Measurement of exclusive vector meson photoproduction in pPb collisions with the CMS experiment

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On behalf of the CMS collaboration

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Ultra-peripheral Collisions (UPC)

- Two relativistic particles interact **electromagnetically** by physically **missing** each other
  - Impact parameter $b > R_1 + R_2$
- Ions are source of EM field
  - Photon **flux ∝ Z^2**
  - In the Weizsäcker-Wiliams approximation :

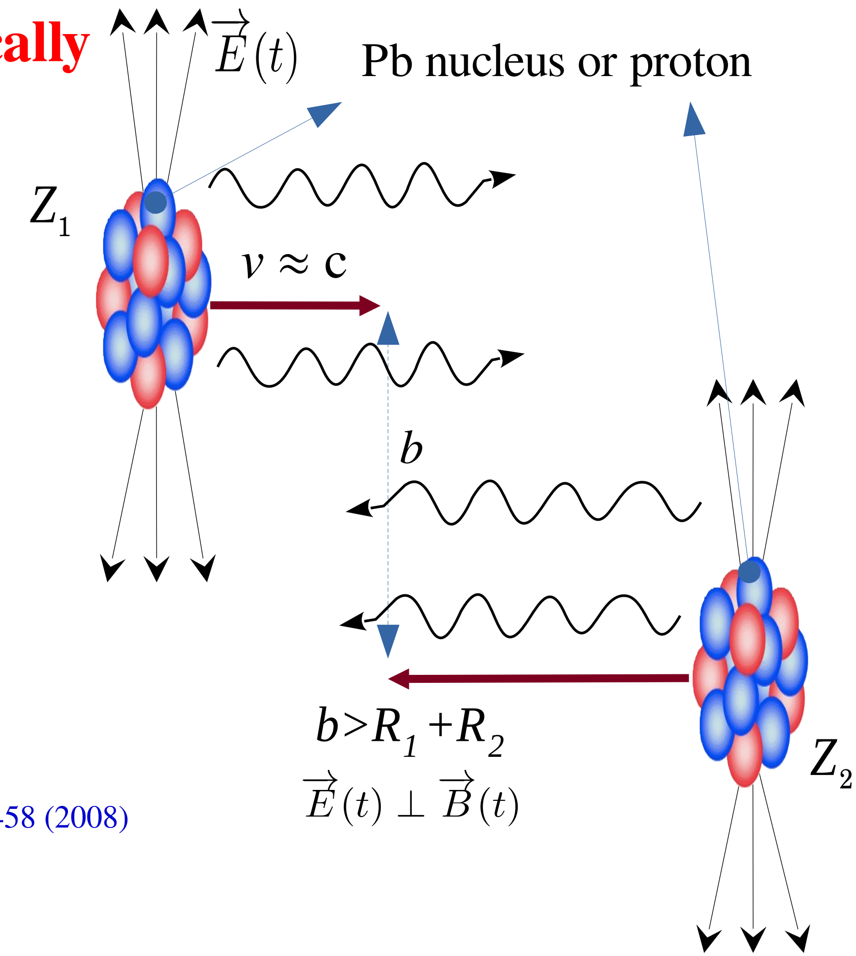
$$N(k,b) = \frac{Z^2\alpha_e}{\pi^2}\frac{k}{(\hbar c)^2}\frac{1}{\gamma_L^2}[K_1^2(x) + \frac{1}{\gamma_L^2}K_0^2(x)]$$

Klein et al., PRC 60 (1999)
A. J. Baltz et al.,Phys. Rep. 458 (2008)

N(k,b) is the photon flux, $x = \frac{kb}{(\gamma\hbar c)}$, $\gamma_L = \frac{E_A}{m_A}$

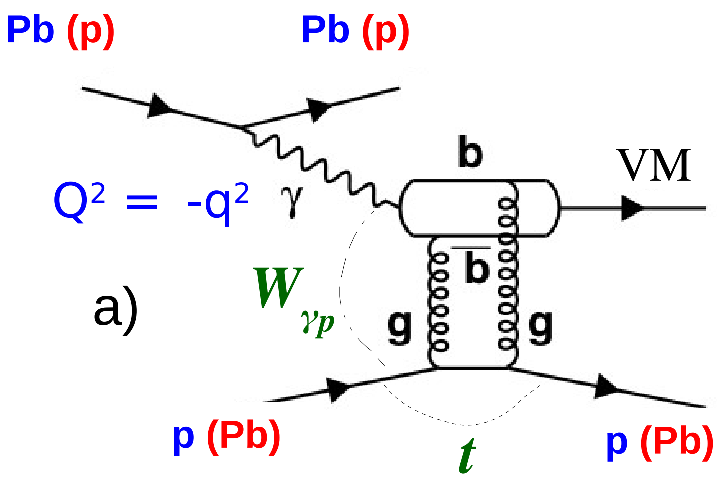
- Flux drops rapidly with increasing energy

