



Recent CMS results on exclusive processes

Alexander Bylinkin

On behalf of the CMS Collaboration

DIS 2019: 8-12 Apr 2019, Torino, Italy

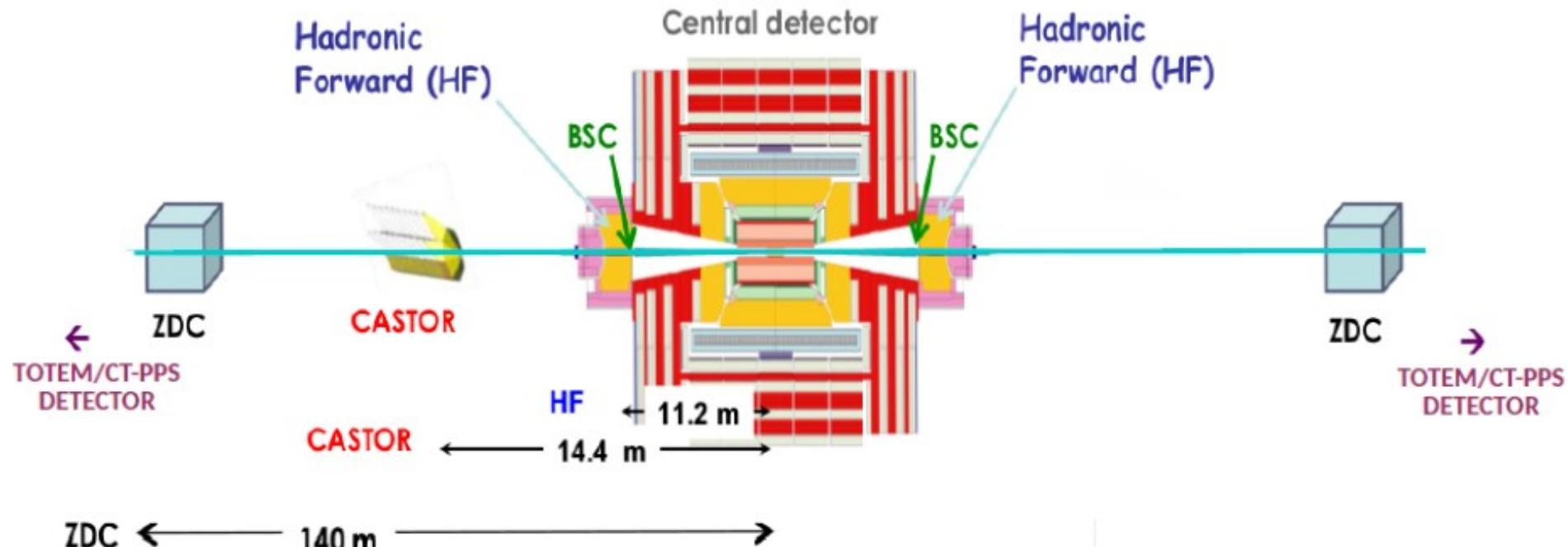
Outline

- CMS Experiment is a perfect facility to study exclusive processes
- Exclusive production in **pp** collisions
- Exclusive production in **PbPb** collisions
 - LbyL scattering in PbPb (FSQ-16-012) – see talk by Ruchi Chudasama in WG3 for more details
- Exclusive photoproduction of VM in **pPb** collisions
 - Motivation
 - Exclusive Υ production in pPb (FSQ-13-009)
 - Exclusive ρ^0 production in pPb (FSQ-16-007)
 - Experimental results
 - Total cross-section as a function of $W_{\gamma p}$
 - Differential cross sections as a function of $|t|$
- Diffractive measurements using CMS-TOTEM data – talk by Katerina Kuznetsova
- Outlook
- More exclusive results available at

<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>

Forward CMS Detectors



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

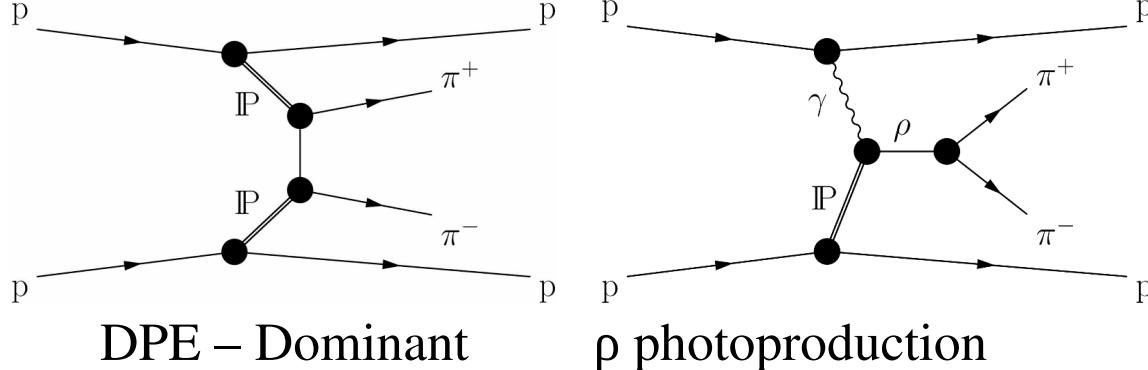
Hadron Forward Calorimeter (HF): $3.0 < |\eta| < 5.2$

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

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

CMS offers perfect coverage in the forward region

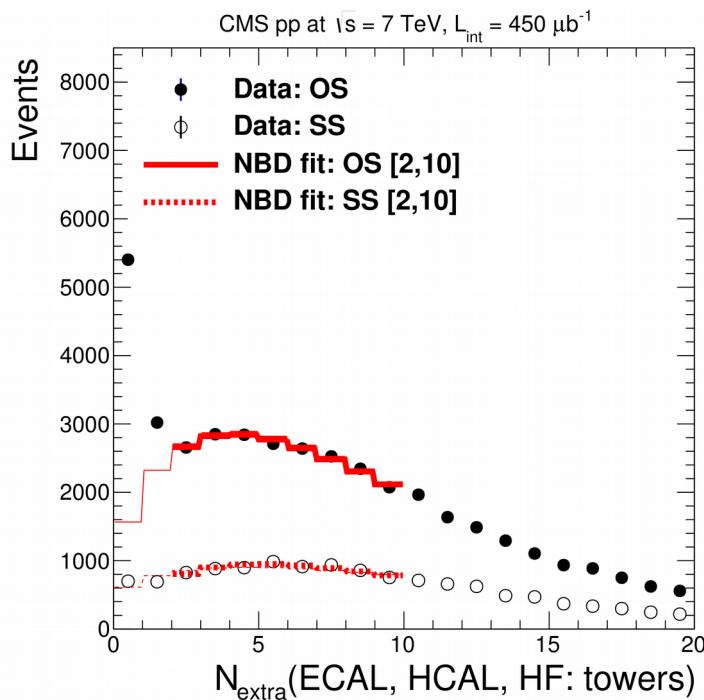
Exclusive production in pp collisions



→ Experimental signature:

