CMS results on hard and soft diffraction, and low-x QCD in pp collisions

International Phenomenology Workshop
devoted to the memory of Prof. Alexei Kaidalov
July 21-25, 2013, Moscow, Russia

Alexander Proskuryakov (SINP MSU)
on behalf of the CMS collaboration

Outline

- Low-x QCD measurements

✓ Measurement of the inclusive production cross sections for forward jets and for dijet events with one forward and one central jet in pp collisions at $\sqrt{s}$=7 TeV (JHEP 1206 (2012) 036)

✓ Azimuthal angle decorrelations of jets widely separated in rapidity in pp collisions at $\sqrt{s}$=7 TeV (FSQ-12-002)

✓ Ratios of dijet production cross sections as a function of the absolute difference in rapidity between jets in proton-proton collisions at $\sqrt{s}$=7 TeV (Eur.Phys.J. C72 (2012) 2216)

- CMS results on soft diffraction

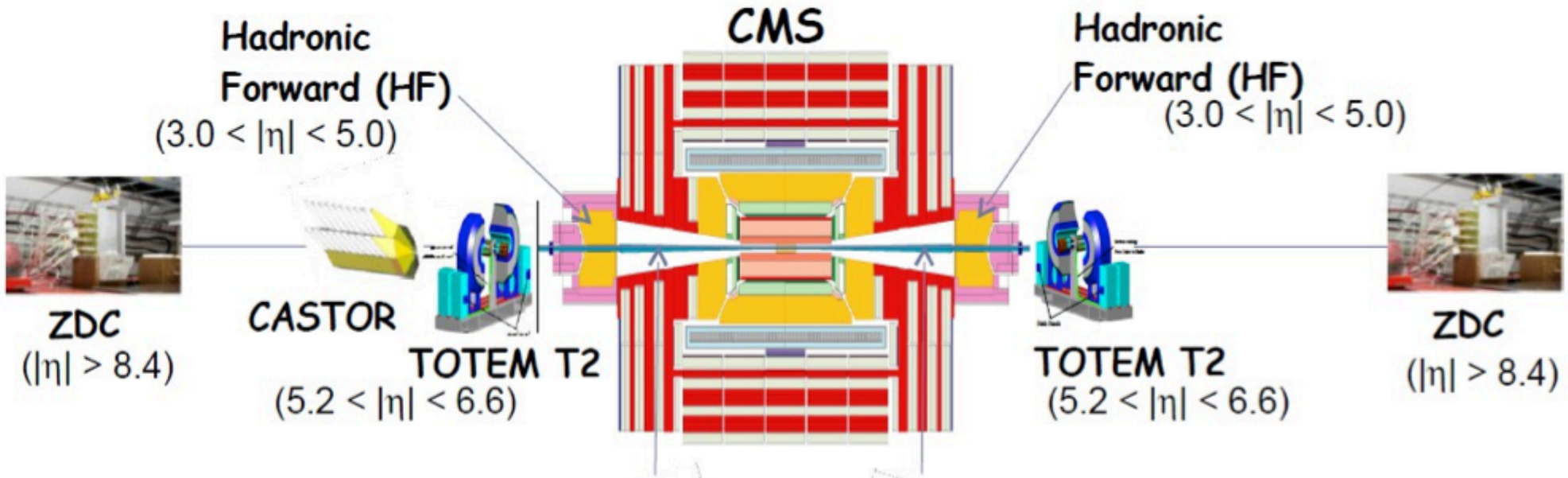
✓ Measurement of pp diffraction dissociation cross section at $\sqrt{s}$=7 TeV at the LHC (FSQ-12-005)

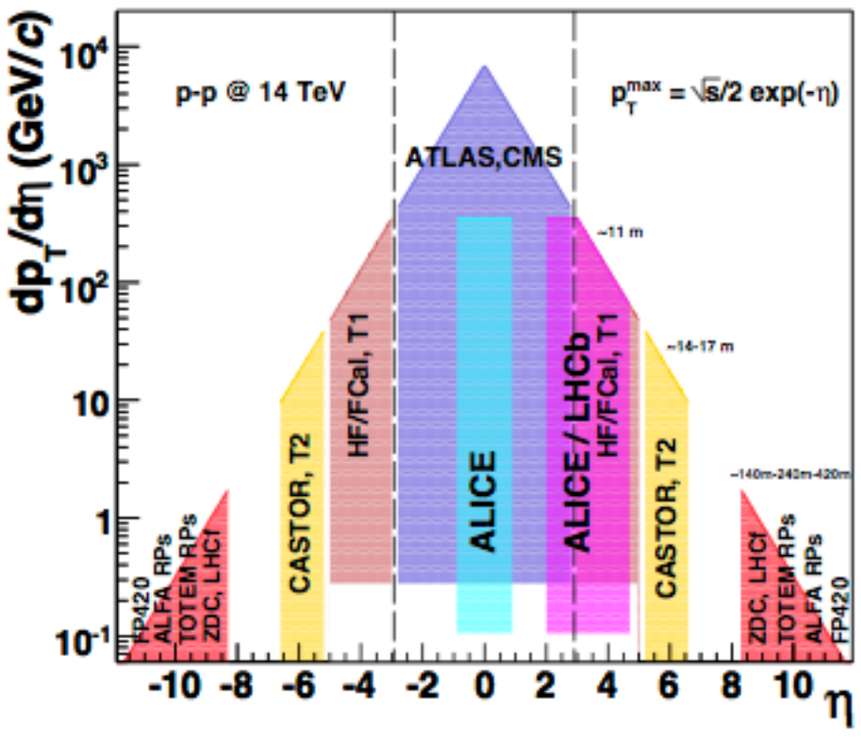
- CMS results on hard diffraction

✓ Observation of a diffractive contribution to dijet production in pp collisions at $\sqrt{s}$=7 TeV (Phys. Rev. D87 (2013) 012006)

✓ Search for exclusive or semi-exclusive $\gamma\gamma$ production and observation of exclusive and semi-exclusive e^+e^- production in pp collisions at $\sqrt{s}$=7 TeV (JHEP 11 (2012) 080)

CMS detector





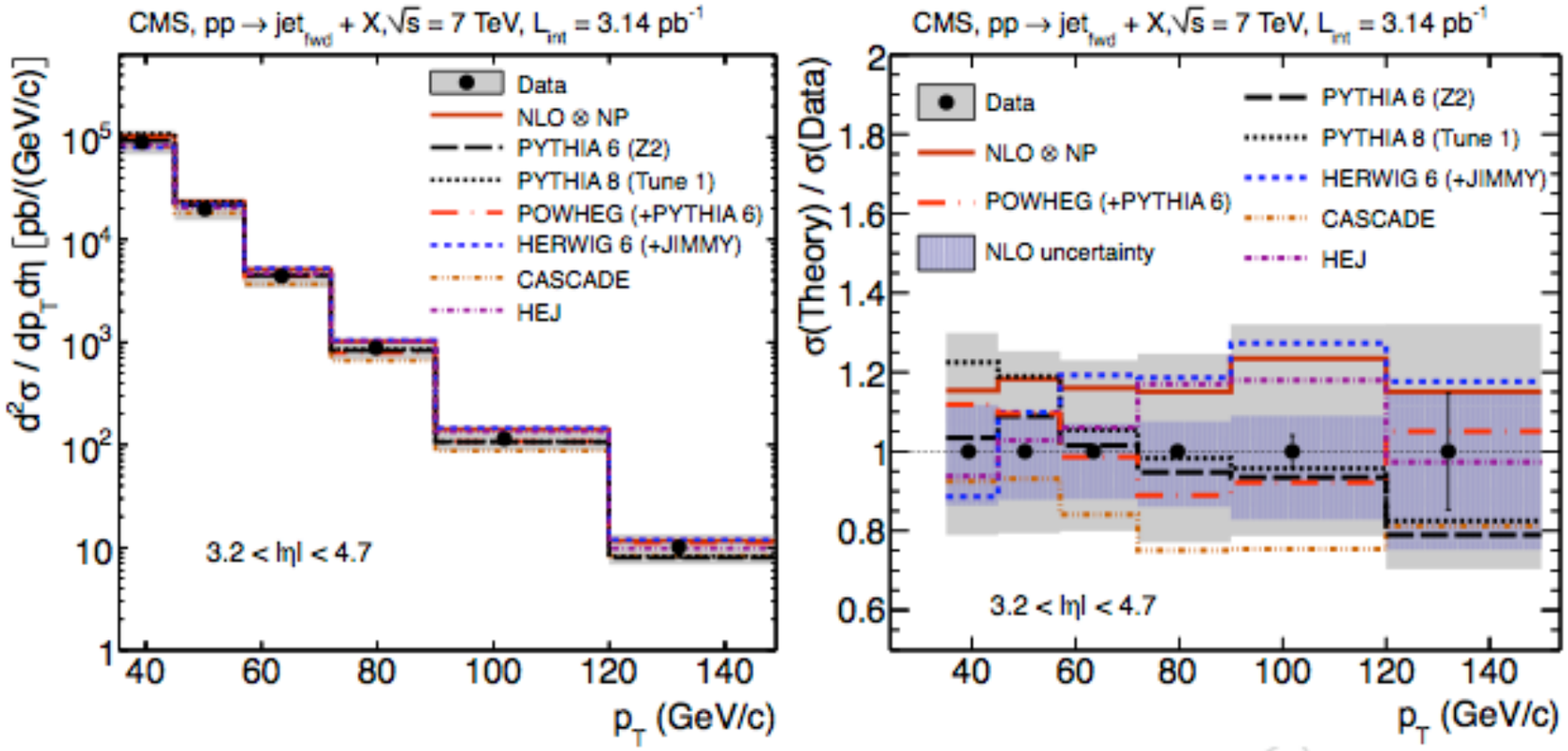
- Hadronic Forward calorimeters (HF)
- Centauro And STrange Objects Research (CASTOR) – calorimeter
- Zero Degree Calorimeter (ZDC)

+ Totem (T1/T2) separate experiment
→ tracking detectors

Low-x QCD

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

FWD-11-002, JHEP 1206 (2012) 036



- Jets with $3.2<|\eta|<4.7$ and $p_T>35$ GeV ($x\sim10^{-4}$)

- All MC predictions describe the data within uncertainties
- NLO prediction (NLOJET++) is 20% above the data
- NLO+PS (POWHEG+PYTHIA6) is the best

