Track Reconstruction at the ILC

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Outline

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- The ILD tracking system
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- Performance
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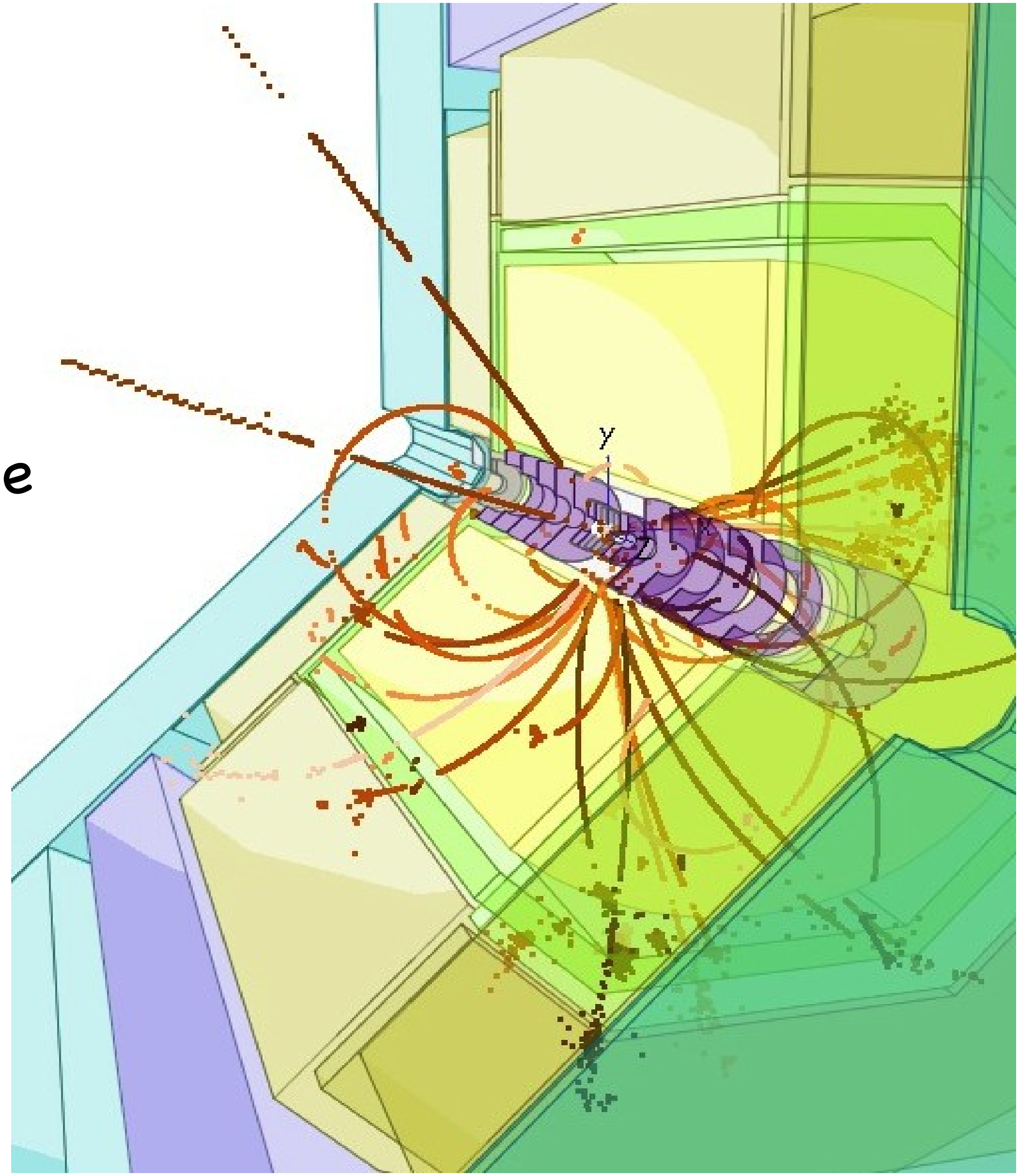
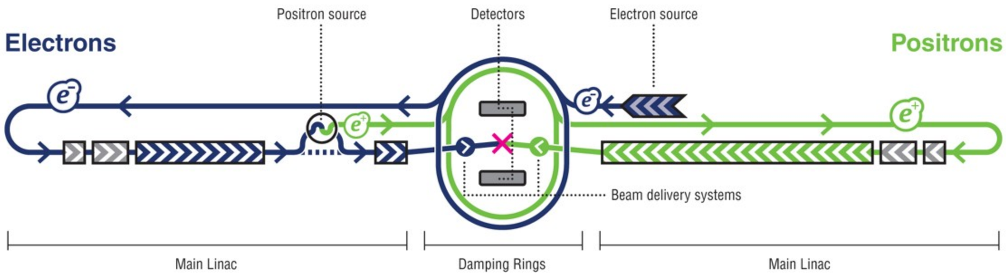
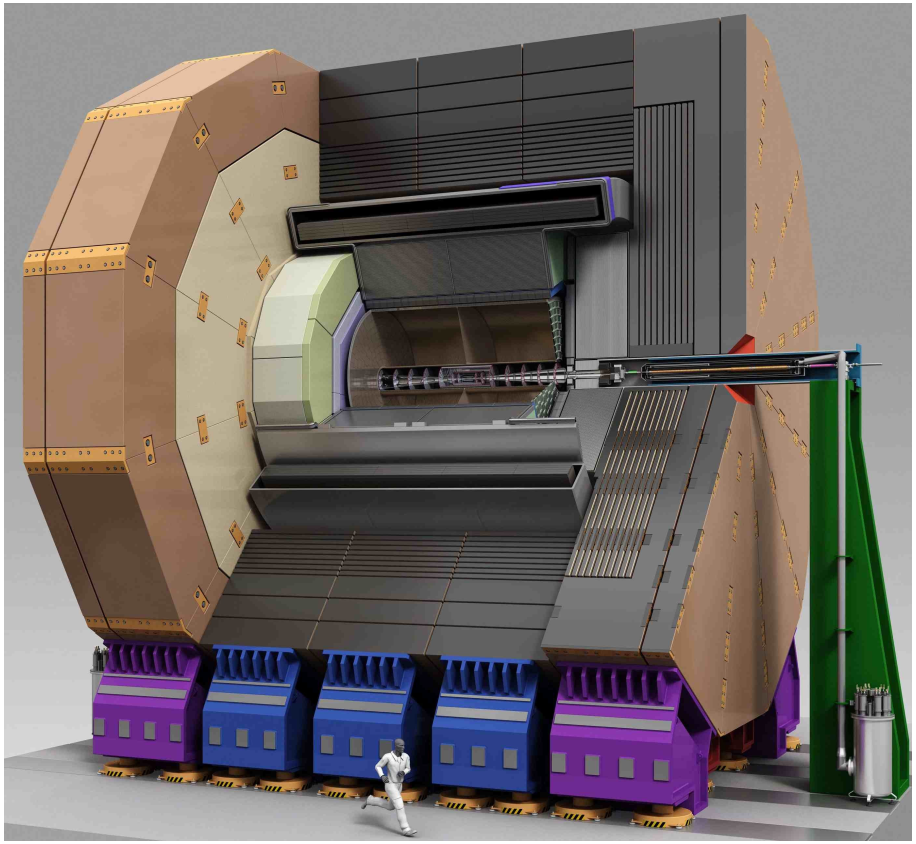


