Prospects and challenges for LHCb upgrades

Manuel Guittière

Contact: manuel.guittiere@subatech.in2p3.fr, manuel.guittiere@cern.ch

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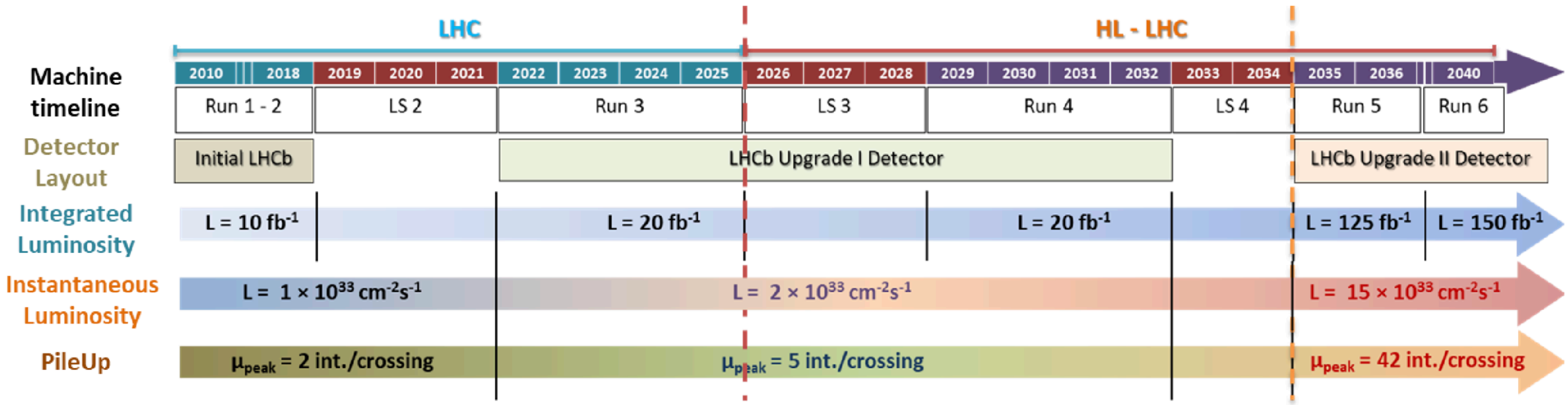
LHC-LHCb timeline

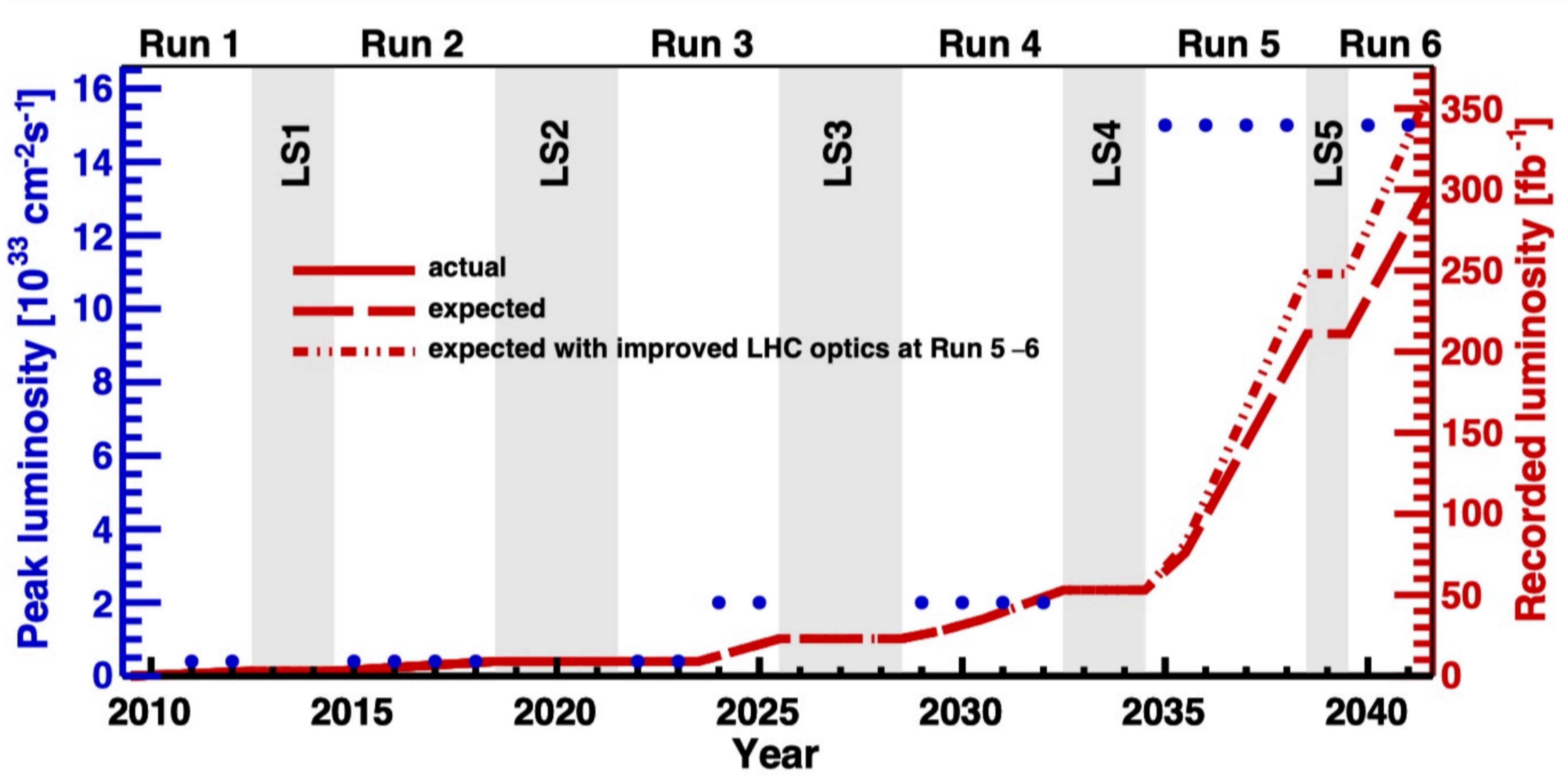


LHCb Upgrade I: LS2 + LS3 enhancement

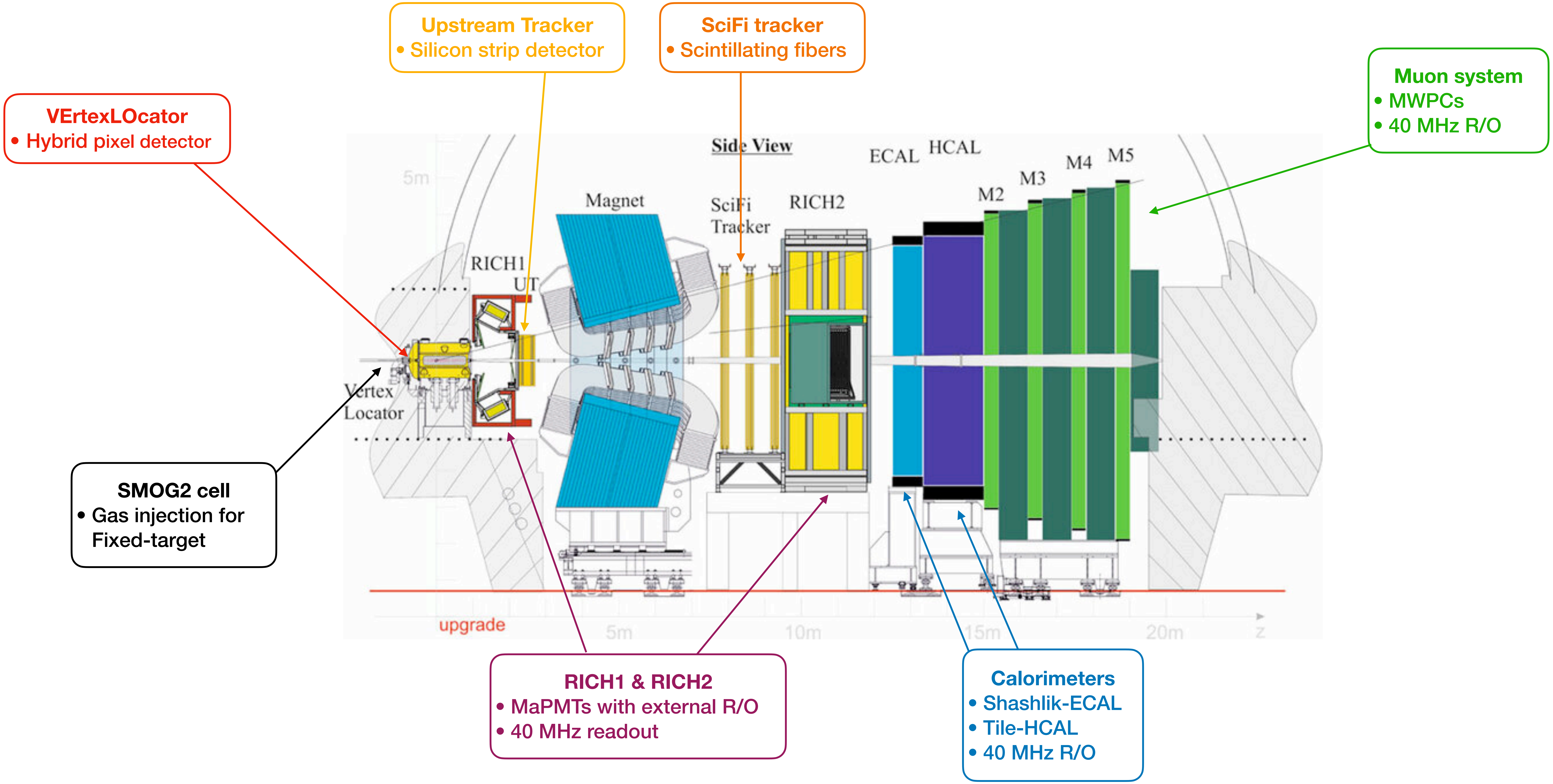
- L_{int} ~50 fb^{-1} (Run3 & Run4)

LHCb Upgrade II: LS4

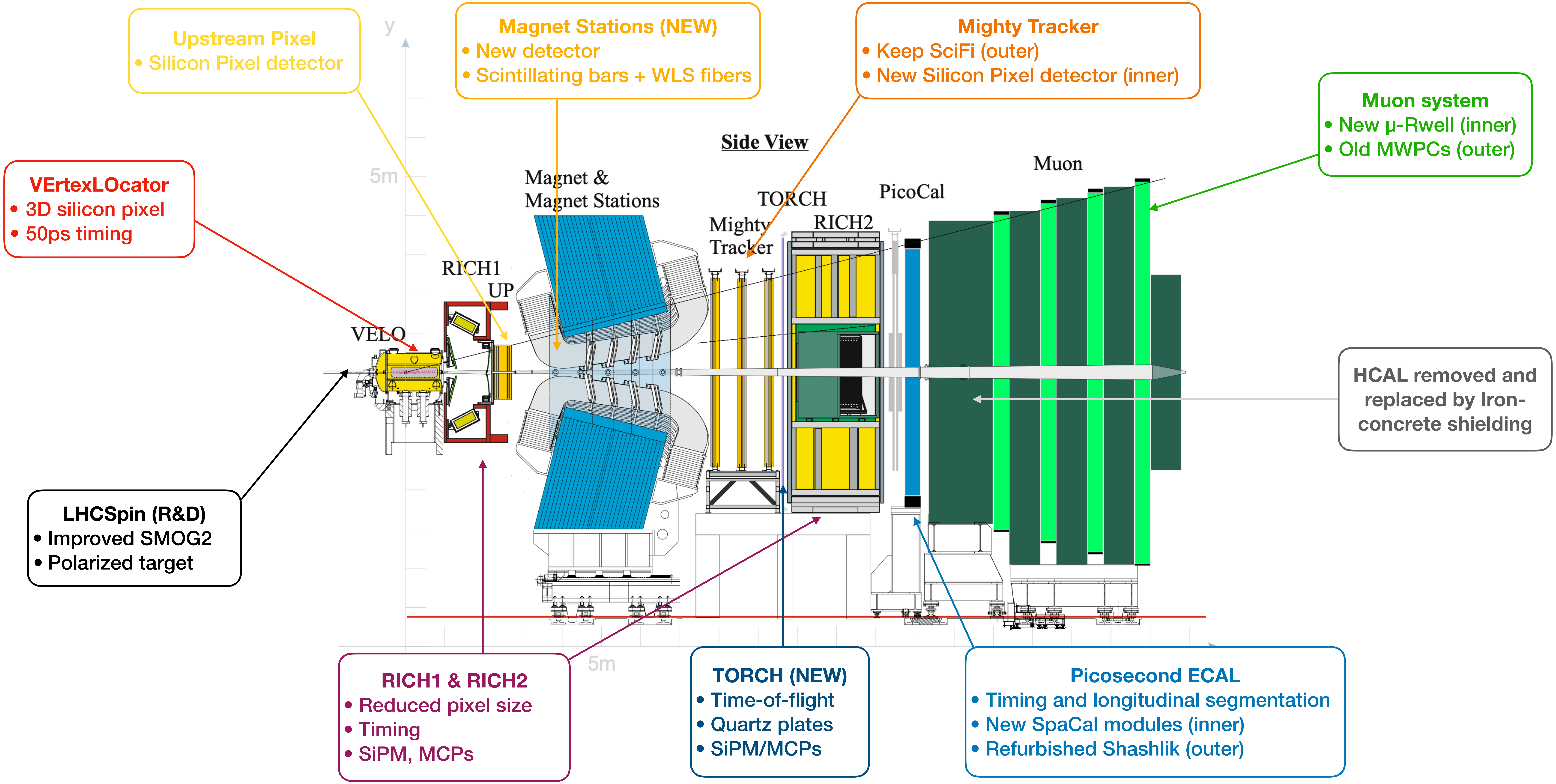
- L_{int} ~300 fb^{-1} (Run5 & Run6)



