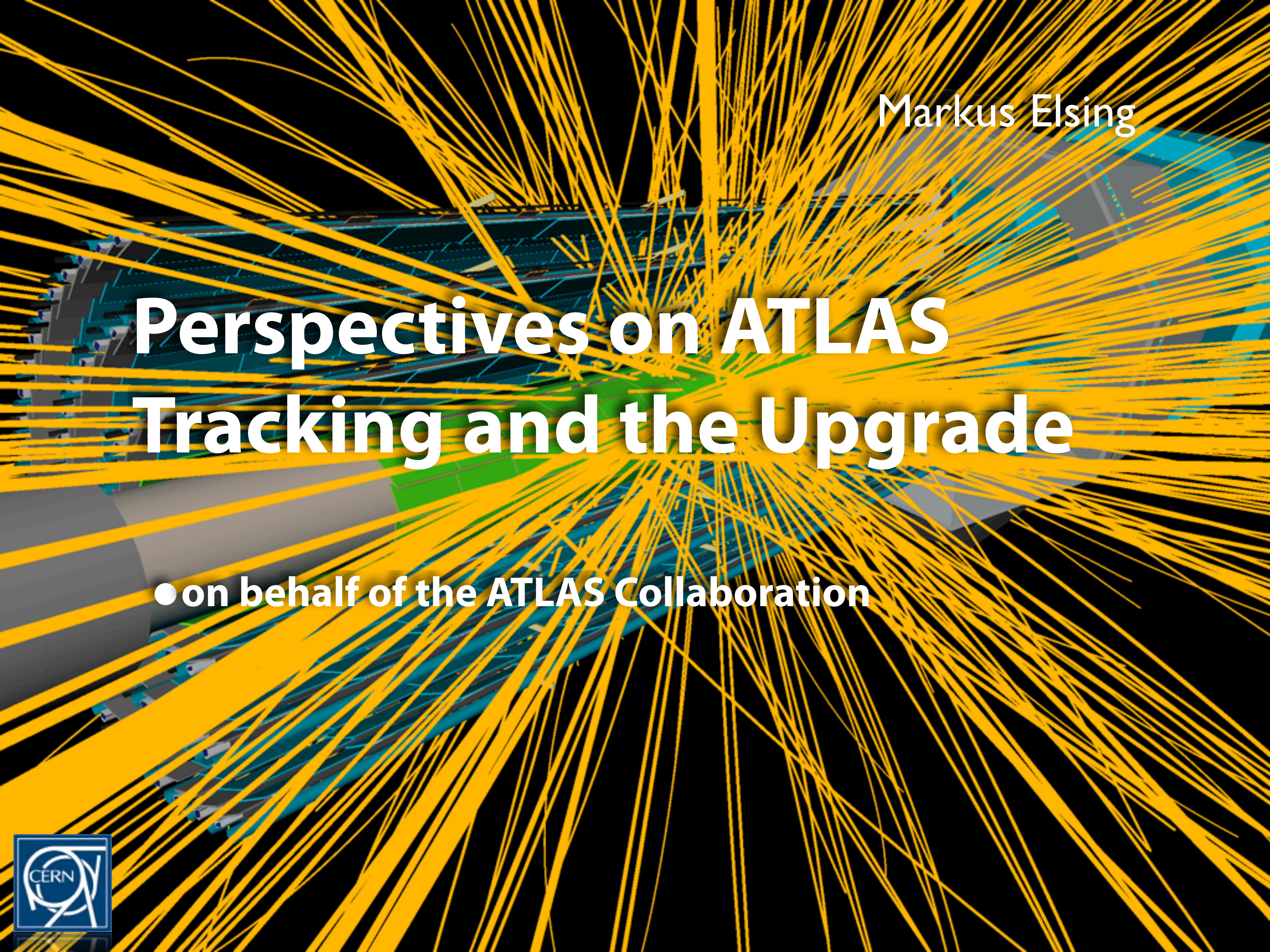


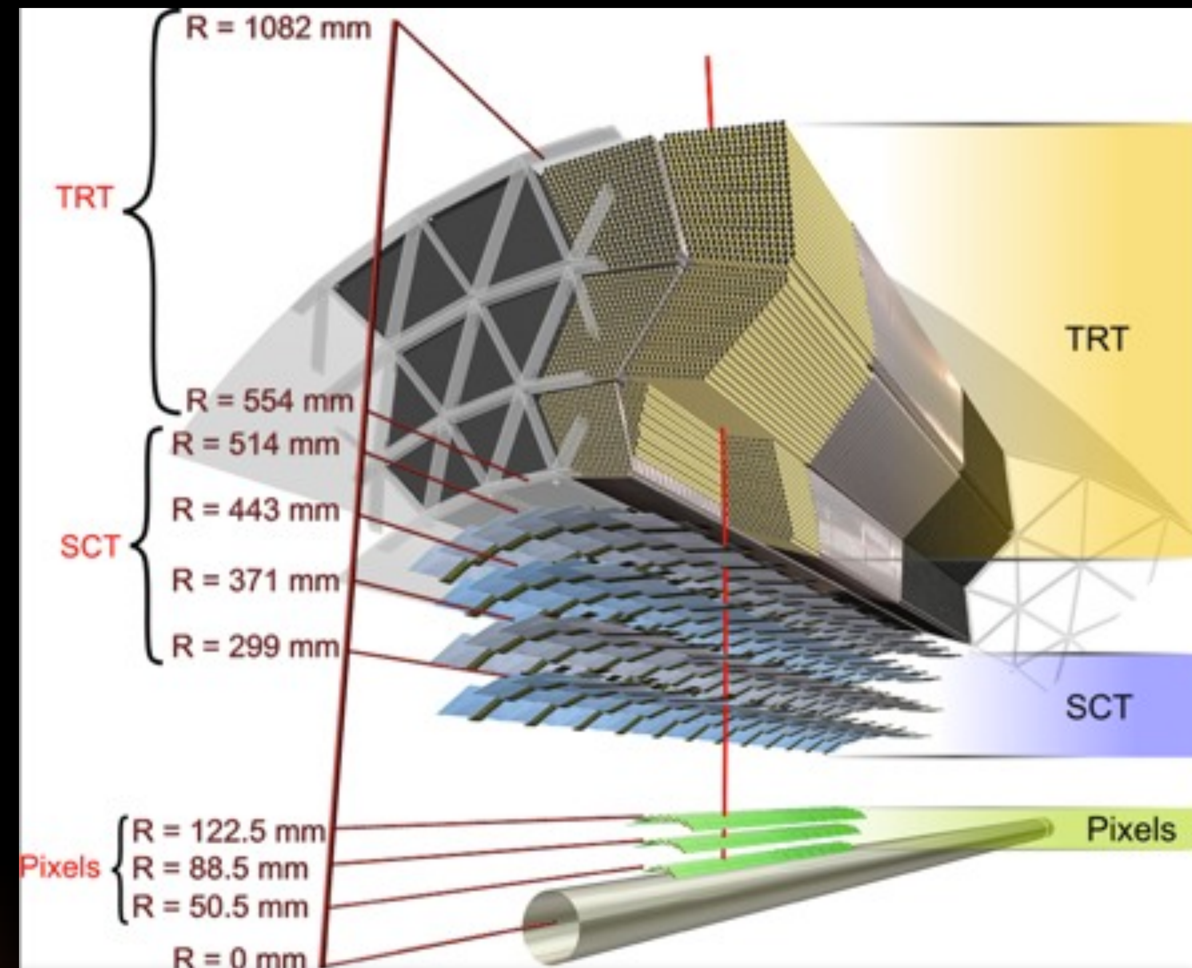
Markus Elsing

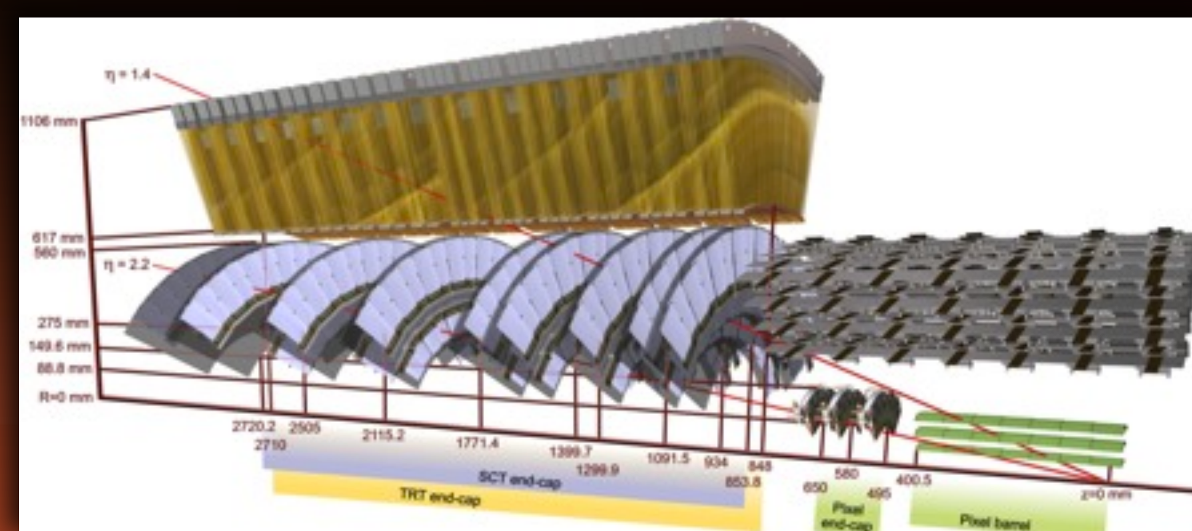
Perspectives on ATLAS Tracking and the Upgrade

- on behalf of the ATLAS Collaboration

ATLAS Inner Detector

- requirements to cover ATLAS physics program
  - ➡ precision tracking at LHC luminosities with a hermitic silicon tracker covering over 5 units in eta
  - ➡ Pixel Detector for precise primary vertex reconstruction and to provide excellent b-tagging
  - ➡ reconstruct electrons and converted photons, including transition radiation in TRT for electron identification
  - ➡ tracking of muons combined with toroid Muon Spectrometer
  - ➡ enable tau reconstruction
  - ➡ V0, b- and c-hadron reconstruction, ...
  - ➡ **and:** fast tracking for high level trigger

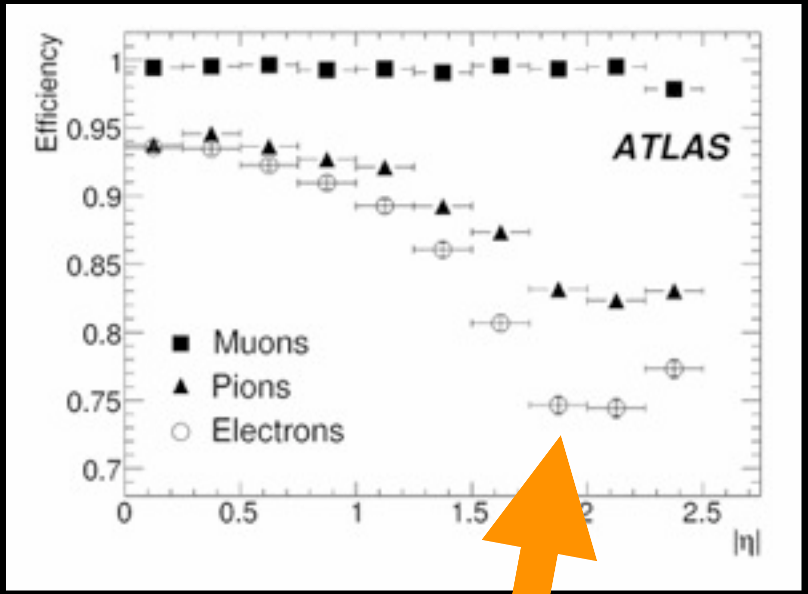


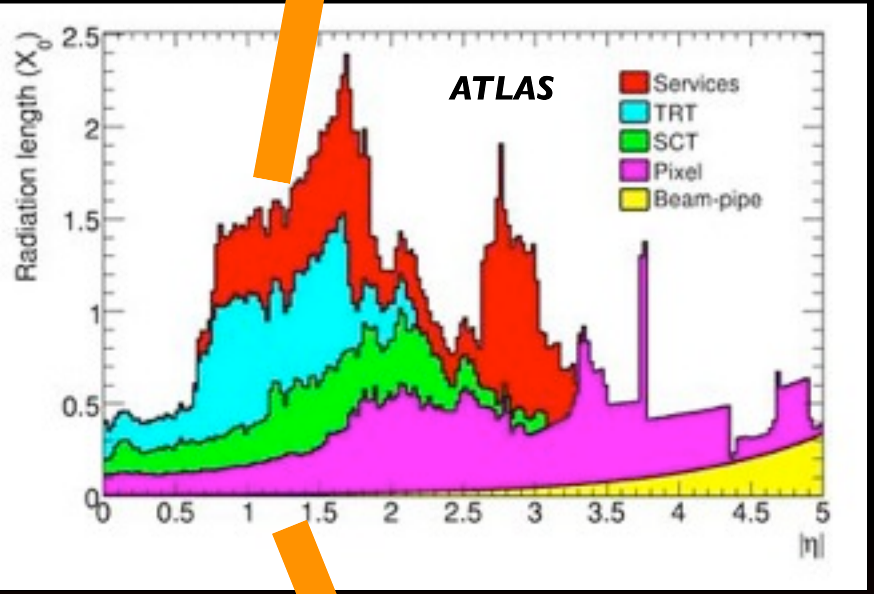


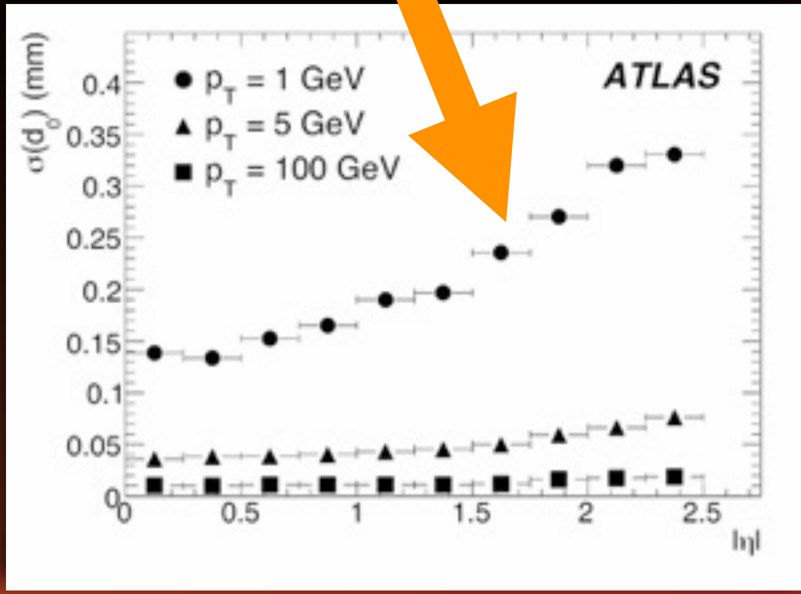
- how to reach those goals ?
  - ➡ give feeling on complexity of those tasks
  - ➡ ... focus on offline side of things

