Jet measurements at the LHC with ATLAS and CMS

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On behalf of ATLAS and CMS collaborations

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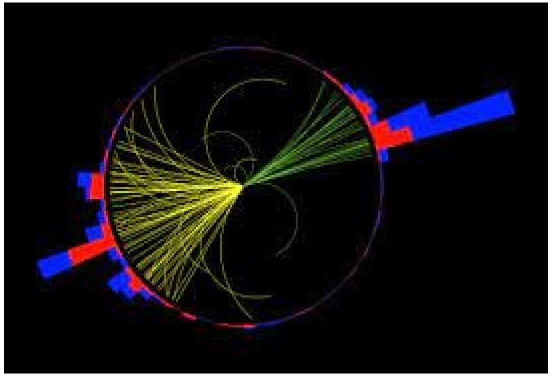
Introduction



- Jets are ubiquitous in hadron collisions
- measurements are crucial to improve :
  - understanding of various pertubative/non-perturbative aspects of QCD
  - Analysis techniques relying on jets
  - A typical example : Jet energy uncertainties due to q/g response differences is often dominating → Improving modelling and discrimination is important
- This presentation : selection of 4 very recent jet studies
  - Jet substructure in CMS and ATLAS
  - Double parton scattering in CMS
  - PDF fit with W/Z+jets events in ATLAS

Quark and gluon jet substructure in CMS

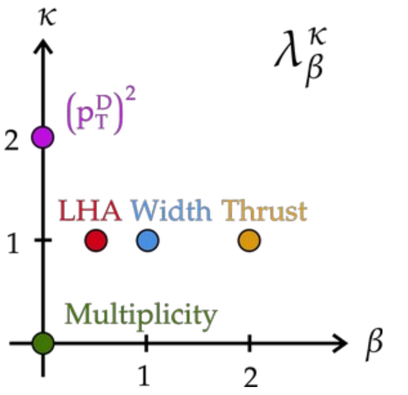
Quark and gluon jet substructure in CMS

CMS-PAS-SMP-20-010

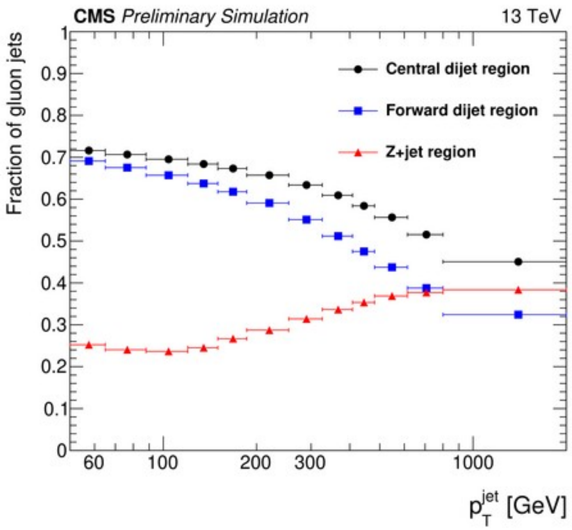
- Measured "generalized angularities" of jets

$$\lambda_\beta^\kappa = \sum_{i \in constituents} z_i^\kappa \left(\frac{\Delta R_i}{R}\right)^\beta, \quad z_i = \frac{p_{Ti}}{p_{Tjet}}$$

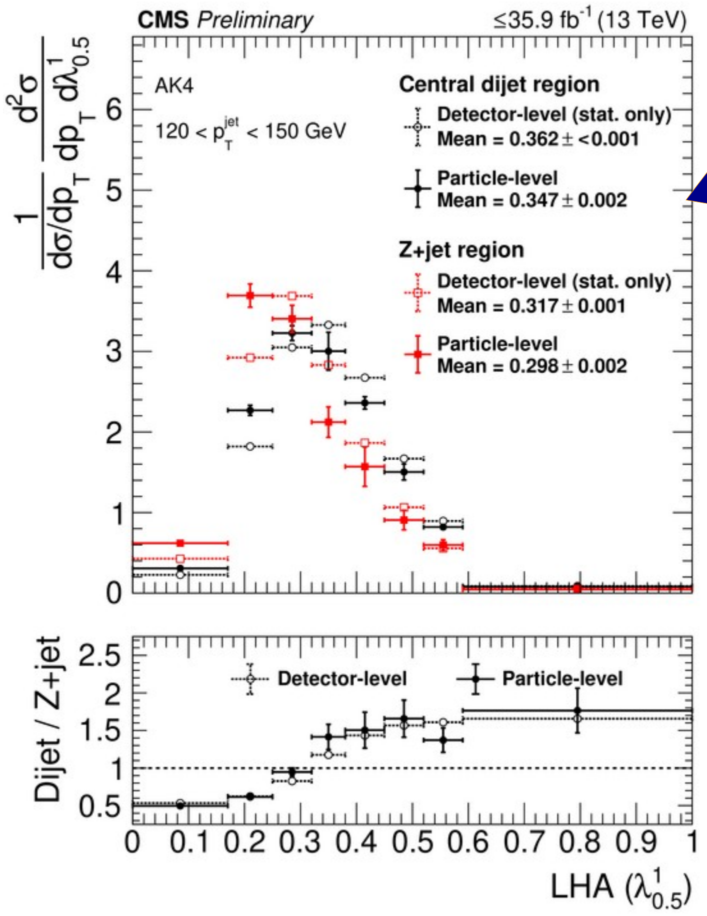
  - Different (β,κ) values emphasis different aspects of jet structure
- Measured in 2 event samples
  - Dijet : dominated by gluon-jets
  - Z+jets : dominated by quark-jets
  - Samples divided in p_T bins
- Observations unfolded to particle level and compared to several generators
- Measured for several jet variants
  - Small R/large R, groomed/ungroomed, ...



