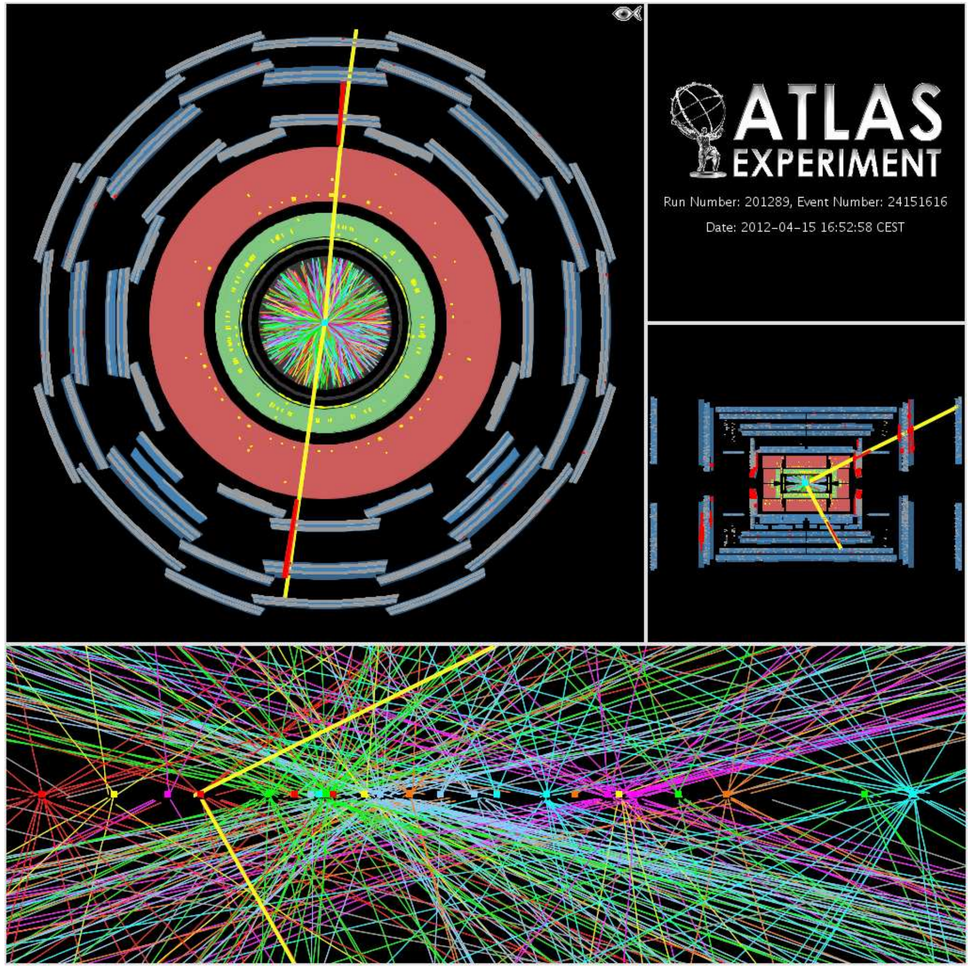
Tracking, Vertexing and B-tagging performance at ATLAS



① Introduction

② Track reconstruction

③ Vertex reconstruction

④ b-tagging

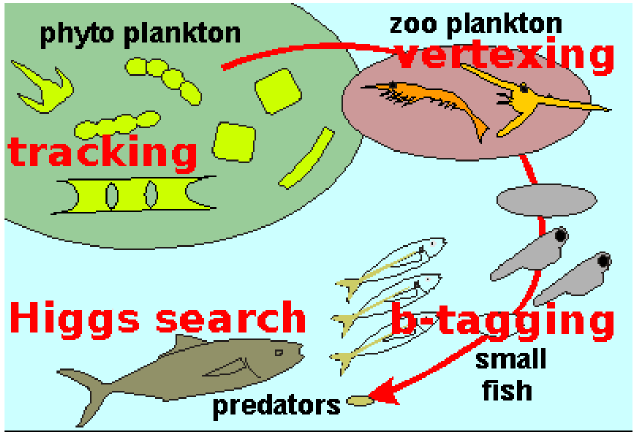
⑤ Summary and Outlook

Sara Strandberg, Stockholm University

for the ATLAS Collaboration

Tracking and Vertexing in Physics Analyses

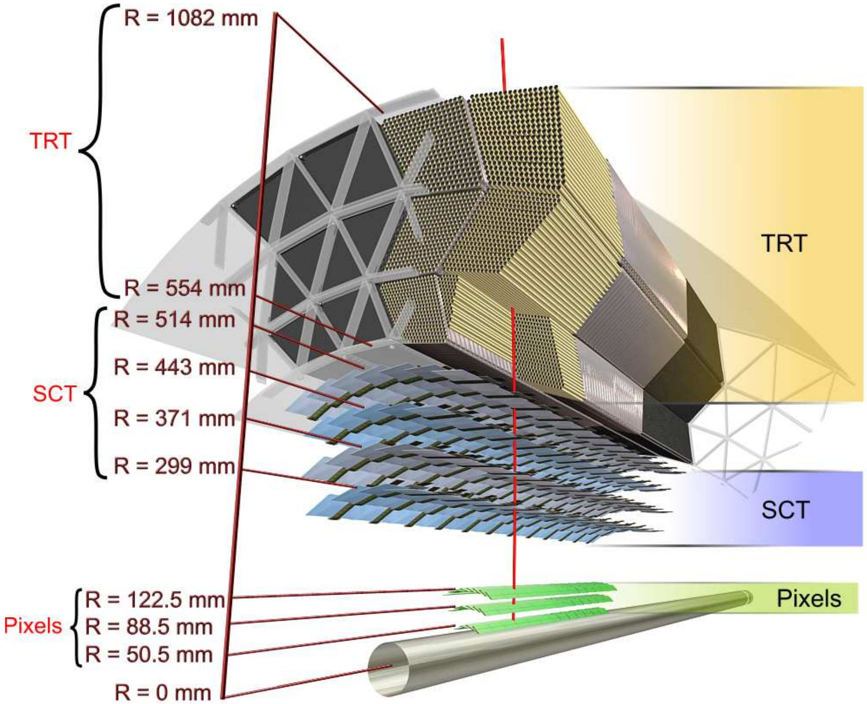
- Tracking and vertexing are fundamental ingredients in essentially all physics analyses:
  - Reconstruction of charged leptons.
  - Track-based isolation.
  - Can also complement calorimeter-based estimates of e.g. $E_{\mathrm{T}}^{\mathrm{miss}}$.
  - Reconstruction of the primary collision point.
  - Identification of jets from b-quarks (b-tagging).



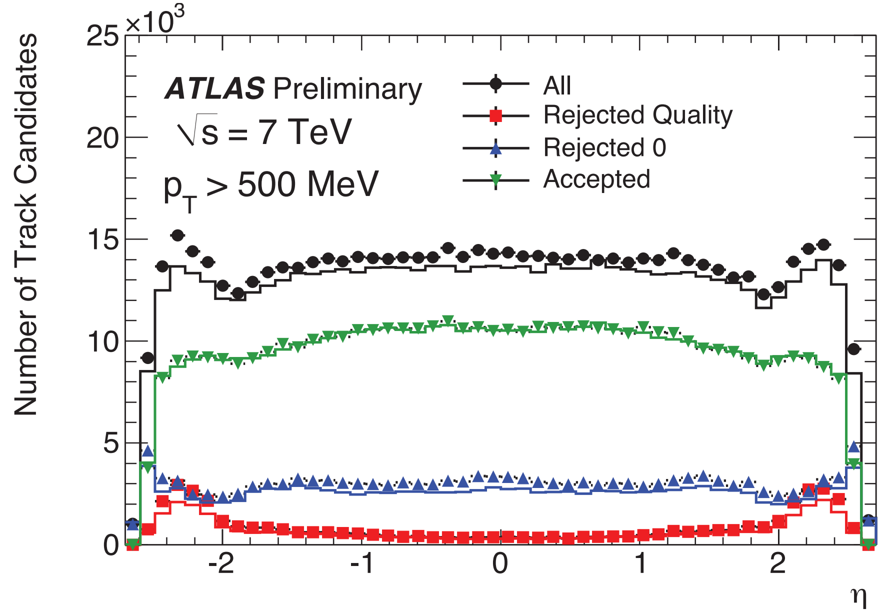
- Good tracking and b-tagging performance in achieved by:
  - High-precision tracking detectors.
  - Good knowledge of the ID material.
  - A precise ID alignment.
  - Performant algorithms (tracking, vertexing, b-tagging).

- Silicon and drift tube technology.

	# channels	# hits /track	resolution $(x \times y)$ (μm)	active (%)
PIX	80×10^6	3	10×115	95.9
SCT	6.3×10^6	8	17×580	99.3
TRT	3.5×10^5	36	130	97.5



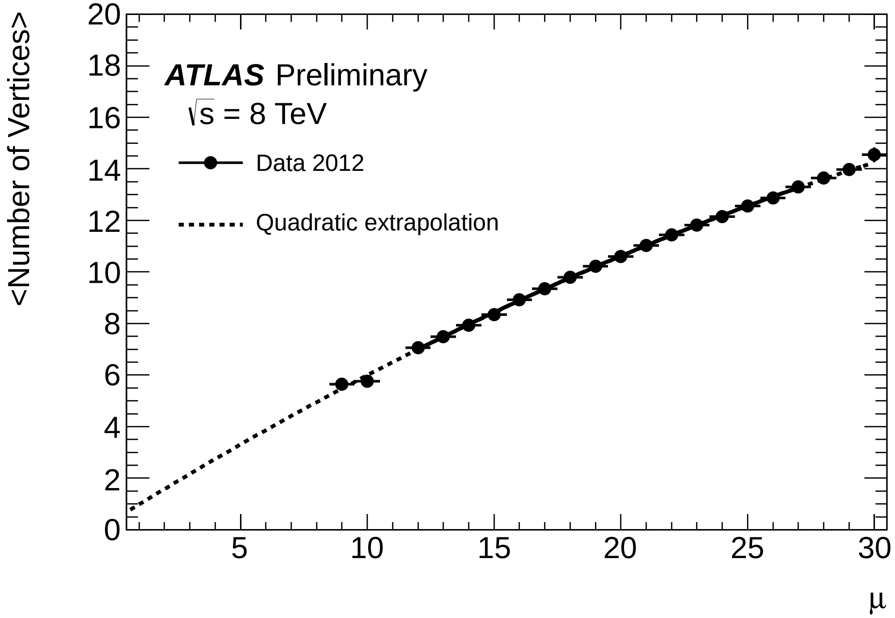
- Covers $|\eta| < 2.5$.
- In 2 T magnetic field.