Expected Performance

- excellent preparation before startup
  - ➡ more than 10 years of simulation and test beam
  - ➡ cosmics data taking in 2008 and 2009
  - ➡ payed off last year !
- detailed simulation studies
  - ➡ document expected performance
  - ➡ few of the known critical items:
    - – material effects limit efficiency and resolution at low p_t
    - – good (local) alignment for b-tagging
    - – momentum scale and alignment "weak modes"
- tracking optimization before startup
  - ➡ robust design of tracking software
    - – common tracking and vertexing project
  - ➡ several redesign phases to optimize both:
    - – physics
    - – CPU and memory usage

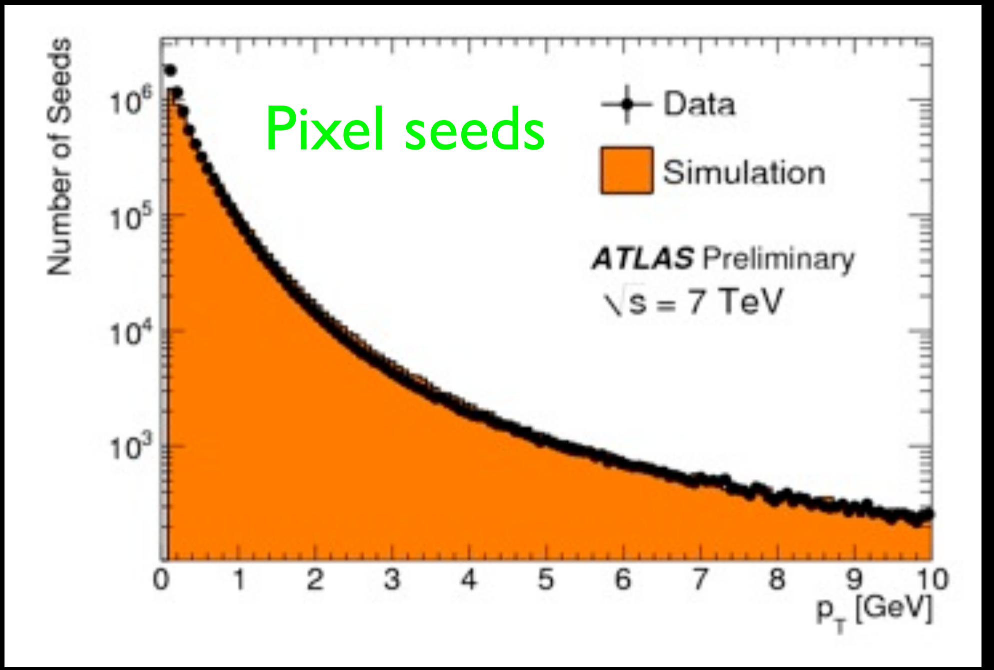


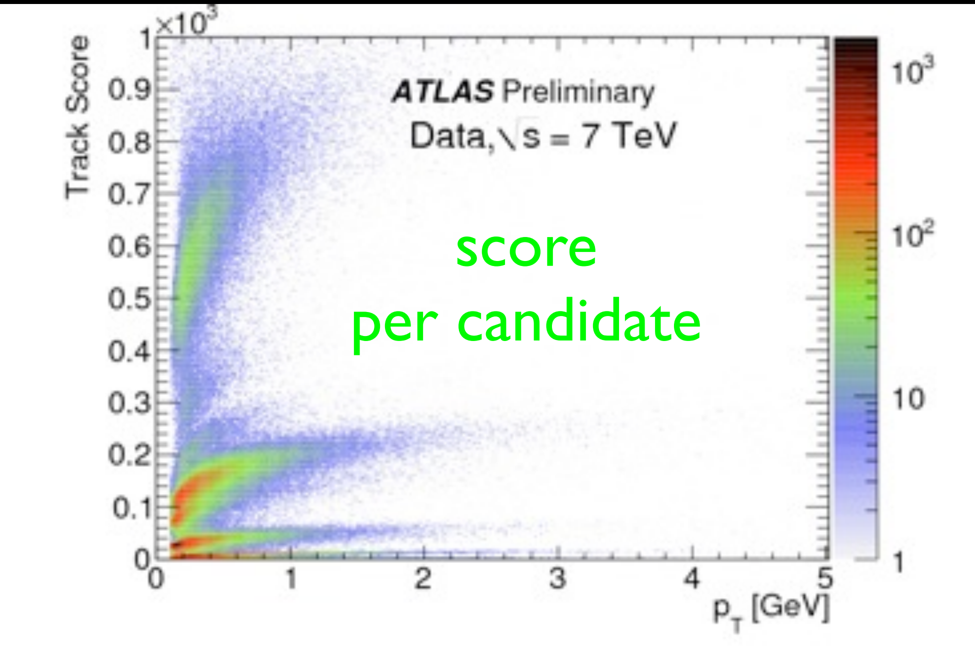


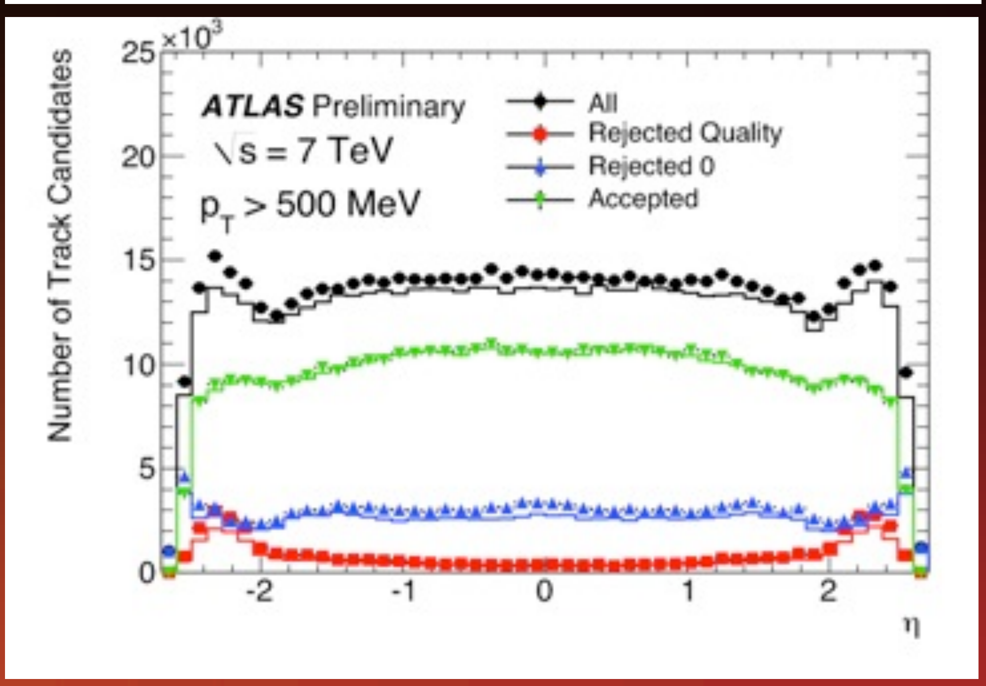


Track Reconstruction

- staged track reconstruction
  - ➡ inside-out: Pixel seeded + extending outwards
  - ➡ outside-in: seeded on TRT segments
- monitor and optimize performance at different levels in reconstruction
  - ➡ seeding / candidate fitting / ambiguity / TRT ex.
- ensure “robustness”
  - ➡ allow for dead/noise modules
  - ➡ error scaling to reflect calibration + alignment
- very good performance even with early data
  - ➡ example: results from summer 2010...