LHA : "Les Houches Angularity"

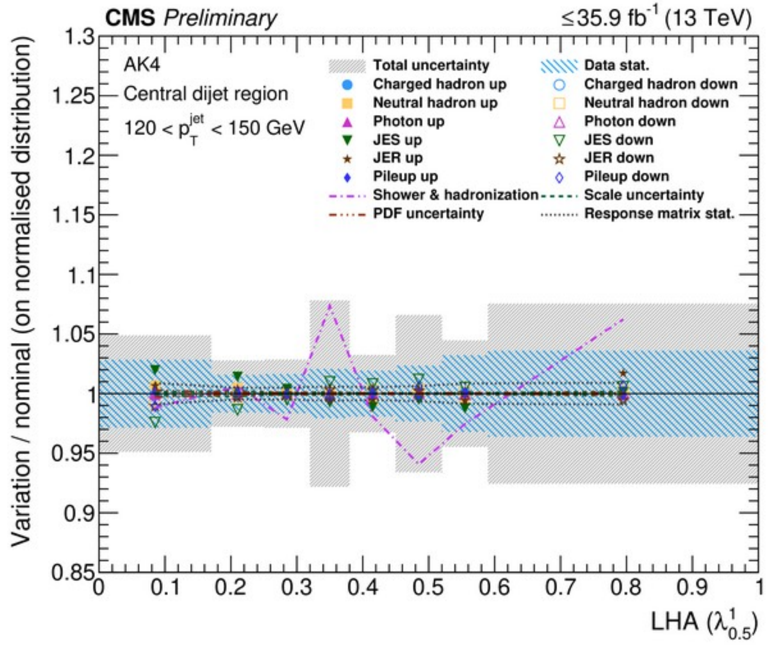


Quark and gluon jet substructure in CMS



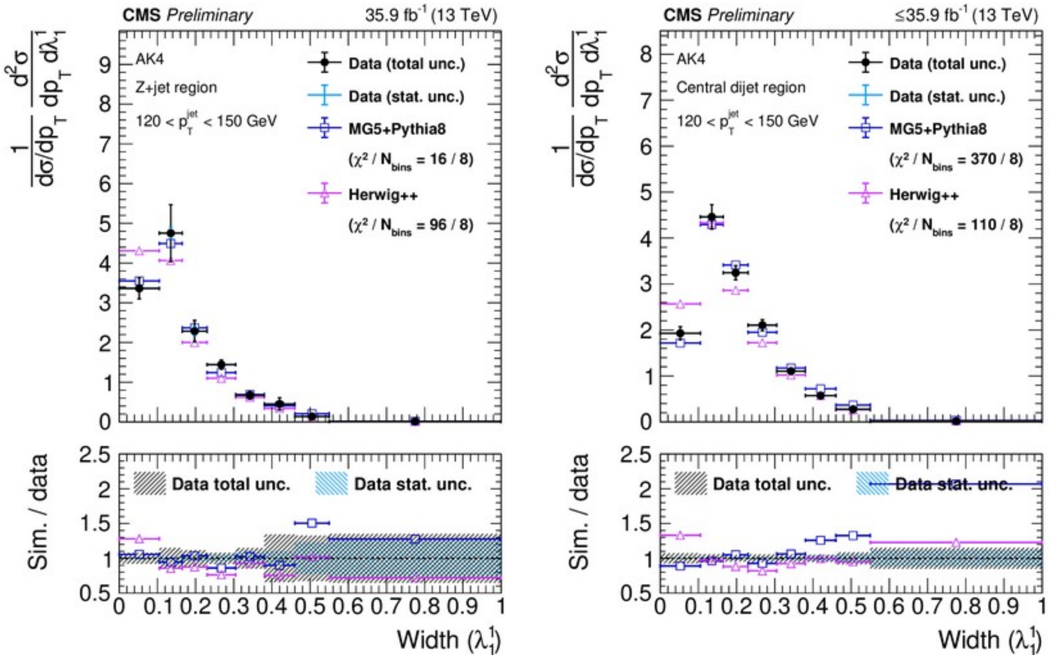
- Data distributions before/after unfolding
  - Detector impact varies according to variable
  - dijet/Zjet ratio indicates q/g discrimination power
- Uncertainties

Distributions normalized by p_T bins
→ dominant uncertainties : hadronisation & shower



