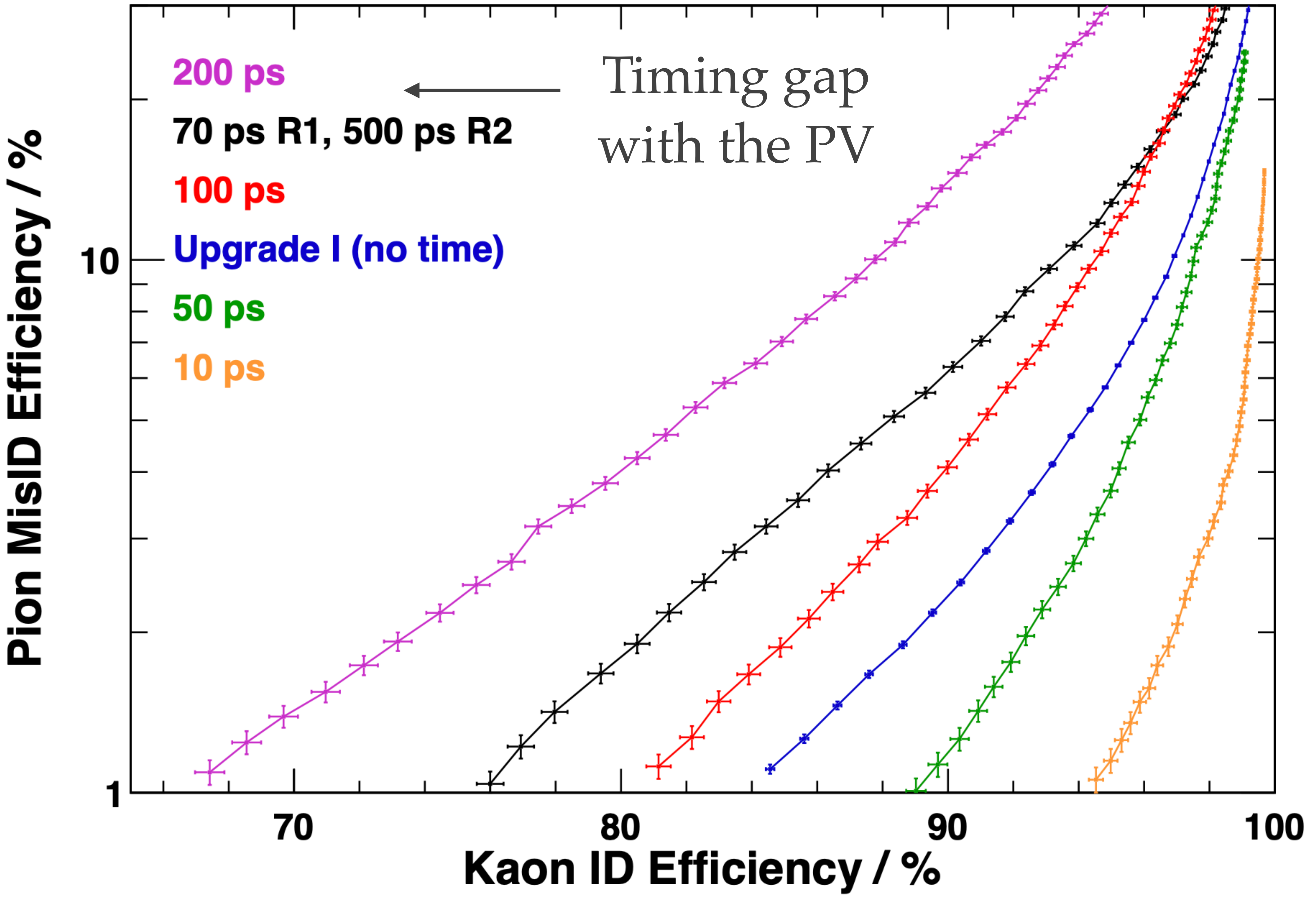


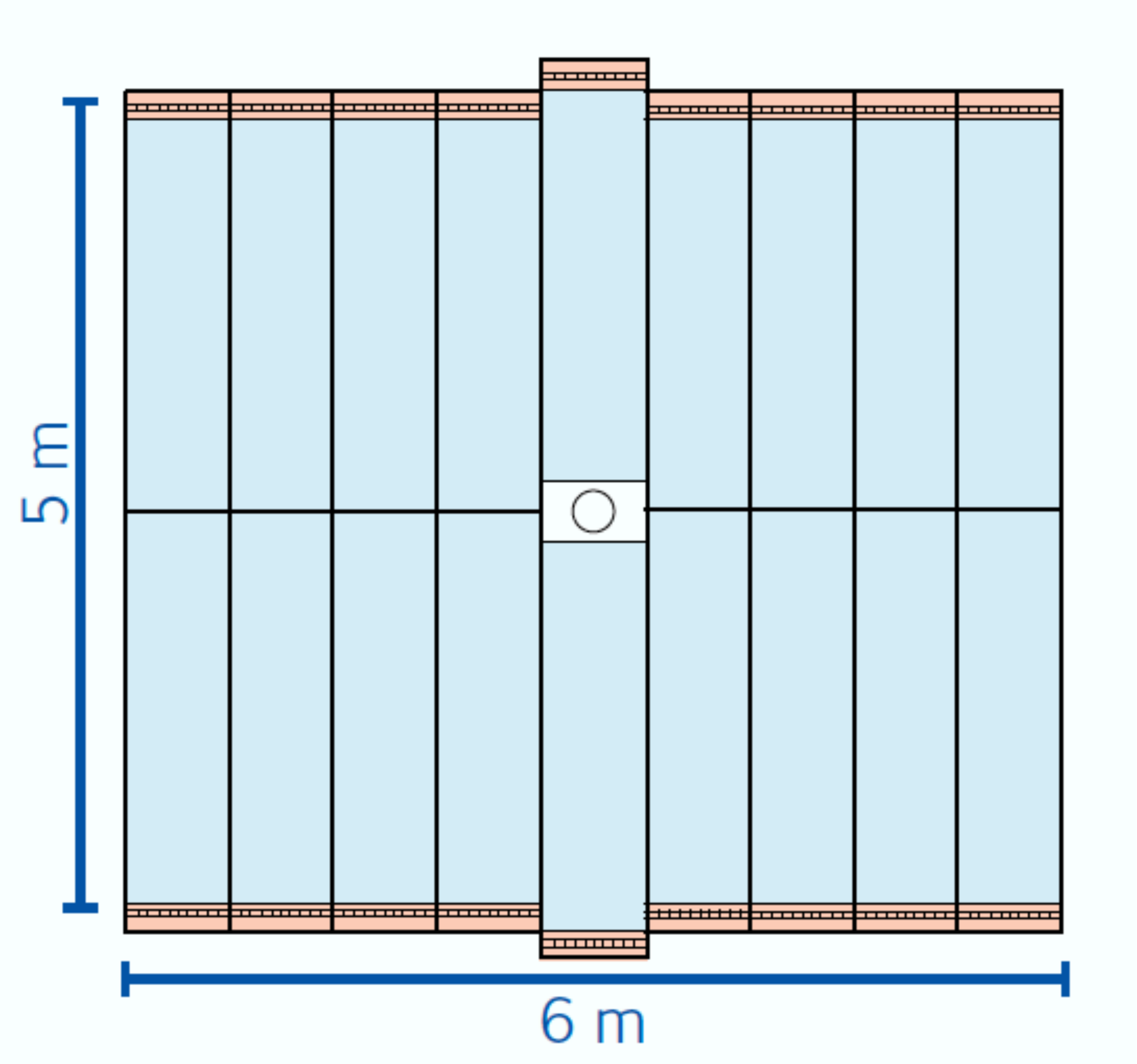
Table 4.2: Examples of peak occupancies in RICH1 obtained using the LHCb simulation framework, assuming a pixel size of $2.8 \times 