
CERN

First results from the operation of a rest gas ionisation profile monitor based on a hybrid pixel detector

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Contents.

Project goal and requirements.

Project goal

Continuous non-destructive bunch-by-bunch and turn-by-turn measurement of the horizontal and vertical transverse beam profile for the CERN Proton Synchrotron (CPS).

Requirements

Transverse beam size measurement with 1% uncertainty:

- Integrated profile @ 1 kHz.
- Bunch-by-bunch measurement every 10ms over the entire PS cycle.

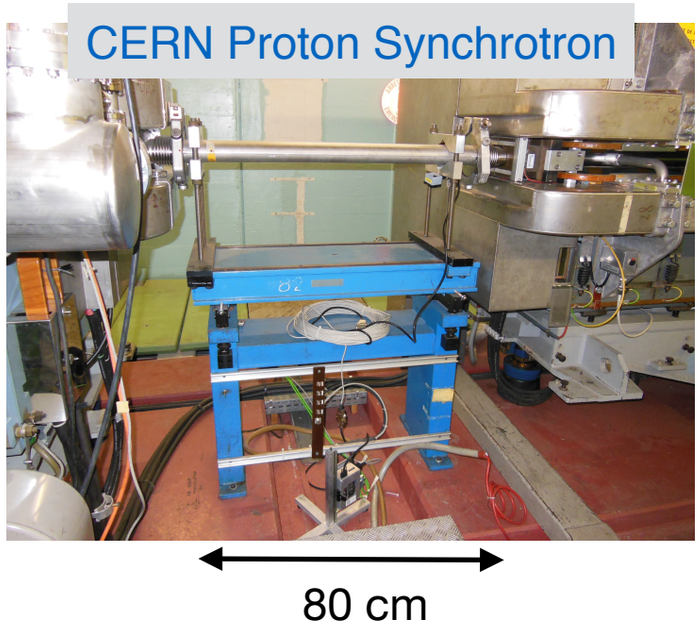
Typical beam

e.g. LHC beam in the CPS:

- 72 bunches, 25 ns spacing,
- 1.3×10^{11} protons / bunch
- beam width = 1.2 mm (1 sigma)

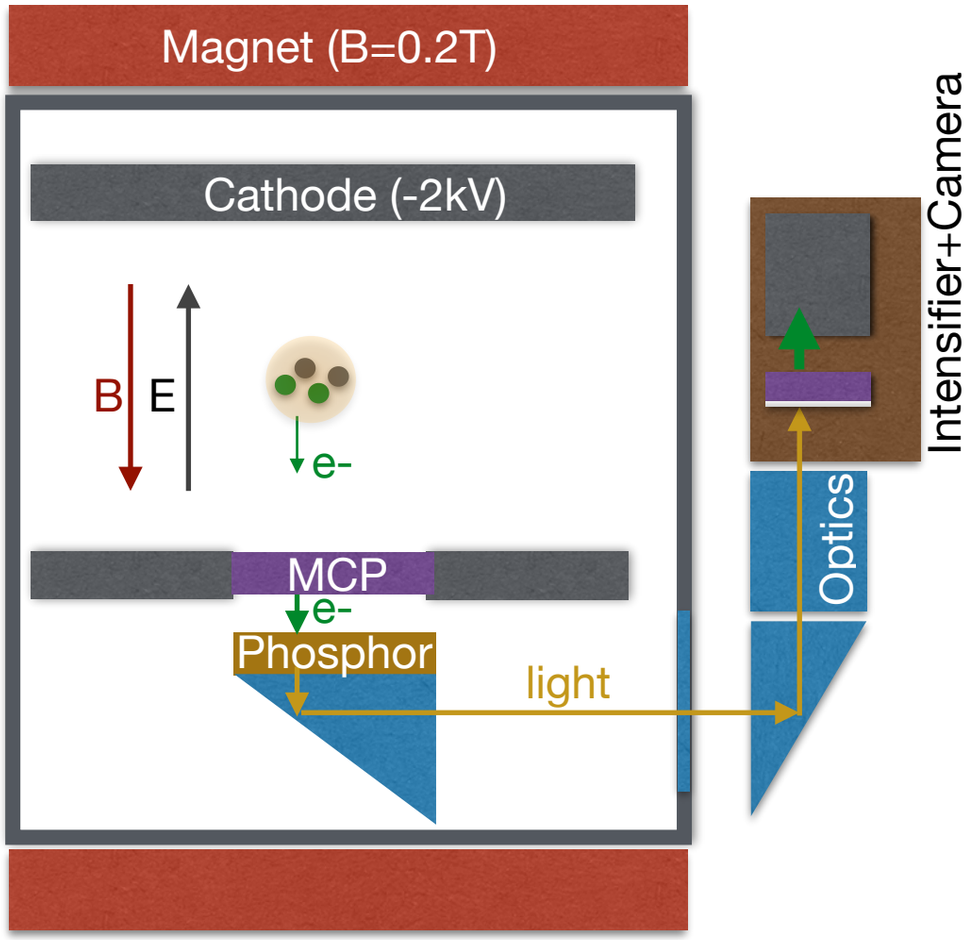
Constraints

- Vacuum: outgassing ≤ 1 · 10-7 mbar · l · s-1.
- Radiation: 10 kGy/yr at beam pipe, 1 kGy/yr at 40 cm.
- Mechanical: straight section length = 80cm.



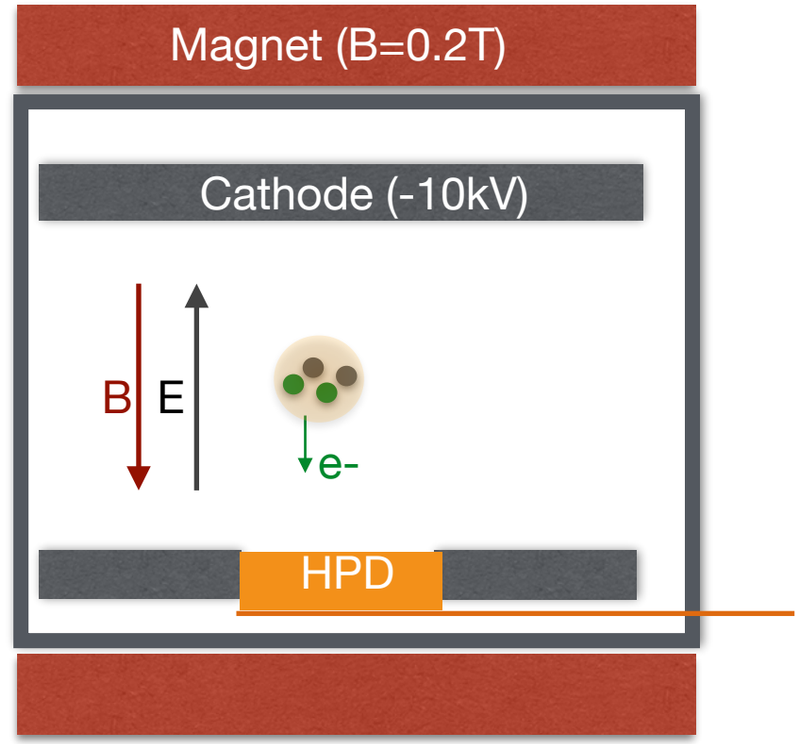
Ionisation profile monitor based on a pixel detector (?)

Electron detection with MCP + Phosphor + Camera



+ Spatial resolution = 10's of microns.
- Time resolution = 10ns (single bunch only).
- Inhomogeneous ageing of the MCP & phosphor.

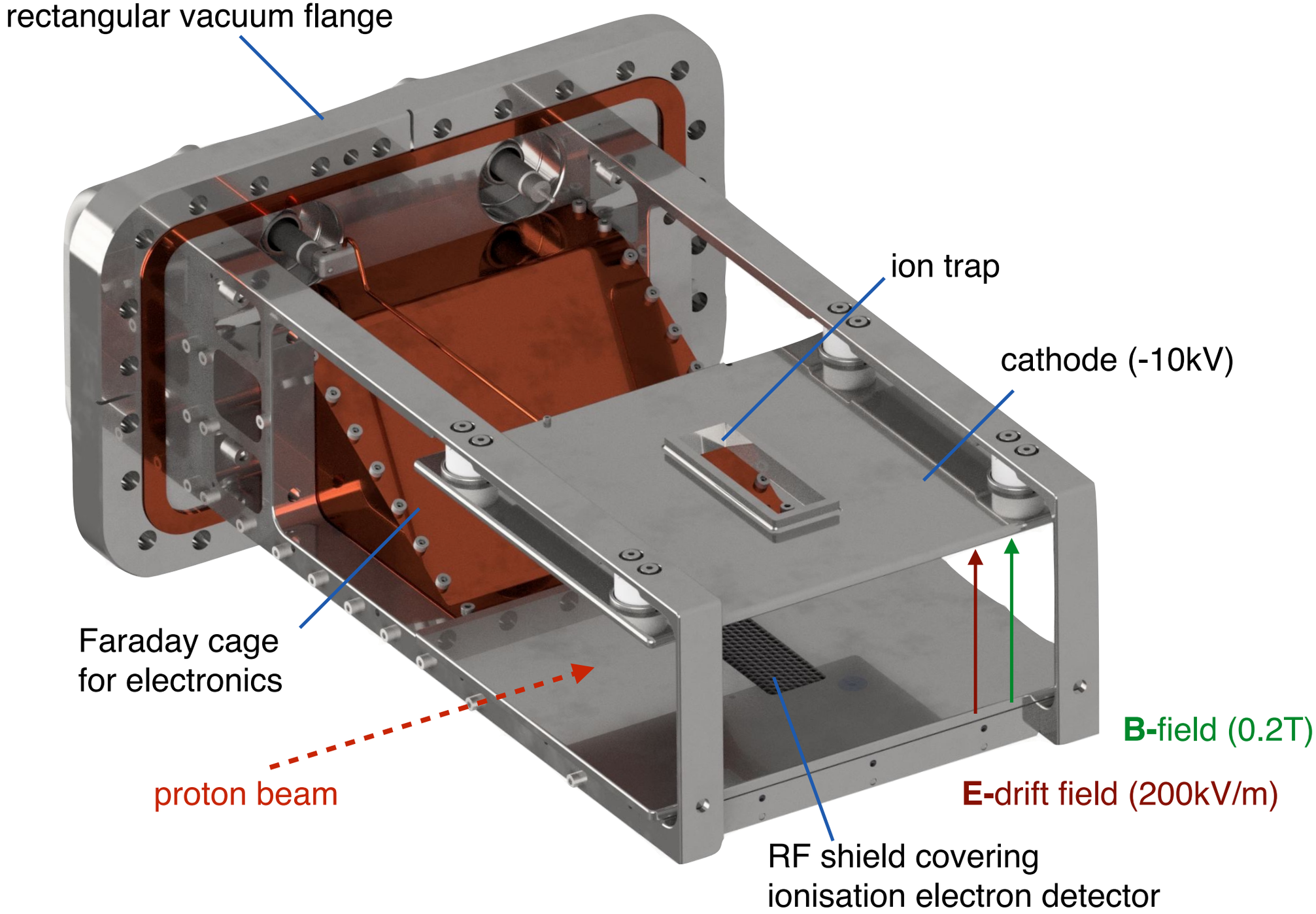
Electron detection with a Hybrid Pixel Detector (HPD)



