ATLAS Fast TracKer Upgrade

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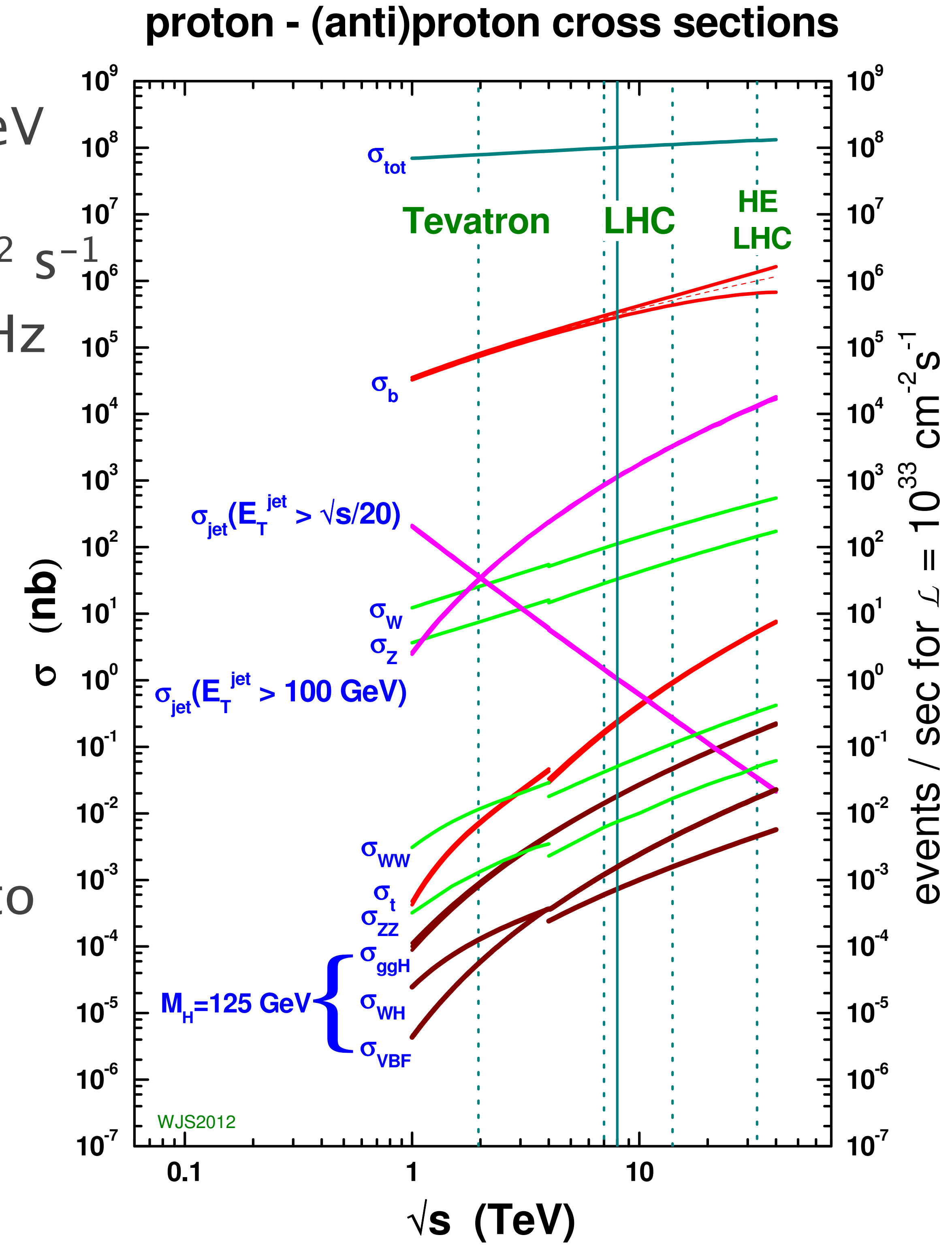
Challenges and Opportunities

- When the LHC returns there will be ~14 TeV collisions
- Instantaneous lumi. will reach 3×10^{34} cm^{-2} s^{-1}
- W bosons produced on the order of 1.2 kHz
  - e and mu from W's alone > 100 kHz
- WH events produced ~ $6*10^{-2}$ Hz

- However currently Level 1 bandwidth is 100 kHz
  - Cannot save all W boson decays to e/mu
  - FTK cannot help at Level 1
- The FTK provides a larger toolbox to use to select events



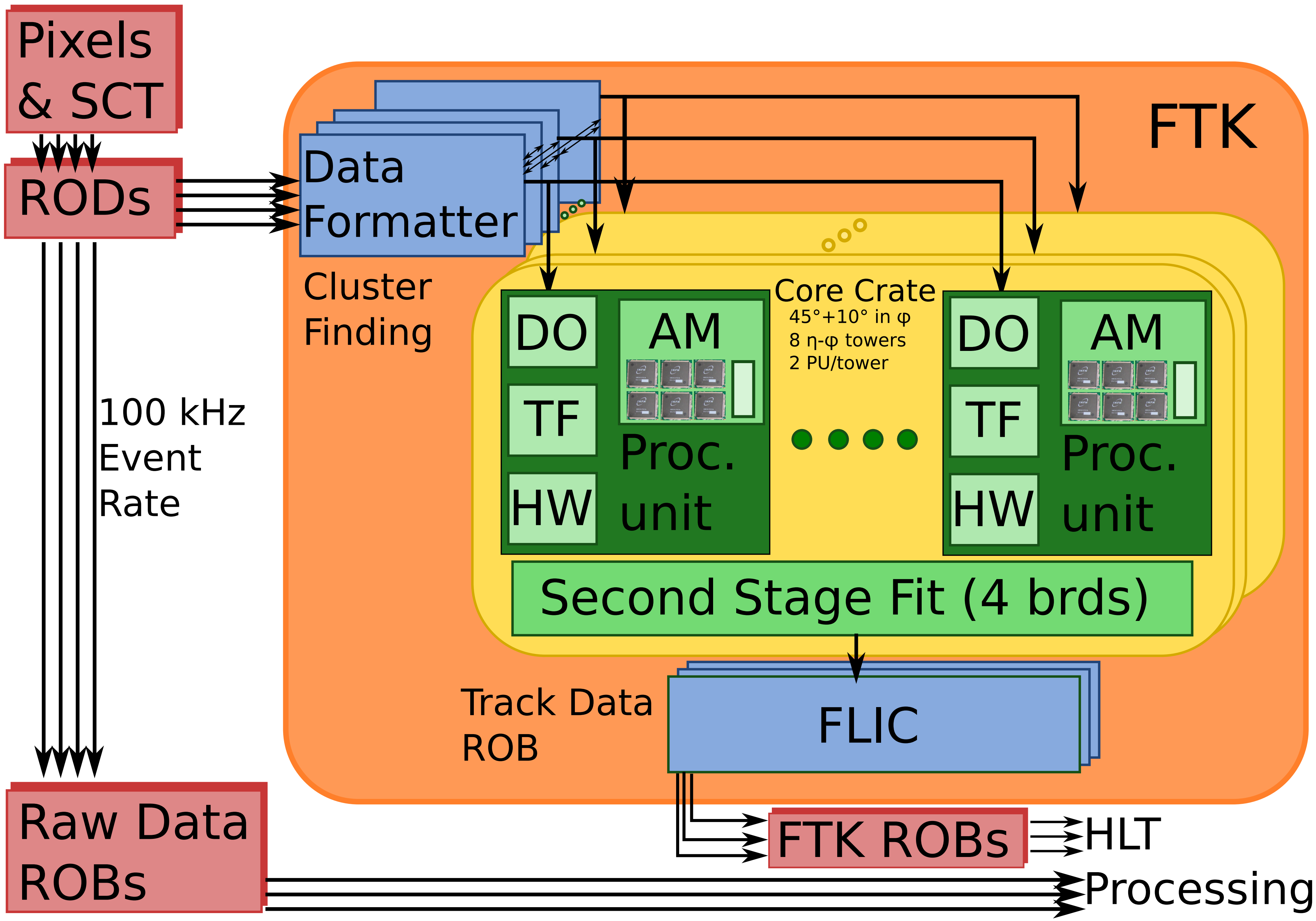
What does the FTK add to the toolbox?

- The pre-FTK TDAQ relies on identifying regions of interest (ROI)
  - These ROIs are then reconstructed at Level 2
  - Tracking in an ROI is fast
  - But limited to a narrow scope(s) of the detector, each ROI is about DR~0.2

- The FTK is designed to provide the full track list @100 kHz
  - For all tracks with $p_T > 1.0$ GeV, $|\eta| < 2.5$
  - At phase 1 luminosity
  - Every event taken at Level 1 will have a full track list at beginning of Level 2
  - Supply all 5 track helix parameters, χ^2, and hits on detector

- Full list of tracks may be used for:
  - Primary Vertex Identification
  - Jet Vertex Fraction, Track-Based e/μ Isolation,
  - b-Tagging Jets, more efficient τ selection

FTK Overview



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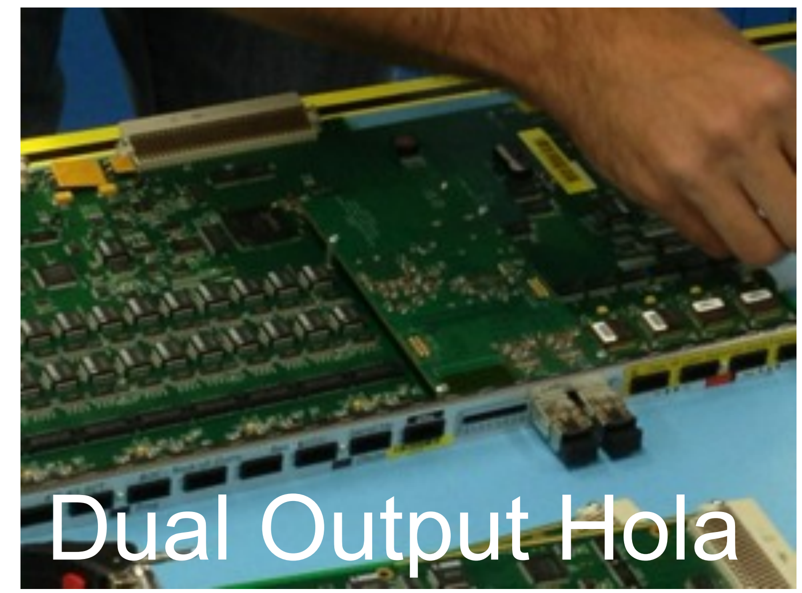
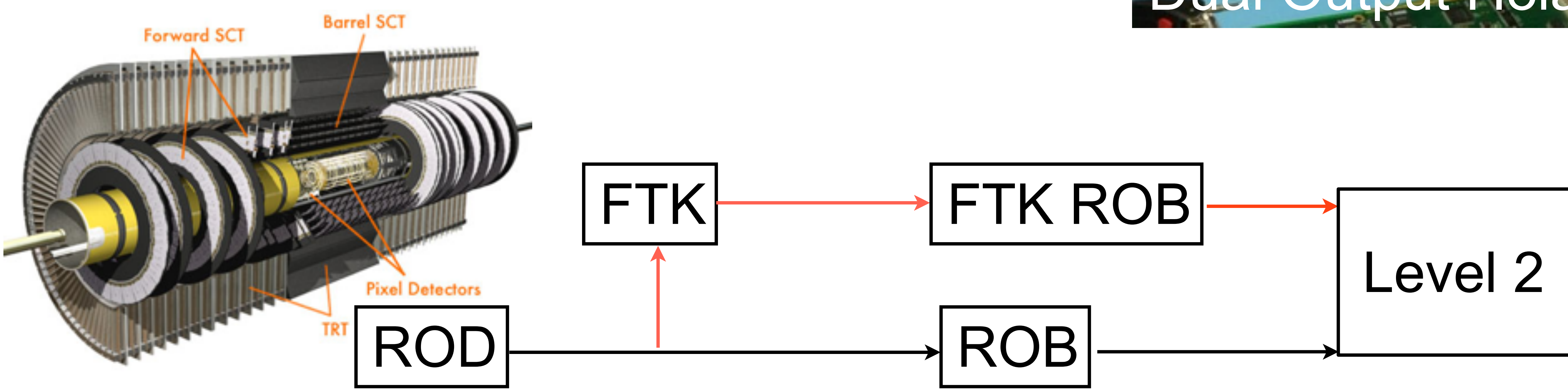
First, do no harm.

