

Recent results on ultra-peripheral heavy-ion processes

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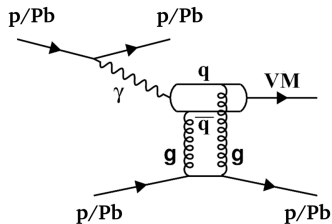
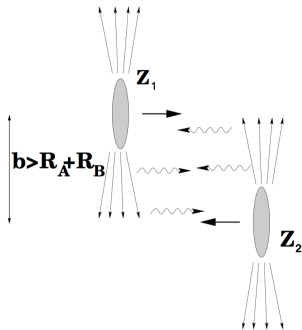
Initial Stages Conference, New York City, June 25, 2019



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- 2 Exclusive Υ photoproduction in pPb data
- 3 Exclusive $\rho(770)$ photoproduction in pPb data
- 4 Exclusive Υ photoproduction in Run2 PbPb data
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Ultra-Peripheral Collisions (UPCs)

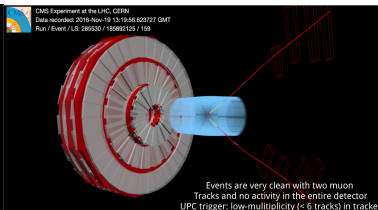
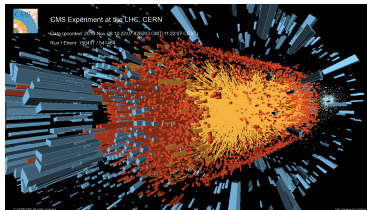
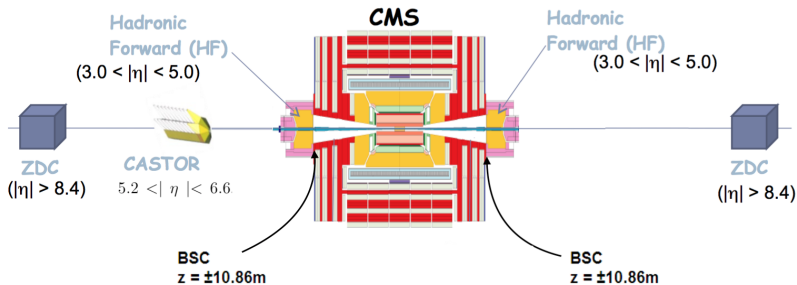


photon flux scales as Z^2

sensitive to the gluon density squared in the hadron at low x



Compact Muon Solenoid (CMS)

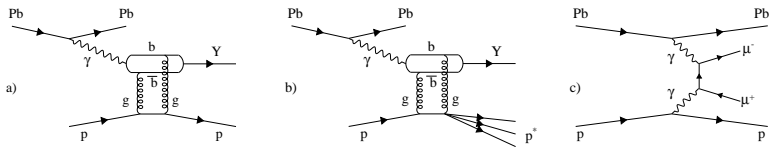


Measurement of exclusive Υ photoproduction from protons
in pPb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV

arXiv:1809.11080

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





a) exclusive Υ photoproduction (signal)

b) semiexclusive Υ photoproduction (background)

c) exclusive QED $\gamma\gamma \rightarrow \mu^+\mu^-$ process (background)

- Run1 pPb data at $\sqrt{s_{NN}} = 5.02$ TeV collected with the CMS detector
- Luminosity: $L = 32.6 \text{ nb}^{-1}$
- Process: $\gamma p \rightarrow \Upsilon(nS)p$ (with $n = 1, 2, 3$), $\mu^+ \mu^-$ decay mode
- Differential cross sections as functions of the $\Upsilon(nS)$ transverse momentum squared p_T^2 , and rapidity y
- Rapidity range $|y| < 2.2$, which corresponds to photon-proton centre-of-mass energies in the range $91 < W_{\gamma p} < 826$ GeV

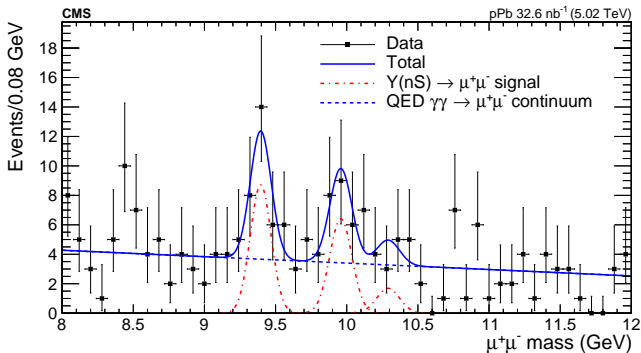
$$W_{\gamma p}^2 = 2E_p m_\Upsilon \exp(\pm y)$$

