Simulation Study for EUDET Pixel Beam Telescope using ILC Software

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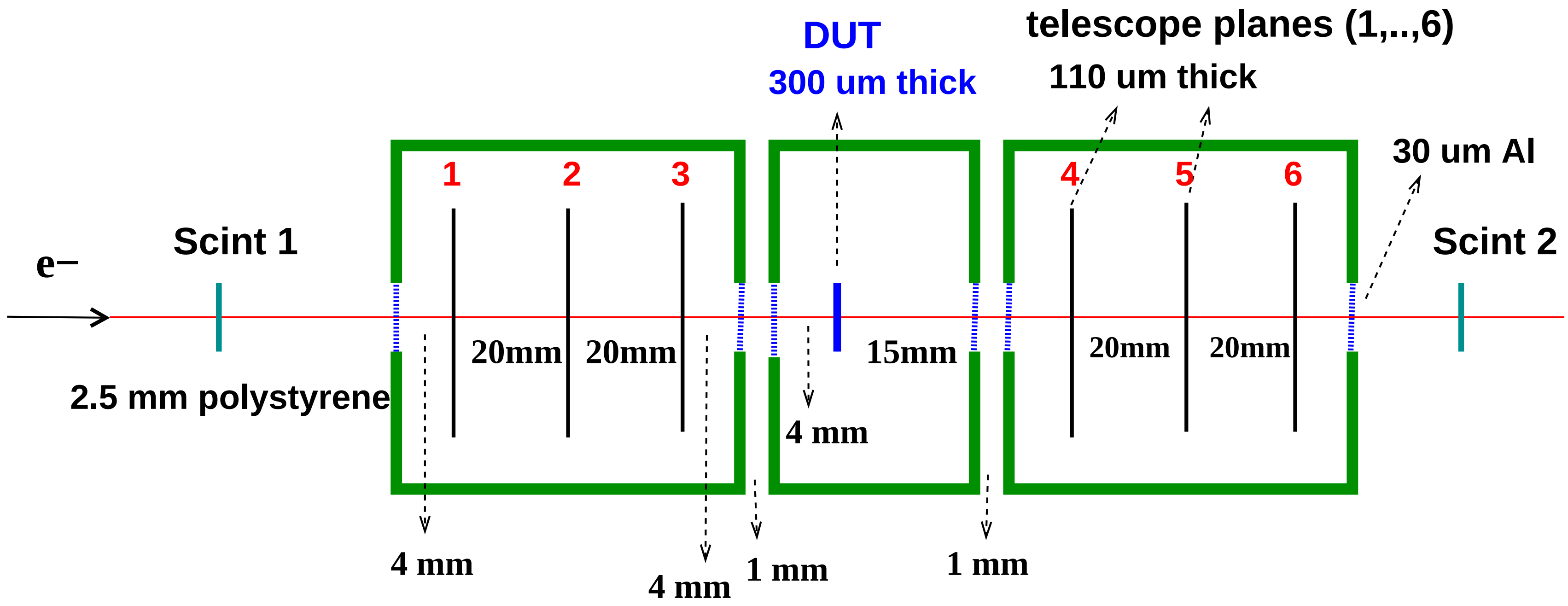
- Telescope geometry
- Software tools
- Comparison of different telescope geometries
- Testing alignment procedures

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/c
  - CERN: pions 100-120 GeV/c
- For telescope planes use CMOS sensors developed by IPHC-Strasbourg
- DAQ development: Switzerland, Italy, France, Germany, UK
- Is being assembled at DESY, first beam tests start in one week

Telescope geometry



- **Electrons: 1-6 GeV/c**
- **Assumed intrinsic resolution of a telescope plane is 3 μm (hit positions are smeared)**
- **Three separate shielding boxes $\Longrightarrow$ flexible setup**
- **For 2- and 4-plane geometries the closest to the DUT planes are considered**

