Simulation of EUDET Pixel Beam Telescope using ILC Software

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DESY

Contents

- EUDET pixel beam telescope project
- Telescope geometries
- Software tools
- Comparison of Mokka and Geant 4 (Prague) simulations
- Comparison of different telescope geometries
- Trying alignment procedures

EUDET pixel beam telescope

- **JRA1: Test beam infrastructure**

  Comprises large bore magnet (B$<$1.2 Tesla) and pixel beam telescope

- **Purpose of telescope: precise track reconstruction used for pixel sensors, as well as for large volume tracking devices (e.g. TPC)**

- **Should have very high precision ($<$3 μm)**

- **Suitable for different test beam environments:**

  - **DESY: electrons up to 6 GeV**

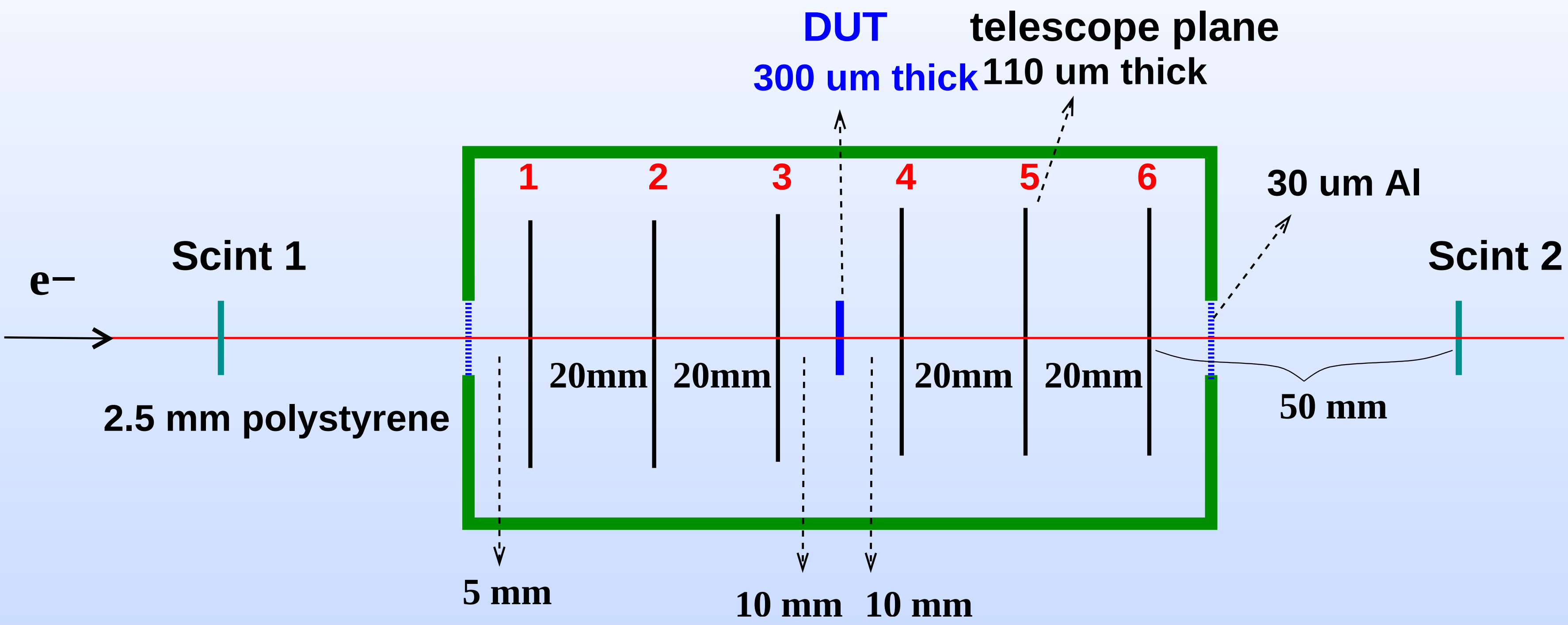
  - **CERN: pions 100-120 GeV**

- **For telescope planes use CMOS sensors developed by IPHC-Strasbourg**

- **DAQ development: Switzerland, Italy, France, Germany, UK**

- **Will be assembled at DESY**

Simulated Configuration I (symmetric geometry)

