Searches of beyond-DGLAP dynamics with multi-jets at CMS

Grigory Safronov
(ITEP, Moscow)

for the CMS Collaboration

Outline

- **Introduction**
- **Experimental capabilities**
  - Dataset
  - Jet reconstruction
  - Jet trigger
- **Measurements**
  - Cross section of inclusive forward jet production
  - Cross section of simultaneous production of forward and central jet
  - Inclusive and exclusive dijet production ratios
  - Azimuthal decorrelation of Mueller-Navelet jets
- **Summary**

Introduction

pQCD resummation → parton showers (PS)

DGLAP PS regime:

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

Strong ordering of emissions in pT

Measure high pT leading jets

BFKL PS regime (QCD high energy limit):

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

Strong ordering of emissions in y

Random walk of emissions in pT

Low pT allows to approach BFKL limit and open the phase space for multiple emissions with similar pT

BFKL prediction: $\hat{\sigma} \approx e^{A\Delta y} \approx \hat{s}^A$

Experimental requirements for the beyond-DGLAP searches:

- Large rapidity coverage
- Capabilities for jet measurements at low pT

Introduction

Observables covered in this talk

Forward jet differential cross-section

An access to x_1<<x_2, sensitive to low-x gluon densities

Forward-central dijet production cross-section

Jets with large rapidity separation cross-section

Inclusive and exclusive dijet production ratio

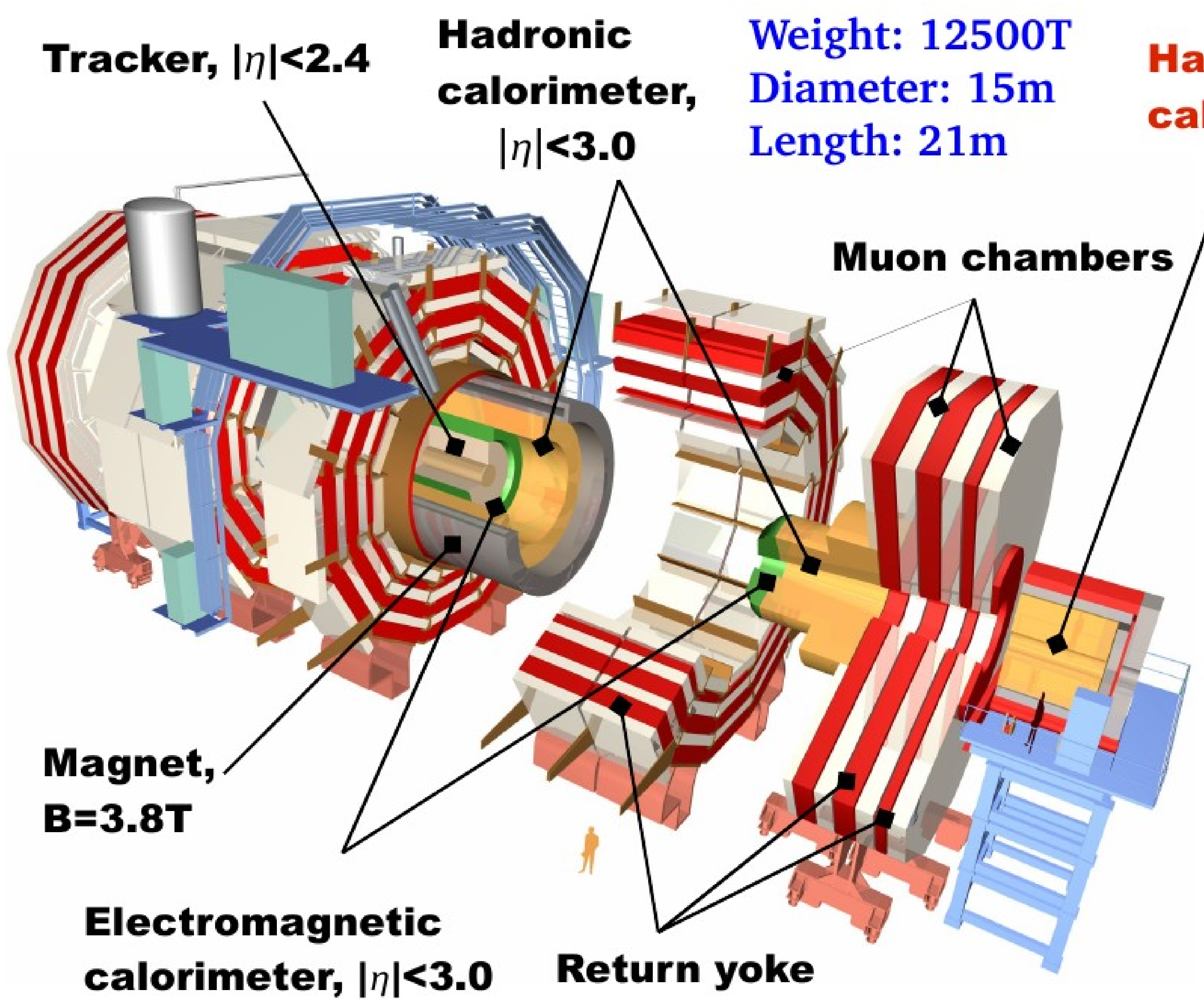
Higher order radiation at large rapidity intervals

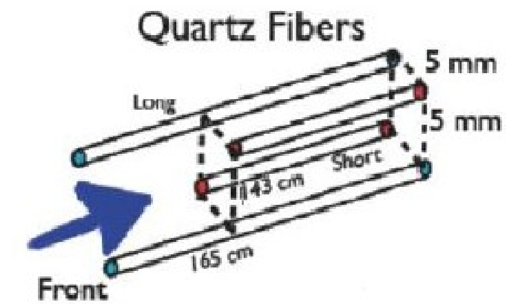
Mueller-Navelet dijet decorrelations

Higher order radiation at large rapidity intervals

All observables are corrected for the detector effects and compared to various Monte Carlo and analytic predictions

