ILD Tracking Software and Performance

With a focus on the TPC

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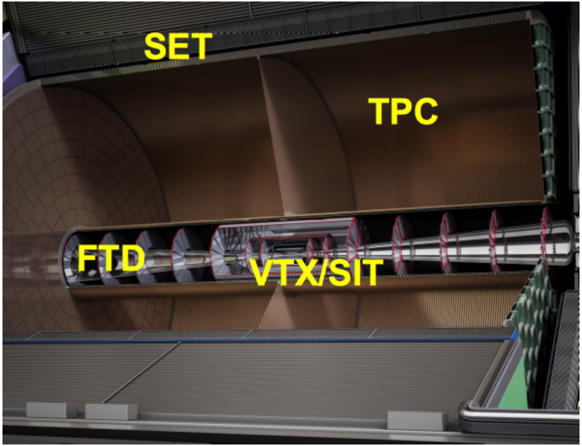
Outline

- Introduction
- ILD Tracking Tools
- TPC Digitizer
- TPC Pattern Recognition
- Tracking and PID Performance for ILD
- Summary and Outlook

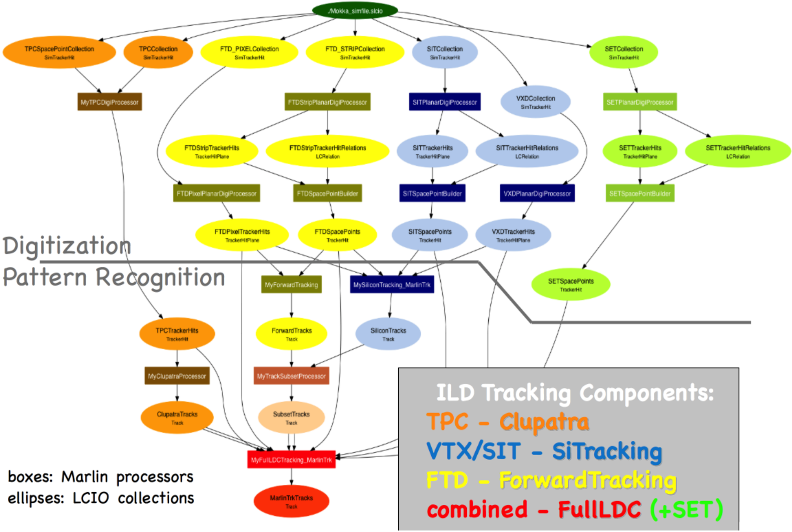
The ILD tracking system



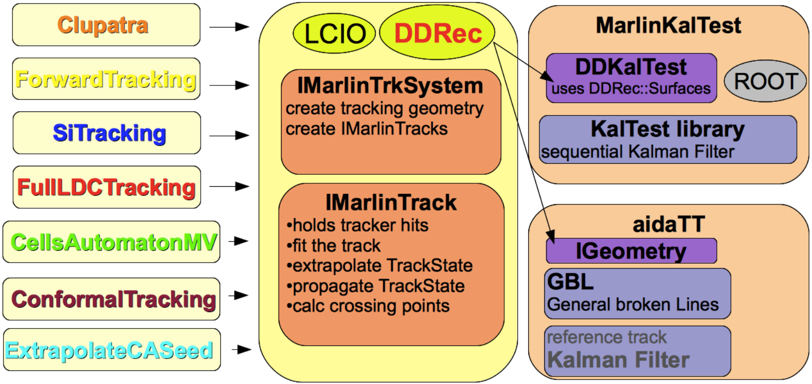
Subdetector			Point Resolution
VTX	$\sigma_{r\phi,z}$	=	3.0 µm (layers 1-6)
SIT	$\sigma_{r\phi,z}$	=	5.0 µm (layers 1-4)
SET	$\sigma_{r\phi}$	=	7.0 µm (layers 1-2, $\phi_{stereo} = 7^\circ$)
FTD_{Pixel}	$\sigma_{r,r_\perp}$	=	3.0 µm (layers 1-2)
FTD_{Strip}	$\sigma_{r\phi}$	=	7.0 µm (layers 3-7, $\phi_{stereo} = 7^\circ$)
TPC	$\sigma^2_{r\phi}$	=	$\left(50^2 + 900^2 \sin^2\phi + \left((25^2/22)\times (4\ \mathrm{T/B})^2 \sin\theta\right)(\mathrm{z/cm})\right)$ µm^2
	σ^2_z	=	$(400^2 + 80^2 \times (z/\mathrm{cm}))$ µm^2
	where ϕ and θ are the azimuthal and polar angle of the track direction		