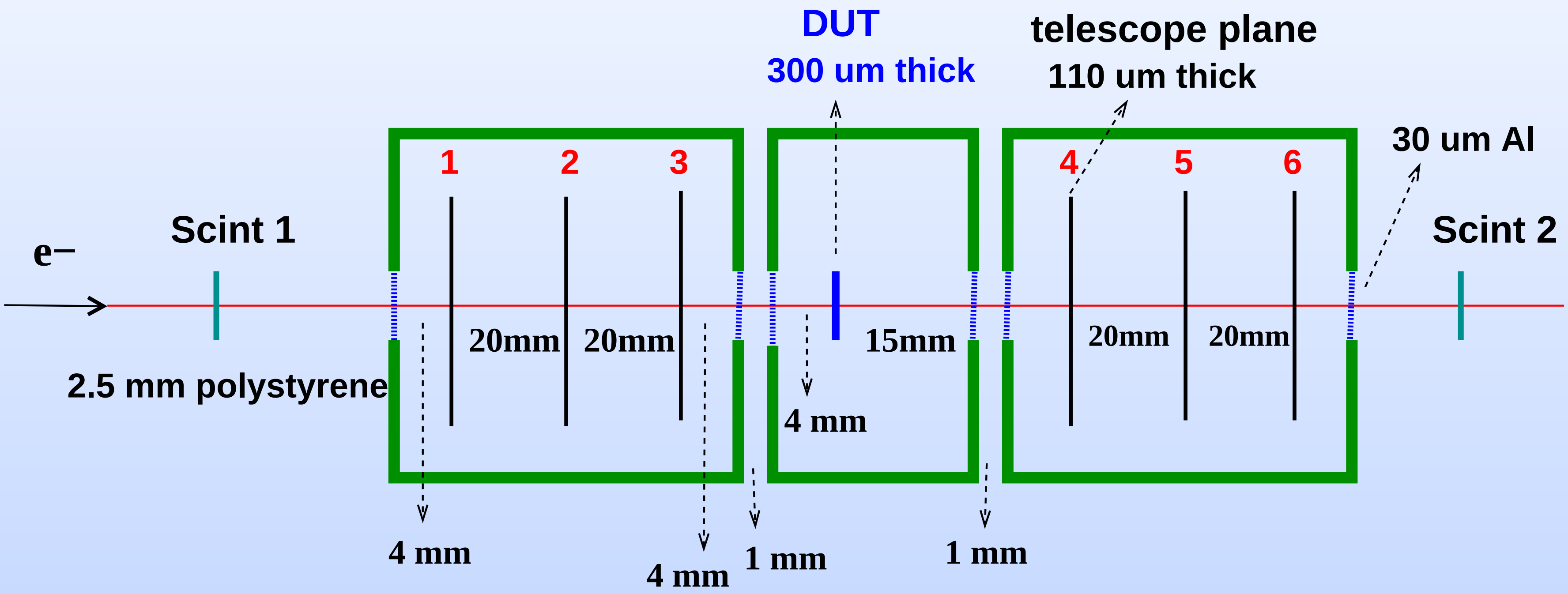


Simulation is important for detector design optimisation

Electron energies: 1, 2, 3, 4, 5, 6 GeV

Assumed intrinsic resolution of a telescope plane is 3 μm (hit positions are smeared)

Simulated Configuration II (asymmetric geometry)



Software Tools

- **Simulation: Mokka 06.00 (based on Geant 4)**
  - **New geometry driver EUTelescope has been created**
  - **Class TRKSD00 is used for telescope and DUT sensitive detectors**
  - **No hard-coded numbers**
  - **All parameters of the model are stored in MySQL database**
  - **Output: LCIO format files**
  - **Stored information: hit positions, deposited energy**
- **Analysis: Marlin 00.09.04 and Root**
- **Simulated 50000 events without magnetic field for different configurations**

Validation of Multiple Scattering model

The width of the projected angular distribution is defined as

$$\theta_0 = \theta^{\rm rms}_{\rm plane} = \frac{1}{\sqrt{2}}\theta^{\rm rms}_{\rm space}$$

For small scattering angles Gaussian approximation is used:

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p} z \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right]$$

