Vertex and track reconstruction in the ATLAS Inner Detector

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On behalf of the Inner Detector software group

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Vertex 2006, Perugia

Contents

- The ATLAS Inner Detector
- Where we are coming from concerning tracking software

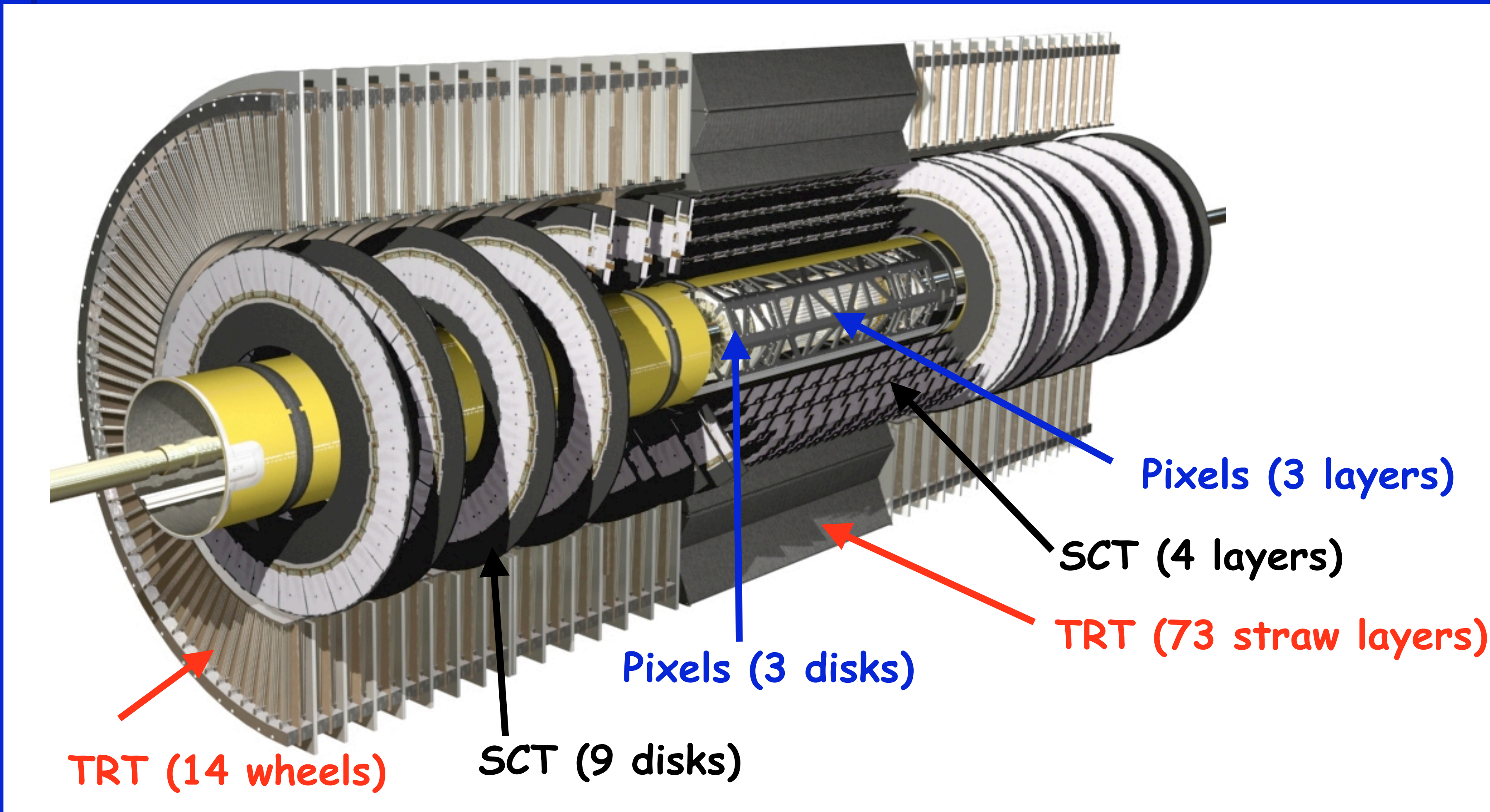
- Inner Dectector reconstruction

  - General flow and Event Data Model
  - Detector description
  - Track extrapolator
  - Tracking algorithms
  - Track fitters
    - Electrons as an special case
  - Vertex reconstruction
  - Trigger

- Commissioning with real data:

  (See as well J. Carter talk about commissioning the tracker and P.Bruckman about Alignment)
- Conclusions

ATLAS Inner Detector



Where we are coming from …

- < 2003: 2 tracking algorithms with incompatible data models:
  - iPatRec: well-tuned inside-out track search with global χ^2 fit
  - xKalman: flexible track search using a combinatorial Kalman Filter fitter

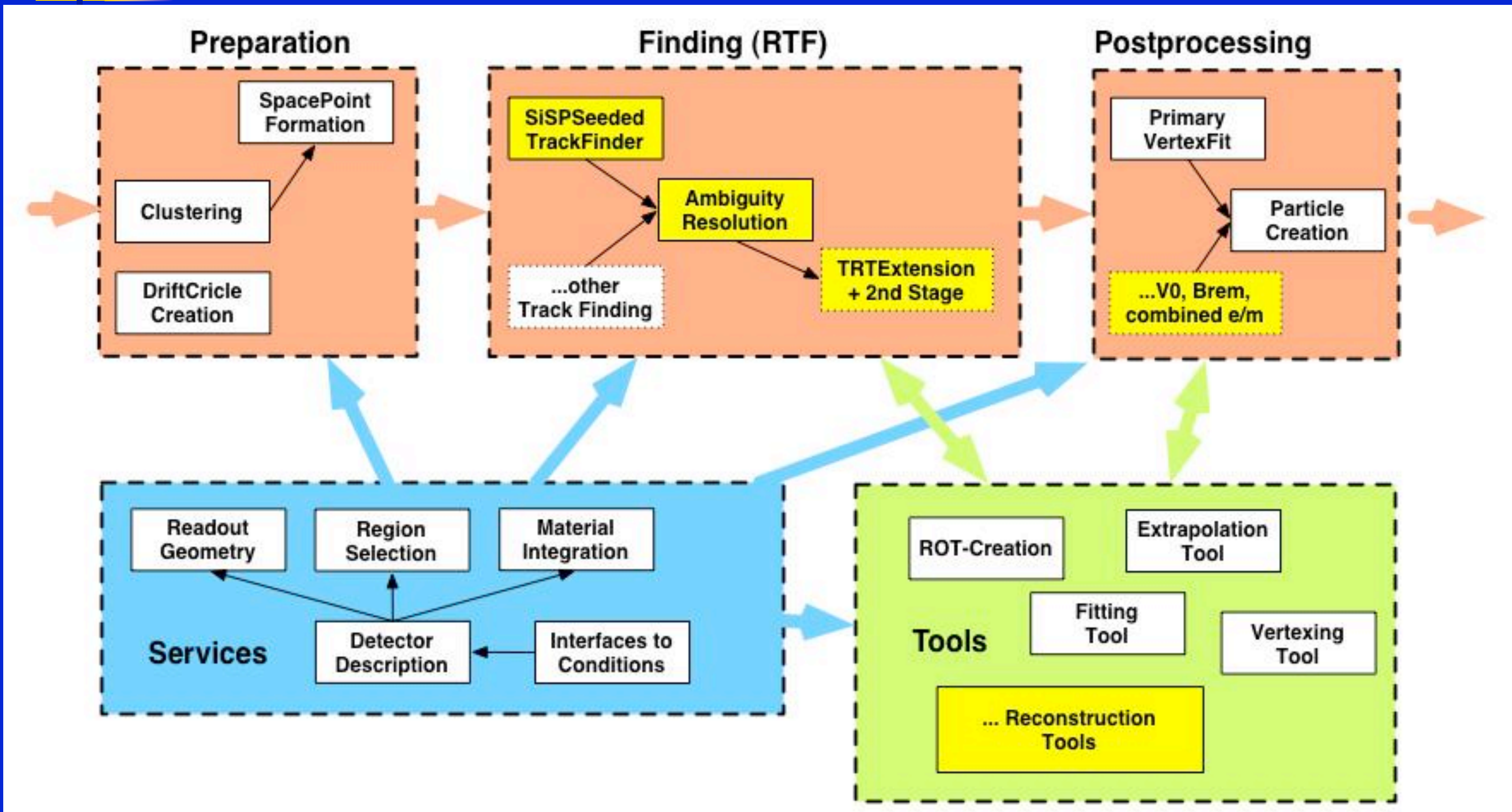
  Both packages were well functional according to physics requirements

- Internal software review in 2003: recommends a re-design:
  - High flexibility (more modular design)
  - Maintainability
  - Common data model, structure and framework
  - State-of-art algorithms

New model and migration to this model starts end 2003!

- Commissioning with real data started in 2004:
  - Combined test beam 2004 (used as an early testbed)
  - Cosmic runs:
    - Combined SCT+TRT barrels at the surface May 2006
    - Pixels endcap A: October 2006
    - Combined SCT+TRT endcap C: mid Nov 2006
  - Cosmics, beam-halo and beam gas events in the pit with other detectors.

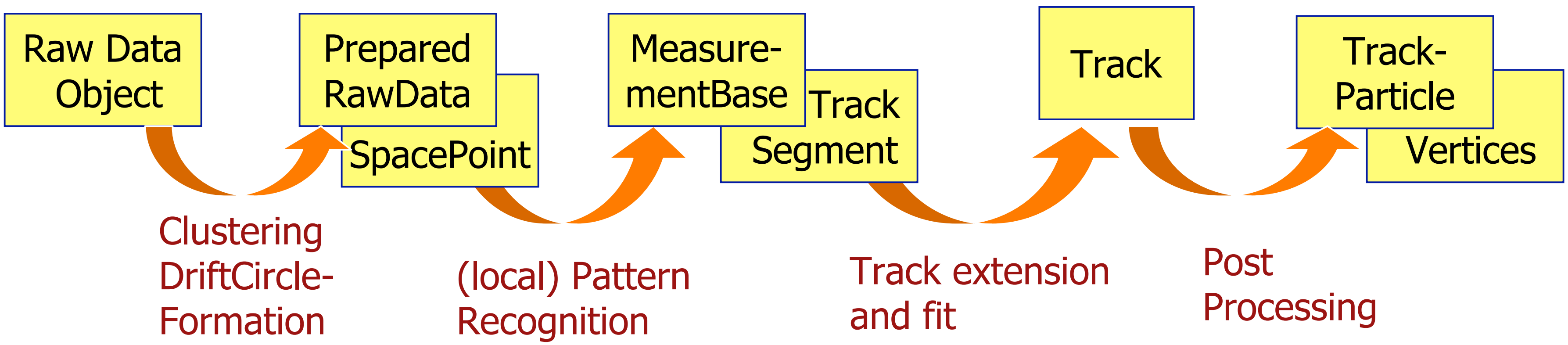
Reconstruction software

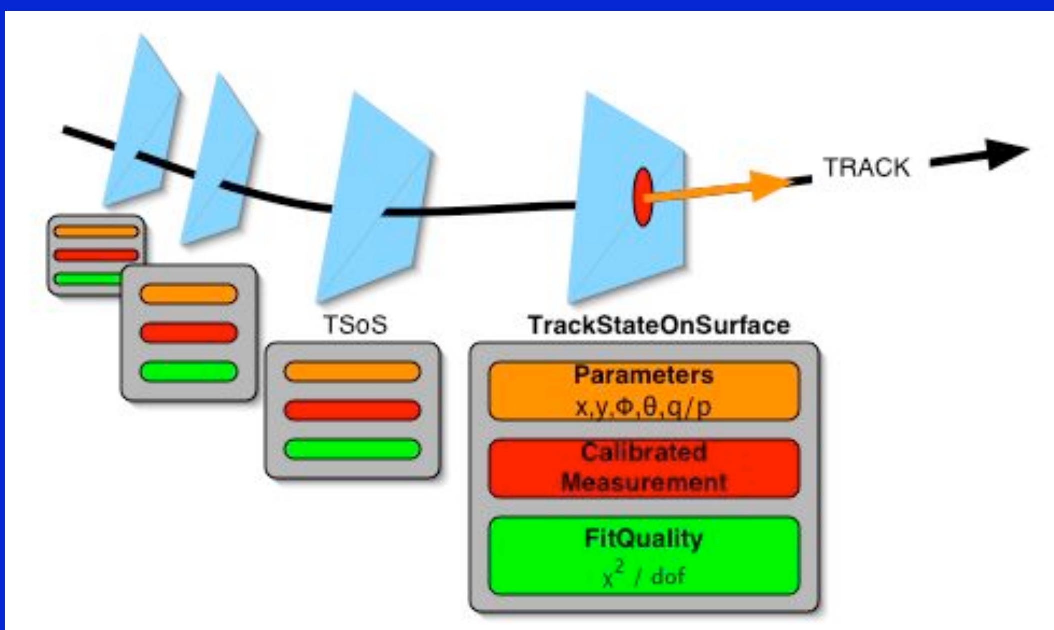


- Common abstract interfaces for all algorithms
- Common Event Data Model.

