Tracking, Vertexing & b-Tagging Performance in ATLAS

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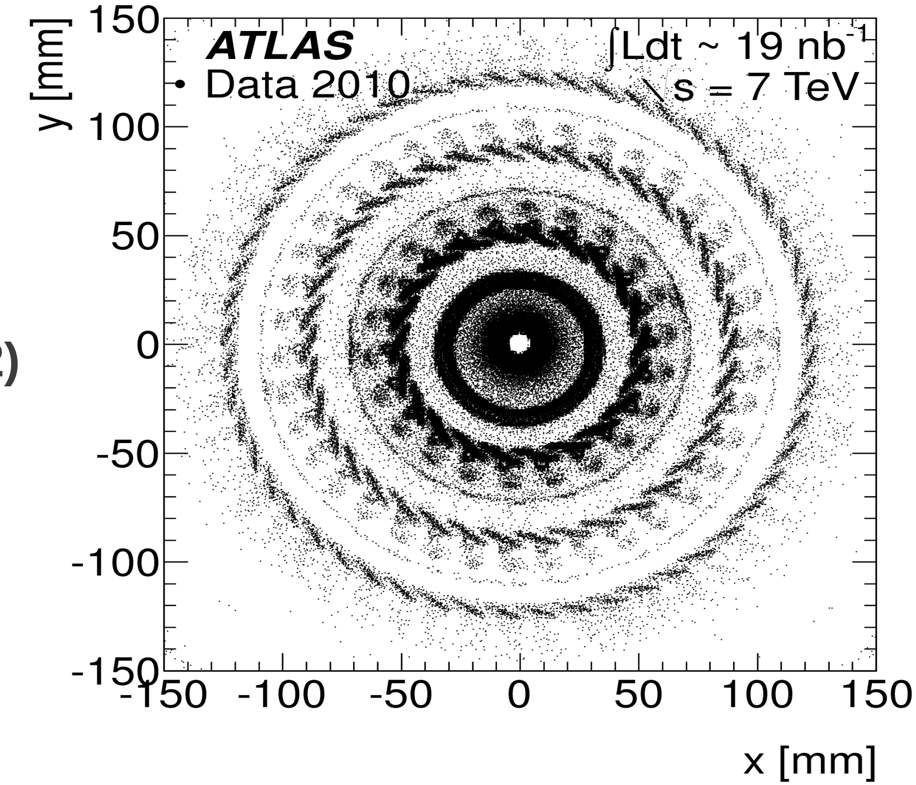
on behalf of the ATLAS Collaboration

- **Physics Motivation**
- **ATLAS Inner Detector**
- **Track & vertex reconstruction (2011/12)**
- **b-Tagging Calibration (2011)**
- **Summary**

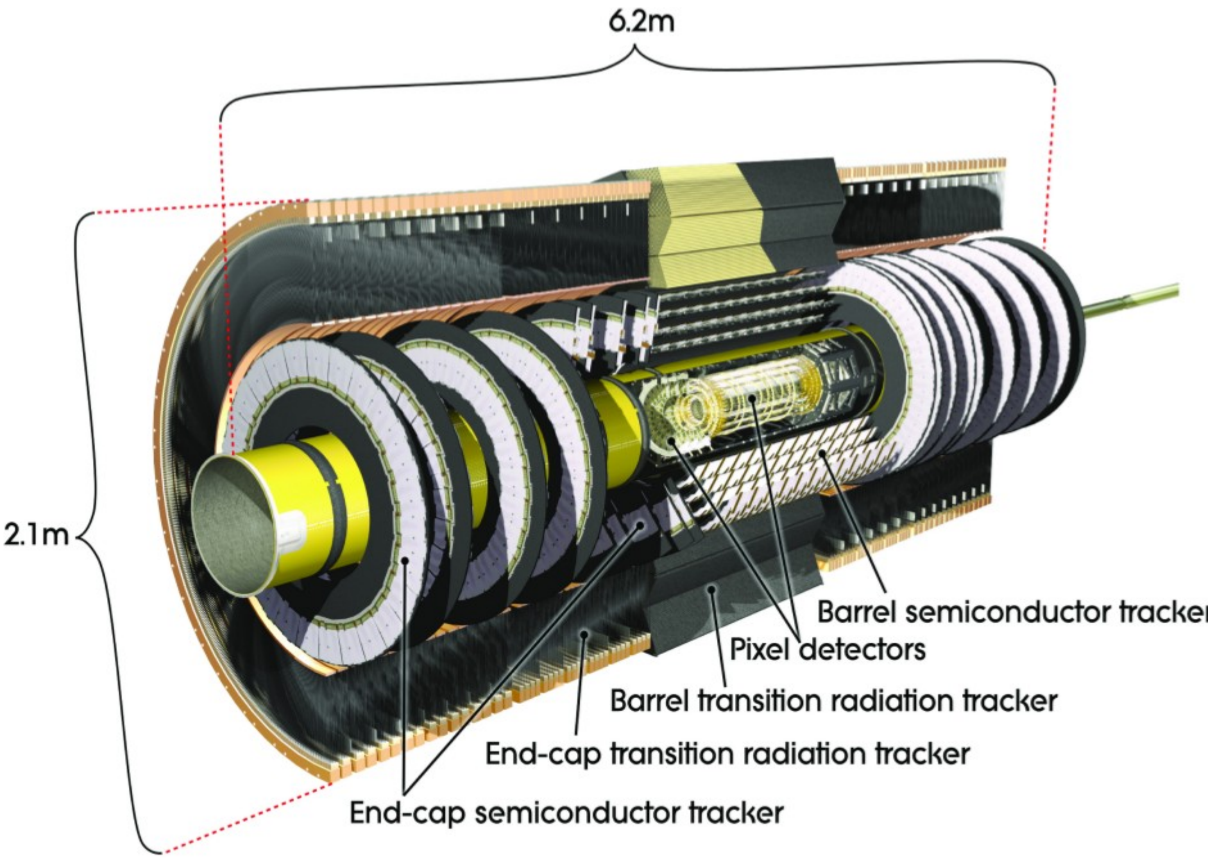


The Eye of ATLAS: Hadronic interaction vertices

Physics Motivation

- pp interactions at ATLAS result in hundreds of primary & secondary charged stable particles ($\tau > 3\text{x}10^{-11}$s)
- Precise measurement of their kinematics is essential to all physics analyses
  - Important for lepton ID, isolation and missing E_T
- Requires high precision and well understood tracking detectors
- Vertex reconstruction important to identify primary interactions
  - Also displaced particle decays and material interactions
- b-Tagging algorithms identify jets and reduce backgrounds for physics signatures with heavy flavour:
  - **From decays:** $t \rightarrow Wb$; $H \rightarrow b\bar{b}$; $b' \rightarrow Zb$; $\tilde{b} \rightarrow b\tilde{\chi}$
  - **Production cross-sections:** $Wb(\bar{b})$; $Zb(\bar{b})$

ATLAS Inner Detector



- **3 detector sub-layers:**
  - Pixel and SCT (microstrips) both silicon based detectors
  - TRT drift tube based detector
- All layers comprise barrel and 2 endcaps
- **$|\eta|<2.5$**
- 2T axial solenoid field for momentum measurement

Subdetector	Element size	Resolution [μm]	Hits/track in the barrel	radii of the barrel layers [mm]
Pixel	$50\,\mu m \times 400\,\mu m$	10×115	3	50.5, 88.5 & 122.5
SCT	$80\,\mu m$	17	8	299, 371, 443 & 514
TRT	4 mm	130	$\sim$30	from 554 to 1082

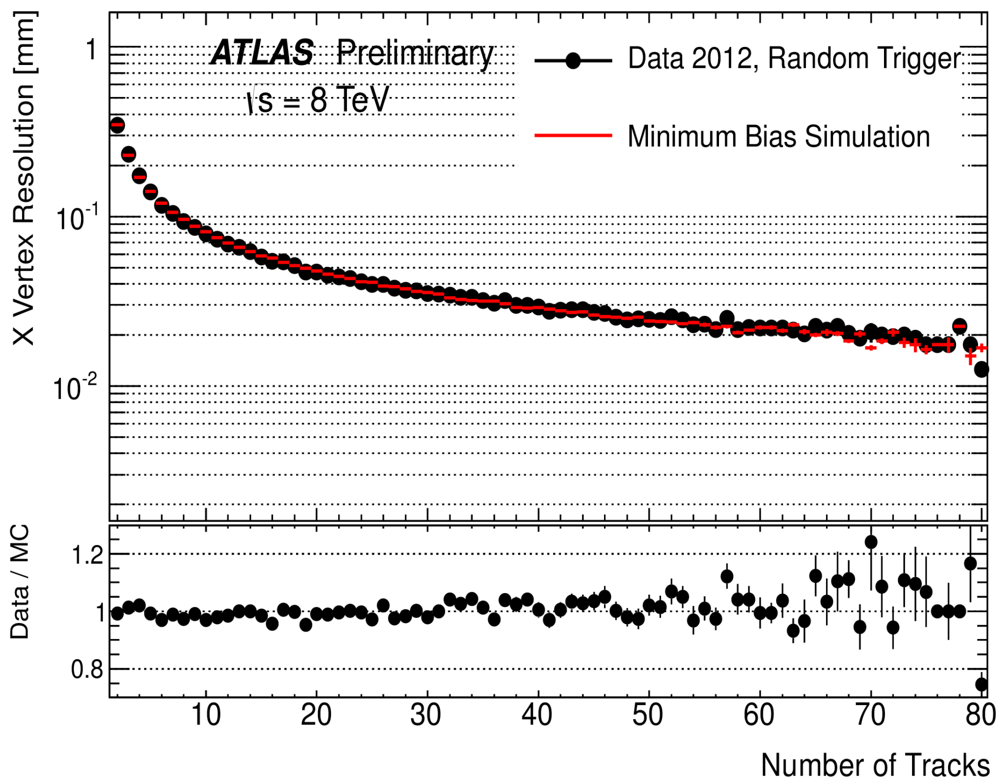
Track & Vertex Reconstruction

Track Reconstruction

- Algorithms based on pattern recognition
  - Inside out
    - Silicon seeds extended out to TRT
    - Reconstructs most primary tracks
  - Back-tracking:
    - TRT seeded with inward extension
    - Recovers secondary tracks (conversions, hadronic interactions, V0 decays)

