University of Victoria

Preparations for a Simulation Study of the Magnetic Field Requirements of the LC TPC

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Objectives

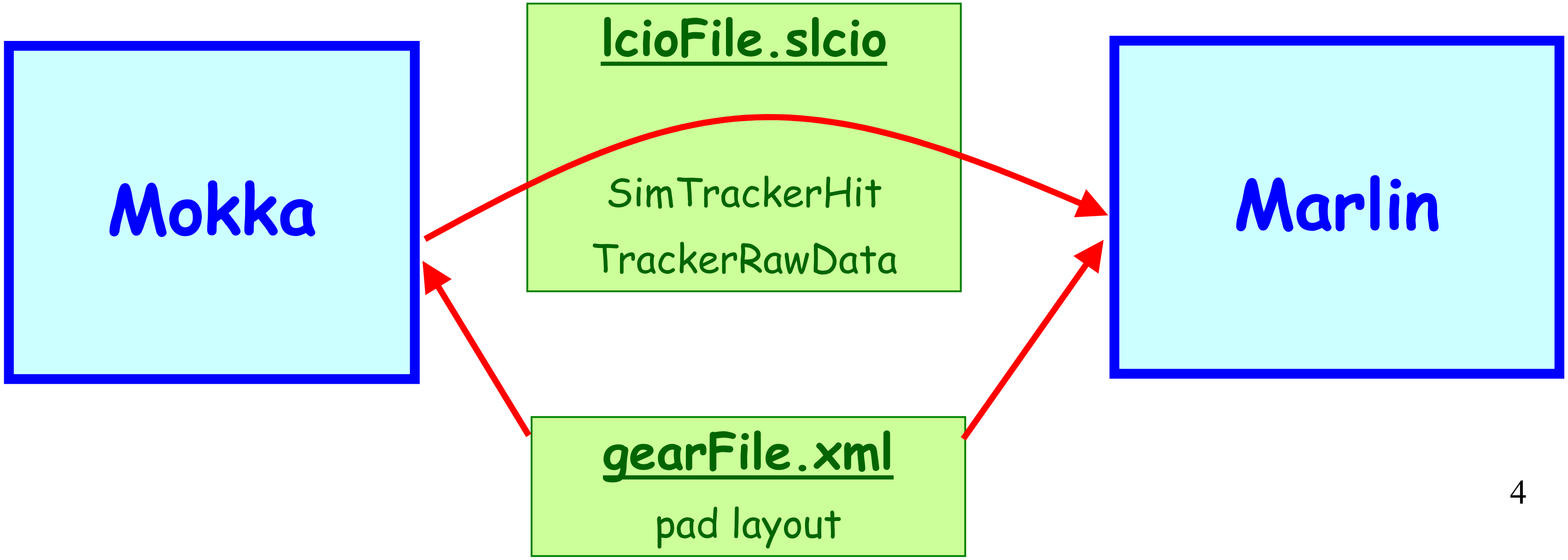
- ILC's crossing angle will cause magnetic field distortions
- Corrections for the inhomogeneous magnetic field will be needed for TPC's required momentum resolution ($d(1/p) \sim 10^{-4} GeV^{-1}$)
- Two ways to correct for magnetic field distortions;
  - a B-field map giving a first approximation
  - external data points (e.g. from the vertex detector)
- Back of the envelope estimations on the possible accuracy of these corrections have been done (see Snowmass 2005 talks by Ron Settles and Don Peterson)
- A simulation study is needed to determine the
  - influence of an inhomogeneous magnetic field on TPC's momentum resolution and the
  - possibility for magnetic field corrections to the reconstruction

Strategy

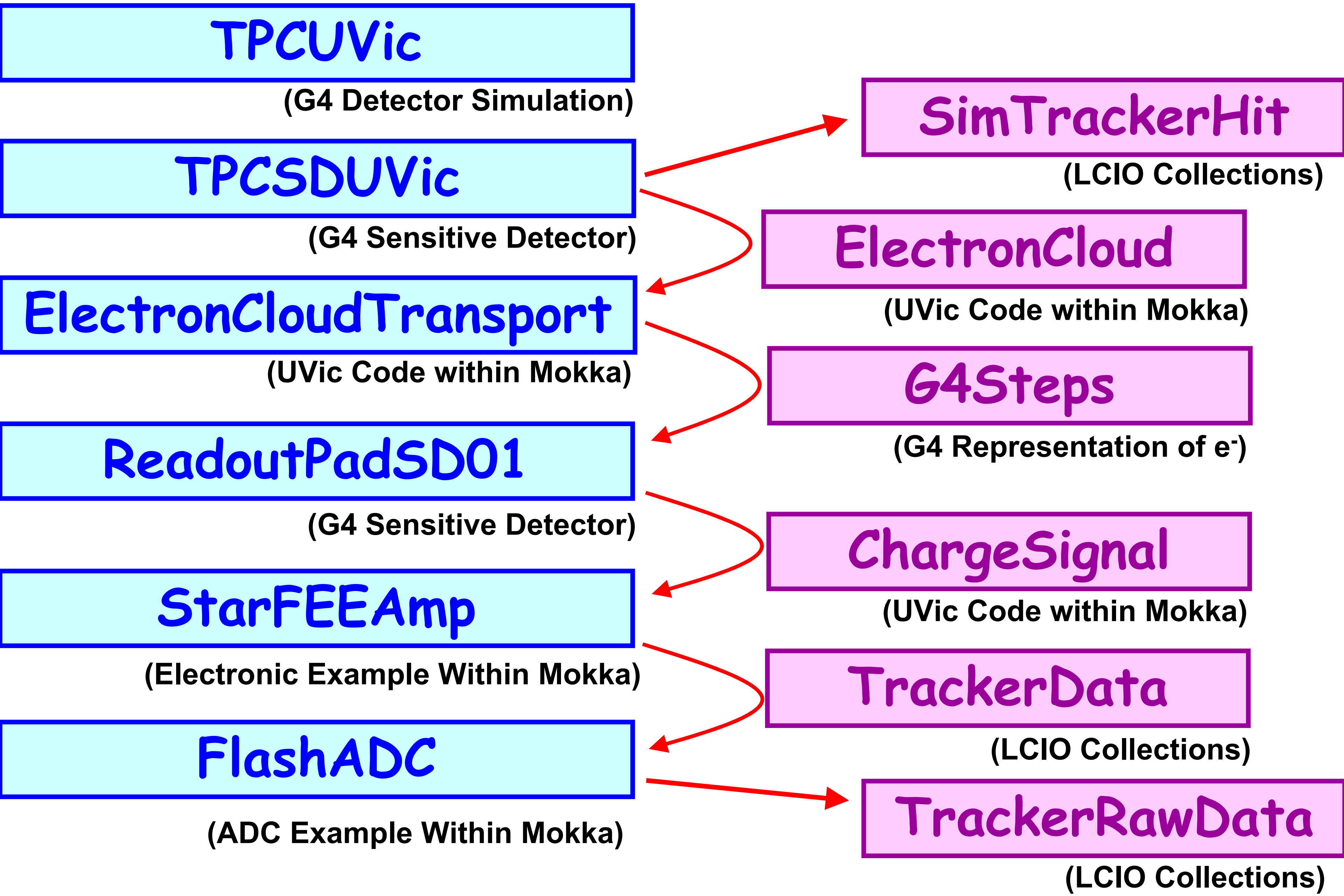
- **To study drift electrons distortion due to inhomogeneous magnetic field we edit Mokka's TPC to include**
  - **Drift electrons**
  - **GEM foils**
  - **Gas gaps**
  - **Endplate pads**
- **To study the effect on reconstruction add Marlin processes to**
  - **Read in and convert raw data**
  - **Make simple seed track fit** **(for now assume pattern recognition done)**
  - **Do the track fit** **(for now only single tracks)**