Reconstruction software

New Event Data Model (EDM)



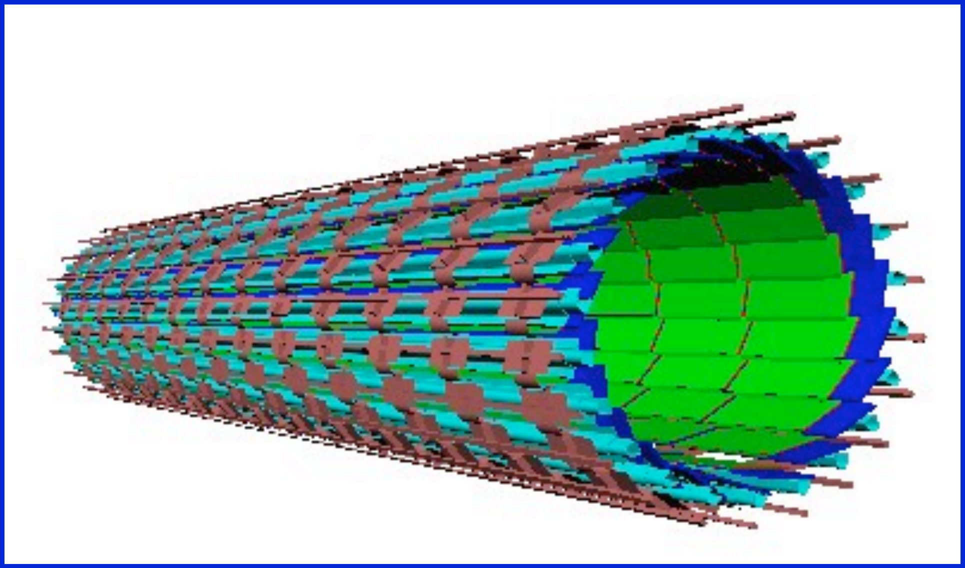


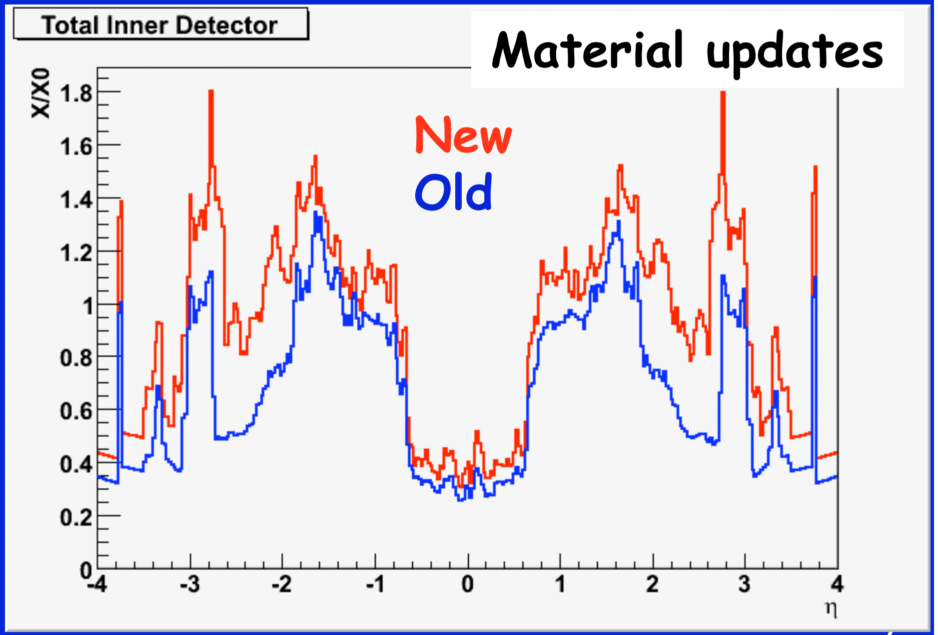
- Common for Event Filter and offline.
- Common tracking EDM defines detector independent EDM base classes
- Concrete implementations exist for all muons and Inner Detector sub-systems (common tracking tools)

Detector description

- Detector description (GeoModel) is a common source for:
  - Geant4
  - Digitization
  - Reconstruction
  - Tracking geometry

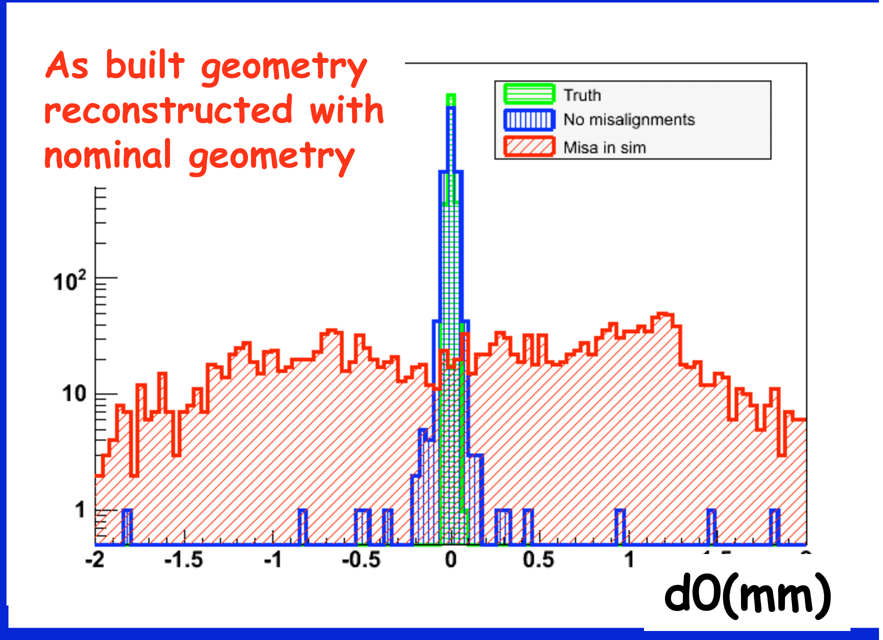
- Recently, a lot of work to get a more realistic description and a better estimation of the material (items are being weighed)





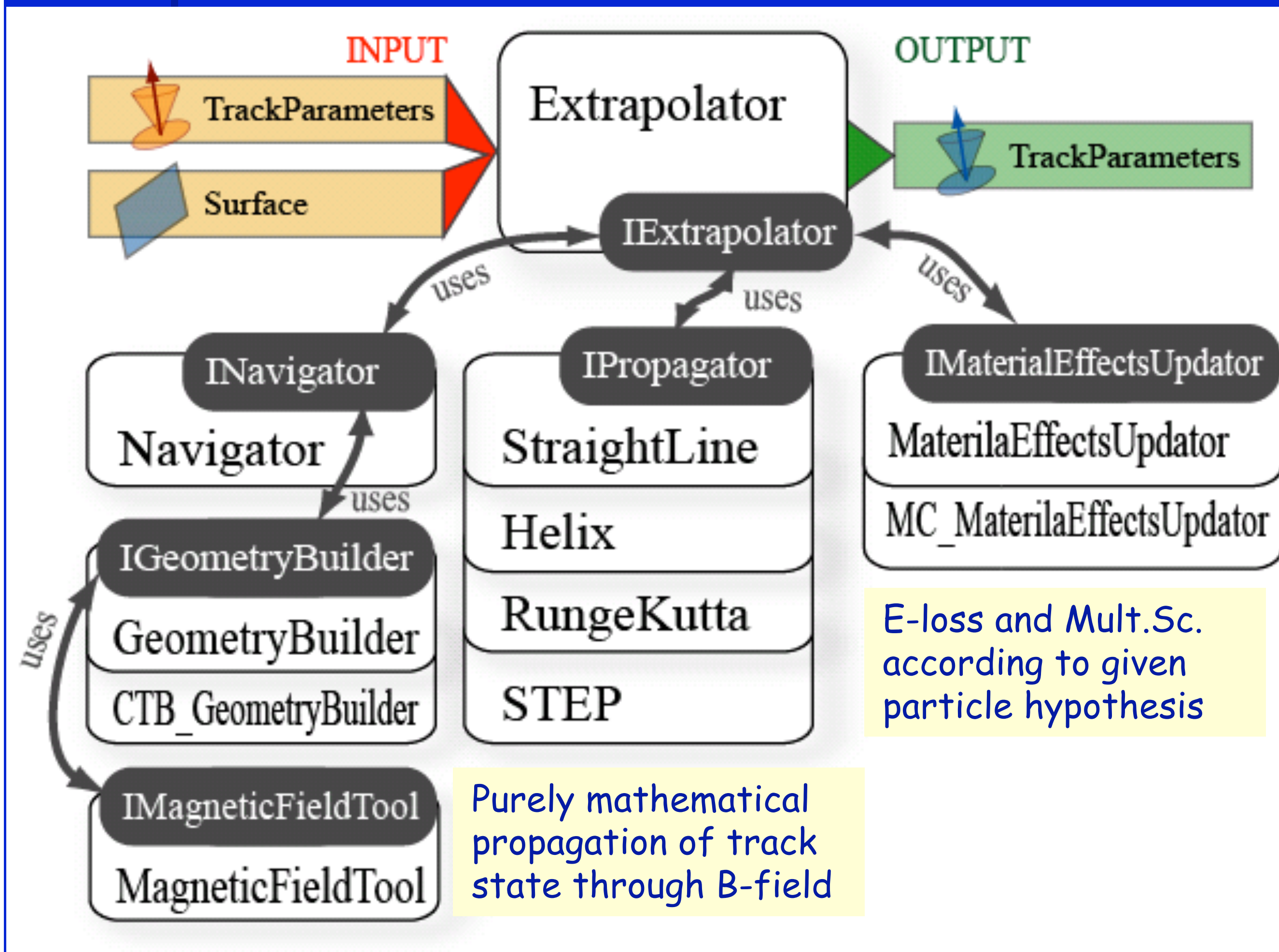
Detector Description

- Next CDC (Calibration Data Challenge):
  - Simulate with:
    - Increased material by conservative estimates in half of the detector (ID material is required to be known with a precision of 1% for the W mass measurement, also important for calorimeter calibration)
    - Misaligned geometry and shifted/tilted magnetic field
  - Reconstruct with nominal detector description and magnetic field, then align and calibrate

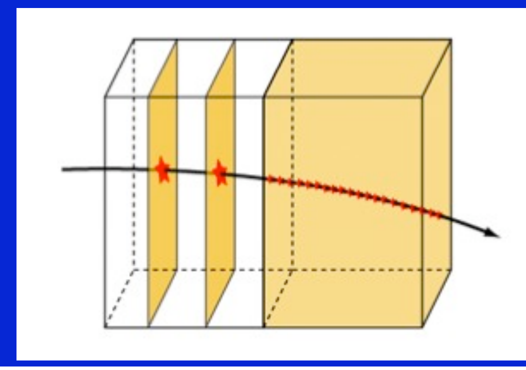


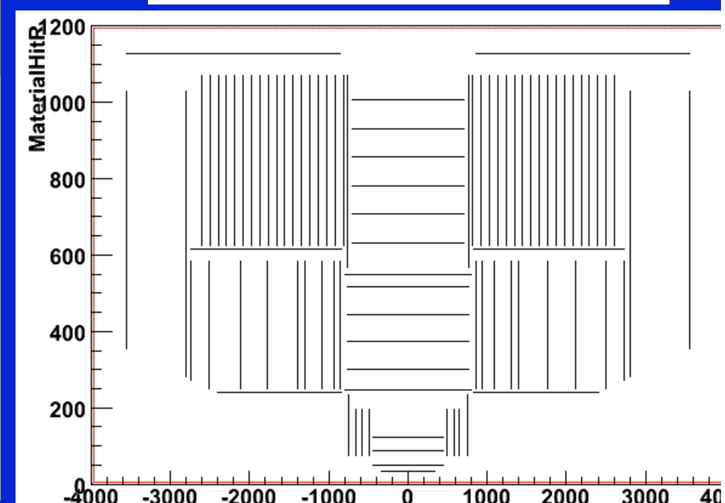
- Misalignments possible at 3 levels (subsystem, layer/disk, module) in both simulation and/or reconstruction
- Alignment constants: Rigid module transforms applied in detector description
- Fine corrections (as distortions) plan to apply then in reconstruction and digitization
- The infrastructure to add material distortions is also in place

Extrapolator Tool



It uses a simplified reconstruction geometry: (fully connective, fast navigation





Use a completely connective tracking geometry and extract material + B-field information.