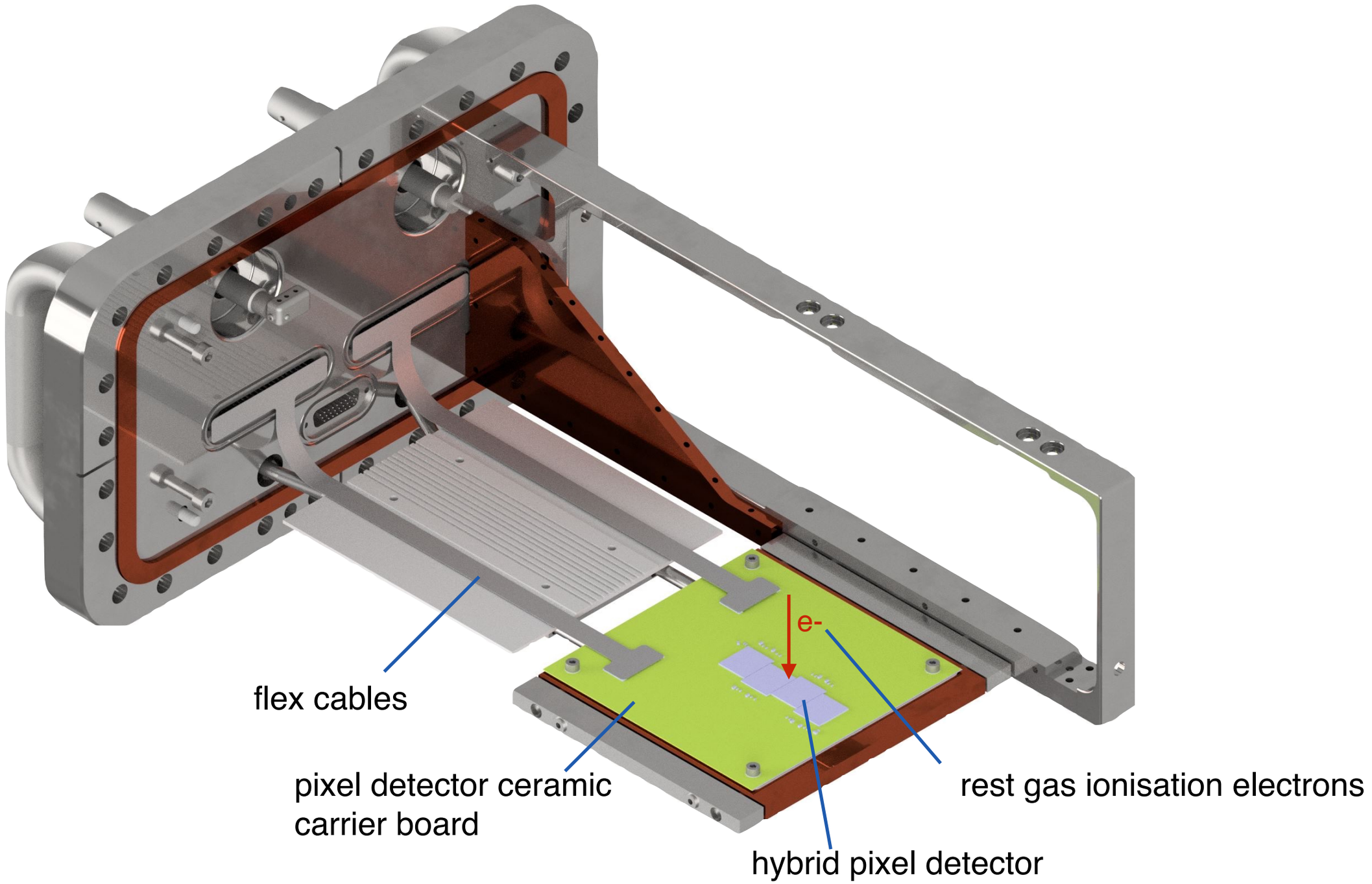
+ Spatial resolution = microns.
+ Time resolution = nanoseconds.
+ Energy information; High electron detection efficiency; Reduced aperture; In-vacuum digitisation….
- **Can a pixel detector operate directly inside the ultra high vacuum environment of the beam pipe?**

Instrument design.

See talk by Kenichiro Satou (KEK)
“Simulation and Progress in Ionization Profile Monitors for High Intensity Proton Beam”



Rest gas ionisation electron detection with a hybrid pixel detector.

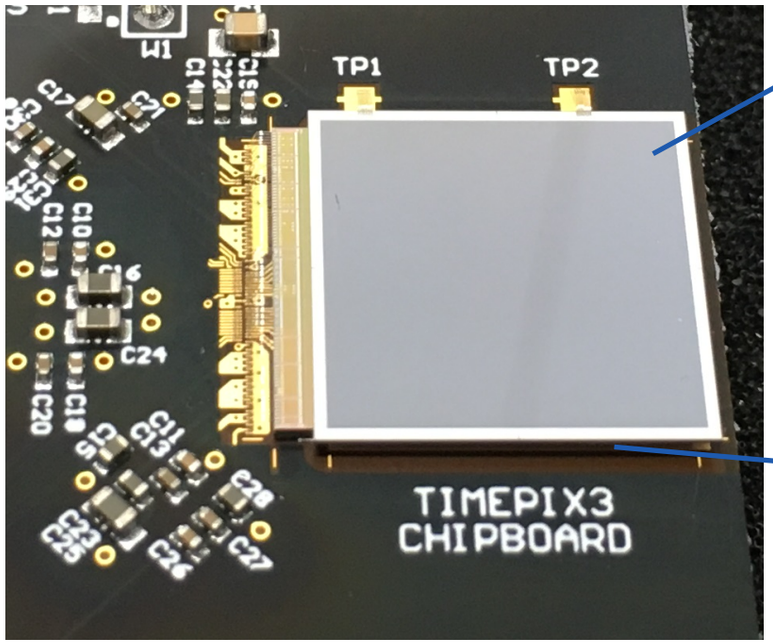


Hybrid pixel detector.

Hybrid Pixel Detector (HPD): Pixelated sensor bump bonded to a pixelated readout chip.

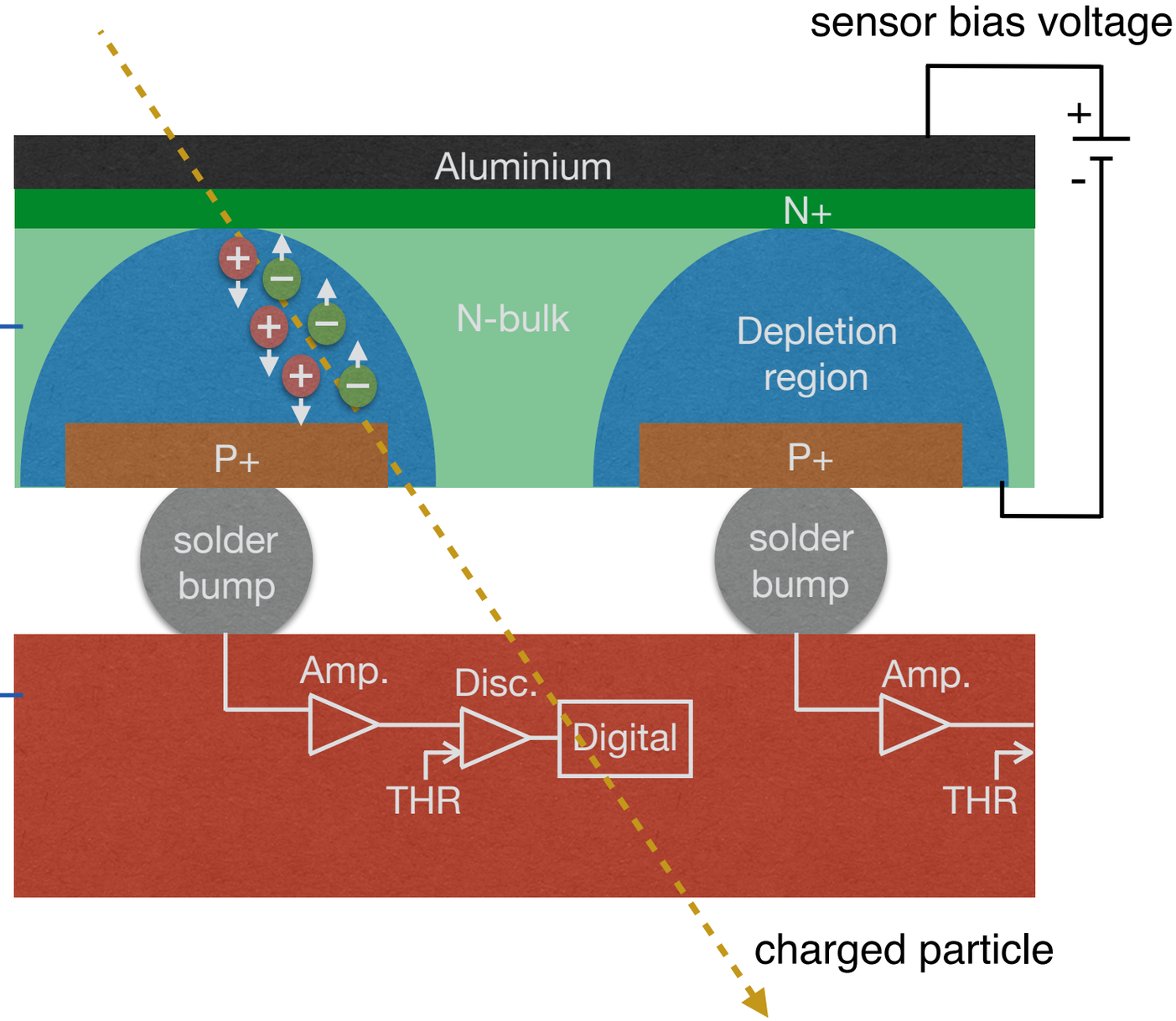
Sensor: 2-dimensional array of PN-diodes processed in high-resistivity silicon.

