Recent developments on monolithic CMOS pixel sensors in TowerJazz 180nm technology

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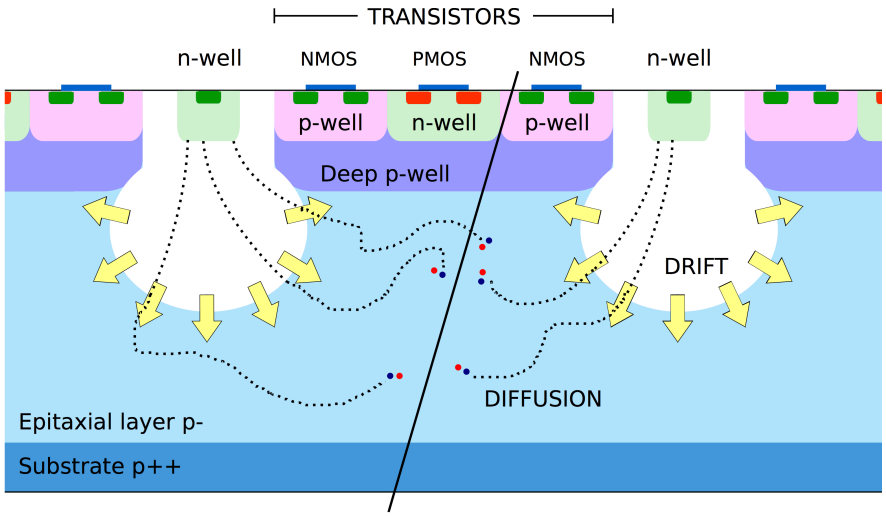
Outlook of this talk

- TowerJazz 180nm technology
  - Test chips
  - Setups and measurement methods
- Outlook for 2018

TowerJazz 180nm technology

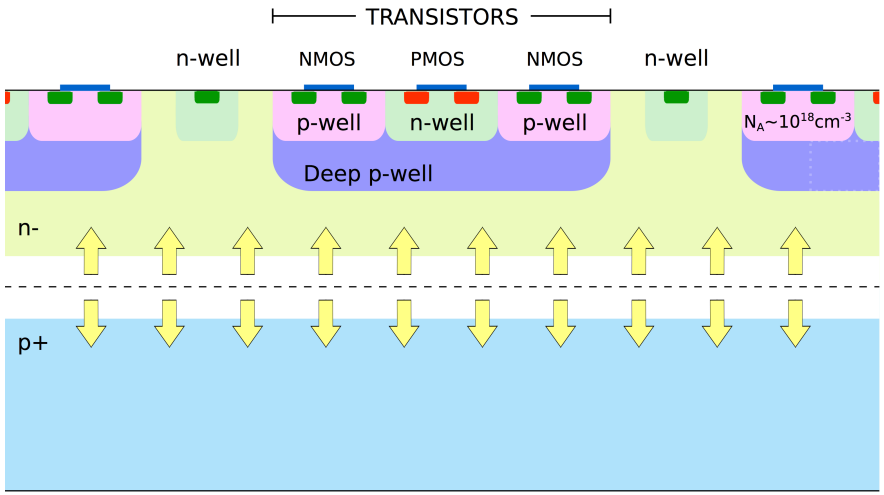
- **Low input capacitance** (~fF) at the collection electrode
- **Large S/N ratio** can be achieved
- **Fast signals**

Standard process



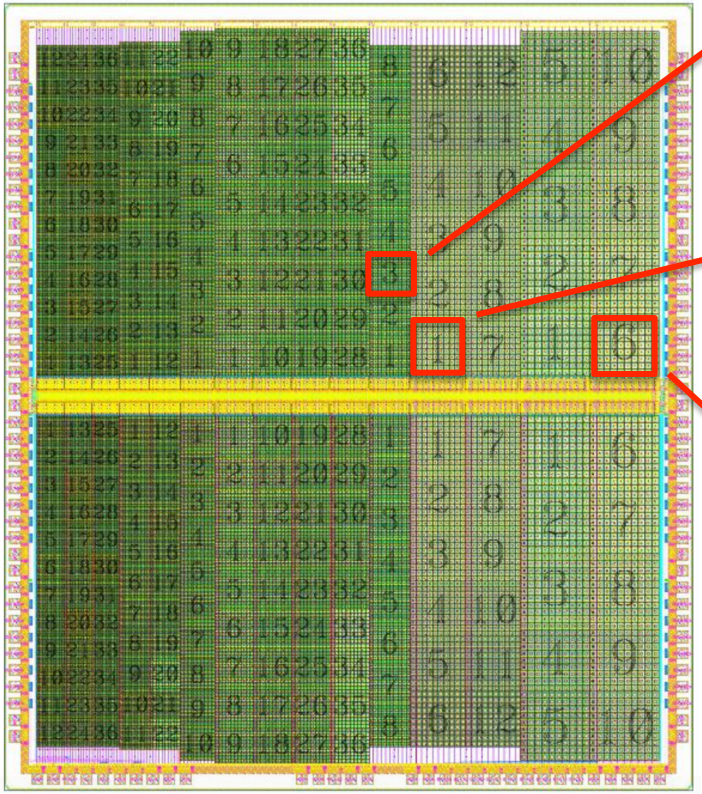
- Difficult to obtain full lateral depletion
- Not radiation hard

Modified process



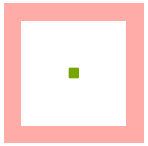
- A planar junction extends across the full pixel surface
- Radiation hard

TowerJazz Investigator

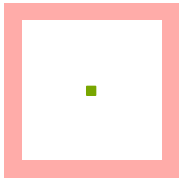


Minimatrix 106
- Pixel size 30x30μm^2
- Electrode size 3x3μm^2
- Opening 3μm

Minimatrix 112
- Pixel size 40x40
- Electrode size 3x3μm^2
- Opening 30μm



Minimatrix 129
- Pixel size 50x50μm^2
- Electrode size 3x3μm^2
- Opening 40μm



First test beam results published in 2017:
http://iopscience.iop.org/1748-0221/12/06/P06008

- Pure analogue test chip
- 134 different substructures for testing geometric properties
- New submission contains Investigator2 -> Separate biasing of deep p-well and substrate

