Diffraction at CMS

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on behalf of

CMS Collaboration

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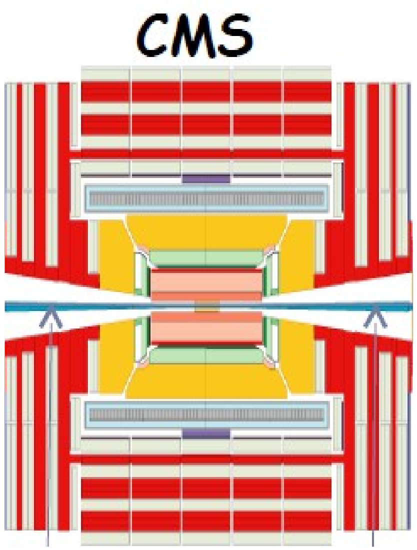
Motivation

- Measurement of the fundamental Standard Model parameter - diffractive cross sections
- Understand mechanism of the diffractive processes dynamics and interplay between soft and hard regimes
- Testing phenomenological models in soft region and pQCD with Pomeron in hard region
- Study beyond DGLAP mechanisms: BFKL, saturation
- Understanding of background for new processes (BSM)

Outline

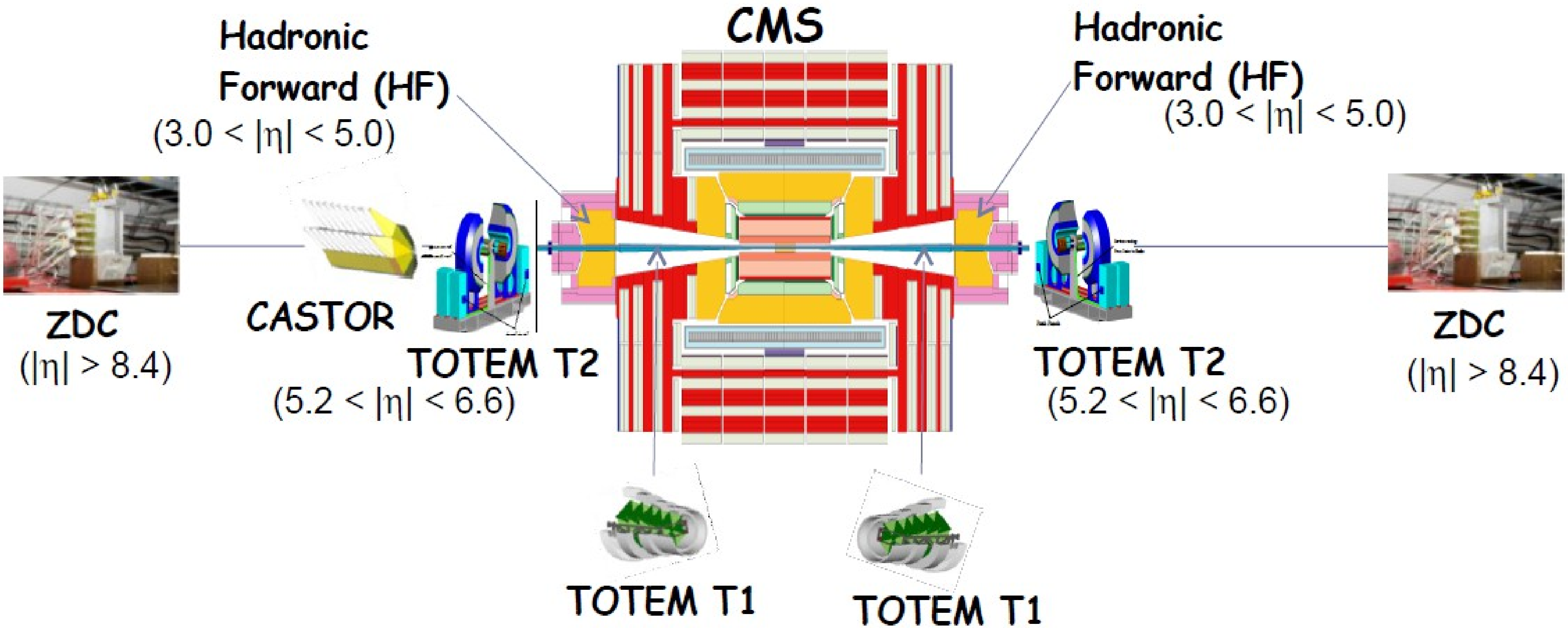
- CMS detector at forward rapidities
- Soft diffraction – topologies
- Events with forward gap, events with central gap, cross section of the single and double dissociation
- Forward rapidity gap cross section
- Hard diffractive dijet production
- Dijet production with a large rapidity gap
- Summary

CMS at forward rapidities



- Tracker $|\eta|<2.4$, $p_T > 100$ MeV
- Electromagnetic calorimeter ECAL
- Hadronic Calorimeter HCAL
- Muon chambers

CMS at forward rapidities



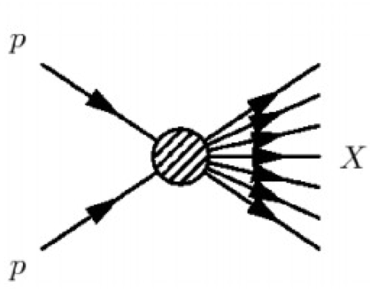
- Tracker $|\eta|<2.4$, $p_T > 100$ MeV
- Electromagnetic calorimeter ECAL
- Hadronic Calorimeter HCAL
- Muon chambers

- **H**adronic **F**orward calorimeters (HF) $3<|\eta|<5$
- Very Forward Calorimeter (CASTOR) $5.2<|\eta|<6.6$
- **Z**ero **D**egree **C**alorimeter (ZDC)
- **B**eam **S**cintillator **C**ounters BSC: $3.2<|\eta|<4.7$
- **F**orward **S**hower **C**ounters FSC: $6<|\eta|<8$

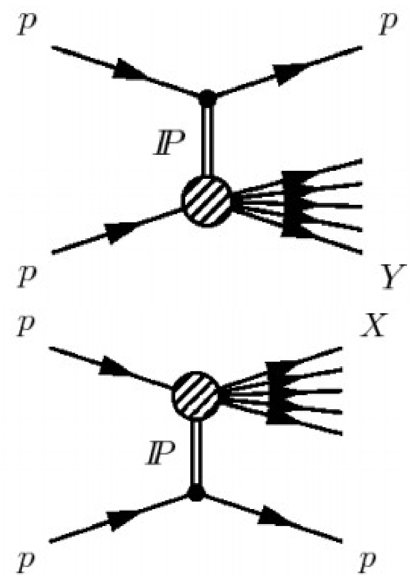
+ Totem (T1/T2 tracking detectors and RP roman pots) separate experiment

Soft Diffraction

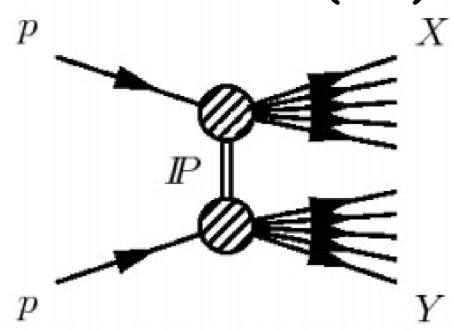
non-diffraction



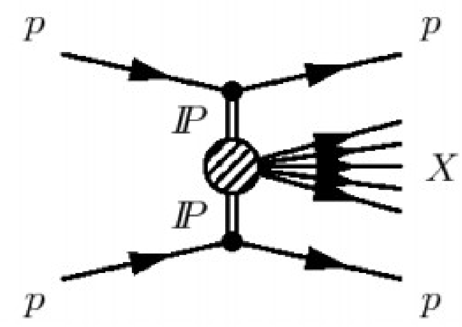
single diffractive dissociation (SD)



double diffractive dissociation (DD)



central diffraction



send to PRD,
arXiv:1503.08689
CMS-PAS-FSQ-12-005

Selection:

- ~20 μb^{-1} of low pile-up data (μ=0.14), from 2010
- Online: activity in either of the BSC – Minimum Bias trigger
- No vertex requirement (low diffractive masses 12<Mx<100 GeV accepted)
- Diffractive offline selection: Large Rapidity Gaps within |η|<4.7

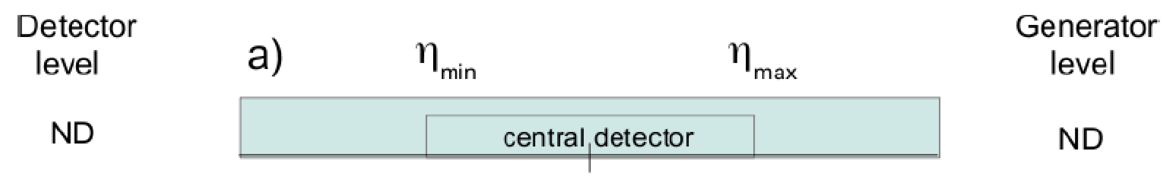
MC Models

Monte Carlo:

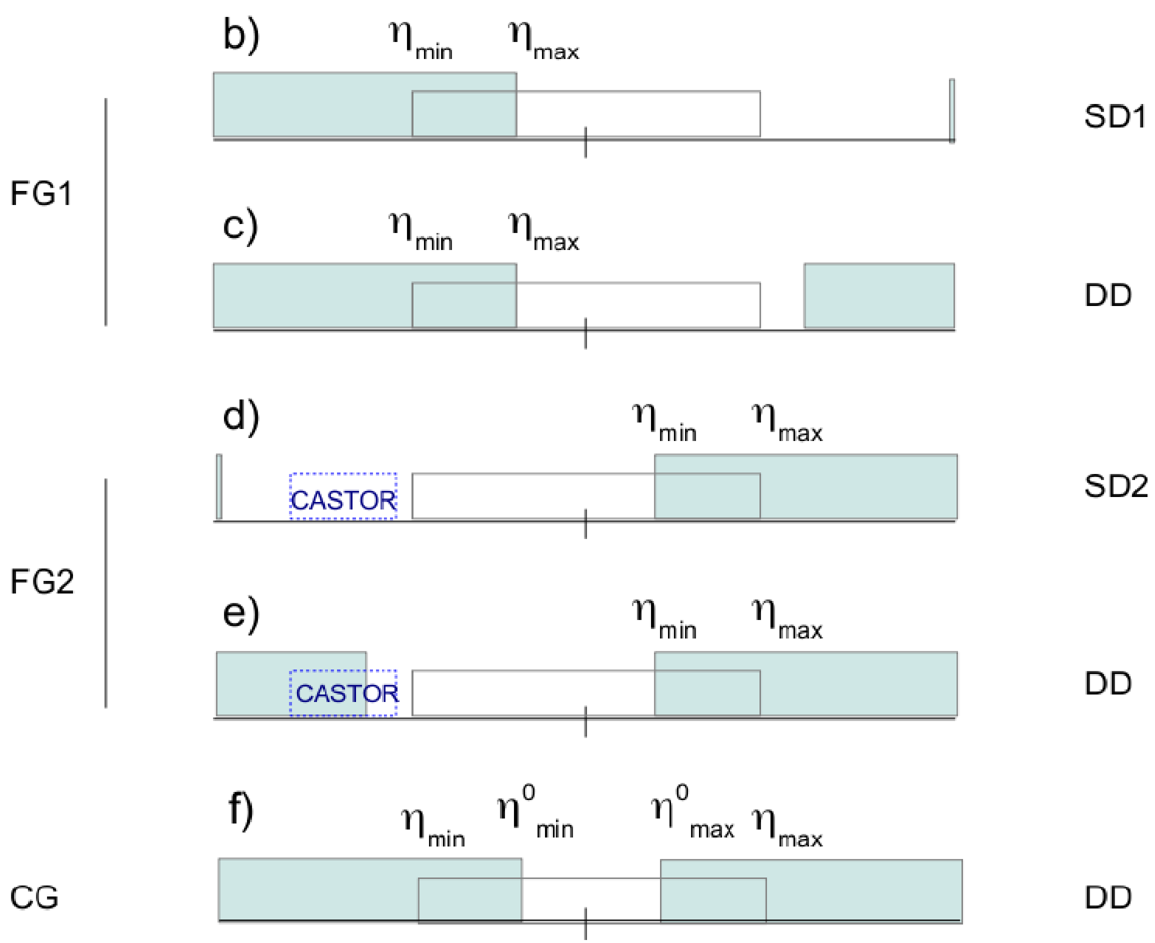
- PYTHIA8-4C
  - diffraction generated according to Schuler&Sjostrand model from PYTHIA6
  - SD and DD cross sections scaled down by 10% and 12%
- PYTHIA8-MBR (Minimum Bias Rockefeler model)
  - diffraction generated based on renormalized Regge theory model
  - developed for CDF
  - linear parametrization of the Pomeron trajectory $\alpha(t) = 1 + \varepsilon + \alpha' t$
  - $\alpha' = 0.25\ \mathrm{GeV}^{-2}$, $\varepsilon = 0.08$ or 0.104
  - DD cross section scaled down by 15%
- PYTHIA6-Z2*
- PHOJET
- QGSJET-II
- EPOS