tracking resolutions used in IDR

ILD tracking processors in Marlin



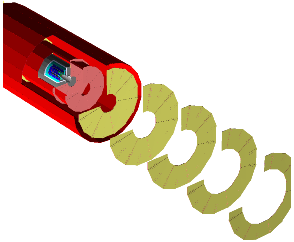
boxes: Marlin processors
ellipses: LCIO collections

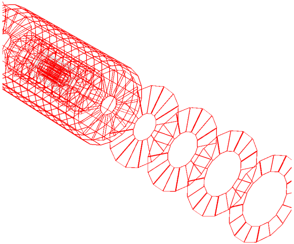


- pattern recognition uses *IMarlinTrk* interface
  - can choose actual track fitter w/o code change

tracking geometry: surfaces

- tracking needs special interface to geometry
- measurement and dead material surfaces (planar, cylindrical, conical)
- surfaces attached to volumes in detailed geometry model



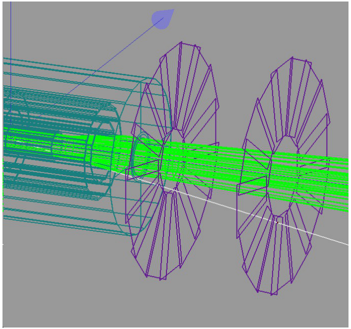


surfaces:

- u,v, origin and normal
- inner and outer thicknesses and material properties
- local to global and global to local coordinate transforms:
  - $(x, y, z) \leftrightarrow (u, v)$

DDKalTest

- provides measurement surfaces:
  - *DDPlanarMeasLayer*
    - 1D,2D Si-tracker - barrel/endcap
    - dead materials (endcaps)
  - *DDCylinderMeasLayer*
    - 2D hits in TPC
    - supports (cryostat, field cage,. . .)
  - *DDConeMeasLayer*
    - conical sections of beam pipe



Generic track fitting

- can run track fitting (w/ KalTest Kalman filter) for any detector that defines these surfaces in DD4hep

surfaces and materials

- material properties are **automatically averaged**
  - from detailed model
  - along normal of the surface along given thicknesses

averaging materials

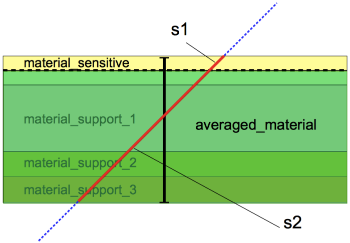
$$< A >= \left(\sum_i^N \rho_i t_i\right) / \left(\sum_i^N \rho_i \frac{t_i}{A_i}\right) \qquad t_i \textit{ thickness}$$

$$< Z >= \left(\sum_i^N \rho_i \frac{t_i Z_i}{A_i}\right) / \left(\sum_i^N \rho_i \frac{t_i}{A_i}\right) \qquad \rho_i \textit{ density}$$