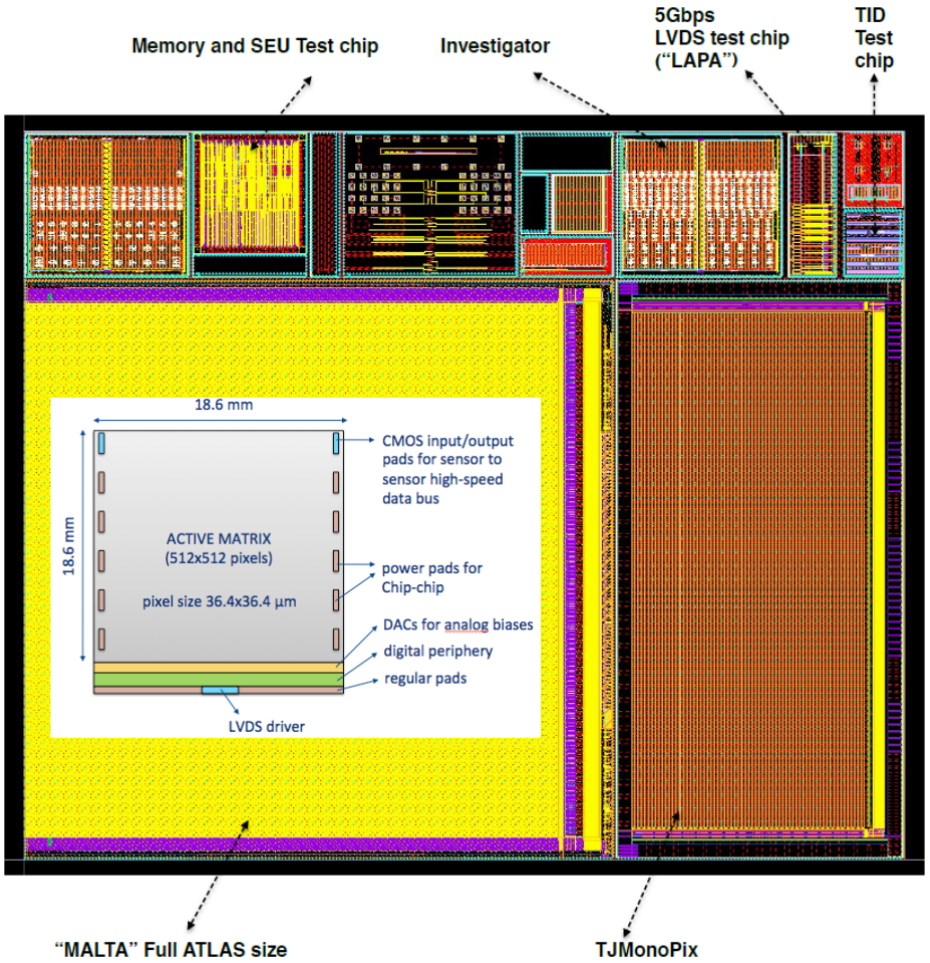
TJ full scale demonstrators

MALTA

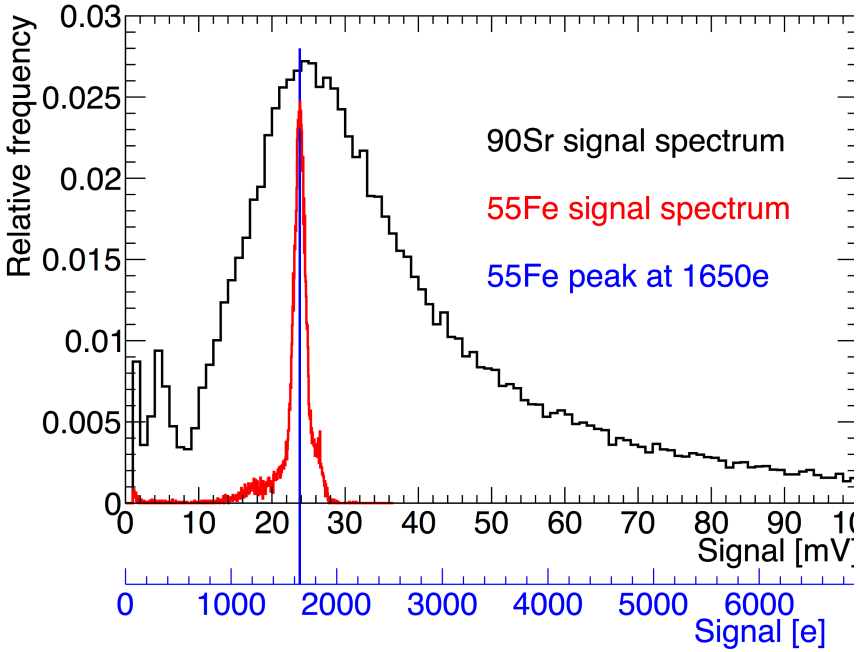
- 20x22mm (full Itk size)
- 512x512 pixels
- 36.4x36.4 um² pixel size
- Fully **asynchronous** readout (no clock over the matrix → low power)
- Fast front-end with pulse clipping (no ToT)
- Charge information retrieved from **timewalk** measurement
- 40 bits output buffer
- Sensor-to-sensor high speed data transmission
- Chip-to-chip power distribution

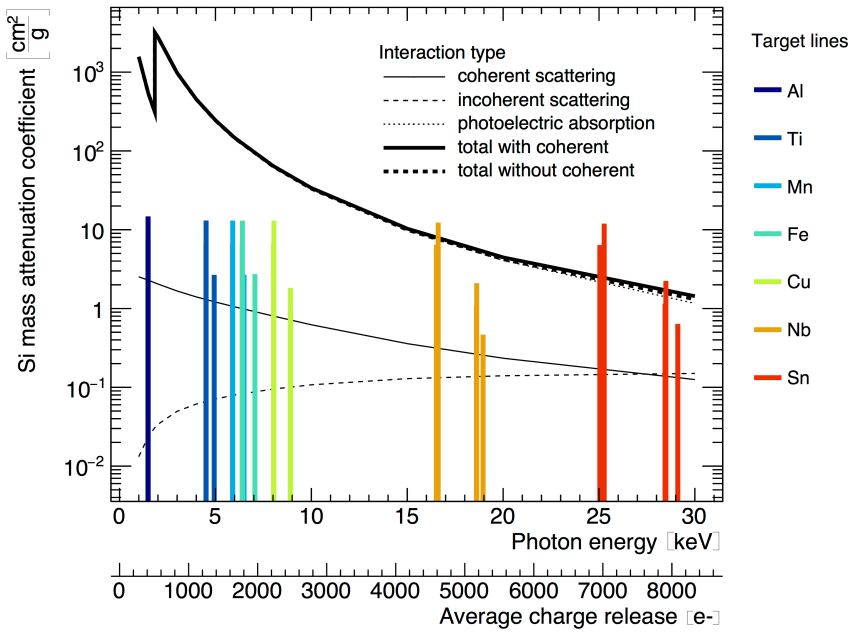
MonoPix

- 20x10mm (half ITk size)
- 512x256 pixels
- 36.4x40.0 um² pixel size
- Front-end inherited from MALTA, without clipping (ToT measured)
- "Classic" **column drain** architecture



X-ray analyses

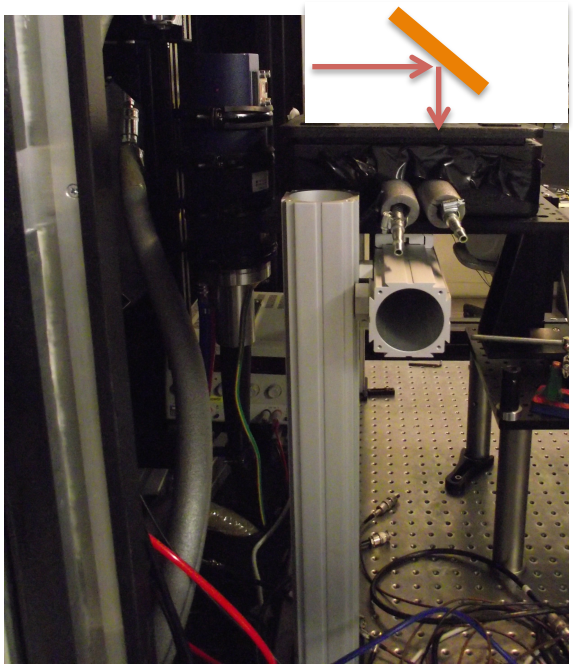


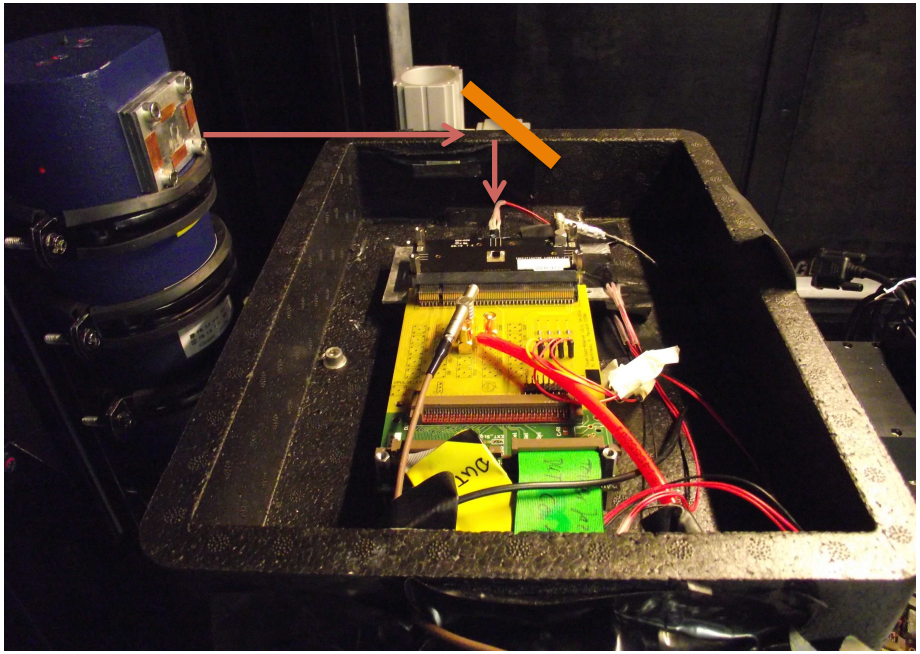


<u>Correlation between signal spectra in mV an energy spectra in electrons</u>

- During laboratory source scans: Only 55Fe as calibration point (-> 1650e)
- Lucky fact: Expected MPV for 25µm sensor is very close to 55Fe point.
- Using the X-ray fluorescence, more lines are available, covering the range