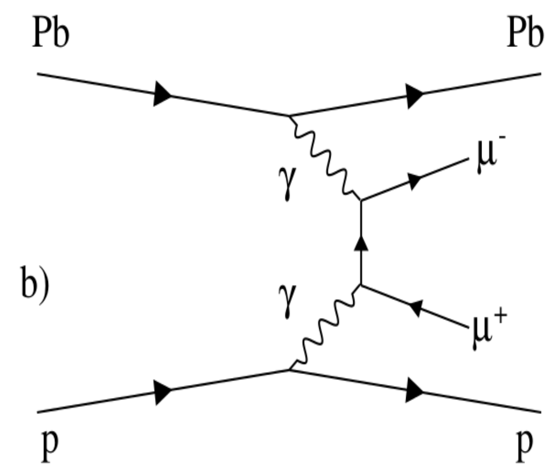
- **No hadronic interaction**

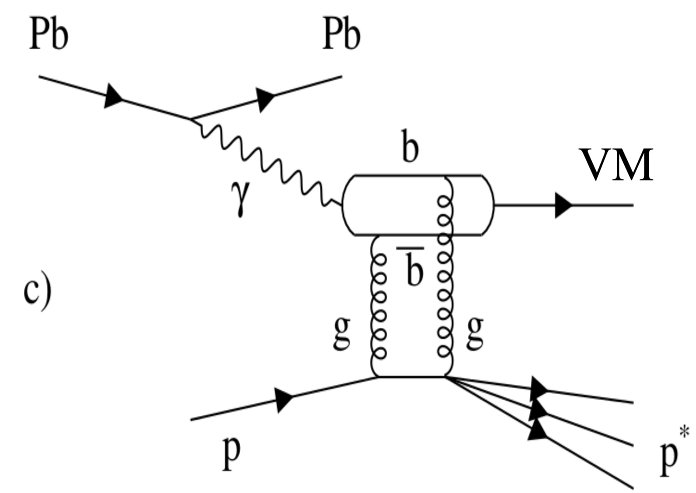


Schematic diagram of UPC

Vector Meson photoproduction in UPC







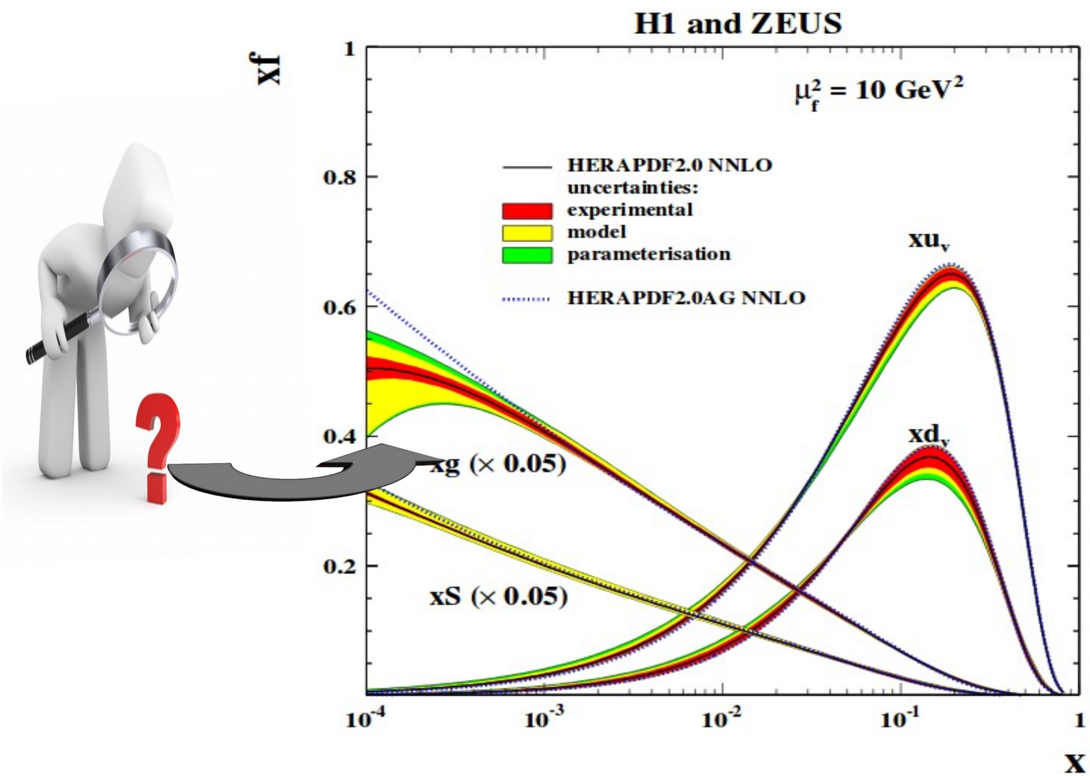
Photon-Nuclear Interaction (Signal)

Photon-Photon Interaction **Proton** (and/or **Lead**) **dissociation**

(Background)

- The upper limit of quasi-real photon energy is $\omega_{max} \approx \gamma_L / R_A$; $\gamma_L = E_A / m_A$
  - **γ from p: ω_{max} ~ 1066 GeV**
  - **γ from Pb: ω_{max} ~ 48 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: $Q^2 \approx 250$ MeV ^{2}**
  - **γ from Pb: $Q^2 \approx 30$ MeV ^{2}**

Probing the target's gluon density



EPJC 75 (2015) 580

- In leading logarithmic approximation of pQCD

$$\left.\frac{d\sigma_{\gamma p\rightarrow\gamma pVM}}{dt}\right|_{t=0} = C(\mu^2)[xG(x,\mu^2)]^2$$

- **Region of interest for PDFs in pPb:**
  -**Gluon distribution** in the proton at low Bjorken-x (10^{-2} to 10^{-4})
  and search for **saturation effects**

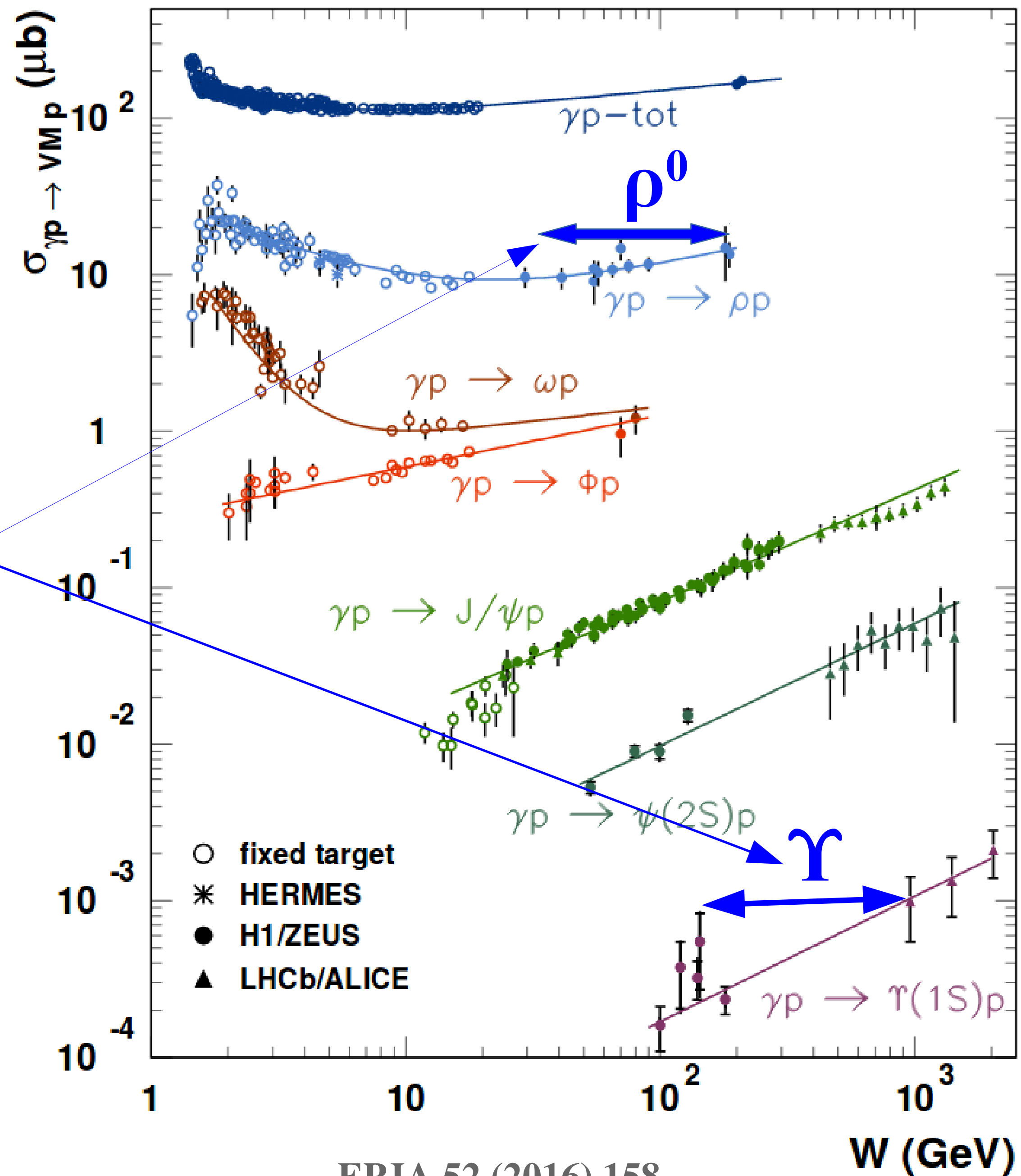
- **Nuclear shadowing in UPC PbPb**

Exclusive Vector Meson (VM) photoproduction in pPb

- **Region of interest in CMS:**
  - $W_{\gamma p}: 29 - 213$ GeV for ρ^0 and 91-826 GeV for Υ