Tracking algorithms

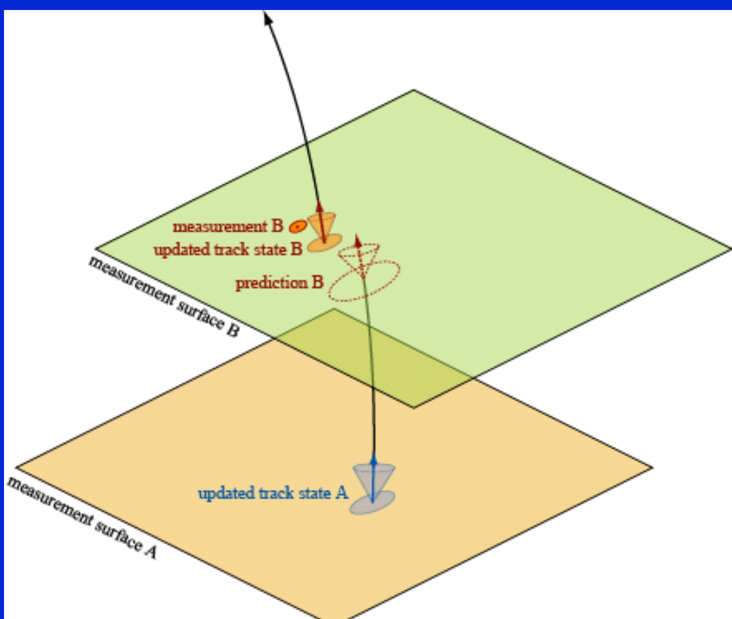
- Different algorithms have been integrated in the new framework.
- Standard pattern recognition strategy (inside-out) (pattern coming from xKalman):
  - Track candidate finding in Pixel and SCT using combinatorial Kalman Filter
  - Select good track candidates, full track fit and resolve ambiguities
  - Extend resolved tracks into TRT
  - Refit of extensions and replace original if better
- TRT seeded reconstruction (outside-in) also now in place:
  - Dedicated tracking for secondary particles
  - Test beam and cosmic reconstruction (in addition to inside-out)
- CTB pattern recognition (inside-out & outside-in): developed for the test beam and used also for cosmics

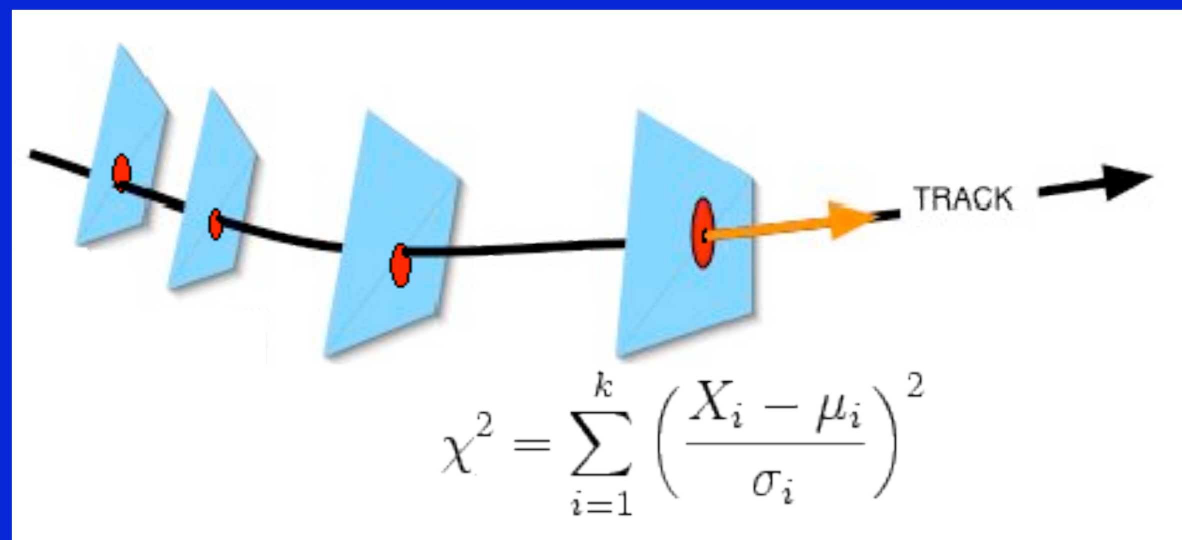
Track fitters

- Different fitter tools are available (abstract interfaces for the fitters).
- Classical fitters implemented:

Kalman Filter (KF) Default

Global Chi2 minimization

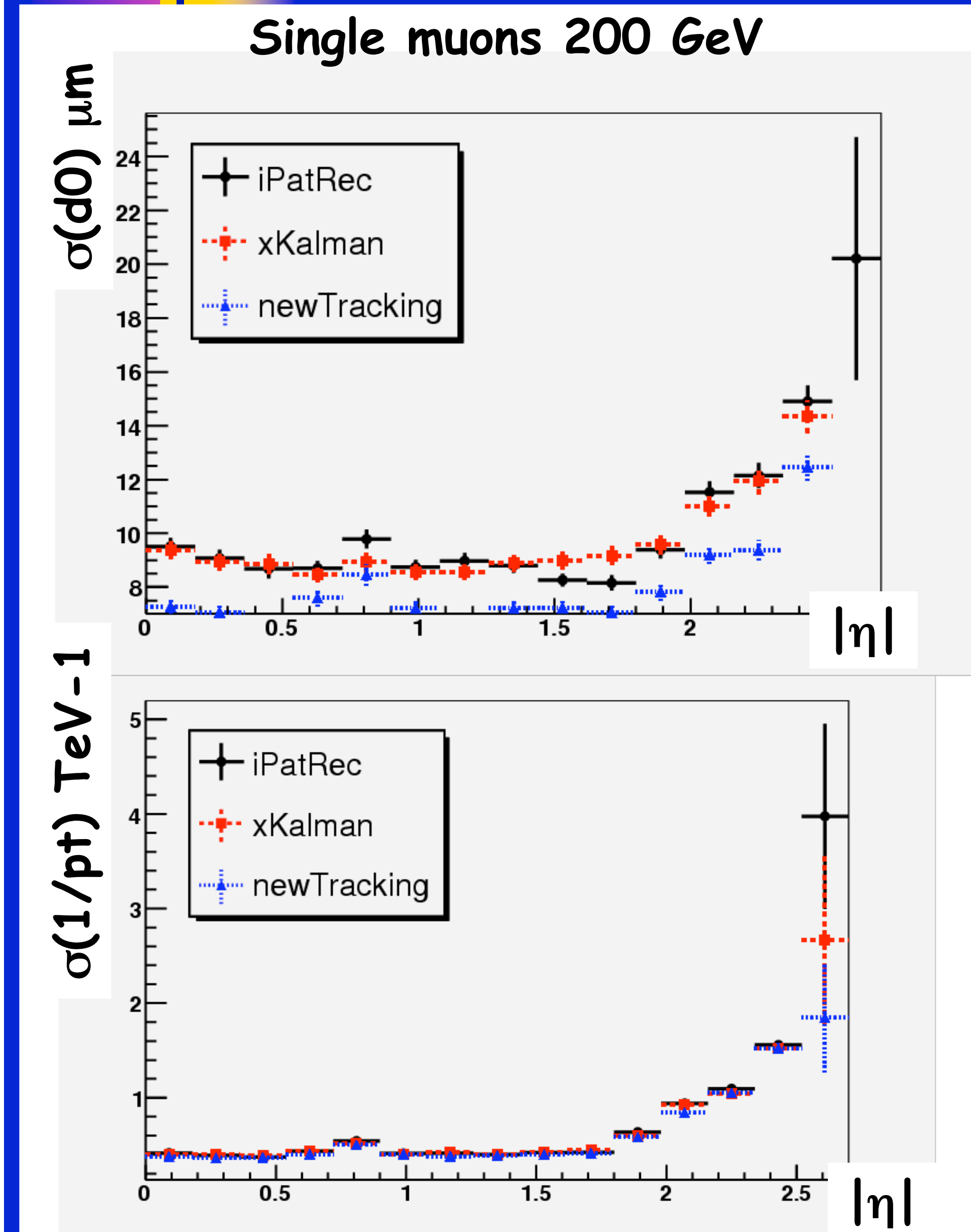


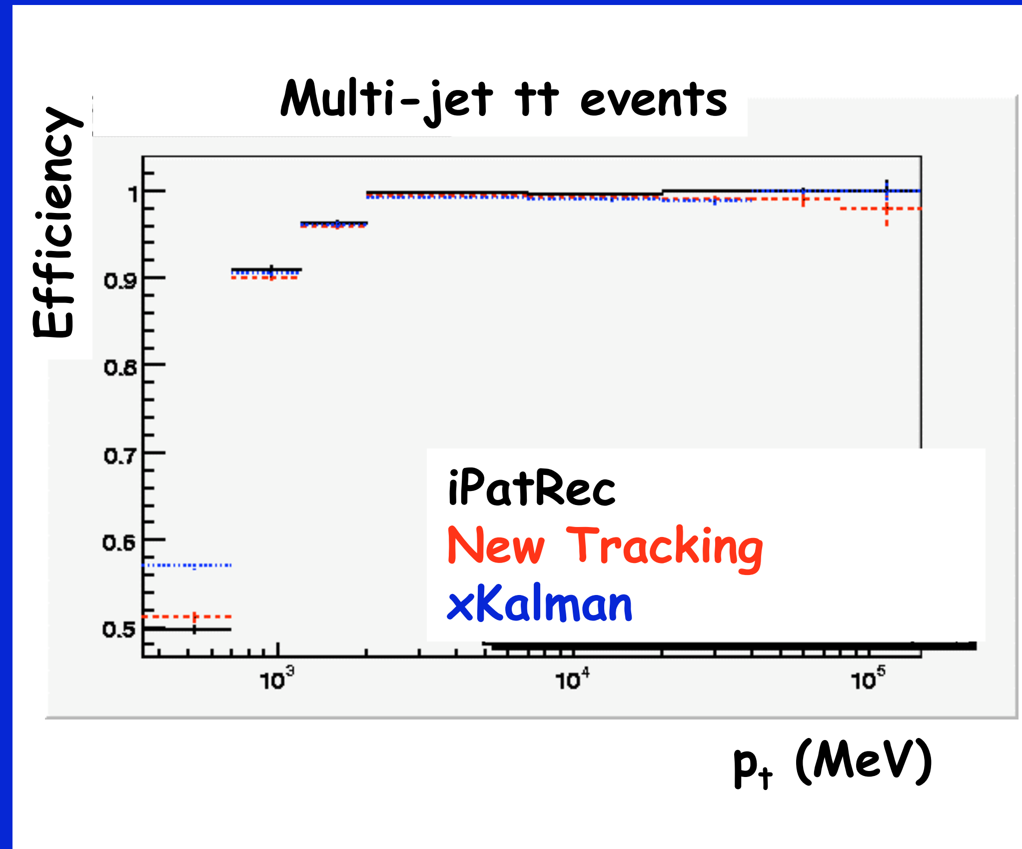


- Use the tracking geometry to take material effects into account taking as input a particle hypothesis

Tracking performance

Preliminary



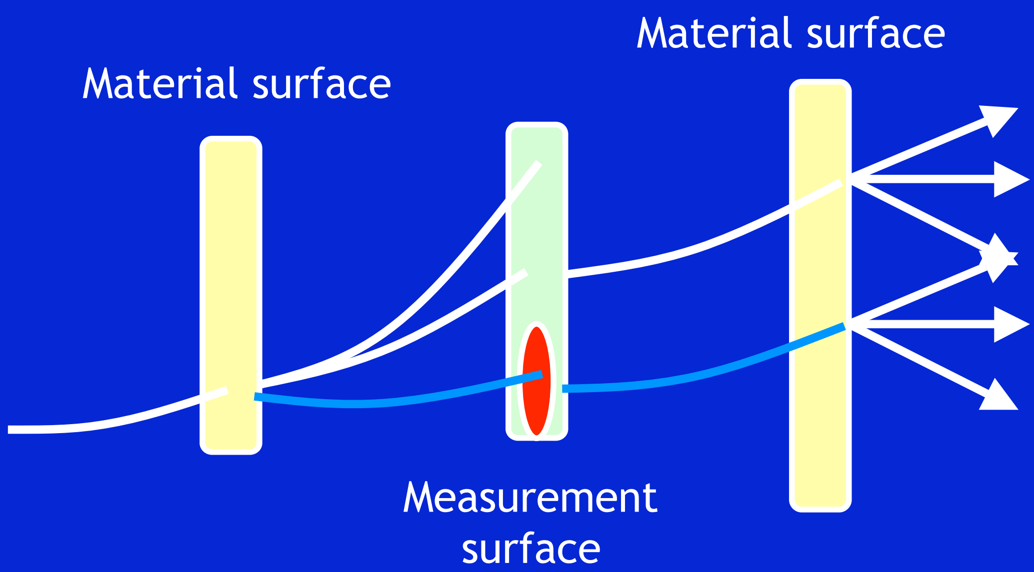


- The code implemented in the new tracking framework has reached similar performance level to the previous algorithms

