Studies for a TPC in a CLIC Detector

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Introduction: Aim of this Study

A TPC at CLIC?

- Can a TPC resolve the tracks inside the narrow jets @ 3 TeV?
- TPC readout time ≈60 µs, time of bunch train (BT) 150 ns
  $\Rightarrow$ 1 BT in $\mathcal{O}(10)$ mm TPC drift
- What is the occupancy after 1 BT?
- Include backgrounds
  - muons parallel to beam axis
  - $\gamma\gamma \rightarrow$hadrons
  - e^+e^- pairs from beamstrahlung
- Can a TPC provide time stamping?

Software Tools Overview

1. Simulation (deposition of charge/energy in the detector)
   - MOKKA / Geant4
   - Stand alone (MarlinTPC)
2. Digitisation (calculation of the detector response)
   - Detailed digitisation chain in MarlinTPC
3. Reconstruction (finding the particles back from the detector response)
   - MarlinTPC
   - LEP-Tracking in MarlinReco
4. Analysis
   - Marlin processors written for this study

MarlinTPC

TPC simulation, digitisation, reconstruction and analysis toolkit developed by the LC-TPC collaboration.

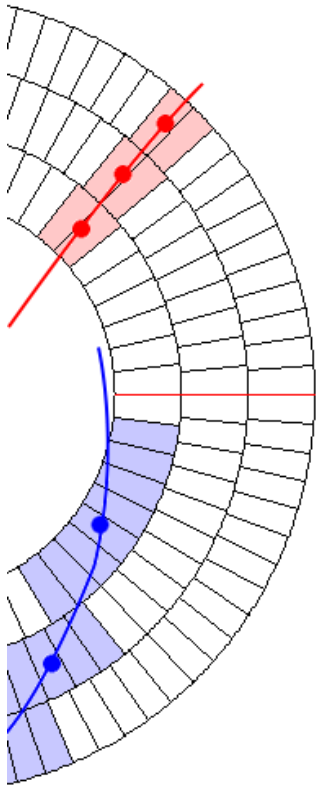
- Main focus: Reconstruction of prototype data

What has to be improved for this study?

- Realistic simulation
- Handle two "half" TPCs
- Overlay events and background
- Improve digitisation of raw data
- Double hit / track separation
- Helix fitting
- Integration into full detector
- Debug and verify existing code

Detector Simulation

- MOKKA (TPC driver with default settings)
  - One hit per pad row
  - \+ Can directly be translated to a reconstructed hits
  - – Pad response not realistic for tracks with low angle
- MarlinTPC stand alone simulation:
  - Realistic cluster sizes and distances due to parameterised HEED and Magboltz data
  - – Tracking is not done within Geant4
  - – No full detector events
  - – No particles from backscattering
  - – No decays in the TPC
- MOKKA (TPC driver with low P_T settings)
  - Distance of step can be limited (default 1 mm)
  - – Details of energy deposition not fully understood
  - – Distance between hits is too large (often above 10 mm, Geant4 limitation in combination with energy cut)



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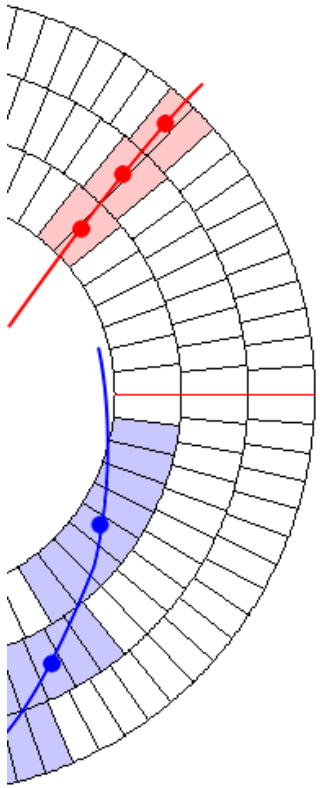
  - – No decays in the TPC
- MOKKA (TPC driver with low P_T settings) (✓)
  - Distance of step can be limited (default 1 mm)
  - – Details of energy deposition not fully understood
  - – Distance between hits is too large (often above 10 mm, Geant4 limitation in combination with energy cut)
  - Set step limit to 200 µm
  - Set "low" P_T threshold to 3 TeV (everything is run in low P_T mode)
  - Is this suitable for full events?



Digitisation and Reconstruction

Digitisation:

- Map of voxels (3D space buckets) resembles readout electronics
- Automatically implements event pile-up
- Background can be added

\+ Output is realistic ADC raw data (`lcio::TrackerRawData`)

Reconstruction:

- Reconstruction chain developed with / for prototype data

\+ Detailed and realistic, no MC information is used

– MC truth information of reconstructed tracks not available

– Only rudimentary track fitting

Idea:

- Use MarlinTPC up to hit level and LEPTracking for pattern recognition and fitting

\+ Can be used in full detector events

\+ MarlinTPC can do preselection to avoid problems with FORTRAN (too many hits per event)

The Second "Half TPC"