Quark and gluon jet substructure in CMS

- Comparing main generators
  - MadGraph5+Pythia (nominal)
  - Herwig++



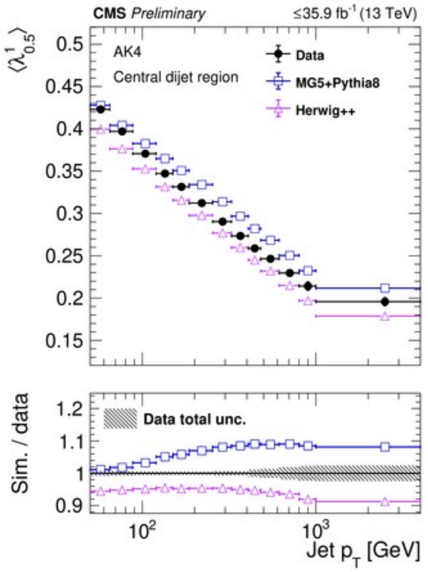
Other comparisons

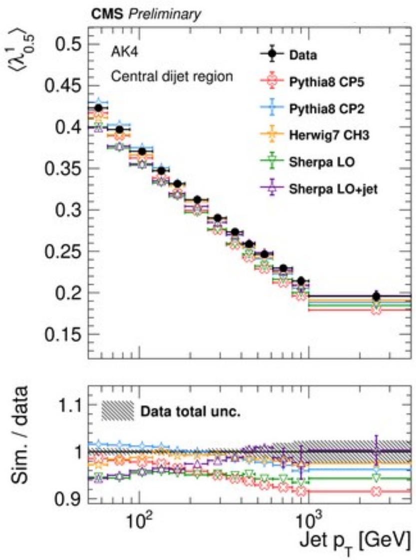
- Jet variants, variables & p_T bins

Show similar “envelopment” of data by MC predictions

Quark and gluon jet substructure in CMS

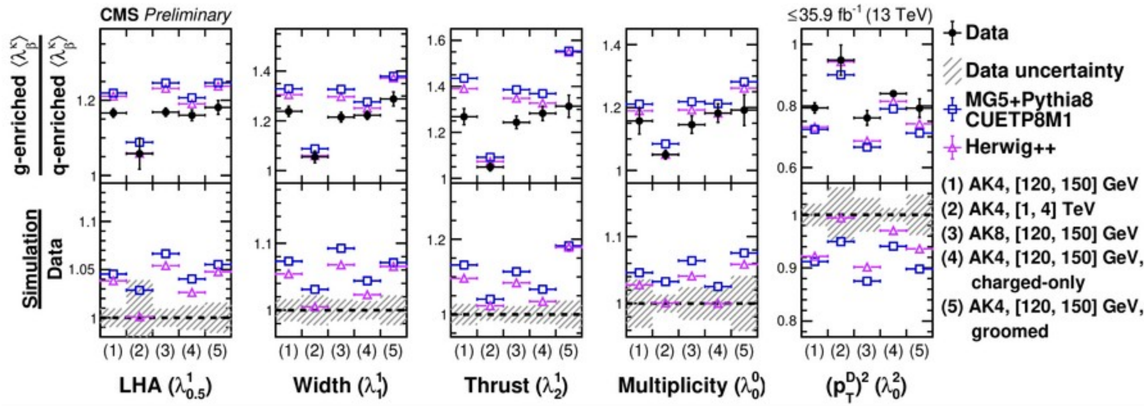
- Synthetic results : showing mean values of observables vs p_T bin
- Include generator variants
  - Pythia8 with CMS tunes CP2 & CP5
  - Herwig, angular ordered showering & CH3 tune
  - Sherpa LO or LO+extra jets

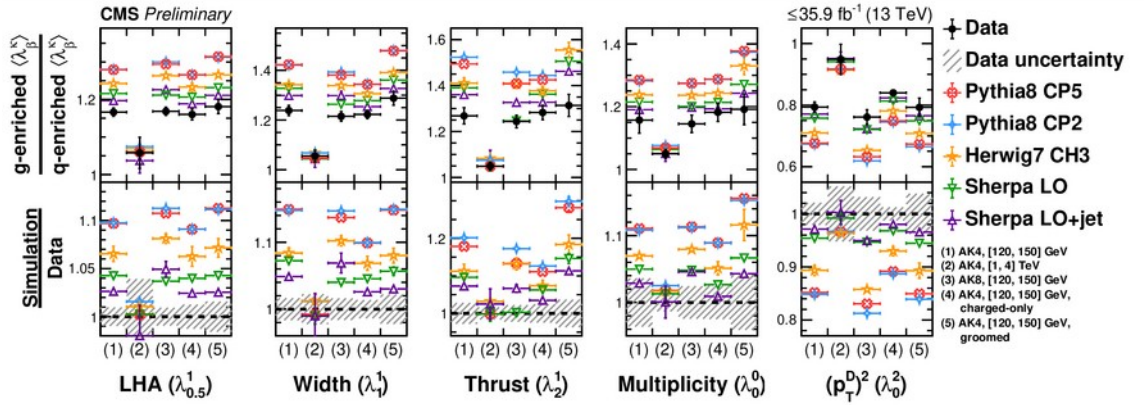




Quark and gluon jet substructure in CMS

- Extensive set of measurements
- Several facts to be noted. Ex:
  - Alternate generators describe gluon-enriched samples better
  - All overestimate the q/g discrimination power
- Study provides handle which can help improve generators and hadronic shower understanding..

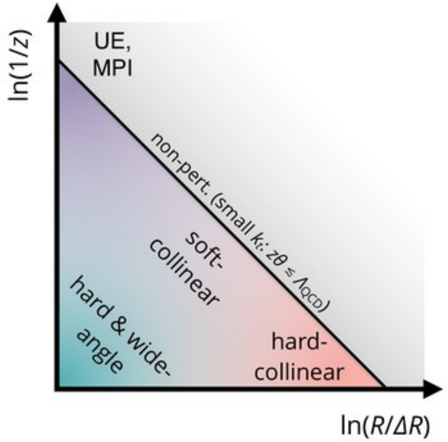




Lund jet plane with ATLAS

Lund jet plane with ATLAS

STDM-2018-57



- In QCD parton emissions are characterized by
  - θ : angle of emission
  - z : momentum fraction

