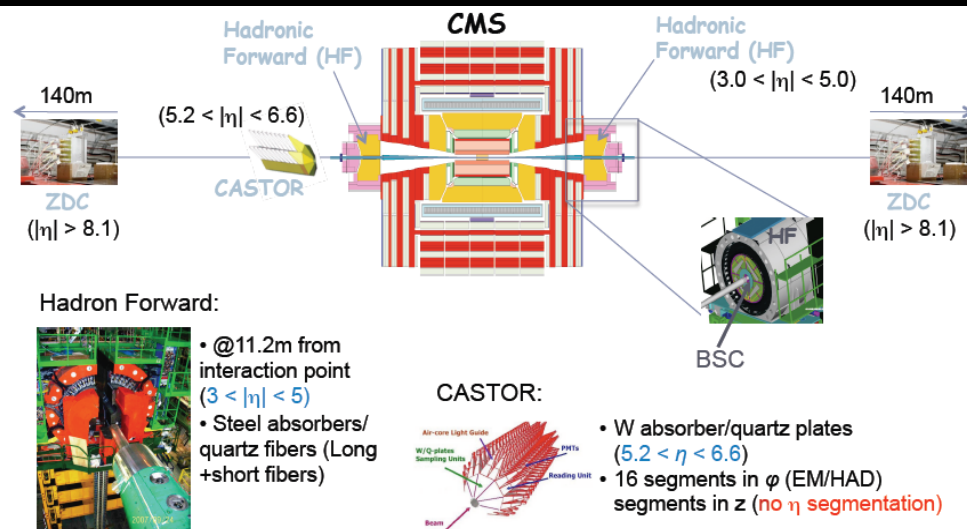


CMS results on exclusive and diffractive production

Gilvan A. Alves – Lafex/CBPF
for the CMS collaboration

The setting: CMS@LHC

- High energy and high luminosity
 - Allows high statistics precision measurements, and sensitivity to “rare” processes (hard diffraction, exclusive production)
 - But high luminosity comes with high “pileup” – average 2-8 in 2010/2011, 21 in 2012
 - Low pileup needed for some analysis



- Good detector coverage
 - Tracking to $|\eta| < 2.4$
 - Hadronic calorimeter (HF) to $|\eta| < 5$
 - Forward calorimeters (cover $-6.6 < \eta < -5.2$ (CASTOR) and $|\eta| > 8.1$ (ZDC))

Overview

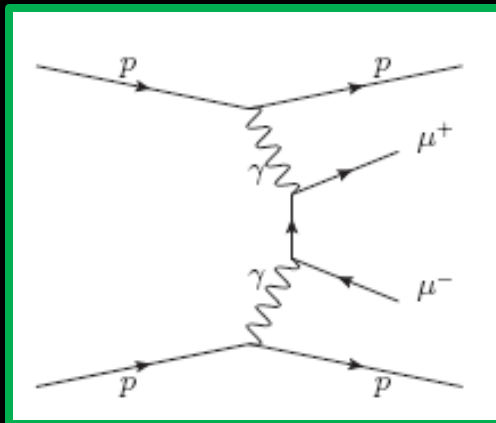
- Studying the exclusive production at CMS
 - Standard candle $\gamma\gamma\rightarrow\mu\mu$
 - WW
- Measurement of diffraction dissociation
 - SD
 - DD
- Many other interesting results not covered here
- <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ>

Studying the exclusive production

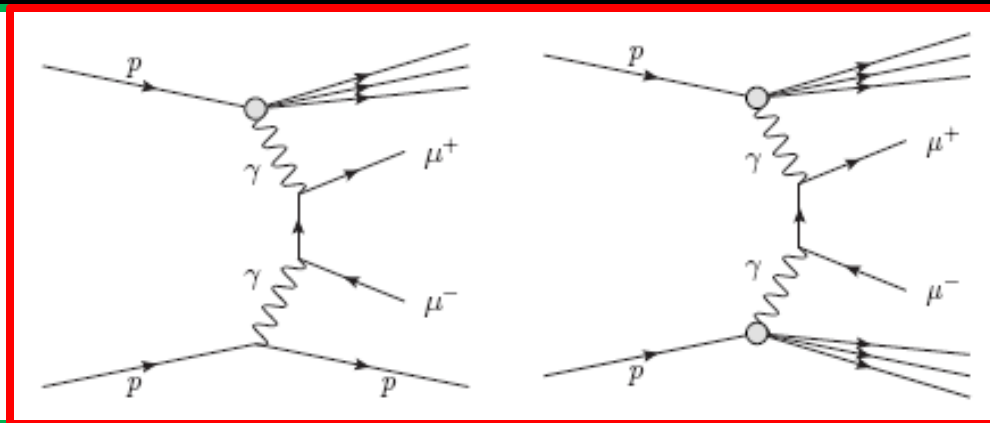
CMS-PAS-FWD-10-005

CMS-PAS-FSQ-12-010

Exclusive production



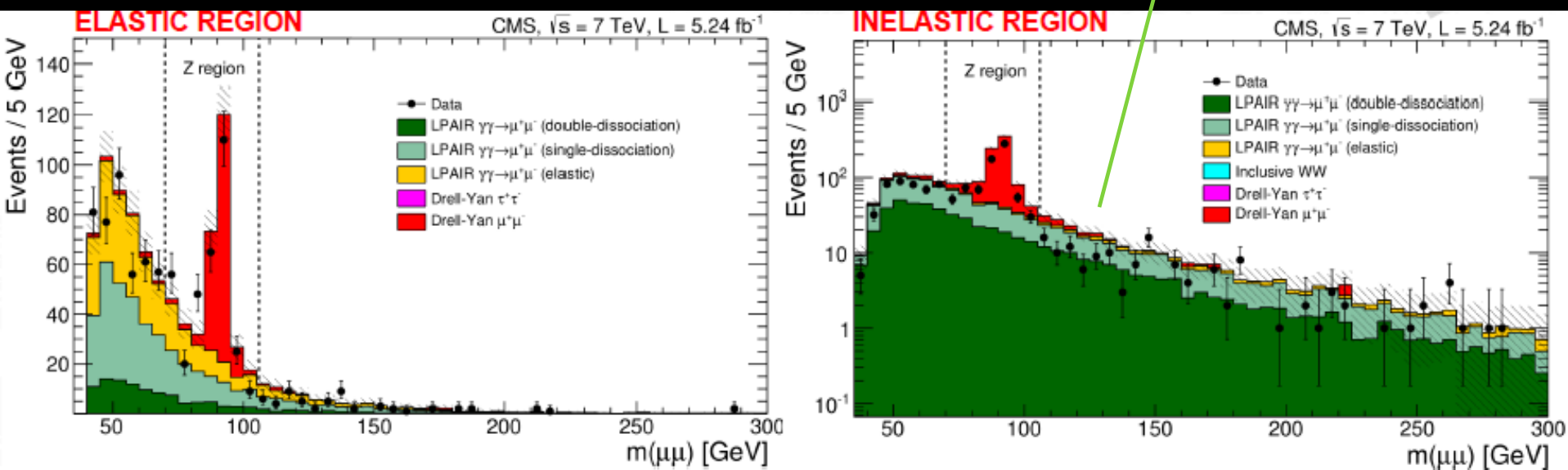
Proton dissociation



- Exclusive production $pp \rightarrow p\mu\mu p$
 - Well known QED like “Standard Candle”
- Largest “background” from $\gamma\gamma \rightarrow \mu\mu$ with proton dissociation
 - $pp \rightarrow p\mu\mu Y$, or $pp \rightarrow X\mu\mu Y$ with proton remnants undetected
 - Can be used to control background for other exclusive searches

