Diffraction, forward physics and soft QCD results from CMS

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on behalf of the CMS collaboration

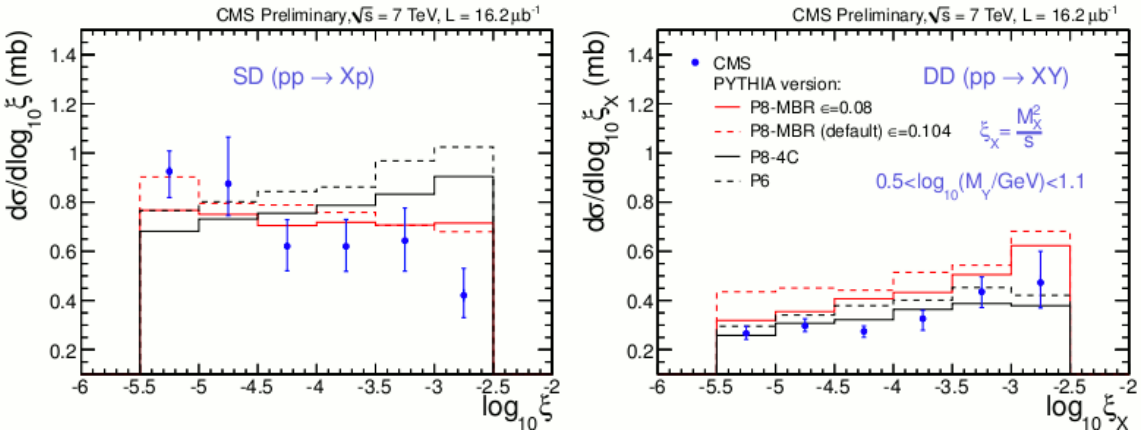
Outlook

Recent CMS results on:

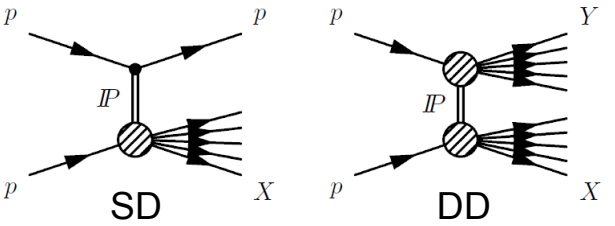
- **Diffractive cross sections**
- **Inclusive measurements at low pT**
- **Forward inclusive jet cross section**
- **Forward-central jets**
- **Forward-backward (Mueller-Navelet, MN) jets**
- **Four-jet cross section and Double Parton Scattering (DPS)**
- **DPS with W+2jets**
- **DY+jets**

Soft diffractive cross sections

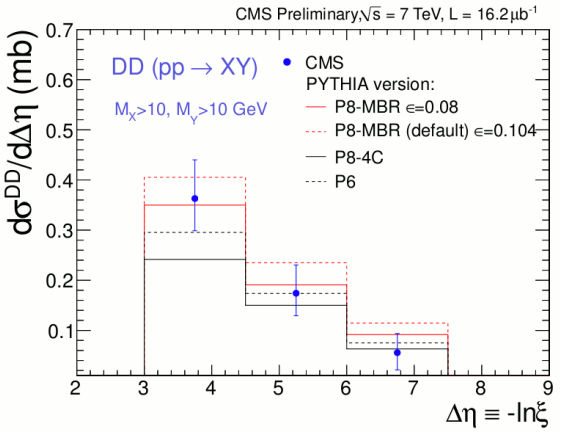
SD and DD cross sections with forward LRG
SD/DD separation with CASTOR calorimeter



$5.5 < \log_{10}\xi < -2.5$ ($12 < M_X < 394$ GeV)



DD cross section with central LRG



PYTHIA8-MBR with ϵ=0.08 (Minimum-Bias Rockefeller, developed and tested at CDF) describes the measured SD and DD cross sections well

PYTHIA8-4C and PYTHIA6 describe well the DD cross section, but fail to describe falling behavior of SD data

SD cross section integrated over
$12 < M_X < 394$ GeV:

$$\sigma^{SD}_{vis} = 4.27 \pm 0.04\ (stat.)\ ^{+0.65}_{-0.58}\ (syst.)\ mb$$

Multiplied by 2 to account for both pp → pX and pp → Xp processes.

consistent with TOTEM result

DD cross section integrated over
$\Delta\eta > 3$, $M_X > 10$ GeV, $M_Y > 10$ GeV:

$$\sigma^{DD}_{vis} = 0.93 \pm 0.01\ (stat.)\ ^{+0.26}_{-0.22}\ (syst.)\ mb$$

Central and forward $dN_{ch}/d\eta$

CMS+TOTEM low-pileup 2012 run @8TeV, high β* optics
Minimum Bias trigger provided by TOTEM T2 telescopes (5.3<|η|<6.5)
Events categorized into 3 samples:

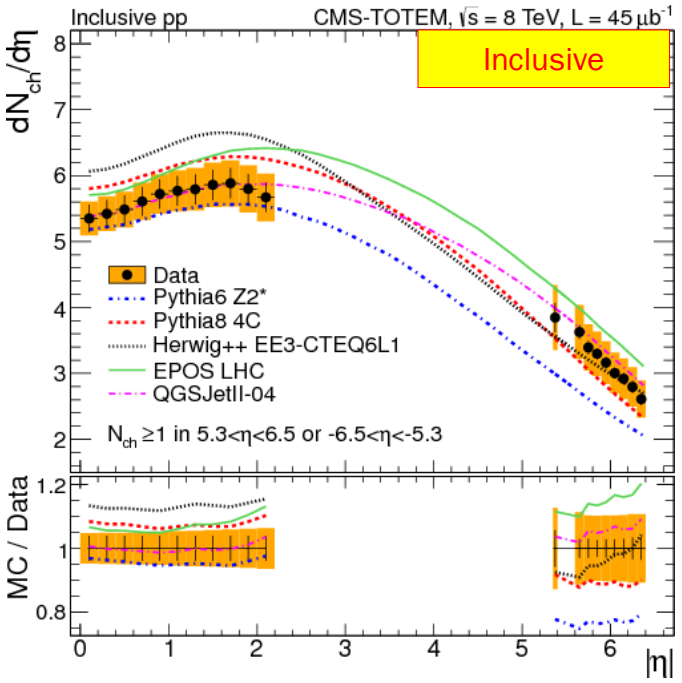
Inclusive – activity in T2

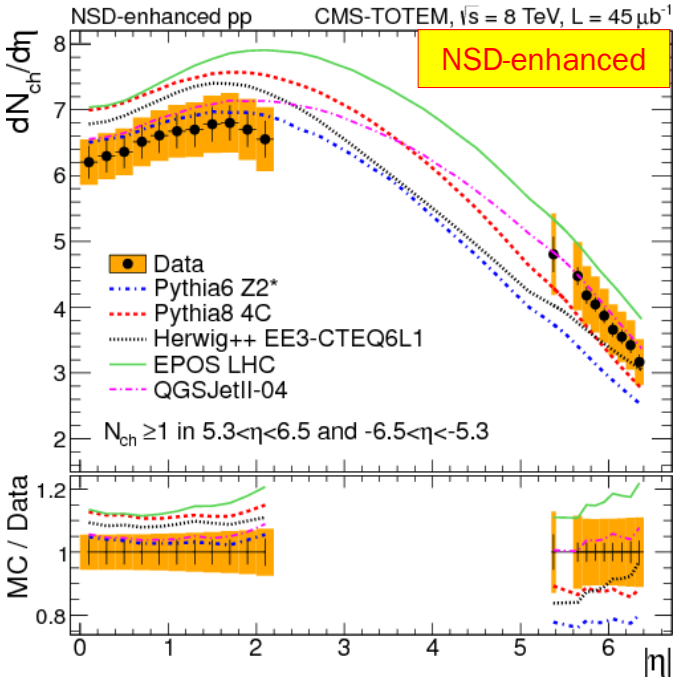
NSD-enhanced – activity in each of T2 (both z+ and z- sides)