- The STARLIGHT Monte Carlo event generator
 - exclusive $\Upsilon(nS)$ photoproduction
 - exclusive QED background
 - acceptance and efficiency corrections
 - $\Upsilon(2S)$ feed-down contribution
 - photon flux Φ



Invariant mass, event selection

arXiv:1809.11080, Eur. Phys. J. C 79 (2019) 277

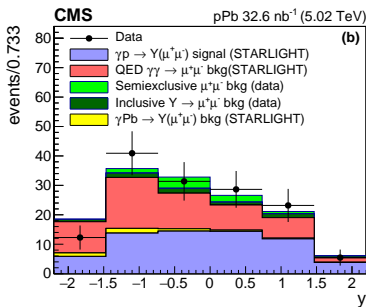
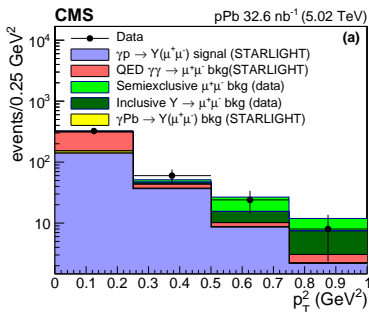


- Two opposite-charge muons with: $p_T^\mu > 3.3$ GeV, $|\eta^\mu| < 2.2$
- Single vertex with no extra charged particles with $p_T > 0.1$ GeV
- HF tower energy deposit < 5 GeV
- Dimuons: 0.1 GeV $< p_T < 1$ GeV

The QED contribution in the signal region amounts to 40%.

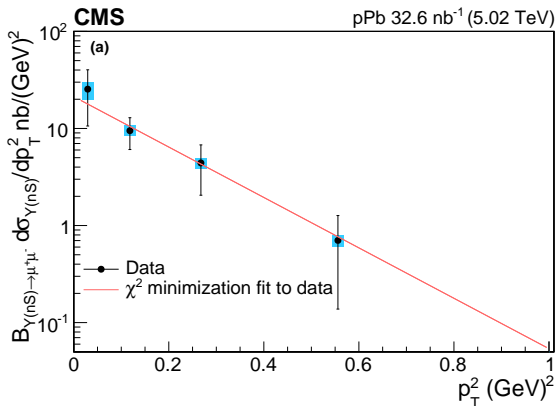


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- $9.1 < m_{\mu+\mu^-} < 10.6$ GeV
- QED estimated by STARLIGHT
- γPb contribution considered as background
- non-exclusive background estimated by data driven method





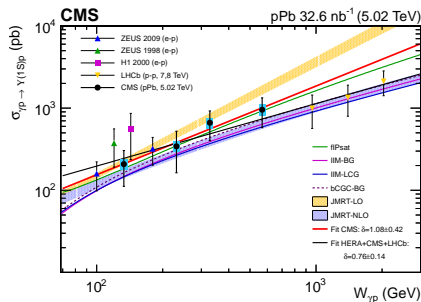
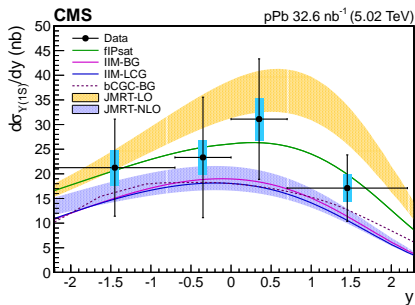
$$\sigma \sim \exp(-bp_T^2)$$

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

consistent with ZEUS results: $b = 4.3_{-1.3}^{+2.0}(\text{stat})_{-0.6}^{+0.5}(\text{syst}) \text{ GeV}^{-2}$



arXiv:1809.11080, Eur. Phys. J. C 79 (2019) 277



$$\frac{d\sigma_{\Upsilon(1S)}}{dy} = \frac{f_{\Upsilon(1S)}}{\mathcal{B}_{\Upsilon(1S) \rightarrow \mu^+\mu^-} (1 + f_{FD})} \times \left[\sum_n \mathcal{B}_{\Upsilon(nS) \rightarrow \mu^+\mu^-} \frac{d\sigma_{\Upsilon(nS)}}{dy} \right]$$

$$\sigma_{\Upsilon p \rightarrow \Upsilon(1S)p}(W_{\Upsilon p}^2) = \frac{1}{\Phi} \frac{d\sigma_{\Upsilon(1S)}}{dy}$$