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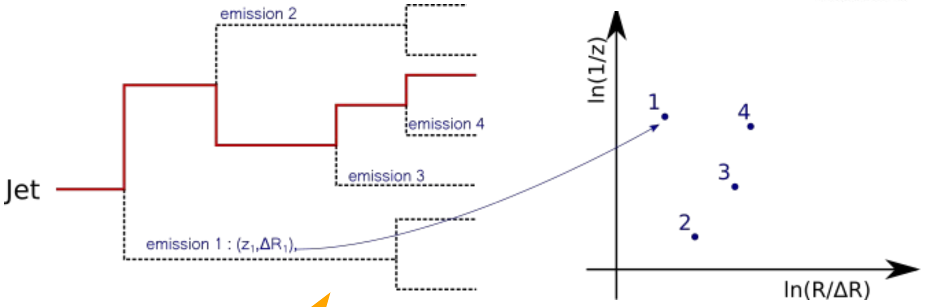
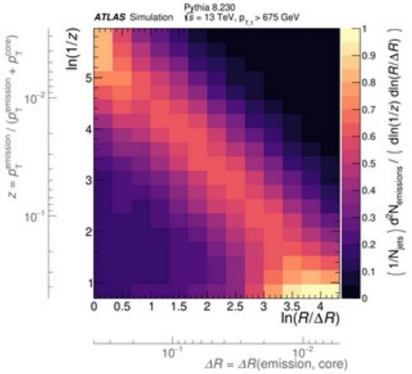
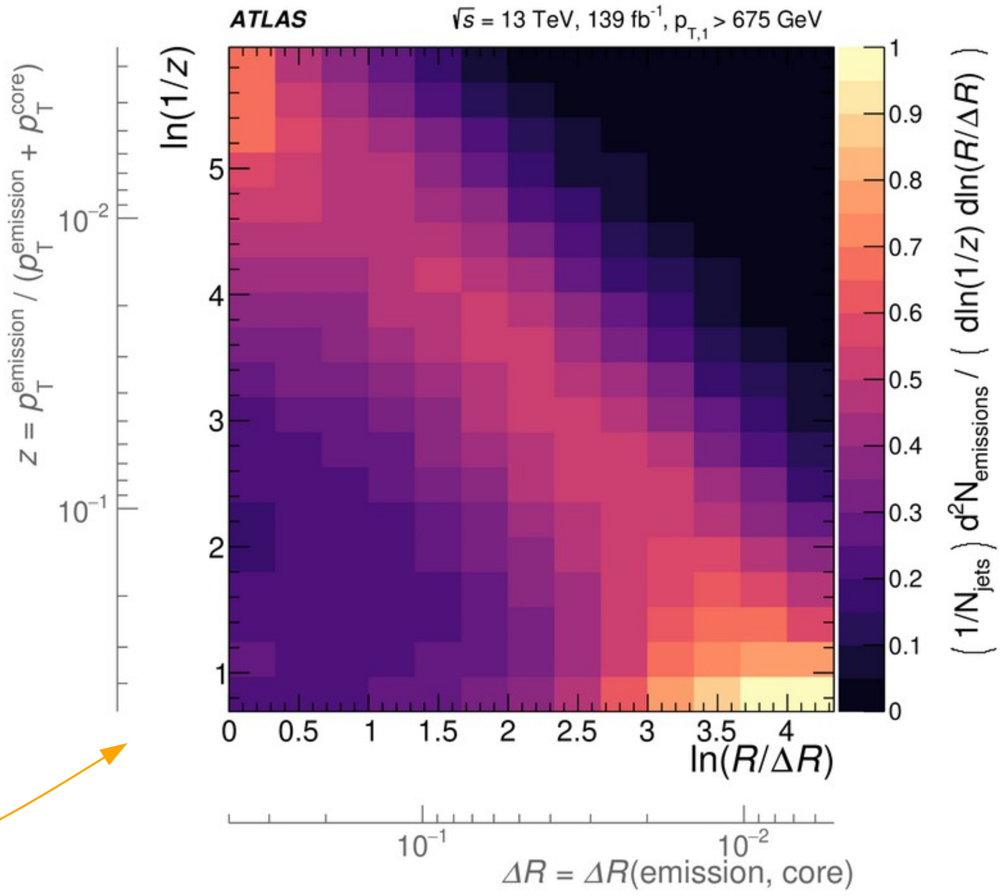
- Plane (ln(1/θ),ln(1/z)) is the "Lund jet plane"
  - Very useful to study jet substructure
- Experimental approximation through jet clustering history :
  - From a jet build with C/A jet algorithm, walk back the proto-jet merging history
  - 1 jet → n points in Lund plane
  - Many jets → 2D distrib of emissions in Lund plane





