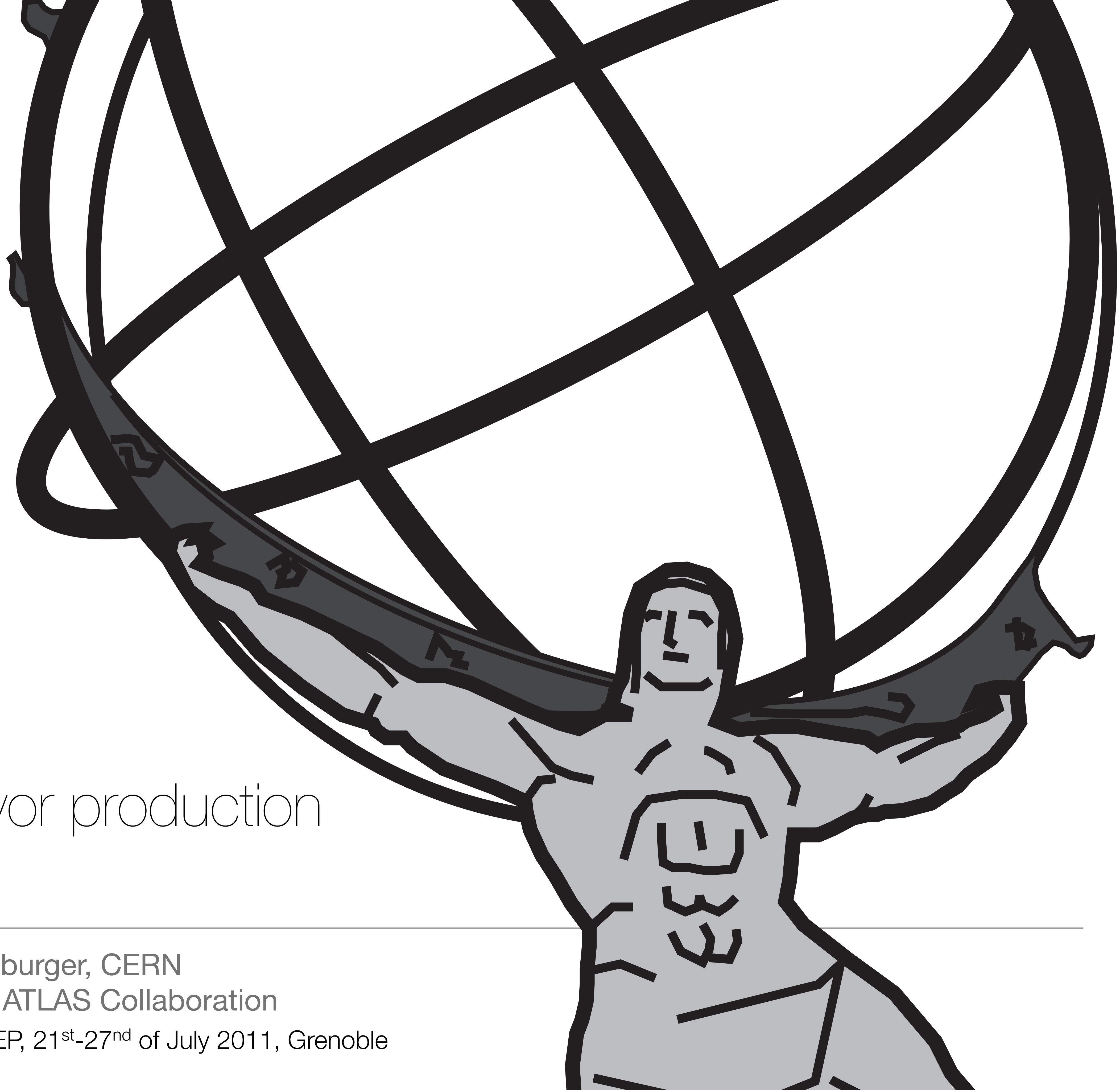


Heavy flavor production in ATLAS

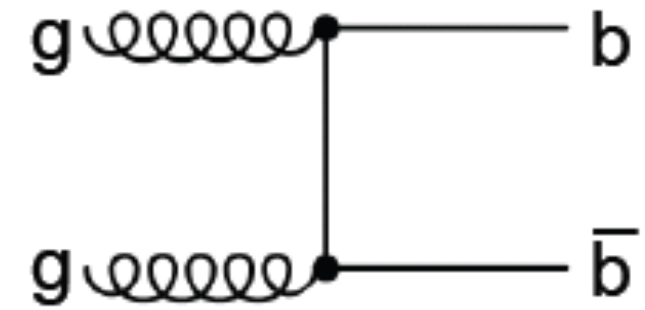
A. Salzburger, CERN
for the ATLAS Collaboration

EPS-HEP, 21st-27nd of July 2011, Grenoble

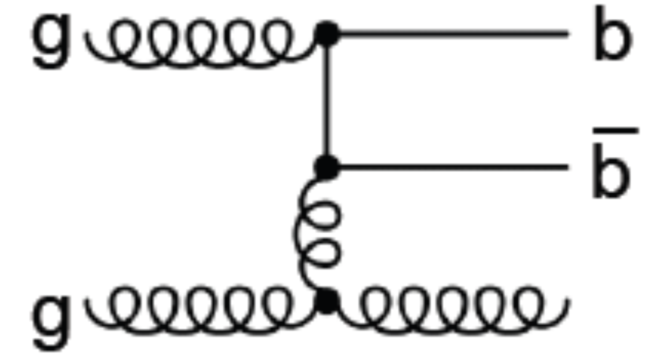
Heavy flavor production

- heavy flavor production at LHC provides testing ground of QCD (calculations) at the energy frontier
  - NLO contributions are large
  - large theoretical uncertainties due to factorization scale and renormalization scale
- heavy flavor tagging is a crucial ingredient in many new physics searches
  - needed to understand the QCD background
  - requires a deep understanding of the detector performance
- several heavy flavor results from ATLAS
  - inclusive b-jet and $b\bar{b}$ dijet production cross section
  - J/ψ and ϒ production
  - exclusive B production

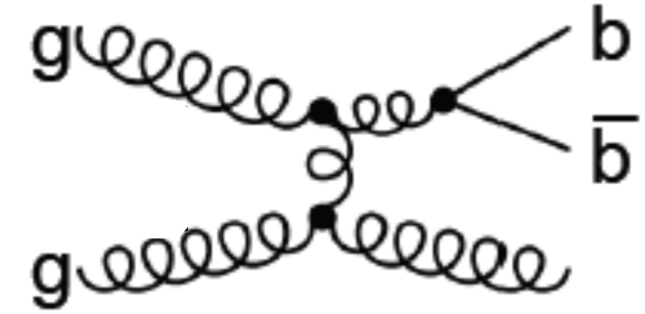
α_S^2



α_S^3



α_S^3



Phys Lett. B697 (2011) 294-312,
arXiv:1106.5325 [hep-ex]
A. Cerri (353)