Mokka and Marlin

- We use a gear.xml file as input to both Mokka and Marlin since the pad layout is needed for both simulation and reconstruction
- The .slcio file from Mokka has both hits from the G4 energy deposition in the TPC (SimTrackerHit) and raw data from the pads (TrackerRawData)



TPCUVic Mokka Simulation

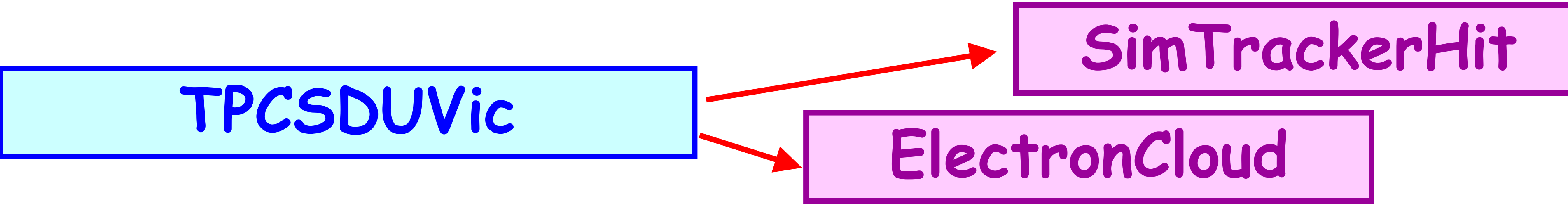


TPC Detector

TPCUVic

- **Geometry and Materials**
- **Edited the Tpc04 driver** (not much, just some lines)
- **User Limits**
  - Maximum step size for ionizing particles (no layers needed)
    - Sometimes new step due to step size and sometimes new step due to EM process. Checked that there is no double counting
  - Maximum amount of time a particle can travel before being stopped
  - Maximum amount of energy it can deposit
- **Sensitive Detector (TPCSDUVic)**
- **Copied and edited the MySQL database table "tpc06" to "tpcuvic" to our local MySQL database**

TPC "Sensitive Detector"



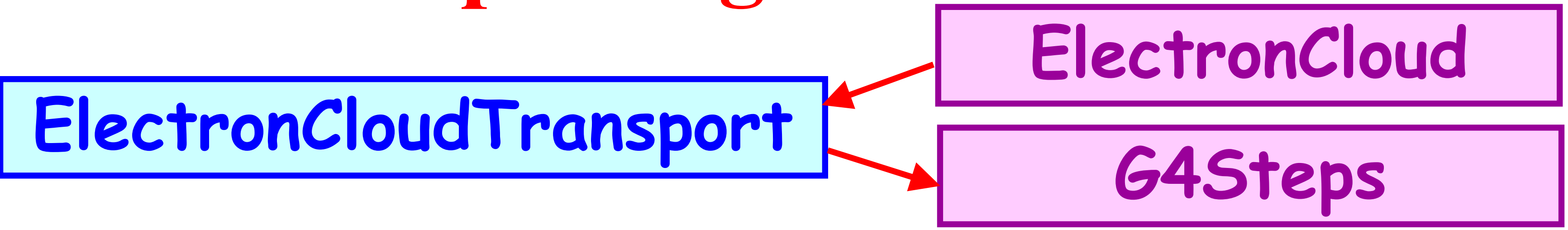
- **ProcessHits() gets the G4Steps**
  - **It stores the "hits" in a G4HitCollection, later saved as SimTrackerHits in a .slcio file**
  - **For each G4Step an ElectronCloud is produced**
    - **Number of electrons = The deposited energy / 26 eV**
  - **Transport the clouds with ElectronCloudTransport**
    - **For now; only primary particles are taken into account**
    - **Change later to deal with multiple tracks**
      - **Then reconstruction and track storage have to be changed as well "Trivial changes"**

A Cloud of Electrons (to save cpu)

ElectronCloud

- **Member variables are**
  - **number of electrons**
  - **x, y, and z coordinates**
  - **standard deviation in xy**
  - **standard deviation in z**
  - **time coordinate**

Transporting the drift electrons



- transportToEnd() gets a cloud
  - transportThroughGap(driftGap, aCloud)
  - transportThroughGEM(gem1, aCloud)
  - transportThroughGap(transferGap, someClouds)
  - transportThroughGEM(gem2, someClouds)
  - transportThroughGap(inductionGap, someClouds)
  - hitReadoutPads(someClouds)
    - Extracts electrons and gives G4Steps (represent e^-) to ReadoutPadSD01

