Inclusive $b\bar{b}$ production in ATLAS

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IOWA STATE UNIVERSITY

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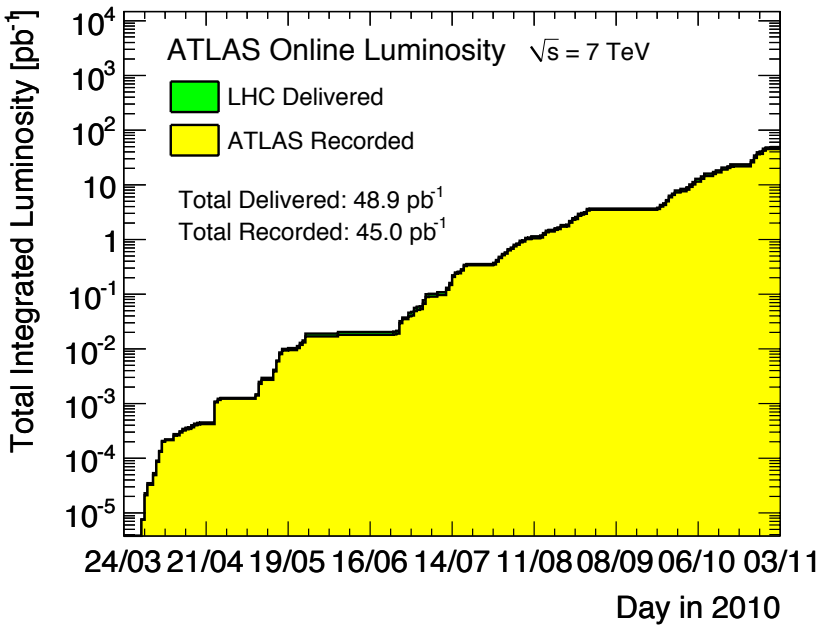
- Conclusions

Introduction

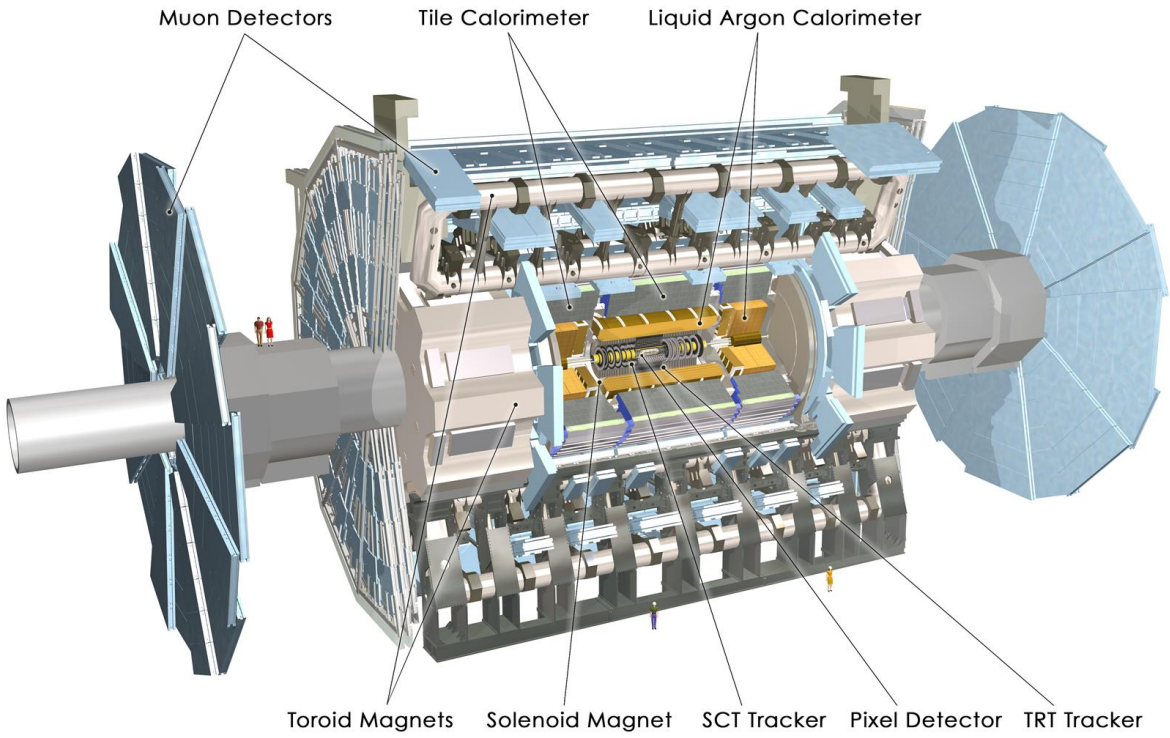
- Production of b-quarks at 7 TeV proton-proton collisions in LHC provides an important test of perturbative QCD
- The measurement of b-jet cross sections tests the NLO theory predictions
- First step in the understanding of other processes (i.e., W or Z boson production associated with b-jets) which are backgrounds for new physics
- Presenting first measurement of the inclusive b-jet and $b\bar{b}$ dijet cross section in ATLAS
- Based on secondary vertex: ATLAS-CONF-2011-056 ($\mathcal{L} = 3.0$ pb^{-1})
- Based on $p_{\mathrm{T}}^{\mathrm{rel}}$ method: ATLAS-CONF-2011-057 ($\mathcal{L} = 4.8$ pb^{-1})

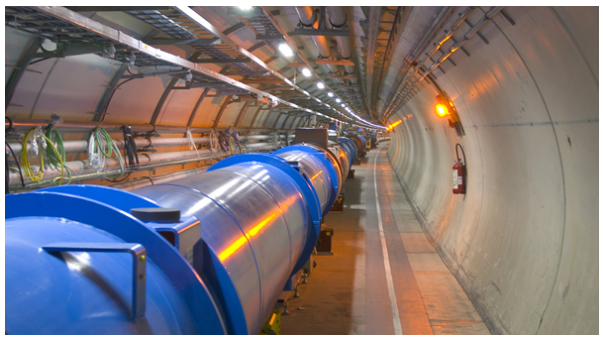


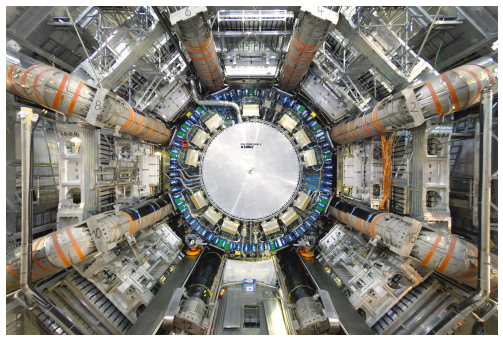
The ATLAS detector

- **Inner Detector:**
  Si pixel, Si strips, TRT straws
  $\sigma/p_T \sim 3.8 \times 10^{-4} p_T(\text{GeV}) \oplus 0.015$
- **Calorimeter:**
  EM:
  LAr-Pb, $\sigma/E \sim 10\%/\sqrt{E}$
  HAD:
  Central: scintillator-steel
  $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$
  Forward: LAr-Cu/W
  $\sigma/E \sim 90\%/\sqrt{E} \oplus 0.07$
- **Muon spectrometer:**
  Gas-based muon chambers
  $\sigma/p_T < 10\%$ up to 1 TeV
- **Magnet system:**
  1 solenoid (2T) and 3 toroids (4T)
- **Trigger system:**
  Level-1 (hardware), Level-2 and Event Filter (software)
  Rate reduced to ∼300 Hz