The ATLAS detector

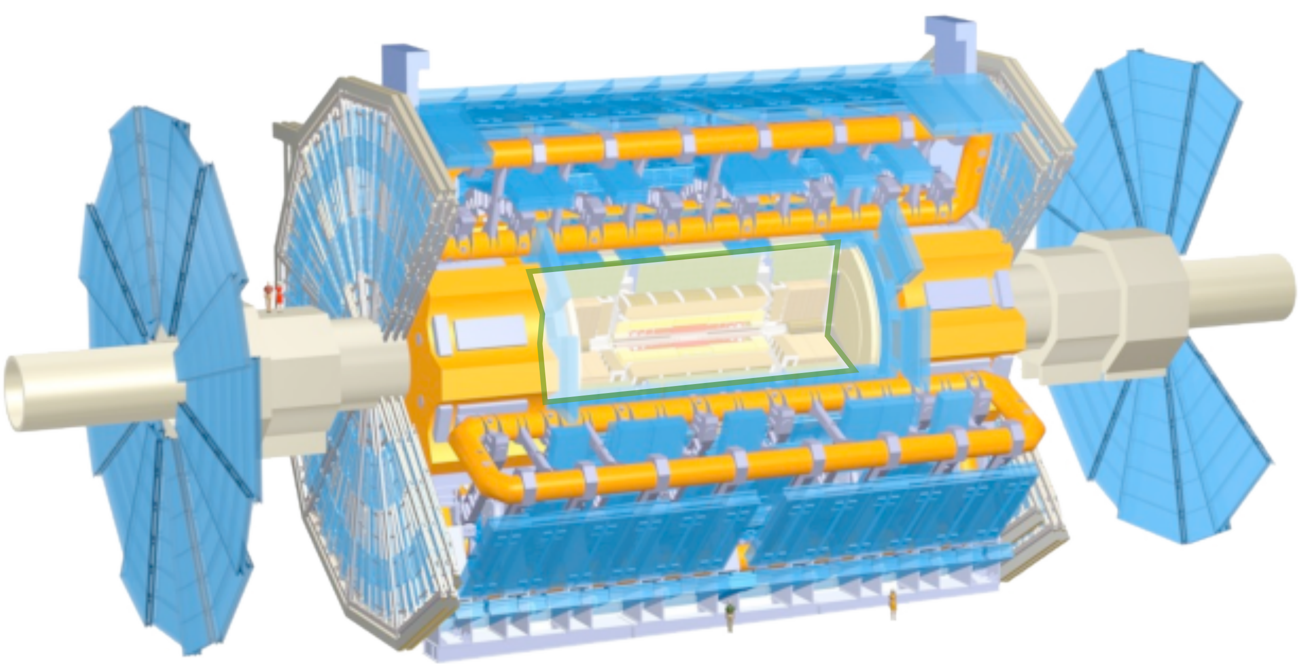
- precise innermost tracking detector

  pixels, strip and transition radiation straws

- hermetic calorimeter with excellent energy and rapidity resolution

  liquid argon EM calorimeter, iron tile HCAL

- stand-alone muon trigger & tracking system



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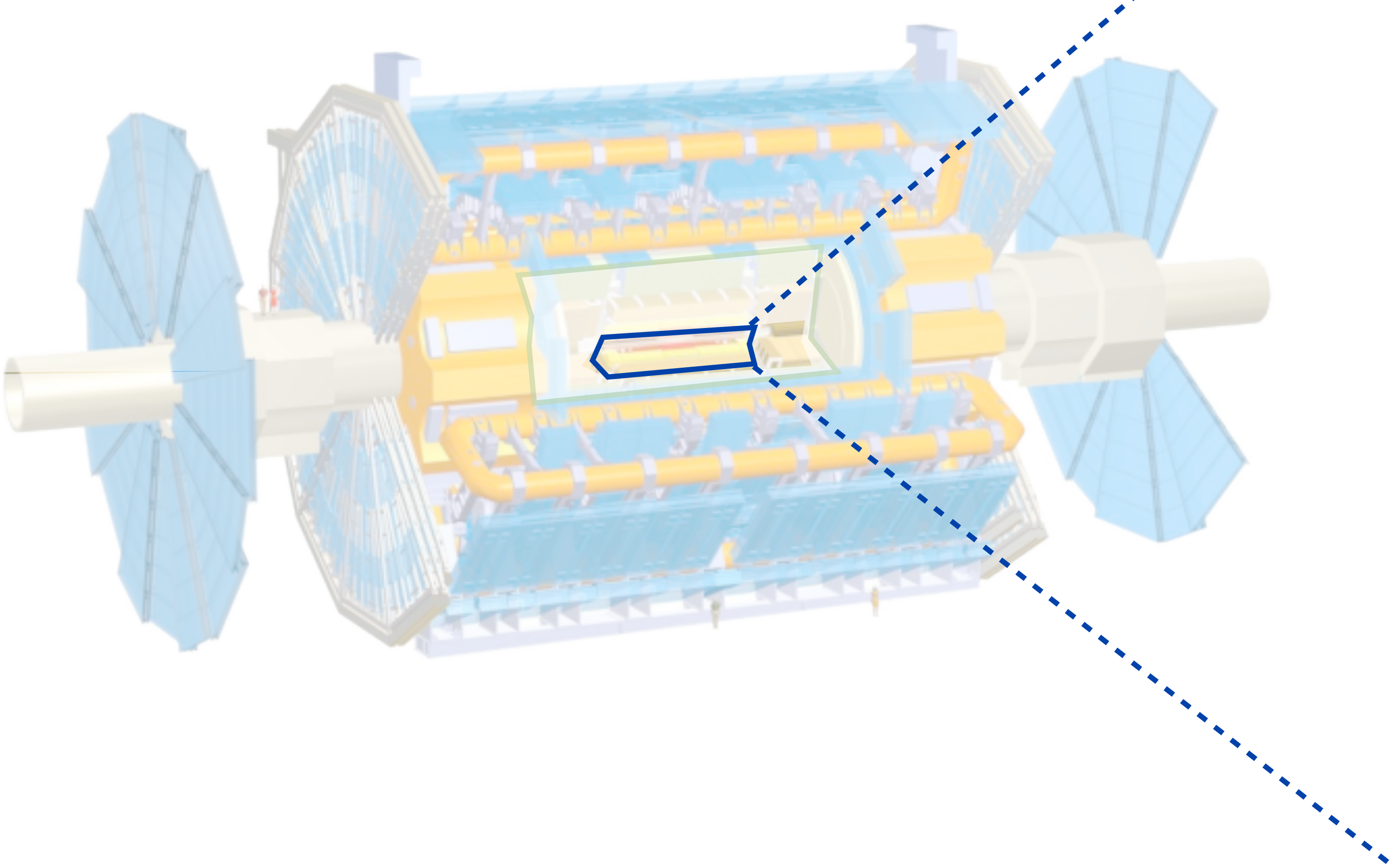
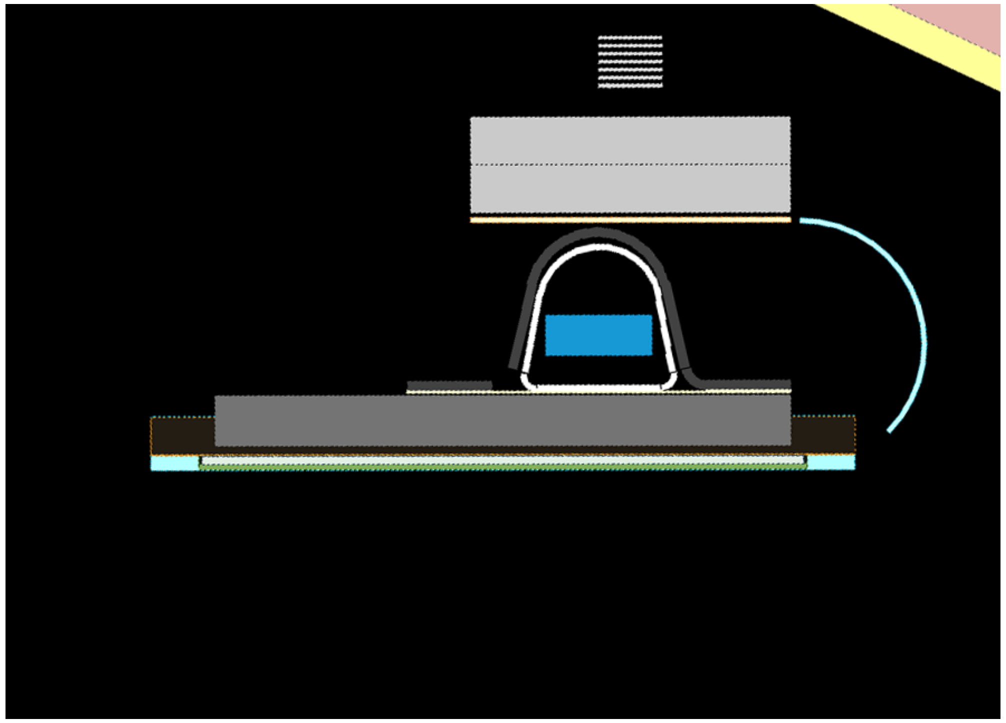
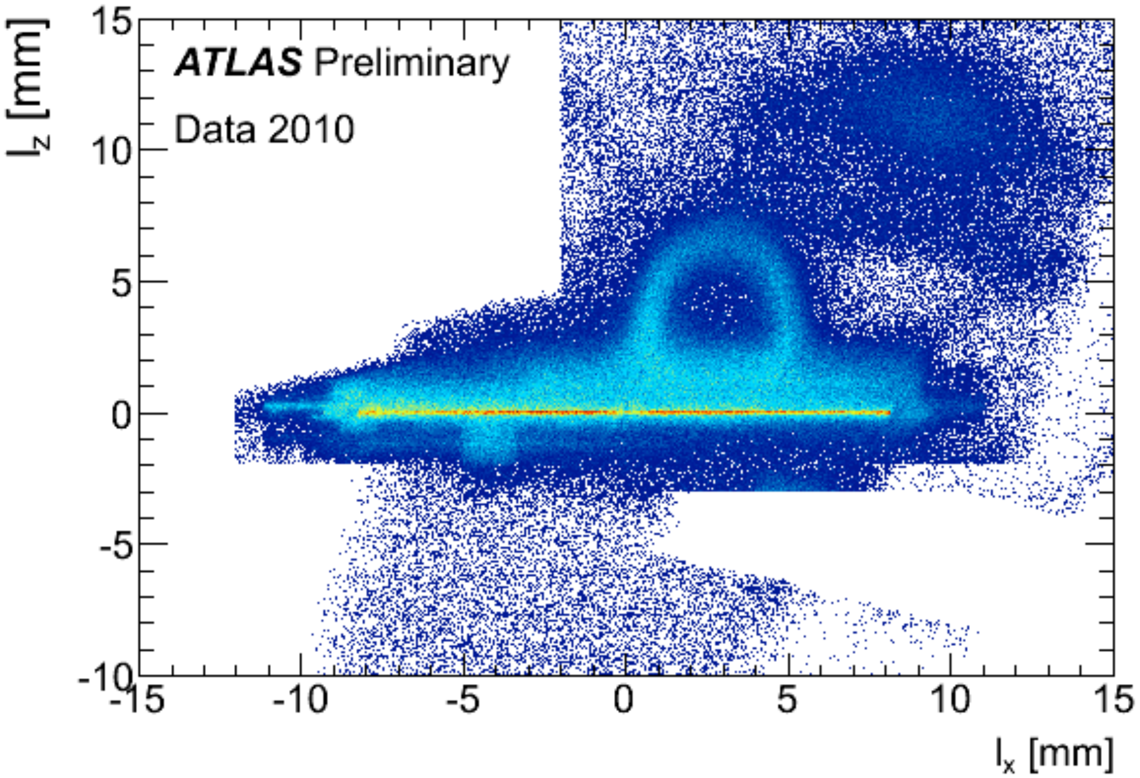


Secondary vertex reconstruction:

- pixel module as described in simulation



- tomography made with data using vertices from hadronic interactions



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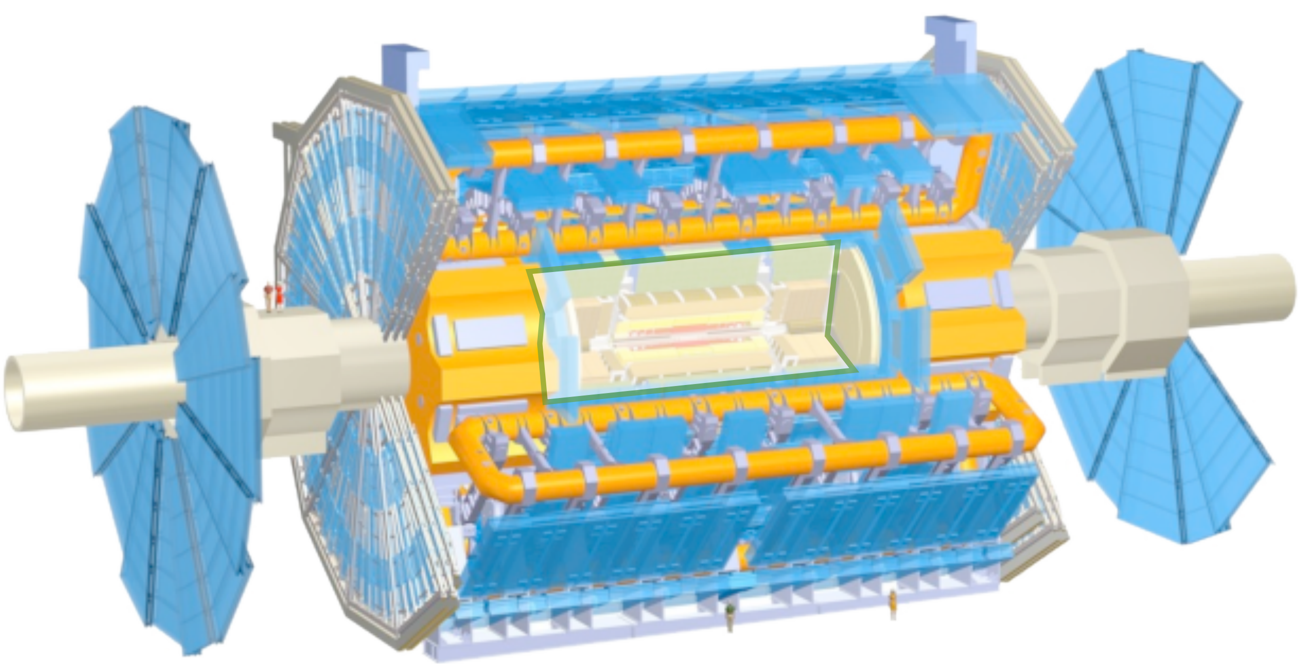

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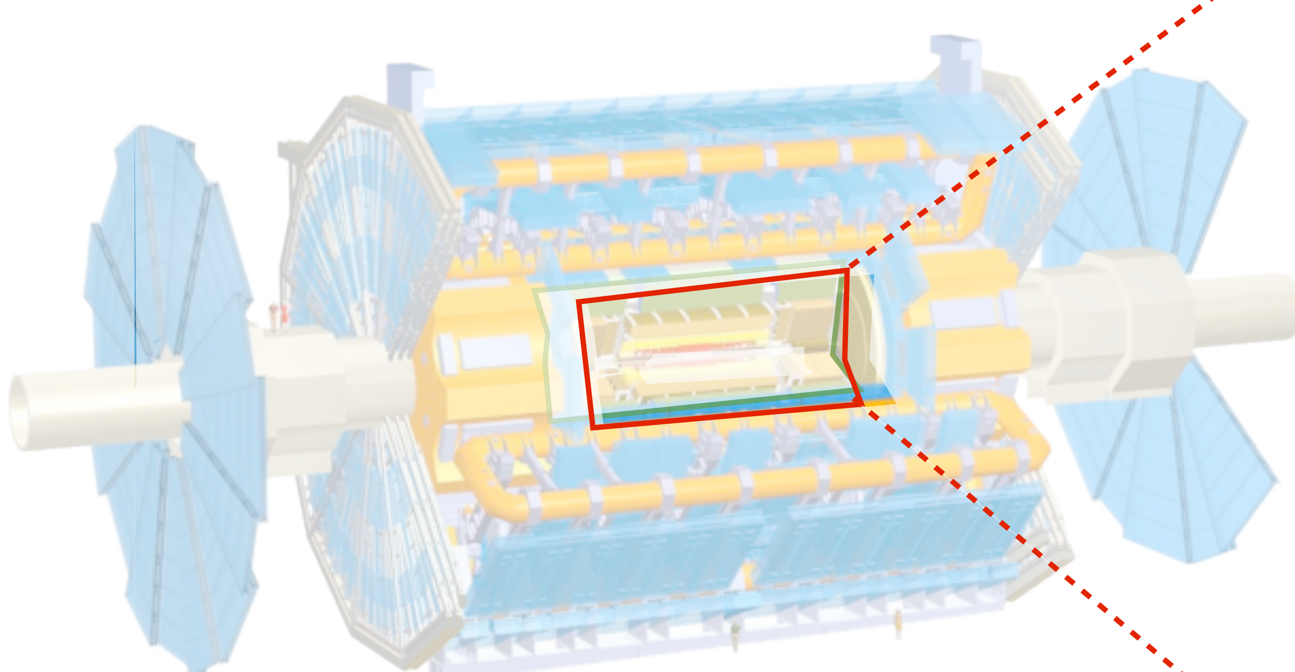
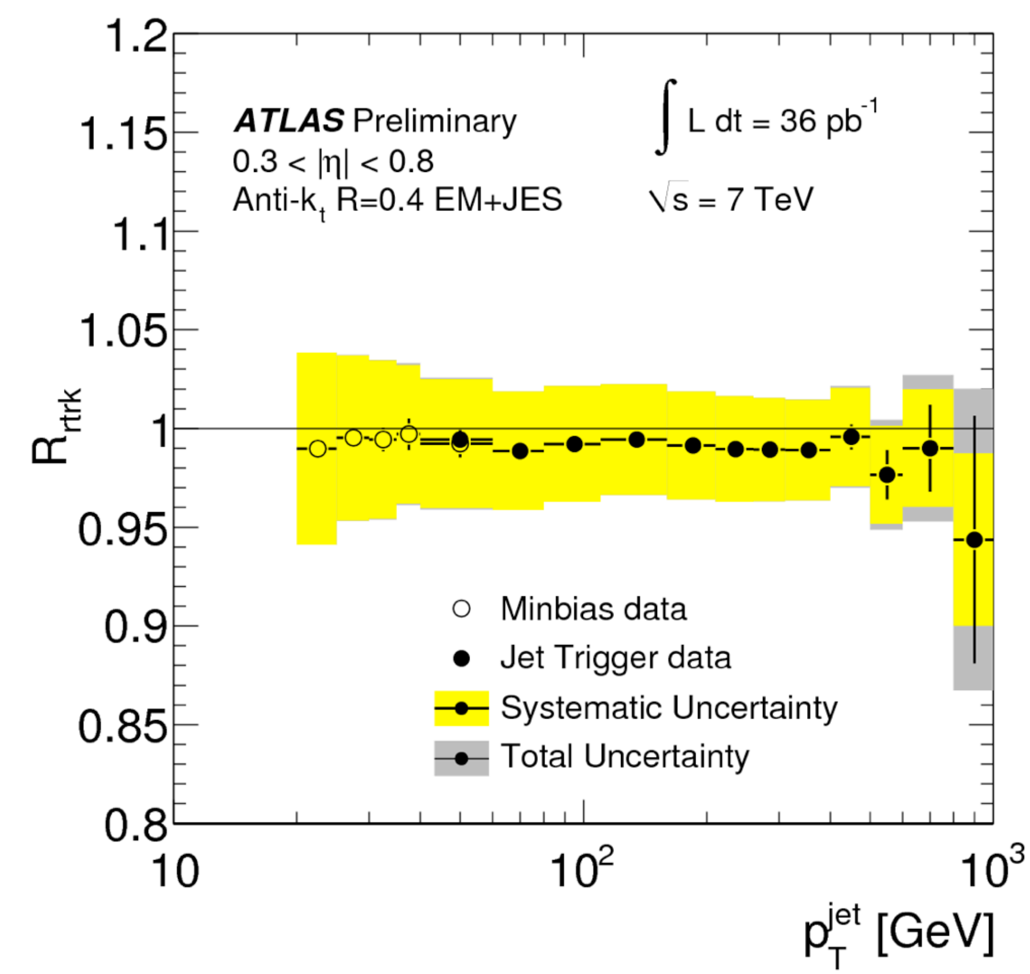


