Multijet correlations at large rapidity intervals at CMS

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on behalf of

CMS Collaboration

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Low-x Workshops
Kyoto

The Outline

- A brief introduction to the topic
- Low p_T and high p_T forward jets differential measurement (PAS FSQ-12-031)
- Forward central jets measurement (PAS FSQ-12-08), inclusive and exclusive dijet production ratio (Eur.Phys.J. C72 (2012) 2216), Mueller-Navelet dijet decorrelations (PAS FSQ-12-02)
- 4-jet production (Phys.Rev. D89 (2014) 092010)
- Summary

DGLAP vs BFKL

DGLAP

$\sqrt{s} \sim p_T > \Lambda_{QCD}$

Strong ordering in p_T

Works for high-p_T objects

eg. high-p_T jets

BFKL

$\sqrt{s} \gg p_T > \Lambda_{QCD}$

Strong ordering in x

No ordering in p_T

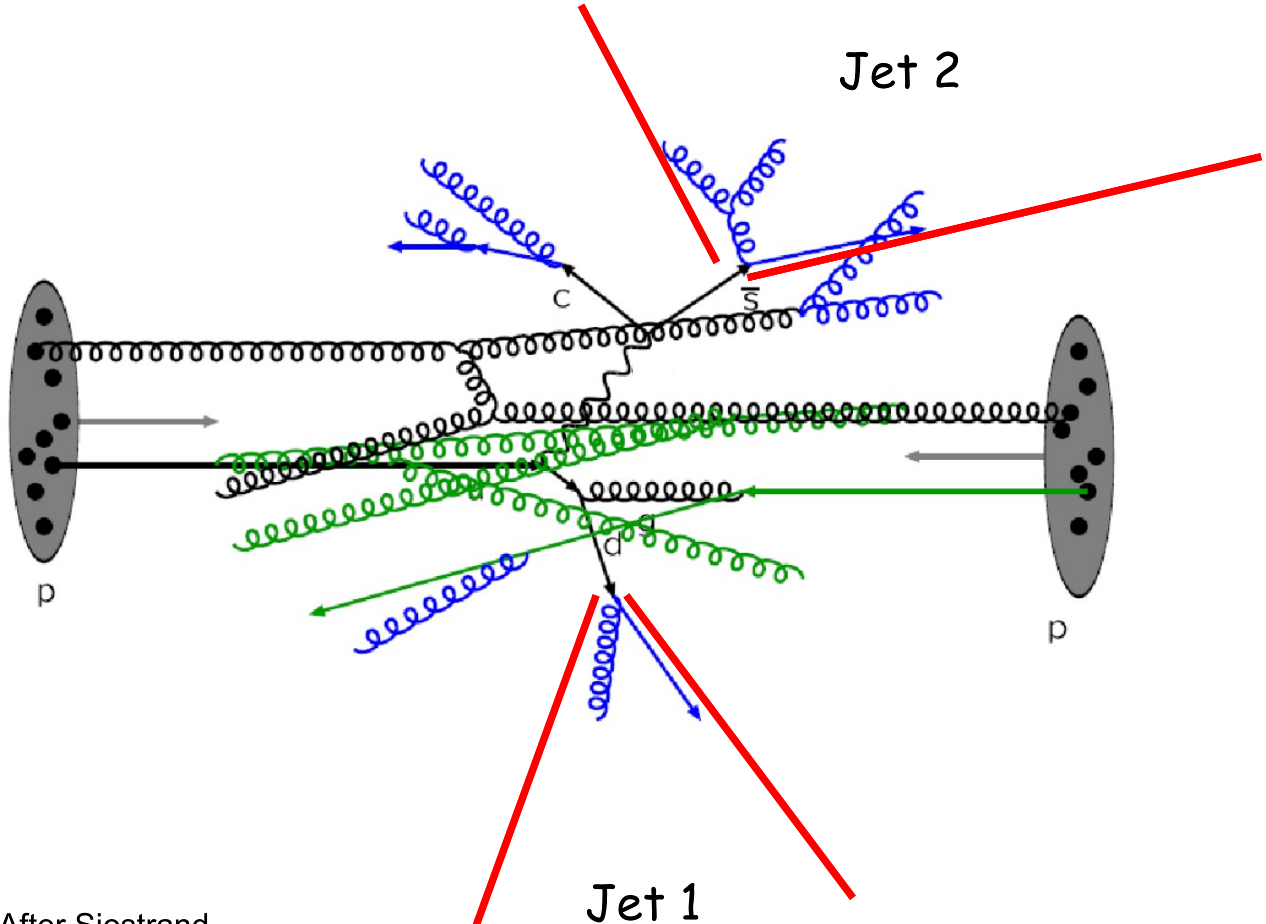
Random walk in p_T

Should work for low-p_T jets

Large distance in rapidity opens phase space for emissions with similar p_T

Jets are perfect tool to study DGLAP and BFKL

Underlying Event



After Sjostrand

Jets are on top of the Underlying Event

- all besides products of hard interaction

- initial state radiation

- final state radiation

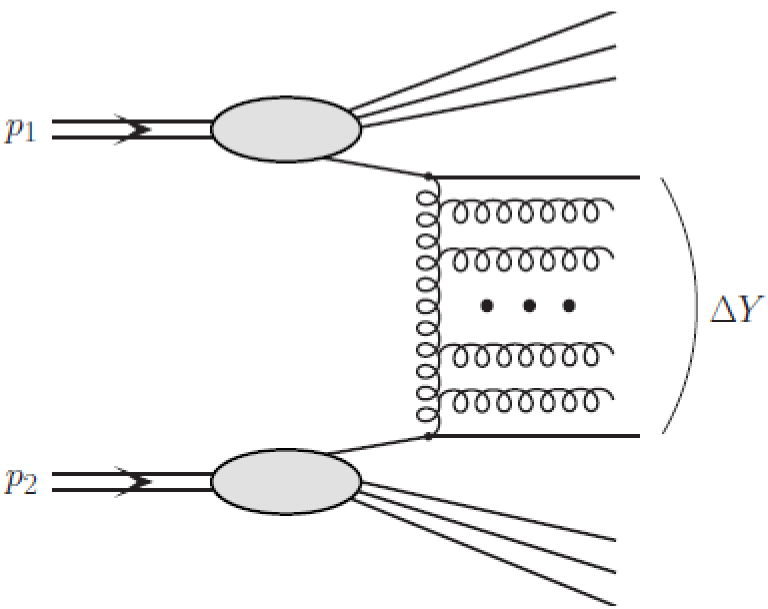
- multiple parton interactions

- beam remnants

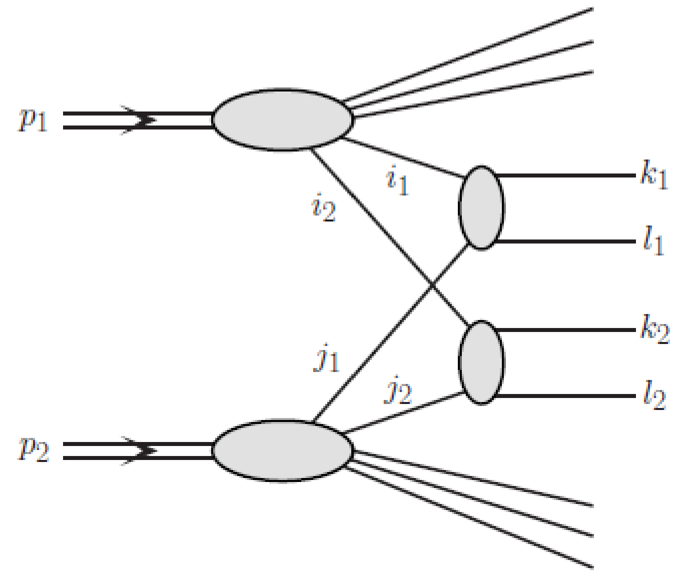
Understanding of underlying event crucial (see Paolo Gunnellini talk)

MN vs DPS

Mueller-Navelet pairs



Double Parton Scattering (DPS)



Forward-backward jets

Decorrelation in azimuthal angle
- probe of the BFKL

Two simultaneous hard parton-parton scattering

Two subprocesses not correlated

The contribution of the DPS mechanism increases with increasing distance in rapidity between jets

