Characterisation of Timepix3 and CLICpix hybrid pixel detector assemblies

Internation workshop on Future Linear Colliders
6-10 October 2014, Belgrade, Serbia

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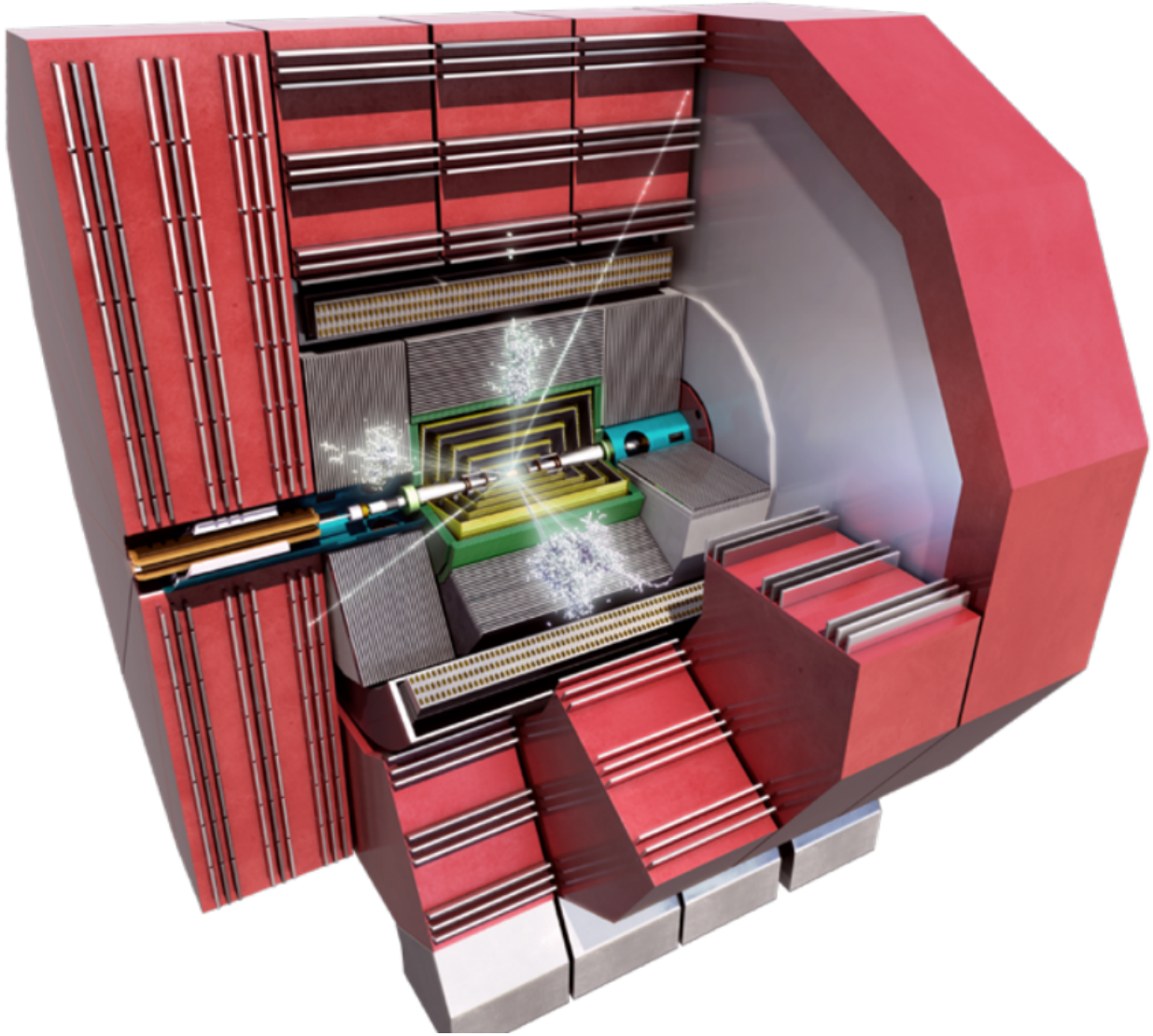
on behalf of the CLICdp collaboration

Outline

- The CLIC detector
  - Vertex Detector requirements
- Timepix/Medipix chip family
- Timepix3 description and readout
- CLICpix, CCPDv3, and readout
- Testbeam at CERN PS using AIDA telescope
  - First results for August 2014
- Conclusions

The CLIC detector



Precision physics in a challenging environment: broad programme of R&D

Highly granular particle flow calorimetry, using tungsten absorber

5.5 m diameter cryostat for superconducting solenoid, B field 4-5 T

All silicon tracker

Instrumented steel return yoke

Complex forward region

Vertex detector requirements

→ Good single point resolution: $\sigma_{SP} \sim 3$ μm
  → Small pixels ~ 25x25 μm^2

→ Low material budget: X ≲ 0.2% X_0 / layer
  → Corresponds to ~200 μm Si
  → Air-flow cooling + Low-power ASICs (~50 mW/cm^2)

→ 156 ns bunch trains, 20 ms train repetition rate
  → trigger-less readout, pulsed powering

→ Time stamping with ~10 ns accuracy, to reject background
  → high-resistivity sensors, fast readout

- No technology option available fulfilling simultaneously all requirements:
  → Simulation studies: impact of layout on performance
  → R&D on sensors & readout
  → Integration/assembly + cooling + power-pulsing studies

The Timepix/Medipix chip family

Chip	Year	CMOS Process	Pitch [μm²]	Pixel operation modes	r/o mode	Main applications
Timepix	2006	250 nm	55x55	∫TOT or ToA or γ counting	Sequential (full frame)	HEP (TPC)
Medipix3RX	2012	130 nm	55x55	γ counting	Sequential (full frame)	Medical
Timepix3	2013	130 nm	55x55	TOT + ToA, γ counting + ∫TOT	Data driven (5 Gbit/s)	HEP, Medical
Velopix	2015	130 nm	55x55	ToA, γ counting	Data driven (20 Gbit/s)	HEP: LHCb
Timepix4/ Medipix4	~2016	65nm	35x35	Similar to v3 familly	---	HEP/Medical
CLICpix demonstrator	2013	65 nm	25x25	TOT + ToA	Sequential (data comp.)	Test chip with 64x64 pixel matrix
CLICpix	tbd	65 nm	25x25	TOT + ToA	Sequential (data comp.)	CLIC vertex detector

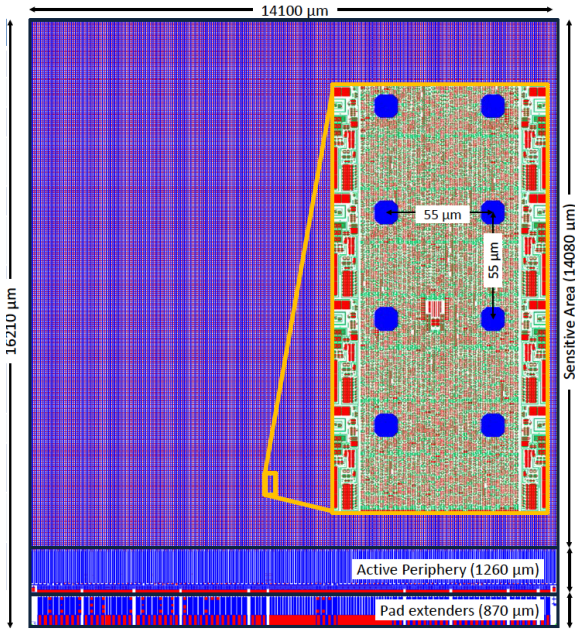
TOT: Time-Over-Threshold → Energy
ToA: Time-of-Arrival → Time stamping

- Taking advantage of smaller feature sizes:
  - Improved noise performance
  - Increased functionality and/or
  - Reduced pixel size

Timepix3 ASIC

Timepix3 ASIC was received at CERN beginning of 2014. it represents a revolution w.r.t. the Timepix1 ASIC, going from:

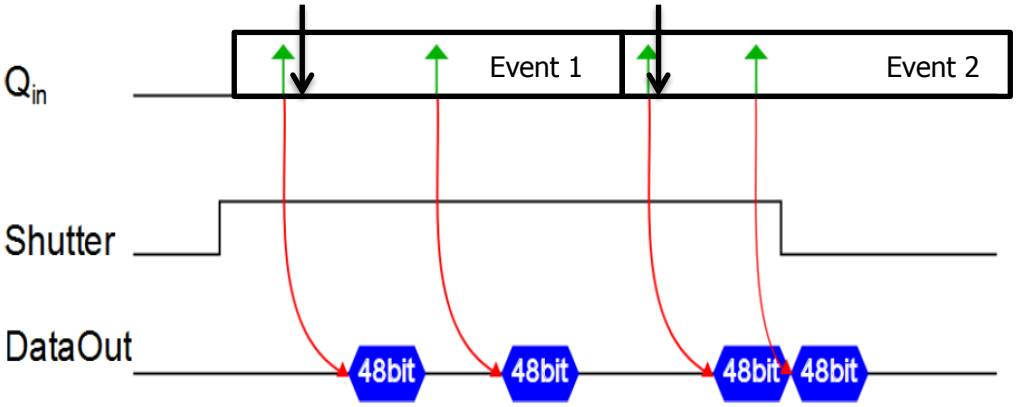
- ~10 ms readout time
  - Data driven @ 10Gb/s
- TOT or TOA
  - TOT(10bits) + TOA
- Proprietary DAQ
  - DAQ developed by NIKHEF and CERN, full control of hardware + software



Integration to EUDET telescope framework was much easier :

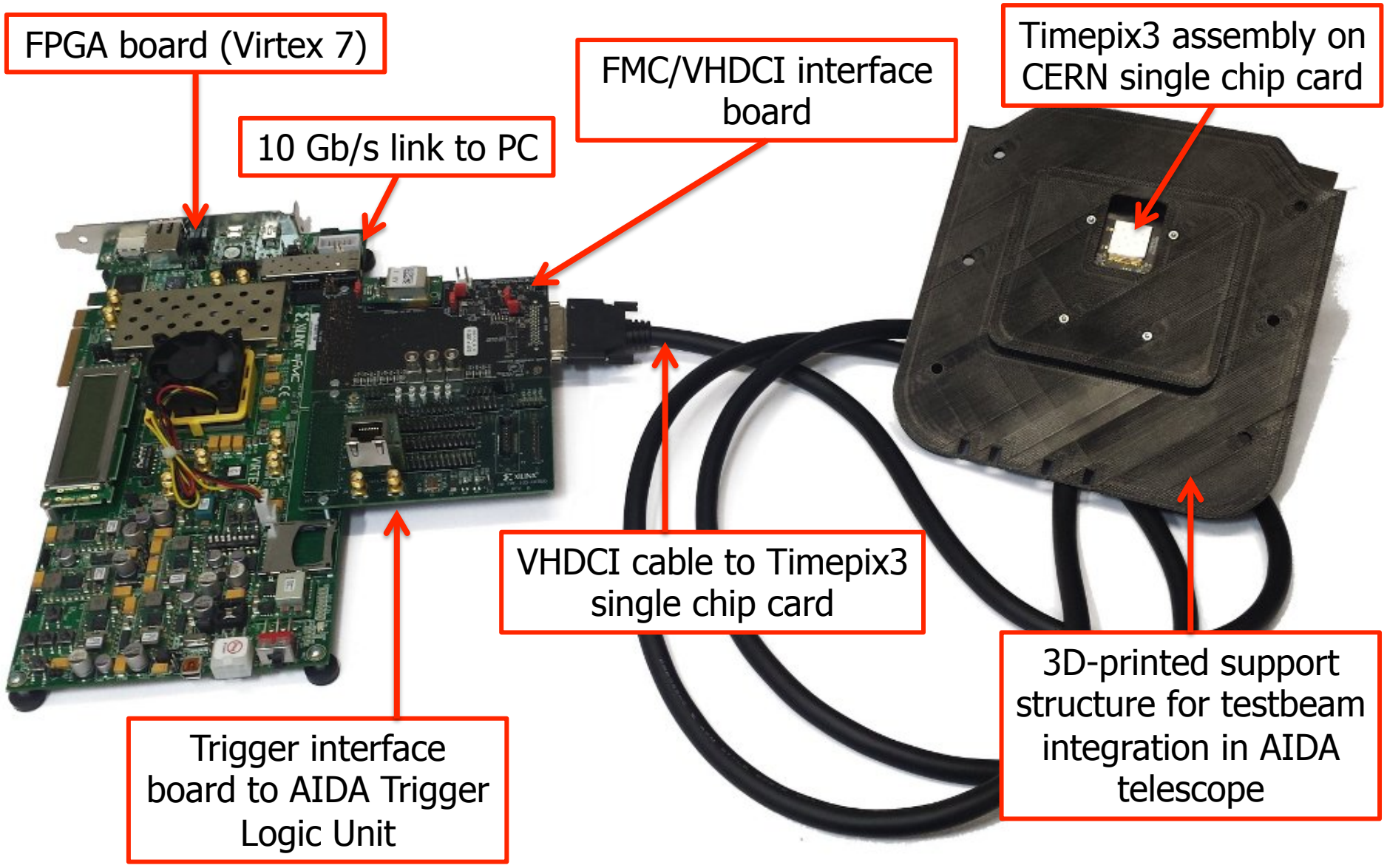
- 100% active during acquisition
- Hits and triggers issued by the telescope are time stamped with the same clock
- Data are sent to EUDET DAQ by TCP/IP, integrated to EUDET reconstruction flow.
- ~2kHz trigger rate reached, limited by beam/telescope

TLU Trigger



Data-driven readout mode.

Timepix3 readout



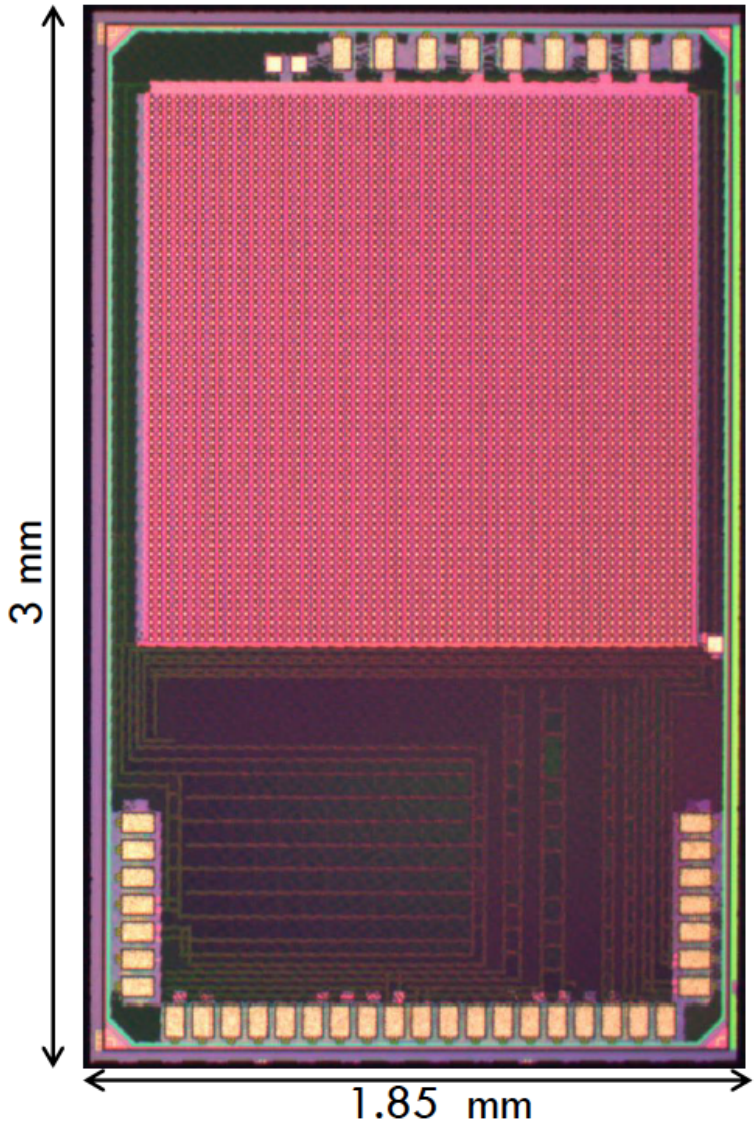
CLICpix ASIC

Main features:

- Small pixel pitch (**25 µm**),
- **Simultaneous TOA** (4 bits) &**TOT** (4 bits) measurements
- **100MHz measurement clock** and 320 MHz readout clock
- **Power pulsing**
- **Data compression**
- Both pulse polarities can be handled

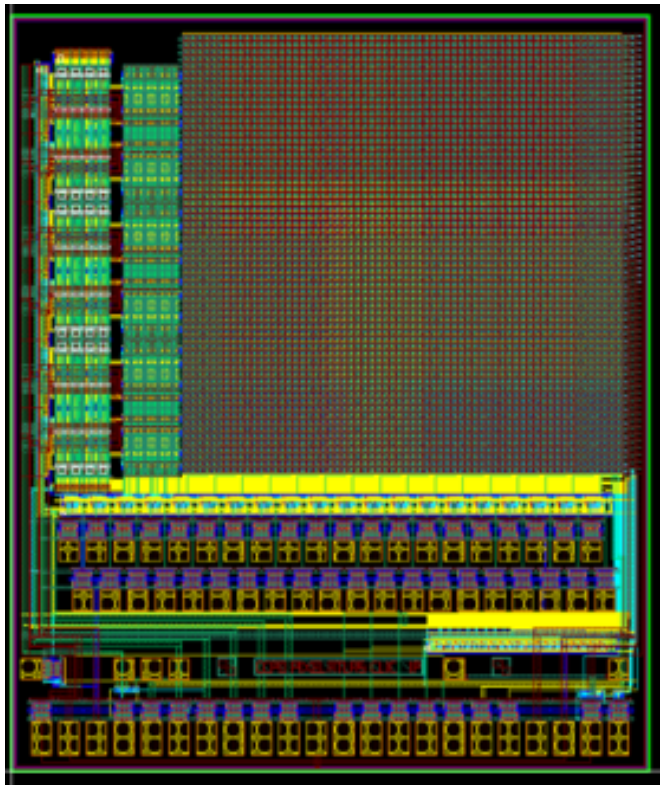
Demonstrator CHIP:

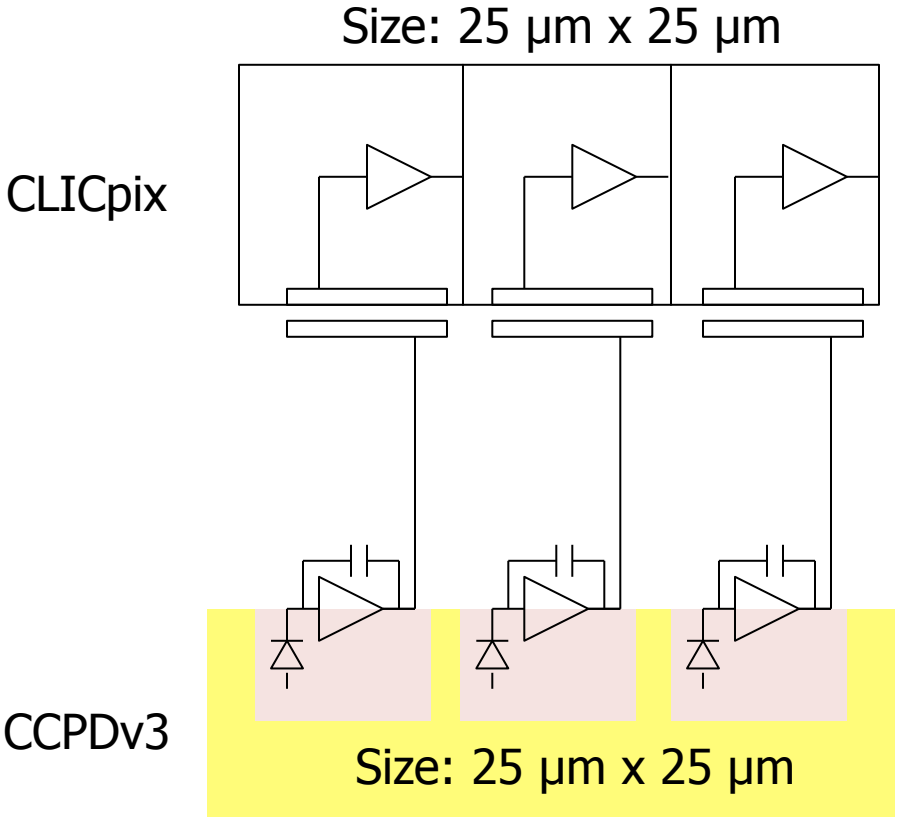
- commercial **65 nm CMOS technology** (proven to be radiation resistant)
- **array of 64x64** pixels
- The **Krummenacher architecture**, with a single ended preamp, a two stage discriminator and a 4-bit DAC