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

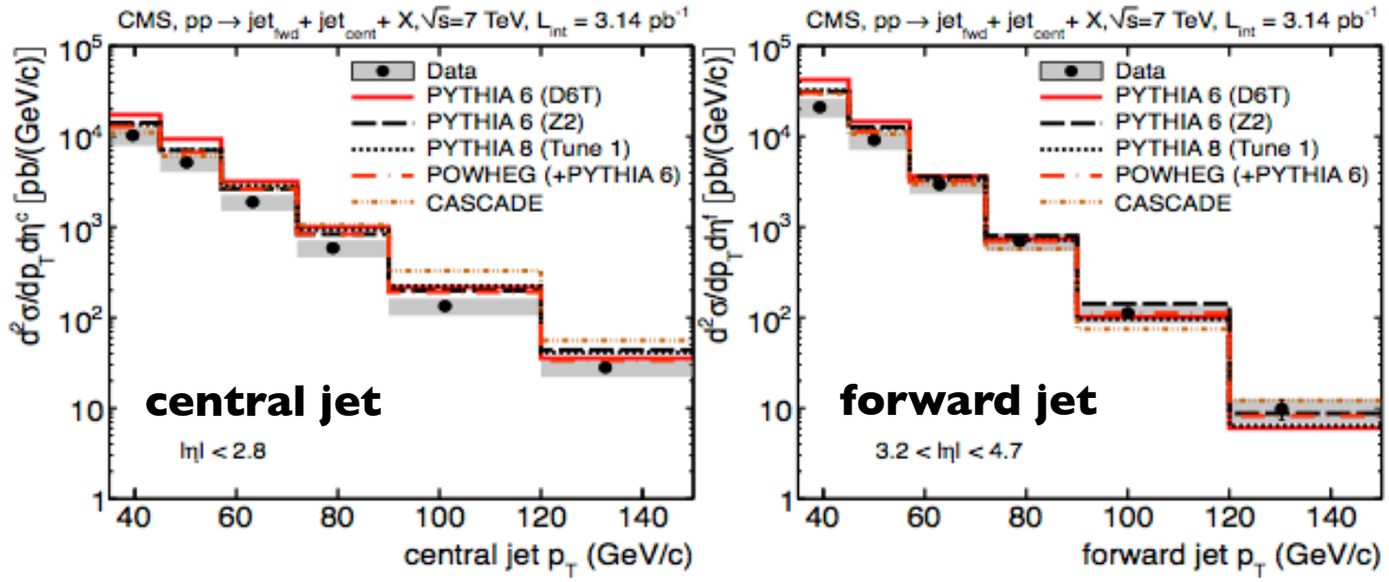
FWD-11-002, JHEP 1206 (2012) 036

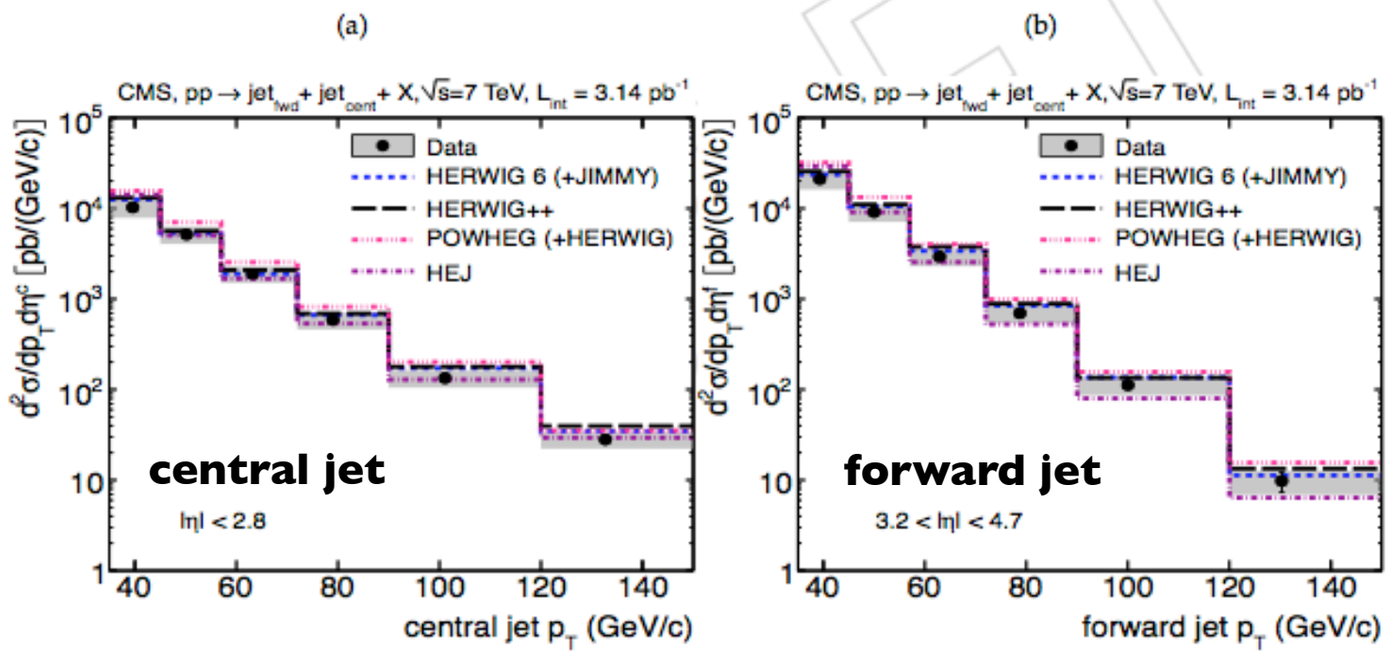
- Events with one forward jet ($3.2<|\eta|<4.7$ and $p_T>35$ GeV) and one central jet ($|\eta|<2.8$ and $p_T>35$ GeV)

- Large disagreement in shape for forward jets

- PYTHIA6, PYTHIA8, CASCADE problems with normalization for central jets

- Herwig6, Herwig++ look the best

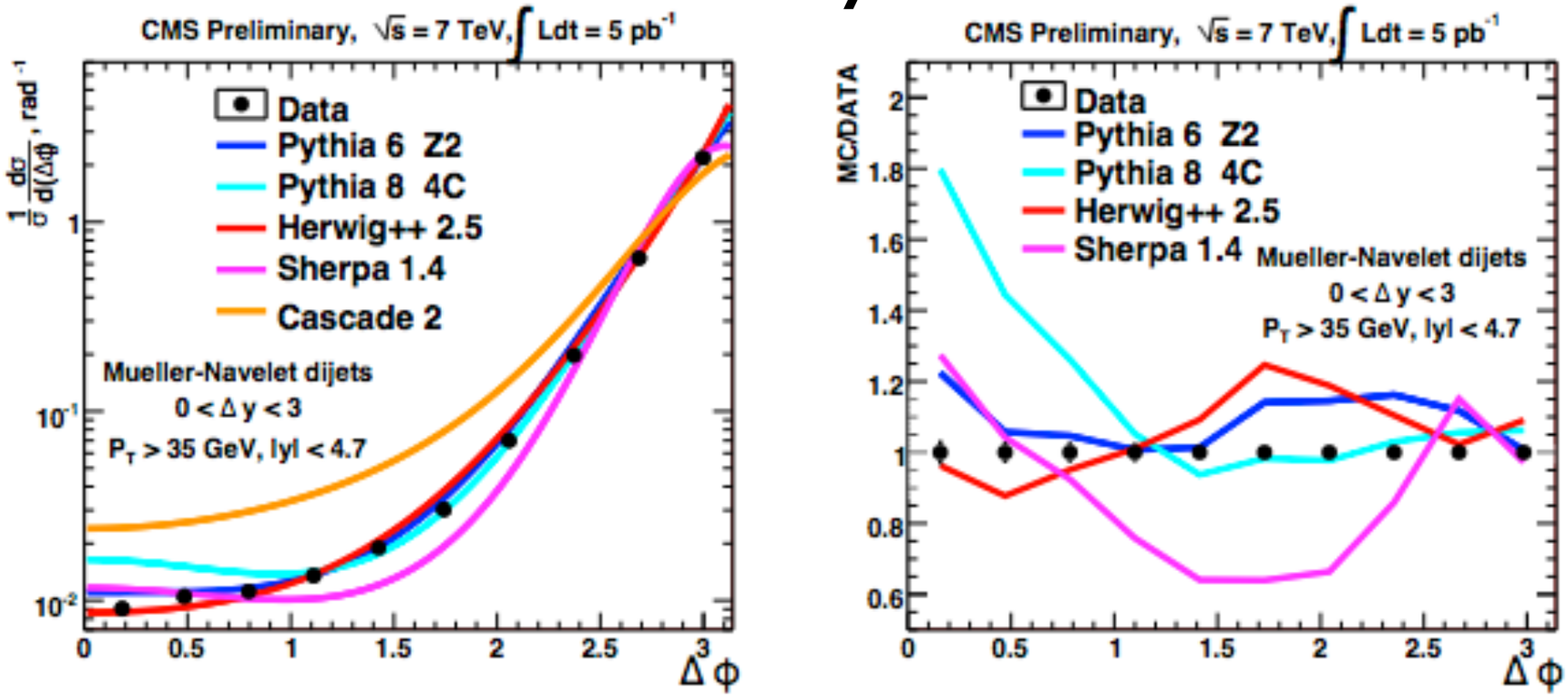




Azimuthal angle decorrelations of jets widely separated in rapidity in pp collisions at $\sqrt{s}$=7 TeV

FSQ-12-002

0<Δy<3



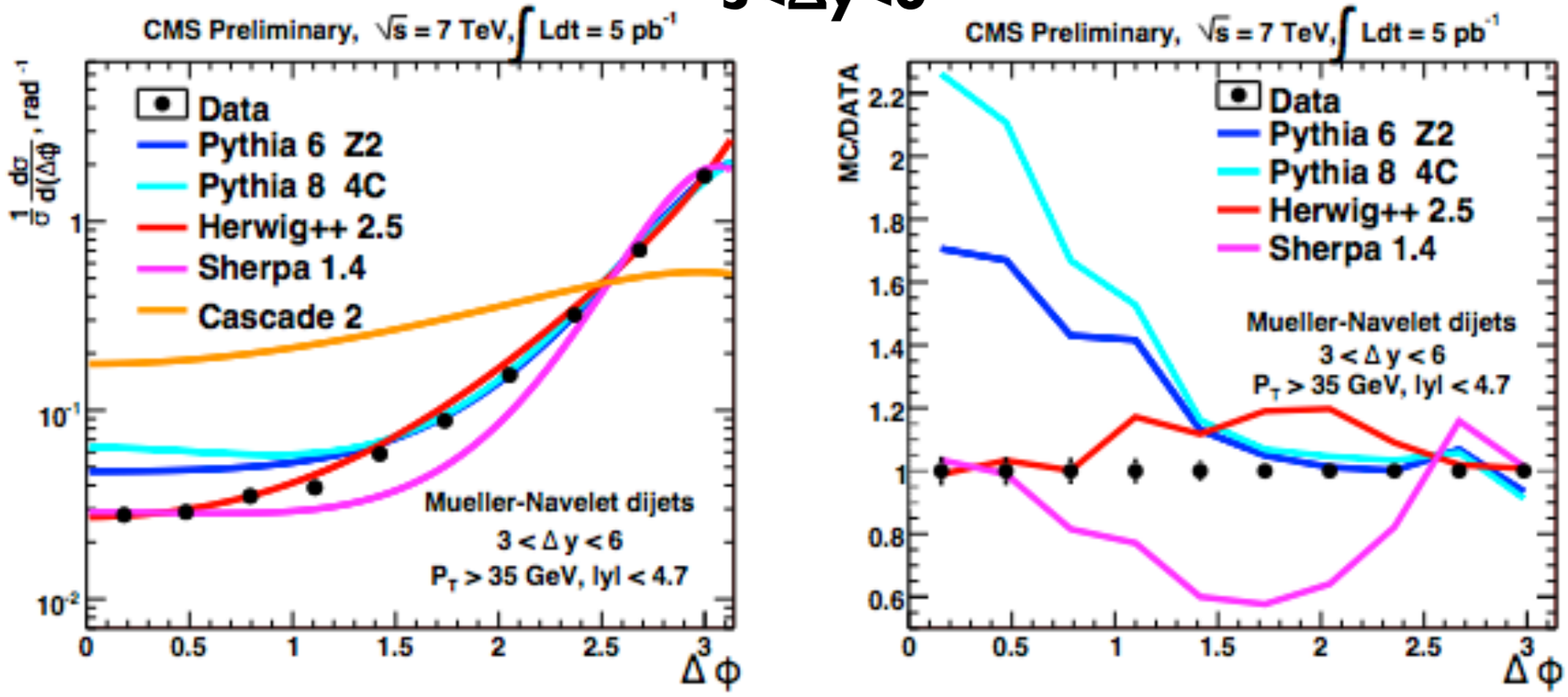
- Jets with p_T>35 GeV and |y|<4.7
- Dijets with the largest rapidity separation (Muller-Navelet dijets)
- Azimuthal angle difference between MN jets in Δy<3 interval

- PYTHIA6 and HERWIG++ describe the data within the experimental uncertainties

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

FSQ-12-002

3<Δy<6



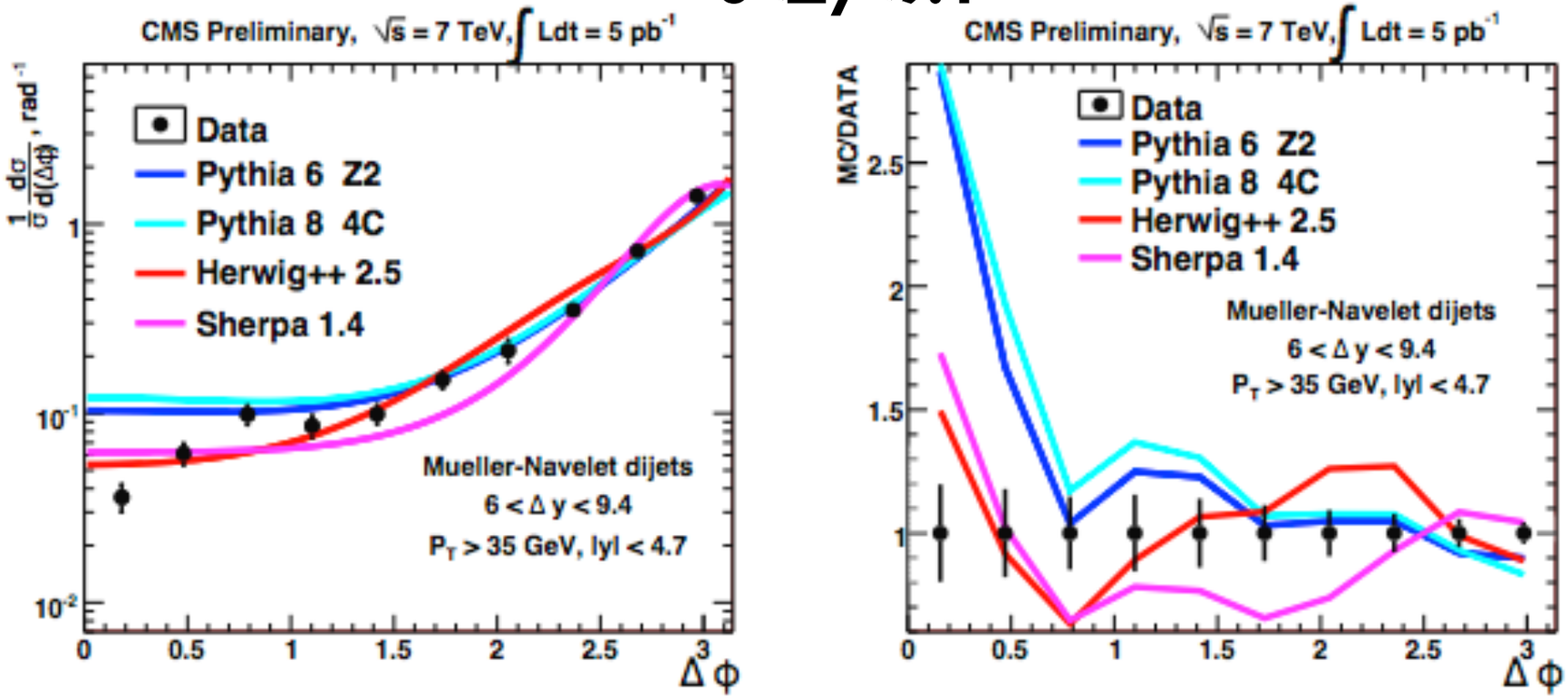
- Azimuthal angle difference between MN jets in 3<Δy<6 interval

- All DGLAP-based MC generators show deviations beyond experimental uncertainties
- Herwig++ provides the best description
- BFKL-inspired generator Cascade 2 predicts too strong decorrelations

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

FSQ-12-002

6<Δy<9.4



- Azimuthal angle difference between MN jets in 6<Δy<9.4 interval

- All DGLAP-based MC generators show deviations beyond experimental uncertainties
- HERWIG++ provides the best description