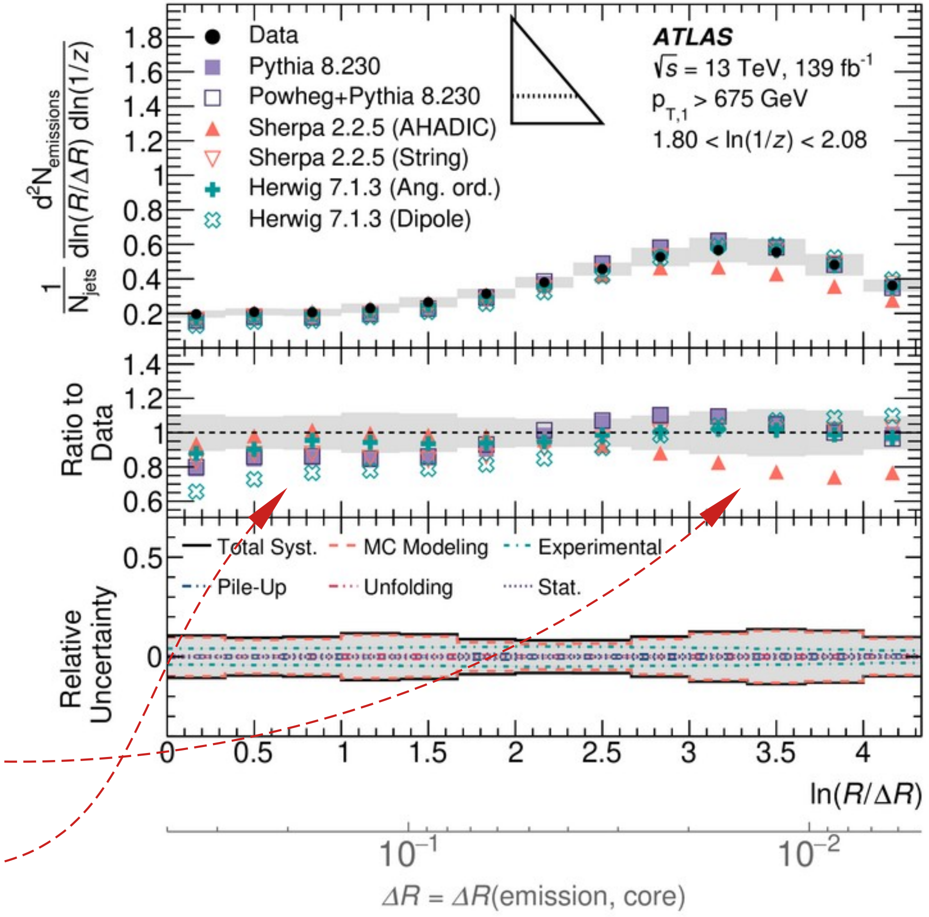
Lund jet plane with ATLAS

- ATLAS measured the Lund Jet plane in dijet events
  - anti-k_T, R=0.4, P_T > 675GeV
- Using only tracks from hard vertex associated to jets
  - Rebuilding C/A jets from tracks close to an identified jet
  - Track ↔ charged assignement possible, (while calo cluster ↔ particle too ambiguous)
  - Data unfolded to particle level
  - Compared to prediction using charged particles only
- Lund Jet Plan measurement



Lund jet plane with ATLAS

- Slicing the plane to see regimes of the jet shower
- Comparing MC generators
  - **Pythia8** & **Pythia8+Powheg**
  - **Sherpa**, varying hadronization : AHADIC & Lund String
  - **Herwig**, varying PS : Angular-ordered & “Dipole-PS”
- No generator match the data in the full plane. Sensitivity to different effects can be compared, for ex:
  - Hadronisation region better described by string-based models
  - Angular-ordered PS perfroms well for hard/wide emissions

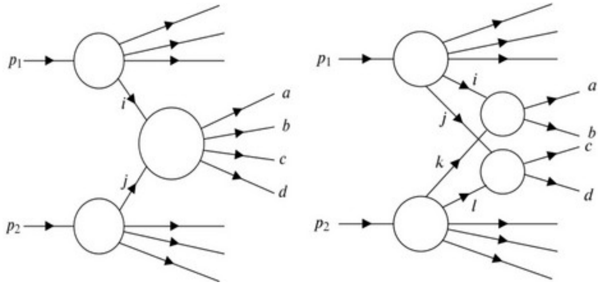


Double parton scattering in 4 jets events with CMS

Double parton scattering in 4 jets with CMS

CMS-PAS-SMP-20-007

- Double Parton Scattering (DPS) contributes to multijets events
  - Important for a better understanding of QCD parton showers
- CMS studied DPS in **inclusive 4-jets** events
  - Low PU run at $\sqrt{s}$=13TeV
- Measured several DPS-sensitive observables, ex:
  - $\Delta\Phi_{soft} = |\Phi_3 - \Phi_4|$ (between 2 softest jet)
  - $\Delta Y = \max(|\eta_i - \eta_j|)$ (maximal η separation)
  - ΔS = angle(hardest jet pair, softest jet pair)
- Measured inclusive 4-jets x-sections for 2 samples
  - I : p_T(jets) > (35,30,25,20) GeV, II : p_T(jets) > (50,30,30,30) GeV
- Also extracted σ_{eff} from sample II where
  - $\sigma_{A(B)}$ are inclusive 1-jet x-sections with p_T> 50(30)GeV