- The FTK is installed to have two copies of the data, from the L1 inner detector systems: Pixel and SCT
- Preserves the pre-FTK data acquisition system
- Dual-output Hola cards replace single-output Hola cards
  - FTK reads one copy of the data
  - Original TDAQ reads the other copy of the data

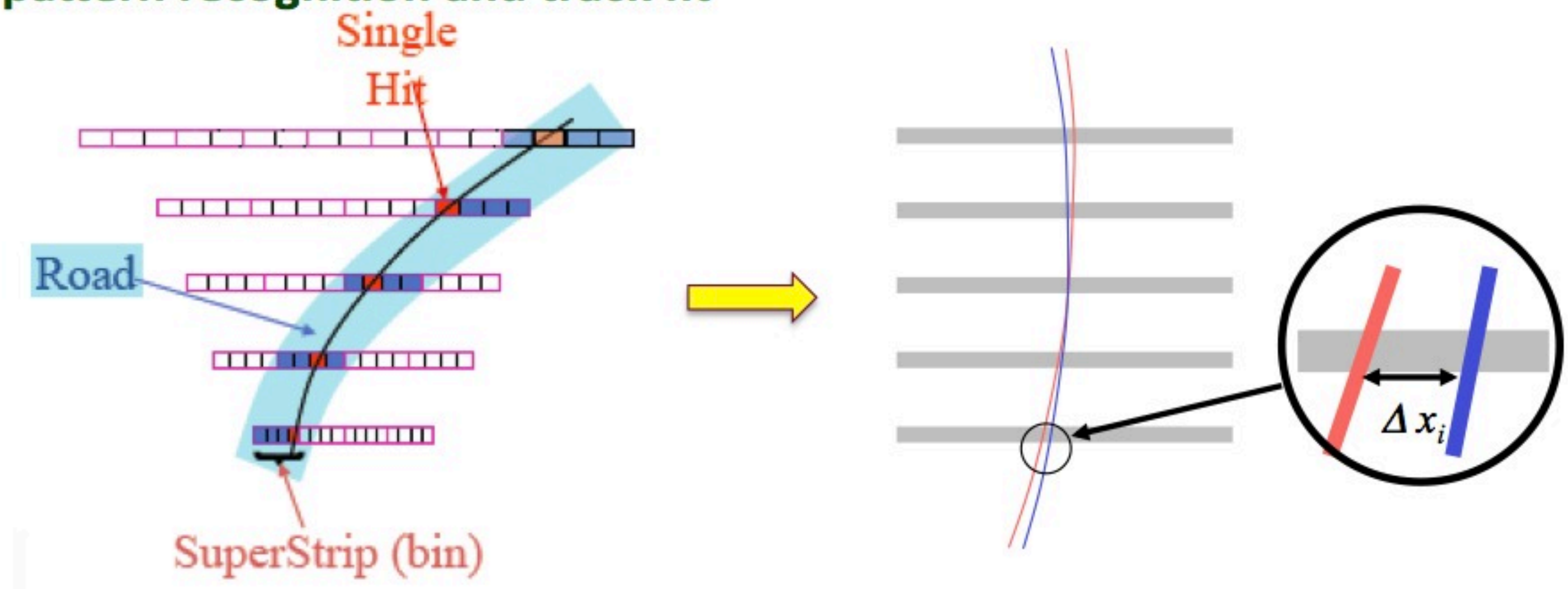




Cartoon

Track Finding

Use hardware to perform the global tracking in two steps pattern recognition and track fit



Pattern recognition in coarse resolution (superstrip→road)

Track fit in full resolution (hits in a road)

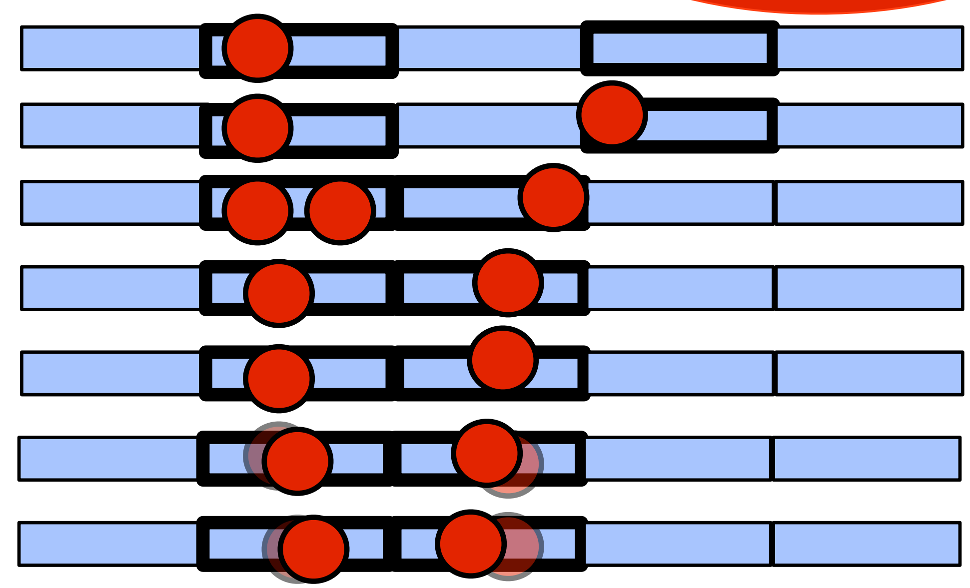
$$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1\Delta x_1 + a_2\Delta x_2 + a_3\Delta x_3 + \ldots = 0$$

Road size to balance the workload between two steps

Track Reconstruction

- Giant device using content addressable memory
- Fit the full resolution hits
- Tracks are approximated as linear
- Tracks are then extrapolated into the other 4 layers for a full 12-layer track
- Fit returns 5 helix parameters and χ^2 for the 12-layer fit