(QGSJET-II and EPOS: cosmic rays MC)

Diffractive event topologies



Three experimental topologies based on the position of the LRG without CASTOR information



SD1 - gap on positive side

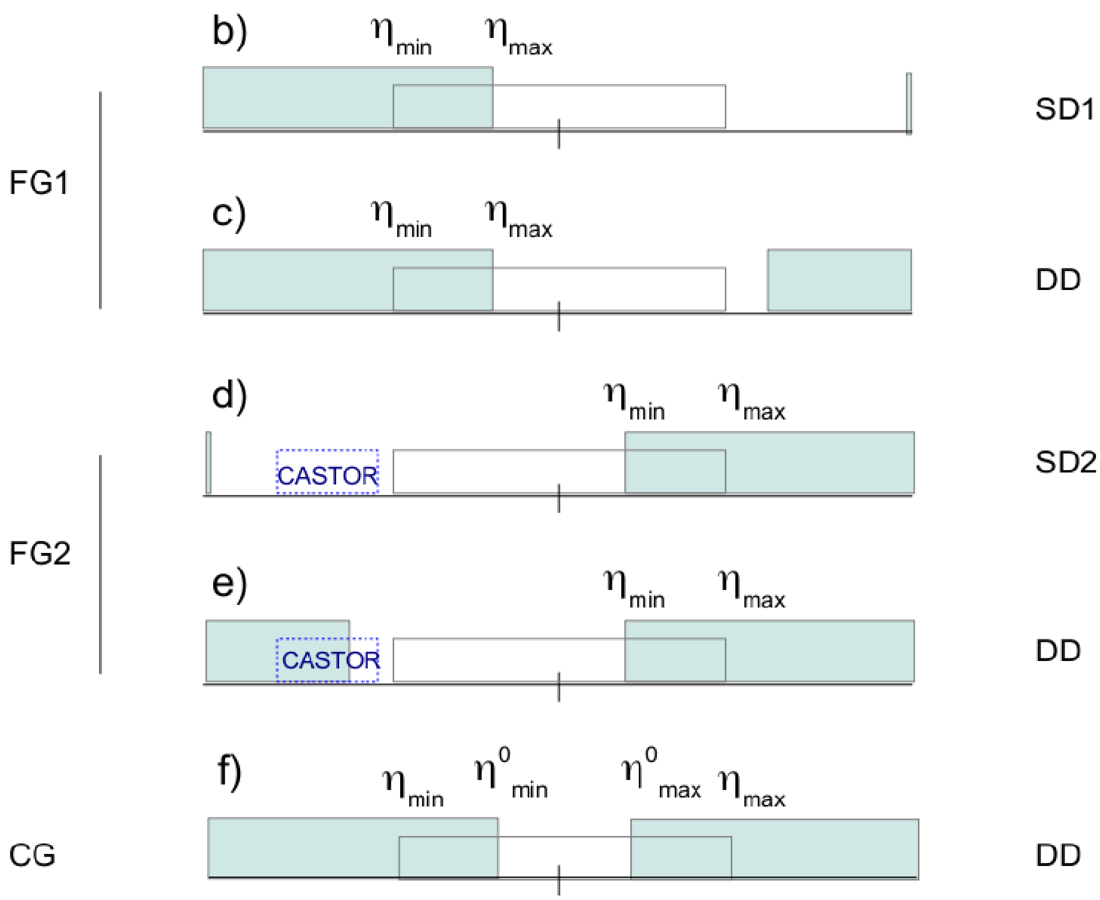
DD – but without detection of particles at "+" side

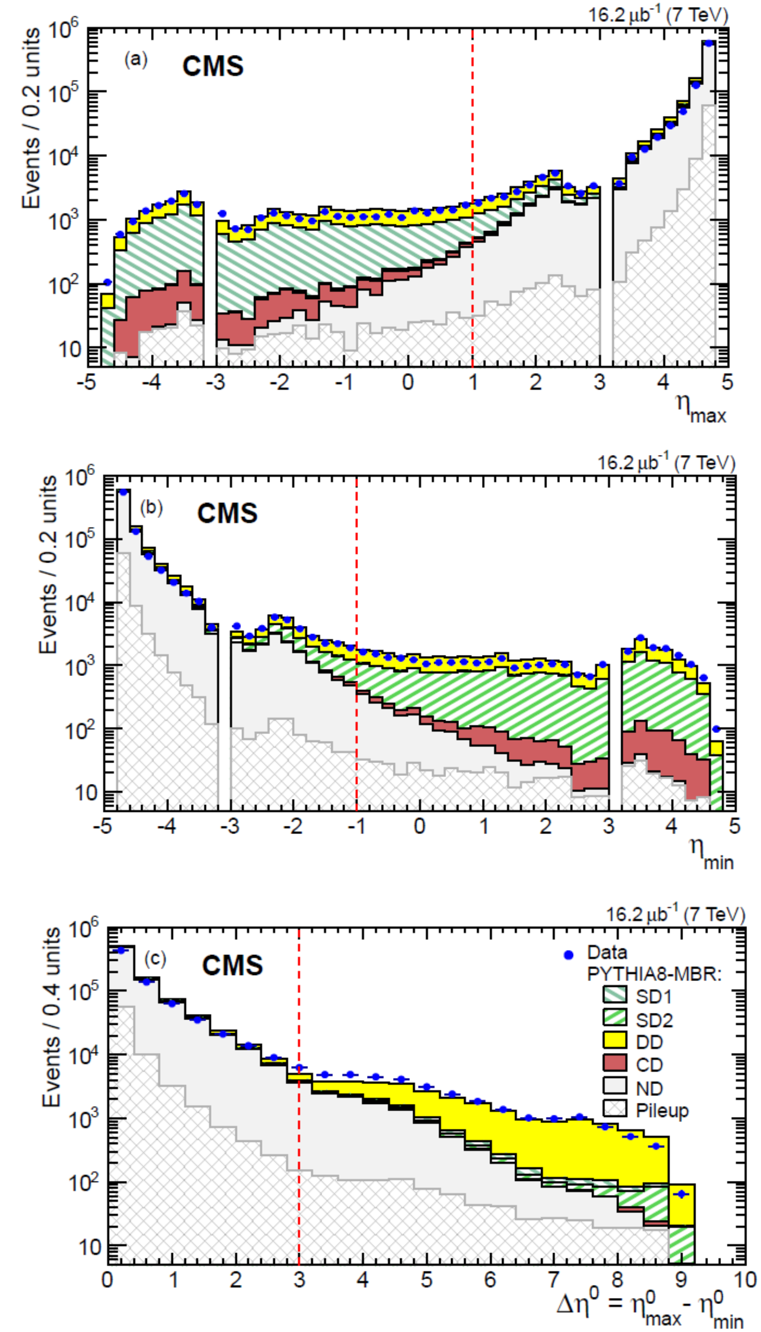
SD2 - gap on negative side

DD – but without detection of particles at "-" side at central detector

DD - gap in the center

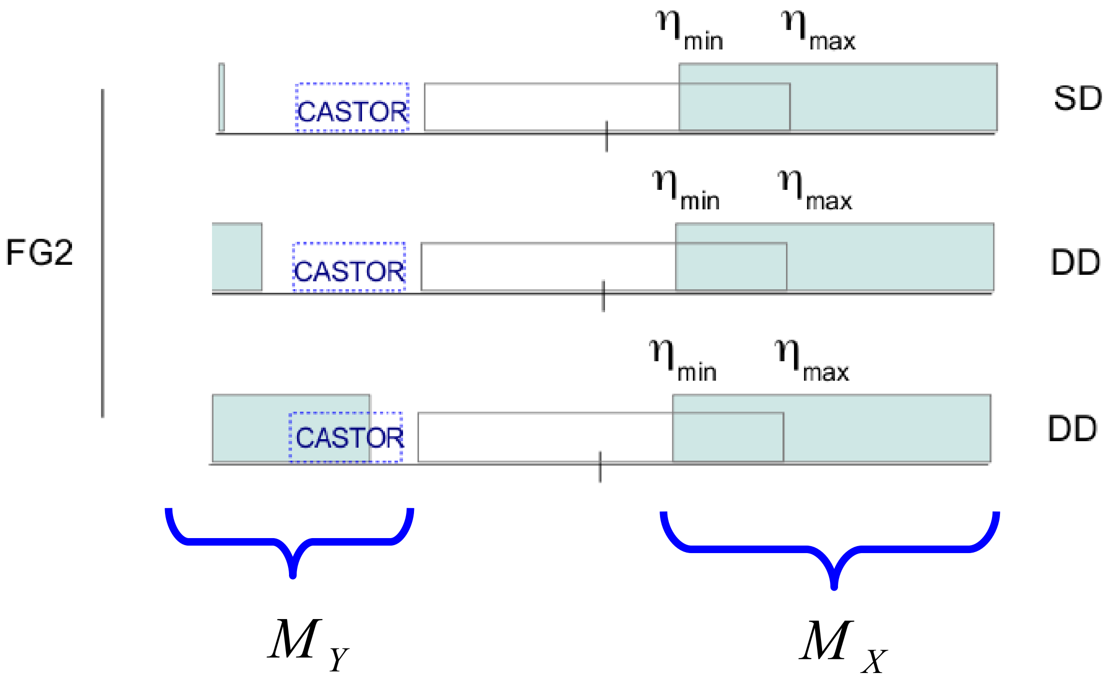
Diffractive event topologies





- η_{max} (η_{min}) highest (lowest) η of the particle candidate with $|\eta|<4.7$
- $\Delta\eta = \eta^0_{max} - \eta^0_{min}$