Glasgow X-ray fluorescence setup



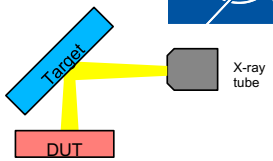


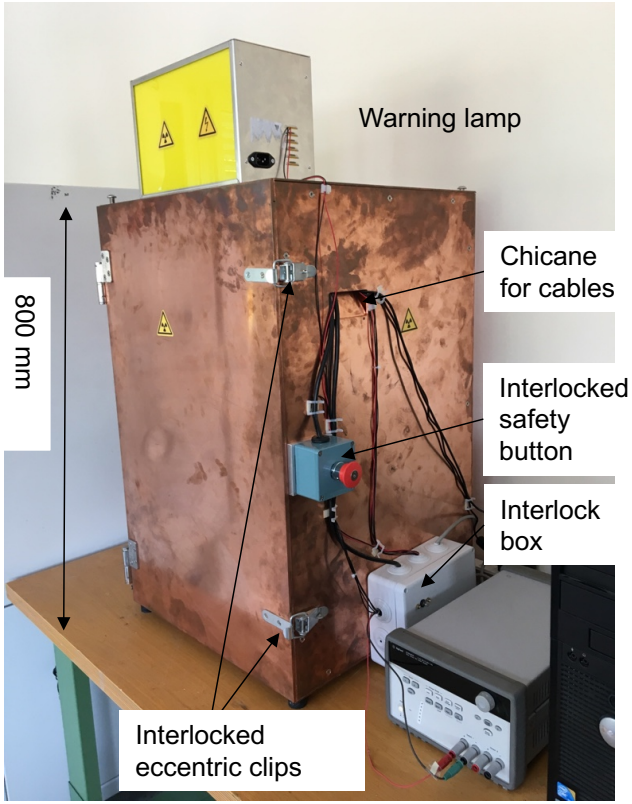
Setup and conditions

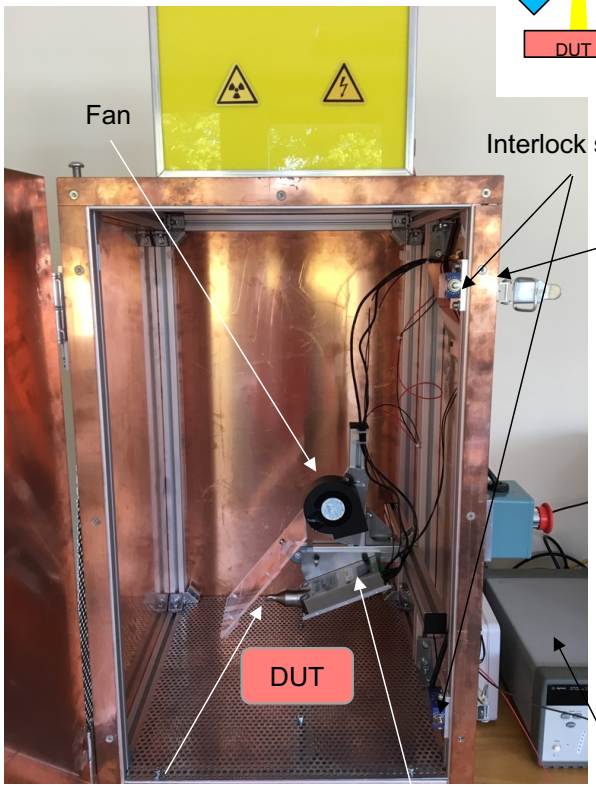
- Sensor mounted in a cooling box
- Cooling jig underneath the sensor
- Silicon oil chiller used for cooling both jig and incoming dry air

X-ray fluorescence setup at CERN

4 mm thick copper wall box with interlock system and x-y-z source mount



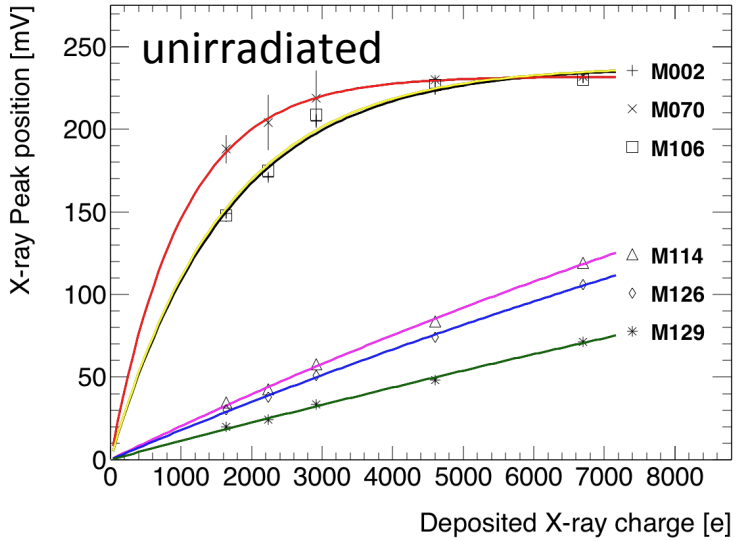


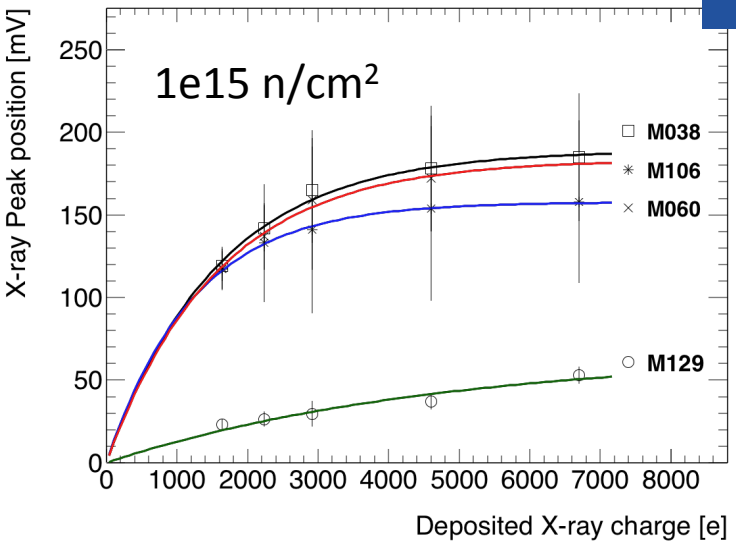


(Slide from 31st RD 50 Workshop)

With support from L. Tluosos, J. Alozy, M. Abbas and CERN EP-DT-EO

Glasgow X-ray fluorescence setup





Observations with flourescense x-rays

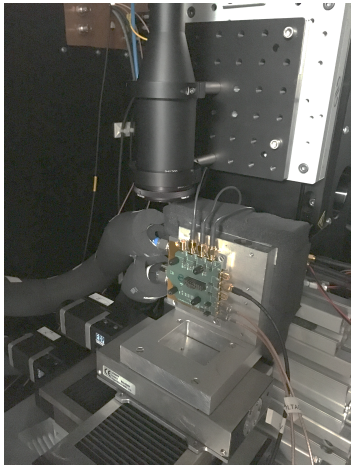
Fit function: $g(x) = s*\exp[-q/\tau]$

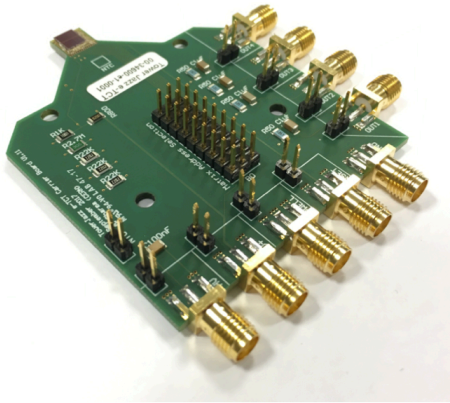
- 'low gain' and 'high gain' structures
- Linear range and saturation (which is expected)
- Gain reduction after irradiation
- TowerJazz Investigator standard process shown above

Suggestion: Measurements with Al or Ti to get additional points in low energy region

eTCT measurements (CERN/Oxford)

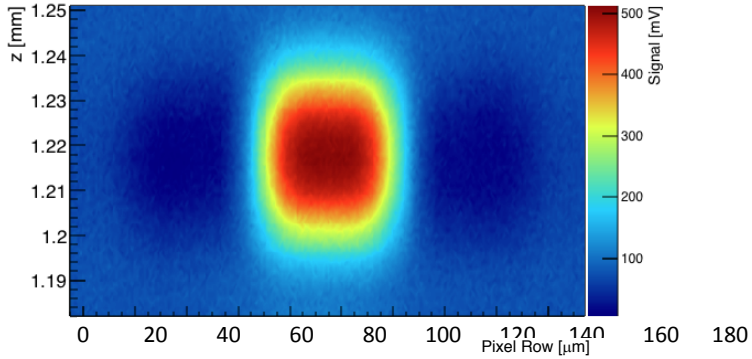
Laser Setup



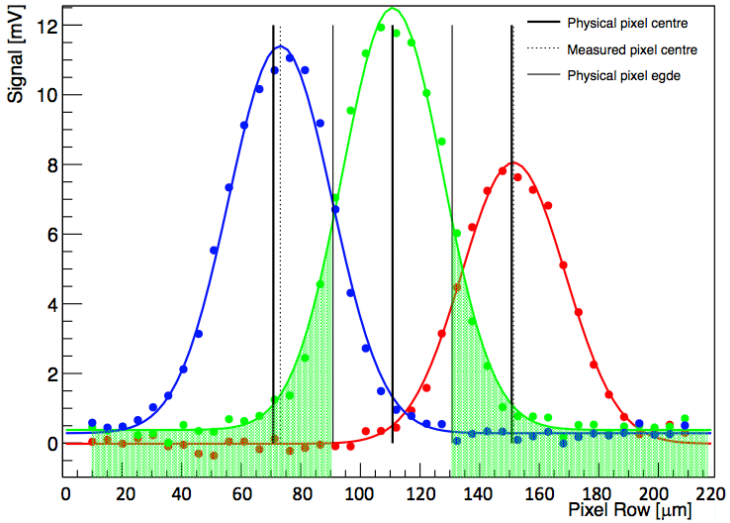


Investigator Carrier board

M129 (50µm) edge scan (single pixel)

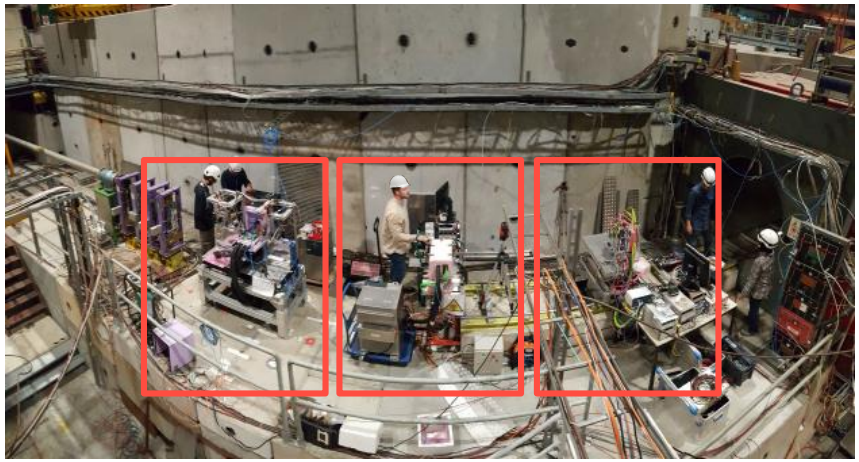


M129 (50µm) charge sharing (3 pixel row)