Measurement of $\gamma\gamma \rightarrow \mu\mu$

- Measure in two kinematic regions
 - Elastic
 - $|\Delta p_T(\ell+\ell-)| < 1.0$ GeV (momentum balance)
 - $1-|\Delta\phi(\ell+\ell-)/\pi| < 0.1$ (back to back leptons)
 - Inelastic \rightarrow opposite requirements



CM Inelastic $\gamma\gamma \rightarrow \mu\mu$



→ Deficit seen mostly in inelastic region due to rescattering effects not modeled by LPAIR

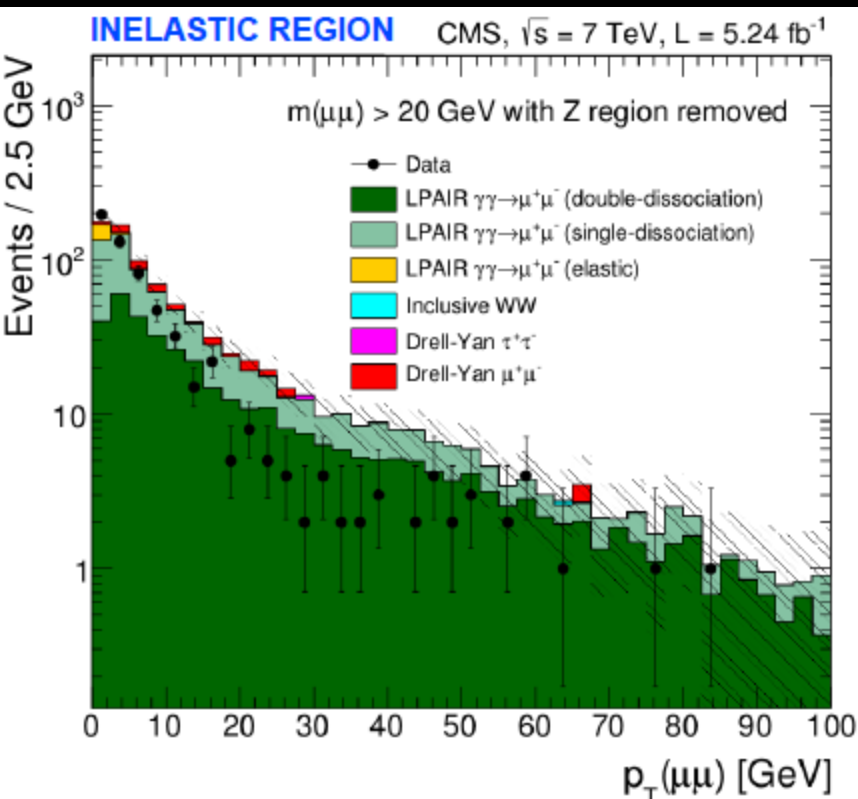
→ A correction factor is estimated for high mass dimuons

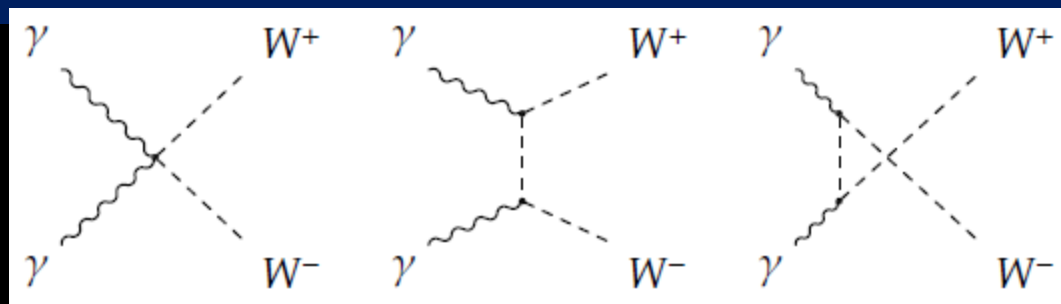
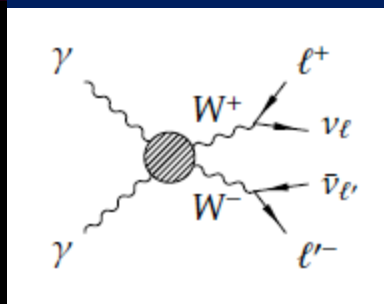
Region	Data	Simulation	Data/Simulation
Elastic	820	906 ± 9	0.91 ± 0.03
Dissociation	1312	1830 ± 17	0.72 ± 0.02
Total	2132	2736 ± 19	0.78 ± 0.02

$$F = \frac{N_{\mu\mu \text{ data}} - N_{\text{DY}}}{N_{\text{elastic}}} \Big|_{m(\mu^+\mu^-) > 160 \text{ GeV}}$$

$$F = 3.23 \pm 0.53.$$

→ This factor can be applied to the predicted cross section for $\gamma\gamma \rightarrow W+W-$





- Triple and quartic coupling in SM
 - Any deviation can signal new physics
- BSM contributions via effective Lagrangian

$$\begin{aligned}
 L_6^0 &= \frac{-e^2}{8} \frac{a_0^W}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W_{\alpha}^{-} - \frac{e^2}{16 \cos^2 \Theta_W} \frac{a_0^Z}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} Z^{\alpha} Z_{\alpha}, \\
 L_6^C &= \frac{-e^2}{16} \frac{a_C^W}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W_{\beta}^{-} - W^{-\alpha} W_{\beta}^{+}) - \frac{e^2}{16 \cos^2 \Theta_W} \frac{a_C^Z}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} Z^{\alpha} Z_{\beta},
 \end{aligned}$$

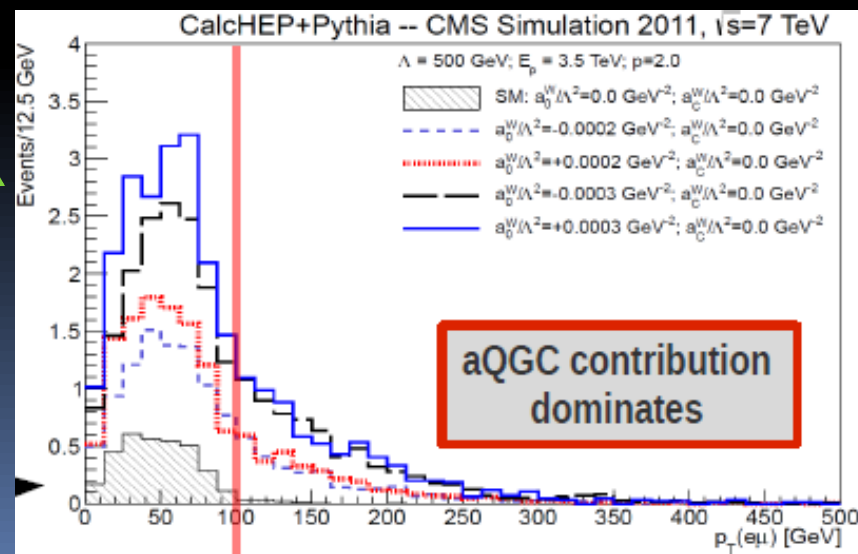
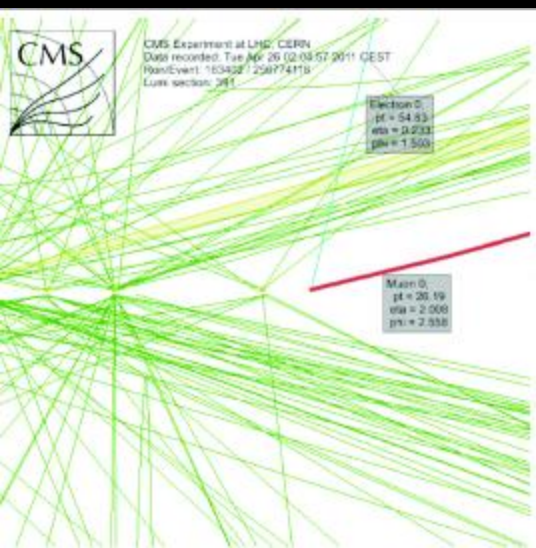
AQGC[†] parameters
Λ: scale for New Physics

