Beyond-DGLAP searches with Mueller-Navelet jets, and measurements of low-pT and forward jets at CMS

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Outline

- **Introduction**
- **CMS detector**
- **Datasets**
- **Measurements**
  - Cross section of inclusive forward jet production
  - Inclusive and exclusive dijet production ratios
  - Azimuthal decorrelation of Mueller-Navelet jets
- **Summary**

Introduction (I)

pQCD resummation → parton showers (PS)

DGLAP PS regime:
$\sqrt{s} \sim p_T > \Lambda_{QCD}$
Strong ordering of emissions in pT

Measure high-p_T 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

Measure low-p_T jets with large rapidity span → approach BFKL limit and open the phase space for multiple emissions with similar p_T

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

Search for beyond-DGLAP effects in low-p_T PS with large rapidity span

Introduction (II)

Measurements covered in this talk

Low-p_T forward jet differential cross-section

Benchmark measurement; an access to $x_1 \ll x_2$

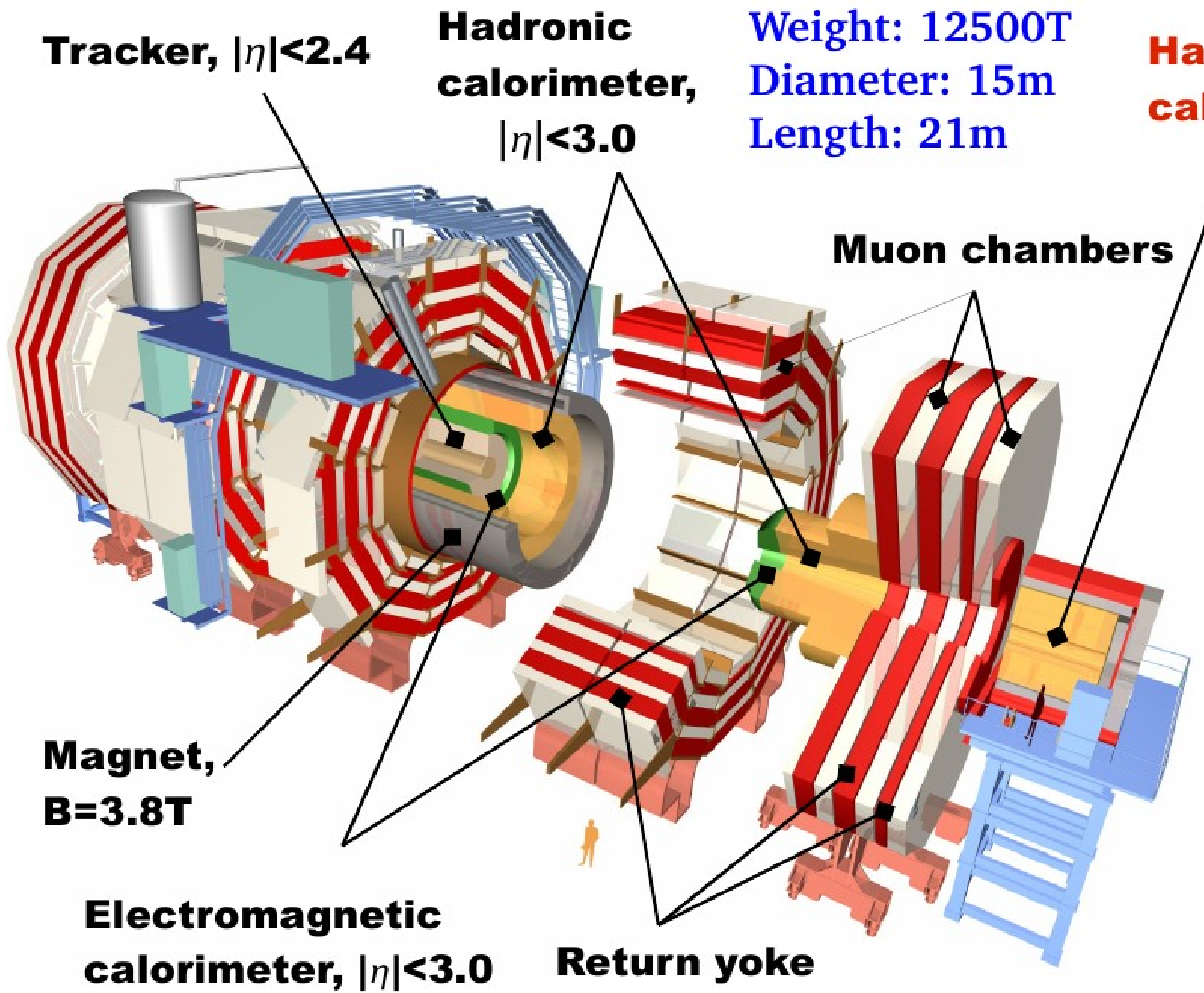
Inclusive and exclusive dijet production ratio