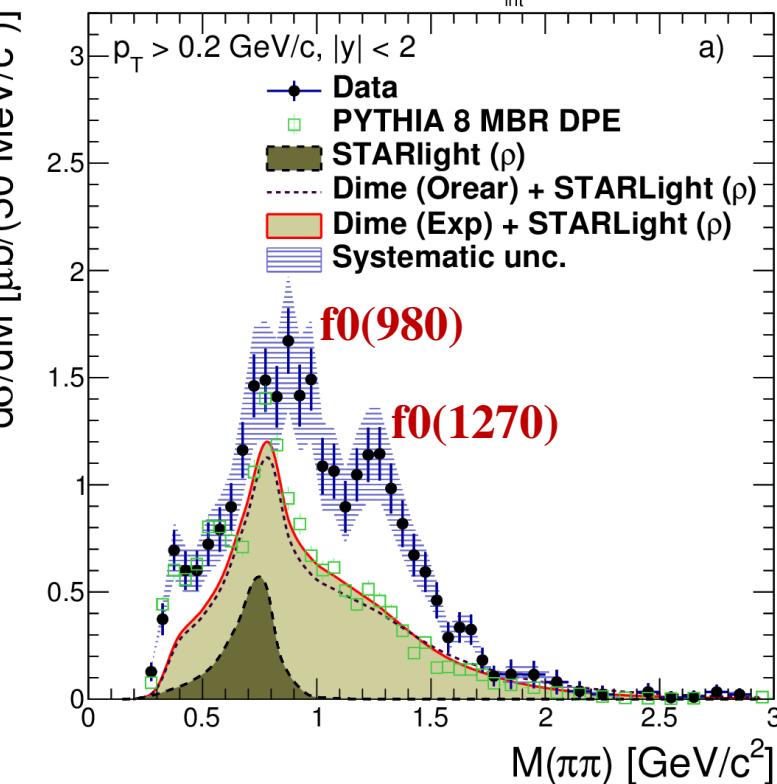
- 2 OS tracks ($\pi^+\pi^-$)
- No calorimeter signal
- $p_T(\pi) > 0.2$ GeV
- $|y(\pi)| < 2$

Non-exclusive background estimated from calorimeter multiplicities



Resonance structure seen by other experiments

CMS pp at $\sqrt{s} = 7$ TeV, $L_{\text{int}} = 450 \mu\text{b}^{-1}$



Similar CMS analyses @5 TeV and @13 TeV are ongoing 4

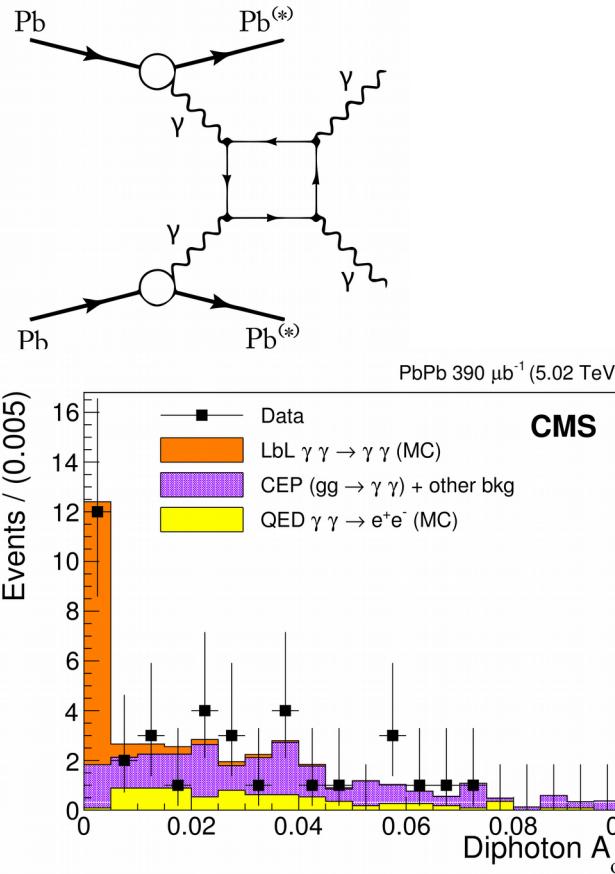
Search for LbyL in PbPb UPC at 5.02 TeV

Two back-to-back photons $E_T > 2$ GeV and $|\eta| < 2.4$, $P_T^{\gamma\gamma} < 1$ GeV, $m_{\gamma\gamma} > 5$ GeV

ArXiv:1810.04602

Submitted to PLB

Exclusivity: no tracks, no extra neutral activity



For $A_\phi < 0.01$

Observed: 14 events

Expected: 11.1 ± 1.1 (th) signal

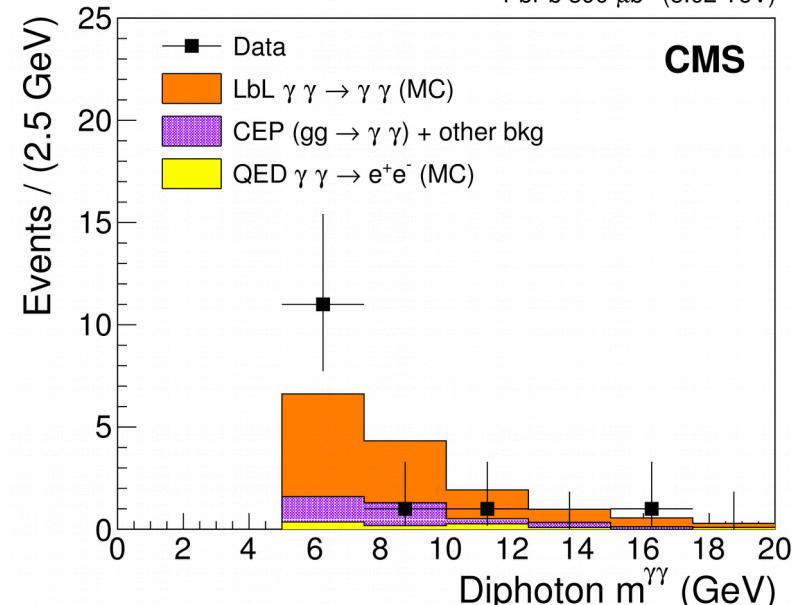
4.0 ± 1.2 (stat) background events

Significance: 4.1σ (expected 4.4σ)

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

- fundamental QED/QCD process
- difficult to observe due to very small $O(\alpha^4)$ cross section
- sensitive to BSM physics, (loop contribution, axions,...)

PbPb $390 \mu\text{b}^{-1}$ (5.02 TeV)



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

Fiducial LbyL cross section derived from R and
QED e^+e^- cross section from STARLIGHT = 4.82 ± 0.15 (th) mb

$$\sigma_{\text{fid}}(\gamma\gamma \rightarrow \gamma\gamma) = 122 \pm 46(\text{stat}) \pm 29(\text{syst}) \pm 4(\text{th}) \text{ nb}$$

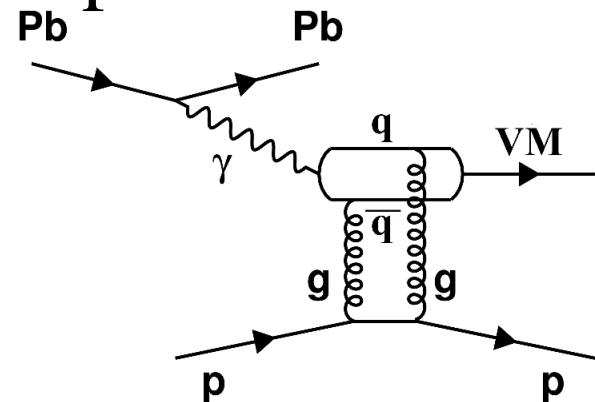
Consistent with SM prediction: $\sigma_{\text{fid}}(\gamma\gamma \rightarrow \gamma\gamma) = 138 \pm 14 \text{ nb}$