Software Tools

- **Simulation**: **Mokka** **(based on Geant 4)**
  - **New geometry driver EUTelescope has been created (on the way to be included into official Mokka release)**
  - **Class TRKSD00 is used for telescope and DUT sensitive detectors**
  - **All parameters of the model are stored in MySQL database**
  - **Output: LCIO format files**
  - **Stored information: hit positions, deposited energy, ..**
- **Telescope geometry interface (within Gear) is implemented (will be included into next Gear release): detector “SiPlanes” of 2 types: TelescopeWithDUT and TelescopeWithoutDUT**
- **Analysis**: **Marlin, Root, C++**
- **Simulated 50000 events for 2, 4 and 6 planes (no magnetic field)**

Validation of Multiple Scattering model

The width of the projected angular distribution is defined as

$$\theta_0 = \theta_{\mathrm{plane}}^{\mathrm{rms}} = \frac{1}{\sqrt{2}}\theta_{\mathrm{space}}^{\mathrm{rms}}$$

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

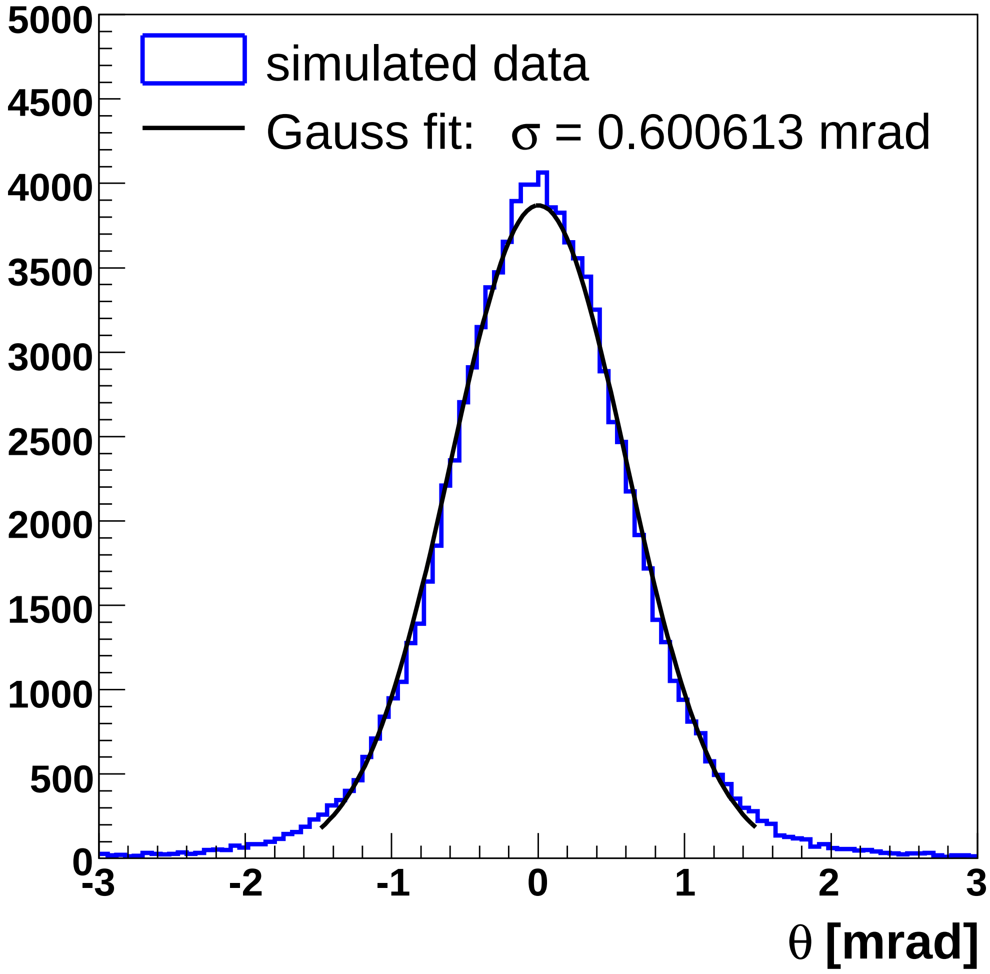
x/X_0 is the thickness of the scattering medium in radiation lengths

