CMS results on soft diffraction

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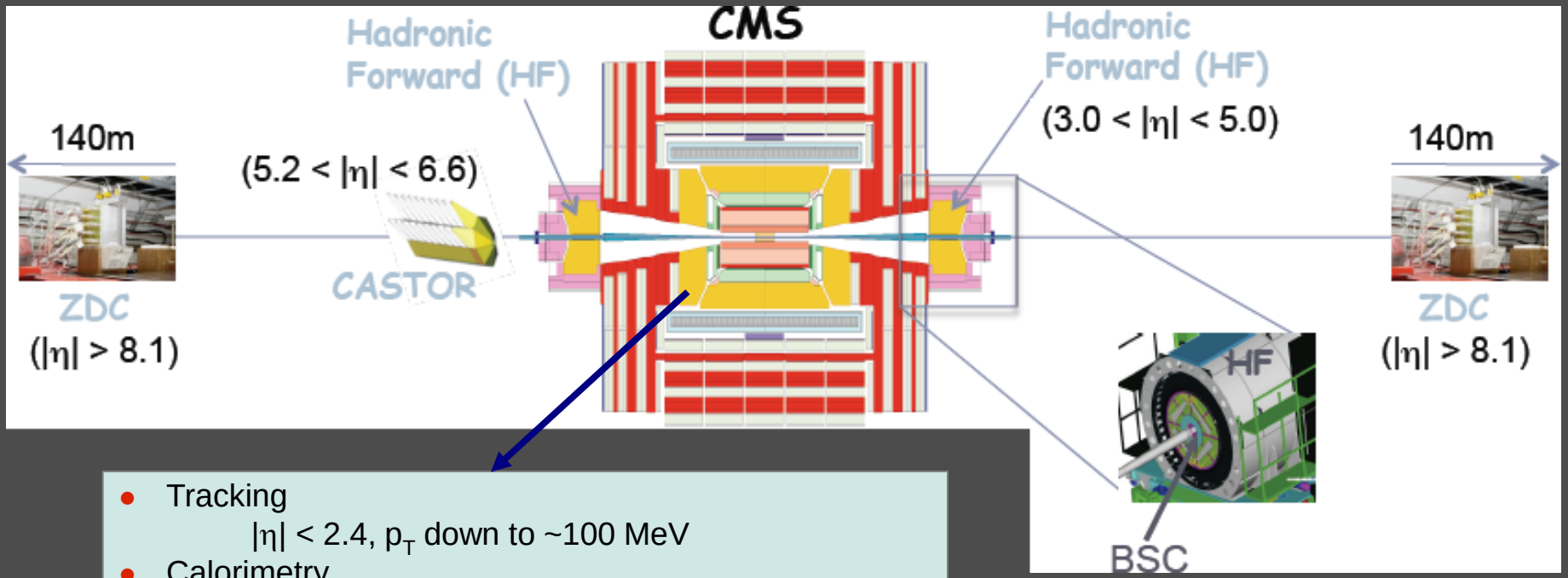
Outline

- CMS detector
- **Soft diffractive cross sections**
- **Forward rapidity gap cross section**
- **Summary**

Reference: *CMS PAS FSQ-12-005*

CMS detector



- Tracking
  - $|\eta| < 2.4$, p_T down to ~100 MeV
- Calorimetry
  - Electromagnetic calorimeter $|\eta| < 3.0$
  - Hadronic calorimeter (HB,HE,HF) $|\eta| < 5.0$

- Forward detectors:
  - HF, hadron forward calorimeter (10m from IP) $3 < |\eta| < 5$
  - BSC, beam scintillator counters (in front of HF) $3.2 < |\eta| < 4.7$
  - CASTOR calorimeter (one side only) $-6.6 < \eta < -5.2$

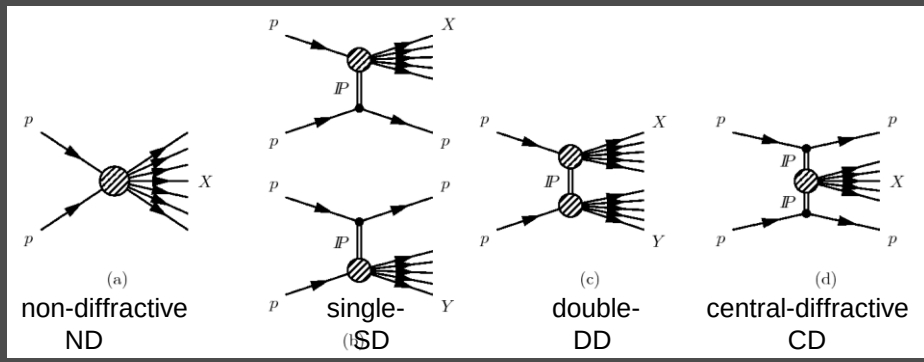
not used in this analysis
- FSC (Forward Shower Counters) $6 < |\eta| < 8$
- ZDC (zero degree calorimeter) $|\eta| > 8.1$

Soft diffractive cross sections

First CMS measurement of inclusive diffractive cross sections.

