Small-x QCD physics probed with jets in CMS

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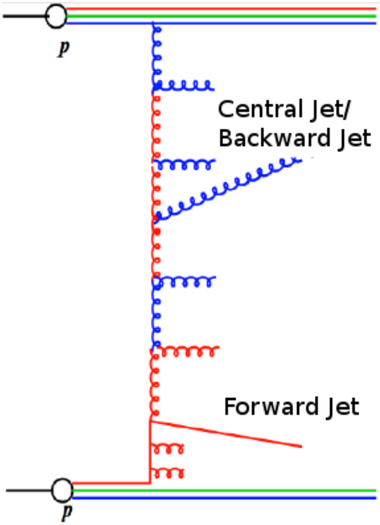
2. Measurements
   - Inclusive forward jet production
   - Events with one forward and one central jet
   - Azimuthal correlations of jets widely separated in η
   - Fourier coefficients ratio of the average azimuthal correlation cosines
   - Ratios of dijet production
3. Summary



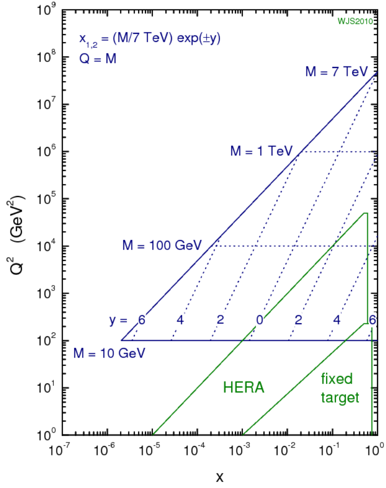
Physics Motivation

Forward Jets

- Excellent probe to low-x dynamics: high y $\rightarrow$ low-x
- Classic final state for studies of higher order QCD, beyond-DGLAP and BFKL effects
- CMS has probed y (rapidity) up to 4.7 (blue area in the figure: LHC reach at $\sqrt(s) = 7 TeV$)

Large rapidity separation

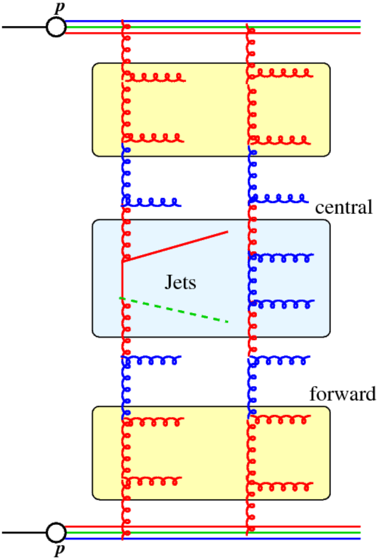
- Large rapidity range ($\Delta y \leq 9.4$) between jets open up phase space for more emissions and opportunity for detailed QCD tests



Physics Motivation

Azimutal Correlations

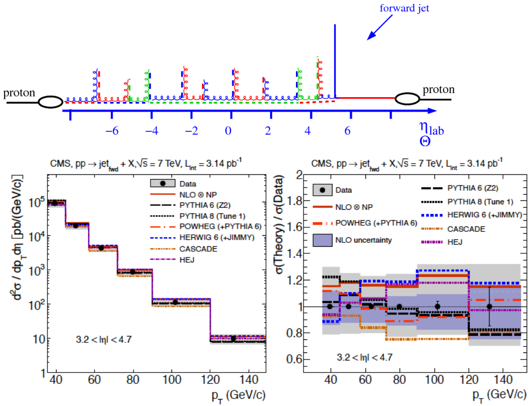
- At leading order: $\Delta\phi = 180$
- Due to strong ordering in DGLAP the dijets are correlated, while in BFKL many emissions lead to strong decorrelations.
- Understanding the contribution of additional jets helps to distinguish between different parton evolution schemes.
- Sensitivity to MPI



