Development of a Stand-alone, Non-invasive Online Beam Monitor using LHCb VELO

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VELO: Homecoming

1. Motivation
2. Monitoring the beam delivery system
3. Detector system
   1. LHCb Vertex Locator (VELO) Detector
   2. Locally-build Faraday Cup
4. Developments
   1. Impedance matching of the FC
   2. Output measurements with an IR-Laser
   3. Implementation in a Proton Therapy Centre
5. Conclusion and Outlook

1. Motivation

Beam Diagnostics are the 'eyes and ears' of the operator to control a modern accelerator system and guarantee the **Quality Assurance**.

Online beam monitoring is essential for ion beam therapy to assure **effective delivery** of the beam and maintain **patient safety** for cancer treatment.

failures (5%), software and other mistakes (5.5%). Three types of direct and contributing causes responsible for almost 62% of all accidents are directly connected to the quality assurance of treatment. The lessons learnt from the accidents are related to frequencies of direct and contributing factors and show that most of the accident are caused by lack, non-application of quality assurance (QA) procedures or by underestimating of QA procedures. The international system for collection of accidents

-Accidents in Radiotherapy: Lack of Quality assurance, J. Novotny, Prag, IAEA report 2000

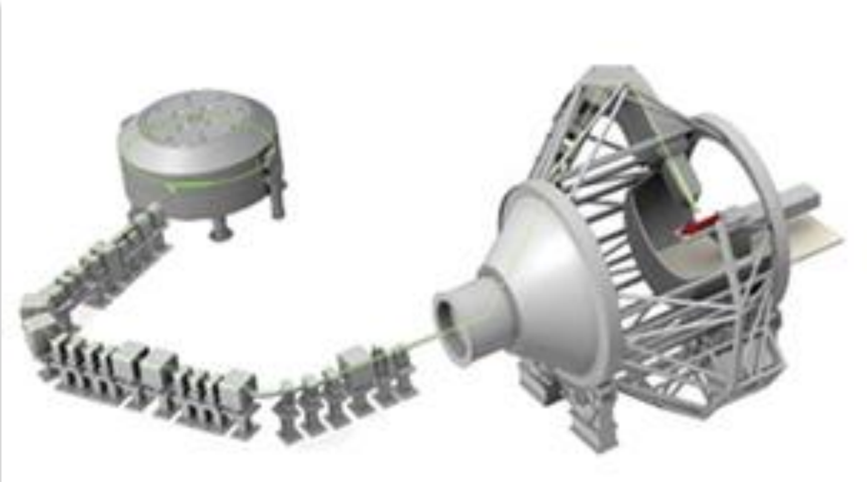
2. Monitoring the beam delivery system

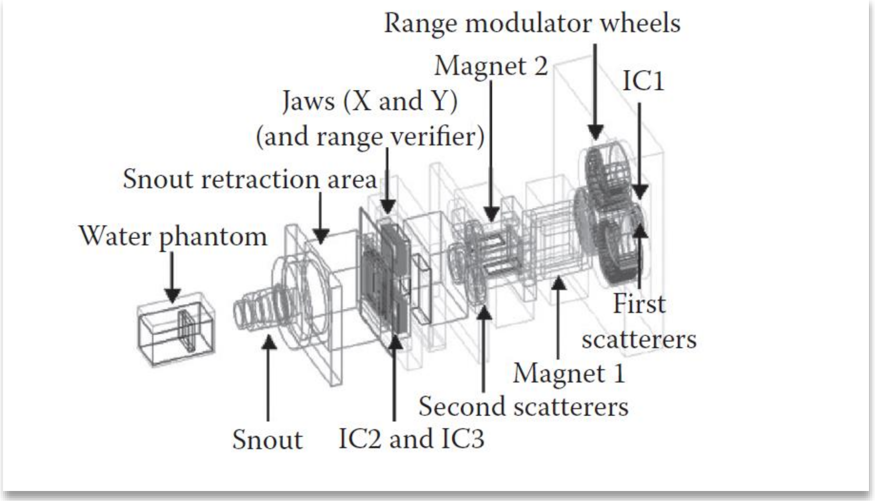
Beam monitors essential for dose measurement and beam profile and position monitoring

Current 'back bone' of the radiation therapy:
Ionization chambers

- Interceptive devices
- Correction of pressure, temperature and the volume effect need to be applied
- Charge recombination

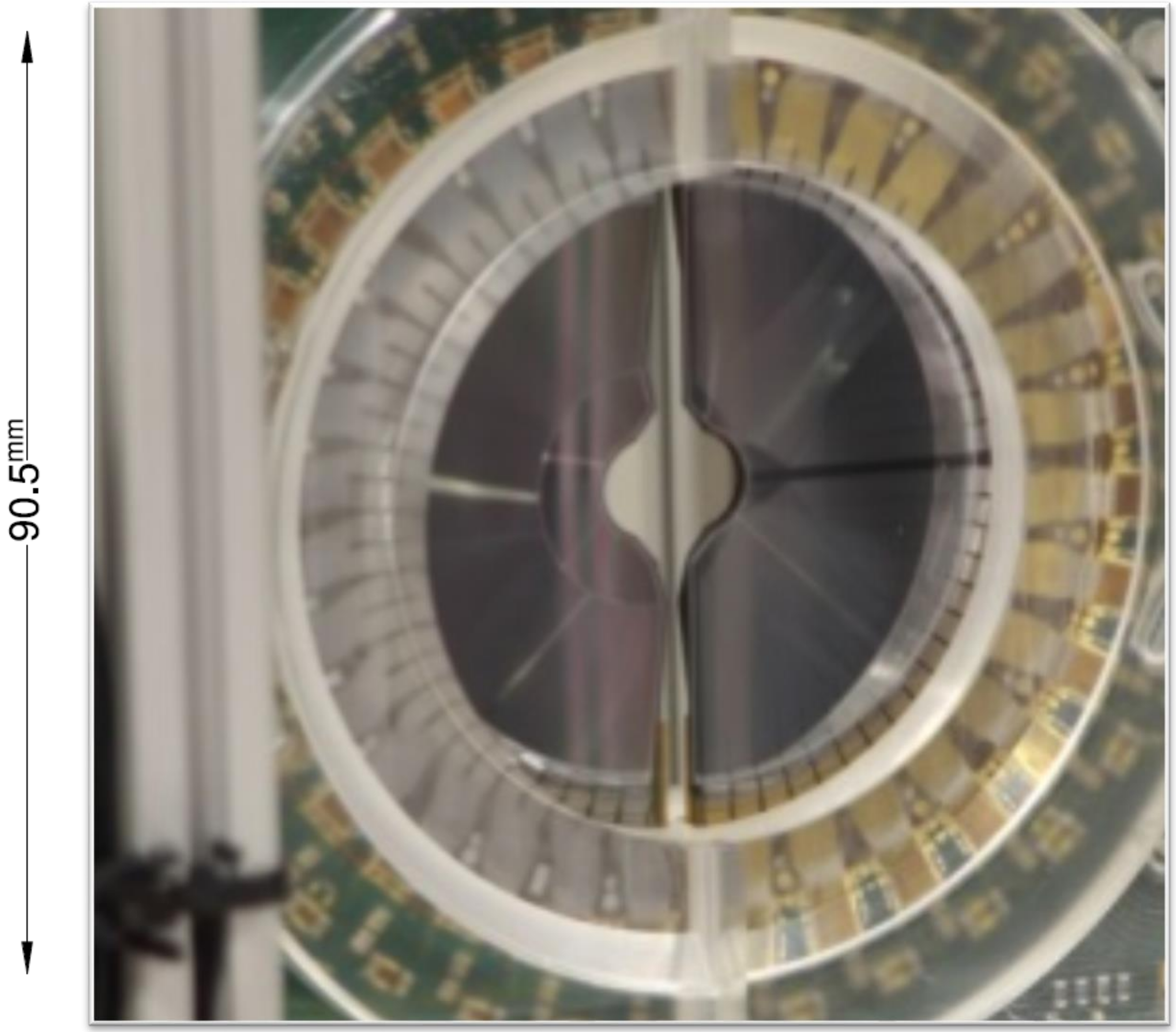
➲ Ultra-fast silicon detectors highly desirable