CMS results bridge the gap between HERA and LHCb



Measurement of exclusive $\rho(770)^0$ photoproduction in
ultraperipheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

arXiv:1902.01339

Submitted to EPJC

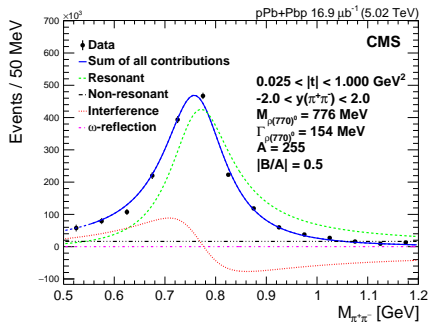
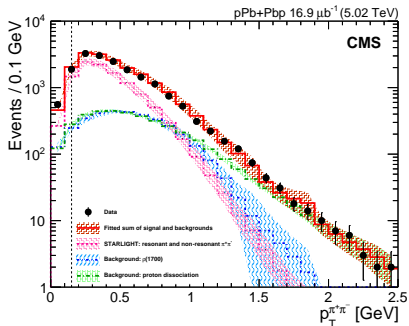


- Run1 pPb data at $\sqrt{s_{NN}} = 5.02$ TeV collected with the CMS detector
- Luminosity: $L = 7.4\mu b^{-1}$ for pPb and $L = 9.6\mu b^{-1}$ for Pbp
- Process: exclusive $\rho(770)^0 \rightarrow \pi^+\pi^-$
- Photon-proton centre-of-mass energies, $W_{\gamma p}$, between 29 and 213 GeV
- $d\sigma/d|t|$ is measured in the $0.025 < |t| < 1.000$ GeV² interval as a function of $W_{\gamma p}$
- Here: $|t| = p_T^2$
- The STARLIGHT Monte Carlo event generator
 - exclusive resonant and nonresonant $\pi^+\pi^-$ production
 - exclusive $\rho(1700)$ events
 - acceptance and efficiency corrections
 - photon flux



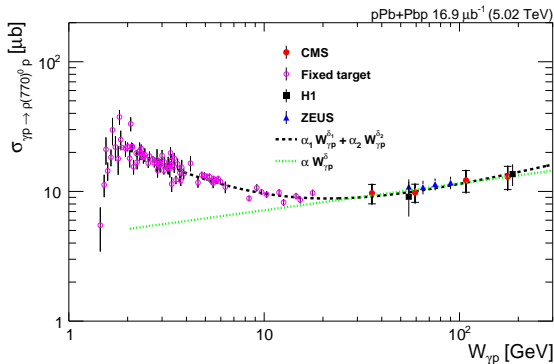
Event selection and signal extraction

arXiv:1902.01339, Submitted to EPJC



- Exactly two tracks, $|\eta_{\text{track}}| < 2.0$, $p_T^{\text{leading}} > 0.4 \text{ GeV}$, $p_T^{\text{subleading}} > 0.2 \text{ GeV}$
- Leading HF tower $< 3.0 \text{ GeV}$
- CASTOR energy $< 9 \text{ GeV}$
- ZDC⁺ energy $< 500 \text{ GeV}$, ZDC⁻ energy $< 2000 \text{ GeV}$

