Precision measurements of jet production at the ATLAS experiment

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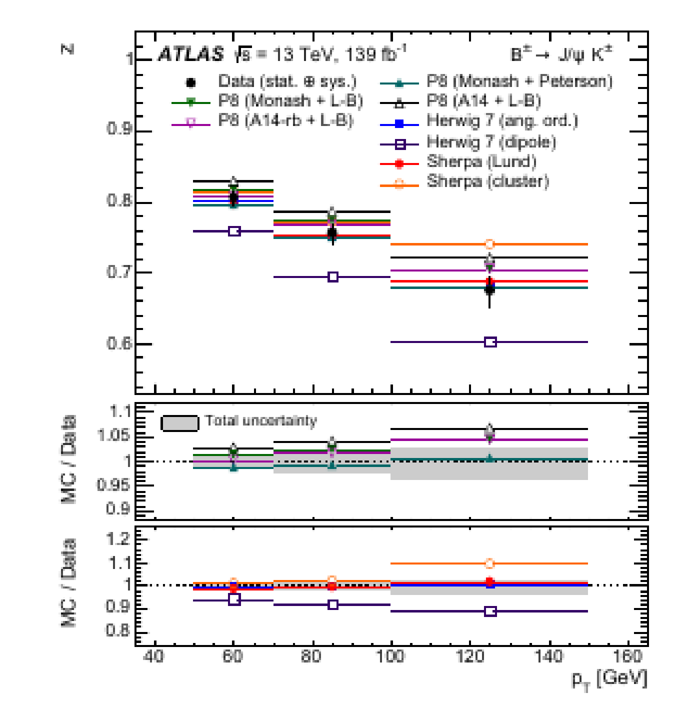
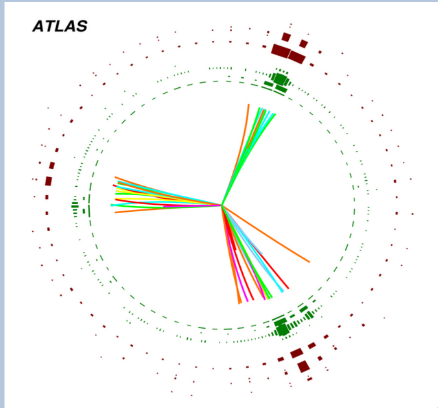
B fragmentation in jets using B→ J/Ψ K





Hadronic event shapes for multijets

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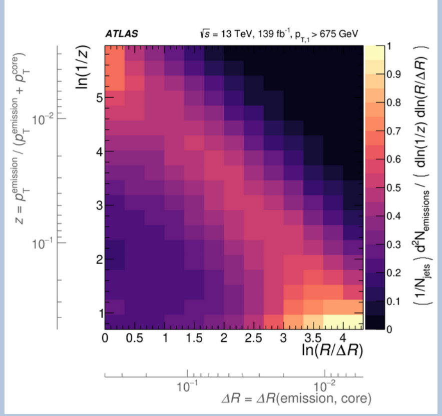

Lund plane on charged particles in dijet events

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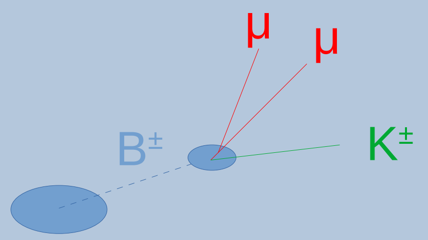
B fragmentation

- Identify B hadron from $B^{\pm} \rightarrow J/\Psi\ K^{\pm}$

  $\rightarrow \mu^{+}\mu^{-} K^{\pm}$



- Associate B meson to jet and compute

$$z = \frac{\vec{p}_B \cdot \vec{p}_j}{|\vec{p}_j|^2}; \quad p_{\mathrm{T}}^{\mathrm{rel}} = \frac{|\vec{p}_B \times \vec{p}_j|}{|\vec{p}_j|},$$

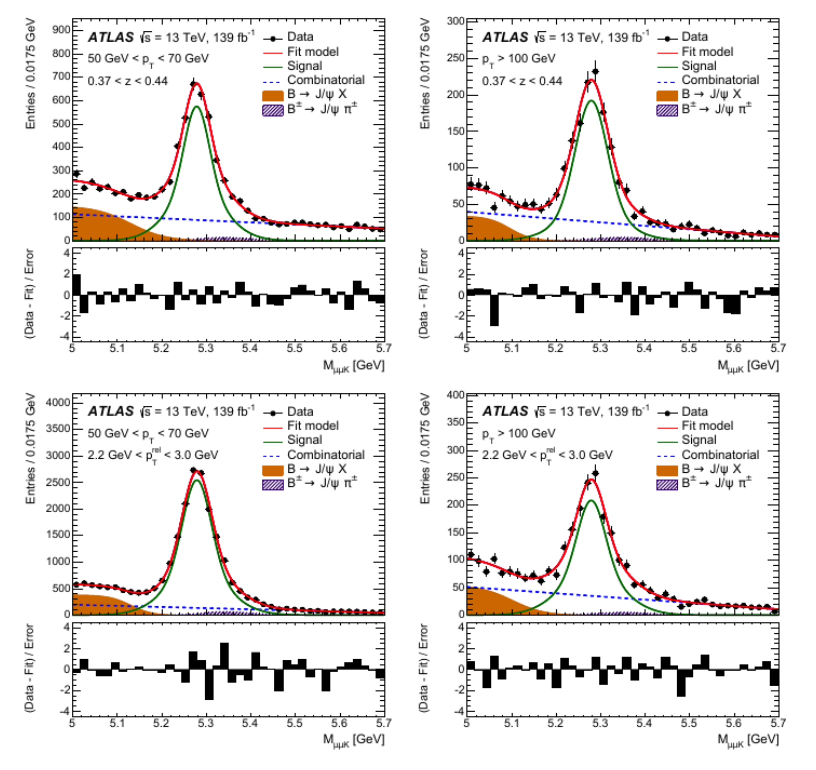
- Unfold at particle level in bins of z, p_T^{rel} for $50<p^T_j<70$, $70<p^T_j<100$, $p^T_j>100$

