Photon-proton and photon-nucleus measurements in CMS

Ruchi Chudasama and Dipanwita Dutta

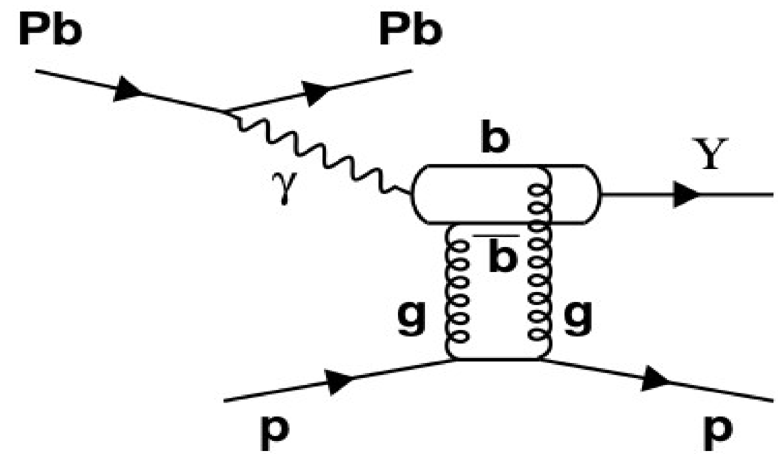
On behalf of CMS collaboration

Photon 2017: International conference on the structure and the interaction of the photon

Outline

- Introduction : Exclusive quarkonia photoproduction is a clean probe of the proton/nucleus gluon density

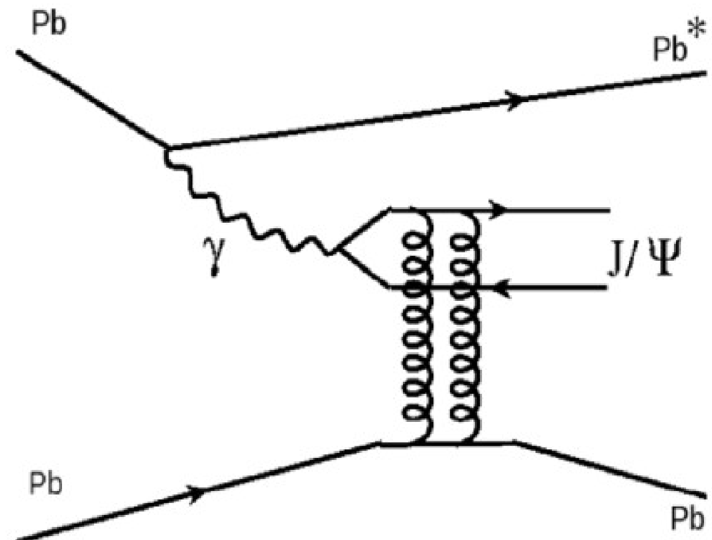
- Exclusive photoproduction of Upsilon in pPb collisions at √s = 5.02 TeV
  - t-differential cross-section
  - total cross-section as a function of c.m. energy



Photon-proton Interaction

- Coherent photoproduction of J/ψ in PbPb collisions at √s = 2.76 TeV
  - cross-section as a function rapidity

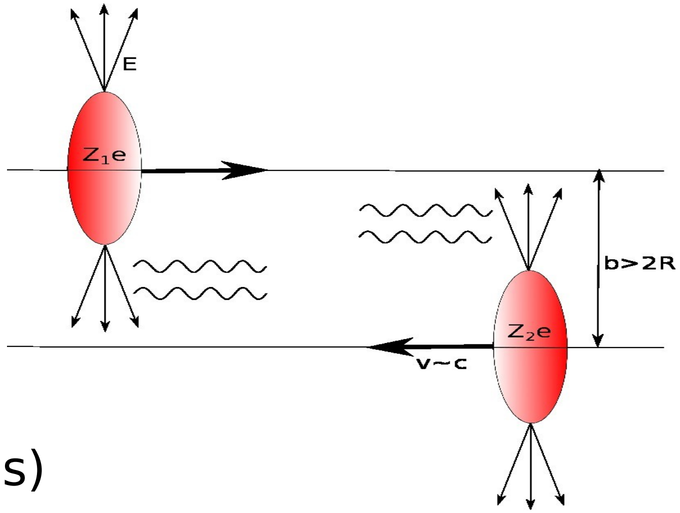
- Summary



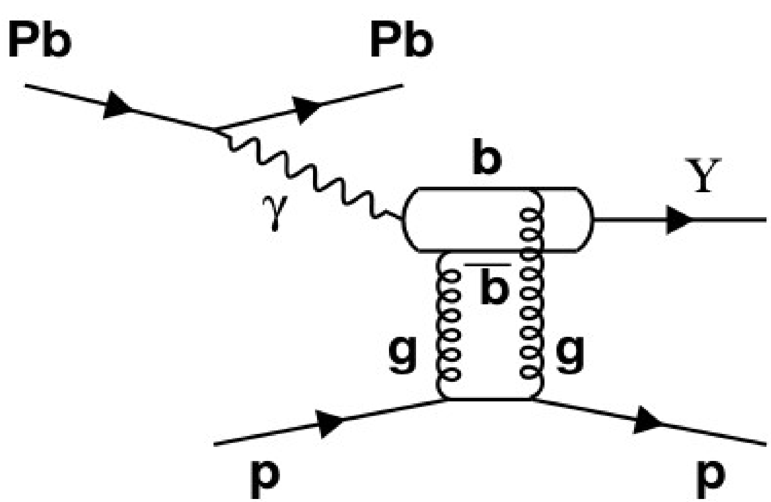
Photon-nucleus Interaction

Photon-proton and photon-nucleus interaction

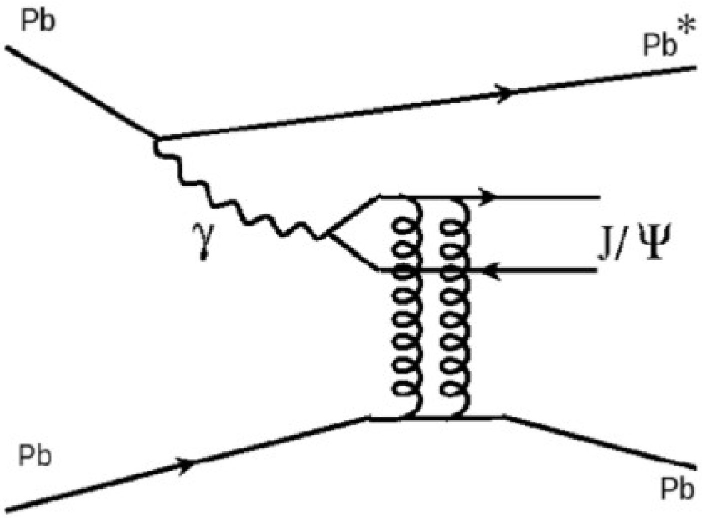
- Peripheral interactions with impact parameter b, greater than sum of nuclear radii, b > 2R (or R_A+R_B) dominated by electromagnetic/diffractive interactions
- The flux of photons is α Z^2.
- γ–proton interaction:
  Pb emits photon, gg(singlet) exchange between $q\bar{q}$ pair and target proton (Dominant contribution in pPb collisions)



- γ– nucleus interaction:
  Proton/Pb emits photon, gg(singlet) exchange between $q\bar{q}$ pair and target Pb nucleus