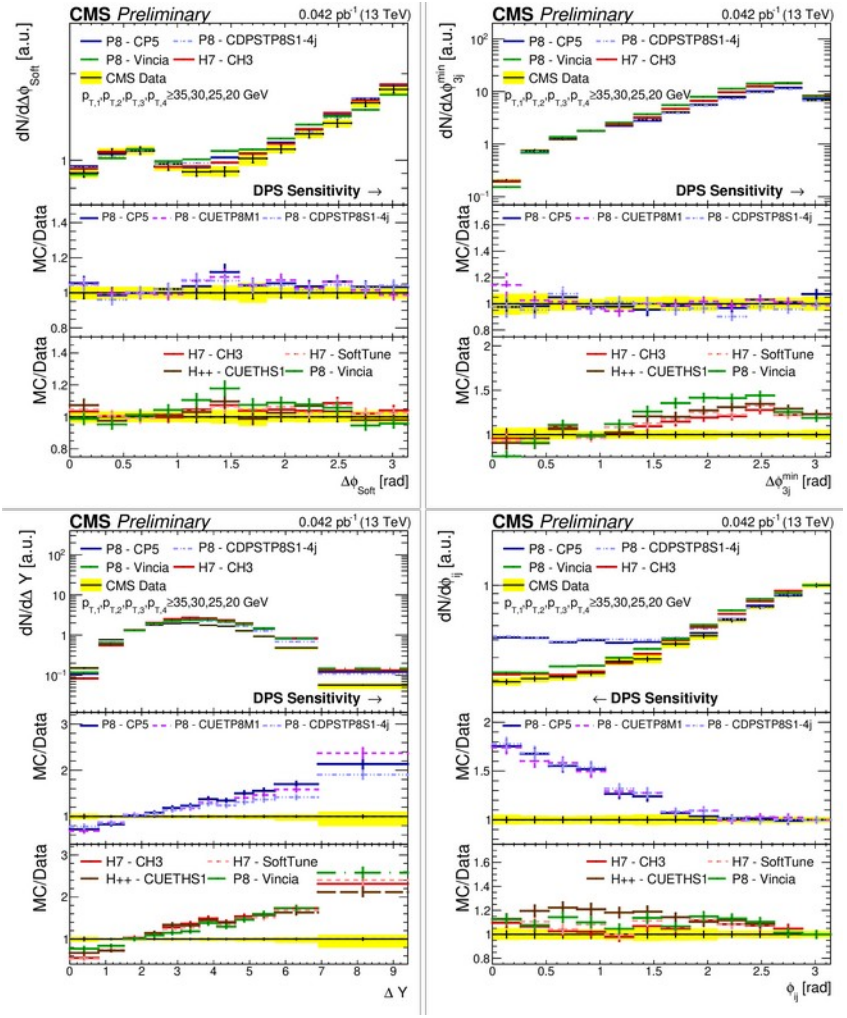


SPS DPS

$$\sigma^{\mathrm{DPS}}_{\mathrm{A,B}} = \frac{m}{2} \frac{\sigma_{\mathrm{A}} \cdot \sigma_{\mathrm{B}}}{\sigma_{\mathrm{eff}}}$$

Double parton scattering in 4 jets with CMS

- Observables are unfolded and compared to many generators x tunes
  - SPS 2→2 processes
    - Pythia, Herwig, Herwig++ & various tunes
  - SPS 2→ 3,4 processes
    - MadGraph, PowhegBox, Katie & various tunes
  - DPS processes
    - Pythia, Katie & various tunes
- Each distribution normalized on bins with low DPS sensitivity
- Some shapes well described by all generators, other (ΔY) by none, others only by specific PS option or higher order generators



Double parton scattering in 4 jets with CMS

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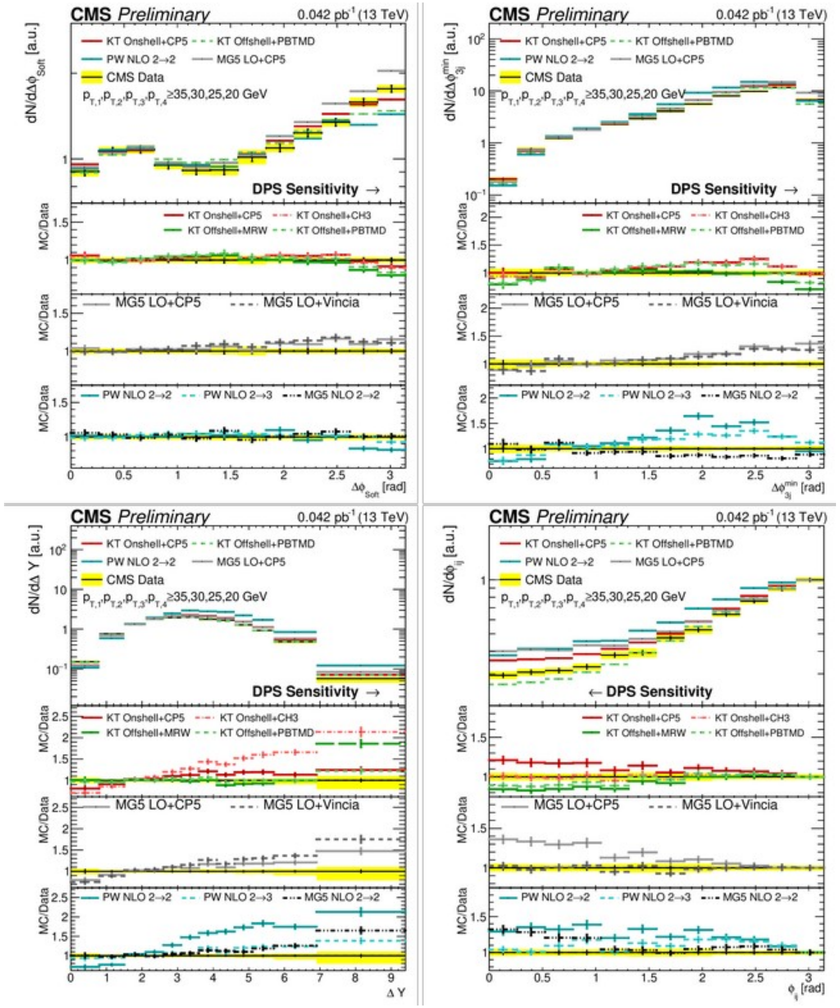
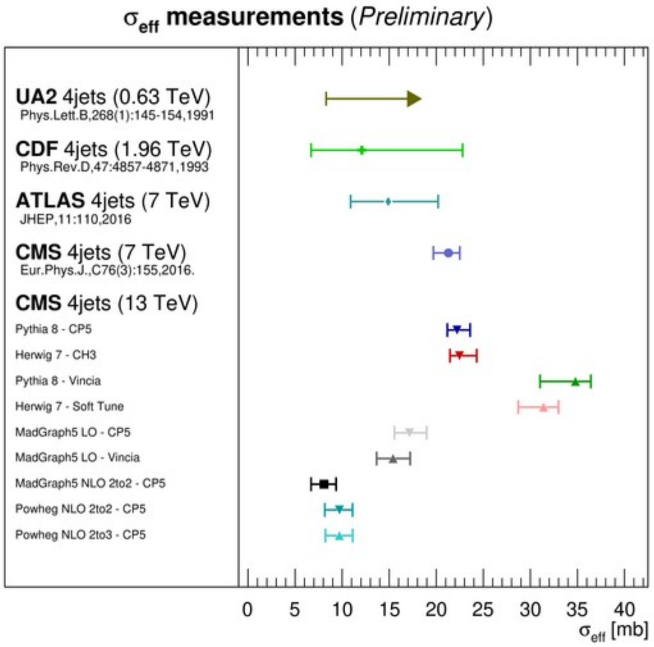


