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# Tracking software status and estimated tracking performance for tau decay products

Sebastian Fleischmann[1]

[1]University of Bonn


naf.desy.de
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# Outline

- Disclaimer: The tracking software is a common effort of a big group, praise them, not me (I will not mention any names here, otherwise I will certainly miss someone)! You can blame me for the following plots, though...
- Talk concentrates on Inner Detector tracking, because most relevant for taus
- Outline:
  - Status of the New Tracking
  - Developments concerning taus
  - Tracking performance for different Inner Detector alignments
  - Conclusions and Outlook

# Overview

- The Inner Detector track reconstruction (New Tracking) uses a single setup (pattern recognition, track fit, ...) by default, but several different options exist

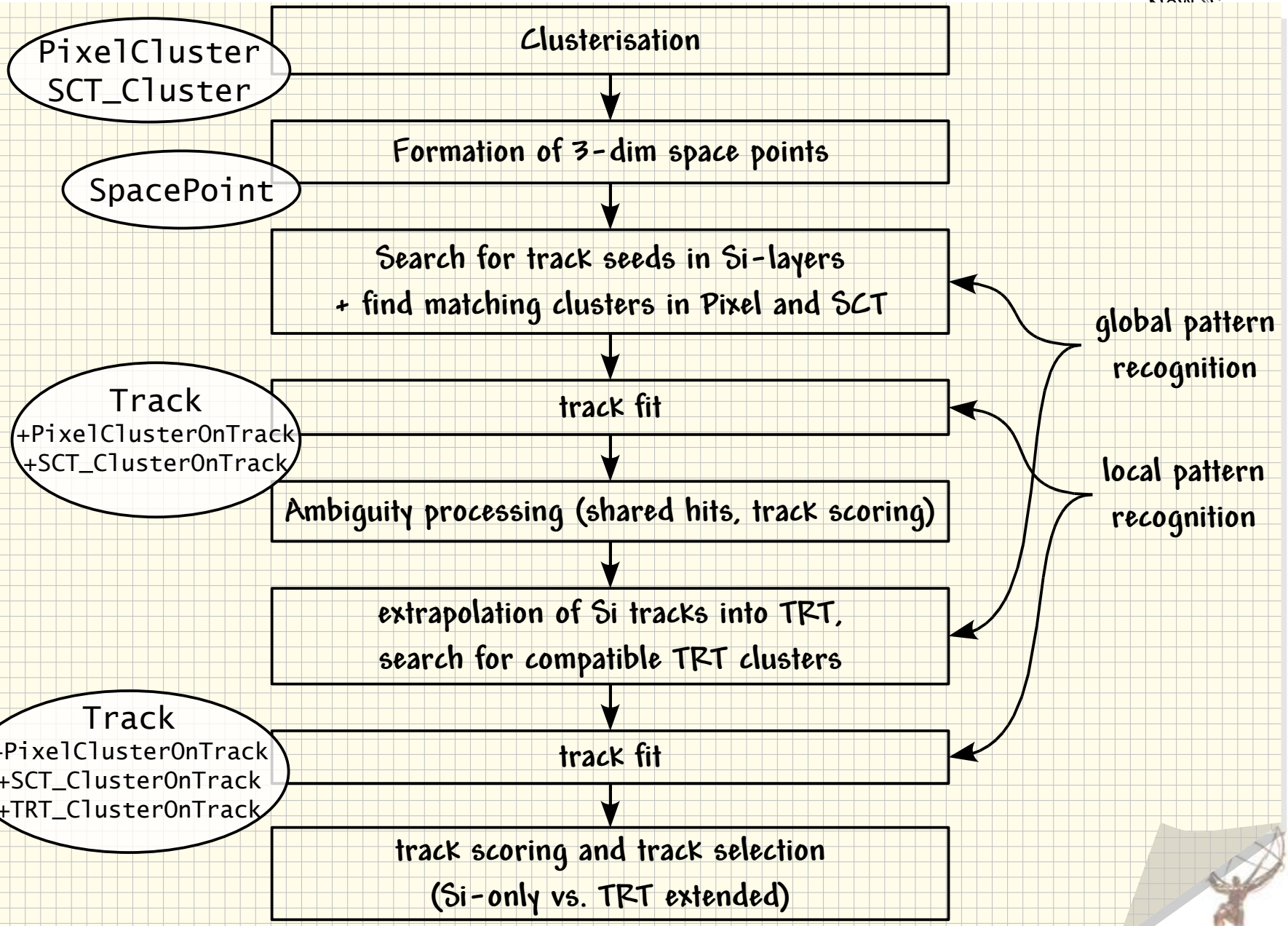
- Track fitter:
  - Global Chi$^2$ Fitter (GXF, current default)
  - Kalman Filter (KF): iterative fitter with different optional extensions:
    - Dynamic Noise Adjustment (DNA) for recovery of bremsstrahlung: Dynamically increase the estimated uncertainty due to energy loss in the track fit
    - Internal annealing for outlier detection
  - Deterministic Annealing Filter (DAF): Uses annealing procedure for dynamic assignments of measurements to a track
  - Gaussian Sum Filter (GSF) for brem fits: Sum of Gaussians to model Bethe-Heitler energy loss of electrons

# Overview

- Pattern recognition:
  - Inside-out tracking: Silicon pattern and track fit + TRT extension
  - Additional outside-in tracking to reconstruct conversions and V0s
  - Special configuration for beam gas / beam halo events, low-$p_T$ tracking
  - Very important: Adapted Combined Test Beam tracking for cosmics
  - New: Heavy ion mode
- A priori it is not clear, whether the default reconstruction is the best choice for tracks from tau decays
  - Especially overlapping tracks in high-$p_T$ 3-prong decays or additional conversion tracks may influence the track reconstruction efficiency
  - The very modular structure allows to easily introduce new algorithms, e.g. a "Multi Track Fitter"
  - Will not go into details on re-running the Inner Detector reconstruction for tau leptons here, see talk by Antonio Limosani