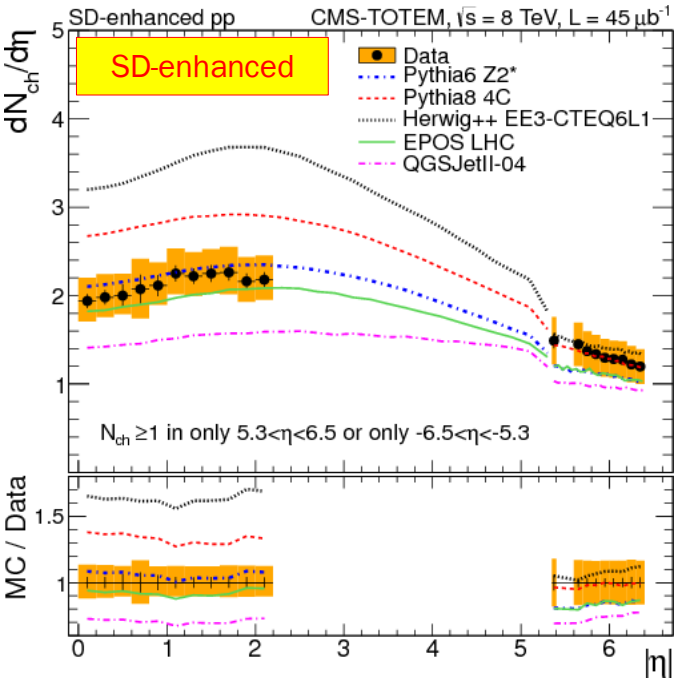
SD-enhanced – activity in only one T2 (z+ or z- side)

CERN-PH-EP-2014-063

arXiv:1405.0722







Multiplicity of SD events significantly smaller than NSD

No prediction able to describe $dN_{ch}/d\eta$ for all the samples in the entire η range

Data can help constrain modelling of hadronic final state and diffractive scattering

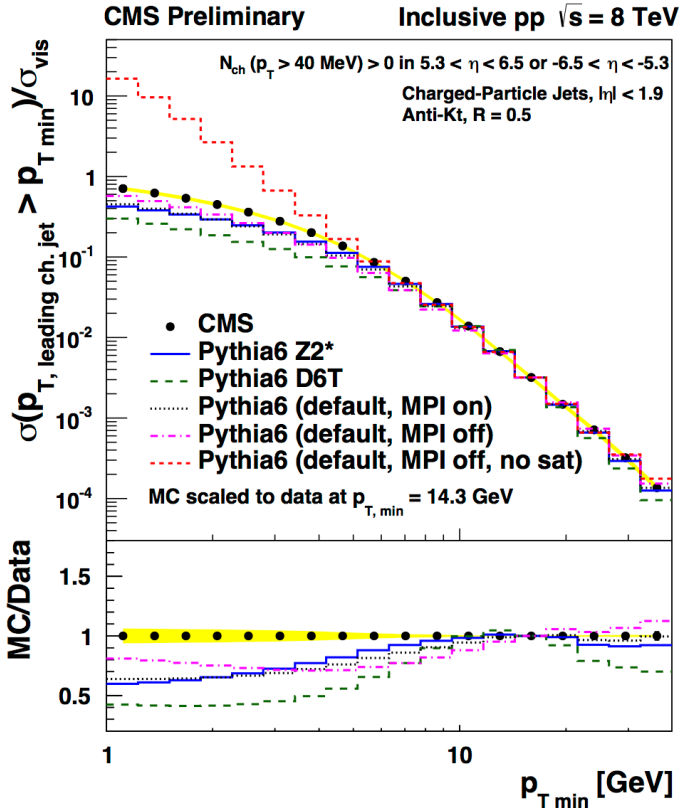
Leading charged particle and leading jet cross sections at small p_T

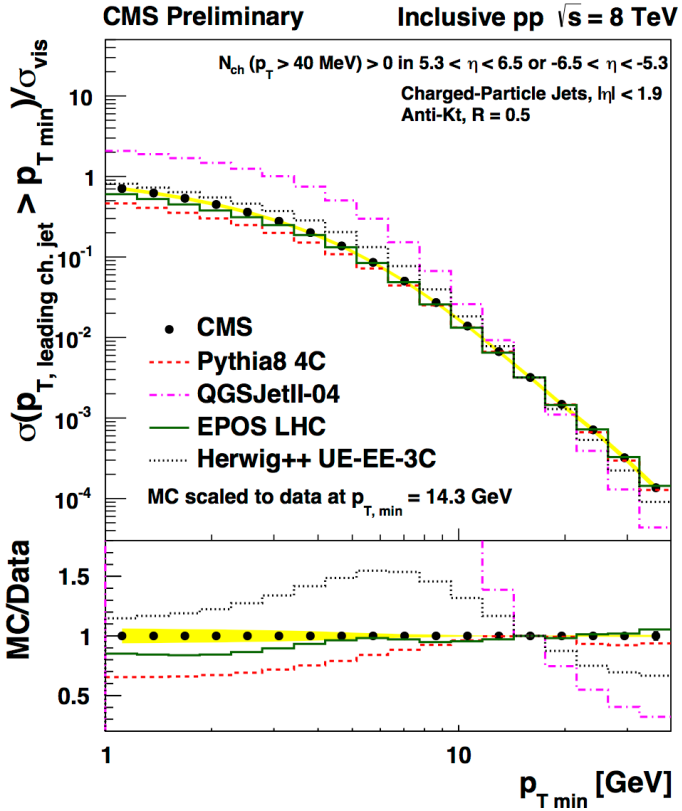
Charged particles with pT>0.8 GeV, |η|<2.4
Charged-particle jets with pT>1.0 GeV, |η|<1.9 (minijets)

CMS-PAS-FSQ-12-032
Common CMS+TOTEM run

Normalized integrated leading charged particle and leading charge-particle jet cross sections

$$\frac{\sigma(p_{T\,\mathrm{lead}} > p_{T\,\mathrm{min}})}{\sigma_{vis}} = \frac{1}{N_{\mathrm{evt}}} \sum_{p_{T\,\mathrm{lead}} > p_{T\,\mathrm{min}}} \Delta p_{T\,\mathrm{lead}} \left(\frac{\Delta N}{\Delta p_{T\,\mathrm{lead}}} \right)$$





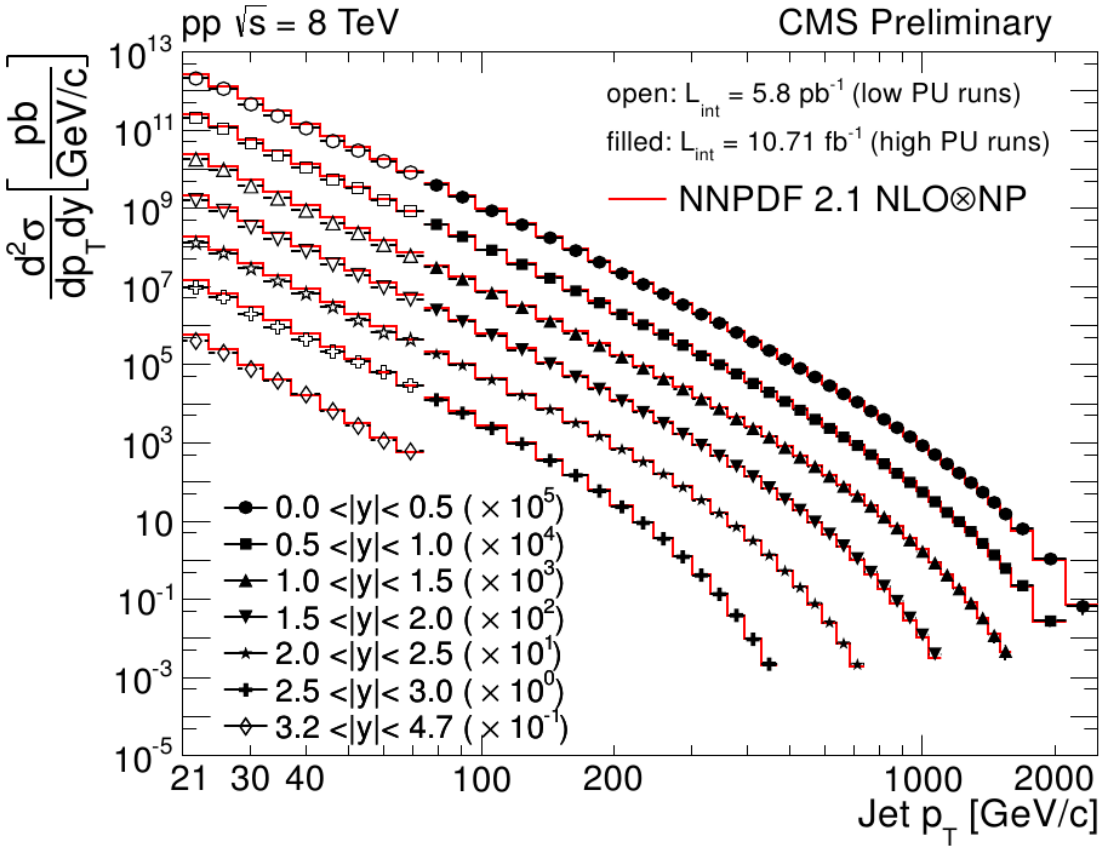
No MC model able to reproduce the data, EPOS provides the best description
Input for MC tunes, sensitive to regularization of partonic cross section at low-p_T