Primary Vertex (PV) Reconstruction

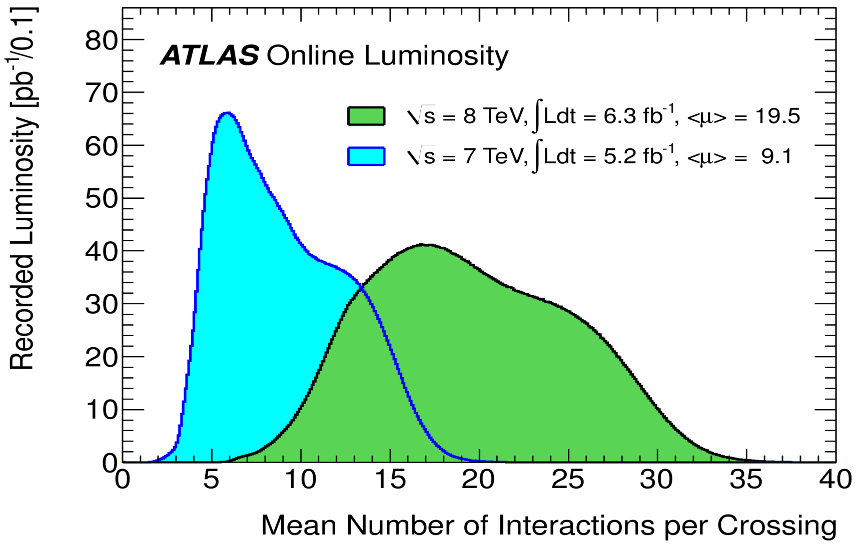
- Iteratively fit tracks consistent with interaction region
- Choose physics PV based on $\Sigma(pT^2)$
  - Becomes reference PV for b-tagging
  - Physics object association is also used

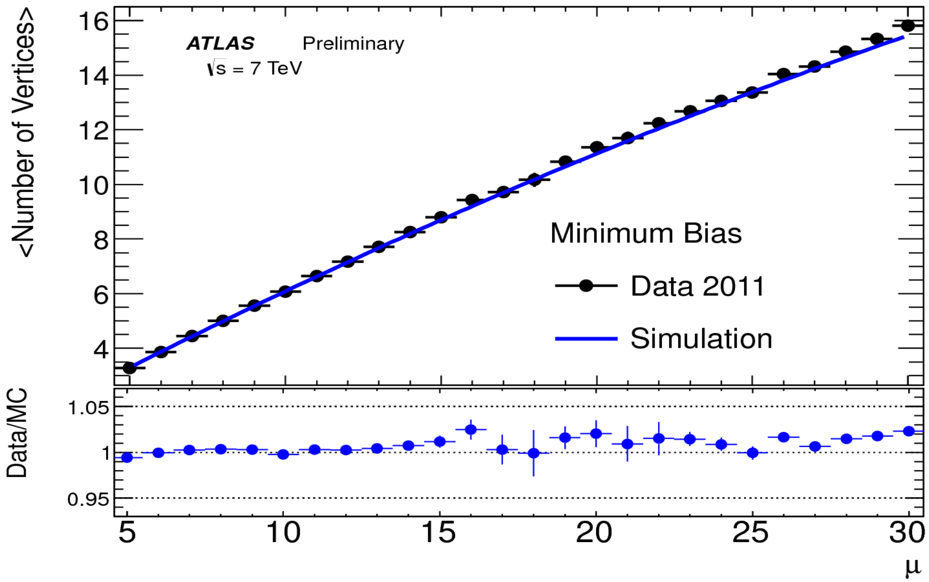


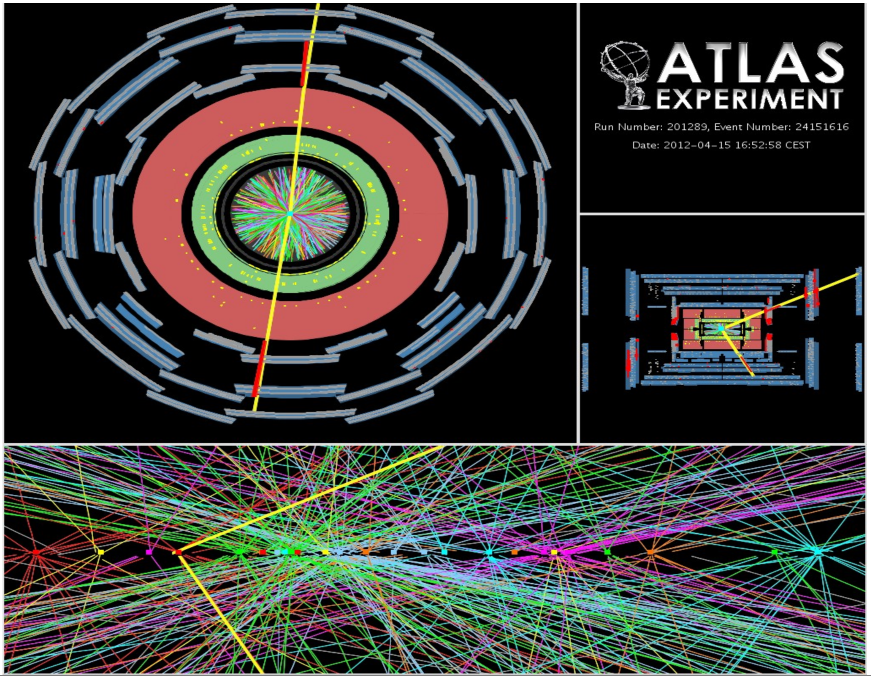
PV resolution in data from 'split vertex' method: well modelled in 2011 & 2012

Impact of Pileup

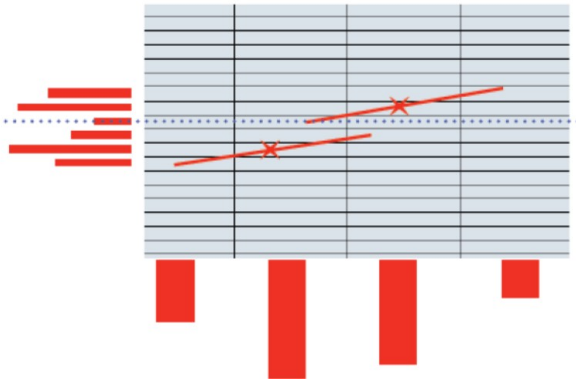
- Current challenge at LHC is impact of high pileup
- Significant effort to understand and mitigate this impact wrt tracking and PV reconstruction
- **In 2012 define more robust track selection for PV reconstruction**
  - Moderate drop in primary efficiency (~2-5%) for significant reduction in fake track fraction (30%+ → <10%)
  - Negligible fake PV probability