Jet energy scale:

- well described response by simulation

- 2010 (w/o significant pileup): uncertainty 2-3 %

$$r_{\rm trk} \equiv \frac{|\sum \vec{p}_T^{\,\rm track}|}{p_T^{\rm jet}} \qquad R_{r_{\rm trk}} \equiv \frac{\langle r_{\rm trk}{}^{\rm data}\rangle}{\langle r_{\rm trk}{}^{\rm MC}\rangle}$$



ATLAS-CONF-2011-067

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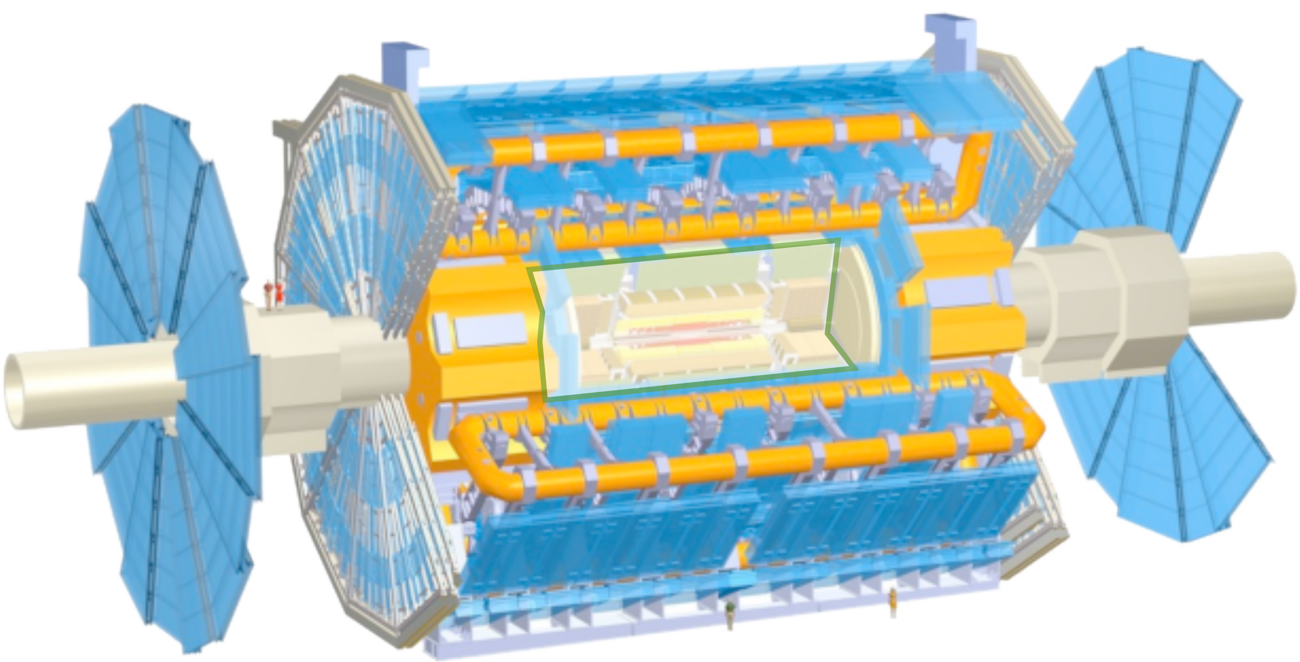

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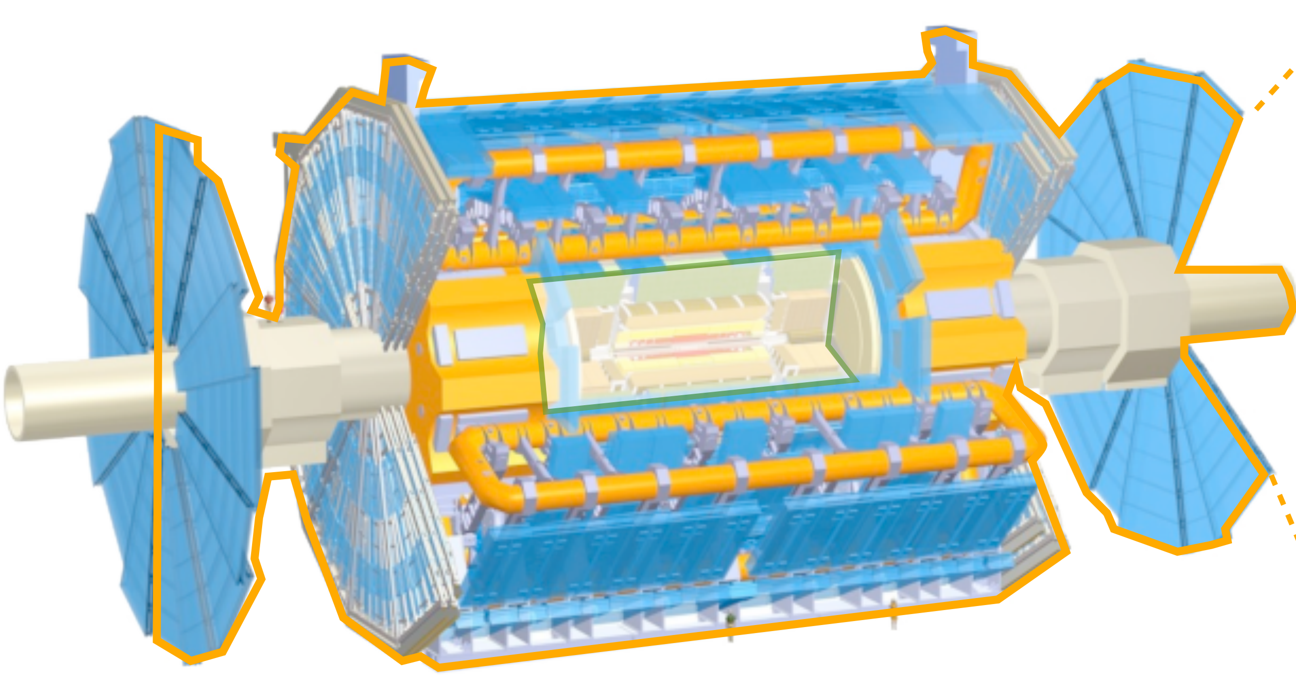
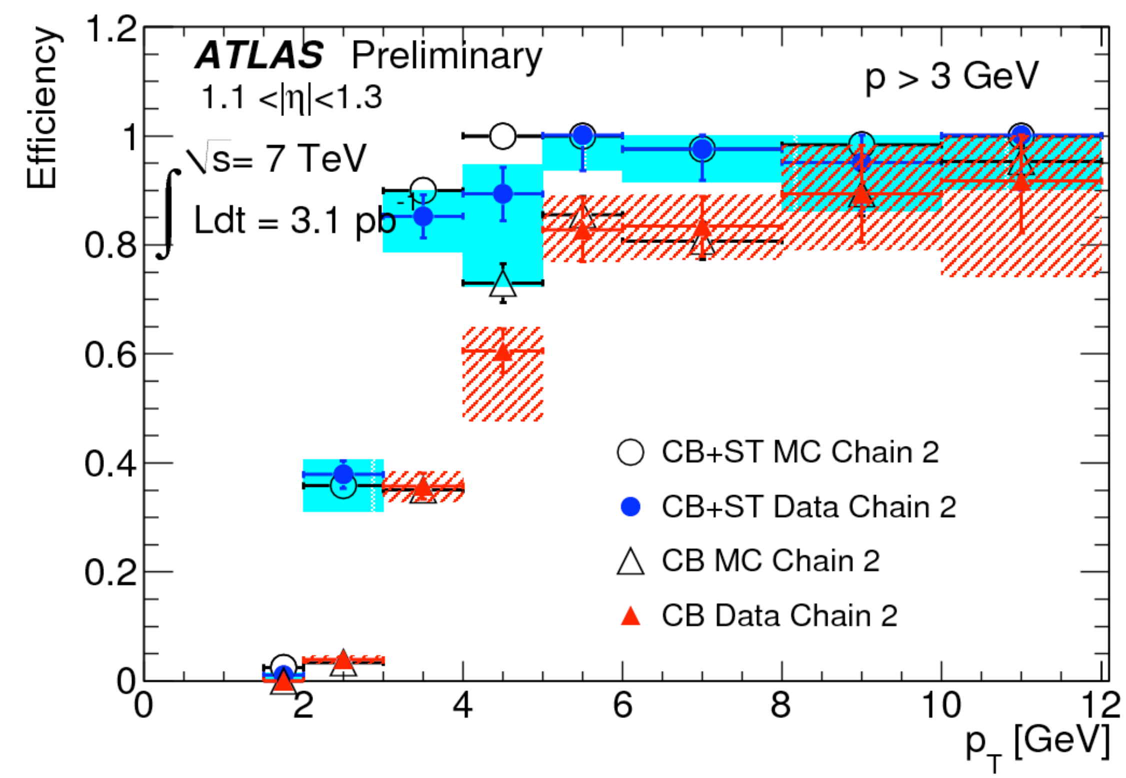


Muon reconstruction setup:

- high efficient stand-alone and combined muon reconstruction efficiency

- very well modeled by simulation

combined reconstruction efficiency
(Inner Detector and Muon System)



ATLAS-CONF-2011-021
ATLAS-CONF-2011-063

Inclusive b-jet cross sections: dataset and strategy (1)

ATLAS-CONF-2011-056

- data taken between March and August 2010
  - p-p collisions at $\sqrt{s}$ = 7 TeV
  - integrated luminosity: $\mathcal{L}$ **= 3.0 pb^{-1}**
  - trigger: level 1 jet trigger, MBTS trigger (extend to low jet p_T)

    trigger efficiency: $\varepsilon_{trig} \sim 98\ \%$

- measurements
  - inclusive cross section: $20\ GeV < p_T^{jet} < 260\ GeV,\ 0 < |\ y^{jet}\ | < 2.1$

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

  - dijet cross section: $m_{jj} < 670\ GeV\ for\ p_T^{jet} > 40\ GeV,\ 0 < |\ y^{jet}\ | < 2.1$

$$\frac{d\sigma_{b\bar{b}}}{dM} = \frac{1}{\Delta M} \frac{N_{b\bar{b}} \cdot frac_b}{\varepsilon_{trig} \cdot \varepsilon_{sel} \cdot \varepsilon_{btag_2} \cdot \mathcal{L}} \times C$$

Inclusive b-jet cross sections: dataset and strategy (1)