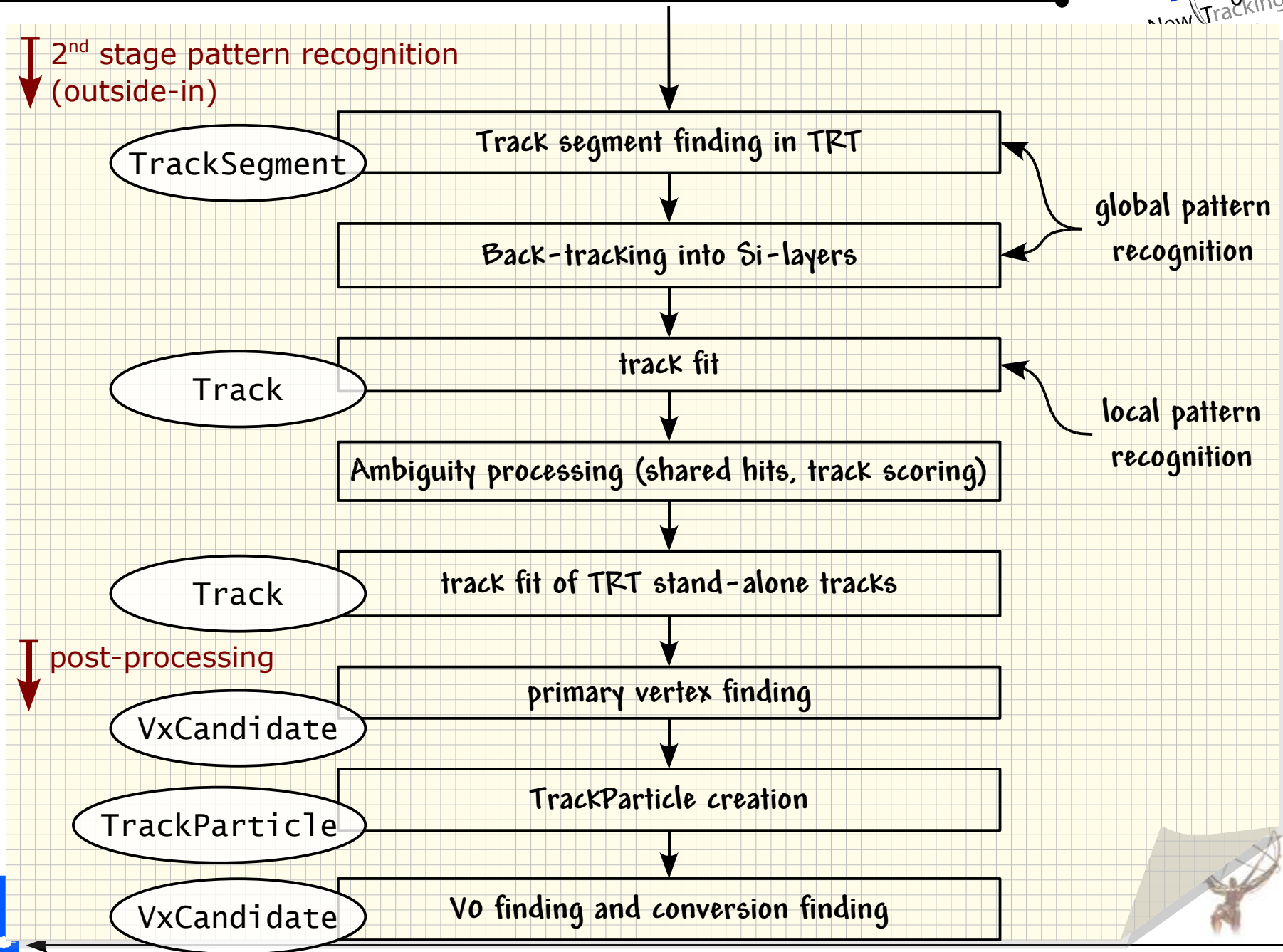
# Overview




PixelCluster
SCT_Cluster
Clusterisation
Formation of 3-dim space points
SpacePoint
Search for track seeds in Si-layers
+ find matching clusters in Pixel and SCT
global pattern recognition
Track
+PixelClusterOnTrack
+SCT_ClusterOnTrack
track fit
local pattern recognition
Ambiguity processing (shared hits, track scoring)
extrapolation of Si tracks into TRT,
search for compatible TRT clusters
Track
+PixelClusterOnTrack
+SCT_ClusterOnTrack
+TRT_ClusterOnTrack
track fit
track scoring and track selection
(Si-only vs. TRT extended)

# Overview




2nd stage pattern recognition
(outside-in)
TrackSegment
Track segment finding in TRT
Back-tracking into Si-layers
global pattern recognition
Track
track fit
Ambiguity processing (shared hits, track scoring)
local pattern recognition
Track
track fit of TRT stand-alone tracks
post-processing
primary vertex finding
VxCandidate
TrackParticle creation
TrackParticle
VxCandidate
V0 finding and conversion finding

# Recent developments

- Software clean-up for release 15
  - Reduce package dependencies to decrease compile time (private/public use statements)
  - Usage of `AthAlgorithm` and `AthAlgTool` to improve CPU time due to `MessageSvc`, etc
  - Force abstract interfaces, avoid dual-use libraries
  - Drop of CBNT and `InDetRecStatistics` ntuples
    - Use standard plots from `InDetPerformanceRTT` or `TrkValidation` ntuple
  - Nearly finished
- Tuning of Global Chi$^2$ Fitter and Kalman Filter regarding efficiency and fake tracks (mainly aimed at b-tagging) and tuning of track scoring / selection
- Modified cuts on MC truth record in simulation to reduce "fake-fakes"
  - Keep in mind: There is a very detailed matching of reconstructed tracks to truth particles. I recommend to use it instead of a simple $\Delta R$ match, because it is much more precise in dense environments! Example how to match MC taus to reco taus using tracks can be found in TauTrackTools