Resummation effects at large rapidity intervals

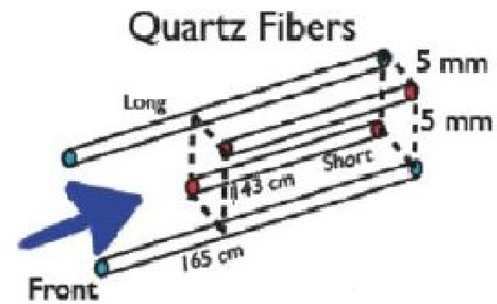
Mueller-Navelet dijet decorrelations

Resummation effects at large rapidity intervals

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



Hadronic Forward (HF) calorimeter, $2.9<|\eta|<5.2$

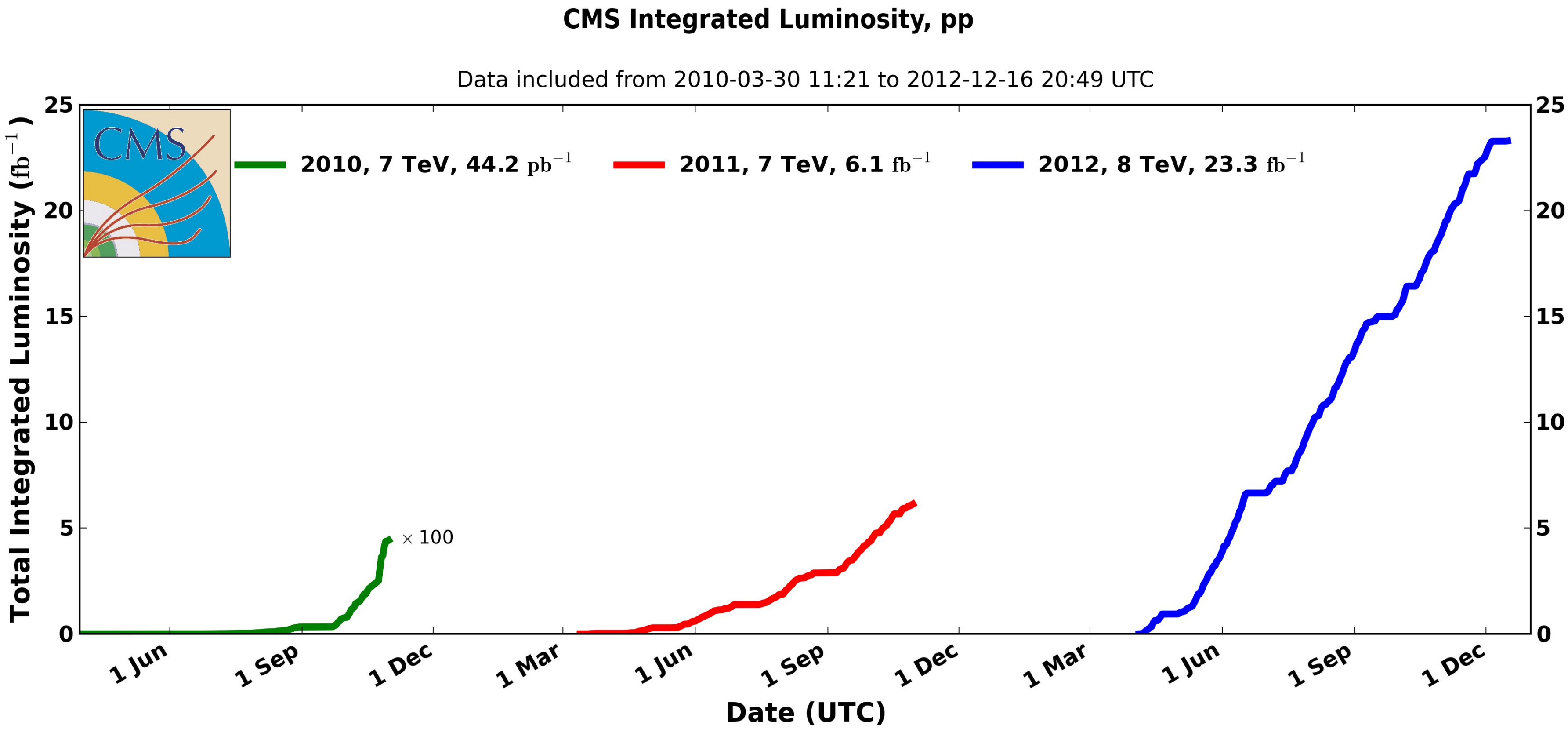


- Steel absorber
- Radiation-hard quartz fibers, Cherenkov light detection
- “Long” and “short” segments allow to distinguish between EM and HAD components of hadronic jet

Datasets (I)

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

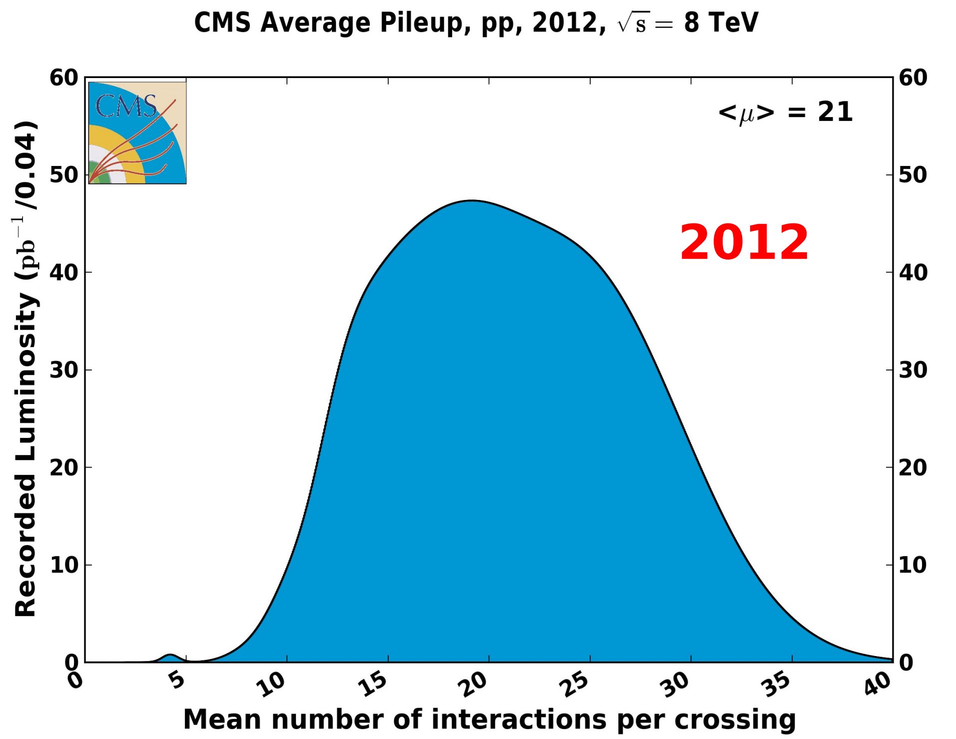
pp data at 7, 8 and 2.76 TeV



Datasets (II)

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

Huge pileup in 2011-2012
- ➔ Not possible to tag low-p_T forward jets belonging to the same interaction



