Event properties and correlations in multijet events in CMS

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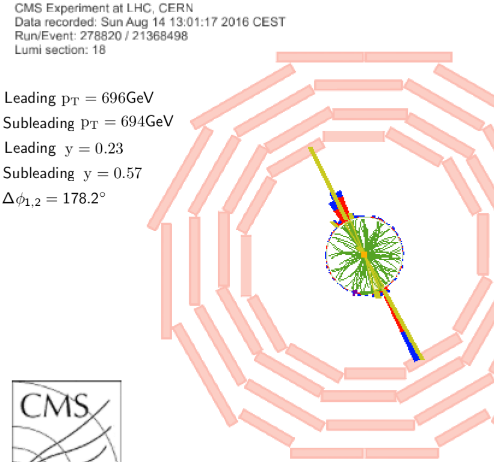
QCD: background or signal?

- Main processes at a hadron collider.
- Underlying any event.
- Access to α_s and PDFs.
- Many subtleties remain unclear:
  - Matching schemes
  - Parton showers and resummation
  - Factorization breaking and color correlations
  - Nonperturbative effects and MPI
  - ...



Jet measurements

- Asymptotic freedom and confinement $\Rightarrow$ hard parton $\sim$ jet of hadrons.

Measurements of jet charge with dijet events in pp collisions at $\sqrt{s} = 8\text{TeV}$

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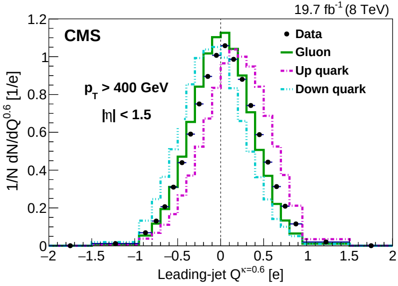
e-Print: arXiv:1706.05868 [hep-ex]

Jet charge @8TeV

JHEP 1710 (2017) 131



$$Q^K = \frac{1}{(p_T^{jet})^K} \sum_i Q_i (p_T^i)^K,$$
$$Q_L^K = \sum_i Q_i (p_{\parallel}^i)^K / \sum_i (p_{\parallel}^i)^K,$$
$$Q_T^K = \sum_i Q_i (p_{\perp}^i)^K / \sum_i (p_{\perp}^i)^K$$

- Different sensitivity to softer and harder particles

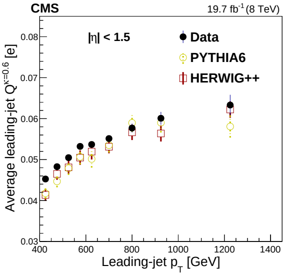
- Understand hadronization models and parton showers

- Double differential: jet charge and p_T

- Gluon jets dominate the lower p_T, up quarks become more relevant at high p_T

- Dominant uncertainties from the track p_T resolution ($\sim 1\%$) and the modelling of the response matrix ($\sim 1.5\%$).

- Experimental unc. larger for small values of K (larger weight to soft gluons)



Jet charge @8TeV

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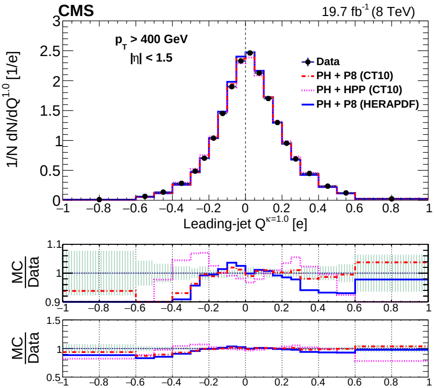
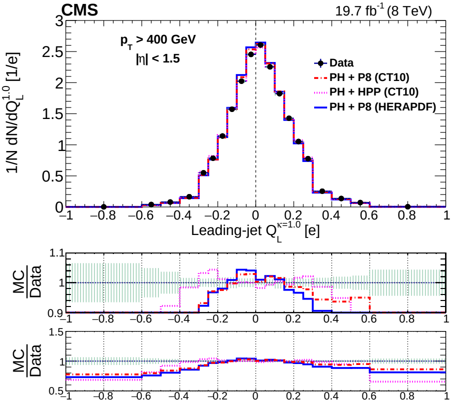
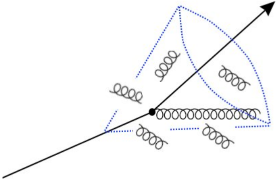




- Different sensitivity of the variables to the showering and fragmentation models
- Quark and gluon composition from the PDF is somewhat better known than that from the parton shower and fragmentation modeling
- The measurements can be used to better understand and tune the underlying models.