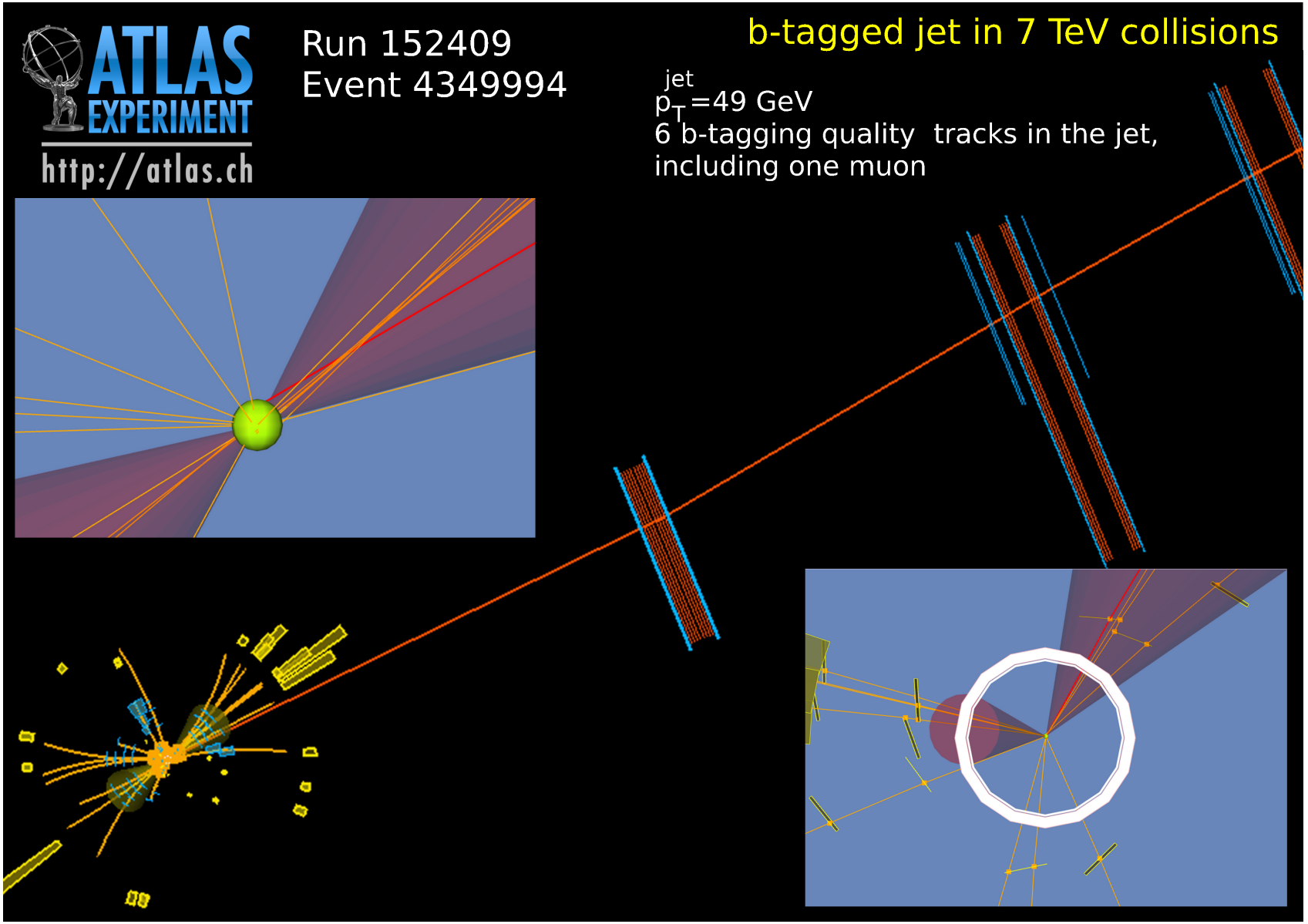
Width: 44 m, Diameter: 22 m, Weight: 7000 t







ATLAS *b*-jet candidate at 7 TeV



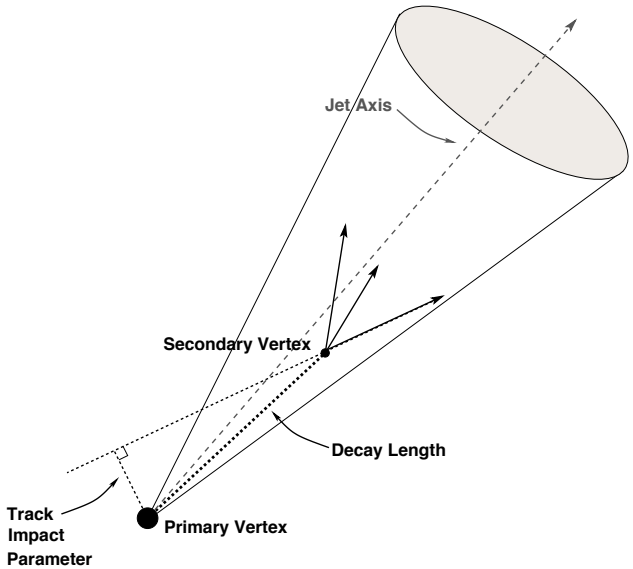
Measurement of the inclusive b-jet and $b\bar{b}$ dijet cross section using secondary vertex tagging

Event selection

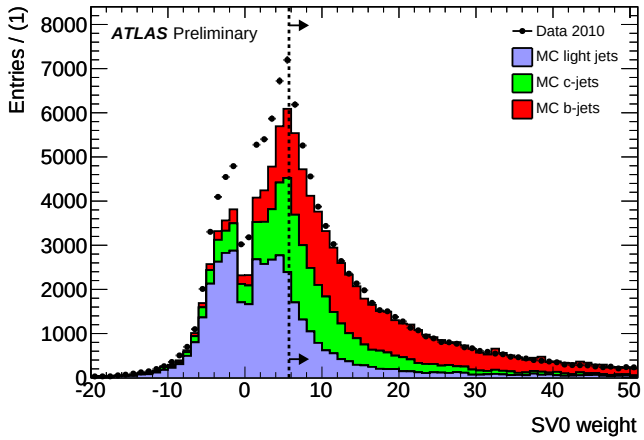
- Primary vertex with at least 10 tracks
- Level-1 jet triggers used for the analysis (except for $20 < p_T < 40$ GeV in the inclusive b-jet cross section analysis for which minimum bias trigger scintillators are used) $\rightarrow$ above 98% efficiency for the p_T ranges used
- Jets are reconstructed from calorimeter topological clusters using the anti-$k_\perp$ algorithm with distance parameter $R = 0.4$
- Jets calibrated to the standard jet energy scale (b-jet energy scale is in agreement with the inclusive jet energy scale within 2.5%, assigned as systematic uncertainty)
- Rapidity range $|y| < 2.1$ (so that the jets are fully contained in the tracking system acceptance)
- Inclusive b-jet cross section:
  - Measured as a function of the jet p_T ($20 < p_T < 260$ GeV) and rapidity
- $b\bar{b}$ dijet cross section:
  - Measured as a function of the dijet mass ($110 < m_{b\bar{b}} < 670$ GeV)
  - $p_T > 40$ GeV

b-jet identification

- Long lifetime of b-hadrons (~ 1.5 ps) $\rightarrow$ Few millimeters flight path and secondary vertex
- SV0 b-tagging algorithm reconstructs the displaced secondary vertex
- Algorithm uses all the tracks associated to a calorimeter jet with the following criteria:
  - $N_{\text{Pixel}} \geq 2$, $N_{\text{SCT}} \geq 4$, $N_{\text{Pixel}} + N_{\text{SCT}} \geq 7$
  - $p_{\text{T}} > 500$ MeV
  - $|d_0| < 2$ mm, $\sigma_{d_0} < 1$ mm
  - $|z_0 \sin\theta| < 2$ mm, $\sigma_{z_0} < 5$ mm
  - $\chi^2/N_{\text{DoF}} < 3$
- Output: decay length (L/σ_L) significance of the reconstructed secondary vertex
- Operating point: 5.72 (50% efficiency for MC $t\bar{t}$ events)
- The discrepancies between data and MC at low weight are due to differences in tracking resolution (accounted as a systematic)