Inclusive jet cross section

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

CMS-PAS-FSQ-12-031 — *21 < jet p_T < 74 GeV*

CMS-PAS-SMP-12-012 — *jet p_T > 74 GeV*



Inclusive data are well described in a wide range of p_T and rapidities by NLO⊗NP theory predictions

Forward-central jet azimuthal correlations

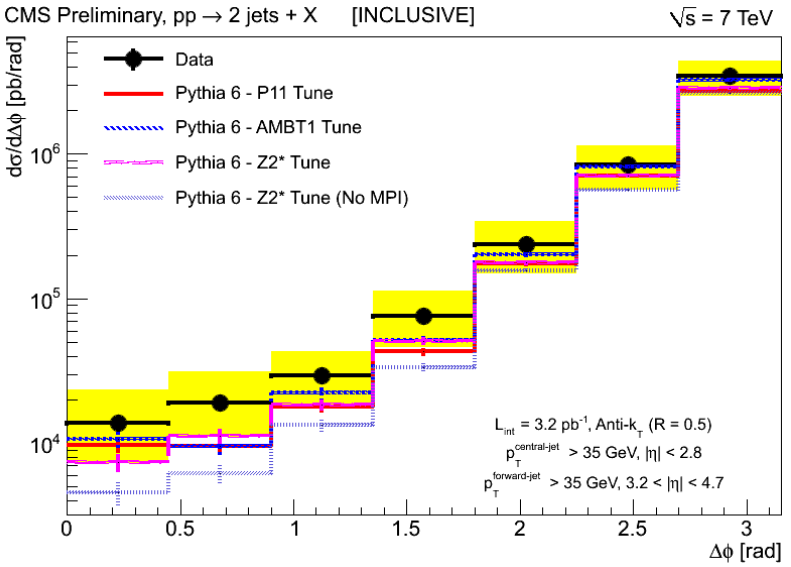
At least two jets with p_T> 35 GeV, central: $|\eta| < 2.8$, forward: $3.2<|\eta| < 4.7$

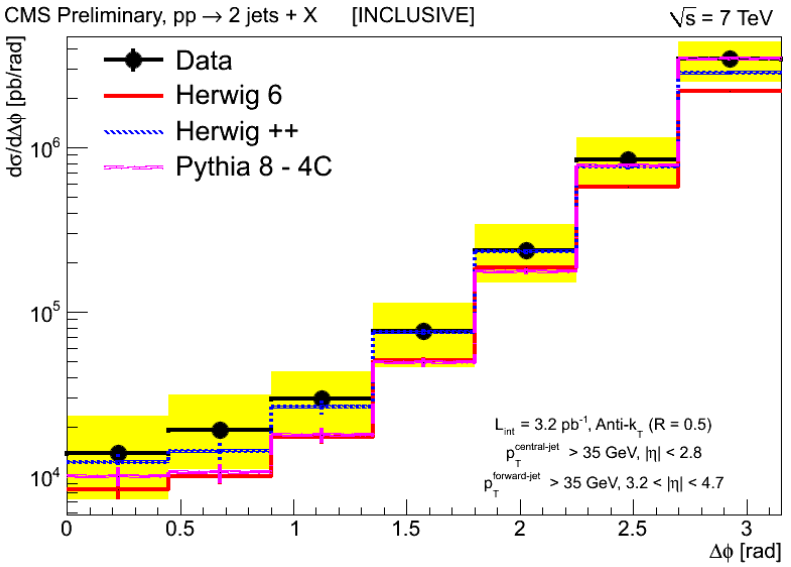
$\Delta\eta<7.5$ opens up phase space for additional radiation (PS and MPI)

Study azimuthal $\Delta\varphi$ (de)correlations

(also in two bins of $\Delta\eta$, and with or w/o additional jet of p_T> 20 GeV, not shown)

CMS-PAS-FSQ-12-008





Theory predictions (PYTHIA6, PYTHIA8, HERWIG6, HERWIG++) describe the data within uncert.

PYTHIA6 w/o MPI is below data at low $\Delta\varphi$.

HERWIG++ describes the measurement best.

