Measurement of exclusive Upsilon Photoproduction off protons in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with CMS

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On behalf of the CMS collaboration

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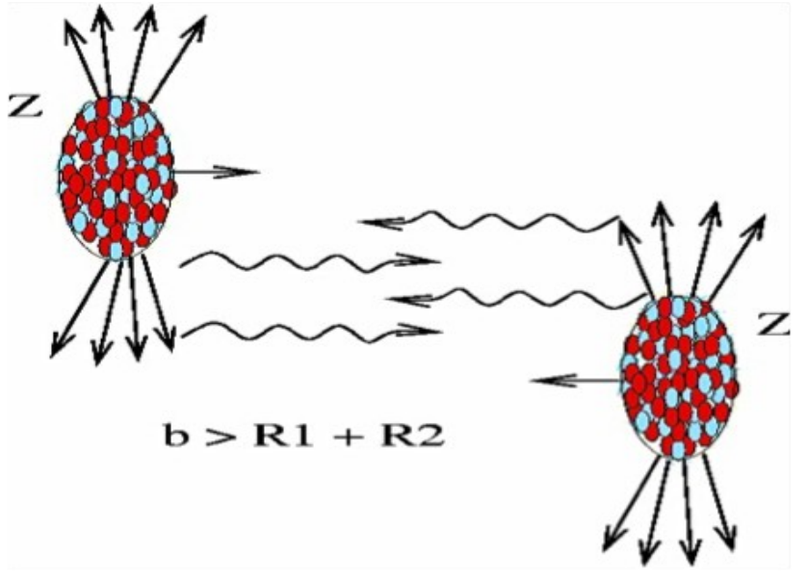
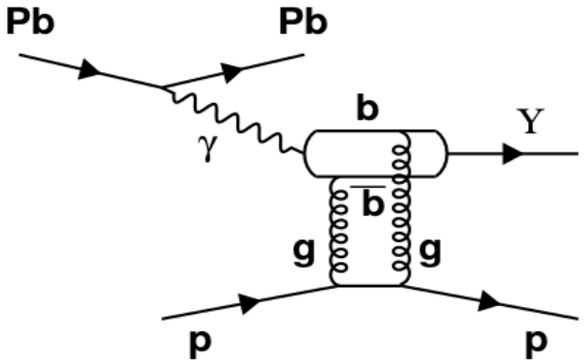
The LHC as a photon collider

- Ultraperipheral (e.m) collisions (UPCs)
  without hadronic overlap: $b_{min} > R_A + R_B$
- Weizsäcker-Wiliams approximation:
  Coherent e.m. field of Z proton(s)
  equivalent to photon spectrum.
- Quasi-real photons with maximum γ energies
  at the LHC: $\omega < \omega_{max} \approx \frac{\gamma}{R}$ ~ 80 GeV (Pb), ~ 2.5 TeV (p)



- Photo-nuclear interaction:
  Exclusive vector meson production
  (this talk)



- Photon-photon interaction:
  Light-by-light scattering
  Talk by David d'Enterria on Wednesday 12.30

Study the photon-induced processes at the LHC at higher energies than available before.

Exclusive Υ photoproduction in pPb collisions

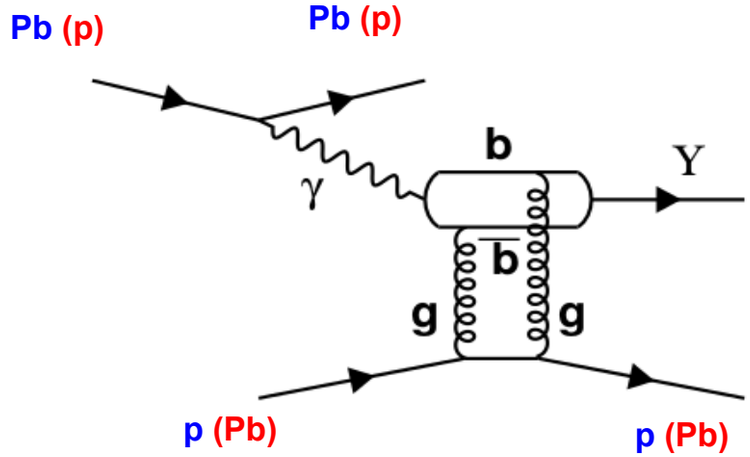
- Ions emit quasi-real photon with flux α Z^2
- γp: Dominant contribution, γPb: Small contribution
- Photoproduction process sensitive to the square of of the gluon density inside the proton