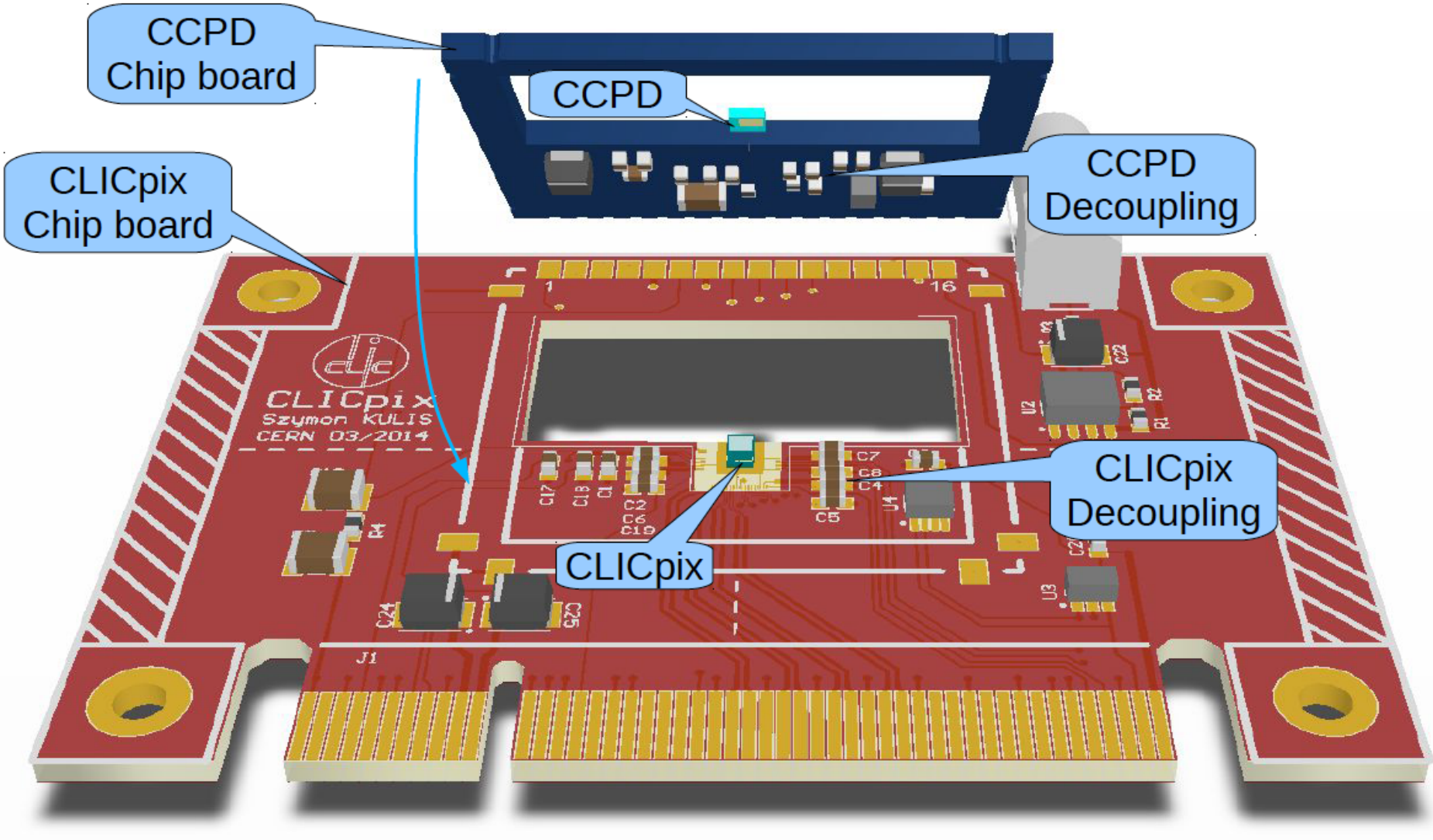
CCPDv3 HV-CMOS sensor

- CLIC requirements – little material, high spatial and time resolution
- Option: capacitively coupled pixel detector (HV-CMOS, AMS180nm)
- Test detector has been produced (CCPDv3) that can be glued and read out with CLICPIX chip
- Pixel size: 25 µm x 25 µm
- Every HVCMOS pixel has its own readout cell