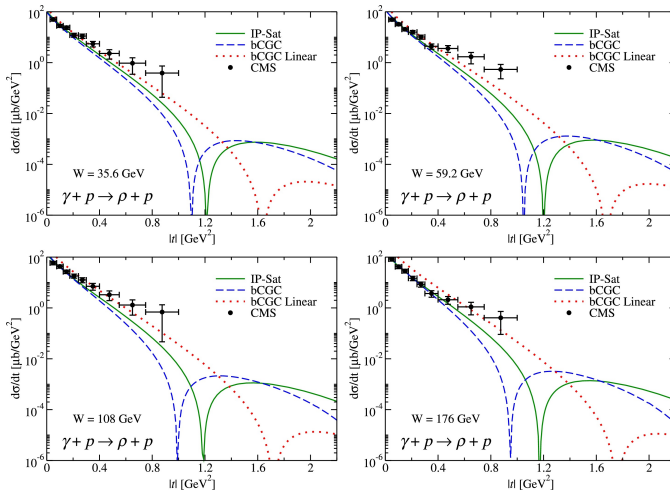




- $\sigma(\gamma p \rightarrow \rho(770)^0) = 11.1 \pm 1.4(\text{stat}) \pm 1.0(\text{syst}) \mu\text{b}$
 - for $29 < W_{\gamma p} < 213$ GeV
- $\delta = 0.23 \pm 0.14(\text{stat}) \pm 0.04(\text{syst})$
 - both CMS and HERA data
- Consistent with H1 and ZEUS Collaborations at HERA
- Ion-proton collisions can be used similarly to electron-proton



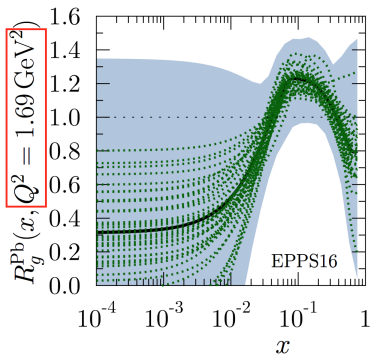
V. Goncalves, et al. Phys. Lett. B791 (2019) 299-304



- First measurement of the energy dependence of the $d\sigma/dt$
- Sensitive to the onset of the gluon saturation

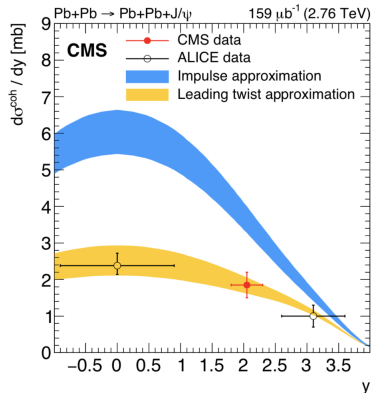
Exclusive Υ photoproduction in Run2 PbPb data from CMS





$$R_i^A(x, Q^2) = \frac{f_i^A(x, Q^2)}{Af_i^P(x, Q^2)}$$

Done for J/ψ . Now with a new kinematic range with Υ .

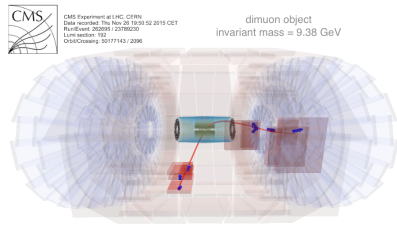
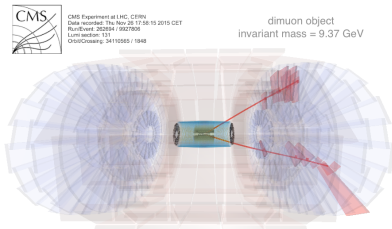


Coherent J/ψ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the CMS experiment



Exclusive Υ photoproduction in Run2 PbPb data

- 2015 PbPb data in CMS
 - $\sqrt{s_{NN}} = 5.02$ TeV
 - integrated luminosity recorded by CMS: $550 \mu\text{b}^{-1}$
 - hundreds of Υ candidates
- 2018 PbPb data in CMS
 - $\sqrt{s_{NN}} = 5.02$ TeV
 - integrated luminosity recorded by CMS: $1700 \mu\text{b}^{-1}$
 - very good performance of the ZDC
 - expected order of thousand of Υ candidates



- CMS is a perfect experiment for UPC studies
- Exclusive $\Upsilon(1S)$ and $\rho(770)^0$ photoproduction in pPb
 - Sensitive to gluon distribution in the proton at $x \sim 10^{-4} - 10^{-2}$
 - Extends HERA results
 - Cross-sections in agreement with the power law dependence of $W_{\gamma p}$ observed at HERA
 - Upcoming measurement at 8 TeV with much larger statistics
- Exclusive Υ photoproduction in PbPb (ongoing)
 - New kinematic range
 - Improve our understanding of the initial state of relativistic nuclei