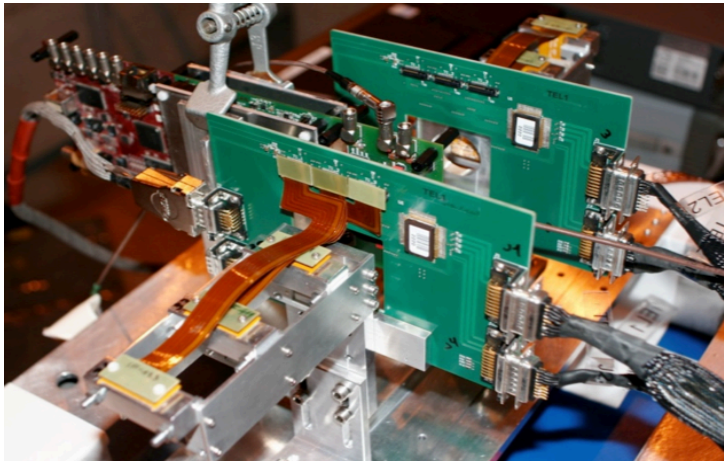


The AIDA SBM telescope

AMS-Geneva | TJ-CERN | LF-Bonn (1 week)



- 3 setups installed in **SPS H8b**
- Mostly **180 GeV pions**
- Overall good data taking

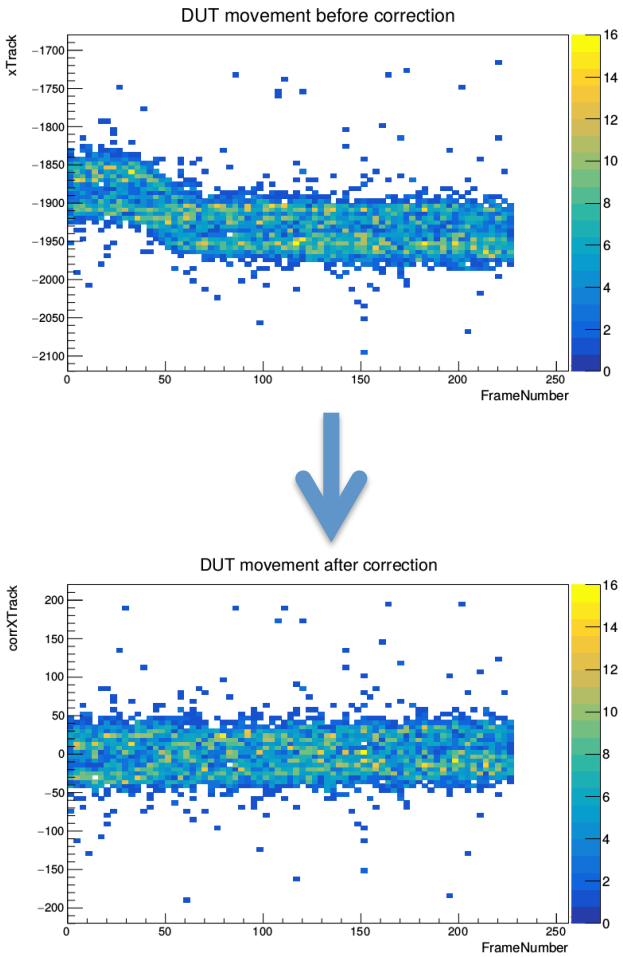


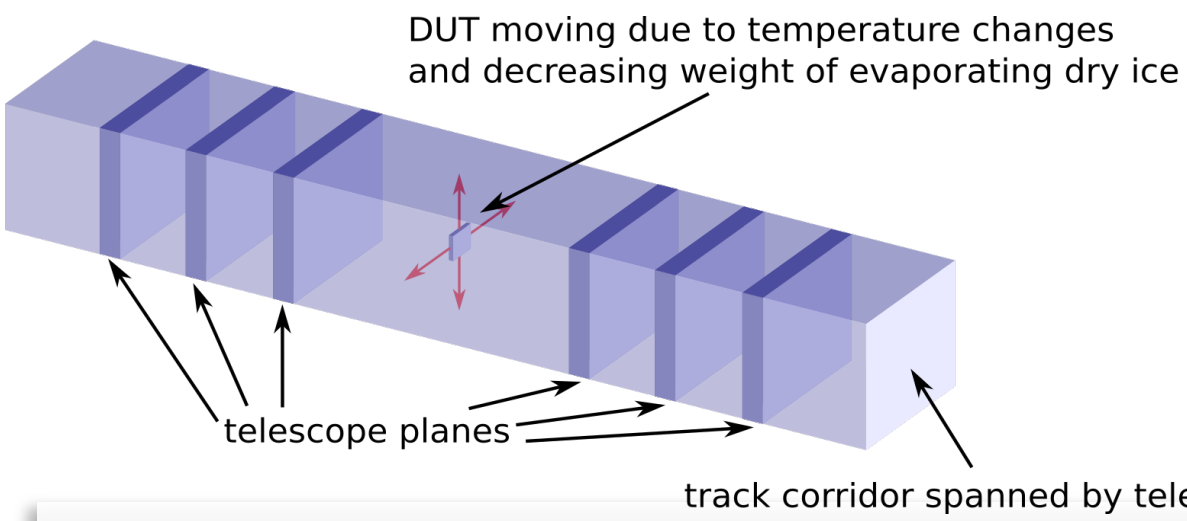
- AIDA SBM telescope
- **6 planes** of FE-I4 chips
- Pixel dimensions: **50x250μm^2**
- Planes and one arm **rotated by 90°**

- Alignment and tracking done with **proteus**
- Originally developed from “Judith” :
  - G. McGoldrick et al, NIM A765 140--145, Nov. 2014
  - Now developed and maintained by M. Kiehn et.al.
    - https://gitlab.cern.ch/unige-fei4tel/proteus

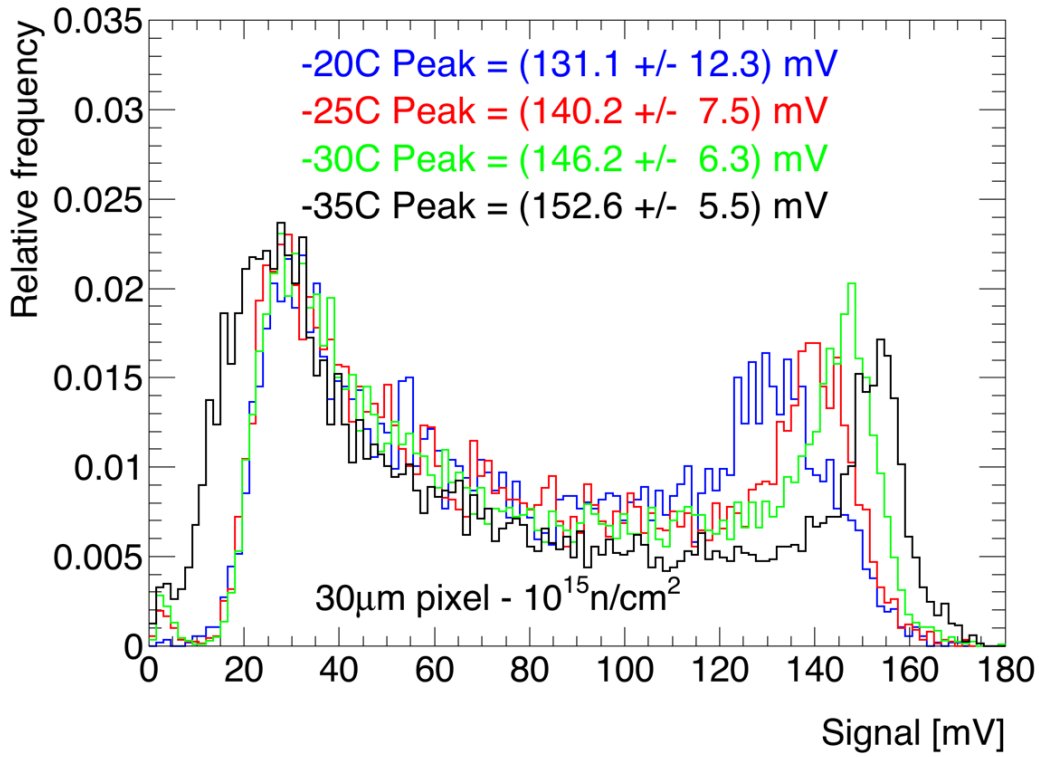
Correction for DUT movement

- DUT was **cooled with dry ice** during first 3 months
  - DUT moves with respect to telescope due to evaporation of dry ice
  - (change of mech. stress on setup) and to temperature changes
- Later runs: silicon oil chiller solved all dry-ice-related issues





Temperature dependence of gain

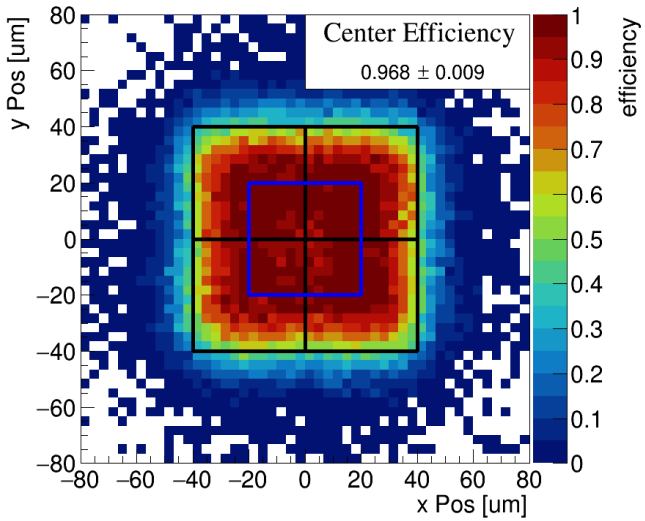


- Sensor tested: Modified process, 30µm pixel after 10^{15} n/cm^2
- Measurement in climate chamber with ^{55}Fe source
- Additional smearing (systematic uncertainty) of charge measurement
- Solution: Calibration with temperature controlled X-ray setup

