Upgrade options and R&D for the LHCb tracking system

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...zoom on the tracker

- **Tracker Turicensis (TT)**
  - Si strips
  - $\sigma \approx 50\mu m$

- **Vertex Locator**
  - Si strips
  - $\sigma \approx 5 - 25\mu m$
  - vertexing + tracking

- **B field**
  - $\approx 4Tm$

- **Inner Tracker (IT)**
  - Si strips
  - $\sigma \approx 50\mu m$

- **Outer Tracker (OT)**
  - Straw tubes
  - $\sigma \approx 250\mu m$

In this talk: consider only TT, IT and OT

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Tracker only (VELO, TT, IT/OT)

B field
\approx 4\text{Tm}

B field vs z

B field equivalent to 1T over 4m

Hypothesis: keep identical geometry for upgrade
Tracking sub-detectors

- 4 tracking stations: 1 upstream (TT) and 3 downstream (IT+OT) of magnet
- 4 layers in each station: $X_1UVX_2$ ($\pm 5^\circ$ stereo angle for U and V)

1. **Tracker Turicensis (TT)**
   - 1.5m×1.3m; 183$\mu$m pitch Silicon strips

2. **Inner Tracker (IT)**
   - 1.2m×0.4m cross around beam pipe
   - Si strip detector; 198$\mu$m pitch

3. **Outer Tracker (OT)**
   - 6m×5m area for full outer acceptance coverage
   - Straw tubes; 70%Ar; 30%CO$_2$; <50ns drift time
   - **Ratio of IT and OT area driven by occupancy** (see later)
LHCb event display

2010 7TeV data

TT hits

IT/OT hits

Hit density ⇔ occupancy
TT and IT occupancy

• with early 2010 data (no pile-up, micro-bias trigger), strip occupancy below 1% for both IT and TT detectors

• now reaches approximately 2% occupancy

(See M. Needham’s presentation for other performance results)
L=2×10^{33} upgrade conditions I

- What will be different at $L=2\times10^{33}\text{ cm}^{-2}\text{s}^{-1}$?

- higher average number of pp interactions per crossing (parameter $\nu$)

- the luminosity is related to the number of bunches $N_{\text{bunches}}$ and to $\nu$

$$\nu \propto \frac{\mathcal{L}}{N_{\text{bunches}}}$$

We obtain $\nu\approx7$ @ $L=2\times10^{33}\text{ cm}^{-2}\text{s}^{-1}$

- A larger value for $\nu$ implies an increase in occupancy...
L=2×10^{33} upgrade conditions II

- ...higher occupancy (MC studies)

- In IT, up to 0.1 particle per cm$^2$ and per event (1 strip area = 0.02cm × 20cm = 0.4cm$^2$)

- TT strip occupancy also increases to about 10% in hottest spots
L=2×10^{33} upgrade conditions III

• What will be different at L=2×10^{33} \text{cm}^{-2}\text{s}^{-1}?

• LHCb will design its electronics for readout at 40MHz

=> develop new fast front-end electronics

=> new “TELL-40” acquisition board able to read events at 40MHz
Tracking requirements

A. \textbf{50\,\mu m resolution} (driven by multiple scattering)

- each station (TT, IT, OT): \( x/X_0 \approx 3-4\% \)
  => multiple scattering angle \( \theta_{\text{ms}} \) (cf. PDG)

\[
\theta_{\text{ms}} = \frac{13.6 \, \text{MeV}}{\beta c p} \sqrt{x/X_0} \left[ 1 + 0.038 \ln \left( x/X_0 \right) \right]
\]

- \( p \approx 20\,\text{GeV/c} \); \( \beta \approx 1 \) => \( \theta_{\text{ms}} \approx 0.12\text{mrad} \)
- \( 0.12\text{mrad} \times 0.6\text{m} = 72\,\mu m \) uncertainty due to multiple scattering from a T-station to the next
  => do not need better than \( \approx 50\,\mu m \) measurement accuracy
- \( 0.12\text{mrad} \times 5.5\text{m} = 660\,\mu m \) in 1\textsuperscript{st} T station due to TT

B. \textbf{low occupancy} (at a few the percent level)
  => implies lower bound on granularity

C. \textbf{fast signal shaping time} (minimize pile-up)
L=2\times10^{33} tracker upgrade options

- Consider combinations of
  1. **Silicon strips**
  2. **Straw tubes**
     - Larger gas detectors (TPC, drift chamber) not fast enough as soon as the drift time $\gg 25\text{ns}$
  3. **Scintillating fibers**
Silicon

- Silicon strips
  - resolution => pitch $\approx 200 \mu m$
  - occupancy => strip length
- Fast shaping time
- Cost is a function of
  - Silicon area ($N_{\text{channels}} \times \text{pitch} \times \text{length}$)
  - $N_{\text{channels}}$ (electronics)
Straw tubes

• Array of $\varnothing=5\text{mm}$ straw tubes to cover large acceptance area

• Use fast drift gas mixture
  • currently 70% $\text{Ar} + 30\% \text{CO}_2 \Rightarrow <50\text{ns}$
  • might need faster gas for upgrade

• Resolution $\approx 200\mu\text{m}$
Scintillating fibers

• Array of densely packed 250μm scintillating fibers (SciFi)

• Readout with Silicon photo-multiplier (SiPM) [0.25mm×1.1mm channels]

