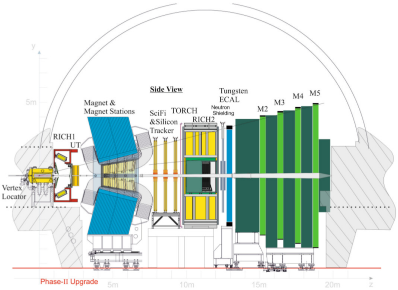
Timing at LHCb post LS4

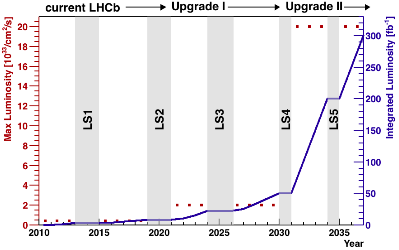
8th annual conference on Large Hadron Collider Physics (LHCP)

C. Betancourt
on behalf of the LHCb Collaboration

25.05.2020

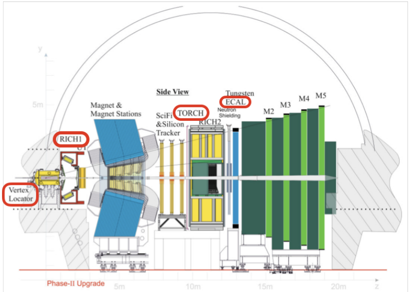
The LHCb Upgrade II

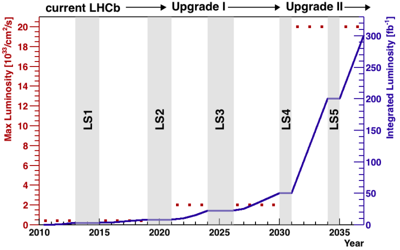




[Expression of Interest for a Phase-II LHCb Upgrade, 2017]
[Luminosity scenarios for LHCb Upgrade II, 2019]

- Major detector upgrade during LS4 of LHC
  $\sim$ 2030
- $\mathcal{L} = 1.5 \times 10^{34} cm^{-2} s^{-}1$
  $\times$ 7.5 increase from U1
- 300-350 fb^{-1}
- Very challenging environment
  $\rightarrow \sim$ 42 Pile-up
  $\rightarrow$ 1.5-3.5k charged particles per bunch-crossing
  $\rightarrow$ Increase ghost rate and PV mismatch
  $\rightarrow \times$10 radiation dose





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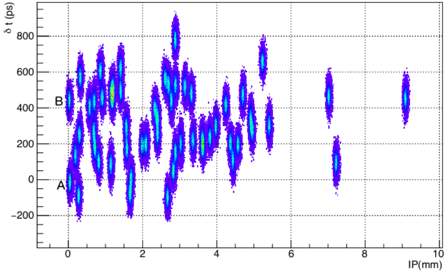
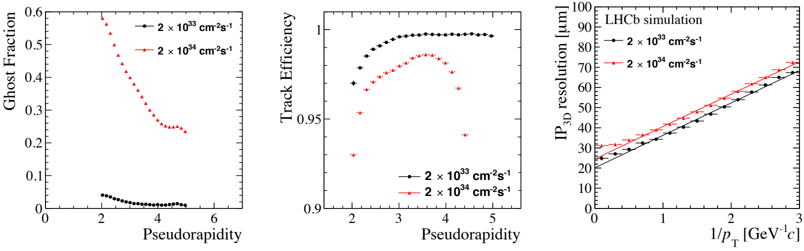
- Many subsystems with fast timing
  VELO, RICH, TORCH, ECAL

- Suppress combinatorics & enabling time-dependent CP-violation measurements
- Correct PV association/reconstruction
- Increase in tracking efficiency and matching
- Reduction in ghost rate
- PID and Calorimetry



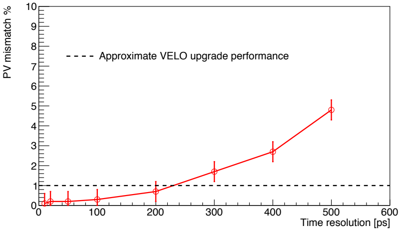
[Physics case for an LHCb Upgrade II, 2019]