- Build track candidates in three steps:
  - seed finding
  - collect hits in roads
  - rank candidates

Primary Vertex Reconstruction

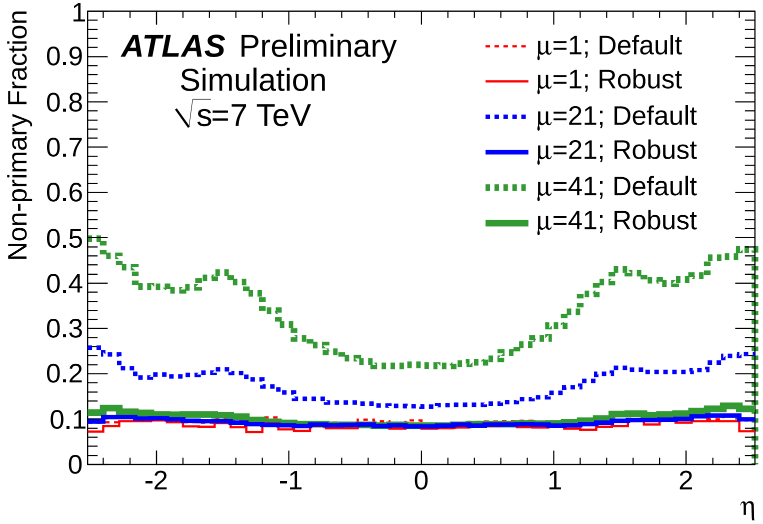
- Vertexing crucial in many areas:
  - Reconstruct and identify hard scatter interaction point.
  - Determine pile-up level.
  - PV is reference for b-tagging.

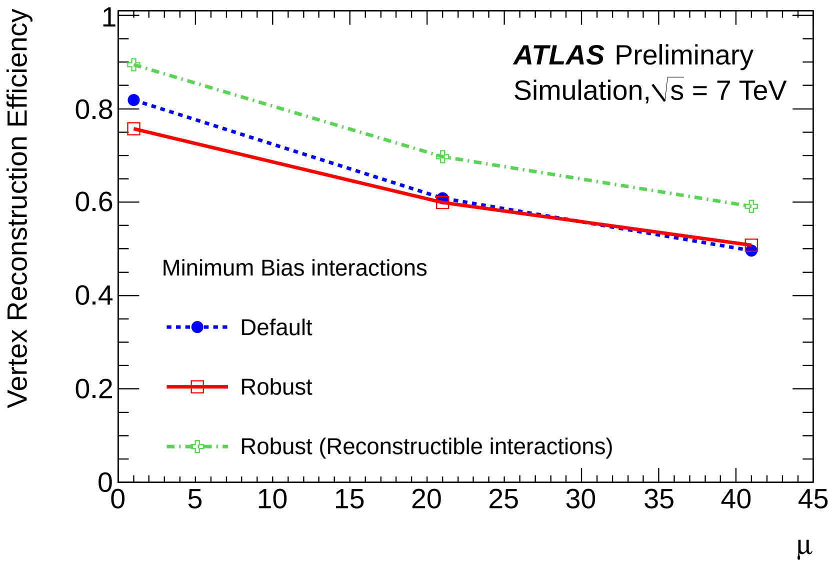


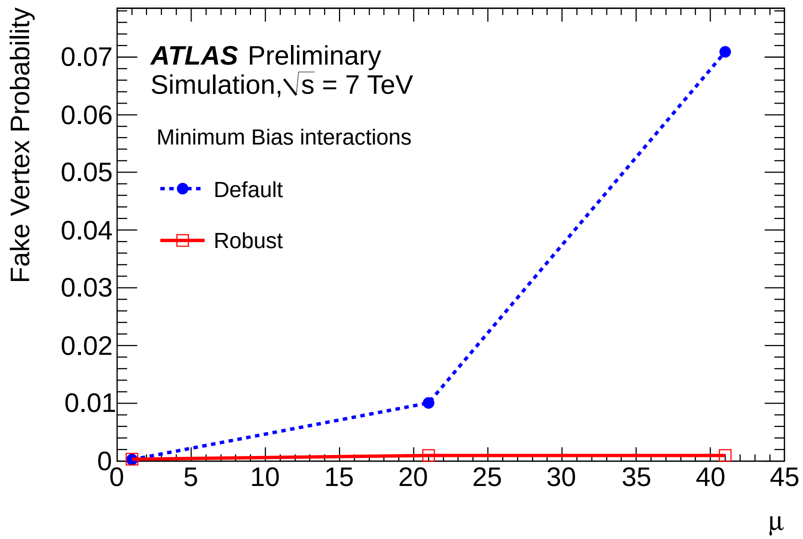
- Iterative vertex finding:
  - Find vertex seeds along z.
  - χ^2-based fit, outliers removal.
- Baseline is to use the PV with the largest $\sum p_{\mathrm{T}}^2$ as hard scatter.
- Association-based selection (jets, e, μ) also supported.

High Pileup Environment

- Tracking in high-pileup environments is very challenging.
- Switch to robust reconstruction setup.
  - Tighter requirements on the silicon hit pattern.
  - Much lower fake rates at minimal loss of efficiency.

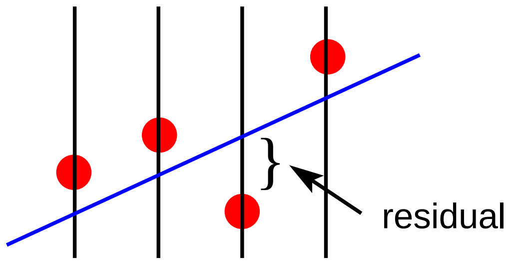




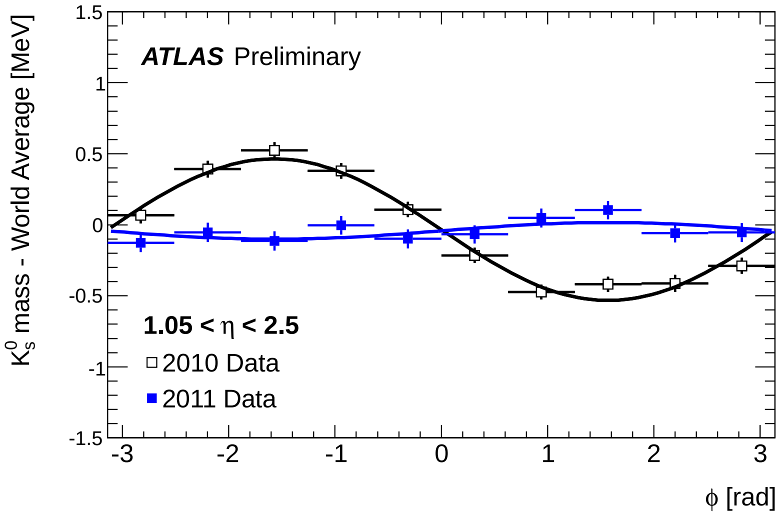


Alignment

- Precise knowledge about position of detector elements needed for
  - IP resolution (crucial for b-tagging)
  - mass resolution (1 μm alignment for 10-15 MeV precision in W mass)



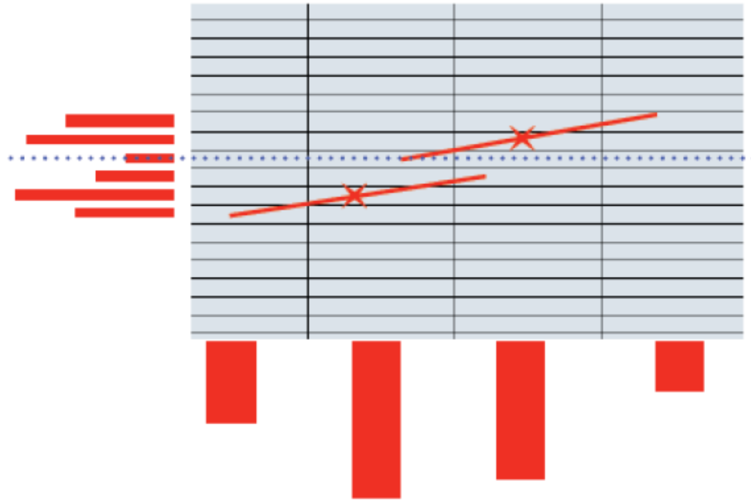
- Alignment carried out iteratively by minimizing residuals.
- So called weak modes are distortions which do not affect residuals. Need to resolve these using e.g. known particle masses.

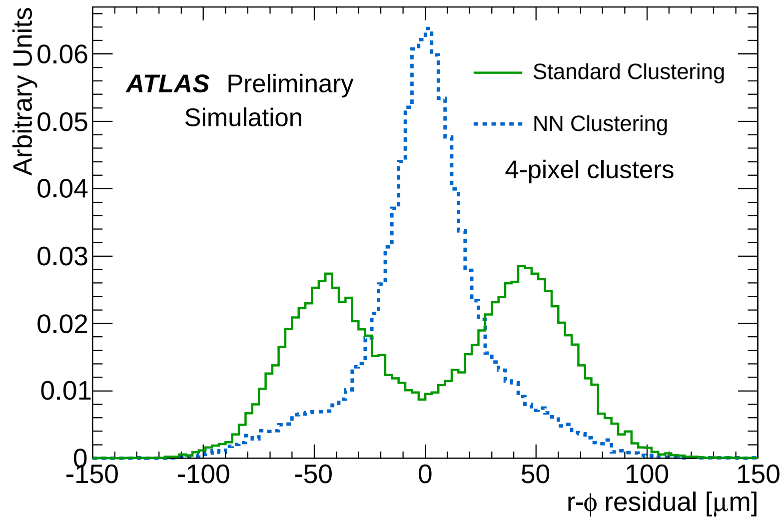


- Need to perform alignment continuously since detector moves due to changes in environment.