$$< \rho >= \left(\sum_i^N \rho_i t_i\right) / \left(\sum_i^N t_i\right)$$

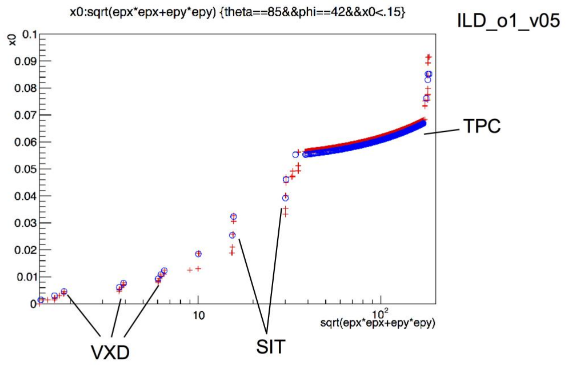
$$< X_0 >= \left(\sum_i^N t_i\right) / \left(\sum_i^N \frac{t_i}{X_{0i}}\right)$$

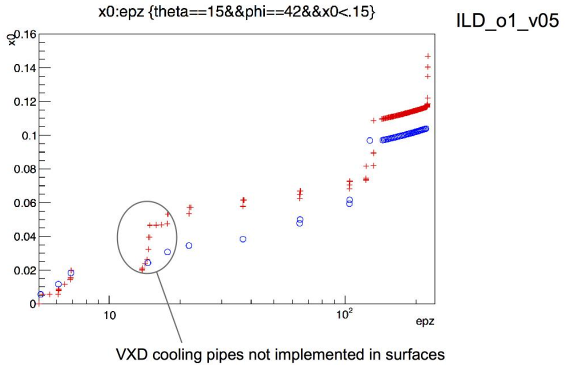
$$< \lambda >= \left(\sum_i^N t_i\right) / \left(\sum_i^N \frac{t_i}{\lambda}\right)$$



roughly equivalent for Bethe-Bloch - identical for multiple scattering

material: comparison surfaces vs. detailed model





- surface describe material well in most regions - but not everywhere . . .

Track Digitizers

DDPlanarDigiProcessor

- Gaussian smearing of mean hit position from particle's energy depositions
- along u,v measurement directions (2D,1D)
- taken from DDRec::Surface
- used for **all Si-Trackers** (pixel, strips)

TPCDigiProcessor

- dedicated TPC digitizer:
- parameterized point resolution as function of $(\phi_{track}, z_{drift})$
- parameterized double hit resolution
  - see next slides For ...

TPC Digitizer: point resolution

- simhits are created at position where track crosses the middle-cylinder of the pad row
  - using 2 x #TPC pad rows cylinders of gas
- energy depositions are accumulated over the pad row

point resolution is parameterized as established by LCTPC:

$$\sigma_{r\phi}^2 = (50^2 + 900^2 \sin^2\phi + ((25^2/22)(4\ T/B)^2 \sin\theta)(z/cm))\mu m^2$$
$$\sigma_z^2 = (400^2 + 80^2 \times (z/cm))\mu m^2$$

- where ϕ and θ are the azimuthal and polar angle of the local track direction

TPC Digitizer: double hit resolution

- two neighbouring sim-hits in the TPC are merged if they are closer than
  - $\Delta r\phi = 2mm$
  - $\Delta z = 5mm$
- with energy weighted mean of the position and the combined deposited energy

- effect in tracking (see later)
- in Clupatra a hit is assigned to the first track segment which has compatible parameters
- no arbitration for individual hit assignements to two neighbouring tracks is done
- there are tracks that simply miss hits in the inner pad rows

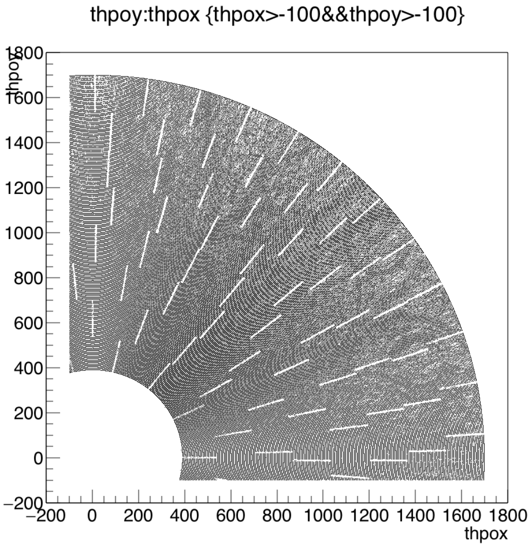
- this **hardly ever happens for complete track** at 250 GeV
  - observed in simulation studies at 1 TeV