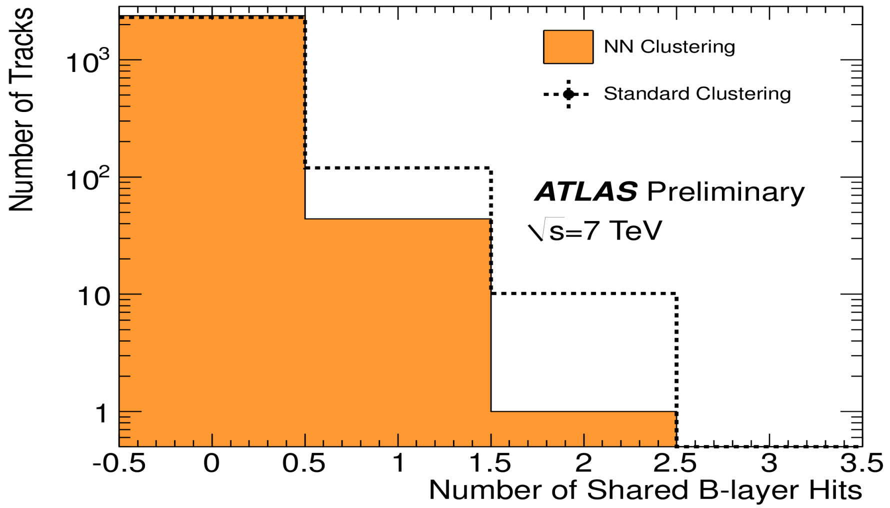






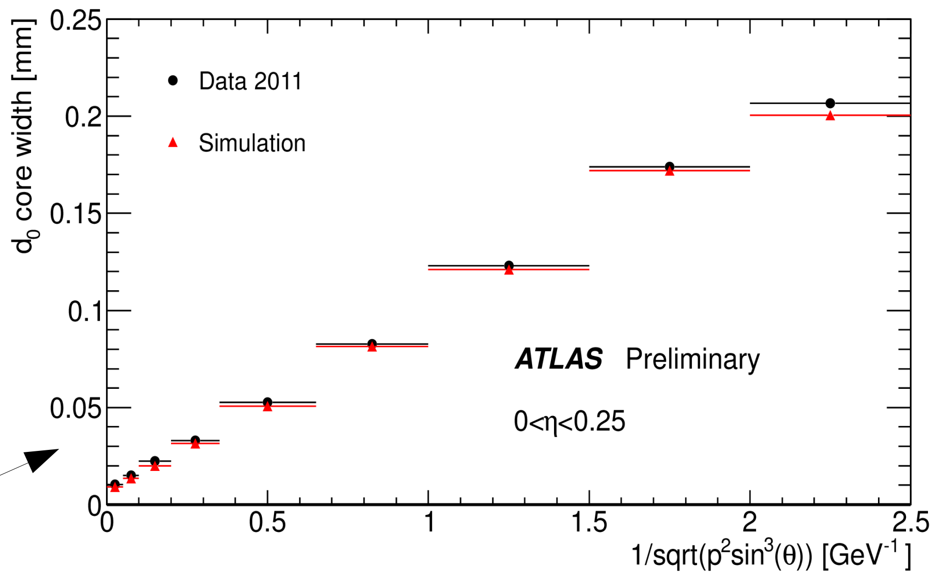
Neural Network (NN) Clustering





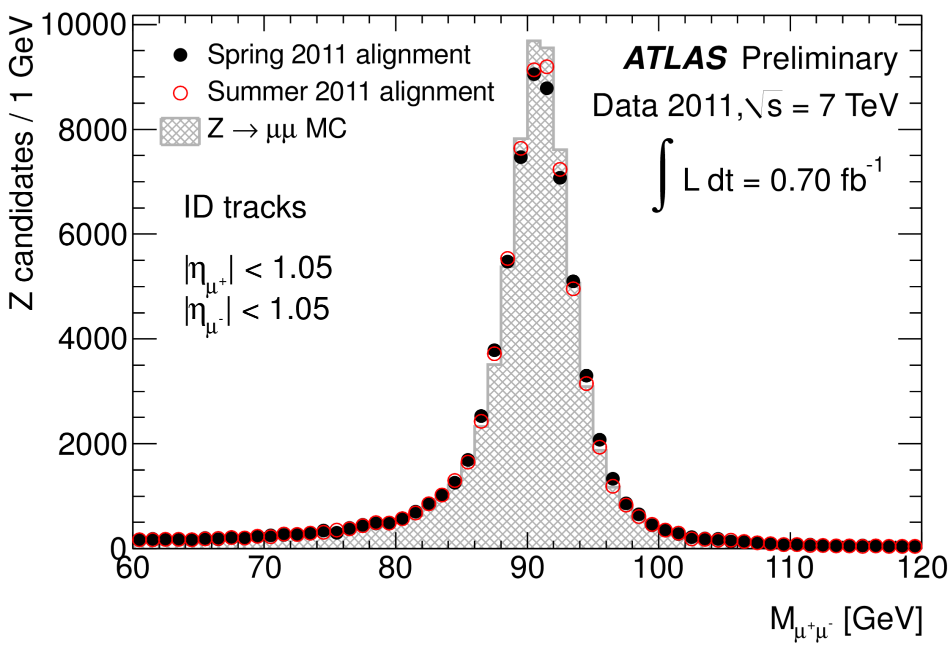
NN recovers previously shared clusters

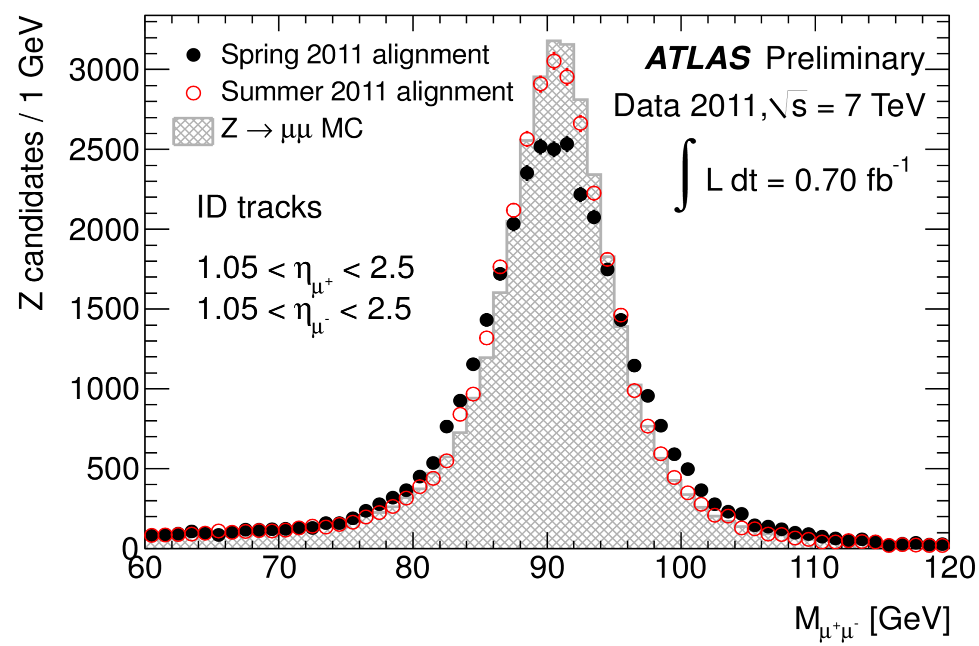
- High density of charged particles presents clustering challenge
  - Different charged particles can contribute to single cluster for pixels
- Pattern recognition from NN can identify and separate each sub-cluster
  - Input is information from 7x7 pixel array & tracking information where available
- NN clustering is now the default in ATLAS reconstruction
- Also improves pixel hit resolution resulting in **excellent impact parameter measurement**



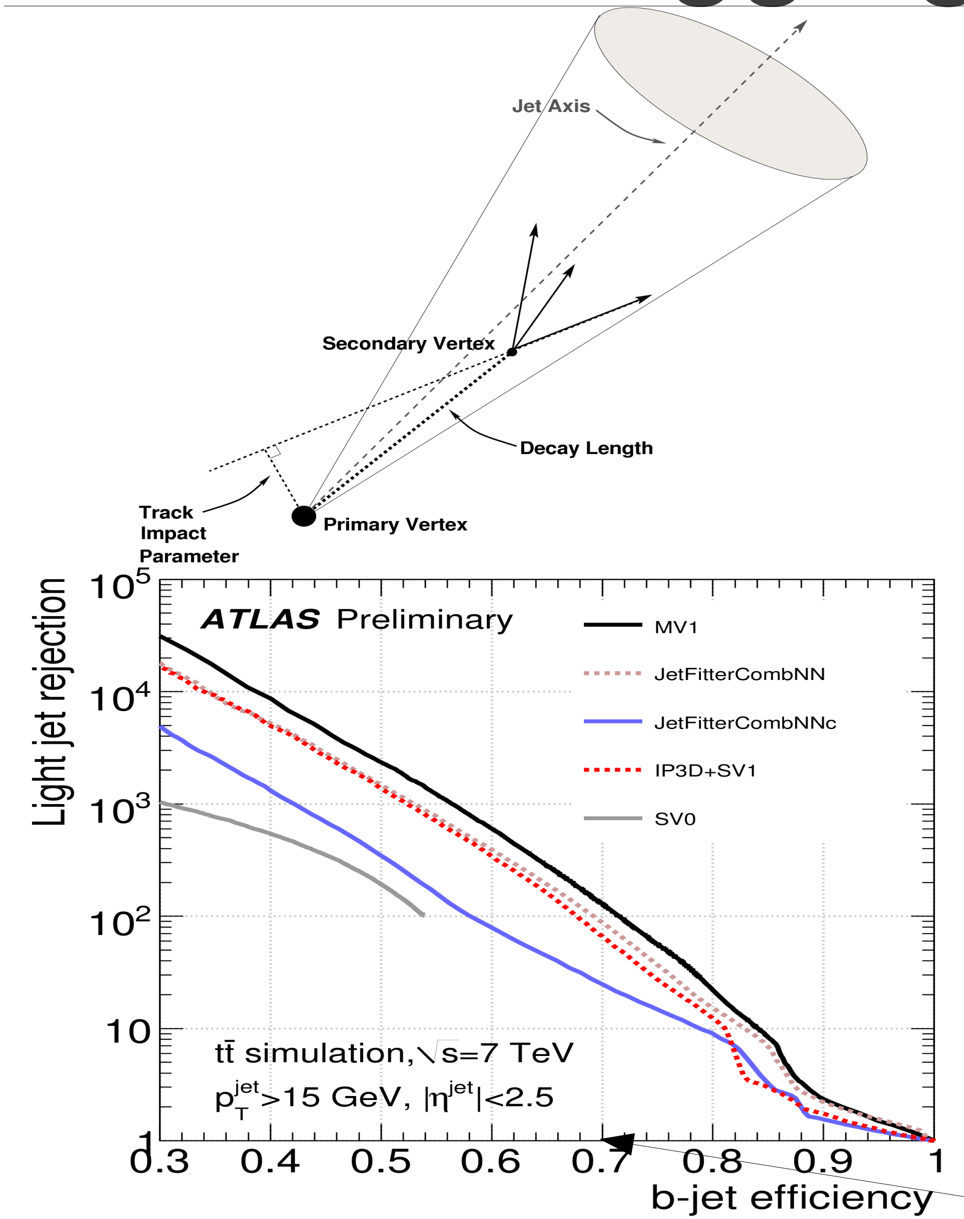
Detector Alignment

- Tracking residuals used for alignment
  - Different levels: Whole ID, barrel vs. endcaps, layer by layer, individual modules
- However misalignment '**weak modes**' exist which cannot be constrained by track residuals
  - Measure through biases in well known invariant masses (Ks & J/ψ)
- Improved alignment description in reconstruction significantly impacts Z mass resolution in data





B-Tagging Algorithms

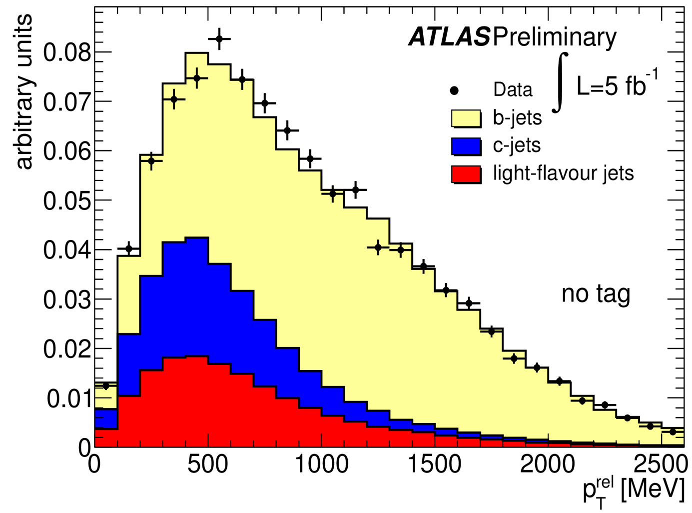


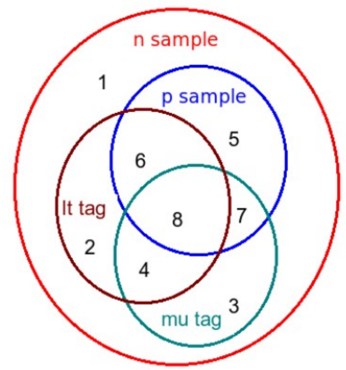
- Algorithms to identify heavy flavour content in reconstructed jets
- Impact parameter of tracks in jet
  - **IP3D** uses track weights based on longitudinal and transverse IP significance
- Displaced secondary vertex
  - **SV1** reconstructs inclusive displaced vertex
  - **JetFitter** reconstructs multiple vertices along implied b-hadron line of flight
    - Cascade decay topologies
- Advanced NN based algorithms
  - **JetFitterCombNN**: IP3D+JetFitter
  - **MV1**: IP3D+JetFitterCombNN+SV1

