

Latest results of diffractive and exclusive measurements with CMS

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On behalf of the CMS Collaboration

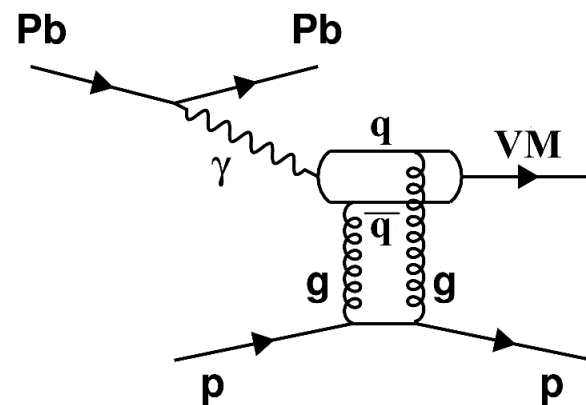
DifLowx 2018: Diffraction and Low-x 2018, 26 Aug-1 Sep 2018,
Reggio Calabria, Italy

Outline

- CMS Experiment is a perfect facility to study exclusive processes
 - Exclusive Upsilon production in pPb (FSQ-13-009) @ Diffraction 2016
 - LbL scattering in PbPb (FSQ-16-012) – see talk by Michael Murray tomorrow
 - Exclusive J/Psi in PbPb (HIN-12-009)
- Exclusive photoproduction of ρ^0 meson in pPb collisions (FSQ-16-007)
 - Motivation
 - CMS Detector
 - Signal extraction and backgrounds
 - Experimental results
 - Total cross-section as a function of $W_{\gamma p}$
 - Differential cross sections as a function of $|t|$ ($t \approx p_T^2$)
- Outlook

Motivation: Exclusive vector meson production

- The exclusive production is studied in ultraperipheral pPb collisions
- Ions interact via photons
- The photon flux grows with the square of the charge, Z^2



Motivation: Exclusive vector meson production

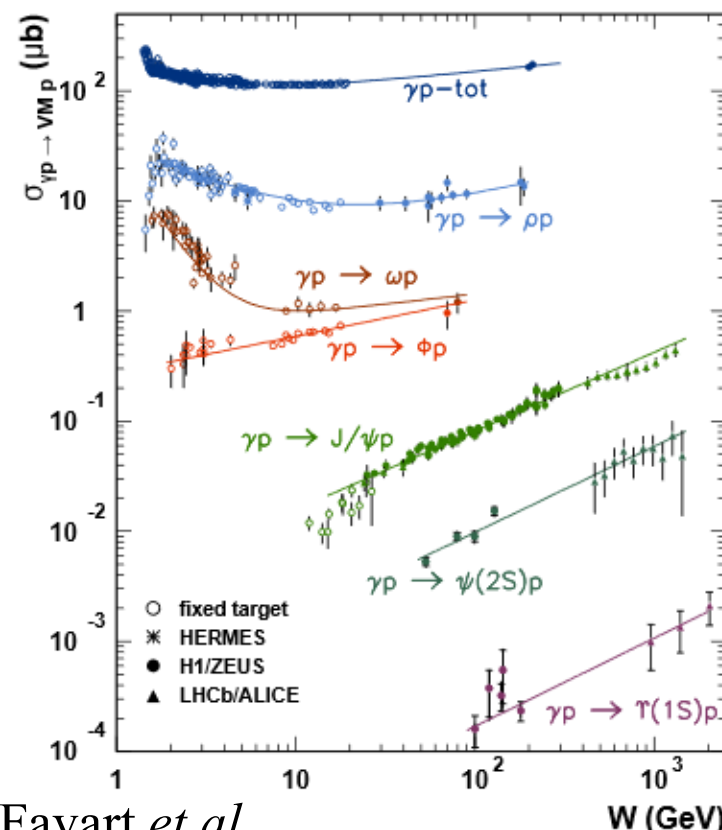
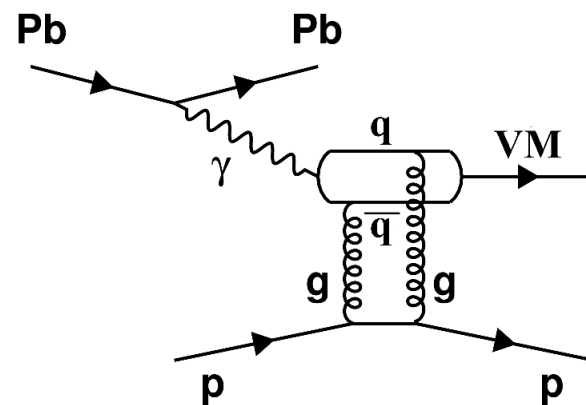
- The exclusive production is studied in ultraperipheral pPb collisions
- Ions interact via photons
- The photon flux grows with the square of the charge, Z^2
- Photoproduction process is sensitive to the gluon density squared in the nucleon (nucleus)

$$\left. \frac{d\sigma_{\gamma p, A \rightarrow V p, A}}{dt} \right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xG(x, Q^2)]^2$$

$$\sigma_{\gamma p \rightarrow VM p} = \frac{1}{b} \left. \frac{d\sigma_{\gamma p, A \rightarrow VM p, A}}{dt} \right|_{t=0}$$

- Probe gluon distributions in the proton at low x (10^{-4} to $2 \cdot 10^{-2}$)
- Photonuclear cross-section shows power law dependence with $W_{\gamma p}$