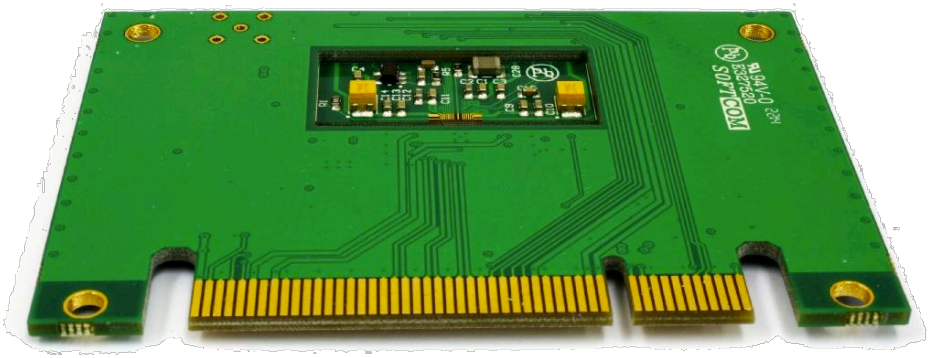


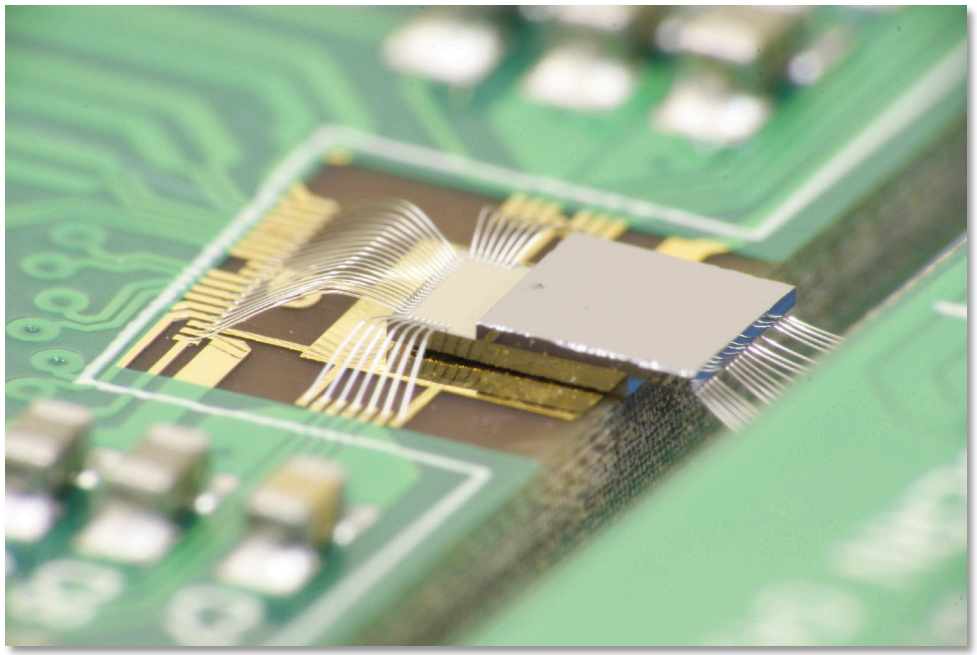


CLICpix + CCPDv3

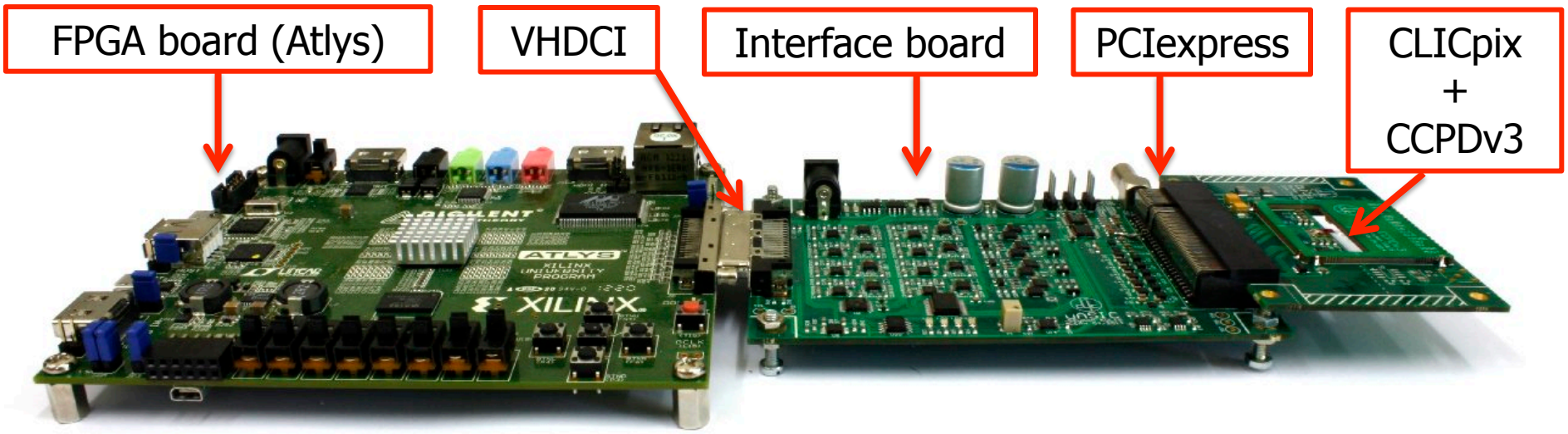


CLICpix + CCPDv3





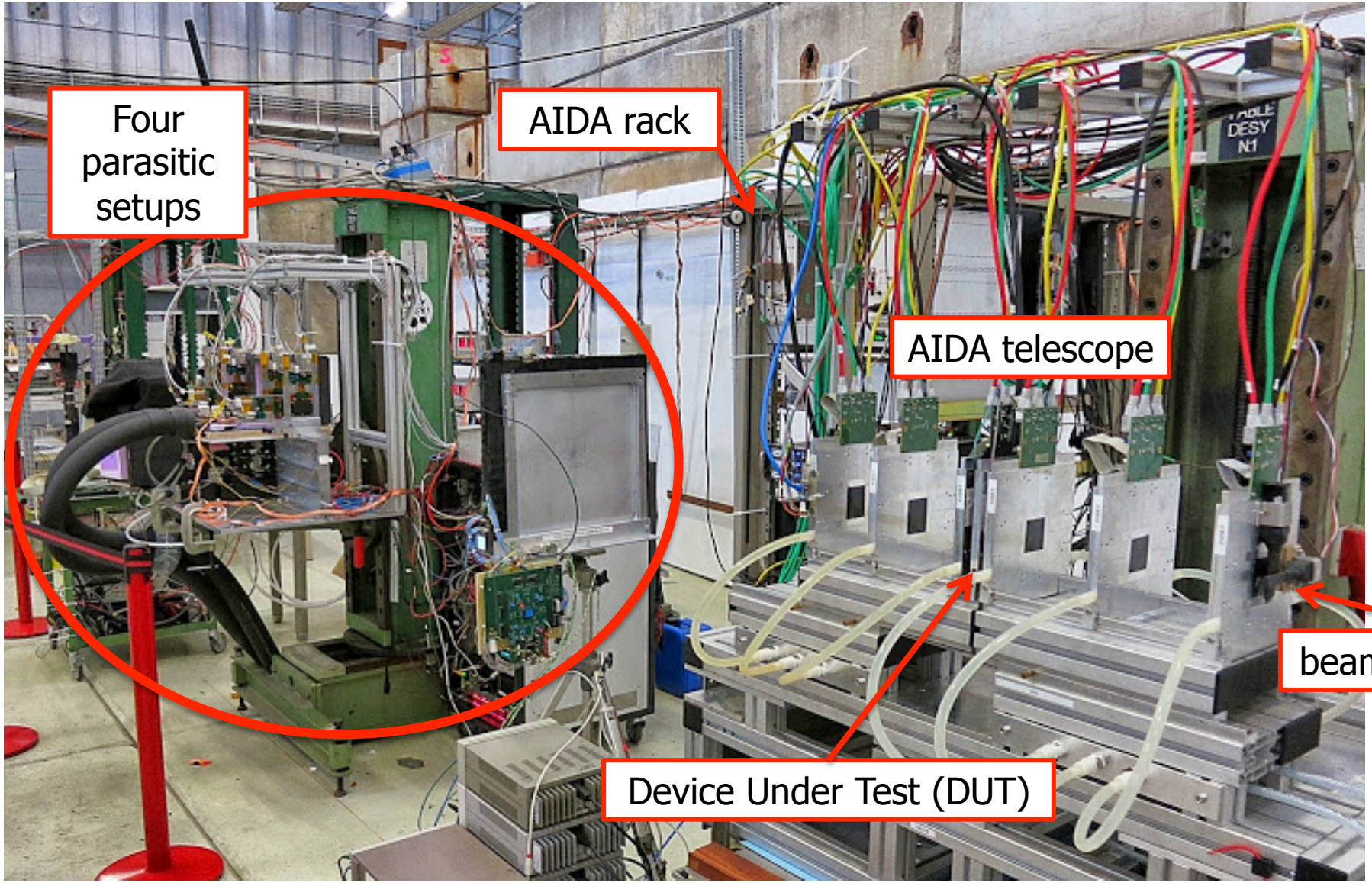
CLICpix + CCPDv3 readout



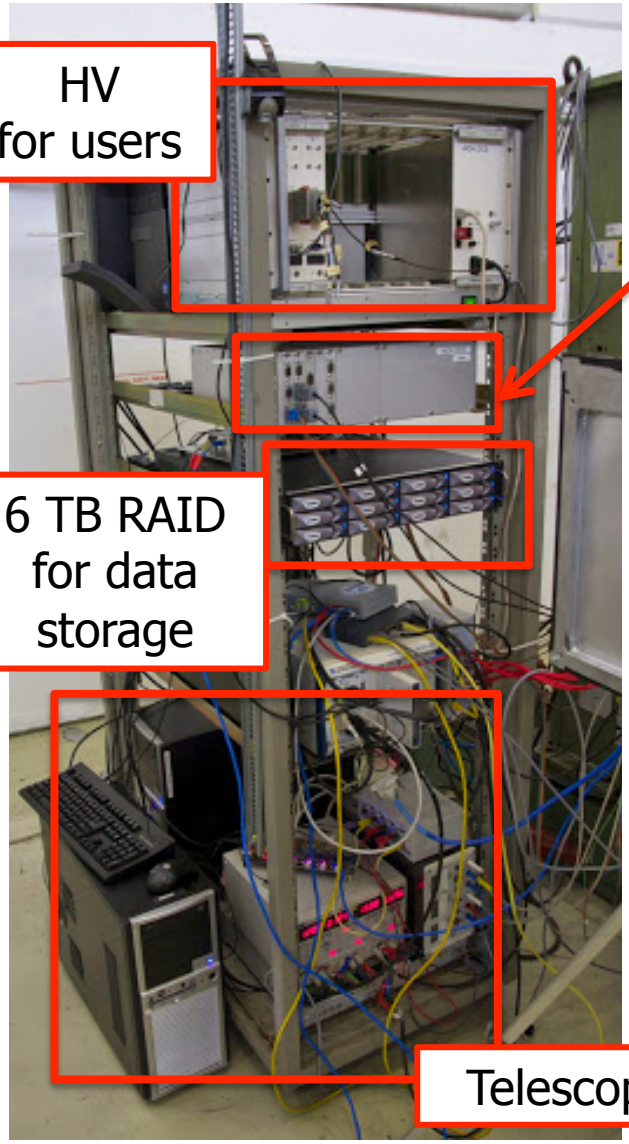
Readout system fully developed at CERN

- Rough integration to EUDET DAQ (EUDAQ) completed, allowing for first test beam in August 2014
- Work ongoing to integrate the readout to the SPIDRman visualization and control software developed for Timepix3 SPIDR readout