Using Large Rapidity Gap (LRG) signatures.

SD and DD separated with CASTOR ($-6.6 < \eta < -5.2$).



- Low-PU 2010 data at $\sqrt{s}$= 7 TeV.
- Minimum-Bias trigger (hit in either of BSCs).
- Based on Particle Flow objects (tracking+calorimetry).
- At least 2 PF objects in the BSC acceptance.
- No vertex requirement (to retain M_X<100 GeV).

Minimum-Bias sample in the central CMS detector ($-4.7<\eta<4.7$).

CMS PAS FSQ-12-005

MC simulations:

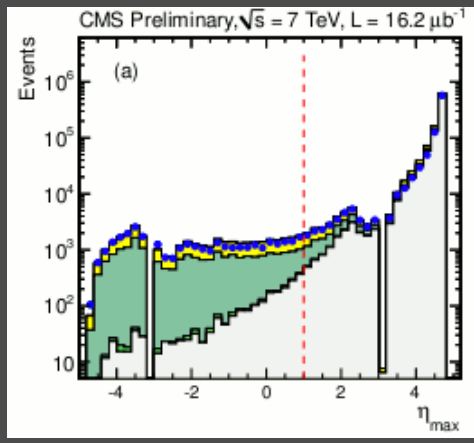
- **PYTHIA8-4C**: diffraction with Schuler&Sjostrand model from PYTHIA6. Tune 4C - additional scaling of SD and DD downwards by 10% and 12%.
- **PYTHIA8-MBR (*)**: diffraction with MBR model. Pomeron intercept ε=0.08 and additional scaling of DD downwards by 15%.

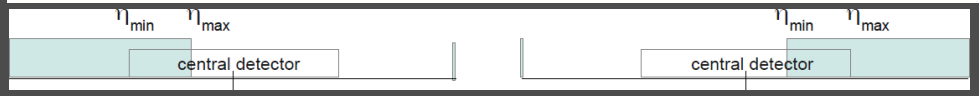
* MBR (Minimum-Bias Rockefeller) – implemented in Pythia8.165. Regge-based model with renormalized flux, developed for and successfully tested at CDF. Hadronization model tuned to describe diffractive masses at lower energies. More details in 'Recent developments on diffraction in Pythia8' talk by Robert Ciesielski at MPI2012@CERN.
http://indico.cern.ch/conferenceOtherViews.pyview=standard&confId=184925

Soft diffractive cross sections

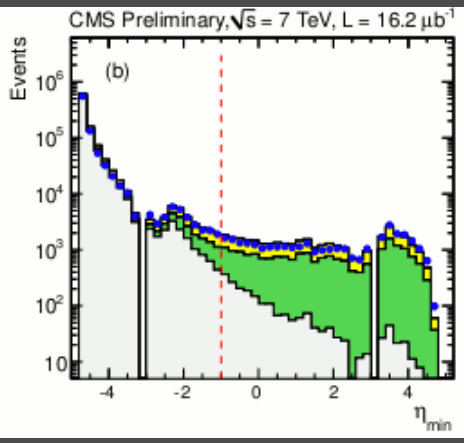
Experimental topologies of diffractive events with LRG

SD1 type – gap on +side

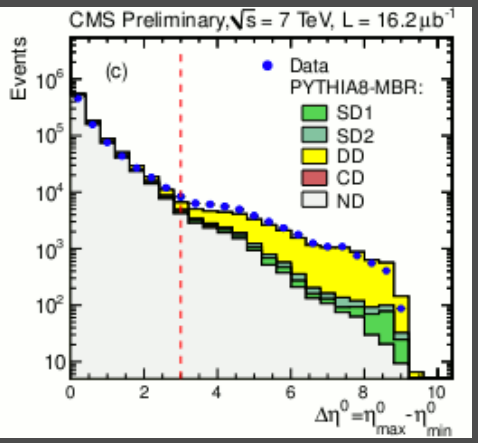


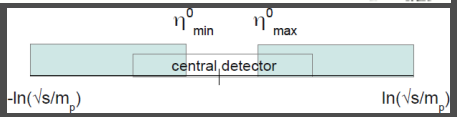


SD2 type – gap on -side



DD type – cental gap





$\eta_{max}(\eta_{min})$ - highest (lowest) η of the particle reconstructed in the cental detector.
$\eta^0_{max}(\eta^0_{min})$ - closest-to-zero positive (negative) η of the particle in the central detector. $\Delta\eta^0 = \eta^0_{max} - \eta^0_{min}$.

All types - measure forward-rapidity-gap cross section (and compare to ATLAS)

No separation of SD and low-mass DD events.