# New features and activities with potential impact on the tau ID

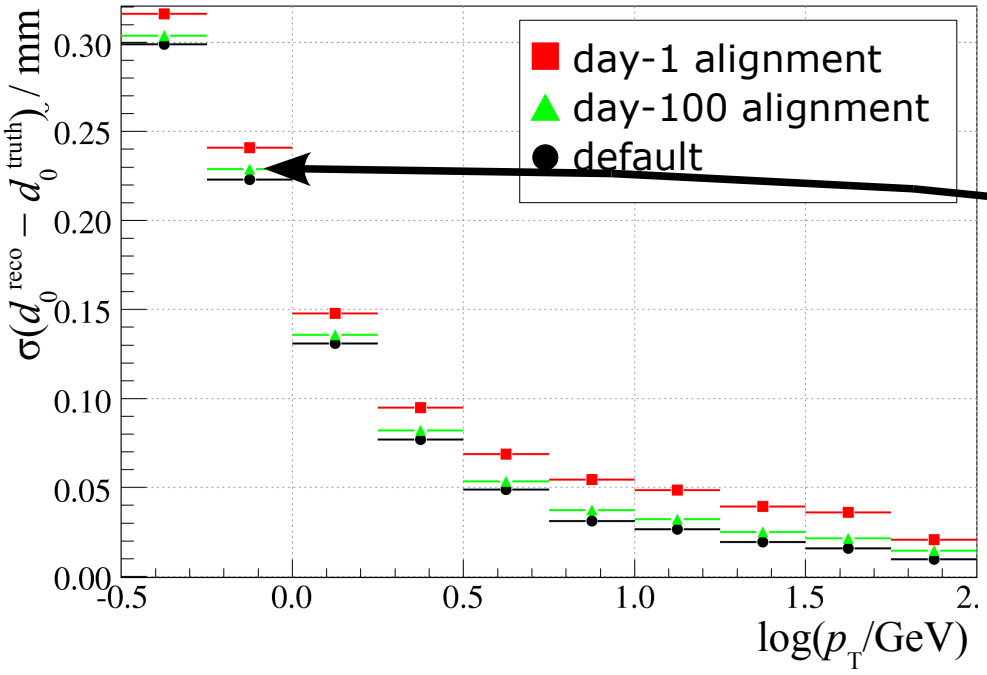


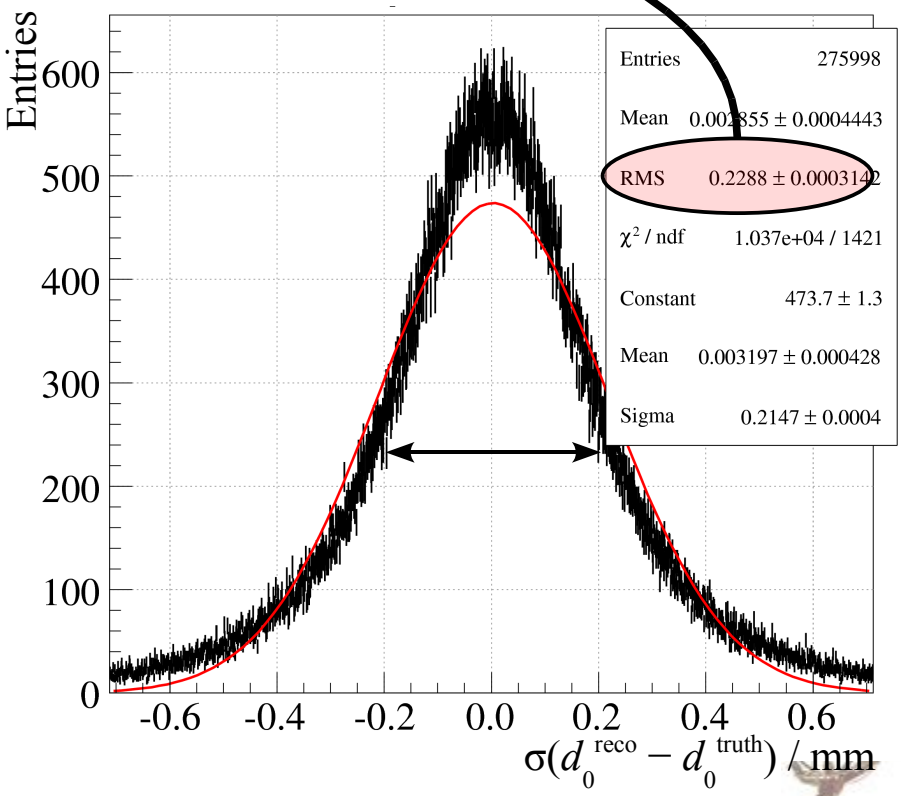
- Electron PID tool (used by conversion ID, see talk by Michael Böhler)
  - Currently uses TRT high-threshold hits only
  - Improved ID possible by using Time over Threshold (ToT) information
  - When using Kalman fitter with DNA: Brem data from the track fit can be used as well
- Refit of conversion electrons with Kalman-DNA and GSF
- Pile-up optimisation ongoining
- Many studies using cosmic data ongoing
  - Needs specialised reco though (vertex constraints, track direction)
- Tracking Material validation
- Tuning of the Combined tracking (Inner Detector + Muon System)
  - Currently mutual validation in the material and energy loss estimates for extrapolations from the ID to the MS for the different muon algorithms

# Expected tracking performance in tau events

- The following performance plots show the estimated tracking performance for $Z \rightarrow \tau\,\tau$ events (106052)
- MC08 simulation with (re-) reconstruction in 15.0.0.2 using the following alignments constants:
  - default (same as in simulation)
  - day-1 (randomly smeared constants with regard to the simulation geometry according to the estimated alignment precision by J. Schieck)
  - day-100
- Partially reconstruction on RDOs (~19k events), partially re-reconstruction (ID tracking including pattern recognition and tauRec) on ESD (~180k events), due to large statistics needed for some plots

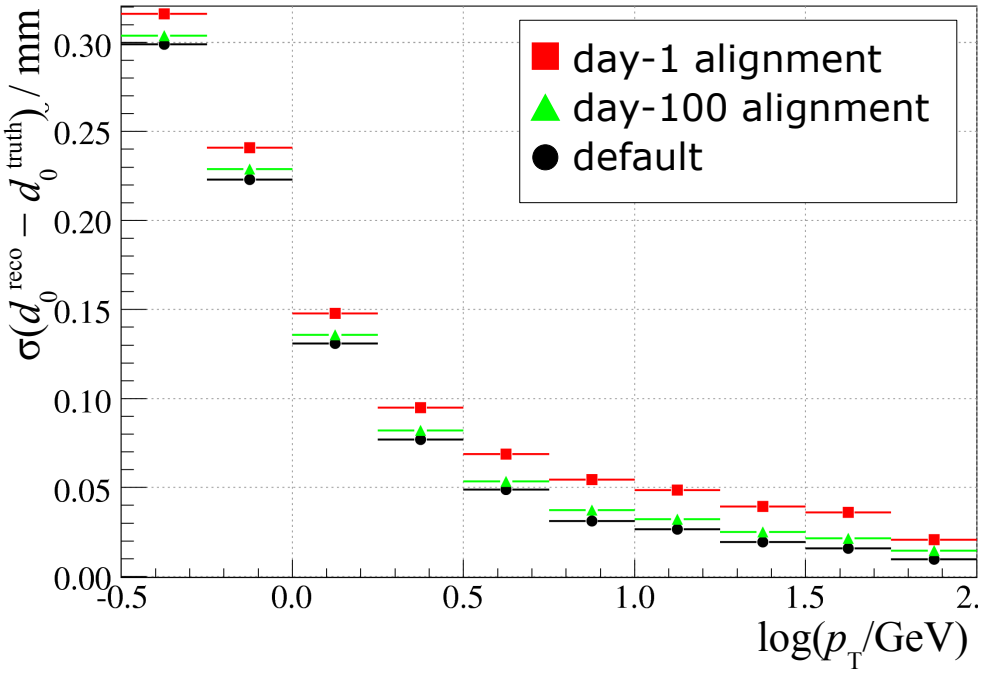
# Expected tracking performance in tau events: Transverse impact parameter resolutions

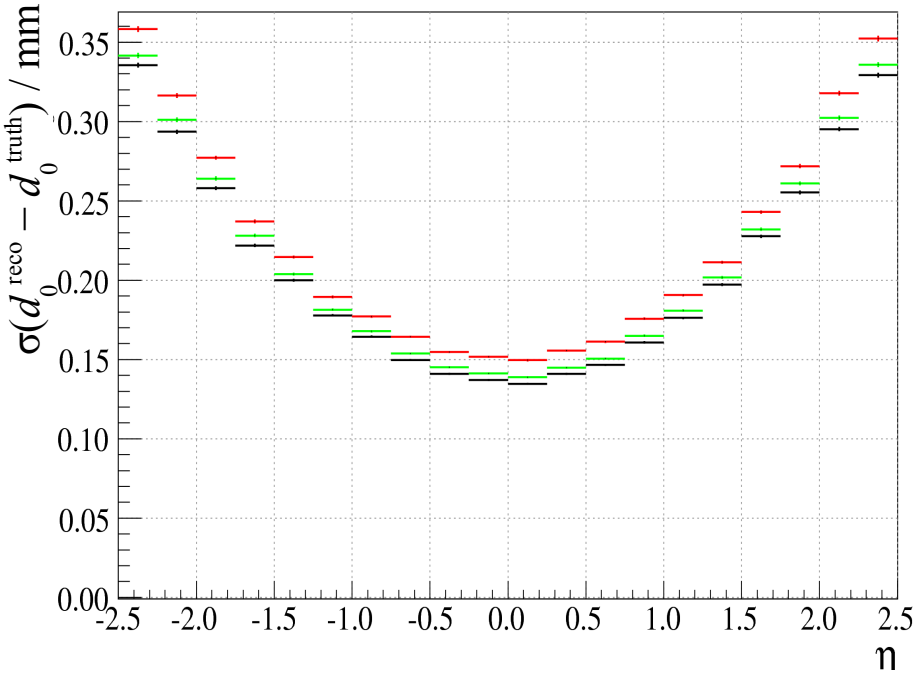



- Track parameter residuals non-Gaussian: take RMS
- pulls (residual/error) are nearly Gaussian, though!