2.8\,\text{mm}^2$ for the MaPMT and $1 \times 1\,\text{mm}^2$ for the SiPM.

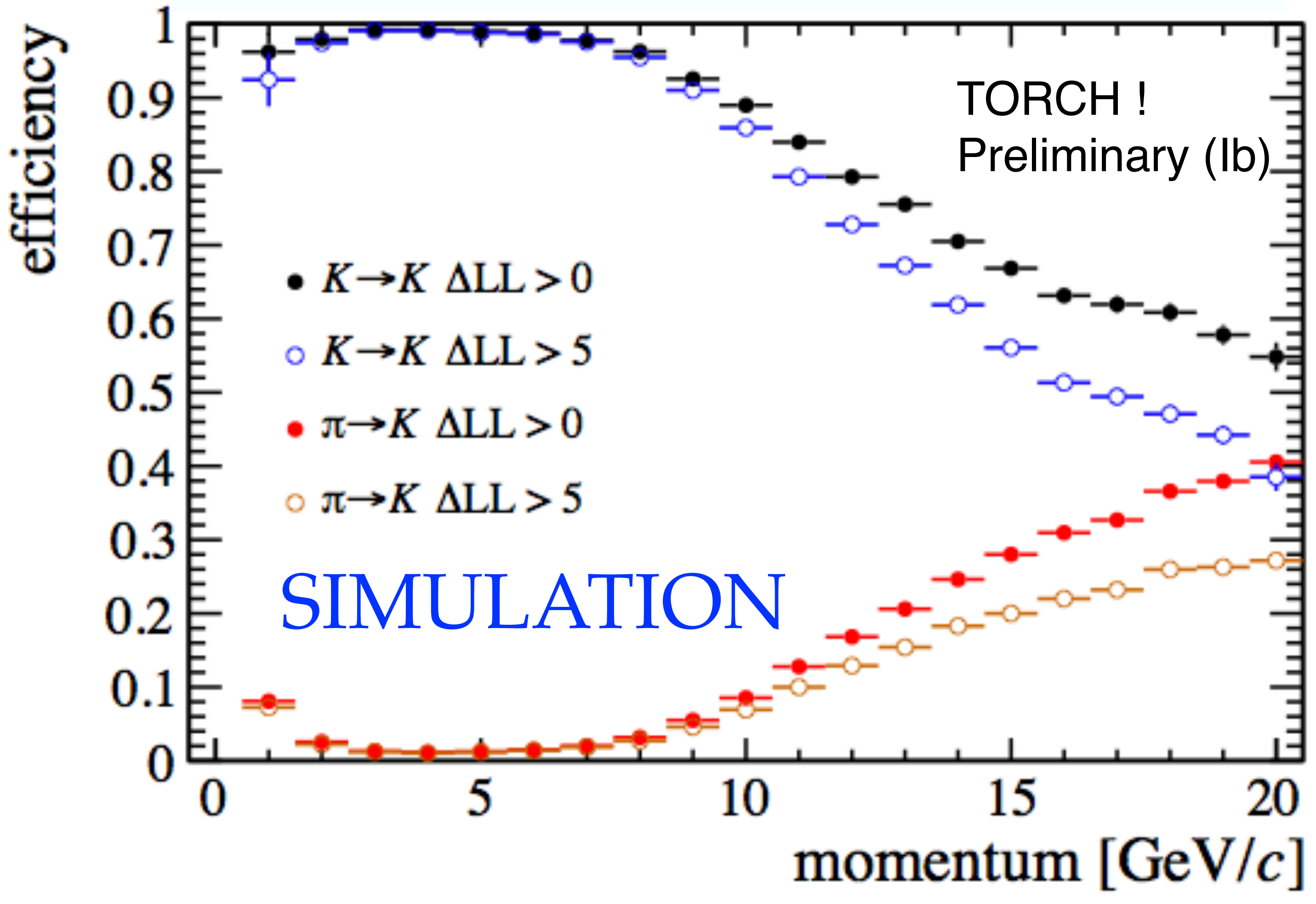
RICH1 peak occupancy	MaPMT	SiPM and geometry update
Upgrade I	35 %	3.9 %
Upgrade II	> 100 %	18 %