- Form factors introduced to preserve unitarity
 - $W_{\gamma\gamma}$: $\gamma\gamma$ center of mass energy
 - Λ_{cutoff} : energy cutoff scale ($\Lambda_{\text{cutoff}} \rightarrow \infty$ = no form factor)

$$a_{0,C}^W \rightarrow a_{0,C}^W(W_{\gamma\gamma}^2) = a_{0,C}^W \left(1 + \frac{W_{\gamma\gamma}^2}{\Lambda_{\text{cutoff}}^2} \right)^{-2}$$

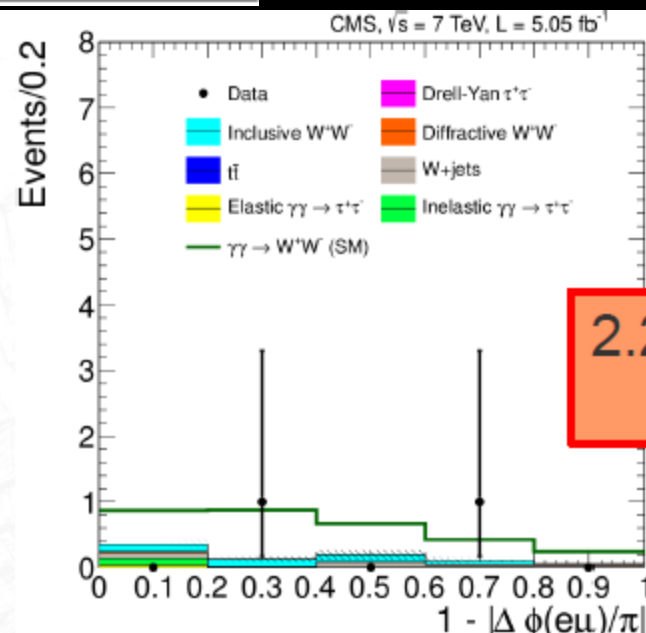
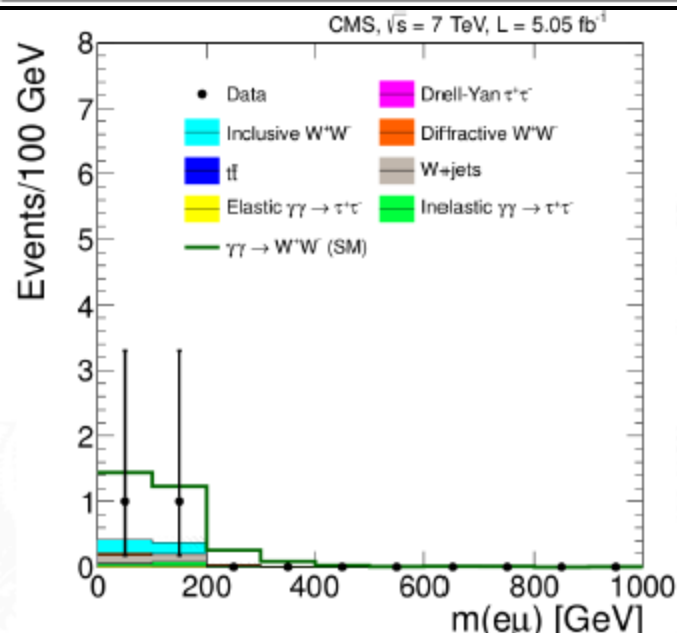
Event selection $\gamma\gamma \rightarrow WW$

- Elastic and proton-dissociative contributions
 - $pp \rightarrow p W^+ W^- p$
 - $pp \rightarrow p^{(*)} W^+ W^- p^{(*)}$
- Unlike-flavor dilepton decay channel: $\gamma\gamma \rightarrow W^+ W^- \rightarrow \mu^- e^+ \nu \bar{\nu}$
 - Avoid large backgrounds
- Data sample – 5.05 fb^{-1} @ 7 TeV
 - Signal $p_T(\mu^- e^+) > 30 \text{ GeV} \rightarrow$ avoid $\tau^+ \tau^-$
 - AQGC Searches $p_T(\mu^- e^+) > 100 \text{ GeV}$



SM signal $\gamma\gamma \rightarrow WW$

Selection step	Signal $\epsilon \times A$	Events in data
Trigger and preselection	28.5%	9086
$m(\mu^\pm e^\mp) > 20 \text{ GeV}$	28.0%	8200
Muon ID and Electron ID	22.6%	1222
$\mu^\pm e^\mp$ vertex with 0 extra tracks	13.7%	6
$p_T(\mu^\pm e^\mp) > 30 \text{ GeV}$	10.6%	2 ←

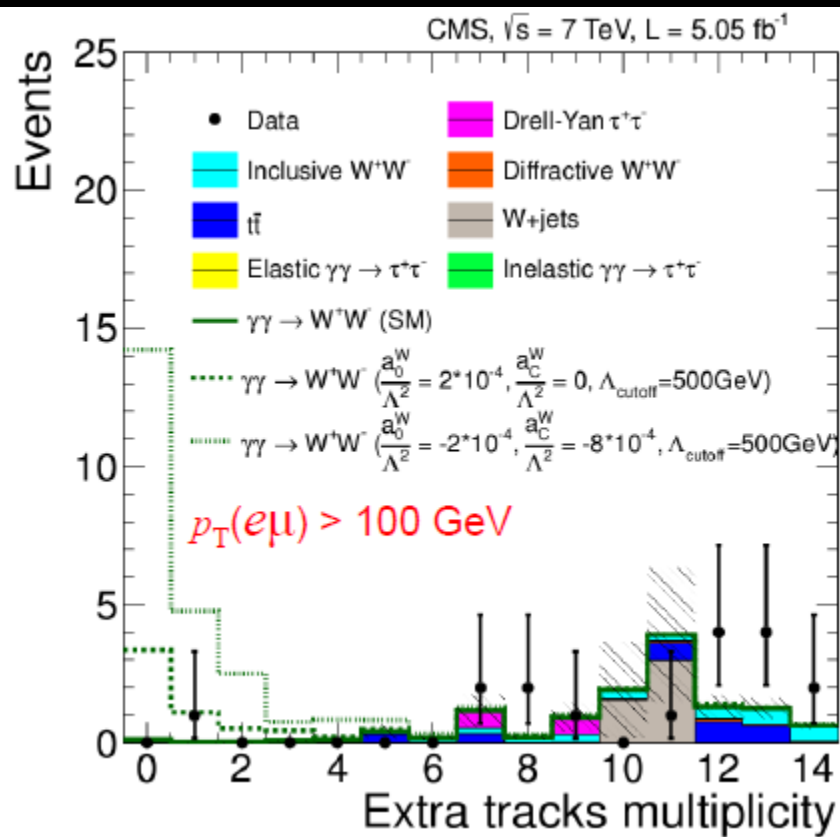
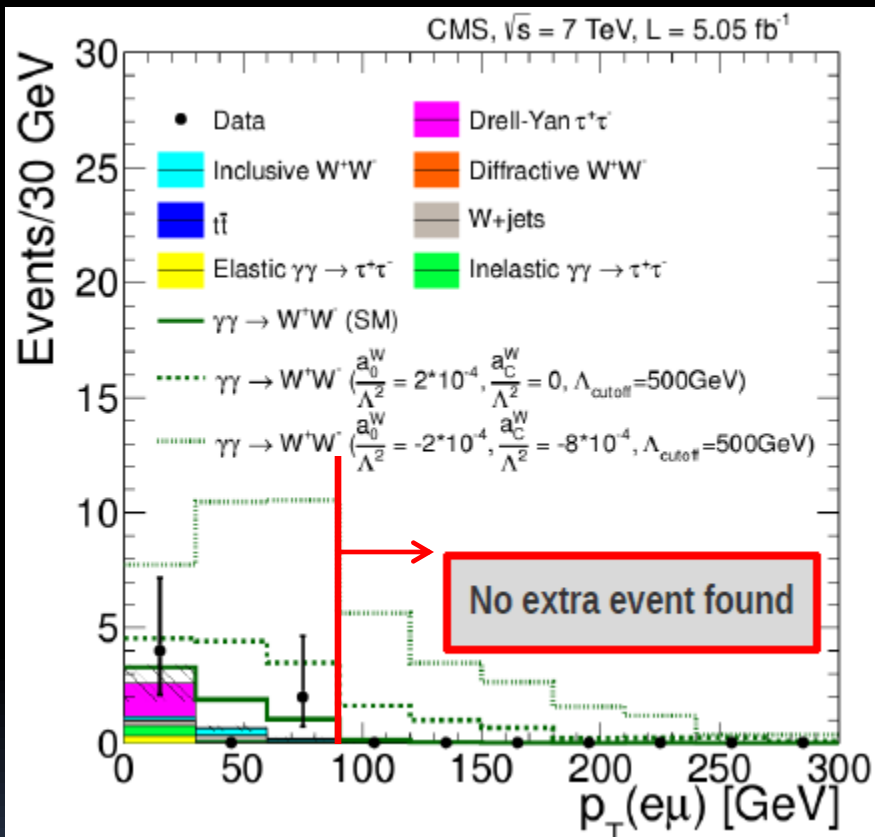