p, βc, z are momentum, velocity and charge number of the incident particle

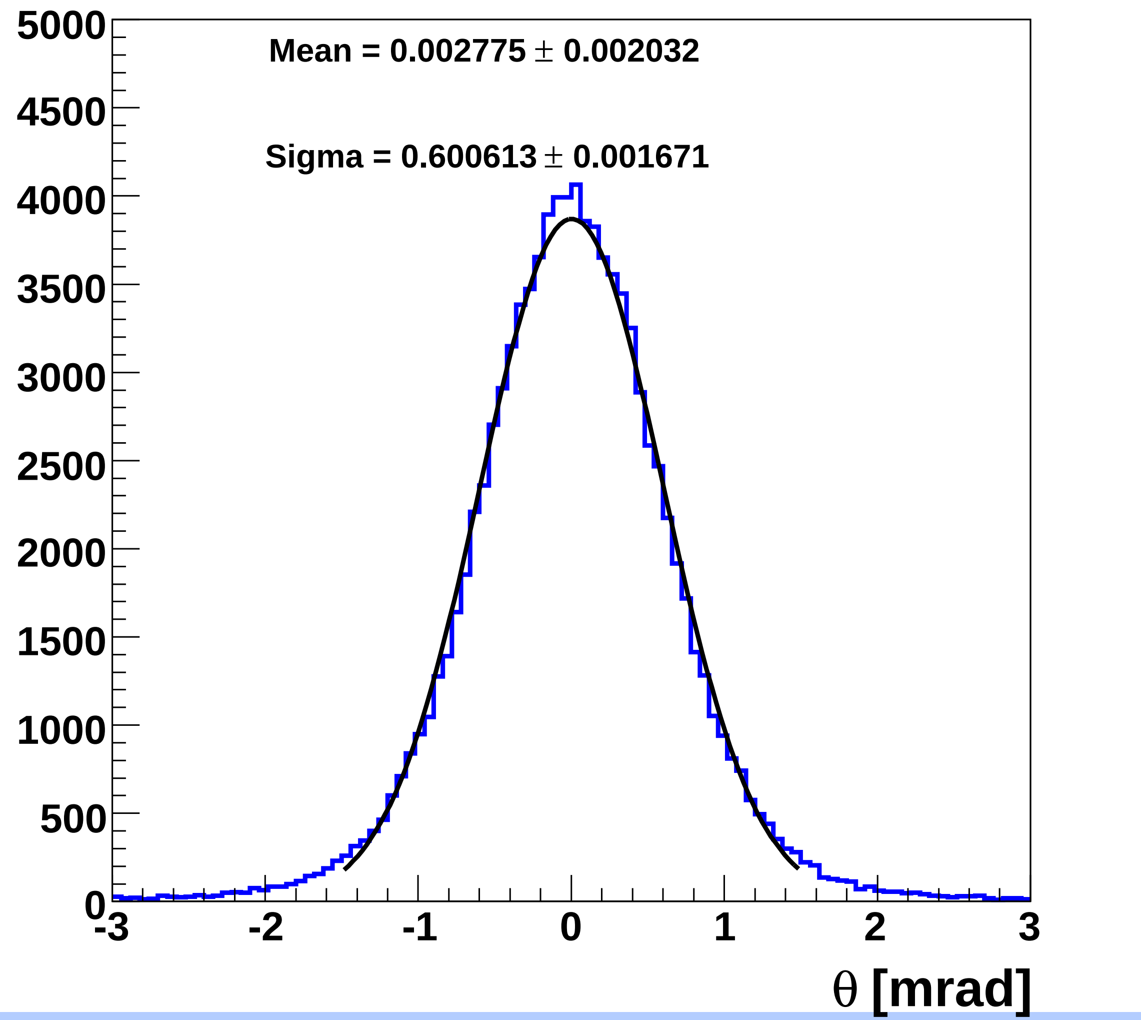
x/X_0 is the thickness of the scattering medium in radiation lengths

To check the validity of MS description:

- Simulate silicon wafer of 300 μm thickness
- Shoot 1 GeV electrons (100000 events)
- Look at the projection of the scattering angles θ
- Compare the width of θ distribution to theoretical prediction: $\theta_0 = 0.602$ mrad

Projection of scattering angle

Theory: $\theta_0 = 0.602$ **mrad**



Analysis Procedure

- Fit a track (straight line model in the absence of magnetic field) through hits in telescope planes
- Find a position of the intersection of the track with the DUT (x_{pred}, y_{pred})
- Find DUT residuals:

$$r_{x\ \text{DUT}} = x_{\text{pred}} - x_{\text{DUT}}$$

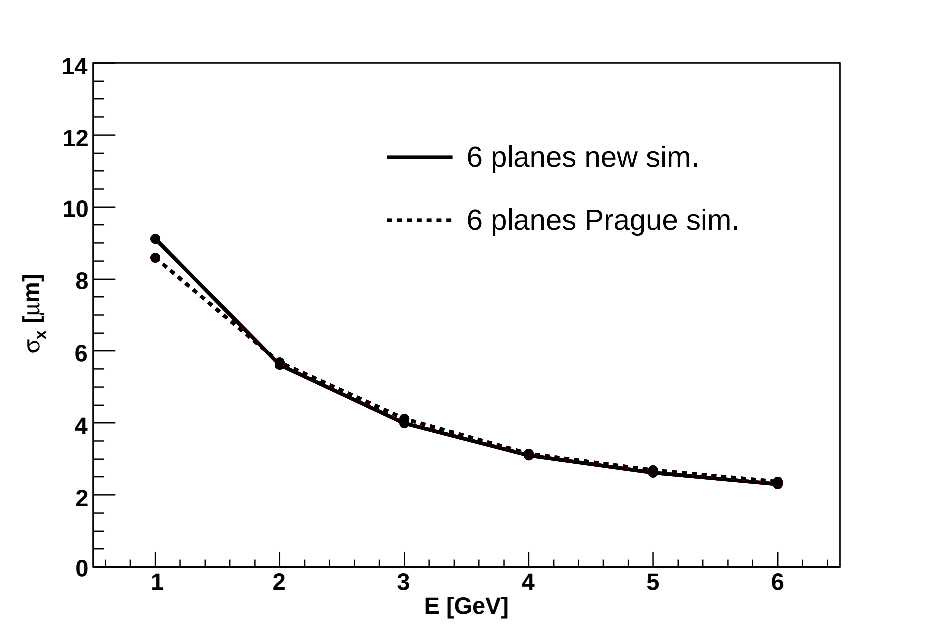
$$r_{y\ \text{DUT}} = y_{\text{pred}} - y_{\text{DUT}}$$