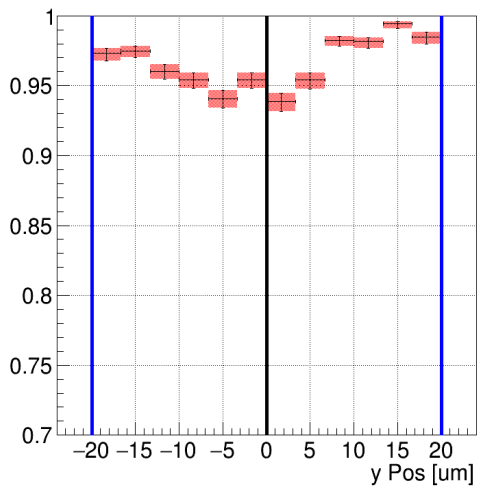
Irradiated 40 µm pixel – 10^{15} n/cm^2

- Pixel size of 40x40µm^2, 30µm spacing, 3µm electrode

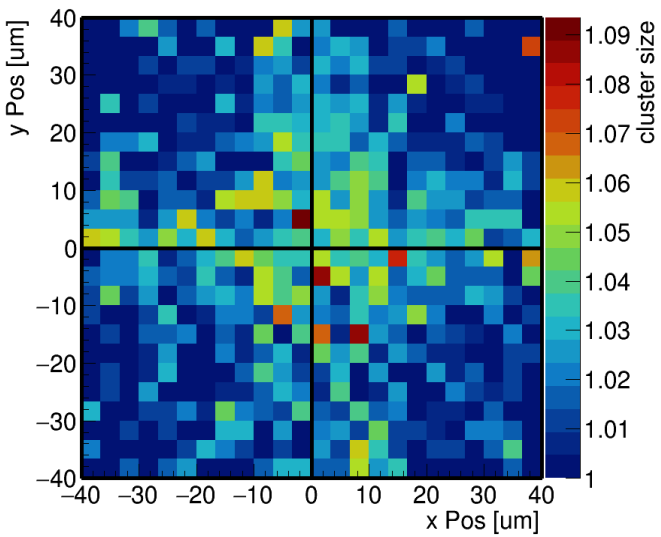
Efficiency



y Projected Efficiency



DUT position resolved cluster size



Status of MALTA testing

Readout

- Based on a Virtex 707 evaluation board
- **Asynchronous oversampling**
- 10MHz slow control
- Communication and software following the **ITk protocol**
- Trigger/busy logic for integration with test setups (e.g. test beam telescope)

Current work

- Two MALTA chips have been wire bonded; two more being wire bonded right now
- Testing started on 31/1: powering, slow control, readout, ...
- Chips (MALTA, MonoPix, Investigator, Investigator2) sent for **neutron irradiation** to nuclear reactor in Ljubljana: $10^{14} n_{eq}/cm^2$, $10^{15} n_{eq}/cm^2$ and $2x10^{15} n_{eq}/cm^2$
- **X-ray irradiation** can be done in-house at CERN

- Intensive **test beam** campaign: ELSA (Bonn) and SPS (CERN)

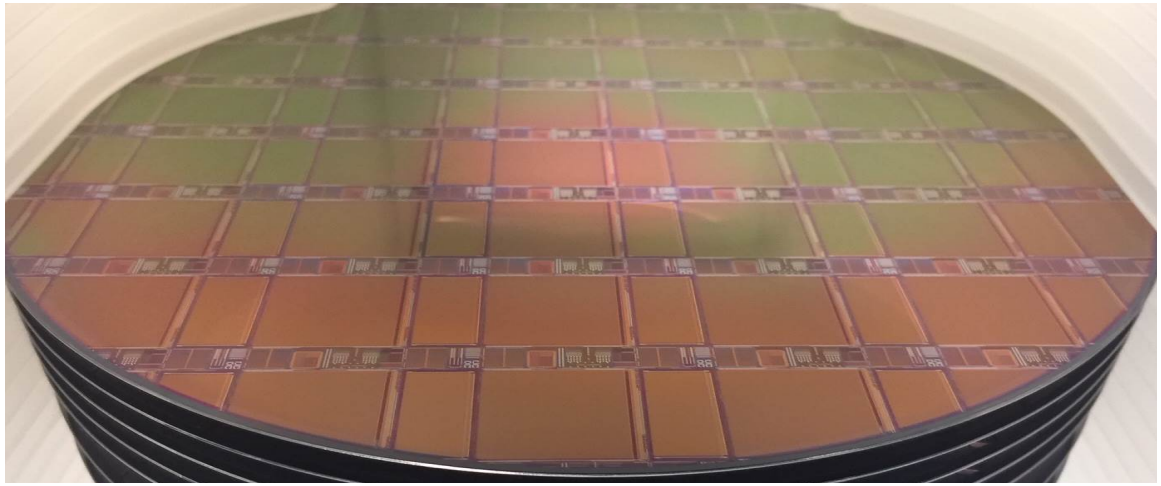
Conclusions

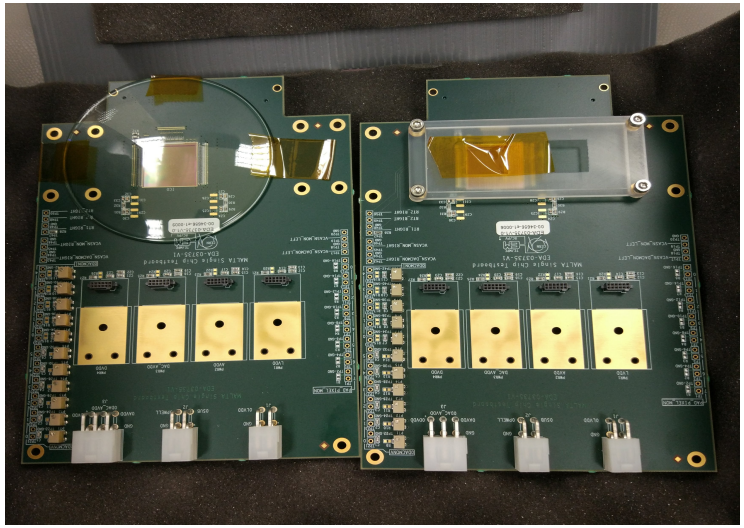
- TowerJazz 180nm CMOS technology has been well established for monolithic sensors in ALICE.
- 2 years of Investigator results have shown that the same technology may be proposed for the **outer layer of the ATLAS ITk.**
- New submission also contains **Investigator2**

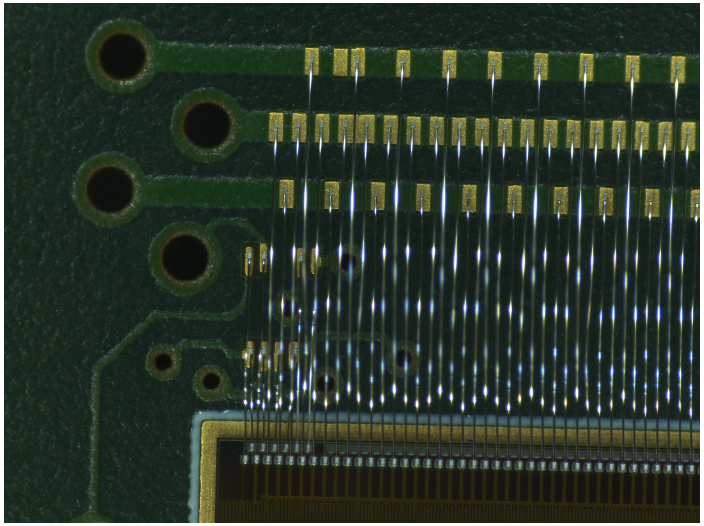
- Two full size demonstrator chips:
  MALTA (asynchronous) and MonoPix (column drain)
- **Very low collection capacitance** (electrode size of a few um²)
  => allowing for low noise and high speed front-end
- Chips of the first wafers sent for neutron **irradiation**
- First tests are ongoing

- **Intensive testing campaign** for the coming months
- Well equipped arsenal of test setups and methods!

Questions?