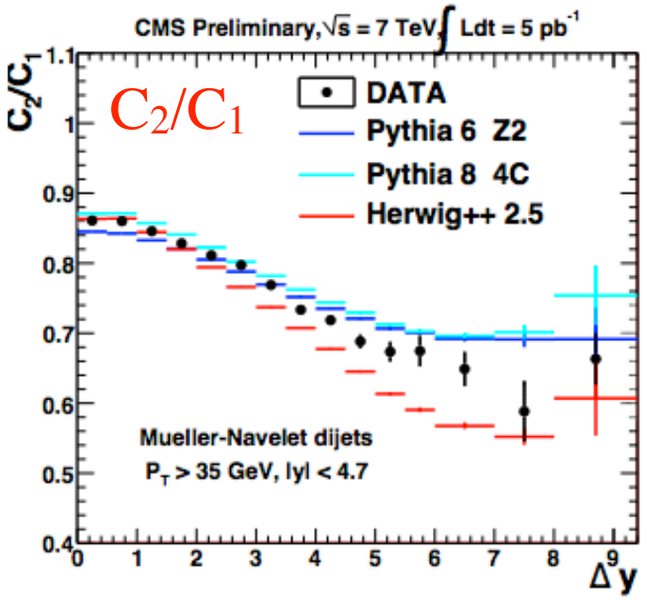
Azimuthal angle decorrelations of jets widely separated in rapidity in pp collisions at $\sqrt{s}$=7 TeV

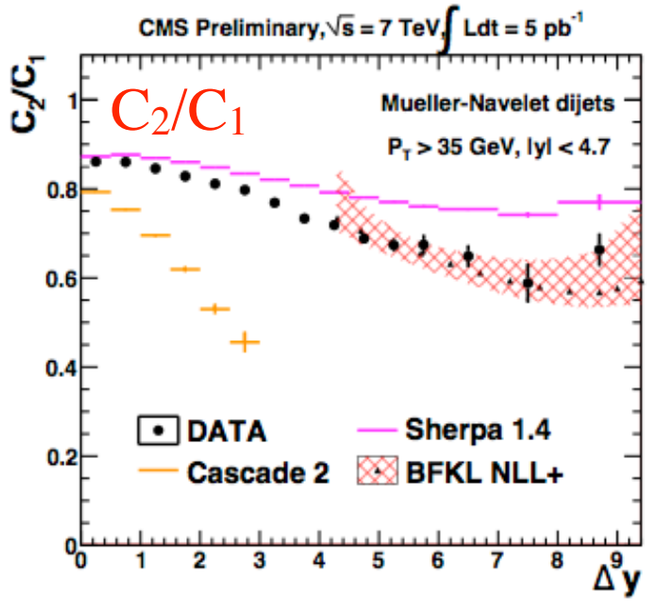
FSQ-12-002

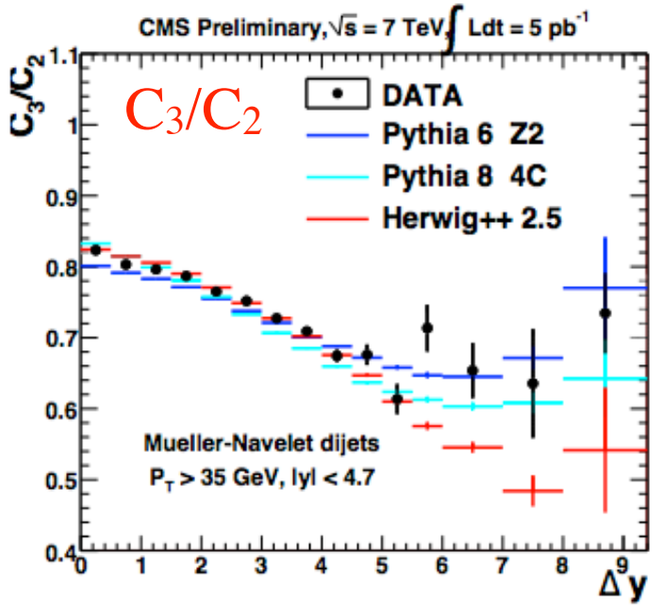
$$\frac{1}{\sigma}\frac{d\sigma}{d(\Delta\phi)}(\Delta y, p_{\mathrm{Tmin}}) = \frac{1}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} C_n(\Delta y, p_{\mathrm{Tmin}}) \cdot cos(n(\pi - \Delta\phi))\right]$$

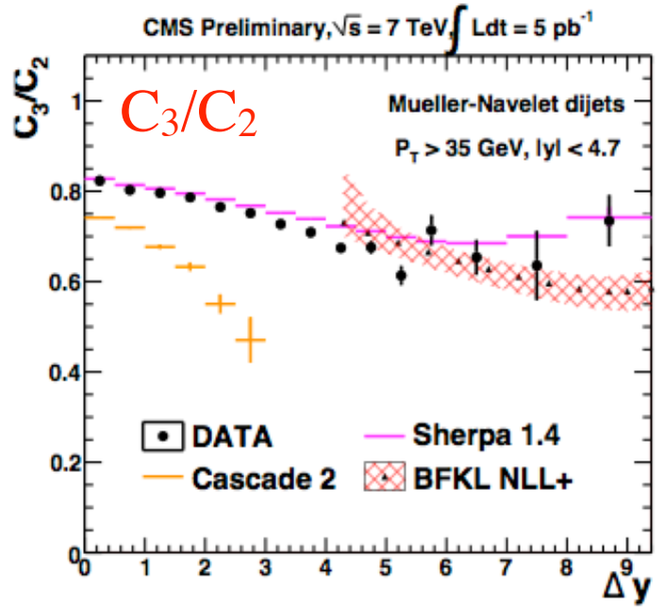
Fourier coefficients C_n~<cos(n(π-Δφ))>

- Ratios of cosines are expected to be more sensitive to BFKL effects
- PYTHIA6, PYTHIA8, SHERPA overestimate C_2/C_1 and consistent with data for C_3/C_2
- HERWIG++ underestimates C_2/C_1 and C_3/C_2 at large Δy
- CASCADE predicts too small ratios
- Analytic NLL BFKL calculation is consistent with the data at large Δy









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

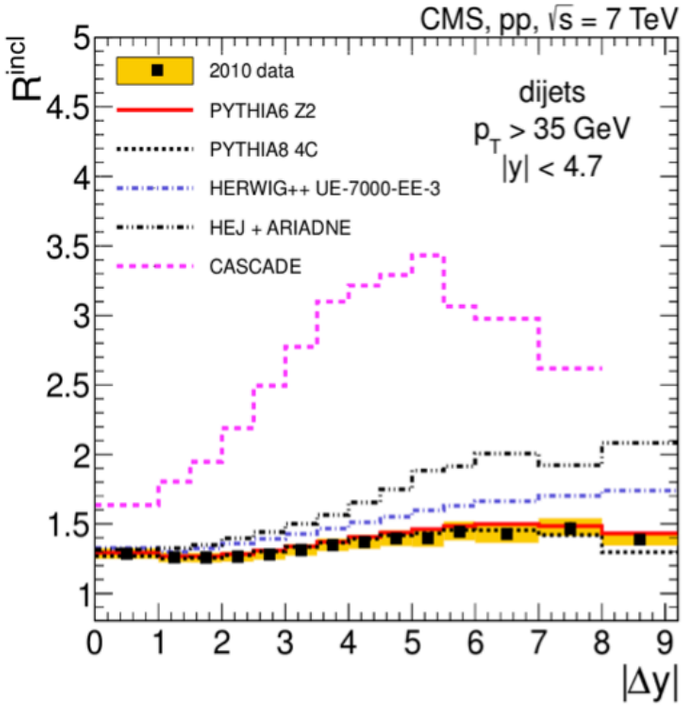
FWD-10-014, Eur.Phys.J. C72 (2012) 2216

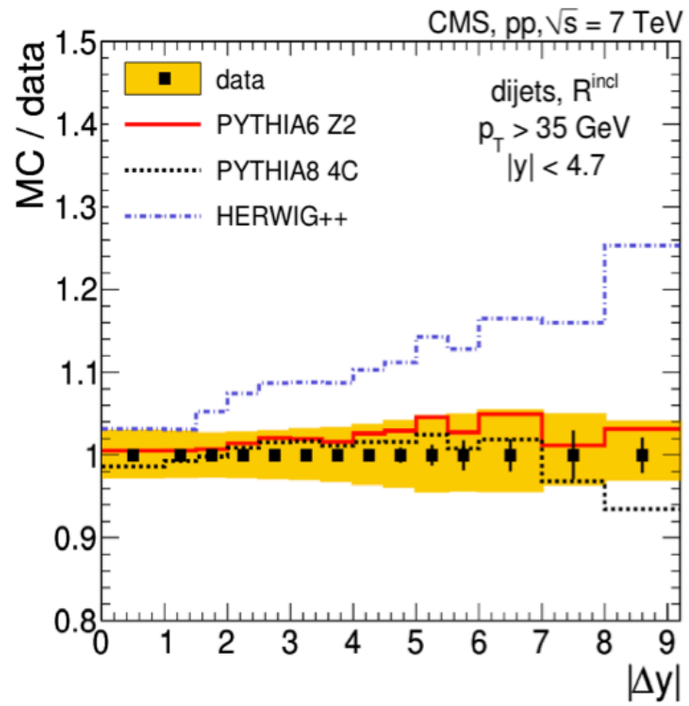
Jets with p_T>35 GeV and |η|<4.7

$$R^{incl} = \frac{\sigma^{inclusive}_{dijet}}{\sigma^{exclusive}_{dijet}}$$

- Inclusive sample - all pairwise combination of jets above p_T threshold
- Exclusive sample - events with exactly two jets above p_T threshold

- PYTHIA6 and PYTHIA8 describe the data
- HERWIG++ and ARIADNE overestimate the results
- BFKL-motivated CASCADE is significantly higher





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

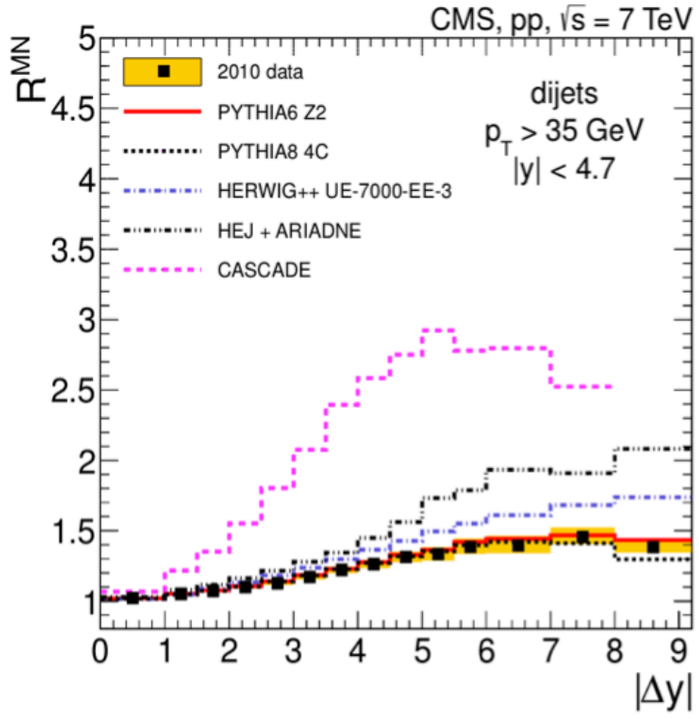
FWD-10-014, Eur.Phys.J. C72 (2012) 2216

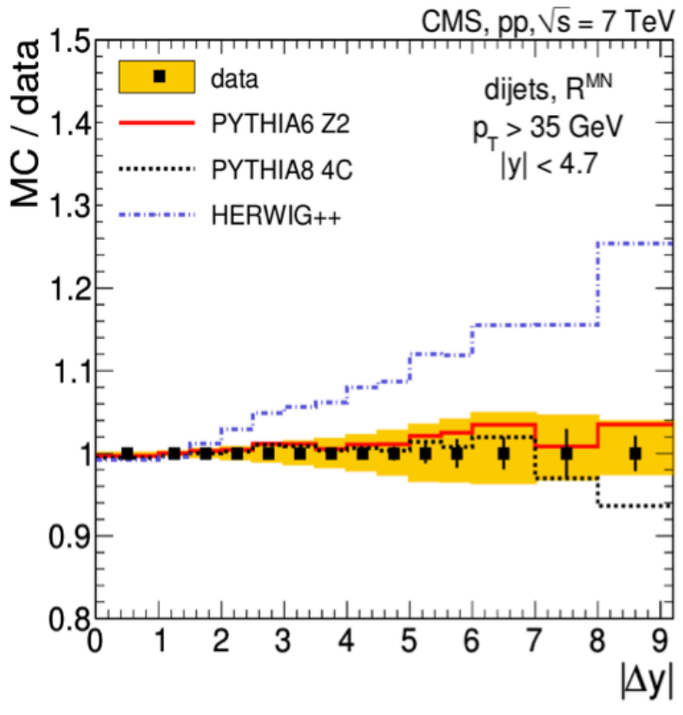
Jets with p_T>35 GeV and |η|<4.7

$$R^{MN} = \frac{\sigma^{MN}_{dijet}}{\sigma^{exclusive}_{dijet}}$$

- Muller-Navelet jets (MN) - the most forward and backward jets in inclusive sample
- Exclusive sample - events with exactly two jets above p_T threshold

- PYTHIA6 and PYTHIA8 describe the data
- HERWIG++ and ARIADNE overestimate the results
- BFKL-motivated CASCADE is significantly higher





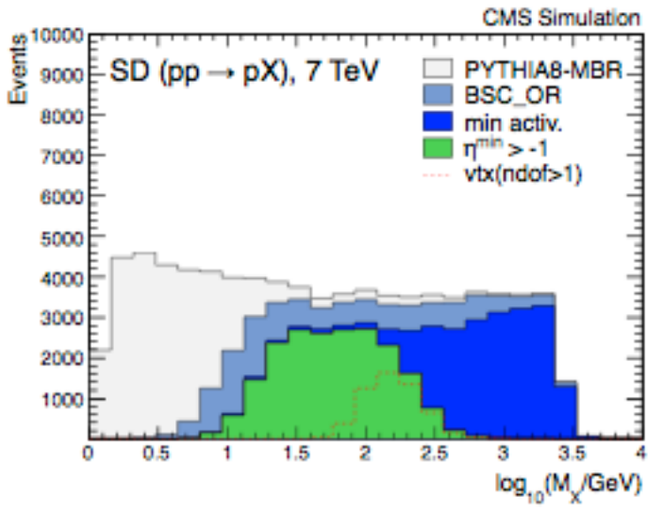
Data/MC comparison for forward jets, forward+central dijets and dijets with large rapidity separation