Measurements

To distinguish different effects a whole spectrum of measurements is needed:

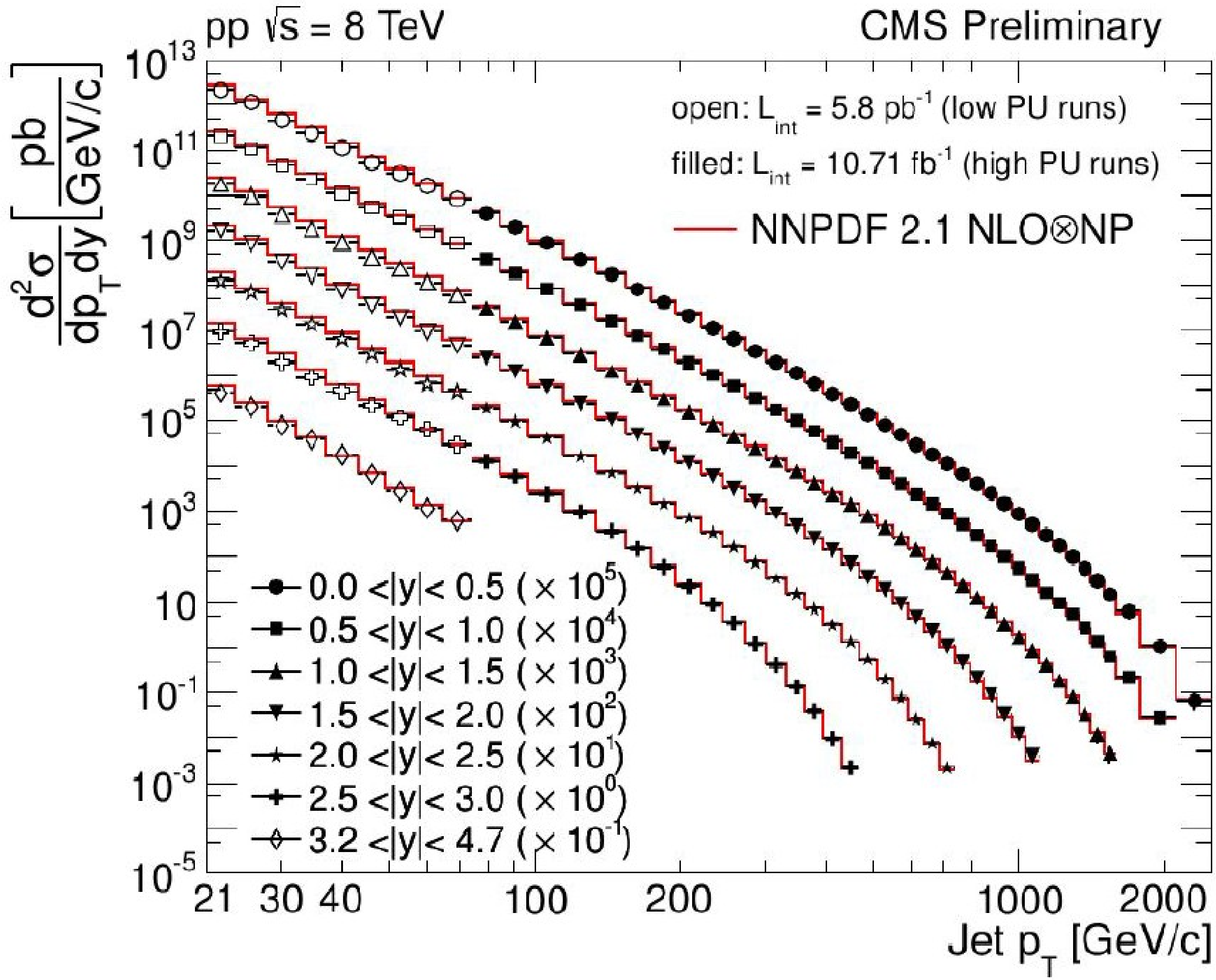
- Low p_T and high p_T forward jets differential measurement
- Forward central jets measurement
- Inclusive and exclusive dijet production ratio
- Mueller-Navelet dijet decorrelations
- 4-jet production

Inclusive jets

- Full coverage of CMS: 0<|y|<4.7
- 2012 data (8 TeV)
- p_T > 21 GeV (for forward jets p_T < 80 GeV)

Data well described by

NLO x NP predictions



Events selection

Same selection for forward-central, dijet and MN analyses:

- Data from 2010 with one primary vertex
- Jets with p_T>35 GeV and $|\eta|<4.7$
    - For forward-central

      forward jet $3.2<|\eta|<4.7$

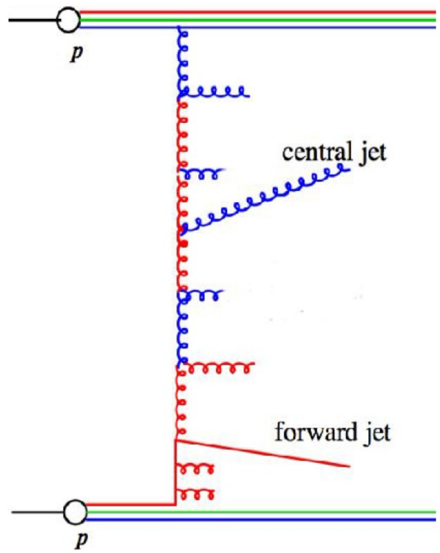
      central jet $|\eta|<2.8$

Systematic uncertainities dominated by Jet Energy Scale uncertainty

Forward-Central

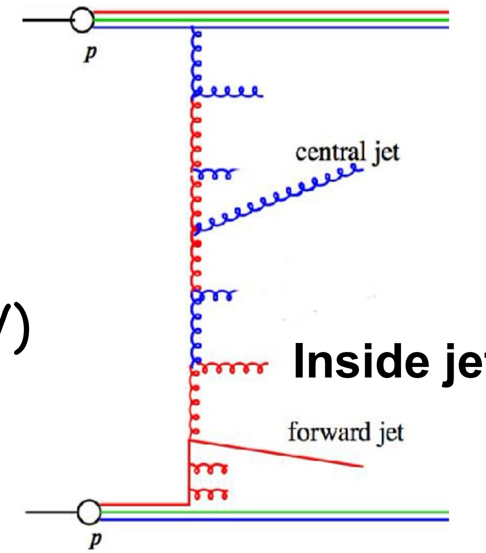
Three samples

Inclusive sample



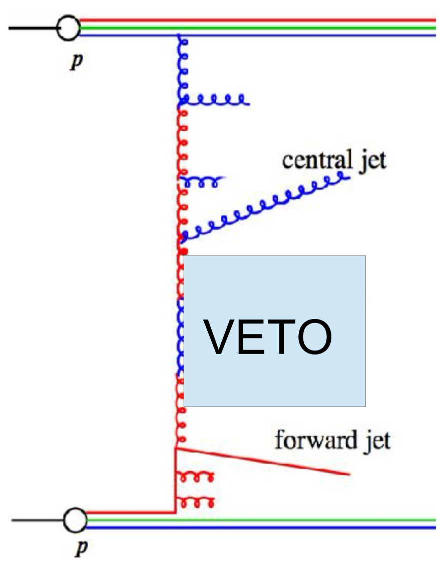
Inside jet tag sample

(p_T>20 GeV)



Inside jet veto sample

(p_T<20 GeV)

