CERN

Current status of the Cern PS Beam Gas Ionization Profile Monitor

Swann Levasseur (BE-BI-BL) on behalf of the PSBGI team
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Before I go further

Beam Gas Ionization profile monitor (BGI) = Ionization Profile Monitor (IPM)

Outline

- Project Context
- Requirement and Specifications
- Timepix3 Hybrid Pixel Detector
- Current Design
- First Data with the horizontal prototype
- Conclusion

Project Context

Context : LHC injector upgrade (LIU) PS

Goal : Install two BGIs in PS (Vertical, Horizontal)

Background:

- Project start, sometime in 2014
- Design Horizontal prototype, 2014 - Beginning 2017
- Installation Horizontal prototype, March 2017
- First Data, May 2017 (last week)

Requirement and Specifications

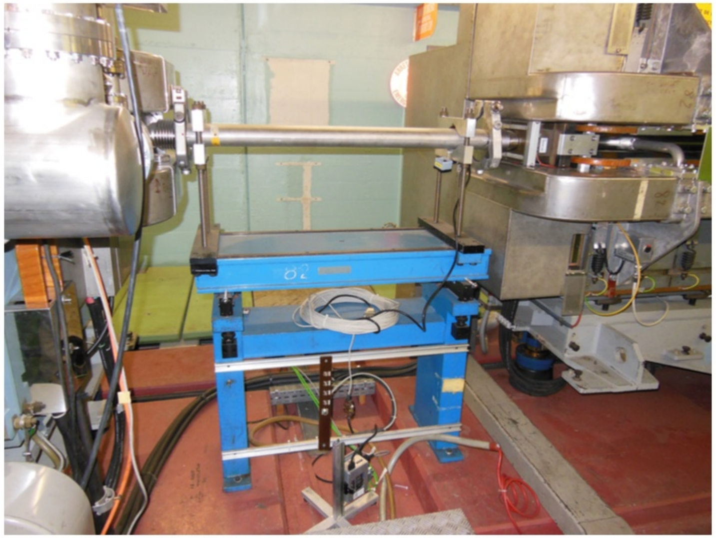
Transverse profile measurement with 1% relative error

- Integrated profile @ 1Khz
- Continuous Bunch by bunch measurement for 10ms (5000 turns)
- One Profile / Bunch / Turn (Difficult to achieve)

Typical beam and environment constraints

- LHC Beam :
  72 Bunches, 25 ns spacing,
  13 E10 p/bunch,
  3σ = 3.7mm (hor) @ 25 GeV
- Vacuum :
  Pressure in the 10^{-8}/ 10^{-9} mBar
- Radiation :
  10 kGy/yr @ contact
  1 kGy/yr @ 40cm

Straight Section 82 (SS82)



80 cm

Timepix3 Hybrid Pixel Detector (HPD)

Hybrid pixel detector

Pixelated Readout chip (CMOS) bonded to Pixelated Sensor (doped semi-conductor)

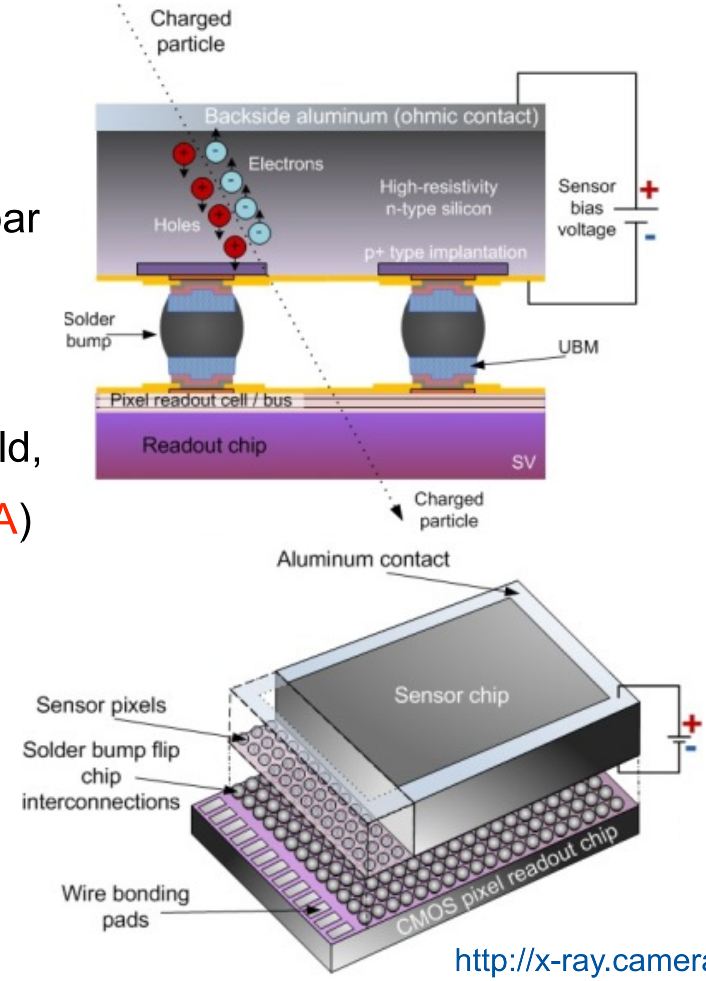
Core concept (with TPX3)

1. Energetic particle creates e^{-}/h^{+} pair in the sensor
2. The bias applied to the sensor forces the e^{-}/h^{+} pair apar
3. e^{-} or h^{+} are collected by the pixels of the readout chip (capacitor charge)
4. If the number of e^{-}/h^{+} is higher than a defined threshold, the Time over Threshold (ToT) and Time of Arrival (ToA) are recorded
5. The ToT, ToA and pixel position are packaged and sent out of the readout chip.

   ToT = Charge (energy)

   ToA = When

   Pixel Position = Where

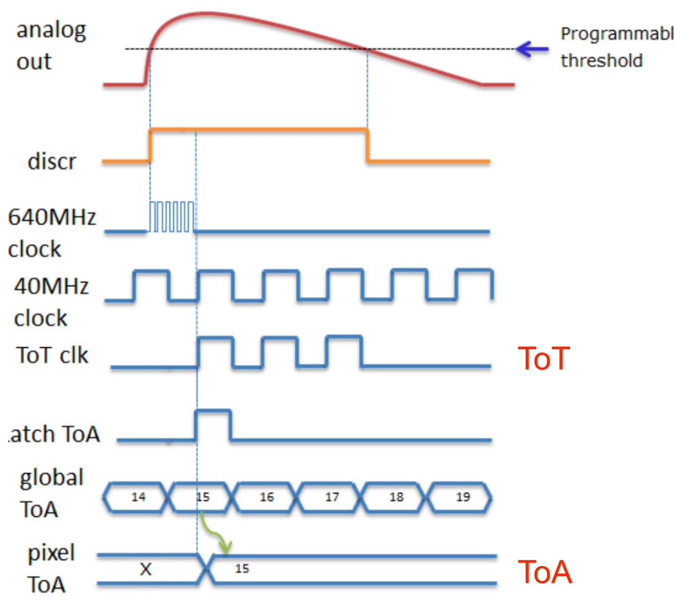


http://x-ray.camera

Timepix3 Hybrid Pixel Detector (HPD)

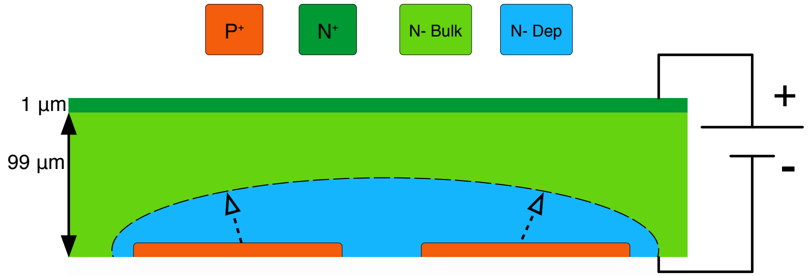
Readout chip => Timepix3** (medipix.web.cern.ch)

- 256 * 256 pixel matrix (65536 pixels)
- Pixel size : 55 µm * 55 µm
- ToA time resolution : 1.5625 ns (640MHz)
- Minimum threshold ≈ 500 e$^-$ (1.8 keV*)
- Max hit/s : 80 Mhit/s (1200 Frame/s)
- Output bandwidth : Up to 8 * 640 Mbps
- Acquisition controlled by a shutter
- Data-Driven readout or Frame Based readout



Sensor

- Silicon
- Non-metallized
- 100um thick
- P in N type => collect h+
- Bias voltage 10 - 20V



P on N sensor with partial depletion

* Assuming no charge sharing and no energy loss

**http://iopscience.iop.org/article/10.1088/1748-0221/9/05/C05013/pdf

Instrument Design and Realization

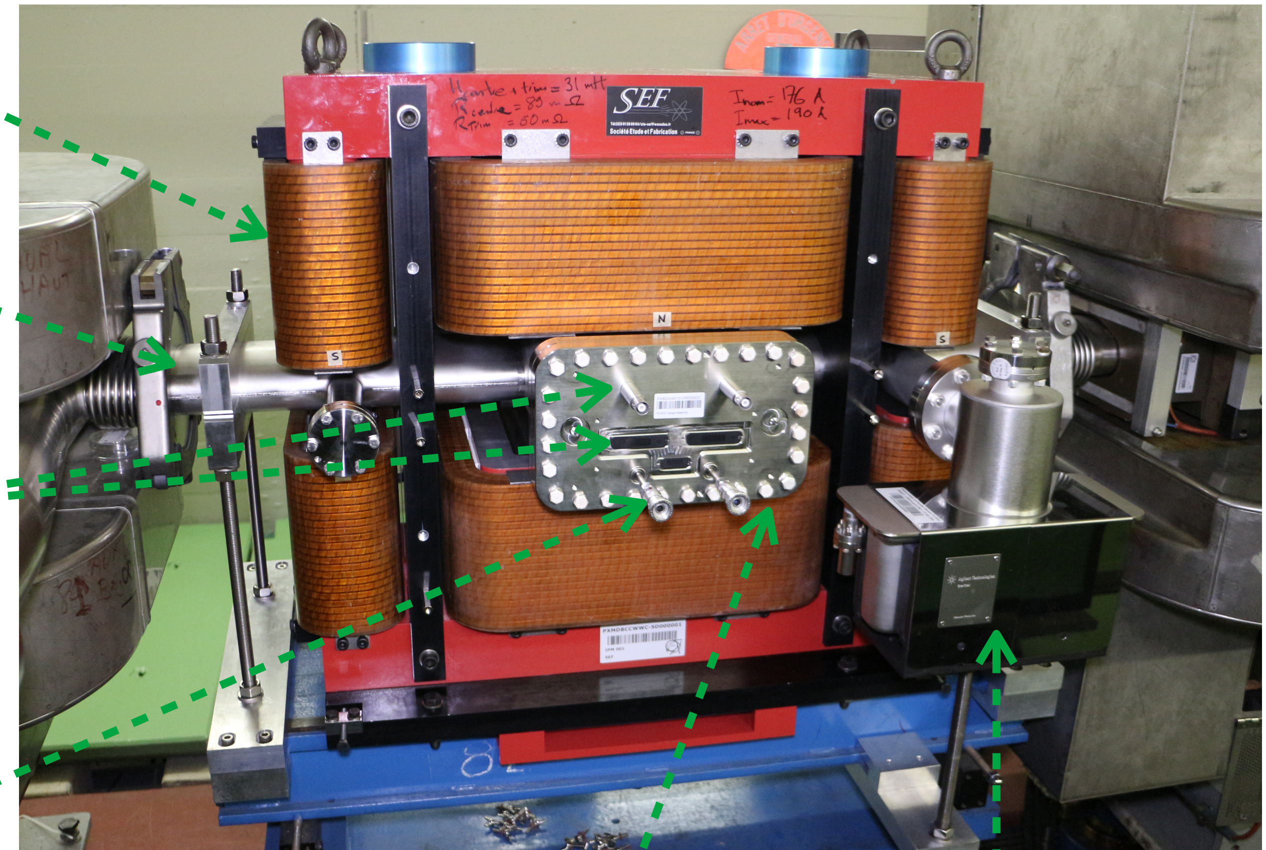
SS82 after installation

PS Magnet
(0.2 T)