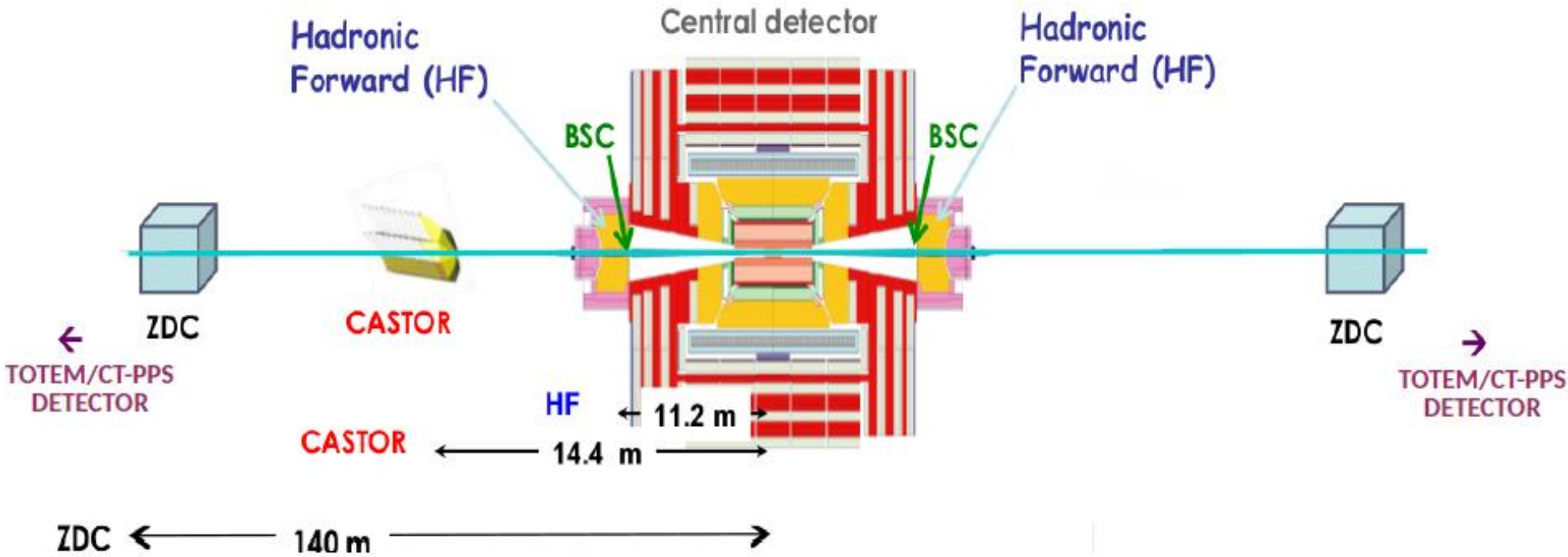
$$\sigma \propto W_{\gamma p}^\delta$$



L. Favart *et al.*

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Forward CMS Detectors



Hadron Endcap Calorimeter (HE): $1.3 < |\eta| < 3.0$

Hadron Forward Calorimeter (HF): $3.0 < |\eta| < 5.2$

CASTOR Calorimeter: $-6.6 < \eta < -5.2$

Zero Degree Calorimeter (ZDC): $|\eta| > 8.3$

CMS offers perfect coverage in the forward region

Exclusive ρ^0 -meson photoproduction

- 2013 pPb data at 5.02 TeV with 16.9 nb^{-1}
 - Ultra-peripheral collisions

CMS-FSQ-16-007

- **Exclusivity selection:**

- Only two tracks (π^\pm)
- No calorimeter signal

Selection	Number of selected events	
	pPb $7.4 \mu\text{b}^{-1}$	Pbp $9.6 \mu\text{b}^{-1}$
Integrated luminosity		
Leading HF tower $< 3.0 \text{ GeV}$	52 508	66 278
Exactly two tracks	17 771	21 583
Track purity [26]	16 085	20 278
$ \eta_{\text{track}} < 2.0,$	12 707	16 037
$p_{\text{T}}^{\text{leading}} > 0.4 \text{ GeV}, p_{\text{T}}^{\text{subleading}} > 0.2 \text{ GeV}$	12 364	15 572
$ z_{\text{vertex}} < 15 \text{ cm}$	11 924	15 052
Leading HE tower $< 1.95 \text{ GeV}$	11 563	14 643
CASTOR energy $< 9 \text{ GeV}$	9405	-
ZDC ⁺ energy $< 500 \text{ GeV}$	-	12 475
ZDC ⁻ energy $< 2000 \text{ GeV}$	9099	-
Opposite-sign pairs	8507	11 553
Same-sign pairs	592	922

The sign of the rapidity is changed for one of the samples before merging

More than 20 000 ρ^0 -candidates found
in the combined pPb and Pbp data sample!

Signal extraction and backgrounds

**Two main backgrounds to ρ^0 signal
known from HERA Experiments:**

1. Proton dissociation – high- p_T region

Data driven approach requiring activity in the forward detectors (HF, CASTOR or ZDC)

Signal extraction and backgrounds

CMS-FSQ-16-007

Two main backgrounds to ρ^0 signal known from HERA Experiments:

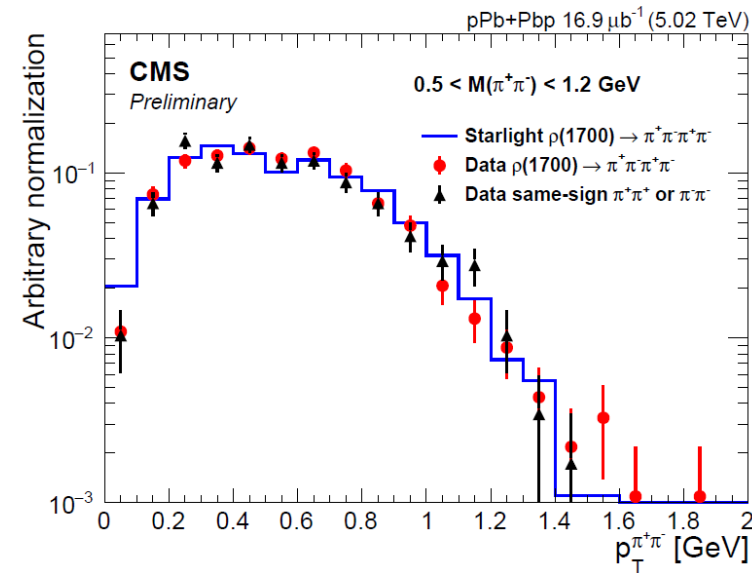
1. Proton dissociation – high- p_T region

Data driven approach requiring activity in the forward detectors

2. $\rho(1700)^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ - mid- p_T region

- Modeled by the STARLIGHT MC Generator
- The main source of same-sign events

Validation is performed by comparing the shapes of p_T distributions of 2 track events



Signal extraction and backgrounds

CMS-FSQ-16-007

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Other considered background contributions:

3. non-resonant $\pi^+\pi^-$ and ω -production

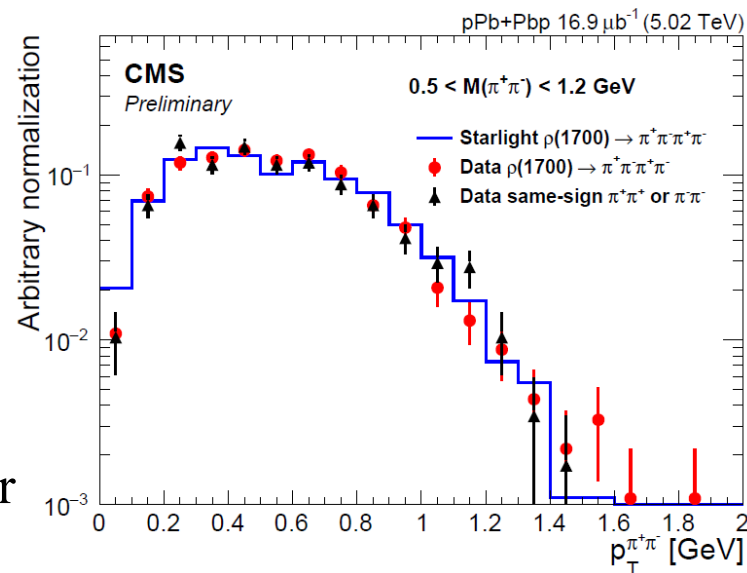
Accounted in the invariant mass fits

4. $\phi \rightarrow K^+K^-$

Removed by $M(K^+K^-) > 1.04$ GeV cut similar to HERA

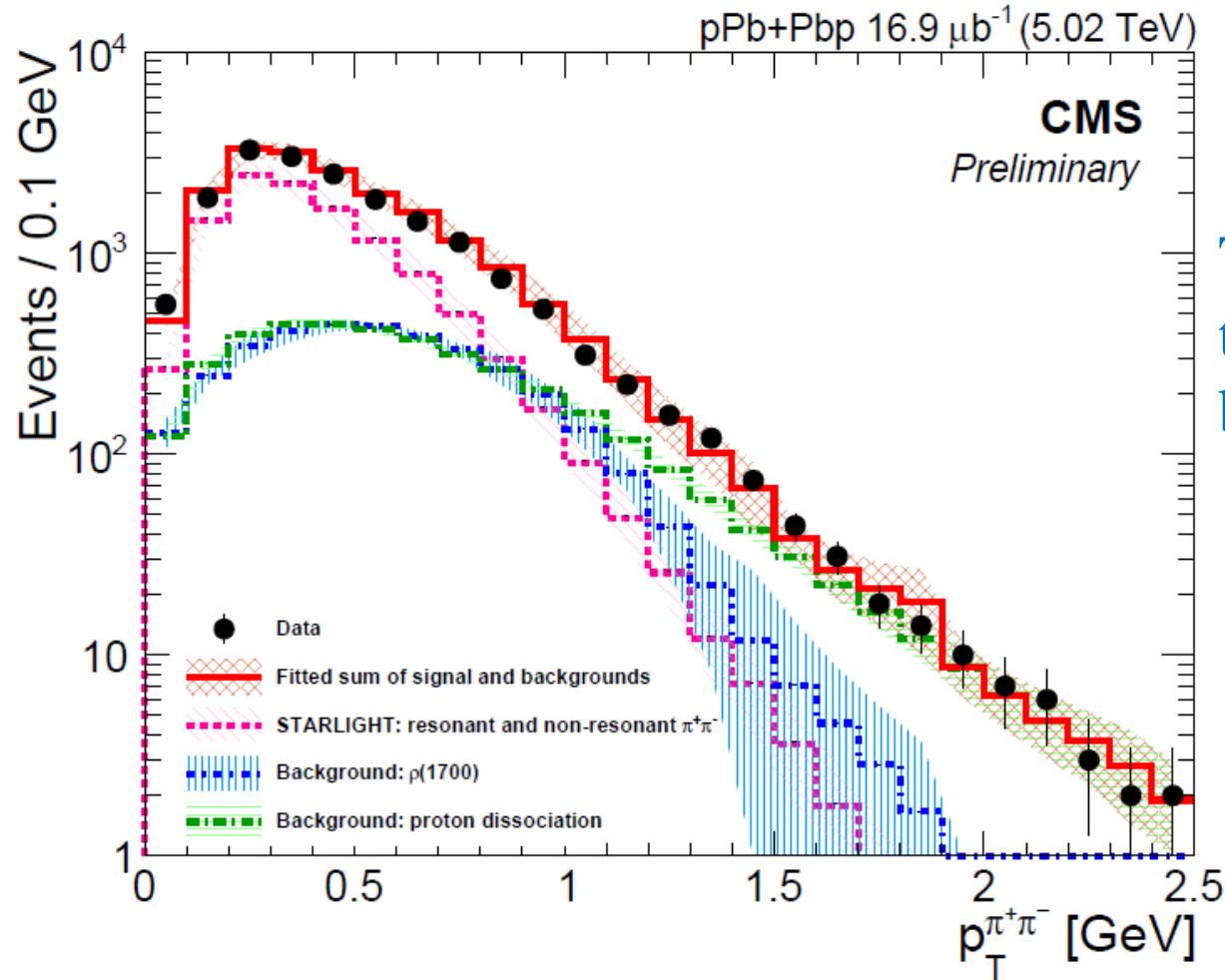
5. DPE and γPb -interactions

Found to be negligible in this analysis



Signal extraction and backgrounds

CMS-FSQ-16-007



Template fit is performed to extract the residual background contributions

Signal:	$\rho^0 \rightarrow \pi^+\pi^-$ & $\pi^+\pi^-$	low- p_T	Starlight
Backgrounds:	$\rho(1700)^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$	mid- p_T	Starlight & Data
	p-diss background	high- p_T	Data

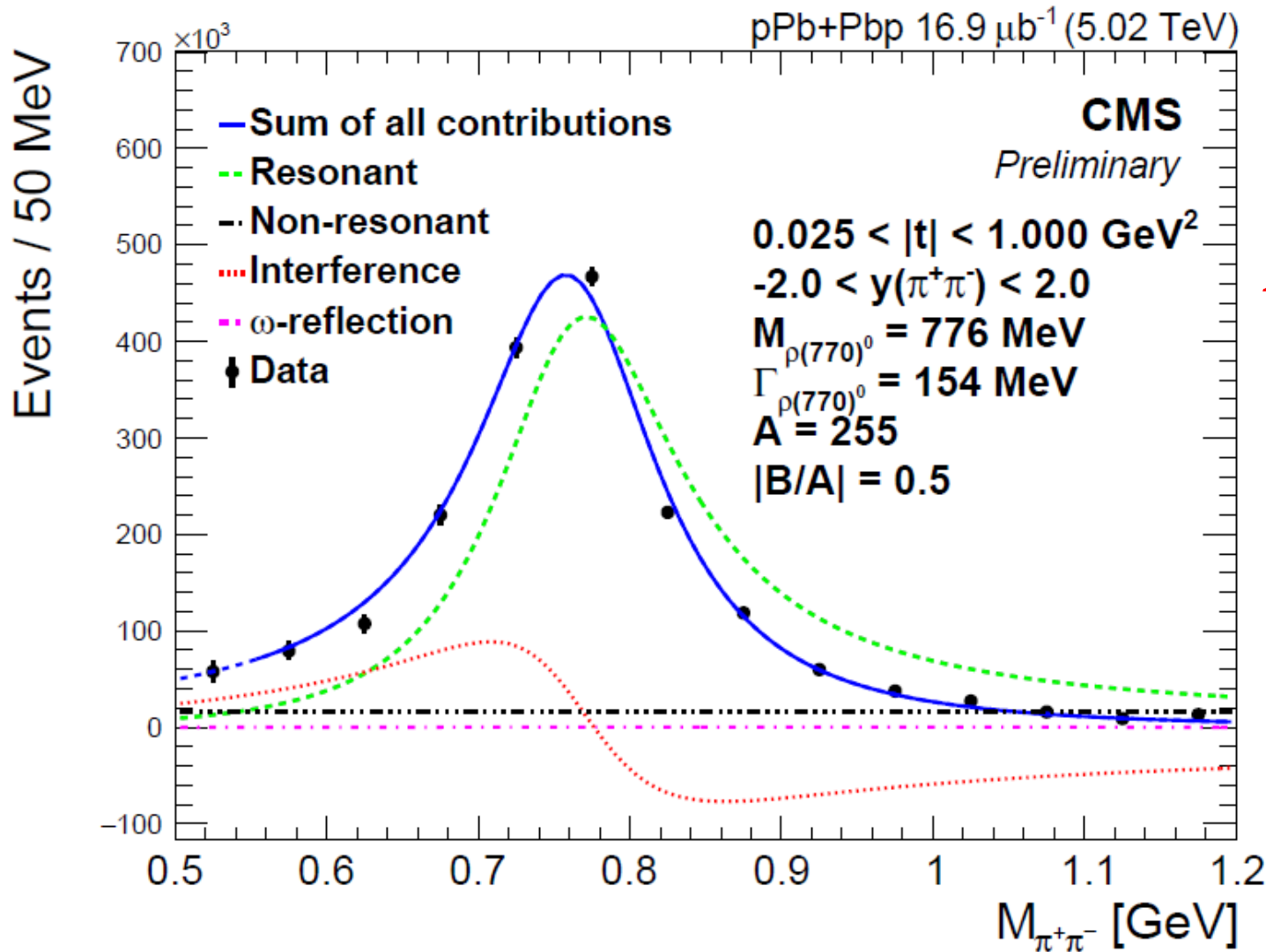
Data is well described by the sum of these contributions after the fit

Invariant mass fits

for unfolded distributions

Söding model

$$\frac{d\sigma}{dM_{\pi\pi}} = \left| A \frac{\sqrt{M_{\pi\pi} M_{\rho^0} \Gamma(M_{\pi\pi})}}{M_{\pi\pi}^2 - M_{\rho^0}^2 + i M_{\rho^0} \Gamma(M_{\pi\pi})} + B \right|^2$$



CMS-FSQ-16-007

PDG-values:

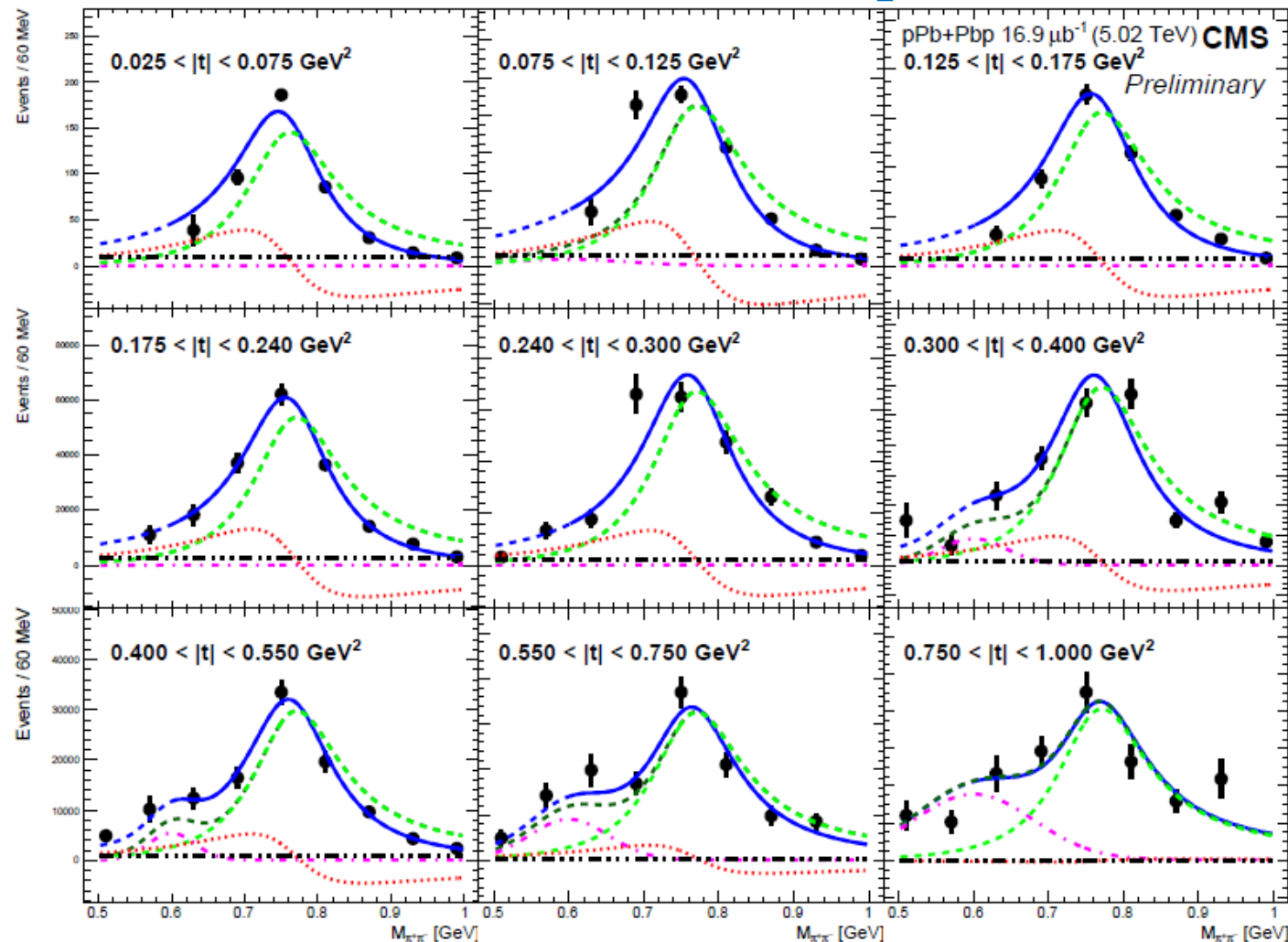
$M = 775 \text{ MeV}$

$\Gamma = 149 \text{ MeV}$

Invariant mass fits

Repeated for each $|t|$ and rapidity bin

CMS-FSQ-16-007



Similar to HERA Experiments:

non-resonant $\pi^+\pi^-$ production decreases at high- $|t|$ values

$\omega \rightarrow \pi^0\pi^+\pi^-$ decay mimics mainly high- $|t|$ events

Exclusive ρ^0 -meson photoproduction cross section

Corrected by the photon flux

CMS-FSQ-16-007

pPb+Pb 16.9 μb^{-1} (5.02 TeV)

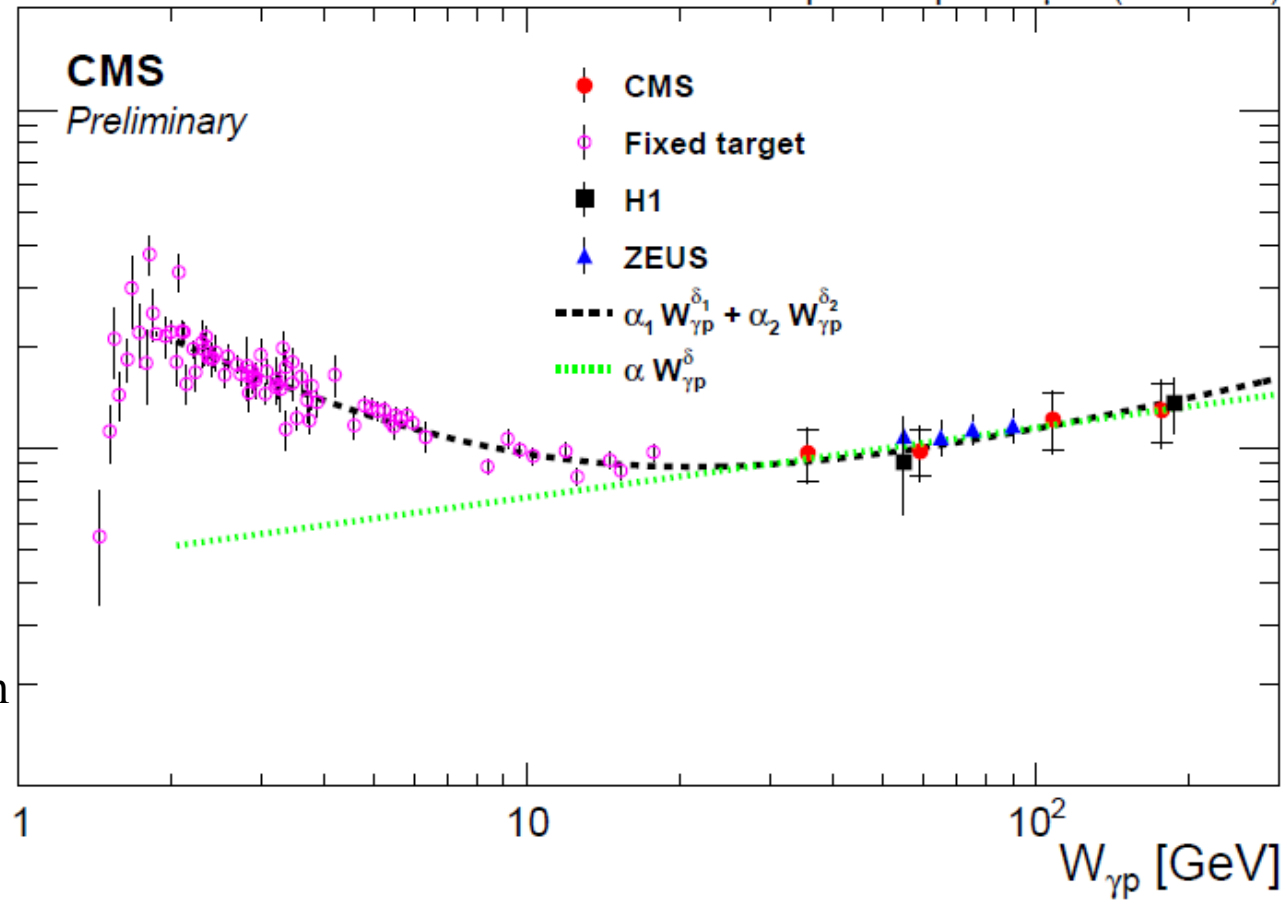
$$\frac{d\sigma}{dy} = \frac{N_{\rho}^{exc}}{BR L \Delta y}$$

$\sigma_{\gamma p \rightarrow \rho(770)^0 p}$ [μb]

N_{ρ}^{exc} - Number of ρ
 BR - branching fraction
 L - Luminosity
 Δy - rapidity interval

$$\frac{d\sigma}{dy}(pPb \rightarrow pPb\rho) = k \frac{dn}{dk} \sigma(\gamma p \rightarrow \rho p)$$

Energy of the γp collision
 $W_{\gamma p}^2 = 2 \cdot E_p \cdot M_{VM} \cdot \exp(-y)$
 E_p - proton beam energy
 M_{VM} - mass of the Vector meson
 y - rapidity of the vector meson