Neural Network Clustering

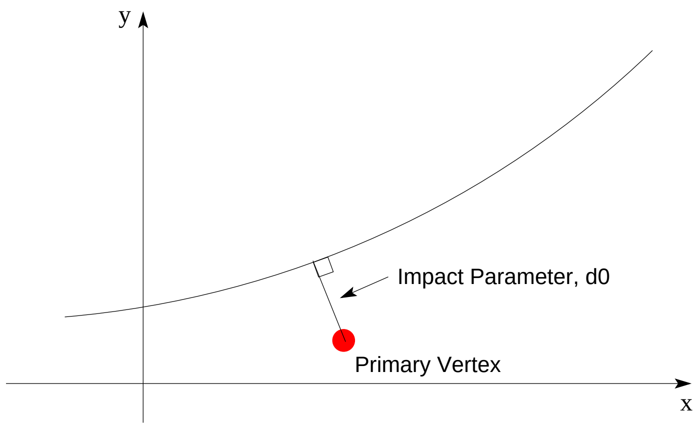
- Good track parameter resolution requires precise knowledge of hit positions in tracker.
- Positions biased in case of merged clusters from nearby particles.
- New NN-based clustering algorithm developed to split clusters which are likely not originating from a single particle.
- Especially relevant in dense environments such as core of high-p_{T} jets.
- Also improves treatment of delta rays.





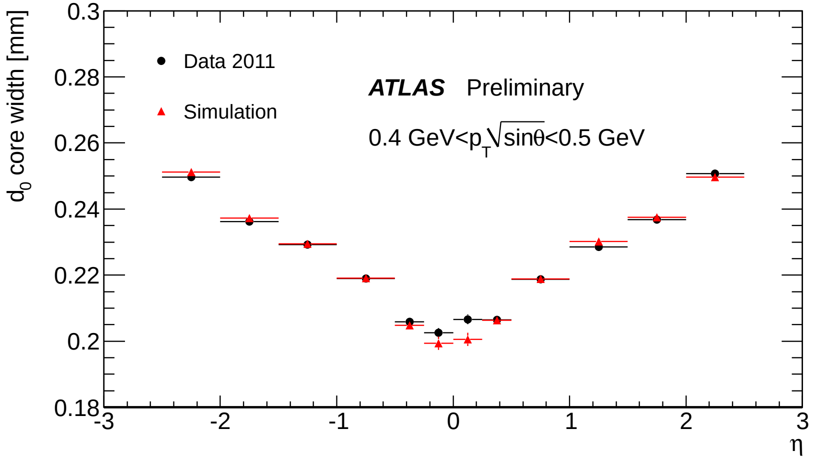
Impact Parameter Resolution

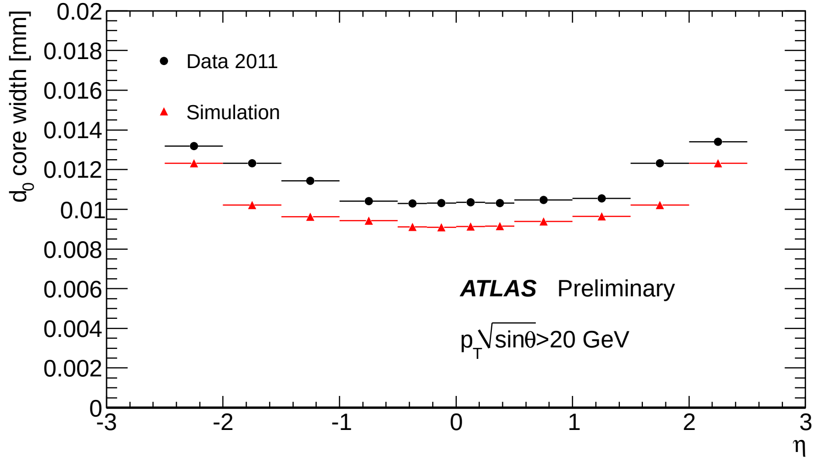
- Impact parameter (d_0,z_0) indicates if track originates from the PV or not.
- Crucial ingredient when identifying long-lived particles, e.g. b-tagging.



- Unfold uncertainty on PV position to measure resolution in data

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

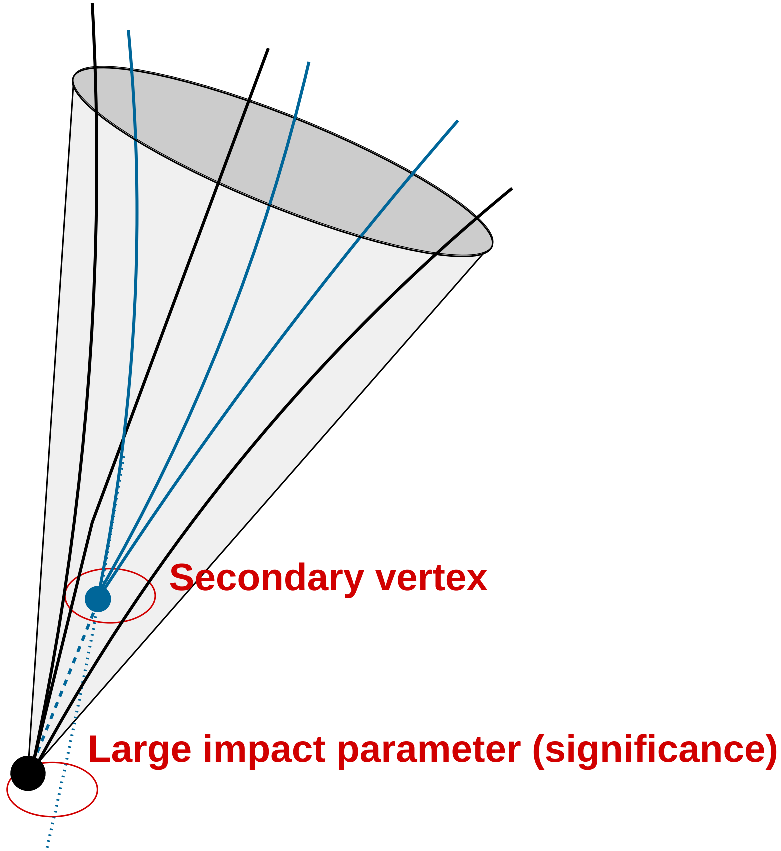




- Low p_{T} well described $\Rightarrow$ material understood.
- Worse IP resolution at high p_{T} in data due to misaligment effects.

b-tagging

- b-tagging is a powerful tool to separate a heavy flavor signal (b, top, Higgs, SUSY) from backgrounds.
- Identify decays of b-hadrons in jets by presence of
  - tracks with large impact parameter and impact parameter significance.
  - secondary decay vertex.
- Crucial to understand and have a good description of the impact parameter of tracks in jets.
- Correct estimate of error on primary and secondary vertex positions.



b-tagging Algorithms

IP-based algorithms

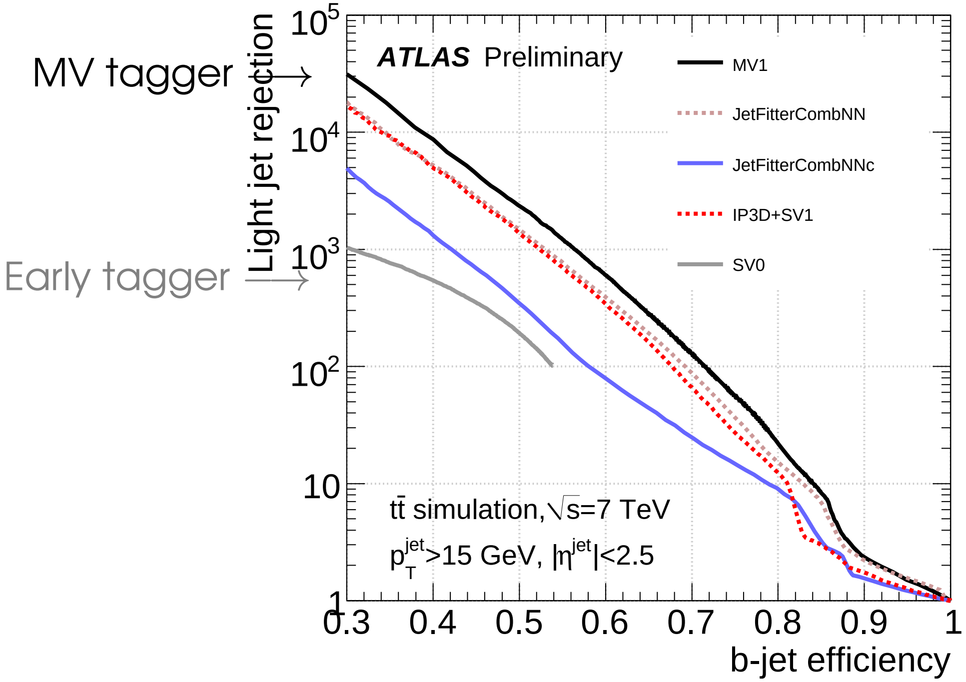
- IP3D uses PDFs in transverse and longitudinal IP significance.
- $w_{\text{track}} = p_b/p_l$.
- $w_{\text{jet}} = \sum_{\text{track}} \log(w_{\text{track}})$.

Combinations

- JetFitterCombNN: JetFitter+IP3D.
- JetFitterCombNNc: Trained to reject c.
- MV1: JetFitterCombNN +IP3D+SV1.