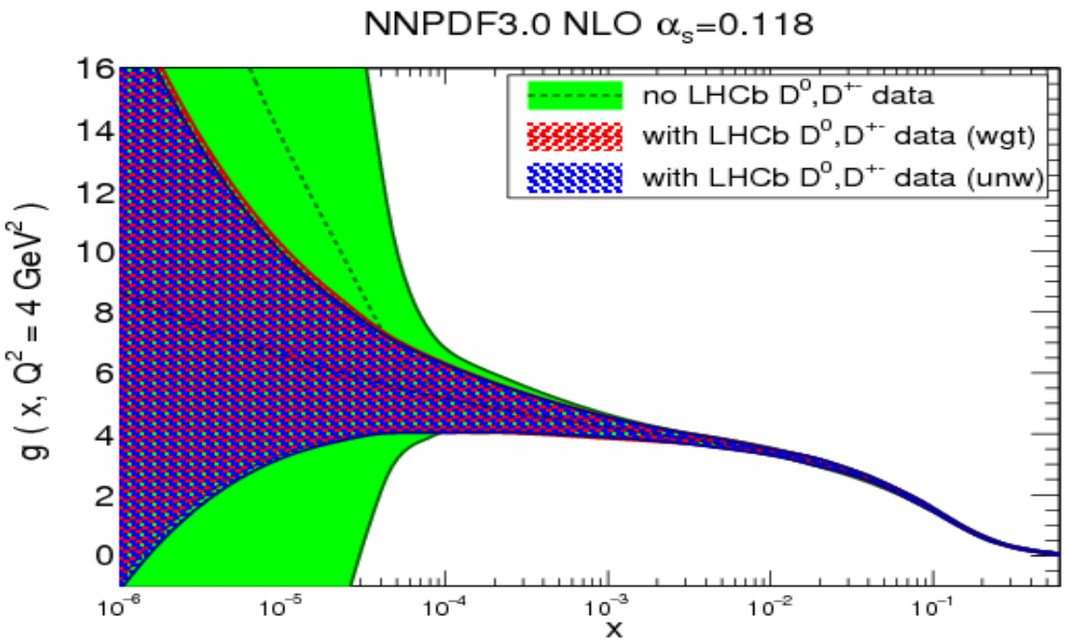
$$\left.\frac{d\sigma_{\gamma p, A\to V p, A}}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xG(x,Q^2)]^2$$

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

- Probe poorly-known gluon distribution (initial state) of the proton at low Bjorken-x (10^{-4} to $2*10^{-2}$)

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





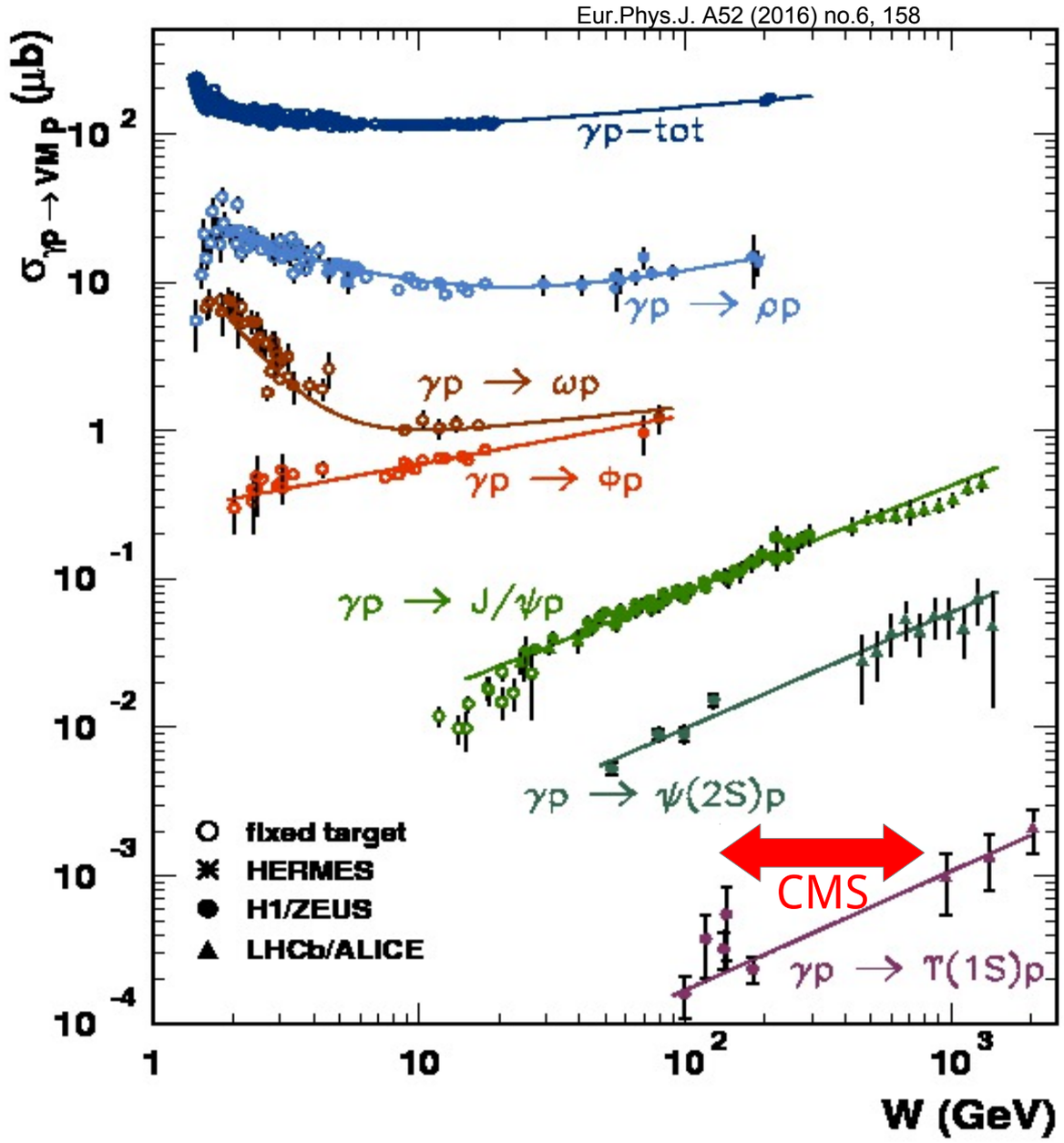
Exclusive Υ photoproduction in pPb collisions