see talk by Ruchi Chudasama in WG3 for more details

Exclusive Vector Meson photoproduction in pPb

Motivation: Exclusive vector meson production

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



Motivation: Exclusive vector meson production

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

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

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

- Probe gluon distributions in the proton at low x

$$x = (M_{VM}/W_{\gamma p})^2$$

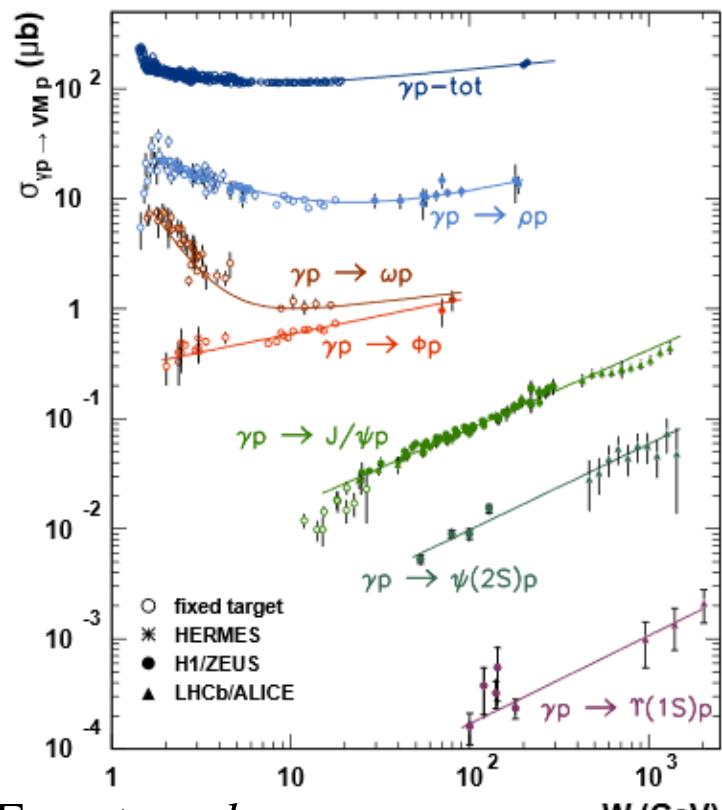
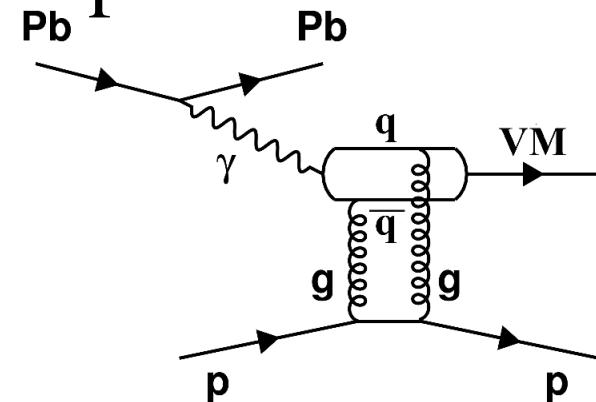
- Photonuclear cross-section shows power law dependence with $W_{\gamma p}$ $\sigma \propto W_{\gamma p}^\delta$
- Energy of the γp collision

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

E_p - proton beam energy

M_{VM} - mass of the Vector meson

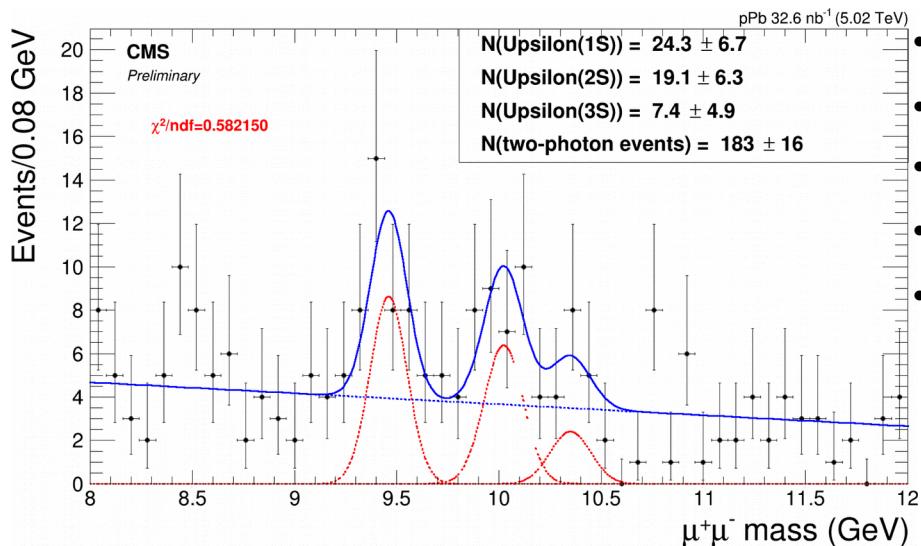
y - rapidity of the vector meson



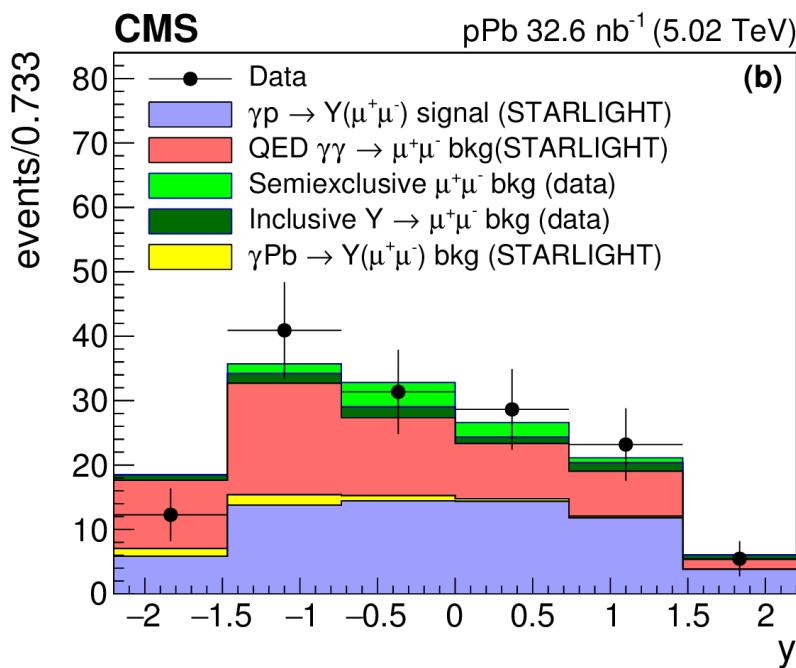
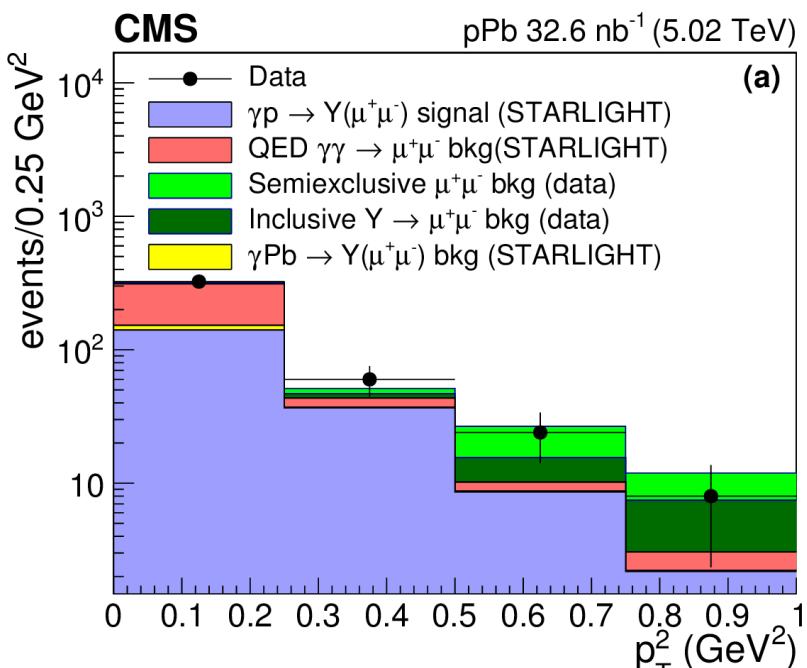
Exclusive upsilon production

Eur. Phys. J. C 79 (2019) 277

- 2013 pPb data at 5.02 TeV with 32.6 nb^{-1}
- Offline exclusive signal selection