Cartoon



Extrapolated into 2 new regions

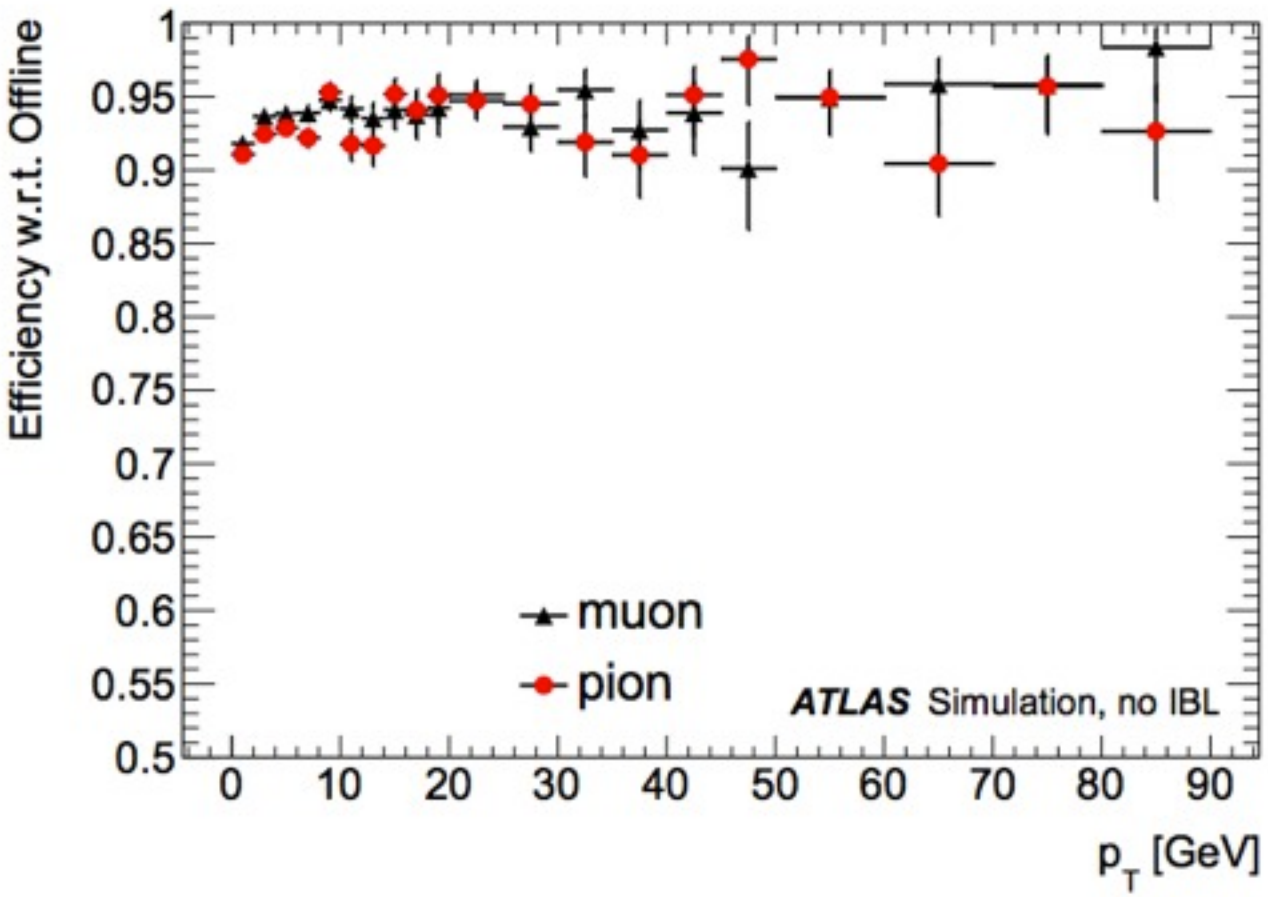
parameters constants

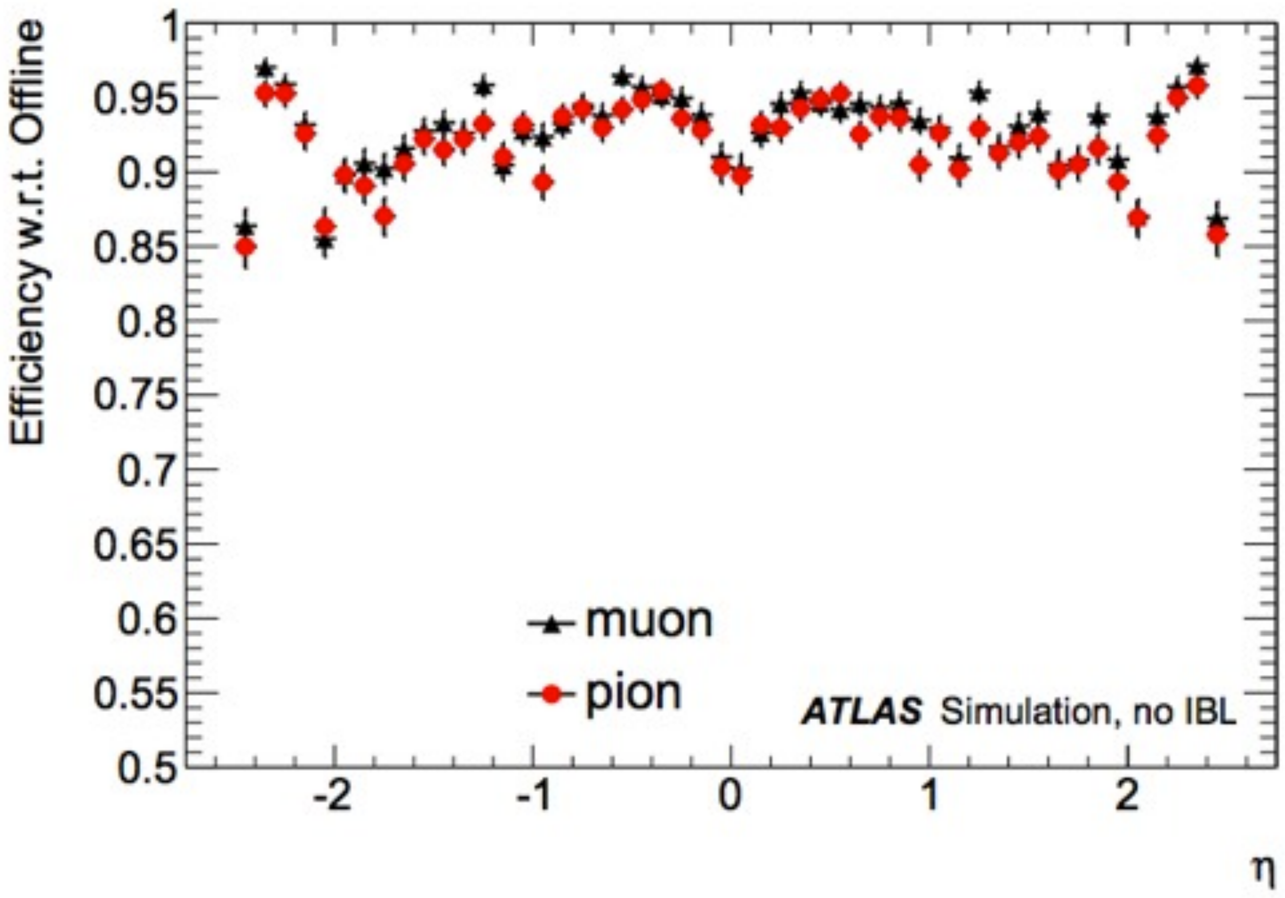
$$p_i = \sum_j c_{ij} \cdot x_j + q_i$$

position in silicon

Tracking Efficiency Comparison to Offline

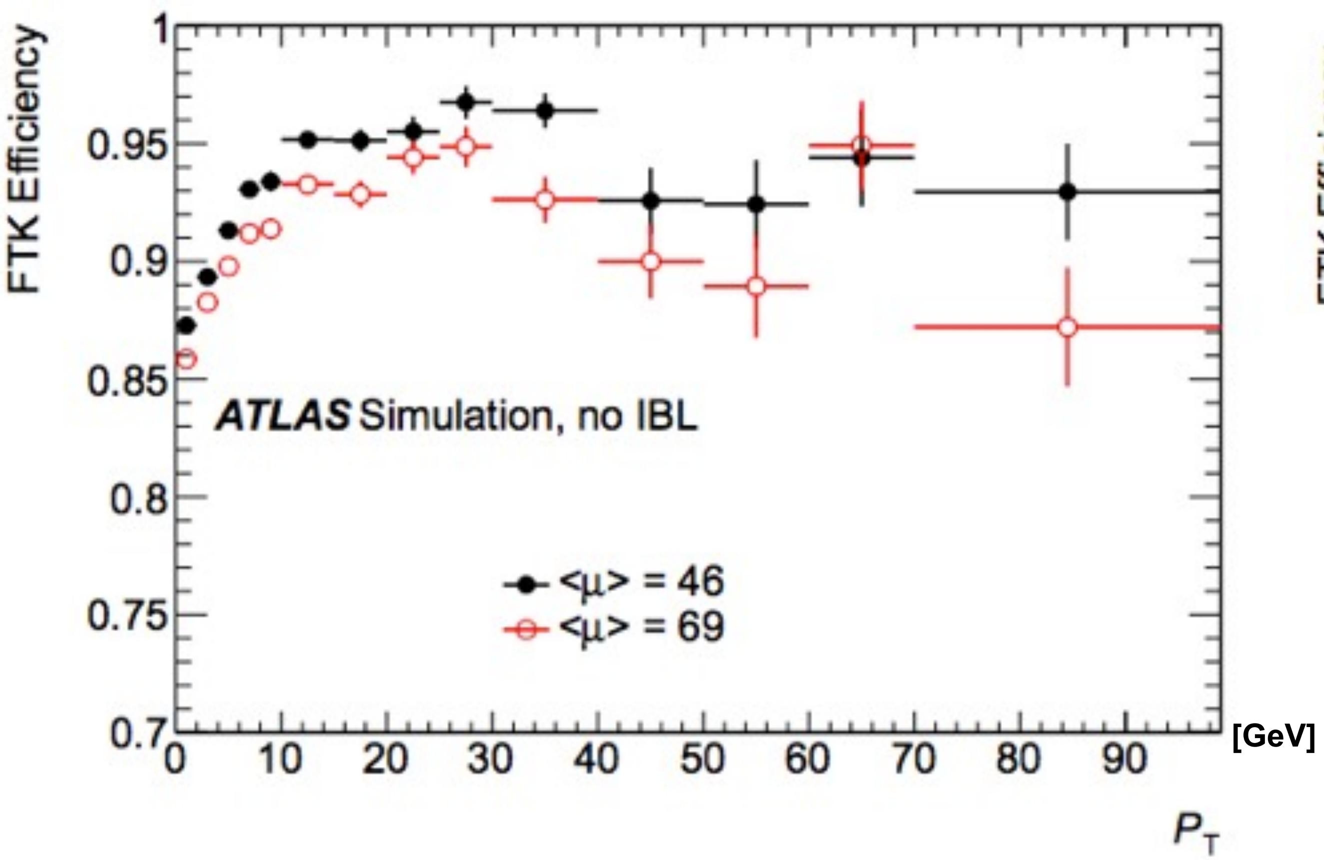
- Based on single particle simulation studies reconstruct 90-95% of tracks relative to offline selection

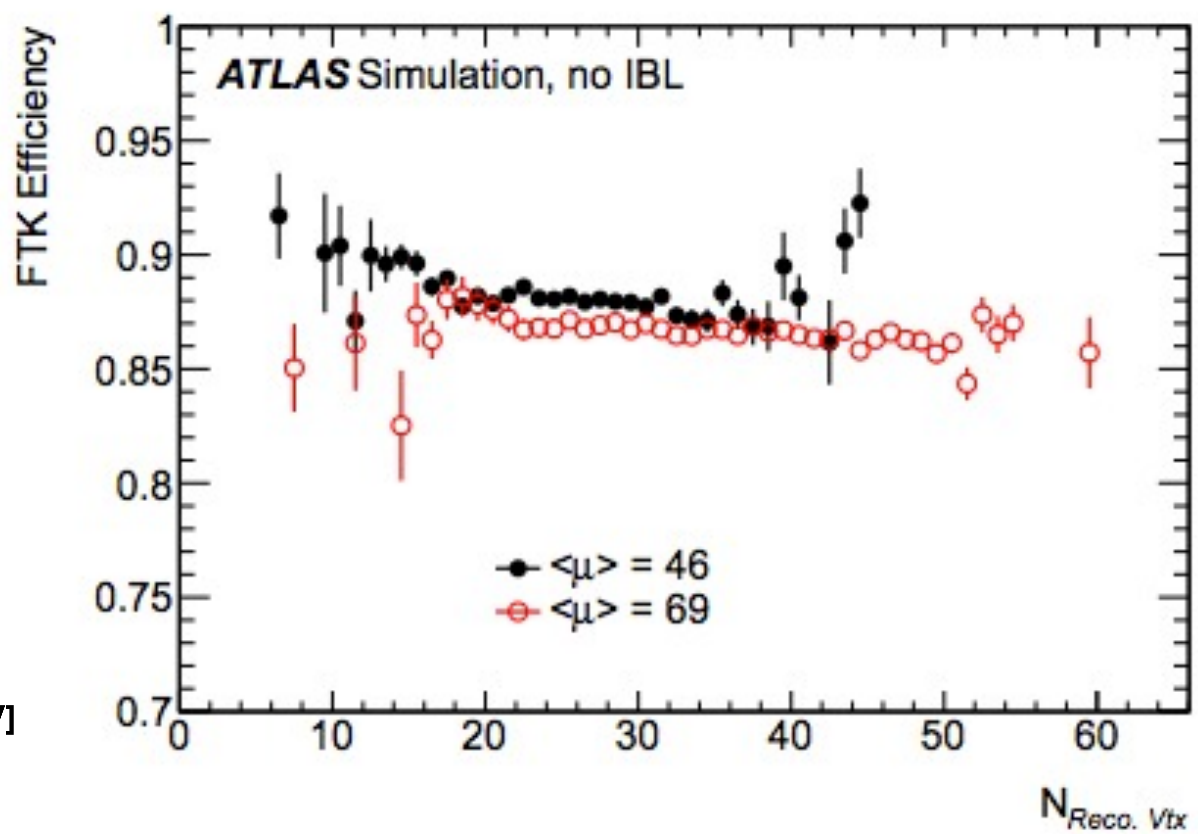




Tracking efficiency in busy environments

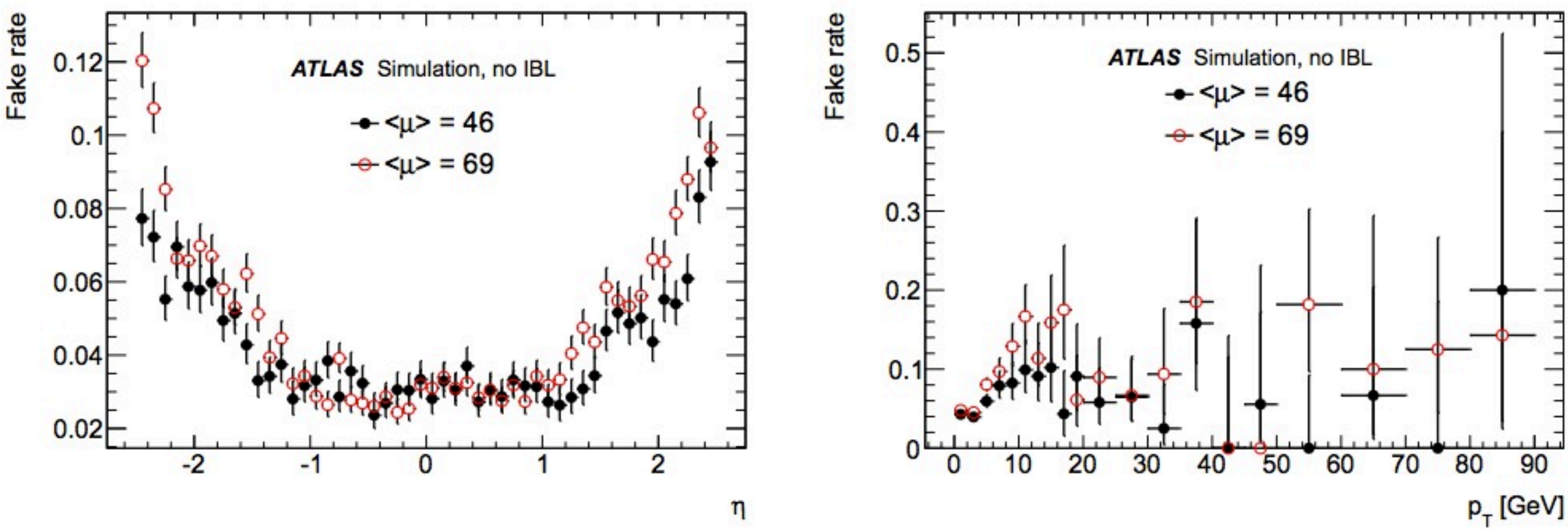
- Using a $t\bar{t}$ sample and in a busy environment
- Tested in simulations of 1.7e34cm^{-2}s^{-1} (<μ> = 46), 2.6e34cm^{-2}s^{-1} (<μ> = 69)
- Efficiency w.r.t Offline (FTK track matched w.in 0.05 of Offline Track)
  - Maintaining a nearly 85-90% efficiency overall