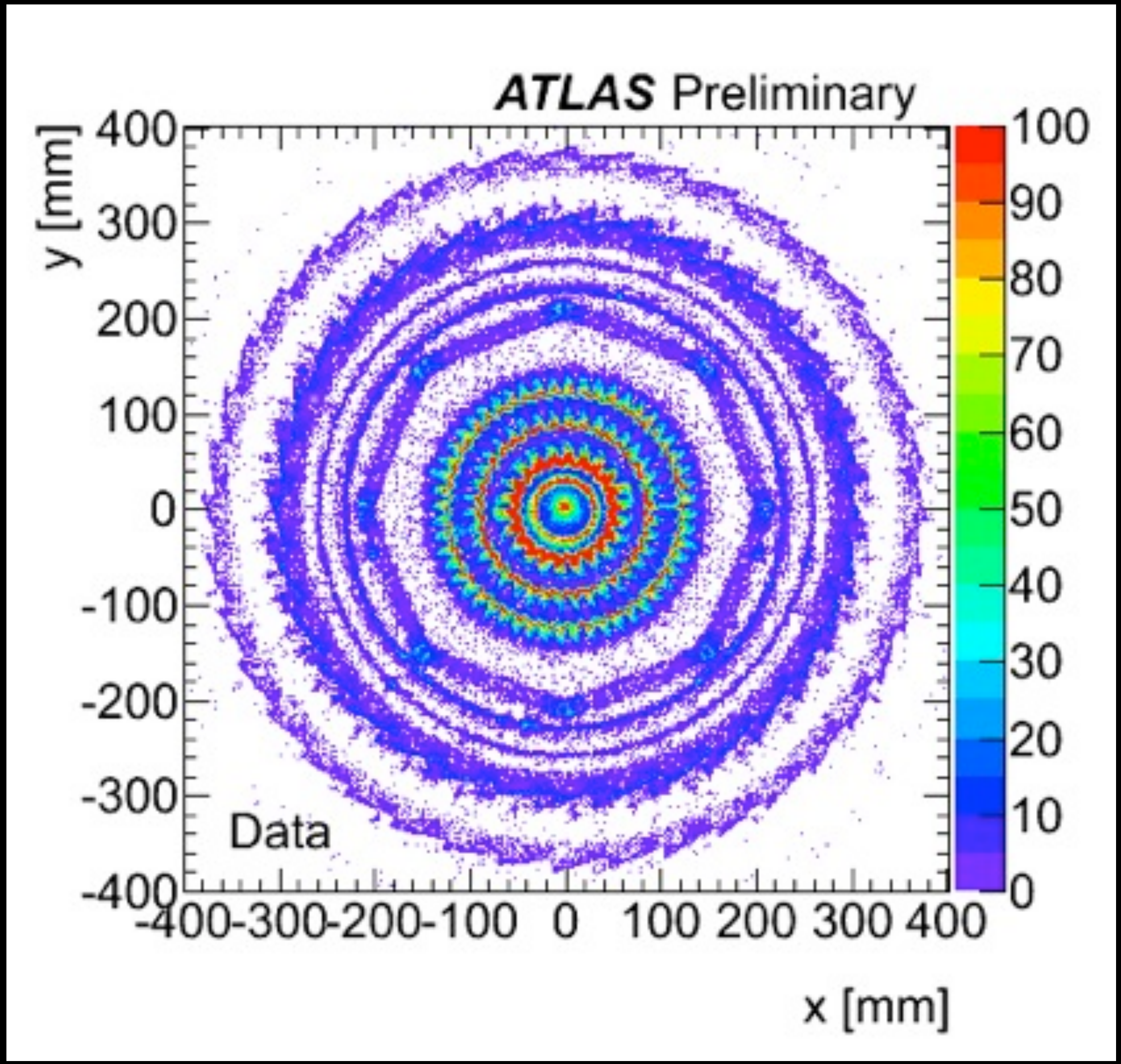


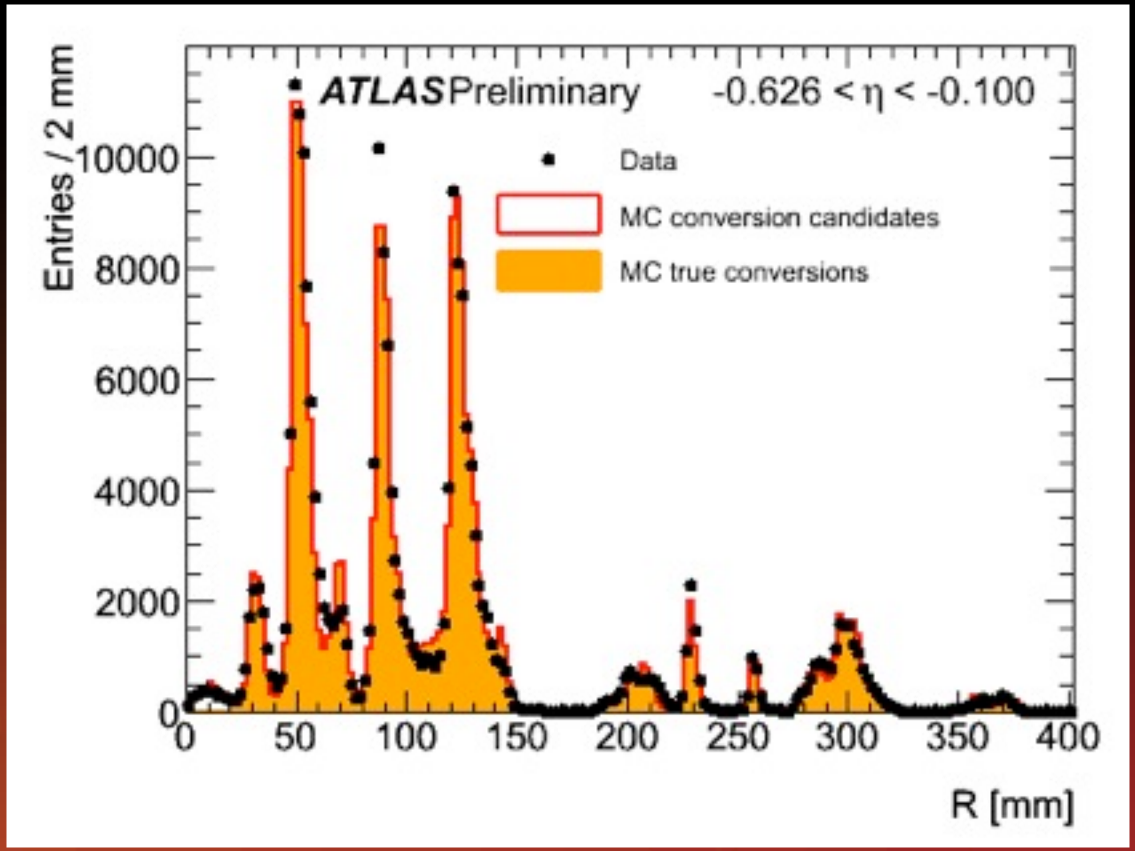


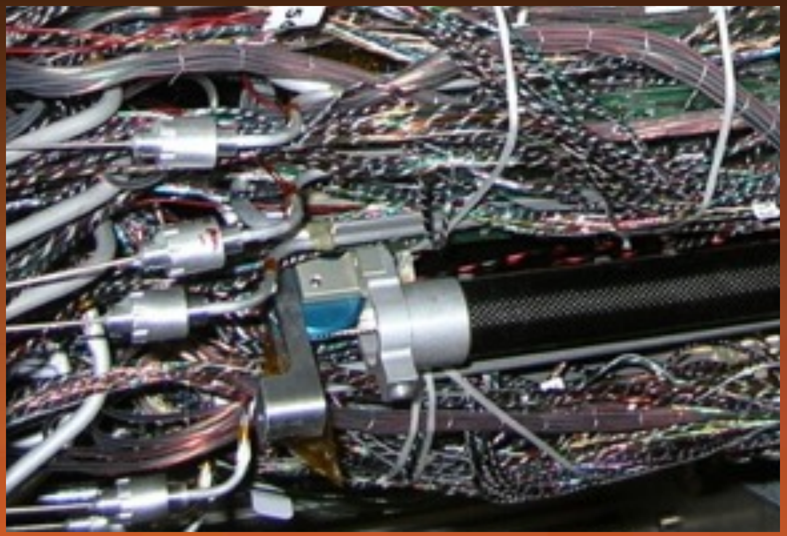


Material Studies

- crucial input to understand tracking performance
- early studies
  - ➡ K^0_s / J/ψ mass signals
  - ➡ efficiency to extend Pixel seeds into SCT
  - ➡ impact parameter resolution vs p_t
- tomography with γ conversions
  - ➡ allows very precise estimate of material
  - ➡ calibrate e.g. on "known" beam pipe
  - ➡ measure difference in data/MC, e.g. PP0







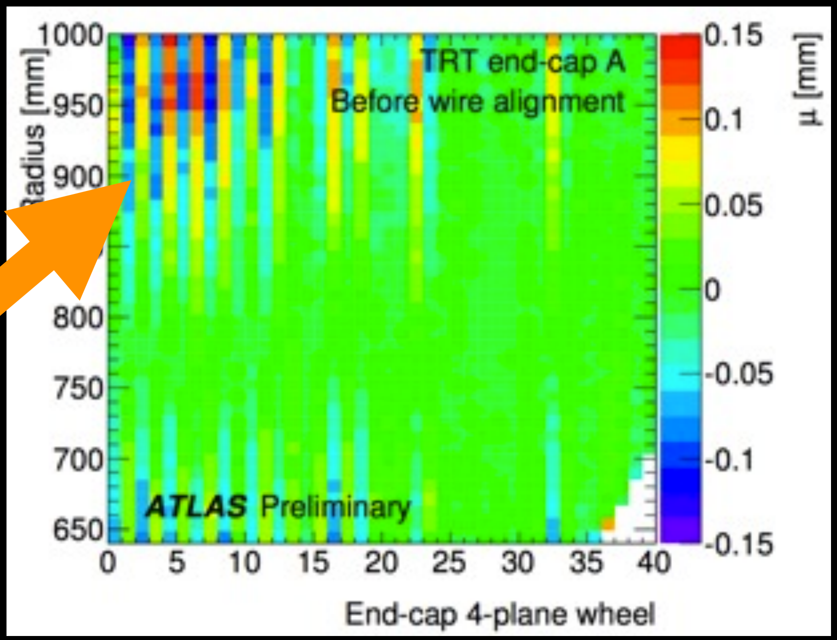
Pixel PP0 region

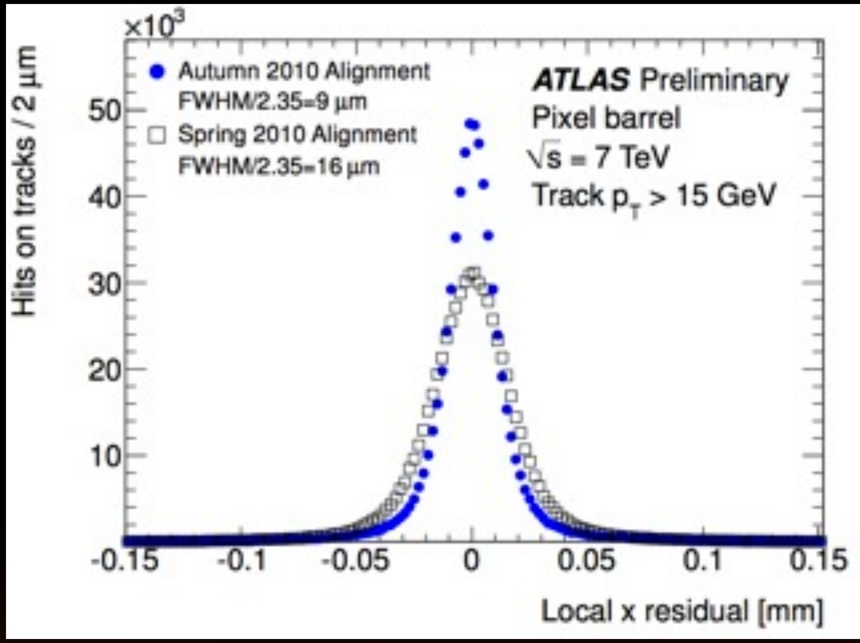
only for information

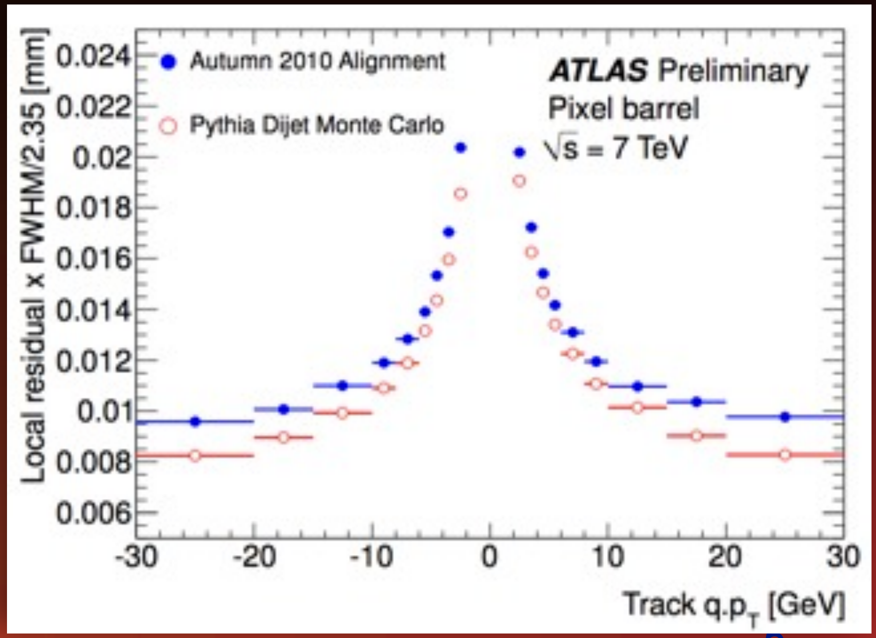
Detector Alignment

- alignment strategy
  - ➡ starting point is detailed survey
  - ➡ alignment stream with high-p_t tracks
  - ➡ define different levels of granularity level 1 (e.g.SCT barrel) to level 3 (module)
  - ➡ global-χ^2 and local alignment
- also allow for
  - ➡ Pixel model deformations (survey)
  - ➡ Pixel stave bowing
  - ➡ TRT wire alignment
  - ➡ movements of the detector
  - ➡ weak modes ...
- to approach design resolutions