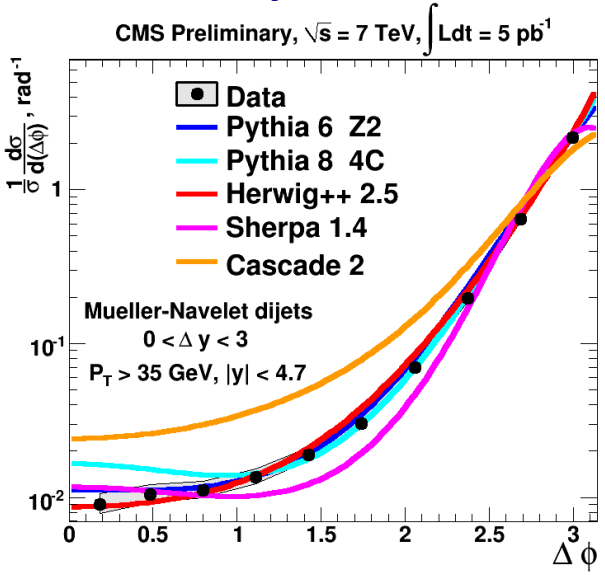
Mullet-Navelet di-jet decorrelation

Most forward and backward jets with $p_T > 35$ GeV, $|\eta| < 4.7$

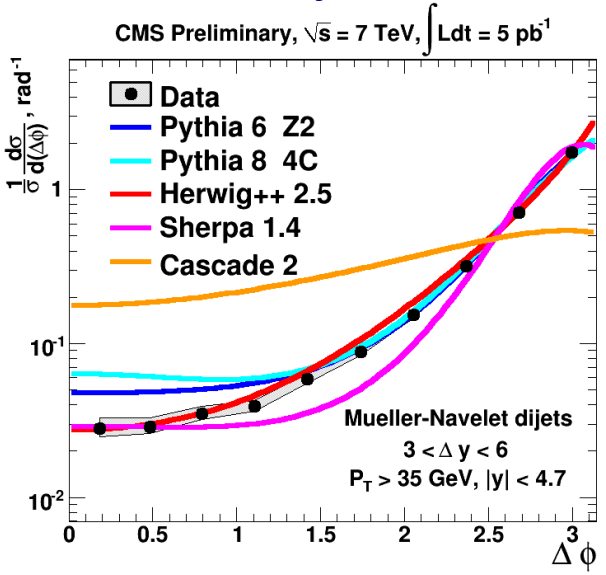
CMS-PAS-FSQ-12-002

$\Delta\varphi$ between jets in bins of Δy

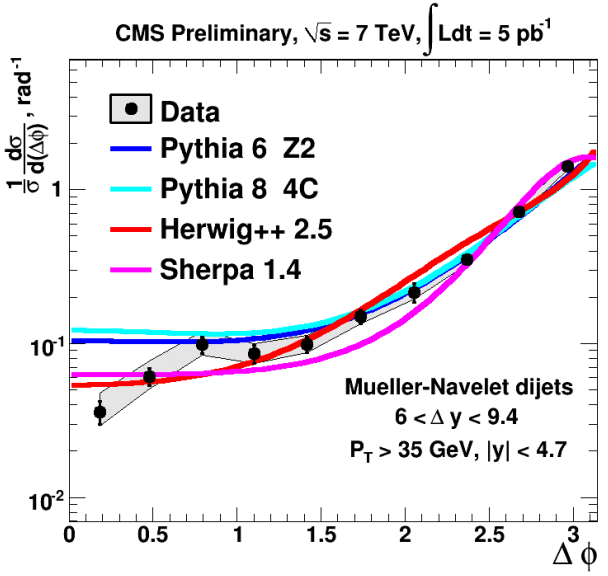
$\Delta y < 3$



$3 < \Delta y < 6$



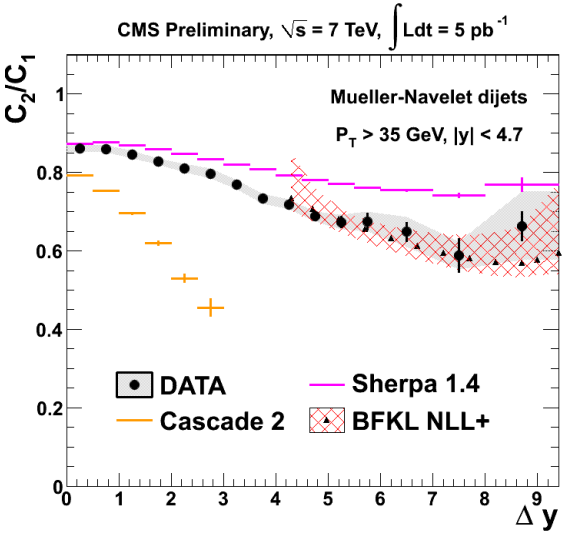
$6 < \Delta y < 9.4$



Decorrelation increases with rapidity separation

DGLAP models give reasonable description of data:

- PYTHIA6/PYTHIA8 show too strong decorrelation
- SHERPA underestimates decorrelation
- HERWIG++ is consistent with the data



LL BFKL-inspired CASCADE predicts too strong decorrelations

NLL BFKL consistent with average cosine ratios →

$C_n = \langle \cos(n(\pi - \Delta\varphi)) \rangle$

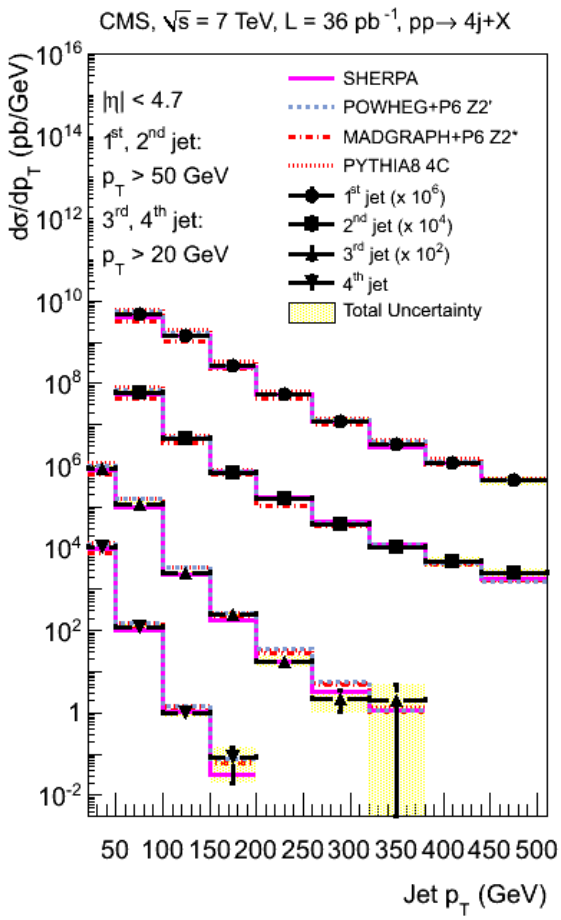
4-jet production

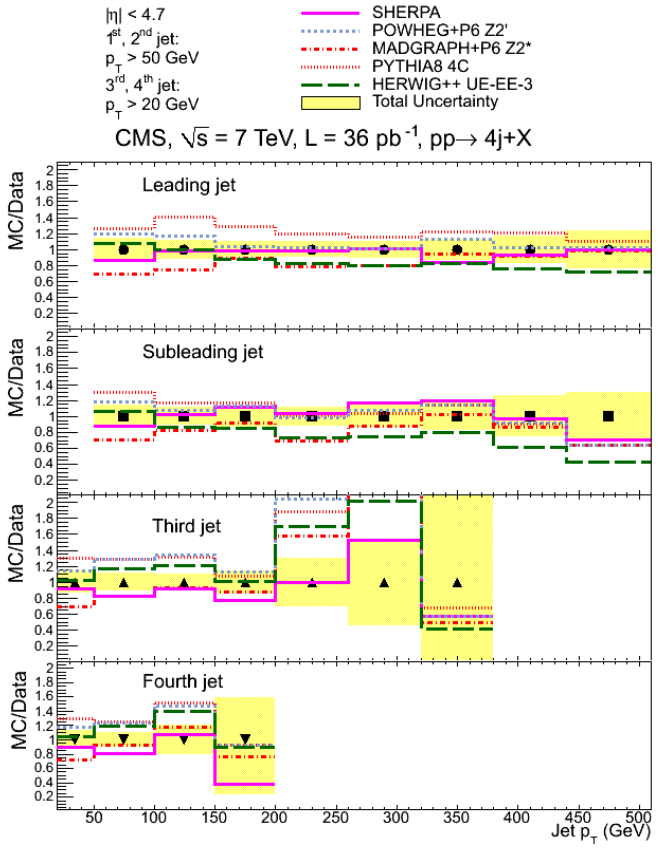
Leading jets p_T> 50 GeV,soft jets p_T> 30 GeV; |η| < 4.7

CERN-PH-EP/2013-229

arXiv:1312.6440

$$\sigma(\mathrm{pp} \to 4\mathrm{j} + \mathrm{X}) = 330 \pm 5\,(\mathrm{stat.}) \pm 45\,(\mathrm{syst.})\,\mathrm{nb}$$





Theory predictions (SHERPA, POMWEG, MADGRAPH, PYTHIA8) are able to describe the differential cross sections only in some regions of phase space.
Discrepancies at lower p_T for subleading and soft jets.