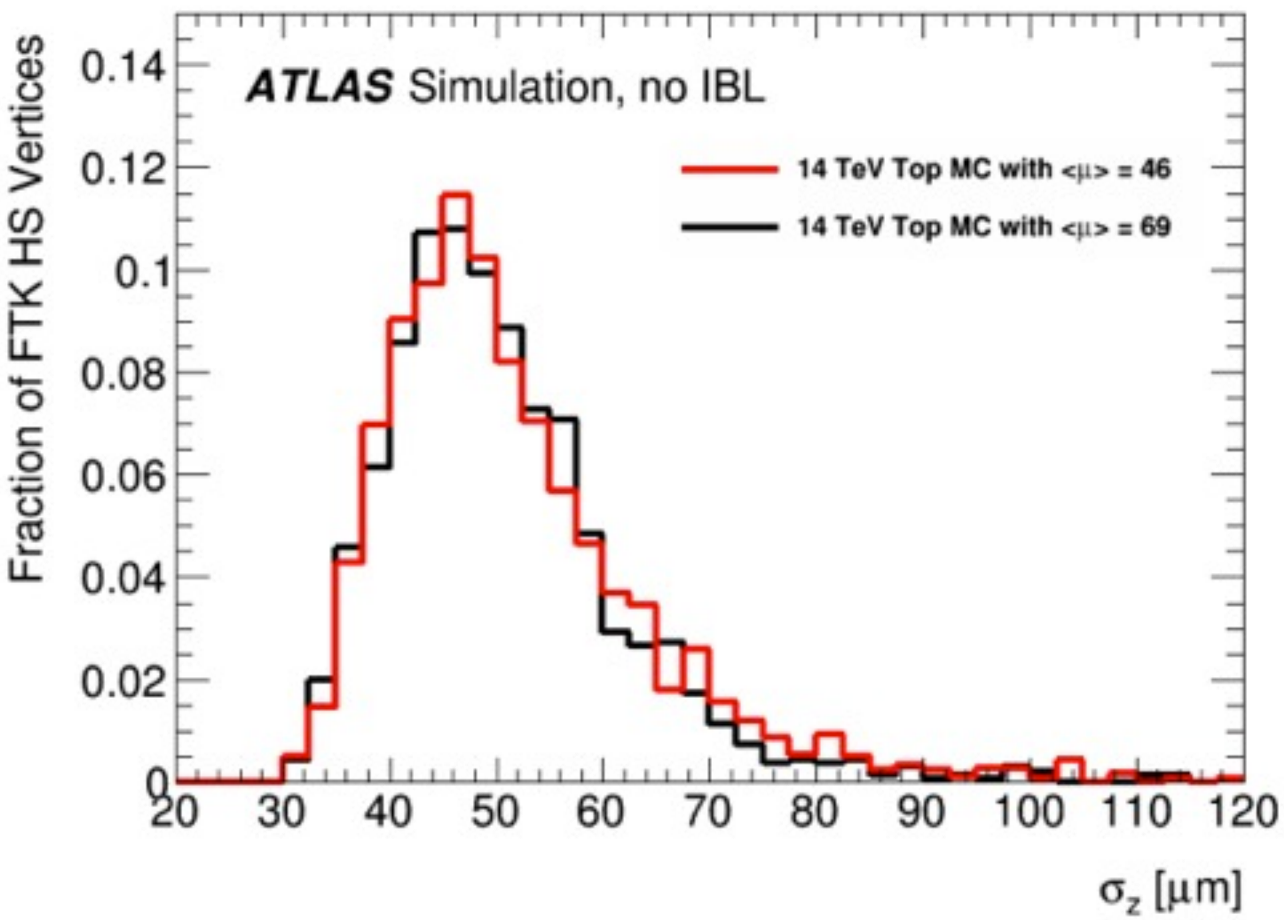
Fake - Track Rates in High Pile Up

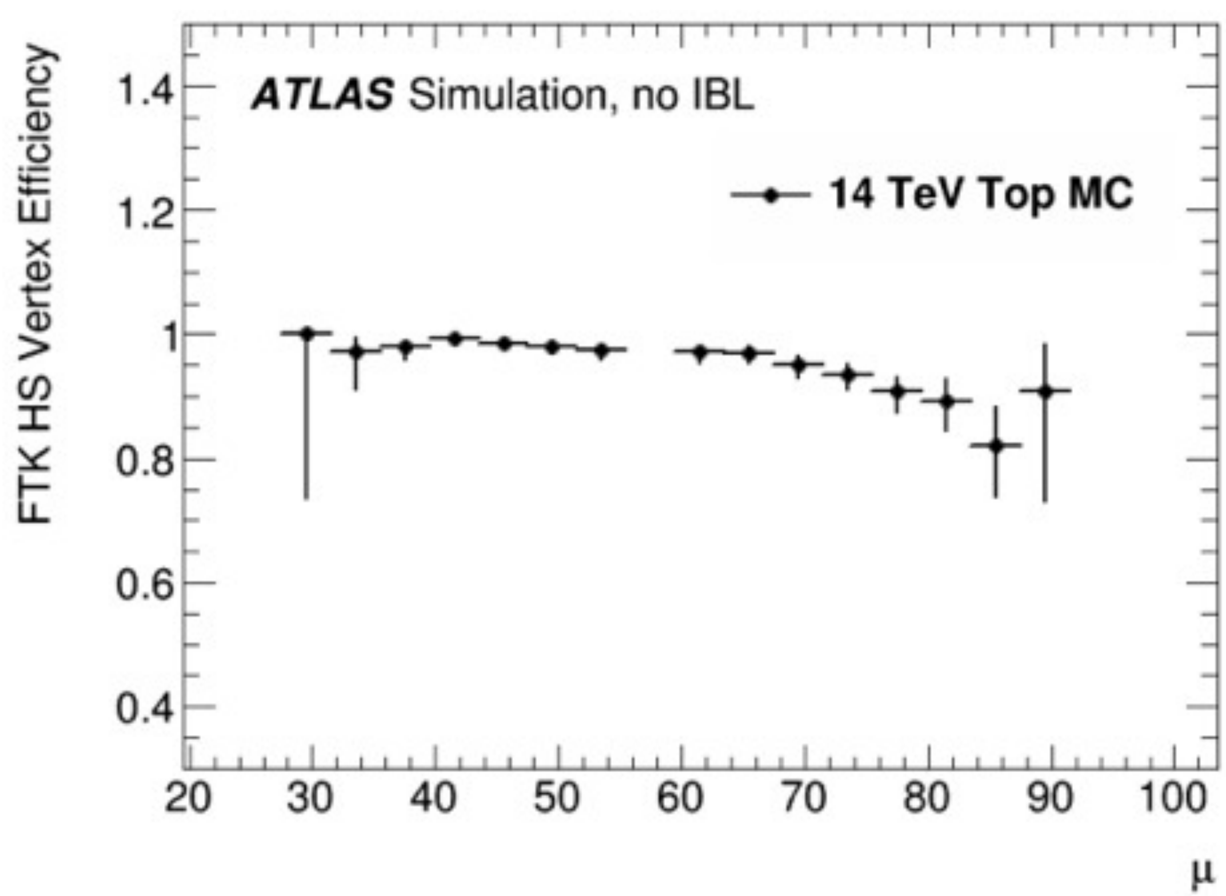
- Match FTK track to offline tracks requiring that 50% of the hits are matched to a single truth particle
- If fewer than 50% of the hits are matched to a single truth particle
  - This track is deemed as fake
- Fake rate less than 3% for the central region, and about 8% in the end caps



Event Information from FTK

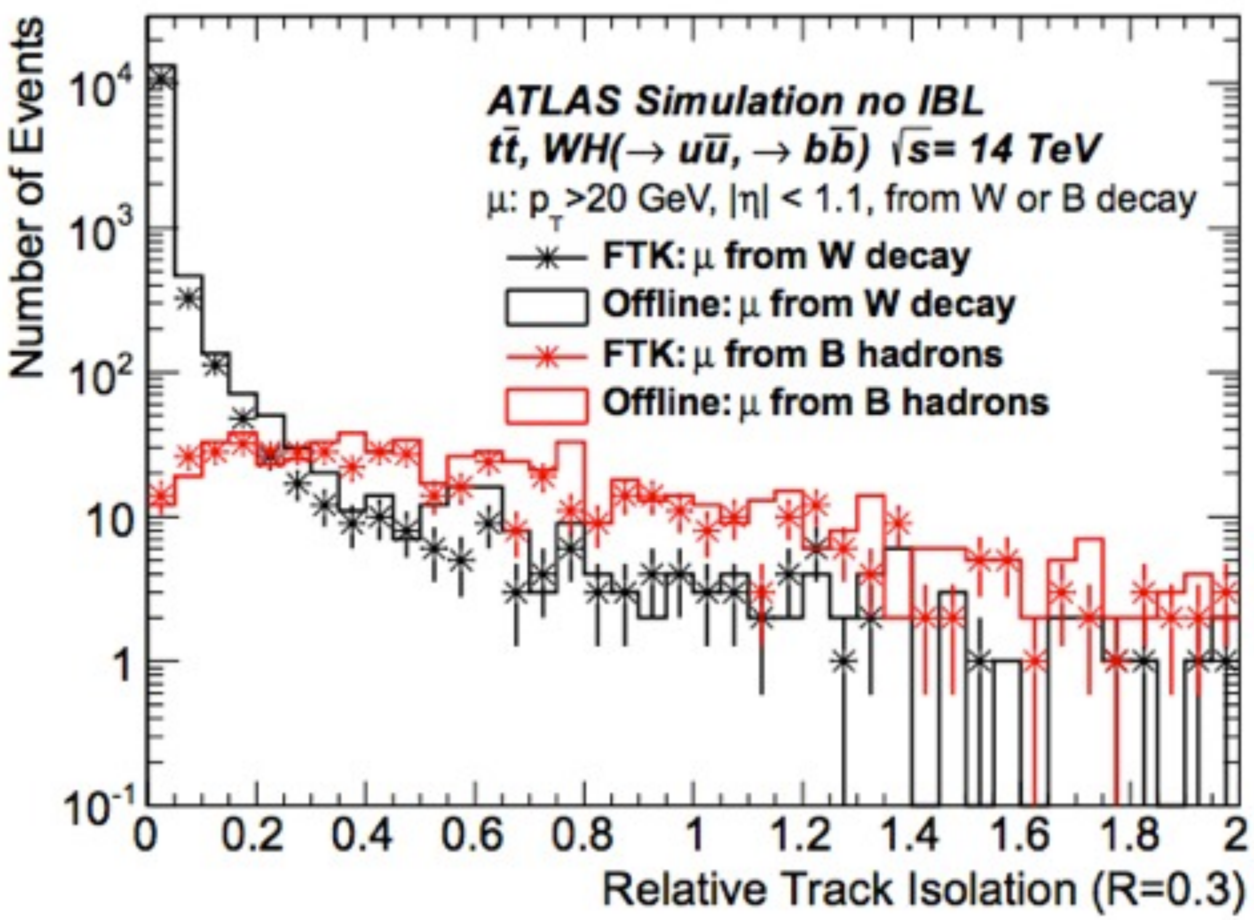
- Reconstruct primary vertices using the full list of tracks
- Can find the hard-scatter primary vertex to within ~50 μm
- Even at high pile up, maintain high efficiency for reconstructing hard-scatter vertex

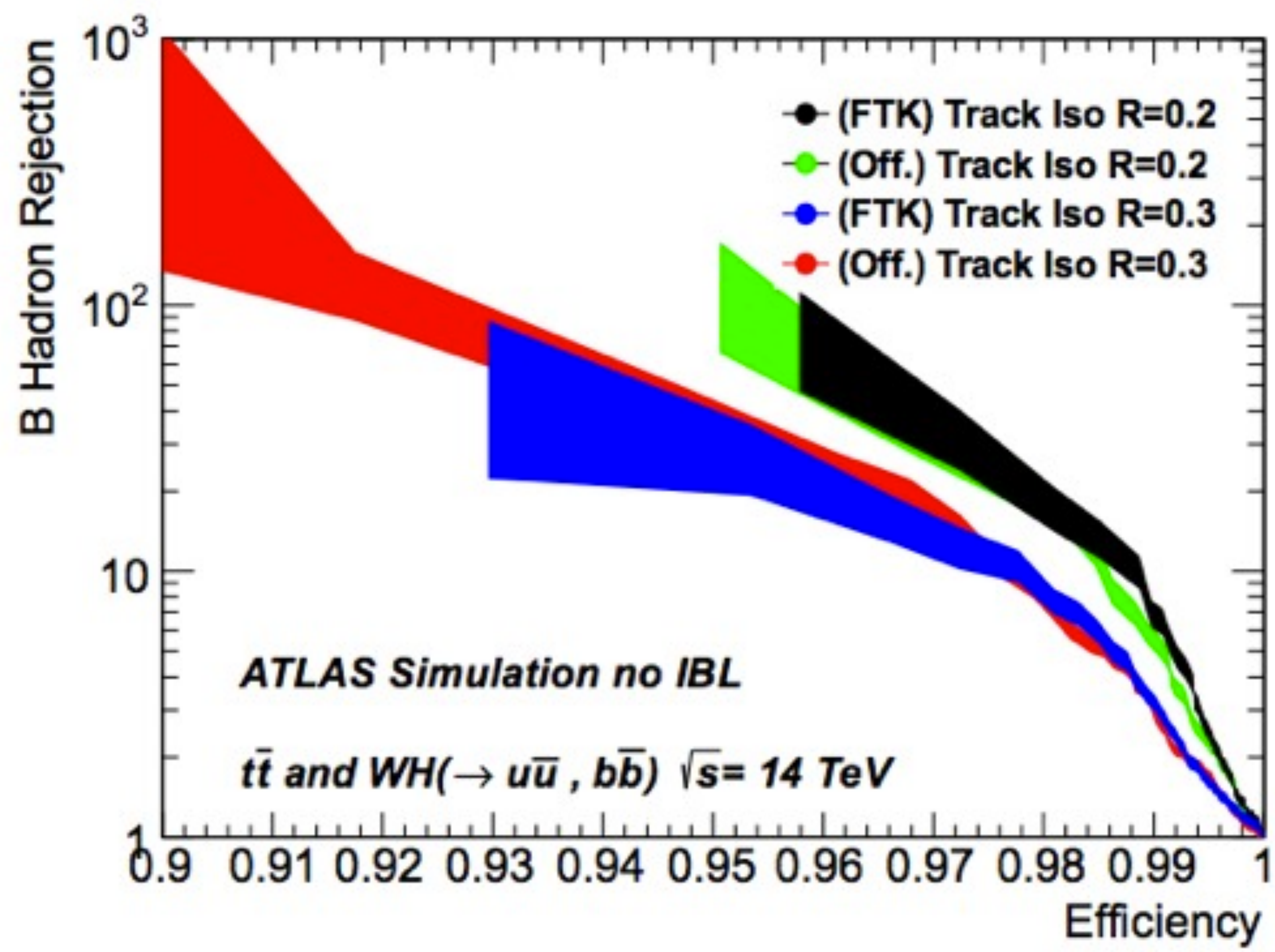




Fast Lepton Isolation

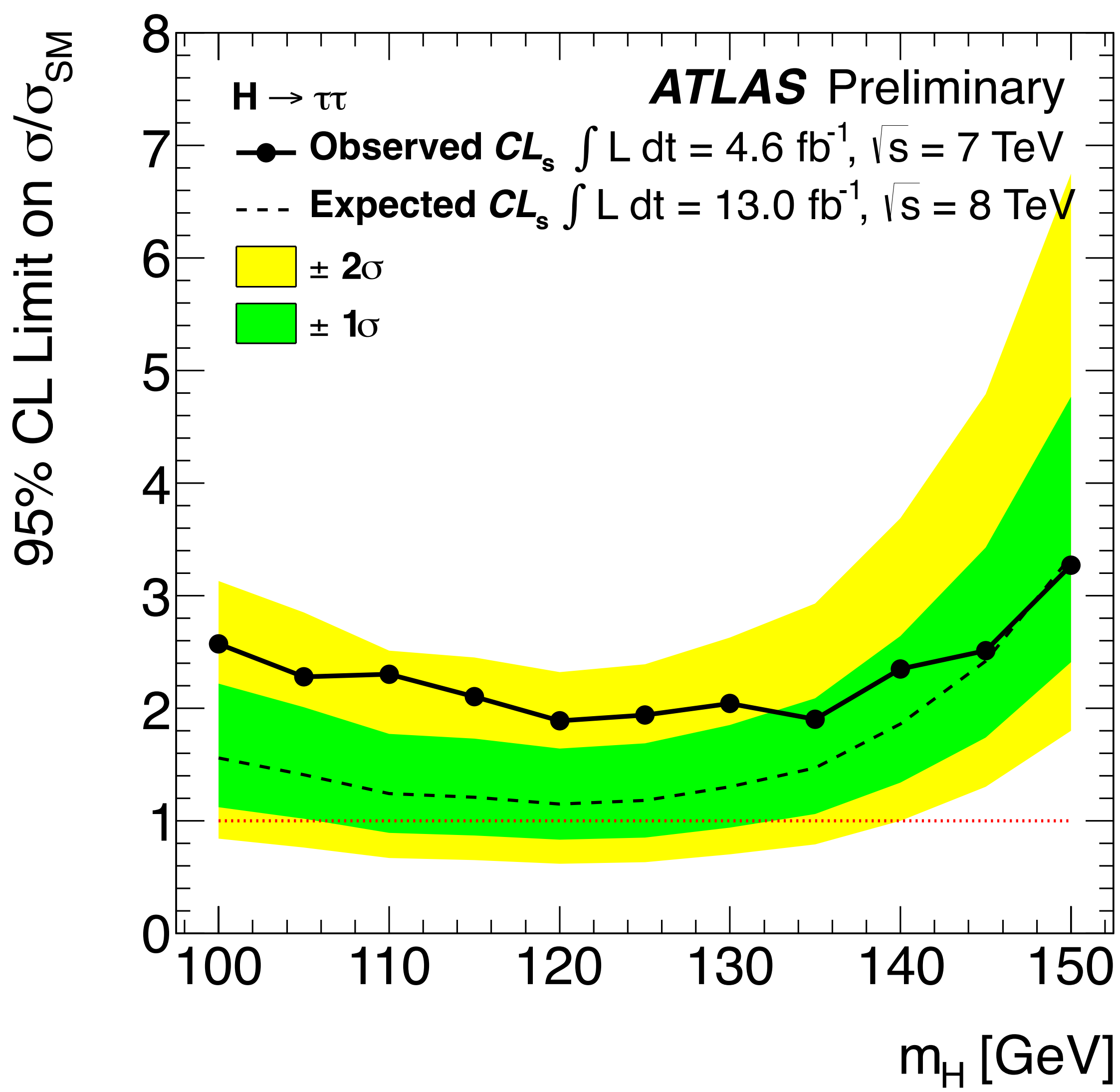
- Leptons from jets likely accompanied by other charged objects
- Reject using track-based isolation
- Comparable rejection or efficiency at Level 2 as at offline

