



Exclusive Υ Photoproduction in Ultra-peripheral pPb Collisions @ 5.02 TeV

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On behalf of the CMS collaboration

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Outline

- **Introduction to UPC**
- **Aim of exclusive Υ photoproduction study**
- **CMS Detector**
- **Event selection**
- **Results**
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 - **Data/MC comparison**
 - **Differential cross section of Υ distribution**
 - **Cross section of $\Upsilon(1S)$ vs $W_{\gamma p}$**
- **Summary and Outlook**

Ultra-peripheral Collisions (UPC)

- Two relativistic nuclei interact **electromagnetically** by physically **missing** each other

➤ Impact parameter $b \gg 2R_A$

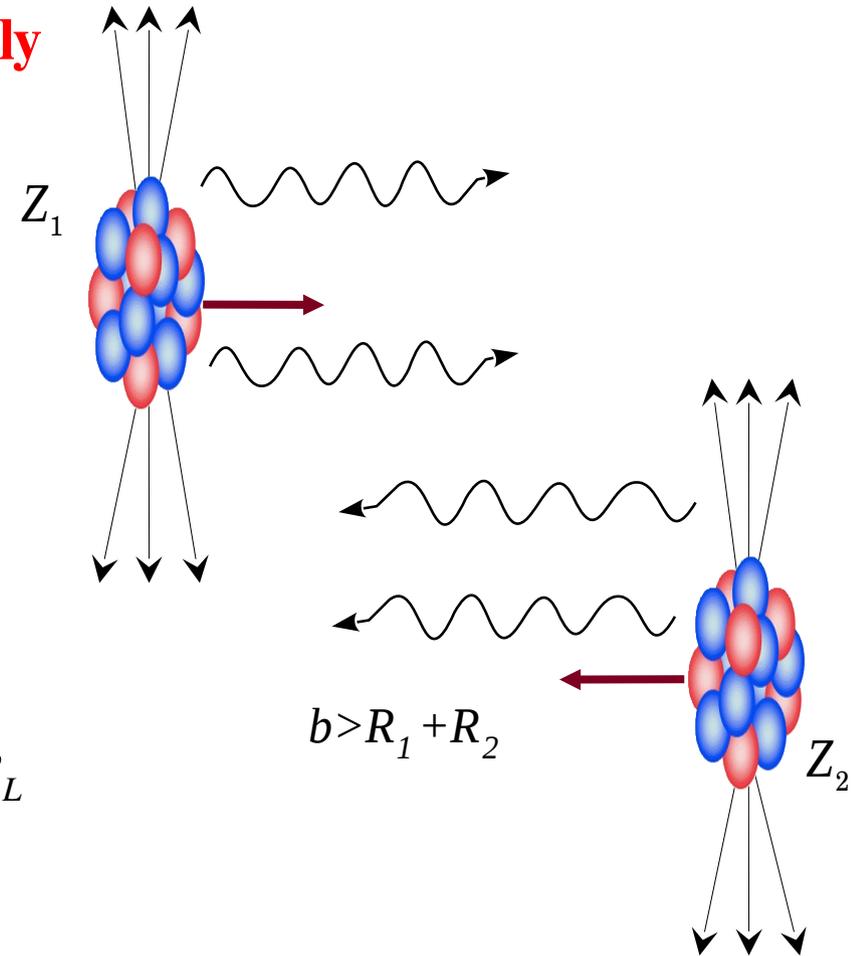
- Ions are source of EM field

➤ Photon **flux** $\propto Z^2$

➤ Weizsäcker-Williams approximation :

$$\frac{d^3 N_\gamma}{dkd^2r} = \frac{Z^2 \alpha w^2}{\pi^2 kr^2} \left[K_1^2(w) + \frac{1}{\gamma_L^2} K_0^2(w) \right], \quad w = kr/\gamma_L$$

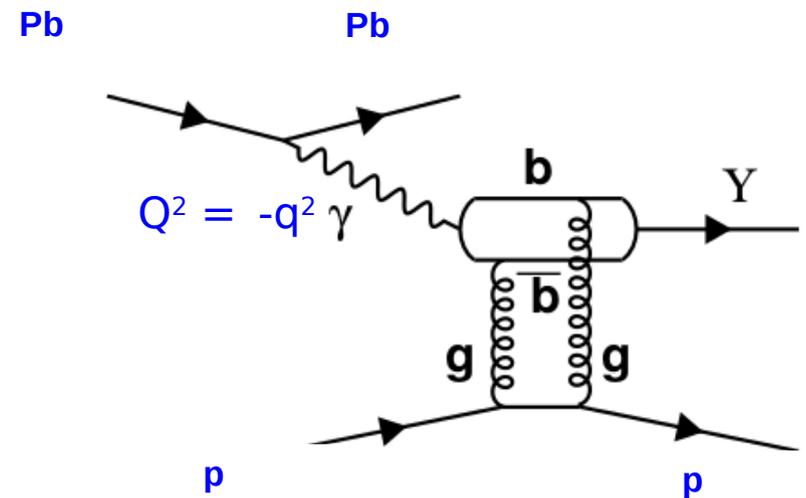
- No hadronic interaction



Schematic diagram of UPC

Kinematics of photon in pPb collisions at the LHC

- The upper limit of quasi-real photon energy is $\omega_{\max} \approx \gamma_L / R_A$; $\gamma_L = E_A / m_A$ (Lorentz factor)
 - γ from p: $\omega_{\max} \sim 1066 \text{ GeV}$
 - γ from Pb: $\omega_{\max} \sim 48 \text{ GeV}$
- The virtuality for the photon is related to the radius of the emitting particle: $Q^2 \approx (\hbar c / R_A)^2$
 - γ from p: $Q^2 \approx 250 \text{ MeV}^2$
 - γ from Pb: $Q^2 \approx 30 \text{ MeV}^2$
- Heavy-ion produces huge EM field
 - Photons are emitted coherently by entire nucleus
 - Flux drops rapidly with increasing energy