BGI Vacuum
chamber

High voltage,
Signal
Feedthrough

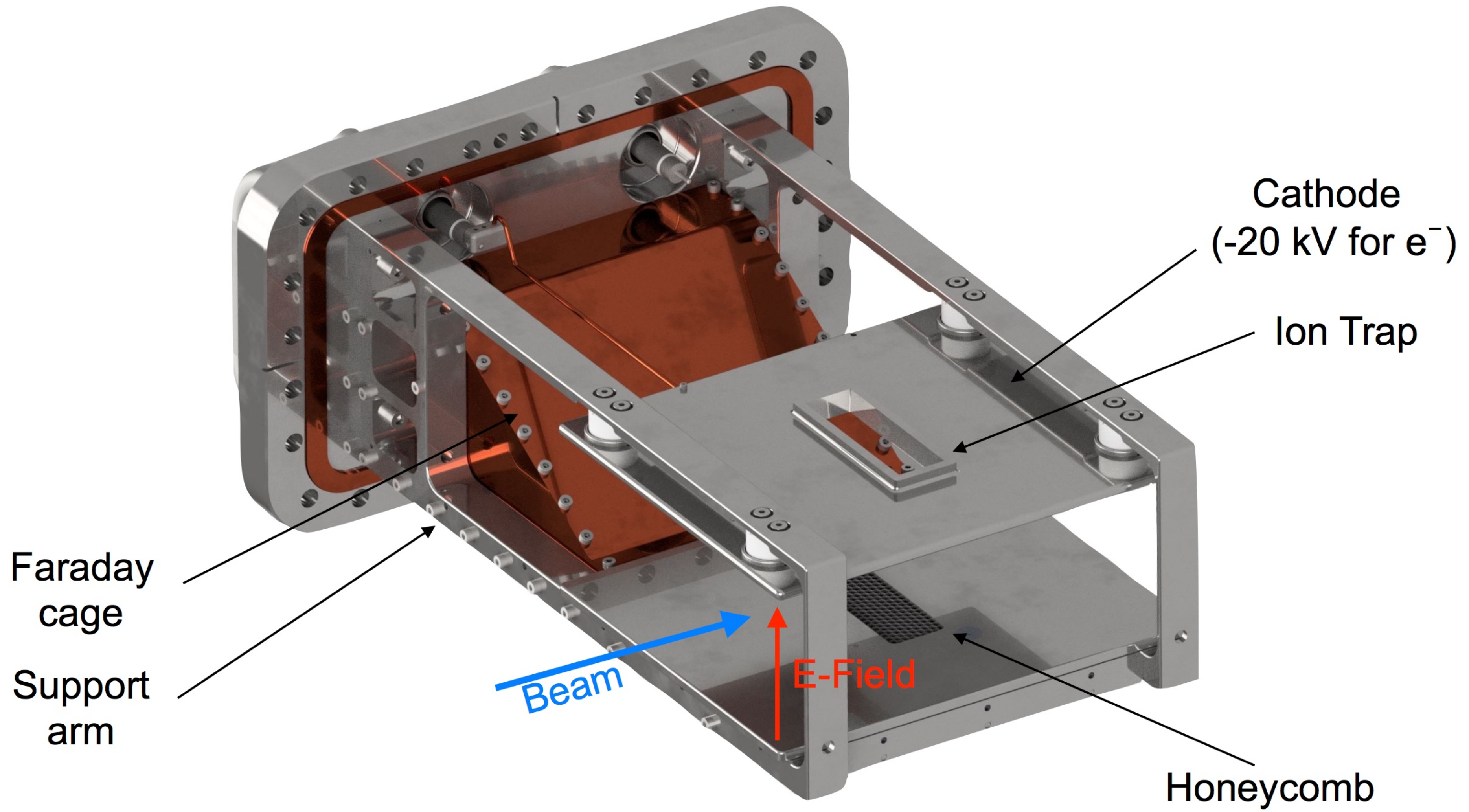
Water cooling
connections



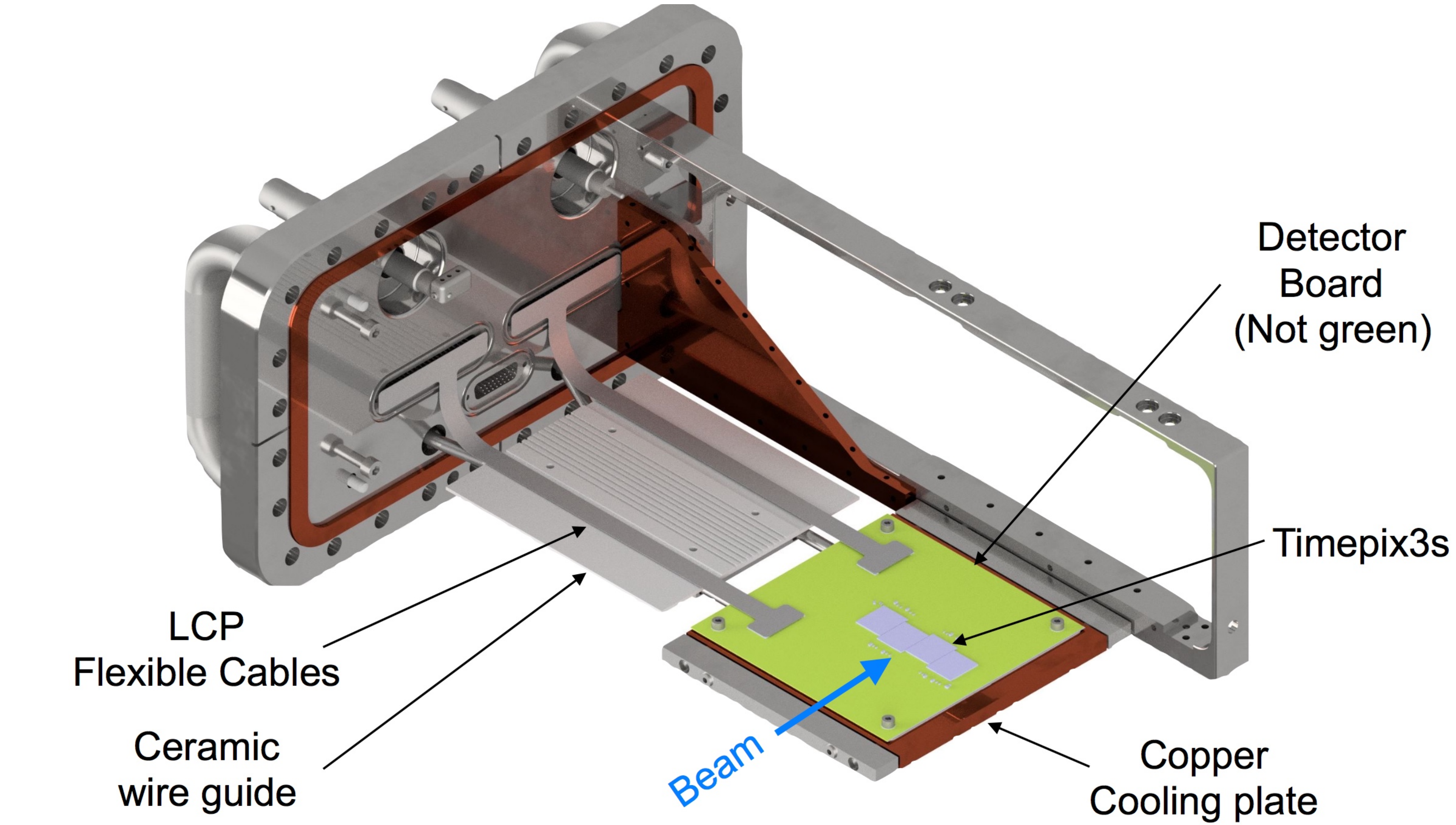
BGI Flange

Ion Pump

Instrument Design and Realization



Instrument Design and Realization



Instrument Design and Realization

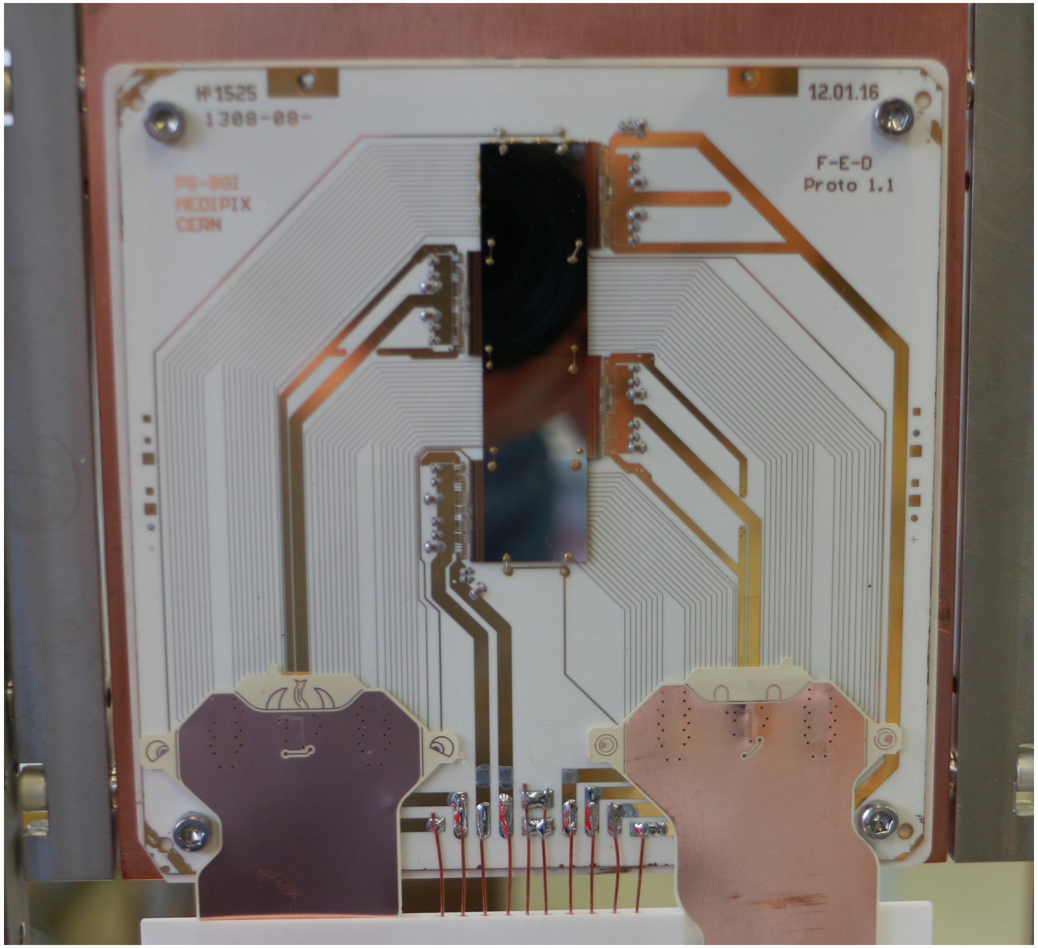
TPX3 based Detector

Pixel detectors:

- 4 TPX3 assemblies
- Full readout
- Independent power and data-in

Carrier board:

- 2 metal layer, Al_2O_3 substrate, no solder mask
- Manufactured and assembled by Hightec (ch)



Signals:

- 100 ohm differential Impedance

WireBond:

- Wedge-wedge aluminum
- Bias: Hand placed gold wire, secured with conductive epoxy

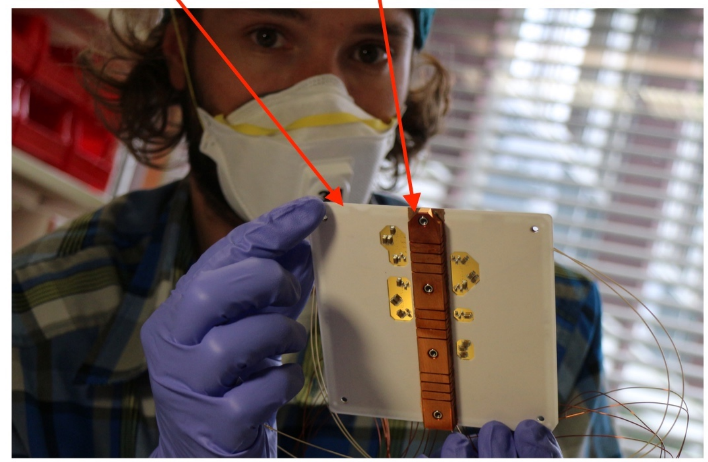
Instrument Design and Realization

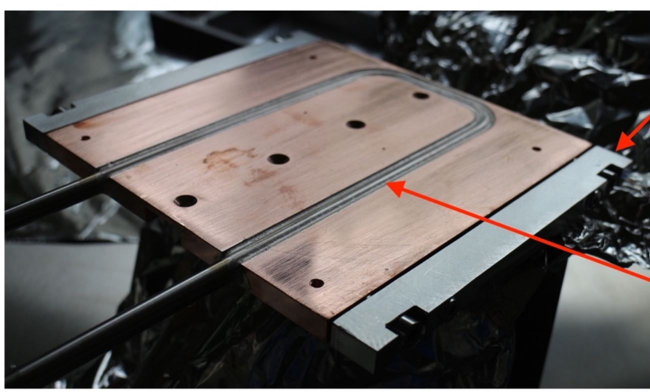
Cooling system

- Each TPX3 need 1-3W power / cooling
- Cooled with room Temperature water (system maintained at 70 to 90 degC)
- Foreseeing the use of “chilled” water at some point.

