The GBL Tracking algorithm in EUTelescope

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EUDET/AIDA Pixel Beam Telescope

- The telescope is a series of pixel sensors used to reconstruct particles trajectories
- To reconstruct a particles trajectory the position/time must be determined with the following
  1. 6 CMOS pixel detectors → 18.4x18.4 μm^2 , 115.2 μs integration time/frame.
  2. Additional FEI4 device used in efficiency measurements to reduce the time resolution to 25 ns.
- EUTelescope is an advanced reconstruction framework for this setup, the latest workshop can be found here.

The mimosa sensors with a device under test (DUT).

Track Reconstruction in EUTelescope

- Deterministic Annealing Filter $\rightarrow$ DAF.
  1. Pattern recognition is combined with track fitting, does not allow easy addition of new pattern techniques
  2. Models all scatterers as thin.
  3. Curved tracks are not reconstructed accurately.
  4. Updates are coming! Watch this space.
- General Broken Lines Algorithm $\rightarrow$ GBL.
  1. A generic track fitting package written by Claus Kleinwort written in C++.
  2. Fit parameters used are curvature and offsets.
  3. Scattering information is included in fit in the form of kink angles.
  4. **Fitting with arbitrary magnetic fields.**
  5. Algorithm implemented in C++.

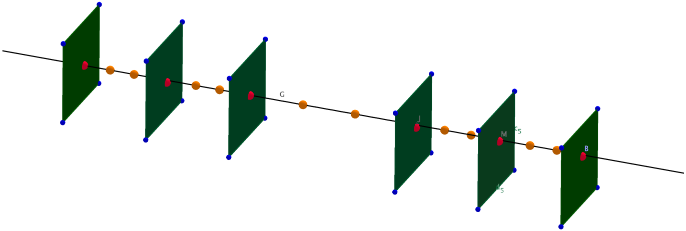
A very preliminary comparison of the current DAFFitter and GBL can be found here.

Track Fitting with GBL Algorithm

- The GBL package has easy interfaces to include the needed information for a track fit and recovering the fit parameters.
- The GBL Algorithm requires additional software to work effectively within EUTelescope.
  1. Millepede → Algorithm designed for least squares fit problems with a large set of parameters.
  2. TGeo → A ROOT geometry package used to describe the small/large scale characteristics of the setup.
  3. Marlin → Used for event by event processing.
  4. LCIO → Data model.

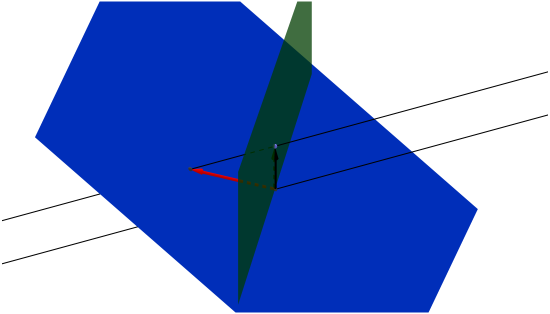
A single track can be constructed in 5 steps...

1 The Discrete Track



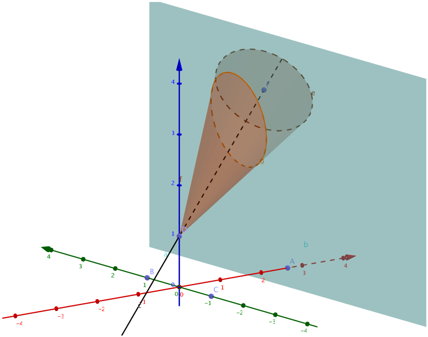
Red Dots: Measurements/Scattering
Orange Dots: Scattering
The location of the scattering points for any trajectory constructed. Thick scattering modeled by two thin scatterers. The scattering locations are dependent on the radiation length distribution with the particles trajectory.