where x_{DUT} and y_{DUT} are hits in the DUT

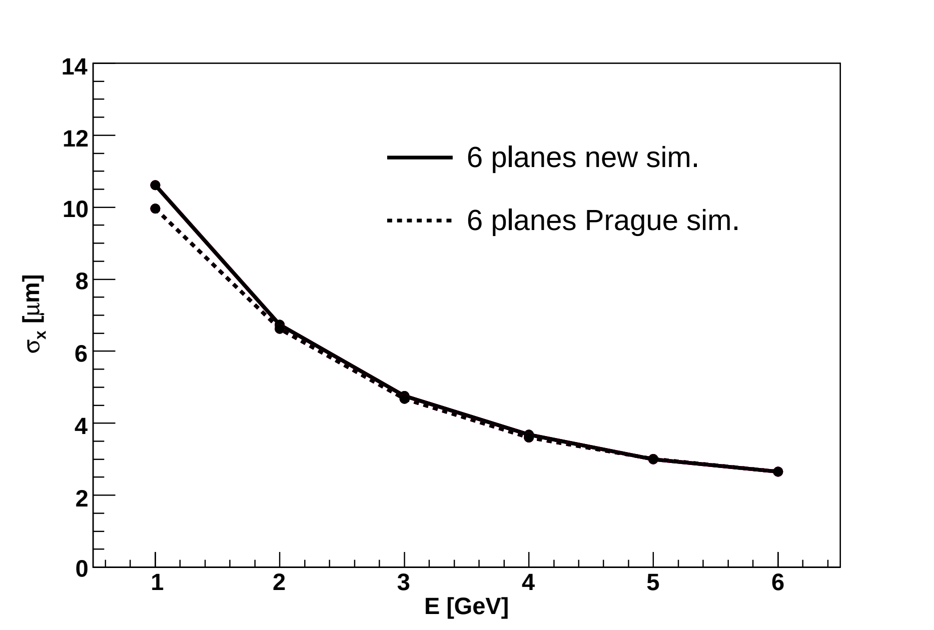
- Fit Gaussian to residual distributions and find σ_x and σ_y

Comparison of Geant 4 (Prague) and Mokka simulations

Symmetric geometry



Asymmetric geometry



The results look similar

In symmetric geometry (1 Al box) DUT is shifted 5 mm left in comparison with picture on slide 4

In asymmetric geometry (3 Al boxes) DUT is shifted right from the center in comparison with picture on slide 5

Track selection

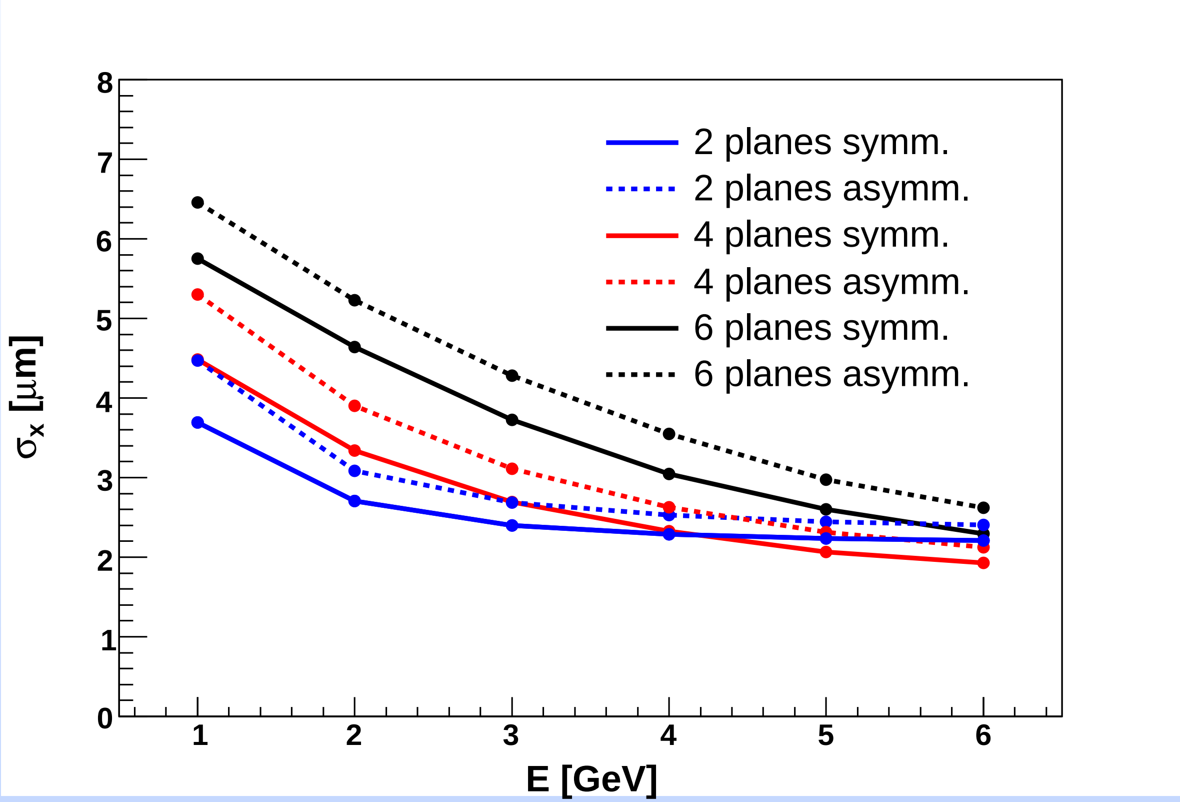
- $\chi^2_{\rm track} < 30$ for 6 plane geom., $\chi^2_{\rm track} < 10$ for 4 and 2 plane geometries
- track slope $<$ 2 mrad
- distance = $\sqrt{(x_{DUT} - x_{pred})^2 + (y_{DUT} - y_{pred})^2} < 200$ μm

