Resolution studies on silicon strip sensors with fine pitch

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Aim of the effort

Evaluate the best strip geometry of silicon strip sensors with 50 micron pitch to achieve the highest possible spatial resolution

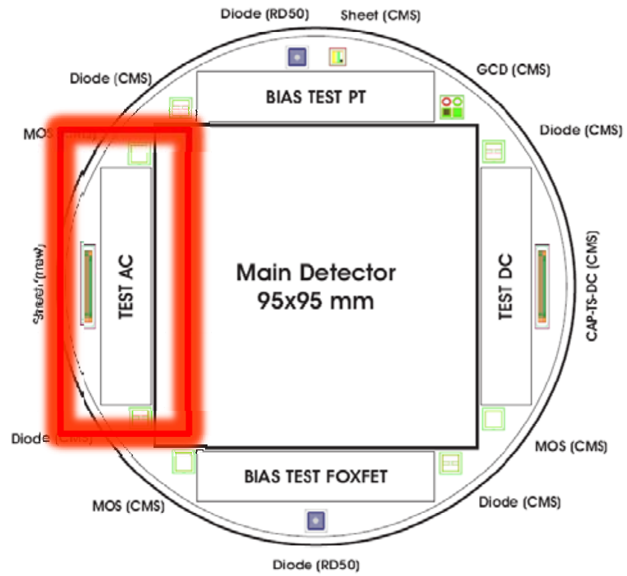
Ingredients:

- Dedicated mini sensor developed by SiLC collaboration
  - Different zones, each with a different strip geometry
- EUDET pixel telescope
  - to get high precision tracks to determine the residuals for our DUTs [Devices under Test]
- 120 GeV Pions from CERN SPS

SiLC Sensor Order

SiLC Collaboration ordered at Hamamatsu (HPK):

- 30 pcs single-sided 6” wafer
- 5 pcs. alignment sensors of same layout, but hole for laser in backplane metallization



Specifications:

- Wafer thickness : 320 μm
- Depletion voltage around 75V
- 1792 AC-coupled strips, individually biased via poly-Si resistor (20MOhm)
- Strip pitch: 50 μm pitch,
- Strip width: 12.5μm
- No intermediate strips

- Additional test structures around the wafer

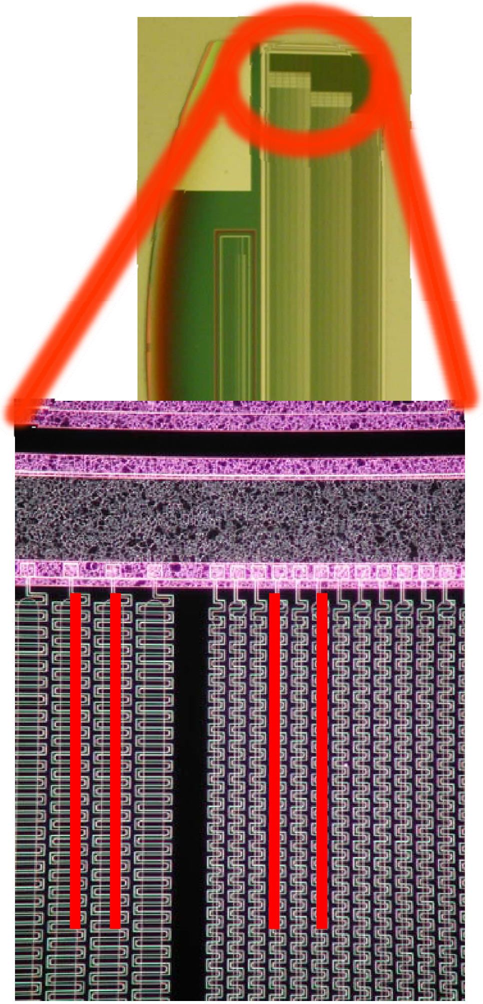
Multi-geometry test structure

TEST-AC structures:

- 256 strips with 50µm pitch
- 3 region with no, one or two intermediate strips
- Different strip widths

- 16 different zones, each consisting of 16 strips
- Layout constant within each zone
- **Strip width** and **number of intermediate strips** vary between the zones

- Idea: Determine best geometry in terms of resolution
- Using a testbeam with high-energy hadrons



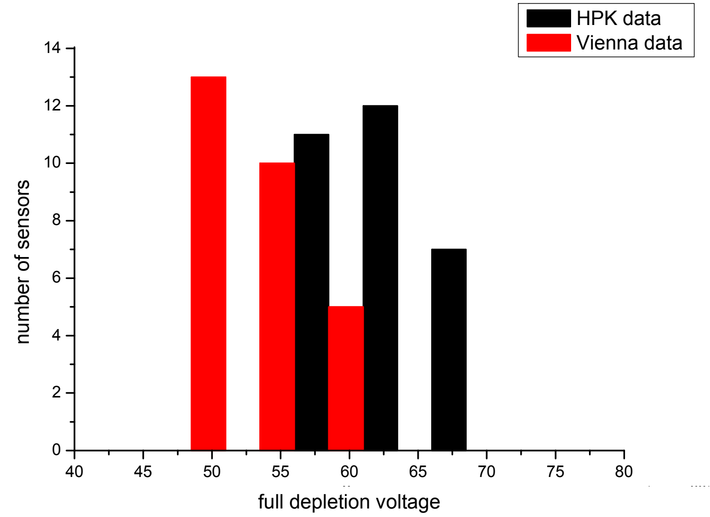
TESTAC:

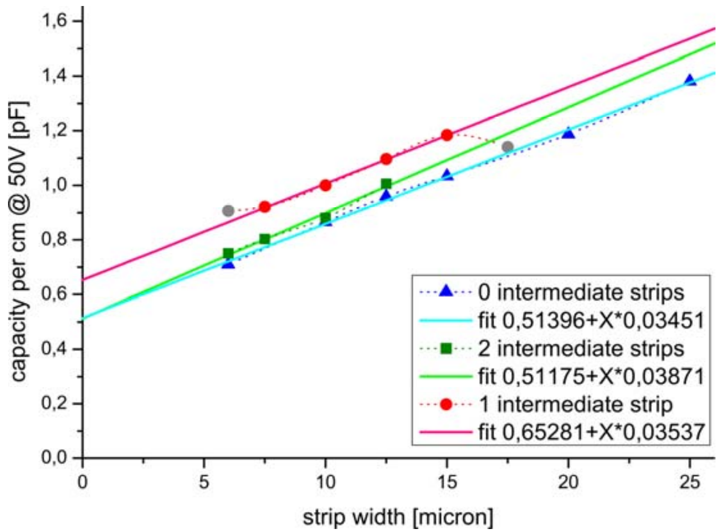
strip width [µm]	intermediate strips
5	no
10	no
12.5	no
15	no
20	no
25	no
5	single
7.5	single
10	single
12.5	single
15	single
17.5	single
5	double
7.5	double
10	double
12.5	double

Sensor Electrical Characterization

- SiLC sensors and test structures have been intensively tested in Vienna
  - IV curves on all sensors
  - CV curves to determine full depletion voltages (approx 50-65V)

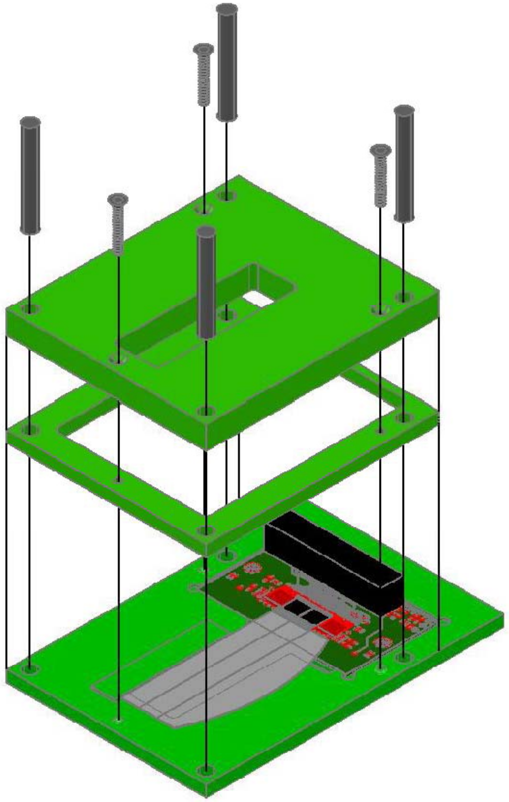
- Measurement of the inter-strip capacitance reveal different values for each zone:
  - Capacitance scales linearly with strip width
  - Different offset for region with one or two intermediate strips