TPC Digitizer: Endplate Module Gaps

- implemted module gaps in digitizer: simply remove hits in gaps
- 8 module rows with 14, 18, 23, 28, 32, 37, 42, 46 modules
- **1 mm** gaps in $r\phi$ and r
  - (use 10mm for visualization in plot)

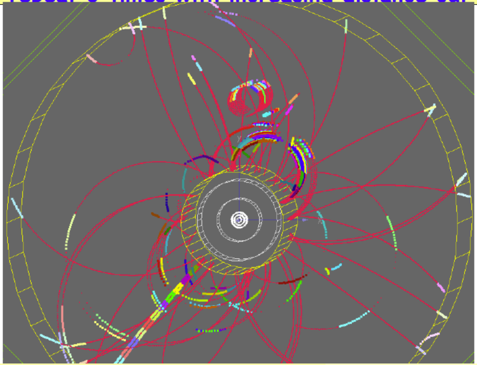
- ϕ-offsets optimized to maximise the minimal $\Delta\phi$ between all modules

a high momentum straight track can loose at most the hits from **one** module



Clupatra: TPC pattern recognition - step 1

- **NN-cluster in pad row ranges** (e.g. 15 rows) **– going inwards**
- identify **clean track stubs**
- **extend clean stubs forward & backward using Kalman fitter**
  - add best matching Hit if delta(chi2) < 35.
  - update track state !
  - search in next row
- **repeat 3 times with increasing distance cut on seed clustering**

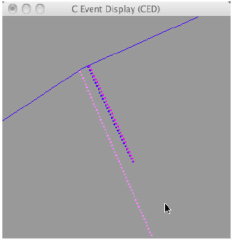


example:

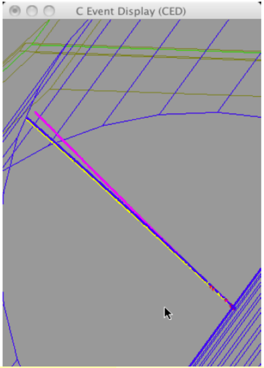
- ttbar event @ 500 GeV
- results in clean tracks and segments for curlers
- little leftover hits
- some very close by tracks lost (fixed in step2)

Clupatra: TPC pattern recognition - step 2

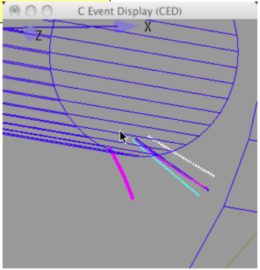
- re-cluster in leftover hits (NN clustering)
- based on pad row multiplicity force into N=2,....9 clusters
- apply KalTest fit to throw out falsely merged hits (rare)
  - higher multiplicity: repeat iteratively in smaller row ranges until only three or two tracks left



