HL/HE detector challenges for LHCb

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on behalf of the LHCb Collaboration

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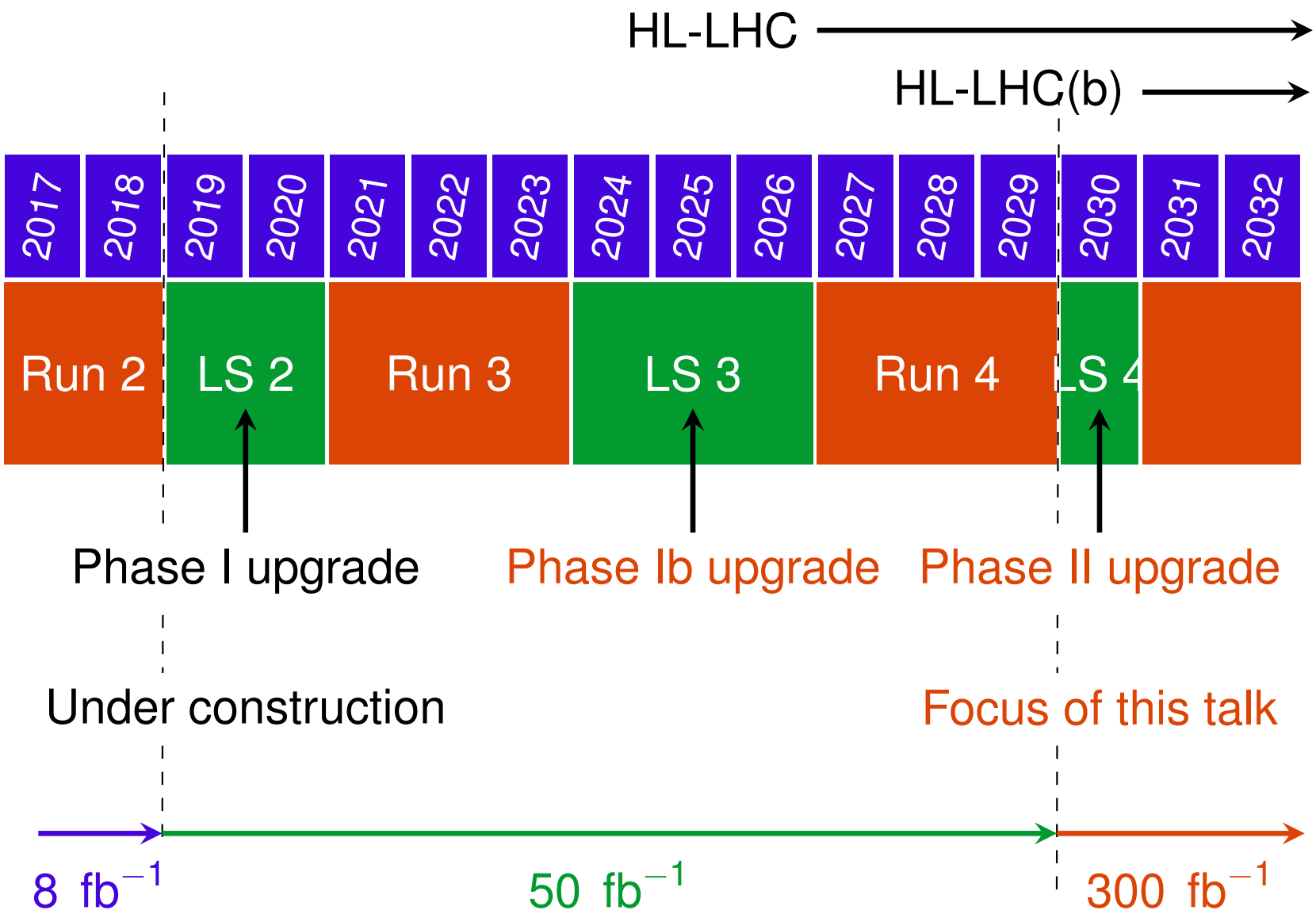
The future of LHCb



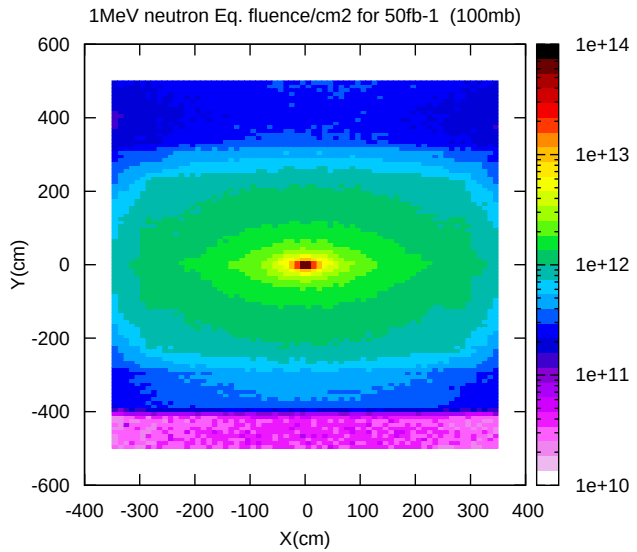
HL-LHC(b)

- LHCb will operate in Run 4 similar to Run 3
- High luminosity era really begins after LS4

	$\mathscr{L}(10^{32}/\text{s/cm}^2)$	Collisions
Run 2	4	1
Run 3-4	20	5
Run 5+	100-200	50

Challenges of luminosity

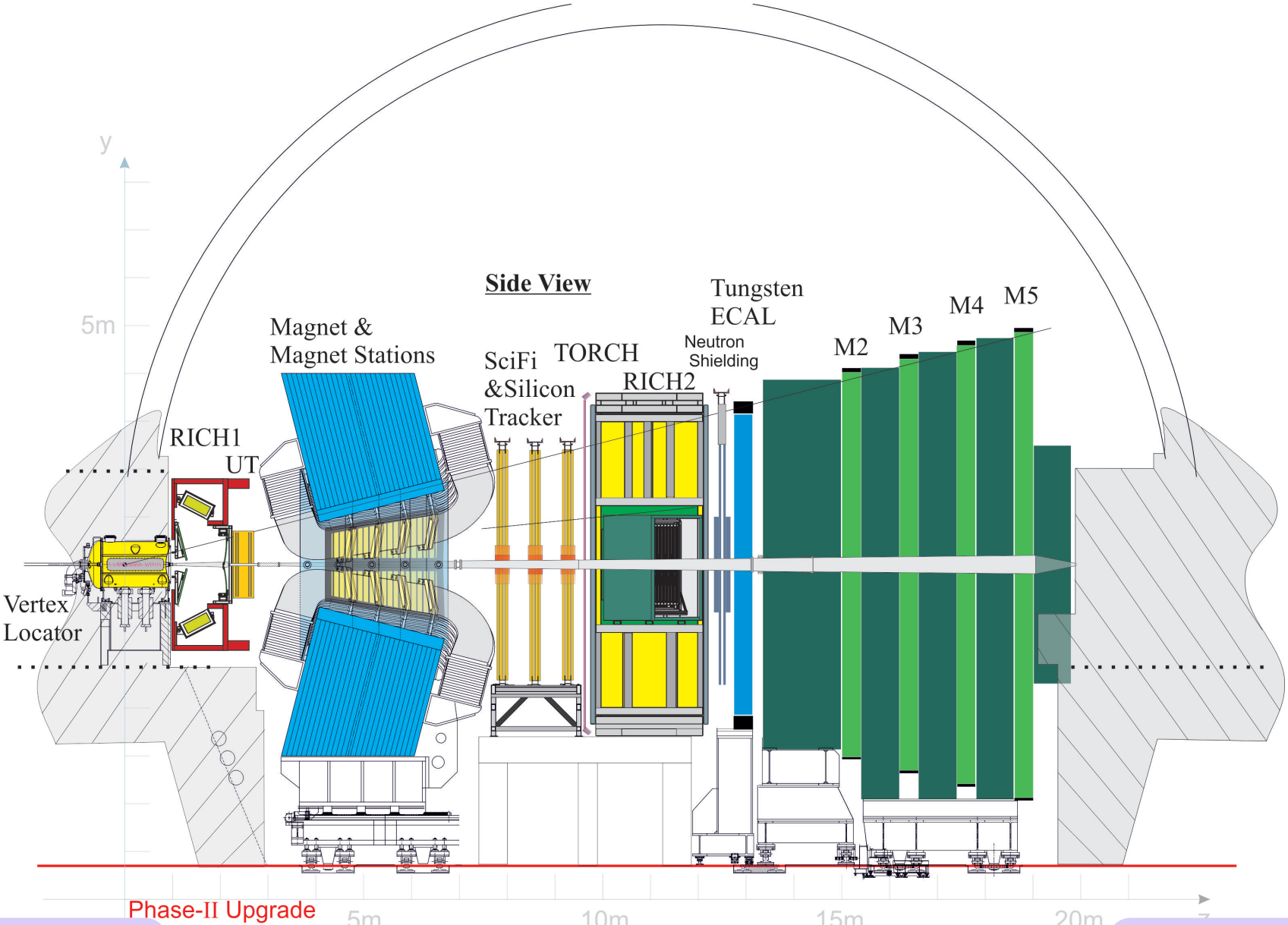
- Ten times more collisions brings:
  - Occupancy
  - Combinatorics – track finding and decay finding
  - Radiation
  - Data rate
- Geometry means every subdetector faces a wide range of flux