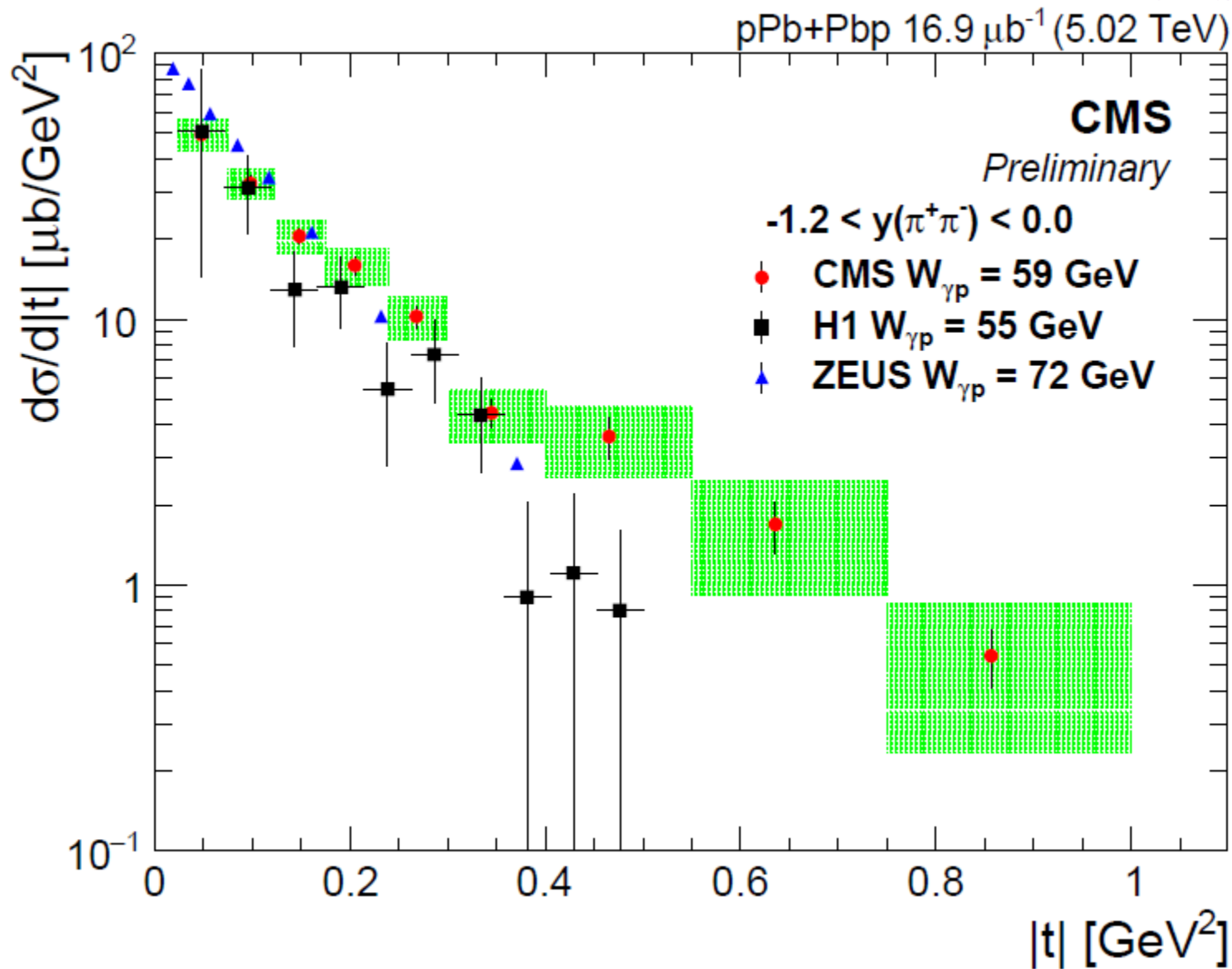
The CMS Experiment extends the energy range measured at HERA
 $29 < W_{\gamma p} < 213$ GeV

Good agreement with the HERA data and theoretical models.

$$\sigma \propto W_{\gamma p}^{\delta} \quad \delta = 0.23 \pm 0.14(\text{stat.}) \pm 0.04(\text{syst.})$$

Differential cross sections

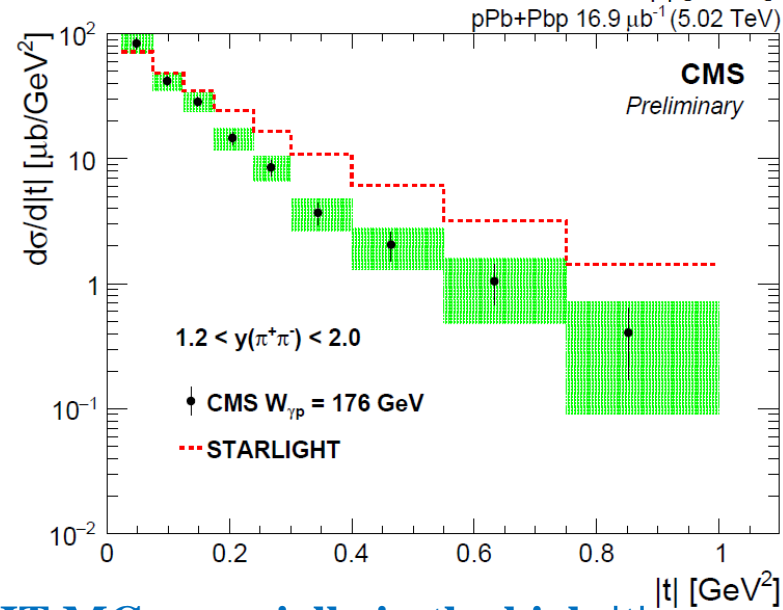
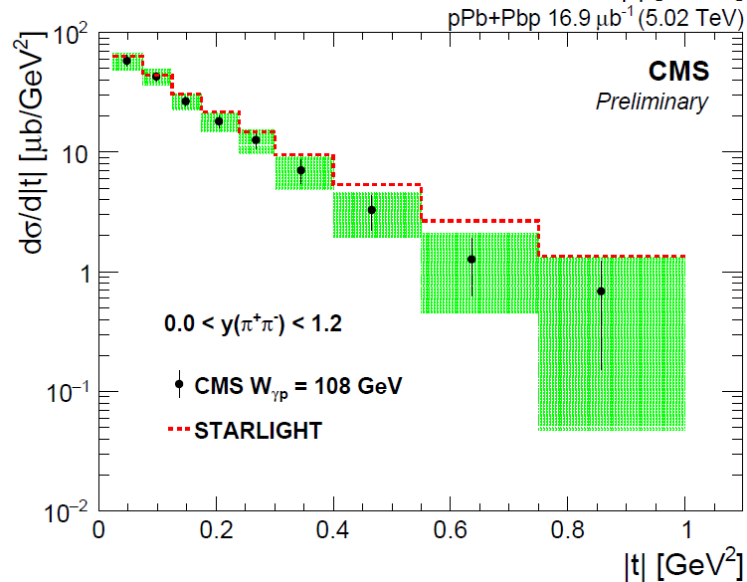
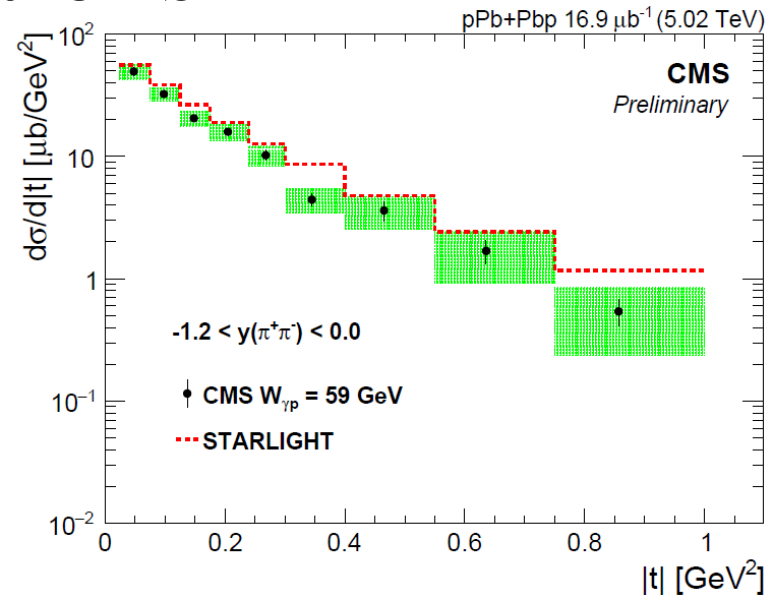
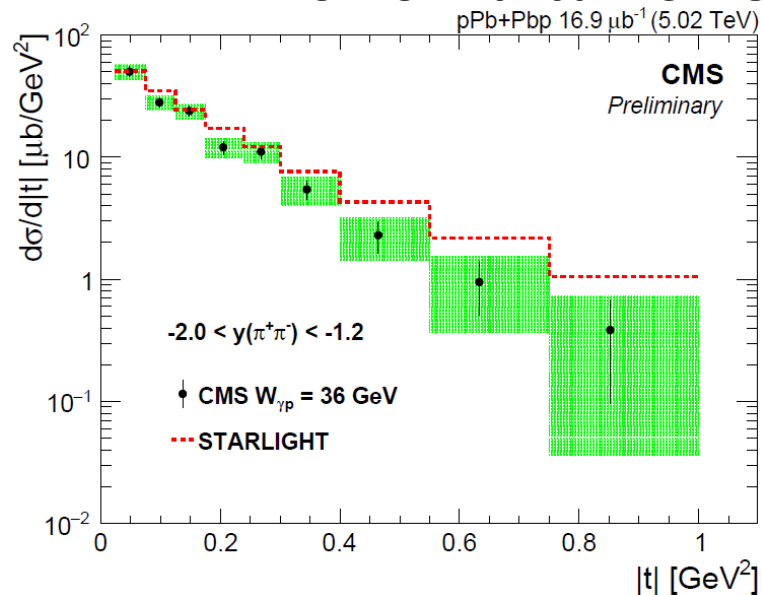
CMS-FSQ-16-007



Good agreement between CMS and HERA data.