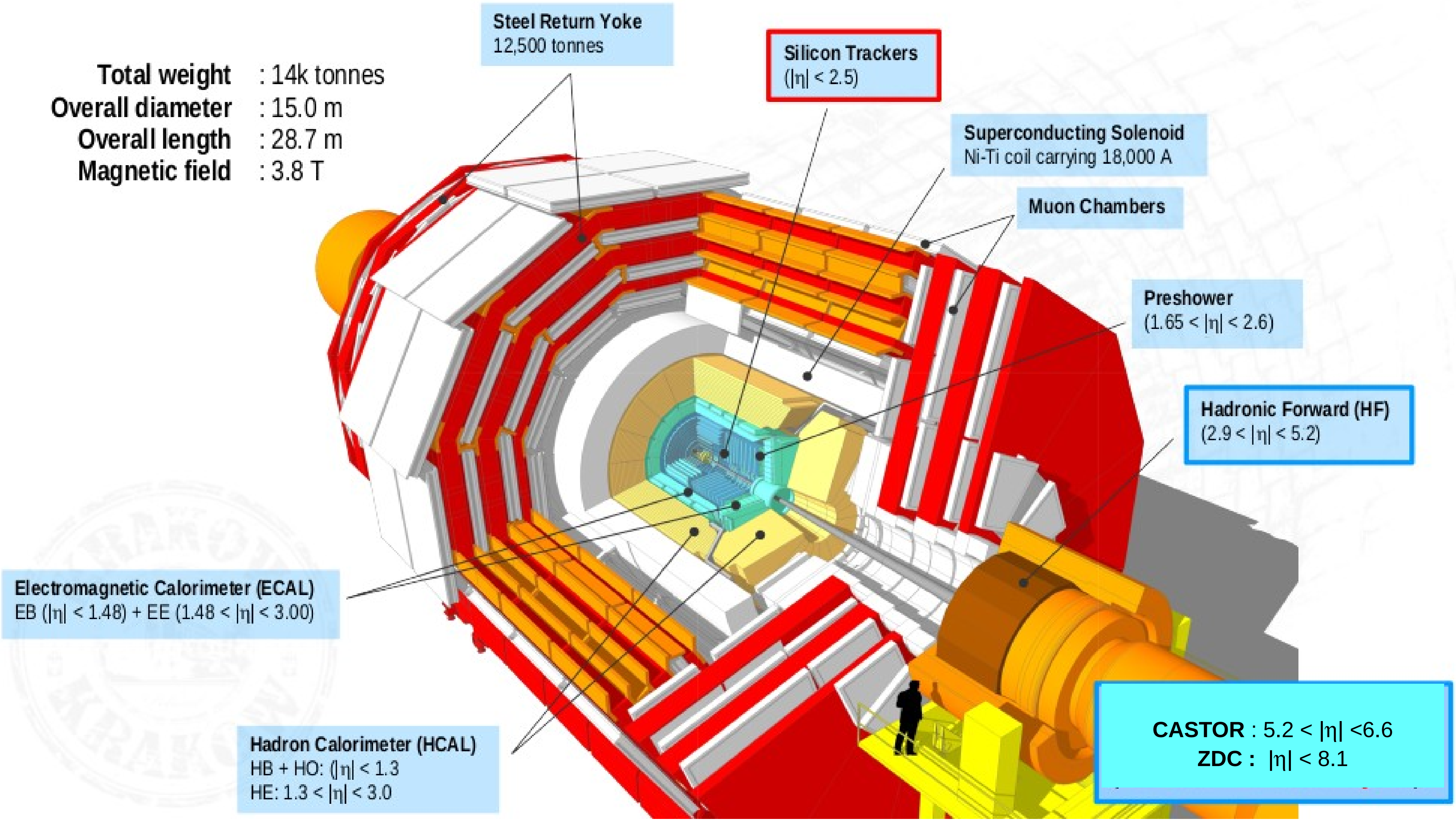


Photon-proton Interaction



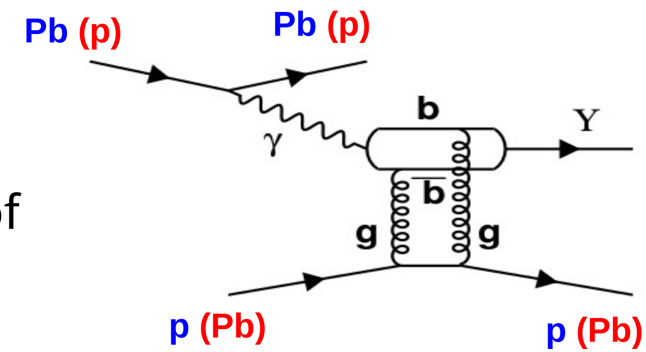
Photon-nucleus Interaction

The CMS Experiment



Exclusive Υ photoproduction in pPb at 5 TeV

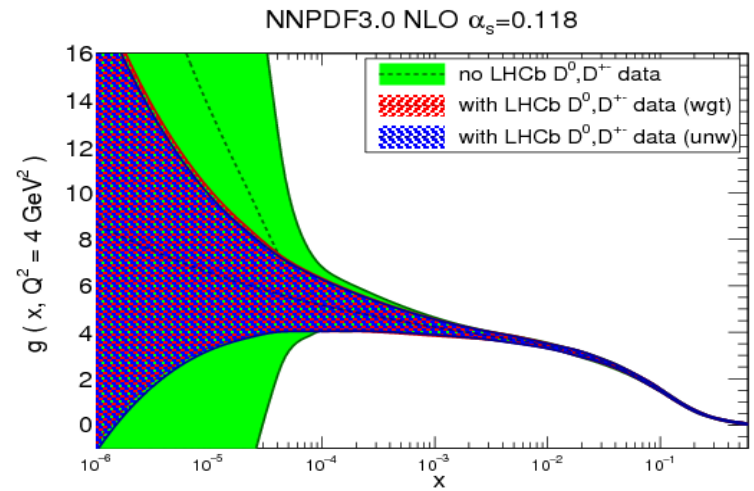
- Ions emit quasi-real photon with flux α Z^2
- γ p: Dominant contribution, γ Pb: Small contribution
- Photoproduction process is sensitive to the square of of the gluon density in the proton



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

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

t =transverse momentum exchanged square
b ~ slope of exp (t)



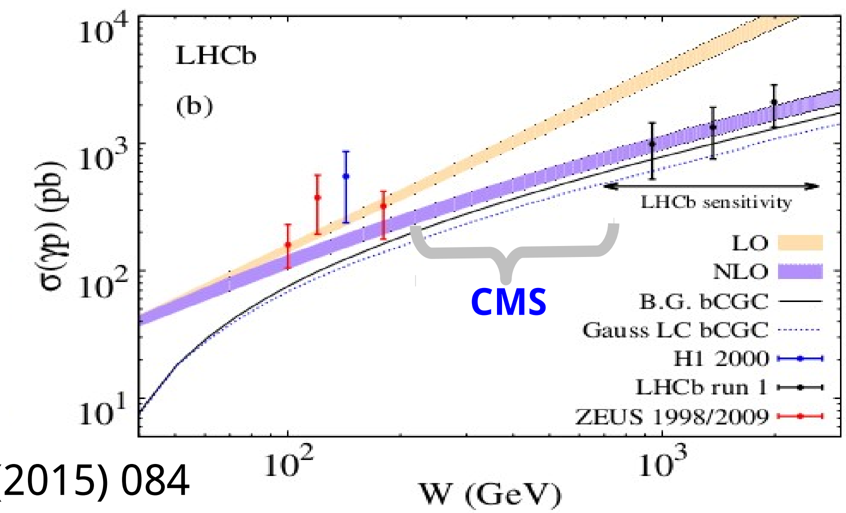
- Probe badly-known gluon distribution in the proton at low x (10^{-4} to $2*10^{-2}$)