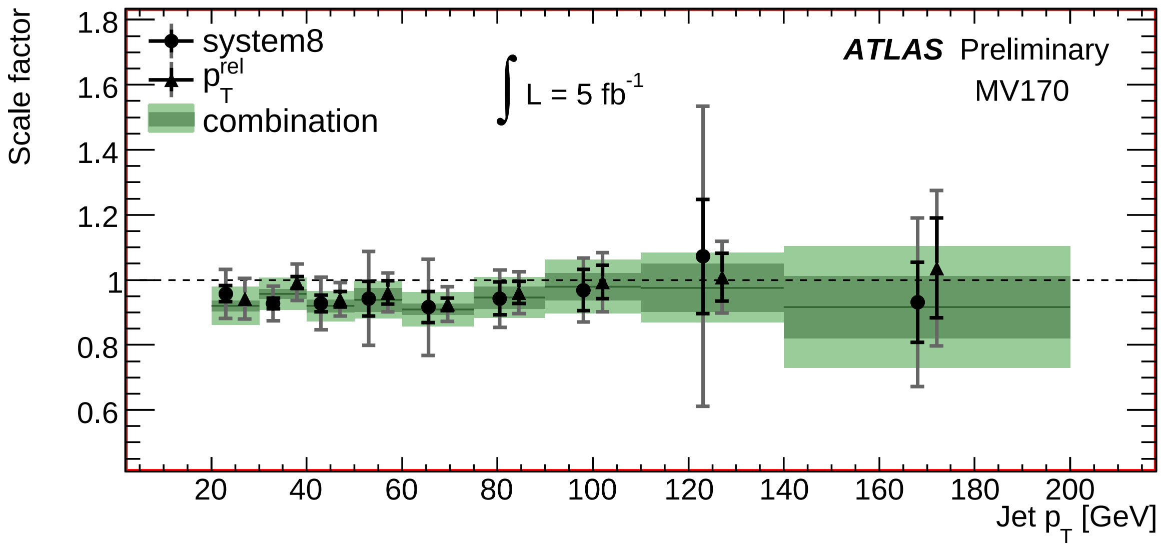
Secondary vertex-based algorithms

- SV1 Reconstructs inclusive SV.
- JetFitter is able to reconstruct full weak ($b \to c \to X$) decay chain.
- Both use SV properties to further separate b-jets from non-b-jets.



Performance in Data - b-tag Efficiency

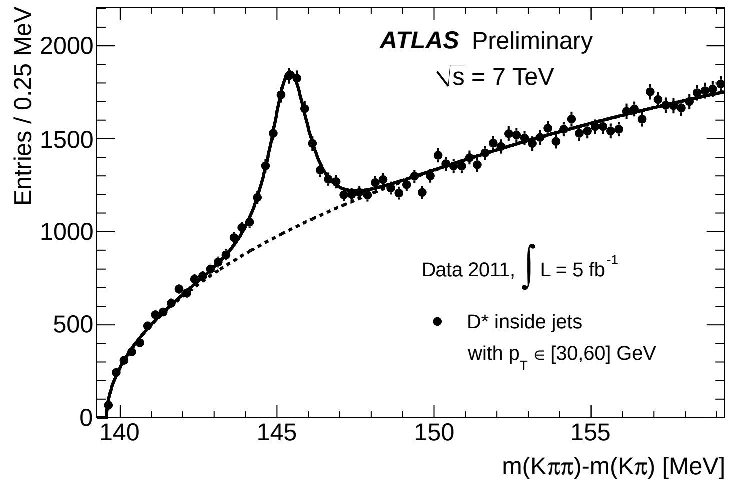
- Currently use two complementary methods based on μ-jet sample.
- $p_{\mathrm{T}}^{\mathrm{rel}}$ method: Template fits of muon p_{T} with respect to the jet axis $p_{\mathrm{T}}^{\mathrm{rel}}$, to get flavor composition before and after b-tagging.
- System8 method: Use 3 uncorrelated selection criteria to construct 8 disjoint samples. Use event counts to solve for b-tag efficiency.
- Present results as data-to-MC scale factors.
- Excellent agreement between methods.
- Total uncertainty is 5-19%.

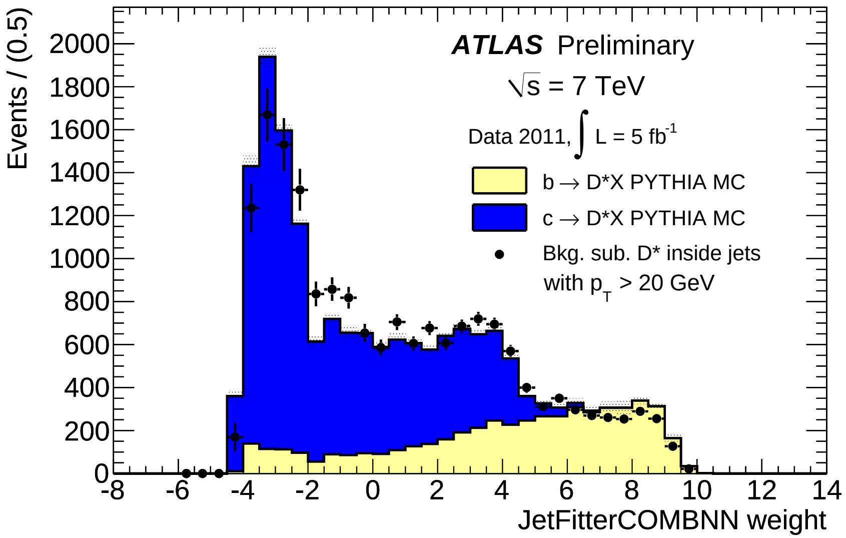


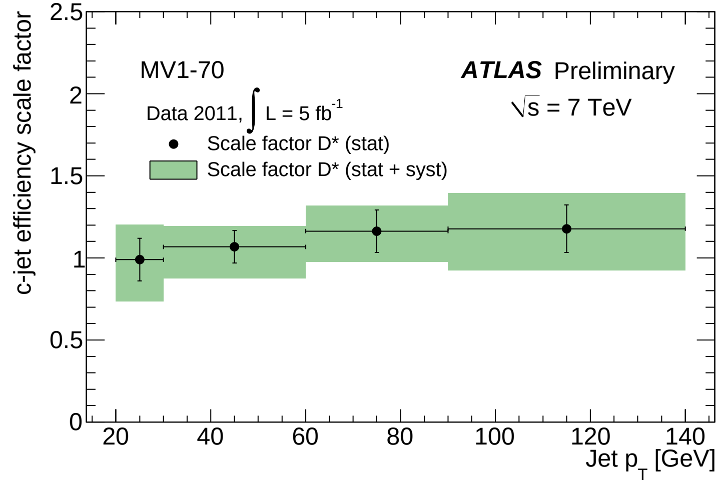
Posters by Dominik Duda, Christian Jung and Gordon Watts

Performance in Data - c-tag Efficiency

- Reconstruct $D^{*+} \to D^0\pi^+$ ($D^0 \to K^-\pi^+$).
- b-contamination from D^0 pseudo proper time fit.
- Can compare e.g. weight distributions in background-subtracted sample.
- Generally very good agreement.





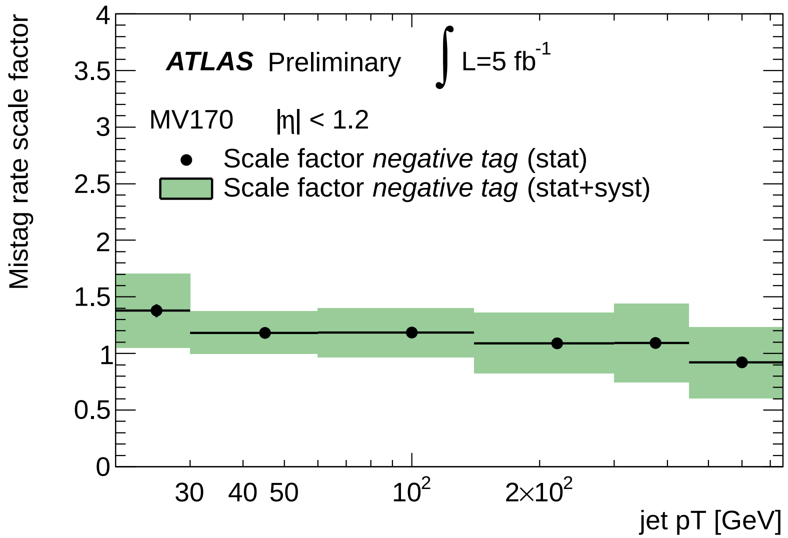


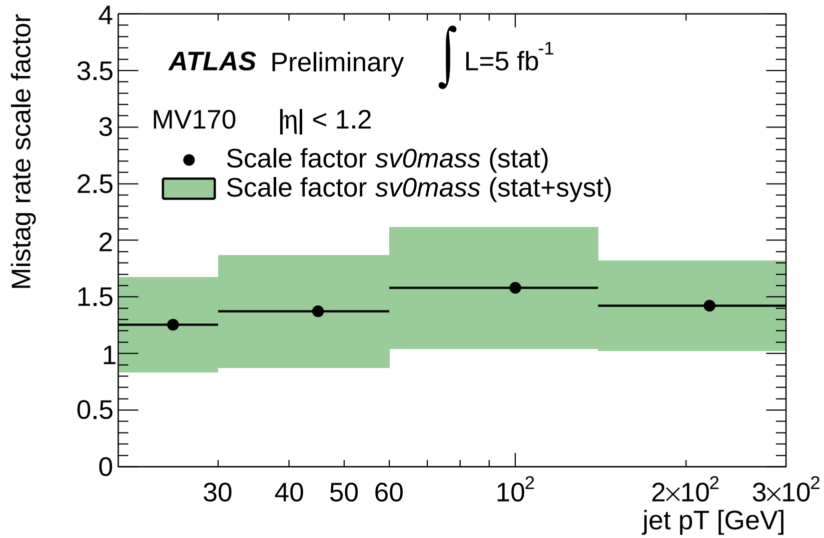
Poster by Andrea Ferretto Parodi

Total uncertainties range from 12% to 25%.

