The New C++ Tracking Code in iLCSoft

- as used by ILD -

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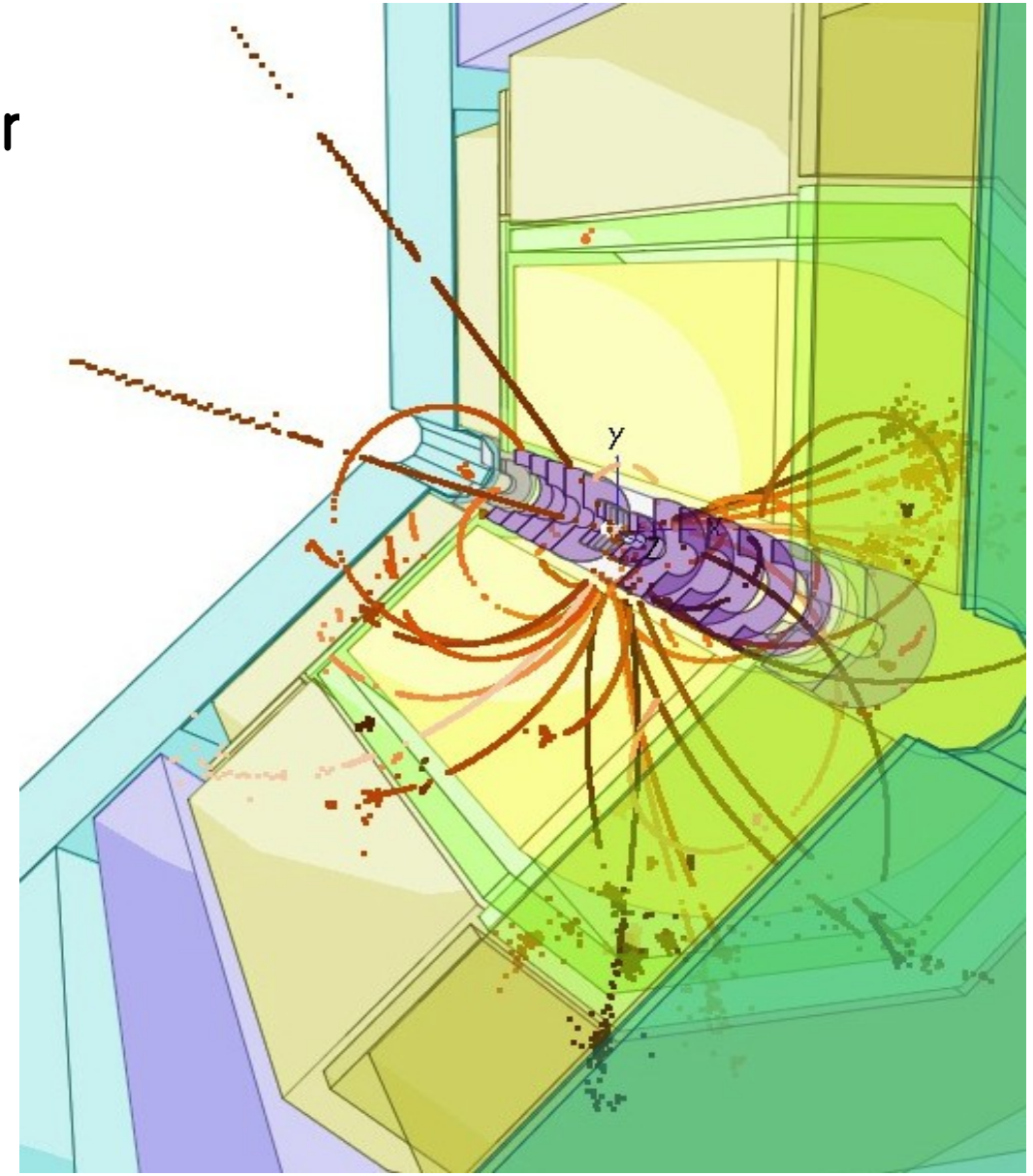
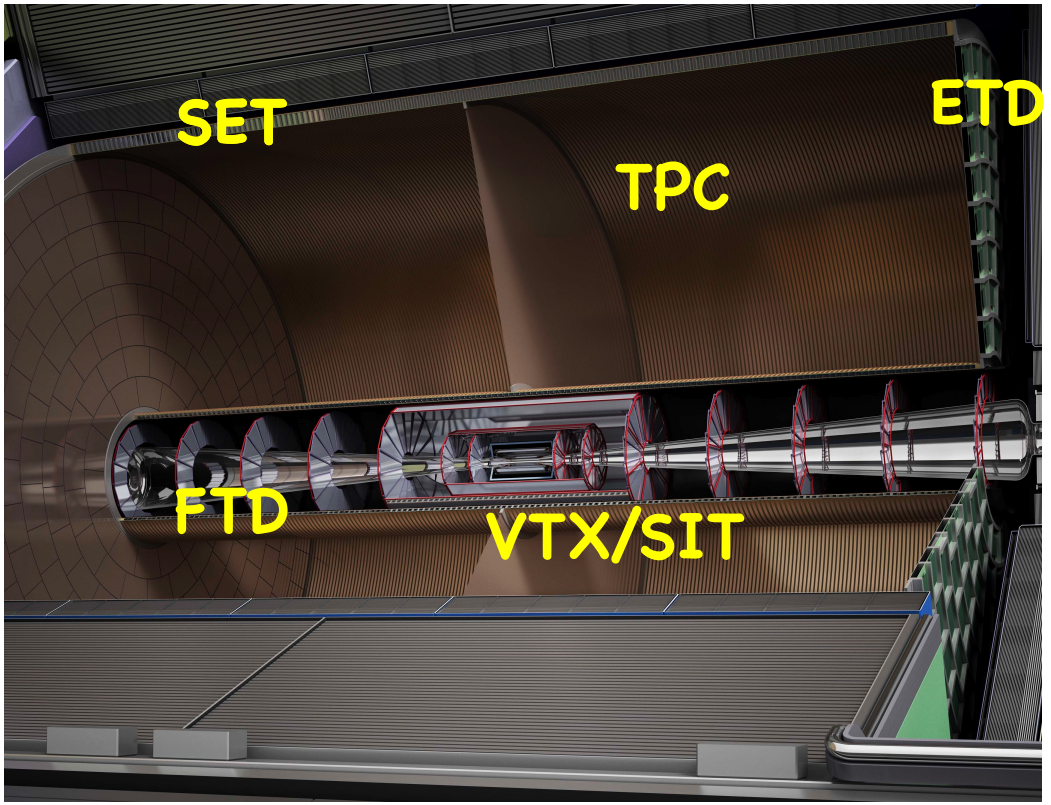
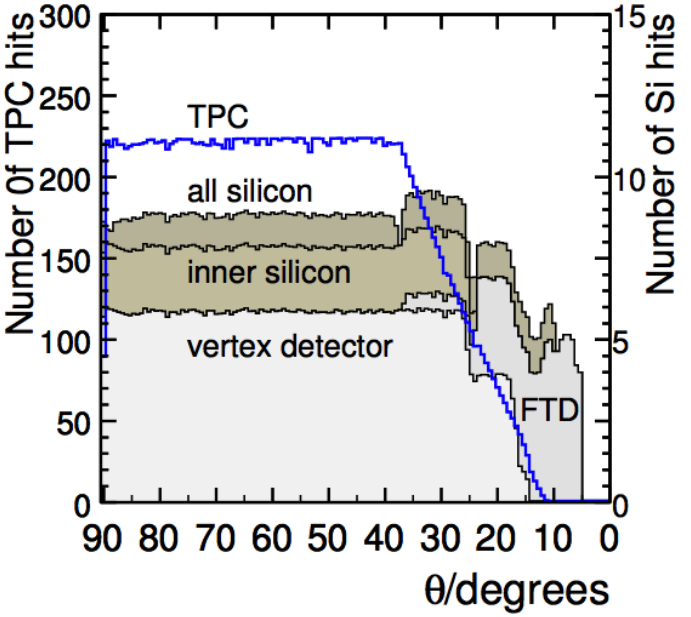
Outline

- The ILD tracking syster
- MarlinTrk
- The algorithms
  - Clupatra TPC patrec
  - C++ Si-Tracking
  - ForwardTracking
- Performance
- Summary & Outlook

