Properties of the jet production in pp collisions

Alexander Solodkov
IHEP, Protvino
on behalf of ATLAS collaboration

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Outline

- ***Measurement of the flavour composition of dijet events in pp collisions at $\sqrt{s}$ =7 TeV with the ATLAS detector***

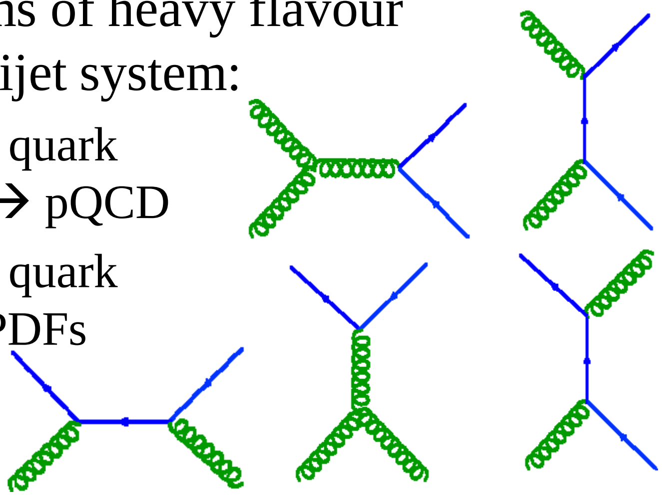
  Eur. Phys. J. C 73(2013) 2301

- ***Measurement of multi-jet cross-section ratios and determination of the strong coupling constant in proton-proton collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector***
  - *ATLAS CONF-2013-041*
- ***Measurement of k_t splitting scales in W→lnu events at $\sqrt{s}$ = 7 TeV with the ATLAS detector***
  - *Eur. Phys. J. C 73 5 (2013) 2432*

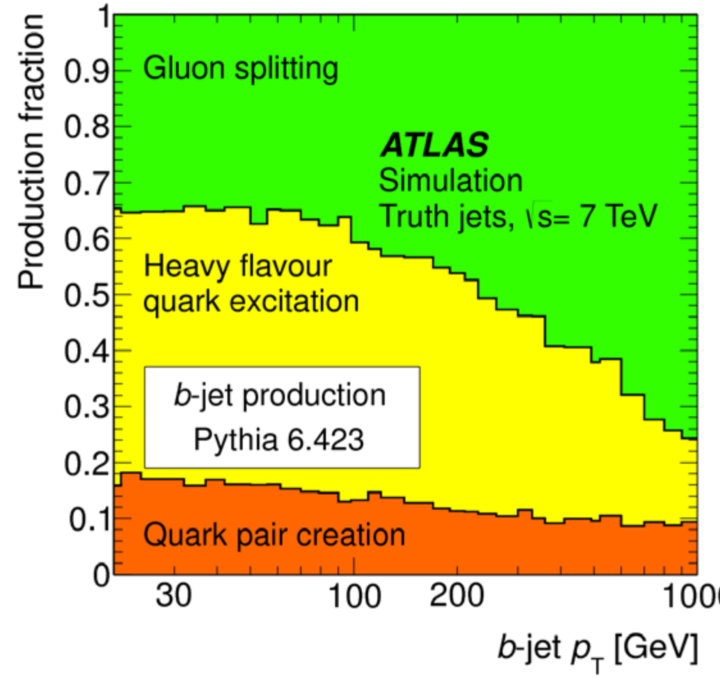
- ***Talk is based on analysis of low-pileup 2010 data***
- ***… see two more ATLAS talks on jet cross-sections and jet properties during QCD session***

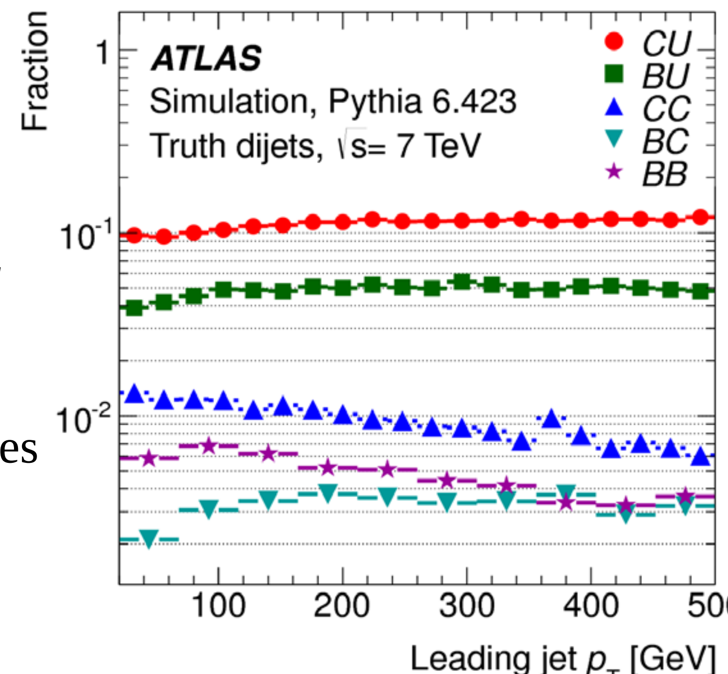
I. Flavour composition

- Three mechanisms of heavy flavour production in a dijet system:
  - Heavy flavour quark pair creation → pQCD
  - Heavy flavour quark excitation → PDFs



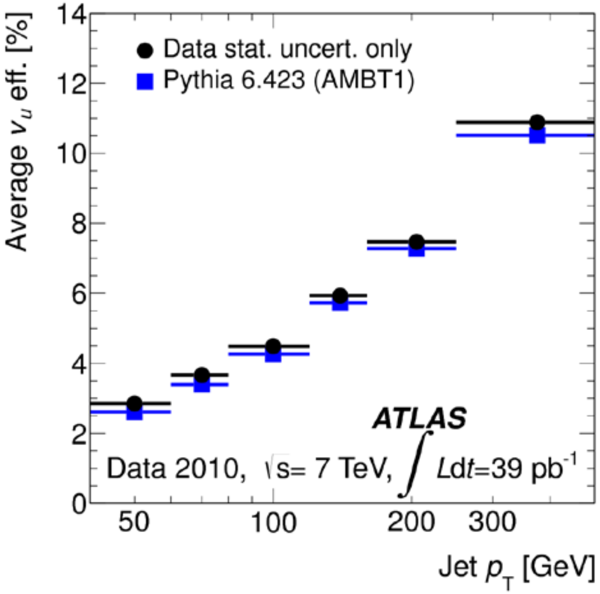
  - Gluon splitting → non-perturbative QCD
- The analysis aims to measure fractions of the six combinations of dijet events: f_{BB} f_{CC} f_{UU} f_{BU} f_{CU} f_{BC}
  - determined from the fit of kinematic variables (combinations of momenta of tracks assigned to the secondary vertex inside jet) with MC based templates for each jet flavour (light jet, c-jet, b-jet and 2b-jet)
  - no flavours assigned to individual jets