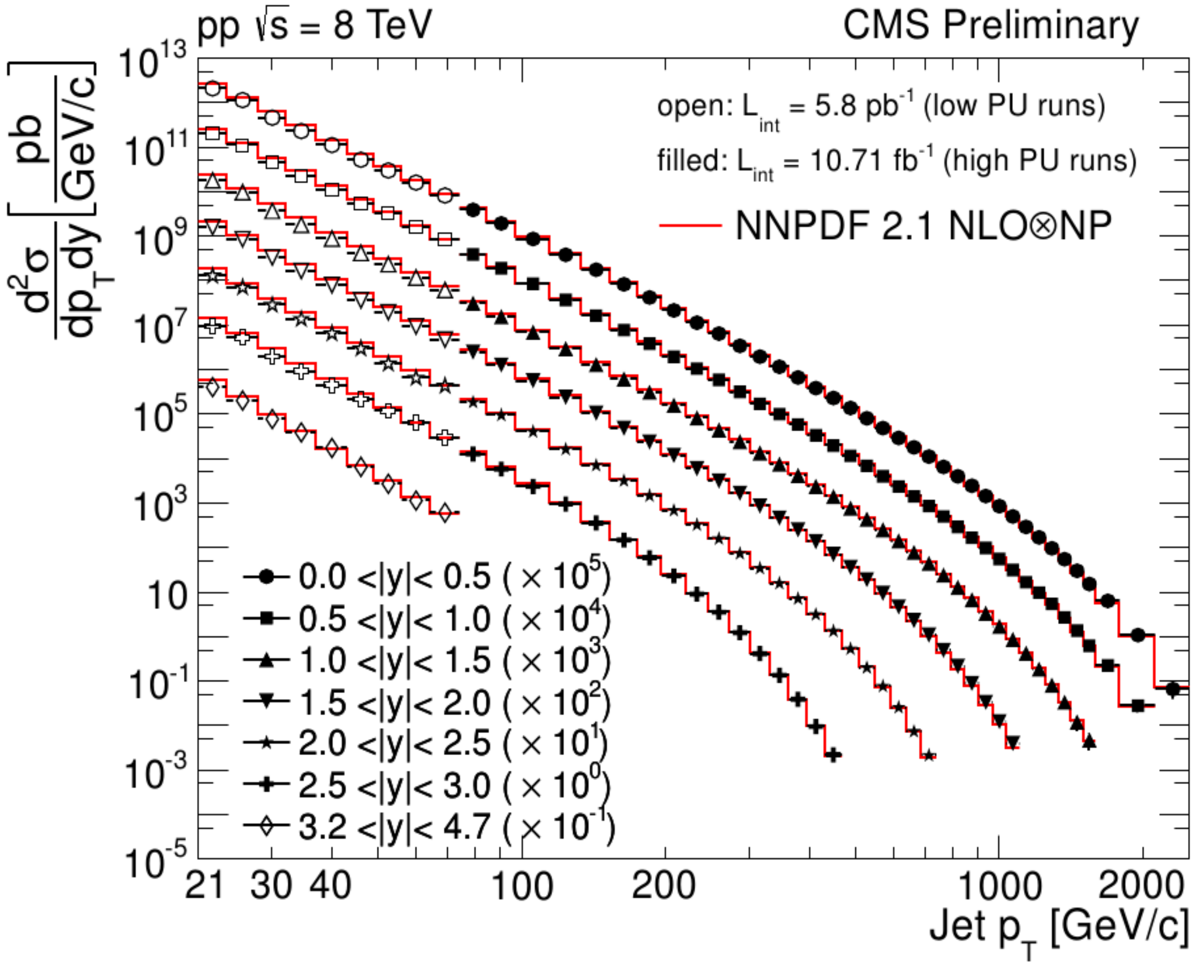
LHC pp runs @ low pileup (1-2) are essential for MN jet studies (tens of pb^{-1})

Analyses presented here use 2010 and 2012 data taken at low pileup
7 TeV 2010: <PU> ~ 2.2, integrated luminosity 44.2pb^{-1}
8 TeV 2012: 2 runs <PU> ~ 4, l = 5.8 pb^{-1}

Measurements

Inclusive jet cross-section

Combined low-pileup runs (Summer 12) and full 2012 dataset



CMS-PAS-FSQ-12-031 [comb. CMS-PAS-SMP-12-012]

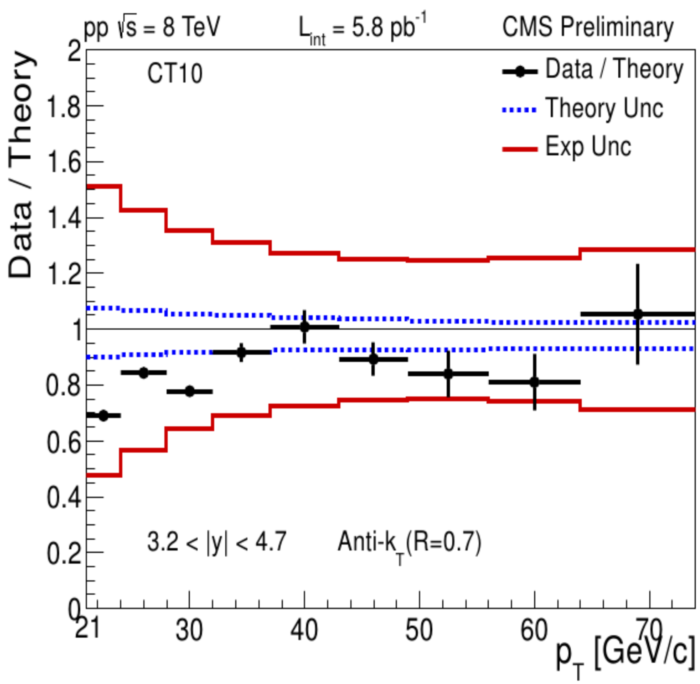
Data is well-described in wide range of p_T and rapidities by NLO⊗NP theory predictions

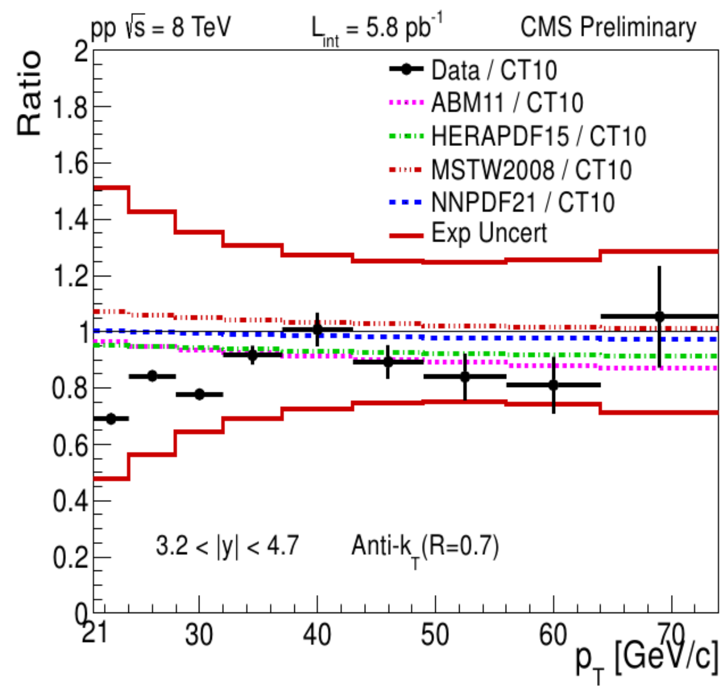
Forward jet cross-section

Closer look at forward jets

3.2 < |η| < 4.7
21 < p_T < 80

Experimental uncertainties:
JES: < 45%
Unfolding: 3-6%
Luminosity: 4%





CMS-PAS-FSQ-12-031

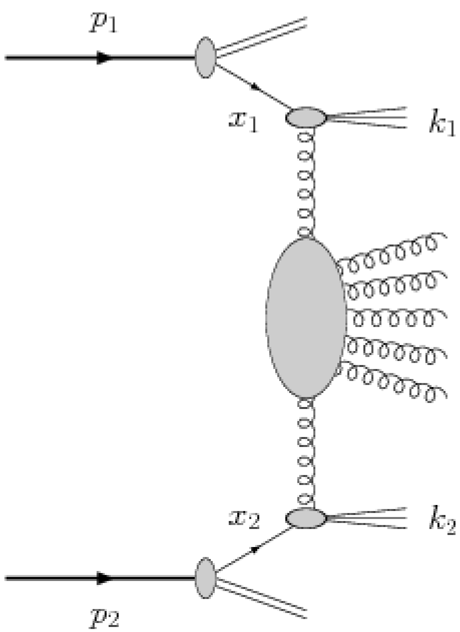
All predictions agree with data within the uncertainties