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- [1] CMS Collaboration, Exclusive $\rho(770)^0$ photoproduction in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the CMS experiment, Submitted to EPJC
- [2] CMS Collaboration, Measurement of exclusive Υ photoproduction from protons in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, Eur. Phys. J. C 79, 277, 2019
- [3] V.P. Gonçalves, F.S. Navarra, D. Spiering, Exclusive ρ and J/ψ photoproduction in ultraperipheral pA collisions: Predictions of the gluon saturation models for the momentum transfer distributions, Phys. Lett. B791 299-304, 2019
- [4] Kari J. Eskola Petja Paakkinen, Hannu Paukkunen, Carlos A. Salgado, EPPS16: Nuclear parton distributions with LHC data, arXiv:1612.05741, 2016
- [5] CMS Collaboration, Coherent J/ψ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the CMS experiment, Phys. Lett. B 772 489, 2017
- [6] CMS Collaboration, Constraining nuclear parton distributions with heavy ion collisions at the HL-LHC with the CMS experiment, CMS-PAS-FTR-18-027, 2018



Systematic uncertainties – exclusive Υ in pPb collisions

Source	$\mathcal{B}_{Y(nS)\rightarrow\mu^+\mu^-} d\sigma/dp_T^2$	b	$\mathcal{B}_{Y(nS)\rightarrow\mu^+\mu^-} d\sigma/dy$	$d\sigma_{Y(1S)}/dy$	$\sigma_{\gamma p\rightarrow Y(1S)p}$
Muon efficiency	± 11	—	± 11	± 11	± 11
Acceptance	± 3	± 2	± 2	± 2	± 2
Unfolding	± 1	± 0.2	—	—	—
Exclusive QED background	± 4	± 3	± 4	± 4	± 4
Nonexclusive background	± 3	± 3	± 6	± 6	± 6
Integrated luminosity	± 4	—	± 4	± 4	± 4
Feed-down	—	—	—	± 2	± 2
Branching fraction $\mathcal{B}_{Y(1S)\rightarrow\mu^+\mu^-}$	—	—	—	± 2	± 2
$f_{Y(1S)}$ fraction	—	—	—	± 6	± 6
Photon flux Φ	—	—	—	—	± 4
Total	± 13	± 5	± 14	± 15	± 16

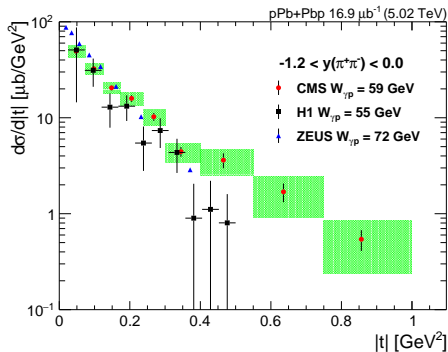


Systematic uncertainties – exclusive ρ in pPb collisions

$y_{\pi^+\pi^-}$ interval	(-2.0, 2.0)	(-2.0, -1.2)	(-1.2, 0.0)	(0.0, 1.2)	(1.2, 2.0)
Integrated luminosity	4.0	4.0	4.0	4.0	4.0
Track reconstruction	7.8	7.8	7.8	7.8	7.8
Unfolding	3.0	3.0	3.0	3.0	3.0
Photon flux calculation	5.0	2.0	4.0	6.0	9.0
Calorimeter exclusivity	1.4	1.4	1.4	1.4	1.4



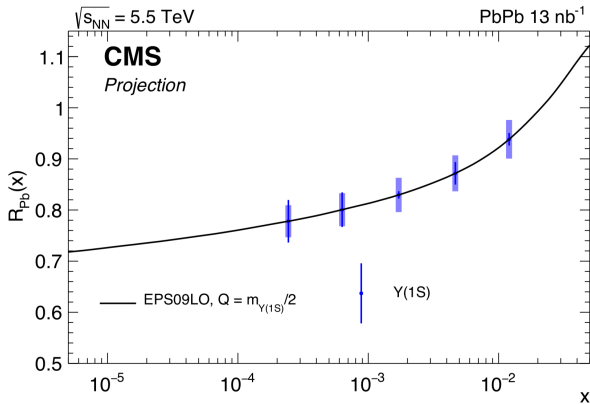
arXiv:1902.01339, Submitted to EPJC



- Fit with the form Ae^{-bt+ct^2} for $0.025 < |t| < 0.5$ GeV^2
- $b = 9.5 \pm 0.6$ (stat) GeV^{-2} and $c = 5.0 \pm 1.5$ (stat) GeV^{-4}



Predictions for HL LHC [6]



Constraining nuclear parton distributions with heavy ion collisions at the HL-LHC with the CMS experiment

