Jet Properties of hadronically decaying massive particles

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On behalf of the ATLAS collaboration

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Introduction

Jets are composite objects so information can be gained by looking at the internal structure

Jet shapes: differential/ integrated measures of energy flow calculated from the jet constituents

The shape of a jet is dependent on the partons that give rise to the jet in the final state:

- Distinguish **highly boosted massive particles** from the QCD background
  becomes increasingly important as the centre of mass energy increases
- Distinguish **quark- and gluon-like jets**
- Constrain **phenomenological models** for parton showering, hadronization and soft physics

Two analyses considered here:

- Differences between b- and light-quark jets in top pair events in terms of jet shapes
  Sensitive to different parton shower models **EPJC(2013) 73:2676**
- Boosted Z→bb cross section measurement
  Tests predictions at high p_T and validates searches for TeV scale resonances
  arXiv:1404.7042

Jet shapes in top pair events

Use top pair events to study the differences in the jet shapes of b- and light-quark jets

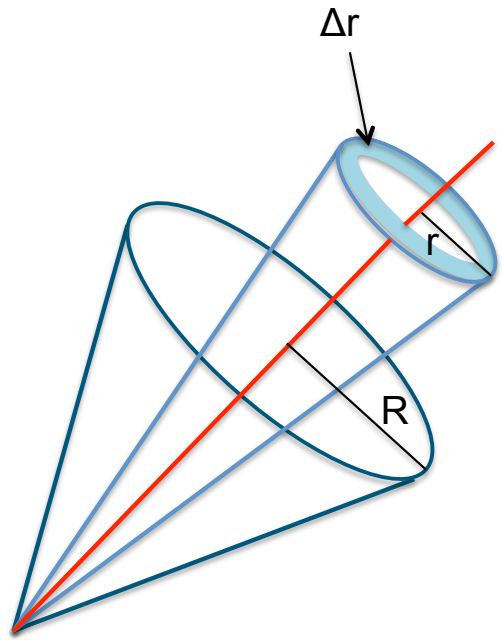
Consider two jet shapes:

- Differential:

$$\rho(r) = \frac{1}{\Delta r}\frac{p_T\left(r-\frac{\Delta r}{2}, r+\frac{\Delta r}{2}\right)}{p_T(0,R)} \qquad r \le R - \frac{\Delta r}{2}$$

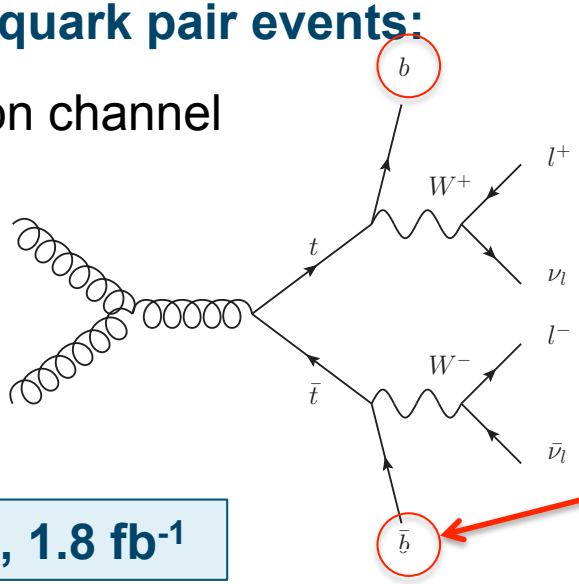
- Integrated:

$$\Psi(r) = \frac{p_T(0,r)}{p_T(0,R)} \qquad r \le R$$

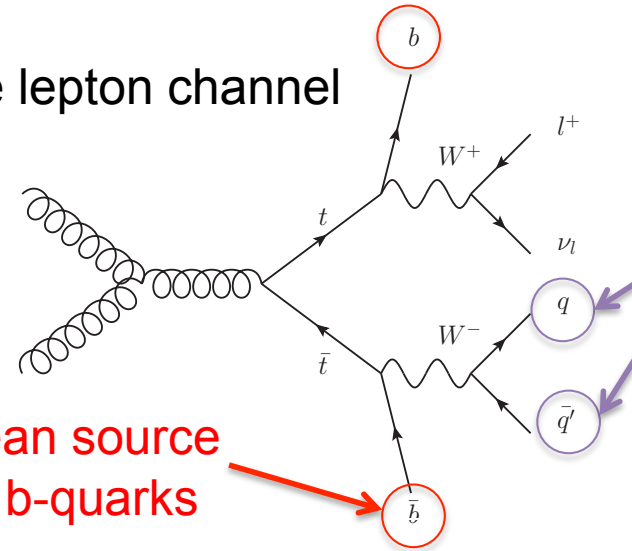


Using top quark pair events:

Dilepton channel



Single lepton channel



Source of light quarks

Clean source of b-quarks

2011 data, 1.8 fb^{-1}

Event Selection (single-lepton)

- **Inclusive Trigger** : 20 GeV electron 18 GeV muon
- **1 isolated lepton** : $p_T^e > 25$ GeV $p_T^\mu > 20$ GeV
- **Missing energy** : $E_T^{miss}(e) > 35$ GeV $E_T^{miss}(\mu) > 20$ GeV
- **Transverse mass** : $m_T > 25$ GeV $m_T + E_T^{miss} > 60$ GeV
- **4 anti-k_T R=0.4 jets :** $p_T > 25$ GeV and $|\eta| < 2.5$
  1 b-tagged

$$m_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos \Delta\phi_{l\upsilon})}$$

Process	Expected events	Fraction
tt	14000 ± 700	77.4%
W+jets	2310 ± 280	12.8%
Other EW	198 ± 18	1.1%
Single top	668 ± 14	3.7%
Multi-jet	900 ± 450	5.0%
Total Expected	18000 ± 900	
Total Observed	17019	

Event Selection (dilepton)

- **Inclusive Trigger** : 20 GeV electron 18 GeV muon
- **2 oppositely charged isolated leptons** : $p_T^e > 25$ GeV $p_T^\mu > 20$ GeV
- **Missing energy** : $E_T^{miss} > 60$ GeV (ee, μμ), $H_T > 130$ GeV (eμ)
- **Dilepton invariant mass** : $m_{ll} > 15$ GeV and $|m_{ll} - m_Z| \geq 10$ GeV
- **2 anti-k_T R=0.4 jets**: $p_T > 25$ GeV and $|\eta| < 2.5$
  1 b-tagged

Process	Expected events	Fraction
tt	2100 ± 110	94.9%
Z+jets	14 ± 1	0.6%
Other EW	4 ± 2	0.2%
Single top	95 ± 2	4.3%
Multi-jet	0^{+2}_{-0}	0.0%
Total Expected	2210 ± 110	
Total Observed	2067	

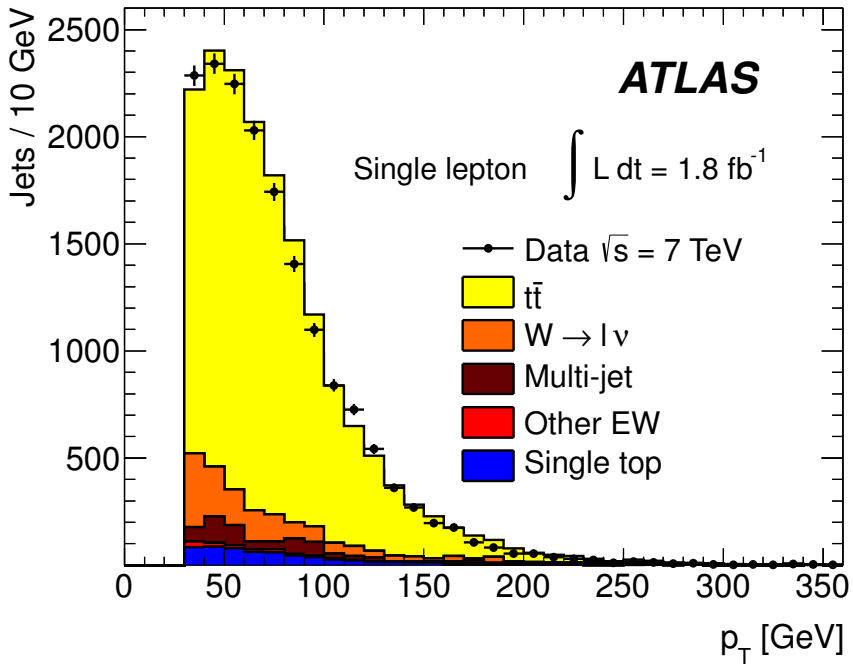
Jet Selection

b-quark jets

- **b-tagged** (efficiency 57%)
- **ΔR_{bj} > 0.8** (isolated)
- **JVF > 0.75** (avoid pileup)