- Measurements from all Run2 data (139 fb^{-1}) compared to MC:

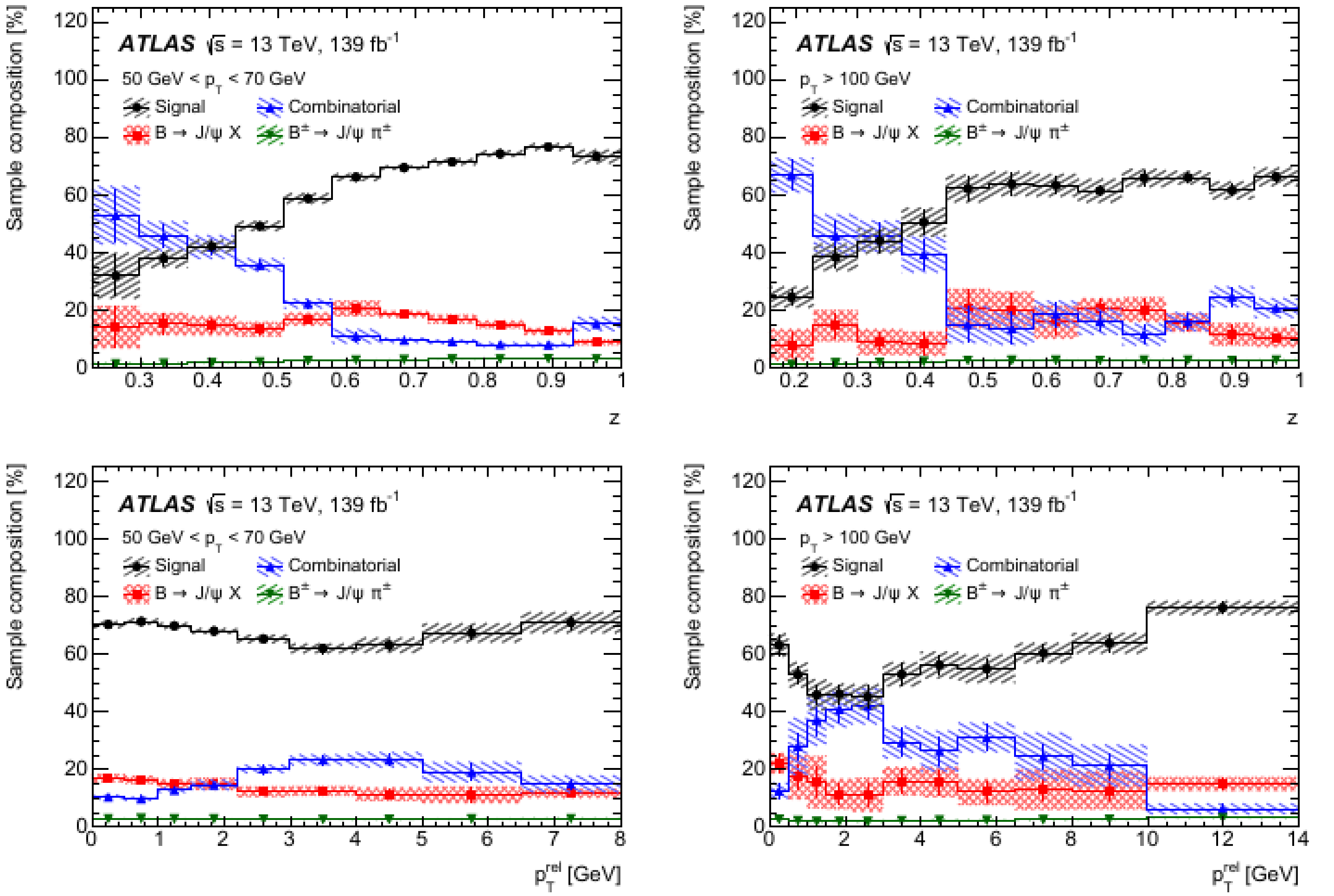
Generator	ME order	Scales μ_r, μ_f	Parton shower	PDF set	Tune	Hadronisation
Pythia 8	$2 \rightarrow 2$ @ LO	$(m_{T3} \cdot m_{T4})^{\frac{1}{2}}$	p_T-ordered	CTEQ6L1	A14	Lund–Bowler
					A14-rb	Lund–Bowler
				NNPDF2.3	Monash	Lund–Bowler
						Peterson
Sherpa	$2 \rightarrow 2$ @ LO	$H(s,t,u)$	CSS (dipole)	CT14	–	Cluster model
						String model
Herwig 7	$2 \rightarrow 2$ @ LO	$\sqrt{\frac{2stu}{s^2+t^2+u^2}}$	Angle-ordered Dipole	MMHT2014	–	Cluster model

B hadron selection

- J/Ψ: 2 OS μs with pT>6 GeV
  |η|<2.5, 2.6 < $m_{\mu\mu}$ < 3.6 GeV
  from displaced vertex
- $K^{\pm}$: third track from same vertex,
  pT > 4 GeV, |η|<2.5
- Assume PDG masses for J/Ψ, K, require
  5 < m_B < 5.7 GeV
- Assuming PDG mass for B,
  $\tau = m_B L_{xy}/p_T > 20$ ps