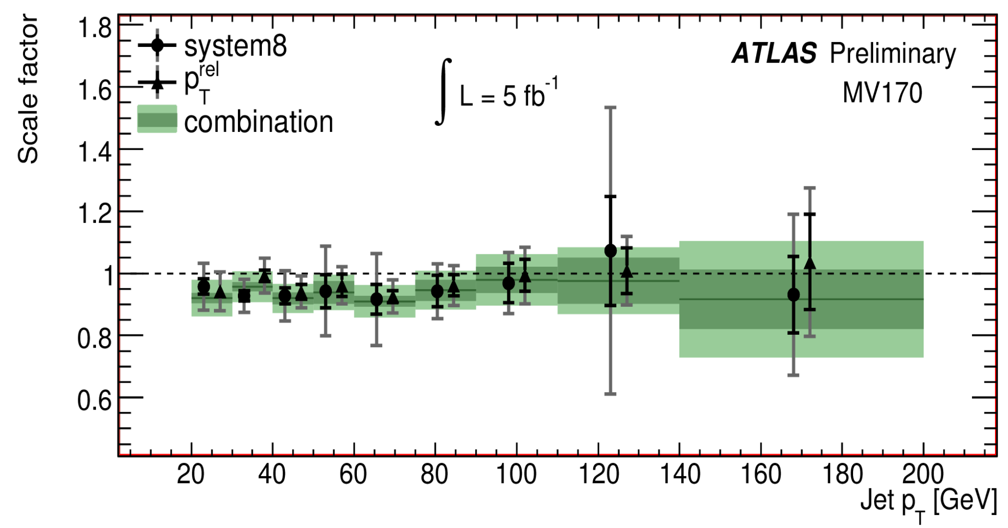
MC calibration results illustrated with MV1 @ 70% b-jet efficiency

b-Jet Efficiency from Muon Jets

- b-jet tag efficiencies measured in data from jets containing muons
- Two complementary methods:
  - **pTrel:** Likelihood fits of muon pT relative to jet axis pre & post tag
  - **System8:** Define 3 independent selection criteria (muon tag, lifetime tag under study & opposite side jet tag); event counts extract b efficiency
- **Results combined for increased precision, excellent agreement!**
- Systematics <20%
  - Dominant contribution at low pT from muon jets → inclusive b-jets extrapolation



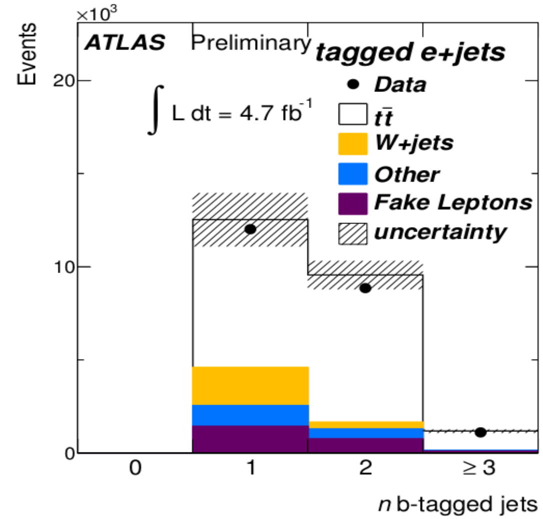


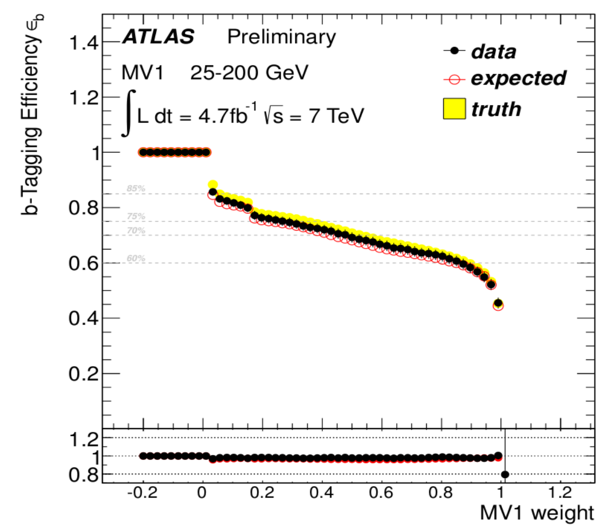


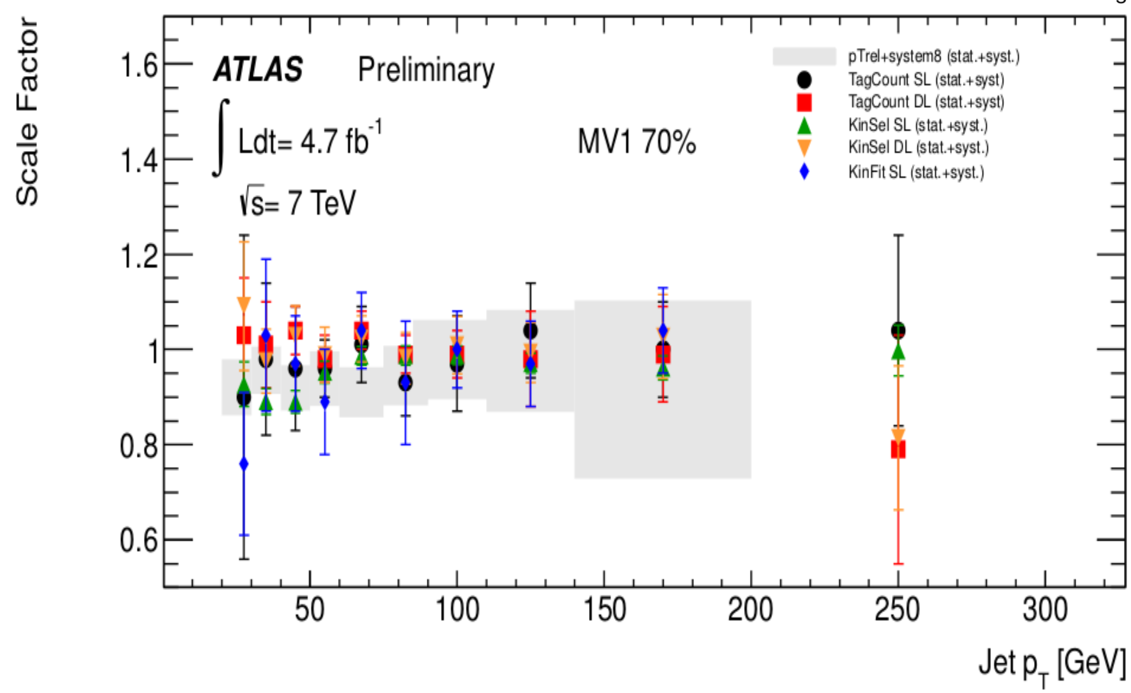
Analyses correct MC with
Scale factor = data eff. / MC eff.

b-Jet Efficiency from Top

- $t \rightarrow Wb$: b-jet control sample; high purity for **single- & di-lepton channel candidate events**
- 3 complementary methods
  - **Tag counting:** multiplicity of tagged jets gives efficiency as expect 2 b-jets (modulo acceptance, $g \rightarrow bb$, etc.)
  - **Kinematic selection:** measure tag rate for lead jets in ttbar candidate events
  - **Kinematic fit:** fits of ttbar event topology derive pure b-jet weight distributions
- Methods agree very well & compatible within uncertainty to muon based results
- Dominant systematics from jet uncertaintie & flavour composition modelling (ISR/FSR)