Transporting the drift electrons (cont)

Drift Volume

implemented

- First approach; homogenous fields in drift volume
  - The clouds are transported with one step to the first GEM
  - Parameterized diffusion of the e^-

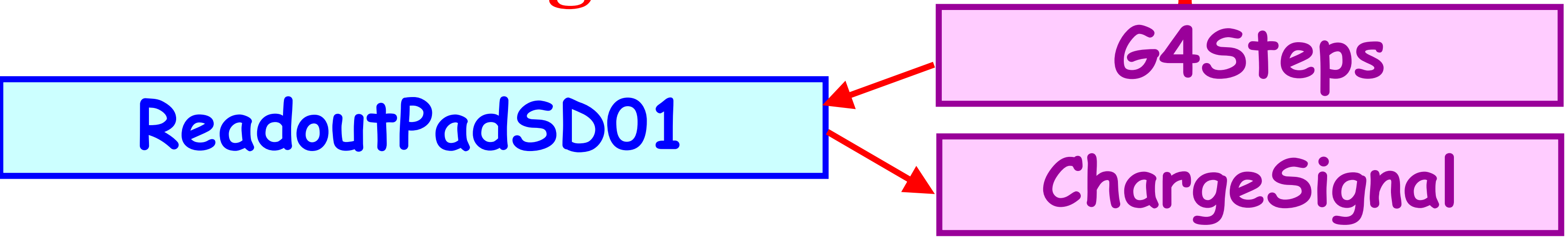
future work

- Later approach; inhomogeneous magnetic field
  - The clouds will be transported with several steps to the GEM
  - In each step a field map (FieldX00Map) will be used to get the Lorentz angle

End Plate

- Parameters for the GEMs (Gain, Collection and Extraction efficiency) is hard coded (in Gear file in future (?))
- Will this narrow area be effected by inhomogeneous magnetic field?
- "TPCEndPlate" is a hard coded name; don't change!

Assign electrons to pads



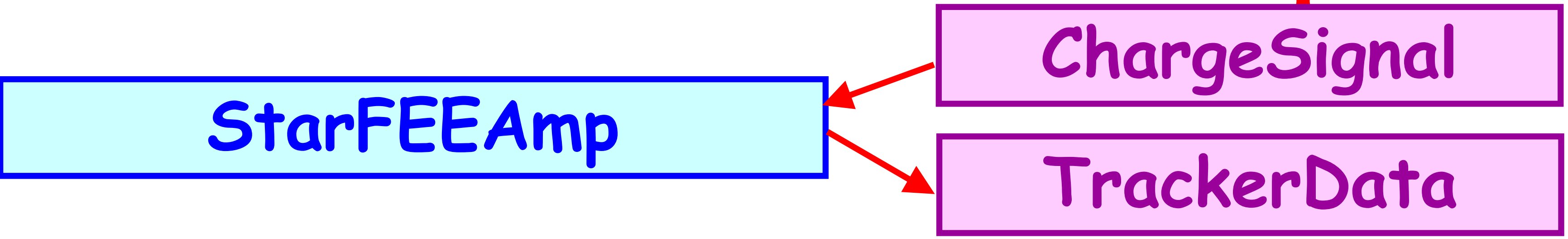
- **The function ProcessHit()**
  - **uses Gear functions to get the PadLayout and checks if electrons hit a pad**
  - **saves it to charge_signals which is a std::map of PadIndex (Gear) to ChargeSignals**
    - **i.e. only pads that are hit are saved in the map**

Electron Saved on a Pad

ChargeSignal

- **Member variables are**
  - number of electrons
  - mean time the electrons hit the pad (t_m)
  - standard deviation from the mean time
  - induction time (t_i)
    - the time the pad induce signal before the electron hit, normally the time the electron spent in the induction gap

Front End Electronics Amplifier



- **As an example of front-end electronics we have implemented Star's amplifier** (from Karlen's JTPC)
- **Shaping according to equation, A(t), that gives #e^- per time bin**
  - Width of time bins from "readoutFrequency" in the Gear file
- **Then convert it to mV per time bin**
  - VoltagePerTimeBin = gain * 10mV/fC * A(t) * CoulumbPerElectron
- **Reads in parameters from Gear file**
  - Gain
    - 3.3
  - Voltage threshold (indirect)
    - 10 mV ⇨ zero suppression, saves storage space
  - Rise and fall time
    - 30 ns and 2000 ns
  - mV per fC
    - 10

Star's FEE Amplifier

For the time shaping equation these time constants $\tau_1 = 729.878$ ns, $\tau_2 = 89.0123$ ns, $\tau_3 = 88.9504$ ns as well as the current rise time (τ_4) and fall time (τ_5) are used. The "star constants" are

$$s_0 = 58 \cdot 4$$

$$s_1 = k_1 \frac{\tau_1^3 \tau_3}{(\tau_1 - \tau_2)(\tau_1 - \tau_3)}$$

$$s_2 = \frac{\tau_1 \tau_2^2 \tau_3}{(\tau_2 - \tau_1)(\tau_2 - \tau_3)}$$

$$s_3 = \frac{\tau_1 \tau_3^3}{(\tau_3 - \tau_1)(\tau_3 - \tau_2)}$$

where $k_1 = 0.32851$.