Performance in Data - Mistag Rate

- Negative tag method primarily targets mistags from resolution effects and corrects for e.g. long-lived particles and material interactions.
- SV0mass method fits invariant mass of secondary vertex.

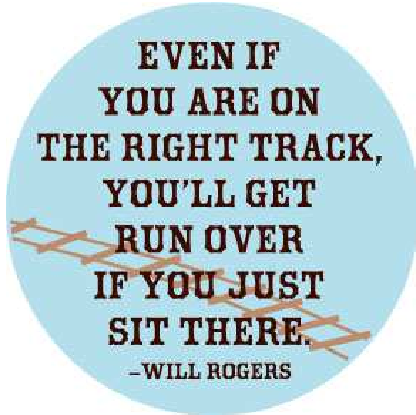




- Very good agreement between methods.
- Total uncertainties 10-100(+)%.

Summary and Outlook

- Excellent performance of ATLAS tracking, vertexing and b-tagging.
  - Improved alignment, new silicon clustering and track reconstruction optimized for high-pileup conditions.
  - New multivariate algorithms have boosted b-tagging performance.



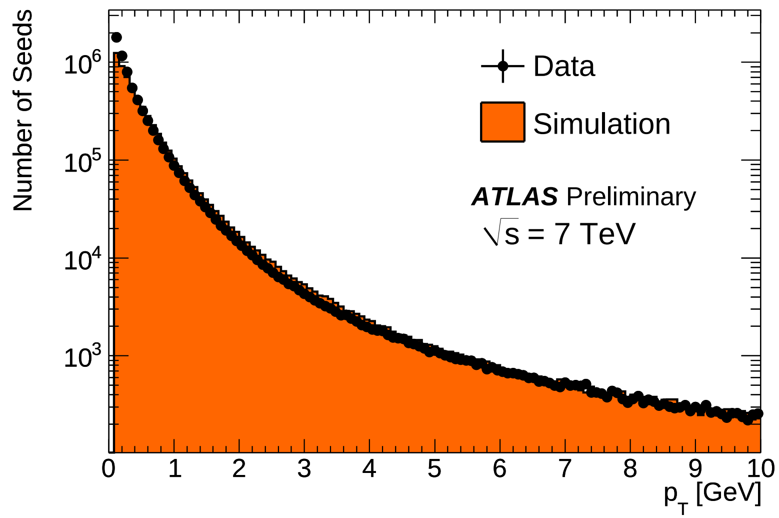
- Wide range of measurements confirm that the ATLAS tracking detector is accurately simulated.
  - Track and vertex properties, e.g. IP resolution.
  - b-tagging data-to-MC scale factors.

- Looking forward to many interesting physics results in 2012!

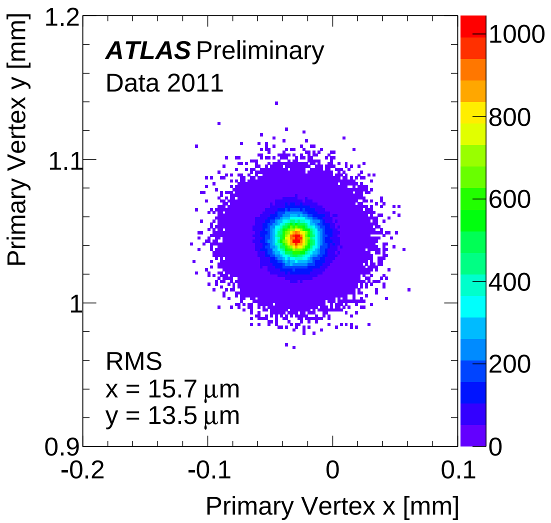
Backup Material

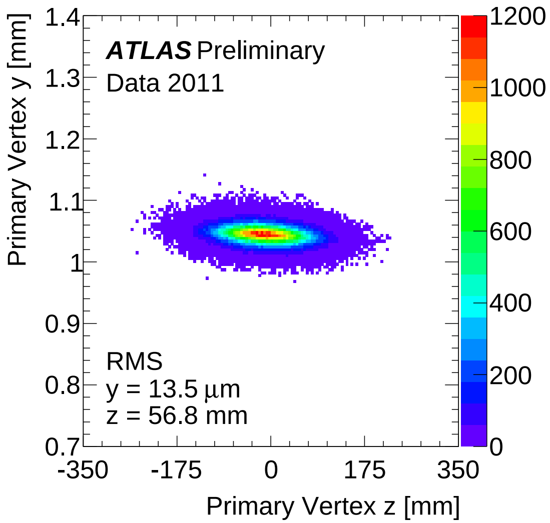
Pattern Recognition and Track Fitting

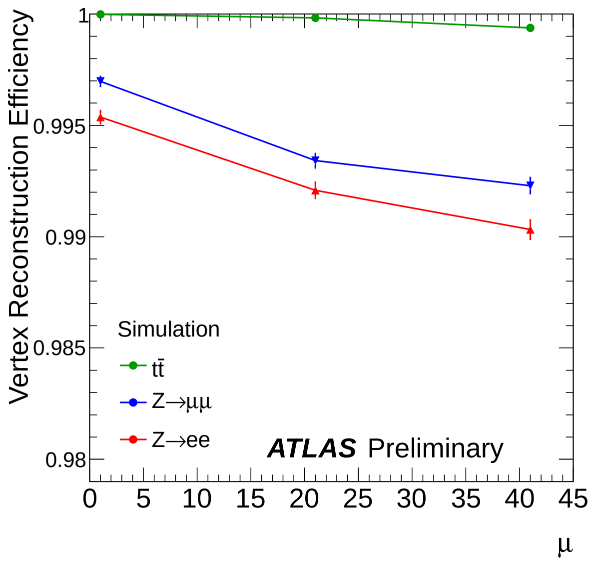
- Two-stage pattern recognition:
  - inside-out: silicon seed + outward extension
  - outside-in: TRT track segment seed + inward extension
- Old reconstruction setup:
  - ≥ 7 silicon hits
  - ≤ 2 pixel holes.
- New reconstruction setup:
  - ≥ 9 silicon hits
  - 0 pixel holes.



