HL/HE detector challenges for LHCb

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The future of LHCb

- **Run 2**: 2017 - 2018
- **LS 2**: 2019
- **Run 3**: 2020 - 2021
- **Phase I upgrade**: Under construction
- **LS 3**: 2022 - 2023
- **Run 4**: 2024 - 2025
- **Phase II upgrade**: Focus of this talk
- **HL-LHC**: 2026 - 2029
- **HL-LHC(b)**: 2030 - 2032

- **8 fb^{-1}** for Run 2
- **50 fb^{-1}** for Run 3
- **300 fb^{-1}** for Run 4
LHCb will operate in Run 4 similar to Run 3
High luminosity era really begins after LS4

$$L \left( 10^{32} \text{/s/cm}^2 \right) \quad \text{Collisions}$$

<table>
<thead>
<tr>
<th>Run</th>
<th>$L$</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Run 3-4</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Run 5+</td>
<td>100-200</td>
<td>50</td>
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</tbody>
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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 it's 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

Studies so far…

VELO

Overview:
Annecy TTFU Workshop
22 March 2018

Mark Williams

Run toy simulations of two-body B decays to assess PV mis-association rate from dual-technology design:

- No timing: pick PV with lowest IP: ~15% mis-association rate
- With timing: additional power to select correct PV using both IP and timing information: 2-4% mis-association rate

Biljana Mitreska
CERN summer student 2017
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

Studies so far... Reducing pixel size to 27.5 μm, and re-optimising PR parameters (e.g., cone size), most of the losses are recovered.

For Upgrade-I VELO design (55 μm pixels), performance at \( L = 2 \times 10^{34} \) particles/cm\(^2\)/s is heavily degraded e.g., Ghost rate increases by factor 20...
Timing even more important than pixel size!

- Goal is $\approx 30\,\text{ps}$ for outer part
- Mis-association scales linearly with luminosity
- Even a 200 $\mu$m pixel would work!

M. Williams et al.
Downstream tracking

Current Scintillating Fibre tracker evolves

Occupancy requires staged upgrades

- **Upgrade 1b Tracker (LS3)**
  - Replace 2 inner SciFi modules
  - Add a Si Inner Tracker
  - Expand IT relative to EOI to assist Sci-Fi

- **Upgrade II Tracker (LS4)**
  - Replace all SciFi modules
  - Add a Si Middle Tracker
  - Expand MT relative to EOI to assist Sci-Fi

- SciFi for large area tracking

**Upgrade 2**
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 ≈ 100ps
TORCH

- New time-of-flight detector design
  - Uses internally reflected Cherenkov light
  - Provides particle ID to lower momenta
Promising recent testbeam results!

Readout pattern in position and time:
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 Gd₃Al₂Ga₃O₁₂) show good radiation tolerance in recent tests.
Increased segmentation a necessity

In space

and in time – Intrinsic or a dedicated silicon timing plane

Pointing Fibers in a Spaghetti Calorimeter

~25 $X_0$

Crystal fibers

Absorber groove

Number of incorrect vertices included in window

Fraction of events [%]

Single plane resolution 20 ps
Single plane resolution 50 ps
No timing information

Number of incorrect vertices included in window

0 2 4 6 8
0 10 20 30 40
Muons

- Occupancy in inner part of muon stations at rates up to 3 MHz/cm²
- Solution is more shielding and more granularity
- One promising solution – $\mu$-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 $> 0.2$ 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

- "Stub" approach:
  - A couple of hits in adjacent planes forms a stub
  - Stubs provide "track hints"
  - Geometrical cuts are applied to filter stubs not compatible with tracks from the luminous region
  - Tracks are formed by multiple stubs with similar parameters

Stubs with time:
- In highly occupied detectors fake stubs can survive the geometrical cuts
- Use of timing allows a combinatoric suppression
- Particle velocity is required to be compatible with the speed of light

[N. Neri et al., JINST 11 (2016) no.11, C11040]
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