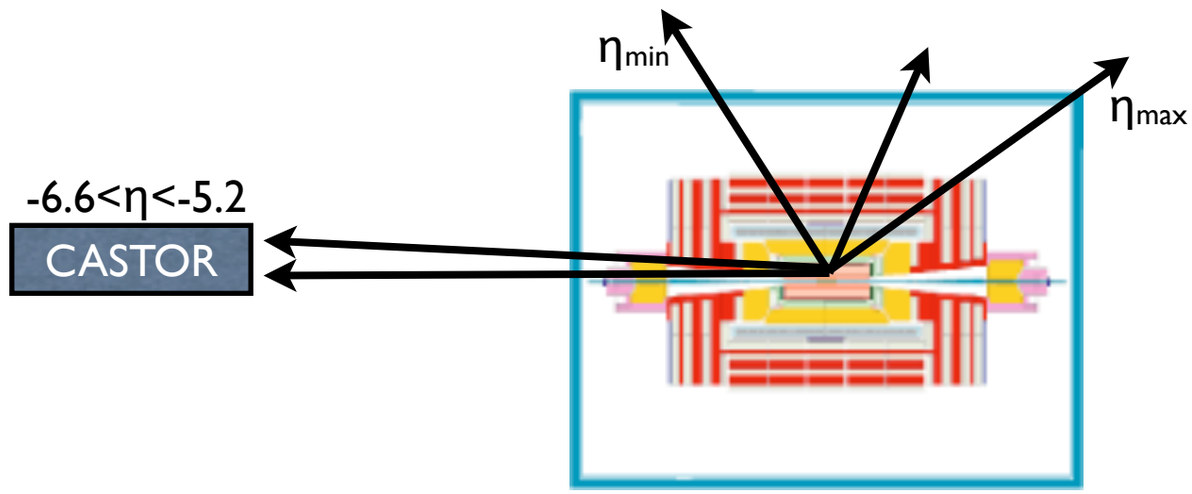
	Inclusive Forward	Forward from fwd-cent	Central from fwd-cent	R	Δφ	C1 , C2 , C3	C2/C1	C3/C2
Pythia6/8	OK	Steeper	Above	OK	Too large decorrelation	OK (a little bit below)	Above	OK
Herwig+Jimmy	OK	OK	OK for medium pT					
Herwig++		A little bit above	OK for medium pT	Above	The best	OK (a little bit below)	Below	OK (except for high Δy)
Powheg+Pythia	OK	Steeper	Above					
Powheg+Herwig		Above	Above					
Cascade	Below	Steeper	Much over	Much over	A lot too large decorrelation	Much below	Much below	Much below
HEJ	OK	Steeper	OK (except for low pT)	Above				
Sherpa					Too small deccorelation	Above	Above	Above
BFKL NLL						Above	OK	OK
NLOJET	OK							

Soft Diffraction

Measurement of pp diffraction dissociation cross sections at $\sqrt{s}$=7 TeV at the LHC

FSQ-12-005





- $\eta_{max}(\eta_{min})$ - pseudorapidity of the most forward(backward) particle (in $|\eta|<4.7$ range)
- $\eta^0_{max}(\eta^0_{min})$ - closest to zero positive (negative) pseudorapidity of the reconstructed particle

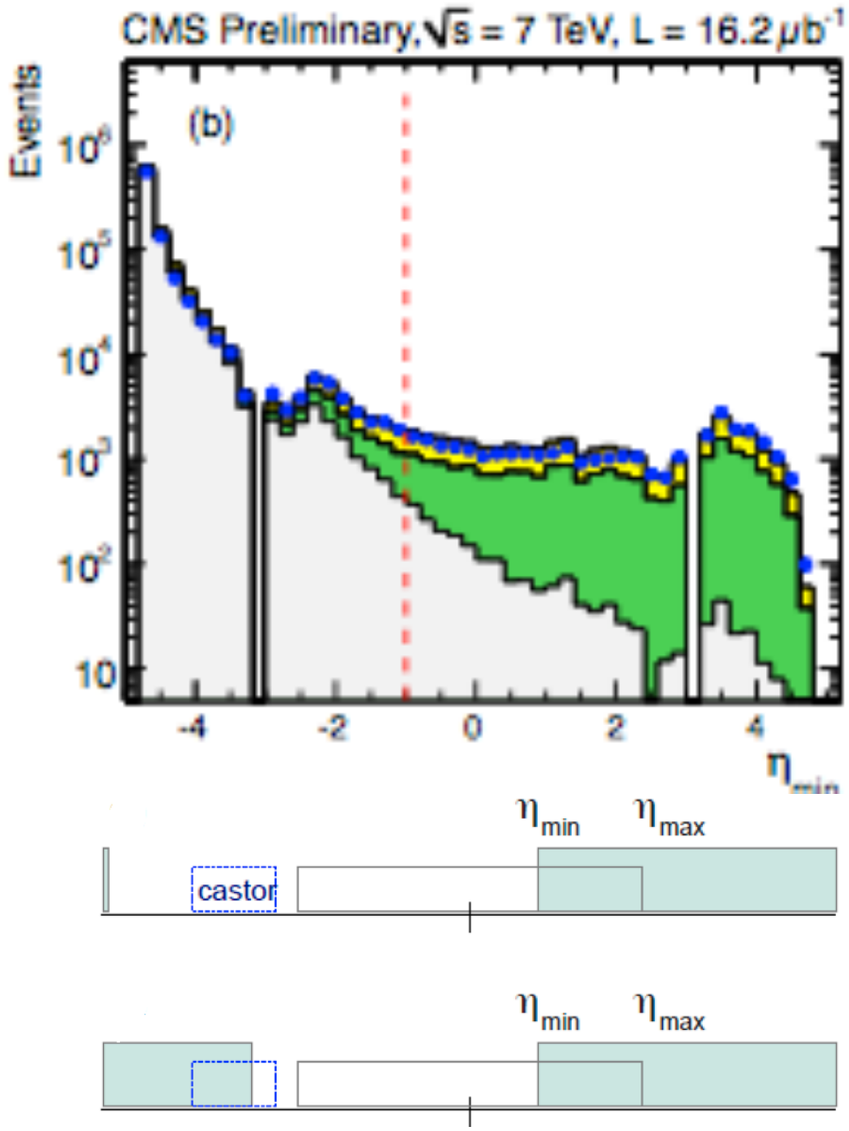
$\Delta\eta^0 = \eta^0_{max} - \eta^0_{min}$ defines the size of the gap in the central detector

- Castor is used as a veto (to select SD events, pp→pX) and as a tag (to select DD events, pp→YX)
  - $1.1<\log_{10}(M_X)<2.5$ for SD events
  - $1.1<\log_{10}(M_X)<2.5$ and $0.5<\log_{10}(M_Y)<1.1$ for DD events

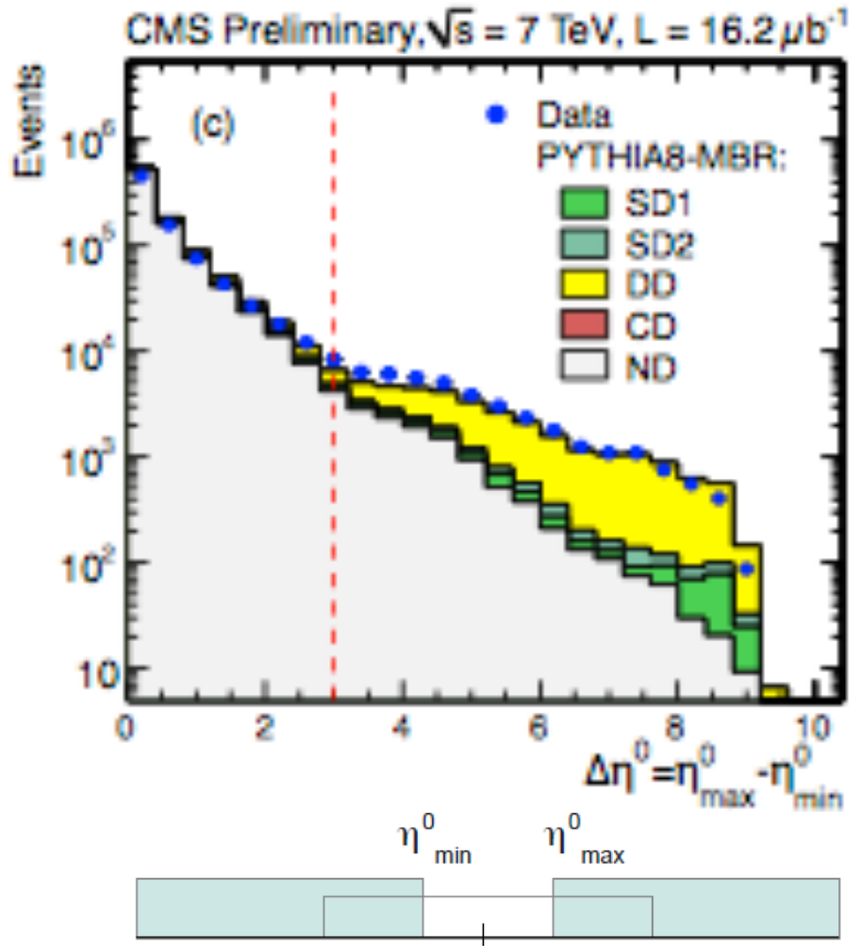
- DD is measured also in the central detector by $\Delta\eta^0>3$ selection
  - $\log_{10}(M_X)>1$ and $\log_{10}(M_Y)>1$

Measurement of pp diffraction dissociation cross sections at $\sqrt{s}$=7 TeV at the LHC

FSQ-12-005



η_{min}>-1 and Castor select SD and DD events



$\Delta\eta^0$>3 select DD events

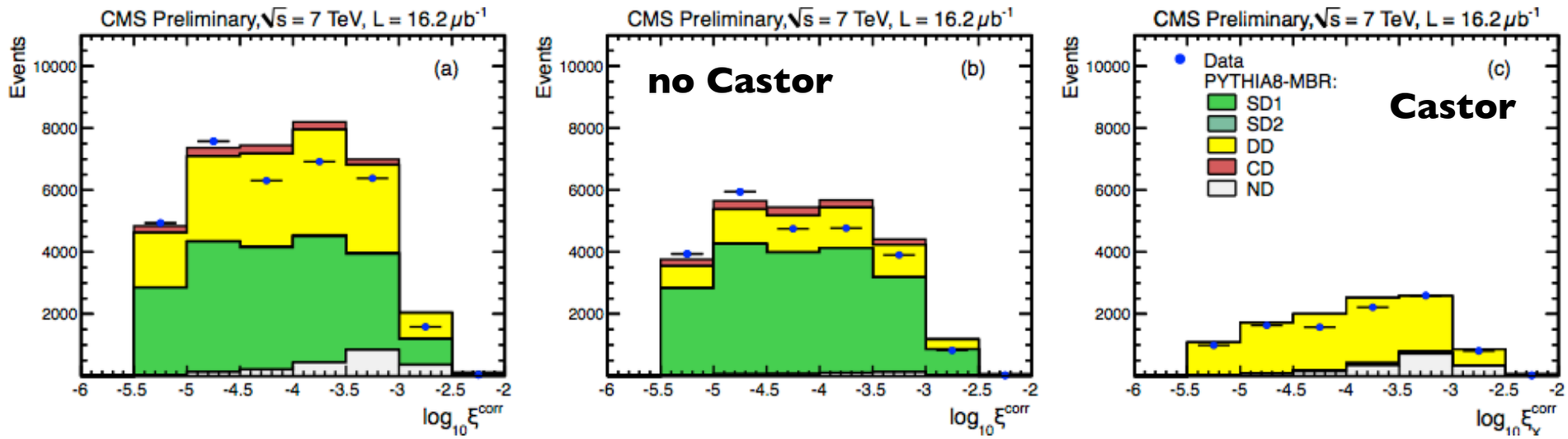
Measurement of pp diffraction dissociation cross sections at $\sqrt{s}$=7 TeV at the LHC

FSQ-12-005

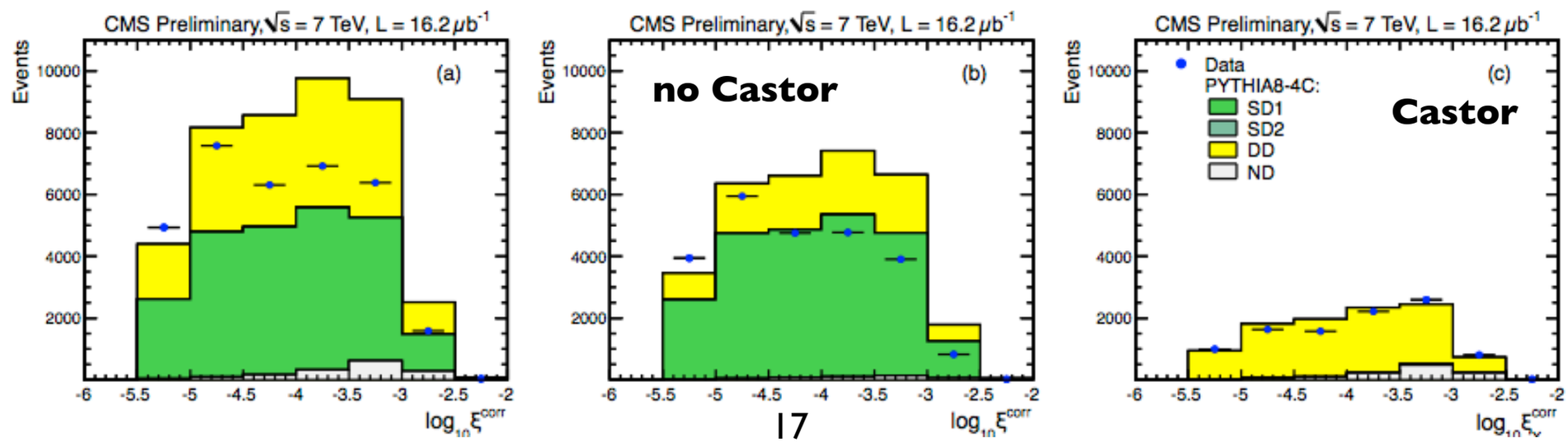
- Detector level ξ distributions for SD events with $\eta_{min} > -1$

$$\xi = \frac{M_X^2}{s} \simeq \frac{\sum (E - p_Z)}{\sqrt{s}}$$ - sum runs over all particles in $|\eta|<4.7$