Copper brazed to ceramic support

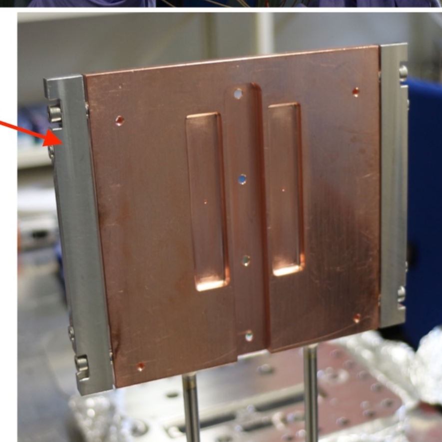
Ceramic support





Intercooler

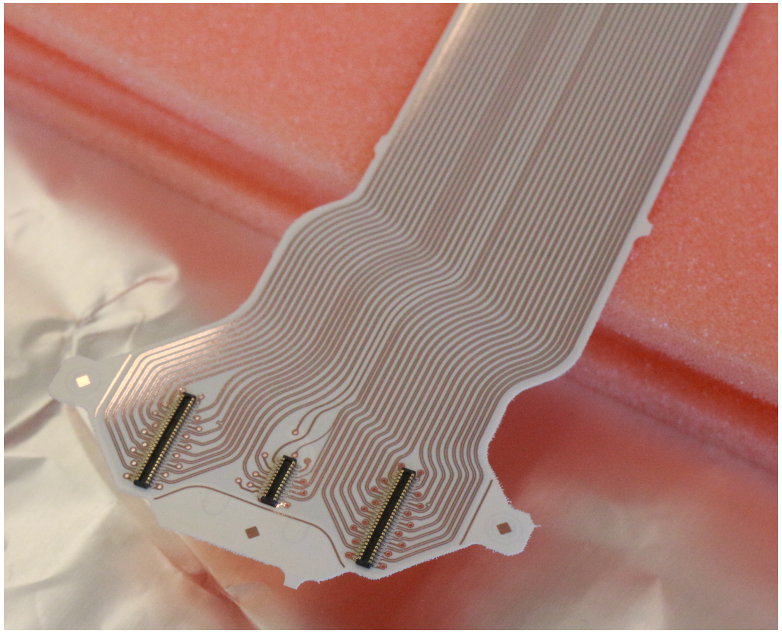
Steel pipe brazed to cooling plate

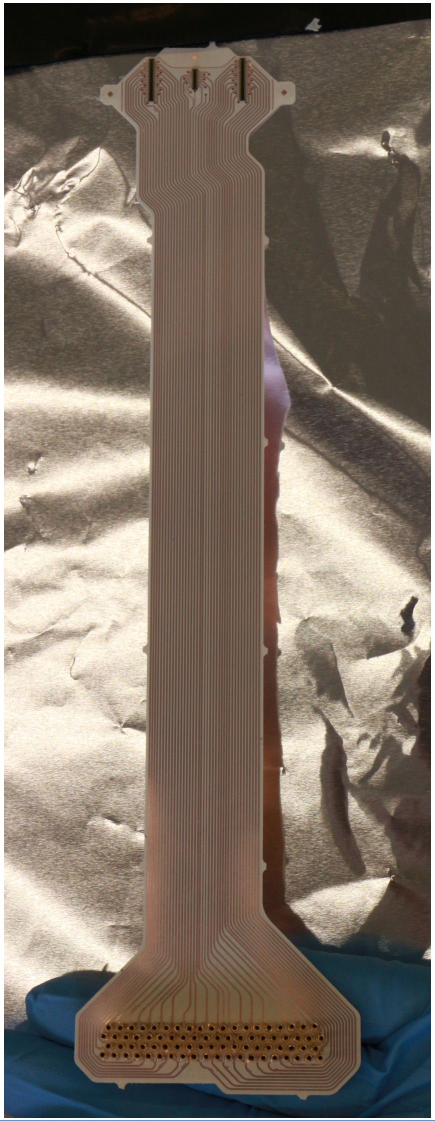


Instrument Design and Realization

Flexible cables

- Connect the Ceramic to the flange
- 2 copper layers with a LCP dielectric
- Produced at CERN
- Tested for UHV by CERN

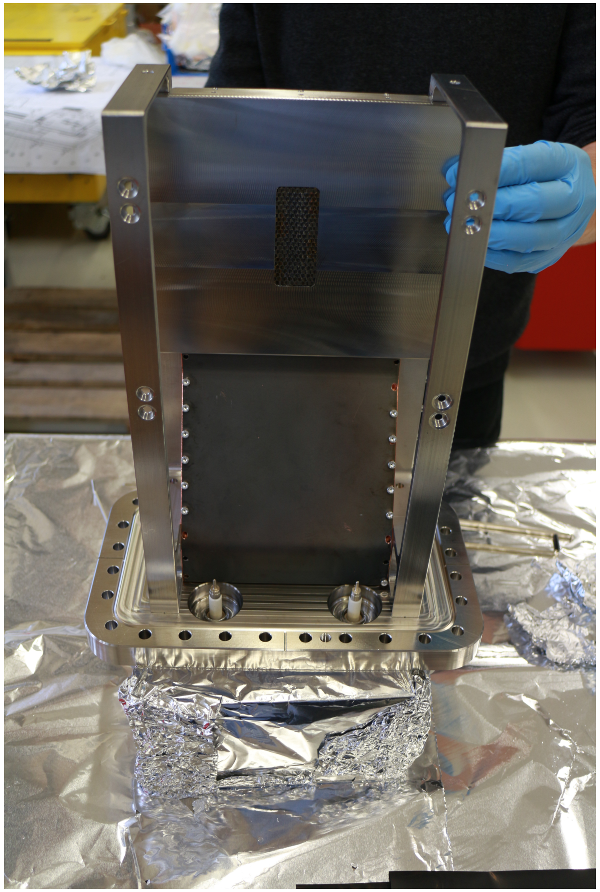




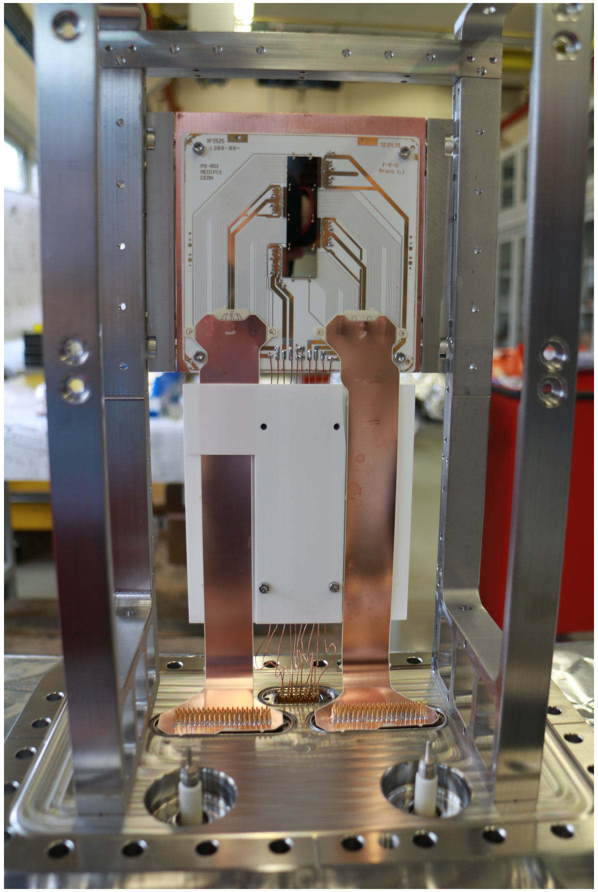
Instrument Design and Realization

Assembled system

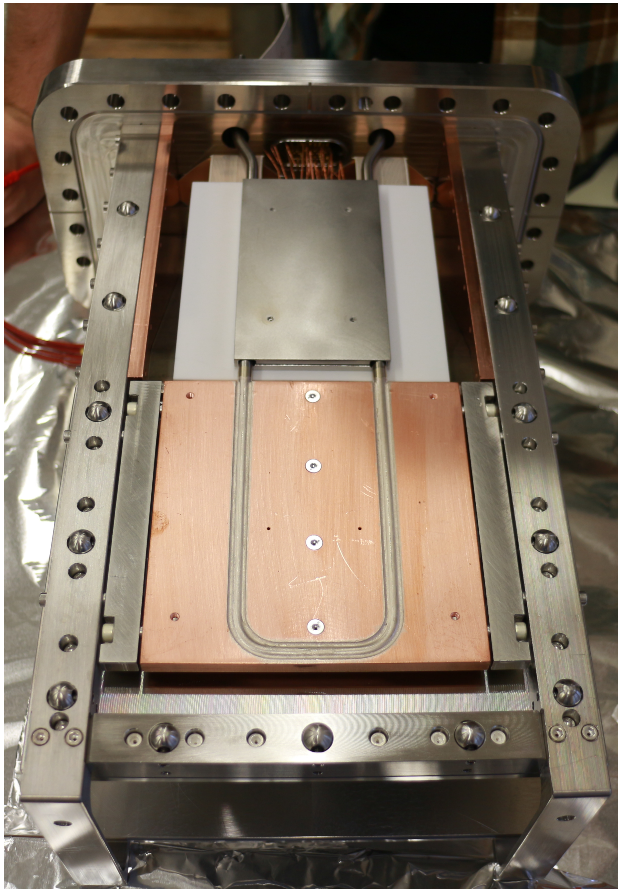
Top-side faraday cage



Top-side detector



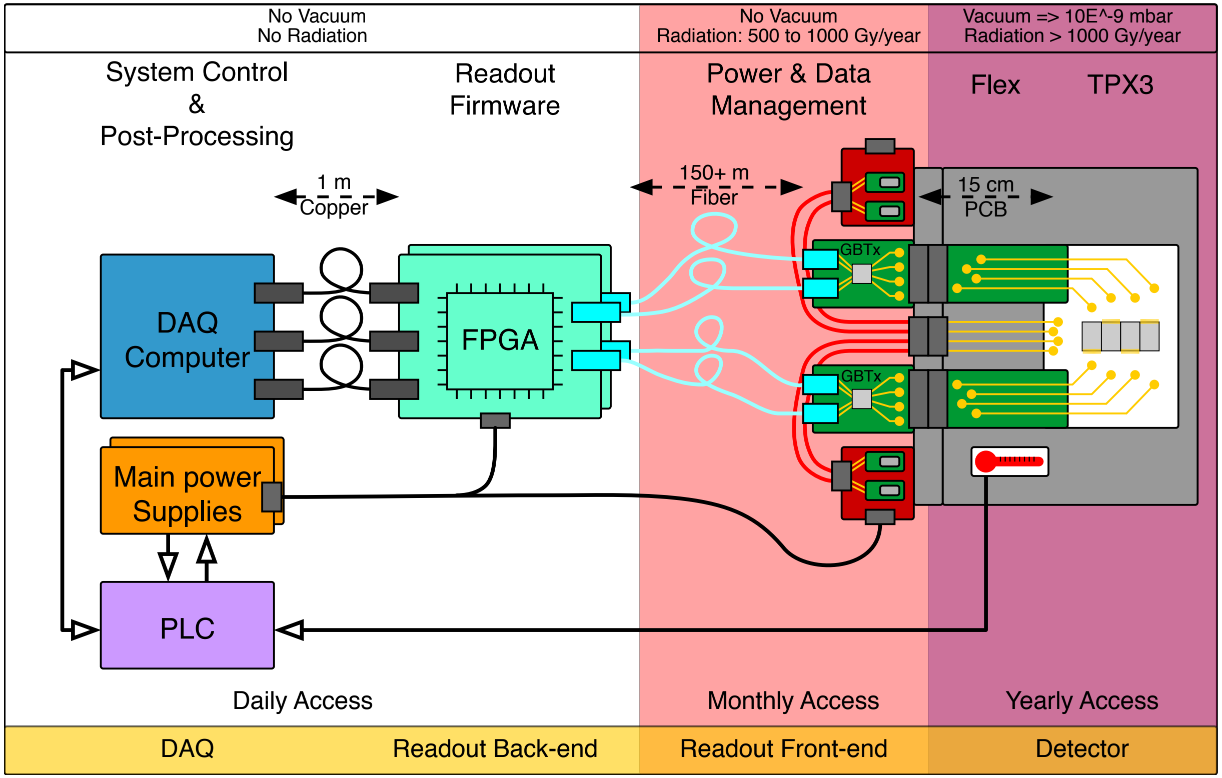
Back-side faraday cage



Instrument Design and Realization

Readout system

- GEFE FPGA front-end (TPX3 to Optic)
- Virtex7 FPGA back-end (Buffer + Optic to Ethernet)
- Linux back-end Computer (Control and DAQ software)
- Subsystem controlled by PLC