Photon-Nuclear Interaction

Photon interactions at the LHC

■ Following processes are the photon interaction in UPC

a) Photon-nuclear interaction(Signal)

- leading to Vector Meson (i.e Υ , J/ψ) photoproduction

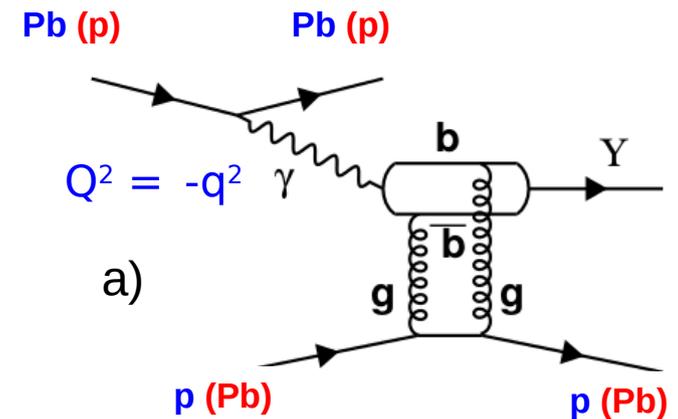
(**This talk**)

b) Photon-photon interaction

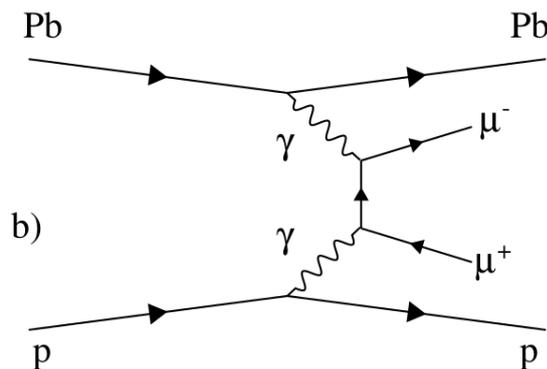
-QED background

c) Proton dissociation

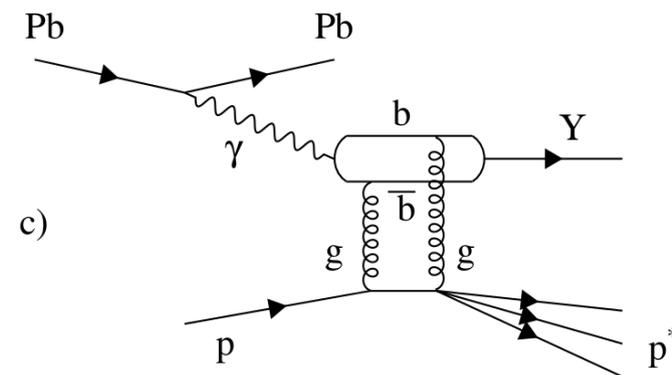
- PD background



Photon-Nuclear Interaction



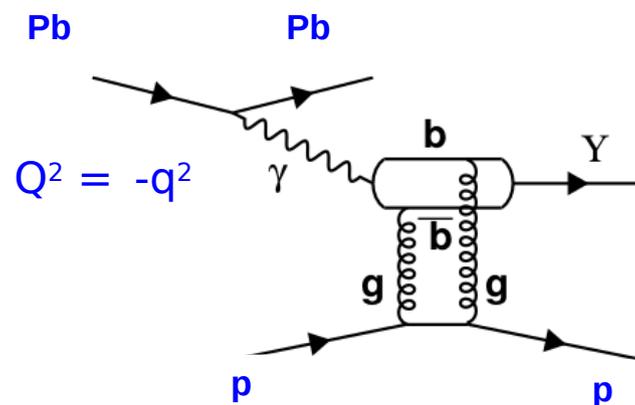
Photon-Photon Interaction



Proton dissociation

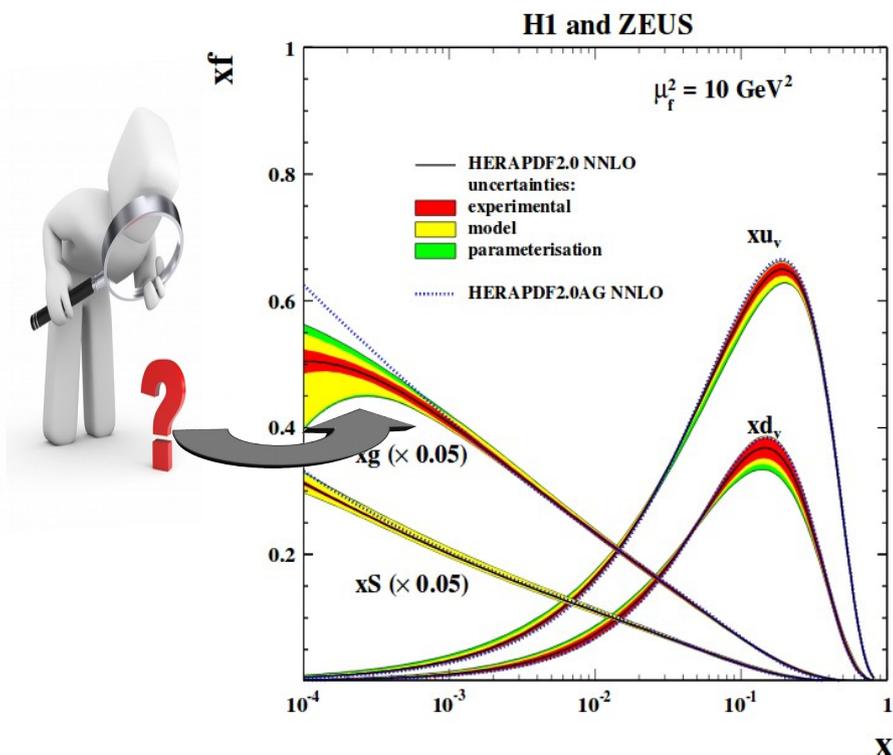
Aim of exclusive Υ photoproduction study in pPb