- Comparison with PYTHIA8 MBR

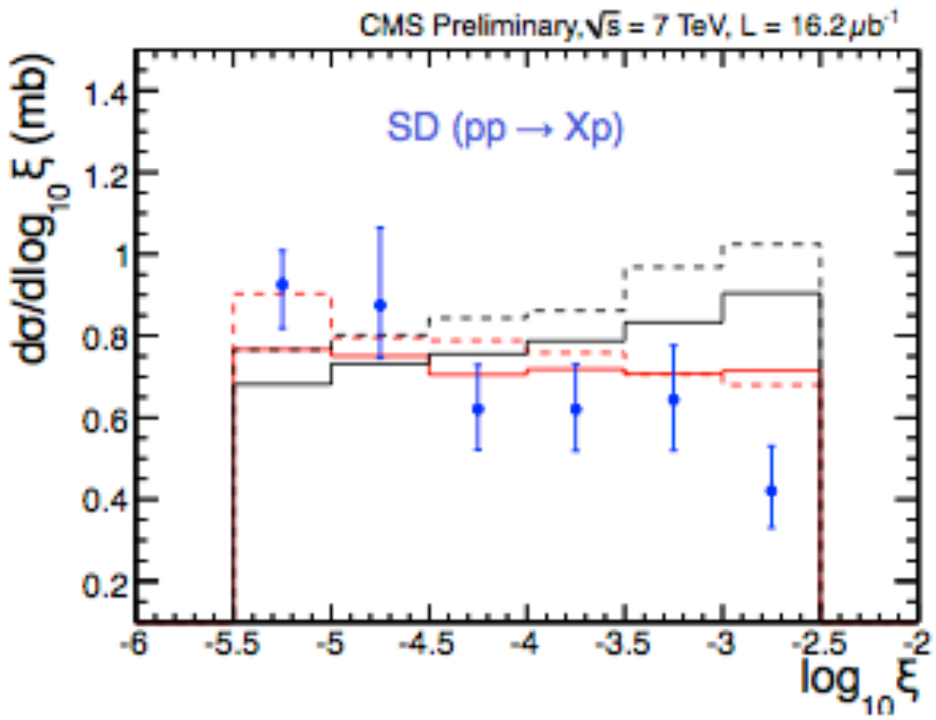


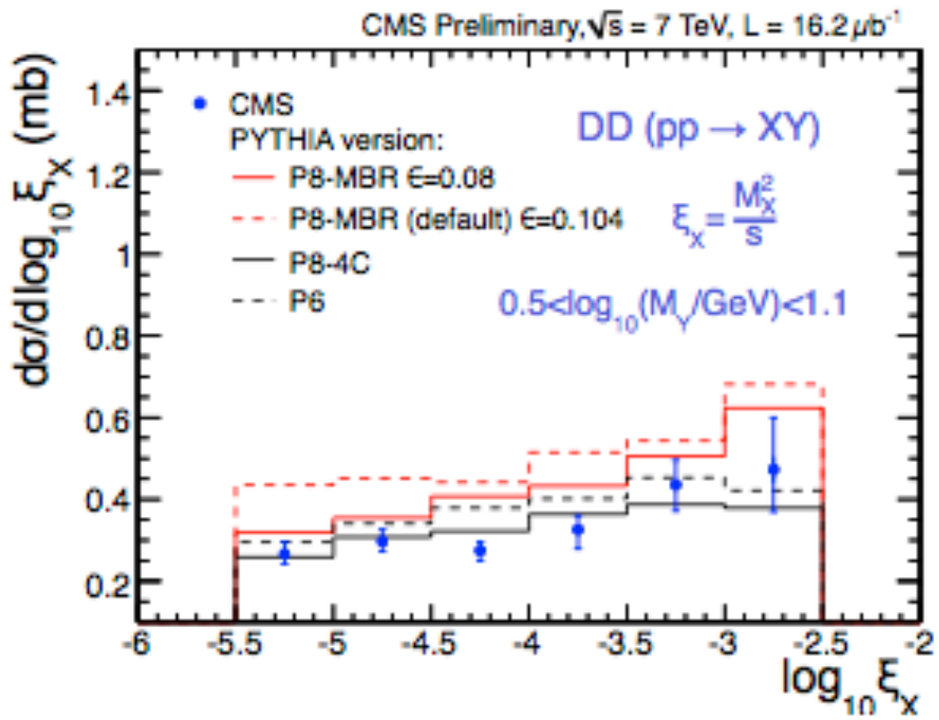
- Comparison with PYTHIA8 4C



Measurement of pp diffraction dissociation cross sections at $\sqrt{s}$=7 TeV at the LHC

FSQ-12-005





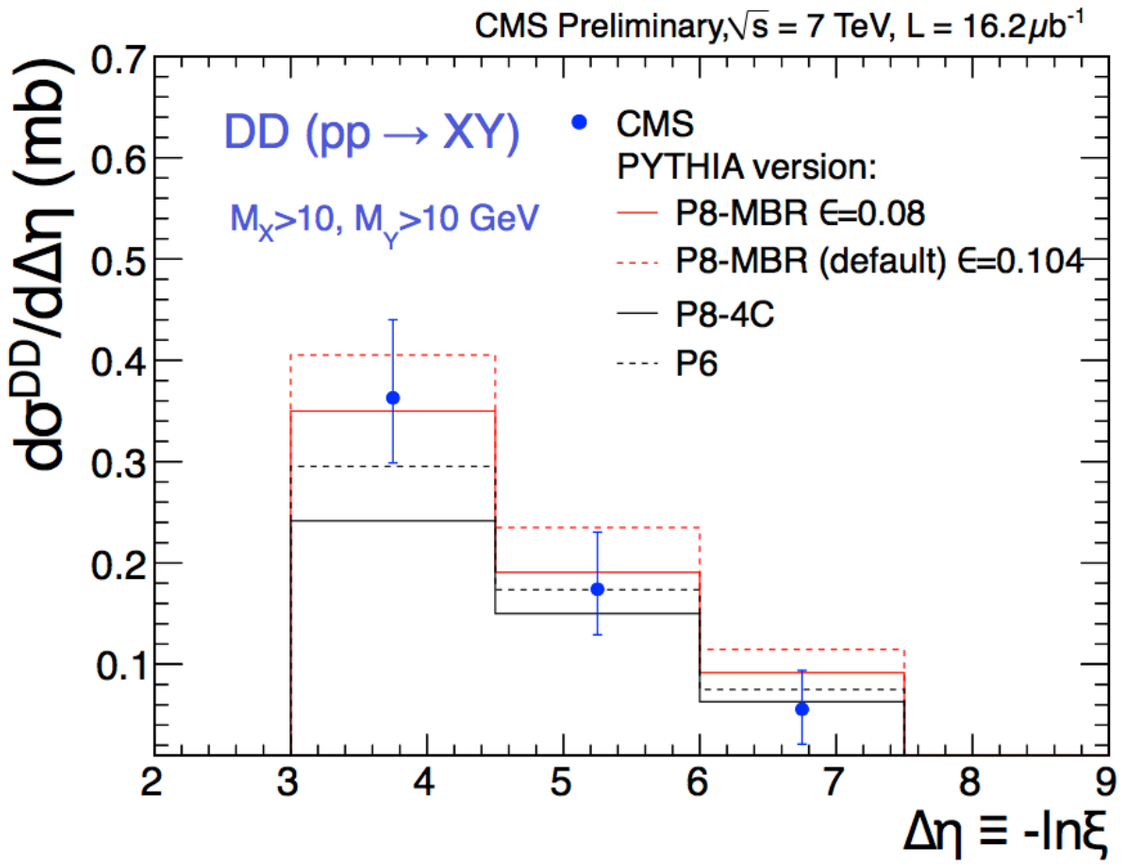
SD and DD cross sections as a function of ξ

- PYTHIA8-MBR with **ε=0.08** agrees with data both for SD and DD
- SD cross section integrated over $-5.5<\log_{10}(\xi)<-2.5$

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

Measurement of pp diffraction dissociation cross sections at $\sqrt{s}$=7 TeV at the LHC

FSQ-12-005



DD cross section as a function of $\Delta\eta$

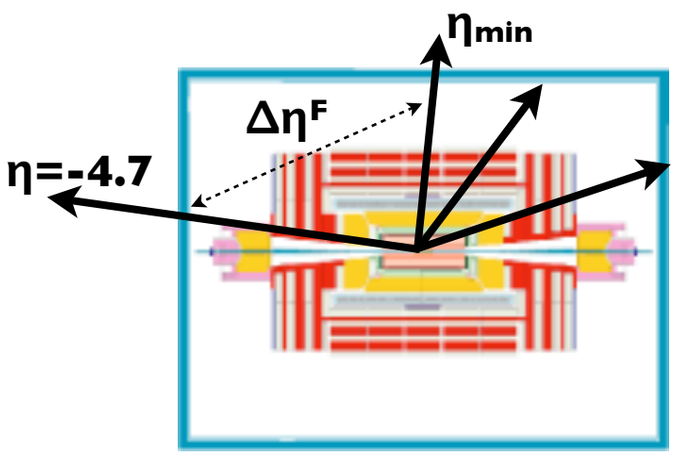
- MC predictions are in agreement with the data
- DD cross section integrated the region $\Delta\eta>3$, $M_X>10$ GeV and $M_Y>10$ GeV

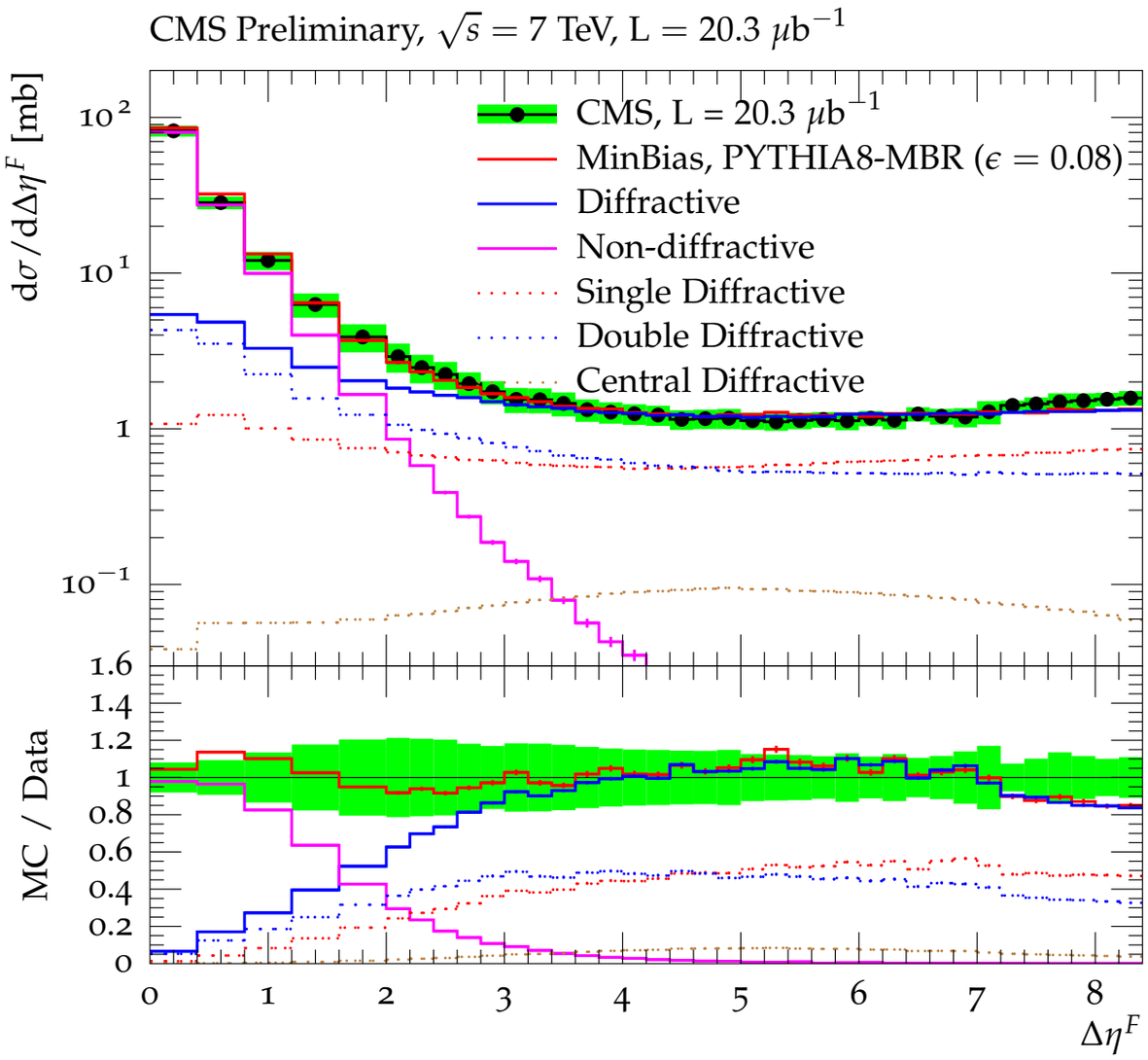
$$\sigma = 0.93 \pm 0.01(stat.)^{+0.26}_{-0.22}\ (syst.)\ \ mb$$