Efficiencies

Energy	2-pl.symm	4-pl.symm.	6-pl.symm.	2-pl.asymm	4-pl.asymm.	6-pl.asymm.
1 GeV	81%	36%	27%	79%	28%	21%
2 GeV	97%	77%	74%	97%	71%	67%
3 GeV	99%	89%	90%	99%	86%	87%
4 GeV	99%	93%	95%	99%	92%	94%
5 GeV	100%	95%	97%	100%	94%	97%
6 GeV	100%	96%	98%	100%	96%	98%

Comparison of different geometries

For 2- and 4-plane geometries the closest to DUT planes are considered



At low energies contribution of MS from telescope planes is big $\Longrightarrow$ 2-plane geometries show better results

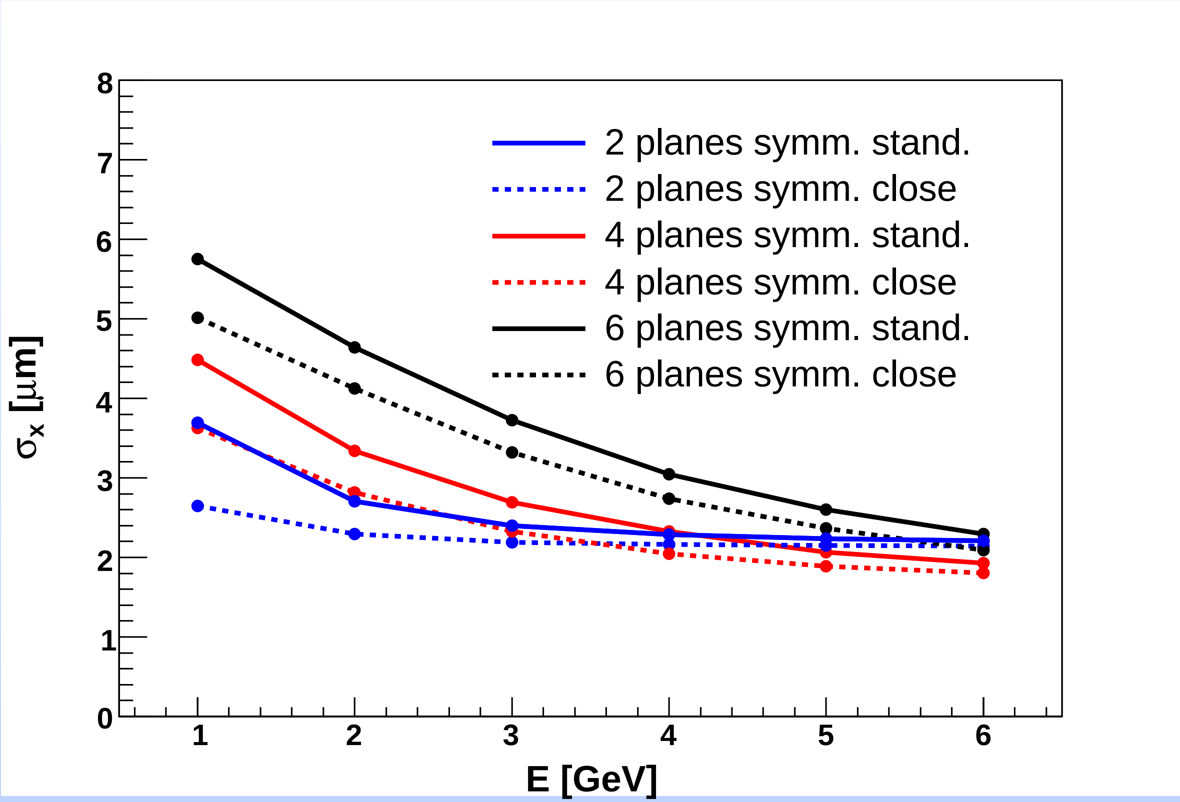
With increasing energy 4-plane geometry is an optimal variant

