Inclusive *b*-jet Production at ATLAS

Patrick Jussel

for the ATLAS Collaboration

Institute of Astro- and Particle Physics at the University of Innsbruck, Austria

PANIC 11, July 24th – 29th 2011

Content

- Motivation
- ATLAS Detector – Overview
- SV0 *b*-tagging + calibration
- Inclusive cross section of *b*-jets(*)
- Di-jet cross section of *b*-jets

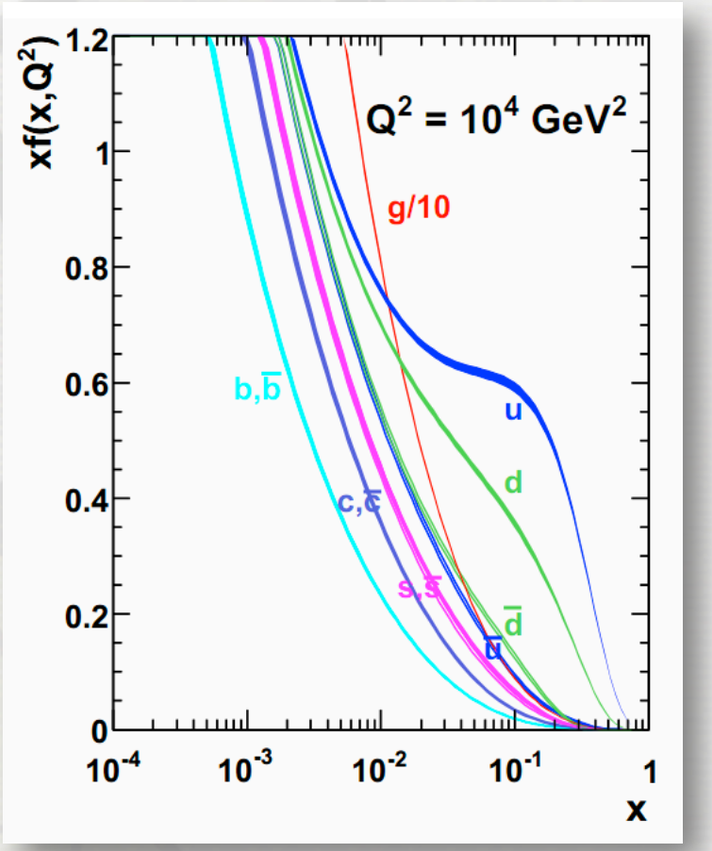
(*) Definition:

b-jet [biː-dʒet], jet containing a hadron with a *b* or an anti-*b* quark

Heavy flavor production

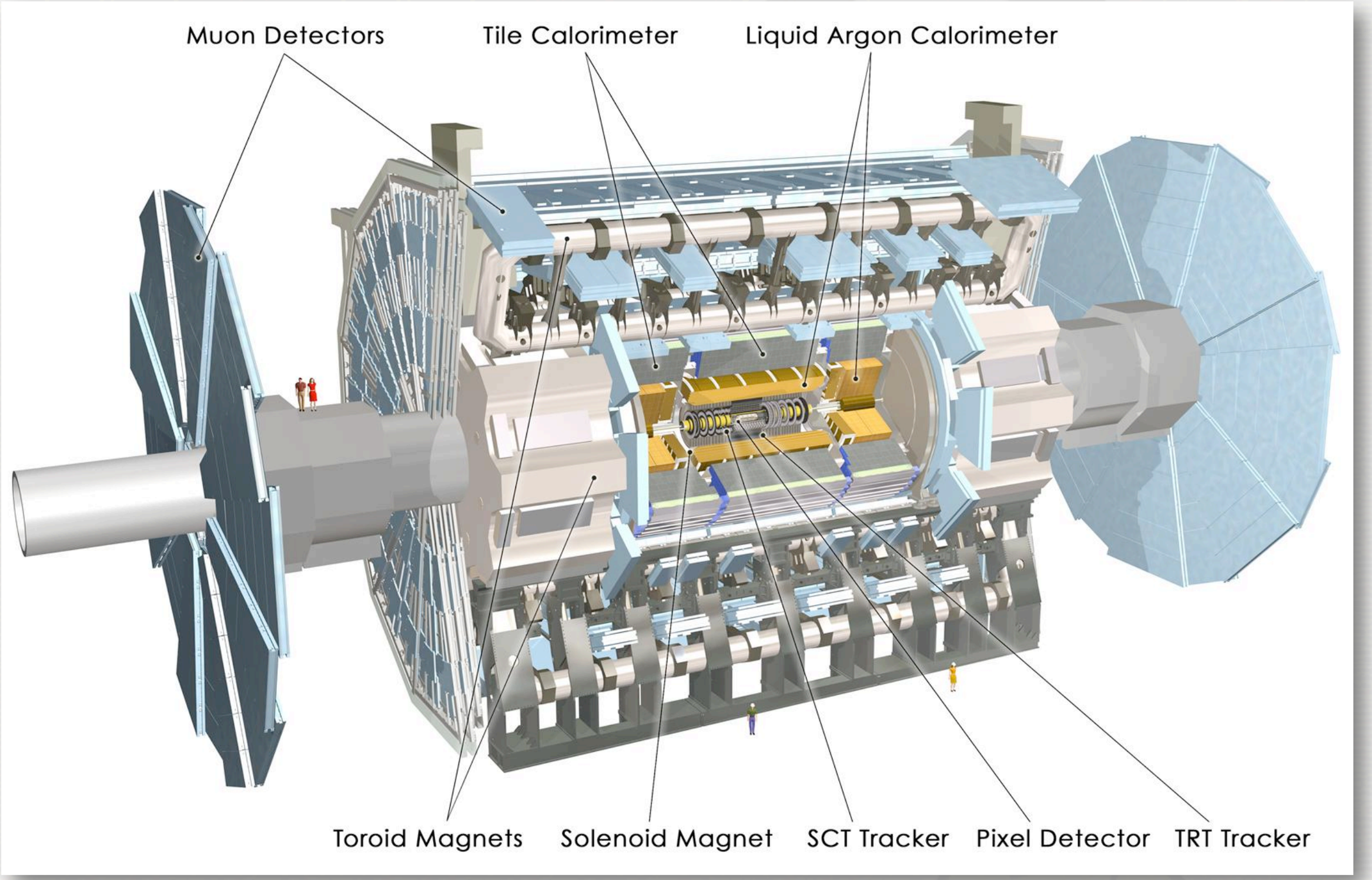
- New energy frontier as excellent testing ground
- Heavy flavor production …
  - … measurements allow tests of theoretical QCD prediction at NLO
  - … has large theoretical uncertainties
  - … is an important background in many searches
  - … measurement constrains heavy flavor component of proton PDF

MSTW 2008 NLO PDFs



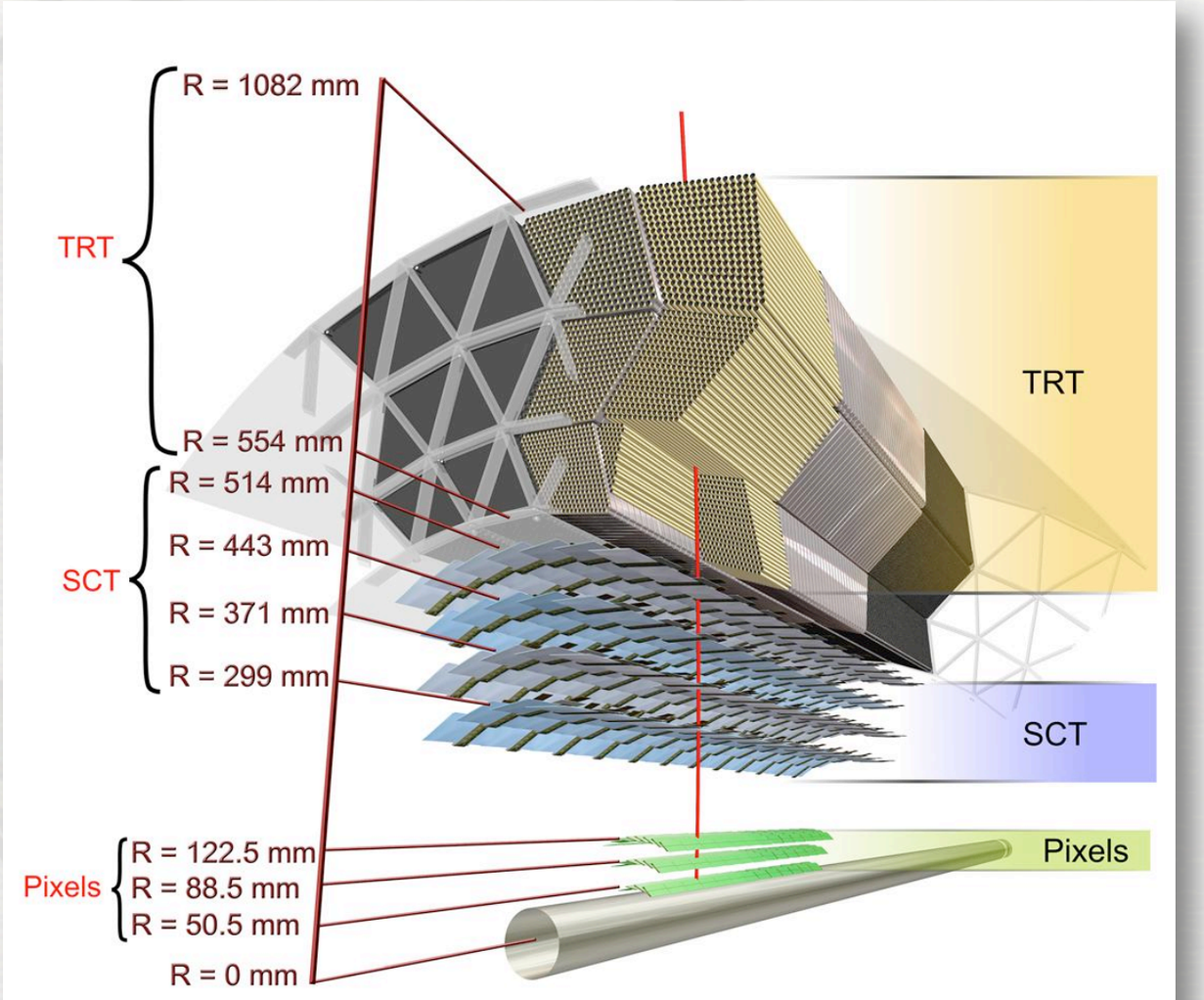
- Heavy flavor results from ATLAS:
  - Inclusive and di-jet cross section of *b*-jets
  - *J/ψ* and *ϒ(1S)* production (see talk by K. Reeves)
  - Top quark (see talks by R. Calkins & D.B.Ta)
  - *B* and *D* production (see talk by E. Rossi)

ATLAS Detector



ATLAS Detector

- Inner Detector
  - excellent tracking
  - *b*-tagging
  - vertexing
- Calorimeter
  - triggering jets
- Muon Spectrometer
  - calibration of *b*-tagging
  - muon tracks

