

# CMS RESULTS ON DIFFRACTION AND EXCLUSIVE PRODUCTION



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ON BEHALF OF CMS COLLABORATION



10th International Workshop on Multiple Partonic  
Interactions at the LHC

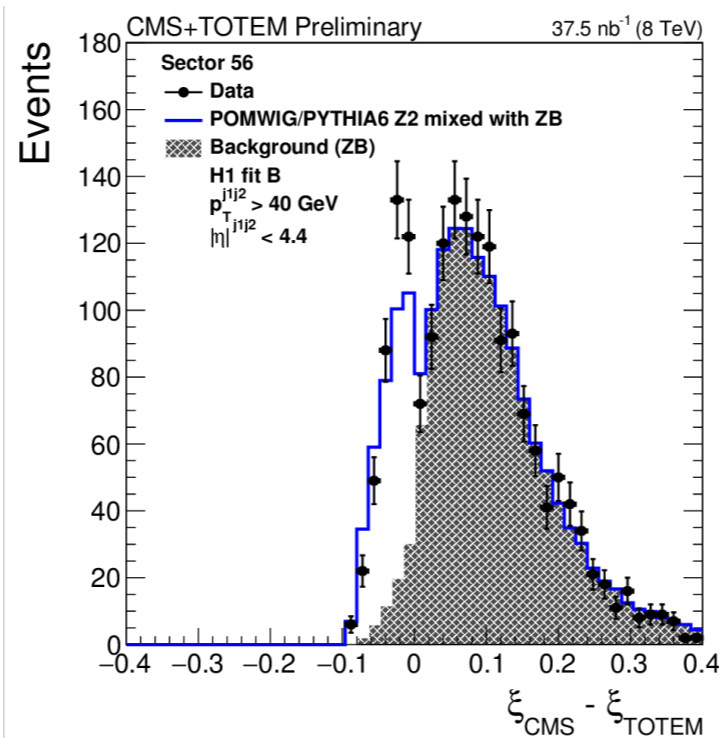
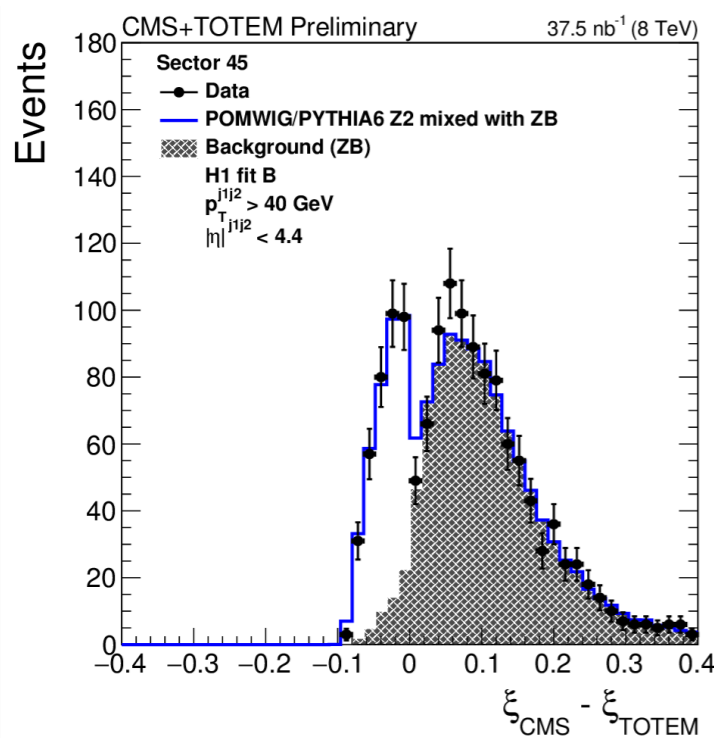
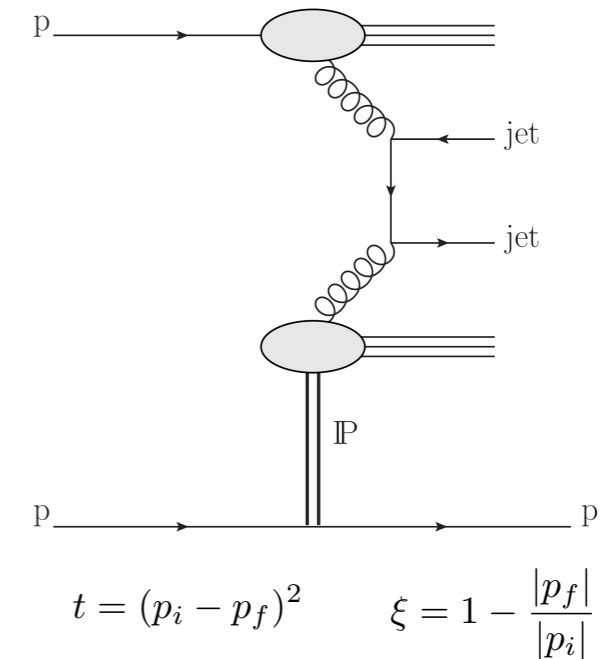
DECEMBER 13, 2018 PERUGIA

# CONTENT

- Measurement of dijet production with a leading proton in proton-proton collisions at  $\sqrt{s} = 8$  TeV
- Exclusive  $\rho^0(770)$  photoproduction in ultra-peripheral pPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV
- Measurement of exclusive  $\Upsilon$  photoproduction from protons in pPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV
- Evidence for light-by-light scattering & searches for axion-like particles in ultraperipheral PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV

# DIFFRACTIVE DIJET PRODUCTION

- First CMS-TOTEM measurement with tagged protons in low pile-up data at 8 TeV
- Dijets in CMS, scattered proton in RP.  
Background: inclusive dijets in coincidence with random RP track from pileup or beam-background proton.



Matching: compare  $\xi$  calculated from protons and from jets

$$\xi_{\text{CMS}}^{\pm} = \frac{\sum (E^i \pm p_z^i)}{\sqrt{s}},$$

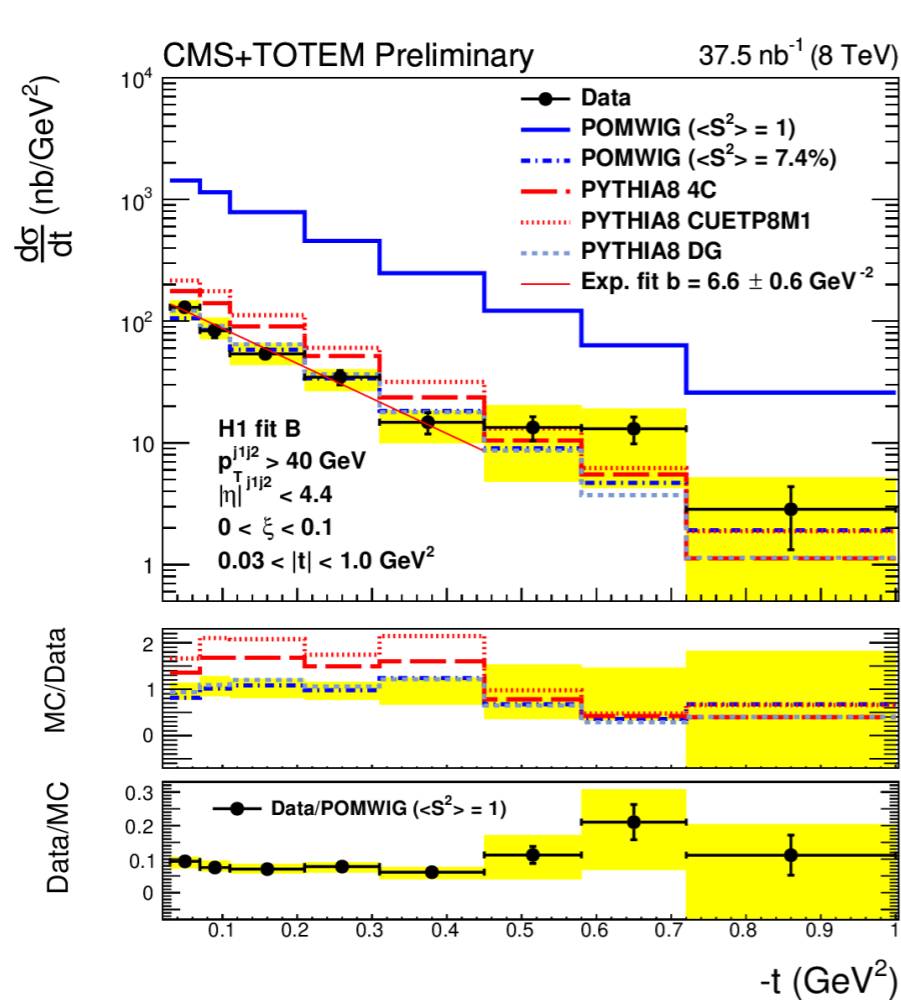
$\xi_{\text{CMS}} - \xi_{\text{TOTEM}} < 0$  selects signal events