2.2 evt expected
2 observed

$$\sigma(pp \rightarrow p^{(*)}(\gamma\gamma \rightarrow W^+W^-)p^{(*)}) \times BR(W^\pm \rightarrow \mu^\pm \nu, e^\pm \nu) = 2.2_{-2.0}^{+3.3} \text{ (stat.) fb (SM prediction } 4.0 \pm 0.7 \text{ fb)}$$

- Includes dissociation correction from $\gamma\gamma \rightarrow \mu\mu$

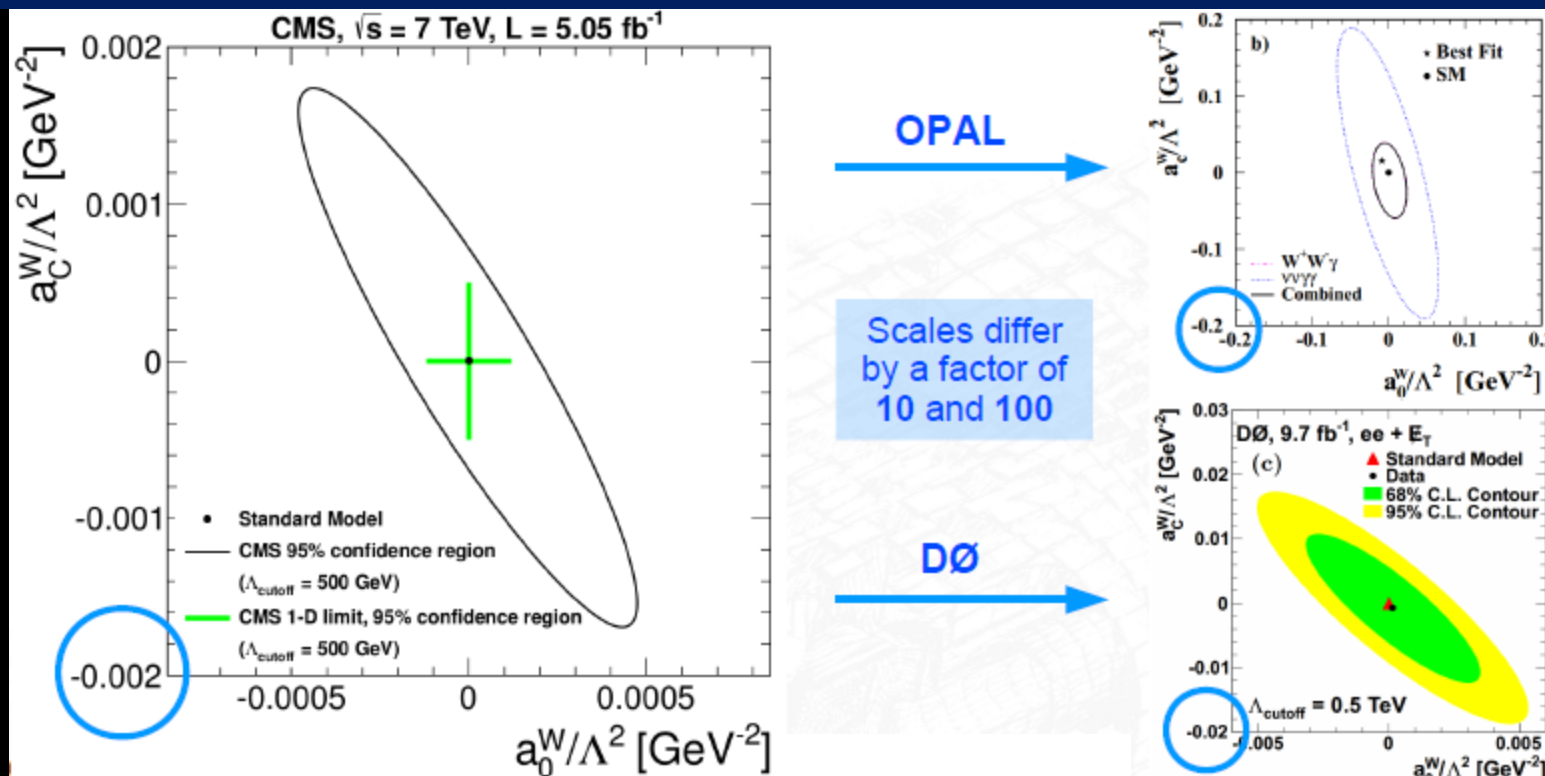
Search for $AQGC \gamma\gamma \rightarrow WW$



- Upper limit @ 95% CL

$$\sigma(pp \rightarrow p^{(*)}(\gamma\gamma \rightarrow W^+W^-)p^{(*)}) \times BR(W^\pm \rightarrow \mu^\pm \nu, e^\pm \nu) < 1.9 \text{ fb}$$

95% CL intervals $\gamma\gamma \rightarrow WW$

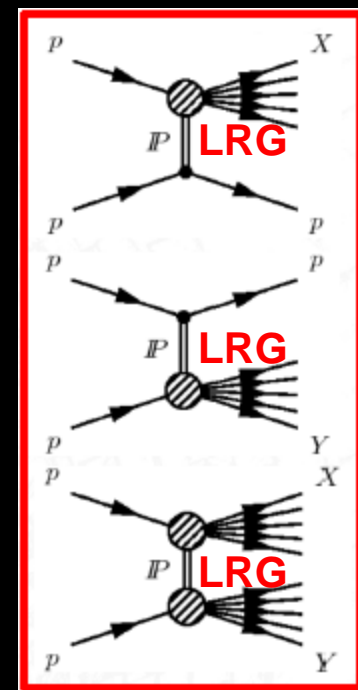


		OPAL (2004)	DØ (2013)	CMS (2013)
a_0^W/Λ^2	no form factor	$\pm 2 \times 10^{-2}$	$\pm 4.3 \times 10^{-4}$	$\pm 4.0 \times 10^{-6}$
	$\Lambda_{\text{cutoff}} = 500 \text{ GeV}$		$\pm 2.5 \times 10^{-3}$	$\pm 1.5 \times 10^{-4}$
a_c^W/Λ^2	no form factor	$^{+3.7}_{-5.2} \times 10^{-2}$	$\pm 1.5 \times 10^{-3}$	$\pm 1.5 \times 10^{-5}$
	$\Lambda_{\text{cutoff}} = 500 \text{ GeV}$		$\pm 9.2 \times 10^{-3}$	$\pm 5.0 \times 10^{-4}$