Inclusive forward jet production at $\sqrt{s} = 7$ TeV

Events with at least one jet with $3.2 < |\eta| < 4.7$ and p_T >35 GeV

- All predictions describe the data within the uncertainties
- NLO prediction (NLOJET++) too high, but agrees with the data within the large theoretical and experimental uncertainties
- NLO+PS (POWHEG+PYTHIA6) best

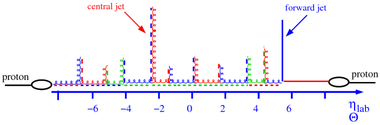


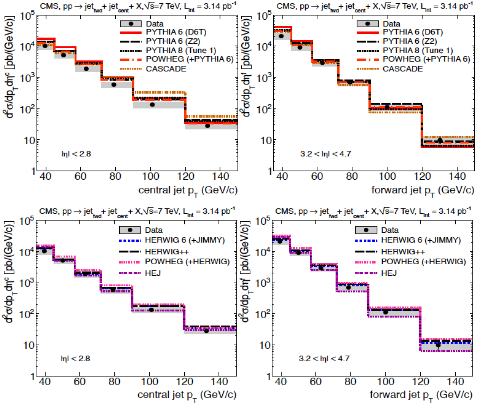
JHEP 1206 (2012) 036, arXiv:1202.0704

Events with one forward and one central jet at $\sqrt{s} = 7$ TeV

Events with at least one jet with one forward jet ($3.5 < |\eta| < 4.7$) p_T >35 GeV and one central jet ($|\eta| < 2.8$) p_T >35 GeV

- Forward jet cross-section steeper than central jet.
- Difference in MC description of data between the forward and the central jet.
- Largest shape difference for forward jet.
- Pythia6 and Pythia8, as well as CCFM based CASCADE problem with normalization of the central jet and shape of the forward jet.
- Herwig6, Herwig++, and the BFKL inspired MC HEJ describe the data best.





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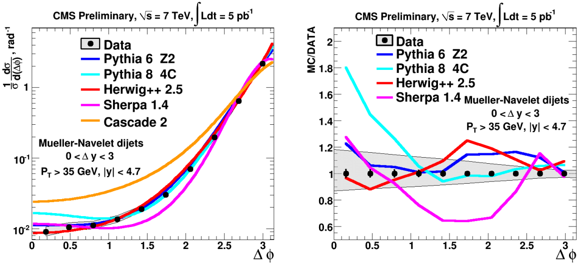
Azimuthal angle decorrelations of jets widely separated in rapidity in pp collisions at $\sqrt{s} = 7$ TeV

Mueller-Navelet $\Delta\phi$ (azimutal correlations) for dijets with $|y| < 4.7$ and
$p_T > 35$ GeV
$0 < |\Delta y| < 3$

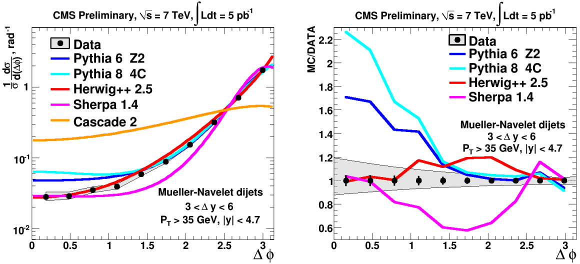


- Pythia 6 and Herwig++ describe the data within uncertainties
- Pythia 8 and Sherpa 1.4 with parton matrix elements matched show deviations at small and intermediate $\Delta\phi$

FSQ-12-002

Azimuthal angle decorrelations of jets widely separated in rapidity in pp collisions at $\sqrt{s} = 7$ TeV

Mueller-Navelet $\Delta\phi$ (azimutal correlations) for dijets with $|y| < 4.7$ and
$p_T > 35$ GeV
$3 < |\Delta y| < 6$



- All predictions show deviations beyond experimental uncertainties
- Herwig ++ provides the best description