- Photon emitted by Pb nucleus oscillates to virtual $q\bar{q}$ pair
- $q\bar{q}$ pair scatters elastically from proton
- Photoproduction **cross-section** of Υ is related to the **gluon density square** in proton



Photon-Nuclear Interaction

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



arXiv:1605.03459

- **Region of interest for PDFs:**

-looking for poorly known **gluon distribution in the proton at low-x** (2×10^{-2} to 10^{-4}) and search for **saturation effects**

Exclusive Υ photoproduction in pPb

- Cross-section for the process $\gamma+p \rightarrow \Upsilon+p$ is

$$\sigma_{\Upsilon}(W_{\gamma p}) = W_{\gamma p}^{\delta}, \text{ where } \delta \text{ is const}$$

- **Region of interest in CMS:**

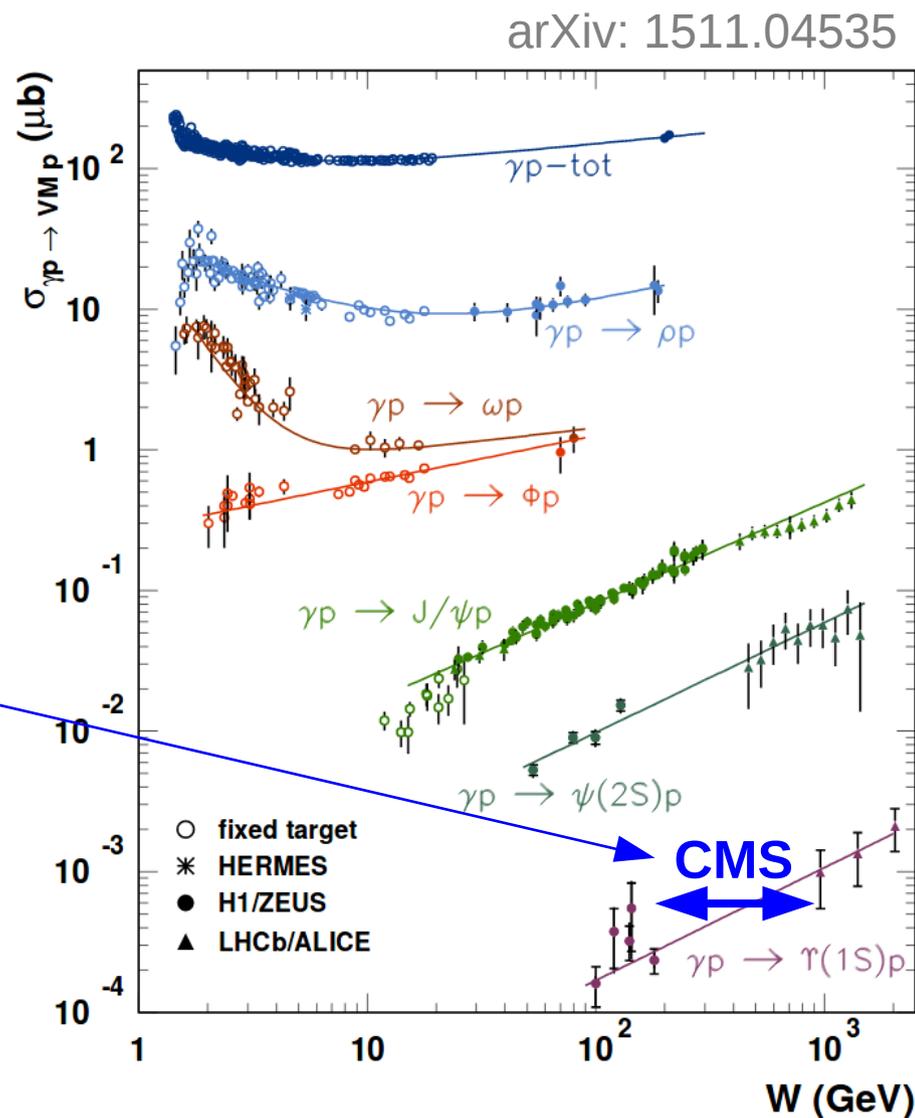
- small Bjorken x
- probe region: photon-proton center of mass energy $W_{\gamma p}$