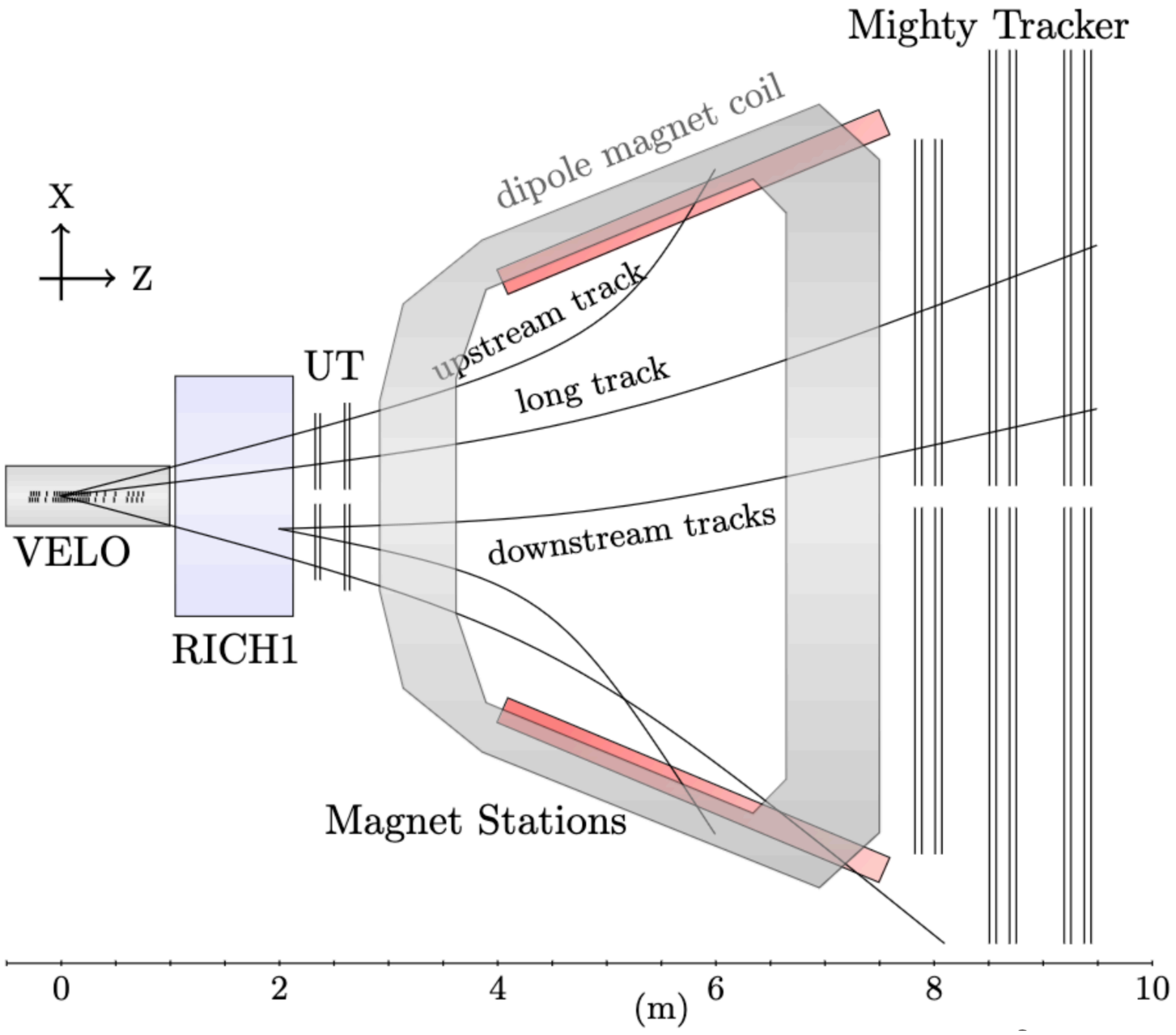
LHCb Upgrade I: Run3 & Run4



LHCb Upgrade II: Run5 & Run6



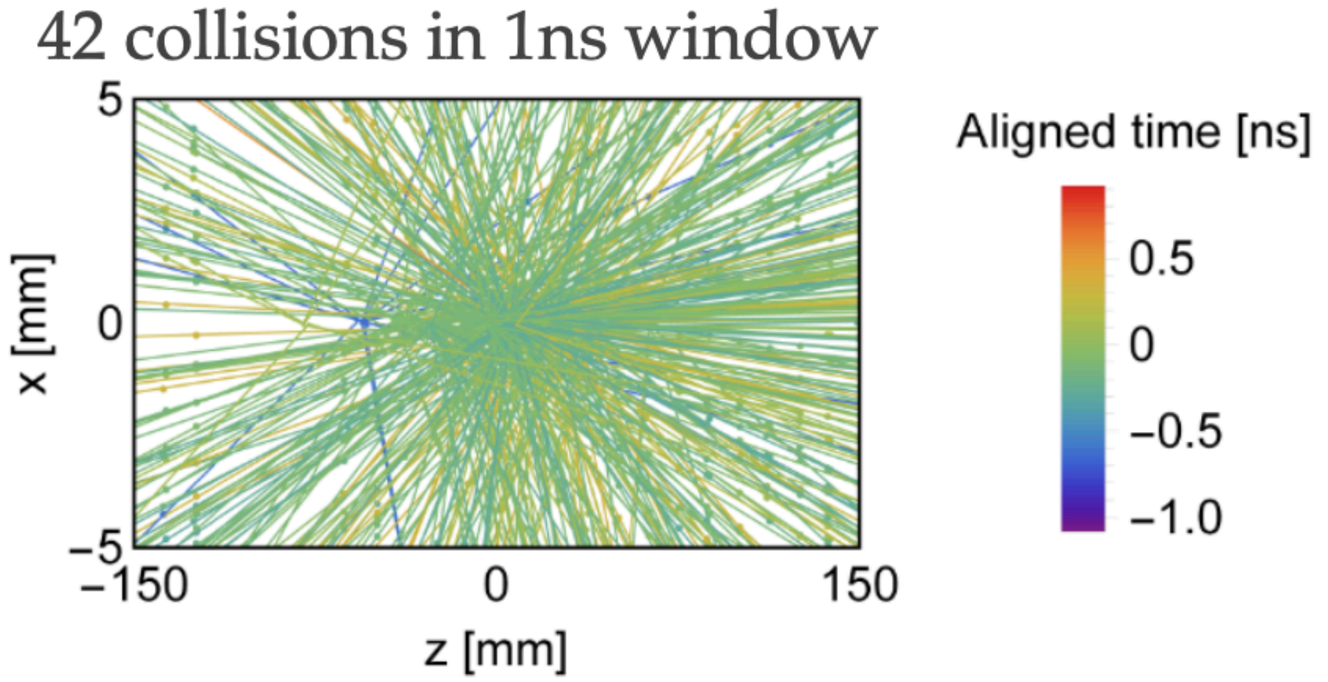
LHCb UII tracking

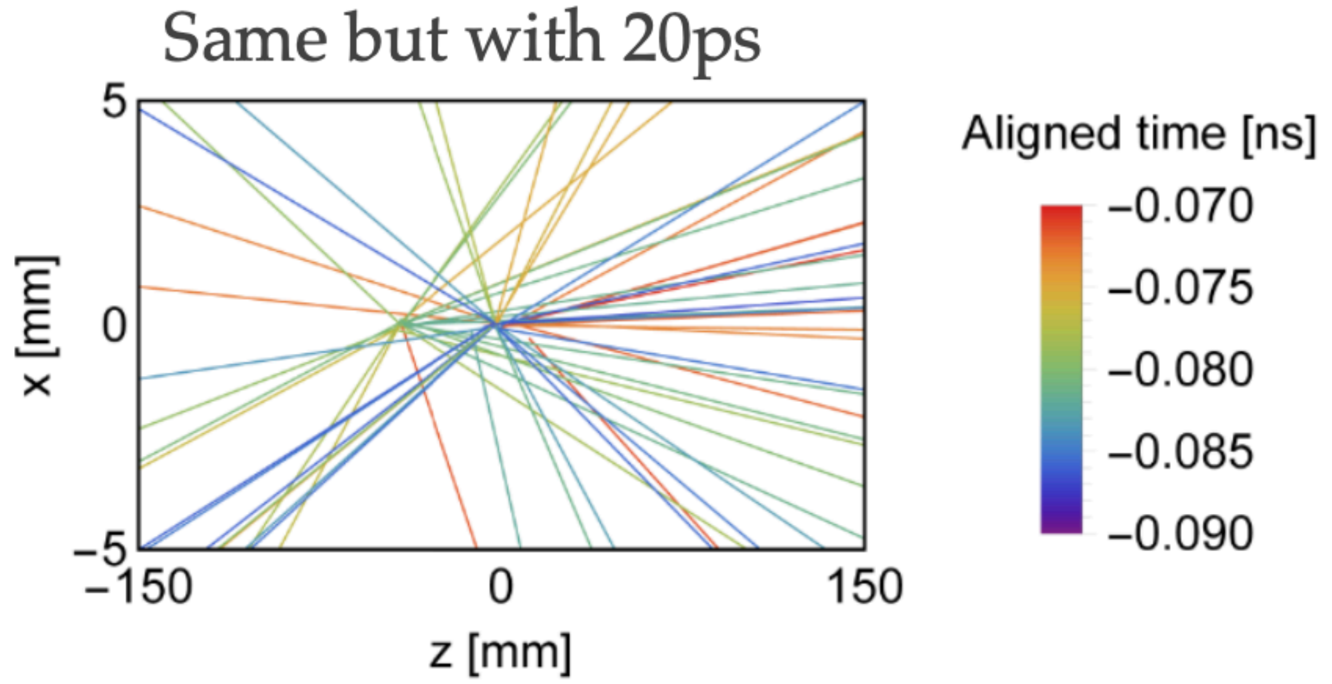


Tracking detectors: VELO

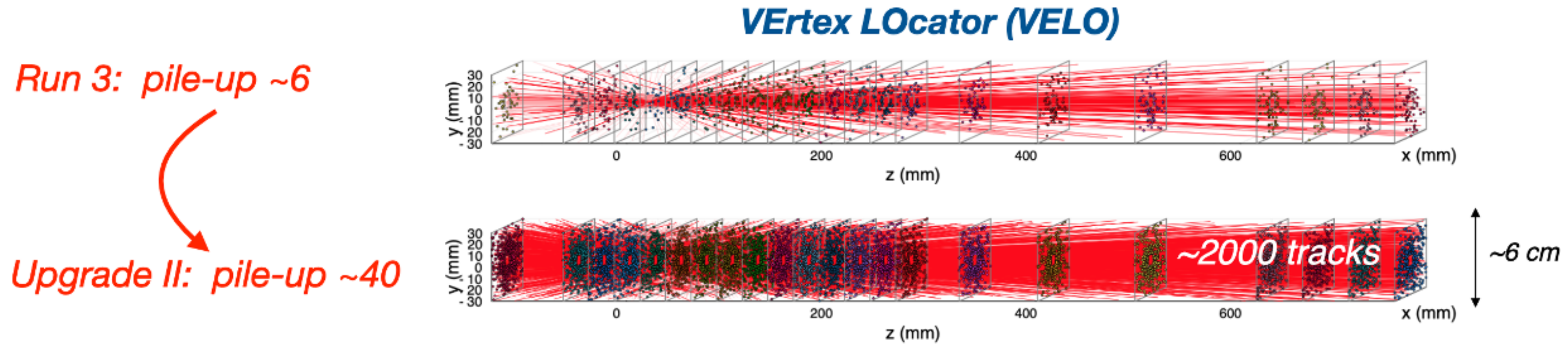
At peak luminosity of 1.5 x 10^{34} $cm^2 s^{-1}$

- ~42 interactions/BX
- ~2000 charged particles in VELO acceptance

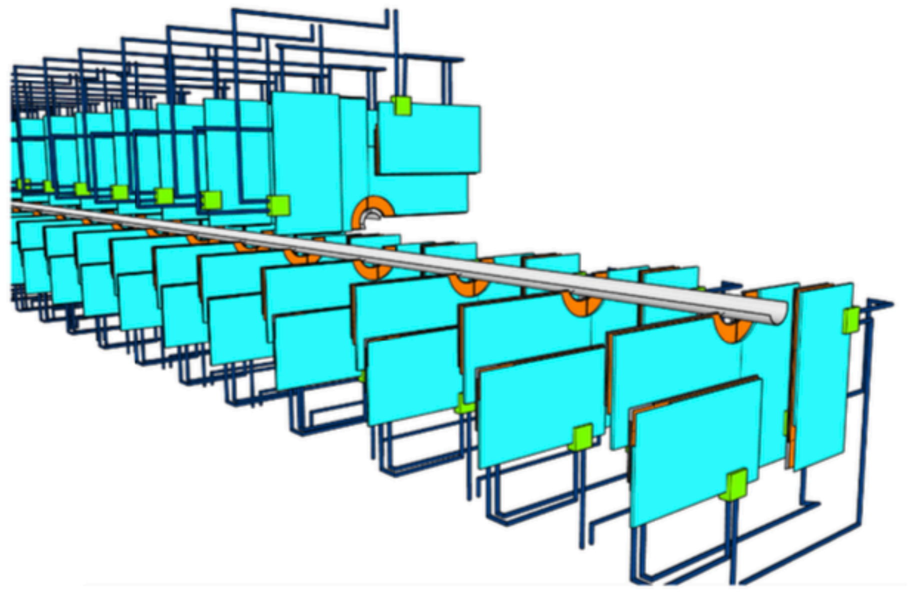


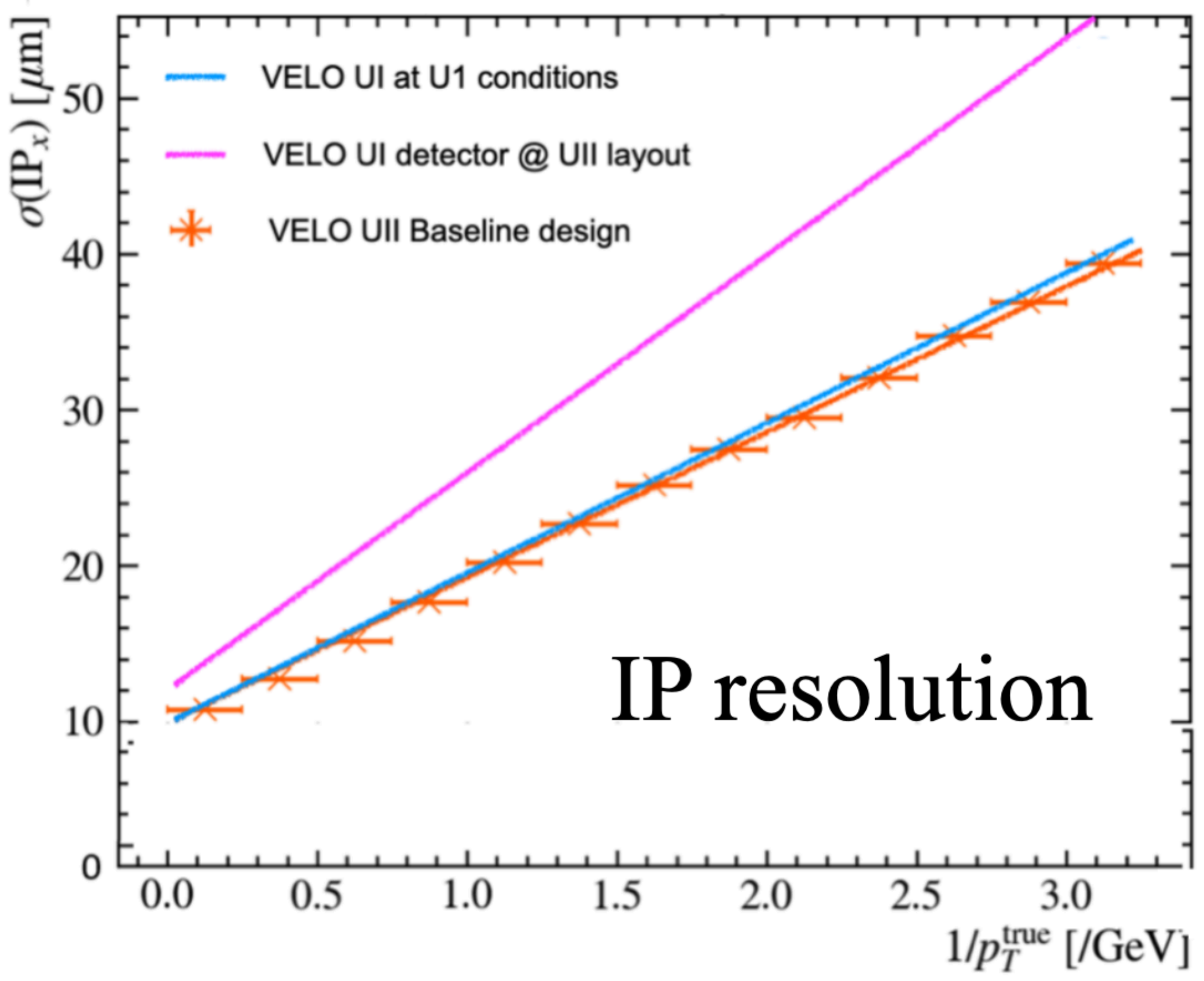


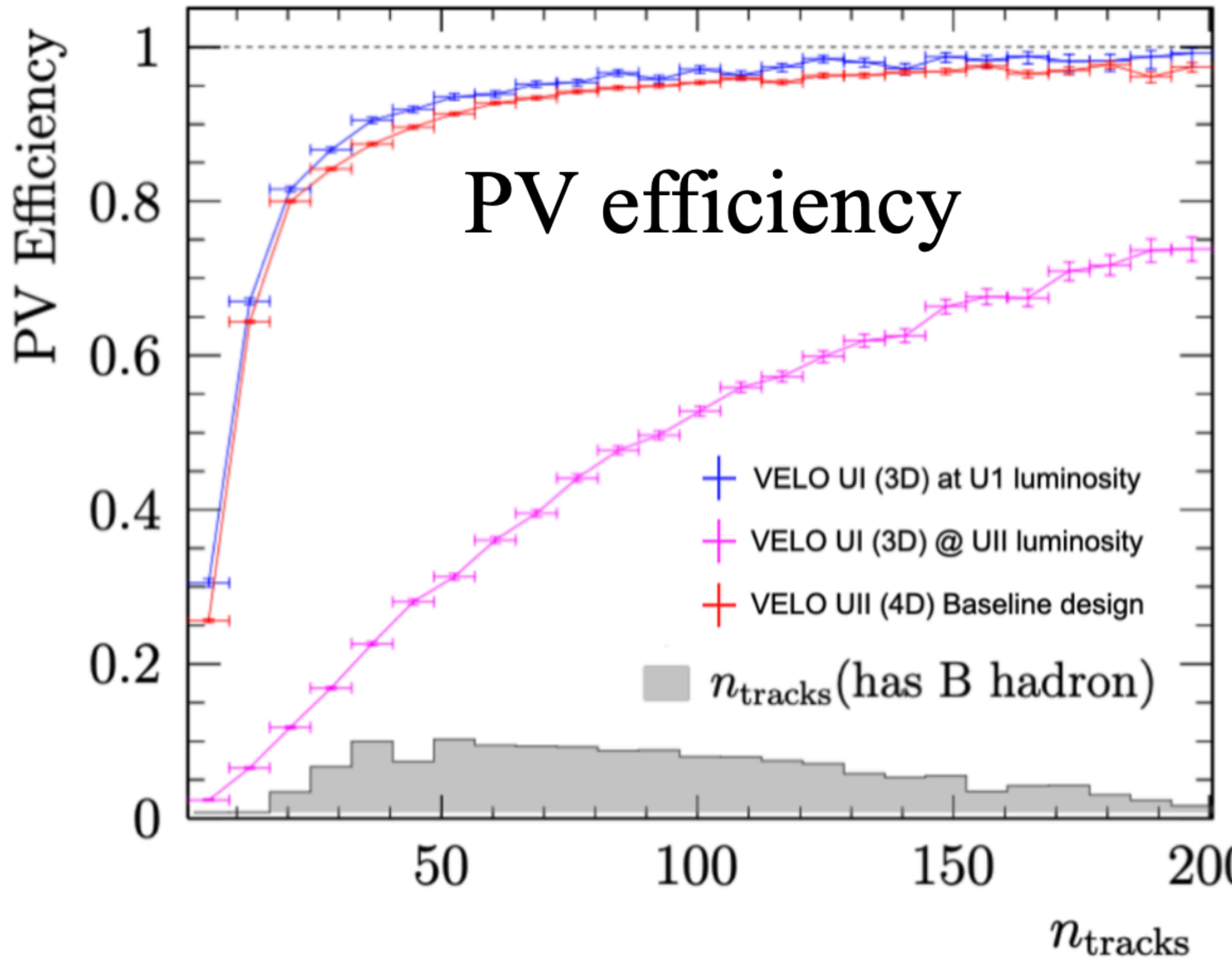
- 50 ps per hit timestamp required (i.e. 20 ps/track)
- With timestamp: similar performance as for UI
- 6 times radiation hardness wrt UI



- Goal to achieve full 4D reconstruction
- 3D silicon pixel sensors provide good time resolution and radiation hardness
- Timespot demo chips in 28nm CMOS match expected performances





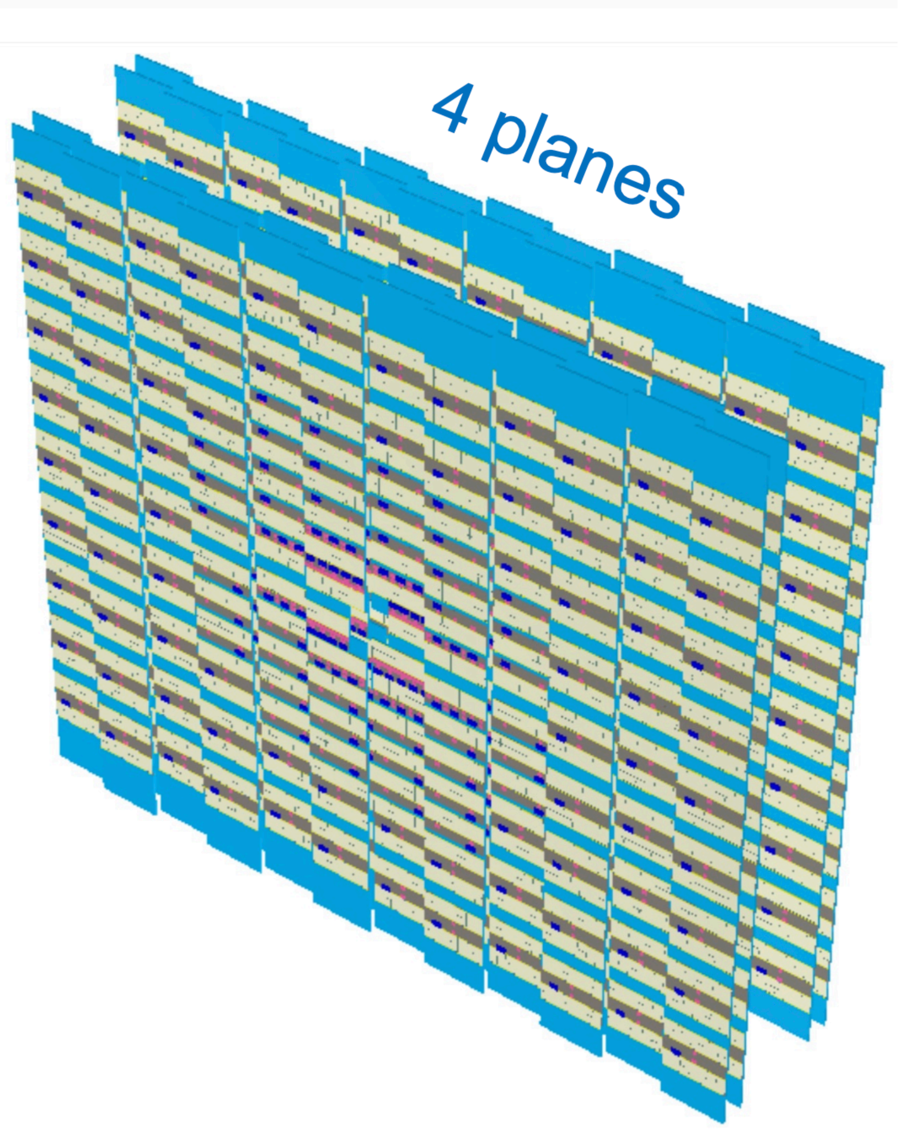


Tracking detectors: Upstream Pixel

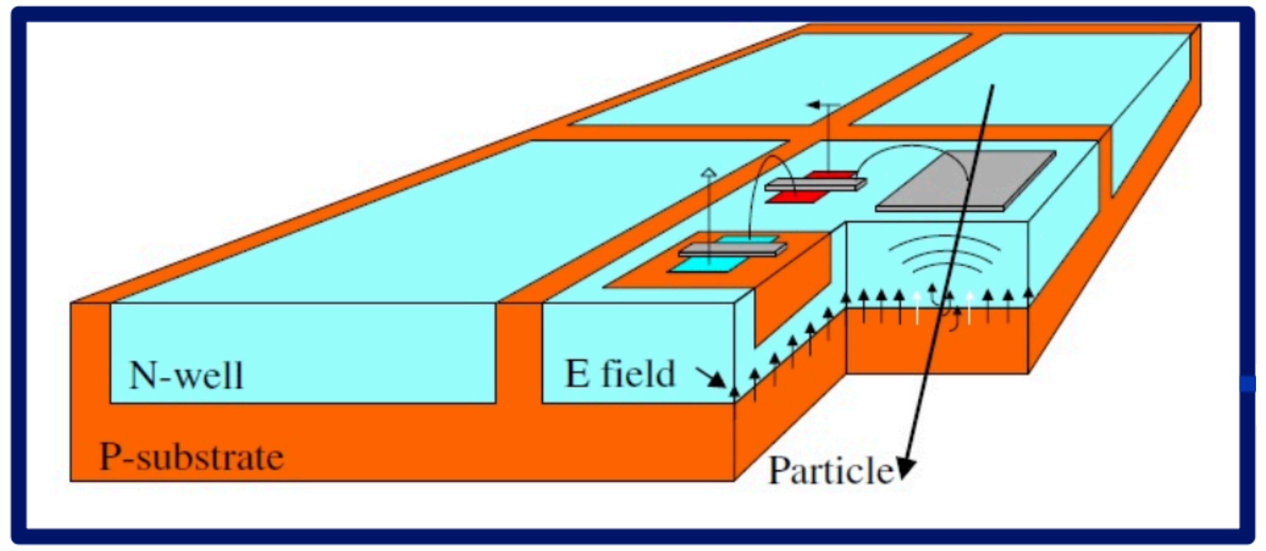
UP to replace current UT (Si strip)