Fluence map for SciFi tracker in Upgrade I

A new experiment

Even if its not obvious from this picture

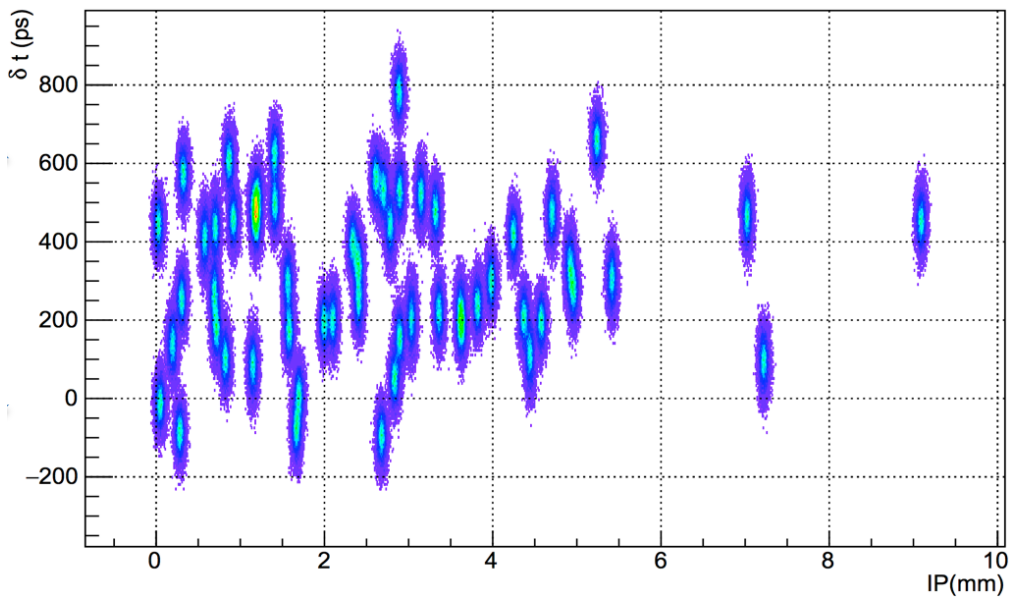


A new experiment

- LHCb must be a new detector for Run 5
- Challenge – maintain detector strengths in tracking and particle ID with 10 times more pile-up than upgrade I
- Essential for finding complex decay chains with manageable combinatorial backgrounds
- But also opportunities to improve the current performance!
  - Some of which may be added early as Upgrade Ib

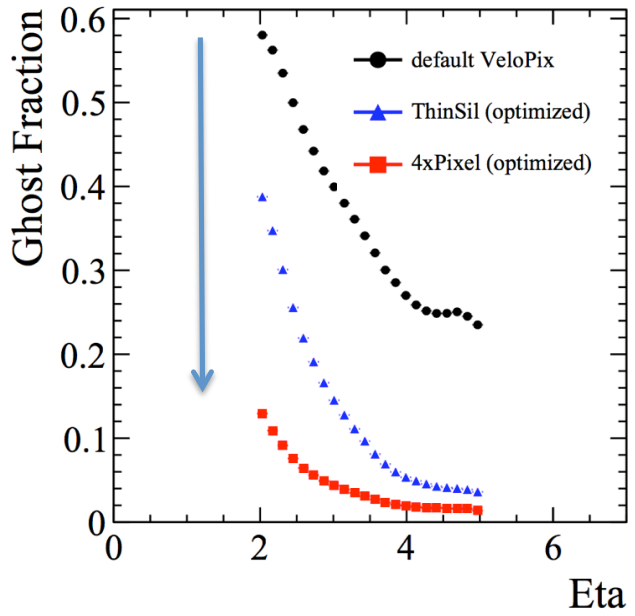
The power of time

- Become a 4D detector – many upgrades exploit precise timing measurements
- Solves challenges in:
  - Track finding
  - Vertex finding and association
  - Matching particles across sub-detectors



Vertex Locator

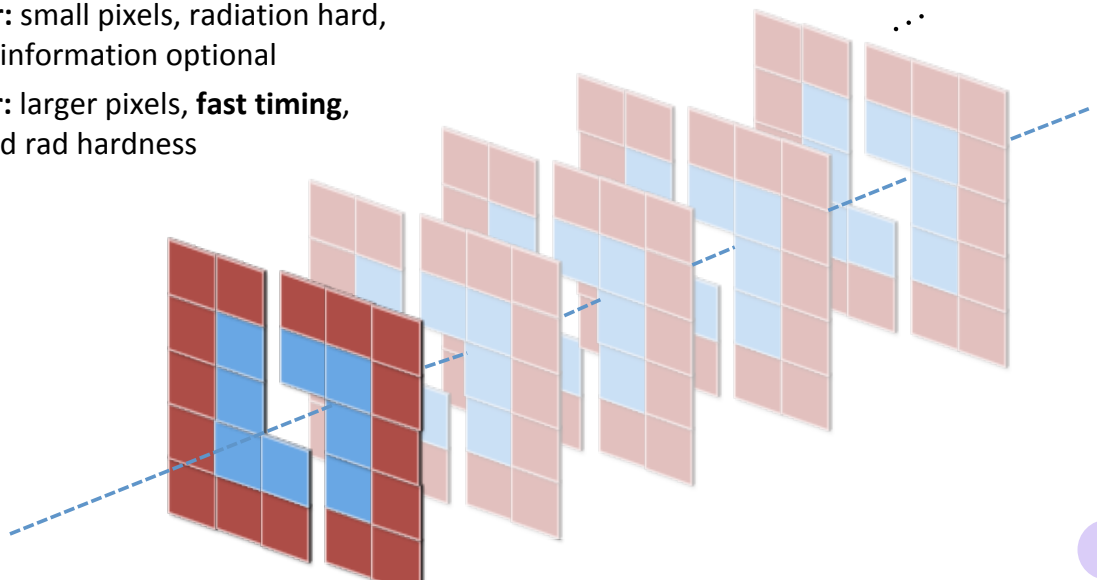
- Current VELO would not work for HL-LHC
  - Huge fraction of fake tracks (ghosts)
- Can reduce with better granularity and timing