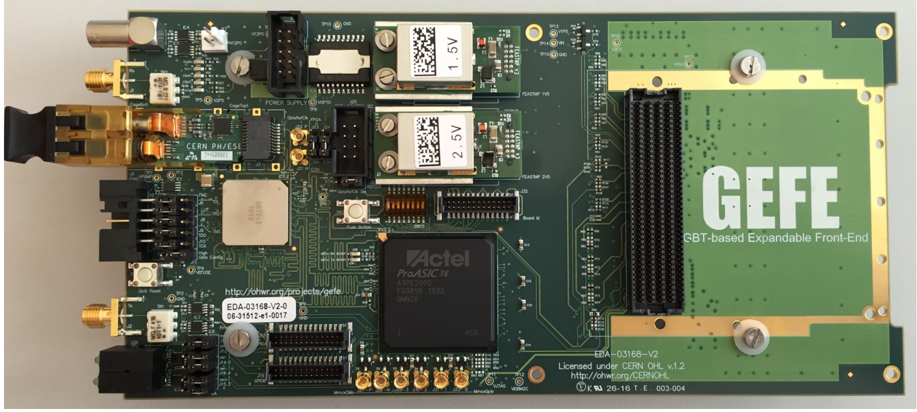
Instrument Design and Realization

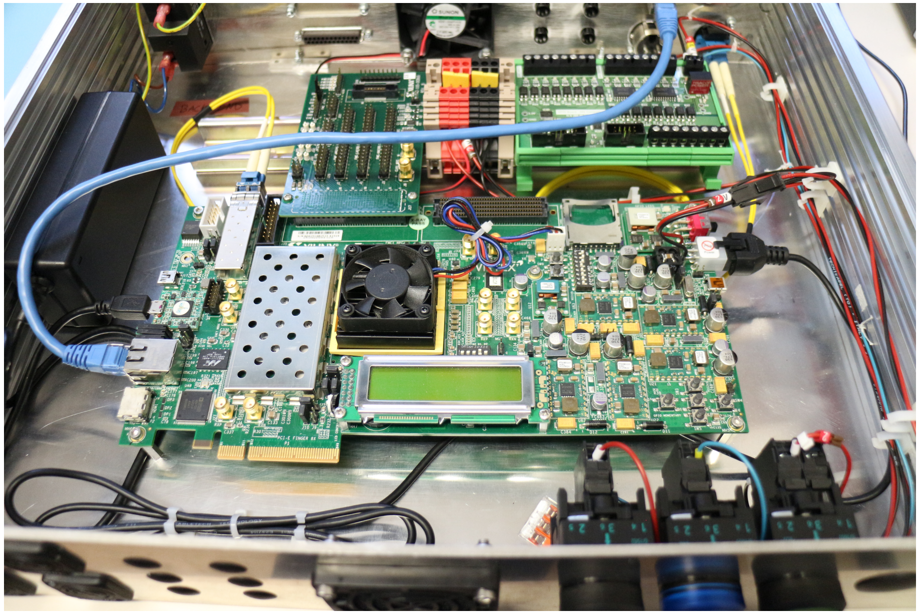
Readout system - Front End

- Rad hard up to 750 Gy
- GBTx + VTRx transceiver
- MicroSemi Pro Asic3 FPGA
- “WaterBear” firmware (Triplicated logic, 2.5 Gbps uplink)
- TPX3 with 4 * 8 * 80 Mbps

Back End

- VC707 with “PolarBear” firmware
- IP-Bus (FPGA to DAQ computer)
- Gigabit Ethernet connection to DAQ
- Injection / Extraction trigger





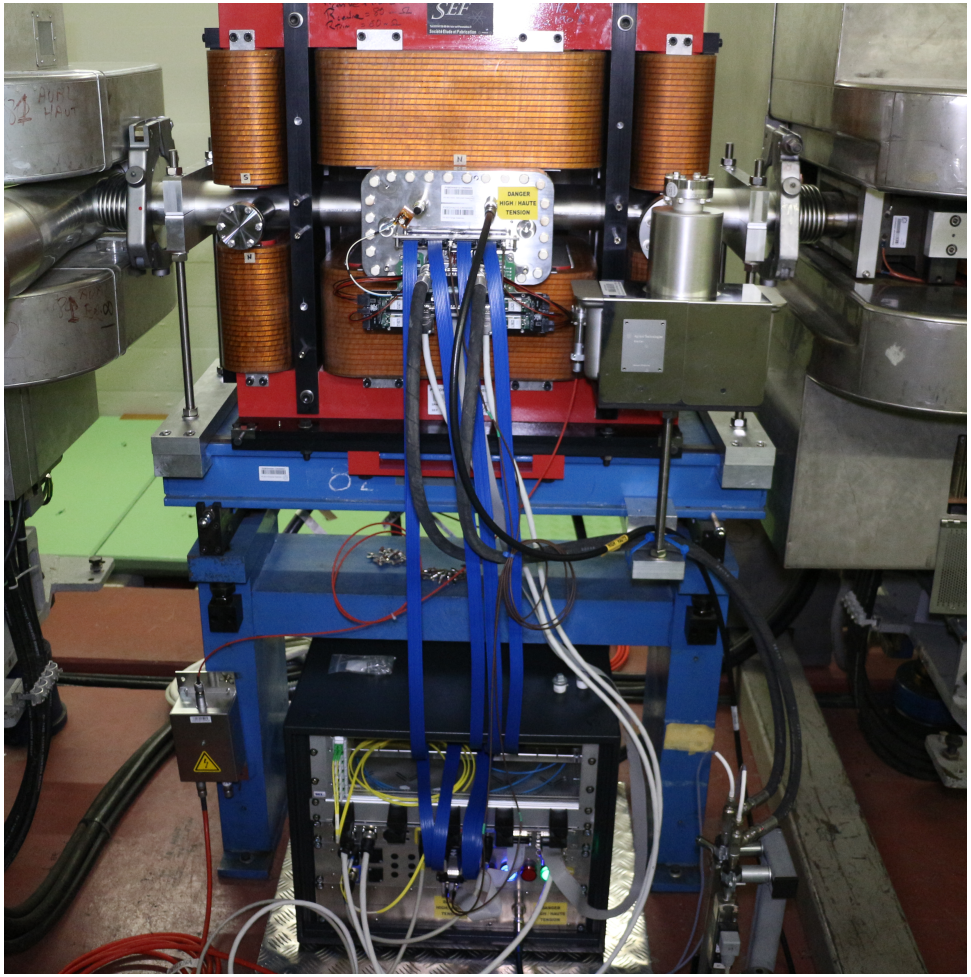
Instrument Design and Realization

Installation in SS82

- High speed signal (blue cables)
- Slow control and power (white cables)
- Water inlet/outlet (Black tubes)
- High voltage (Black cable)

Front-end Rack

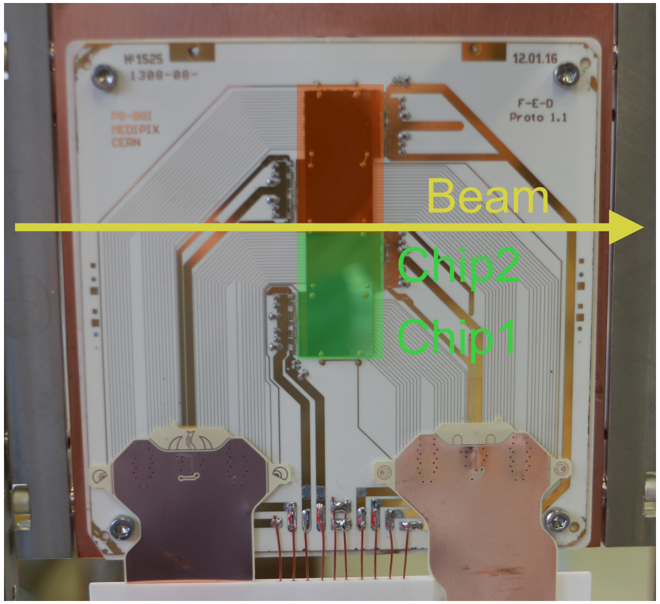
- Patch panels (Copper, optic, HV, Power)
- Front-end FPGA (GEFE)



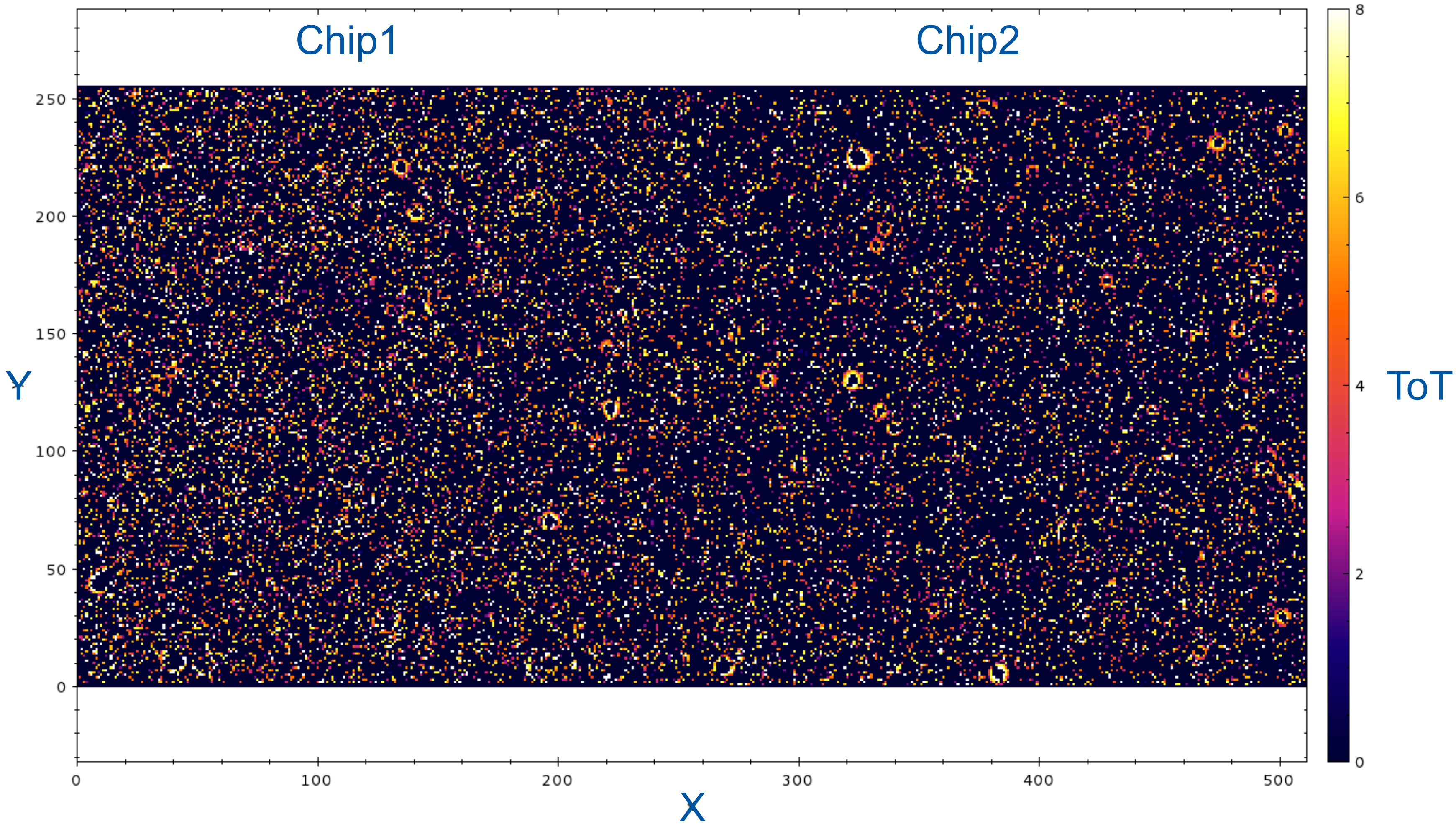
First Data

Current Setup

- All take shown here are taken with the MTE-OP-2016 beam
    - Total intensity 1200 e10 P+, wide beam
- High voltage => -10 kV
    - Ionization e- => 5 keV @ TPX3
- Sensor bias voltage => 10V
- Only two TPX3s are operational (Chip1/2)
- The threshold is set to 780 e- ≈ 2.8 keV
- We do not have an energy calibration yet
    - ToT is in 40 MHz clock cycle
    - 5 keV ≈ ToT 5-10 (based on prior experience)