apparent twist between TRT 4-plane wheels

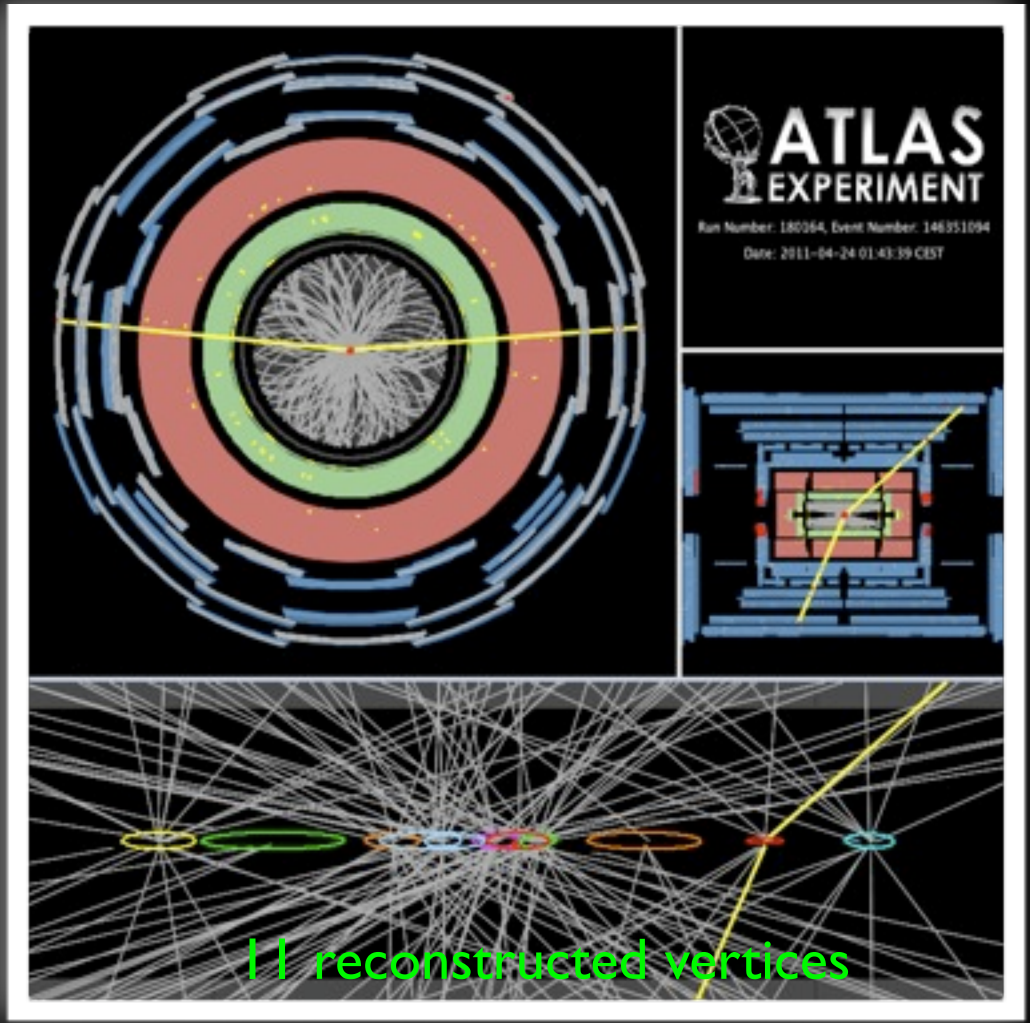


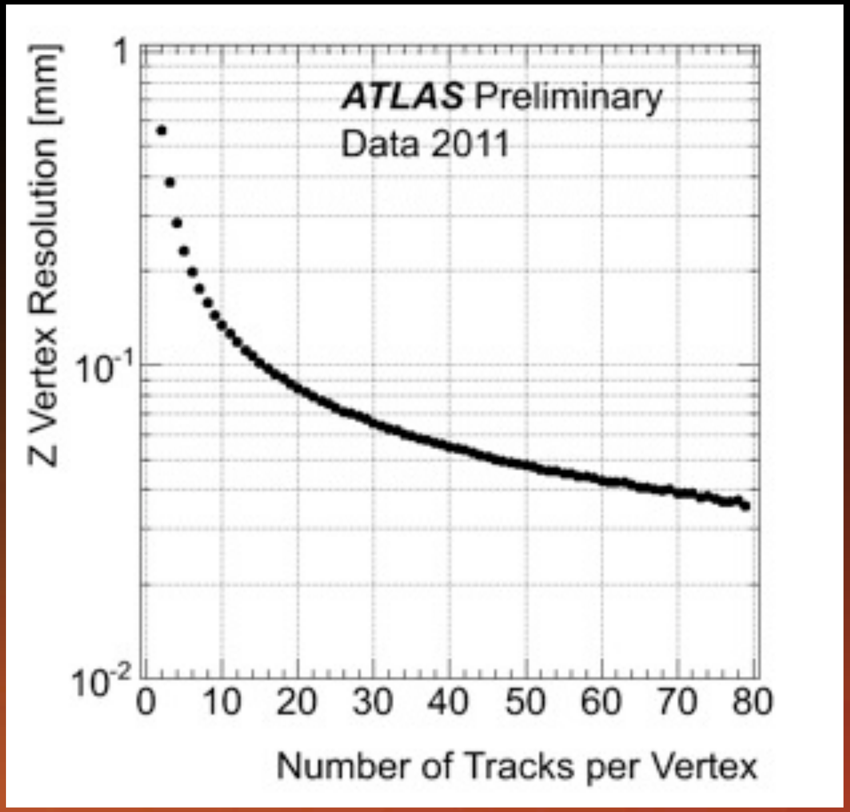


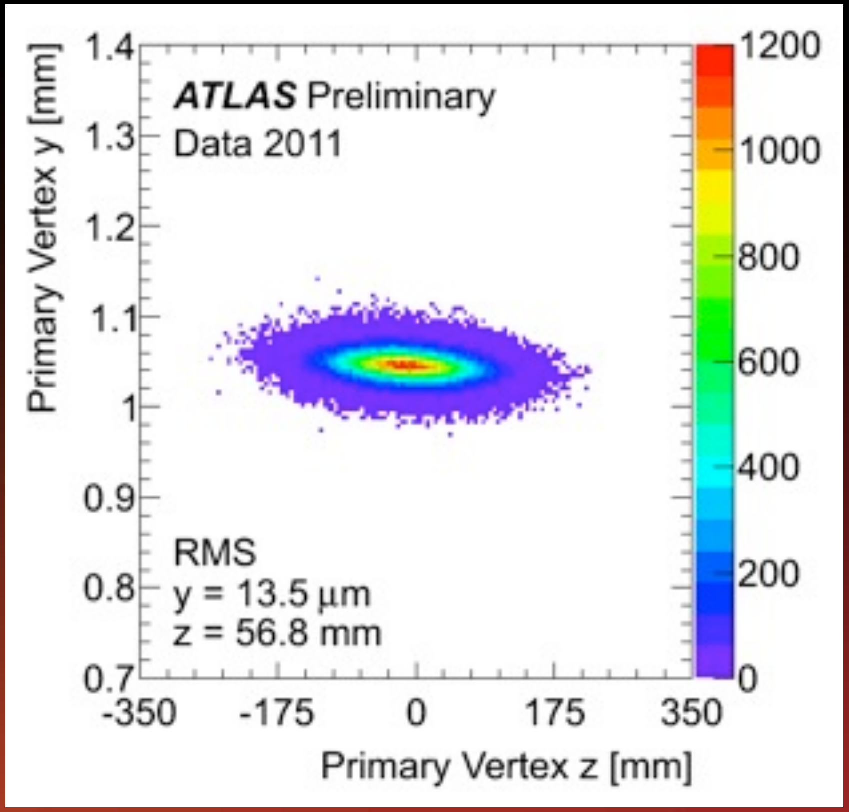


Primary Vertexing

- iterative vertex finder, adaptive fitter
  - ➡ reconstruct primary and pileup vertices
- measure primary vertex resolution
  - ➡ split vertex technique on data
- beam spot routinely determined
  - ➡ input to vertexing
- primary vertex counting
  - ➡ luminosity monitor
  - ➡ event by event pileup corrections (jets)

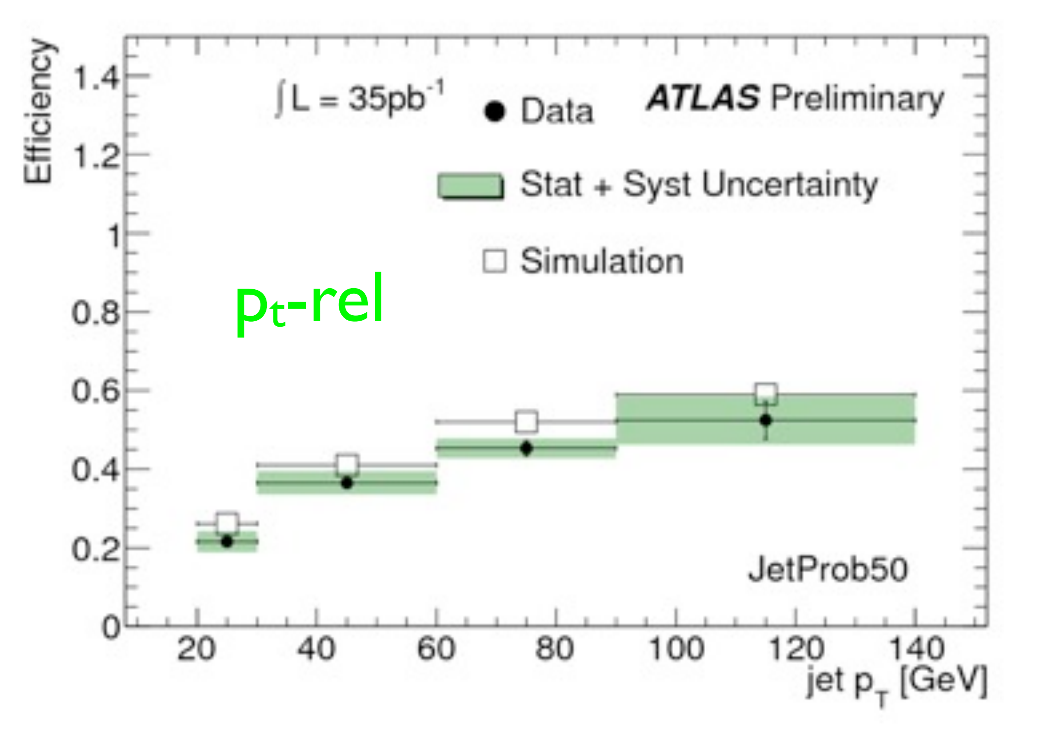


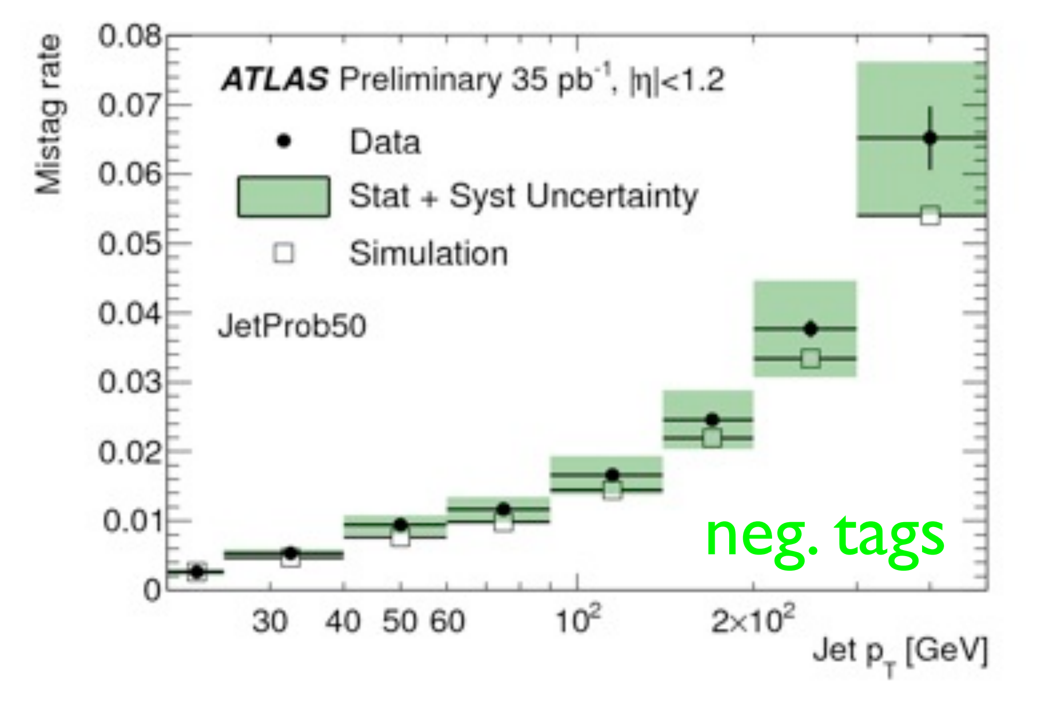


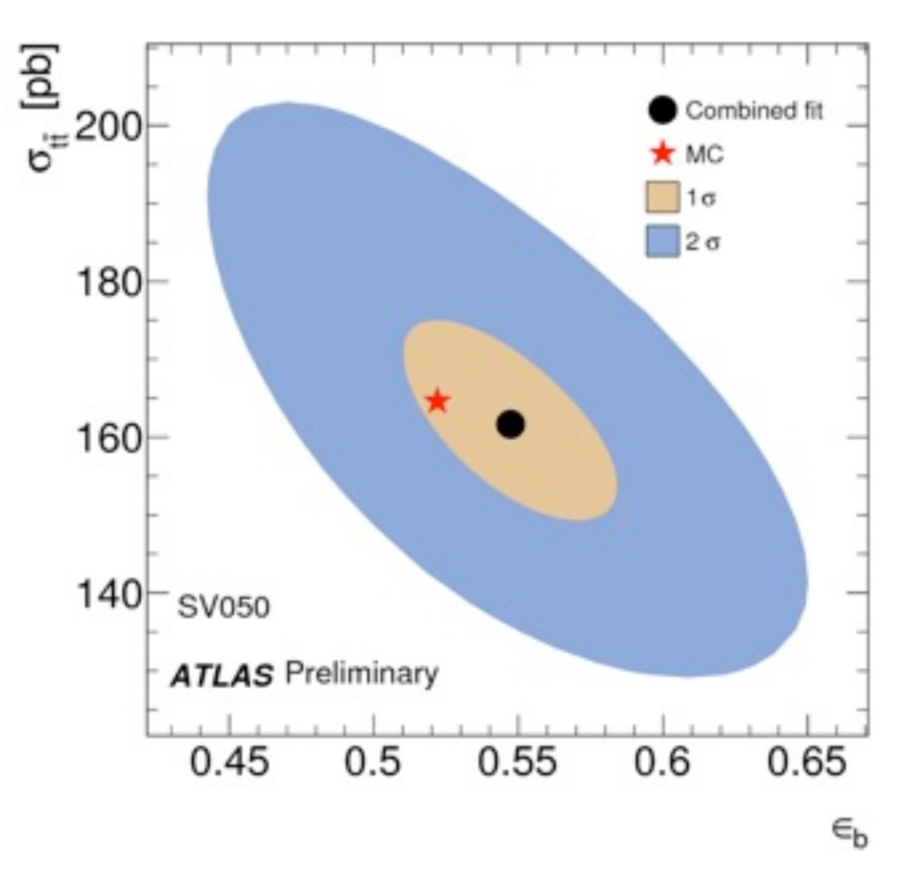


b-Tagging

- conservative taggers
  - ➡ inclusive secondary vertex tagger (SV0)
  - ➡ impact parameter significance (JetProb)
- performance well studied
  - ➡ efficiency e.g using "p_t-rel", "D*μ", "tt" ...
  - ➡ mistags e.g. using "vtx mass", "neg. tags" ...