Purity (lqq) = (88.5 ± 5.7)%

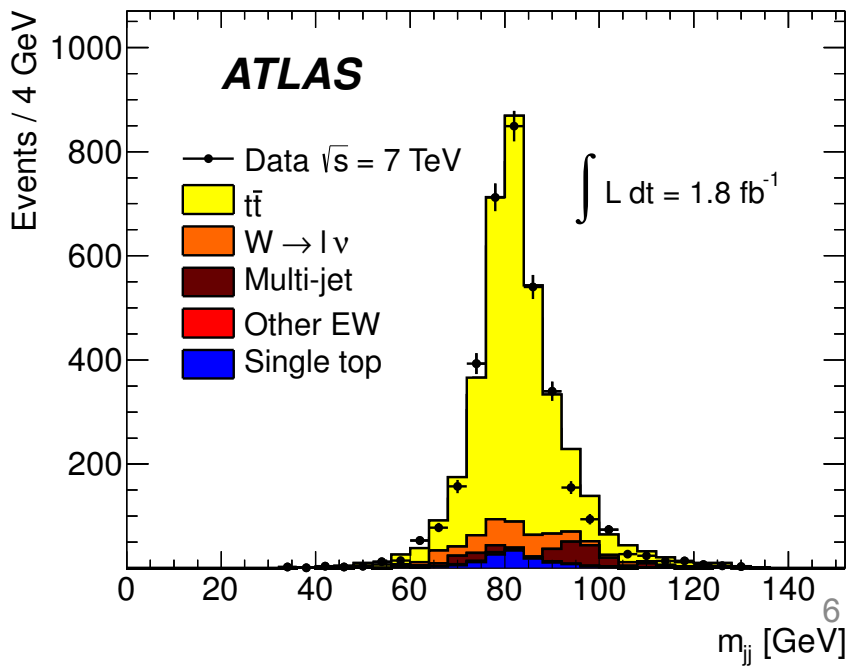
Purity (ll) = $(99.3^{+0.7}_{-6.5})$%



light-quark jets

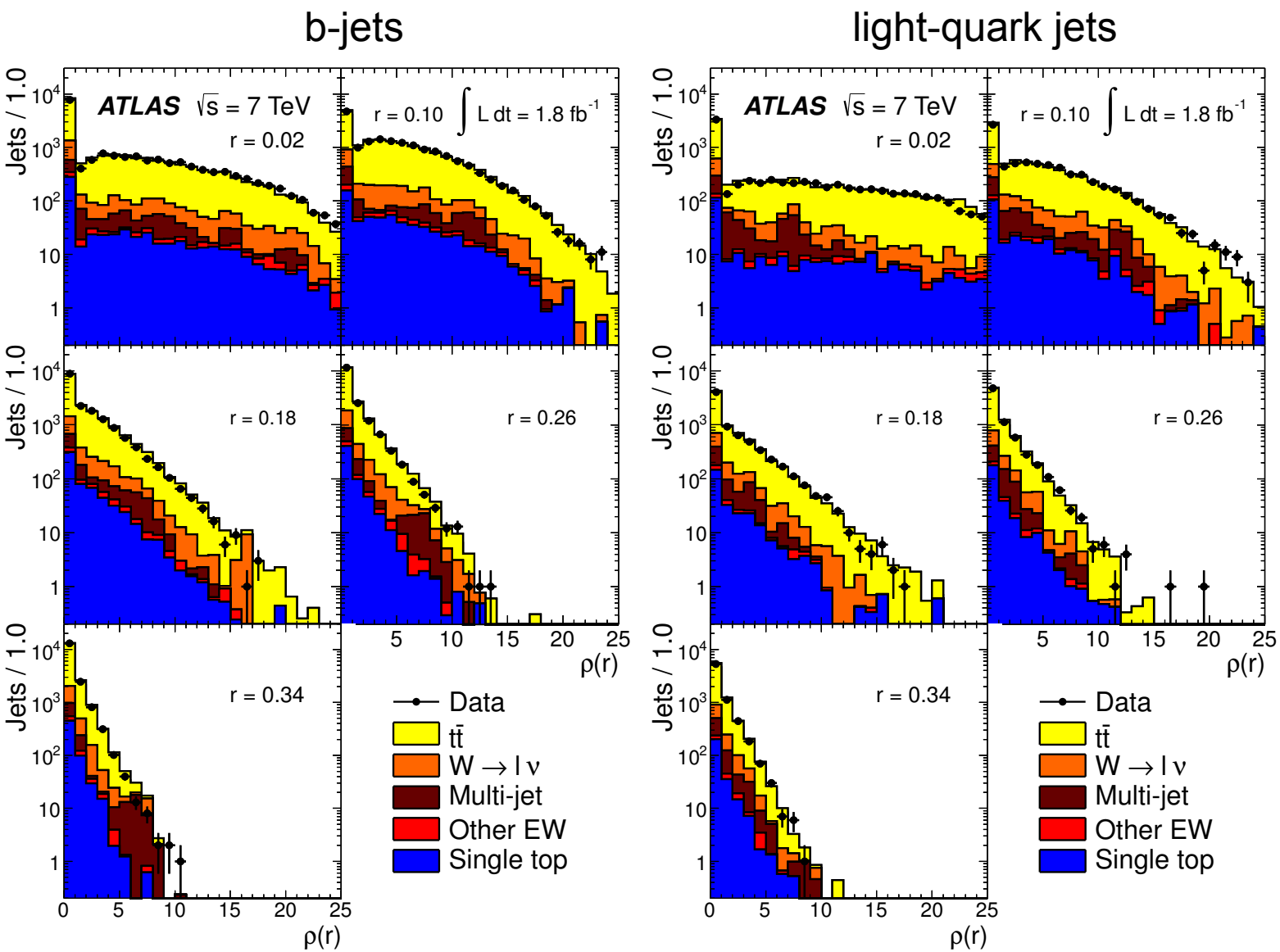
- pair with **closest mass to the W**
- **anti b-tagged** (efficiency 57%)
- **ΔR_{lj} > 0.8** (isolated)
- **JVF > 0.75** (avoid pileup)

Purity (lqq) = (66.2 ± 4.1)%



ρ(r) – detector level

The distribution of the differential jet shape ρ(r) for b- and light-quark jets in the single lepton channel



Peak at 0

energy concentrated around a few particles

Falls off faster at high r

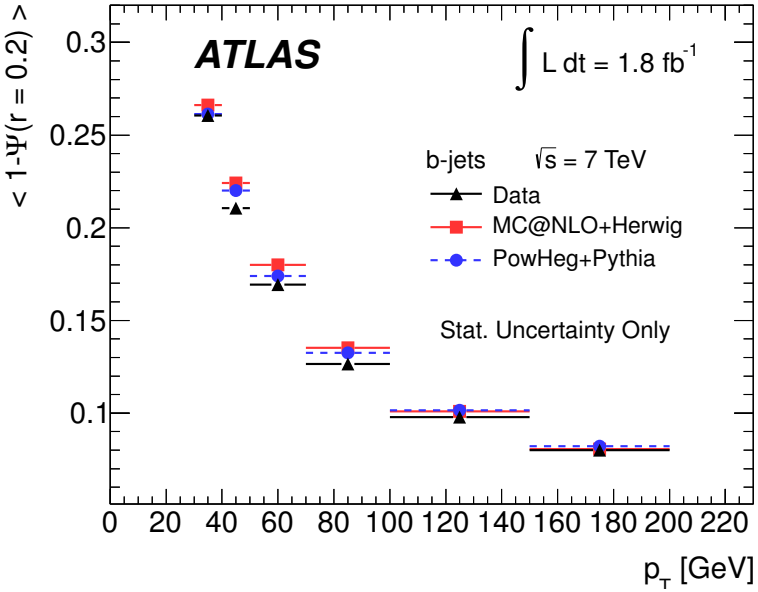
less energy on the edge of the jet

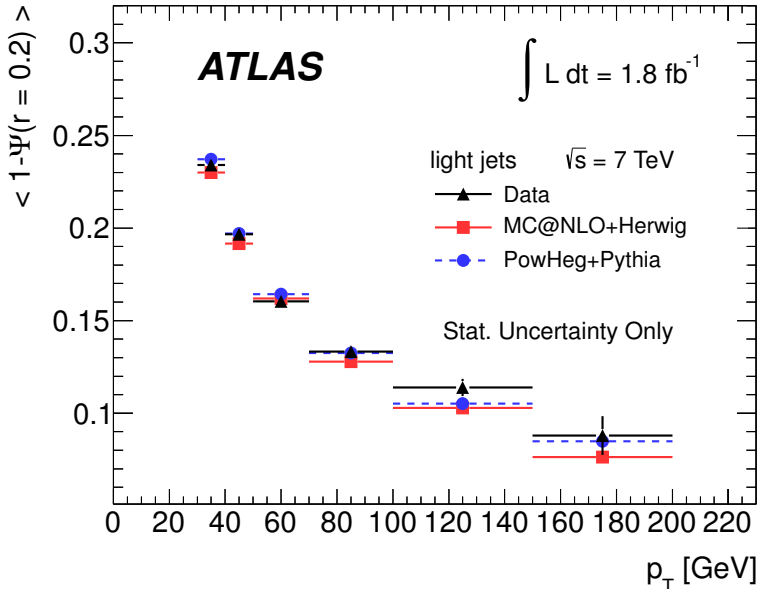
Light jets have a flatter distribution at low r

Kinematic dependence

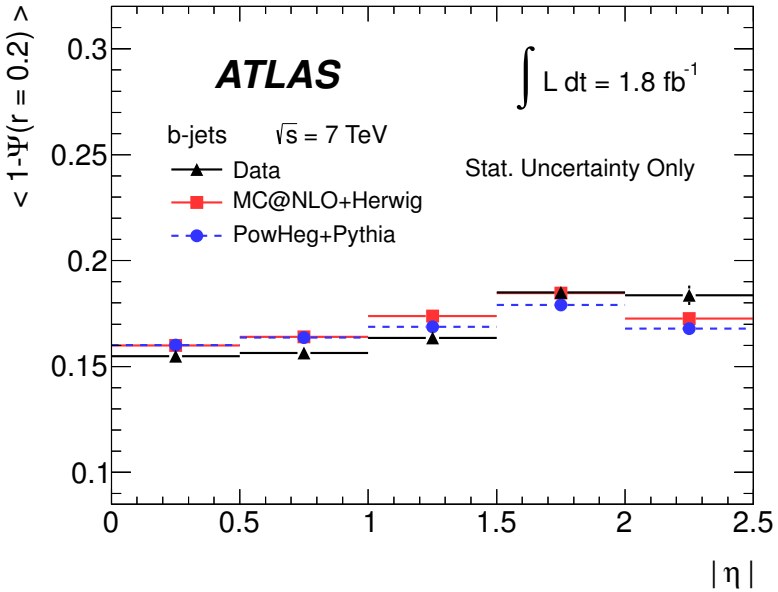
Look at the dependence of the average values with p_T and η

