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

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1. Introduction

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.

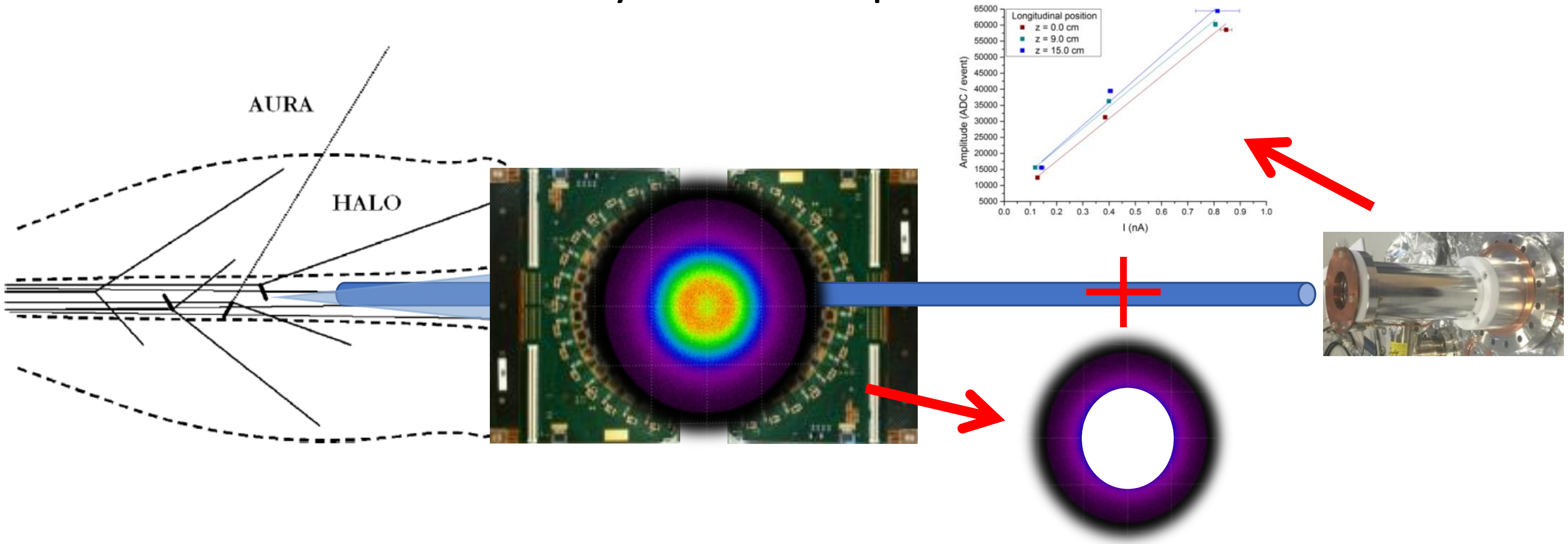
➲Look into **novel** **silicon** based detector technologies.