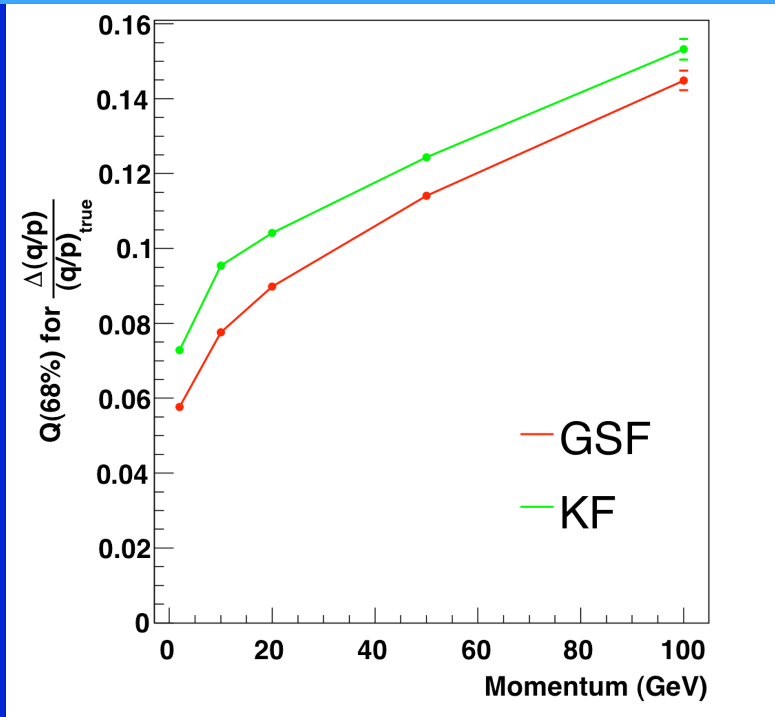
Specific fitters for electrons

Gaussian Sum Filter (GSF)

- The GSF is a generalization of the KF that models the asymmetry of the Bethe-Heitler distribution as a Gaussian mixture.
- It works as a series of Kalman Filters running in parallel



q/p resolution as a function of p



Specific fitters for electrons

Dynamic Noise Adjustment (DNA) in the Kalman Filter

- Used by the Kalman Filter to adjust the track momentum if a strong brem is detected

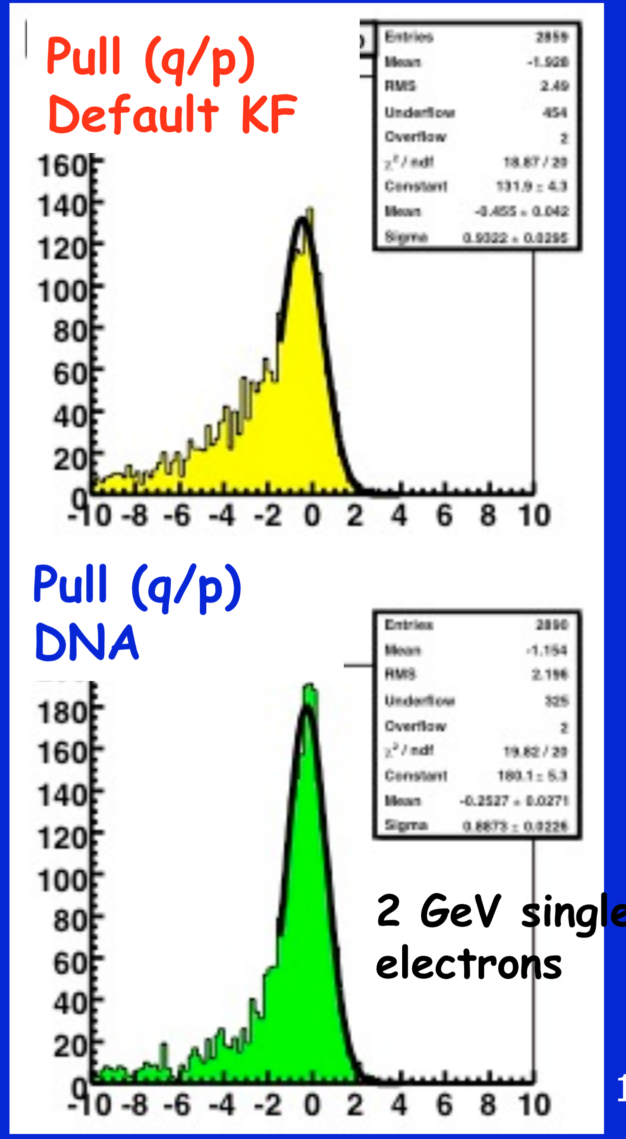
Procedure

- Algorithm to locate and flag hits which might be associated with strong brem.

- If so, estimate the fraction of energy z retained by the electron

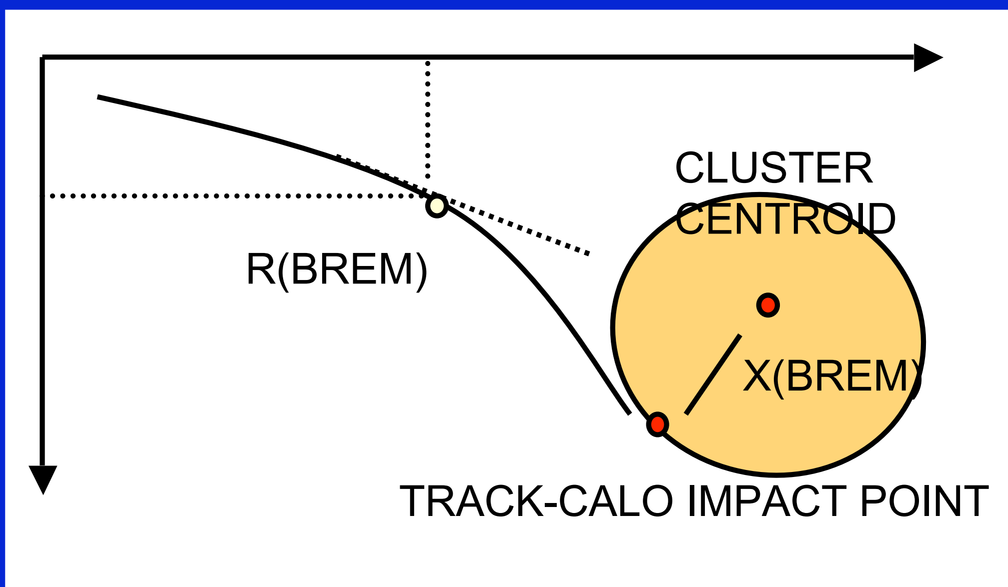
- Calculate the effective σ(noise) which matches the probability of such z

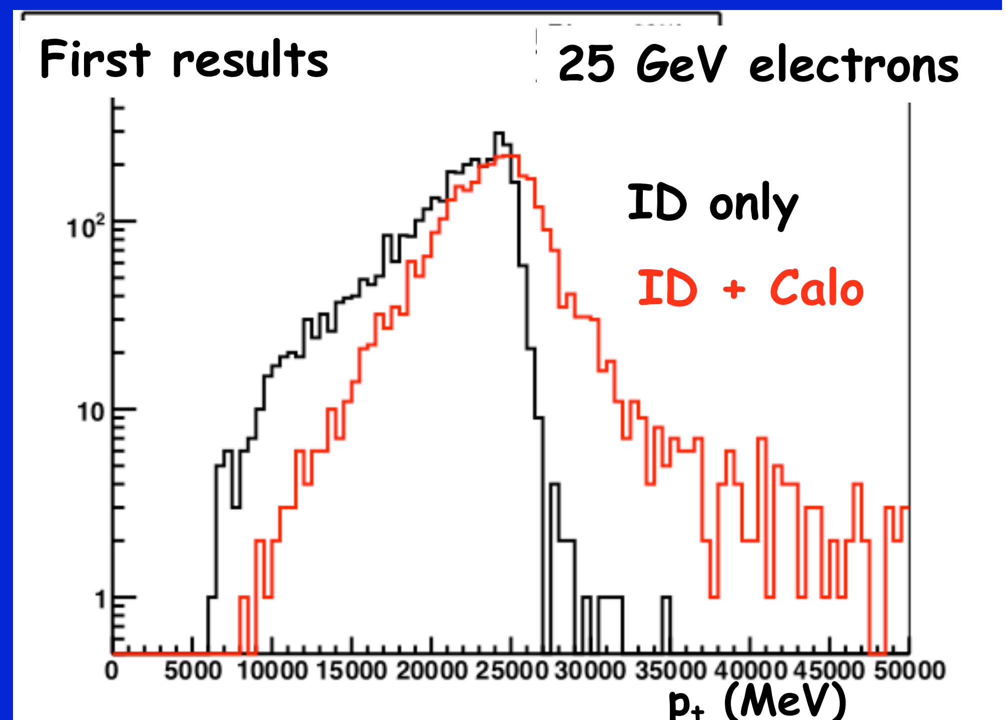
- Adjust the covariance matrix accordingly



Brem recovery using the EM calorimeter

- For higher p_t electrons the cluster position of the calorimeter can be used to improve the electron momentum measurement





Fit track with 7 parameters:
- 5 helix parameters
- 2 bremstrahlung (R, X)

Vertex reconstruction

- All methods try to minimize:

$$\chi^2 = \sum_{i=1}^{N} (\vec{q}_i^{\,meas} - \vec{F}(\vec{V},\vec{p}_i))^T W_i (\vec{q}_i^{\,meas} - \vec{F}(\vec{V},\vec{p}_i))$$

  - Global χ^2 (by an iterative method)
  - Kalman Filter
  - Adaptive vertex fitter (based on a deterministic annealing filter)
  - Adaptive multivertex fitter (dynamic assignment of tracks to vertices)

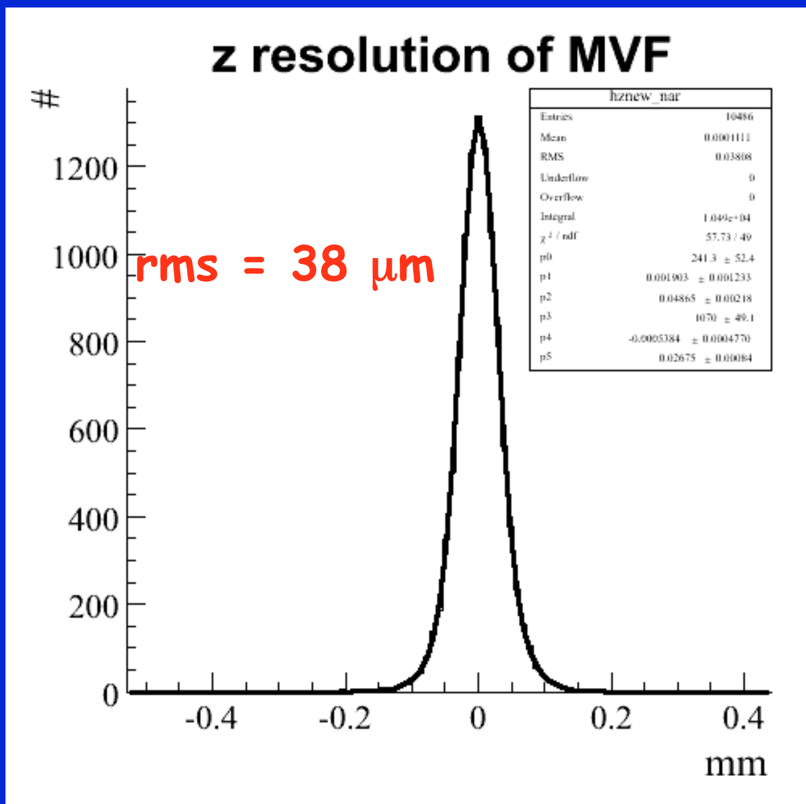
- 2 ways of obtaining unbiased estimator of the vertex are used:

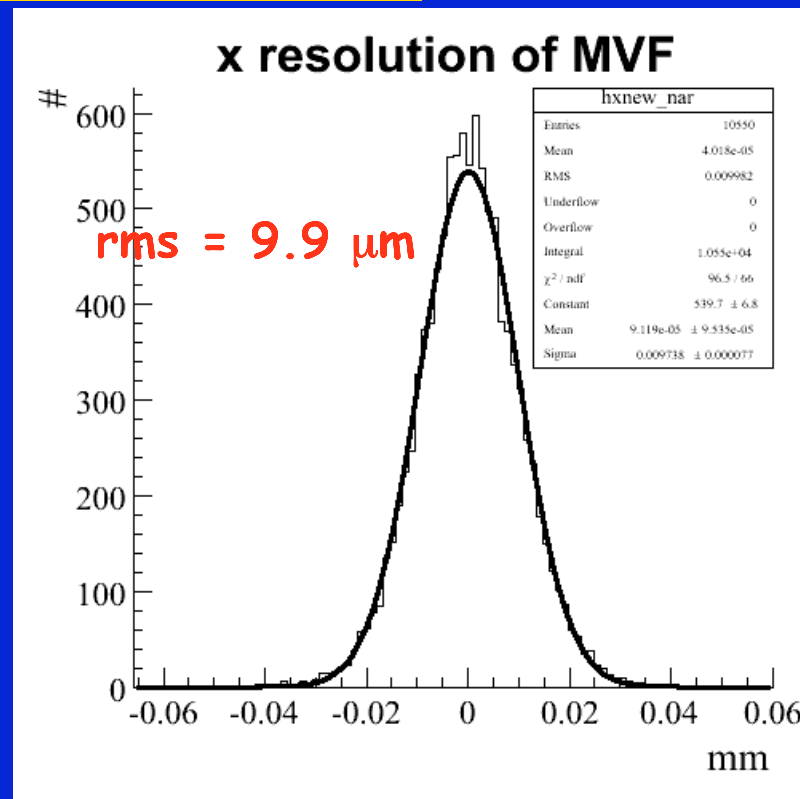
  - (1) Iteratively remove tracks incompatible with the actual vertex and fit again (used by global χ^2 and Kalman Filter)
  - (2) Weight the track contribution to the chi2 with the estimated "a priori" probability of that track to belong to the vertex to fit (used in adaptive fitter)

Vertex reconstruction performance

Primary vertex in tt with pile up at low lumi

Adaptive Multivertex fitter (default)

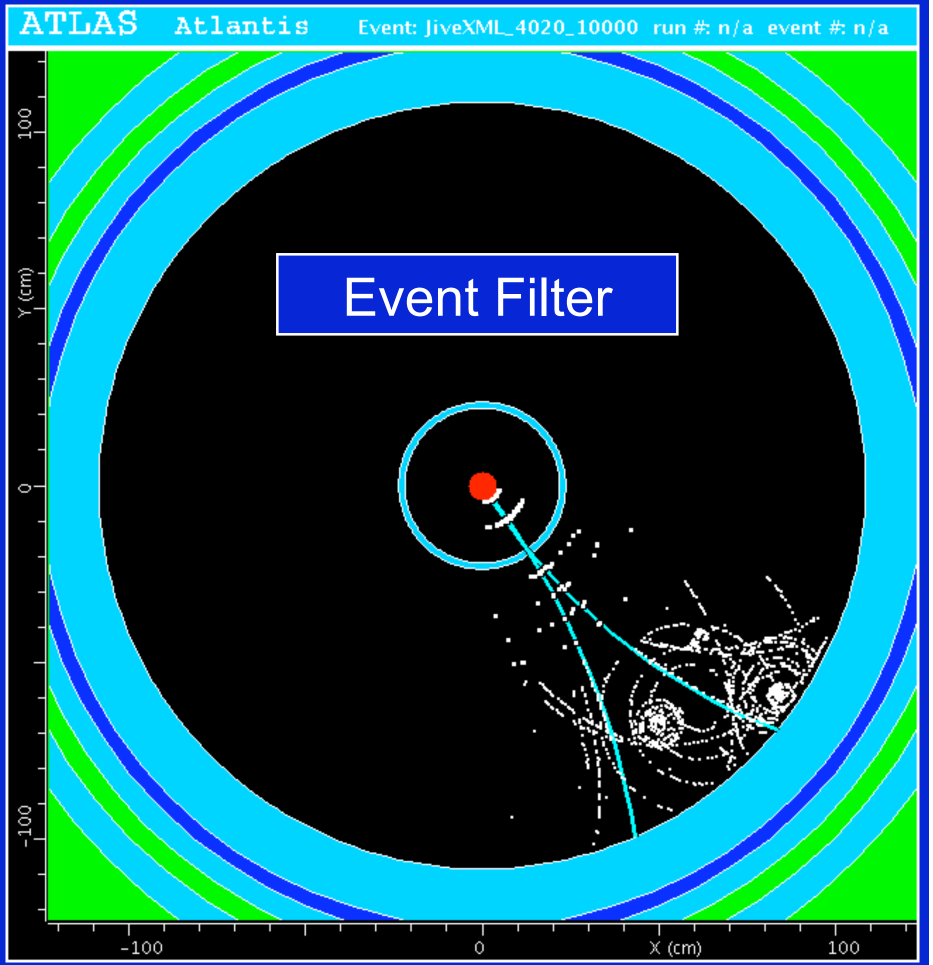




- Efficiency to find the right vertex: 99.5 %
- Efficiency for having the signal vertex among the fitted ones: 99.99%

Trigger reconstruction

- 2 different domains - Event Filter and Level-2
  - Timing budget ~1 sec vs 10 msec on equivalent 8 GHz Pentium 4
- Level-2 runs dedicated reconstruction software (some common code with offline)
- Event Filter is using same code as offline, but runs in seeded mode.



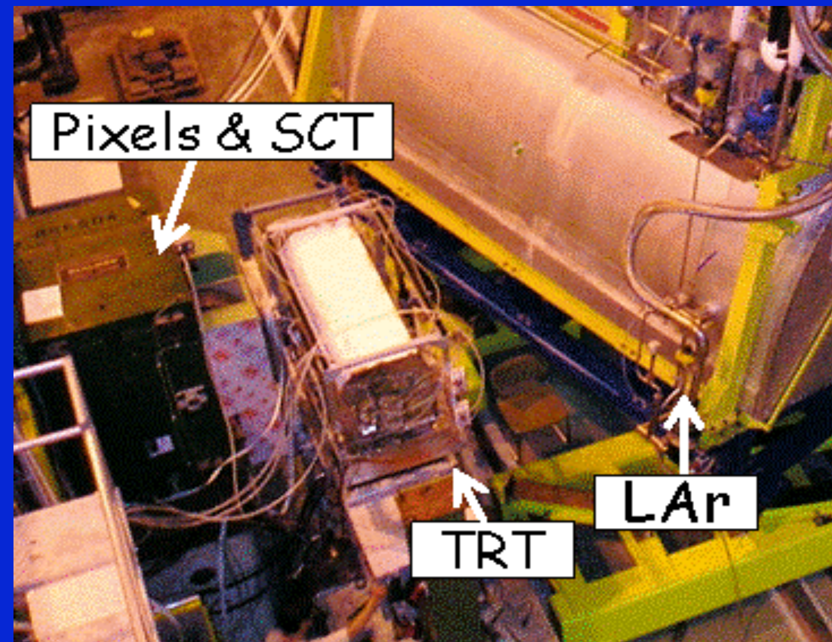
Full reconstruction time per RoI for 25 GeV electrons: **~ 94 ms (KF, KF+DNA)**
~ 213 ms (GSF)

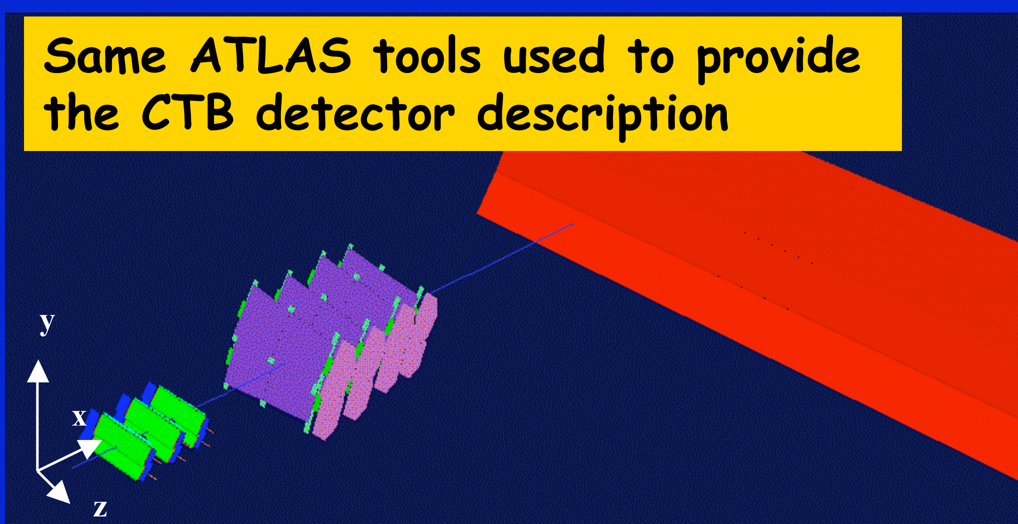
Commissioning with real data

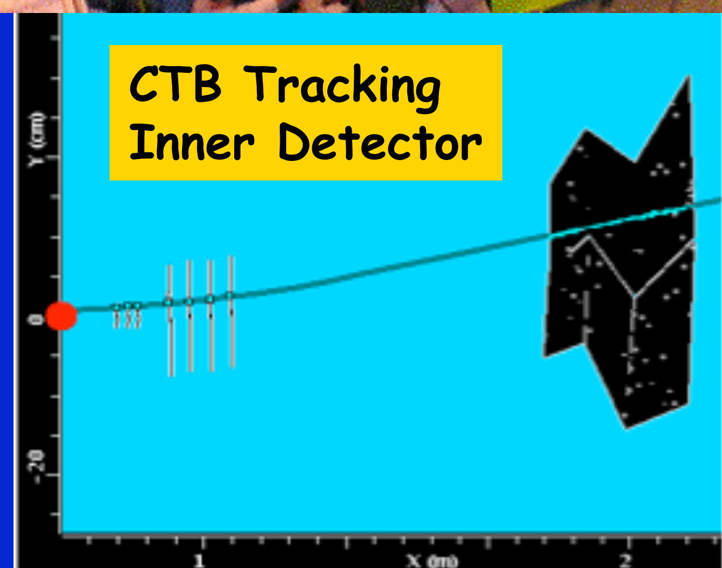
- The tracking software is being commissioned with real data:
  - Combined test beam in 2004 (full ATLAS barrel slice)
  - Cosmic runs at the surface (final detectors before installation in the pit, different configurations)
- Common software motivations for both tests:
  - Exercise the full reconstruction chain with real data
  - Real data means:
    - Realistic detectors (imperfections and misalignments)
    - Need to decode data
    - Need to deal with conditions data base (cabling, DCS, DAQ, calibration & alignment corrections)
    - Need monitoring during data taking
  - Study detector performance (efficiency, noise, resolution, etc)
  - Improve simulation
  - Get detector, DAQ, DCS, HLT, offline, … communities working together!