SD2 type, η_{min}>-1 selection + CASTOR (to separate SD/DD events) - measure SD and DD cross sections

CASTOR only one-side.

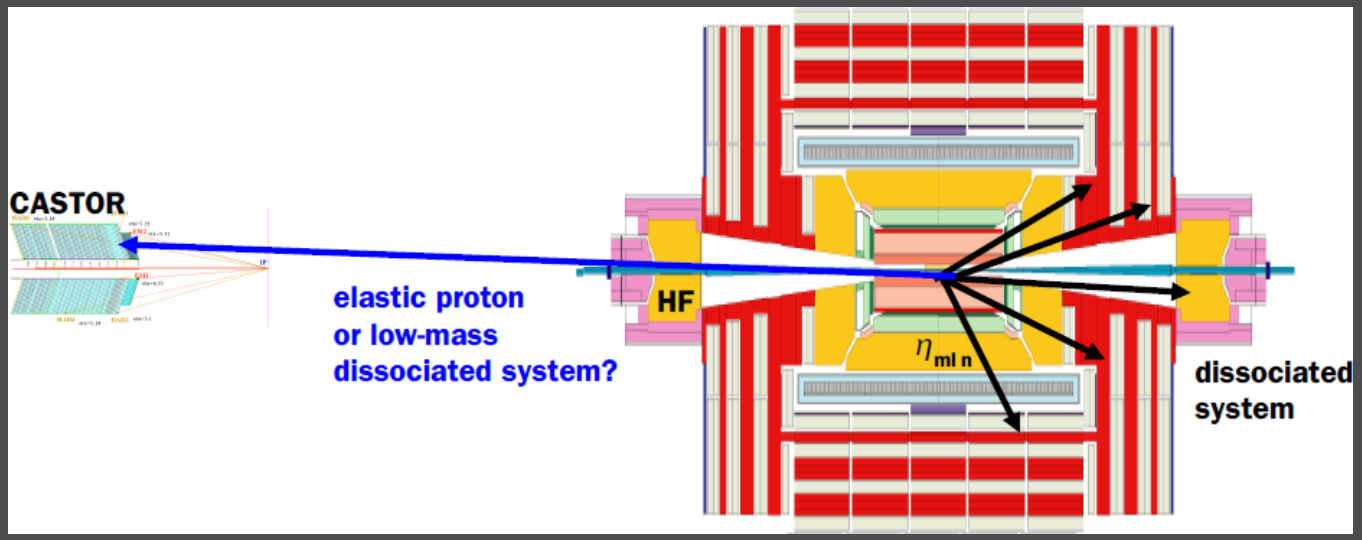
DD type, $\Delta\eta^0$ >3 selection - measure DD cross section

CMS PAS FSQ-12-005

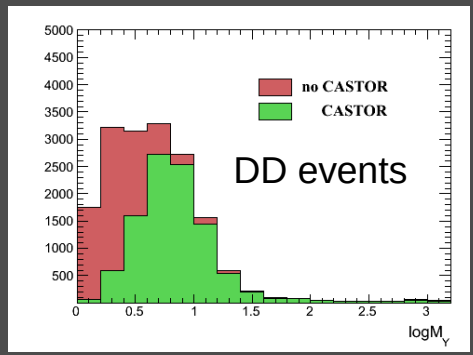
Soft diffractive cross sections

Separation of SD/DD events with CASTOR

SD2-type + η_{min}>-1 selection - SD events and DD events with low-mass hadronic system escaping detection in the central detector
→ CASTOR tag to select the sample enhanced in DD events and calculate SD and DD cross sections.



CASTOR calorimeter – layers of tungsten absorber and quartz plates.
12 longitudinal modules and 16 azimuthal sectors.
Sensitivity: $0.5 < \log_{10}(M_Y/\mathrm{GeV}) < 1.1$ $(3.2 < M_Y < 12\ \mathrm{GeV})$.

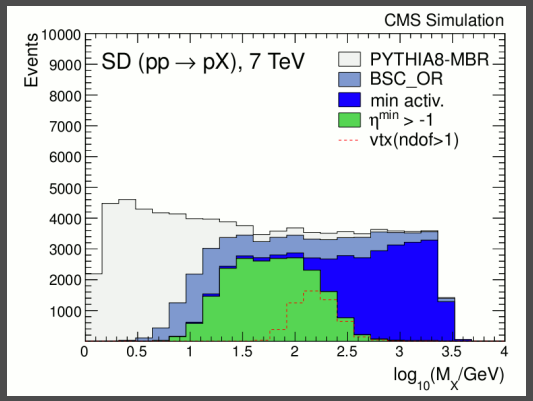


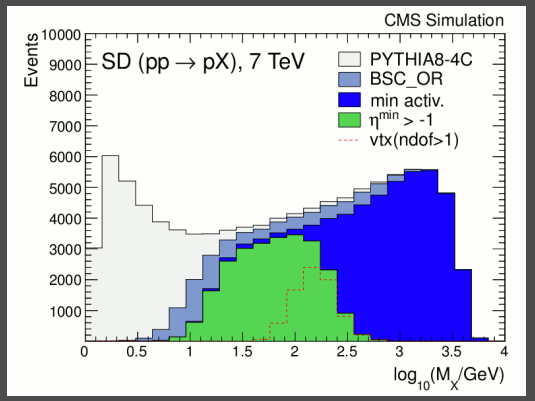
CASTOR tag – signal above threshold (1.48 GeV) in at least one of 16 sectors (summed over the first 5 modules).