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

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

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

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



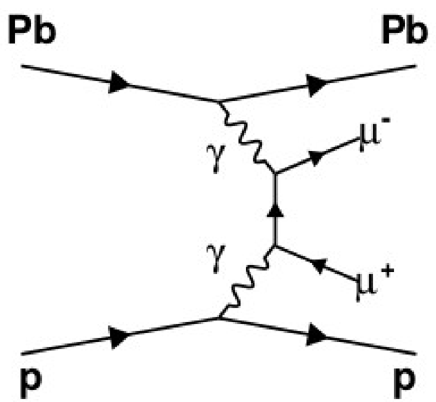
JHEP 1509(2015) 084

Exclusive Υ photoproduction in pPb at 5 TeV

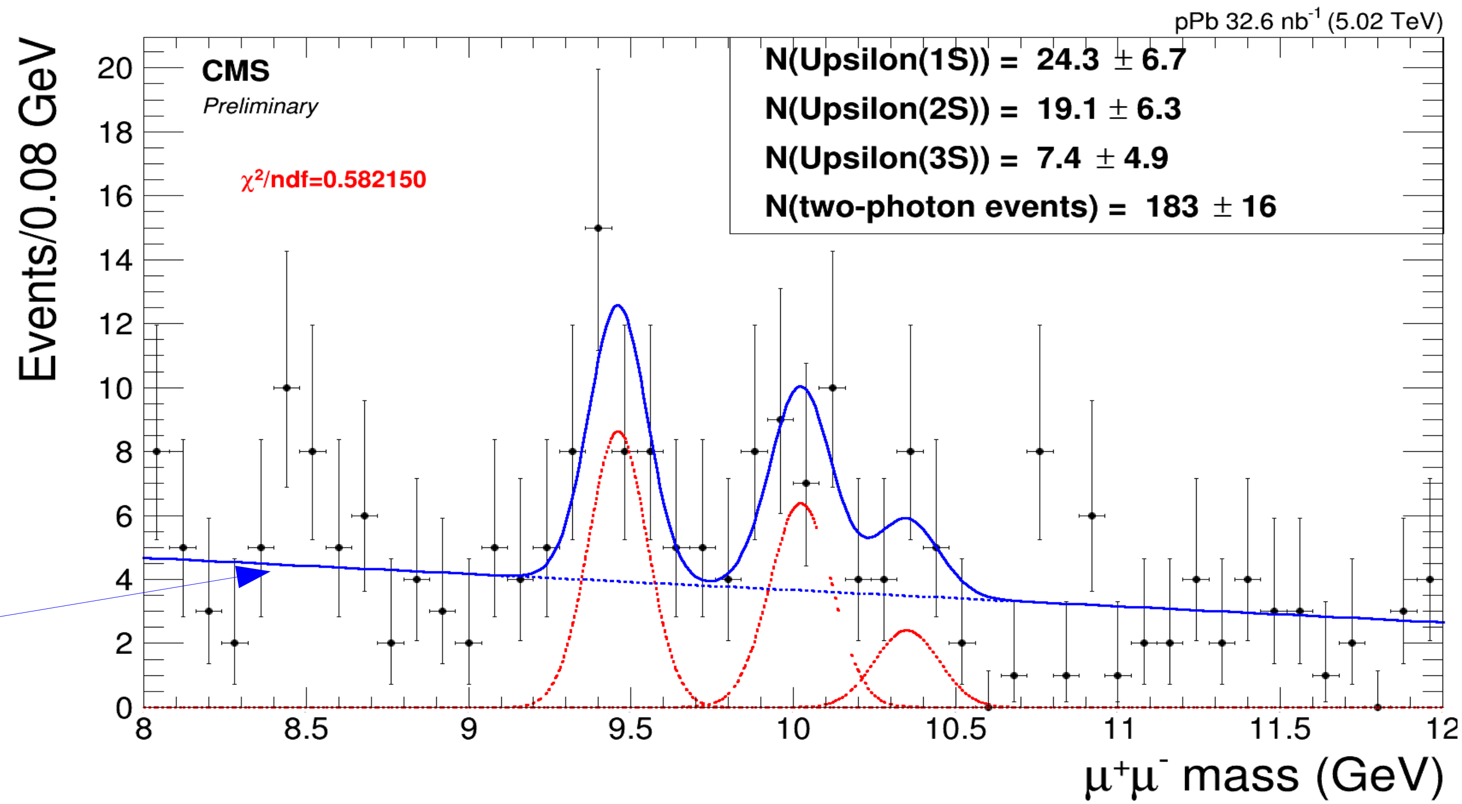
- 2013 pPb data at 5.02 TeV with 32.6 nb^{-1}

CMS-FSQ-13-009

- Offline exclusive pPb → Υ (γp) → $\mu^+\mu^-$ signal selection
  - Invariant mass (μμ) : 9.12-10.64 GeV
  - Opposite-sign μμ pair (final state) originating from commom primary vertex
  - No extra tracks at μμ vertex **to suppress non-exclusive background**
  - Upsilon p_T : 0.1-1 GeV **to suppress QED and non-exclusive background**
  - Upsilon rapidity : |y| < 2.2 **high muon finding efficiency**