2 Add Measurements



Green Plane: Local coordinate system XY plane (The sensor surface)
Blue Plane: Global Coordinate system which is shared by all sensors
Black Lines: Track before/after motion
Black Arrow: Change on track position in local frame
Red Arrow: Change in track position in global frame

3 Add Scattering

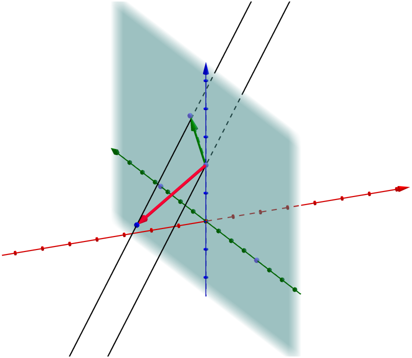


Black Line: Track

Orange Cone: The position errors due to scattering at a location

Blue Plane: Measurement plane. Note correlation of positions due to cone orientation on measurement plane

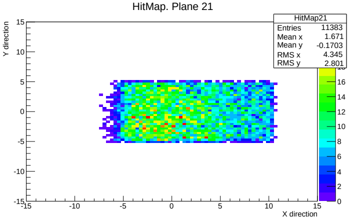
4 Alignment



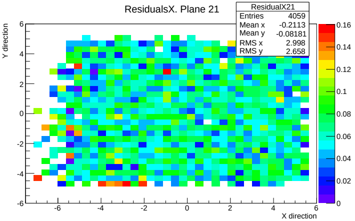
Black Line: Track
Red Arrow: The change in location of track due to change in orientation of sensor
Green Arrow: Change on sensor surface in global frame.

This information is then used by millepede to determine alignment constants which are used to update the geometry file.

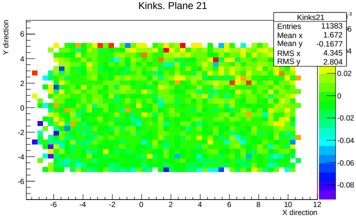
Example Output from the Quad Module



Hit map after tracking in local frame



Residual on surface of sensor in local X direction



Kinks in local frame

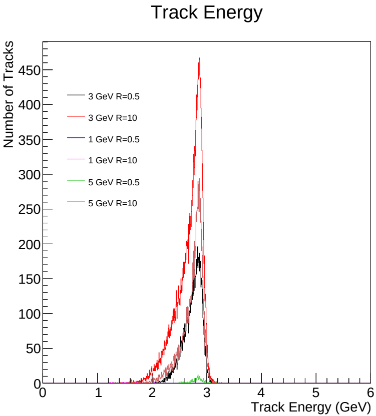
Results look as expected for 250x50 μm^2 sensor assuming uniform distribution on each pixel.

Kinks in local frame depend on assumed radiation length and are not the same as using local derivatives.

All track parameters are output by default to check track model.

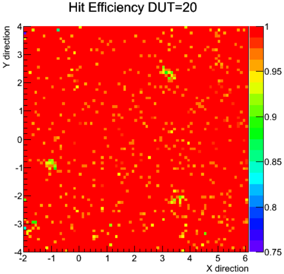
Track/State/Hit/Cluster objects are arranged in a simple hierarchy to allow easy additions to code.

Magnetic Fields

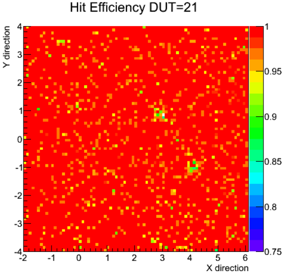


Measurement of beam energy using the curvature of the tracks with 1T magnetic field. The clustering pattern recognition was used to find tracks to be fitted. The R parameter is the clustering window in which hits will be assumed to form a track if inside. The beam energy is the pattern recognition assumption during clustering. No bias was found between pattern recognition settings and the final measured beam energy.