Conclusion: inclusive jet production is well-described by theory predictions over the wide range of p_T and rapidity

Jets with large rapidity separation (I)

QCD events with jets widely separated in rapidity -
sensitive probe for parton shower structure

Central - forward dijet production (covered in talk by Pedro Cipriano)



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

- Rapidity-ordered jets define the phase space for BFKL-type parton shower
- No p_T ordering

Observables sensitive to higher order QCD radiation between MN jets were measured:

- **Inclusive to "exclusive" dijet production ratio**
- **Azimuthal angle decorrelation within MN pair**

Jets with large rapidity separation (II)

Common selections for both analyses:

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

Calorimeter **jet p_T > 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 (I)

Measurement of dijet production cross-section ratios as a function of rapidity separation

Mueller-Navelet | **inclusive**

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

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

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

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

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

Properties of observables:

- **Ratio emphasizes 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

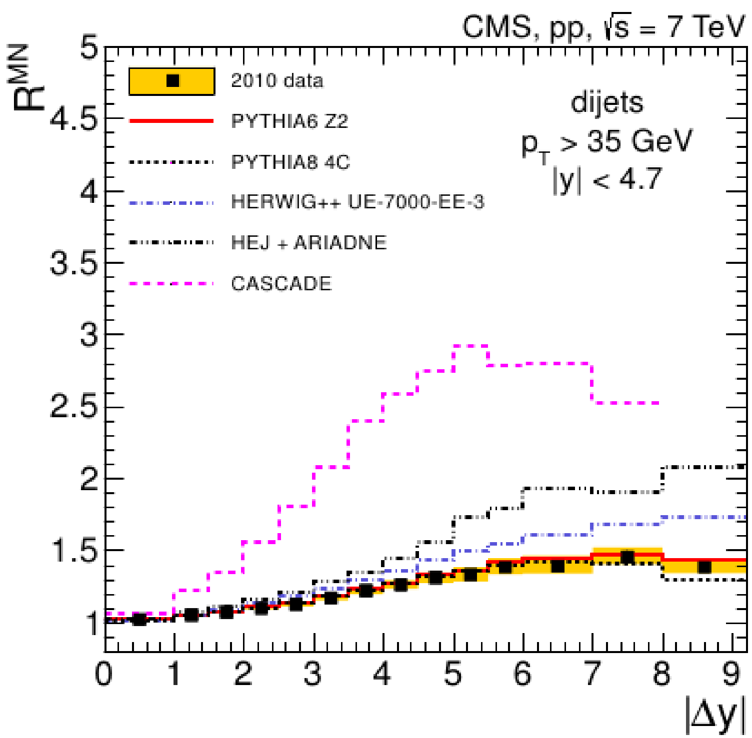
Dijet production ratios (II)

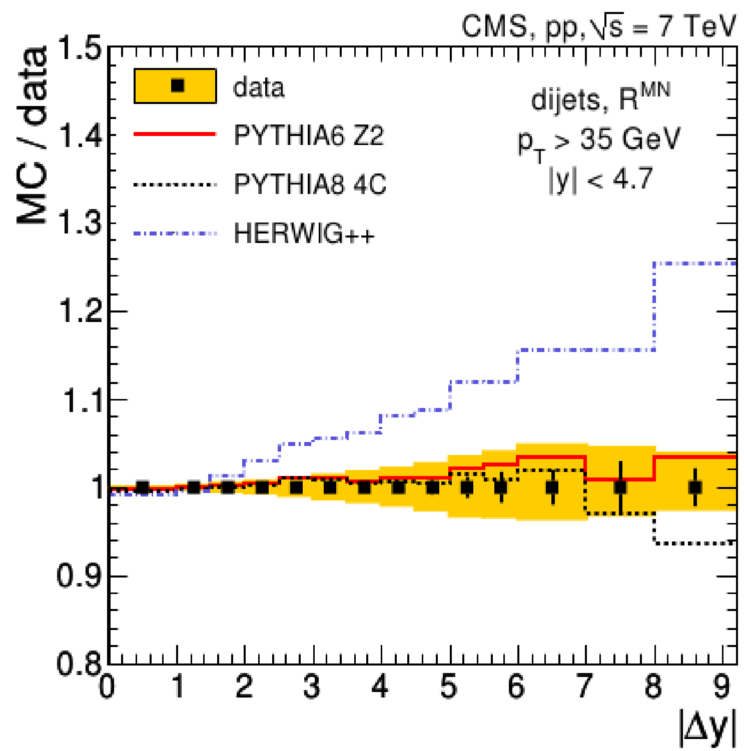
$$R^{\mathrm{MN}} = \sigma^{\mathrm{MN}} / \sigma^{\mathrm{excl}}$$