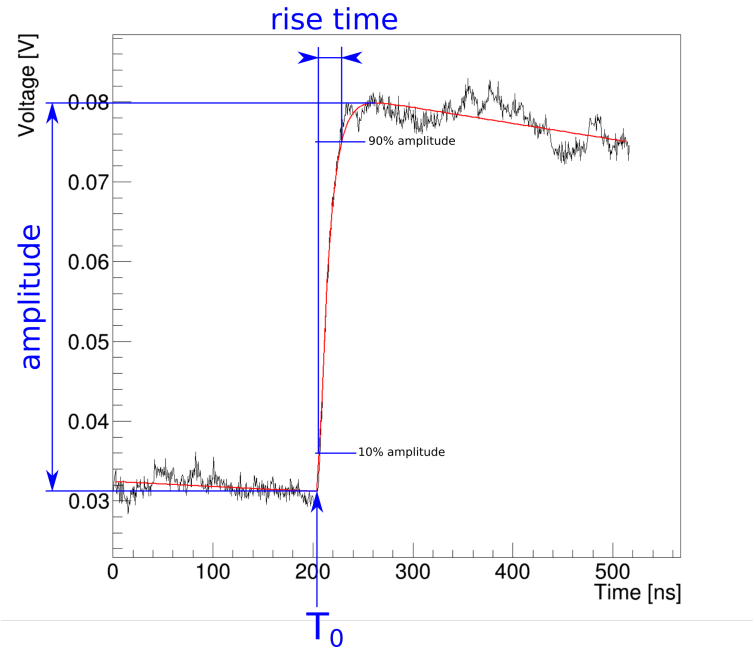






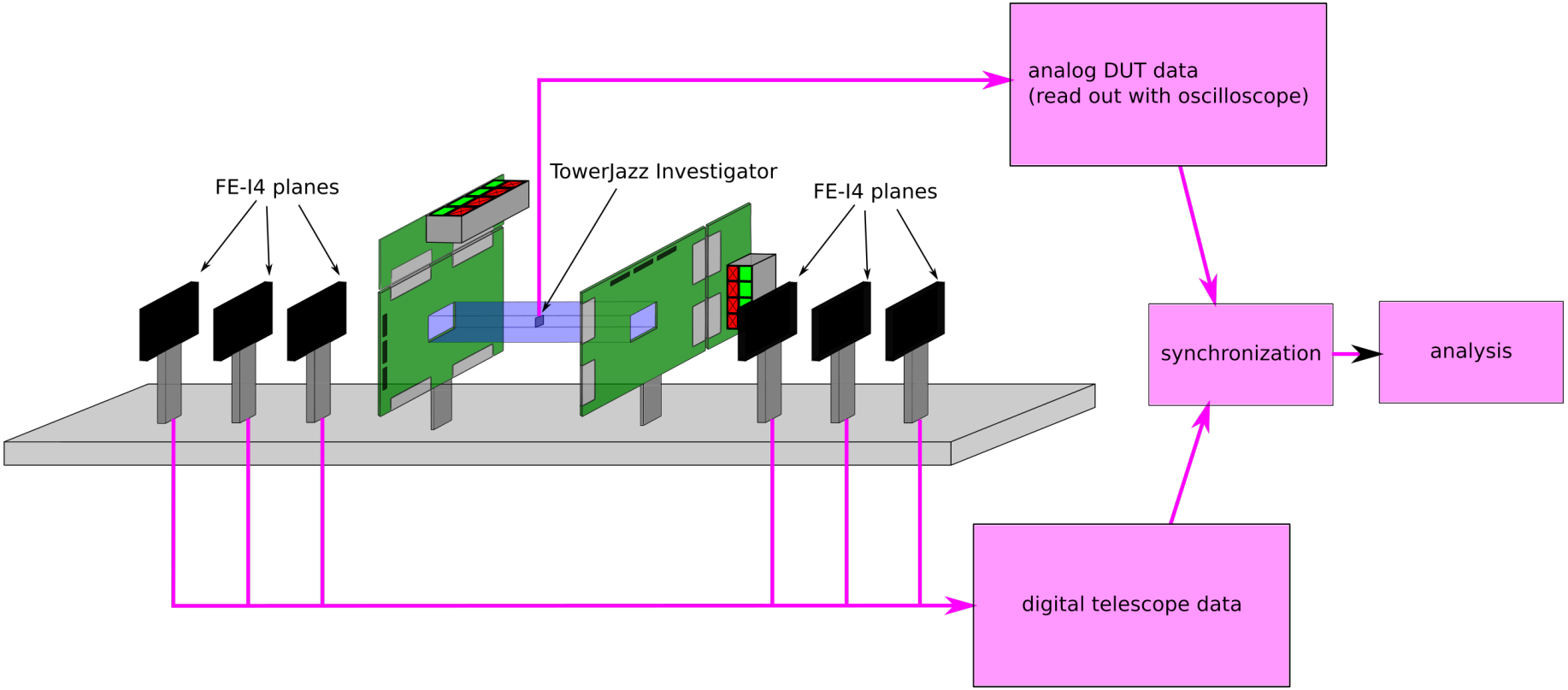
BACKUP

Fitting the analogue waveform



- x_1: offset
- x_2: slope
- x_3: amplitude (infers energy when calibrated)
- x_4: T_0
- x_5: rise time parameter (rise time = $2.2*x_5$)
- x_6: pulse decay (i.e. another slope after the pulse)

Combined setup of telescope and DUT



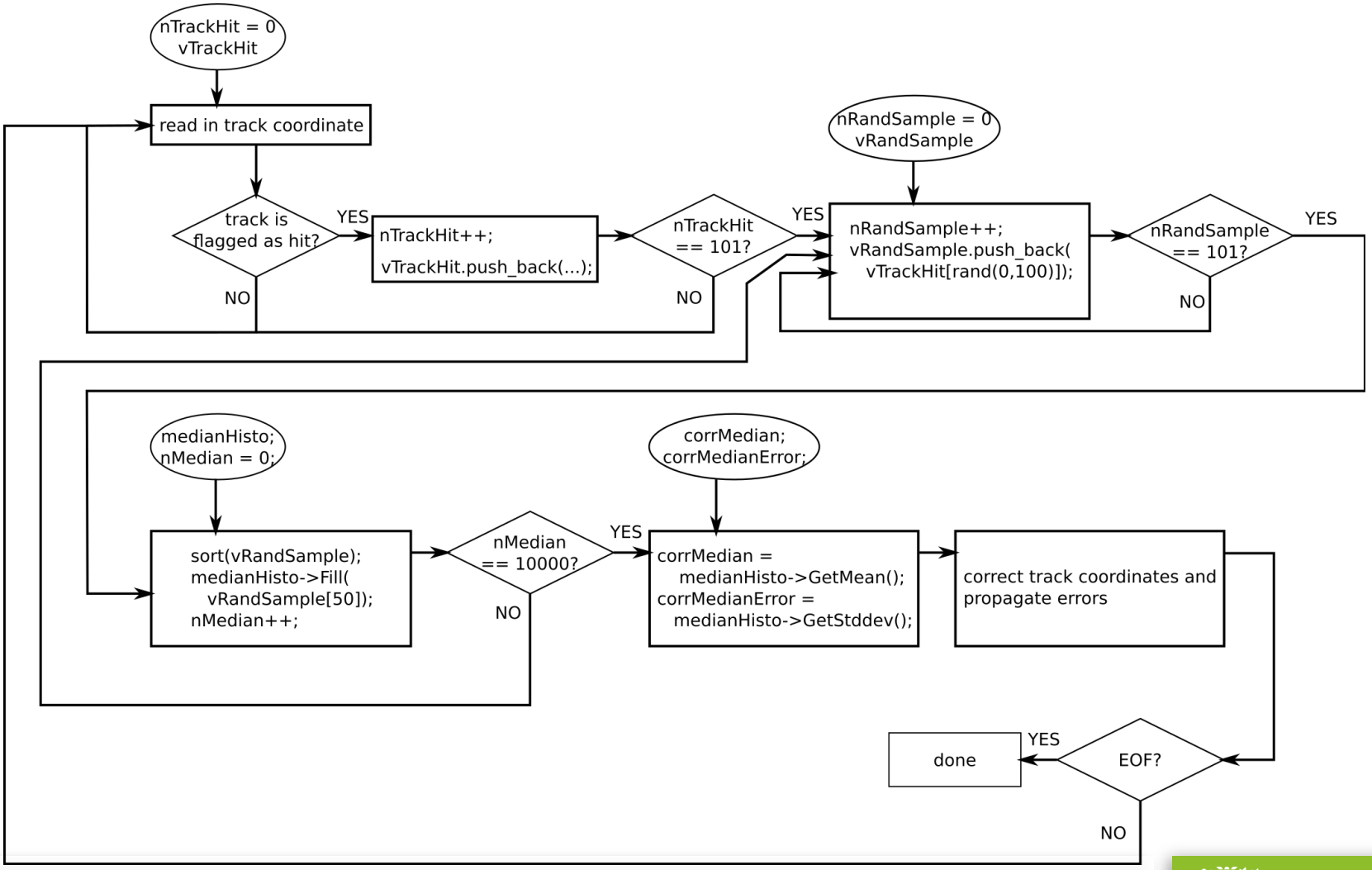
Correction for DUT movement

- It is assumed that the **DUT moves slowly** compared to the rate at which events are recorded.