Forward gap



$\log_{10} M_Y < 0.5$

$0.5 < \log_{10} M_Y < 1.1$

M_X, M_Y in GeV

- Variable ξ defined as:

$$\xi_X = \frac{M_X^2}{s}$$

- Reconstructed:

$$\xi_X^{rec} = \frac{\sum (E^i - p_z^i)}{\sqrt{s}}$$

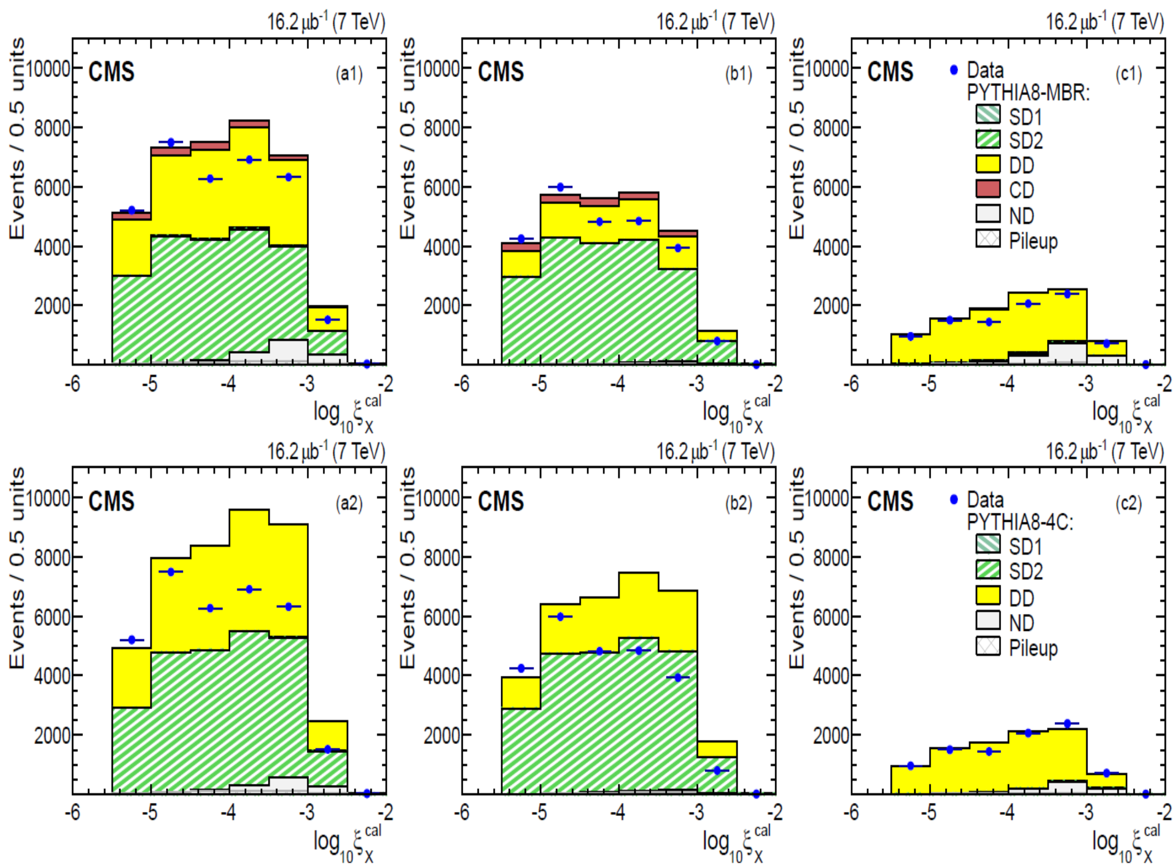
- And corrected for undetected particles: (PYTHIA 8 MBR)

$$\log_{10} \xi_X^{cal} = \log_{10} \xi_X^{rec} + C(\xi_X^{rec})$$

Forward gap

Detector level distributions

full sample   no-CASTOR tag   CASTOR tag

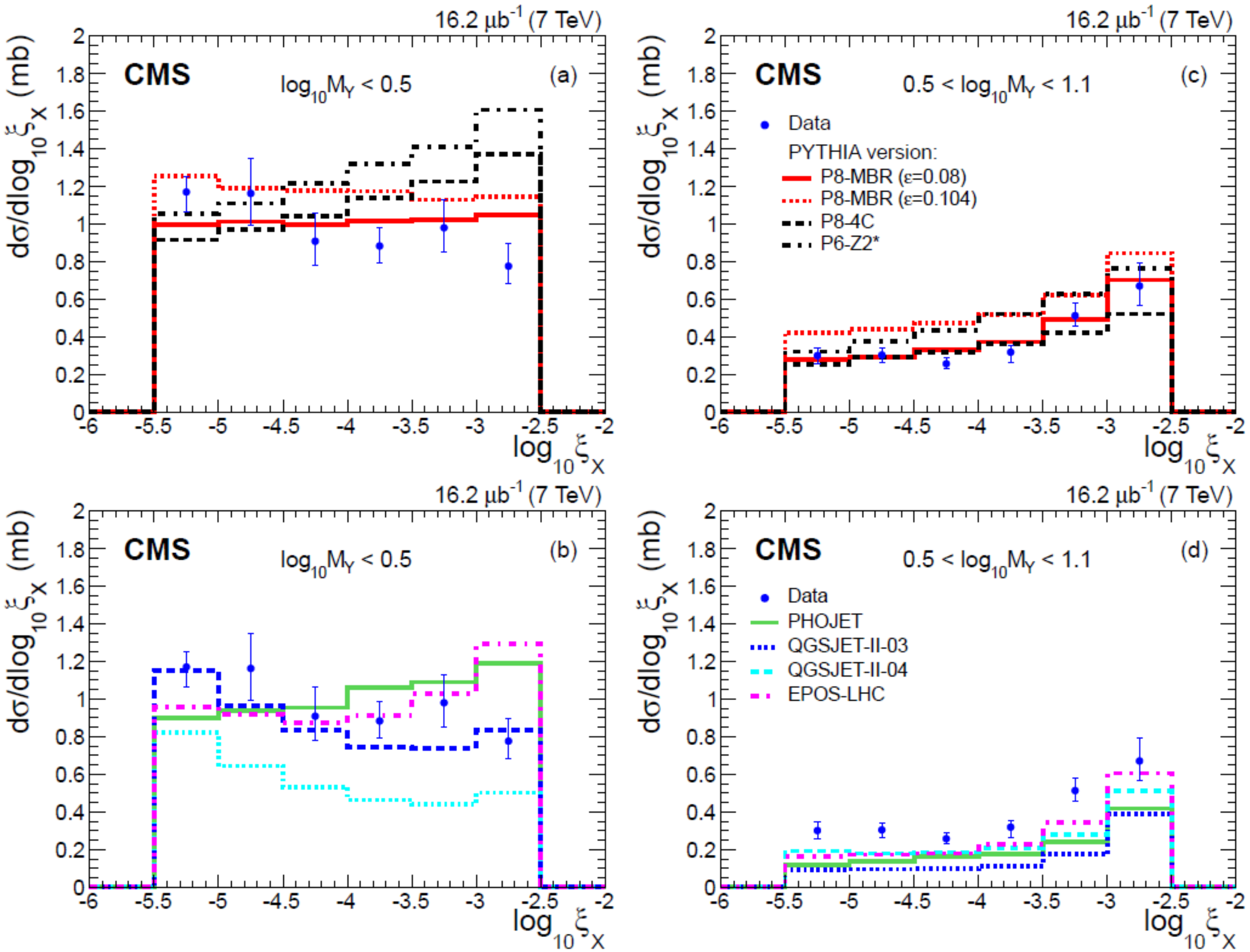


Cross section measured in bins of ξ_X

- Data unfolded (acceptance and migration corrections)
- PYTHIA 8 MBR
- Corrections for pile-up

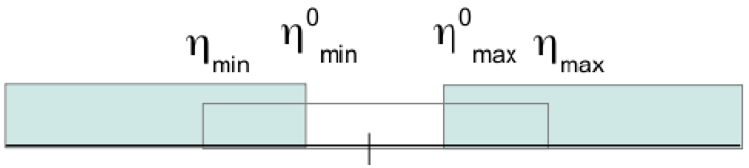
Forward gap

no-CASTOR tag Castor tag



- Data with tag favor ε = 0.08
- P8-4C and P6-2Z* higher than data in no-CASTOR tag
- P8-4C and P6-2Z* predicts raising behavior in no-CASTOR tag
- PHOJET, QGSJET, EPOS cannot describe data in tag sample

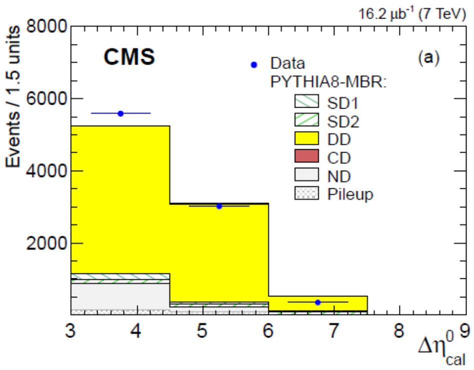
Central gap

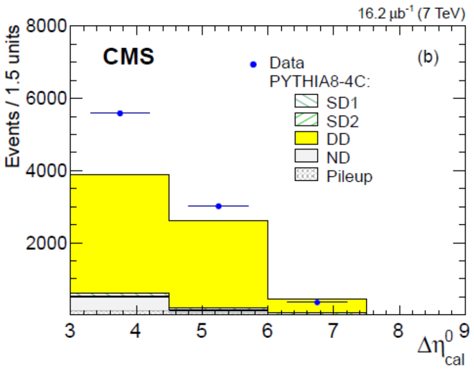


$$\Delta\eta = \eta^0_{max} - \eta^0_{min}$$

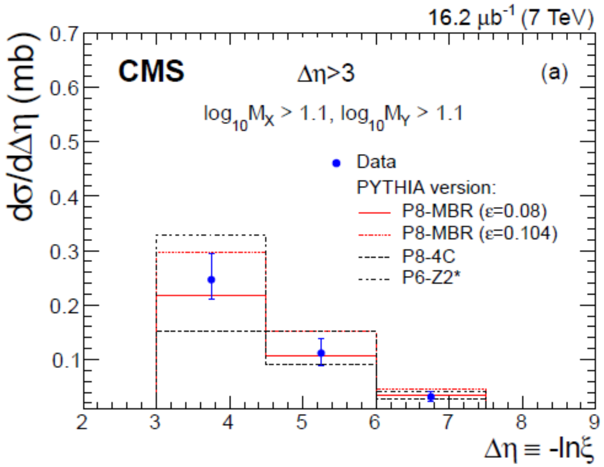
Range: $\log_{10} M_X > 1.1$

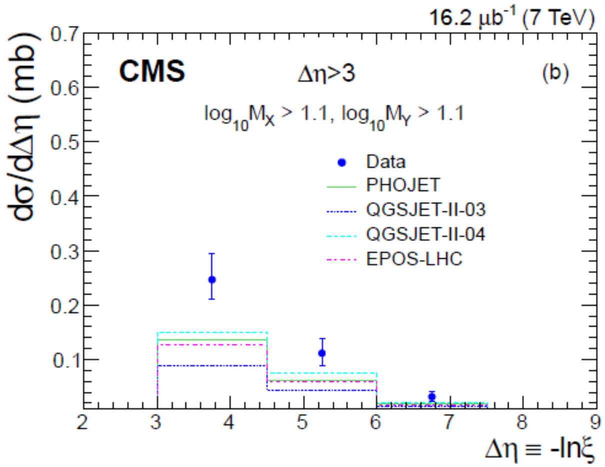
$\log_{10} M_Y > 1.1$





- Reconstructed: $\Delta\eta_{rec}$
- And corrected for detector effects: $\Delta\eta_{cal} = \Delta\eta_{rec} - C$
- Unfolding (response matrix from PYTHIA MBR)





- P8-MBR describes the data
- P8-4C underestimates
- P6-Z2* overestimates
- PHOJET, QGSJET, EPOS underestimates