Introduction: ILC & ILD

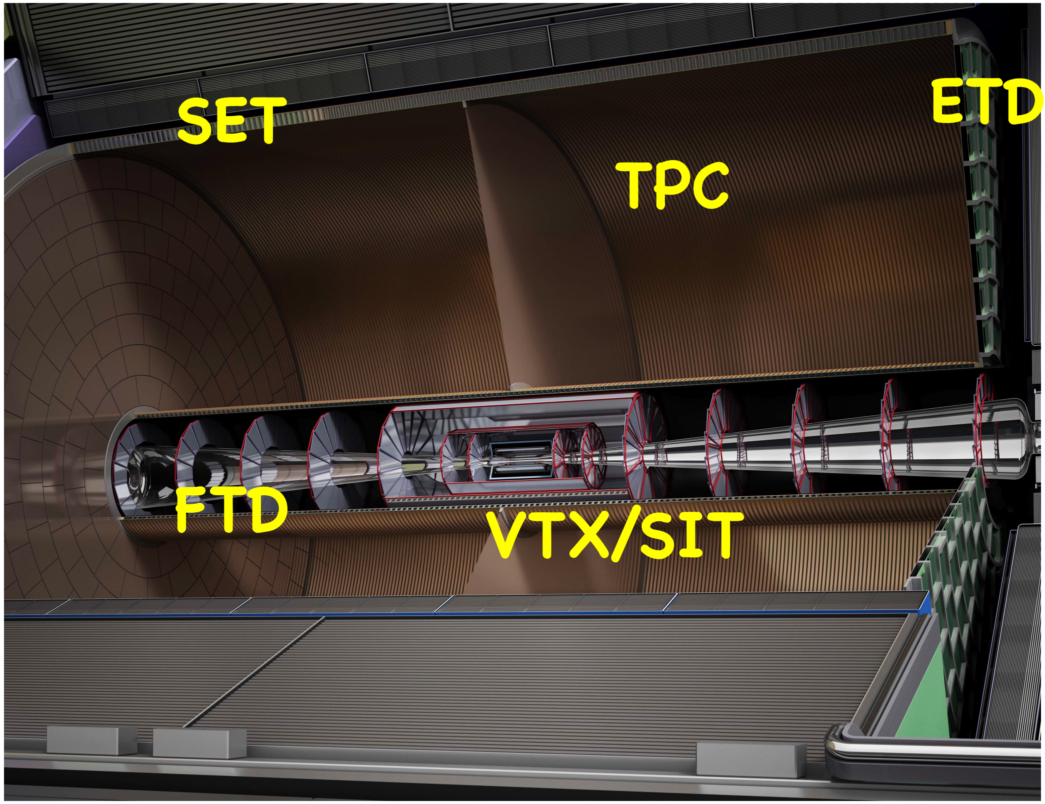
- ILC
  - linear e+e- collider
  - 250-500 GeV (1 TeV)
  - super conduction RF technology
  - TDRs submitted early 2013
  - (soon) to be build in Japan

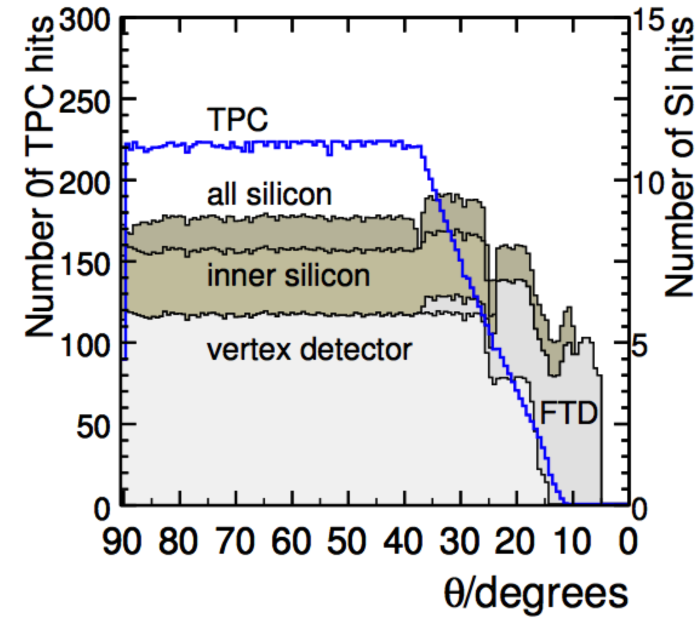




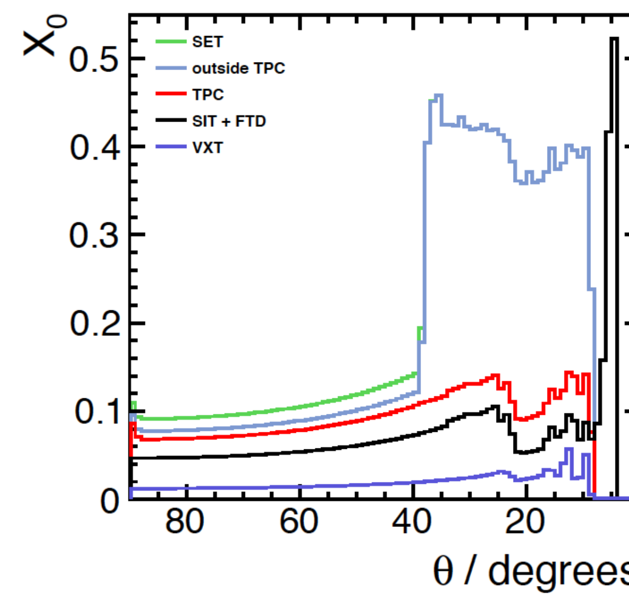
- ILD
  - one of two detector concepts for the ILC (push pull)
  - optimized for PFA
    - highly granular calorimeters
    - excellent momentum resolution
    - and vertexing capabilities

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 first two discs
	$\sigma_{r_\perp}$	=	3.0μm
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		



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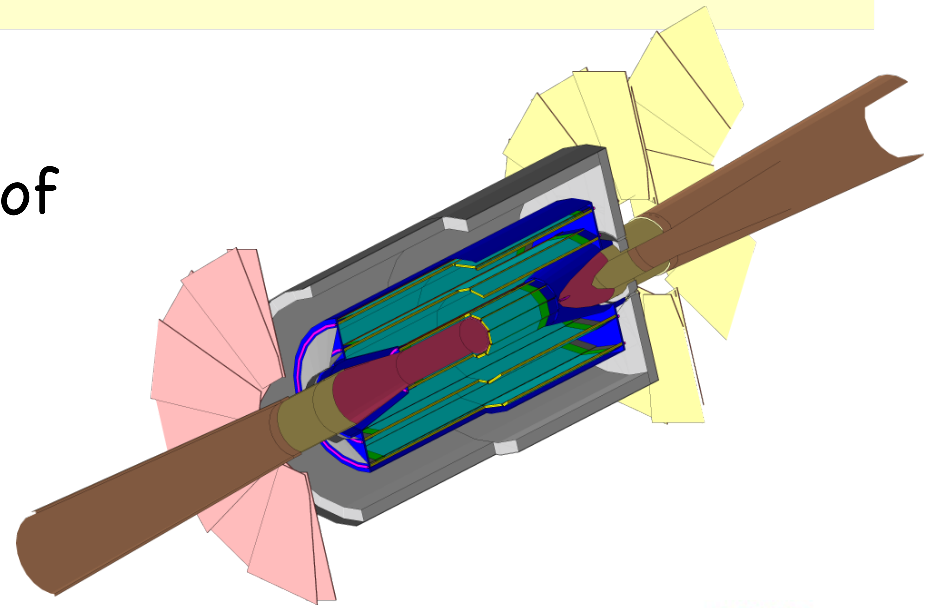
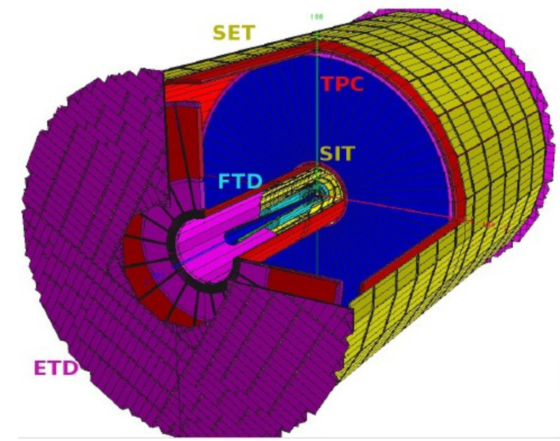
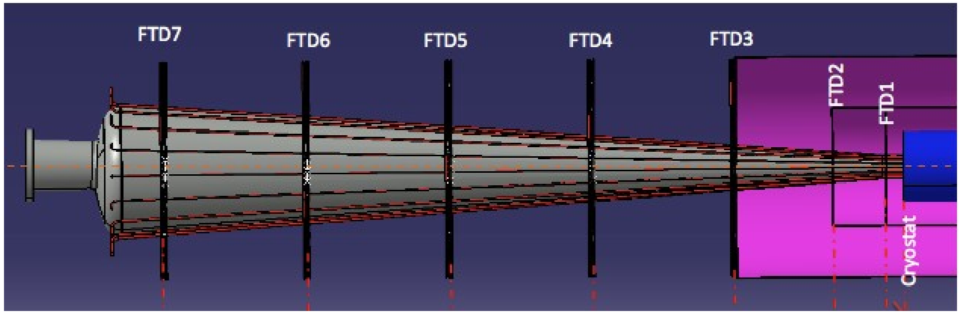
ILD tracking in the simulation