Star's FEE Amplifier (cont)

The amplitude we then get from

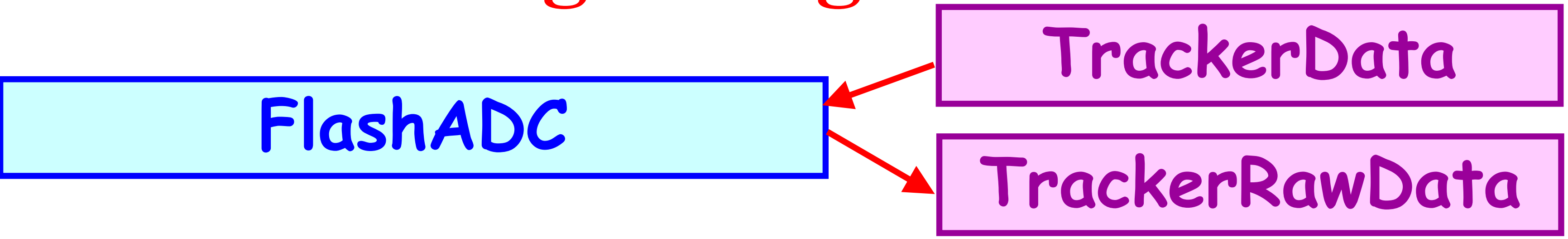
$$A = \begin{cases} 0, & t < 0 \\ \Sigma_{i=1}^{3} \frac{s_i}{\tau_4 s_0} \left(e^{-t/\tau_i} + \frac{t}{\tau_i} - 1 \right), & t \in [0, \tau_4] \\ \Sigma_{i=1}^{3} \frac{s_i}{s_0} \left(\frac{\tau_i + \tau_4 + \tau_5 - t}{\tau_i \tau_5} + \frac{1}{\tau_4} e^{-t/\tau_i} - \left(\frac{1}{\tau_4} + \frac{1}{\tau_5} \right) e^{(\tau_4 - t)/\tau_i} \right), & t \in [\tau_4, \tau_4 + \tau_5] \\ \Sigma_{i=1}^{3} \frac{s_i}{s_0} e^{-t/\tau_i} \left(\frac{1}{\tau_4} + \frac{1}{\tau_5} e^{(\tau_4 + \tau_5)/\tau_i} - \left(\frac{1}{\tau_4} + \frac{1}{\tau_5} \right) e^{\tau_4/\tau_i} \right), & t > \tau_4 + \tau_5 \end{cases}$$

Where 0 = meantime - induction time = $t_0 = t_m - t_i$

This is a semi-emperical fitted equation to front-end electronics used in the Star Experiment

Implemented into Mokka just as an example

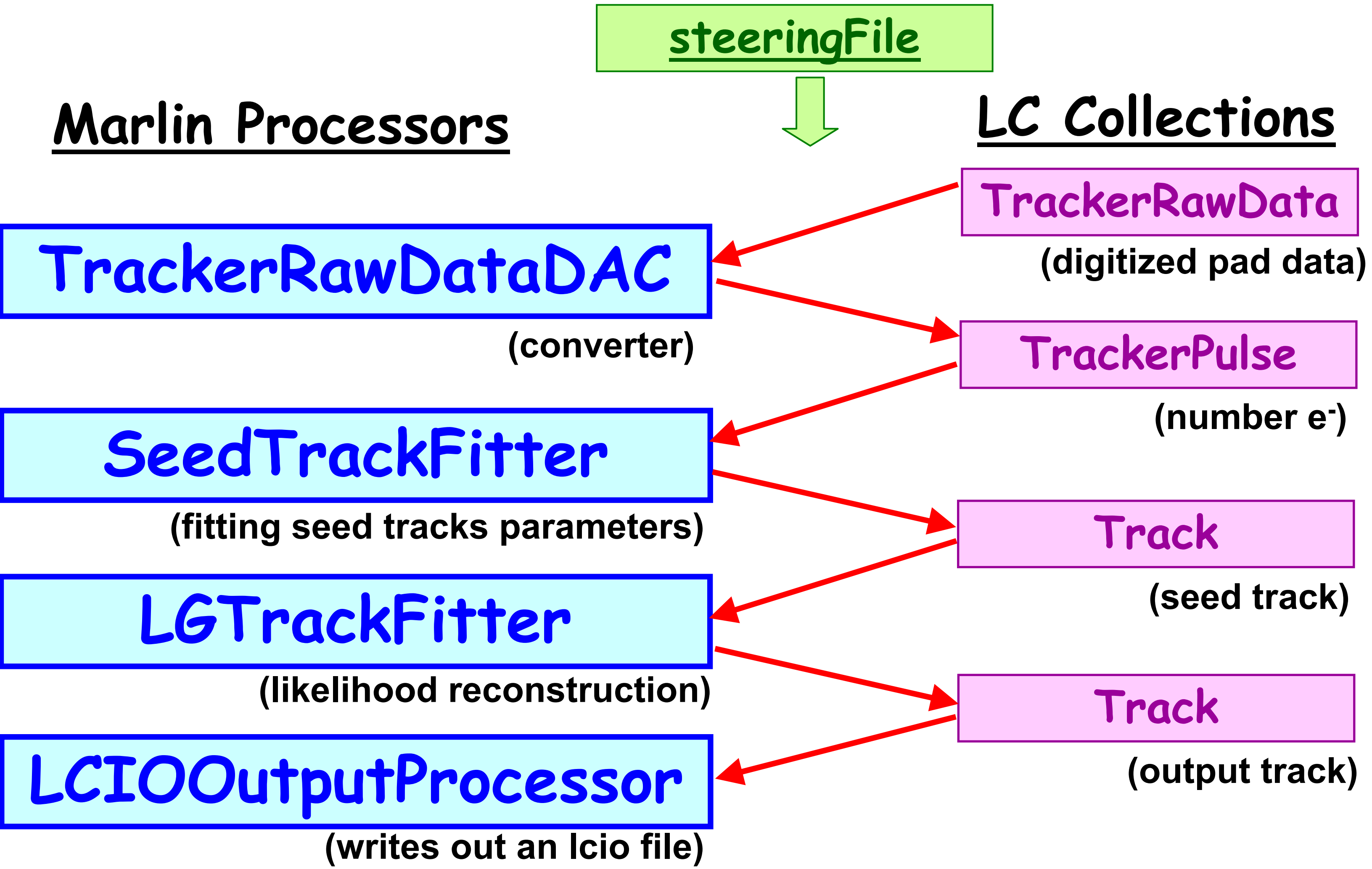
Analog to Digital Converter



- **Calculates the pedestal** (hard coded for now ... Gear?)
- **Converts time bins into channels**
  - Floating numbers → integers
  - Add pedestal → unsigned integers
    - if pedestal not big enough some values are truncated
- **Reads in parameters from Gear file**
  - gain 1
  - bits per channel 10
  - mV per channel 0.1