TORCH - Low momentum PID

- TORCH is a large area time of flight detector that is designed to provide PID in the GeV/c momentum range
  - Considered for use in Upgrade Ib.
  - Exploit prompt production of Cherenkov light in a quartz radiator plate to provide a fast timing signal.
  - Aim for a resolution of 10-15 ps per track
  - A large-scale prototype has been developed.
  - **Good separation between between π/K/p is possible in 2-10 GeV/c range.**

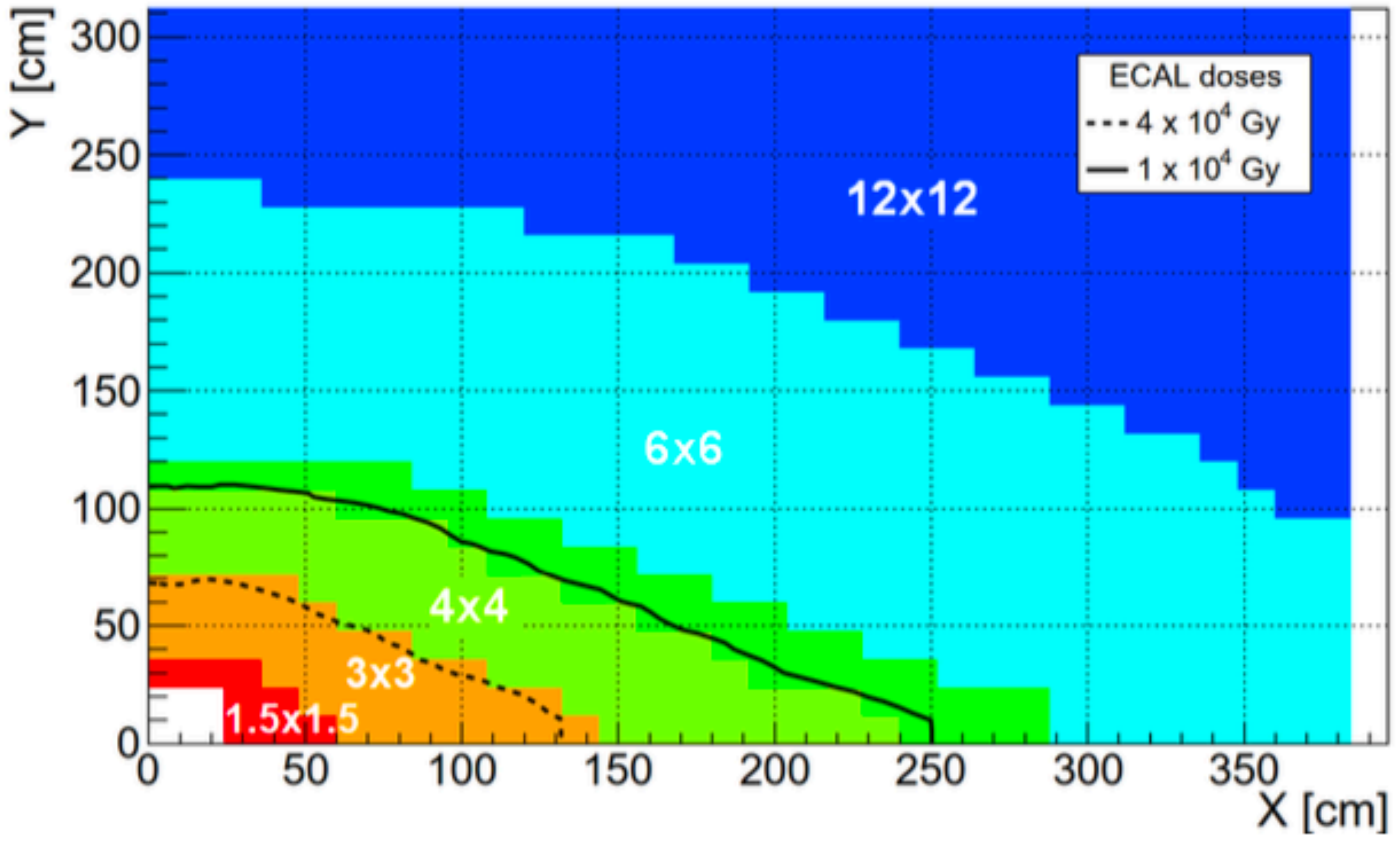


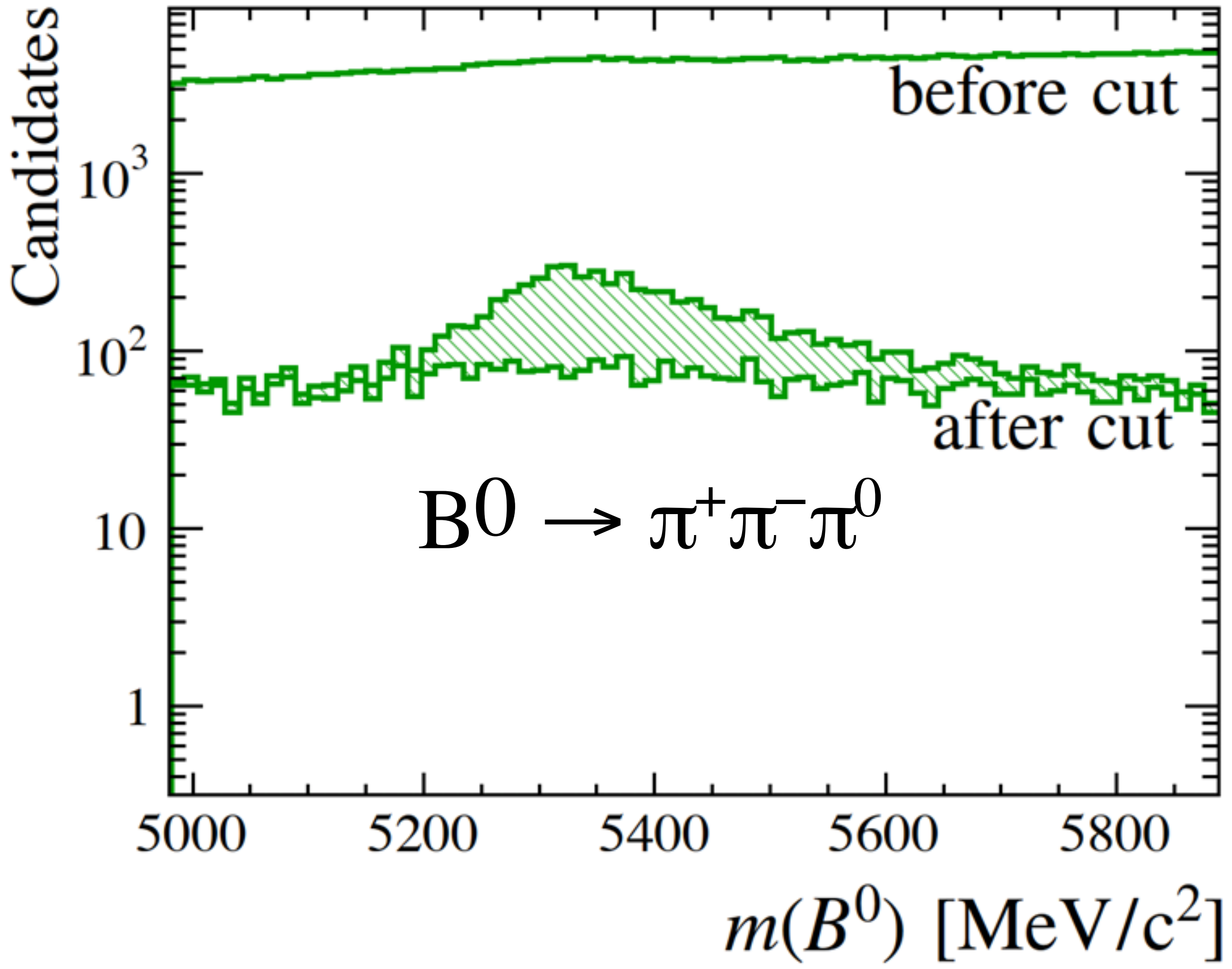