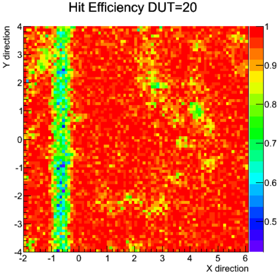
Efficiency Measurements



AC Sensor biased 20V



DC Sensor biased 20V



AC Sensor irradiated to 10^{15} $n_{eq} cm^{-2}$ **biased 200V.**

In effort toward the ATLAS upgrade, efficiency measurements have been performed on different sensors irradiated to different fluencies at the DESY testbeam.

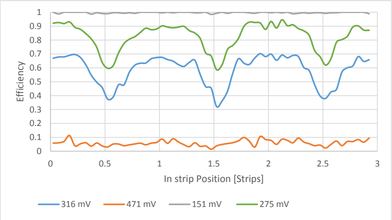
Pitch 250x50 μm with different coupling.

Analysis code for efficiency measurements exist + tbmon reconstruction software can be used

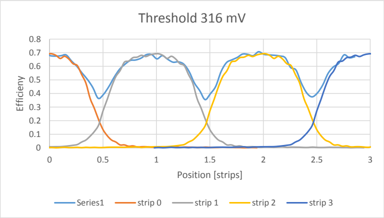
FEI4 timing plane used to identify track causing DUT readout.

Plots: Helen Hayward.

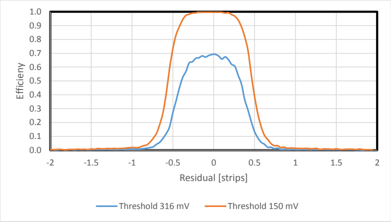
Efficiency Measurements with ATLAS12 Strip Sensor



Combined efficiency for each strip with different thresholds



Combined efficiency for each strip for 316 mV threshold.



Efficiency with distance from centre of strip.

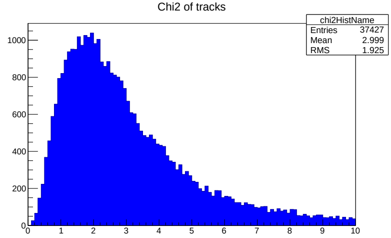
ATLAS12 Strip Sensor (74.5 μm pitch).

Interested in individual strips efficiency. Requires accurate prediction on DUT.

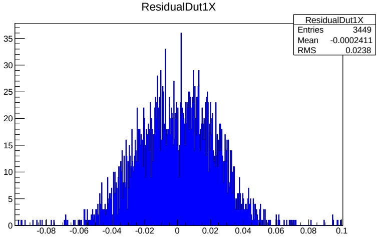
Using analysis code which is part of the SCT example.

Plots: Richard Peschke.

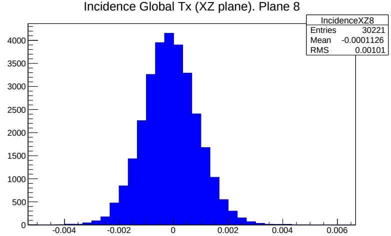
Current Testbeam Reconstruction (October 2015)



Not so perfect Chi2.



Residual on DUT for local X axis.



Incidence of track on DUT for local X axis.

Some initial results from this weeks testbeam.

Reconstructed tracks is lower than expected at 0.5 per event (Expect about 1.5 in most cases).

Beam divergence is as expect and the residual RMS is dominated by the intrinsic error: $\sim 25\ \mu m$.

However overall fit is still not perfect.

Looking to the Future/Conclusion

A generic track fitting model has been implemented into EUTelecope with working examples. Analysis is still ongoing and new challenges await.