- Photonuclear cross-section follows power law dependance with $W_{\gamma p}$ (same as gluon PDF evolution)

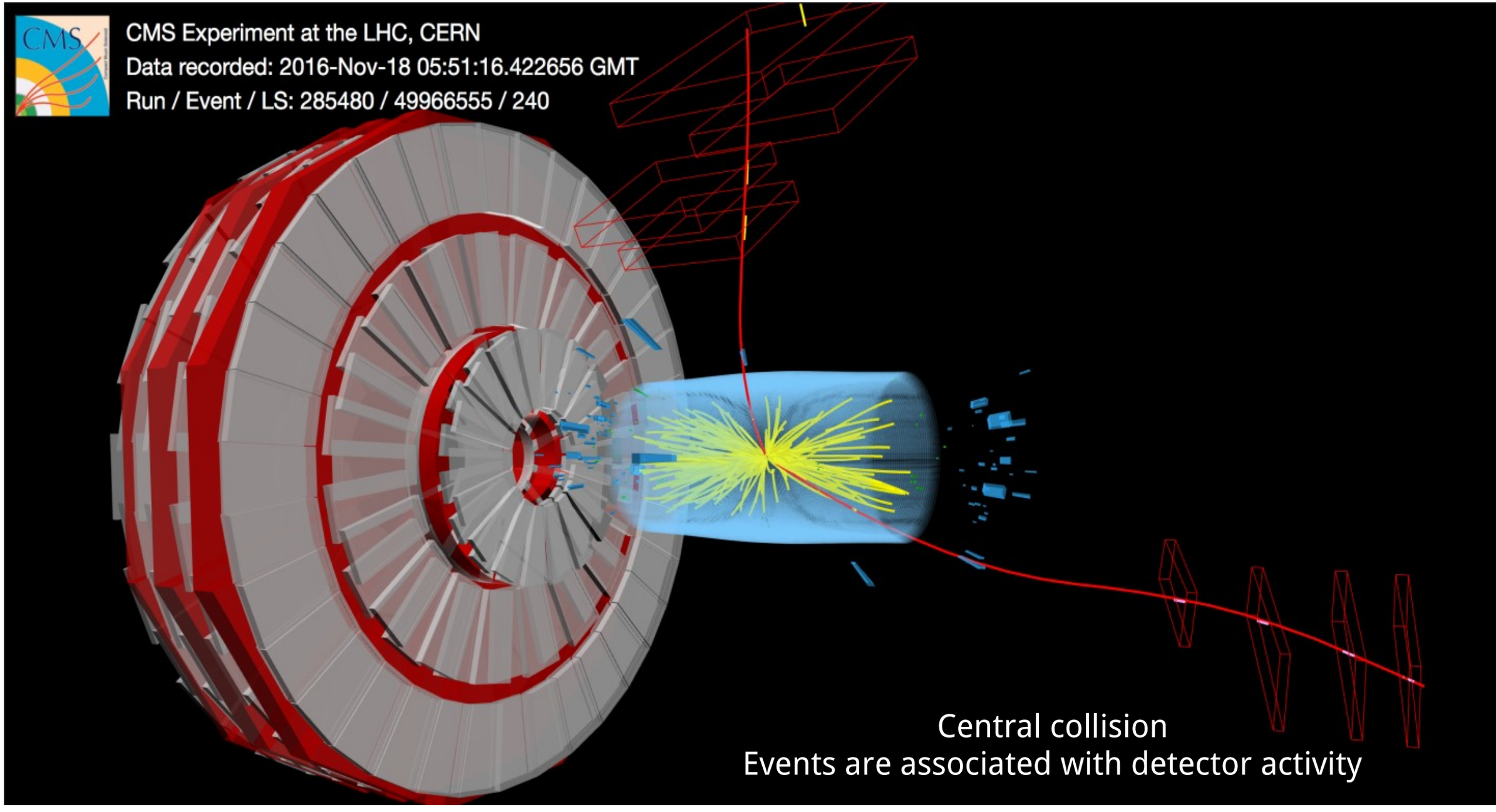
$$\sigma \propto W_{\gamma p}^{\delta}$$