- gamma conversion in barrel
- forced into two tracks



- three prong tau - barrel

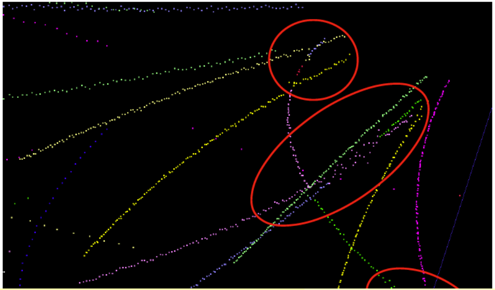


- five prong tau - forward
- three close-by tracks forced into three tracks

Clupatra: TPC pattern recognition - step 3

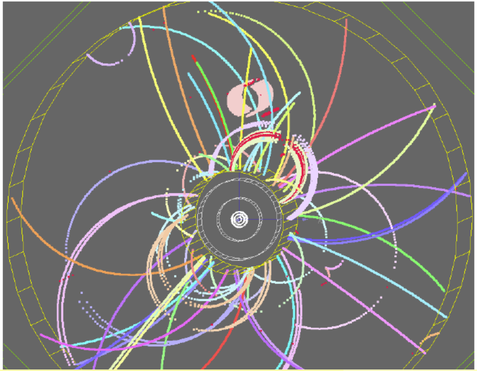
- repair split tracks:
  - **identify incomplete track segments** that:

    don't start at the inner field cage and/or that don't end at the outer field cage or endplate
  - **merge segments that have consistent tracks states** (based on delta chi2 after hits are added)
- problem mostly due to double hit resolution (merged hits)



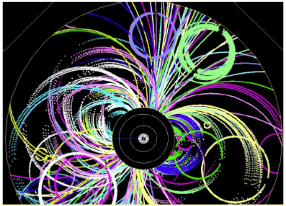
example: WW @ 1TeV
one lower pt track
crossing four higher pt
tracks in a dense jet

- **merge track segments (from curlers)**
- based on rough (O(10%)) criterion for R, delta(xc,yc), tan(lambda)
- disallow overlaps in z



examples:

- ttbar event @ 500 GeV
- only few segments are not merged
- most of these curler segments
- where lost in old patrec
- also works in higher multiplicities, e.g. @ 3 TeV:



Performance of ILD Tracking

- for the IDR (Interim Design Report) of ILD of we have studied the tracking performance for two different detector models:

large and small ILD model

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- TPC radius reduced from 1.77 m to 1.43 m
- B-field increased from 3.5 T to 4 T
- inner tracking and calorimeter thicknesses kept constant
- changed aspect ratio
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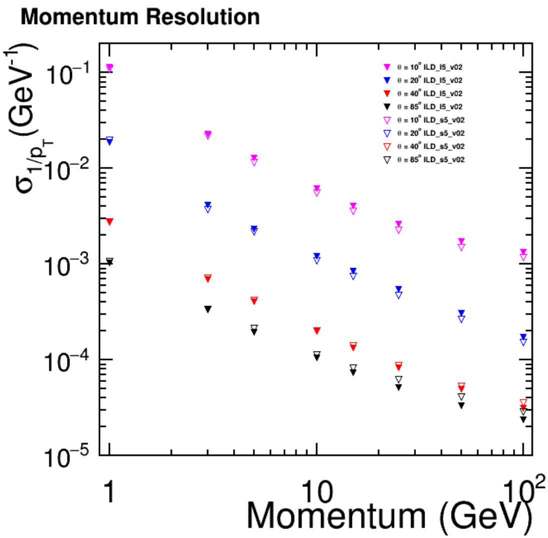
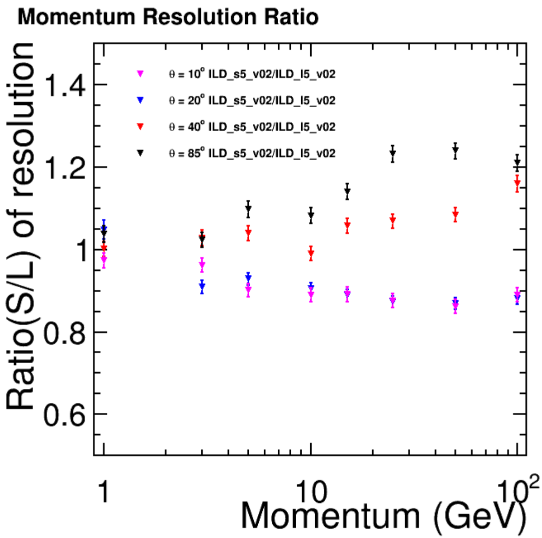
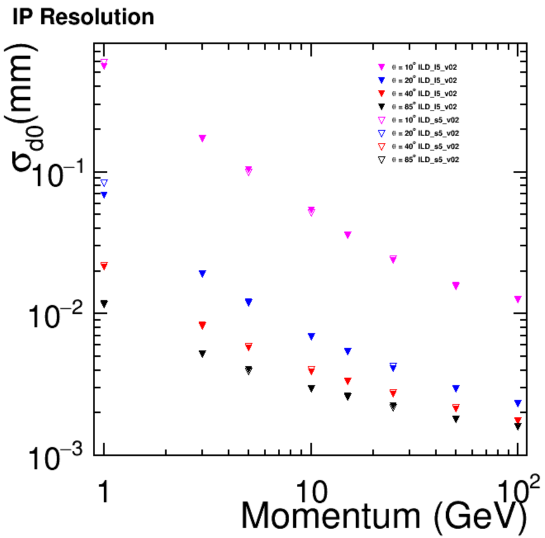
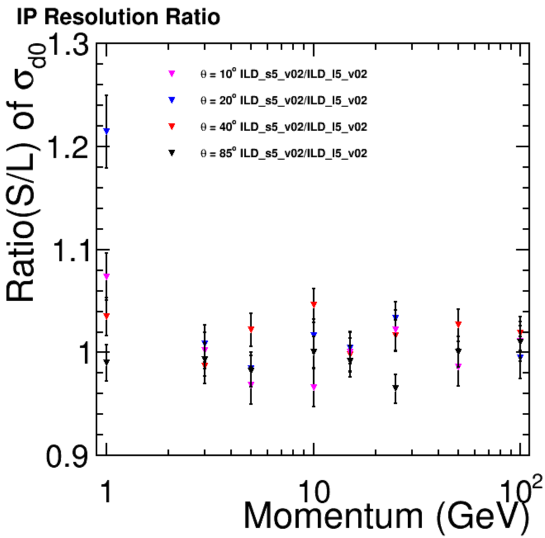
Momentum resolution