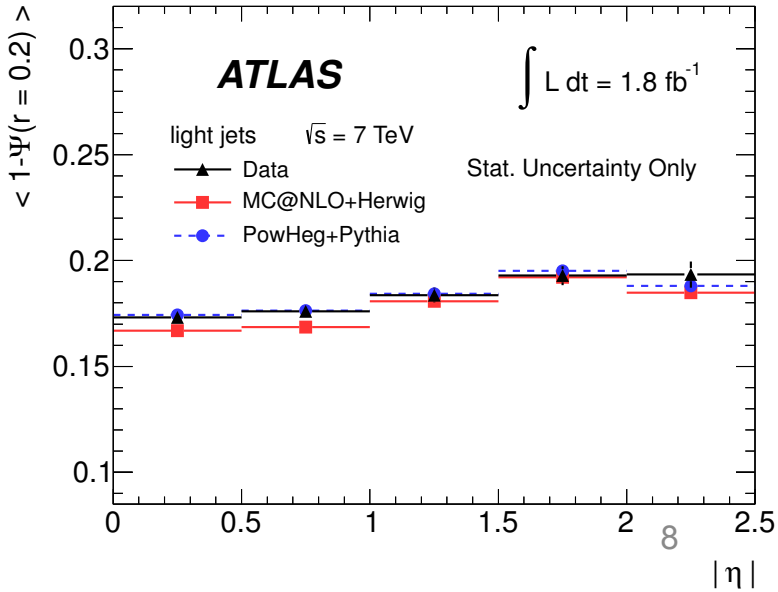
Strong dependence on p_T





Only weak dependence on η





Unfolding and systematics

Correct to particle level using bin-by-bin factors for the average values of both shapes:

$$F^{\rho}_{l,b}(r) = \frac{\langle \rho(r)_{l,b} \rangle_{MC,part}}{\langle \rho(r)_{l,b} \rangle_{MC,\det}} \qquad F^{\Psi}_{l,b}(r) = \frac{\langle \Psi(r)_{l,b} \rangle_{MC,part}}{\langle \Psi(r)_{l,b} \rangle_{MC,\det}}$$

Particle jet : anti-k_T jet formed from stable particles excluding muons and neutrinos must pass the same kinematic requirements: $p_T > 25$ GeV, $|\eta| < 2.5$, $\Delta R_{jj} > 0.8$

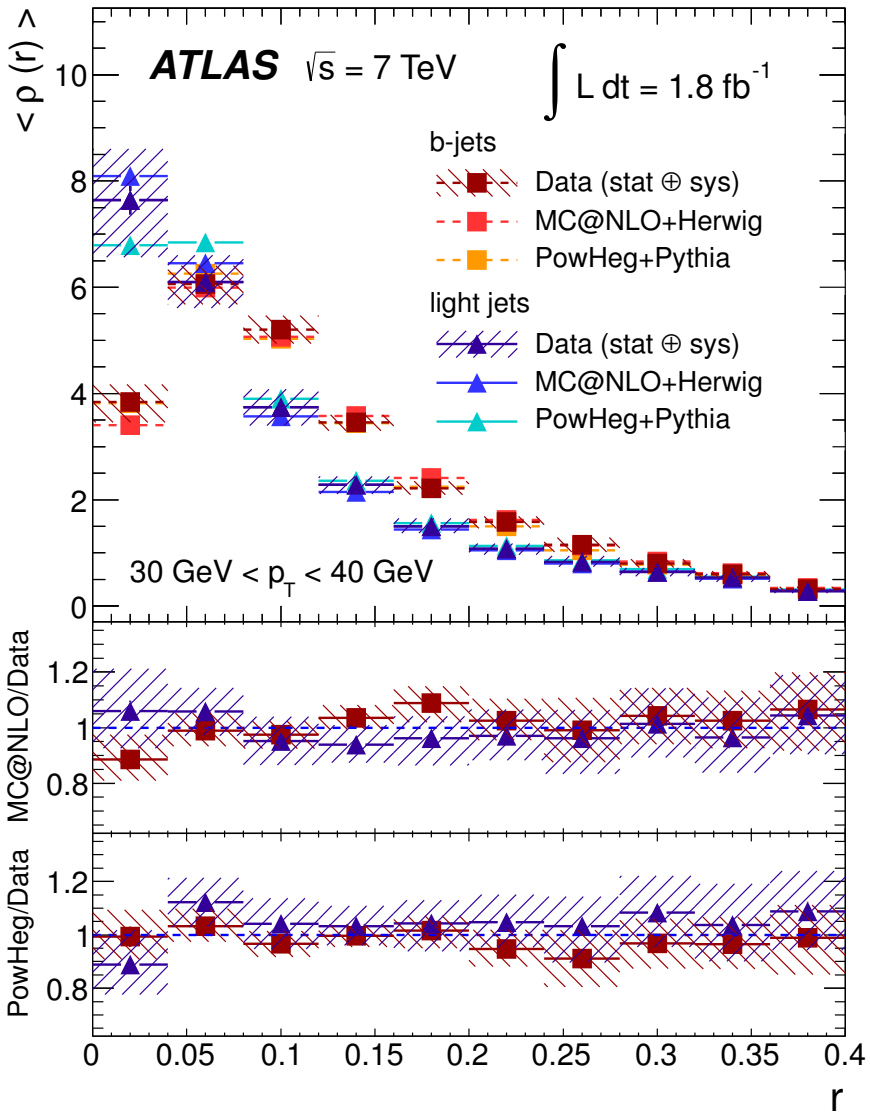
Particle b-jet: has a b-hadron within $\Delta R_{Bj} = 0.3$ of the jet axis

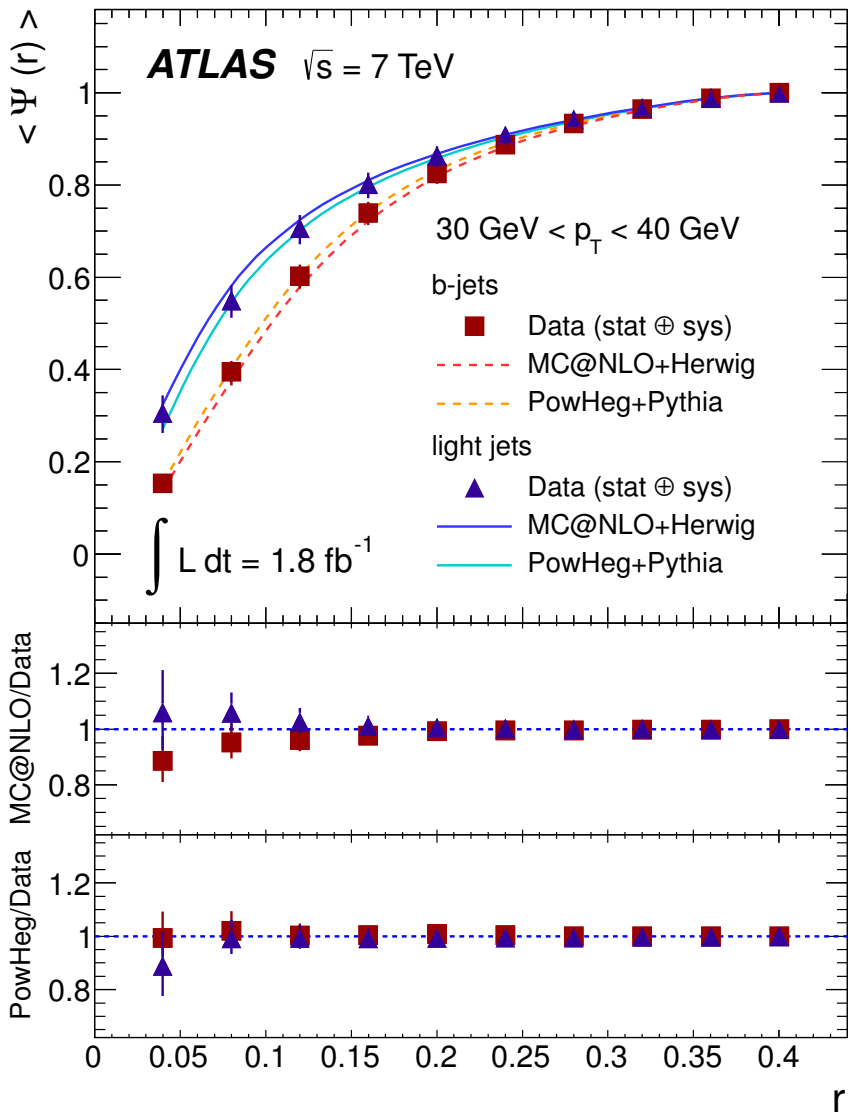
Particle light-jets: pair of non-b particle jets with mass closest to the W

Systematic Uncertainties:

Source	Description	Impact: Δρ/ρ
Cluster systematics	Energy scale, angular resolution	2 - 10%
Pileup	Number of primary vertices	2 - 10%
Unfolding Model	Parton shower model	1 - 8%
Jet Energy Scale	Uncertainty on jet calibration	~5%
Jet Energy Resolution	Calorimeter energy resolution	~5%
JVF	JVF related uncertainty	< 1%