$$W_{\gamma p} : 91 - 826 \text{ GeV},$$

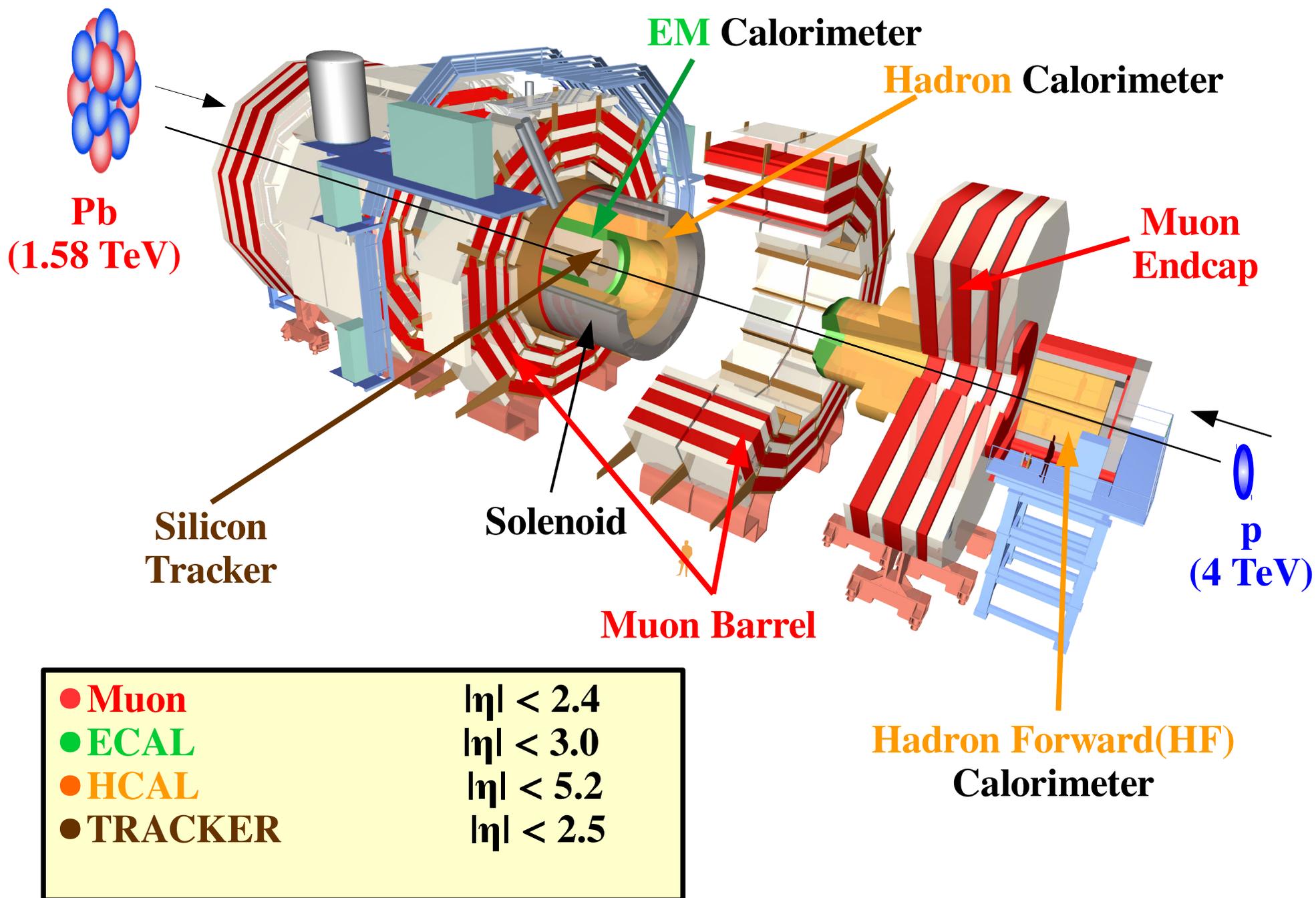
$$\text{for } x = 2 \times 10^{-2} - 10^{-4}$$

$$x = (M_{\Upsilon}/W_{\gamma p})^2, W_{\gamma p}^2 = 2E_p M_{\Upsilon} \exp(\pm y)$$

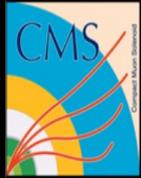
- Low-mass states with higher rapidity probe low Bjorken x