Measurement of the differential jet production cross section with respect to jet mass and transverse momentum in dijet events from pp collisions at $\sqrt{s} = 13\text{TeV}$

CMS-PAS-SMP-16-010

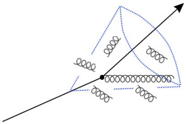


Jet mass @13TeV

CMS-PAS-SMP-16-010

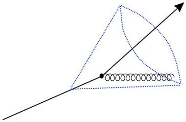
- Sensitive to the internal structure of jets (PS in MC generators)
- Soft and collinear singularities
- Sudakov peak ($m/p_T \approx 0.1$), splitting threshold ($m/p_T \approx 0.3$)

Ungroomed



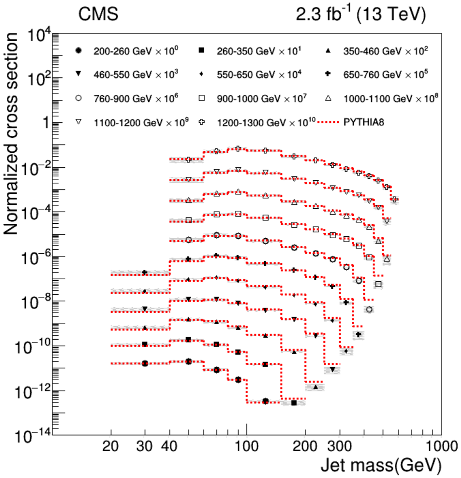
- Soft and hard parts of the jet

Groomed



- "soft drop" to remove the soft part of the jet
- Sensitive to the hard part of the jet

Ungroomed double differential cross section



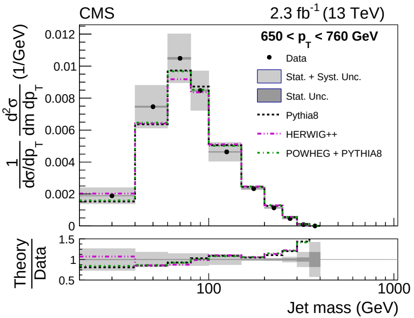
Sensitive to physics modeling

- Possible use in global fits for parameter tuning

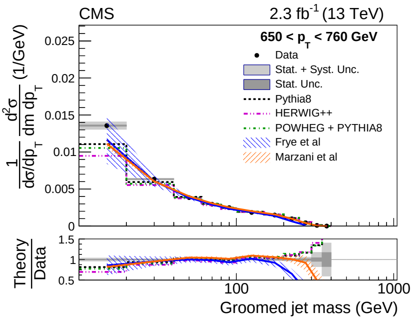
Jet mass @13TeV

CMS-PAS-SMP-16-010

Ungroomed



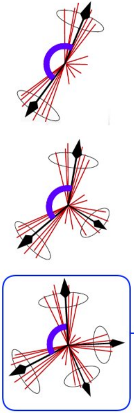
Groomed

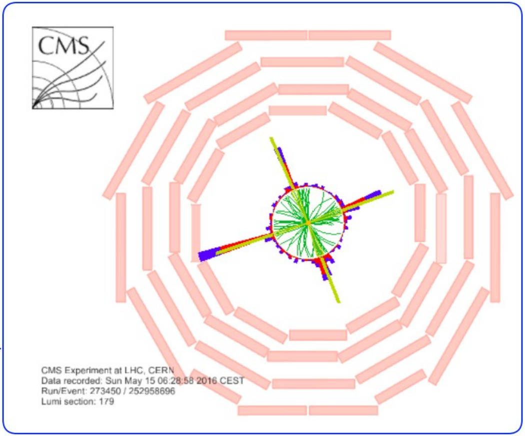


- For groomed jets, the Sudakov peak is suppressed and the precision in the intermediate mass region improves
- For $m/p_T > 0.3$, the fixed-order matrix element matching is insufficient to capture the true dynamics
- Semi-analytical calculations beyond NLL accuracy of the groomed jet mass agrees for masses lower than 30% of the p_T
- PS has the largest effect on the jet mass (agreement between PH + P8 and P8)