- realistic and detailed description of the tracking system is key requirement for optimizing the detector performance
- ILD has a sophisticated geant4 simulation model with engineering level of detail:
  - space frames for support
  - cryostats, cables and services (cooling)
  - planar Si-sensors (wafers) with gaps and overlap

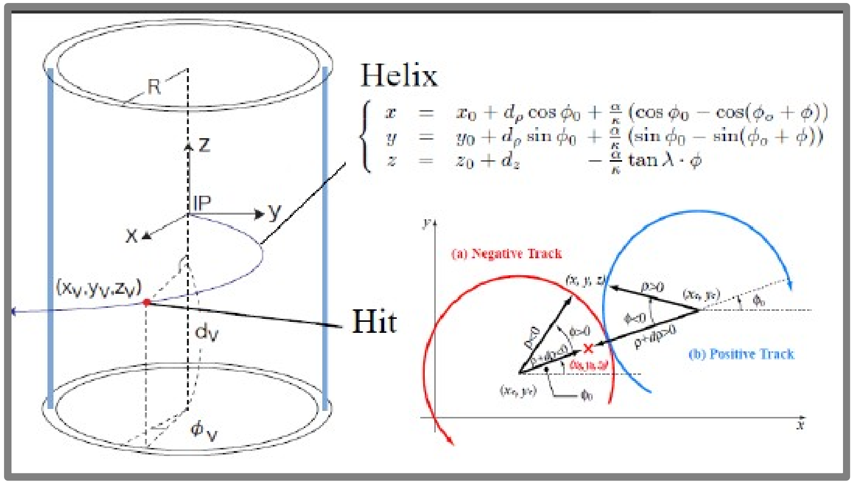




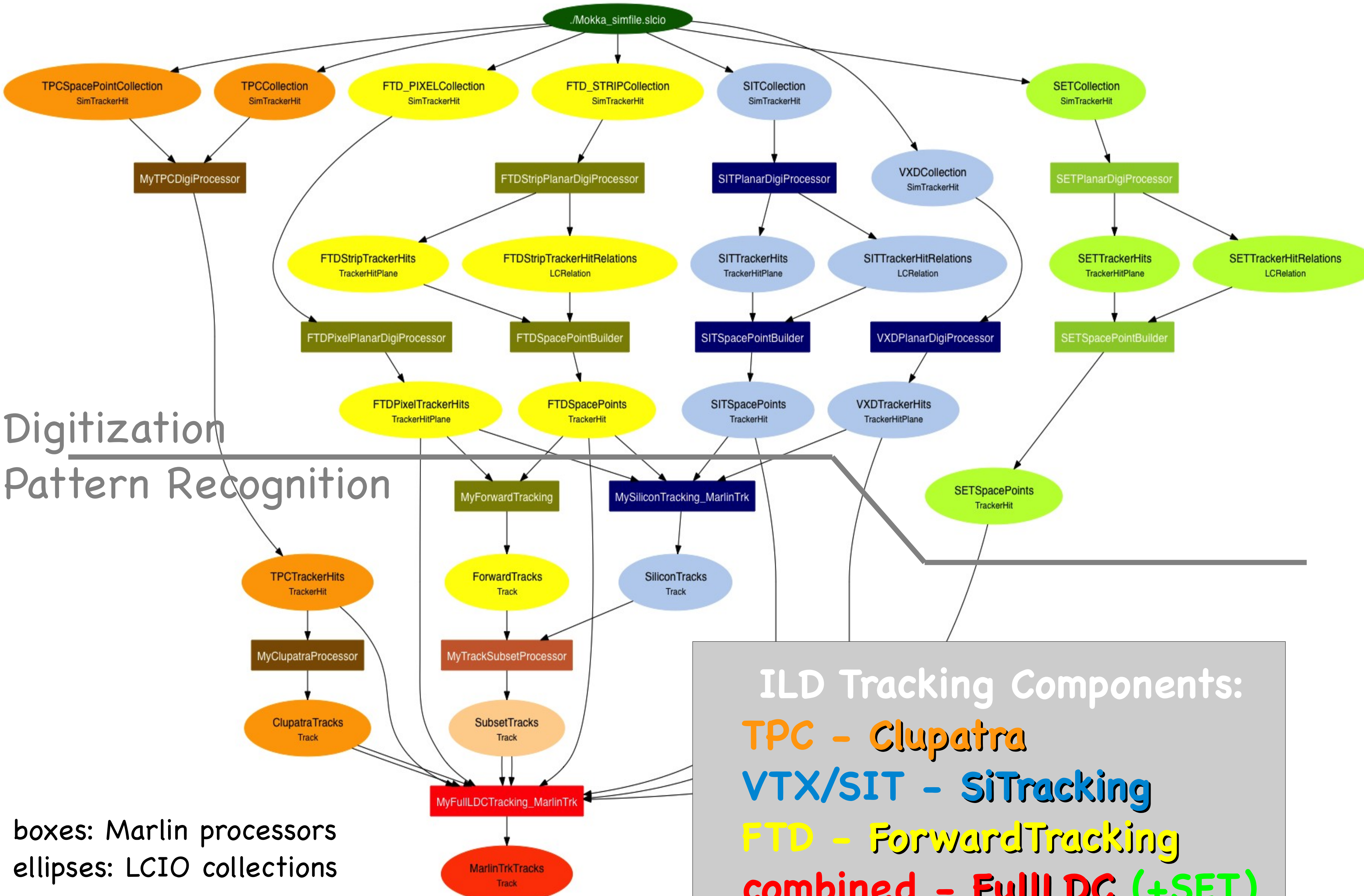


Overview - ILD Tracking code

- in late 2009 ILD decided to replace the existing, recycled LEP tracking code (f77) with more maintainable modern software:
  - use iLCSoft software framework - Marlin and LCIO
  - (re-)write pattern recognition for TPC, Si-Trackers and forward region
  - define and implement an abstract API : MarlinTrk to allow easy replacement of fitting algorithms
  - re-use a light weight Kalman Filter:
  - KalTest/KalDet
    - Kalman Filter tool (K. Fujii et al)
    - use ILC track parameters (perigee)
    - both also used in MarlinTPC test beam software



Marlin modules for ILD Tracking



ILD Tracking Components:

- TPC - Clupatra
- VTX/SIT - SiTracking
- FTD - ForwardTracking
- combined - FullLDC (+SET)

boxes: Marlin processors
ellipses: LCIO collections

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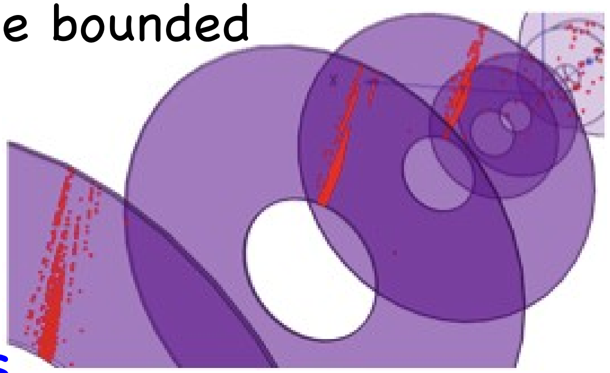
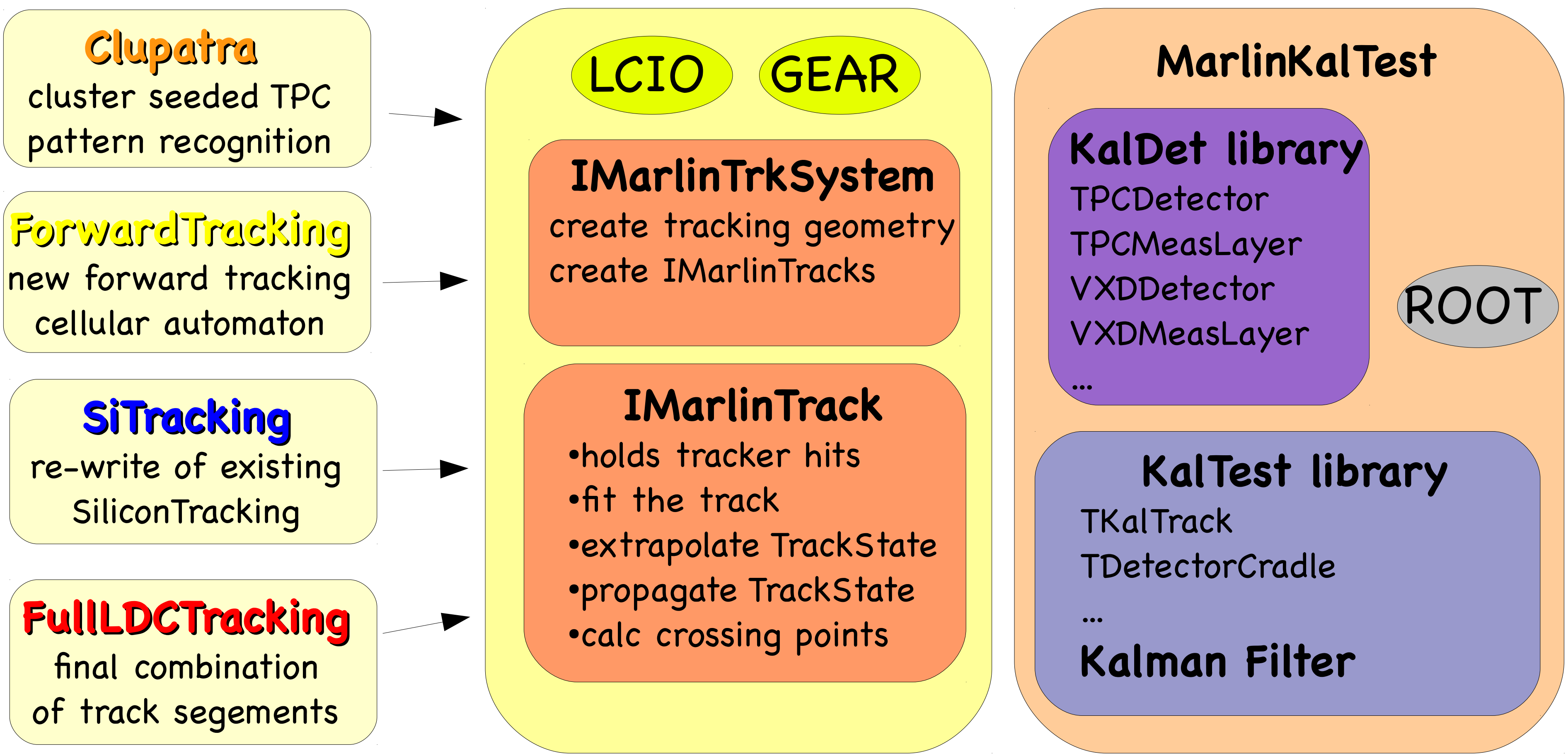
Digitization and Space points

- 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



IMarlinTrk interface for tracking

- common API for developing tracking code (TPC, Silicon, Fwd)
- provides loose coupling between pattrec and fitting
- defined abstract interface IMarlinTrk and implement using KalTest/KalDet
- serves as prototype for *generic tracking package* (AIDA WP2)



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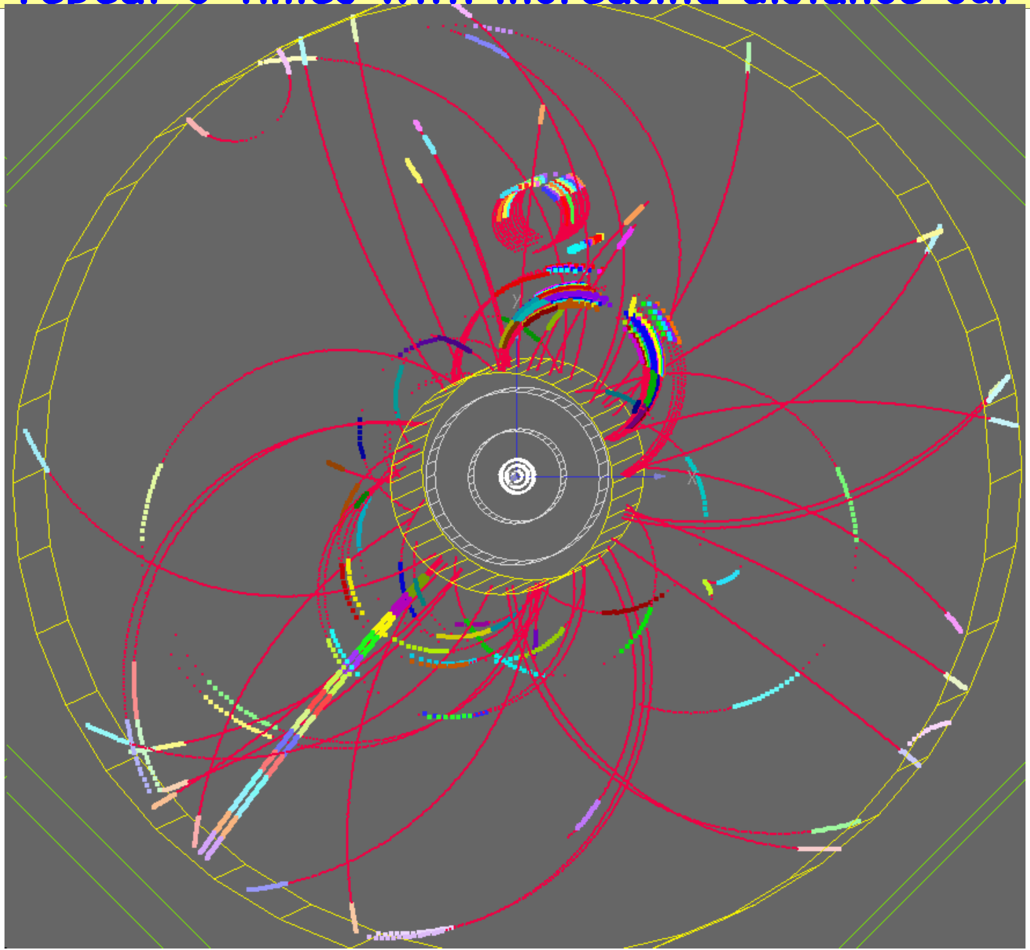
Clupatra TPC pattrec – step 1