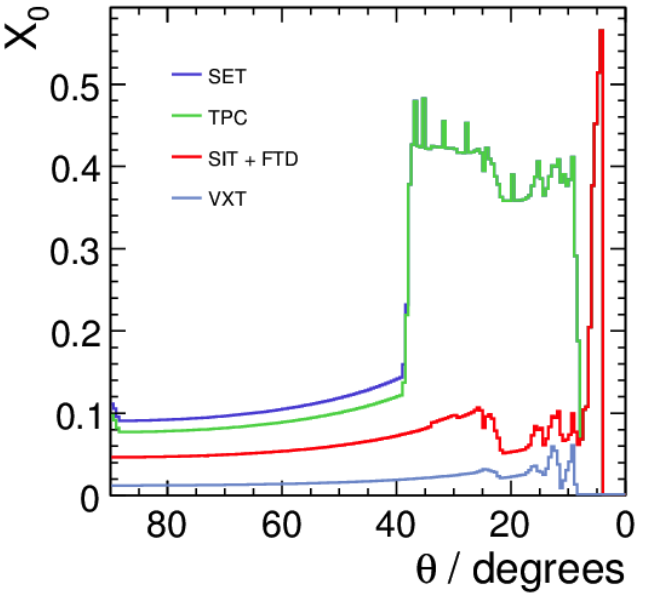


The ILD tracking system



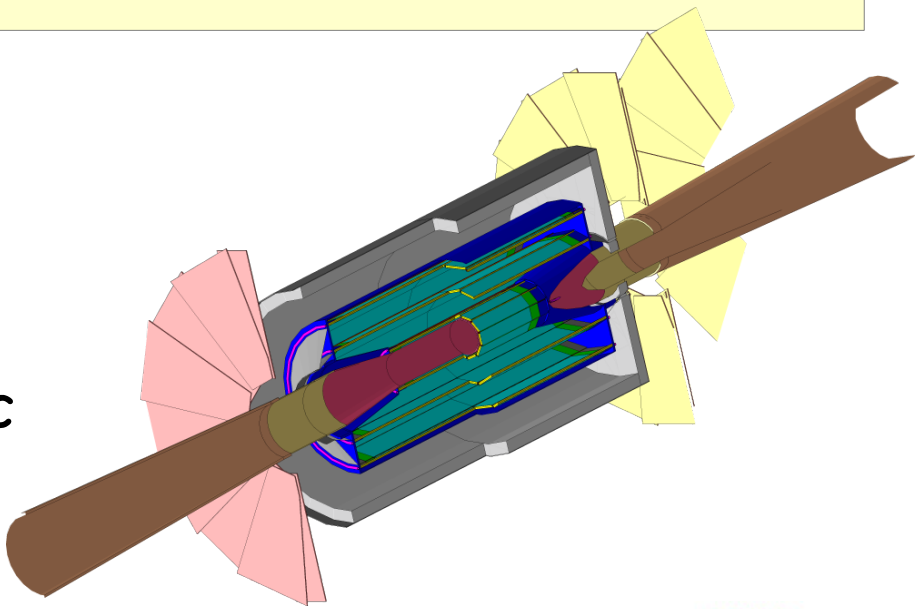


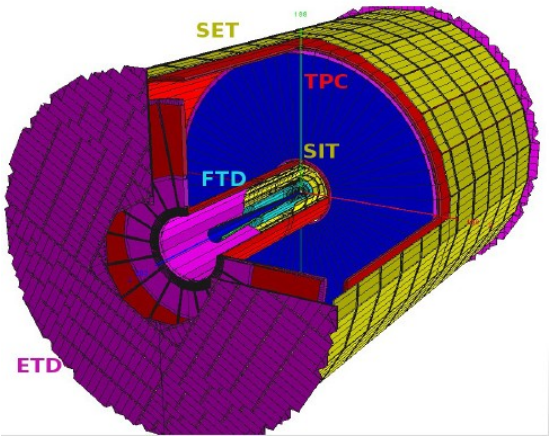
Detector	Point Resolution		
VTX	$\sigma_{r\phi,z}$	=	2.8μm (layer 1)
	$\sigma_{r\phi,z}$	=	6.0μm (layer 2)
	$\sigma_{r\phi,z}$	=	4.0μm (layers 3-6)
SIT	σ_{α_z}	=	7.0μm
	α_z	=	$\pm$7.0° (angle with z-axis)
SET	σ_{α_z}	=	7.0μm
	α_z	=	$\pm$7.0° (angle with z-axis)
FTD *Pixel*	σ_r	=	3.0μm
	$\sigma_{r_\perp}$	=	3.0μm first two discs
FTD *Strip*	σ_{α_r}	=	7.0μm
	α_r	=	$\pm$5.0° (angle with radial direction)
TPC	$\sigma^2_{r\phi}$	=	$(50^2 + 900^2 \sin^2\phi + ((25^2/22) \times (4T/B)^2 \sin\theta)\ (z/\mathrm{cm}))\ \mu\mathrm{m}^2$
	σ^2_z	=	$(400^2 + 80^2 \times (z/\mathrm{cm}))\ \mu\mathrm{m}^2$
	where ϕ and θ are the azimuthal and polar angle of the track direction		

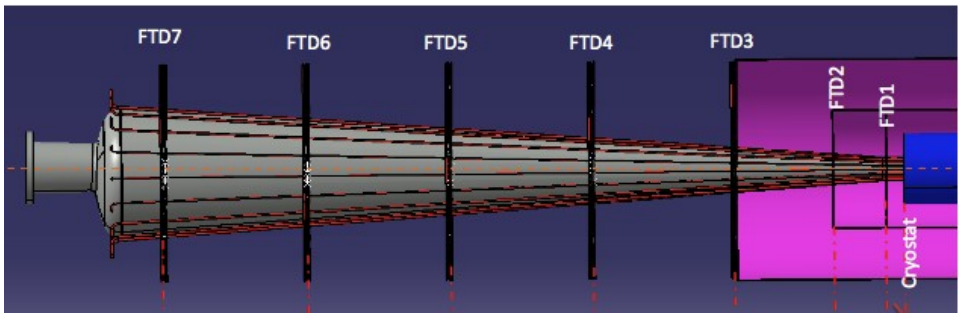


ILD tracking in the simulation

- increased realism of tracking simulation models since LOI:
- SIT/SET moved from cylinders to planar wafers/sensors w/ realistic support material
- FTD moved from simple discs to staggered petal wafers w/ space frame support
- added dead material for cabling of inner tracking detector
- increased support material of VTX
- added cooling pipes to TPC
- ...

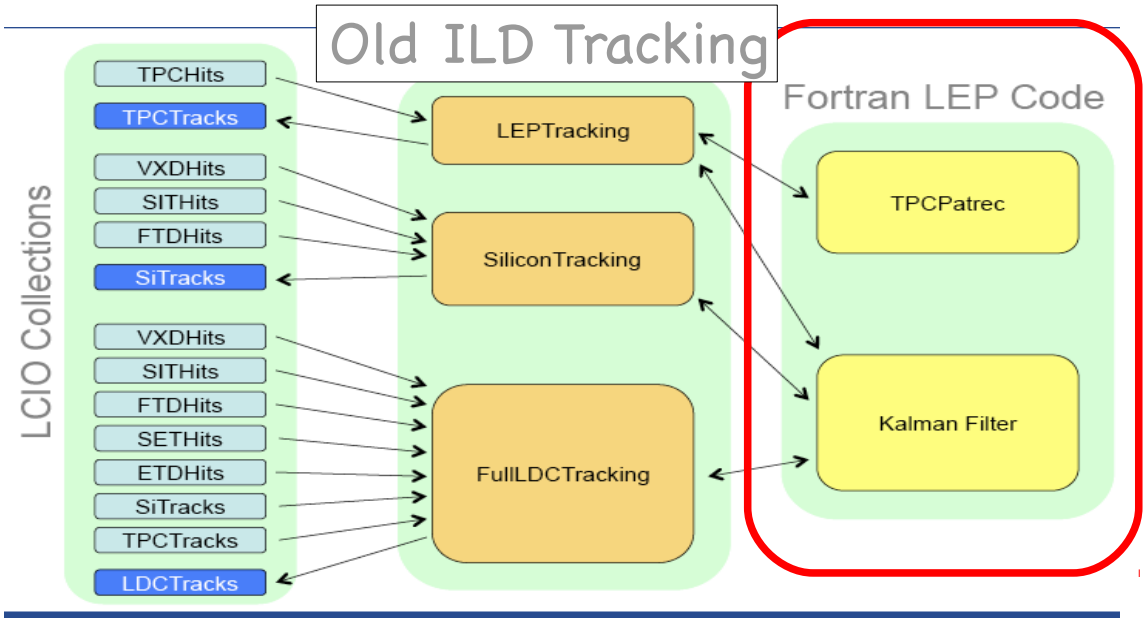






Tracking Software after the LOI

- for ILD we identified the need to replace old f77-tracking code in order to improve the sw maintenance and the performance (background studies, 1 TeV)

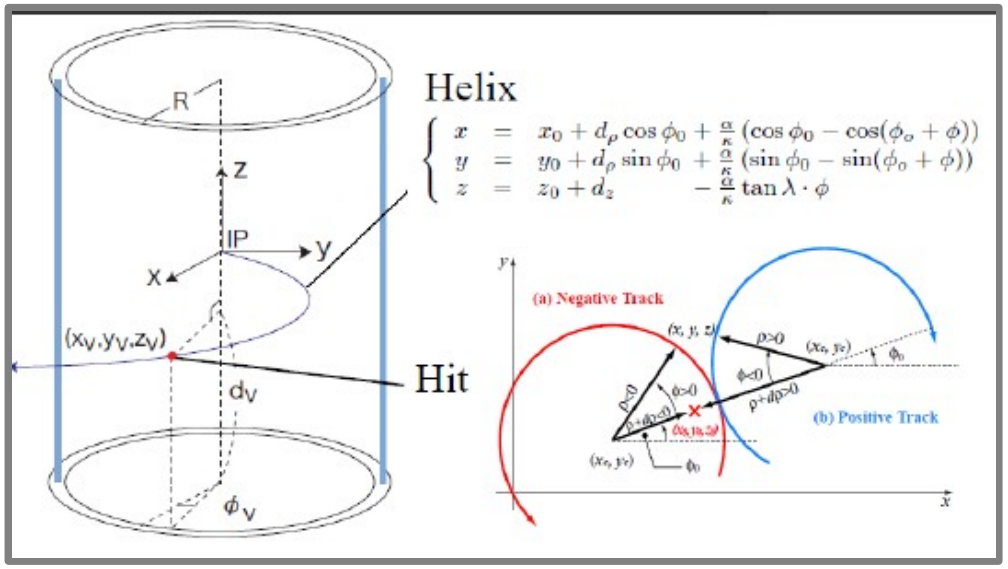


- for this we need:

  - a new C++ Kalman filter tool
  - rewrite the TPC pattern recognition (FG)
  - adapt SiTracking to new Kalman fitter (SA)
  - develop new algorithm for Forward (RG)