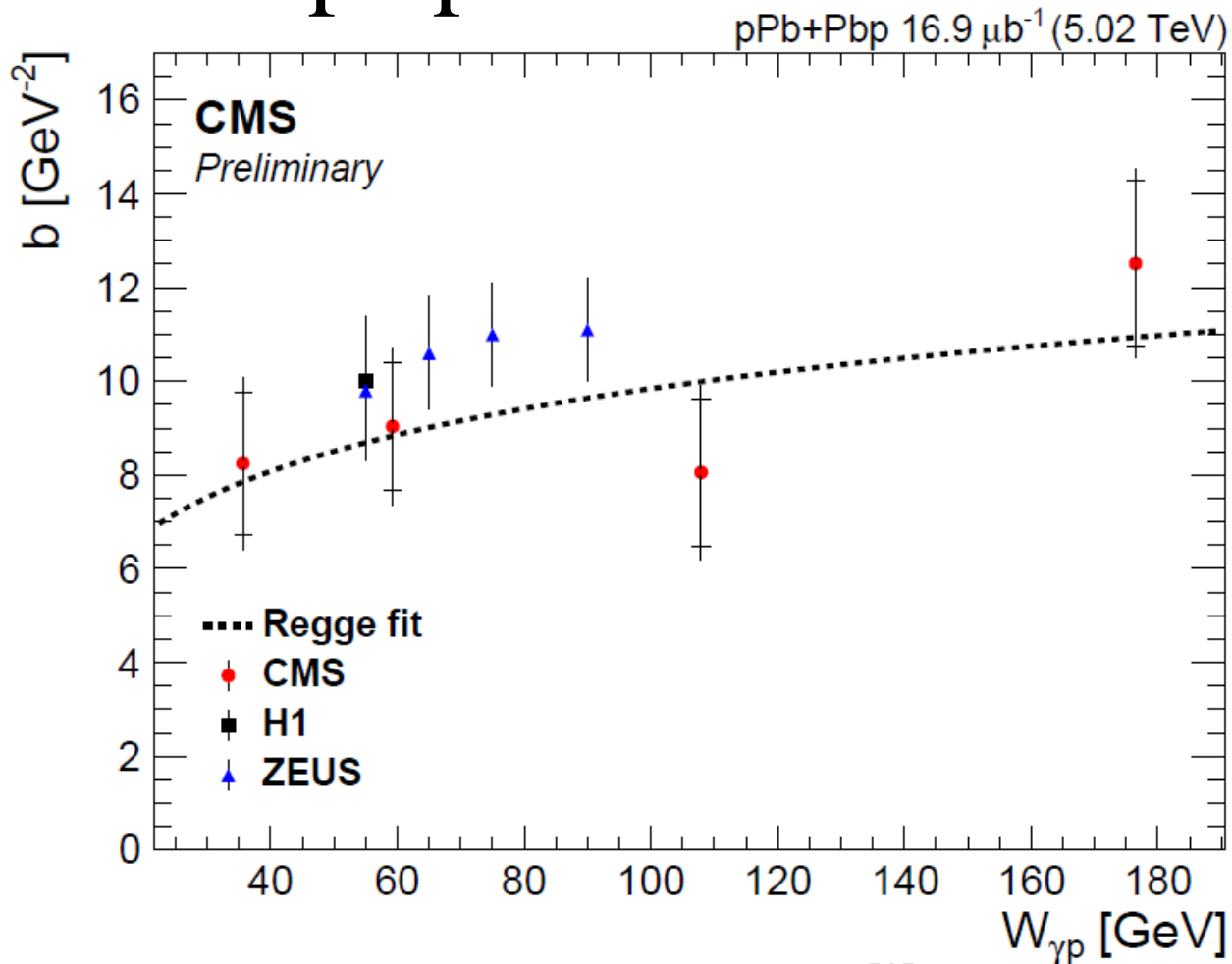
Differential cross sections

CMS-FSQ-16-007



The data are systematically lower than STARLIGHT MC, especially in the high- $|t|$ region. This trend becomes more significant as $W_{\gamma p}$ increases.

b-slope parameter



CMS-FSQ-16-007

Exponential fits

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

$$\text{Regge fit } b = b_0 + 2 \alpha' \ln\left(\frac{W}{W_0}\right)^2$$

Pomeron slope extracted using the CMS data only:

$$\alpha' = 0.48 \pm 0.33(\text{stat.}) \pm 0.12(\text{syst.})$$

Consistent with the ZEUS value ($0.23 \pm 0.15(\text{stat.}) \pm 0.10(\text{syst.})$) and Regge expectations. 14

Summary

- The first measurement of exclusive ρ^0 photoproduction in pPb collisions at $\sqrt{S_{NN}} = 5.02$ TeV at the LHC has been presented
- The measured cross-sections are compatible with the power-law dependence of $(W_{\gamma p})$ observed at HERA
- The differential cross-sections $d\sigma/dt$ are in agreement with earlier measurements and consistent with Regge expectations
- The CMS Experiment has good capabilities to study photoproduction in ultra-peripheral heavy-ion collisions. More analyses ongoing.

Thank you for your attention!