Cross section

Integrated cross section measured for 3 samples:

- FG2, no-CASTOR tag $-5.5 < \log_{10}\xi_X < -2.5$ $\log_{10} M_Y < 0.5$
- FG2, CASTOR tag $-5.5 < \log_{10}\xi_X < -2.5$ $0.5 < \log_{10} M_Y < 1.1$
- CG $\Delta\eta > 3$ $\log_{10} M_X > 1.1$ $\log_{10} M_Y > 1.1$

Cross section	$\sigma_{\text{no-CASTOR}}$ (mb) SD dominated	σ_{CASTOR} (mb) DD dominated	σ_{CG} (mb) DD dominated
Data	$2.99 \pm 0.02^{+0.32}_{-0.29}$	$1.18 \pm 0.02 \pm 0.13$	$0.58 \pm 0.01^{+0.13}_{-0.11}$
PYTHIA 8 MBR	3.05	1.24	0.54
PYTHIA 8 4C	3.31	1.10	0.40
PYTHIA 6 Z2*	3.86	1.52	0.78
PHOJET	3.06	0.63	0.32
QGSJET-II 03	2.63	0.48	0.22
QGSJET-II 04	1.70	0.78	0.37
EPOS	2.99	0.85	0.31

Cross section

From no-CASTOR tag sample, visible SD cross section:

- Substraction of DD component → from PYTHIA 8 MBR
- $\sigma^{SDvis} = 4.06 \pm 0.04 (stat)^{+0.69}_{-0.63} (syst)\, mb$ $\quad -5.5 < \log_{10}\xi_X < -2.5$

From CASTOR tag sample, visible DD cross section:

- $\sigma^{DDvis}_{CASTOR} = 1.06 \pm 0.02 (stat) \pm 0.12 (syst)\, mb$ $\quad -5.5 < \log_{10}\xi_X < -2.5$, $\quad 0.5 < \log_{10} M_Y < 1.1$

From CG sample, visible DD cross section:

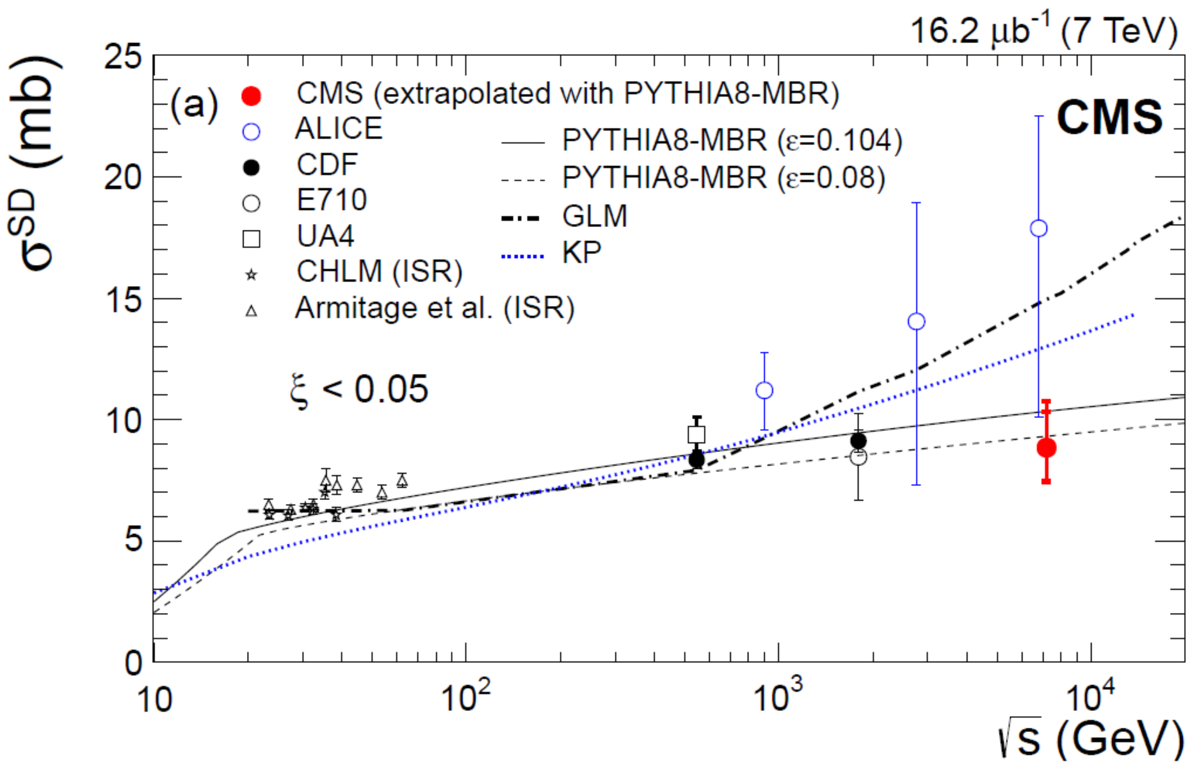
- $\sigma^{DDvis}_{CG} = 0.56 \pm 0.01 (stat)^{+0.15}_{-0.13} (syst)\, mb$ $\quad \Delta\eta > 3$, $\quad \log_{10} M_X > 1.1$, $\quad \log_{10} M_Y > 1.1$

Cross section

Extrapolation to the not observed region: PYTHIA 8 MBR (ε = 0.08)

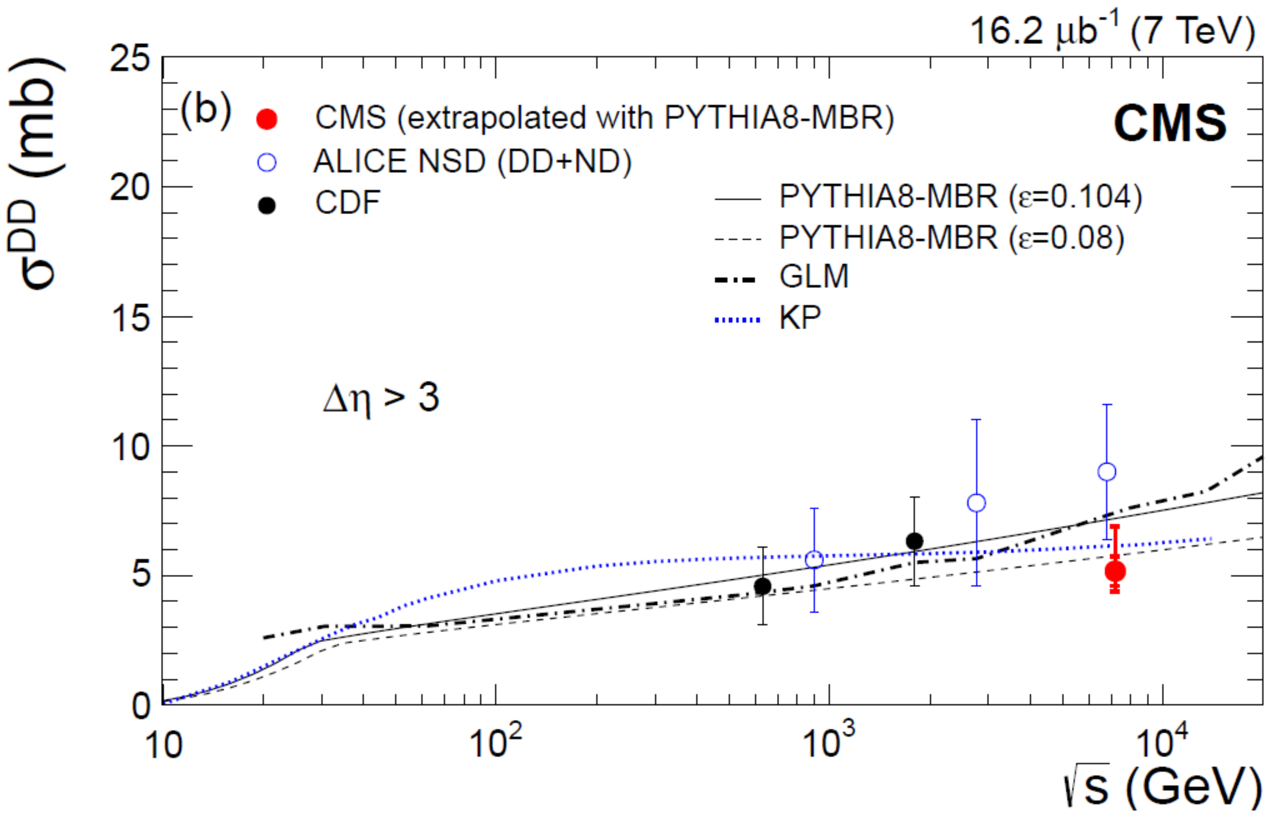
$$\sigma^{SD} = 8.84 \pm 0.08 (stat)^{+1.49}_{-1.38} (syst)^{+1.17}_{-0.37} (extr)\, mb \qquad \xi_{X(Y)} < 0.05$$

$$\sigma^{DD} = 5.17 \pm 0.08 (stat)^{+0.55}_{-0.57} (syst)^{+1.62}_{-0.51} (extr)\, mb \qquad \Delta\eta > 3$$



CMS results consistent with MBR predictions – SD cross section weakly rising with energy

Cross section

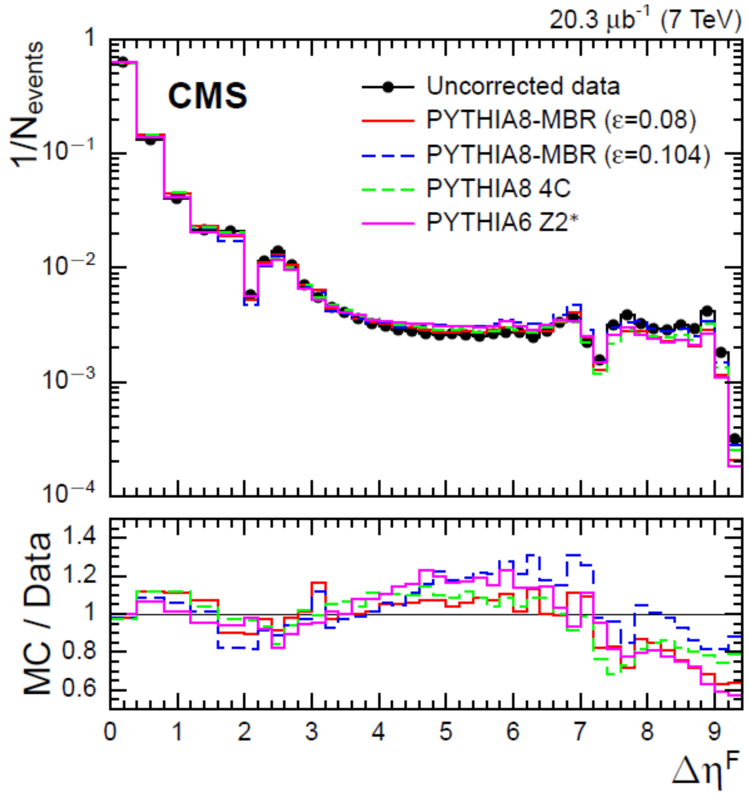


CMS results consistent with MBR and KP model predictions – DD cross section weakly rising with energy