Measurement of pp diffraction dissociation cross sections at $\sqrt{s}$=7 TeV at the LHC

FSQ-12-005

Forward rapidity gap $\Delta\eta^F=\max(4.7-\eta_{max}, 4.7+\eta_{min})$





- Exponential non-diffractive contribution at low $\Delta\eta^F$
- Diffractive plateau at $\Delta\eta^F$>3 and slow rise at $\Delta\eta^F$>5-6

- PYTHIA8 MBR with ε=0.08 is in reasonable agreement with the data

Measurement of pp diffraction dissociation cross sections at $\sqrt{s}$=7 TeV at the LHC

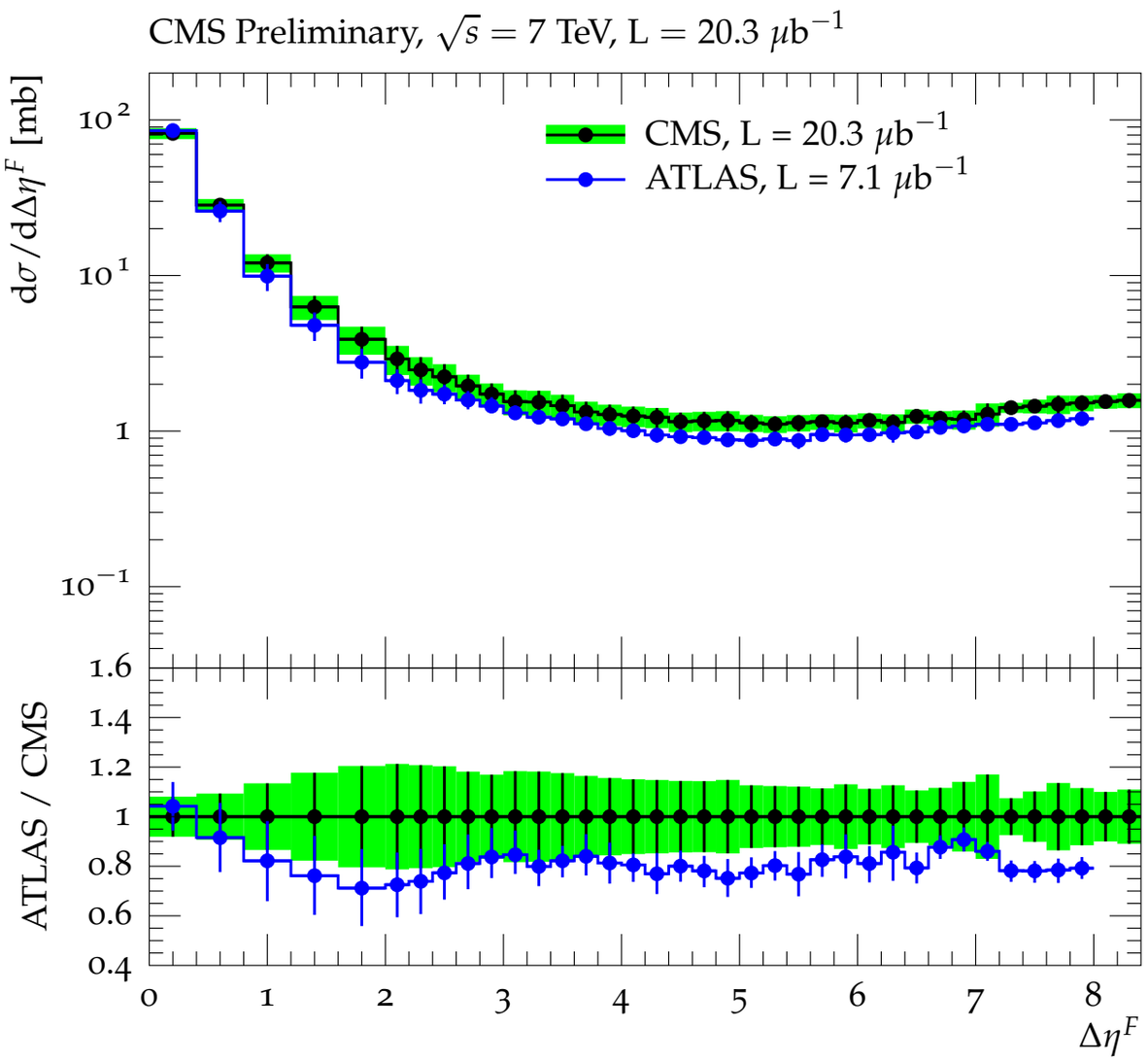
FSQ-12-005

Comparison with ATLAS measurements
Eur. Phys. J. C72 (2012) 1926

- Different forward gap definitions:
$|\eta|<4.9$ (ATLAS) and $|\eta|<4.7$ (CMS)
Small difference (~5%) is expected

- The results from CMS and ATLAS are consistent

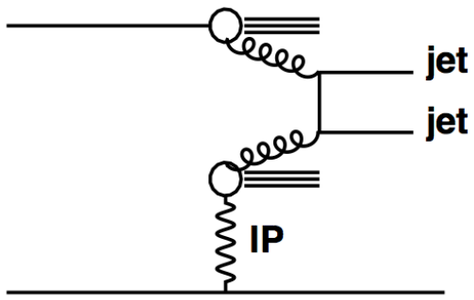
- CMS extends the ATLAS measurements by 0.4 unit of gap size



Hard Diffraction

Observation of a diffractive contributions to dijet production in pp collisions at $\sqrt{s}$=7 TeV

FSQ-10-004, Phys. Rev. D87 (2013) 012006

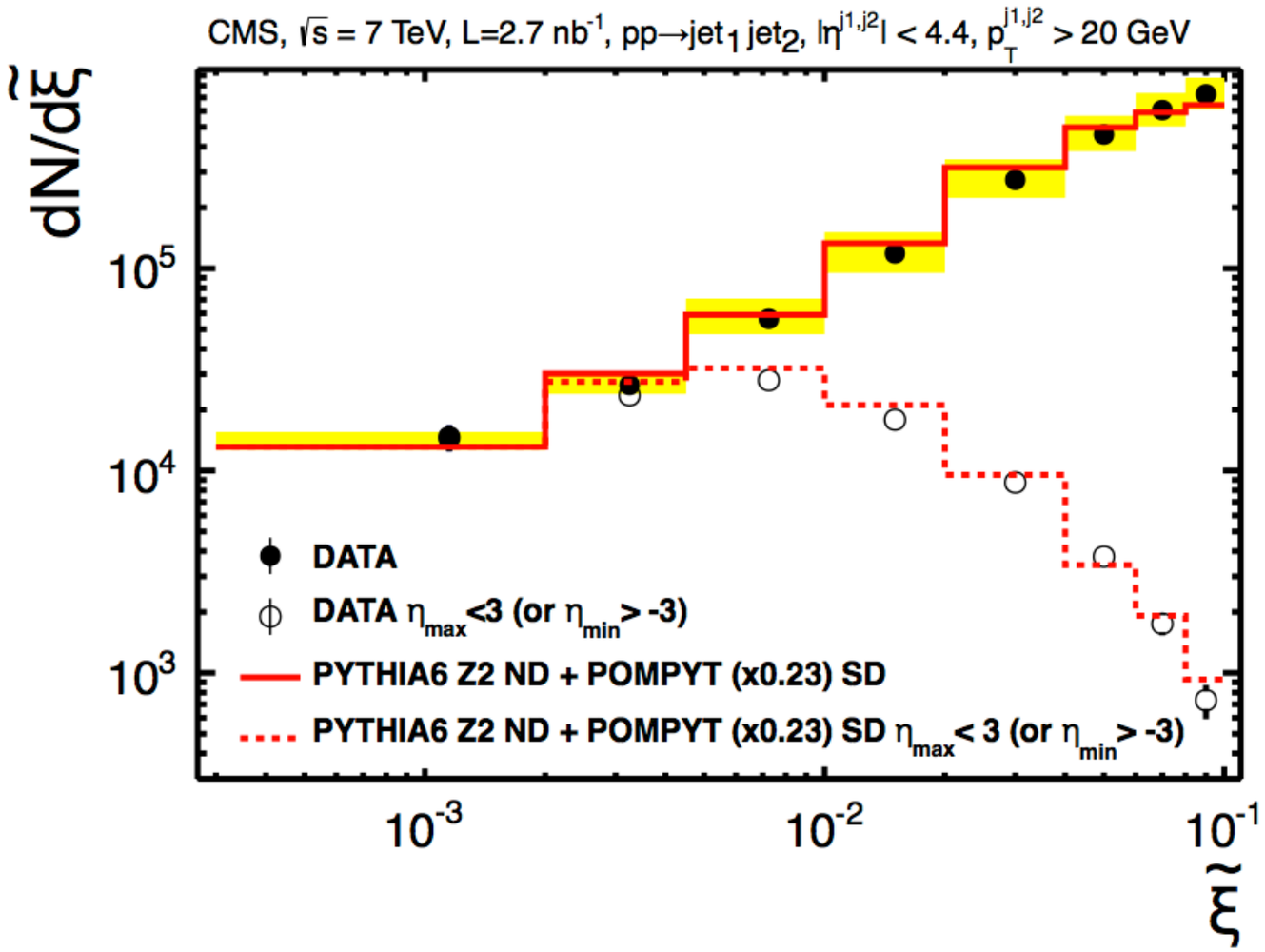


- Dijet events with p_T>20 GeV and $|\eta|$<4.4
- ξ approximated by

$$\xi^{\pm} = \frac{\sum (E \pm p_Z)}{\sqrt{s}}$$

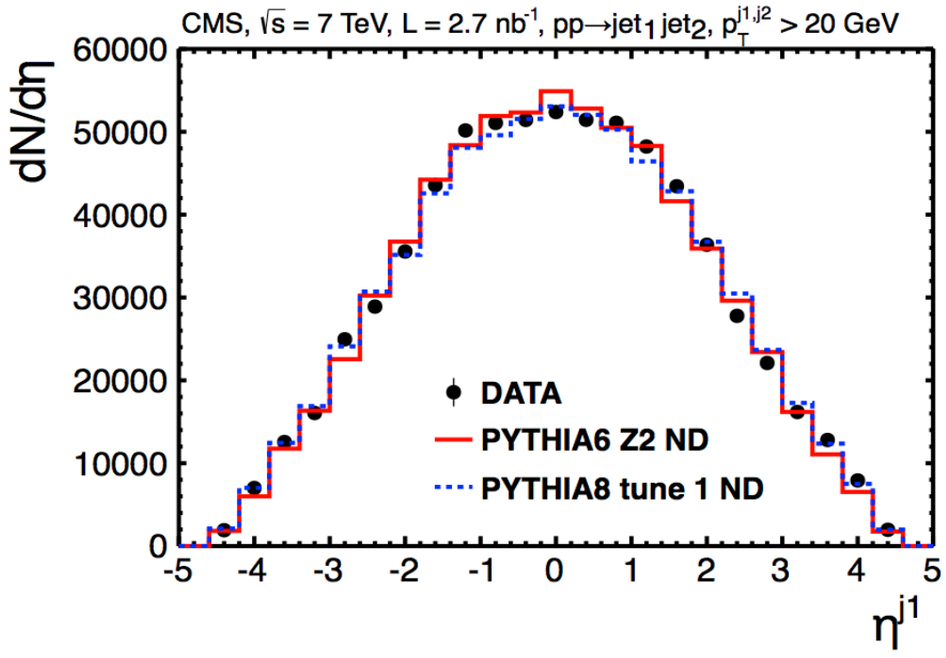
where sum runs over all particles in the detector acceptance

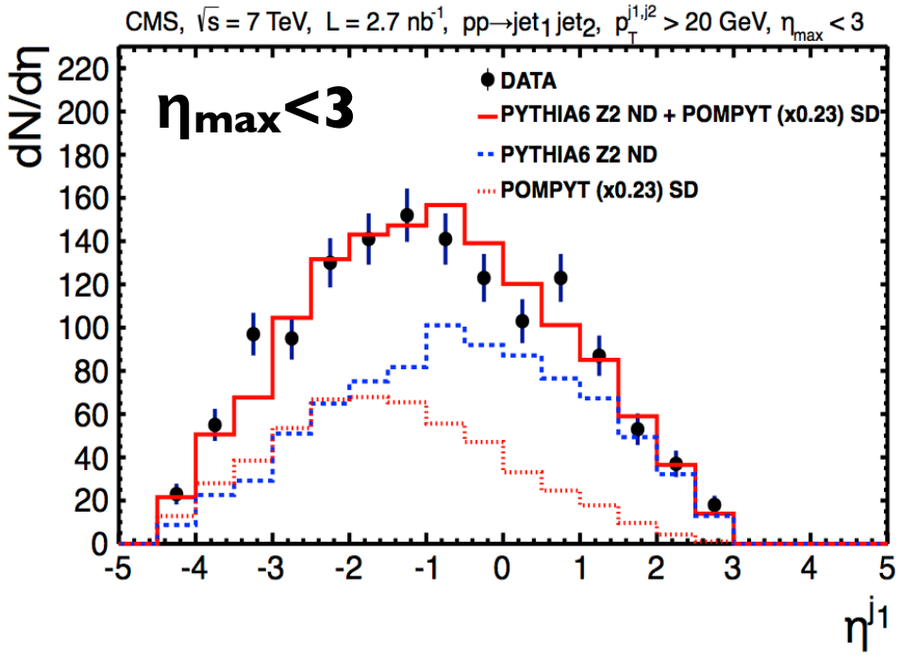
- The combination of diffractive and non-diffractive MC models should be used to describe the data (e.g. PYTHIA6 + POMPYT)