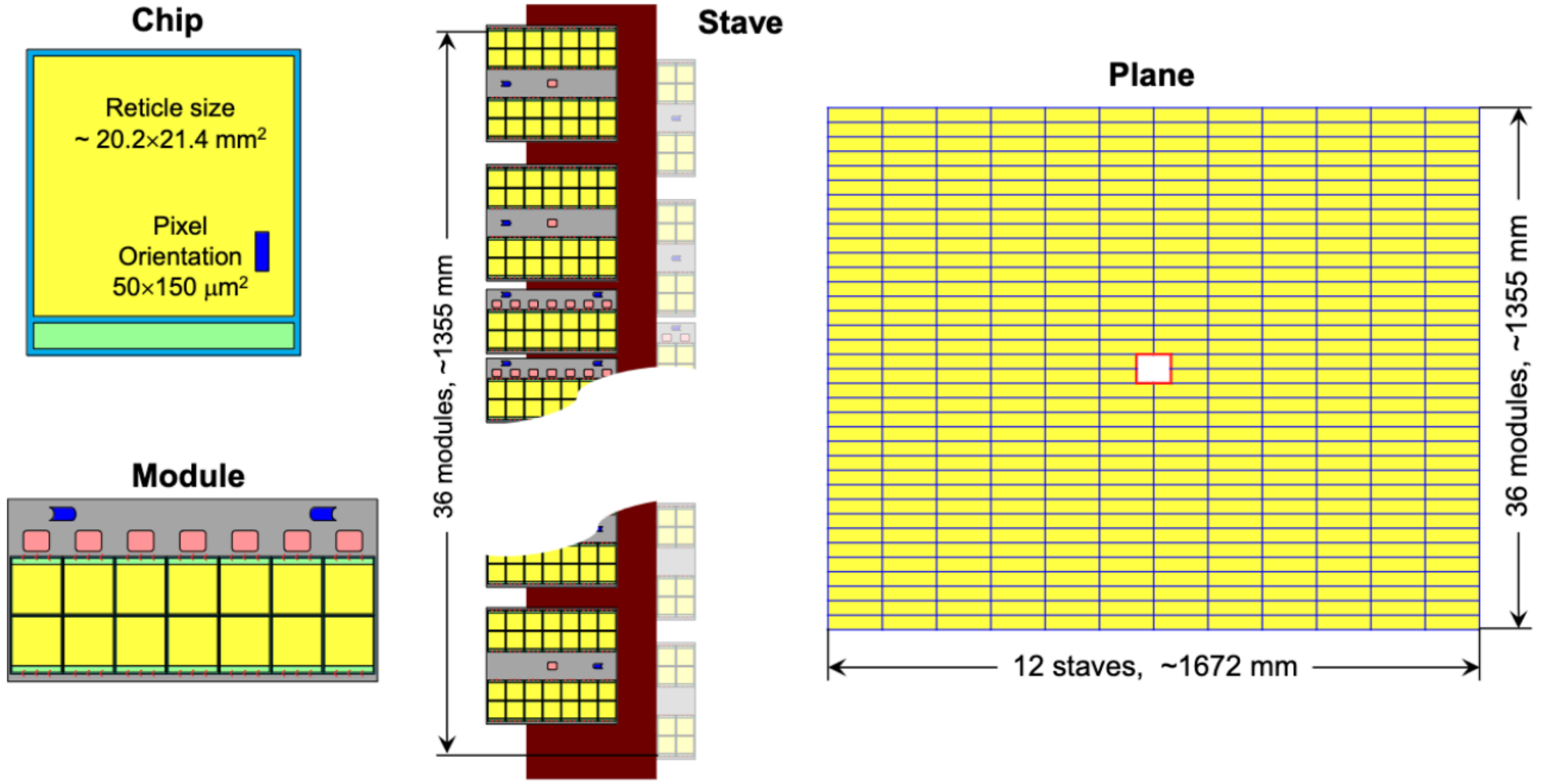
- Baseline design: 4 planes, 48 staves, 1728 modules, 24128 chips ~9m^2 of silicon sensors

- Silicon pixels to cope with data rate and occupancy up to 160 MHz/cm^2 in the innermost region
- Radiation dose ~3x10^{15} n_{eq}/cm^2, 240 Mrad
- Candidate technologies: HVMAPS & LVMAPS
- Extensive ongoing R&D with several chips
  - Synergy with Mighty-Pixel (similar requirements)
- Material budget aimed to be less than 1% X/X0 per plane to keep good momentum resolution



Monolithic Active Pixel Sensor (MAPS)



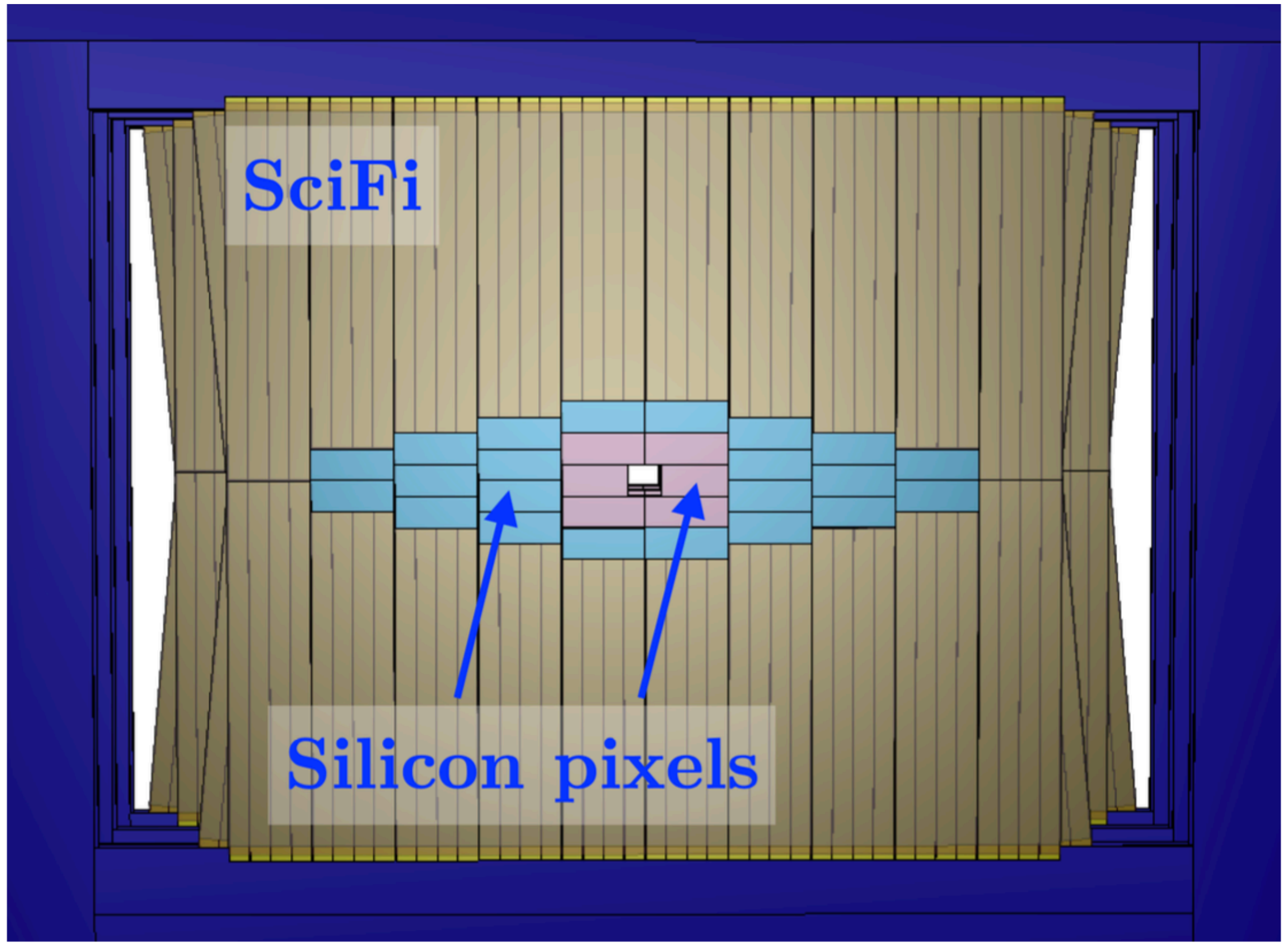


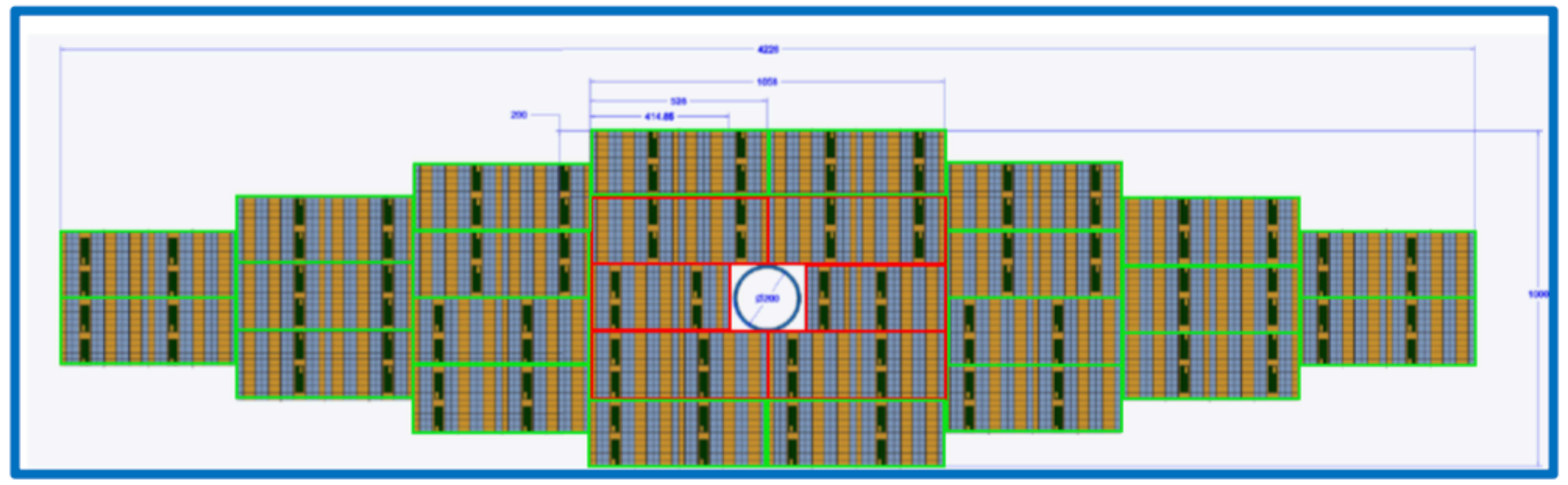
Tracking detectors: MightyTracker

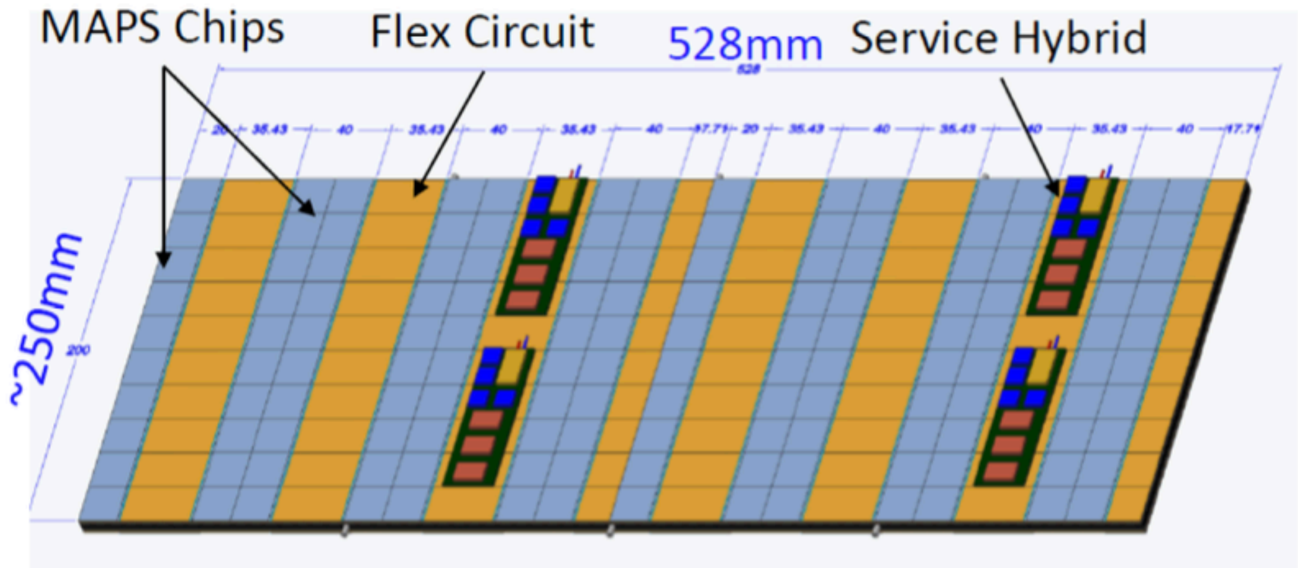
MightyTracker to replace SciFi tracker in inner region

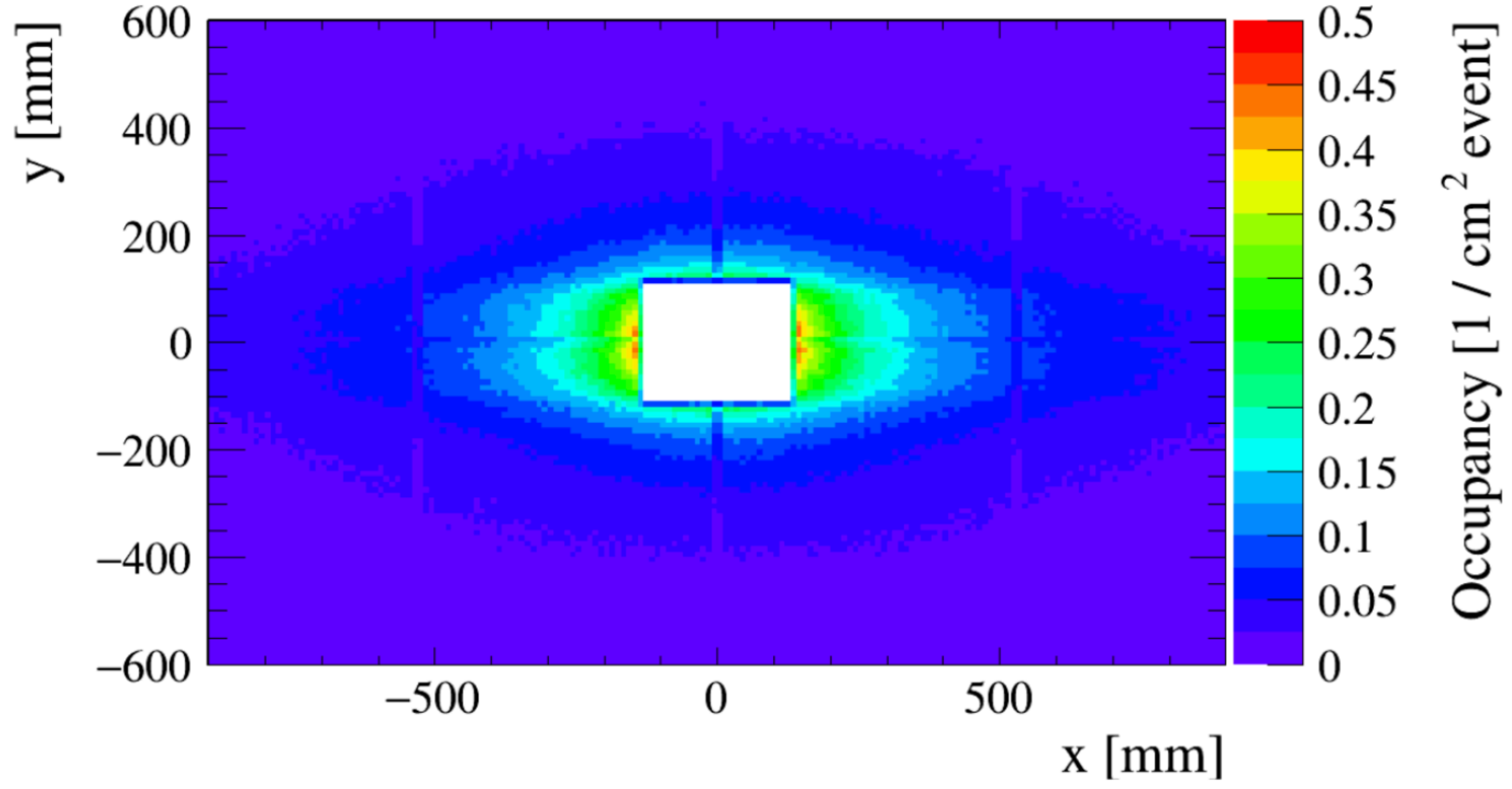
- Keep SciFi design (scintillating fibers) in outer region but reduce SiPM noise and improve radiation hardness:
  - Further away from beam → less radiation
  - Micro-lens on SiPM → better light collection
  - Cryogenic cooling for SiPM: -40→-120°C

- Silicon pixels in inner region (Mighty-Pixel) to cope with Run5 data rate and radiation hardness requirements
  - Foreseen technology: HVMAPS (synergy with UP)
  - 6 layers → ~18m²