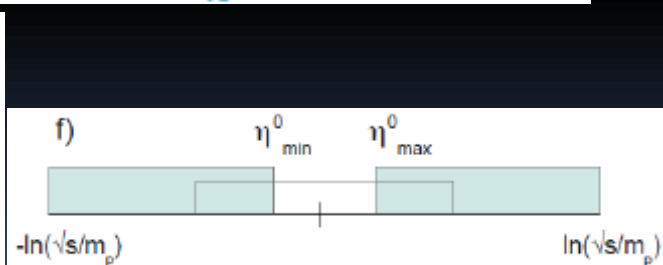
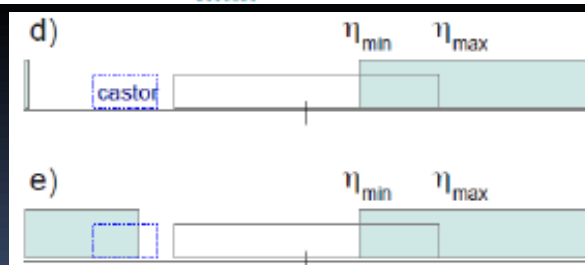
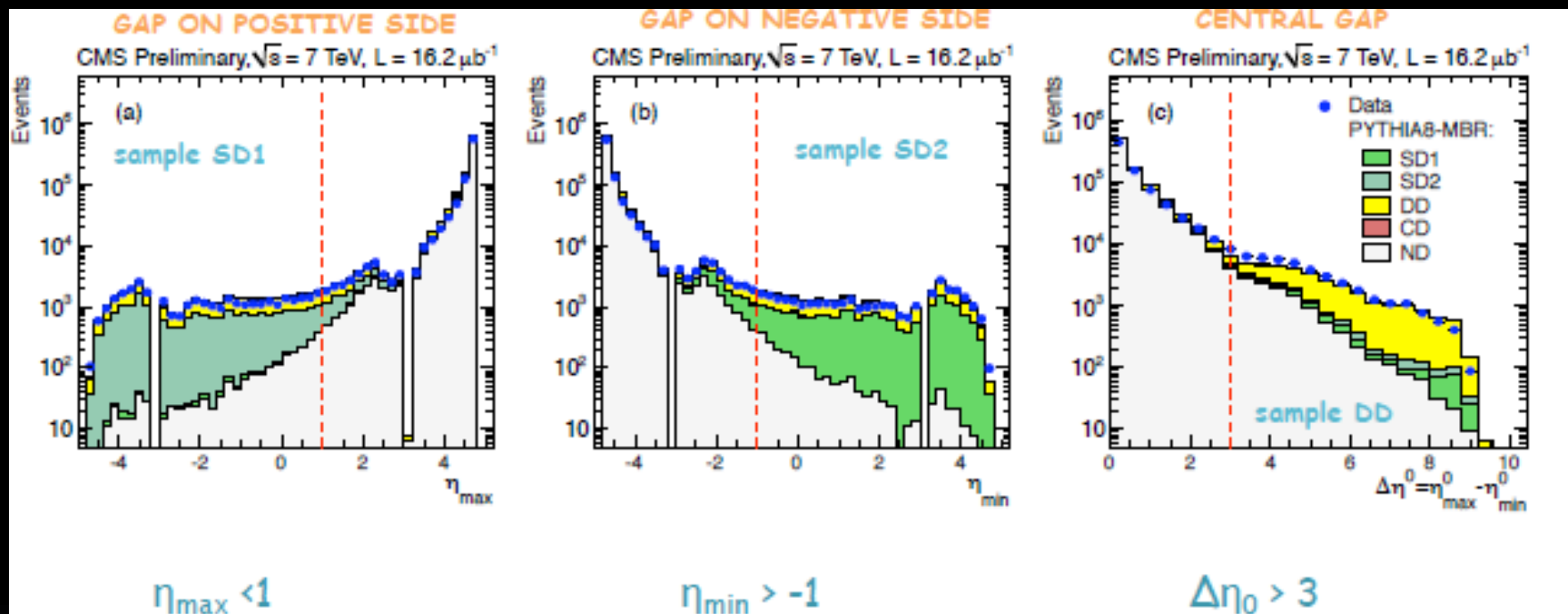
Diffractive Dissociation @ 7 TeV

CMS PAS FSQ 12-005

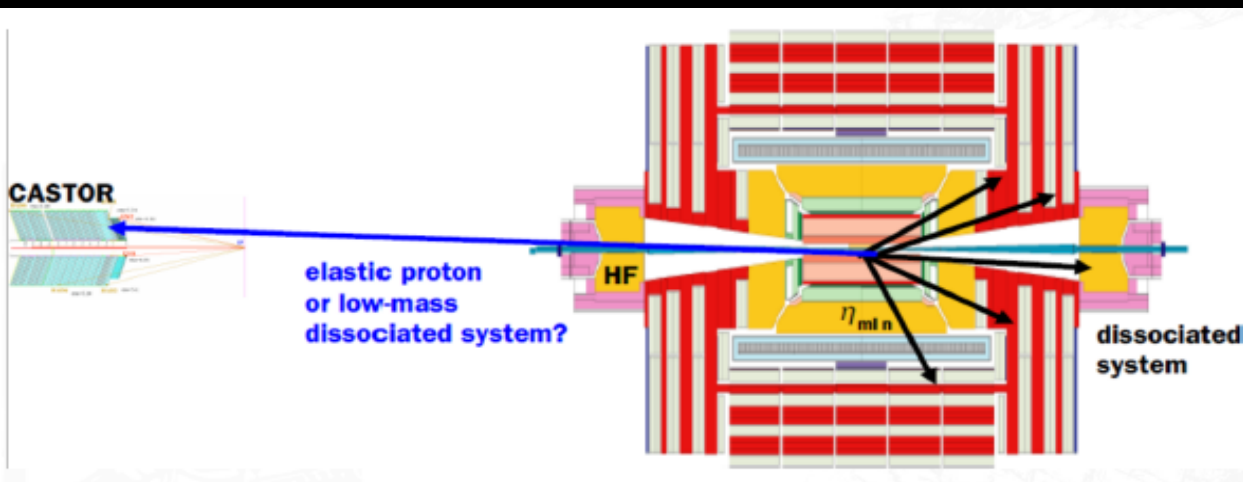
- Data sample – $16.5 \mu\text{b}^{-1}$ low pileup ($\mu=0.14$) @ 7 TeV
 - Minimum bias trigger
 - Hit in both BPTX and either BSC
- Offline selection
 - Large Rapidity Gap (LRG) tagging
 - At least 2 PF objects in BSC acceptance
 - No vertex requirement (low mass)
- MC simulation
 - PYTHIA8-MBR – Minimum Bias Rockefeller model
 - PYTHIA8-4C – for systematic studies