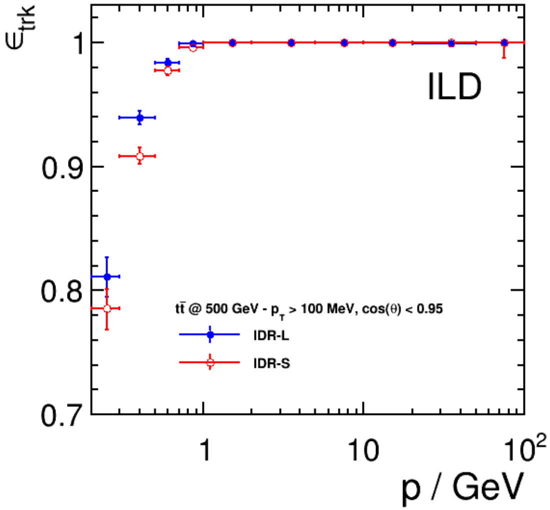


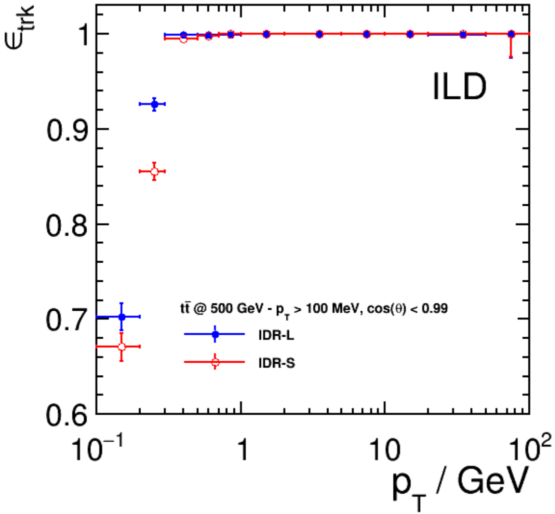
Impact parameter resolution



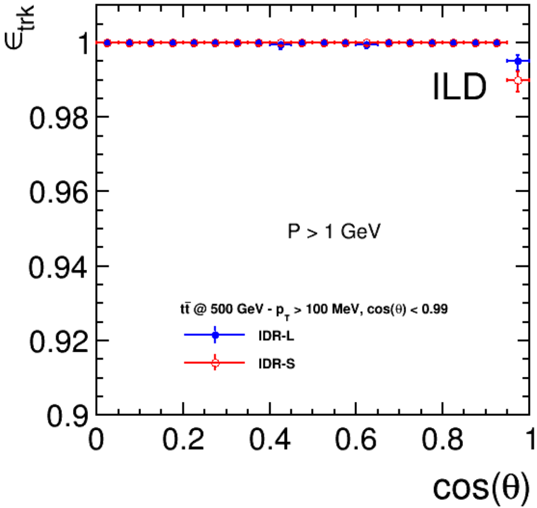


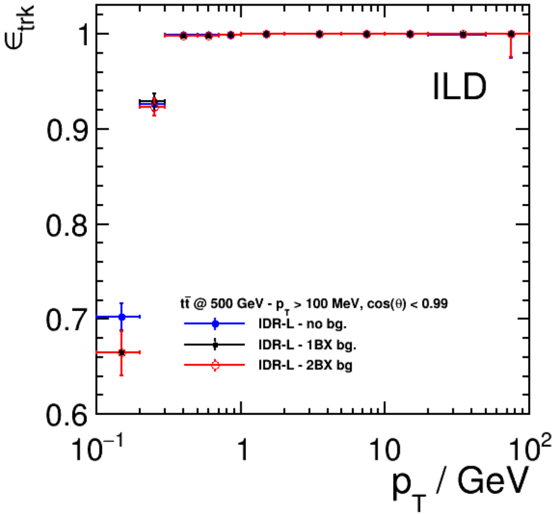
Tracking efficiency



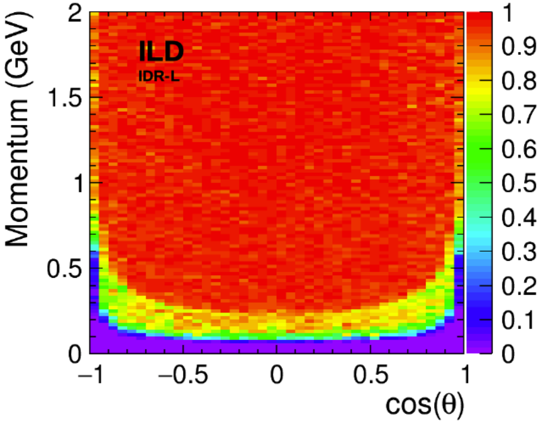


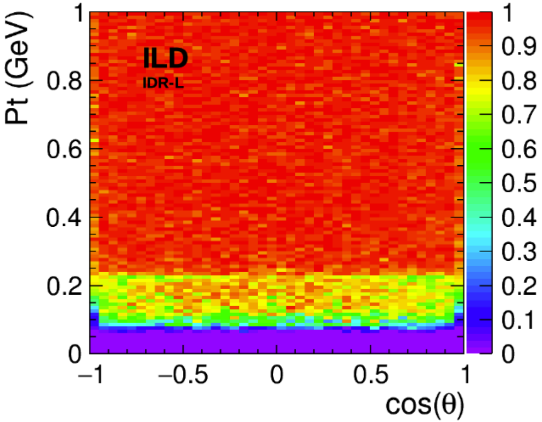
Tracking efficiency





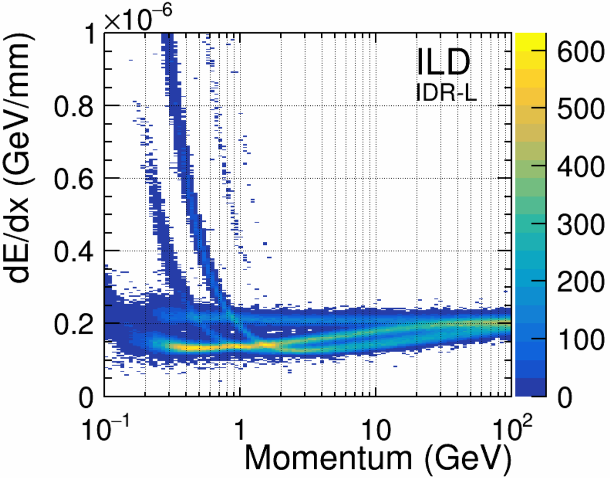
Tracking efficiency - 2D



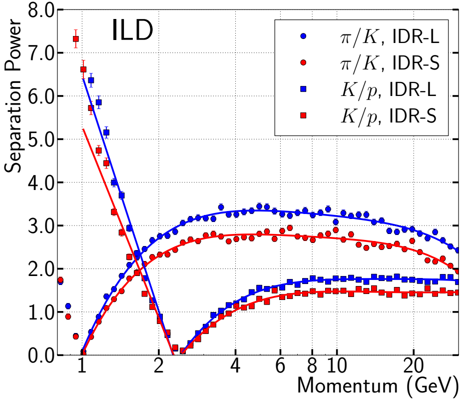


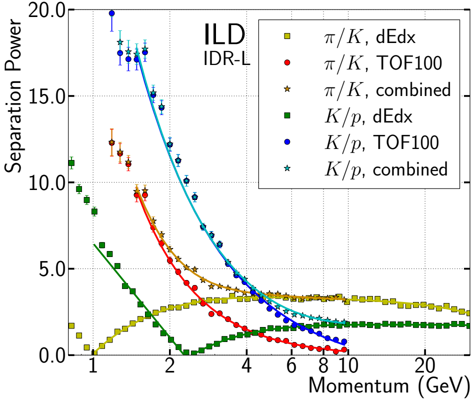
dE/dx (U.Einhaus et al)

- dE/dx is computed from deposited energy (Geant4) and the path length from the track fit
- a correction is applied to receive the overall resolution of the dE/dx as established from the LCTPC prototype - scaled to the number of TPC hits in ILD
- dE/dx shown for single particle events (e, μ, π, K, p) with logarithmic momentum and isotropic directions
    - also spurious tracks from secondaries (back scatter) visible



dE/dx and Particle ID (U.Einhaus et al)





- TOF estimator computed from first 10 ECal layers assuming 100 *ps* resolution

Summary and Outlook

- ILD has a rather realistic description of the tracking system
- attempt to get the correct material estimates and - wherever possible - use parameterizations of the point resolutions and double hit resolutions as established form **test beams**
- the overall tracking performance for both resolutions and efficiencies matches the physics goals of ILD
- the **smaller ILD detector** model with a reduced TPC radius shows **slightly worse** performance

Potential future studies

- modify the parameters for point resolutions and double hit resolutions in the TPC digitizer and study the effect on the performance for resolution and efficiency
- could get estimate on the expected complete loss of close by high momentum tracks already from generator studies (if not separated enough along the full path length)
-

Pointers to ILD Tracking Software

- all code is in Github under : **https://github.com/iLCSoft** - packages:
- *MarlinTrk*
  - generic tracking code: MarlinTrk interface
- *MarlinTrkProcessors*
  - TPC digitizer (and other tools)
- *Clupatra*
  - TPC pattern recognition
- *KalTest*
  - Kalman filter
- *DDkalTest*
  - measurement surfaces - used for KalTest