Readout chip: array of readout channels designed in CMOS technology.

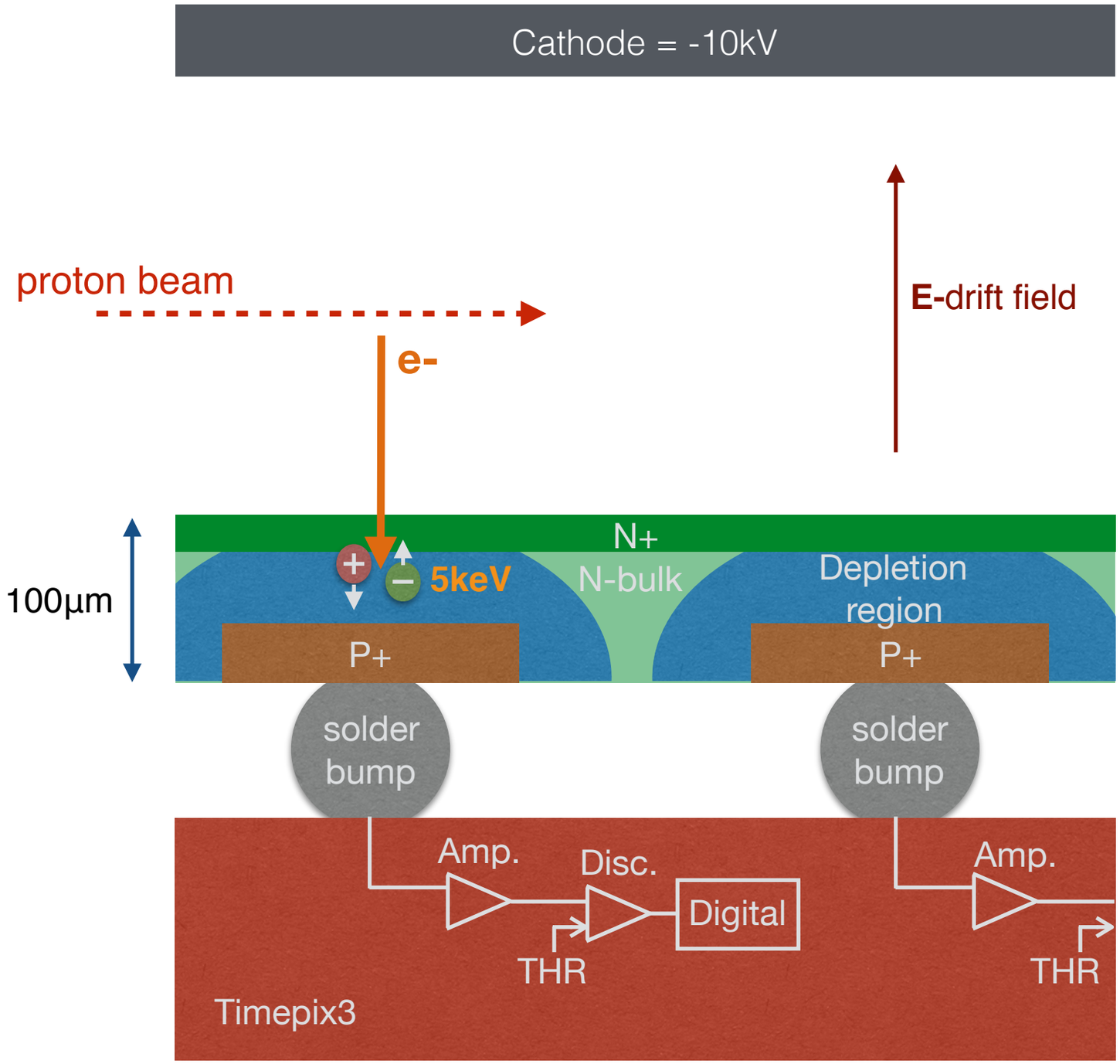


sensor

readout chip



Hybrid pixel detector for detection of ionisation electrons.



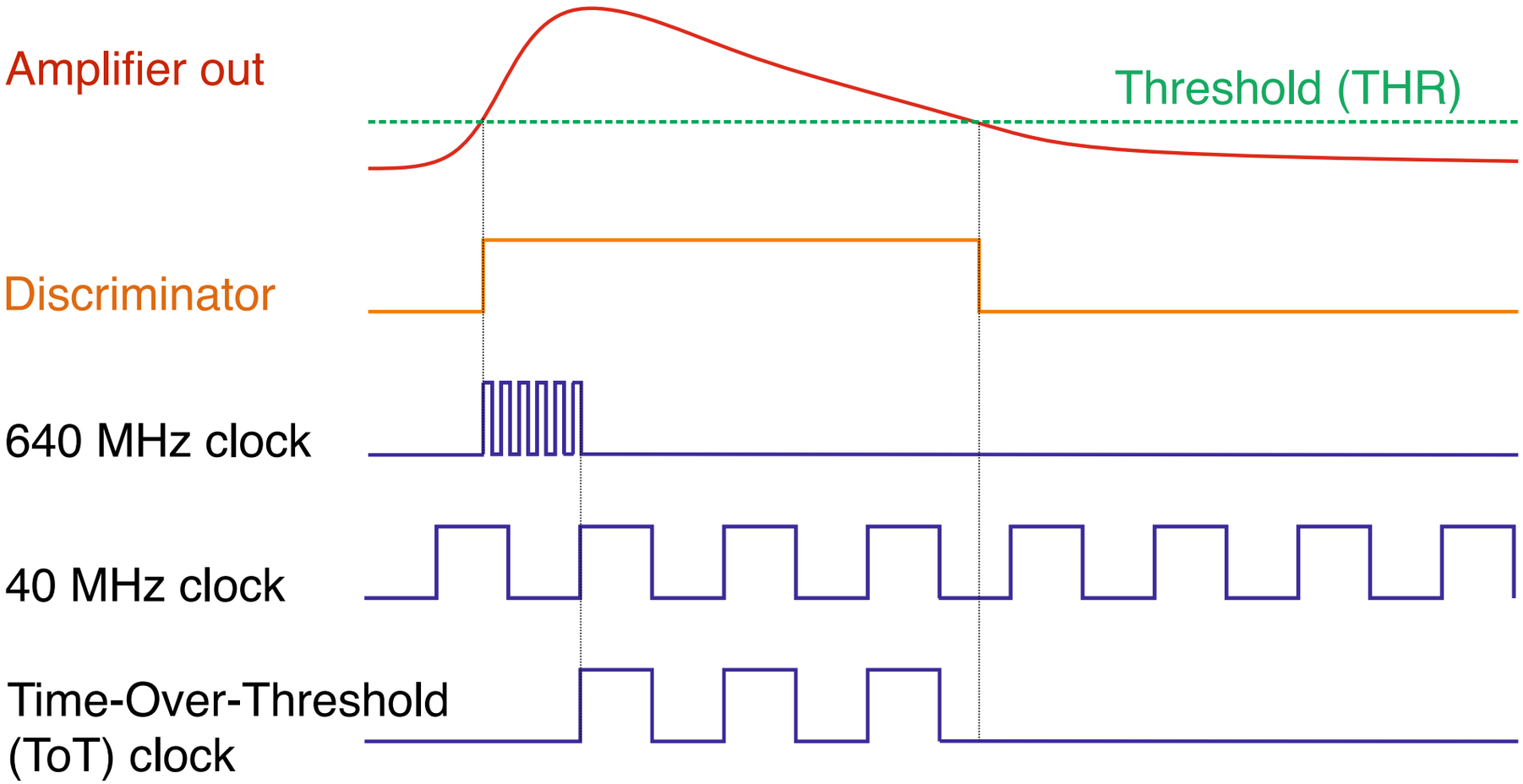
Sensor

- non-metalised, 100µm thick
- 256 x 256 array of PN-diodes (pixels)
- pixel size = 55 µm x 55µm
- area per detector = 14mm x 14mm

Timepix3 readout chip

- each sensor pixel is connected to a corresponding readout channel (pixel)

Timepix3 response to an ionisation electron.