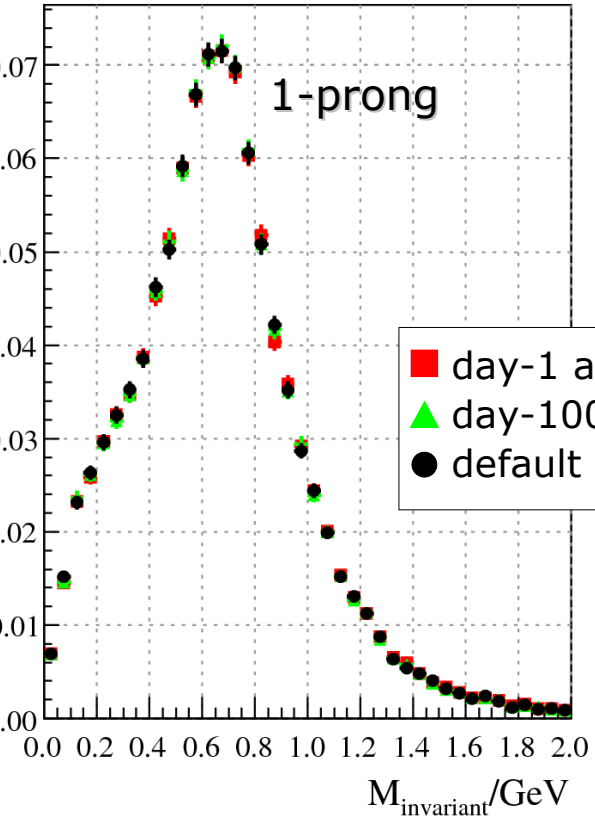
# Expected tracking performance in tau events: Transverse impact parameter resolutions

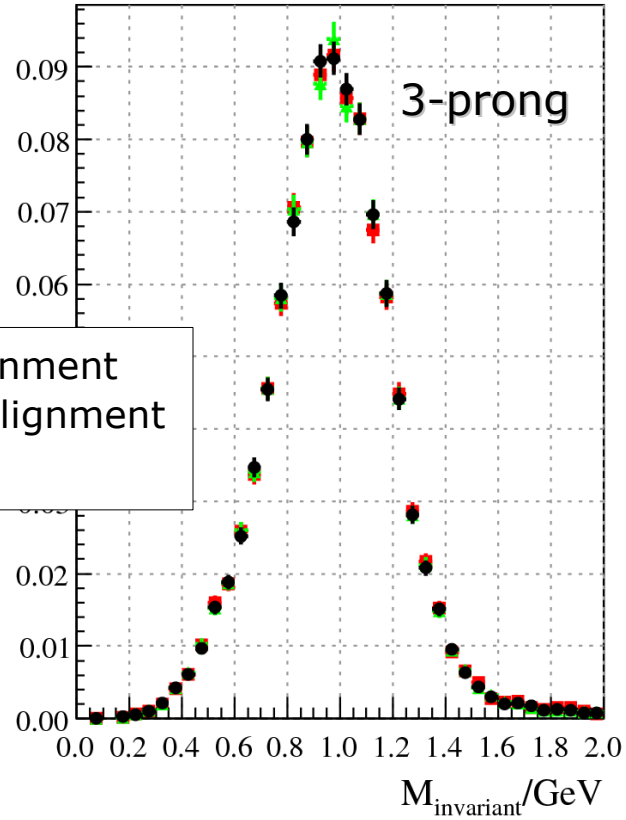


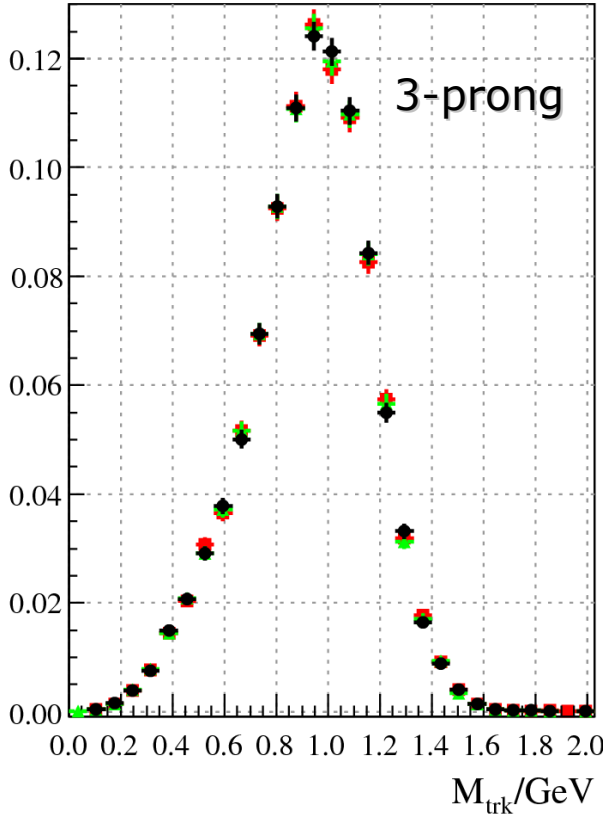

- 15.0.0.2 InDetRecExample reconstruction on RDO with "standard plots"
  - Global Chi$^2$ Fitter, all "good" tracks after TRT extension (no backtracking)
- Only a very slight degradation in the impact parameter resolution