Radial dependence motivates a dual-technology design

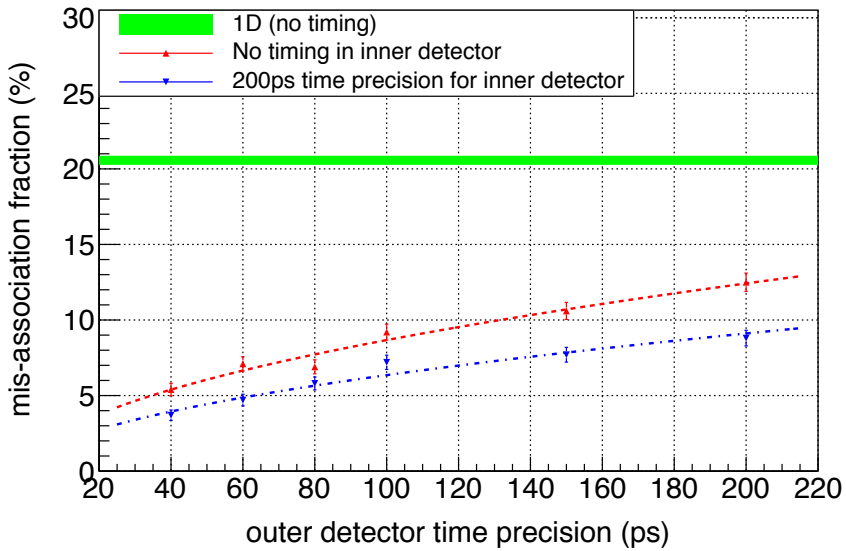
Small-r: small pixels, radiation hard, timing information optional

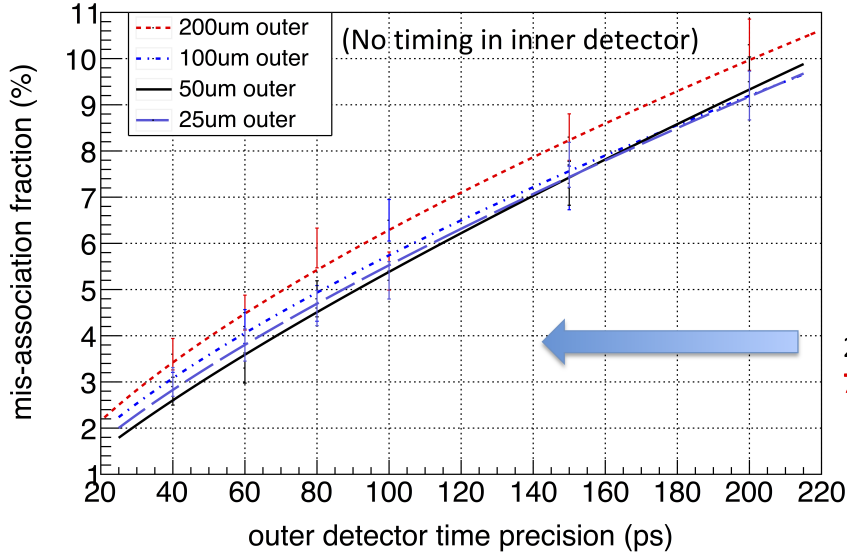
Large-r: larger pixels, **fast timing**, reduced rad hardness



VELO with time

- Timing even more important than pixel size!

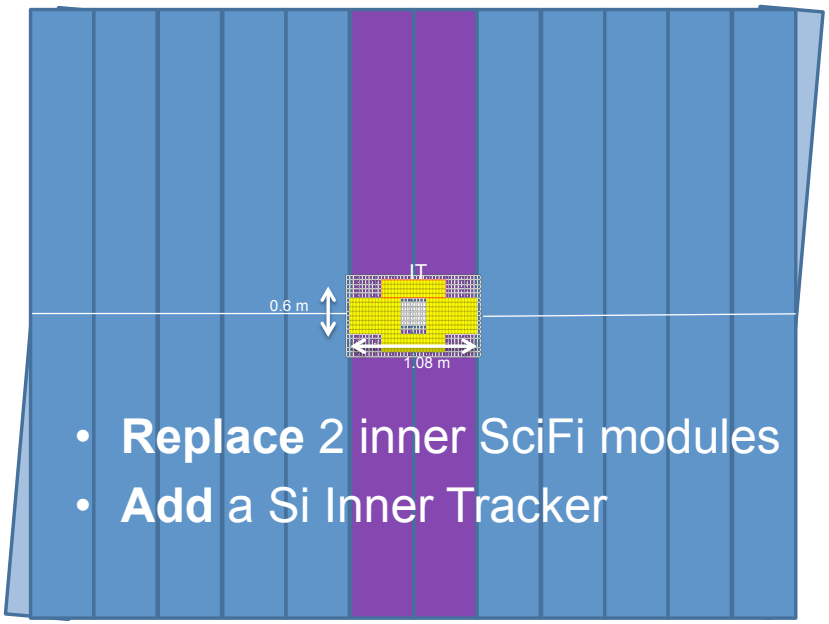




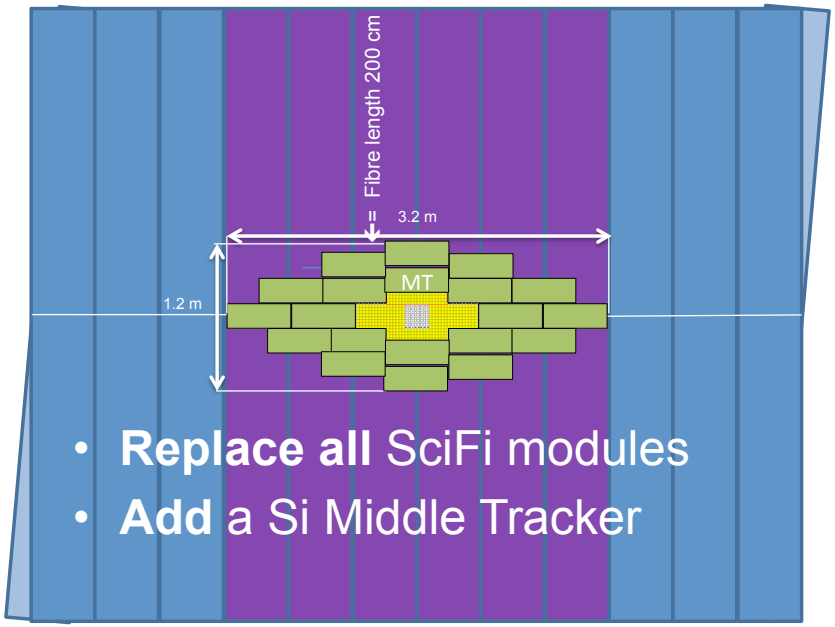
- Goal is ≈ 30 ps for outer part
- Mis-association scales linearly with luminosity
- Even a 200 µm pixel would work!