Pseudorapidity gap cross section

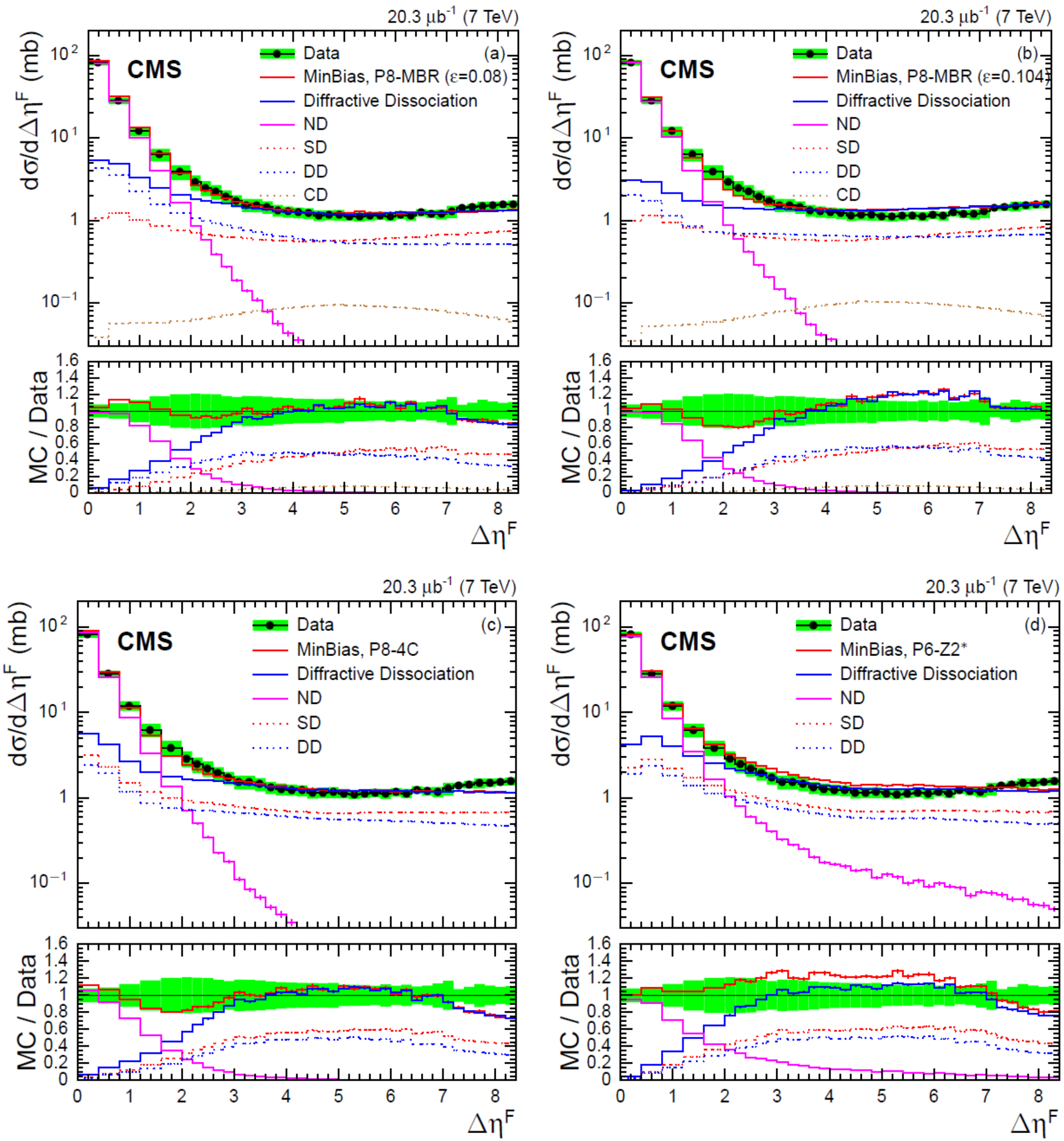
- Forward rapidity gap – the largest of the two empty regions extending from the edge of the detector acceptance (|η|=4.7) to the nearest particle candidate

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

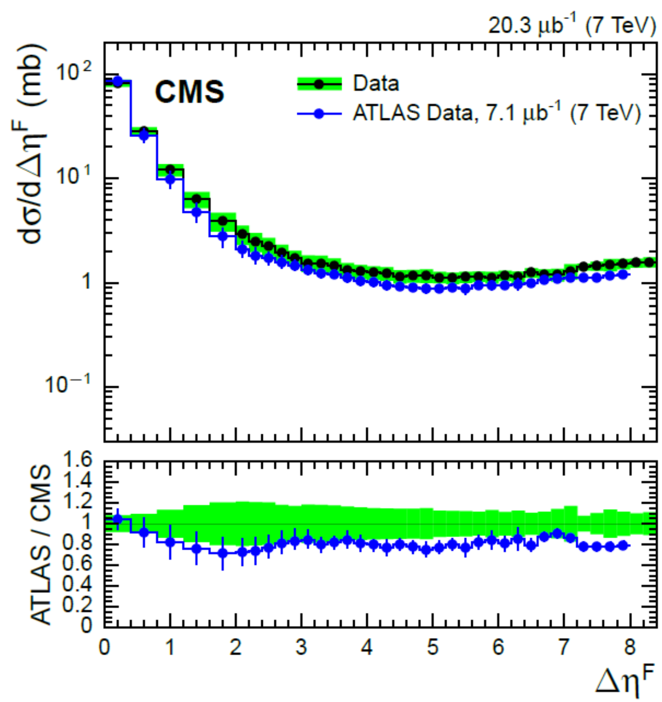


- Unfolding done with PYTHIA 8 MBR with demand of at least 1 stable particle with p_T>200 MeV and |η|<4.7

Pseudorapidity gap cross section

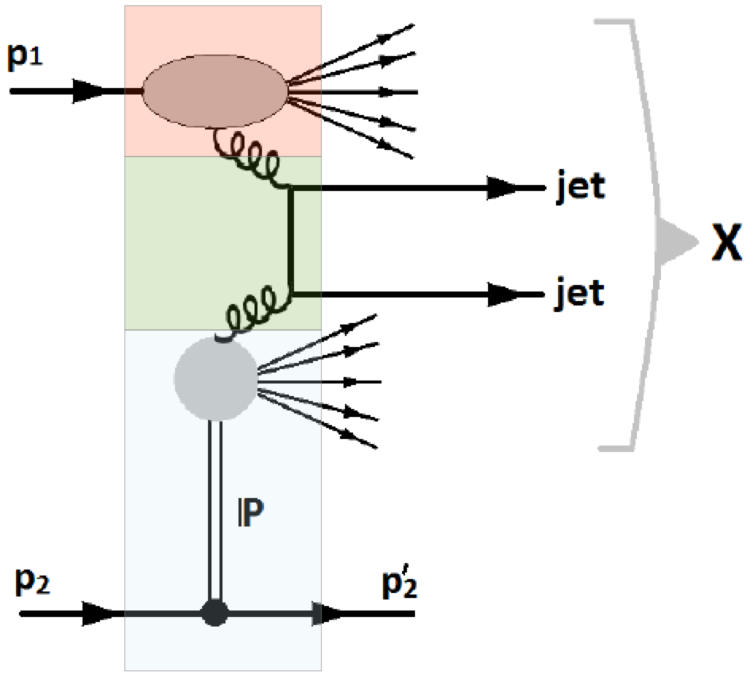


- Exponential falling non-diffractive contribution
- Diffractive plateau at $\Delta\eta_F > 3$
- mixture of SD and DD events
- Best described: PYTHIA8+MBR with 0.08 intercept.



Differences in acceptance

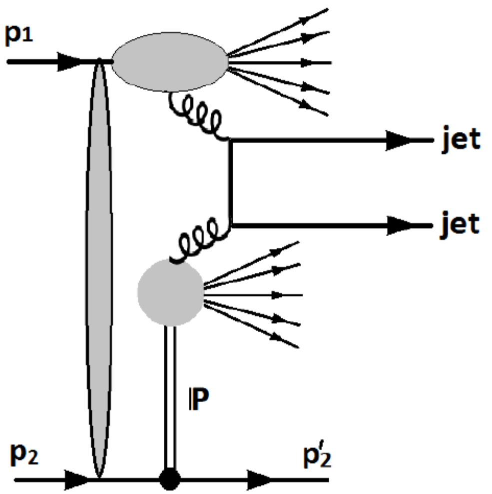
Hard diffractive dijet production

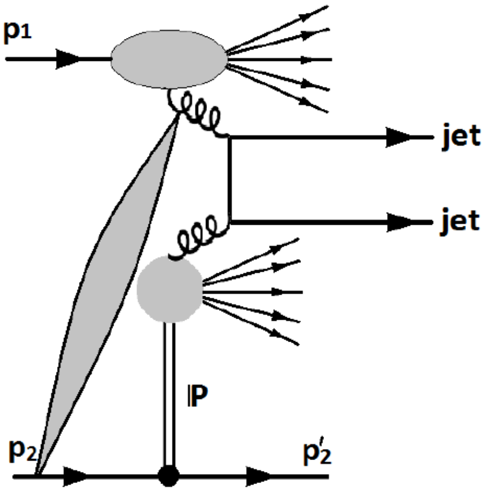


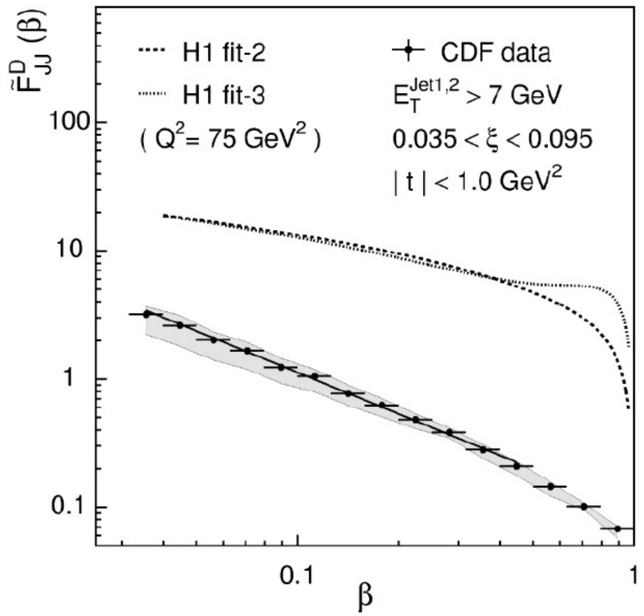
- Cross section:

$$\frac{d\sigma}{d\xi dt} = \sum \int dx_1 dx_2 x_1 x_2 f(\xi, t) f_{IP}(x_1, \mu) f_p(x_2, \mu) \hat{\sigma}$$

- Rescattering processes (soft, semi-hard)
- Reduction of the cross section: $\frac{d\sigma_{\exp}}{d\xi dt} = S^2(\dots) \frac{d\sigma}{d\xi dt}$







Hard diffractive dijet production

Selection:

- ~2.7 nb^{-1} of low pile-up data (μ=0.09), from 2010
- Online: 6 GeV uncorrected jet p_T (>95% efficient for dijets with p_T>20 GeV)
- A primary vertex with |z|<24 cm
- Quality cuts imposed on jets
- Two jets with p_T>20 GeV and in |η| < 4.4