# Expected tracking performance in tau events: Impact on tau variables




Invariant mass of the tau jet

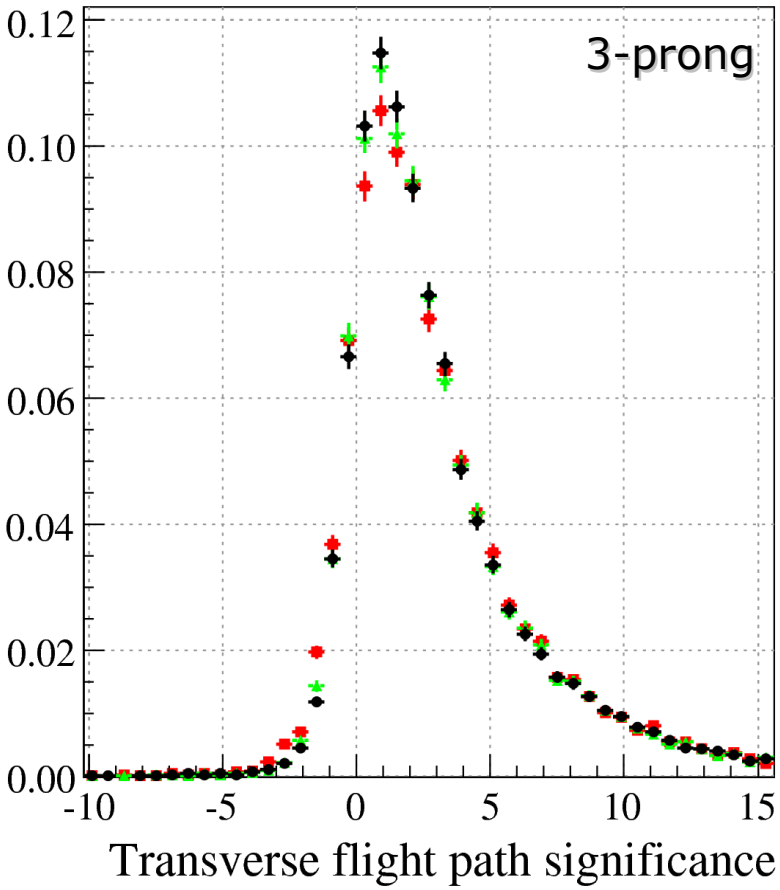


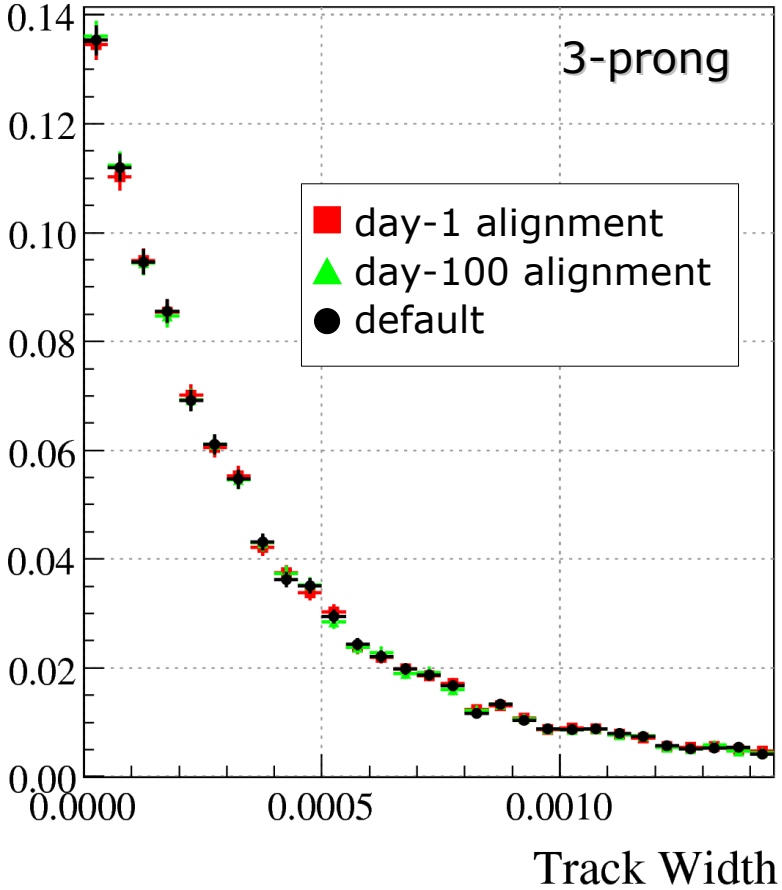

Invariant mass of the track system

- 15.0.0.2 re-reconstruction (ID tracking and tauRec) on ESD with TauValidation
- Only small impact observable

# Expected tracking performance in tau events: Impact on tau variables



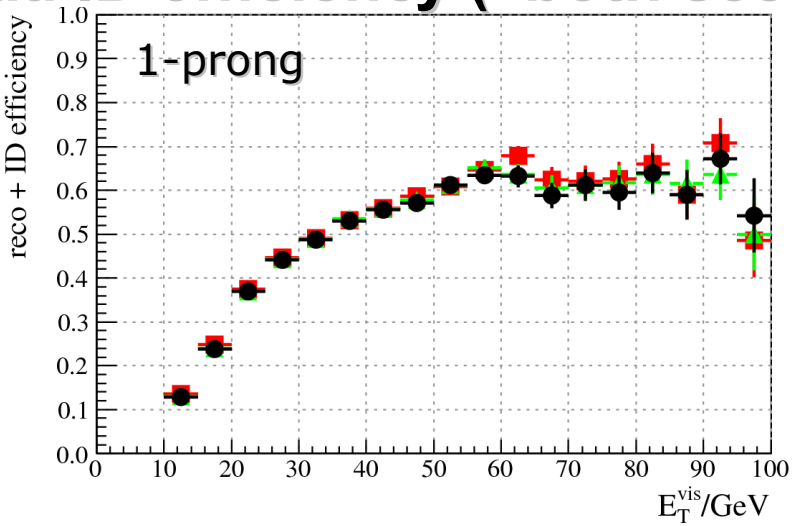


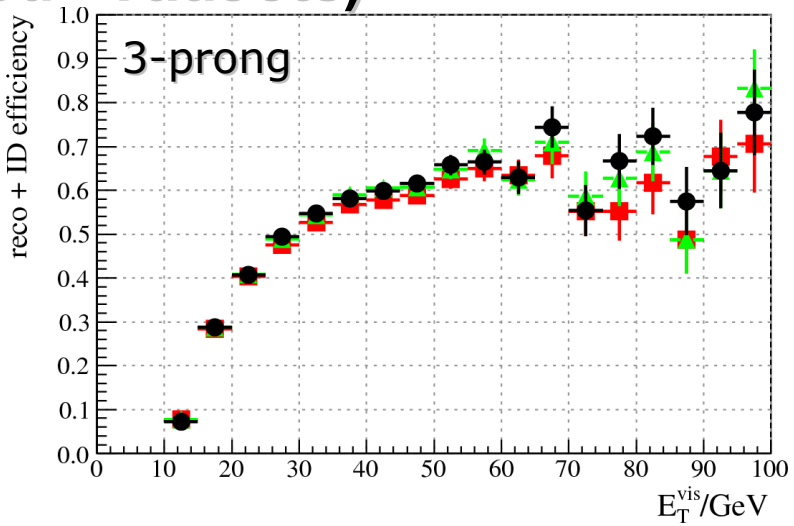



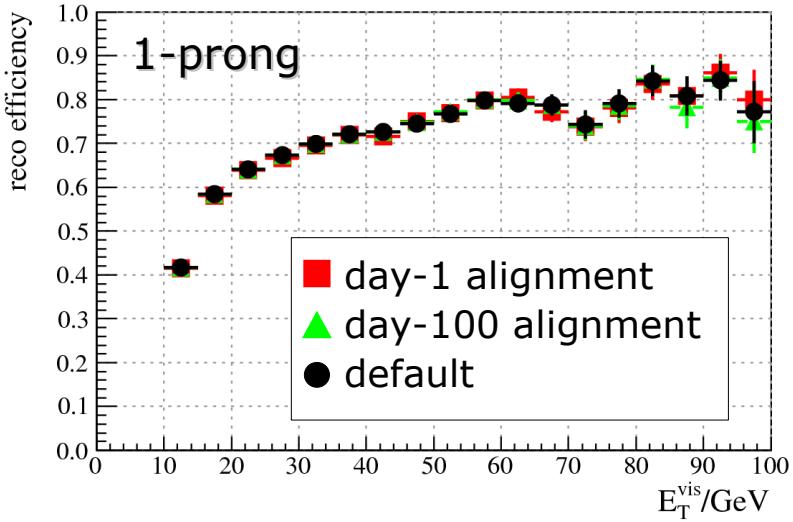

- 15.0.0.2 re-reconstruction (ID tracking and tauRec) on ESD with TauValidation
- Only small impact observable