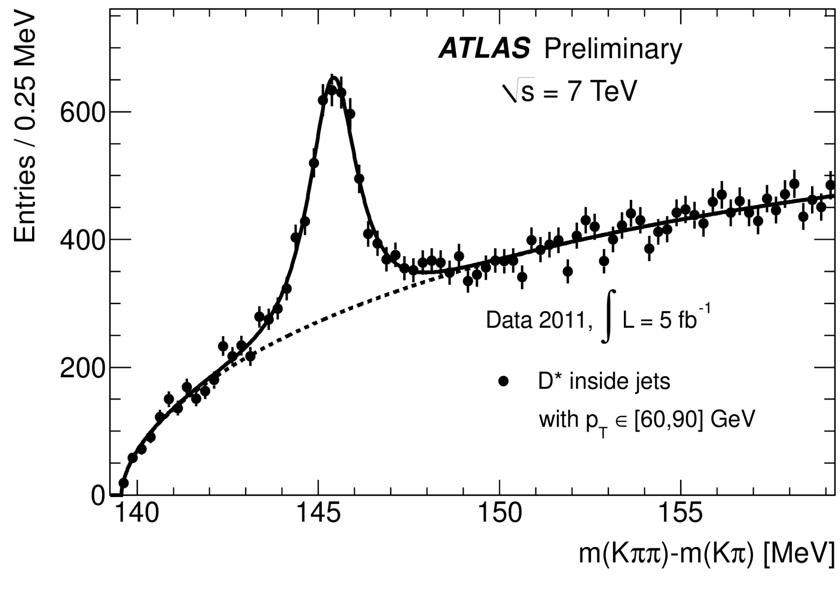


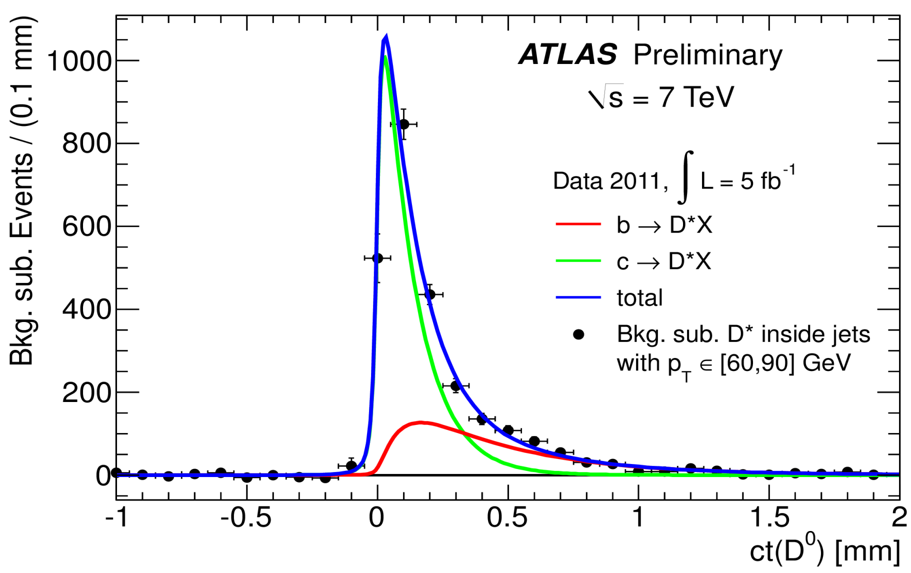


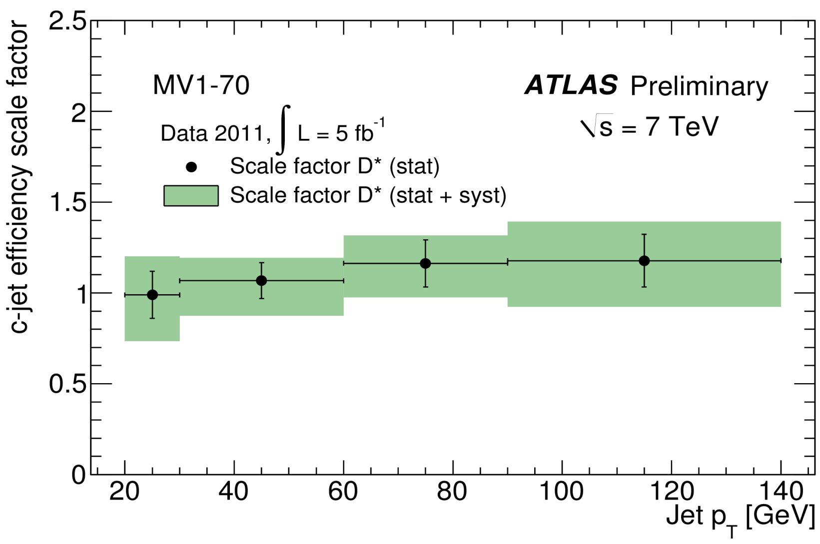


c-Jet Efficiency from D*+ Decays

- Tag c-jets with exclusive $D^{*+} \rightarrow D^0(K\pi)\pi$ reconstruction
- Background subtracted fit of pseudo proper D^0 time to extract $B \rightarrow D^*X$ contribution
- Systematics < 25%
  - Dominant contribution from extrapolating to inclusive c-jets

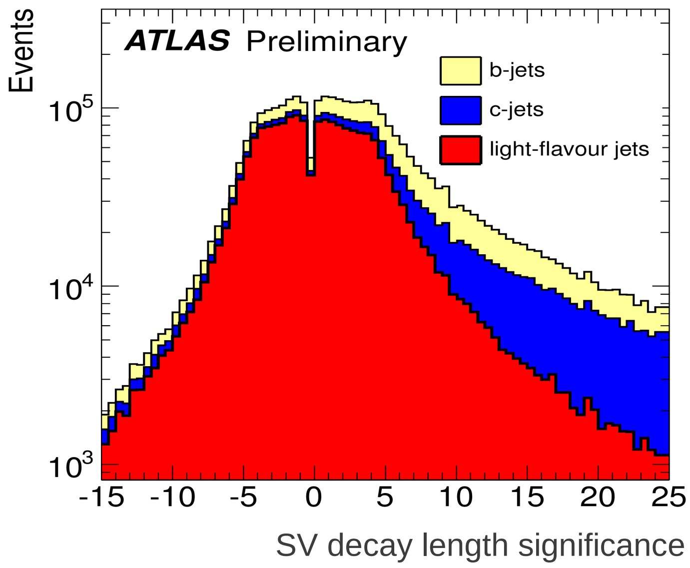


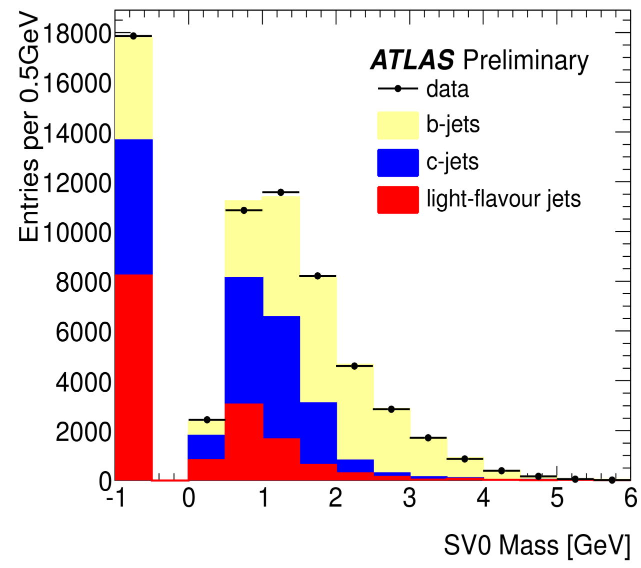


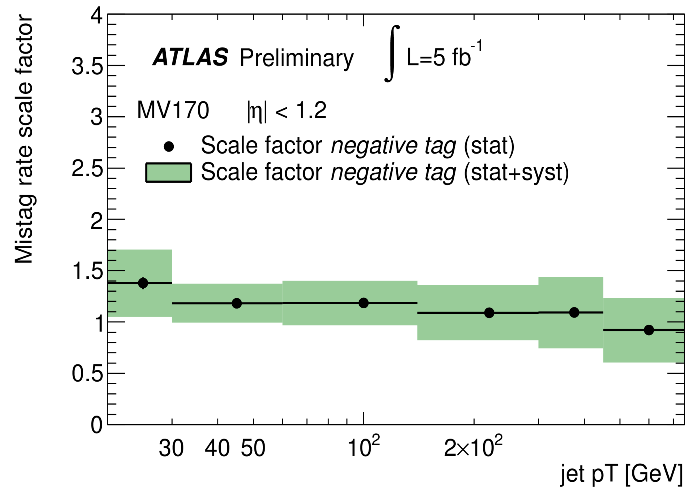


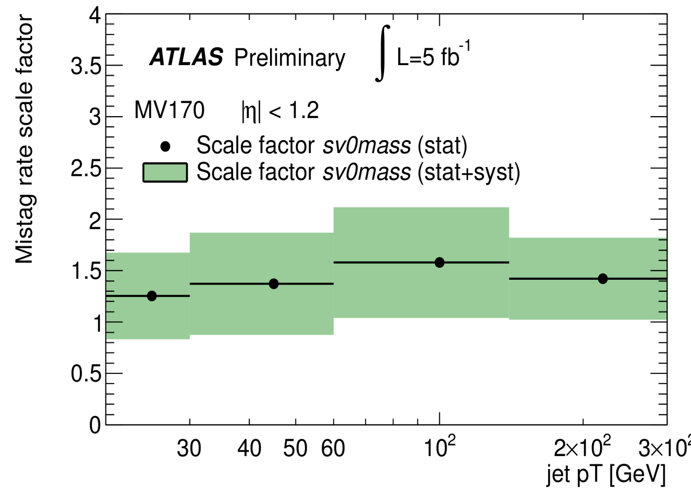
Mistag Rates from Multi-Jets

- Rate of non-heavy flavour jets passing tag criteria measured in dijet data
- Two complimentary methods
  - **Negative tag:** mistag from resolution effects; correct for long lived hadrons & material interactions
  - **SV0 mass:** Likelihood fit of SV invariant mass
- Methods agree well; systematics up to 100% depending on method & jet kinematics







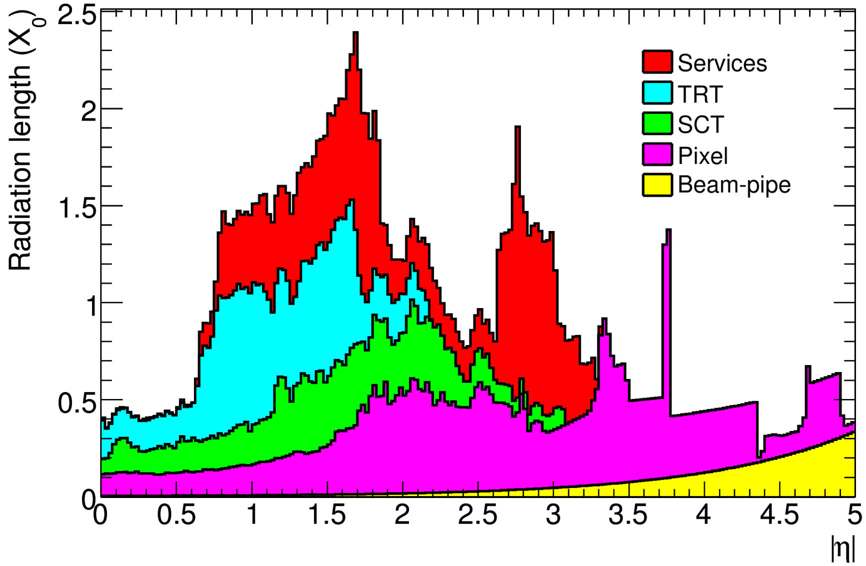


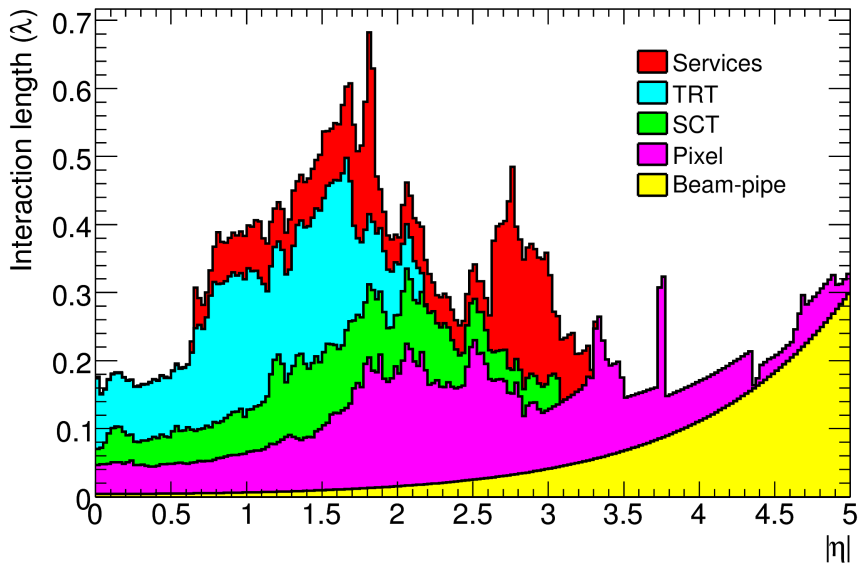
Summary

- **ATLAS is maintaining excellent performance with tracking, vertexing & b-tagging in the large datasets already collected in 2011 & 2012**
- Impact of tracking and PV reconstruction with high pileup well understood
- Advanced clustering to disentangle high density tracking in high pT jets
- Measurements of tracking detector alignment weak modes used to improve resolution in data
- **Multivariate b-tagging algorithms significantly improve mistag rates**
- Performance of b-tagging algorithms calibrated with full 2011 dataset
  - **First calibrations from top events in 2011 for ICHEP2012**
    - ATLAS-CONF-2012-097
  - Initial calibrations for 2012 data under way