KalTest/KalDet Tools

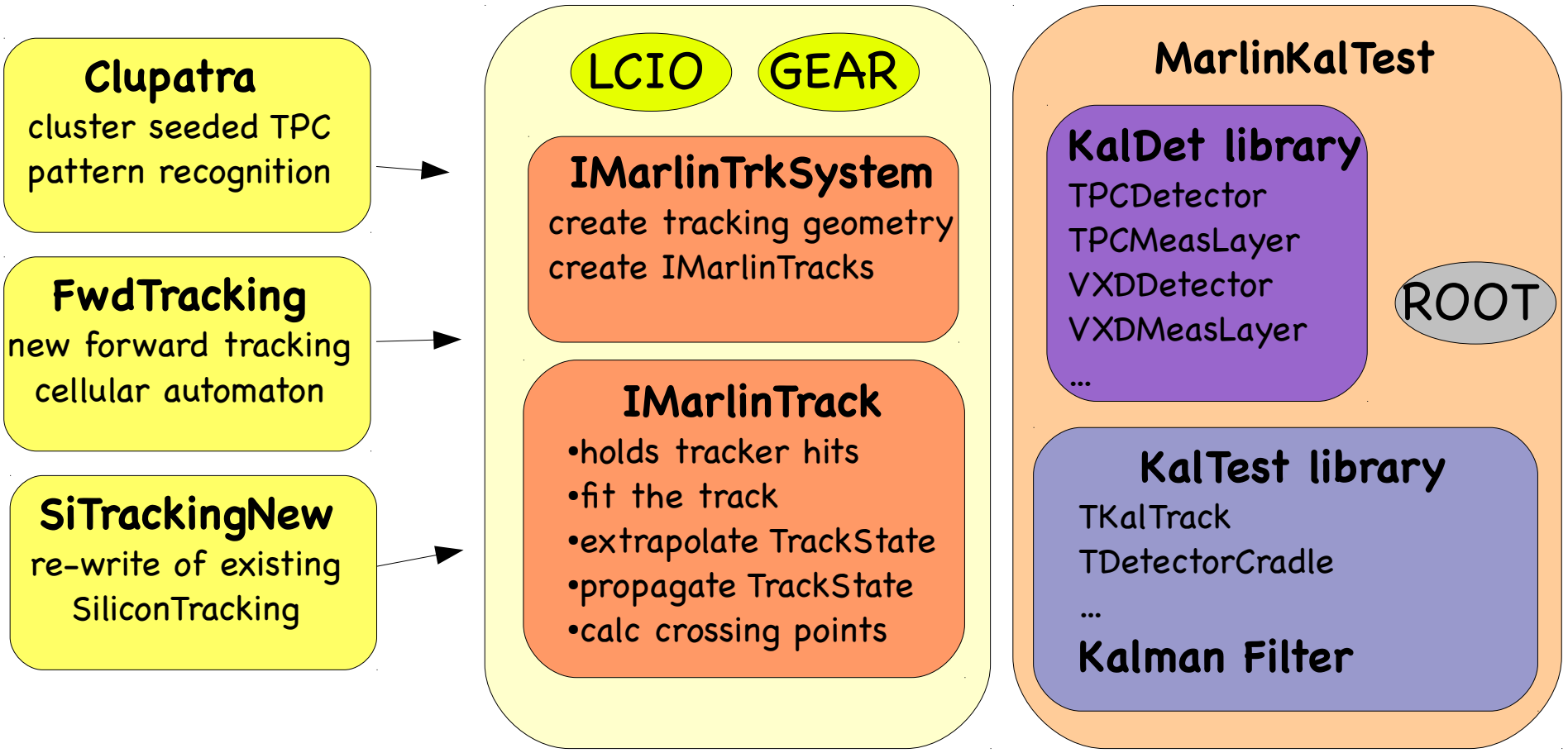
- KalTest
  - Kalman Filter tool (K. Fujii et al)
  - based on ROOT
    - TGeo, TMath, TObjArray
  - developed in Jupiter framework now included in iLCSoft
- KalDet
  - define detector geometry
    - meas. layer, coordinate to track state transform. ...
    - position of meas. layer and material properties
- both packages also used in MarlinTPC testbeam software



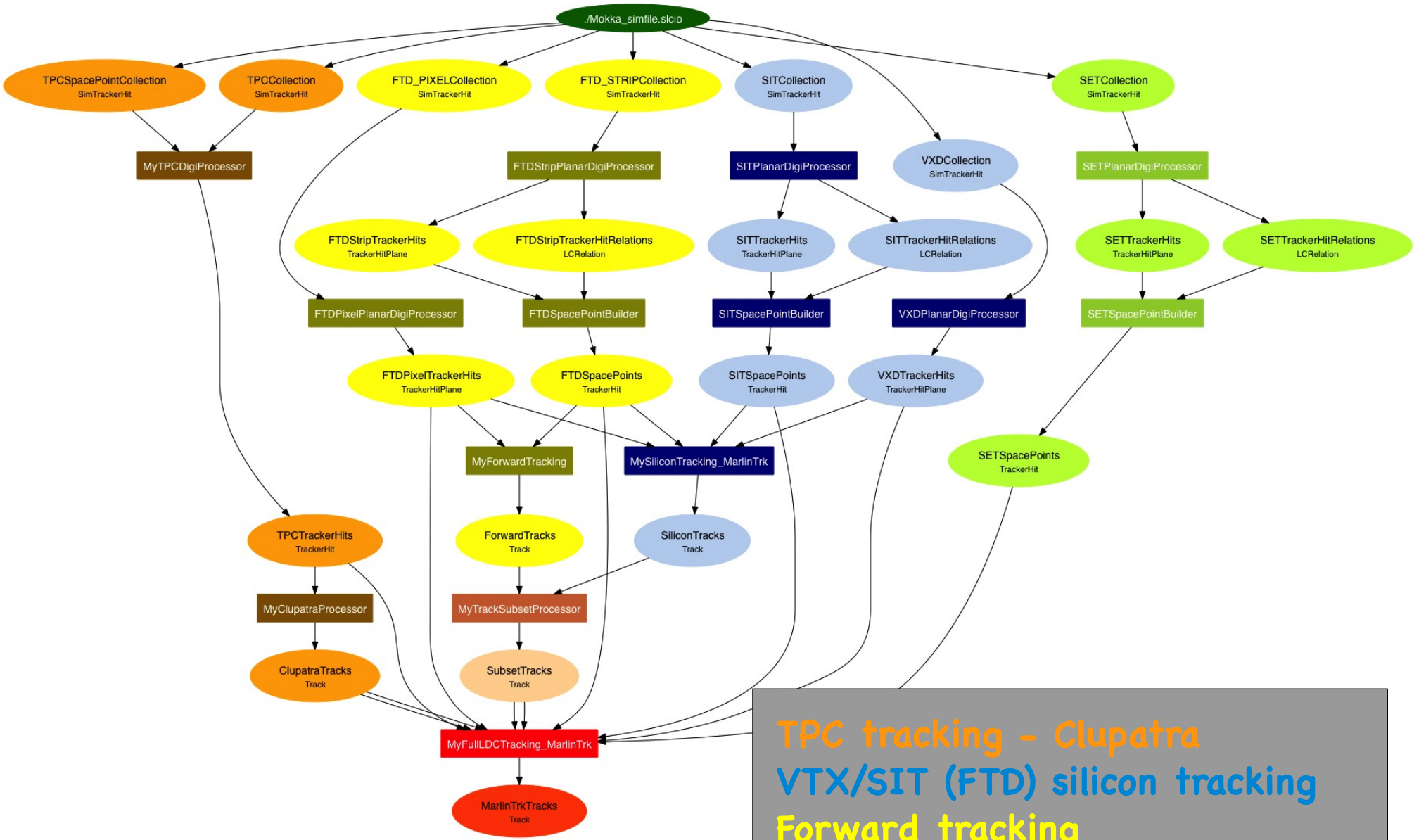
track parameters very close to canonical LCIO set:
d0, phi0, omega, tanL, z0
-> trivial transform

the MarlinTrk interface for tracking

- new common API for developing tracking code (TPC, Silicon, Fwd)
- provides loose coupling between patrec and fitting
- defined abstract interface IMarlinTrk and implement using KalTest/KalDet
- currently lives in MarlinTrkProcessors



New C++ tracking in Marlin



TPC tracking - Clupatra

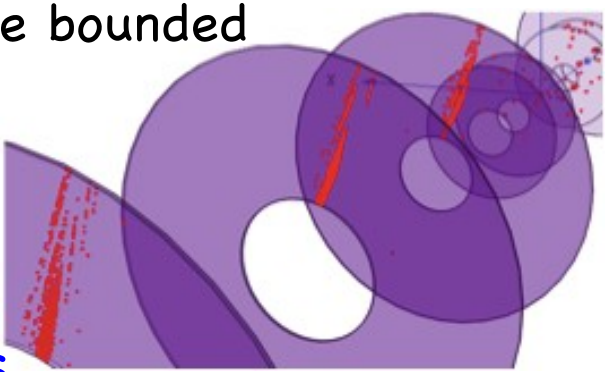
VTX/SIT (FTD) silicon tracking

Forward tracking

FullLDC combined tracking (+SET)