2. LHCb VELO as a non-invasive beam monitor

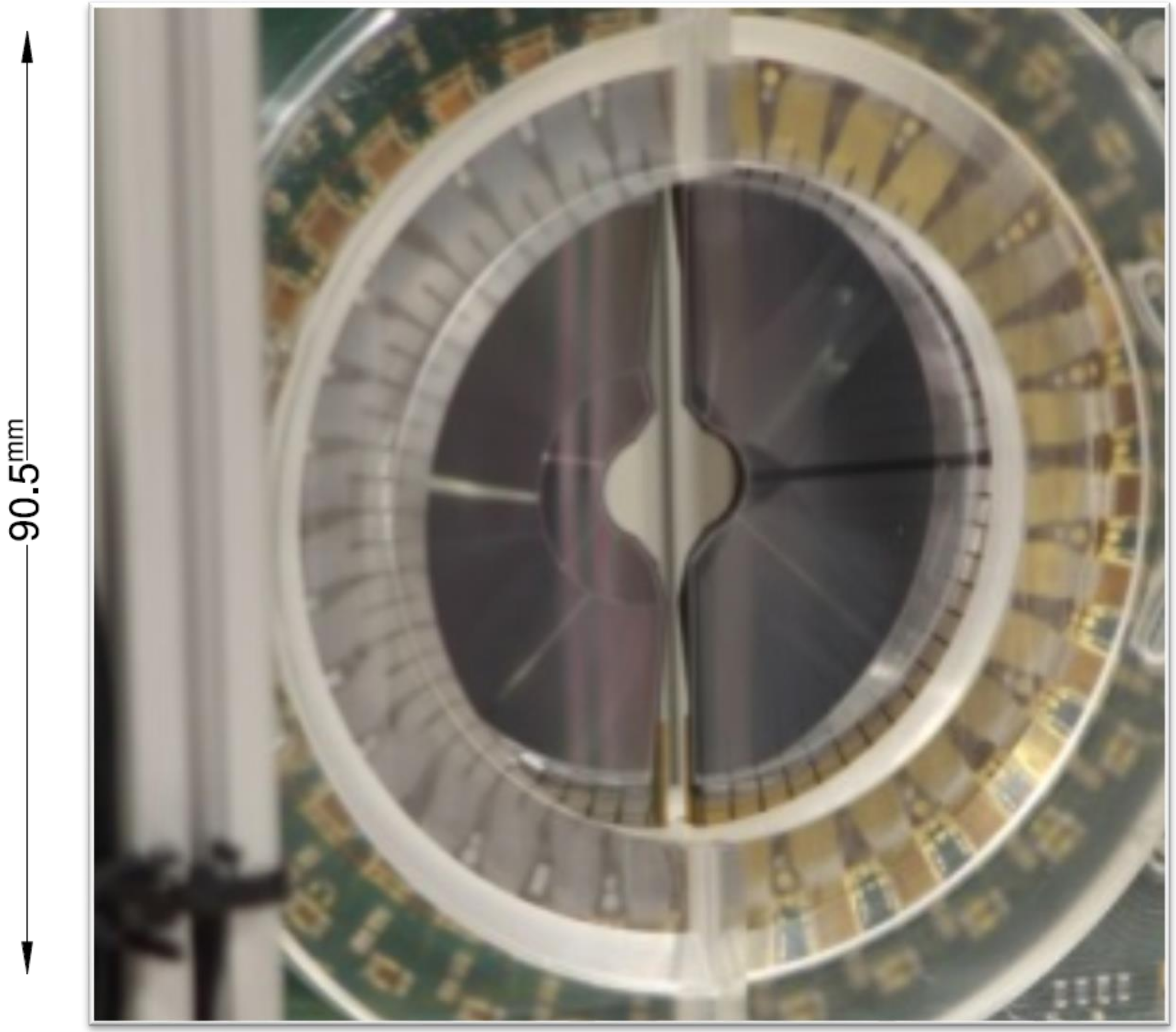
Concept of beam halo measurement

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

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



LHCB Vertex Locator (VELO) Detector



	VELO detector	
Silicon technology	$n^{+} - in - n$	
Number of readout channels	2048	
Thickness of sensor	300 µm	
Number of regions	R: 4	Φ: 2

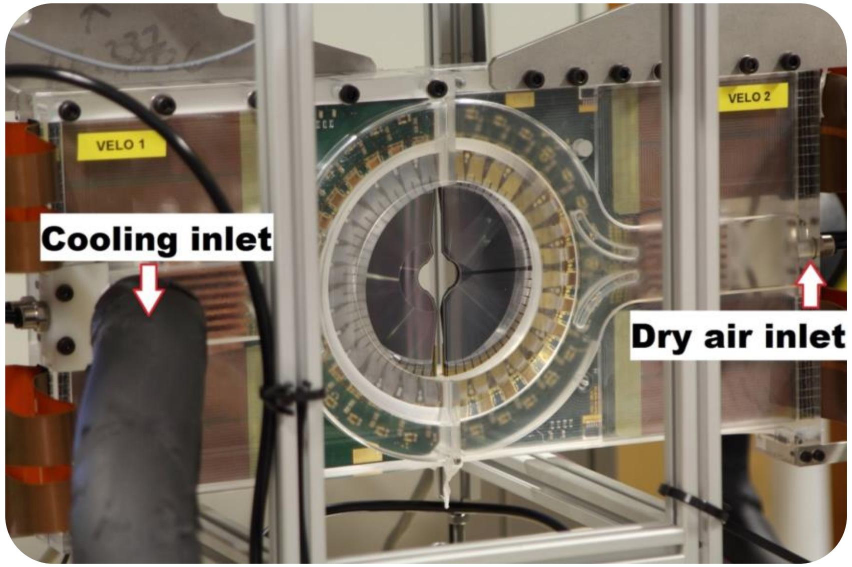