Backup

Motivation: Exclusive Υ production

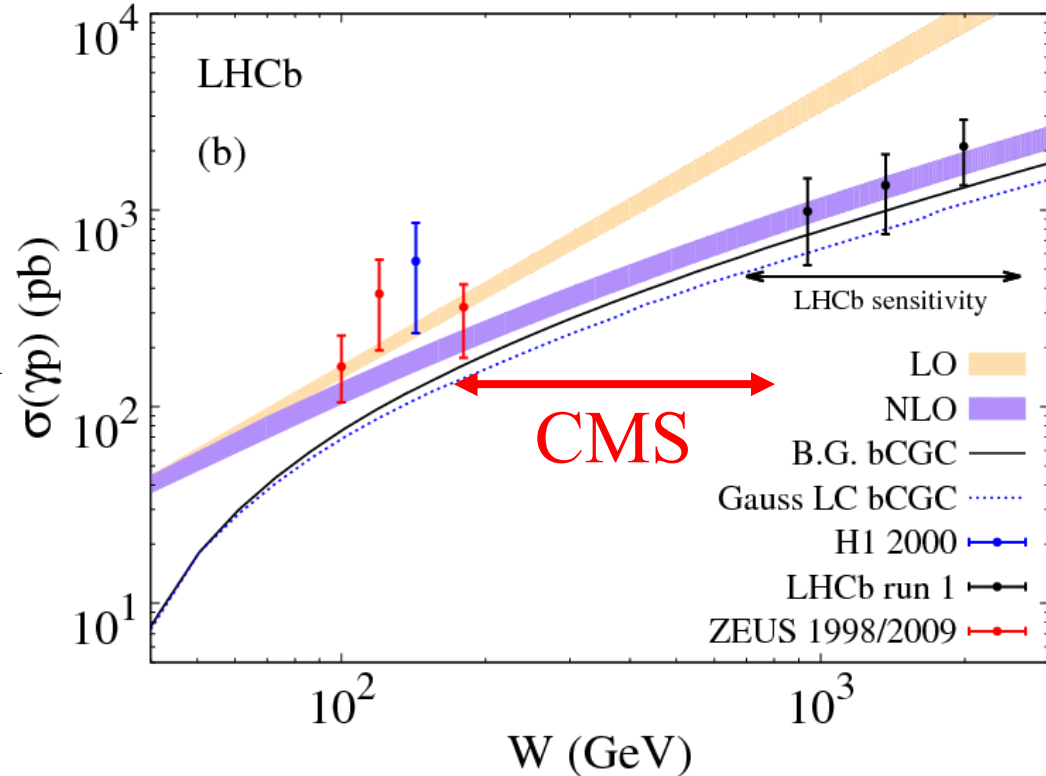
- Energy of the photon-proton collision

$$W_{\gamma p}^2 = 2 \cdot E_p \cdot M_{VM} \cdot \exp(-y)$$

E_p - proton beam energy

M_{VM} - Mass of the Vector meson

y - Rapidity of the vector meson

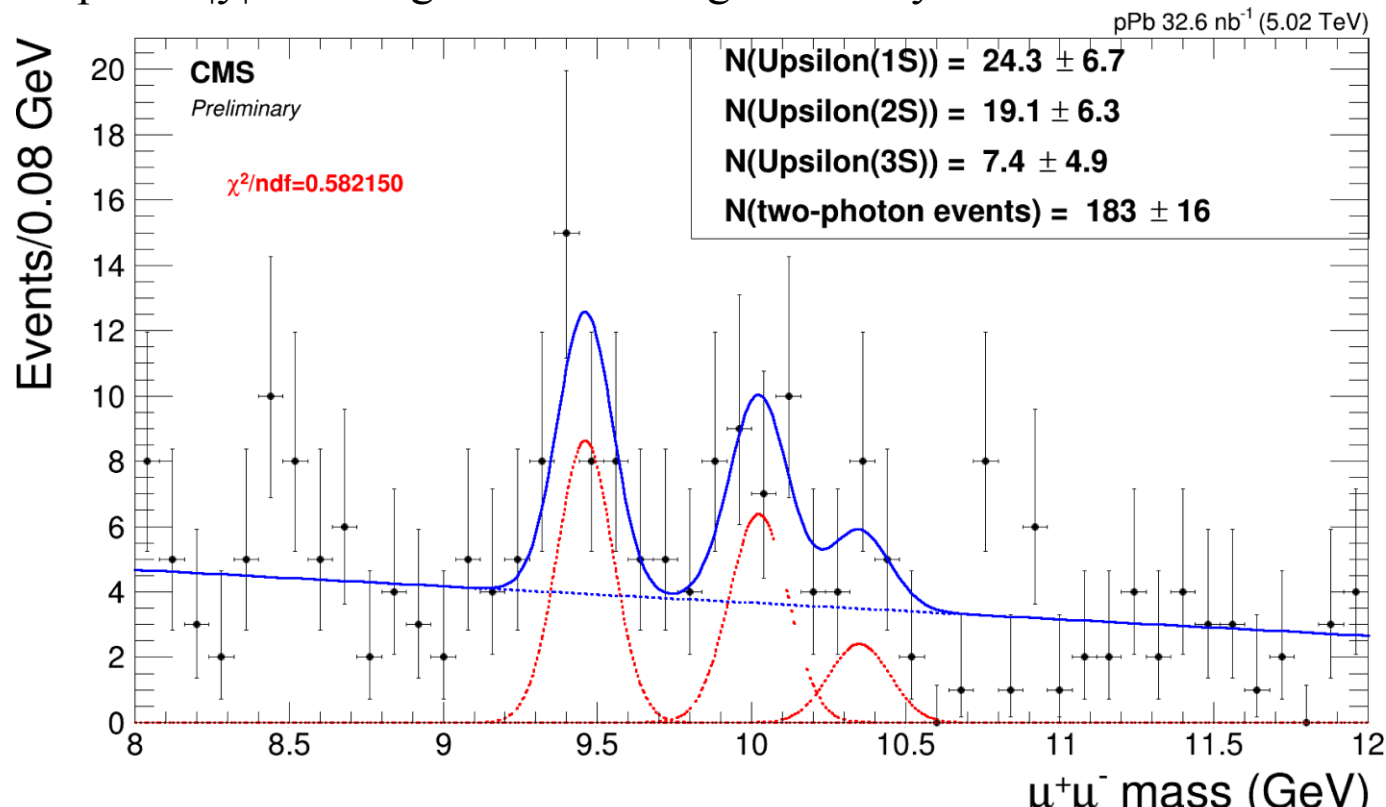


	CMS	HERA	LHCb
E_p [GeV]	4000	820	3000, 4000
y-range	(-2.2;2.2)	(-1.5;1.5)	(2;4.5)
$W_{\gamma p}$ [GeV]	91-826	60-220	900-2000

Exclusive upsilon production

- 2013 pPb data at 5.02 TeV with 32.6 nb^{-1}
- Offline exclusive $pPb \rightarrow Y(\gamma p) \rightarrow \mu^+ \mu^-$ signal selection
 - Invariant mass ($\mu\mu$): 9.12 – 10.64 GeV
 - Opposite-sign $\mu\mu$ pair (final state) originating from common primary vertex
 - No extra tracks at primary vertex to remove non-exclusive background
 - Upsilon p_T : 0.1-1 GeV to suppress QED and proton dissociation
 - Upsilon $|y| < 2.2$ high muon finding efficiency

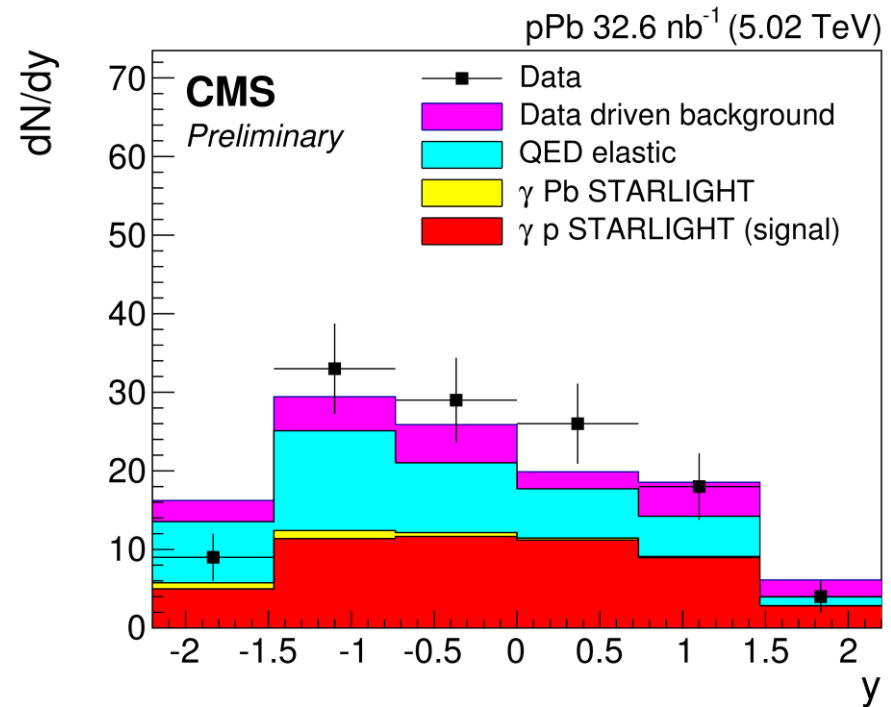
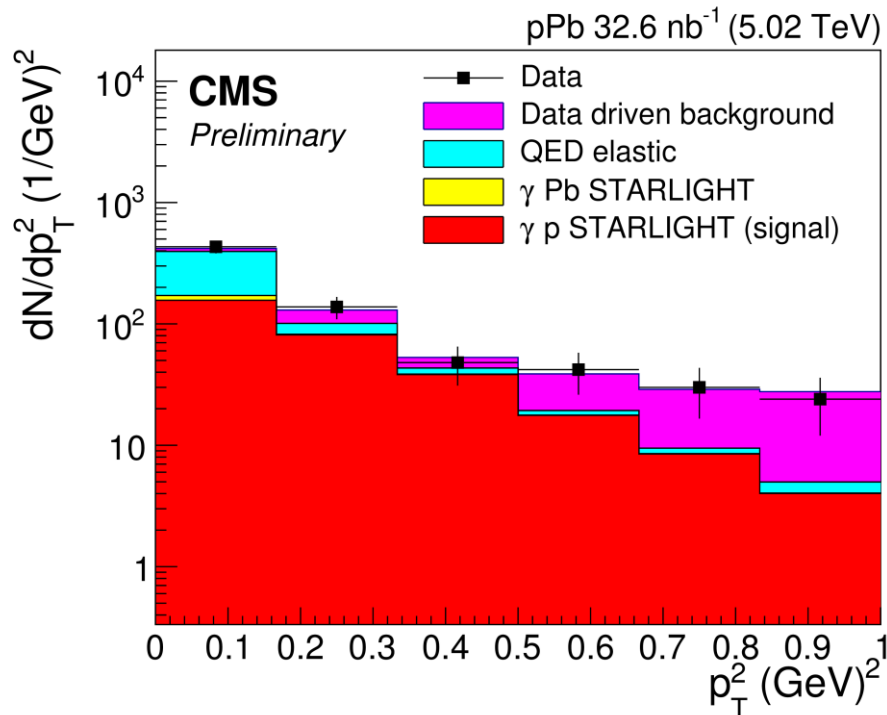
CMS-FSQ-13-009