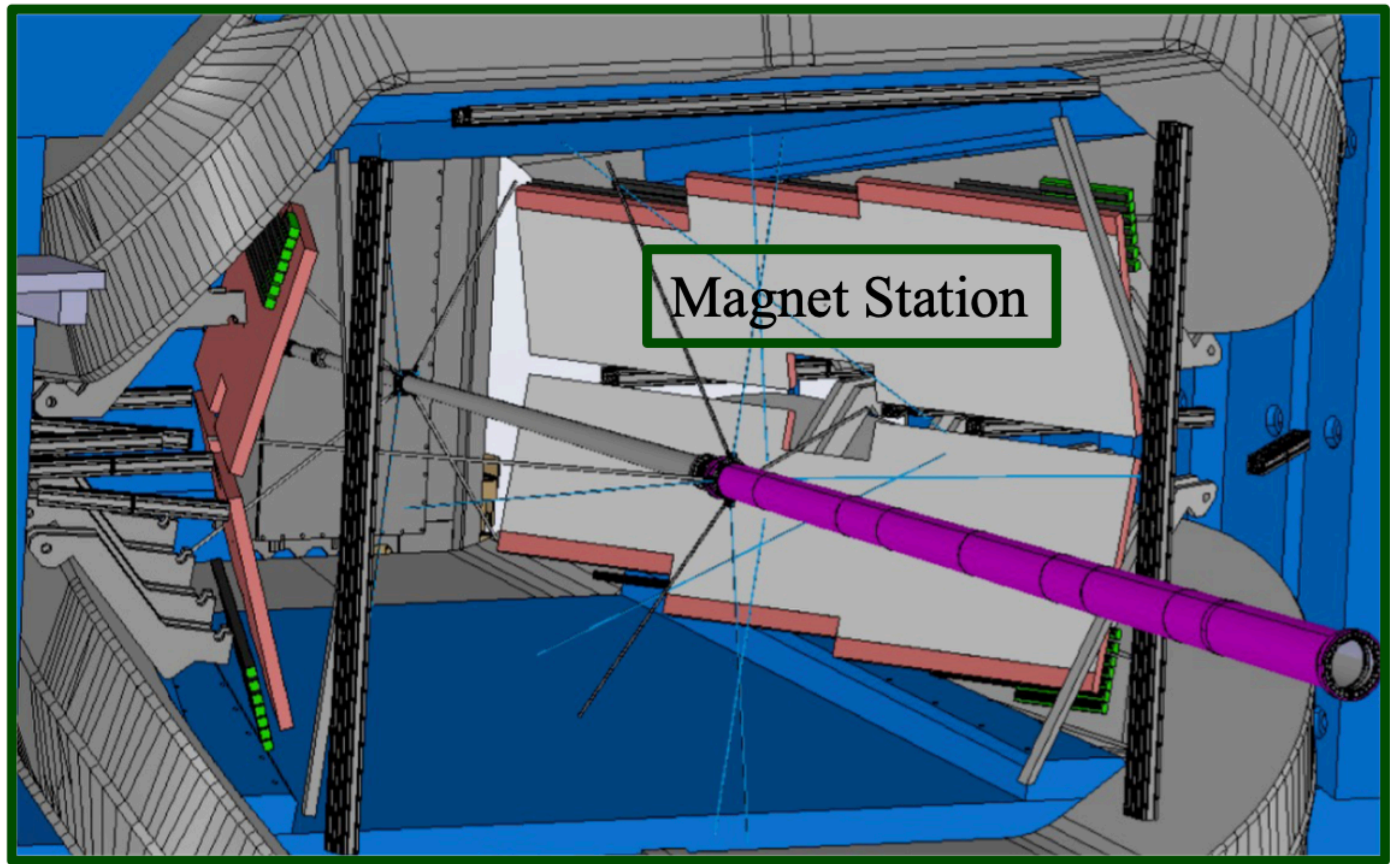


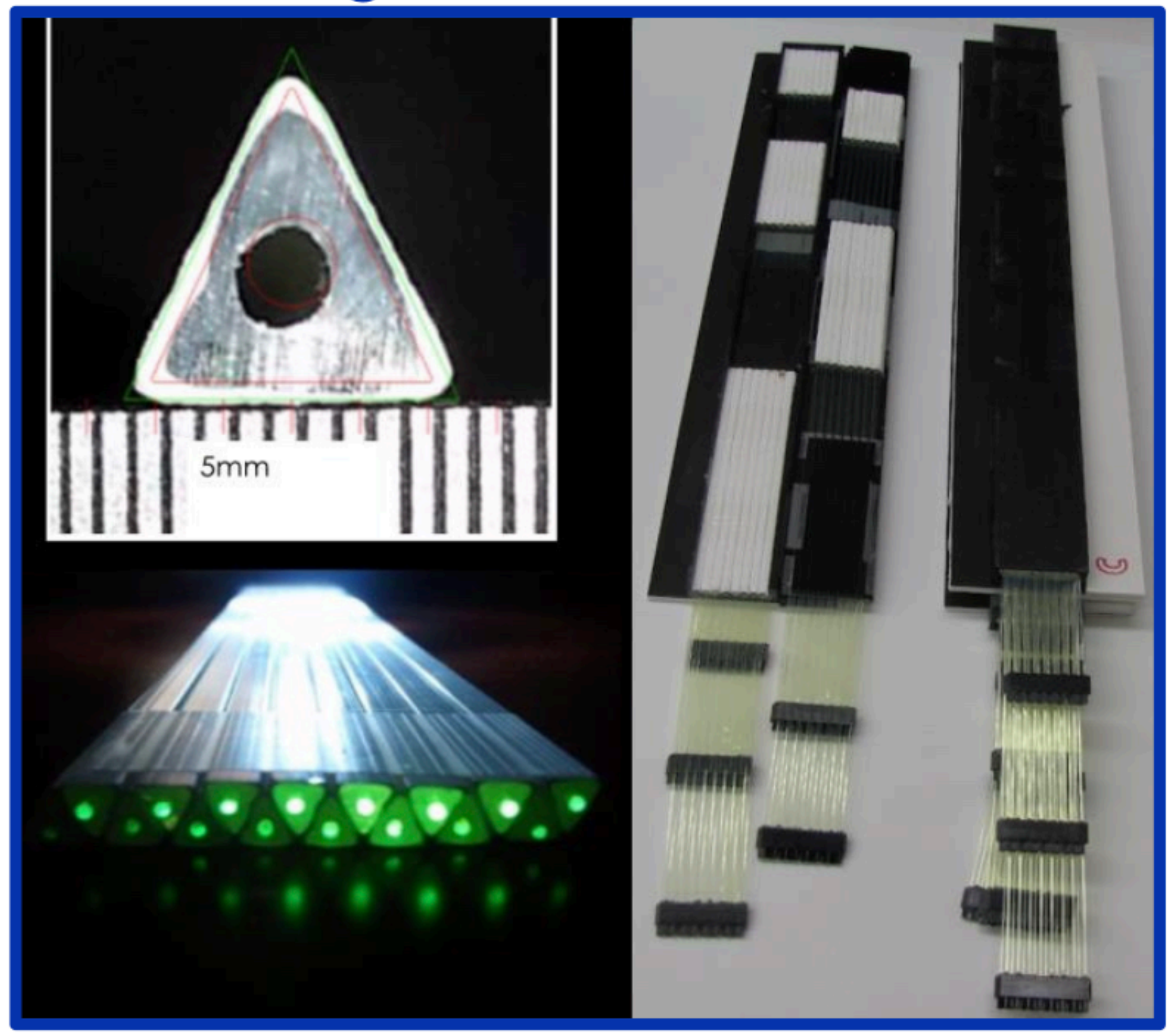


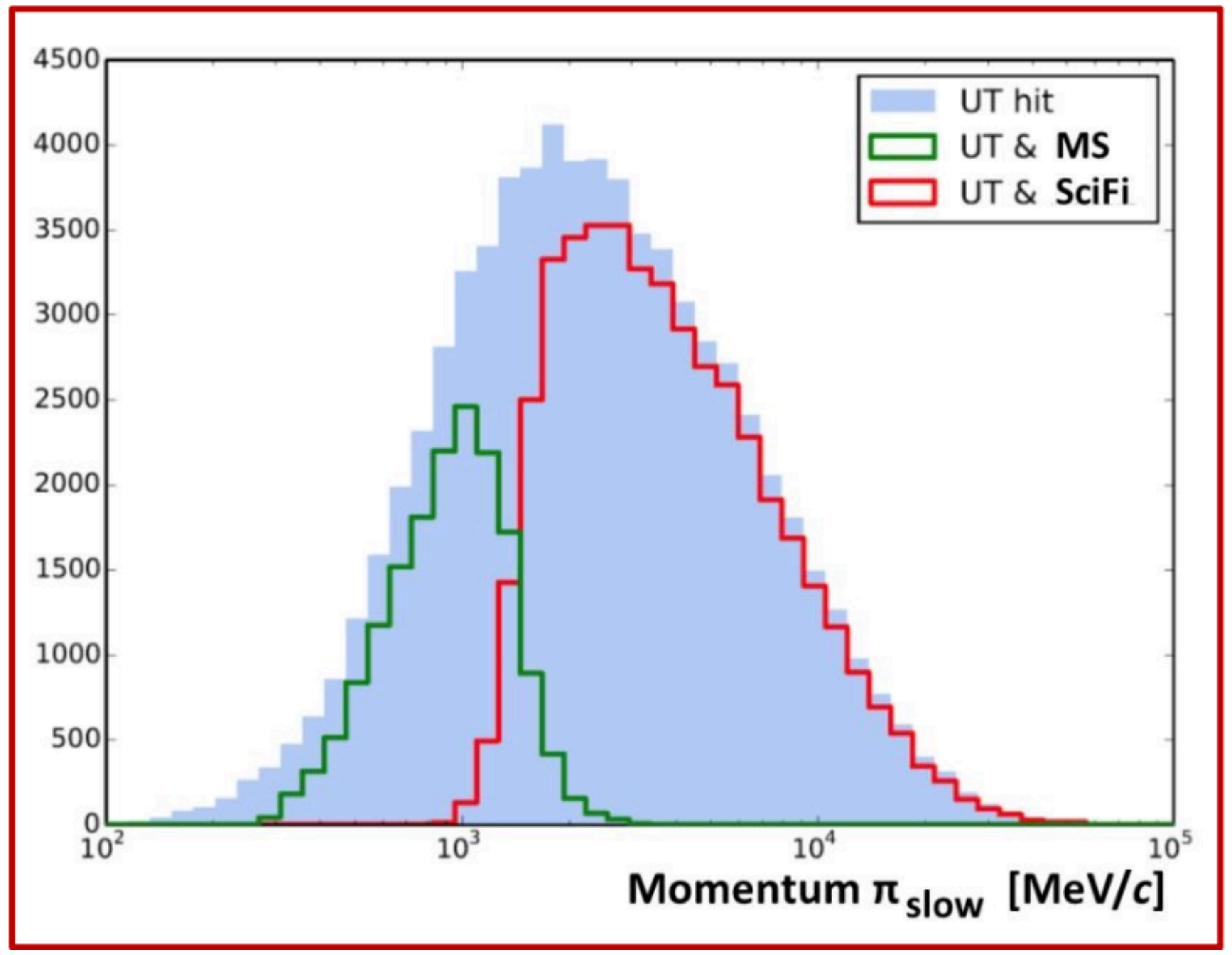




Tracking detectors: Magnet stations



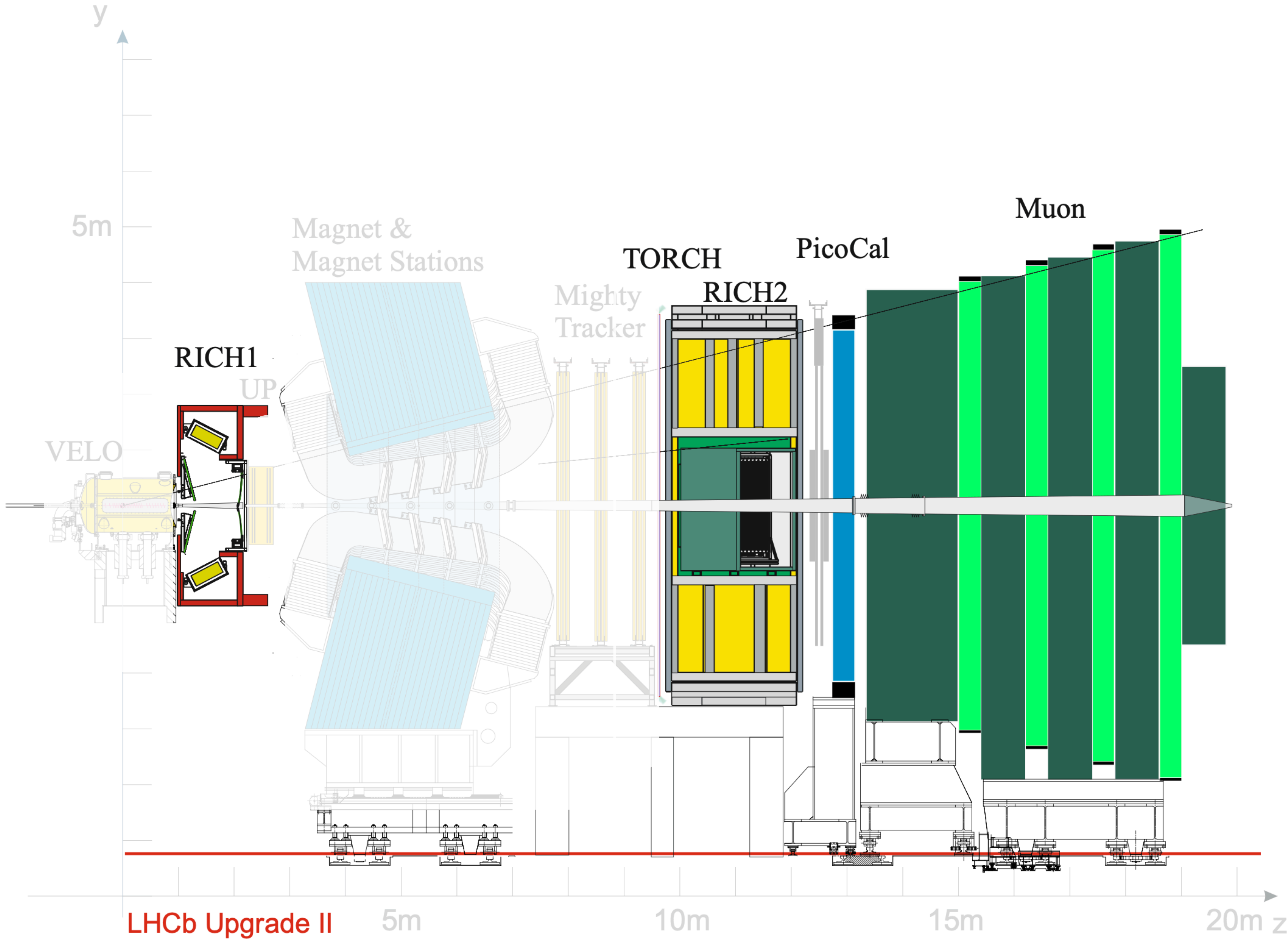




New subsystem for LHCb Upgrade II

- Scintillator-based tracking system to measure position/direction of particles hitting the magnet inner walls
- Triangular scintillating bars with 1mm WLS-fibers and SiPM readout (outside the magnet)
- Improves momentum resolution of upstream tracks
- Significant increase in acceptance for low-momentum tracks