To check the validity of MS description:

- Simulate silicon wafer of 300 μm thickness
- Shoot 1 GeV/c electrons (100000 events)
- Look at the projection of the scattering angles θ

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 ($x_{\mathrm{pred}}, y_{\mathrm{pred}}$)
- Find DUT residuals:

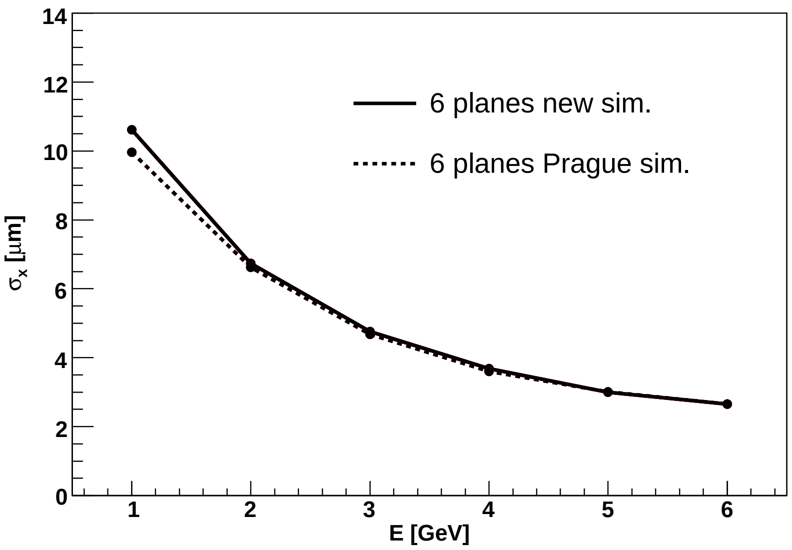
$$r_{x\ \mathrm{DUT}} = x_{\mathrm{pred}} - x_{\mathrm{DUT}}$$

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

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

- Fit Gaussian to residual distributions and find σ_x and σ_y

Geant 4 (Prague) and Mokka simulations



- **The results look similar**
- **In this simulation DUT is shifted right from the center in comparison with picture on slide 3**

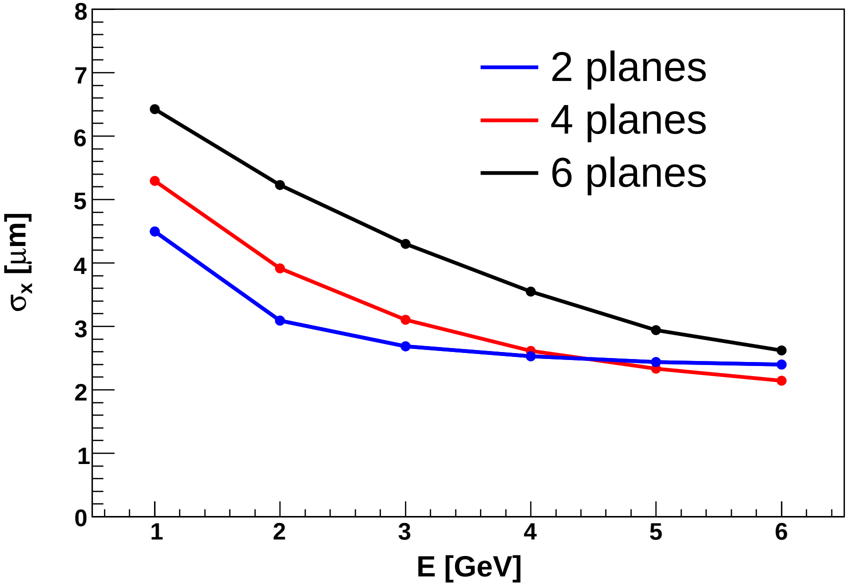
Track selection

- $\chi^2_{\text{track}} < 30$ for 6 plane geometry
  $\chi^2_{\text{track}} < 10$ for 4 and 2 plane geometries
- track slope $<$ 2 mrad
- distance = $\sqrt{(x_{\text{DUT}} - x_{\text{pred}})^2 + (y_{\text{DUT}} - y_{\text{pred}})^2} < 200\ \mu$m