CMS detector



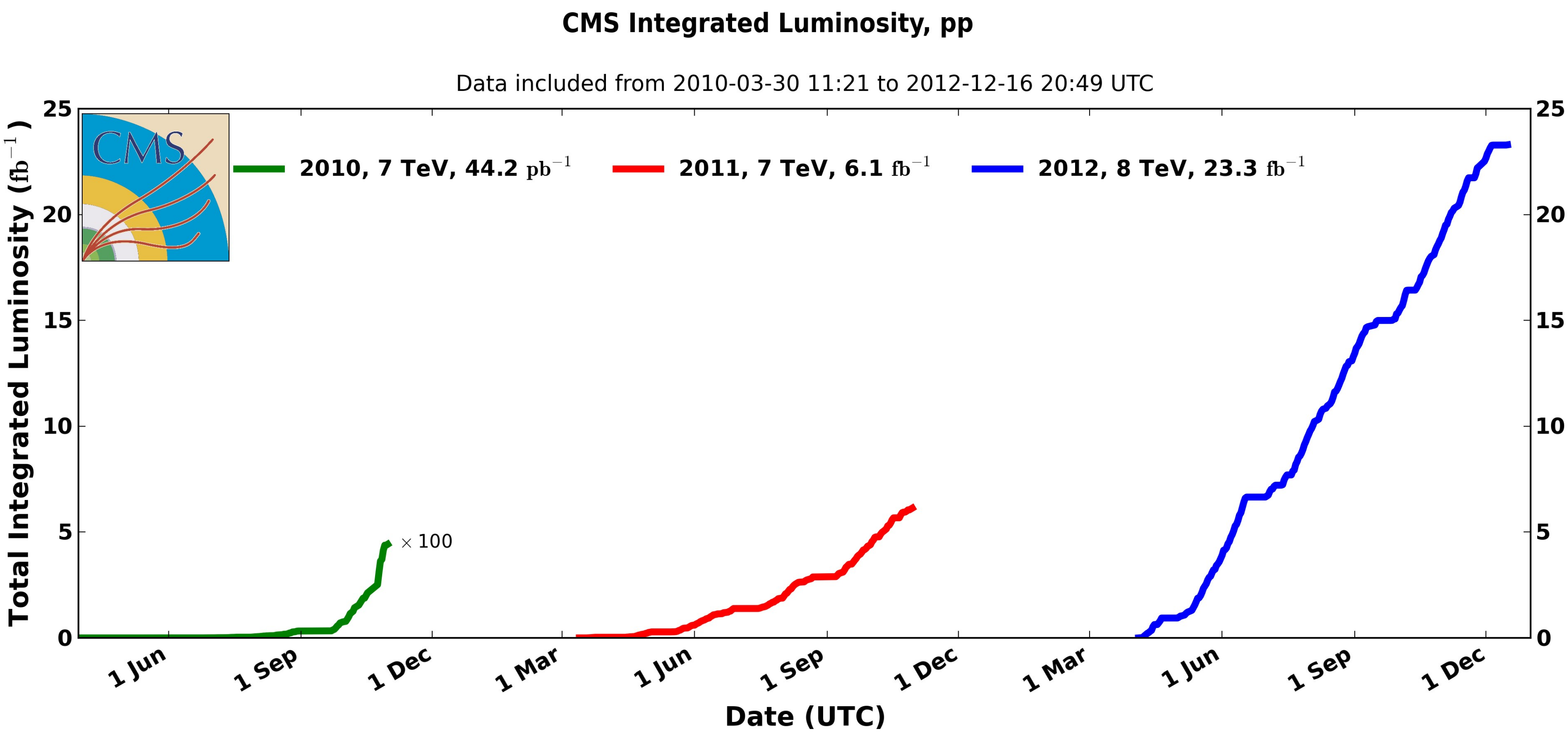


- Steel absorber
- Radiation-hard quartz fibers, Cherenkov light detection
- “Long” and “short” segments allow to distinguish between EM and HAD components of hadronic jet

Available data

LHC pp runs: ~30 fb^{-1} is collected in 2010 - 2013

pp data at 7, 8 and 2.76 TeV is available

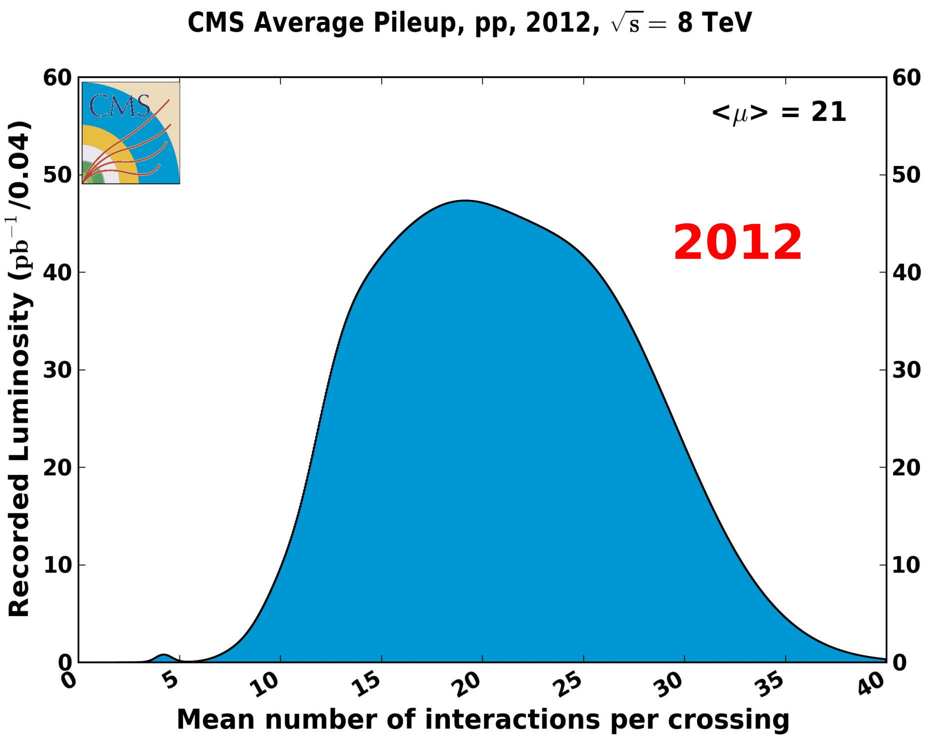


Available data

Not all LHC data can be used for beyond-DGLAP searches

Huge pileup in 2011-2012

- Not possible to tag low-pT forward jets belonging to the same interaction



Analyses presented here use 2010 data
<PU> ~ 2.2, integrated luminosity 44.2pb^{-1}

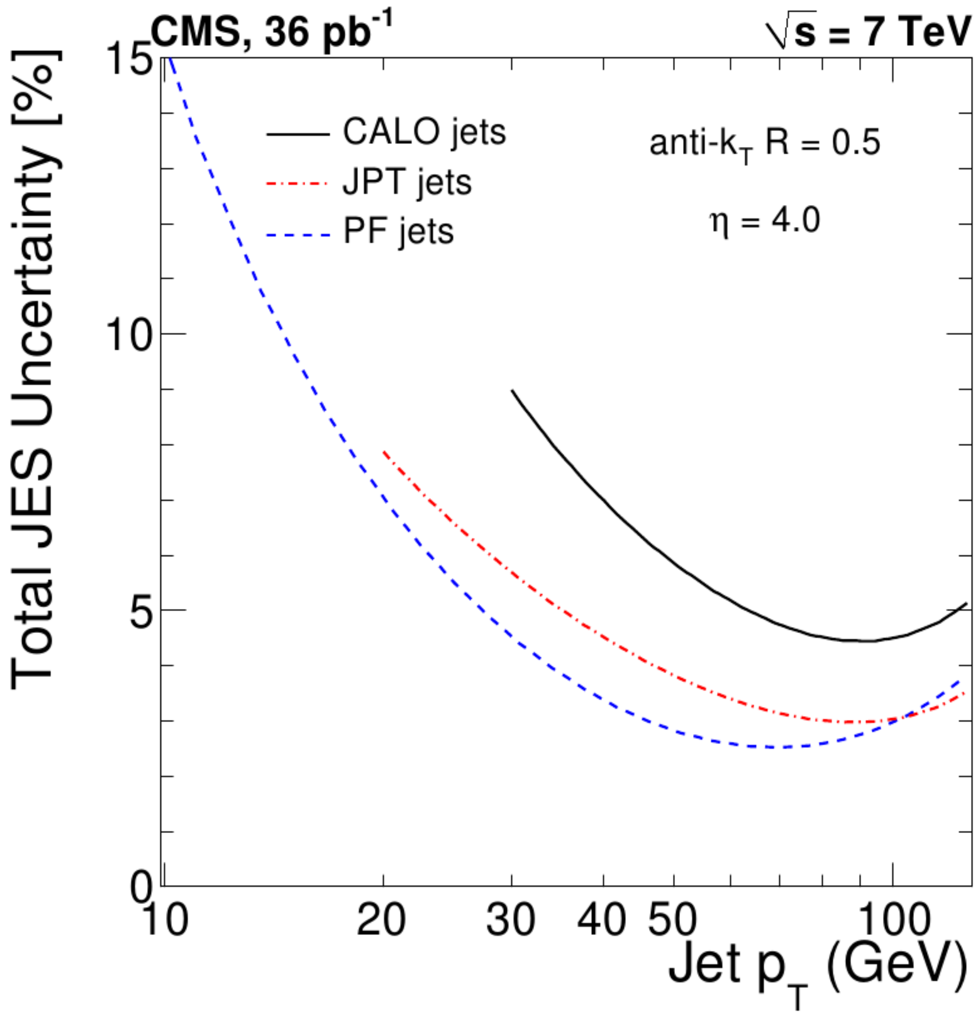
Much benefit from dedicated LHC pp runs @ low pileup (not covered here)
8 and 2.76 TeV datasets are available (O(10pb^{-1}) each)

Jet reconstruction

Several jet reconstruction techniques
- Calorimeter jets
- "Jet Plus Track" jets
- Particle Flow jets

MC and data driven jet energy scale (JES) calibration techniques
- Uncertainty of calibration < 10% for pT > 30 GeV
- Uncertainty grows as pT decreases