-Michael Gotein: Radiation Oncology: A Physicist's-Eye View. Springer, Boston, 1st edition, 2008.

3. 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.

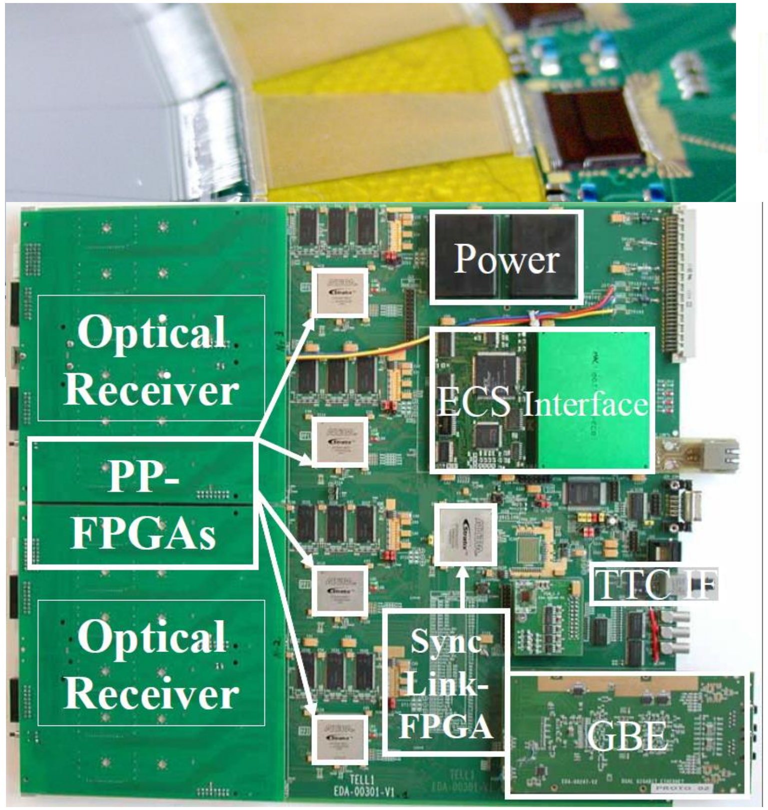
Approaching the core of the beam without interfering with it.

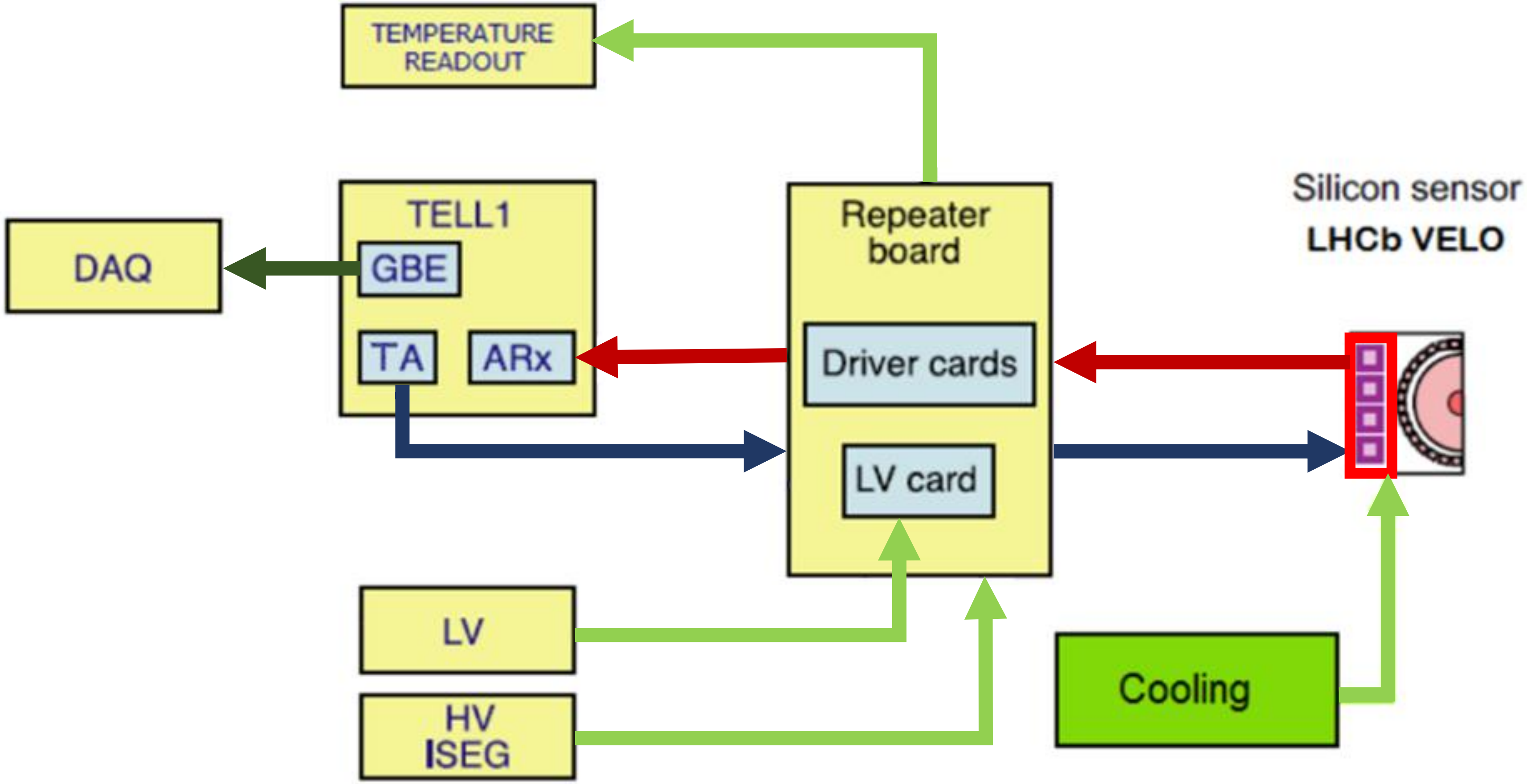
➲Precise measurement of the **beam halo**