- Based on the LRG position

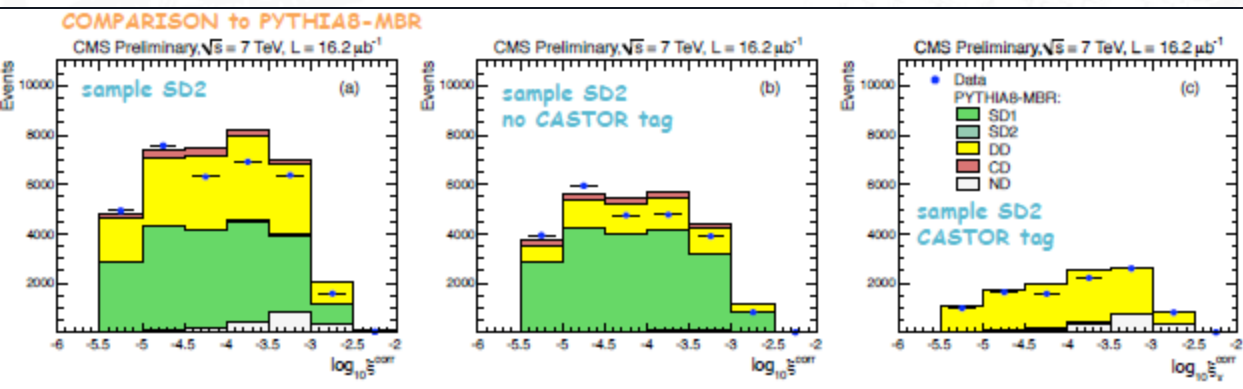


- Proton fractional momentum loss $\xi = M^2 x / s$
 - $M^2 x$ – Mass of the dissociated system
- At detector level it is reconstructed as $\xi = \sum E^i - p_z^i / \sqrt{s}$
 - Sum over all PF objects
 - ξ corrected (MC) for undetected particles (low E, low η)



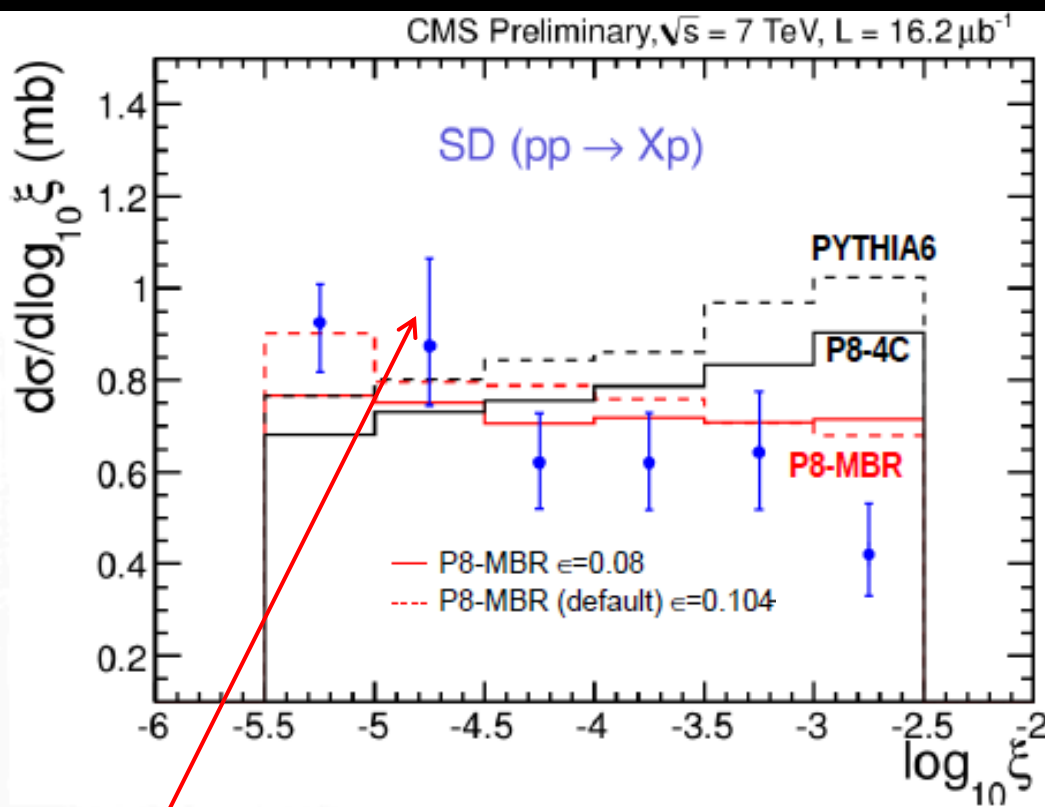
Castor tag selects low mass systems $Mx \approx 3.2 \text{ GeV}$

Separate SD & DD



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

SD2 Sample only

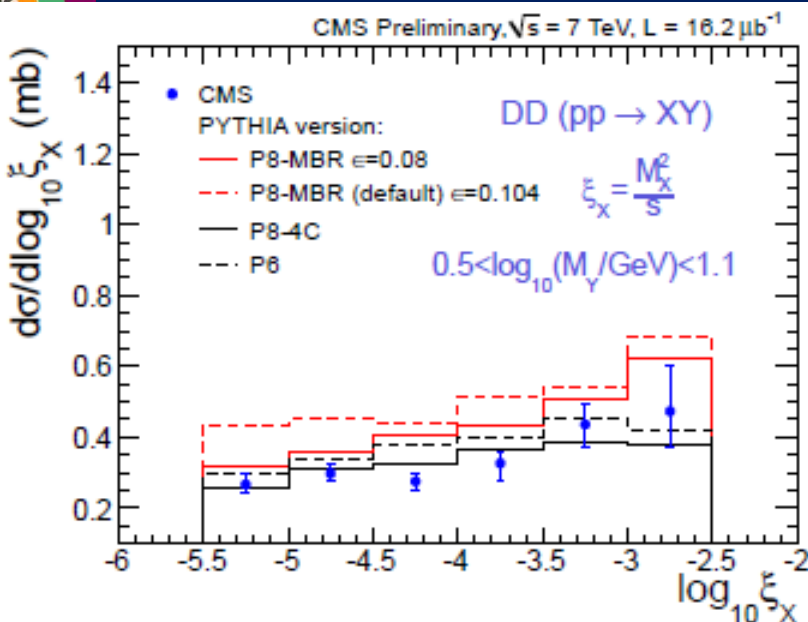


- SD falling behaviour well modeled by PYTHIA8-MBR

- PYTHIA8-4C and PYTHIA 6 do not follow the data trend

- Integrating over $-5.5 < \log\xi < -2.5$ (X 2)
 $\sigma_{vis}^{SD} = 4.27 \pm 0.04 \text{ (stat)} \pm {}^{0.65}_{0.58} \text{ (syst) mb}$