Asymmetric geometry gives worse results due to bigger MS from Aluminium

Comparison with close setup

Standard setup: symmetric setup with closer planes 10 mm from DUT

Close setup: symmetric setup with closer planes 5 mm from DUT



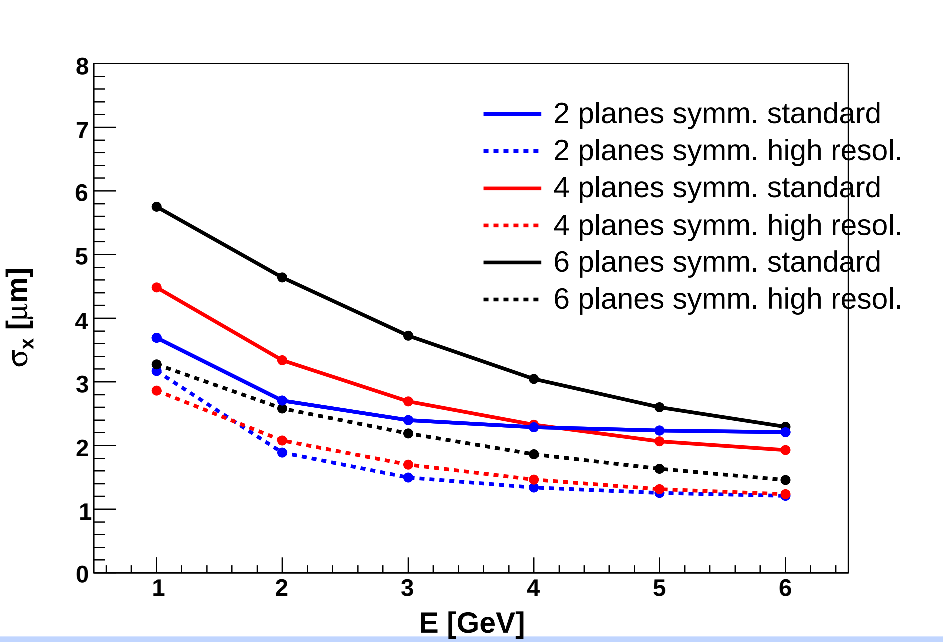
⟹ **Telescope planes should be put as close as possible to the DUT**

Comparison with high resolution setup

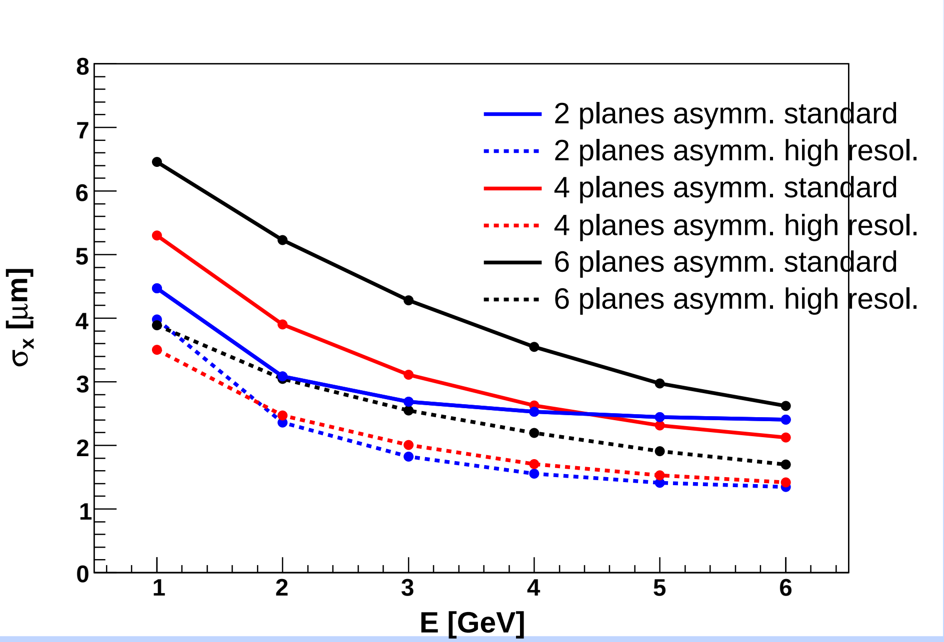
Standard setup: all telescope planes have 3 μm intrinsic resolution

High resolution setup: two telescope planes closer to DUT have 1.5 μm intrinsic resolution (high density sensors); all other planes - 3 μm