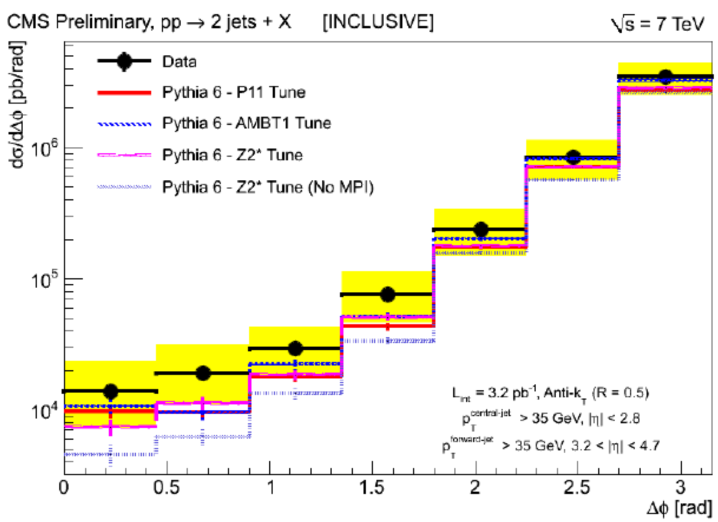


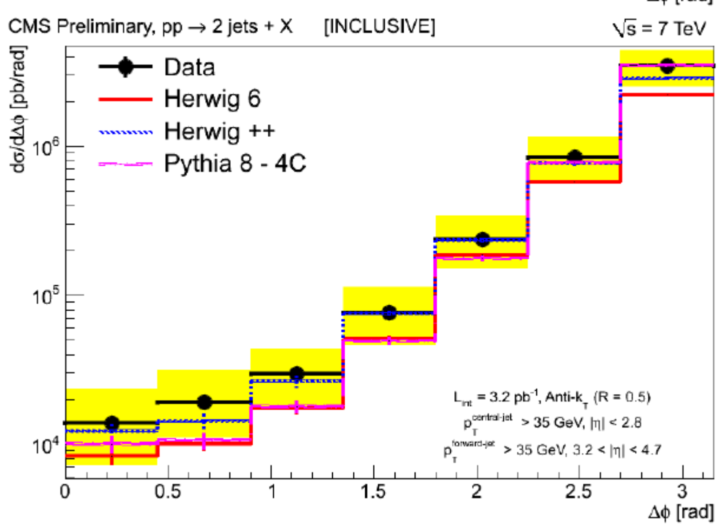
Azimuthal correlations studied

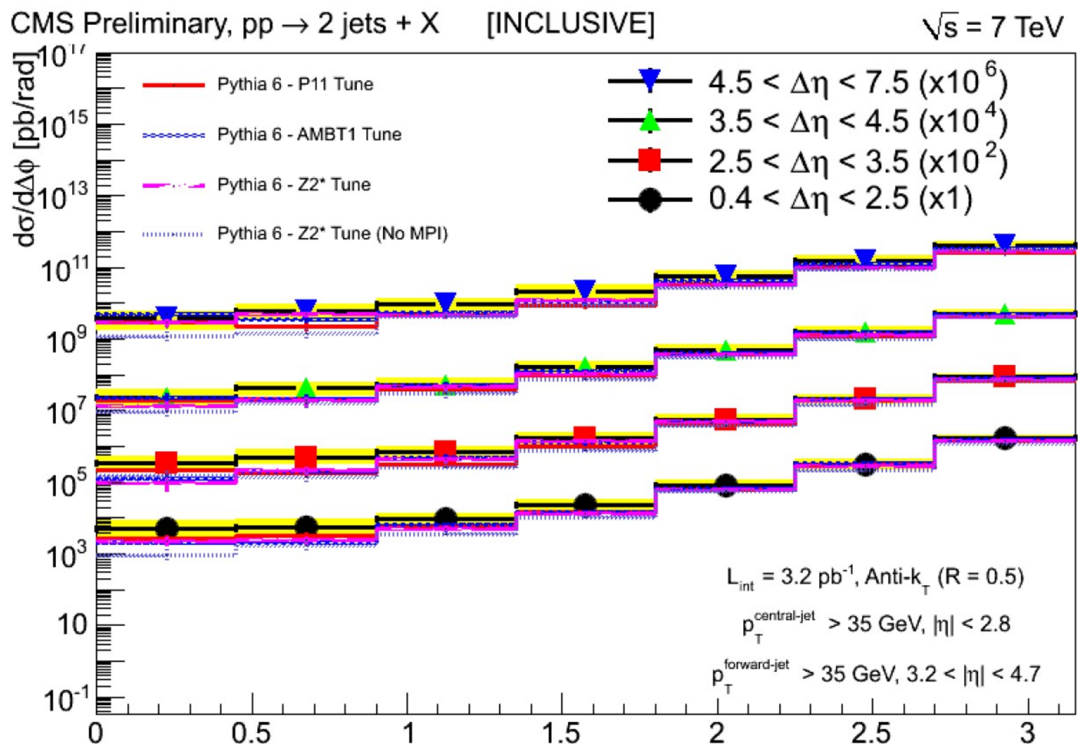
Azimuthal correlations vs $\Delta\eta$

Forward-Central

Inclusive sample





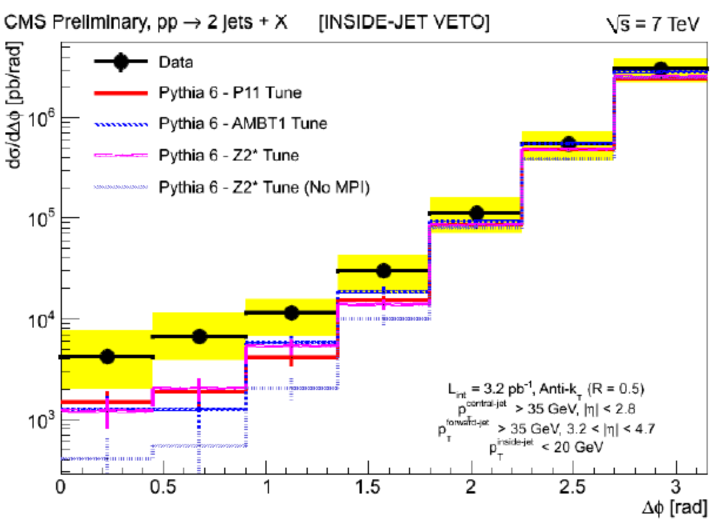


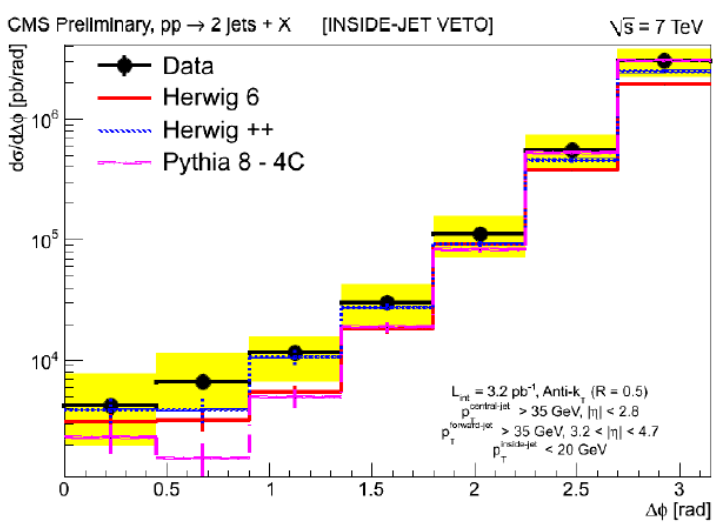
Herwig++ the best description

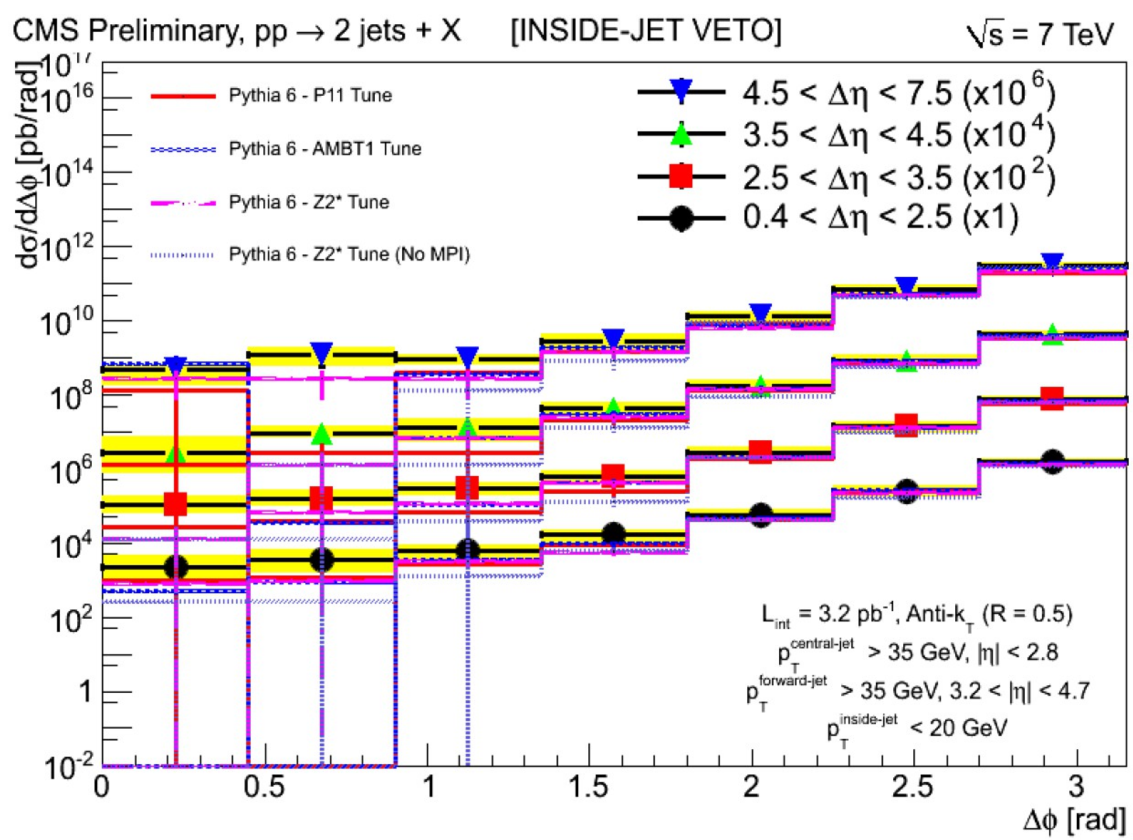
Pythia6 without MPI deviates from the data

Forward-Central

Inside jet veto sample







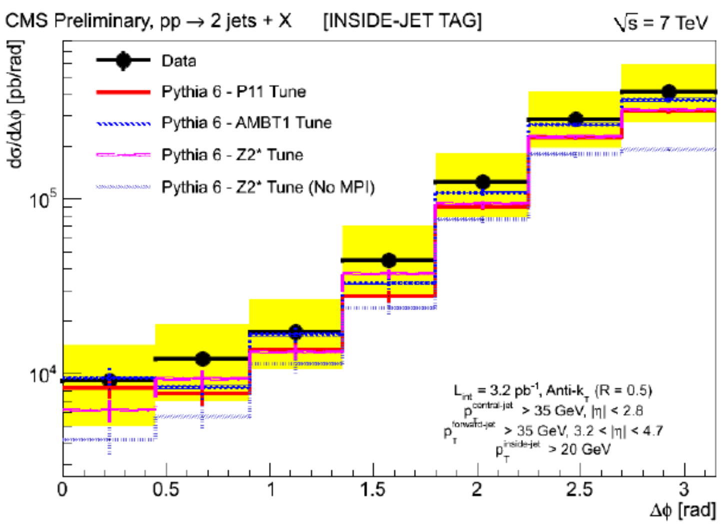