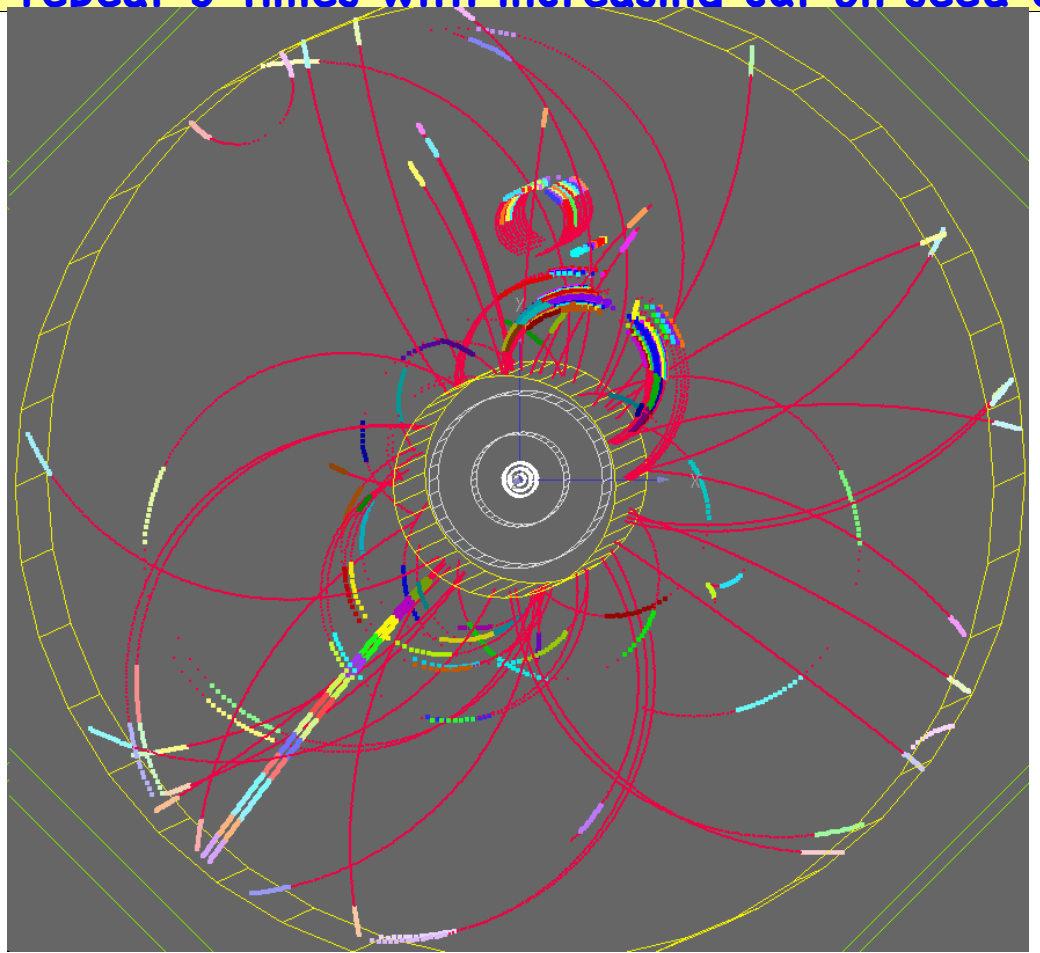
Digitization

- apply parameterized smearing to the position of the SimTrackerHits - according to resolution established by R&D groups (as shown on slide 2)
- for Si-Trackers SIT, SET and FTD do this on individual sensors with proper treatment of 1D strip measurement
- SpacePointBuilder:
  - combine pairs of digitized 1d TrackerHitPlanes from double layers with strip stereo angle into TrackerHits with 3d space points - incl. correct covariance matrix
  - avoid parallax problem by projecting to the IP
  - all possible hit pairs that result in hits laying within the bounded surface of the wafer (rectangle/trapezoid) are used
  - including ghost hits
- space points are used for pattern recognition
- final track fit uses 1d measurements and errors



Clupatra 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 cut on seed clustering

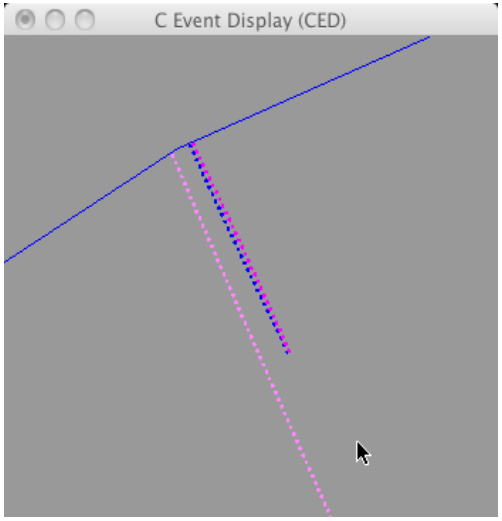


example:

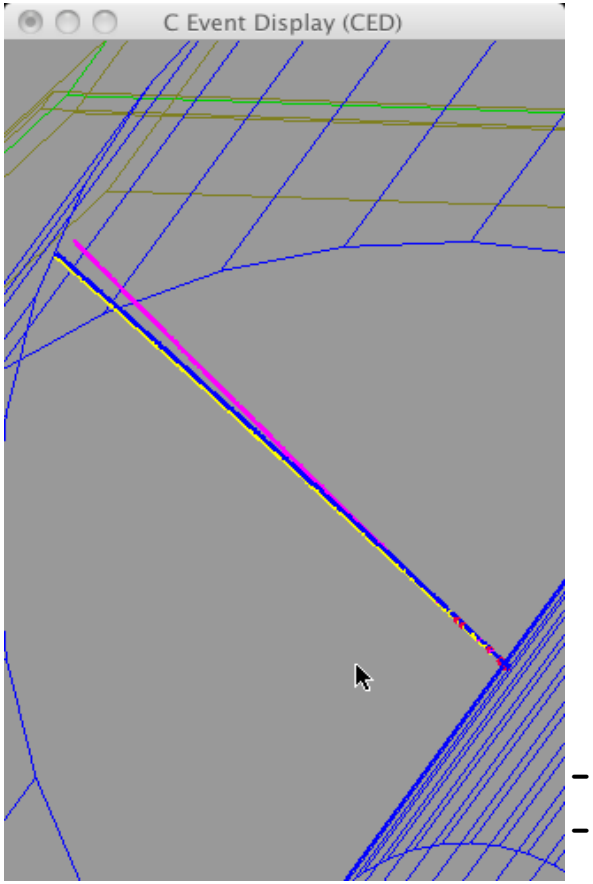
- ttbar event @ 500 GeV
- results in clean tracks and segments for curlers
- little leftover hits
- some very close by tracks lost (fixed in step2)

Clupatra step 2

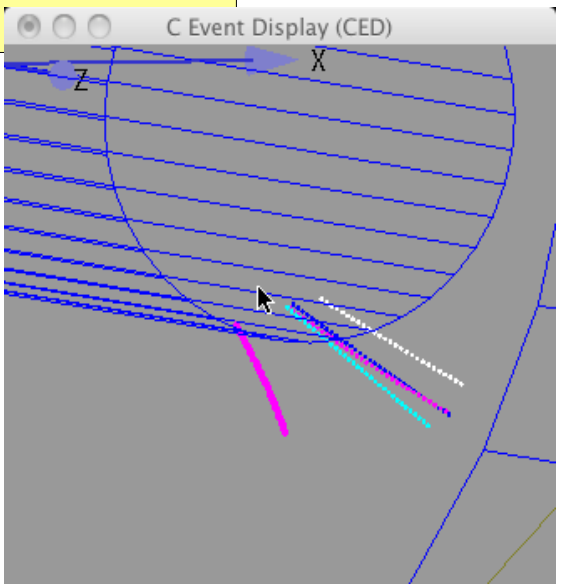
- re-cluster in leftover hits (NN clustering)
- based on pad row multiplicity force into
  N=2,....9 clusters
- apply KalTest fit to throw out falsely merged hits (rare)
  - higher multiplicity: repeat iteratively in smaller row ranges until only three or two tracks left