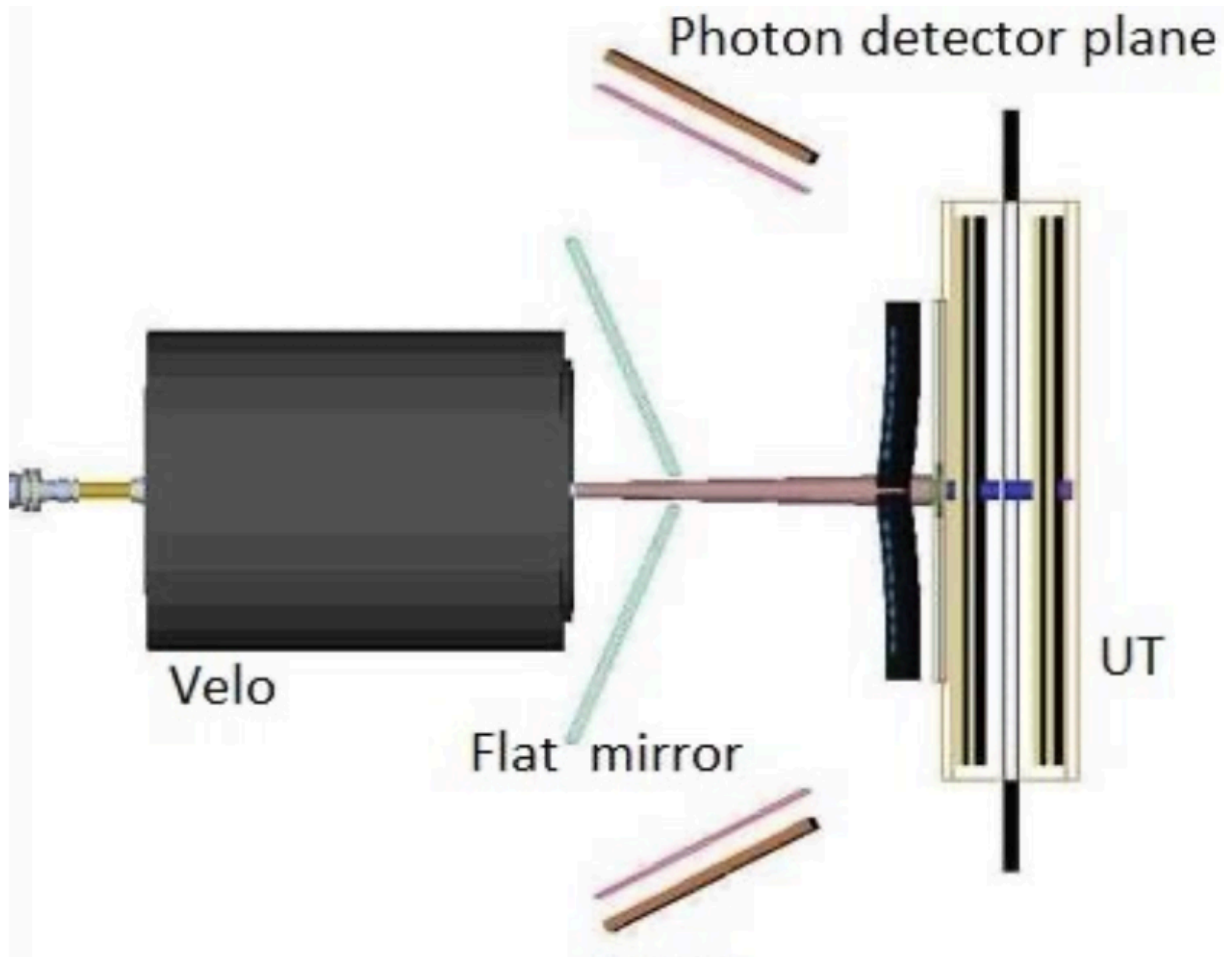
LHCb UII Particle Identification



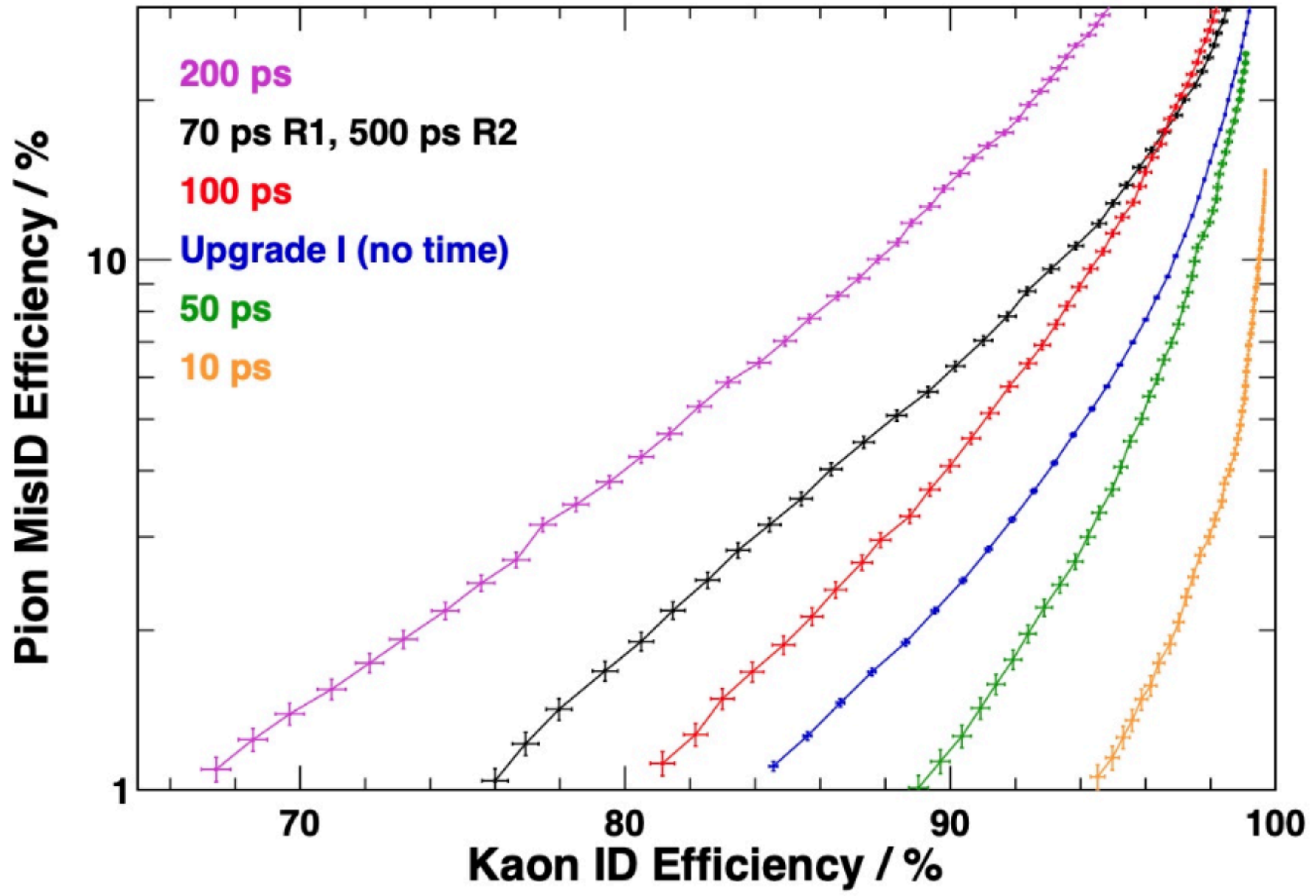
PID detectors: RICH1 & RICH2

RICH system to be re-designed

- Increased luminosity → high-resolution timing, better angular resolution
- Reduced tilt in mirrors to decrease chromatic aberration → flat mirror in acceptance
- Testing new gas mixtures → improve angular precision
- Foreseen resolutions: 0.22(0.13) mrad for RICH1(2)
- Photon detectors with high radiation tolerance and good space & time resolution
    - **SiPMs** for high occupancy regions: good time resolution ~100ps, good PDE, no B shielding needed but needs cryogenic cooling and n shielding, micro-lensing can reduce dark count rate
    - **Microchannel-plate (MCP)** for lower occupancy regions: good time resolution ~30ps and low DCR but less rad. hard (new design with CMOS ASIC pixelated anode under study)



Kaon ID efficiency vs pion MisID as function of time gate

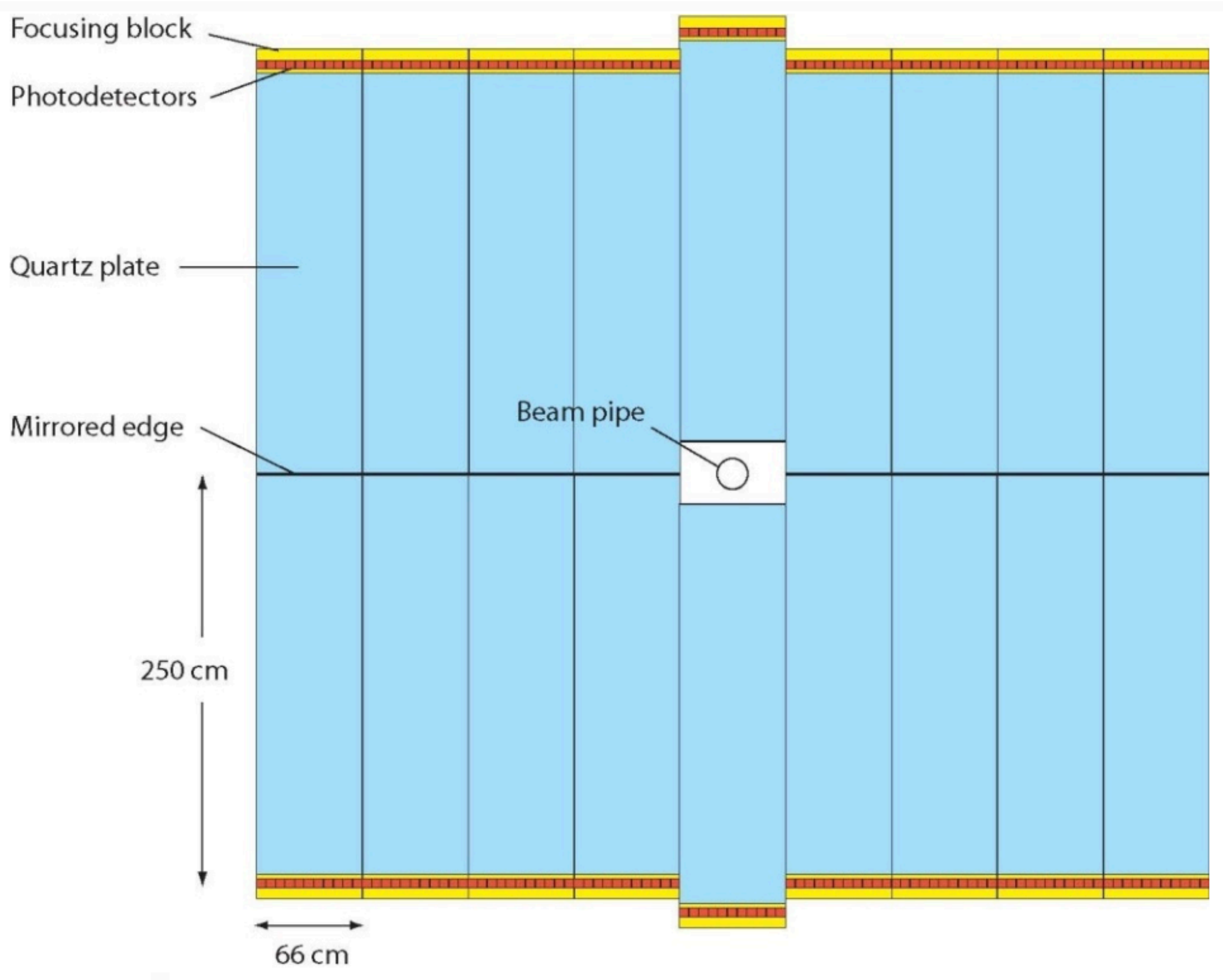


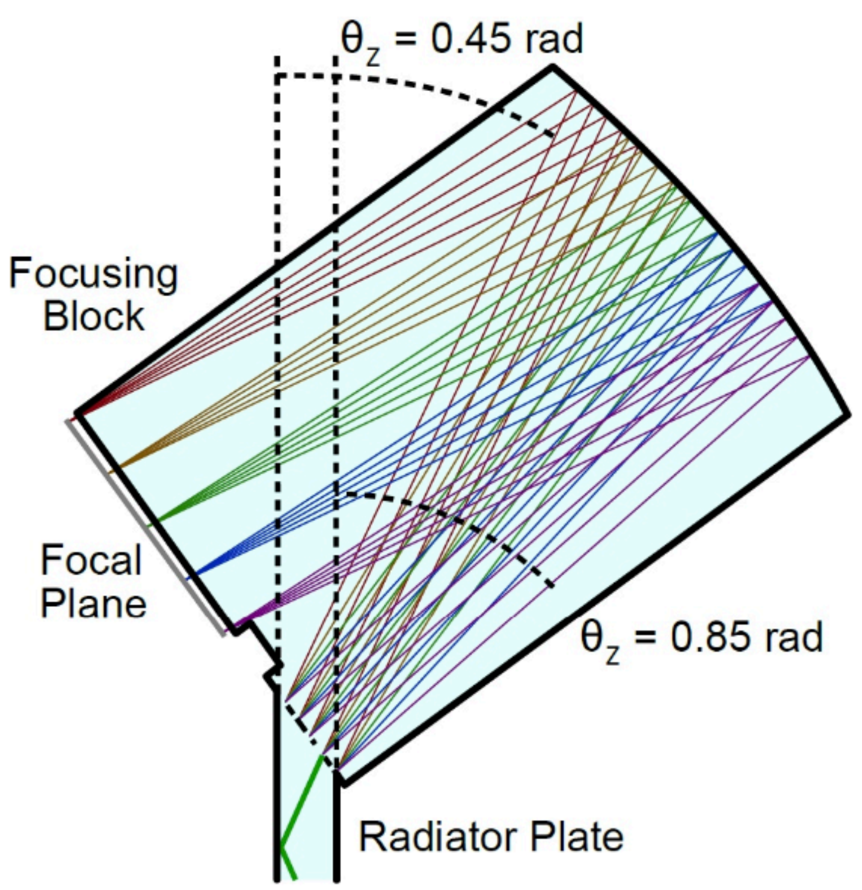
PID detectors: TORCH

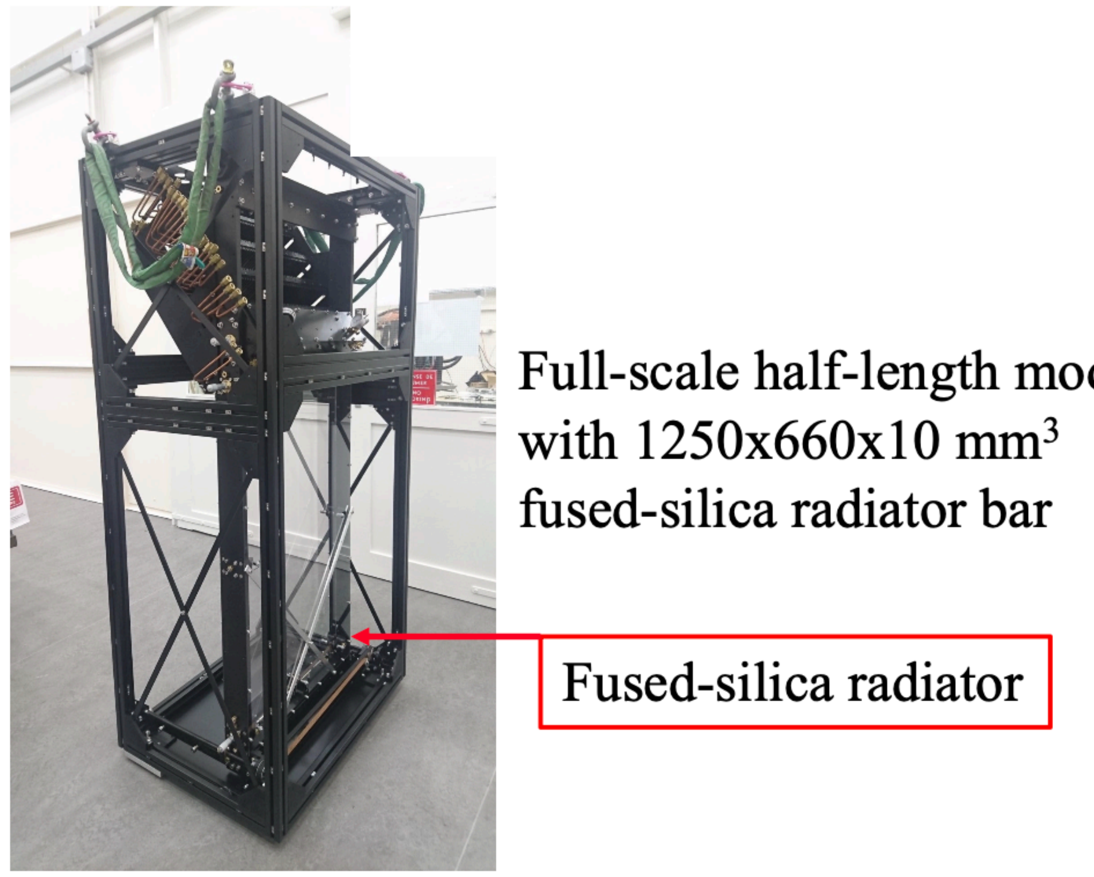
New subsystem for Run5

- ToF detector with quartz planes read by MCP-PMTs in front of RICH2
- 10-15ps time resolution per track
- Provides p/K (improves π/K) separation below 10(5) GeV

- Exploit prompt production of Cherenkov light in an array of fused-silica bars to provide timing
- Cherenkov photons are propagated to detector plane via total internal reflection from quartz surfaces
- Cylindrical focussing block, focusses the image onto a detector plane (to correct for chromatic dispersion)
- Large area detector required to cover LHCb acceptance (5x6m^2)





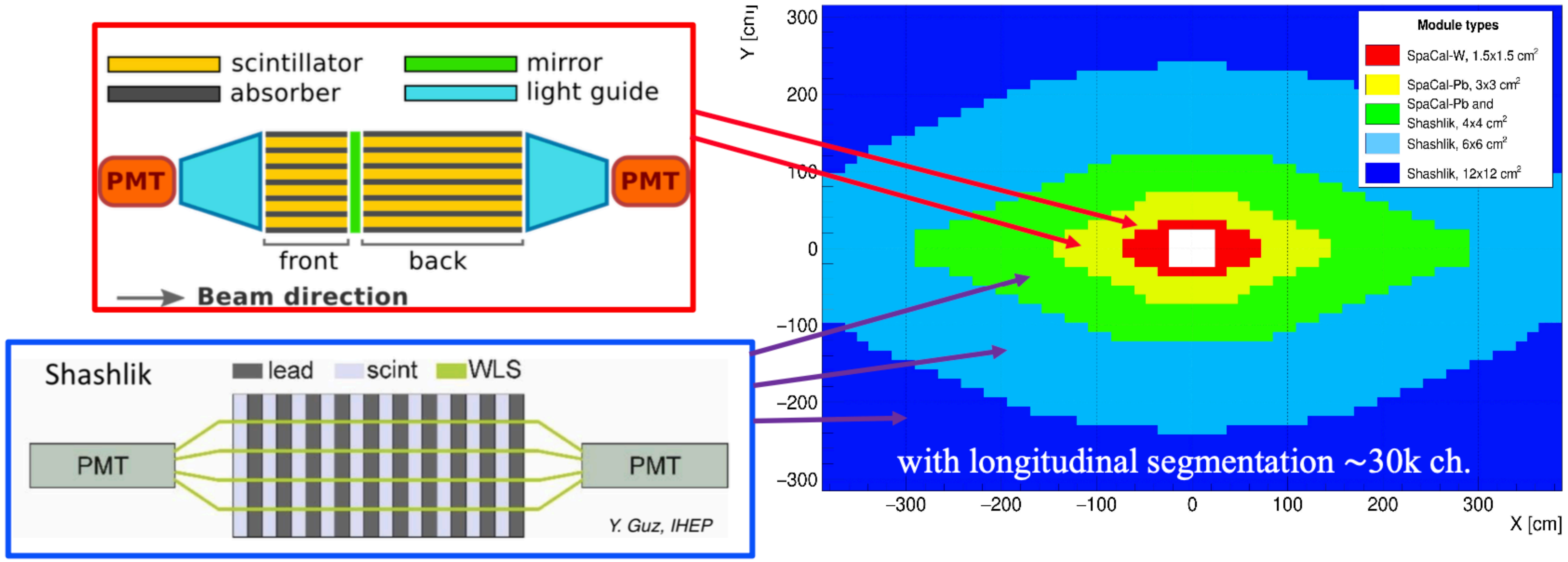


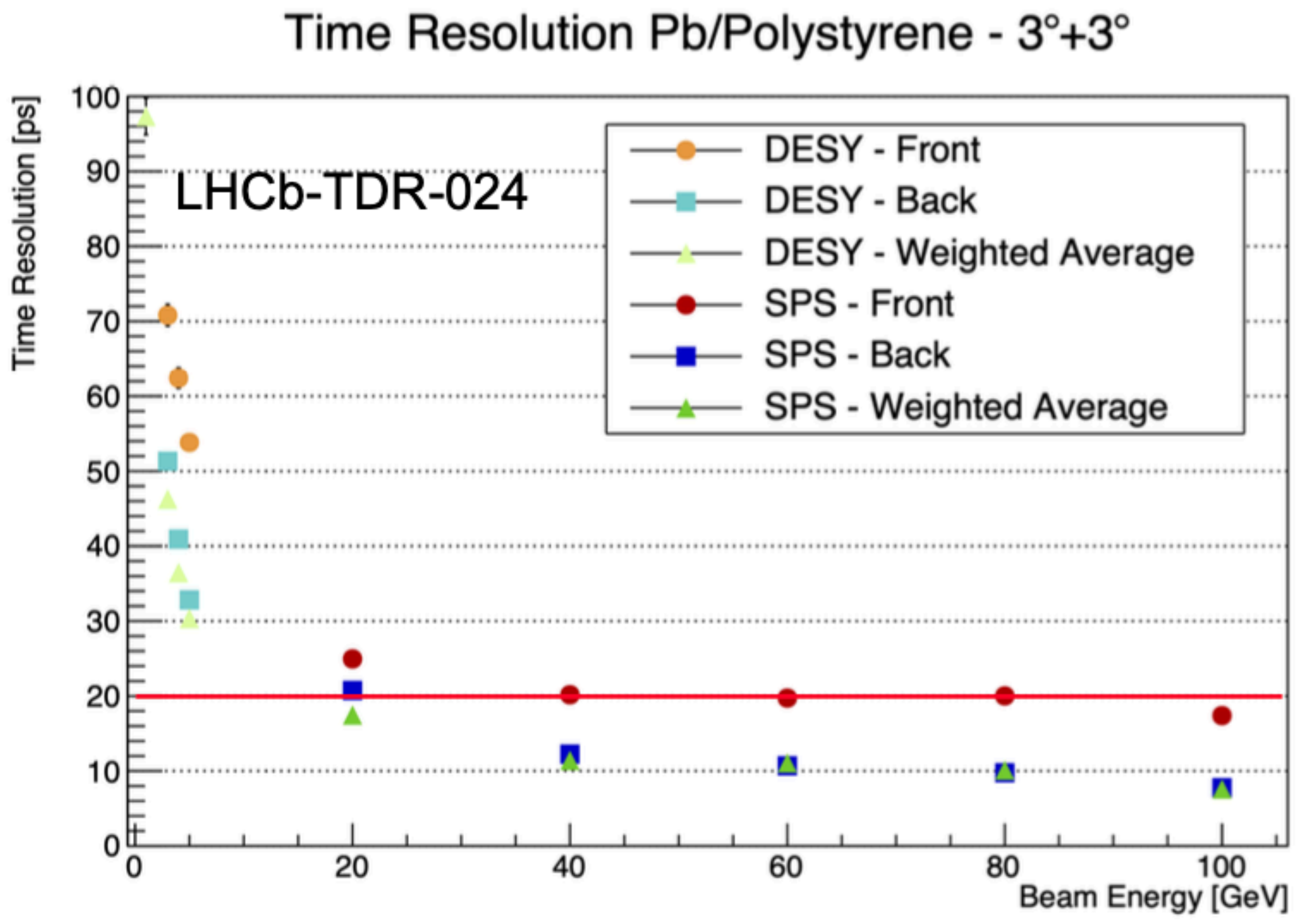
Full-scale half-length module with 1250x660x10 mm^3 fused-silica radiator bar