Stronger correlation than in the inclusive sample

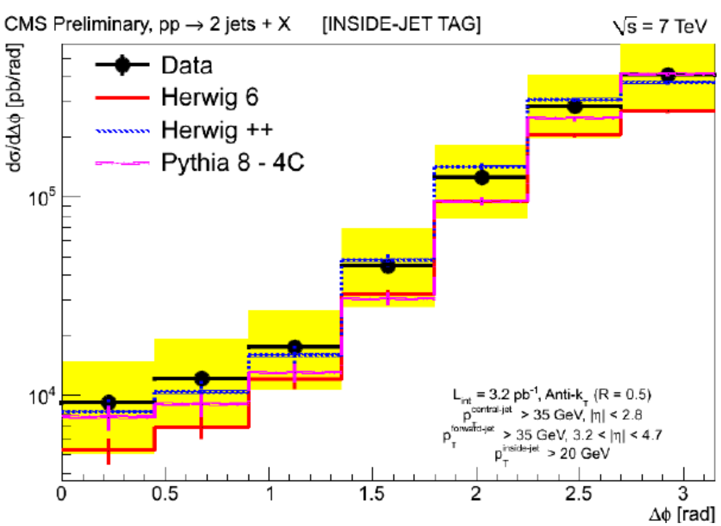
Herwig++ the best description

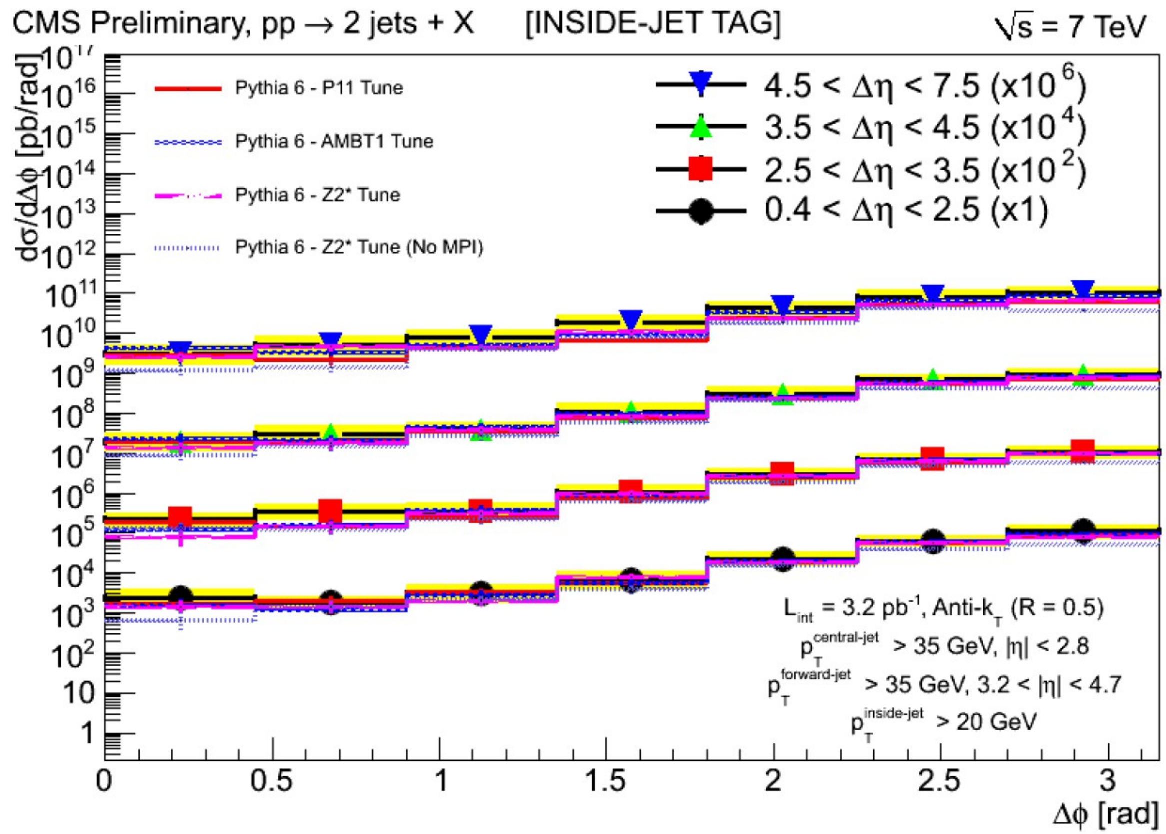
Pythia6 deviates from the data

Forward-Central

Inside jet tag sample







Weaker correlation than in the inclusive sample

Herwig++ the best description

Pythia6 without MPI deviates from the data

Inclusive and Exclusive Dijets

- Three samples of dijets are defined. In all samples:

  (1) Exclusive sample: exactly two jets are allowed for an event.