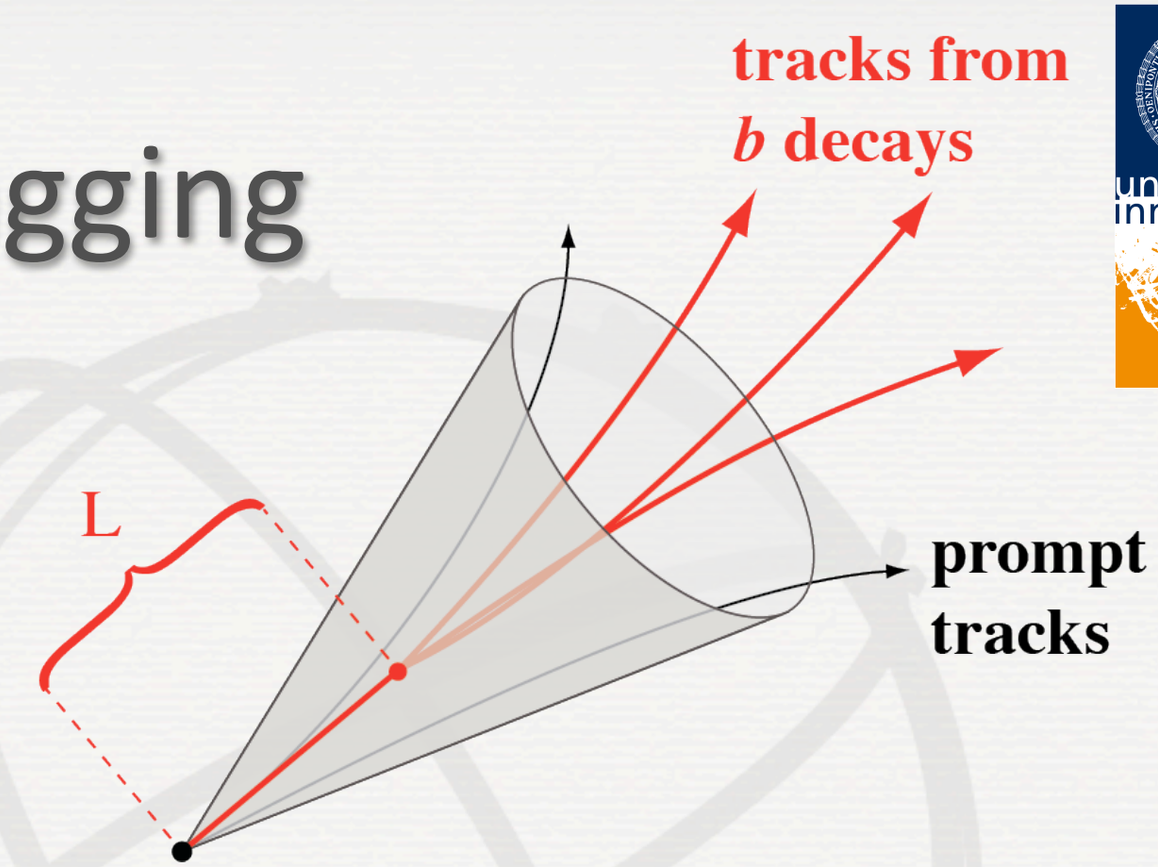


Track traversing Inner Detector

Data Taking and Trigger

- Data taking: Mar – Aug 2010
  - Proton-proton collisions at $\sqrt{s}$ = 7 TeV
  - Integrated Luminosity: 3.0 ± 0.1 pb^{-1}
- Trigger
  - Searching for *b*-jets in the range 20 GeV < p_T < 260 GeV, $|y|$ < 2.1
  - Level-1 jet trigger + MinBias trigger for low p_T jets
  - Triggers thresholds chosen, to have fully efficient triggers
  - Trigger efficiency > 98%
- Reconstruction
  - Reconstruct PV, reconstruct jet from topological clusters
  - Anti-k_t algorithm with radius R = 0.4
  - Reconstruction and selection efficiency for *b*-jets > 99%

b-tagging: SV0 *b*-tagging



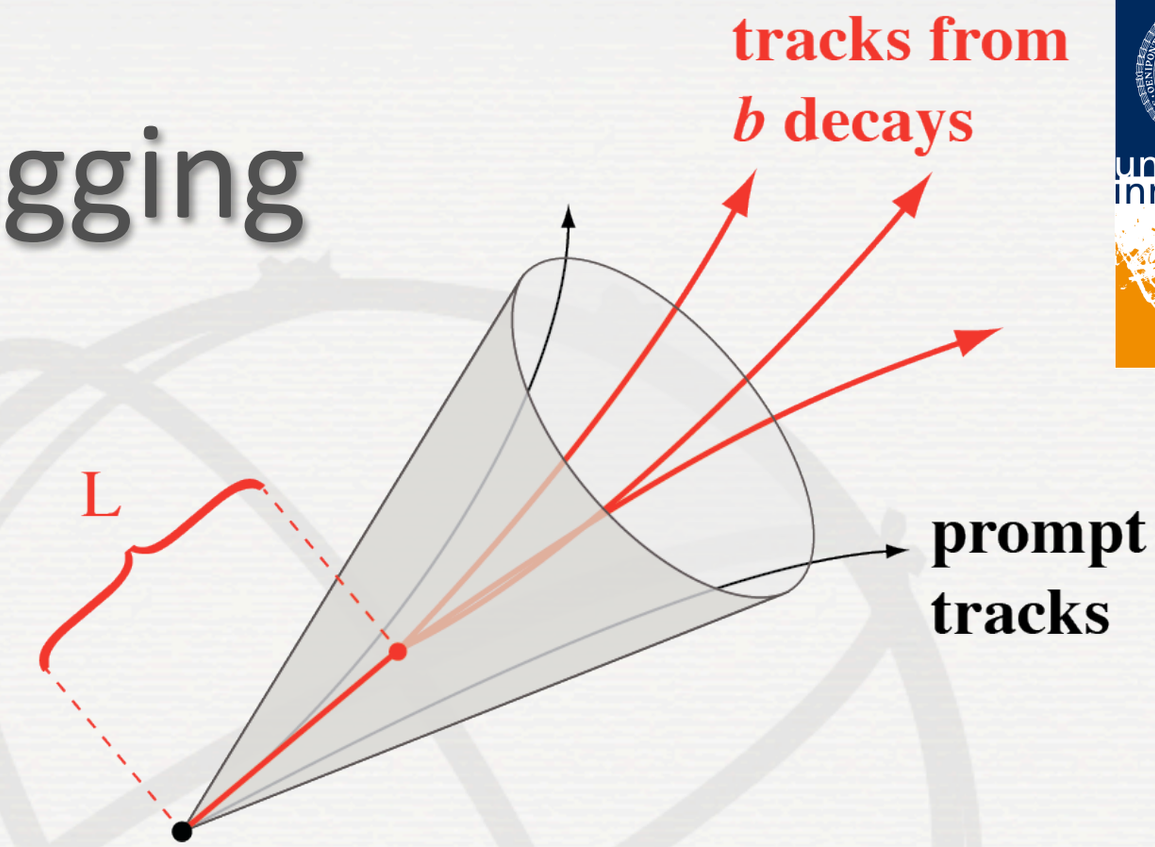
- Reconstruction of secondary vertex using tracks associated to calorimeter jet
- Merge two-track vertices (each not compatible with the PV) into common vertex
- Remove tracks with large χ^2 contribution…
- … until several criteria(*) are fulfilled
- Signed decay length (in 3D) significance $L/\sigma(L)$ is the *b*-tagging weight

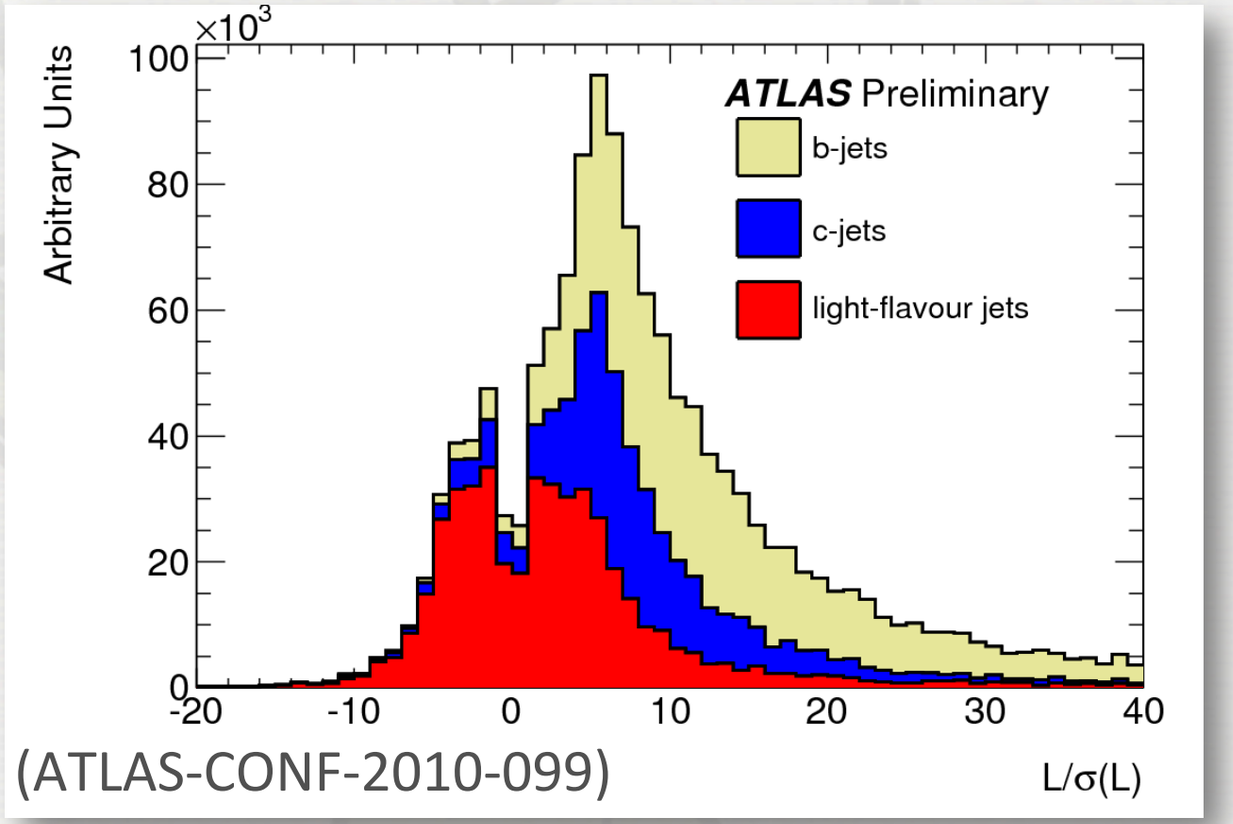
(*) Criteria:

- vertex mass < 6 GeV
- each track $\chi^2 < 7$

b-tagging: SV0 *b*-tagging

- Reconstruction of secondary vertex using tracks associated to calorimeter jet
- Merge two-track vertices (each not compatible with the PV) into common vertex
- Remove tracks with large χ^2 contribution…
- … until several criteria(*) are fulfilled
- Signed decay length (in 3D) significance $L/\sigma(L)$ is the *b*-tagging weight

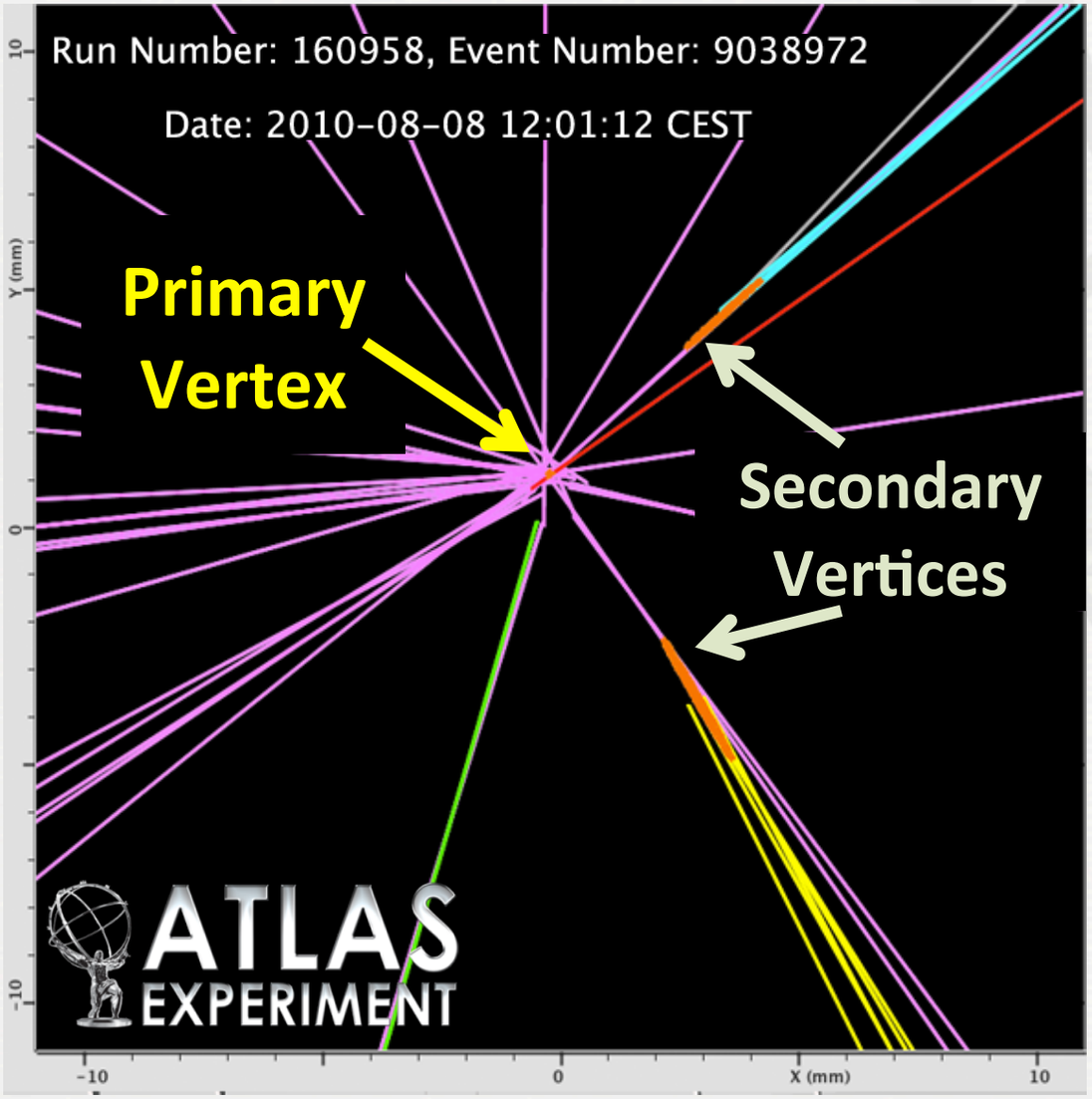




(ATLAS-CONF-2010-099)