Symmetric geometry



Asymmetric geometry

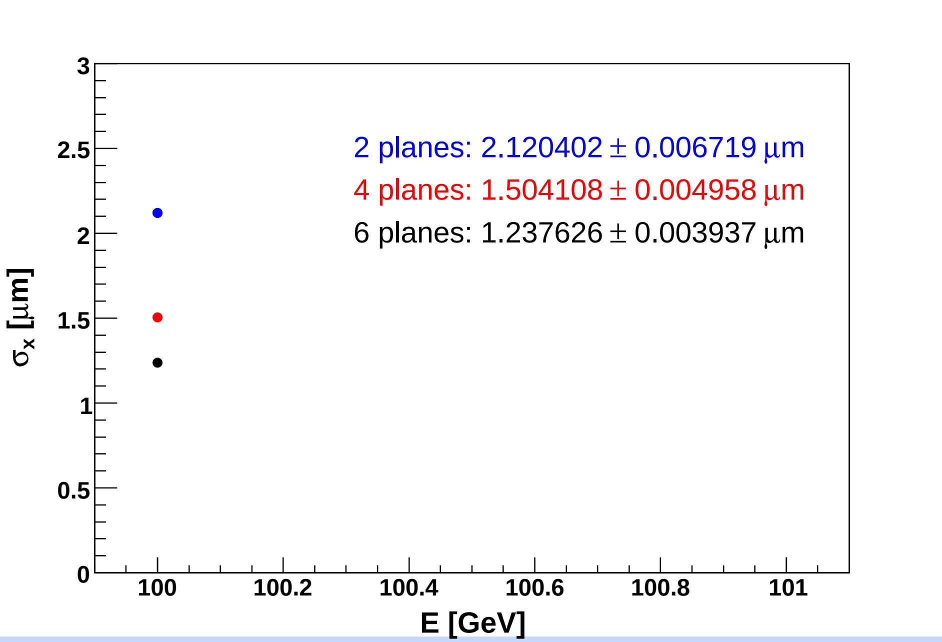


In both cases the configurations with high density sensors for closest telescope planes give the best results

