Simulation Study for EUDET Pixel Beam Telescope using ILC Software

Linear Collider Workshop, Hamburg, May/June 2007

Tatsiana Klimkovich
DESY
Contents

- Telescope geometry
- Software tools
- Comparison of different telescope geometries
- Testing alignment procedures
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 \( \mu \)m)

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
Electrons: 1-6 GeV/c

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

Three separate shielding boxes → 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

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

For small scattering angles Gaussian approximation is used:

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

$p, \beta c, z$ 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 $\mu$m thickness
- Shoot 1 GeV/c electrons (100000 events)
- Look at the projection of the scattering angles $\theta$
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 \((x_{\text{pred}}, y_{\text{pred}})\)
- Find DUT residuals:
  
  \[
  r_x \text{ DUT} = x_{\text{pred}} - x_{\text{DUT}}
  \]
  
  \[
  r_y \text{ DUT} = y_{\text{pred}} - y_{\text{DUT}}
  \]

  where \(x_{\text{DUT}}\) and \(y_{\text{DUT}}\) are hits in the DUT
- Fit Gaussian to residual distributions and find \(\sigma_x\) and \(\sigma_y\)
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 $= \sqrt{(x_{\text{DUT}} - x_{\text{pred}})^2 + (y_{\text{DUT}} - y_{\text{pred}})^2} < 200 \, \mu\text{m}$

### Yield

<table>
<thead>
<tr>
<th>Momentum</th>
<th>2 planes</th>
<th>4 planes</th>
<th>6 planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 GeV/c</td>
<td>78%</td>
<td>27%</td>
<td>21%</td>
</tr>
<tr>
<td>2 GeV/c</td>
<td>97%</td>
<td>71%</td>
<td>67%</td>
</tr>
<tr>
<td>3 GeV/c</td>
<td>99%</td>
<td>86%</td>
<td>87%</td>
</tr>
<tr>
<td>4 GeV/c</td>
<td>99%</td>
<td>91%</td>
<td>94%</td>
</tr>
<tr>
<td>5 GeV/c</td>
<td>100%</td>
<td>94%</td>
<td>97%</td>
</tr>
<tr>
<td>6 GeV/c</td>
<td>100%</td>
<td>95%</td>
<td>98%</td>
</tr>
</tbody>
</table>
Comparison of different geometries

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

<table>
<thead>
<tr>
<th>$E$ [GeV]</th>
<th>2 planes</th>
<th>4 planes</th>
<th>6 planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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
Assumed telescope plane resolution 3 μm

- With increasing energy MS effects become negligible
  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
- 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

x shifts

y shifts

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**
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 $\mu$m) may be used for “demonstrator” phase
- Simulate 4- and 6-plane geometries

Yield (after cuts mentioned before):

<table>
<thead>
<tr>
<th>Momentum</th>
<th>4 planes</th>
<th>6 planes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110 $\mu$m</td>
<td>700 $\mu$m</td>
</tr>
<tr>
<td>1 GeV/c</td>
<td>27%</td>
<td>5%</td>
</tr>
<tr>
<td>2 GeV/c</td>
<td>71%</td>
<td>35%</td>
</tr>
<tr>
<td>3 GeV/c</td>
<td>86%</td>
<td>60%</td>
</tr>
<tr>
<td>4 GeV/c</td>
<td>91%</td>
<td>75%</td>
</tr>
<tr>
<td>5 GeV/c</td>
<td>94%</td>
<td>83%</td>
</tr>
<tr>
<td>6 GeV/c</td>
<td>95%</td>
<td>87%</td>
</tr>
</tbody>
</table>
Non-thinned sensors

Can get reasonable precision by adjusting selection cuts