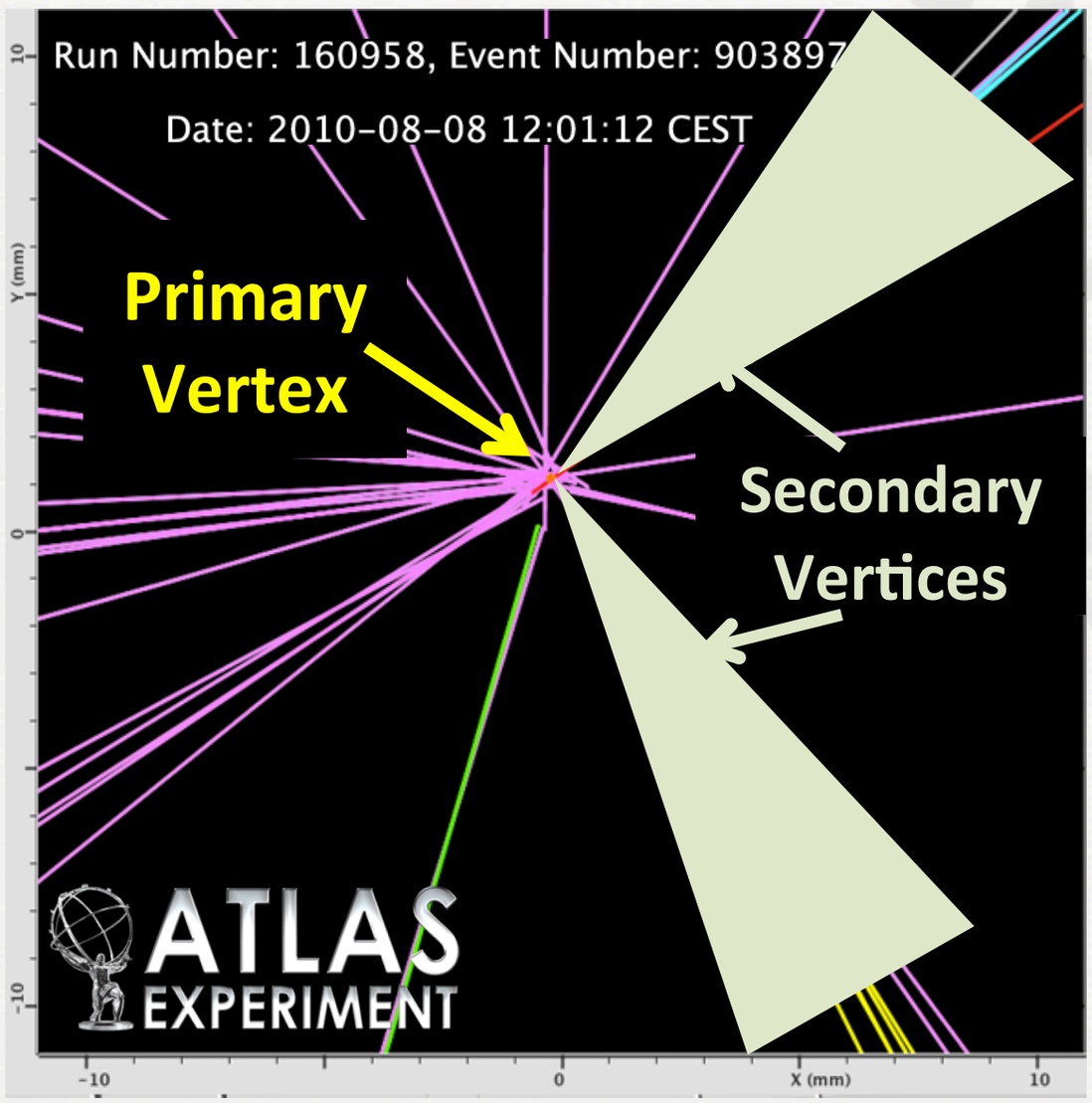
b-tagging: example

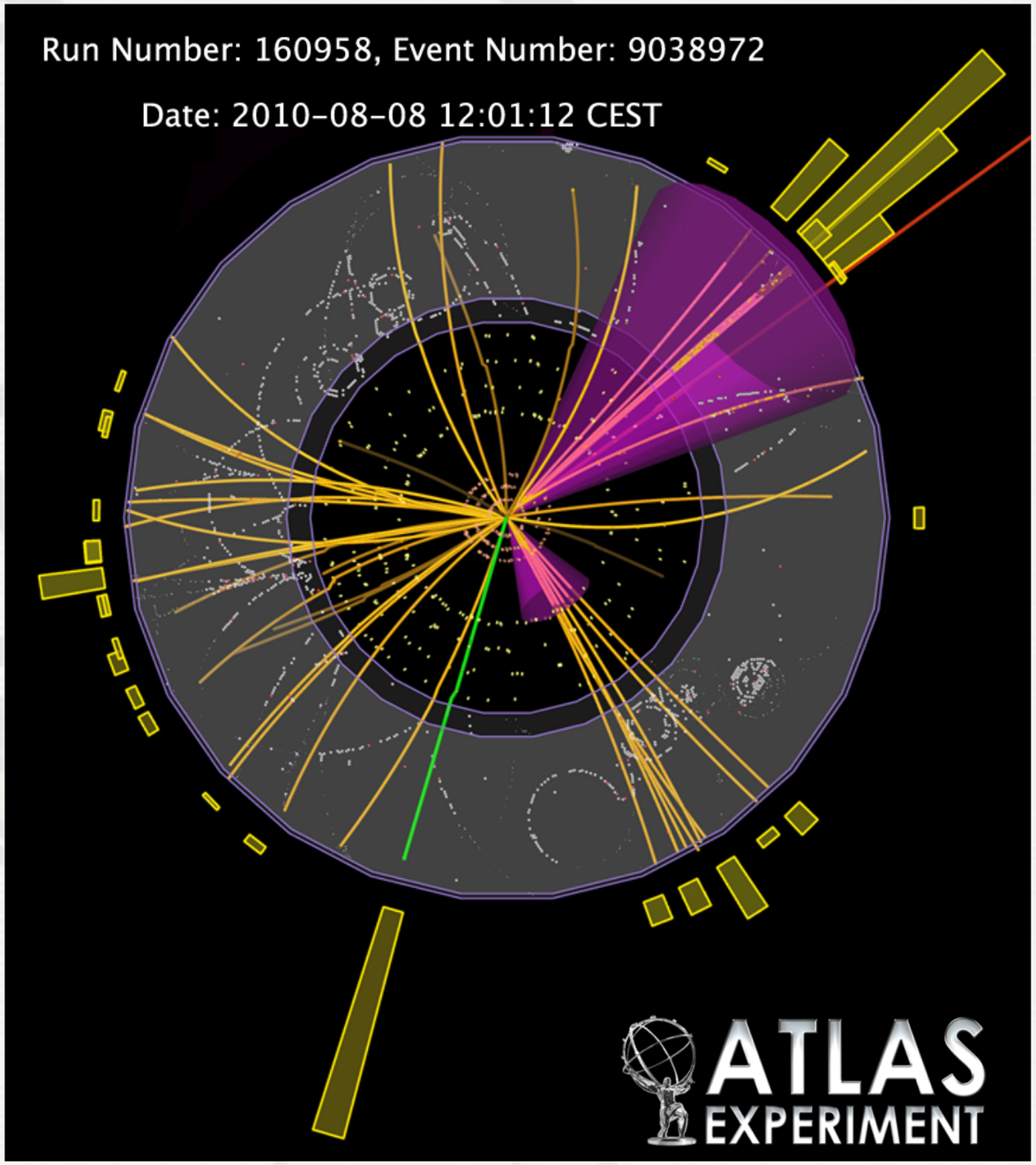
- Top pair e-mu di lepton candidate, two *b*-jet cones



b-tagging: example

- Top pair e-mu di lepton candidate, two *b*-jet cones

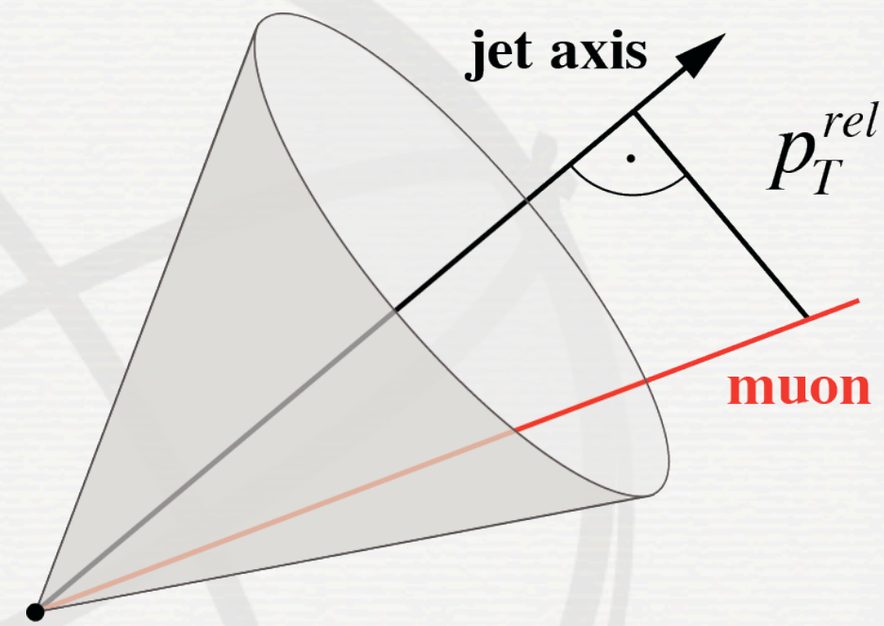




b-tagging calibration

(ATLAS-CONF-2010-099)

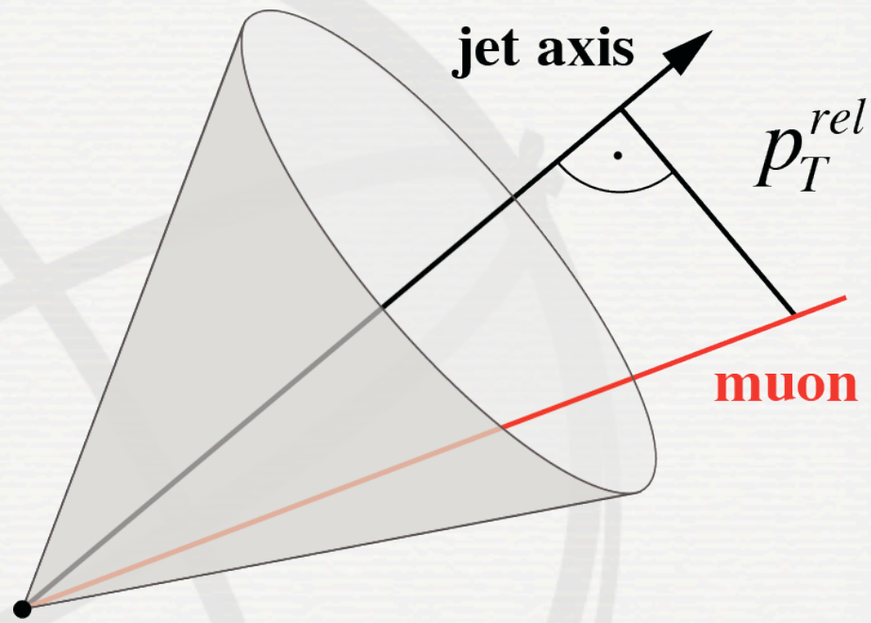
- Select events with muon, calculate p_T^{rel}, transverse momentum relative to jet
- Harder spectrum for *b*-jets
- Idea: create template spectra, fit to data to obtain *b*-tagging efficiency