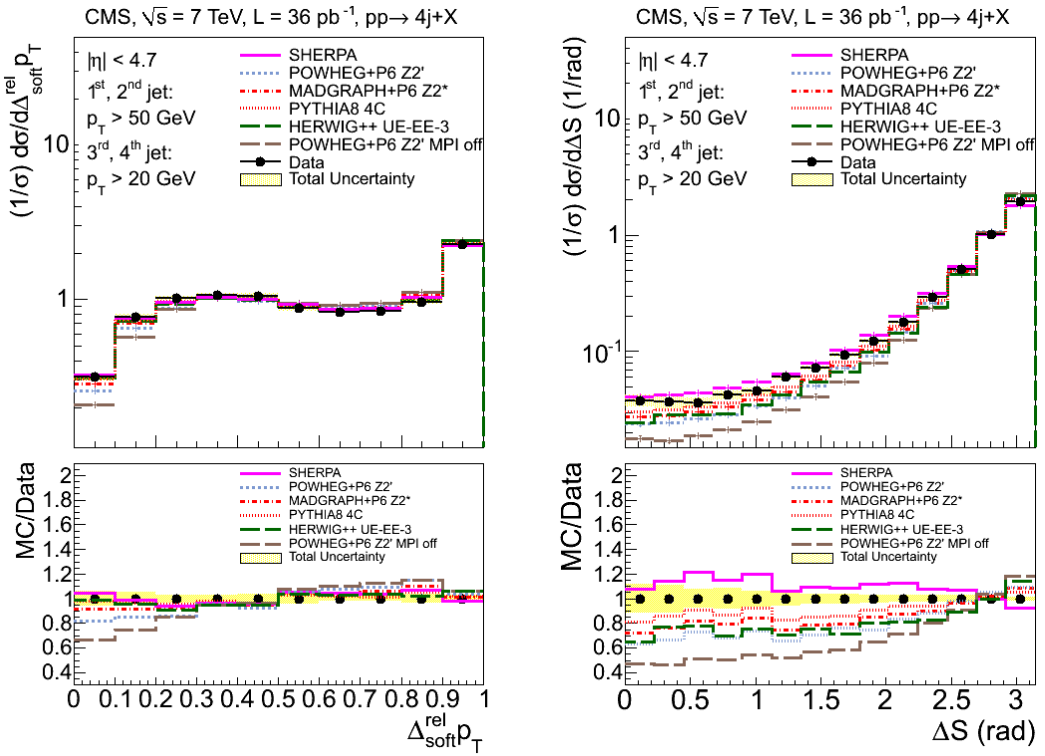
4-jet production, DPS

The 2 additional jets may be produced by parton showers or a second hard scattering.
Access to DPS! Discriminate between SPS and DPS by studying:

- $\Delta^{rel}_{soft}p_T$ - transverse momentum balance of two soft jets (DPS around 0)
- ΔS - azimuthal angle between two di-jet pairs (DPS flat)

CERN-PH-EP/2013-229

arXiv:1312.6440



Valuable input for MPI tunes

Recent tune to 4j DPS gives

$\sigma_{eff} = 21.3^{+1.2}_{-1.6}$ mb,

compared to σ_{eff} ~ 30 mb of PYTHIA8-4C and UE tunes

No significant differences between theory predictions

POMWEG without MPI is far below data at low $\Delta^{rel}_{soft}p_T$ and ΔS

SHERPA and PYTHIA8 give the best description of ΔS

CMS-PAS-GEN-14-001

DPS with W+2jet events

Iso μ with pT>35 GeV, |η|<2; $\not{E}_T$>30 GeV; M^W_T > 50 GeV

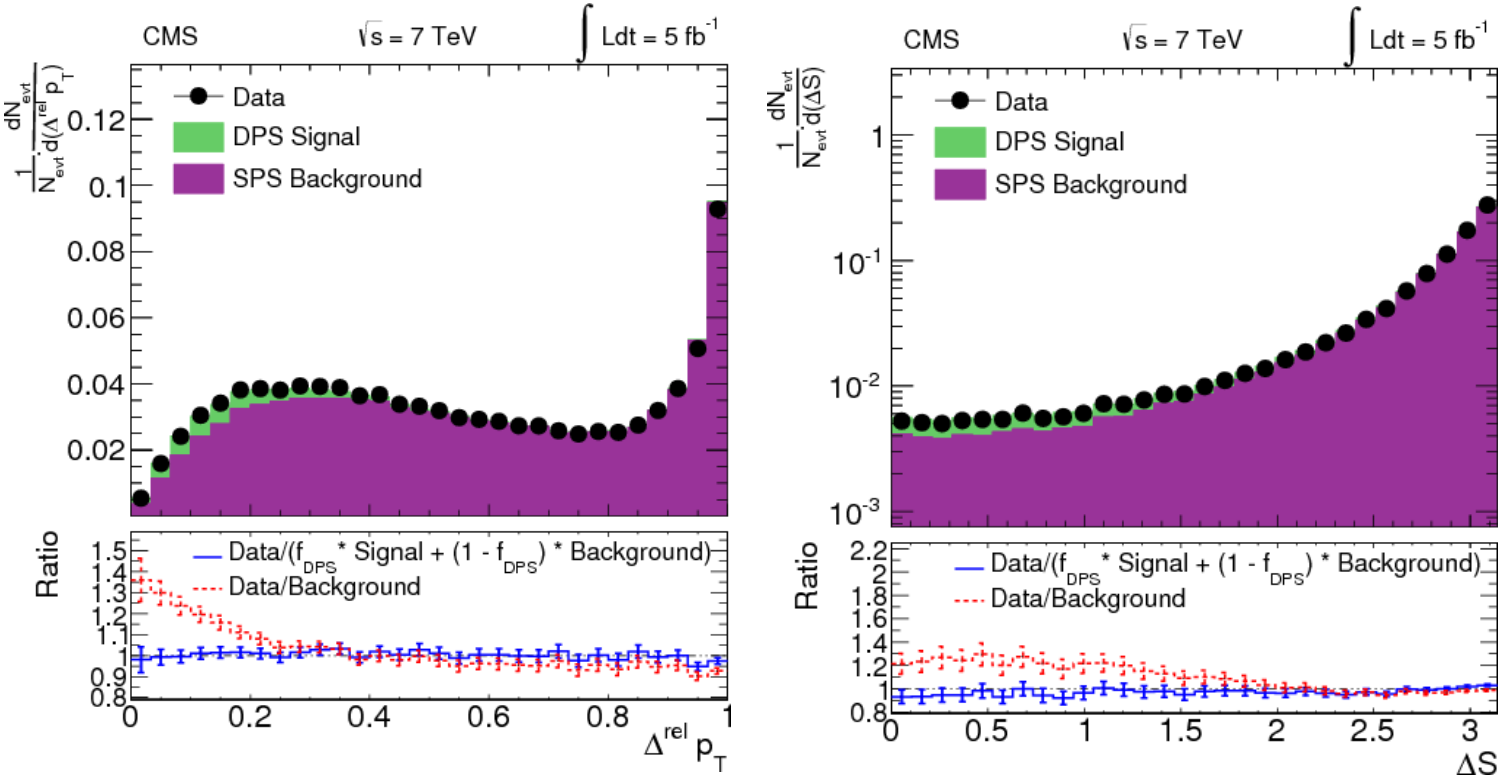
jets with pT>20 GeV, |η|<2

JHEP 03 (2014) 032

arXiv:1312.5729

Discriminate DPS W+2jet (W+0jet and dijets) from SPS W+2jet with:

- $\Delta^{rel}p_T$ - transverse momentum balance of two jets
- ΔS - azimuthal angle between W and di-jet system



Fully-corrected data fitted with DPS and SPS templates (MC based, MADGRAPH5+PYTHIA8) to extract DPS fraction

$$f_{\mathrm{DPS}} = 0.055 \pm 0.002\,(\mathrm{stat.}) \pm 0.014\,(\mathrm{syst.})$$

DPS with W+2jet events

Measurement of σ_{eff} - effective area parameter, input to theoretical model

JHEP 03 (2014) 032

arXiv:1312.5729

$$\sigma_{\text{eff}} = \frac{1}{\text{m}} \frac{\sigma_A \cdot \sigma_B}{\sigma^{\text{DPS}}_{A+B}} \qquad \begin{matrix} \text{m} = 1 \text{ when } A \neq B \\ \text{m} = 2 \text{ when } A = B \end{matrix}$$