Setup at CERN PS

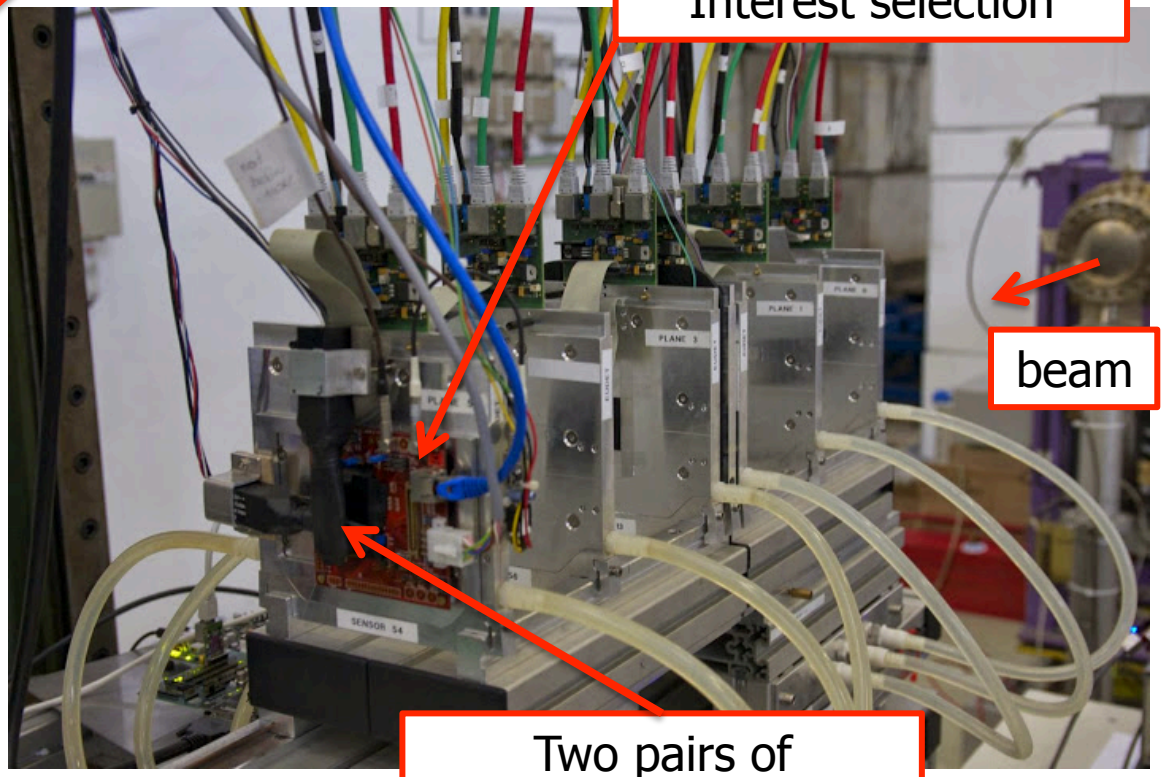


AIDA infrastructure



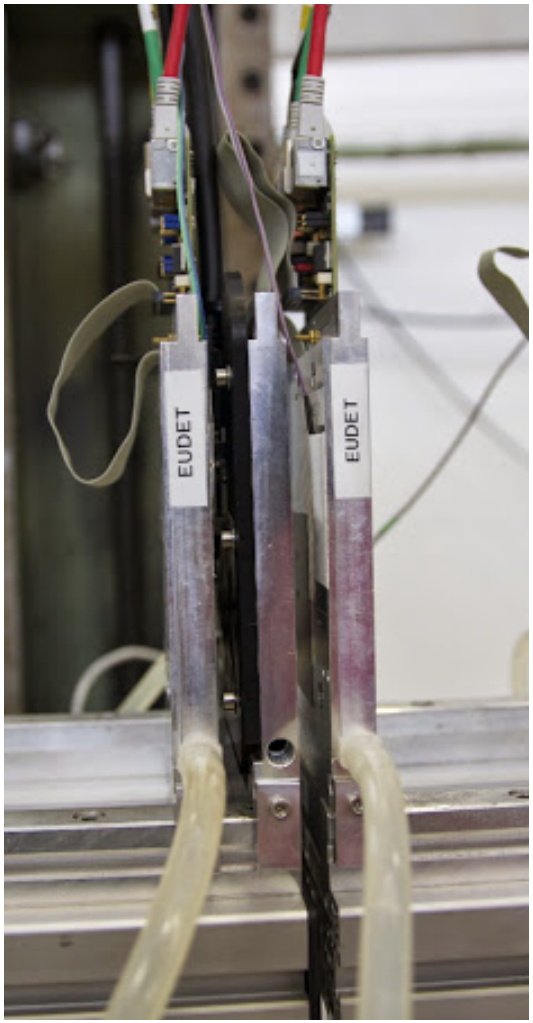
Temperature/Humidity monitoring

ATLAS FEI4 plane for timing and Region-Of-Interest selection

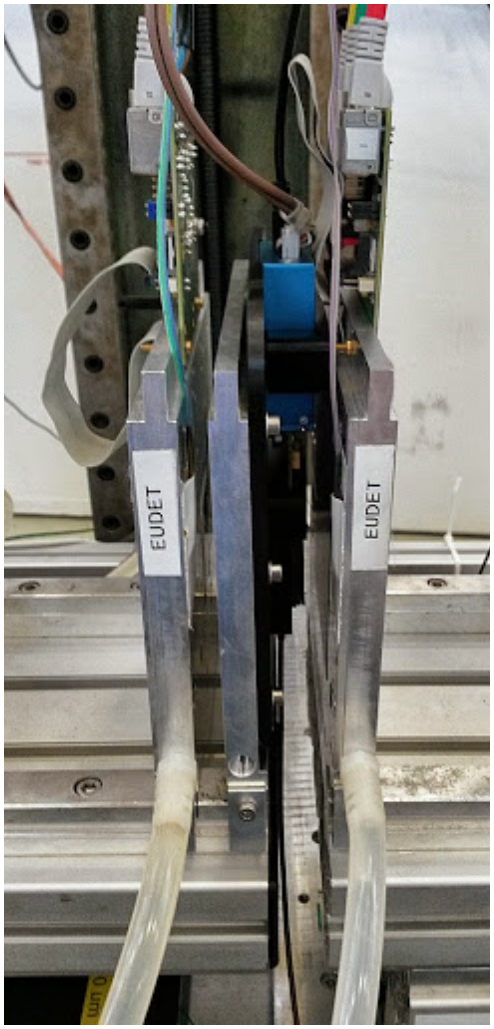


DUT integration

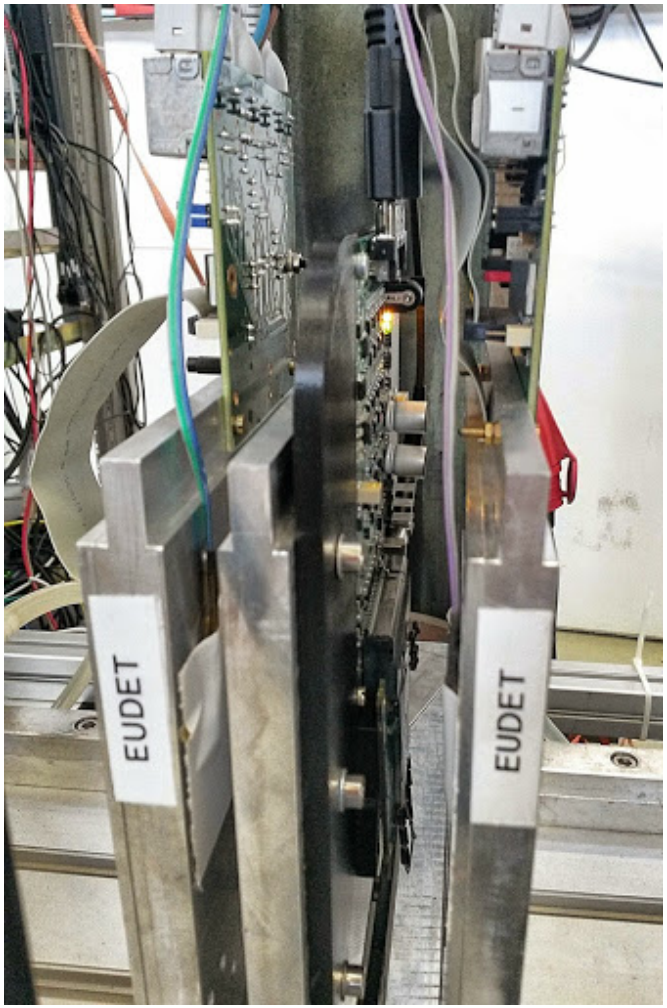
Timepix3



Timepix1



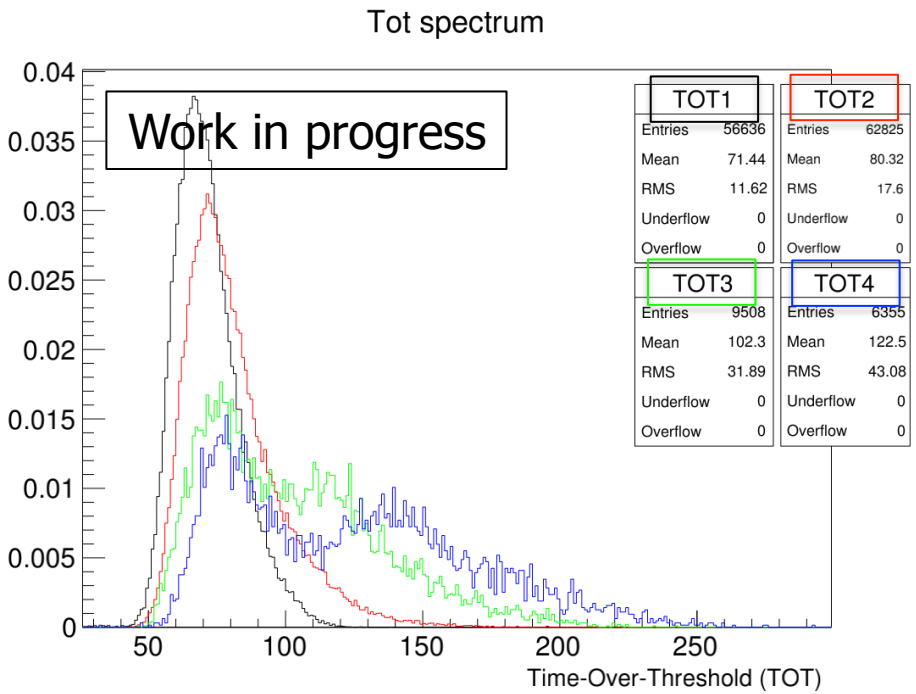
CLICpix

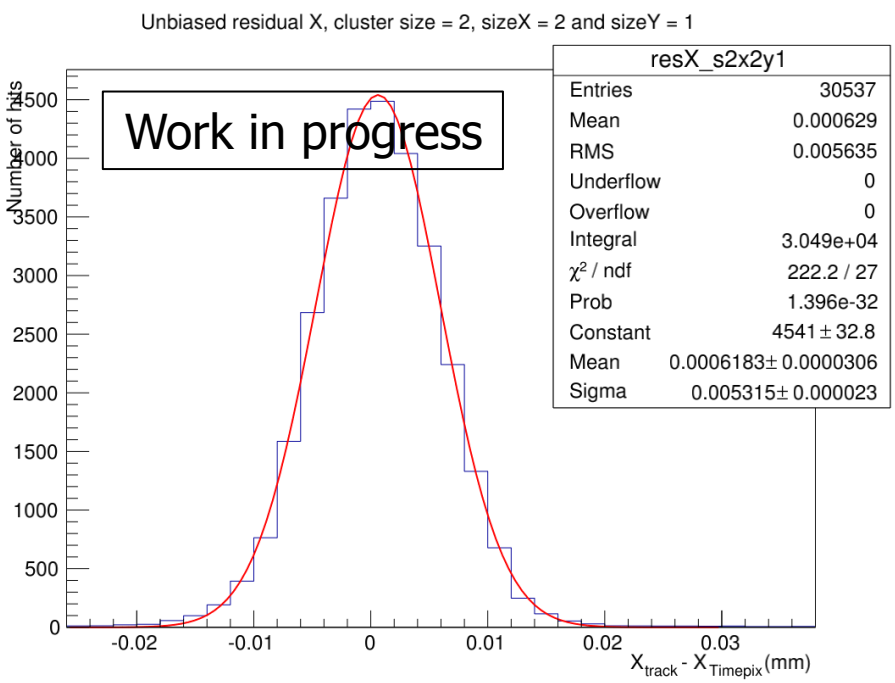


Beam conditions

- 10 GeV beam (positive polarity)
  - Protons, pions, muons
- Between 2 and 4 spills per 20-35sec (PS sypercycle)
  - spill duration: 400ms
- Rate:
  - ~150k particles/spill (beam scintillators)
  - Through the telescope acceptance (trigger scintillators): ~20k particles/spill
- Beam focusing
  - We mostly used parallel beam settings: better for track reconstruction in the telescope

Timepix3 2014 testbeam results (1/2)