$W_{\gamma p}$ – photon proton center of mass energy

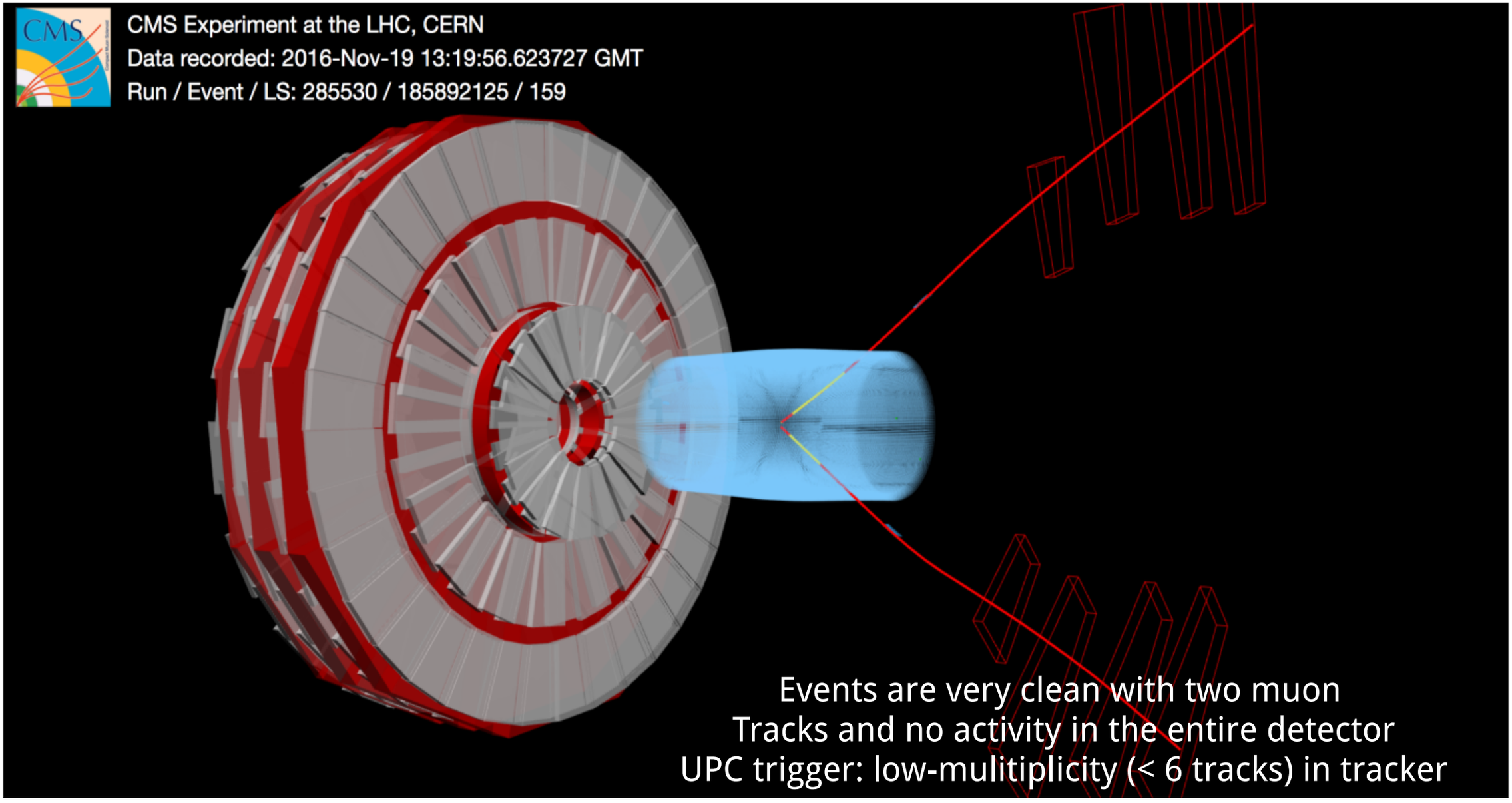
- CMS UPCs probe the c.m. energy range $W_{\gamma p}$ = 91 – 826 GeV



Typical Υ event in pPb collisions



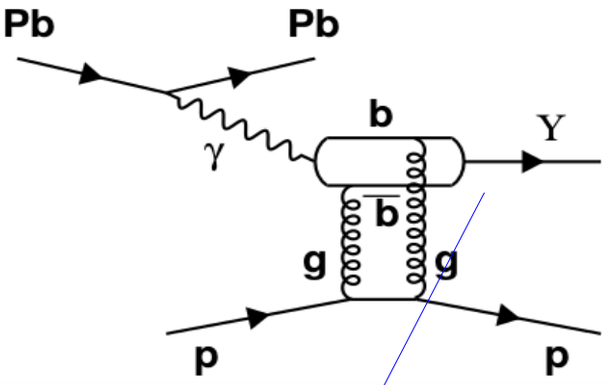
Typical ϒ event in pPb ultra-peripheral collisions