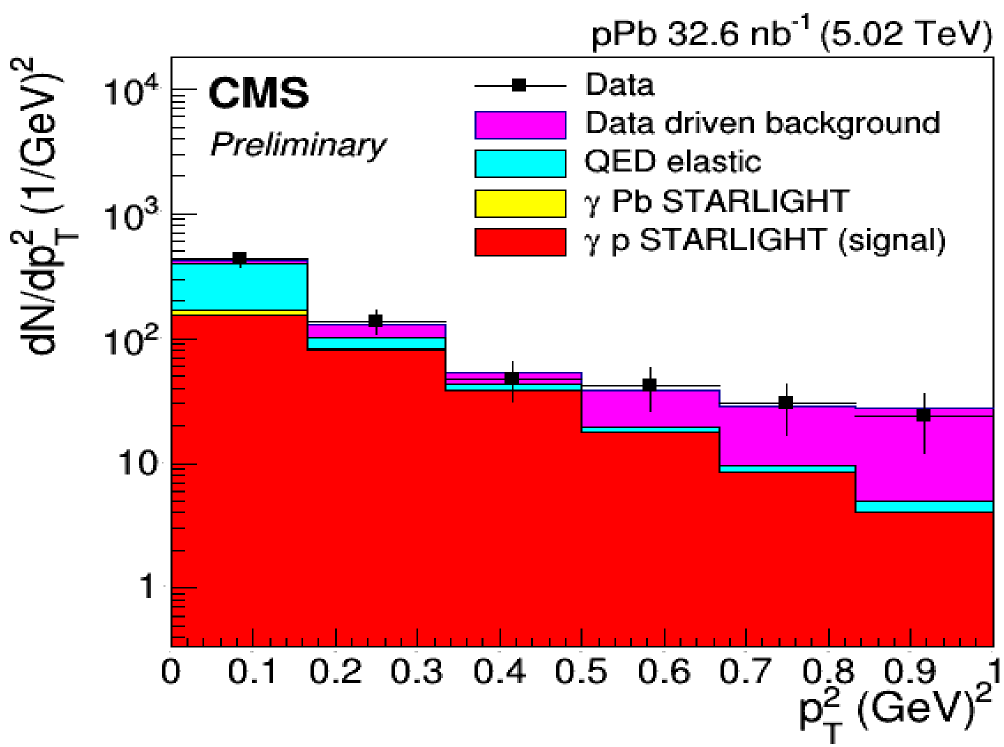
QED continuum Background

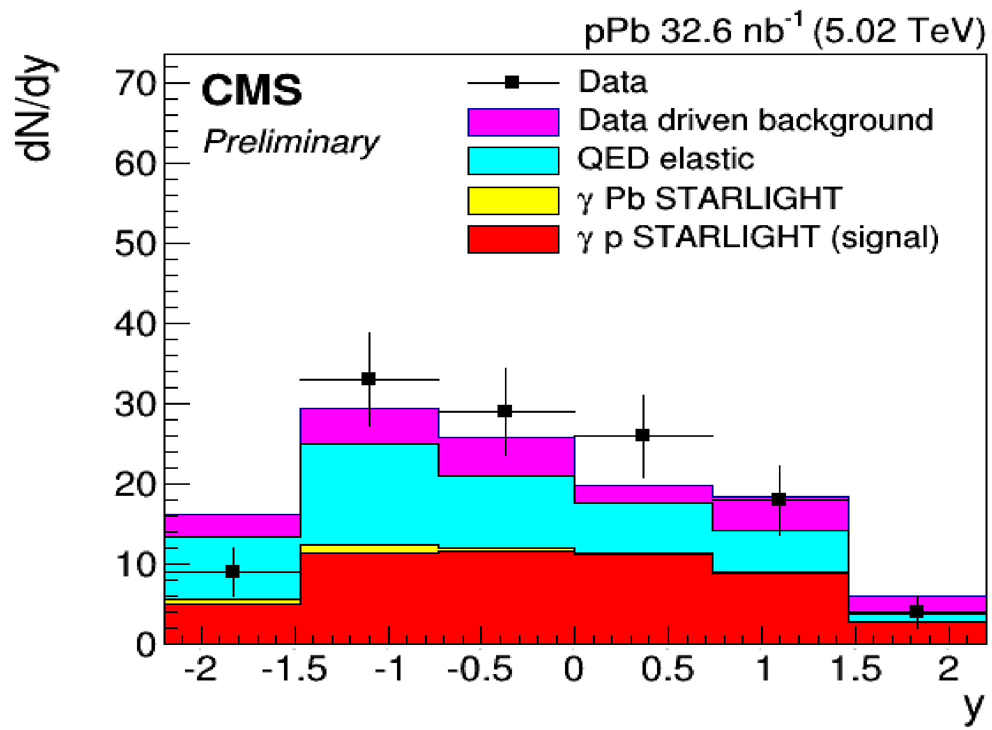


Exclusive Y in pPb at 5 TeV: Data-MC comparison

CMS-FSQ-13-009

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





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

Υ excl. Photoproduction cross section vs. |t|

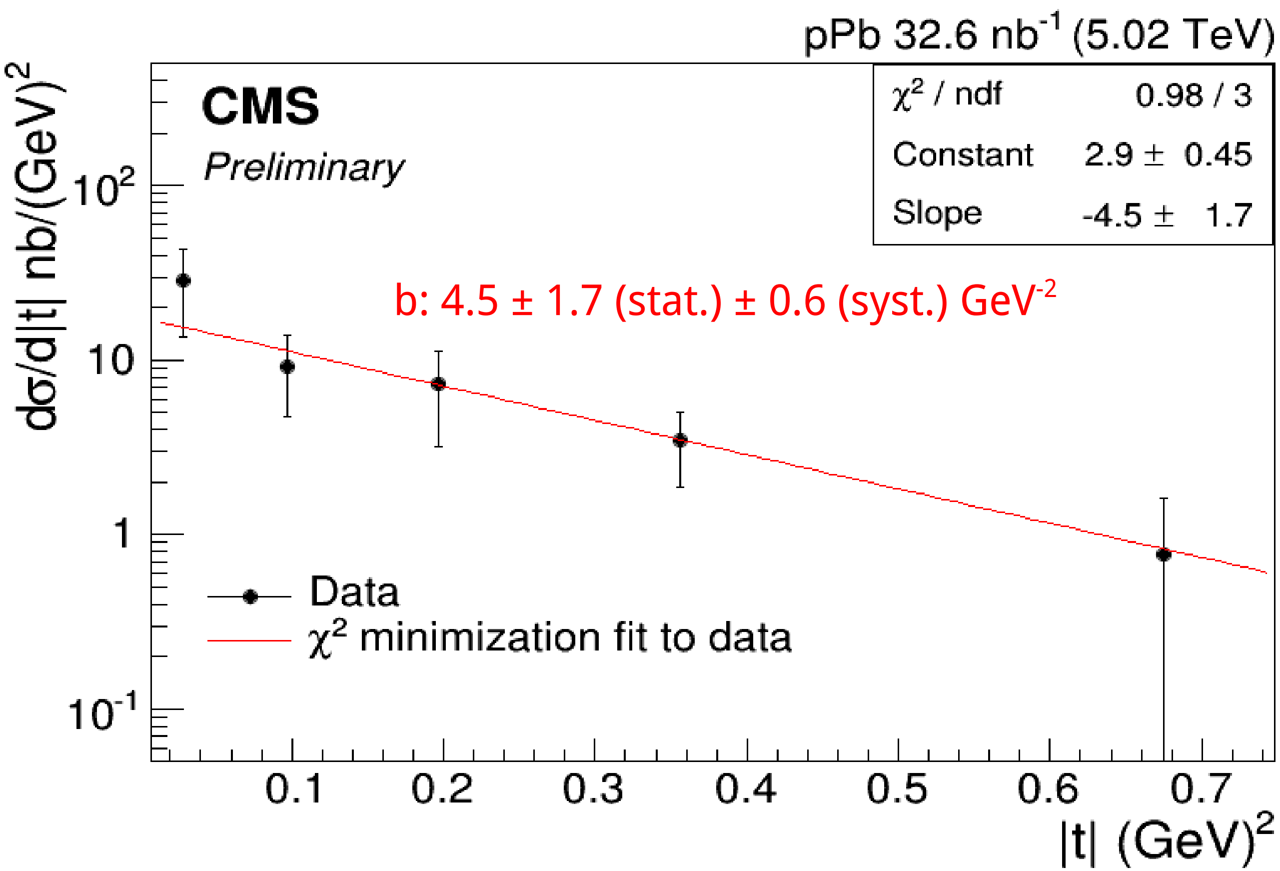
CMS-FSQ-13-009

- dσ/dt (t=transverse momentum exchanged square) fitted with an exponential function, provides information on the transverse profile of the proton.

- The differential cross section is determined according to

$$\frac{d\sigma_{\Upsilon}}{dt} = \frac{N_{sig}^{Unfolded}}{L \times \Delta t}$$

- N_{sig} , the background subtracted, unfolded and acceptance corrected number of upsilon events in each |t| bin.



CMS Results:
b= 4.5 ± 1.7 (stat.) ± 0.6 (syst.) GeV^{-2}
Data is in agreement with ZEUS measurements & consistent with pQCD predictions