Measurements of inclusive 2-jet, 3-jet and 4-jet azimuthal correlations in pp collisions at 13TeV

CMS-SMP-16-014, CERN-EP-2017-290
e-Print: arXiv:1712.05471 [hep-ex]





Azimuthal angular correlations in 2-jets events

$$\frac{1}{d\sigma_{1,2}} \frac{d\sigma_{1,2}}{d\Delta\phi_{1,2}}$$

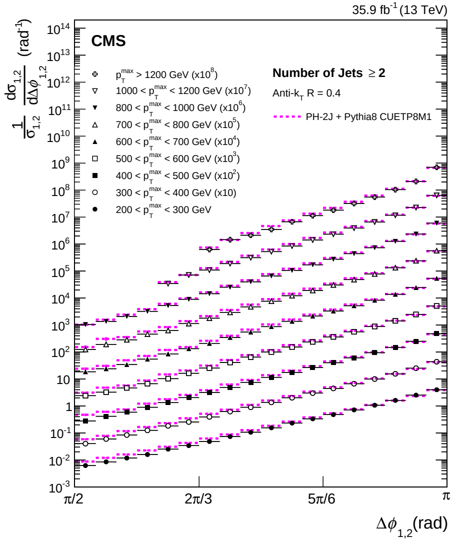
- Bin size 5° - Interesting tool to test theoretical predictions of multijet production processes

  - Region away from π is sensitive to hard radiation from ME

  - Region close to π is sensitive to resummed contributions from PS

- Overall description of the data is achieved and understood

  - JES is the dominant systematic uncertainty (from 3% at $\pi/2$ to 0.1% at π)



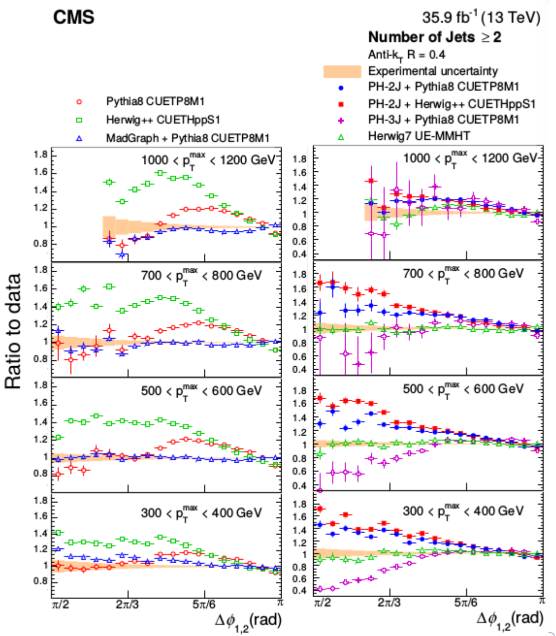
Azimuthal angular correlations in 2-jets events

- MadGraph (up to 2→4 LO) describes well the data whereas P8 and Herwig++ (2→2 LO) fail significantly

- Powheg 2J and Powheg 3J are not able to describe the data better than P8 and Herwig++, even though they provide multi-leg ME

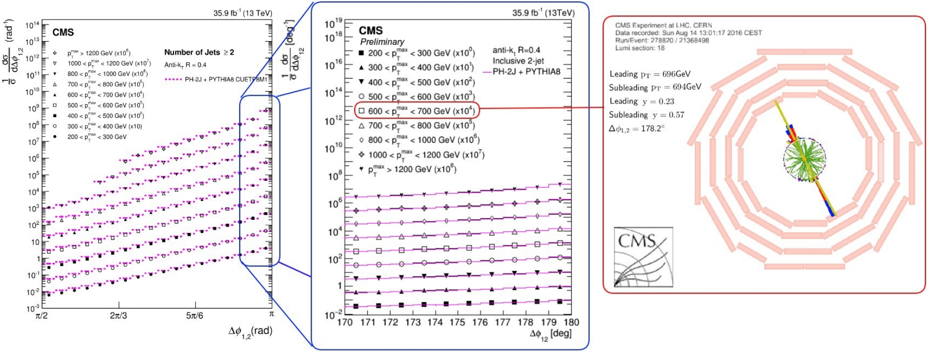
- Herwig7 (MC@NLO for matching to PS), formally NLO but effectively 2→3 LO, gives a good description of the data