First Data - ToT - No HV - 665 ms shutter

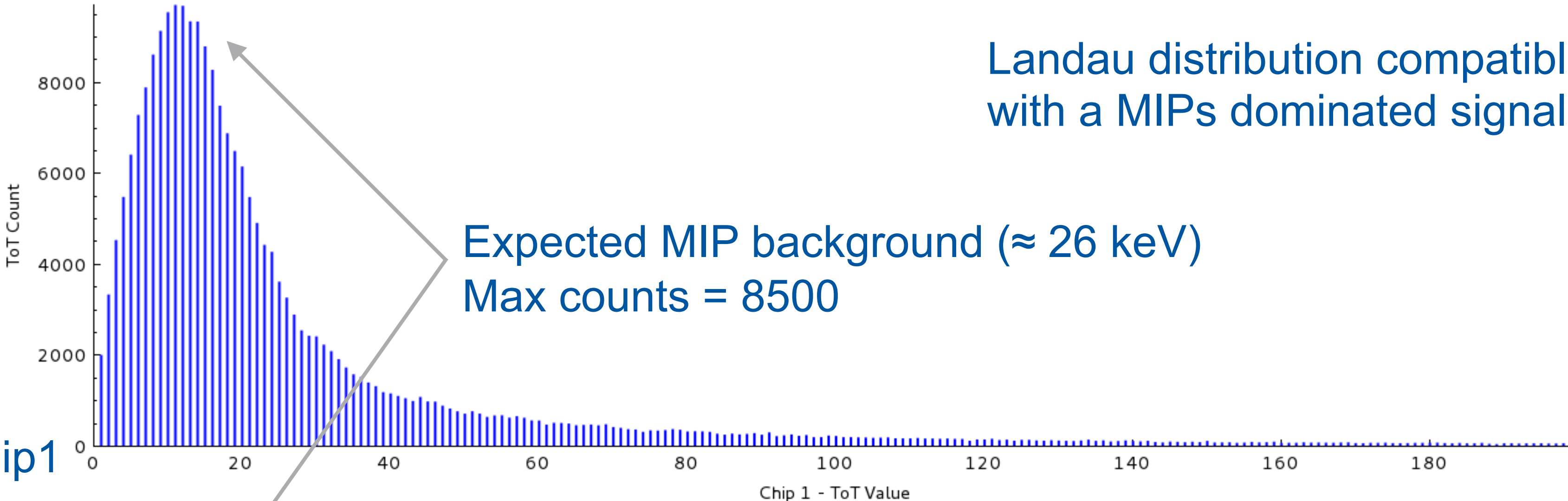


Homogenous background = Activated material + Beam loss

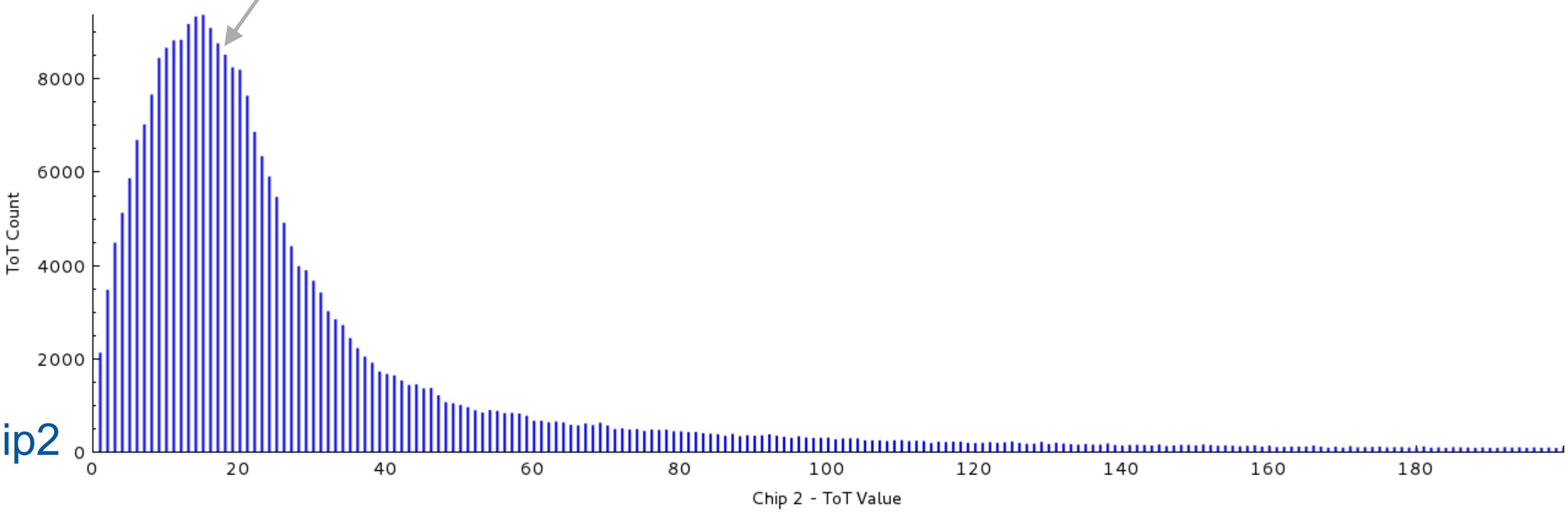
First Data - ToT Hist - No HV - 665 ms shutter

Landau distribution compatible
with a MIPs dominated signal

Expected MIP background (≈ 26 keV)
Max counts = 8500

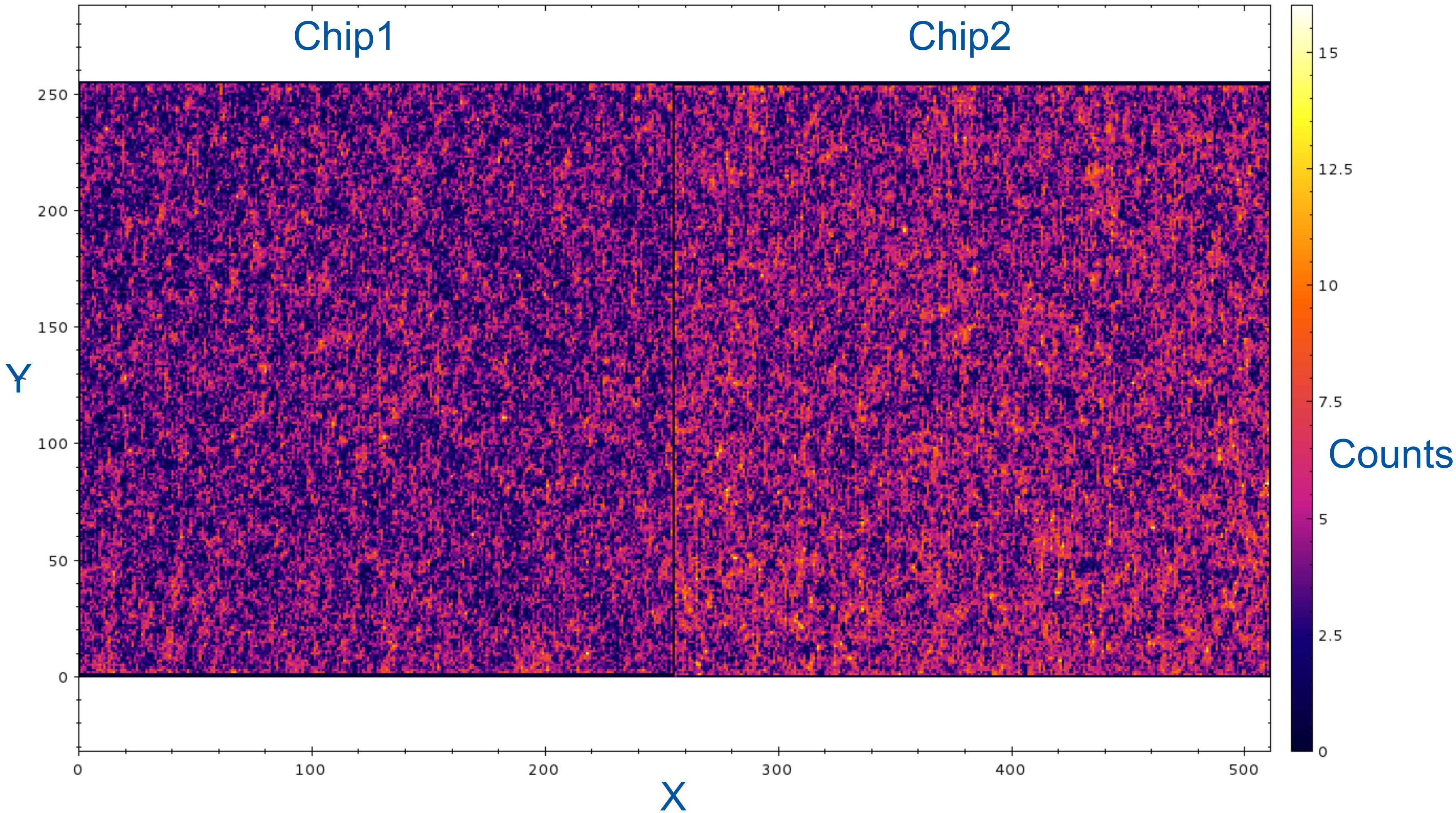


Chip1



Chip2

First Data - Counts - No HV - 665 ms shutter

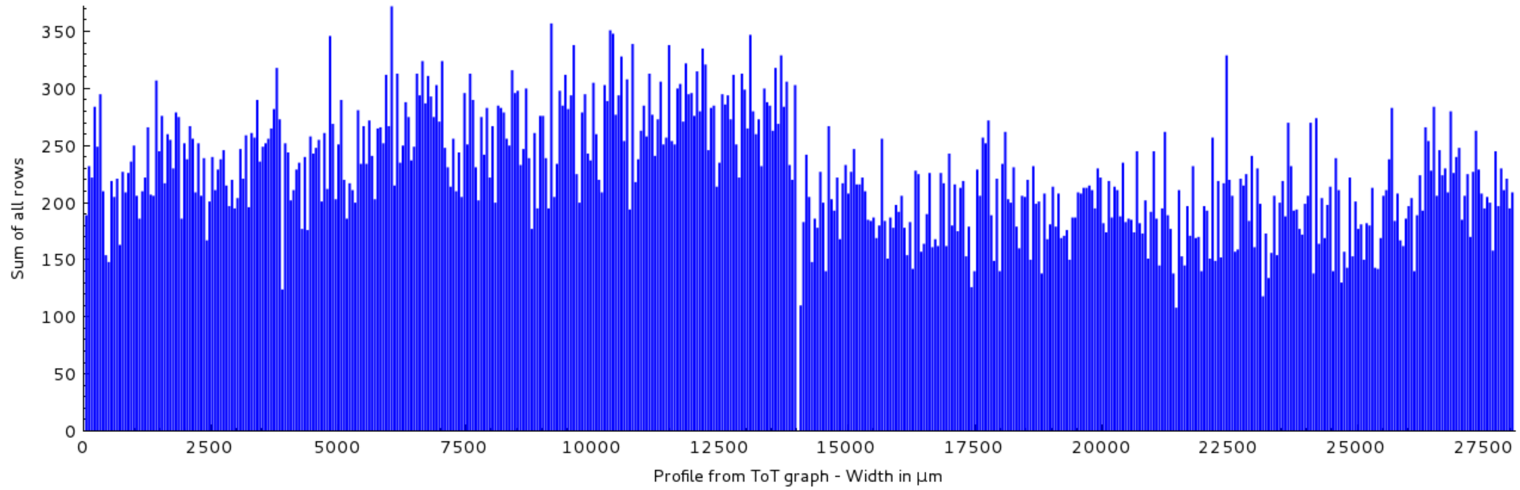


Homogenous background = Activated material + Beam loss

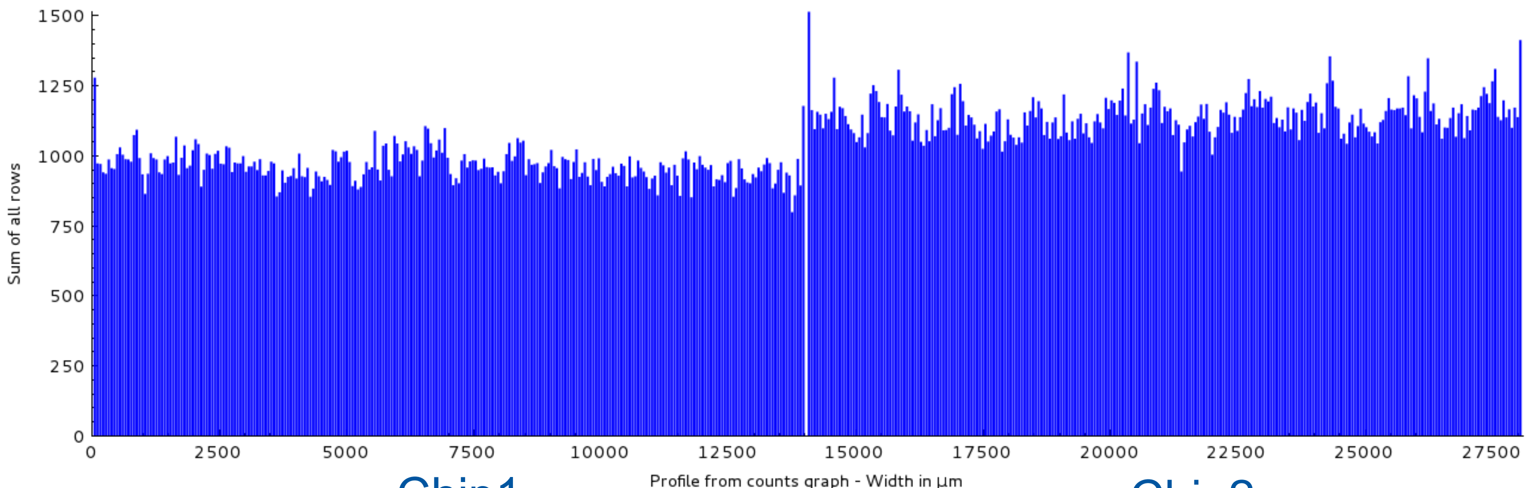
First Data - “Profile” - no HV - 665 ms shutter