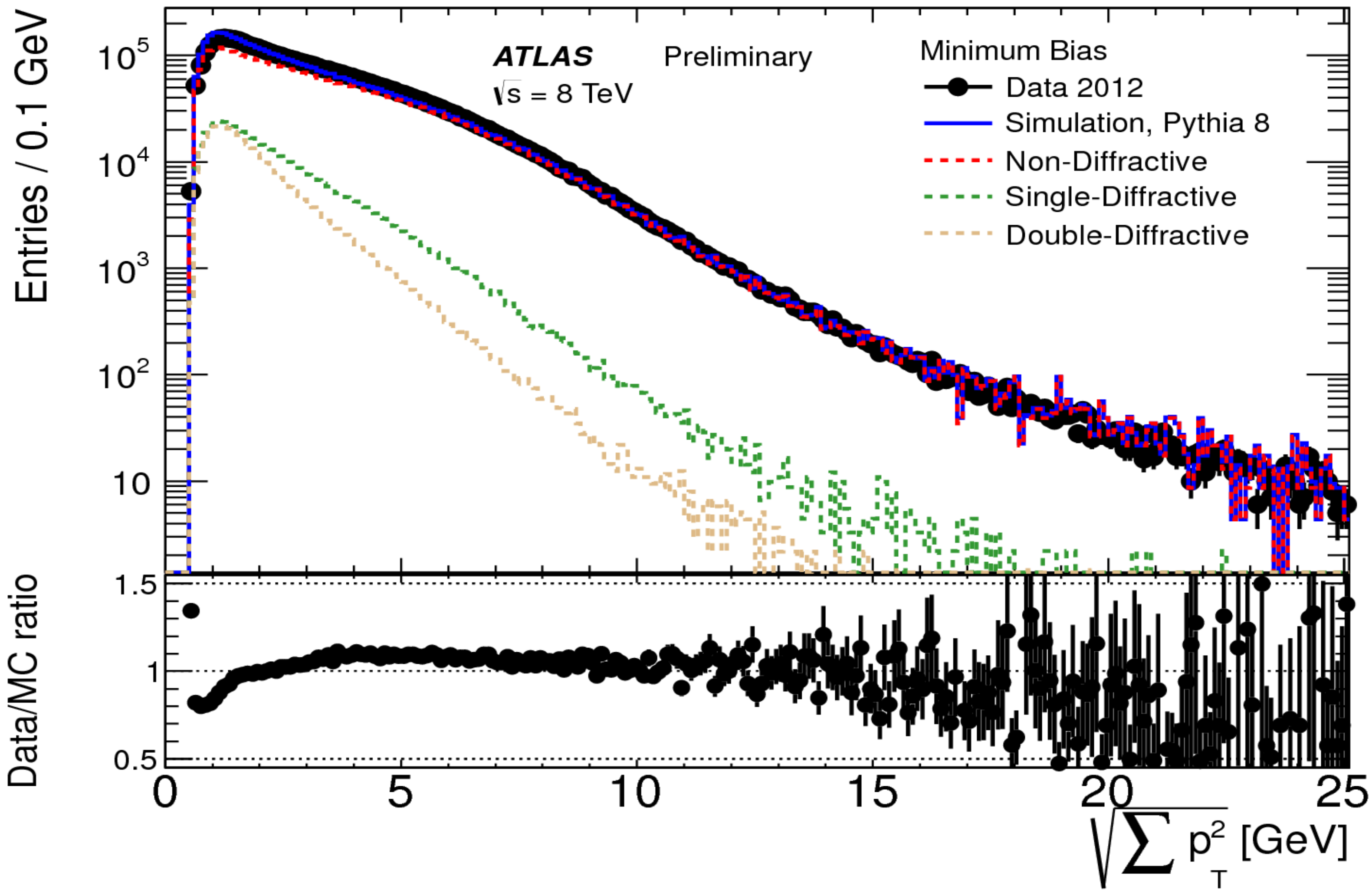
BACK UP

Inner Detector Material

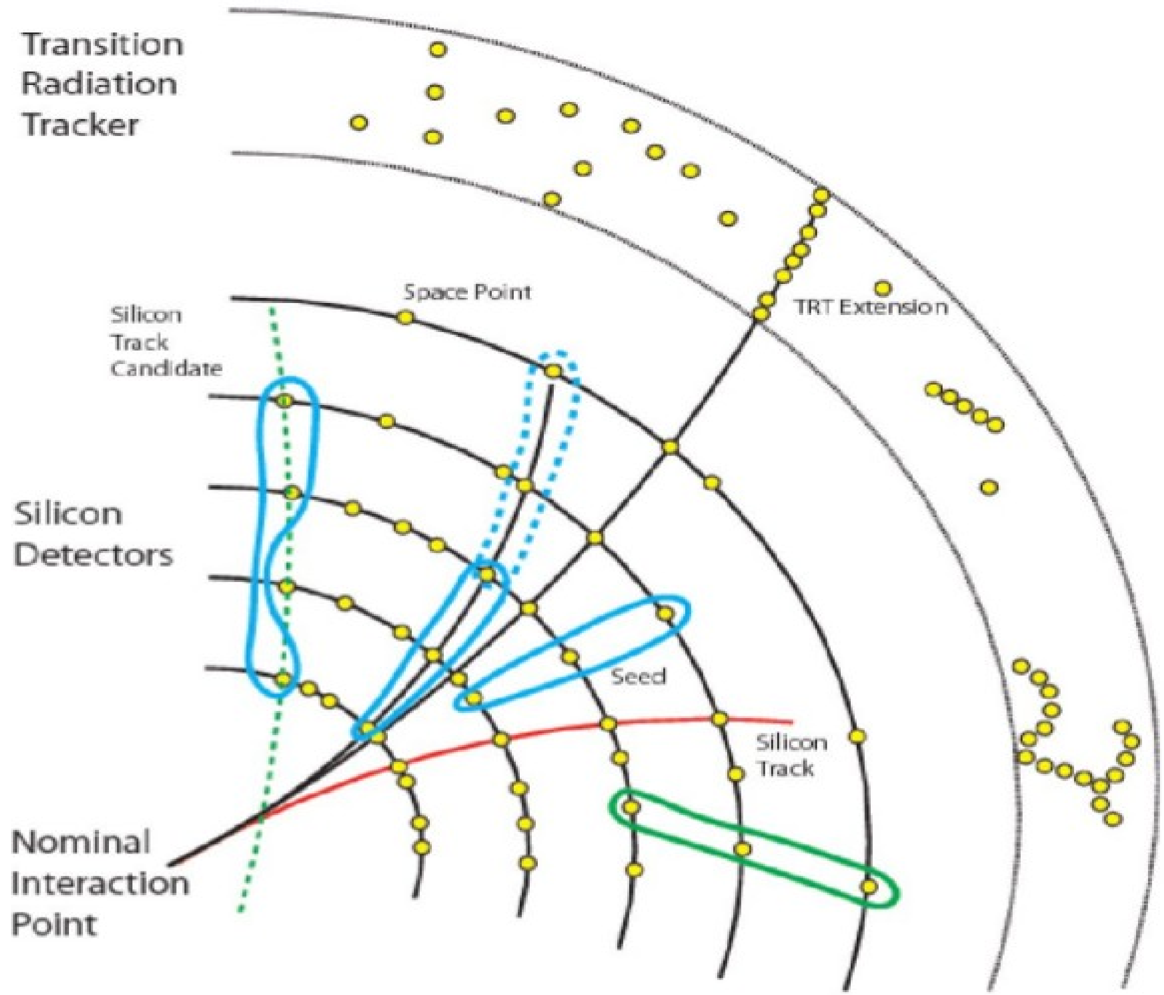




Physics Vertex Selection

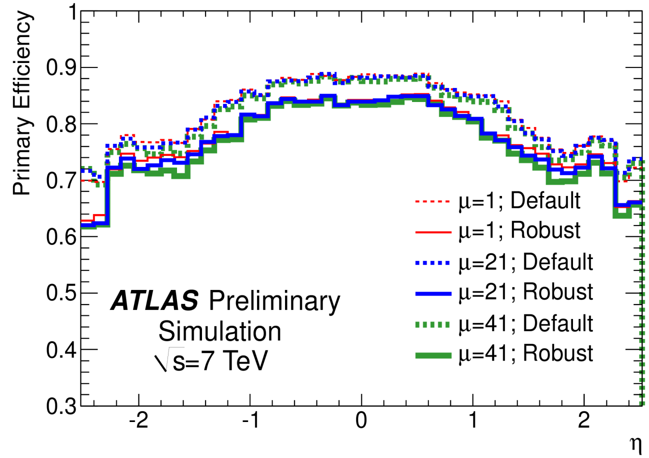


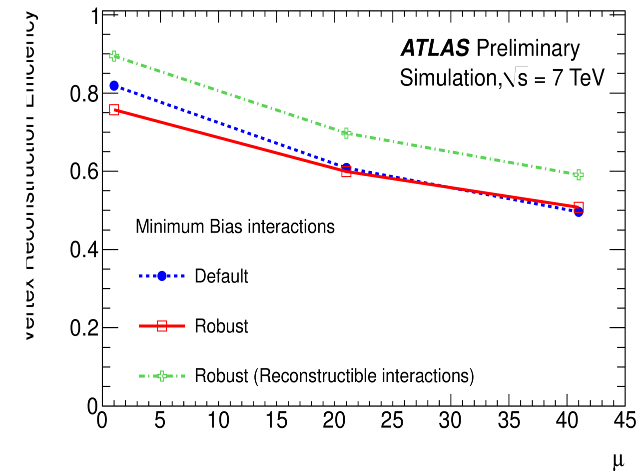
Track Reconstruction Algorithms

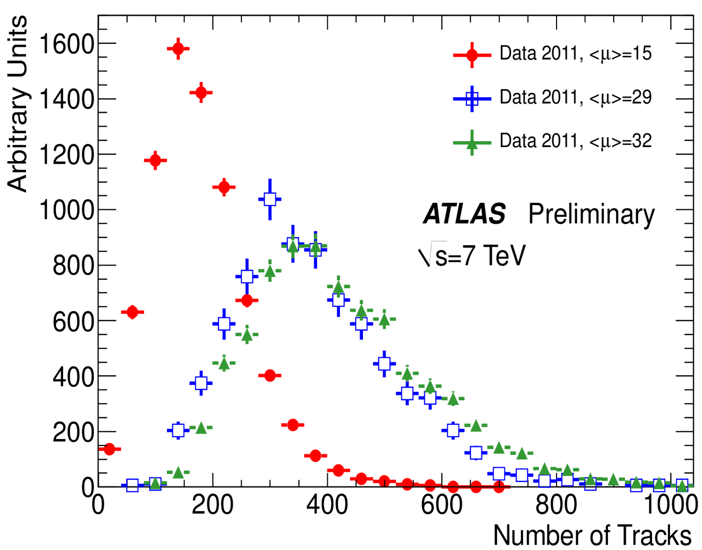


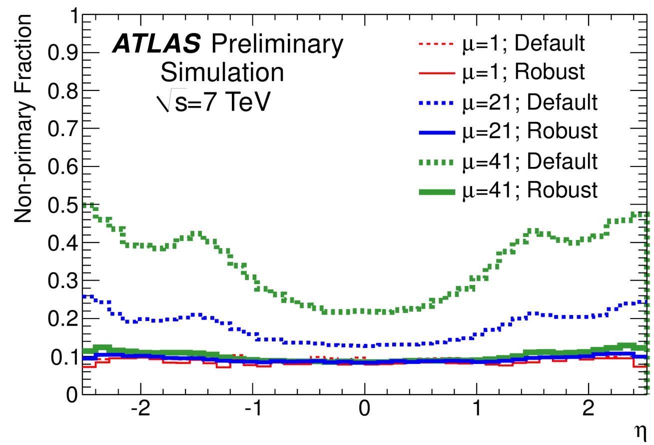
Impact of High Pileup

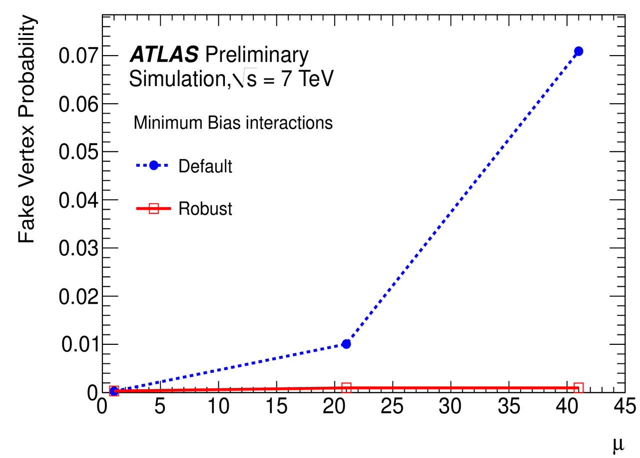
- Higher pileup means higher charged particle multiplicity
- More inner detector hits
- Higher probability of fake tracks and hence fake PVs
- Decrease in PV reconstruction efficiency