Jet selection:

$p_T > 40 \text{ GeV}$ ,  $|\eta| < 4.4$ ,  $\xi < 0.1$  and  $0.03 < |t| < 1 \text{ GeV}^2$

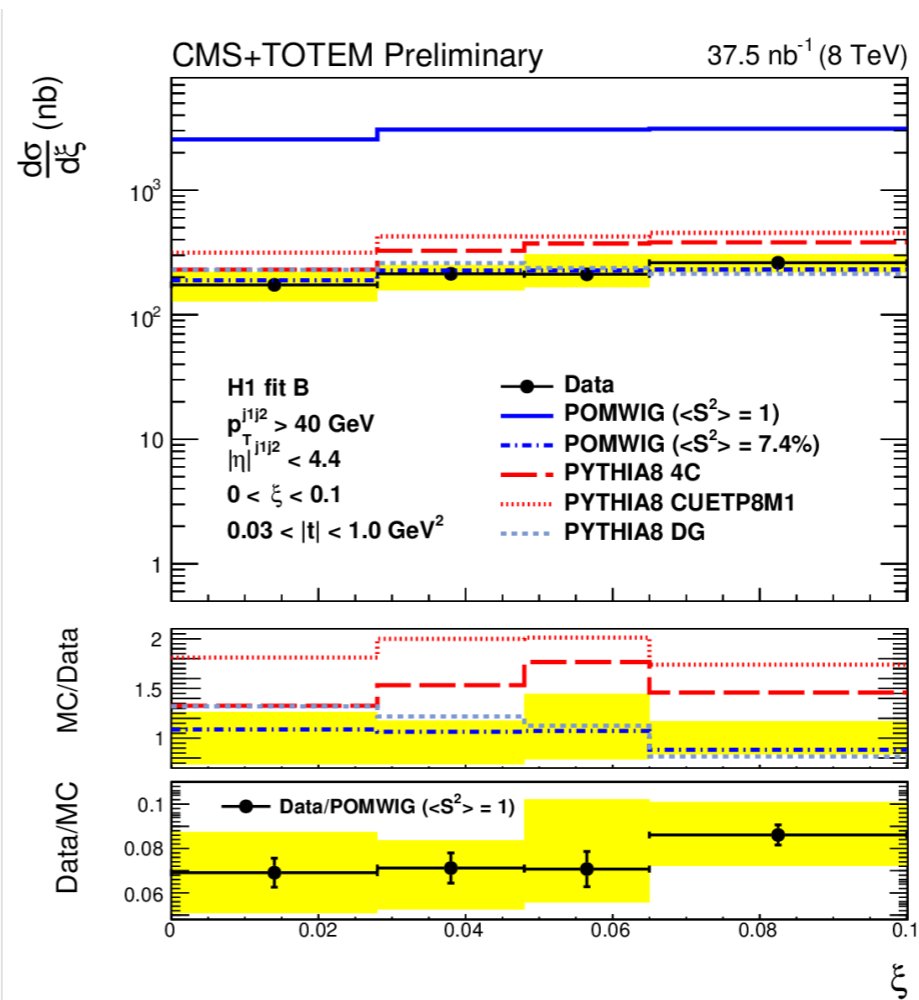
# DIFFRACTIVE DIJET PRODUCTION

- Differential cross section as a function of  $t$  and  $\xi$ :



Exponential fit in the region  $0.03 < |t| < 0.45 \text{ GeV}^2$

$$d\sigma/dt \propto \exp^{-b|t|} \quad b = 6.6 \pm 0.6 \text{ (stat)} \text{ }^{+1.0}_{-0.8} \text{ (syst)} \text{ GeV}^{-2},$$



Total integrated cross section in kinematic region:

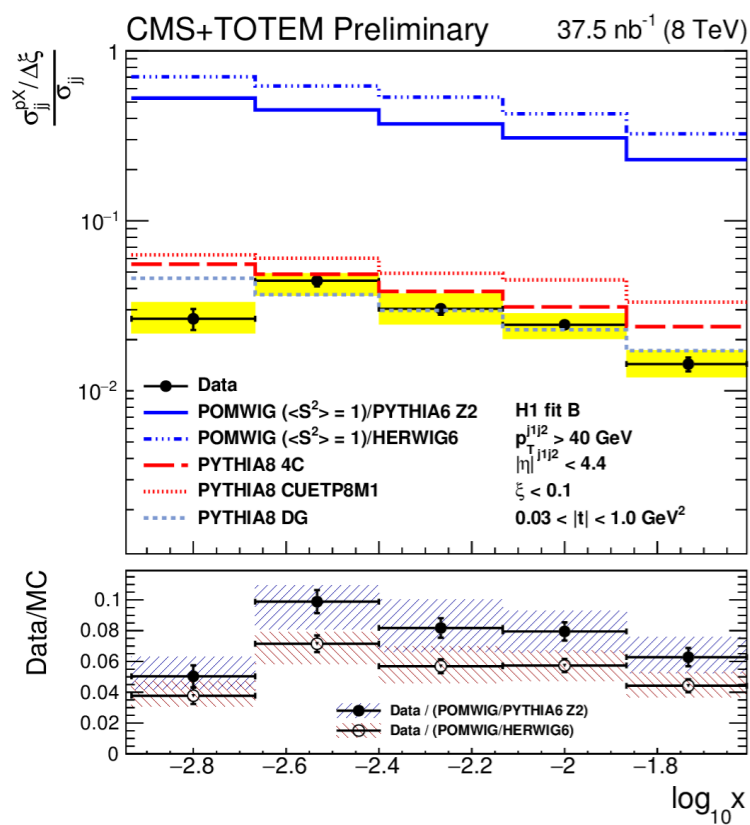
$$\sigma_{jj}^{pX} = 21.7 \pm 0.9 \text{ (stat)} \text{ }^{+3.0}_{-3.3} \text{ (syst)} \pm 0.9 \text{ (lumi)} \text{ nb.}$$

# DIFFRACTIVE DIJET PRODUCTION

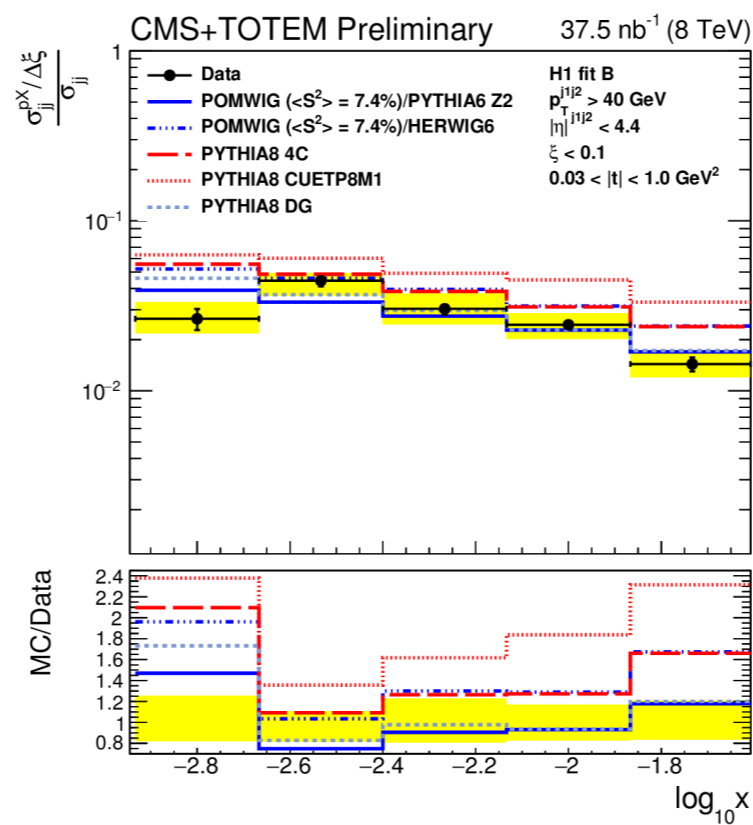
- Ratio of diffractive to inclusive dijets as a function of  $x$ .

$$x^\pm = \frac{\sum_{\text{jets}} (E^{\text{jet}} \pm p_z^{\text{jet}})}{\sqrt{s}}$$