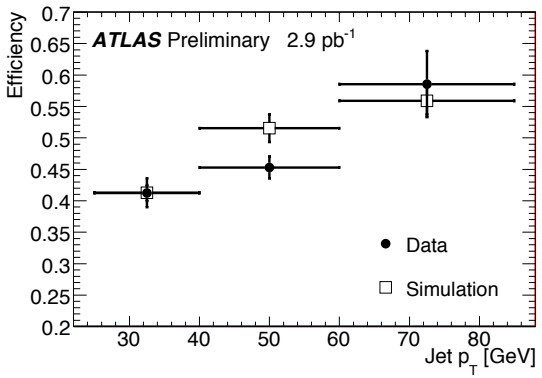


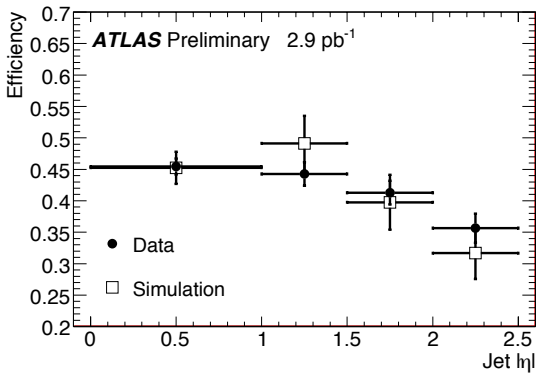
$L = 3$ pb^{-1}



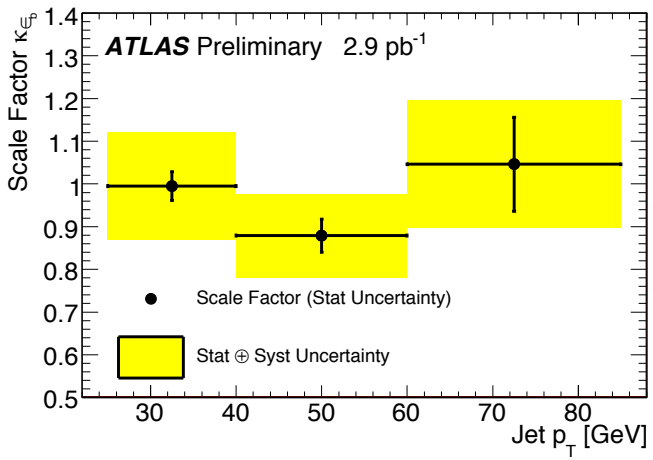
SV0 *b*-tagging efficiency

- *b*-tagging efficiency evaluated in data with a sample of jets with a muon using the $p_{\mathrm{T}}^{\mathrm{rel}}$ method (ATLAS-CONF-2010-099)
- Data and Monte Carlo comparisons performed as a function of the jet p_{T} and η





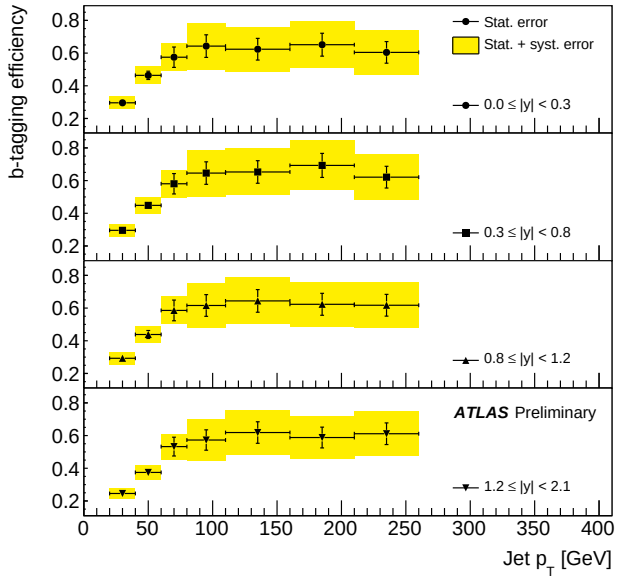
- Scaling factors: ratio of *b*-tagging efficiency in data and MC



b-tagging efficiency

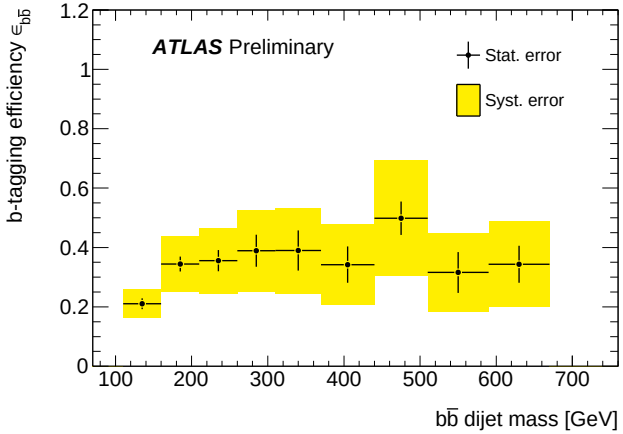
Inclusive b-jet cross section:

- b-tagging efficiency obtained from a sample of jets with a muon in data using the $p_{\mathrm{T}}^{\mathrm{rel}}$ method
- Using systematic uncertainties from scaling factors
- For higher p_{T} bins, the scaling factor in $60 < p_{\mathrm{T}} < 85$ GeV is used increasing the systematic uncertainty by a factor two



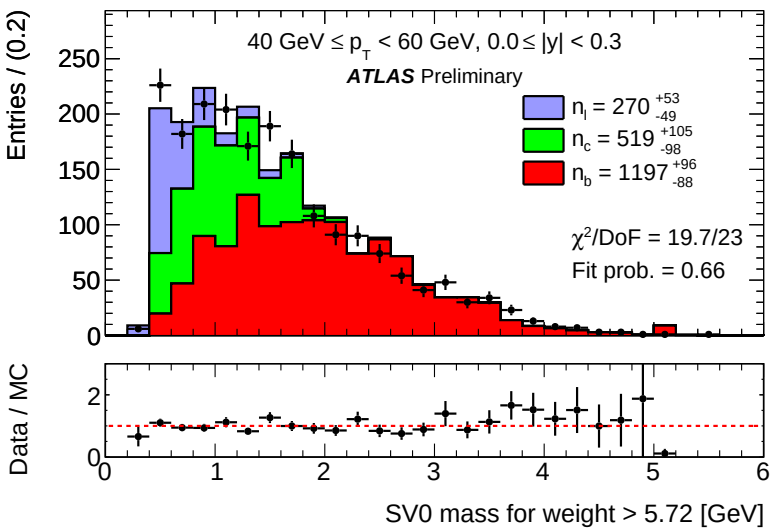
$b\bar{b}$ dijet cross section:

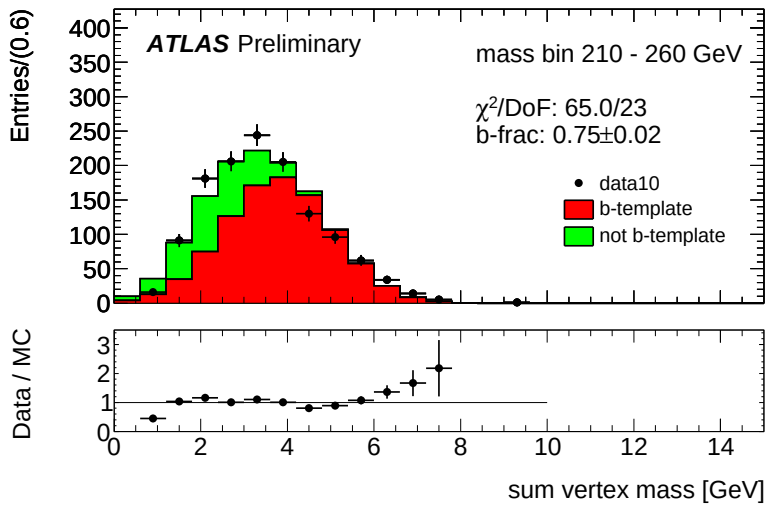
- Dijet b-tagging efficiency in each dijet invariant mass bin based on MC
- Systematics estimated varying single-jet b-tagging efficiency using the uncertainties in the scaling factors



SV0 mass template fits

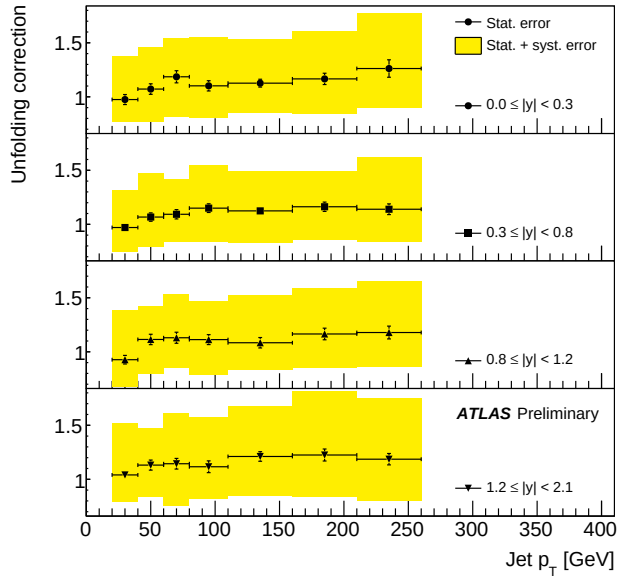
- Fraction of b-jets in the final sample determined by a binned likelihood fit of MC-derived templates
- Inclusive b-jet cross section:
  - Fits of the secondary vertex mass distribution
  - Templates for b, c and light jets
- $b\bar{b}$ dijet cross section:
  - Fits to the sum of vertex masses of the two b-tagged jets
  - b-jet templates (both jets matched to a b-hadron) and non-b-template (at least one c or light jet)

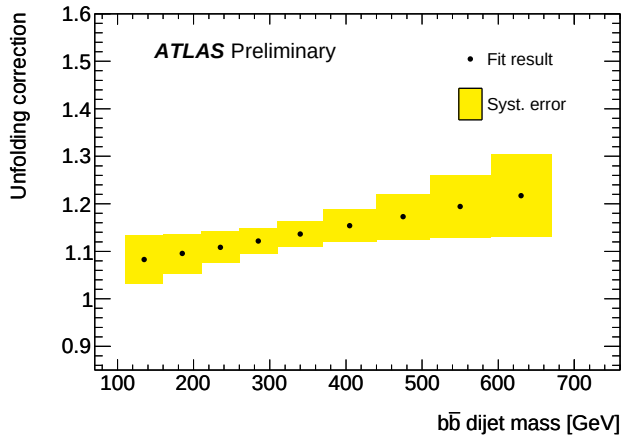




Unfolding

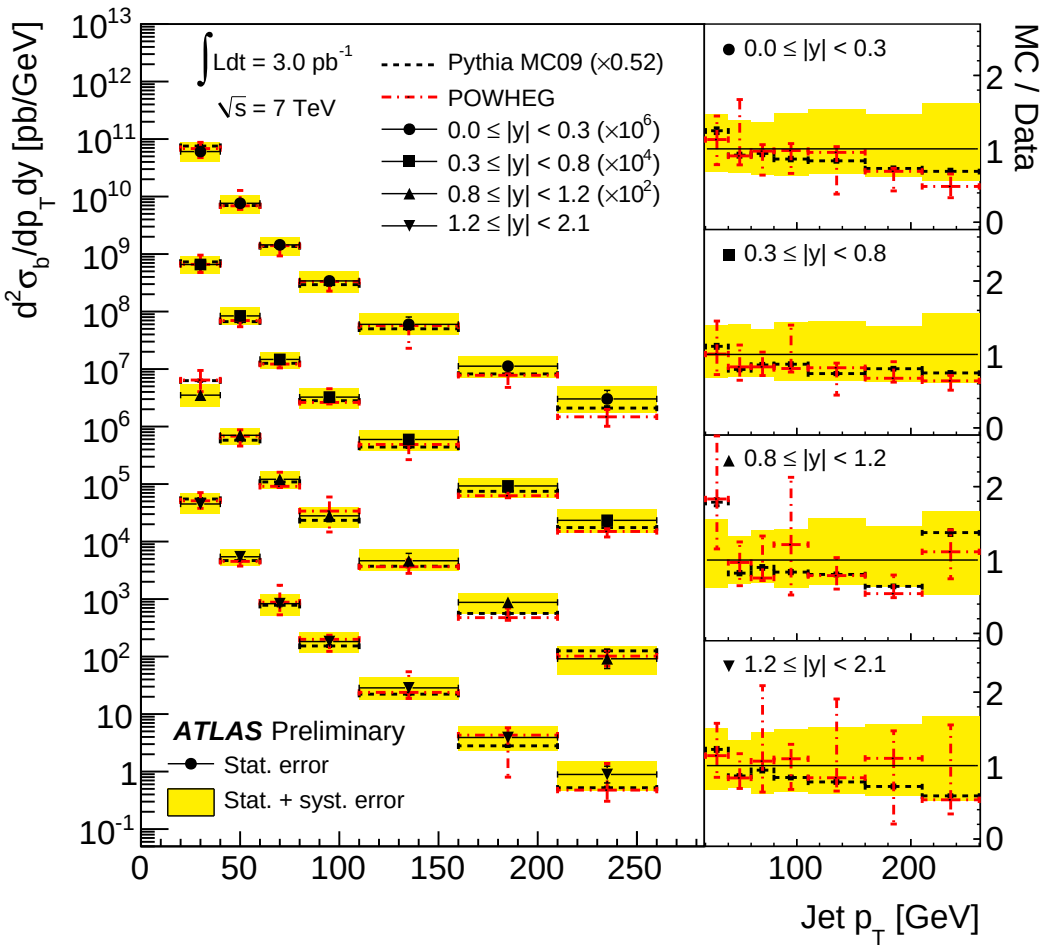
- Bin-by-bin correction factors obtained using PYTHIA Monte Carlo to take into account bin migrations from the truth to reconstruction
- Inclusive b-jet cross section:
  - Factors: ratio of $p_{\mathrm{T}}^{\mathrm{truth}}$ and $p_{\mathrm{T}}^{\mathrm{reco}}$ distributions
  - Systematics: b-jet energy scale and resolution, shape uncertainties
- $b\bar{b}$ dijet cross section:
  - Factors: ratio of $m_{b\bar{b}}^{\mathrm{truth}}$ and $m_{b\bar{b}}^{\mathrm{reco}}$ fitted to an exponential
  - Systematics: b-jet energy scale and resolution, shape uncertainties