Primary Vertex Reconstruction

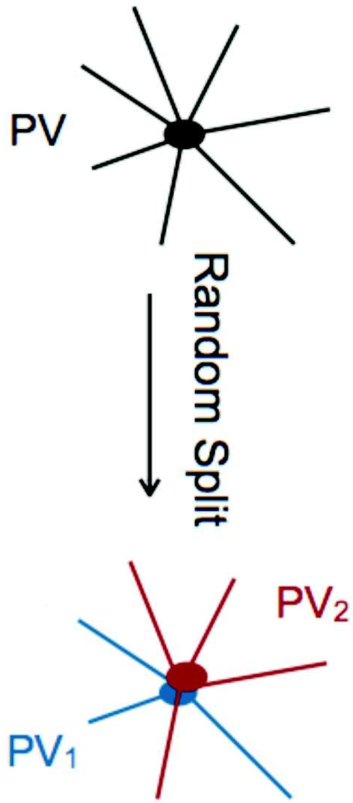


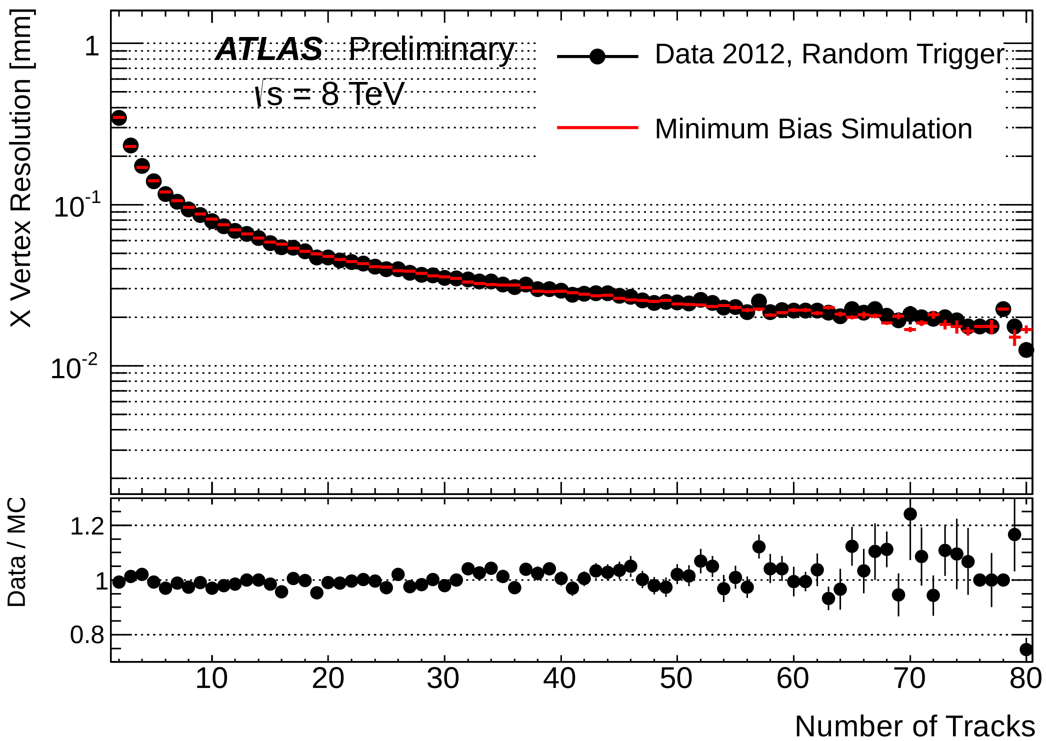




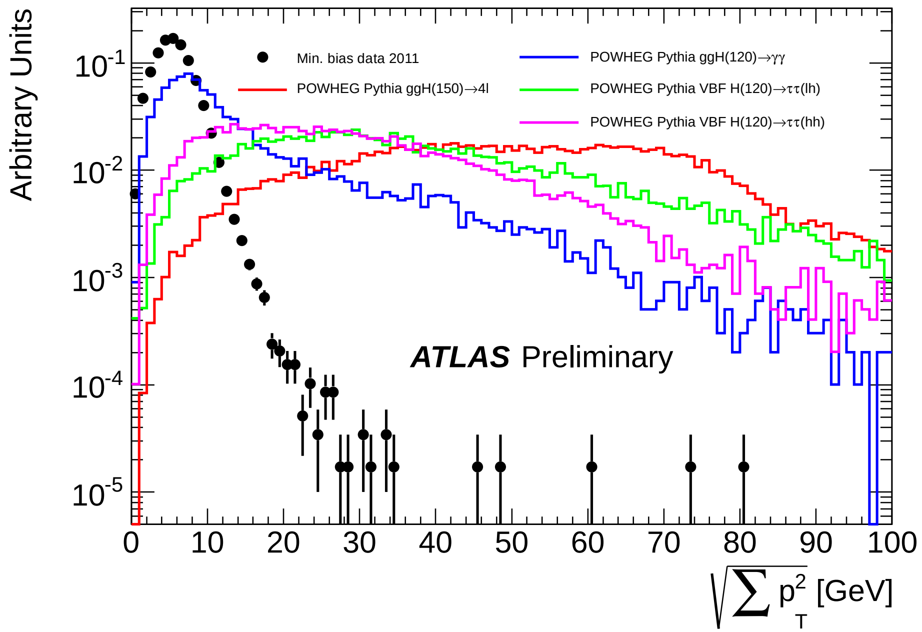
Primary Vertex Resolution

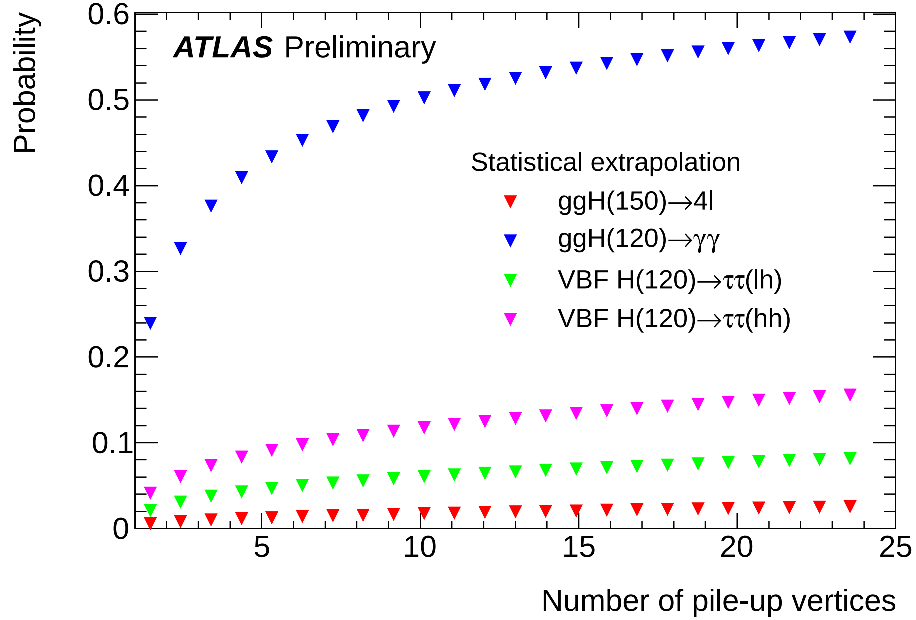
- Measure resolution in data using vertex-splitting technique.
  - Split tracks associated to vertex in two groups.
  - Fit two separate PVs.