→ **277 953 events**

- η_{MAX} < 3 (η_{MIN} > -3), corresponding to rap-gap >1.9

→ **442 events**

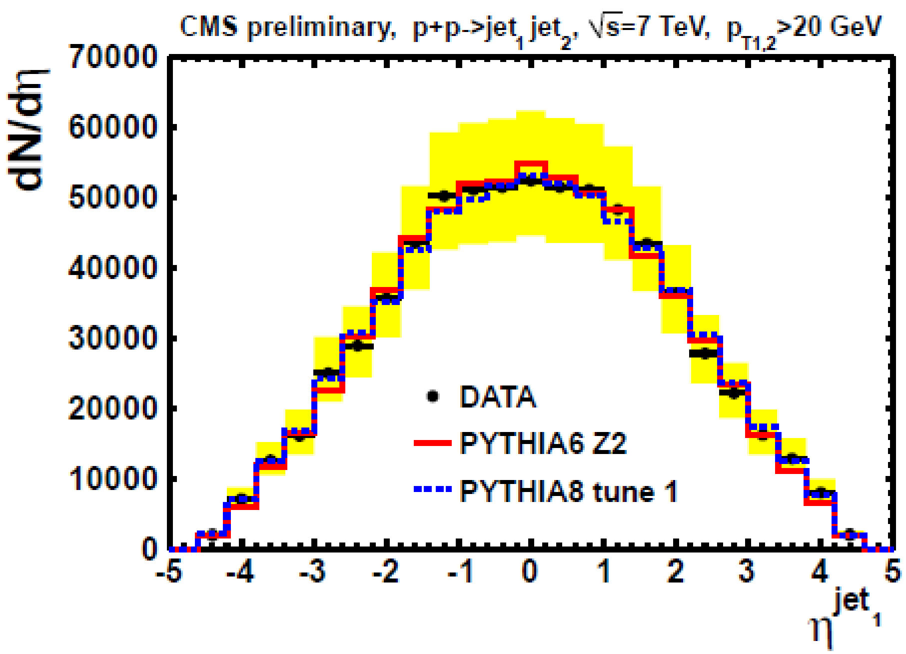
Hard diffractive dijet production

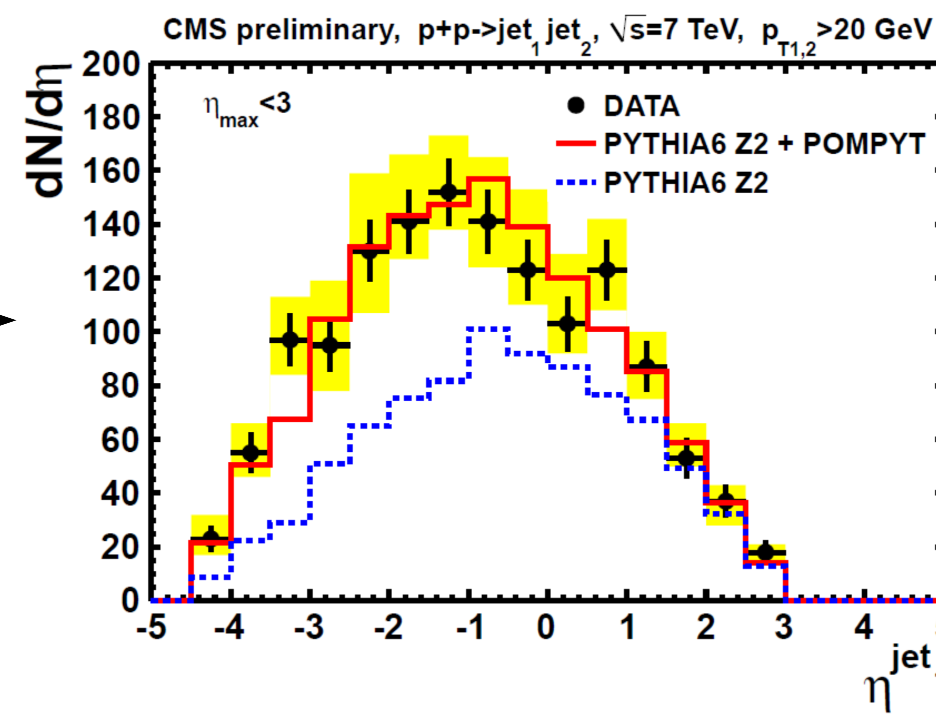
Monte Carlo:

- PYTHIA8-tune1
  - Inclusive sample
  - Non-diffractive dijets sample
  - Diffractive dijets sample
- PYTHIA6-Z2, PYTHIA6-D6T
- POMPYT, POMWIG
  - SD events
  - Pomeron flux is based on the QCD fits to HERA
- POWHEG
  - NLO calculations
  - Hadronisation with PYTHIA8-tune1
- Difference between PYTHIA8 and POMPYT/POMWIG in Pomeron flux

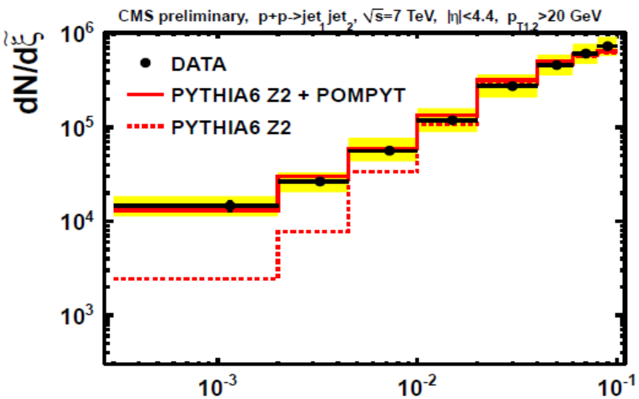
Hard diffractive dijet production

Leading jet η (before and after η_{MAX} cut)