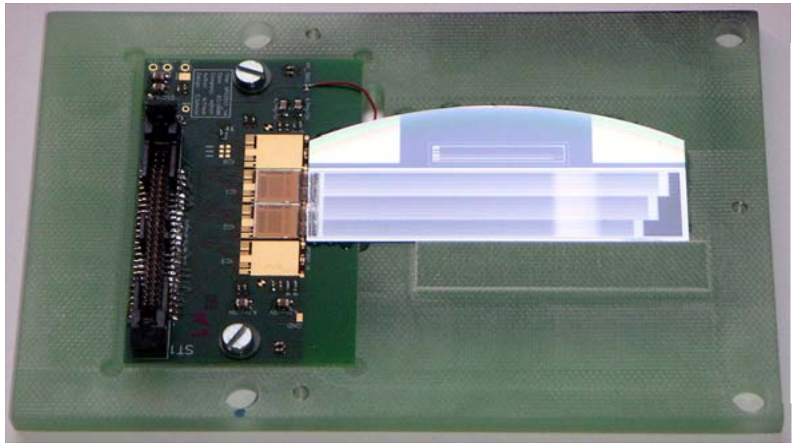




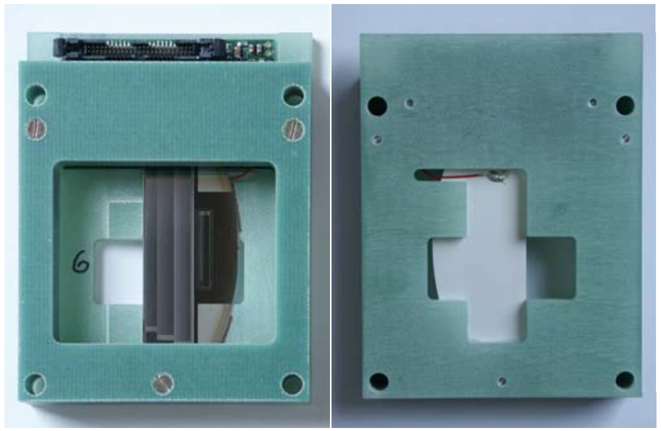
Modules

9 modules have been built in Vienna using self-developed hybrid based on APV25 readout chip (similar to CMS Tracker)





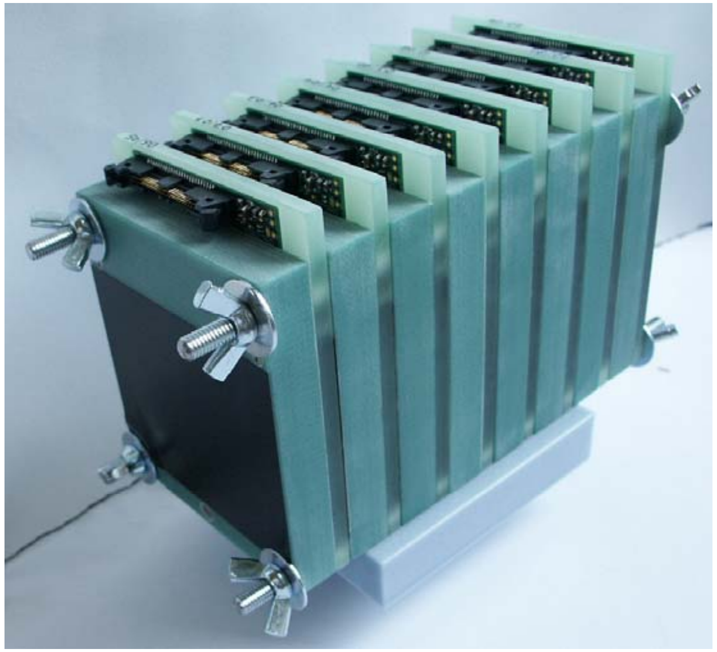
Front side: Back side:

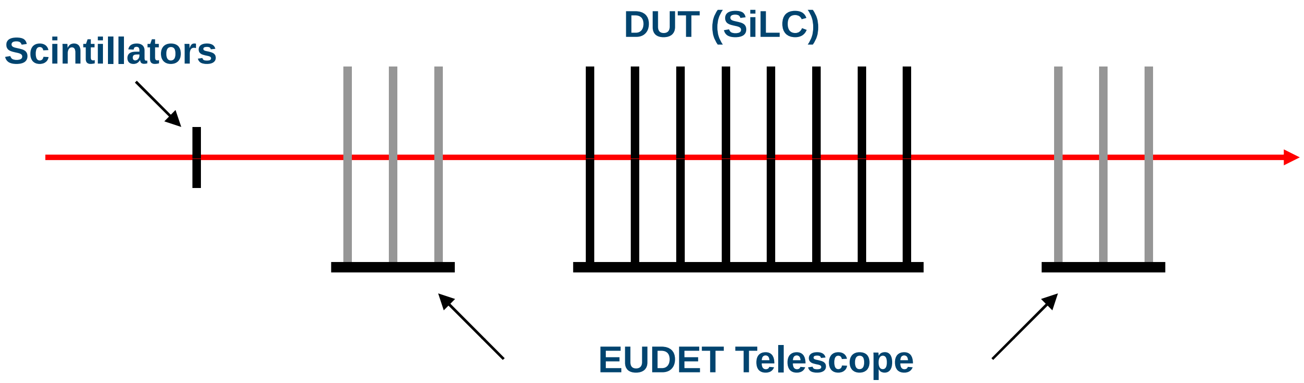


Module Stack

- 8 Modules have been screwed together
- To be mounted in between EUDET telescope

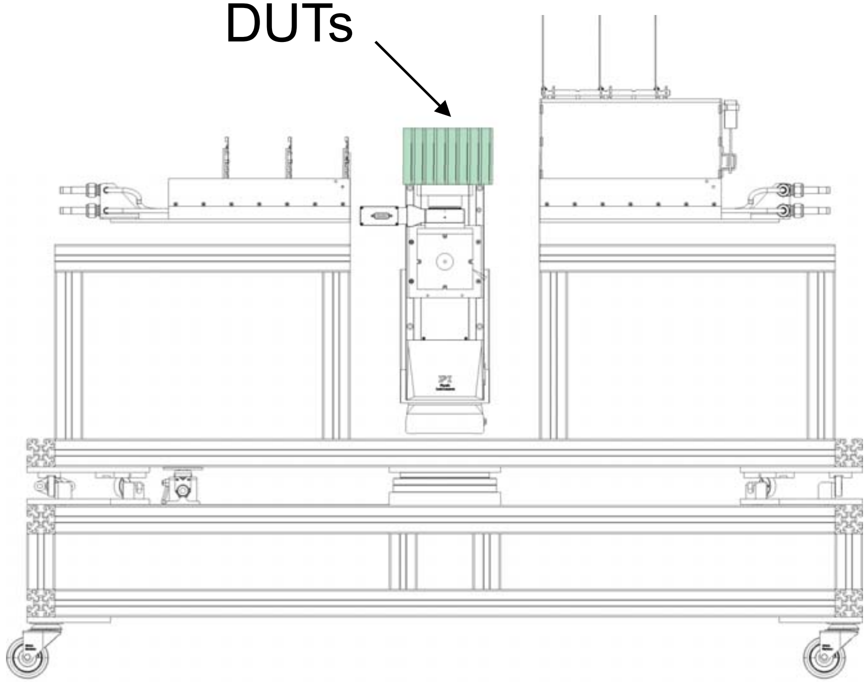
- Stack of 8 modules would allow us autonomous tracking