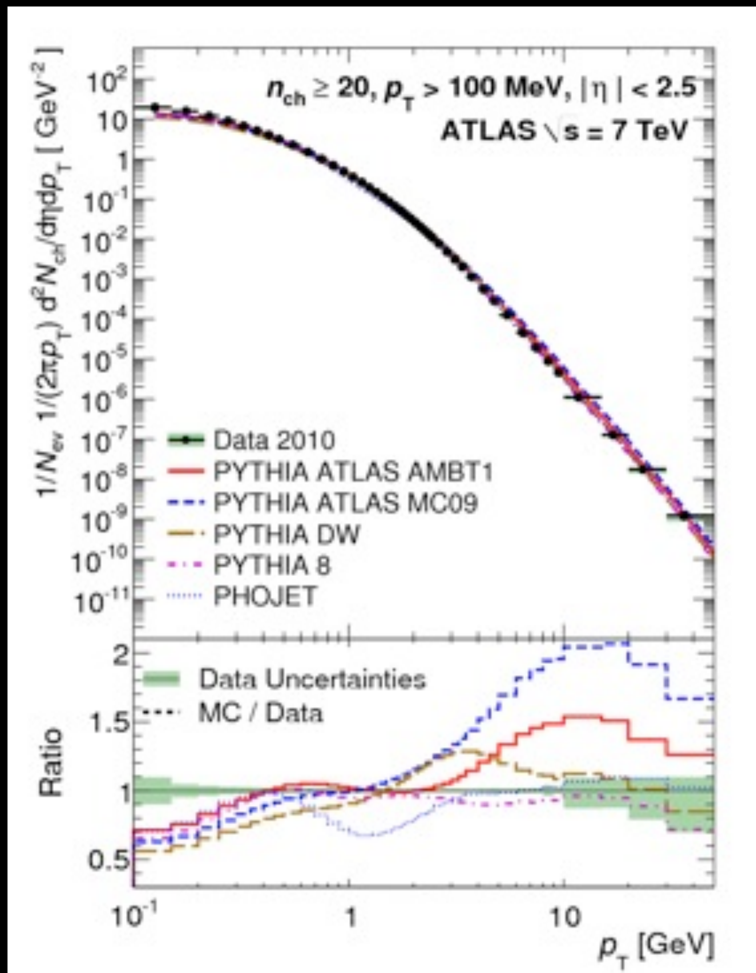




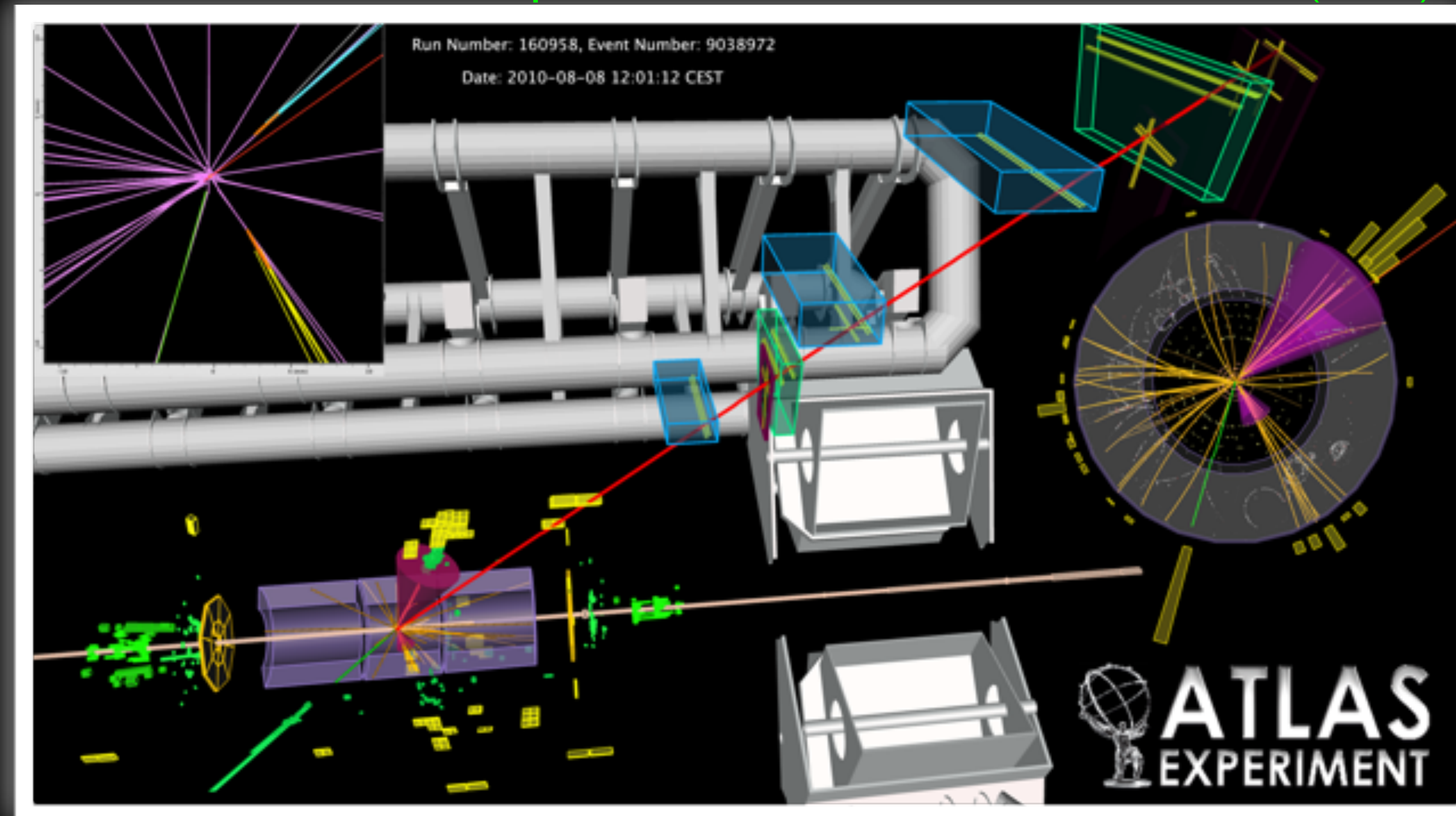


- used in analysis up to now
- towards using likelihood based taggers
  - ➡ optimal combination of IP and vertex information
  - ➡ interplay between tracking performance, properties of jets and fragmentation in different event topologies

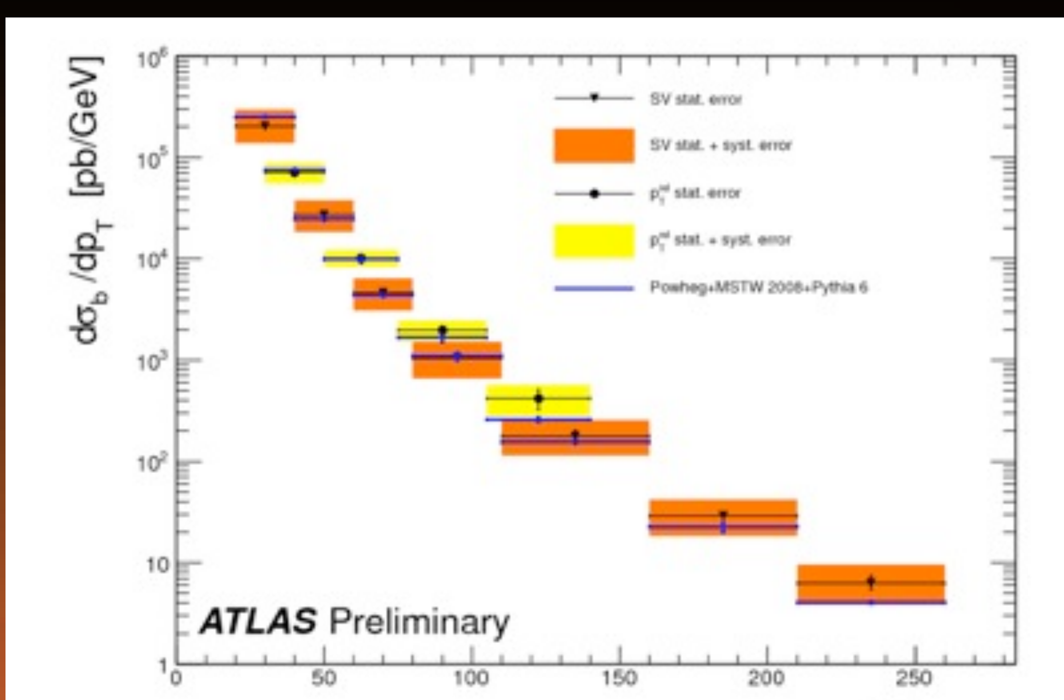
to do Physics ...



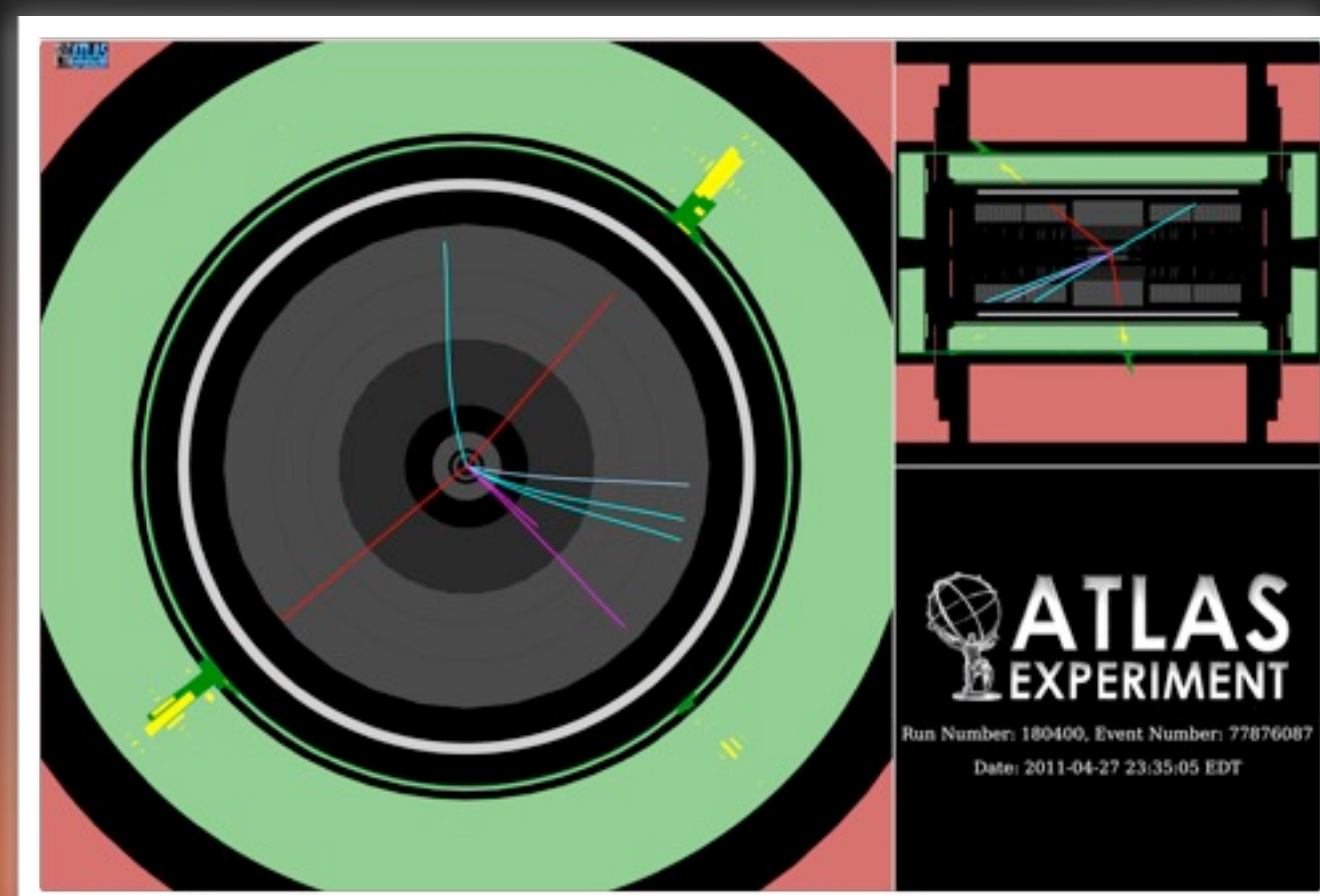
min.bias charged particle spectra



first top event in ATLAS with nice b vertices (2010)



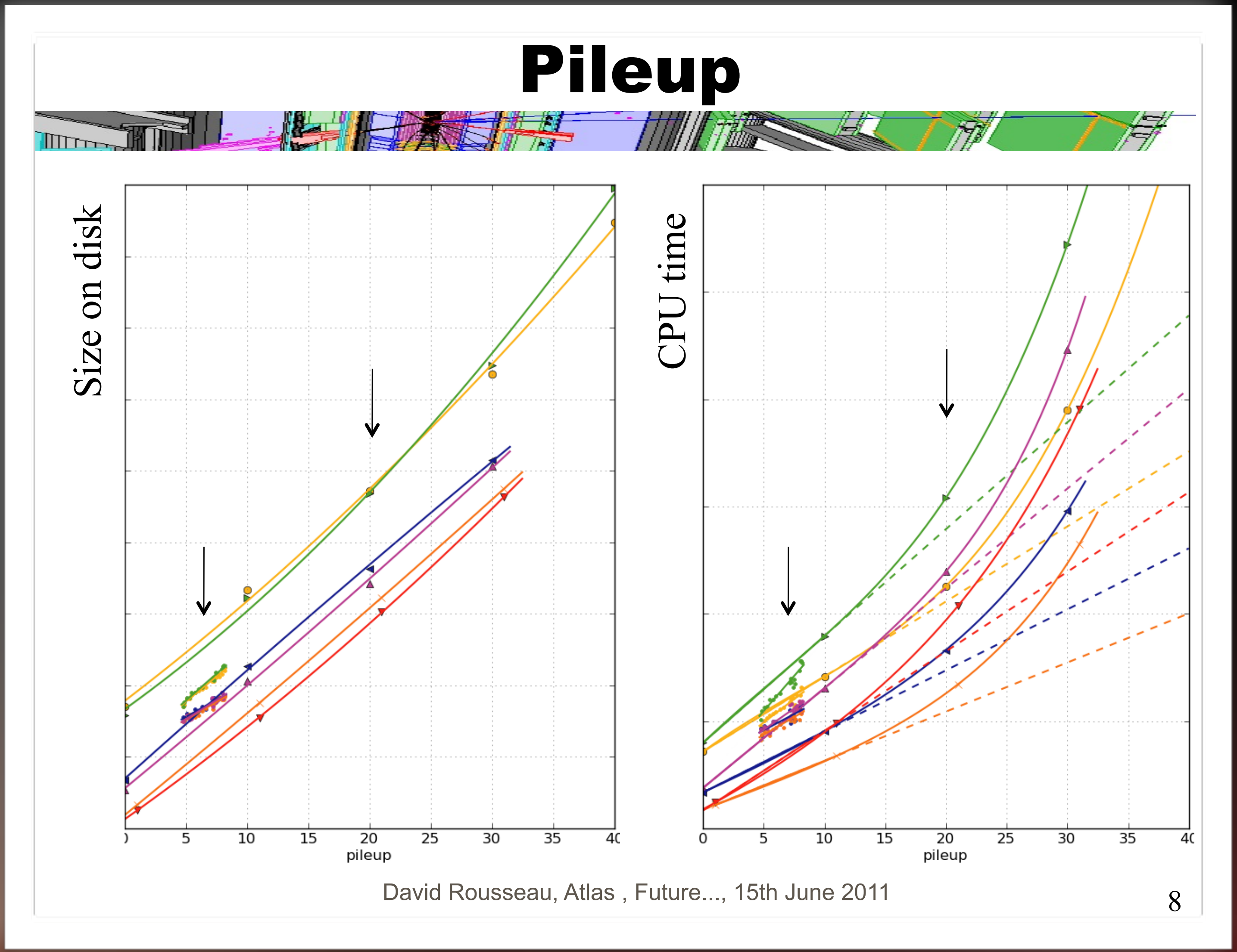
inclusive b-jet cross-section



highest mass Z’→ee candidate (2011)

Luminosity and Computing Resources

- see slide from David Rousseau (Wednesday session):
  - ➡ resource needs scale fast
  - ➡ tracking is a resource driver



- tracking principles:
  - ➡ combinatorial problem
  - ➡ naive scaling
    - like ~n!
  - ➡ clever tracking strategies
    - dampen it to $\sim n^2$ or $\sim n^3$