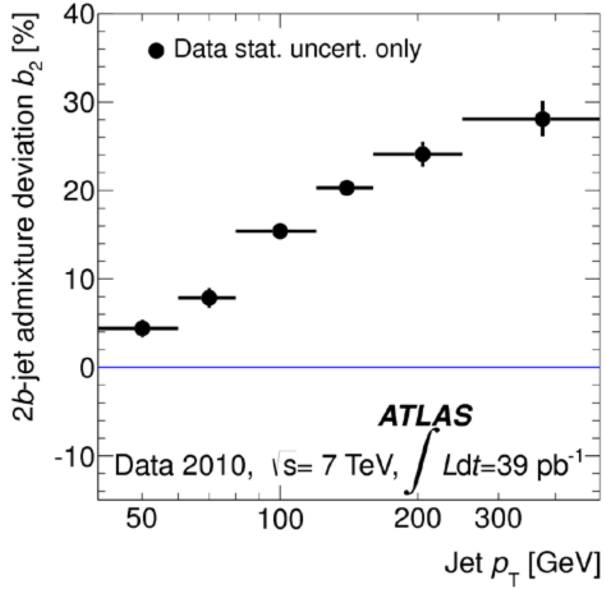


Fit results

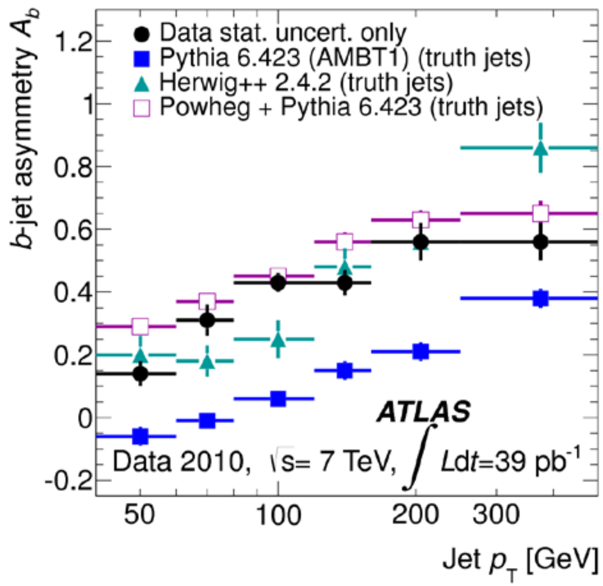
Average fake vertex probability in light jets



2b-jet admixture



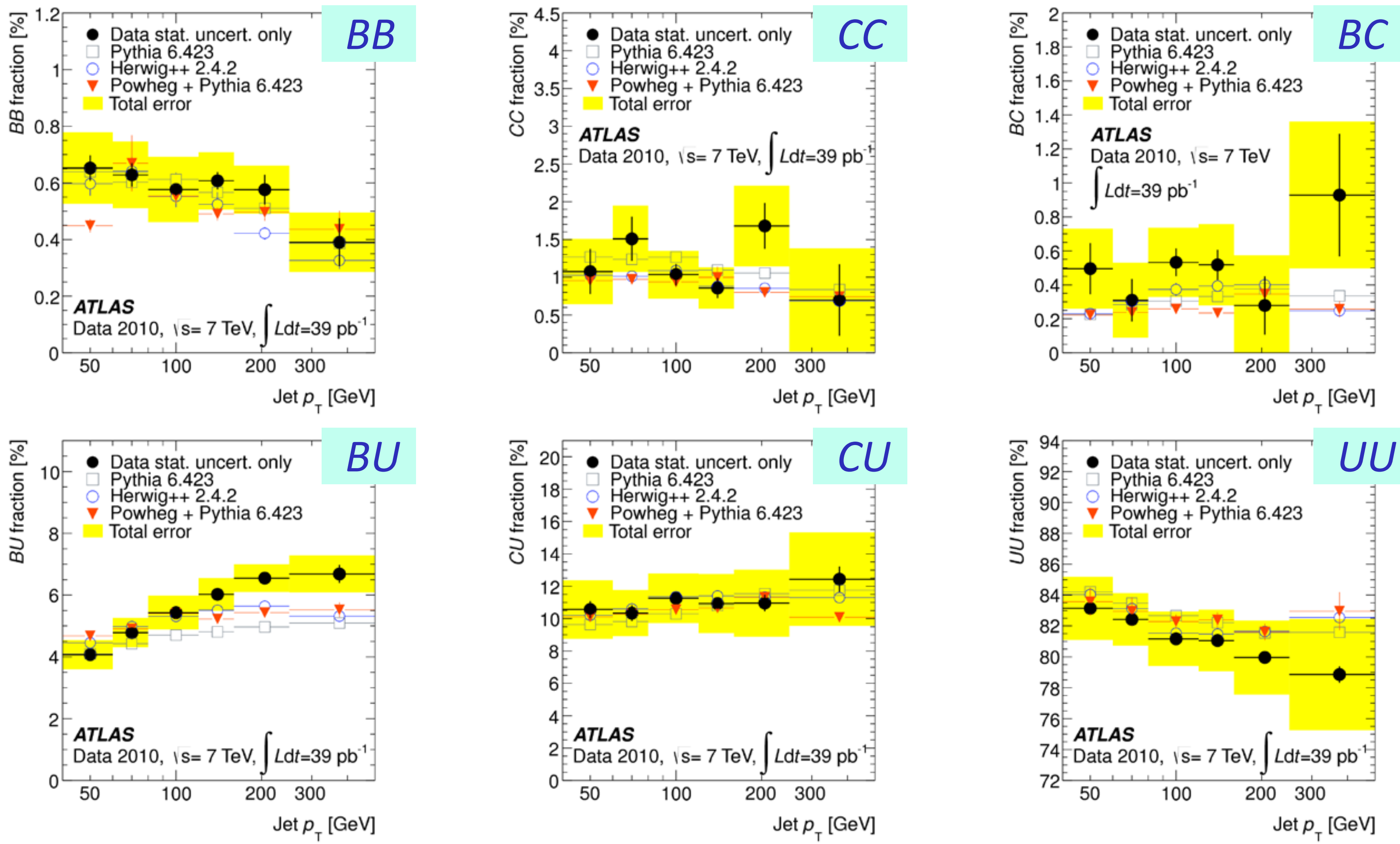
$$A_b = \frac{f_{BU}^{subleading\_B}}{f_{BU}^{leading\_B}} - 1$$



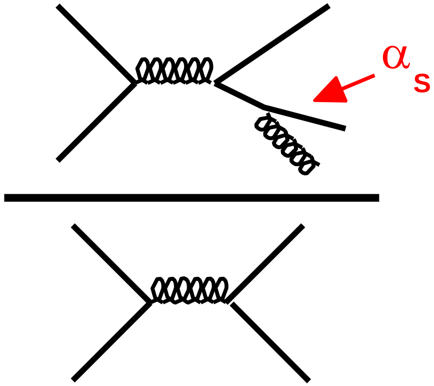
- Average fake vertex probability in light jets in data is well reproduced by MC.
- Large contribution of additional 2b-jet template with respect to Pythia
  - Sensitive to gluon splitting
  - Larger contribution for higher jet p_T
- Bottom dijet asymmetry is better described by POWHEG (NLO ME) + Pythia than by Pythia only (LO ME).