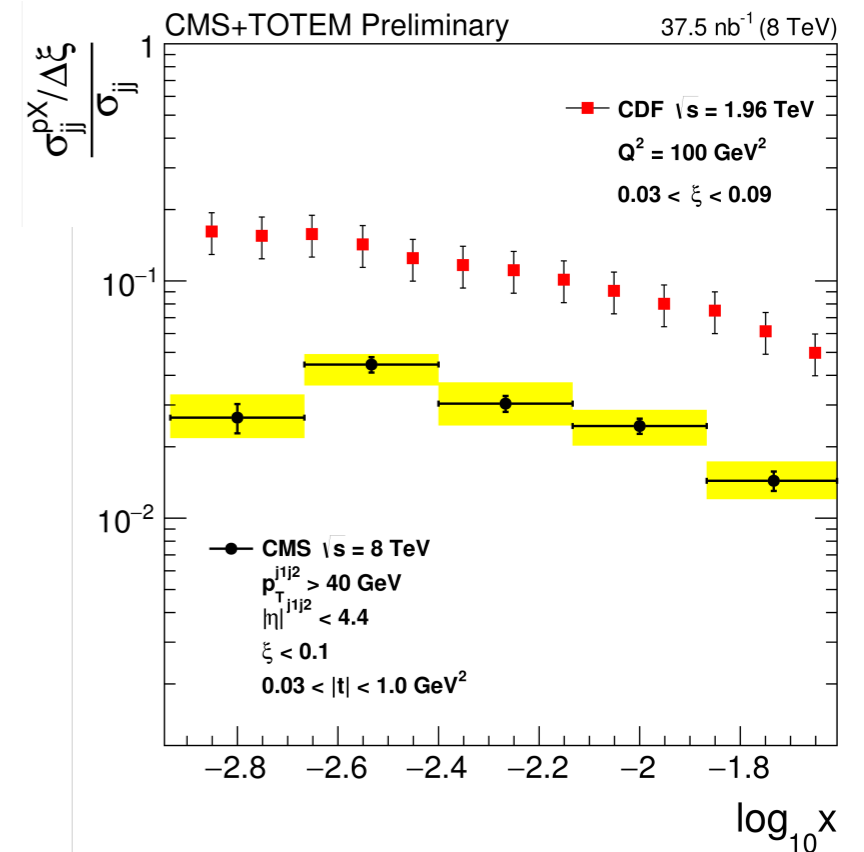
$$R = \left( \sigma_{\text{jj}}^{\text{PX}} / \Delta\xi \right) / \sigma_{\text{jj}} = 0.025 \pm 0.001 (\text{stat}) \pm 0.003 (\text{syst})$$



Pythia8 DG: gap survival with Dynamic Gap model based on MPI shows good agreement with data



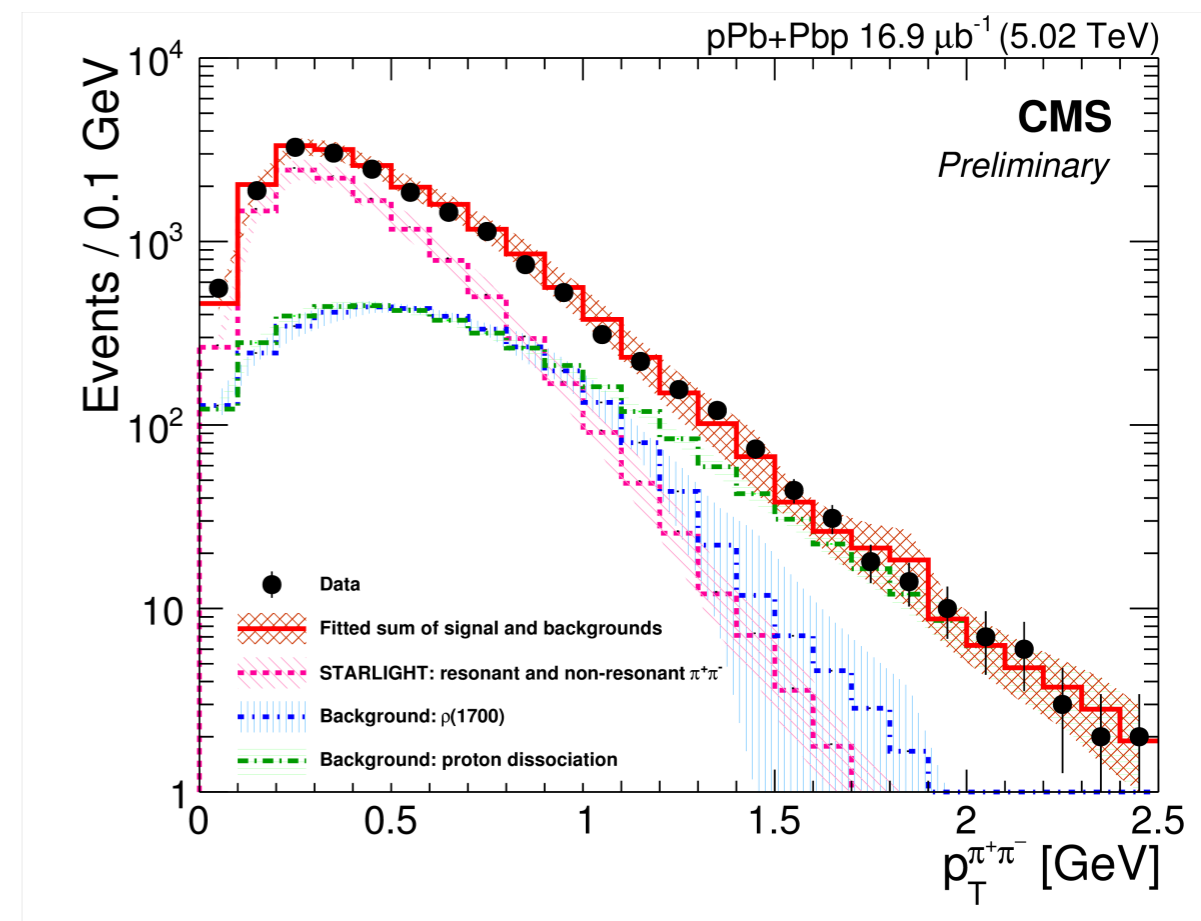
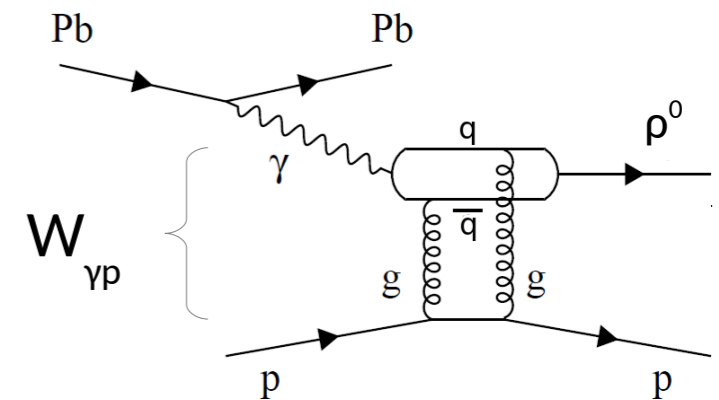
Region:  $-2.9 < \log_{10} x < -1.6$



Comparison to CDF results:  
factor of  $\sim 3$  suppression wrt to 1.96 TeV,  
larger contributions from  
rescattering processes