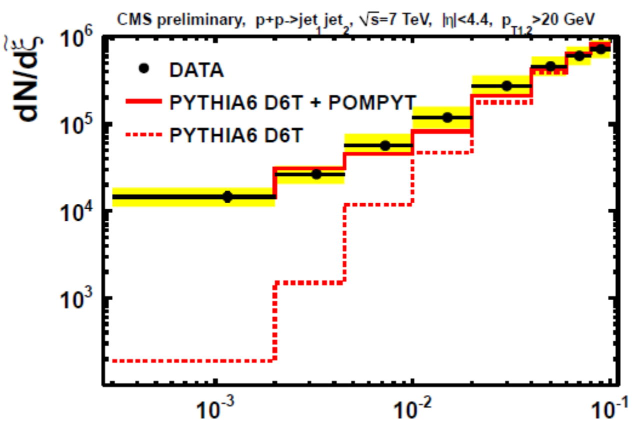




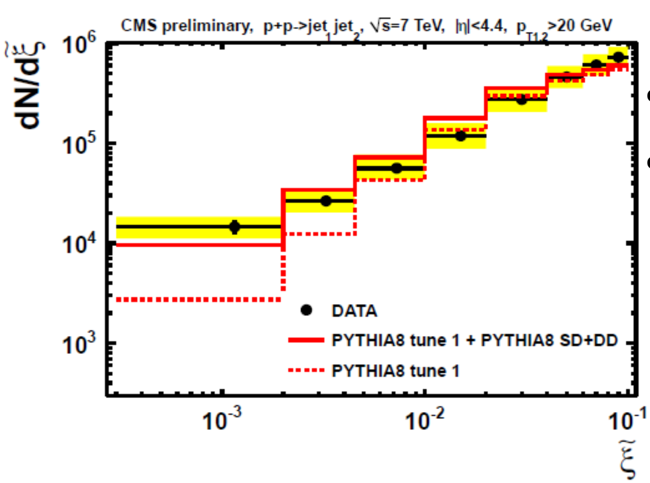
Hard diffractive dijet production



- PYTHIA6-Z2+POMPYT
- POMPYT x 0.23

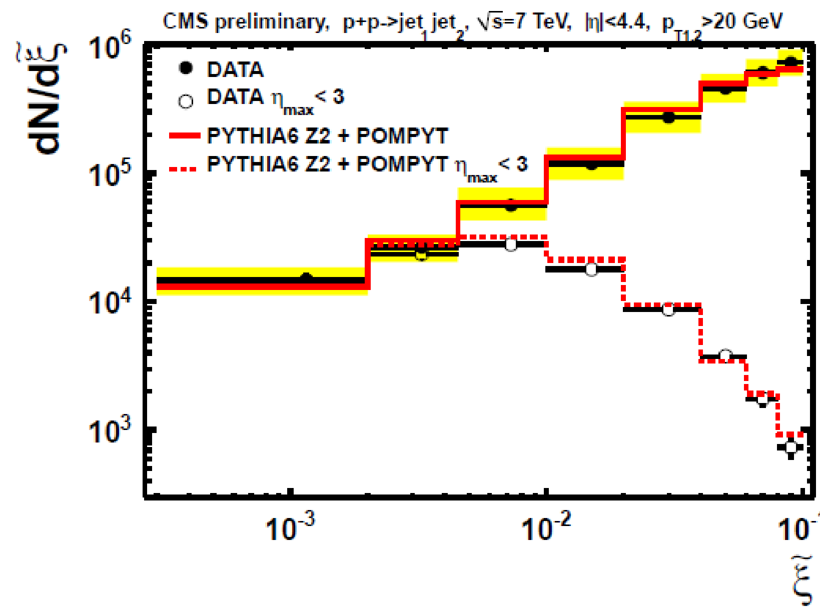


- PYTHIA6-D6T+POMPYT
- POMPYT x 0.17



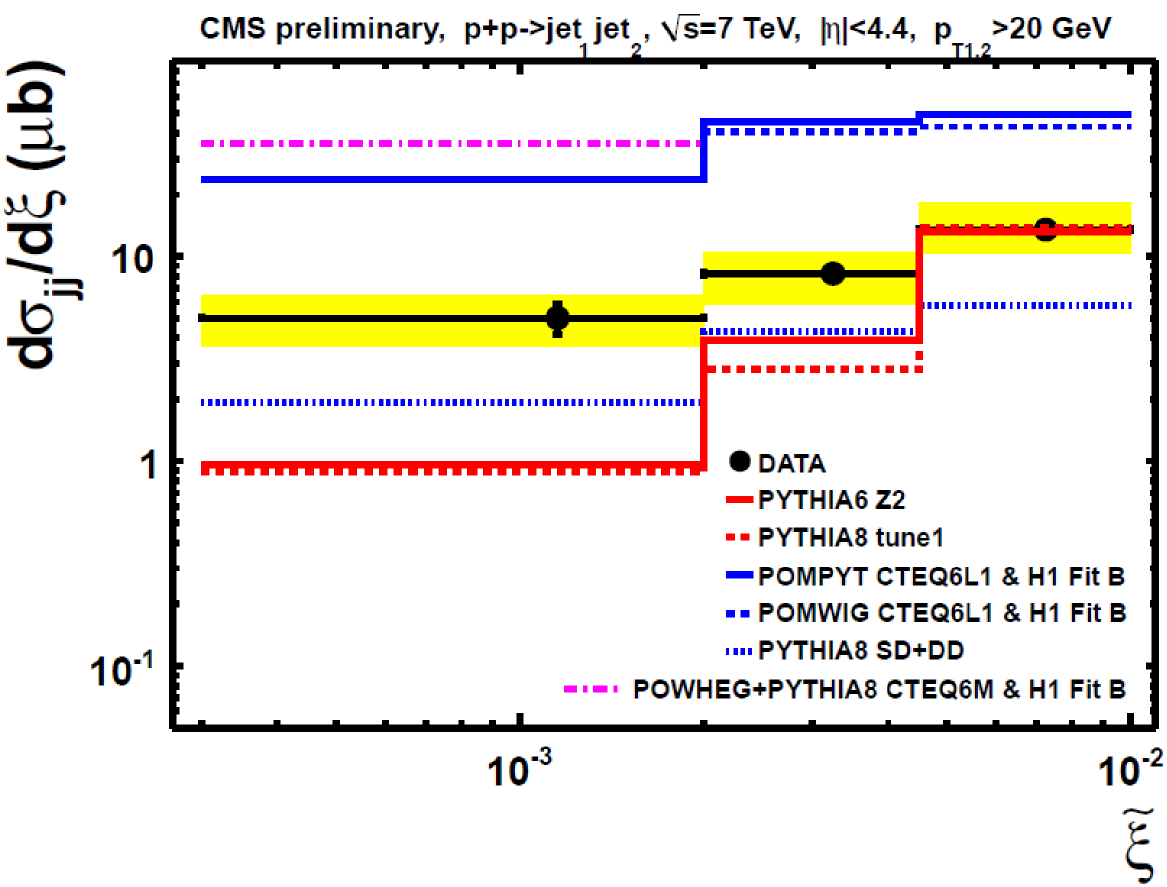
- PYTHIA8-tune1
- SD+DD x 2.5

- After η_{MAX} cut – diffractive part enhanced



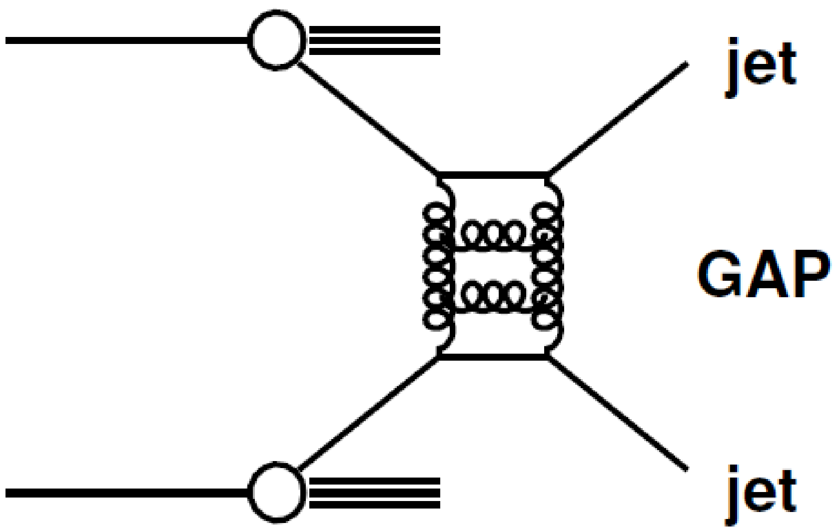
Hard diffractive dijet production

- Cross section: $$\frac{d\sigma_{jj}}{d\tilde{\xi}} = \frac{N^i_{jj}}{L \cdot \epsilon \cdot A^i \cdot \Delta\tilde{\xi}^i}$$



- PYTHIA6 and PYTHIA8 without hard diffraction cannot describe the data
- POMPYT, POMWIG predicts more events than in data (factor ~5)
- PYTHIA8 SD+DD has to be scaled by a factor ~2 up
- Estimate of the rapidity-gap survival probability: 0.12 (from POMPYT/POMWIG)
- From POWHEG it is: 0.08

Dijets with large rapidity gap



- Jets separated by a large rapidity gap
- Color singlet exchange
- Probe BFKL dynamics
- Rescattering processes – rap-gap survival

Selection:

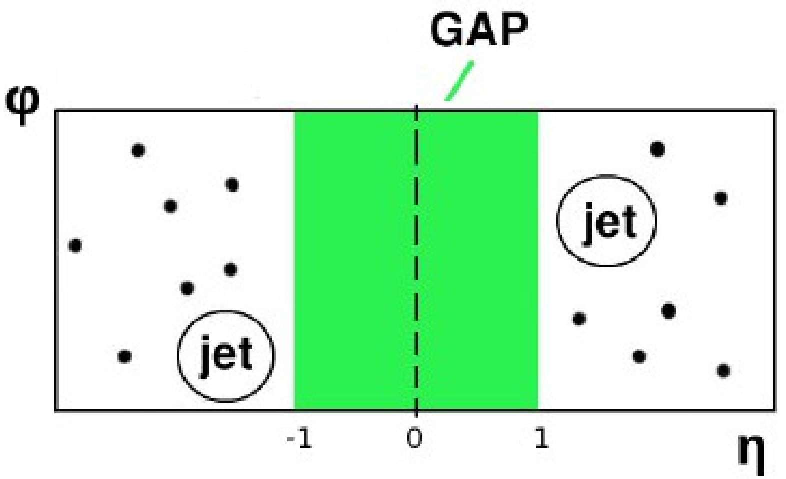
- ~8 pb^{-1} of low pile-up data from 2010
- Three samples of dijets with the lower energy jet in p_T bins:

  40-60 GeV, 60-100 GeV, 100-200 GeV
- A primary vertex with $|z|<24$ cm (0, 1 vertices)
- Quality cuts imposed on jets

Dijets with large rapidity gap

Selection:

- $\eta_{jet1} \times \eta_{jet2} < 0$ (jets in different hemispheres)
- $|\eta_{jet1,2}| > 1.5$
- Number of tracks calculated in $|\eta|<1$ interval
  → tracks with $p_T > 0.2$ GeV



Monte Carlo:

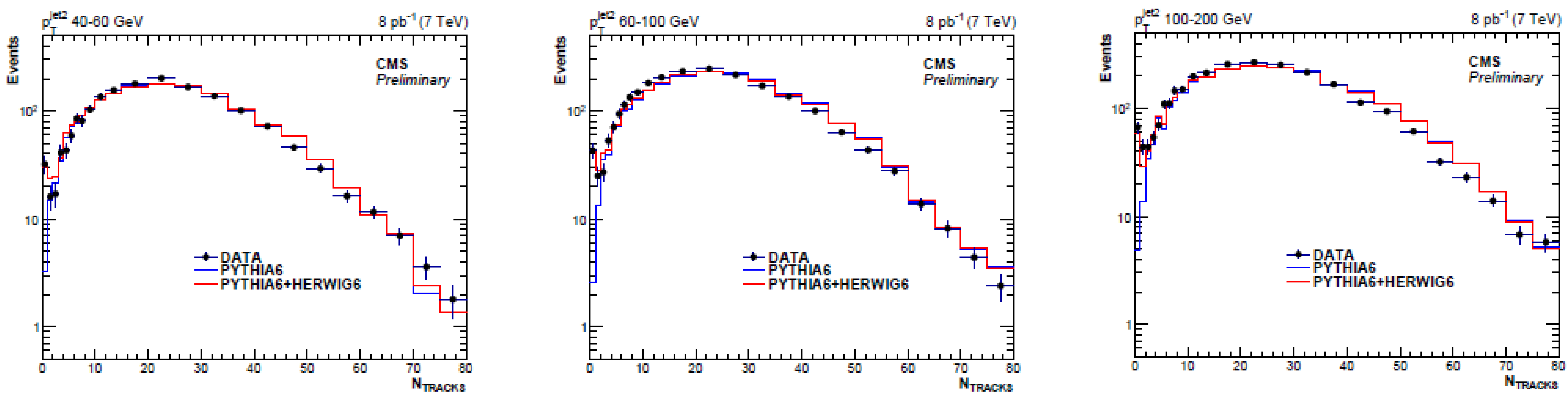
- PYTHIA6-Z2* → LO DGLAP
- HERWIG6 → the hard color-singlet exchange included according to Mueller-Tang model (simplified BFKL calculations containing the LL terms) + JIMMY

Events generated by HERWIG6 reweighted: $\exp(a + b \cdot p_T^{\mathrm{jet2}})$

$a = -0.88$, $b = 0.01\ \mathrm{GeV}^{-2}$

Dijets with large rapidity gap

Number of tracks in the central rapidity interval



- Clear excess of gap events over PYTHIA6 predictions – first bins
- Excess can be described with:

$$f_{CSE} = \frac{N_{events}(S) - N_{bkg}(S)}{N_{events}}$$

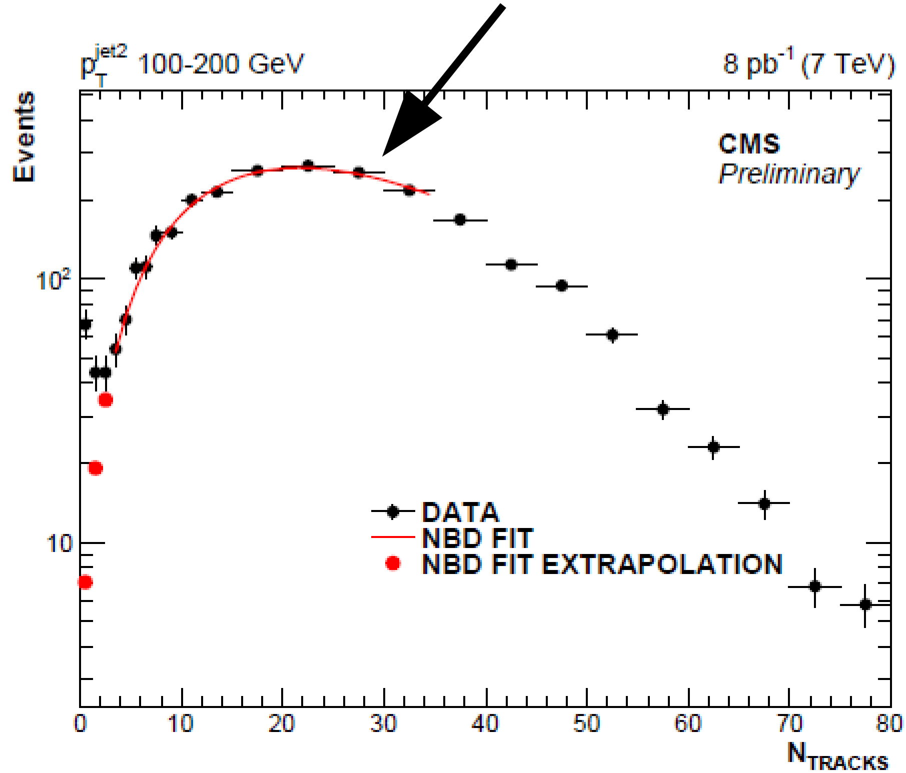
Number of events in first S bins

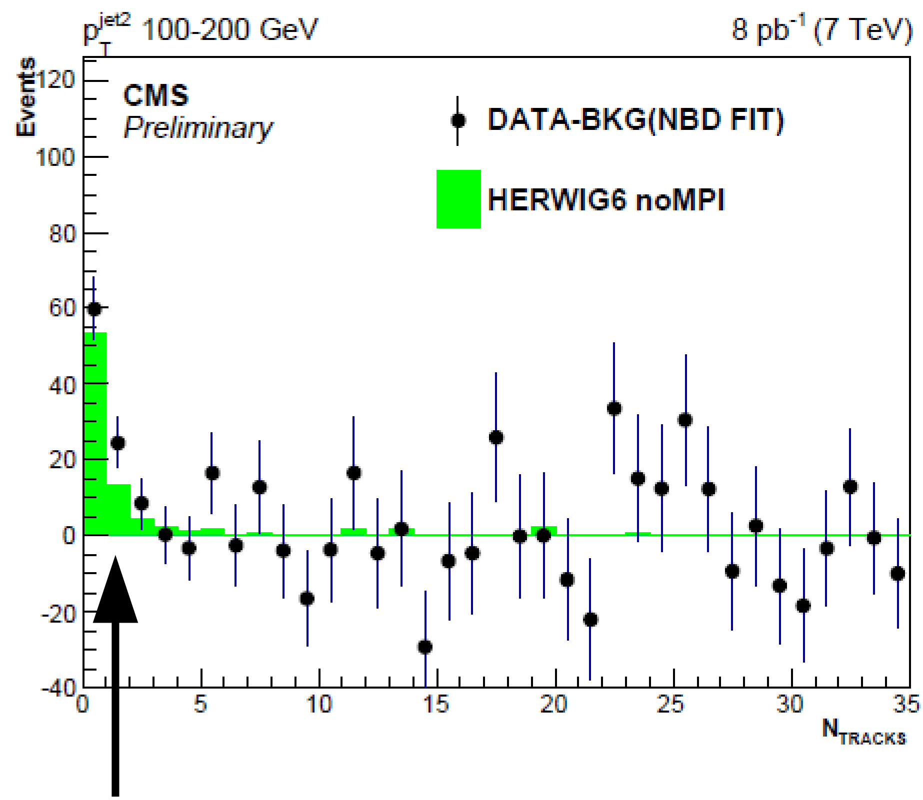
Total number of events

Number of events in first S bins from non Color Singlet Exchange (CSE)