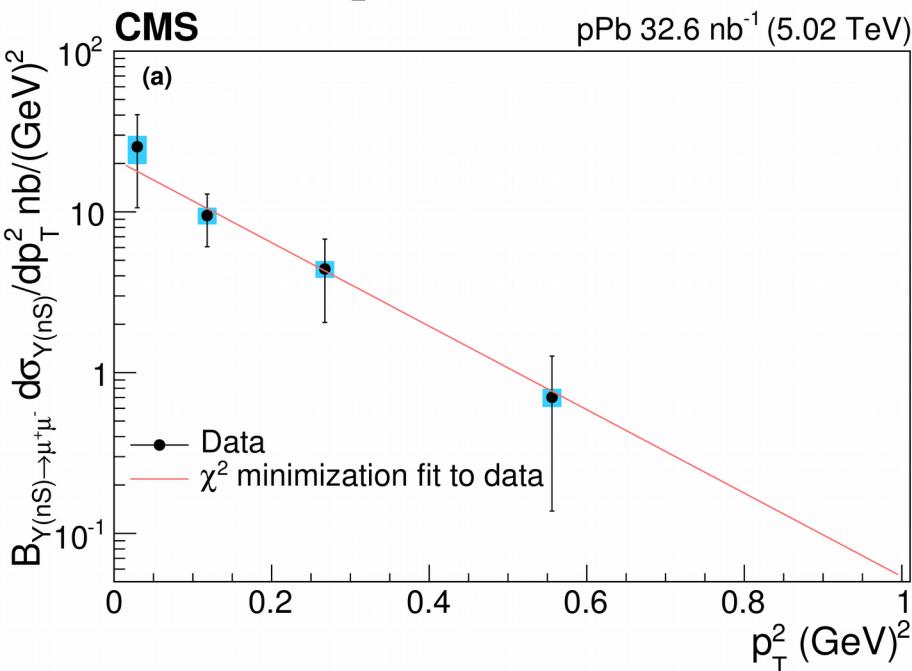
- Invariant mass ($\mu\mu$): $9.12 < M_{\mu\mu} < 10.64 \text{ GeV}$
- OS $\mu\mu$ pair originating from common primary vertex
- No extra tracks at primary vertex
- Upsilonon $0.1 < p_T < 1 \text{ GeV}$ to suppress QED and p-diss
- Upsilonon $|y| < 2.2$ high muon finding efficiency



Exclusive upsilon production

Eur. Phys. J. C 79 (2019) 277

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

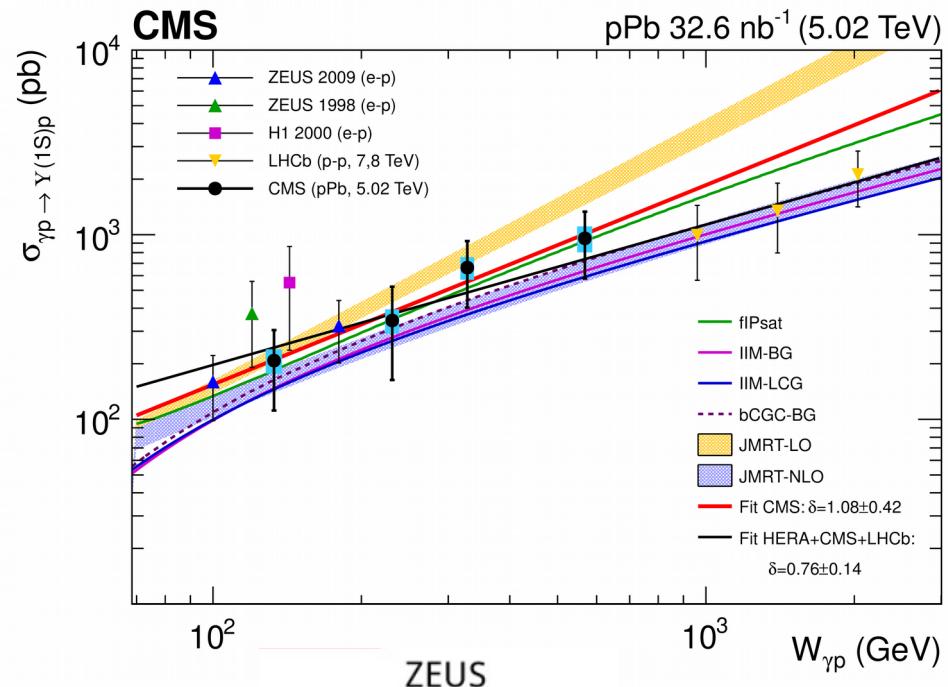


Exponential fit:

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

ZEUS for $\Upsilon(1S)$
 $b = 4.3^{+2.0}_{-1.3} \text{ (stat)}$

Phys.Lett.B 708 (2012) 14



$$\delta = 1.2 \pm 0.8$$

PLB 680(2009) 4-12

Data sensitive to signs of saturation,
 put new constraints on the evolution
 of gluon density at low x

Exclusive ρ^0 -meson photoproduction

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

• Exclusivity selection:

- Only two tracks ($\pi^+\pi^-$)
- No calorimeter signal

arXiv:1902.01339
Submitted to EPJC

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 [28]	16 085	20 278
$ \eta_{\text{track}} < 2.0$,	12 707	16 037
$p_T^{\text{leading}} > 0.4 \text{ GeV}$, $p_T^{\text{subleading}} > 0.2 \text{ GeV}$	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

Signal extraction and backgrounds

Two main backgrounds to ρ^0 signal

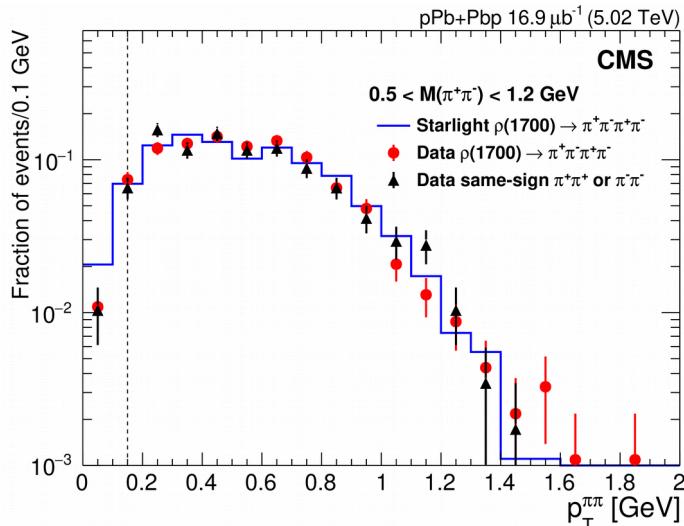
known from HERA Experiments:

1. Proton dissociation – high- p_T region

Data driven approach requiring activity in the forward detectors

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

- Generated 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

Two main backgrounds to ρ^0 signal

known from HERA Experiments:

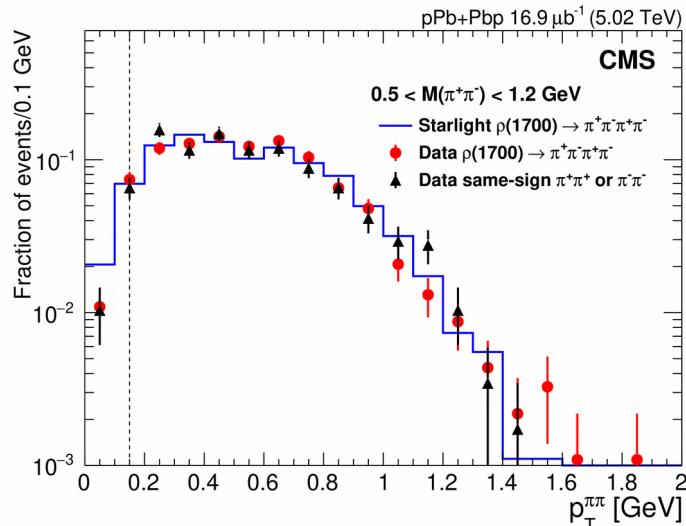
1. Proton dissociation – high- p_T region