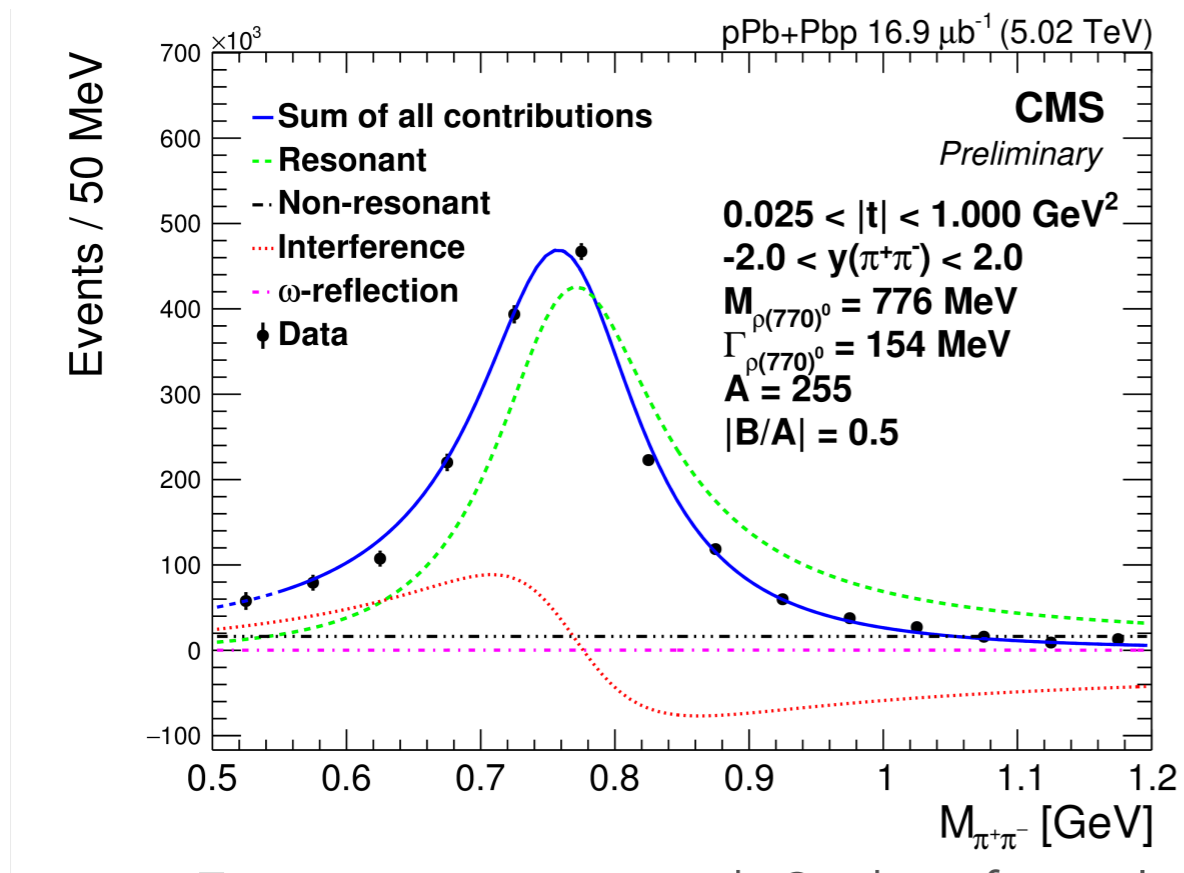
# EXCLUSIVE RHO

- Exclusive vector meson photoproduction in ultra-peripheral pPb collisions (5.02 TeV)  
 $\gamma p \rightarrow \rho^0(770)p$  in  $\pi^+\pi^-$  decay channel
- Kinematics and event selection:  
 $p_T > 0.4$  (0.2) GeV for lead. (sublead.)  $\pi$ ,  
 $|\eta| < 2.0$ .  
 exclusivity condition: calorimeter vetos including CASTOR, ZDC
- Main remaining backgrounds:  
 non-resonant  $\pi^+\pi^-$ ,  $\rho^0(1700) \rightarrow 4\pi$ ,  
 $\omega$  production, proton dissociation.

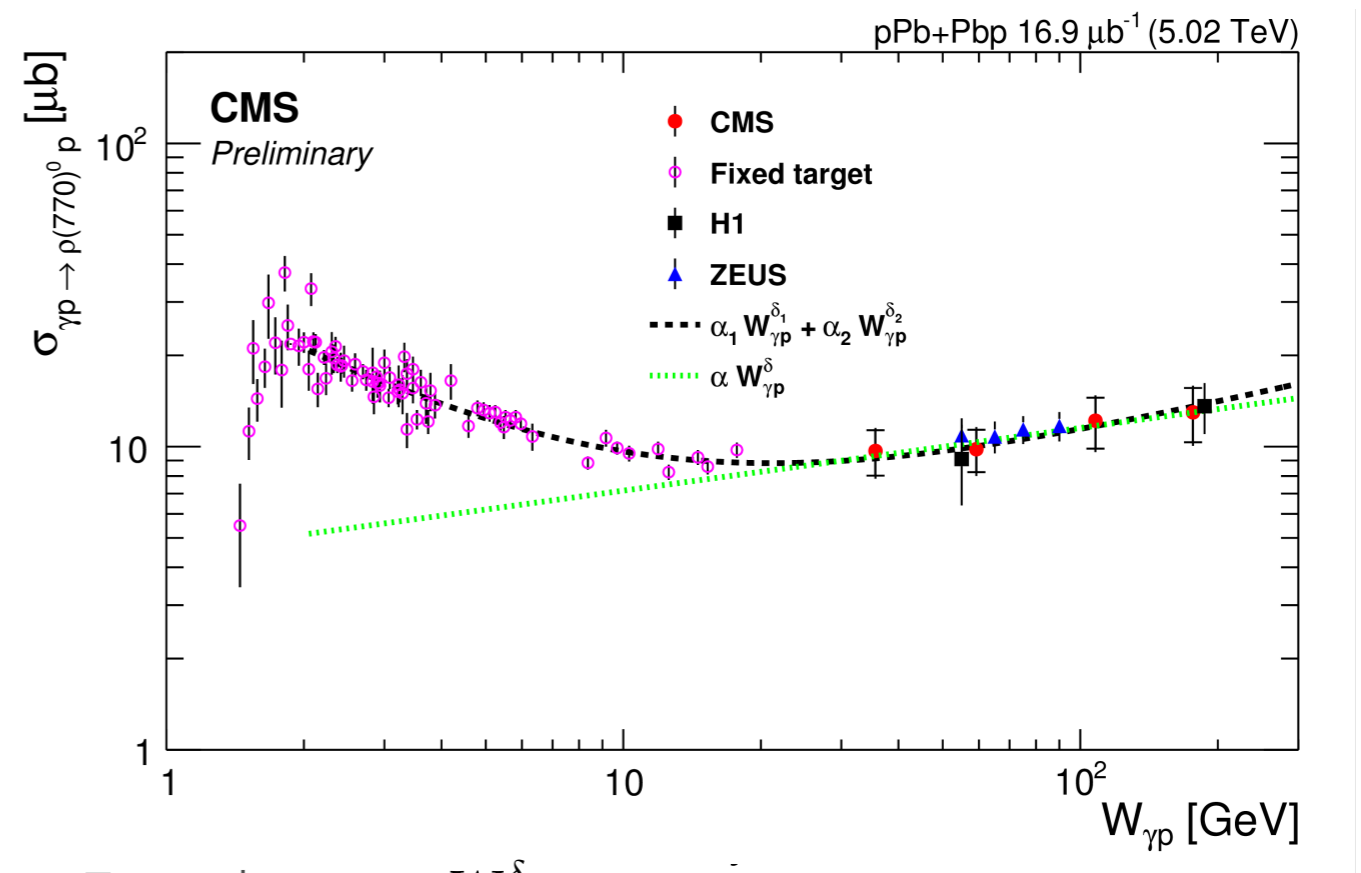


# EXCLUSIVE RHO

- Invariant mass and cross section as function of  $W_{\gamma p}$ :



Fit invariant mass with Söding formula



Fit with:  $\sigma = \alpha W_{\gamma p}^\delta$   $\delta = 0.23 \pm 0.14$  (stat)  $\pm 0.04$  (syst)

Good agreement with HERA data and Regge theory (soft Pomeron)

Integrated cross section:  
 $11.2 \pm 1.4$  (stat)  $\pm 1.0$  (syst)  $\mu\text{b}$ .