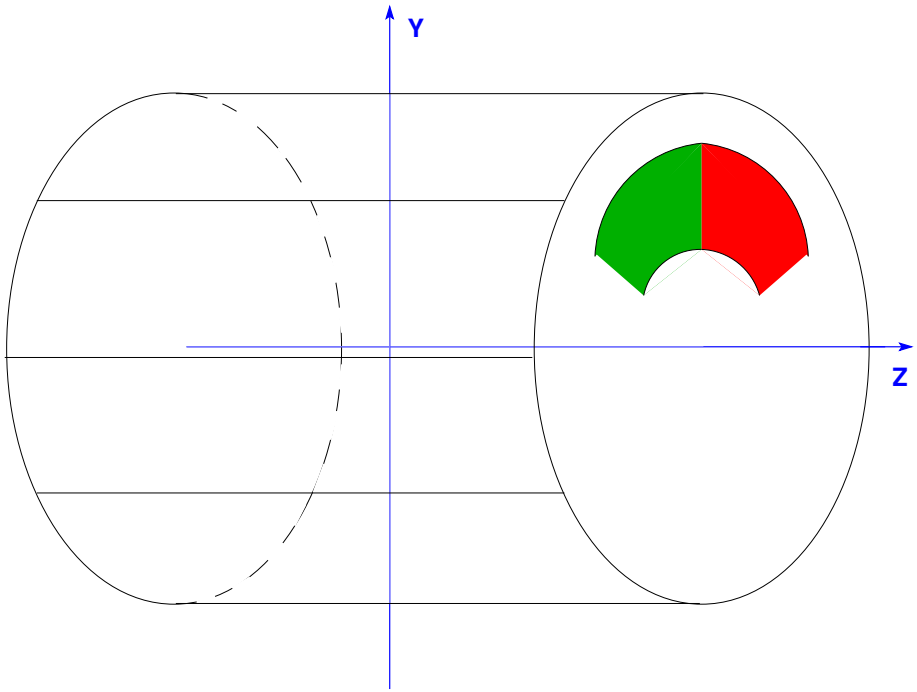
New in GEAR:

- Introduce a z position for each module
  - $z > 0$: Positive side
  - $z < 0$: Negative side
  - $z = 0$: Prototype
- Extend `TPCParameters::getNearestPad()` and `TPCParameters::getNearestModule()` with z coordinate
  - Determine correct side from z coordinate
  - Run the 2D version on the modules of one side

Implicit assumption for full TPC (no z information given):

- GEAR end plate is on positive side
- Coordinates match with global coordinates

$\Rightarrow$ Pads as seen from the outside



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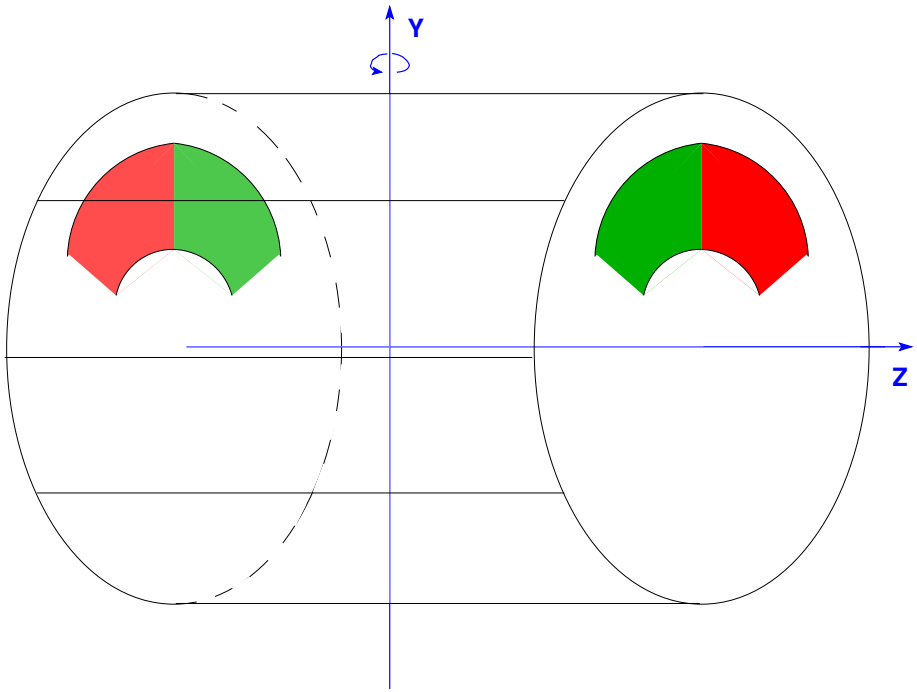
Second, identical end plate:

- Rotated to face the other end plate

$\Rightarrow$ z and x coordinate are exchanged

- Drift direction is along negative z axis

$\Rightarrow$ x coordinate has to be inverted by GEAR



Second "Half TPC" and the Prototype

Prototype:

- Anode position is at $z = 0$
- Z coordinate is proportional to drift distance
- Drift direction is in negative z direction

$\Rightarrow$ Prototype is negative "half TPC"

Problem:

- x coordinate will be inverted, not backward compatible

Solution:

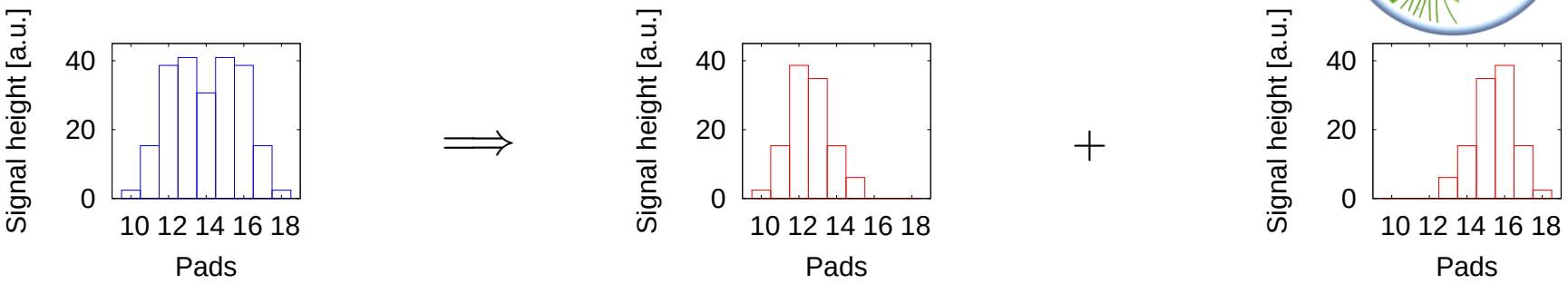
- New feature is only activated if z coordinate is explicitly set (either in XML file or in the C++ code)
- Flag is only written to XML if it has been set before

$\Rightarrow$ Full backward compatibility

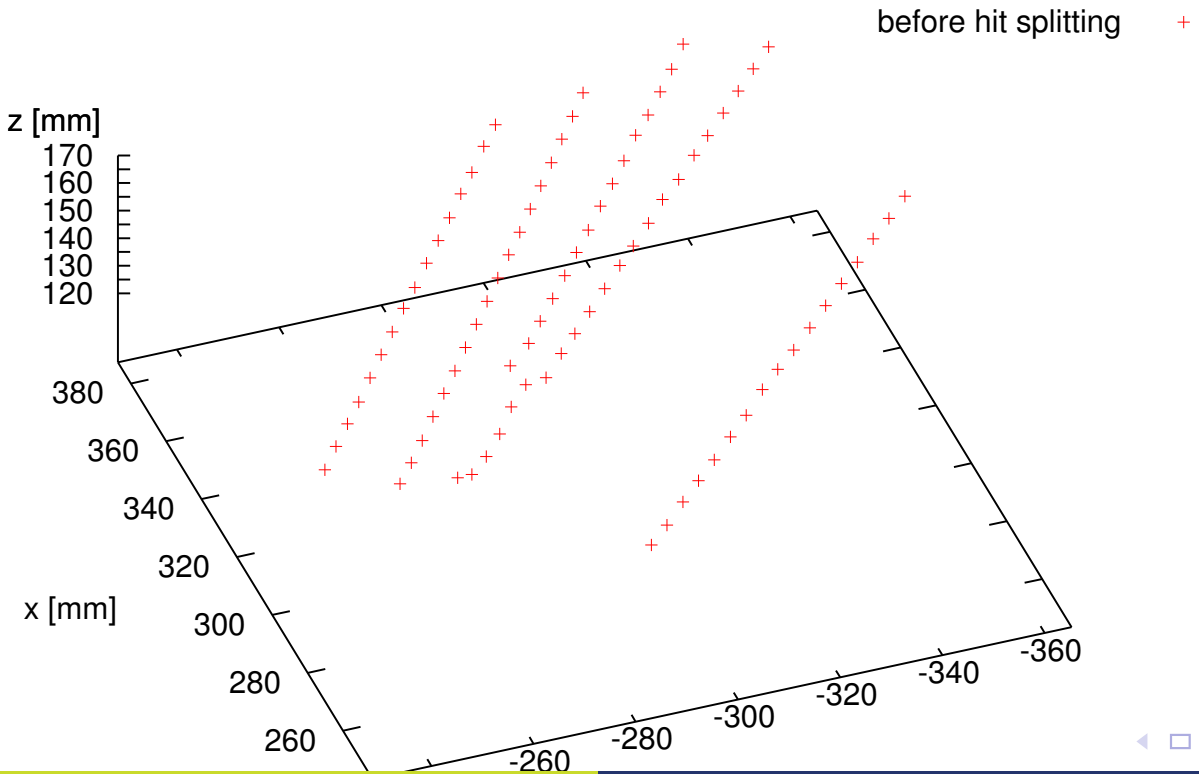
- Feature is in the GEAR trunk, will be available with v00-15
- Has to be integrated into MarlinTPC

Hit Splitter

For a better separation the signal distributions can be split:



- Hits from two tracks merge on the inner pad rows



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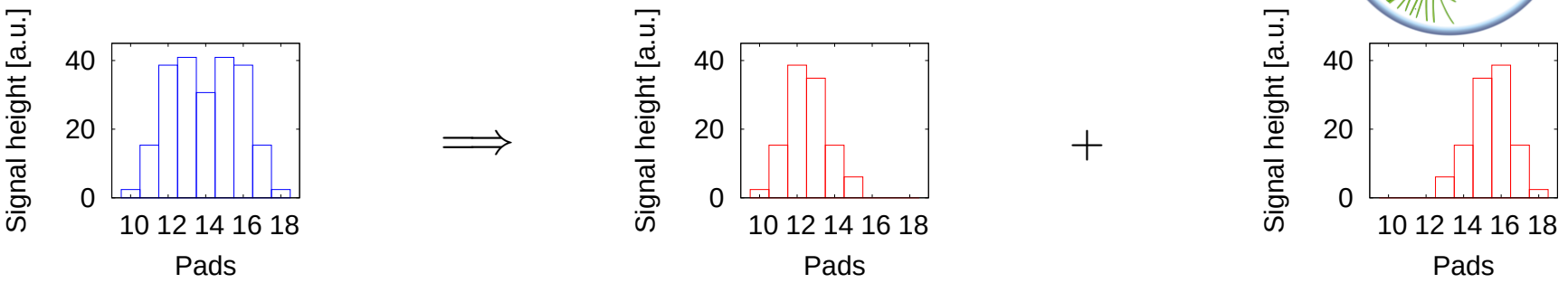

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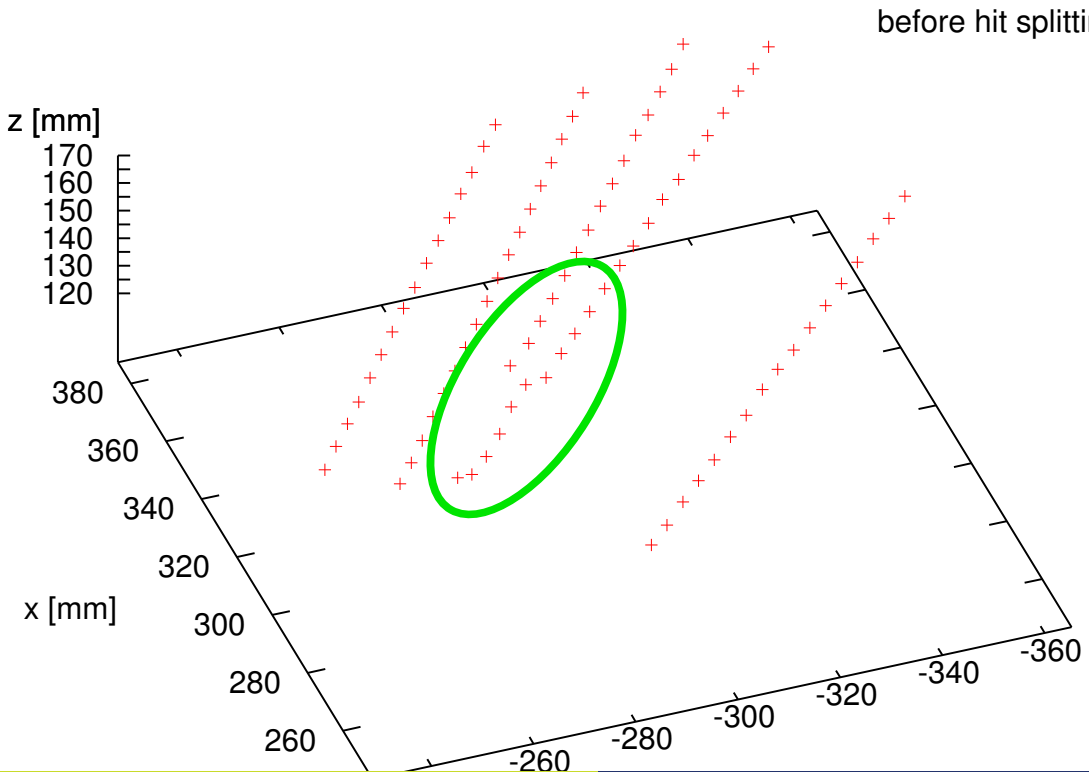