Soft diffractive cross sections

Kinematic phase space (diffractive-mass range) after all selections.

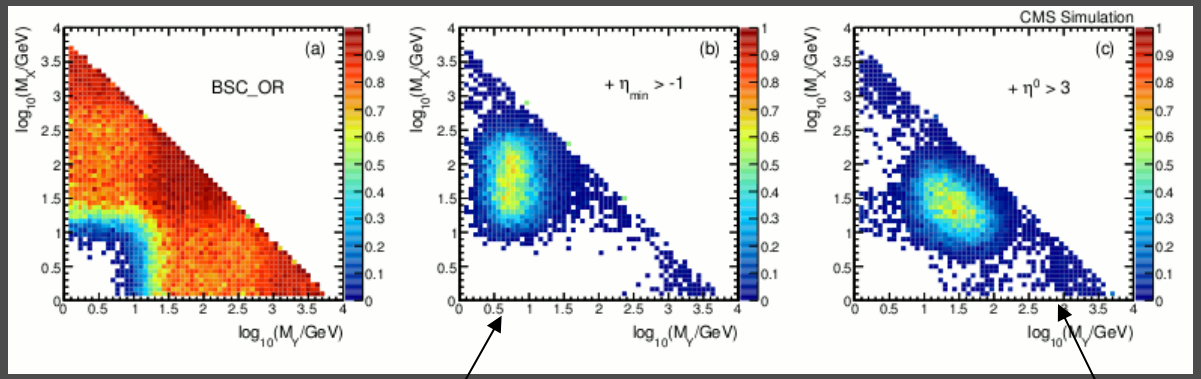
Generator level SD process →





SD2-type events with the η_{min}>-1 selection (forward gap) and no CASTOR tag:

$12 < M_X < 394$ GeV



← Generator level DD process

SD2-type events with the η_{min}> -1 selection (forward gap) and a CASTOR tag: $12 < M_X < 394$ GeV, $3.2 < M_Y < 12$ GeV

DD-type events with the $\Delta\eta^0 > 3$ selection (central gap): $\Delta\eta > 3$, $M_X > 10$ GeV, $M_Y > 10$ GeV

Two complementary measurements of DD.

Soft diffractive cross sections

Detector-level distribution of fractional proton momentum loss, ζ.
CASTOR tag performance.

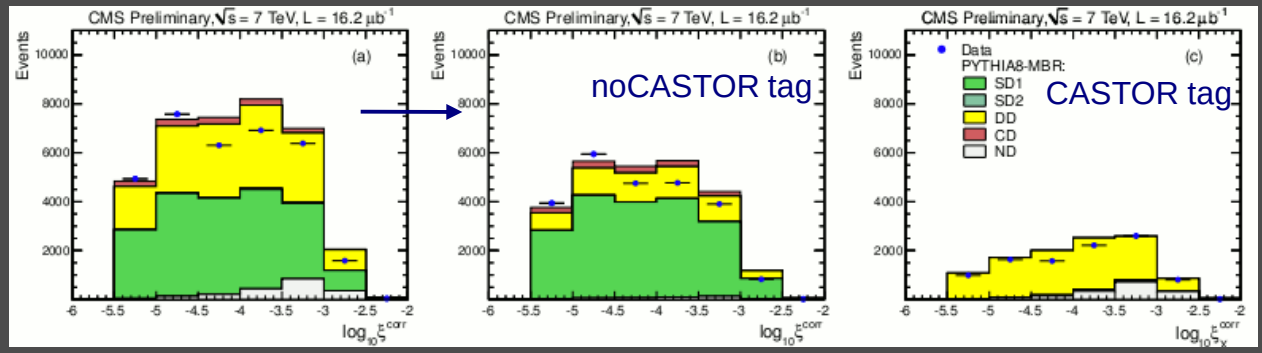
SD2 with an $\eta_{min} > -1$ selection.

SD and DD cross sections measured as a function of ζ.