Downstream tracking

- Current Scintillating Fibre tracker evolves
- Occupancy requires staged upgrades



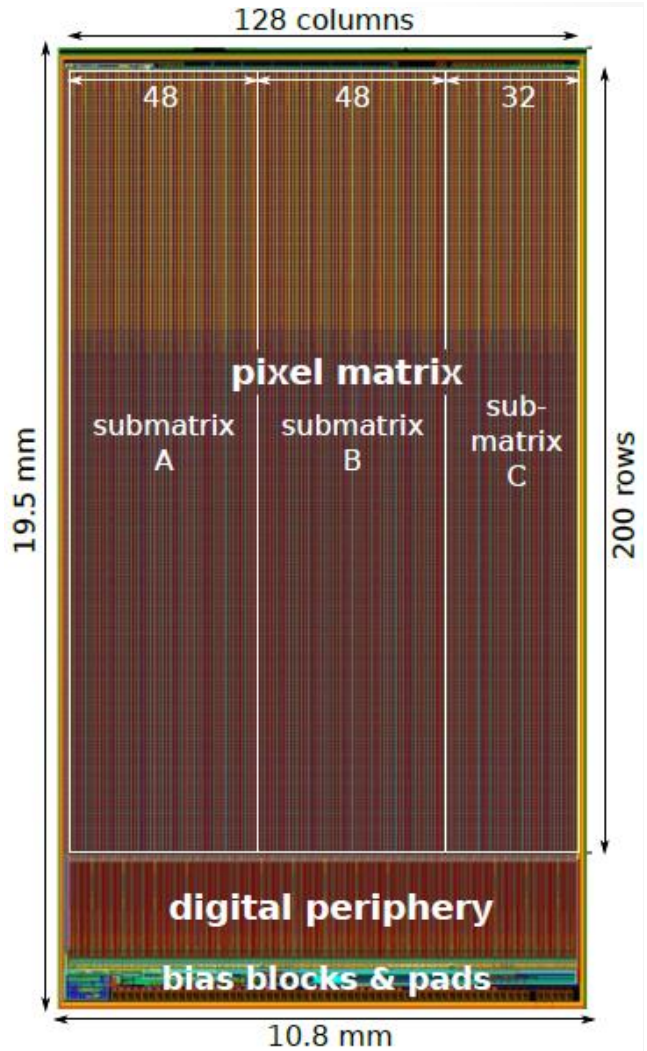
Upgrade 1b



Upgrade 2

HV-CMOS

- HV-CMOS devices potential low-cost solution for downstream tracker
  - Good segmentation, performance after irradiation
  - Monolithic design with readout
- Watching results from other experiments like Mu3e



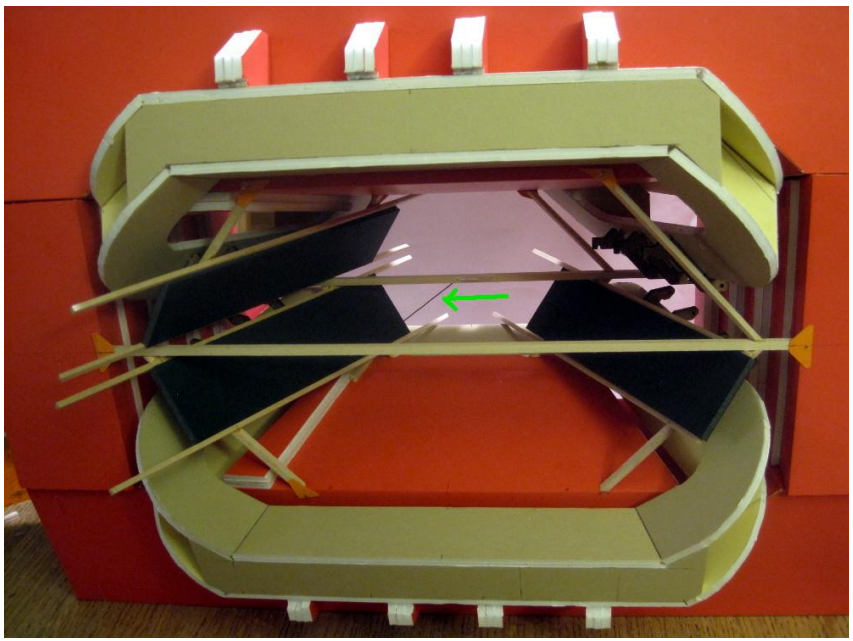
MuPix8

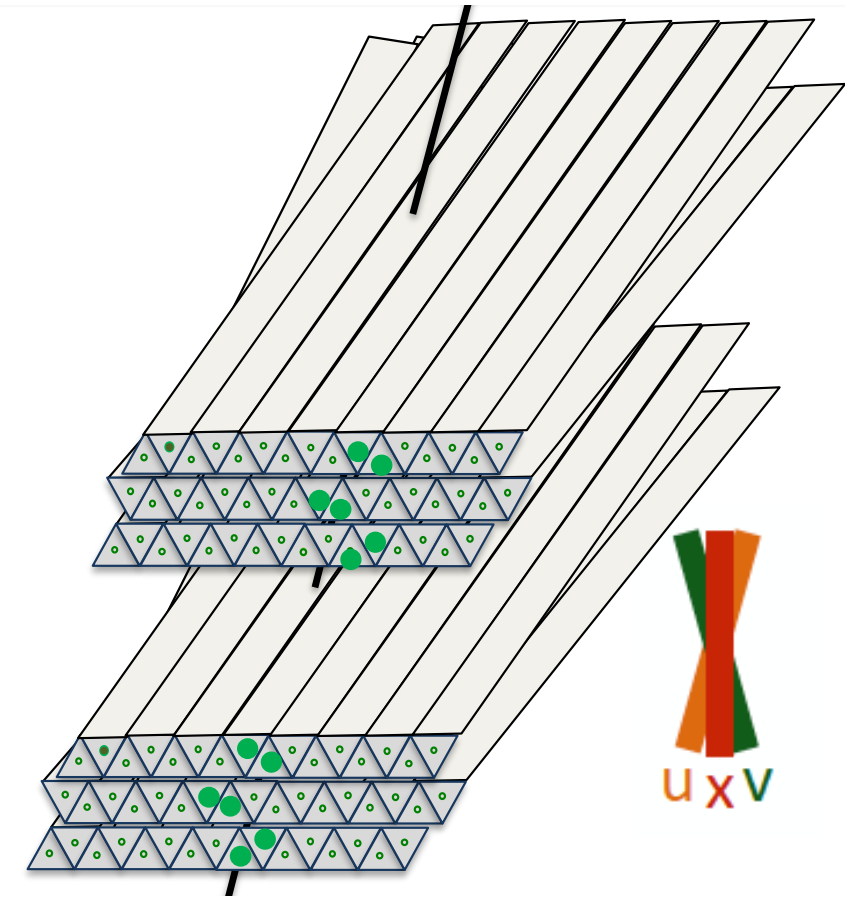
sensor for Mu3e

Magnet stations

Opportunity for improvement

- R&D underway to place tracking in the magnet
- Only need granularity of 1 mm for huge gains at low momentum