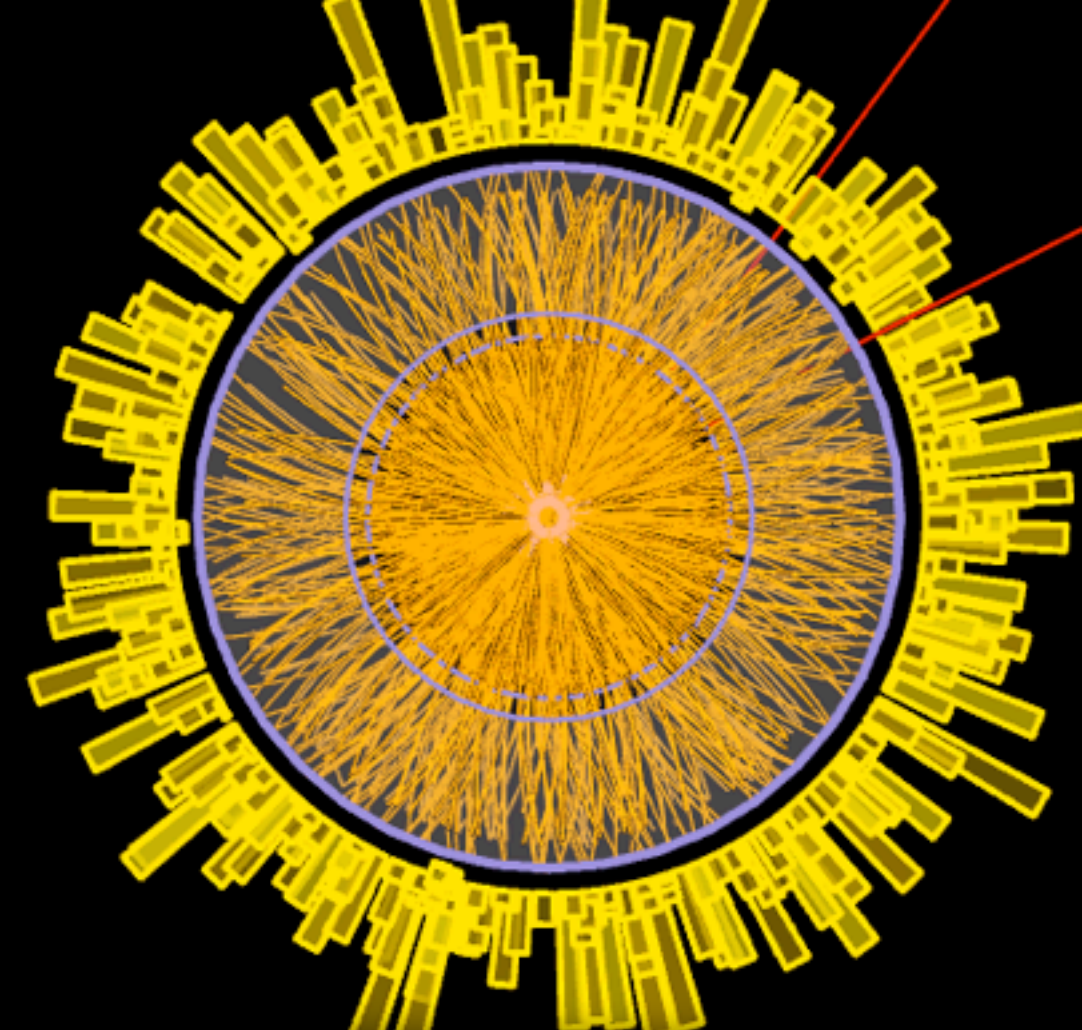
- natural tension between
  - ➡ desire to maximize physics
  - ➡ requirement to stay within available resources

Reconstruction Strategy vs Time

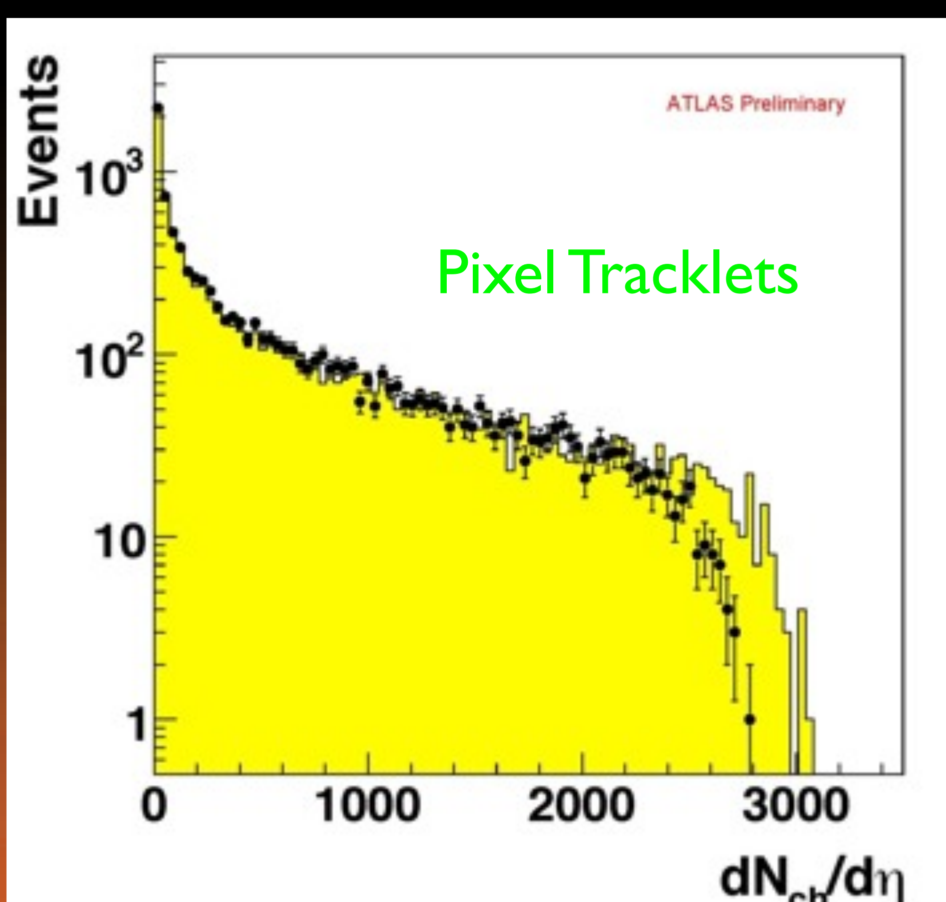
2009 / early 2010	commissioning Min.Bias	pt > 50 MeV open cuts, robust settings min. 5 clusters
2010 stable running < ~4 events pileup	low lumi physics program (soft QCD, b-physics, ...), b-tagging...	pt > 100 MeV min. 7 clusters
Heavy Ion 2010	high occupancy, soft QCD	pt > 500 MeV z-vertex seeding, min. 9 clusters
2011 pp running ~8 events pileup	focus more on high-pt physics (top, W/Z, ...), b-tagging...	pt > 400 MeV, harder cuts in seeding min. 7 clusters
Phase I upgrade, including IBL 24-50 events pileup	high-pt physics, study new physics (I hope), b-tagging....	pt > 900 MeV, harder tracking cuts, min. 9 clusters
SLHC up to 100-200 events pileup	replace Inner Detector to cover very high luminosity physics program	further evolve strategy... R-o-I or z-vertex seeding, reco. per trigger type, GPUs

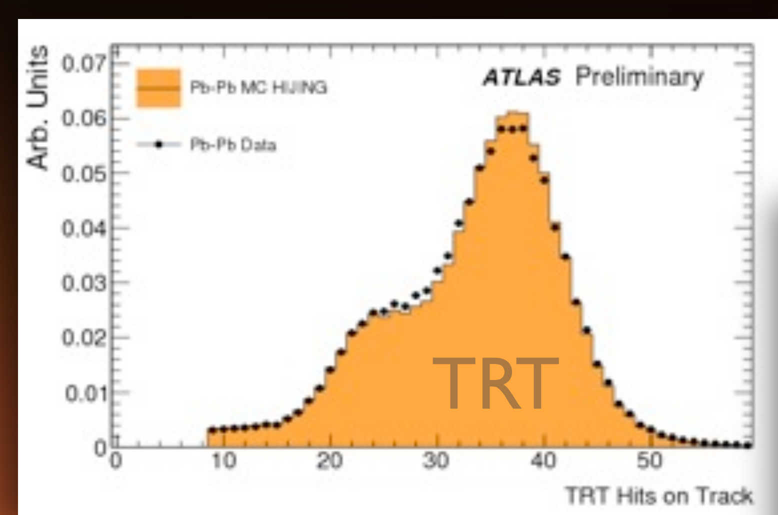
➡ requirements on tracking evolves with physics ATLAS program
➡ different luminosity regimes require different working points

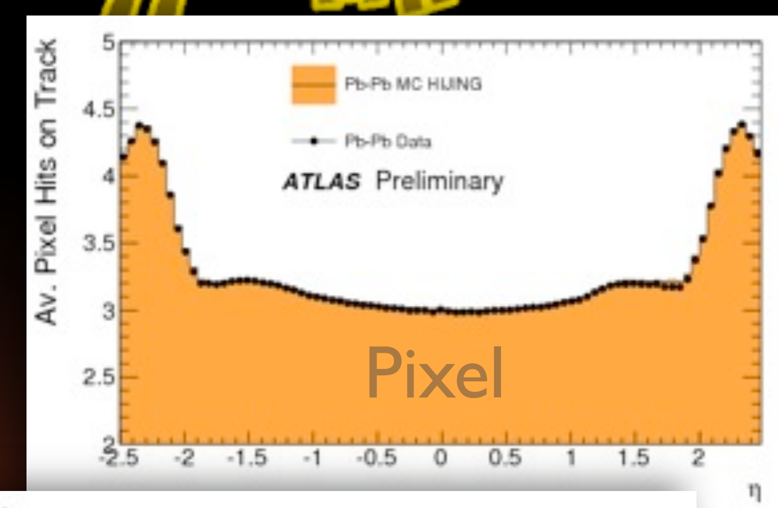
Heavy Ion Tracking

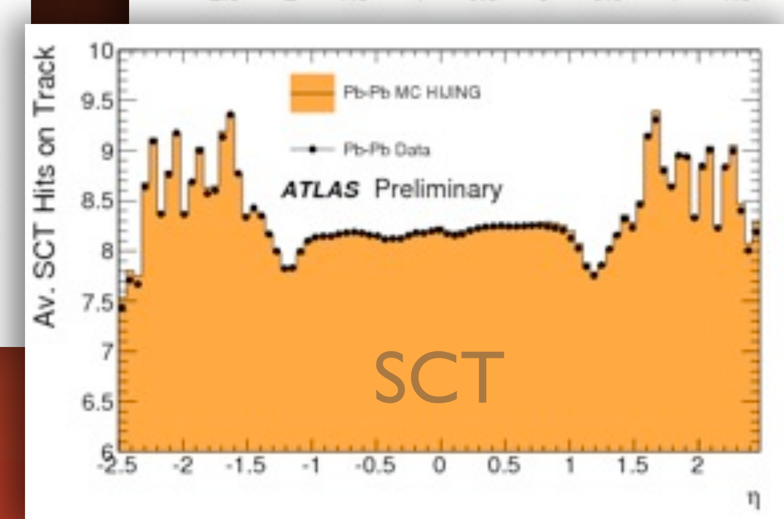


- high multiplicity tracking
  - ➡ adapt seed finding (z vertex constraint to save CPU)
  - ➡ tighten hit requirement to control fakes in central events (similar to SLHC setup)
- excellent tracking performance
  - ➡ as well good testing ground for high in-time pileup