minimum threshold = 500 e^- (1.8 keV)

time resolution = 1.5625 ns

Amplifier out > threshold → Event

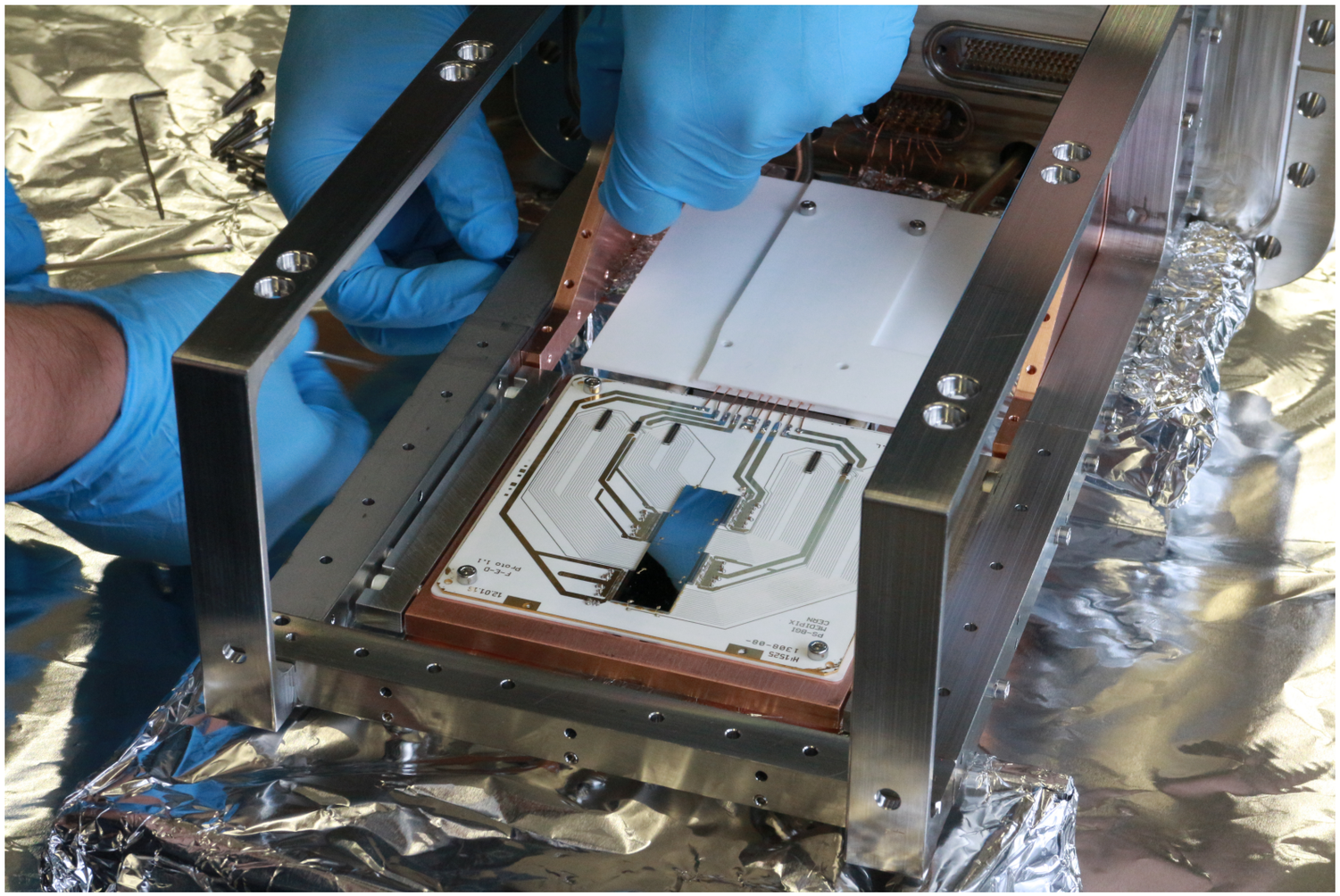
Each event consists of:
- Pixel position → Where
- Time of Arrival (ToA) → When
- Time-Over-Threshold (ToT) → Energy

Max 80M events / s

Realisation.

Challenges - develop pixel detector compatible with

1. **operation directly inside the ultra high vacuum of the beam pipe,**
2. operation during the acceleration cycle,
3. the radiation environment.



Pixel detector

- 4 x HPD's with Timepix3 readout chips.
- Independent power and data lines.

Carrier board

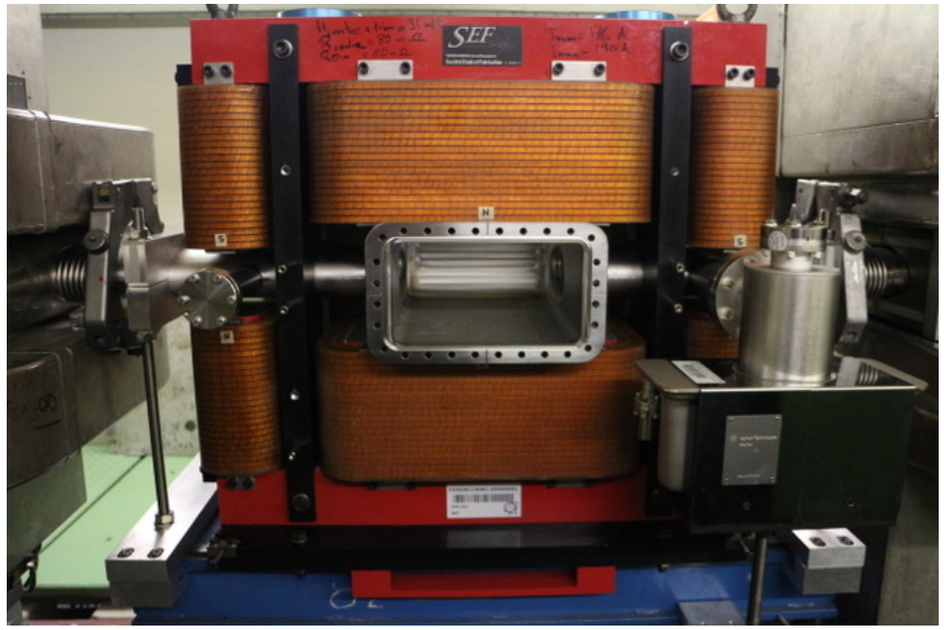
- 2 metal layers, Al_2O_3 substrate.
- Timpix3 wire bonded to board.
- Sensor bias gold wire secured with conductive epoxy.

Flexible cables

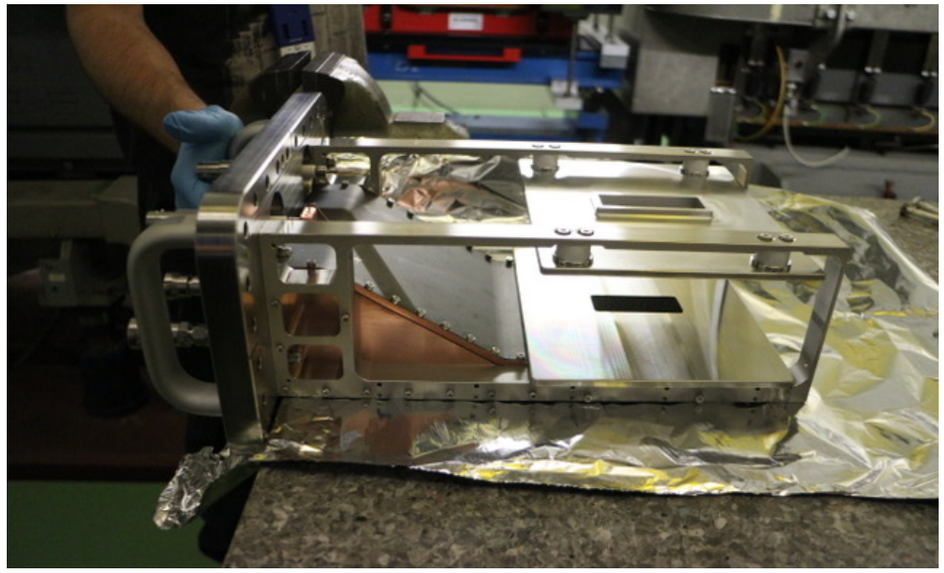
- Connects ceramic board to electrical vacuum feedthrough.
- Two metal layers with a Liquid Crystal Polymer (LCP) substrate.

Installation in the CERN PS.