- Robust tracks: >=9 Si hits, 0 pixel holes





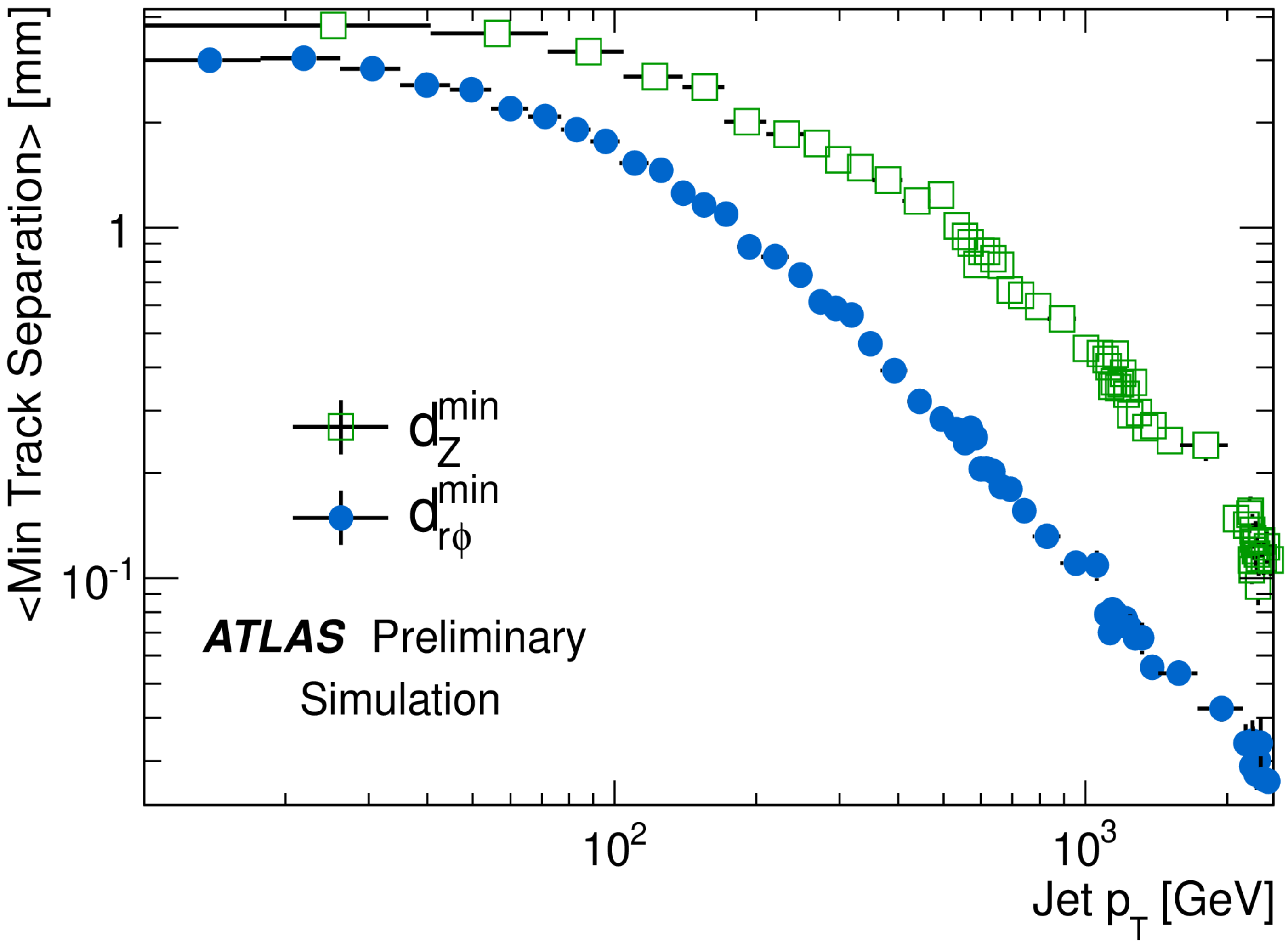






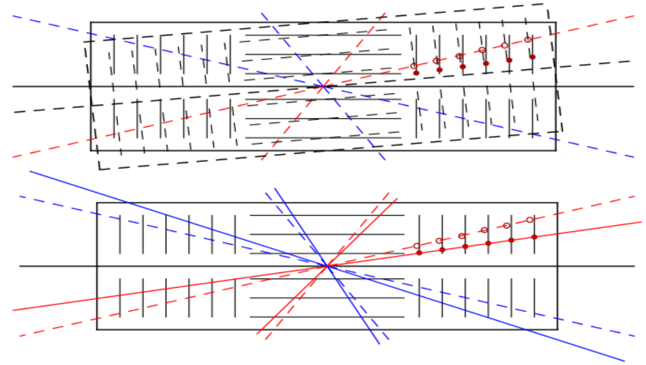
Robust track reconstruction cuts shown to significantly reduce impact of pileup for moderate efficiency loss

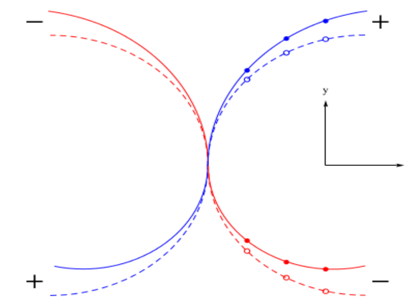
Track Multiplicity in High pT Jets

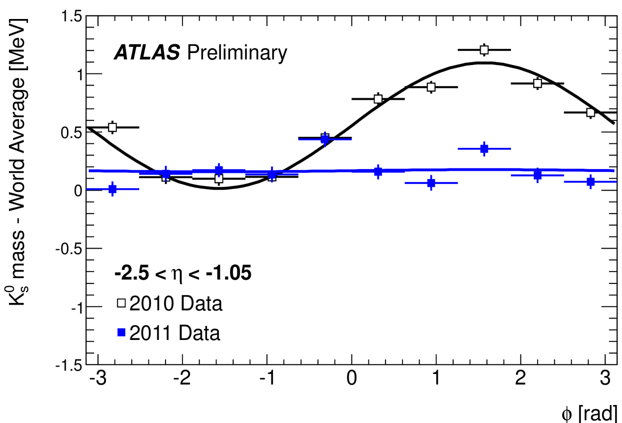


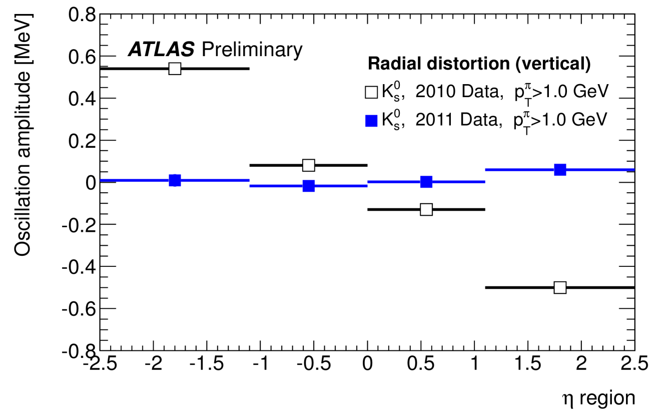
Detector Alignment

- Tracking residuals used for alignment
- However '**weak modes**' can exist which don't impact helical shape
  - e.g., B-field