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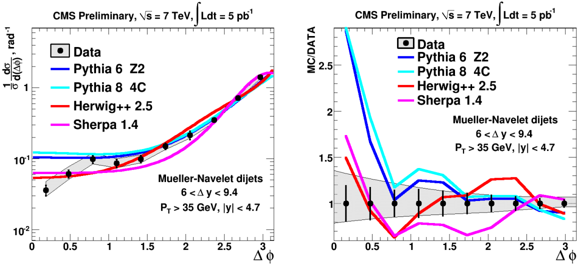
Azimuthal angle decorrelations of jets widely separated in rapidity in pp collisions at $\sqrt{s} = 7$ TeV

Mueller-Navelet $\Delta\phi$ (azimutal correlations) for dijets with $|y| < 4.7$ and
$p_T > 35$ GeV
$6 < |\Delta y| < 9.4$



- Dijets are strongly decorrelated
- Herwig is the best description
- Pythia 6 and Pythia 8 fail for the lower $\Delta\phi$ region

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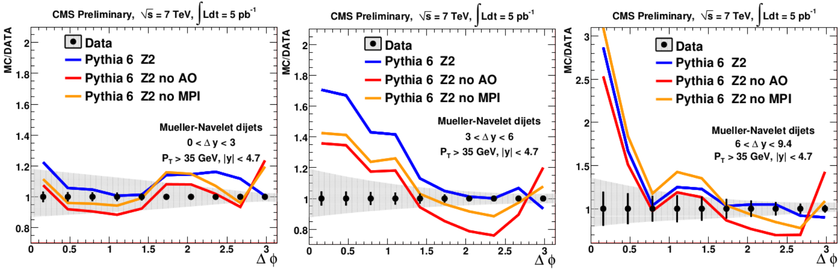
Azimuthal angle decorrelations of jets widely separated in rapidity in pp collisions at $\sqrt{s} = 7$ TeV

Mueller-Navelet $\Delta\phi$ (azimutal correlations) for dijets with $|y| < 4.7$ and $p_T > 35$ GeV



- Contributions of the angular ordering and multi-parton interactions are very similar
- No-MPI is better in the internediate Δy region
- Overall data better described with AO and MPI

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Fourier coefficients ratio of the average azimuthal correlation cosines

Mueller-Navelet $\Delta\phi$ (azimutal correlations) for dijets with $|y| < 4.7$ and $p_T > 35$ GeV
Fourier coefficients, C_n : $d\sigma/d(\Delta\phi) \sim \sum C_n$
$C_n =< cos(n(\pi - \Delta\phi)) >$

- DGLAP contributions are expected to partly cancel in the C_{n+1}/C_n
- C_{n+1}/C_n described by LL DGLAP based generators towards low Δy
- Sherpa, Pythia8 and Pythia6 Z2 overestimate C_2/C_1
- Herwig++ underestimate C_1/C_2
- CCFM based CASCADE predicts too small C_{n+1}/C_n
- At $\Delta y > 4$ theoretical BFKL NLL describe in particular C_2/C_1 within uncertainties

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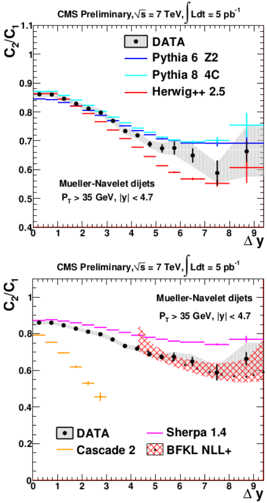


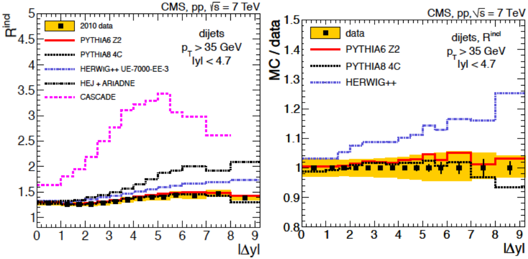
Ratios of dijet production as a function of the absolute difference in rapidity between jets at $\sqrt{s} = 7$ TeV

Jets with p_T >35 GeV and $|\eta|$ <4.7
Observable: Rapidity difference between jets, Δy