Combined test beam

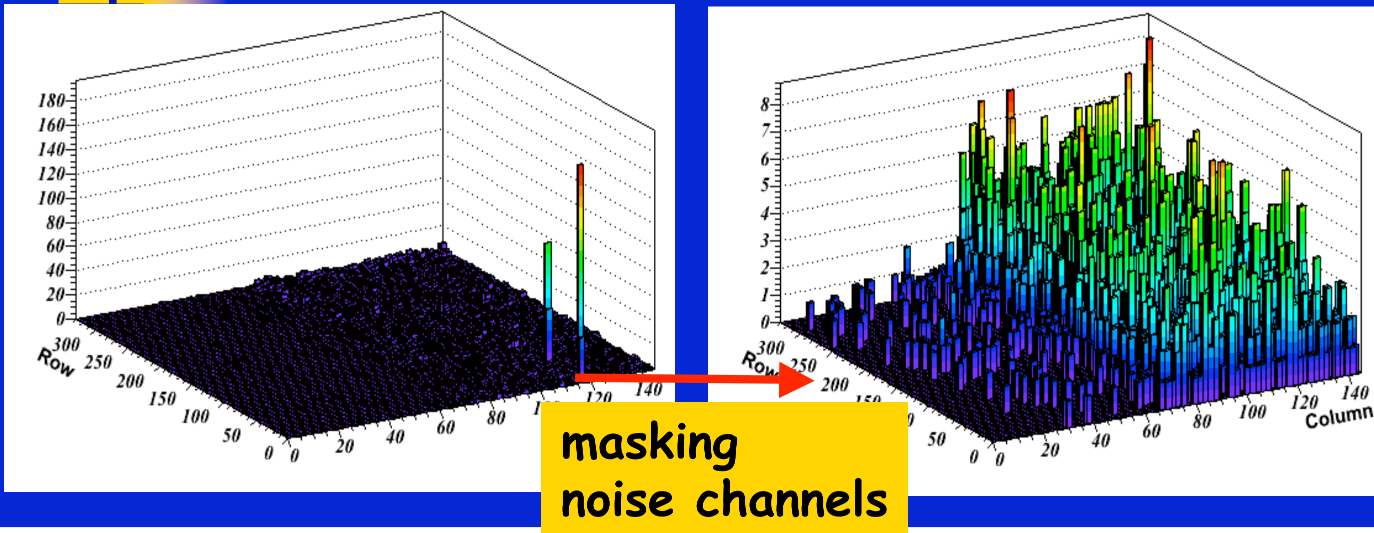
- 22.1 millions events taken with the full ID setup were validated by offline monitoring:
  - e^{+-}, π^{+-}, μ^{+-}, γ
  - E scan: 1 - 350 GeV
  - B scan: 0 - 1.4T
  - Additional material (η=1.6):
    - Pixels/SCT: 11% X/X0
    - SCT/TRT: 22% X/X0



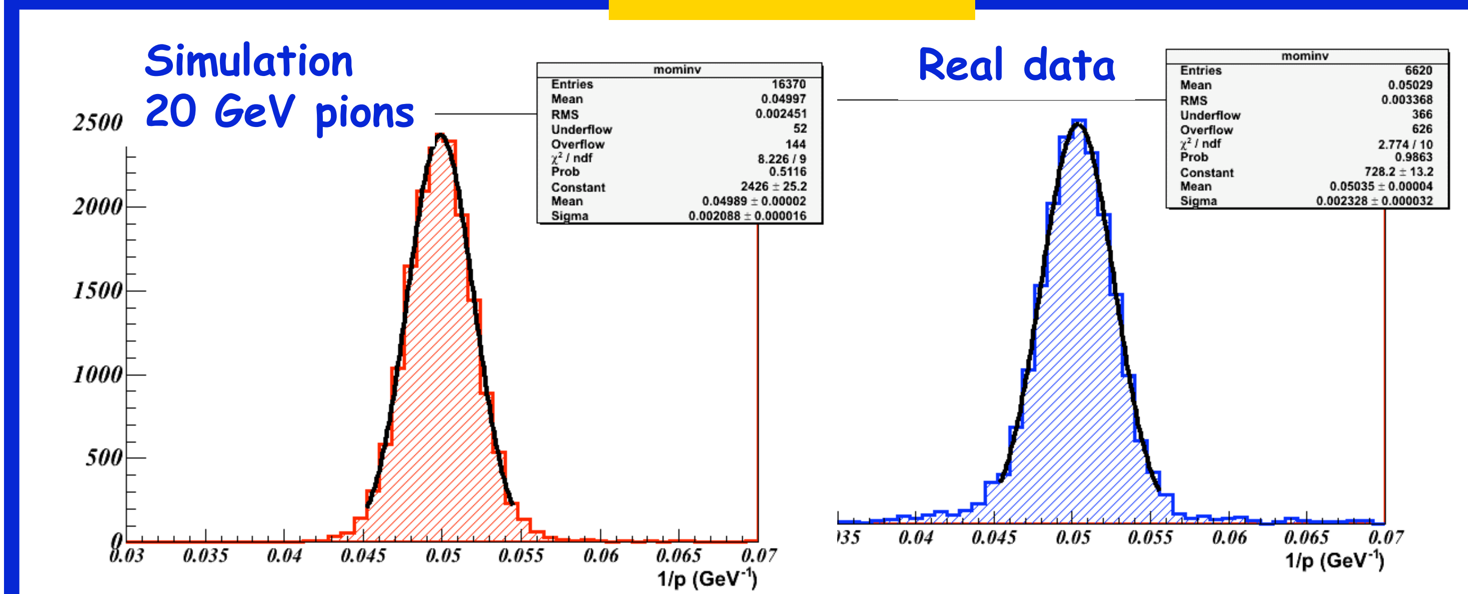




Combined test beam



Infrastructure to get bad channels, calibration and alignment corrections from conditions data base in place



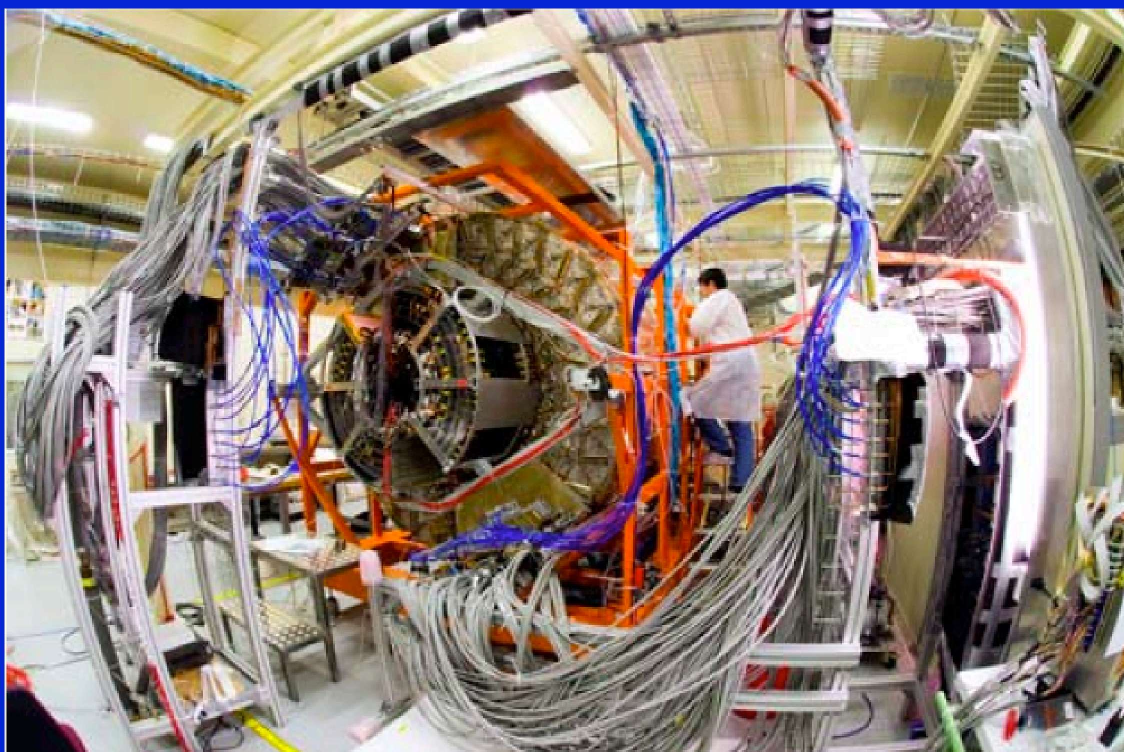
$\mu(1/p) = 0.050 \pm 0.002$ GeV^{-1}

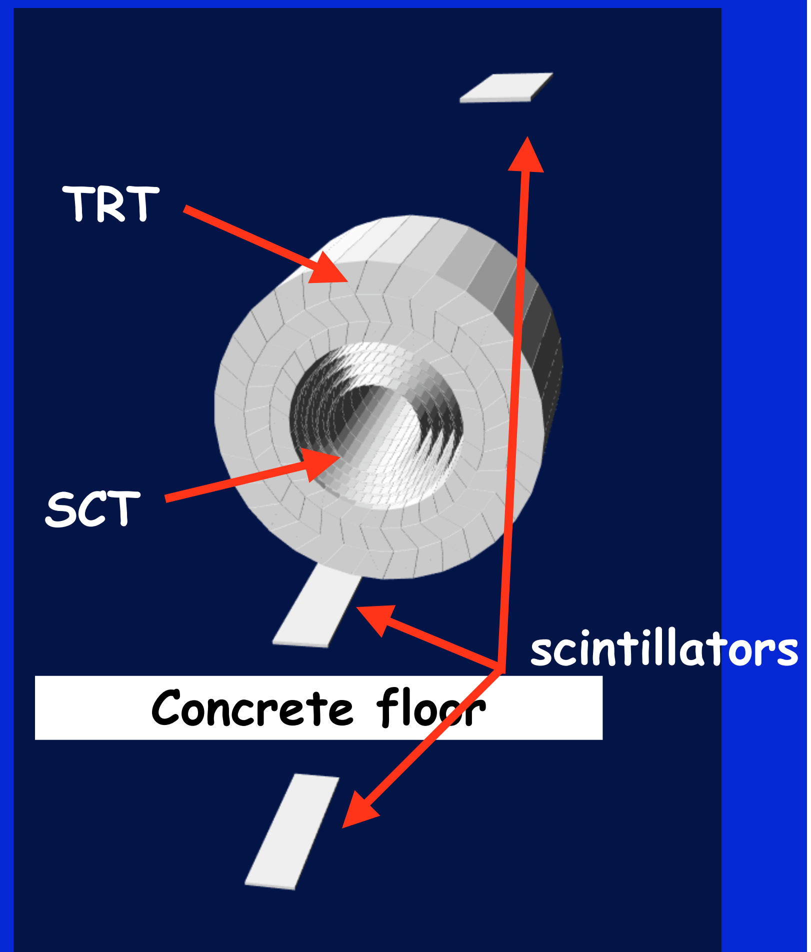
$\mu(1/p) = 0.050 \pm 0.002$ GeV^{-1}

Good data/MC agreement on the momentum resolution (after alignment!)

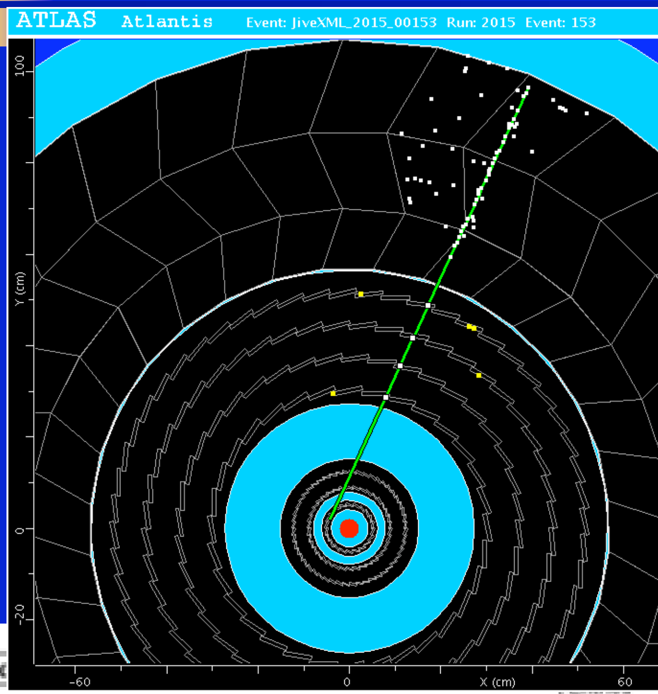
Combined cosmic run with SCT and TRT barre

- 1/8 TRT and 1/4 SCT cabled
- No B field → no material effects can be taken into account
- ~450K events recorded