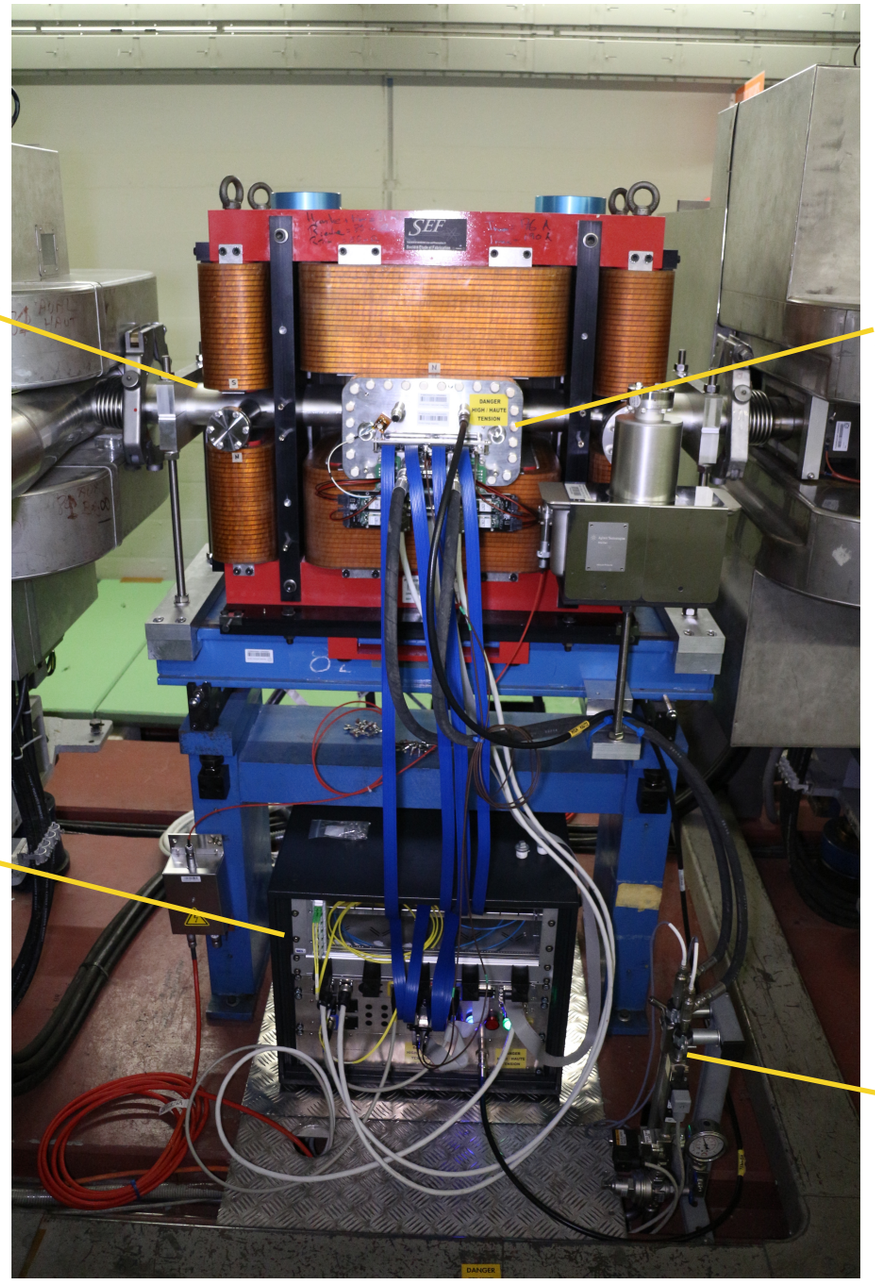
0.2 T self-compensating dipole magnet + vacuum tank



assembled ionisation profile monitor



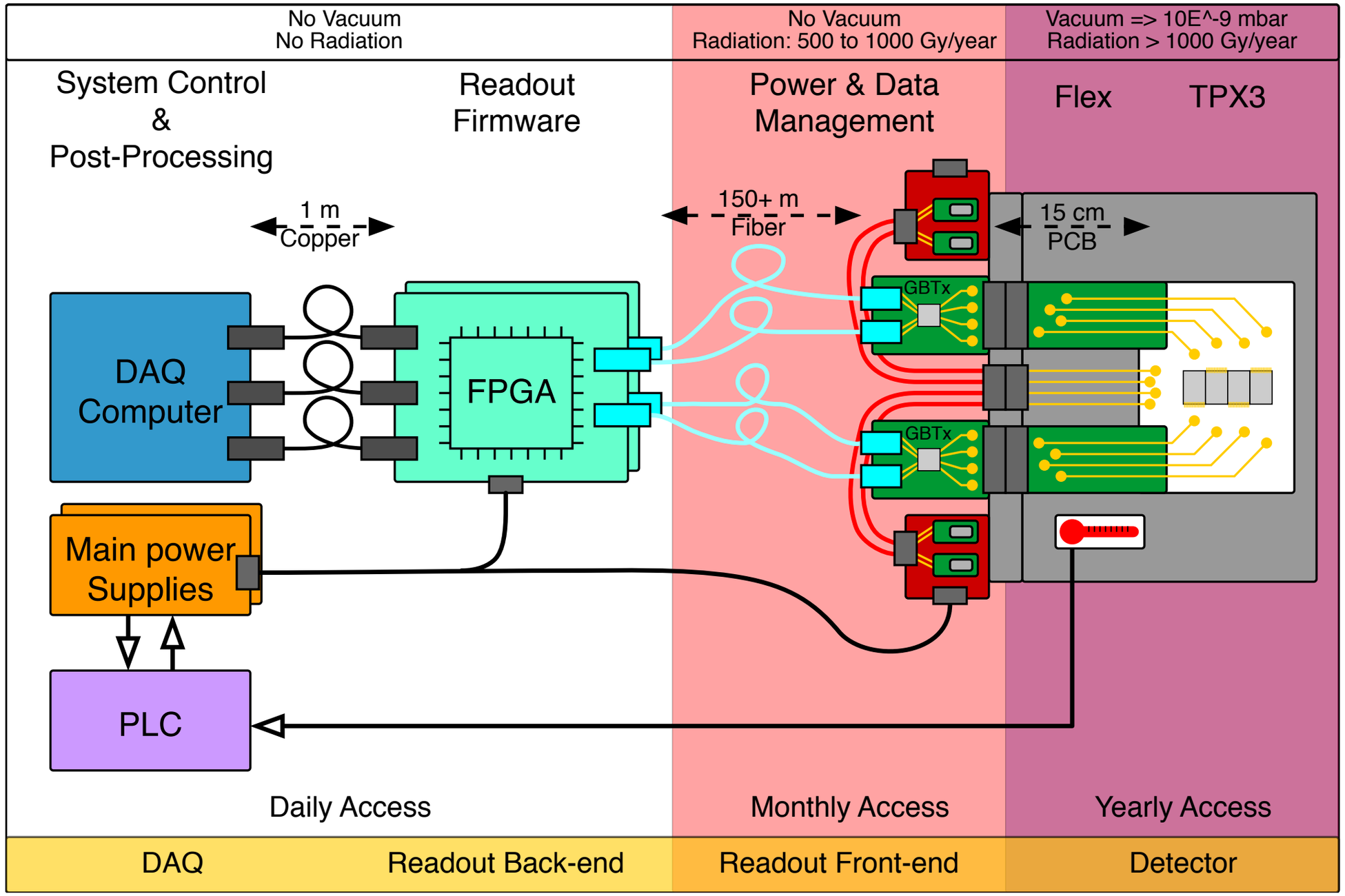
complete installation



Vacuum pump down:

- 1 x 10^{-8} mbar after 24 hours,
- 2 x 10^{-10} mbar steady state.

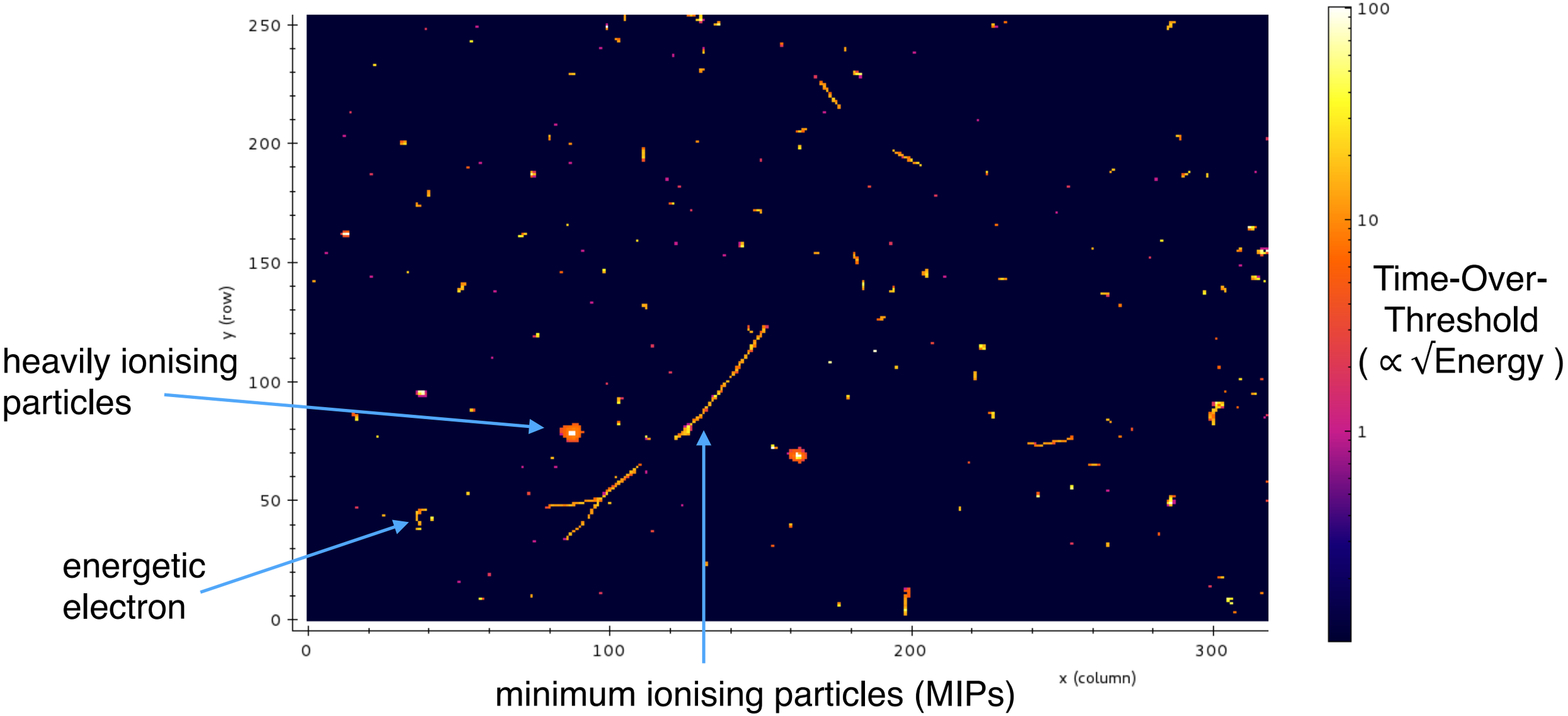
Data acquisition, control & monitoring.