Yield

Momentum	2 planes	4 planes	6 planes
1 GeV/c	78%	27%	21%
2 GeV/c	97%	71%	67%
3 GeV/c	99%	86%	87%
4 GeV/c	99%	91%	94%
5 GeV/c	100%	94%	97%
6 GeV/c	100%	95%	98%

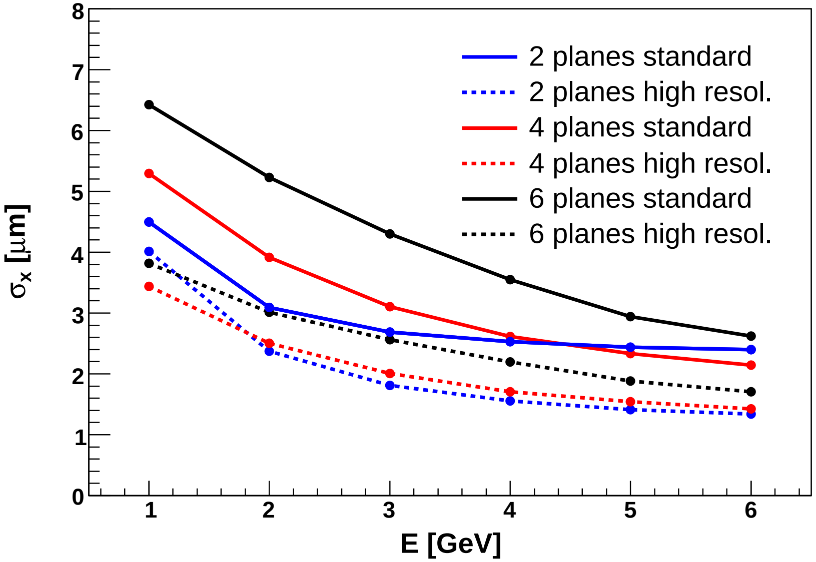
Comparison of different geometries



- **At low energies contribution of multiple scattering (MS) from telescope planes is big $\Longrightarrow$ 2-plane geometry gives better results**
- **With increasing energy 4-plane geometry is an optimal variant**
- **Here track fit: straight line $\Longrightarrow$ should use fit taking into account MS**

Comparison with high resolution setup

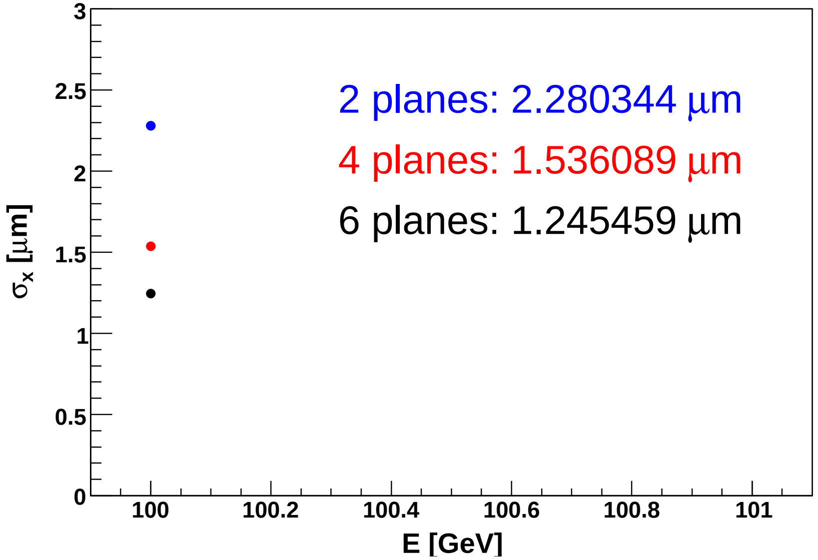
- **Standard setup**: all telescope planes have 3 μm intrinsic resolution
- **High resolution setup**: two telescope planes closer to the DUT have 1.5 μm intrinsic resolution (with smaller pixel size); all other planes - 3 μm



