Measurements with the EUDET Pixel Telescope

Mechanical Stability - Resolution - Efficiency - Fake Hit Rate

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Outline

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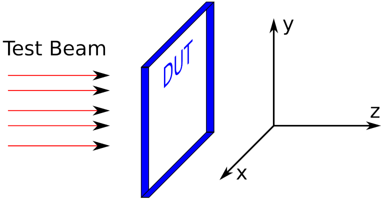
Purpose of a Pixel Telescope



What is a pixel telescope?

- Newly designed tracking devices need to be characterized e.g. in terms of resolution power, efficiency, etc.
- Beam Telescopes precisely define tracks of charged particles in test beam facilities
- Essential to examination of DUT (device under test) response

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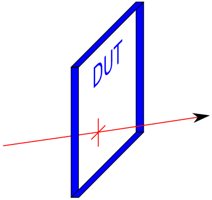

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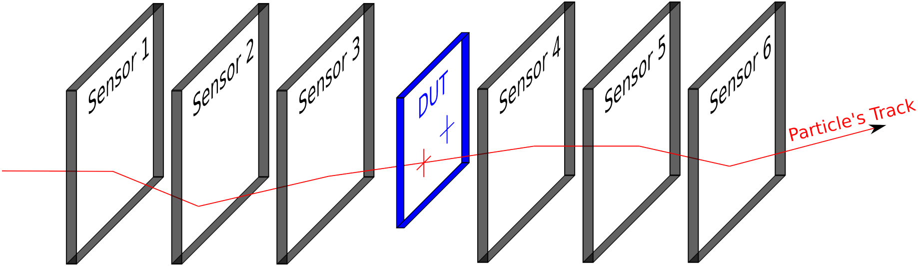

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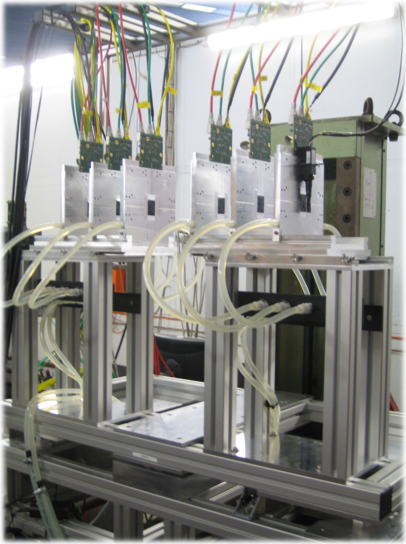
The EUDET Pixel Telescope

Some facts

- Mimosa26 CMOS pixel sensors
- Desired resolution of a few μm
- Dedicated software for data acquisition and event reconstruction
- Highly modular: easy integration of many different DUTs
- Currently at CERN SPS test beam
- Improved copy "ANEMONE" at DESY II test beam



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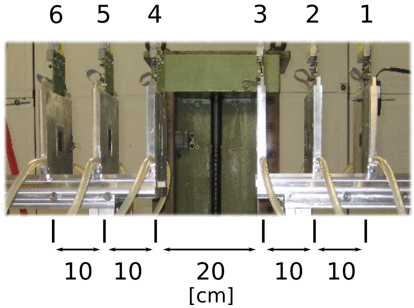


Offline Analysis

EUTelescope software packages

Modular **A**nalysis & **R**econstruction for the **L I N**ear Collider

- Based on "Marlin" analysis framework
- Provides several distinct "processors"
- LCIO data format

Full analysis chain:

1. File conversion
   - raw format $\rightarrow$ LCIO
2. Clustering
   - Identification of "seed pixels"
   - Formation of clusters
3. Alignment
   - Correct for deviations from nominal geometry
   - Parametrization in terms of "alignment constants"
4. Track fitting

Outline

Taking the Data

CERN SPS Test Beam:

- Four beam lines at north area
- Electrons and hadrons (pions used)
- Wide energy range

DESY II Test Beam:

- Bremsstrahlung converted with carbon fibre targets
- 1 to 6 GeV electrons or positrons

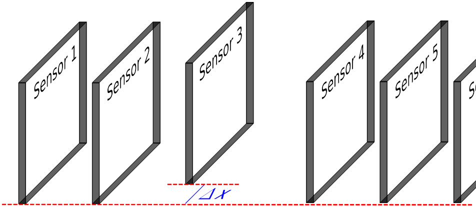
E / GeV	Threshold setting S/N 5	6	7	8	9	10
120	✓	✓	✓	✓	✓	✓
80	✓	✓		✓		