- Data from a single run is **split into time ordered "slices"**
  - A number of events is **read in until at least 100 tracks** with an associated signal from the DUT are found
  - From this set of events the **median of the track coordinates** and its error is calculated (for both x and y direction)
  - The coordinates of each track of this set of events are then **corrected by subtracting the median** value
  - The median error is added in quadrature to the track position errors

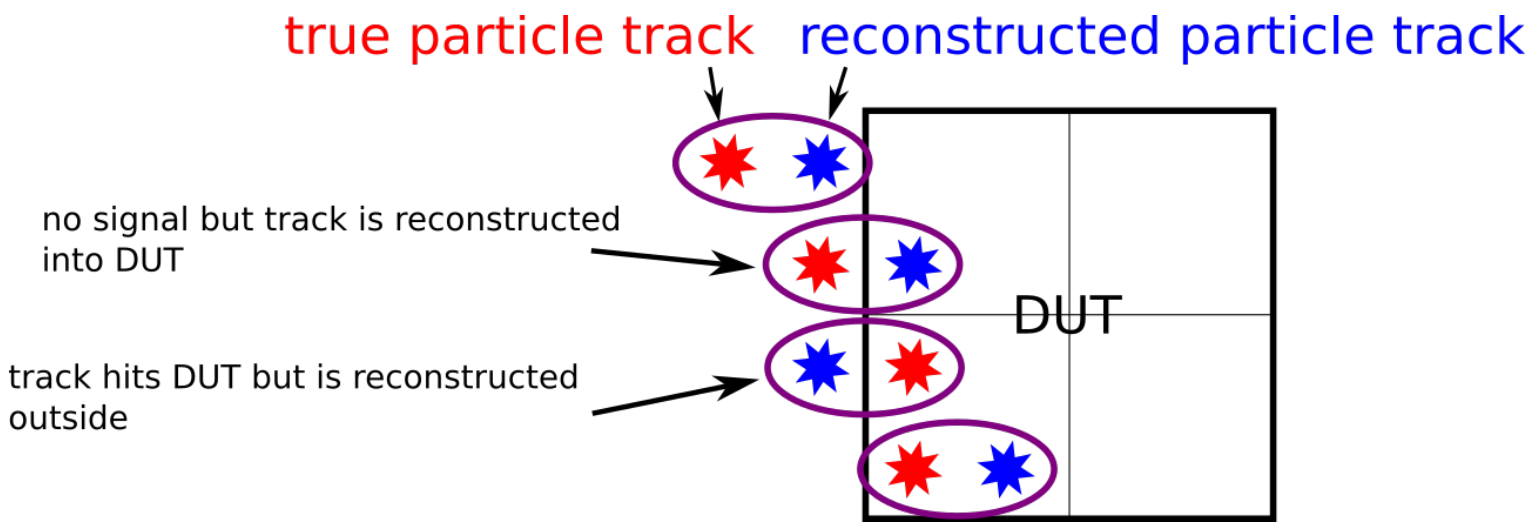
- This procedure **increases the error on track positions** and reduces the effective resolution of the telescope

Correction for DUT movement



Edge effects

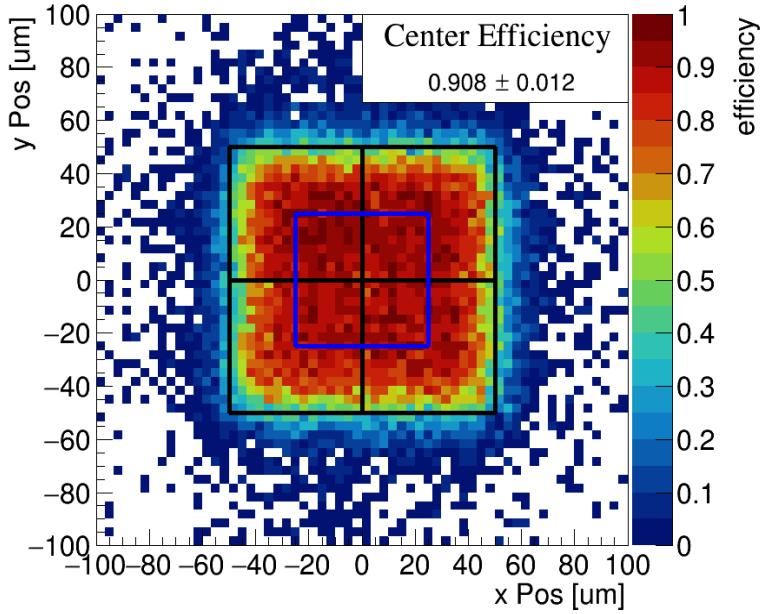
- Edge effects are considerable
  - Telescope resolution almost in the order of DUT dimensions
  - Efficiency only unaffected in the center of the DUT