The configurations with high resolution sensors for closest telescope planes give the best results

Simulation of pion beam 100 GeV/c

Assumed telescope plane resolution 3 μm

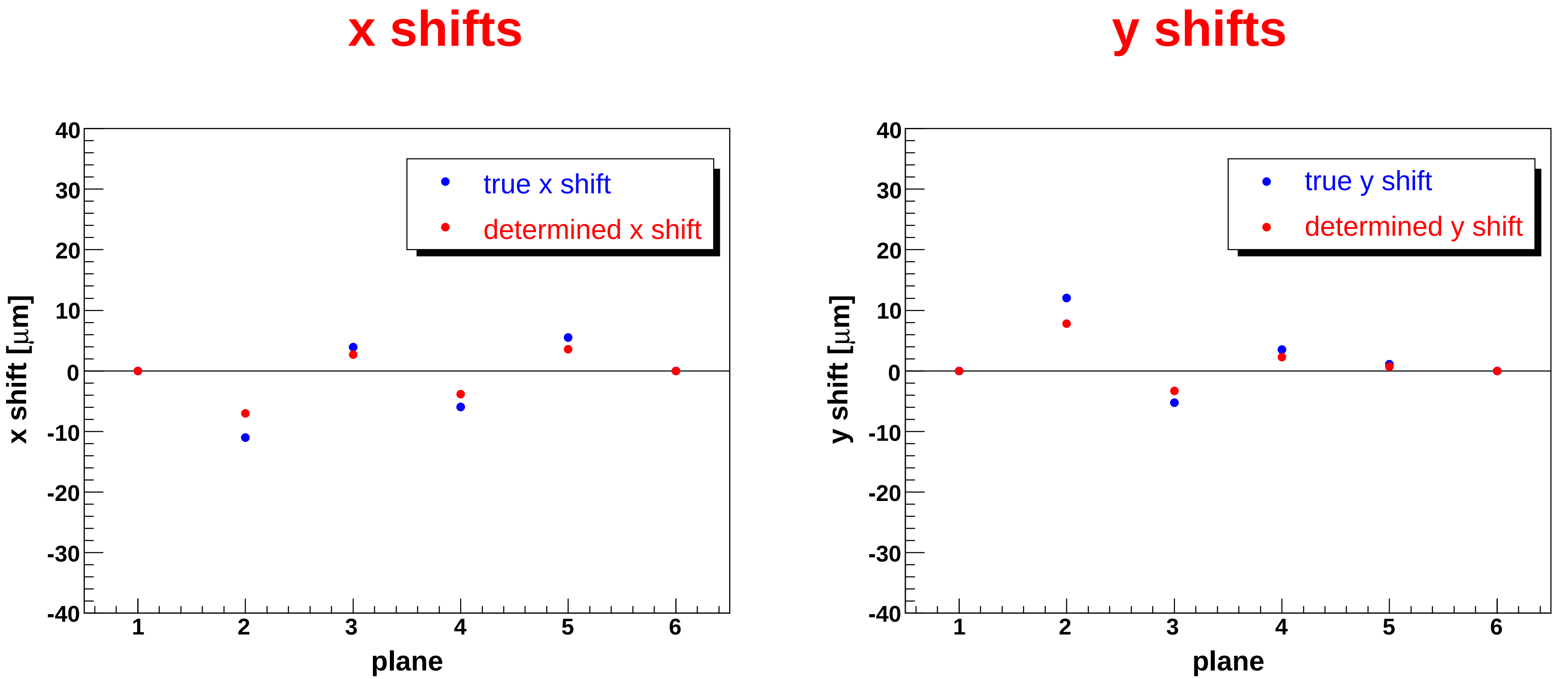


- **With increasing energy MS effects become negligible**
  $\Longrightarrow$ 6-plane geometry is better even after fitting straight line

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 telescope configuration without DUT

First try to use Millepede



Should investigate more and play around with constraints, etc.