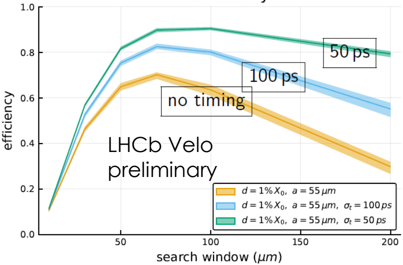


[Expression of Interest for a Phase-II LHCb Upgrade, 2017]

The upgrade of the VELO detector

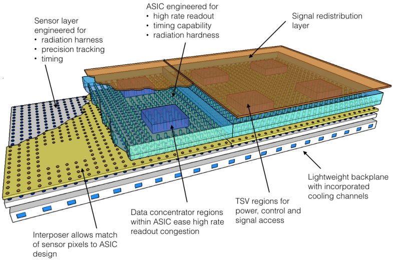
- VErtex LOcator: Silicon pixel detector
- $\sim$ 200 ps time resolution needed to keep PV mismatch to current performance
- 4D tracking: hits separated in time $\sim$ 170 ps RMS
  $\rightarrow$ tens of ps/hit to distinguish spatially overlapping hits
- Fast timing needed to maintain adequate efficiency
- Needs to cope with high radiation environment without sacrificing spatial and timing resolution
  $\rightarrow$ Up to $\sim 10^{17}$ 1 MeV n_{eq}/cm^2
- 50 ps/hit, 20 ps/track seems optimal

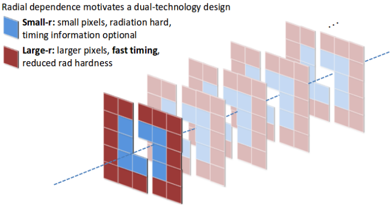




(parametric sim w/o full sim)

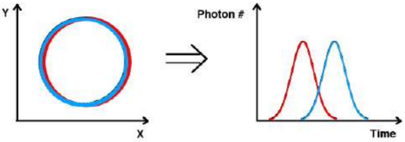
Detector technologies for VELO

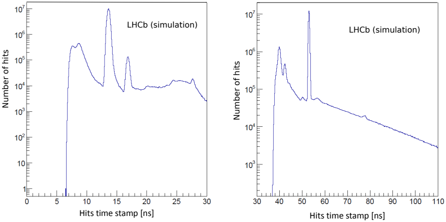




- ASIC: Based on VeloPix/TimePix family
- Some options include:
  - Thin Planar
  - LGADs
  - 3D
  - Monolithic design
  - Others (Diamond, CMOS, ...)
- No single technology exist yet (ASIC or sensors) that satisfies: small pixel size, fast timing, rad-hard

Timing with RICH



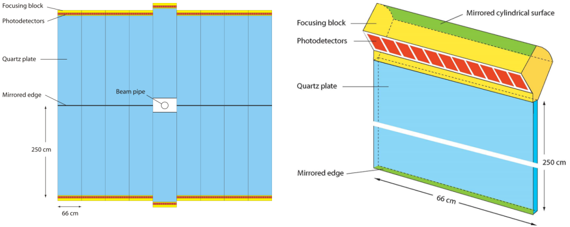


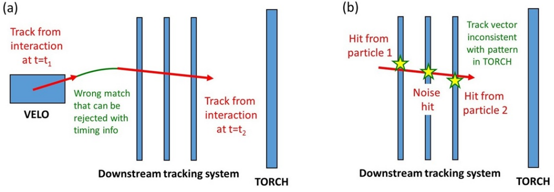
[LHCb-PUB-2017-014]

- RIng Imaging CHerenkov (RICH) detectors
- Same occupancy level of current RICH1 needs:
  - smaller pixel size - Precise timing
- Timing information can improve pattern recognition and ratio of signal photons to background
- Separating different PV using hit time:
  - 0.2-1 ns/photon $\rightarrow$ 50-150 ps/track
- Resolution of 1 ns enough to reject out of time photons
  - 3 ns gate to remove background (sim)
  - a few % in RICH1, $\sim$ 10% in RICH2