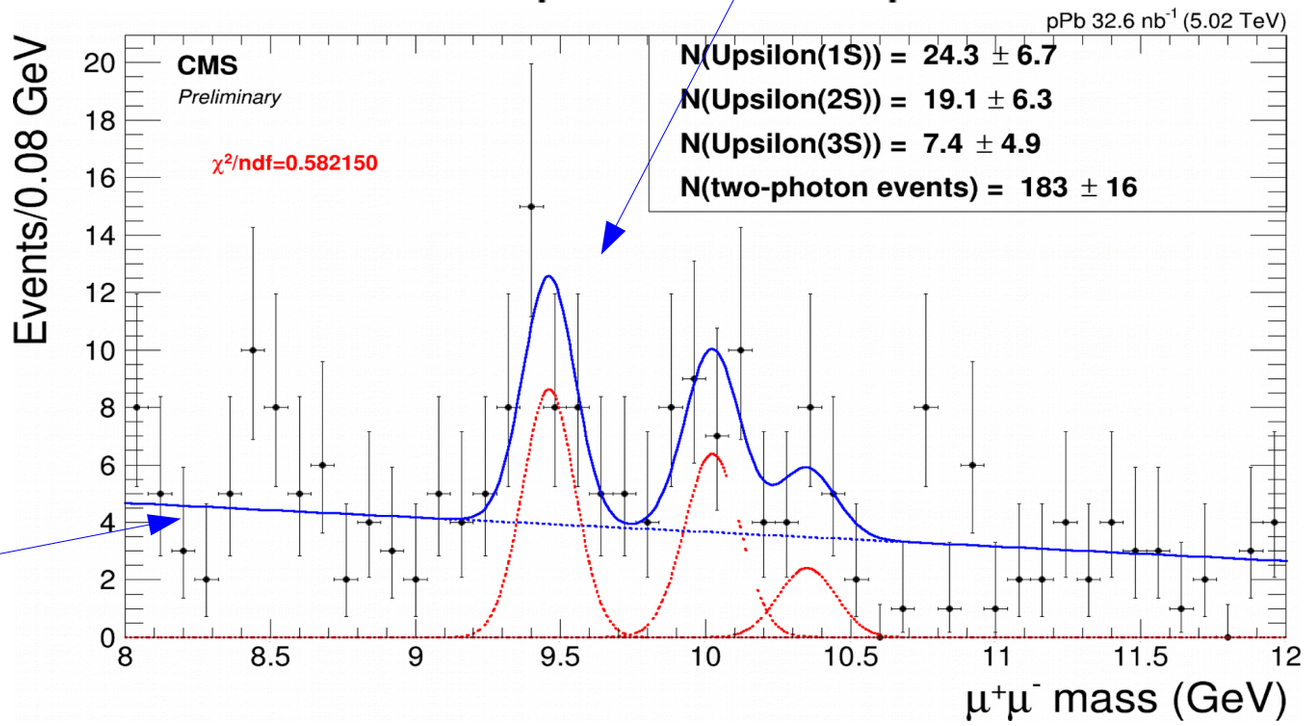


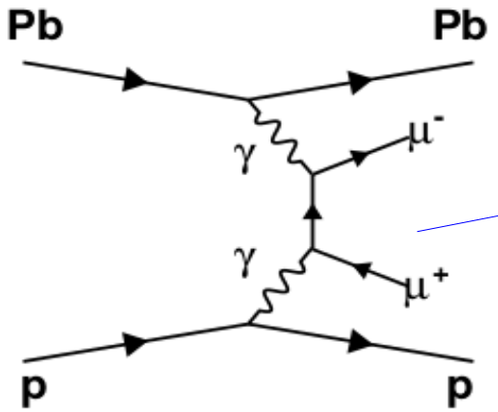
Exclusive ϒ event selection

CMS-FSQ-13-009

- 2013 pPb data at 5.02 TeV with integrated luminosity 32.6 nb^{-1}
- Muon p_T > 3.3 GeV , |n| < 2.2
- **Exclusivity cuts:**
  Exactly two opposite sign muons with no extra tracks reconstructed with p_T > 0.1 GeV
- Upsilon p_T : 0.1 - 1 GeV
  - Low- p_T cut: reduce QED
  - High-p_T cut: reduce non-exclusive background
- Signal region:
  - Invariant mass (μμ) : 9.1-10.6 GeV