E / GeV	Threshold setting S/N 5	6	7	8	9	10
2	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	✓

✓: Data taken and reconstructed
✓: Data taken but not yet reconstructed

Outline

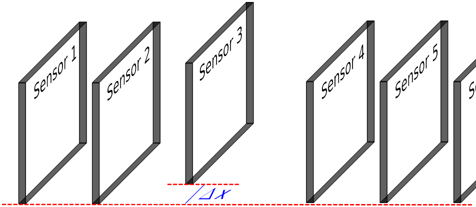
Alignment



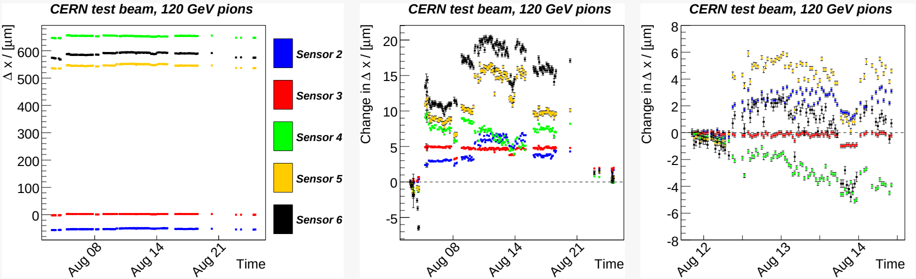
Alignment parameters

- Δx, Δy, angles of rotation
- Alignment is done for each data taking run individually (see results)
- Change in alignment parameters indicate deformation
- Parameters can be used to monitor mechanical stability

Monitoring the Alignment Parameters



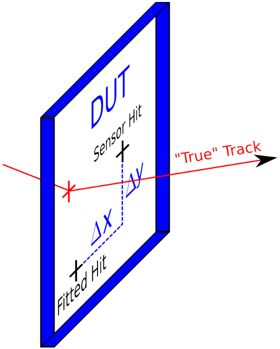
Results - x displacement (plots adapted from Cora Fischer)



Outline

The Pointing Resolution

Expected residual $(x_{fit} - x_{meas})$ distribution at the DUT:



- Gaussian shape
- Contributions from the track fit and DUT resolution:

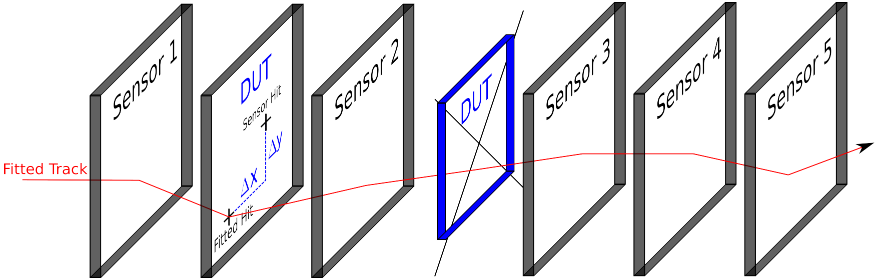
$$\sigma_{tot}^2 = \sigma_{fit}^2 + \sigma_{DUT}^2$$

- σ_{fit} can be computed from telescope parameters::
  - Sensor thickness d
  - Distances between sensors
  - The telescope's sensor resolution σ_s

Telescope's pointing resolution

$$\sigma_{tel}^2 := \sigma_{fit}^2$$

Measuring the Pointing Resolution

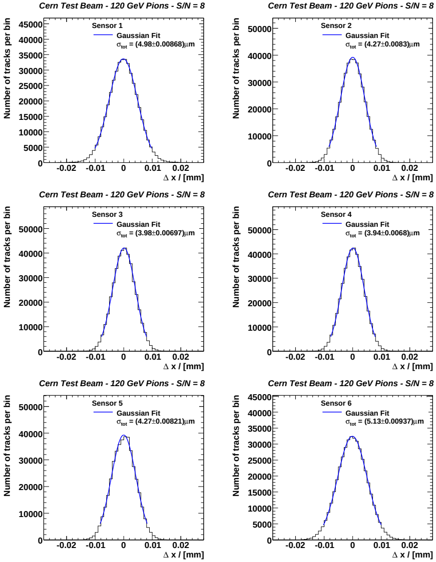


Strategy:

- For each track,
  perform fit six times with each of the sensors treated as DUT once
- Measure residual ($\Delta x = x_{fit} - x_{meas}$) distribution for each sensor
- Fit analytic expression with σ_s as free parameter

$$\sigma^2_{tot} = \sigma^2_{tel} + \sigma^2_{DUT} = \sigma^2_{tel}(\sigma_s) + \sigma^2_s$$

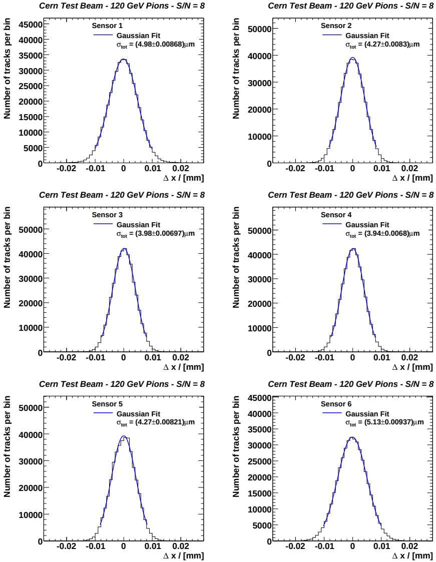
Extracting the Sensor Resolution

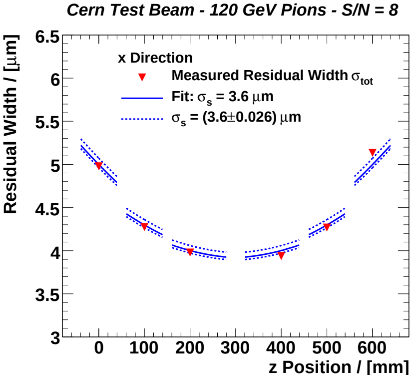


Residual width σ_{tot} depends on σ_s

$$\sigma_{tot}^2 = \sigma_{tel}^2(\sigma_s) + \sigma_s^2$$

Extracting the Sensor Resolution





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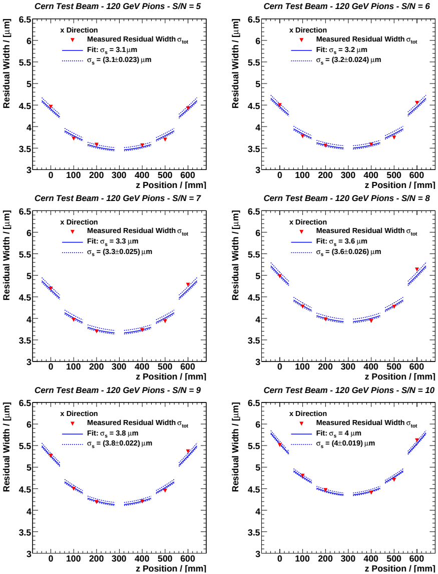
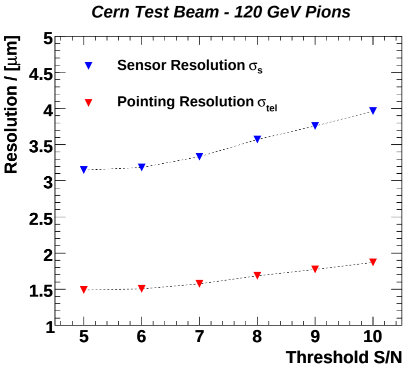
Pointing Resolution vs. Threshold Setting





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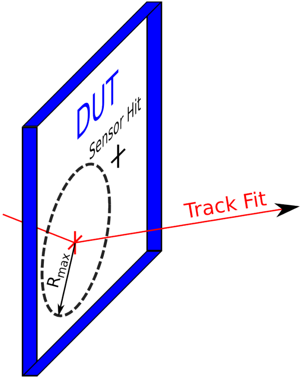
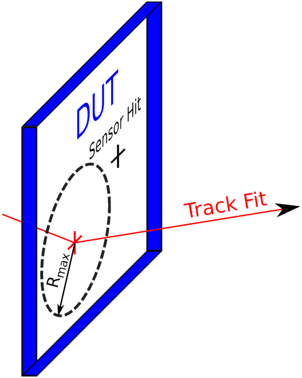
Efficiency