ATLAS-CONF-2011-056

- data taken between March and August 2010
  - p-p collisions at $\sqrt{s}$ = 7 TeV
  - integrated luminosity: $\mathcal{L}$ = 3.0 pb^{-1} — systematic uncertainty: ± 0.1 pb^{-1} (*ATLAS-CONF-2011-011*)
  - trigger: level 1 jet trigger, MBTS trigger (extend to low jet p_T)

    trigger efficiency: $\varepsilon_{trig} \sim 98\,\%$ — systematic uncertainty negligible
- measurements
  - inclusive cross section: $20\ GeV < p_T^{jet} < 260\ GeV,\ 0 < |y^{jet}| < 2.1$

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

selection and reconstruction efficiency

unfolding corrections (resolution effects)

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- measurements
  - inclusive cross section: $20\ GeV < p_T^{jet} < 260\ GeV,\ 0 < |y^{jet}| < 2.1$

will be covered in detail in the following

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

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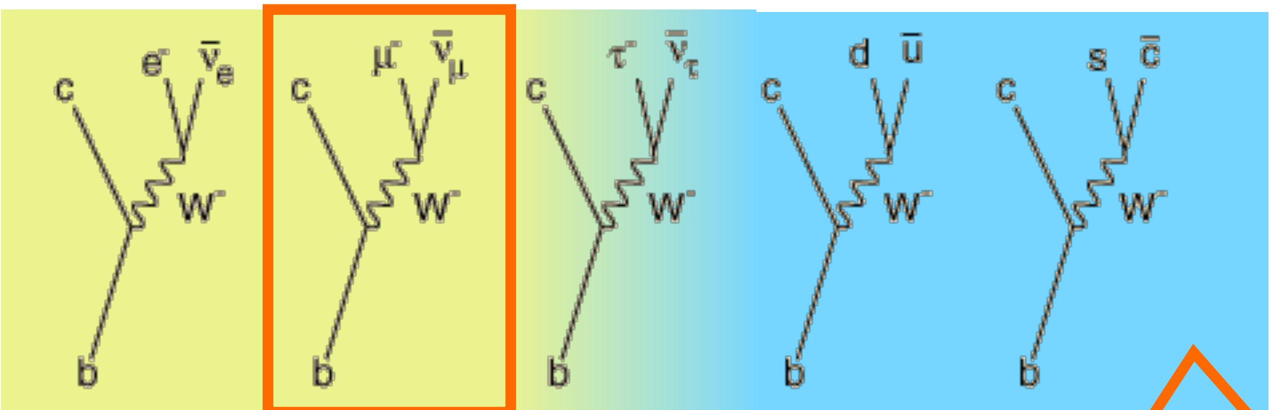
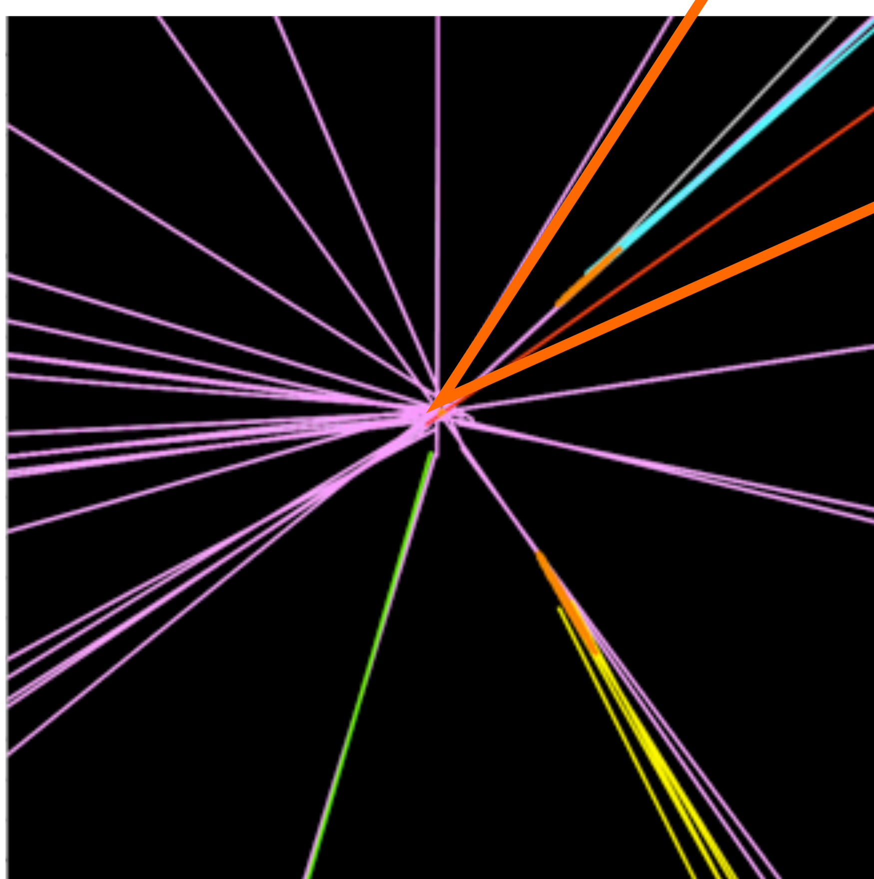
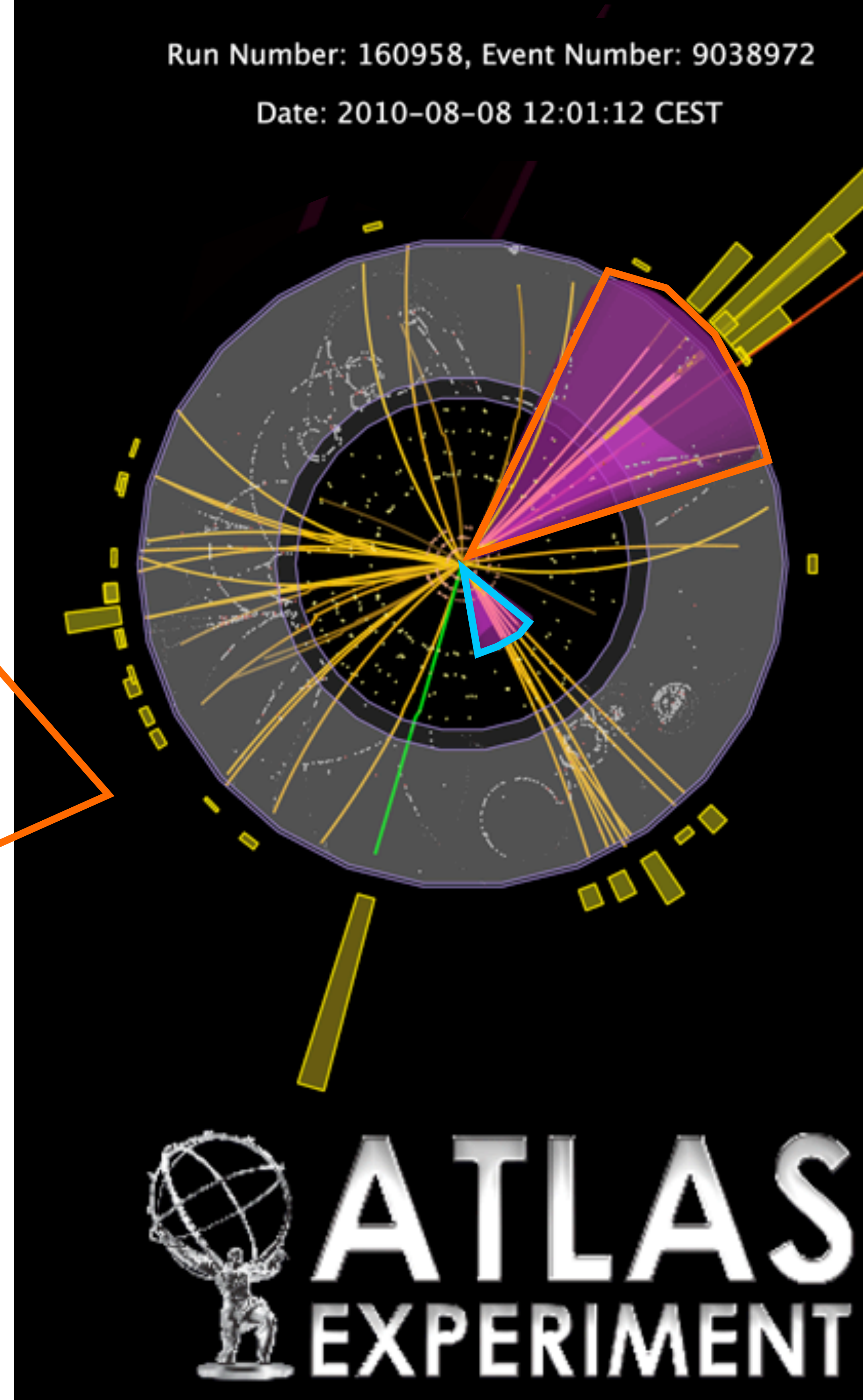
b-jet topology

- exploit long lifetime of the B-hadrons
  - displaced decay vertex



used for calibration





Event display of a top pair e-mu dilepton candidate with two b-tagged jets.

b-tagging with secondary vertexing (SV0)

ATLAS-CONF-2010-099, ATLAS-CONF-2011-089

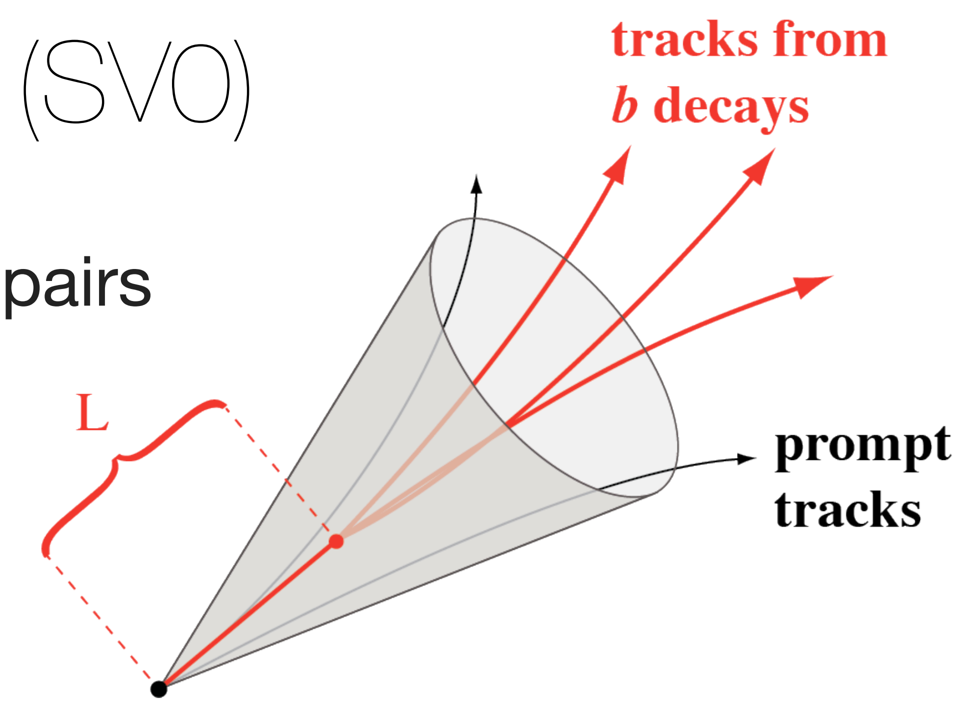
- iterative secondary vertexing seeding from track pairs

  vertex mass < 6 GeV, largest χ^2/n.d.o.f. per track < 7

  exclusion of vertices on pixel layers (material)

- separation power: decay length significance

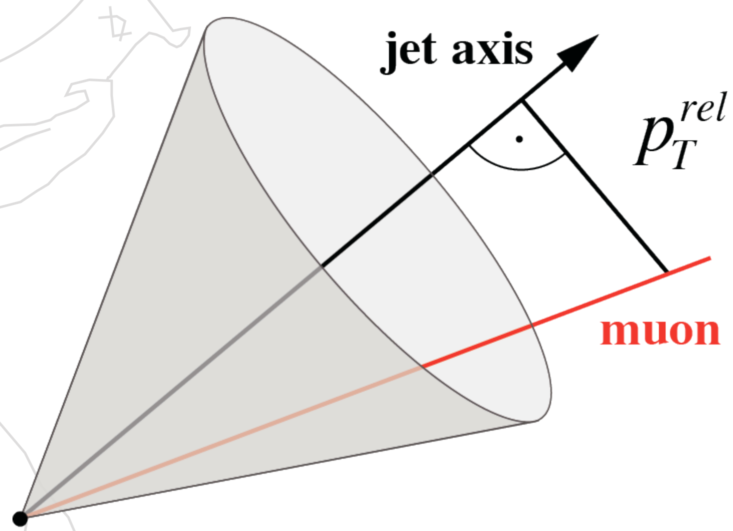
  ***b-tag** if $L/\sigma_L > 5.72$ (≈50 % efficiency on MC $t\bar{t}$)*