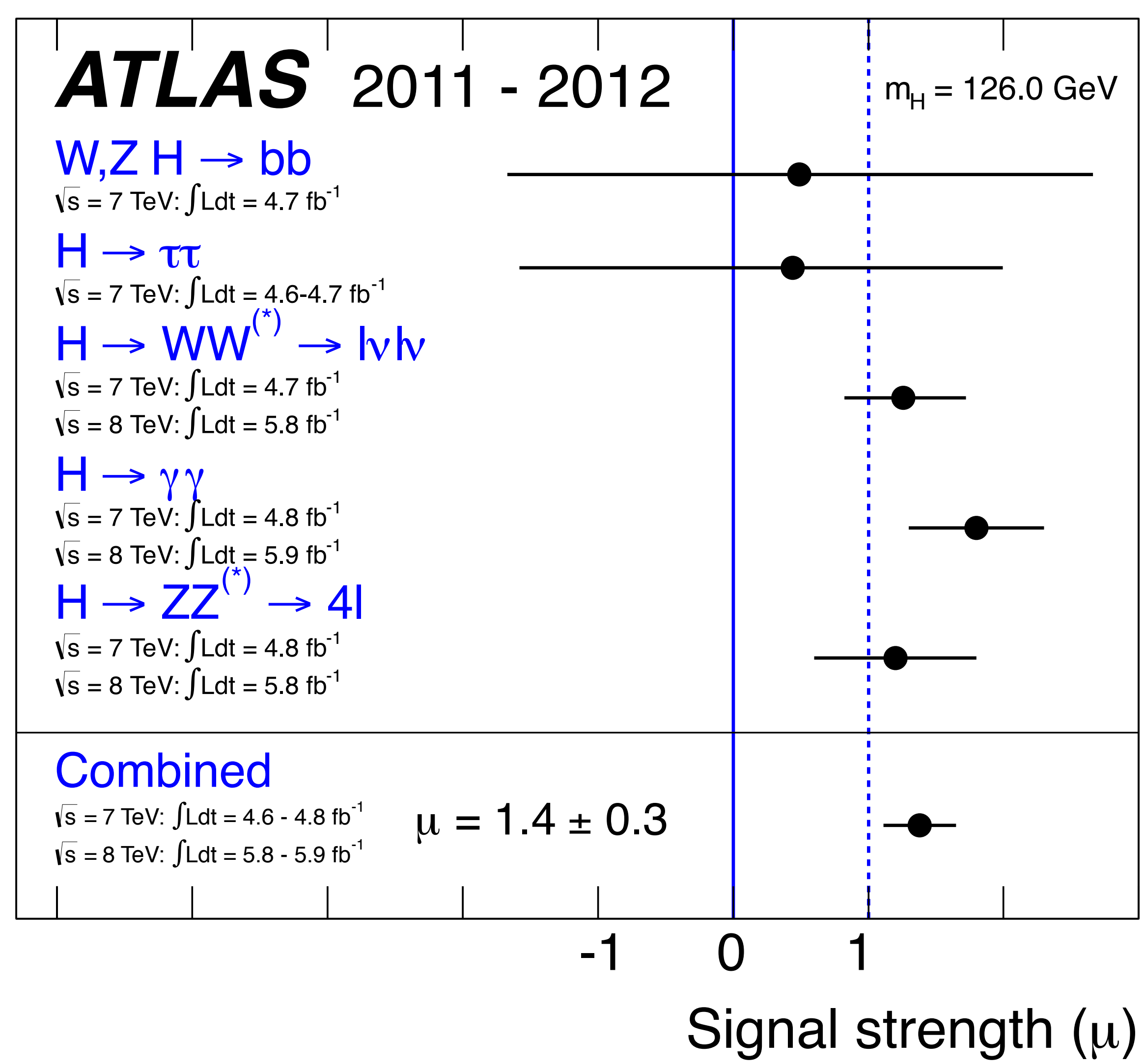




Physics Case: Higgs $\rightarrow \tau^+\tau^-$

- Measuring coupling of Higgs to $\tau+\tau-$ is an important ATLAS physics goal
- Not yet observed in ATLAS, limits set using 4.7 fb^{-1} and 13.0 fb^{-1}
- Using the FTK can help!

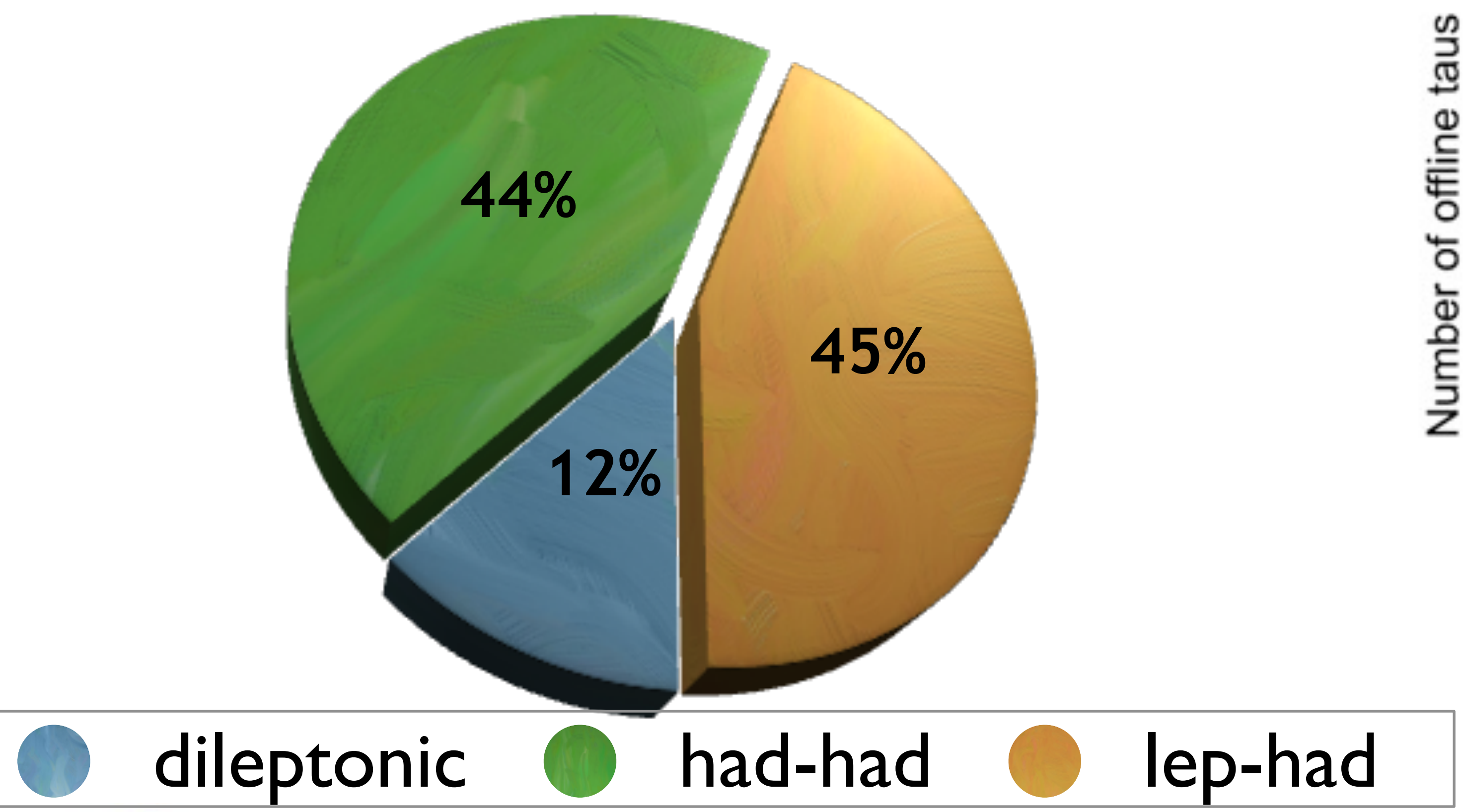




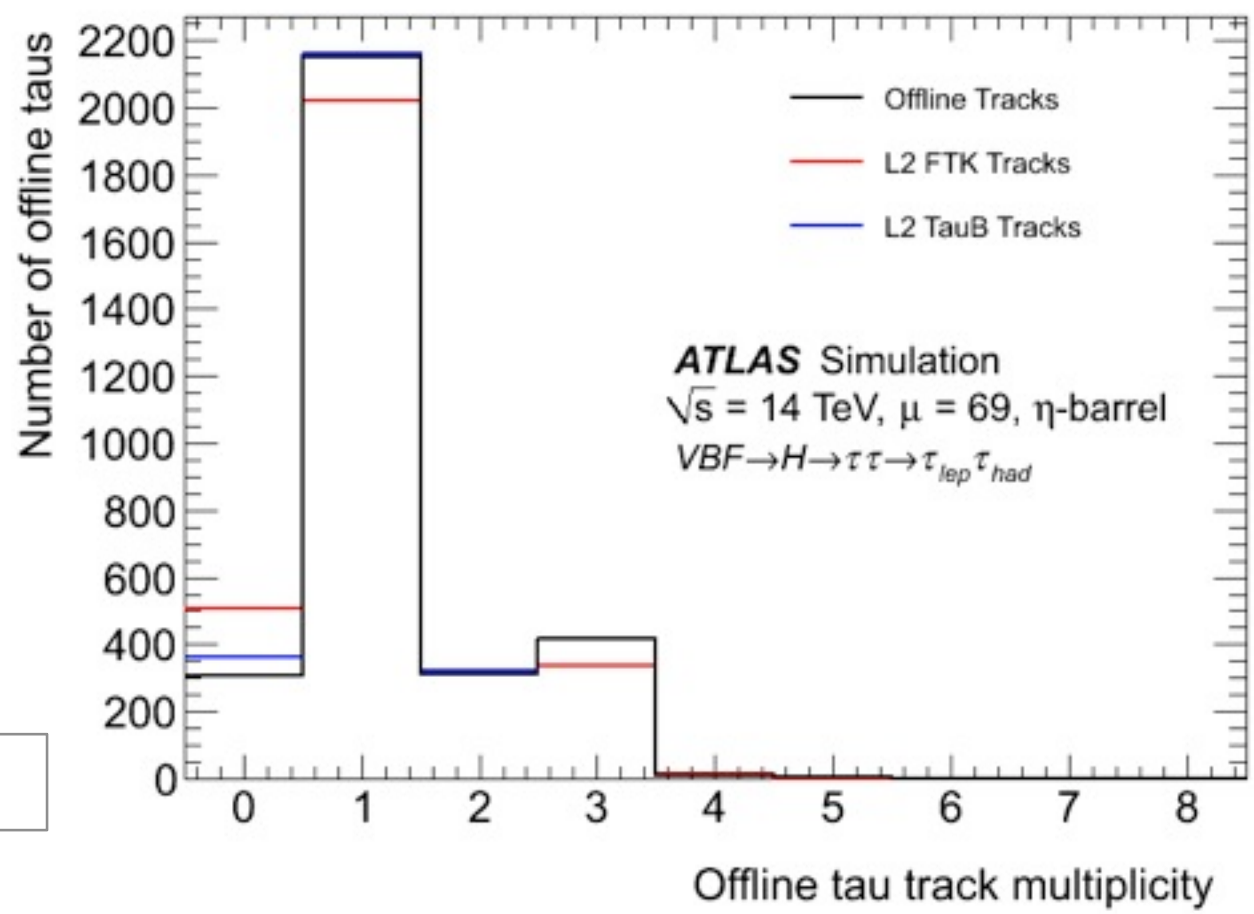
Basics of Tau Identification

- The tau lepton can decay to e's or mu's
  - Relatively easy to select but only occur 34% of the time, e's and mu's are soft
- The tau lepton can also decay hadronically via "one-prong" or "three-prong" modes
  - Hadronic one prong mode occurs ~50% of the time
  - Three prong 15% of the time