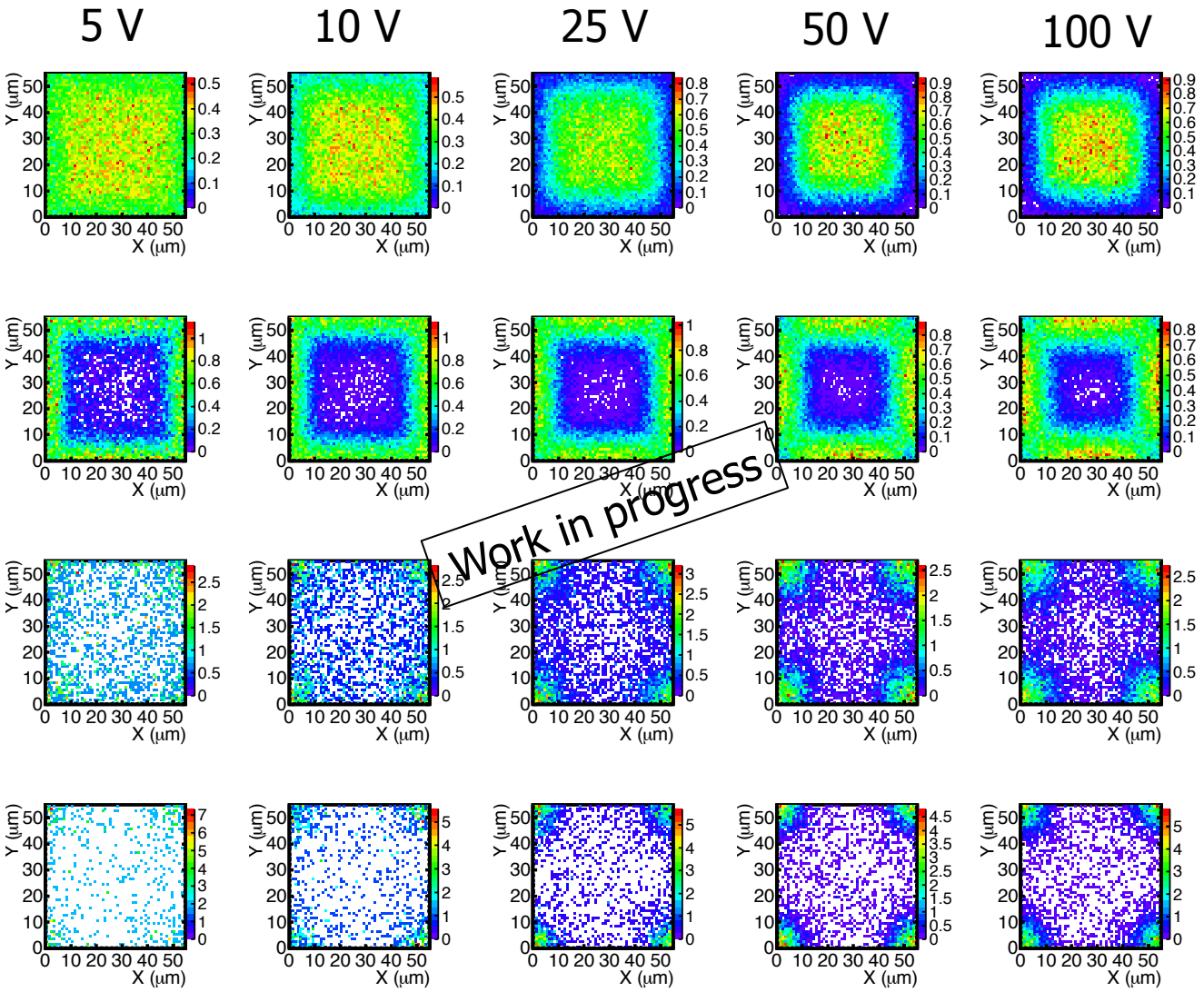




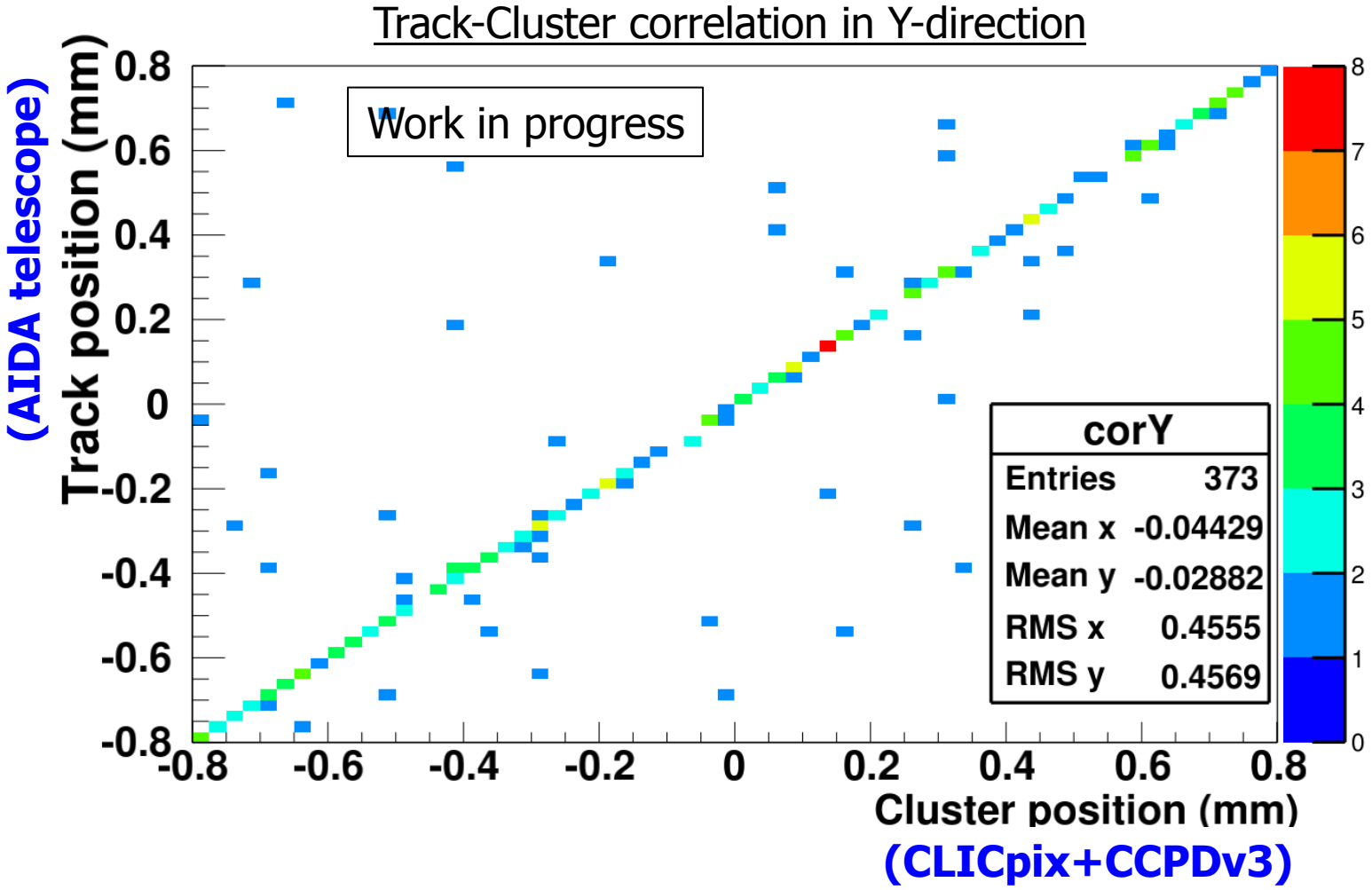
- Overall good performance of the Timepix3 integration in the AIDA telescope
- ~99.4% detection efficency
- TOT spectra require TOT->energy calibration of the assembly
  - Second peak for cluster size 3 and 4 and thought to stem from delta electrons
- Residual for cluster size 2:
  - σ=5.3μm, assuming $\sigma_{pointing}$ = 3μm --> σ_{sp} = 4.4μm

Timepix3 2014 testbeam results (2/2)

Track hit probability inside a pixel – a good visualisation of charge-sharing



CLICpix 2014 testbeam results (1/2)

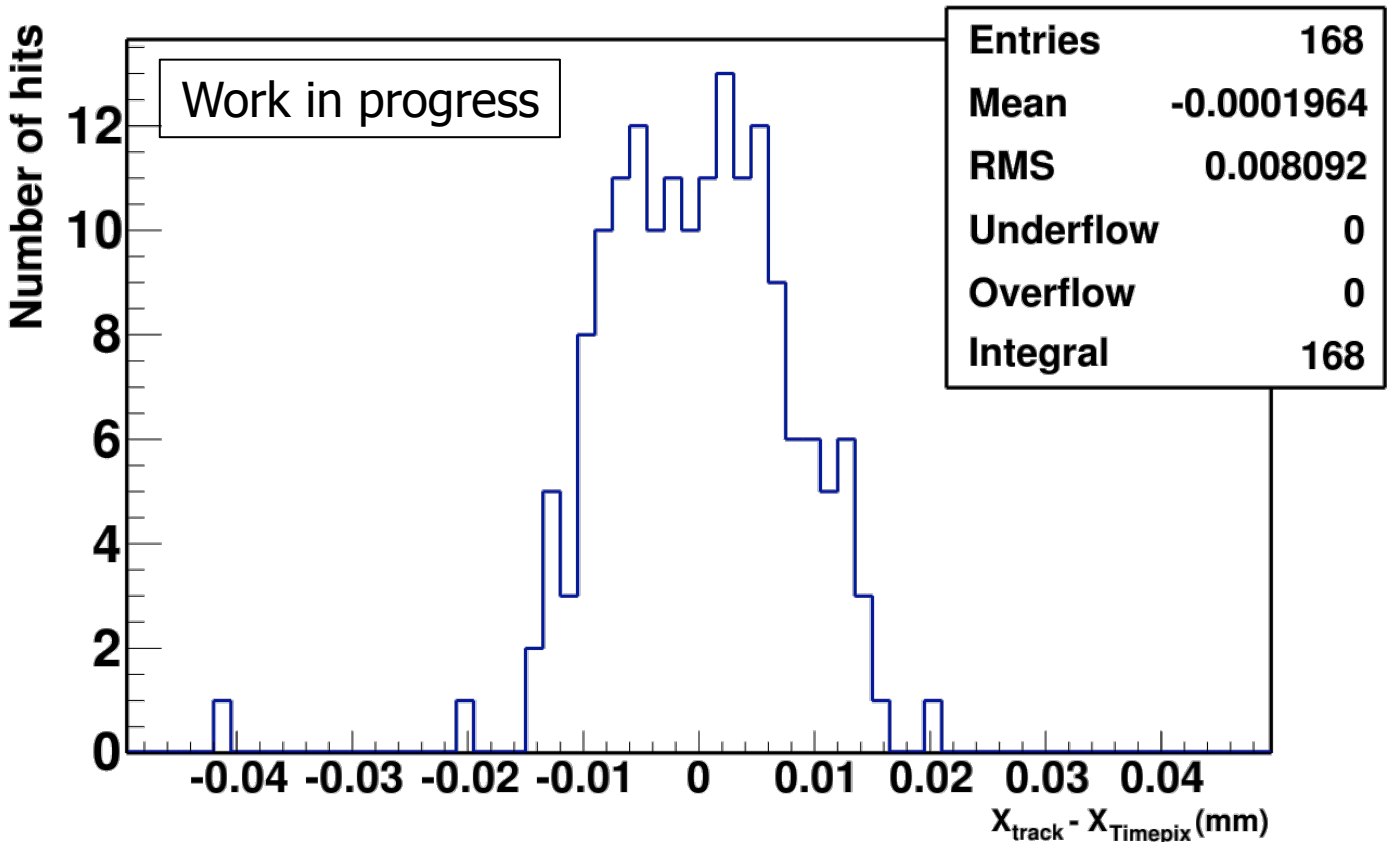


This correlation demonstrates the usage of the CLICpix+CCPDv3 assembly as a particle detector

More data coming during October testbeam period at CERN PS

CLICpix 2014 testbeam results (2/2)

Tracking resolution



Mostly single-pixel clusters --> little charge-sharing --> behaves like digital sensor

$\sigma_{expected}$ = 25µm / sqrt(12) = 7.2µm

Assuming $\sigma_{pointing}$ = 3µm --> σ_{sp} = 7.4µm, here dominated by statistics

More data to come from October testbeam at CERN PS

Summary

- R&D on sensor and readout for the CLIC Vertex detector is well under way
- The faster Timepix3 has been sucessfully integrated within the AIDA telescope infrastructure with its newly developed SPIDR readout
- CLICpix + CCPDv3 HV-CMOS assemblies have been successfully glued and read out, as well as tested with beam
- Overall very successful data taking period at CERN PS
  - Second PS period is about to finish
  - Future beam tests will be at CERN SPS North Area later this year
- More information
  - https://wiki.nikhef.nl/detector/Main/SpiDr
  - https://twiki.cern.ch/twiki/bin/view/MimosaTelescope/WebHome
  - http://clicdp.web.cern.ch/content/wg-clic-vertex-detector-technology

Data taken in August 2014

	Run types	Total #tracks
Timepix3 W2_H5	Vbias scan Threshold scan	597M
Timepix3 W2_J5	Vbias scan Threshold scan	318M
CLICpix	Nominal bias, photon counting mode (no ToT)	6.9M (of which ~1% contains CLICpix hits because of its size)
Timepix1 (300um assembly)	Vbias scan Threshold scan	13M
Telescope only	Rate tests	19M