Purity and BG components



The b-hadron invariant mass was fitted in each z, p_T^{rel} bin using components from MC templates:

$$\mathcal{F}(m) = \lambda_s \mathcal{F}_s(m) + \lambda_{B_x} \mathcal{F}_{B_x}(m) + \lambda_{B_\pi} \mathcal{F}_{B_\pi}(m) + \lambda_c \mathcal{F}_c(m),$$

Fit shows

signal purity ~ 70%,

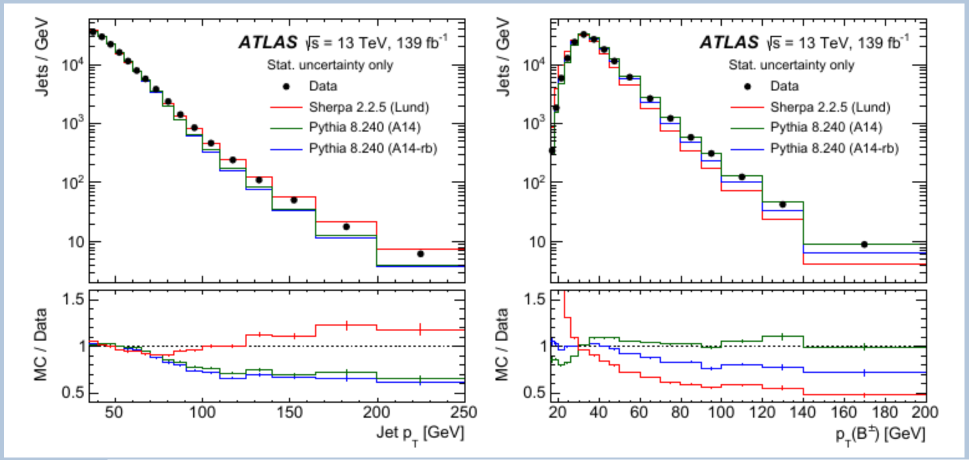
lost pion 15%,

combinatorial 12%,

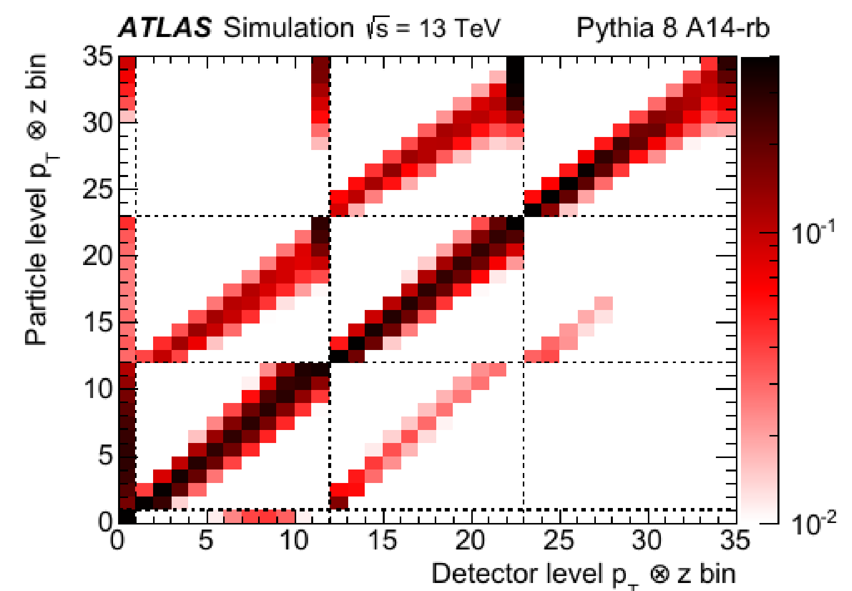
J/Ψ π 3%

Jet, mesons and unfolding

- Anti-kt 0.4 jets from p-flow within R=0.4 from meson.
- Jet pT>50 GeV in 3 bins