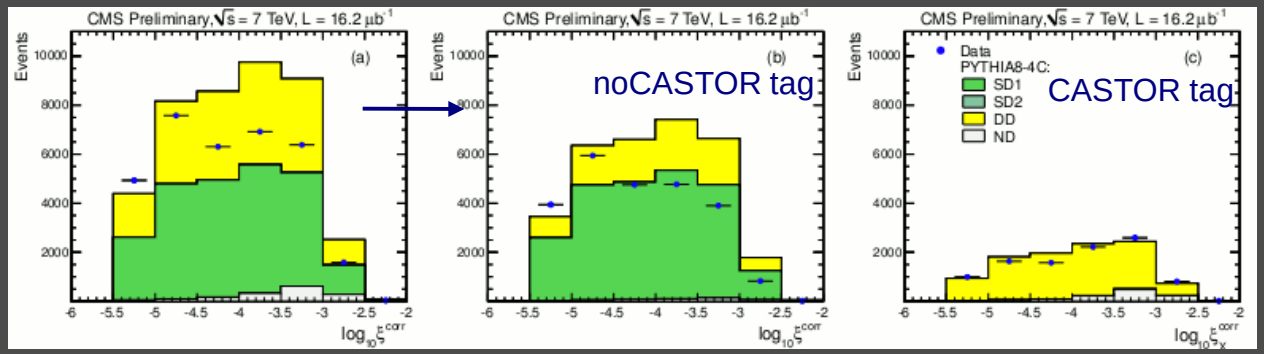
$$\xi = \frac{\sum(E^i + p_z^i)}{\sqrt{s}} \sim \frac{M_X^2}{s}$$

ζ reconstructed from PF objects, corrected for particles lost in the beam hole or below PF thresholds (MC-based ζ-dependent correction).

PYTHIA8-MBR



PYTHIA8-4C

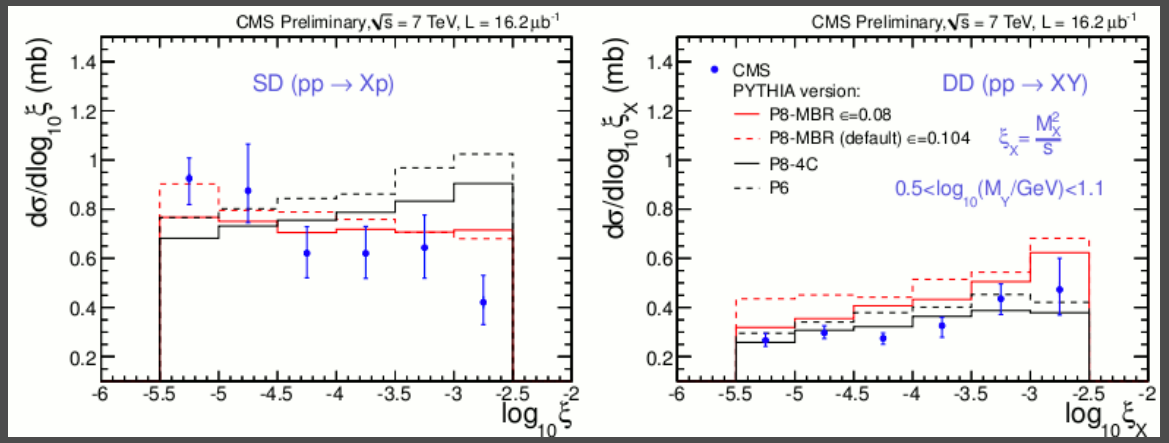


The DD contribution to the no-CASTOR tag sample reduced to ~20% (dominant background).
DD simulation validated with the CASTOR tag sample.

PYTHIA8-MBR gives a better description of the data and is used to extract cross section.
PYTHIA8-4C used for systematic checks (hadronization, diffraction model).

Soft diffractive cross sections

SD and DD cross sections (bin-by-bin correction)



$$\frac{d\sigma^{SD}}{d\log_{10}\xi} = \frac{N^{data}_{noCASTOR} - (N_{DD} + N_{CD} + N_{ND})^{MC}}{acc \cdot \mathcal{L} \cdot (\Delta \log_{10}\xi)_{bin}}$$

$$\frac{d\sigma^{DD}}{d\log_{10}\xi_X} = \frac{N^{data}_{CASTOR} - (N_{ND} + N_{SD} + N_{CD})^{MC}}{acc \cdot \mathcal{L} \cdot (\Delta \log_{10}\xi_X)_{bin}}$$

MC-based background subtraction (see previous slide).
acc – acceptance (pileup correction included, ~7%).
Hadron level – generated masses.

Error bars dominated by systematic uncertainties (HF energy scale and hadronization+diffraction model uncertainties dominate).

Results compared to predictions of theoretical models used in PYTHIA8-MBR, PYTHIA8-4C, and PYTHIA6:

→SD cross section integrated over $-5.5 < \log_{10}\xi < -2.5$:
→ multiplied by 2 to account for both pp → pX and pp → Xp processes.