• can achieve 50μm resolution

• high efficiency

• cost dominated by SiPM and electronics
  => N\text{channels} is the critical parameter
  => fiber length is not a dominant contribution to the cost!
Options for TT

- **R&D for upgrade:**
  - higher granularity near beam to keep occupancy at a low level
  - lower material budget
  => better extrapolation to T1
  => impact of 3 TT layers U+X+V?
- **Silicon fulfills all the requirements for TT**
  - 50μm resolution, etc...
  - infrastructure can be kept outside of acceptance (FE-electronics, cooling, HV)
- **SciFi detector could also be considered:**
  - would necessitate R&D (combined with IT R&D)
  - Single technology in LHCb if SciFi used for IT too
Options for IT+OT

A. revisit relative size of IT and OT active area to minimize occupancy

B. detector technology configurations:

<table>
<thead>
<tr>
<th></th>
<th>IT</th>
<th>OT</th>
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<tbody>
<tr>
<td>1</td>
<td>Silicon</td>
<td>Straw tubes</td>
</tr>
<tr>
<td>2</td>
<td>SciFi</td>
<td>Straw tubes</td>
</tr>
<tr>
<td>3</td>
<td>SciFi</td>
<td>SciFi</td>
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Optimizing IT/OT area ratio

- Hit occupancy from 2D plot
- Determine the hit occupancy at closest points left and right of beam pipe as a function of the length of the strips
- single long strips [-y,+y]
- two shorter strips [-y,0] and [0,+y]
- \( \approx 3.3\% \) occupancy with current geometry (×)
- occupancy divided by 2 if IT detector split between \( y<0 \) and \( y>0 \) (★) => can cover twice the area of current design!
Silicon IT + straw tubes OT

• **Advantage:**
  - well known technology
    => little R&D needed

• **Difficulties:**
  - significant material in acceptance from IT
  - electronics, readout cables, HV cables
  - cooling of Si sensors is difficult
  - Straw tube gas might be too slow => R&D
SciFi IT + straw tubes OT

- OT: straw tubes (cf. previous slide)
- IT: R&D at EPFL and Dortmund to replace IT Silicon detector boxes with SciFi detectors (acting as spares)
- mechanical and electronics constraints for compatibility with current detector (not relevant for upgrade)
SciFi R&D

- 5 layers of densely packed 250\(\mu\)m fibers
- readout in 250\(\mu\)m x 1100\(\mu\)m channels
- standalone simulation to study effects of:
  - integrated photon efficiency (assume 20pe/mm)
  - noise (assume 0.3pe/channel)
  - track angle (up to ±10\(^\circ\))
  - gaps / dead regions
  - saturation

- **Efficiency >99.9%** with 1 noise / 1000 signal clusters

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SciFi R&D: S/N

- For IT replacement detector:
  - must adapt strong signal from Silicon PM to high-gain Beetle chip
  - use passive current divider (~1/40)
  - S/N ≈ 30 for 1MIP (~15 photo-electrons)
  - dynamics ≈ 30 photo-electrons
SciFi R&D: efficiency in gaps

- Simulated inactive SiPM channels:
  - 250\(\mu\)m gaps built in SiPM (\(\equiv 1\) channel)
  - 500\(\mu\)m gaps between adjacent sensors (\(\equiv 2\) channels)

![Graph showing efficiency in gaps]

- 0.1 channel loss from 250\(\mu\)m gap
- 1 channel loss from 500\(\mu\)m gap
SciFi R&D: resolution

- PEBS test beam (2009):
  - 25pe/MIP/1.1mm
  - 50μm resolution

- Resolution depends on electronics saturation and cluster size

- **Average resolution ≈ 50μm**
  (compare to binary resolution of $250/\sqrt{12} = 72\mu$m)

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SciFi R&D: radiation hardness?

- SiPM possibly not sufficiently radiation hard to survive in high flux region
- currently testing SiPM samples with neutron source
- MC of neutron fluxes in LHC @ $2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$
- can be a show stopper for replacement
- for upgrade, will consider shielding SiPMs outside of acceptance
IT SciFi upgrade option

• Scintillating fibers satisfy the requirements for resolution, efficiency, signal shaping time, etc...

• Several advantages:

  1. signal can be sent outside of acceptance via clear fibers for readout
     => keep electronics outside of acceptance
     => SiPM radiation hardness is not critical

  2. no active cooling of the sensors (only for electronics)

  3. no HV => no cables in acceptance

• Main difficulty:

  • R&D for SciFi to clear fiber coupling!
IT SciFi: possible layout

1 half station

FE electronics

← clear fibers →

coupling

SciFi

FE electronics

beam pipe

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IT + OT SciFi

- 250μm IT channels and 750μm OT channels
- IT signal sent out of acceptance with clear fibers
- Advantages:
  - uniform technology for entire tracker
  - all electronics, cooling, cables outside of acceptance
  - same technology for both IT and OT (and TT?)
- R&D needed for
  - mechanical structure
  - electronics
  - SciFi to clear fiber coupling
Conclusion

• Presented upgrade options for the LHCb tracker to run at $L=2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

• From status quo “hybrid” option
  
  Silicon TT + SciFi IT + straw-tubes OT

• ...to more elegant “uniform” option
  
  Scintillating Fiber TT + IT + OT

• Dedicated global design of the tracker is now necessary to converge to the optimal solution