Dijets with large rapidity gap

Negative binomial distribution fitted

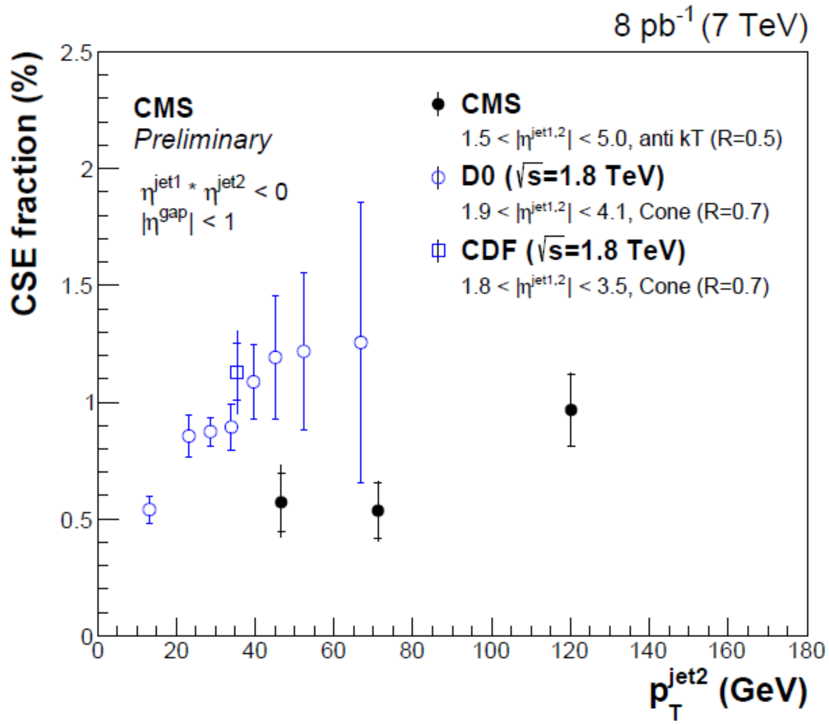




Tracks from jet (noMPI)

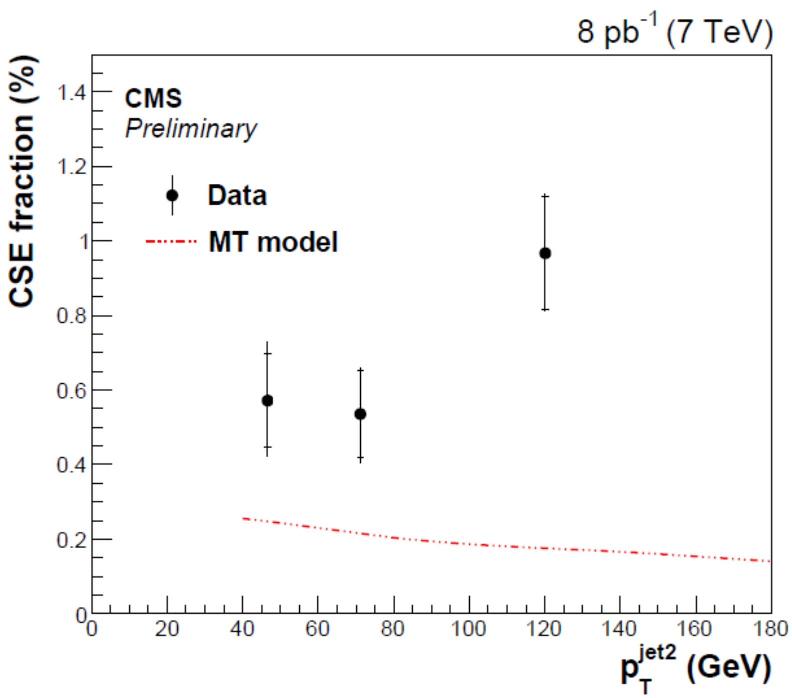
Dijets with large rapidity gap

- f_{CSE} calculated in 2 first bins (for low and medium range) and 3 first bins (for the highest range)



- Similar measurements for CDF and D0 (increase with jet2 p_T)
- Suppresion with the center-of-mass energy factor ~2

- Comparison with Muller-Tang model without scalling factor



Summary

- CMS performed measurement of diffractive dissociation cross section in pp
- Extrapolation of the SD and DD to the regions $\xi < 0.05$ and $\Delta\eta > 3$ gave:

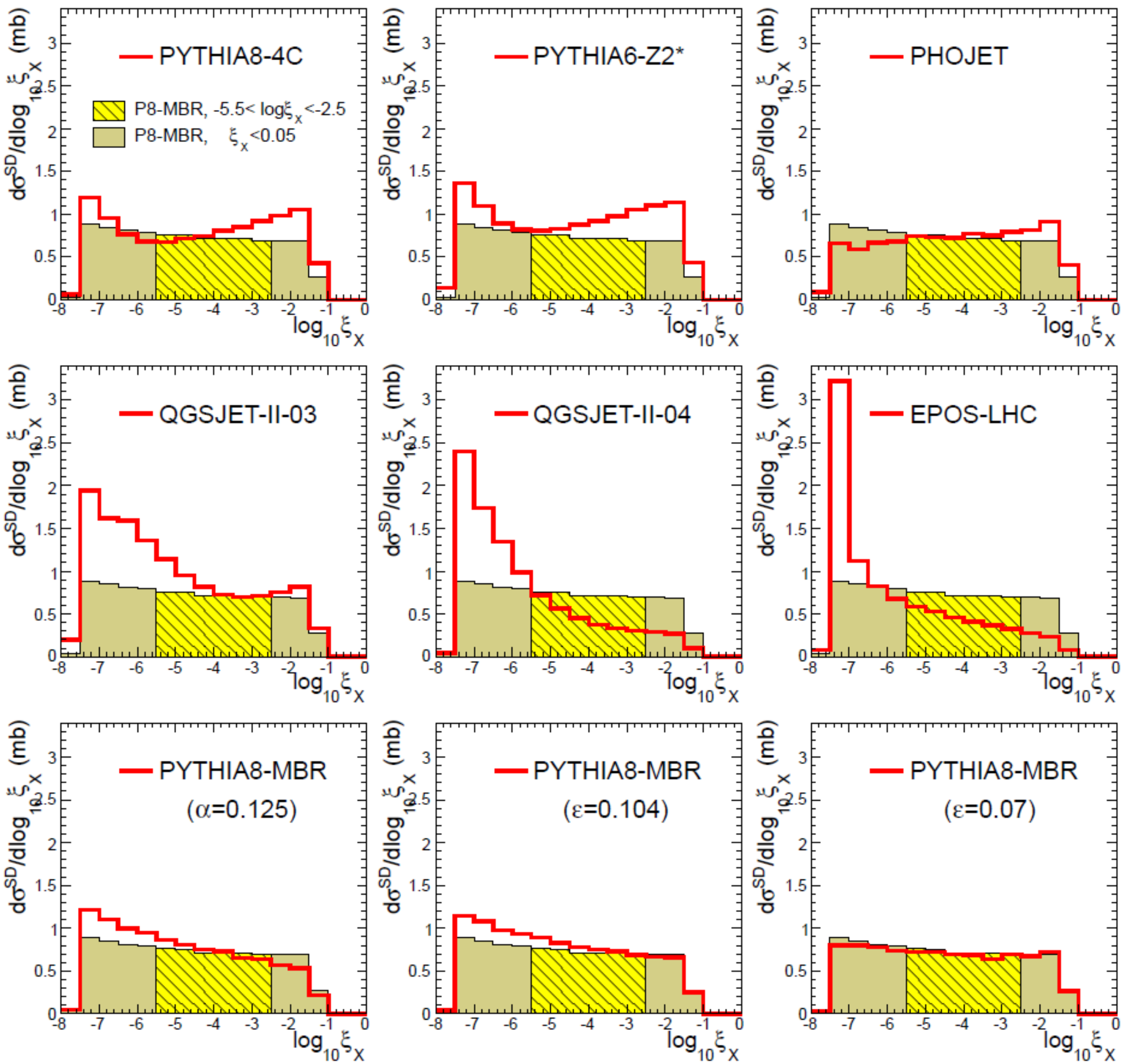
$$\sigma^{SD} = 8.84 \pm 0.08(stat)^{+1.49}_{-1.38}(syst)^{+1.17}_{-0.37}(extr)\,mb$$

$$\sigma^{DD} = 5.17 \pm 0.08(stat)^{+0.55}_{-0.57}(syst)^{+1.62}_{-0.51}(extr)\,mb$$

- PYTHIA8-MBR describes the data in all the measured regions
- Data are consistent with SD and DD cross sections weakly rising with energy
- Hard diffractive jets observed and cross-section measured
- Jet-gap-jet events observed for the first time at the LHC
- Clear beyond LO DGLAP dynamics needed to describe the spectra shapes

Spares

Extrapolation



i	MC model	f^{SD}	f^{SD}_{MBR}
1	PYTHIA 8 MBR ($\varepsilon = 0.08$)	2.18 (1.00)	2.18 (1.00)
2	PYTHIA 8 4C	2.32 (1.06)	2.51 (1.15)
3	PYTHIA 6 Z2*	2.29 (1.06)	2.89 (1.34)
4	PHOJET	2.06 (0.95)	2.18 (1.00)
5	QGSJET-II 03	2.72 (1.25)	3.19 (1.46)
6	QGSJET-II 04	3.62 (1.66)	2.30 (1.06)
7	EPOS	3.44 (1.58)	2.15 (0.99)
8	PYTHIA 8 MBR ($\alpha' = 0.125$)	2.27 (1.04)	2.34 (1.07)
9	PYTHIA 8 MBR ($\varepsilon = 0.104$)	2.23 (1.03)	2.42 (1.11)
10	PYTHIA 8 MBR ($\varepsilon = 0.07$)	2.16 (0.99)	2.09 (0.96)

i	MC model	f^{DD}	f^{DD}_{MBR}
1	PYTHIA 8 MBR ($\varepsilon = 0.08$)	1.92 (1.00)	1.92 (1.00)
2	PYTHIA 8 4C	2.52 (1.32)	1.86 (0.97)
3	PYTHIA 6 Z2*	2.39 (1.25)	2.15 (1.13)
4	PHOJET	1.80 (0.94)	0.60 (0.31)
5	QGSJET-II 03	—	—
6	QGSJET-II 04	2.04 (1.07)	0.94 (0.49)
7	EPOS	4.73 (2.47)	1.93 (1.01)
8	PYTHIA 8 MBR ($\alpha' = 0.125$)	1.97 (1.03)	2.32 (1.21)
9	PYTHIA 8 MBR ($\varepsilon = 0.104$)	2.00 (1.04)	2.37 (1.24)
10	PYTHIA 8 MBR ($\varepsilon = 0.07$)	1.88 (0.98)	1.73 (0.90)