JES uncertainty – leading source of experimental uncertainty



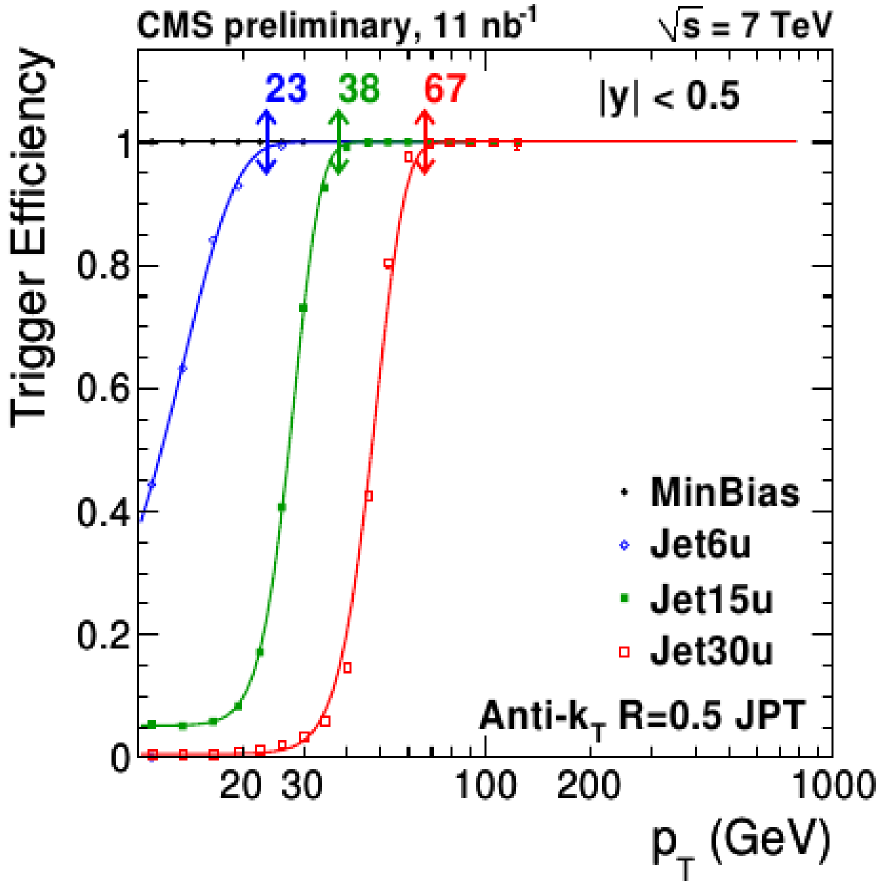
Presented analyses use jets clustered from calorimeter energy
Anti-kT, R=0.5 clustering algorithm

Jet triggers

Jet triggers are based on uncorrected calorimeter energy deposits

Lowest available trigger threshold pT > 15 GeV

- Turn-on point depends on η and type of the jet
- **100% efficiency in full acceptance for calojets with pT > 35 GeV**



Presented analyses use triggers requiring one or two jets with uncorrected ET > 15 GeV

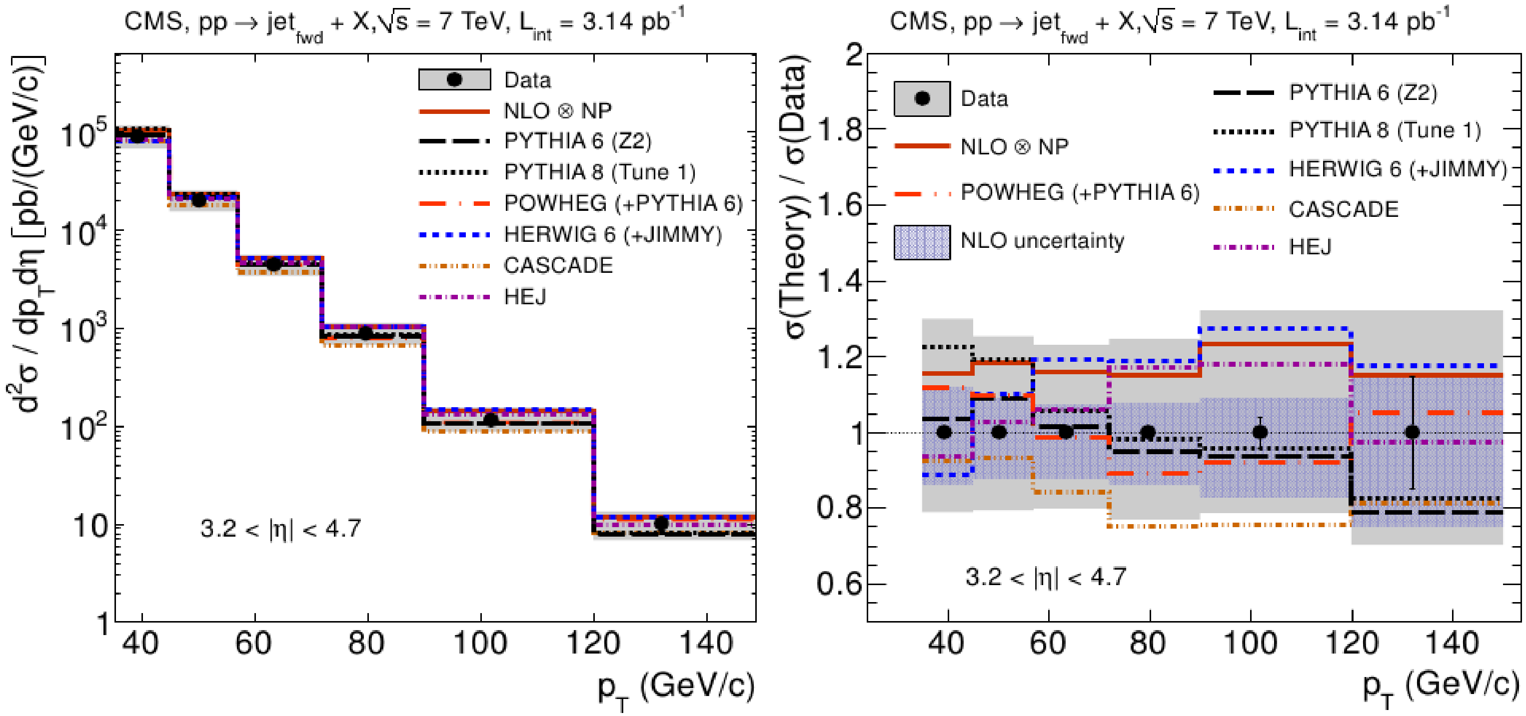
Measurements

Forward jet cross-section

At least one jet **3.2 < |η| < 4.7**
35 < pT < 150

Sensitive to x ~10^{-4}

Experimental uncertainties:
JES: 20-30%
Unfolding: 3-6%
Luminosity: 4%



All predictions agree with the data within uncertainties

NLO prediction (NLOJET++) is above by ~20% but still within uncertainties

Best description – POWHEG (+ PYTHIA6)

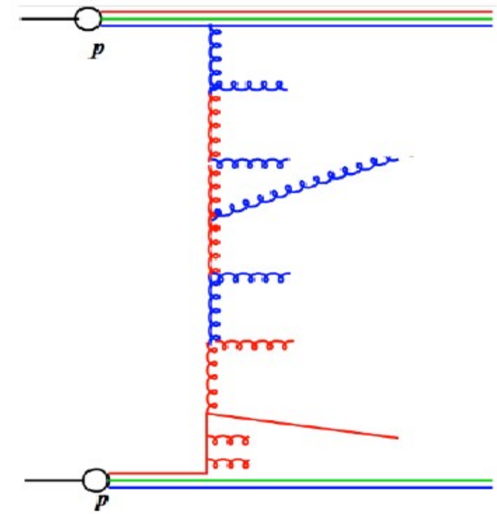
CMS-PAS-FWD-10-003 10.1007/JHEP06(2012)036