Provides r and ϕ-coordinates in the **polar coordinate** system.

Approaching the core of the beam without interfering with it.

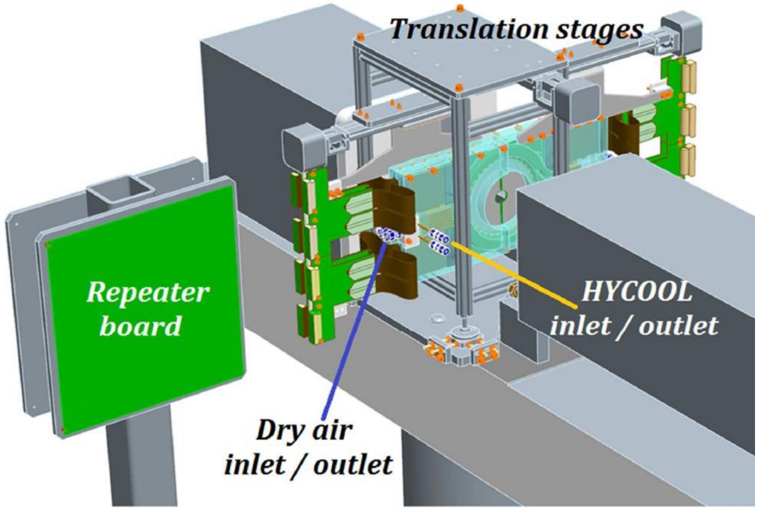
➲Precise measurement of the **beam halo**

The VELO detector (sketch)

Changes to the original setup



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.

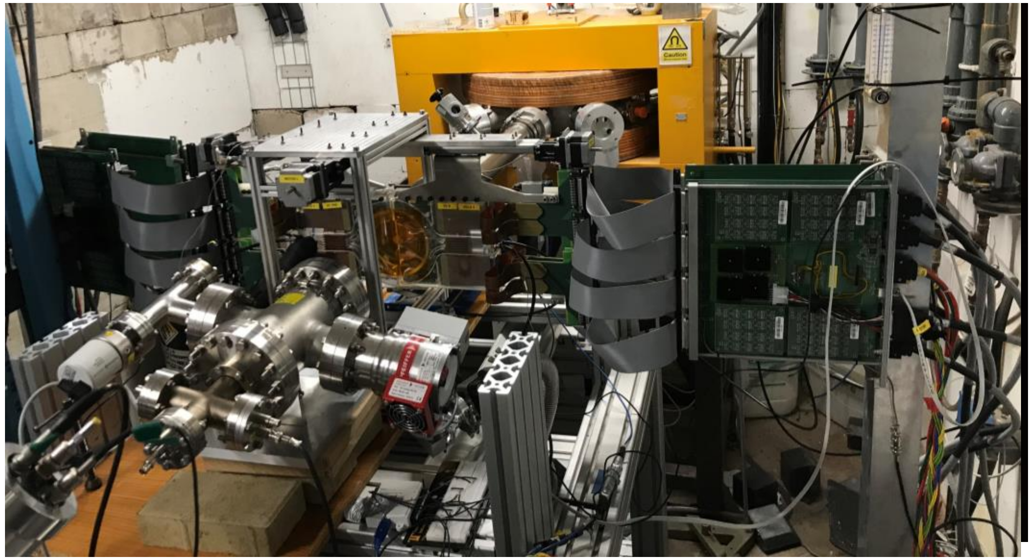
Roland Schnuerer et al. Instruments 2019, 3(1), 1; https://doi.org/10.3390/instruments3010001