- PYTHIA8 MBR shown for two values of the Pomeron trajectory ($\alpha(t) = 1+\varepsilon+\alpha' t$), ε=0.08 and ε=0.104. Both describe the measured SD cross section well. The DD data favour the smaller value of ε.

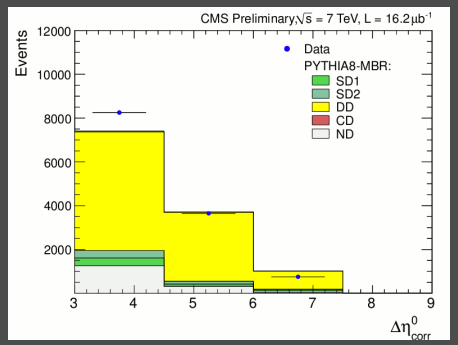
- The Schuler&Sjostrand model used in PYTHIA8-4C and PYTHIA6 describes the DD cross section, but fails to describe the falling behavior of the SD data.

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

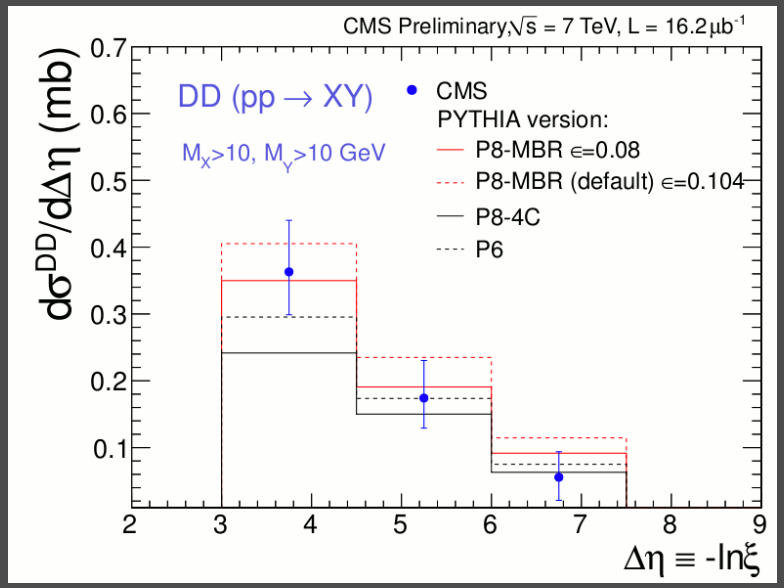
$12 < M_X < 394$ GeV

CMS PAS FSQ-12-005

Soft diffractive cross sections



DD cross section with central LRG (bin-by-bin correction)



$$\frac{d\sigma^{DD}}{d\Delta\eta} = \frac{N^{data} - (N_{ND} + N_{SD} + N_{CD})^{MC}}{acc \cdot \mathcal{L} \cdot (\Delta\eta)_{bin}}$$

MC-based background subtraction, ND dominant.
acc – acceptance (pileup correction included, extrapolation from $\Delta\eta^0 > 3$ to $\Delta\eta > 3$) .
Hadron level – generated masses, $\Delta\eta = -\log(M_X^2 M_Y^2/ss_0)$.

Error bars dominated by systematic uncertainties (HF energy scale, and hadronization+diffraction model uncertainties dominate).

Results compared to predictions of theoretical models used in PYTHIA8-MBR, PYTHIA8-4C and PYTHIA6. The predictions are in agreements with the data.

The DD cross section integrated in the region $\Delta\eta > 3$, $M_X > 10$ GeV, $M_Y > 10$ GeV:

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

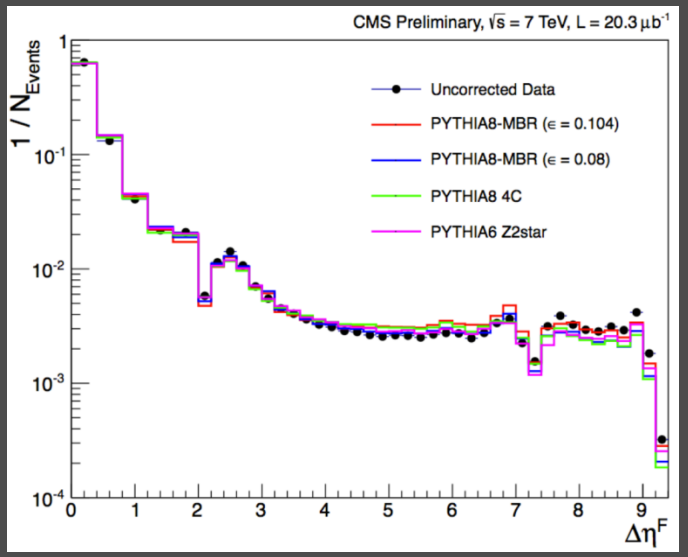
Forward rapidity gap cross section

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

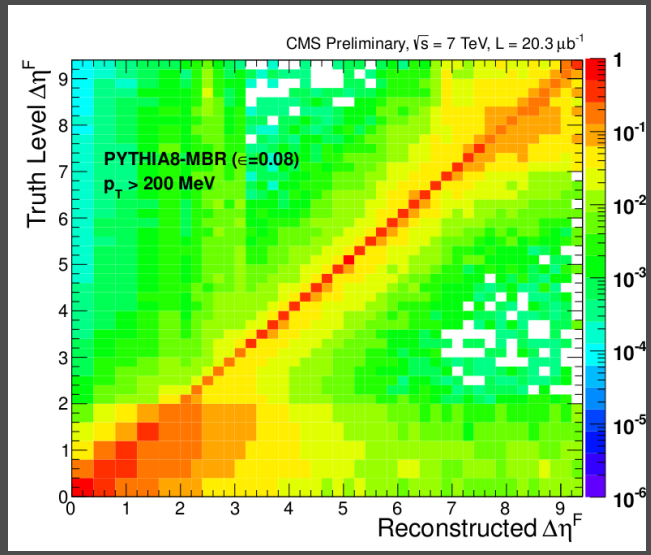
$$\frac{d\sigma(\Delta\eta^F)}{d\Delta\eta^F} = \frac{A(\Delta\eta^F)}{\Delta\eta_{binwidth}} \frac{N(\Delta\eta^F) - N_{BG}(\Delta\eta^F)}{\varepsilon(\Delta\eta^F) \times \mathcal{L}}$$

N – number of Minimum-Bias events.
N_{BG}– number of background events (beam-gas, estimated from unpaired bunches, < 1%).
A – correction factor for the migrations between bins.
ε - trigger efficiency,

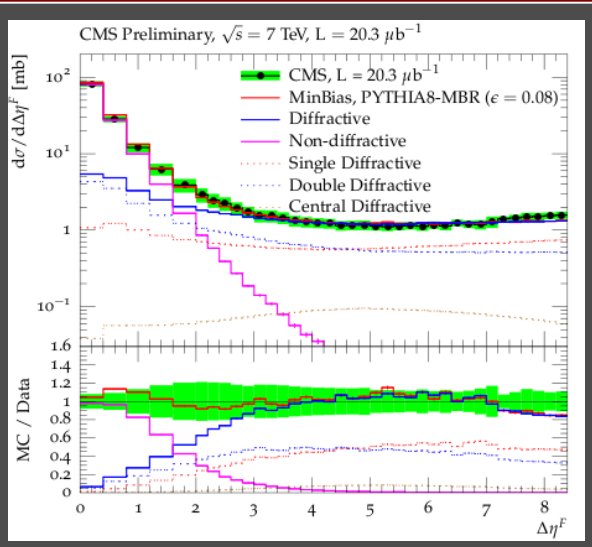
Bayesian unfolding.
Hadron level: stable FS particles with p_T>200 MeV, |η|<4.7.
Migration matrix from PYTHIA8-MBR.
Cross section limited to $\Delta\eta^F$<8.4 (small trigger efficiency uncertainty) Different run than for SD/DD cross sections.

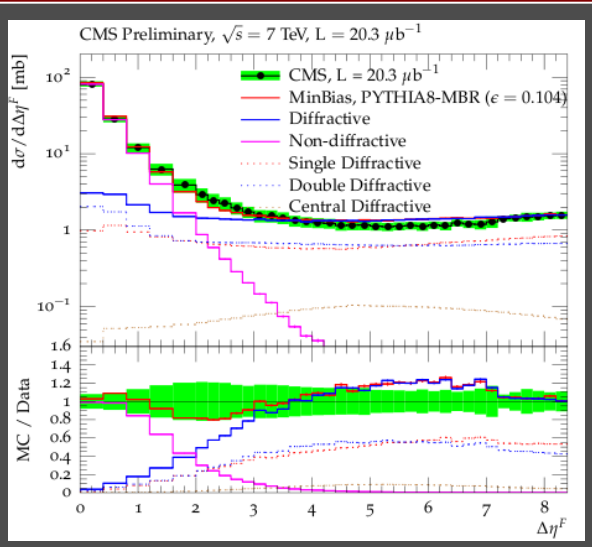


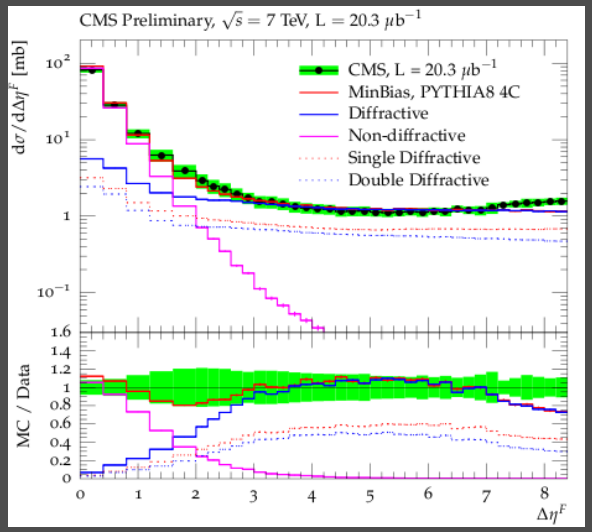
Detector-level $\Delta\eta^F$ distribution.