  (2) Inclusive sample: each pair of selected jets is taken

  (3) Muller-Navelet (MN) sample: a subset of inclusive sample where only most forward-backward jets are selected

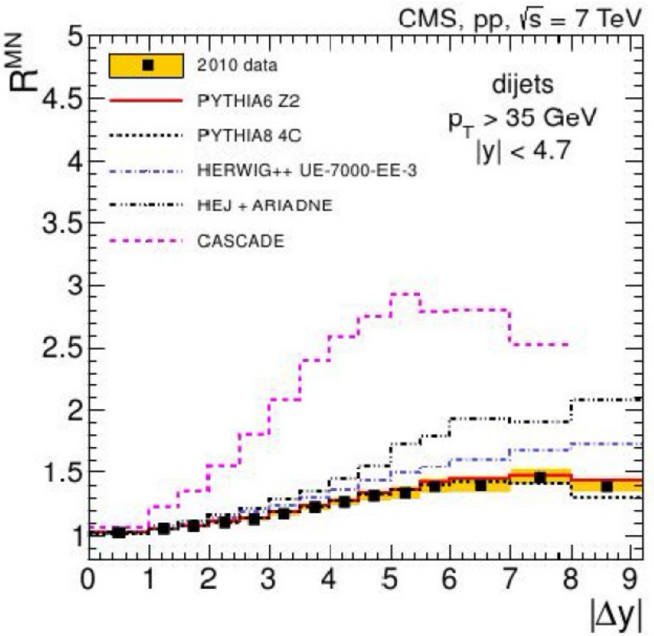
- Cross sections for events from samples are calculated as functions of $|\Delta y|$ between the jets

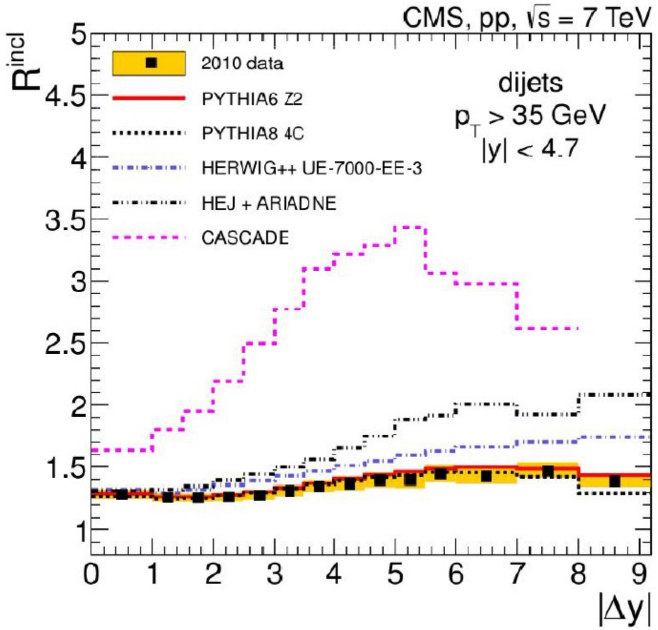
- Finally cross-section ratios:

$$R_{incl} = \frac{\sigma_{incl}(\text{dijet})}{\sigma_{excl}(\text{dijet})}, \quad R_{MN} = \frac{\sigma_{MN}(\text{dijet})}{\sigma_{excl}(\text{dijet})}$$

Inclusive and Exclusive Dijets

- σ(inclusive) = 1.2-1.4 σ(exclusive)
- R rises with |Δy| as expected
- For largest |Δy| the drop in R is observed - kinematic limit
- PYTHIA Z2 and PYTHIA8 4C agrees perfectly with the data
- HERWIG++ predicts higher R at medium and large rapidity separation
- HEJ+ARIADNE and CASCADE (BFKL-motivated generators) predict much faster rise of R

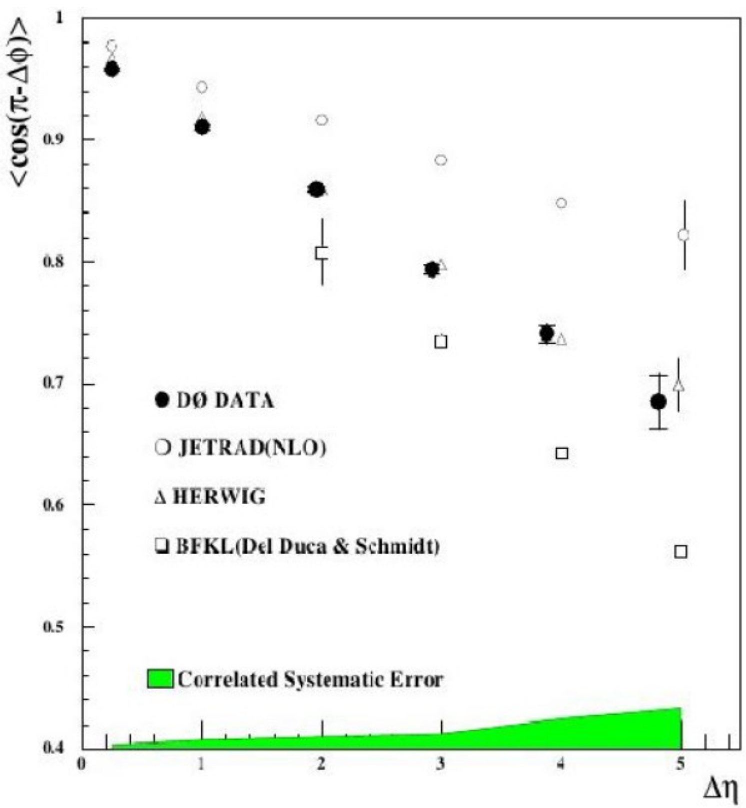




MN dijets azimuthal decorellations

D0 measurement in 1996
(Phys.Rev.Lett 77 595)

$\Delta\eta<6$
$E_T>50$ GeV
 Herwig gives best description



CMS measurement in 2014

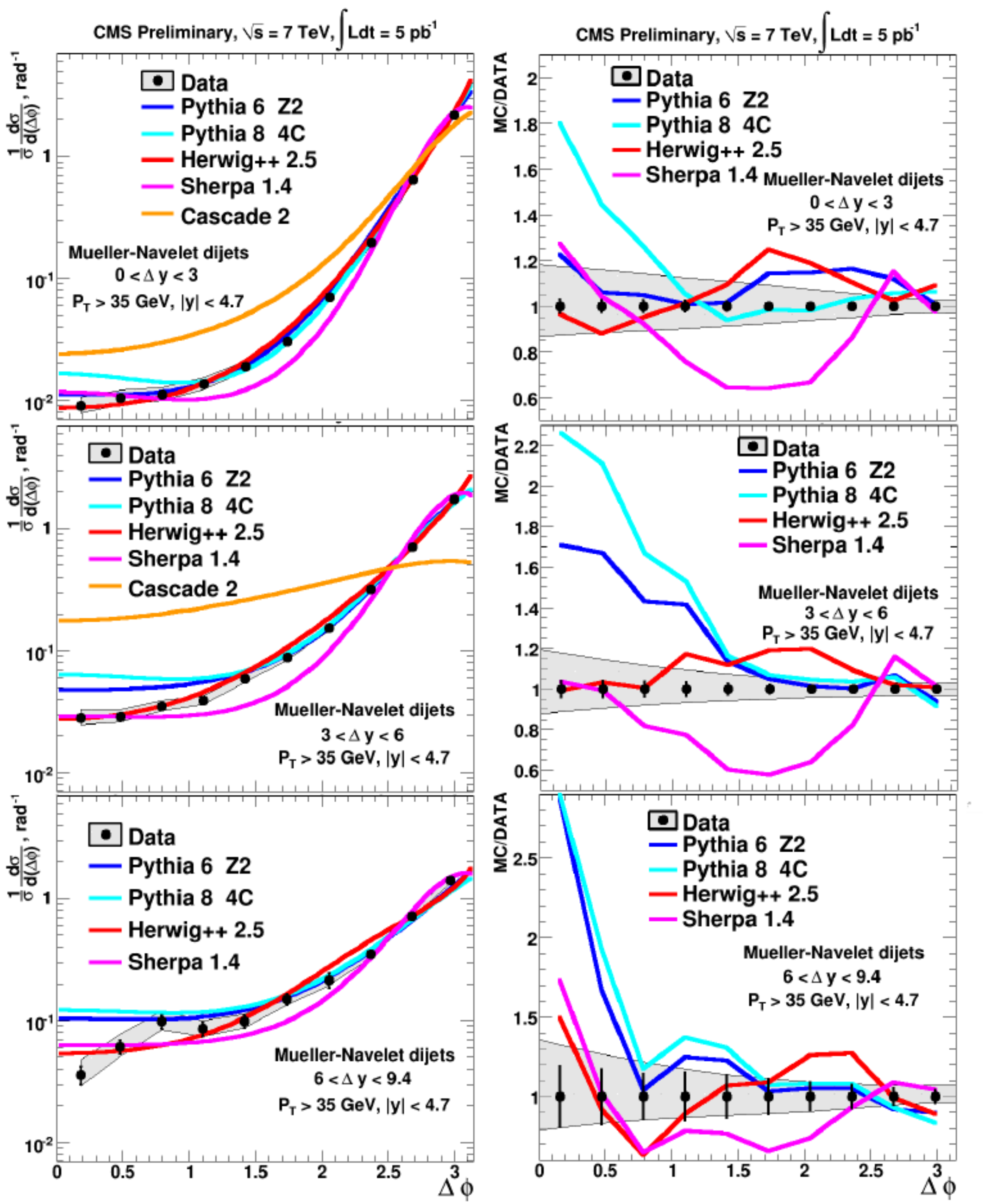
$\Delta\eta<9.4$
$p_T>35$ GeV
Dedicated triggers - large statistisc