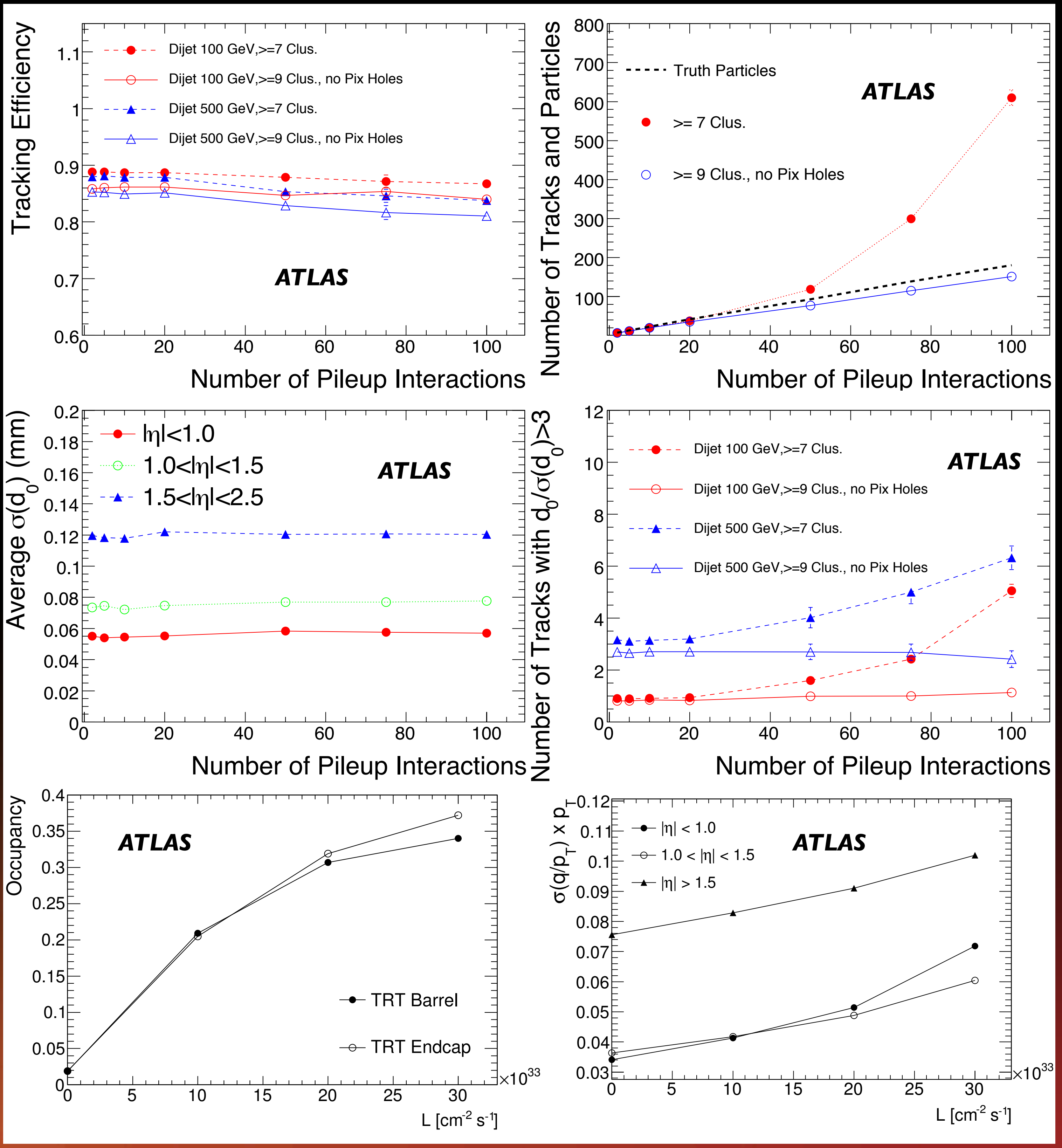






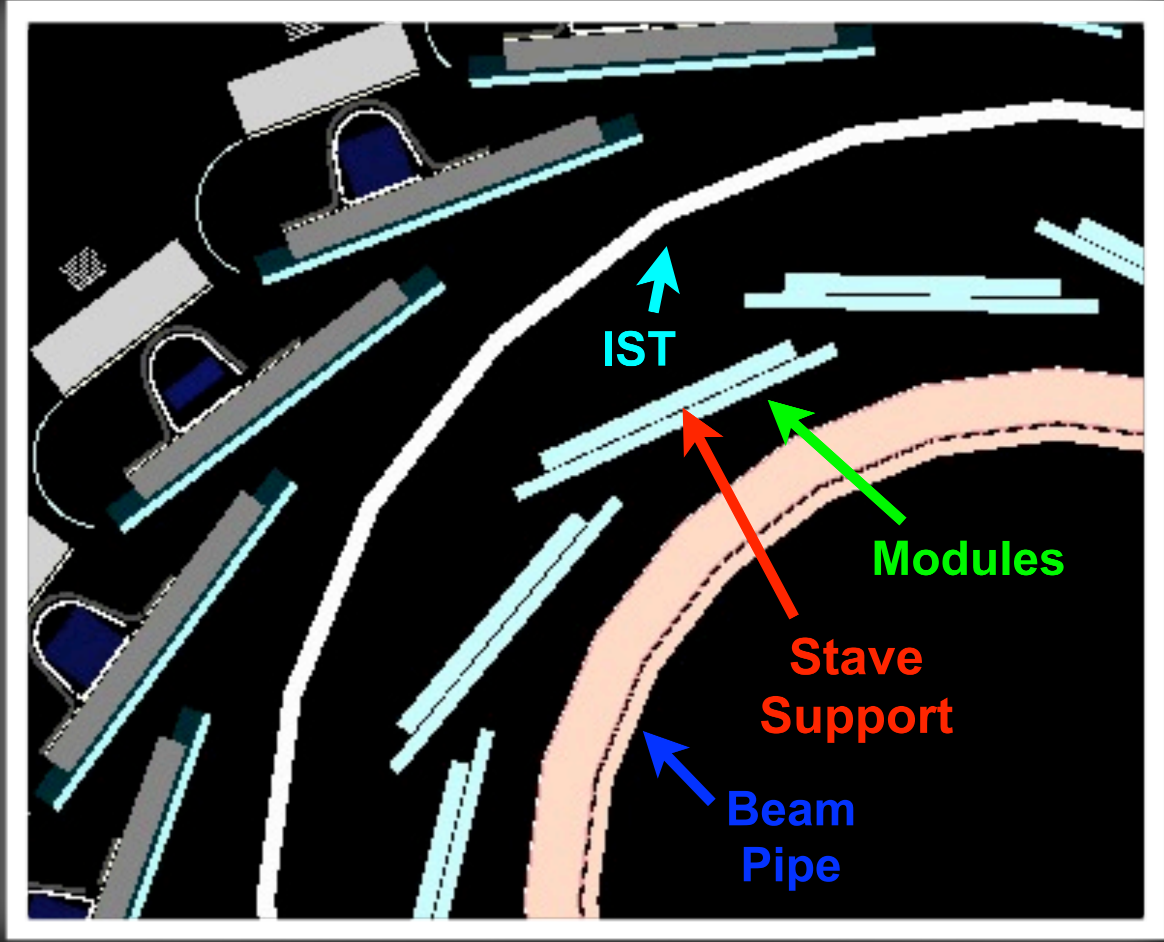
Tracking at High Luminosity (pp)

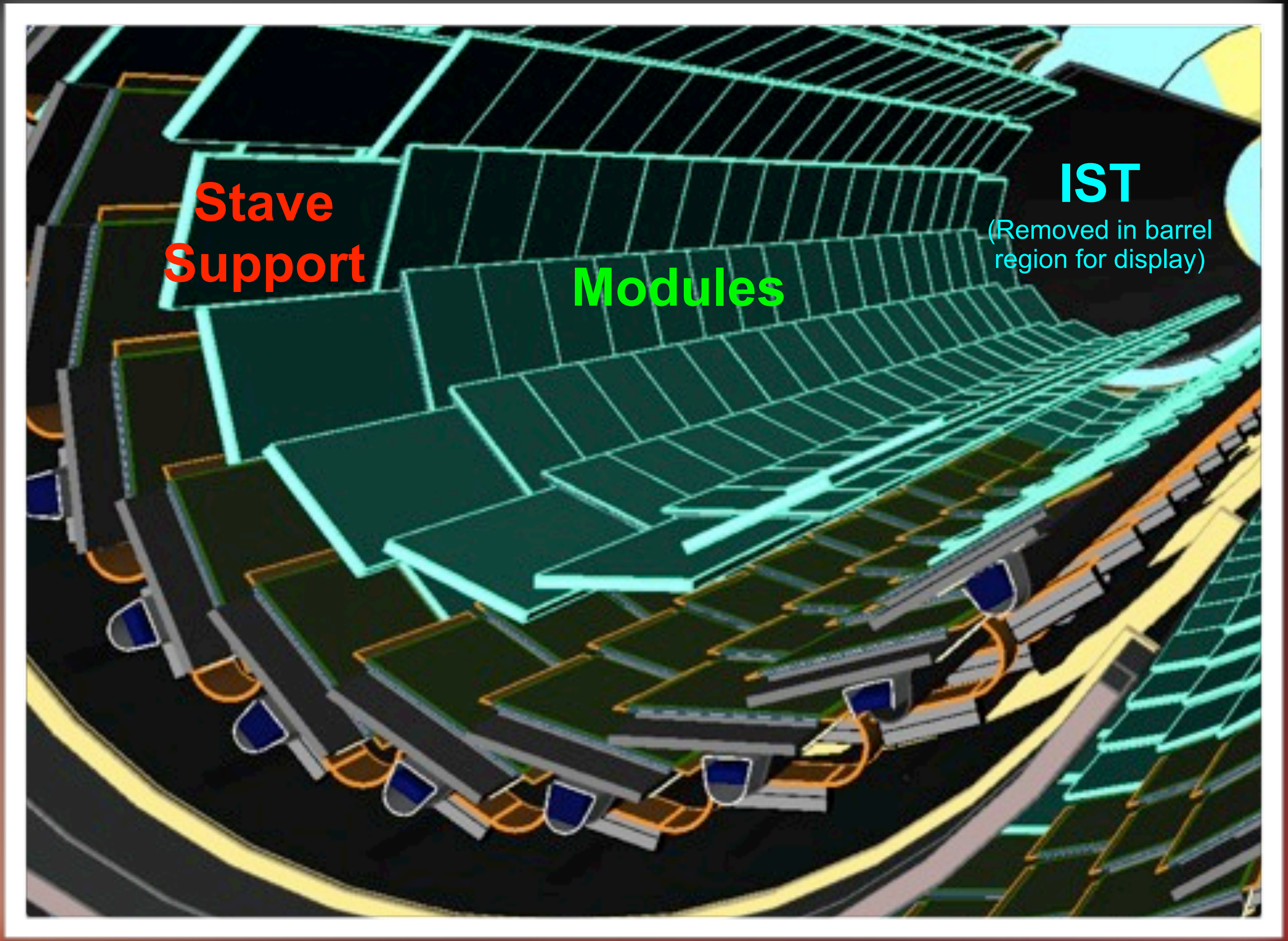
- occupancy
  - ➡ Pixel and SCT scales linearly
  - ➡ TRT good hit occupancy vs efficiency
- tracking in pileup
  - ➡ efficiency, most resolutions same
  - ➡ momentum resolution slowly deteriorates with TRT occupancy
  - ➡ rate of fake tracks and rate of significant impact parameters increases fast
- pileup track selection
  - ➡ suppresses fakes at expense of some efficiency
  - ➡ requiring 9 out of 11 hits - robust ?
    - ▸ cut on “no Pixel holes” ...

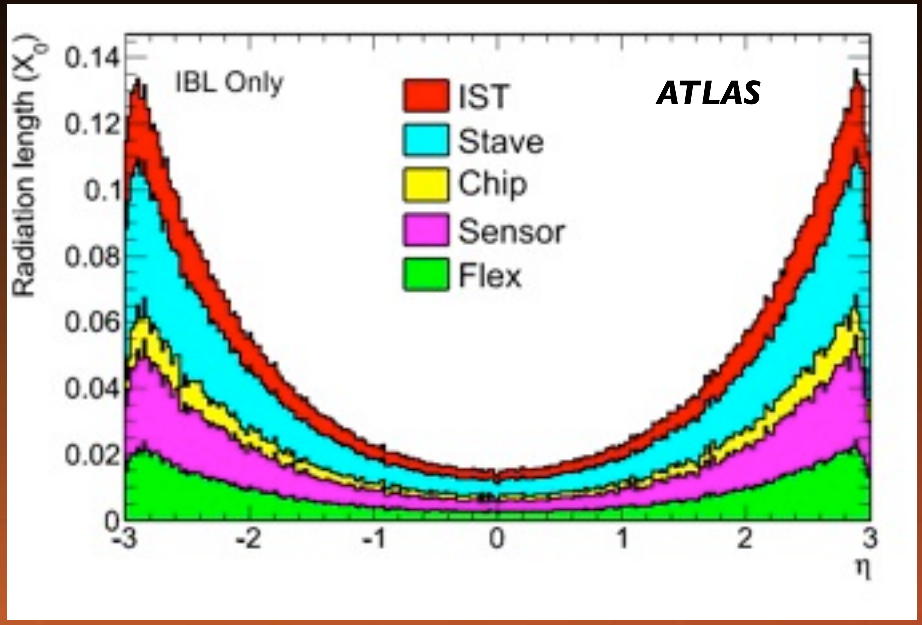


Phase 1 (IBL) Tracking

- performance studies in G4
  - ➡ smaller beam pipe (R_{min} = 25 mm)
  - ➡ reconstruction: 4th Pixel layer
  - ➡ IBL material adjusted to 1.5% X0
  - ➡ smaller z pitch (400 um)
- installation next shutdown
  - ➡ ready for 14 TeV running
  - ➡ peak luminosities of $2{*}10^{34}\ cm^{-2}s^{-1}$
  - ➡ 25-50 pileup events

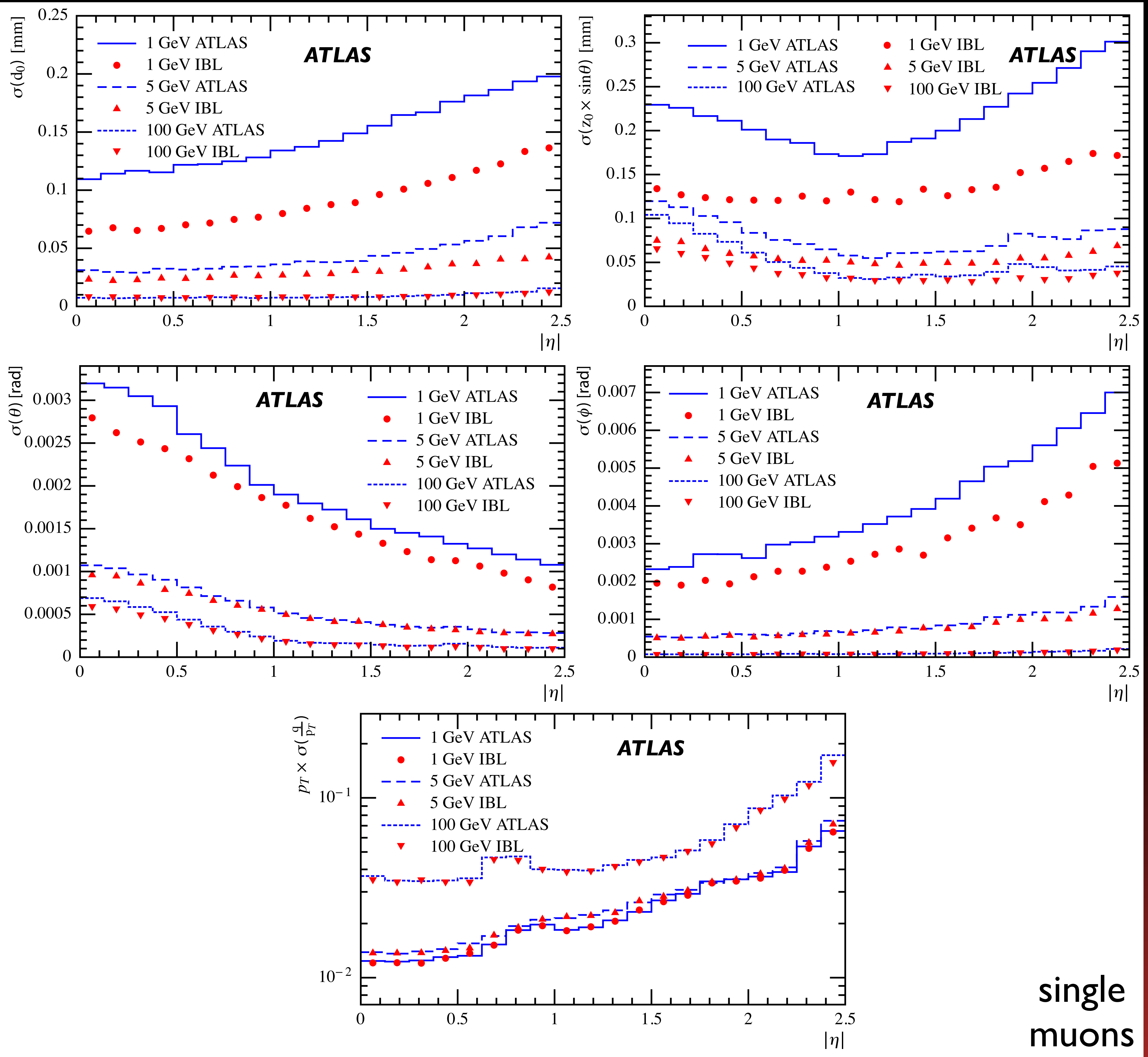






Tracking Performance with no Pileup

- expected results
  - ➡ smaller radius
  - ➡ small z pitch
  - ➡ less material between first and 2nd layer
  - ➡ track length ~ same
- improvements
  - ➡ better d_0 resolution
  - ➡ better z_0 resolution
  - ➡ θ and ϕ improved at low-pT
  - ➡ momentum resolution ~ unchanged
- as expected !