- 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

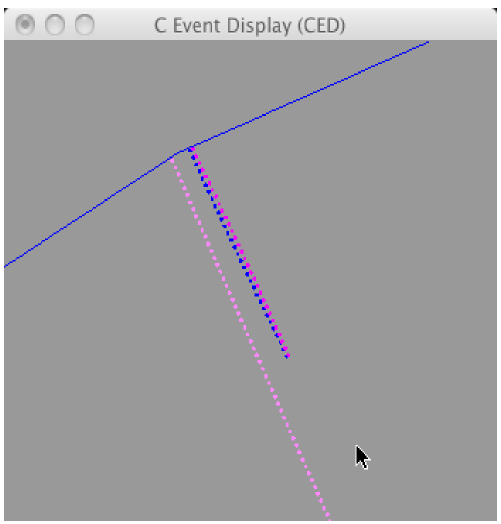


example:

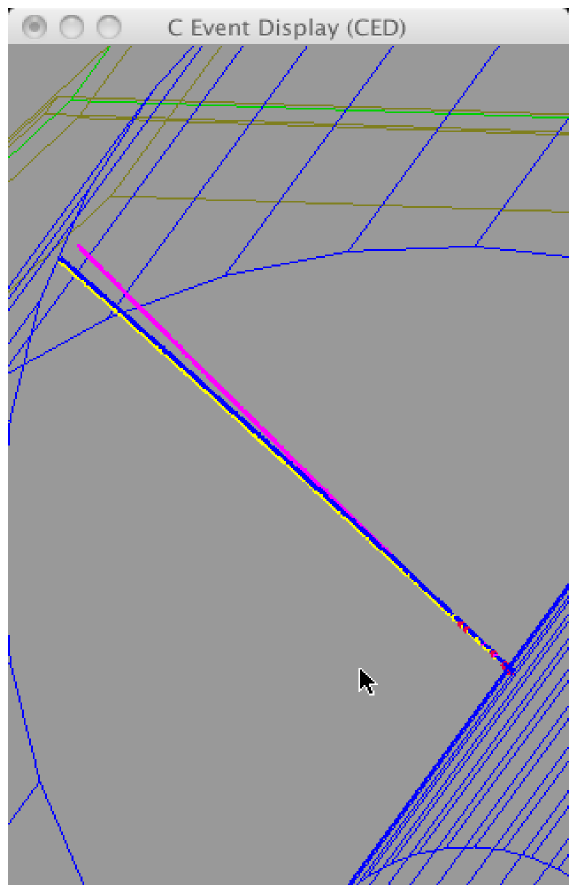
- ttbar event @ 500 GeV
- results in clean tracks and segments for curlers
- little leftover hits
- some very close by tracks lost (fixed in step2)

Clupatra TPC pattrec - step 2

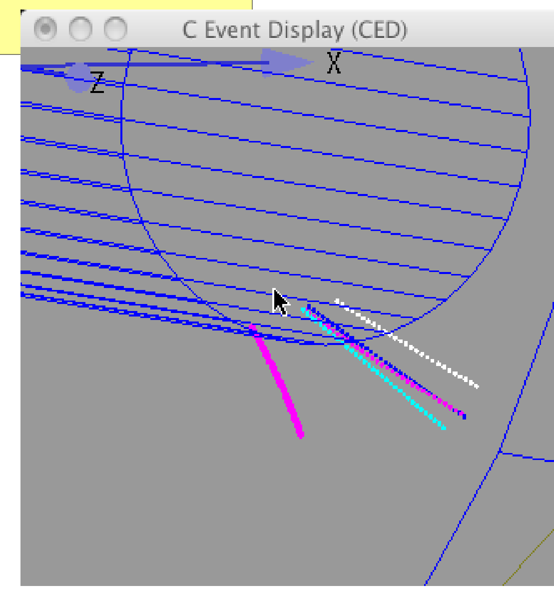
- re-cluster in leftover hits (NN clustering)
- based on pad row multiplicity force into N=2,....9 clusters
- apply KalTest fit to throw out falsely merged hits (rare)
  - higher multiplicity: repeat iteratively in smaller row ranges until only three or two tracks left



- 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

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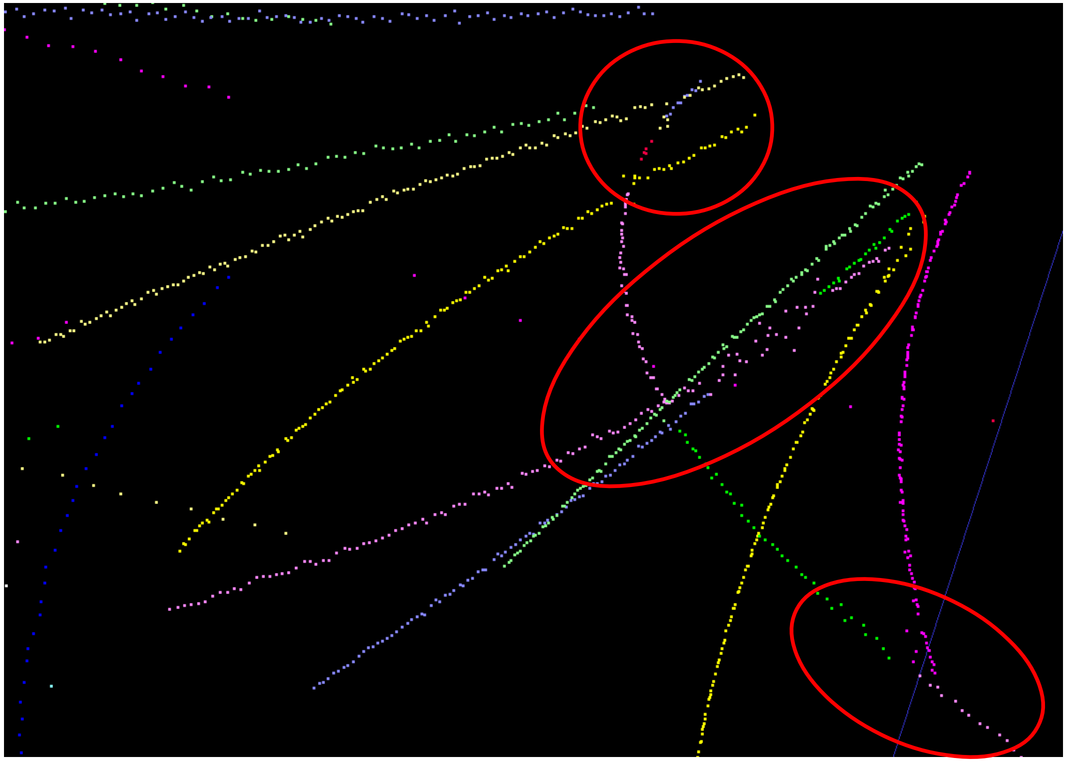
Clupatra TPC pattrec – step 3