The VELO detector (sketch)

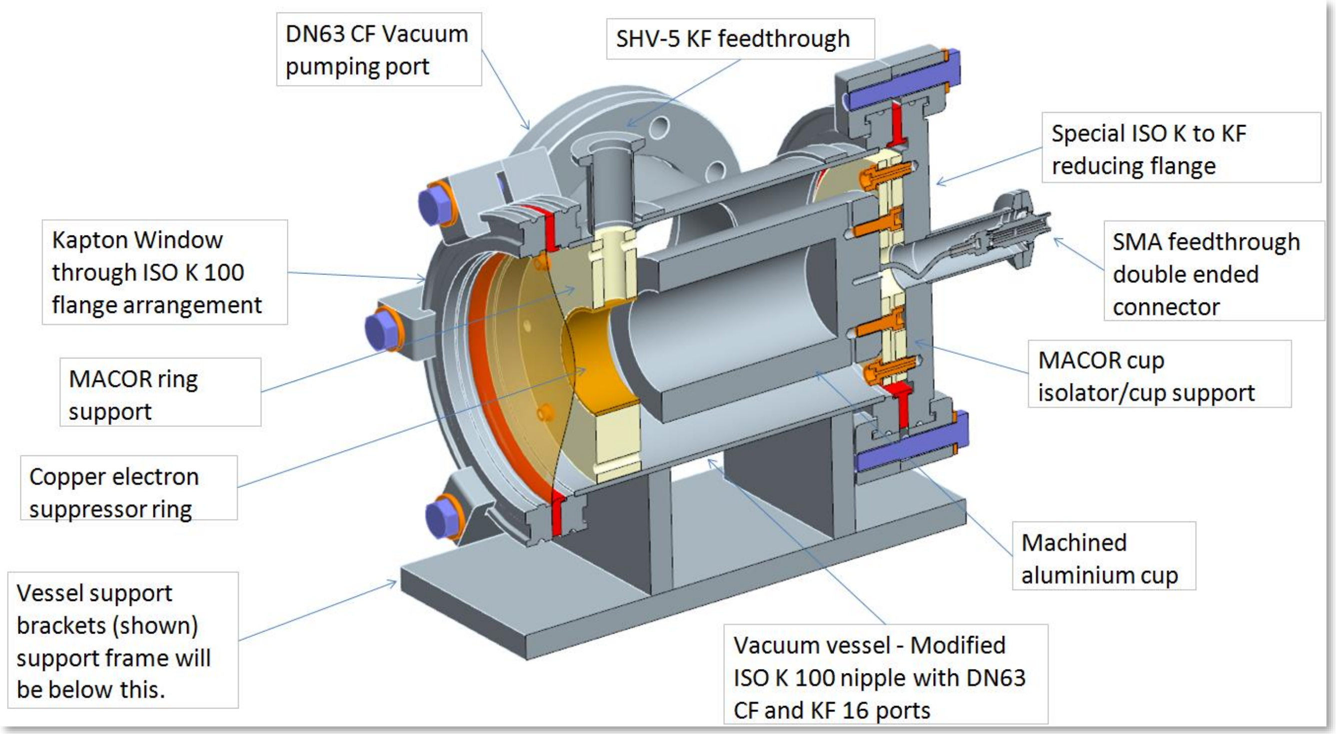
Electronics of the VELO detector

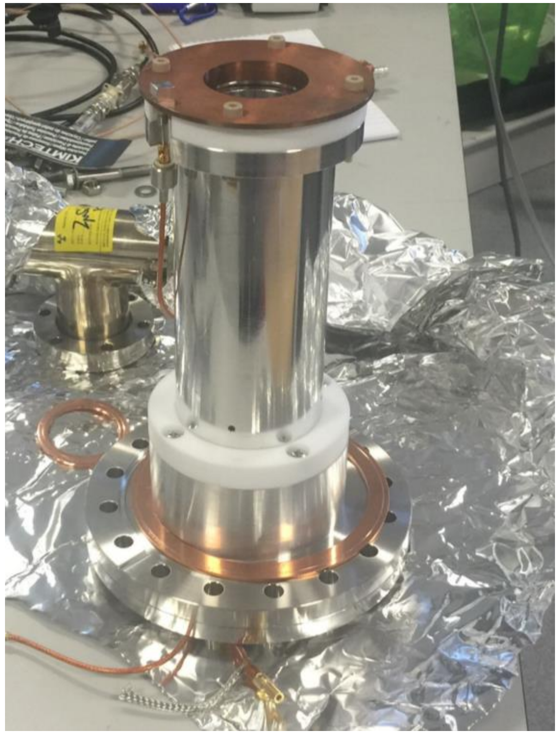
The 16 analogue readout **Beetle chips** integrate 128 strip channels per sensor at 40 MHz.





Locally-build Faraday Cup





Aluminium FC
Optimized for 60 MeV proton

FC impedance: 25 Ohm

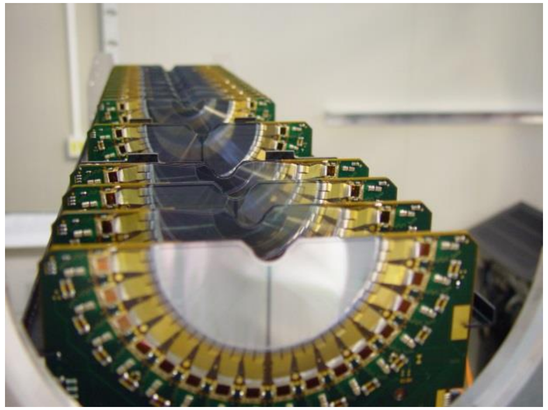
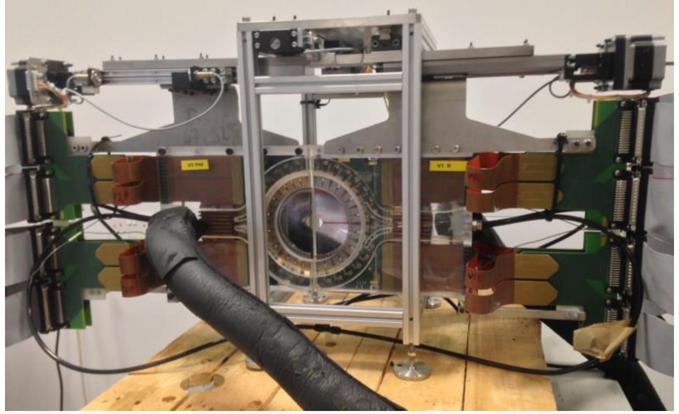
Mismatch to 50 Ohm cable