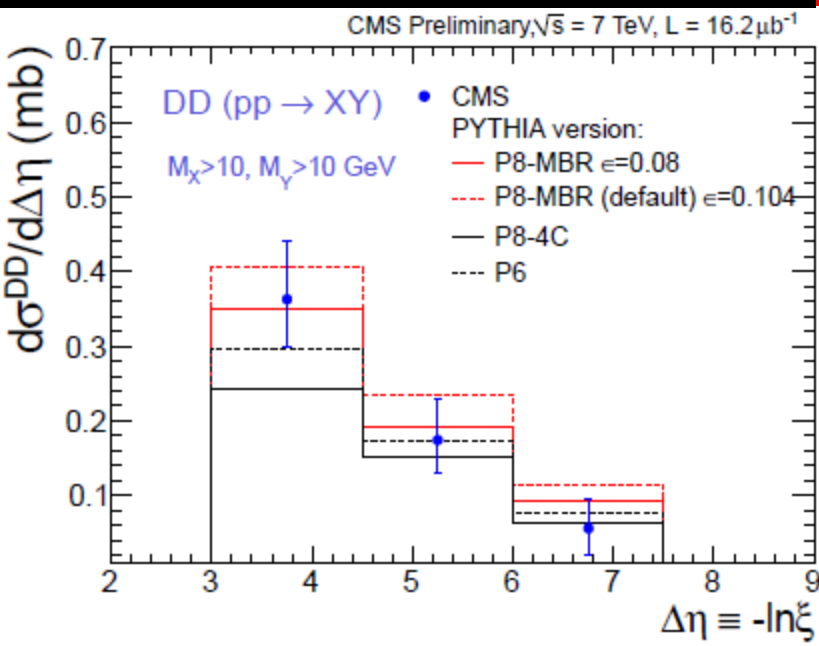
- Systematic dominated by energy scale and background subtraction



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

SD2 Sample only

Trajectory
with $\epsilon = 0.08$
is favored in
DD events

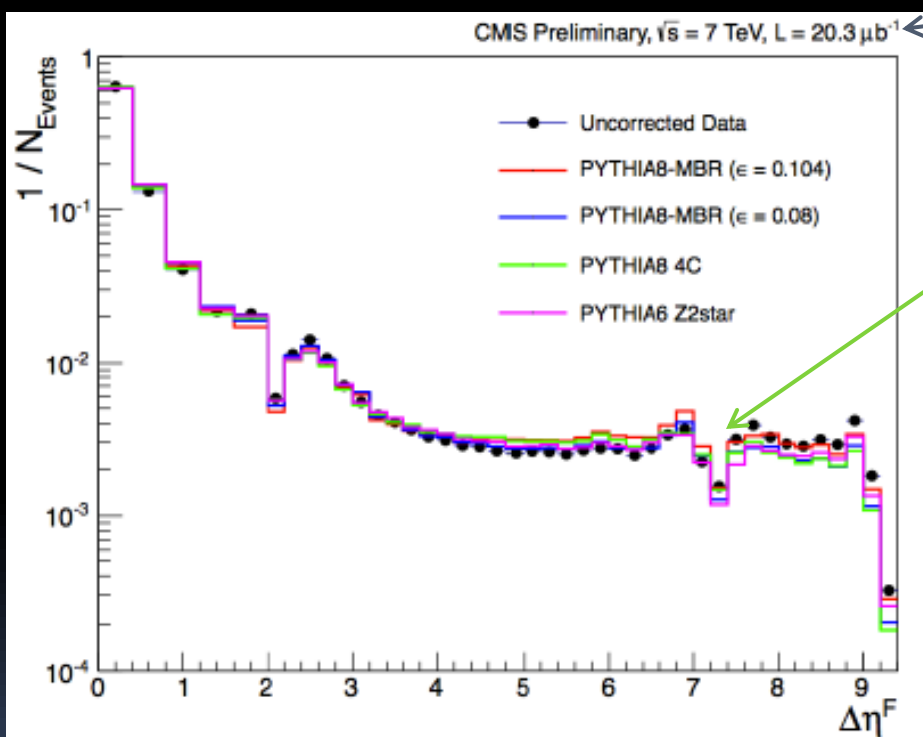


$$\frac{d\sigma^{DD}}{d\Delta\eta} = \frac{N^{data} - (N_{ND} + N_{SD} + N_{CD})^{MC}}{acc \cdot \mathcal{L} \cdot (\Delta\eta)_{bin}}$$

DD Sample only

- Integrating over $\Delta\eta > 3$ and $M_{X,Y} > 10$ GeV
- $\sigma_{vis}^{DD} = 0.93 \pm 0.01$ (stat) $\pm_{0.22}^{0.26}$ (syst) mb

- Difficult to measure the whole $M_x \rightarrow$ measure size of LRG
 - Inclusive – measure the largest forward gap $\Delta\eta_F = \max(4.7 - \eta_{\max}, 4.7 + \eta_{\min})$
 - largest gap between each edge of the detector and the position in η of the first particle moving away from the edge