Observation of a diffractive contributions to dijet production in pp collisions at $\sqrt{s}$=7 TeV

FSQ-10-004, Phys. Rev. D87 (2013) 012006





- Pseudorapidity distribution of the leading jet is symmetric for inclusive selection and asymmetric for events with η_{max}<3

- Well described by the combination of non-diffractive (PYTHIA6) and diffractive (POMPYT) MC models

Observation of a diffractive contributions to dijet production in pp collisions at $\sqrt{s}$=7 TeV

FSQ-10-004, Phys. Rev. D87 (2013) 012006

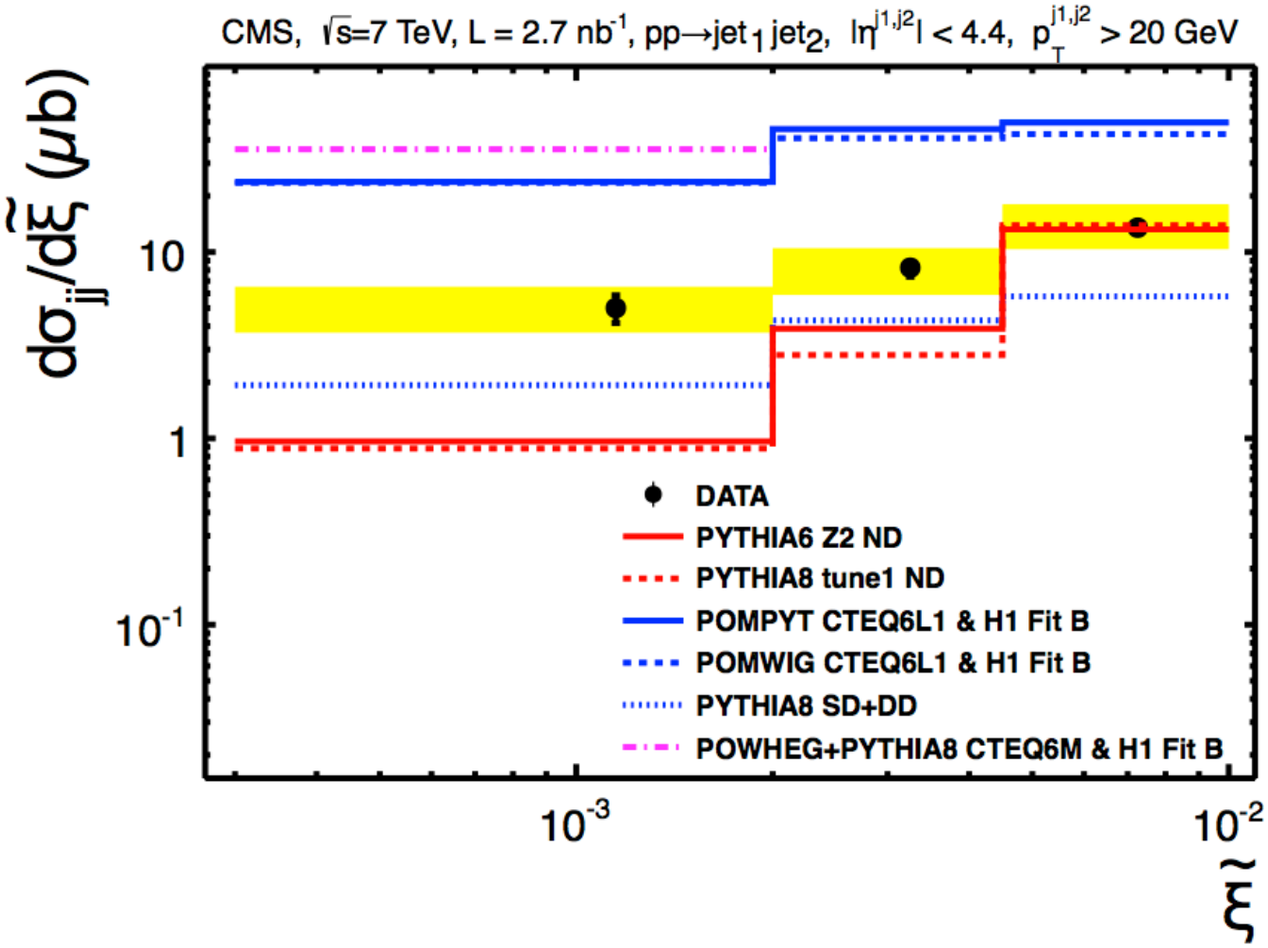
Dijet cross section as a function of ξ

•At low ξ cross section is dominated by diffraction

•The predictions of diffractive MC models (POMPYT, POMWIG) overestimate the measured cross section by a factor of ~5

•The ratio the measured cross section and diffractive MC predictions gives the upper limit for gap survival probability for 0.0003< ξ<0.002 bin:
0.21±0.07 (LO)
0.14±0.05 (NLO)

•After (MC dependent) correction for proton dissociation the survival probability
0.12±0.05 (LO)
0.08±0.04 (NLO)



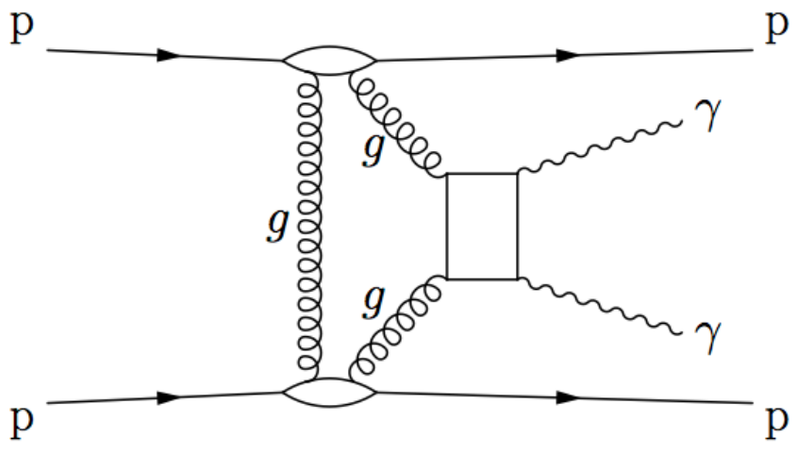
Search for exclusive γγ production

FWD-11-004, JHEP 11 (2012) 080

- Data collected in 2010 (low pileup), L=36 pb^{-1}

- Events with two isolated photons with E_T>5.5 GeV and |η|<2.5 and no additional activity in the range |η|<5.2

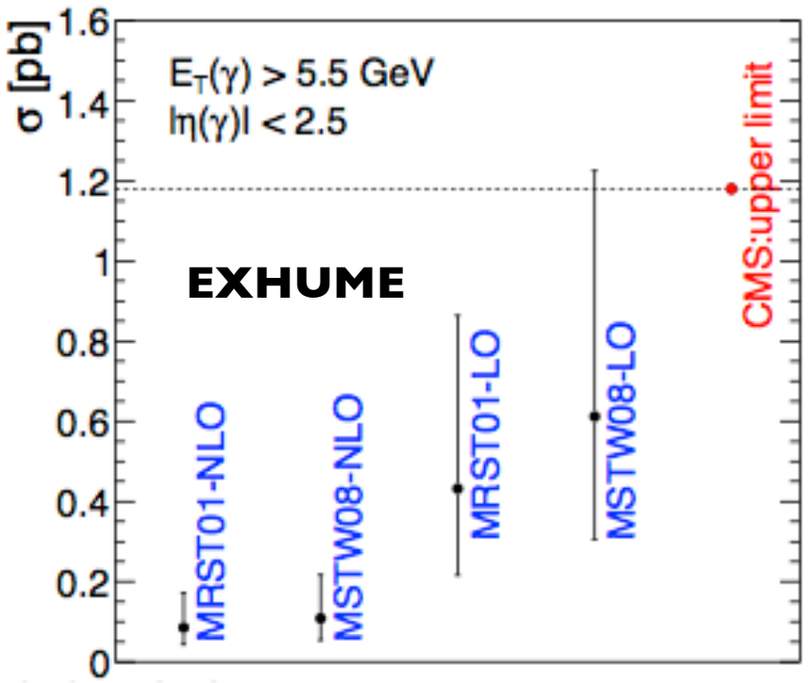
- Protons are not detected, proton dissociative events are also selected



- No exclusive diphoton event observed

- Upper limit on the cross section is 1.18 pb

- Exclusive dijet production is under study



Summary

- Lots of results on forward jets, forward+central dijets and dijets with large rapidity separation. DGLAP-based and BFKL-inspired MC models do not describe all observables. More results are coming.

- SD and DD cross sections measured as a function of ξ. PYTHIA8 MBR predictions are consistent with the data.

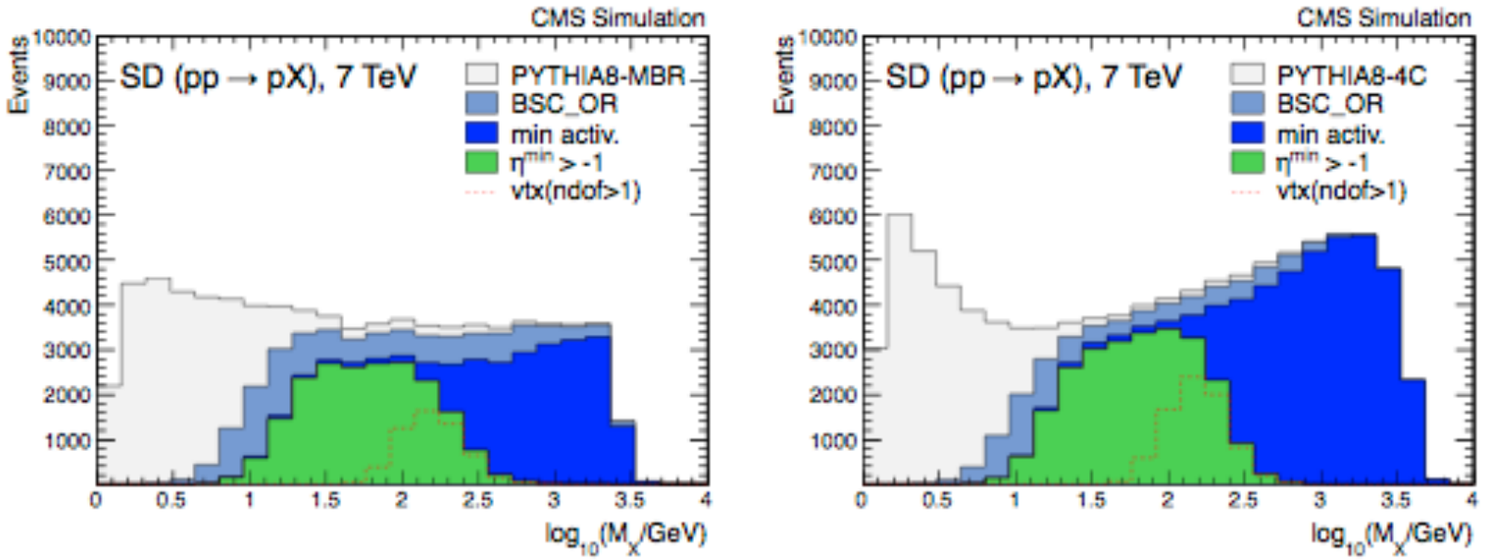
- The forward rapidity gap cross section extends the ATLAS measurements by 0.4 units of gap size. PYTHIA8 MBR predictions are consistent with the measurements.

- The dijet production cross section is measured as a function of ξ. The results are compared to the predictions of diffractive and non-diffractive MC models. The associated rapidity gap survival probability is estimated.