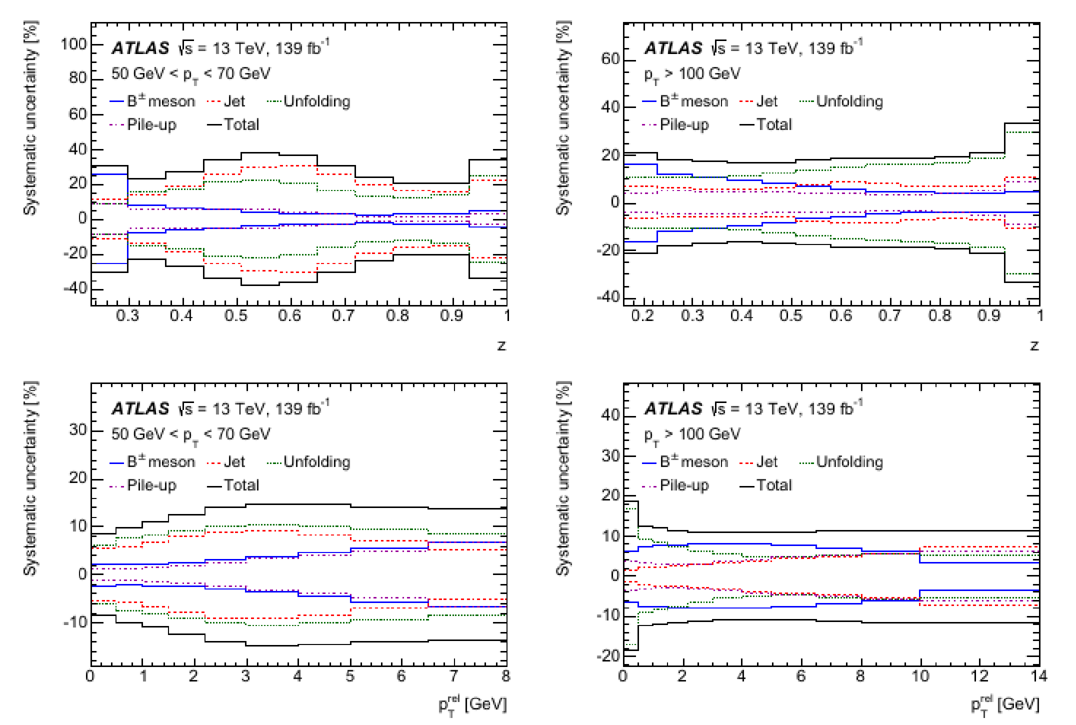


- Unfolding performed with RooUnfold Iterative Bayesian, with purity of transfer matrix between 60% and 100%



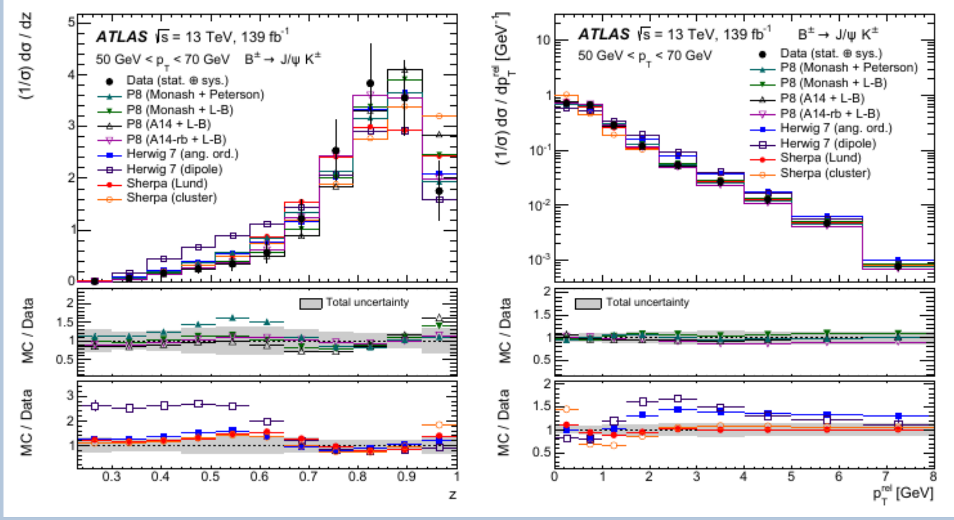
Systematic uncertainties

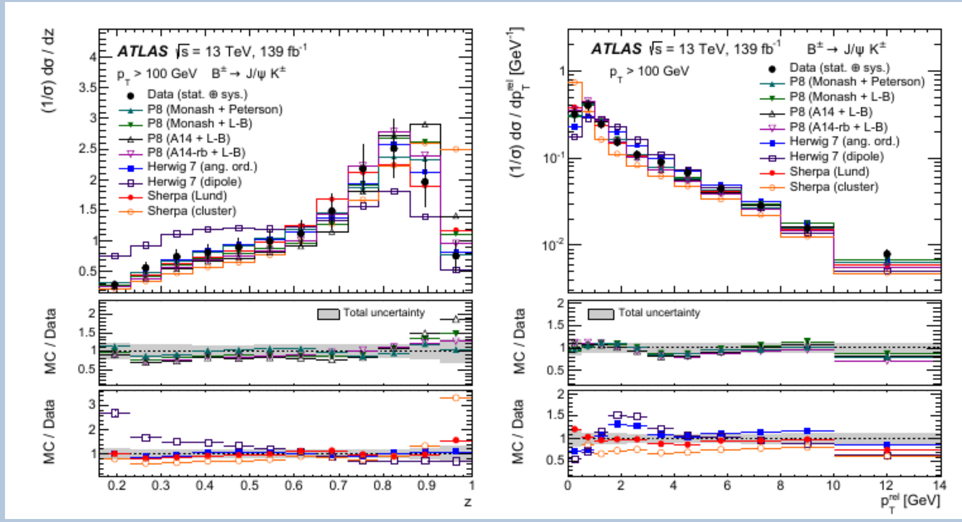
- B meson reconstruction
  - Purity corrections (from different models)
  - Muon momentum scale and resolution
  - Muon identification
  - Trigger and kaon reconstruction
- Jets
  - Jet Energy Scale, Jet Energy Resolution (main)
    Jet Angular Resolution
  - Jet vertex Tagger for pileup mitigation
- Unfiolding
  - Mis-modeling from MC used in unfolding
  - Use of a specific MC model
- Pileup
  - Compare μ<32 and μ≥32



Results: z and p_T^{rel}

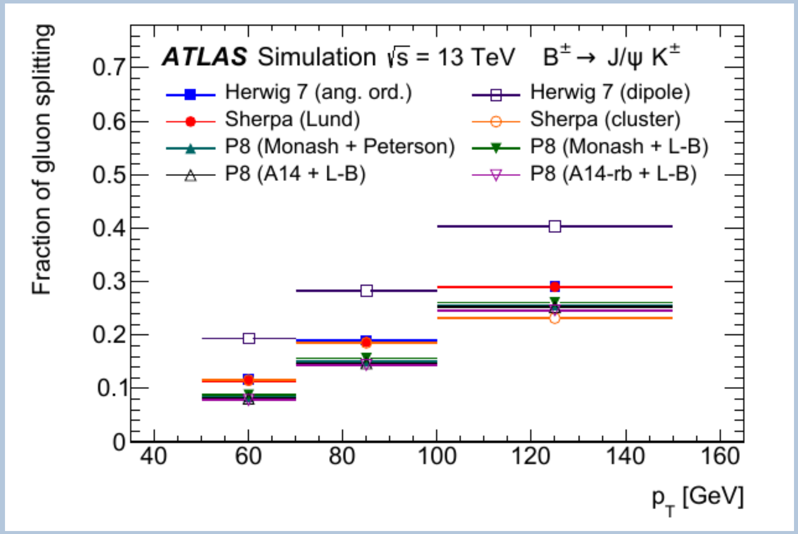
- Gluon splitting $g \rightarrow bb$ results in smaller z and higer p_T^{rel}
- Disagreement with Herwig7 dipole PS due to larger GS
- Sherpa cluster model disagrees at high z and low p_T^{rel}
- Pythia8 Monash overestimates data at mid-z and low p_T