Integrated over the Y axis

Energy



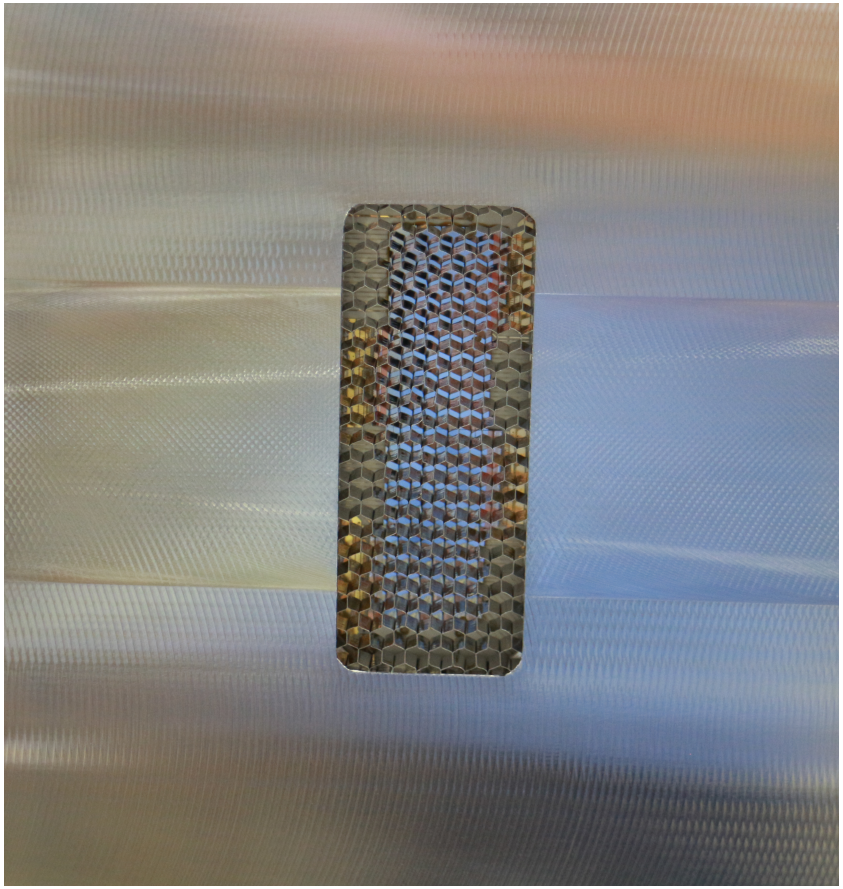
Counts

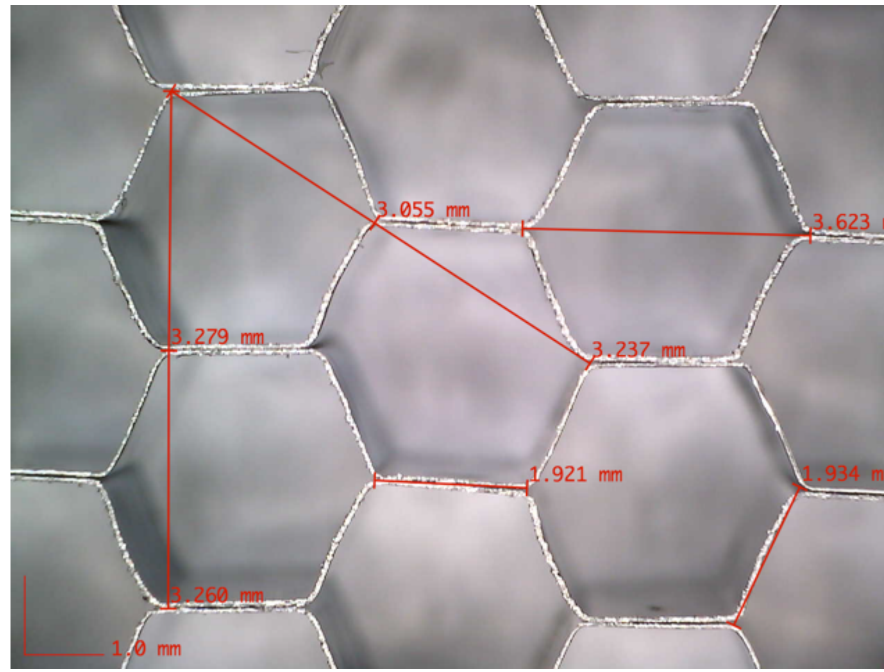


Chip1 Chip2

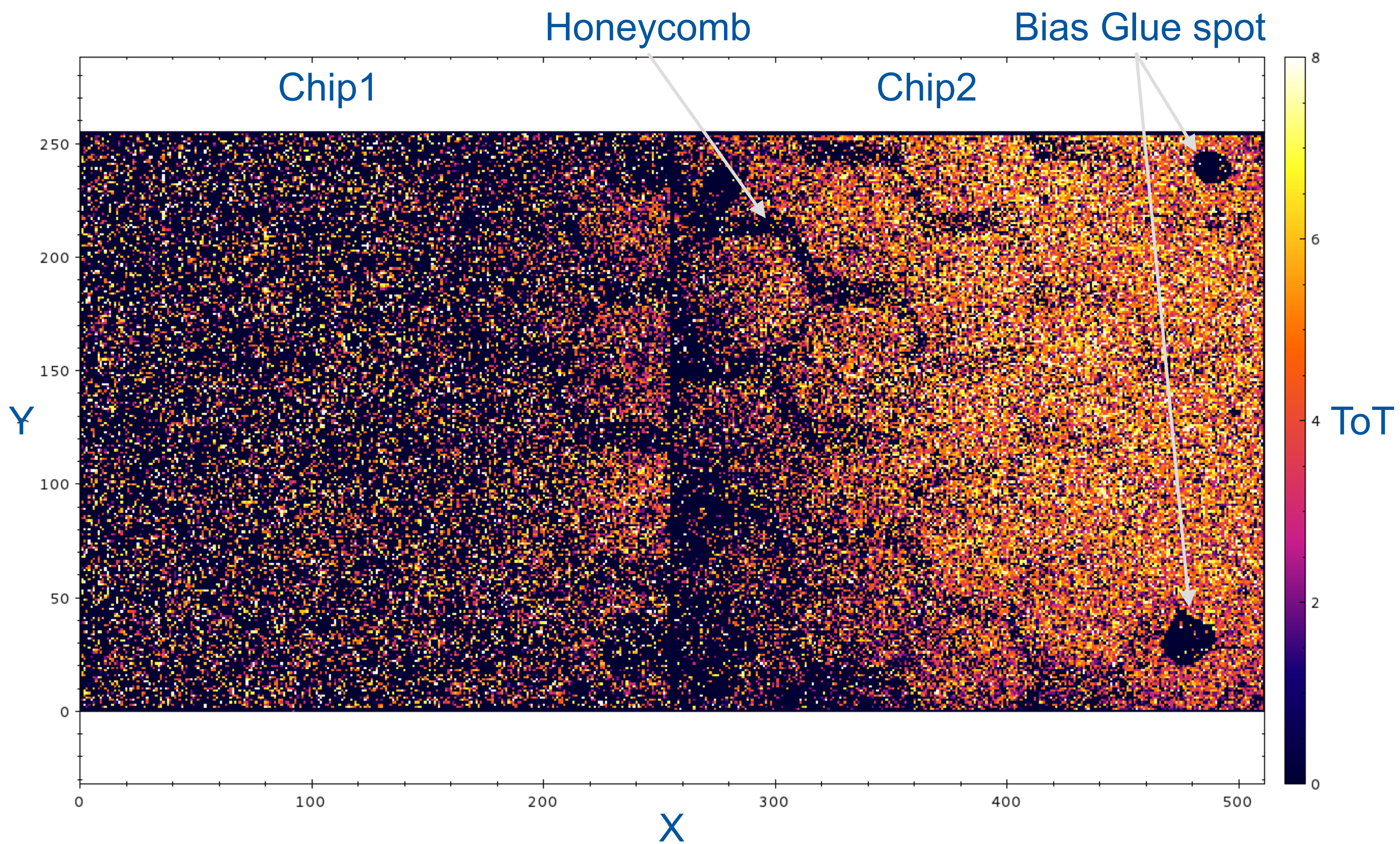
First Data

Remember the Honeycomb !





First Data - ToT - HV - 665 ms shutter

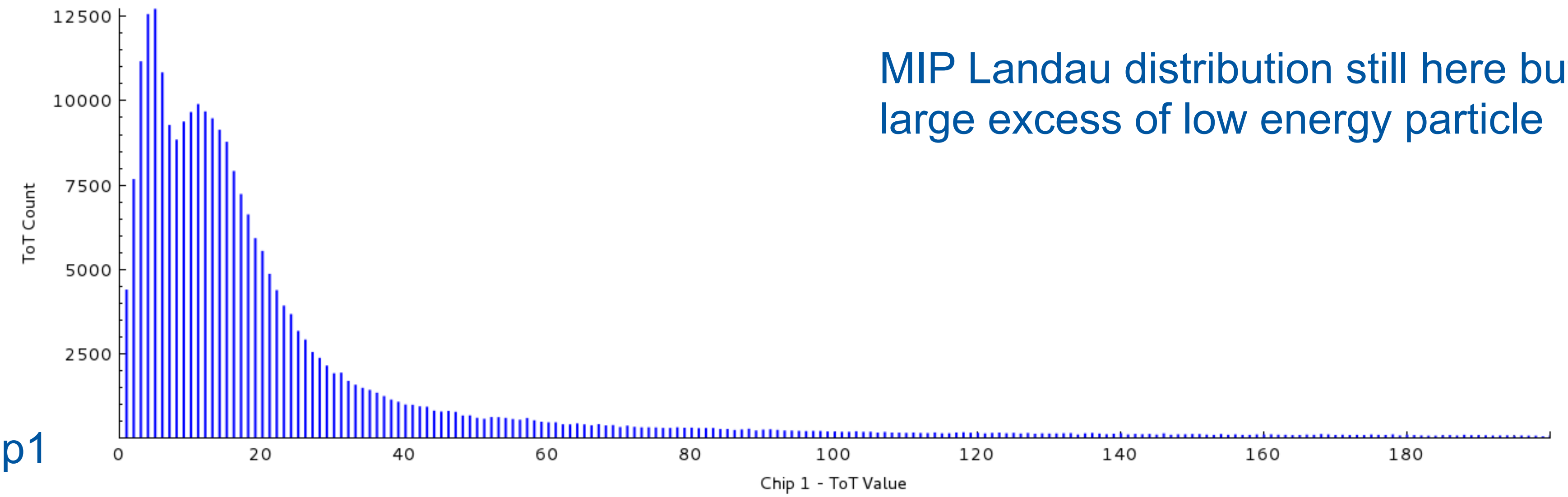


It looks like a “X-ray” of the honeycomb

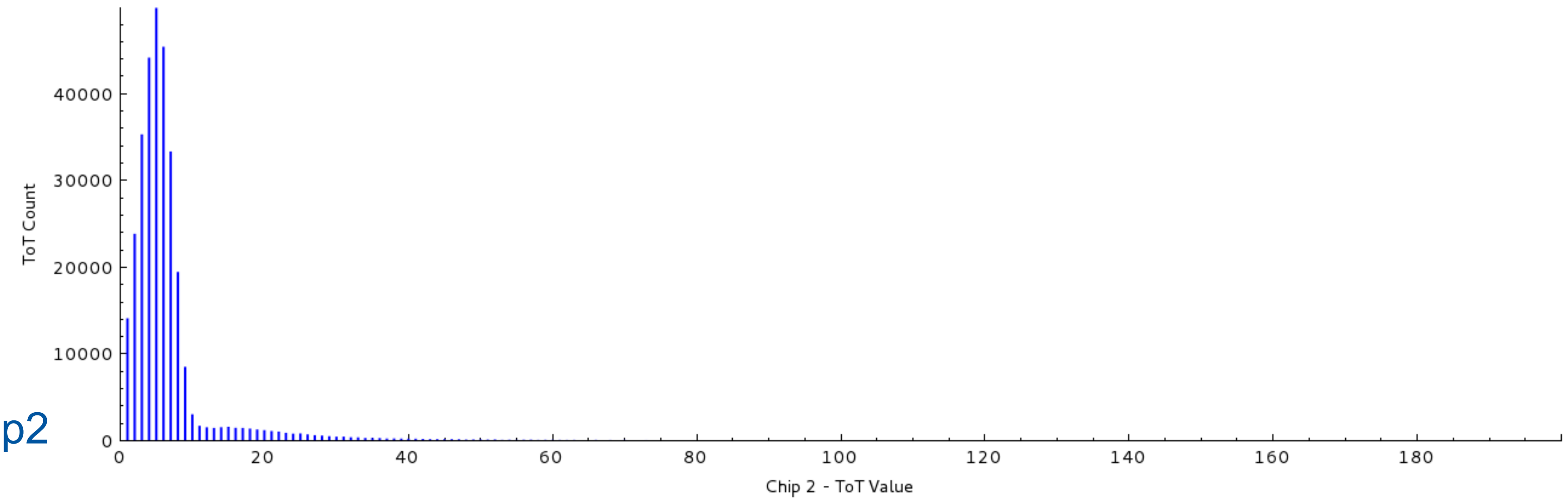
First Data - ToT Hist - HV - 665 ms shutter