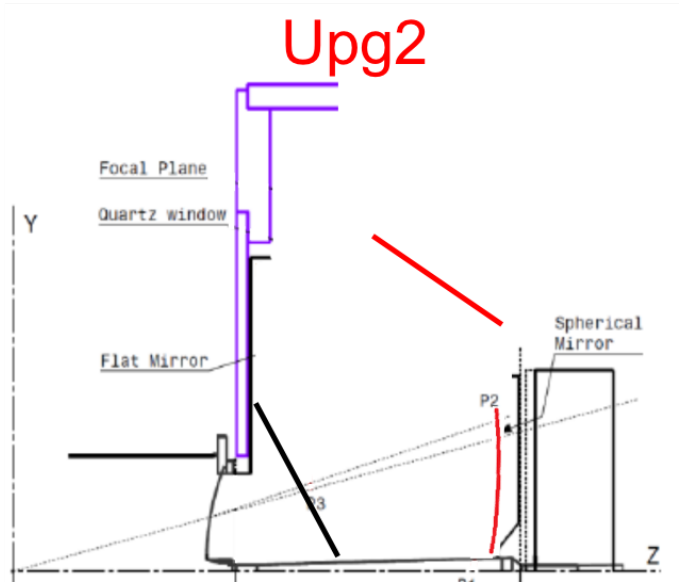


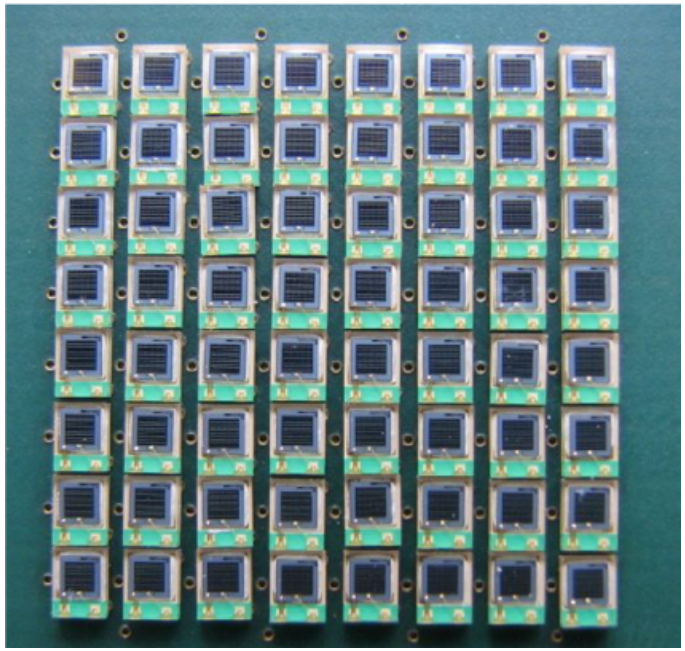


- Possible design with extruded scintillator bars as in D0 preshower

RICH detectors

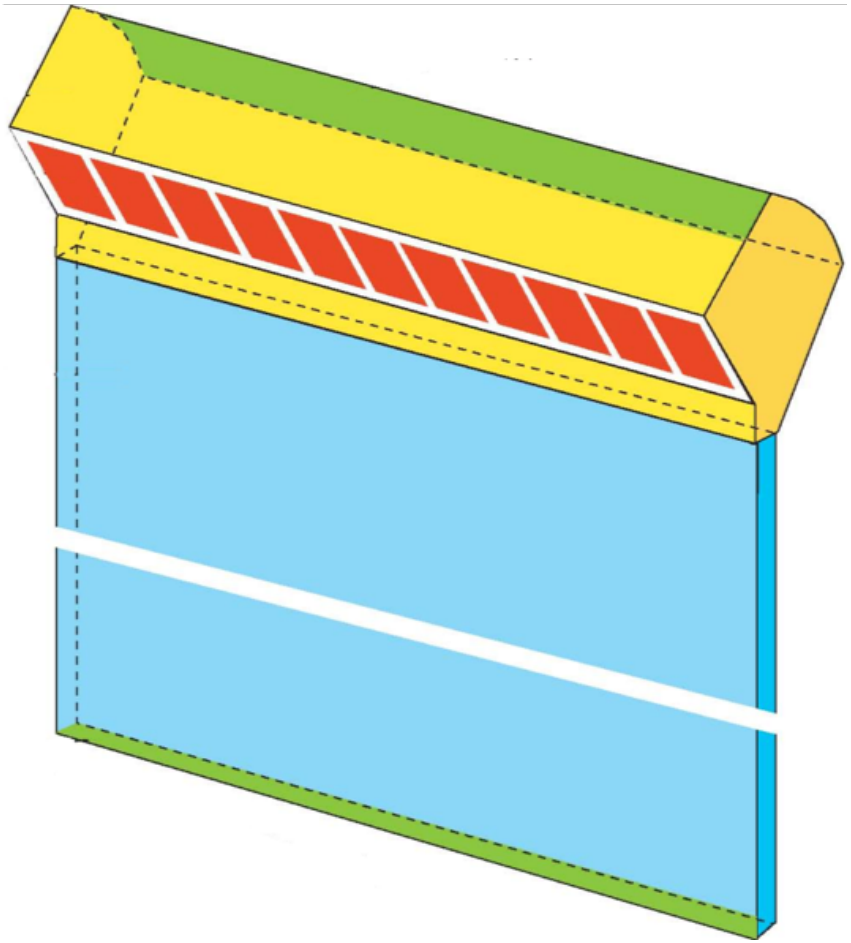
- Current detectors would have 100% occupancy
- Three-fold plan:
  - Adjust optics
  - Finer segmentation
  - Shift sensitivity towards green
- SiPM may be a solution
- Can improve RICH1/2 resolution from 1.6/0.7 mrad to 0.2/0.1!
- Possible time resolution of $\approx 100\,\mathrm{ps}$

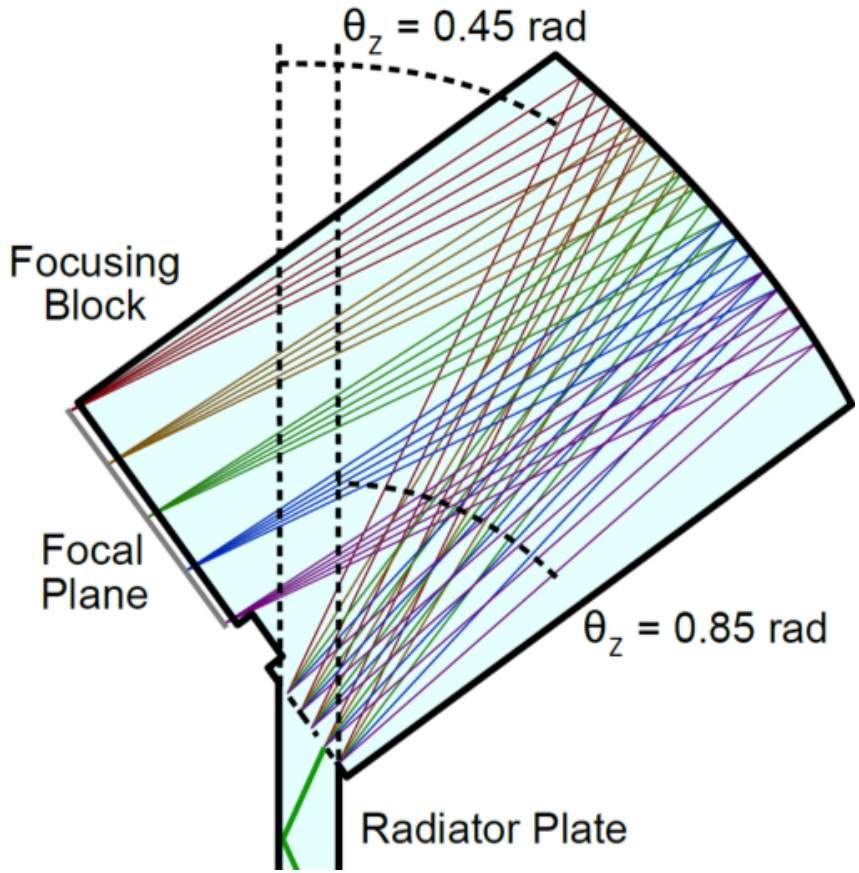




TORCH

- New time-of-flight detector design
  - Uses internally reflected Cherenkov light
  - Provides particle ID to lower momenta