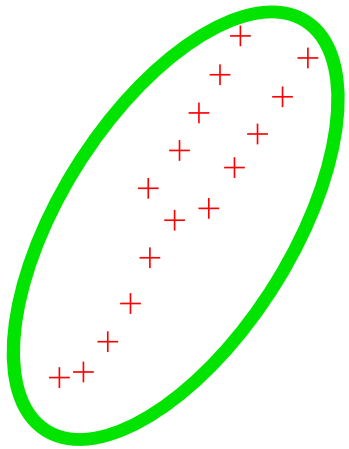

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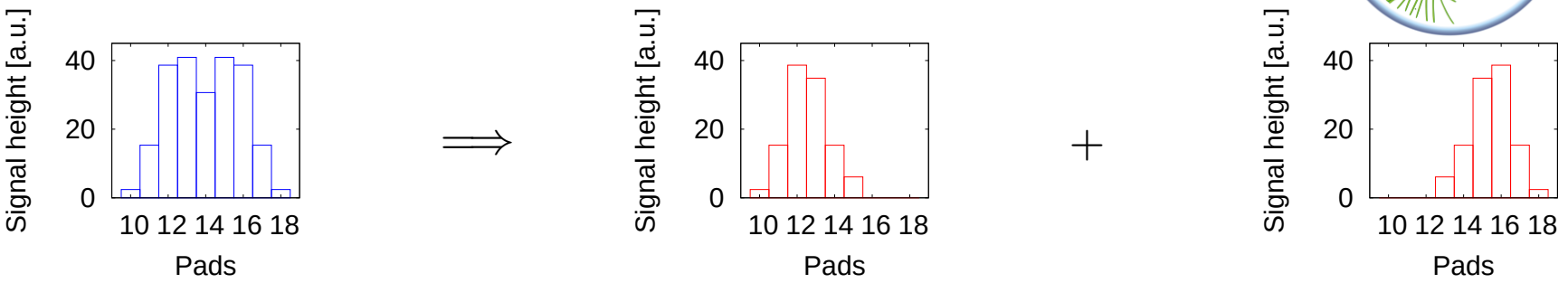
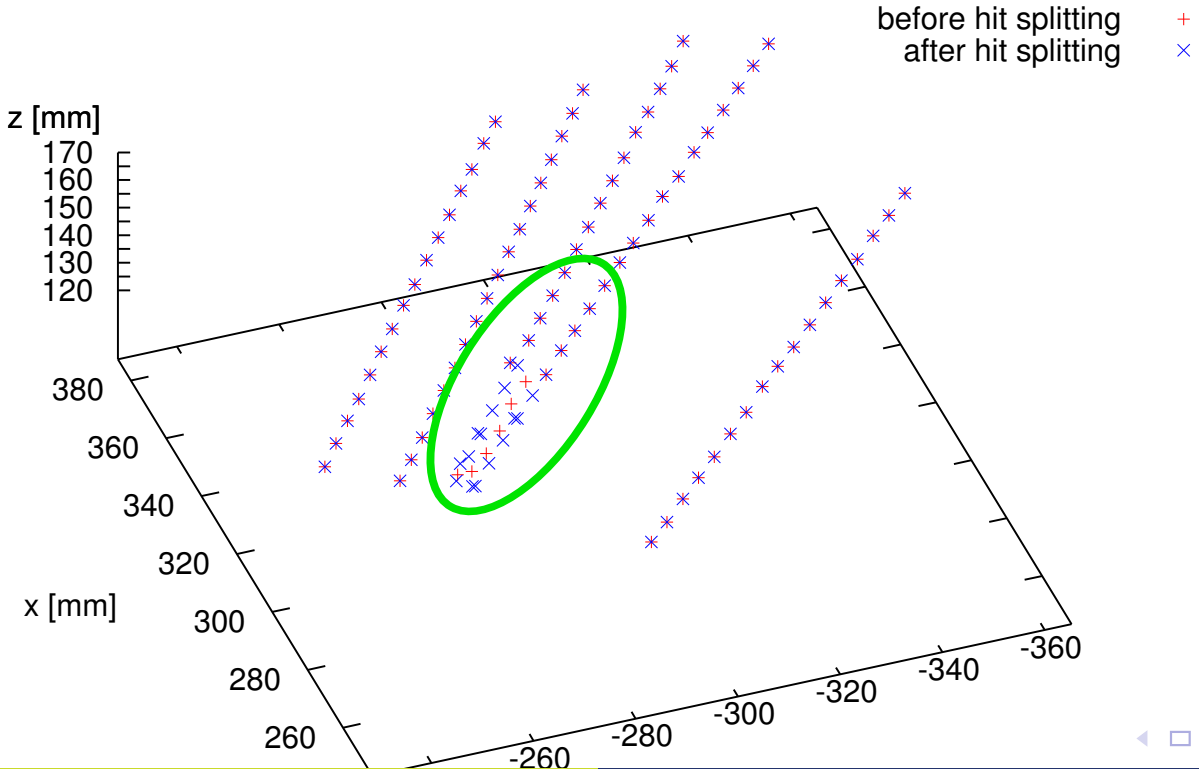
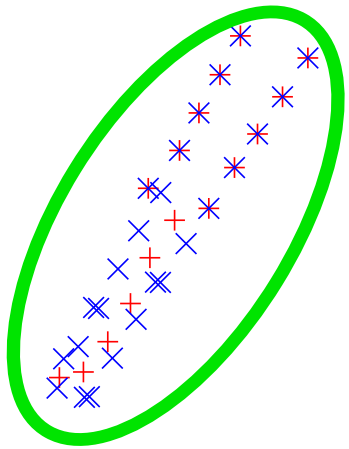


- Hits from two tracks merge on the inner pad rows
- After hit splitting the tracks can well be separated