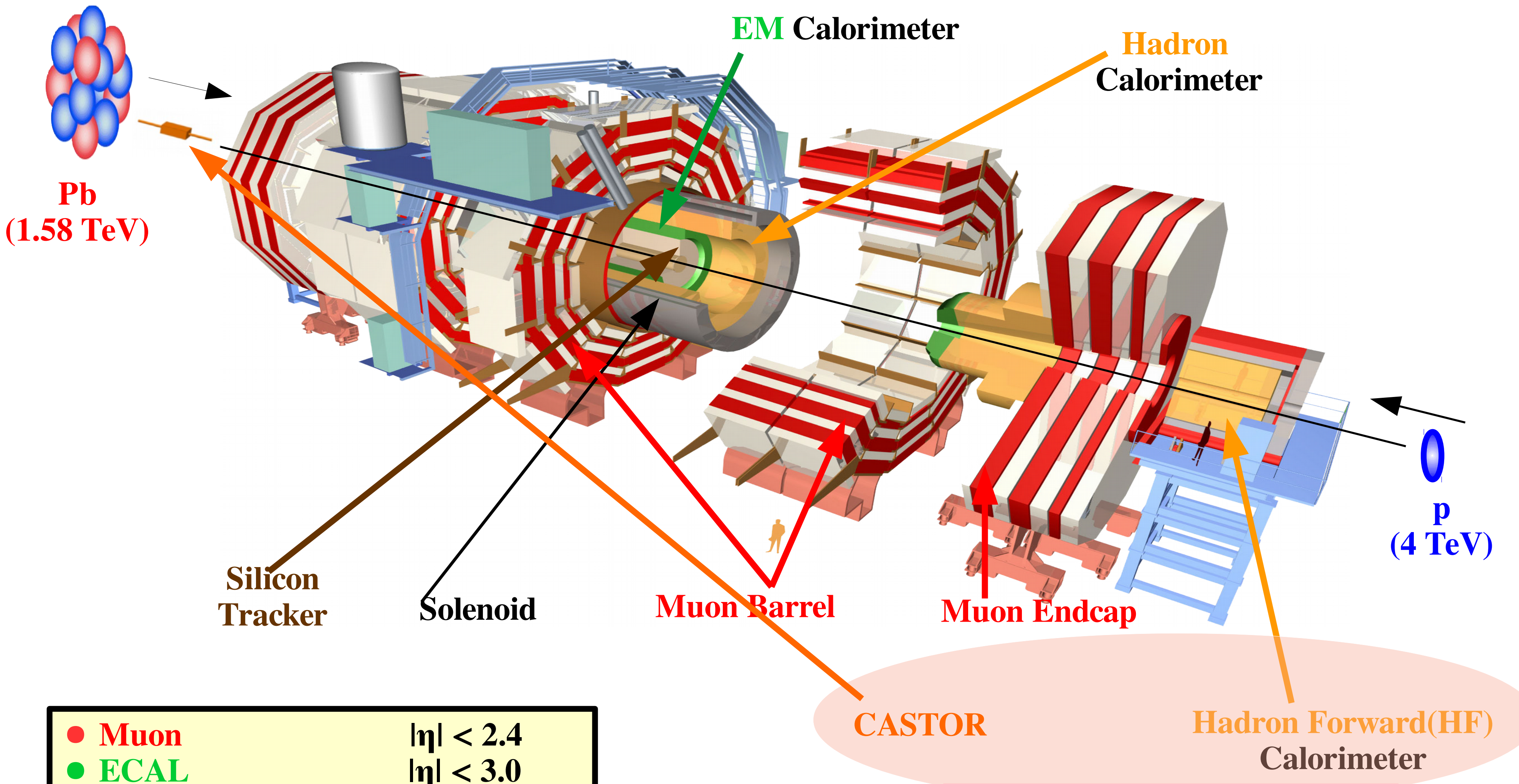
$$x = (M_{VM}/W_{\gamma p})^2 \, ,$$

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



EPJA 52 (2016) 158

CMS Detector

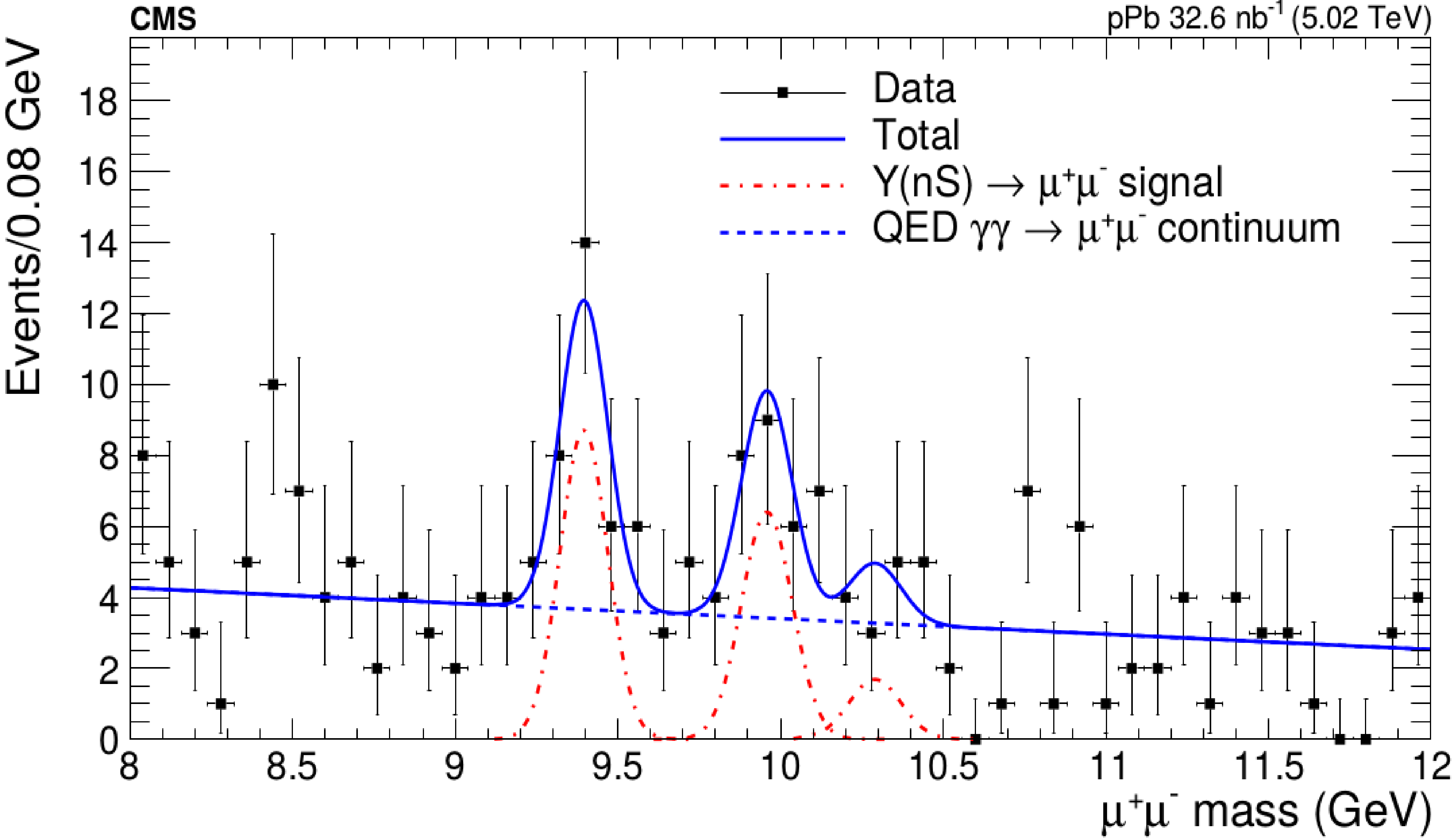


Muon	$\|\eta\| < 2.4$
ECAL	$\|\eta\| < 3.0$
HCAL	$\|\eta\| < 5.2$
TRACKER	$\|\eta\| < 2.5$
CASTOR	$-6.6 < \eta < -5.2$

Sub-detectors to reject Proton (and/or Lead) dissociation background