ZEUS for Υ(1S)
b = $4.3^{+2.0}_{-1.3}$ (stat)
Phys.Lett.B 708 (2012) 14

Y(1S) excl. photoproduction x-section vs. $W_{\gamma p}$

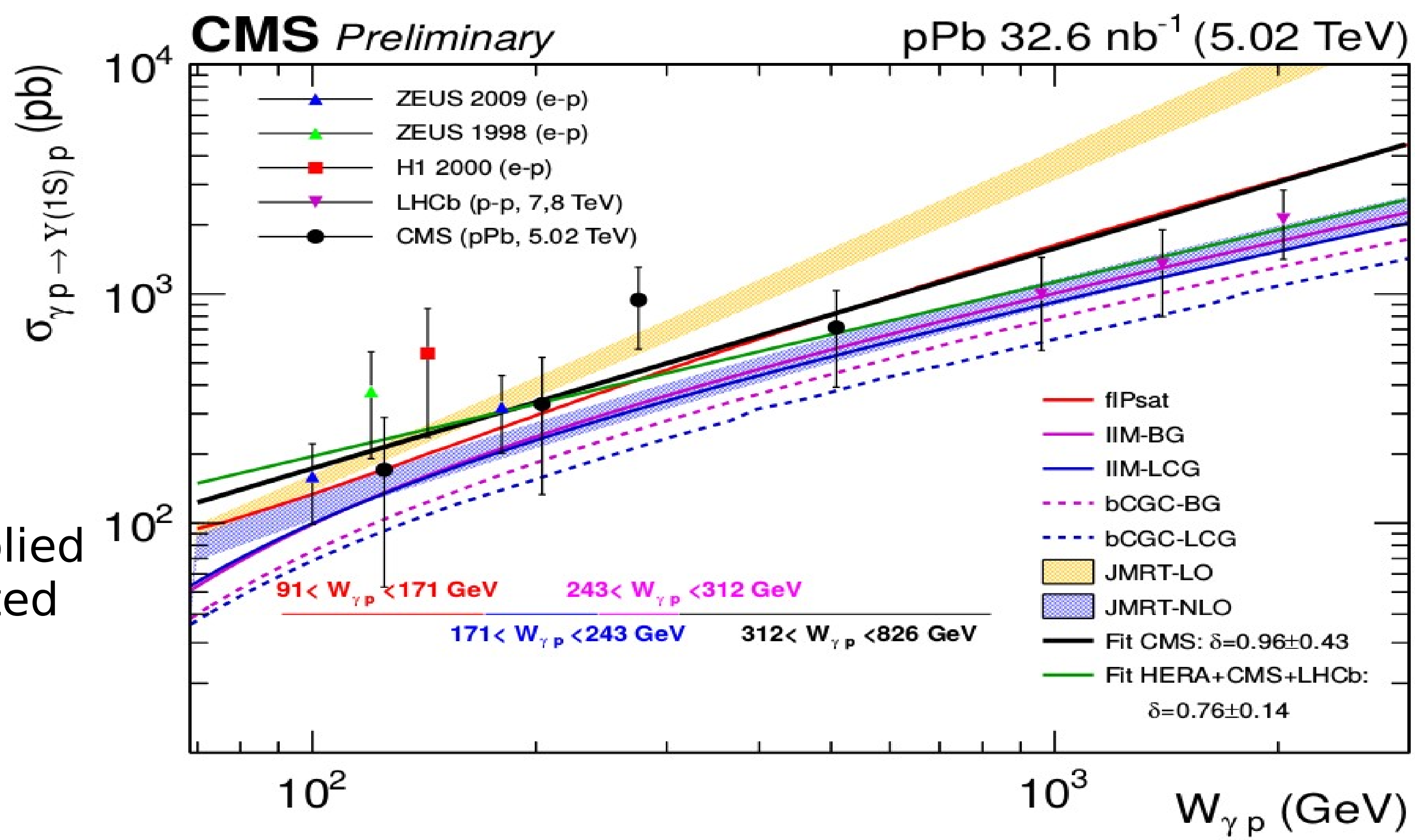
CMS-FSQ-13-009

- Total cross-section is estimated by

$$\sigma_{\gamma p \to \Upsilon(1S) p}(W^2_{\gamma p}) = \frac{1}{\Phi}\frac{d\sigma_{\Upsilon(1S)}}{dy}$$

  - ϕ = Photon flux
  - Rapidity distribution of Υ(1S+2S+3S)

- Y(1S) cross-section (multiplied by branching ratio) corrected for feed-down from Y(2S)



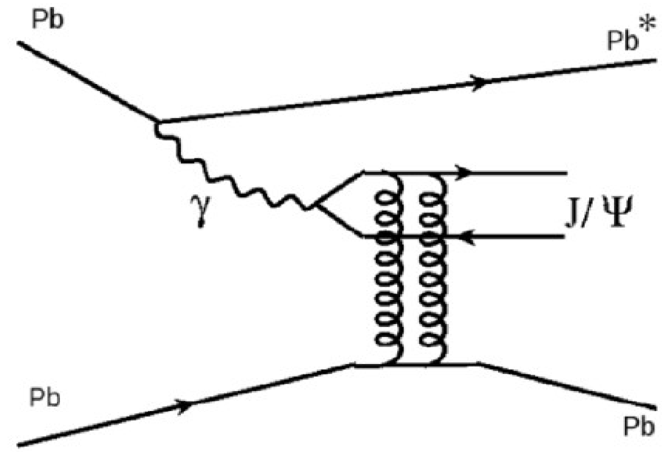
A fit with power-law A X $(W/400)^{\delta}$ to CMS data
δ = (0.96 ± 0.43) , A = 655 ± 196

ZEUS
δ = 1.2 ± 0.8
Phys.Lett. B680 (2009) 4

Data compatible with power-law dependence of $\sigma(W_{\gamma p})$, disfavours steeper LO pQCD predictions.
Evolution consistent with previous HERA/LHCb results

Exclusive J/ψ photoproduction in PbPb at 2.76 TeV

- Coherent vector meson production:
  - Quasireal photons emitted coherently from whole Pb ion:
    ($\omega_{max} \sim \gamma/R$) , $< p_T > \sim 1/R_{Pb} \sim 60$ MeV/c
- Incoherent vector meson production:
  - Photon couples to single nucleon
  - $< p_T > \sim 1/R_p \sim 200$ MeV/c
  - Target nucleus normally breaks up

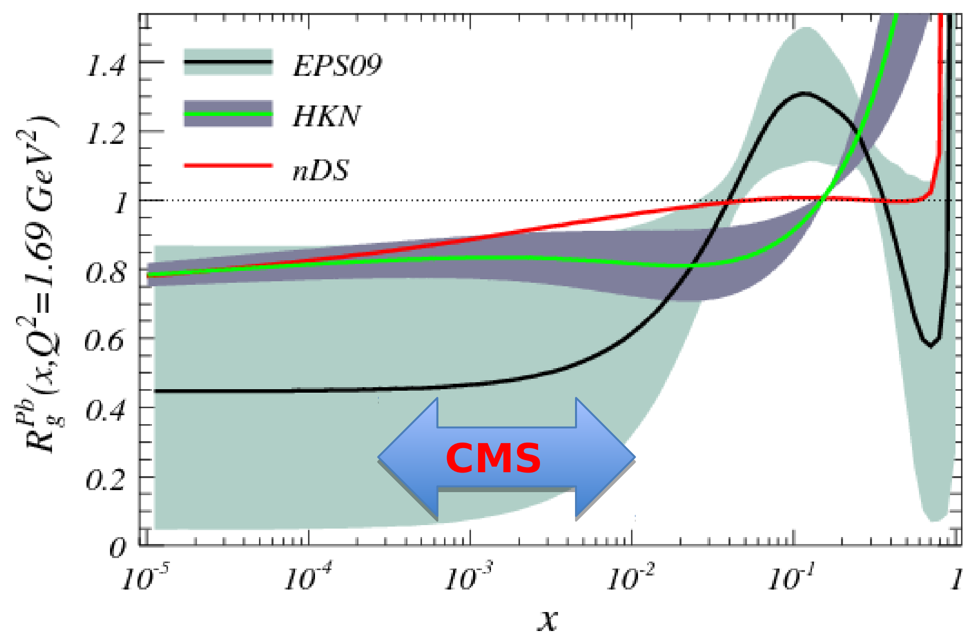


- Photoproduction process is sensitive to very badly-known gluon PDF (squared) in Pb

$$\left.\frac{d\sigma_{\gamma A \to J/\Psi A}}{dt}\right|_{t=0} = \xi_{J/\Psi}\left(\frac{16\pi^3\alpha_s^2\Gamma_{l+l-}}{3\alpha M_{J/\Psi}^5}\right)\boxed{[xG_A(x,\mu^2)]^2}$$