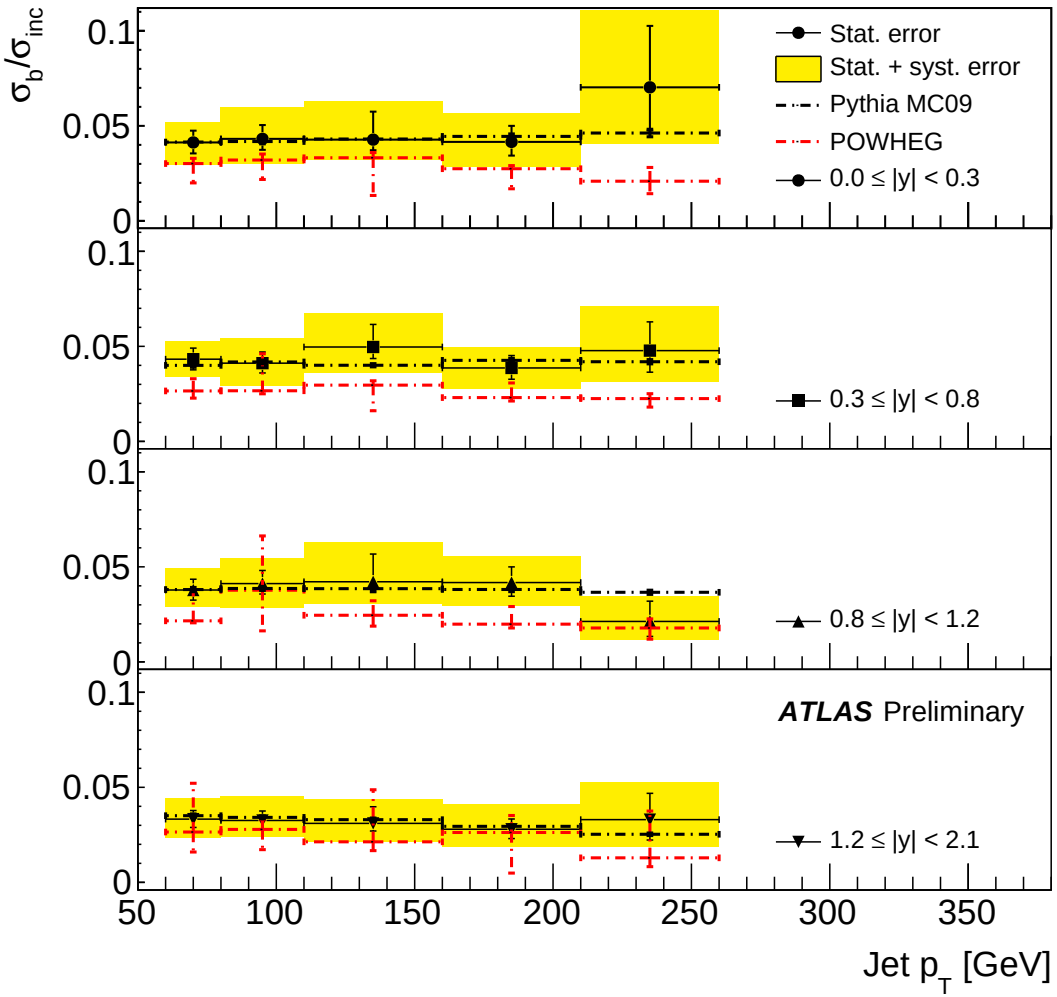
Inclusive b-jet cross section using SV0

- Double differential cross section as a function of p_T for different y bins
- NLO predictions from POWHEG shows a steeper drop as a function of p_T than in data
- PYTHIA LO MC also shown (normalized to area, rescaled by a factor 0.52): good shape agreement
- Agreement within systematic uncertainties



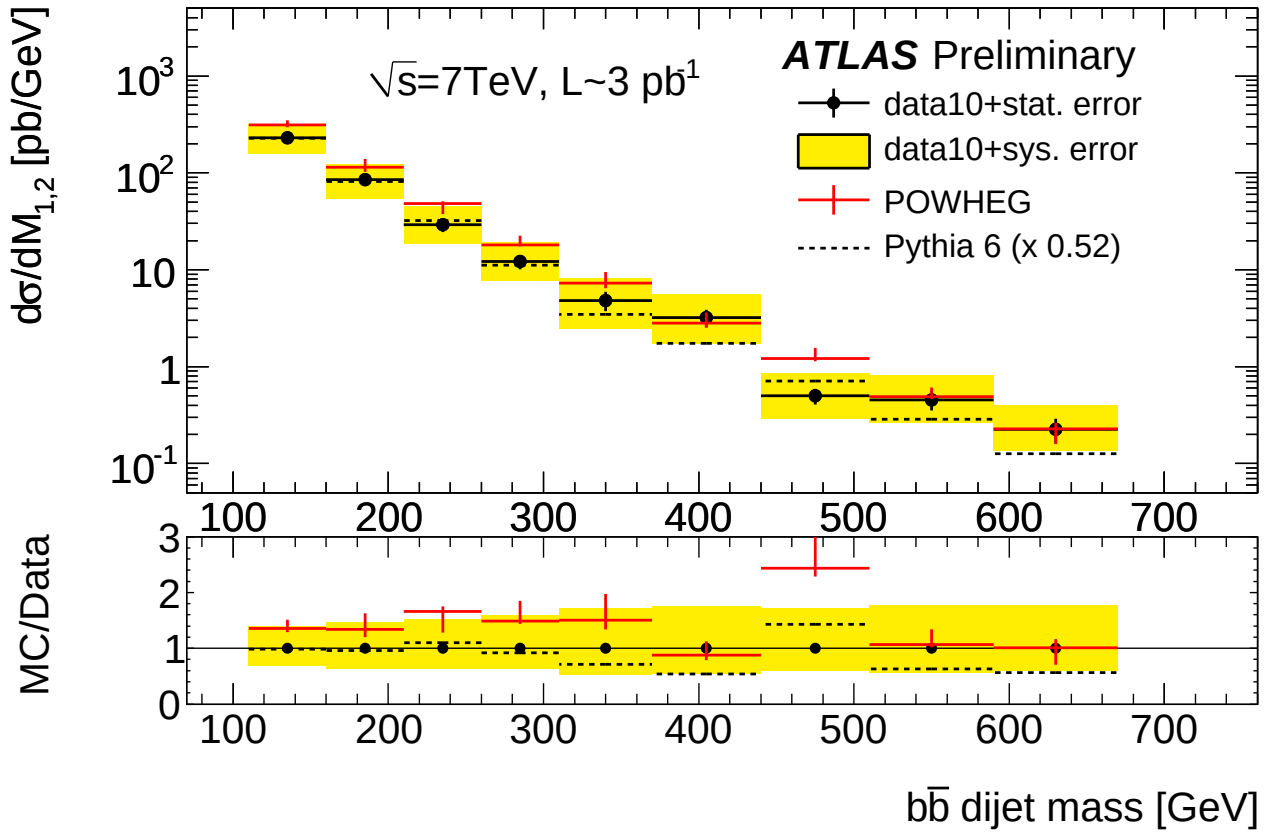
Ratio between b-jet and inclusive jet cross sections

- Ratio between b-jet and inclusive jet cross sections as function of the p_T in different rapidity regions
- Compared to PYTHIA and POWHEG (which is about 30% lower than in data, 1σ of the systematic uncertainties)
- Cancellation of syst. uncertainties: luminosity, jet energy scale (except b-jet component: 2.5%)
- Dominant uncertainties: b-tagging efficiency and purity