Analysis: Time Stamping with the TPC

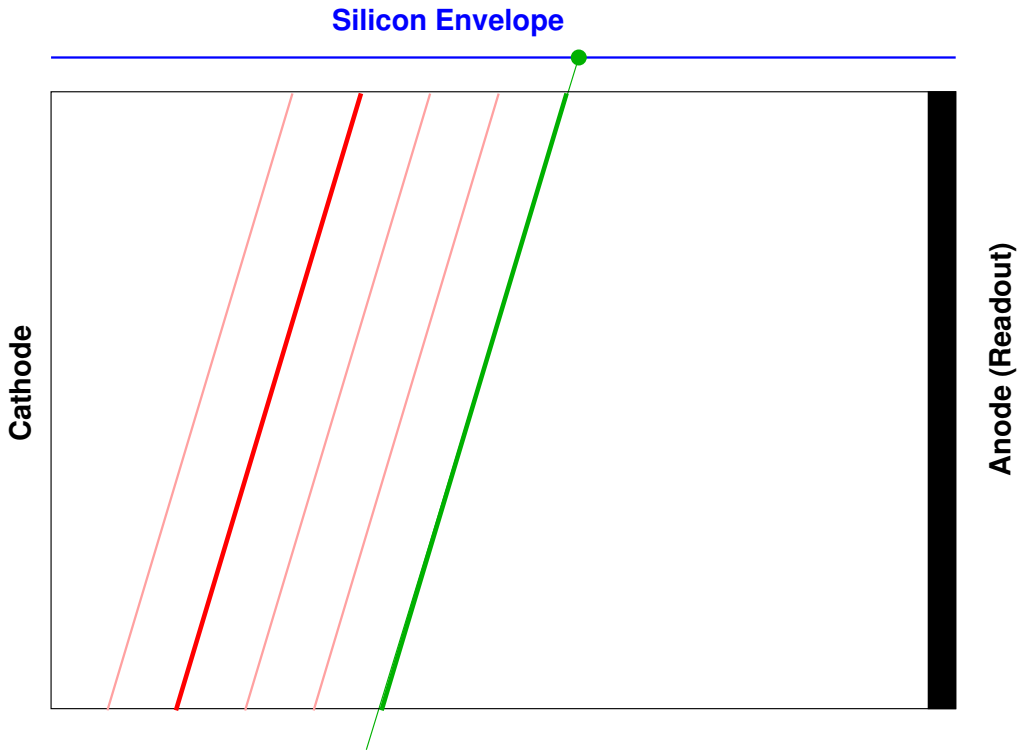
- In the barrel time stamping only works in combination with an external silicon detector
- The TPC measures time since beginning of the bunch train

$$z = (t_{\mathrm{drift}} + BX \cdot \Delta t_{BX}) \cdot v_{\mathrm{drift}}$$

- The silicon sensor measures z directly, without timing information.
- From this the time stamp $BX \cdot \Delta t_{BX}$ is determined.

ILC $\Delta t_{BX} = 369$ ns
$\Delta z_{BX} = 29.1$ mm[a]

CLIC $\Delta t_{BX} = 0.5$ ns
$\Delta z_{BX} = 39.5$ µm



[a] at $v_{\mathrm{drift}} = 79$ mm/µs

Details of the study

- Shoot muons from the vertex (MarlinTPC stand alone)
- Run full digitisation and reconstruction
- Shift the reconstructed track to a random event within the bunch train

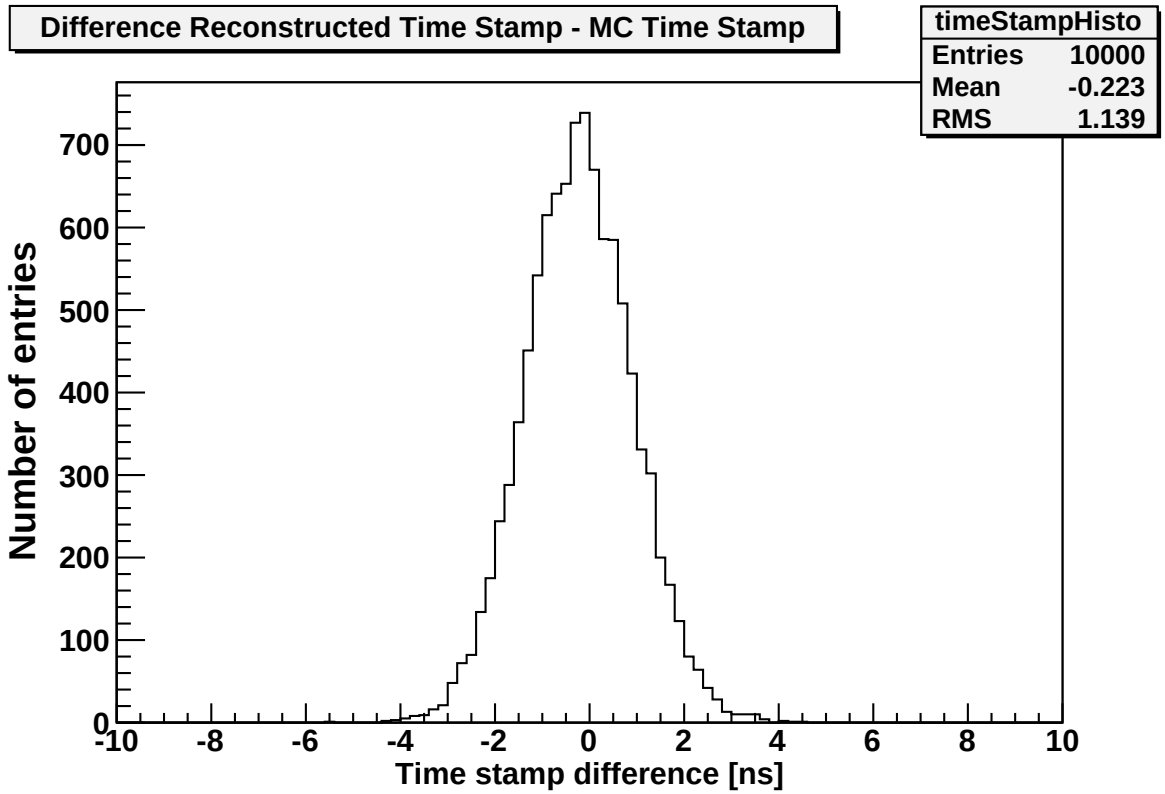
Barrel region:

- Calculate intersection of reconstructed helix with silicon envelope
- Scatter the MC truth particle at the outer field cage
- Calculate intersection of scattered MC truth with silicon envelope tracker (SET)
- Smear SET hit with detector resolution
- Calculate time stamp and difference to MC truth
- Calculate the bunch crossing from the time stamp

End cap region (no results yet, work in progress):

- Scattering of MC truth in the end cap
- Compare with hits in end cap tracking discs

Barrel Time Stamping

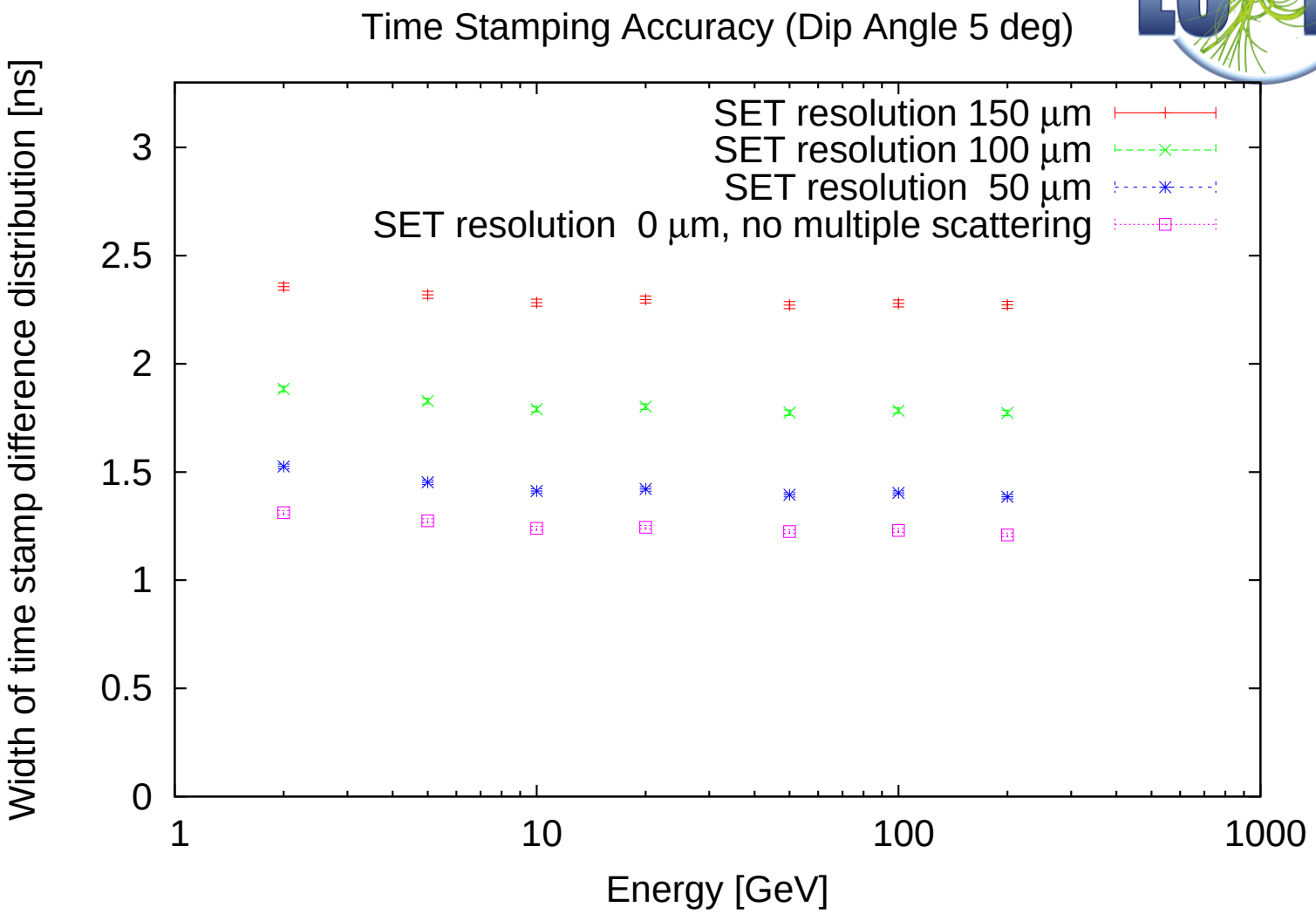


Example:
50 GeV muons, $\lambda = 50^\circ$ (corner of the TPC), 50 µm SET resolution