TPC Marlin Reconstruction

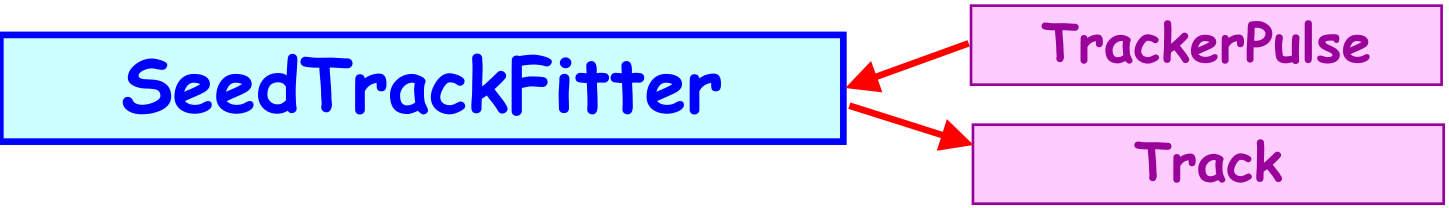
- **A steering file will control the LC Collections flow between the Marlin Processors**



Digital to "Analog" (#e^-) Converter

- The processEvent() function gets an LCEvent
  - Opens TrackerRawData collection from the LCEvent
  - Checks that all parameters are in the LCEvent
  - Converts all ADC values in the TrackerRawData to
    - TrackerData = Number electrons per time bin
    - TrackerPulseData = TrackerData and total number of electrons in the pad

Fitting the Seed Track



- **The SeedTrackFitter gives a rough estimate of a Track to LGTrackFitter**
- **Assumes pattern recognition already done, i.e. all hit pads from one track**
  - **will add established pattern recognition code later**

future work

Parameters of an LCIO Track

Track

(LCIO)

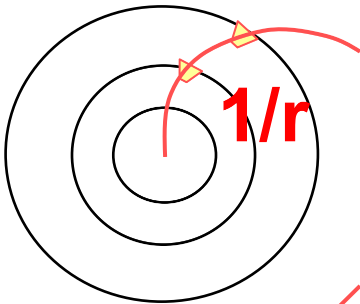
- To define a Track it's needed
  - Reference point
    - default; PCA ... to what? To origo or to collision point?
  - Ω
    - curvature, 1/r, sign = charge of particle
  - φ
    - phi angle for the track at the reference point
  - tan(λ)
    - lambda is the dip angle at the reference point
  - D_0
    - impact parameter in the r-φ plane (= 0 if PCA is **0**)
  - Z_0
    - signed impact parameter in the r-z plane (= 0 if PCA is **0**)
      - Z_0 = (z @ r = 0)
- Is there a documentation of LCIO's Track parameters?

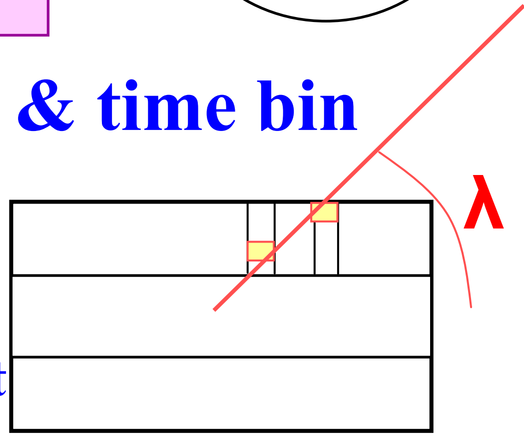
implementing

Fitting the Seed Track

SeedTrackFinder ← TrackerPulse

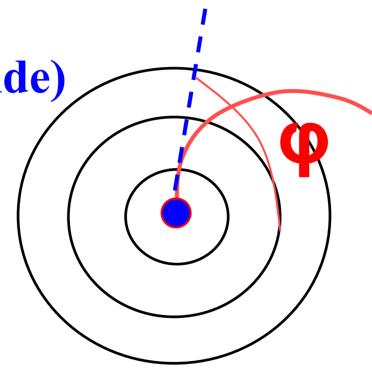
SeedTrackFinder → Track





- SeedTrackFinder gets #e⁻ in each pad & time bin

Ω
- Find two seed rows
  - First seed row: the first hit from outside
  - Second seed row: mid between origo and first
- Find seed pad with maximum # e⁻ for each seed row
- Radius from seed pads and origo (eq on next slide)
- Assume reference point = 0



λ
- Get lambda using seed pads (more later)

φ
- Get phi using seed pads (more later)