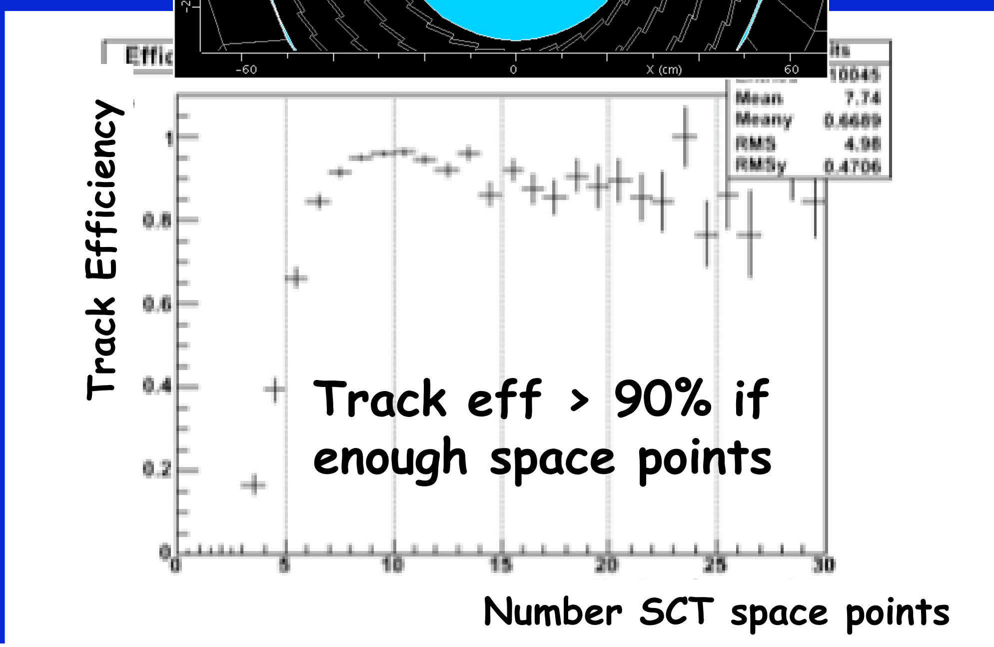


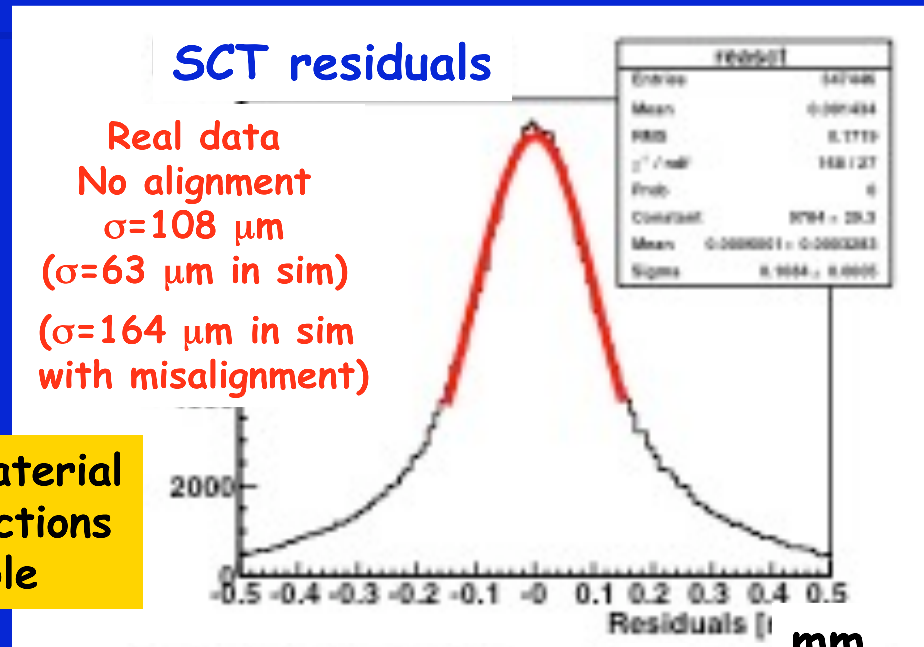


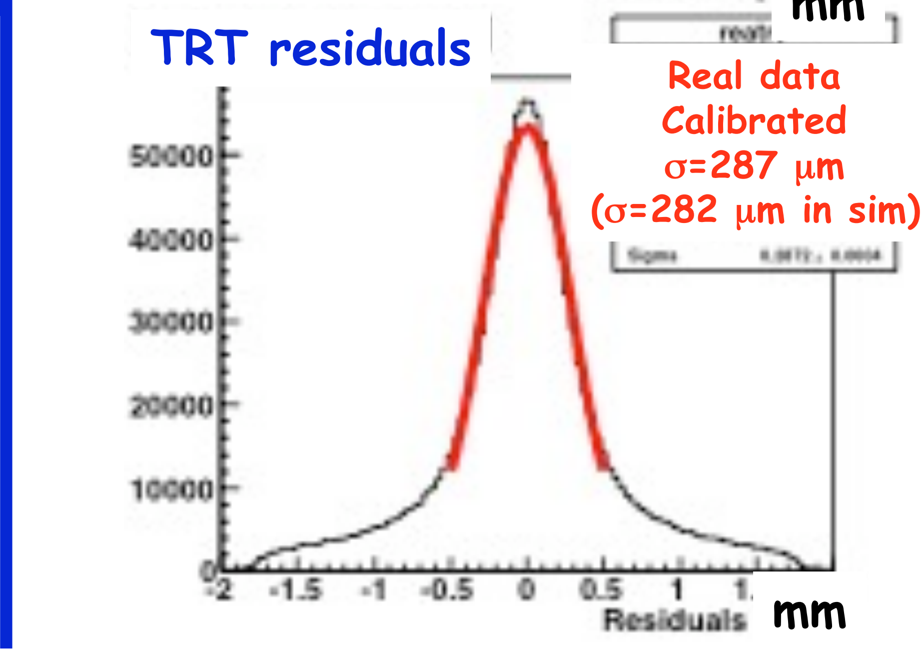
Combined cosmic run with SCT and TRT barre



No material Corrections possible

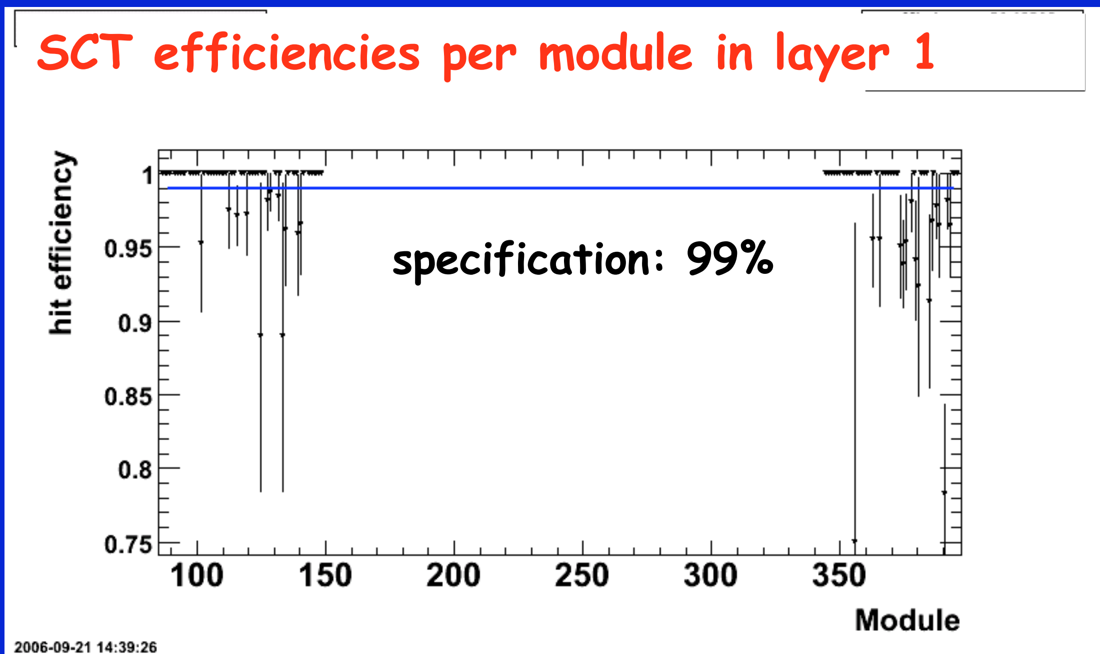


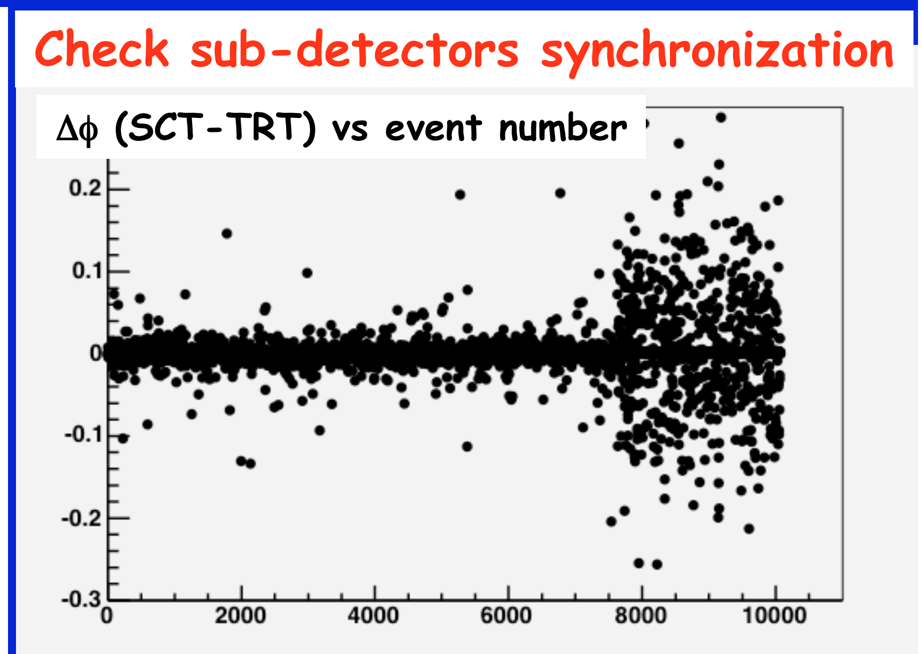




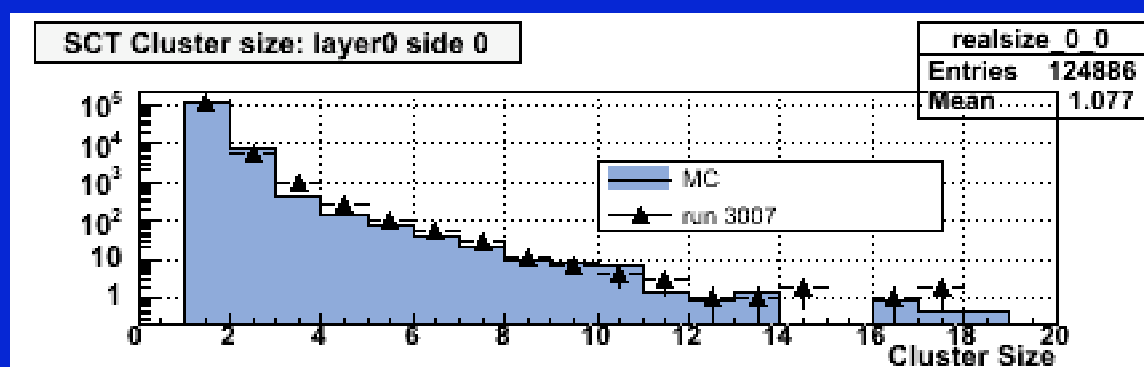
Combined cosmic run with SCT and TRT barrel

- Monitoring code developed to check the data quality:





- Data/MC comparisons are being done to improve the simulation



Conclusions

- ATLAS has re-designed his tracking software following an internal review:
  - Modularity, common interfaces and EDM
  - Full trigger and offline integration
  - First use case was combined test beam data analysis
  - Performance of new code is at TDR level
  - Several new developments integrated in new software

- Emphasis on realism and on real data analysis:
  - Integration of alignment and calibration in reconstruction framework
  - Conditions support to cope with real detector
  - Precise description of detector material
  - Deformations and realistic field

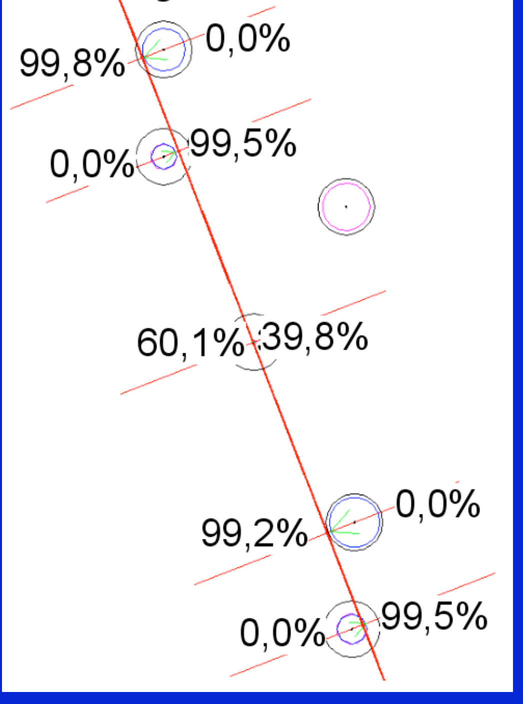
- Computing System Commissioning in 2006/2007:
  - Demonstrate complete functionality of close to final software
  - Alignment and calibrations test for full system
  - Full chain "dress rehearsal" from Point-1 trigger farm to physics analysis
- ATLAS Inner Detector tracking software will be well prepared for LHC turn-on