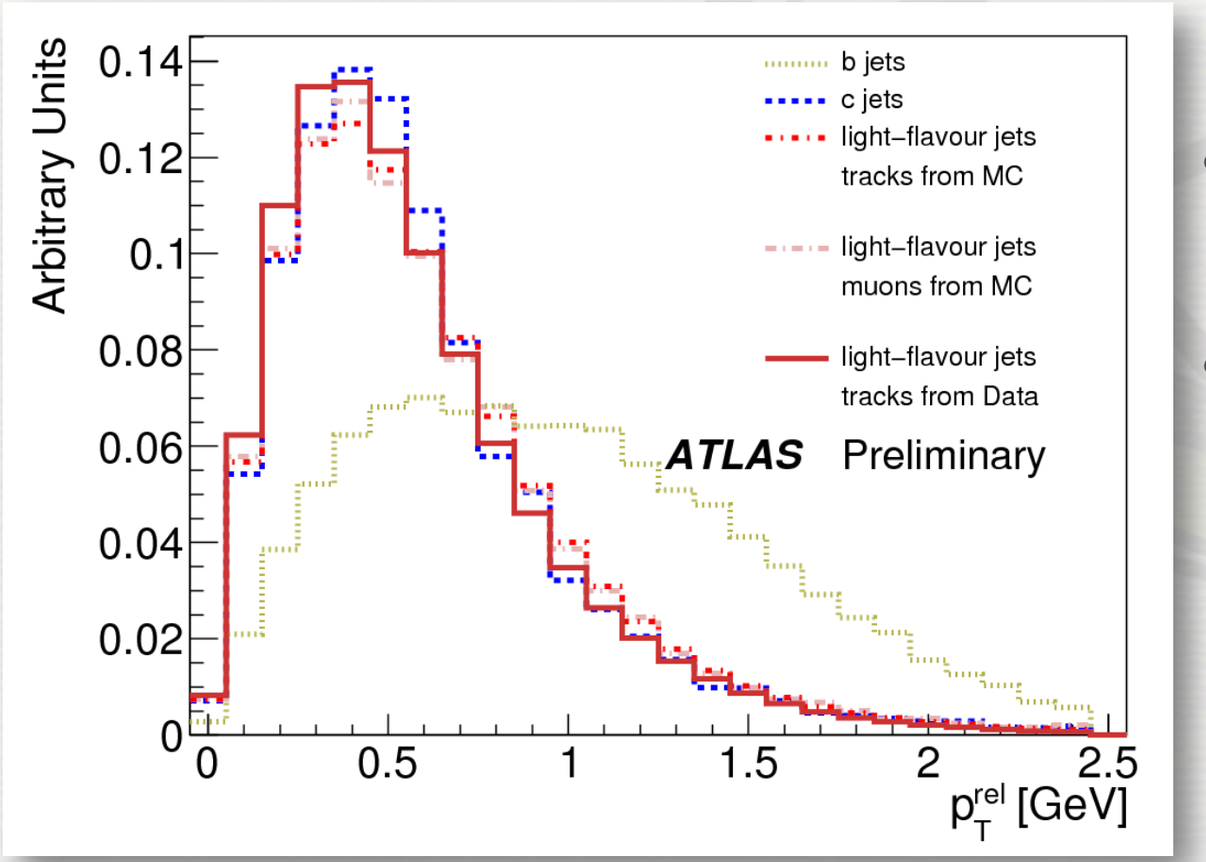


b-tagging calibration

(ATLAS-CONF-2010-099)

- Select events with muon, calculate p_T^{rel}, transverse momentum relative to jet
- Harder spectrum for *b*-jets
- Idea: create template spectra, fit to data to obtain *b*-tagging efficiency



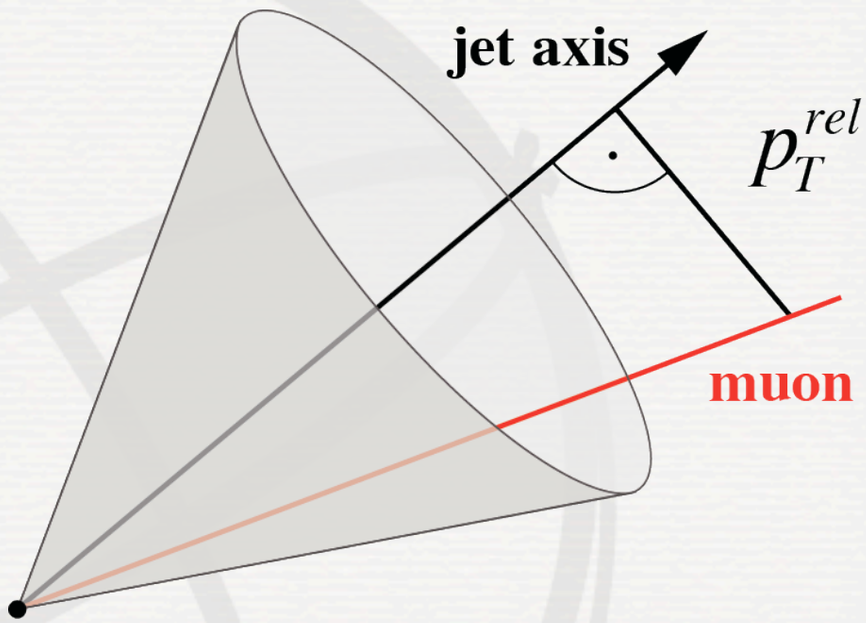


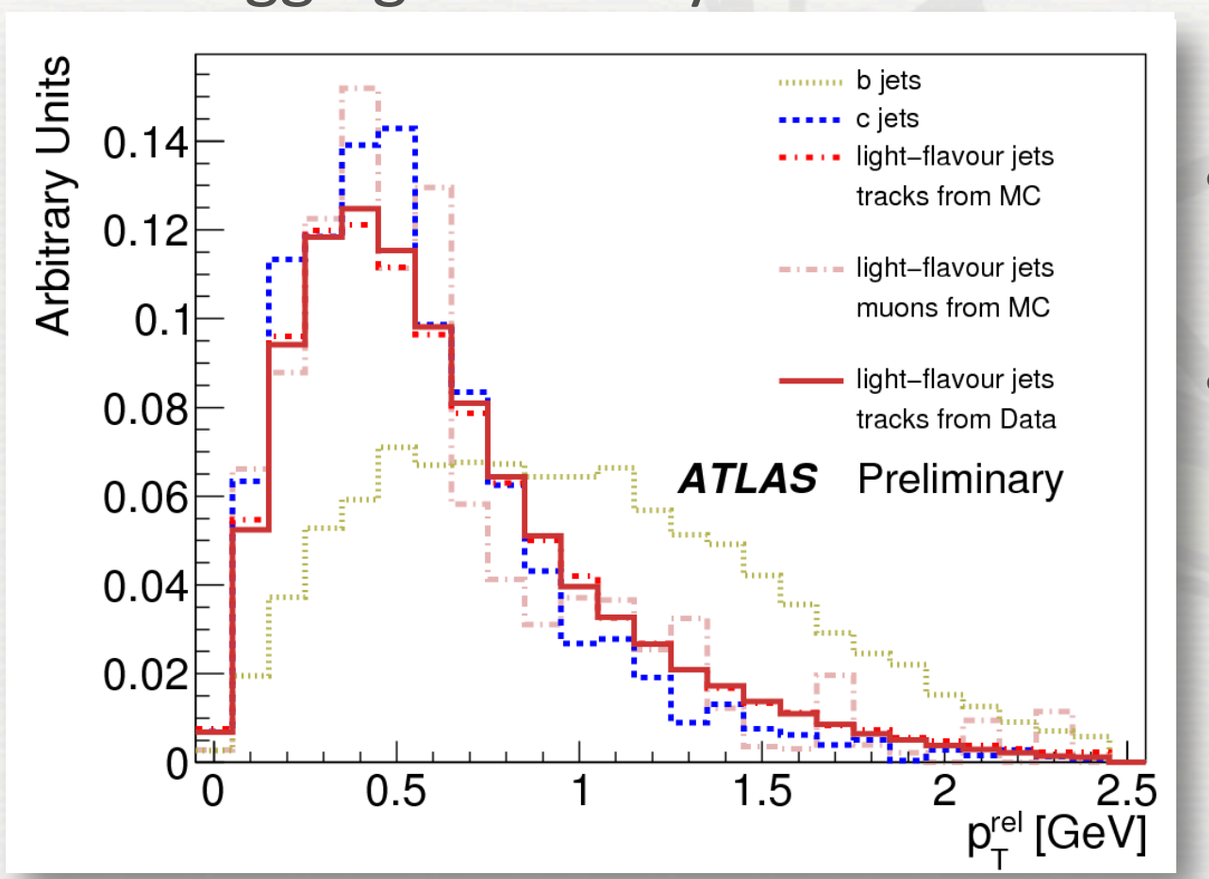
- template for light flavors and *c*-jets and *b*-jets
- templates of jets before some cut on *b*-tagging weight

b-tagging calibration

(ATLAS-CONF-2010-099)

- Select events with muon, calculate p_T^{rel}, transverse momentum relative to jet
- Harder spectrum for *b*-jets
- Idea: create template spectra, fit to data to obtain *b*-tagging efficiency





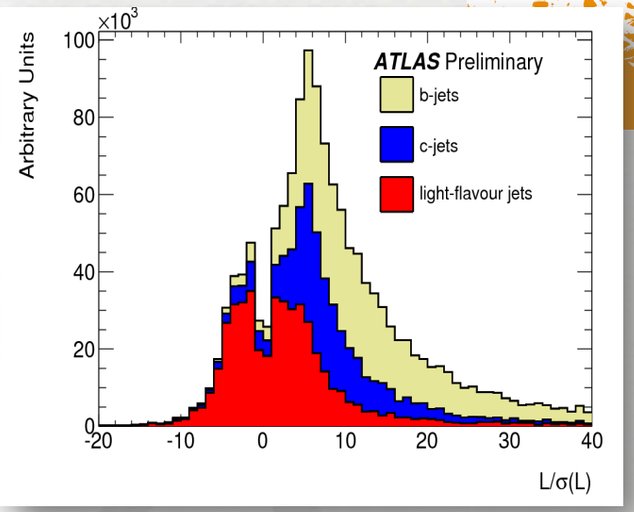
- template for light flavors and *c*-jets and *b*-jets
- templates of jets before some cut on *b*-tagging weight

… and after

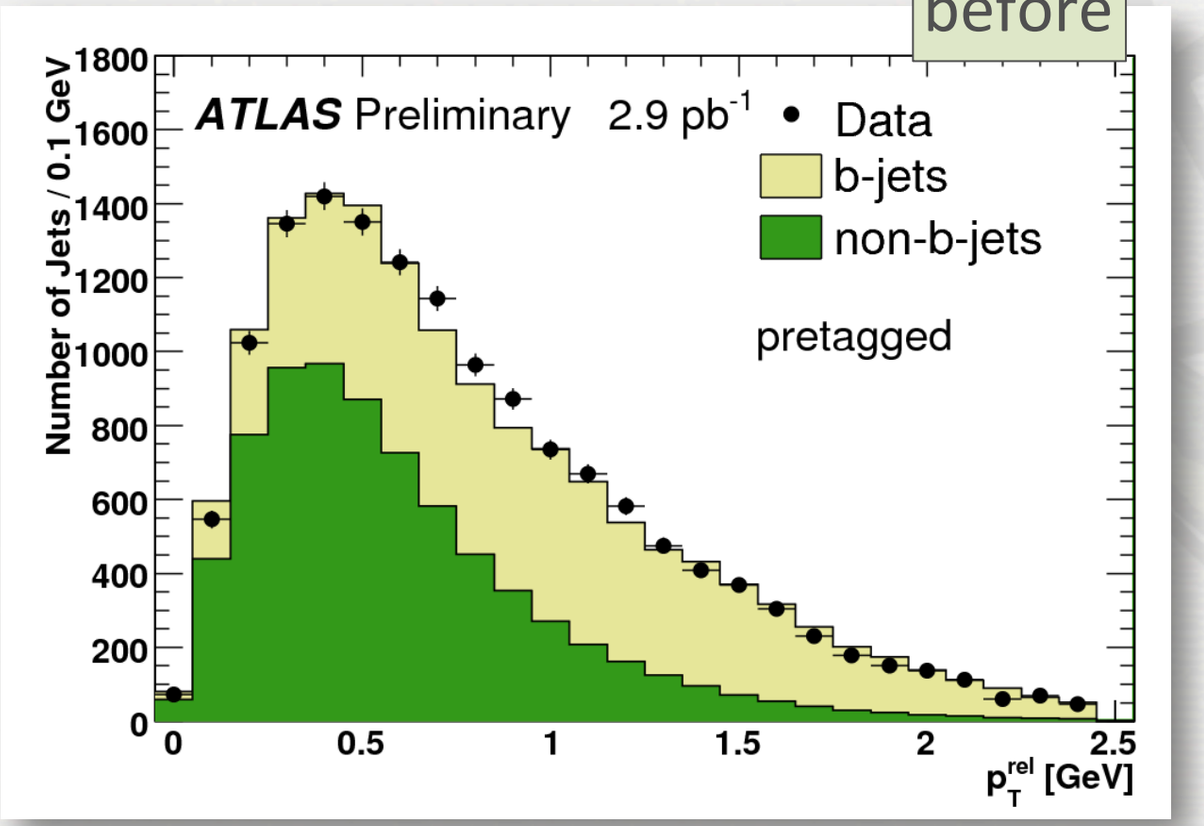
b-tagging calibration

(ATLAS-CONF-2010-099)

- Fitting templates by adjusting templates to data in a binned maximum likelihood fit
- Data vs. fit before any cut