D_0, Z_0
- Assume both impact parameters zero

Curvature

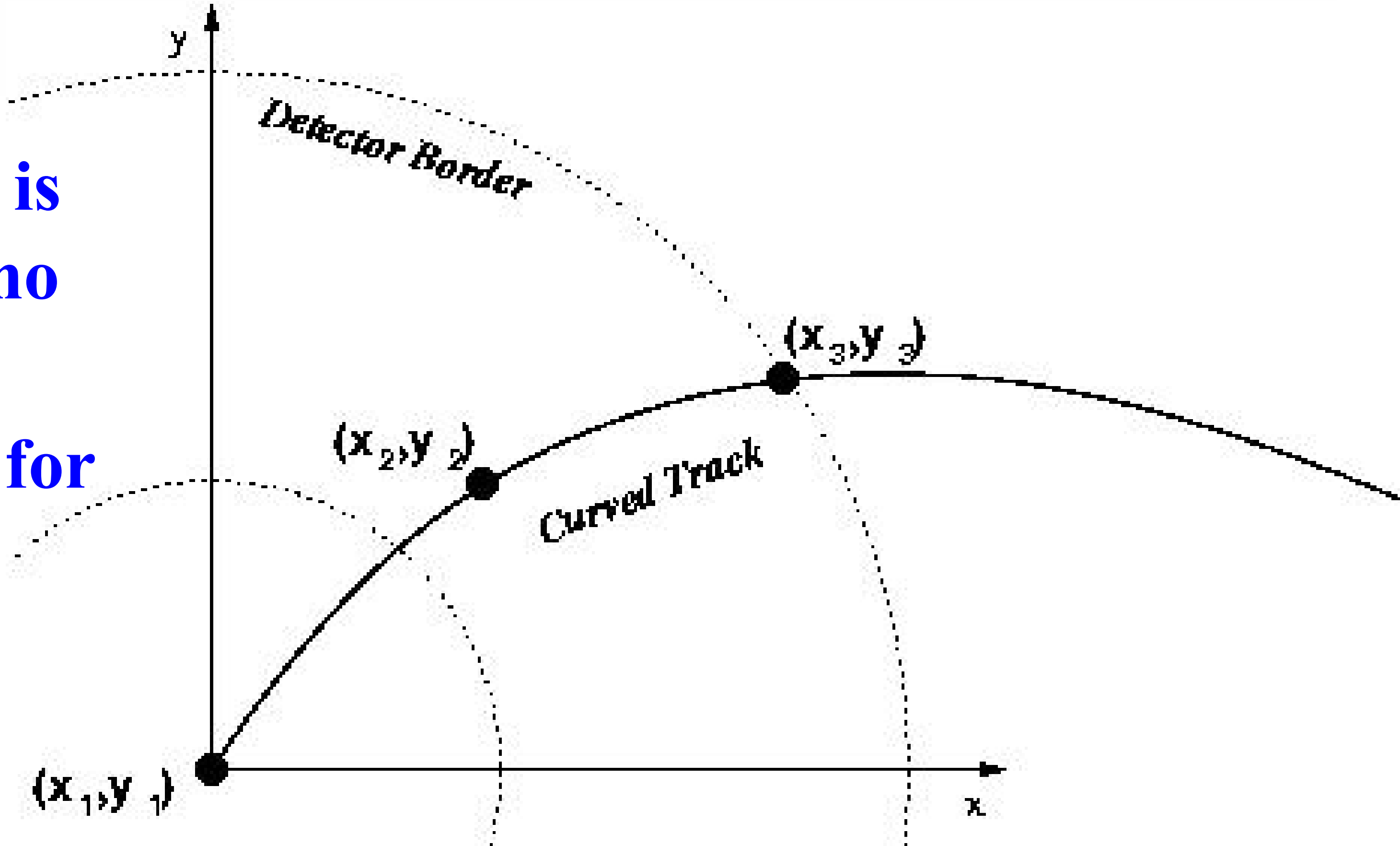
Three points on a circle $([x_1, y_1], [x_2, y_2], [x_3, y_3])$ give the radius:

$$r = \sqrt{\frac{(y_2(x_3^2 + y_3^2) - y_3(x_2^2 + y_2^2))^2 + (x_3(x_2^2 + y_2^2) - x_2(x_3^2 + y_3^2))^2}{4(x_2 y_3 - x_3 y_2)^2}}$$

if $x_1 = y_1 = 0$.

Perfect circle is assumed, i.e. no energy loss

Good approx for Seed Track



Lambda and Phi

Three points on a circle $([x_1, y_1], [x_2, y_2], [x_3, y_3])$, assuming $x_1 = y_1 = 0$, give the center of the circle:

$$x_c = -\frac{y_2(x_3^2 + y_3^2) - y_3(x_2^2 + y_2^2)}{2(x_2 y_3 - x_3 y_2)}$$

$$y_c = -\frac{x_3(x_2^2 + y_2^2) - x_2(x_3^2 + y_3^2)}{2(x_2 y_3 - x_3 y_2)}$$

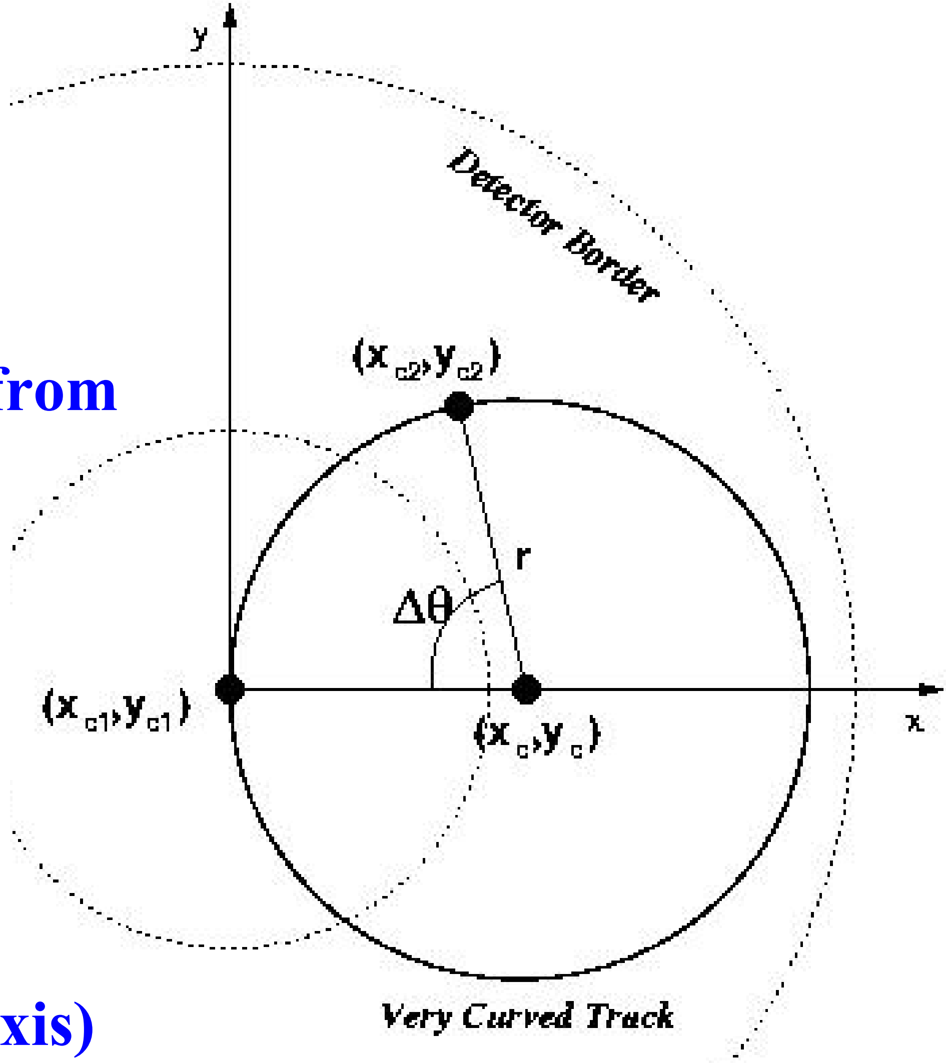
Changing origo to $[x_c, y_c]$ we get λ from