$$d = \frac{D}{e^{Z_0 \cdot 2\pi \cdot \sqrt{\frac{\varepsilon}{\mu}}}}$$

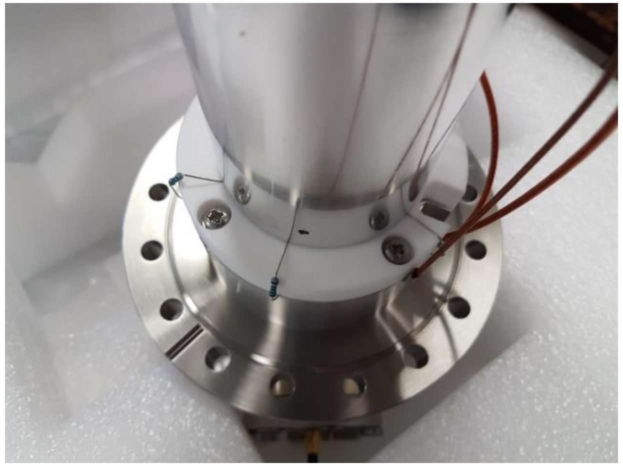
Z0: Impedance
D: Diameter outer conductor
d: Diameter collector

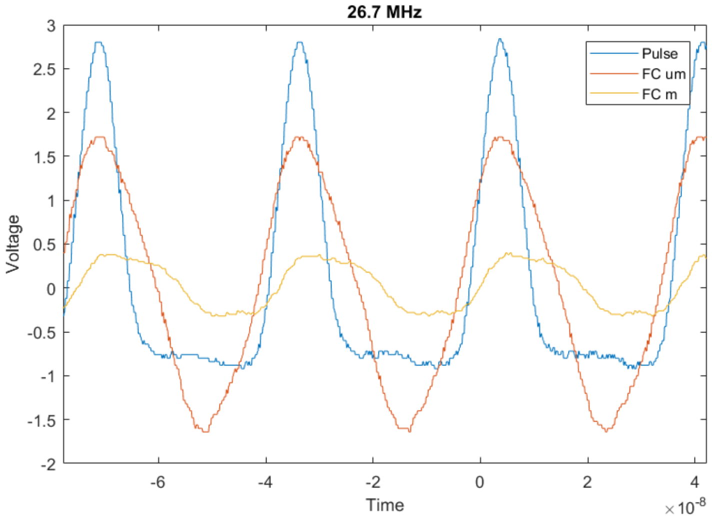
4. Developments

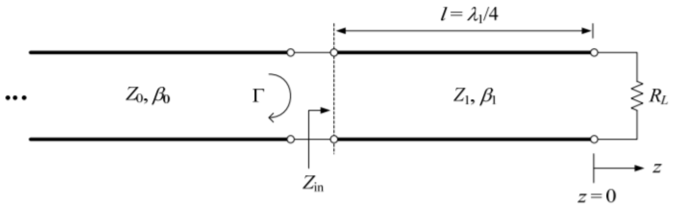
From fundamental physics to the ‘Real World’

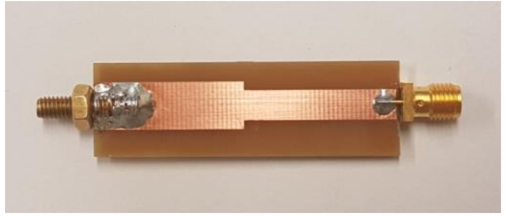
Then	Now	Next
		
CERN	Cockcroft Institute (CI)	Proton Therapy Centre

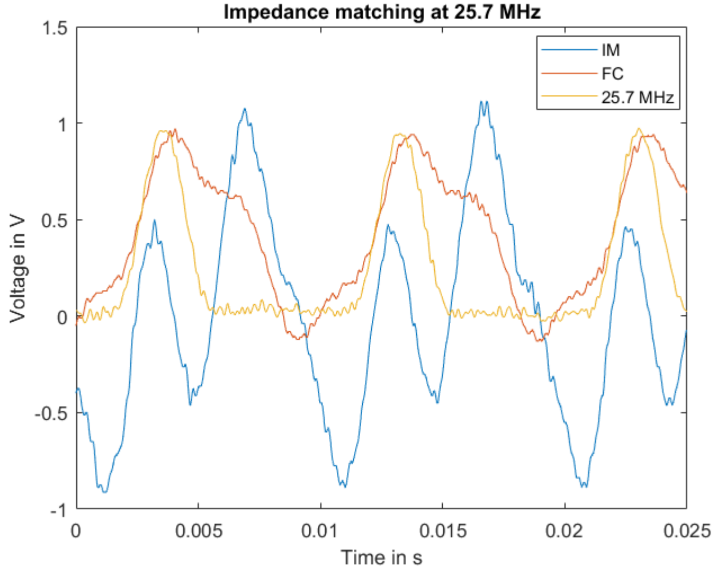
Impedance matching for the FC











First test:

25 Ω in series (6*150 Ω in parallel)

Quarter-Wave-Transformer:

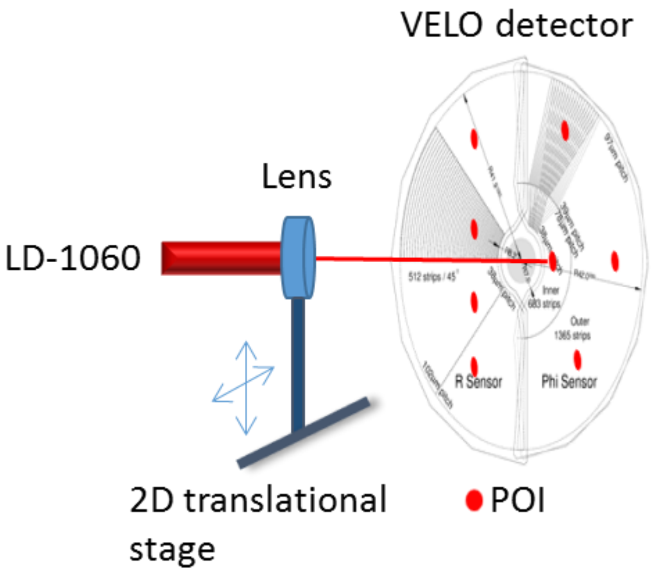
$$Z_1 = \sqrt{Z_0 R_L} = \sqrt{(25 \cdot 50)\Omega^2} = 35.36\Omega$$