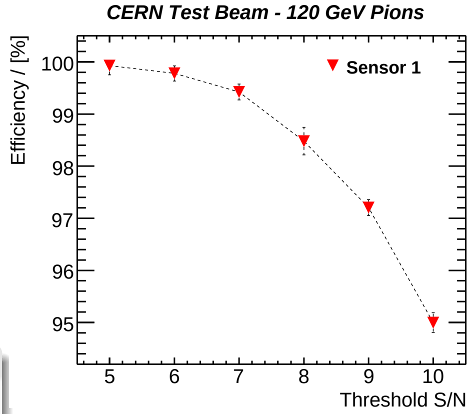


Definition

Probability of a sensor to measure a hit within a reasonable distance R_{max} from the actual track hit position, given that a particles has struck the sensor.

Efficiency





[Plot adapted from Cora Fischer]

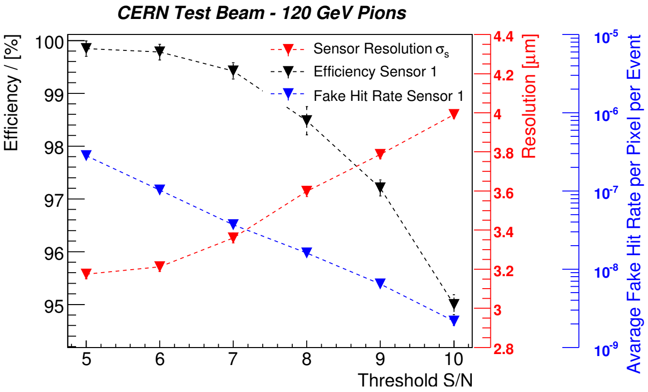
Definition

Probability of a sensor to measure a hit within a reasonable distance R_{max} from the actual track hit position, given that a particles has struck the sensor.

Fake Hit Rate

Definition

Probability of a pixel to fire in an event in which it was **not** hit by a particle



[Fake hit rate analysis by Ilya Khvastunov]

Outline

Summary and Outlook

Results

- Very rigid mechanical setup
- Decrease of resolution power and efficiency with rising threshold consistent with expectations
- Fake hit rate highly suppressed by high threshold settings
- Excellent pointing resolution below 2μm between telescope arms can be achieved

Open questions

- How does the hit cluster size correlate with the sensor resolution?
- How does the telescope resolution vary with energy of particles?
- Does the presented approach account for increased multiple scattering effects at lower energies correctly?
- Lots of data on disk ready to be analyzed to answer these questions!

Acknowledgments...

Backup Slides

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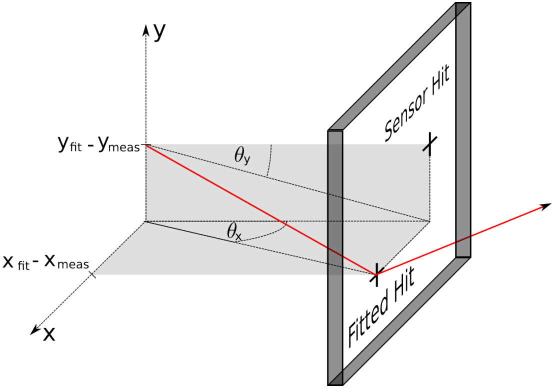
Track Reconstruction via χ^2 Minimization



Track fit must account for:

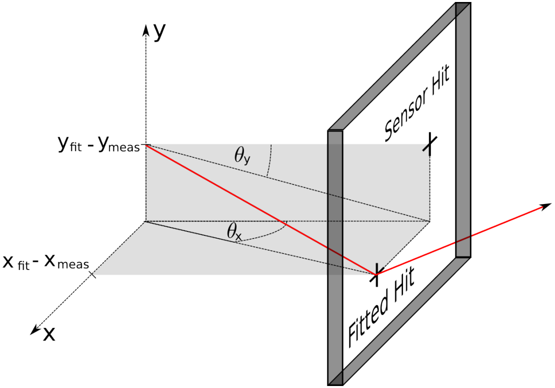
- Position of sensor hits
- Expected scattering angle distribution (gaussian)
- $\sigma_\theta \approx 2 \times 10^{-6}\text{rad} \mathrel{\widehat{=}} 0.4\mu\text{m}$

$$\sigma_\theta = \frac{13.6\mathrm{MeV}}{\beta cp}\sqrt{\frac{d}{X_0}}\left[1 + 0.038\ln\left(\frac{d}{X_0}\right)\right]$$