$$\tan\lambda = \frac{p_z}{p_t} = \frac{\Delta z/\Delta t}{\Delta\theta r/\Delta t} = \frac{\Delta z}{\Delta\theta r}$$

where

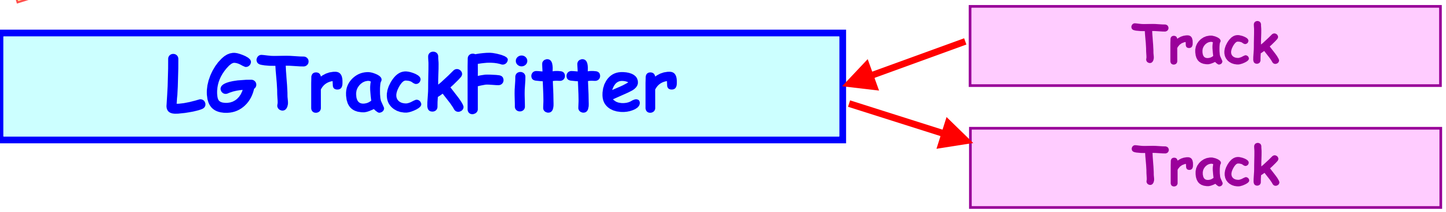
$$\Delta\theta = \left|\arctan\frac{y_{c1}}{x_{c1}} - \arctan\frac{y_{c2}}{x_{c2}}\right|$$

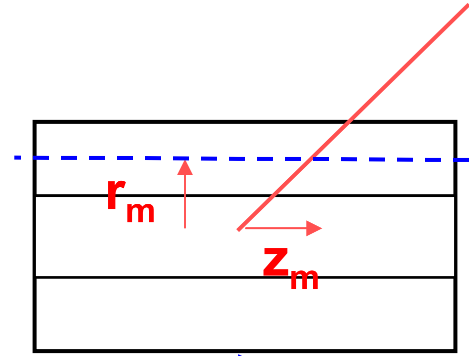
And φ from using Hep3Vector::deltaPhi(tangent, x-axis)



future work

Fitting the Track





- The processEvent() gets the seed track
  - Initilize Minuit(LogLikelihoodFunction)
  - Call Minuit(seed track)
- The LogLikelihoodFunction(track parameters, σ_m)
  - $\sigma^2 = \sigma_m^2 + (z - z_m)\, D^2$
    - D = diffusion constant (in Gear file ?)
    - σ_m = characteristic diffusion for that track ($\sigma_m = \sigma$ @ $r=r_m$)
    - σ_m is good to add to the minimization parameters since it
      - is uncorrelated to the others → does not increase errors in the other parameters
      - can be used to check gas properties from experimental data
      - indicates the fit quality (a σ_m way off → bad fit)
  - Impact parameters not zero due to
    - reconstruction imperfections
    - b-hadron → new vertex

Suggestions of use of GEAR

- We use Gear as input both to Mokka and Marlin
  (e.g. PadLayout is needed by both simulation and reconstruction)
- In Gear now; Drift velocity and readout frequency, so not only geometry... (?)
- Could Gear be edited to take care of dimensions?
- Organize the Gear file in sections
  - Gap Sections
  - Gem Sections
  - ... and so on ...

```
<!-- build the TPC inward from the readout electronics -->
<gap name="induction_gap" width="5mm" eField="0 0 1000V"/>
<gem name="gem2" gain="40" width="0.5mm" eField="0 0 1000V"/>
<gap name="transfer_gap" width="0.5mm" eField="0 0 1000V"/>
<gem name="gem1" gain="40" width="0.5mm" eField="0 0 1000V"/>
<gap name="drift_gap" width="*" eField="0 0 1000V"/>
```

Upgrade of CED

- **Can now draw curved tracks in 3D**
- **Can now draw keystones (for pads)**
- **Much faster**
  - **changed so that “DisplayList” is used to redraw objects and store geometry**
  - **and more ...**

UVic's "Wish List"

- **Standardized description of <u>whole</u> of the TPC** (Gear or MySql ...?)
  - **GEM's** (positions, widths, gains ...)
  - **Micromegas** (positions, widths, gains ...)
  - **GasVolume** (drift velocity, widths, gains ...)
  - **and more ...**
- **More structured Gear file**
  - **Sections**
  - **Dimensions**

```
<!-- build the TPC inward from the readout electronics -->
<gap name="induction_gap" width="5mm" eField="0 0 1000V"/>
<gem name="gem2" gain="40" width="0.5mm" eField="0 0 1000V"/>
<gap name="transfer_gap" width="0.5mm" eField="0 0 1000V"/>
<gem name="gem1" gain="40" width="0.5mm" eField="0 0 1000V"/>
<gap name="drift_gap" width="*" eField="0 0 1000V"/>
tpcParemeters.getGem("gem1").getGain();
theGems = tpcParameters.getGems();
```

- **Better documentation for the LCIO Track Parameters**
  - **Reference point is the PCA ...to what? Collision point or origo?**
  - **Signed impact parameters?**
  - **Diagram for angles**
    - **Phi and Lambda are respect of which axis?**
- **Can phpMyAdmin handle Mokka's MySQL database**