TORCH

- Time Of internally Reflected CHerenkov light
- ToF Detector
- Comprises position-sensitive Micro-Channel Plate Photo-Multiplier Tubes (MCP-PMT) detectors
- Time resolution:
  $\sim$ 70 ps/photon
  $\rightarrow \sim$ 15 ps/track
- Fast timing helps with:
  - Possibly suppressing ghosts stemming from mismatching between VELO & UT
  - Timestamp particles decaying after VELO
  - ToF measurement to improve low momentum 2-10 GeV/c PID of π/K

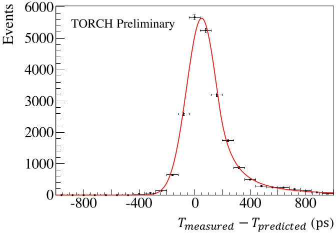




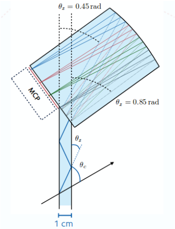
[Expression of Interest for a Phase-II LHCb Upgrade, 2017]

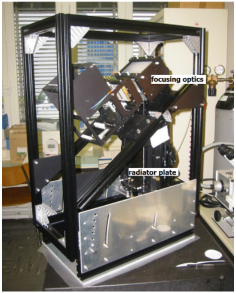
A large-scale TORCH demonstrator

- Quartz plate of dimensions 660 × 1250 × 10 mm^3
- Read out by customized 53 × 53 mm^2 MCP-PMTs with 8 × 128 pixel-equivalent granularity
- Tested at CERN PS T9 beamline at 8 GeV$/c$
- 70 ps/photon time resolution



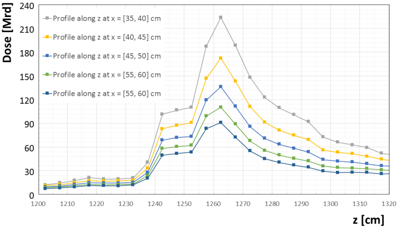
[T. H .Hancock et al., Nuclear Inst. & Meth. , A 958 (2020)]

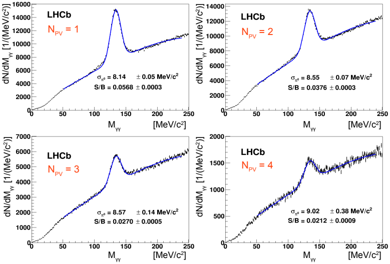




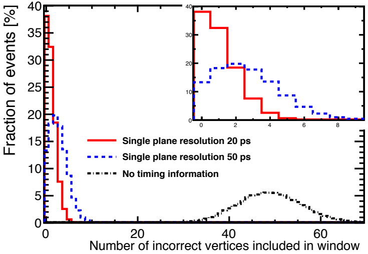
ECAL

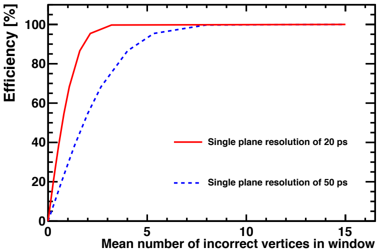
- Challenge to optimize simultaneously energy resolution, radiation hardness, cell size
- Fast timing:
  - Suppress combinatorics when forming π^0 candidates and b-hadron decays
  - Allow combinatorics from high pile-up to be rejected





Timing in ECAL





- Spatial and timing provided by silicon detectors
- Embedded in the absorber layers or at front of the module OR
  Deeper within detector to benefit from larger signal
- Time resolution of a few tens of ps needed

- LHCb Upgrade 2 will provide a challenging detector environment
- $\times$10 higher Luminosity
  $\rightarrow$ Increased Pile-up, ghost rate, PV mismatch and radiation dose
- Fast timing in many subsystems becomes crucial to maintain physics performance
  VELO, RICH, TORCH, ECAL