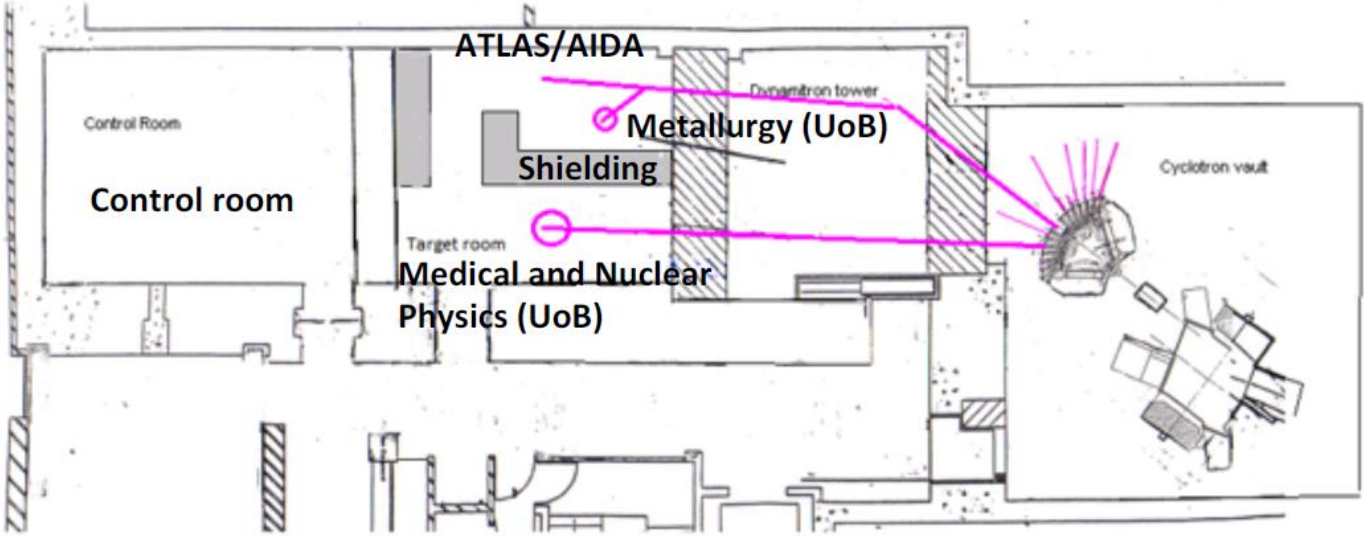
2.1. Implementation in Birmingham proton beamline

First tests at the MC40 proton beamline of the University of Birmingham in March.

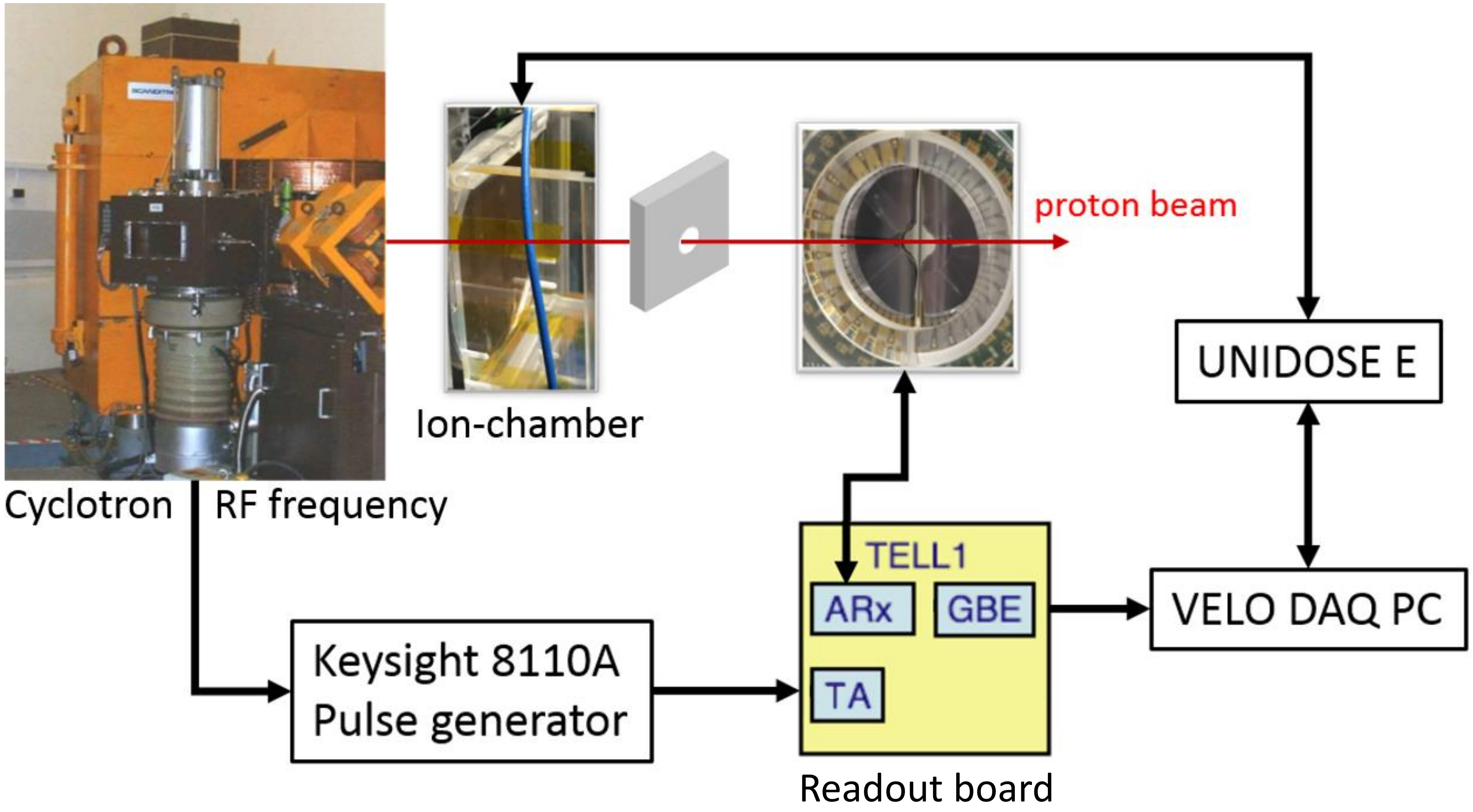
Objectives of the measurements:

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.





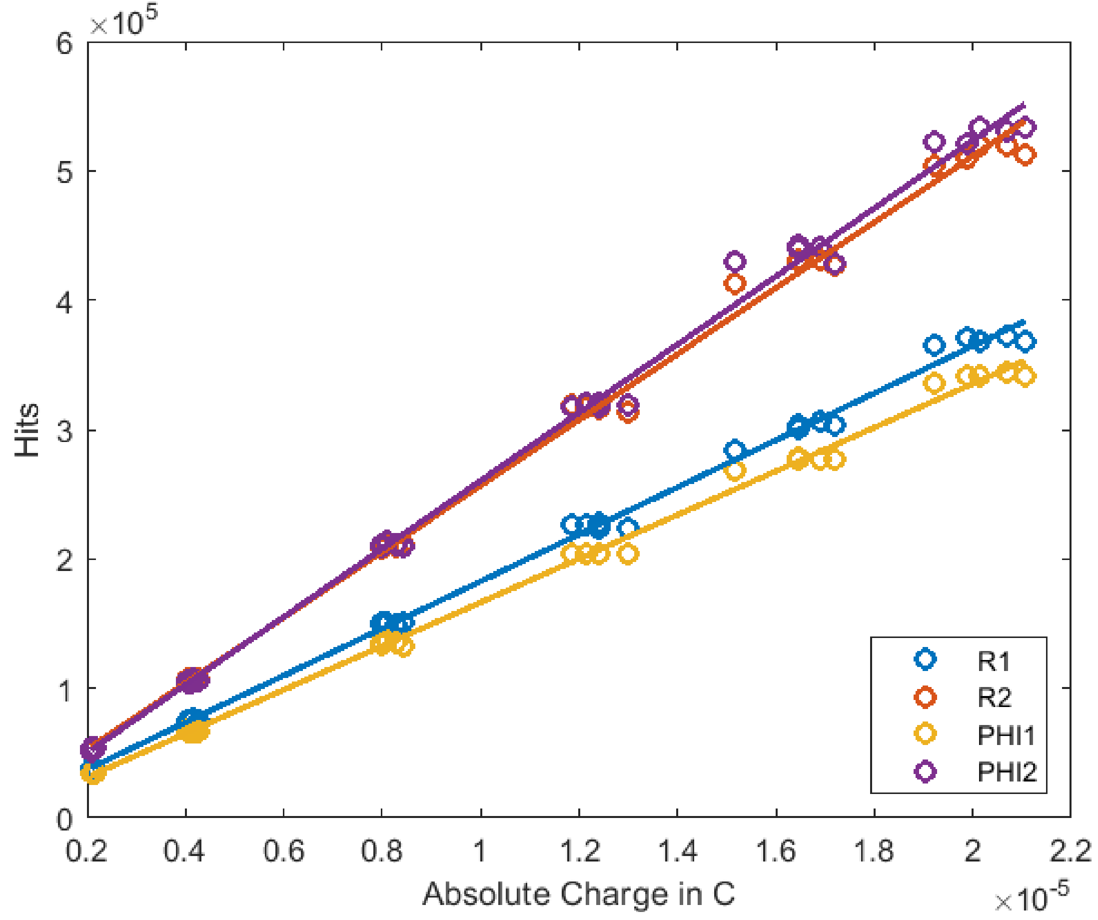
Synchronising the readout



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

3. Results

Beam current measurements



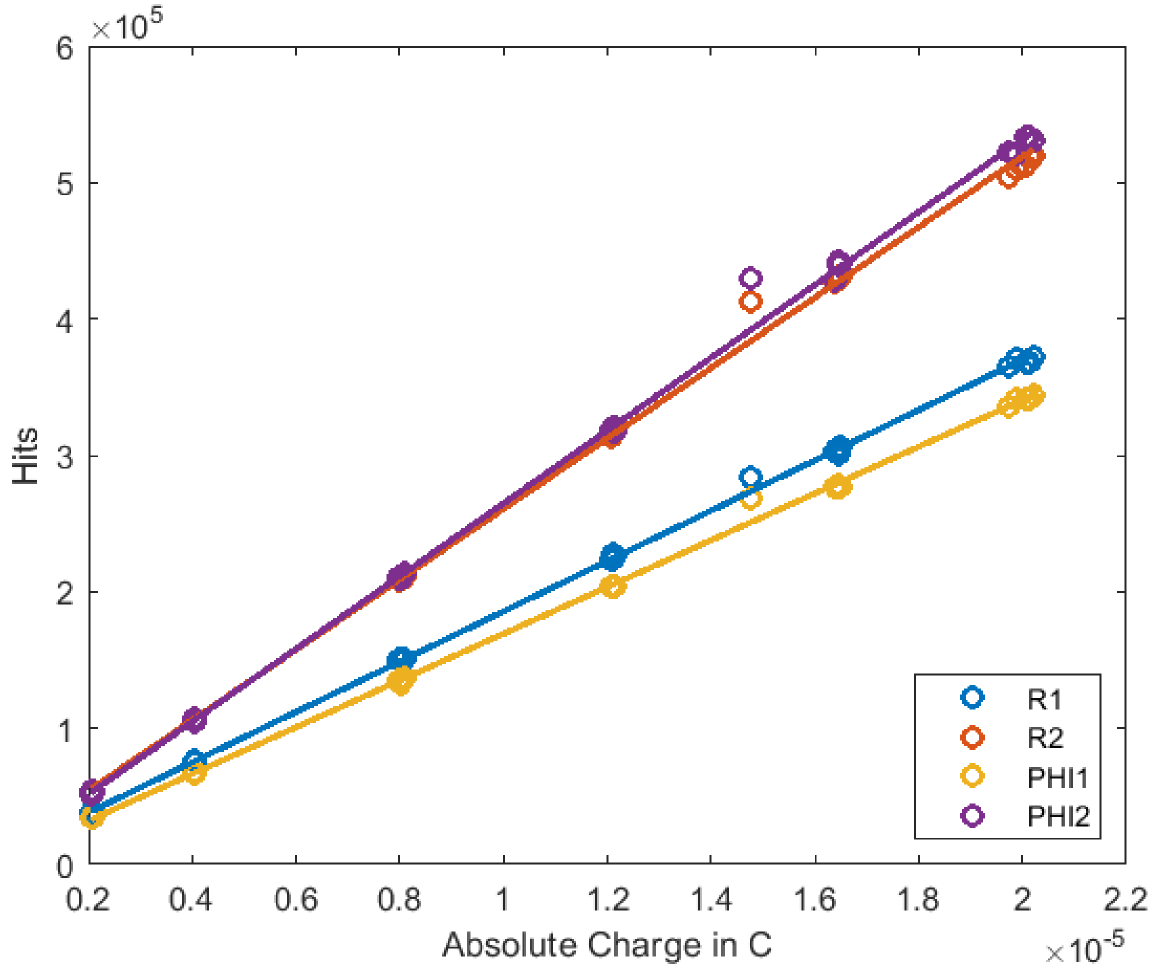
Case:

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

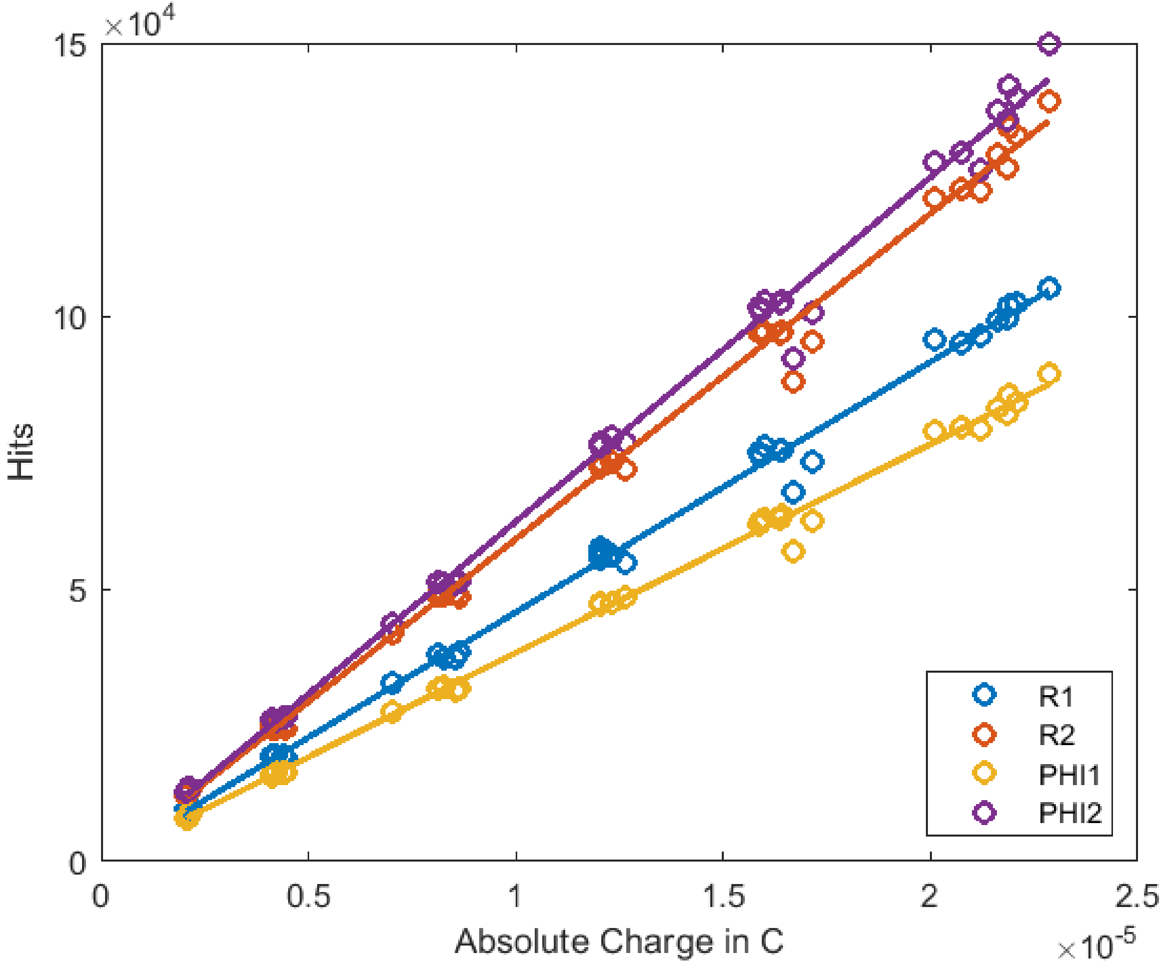
Beam current measurements



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:

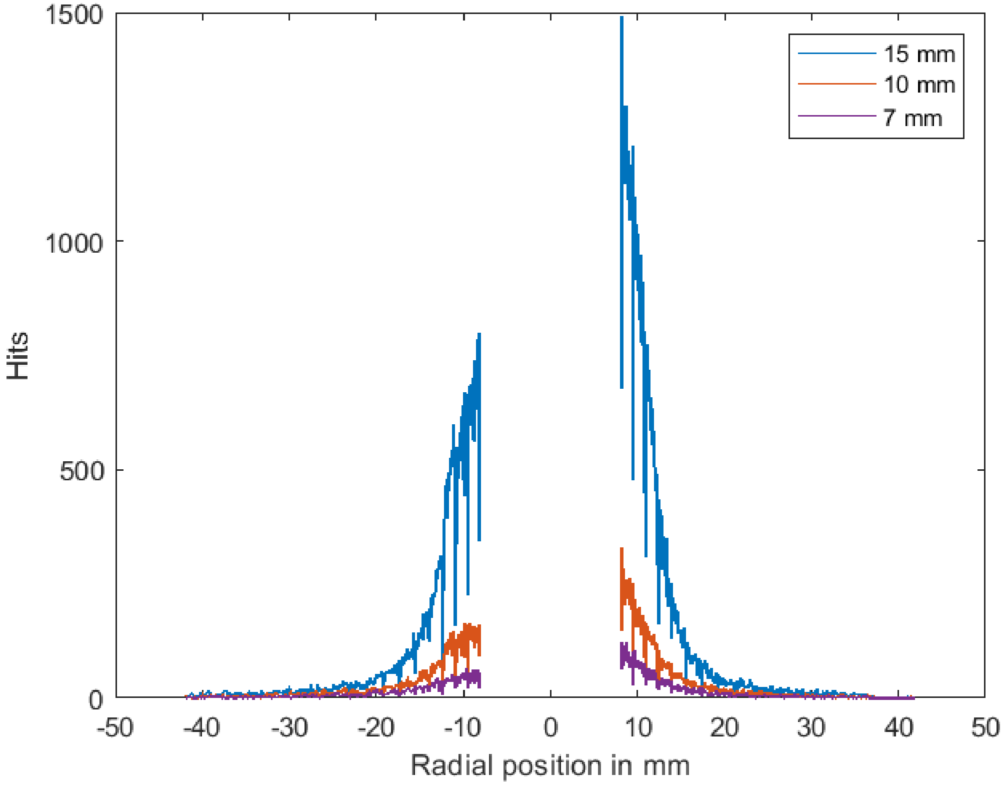
- Beam current fluctuations of the cyclotron visible
- Still show an excellent trend

☺☺ Very accurate beam current measurements

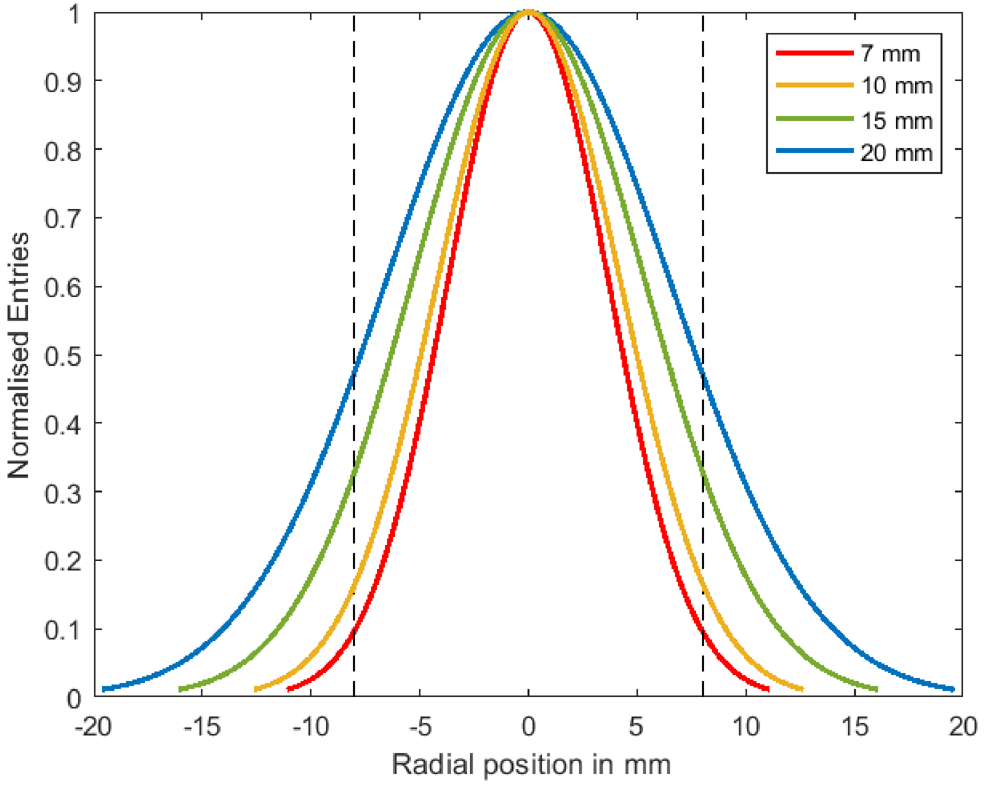
Beam profile measurements

Beam profiles compared to GEANT4 simulation and film measurements.