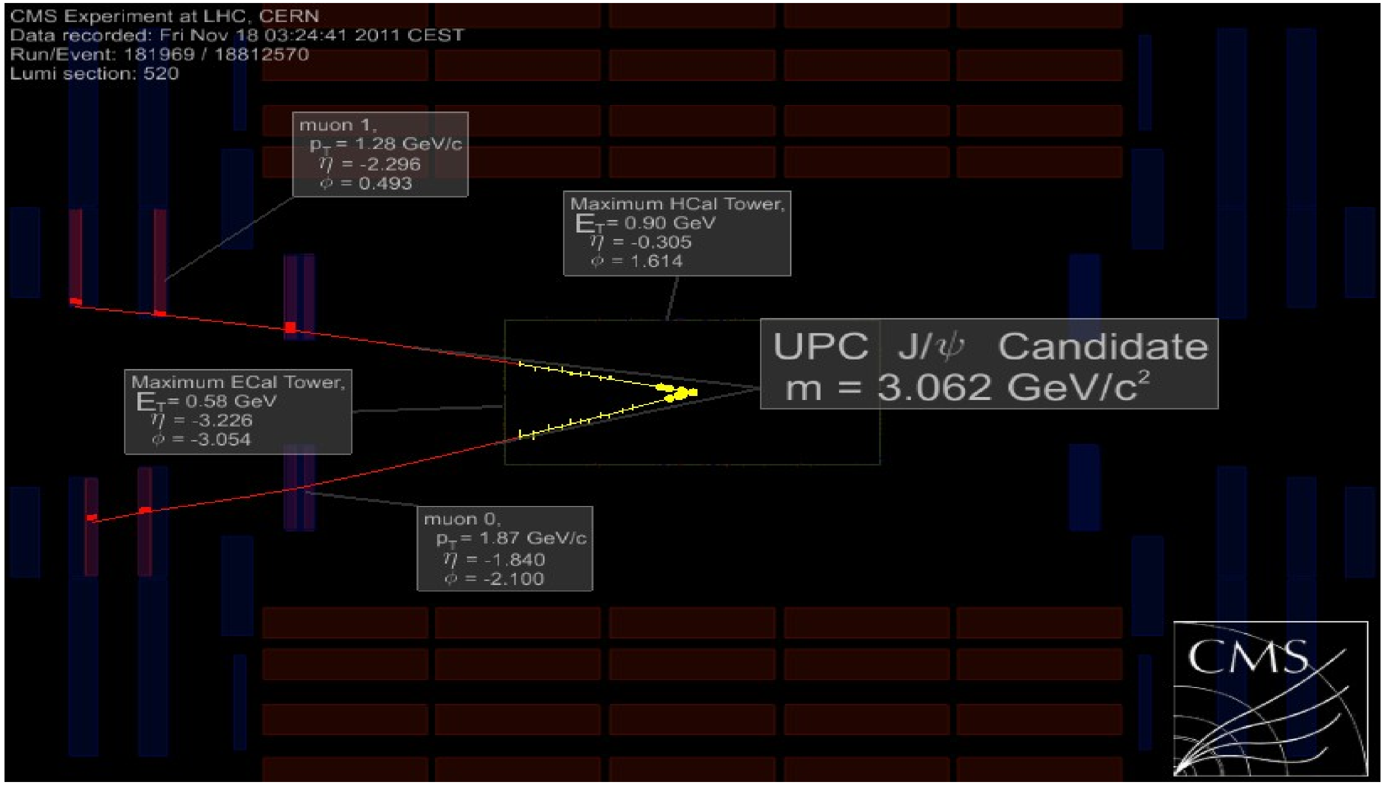
- Probe gluon distribution in Pb at low x
  x(J/ψ) ~ 10^{-5} to $2*10^{-2}$
- Promising probe to study nuclear gluon saturation/shadowing at small Bjorken x

$$R_g^A(x,Q^2) = \frac{G_A(x,Q^2)}{AG_p(x,Q^2)}$$ – gluon shadowing factor



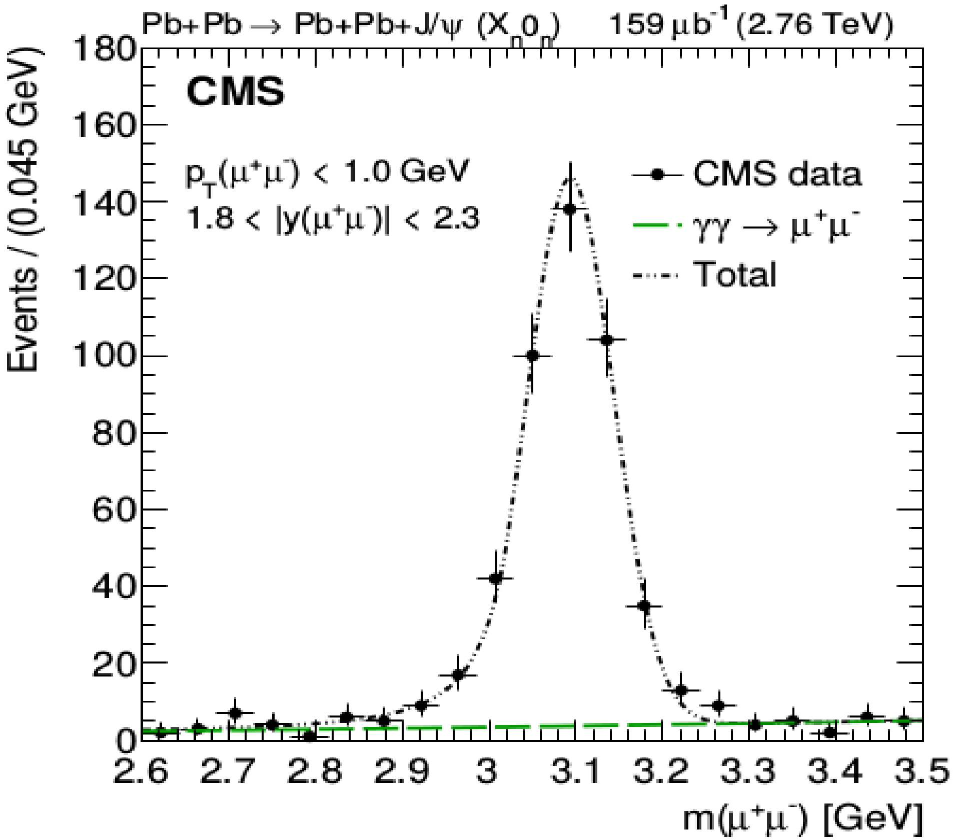
Exclusive J/ψ photoproduction in PbPb at 2.76 TeV

- 2011 PbPb data at 2.76 TeV with 159 μb^{-1}
- Offline exclusive **PbPb → J/ψ → $\mu^+\mu^-$** signal selection
  - Muons within $1.2 < |\eta| < 2.4$ & $1.2 < p_T < 1.8$
  - No extra tracks at μμ vertex **to suppress non-exclusive background**
  - Invariant mass (μμ) : 2.6-3.5 GeV
  - J/ψ $p_T < 1$ GeV and rapidity : $1.8 < |y| < 2.3$
  - No HF activity
  - (Xn0n) nuclear break up mode: at least one neutron in one ZDC and other ZDC empty

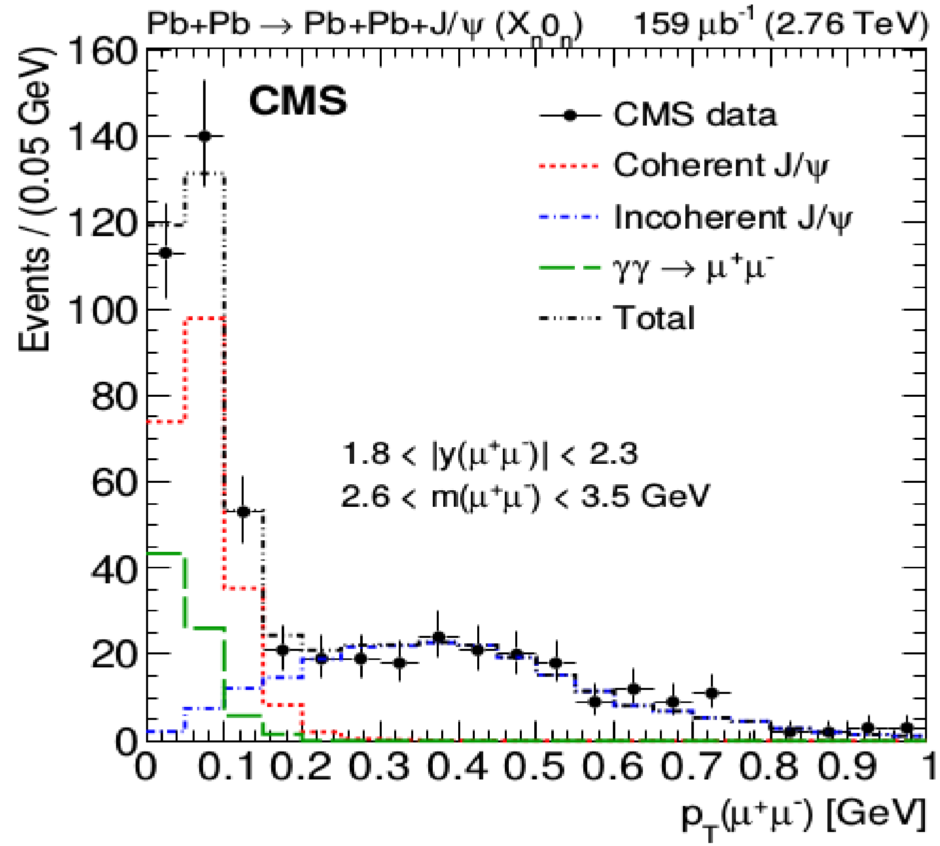


Coherent J/ψ yield in PbPb at 2.76 TeV

arXiv: 1605.06966



arXiv: 1605.06966



- Yield extraction via maximum likelihood fit to dimuon p_T
- Coherent J/ψ dominant for p_T < 0.15 GeV
- Fit yields: 207 ± 18 (stat) coherent J/ψ candidates,
  75 ± 13 (stat) incoherent J/ψ candidates,
  75 ± 13 (stat) γγ QED events with p_T < 0.15 GeV