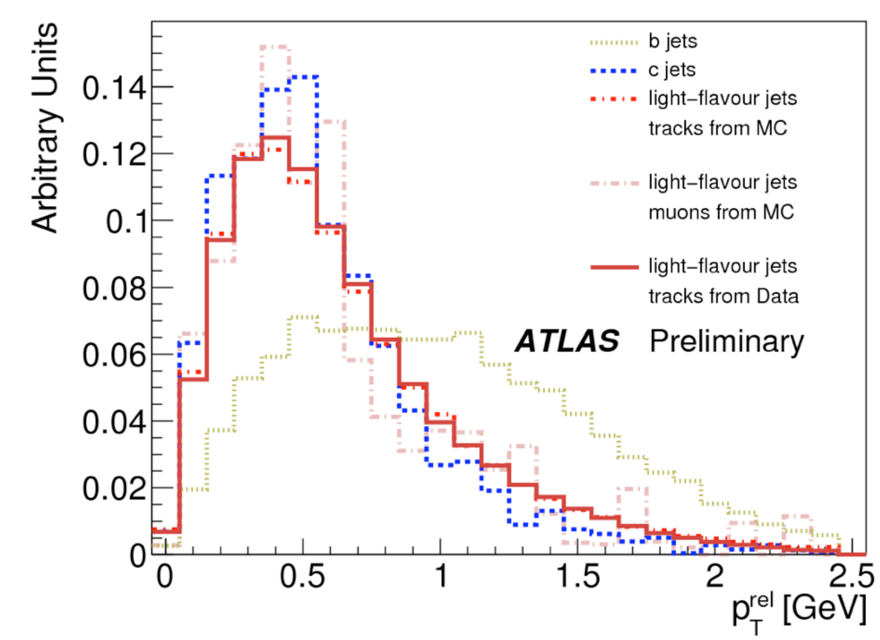


- calibration (**ε_{btag}**, **mistag rate**) using p_T^{rel} method & secondary vertex mass
  - data: μ-enriched sample, MC: μ-filtered sample for templates to p_T^{rel}

$$\kappa_{\varepsilon_b}^{data/sim} = \frac{\varepsilon_b^{data}}{\varepsilon_b^{sim}}$$

relative transverse μ momentum



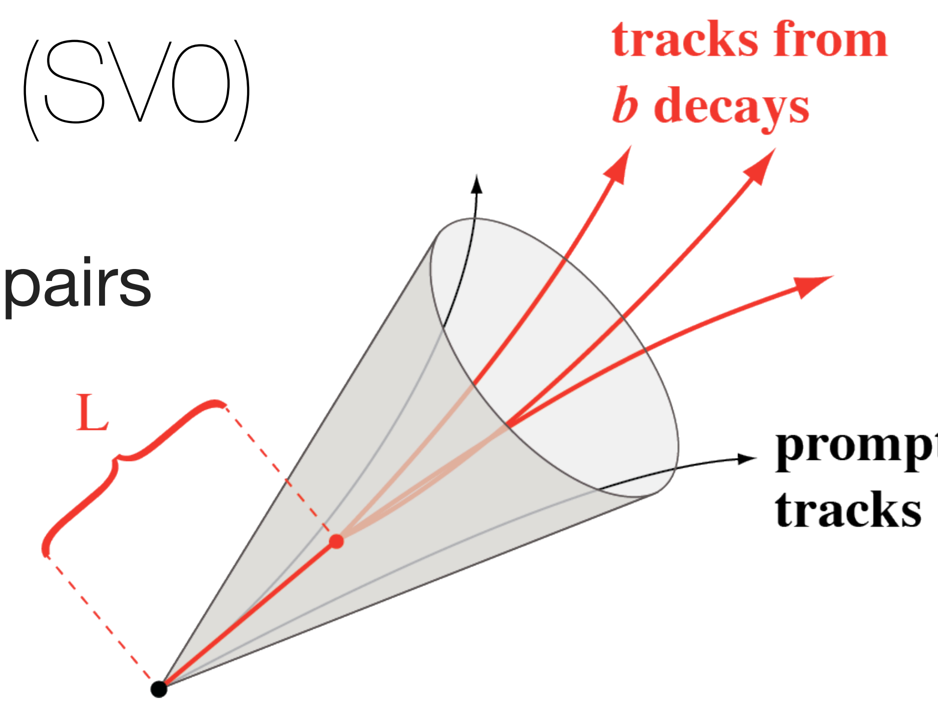


$$\kappa_{\varepsilon_l}^{data/sim} = \frac{\varepsilon_l^{data}}{\varepsilon_l^{sim}}$$

template fits to **secondary vertex invariant mass** (combined with negative tags)

b-tagging with secondary vertexing (SV0)

ATLAS-CONF-2010-099, ATLAS-CONF-2011-089



- iterative secondary vertexing seeding from track pairs
  - *vertex mass < 6 GeV, largest χ^2/n.d.o.f. per track < 7*
  - *exclusion of vertices on pixel layers (material)*
- separation power: decay length significance
  - ***b-tag** if $L/\sigma_L > 5.72$ (≈50 % efficiency on MC tt̄)*
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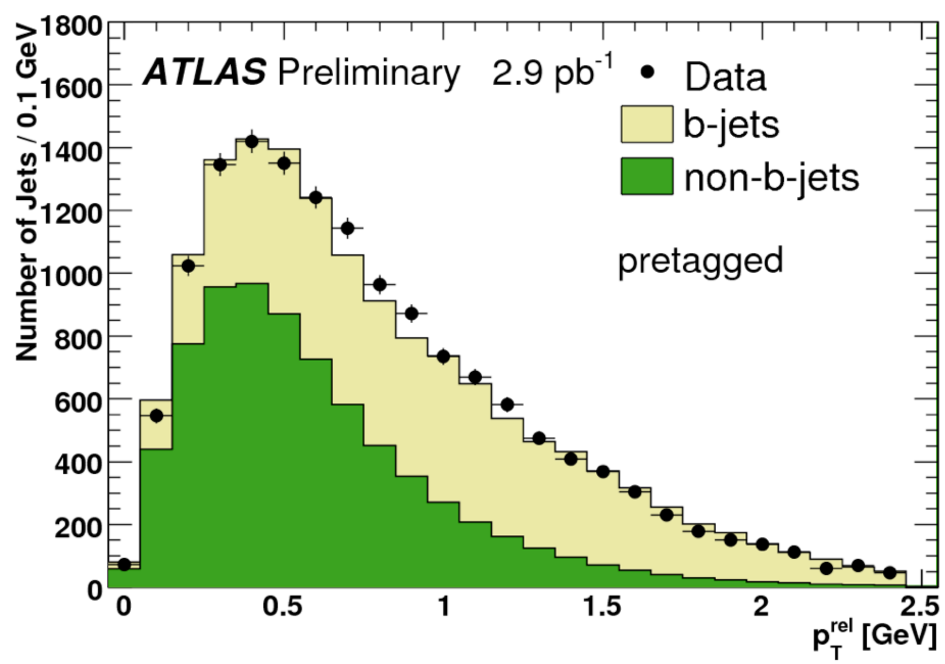
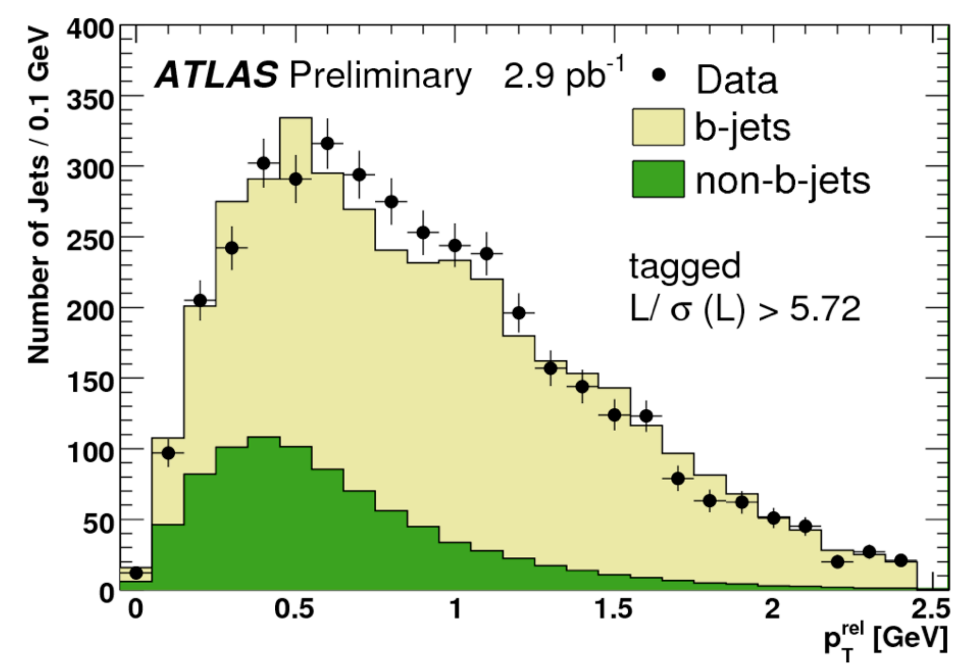