Exclusive Υ in ultraperipheral pPb at 5.02 TeV

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

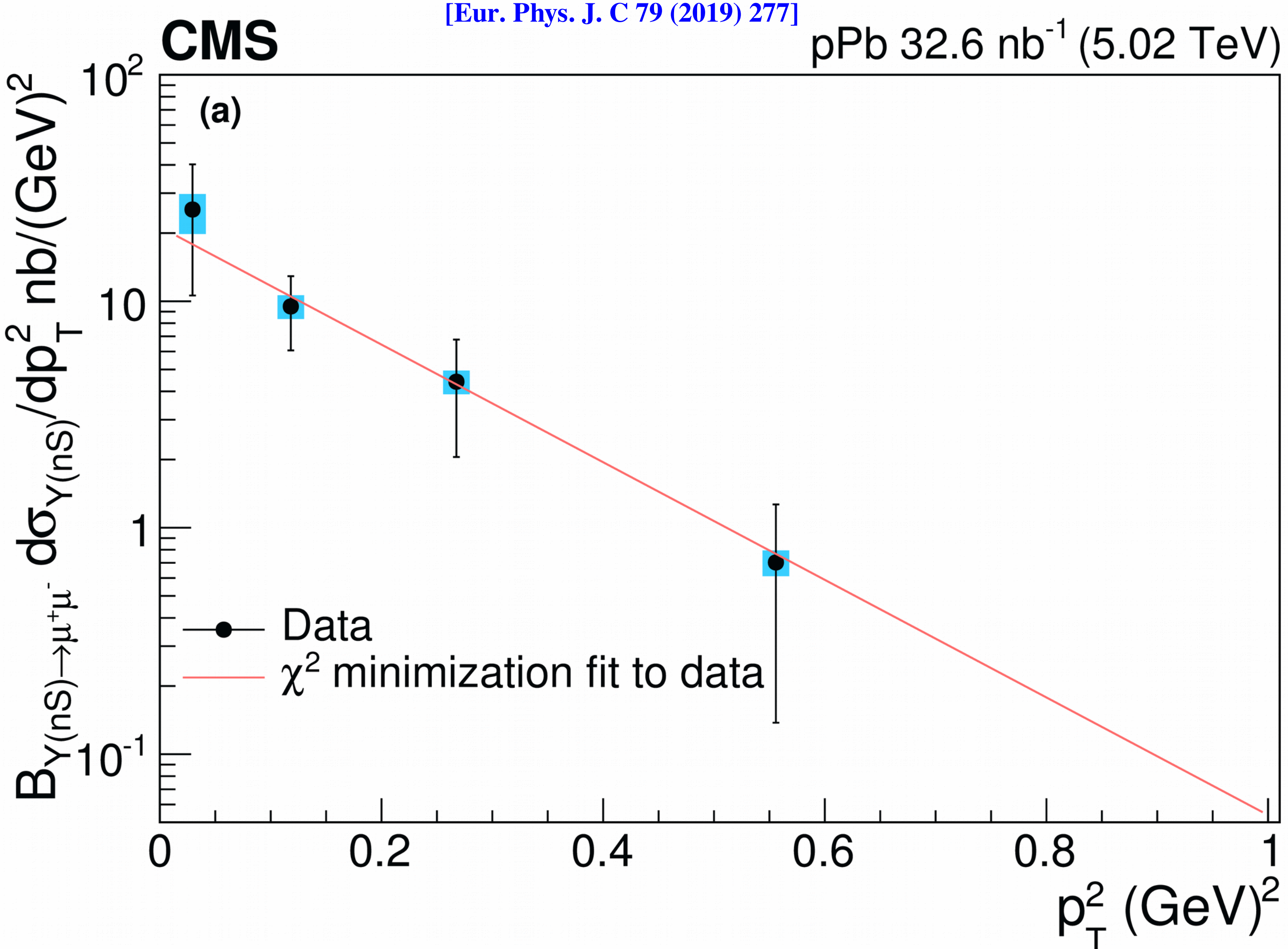


- **Dimuon p_T cut:** $0.1 < p_T < 1.0$ GeV/c

  -Low p_T cut to have good signal/background ratio, high p_T cut to suppress background from **inclusive Υ** and **Proton Dissociation** (PD)