χ^2 contribution from fit in x-z-plane

$$\chi_x^2 = \sum_{\substack{i=1 \\ i \neq i_{DUT}}}^{N}\left(\frac{x_{fit}^i - x_{meas}^i}{\sigma_s}\right)^2 + \sum_{i=2}^{n-1}\left(\frac{\theta_x^i - \theta_x^{i-1}}{\sigma_\theta}\right)^2 \qquad \theta_x^i \approx \frac{x_{fit}^{i+1} - x_{fit}^i}{z^{i+1} - z^i}$$

Track Reconstruction via χ^2 Minimization



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Analytic χ^2 Minimization

χ^2 is quadratic in all degrees of freedom:

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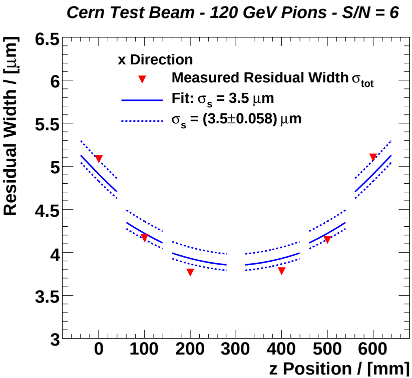
Minimization of χ^2 can be achieved by solving a set of linear equations:

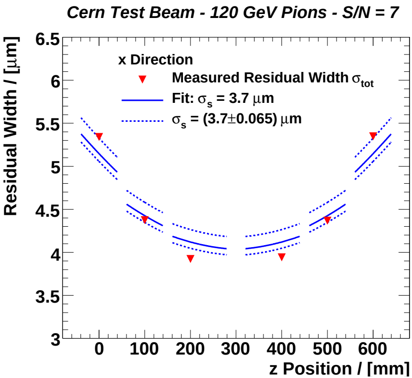
$$\frac{\partial \chi^2}{\partial x_{fit}^j} = 0 \quad \Leftrightarrow \quad \sum_{i=1}^{N} \mathcal{M}_{ij} x_{fit}^i = \varepsilon_j x_{meas}^j \qquad \mathcal{M}_{ij} = \frac{1}{2} \frac{\partial^2 \chi^2}{\partial x_{fit}^i \partial x_{fit}^j}$$

Fit can be reduced to finding the inverse of $\mathcal{M}$

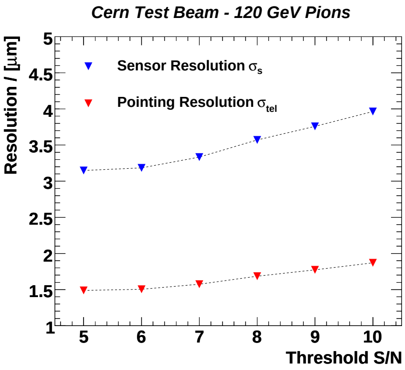
$$x_{fit}^j = \sum_{i=1}^{N} \mathcal{M}_{ij}^{-1} \varepsilon_i x_{meas}^i \qquad \sigma_{x_{fit}^j}^2 = \mathcal{M}_{jj}^{-1}$$

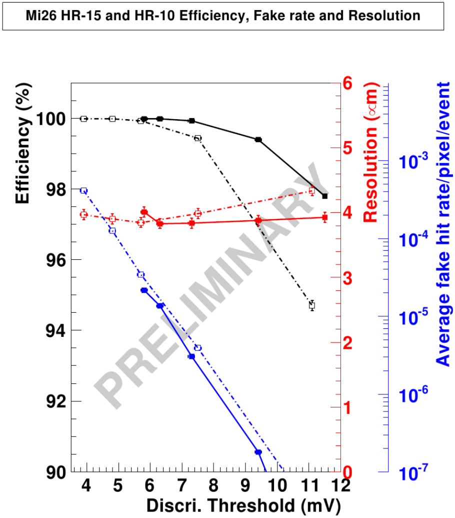
No Track Preselection





Comparison with IPHC Measurements





Marc Winter, IPHC Strasbourg