J/ψ cross-section for X_n0_n mode in PbPb at 2.76 TeV

HIN-12-009

- Cross-section estimated via:

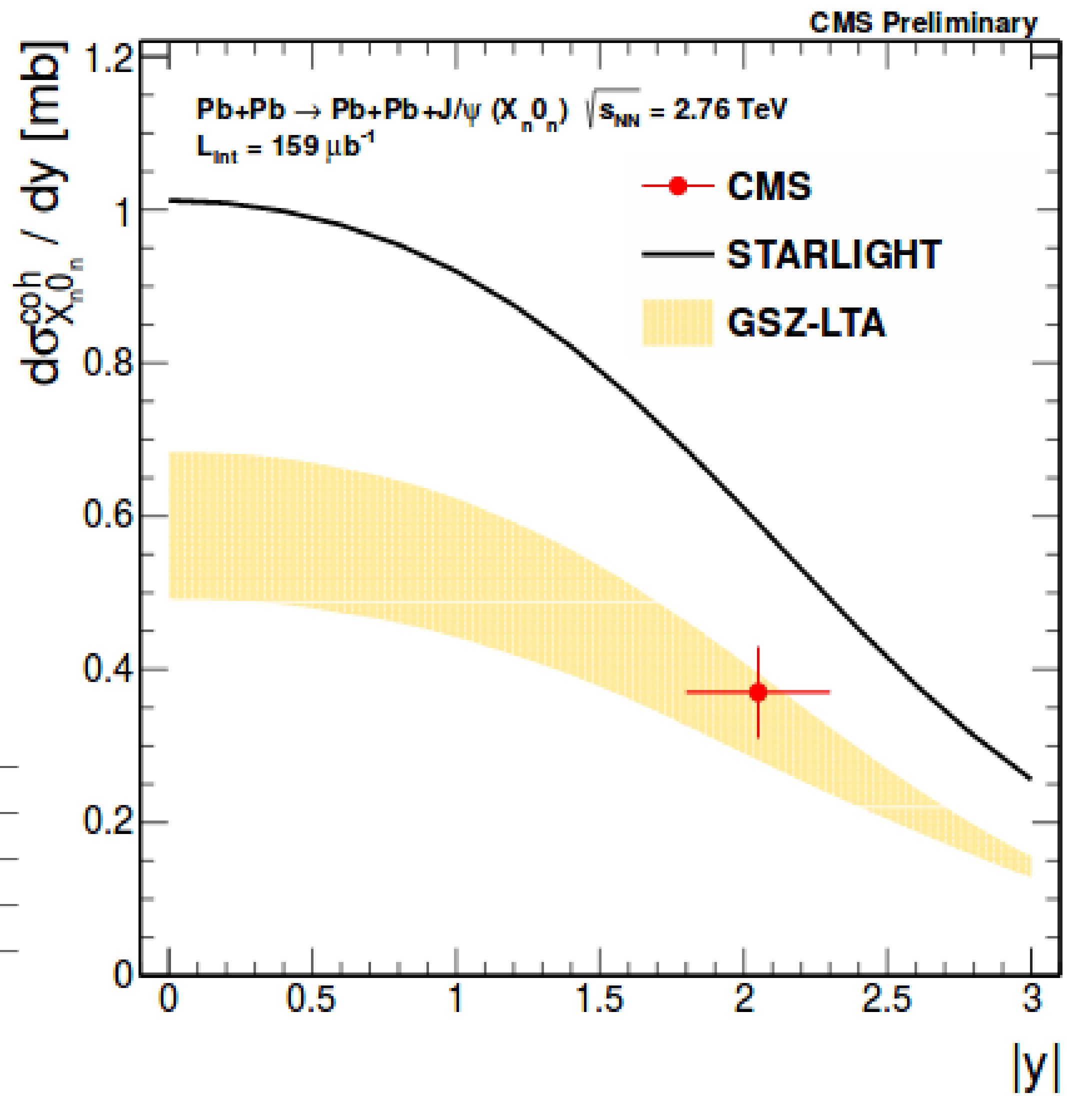
$$\frac{d\sigma^{coh}_{X_n0_n}}{dy}(J/\psi) = \frac{N^{coh}_{X_n0_n}}{\mathcal{B}(J/\psi \to \mu^+\mu^-)\,\mathcal{L}_{int}\,\Delta y\,(A\,\varepsilon)^{J/\psi}}$$

corrected for feed-down
fraction of J/ψ meson coming from ψ(2S)

- Coherent cross-section for X_n0_n mode
$d\sigma/dy = 0.36 \pm 0.04(stat) \pm 0.04(syst)$ mb

- Extrapolate X_n0_n mode cross-section to total cross-section:

J/ψ with $p_T < 0.15$ GeV/c	X_nX_n/X_n0_n	$1_n0_n/X_n0_n$	$1_n1_n/X_n0_n$
Data	0.36±0.04	0.26±0.03	0.03±0.01
STARLIGHT	0.37	N/A	0.02
GSZ	0.32	0.30	0.02