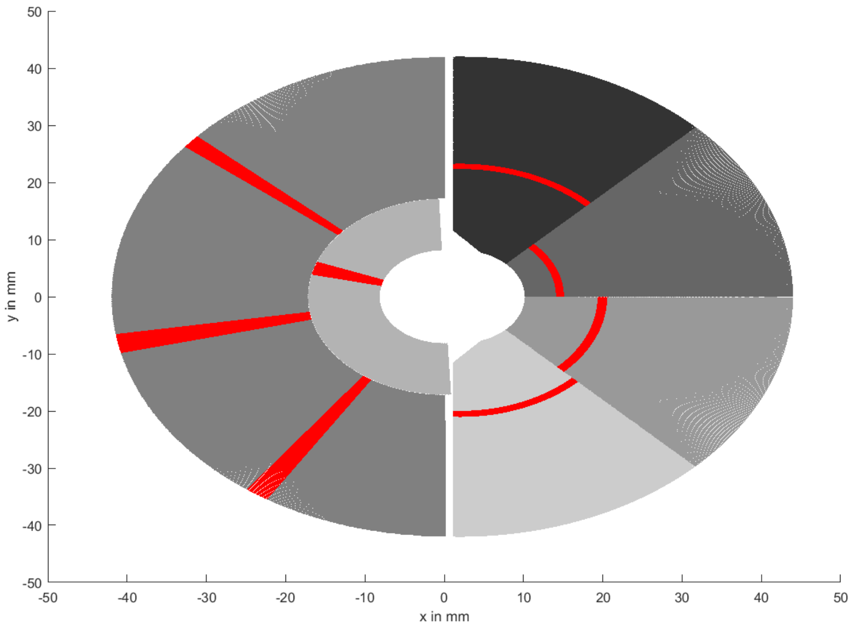
$$f_0 = 1.5GHz = \lambda_1 = 20\ cm$$

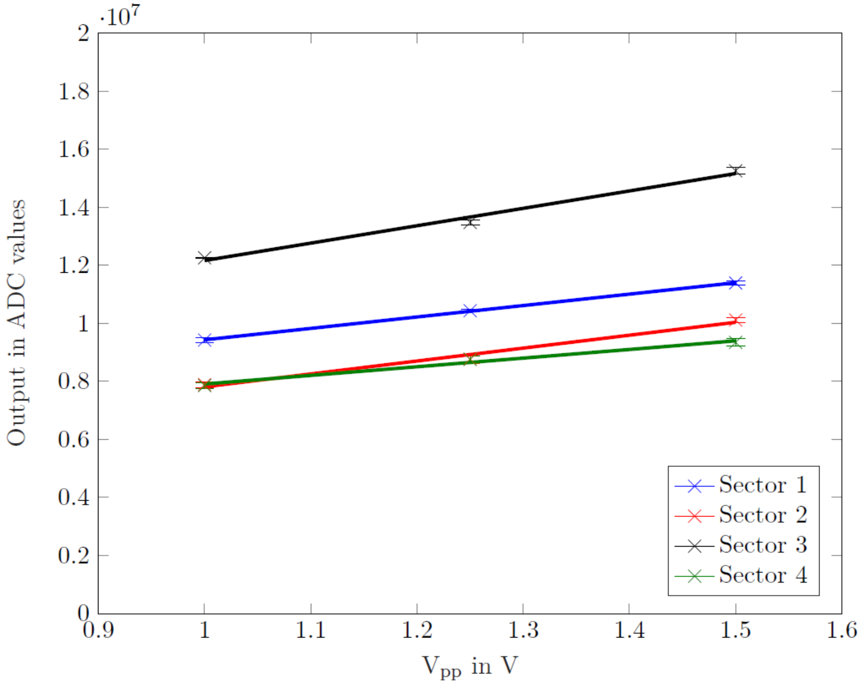
Output measurements with an IR-Laser

1060 nm Infra-red laser used to look at VELO detector behaviour

Laser spot position is shown and linear trend was observed.







R. Schnuerer, J. Yap et al. in Proc. of IPAC'17, Copenhagen, Denmark
http://accelconf.web.cern.ch/AccelConf/ipac2017/papers/thpva136.pdf

Implementation in a Proton Therapy Centre

Treatment room in CCC

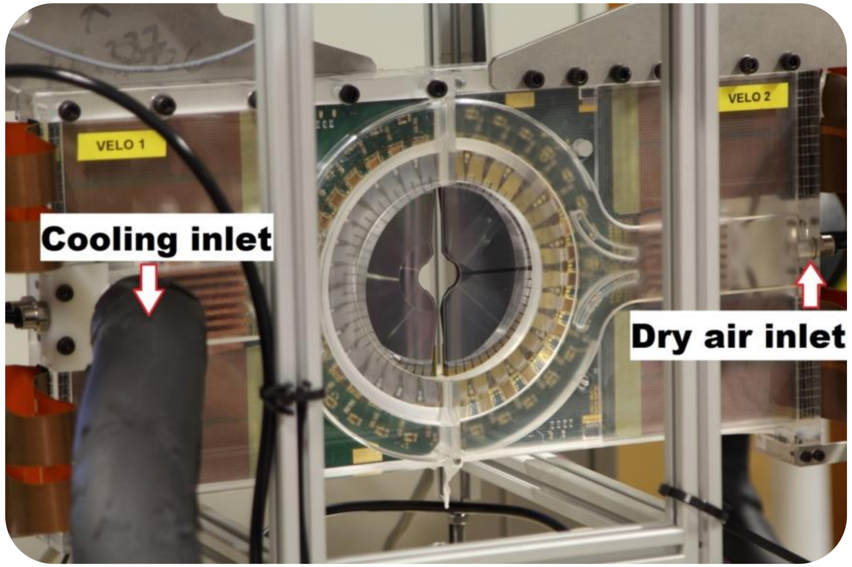
Eye Proton Therapy at the Clatterbridge Cancer Centre