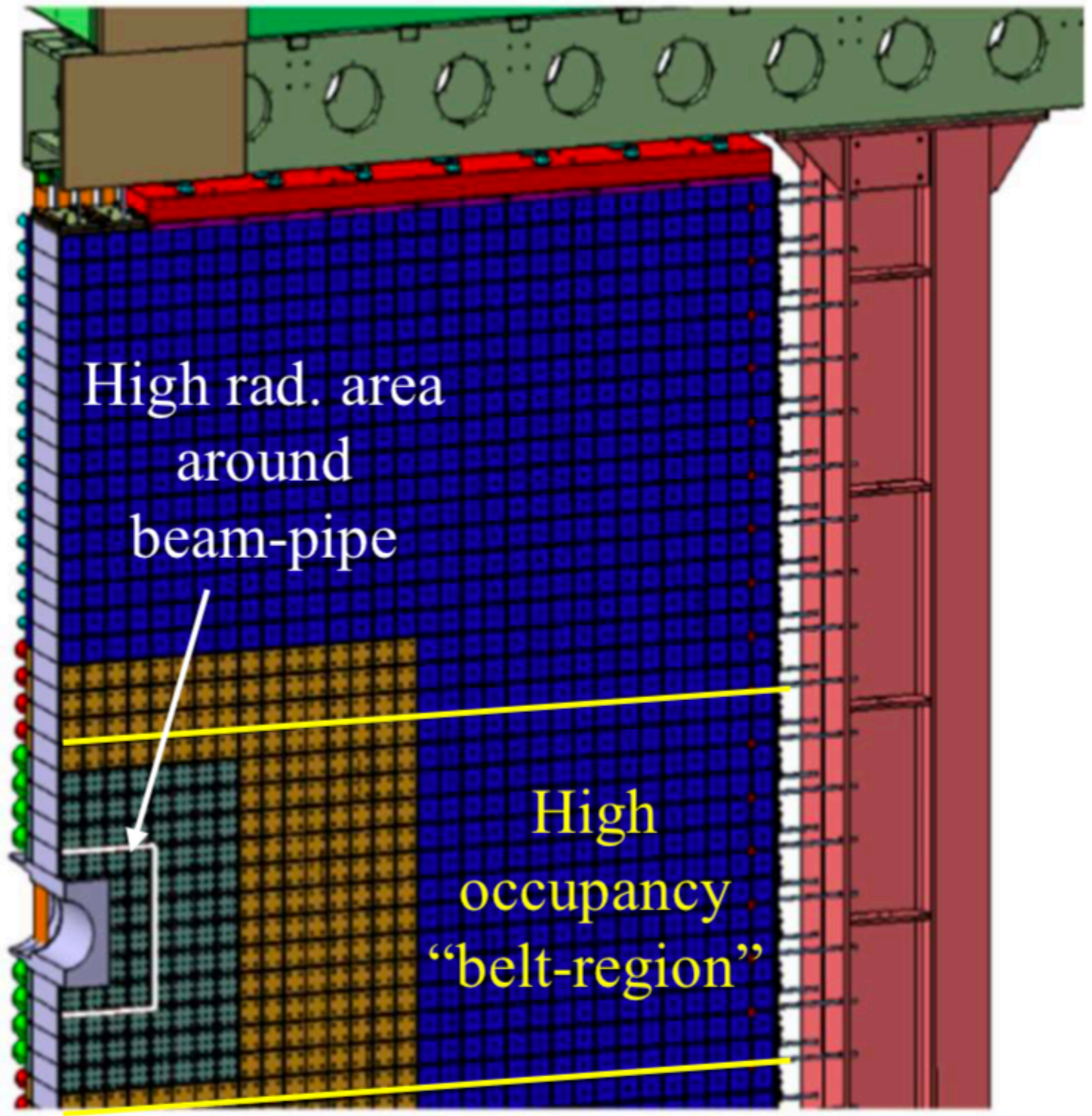
Half-scale demonstrator

PID detector system: ECAL

- Upgrade schedule:
  - LS3: replace modules around beam-pipe.
  - LS4: rebuilt the high occupancy ‘belt-region’ and include timing
- Studies on module’s technology ongoing.