Forward-central jet cross-section

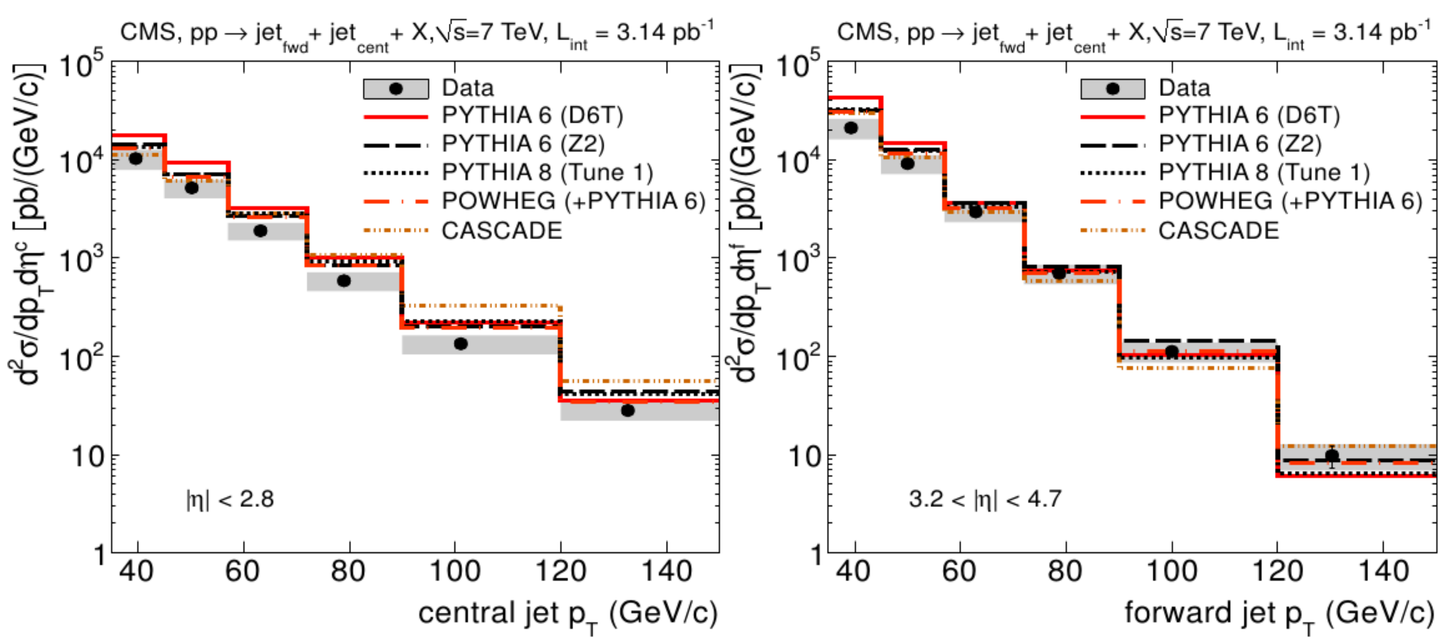
Events with at least one jet with pT > 35 GeV
In each of the regions:

forward **$3.2 < |\eta| < 4.7$**
central **$|\eta| < 2.5$**

Leading jet selection



Similar experimental systematics



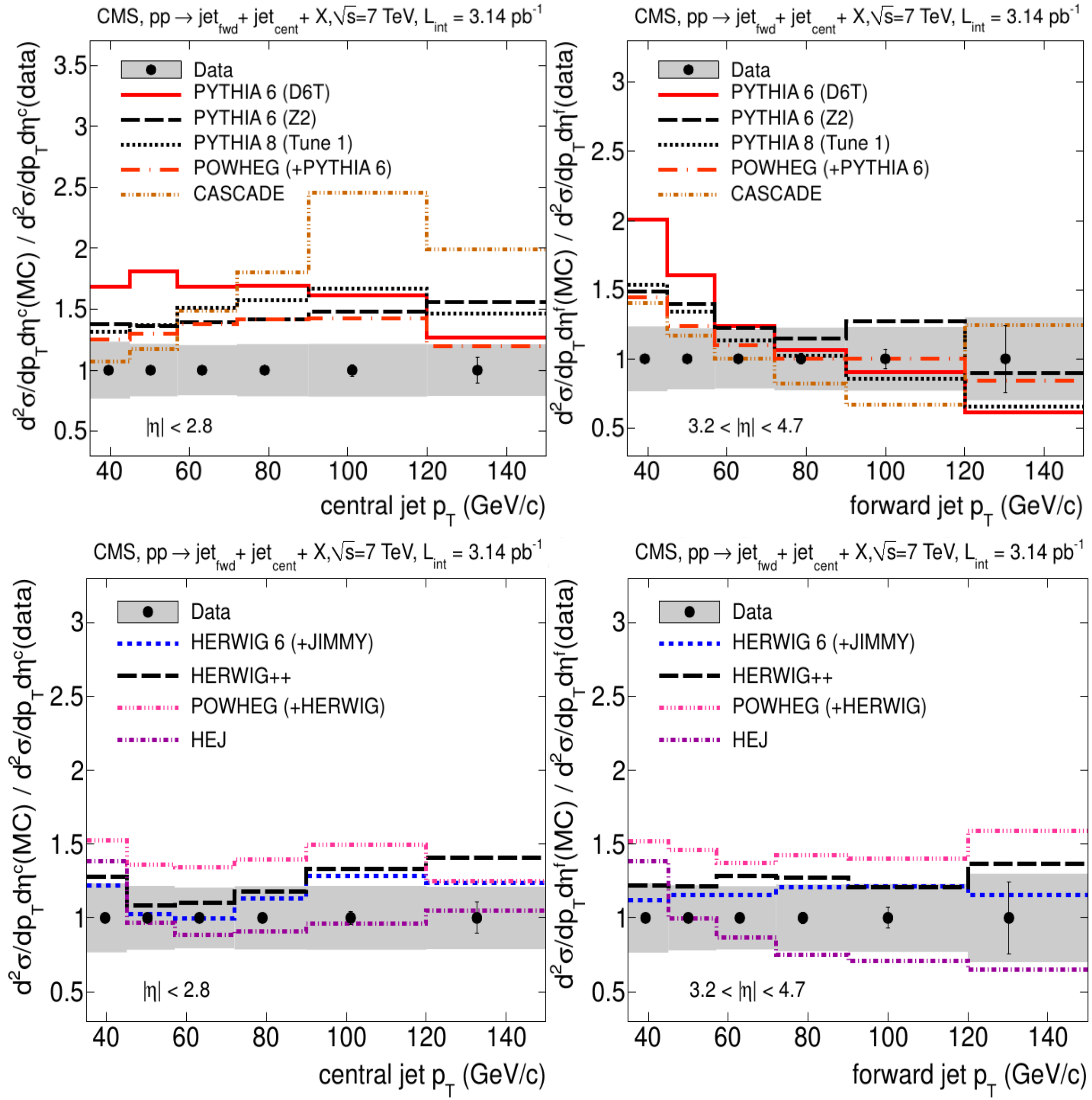
CMS-PAS-FWD-10-006 10.1007/JHEP06(2012)036

Forward-central jet cross-section

PYTHIA6, PYTHIA8 and CASCADE problem with central normalization and forward shape

HERWIG6, HERWIG++ and HEJ best agreement with data

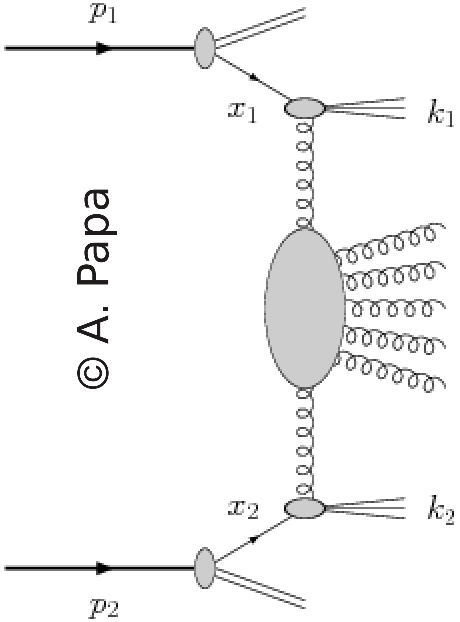
POWHEG matched to PYTHIA and HERWIG disagree with the data