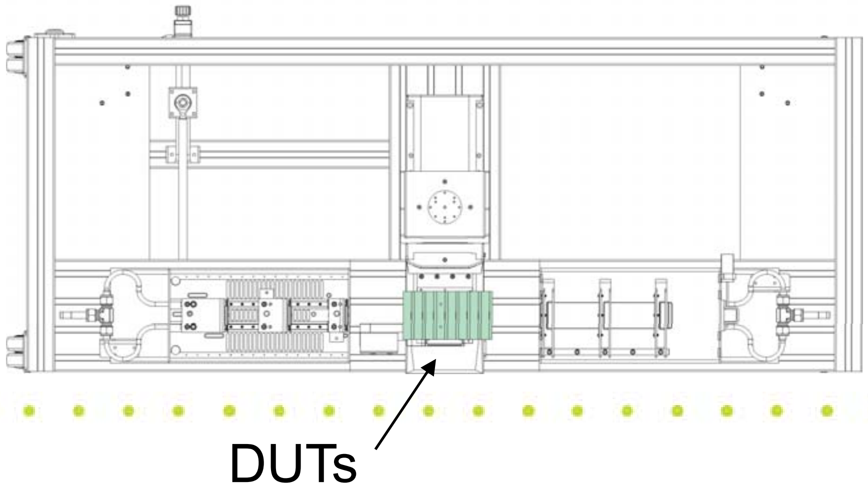




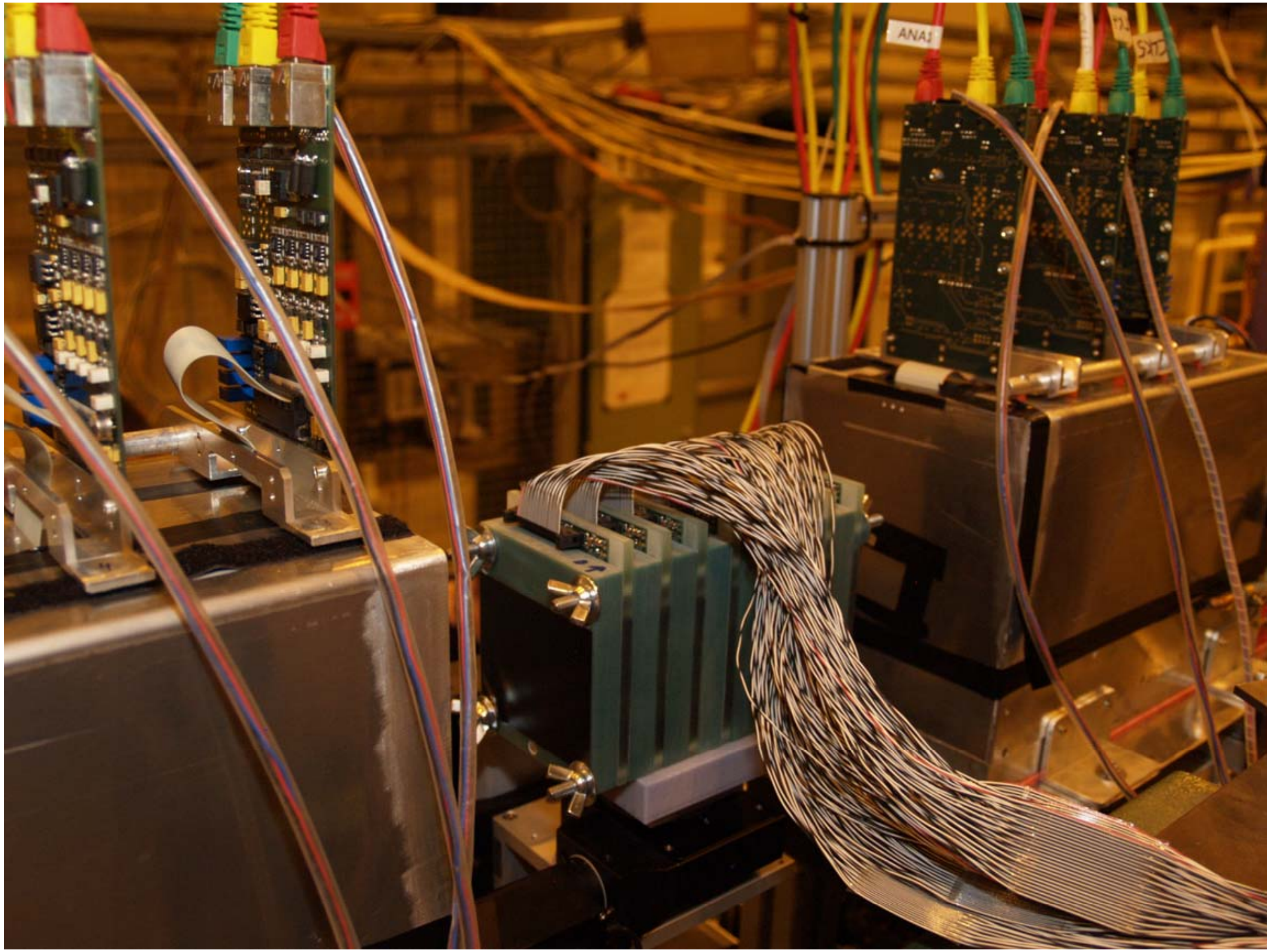
Arrangement on Telescope

- Stack of 8 DUT modules are mounted onto XYZ-stage of telescope by the help of a small adapter table
  - Construction drawings of Telescope support and XYZ table were very helpful in designing this table
  - Everything was installed in H6B aera at CERN (SPS NA Hall)
  - From 30. May to 5. June 2008