Measured flavour composition

- In agreement with LO and NLO MC predictions, except for bottom+light jet fraction.
- Measured BU fraction is higher than predictions at p_T>100 GeV.



II. Multi-jet ratio measurement



- Study ratio of events with ≥ 3 jets and ≥ 2 jets
  - cancellation of systematic uncertainties in ratio
  - ≥ 3 jets suppressed by α_S
  - **Determine α_S (M_Z) and α_S (Q)**
- Observables
  - Event ratio

hardest jet in the event

$$R_{3/2}\left(p_T^{\text{lead}}\right) = \frac{d\sigma_{N_{\text{jets}}\geq 3}}{dp_T^{\text{lead}}} \Bigg/ \frac{d\sigma_{N_{\text{jets}}\geq 2}}{dp_T^{\text{lead}}}$$

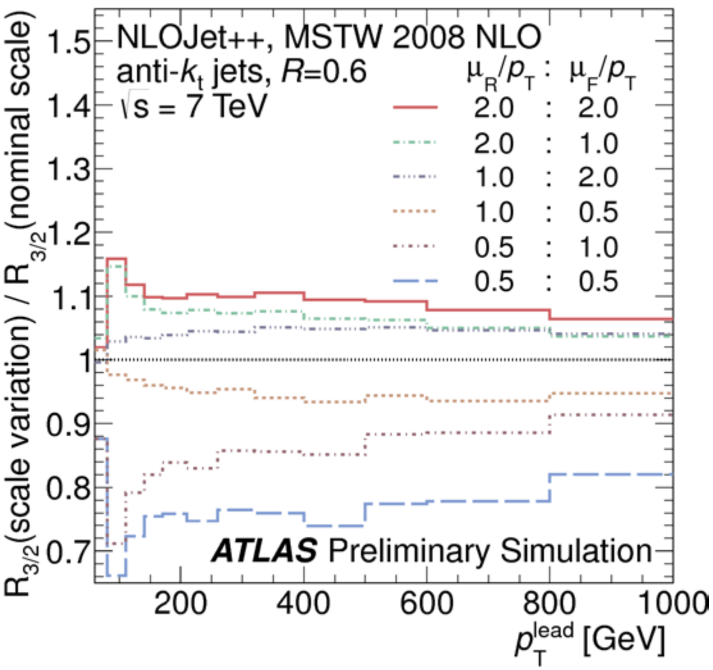
  - Ratio of the inclusive jet cross-sections (similar sensitivity)

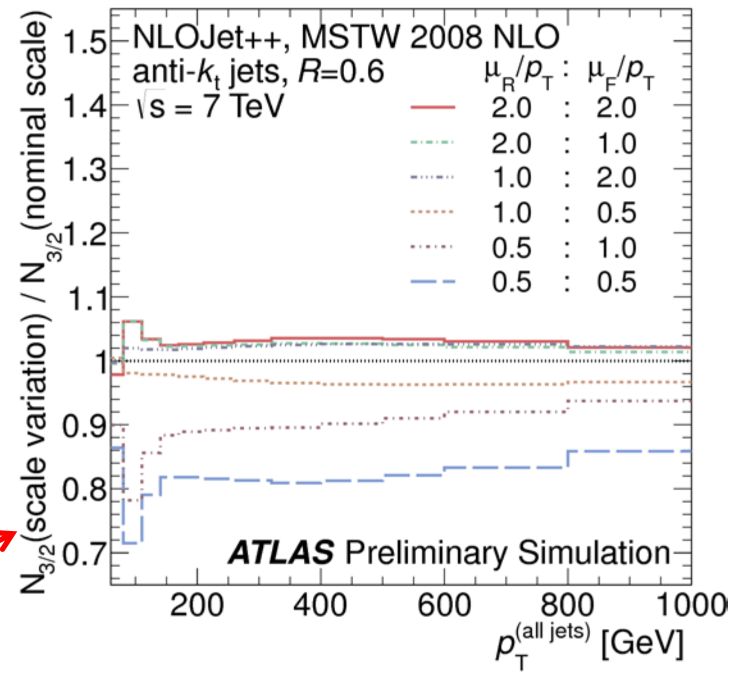
$$N_{3/2}\left(p_T^{\text{all jets}}\right) = \sum_i^{N_{\text{jets}}} \frac{d\sigma_{N_{\text{jets}}\geq 3}}{dp_{T,i}} \Bigg/ \sum_i^{N_{\text{jets}}} \frac{d\sigma_{N_{\text{jets}}\geq 2}}{dp_{T,i}}$$

all jets in the event

Scale Dependence of pQCD Calculations

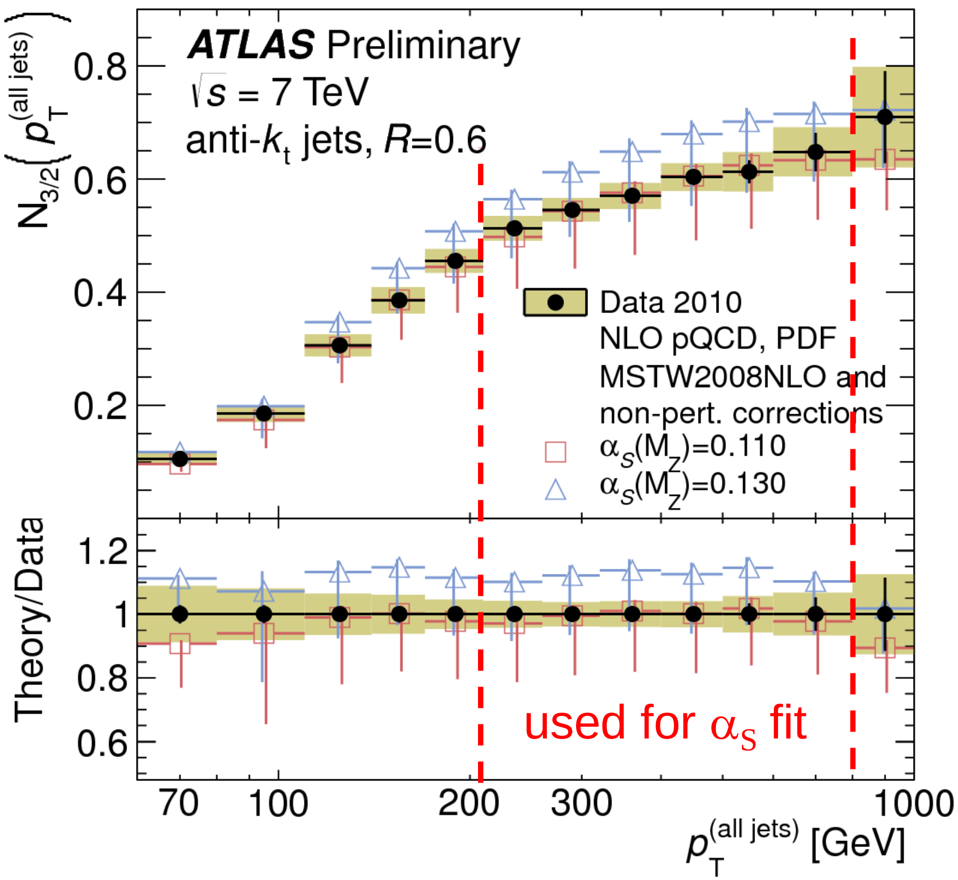
- α_S is determined from comparison to theory prediction
  - fixed-order NLO perturbative QCD calculations with non-perturbative corrections
- $R_{3/2}$ predictions use renormalization and factorization scales set to the leading jet p_T ($\mu_R = \mu_F = p_T^{lead}$)
- For $N_{3/2}$, the scales are set to the p_T of each jet