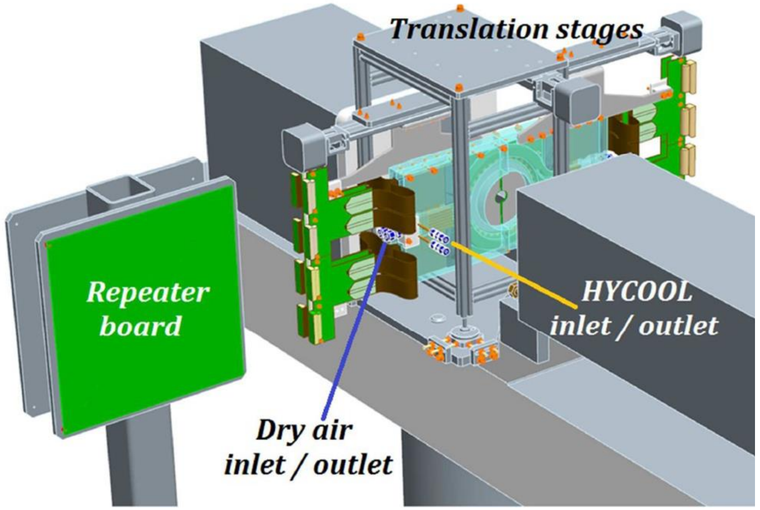
- Scanditronix MC-60 PF cyclotron produces 60 MeV protons
- Cyclotron RF sinusoidal frequency of **25.7 MHz**
- Average beam current of **5 nA**

Tasks

1. Transition from the LHC environment to a therapy facility
2. Synchronizing of the setup
    1. Current readings of the FC and the output of the VELO detector
    2. Readout of the VELO detector with the proton bunch arrival at 25.7 MHz

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.

Ekom DK50 2V-S/M, Nano DL030 dryer:

- 60l/min Dry air at 5 - 6 bars for the dew point at T= -70°C

Furthermore, a remotely controlled **multi-axes positioning system** was built for the detector to move the detector along the beamline.

- MacLennan THK translation stages

Trigger adaption for VELO

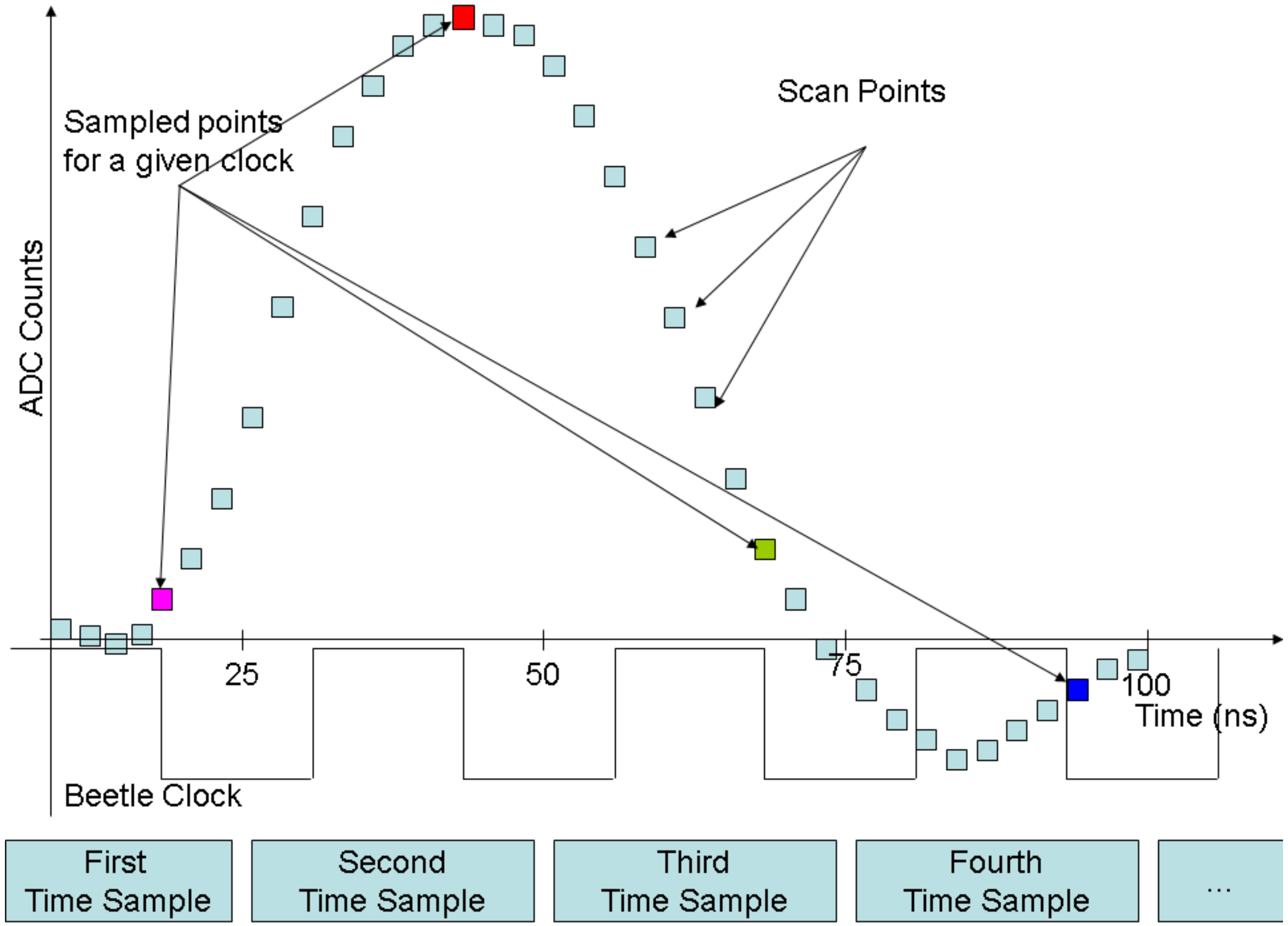
Goal: Synchronize Beetle clock (40 MHz) with RF frequency of Cyclotron (25.7 MHz)

What was given:

- Internal trigger (100 Hz) samples events at random spots of the signal pulse.
- Non interchangeable quartz crystal oscillators are used to generate the internal frequency
- Changing the clock of the Beetles or TELL1 boards not possible
- Injecting the RF cyclotron frequency directly into TELL1 board not possible

Solution:

Synchronizing the RF cyclotron frequency with an external injected readout trigger.