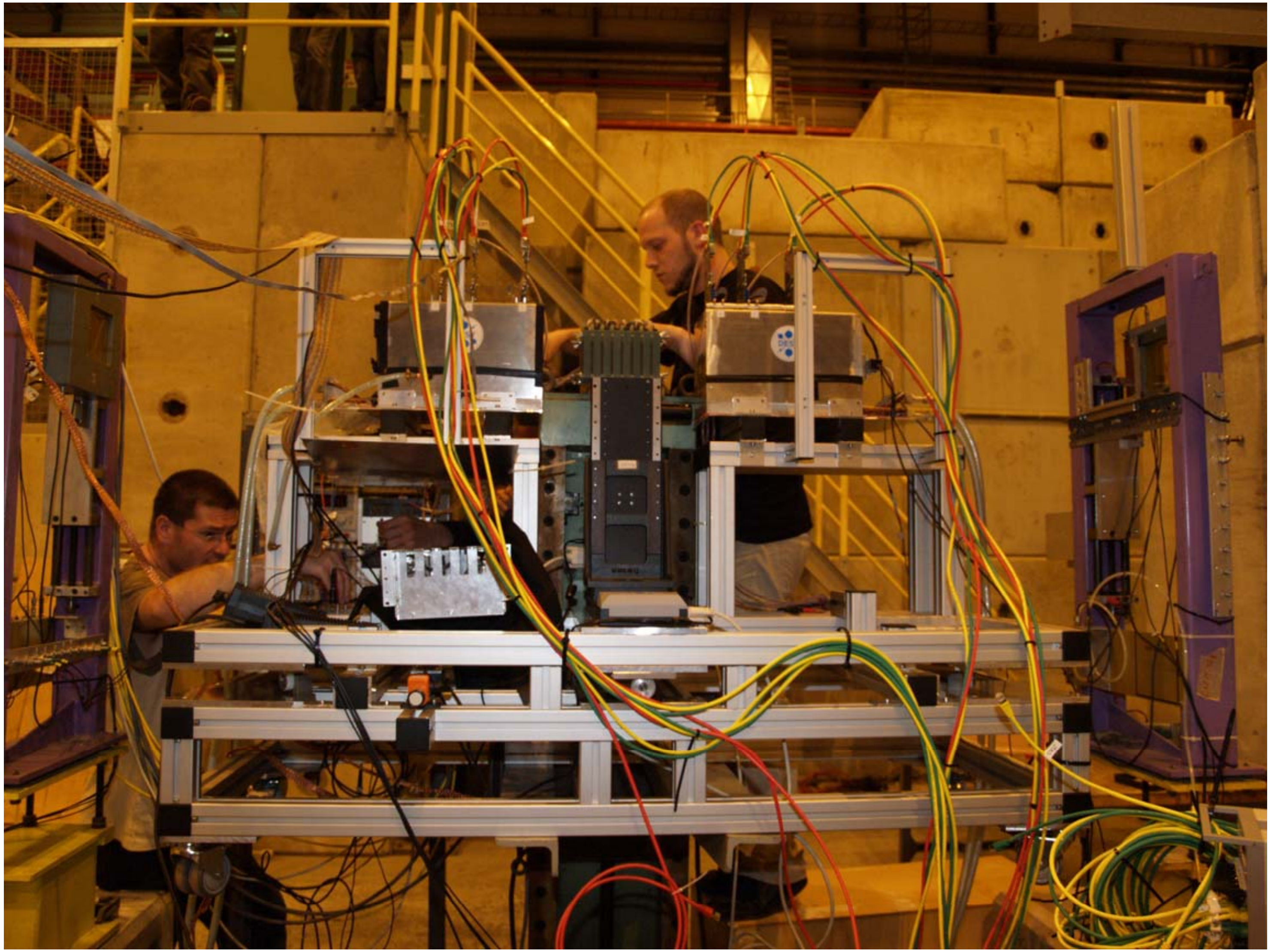




Setup (I)



Setup (II)

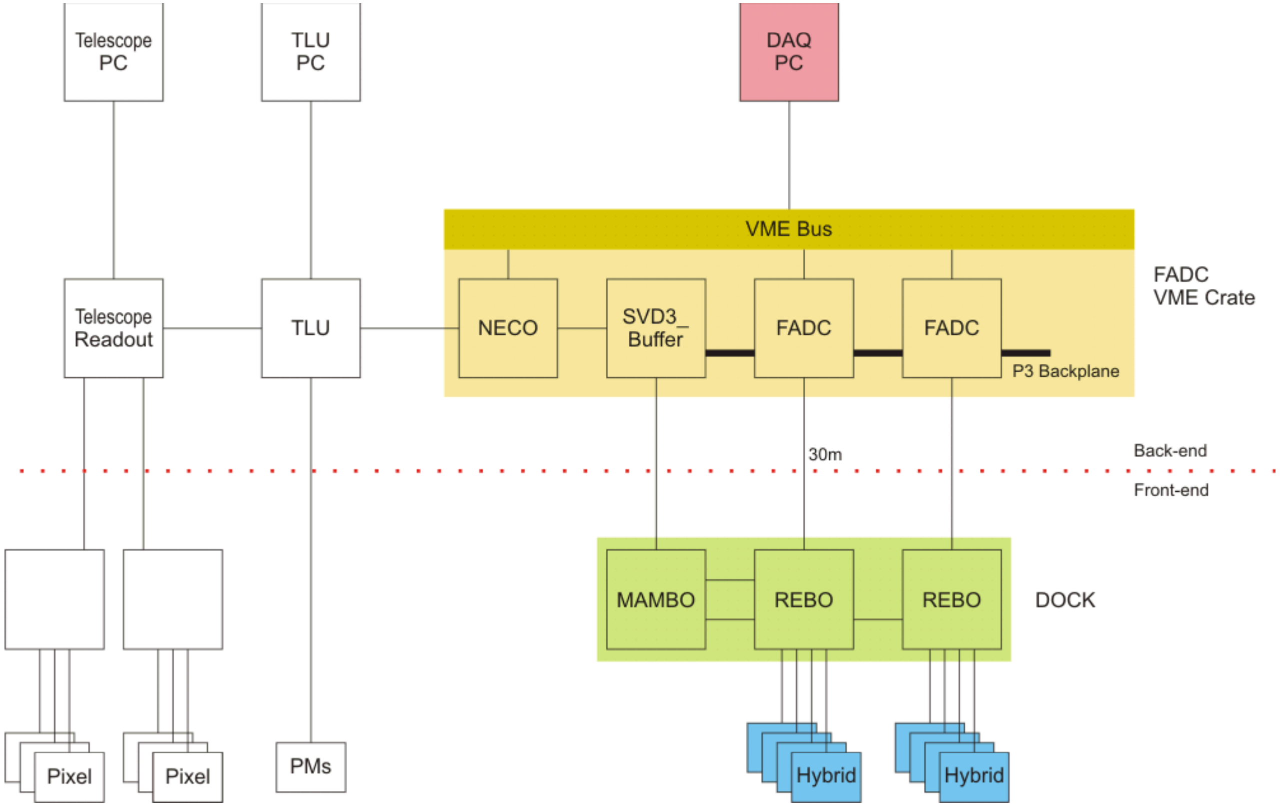


DAQ for the APV25 chip

- Frontend (FE) Hybrids are connected to Repeater Boards (REBO) located in DOCK box
- HV is coming from Keithley Source-meter via small board directly to FE (not shown)
- Two 9U VME Boards with FADCs are reading data and digitalize them
- NECO Board is the controller and distributes clock and trigger (via SVD3_Buffer board)
- PC running CVI (LabWindows) is used for online monitoring and to store data

NECO board has LVDS I/O to directly read trigger and timestamp data from TLU box

(Thanks to David Cussins for providing us a TLU box prior the TB)



DAQ Hardware and Software

- DAQ Hardware was installed outside of testbeam zone to allow intervention without cutting the beam
  - We had 30m cables between crate and front-end
- Ethernet connection was used to communicate with DAQ from control room
- DAQ Hard- and Software (including predecessors) has already been used for more than 10 test beams in the past.
  - Thus, everything was pretty stable.