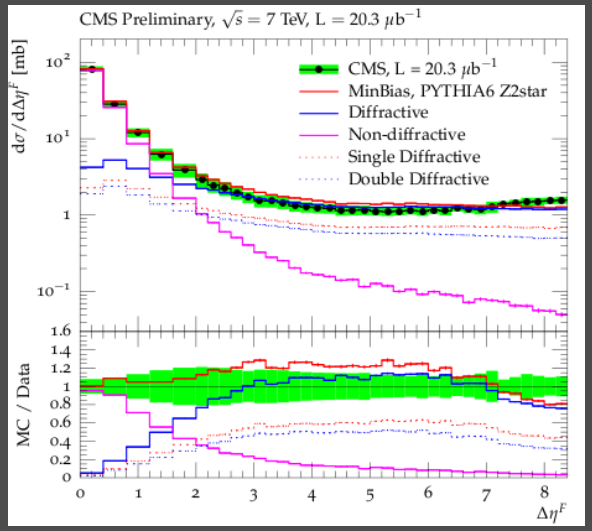


Forward-rapidity gap cross section









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.

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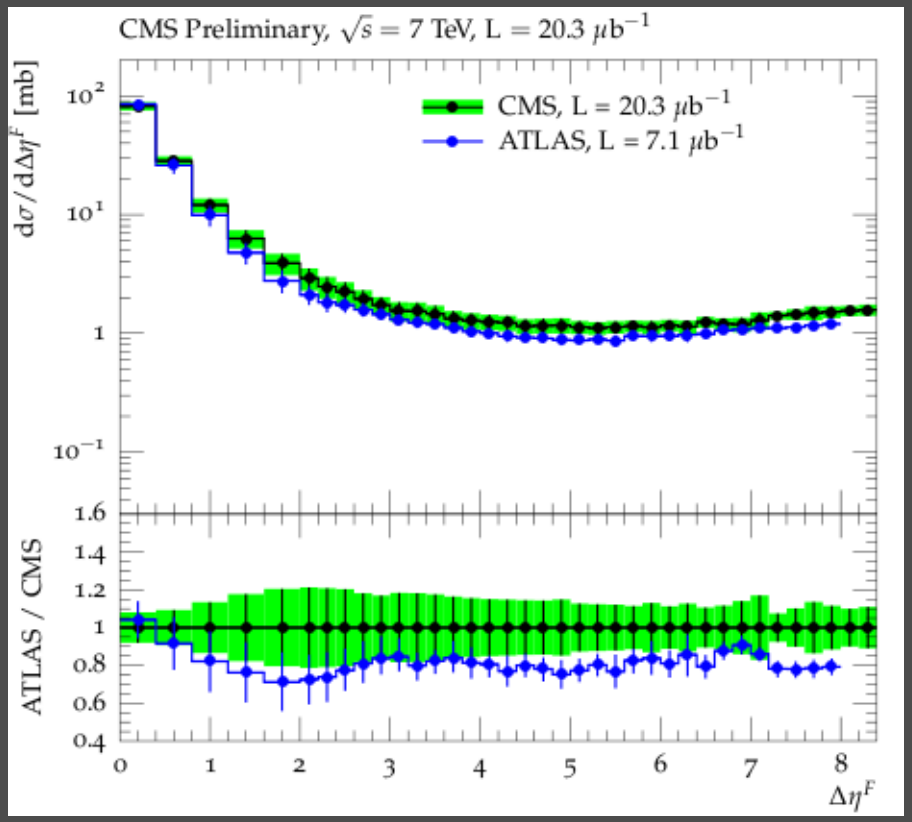
Forward-rapidity gap cross section

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

Summary

- Inclusive SD and DD diffractive cross sections measured at 7 TeV
  - ✓ $\sigma^{SD}_{vis} = 4.27 \pm 0.04\ (stat.)\ ^{+0.65}_{-0.58}\ (syst.)$ mb for $-5.5 < \log_{10}\xi < -2.$
  - ✓ $\sigma^{DD}_{vis} = 0.93 \pm 0.01\ (stat.)\ ^{+0.26}_{-0.22}\ (syst.)$ mb for $\Delta\eta > 3$, $M_X > 10$ GeV, $M_Y > 10$ GeV
- Forward rapidity gap cross section compared to ATLAS measurement
  - ✓ extends the ATLAS measurement by 0.4 units of gap size.

New results on the way. Check the latest CMS results at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