Exclusive upsilon production

CMS-FSQ-13-009

- Data compared to simulation (contains different contributions)
- Low p_T : QED elastic background, estimated by STARLIGHT
- High p_T : Non-exclusive background estimated from data
- Starlight MC: γPb (small contribution) and reweighted γp contribution



Good agreement between data and MC

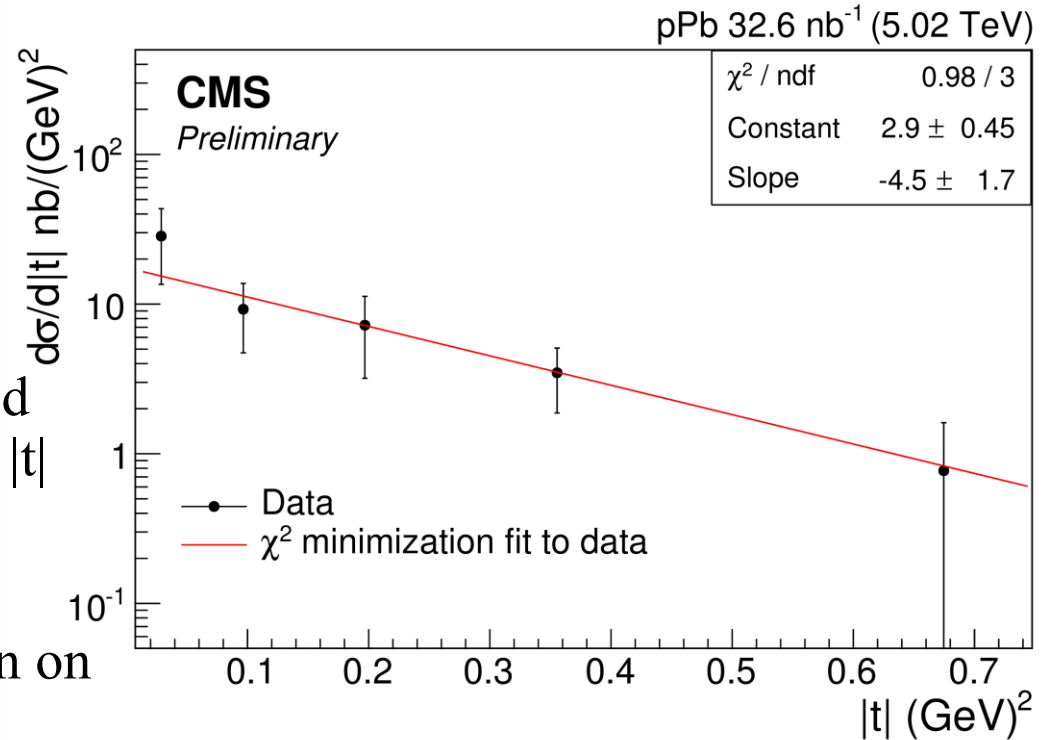
Photoproduction cross-section as a function of $|t|$

CMS-FSQ-13-009

- The differential cross section is calculated according to

$$\frac{d\sigma_Y}{dt} = \frac{N_{sig}^{Unfolded}}{L \cdot \Delta t}$$

- N_{sig} , the background subtracted, unfolded and acceptance corrected number of upilon events in each $|t|$ bin.
- $d\sigma/dt$ fitted with an exponential function, provides the information on the transverse profile of the interaction region.



CMS Results

$$b = 4.5 \pm 1.7 \text{ (stat.)} \pm 0.6 \text{ (syst.) GeV}^{-2}$$

Data is in agreement with ZEUS measurements and consistent with predictions based on pQCD models

ZEUS for $Y(1S)$

$$b = 4.3^{+2.0}_{-1.3} \text{ (stat)}$$

Phys.Lett.B 708 (2012) 14

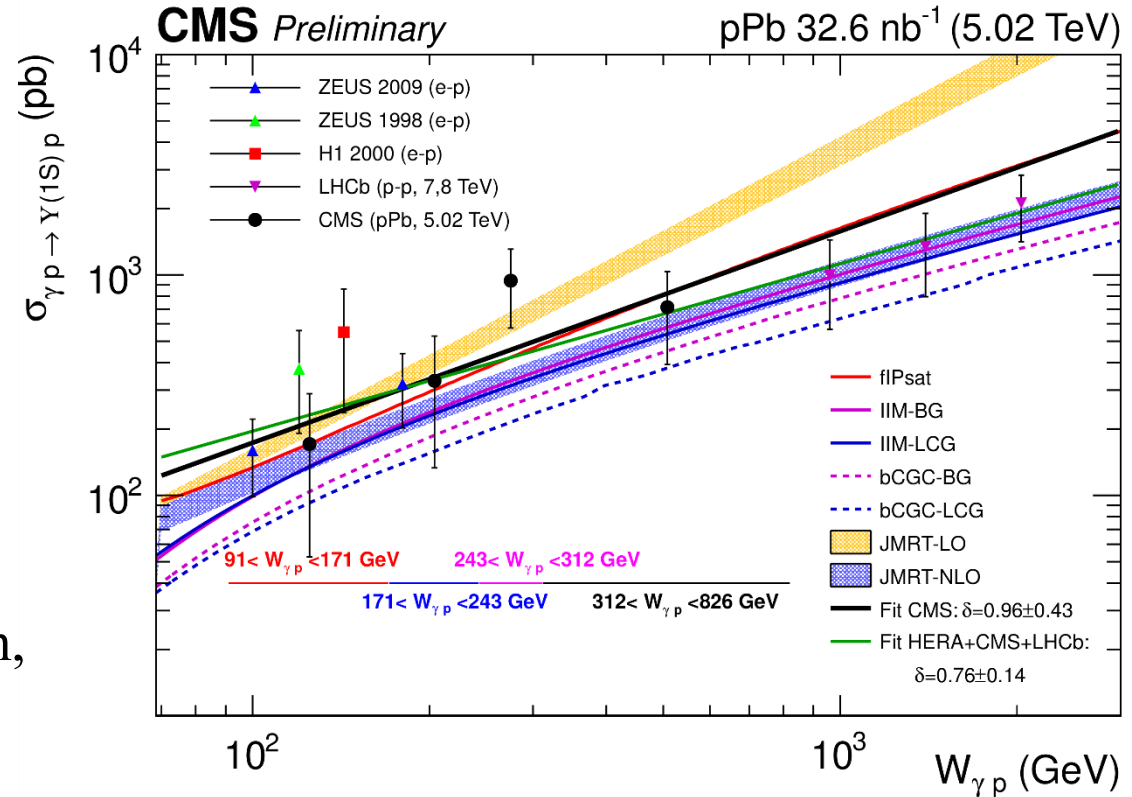
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Cross-section as a function of $W_{\gamma p}$

CMS-FSQ-13-009

- The cross section is estimated by

$$\sigma_{\gamma p \rightarrow Y(1S)p} = \frac{1}{\Phi} \frac{d\sigma_{Y(1S)}}{dy}$$
- Rapidity distribution of $Y(1S+2S+3S)$ used to estimate $\sigma_{Y(1S)}$ vs $W_{\gamma p}$
- The cross-section is corrected for muonic branching ratio, feed-down, up-silon (1S) fraction



A fit with power-law $A X (W/400)^\delta$ to the CMS data
 $\delta = (0.96 \pm 0.43)$, $A = 655 \pm 196$
 Data compatible with power-law dependence
 of $\sigma(W_{\gamma p})$, disfavours LO pQCD predictions

ZEUS
 $\delta = 1.2 \pm 0.8$
 PLB 680(2009) 4-12 **b5**