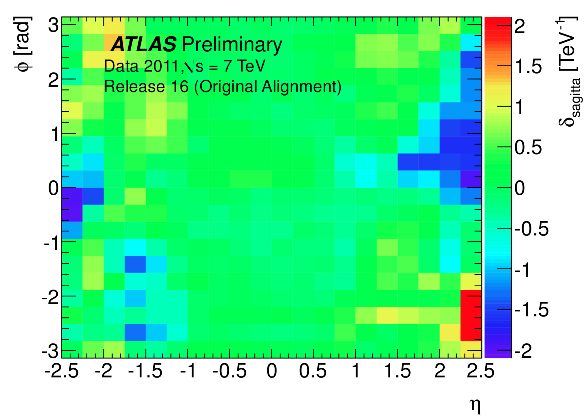


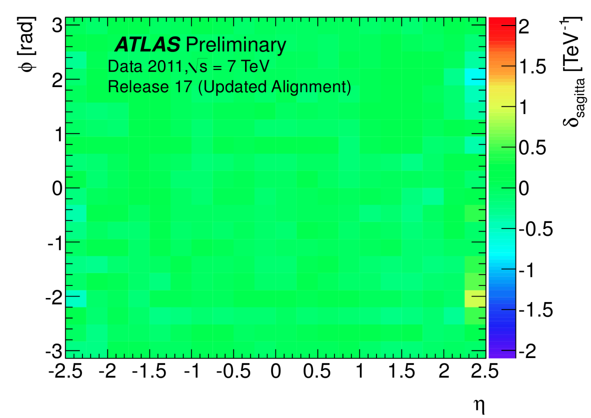


- Weak modes bias track parameters (pT, etc.)
- Determine their presence and correct with e.g., Ks reconstruction
- Charge asymmetric momentum bias measurement from Z → mumu improves with new alignment

$$q/p \longrightarrow q/p(1 + qp_T\delta_{\mathrm{sagitta}})$$

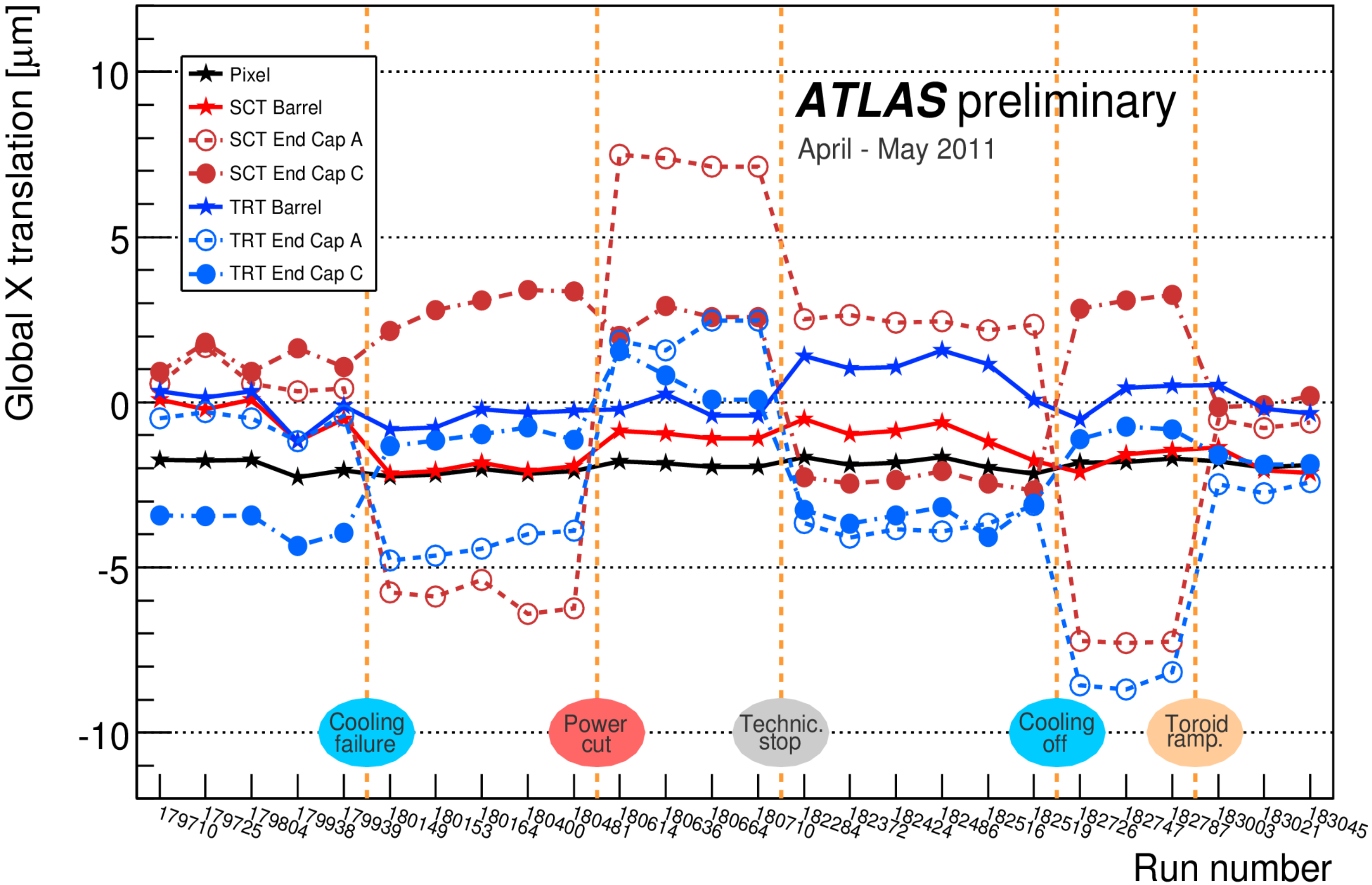
- Correction derived from electron E/p





Alignment Evolution

Level 1 alignment

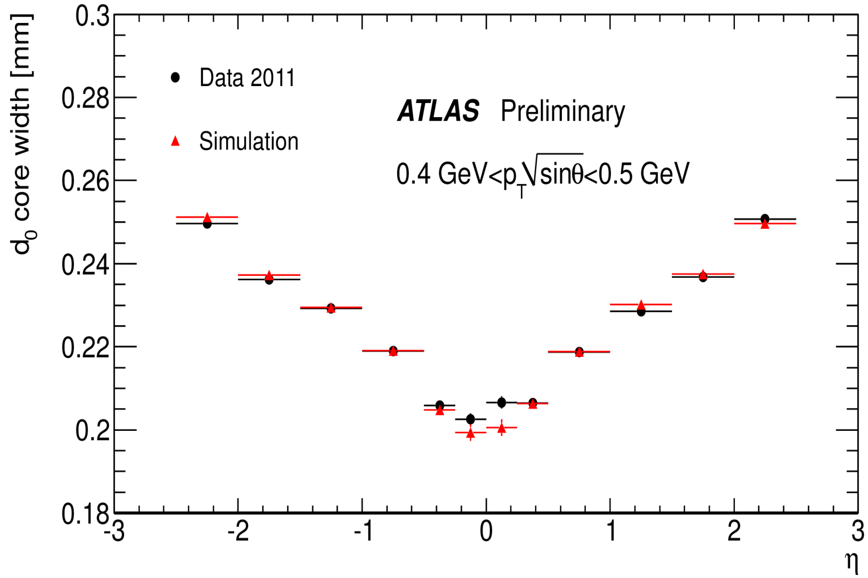


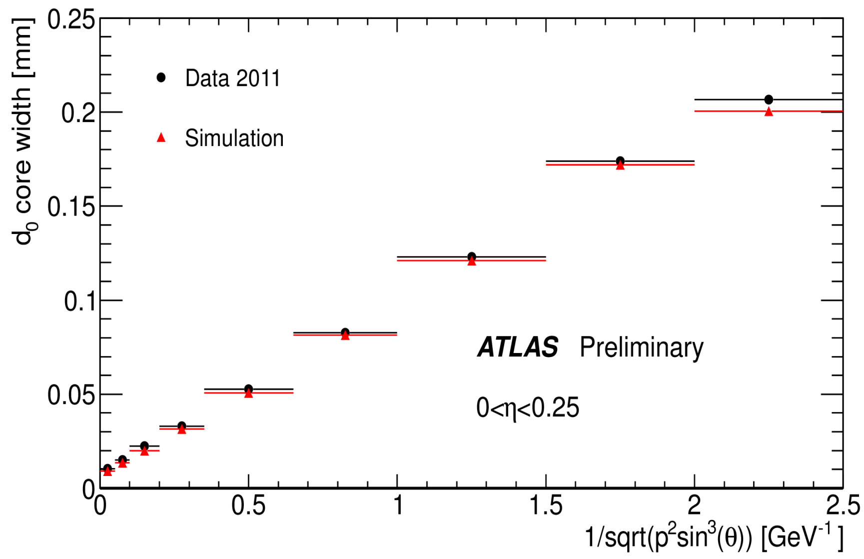
Impact Parameter Resolution

- Impact parameter (d_0,z_0) significance measures whether track comes from given PV
- Critical component of many b-tagging algorithms
- Track IP resolution in data dependent on PV resolution, needs to be unfolded

$$\sigma^2(d_0) = \sigma^2(d_0^{\text{track}}) + \sigma^2(PV)$$

- Good agreement between data and MC for range of track pT
- Resolution worse in forward region due to multiple scattering





References

- **Papers:**
  - “A measurement of the material in the ATLAS inner detector using secondary hadronic interactions”
    arXiv:1110.6191
- **CONF Notes:**
  - “Measuring the b-tag efficiency using top-pair events with 4.7 fb$^−1$ at the ATLAS detector”
    ATLAS-CONF-2012-097
  - “Measurement of the b-tag Efficiency in a Sample of Jets Containing Muons with 5 fb^{-1} of Data from the ATLAS Detector”
    ATLAS-CONF-2012-043
  - “Performance of the ATLAS Inner Detector Track and Vertex Reconstruction in the High Pile-Up LHC Environment”
    ATLAS-CONF-2012-042
  - “Measurement of the Mistag Rate of b-tagging algorithms with 5~fb^{-1} of Data Collected by the ATLAS Detector”
    ATLAS-CONF-2012-040
  - “b-jet tagging calibration on c-jets containing D* mesons”
    ATLAS-CONF-2012-039
  - “Alignment of the ATLAS Inner Detector Tracking System with 2010 LHC proton-proton collisions at sqrt{s} = 7 TeV”
    ATLAS-CONF-2011-012