Ratio $= \frac{\sigma_{dijet}(inclusive)}{\sigma_{dijet}(exclusive)}$

- Increasing Δy $\rightarrow$ Larger phase space for radiation
- Pythia6 and Pythia8 agrees well with data
- Herwig++ and HEJ+Ariadne too high at high Δy
- Small effect from MPI (not shown)
- Cascade off

Inclusive jets: All jet pairs in the events considered
Exclusive jets: Events with exactly two jets above the threshold



Eur.Phys.J.C72(2012)2216; arXiv:1204.0696

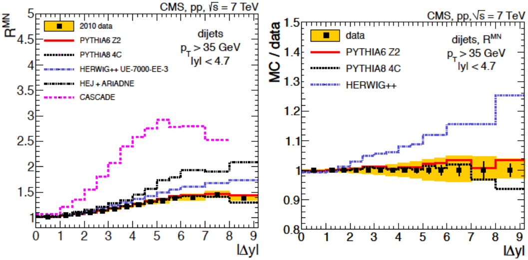
Ratios of dijet production as a function of the absolute difference in rapidity between jets at $\sqrt{s} = 7$ TeV

Jets with p_T >35 GeV and $|\eta|$ <4.7
Observable: Rapidity difference between jets, Δy

$$\text{Ratio} = \frac{\sigma_{dijet}(MN)}{\sigma_{dijet}(exclusive)}$$

- Low Δy: Ratio(MN/exc.) per definition smaller than Ratio(inc./exc.)
- High y: Ratio(MN/exc.) per definition same as Ratio(inc./exc.)
- MC data comparison: same as on previous slide
- Why only Pythia is describing the data while all others are far off?

Exclusive jets: Events with exactly two jets above the threshold
Mueller-Navelet jets: Most forward and backward jet in the inclusive sample



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Summary

CMS has probed the small-x region with jets in different measurements:

Observable	Pythia	Herwig	Sherpa	Cascade	HEJ
Forward jet p_T	🙂	🙂	–	😐	😐
Central-forward jet p_T	☹️	😐	–	☹️	🙂
Azimutal correlations	😐	🙂	😐	☹️	–
Fourier coefficients ratio	😐	☹️	☹️	☹️	–
Dijet ratios	🙂	😐	–	☹️	☹️

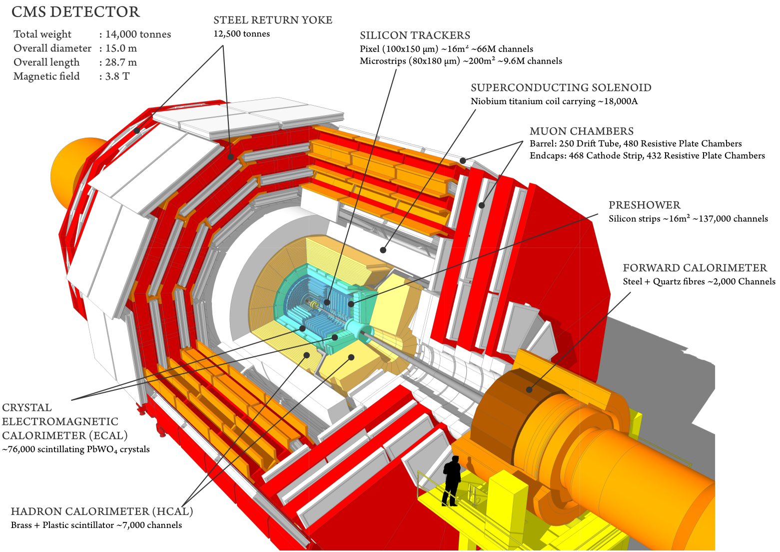
- Inclusive measurements are reasonably well described
- In more exclusive measurements the description becomes more difficult

New results comming soon: Low p_T jets at $\sqrt{8}$ TeV and Central-Forward jets correlations

Legend: 🙂 $\rightarrow$ good agreement; 😐 $\rightarrow$ decent agreement; ☹️ $\rightarrow$ bad agreement

Backup slides

CMS Detector



Central-Forward Jets