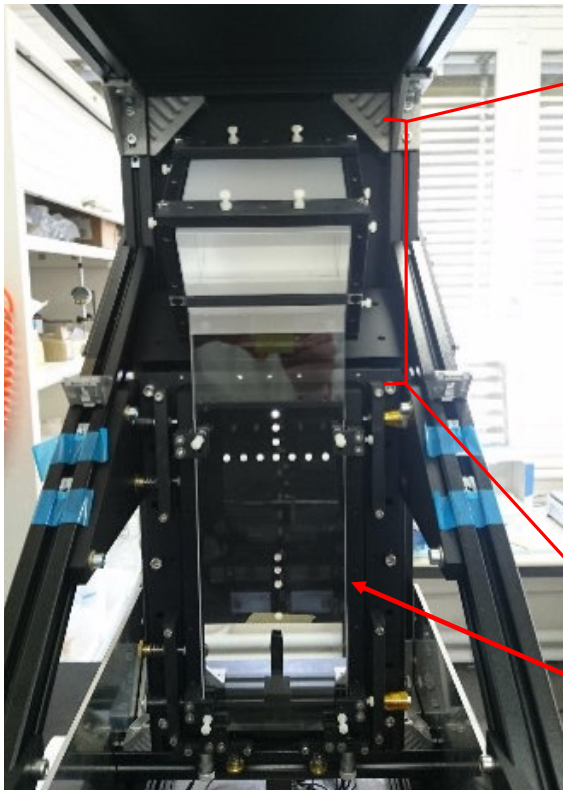


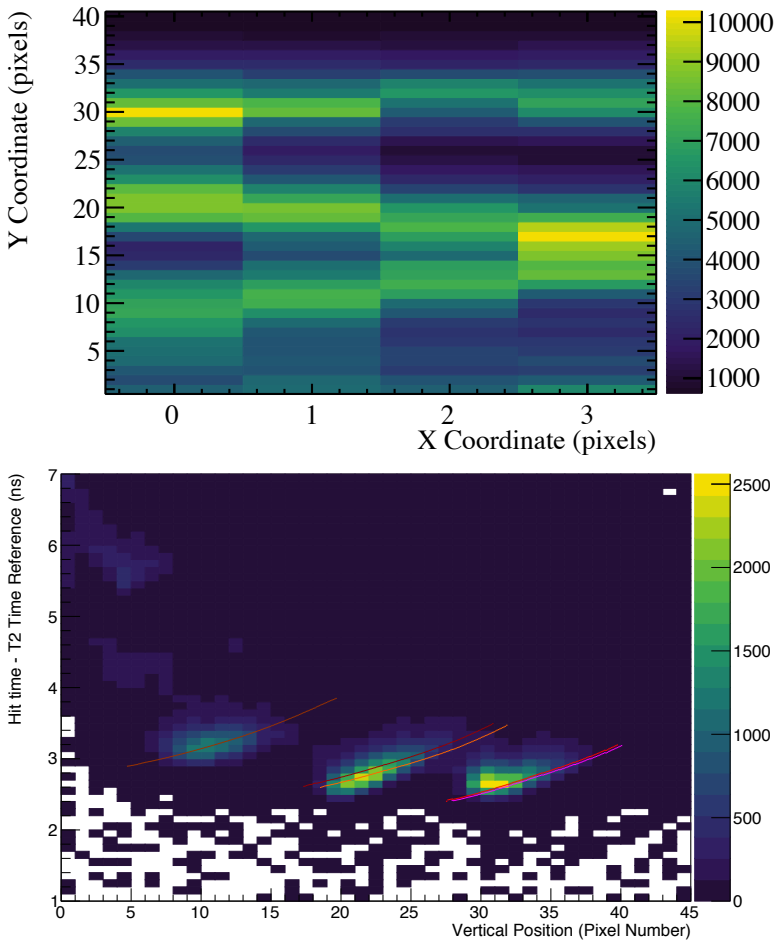


Testing TORCH

- Promising recent testbeam results!

Readout pattern in position and time:

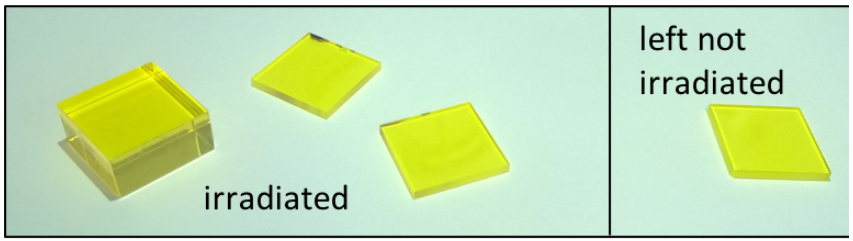


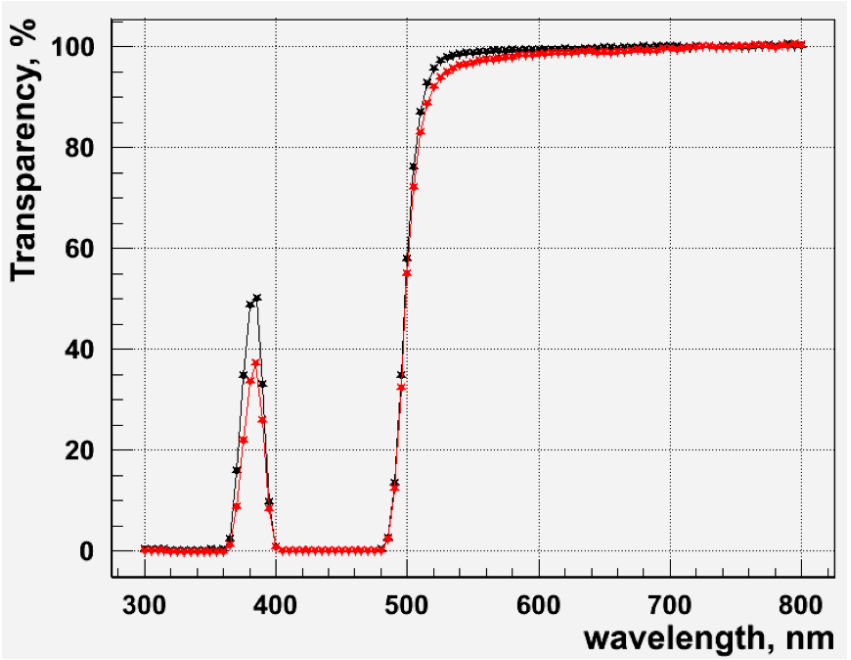


ECAL

- Part of current ECAL must be replaced in LS3 – chance to start upgrade early?
- Opportunity to improve reconstruction of electrons and photons – many physics applications