- gamma conversion in barrel
- forced into two tracks



- three prong tau - barrel
- two close-by tracks forced into two tracks

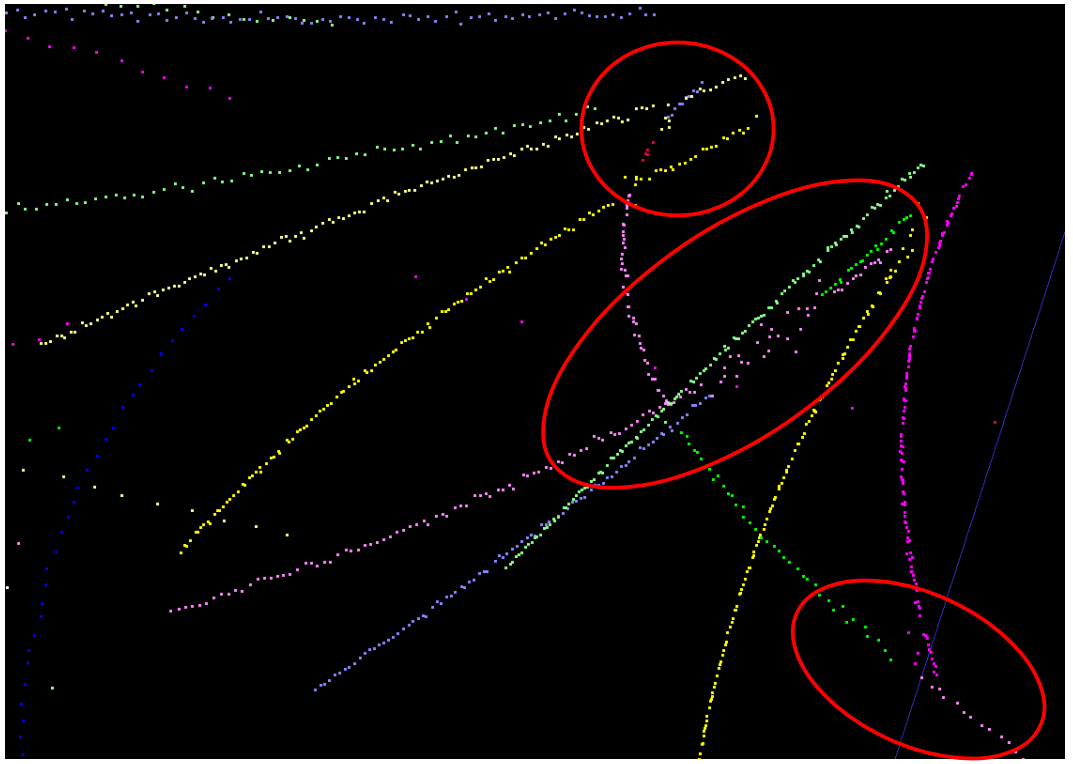


- five prong tau - forward
- three close-by tracks forced into three tracks

Clupatra step 3

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

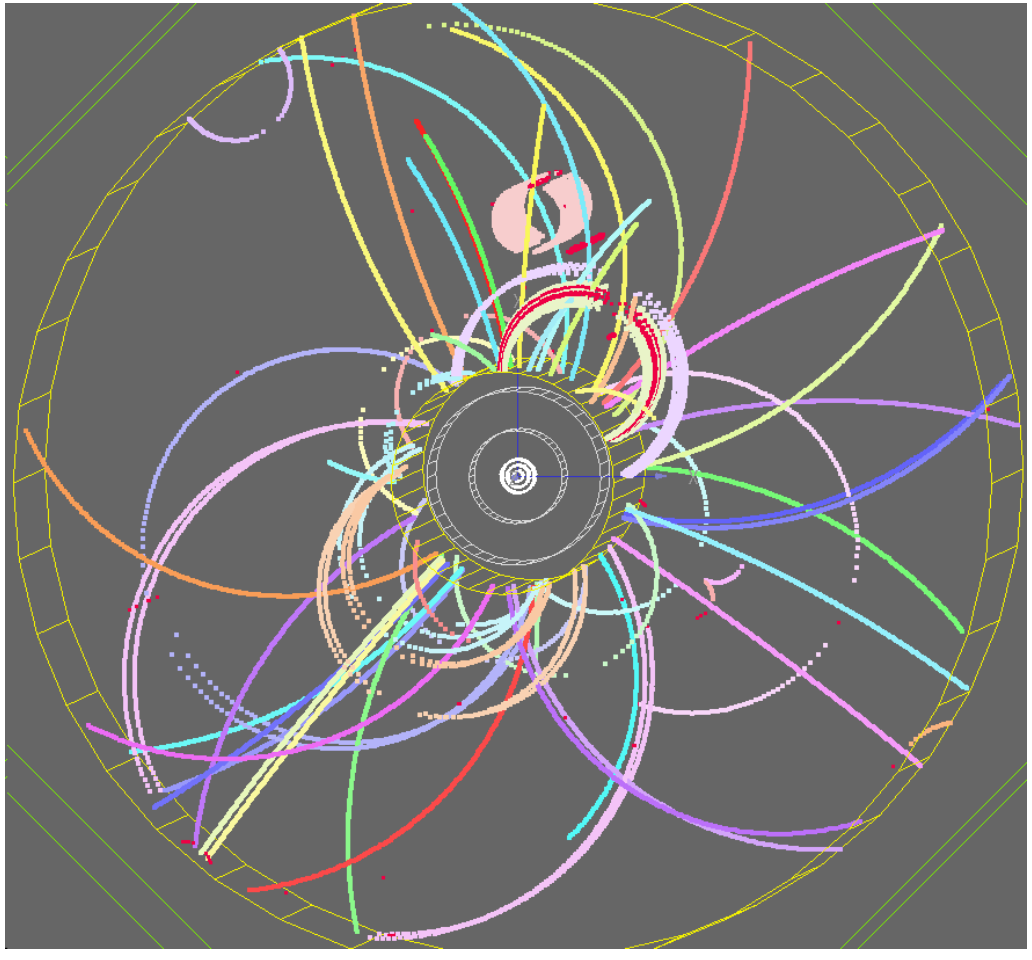
    don't start at the inner field cage and/or that don't end at the outer field cage or endplate
  - **merge segments that have consistent tracks states** (based on delta chi2 after hits are added)
- problem mostly due to double hit resolution (merged hits)



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

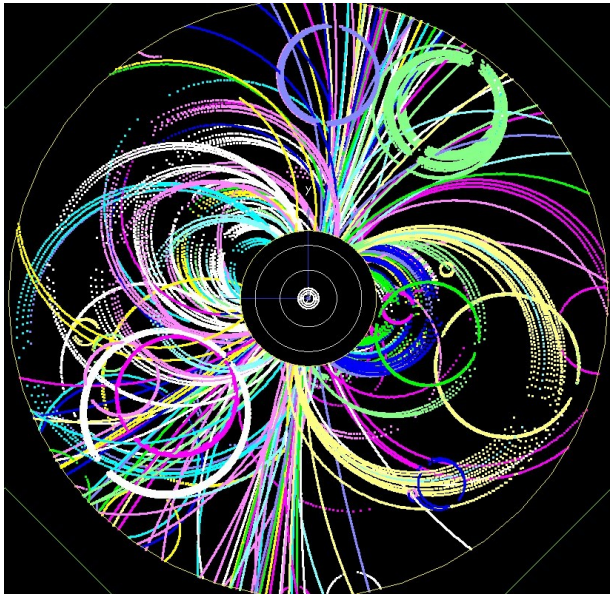
Clupatra step 4

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



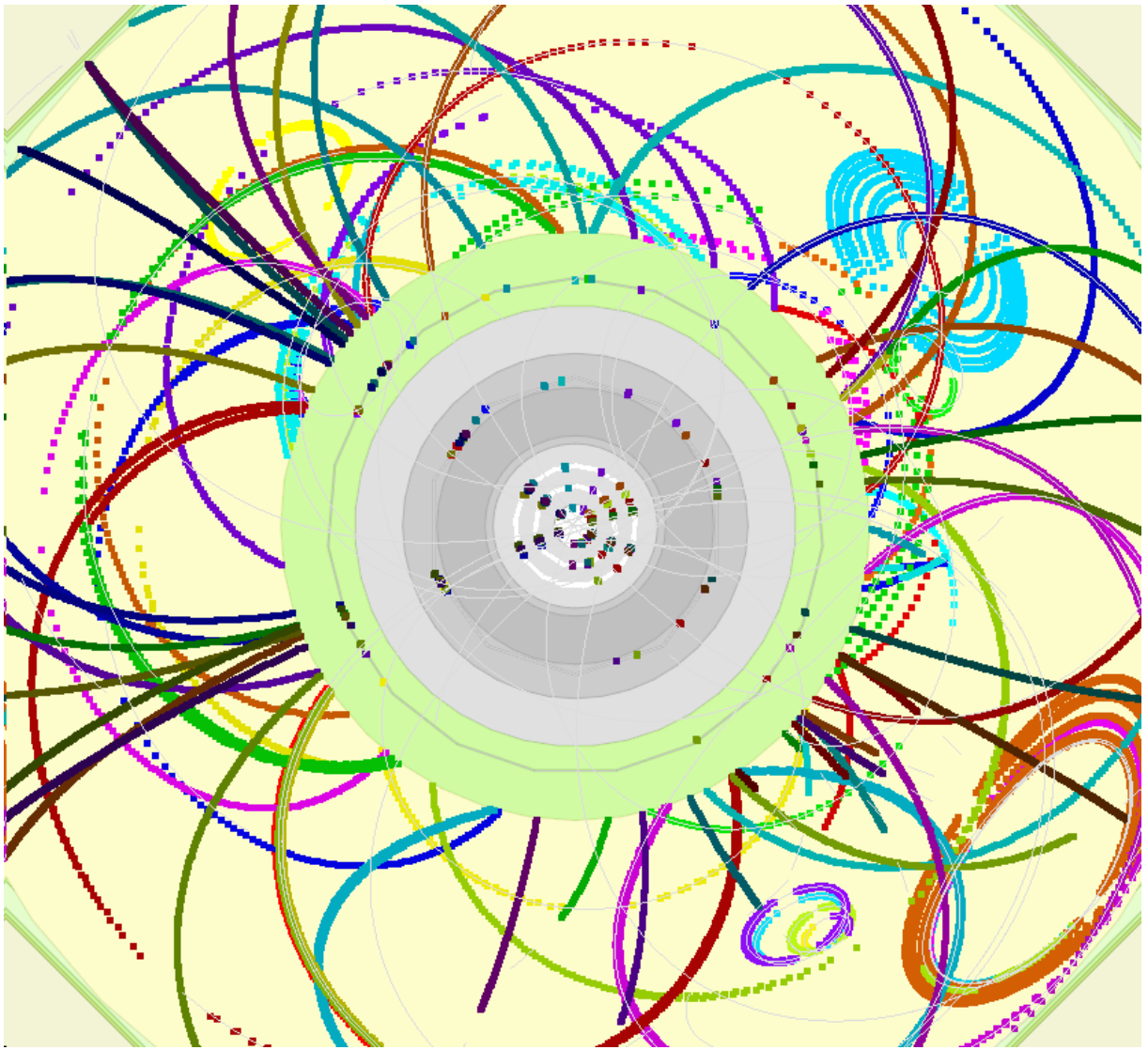
examples:

- 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:



extending Clupatra inwards

- extended Clupatra to optionally extend hit search further inwards using MarlinTrK interface
- try to pick up hits from SIT and VXD
  - **use 1d Hits for SIT !**
  - FTD not yet
- **could use as backup strategy for large background**
- standard ILD tracking:
  - have standalone tracking in TPC and Si-trackers and then merge

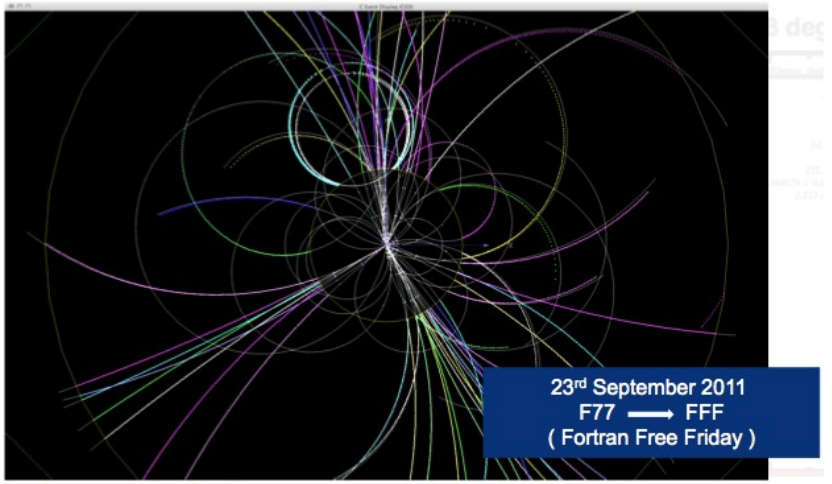


fisheye view of Clupatra tracks with SIT and VXD hits picked up (ttbar @ 500 GeV)

SiTracking - FullLDC Tracking

- existing algorithms (used in LOI) re-written to use new MarlinTrk instead of old f77 fitter
- adapted to use space points for the patrec and 1D hits for the fitting
- plus improvements and fixes...