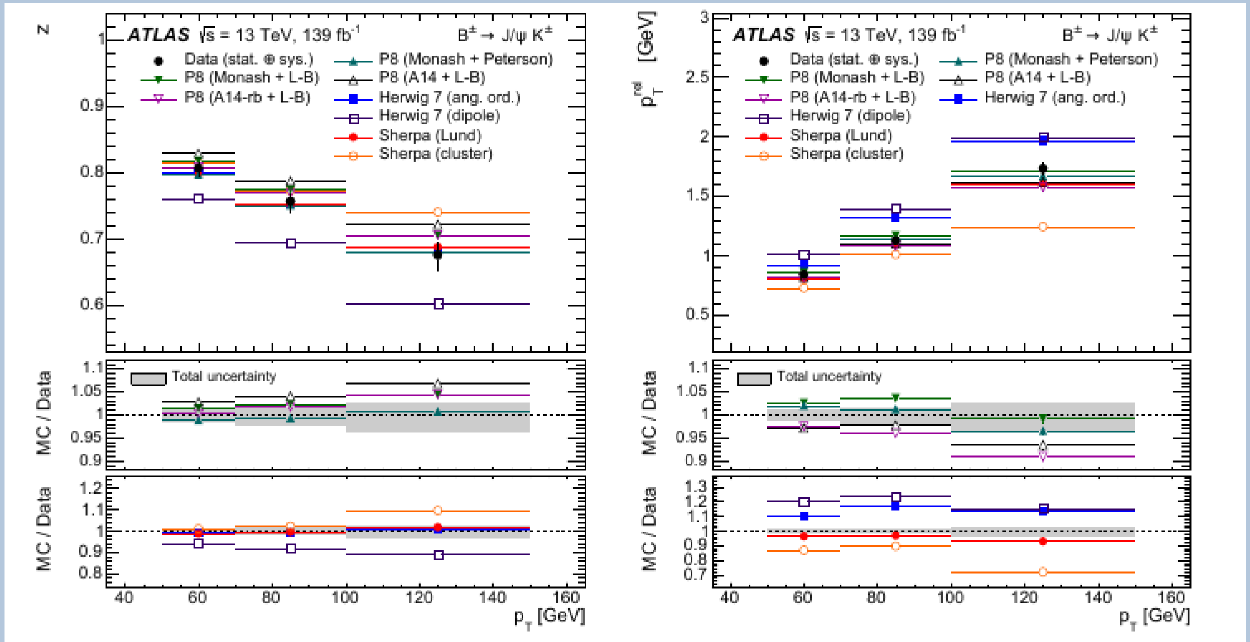




Scale dependence

- Large differences in the amount of gluon splitting in model
- Strong correlations between these differences and the observed discrepancies with data on the average values of z and p_T^{rel} vs p_T^{jet}





Event shapes in multijets

- Six event-shape variables measured as a function of jet multiplicity in three intervals of HT
- Thrust major/minor

$$T_\perp = \frac{\sum_i |\vec{p}_{T,i} \cdot \hat{n}_T|}{\sum_i |\vec{p}_{T,i}|}; \quad T_m = \frac{\sum_i |\vec{p}_{T,i} \times \hat{n}_T|}{\sum_i |\vec{p}_{T,i}|},$$

- Sphericity and aplanarity, from linear combinations of eigenvalues of

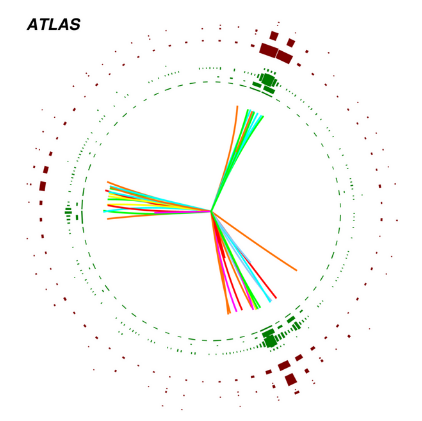
$$\mathcal{M}_{xyz} = \frac{1}{\sum_i |\vec{p}_i|} \sum_i \frac{1}{|\vec{p}_i|} \begin{pmatrix} p_{x,i}^2 & p_{x,i}p_{y,i} & p_{x,i}p_{z,i} \\ p_{y,i}p_{x,i} & p_{y,i}^2 & p_{y,i}p_{z,i} \\ p_{z,i}p_{x,i} & p_{z,i}p_{y,i} & p_{z,i}^2 \end{pmatrix}.$$