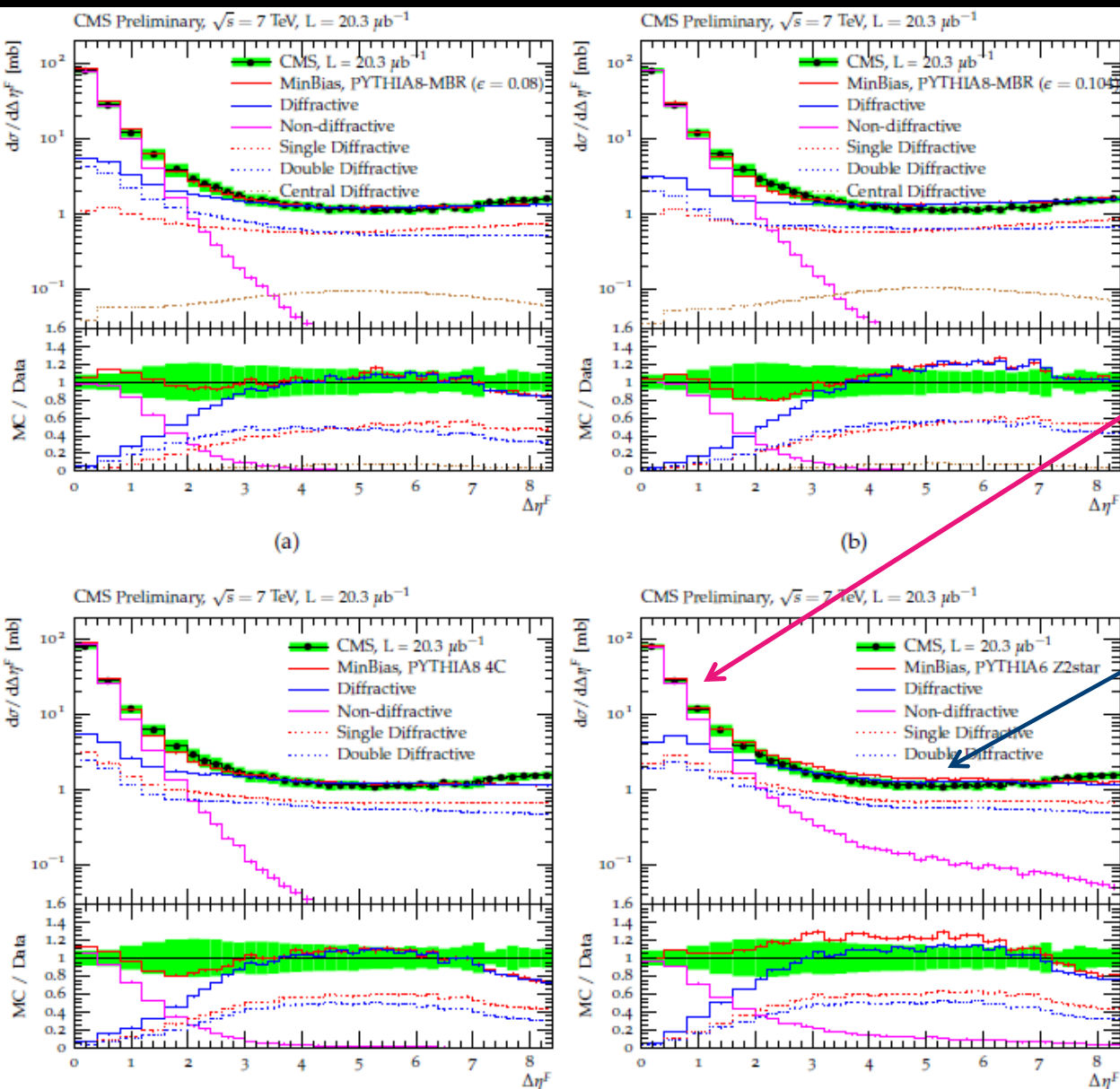


Larger data sample
Negligible pileup

Uncorrected distribution

Has to be corrected by detector
resolution and beam backgrounds

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

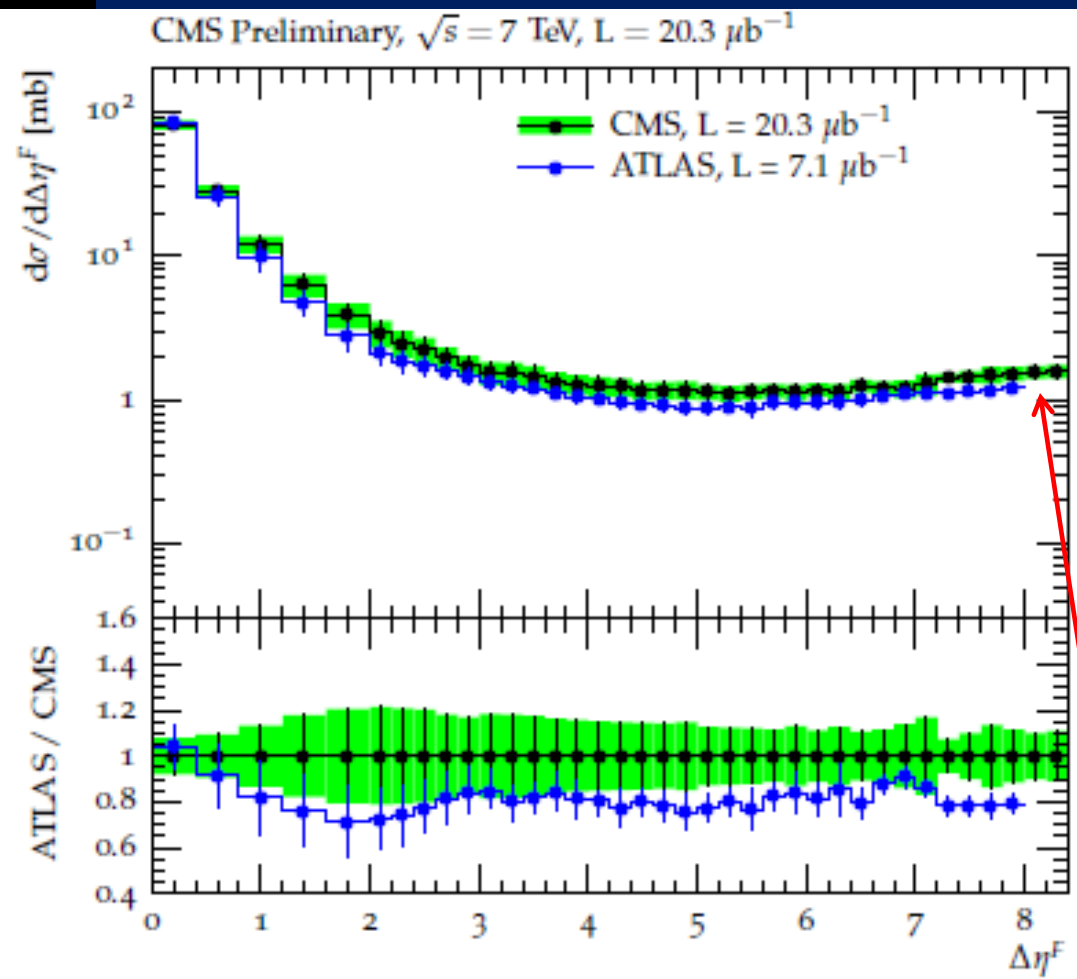


Unfolded and fully corrected distribution compared to MC

Exponential suppression (ND)

Diffractive plateau $\sim 1 \text{ mb} / \Delta\eta_F$

Best description of the data by PYTHIA8-MBR with smaller intercept



Comparison with ATLAS

- Different hadron level definition:
 $|\eta| < 4.7$ (CMS) vs $|\eta| < 4.9$ (ATLAS)
→ up to 5% effect
 - Unfolding based on different MCs:
PYTHIA8-MBR (CMS) vs PYTHIA8 (ATLAS)
→ up to 10% effect
- Agreement within uncertainties

□ → CMS result extends ATLAS measurement by 0.4 unit of gap size

- CMS measured exclusive and diffractive processes at the LHC
- Exclusive processes
 - Standard candle $\gamma\gamma \rightarrow \mu\mu$ used to correct for proton dissociation
 - Search for $\gamma\gamma \rightarrow WW$ → two potential candidates → agreement with SM

$$\sigma(pp \rightarrow p^{(*)} W^+ W^- p^{(*)} \rightarrow p^{(*)} \mu^\pm e^\mp p^{(*)}) = 2.2_{-2.0}^{+3.3} \text{ fb},$$

- AQGC limits two orders of magnitude more stringent than LEP and Tevatron
- Diffractive cross sections measured at 7 TeV
 - $\sigma_{\text{vis}}^{SD} = 4.27 \pm 0.04(\text{stat.}) + 0.65/-0.58(\text{syst.}) \text{ mb for } -5.5 < \log \xi < -2.5$
 - $\sigma_{\text{vis}}^{DD} = 0.93 \pm 0.01(\text{stat.}) + 0.26/-0.22(\text{syst.}) \text{ mb for } \Delta\eta > 3, M_X > 10 \text{ GeV}, M_Y > 10 \text{ GeV}$
 - Good agreement with ATLAS on LRG cross section
- More results coming soon

Extra

- The integrated luminosity (L) is based on the Van der Meer scans
- The uncertainty of the luminosity is 4%: dominates the systematic uncertainties of this analysis
- Number of collisions per bunch crossing follows Poisson
 - Average λ (*pile-up*)

$$\begin{aligned} F_{\text{pileup}} &= \frac{\sum_{i=1}^{\infty} iP(i, \lambda)}{\sum_{i=1}^{\infty} (1 - (1 - \epsilon_{\text{inel}})^i)P(i, \lambda)} \cdot \epsilon_{\text{inel}} = \frac{\epsilon_{\text{inel}}\lambda}{\sum_{i=1}^{\infty} (1 - (1 - \epsilon_{\text{inel}})^i)P(i, \lambda)} = \\ &= 1 + \frac{1}{2}\lambda\epsilon_{\text{inel}} + \frac{1}{12}\lambda^2\epsilon_{\text{inel}}^2 + \mathcal{O}(\lambda^3) \end{aligned}$$

- Correction factor – accounts for multiple collisions being counted as one.

- LHC can access lowest x values

- for central W/Z production at

7 TeV: $x \sim 0.01$

14 TeV: $x \sim 0.005$

- at forward rapidities ($\eta \sim 5$):

7 TeV $x \sim 6 \cdot 10^{-5}$

14 TeV $x \sim 3 \cdot 10^{-5}$

- for central jets with $p_t > 20 \text{ GeV}$

7 TeV: $x \sim 0.006$

14 TeV: $x \sim 0.003$

- at forward rapidities ($\eta \sim 5$):

7 TeV: $x \sim 4 \cdot 10^{-5}$

14 TeV: $x \sim 2 \cdot 10^{-5}$

J. M. Campbell, J. W. Huston, and W. J. Stirling.
Hard Interactions of Quarks and Gluons: A Primer for LHC Physics.
Rept. Prog. Phys., 70:89, 2007.

LHC parton kinematics