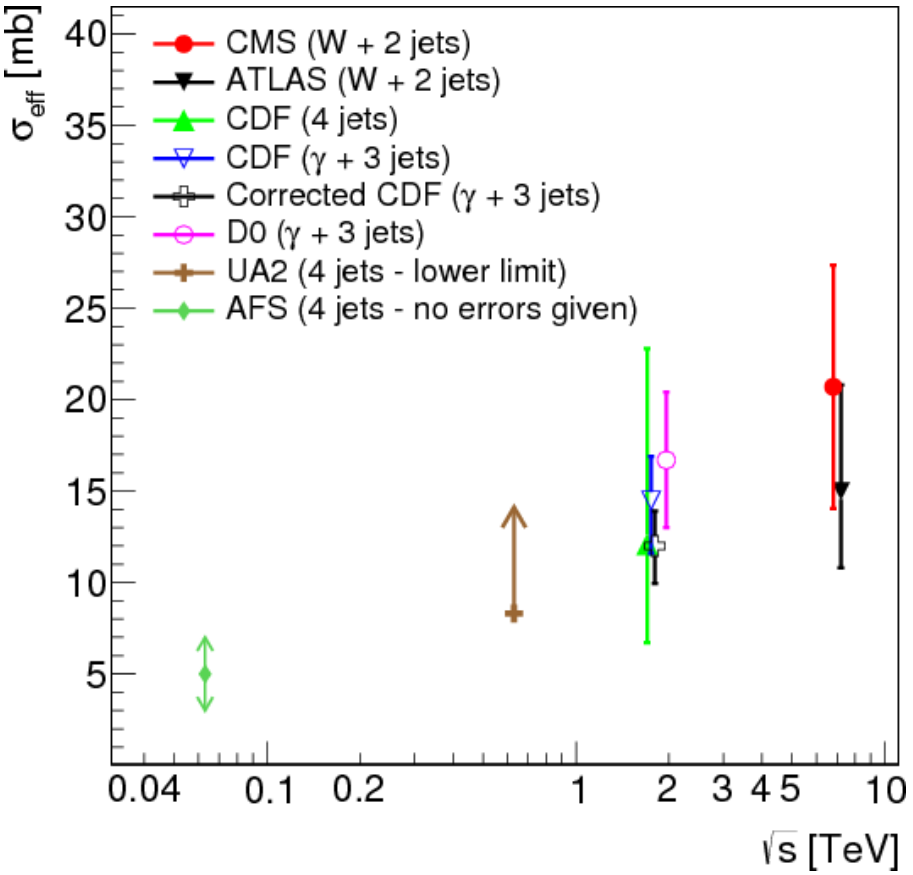
$$\sigma_{\text{eff}} = \frac{\sigma'_{\text{W+0jet}}}{\sigma'^{\text{DPS}}_{\text{W+2j}}} \cdot \sigma'_{\text{2j}} \longrightarrow \sigma_{\text{eff}} = \frac{R}{f_{\text{DPS}}} \cdot \sigma'_{\text{2j}}$$

f_{DPS} - fraction of $(W+2j)^{DPS}$ to all W+2j (previous slide)

R - fraction of W+0j to W+2j events (from data)

σ'_{2j} - di-jet cross section at particle level (from data)

$$\sigma_{\text{eff}} = 20.7 \pm 0.8\,(\text{stat.}) \pm 6.6\,(\text{syst.})\ \text{mb}$$



Measurement consistent with ATLAS, CDF and D0 results

Large uncertainties, difficult to conclude on energy dependence of σ_{eff}

PYTHIA8: σ_{eff} ~ 20-30 mb, tune dependent

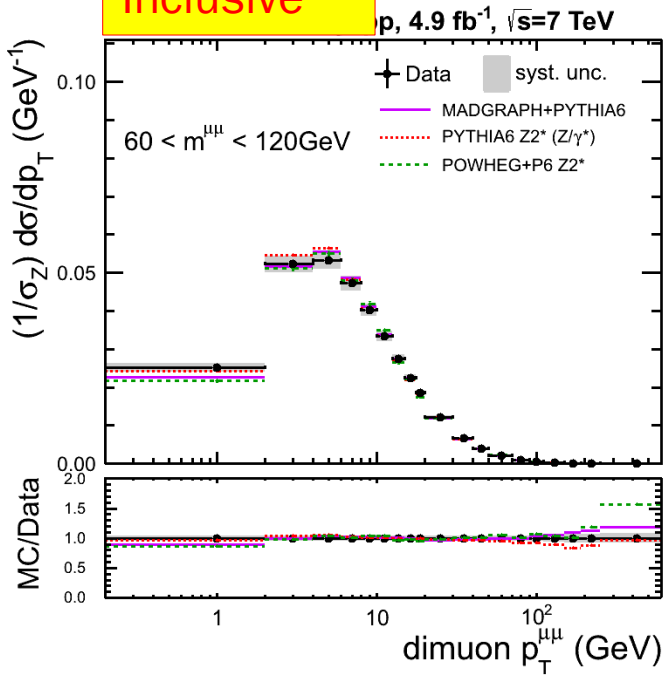
DY+jets

Di-muons with pT>20(10) GeV, |η|<2.1(2.4)
jets with pT>30 GeV, |η|<4.5

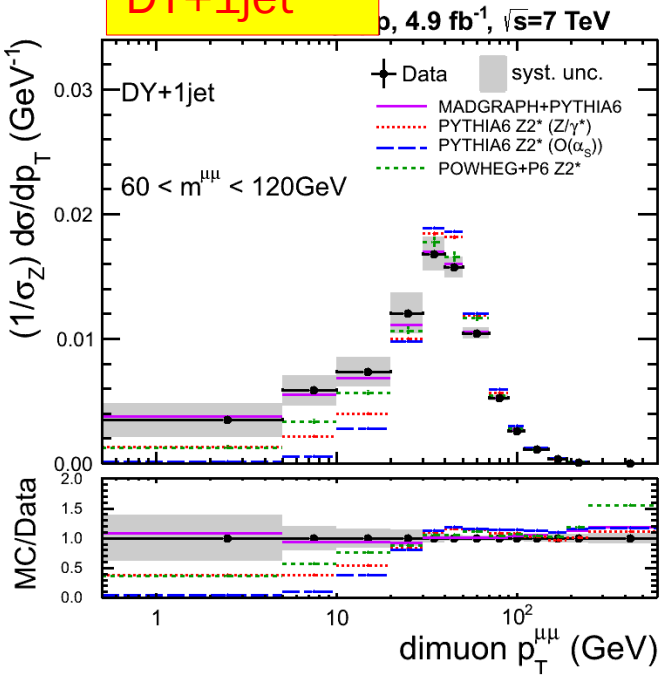
CMS-PAS-FSQ-13-003

Double-differentially in $m^{\mu\mu}$ and $p_T^{\mu\mu}$

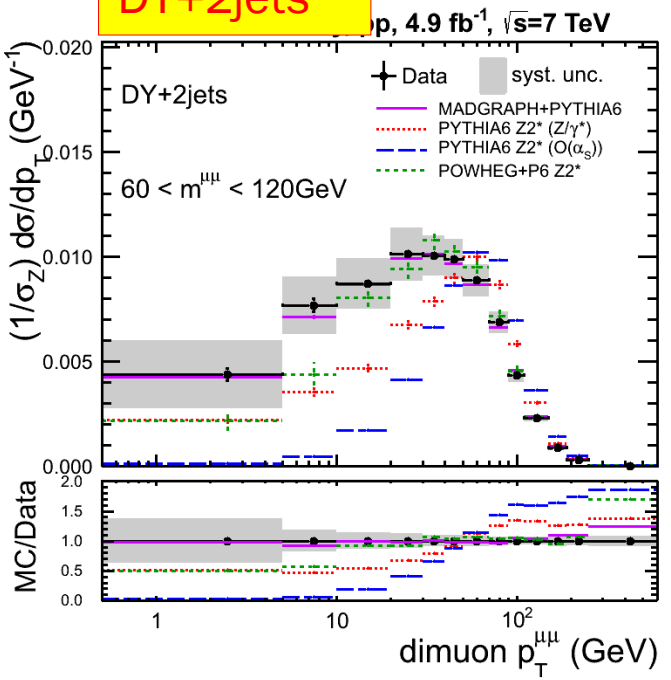
Inclusive



DY+1jet



DY+2jets



DY – maximum at 5 GeV, below non-perturbative and pert. soft gluon emissions
DY+jets – maximum shifted to higher value (~30 GeV), perturbative soft gluon emissions
→ Test of gluon ressumation in perturbative regime

PYTHIA6(lowest order in α_s) predicts too low cross section at low $p_T^{\mu\mu}$