10.1007/JHEP06(2012)036

CMS-PAS-FWD-10-006

Jets with large rapidity separation



Mueller-Navelet jets – pair above threshold with the largest rapidity separation in the event

- Rapidity ordered selection defines the phase space for BFKL-type parton shower
- No pT ordering

Observables sensitive to higher order QCD radiation between MN jets:

- Inclusive to “exclusive” dijet production ratio
- Azimuthal decorrelations

Jets with large rapidity separation

Common selections for both analyses:

Require single primary vertex (~1/3 of 2010 data)

Calorimeter **jet pT > 35 GeV, |η| < 4.7**

Rapidity separation coverage of the measurement: **Δy < 9.4**
- Combination of inclusive and forward-backward jet triggers

Systematic uncertainties

Dominated by JES and unfolding uncertainties

Pileup influence is reduced (or even removed) by single vertex requirement

Dijet production ratios

Measurement of ratios of dijet production ratios as a function of rapidity separation

Mueller-Navelet

$$R^{\mathrm{MN}} = \sigma^{\mathrm{MN}}/\sigma^{\mathrm{excl}}$$

inclusive

$$R^{\mathrm{incl}} = \sigma^{\mathrm{incl}}/\sigma^{\mathrm{excl}}$$

σ^{excl} - veto on additional jets above the threshold in the event

σ^{MN} - inclusive selection, no veto, MN pair

σ^{incl} - inclusive selection, no veto, all pairwise combinations

R^{incl} is proposed in **10.1103/PhysRevD.53.6**

Properties of observables:

- **Ratio emphasize higher orders enhanced by $(\alpha_s \Delta y)^n$ in the BFKL limit**
- **Remove PDF contributions**
- **Experimental systematic uncertainties are decreased**

CMS-PAS-FWD-10-014 10.1140/epjc/s10052-012-2216-6

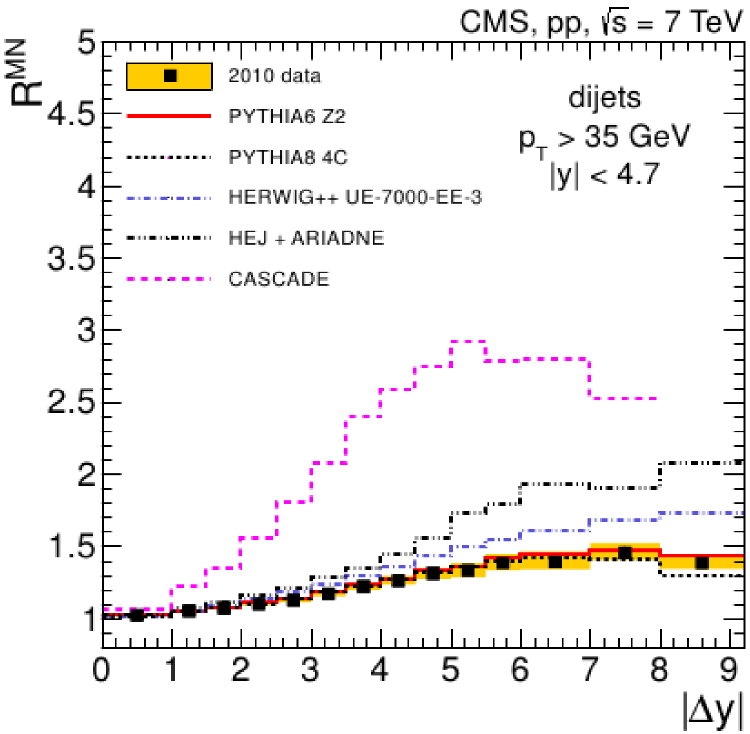
Dijet production ratios

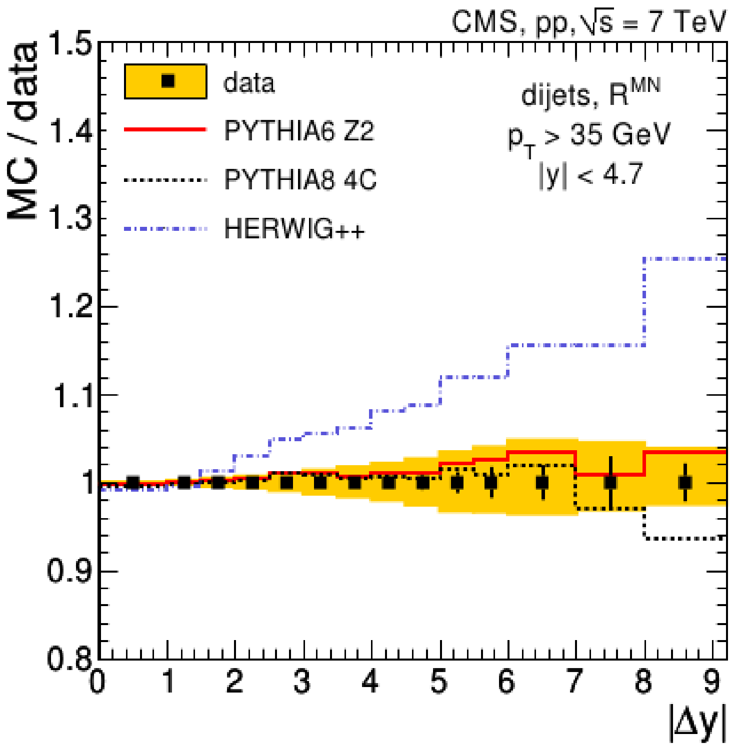
$$R^{\mathrm{MN}} = \sigma^{\mathrm{MN}} / \sigma^{\mathrm{excl}}$$