p_T^2 differential cross-section

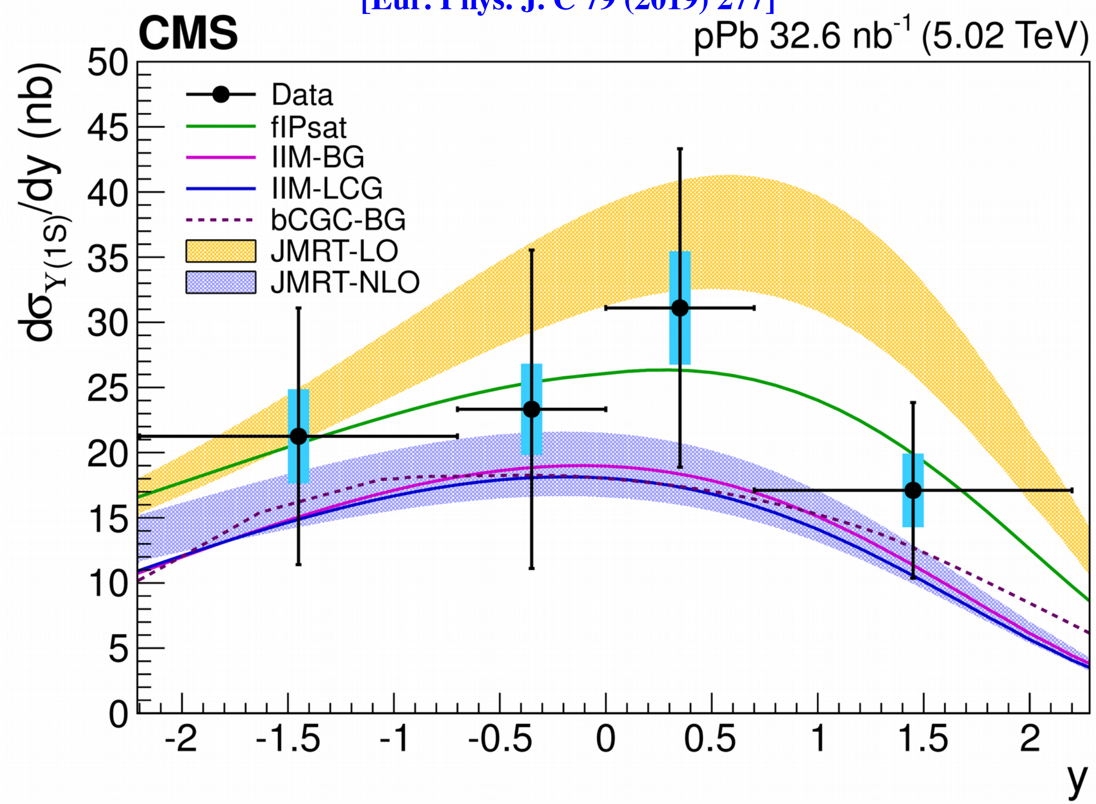
[Eur. Phys. J. C 79 (2019) 277]



- Result for Υ(nS): **b = 6.0 ± 2.1(stat.) ± 0.3 (syst.) GeV^{-2}**
- Consistent with ZEUS measurement for Υ(1S): b = $4.3_{-1.3}^{+2.0}$ (stat.) GeV^{-2} [PLB 708 (2012) 14]
- Exponential slope-b provides information on the transverse density profile of the proton [JHEP 03 (2001) 045, PRD 58 (1998) 114001]

Rapidity dependence

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

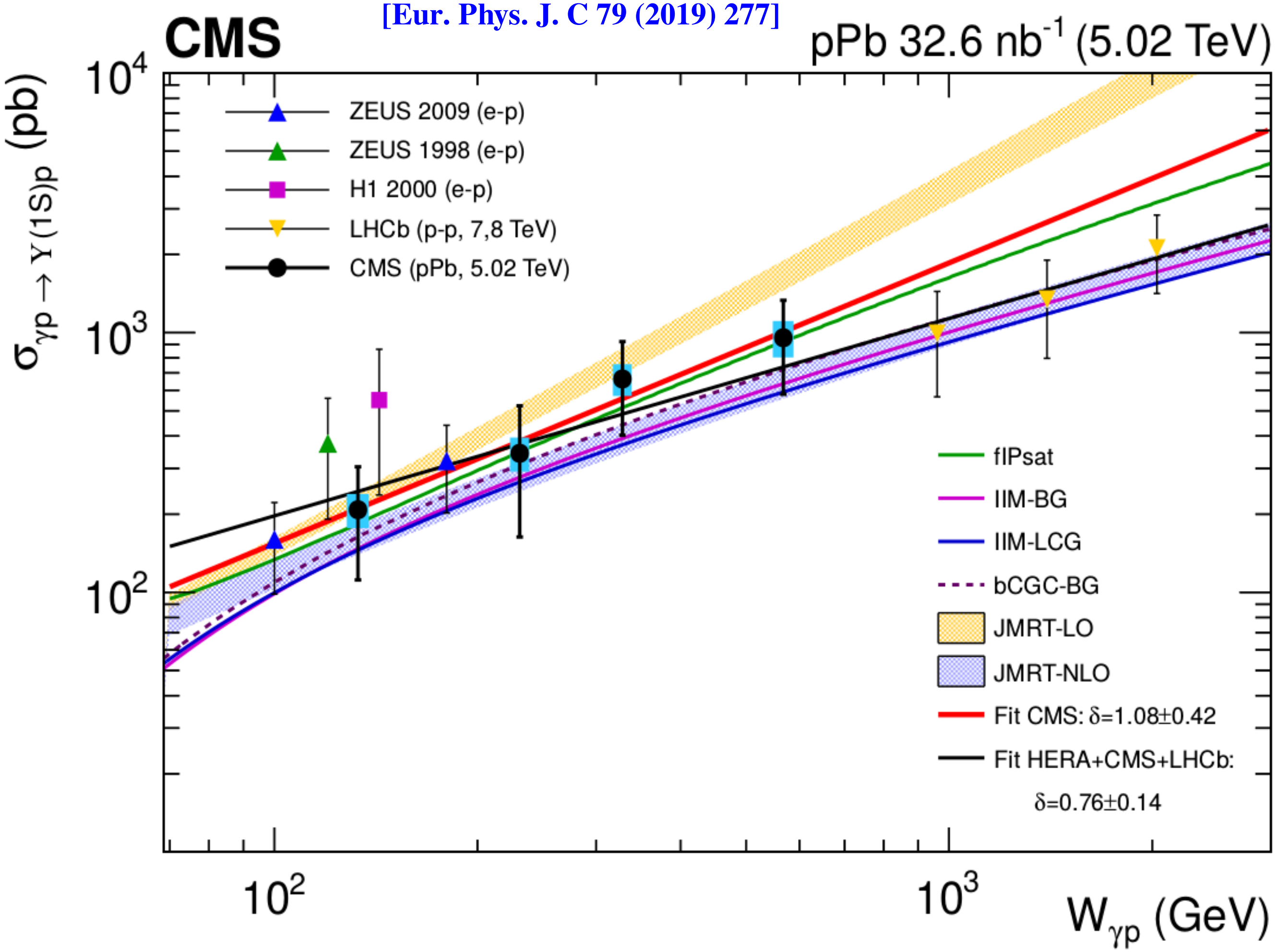


⇒ Consistent with theoretical predictions

- JMRT model : pQCD calculations at LO and NLO [JHEP 11 (2013) 085]
- fIPsat: CGC-based model for low-x gluon saturation [PRC 83 (2011) 065202, PRC 87 (2013) 032201]
- IIM: Colour dipole formalism [PLB 590 (2004) 199] with two sets of meson wave functions (BG and LCG), which also incorporates saturation effects [PRC 89 (2014) 025201, JPG 42 (2015) 105001]
- bCGC: model accounting for the t-dependence of the differential cross section [PRD 95 (2017) 054011, PRD 96 (2017) 094027]