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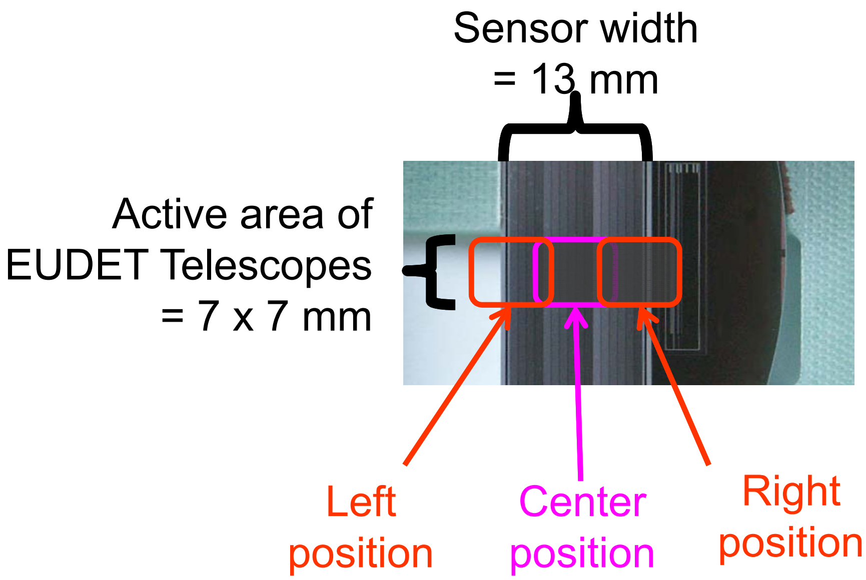
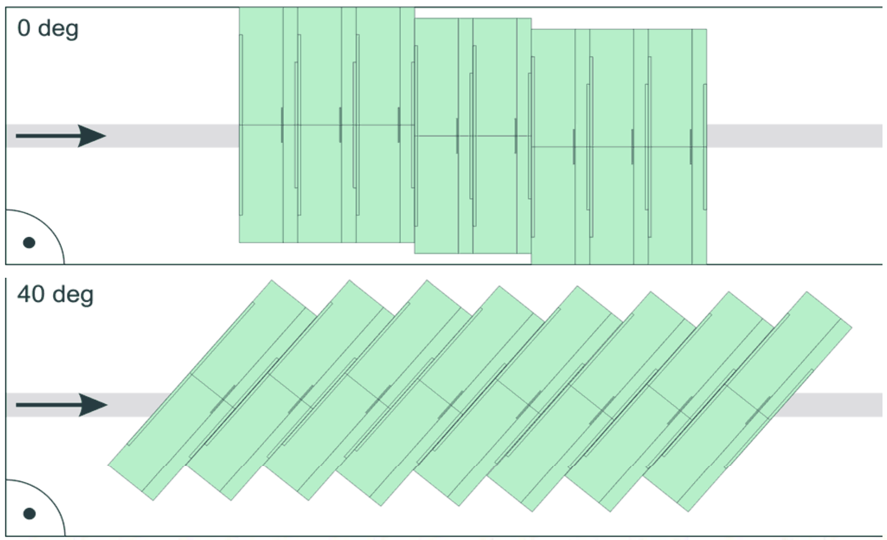
List of runs

- Resolution runs
  - To be repeated 3 times to cover full area
  - Run numbers 2718, 2719, 2720 (each 100k events)
- HV Voltage scan
  - Between 10 and 100V
  - Run# 2787-2828 (10k events each)
- Angle scan
  - Between 0 and 60 deg (in steps of 10deg)
  - Had to be performed manually since rotational stage of EUDET was not working
  - Run 2831-2837 (10k each)





Timing

- SPS Beam structure: 5 seconds particles during slow extraction ("spill"), then pause of 20-40 sec
  - Beam intensity has been reduced by closing collimators in the beam line
- Trigger rates:
  - APVDAQ alone (zero-suppressed): 400Hz (during spill)
  - APVDAQ (raw) + Telescope (ZS): 50Hz (during spill)
  - APVDAQ (raw) alone: 70-75 Hz
  - Telescope (raw): 5 Hz (during spill)

- APV chip has 50ns shaping time
- Delays introduced by cables
- DAQ online monitoring allows easy live adjustment of timing
- Latency was adjusted by both NECO and APV chips **to see the triggering particle by APV-DAQ**

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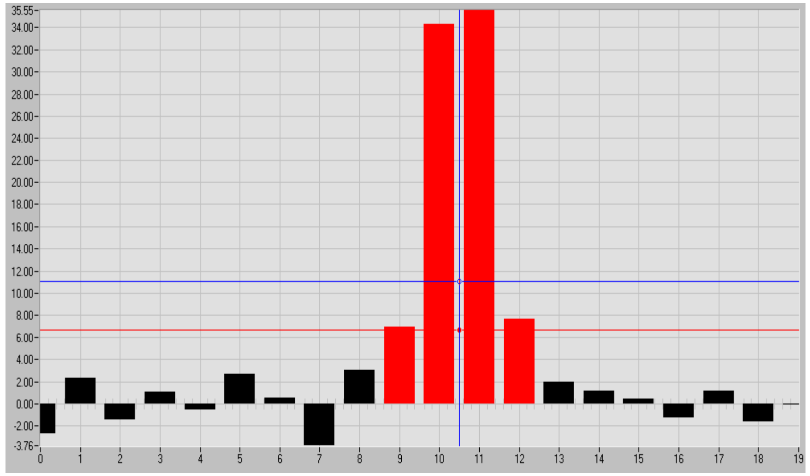
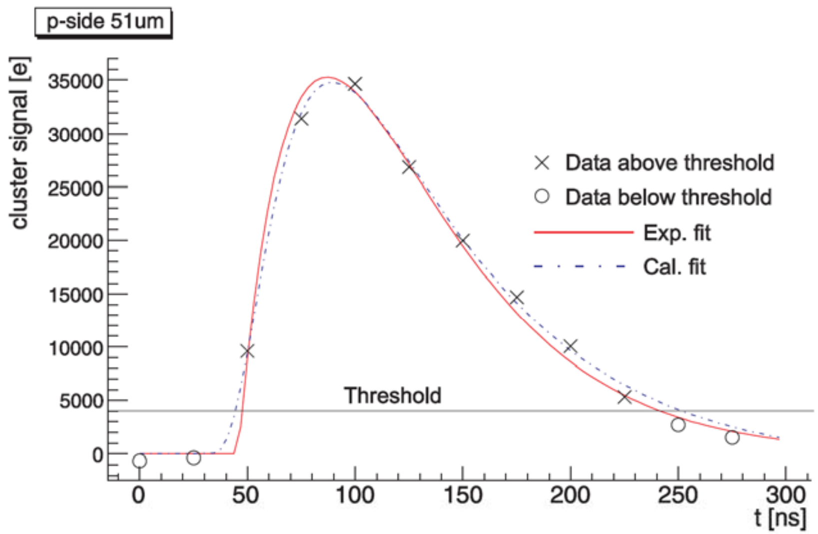
Offline Data Analysis split in two parts

1. “low-level” Data analysis of APV DAQ data using Vienna code:
   - Pedestal subtraction
   - Common mode correction
   - Hit finding, Clustering by center-of-gravity (top pic.)
   - Peak time reconstruction (bottom pic.)





2. “high level” Tracking and residual calculation (see next slides)

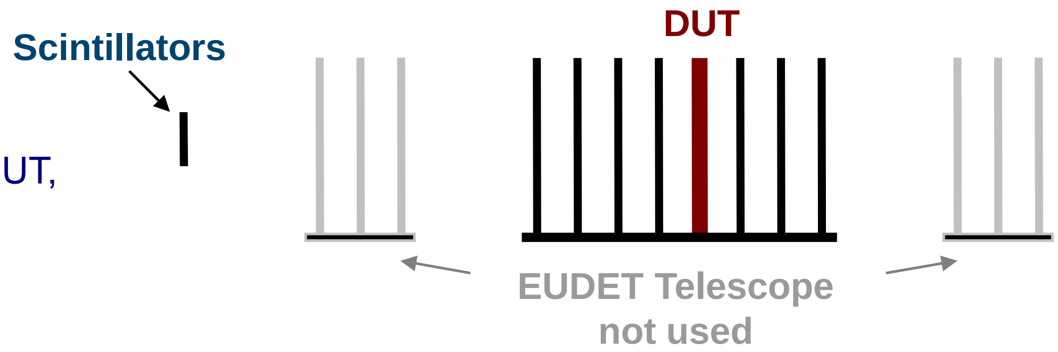
Tracking: Overview

- Specific tasks:
  - Determine resolutions in individual zones of the sensor to find optimum strip configuration
  - Two independent tracking schemes:

A

Only strips

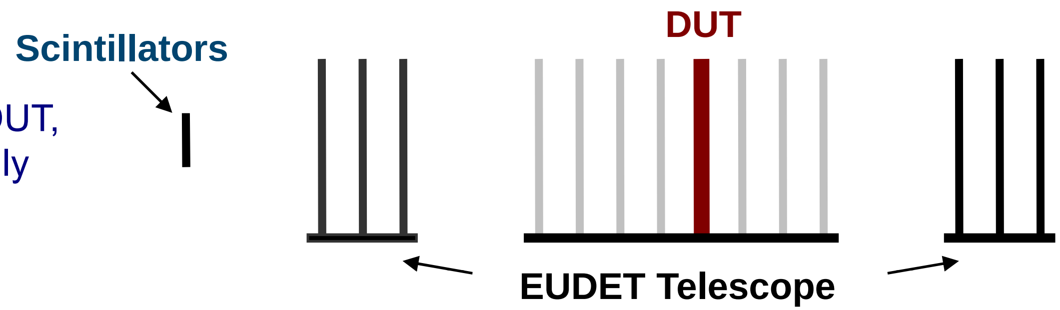
One strip detector as DUT, other 7 as telescopes