- $N_{3/2}$ is more stable against the choice of scale ⇒ use it for α_S extraction

Measurement of $N_{3/2}$ and fit of $\alpha_S(M_Z)$



- $\alpha_S(M_Z)$ is extracted by comparison to NLOJet++ predictions made with different values of $\alpha_S(M_Z)$ [0.110, 0.130]
  - Least Squares fit to data, minimizing $\chi 2$ w.r.t. $\alpha_S(M_Z)$
  - Over 6 p_T bins $\in$ [210, 800 GeV] simultaneously
- Correlated systematic uncertainties included as nuisance parameters
- Theoretical uncertainties estimated by altering theoretical predictions

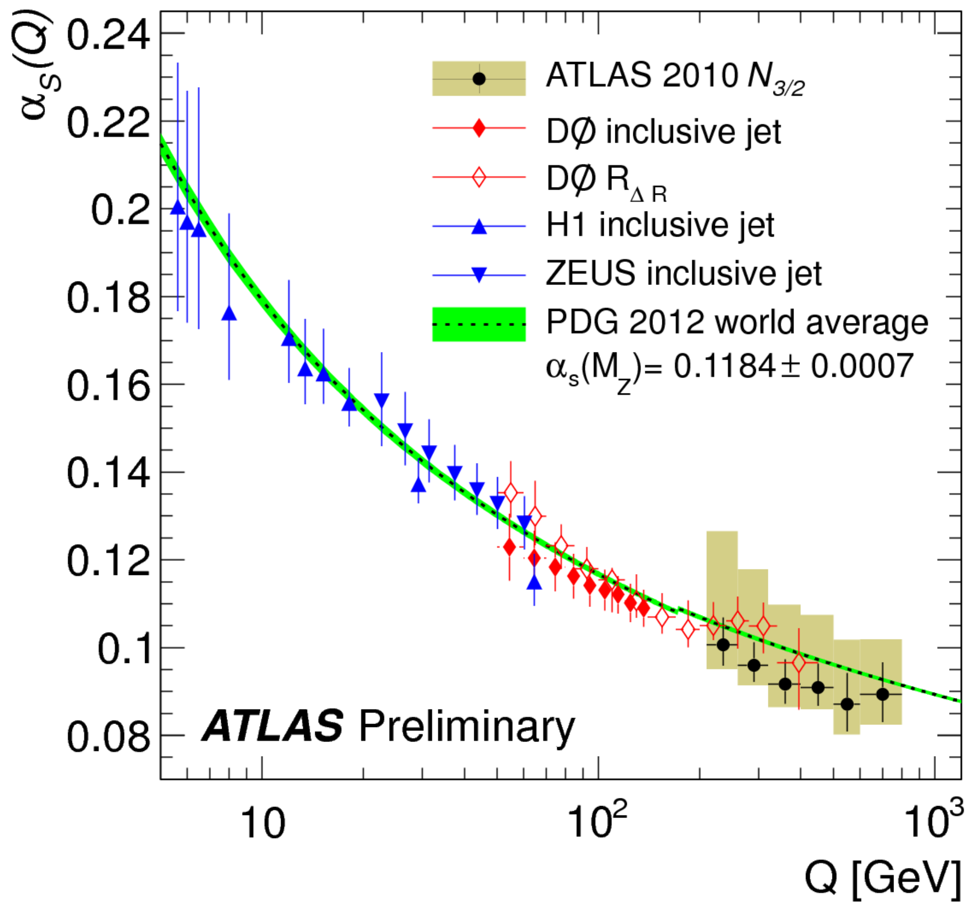
$$\alpha_S(M_Z) = 0.111 \pm 0.006(\text{exp.})^{+0.016}_{-0.003}(\text{theory})$$

PDG value – $\alpha_S(M_Z) = 0.1184 \pm 0.0007$

In agreement

The running of α_s

- $\alpha_S(Q)$ is determined by extracting $\alpha_S(M_Z)$ from each pT bin individually
- These $\alpha_S(M_Z)$ are transformed to $\alpha_S(Q)$ using 2-loop approximate RGE solution
  - Q = average jet pT for that bin
- Scale probed is extended beyond previous measurements to Q = 800 GeV