Di-tau branching ratios

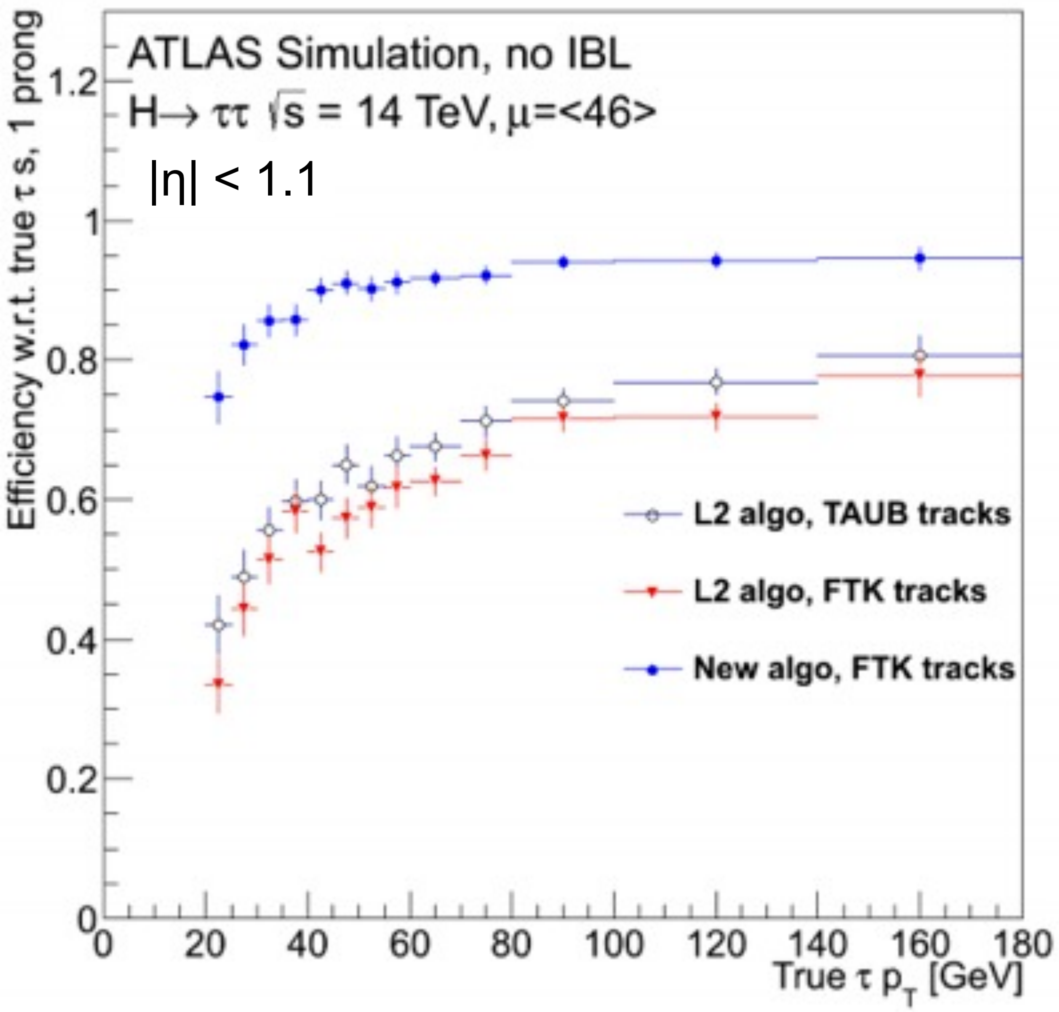


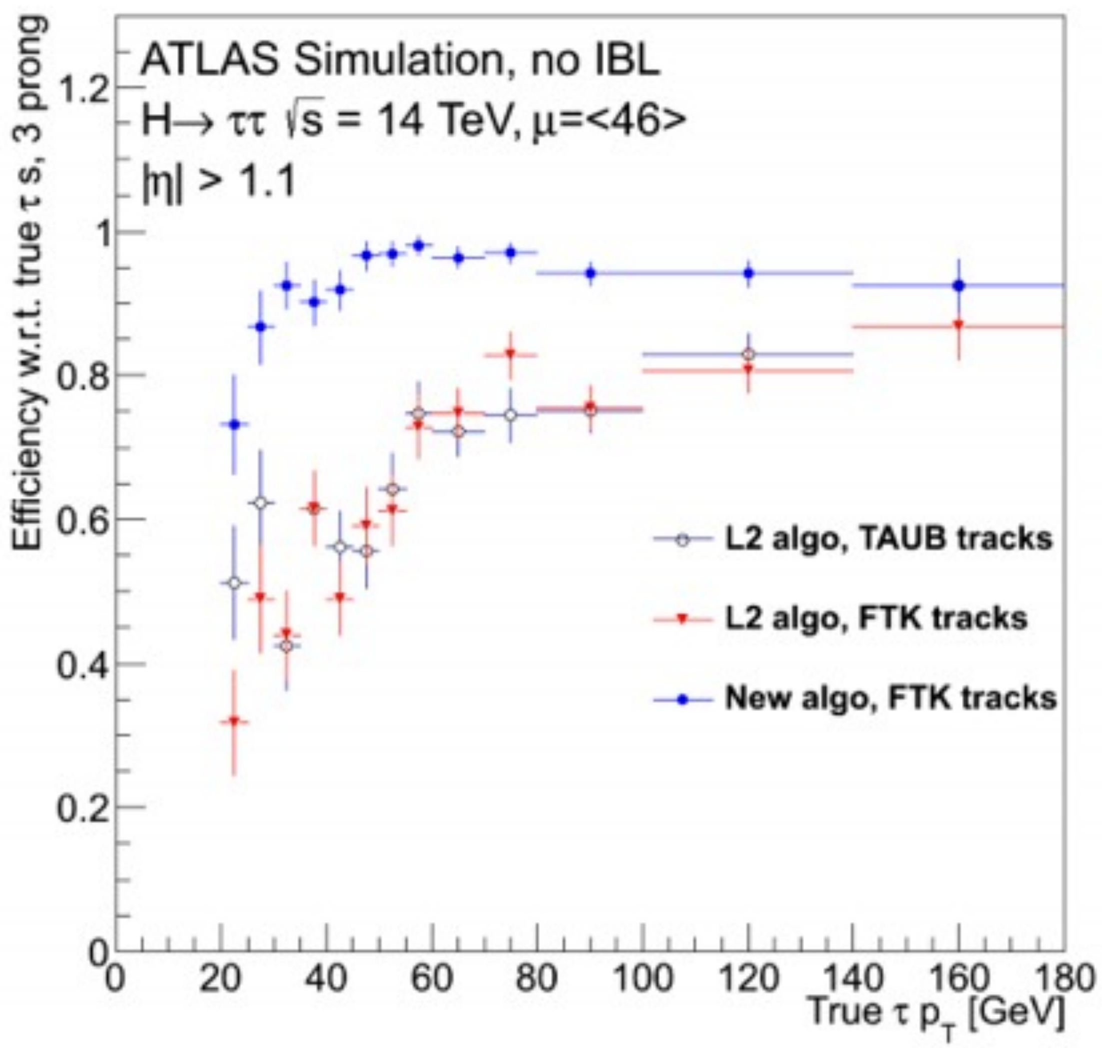
Tracks matched to hadronic taus



FTK can help increase the hadronic taus

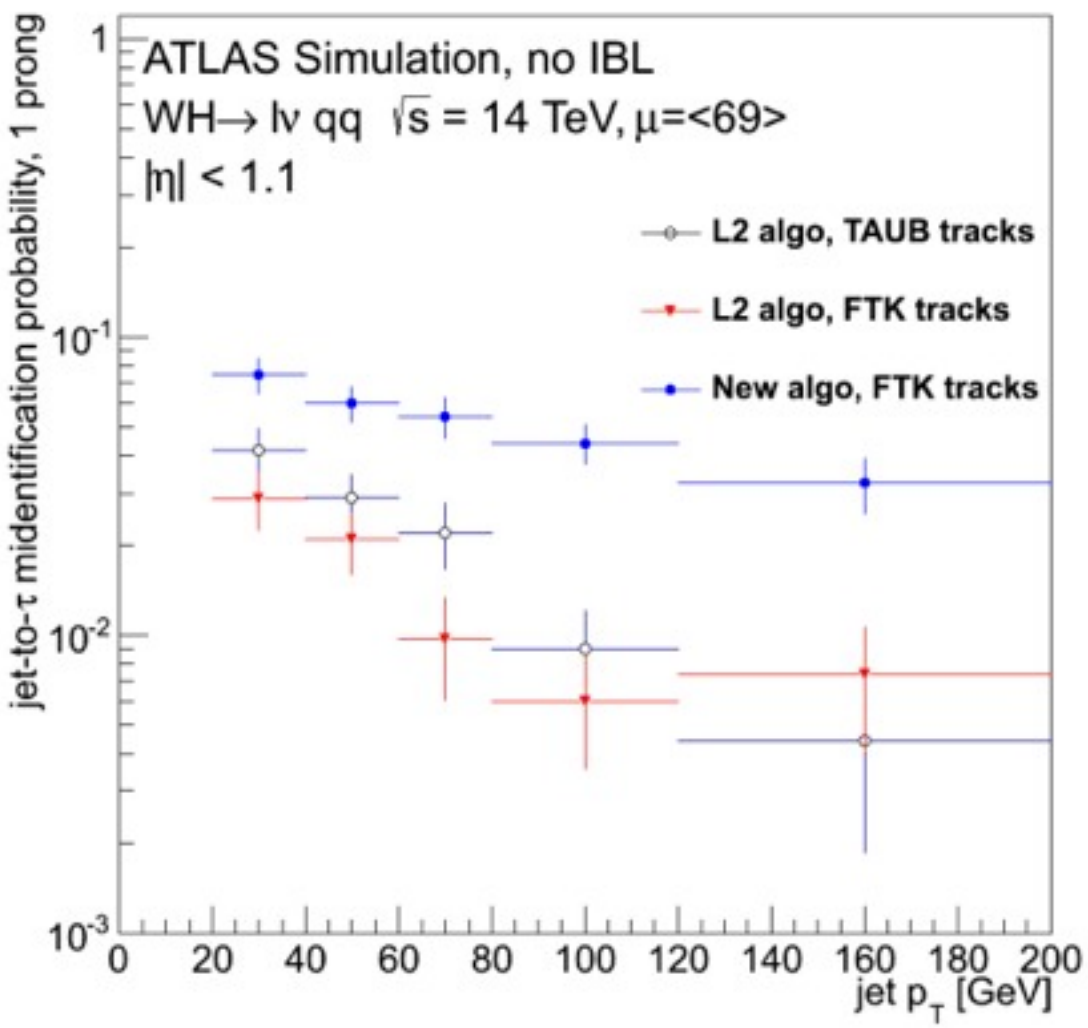
- More true taus saved using additional tau identification provided by FTK
- Applying an algorithm using FTK tracks, and calorimeter information can save 90% of true taus
  - Nearly doubling the efficiency of saved tau candidates