Double parton scattering in 4 jets with CMS

- ΔS distributions both sensitive to DPS and reasonably described
- f_{DPS} (fract of DPS events), and σ_{eff} extracted from fit of MC-based ΔS templates
  - Values depend on generators
- Measured inclusive x-sections over-estimated by all generators
  - Uncertainties dominated by JES (dedicated JES calib applied to these lowPU/low p_T jets)
  - Better estimations with NLO or high multiplicity generators



σ_{I} [μb]	σ_{II} [μb]
$2.77 \pm 0.02\ ^{+0.68}_{-0.55}$	$0.61 \pm 0.01\ ^{+0.12}_{-0.10}$

PDF fit with W/Z+jets in ATLAS

PDF fit with W/Z+jets in ATLAS

STDM-2019-18

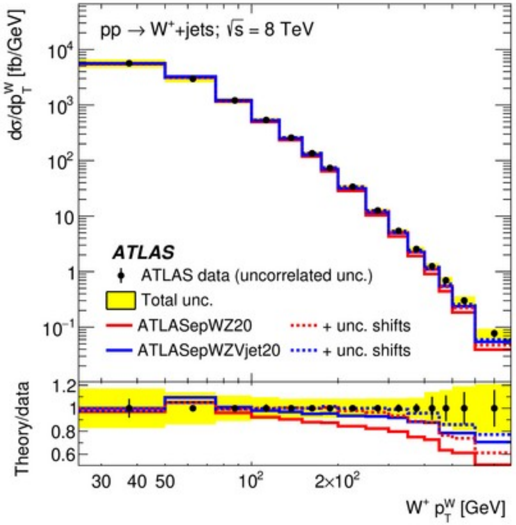
- Physics processes accessible at LHC can help with aspects of PDF descriptions
  - ATLAS previously used W and Z production at √s=7TeV and HERA data to produce a PDF fit : ATLASepWZ16, resulting in improved description of the s-quark content of the sea quark
- New PDF fit also include **W/Z+jets** processes (together with HERA and W/Z samples)
  - Samples for √s=8TeV
  - Fit $p_T(W)$ for W+jets events
  - Fit |y(jet)| in bins of p_T(jets) for Z+jets events
  - Quark and gluon distributions fitted in the form :

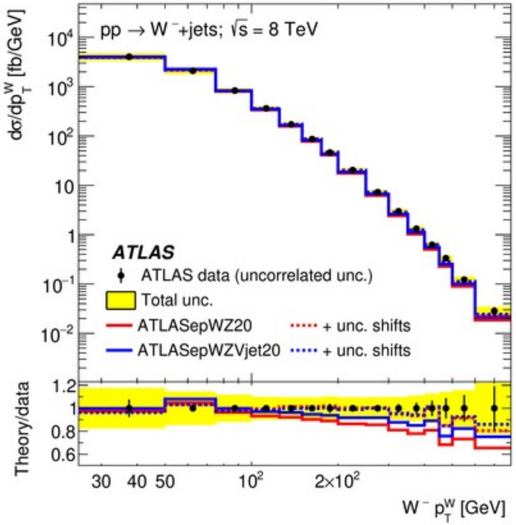
$$xq_i(x) = A_i x^{B_i}(1-x)^{C_i} P_i(x)$$

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} P_g(x) - A'_g x^{B'_g}(1-x)^{C'_g}$$

PDF fit with W/Z+jets in ATLAS

- Fit results compared to re-fit of ATLASepWZ16 named ATLASepWZ20
  - No tension from additional W/Z+jets input data
- ATLASepWZ20jets improve significantly the W p_T spectrum prediction
  - Up to 20% at high p_T