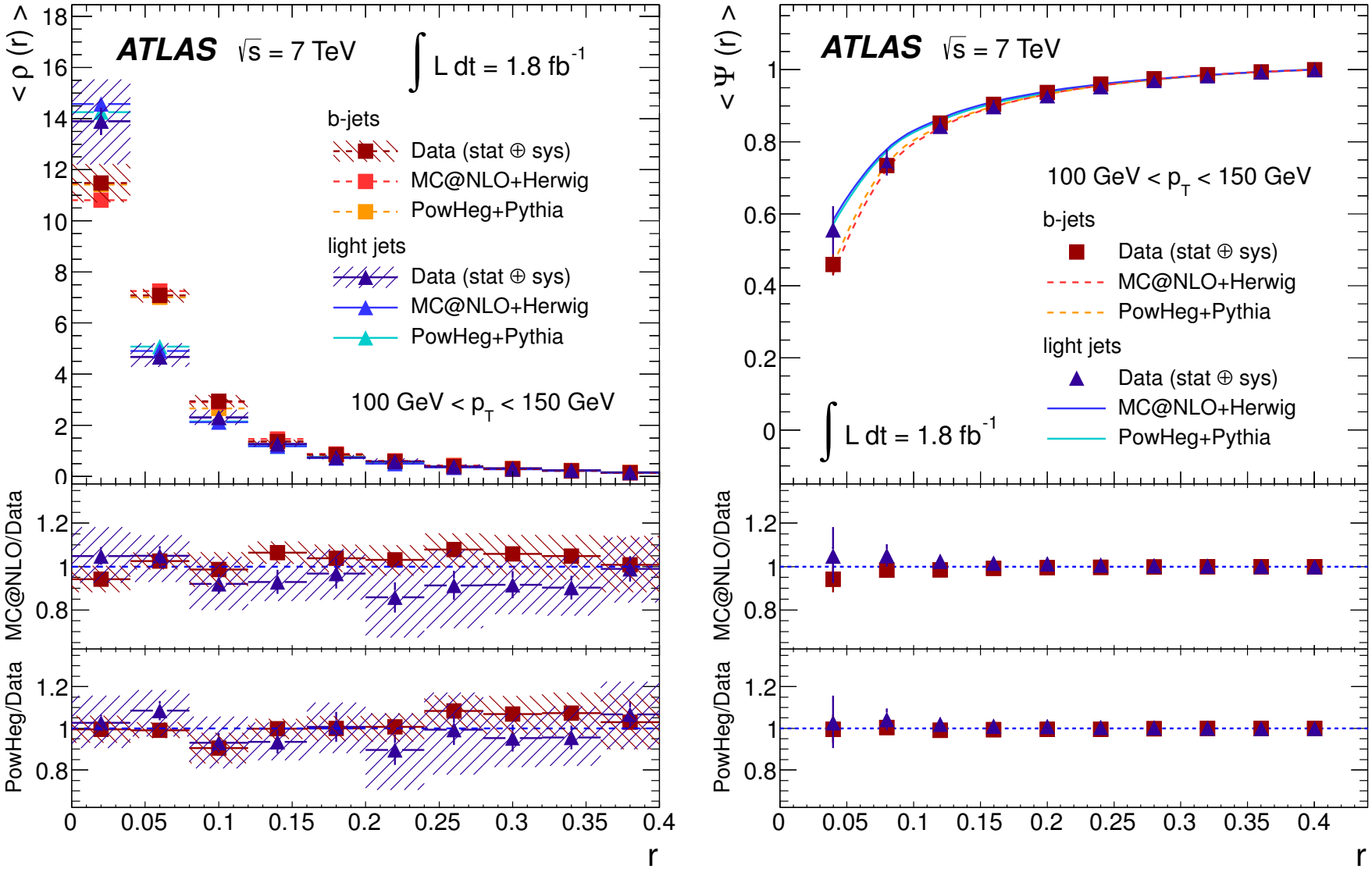
Unfolded results (30 < p_T < 40 GeV)





b-jets wider than light jets, good agreement with MC

Unfolded results (100 < p_T < 150 GeV)



Differences between b- and light-jets less pronounced than at lower p_T

Boosted Z -> bb analysis

Observation and cross section measurement of boosted Z->bb in a fully hadronic final state

Measure the production cross section and compare to NLO matrix element plus parton shower predictions:

- Useful in the search for a **H→bb signal**
- Useful in future searches for **TeV scale resonances** decaying to ZZ, ZH, HH
- Tests **theoretical predictions** at high p_T

Event Pre-selection:

- **Trigger:** OR of 6 jet-based triggers using online b-tagging
- **2 anti-k_T R=0.4 jets**:
  - p_T > 40 GeV
  - $|\eta|$ < 2.5
  - **b-tagged** (efficiency 70%)

→ Form a **dijet:**
  - p_T > 200 GeV
  - ΔR < 1.2

- N_{jets} < 6, $N_{b\text{-}jets}$ == 2 → reduces tt background

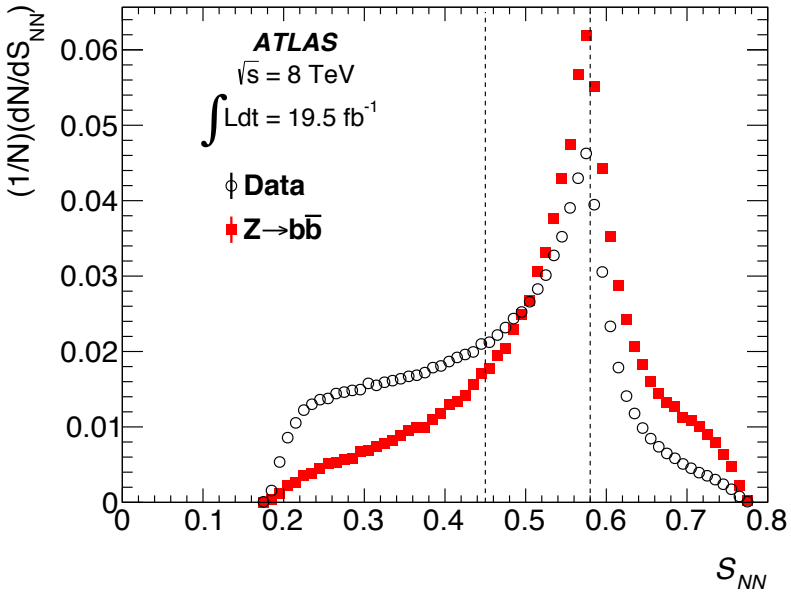
2012 data, 19.5 fb^{-1}

Signal and Control regions

Form an artificial neural network from the **dijet η and Δη : S_{NN}**

Control region: $S_{NN} < 0.45$

Signal region: $S_{NN} > 0.58$

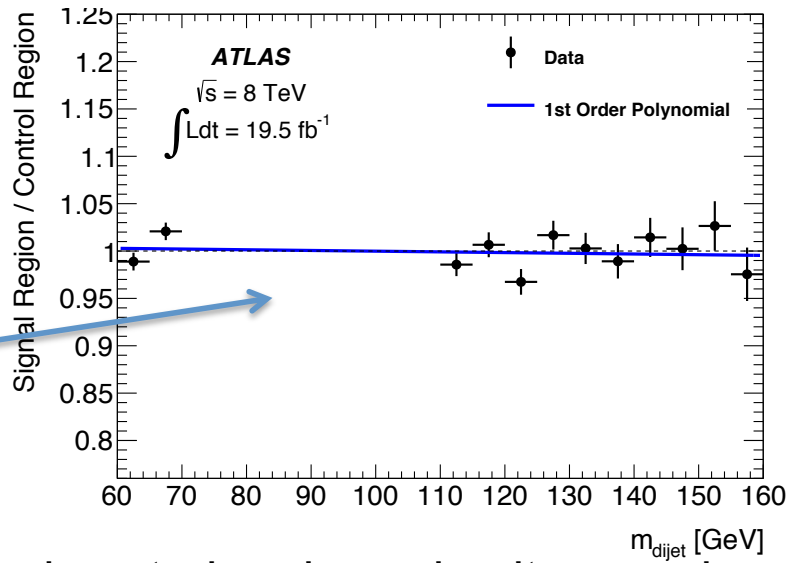


S_{NN} is minimally correlated with the dijet mass

→ control region provides a data driven background model

Look at the normalised ratio of the control and signal regions outside the z mass window

→ fits with a flat line at 1



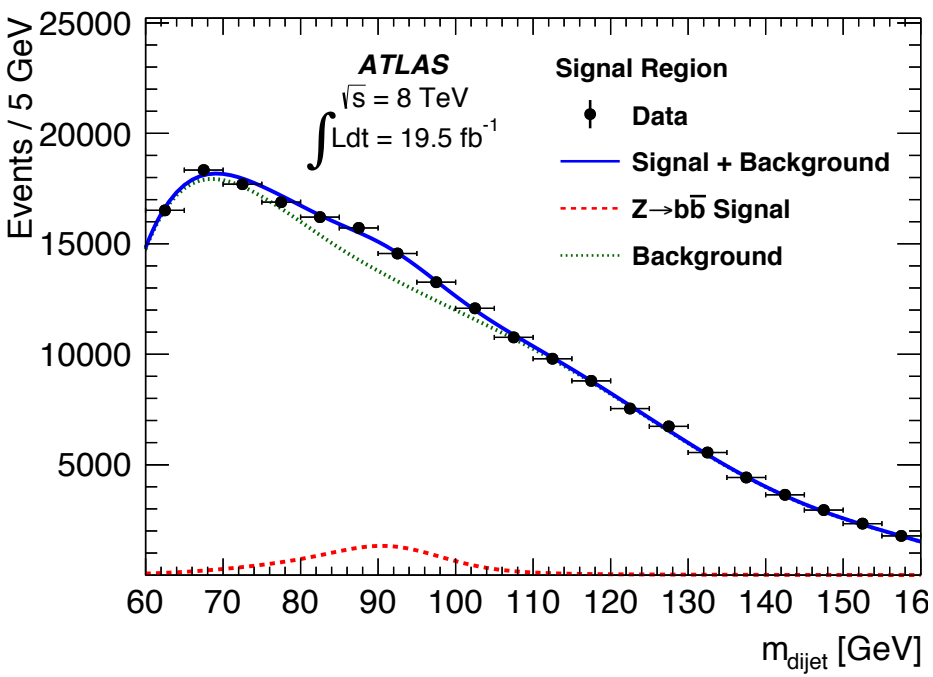
→ Fit both the signal and control regions simultaneously using a binned extended maximum likelihood fit