$b\bar{b}$ dijet cross section using SV0

- $b\bar{b}$ dijet cross section as a function of the dijet invariant mass for $p_T > 40$ GeV and $|y| < 2.1$
- Compared to PYTHIA and NLO predictions derived with POWHEG
- Agreement within systematic uncertainties



Measurement of the b-jet cross section using the $p_{\mathrm{T}}^{\mathrm{rel}}$ method

b-jet cross section using muons in jets

- Independent measurement of the b-jet cross section based on a sample of jets containing muons
- Event selection:
  - Muon-plus-jet trigger (4.8 pb^{-1}): requires a reconstructed jet with $p_{\mathrm{T}}^{\mathrm{EM}} > 5$ GeV matched to a reconstructed muon with $p_{\mathrm{T}} > 4$ GeV
  - Primary vertex with at least 10 tracks
  - $p_{\mathrm{T}}^{\mu} > 4$ GeV, associated with jets in $\Delta R < 0.4$
- Energy of the jet corrected for the energy of the muon and neutrino, correction from MC and parametrized in ($p_{\mathrm{T}}^{\mathrm{jet}}$, p_{T}^{μ}, η^{jet}) $\rightarrow$ average correction: $\sim$30% (10% from the neutrino)
- Efficiency:
  - Trigger efficiency estimated from data
  - All other efficiencies (reconstruction, selection, acceptance) obtained from PYTHIA MC

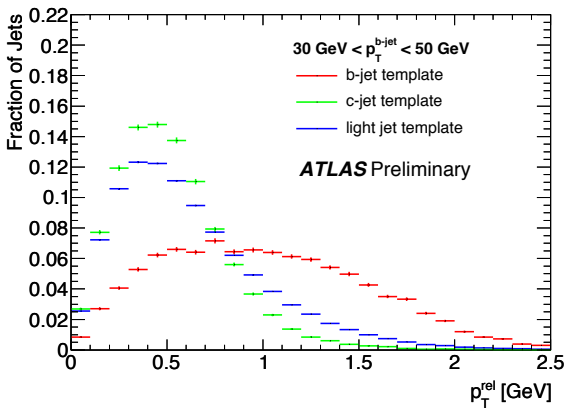
b-jet purity

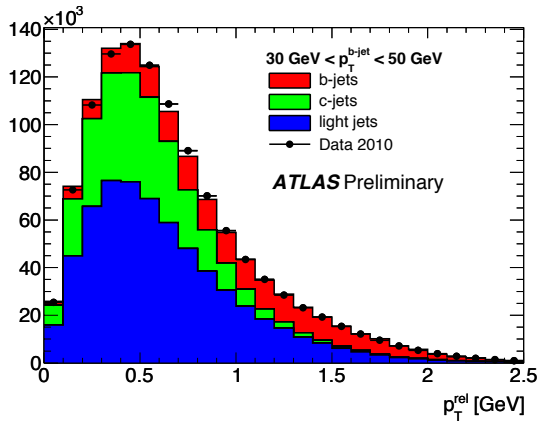
- Use the $p_{\mathrm{T}}^{\mathrm{rel}}$ method to extract the fraction of b-jets in the sample
- Momentum of the muon relative to the jet axis:

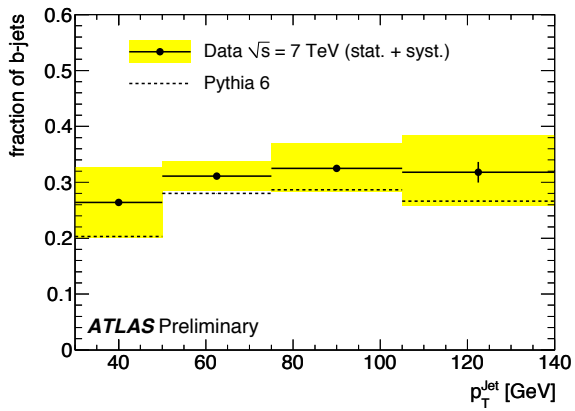
$$p_{\mathrm{T}}^{\mathrm{rel}} = p_{\mu} \cdot \sin\theta$$

where θ is the angle between the muon momentum and the direction of the associated jet

- $p_{\mathrm{T}}^{\mathrm{rel}}$ templates for b- and c-jets are constructed using MC
- Data driven templates for the light jets (poor statistics in MC)

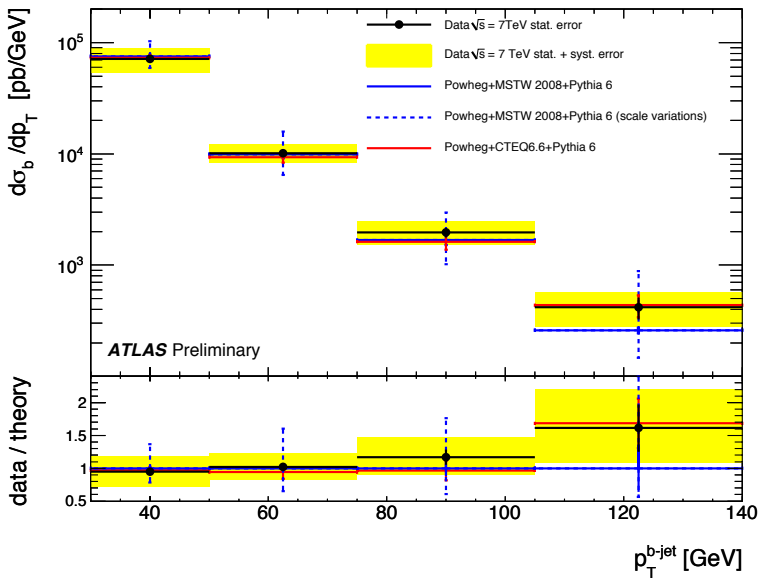


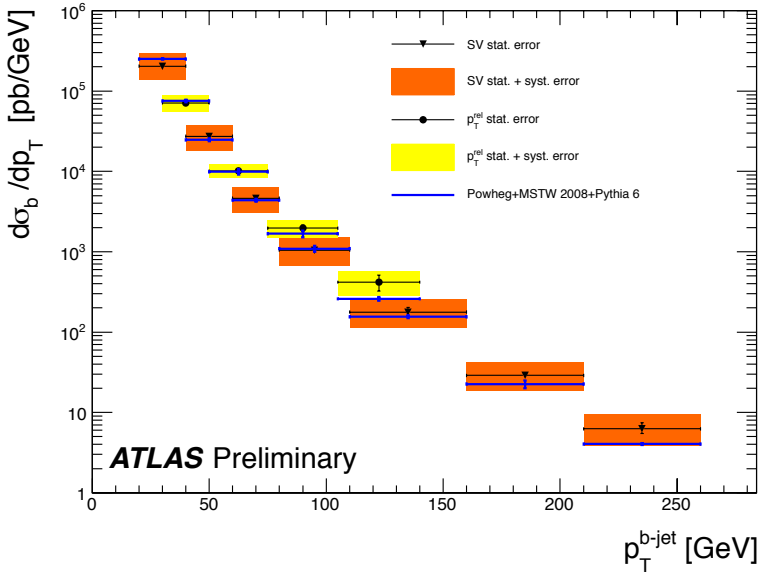




b-jet cross section using the p_T^{rel} method

- Final result after bin-by-bin unfolding and evaluation of systematic uncertainties
- Measurement is compatible with the NLO predictions by POWHEG
- Results consistent with the measurement based on secondary vertex tagging