- Radial strips and improvement in the implementation of the measurement frame
- Replacing the old GEAR file format
  1. Allow multiple global frames imposed on one another. This allows different orientated sensors on the same plane.
  2. Include addition global parameters for a set of runs. Scale factors between the first and last plane as an example
- General re-factorization, moving to c++11 and beyond
- Examples should be incorporated into Ctest.
- Improvements to DAFFitter needs to be made more generic if possible
- pyGBL should be added as additional analysis code

Backup

A Quick Detour: EUDET/AIDA Pixel Beam Telescope

- 6 CMOS pixel detectors (18.4x18.4 μm^2) $\rightarrow$ 1152 columns x 576 rows 2x1 cm^2.
- Rolling shutter $\rightarrow$ continuous readout $\rightarrow$ 115.2 μs integration time/frame.
- Additional FEI4 device used for Region of Interest (ROI) and time stamping.
- TLU and EUDAQ act as hard/soft layer for data acquisition.
- EUTelescope is an advanced reconstruction framework for this setup, the latest workshop can be found here.

The mimosa sensors with a device under test (DUT).

EUTelescope

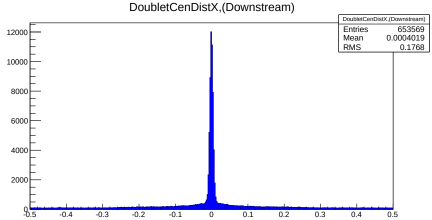
- EUTelescope is a highly generic testbeam reconstruction and analysis framework.
- It is a software package which is part of ILCsoft. A list of packages can be found here.
- Relies on two packages for data structures and reconstruction.
  1. Modular Analysis Reconstruction for the LINear Collider →. Marlin.
  2. Linear Collider Input Output → LCIO.
- On top of this additional software packages are used.
  1. Millepede → Algorithm designed for least squares fit problems with a large set of parameters.
  2. TGeo → A ROOT geometry package used to describe the small/large scale characteristics of the setup.

The idea is to go from individual hit strips/pixels - or more complex - to the final reconstructed tracks. A general introduction is given here.

Pattern Reconstruction

You want to associate hits on each plane to a single track. This is more art than a science with many different procedures appropriate for different geometries and enviroments.

- Pattern Recognition comes with two regimes with GBL in EUTelescope.
  1. Clustering: Extrapolate all hits to first plane and cluster (Useful if some planes have a low efficiency).
  2. Triplets Use both arms of the telescope to form triplets then link (Low fake rate. Recommended!).
- Both regimes work with arbitrary magnetic field.



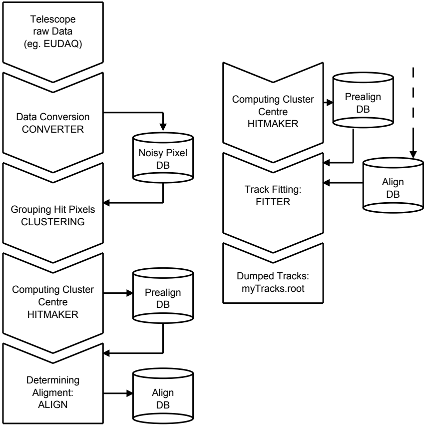
Residual (mm) of prediction - measurement. A series of cuts is applied to determine signal from background.

The Fitter in Action

EUTelescope is a collaborative effort first and foremost and to that end many working examples have been created to aid further analysis. The full analysis chain is described for each example and works from installation (Data on DESY AFS). Brief Manual here

- **noDUTExample** This example demostrates the use of the fitter with magnetic fields and varying beam energies.
- **Quad** Quad module with reference DUT at the DESY testbeam .
- **QuadSLAC** Quad module and reference DUT at the SLAC testbeam.
- **Pixels** High radiation length enviroment using the gear file to describe dead material. Two APIX devices at DESY testbeam.
- **mappingAPIX** Two APIX DUTs using the mapping processor between channel number and geometric cluster position.
- **mappingAPIXSLAC** This is the same as the other mapping example but at SLAC and with highly irradiated sensors.
- **SCT** Strip example which has been used for efficiency measurements.
- **StripAlibava** ATLAS12 strip device using the alibava system as readout.
- **X0** The use of the kink angle estimation is demonstrated here.