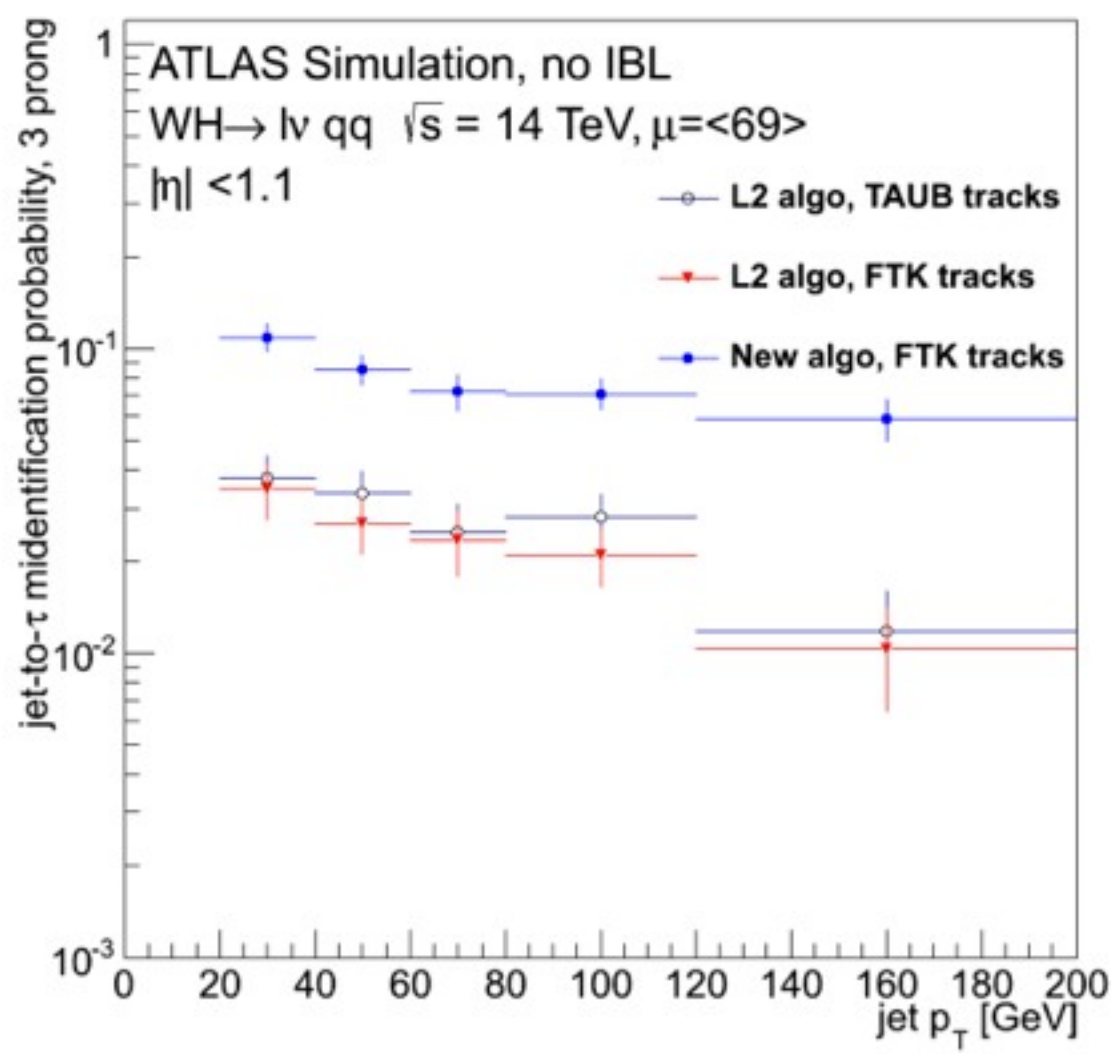




Tau misidentification rate

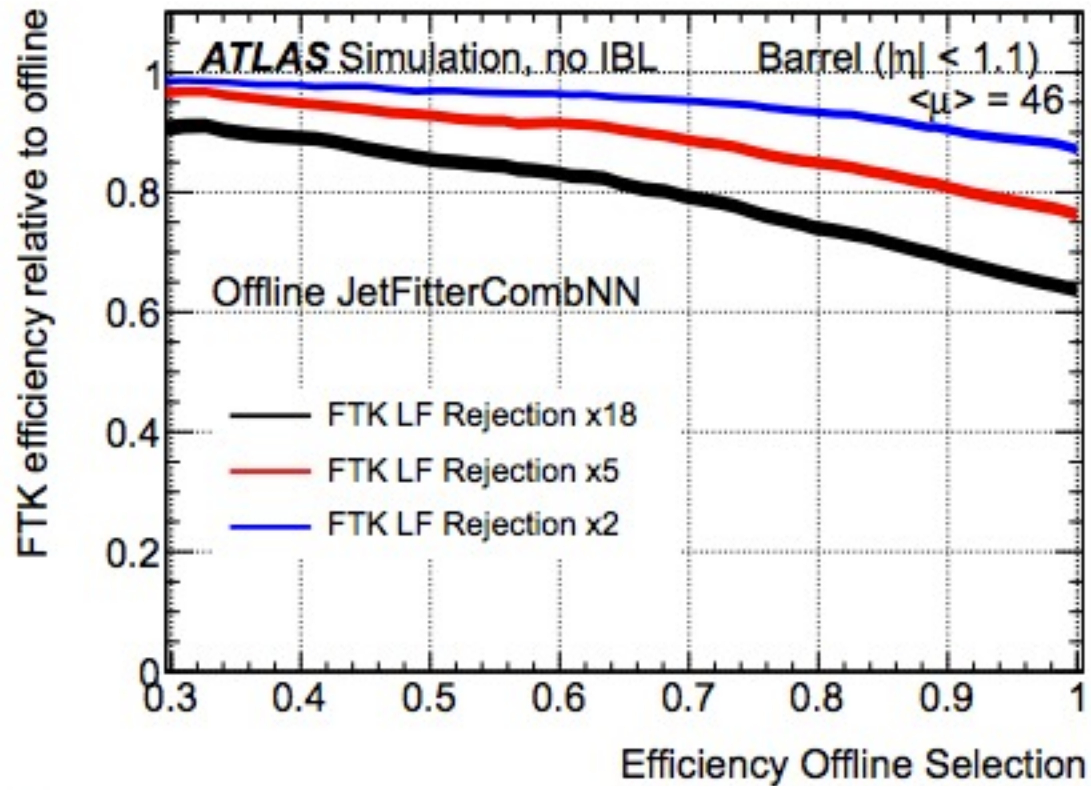
- More accepted taus, leads to more misidentified taus
- Fake rate rises by a factor of two, but this is a manageable rate for Level 2
- Further rejection can be done upstream
  - But if the taus are not accepted by the trigger, they are lost

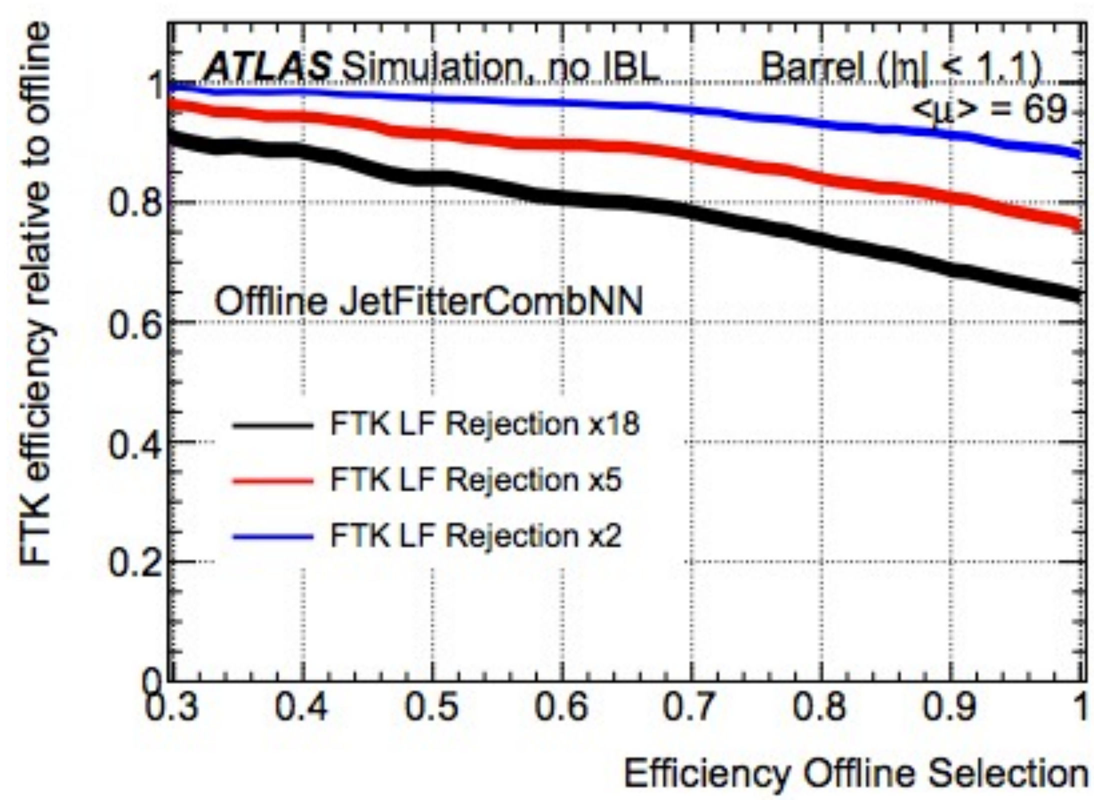




FTK and B-jet tagging

- FTK tracks in jets can be used to b-tag them at Level 2
- Different b-tagging operating points
  - Allows varying sensitivity for b-tagging
- Provide early rejection of light-jets
  - Free up bandwidth to run offline selection
- Improvements to FTK-based b-tagging may be possible
- Jet Vertex Fraction cuts can identify jets coming from the hard scatter





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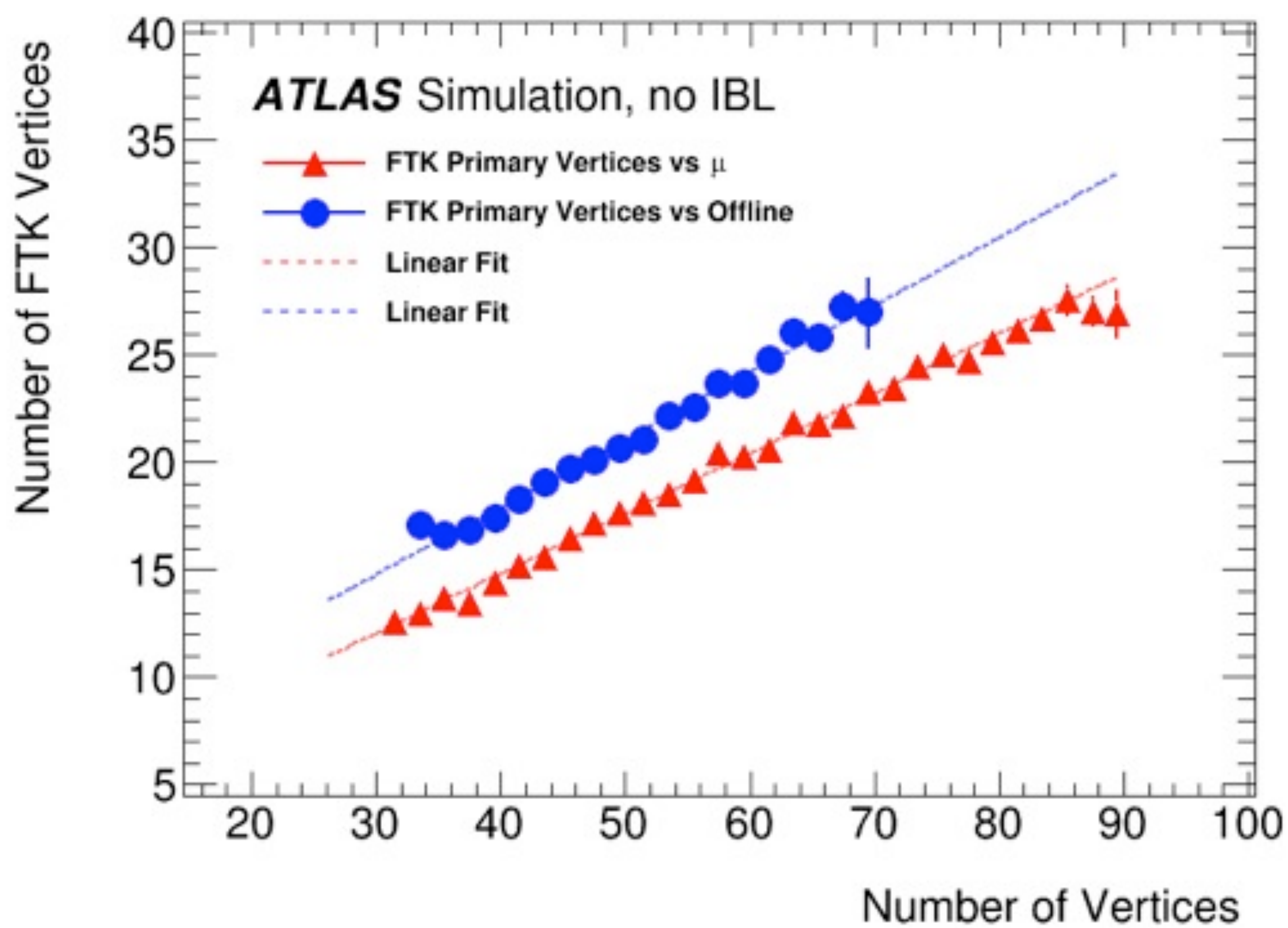
Other possible improvements

