Characterisation of the LHCb VELO detector modules as a non-invasive Proton Beam Monitor

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1. Introduction
2. LHCb Vertex Locator (VELO) Detector as a non-invasive beam monitor
   1. Implementation in the University of Birmingham proton beamline
3. Results
   1. Beam current measurements
   2. Beam profile measurements
4. Beam Halo to Dose correlation
5. Conclusion
Online beam monitoring assures effective delivery of the beam and maintains patient safety.

New emerging particle therapy treatment technologies (FLASH) require fast, ideally non-invasive devices.

Current beam monitors, e.g. ion-chambers, are lacking these characteristics.

Look into novel silicon based detector technologies.
2. LHCb VELO as a non-invasive beam monitor

In LHCb experiment:
• Reconstruction of vertex tracks from particle collisions

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The halo of the proton beam is generated from scattering components.

- Halo measurement for **beam monitoring**
  - Correlation to dose delivery and beam profile
The VELO detector

<table>
<thead>
<tr>
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<th>VELO detector</th>
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<tbody>
<tr>
<td>Silicon technology</td>
<td>$n^+ - in - n$</td>
</tr>
<tr>
<td>Number of readout channels</td>
<td>2048</td>
</tr>
<tr>
<td>Thickness of sensor</td>
<td>300 $\mu$m</td>
</tr>
<tr>
<td>Number of regions</td>
<td>R: 4, $\Phi$: 2</td>
</tr>
</tbody>
</table>

Provides $r$ and $\phi$-coordinates in the polar coordinate system.

Approaching the core of the beam without interfering with it.

 Precise measurement of the beam halo
For the **safe operation** of the detector in air to avoid overheating and to minimize noise, an efficient **venting and cooling system** was designed and successfully implemented.

Hardware and software **optimisation** to fulfil requirements for proton beamline facilities.

Roland Schnuerer et al. Instruments 2019, 3(1), 1; https://doi.org/10.3390/instruments3010001
First tests at the MC40 proton beamline of the University of Birmingham in March.

**Objectives** of the measurements:

1. Verification of a reliable operation in a proton beamline.
2. Characterisation of VELO regarding changes in the beam current and different sizes of the beam.
3. Combining results to develop a *Halo to Dose relationship* for the VELO detector modules.
Synchronising the readout

1. Synchronisation of proton bunch arrival
2. Synchronised readout of VELO modules and ion-chamber
3. Results

Beam current measurements

Case:
18 MeV protons, 15 mm collimator diameter:

- Output is very linear
- Module 2 received more hits than Module 1
- Charge values show a little spread for nearly constant hit values
  - slow integration time of electrometer, software delay

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Beam current measurements

Time correction factor is applied for charge values.

$R^2$-values of linear fit are 0.999 on average.
Beam current measurements

10 mm collimator diameter:
- Beam current fluctuations of the cyclotron visible
- Still show an excellent trend

😊😊 Very accurate beam current measurements
Beam profiles compared to GEANT4 simulation and film measurements.

**VELO**

**GEANT4 simulation**

**FILM**

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Beam profile measurements

- VELO and simulation profiles show a good agreement
- Beam spot on film not intense enough
  - Low dose tail is lost in background
- VELO modules misaligned of 2 mm

Beam profile measurements good, but improvable
Correlation of the output for different collimators:

1. Collimator diameter difference:

\[ k_{area} = \frac{A_{C1}}{A_{C2}} = \frac{r_{C1}^2}{r_{C2}^2} \]

2. Halo area difference:

Percentage determined by the area ratio of the normal distribution.

\[ k_{norm} = \frac{p_{C1}}{p_{C2}} \]

\[ k_{corr} = k_{area} \times k_{norm} \]

<table>
<thead>
<tr>
<th>Collimator diameter</th>
<th>7 mm</th>
<th>10 mm</th>
<th>15 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of Entries (</td>
<td>x</td>
<td>&gt; 8 \text{ mm})</td>
<td>6.30 %</td>
</tr>
</tbody>
</table>
Beam Halo to Dose correlation

Beam current comparison for different collimators (all sensors summed up).

Results of the measurements and simulation are agreeing well.
Halo to Dose correlation

1. Dose for one proton deposit in the VELO detector:

\[ D_p = \frac{E_p}{m_{VELO}} = \frac{S \cdot \rho \cdot d}{\rho \cdot d \cdot A} = 205.65 \, \text{MeV} \cdot \frac{1}{\text{kg}} = 3.295 \cdot 10^{-11} \, \text{Gy} \]

2. Total number of protons:

\[ N_{tot} = \text{Hits} \times 1.0835 \cdot 10^{-10} \frac{c}{\text{Hits}} \cdot \frac{1}{160 \cdot e} \times k_{corr} \]

3. Total dose for the VELO detector:

\[ D_{VELO} = \text{Hits} \times 1.395 \cdot 10^{-4} \frac{1}{\text{Hits}} \times k_{corr} \, \text{Gy} \]
The **VELO detector modules** were successfully integrated in the MC40 proton beamline at the University of Birmingham.

A **synchronised readout** resulted in **precise** beam current measurements.

The results of the GEANT4 simulation, beam current and beam profile measurement were combined to **correlate the output** for different collimator diameters.

A beam **Halo to Dose relationship** was derived successfully showing the capability of the VELO detector modules as a **beam monitor**.
Thank you for your attention!
Please ask your questions!