B

EUTels

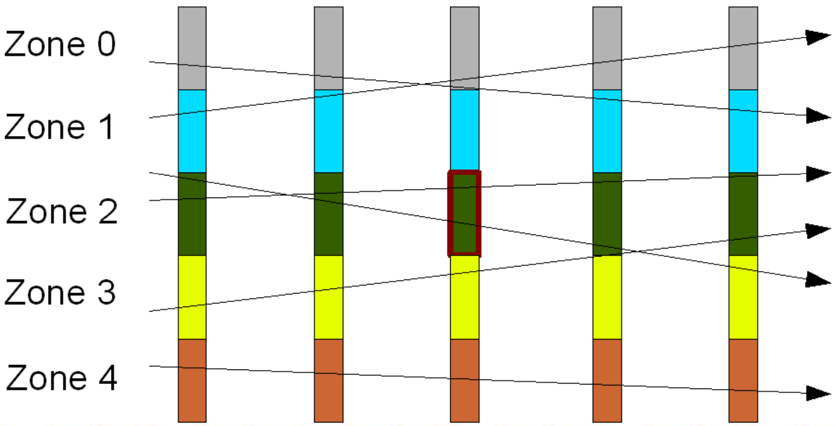
One strip detector as DUT, other strip detectors only accounted for multiple scattering



Zones on strip detectors

- 16 zones of 16 strips, separated by one missing strip
- Account for / describe position-dependent detector properties
- Must have enough tracks passing through each zone

- Non-standard properties in border regions between zones.
- We cannot simply discard tracks passing through boundaries – we would lose 98 per cent tracks!

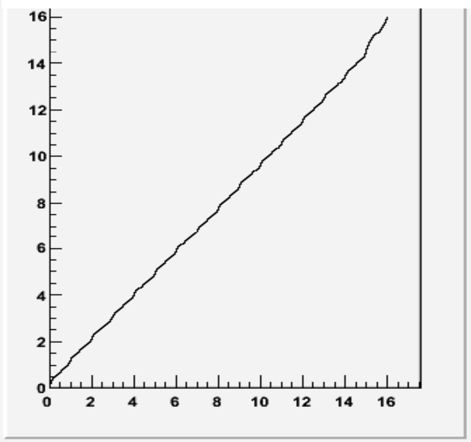


Zone	Strip width [µm]	Intermediate strips
1	6	no
2	10	no
3	12,5	no
4	15	no
5	20	no
6	25	no
7	6	single
8	7,5	single
9	10	single
10	12,5	single
11	15	single
12	17,5	single
13	6	double
14	7,5	double
15	10	double
16	12,5	double

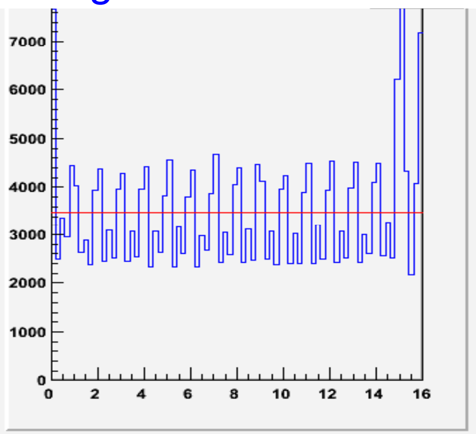
The zone η correction

- Zone η correction = η for 16 strips (rather than for 1): Calculate displacements so that the distribution of hits over the whole zone becomes uniform.
- Boundary effects between zones with different strips are handled by the zone eta in a straightforward manner.
- A simple method relying on the large statistics that we have.

η correction map



Hit distribution:
- Original - Corrected



The zone η correction:
Left: The correction map.
Right: The original distribution of hits (blue) and distribution of η-corrected hits.

Note that zone boundaries are handled automatically.

Zone resolutions

- Resolutions were calculated using the Prague DEPFET tracking package.
- Resolutions are calculated directly (no infinite energy extrapolation) and simultaneously for all detectors.
- First approximation:
  - Calculate resolutions for zones on detector 3, using tracks going through the respective zone
  - On other detectors, use average resolution
- Iterate: use zone resolutions from previous step.
  - Very small improvement.

The Prague tracking package

- Package developed for tracking of DEPFET pixels
- A standard analysis chain, comprising
  - hit reconstruction
  - track identification
  - detector alignment and track fitting
  - calculation of detector resolutions
  - sensibility/reliability study on simulated data
- Features:
  - hit alignment based on the Scott and Longuet-Higgins algorithm
  - track filter based PCA
  - robust linearized alignment
  - direct computation of detector resolutions using a track model that explicitly takes into account multiple scattering
  - calculation of alignment and resolution errors using bootstrap resampling

Resolution calculations

In detector resolution calculations we decompose track projection errors (fit residuals) into contributions of

- measurement error (detector resolution)
- telescope error (error of track projection on the detector)
- contribution of multiple scattering to telescope error

$$diag^{-1} cov\left(u^{(c)}\right) = \mathbf{M}_{\Delta} \cdot \mathbf{\Delta}^2 + \mathbf{M}_{\Sigma} \cdot \mathbf{\Sigma}^2$$

vector of diagonal elements of the matrix

covariance matrix of fit residuals (from tracking)

Matrices depending on the method of calculation - whether fits are calculated using the given detector or not

Vector of squared detector resolutions

vector of mean square angular deflections

- We need positive solution of the matrix equation, so we use quadratic programming or bootstrap resampling of the residual covariances to assure positivity