Observables:

- $\Delta\varphi$ as a function of Δy
- Average cosines: $Cn = \langle\cos(n(\pi-\Delta\varphi))\rangle$
- Ratios: $C2/C1$, $C3/C2$

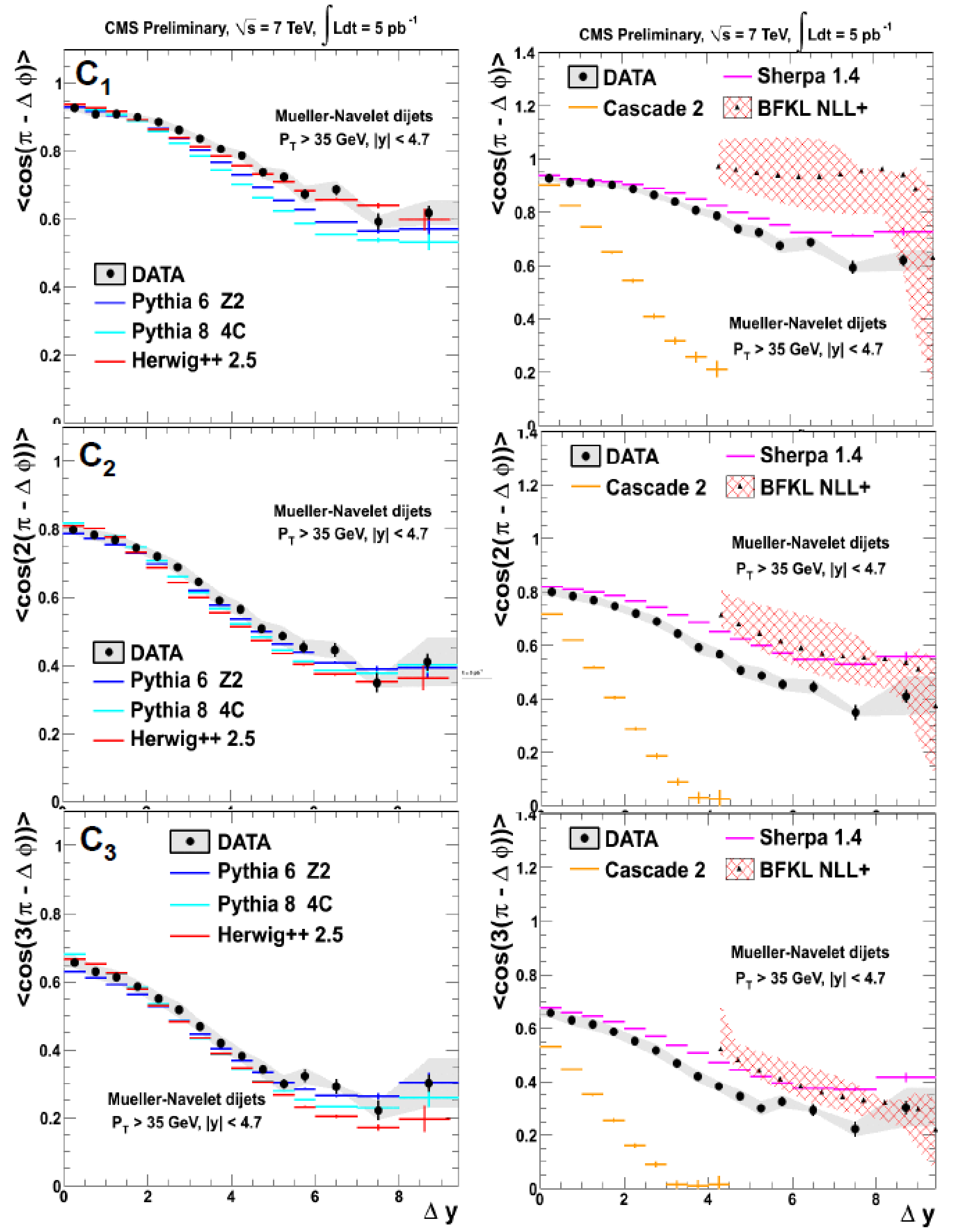
MN dijets azimuthal decorellations

- Azimuthal decorrelation raises with increasing |Δy|
- Herwig++ provides the best description in all bins
- Pythia6 and Pythia8 too large decorrelation
- Sherpa (4 final state partons) too large correlation
- Cascade – too large decorrelation