Data driven approach requiring activity in the forward detectors

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

- Generated 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



Other considered background contributions:

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

Accounted in the invariant mass fits

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

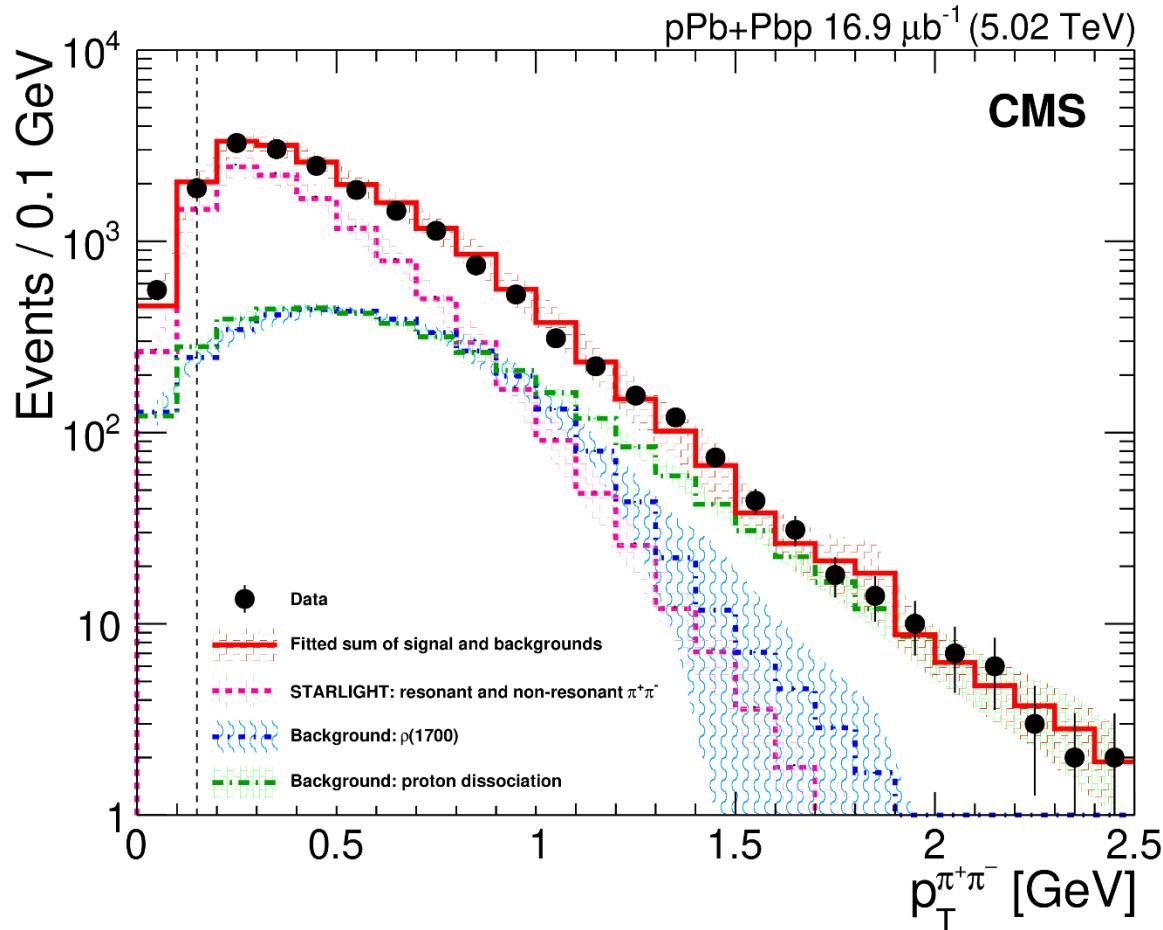
Removed by $M(K^+ K^-) > 1.04$ GeV cut similar to HERA

5. DPE and γ Pb-interactions

Found to be negligible in this analysis

Signal extraction and backgrounds

arXiv:1902.01339
Submitted to EPJC



Template fit is performed
to extract the residual
background contributions

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

Starlight
Starlight & Data
Data

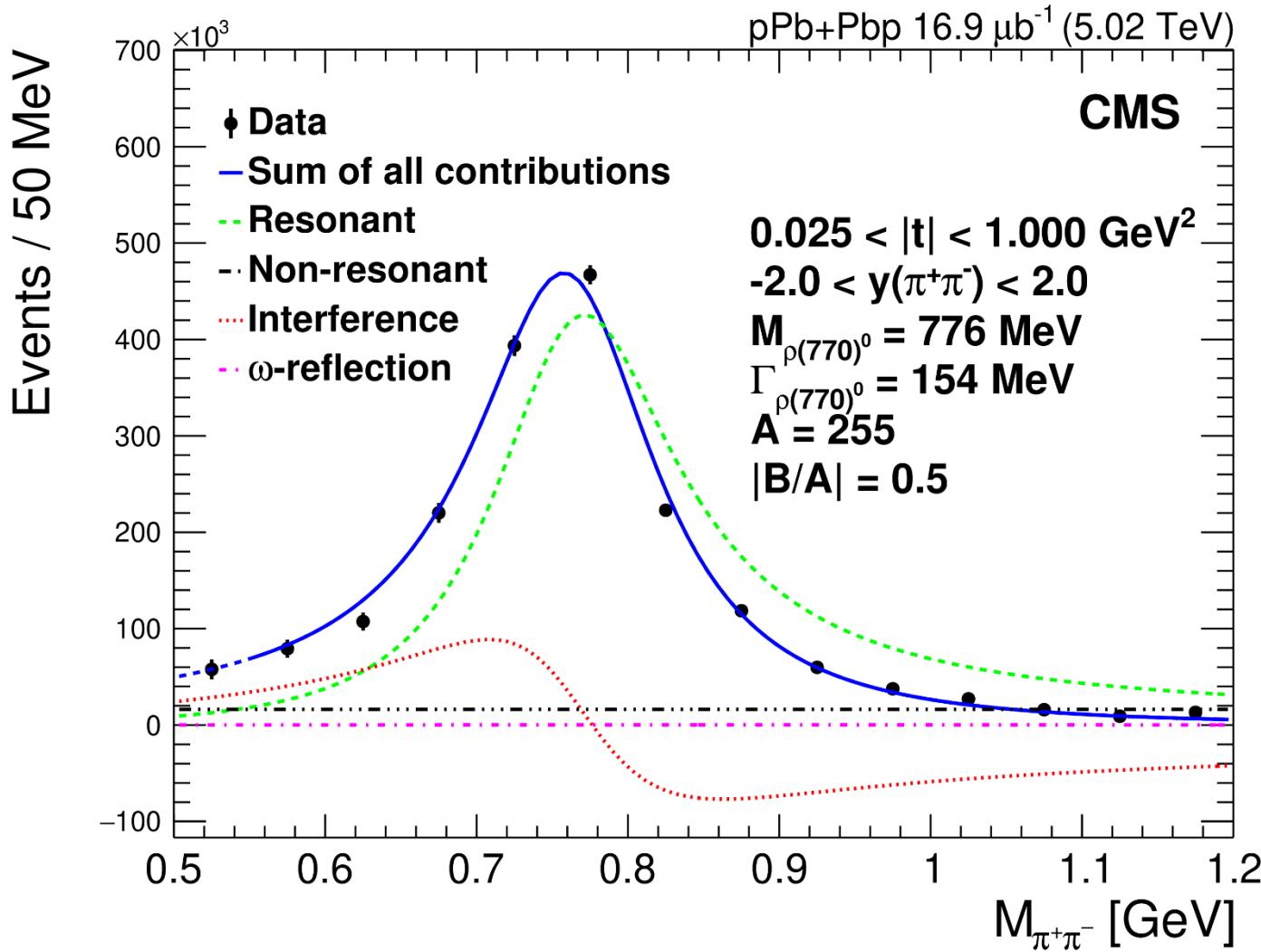
Data is well described by the sum of these contributions after the fit