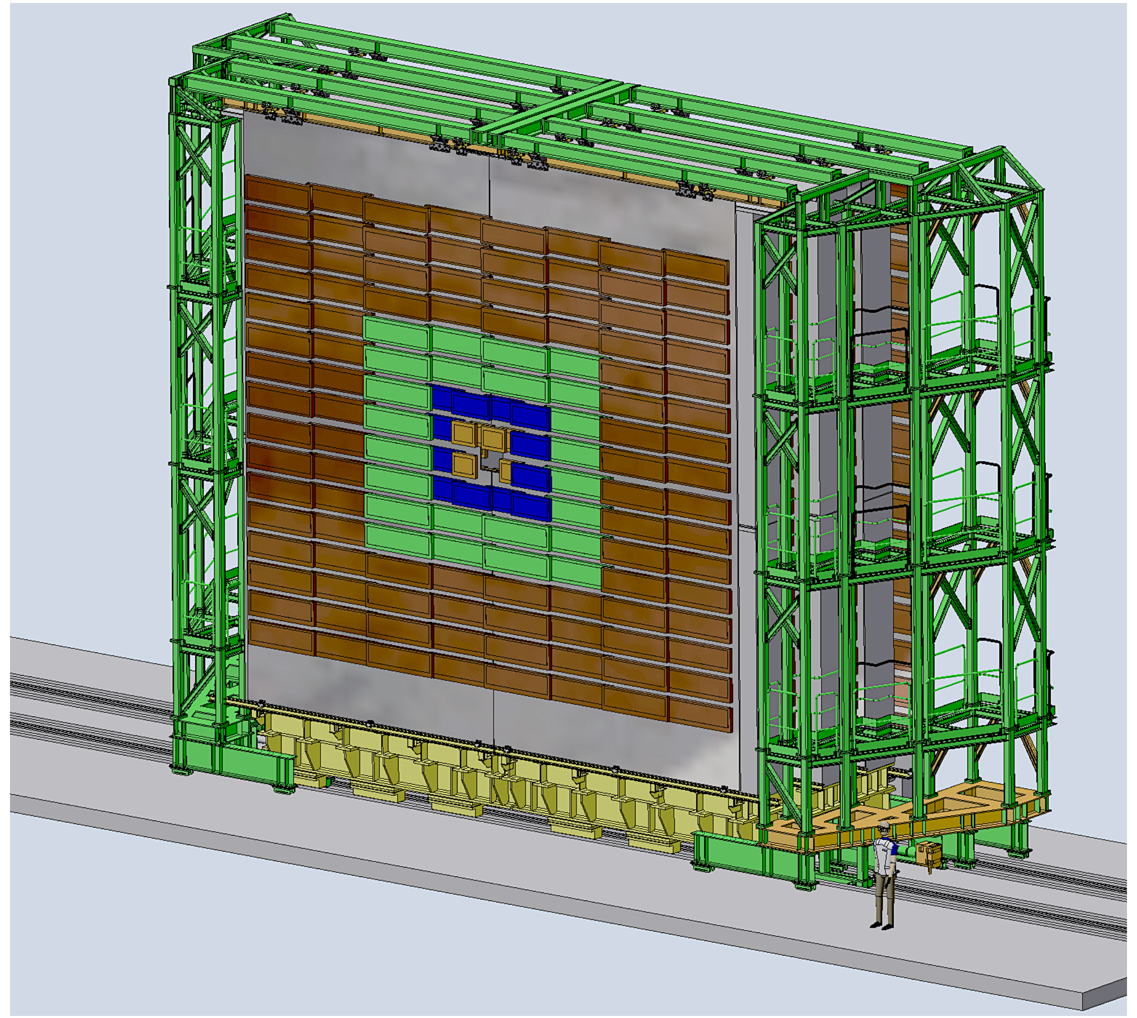


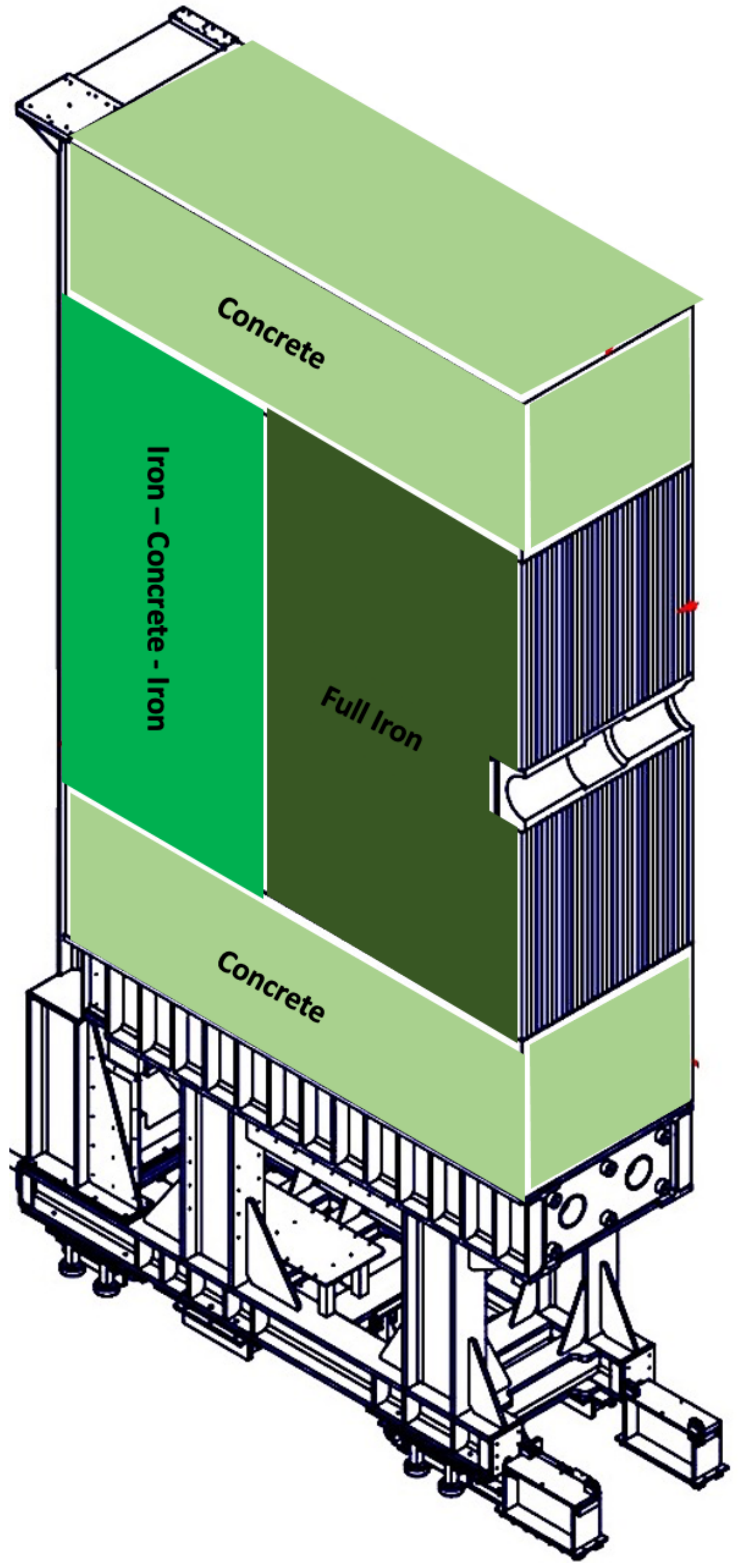




PID detector system: muon

- Main considerations:
  - Data rate too high for the current granularity.
  - No more shielding from HCal …
- General structure will remain the same with two different technologies:
  - μ–RWELL detectors for the high rate regions.
  - MWPC detectors for the low-rate regions.