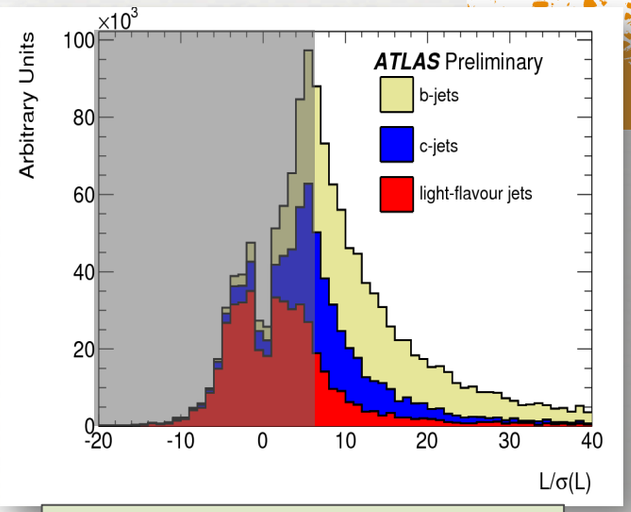
before



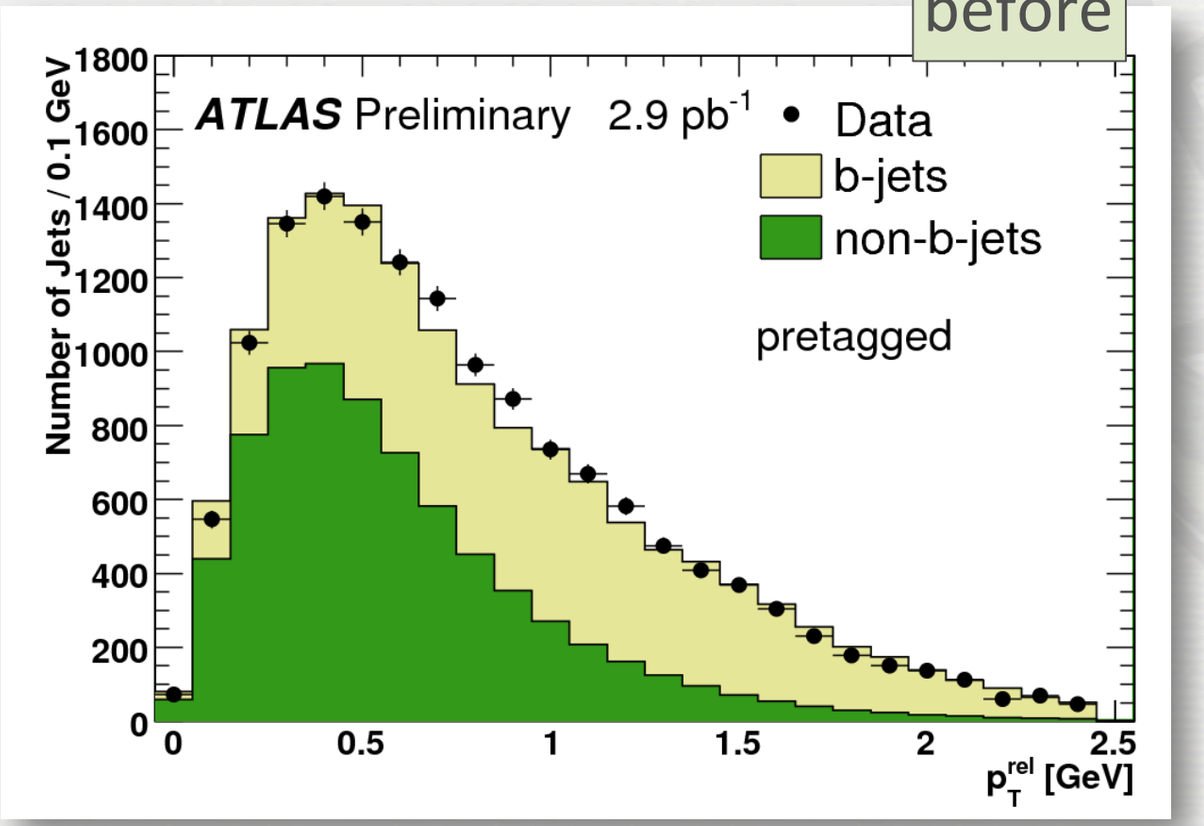
b-tagging calibration

(ATLAS-CONF-2010-099)

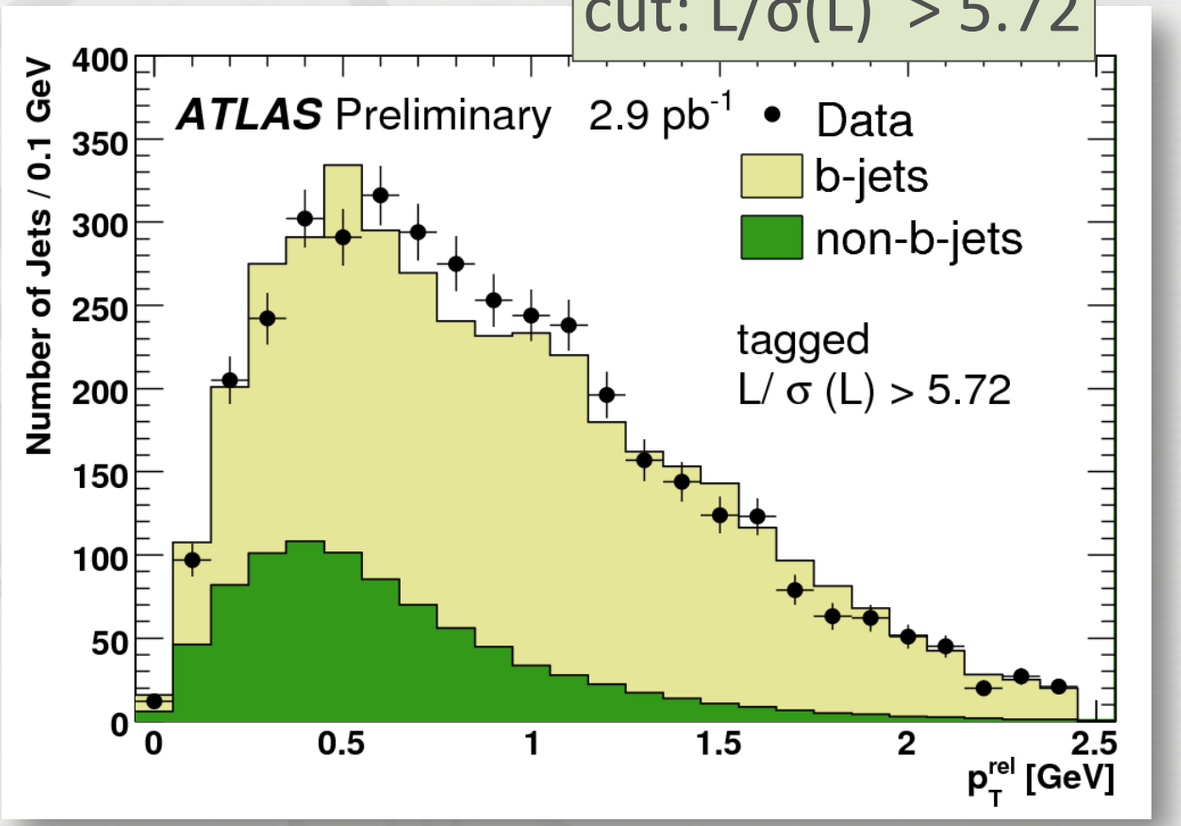
- Fitting templates by adjusting templates to data in a binned maximum likelihood fit
- Data vs. fit before and after cut on $L/\sigma(L) > 5.72$



before



cut: $L/\sigma(L) > 5.72$



- Cut $L/\sigma(L) > 5.72$: 50% *b*-tagging efficiency in simulated *tt* events

Measurement: Inclusive *b*-jet cross section at √s = 7 TeV

(ATLAS-CONF-2011-056)

- *b* jet cross section (20 GeV < p_T < 260 GeV, |*y*| < 2.1)

$$\frac{d^2\sigma_b}{dp_T dy} = \frac{1}{\Delta p_T \Delta y} \frac{N_b \cdot frac_b}{\varepsilon_{trig} \cdot \varepsilon_{sel} \cdot \varepsilon_{btag} \cdot \mathcal{L}} \times C$$

- *bb* di-jet cross section (di-jet mass M < 670 GeV, |*y*| < 2.1)

$$\frac{d\sigma_{b\bar{b}}}{dM} = \frac{1}{\Delta M} \frac{N_{b\bar{b}} \cdot frac_b}{\varepsilon_{trig} \cdot \varepsilon_{sel} \cdot \varepsilon_{btag,2} \cdot \mathcal{L}} \times C$$

- Trigger: level 1 jet trigger, MBTS trigger (for low jet p_T)

Measurement: Inclusive *b*-jet cross section at √s = 7 TeV

Number of events tagged by SV0 b-tagging algorithm…

… and fraction of those events, which are *b*-jets

$$\frac{d^2\sigma_b}{dp_T dy} = \frac{1}{\Delta p_T \Delta y} \frac{N_b \cdot frac_b}{\underbrace{\varepsilon_{trig} \cdot \varepsilon_{sel} \cdot \varepsilon_{btag} \cdot \mathcal{L}}} \times C$$

Efficiencies: trigger (> 98%), jet reconstruction and selection, *b*-tagging

Integrated luminosity for triggers: 3.0 ± 0.1 pb^{-1}

bin-by-bin unfolding correction applied, to compare to "truth *b* jets", true b-hadron within R=0.3

Measurement: Inclusive *b*-jet cross section at √s = 7 TeV

Number of events tagged by SV0 b-tagging algorithm…

… and fraction of those events, which are *b*-jets

$$\frac{d^2\sigma_b}{dp_T dy} = \frac{1}{\Delta p_T \Delta y} \frac{N_b \cdot frac_b}{\underbrace{\varepsilon_{trig} \cdot \varepsilon_{sel} \cdot \varepsilon_{btag}} \cdot \mathcal{L}} \times C$$

Efficiencies: trigger (> 98%), jet reconstruction and selection, *b*-tagging

Integrated luminosity for triggers: 3.0 ± 0.1 pb^{-1}

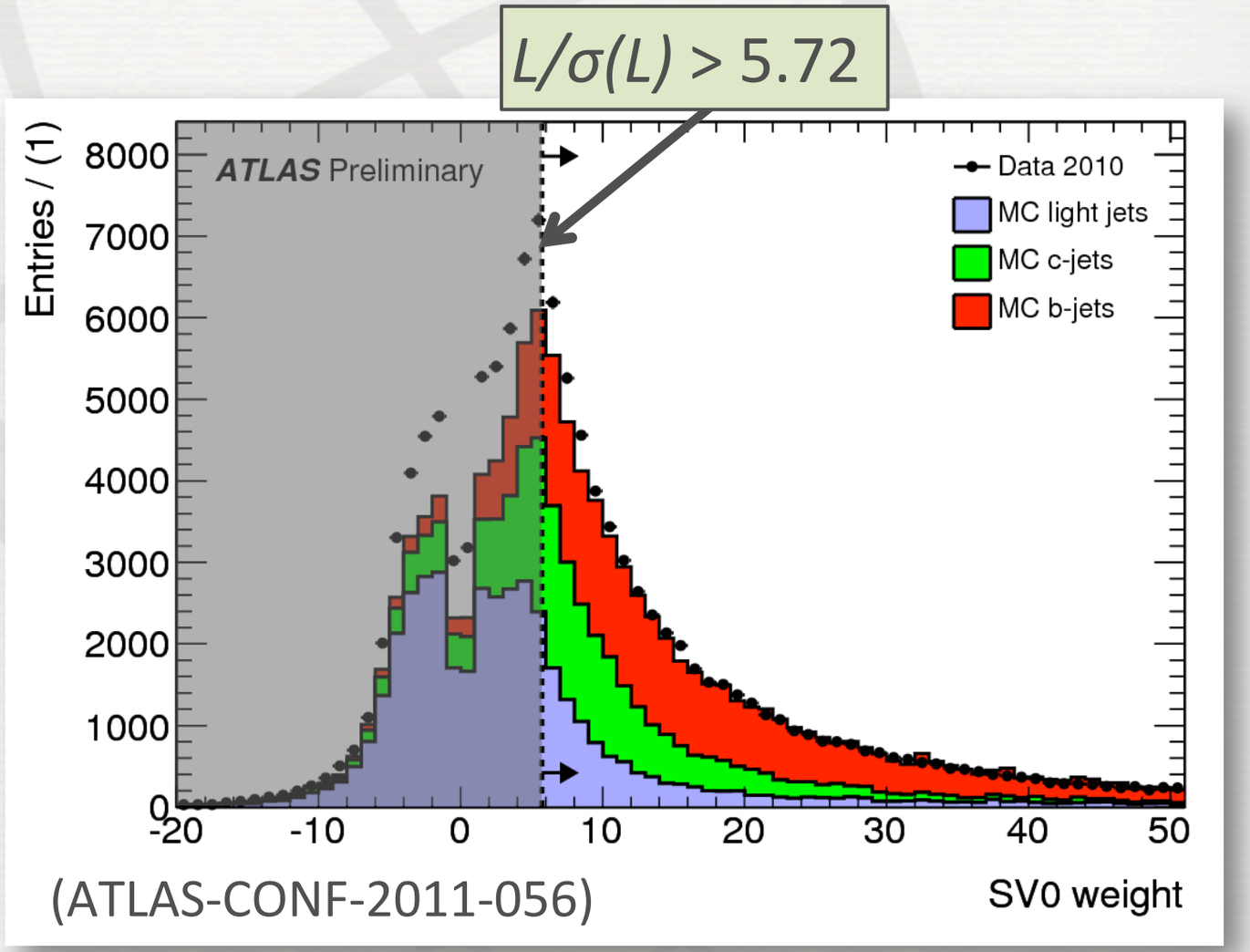
bin-by-bin unfolding correction applied, to compare to "truth *b* jets", true b-hadron within R=0.3

Number of *b*-tagged events…

- Weight of SV0 b-tagger: signed decay length significance $L/\sigma(L)$

- Excess in data: tracking performance difference between data and MC.
- But: affects light jets with small SV0 weight.