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



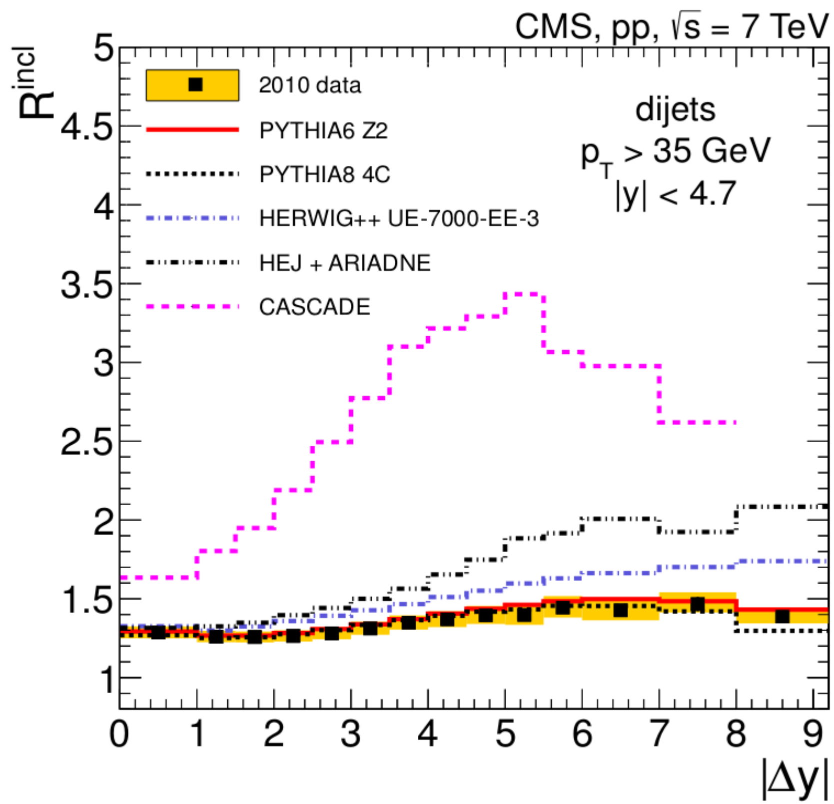


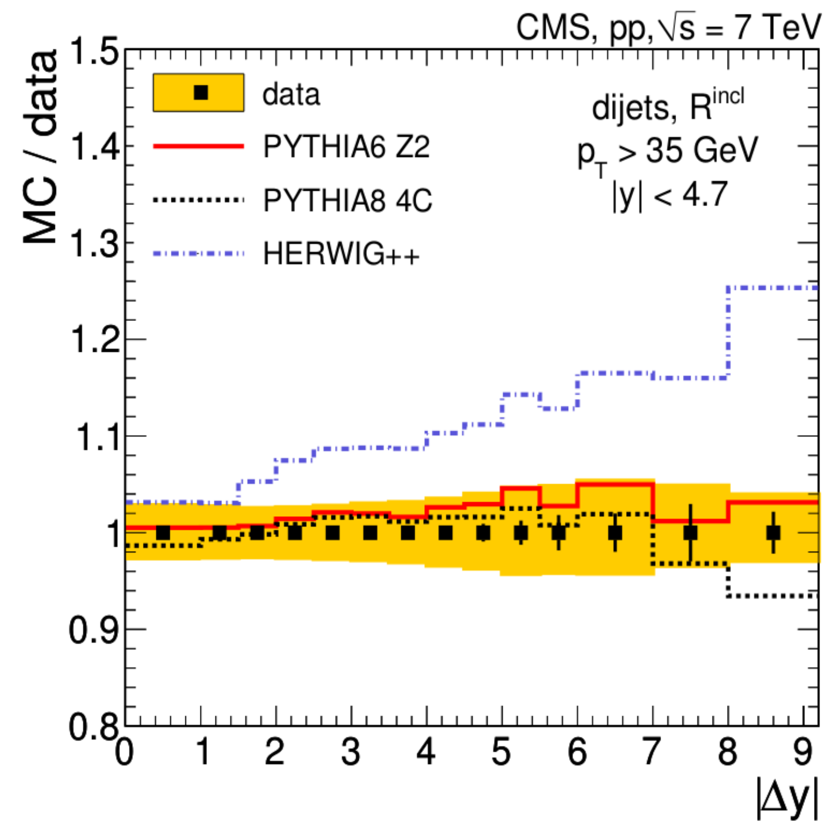
CMS-PAS-FWD-10-014 10.1140/epjc/s10052-012-2216-6

Dijet production ratios (III)

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

Similar quality of MC description





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

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

MN azimuthal decorrelations (I)

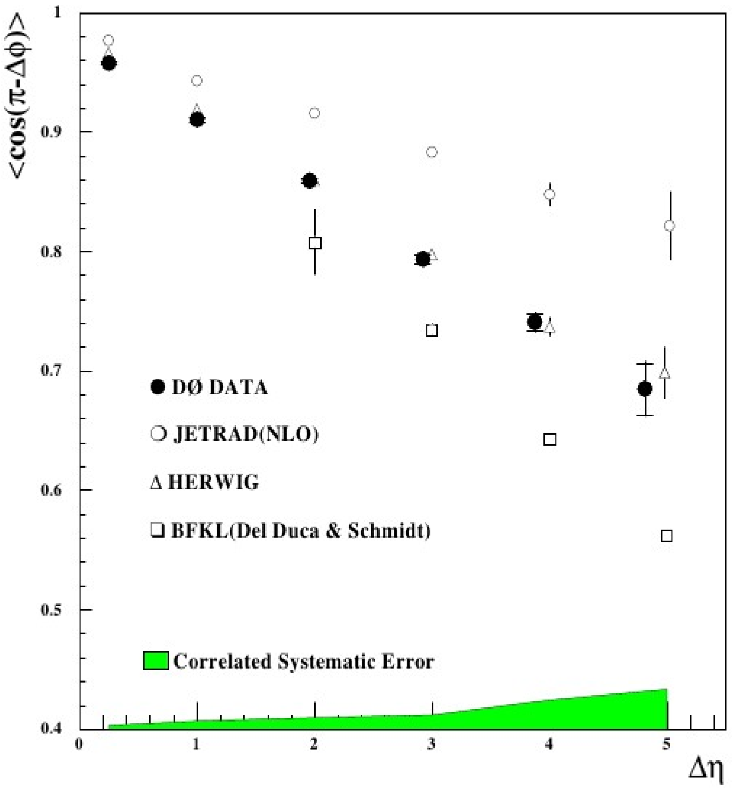
Measurement at D0 in 1996

[10.1103/PhysRevLett.77.595]