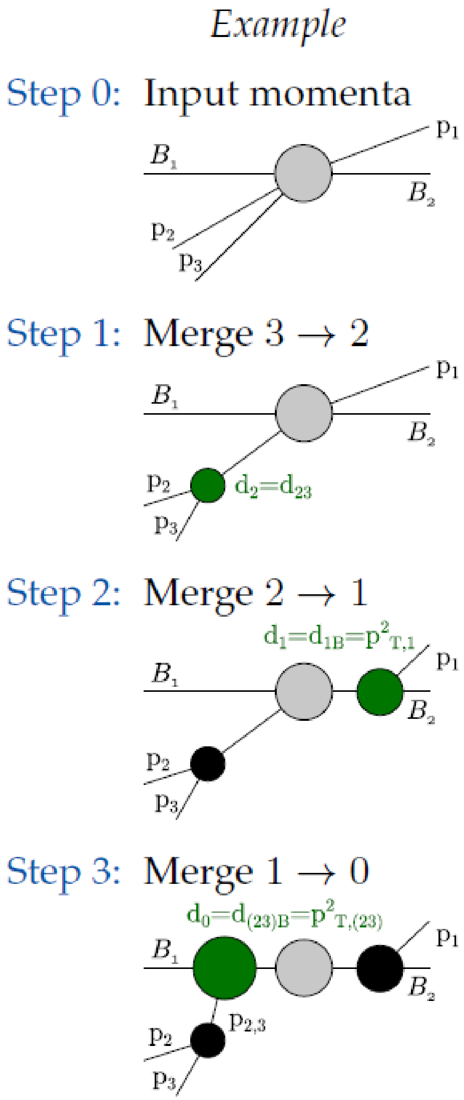


Data
L = 36 pb^{-1} at 7 TeV (2010)
$|\eta|$ < 2.8, p_T^{lead} > 60GeV

Confirms scaling behavior at high Q

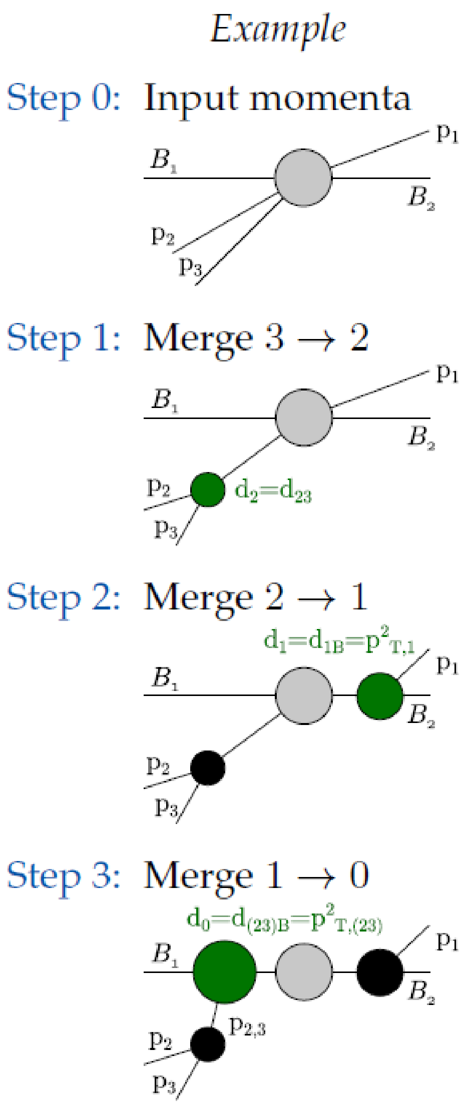
III. K_T splitting scales in W+jets events

- K_T clustering algorithm finds at every step minimum among all distances between momenta
  - $d_{ij} = \min\left(p_{ti}^2, p_{tj}^2\right)\frac{\Delta R_{ij}^2}{R^2}$
  - and distance to the beam $d_{iB} = p_{ti}^2$
- If minimal distance d_{ij} is smaller than distance to the beam d_{iB}, i-th and j-th momenta are combined together, otherwise new jet is created
- Input for cluster sequence in W+jets events - everything except the W decay products
  - Use W only as clean but abundant signal
- Define splitting scale $\sqrt{d_k}[GeV]$ as the $\sqrt{d_{min}}$ found at the step going from k + 1 → k