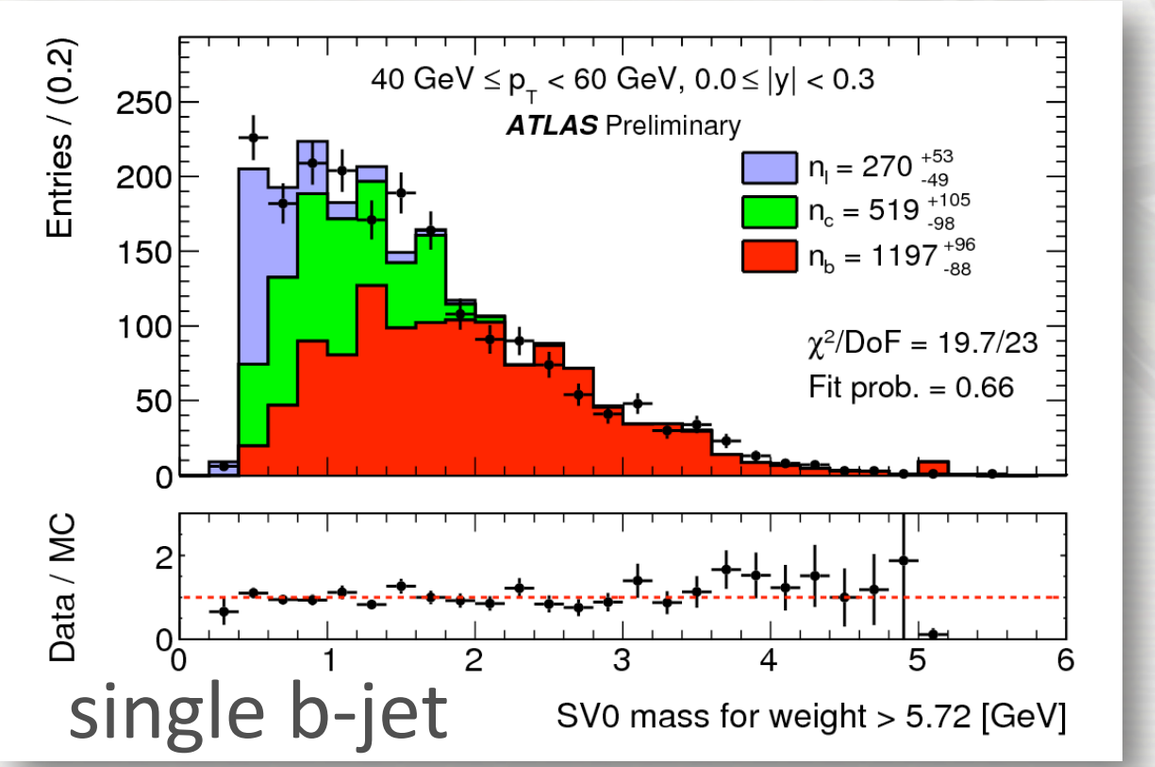
- Next: what is the fraction of *b*-jets in data?
- Like before, MC derived templates fitting to data



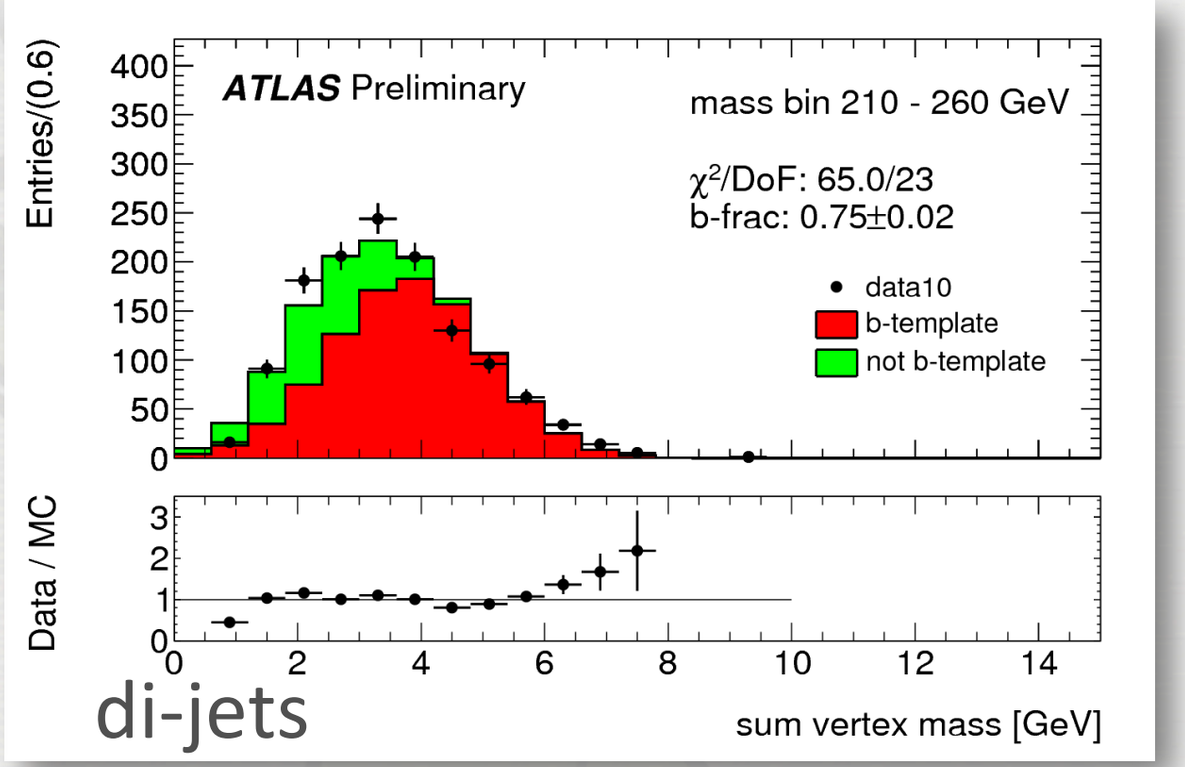
(ATLAS-CONF-2011-056)

… and fraction of *b*-jets

- SV0 vertex mass
- Templates of light, charm and b-jets (single jets)
- Sum of SV0 vertex mass
- Templates of b and non-b jets (di-jets)
  - Log-likelihood fit to data, stat. uncertainty in data and MC templates
  - two example fits...