- Studies ongoing to optimise granularity + new shielding.

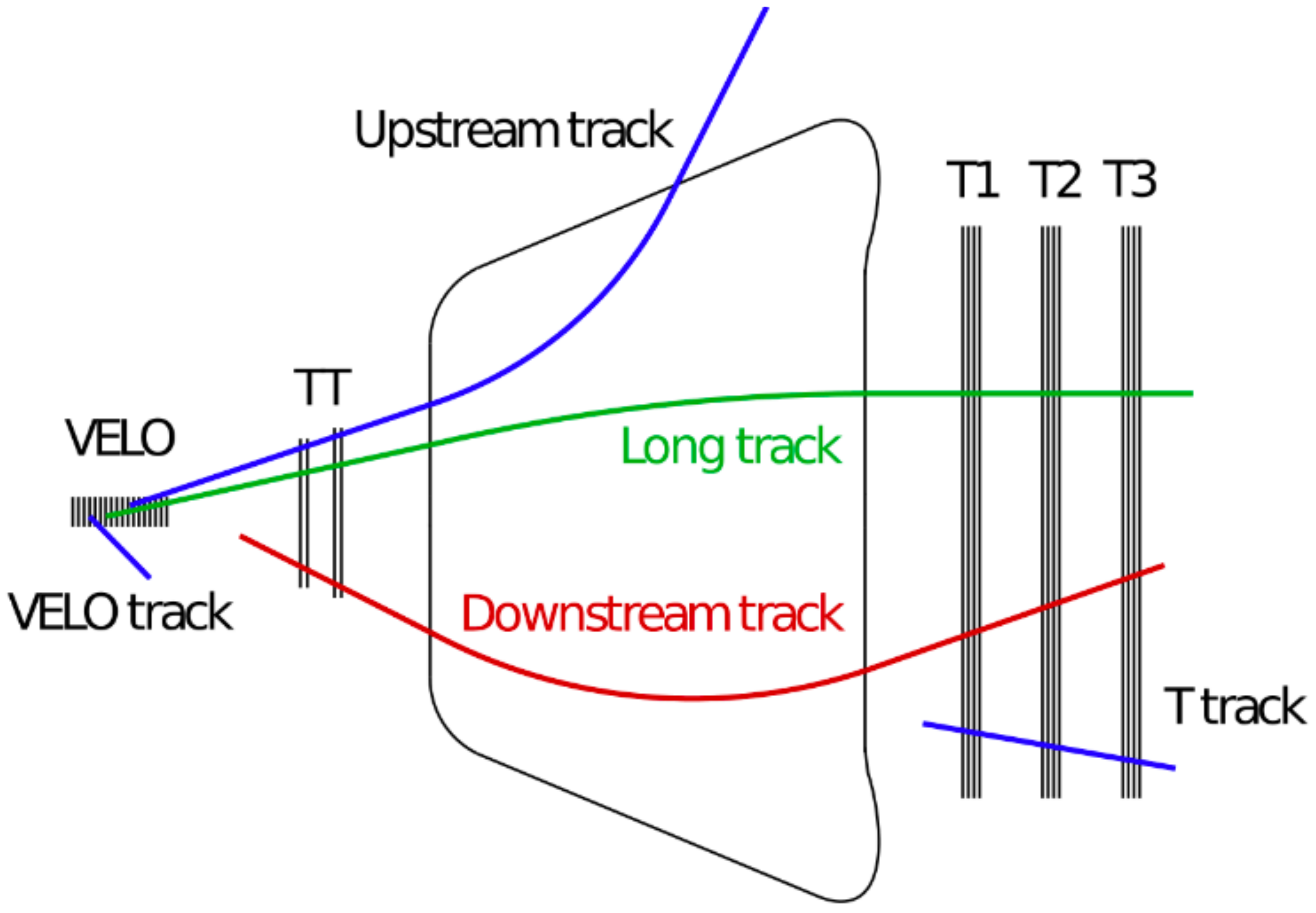




Tracking in LHCb

- Many types of tracks in LHCb, the most important ones are
  - Long tracks.
  - Downstream tracks
- Tracking algos :
  - Forward Tracking algorithm.
    - Combine VELO seeds with hits in the T-stations
  - Matching algorithm.
    - Match VELO tracks and seeds from T-stations