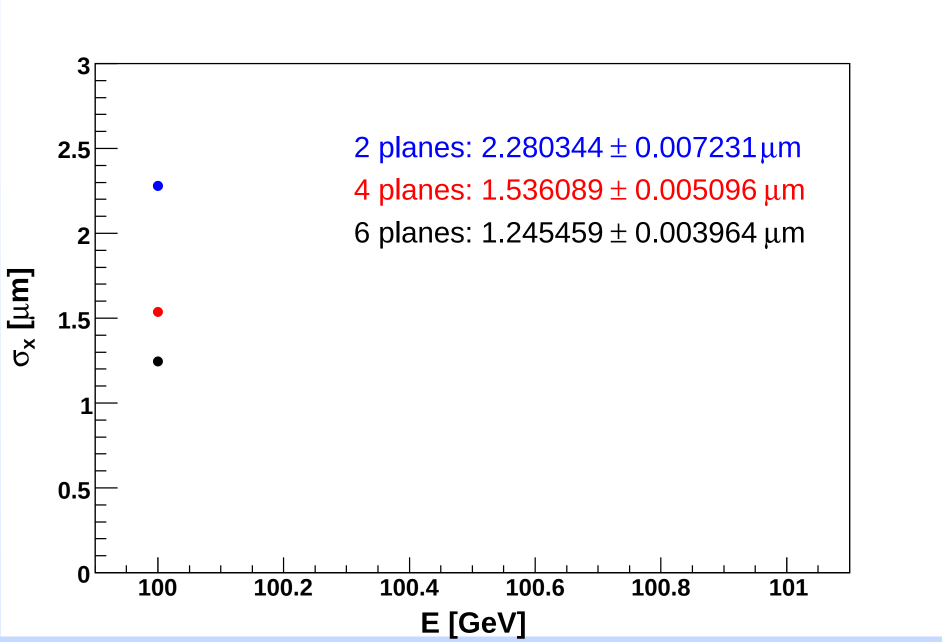
Simulation of pion beam 100 GeV

Assumed telescope plane resolution 3 μm

Symmetric geometry



Asymmetric geometry



With increasing energy MS effects become negligible

$\Longrightarrow$ 6-plane geometry is better

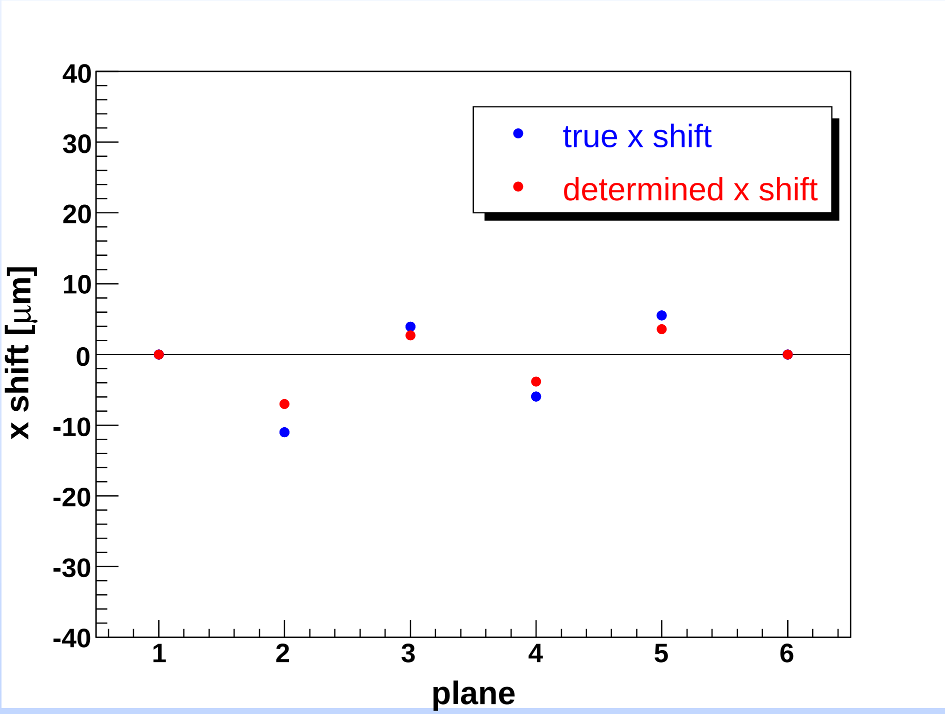
The results for symmetric and asymmetric geometries are similar

Alignment package Millepede

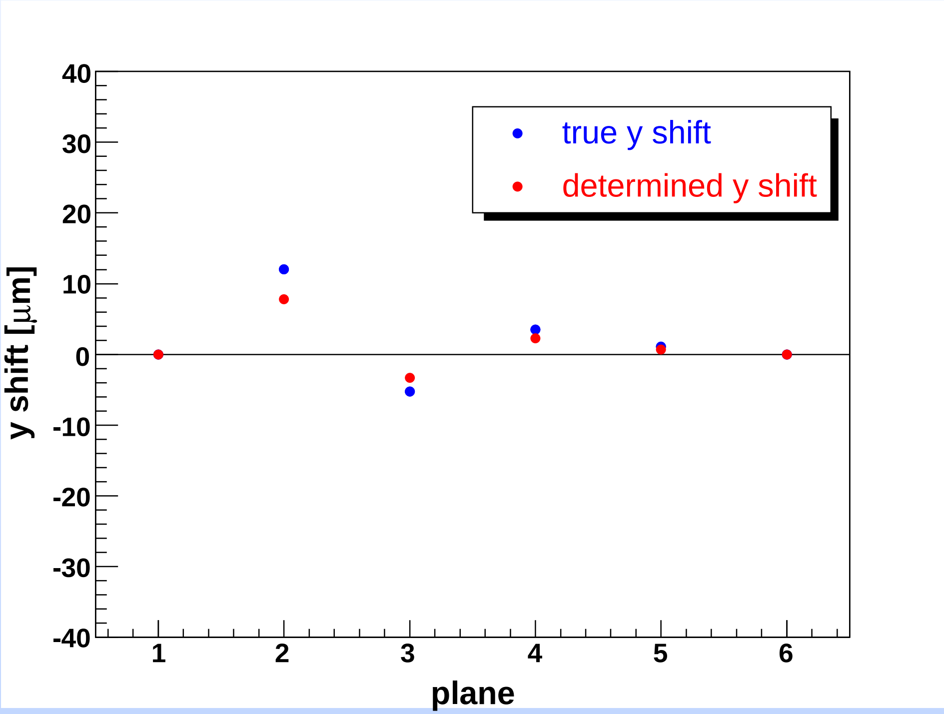
- When detector is ready a proper software alignment will be an important issue for telescope precision
- $\Longrightarrow$ Test alignment procedures with simulated data
- Alignment package Millepede is developed by Volker Blobel (Uni Hamburg)
- Used in H1, ZEUS, CMS for tracker alignment
- Aligns all planes simultaneously
- Based on linear least squares fits
- Local parameters: track parameters (here track slopes and curvatures)
- Global parameters: alignment coefficients (here x and y shifts)
- Simulated 50000 events (6 GeV electron beam) for 6-plane symmetric telescope configuration without DUT

First attempt to find x and y shifts using Millepede

x shifts



y shifts



Should investigate more and play around with constraints, etc.

Conclusions

- **Simulation of future pixel beam telescope is done using ILC software**
- **In general all geometries show good performance**
- **For high energy beams 6-plane geometry gives the best results**
- **For use in both high energy and low energy beams an optimal variant would be 4-plane telescope**

Outlook

- **Track fit taking into account multiple scattering (Kalman filter fit)**
- **Make simulation with magnetic field**
- **Implement alignment for plane rotations**
- **Many thanks to Adrian Vogel, Alexei Raspereza, Predrag Krstonosic, Oliver Wendt, Serguei Gorbounov (H1) and Markus Stoye (CMS) for their help, explanations and valuable advices. Thanks to Alexey Zhelezov for help in computing**