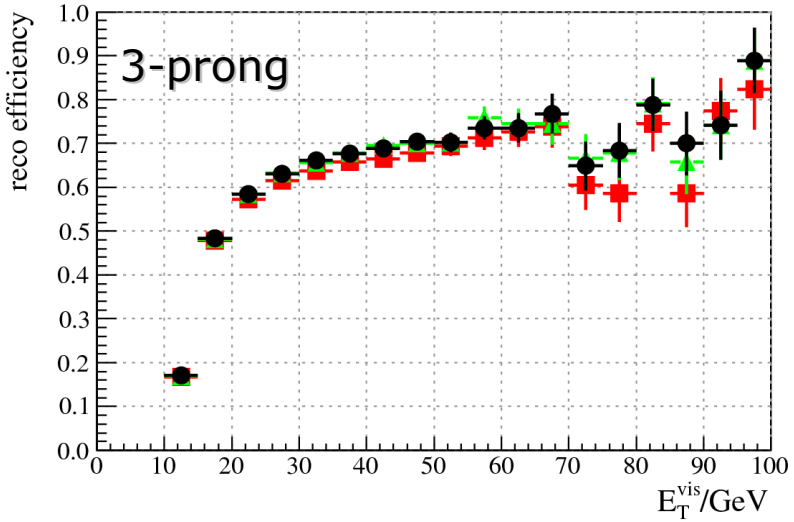
# Expected tracking performance in tau events: Tau ID efficiency ("both seeded" TauJets)





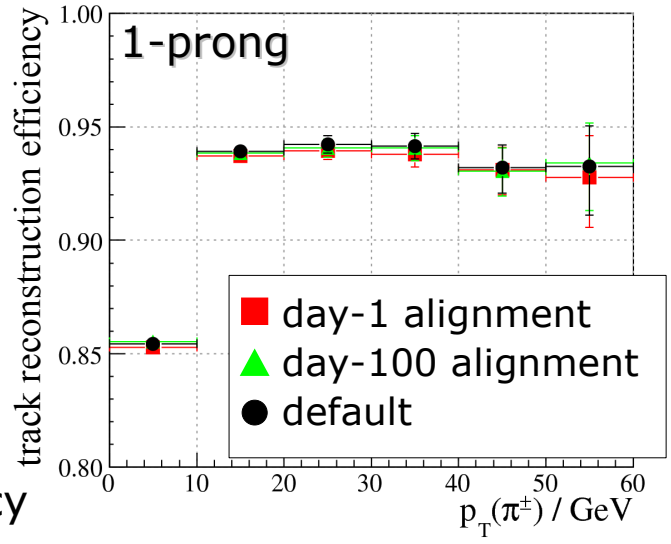



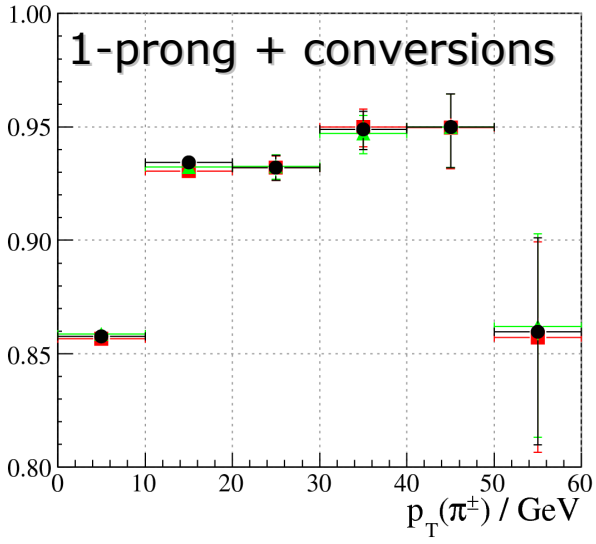



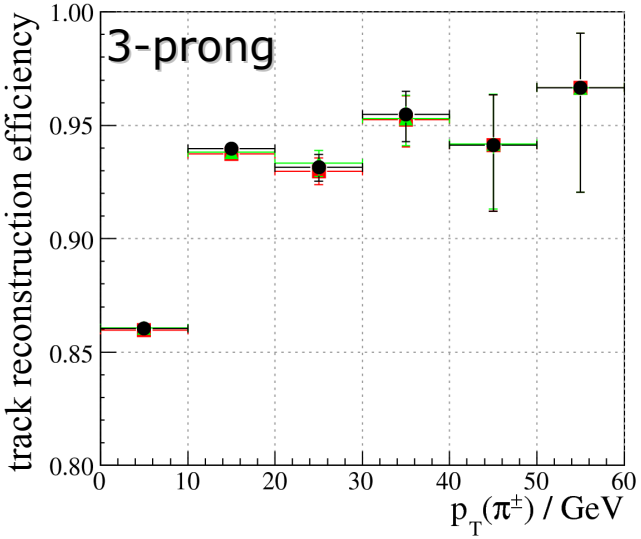

- ID efficiency for 1-prongs even increases with misalignments, may be an effect of worse impact parameter resolution

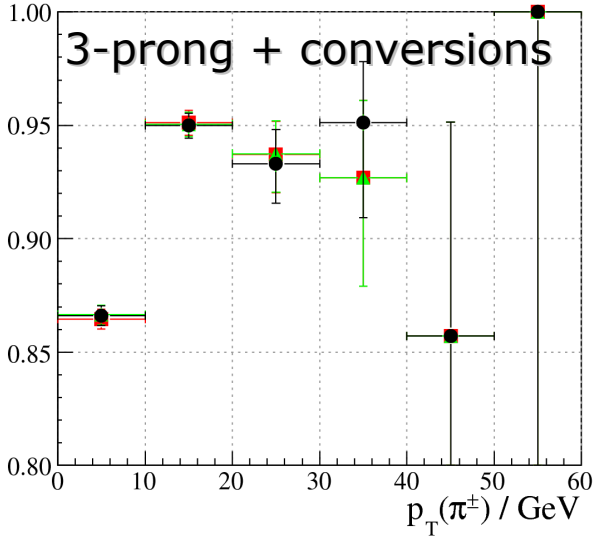
# Expected tracking performance in tau events:
# Track reconstruction efficiencies for pions

- Efficiency for pions from tau decays using standard track selection cuts
- 15.0.0.2 re-reconstruction (ID tracking and tauRec) on ESD with TauTrackTools
- inefficiencies mainly due to hadronic interactions (efficiency increases to nearly 100%, if pions with hadronic interactions are not counted)



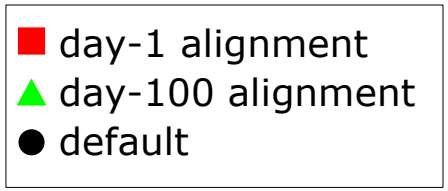



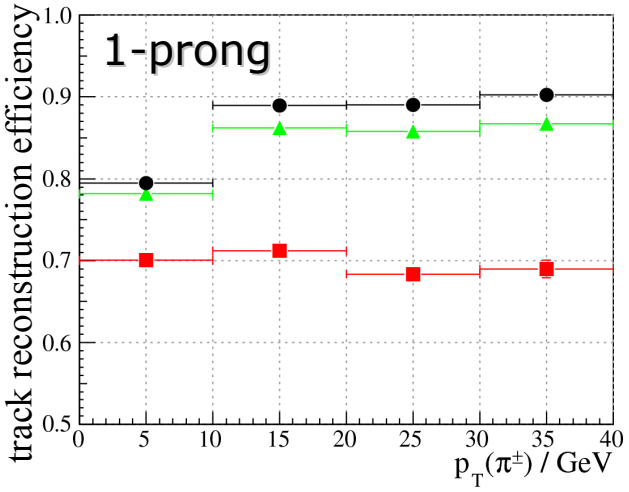



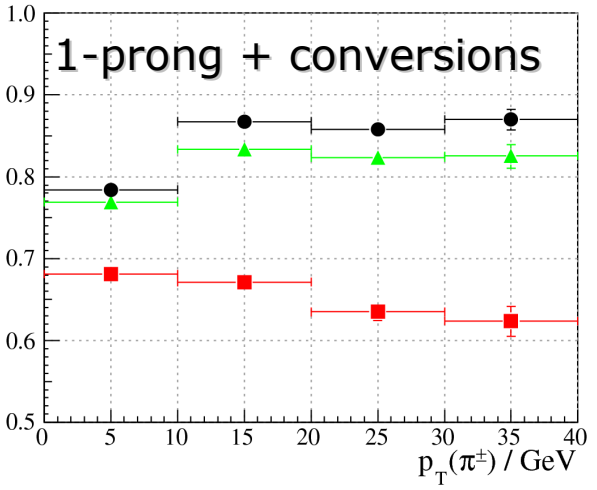
# Expected tracking performance in tau events: Track reconstruction efficiencies for pions