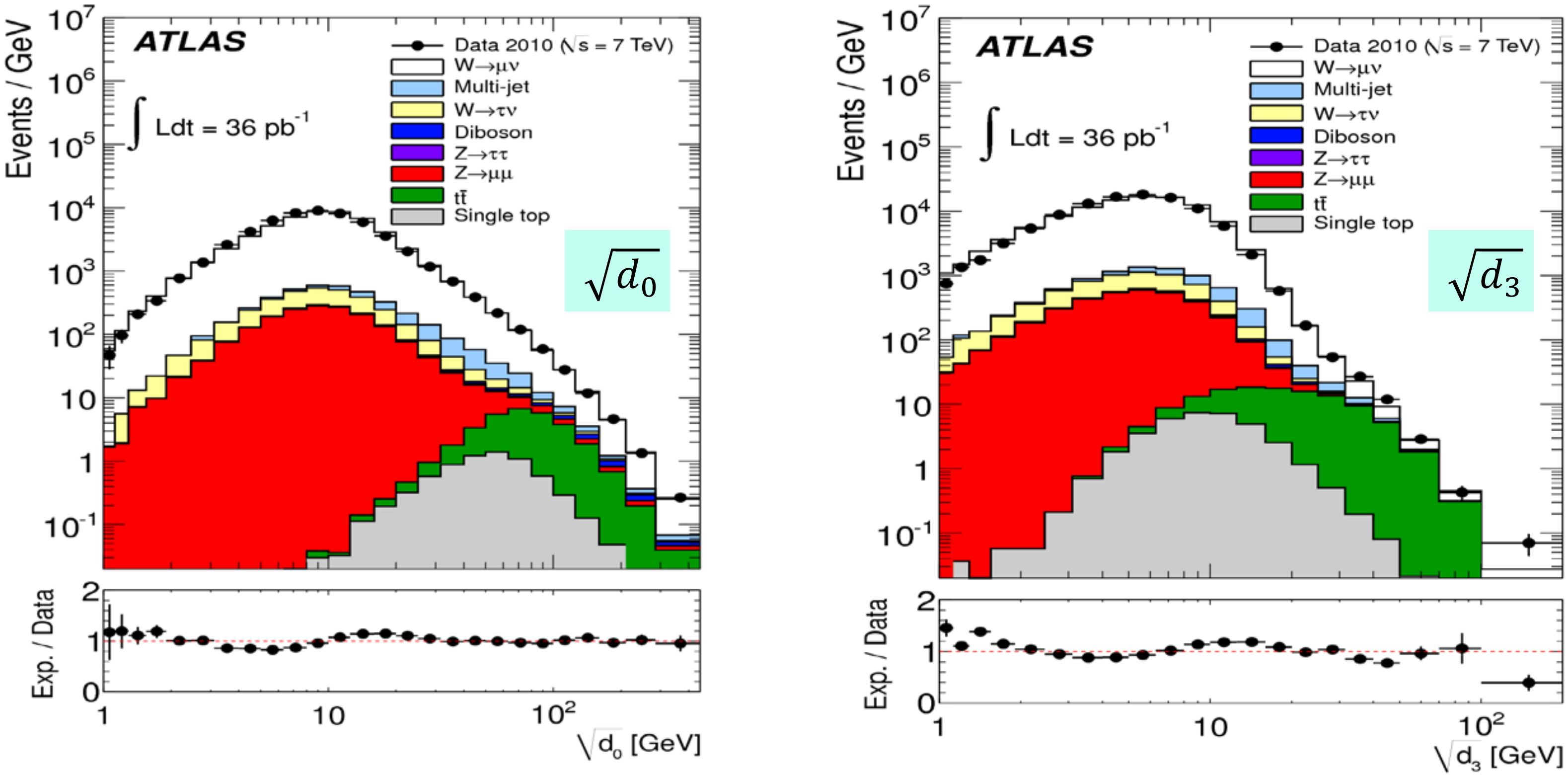


K_T observables

- 7 observables were measured in W+jets events (with W→μν, W→eν)
  - Splitting scale $\sqrt{d_k}$ for 0 <= k <= 3
    - Clean separation of soft and hard regions
  - Ratio of subsequent scales $\sqrt{\frac{d_{k+1}}{d_k}}$ for 0<=k<=2
    - Systematics cancel to some extent
    - Cut on $\sqrt{d_k}$ > 20 GeV to avoid domination by non-perturb. Effects
- K_T measure identifies most singular pair in each step of the sequence
  - Measurement can probe QCD evolution
  - provides useful test of LO and NLO QCD Monte-Carlo generators and analytical calculations
  - $\sqrt{d_{k+1}/d_k} \rightarrow 1$ is of particular interest



Signal and background before unfolding
Splitting scale $\sqrt{d_0}$ vs $\sqrt{d_3}$

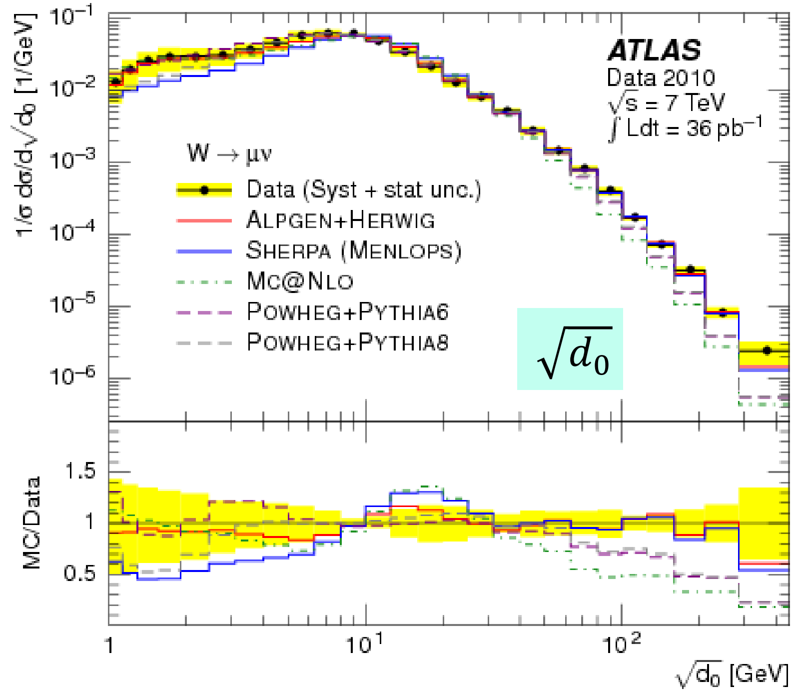


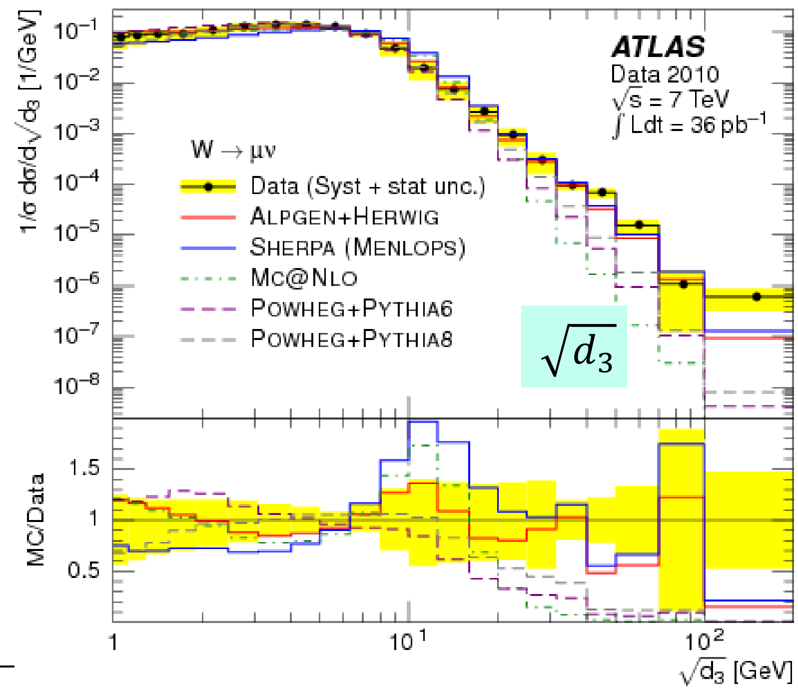
- Hardest and softest splitting scale measurement
  - Only muon results displayed here, electron channel is similar
  - Good Data/MC agreement (ALPGEN+HERWIG as signal MC)
  - At high $\sqrt{d_3}$: sensitive to 4-jet production $\Rightarrow$ large $t\bar{t}$ background