Scaling with the photon-proton energy

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

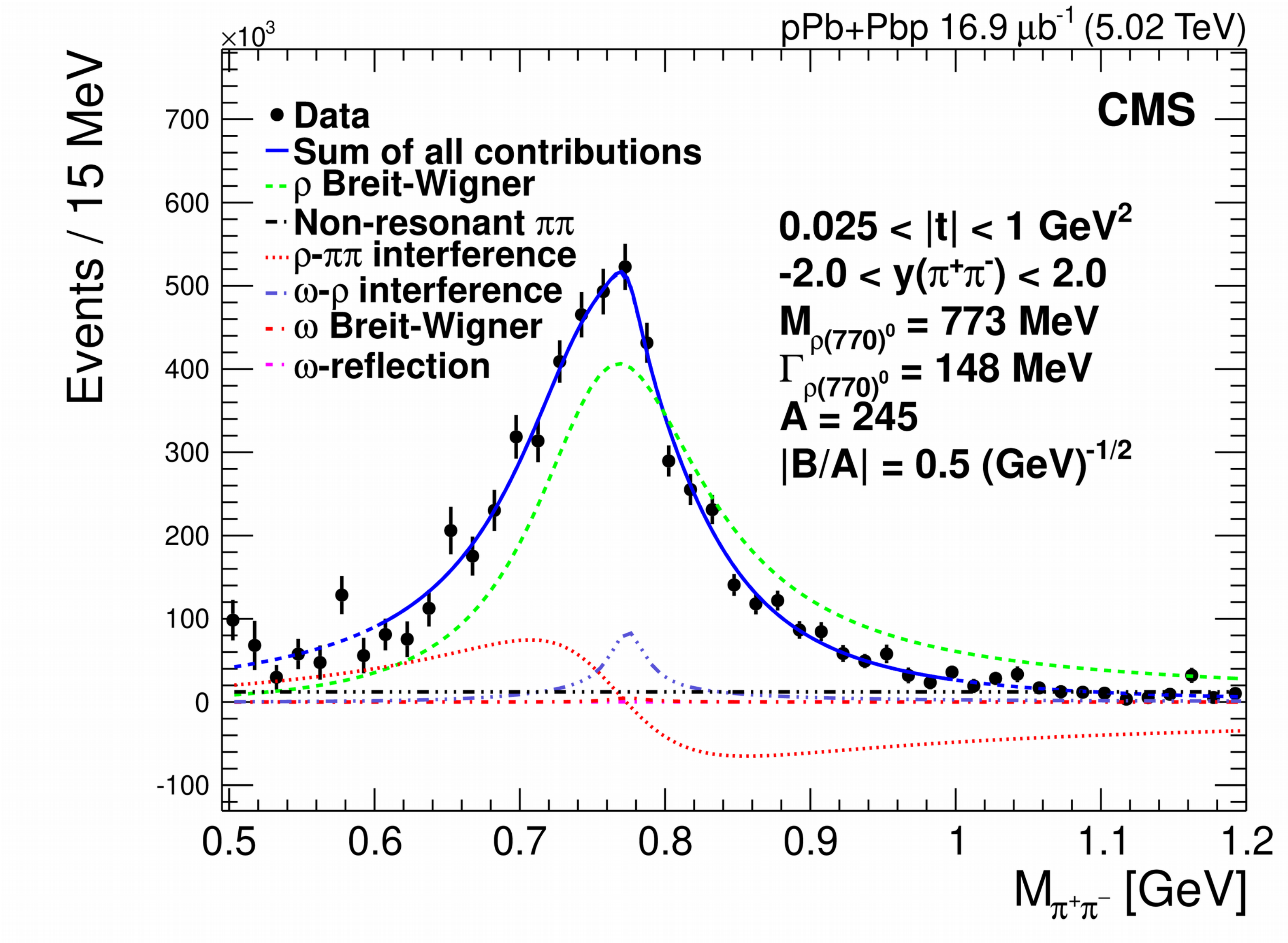


- Fit parameters of power law dependent cross section: $\boldsymbol{\sigma_{\Upsilon}(W_{\gamma p}) = A \times (W/400)^{\delta}}$
  - CMS result: **δ = 1.08 ± 0.42, A = 690 ± 184 pb**
  - ZEUS result: **δ = 1.2 ± 0.8** [PLB 680 (2009) 4]

  ⇒ It is consitent with other experimental results and most predictions
- Combined fit to all measurements (black line) disfavour the LO pQCD calculations [JHEP 11 (2013) 085]

Exclusive ρ in ultraperipheral pPb at 5.02 TeV

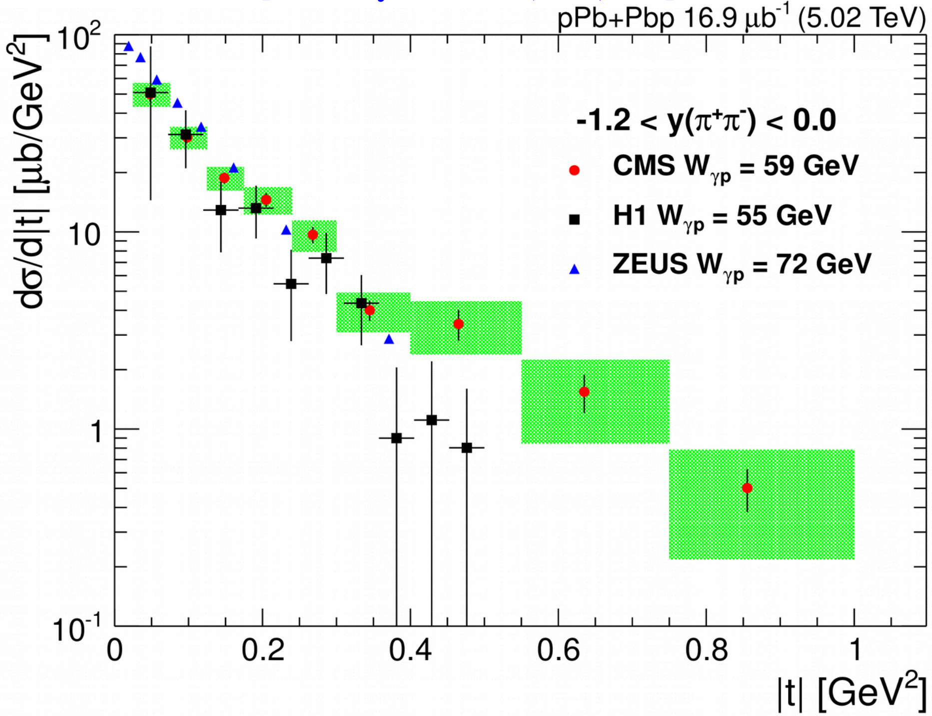
[Eur. Phys. J. C 79 (2019) 702]