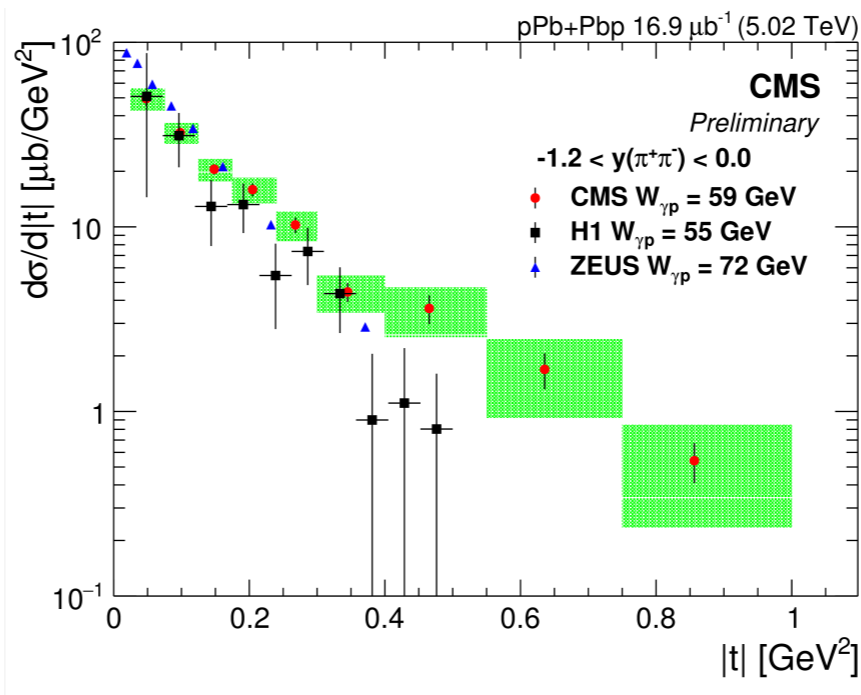
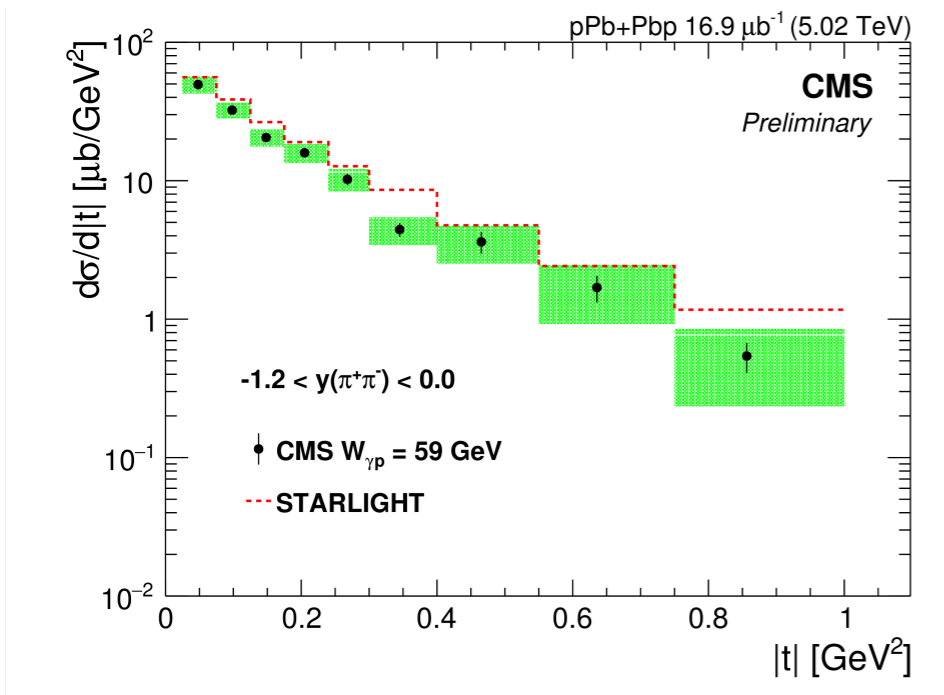
Ratio of the nonres. to res. contributions:

$|B/A| = 0.50 \pm 0.05$  (stat);  $0.56 \pm 0.06$  (stat) (for  $|t| < 0.5$ )

H1:  $0.57 \pm 0.09$  (stat) and ZEUS:  $0.70 \pm 0.04$  (stat)

# EXCLUSIVE RHO

- Cross section as function of  $|t|$ :  $|t| \approx p_T^2$



Fit  $|t|$  spectra with exponential:

$$e^{-bt+ct^2}$$

$$0.025 < |t| < 0.500 \text{ GeV}^2.$$

Good agreement with HERA data

- Fit  $b$  versus  $W_{\gamma p}$ :

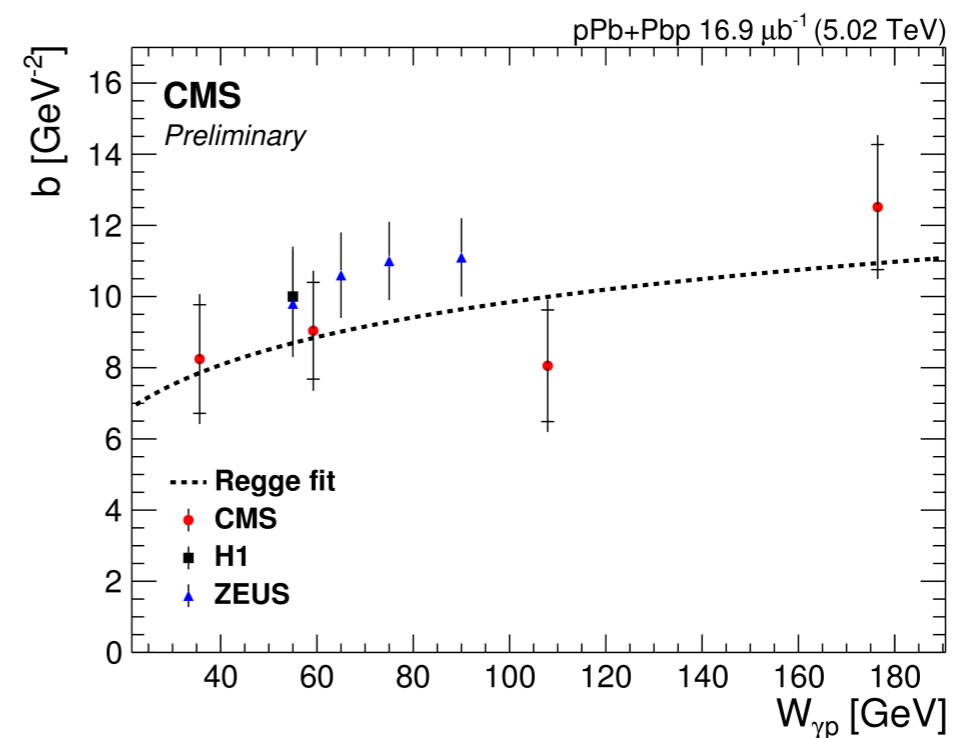
$$b = b_0 + 2\alpha' \cdot \ln\left(\frac{W_{\gamma p}}{W_0}\right)^2$$

Pomeron slope:

CMS:  $\alpha' = 0.48 \pm 0.33$  (stat)  $\pm 0.12$  (syst)  $\text{GeV}^{-2}$

ZEUS:  $\alpha' = 0.23 \pm 0.15$  (stat)  $\pm 0.11$  (syst)  $\text{GeV}^{-2}$

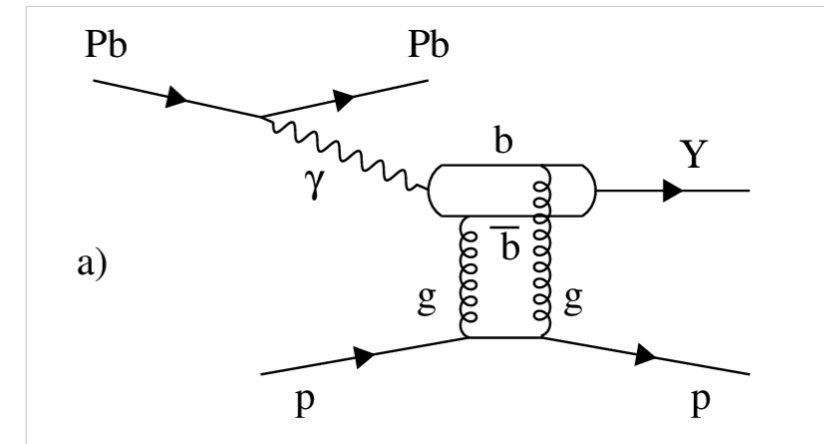
Regge theory (soft Pomeron):  $\alpha' \approx 0.25 \text{ GeV}^{-2}$





# EXCLUSIVE $\Upsilon$

- Exclusive vector meson photoproduction in ultra-peripheral pPb collisions (5.02 TeV)  
 $\gamma p \rightarrow \Upsilon(nS)(n = 1, 2, 3) p$  in  $\mu^+\mu^-$  decay channel



- Kinematics:

$p_{T\mu} > 3.3$  GeV; Di-muon system:  $0.1 < p_T < 1$  GeV and  $|\eta| < 2.2$ .