First results

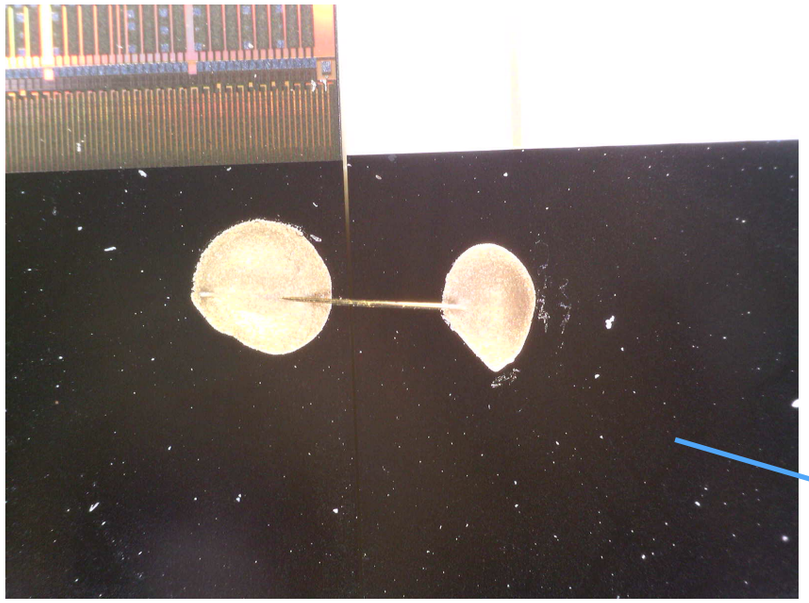
Operation inside the beam pipe during the acceleration cycle.

Acquisition for 100 ms during acceleration cycle with **high voltage off** (no ionisation electrons).

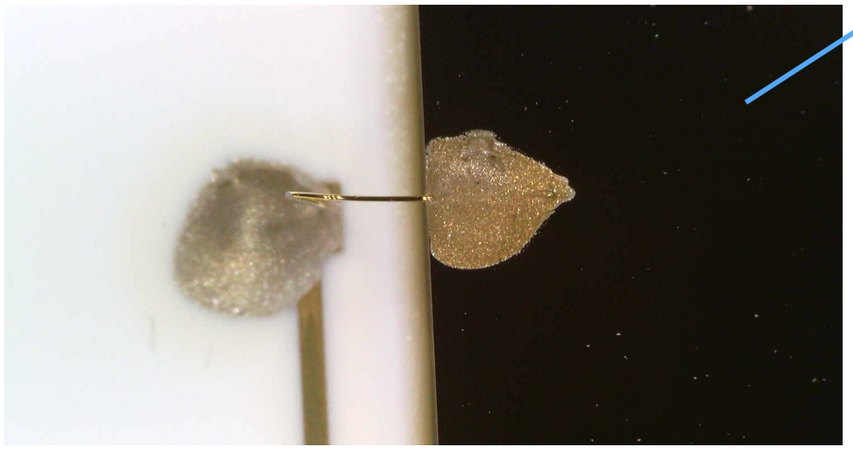


Pixel detector successfully operated inside the beam pipe during the acceleration cycle.

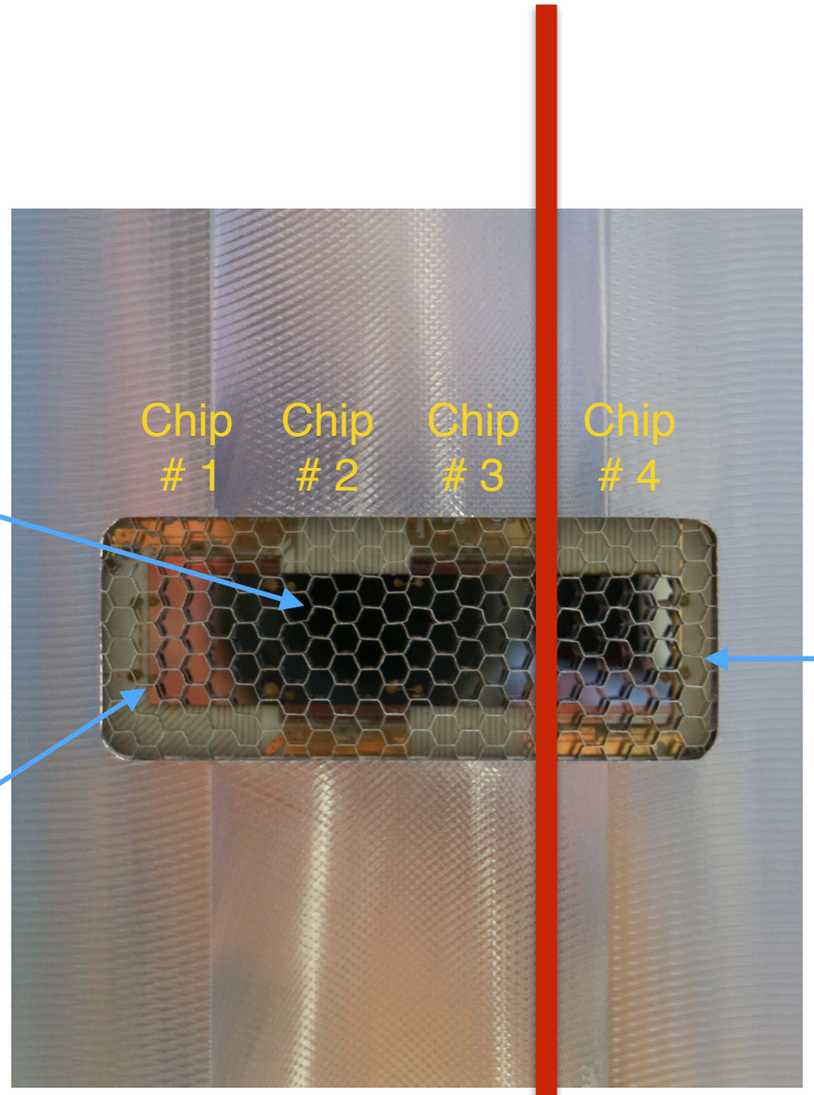
Detection of rest gas ionisation electrons.



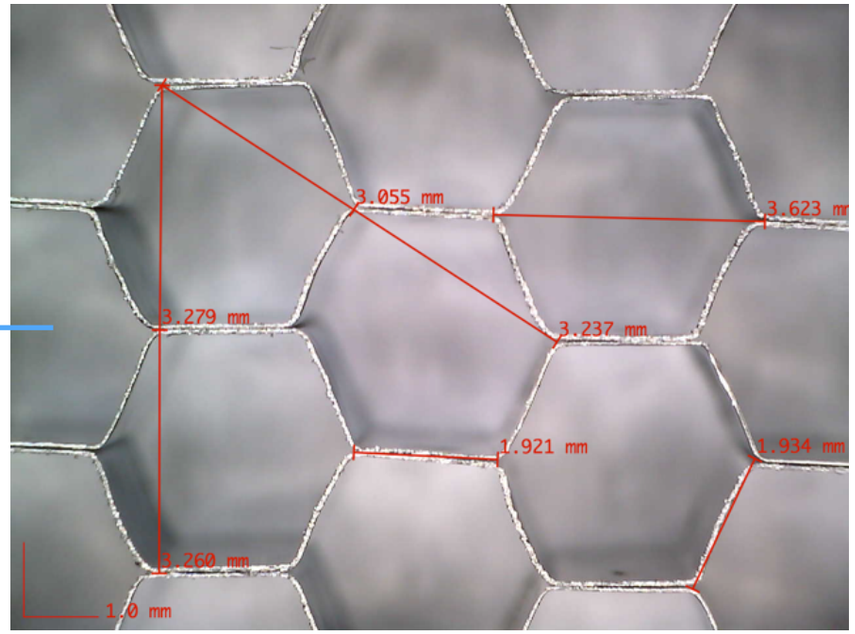
Silicon bias wire between chips



Silicon bias wire attached to (non-metalised) silicon sensor with conductive glue