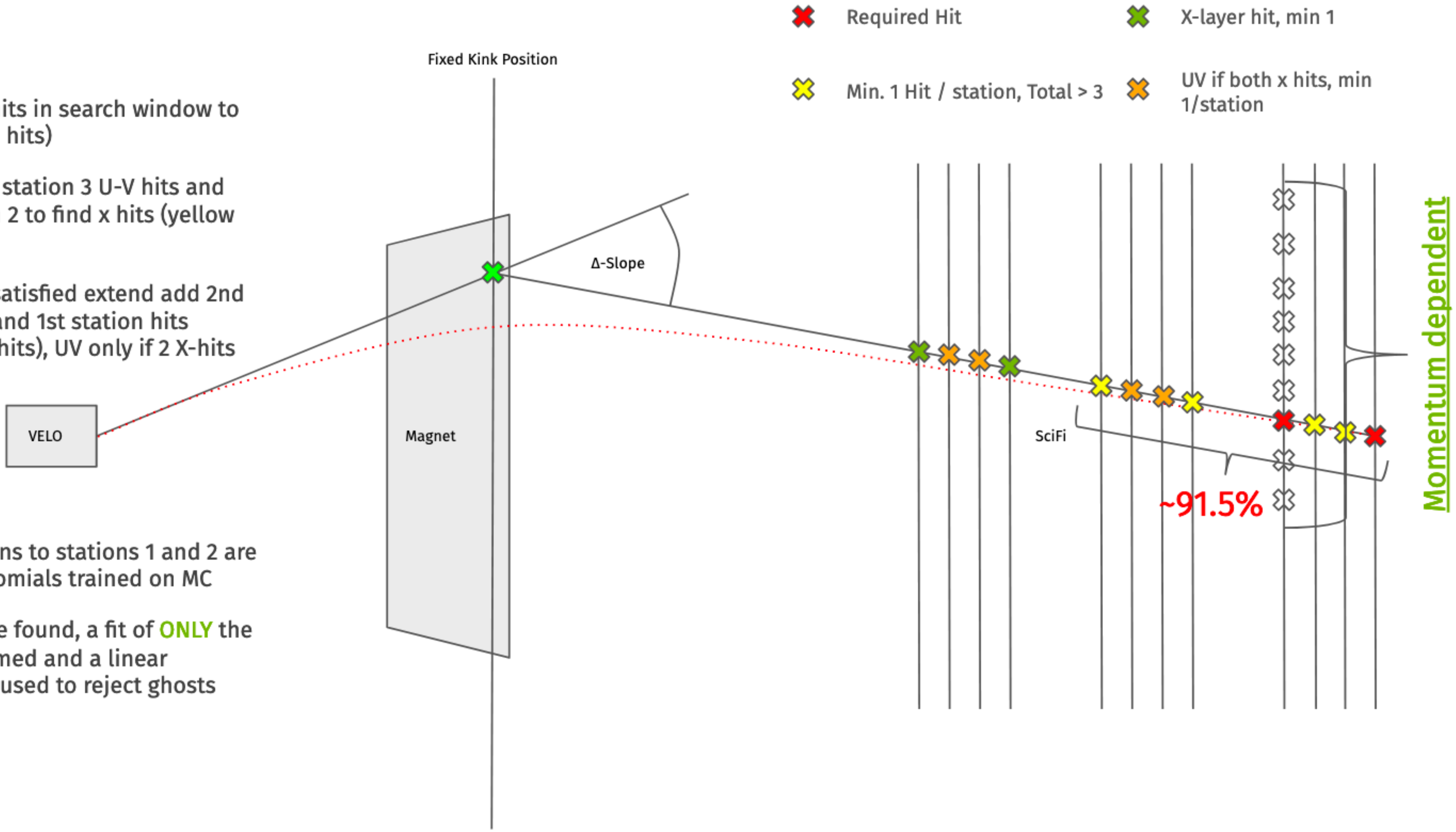
The LHCb tracks



New Tracking Algorithm

Our Approach

- Kink point, and hits in search window to find doublet (red hits)
- For doublet, add station 3 U-V hits and extend to station 2 to find x hits (yellow hits)
- If requirements satisfied extend add 2nd station U-V hits and 1st station hits (orange & green hits), UV only if 2 X-hits



- All extrapolations to stations 1 and 2 are done via polynomials trained on MC
- Once all hits are found, a fit of ONLY the x-hits is performed and a linear discriminant is used to reject ghosts