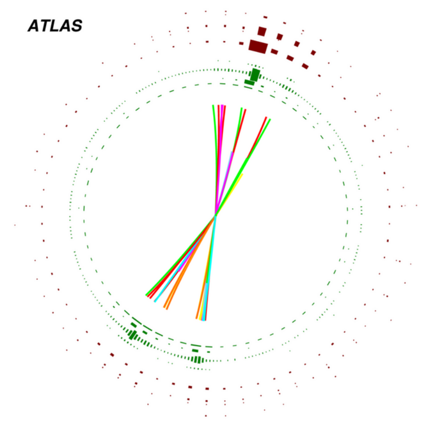
$$S = \frac{3}{2}(\lambda_2 + \lambda_3); \quad A = \frac{3}{2}\lambda_3.$$

- C and D from cubic and quartic combinations

$$C = 3(\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_2\lambda_3),$$
$$D = 27(\lambda_1\lambda_2\lambda_3).$$

3-jet event with high values of $T_\perp$ and S

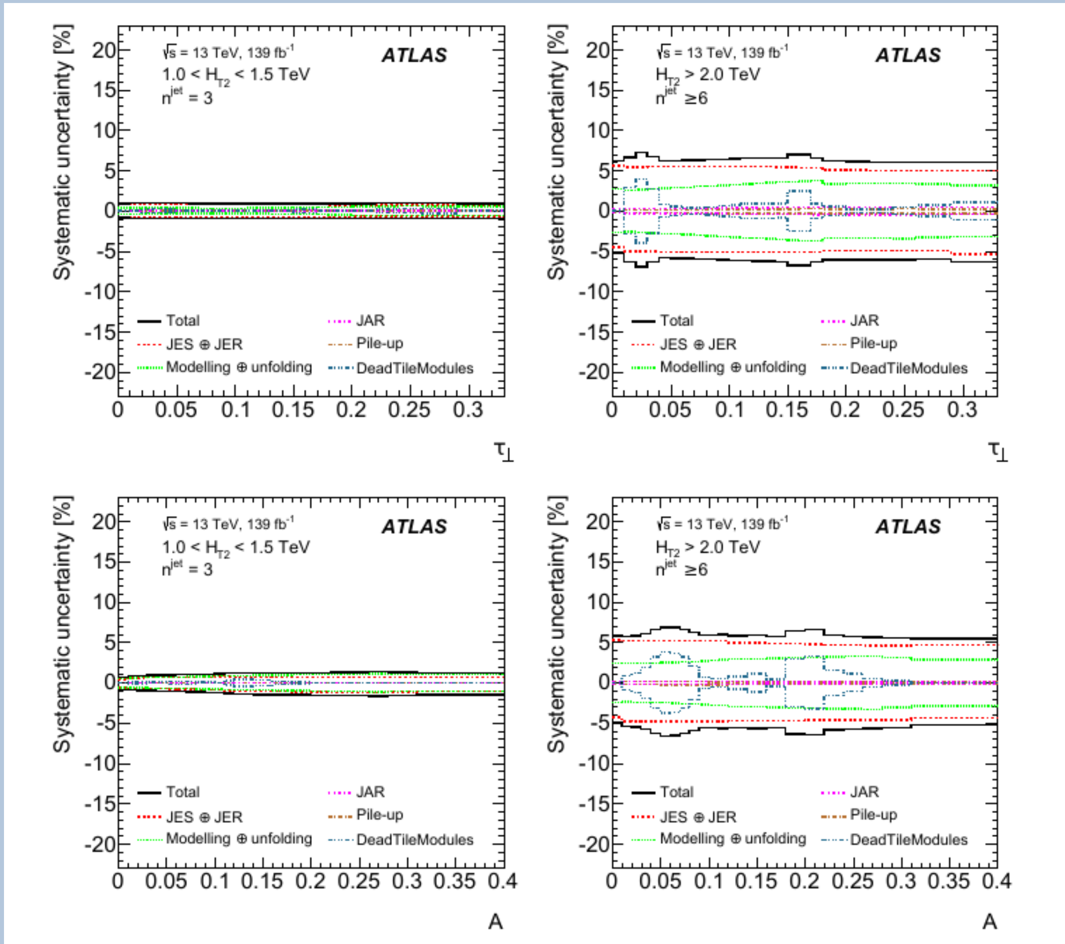




5-jet event with low values of $T_\perp$ and S

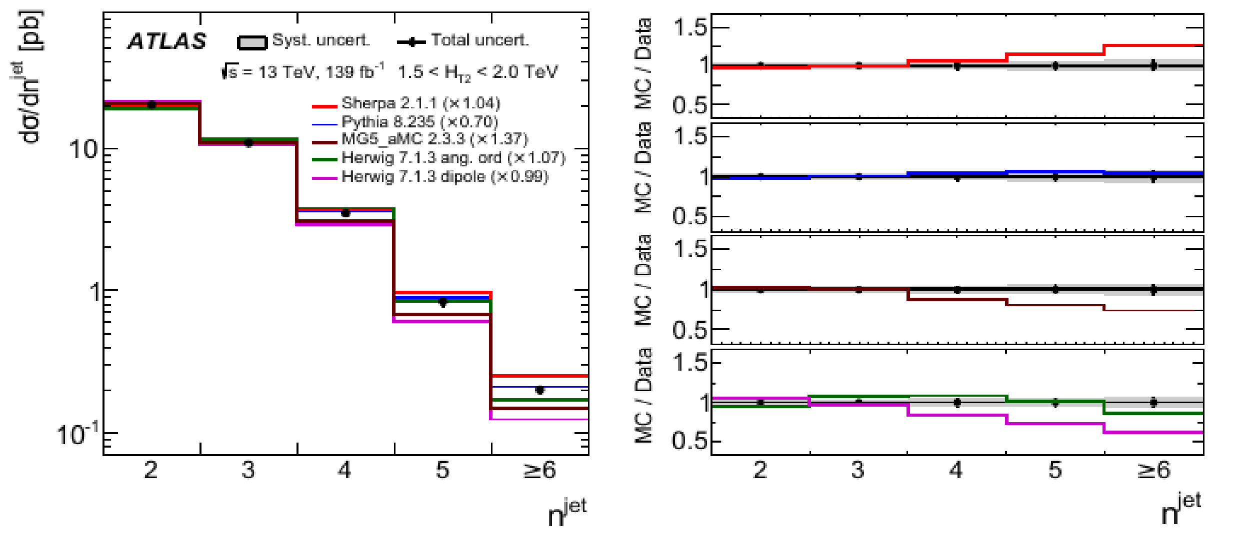
Selection and uncertainties

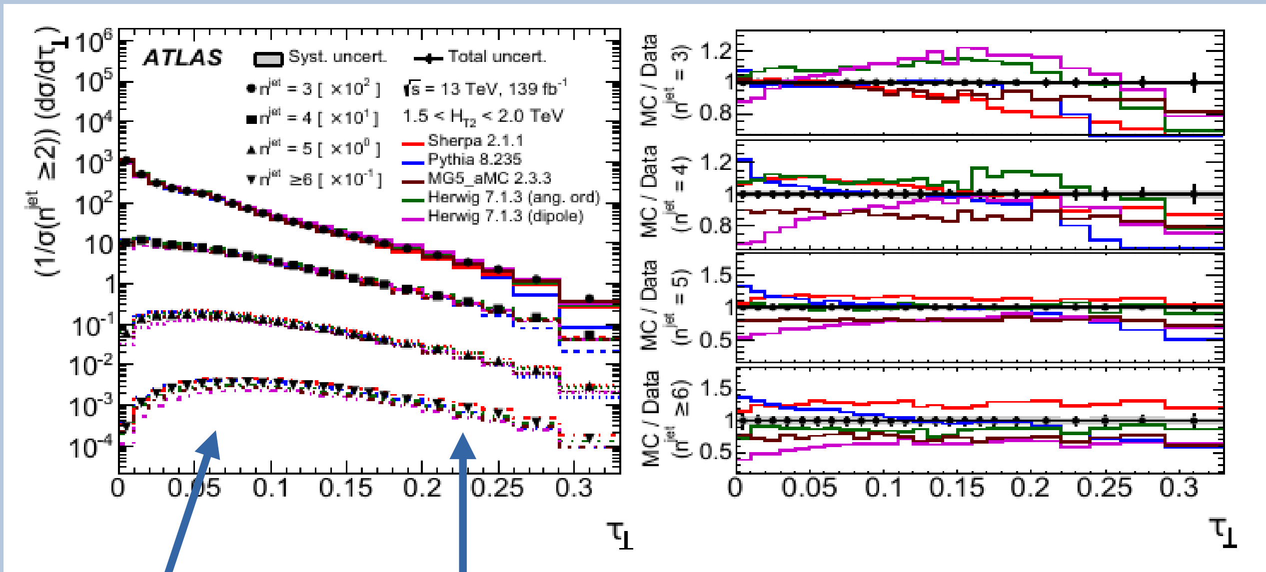
- AntiKt04 jets from Pflow with p_T>100 GeV, |η|<2.4, H_T1,2 > 1 TeV.
- Data from whole Run2
- Systematics:
  - JES, JER, JAR
  - Pileup (vary reweighting)
  - Unfolding (difference when MC reweighted to data)
  - Modeling (change MC reference in unfolding)
  - Luminosity
  - Dead-tiles