Invariant mass fits

for unfolded distributions

Söding model

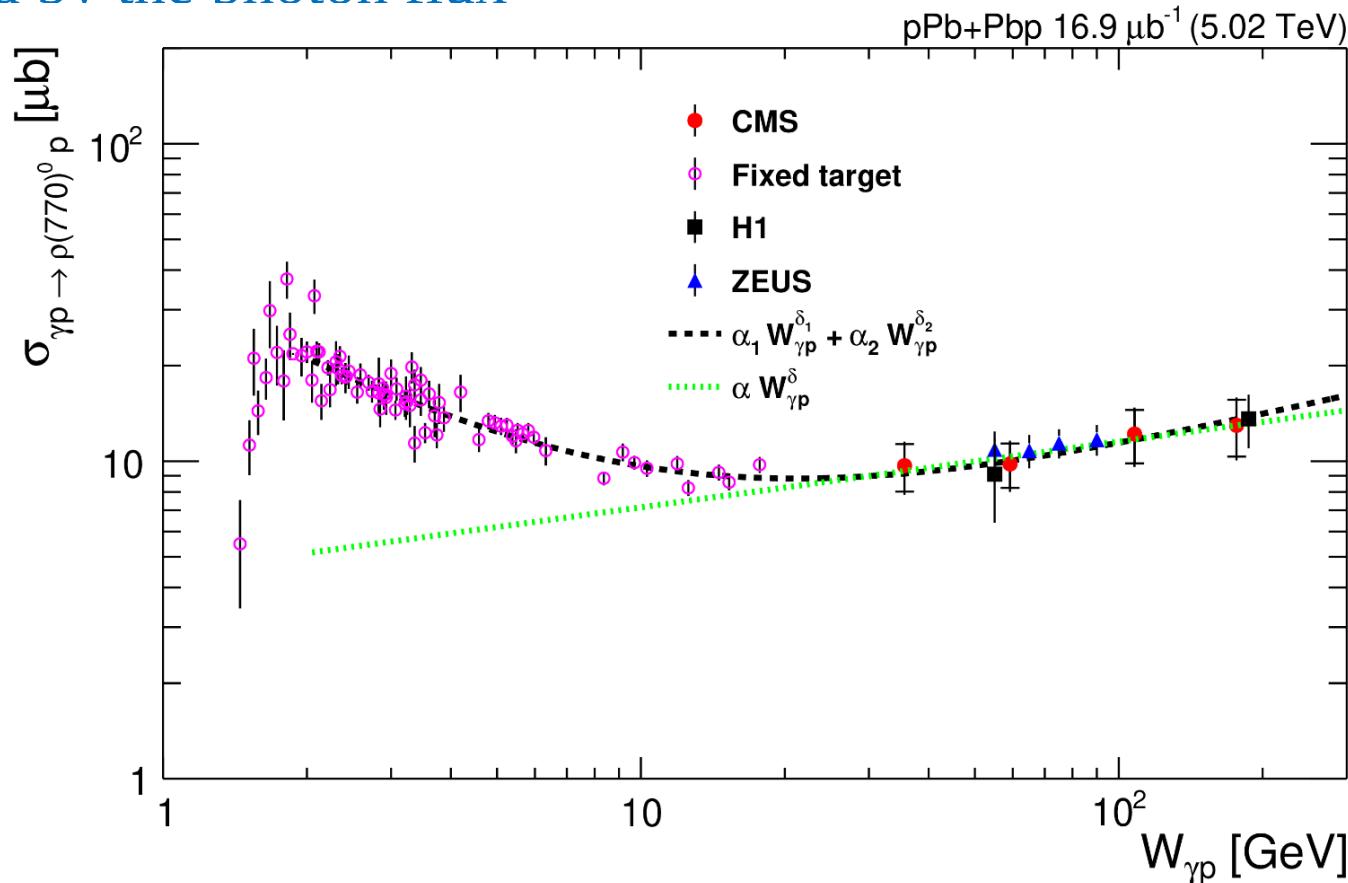
$$\frac{d\sigma}{dM_{\pi\pi}} = \left| A \frac{\sqrt{M_{\pi\pi} M_{\rho^0} \Gamma(M_{\pi\pi})}}{M_{\pi\pi}^2 - M_{\rho^0}^2 + i M_{\rho^0} \Gamma(M_{\pi\pi})} + B \right|^2$$



PDG-values:
 $M = 775 \text{ MeV}$
 $\Gamma = 149 \text{ MeV}$

Exclusive ρ^0 -meson photoproduction cross section

Corrected by the photon flux

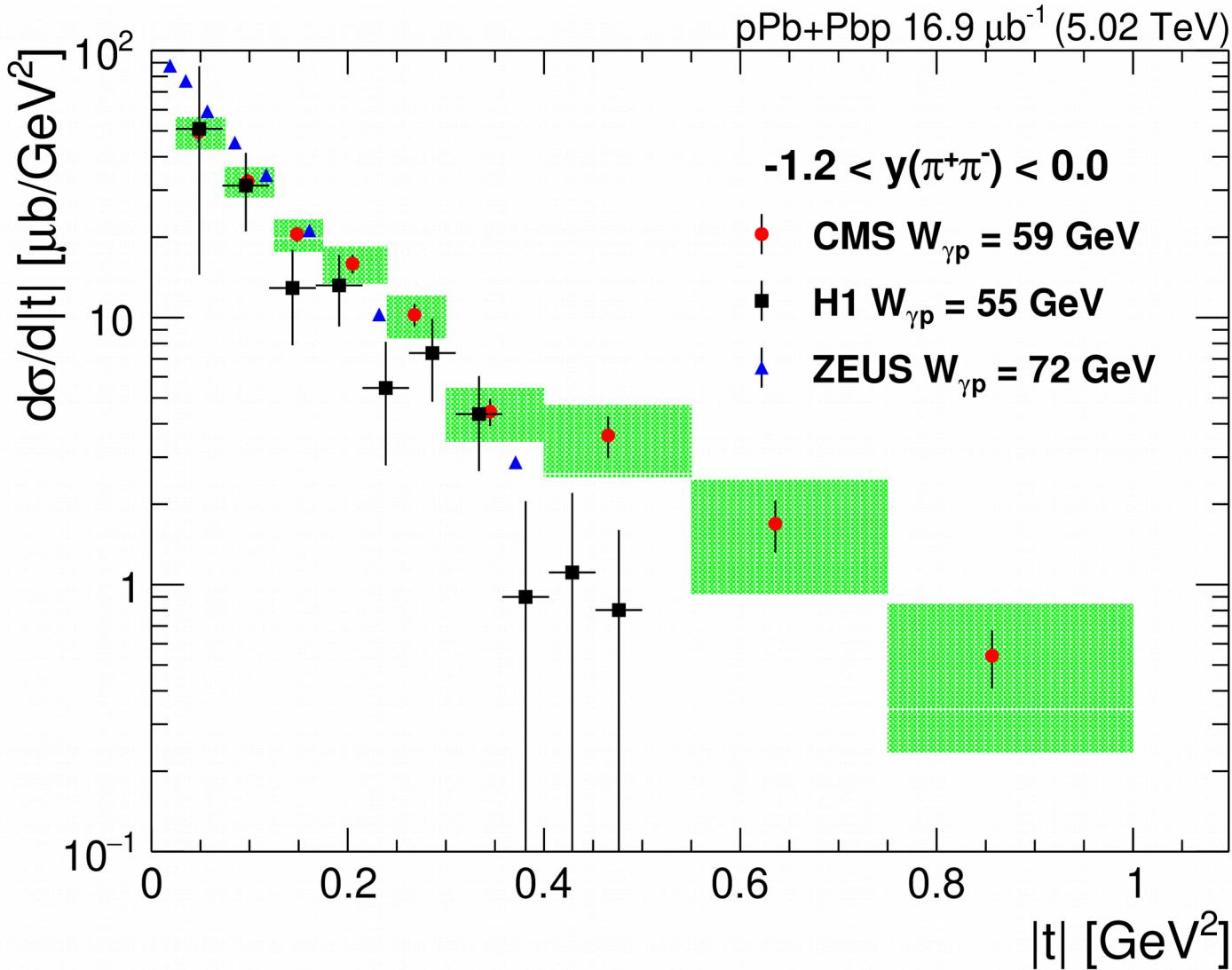


The CMS Experiment extends the energy range measured at HERA
 $29 < W_{\gamma p} < 213 \text{ GeV}$

Good agreement with the HERA data and theoretical models.