Unfolded results

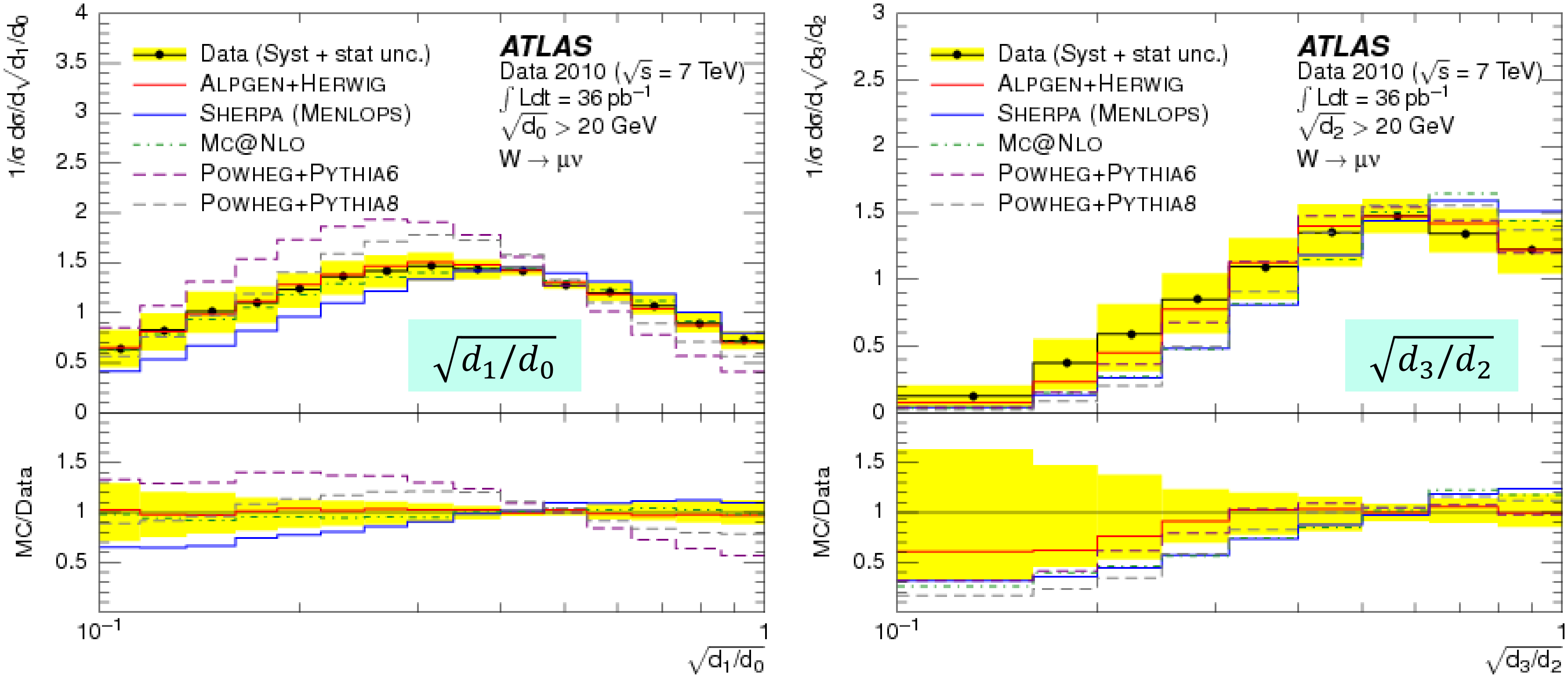
- ALPGEN+HERWIG (ME+PS) work very well at hard tail
- NLO+PS generators are low at hard tail (even in $\sqrt{d_0}$)
- HERWIG-based PS generators are best in soft (resummation) region
- Excess of SHERPA and MC@NLO in intermediate region

	W_{inc}	+1jet	+2-5jet	+≥6jet
ALPGEN+HERWIG	LO	LO	LO	PS
SHERPA (MENLOPS)	NLO	LO	LO	PS
MC@NLO+HERWIG	NLO	LO	PS	PS
POWHEG+PYTHIA6	NLO	LO	PS	PS
POWHEG+PYTHIA8	NLO	LO	PS	PS





Unfolded results for ratio observables



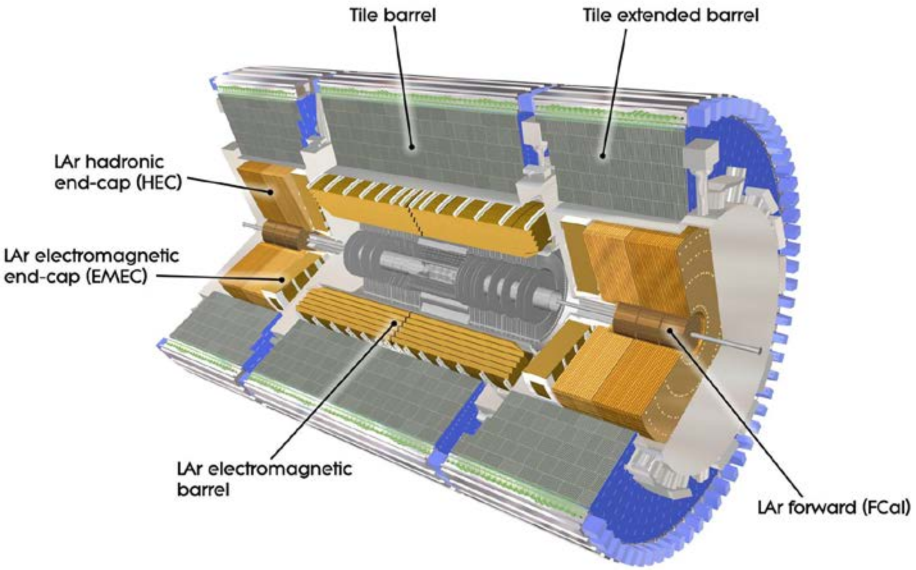
- HERWIG-based PS generators provide good description of leading ratio
- Outlier POWHEG+PYTHIA6
- Higher ratios: Most generators just outside uncertainty

Conclusions

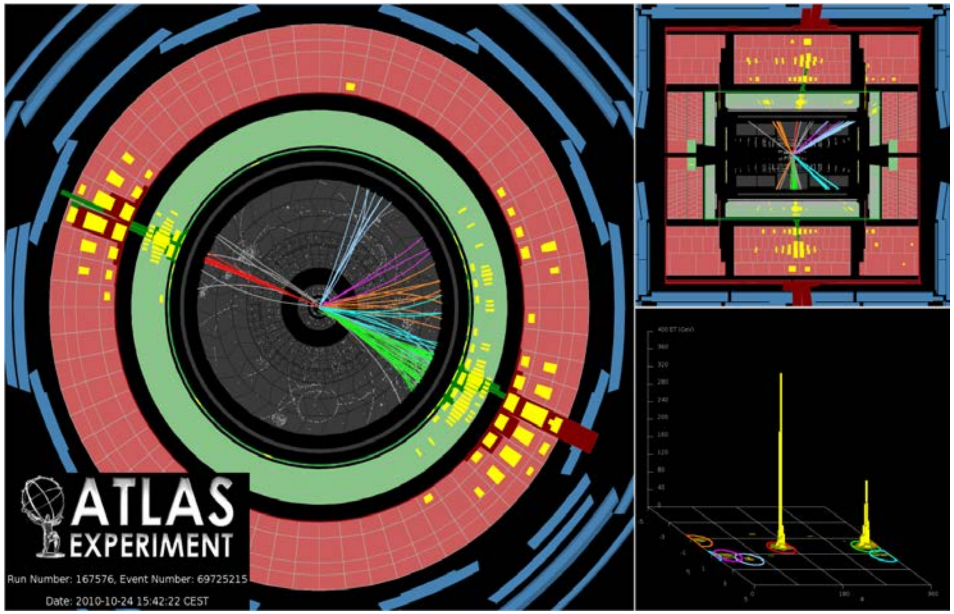
- Analysis of jet flavour composition of dijet events is an excellent tool to study perturbative QCD and to validate MC generators
  - Bottom-light flavour composition is found to be larger than the NLO or LO predictions.
  - Other flavour compositions are reproduced by the predictions.
- New observable $N_{3/2}$ in analysis of the multi-jet events provides direct measurement of strong coupling constant
  - $\alpha_S(M_Z)$ derived with global fit is in agreement with PDG value
  - Measurement of $\alpha_S(Q)$ is extended to Q = 800 GeV
- Measurement of k_T splitting scales in $W \rightarrow l\nu$ events improves the theoretical modeling of QCD effects and provides useful test of LO and NLO QCD Monte-Carlo generators
  - LO multi-leg predictions perform better than NLO+PS generators especially in hard tails
  - Significant differences found in soft region