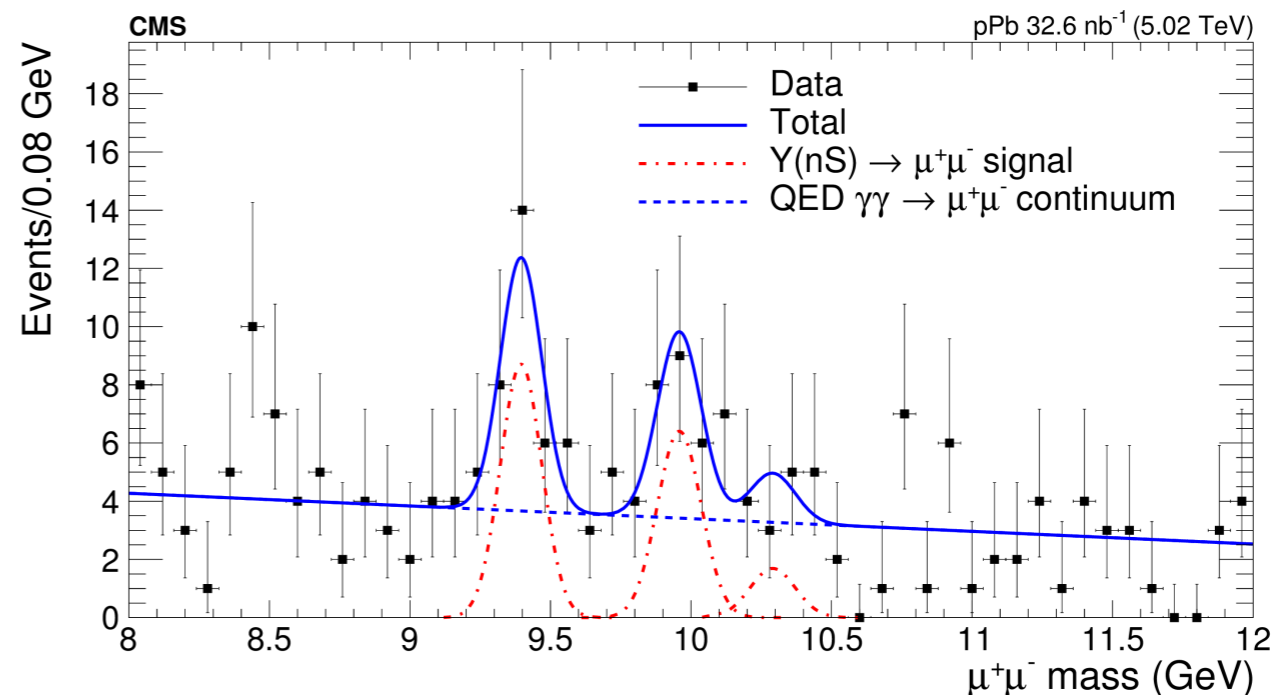
exclusivity: no extra charged particles with  $p_T > 0.1$  GeV & no activity in HF

- Backgrounds:

QED:  $\gamma\gamma \rightarrow \mu^+\mu^-$

proton dissociation  
(semi-exclusive)

inclusive



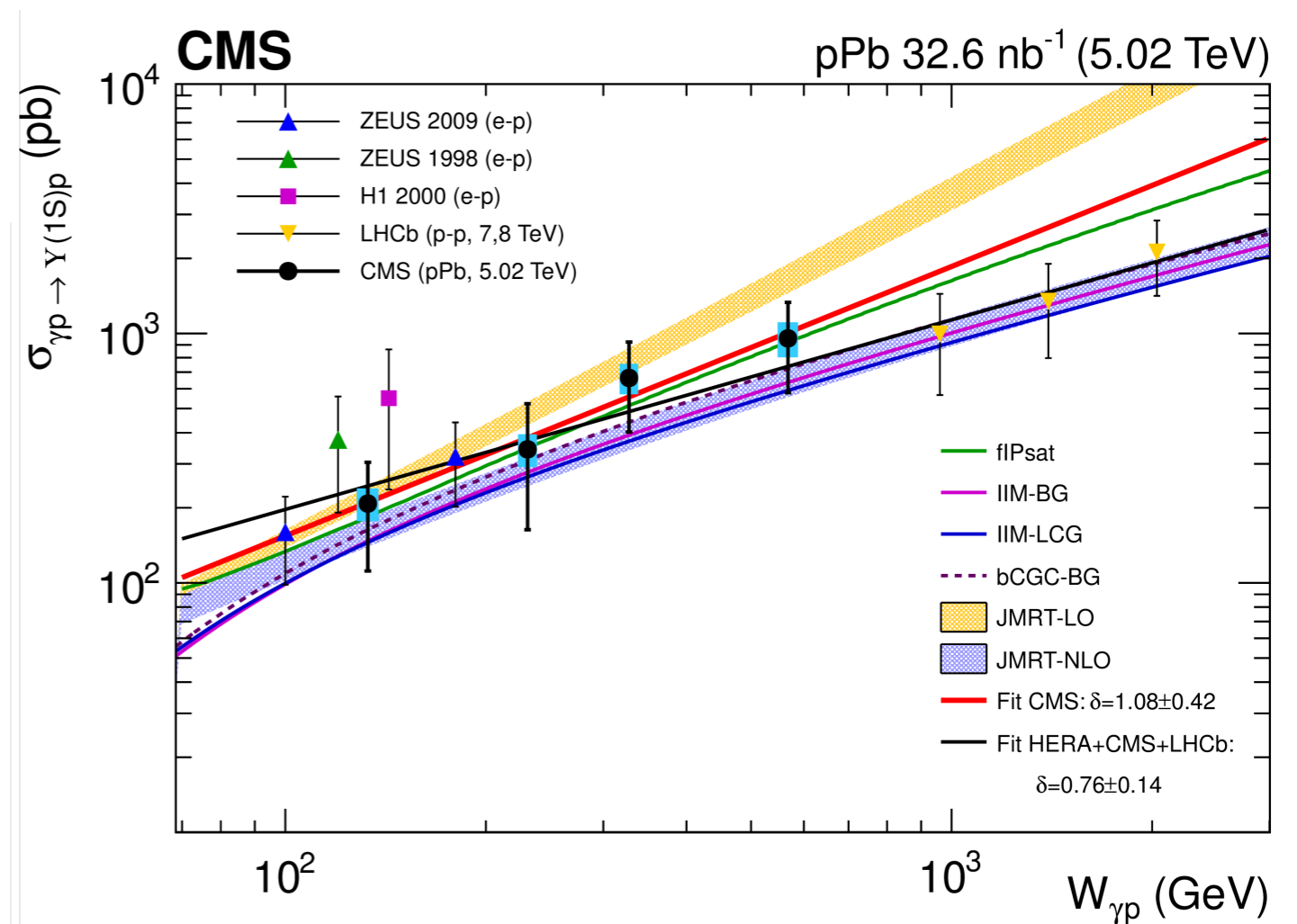
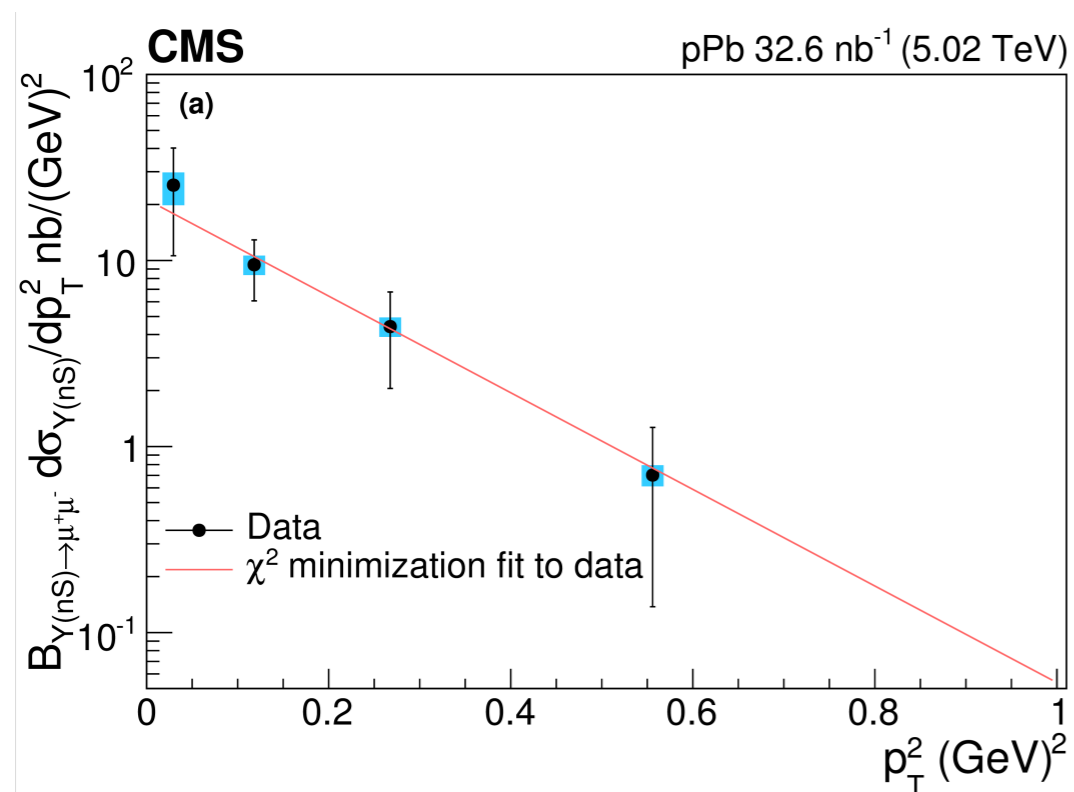
arXiv:1809.11080

# EXCLUSIVE $\gamma$

- Cross section as function of  $p_T^2$  and  $W_{\gamma p}$ :

Perform exponential fit:

$$b = 6.0 \pm 2.1 \text{ (stat)} \pm 0.3 \text{ (syst)} \text{ GeV}^{-2}$$



Data sensitive to signs of saturation: new constraints on the evolution of gluon density at low  $x$ .