$\Delta\eta < 6.0$, $E_T > 50$ (20) GeV

LL BFKL overestimates decorrelation

HERWIG gives best description



CMS measurement

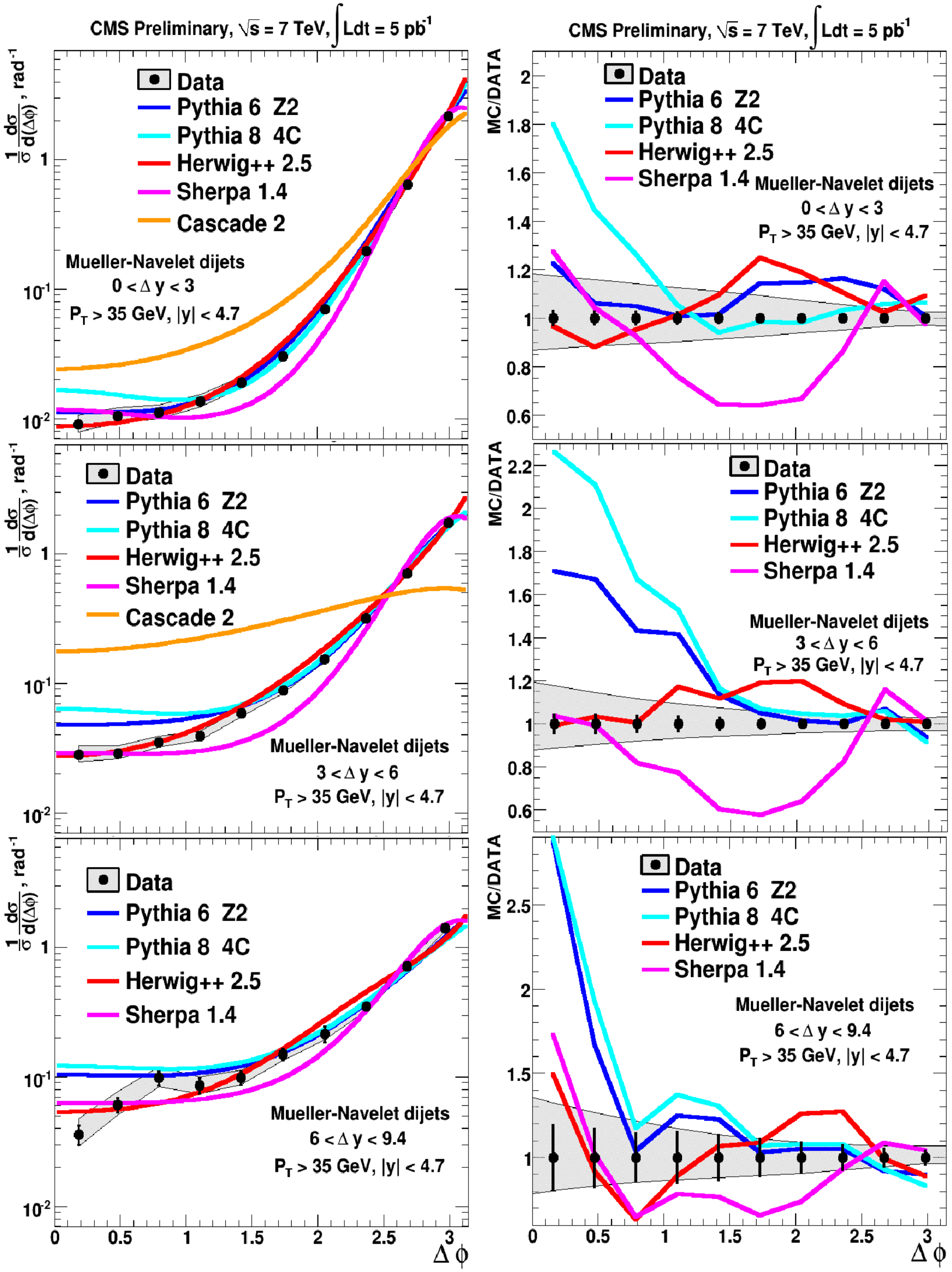
Extends to **$\Delta y < 9.4$**

Symmetric **$p_T > 35$ GeV**

Observables

- **Azimuthal angle separation $\Delta\varphi$ 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**

Δφ shapes



Shapes of Δφ distributions

PYTHIA6 and PYTHIA8 show too strong decorrelation

SHERPA underestimates decorrelation

HERWIG++ gives the best description

CMS-PAS-FSQ-12-002

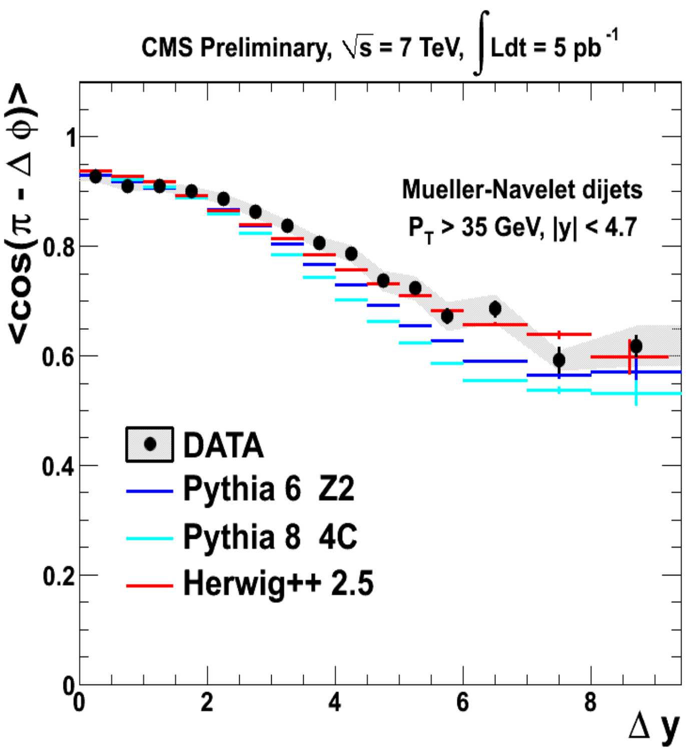
Average cosines (I)

First 3 coefficients of Fourrier transform of Δφ distribution

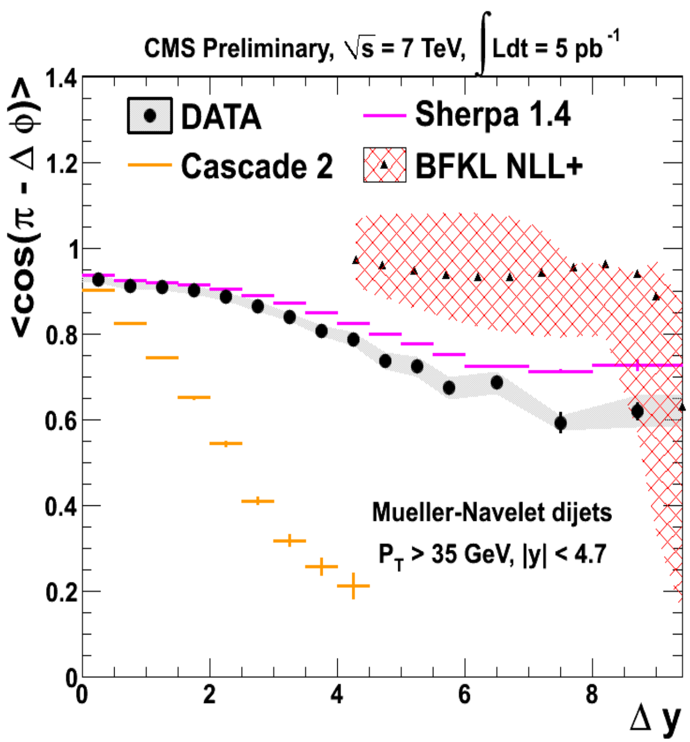
Equal to average cosines: $C_n = \langle\cos(n(\pi - \Delta\varphi))\rangle$

BFKL NLL predictions (valid from Δy=4) provided by
B. Ducloué, L. Szymanowski, S. Wallon, **[10.1007/JHEP05(2013)096]**
Parton level predictions