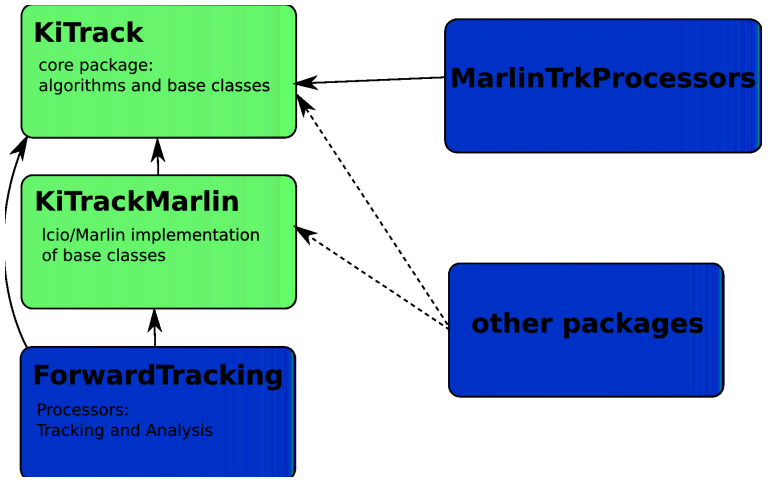
- **SiliconTracking_MarlinTrk**
  - sliding window binned triplet seed search
  - followed by a road search
- **FullLDC_MarlinTrk**
  - combines track from TPC - SiTracking - ForwardTracking
  - based on track parameter compatibility
  - and multiple refitting

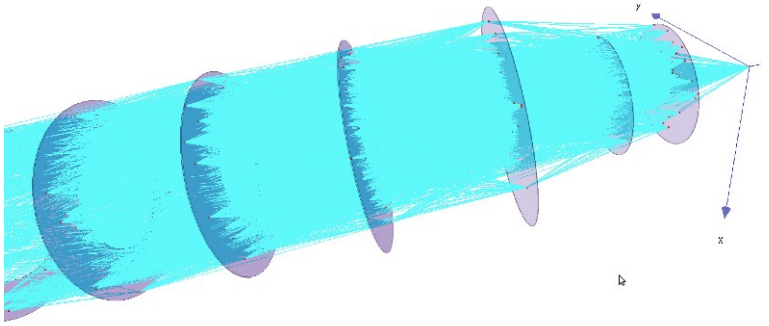


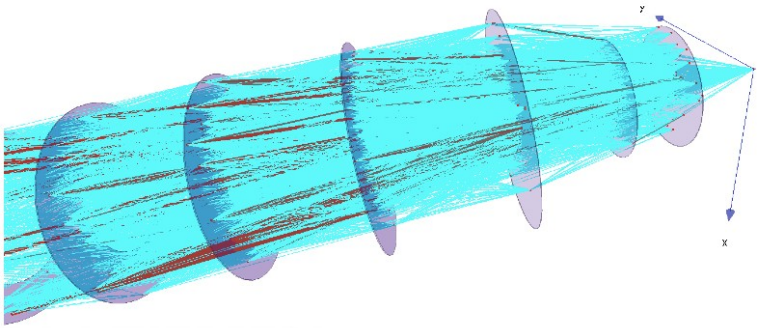
code not optimal and maintenance difficult - might need replacement

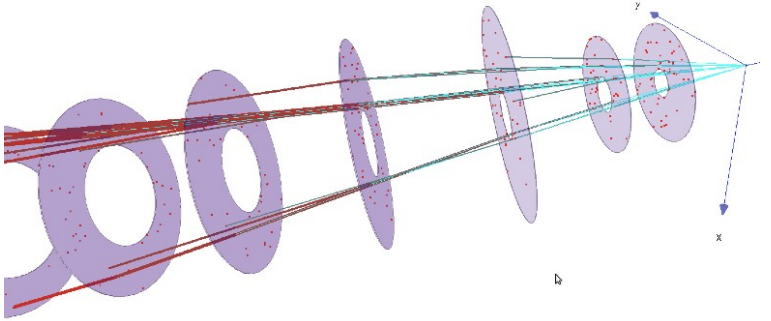
New forward tracking

- **ForwardTracking**: new standalone forward tracking package - uses:
- Cellular Automaton for track finding
- Hopfield networks to arbitrate between candidates w/ mutual hits)
- SubsetProcessor to find consistent set w/ tracks from SiliconTracking