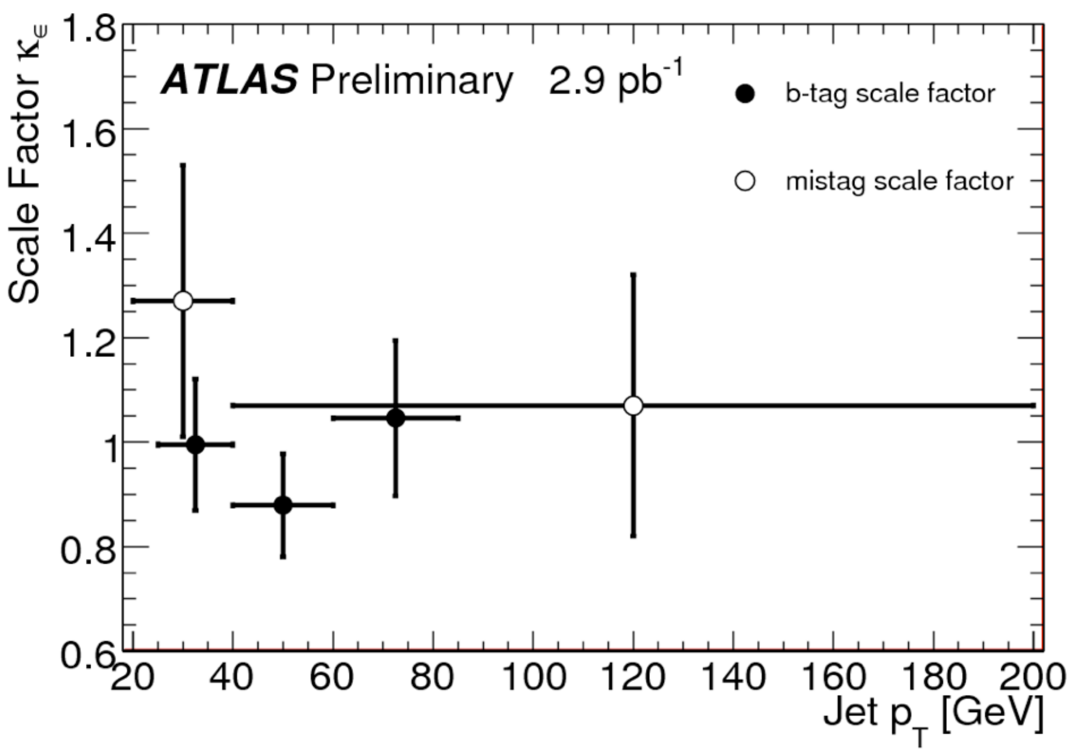


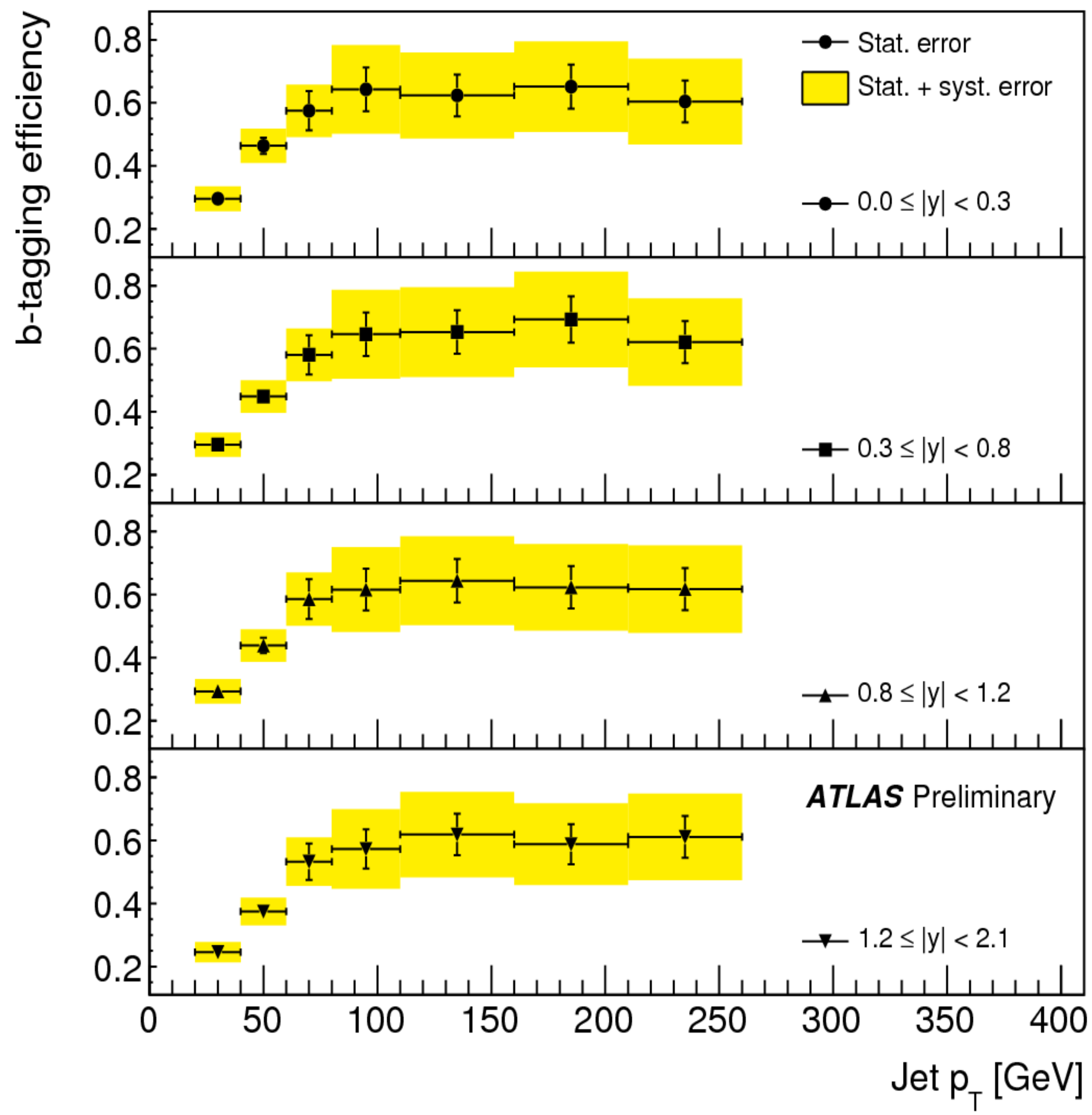
$$\kappa_{\varepsilon_l}^{data/sim} = \frac{\varepsilon_l^{data}}{\varepsilon_l^{sim}}$$

template fits to **secondary vertex invariant mass**
(combined with negative tags)

b-tagging efficiency & data/MC scale factor

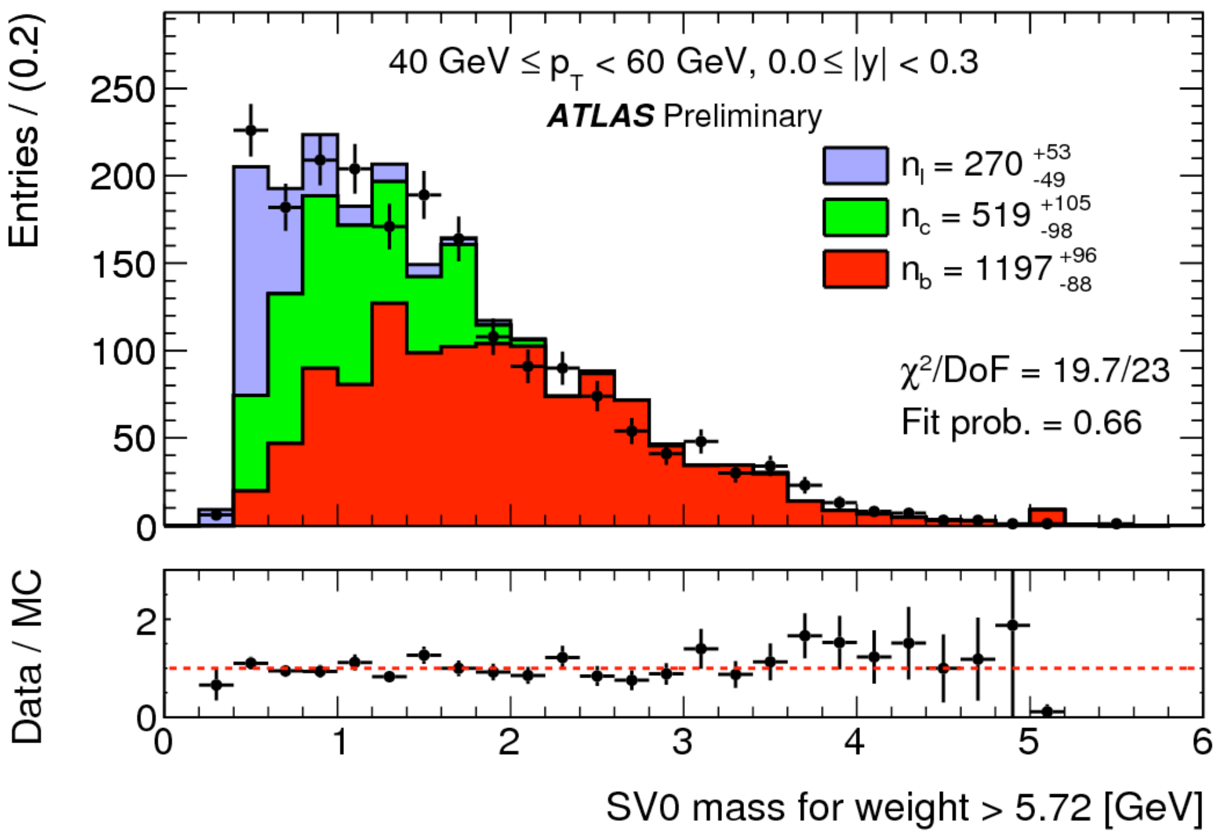
- scale factors for b-tag efficiency and mistag rate
  - p_T^{rel} method is used up to p_T > 80 GeV, then collimation becomes dominant
  - above p_T > 80 GeV: value of highest p_T bin taken with double syst. uncertainty for jet
  - obtained as $\boldsymbol{\varepsilon_{b\text{-}tag}(p_T,y)}$, $\boldsymbol{\varepsilon_{bb\text{-}tag}(M,y)}$
  - mistag rate between 0.2 and 1%

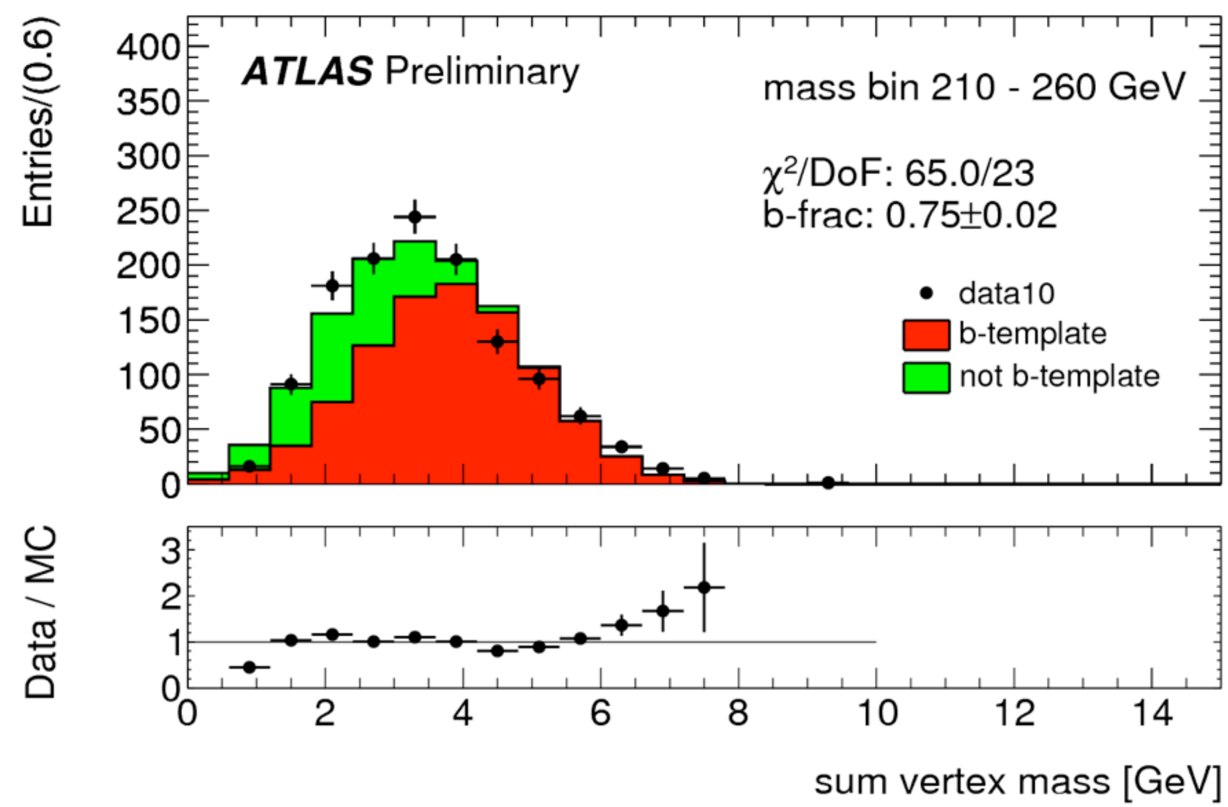




Extraction of N_b and $N_{b\bar{b}}$

- light, charm and b-quark templates for SV0 mass/sum vertex mass obtained from MC QCD samples





- main sources of syst. uncertainties
  - b-tagging efficiencies, mistag rate
  - jet energy scale, b-jet energy correction

- unfolding to compare to “truth b-jets”
  - a jet is labelled as a b-jet if a b-quark is found within an η-φ cone of R = 0.3 of the truth jet direction
  - bin-by-bin unfolding correction applied

Inclusive b-jet cross sections: dataset and strategy (2)

ATLAS-CONF-2011-057

- 2010 data set & reconstruction setup
  - trigger: μ trigger with $p_T > 5$ GeV (matched to an offline μ with $p_T > 4$ GeV)
  - integrated luminosity (for prescaled trigger): $\mathcal{L}$ **= 4.8 pb^{-1}**
  - jet reconstruction : anti-k_t with R = 0.4,
    jet p_T corrected for ν and μ using a MC correction function
  - μ-jet association if μ and jet are within a η-φ cone of R = 0.4