BACKUP

Calorimetry in ATLAS



High mass (2.6 TeV) dijet event



- Fine granularity calorimeters
  - $\Delta\eta \times \Delta\varphi$ = 0.025 x 0.025 in EM barrel
  - 0.1 x 0.1 elsewhere (0.2 x 0.1 outer most layer)
- Good EM, HAD longitudinal segmentation (up to 7 samplings in barrel)
- Good η coverage: EM - $|\eta| < 3.2$, HAD - $|\eta| < 4.9$
- Excellent jet energy resolution: $\sigma/E \approx 0.55/\sqrt{E} + 5/E$

Jet Reconstruction and Calibration

Calorimeter cells
(EM-scale)

Noise suppression,
local hadronic /EM-scale
calibration

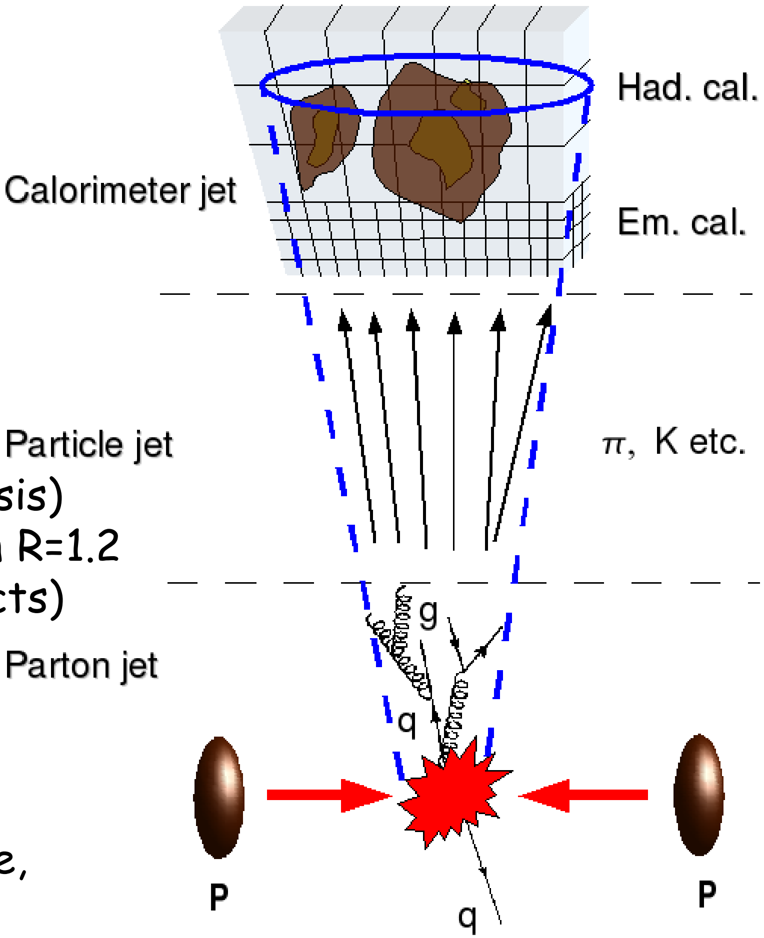
Topological clusters

- Anti-k_T R=0.4,0.6 (most of analysis)
- Anti-k_T R=1.0,Cambridge-Aachen R=1.2
 (jet substructure, boosted objects)

Calorimeter Jets

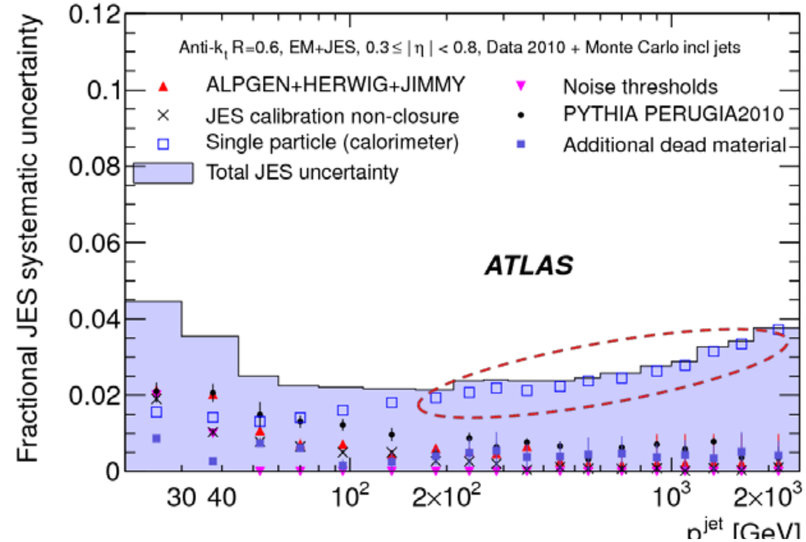
Offset correction (pile-up),
MC-based energy, η calibration
(inactive material, shower leakage,
residual insitu calibration)

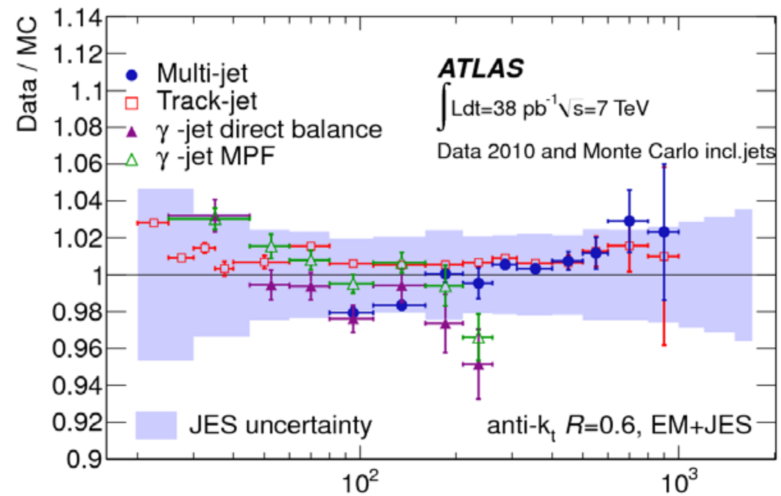
Particle Jets



Jet energy scale and its uncertainty

- Dominant source of experimental uncertainty is the jet energy scale
- Six (+1 in forward bins) JES components
- Calorimeter response is the major one with complex correlation.
- The others are independent and 100% correlated between bins
- In-situ techniques confirm the single particles based JES uncertainty
- In case of ratio measurements most of JES uncertainty is canceled out





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