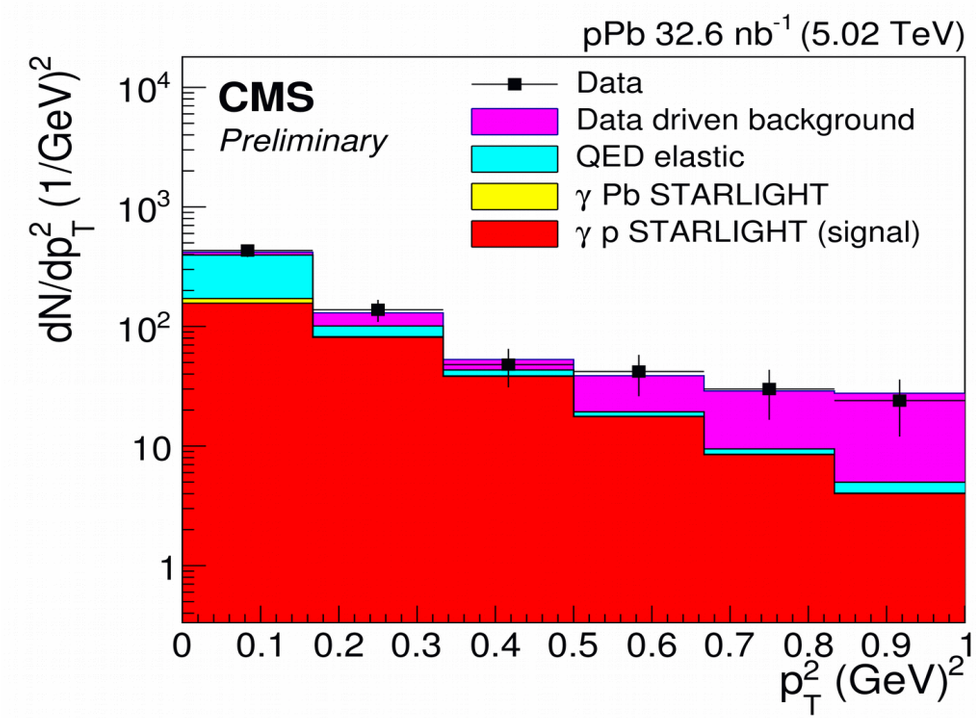


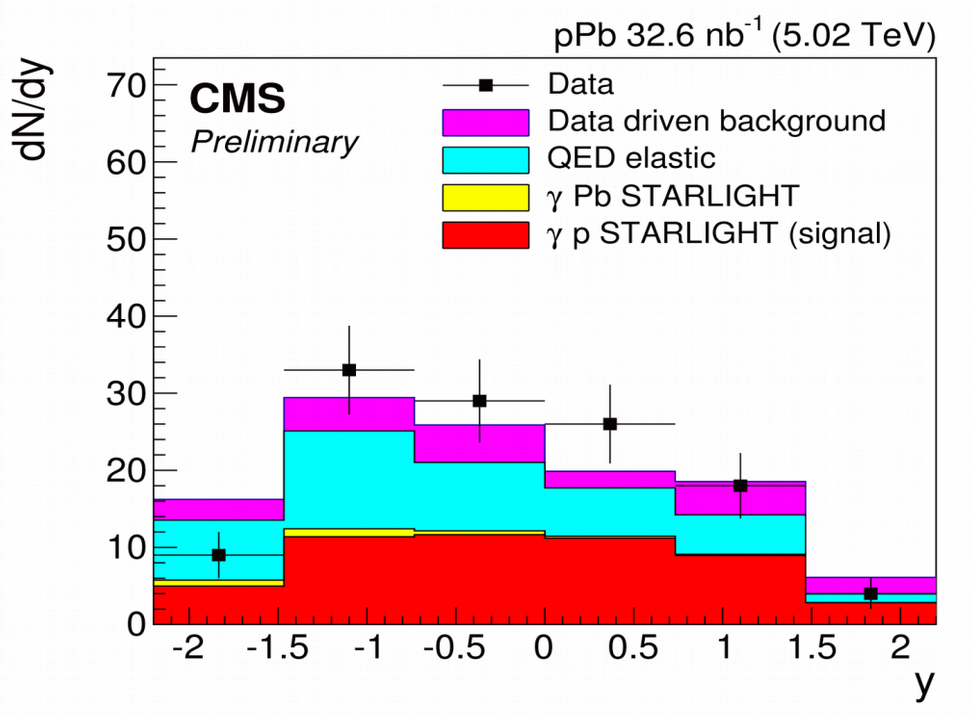


Data-MC comparison

CMS-FSQ-13-009

- Data compared to 4 different contributions:
  - ➔ STARLIGHT MC : **γp signal (MC reweighted to match the data), γPb(small contribution)** and **QED** elastic background (dominant at dimuon $p_T < 0.1$ GeV)
  - ➔ **Data-driven:** Non-exclusive backgrounds are estimated by inversing the exclusivity criteria (and normalizing them at dimuon $p_T > 1$ GeV)





Good agreement between data and MC
Number of signal events estimated by subtracting all background contributions.