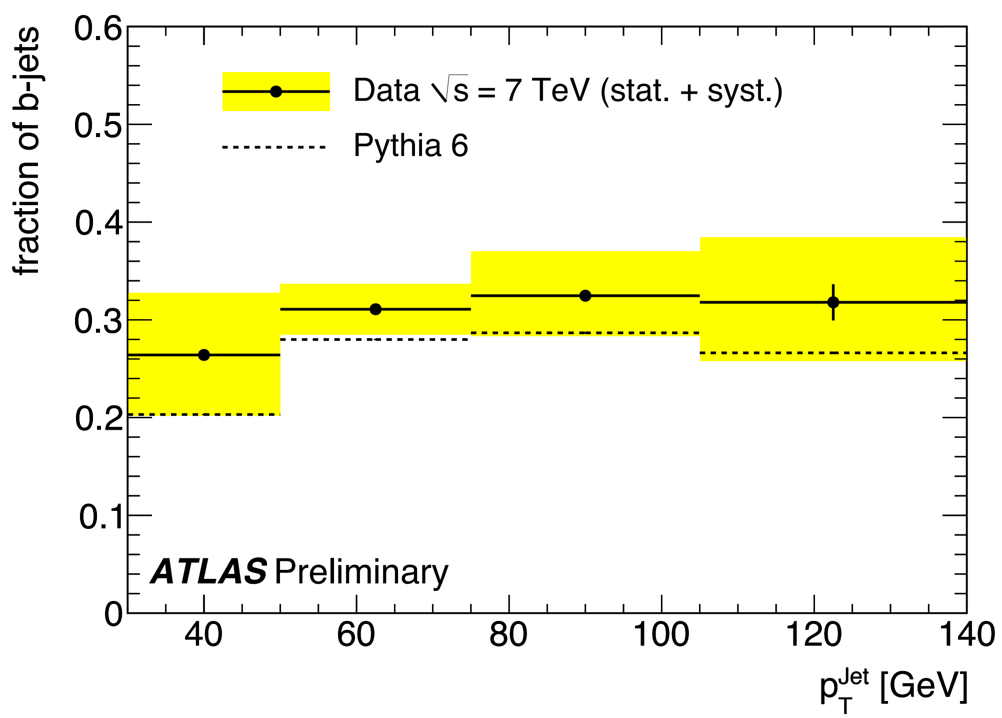
- measurement
  - inclusive cross section: $25\ GeV < p_T^{b\text{-}jet} < 180\ GeV,\ 0 < |y^{jet}| < 2.1$

template fit using p_T^{rel} templates from MC (binned maximum likelihood

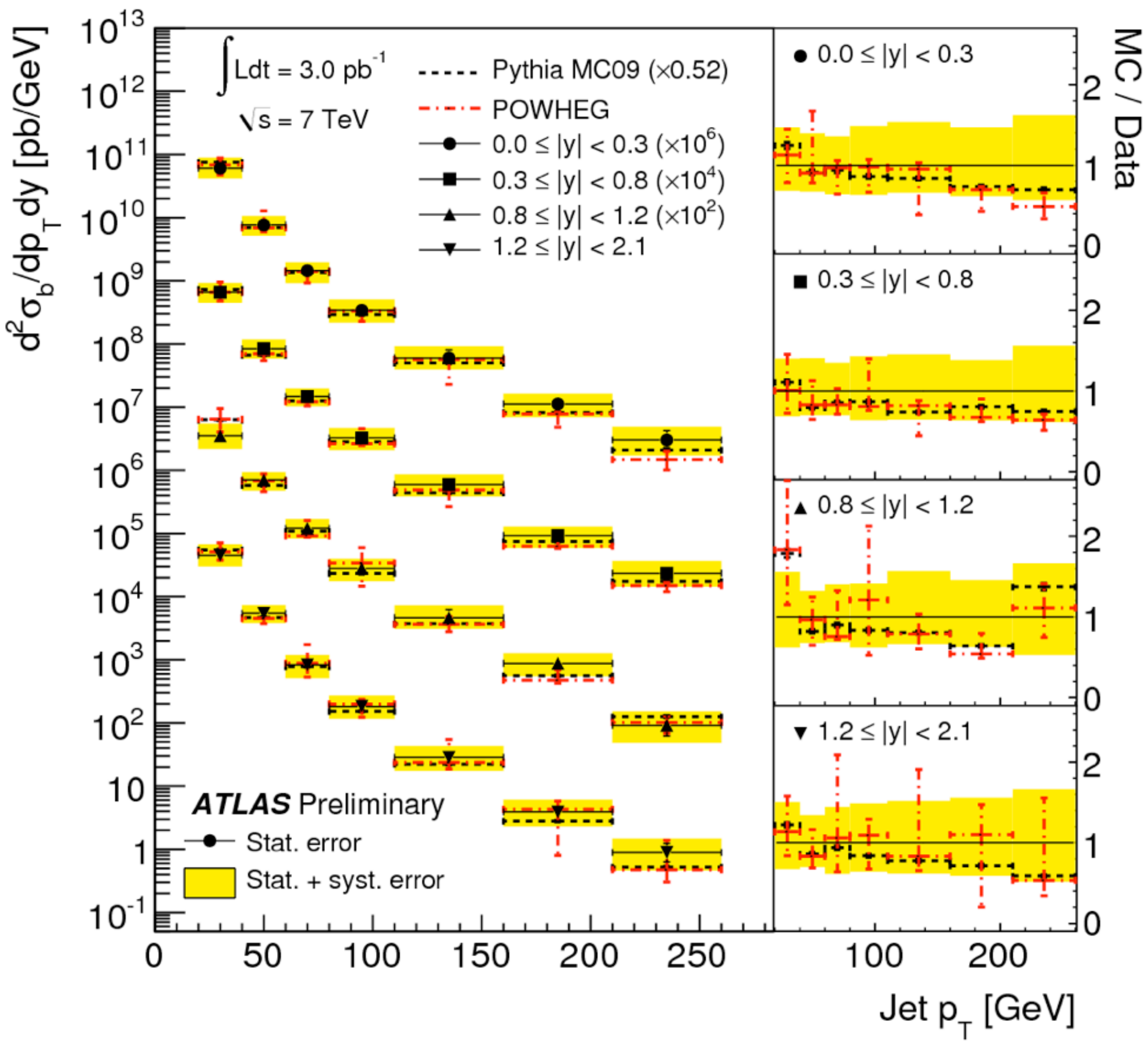
$$\frac{d\sigma}{dp_T^{b-jet}} = \frac{F_b N^{Jets}}{B \mathcal{L}_{int} \epsilon^{\mu J}} \frac{1}{\Delta p_T^{b-jet}}$$

branching ratio of inclusive decay b⟶μX

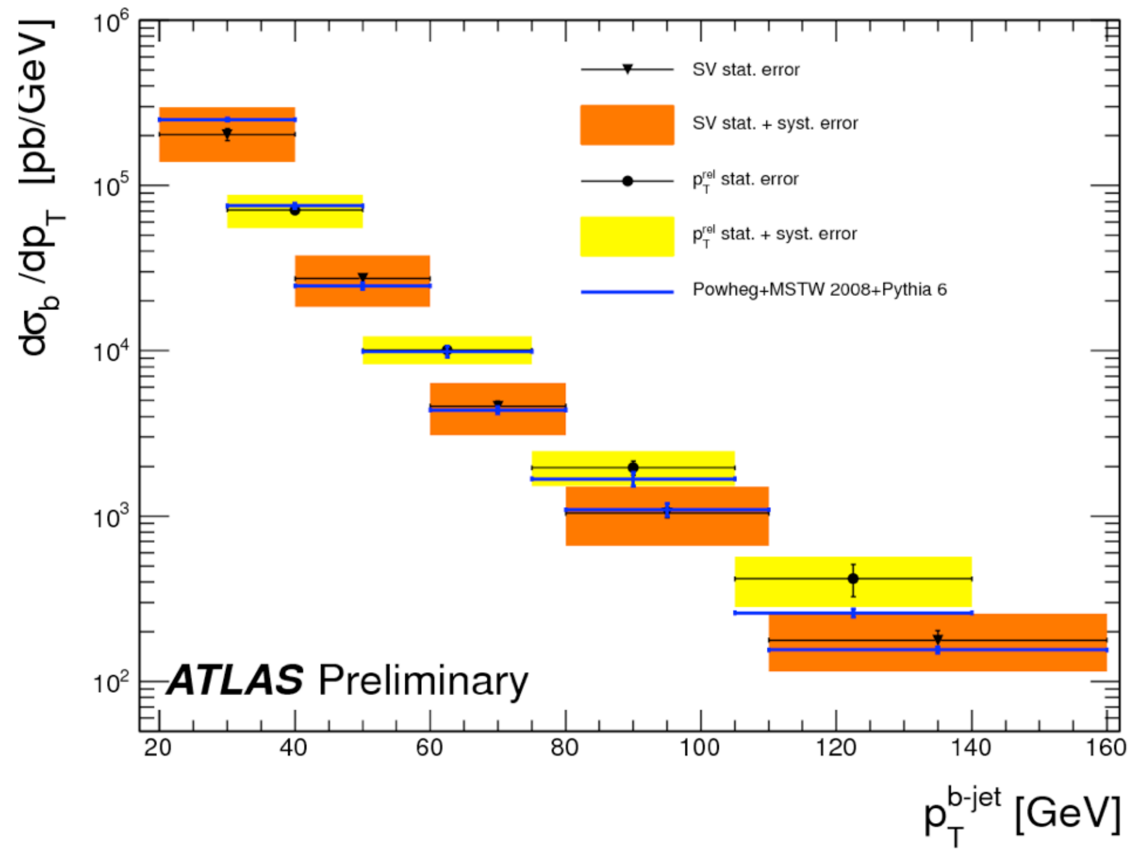
efficiency to detect and select a jet with associated μ



Inclusive b-jet cross section



- ▸ POWHEG (NLO):
  - broad agreement, steeper drop
- ▸ PYTHIA (LO):
  - not expected to get normalization correct, scaled by 0.52*, but shape well described

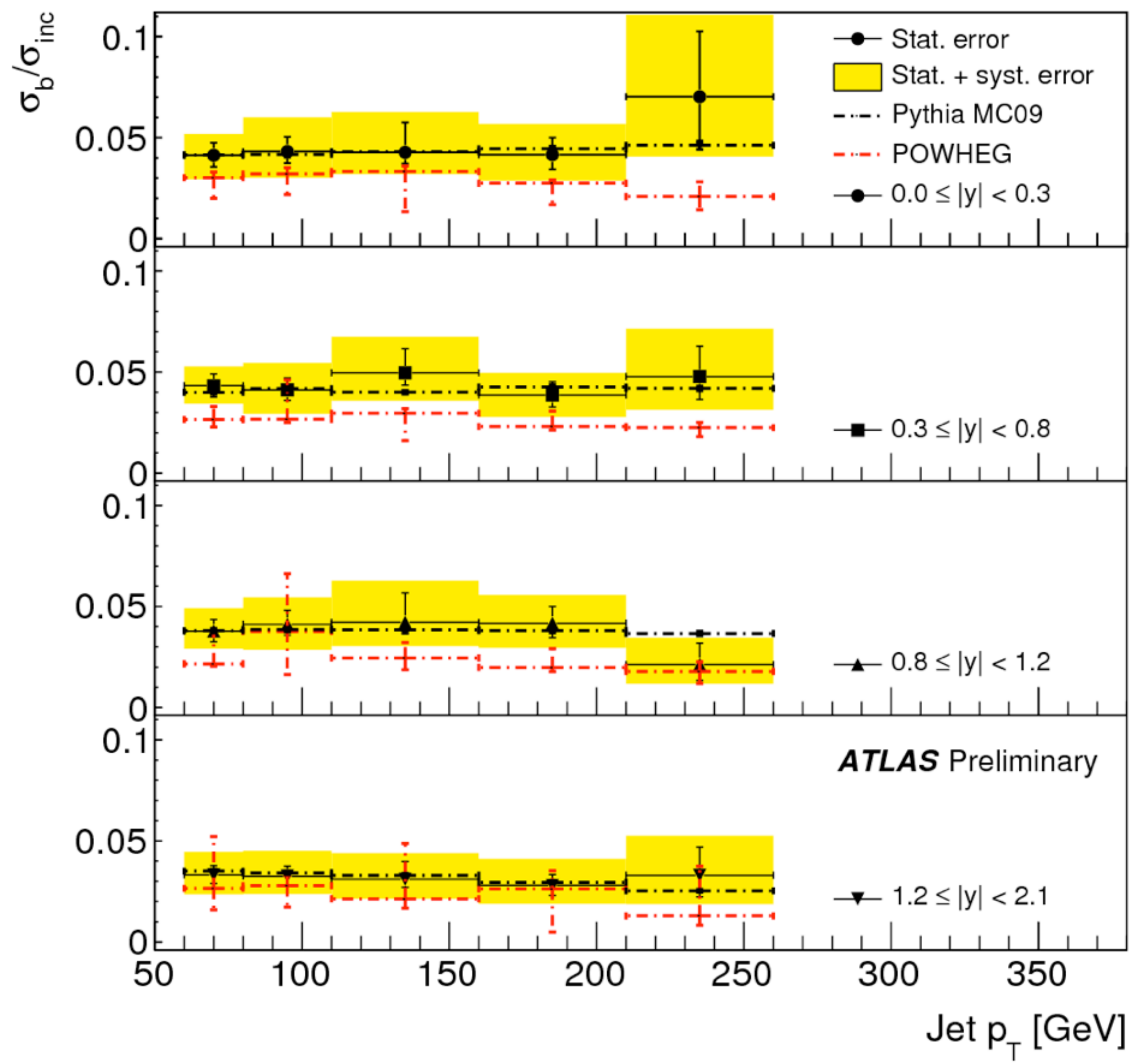


*0.52 is calculated by normalizing the PYTHIA prediction to the measured integrated cross section

p_T^{rel} and SV0 method agree well !