MADGRAPH(N⩽4 ME)+PYTHIA6 describes the data best

Summary

Recent CMS results on diffraction, soft QCD and forward physics presented

Abundant source of data to test and help improve theory predictions

Need for better modelling of MPI and MC tuning

Access to hard DPS

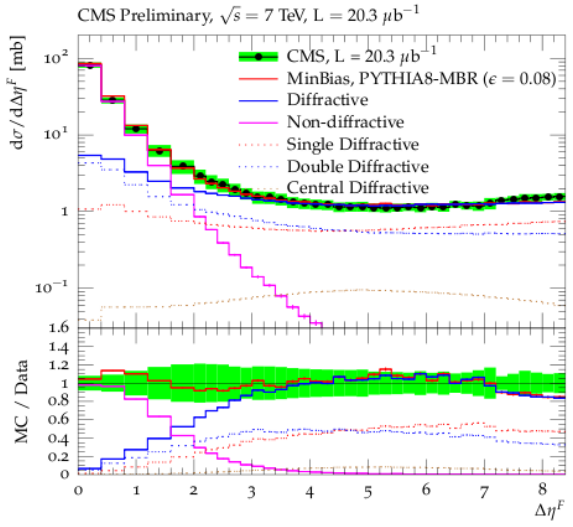
No evidence for new QCD parton dynamics

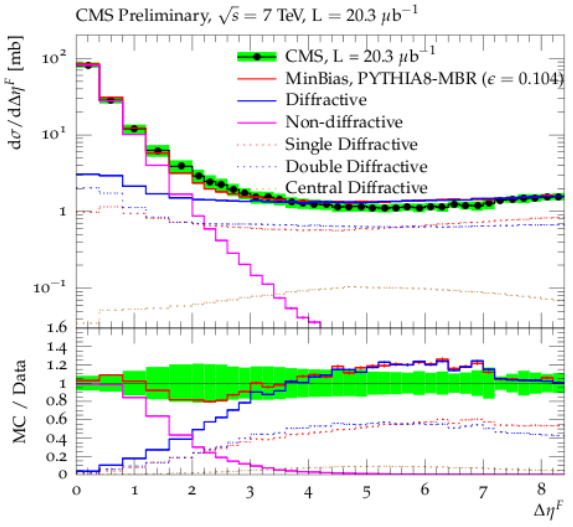
More measurements to come. Check the latest CMS results at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ

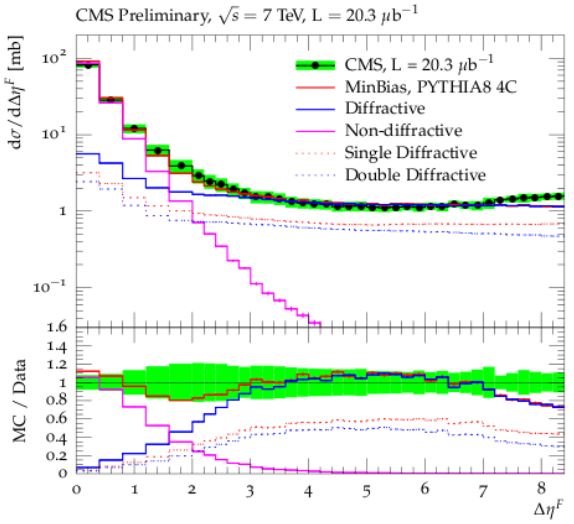
Thank you for your attention!

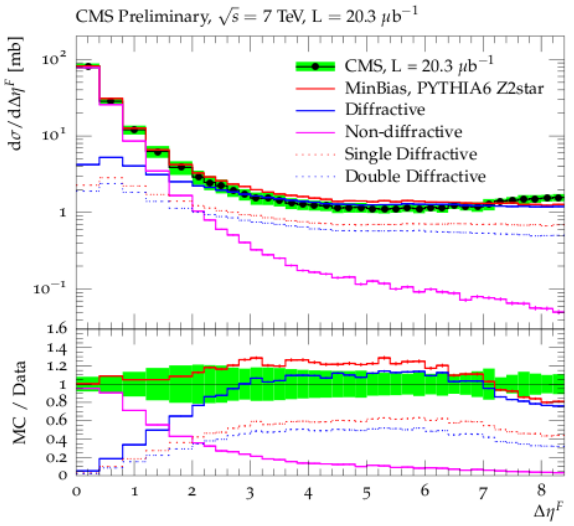
Backup slides

Forward-rapidity gap cross section









Hadron-level comparison of the forward rapidity gap cross section to predictions of PYTHIA8-MBR (ε=0.08 and ε=0.104), PYTHIA8-4C and PYTHIA6-Z2* simulations.

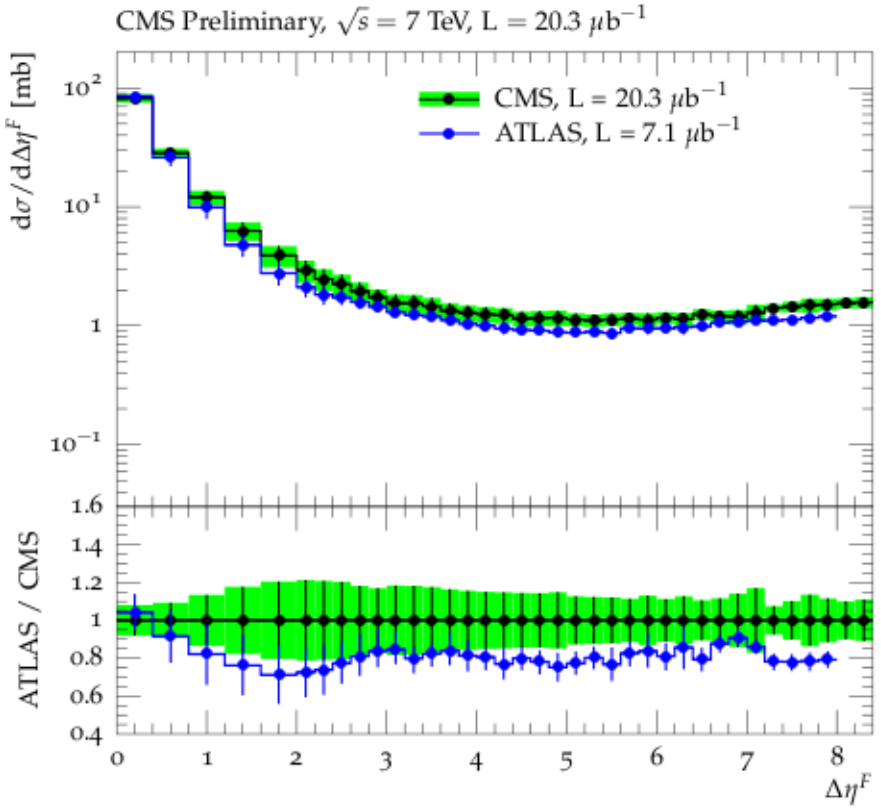
Exponentially falling ND contribution dominant for $\Delta\eta^F<3$, above this value cross section weakly changing with $\Delta\eta^F$:

Sensitivity to model dependence.
PYTHIA8-MBR (ε=0.08) – best description within uncertainties.

CMS-PAS-FSQ-12-005

Forward-rapidity gap cross section

Comparison to the ATLAS measurement (EPJ C72 (2012) 1926).



Different hadron level definition: |η|<4.7 (CMS) vs |η|<4.9 (ATLAS) – up to 5% effect.
Different MC sample used for unfolding – ~10% effect.
Agreement with ATLAS within uncertainties.
CMS extends the ATLAS measurement by 0.4 unit of gap size.