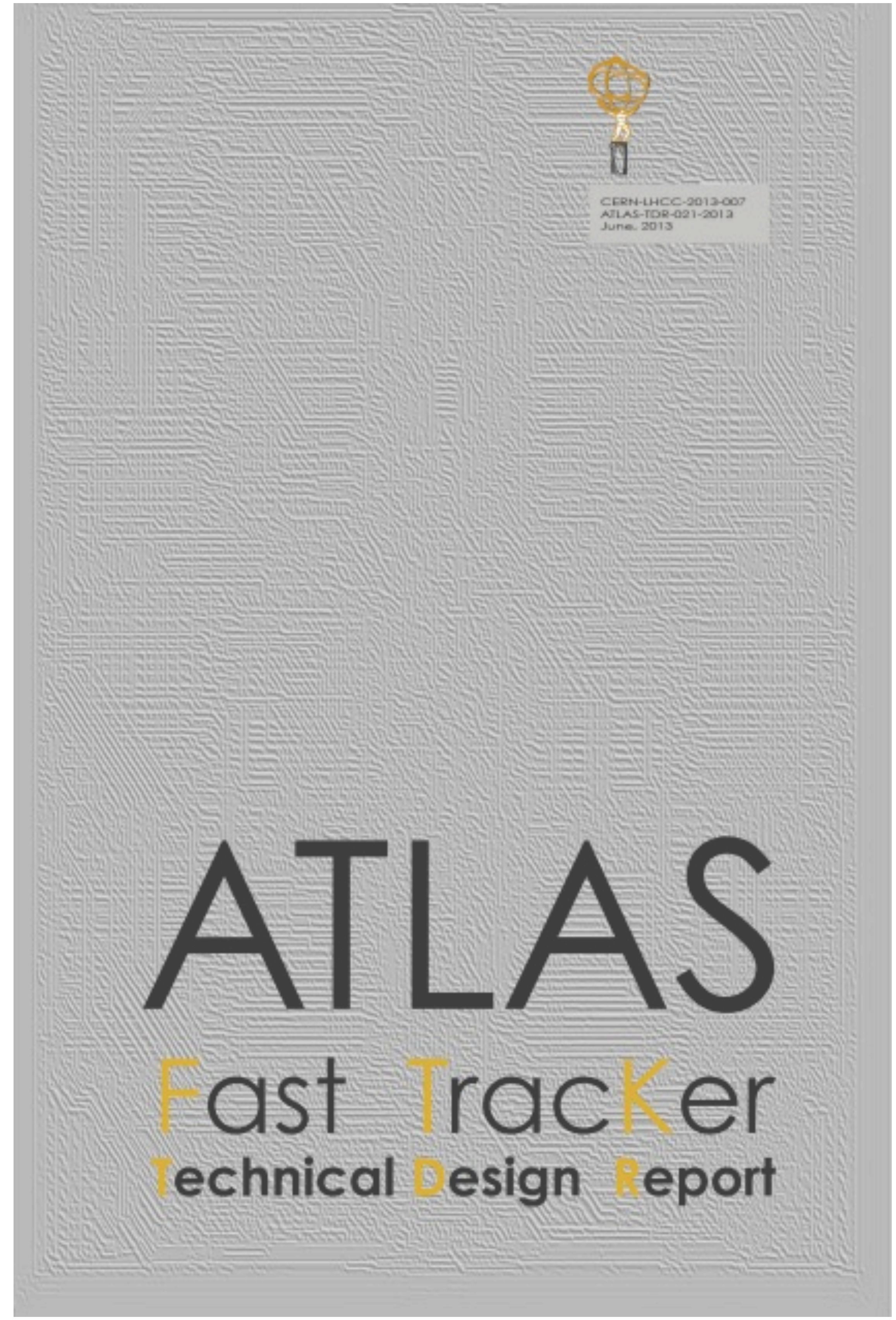
- FTK tracks may be used to help identify total number of primary vertices
  - Useful for jet calibrations
- Identify events with real missing transverse energy
- May be able to aid in beamspot finding as well



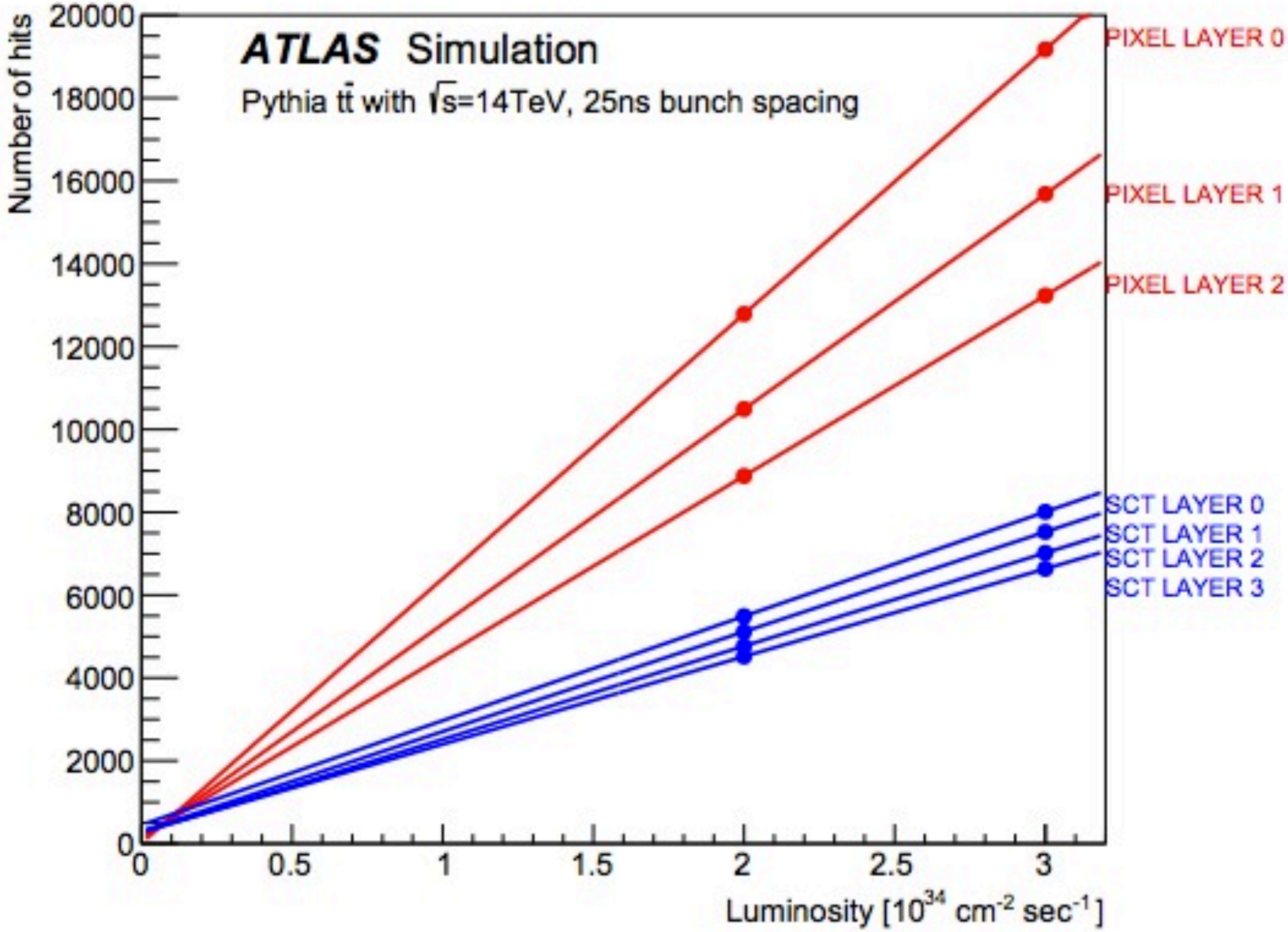
Conclusions

- Initial performance studies have been completed
  - Several ways to help improve background rejection or signal efficiency proposed
- Providing new information which can be incorporated into L2 triggers
- Hardware installation has begun, prototype board testing ongoing
- Many more results in the FTK TDR
  - https://cds.cern.ch/record/1552953?ln=en

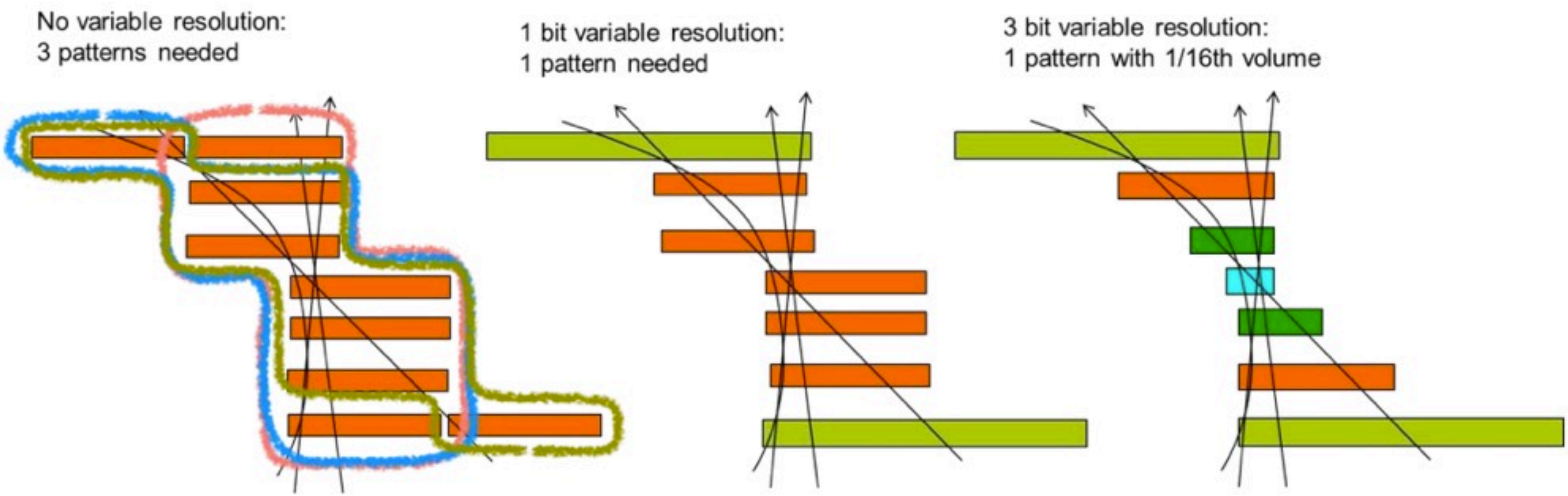
- Very exciting times for the ATLAS FTK in 2014



Inner detector occupancy vs. instantaneous luminosity

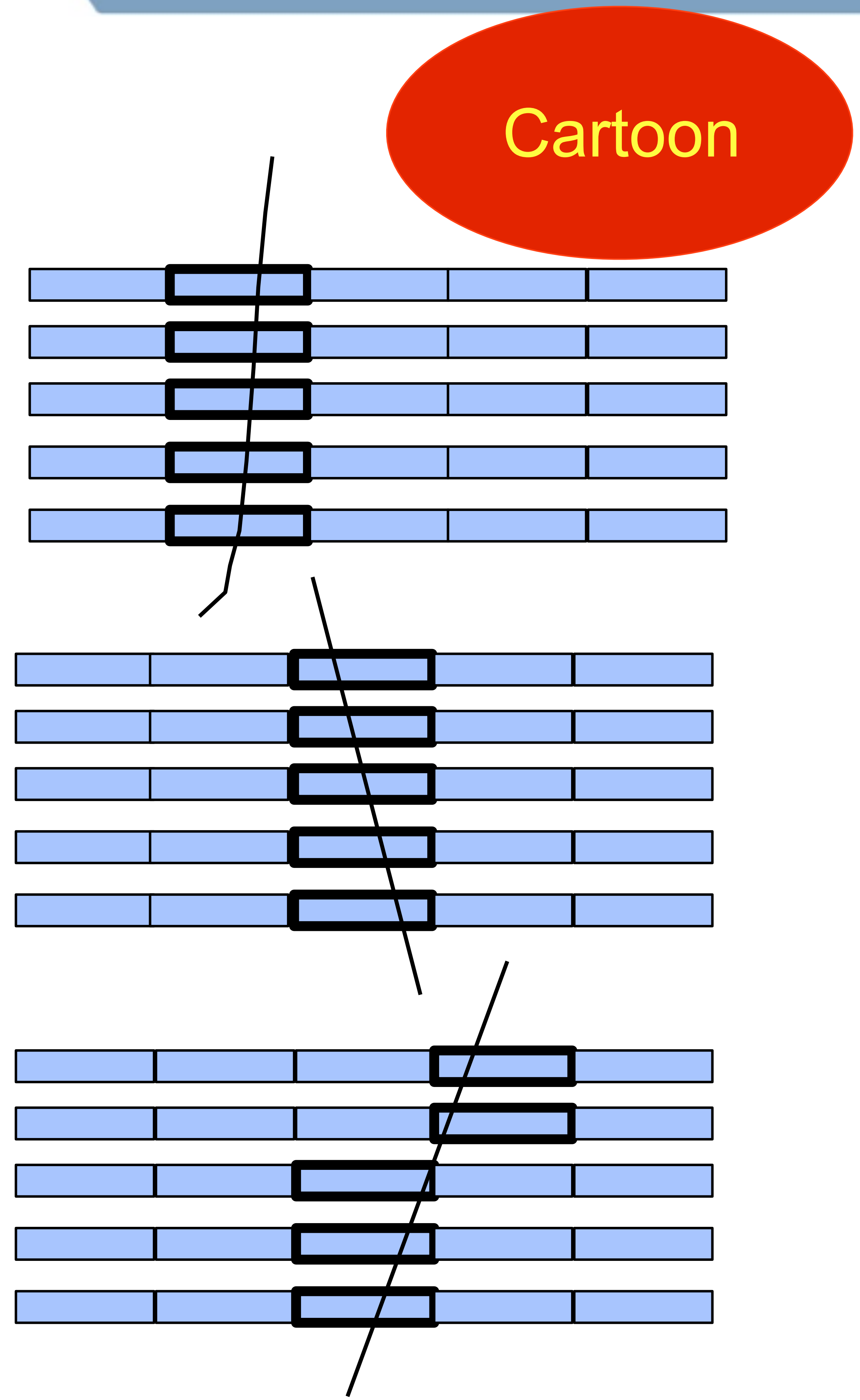


Variable layer resolution



Track Finding

- Start with an simulation of perfect ATLAS inner detector
- Divide the detector into 64 eta-phi towers (16 in phi, 4 in eta)
  - Parallel processing
- Coarse resolution roads are saved in Associative Memories
  - Road widths optimized
  - Trained using MC
  - Super-strips used rather than looking at individual hits
  - Create massive lookup table of the SS patterns from training
- Only 8 (of 12) layers used for training: 5 SCT and 3 pixel layers



Track Finding

- All detector hits enter an AM board as the data is being taken
- Simultaneously compared to all stored patterns
- Matching pattern IDs and the hits sent to the next stage
- Hits not matching a pattern are not passed to the next stage
- Matched pattern IDs with 1 missed hit are also passed to the next stage