Best description of the data is given by PYTHIA6 and PYTHIA8

Herwig++ shows larger growth with increase of rapidity separation

BFKL inspired models CASCADE and HEJ overestimate data



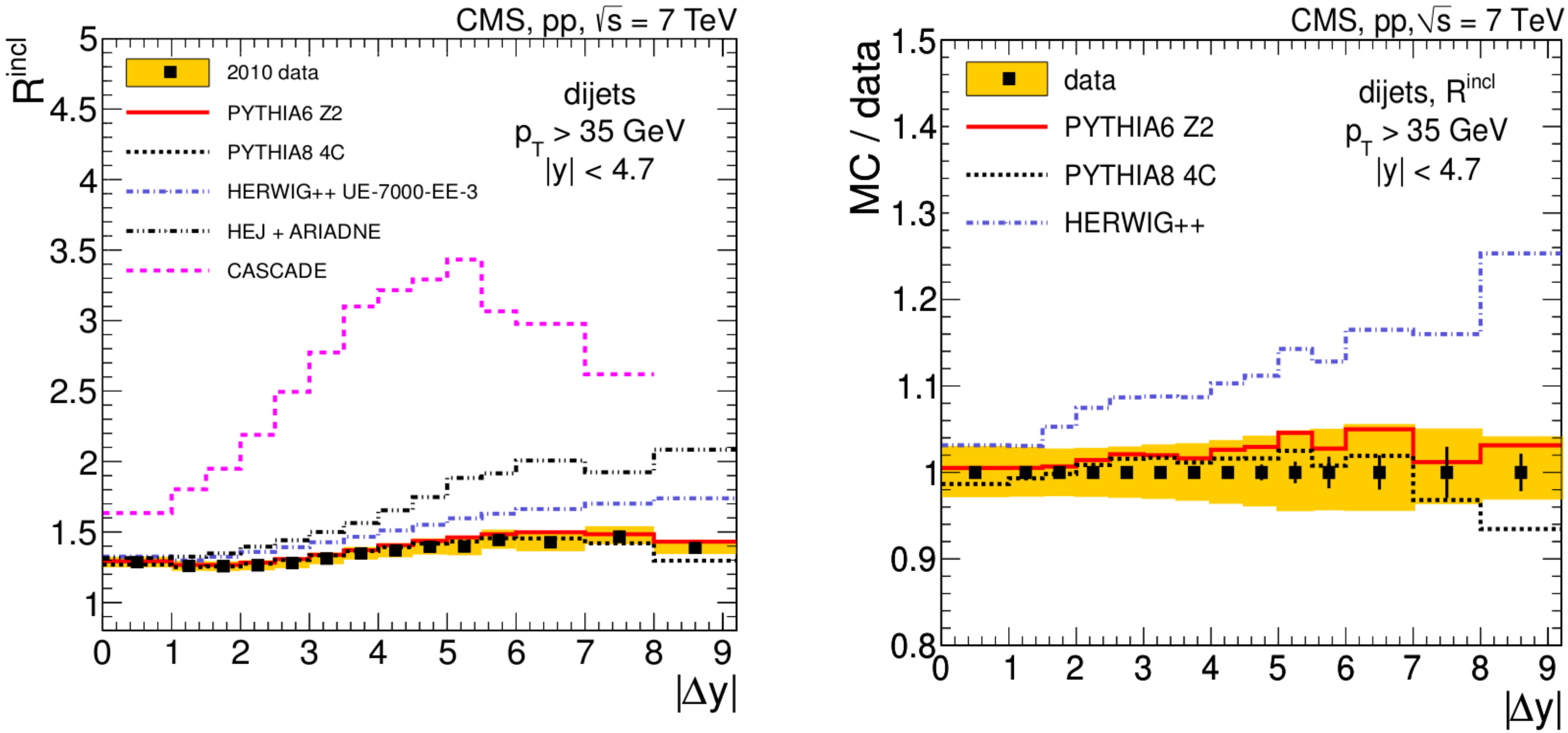


CMS-PAS-FWD-10-014 10.1140/epjc/s10052-012-2216-6

Dijet production ratios

$$R^{\rm incl} = \sigma^{\rm incl} / \sigma^{\rm excl}$$

Similar quality of MC description

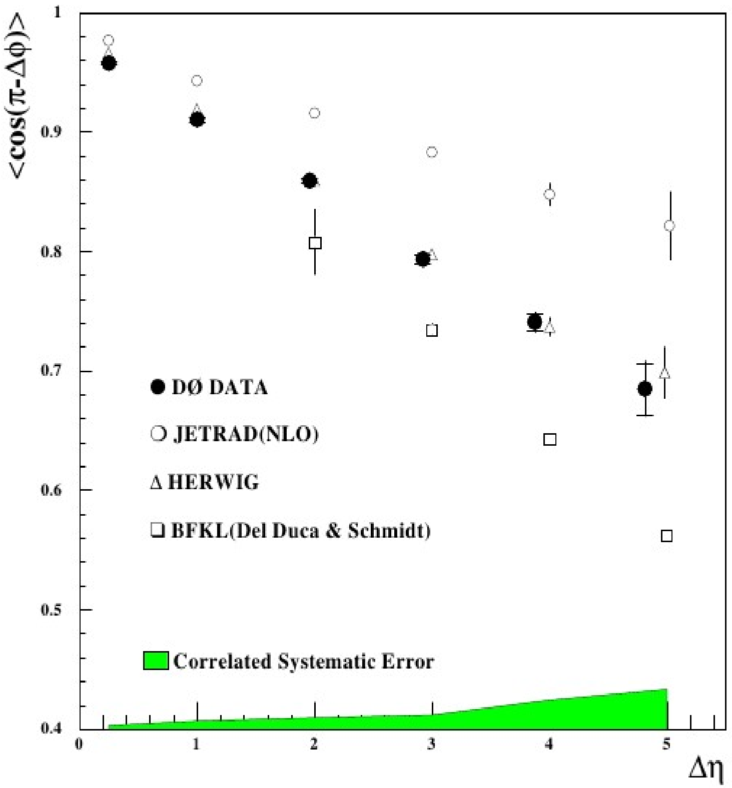


CMS-PAS-FWD-10-014 10.1140/epjc/s10052-012-2216-6

Conclusion: both ratios are well described by DGLAP-based PS models

MN azimuthal decorrelations

Measurement at D0 in 1996
[10.1103/PhysRevLett.77.595]
$\Delta\eta < 6.0$, E_T > 50 (20)
LL BFKL overestimates decorrelation
HERWIG gives best description



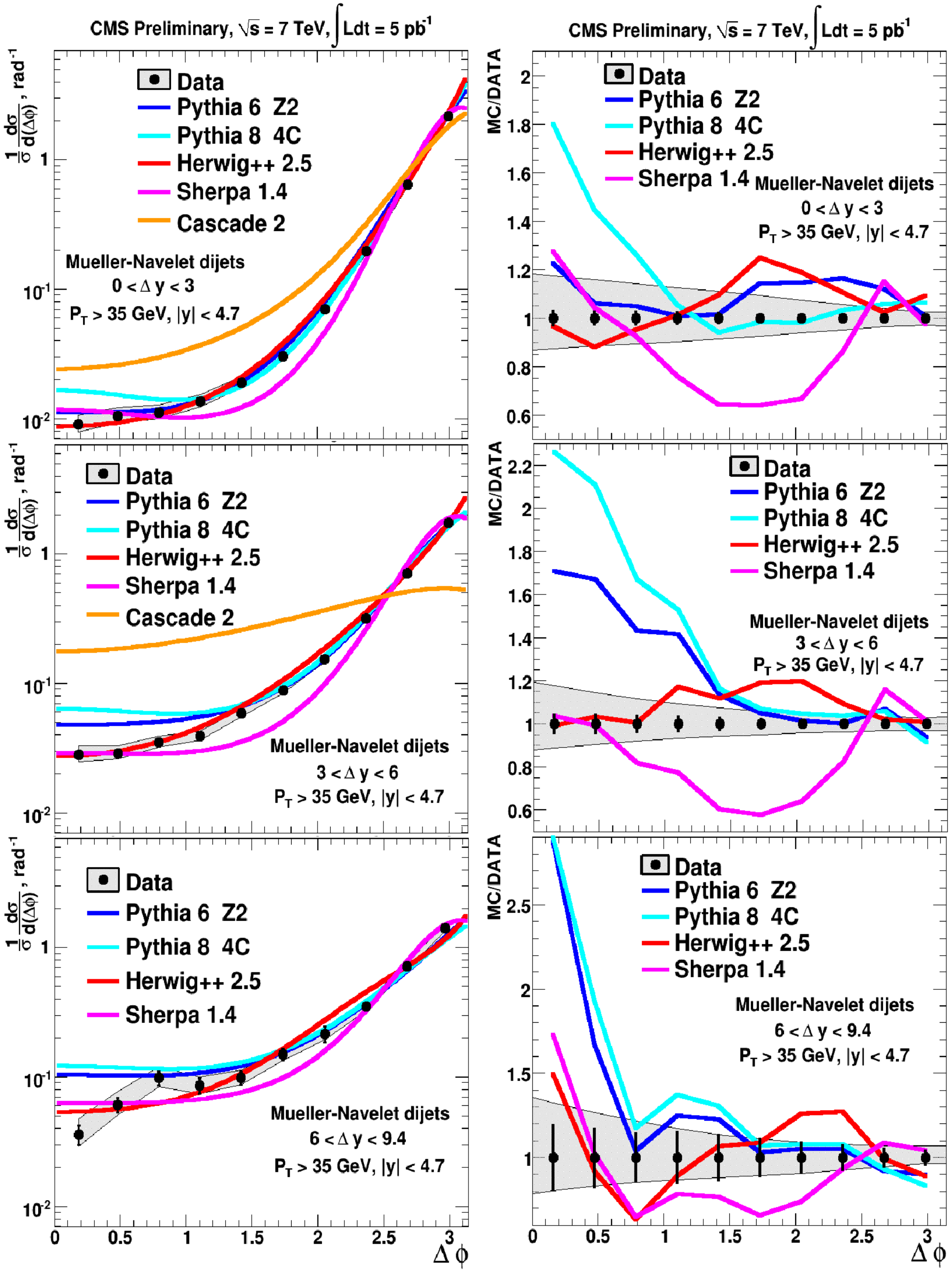
CMS measurement

Extends to **Δy < 9.4**
Symmetric **pT > 35 GeV**

Observables
- Azimuthal angle separation Δφ in Δy bins
- Average cosines C_1, C_2, C_3 as a function of Δy
- Ratios C_2/C_1, C_3/C_2