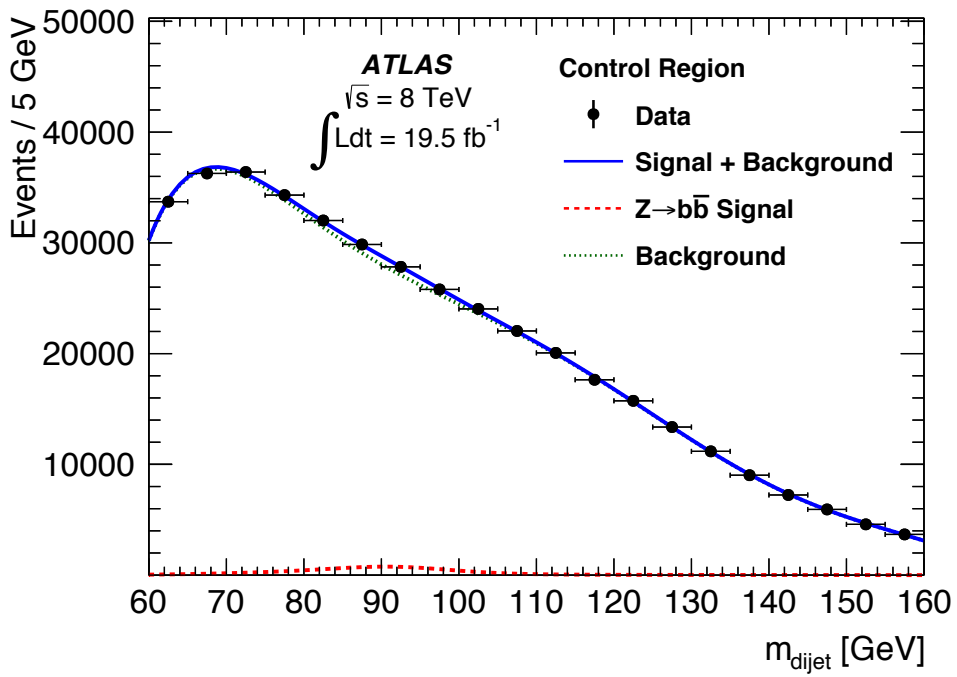
Fitting procedure

Signal model: sum of 3 gaussians

→ normalisation and peak position free parameters
→ ratio of yield in signal and control regions fixed
validated using Z → μμ events

Multijet background: 7th order Bernstein polynomial
Coefficients the same for the signal and background fit
Other backgrounds: taken from MC





Systematic Uncertainties

Source of uncertainty	$\Delta\sigma^{\text{fid}}_{Z\to b\bar{b}}(\%)$
Jet Energy Scale	+6.5/-5.0
Jet Energy Resolution	±5.1
b-tagging	±3.6
Trigger Modelling	±6
Control Region Bias	+4.9/-5.5
Signal $\mathcal{S}_{\mathcal{NN}}$ Modelling	±2.9
Signal m_{dijet} Shape	±2.2
$Z\to c\bar{c}$ Normalisation	±0.4
$t\bar{t}$ Normalisation	±1.1
$W\to q\bar{q}'$ Normalisation	±1.0

Efficiency cross-checked in data using a prescaled trigger

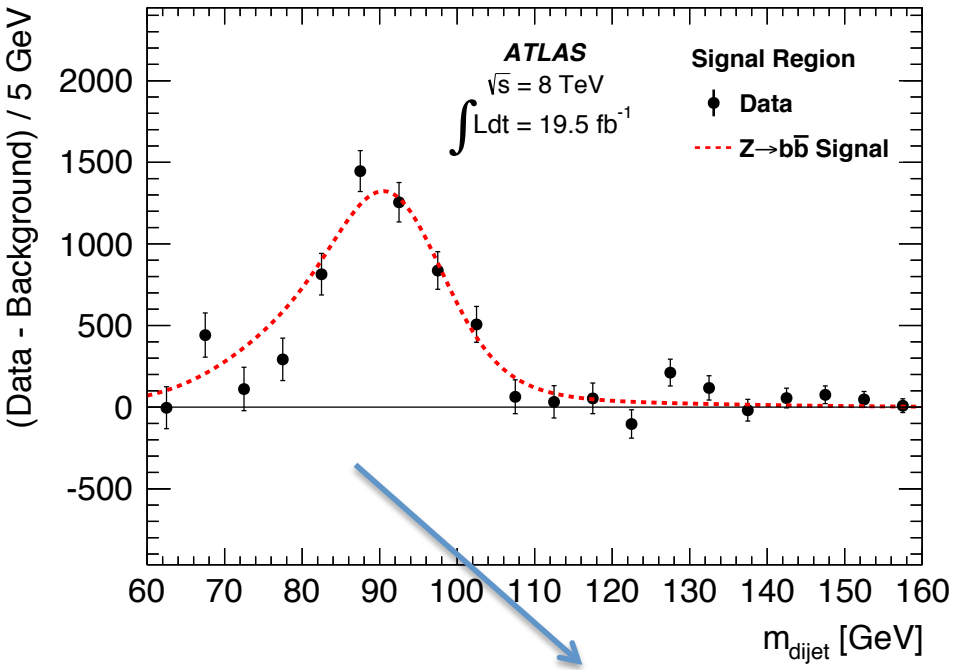
Vary the S_{NN} cut used for the control region

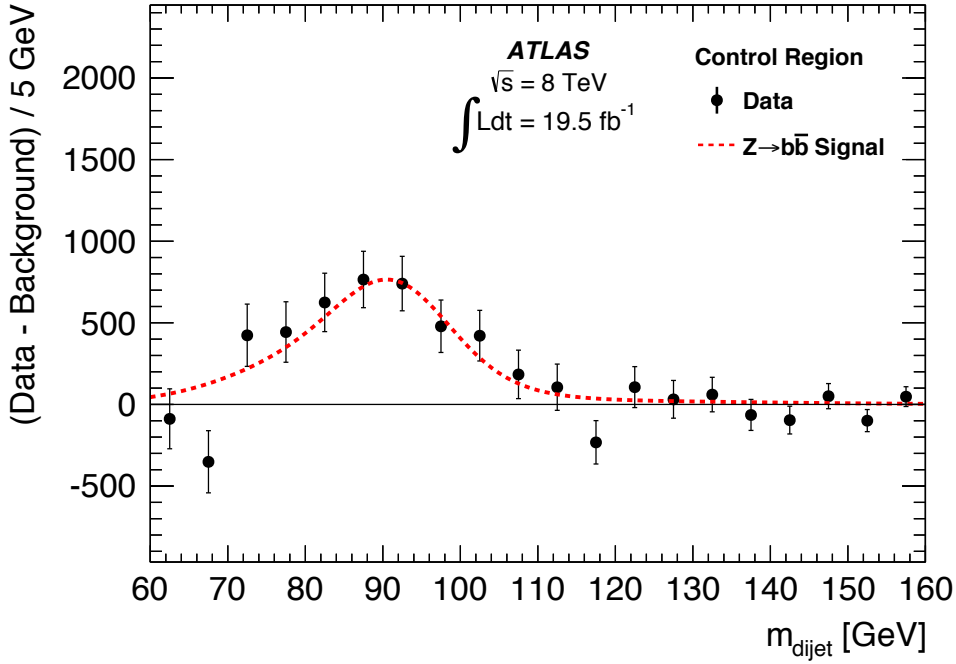
Compare data and MC using Z→μμ events

Use Pythia 8 rather than Sherpa to define the signal shape

Total systematic sums the sources in quadrature

Z -> bb results





Extracted signal yield: $N_{Z\to b\bar{b}} = 6420 \pm 640\,(stat)$

Calculate the cross section using: $\sigma^{fid}_{Z\to b\bar{b}} = \dfrac{N_{Z\to b\bar{b}}}{L \times C_{Z\to b\bar{b}}}$

Efficiency correction factor (16.2%)

$$\sigma^{fid}_{Z\to b\bar{b}} = 2.02 \pm 0.2\,(stat.) \pm 0.25\,(syst.) \pm 0.06\,(lumi.)\,pb$$

Compared to: POWHEG+PYTHIA: $\sigma^{fid}_{Z\to b\bar{b}} = 2.02^{+0.25}_{-0.19}\,(scales)^{+0.03}_{-0.04}\,(PDF)\,pb$

aMC@NLO+HERWIG++: $\sigma^{fid}_{Z\to b\bar{b}} = 1.98^{+0.16}_{-0.08}\,(scales) \pm 0.03\,(PDF)\,pb$

Good agreement with NLO + PS predictions

Conclusions

The **jet structure of b- and light-jets** has been studied in the context of top pair events

- The jet shapes are **strongly dependent on the jet p_T** and only **weakly dependent on the jet η**
- **Light-jets are narrower than b-jets** with the difference most pronounced at low p_T
- The shapes are **well described by the MC** using NLO generators with either the Pythia or Herwig+jimmy parton showers