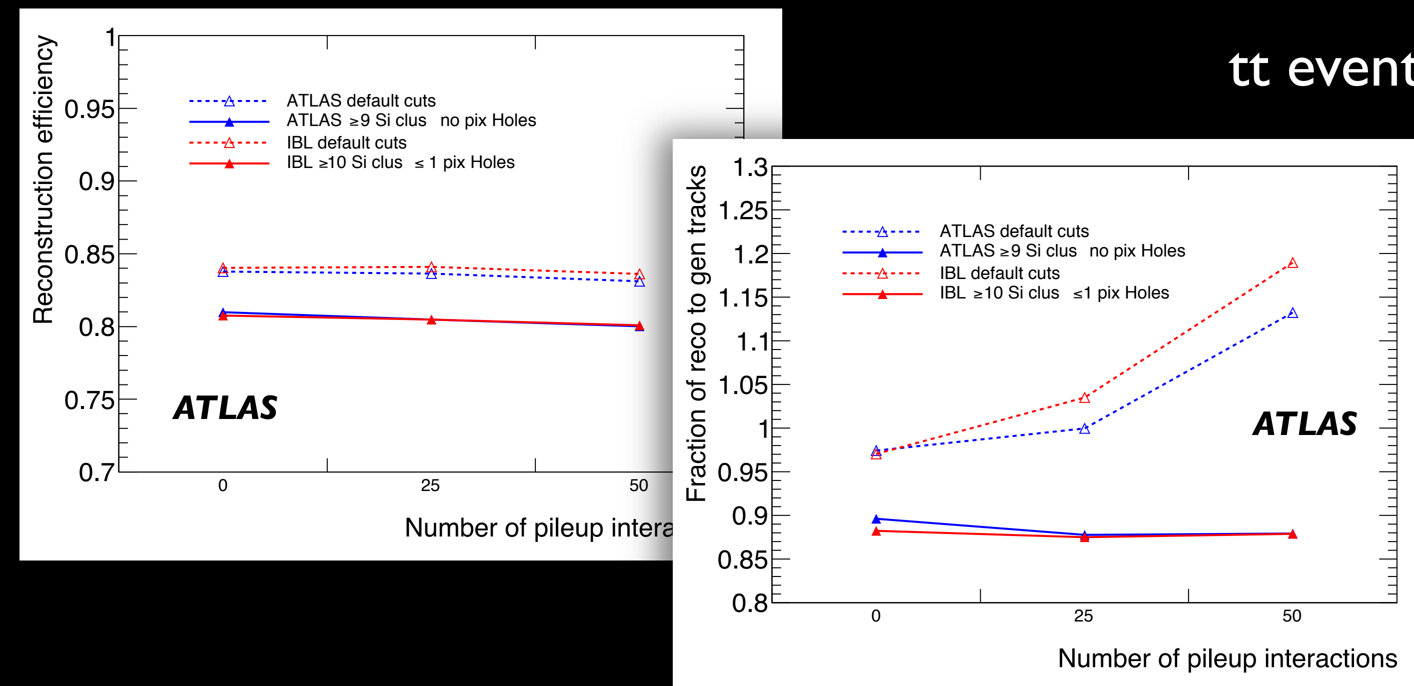


single muons

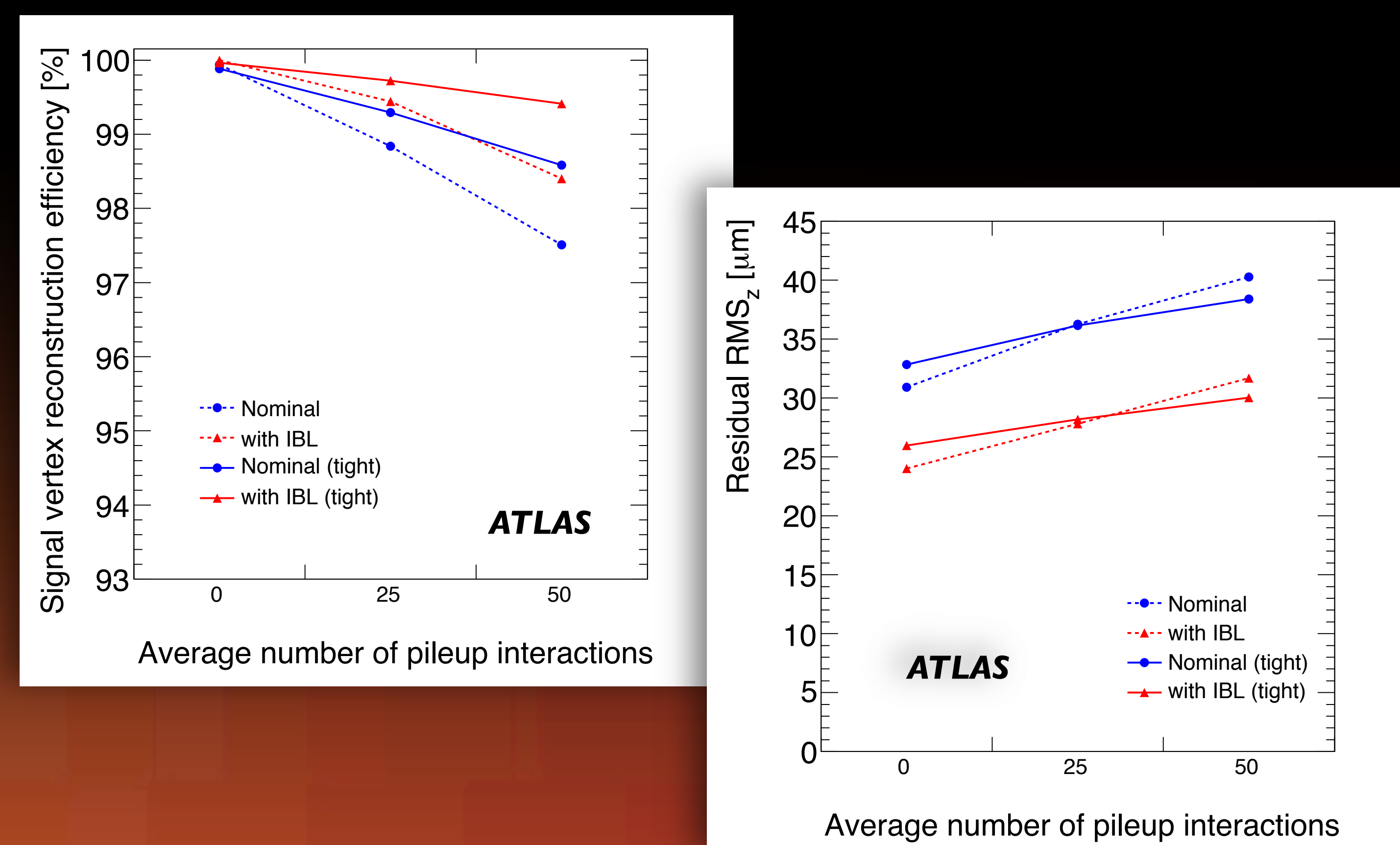
Tracking and Vertexing with Phase 1 Pileup

- pileup selection with IBL
  - ➡ ≥10 IBL+Pixel+SCT hits, ≤1 pixel hole
  - ➡ benefit from additional layer
  - ➡ leaves room for eventual inefficiencies in b-layer (tracking robustness)

tt events

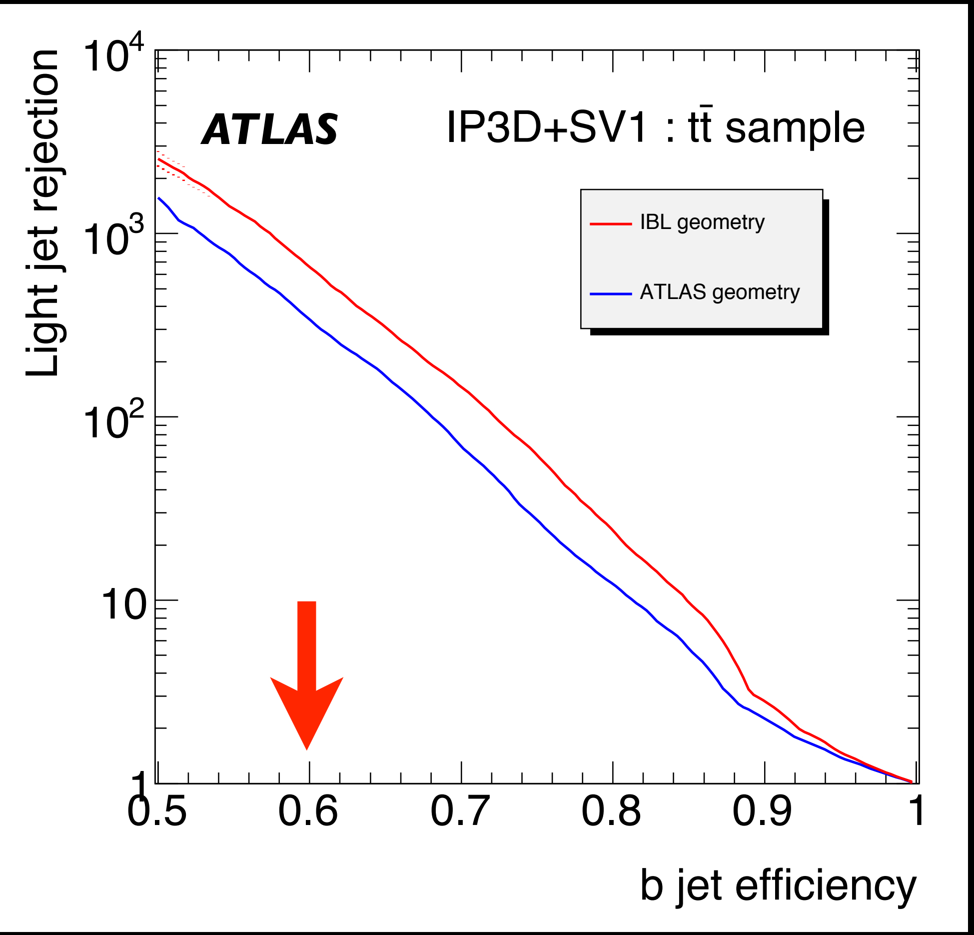


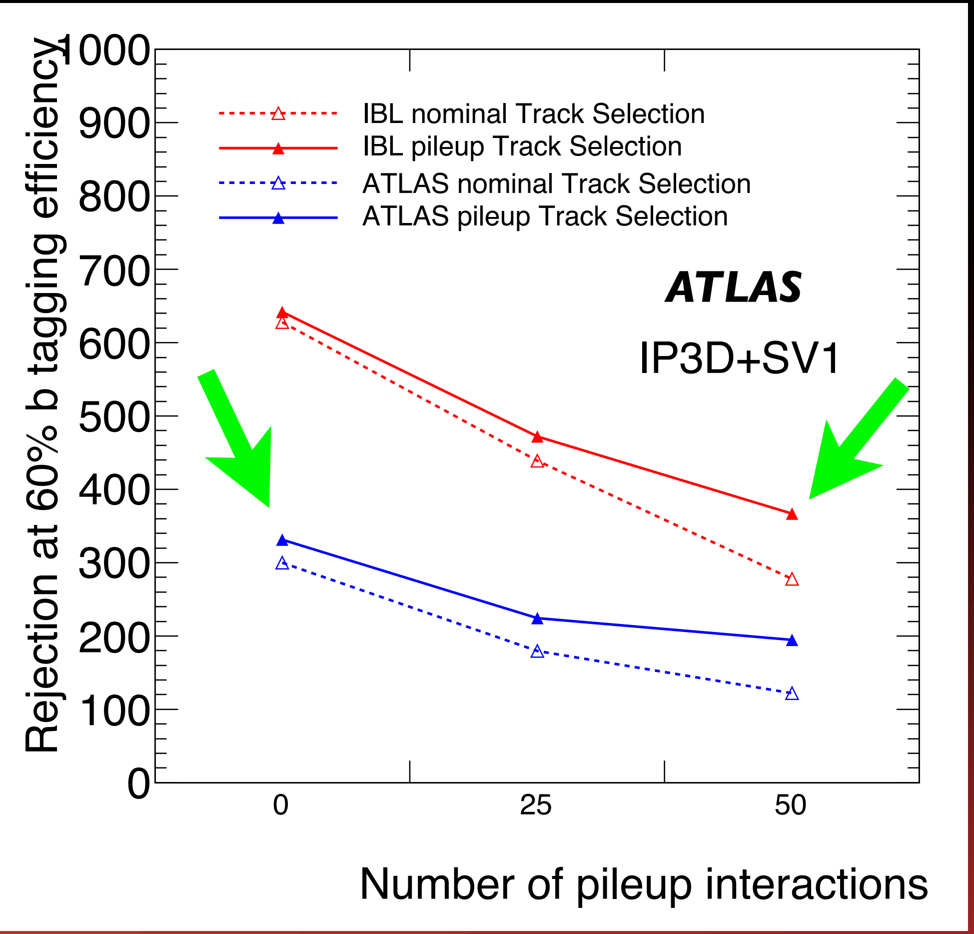
- vertexing with IBL
  - ➡ pileup effects visible
  - ➡ gains in resolution and vertex tail fraction as well with pileup
  - ➡ signal vertex efficiency better
  - ➡ pileup selection better overall



b-Tagging with IBL

- state of the art b-tagging
  - ➡ "IP3D" ~ $d_0 \oplus z_0$ impact significance likelihood
  - ➡ "IP3D+SV1" ~ adding secondary vertex information
- pileup affects b-tagging in many ways
  - ➡ additional jets and fake jets from in/out of time pileup
    - restrict to truth jets to get comparable results
    - real data: can use e.g. Jet-Vertex-Fraction
  - ➡ close-by pileup vertices
    - additional b-tag tracks
    - lead to significant z_0 offsets affecting IP3D
- good performance with IBL and pileup
  - ➡ as good or better as for current ATLAS without pileup





Summary

- stringent requirements on Inner Detector track reconstruction to cover ATLAS physics program
  - ➡ excellent performance of current detector and software chain
- complexity will increase with rapid rise in luminosity
  - ➡ need to adapt tracking strategies to evolving physics program and available resources
- tracking in Heavy Ion events is excellent testing ground for high luminosity
- studies for tracking at high luminosity are quite mature up to Phase I (IBL)
- SLHC will require a new Inner Detector and probably R&D on novel tracking strategies