First presented at DIS13

Δφ shapes



Shapes of Δφ distributions

PYTHIA6 and PYTHIA8 show too strong decorrelation

SHERPA underestimates decorrelation

HERWIG++ is consistent with the data

CMS-PAS-FWD-12-002

Average cosines of n(π-Δφ)

First 3 coefficients of Fourrier transform of Δφ distribution

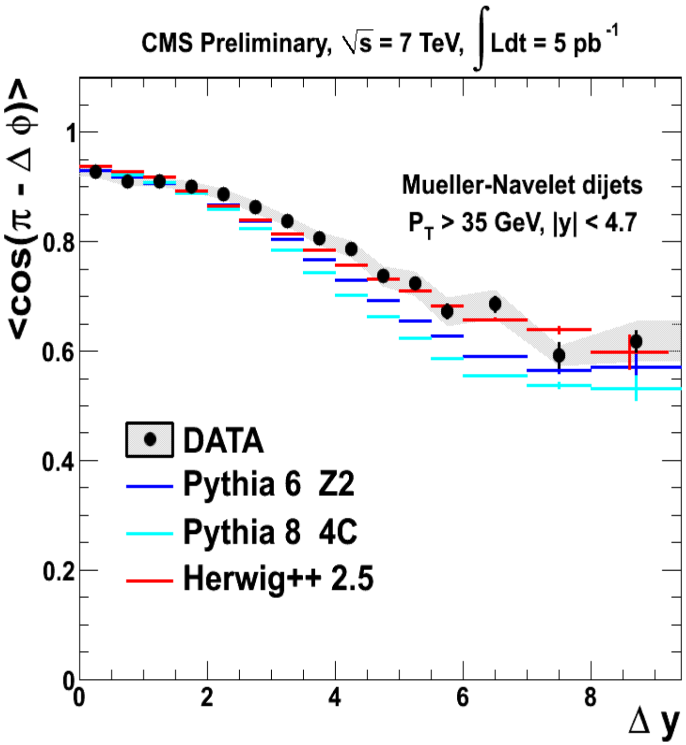
Equal to average cosines: $C_n = \langle \cos(n(\pi - \Delta\varphi)) \rangle$

BFKL NLL predictions (valid from Δy=4) provided by

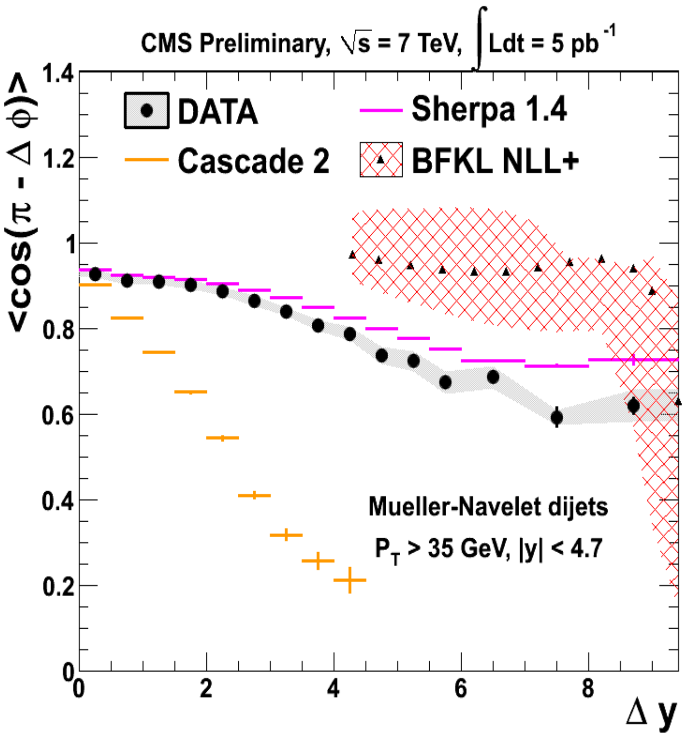
B. Ducloué, L. Szymanowski, S. Wallon, **[10.1007/JHEP05(2013)096]**

Parton level predictions, negligible hadronization effect

CMS-PAS-FWD-12-002



C1



Average cosines of n(π-Δφ)