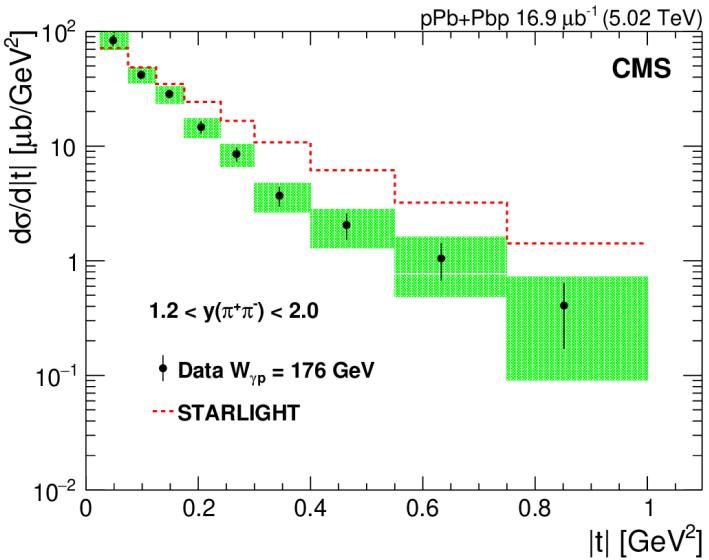
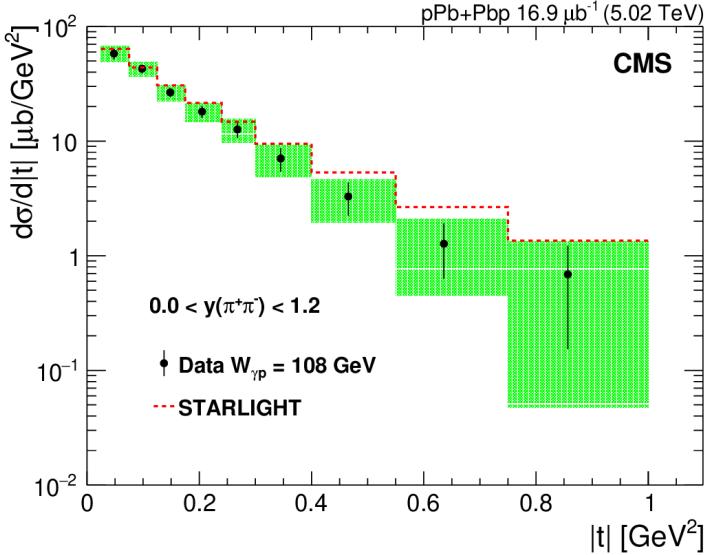
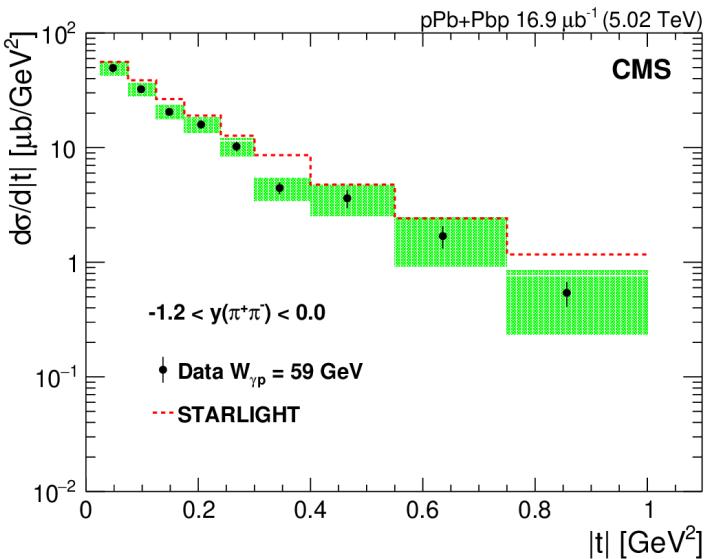
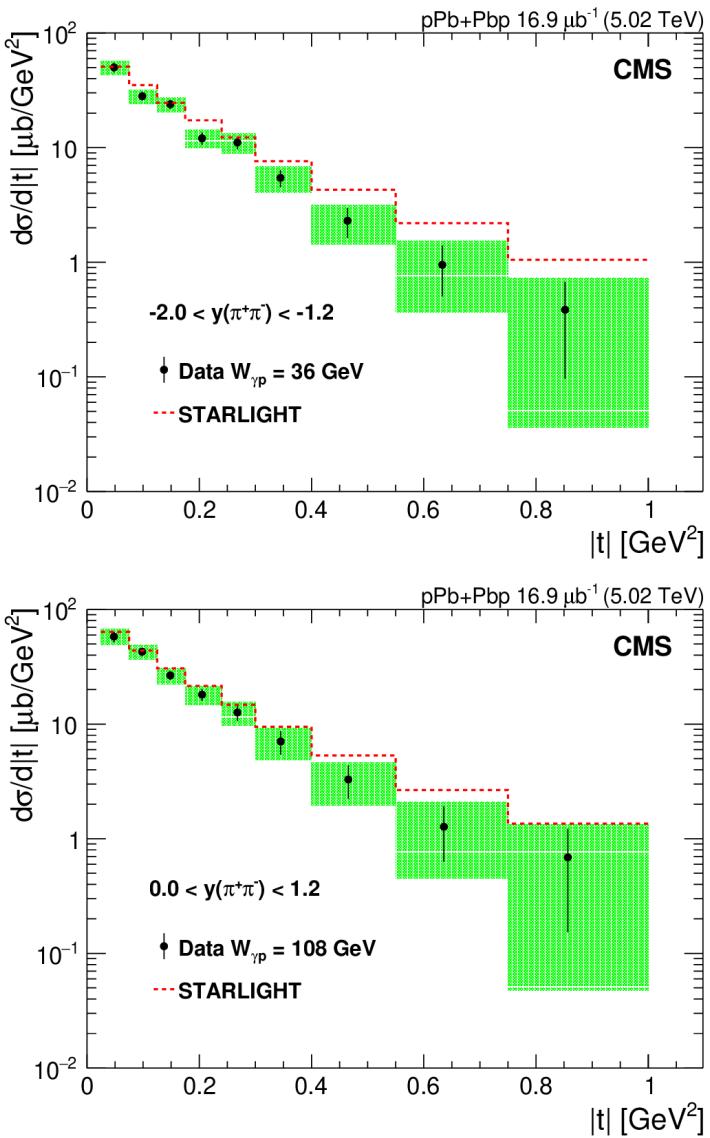
$$\delta = 0.23 \pm 0.14(\text{stat}) \pm 0.04(\text{syst})$$