CMS-PAS-FSQ-12-002

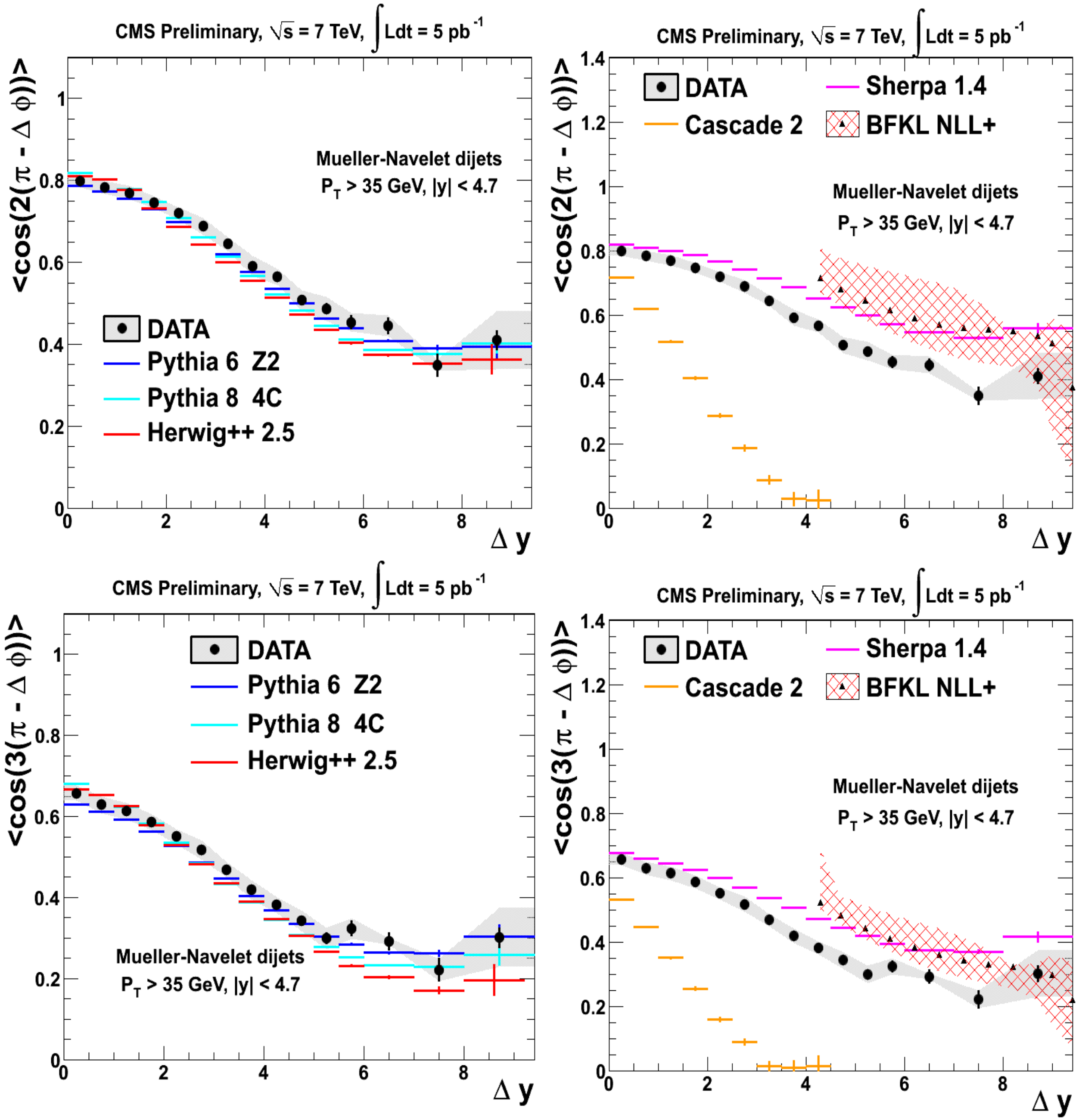


C1



Average cosines (II)

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

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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

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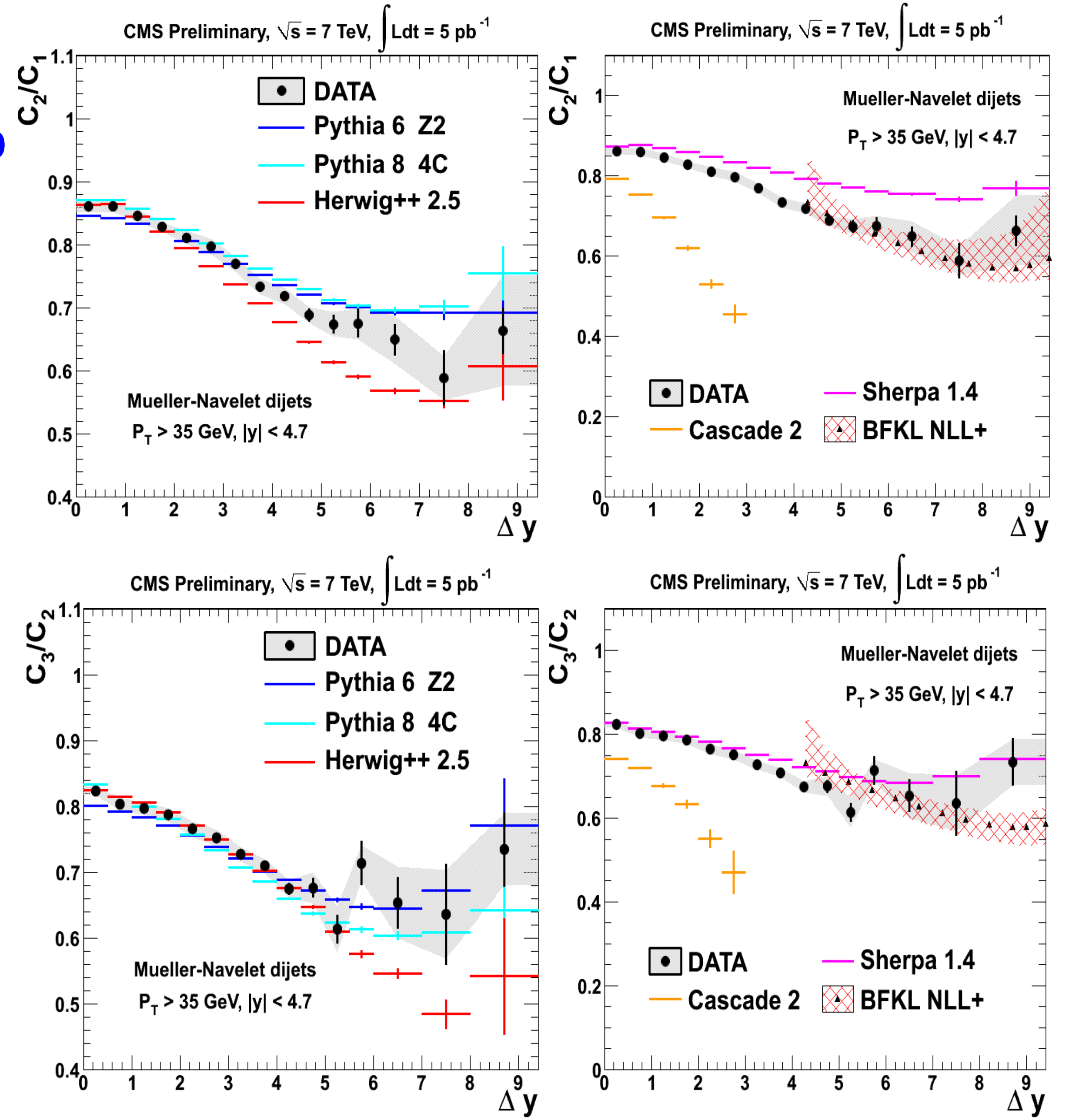