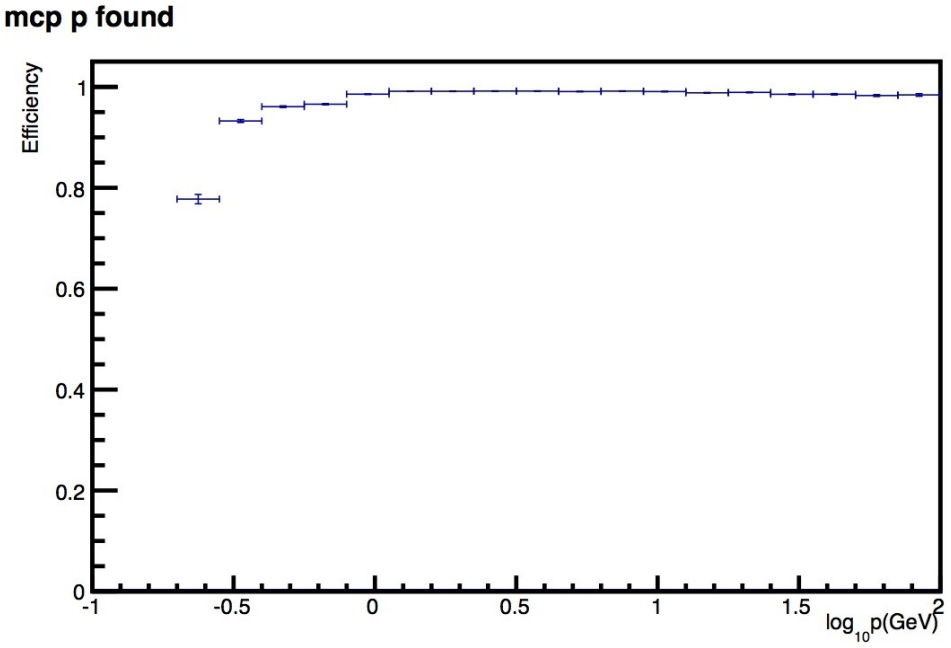


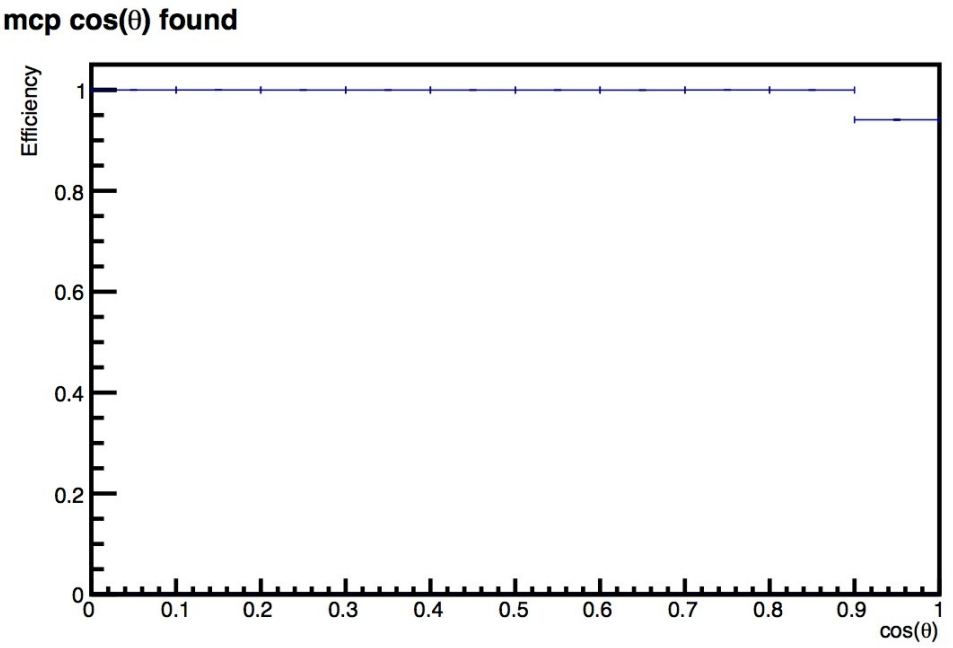






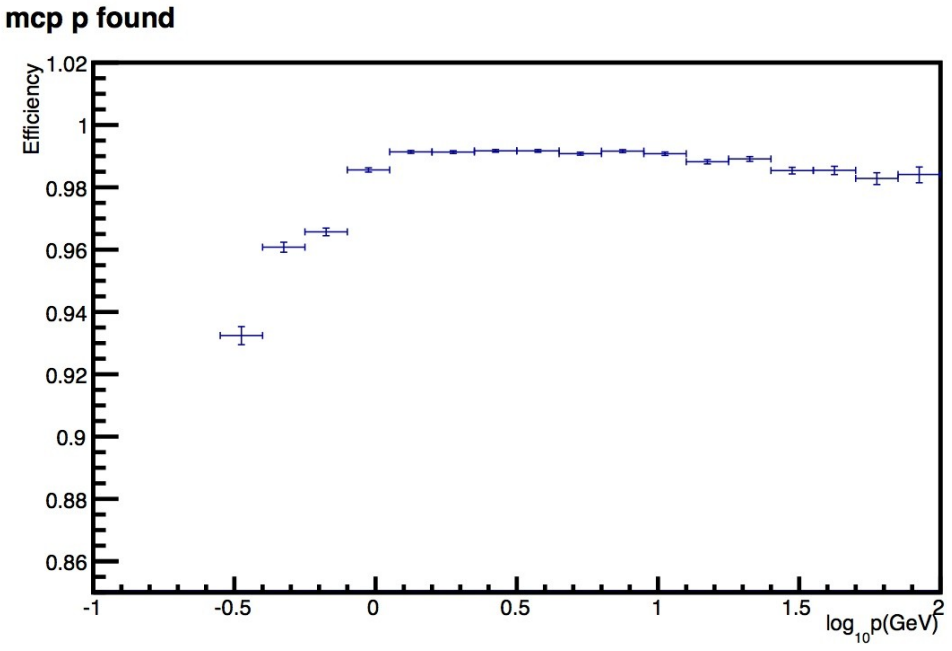
Tracking efficiencies new ILD tracking

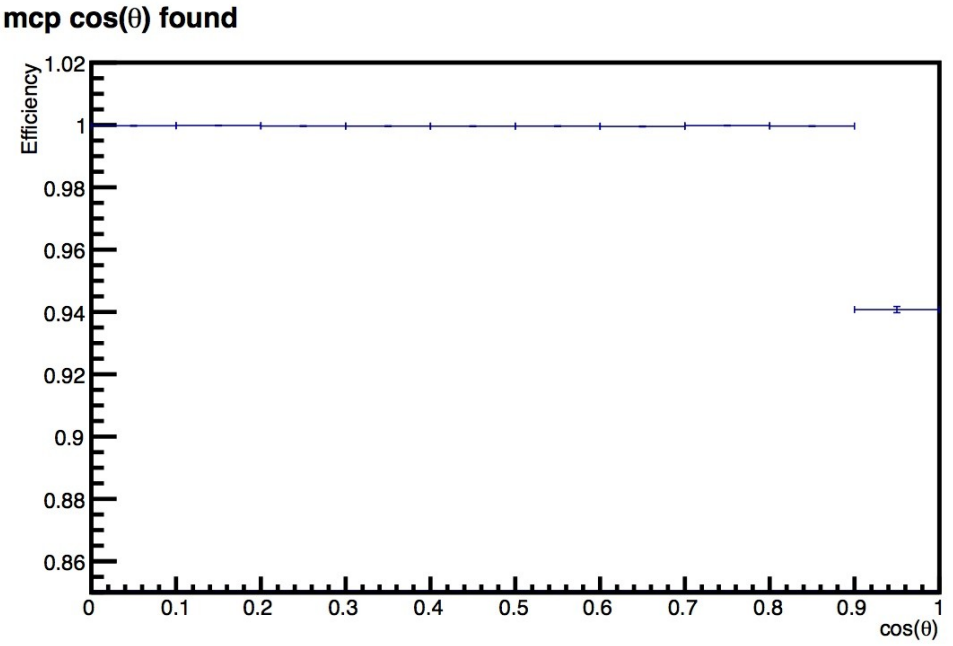




- track finding efficiency of new MarlinTrk tracking - combined TPC, Si-Tracking and ForwardTracking
- prompt primary charged particles from within 10 mm of IP
- that leave at least 4 hits in detector and reach the calorimeter
- cos(theta) plot: p>1GeV

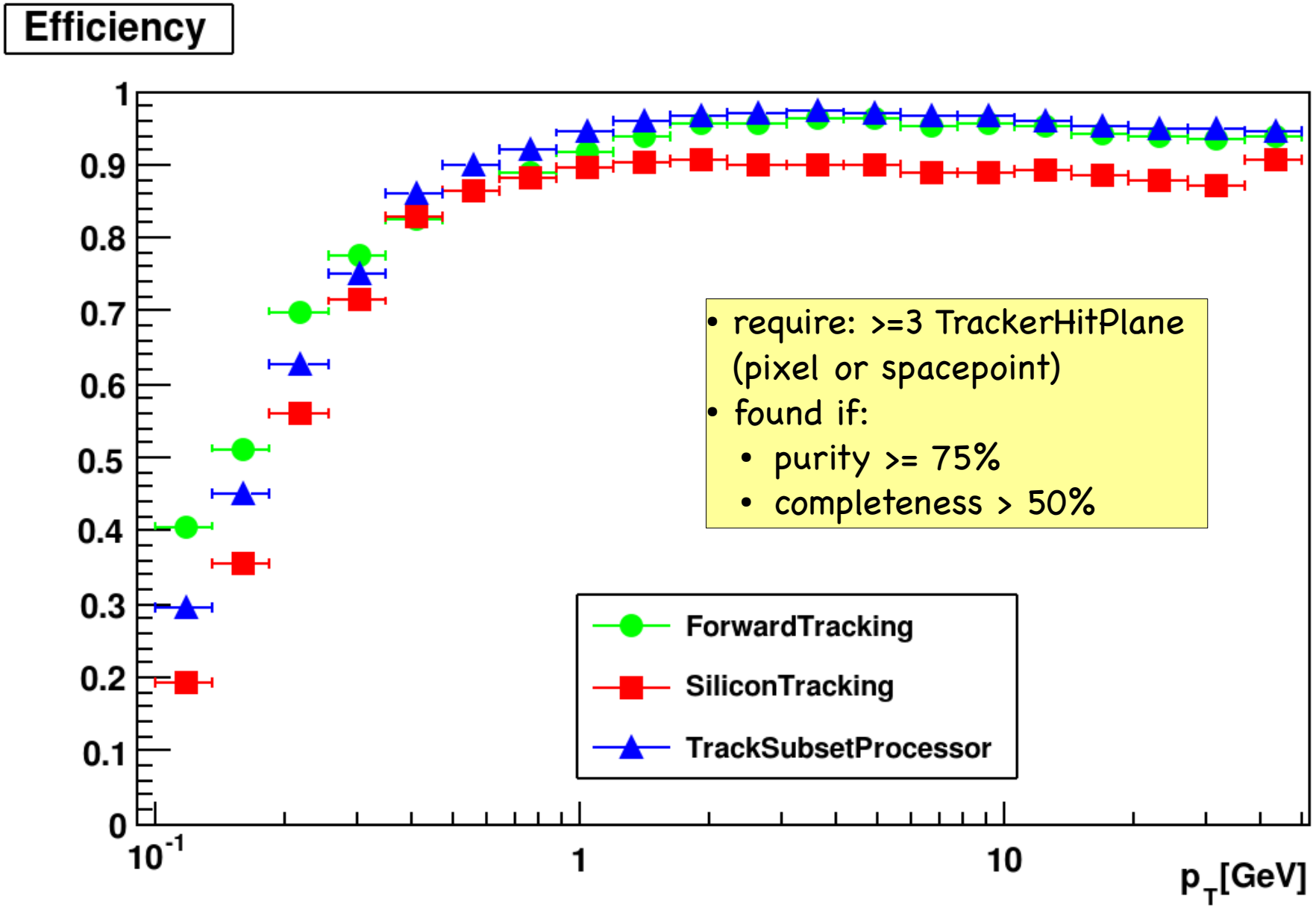
Tracking efficiencies new ILD tracking



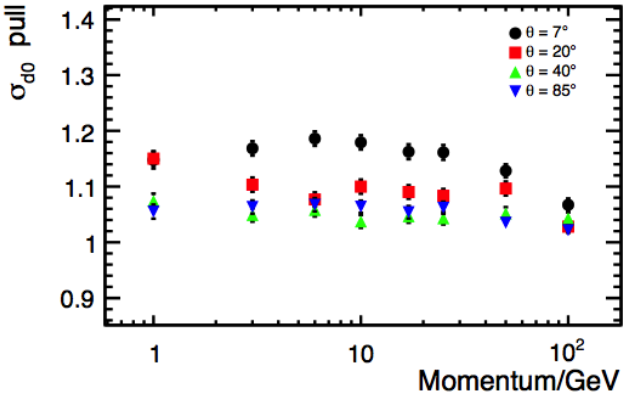


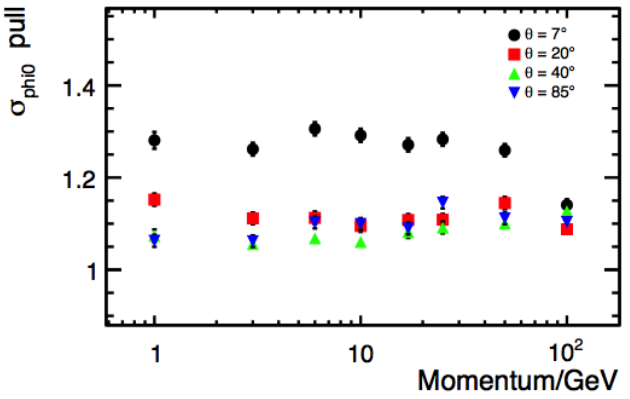
- track finding efficiency of new MarlinTrk tracking - combined TPC, Si-Tracking and ForwardTracking
- prompt primary charged particles from within 10 mm of IP
- that leave at least 4 hits in detector and reach the calorimeter
- cos(theta) plot: p>1GeV
  - -> above 1 GeV effectively only losses in forward region