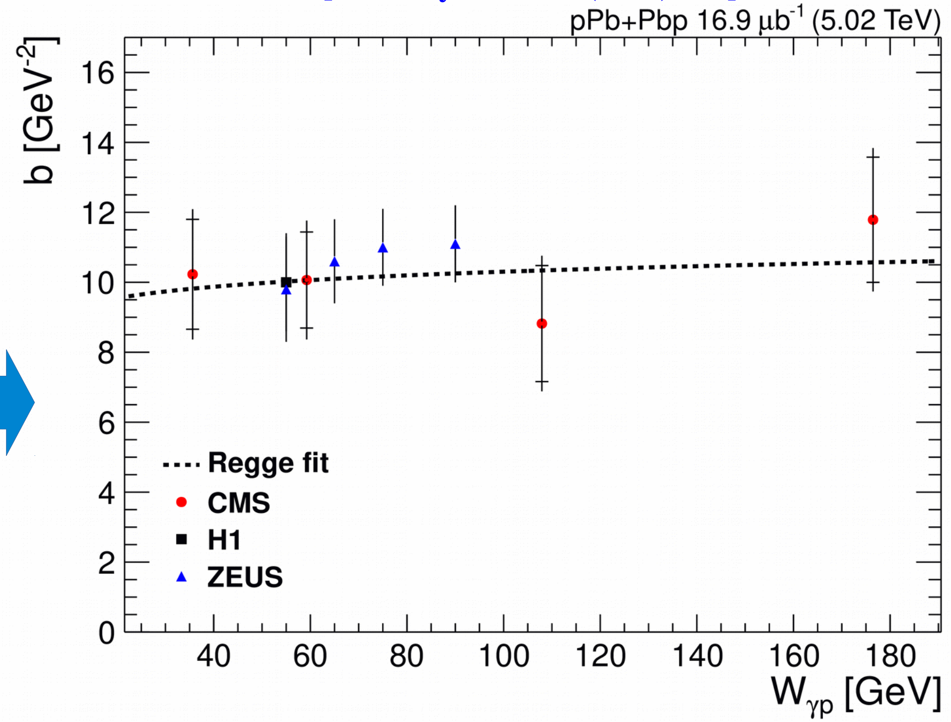
- Complex signal extraction due to the interference with the ω(783) meson

Results: Exclusive $\rho(770)^0$ photoproduction at 5.02 TeV

[Eur. Phys. J. C 79 (2019) 702]



[Eur. Phys. J. C 79 (2019) 702]



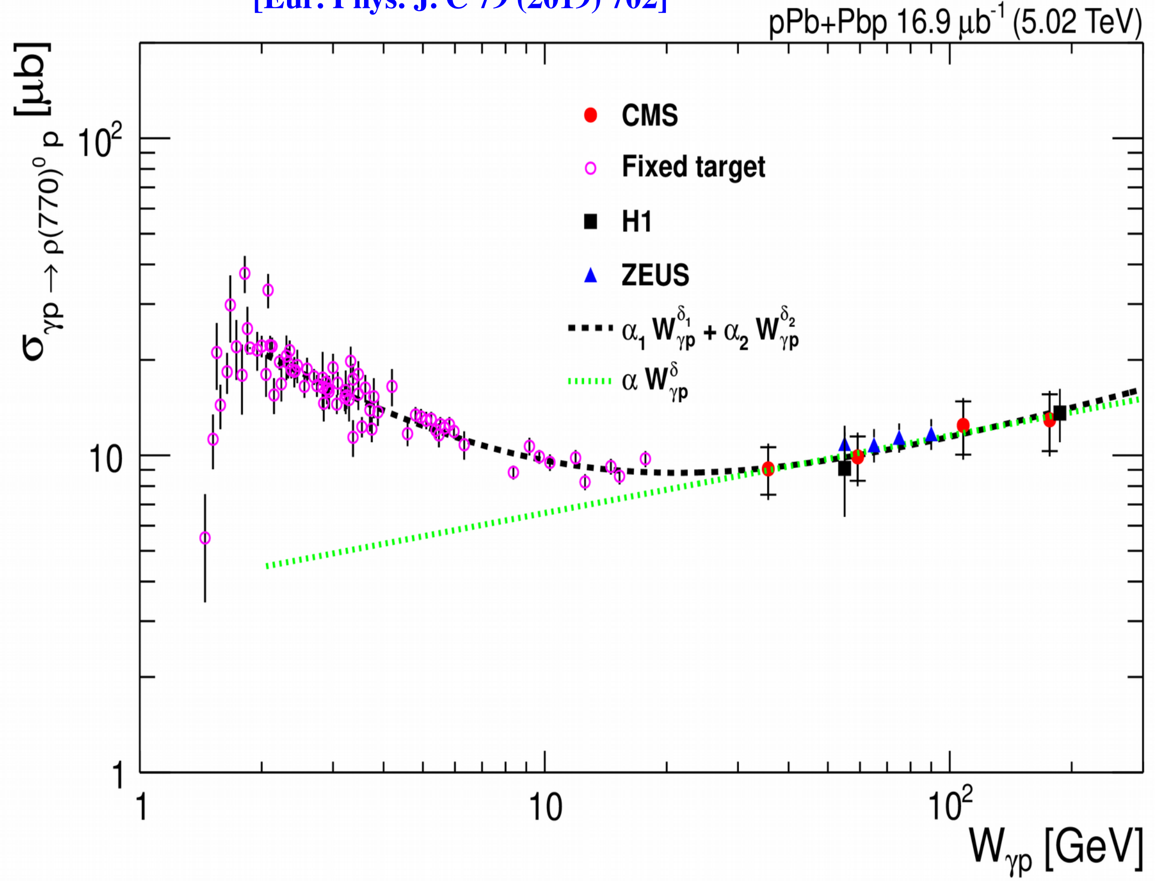
- Left plot is fitted with an exponential function $Ae^{(-b|t|+c|t|^2)}$
  - CMS result: $b = 9.2 \pm 0.7$(stat.) GeV^{-2}, $c = 4.6 \pm 1.6$(stat.) GeV^{-4}

- From Regge formula $b = b_0 + 2\alpha\, ln(W_{\gamma p}/W_0)^2$
  - CMS result: $\alpha = 0.28 \pm 0.11$ (stat) ± 0.12 (syst) GeV^{-2},