CMS Detector



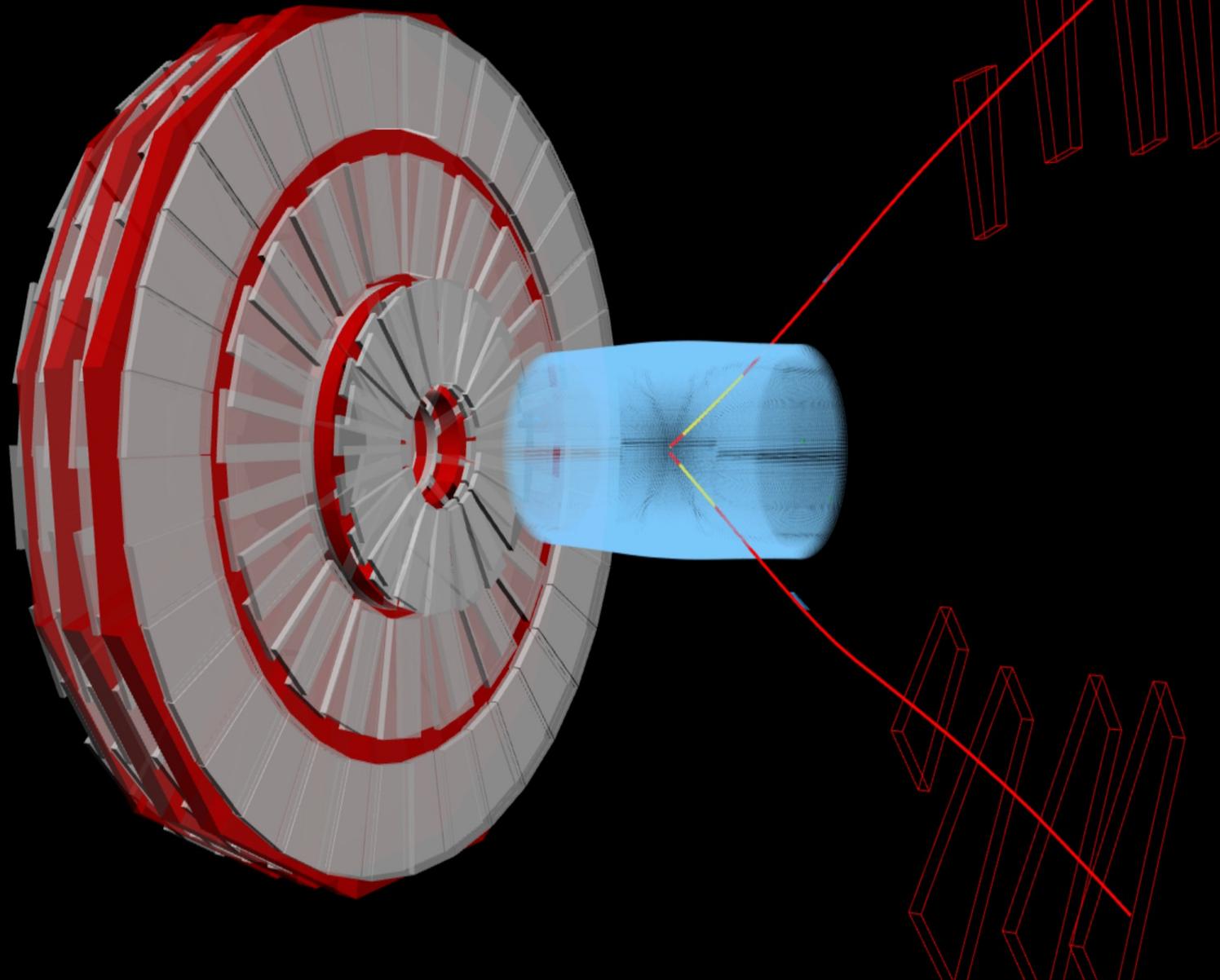
Typical Υ event in pPb UPC collision



CMS Experiment at the LHC, CERN

Data recorded: 2016-Nov-19 13:19:56.623727 GMT

Run / Event / LS: 285530 / 185892125 / 159

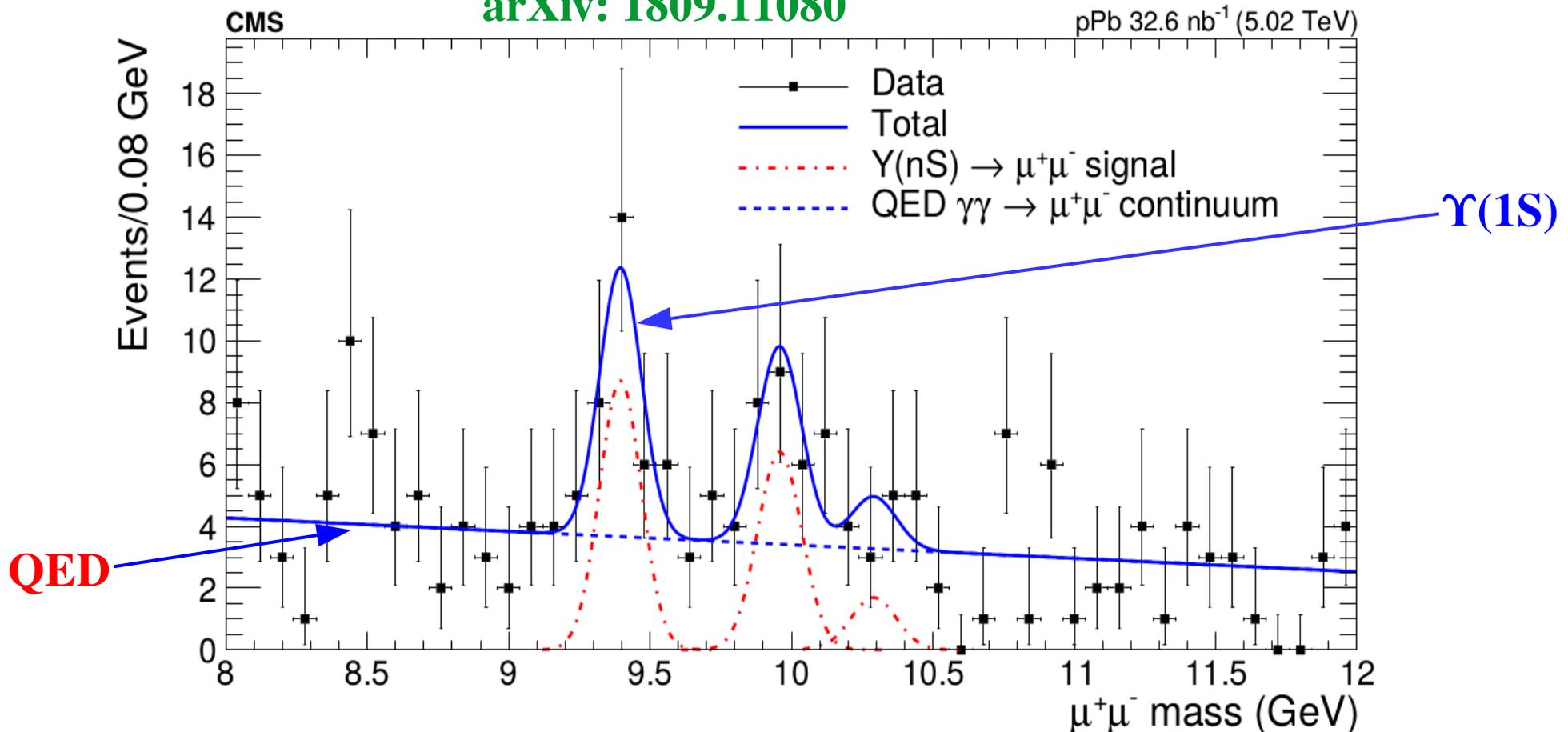


Event Selection

- Data was taken for pPb collision with $\sqrt{s_{NN}} = 5$ TeV in 2013
- **Total Intergrated Luminosty: 32.6 nb^{-1}**
- **Dimuon Mass cut: $9.1 < \text{Mass}_{\mu\mu} < 10.6 \text{ GeV}/c^2$**
- **Exclusivity Cut:**
 - No. of Tracks should be 2 in an event ($N_{\text{Tracks}} = 2$, $\text{trk } p_T > 0.1 \text{ GeV}$)
 - Leading Tower Energy in **HFPlus** and **HFMinus** $< 5.0 \text{ GeV}$
- **Muon selection**
 - **Single muon Cut:**
 - To have good muon efficiency
 - $\mu^+, \mu^- p_T > 3.3 \text{ GeV}/c$, $|\eta| < 2.2$
- **Υ selection**
 - **Dimuon p_T Cut:**
 - Low p_T cut to have good signal/bkd. ratio, high p_T cut to suppress background from **inclusive Υ** and **Proton Dissociation(PD)**
 - Dimuon p_T : $0.1 < p_T < 1.0 \text{ GeV}/c$