proton beam

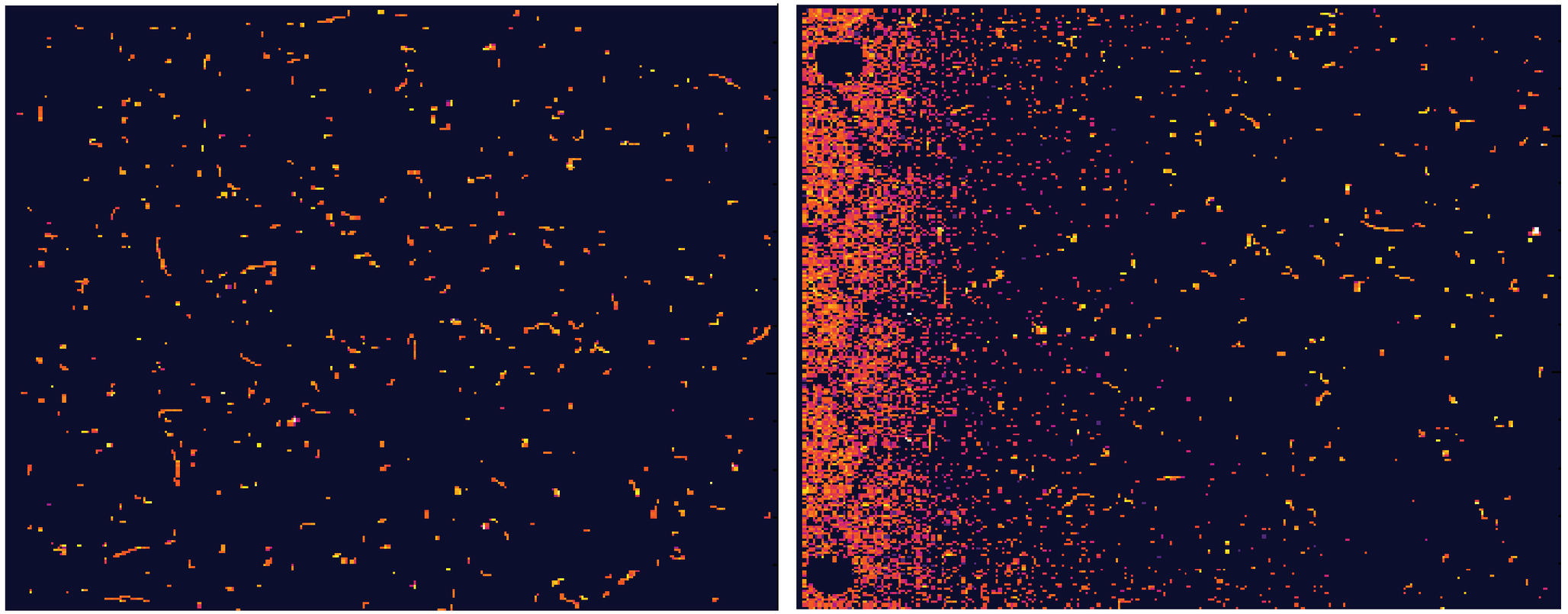


Honeycomb structured RF shield

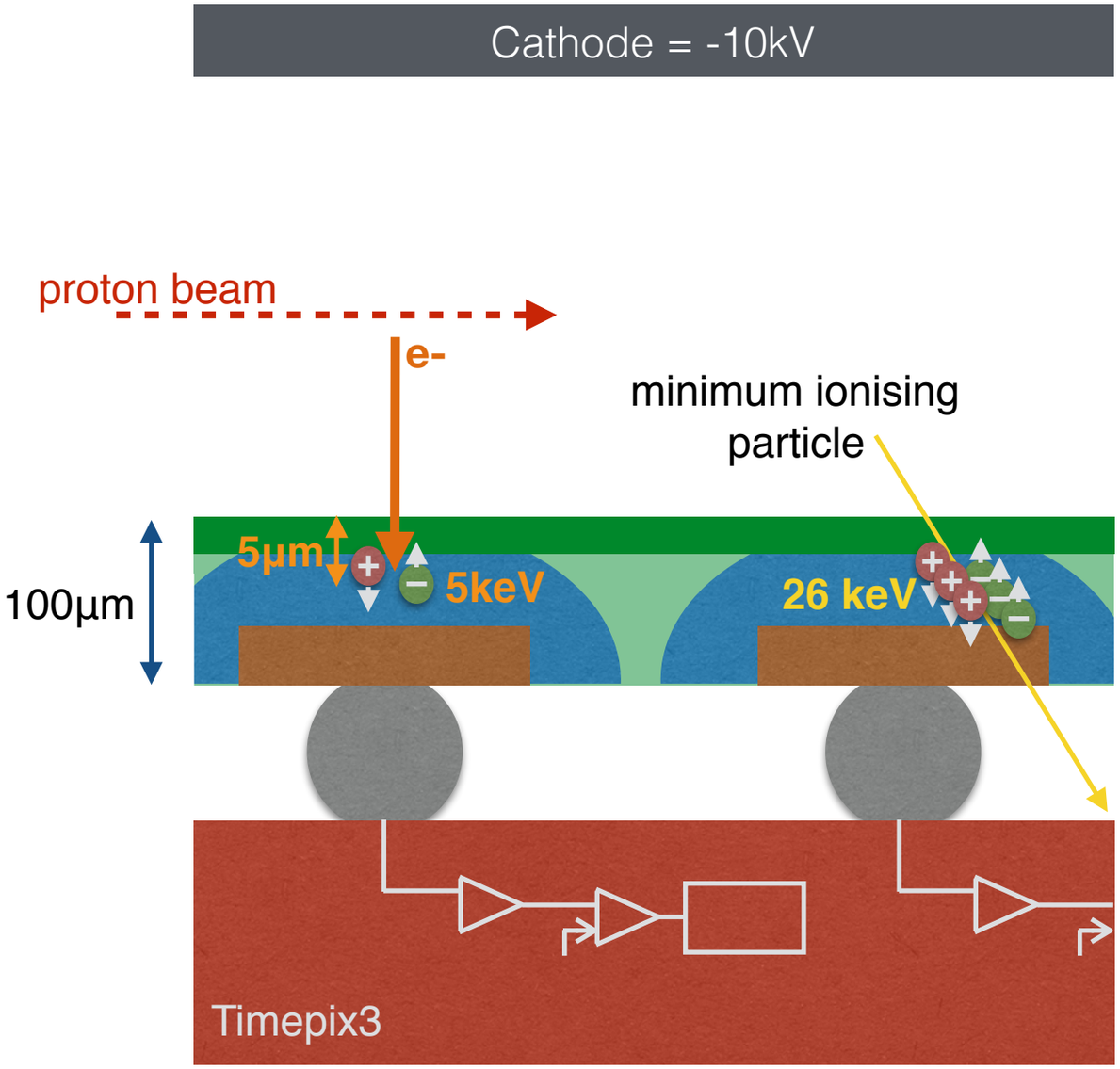
Detection of rest gas ionisation electrons.