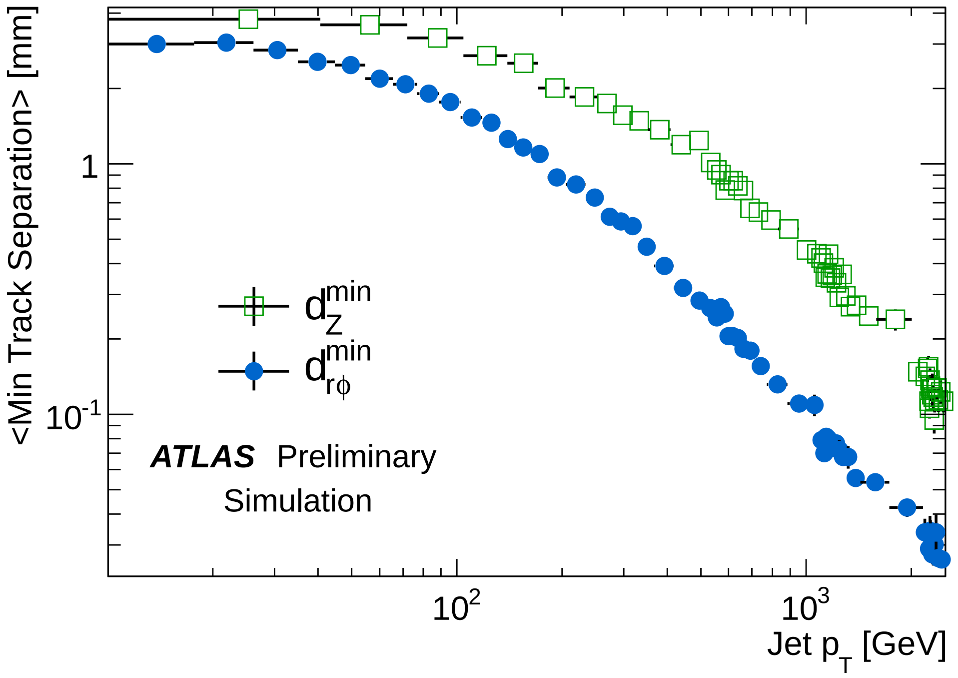


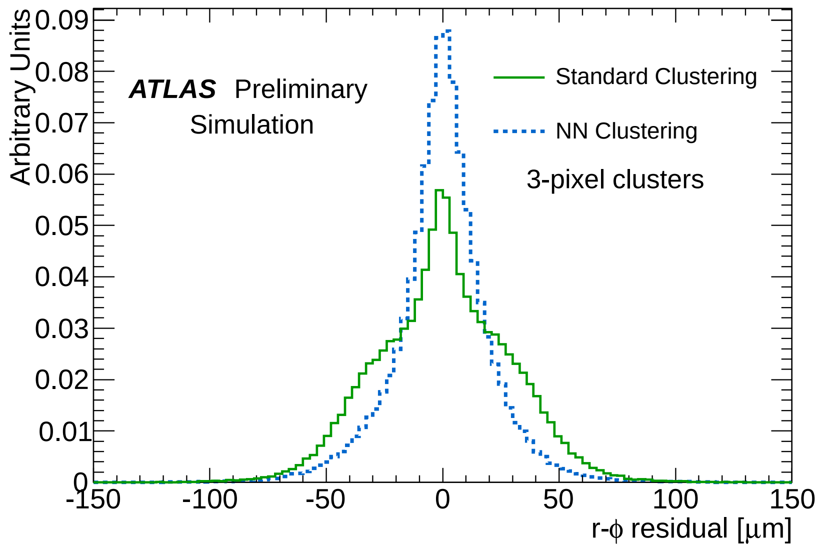
Selecting the Hard Scatter Vertex

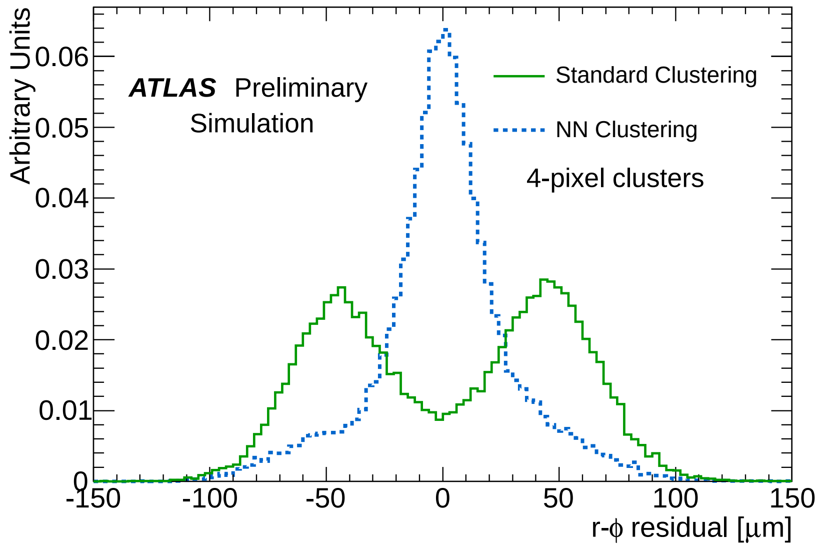




Neural Network Clustering

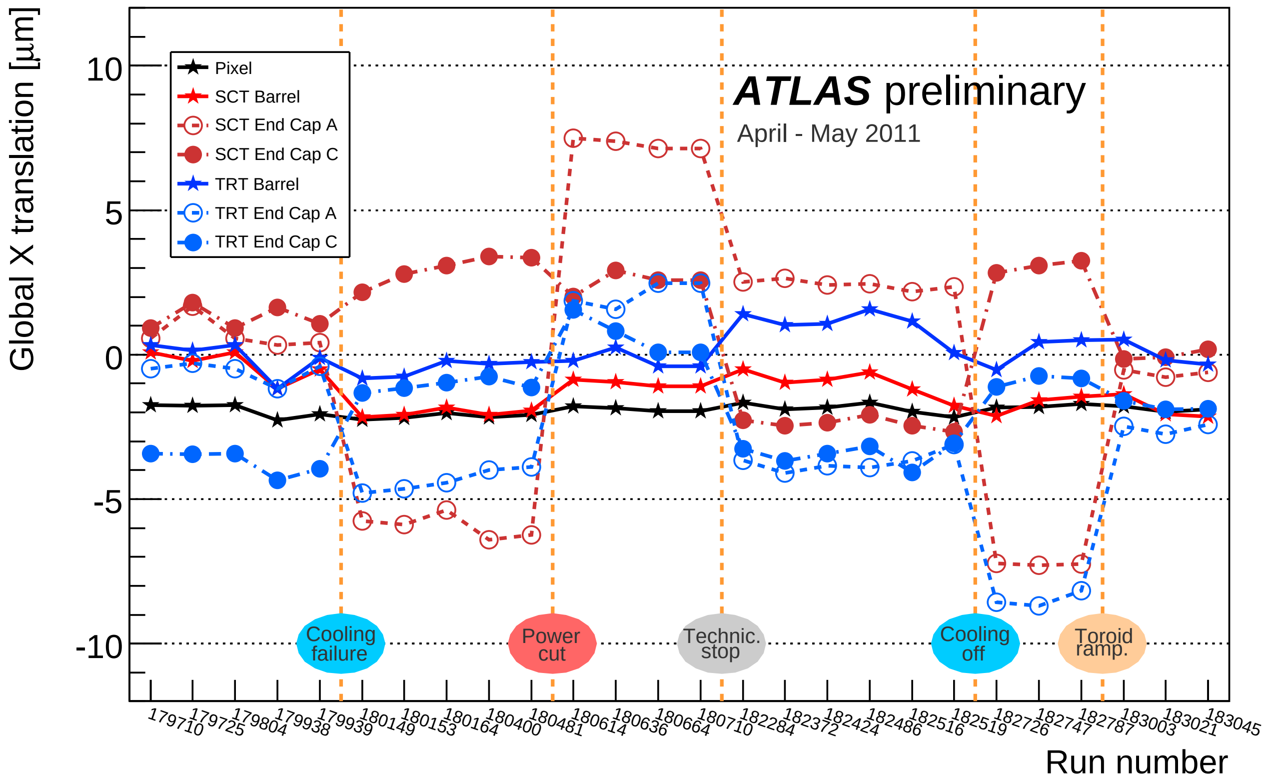






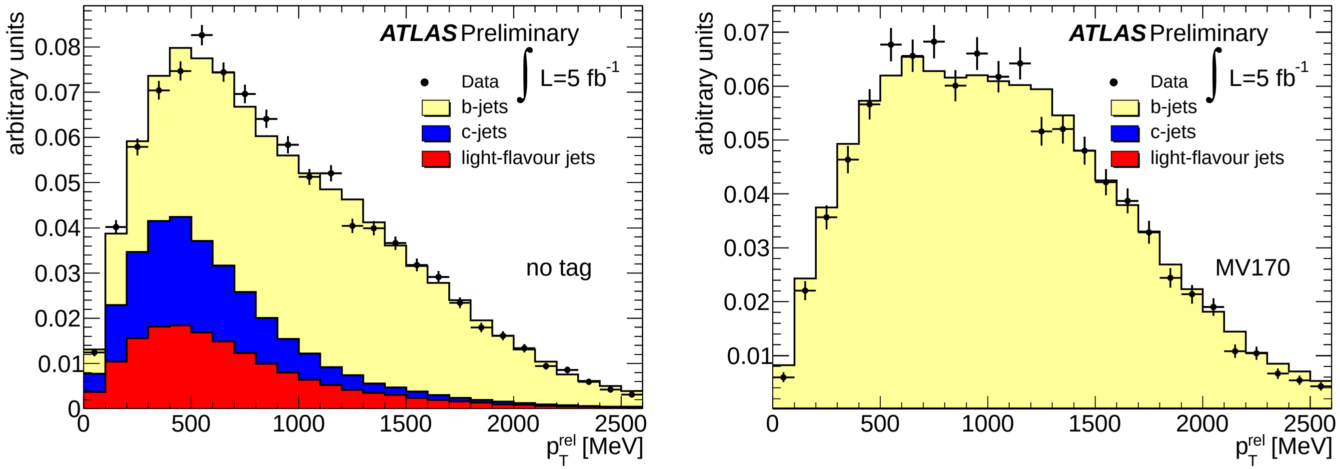
Time Dependence of Alignment

Level 1 alignment



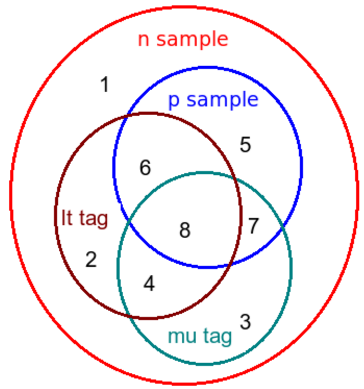
Performance in Data - b-tag Efficiency

- $p_{\mathrm{T}}^{\mathrm{rel}}$ method: Template fits of muon p_{T} with respect to the jet axis, $p_{\mathrm{T}}^{\mathrm{rel}}$, to get flavor composition before and after b-tagging.

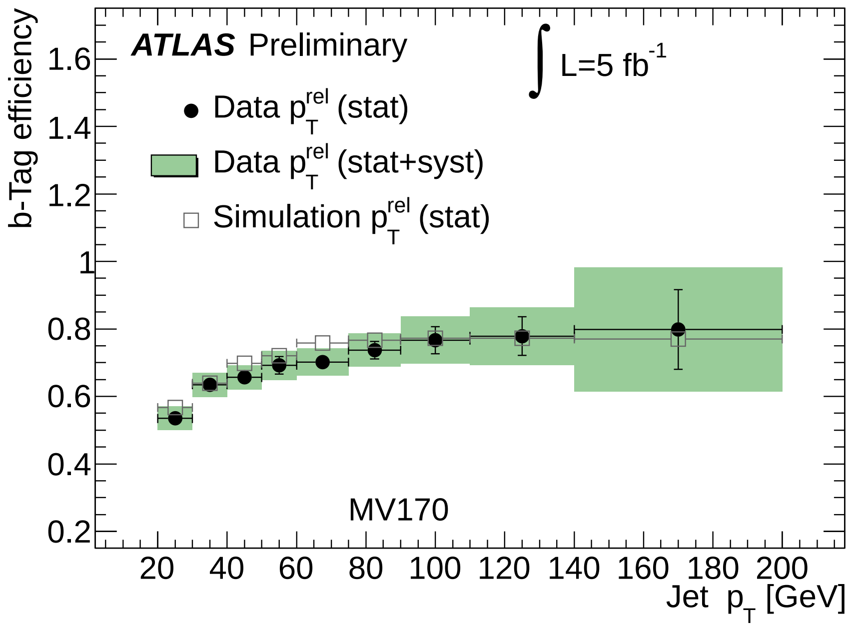


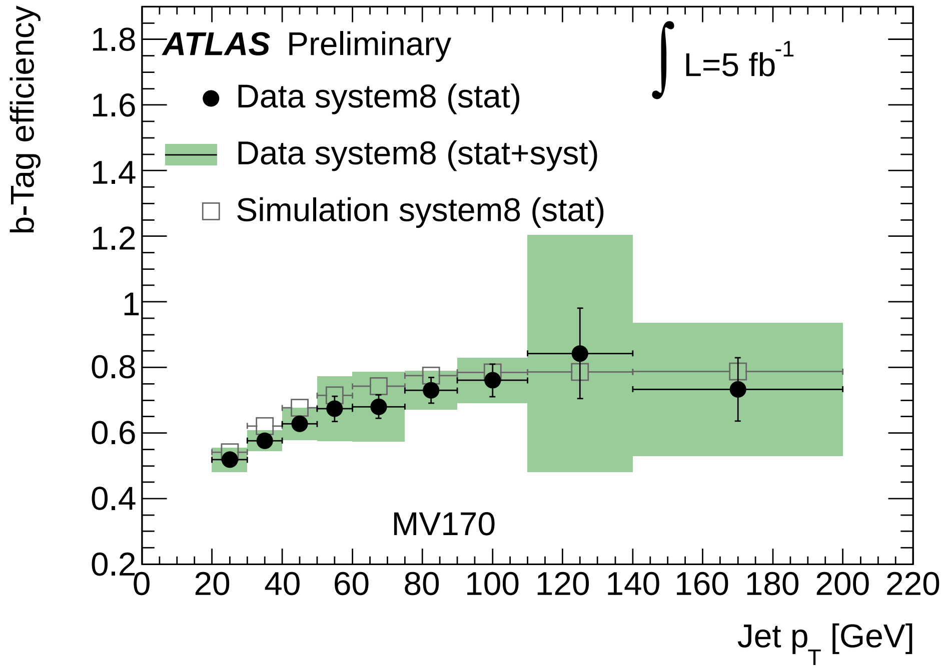
$$\epsilon_b^{\mathrm{data}} = \frac{f_b^{\mathrm{tag}} \cdot N^{\mathrm{tag}}}{f_b \cdot N} \cdot C$$

- System8 method: Use 3 uncorrelated selection criteria to construct 8 disjoint samples:

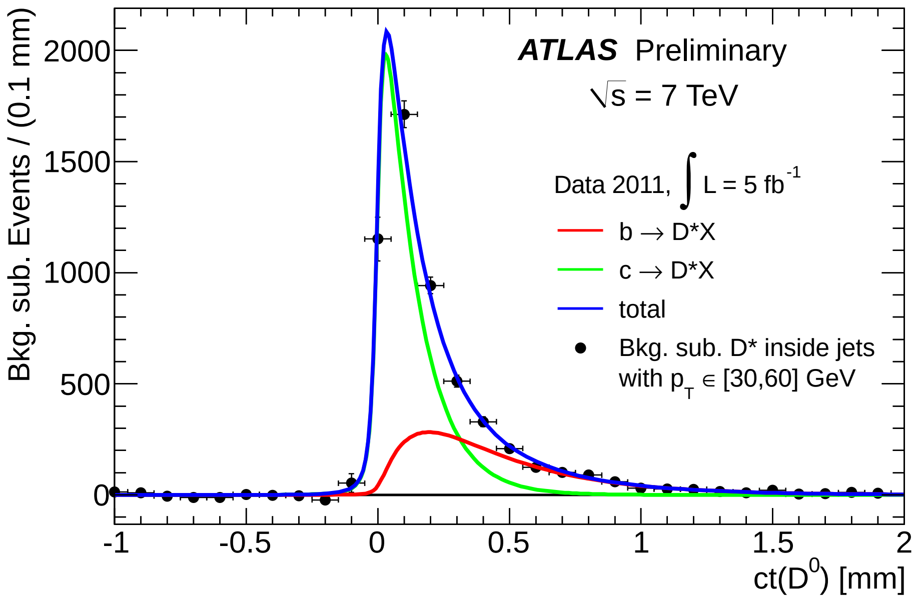


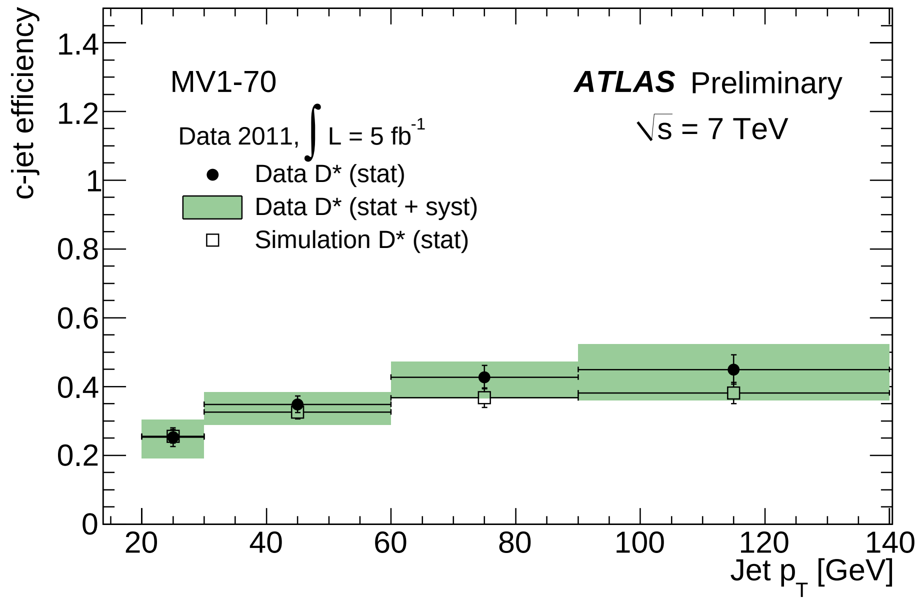
- The lifetime tagging criterion under study.
- A muon tagging criterion (muon $p_{\mathrm{T}}^{\mathrm{rel}} > 700$ MeV).
- Opposite side jet tagged by SV0 ($L/\sigma(L) > 1$)


ATLAS Preliminary
L=5 fb-1
Data pTrel (stat)
Data pTrel (stat+syst)
Simulation pTrel (stat)
MV170
b-Tag efficiency
Jet pT [GeV]


ATLAS Preliminary
L=5 fb-1
Data system8 (stat)
Data system8 (stat+syst)
Simulation system8 (stat)
MV170
b-Tag efficiency
Jet pT [GeV]

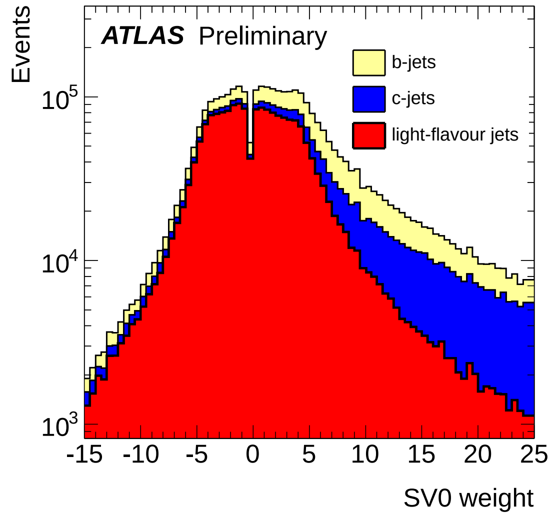
Performance in Data - c-tag Efficiency



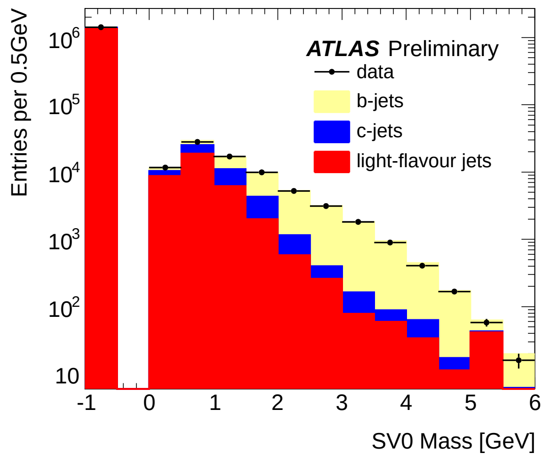


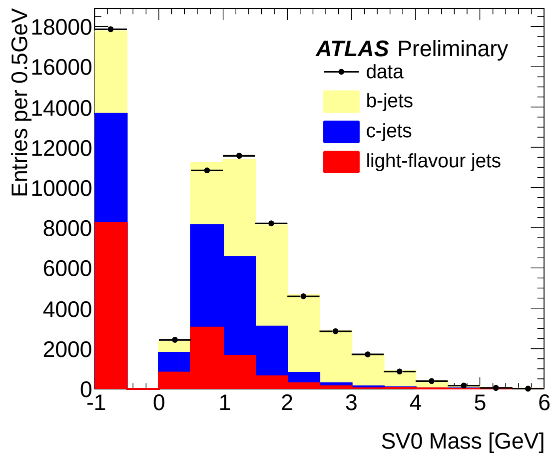
Performance in Data - Mistag Rate

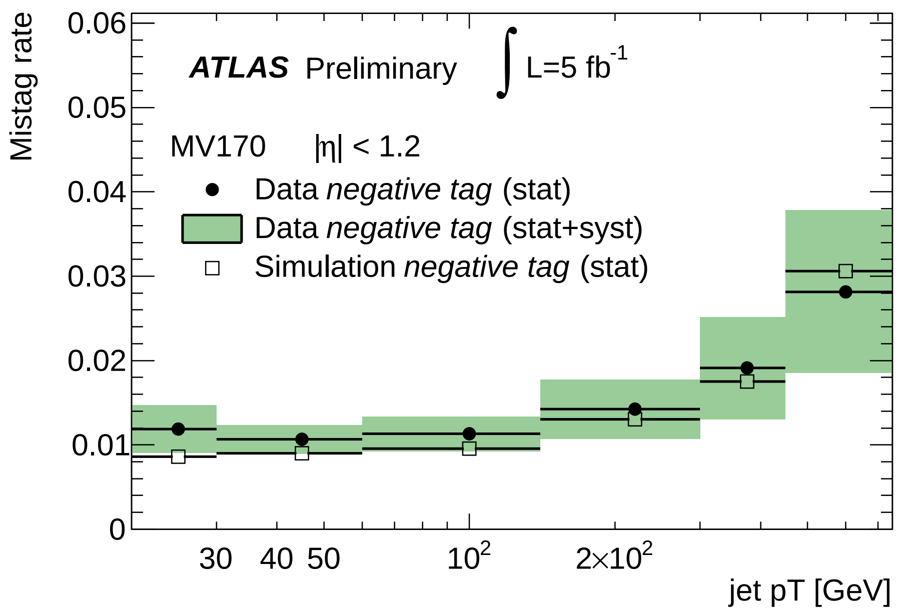
- Negative tag method: Exploits that mistags from resolution effects are blind to jet direction.
- Negative tag rate ≈ mistag rate.
- Correct for long-lived particles and material interactions plus heavy-flavor in negatively tagged sample.

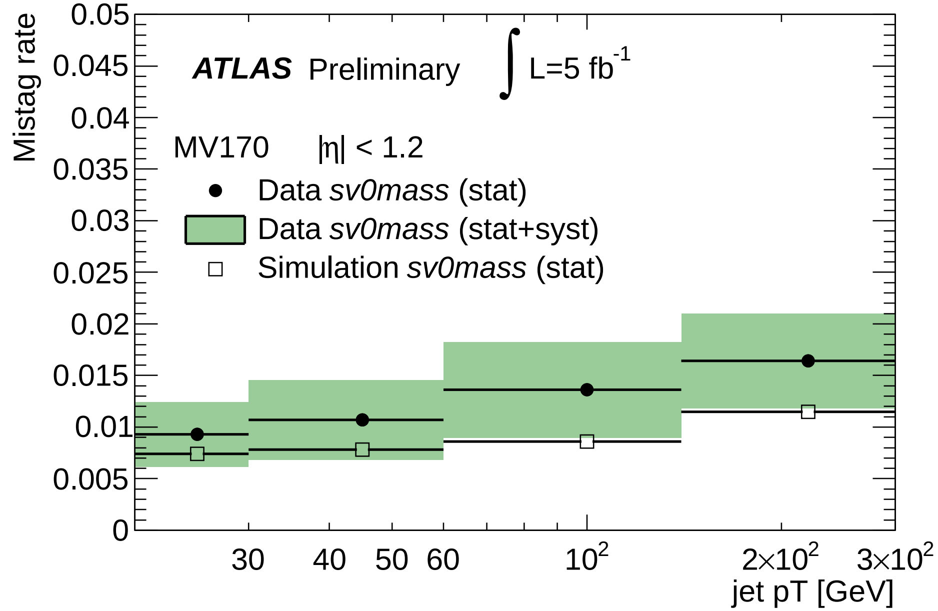


- SV0mass method: Fits the invariant mass of tracks associated to secondary vertices.
- Many jets without a SV.






ATLAS Preliminary
$\int$ L=5 fb^{-1}
MV170 |η| < 1.2
Data *negative tag* (stat)
Data *negative tag* (stat+syst)
Simulation *negative tag* (stat)
Mistag rate
jet pT [GeV]


ATLAS Preliminary
$\int$ L=5 fb^{-1}
MV170 |η| < 1.2
Data *sv0mass* (stat)
Data *sv0mass* (stat+syst)
Simulation *sv0mass* (stat)
Mistag rate
jet pT [GeV]