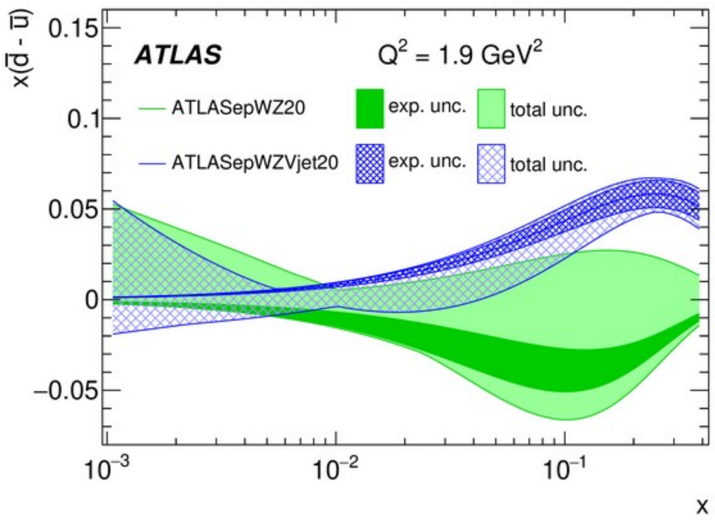


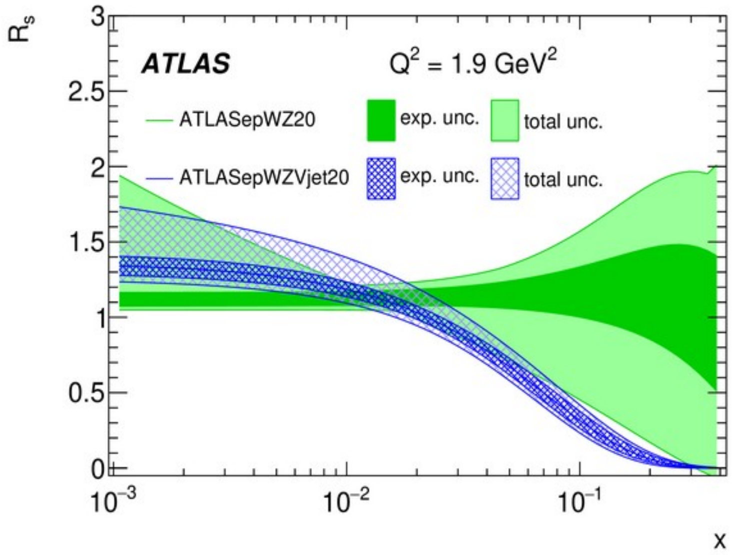
PDF fit with W/Z+jets in ATLAS

Results differ with other PDF sets on 2 aspects

- Sea-quark density at high x
  - ATLASepWZ16 predicts neg value
  - W/Z+jets data constrains high x → retrieve pos values
- Strange quark density
  - Ratio R_s previously expected to be constant over x
  - W/Z+jets data implies steep fall at high x

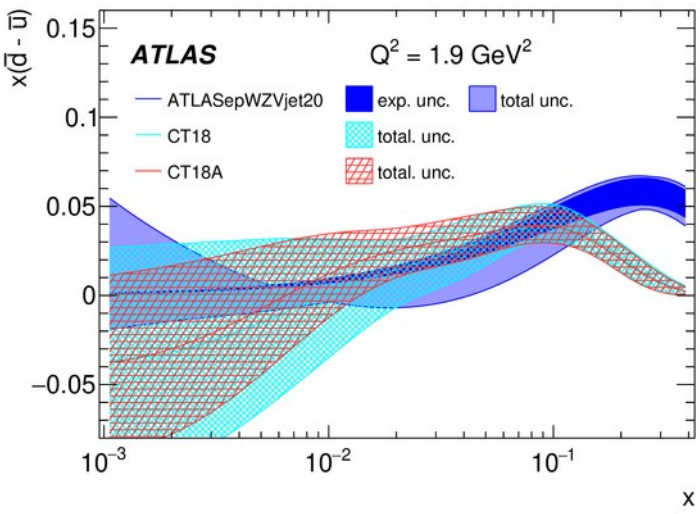
$$R_s = \frac{s + \bar{s}}{\bar{d} + \bar{u}}$$

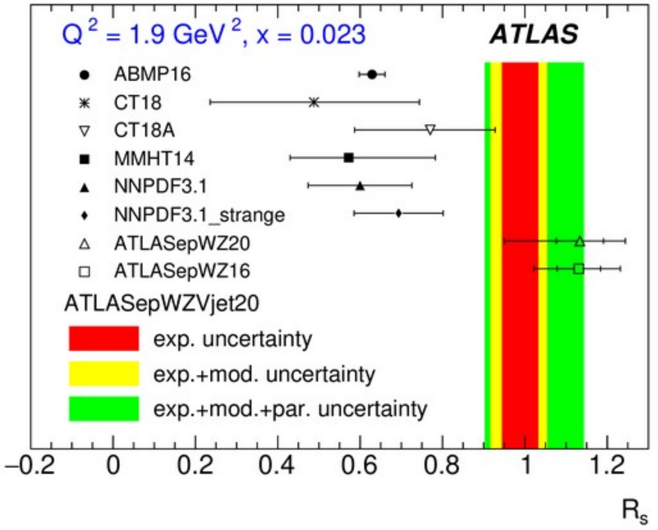


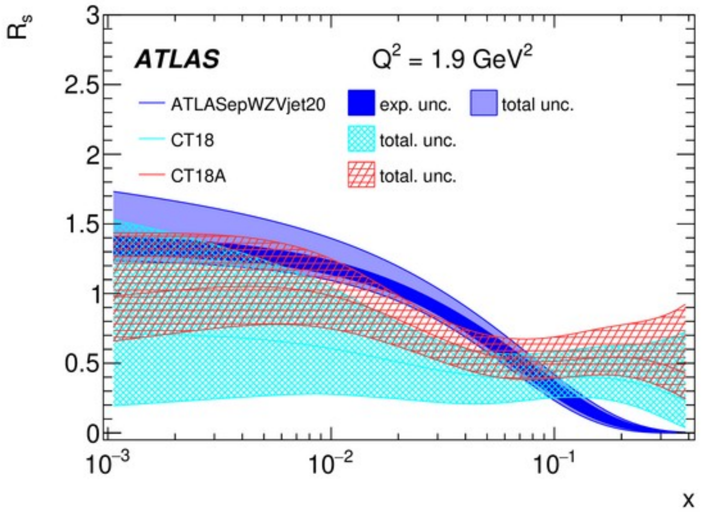


PDF fit with W/Z+jets in ATLAS

- Comparisons to other PDF sets
  - Significant differences at high x (as expected from previous slide)
  - R_s ratio closer to other PDF measurements than ATLASepWZ16







Other jet-related measurements

- In ATLAS
  - Transverse Energy-Energy Correlations and fit of α_s ATLAS-CONF-2020-025
  - soft-drop jet observables STDM-2017-33
  - hadronic event shapes in multijet STDM-2019-02
  - SM results page
- In CMS
  - double parton scattering using Z+jets CMS-PAS-SMP-20-009
  - Hard color-singlet exchange in dijet CMS-SMP-19-006
  - x-section of Z+jets and γ+jets, Z vs jet angle CMS-SMP-19-010
  - differential cross sections Z+c-jet CMS-SMP-19-011
  - SM results page
- See also the LHC EW working group page on JSS measurements

Conclusions

- Various jet measurements regularly performed at LHC
- No generator predicts well all of the various tested aspects of QCD
- But these many tests help to understand and show what works and where
  - Many analysis now publish HEPData and Rivet routine so they're usable by MC generator authors

These studies improve our understanding of QCD

… **and thus benefit all LHC analysis**