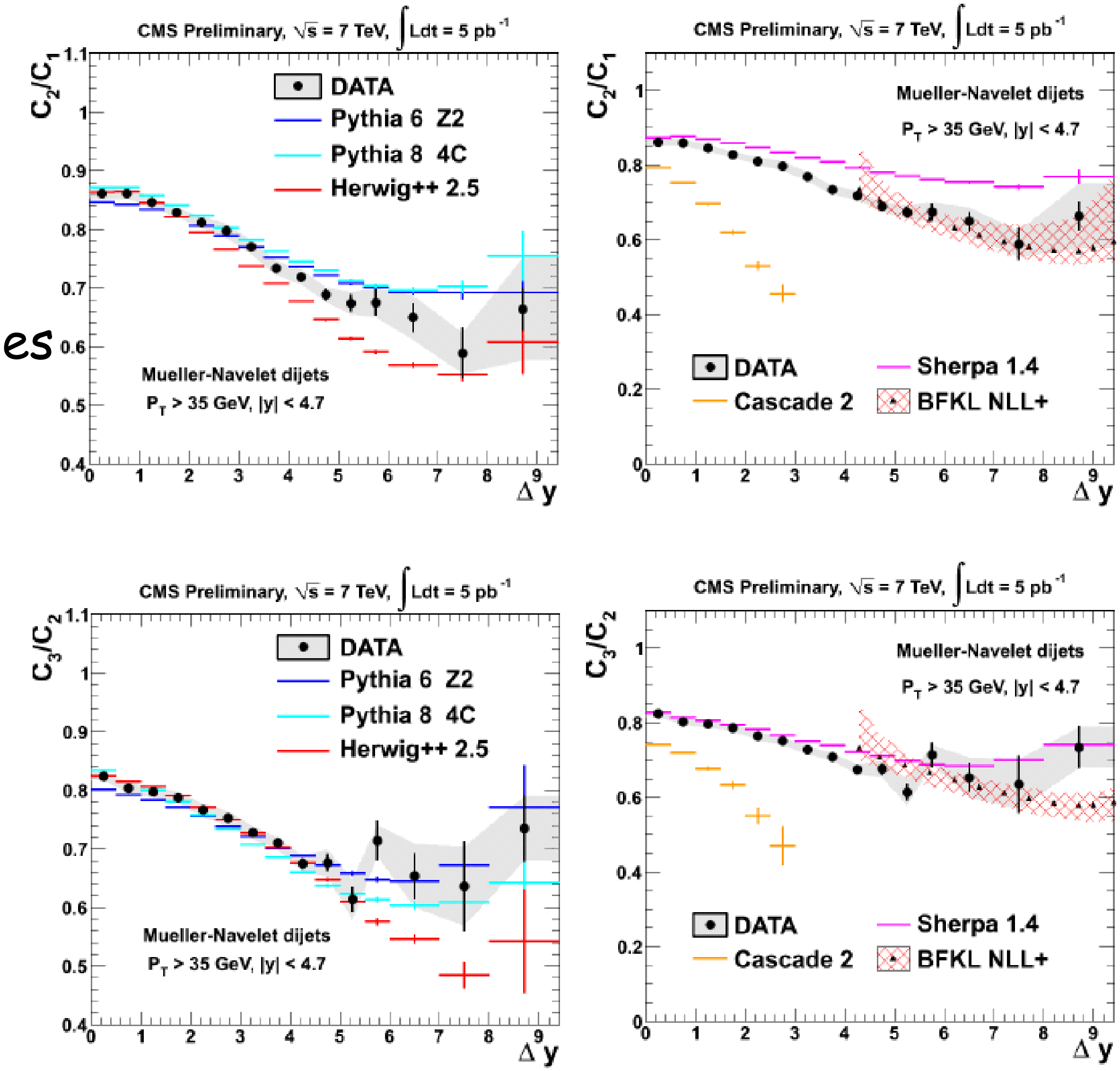
MN dijets azimuthal decorellations

- Herwig++ and Pythia describes qualitatively the data
- Sherpa is above the data
- Cascade is much below the data
- BFKL NLL calculations, parton level (small effects from hadronization) - too strong correlations
  (**JHEP 1305 (2013) 096** [Ducloue et al])



MN dijets azimuthal decorellations

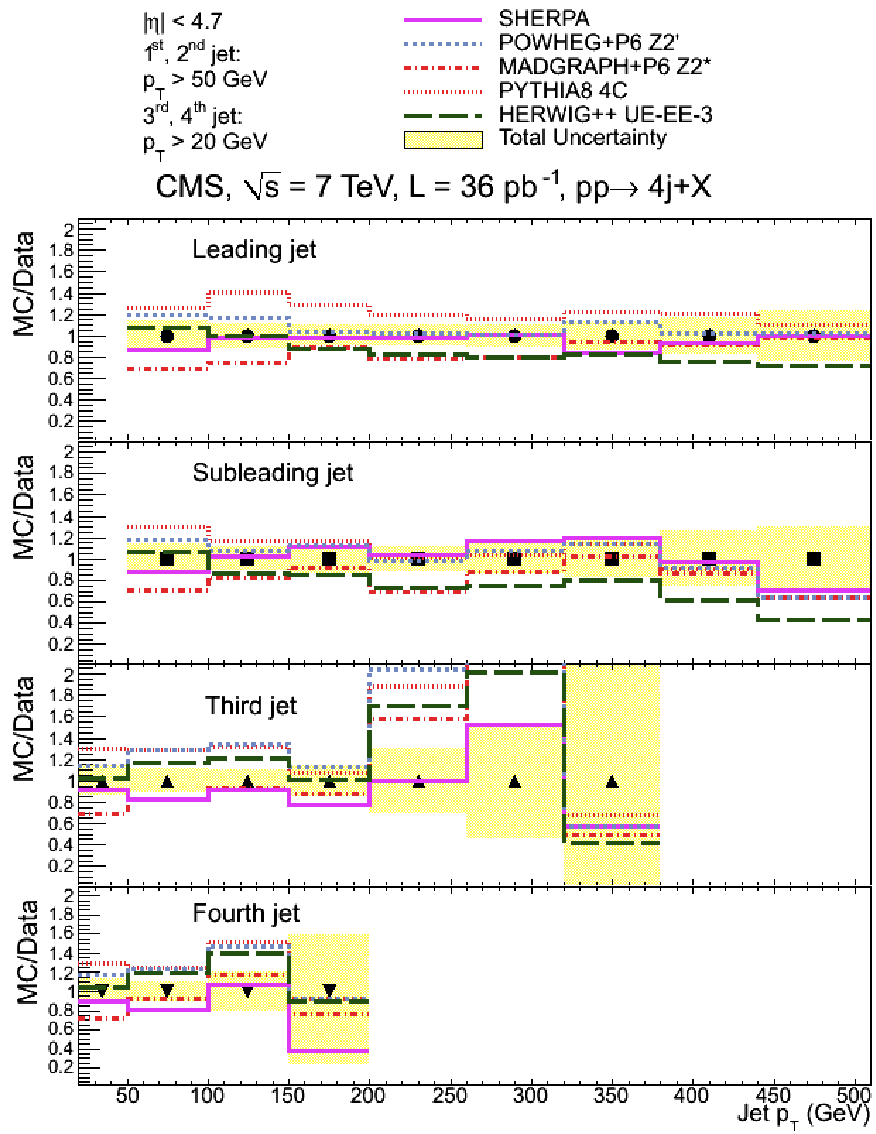
- In ratios DGLAP contributions are suppresed
- Pythia/Herwig good agreement at low Δy, at large Δy discrepancies
- Sherpa is above the data
- Cascade is far below the data
- BFKL NLL calculation describes well the ratios, especially C_2/C_1



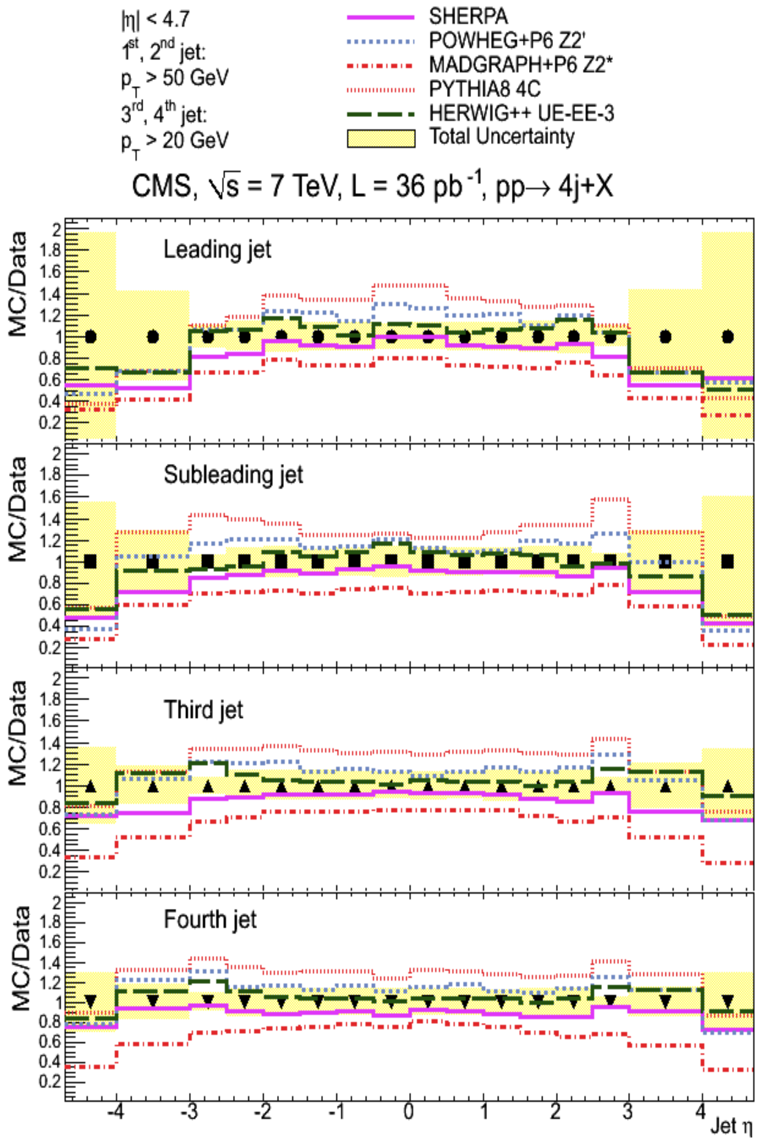
4-jet production

Selection:

- Data from 2010 with one primary vertex
- All jets in |η|<4.7
- Two leading jets pT>50 GeV
- Two subleading jets pT>20 GeV
- Correction factors taken from PYTHIA/HERWIG
- Systematic uncertainities dominated by Jet Energy Scale uncertainty
- SHERPA is the best
- Largest discrepancies in low p_T region



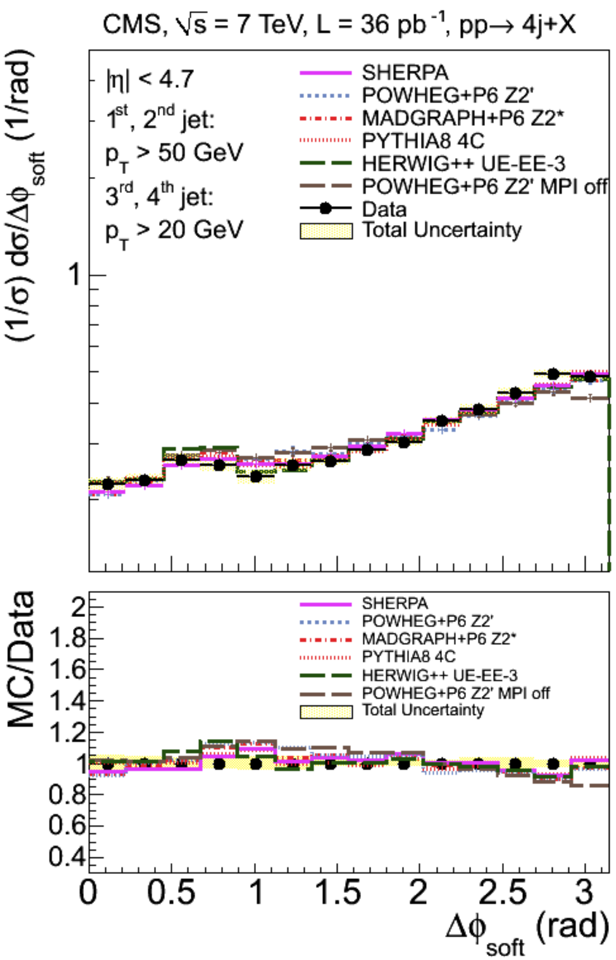
4-jet production



- Herwig++ and SHERPA describe data best
- Pythia8 tends to be above the data
- Description of the differential cross sections as funct. of p_T or η not trivial

$$\Delta\phi_{soft} = \phi_{soft_1} - \phi_{soft_2}$$

- Well described by all predictions
- Even by Powheg without MPI

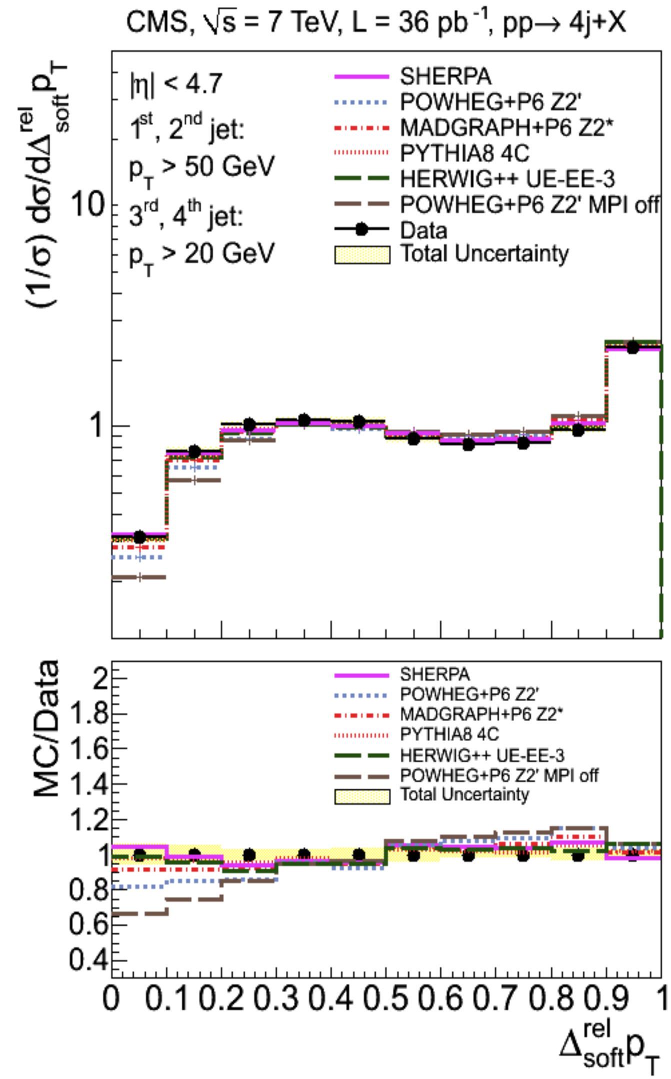


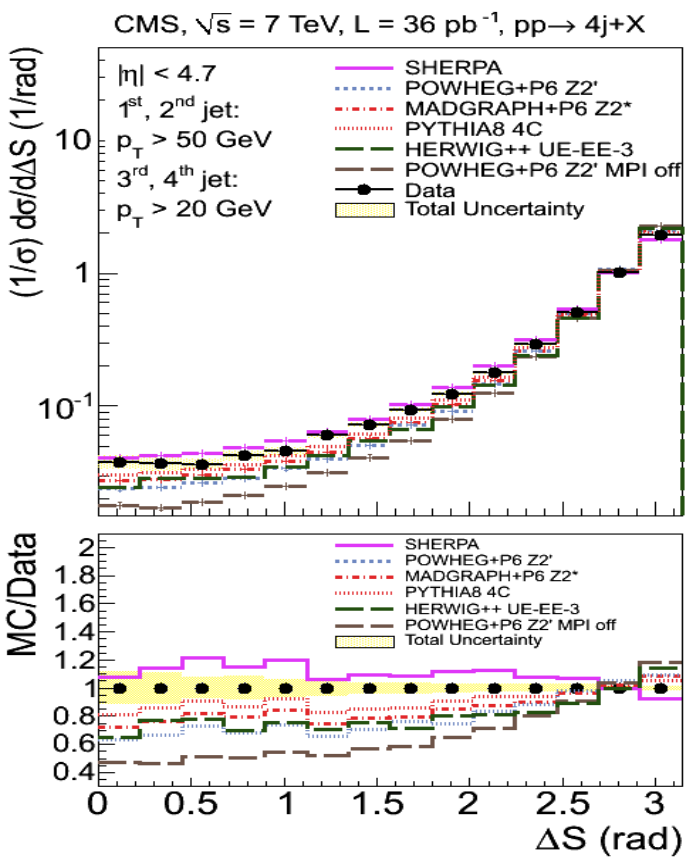
4-jet production

$$\Delta^{rel}_{soft} p_T = \frac{|\vec{p}_T^{\,soft_1} + \vec{p}_T^{\,soft_2}|}{|p_T^{soft_1}| + |p_T^{soft_2}|}$$

- Most soft jets not balanced
- Well description at larger values
- Powheg MPI – bad description

$$\Delta S = \arccos\left(\frac{\vec{p}_T(j^{hard_1}, j^{hard_2}) \cdot \vec{p}_T(j^{soft_1}, j^{soft_2})}{|\vec{p}_T(j^{hard_1}, j^{hard_2})| \cdot |\vec{p}_T(j^{soft_1}, j^{soft_2})|}\right)$$





- Not well described by any prediction
- Powheg without MPI at 0-2.5 range below data
- Indication of DPS

σ(4 jet) = 330 +/- 5(stat) +/- 45(syst) nb

Summary

- Comprehensive studies of multijet correlations at large rapidities performed by CMS
- So far Herwig++ seems to describe data best – inclusive and exclusive jets ratios described by Pythia
- Underlying event is important to understand data
- No clear deviation from DGLAP motivated MC observed
- Pay attention on C2/C1 describer by NLL BFKL calculations
- Indication of a need of DPS
- More to come, next – x-sections for Mueller-Navelet