Differential cross-sections



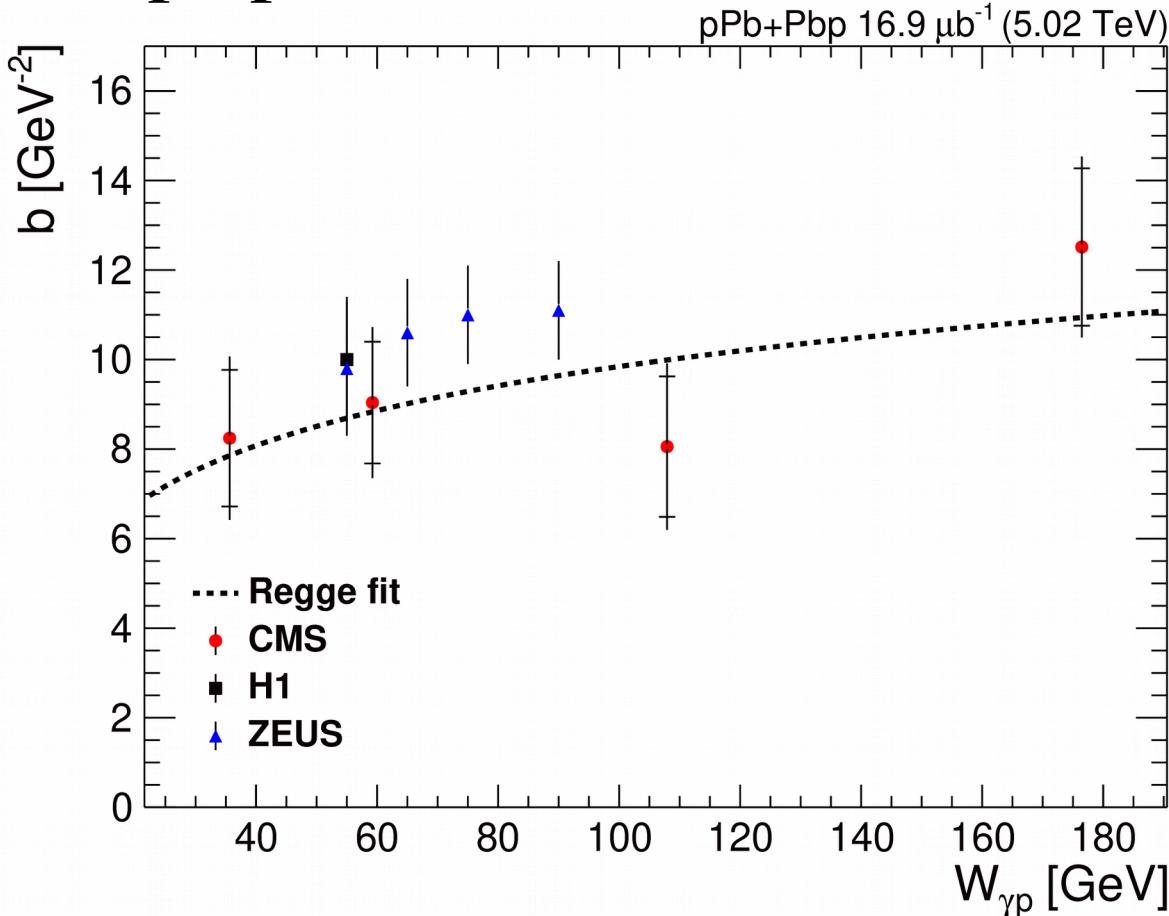
Good agreement between CMS and HERA data.

Differential cross-sections



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



Exponential fits
 e^{-bt+ct^2}

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

Pomeron trajectory 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.

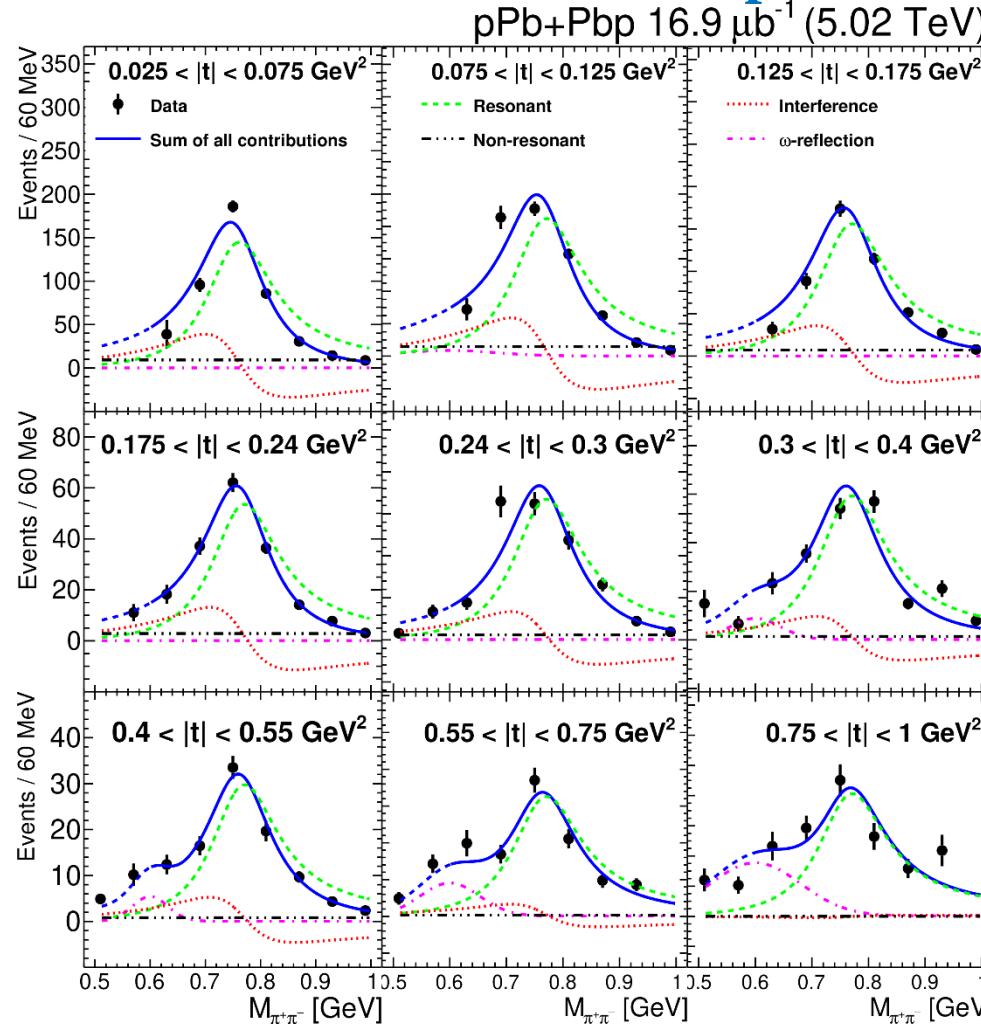
Summary

- Exclusive production in **pp** collisions
- Search for LbyL in **PbPb**
- Exclusive photoproduction of VM in **pPb** collisions
 - CMS is the perfect facility to study photoproduction in UPC
 - CMS extends HERA results on photoproduction of Υ and ρ^0 mesons
 - The first measurement of exclusive ρ^0 photoproduction in pPb collisions at 5.02 TeV at the LHC has been presented
 - The measured cross-sections are compatible with the power-law dependence of $W_{\nu p}$ observed at HERA
 - The differential cross-sections are in agreement with earlier measurements and consistent with Regge expectations
 - The CMS Experiment has good capabilities to study exclusive production.
 - More analyses coming soon.

Thank you for your attention!

Invariant mass fits

Repeated for each $|t|$ and rapidity bin



Similar to HERA Experiments:

non-resonant production decreases at high- $|t|$ values
decay mimics mainly high- $|t|$ events