Jet multiplicity and Thrust

- MC normallised to data in each HT2 bin (pythia Xsec +30%, MG5 -35%)
- Sherpa overestimates high multiplicities, Herwig dipole underestimate
- MC above data for intermediate thrust, below for high thrust



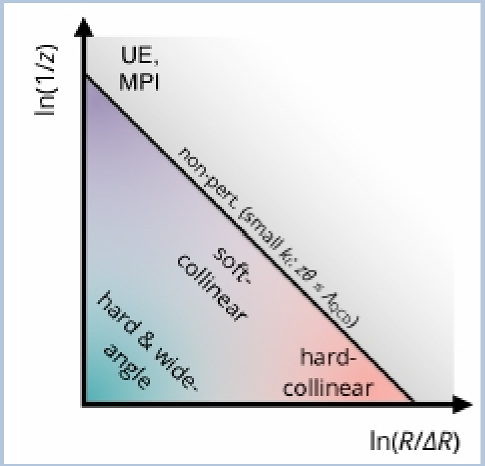


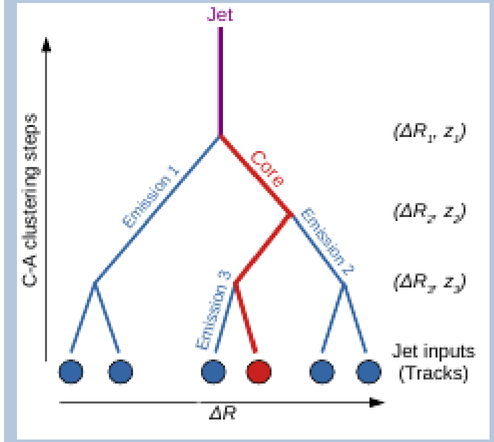
dijet-like

multijet-like

Lund Jet Plane from charged particles in hadronic events

- The LJP is an abstract description of jet development, with each entry corresponding to the transverse momentum and angle of any given emission with respect to the emitter
- Regions of plane point to various physical processes; uniform at LL
- Reconstructed by reversing CA clustering
- For experimental reasons, only on charged tracks, on jets with pT> 675 GeV
- 2-d unfolding on the plane using closest matching