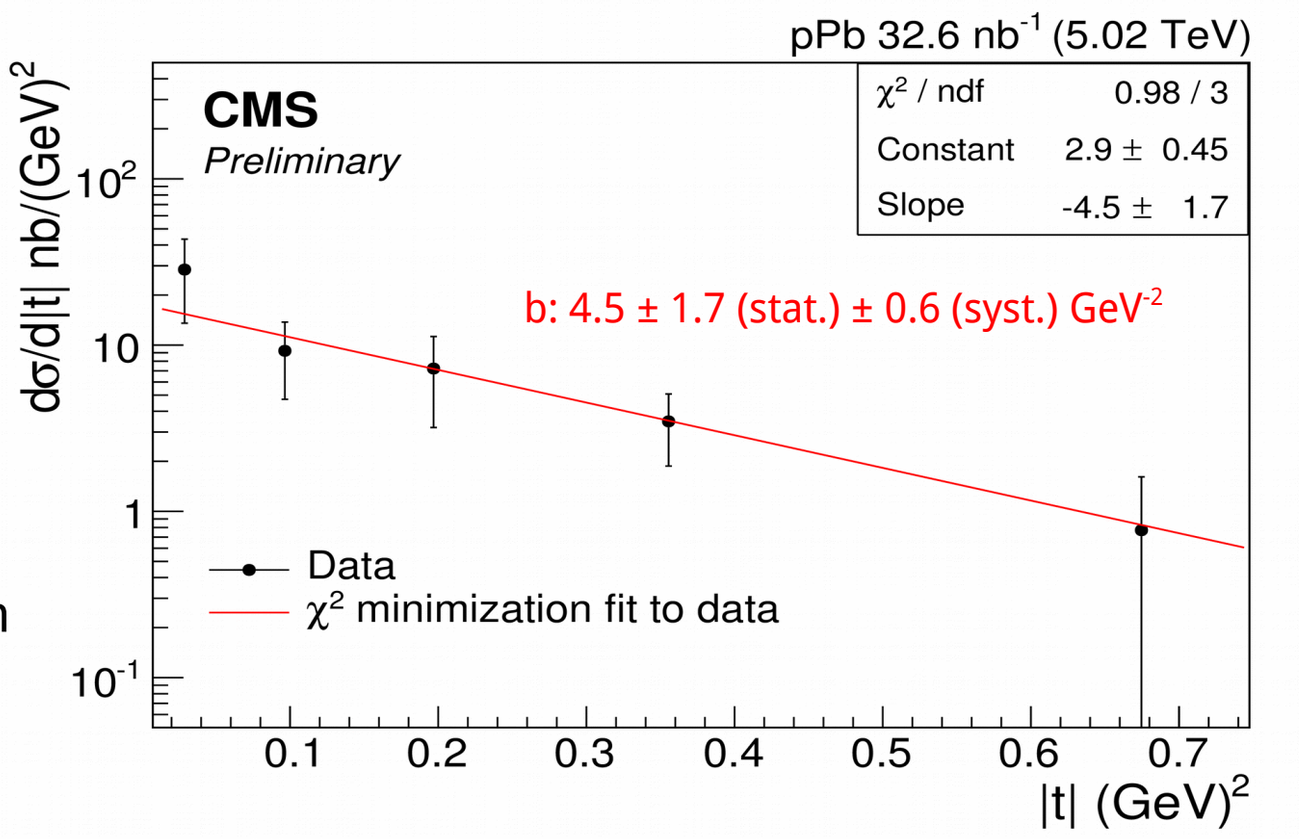
Excl. Υ photoproduction p_T^2 distribution

CMS-FSQ-13-009

- The background-subtracted p_T^2 ~ $|t|$ distribution, unfolded with Bayesian method, corrected for the acceptance.
- The differential cross section estimated by

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

- The p_T^2 fitted with an exponential function ($\exp^{-b|t|}$), provides the information on the transverse profile of the interaction region.



- **CMS Results :**
  b= 4.5 ± 1.7 (stat) ± 0.6 (syst) GeV^{-2}
- ZEUS for Y(1S) :
  b = $4.3^{+2.0}_{-1.3}$ (stat) GeV^{-2}
  Phys.Lett.B 708 (2012) 14