Backup slides

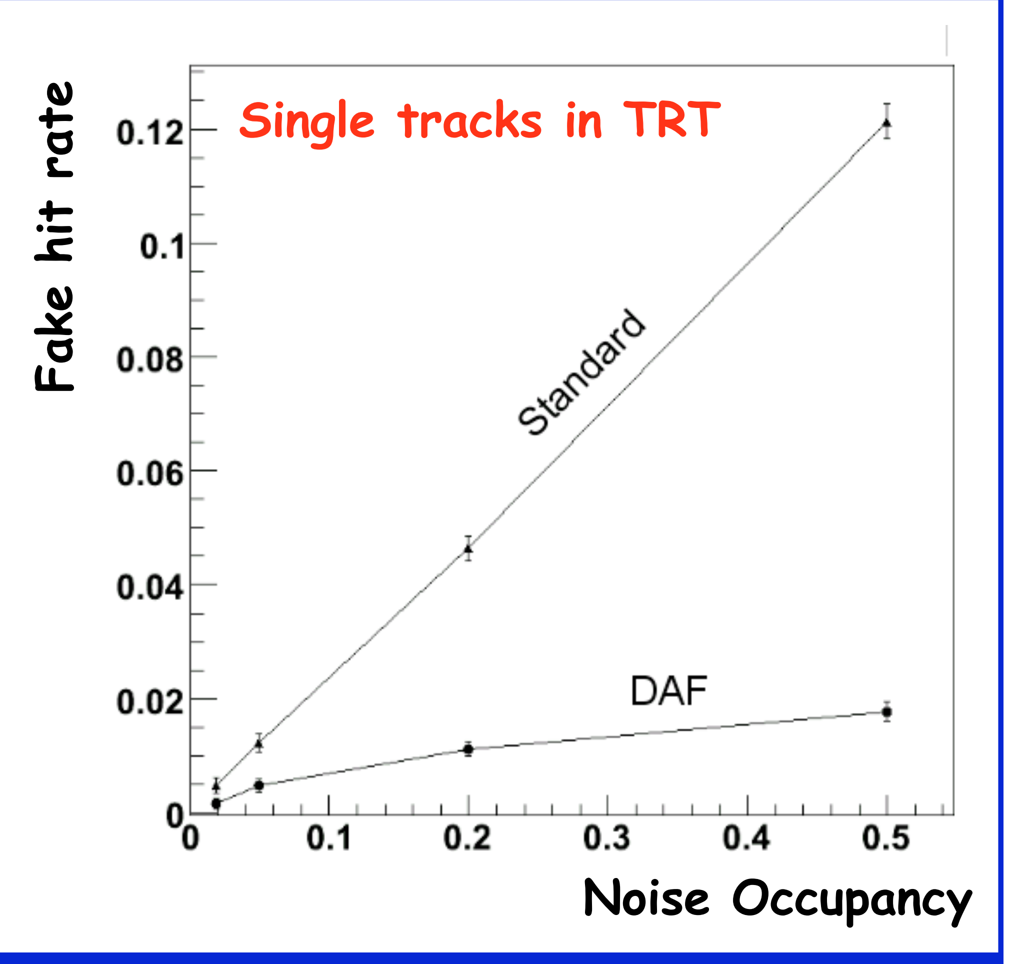
Specific fitters for high occupancy

Deterministic Annealing Filter

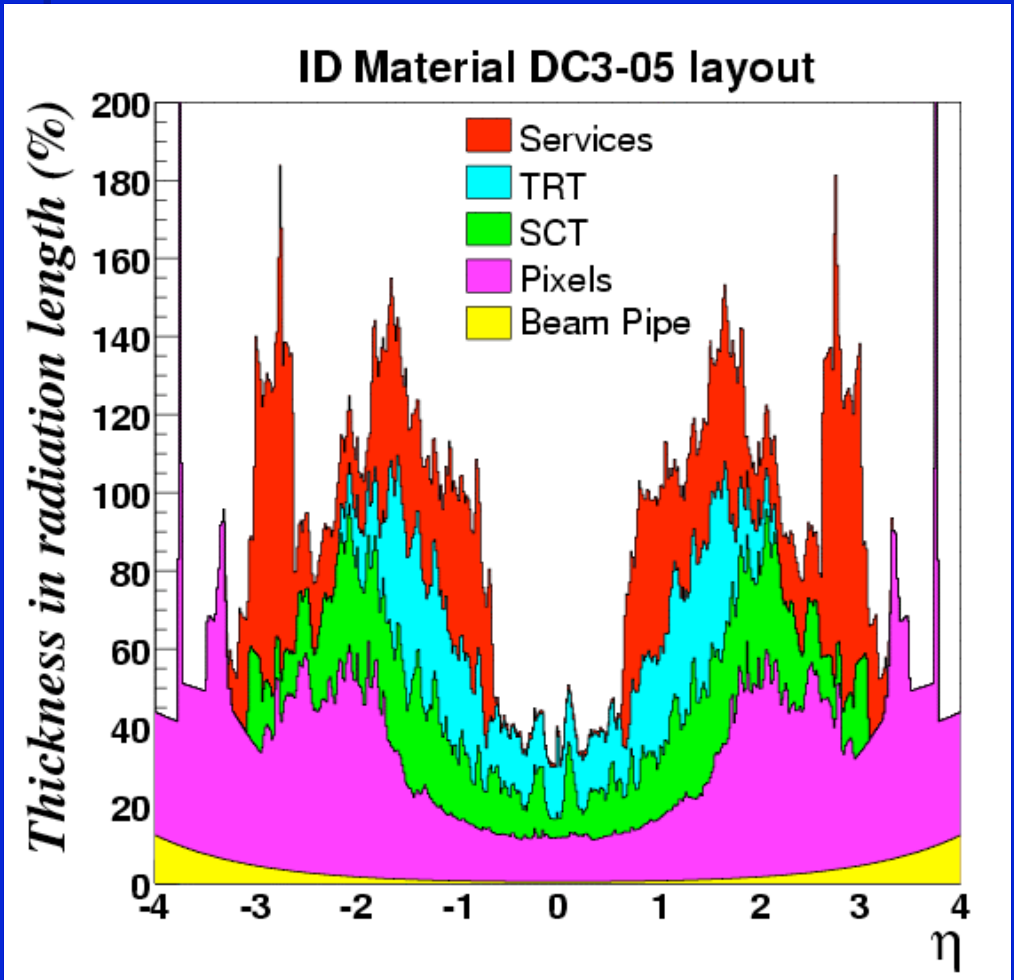
- Extension of a simple Kalman Filter
- Annealing scheme to allow for fuzzy track to hit assignment:
    - Assign weights to competing hits, freeze out correct assignment



Example use case:
TRT high occupancy tracking



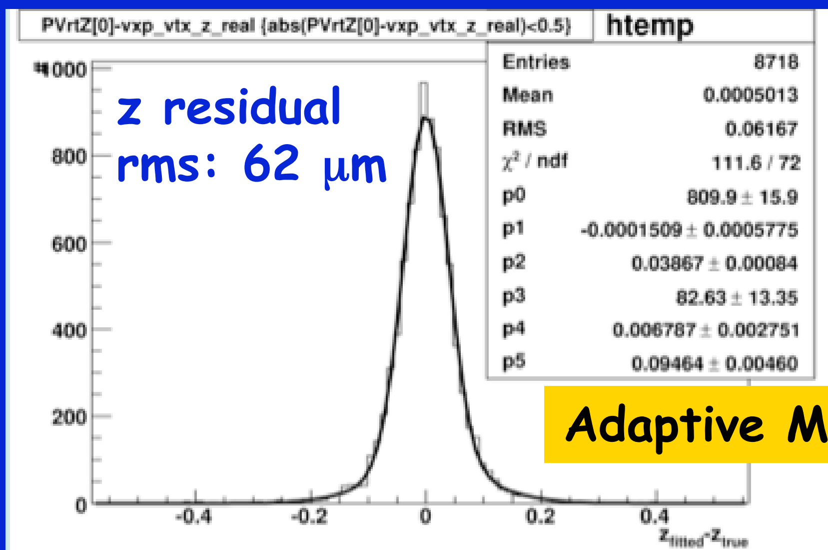
Material

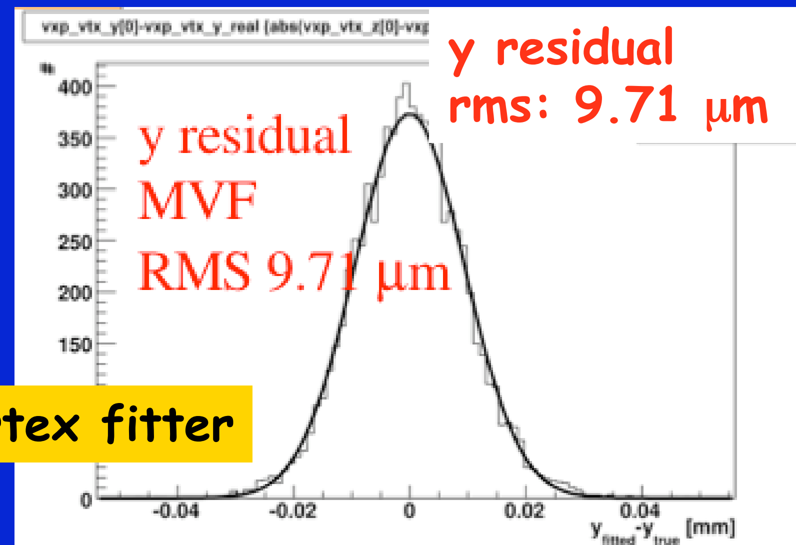


ID Material DC3-05 layout
Services
TRT
SCT
Pixels
Beam Pipe
Thickness in radiation length (%)
0
20
40
60
80
100
120
140
160
180
200
-4
-3
-2
-1
0
1
2
3
4
η

Vertex reconstruction performance

Primary vertex in WH(120) H(bb) with pile up at low lumi



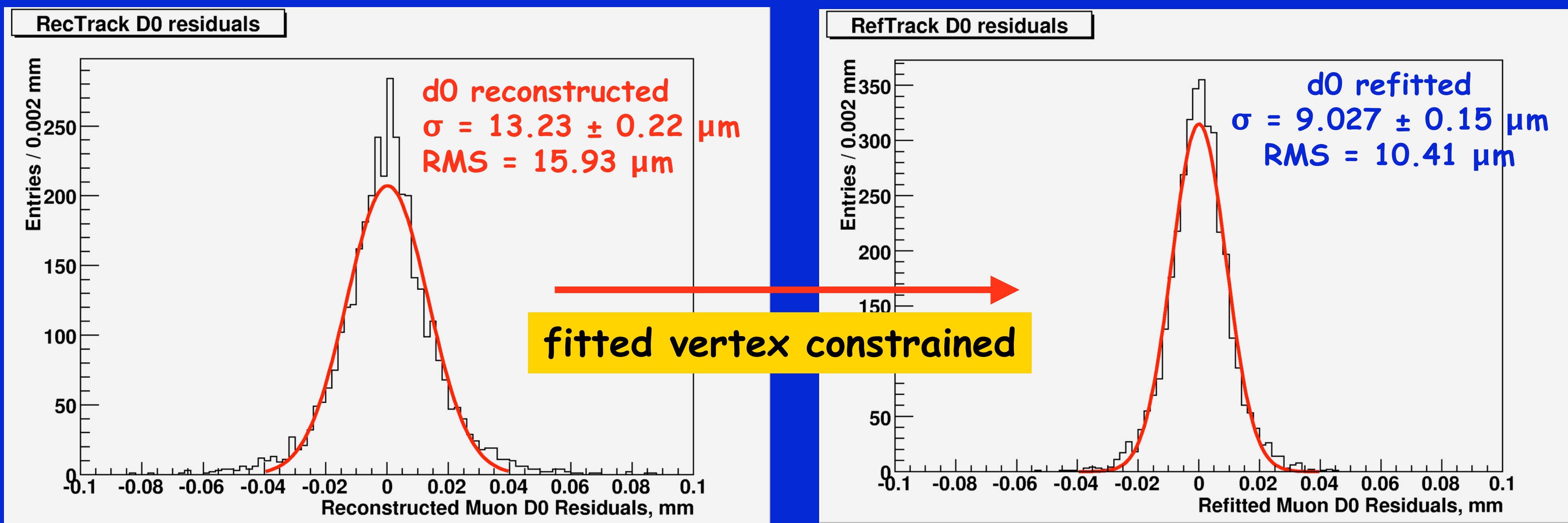


Adaptive Multivertex fitter

Fake rate: 4.19% (±0.21)

Vertex reconstruction performance

$H \rightarrow 4\mu$



- Tracks can be refitted with the knowledge of the fitted vertex → improves track parameters resolution in exclusive decays

CTB

Momentum resolution as a function of energy using Silicon