Invariant Mass Fitting

arXiv: 1809.11080

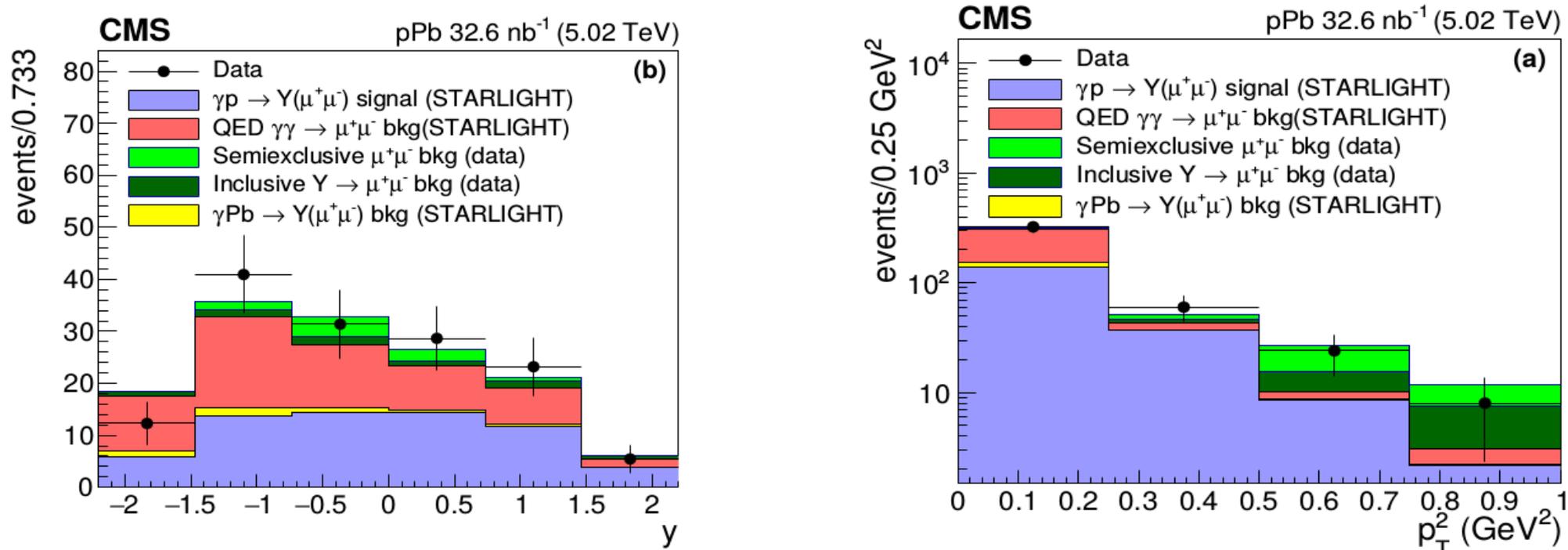


■ Data fitting (using ROOFIT)

- QED ($\gamma\gamma \rightarrow \mu^+\mu^-$) is fitted with 1st order polynomial
- **Three Gaussian peaks are signal($\Upsilon(nS)$)**
 - Mass and width of $\Upsilon(1S)$ are free parameters
 - The $\Upsilon(2S)$ - $\Upsilon(1S)$ and $\Upsilon(3S)$ - $\Upsilon(1S)$ mass differences are set to the PDG values
 - The widths of the higher states($\Upsilon(2S)$, $\Upsilon(3S)$) are scaled by width of $\Upsilon(1S)$ times the ratio of masses($\Upsilon(nS)/\Upsilon(1S)$)

Data/MC comparison

arXiv: 1809.11080



- Dimuon distribution (y, p_T^2) of **Data** compared with the 5 different contributions in the mass range $9.1 < \text{Mass}_{\mu\mu} < 10.6 \text{ GeV}/c^2$
- **Data driven background(Semiexclusive & Inclusive):**
 - Estimated from non-exclusive criteria by normalizing with exclusive **Data** at $p_T > 1 \text{ GeV}$
- **MC STARLIGHT:**
 - γp MC signal
 - **QED** elastic background
 - γPb small contribution

The Data(Bkg. Subtracted)/MC comparison is quite promising

Exclusive Υ differential cross section distribution with p_T^2

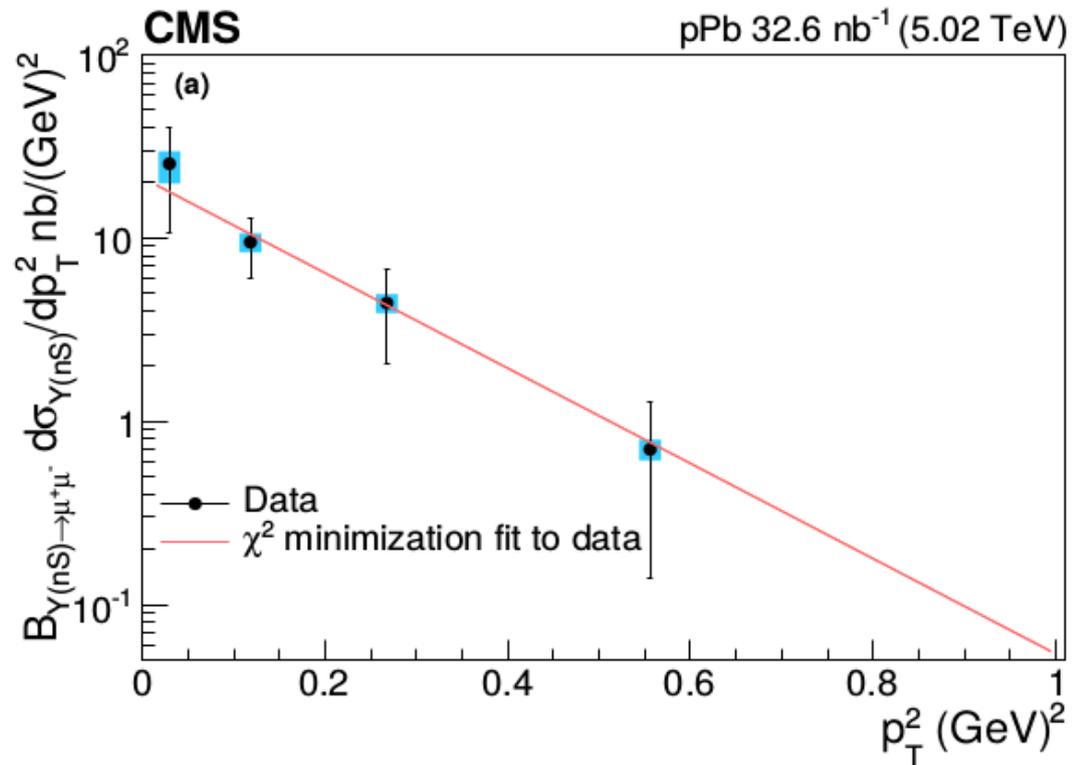
arXiv: 1809.11080

- $d\sigma/dp_T^2$ of Υ is measured in the range $0.01 < p_T^2 < 1 \text{ GeV}/c^2$, where $|t| \approx p_T^2$