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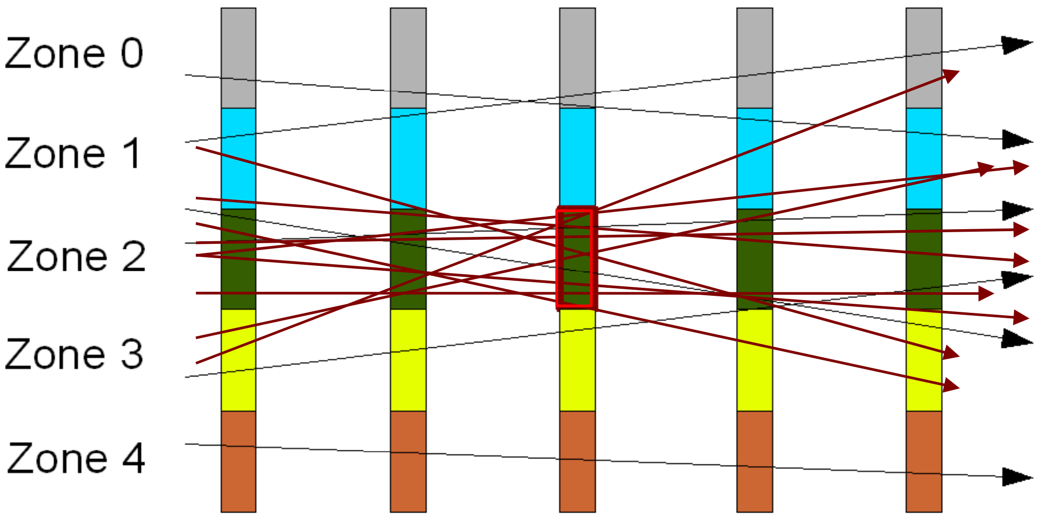
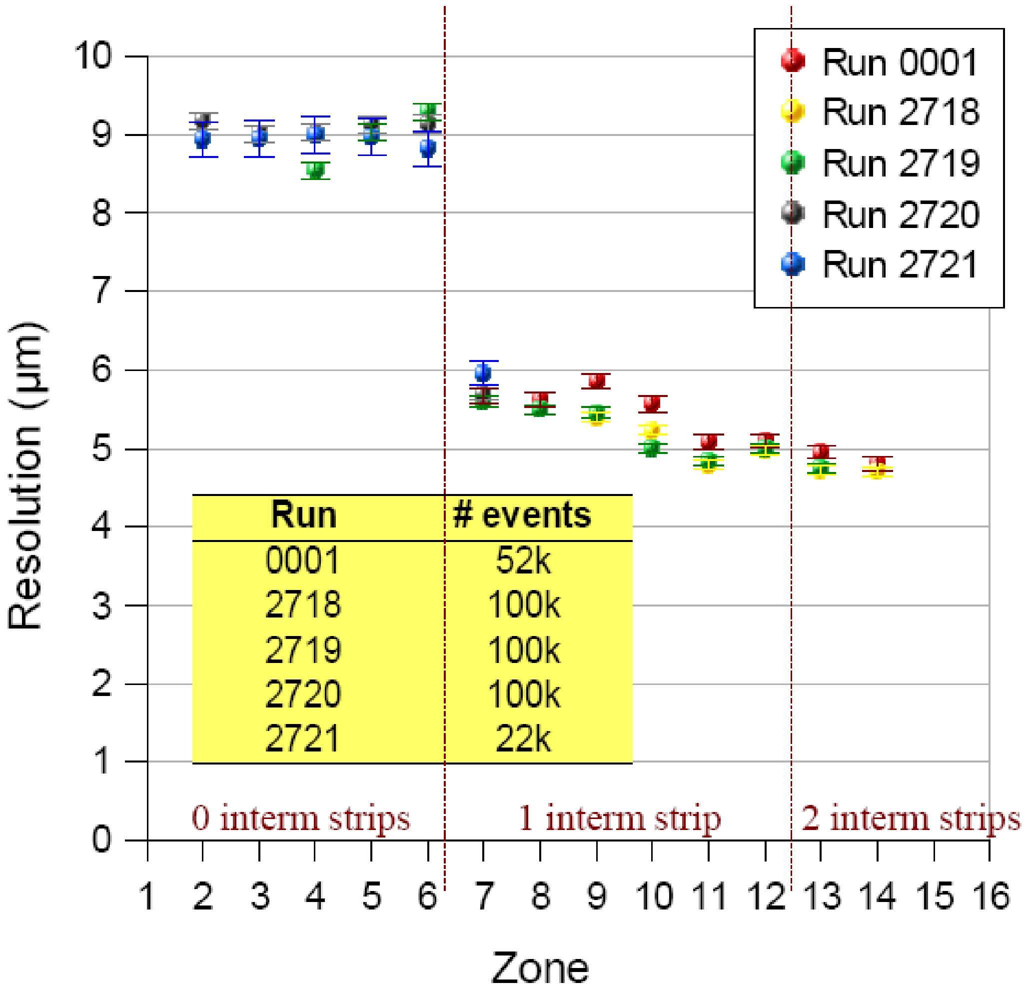
Zone resolutions - Overview

- We calculated zone resolutions by using only tracks that passed the required zone on detector 3.
- Each time, resolutions are calculated for all detectors, but we have a “clean” resolution only on detector 3.
- Resolutions on other detectors are “mixed”, arising from tracks passing different zones.
- In the following step, the resolutions obtained this way were used on other detectors as appropriate for individual tracks.



- No special treatment for edge zones was used.

Zone resolutions - Results



Run	# events
0001	52k
2718	100k
2719	100k
2720	100k
2721	22k

- We have to combine results of several runs with a different position of the setup relative to the beam) to reach sufficient occupancy over the whole area of the detector.
- Even so, we don't have enough data for edge zones.
- Overlap regions allow to assess the precision of calculated resolutions.

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Route B: EUDET telescopes

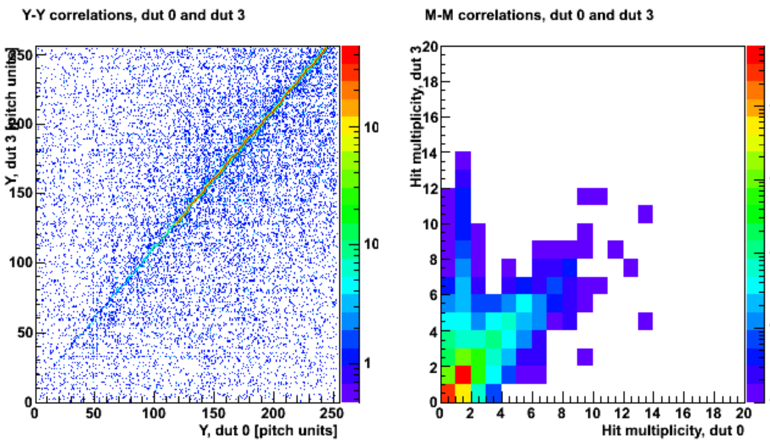
- EUDET telescopes: provide an independent path to the same results.
- Nearly in all cases, analysis can be carried out using strip detectors alone, or using EUDET telescopes to look at a single strip detector, accounting other strip detectors only for multiple scattering.

- Multiple scattering contributes tenths of microns to measurement errors
- Hit multiplicity is not serious in the data.

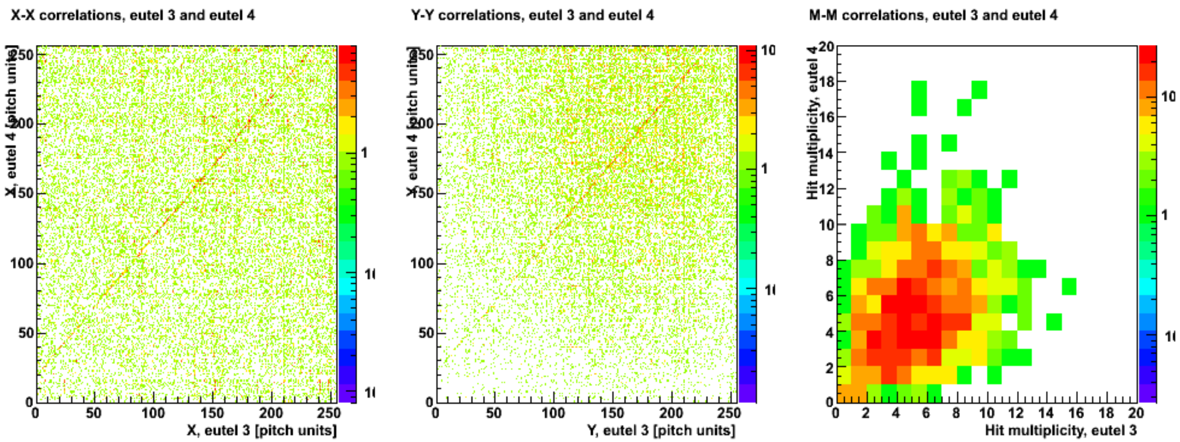
- We have rougher hit reconstruction for EUDET telescopes (using the ClusterExtractor macro)
- We need alignment among EUDET telescopes and strips

Route B: EUDET telescopes

- Still in progress: we don't see correlations between strip detectors and EUDET telescopes.