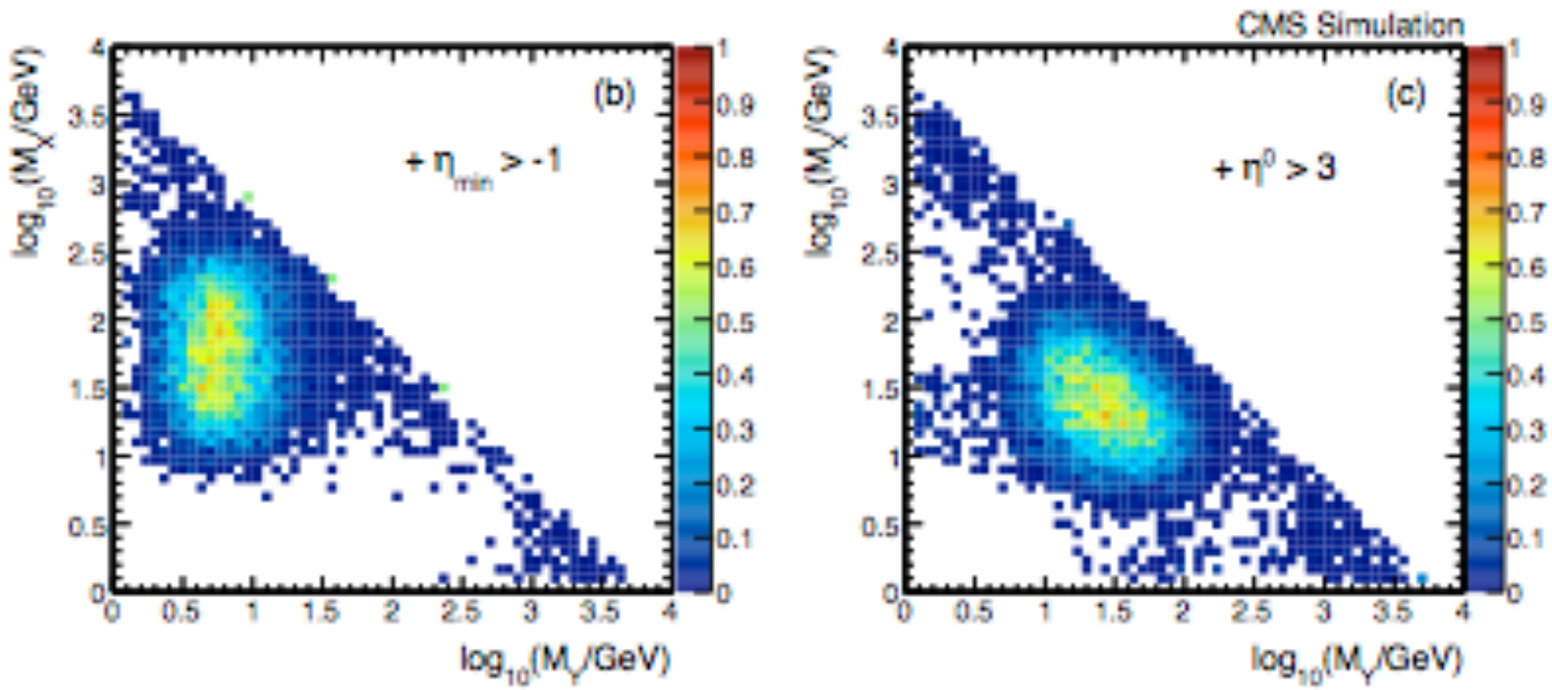
Backup Slides

SD and DD selection

SD selection

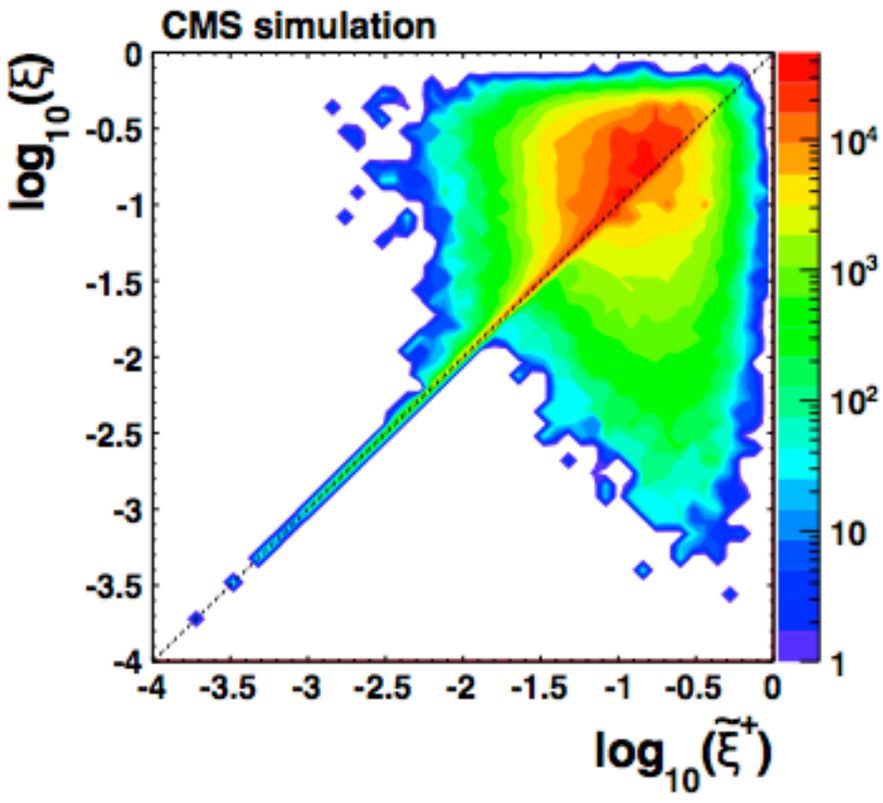


DD selection

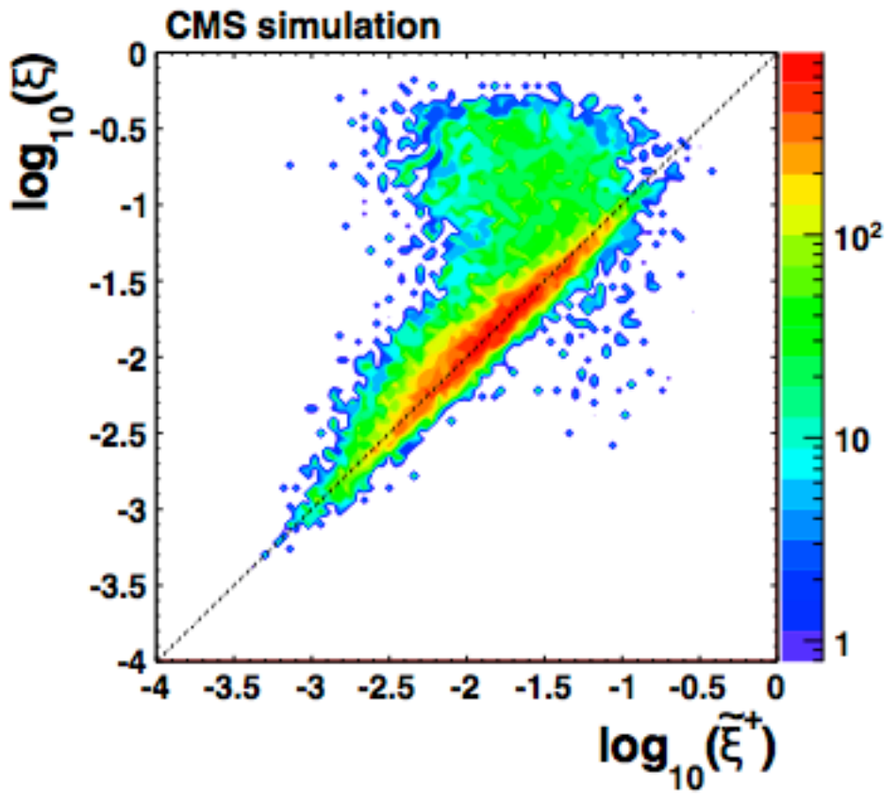


ξ reconstruction

$$\xi^{\pm} = \frac{\sum (E \pm p_Z)}{\sqrt{s}}$$

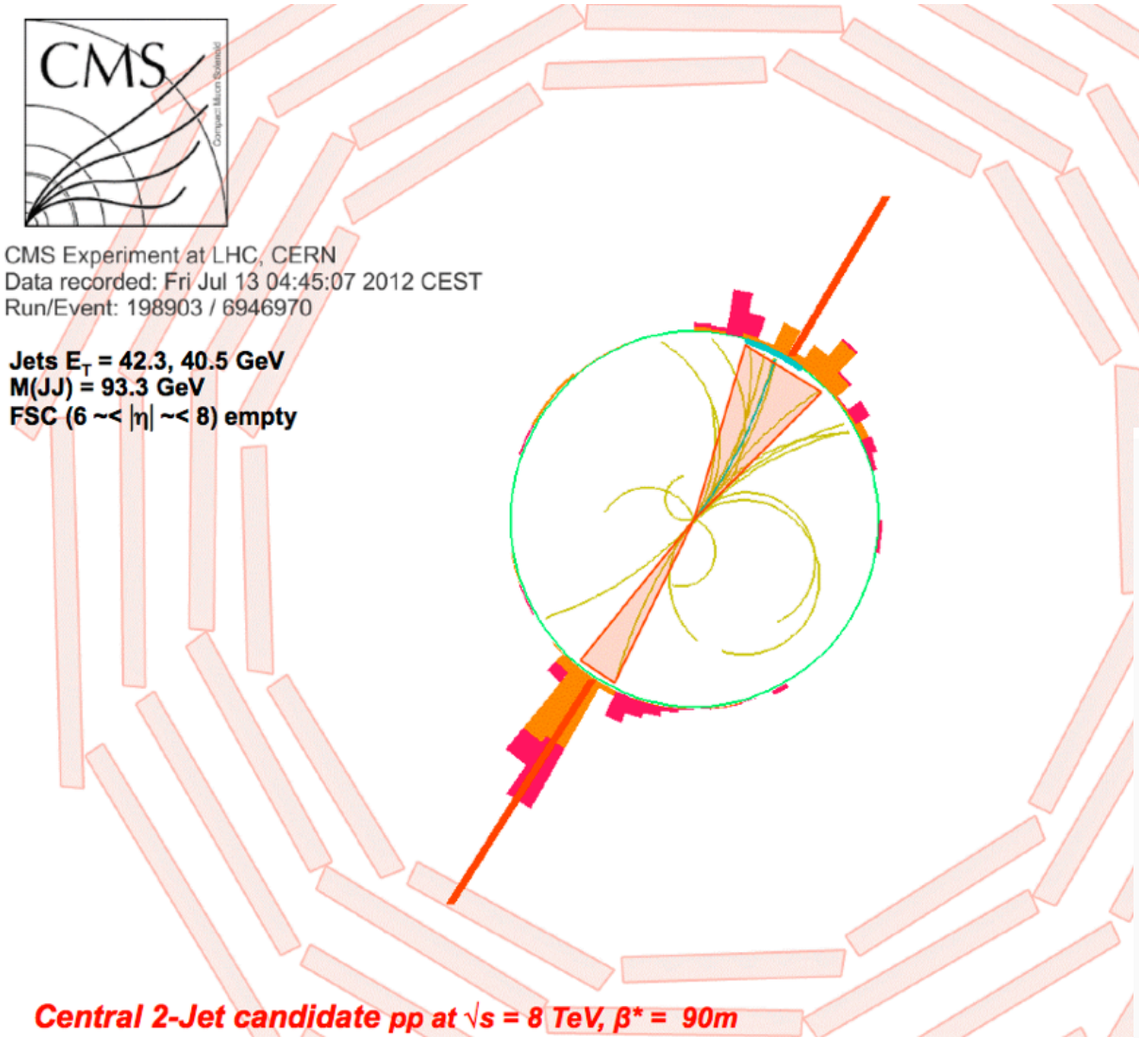


Generated (true) versus generated (ξ^{+}) for SD events

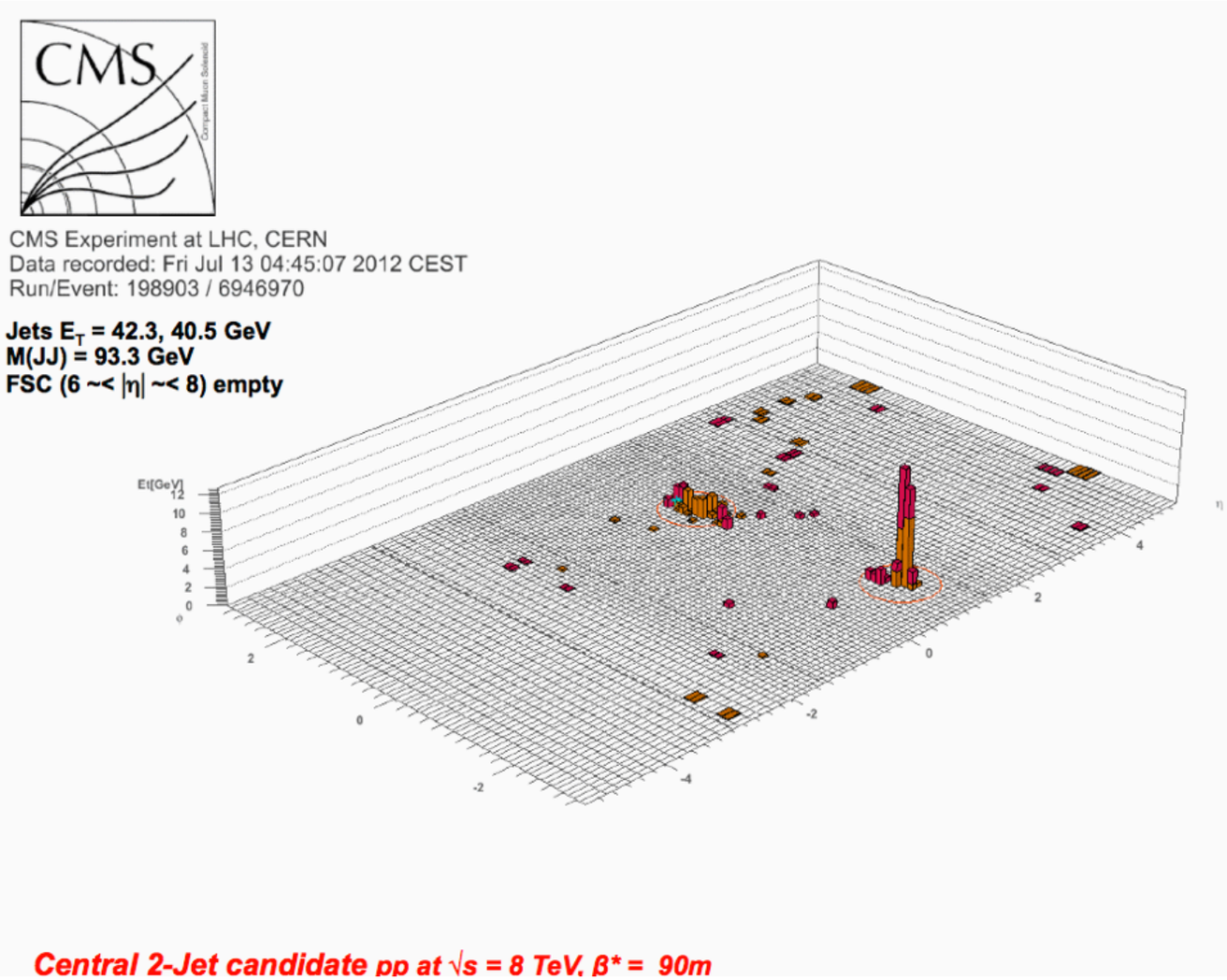


Generated (true) versus reconstructed (ξ^{+}) for SD events

High p_T jets with two leading protons detected in Totem



Central 2-Jet candidate pp at √s = 8 TeV, β = 90m*



Central 2-Jet candidate pp at √s = 8 TeV, β = 90m*