- Following equation was used to measure $d\sigma/dp_T^2$

$$\frac{d\sigma_{\Upsilon(nS)}}{dp_T^2} \mathcal{B}_{\Upsilon(nS) \rightarrow \mu^+ \mu^-} = \frac{N_{\Upsilon(nS)}^{\text{corr}}}{\mathcal{L} \times \Delta p_T^2}$$

$N_{\Upsilon(nS)}^{\text{corr}}$ denotes the background subtracted, unfolded (bayesian method) and acceptance corrected number of signal events in each p_T^2 bin



- This plot is fitted with an exponential function $Ne^{-b|t|}$ with χ^2 minimization

- **CMS Result:**

b-slope for all $\Upsilon(nS)$: **$b = 6.0 \pm 2.1(\text{stat.}) \pm 0.3(\text{syst.}) \text{ GeV}^{-2}$**

- **Zeus Result:**

b-slope for $\Upsilon(1S)$: **$b = 4.3_{-1.3}^{+2.0}(\text{stat.}) \text{ GeV}^{-2}$** [Physics Letters B 708 (2012) 14–20]

\Rightarrow CMS and ZEUS results are consistent

Exclusive Υ differential cross section distribution with y

arXiv: 1809.11080

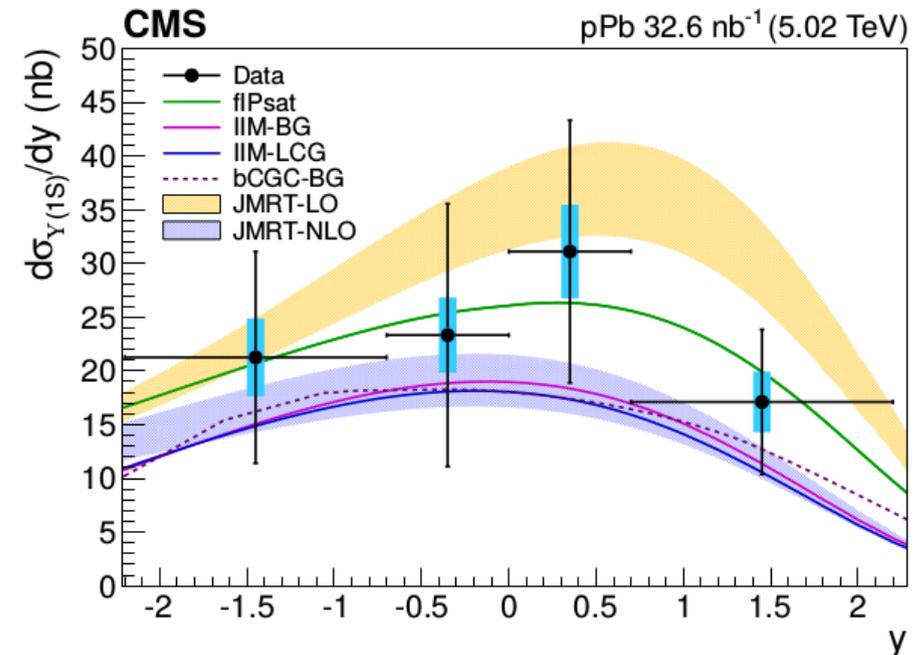
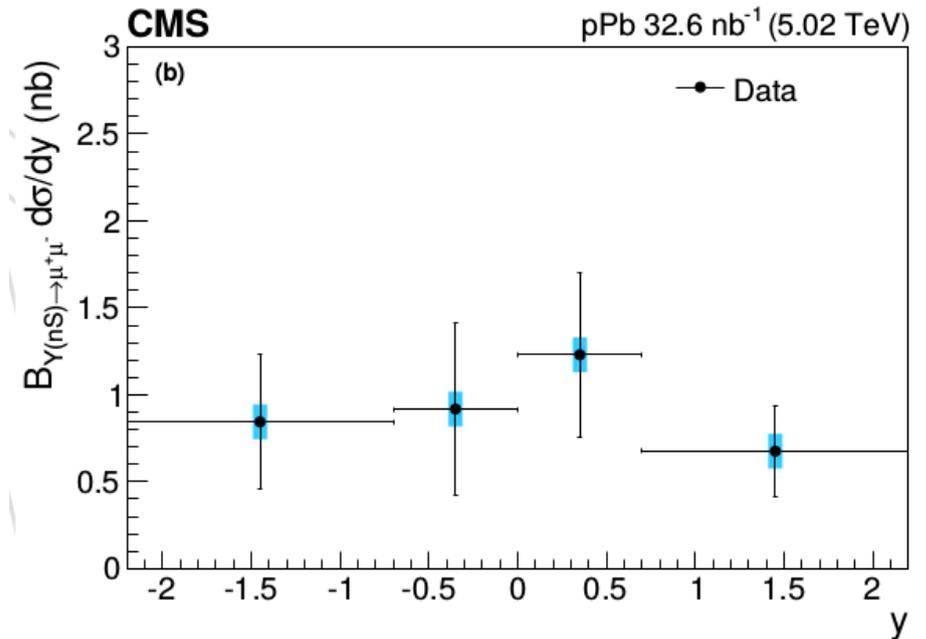
- $d\sigma/dy$ of $\Upsilon(nS)$ is measured in the range $|y| < 2.2$

$$\frac{d\sigma_{\Upsilon(nS)}}{dy} \mathcal{B}_{\Upsilon(nS) \rightarrow \mu^+ \mu^-} = \frac{N_{\Upsilon(nS)}^{\text{corr}}}{\mathcal{L} \times \Delta y}$$