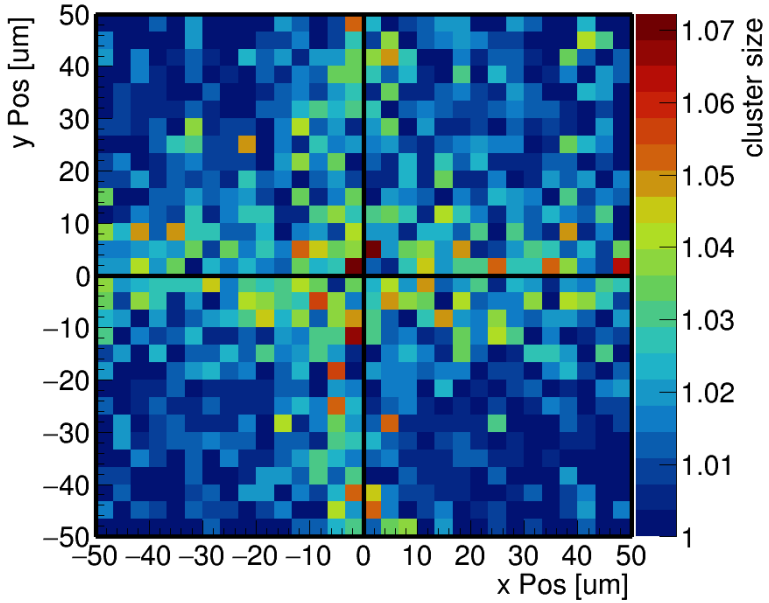
Unirradiated 50 µm pixel

- Pixel size of 50x50µm^2, 40µm spacing, 3µm electrode

Efficiency



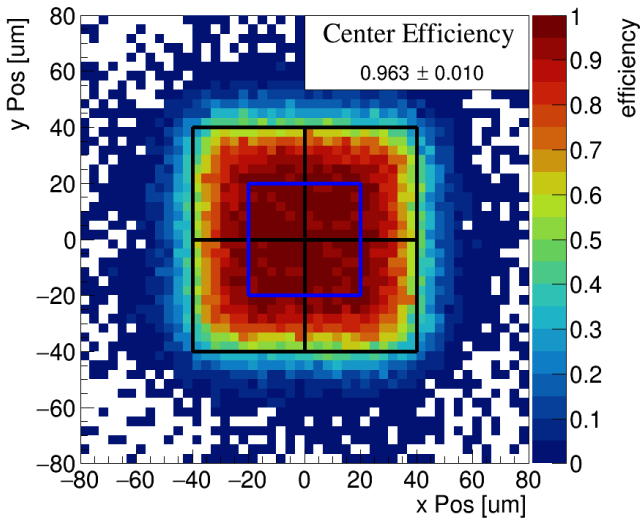
DUT position resolved cluster size



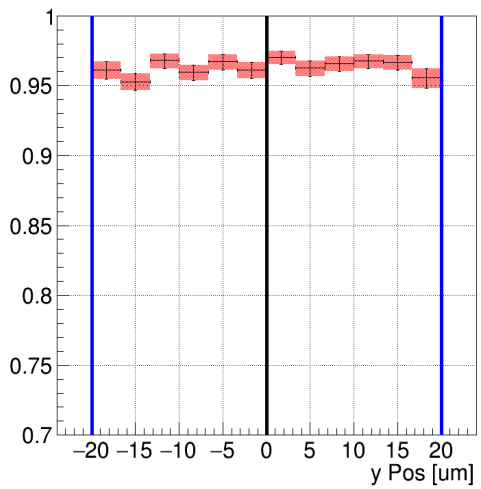
Unirradiated 40 µm pixel

- Pixel size of 40x40µm^2, 30µm spacing, 3µm electrode

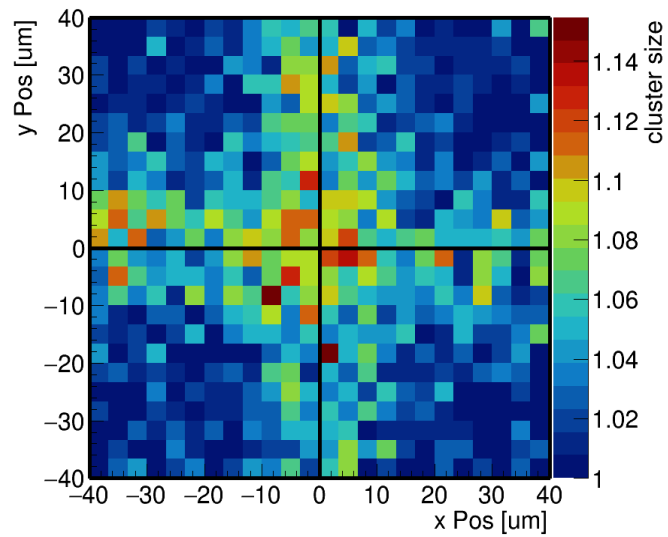
Efficiency



y Projected Efficiency



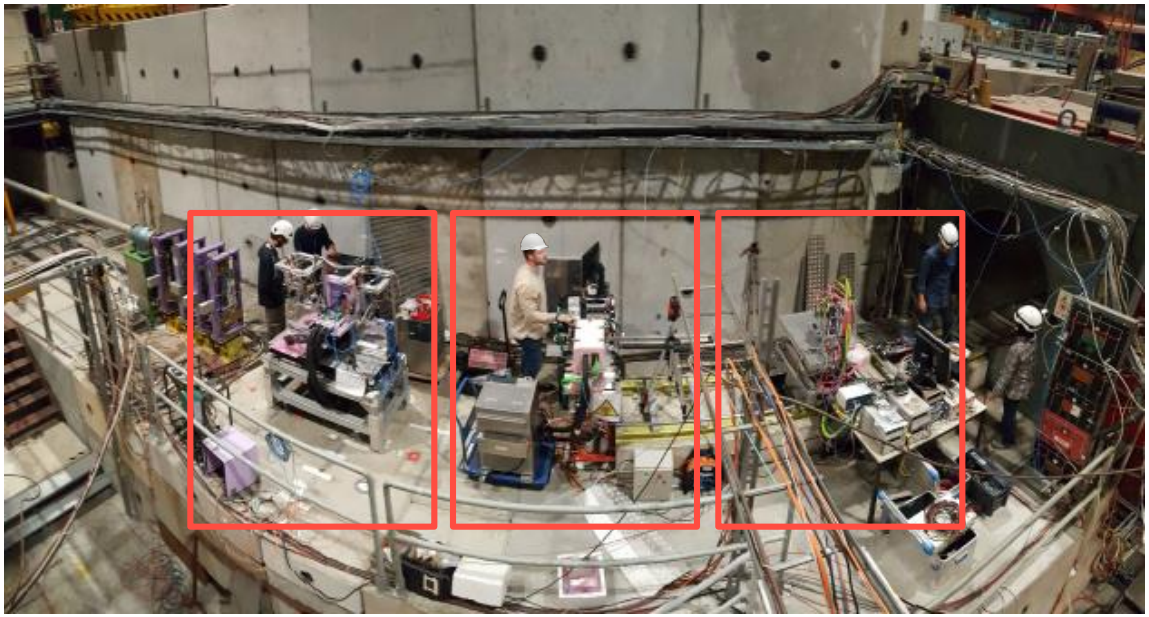
DUT position resolved cluster size



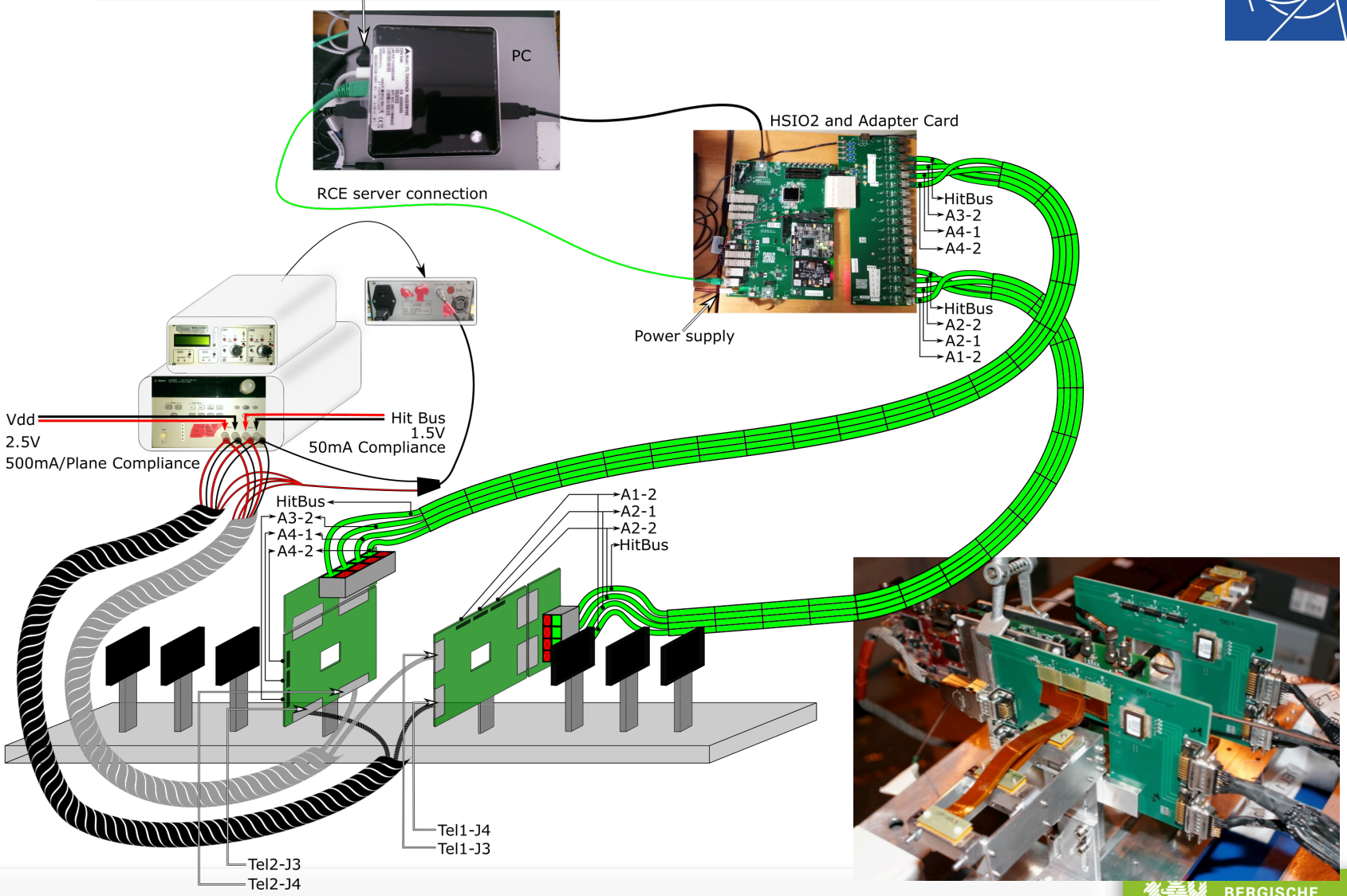
CERN SPS testbeam campaign 2017

- 3 setups installed in **SPS H8b**
- 3 weeks as main users (1 in May, 2 in September)
- Mostly **180 GeV pions**
- Overall good data taking

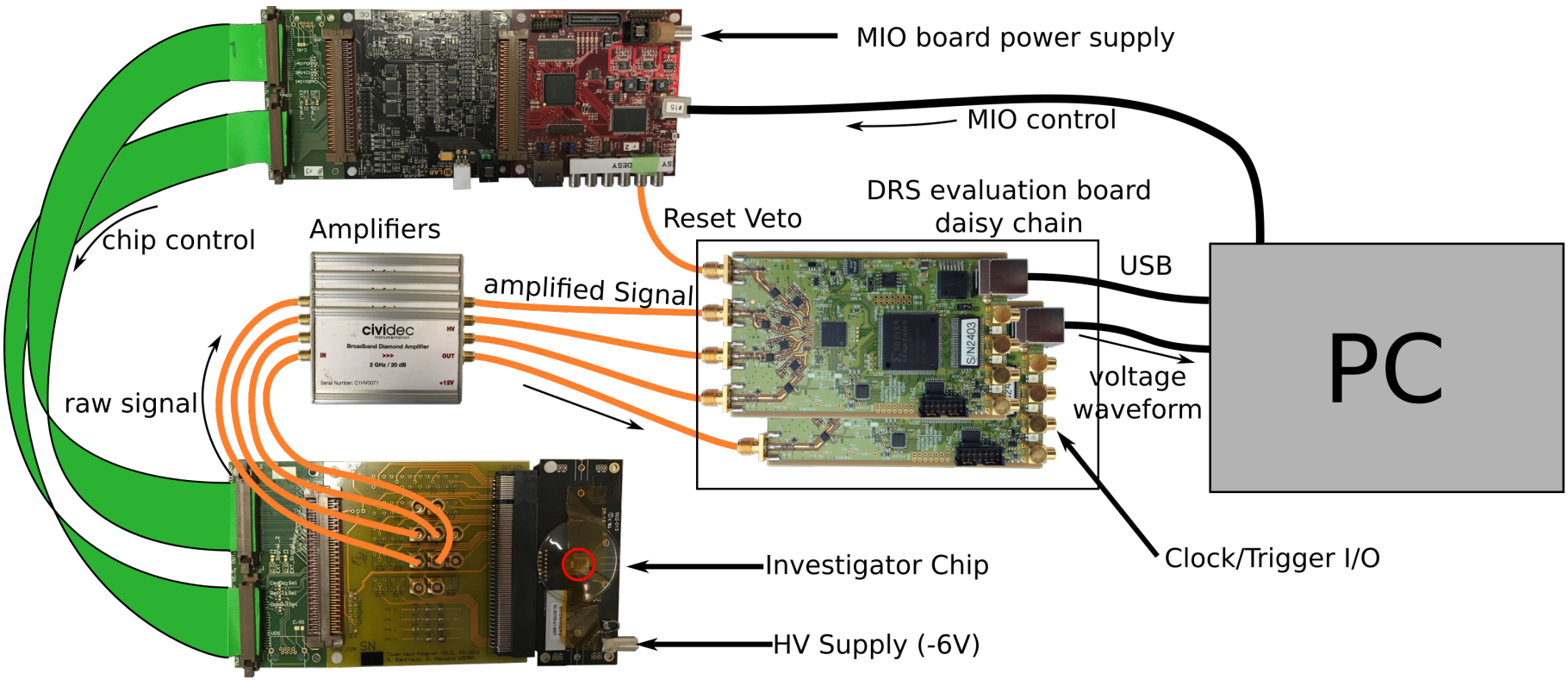
AMS-Geneva | TJ-CERN | LF-Bonn (1 week)



Telescope setup



Integration of the DUT



Correcting edge effects

- In order to correct for edge effects, the probability p that the true track was inside the DUT is calculated for each track
- This is done by integrating a 2D gaussian over the DUT area
- The gaussian is centered around the track position and the sigmas of the gaussian are the errors of the track position
- The count of the bin where the track landed is then increased by 1/p