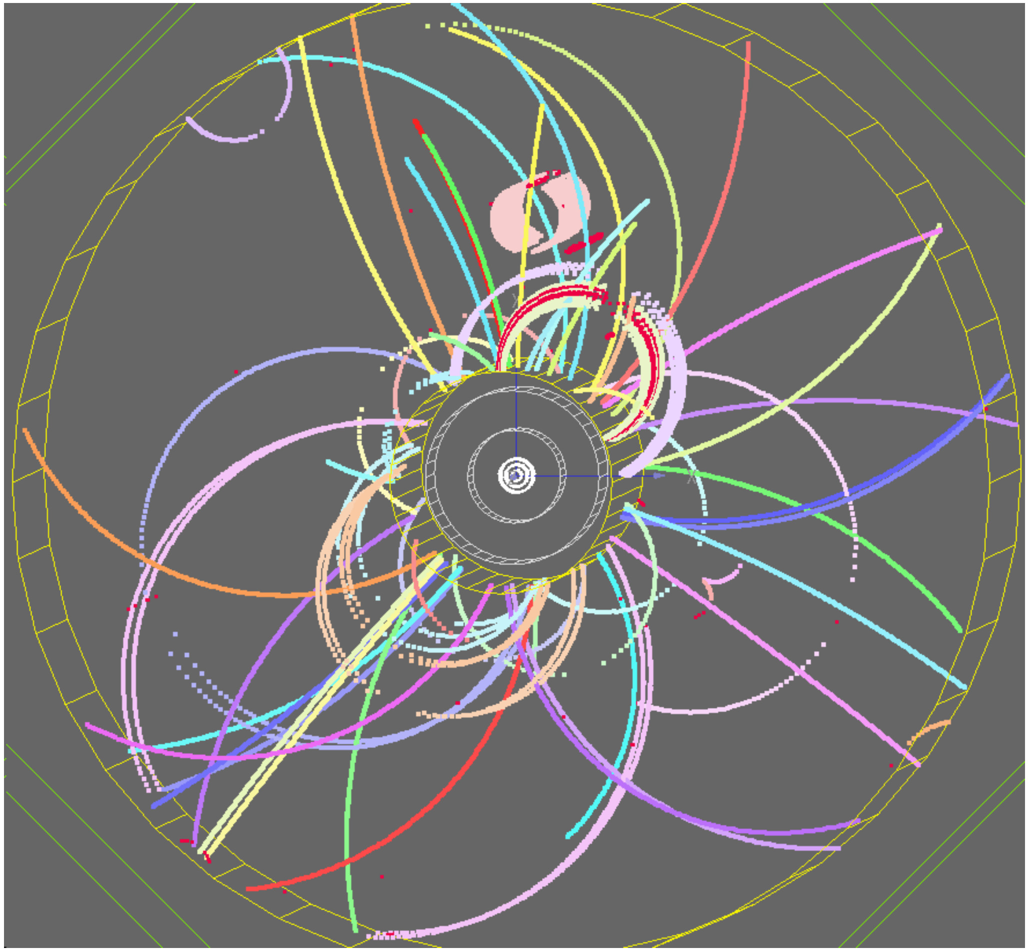
- repair split tracks:
  - **identify incomplete track segments** that:
    don't start at the inner field cage and/or that don't end at the outer field cage or endplate
  - **merge segments that have consistent tracks states** (based on delta chi2 after hits are added)
- problem mostly due to double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



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

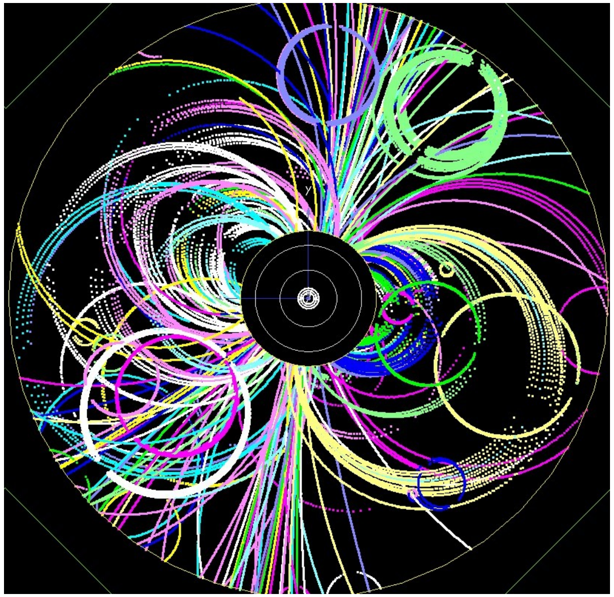
Clupatra TPC pattrec – step 4

- **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:

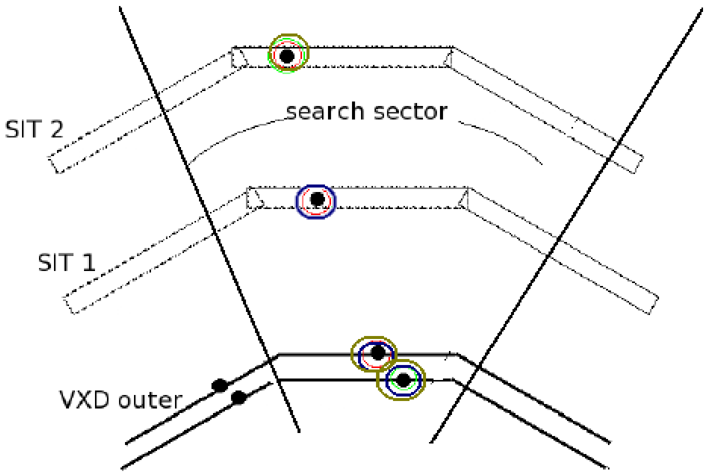


SiliconTracking FullLDCTracking S.Aplin

- existing algorithms re-implemented to use new MarlinTrk instead of old f77 fitter
  - adapted to use space points for the patrec and 1D hits for the fitting

- **SiliconTracking**
  - brute force triplet search in stereo angle sectors based on a set of seed-layer-triplets
  - road search based on helix fit
  - attach leftover hits
  - refit

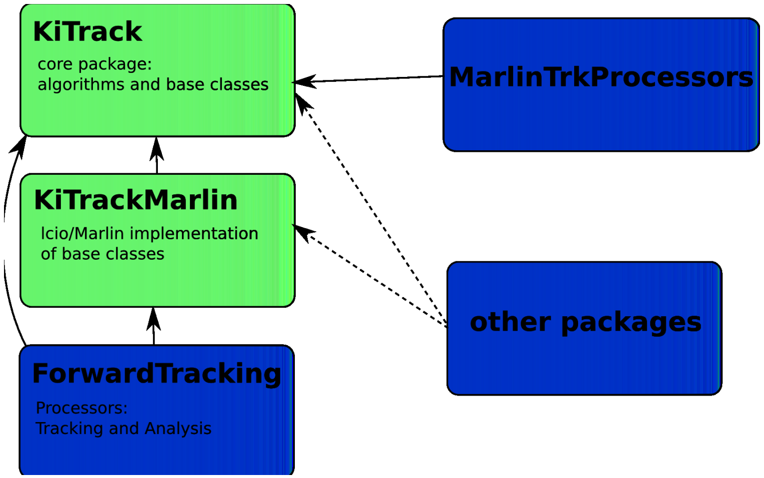
- **FullLDCTracking**
  - combines track from TPC - SiTracking - ForwardTracking
  - based on track parameter compatibility
  - adding spurious leftover hits
  - final track fit