Conclusions

- **Simulation of pixel beam telescope is done using ILC software**
- **Gear interface for beam telescope is almost complete. It is tested and in use by telescope software group**
- **For high beam momenta 6-plane geometry gives the best results**
- **At low beam momenta multiple scattering plays a big role**
- **Alignment package Millepede has demonstrated promising results. More checks are needed**
- **The results of simulation study are summarised in EUDET memo EUDET-Memo-2007-06**

Outlook

- To make Mokka code for telescope simulation being ready for next Mokka release
- Implement track fit taking into account multiple scattering
- Make simulation with magnetic field and modify track reconstruction
- Implement alignment for plane rotations
- Analysis software group effort: develop common analysis framework for beam telescope data using existing ILC software (use experience and help from ILC software community)
- Getting ready for beam tests at DESY in one week !

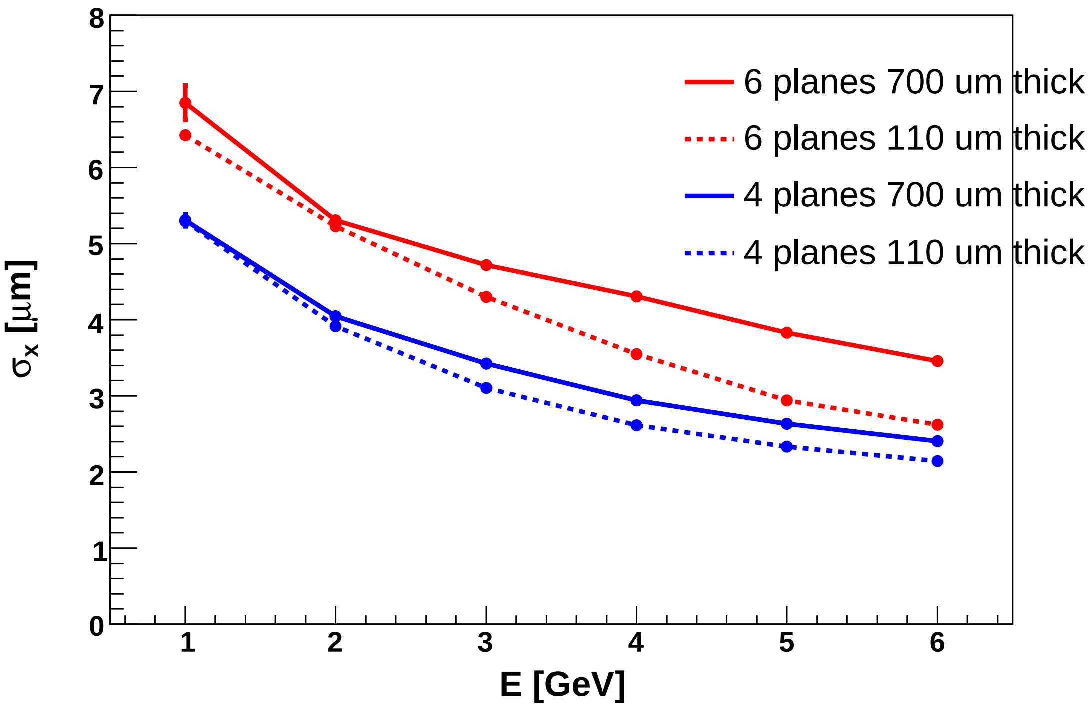
Non-thinned sensors

- Non-thinned sensors (700 μm) may be used for “demonstrator” phase
- Simulate 4- and 6-plane geometries

Yield (after cuts mentioned before):

Momentum	4 planes		6 planes	
	110 μm	700 μm	110 μm	700 μm
1 GeV/c	27%	5%	21%	2%
2 GeV/c	71%	35%	67%	21%
3 GeV/c	86%	60%	87%	48%
4 GeV/c	91%	75%	94%	68%
5 GeV/c	94%	83%	97%	80%
6 GeV/c	95%	87%	98%	87%

Non-thinned sensors



Can get reasonable precision by adjusting selection cuts