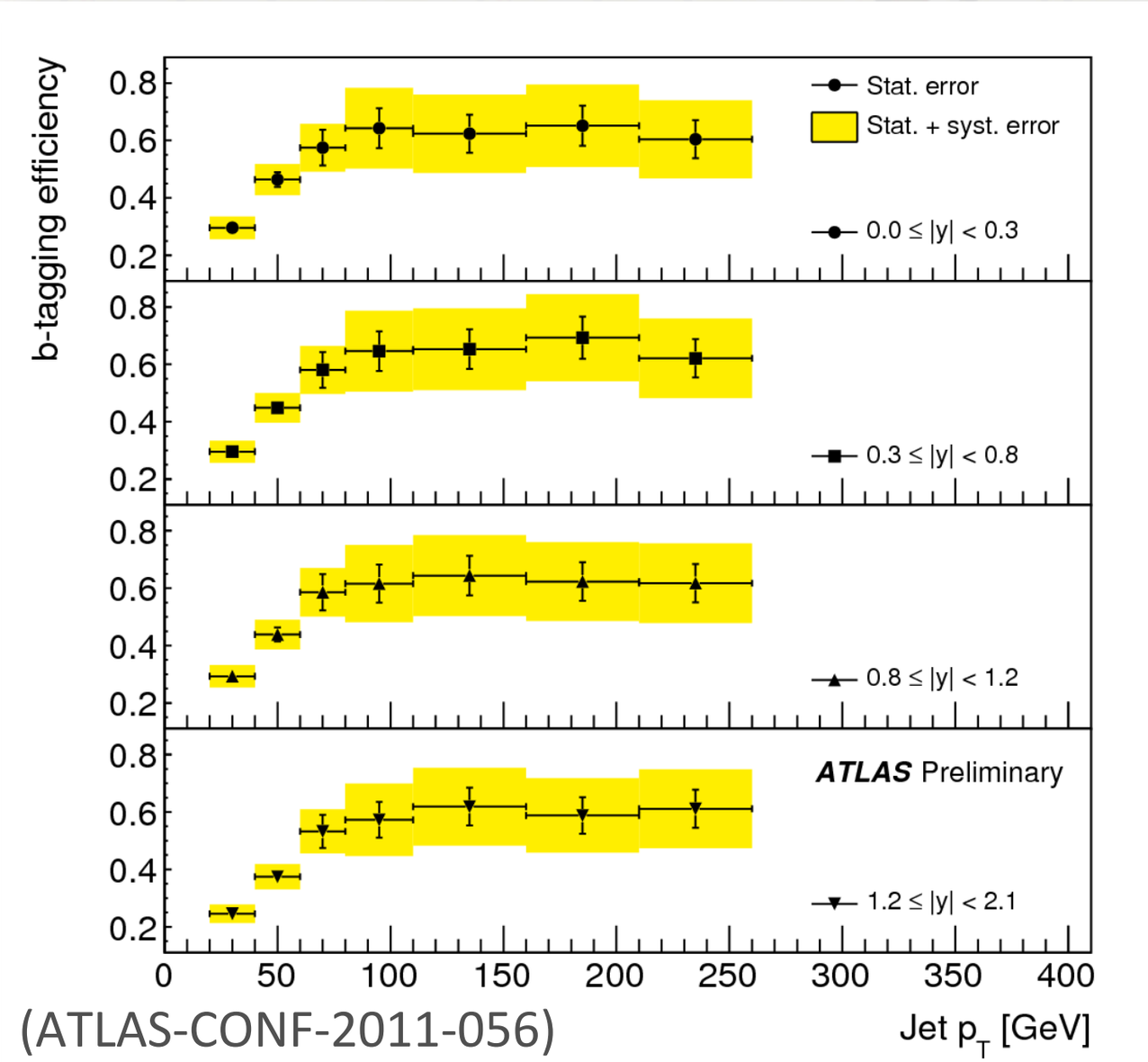


single b-jet



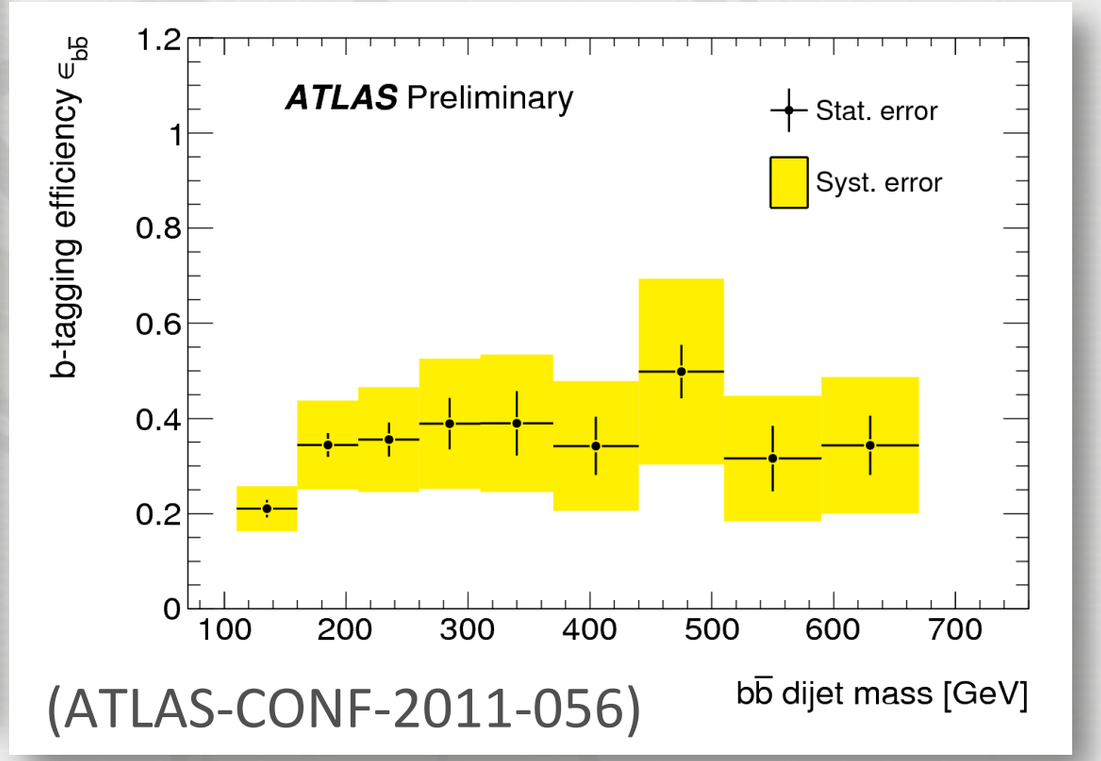
di-jets

b-tagging efficiencies



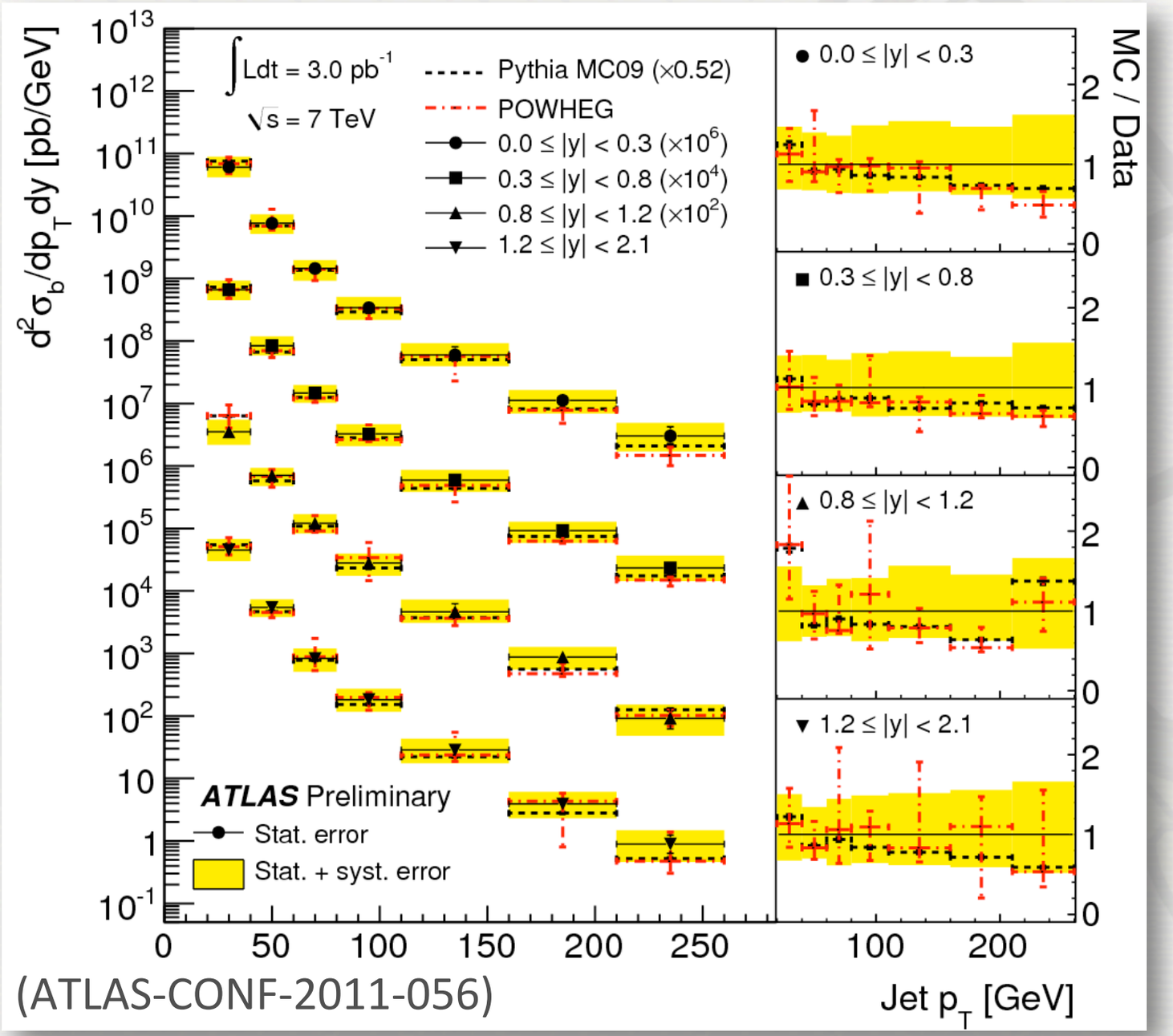
(ATLAS-CONF-2011-056)

- Efficiency estimated using p_T^{rel} method using sample with muons



(ATLAS-CONF-2011-056)

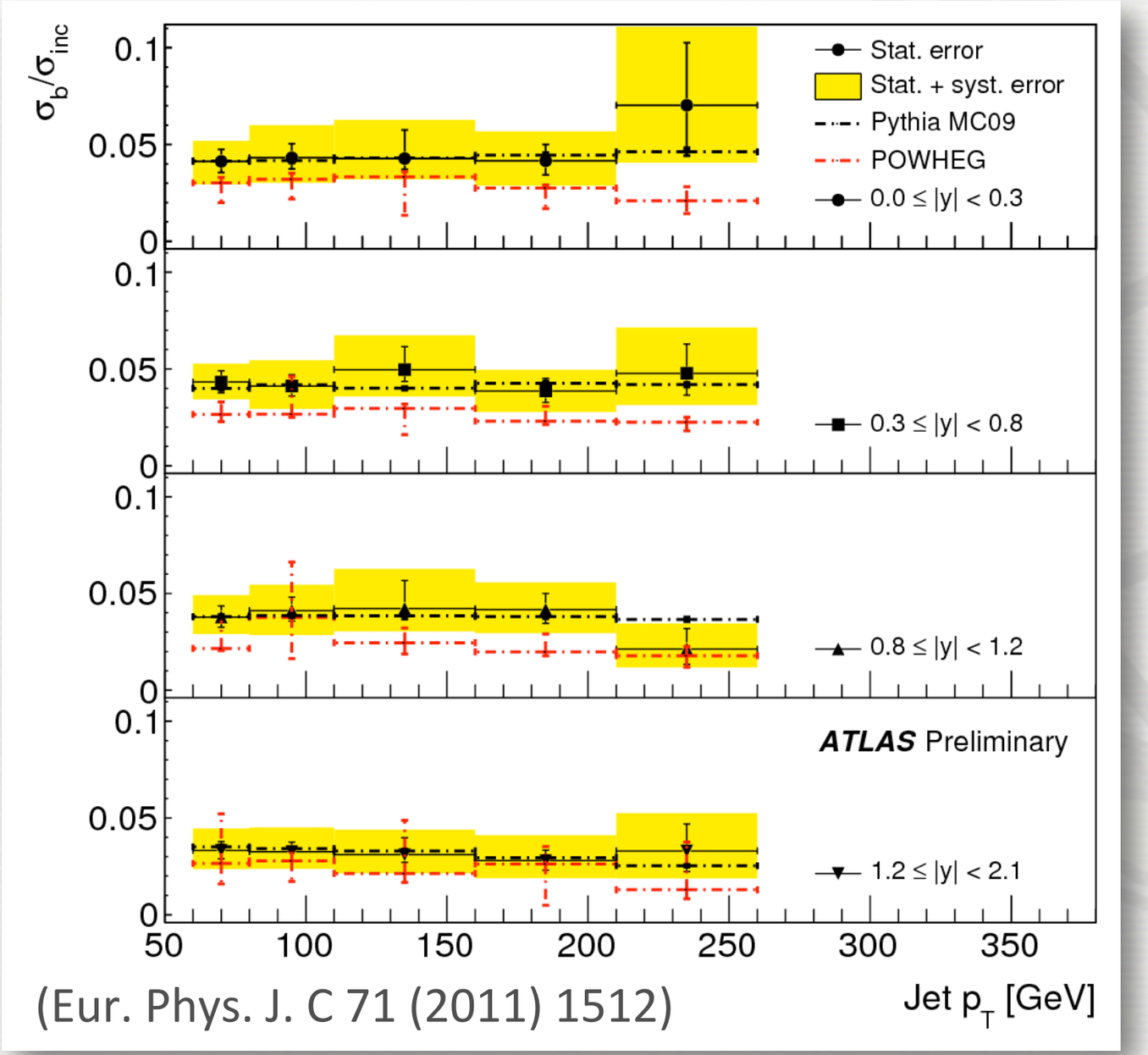
Inclusive *b*-jet cross section



(ATLAS-CONF-2011-056)

- Main uncertainties: jet energy scale and *b*-tagging efficiency and purity
- POWHEG (NLO): broad agreement, but drop steeper in MC
- Pythia (LO): normalization scaled by 0.52 (note expected to get norm. correct), shape well described

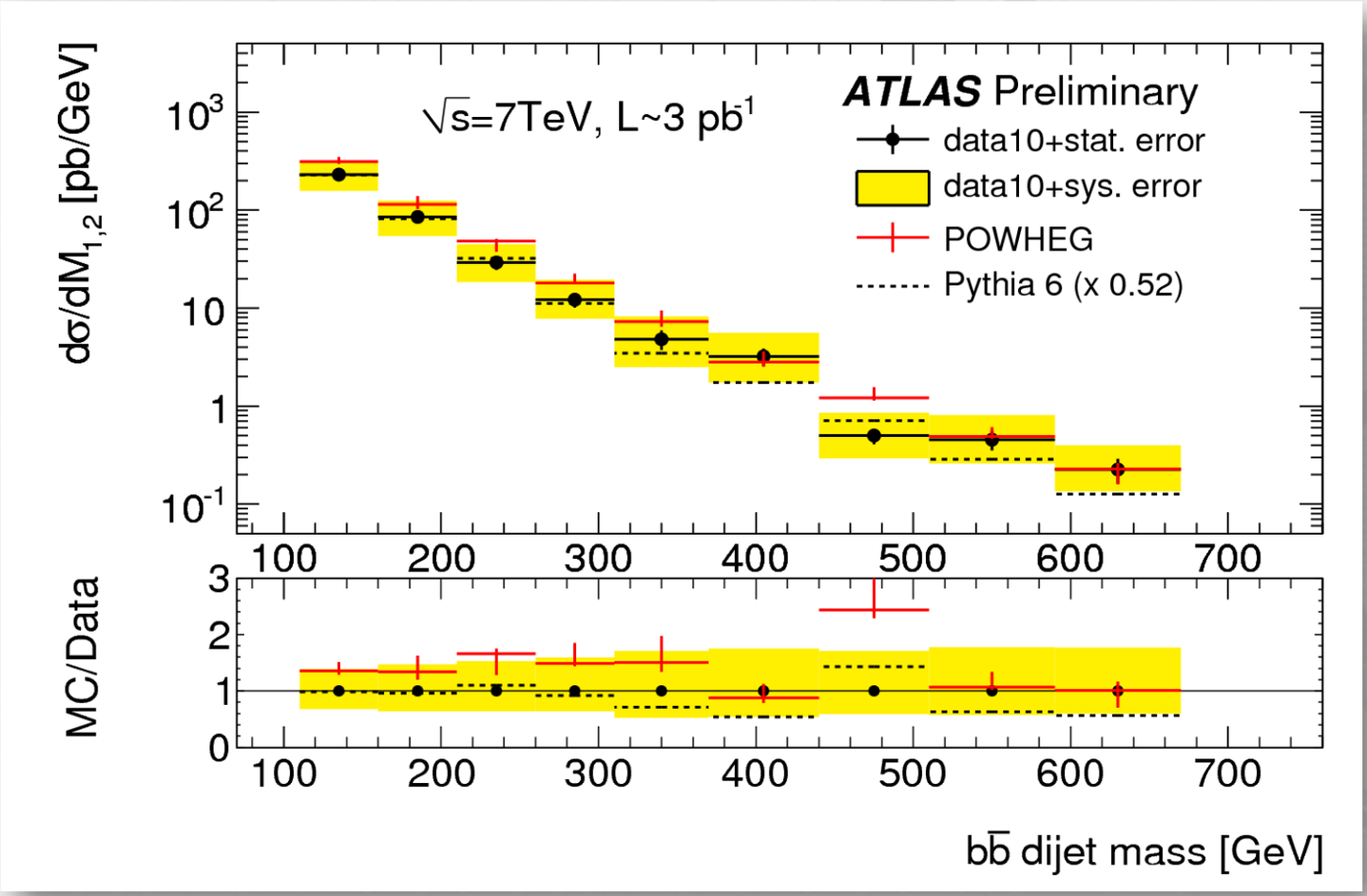
Ratio of *b*- to any jet cross section



(Eur. Phys. J. C 71 (2011) 1512)

- Main uncertainties: *b*-tagging efficiency and purity
- POWHEG (NLO): underestimates fraction of *b*-jets by approx. 30% (≈1σ)
- Pythia (LO) is closer