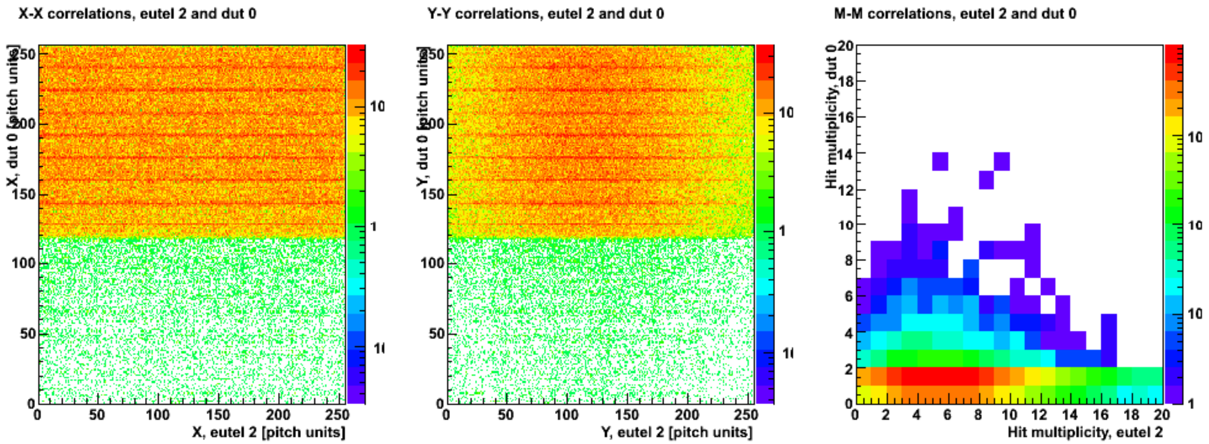
- We see correlations between strip detectors (including correlations in hit multiplicities)



- and EUDET telescopes are nicely correlated, too...

Route B: EUDET telescopes

- but no correlations between strips and EUTels.



- We believe all detectors see the same particle(s). There has to be some de-synchronisation between event numbers, which is not easy to identify.
- This is very preliminary: We still haven't looked at event timestamps.

Summary

- We have performed a test beam to determine the spatial resolution of a mini sensor with different geometric zones using the EUDET telescope as reference

- The testbeam took place at CERN between May, 30th and June 5th, 2008
- SPS performed "reasonable" (some beam outages)
- Trigger was working well thanks to TLU integration during preparation
- Support by EUDET during data taking was excellent (even on weekends and night)

- We see tracks within 8 DUT planes
- We see tracks within the telescope planes
- But, we do not see any correlation between both

Resolution: 9 um with no intermediate strips, 5-6 um with either one or two intermediate strip

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Thanks for your attention.

Backup slides follow

Zone resolutions - Results

Strip width [μm]	Intermediate strips	Run 0001	Run 2718	Run 2719	Run 2720	Run 2721
6	no					
10	no				9.17±0.11	8.93±0.21
12,5	no				9.01±0.10	8.94±0.23
15	no			8.54±0.11	9.02±0.10	8.99±0.21
20	no			9.03±0.10	9.12±0.10	8.97±0.21
25	no			9.29±0.11	9.13±0.10	8.81±0.21
6	single	5.66±0.10		5.60±0.07	5.69±0.07	5.95±0.14
7,5	single	5.61±0.09		5.49±0.06		
10	single	5.85±0.09	5.39±0.07	5.45±0.07		
12,5	single	5.56±0.09	5.23±0.06	5.00±0.06		
15	single	5.08±0.08	4.78±0.05	4.84±0.06		
17,5	single	5.09±0.08	4.97±0.06	5.00±0.06		
6	double	4.95±0.08	4.72±0.05	4.75±0.06		
7,5	double	4.80±0.08	4.70±0.05			
10	double					
12,5	double					

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MAPS readout

Thanks to Emlyn Corrin and Antonio Bulgheroni!

- MAPS sensors are read-out continually, 3 ms per plane
- Trigger works at frame-processing level
- The sensors are not cleared, they discharge spontaneously; therefore, subtraction of consequent frames is used to uncover data that appeared newly
- In each pixel, we see hits accumulated in that pixel since it was previously read, i.e., during the previous 3 milliseconds.
- Frames are temporarily stored in a circular buffer
- The effect of a trigger is that some frame data are stored.

MAPS readout

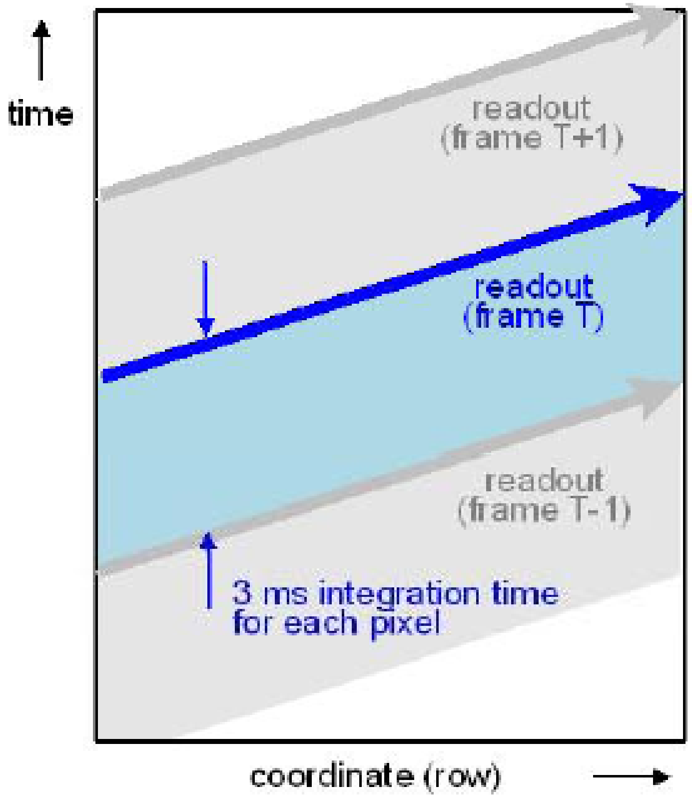

Figure: Time-coordinate representation of the readout process

MAPS readout

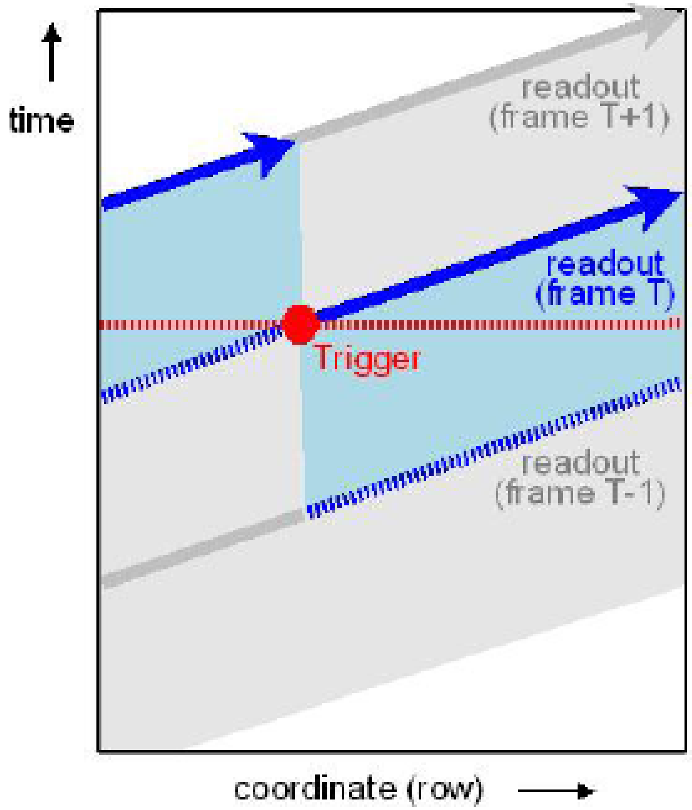

Figure: When a trigger comes, data frame containing the trigger particle si constructed from three consecutive frames and saved.

MAPS readout

- The reconstructed data frame almost surely contains the triggering particle
- Incorrect time settings may lead to slight inefficiency of the detector
- In each pixel, we get what hit it within a 3 ms window, but the windows for individual pixels are different.