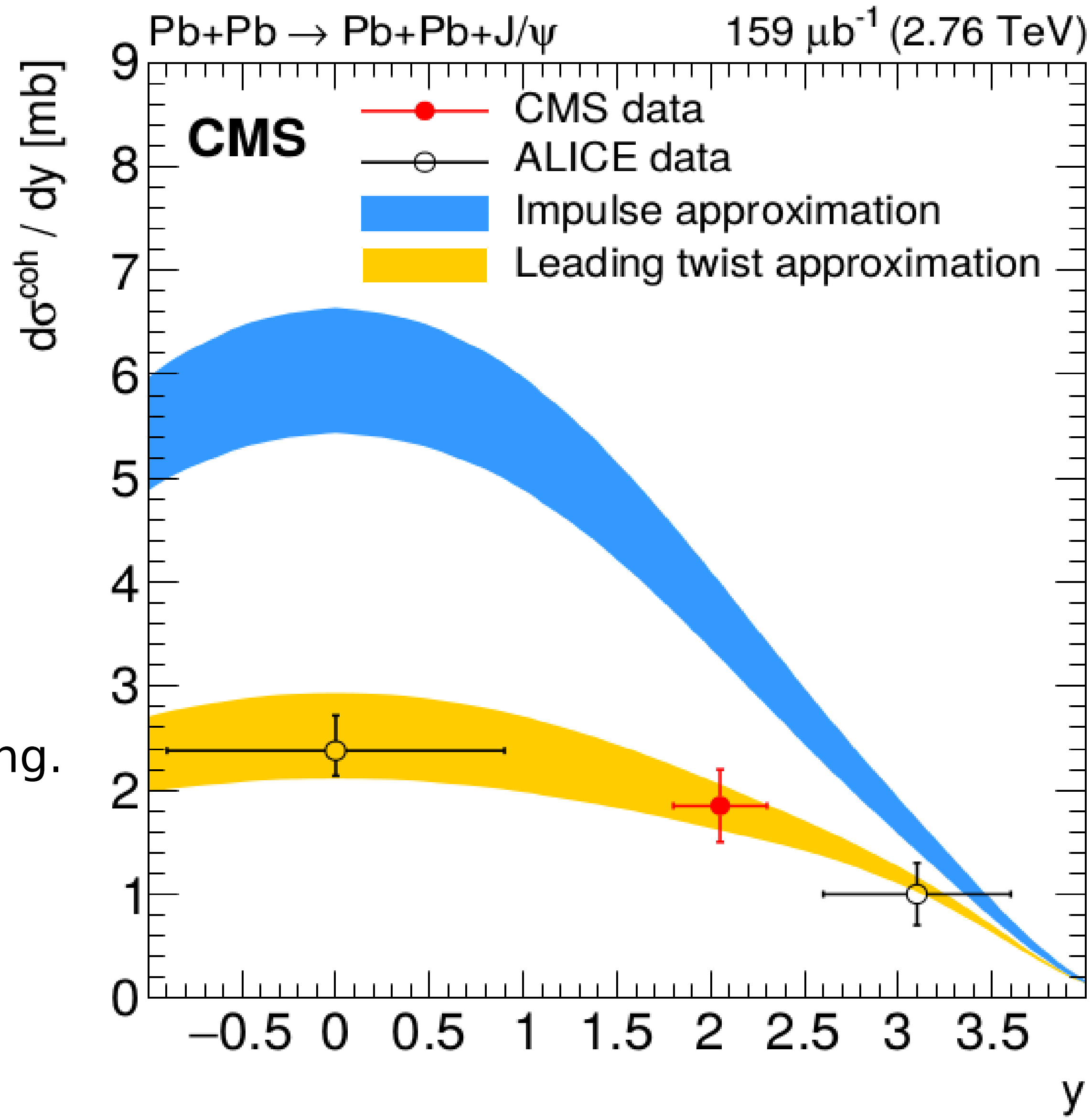


Leading-Twist Approximation (GSZ) reproduces better data than Starlight MC

Coherent J/ψ cross-section in PbPb at 2.76 TeV

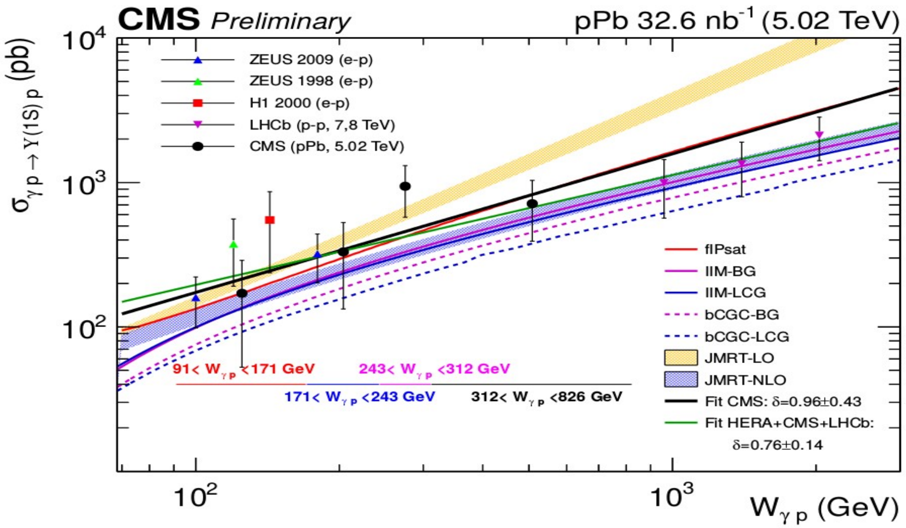
arXiv: 1605.06966

- Total coherent cross-section for J/ψ
  $d\sigma^{coh}/dy$ = 1.82 ± 0.22 (stat) ± 0.20 (syst) ± 0.19 (theo) mb.
- The data strongly disfavour the impulse approximation model prediction (proton PDF), indicating that nuclear effects are needed to describe coherent J/ψ photoproduction in γ + Pb interactions.
- The data are found to be consistent with the leading twist approximation, which includes nuclear gluon shadowing.

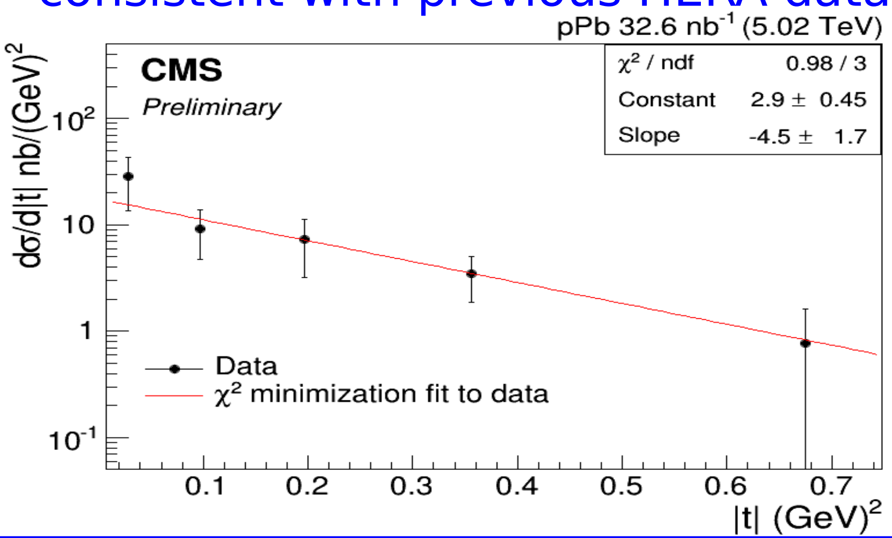


Summary

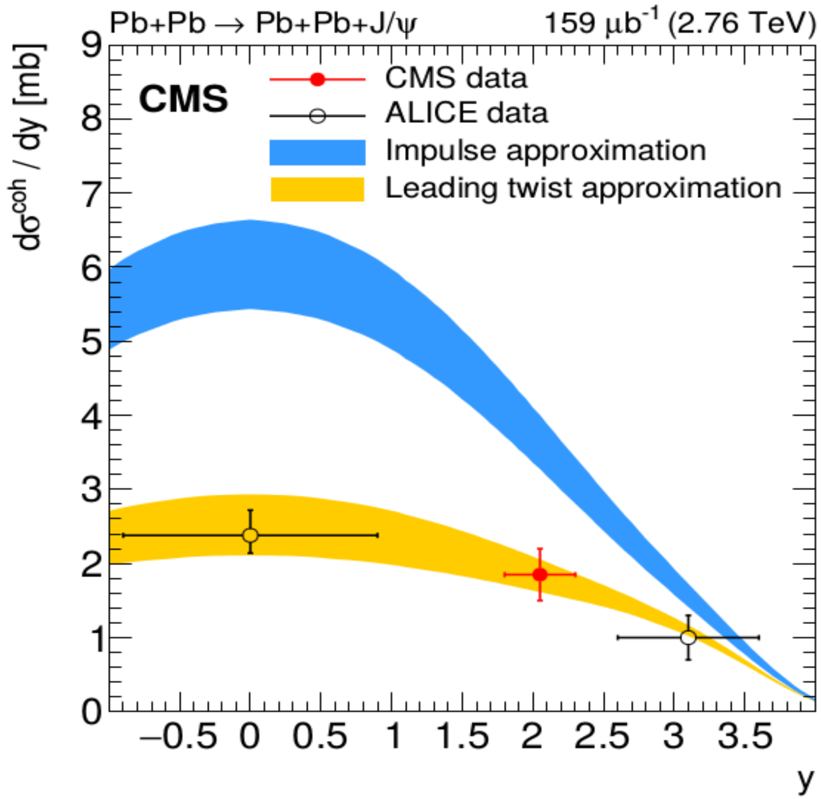
Proton data compatible with powerlaw dependence of σ(Wγp) in agreement w/ NLO predictions & HERA/LHCb data



Proton exponential dσ/dt slope consistent with previous HERA data



Pb data consistent with the leading twist approximation including nuclear gluon shadowing.



Both measurements provide new constraints on the (badly known) proton/nuclear low-x glue