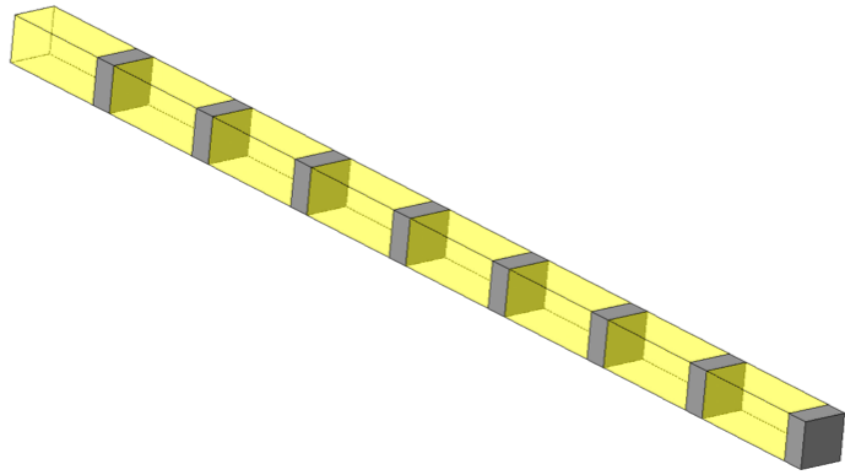
- Inorganic scintillators like GAGG (Ce doped $Gd_3Al_2Ga_3O_{12}$) show good radiation tolerance in recent tests

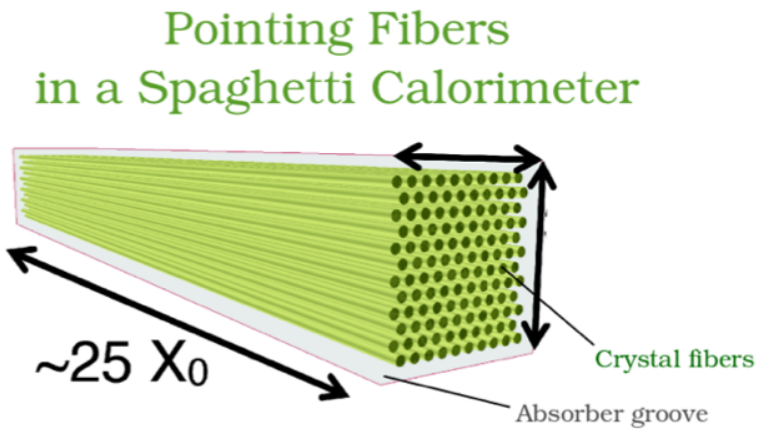




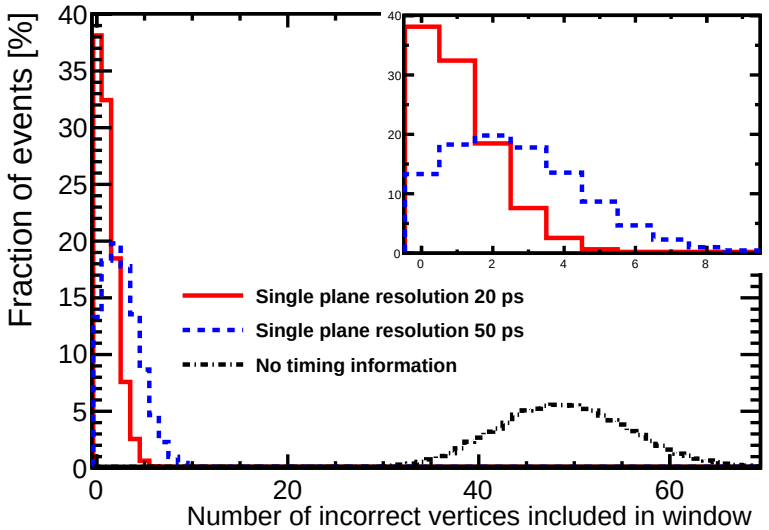
ECAL segmentation

- Increased segmentation a necessity
- In space



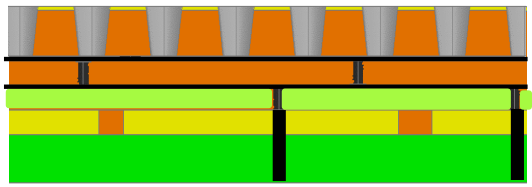


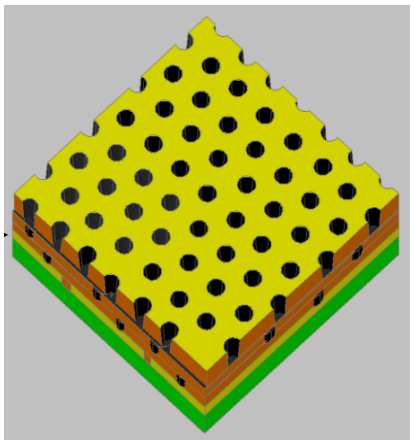
- and in time – Intrinsic or a dedicated silicon timing plane

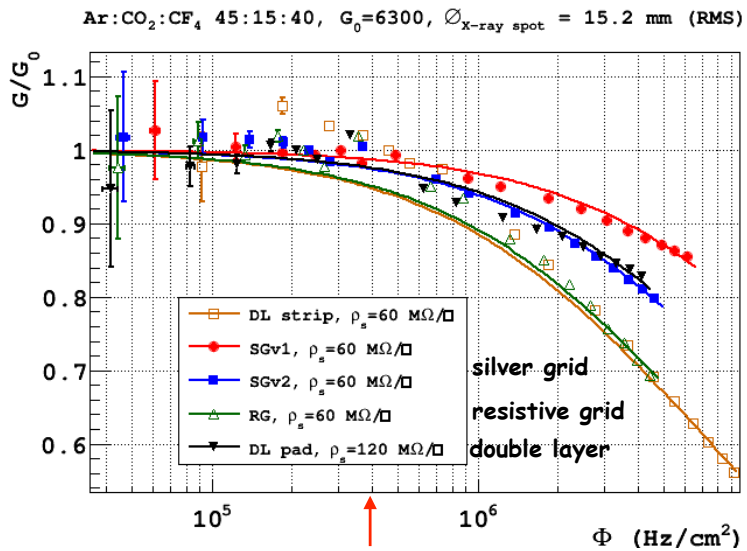


Muons

- Occupancy in inner part of muon stations at rates up to 3 MHz/cm^2
- Solution is more shielding and more granularity
- One promising solution – μ-RWELL micropattern detector
- Tests show good gain performance at expected rates





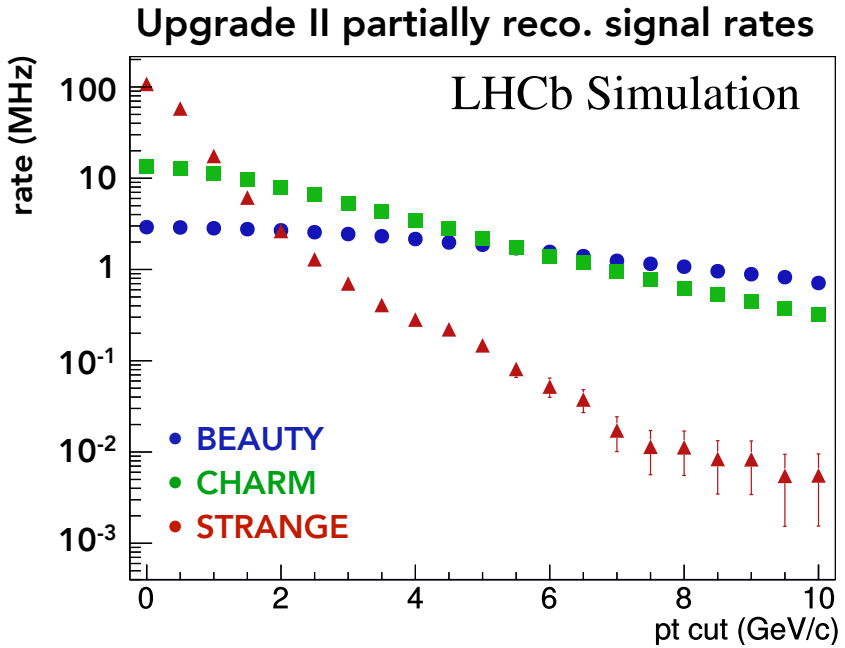


Relative gain v. x-ray rates
(arrow for MIPs at 3 MHz)

Data

The biggest challenge?