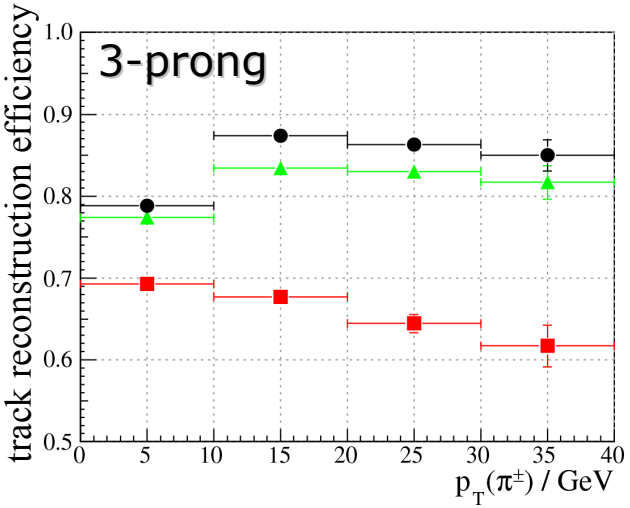


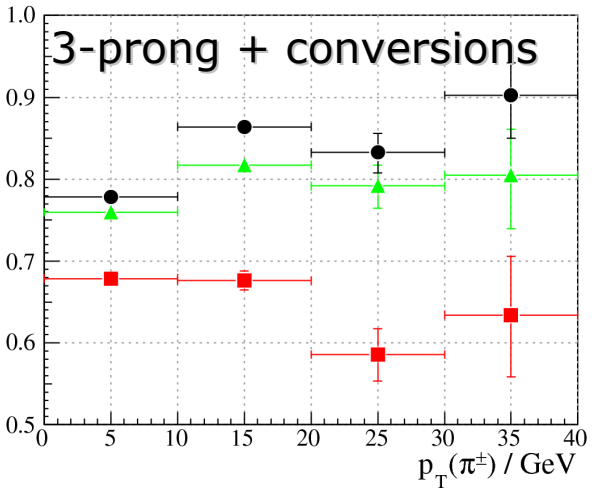
- Efficiency for pions from tau decays using track selection cuts with b-layer hit and $\chi^2/\mathrm{ndof} < 1.7$
  - $\chi^2$-cut very sensitive to misalignments



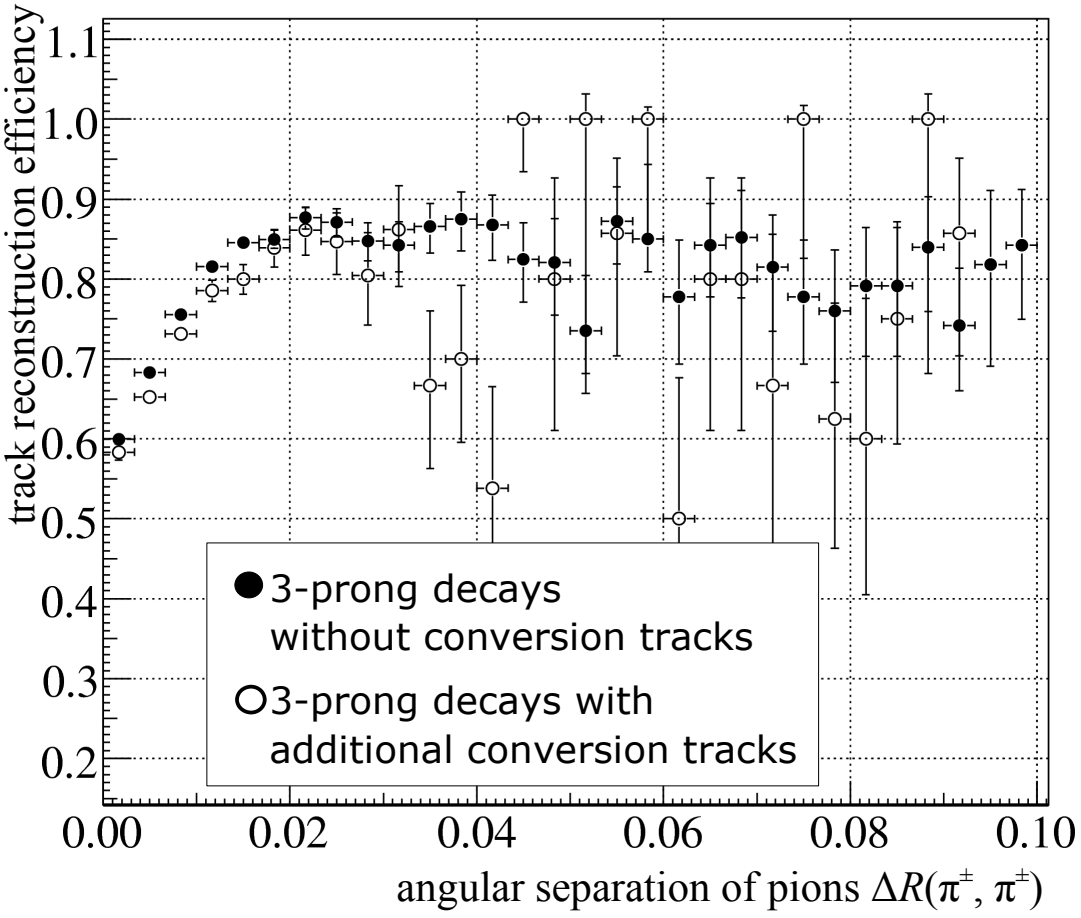



# Expected tracking performance in tau events: Track reconstruction efficiencies for pions

- Impact of overlapping tracks on the tracking efficiency for pions from tau decays
- $A \rightarrow \tau\,\tau$ events reconstructed in 14.2.0 (effect only for high-$p_T$ taus strongly pronounced)