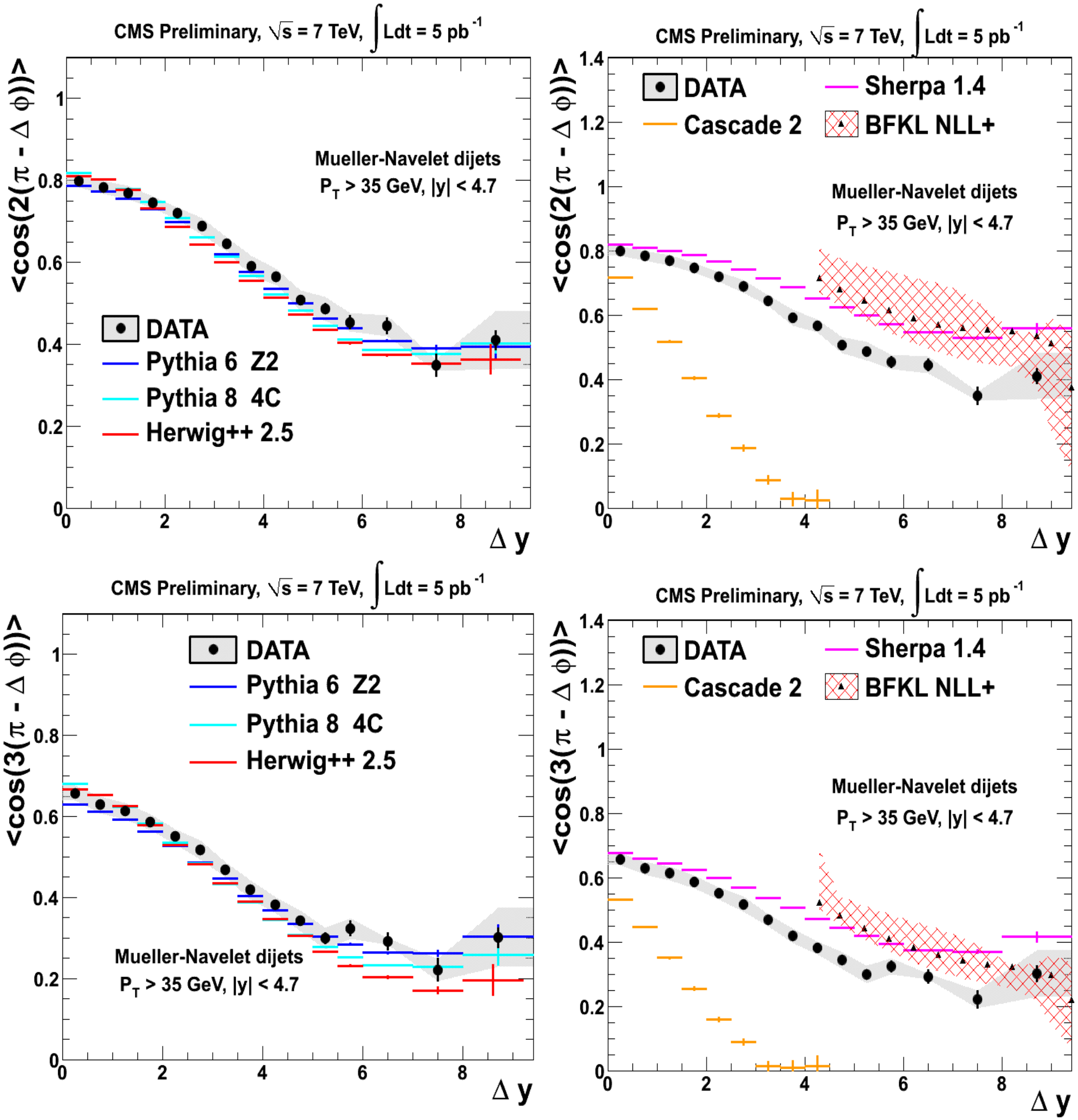
C2

CASCADE predicts too strong radiation

Correlation in SHERPA and NLL BFKL is stronger than in data

PYTHIA and HERWIG describe the data well

C3



CMS-PAS-FWD-12-002

Cosine ratios

Ratios of cosines as proposed in **10.1016/j.nuclphysb.2007.03.050**

DGLAP contributions cancel

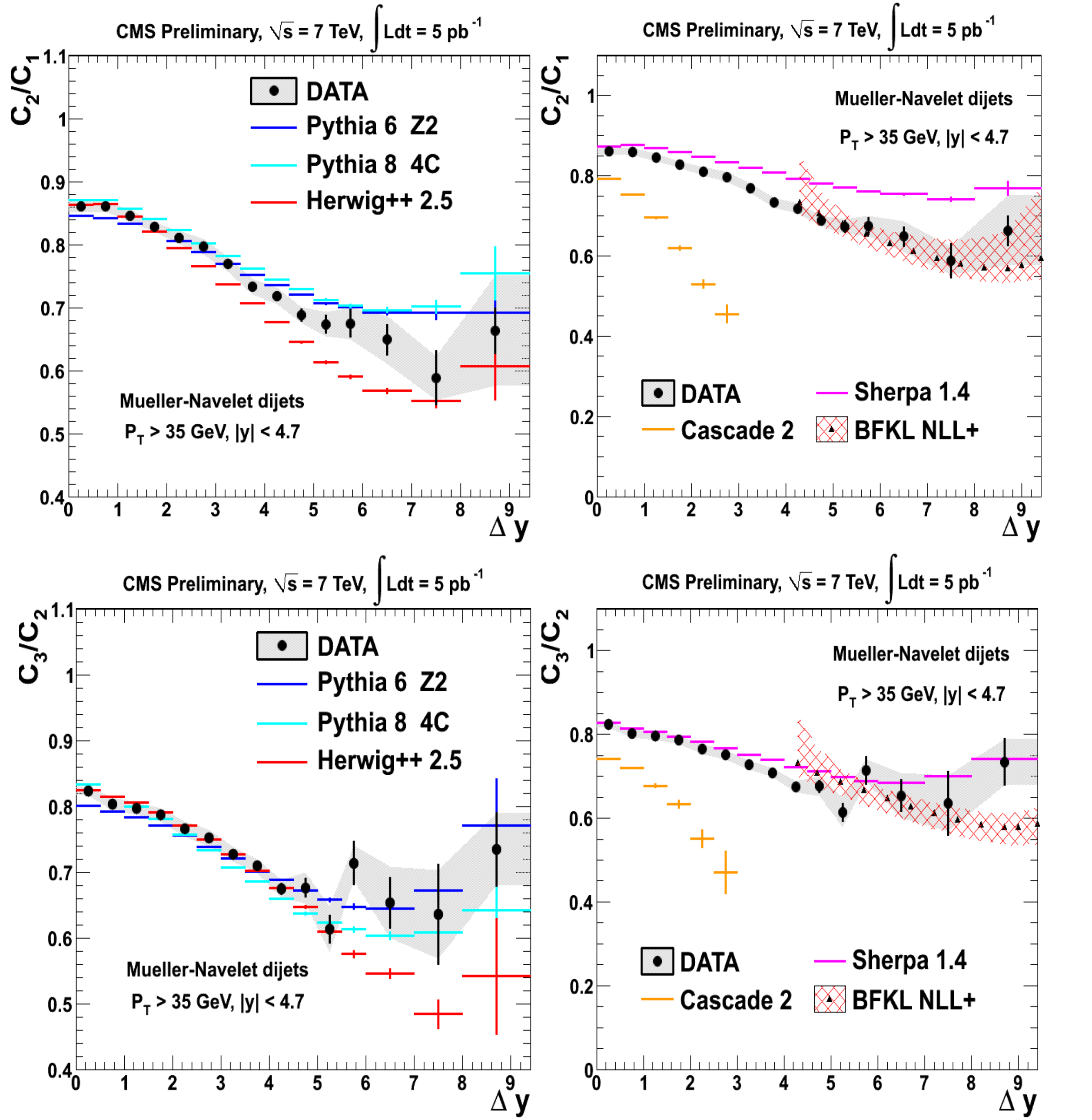
More stable calculations in NLL BFKL

PYTHIA6, 8 show better agreement than HERWIG++

SHERPA overestimate C2/C1, Consistent with C3/C2

NLL BFKL is consistent with ratios

CMS-PAS-FWD-12-002

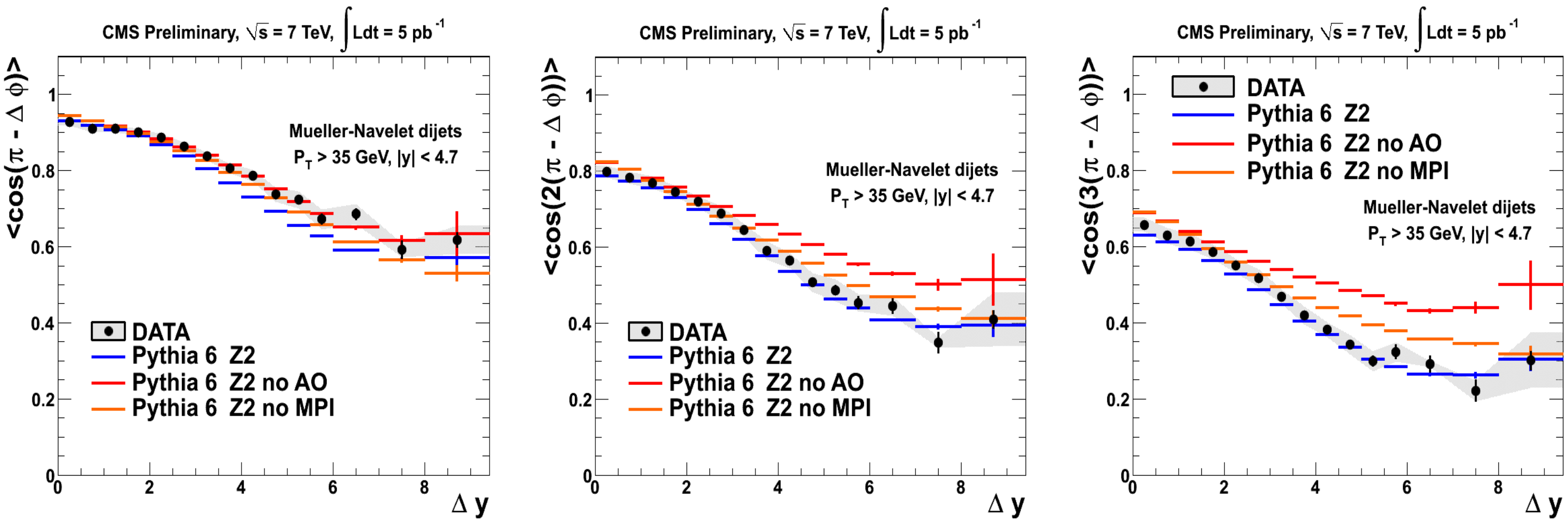


AO and MPI study

CMS-PAS-FWD-12-002

AO and MPI were studied in PYTHIA6 (switched off and on)

Angular ordering in parton shower is essential for good data description



CMS-PAS-FWD-12-002

SUMMARY

- For the first time decorrelations are measured up to $\Delta y = 9.4$
- Best description of all observables is given by HERWIG++
- PYTHIA6, PYTHIA8 and SHERPA do not describe all observables
- Cosine ratios are well described by NLL BFKL calculation
- **Angular ordering has large impact on decorrelation (in PYTHIA6)**

Conclusion: No clear evidence for BFKL dynamics

SUMMARY

pT-ordered selections

Inclusive forward jet cross-section:

- All theory predictions agree with the data (DGLAP-based MC, BFKL/CCFM-based MC, NLO DGLAP)

Forward-central jet cross-sections

- Best description is given by HERWIG++, HERWIG6, HEJ

y-ordered selections

Inclusive to exclusive dijet production ratios

- PYTHIA6 and PYTHIA8 predictions are with the experimental uncertainties
- HERWIG++, HEJ, CASCADE fail to describe

Mueller-Navelet jets angular decorrelations

- Best description is given by HERWIG++
- NLL BFKL predictions provide good description of cosines ratios

General conclusion:

No clear evidence for high energy limit asymptotics

Backup