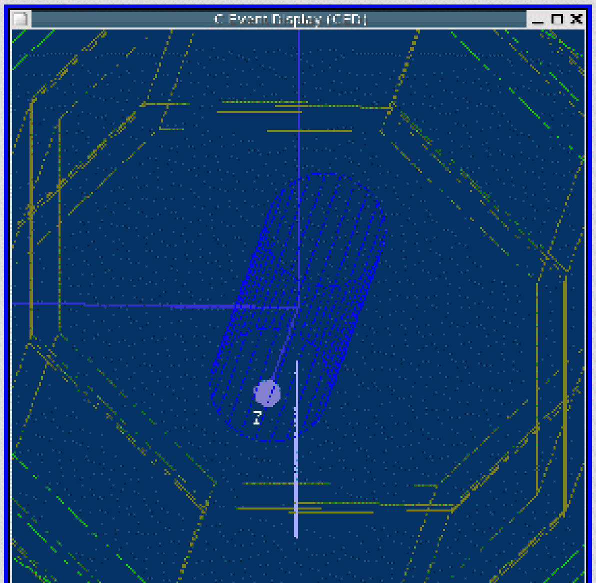
Home Pages

- **Installation Home Page:**

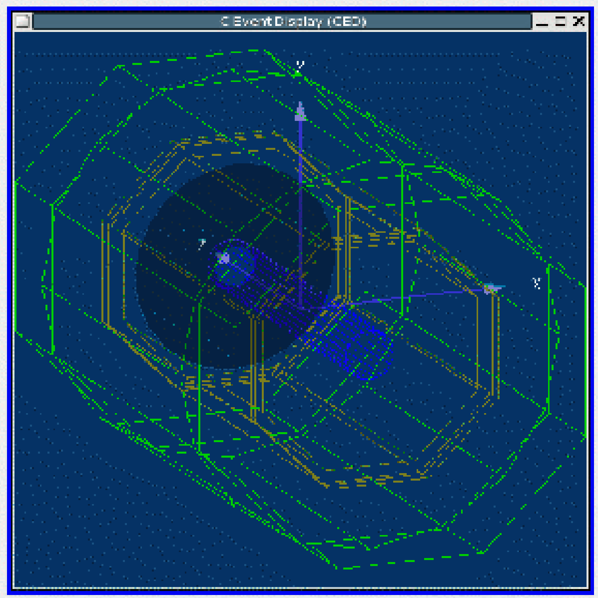
http://particle.phys.uvic.ca/~hansen/ILC/MOKKA/installation.html

- **Results and Download Home Page:**

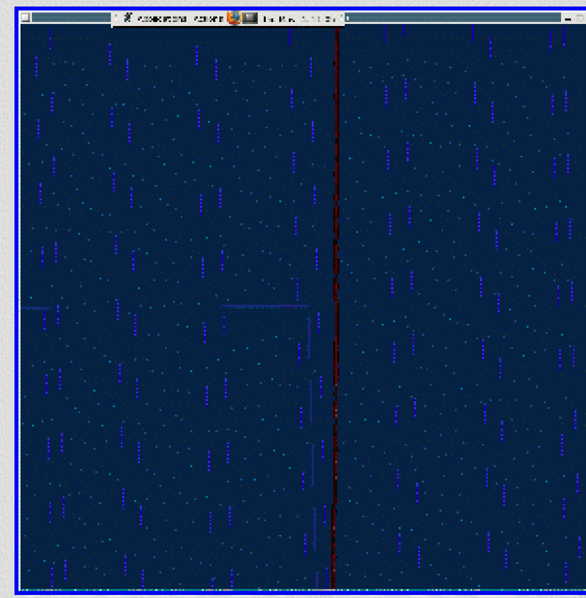
http://particle.phys.uvic.ca/~mcgeac00



Raw track data generated from Mokka *single colour pads - about 2000 were hit in this picture*



The TPC viewed in CED with Marlin. The semi-transparent circle is the pad layout.



A close-up of the representation of the TrackerPulse data reproduced in Marlin

Conclusions and Future Work

Installation

- Installation of Mokka, LCIO, Gear and Marlin has been done on SL3 and FC4

Objective

- Simulation is needed to understand the LC TPC's magnetic field requirements and possible corrections for the magnetic field distortions

Strategy

- Make a more detailed TPC simulation in Mokka
- Study what effect inhomogeneous magnetic field has on the momentum resolution of the LDC concept
- Study possibility to correct for field distortions with either a B-field map or external track points

Web

- More info here:

http://particle.phys.uvic.ca/~mcgeac00

http://particle.phys.uvic.ca/~hansen/ILC/MOKKA/installation.html

Extra Slides

Momentum Resolution from a Toy MC

- Plan to study momentum resolution from SeedTrackFinder with a Toy Monte Carlo
- Send out many charged tracks with random (reasonable) momentum
- Get the reconstructed momentum, p, from the reconstructed curvature
- Histogram the resolution, $(p - p_0) / p_0$
  - where p_0 is the true momentum

future work

Mokka installation

- **Installations done on two different system**
  Scientific Linux 3 (SL3) and Fedora Core 4 (FC4)
- **Installed needed software**
  CLHEP, Wired, OpenGL, Geant4, MySQL...
- **Installed LCIO**
  Had to add an include statement due to new gcc version in FC4
- **Installed Mokka**
  Had to create shared libraries and edit files for compile and link
- **Created Local Mokka MySQL Database**
  To be able to define our own Sub Detector
- **Installed Gear and linked it inside Mokka**
  Upgraded the implementation of Gear to define the TPC pads
- **Installed Marlin and CED** **(C Event Display)**

Details described step by step:

http://particle.phys.uvic.ca/~hansen/ILC/MOKKA/installation.html

Ionization in Mokka's TPC

- **Control stepsize for ionizating particles in the TPC gas**
  E.g. 1mm
- **G4 gives the energy loss for that step**
  100-400 eV/mm
- **One electron cloud per step**
- **Number electrons per cloud is given by the energy loss from G4 (26 eV/e^-)**

ElectronCloud.hh/cc

TPCSDUVic.hh/cc