MIP Landau distribution still here but large excess of low energy particle

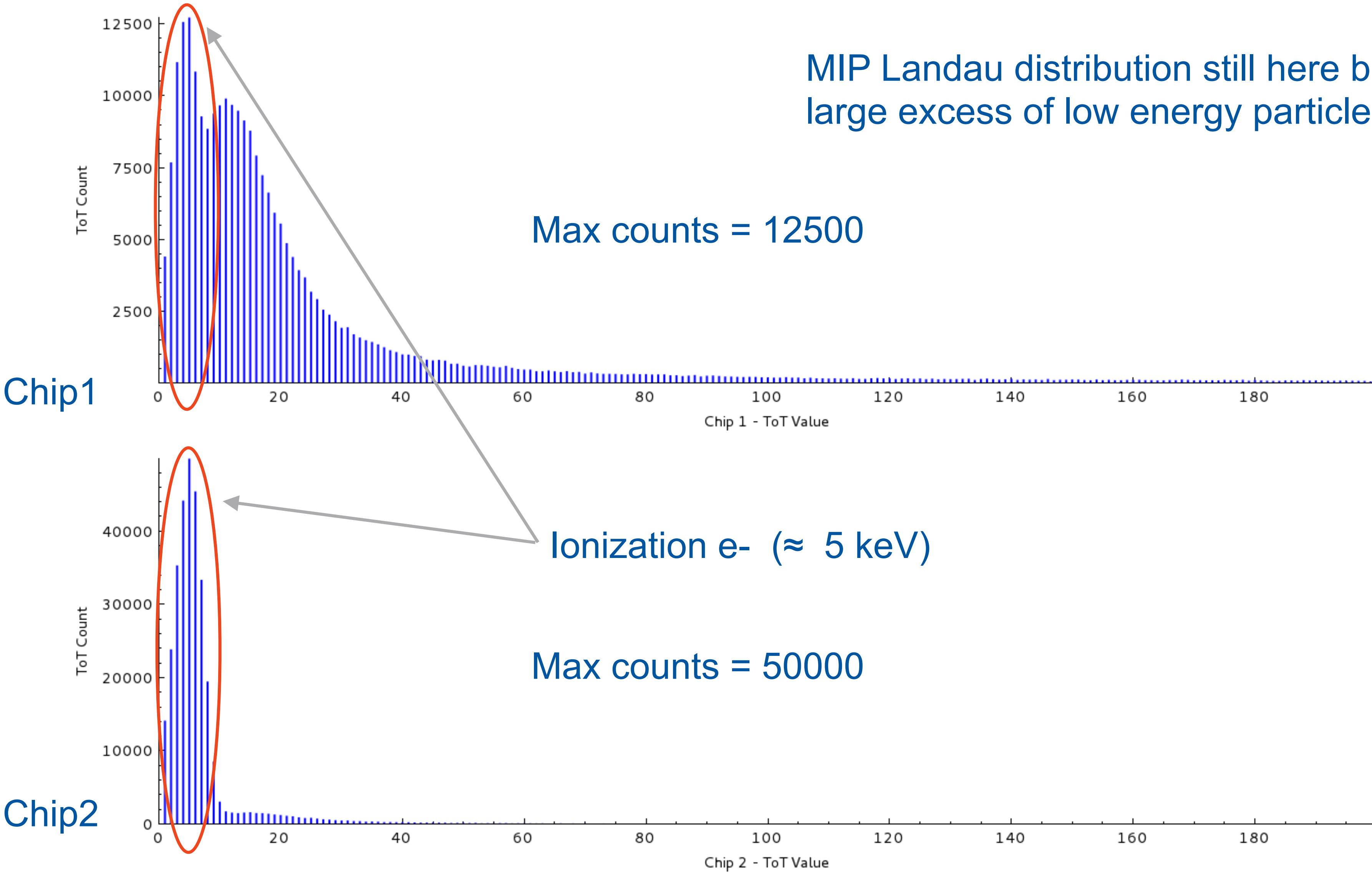
Chip1



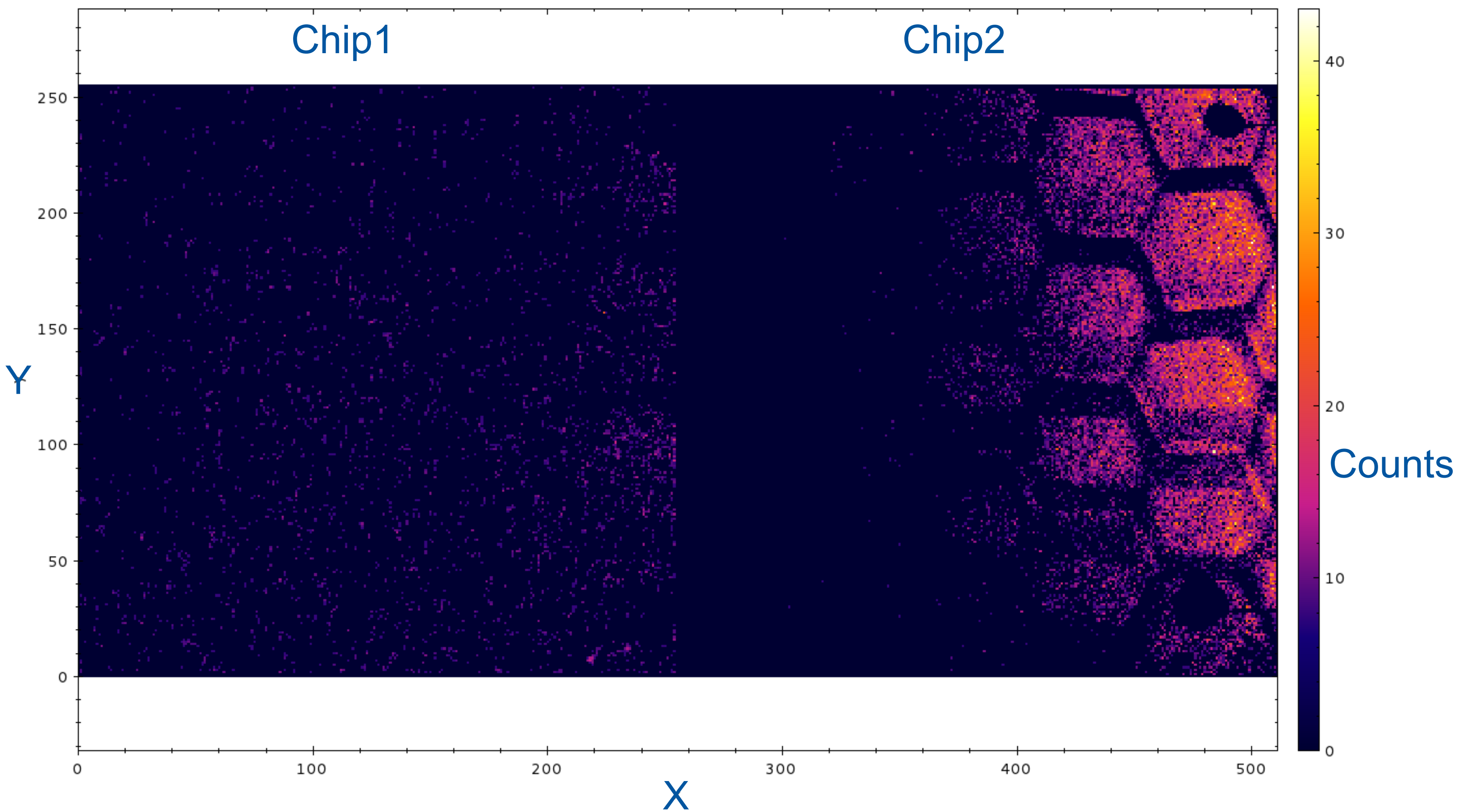
Chip2



First Data - ToT Hist - HV - 665 ms shutter



First Data - Counts - HV - 665 ms shutter



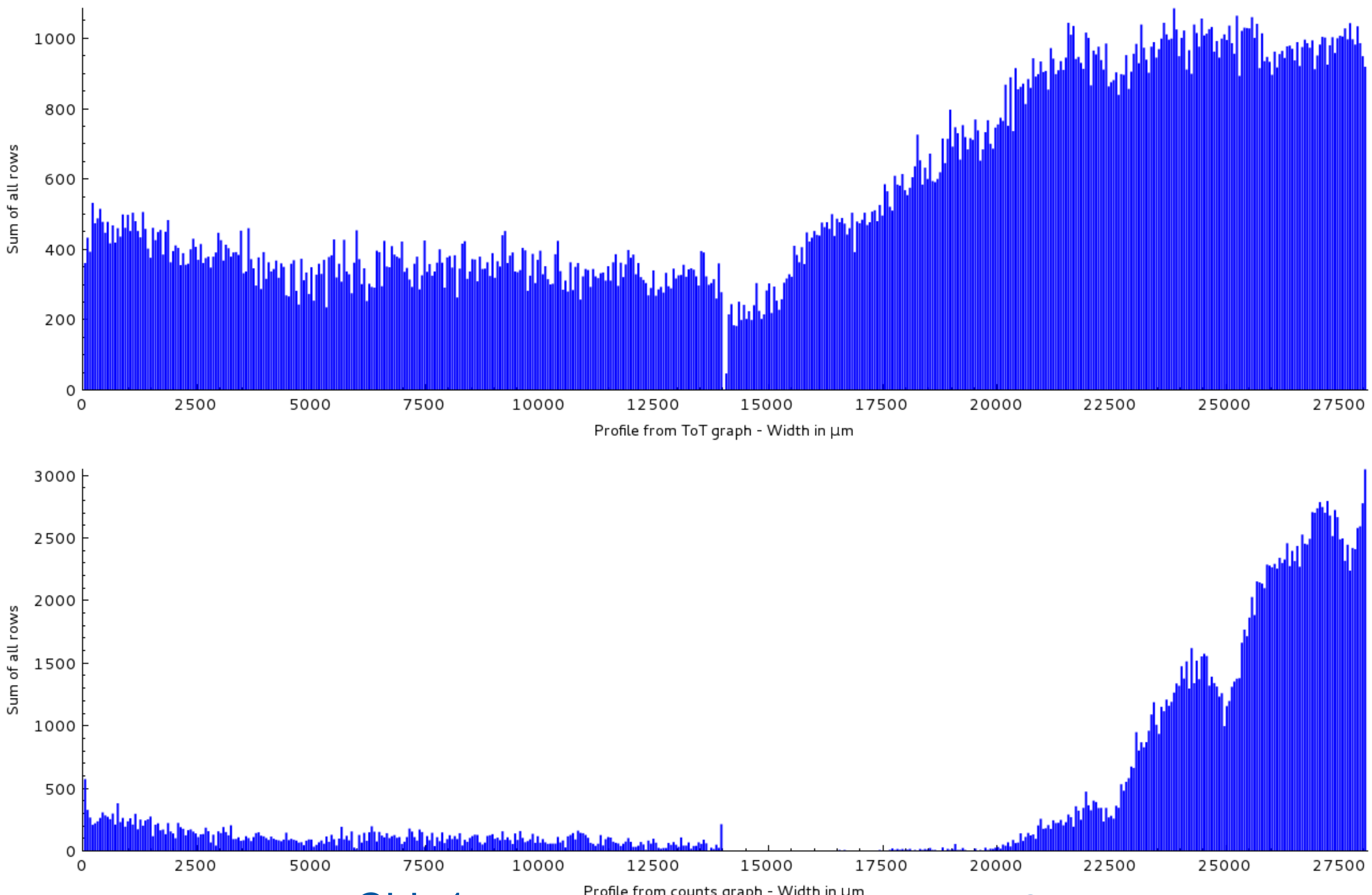
Honeycomb very visible

First Data - “Profile” - HV - 665 ms shutter

Integrated over the Y axis - filtered (only low ToT)