# Conclusions



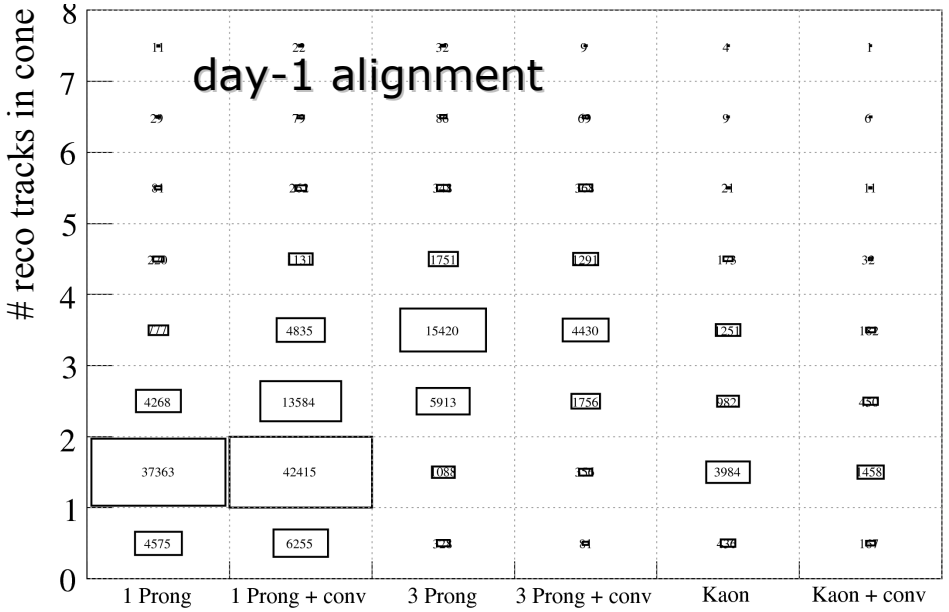
- The ATLAS tracking software is in good shape for collision data
  - no important features missing
  - performance is continuously improving
- No big impact of Inner Detector misalignments as predicted for day-1 on the tau reconstruction is expected
  - BUT: In this study just looked at different alignment sets, the outage of whole detector modules may have a big impact on the track finding efficiency

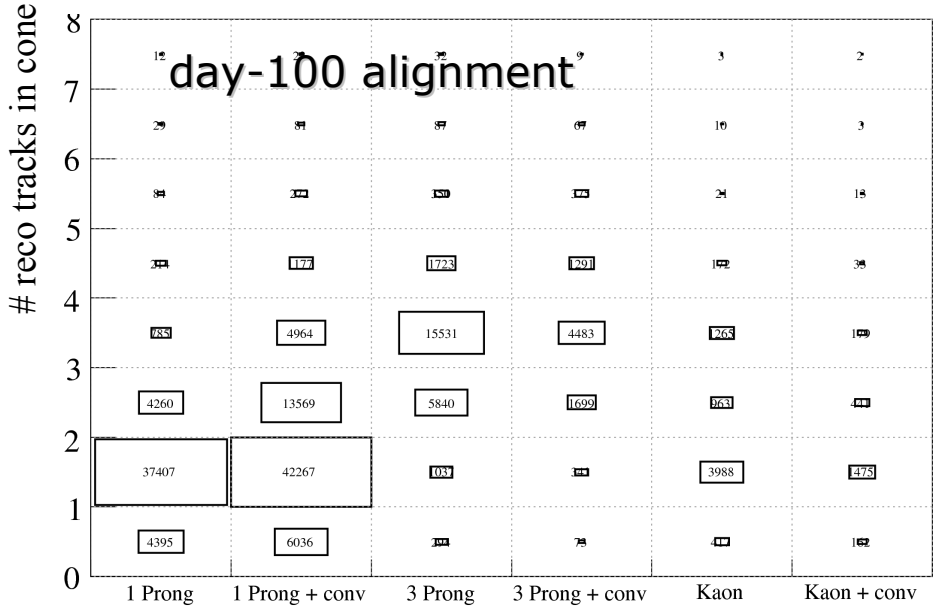
# Backup

- Thanks to Jochen Schieck for providing the alignment constants
- Thanks to Wolfgang Liebig for valuable input

# Expected tracking performance in tau events:
## Number of reconstructed tracks

- Number of reconstructed tracks using standard track selection cuts inside $\Delta R < 0.4$ around the visible component of the tau vs. the true decay mode
- 15.0.0.2 re-reconstruction (ID tracking and tauRec) on ESD with TauTrackTools



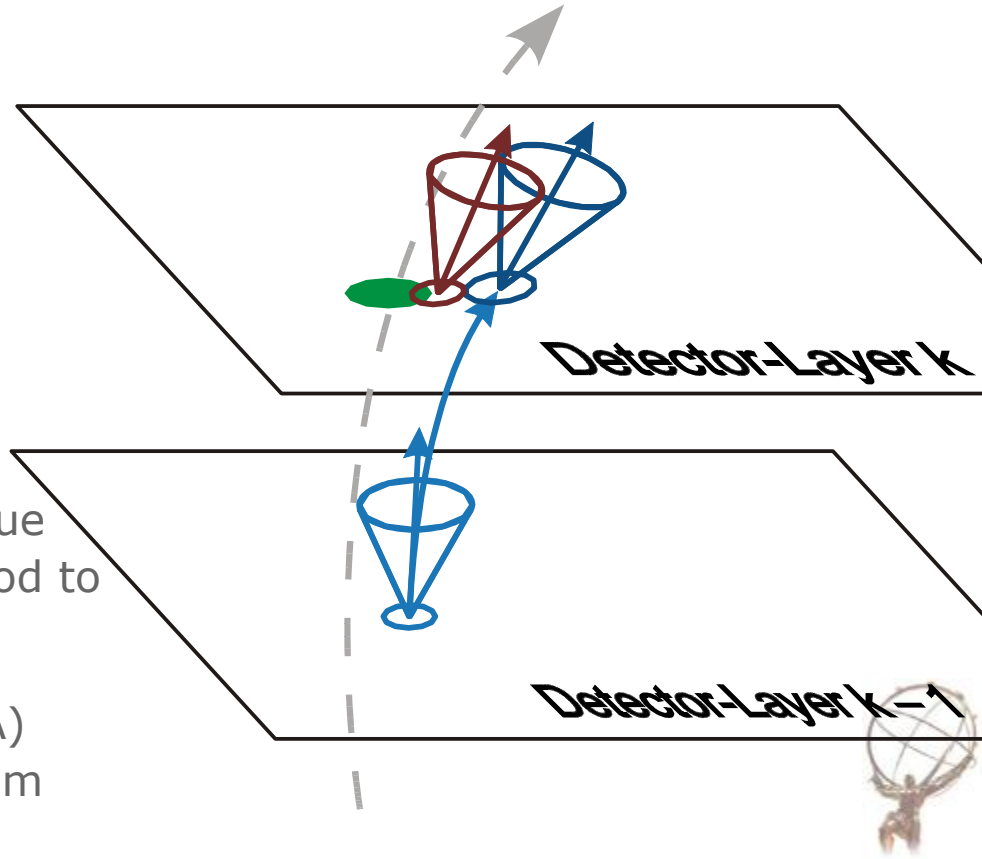
# Known problems



- Navigation problem at phi=pi can cause higher number of selected tracks in this region, because less holes are found
  - effect only visible in dense jets
  - see bug#48591, fixed in 15.1.0

# Algorithms in ATLAS Tracking: Kalman Filter

- Kalman Filter use an iterative approach for the track fit:
  - The track parameters on surface *k*–1 are propagated to surface k (*prediction*)
  - Those track parameters on layer *k* can be projected to get the predicted measurement position
  - The updated track parameters including the measurement on layer *k* are calculated as weighted mean (*update*)
- Material effects (MS, Eloss, ...) have to be considered in prediction only
  - Advantage: Prediction follows true position closely, i.e. material good to estimate
  - Dynamic noise adjustment (DNA) increases noise term to take brem into account



# ATLAS Tracking Event Data Model

- Basic classes:
  - `Trk::Track`: contains several `Trk::TrackStateOnSurface`
  - `Trk::MeasurementBase`: Base class for all kind of measurements which can be used in a track fit