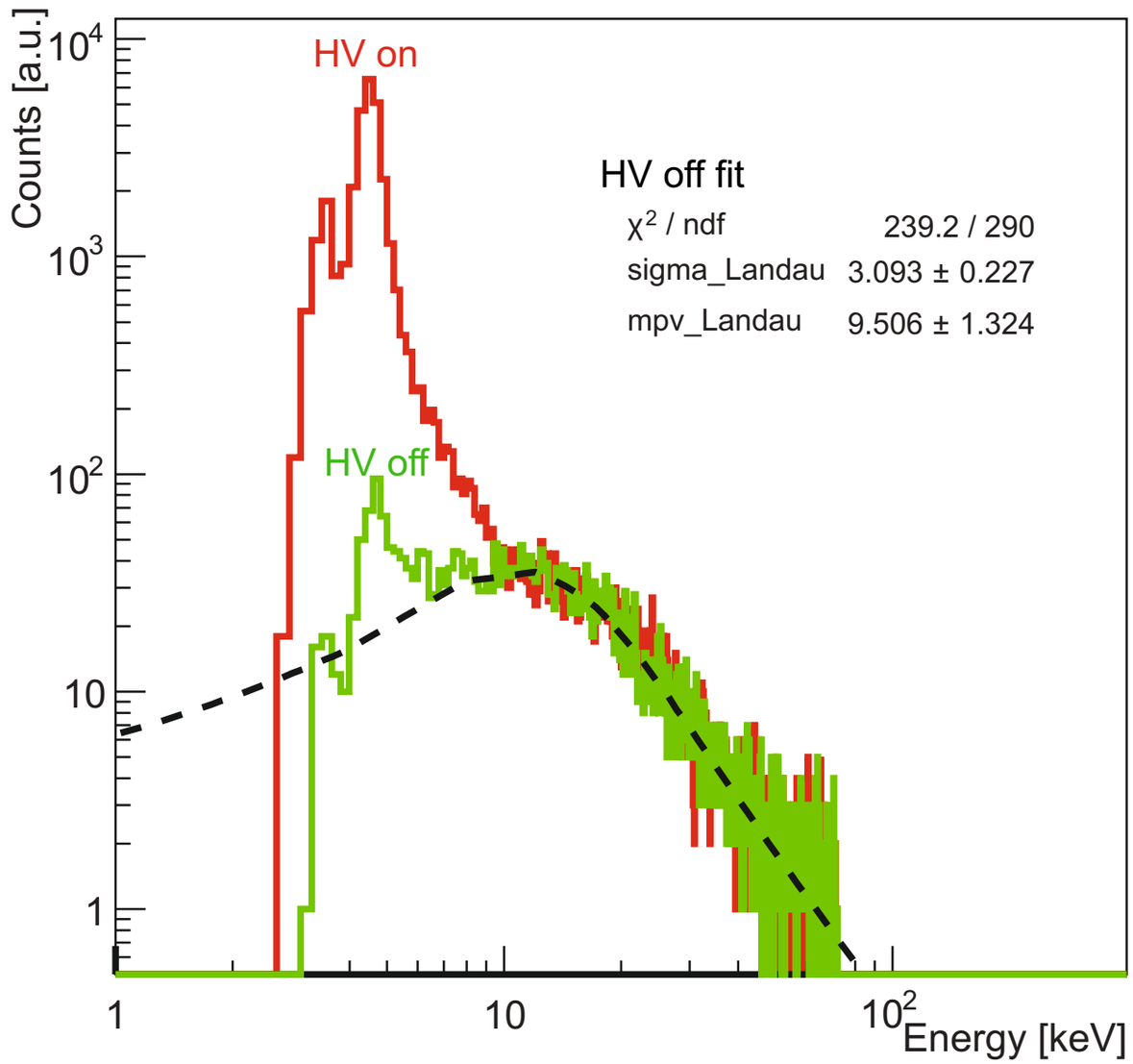
HV off

HV on



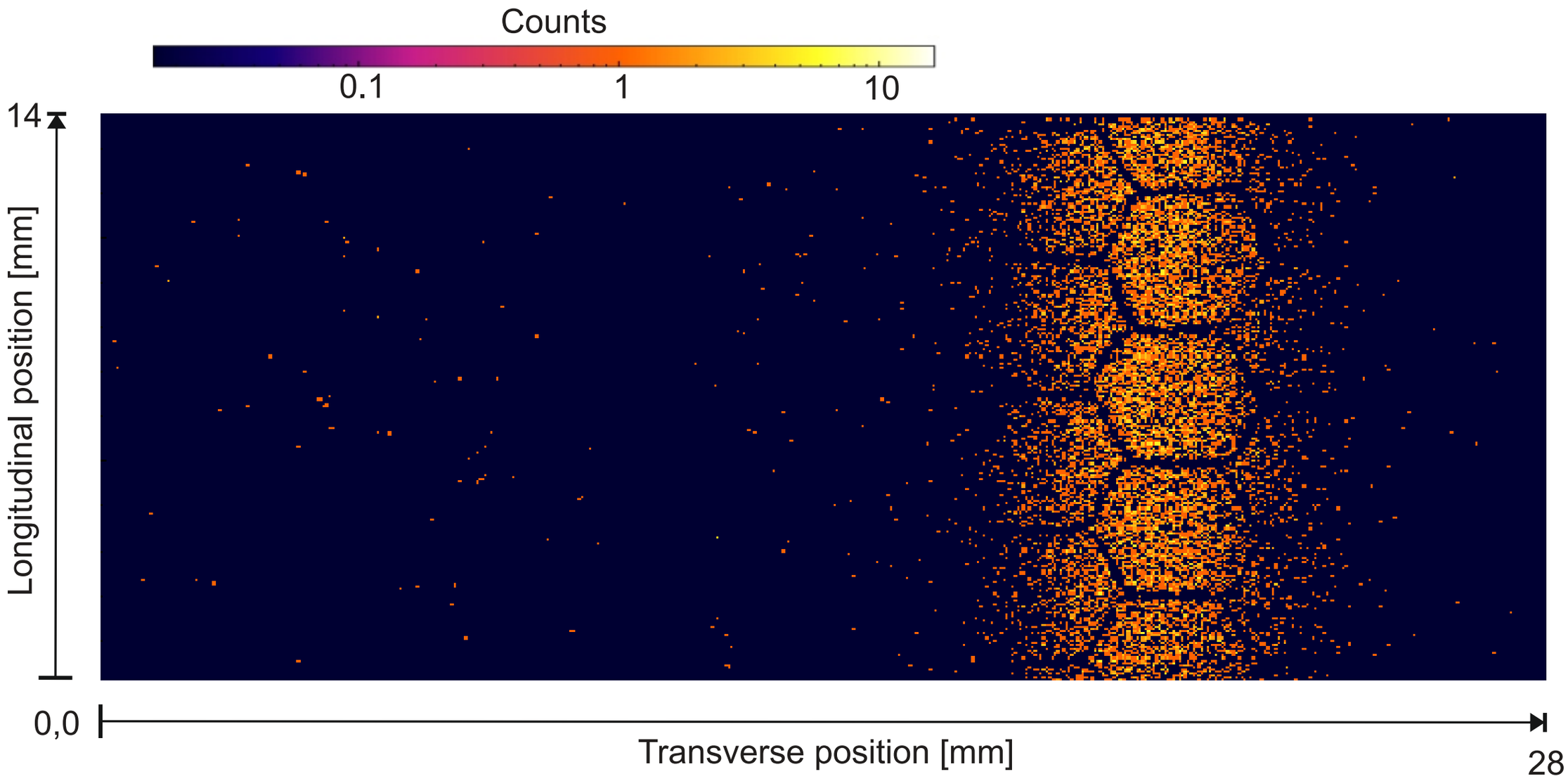
Detection of rest gas ionisation electrons.





Successful detection of rest gas ionisation electrons!

Image of LHC cycle in the PS at flat top.



Continuous acquisition for 10 ms at extraction energy (25 GeV).

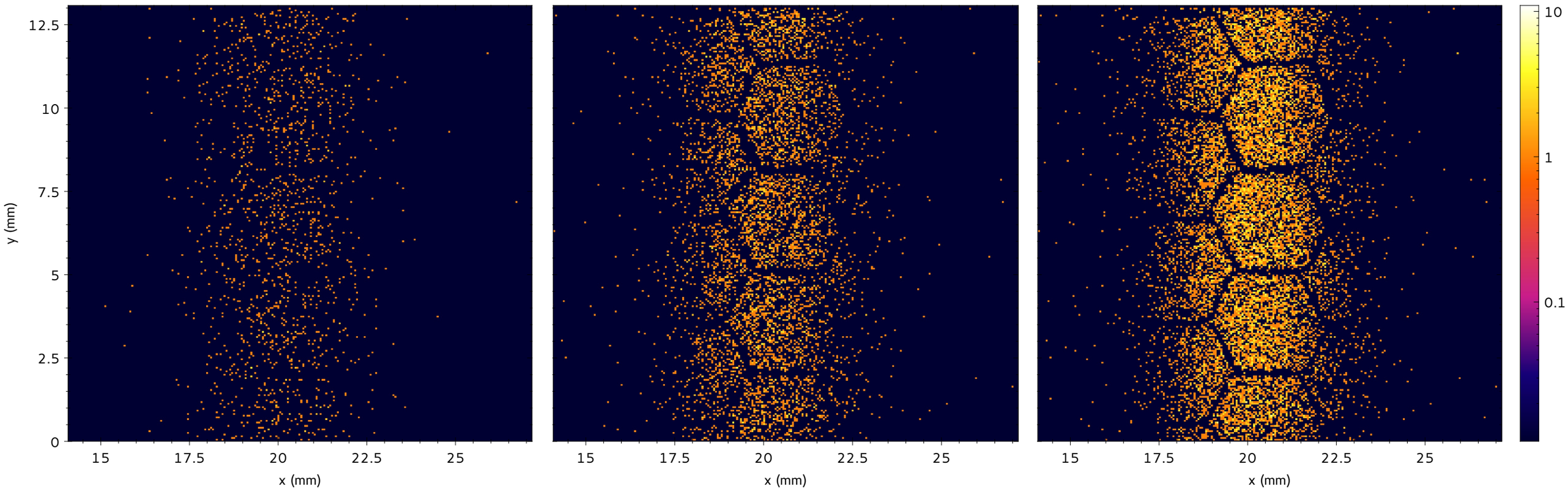
Image of LHC cycle in the PS at flat top.

Offline integration of the data (time resolution of each count = 1.5625ns)

2ms window

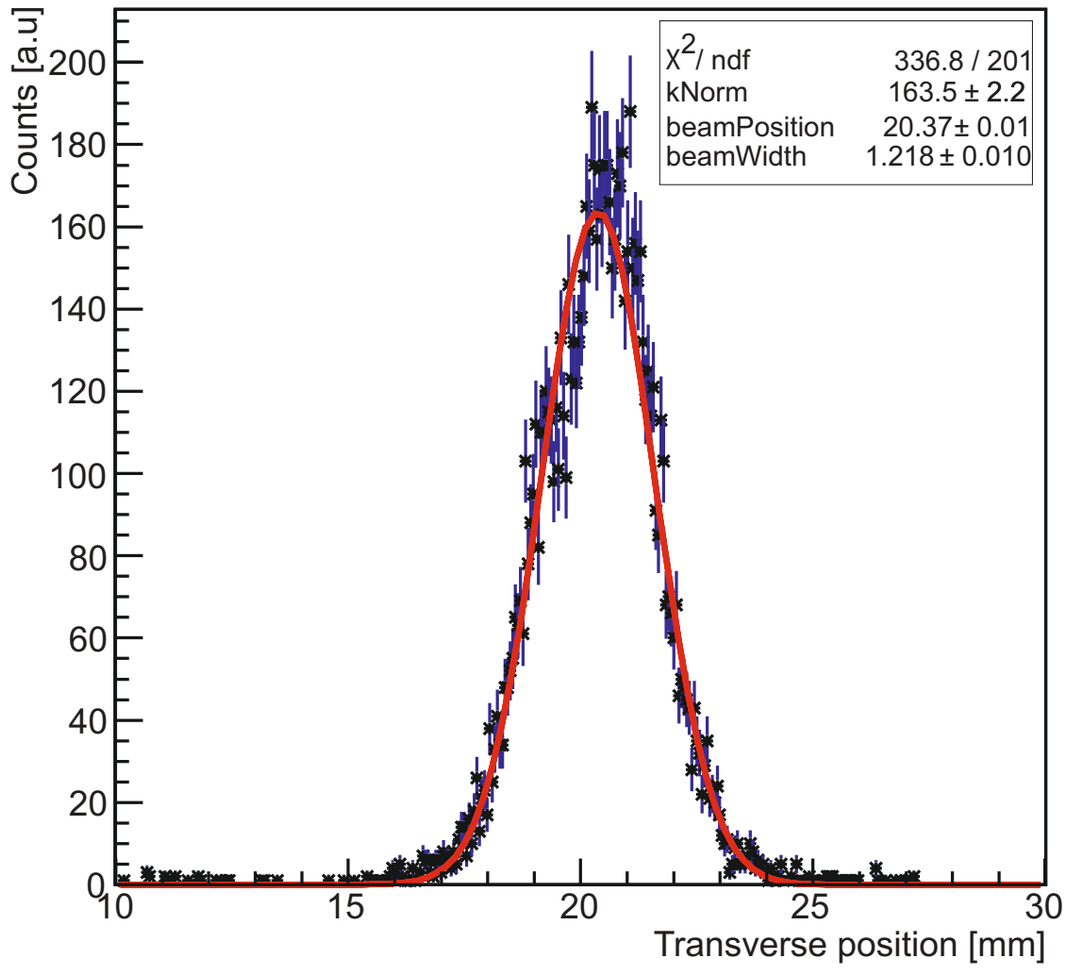
5ms window

10ms window



Beam profile measurement of LHC cycle in the PS at flat top (25 GeV).

2ms window



Ionisation profile monitor:

beam width = 1.22 ± 0.01 mm

Wire scanner:

beam width = 1.20 ± 0.01 mm

Beam profile measurement in very good agreement with wire scanner measurement!

Summary and outlook.

- A rest gas ionisation profile monitor has been successfully installed in the CERN PS which, for the first time, uses a **hybrid pixel detector directly inside in the ultra high vacuum of the beam pipe.**
- The pixel detector has been **successfully operated during the acceleration cycle** and used to **detect rest gas ionisation electrons.**
- **The first beam profile measurements are consistent with wire scanner measurements.**

- Next steps: exploit the unique characteristics of the pixel detector technology to improve the accuracy of the beam profile measurement and to minimise the number of turns needed to measure the profile of a single bunch.

Acknowledgements

Thanks to Michael Campbell, Xavi Llopart Cudie and Jerome Alozy from the CERN Micro-electronics group for expert help with the TImepix3 chip.

Results are dedicated to the memory of Bernd Dehning, who initiated the project, but sadly passed away earlier this year.