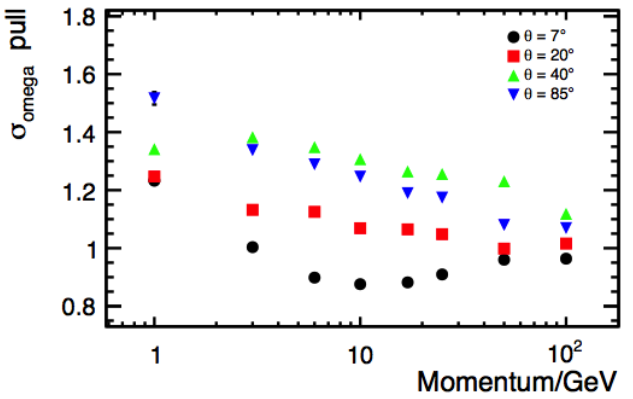
ForwardTracking efficiency

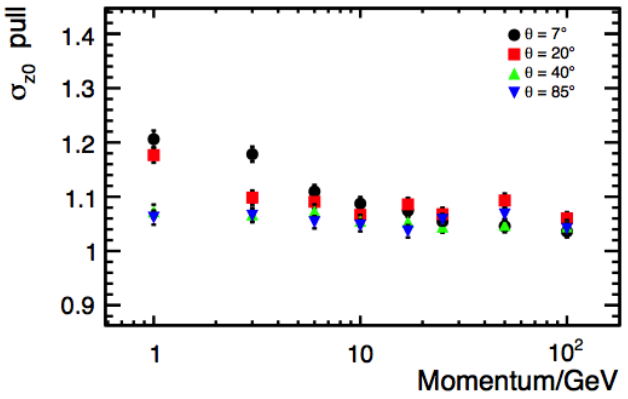


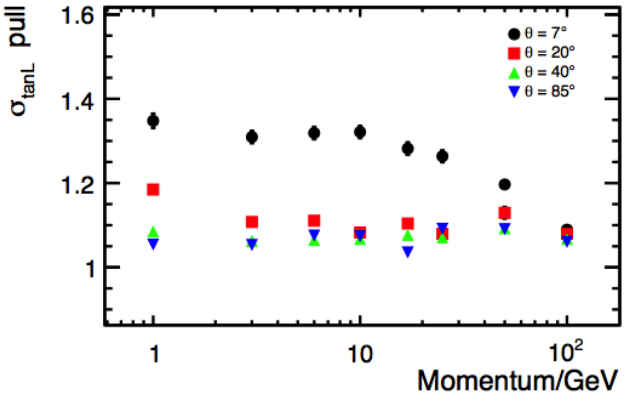
Pull distributions new ILD tracking









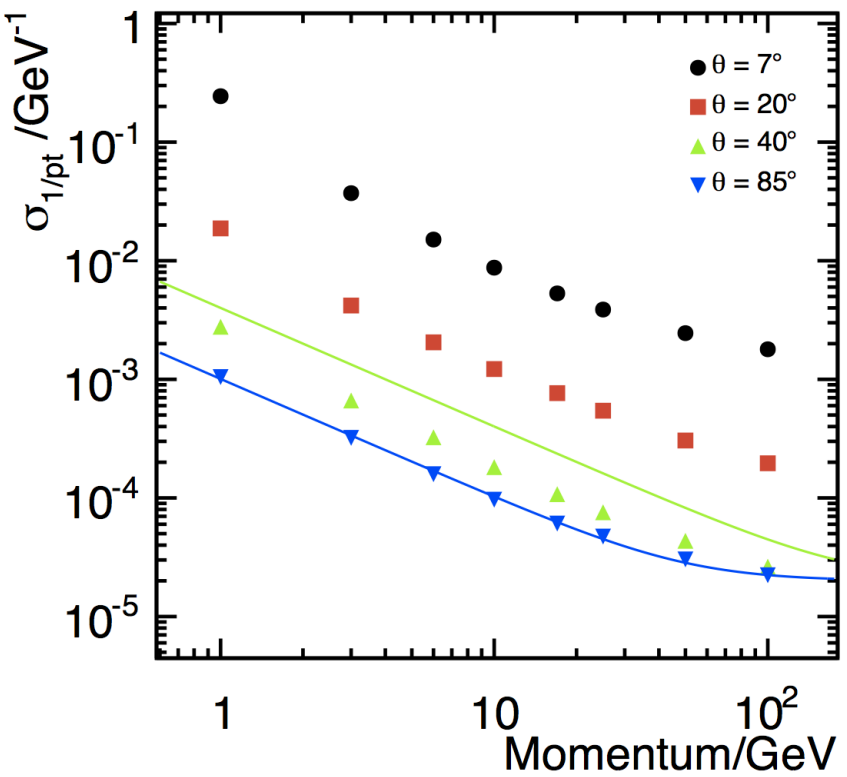


single muons:

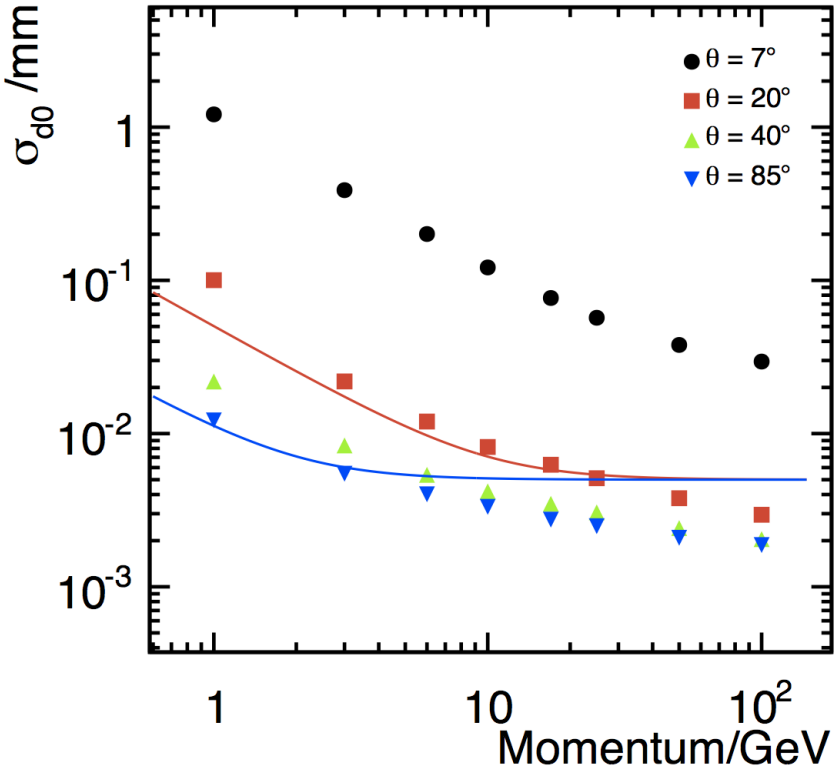
pull scans for all track parameters

- generally within 10% of unity
- small issue in fwd direction:
  - space frame vs. averaged material

Resolution of new ILD tracking



$$\sigma_{1/p_T} = \frac{2 \times 10^{-5}}{GeV} \oplus \frac{1 \times 10^{-3}}{p_T \sin\theta}$$



$$\sigma_{r\phi} = 5\,\mu\mathrm{m} \oplus \frac{10}{\mathrm{p(GeV)}\sin^{3/2}\theta}\,\mu\mathrm{m}$$

single muons:

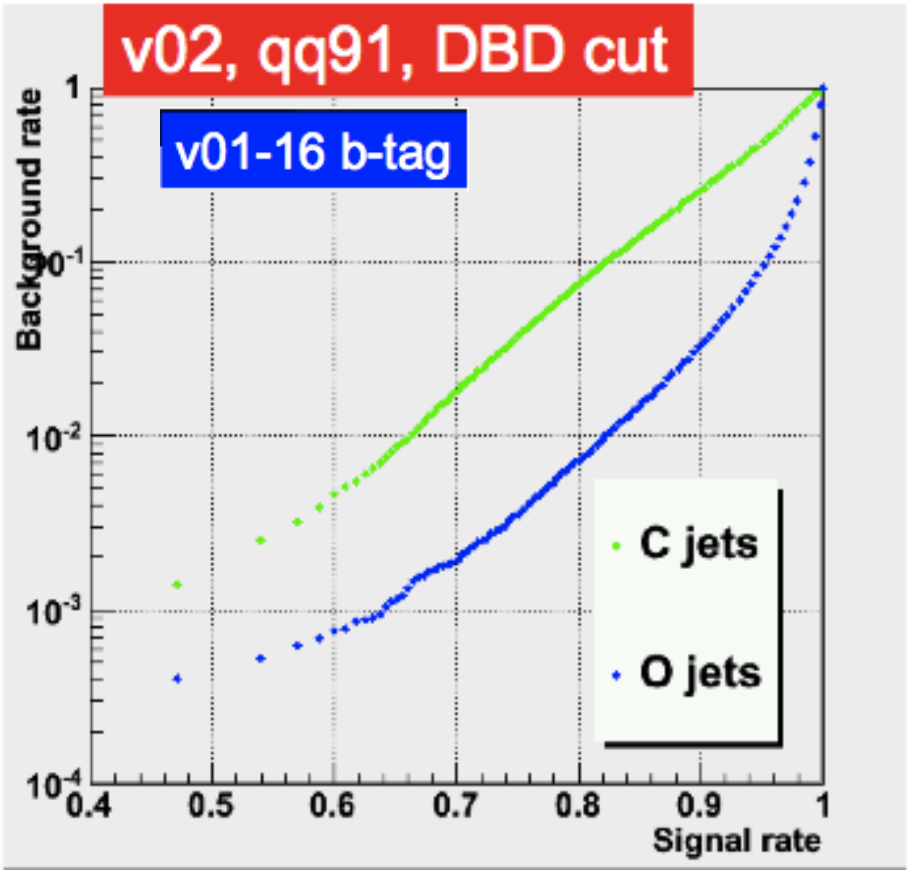
transverse momentum and impact parameter resolution as function of momentum

-> achieve design goal for ILD

PFA and flavor tag performance

91 GeV	rms90	dE/E [%]*
ILD_00 [LOI]	2.40	3.71+-.05
v01-16	2.32	**3.65+-.05**
500 GeV		
ILD_00 [LOI]	11.10	3.17+-.05
v01-16	10.76	**3.01+-.04**

*dE/E=rms90*sqrt(2)/<E>
cos|th_t|<0.7



- tracks from new tracking with **much increased realism** are used in new PFA and flavor tag
- **same performance (or slightly better) as in LOI reached !**

Summary & Outlook

- a new C++ tracking for ILD has been developed
  - **MarlinTrk interface to KalTest/KalDet**
  - **Clupatra (topological TPC patrec)**
  - **C++ re-write of SiliconTracking and FullLDCTracking**
  - **ForwardTracking**
- including proper treatment of 1d hits for double strip stereo layers in SIT/SET and FTD - incl. ghost hits

-> similar or better performance compared to LOI with much increased realism in the simulation and digitization of the tracking system

- more dead material, gaps, cables,...