CMS-PAS-FSQ-12-005

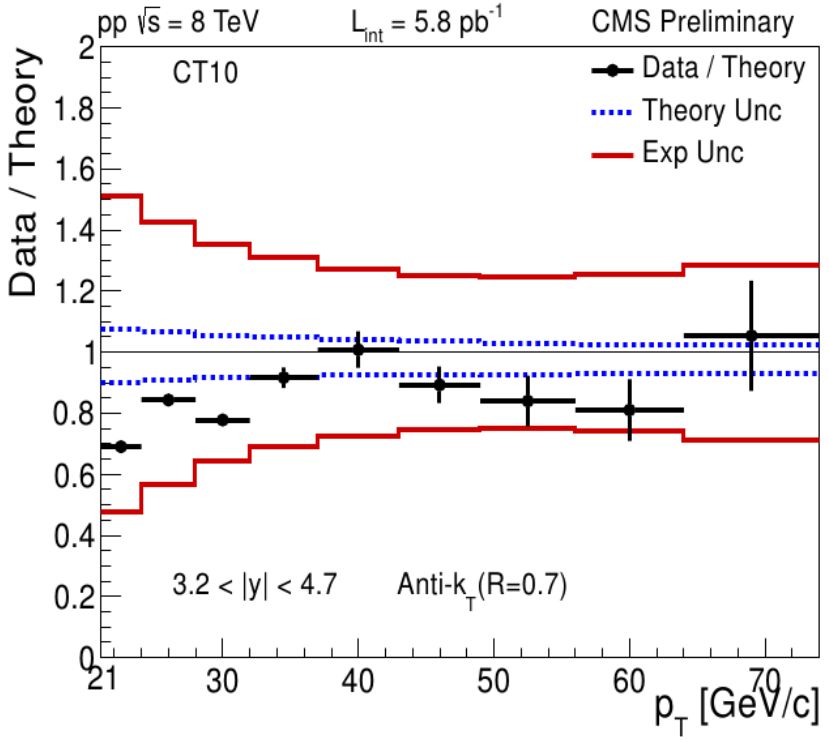
Forward jet cross section

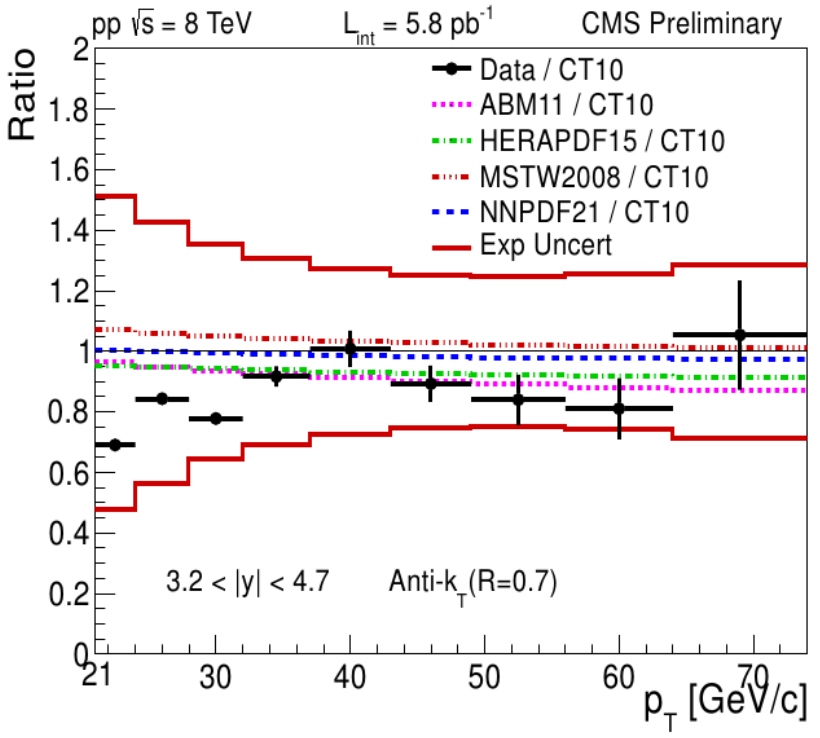
Closer look at forward jets

$3.2 < |\eta| < 4.7$

$21 < p_T < 74$ GeV

CMS-PAS-FSQ-12-031





All predictions agree with data within the uncertainties (dominant: JES unc. < 45%)

Inclusive jet production is well described by theory predictions in wide range of p_T and rapidities

DPS with W+2jet events

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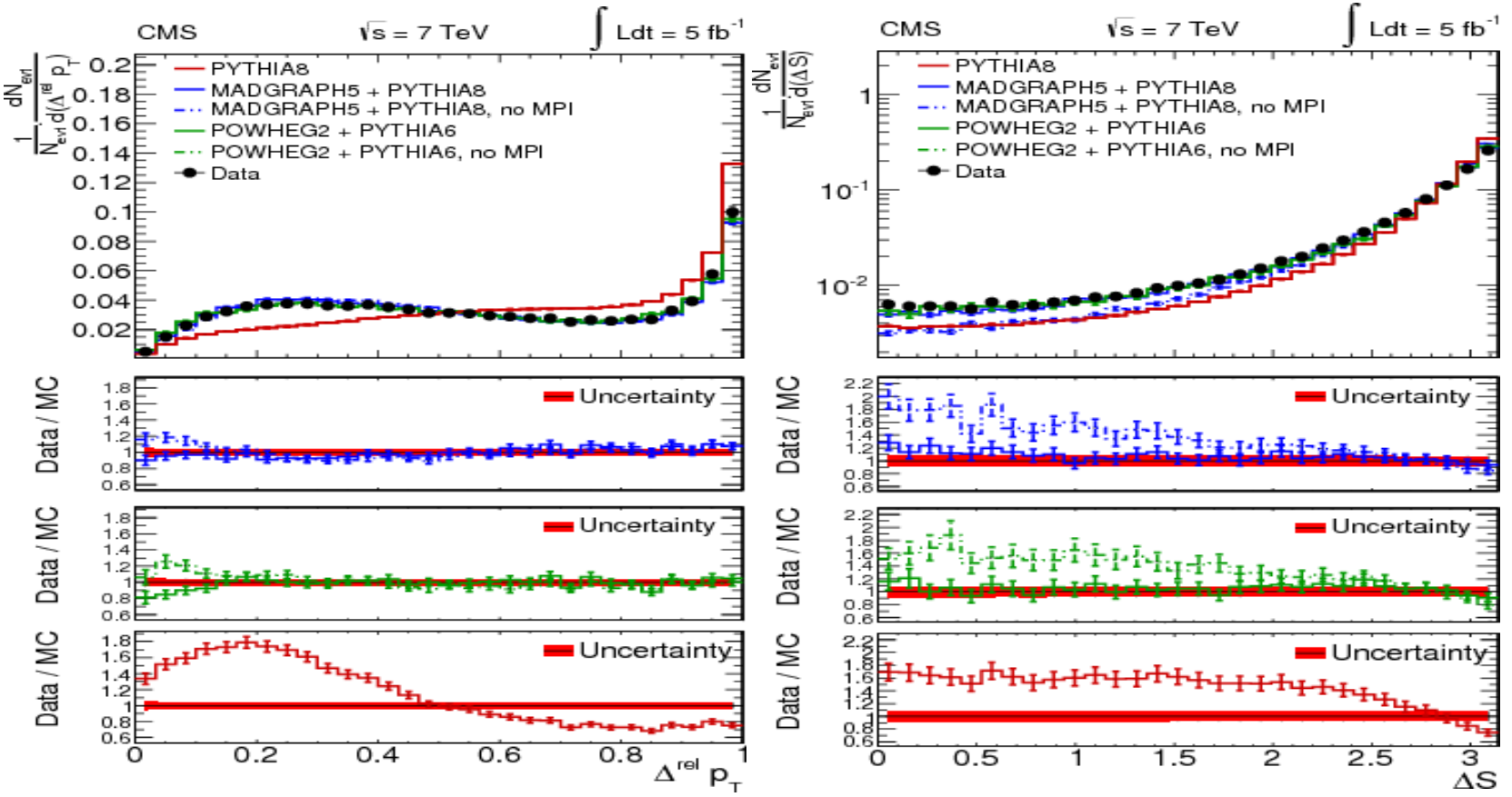
arXiv:1312.5729

Normalized distributions compared to theory predictions.



MADGRAPH+PYTHIA8 and POMWEG+PYTHIA6 give a good description of the data, both of them fail in absence of MPI

PYTHIA8 fails to describe the data (missing higher order processes)