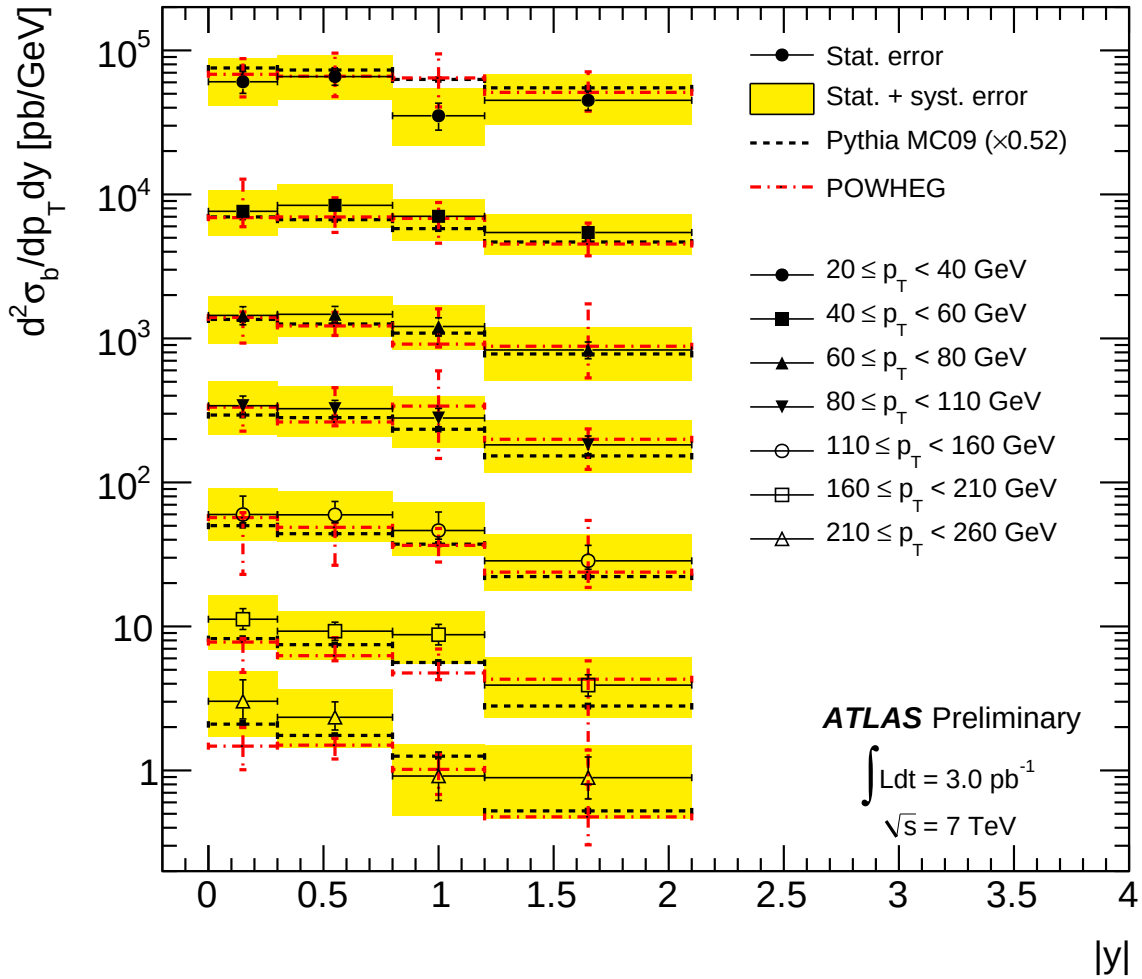
Conclusions

- First results on the production of single jets and jet pairs from b-quarks at 7 TeV proton-proton collisions in ATLAS have been presented
- Measurement based on secondary vertex tagging (3.0 pb^{-1}):
  - b-tagging efficiency measured from data
  - b-jet purity obtained from a template fit to the invariant mass distributions of tracks in the secondary vertex
  - Inclusive b-jet cross section measured as a function of the p_{T} and y
  - $b\bar{b}$ dijet cross section measured as a function of the dijet invariant mass
- Measurement based on $p_{\text{T}}^{\text{rel}}$ method (4.8 pb^{-1}):
  - Efficiencies estimated from MC
  - Fraction of b-jets obtained from a template fit to the $p_{\text{T}}^{\text{rel}}$ distributions
  - b-jet cross section measured as a function of p_{T}
- Both measurements dominated by systematics
- Results in broad agreement with NLO QCD predictions from POWHEG

Backup

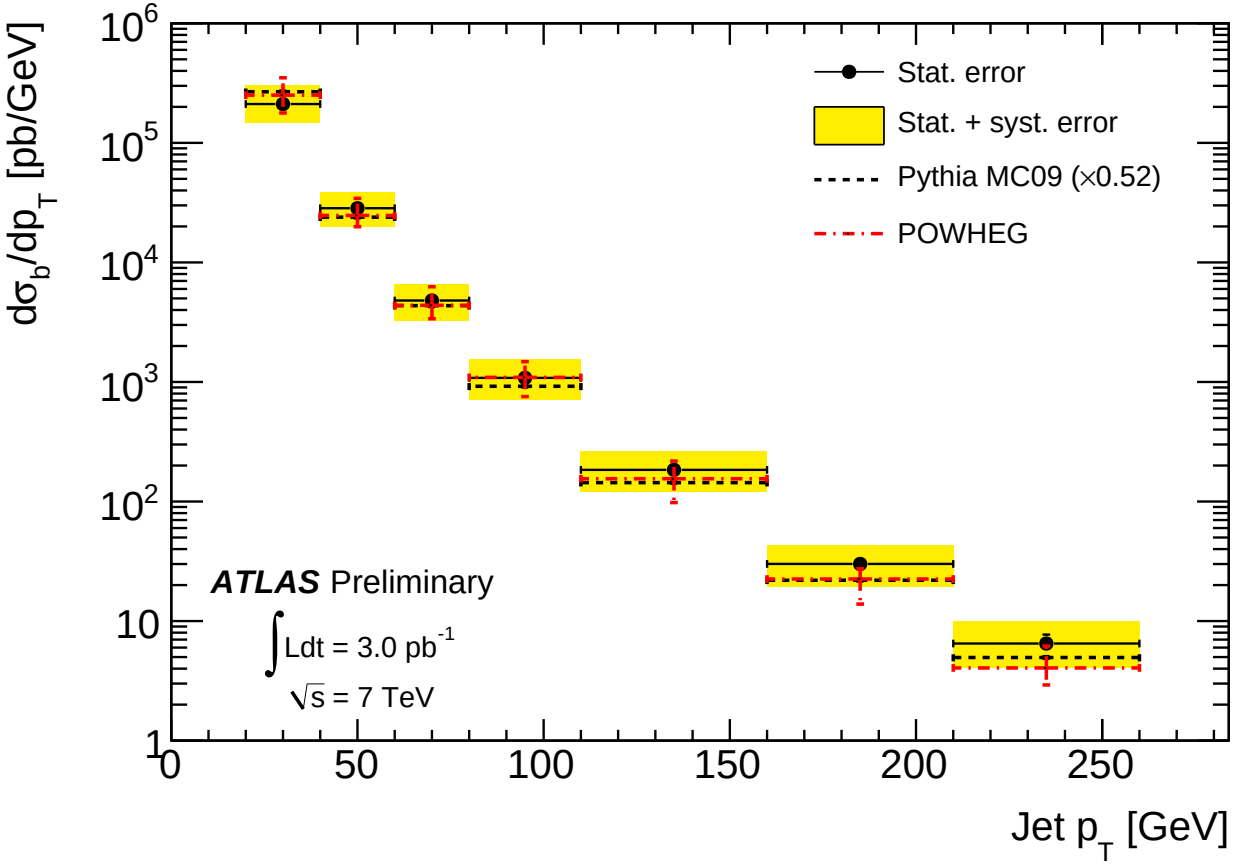
Backup: inclusive b-jet cross section using SV0