External Trigger

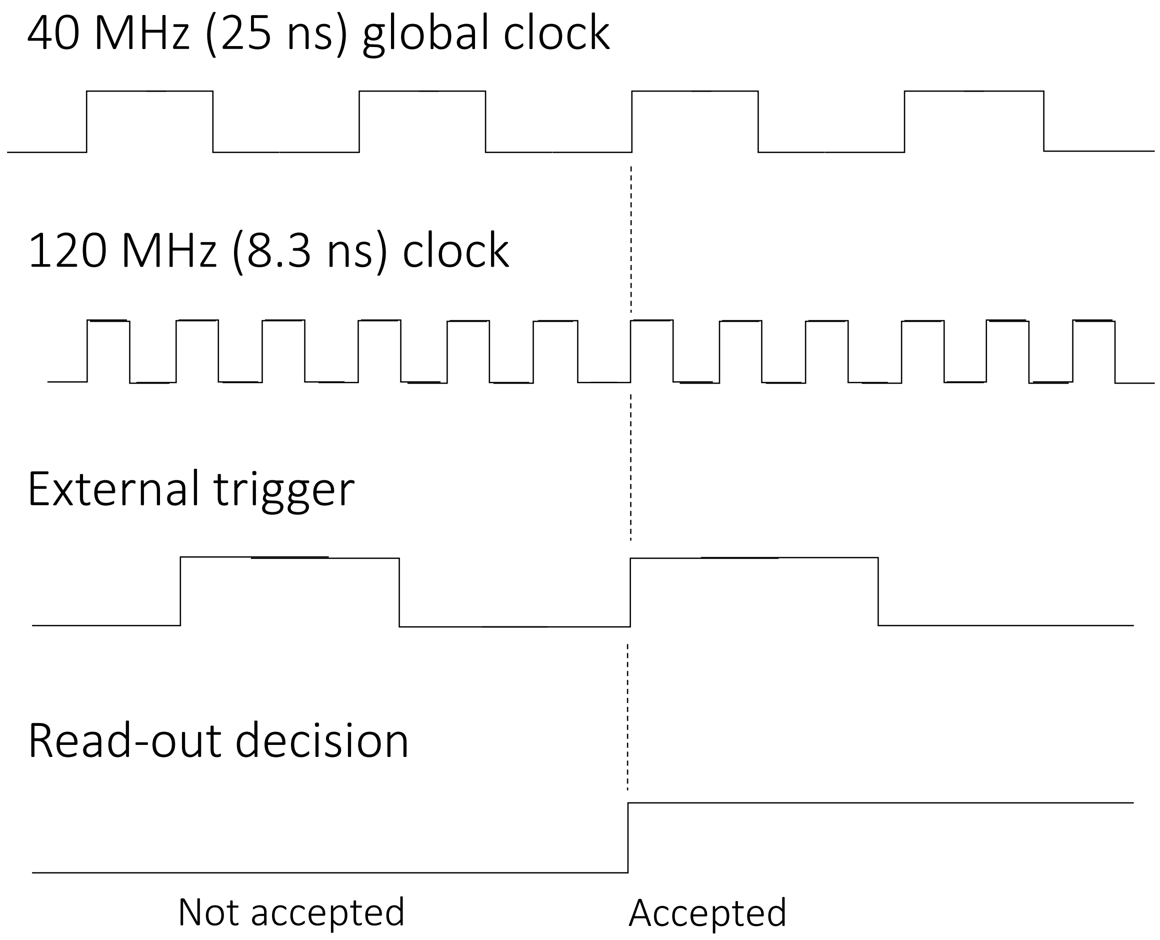
Signal injected into TELL1 board supplied by pulse generator triggered by the RF cyclotron frequency.

The rising edge of the trigger is detected with a 120 MHz clock in phase with the 40 MHz global clock cycle.

The external trigger is accepted if the edge is within the first 0 to 8.3 ns of the 40 MHz clock.

The external trigger can reach up to 20 kHz.

Fine adjusting the signal for the maximum signal by delaying the external trigger pulse.



VELO software

The **Vetra** project will be used by the VELO sub-detector during data taking as a **monitoring tool** and for parameter tuning. It will be used to calculate the values of parameters of the TELL1 processing algorithms, for example cross talk coefficients or clusterization seeding and inclusion thresholds.

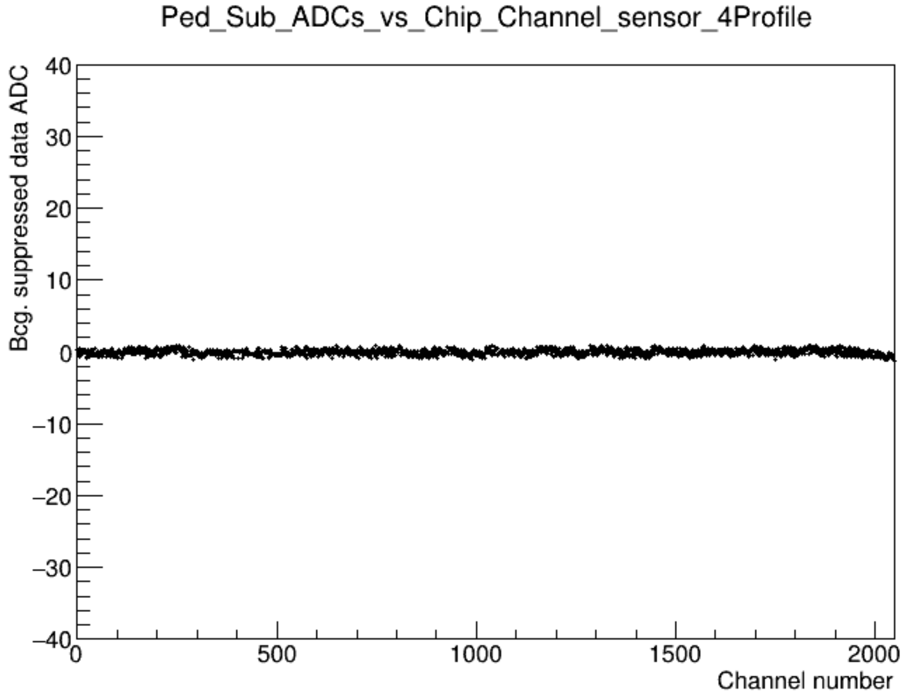
T. Szumlak, "Description of the Vetra Project and its Application for the VELO Detector", LHCb-2008-022, University of Glasgow, Glasgow, UK, 2008.