b-jet to inclusive jet production: ratio measurement

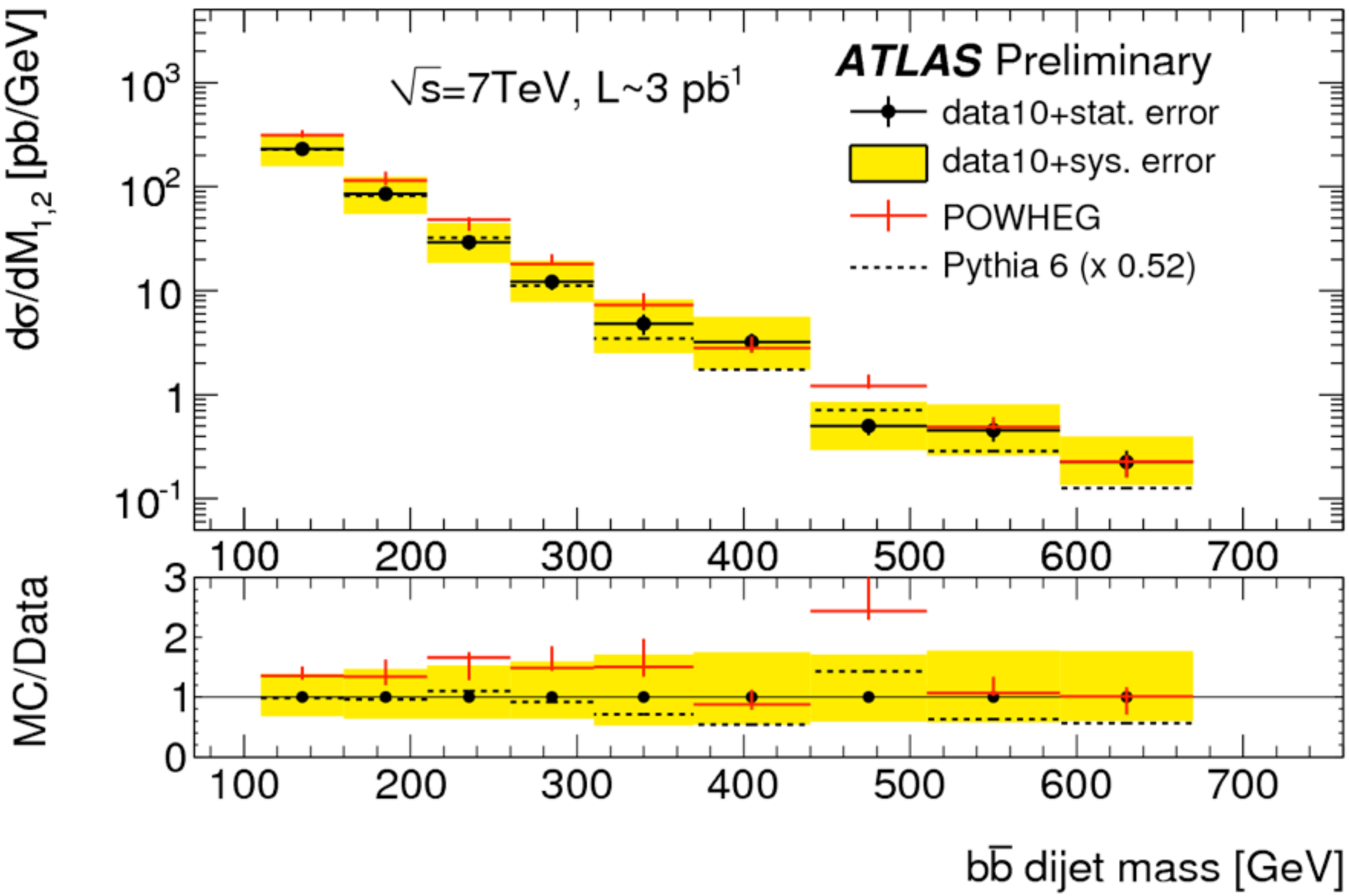
- many systematic uncertainties cancel in the ratio
  - luminosity uncertainty cancels
  - largely independent of jet energy scale
  - dominated by uncertainty on b-tagging efficiency



- Inclusive jet cross section measurement from ATLAS [Eur. Phys. J. C 71 (2011) 1512]

- POWHEG underestimates the b-jet fraction by 30 % (≈1σ effect)

Inclusive bb dijet cross section



- POWHEG (NLO):
  - predicts systematically higher cross-section
- PYTHIA (LO):
  - renormalized by 0.52
  - shape reasonably well described

Conclusions

- presented inclusive b-jet cross section as a function of transverse momentum and rapidity (with two methods that yield consistent results)
  - secondary vertex based, semi-leptonic b-decays via μ associated to jet
- inclusive $b\bar{b}$ dijet cross section measurement as a function of the dijet mass
- measurements are dominated by systematic uncertainties
  - jet energy scale and b-tagging efficiency
- measurement compared with POWHEG (NLO) and PYTHIA (LO) predictions
  - POWHEG, PYTHIA describe shape dependence on y, p_T rather well
  - POWHEG shows an underestimation of the b-jet to inclusive jet fraction by about 30% ($\approx 1\sigma$ effect)

Backup Section

Subdetector	Number of Channels	Operational Fraction
Pixels	80 M	96.9%
SCT Silicon Strips	6.3 M	99.1%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.5%
Tile calorimeter	9800	97.9%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.8%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.4%

Simulation & Reconstruction setup

- Track and vertex reconstruction in Inner Detector (ID)
  - *track reconstruction with $p_T > 400$ MeV and 6 silicon cluster requirements*
  - *multi-adaptive primary vertex finding (requiring at least 10 tracks in the PV)*
  - *iterative secondary vertex reconstruction*

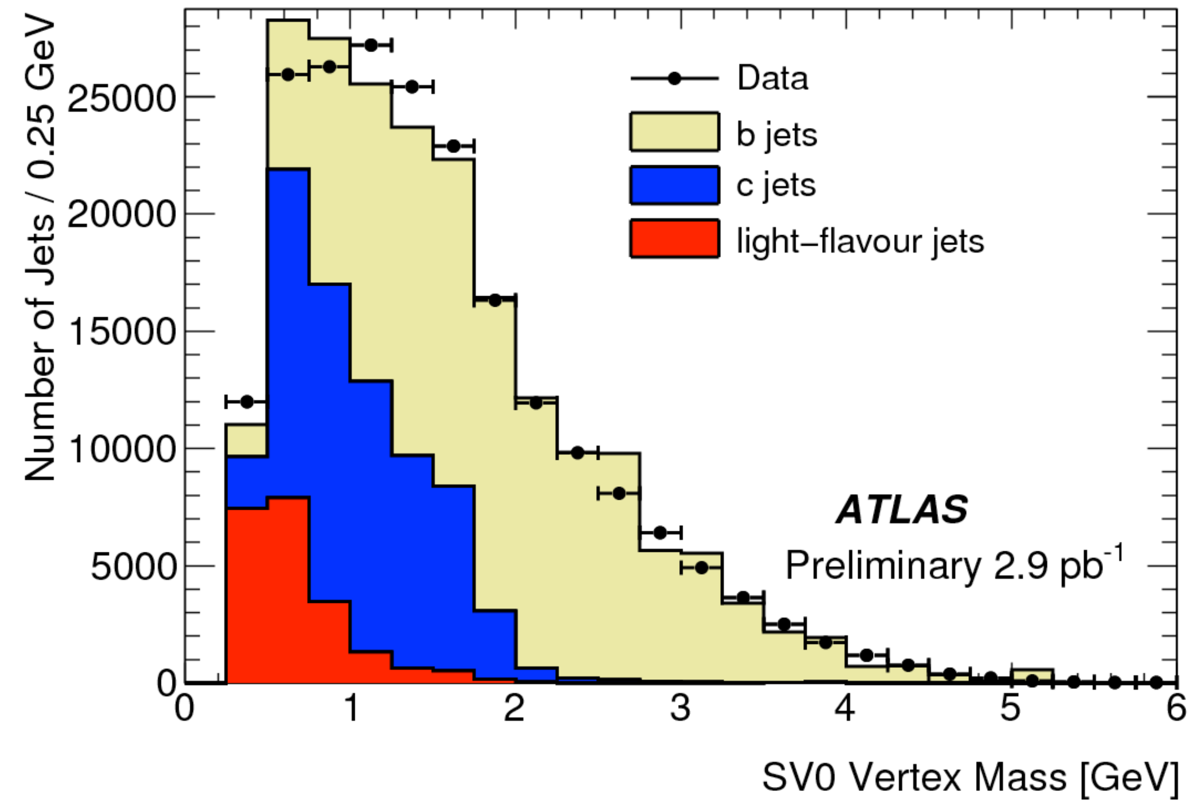
- Jet reconstruction
  - *jets reconstructed from topological clusters on EM scale*
  - *anti-k_t algorithm, with $R = 0.4$*

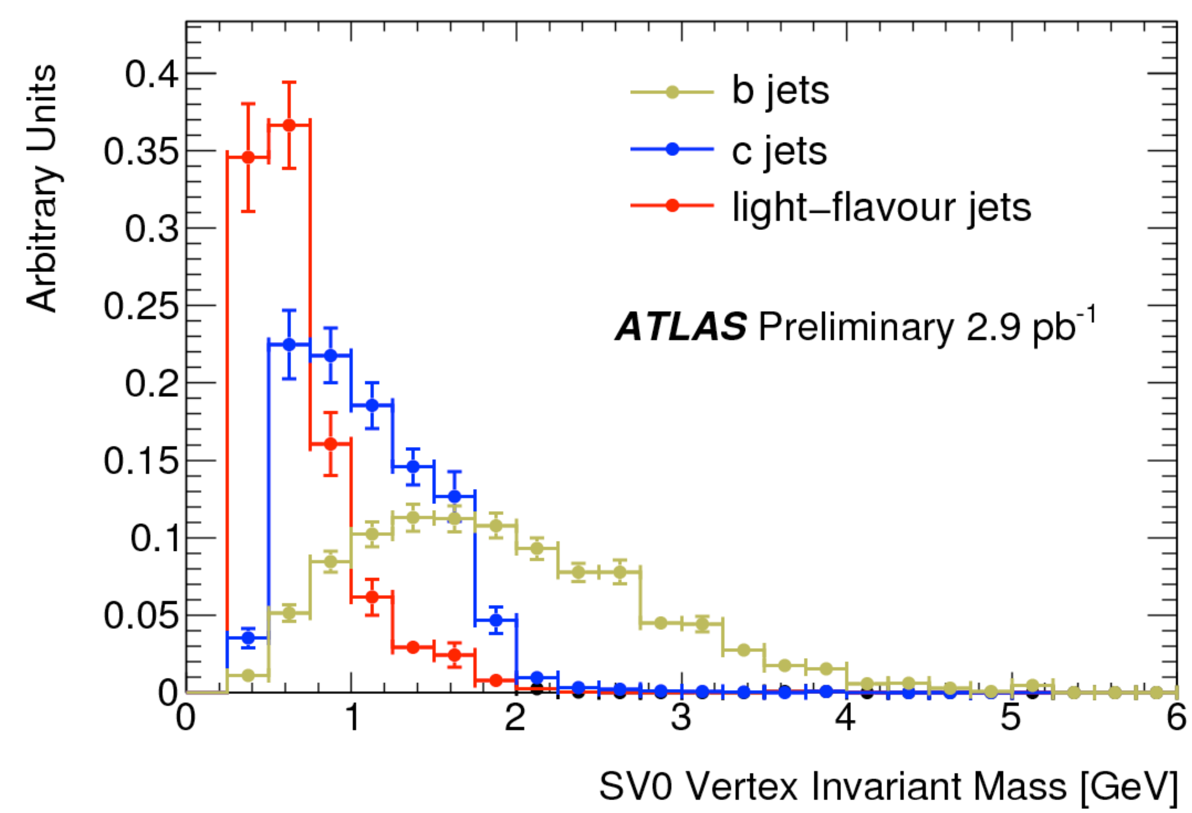
- Muon reconstruction (for b-tagging calibration)
  - *combined muon reconstruction starting from stand-alone muon tracks*
  - *combination of muon track and ID track parameters*

Geant 4

- Simulation
  - *simulated data from event generator output processed by Geant4 detector simulation*
  - *reconstructed with identical setup as data (applying detector condition calibration)*

SV0 mass templates





b-tagging calibration: summary of systematics

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%

Source	Relative Uncertainty	
	$20 < p_T < 40$ GeV	$p_T > 40$ GeV
Track Impact Parameter Resolutions	12%	14%
Run Dependence, Trigger	16%	19%
Other	7%	4%
Total	21%	24%

Summary of (fractional) systematic errors: SV0 method