Energy

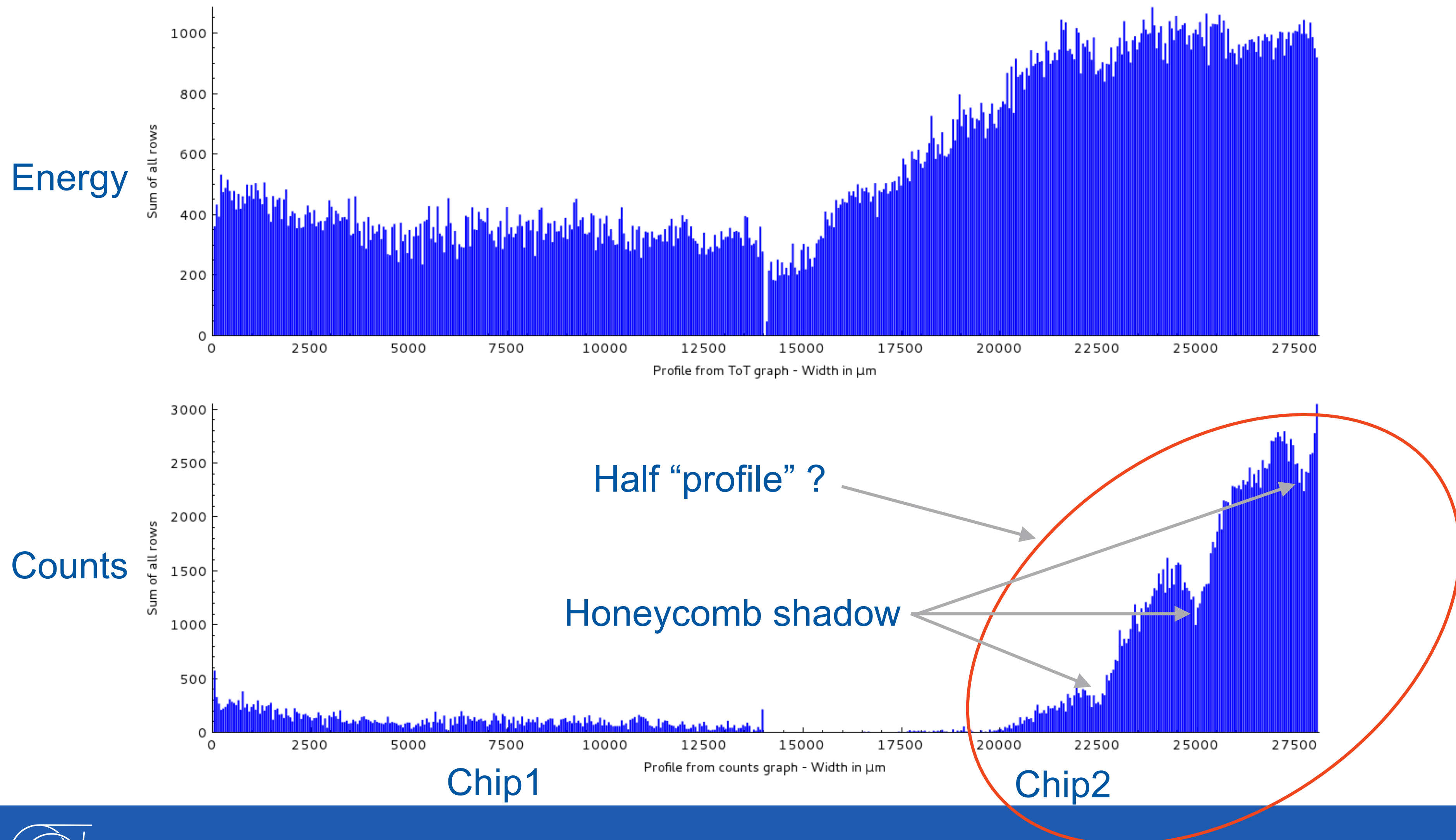
Counts



Chip1 Chip2

First Data - “Profile” - HV - 665 ms shutter

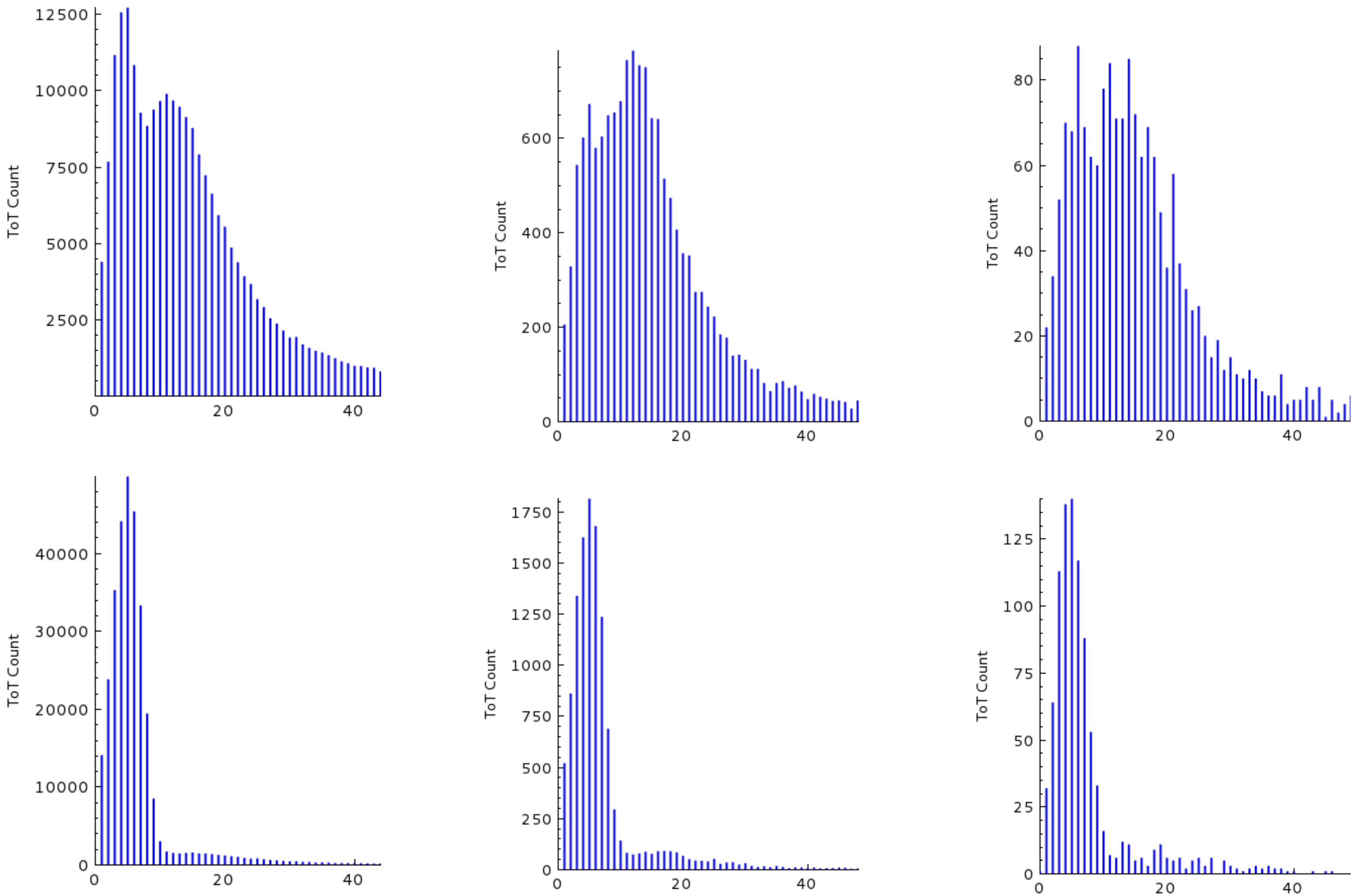
Integrated over the Y axis - filtered (only low ToT)



First Data - ToT Hist - HV - 665,10, 1 ms shutter

Chip1

Chip2



665 ms

10 ms

1 ms

Conclusion

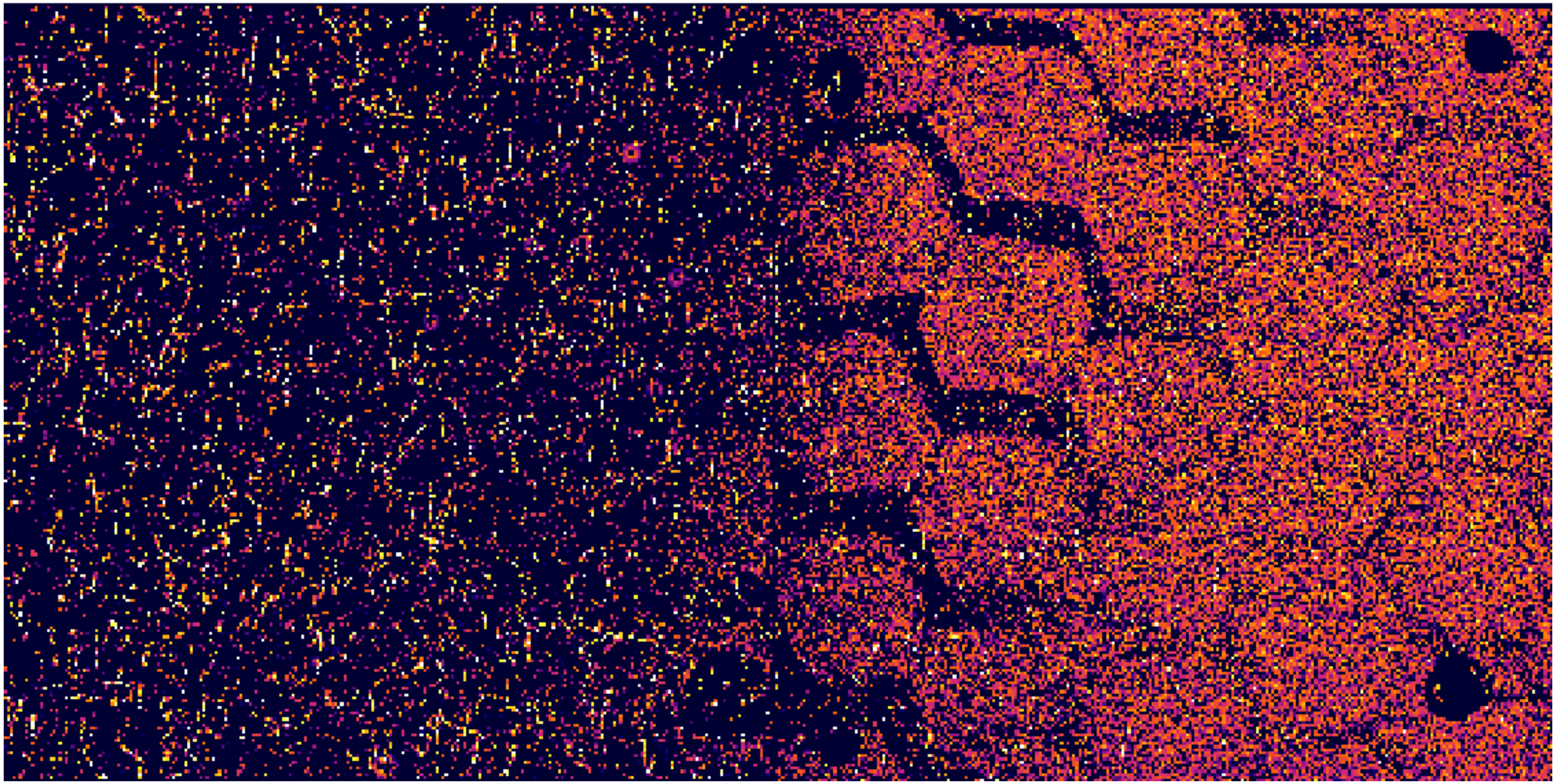
- **We have successfully operated a pixel detector inside the beam pipe vacuum !**
- **We have observed a strong signal from 5 keV ionization electrons !**

- Exact event rates have yet to be estimated
  but the signal is still significant with short shutter time
- The signal will significantly improve as we tweak the TPX3 settings (e.g. Bias voltage) & do some signal processing (e.g. correction for honeycomb shadow)
- The potential in the ToA information has yet to be exploited
  (Bunch / turn / cycle)
- Only two TPX3 fully working (#1 and 2)
- The readout system is working as expected
- Pressure in the chamber is around 4*10^-10 mBar
  (Better than ever expected, almost too good)

Conclusion

These results demonstrate the concept of Hybrid Pixel Detector based IPMs

(Achievement unlocked !)



Thanks for you attention!

Questions ?

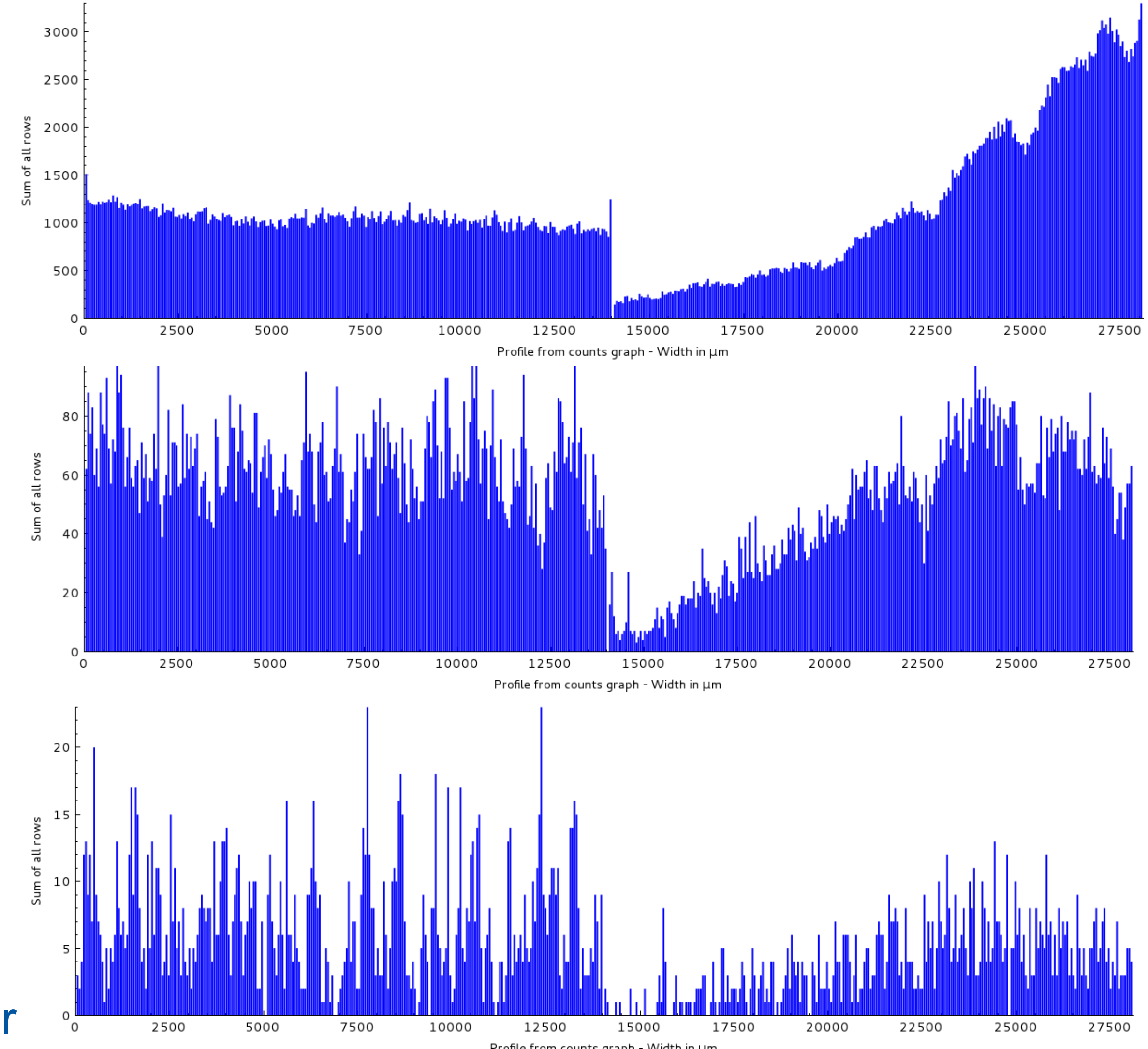
Backup - Profile - HV - 665,10, 1 ms shutter

665 ms

10 ms

1 ms

Signal is persistent even with short shutter



Chip1 Chip2

Backup - ToT hist - HV - 10 to 18 V Bias