- For this observable MC@NLO method of combining parton shower with the NLO parton level calculations has advantages compared to the POWHEG method



Azimuthal angular correlations in inclusive back-to-back dijets events in pp collisions at 13TeV

CMS-PAS-SMP-17-009



Azimuthal correlations in 2-jets events

$$\frac{1}{d\sigma_{1,2}} \frac{d\sigma_{1,2}}{d\Delta\phi_{1,2}}$$

- In inclusive 2-jets and 3-jets events

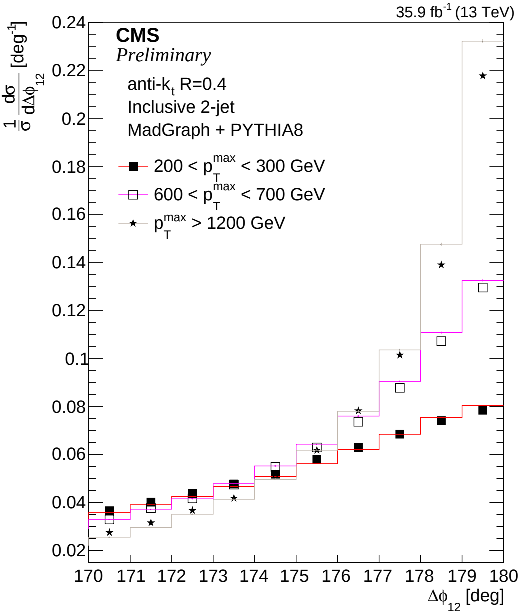
- Finer binning of 1°

- Detailed investigation of the resummation region ($\Delta\phi \sim 180°$)

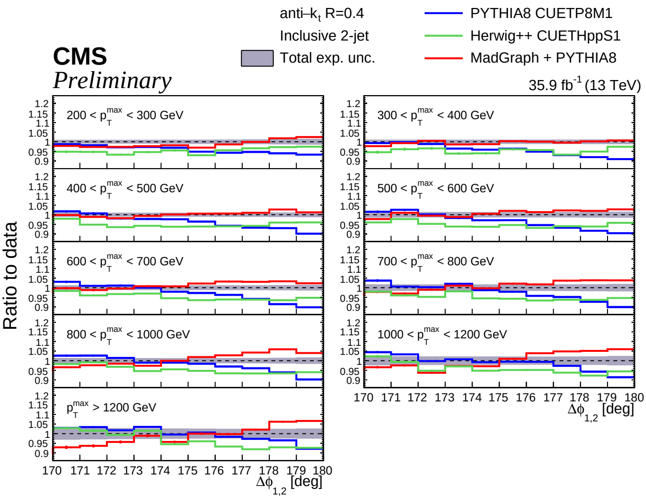
- Testing the resummed predictions coming from different Parton Shower models

- Studying matching and merging formalisms

- Soft radiation interference and factorization breaking



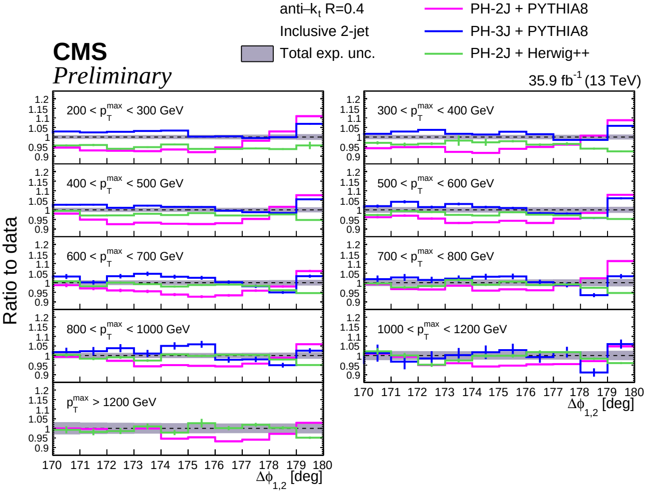
Azimuthal correlations in inclusive 2-jets events