Parameters

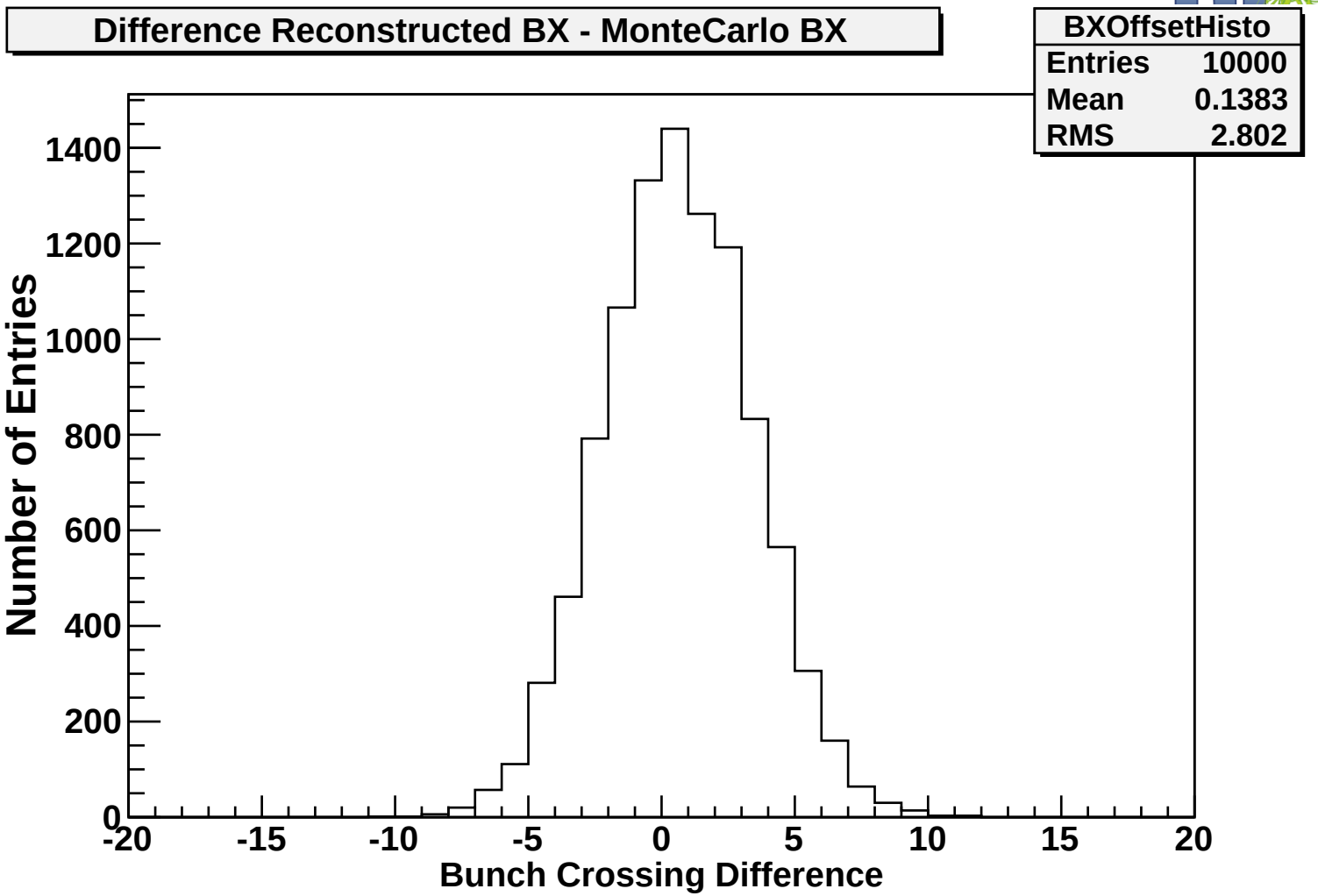
- 3 dip angles: 5.71° ($\tan(\lambda) = 0.1$), 30°, 50°
- 7 energies (2 – 200 GeV)
- 4 SET resolutions: 0 µm, 50 µm, 100 µm, 150 µm

Barrel Time Stamping



- Very weak dependency on particle energy
- Intrinsic TPC resolution $\mathcal{O}(1.2$ ns$)$
- With multiple scattering and realistic SET resolution < 1.5 ns

Barrel: Determining the Bunch Crossing



90 % of the muons are assigned correctly to within $\pm$ 5 bunch crossings[1]

[1] Energy 50 GeV, dip angle 5°, SET resolution 50 µm

Conclusion

Simulation:

- MOKKA driver in low P_T mode is currently being looked at
- MarlinTPC stand alone simulation does not cover full detector events

Digitisation: MarlinTPC

- Basic digitisation chain is ready and debugged
- Event and background overlaying not tested yet
- Work on second half TPC

Reconstruction: MarlinTPC + LEPTracking

- Basic chain up to Hit reconstruction is ready
- Interface to LEPTracking has to be created

Analysis:

- Time stamping
  - Barrel: better than 1.5 ns (SET 50 µm)
  - End cap: no results yet, work in progress