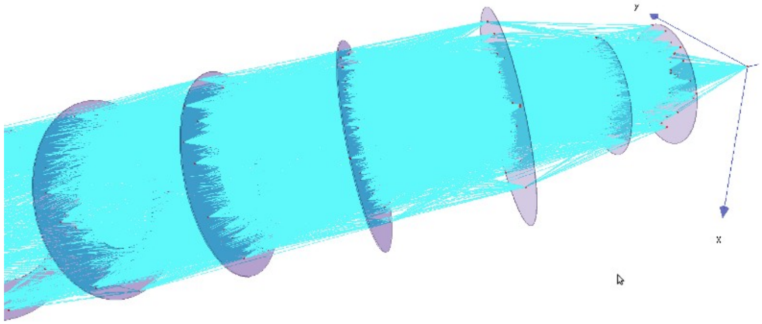


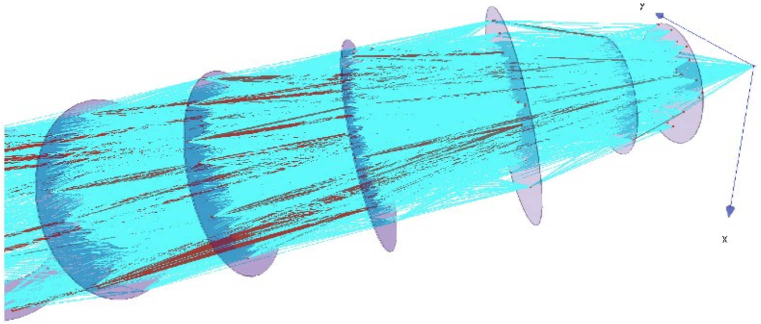
ILD forward tracking

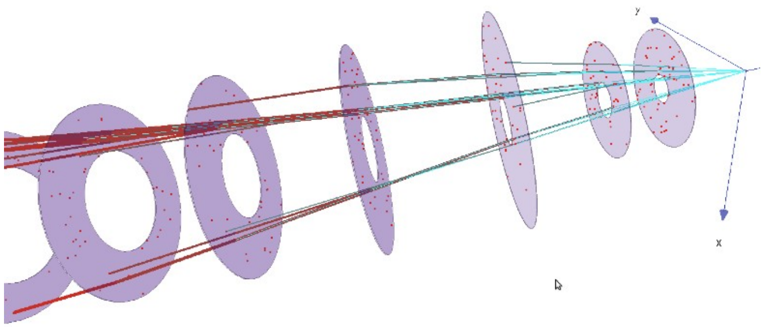
R.Glattauer

- **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









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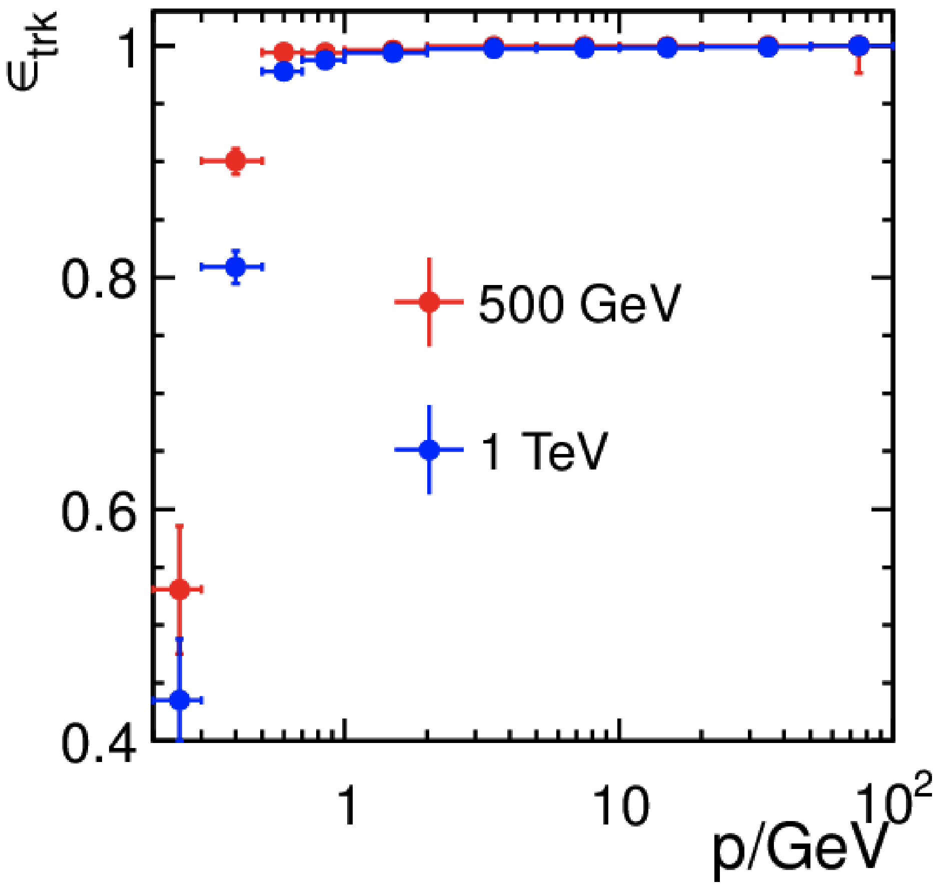
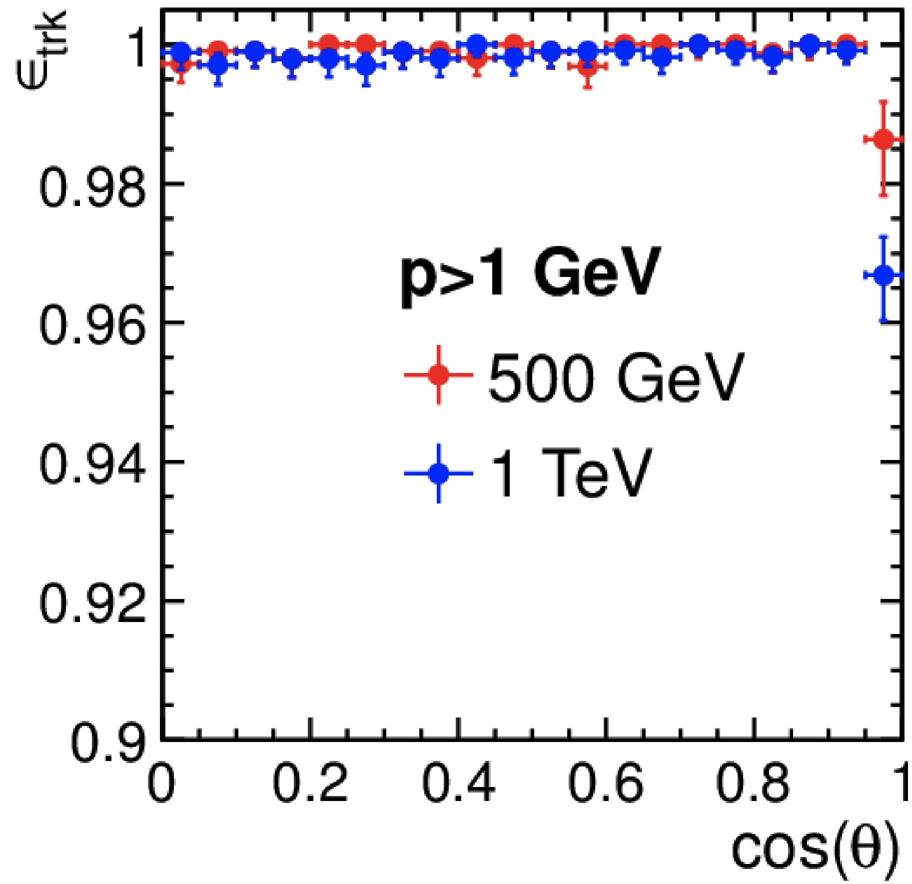
Combined ILD Tracking Efficiency





- ee->ttbar events: primary particles from within 10 mm of IP
- that leave at least 4 hits in detector and reach the calorimeter
- included full background from incoherent pair production - O(10e6) hits in VXD !