➲ CVetra – Cockcroft Vetra

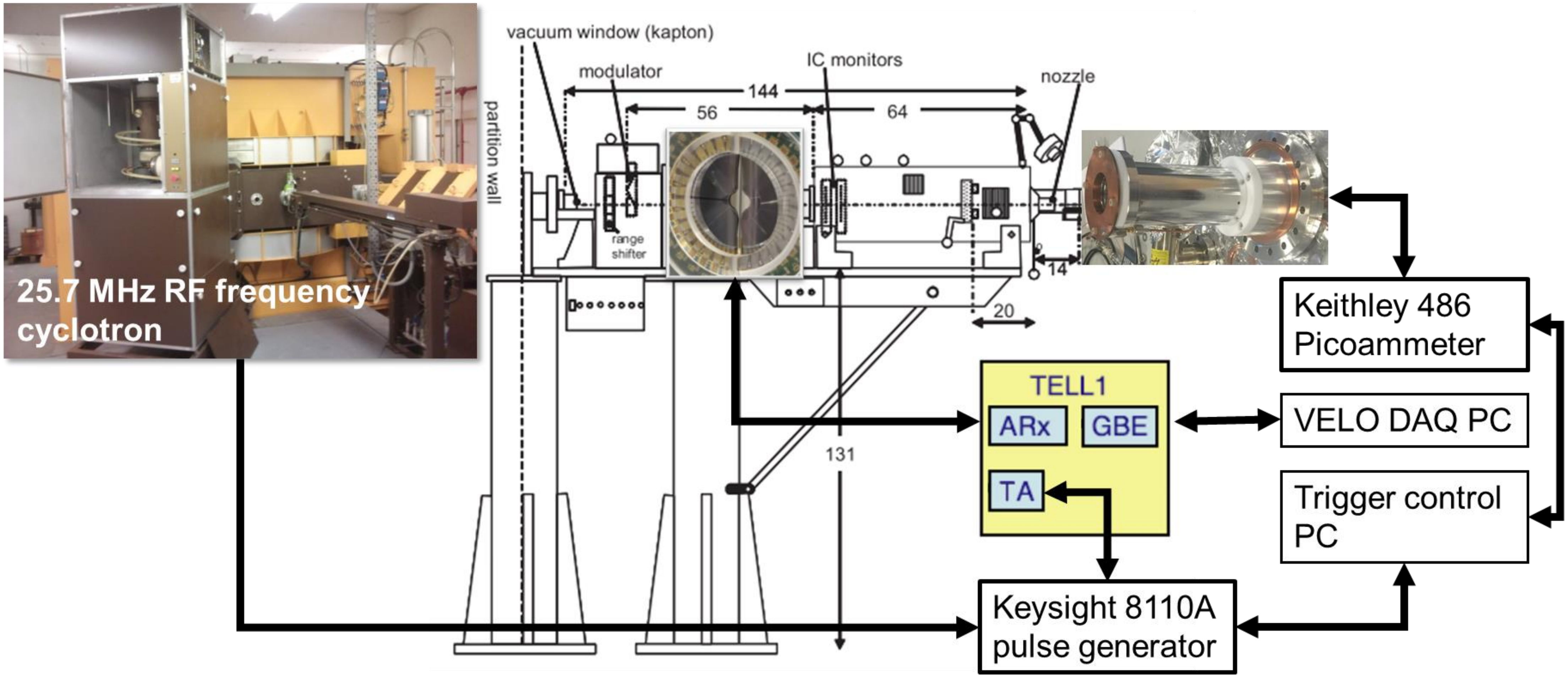
Improvements in the post read-out process

- Automated algorithms for signal processing:
  - Instant background correction
  - Sum of ADC values per event/channel/sensor
  - 2D/3D Hit map generation

⯑ Other quantities …



The setup



R. Schnuerer, J. Yap et al. in Proc. of IPAC'18, Vancouver, Canada
http://ipac2018.vrws.de/papers/mopml024.pdf

Problems

I2C bus for communication with Beetle chips fails

```
[dtell1] /home/cc > ./dvi2c.py -c -v
karol 48
Error writing to I2C - bus 1 address 0x30 : i2c no ack on address

wrote to bus 1 address 0x30
(21, 75, 10, 10, 15, 71, 0, 0, 0, 0, 13, 130, 105, 20, 29, 114, 22, 28, 0, 10)
(0, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255)
karol 49
Error writing to I2C - bus 1 address 0x31 : i2c no ack on address

wrote to bus 1 address 0x31
(21, 75, 10, 10, 15, 71, 0, 0, 0, 0, 13, 130, 105, 20, 29, 114, 22, 28, 0, 10)
(0, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255)
karol 50
Error writing to I2C - bus 1 address 0x32 : i2c no ack on address

wrote to bus 1 address 0x32
(21, 75, 10, 10, 15, 71, 0, 0, 0, 0, 13, 130, 105, 20, 29, 114, 22, 28, 0, 10)
(0, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255, 255)
karol 51
Error writing to I2C - bus 1 address 0x33 : i2c no ack on address
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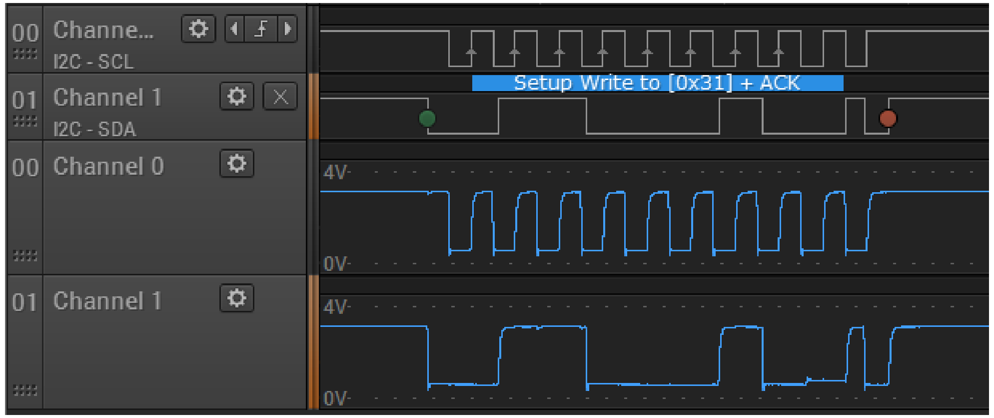

- I2C: bi-directional two-wire serial bus that provides communications between ICs
- I2C communication with Beetle chips not possible from TELL1 board.
- Accessing the address Beetle chips for boot up and read out fails.
- Signal integrity? Grounding? Voltage Output?

Measurement

1. Beam current measurement at different dose rates.
2. Beam halo profile measurements along the integration zone.

Validation and Verification of beam halo simulation studies by Jacinta Yap.

3. Joined forces with Navrit Bal, Amsterdam Scientific Instruments (ASI) to use the Medipix3 pixel detector is intended for complimentary particle imaging and detection measurements at CCC.

Conclusion and Outlook

The beneficial sensor design of the LHCb VELO detector with a central semi-circular aperture enables the core of the beam to potentially pass through with **minor distortions** to its profile or energy.

The capability of VELO as a beam monitor will be assessed by measuring the beam current and by monitoring the beam profile along the beamline at CCC this summer.

Further improvement of the VELO detector are envisaged as well as additional measurements in other proton therapy facilities are desirable.

The collaboration with OMA fellows and OMA institutes will be crucial for these developments.

Thank you for your attention!
Please ask your questions!

Acknowledgments:
Jacinta Yap, Hao Zhang, Guido Haefeli, Olivier Girard, Tomasz Szumlak, Karol Hennessy, Tony Smith and Carsten Welsch