Inclusive *bb* di-jet cross section



- Analysis dominated by statistics
- Pythia 6 (LO): shape well described
- POWHEG (NLO): somehow higher *bb* cross section predicted

Conclusions

- Inclusive *b*-jet cross section measured as a function of jet transverse momentum and rapidity, based on secondary vertex method
- Inclusive *bb* di-jet cross section measured as a function of the invariant di-jet mass
- Measurements dominated by uncertainties of…
  - *b*-jet energy scale, *b*-tagging
- Unfolding corrections to compare with Pythia (LO) and POWHEG (NLO)
  - Shape of differential distribution rather well described
  - POWHEG underestimates ratio of *b*-jets to inclusive jets by 30%

    - more details:

      Eur. Phys. J. C 71 (2011) 1512, ATLAS-CONF-2011-056, ATLAS-CONF-2010-099

Outlook

- Coming soon, same analysis with all 2010 data

- 2011 data
  - improved *b*-tagging, e.g. identify two *b*'s in one jet
  - improvement in handling close-by pixel hits
  - improvement in reconstructing high-p_T *b*-jets

    - more details:

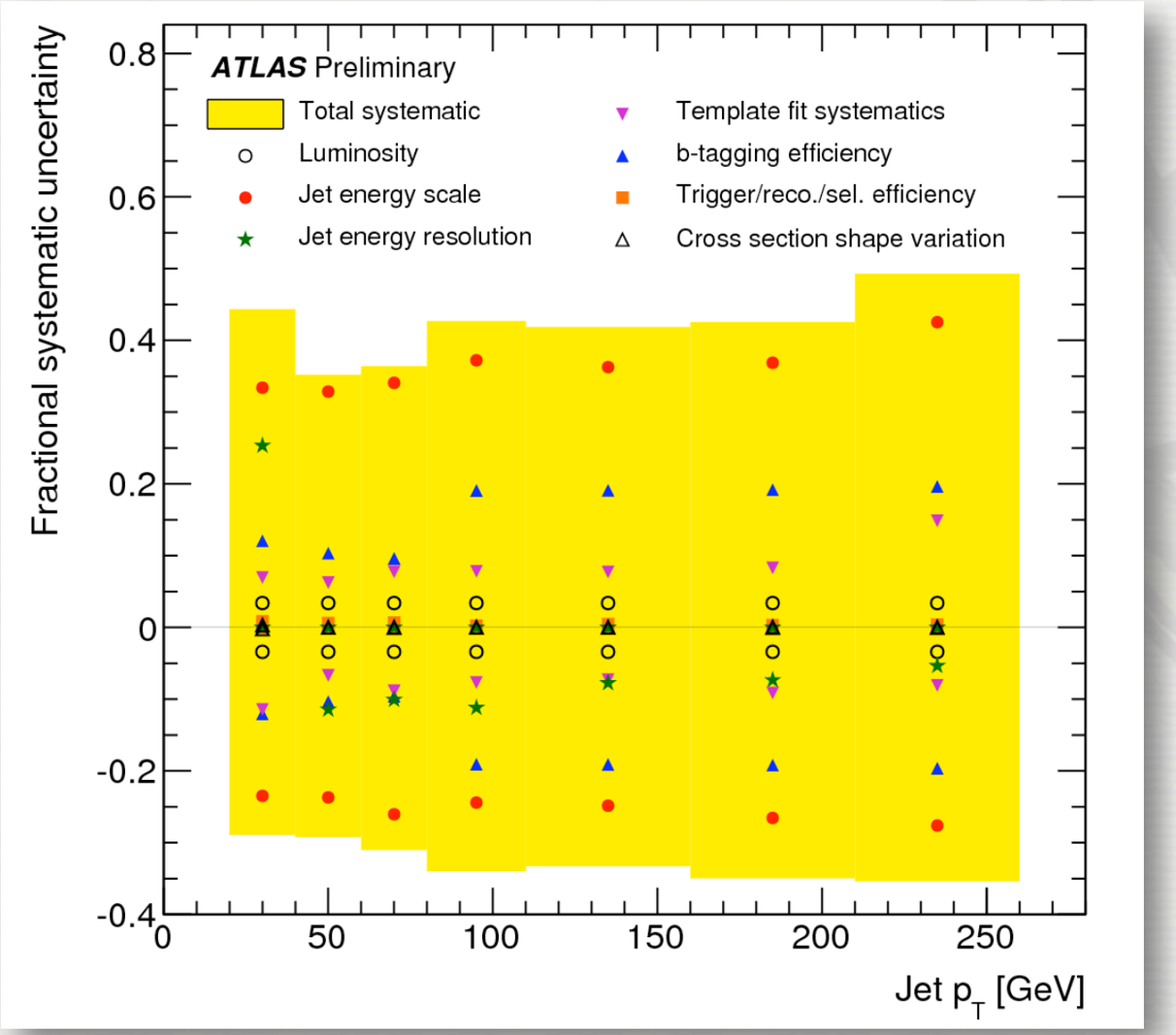
      Eur. Phys. J. C 71 (2011) 1512, ATLAS-CONF-2011-056, ATLAS-CONF-2010-099

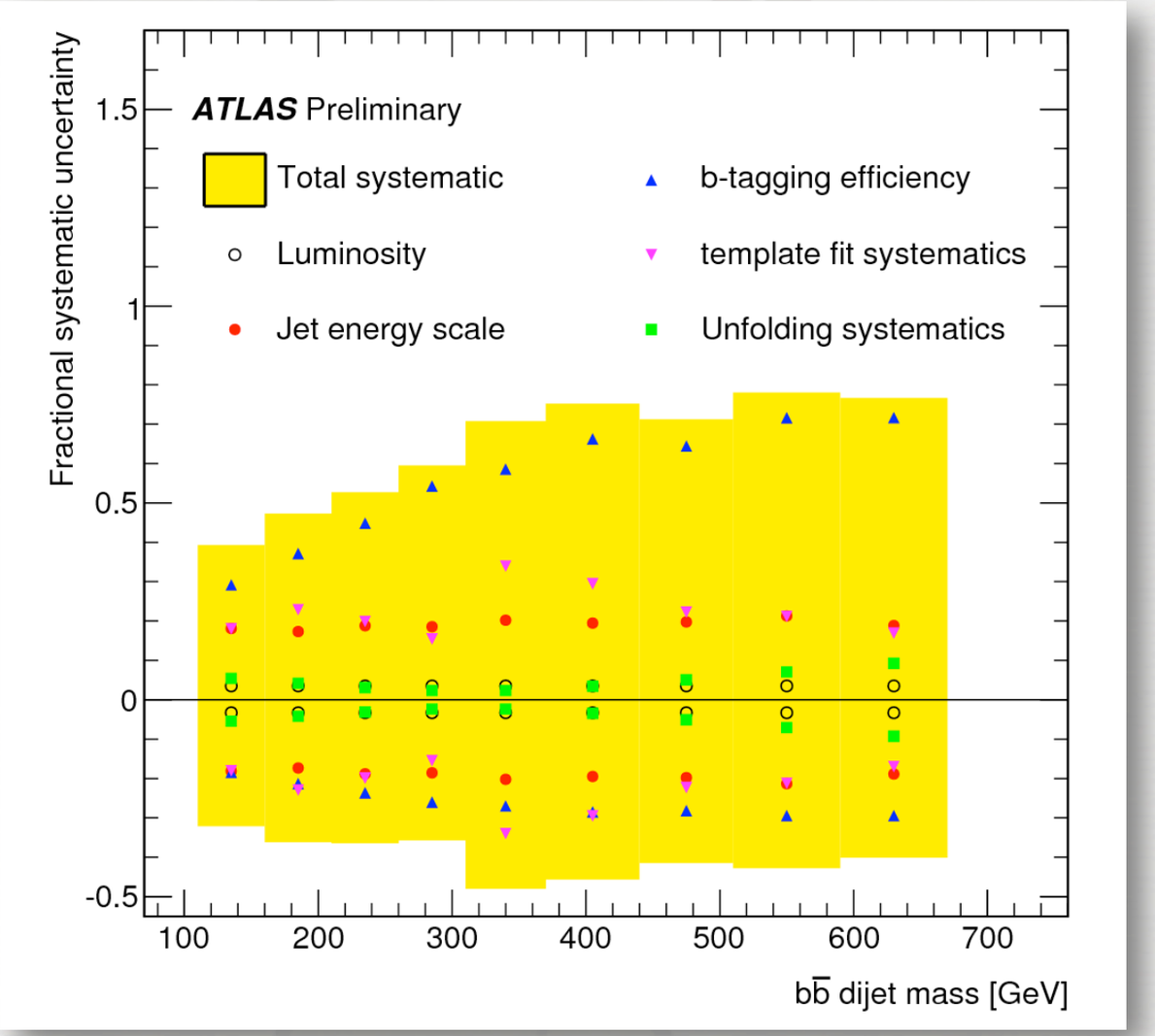
Backup

- Track & vertex reconstruction:
  - p_T > 400 MeV, 6 silicon cluster requirements
  - 10 tracks in the primary vertex
  - Iterative secondary vertex reconstruction
- Jet reconstruction:
  - Starting with topological clusters
  - Anti-kT algorithm with R=0.4
- Muon reconstruction
  - Combined muon reconstruction, starting from stand-alone muons
  - Combination of muon tracks and Inner Detector tracks

Backup

- Fractional systematic uncertainties in single *b*-jet cross section





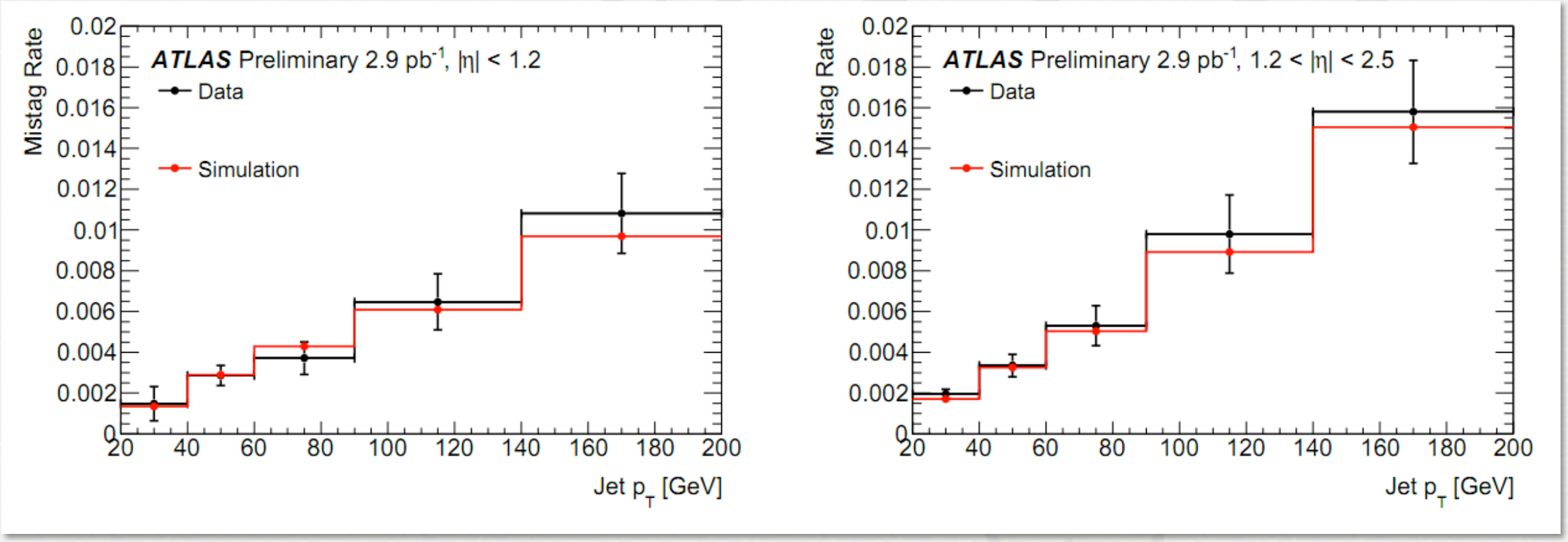
Backup

- Systematics in *b*-tagging

Source	Relative Uncertainty		
	$25 < p_T^{jet} < 40$ GeV	$40 < p_T^{jet} < 60$ GeV	$60 < p_T^{jet} < 85$ GeV
Modelling of the *b*-hadron direction	6%	6%	6%
Non-*b*-jet templates	6%	6%	6%
Jet p_T spectrum	6%	3%	3%
Scale factor for inclusive *b*-jets	5%	4%	0.7%
p_T^{rel} template statistics	2%	2%	2%
Modelling of *b*-decays	1.3%	0.2%	0.5%
Fake muons in *b*-jets	0.7%	0.7%	0.7%
Jet energy scale	0.2%	0.2%	0.2%
Modelling of *b*-production	0.2%	0.2%	0.2%
Fragmentation	0.1%	0.1%	0.1%
Total	12%	10%	10%

Backup

- Mistag rate in *b*-tagging



Backup

- Discrepancy between Data and MC, closer look at vertex mass...