- Double differential cross section as a function of y for different p_T bins
- Comparisons to PYTHIA and POWHEG predictions are shown



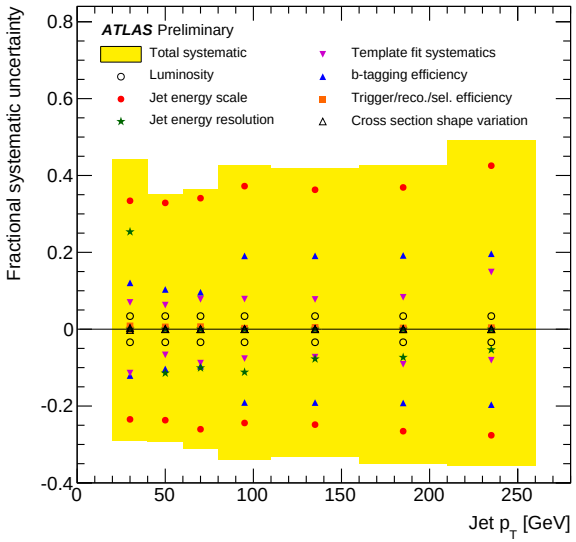
Backup: inclusive b-jet cross section using SV0

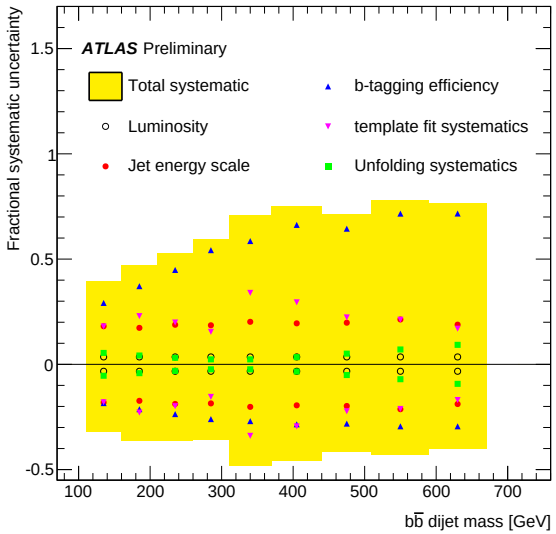
- Single differential cross section as a function of p_T (integrated over rapidity for $|y| < 2.1$)
- Comparisons to PYTHIA and POWHEG predictions are shown



Systematic uncertainties

- Luminosity uncertainty 3.4%
- Jet energy scale: inclusive jet energy scale uncertainty (5-9%) + 2.5% for b-jets
- b-tagging efficiency: obtained from the scaling factor uncertainty
- Impact of template fit evaluated by:
  - Reweight the number of tracks in SV0 vertex in MC to data
  - Shift the b-jet mass template by a 150 MeV (disagreement between MC and a very pure sample of b-jets)
- Jet energy resolution, trigger, selection efficiency, unfolding, etc.
- Dominant systematic uncertainties:
  - Inclusive b-jets: jet energy scale ($\sim$35%) and b-tagging efficiency ($\sim$20%)
  - $b\bar{b}$ dijets: b-tagging efficiency ($\sim$65%), jet energy scale and template fit ($\sim$25%)





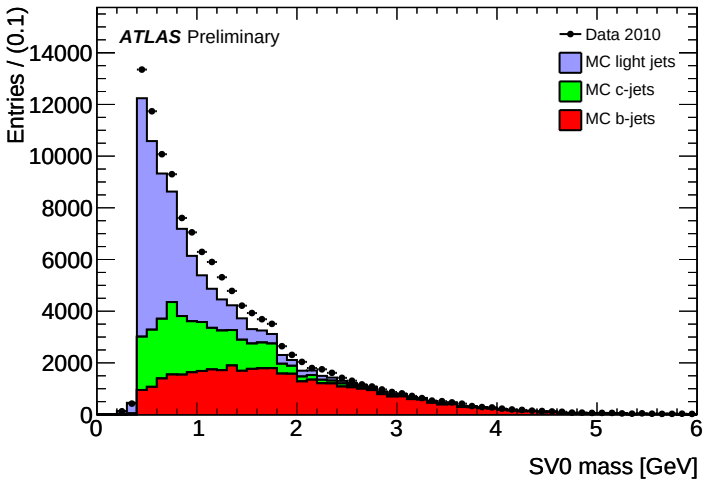
Backup: secondary vertex tagger SV0

- SV0 algorithm performance described in ATLAS-CONF-2010-042
- Input: list of tracks associated to a calorimeter jet
  - $\Delta R < 0.4$ matching (tracks not allowed to be associated to multiple jets)
  - Quality criteria applied to the tracks
- Starts reconstructing two-track vertices significantly displaced from the PV
- Two-track vertices must have $\chi^2 < 4.5$ and be incompatible with the PV by requiring the χ^2 of the distance between the PV and SV to be > 6.25
- Remove two-track vertices with a mass consistent with K_s^0, Λ or photon conversion or with r consistent with one of the three Pixel detector layers (material interactions)
- All the surviving tracks are fitted to a single SV
- Iteratively remove the track with the largest χ^2 contribution to the common vertex until:
  - Vertex fit probability > 0.001
  - Vertex mass < 6 GeV
  - Largest χ^2 contribution from any one track is ≤ 7
- Finally, try to re-incorporate into the vertex fit the tracks failing the selections made during the formation of two-track vertices

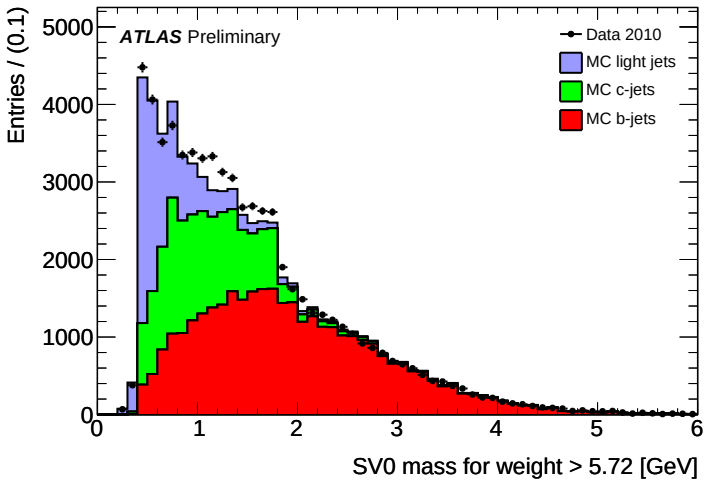
Backup: SV0 mass

- SV0 mass distribution in data and MC (normalized to the number of jets in data with at least one track passing the SV0 track selection criteria)

Without a cut on the SV0 weight



For jets with SV0 weight > 5.72



Backup: trigger efficiency

- Inclusive trigger efficiencies for b-jets estimated from data ($> 98\%$):
  - MBTS trigger efficiency is estimated in events selected by random triggers
  - Low threshold jet trigger efficiencies are estimated using events triggered by MBTS
  - High threshold jet trigger efficiencies are estimated using events triggered by low theshold jet triggers
- Trigger efficiencies for inclusive jets (ATLAS-CONF-2010-094):