$$\epsilon_{trk} > 99.8\%, \quad p_{trk} > 1GeV, \cos(\theta_{trk}) < 0.95$$

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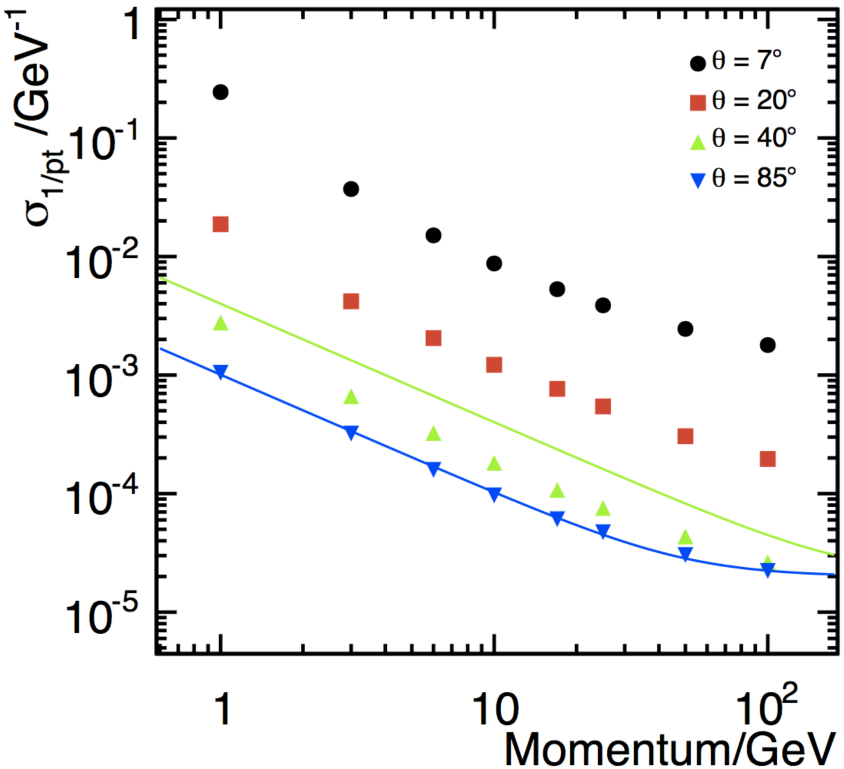
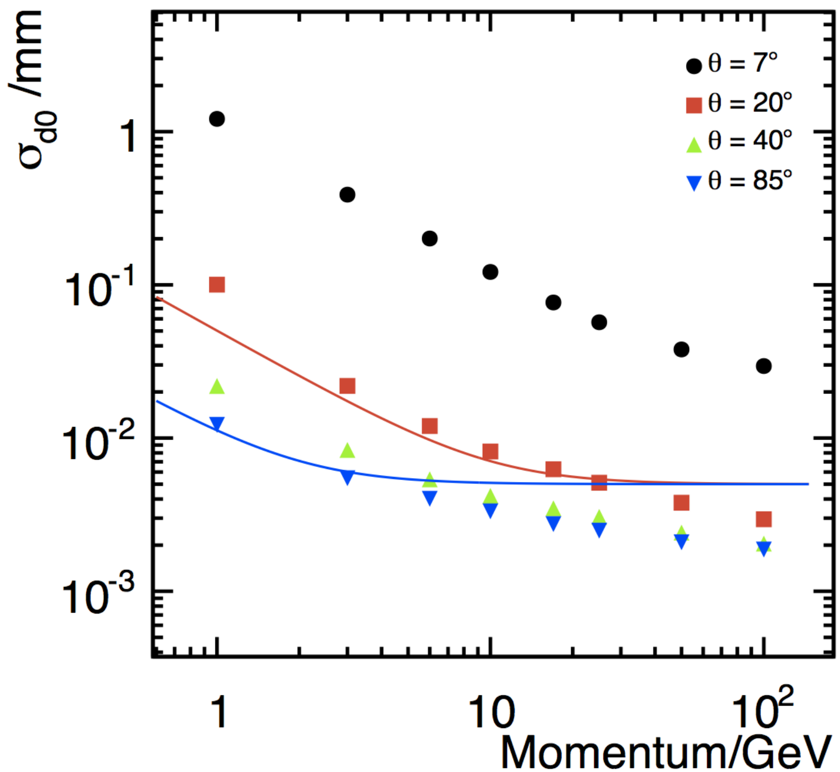
Resolution of ILD tracking



$$\sigma_{1/p_T} = \frac{2\times10^{-5}}{GeV} \oplus \frac{1\times10^{-3}}{p_T \sin\theta}$$



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

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single muons:

transverse momentum and impact parameter resolution as function of momentum

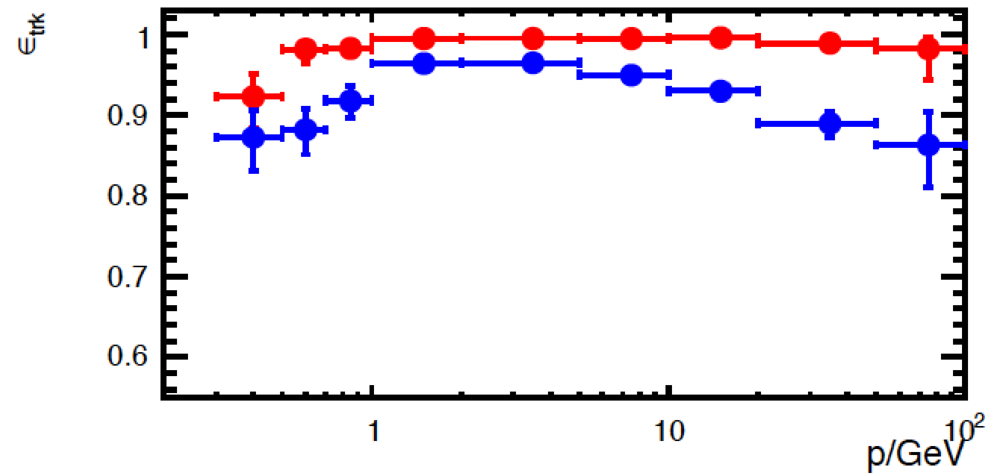
-> achieve design goal for ILD

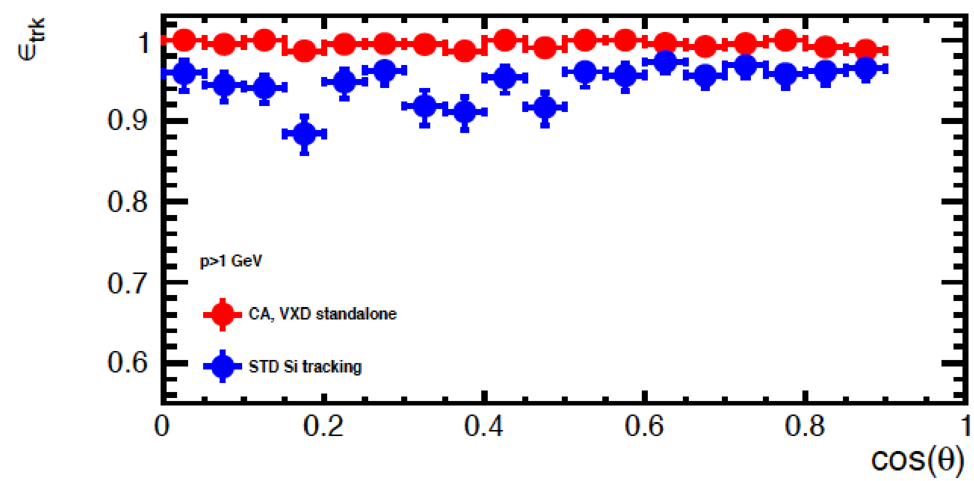
Current Work

Y.Voutsinas

- ILD has achieved its performance goals for the tracking system
- yet there is always room for improvement - in particular for the standalone Si-Tracking:
  - CPU needs with pair background
  - efficiency for low pt tracks

- application of Cellular Automaton code to central Si-Tracking shows
  - very much improved efficiency :-)
  - at increased CPU cost :-(
- next steps are to work on smarter track seeding in outer Si layers to reduce CPU needs
  - some first promising results
  - ongoing work ...





tracking efficiency for standalone Si-Tracking with old and new algorithm based on Cellular Automatons

Summary & Outlook

- ILD has developed new C++ tracking software with
  - quite realistic simulation including gaps and dead material
  - standalone pattern recognition in the TPC, central Si-Trackers and forward region, eventually combined into complete tracks
  - achieved tracking goals for ILD with excellent efficiency and resolution
    - delta(1/pt)->2*10e-5 GeV^2, e = 99.8% for p>1GeV and cos(th)<0.95

- Ongoing and future work
  - improve CPU performance and efficiency for low pt tracks in standalone Si-Tracking
  - provide *generic tracking toolkit* based on recent work in the context of AIDA WP2