# LIGHT-BY-LIGHT SCATTERING

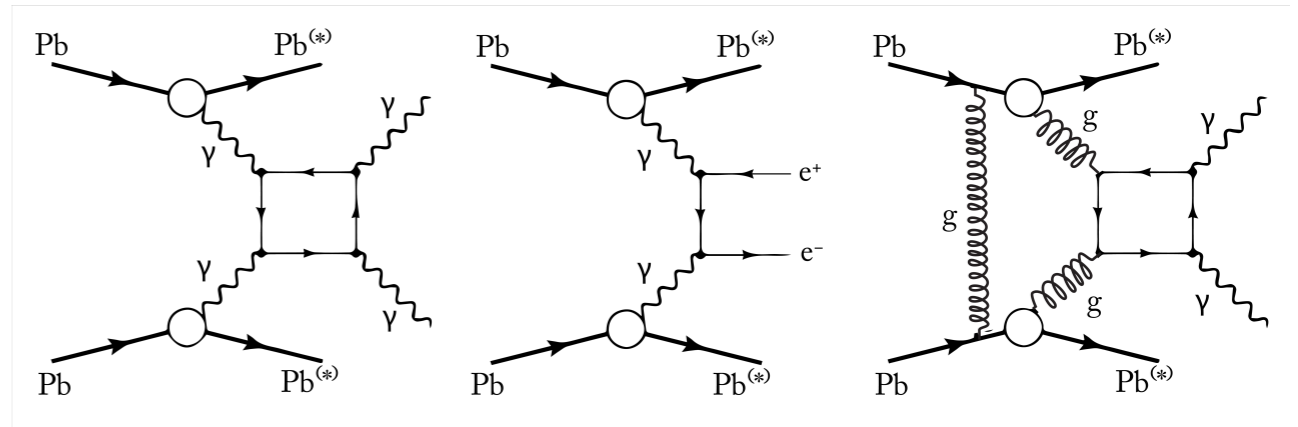
- Elastic  $\gamma\gamma \rightarrow \gamma\gamma$  scattering

in PbPb collisions at 5.02 TeV

fundamental QED/QCD process

difficult to observe due to very small  $O(\alpha^4)$  cross section

sensitive to BSM physics (loop contributions, axions)



- Event selection:

Two back-to-back photons:  $E_T > 2 \text{ GeV}$  and  $|\eta| < 2.4$ .

$P_{\gamma\gamma} < 1 \text{ GeV}$ ,  $m_{\gamma\gamma} > 5 \text{ GeV}$

Exclusivity: no tracks, no extra neutral activity.

- Backgrounds: CEP:  $gg \rightarrow \gamma\gamma$  and QED:  $\gamma\gamma \rightarrow e+e-$

# LIGHT-BY-LIGHT SCATTERING

- Signal selection  $A_\phi < 0.01$ :

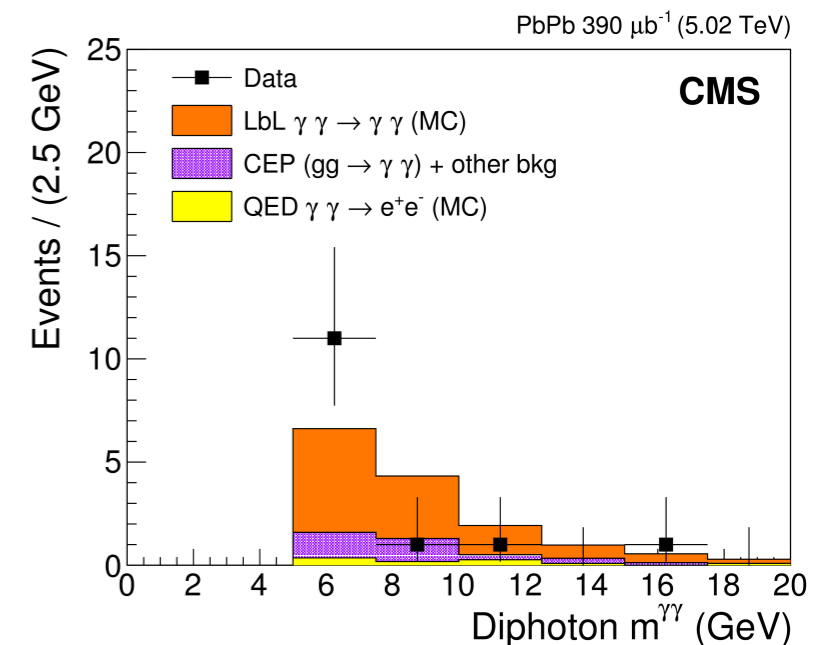
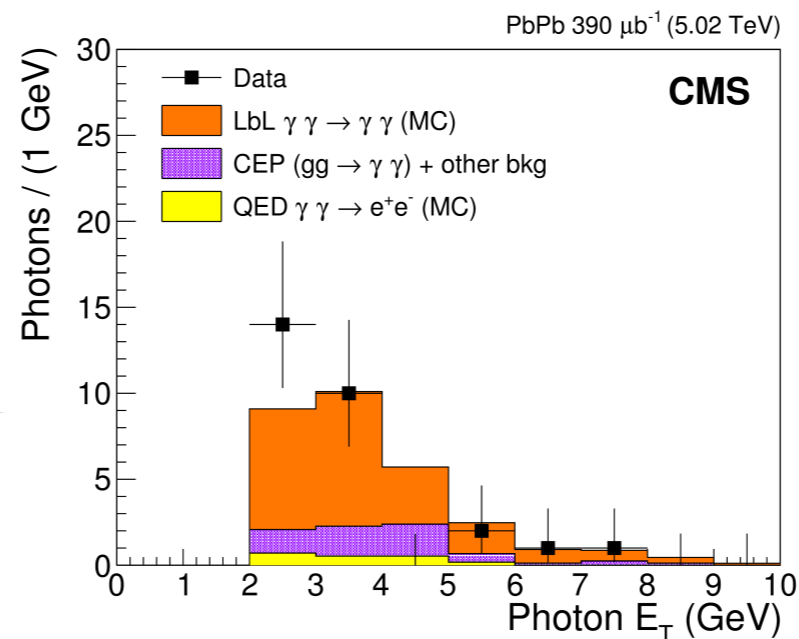
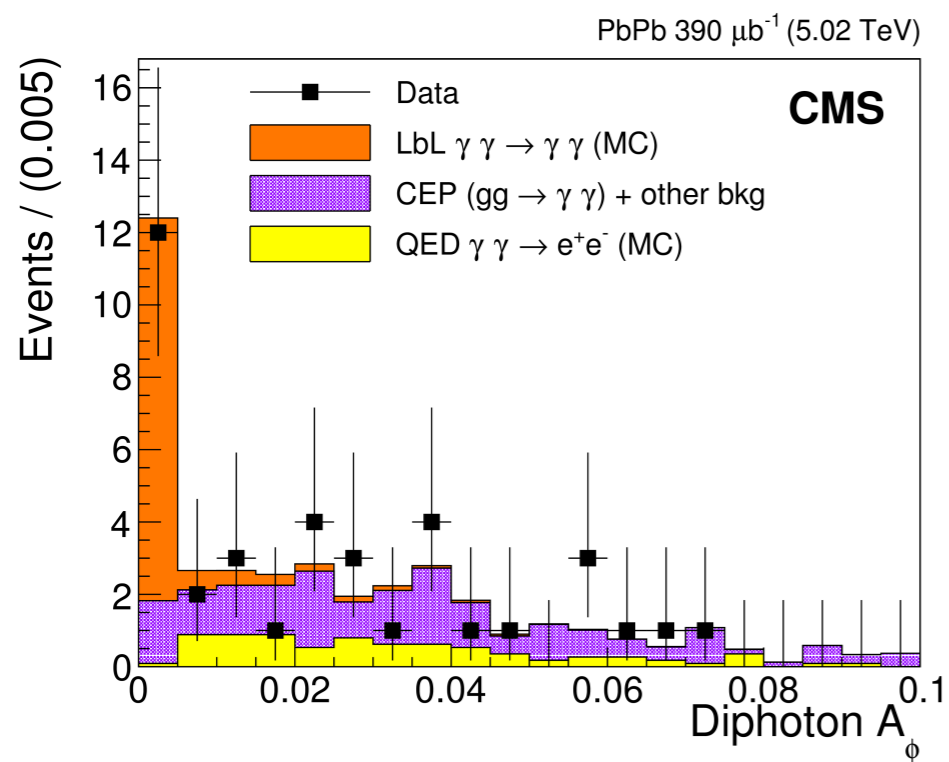
Acoplanarity distribution:

Observed: 14 events

Expected:  $11.1 \pm 1.1$  (th) signal

$4.0 \pm 1.2$  (stat) background events,

Significance:  $4.1 \sigma$  (expected  $4.4 \sigma$ )



$$\sigma(\Upsilon\Upsilon \rightarrow \Upsilon\Upsilon) / \sigma(\Upsilon\Upsilon \rightarrow e^+e^-) = [25.0 \pm 9.6 \text{ (stat)} \pm 5.8 \text{ (syst)}] \times 10^{-6}$$

Measured fiducial  $\sigma(\Upsilon\Upsilon \rightarrow \Upsilon\Upsilon)$  cross section:

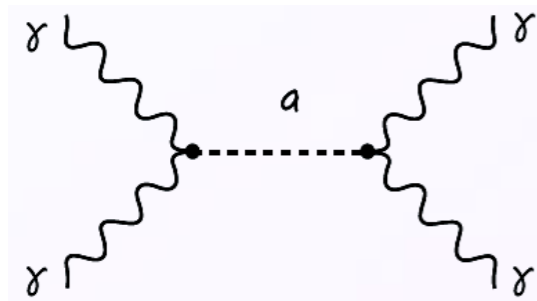
$$120 \pm 46 \text{ (stat)} \pm 28 \text{ (syst)} \pm 4 \text{ (th)} \text{ nb}$$

Compare with theory:  $138 \pm 14 \text{ nb}$

ATLAS in a similar region: 13 candidates, expected background of  $2.6 \pm 0.7$  events. NP 13 (2017) 852

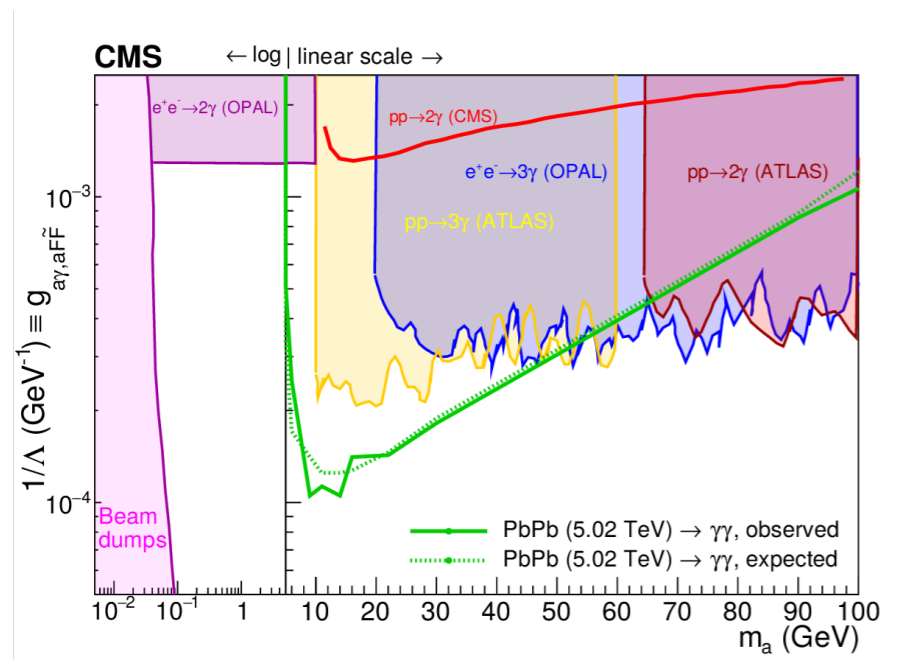
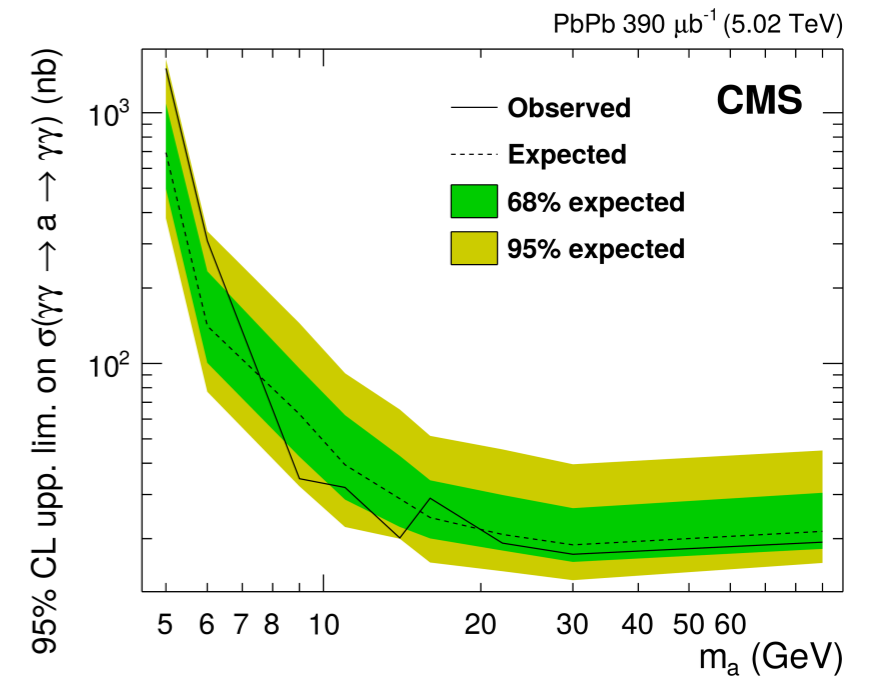
# LIGHT-BY-LIGHT SCATTERING

- Exclusion limits on Axion-Like Particles (ALPs):

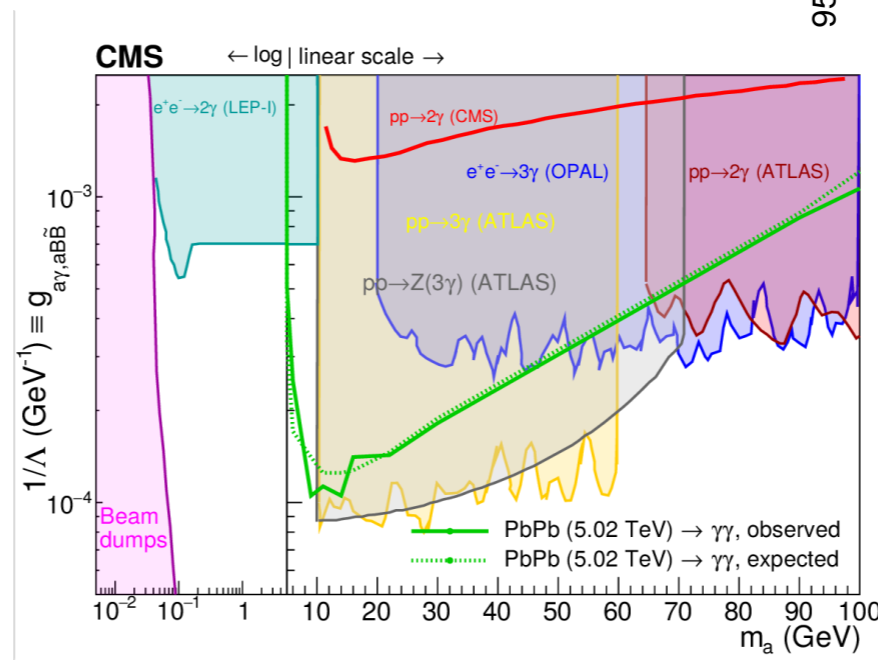


possible narrow resonances in  $\Upsilon\Upsilon$  mass spectra

Light-by-light scattering events treated as background.



ALPs coupling to EM currents



ALPs coupling to EW currents

Most stringent limits at low masses:  
5-50 GeV for EM and  
5-10 GeV for EW

# SUMMARY

- Diffractive dijets with proton tag measured for the first time at the LHC at 8 TeV
- Results on exclusive vector meson photoproduction in pPb collisions at 5.02 TeV for  $\rho^0(770)$  and  $\Upsilon(nS)(n = 1, 2, 3)$ : new input to constrain gluon densities
- Measurement of light-by-light scattering: set new limits on axion-like particle production

<https://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ/index.html>

<https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FSQ/index.html>