- $d\sigma/dy$ of $\Upsilon(1S)$ is estimated using following equation

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

where $f_{\Upsilon(1S)}$ is ratio of $\Upsilon(1S)$ to $\Upsilon(nS)$ events and f_{FD} is the feed-down contribution to the $\Upsilon(1S)$ events originating from the $\Upsilon(2S) \rightarrow \Upsilon(1S) + X$ decays (where $X = \pi^+ \pi^-$ or $\pi^0 \pi^0$)



Exclusive Υ photoproduction cross section vs $W_{\gamma p}$

- Cross section of $\Upsilon(1S)$ with $W_{\gamma p}$ is measured in an unexplored region of photon-proton center-of-mass energy ($W_{\gamma p}$: 91 – 826 GeV) using following equations

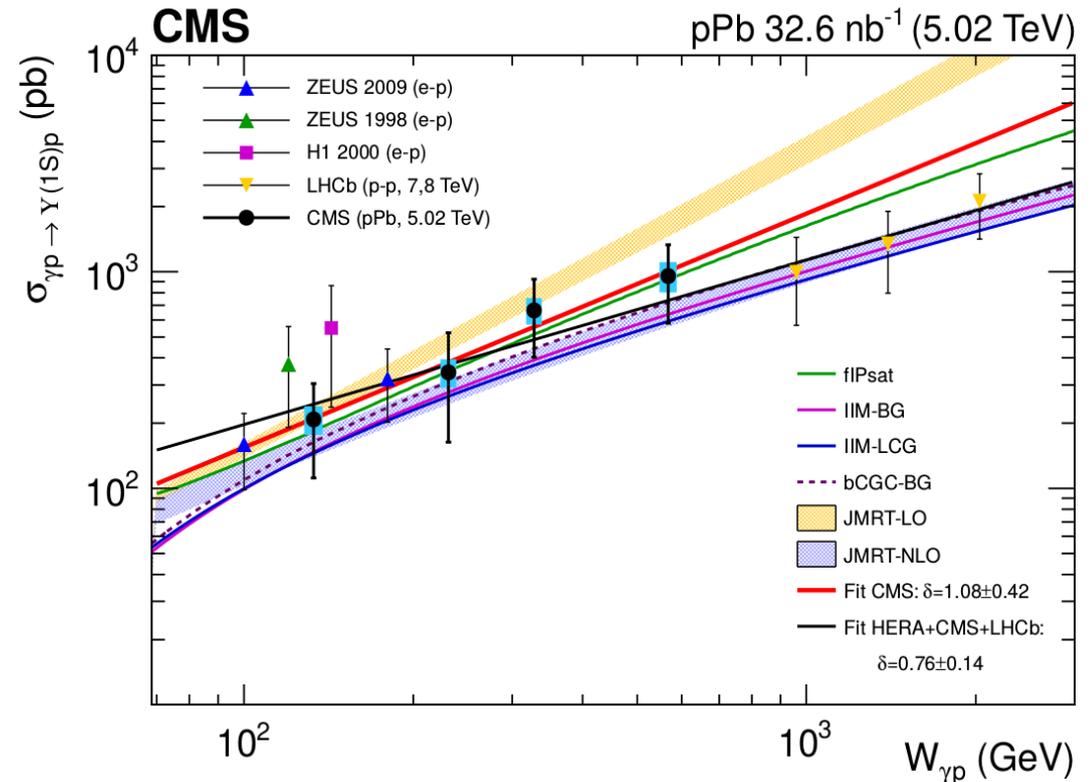
$$W_{\gamma p}^2 = 2E_p M_\Upsilon \exp(\pm y),$$

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

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

where Φ is photon flux

arXiv: 1809.11080



- Fit parameters of power law dependent cross section: $\sigma_\Upsilon(W_{\gamma p}) = A \times (W/400)^\delta$
 - **CMS result:** , $\delta = 1.08 \pm 0.42$, $A = 690 \pm 184$ pb
 - **ZEUS result:** $\delta = 1.2 \pm 0.8$

Summary and Outlook

- Invariant mass plot shows three distinct peaks of $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$ after exclusive event selection.
 - 1st measurement of $\Upsilon(nS)$ for **5 TeV** with pPb collision in **CMS**
- Slope-b measured by exponential fitting of $d\sigma/dp_T^2$ vs p_T^2 plot with χ^2 minimization
 - **CMS**($b_{\Upsilon(nS)} = 6.0 \pm 2.1(\text{stat.}) \pm 0.3(\text{syst.}) \text{ GeV}^{-2}$) and ZEUS($b_{\Upsilon(1S)} = 4.3_{-1.3}^{+2.0}(\text{stat.}) \text{ GeV}^{-2}$) results are in good agreement
- $d\sigma/dy$ of $\Upsilon(1S)$ is consistent with most theoretical predictions
- Cross section of exclusive $\Upsilon(1S)$ is measured in an unexplored region of photon-proton center-of-mass energy **$W_{\gamma p} : 91 - 826 \text{ GeV}$**
 - It shows a power law dependence cross section of $\Upsilon(1S)$
 - $\sigma_{\Upsilon}(W_{\gamma p}) = W_{\gamma p}^{\delta}$, where **$\delta = 1.08 \pm 0.42(\text{CMS})$** , ZEUS result: **$\delta = 1.2 \pm 0.8$**
 - It is consistent with other experimental results and disfavours fast rising LO pQCD prediction
- This analysis puts a new constraint for the evolution of gluon density at low Bjorken x in proton
- Ongoing exclusive $\Upsilon(nS)$ analysis at **8 TeV** with higher statistics

Thank you for attention!