SUMMARY

CMS-PAS-FSQ-12-002

- MN azimuthal 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

Conclusion: No clear evidence for BFKL dynamics

SUMMARY

Inclusive jet production

Data is well described by theory predictions in wide range of rapidity and transverse momentum

Mueller-Navelet jets

Inclusive to exclusive dijet production ratios

- PYTHIA6 and PYTHIA8 predictions are with the experimental uncertainties
- HERWIG++, HEJ, CASCADE predict too strong parton radiation

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

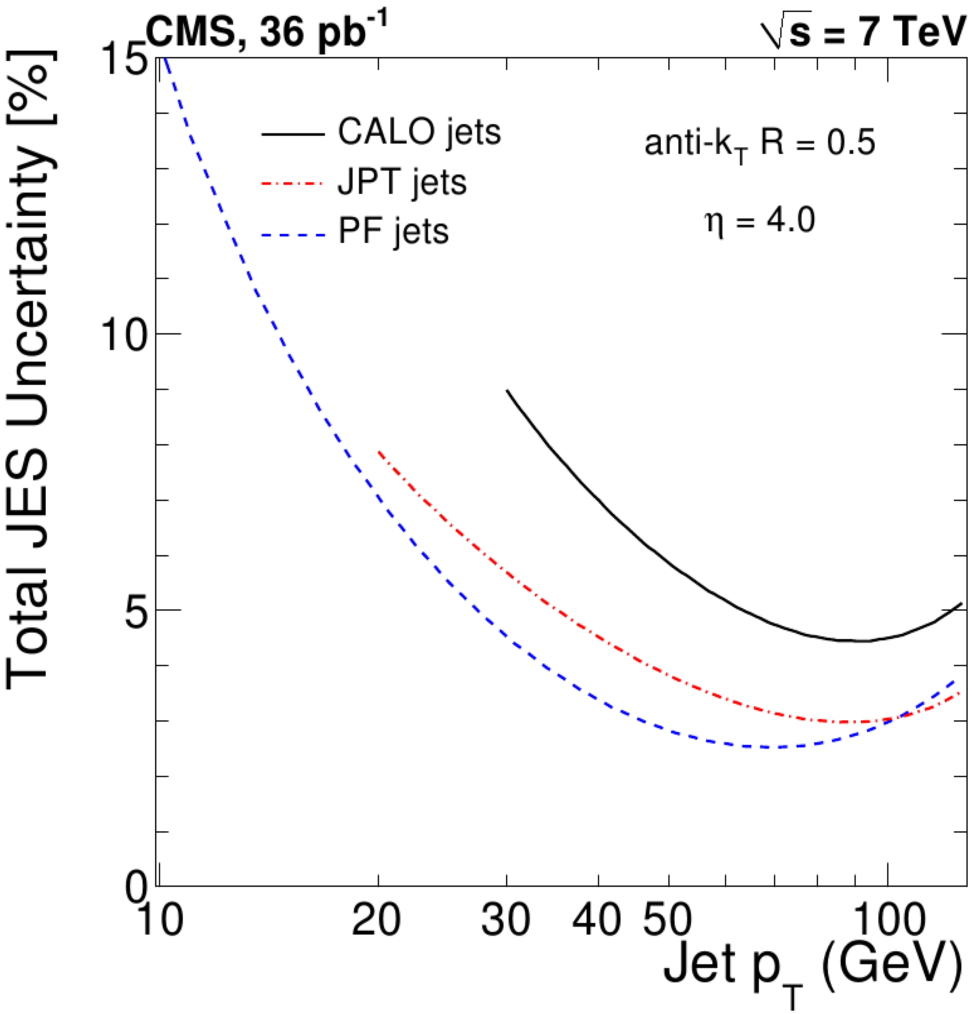
BACKUP

Jet reconstruction

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

Anti-k_T, R=0.5 or 0.7 clustering algorithm

MC- and data-driven Jet Energy Scale (JES) calibration techniques
- Uncertainty of calibration < 5% for high-p jets
- Uncertainty for low-$_{pT}$ jets can be as high as 10%



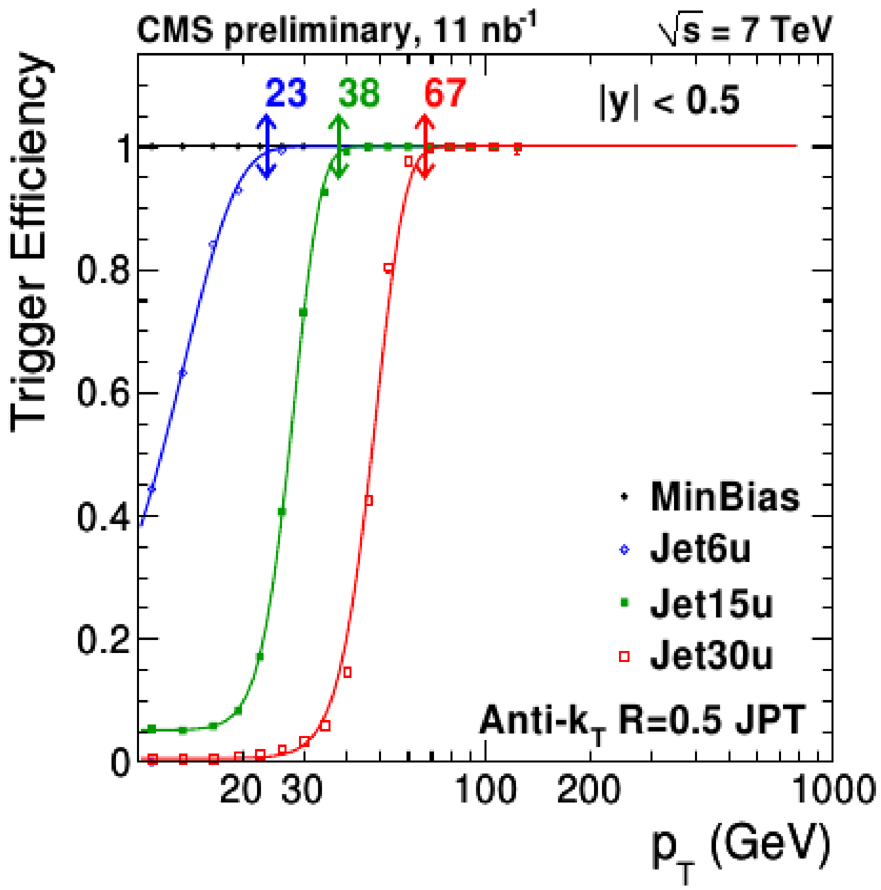
JES uncertainty – leading source of experimental uncertainty

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
- **99% efficiency in full acceptance for calojets with pT > 35 GeV**



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