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

Excl. Υ(1S) photoproduction cross section vs $W_{\gamma p}$

CMS-FSQ-13-009

- Differential cross section estimated

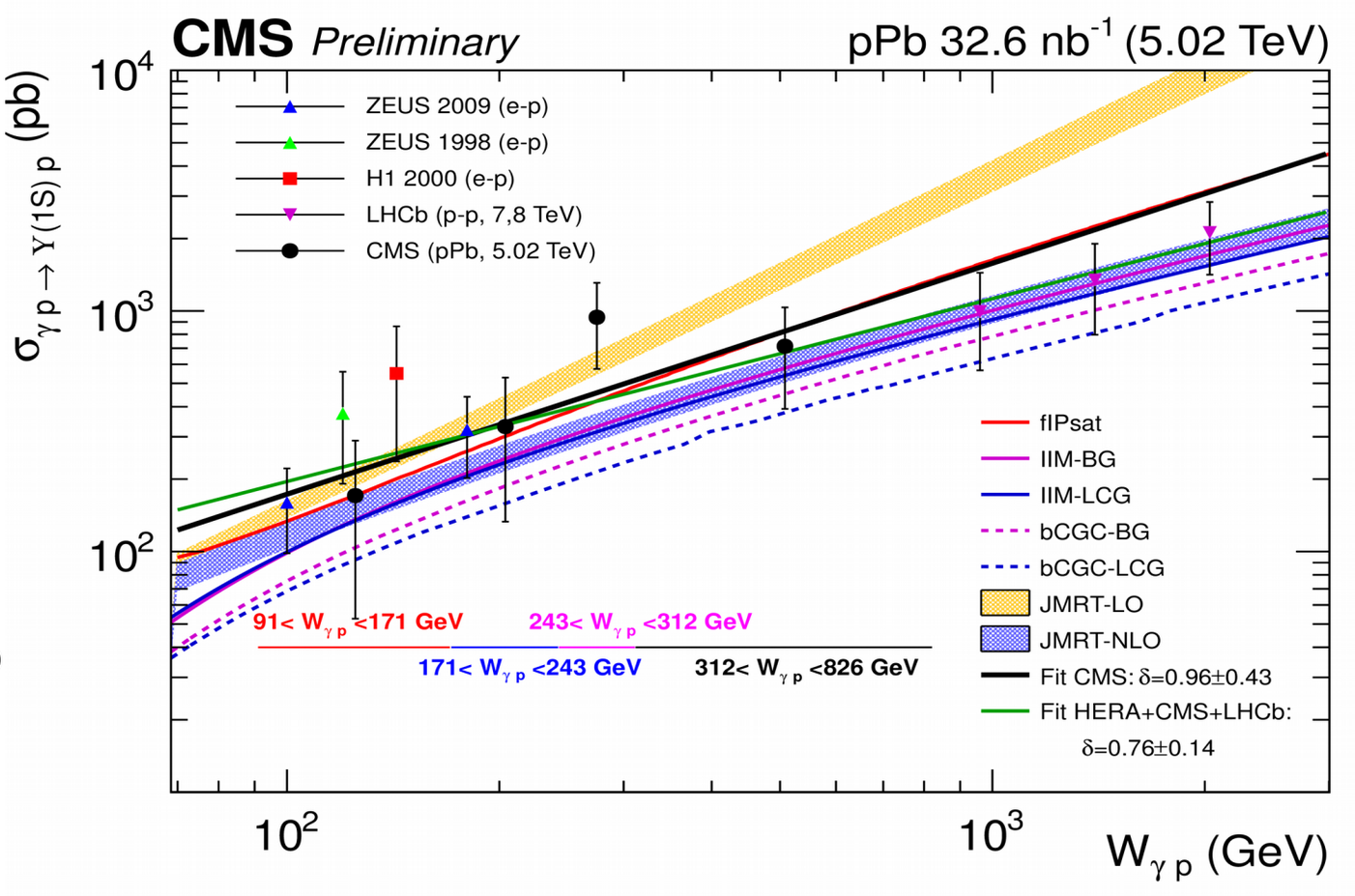
$$\frac{d\sigma_{\Upsilon(nS)}}{dy}\mathcal{B}_{\Upsilon(nS)\to\mu^+\mu^-} = \frac{N^{corr}_{\Upsilon(nS)}}{\mathcal{L}\times\Delta y}.$$

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

- The differential Υ(1S) cross-section extracted by correcting for branching ratio, feed-down, Υ(1S) fraction
- The cross-section as a function of $W_{\gamma p}$ is estimated by

$$\sigma_{\gamma p\to\Upsilon(1S)p} = \frac{1}{\Phi}\frac{d\sigma_{\Upsilon(1S)}}{dy}$$

- A fit with power-law **A X ($W_{\gamma p}$/400)$^{\delta}$** to the CMS data gives,
  δ = 0.96 ± 0.43
  A = 655 ± 196 pb
- ZEUS: δ = 1.2 ± 0.8
  Phys.Lett. B680 (2009) 4



Data compatible with power-law dependence of $\sigma(W_{\gamma p})$, disfavours (fast rising) LO pQCD predictions

Summary and outlook

- The first measurement of exclusive $\Upsilon(1S)$ photoproduction in pPb collisions at 5.02 TeV: Sensitive to gluon distribution in the proton at $x \sim 10^{-4}$-10^{-2}.
- The $b = 4.5\ \text{GeV}^{-2}$ slope of the differential cross section $d\sigma/dp_T^2$ is consistent with previous HERA results and with predictions based on pQCD models
- The $\Upsilon(1S)$ cross section shows a power-law dependence with $W_{\gamma p}$, that disfavours fast-rising LO pQCD predictions.
- Upcoming measurement at 8 TeV with much larger statistics.