- Almost all crossings will have signal!
- Upgrade I full software trigger is huge physics gain
- Upgrade II could result in throughput of 500 Tb/s with storage rate of 50 GB/s!

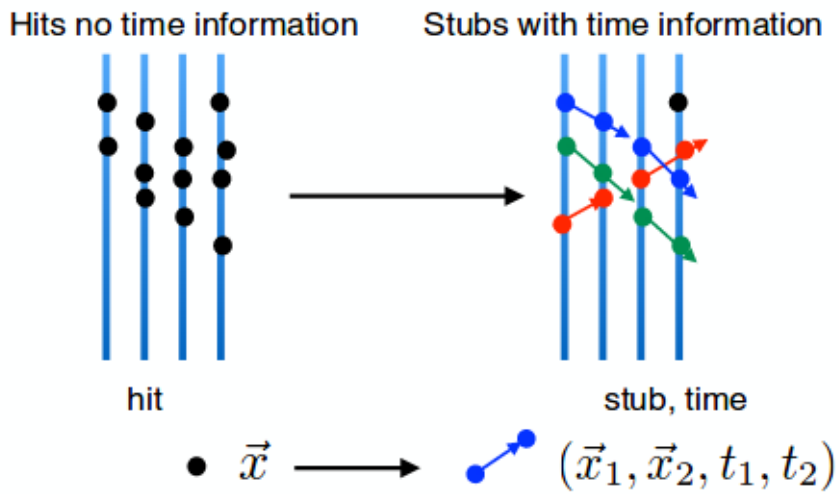


Requiring decay time $> 0.2\,\text{ps}$

- Will be data rate 10x ATLAS/CMS in HL-LHC!
- Will take more creativity than waiting for hardware improvements

Is timing the answer?

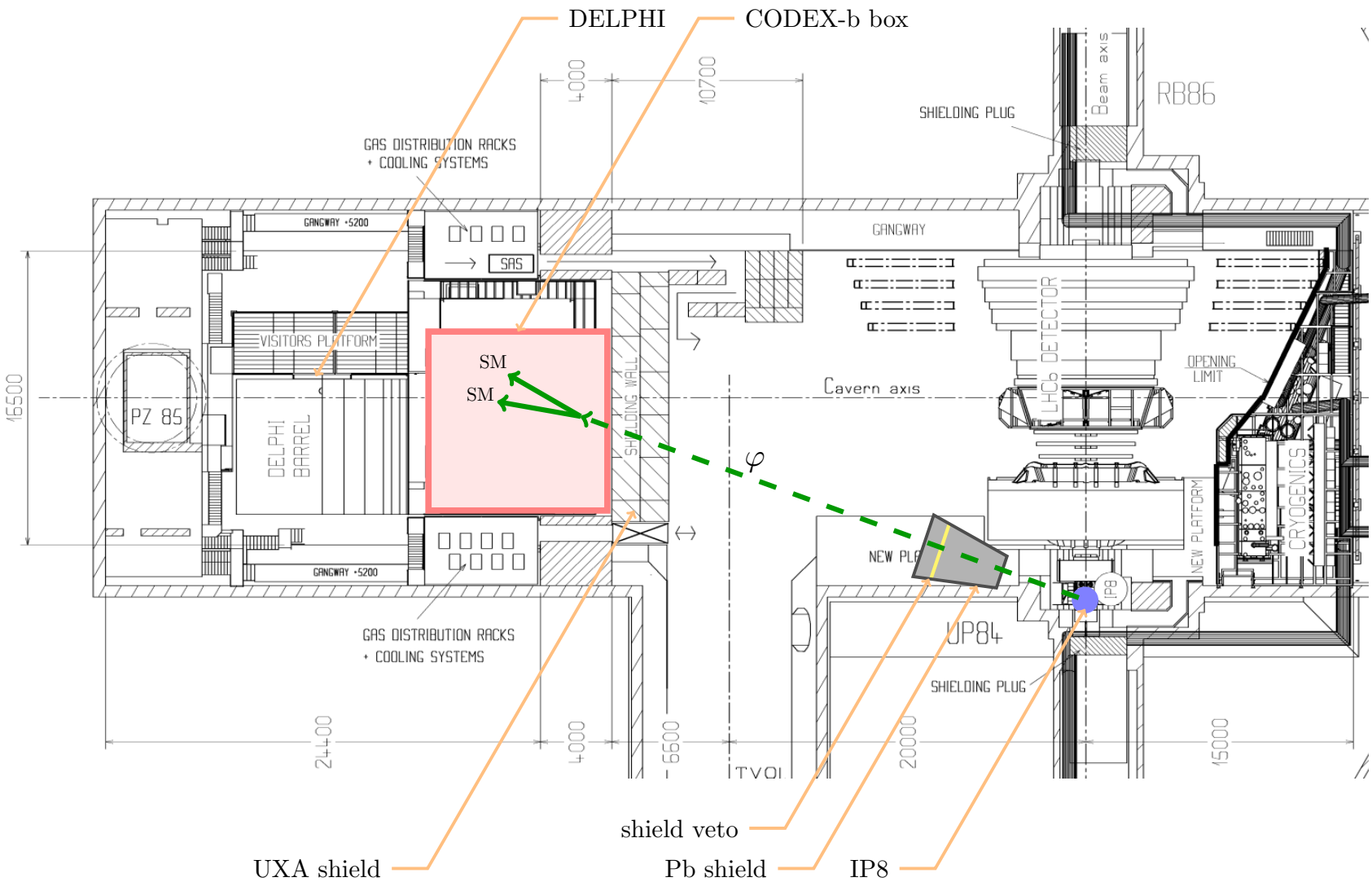
- Can we use timing to remove pile-up?
- Can timing be used to speed-up tracking?



- Investigating possibility of VELO fast reconstruction based on track stubs with timing
- First investigations for implementation in FPGA
- Will need to closely follow development of computing technologies over coming years

Codex-b

A new detector for long-lived particles



- Was more discussion in Mike Williams's talk yesterday

HE-LHCb?

- A lot of ongoing work for physics case and detector for Upgrade II, further future is much more speculative
- What might HE era mean for LHCb?
- Would be at even higher pile-up – 10x upgrade II?
- Further multiplication of challenges
  - Would need finer segmentation in space and time
  - Data challenges will grow even greater

Conclusions

- High luminosity running presents many challenges for LHCb
  - Occupancy, radiation, and data rate
- Planning underway to identify upgrade solutions that would make it possible
- R&D just beginning
- Use of timing is key strategy to overcome challenges
- Sources and more information available from recent workshop on Upgrade II at Annecy – link