- MadGraph gives the best description, and starts to fail towards high p_T^{max}
- P8 and Herwig++ perform similarly
- Differences of up to 10%

- Pythia8 and Herwig++ resum in the same way (only evolution variable differs)
- There are correlations towards high p_T^{max} which are not captured either by the parton shower nor the multi-leg final state ME from MadGraph

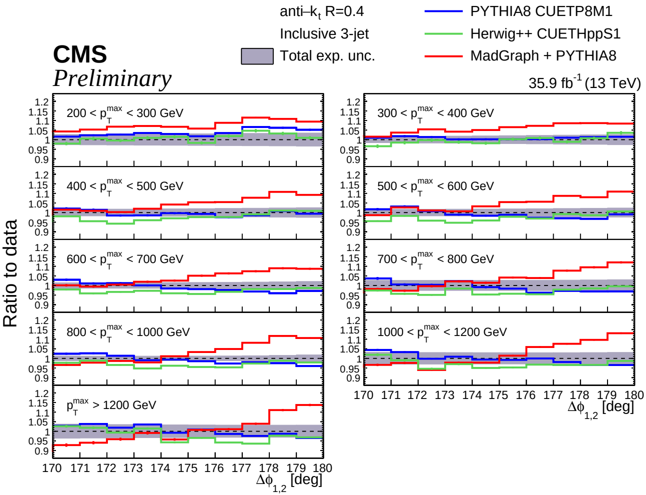
Azimuthal correlations in inclusive 2-jets events



- MadGraph and Powheg 3J give the best description
- Powheg 2J fails to describe the data
- Biggest discrepancies in the last bin

- MadGraph and Powheg 3J, both go to up to 2→4 partons
- Powheg 2J is effectively 2→3 LO

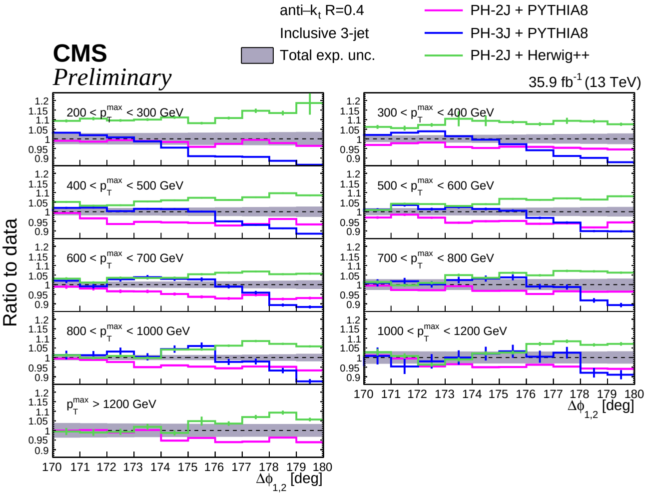
Azimuthal correlations in inclusive 3-jets events



- Two scale process by requiring at least a third jet with $p_T > 30$GeV
- MadGraph fails in up to 15% despite the fact that it performs well in the inclusive 2-jets case

- P8 and Herwig++ describe the data in all the p_T^{max} regions

Azimuthal correlations in inclusive 3-jets events



- MadGraph, Powheg 2J and Powheg 3J fail to describe the data in up to 10% towards 180°
- Powheg 2J and Powheg 3J have a similar trend

- Decorrelations in the 3-jets inclusive case are well described by partons coming from PS exclusively, whereas a mixture of partons from PS and ME are not able to

Summary

Jet charge @8TeV
- Sensitivity showering and fragmentation models
- The measurements can be used to better understand and tune the underlying models.

Jet mass @13TeV
- Sensitive to the internal structure of jets
- PS has the largest effect on the jet mass
- Semi-analytical calculations beyond NLL accuracy of the groomed jet mass agrees for masses lower than 30% of the p_T

Dijet azimuthal angular correlations @$\sqrt{s} = 13$TeV
- Overall description of the data is achieved and understood
- For this observable MC@NLO method of combining parton shower with the NLO parton level calculations has advantages compared to the POWHEG method

Azimuthal angular correlations in high transverse momentum dijet events
- Sensitive to resummation region
- Differences of up to 15%
- Non of the generators is able to describe the 2- and 3-jet observables simultaneously

Thank you for your attention.