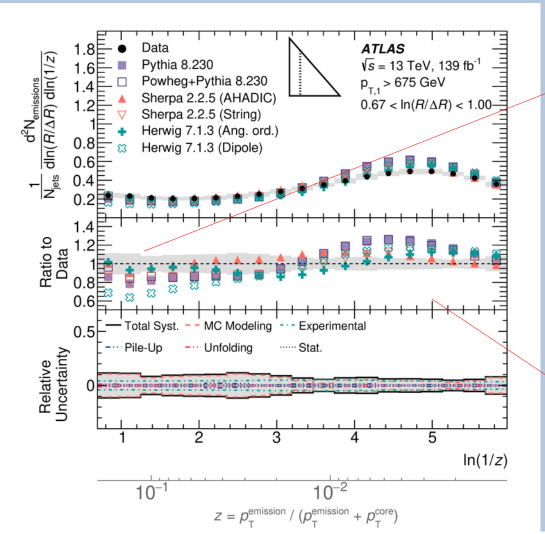


$$\Delta R = \sqrt{(y_{emision} - y_{core})^2 + (\phi_{emision} - \phi_{core})^2}$$

$$z = \frac{p_T^{emission}}{p_T^{emission} + p_T^{core}}$$

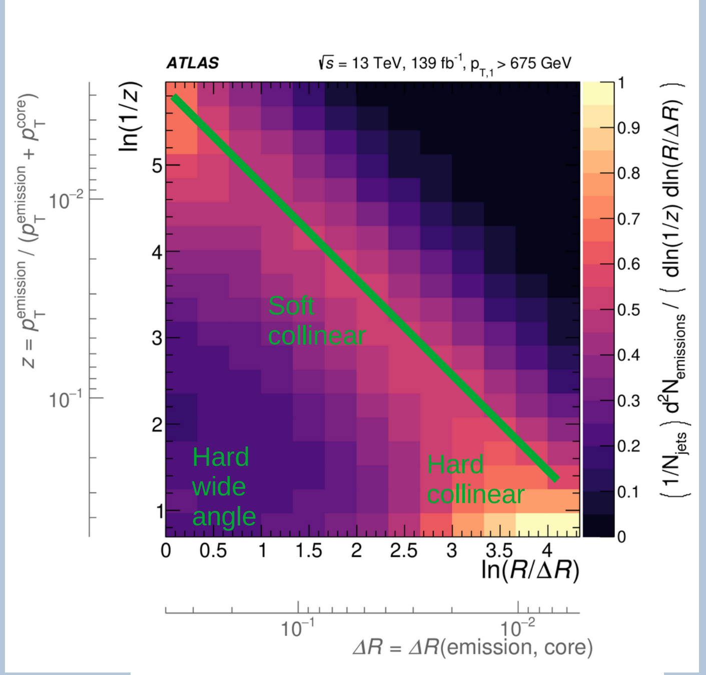
Undo last clustering step, defining two subjets j1, j2 ordered in pt
Use in plane the kinematics of this declustering
Define j = j1 and iterate until j is a single particle.

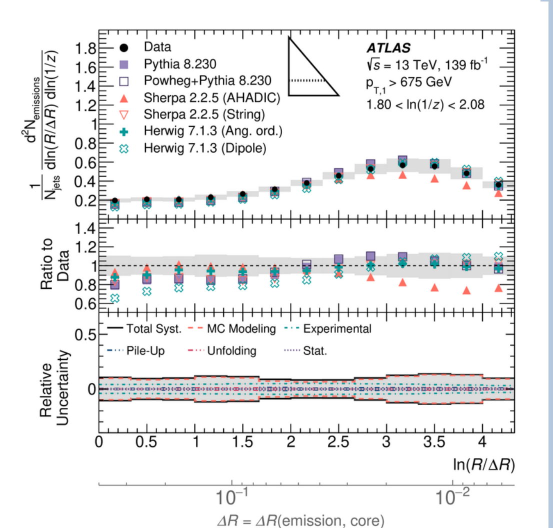
Lund Plane measurement and slices



Hard-wide angle: Differences in PS algorithms in Herwig as well as Pythia vs POWHEG

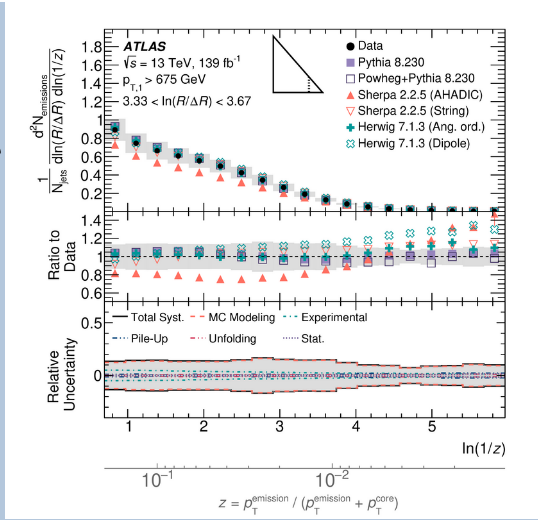
Soft collinear: highlight different hadronisation models in SHERPA





Most MC good in describing jet core, but fail at small z, i.e. large angle emission

Move from wide angle to collinear, probing PS (left) to hadronisation (right)



Conclusions

- QCD is an essential ingredient of SM, its apparent formal simplicity covering a very complex phenomenology
- Important to improve precision on other measurements, but a very interesting and intellectually challenging by itself
- Enormous theory effort to improve precision, now being matched by important measurements in specific regions of phase space
- Despite many improvements, still many divergences exist, and more corners of phase space yet to measure: many more clever measurements needed, I just presented some of them