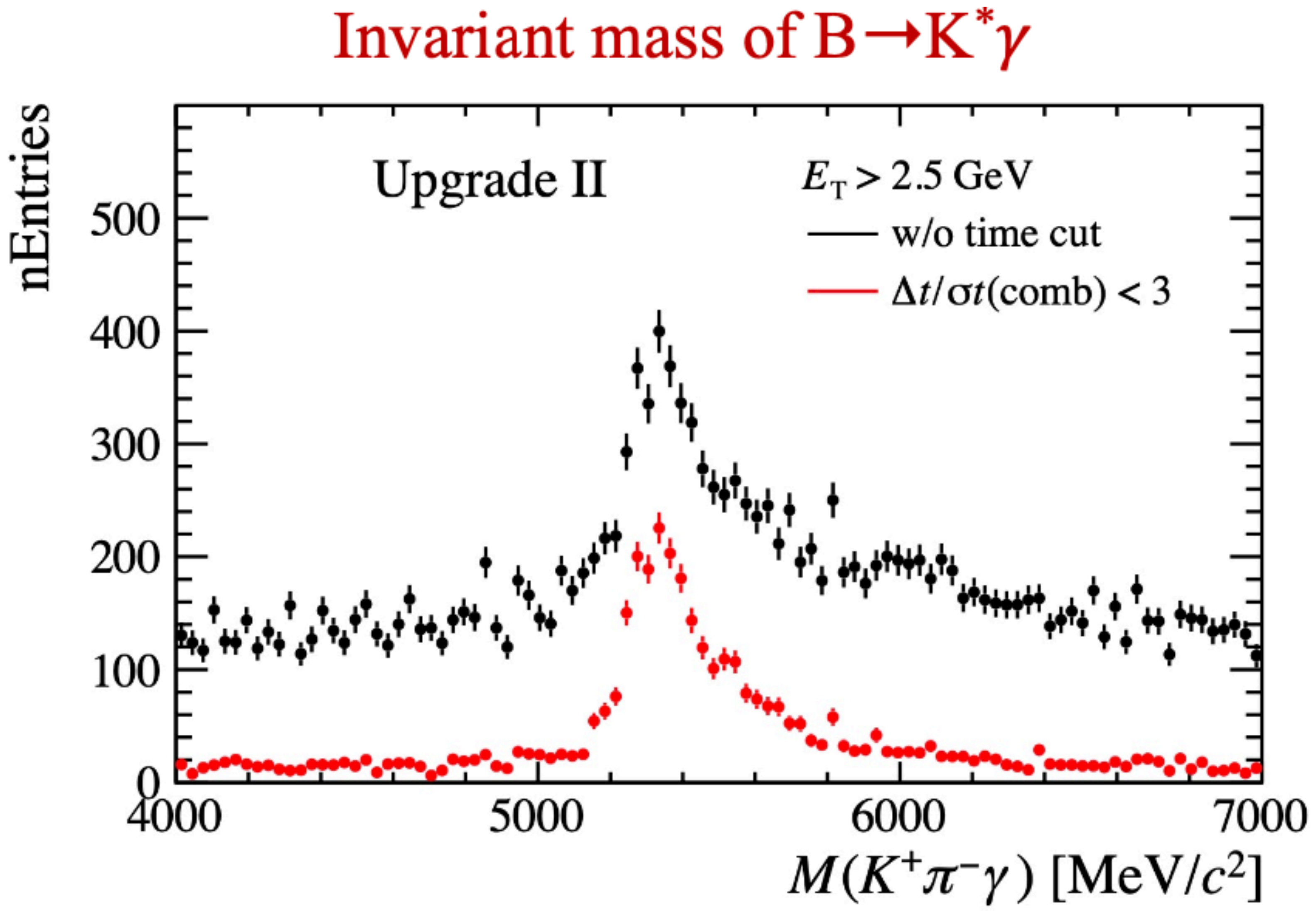
PID detectors: PicoCal

Picosecond Electromagnetic calorimeter

- Sustain radiation doses up to 1 MGy and up to 6×10^{15} 1MeV n_{eq}/cm (inner region)
  - SpaCal with rad. hard garnet crystals
- Keep UI energy resolution:
  - $\sigma(E)/E \approx 10\%/\sqrt{E} \oplus 1\%$
- Mitigate pile-up:
  - Timing capabilities ~10ps
  - Increase granularity
- Introduce longitudinal segmentation
  - Better time resolution
  - Less impact of radiation damage
  - Improved event reco. and particle identification
- New fast electronics →SPIDER chip







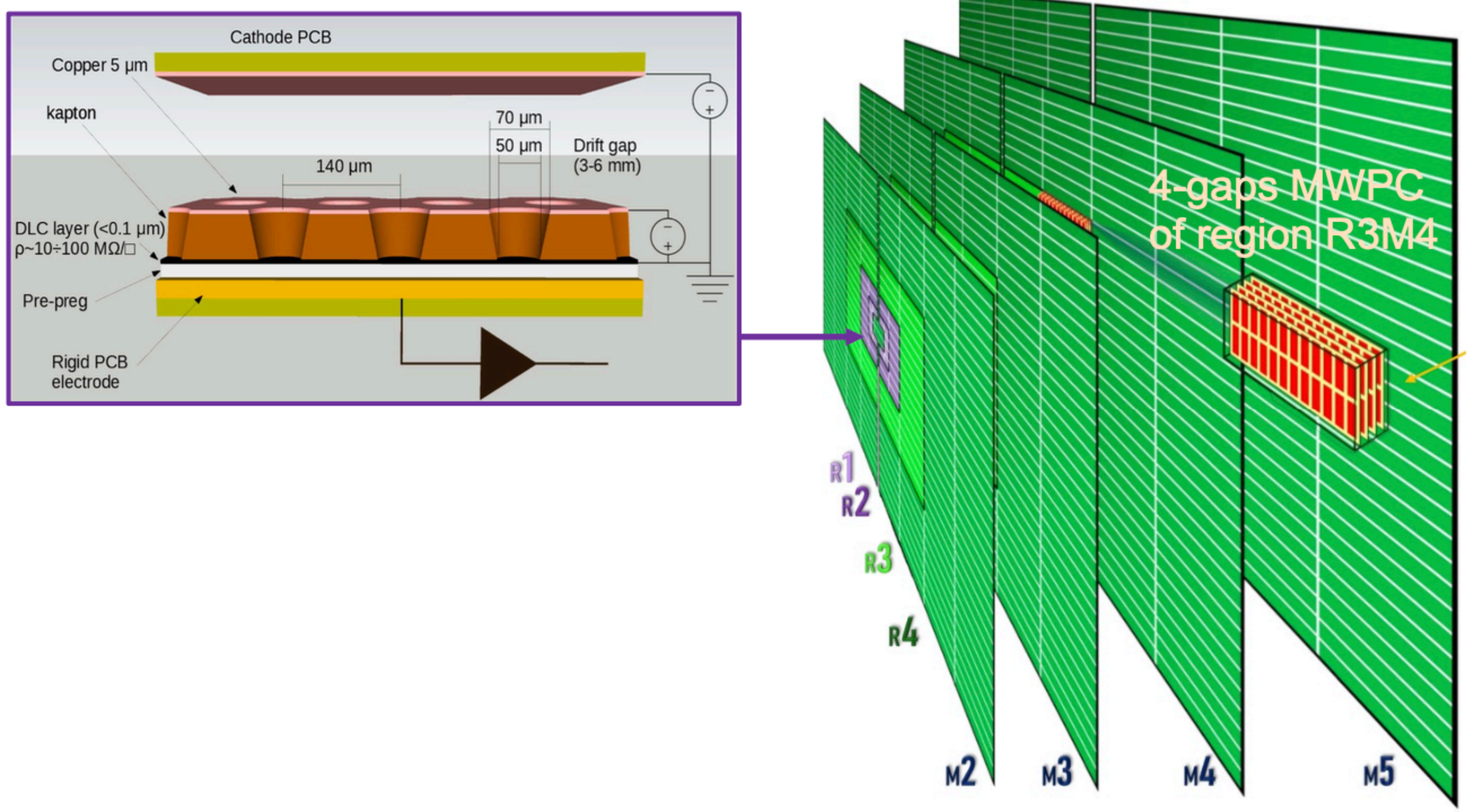
PID detectors: Muon system

Improved muon identification system

- Maintain current system performance in Run5 luminosity conditions
- **Limitations**:
  - FEE dead time for muon detection efficiency
  - High misID due to increased combinatorial rate & part. flux
- **3 main handles to solve it:**
  - Increase granularity → μ-Rwell detectors with small pads in inner regions
  - New R/O architecture
  - Additional shielding → replace HCAL and increase its shielding capacity

→ High inefficiency strongly mitigated in innermost regions with μ-Rwell chambers

μ-Rwell detectors in R1&R2



Deadtime induced inefficiency: **MWPC**

Maximum deadtime inefficiency % HCAL - MWPC				
	M2	M3	M4	M5
R1	17.14	6.65	7.50	8.66
R2	17.81	4.62	5.69	7.34
R3	7.21	1.72	3.49	5.68
R4	8.24	3.37	2.30	8.55

Deadtime induced inefficiency: **μ-Rwell**

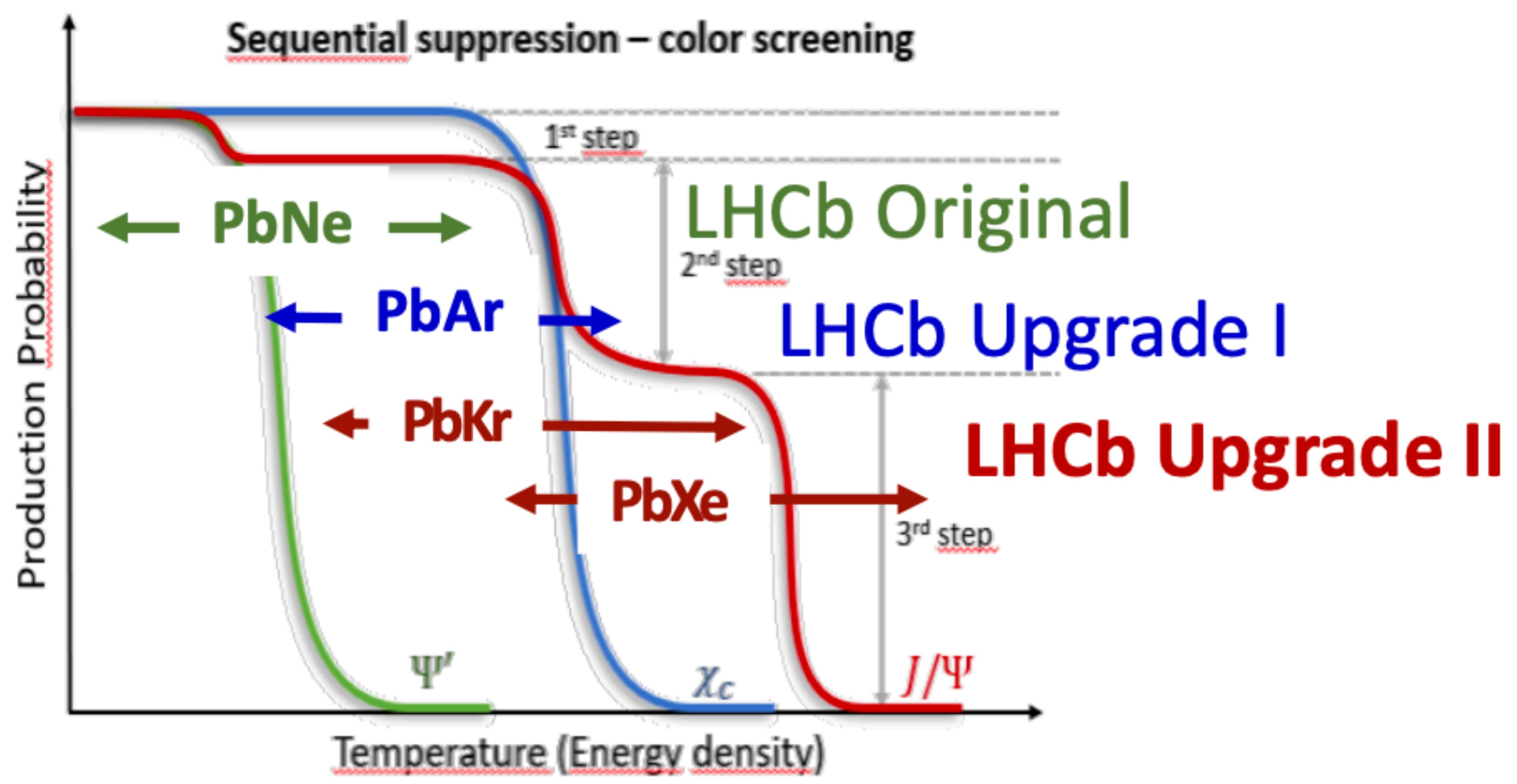
Maximum deadtime inefficiency % HCAL - μRWELL				
	M2	M3	M4	M5
R1	1.18	0.48	0.79	0.95
R2	1.22	0.32	0.31	0.41
R3	7.21	1.72	3.49	5.68
R4	8.24	3.37	2.30	8.55

Moving to high-granularity μRWell chambers

Fixed-target: SMOG2 and LHCSpin

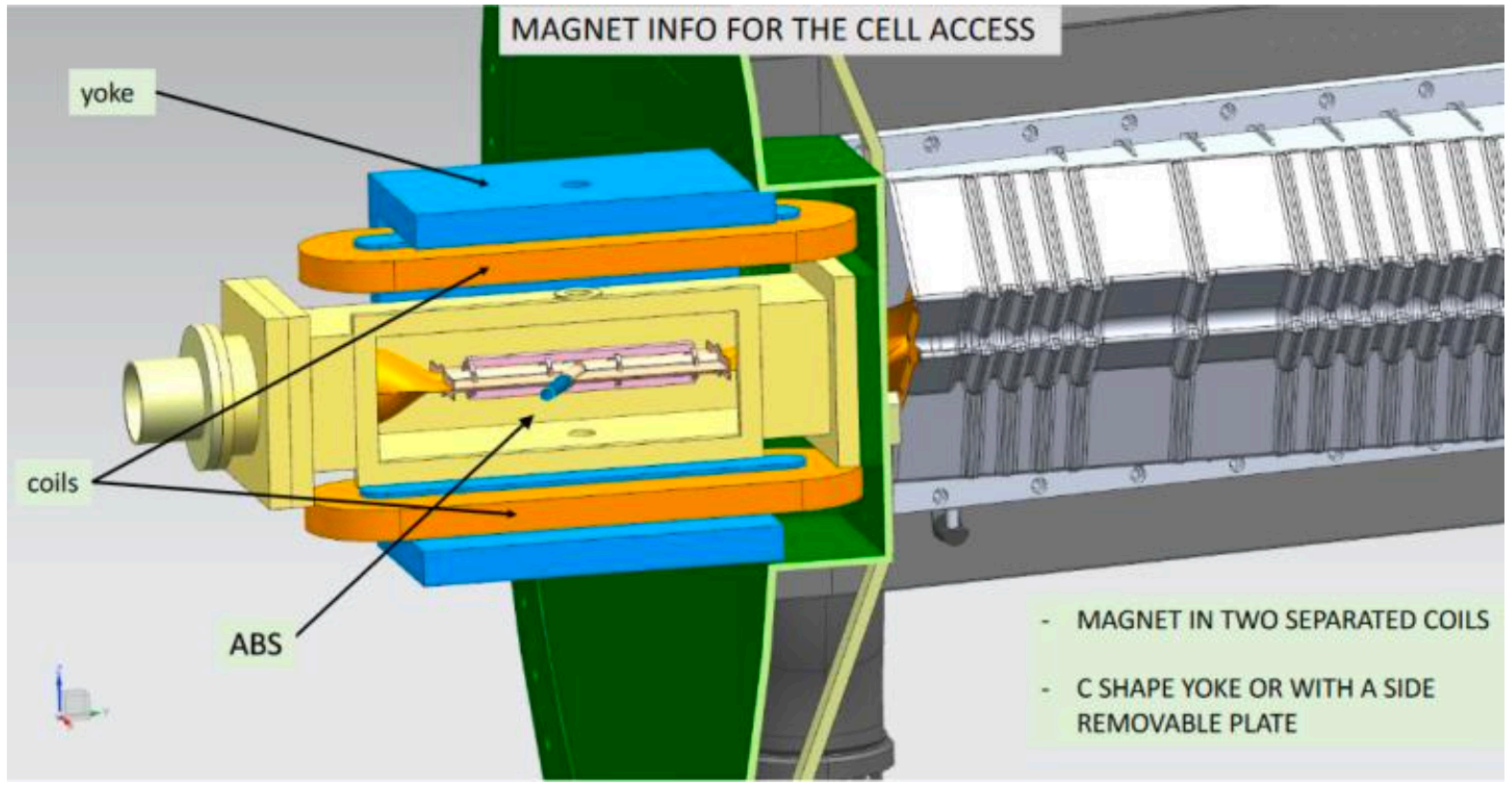
Non-polarized target: SMOG2

- Gas injection with displaced IP → operating in parallel with collider mode
- In Run3 and Run4 (UI)
  - High pA statistics will be recorded
  - In PbA, limited to Ar (A=40) due to occupancy limitations
- In Run5 and Run6 (UII)
  - No limitation for PbA
  - Explore QGP at high energy density (e.g. sequential suppression)