Reconstruction in a Nutshell

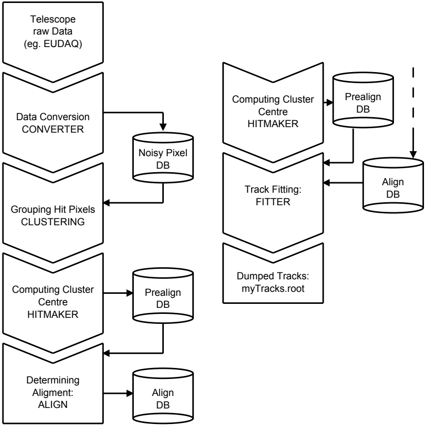


A typical reconstruction chain. Different processors can reconstruct the clusters/hits/track in different ways depending on the analysis.

Reconstruction comes in a series of steps with track fitting coming last in the chain.

- Converter: Takes unique output from readout system and creates an LCIO file with the required format. (Can combine telescope and DUT data further down the chain).

Reconstruction in a Nutshell



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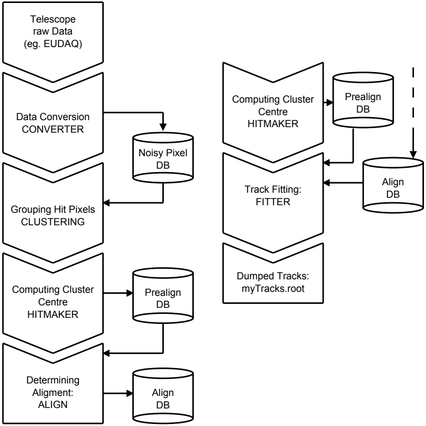

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- Hitmaker: Relates clusters to a single hit position with intrinsic measurement errors.

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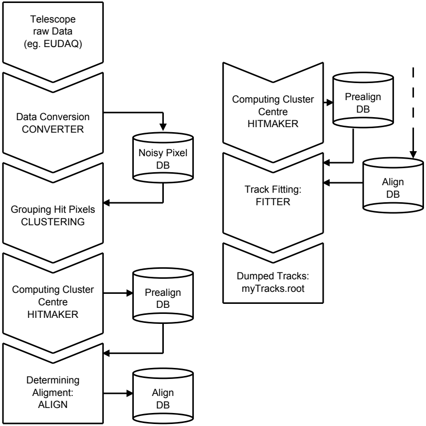

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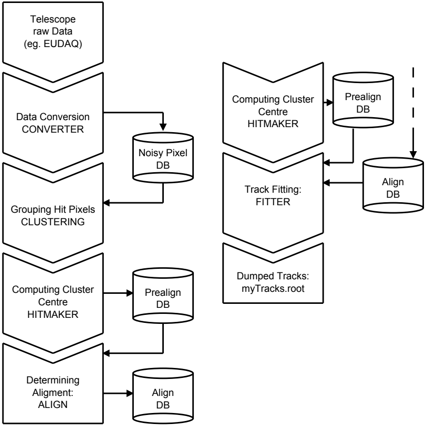

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- Pre/Full Alignment: Determines physical position of sensors. Different track models and alignment parameterizations can be used. However all methods depend on Millepede for least squares fitting for local/global parameters.
- Tracking: The most likely track given initial assumptions is deduced, the final tracks are output in lcio/root formats.

Track Fitting with GBL Algorithm

The GBL algorithm has easy interfaces to include the needed information for a track fit and recovering the fit parameters. This information would be needed in any tracking situation and a quick introduction is presented now:

The five fold way

1. Need to link discretized points to form a full trajectory. Figure 5 shows the specific setup for EUTelescope.
2. The trajectory must contain measurements with errors. Figure 5 Red Points.
3. Points which model scattering have kink angles and errors added. Figure 5 Orange Points.
4. Global derivatives which relate motions of the sensors with local frame residuals are added for alignment.
5. *If needed: Local derivatives are added to determine parameters which relate to the track's residual on certain planes.*