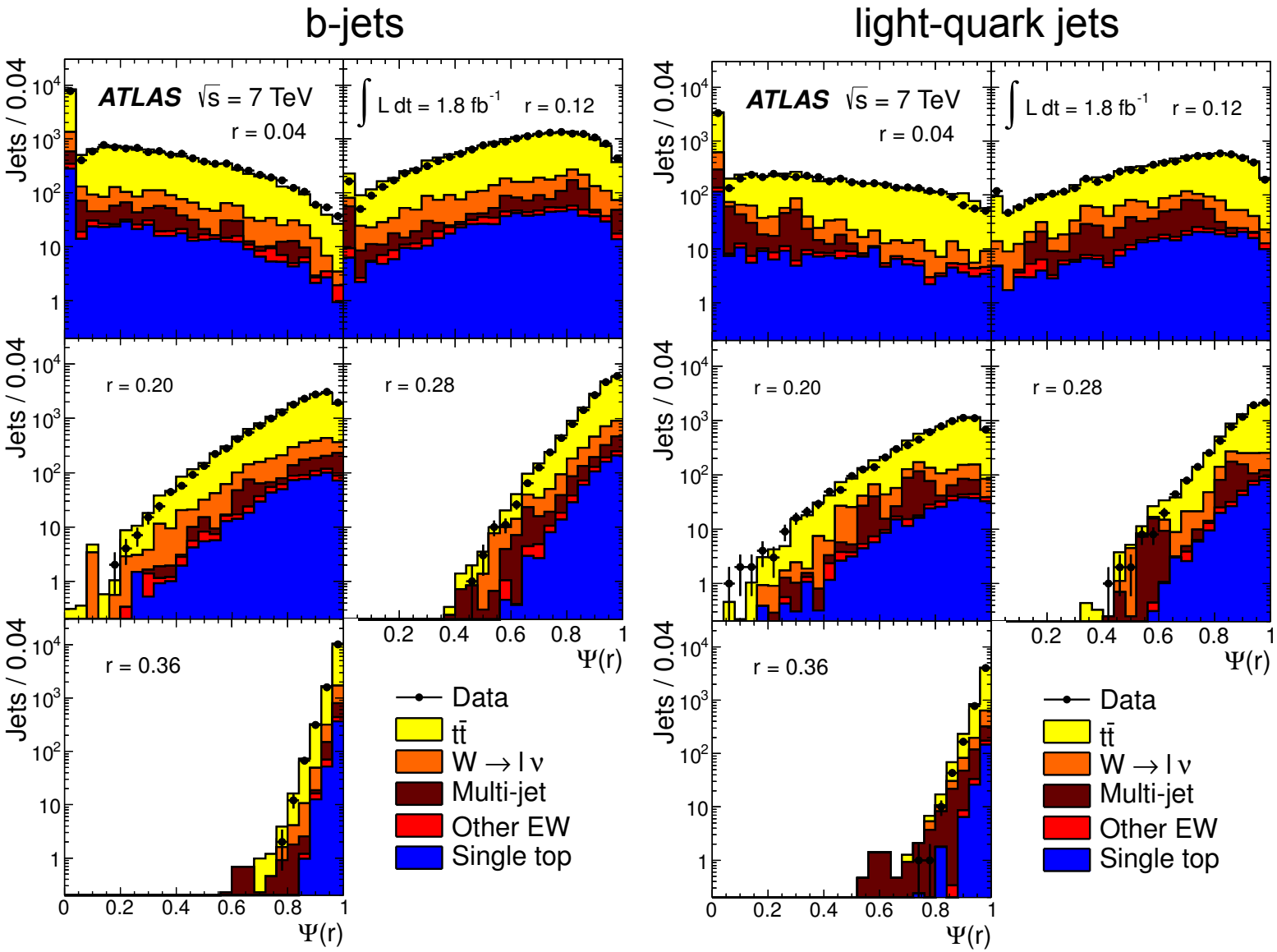
A **high p_T Z →bb signal** was observed and the cross section extracted

- There is **good agreement** between data and NLO+PS predictions
- This **opens up opportunities** for further studies of high p_T bb resonances
  Increasingly important as the LHC centre of mass energy increases

Back up

Ψ(r) – detector level

The distribution of the integrated jet shape Ψ(r) for b- and light-quark jets in the single lepton channel



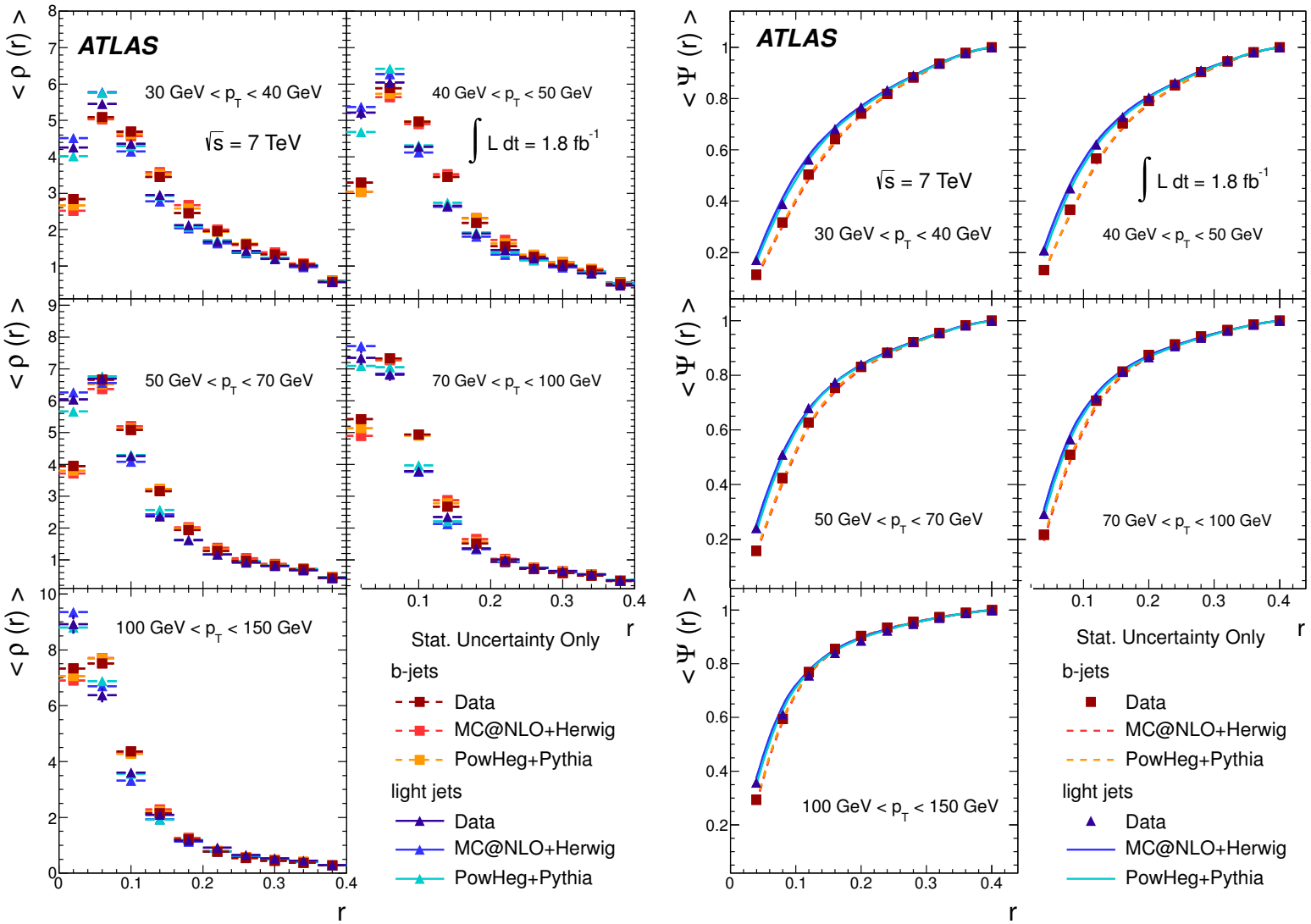
Very close to 1 at high r:

all contained within that radius

Flatter at low r for light jets

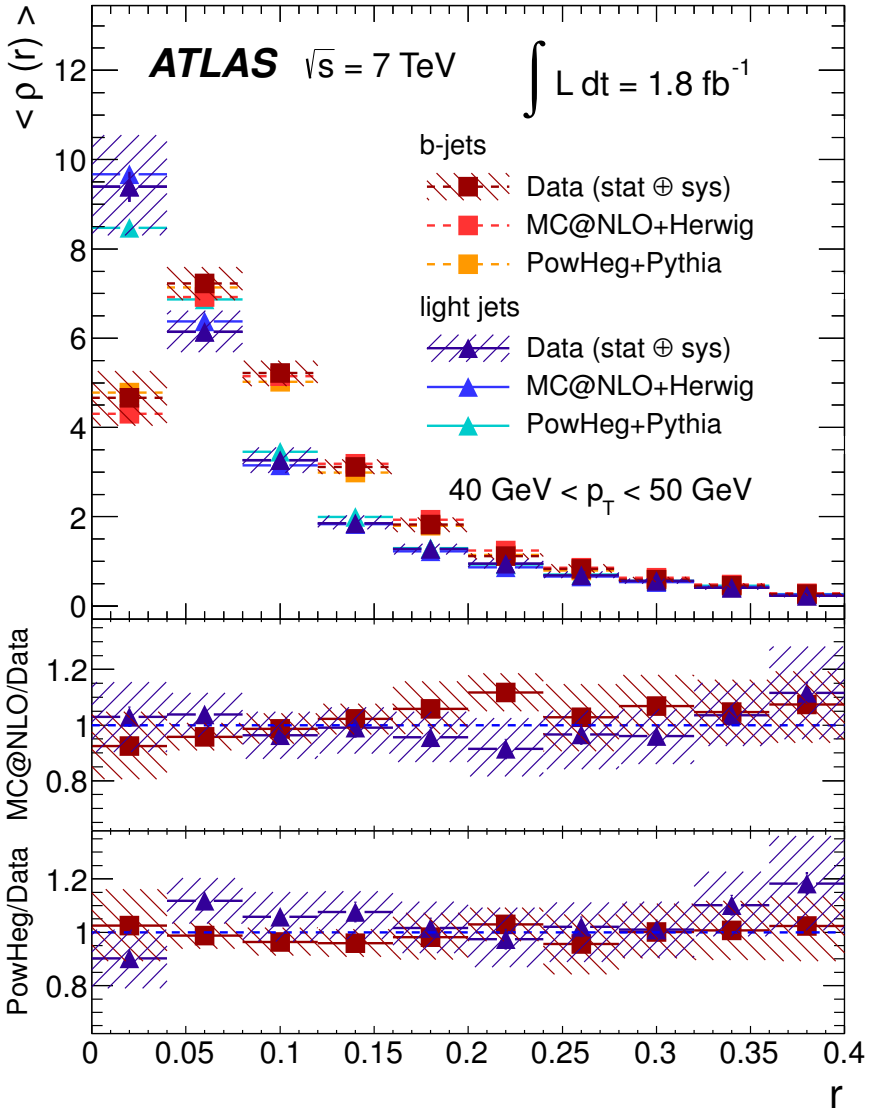
Comparing b- and light-jets

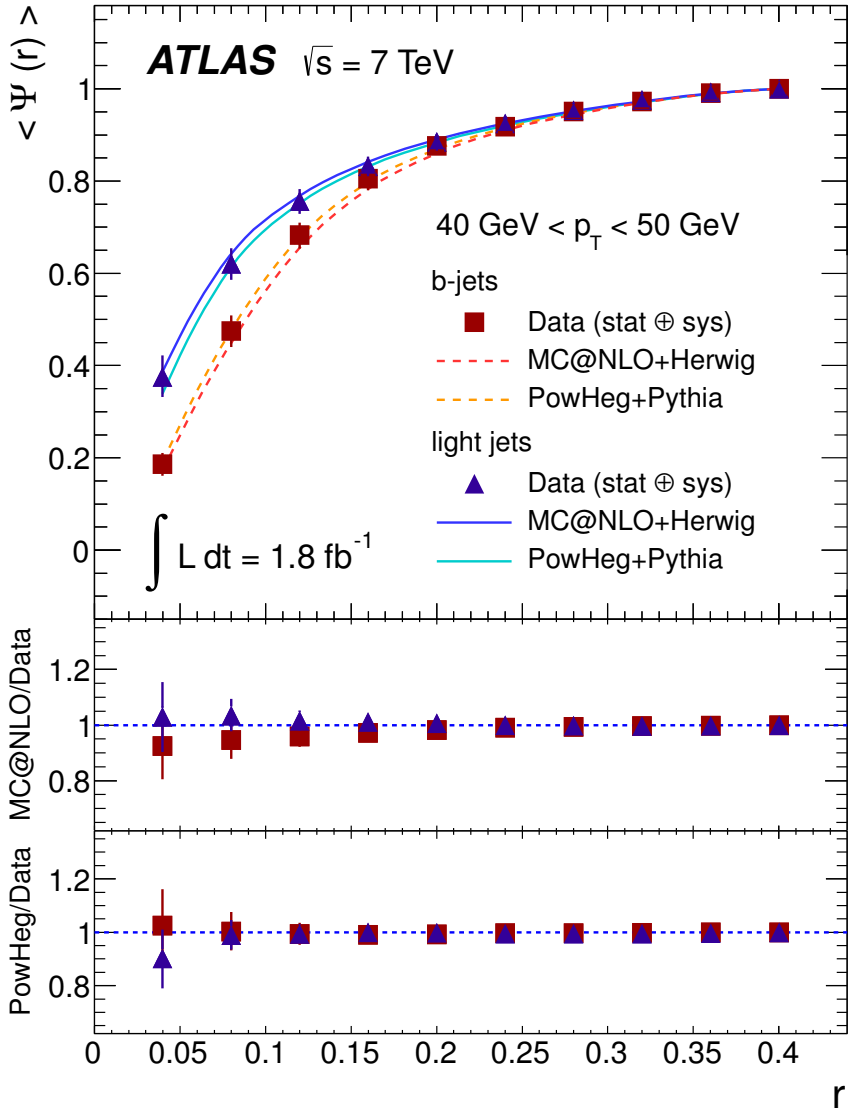
Compare the distributions of the average values as a function of r



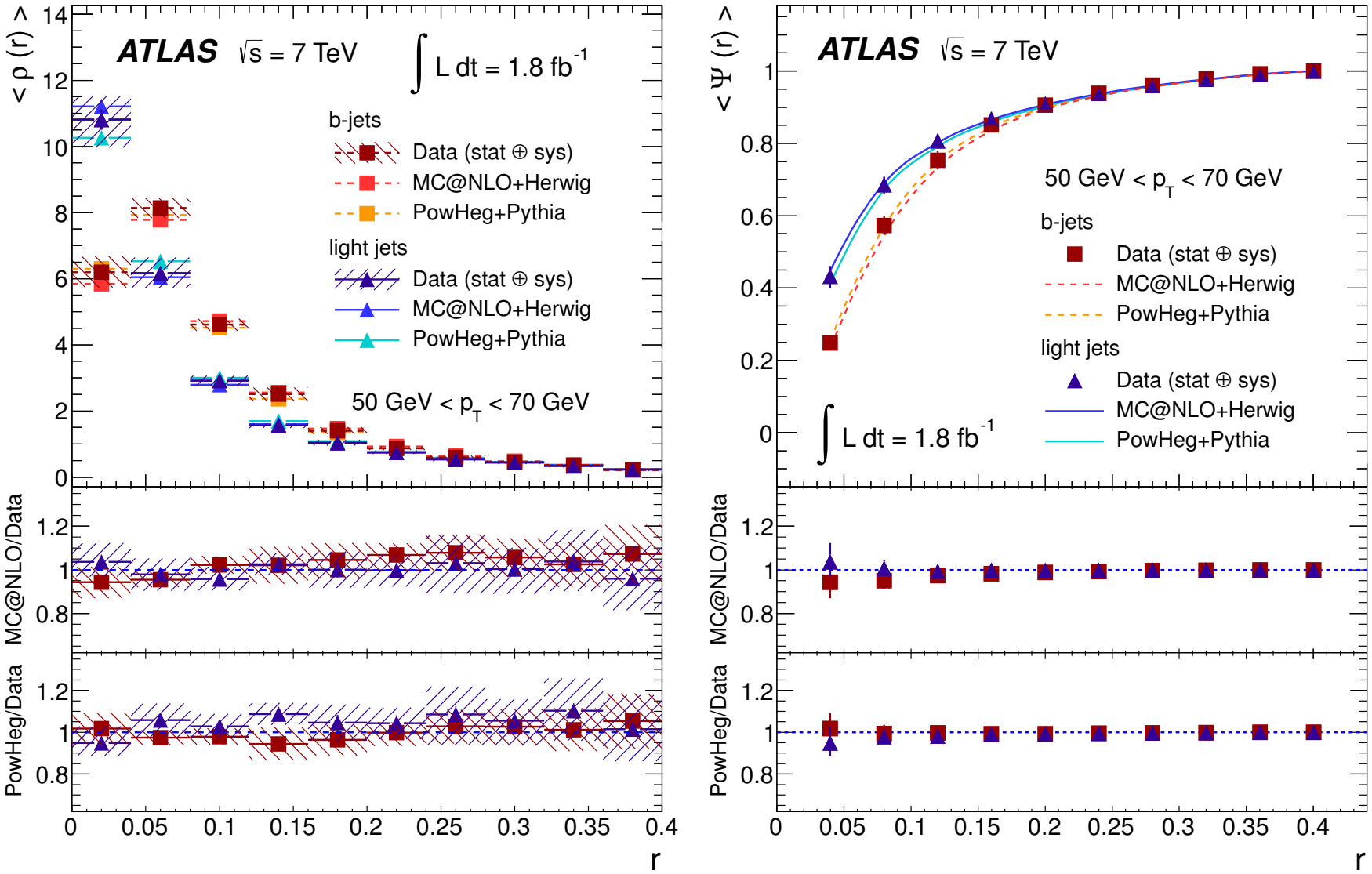
Slight differences between b- and light-jets, especially for low values of r

Unfolded results (40 < p_T < 50 GeV)