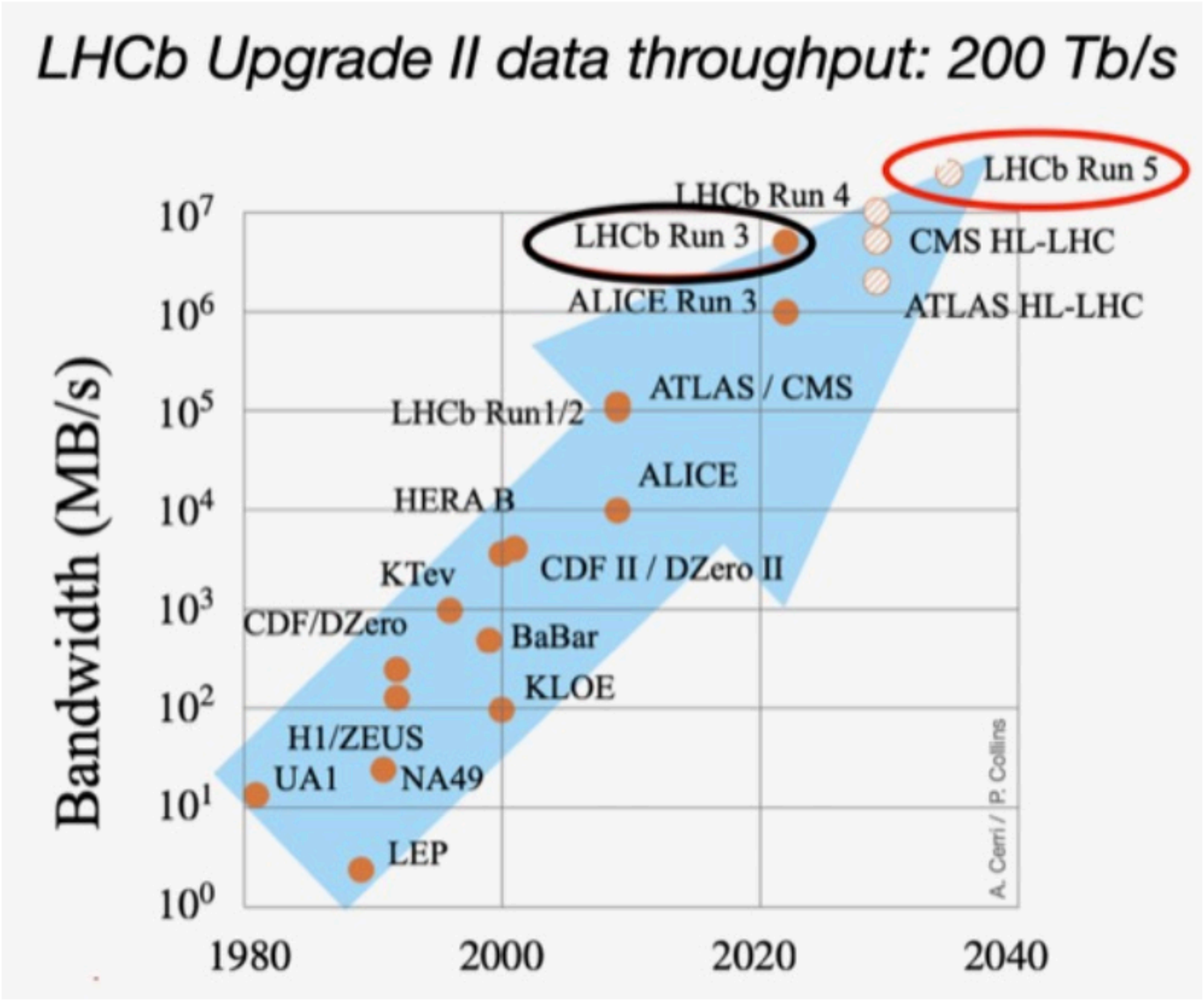
Polarized target: LHCSpin

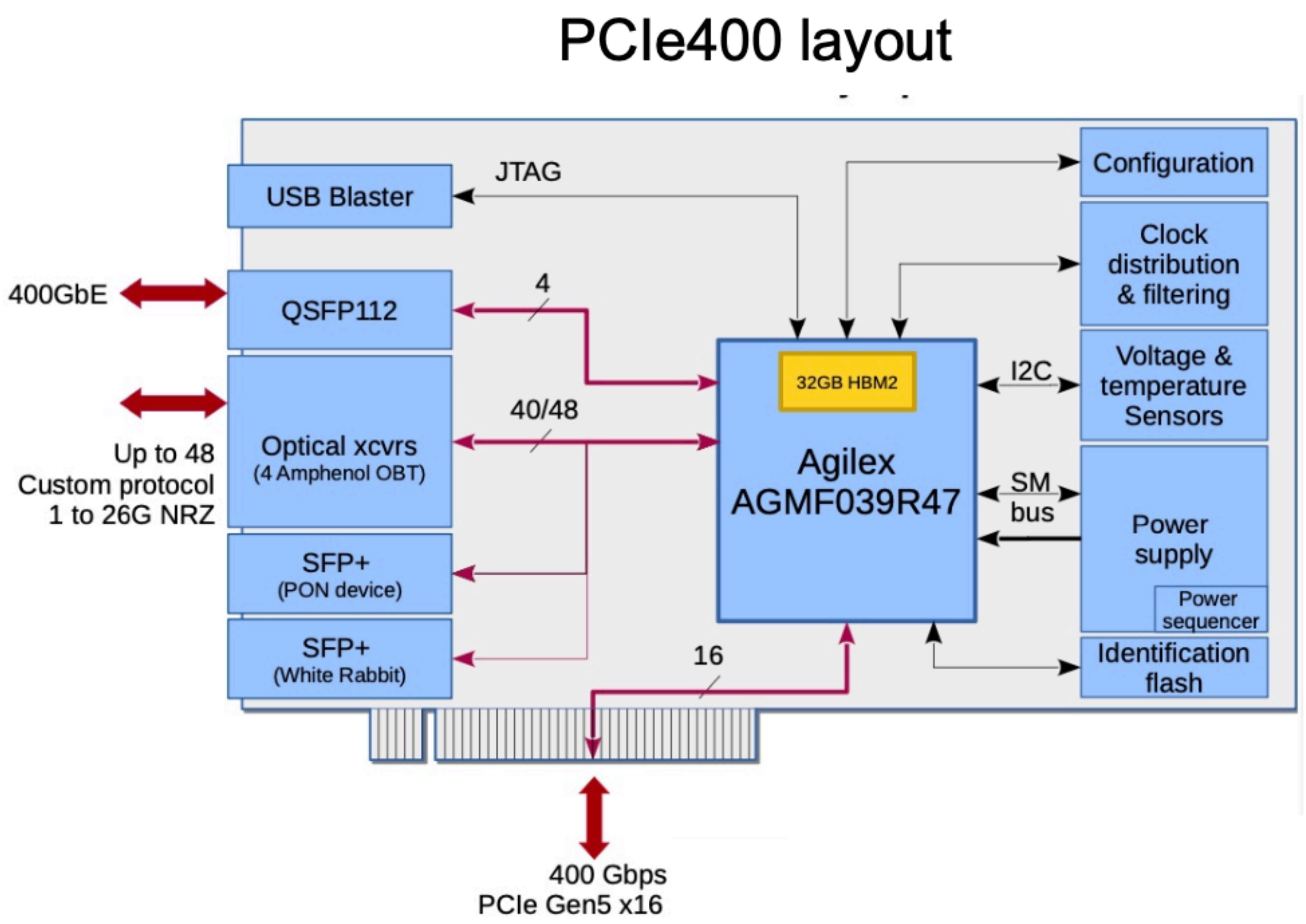
- Extensif the fixed-target physics program in Run4+
- Will allow injection of unpolarized gases

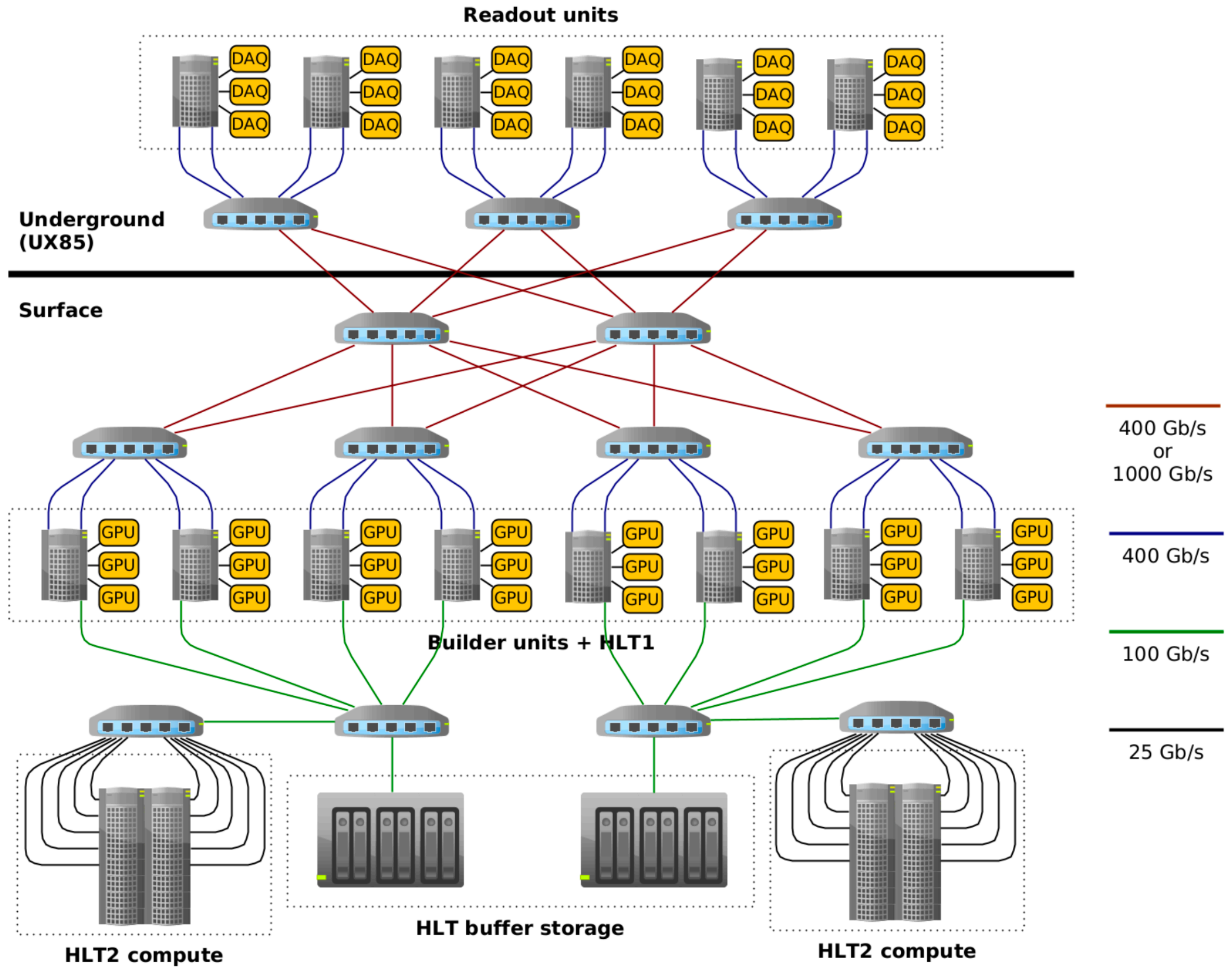


- Compact dipole magnet (300mT) → static transverse field
- Possibility to switch to a solenoid and provide longitudinal polarisation
- Alternative setup (jet target) being investigated in parallel

DAQ and processing





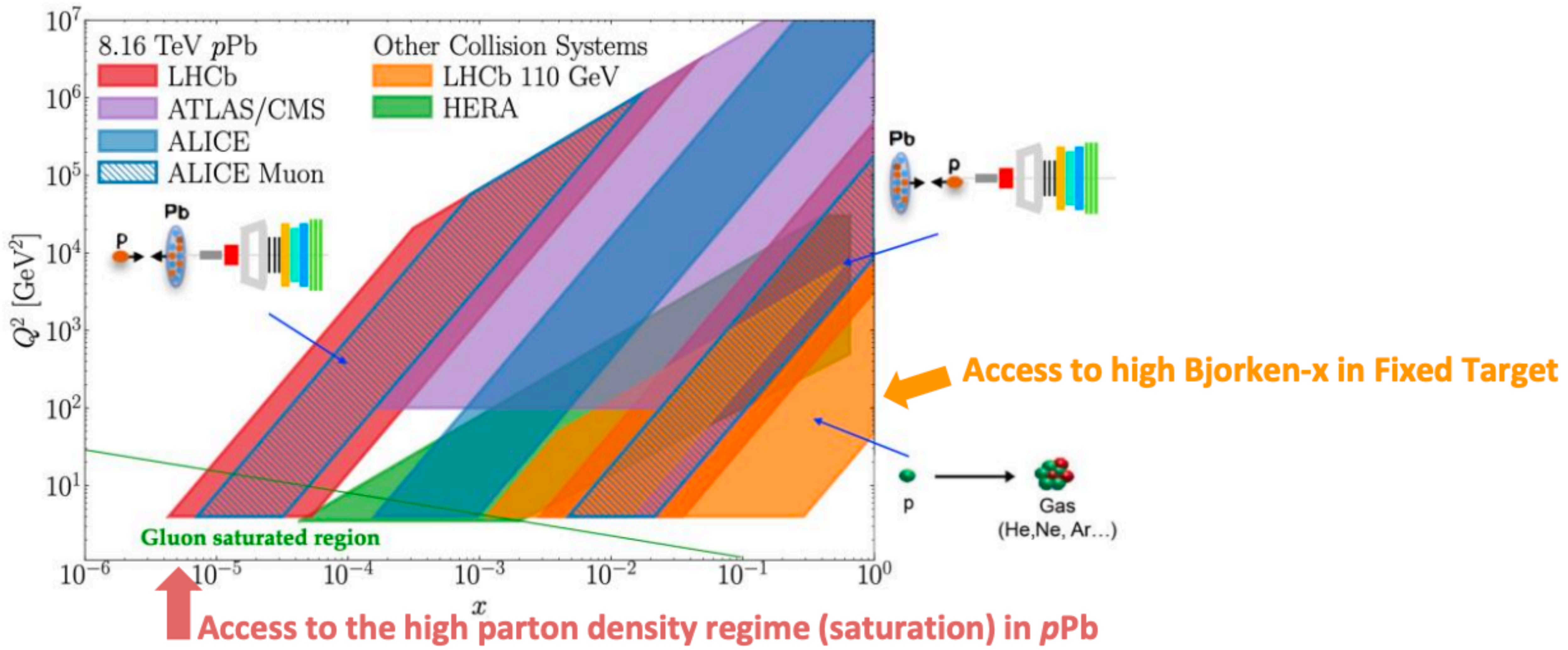


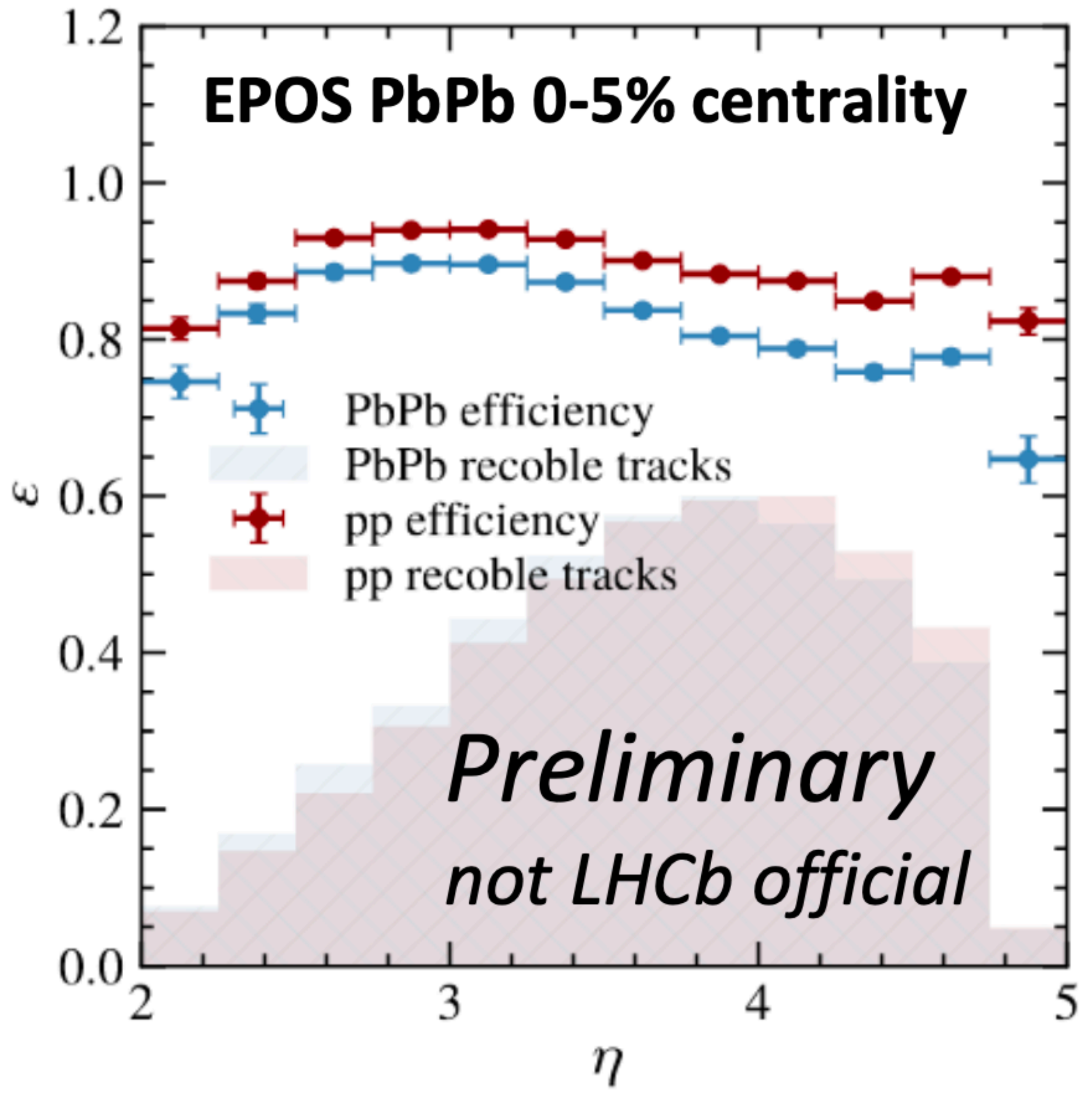
- Run5 luminosity increase and detector upgrades (↗granularity + high-precision timing): LHCb UII data throughput ~200Tb/s
- New generation of readout boards: PCIe400 (400Gb/s) under development (to be available for LS3 enhancement)
- Processing strategy: push forward UI concept (fully software trigger, HLT1 based on GPUs):
  - Increase computing ressources
  - Further exploitation of hybrid architectures: FPGA+GPU+CPU…
  - ML techniques to speed up data processing and optimize the use of computing ressources