VELO

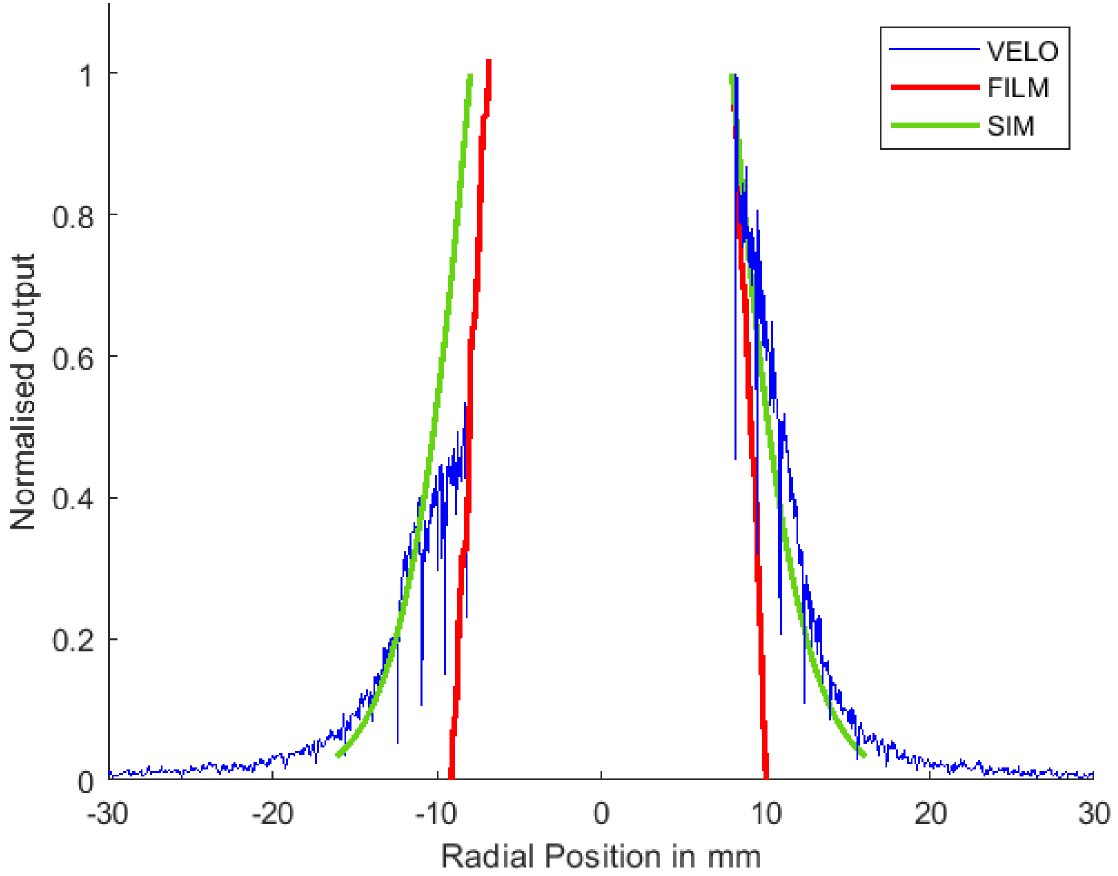


GEANT4 simulation



FILM

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

4. Halo to Dose correlation

Correlation of the output for different collimators:

1. Collimator diameter difference:

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

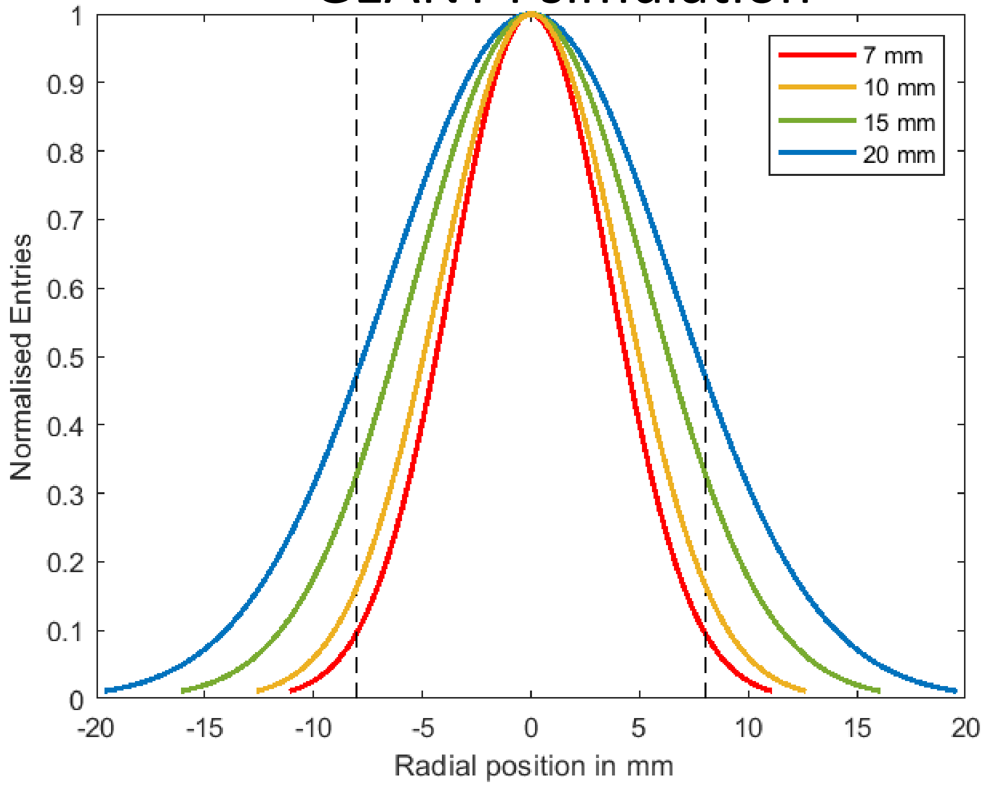
2. Halo area difference:

Percentage determined by the area ratio of the normal distribution.

$$k_{norm} = \frac{p_{C1}}{p_{C2}}$$

$$\Rightarrow k_{corr} = k_{area} \times k_{norm}$$

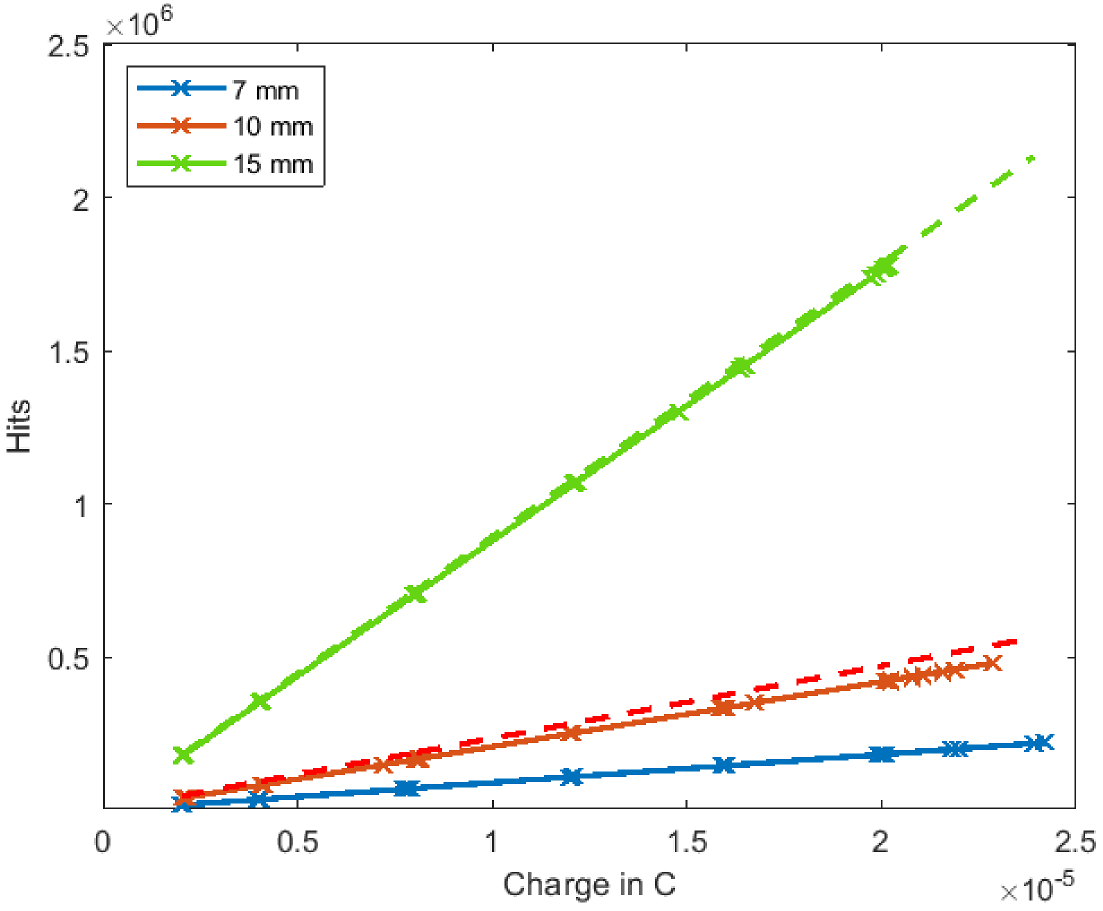
GEANT4 simulation



Collimator diameter	7 mm	10 mm	15 mm
Percentage of Entries |x| > 8 mm	6.30 %	7.92 %	13.31 %

Beam Halo to Dose correlation

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



Collimator ratio	Gradient ratio	k_{corr}
10/7	2.2572	2.566
15/7	9.5352	9.703

Results of the measurements and simulation are agreeing well.

Halo to Dose correlation

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

$$D_p = \frac{E_p}{m_{VELO}} = \frac{S \cdot \rho \cdot d}{\rho \cdot d \cdot A} = 205.65 \frac{MeV}{kg} = 3.295 \cdot 10^{-11} Gy$$

2. Total number of protons:

$$N_{tot} = Hits \times 1.0835 \cdot 10^{-10} \frac{C}{Hits} \cdot \frac{1}{160 \cdot e} \times k_{corr}$$

3. Total dose for the VELO detector:

$$\boldsymbol{D_{VELO} = Hits \times 1.395 \cdot 10^{-4} \frac{1}{Hits} \times k_{corr}\, Gy}$$

5. Conclusion

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!

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