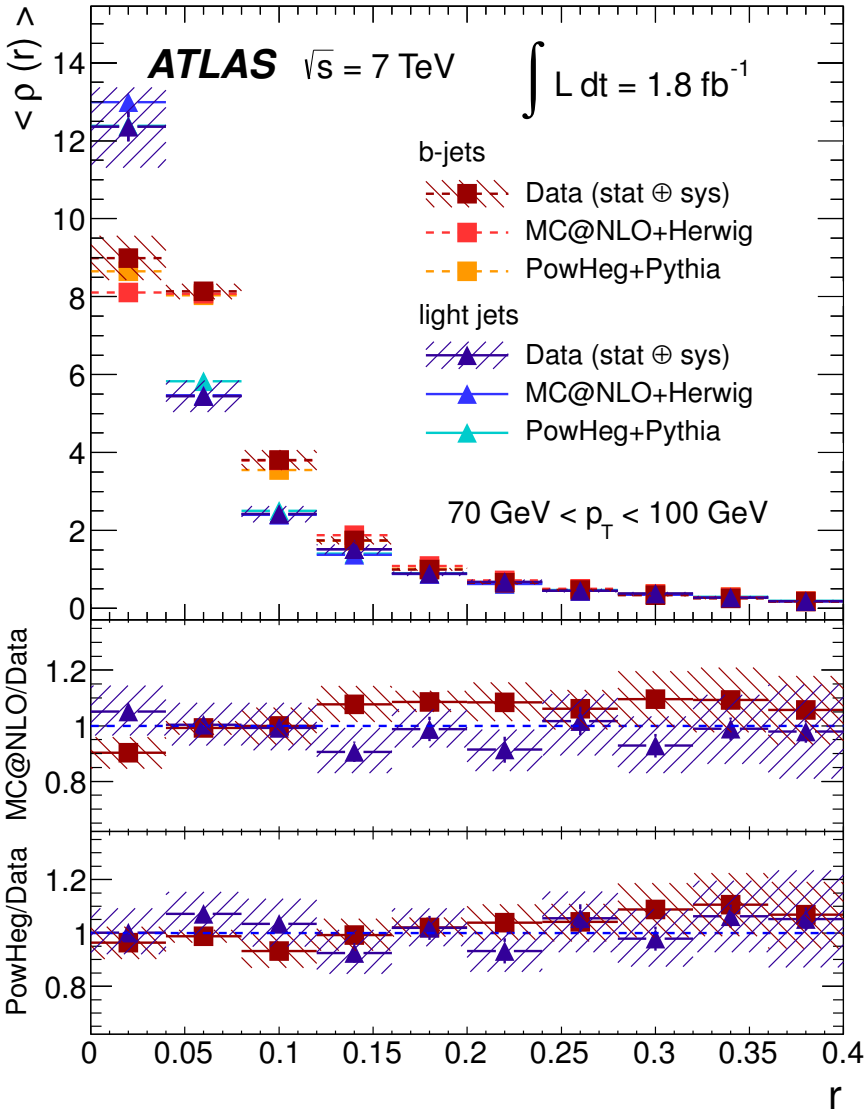


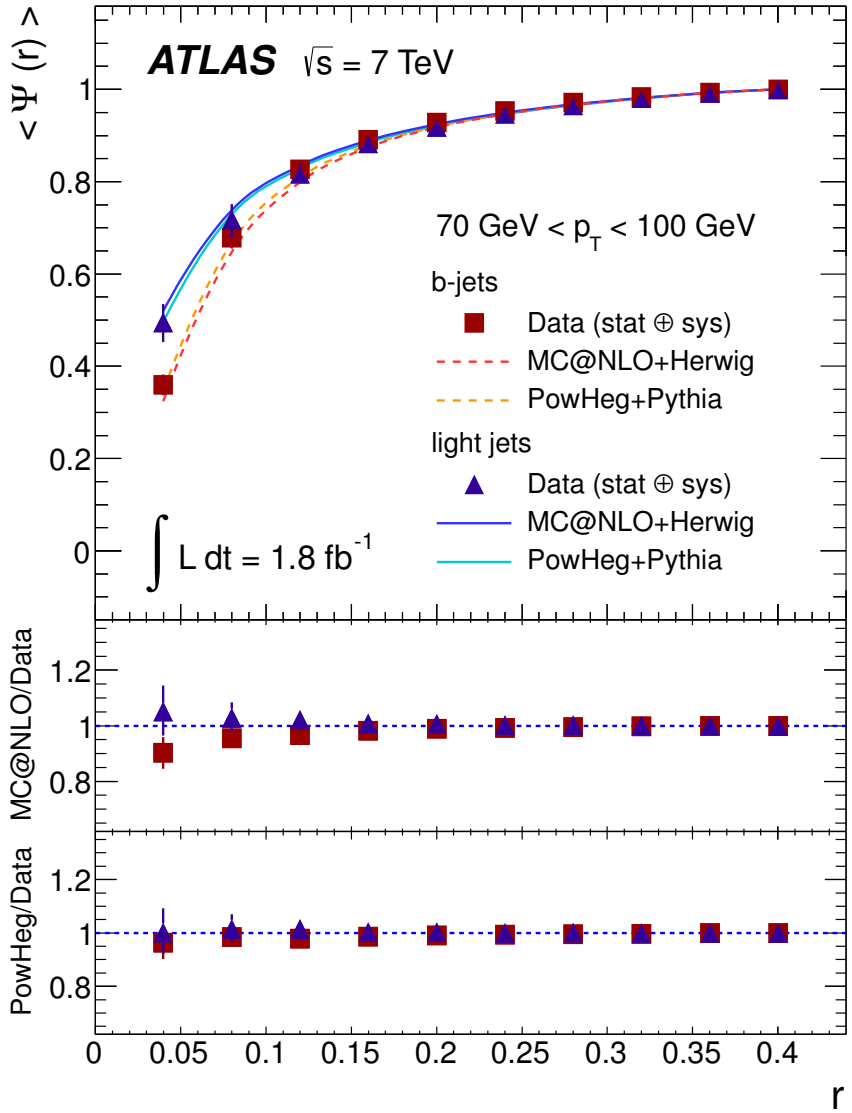


Unfolded results (50 < p_T < 70 GeV)

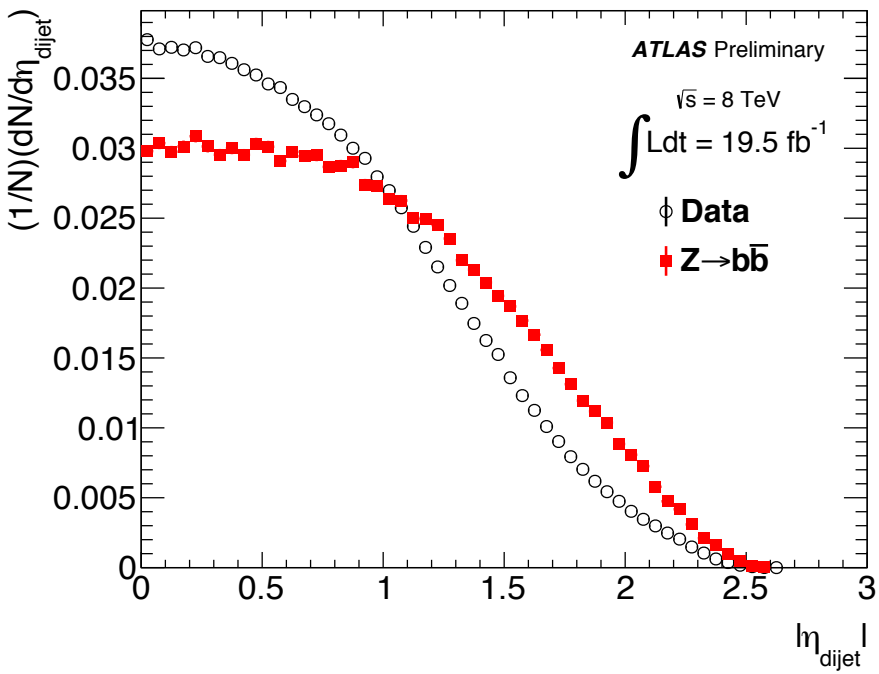


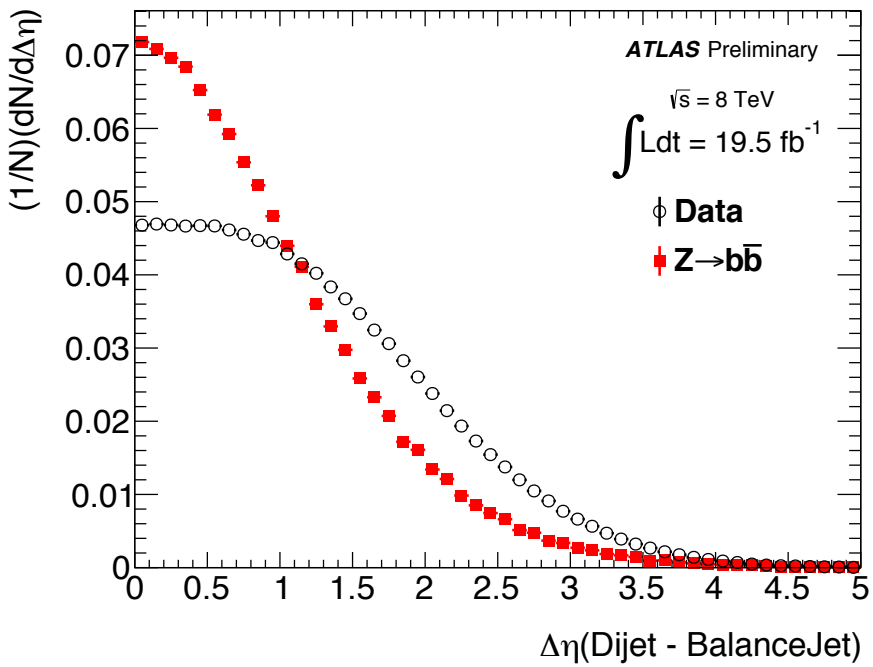
Unfolded results (70 < p_T < 100 GeV)





Z -> bb


ATLAS Preliminary
√s = 8 TeV
∫Ldt = 19.5 fb-1
Data
Z→bb̄
(1/N)(dN/dη_dijet)
|η_dijet|


ATLAS Preliminary
√s = 8 TeV
∫Ldt = 19.5 fb-1
Data
Z→bb̄
(1/N)(dN/dΔη)
Δη(Dijet - BalanceJet)