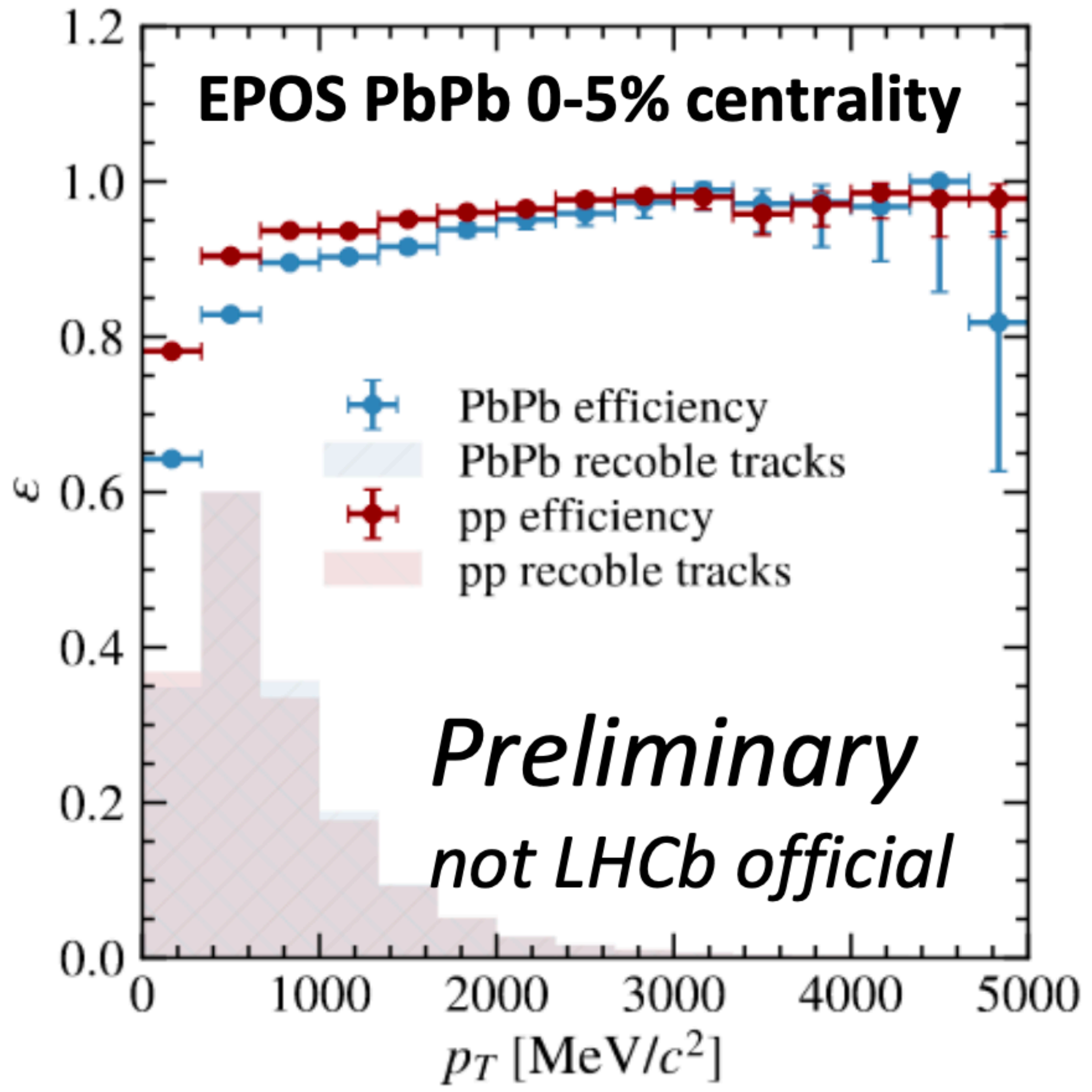
→ **Many ongoing studies and developments within this area**

HI-Physics opportunities with LHCb

- Pseudo-rapidity coverage : 2<η<5 providing full detection capabilities
- Bjorken-x coverage: collider mode and Fixed-Target mode (unique at LHC):
  - pPb: $10^{-6}<x<10^{-4}$
  - Pbp: $10^{-3}<x<10^{-1}$
  - FT: $10^{-3}<x<0.5$
- **LHCb Upgrade II:**
  - Full tracking performances for PbPb collisions within 0< centrality <100%
  - Expected PbPb luminosity during Run5 & Run6 ~10 nb^{-1}







HI-Physics opportunities with LHCb

- Precise vertexing: prompt/from-b separation
- Precise tracking: reconstruction down to $p_T=0$
- Precise PID: full reconstruction of hadronic decays of charm or beauty (e.g. $D^0 \to K\pi$)
- Upgrade II projection on bottomonia R_{PbPb} →study of QGP temperature through color screening
- High Run5 statistics and PID capability will make η_c, $\chi_{c,b}$ R_{PbPb} measurements possible
- … (non-exhaustive)

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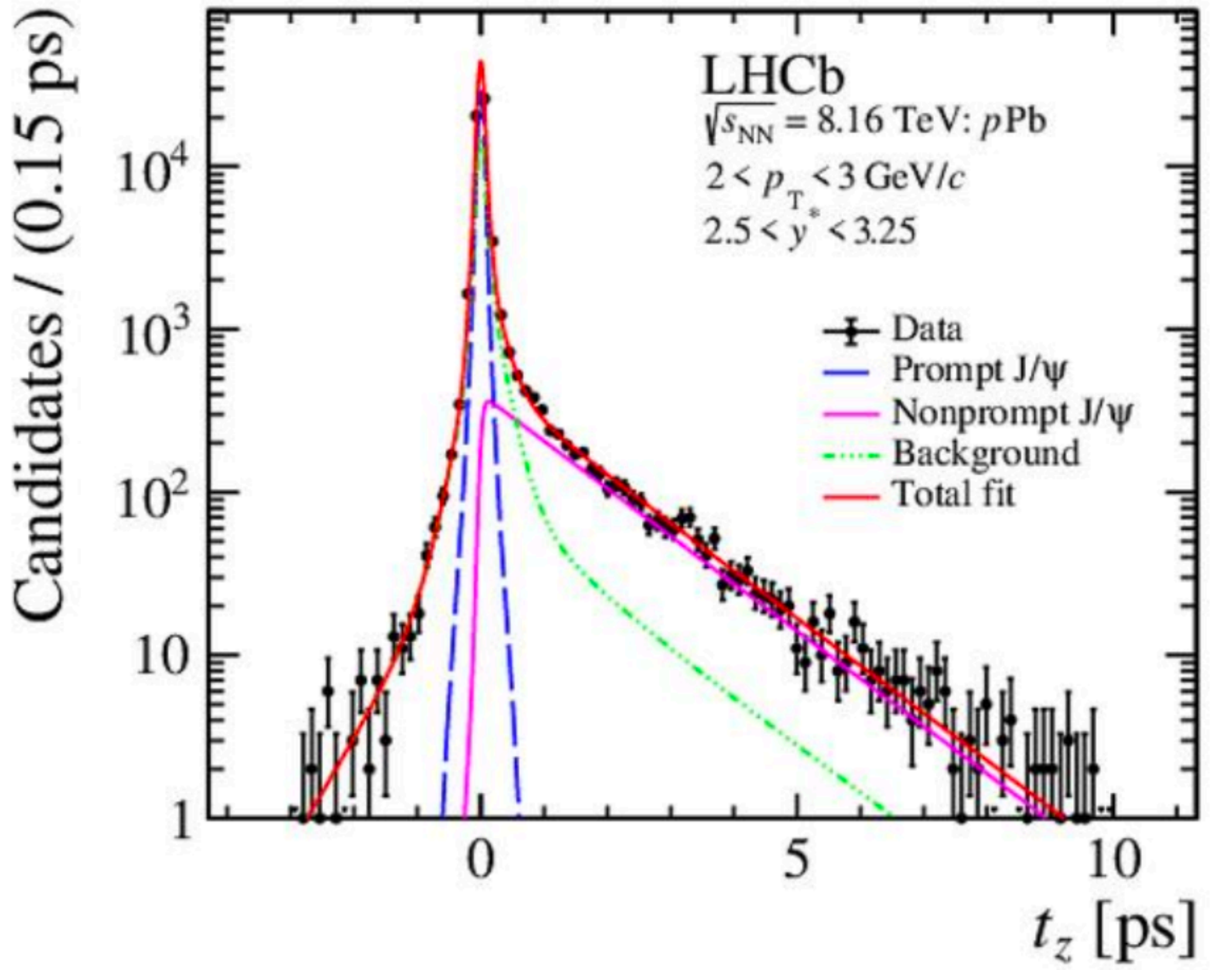

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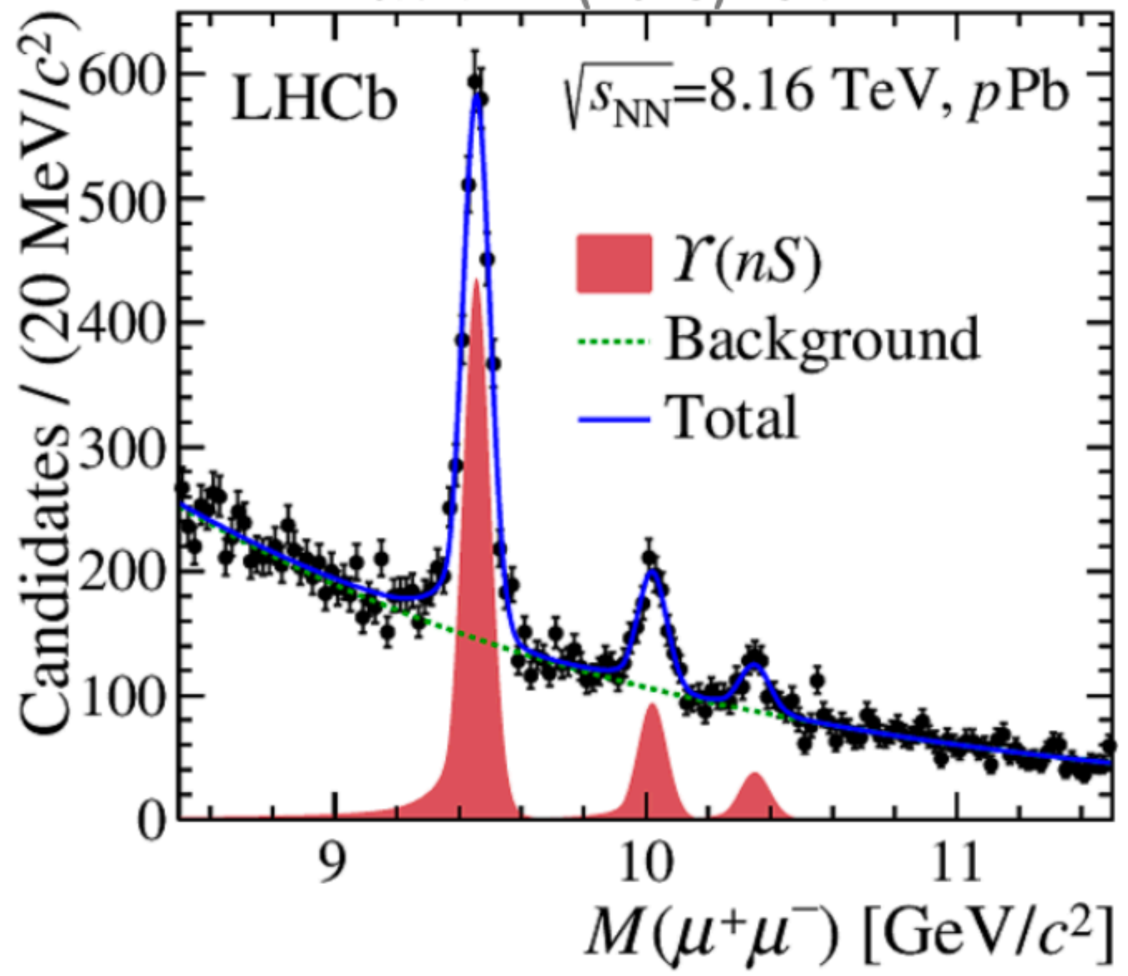
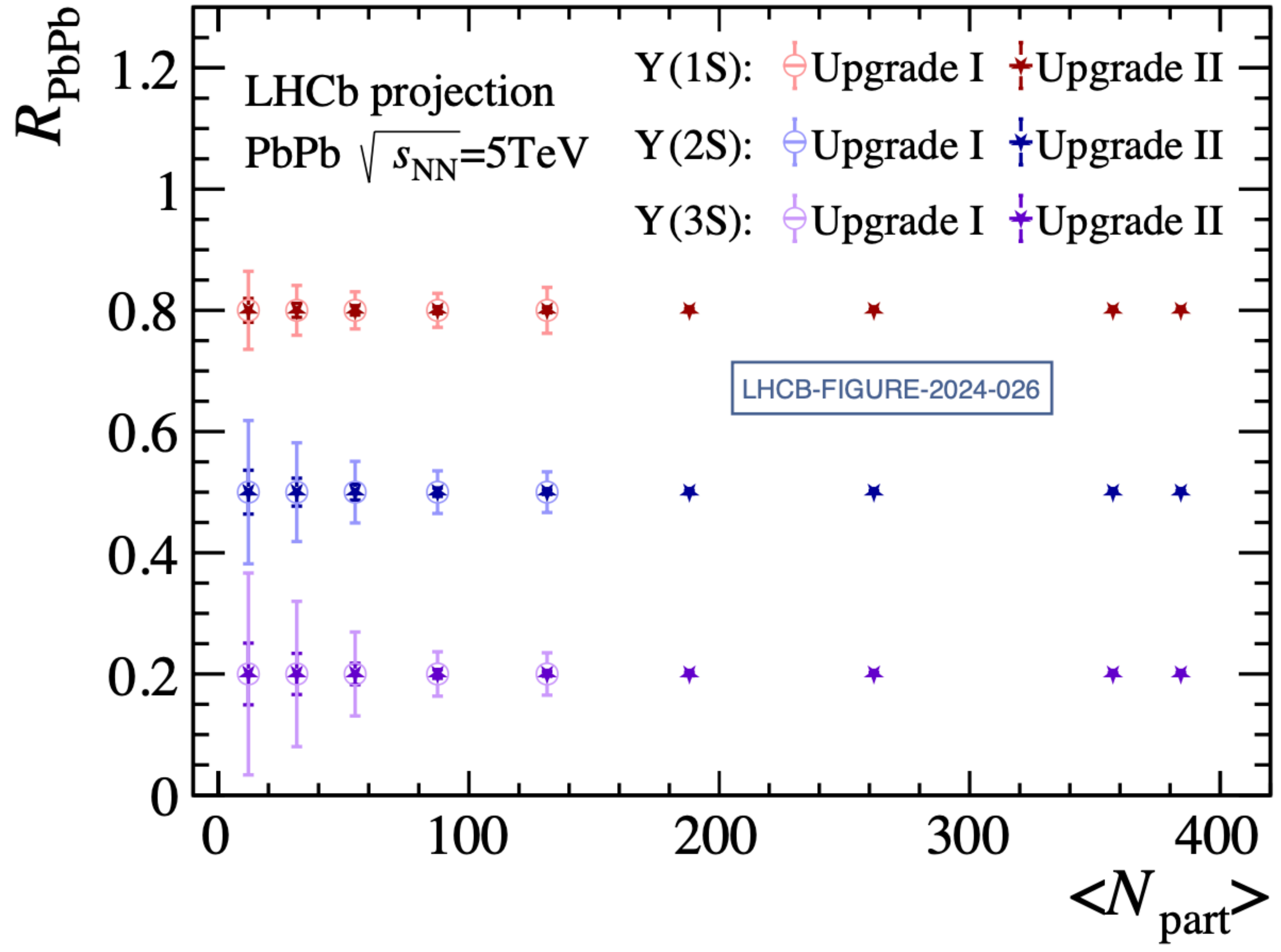


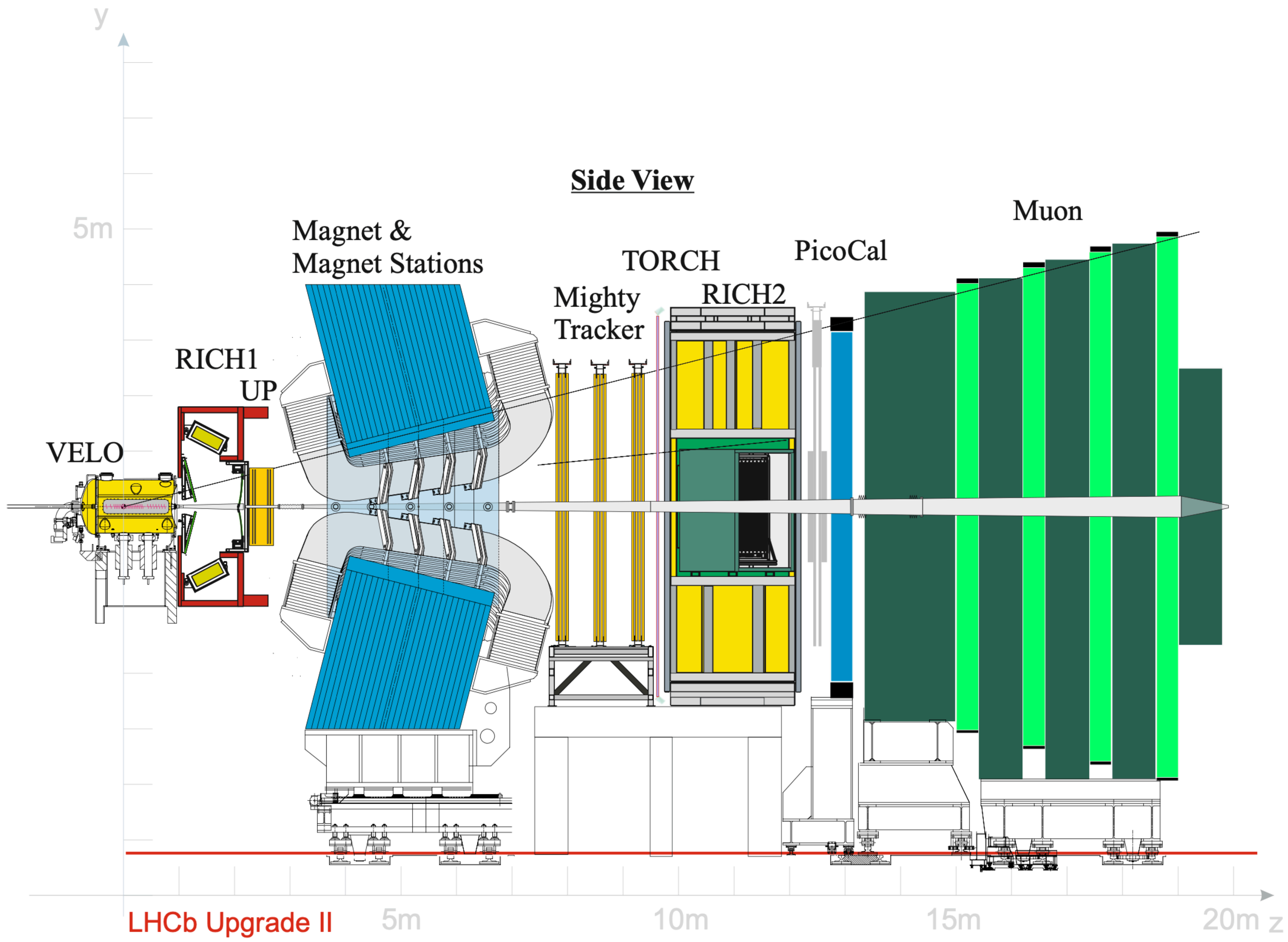


Summary and conclusions

Upgrade phase II: a new LHCb detector for LHC Run5 & Run6

- Adapt and improve LHCb subsystems to operate in HL-LHC luminosity conditions → maintain (and improve if possible) LHCb UI performances
  - Increase granularity
  - Add high-precision timing
  - Increase and optimize DAQ and processing capabilities

→ **Ambitious ongoing R&D program**



HI-Physics opportunities with LHCb:

- Fully instrumented detector in 2<η<5
- Designed for high precision Heavy-Flavor measurements
- Operates fixed-target setup (future polarized target with LHCSpin)
- Full centrality coverage in PbPb at Run5
- LHCb IFT community growing

New collaborators from the HI-Physics community (and others) are very welcome!

Thank you!

Evolution of sensitivity on key flavor observables

Summary table for Upgrade II sensitivities on some key flavor observables

Observable	Current LHCb (up to 9 fb^{-1})	Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests				
γ ($B \to DK$, *etc.*)	$4°$	$1.5°$	$1°$	$0.35°$
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	3%	2%	1%
$a_{\rm sl}^d$ ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	8×10^{-4}	5×10^{-4}	2×10^{-4}
$a_{\rm sl}^s$ ($B_s^0 \to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm				
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_S^0\pi^+\pi^-$)	18×10^{-5}	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays				
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—	—	—	0.2
$A_{\rm T}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	0.060	0.043	0.016
$A_{\rm T}^{\rm Im}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}(B_s^0 \to \phi\gamma)$	$^{+0.41}_{-0.44}$	0.124	0.083	0.033
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	0.148	0.097	0.038
Lepton Universality Tests				
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	0.007	0.005	0.002