  $\Rightarrow$ Consistent with Regge expectation [PR 101 (1983) 169] and ZEUS value [EPJC 2 (1998) 247]

Scaling with the photon-proton energy

[Eur. Phys. J. C 79 (2019) 702]

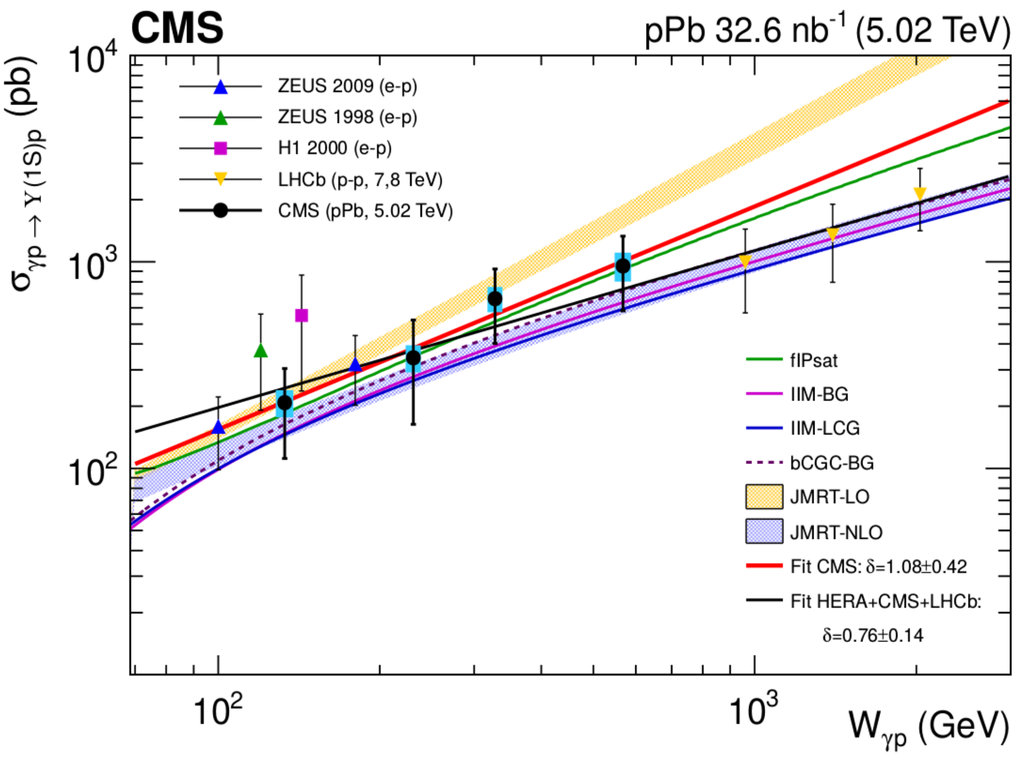


- Cross-section: $\sigma = 11 \pm 1.4\ (\mathrm{stat}) \pm 1.0\ (\mathrm{syst})\ \mu\mathrm{b}$
  (within $W_{\gamma p}$: *29 –213* GeV and $0 < |t| < 0.5$ GeV^2)
- Results consistent with measurements at HERA [EPJC 2 (1998) 247, NPB 463 (1996) 3]
- Fit parameters of power law dependent cross section: $\sigma_\rho(W_{\gamma p}) = \alpha \times (W_{\gamma p})^\delta$

  $\delta = 0.24 \pm 0.13\ (\mathrm{stat}) \pm 0.04\ (\mathrm{syst})$

Summary and Outlook

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



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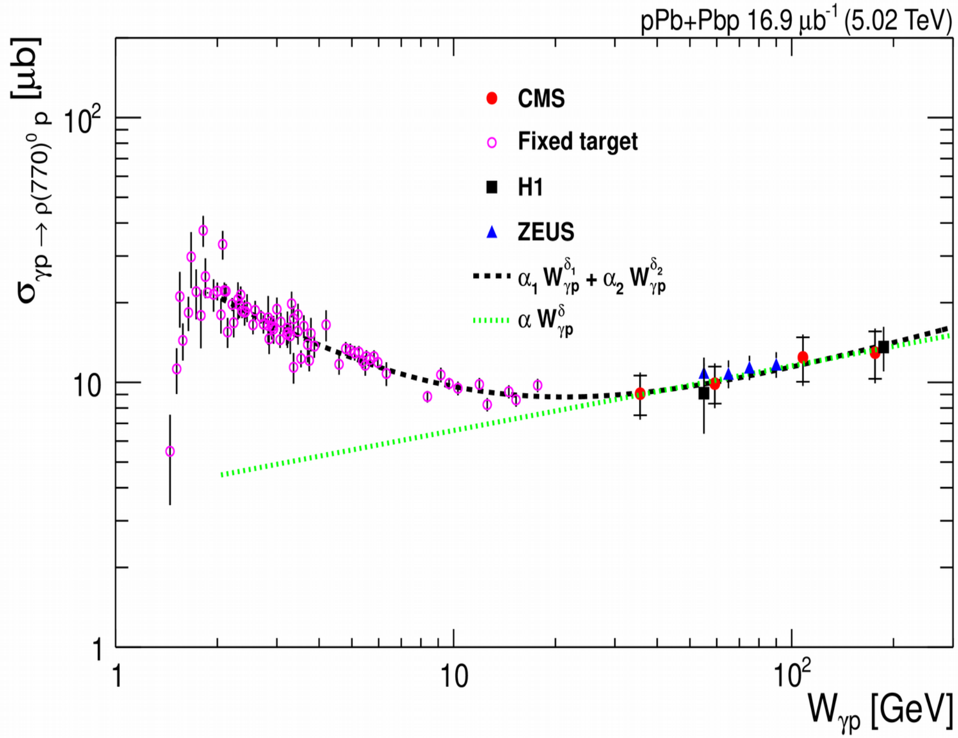

- 1st measurement of **Υ(nS)** and **ρ(770)^0** photoproduction in pPb collisions
- These cross-section measurements provide constraints on the evolution of the gluon density in the proton at low Bjorken-*x*
- Stay tuned for new exclusive quarkonium measurements with the large Run 2 data samples!

Thank you for attention!

Event Selection

- Data from pPb collisions at $\sqrt{S_{NN}}$ = 5.02 TeV in 2013
- Integrated luminosities: **32.6 nb^{-1}** for Υ and **16.9 μb^{-1}** for ρ

Υ selection

- **Mass cut: $9.1 < Mass_{\mu\mu} < 10.6$ GeV**
- **Exclusivity Cut:**
  - -($N_{Tracks}=2$, trk $p_T > 0.1$ GeV/c)
  - -Leading tower Energy in HF calorimeter < 5.0 GeV
- **Muon selection**
  - **Single muon Cut:**
    - To have good muon efficiency
    - μ^+, μ^- $p_T > 3.3$ GeV/c, $|\eta| < 2.2$
- **Υ selection**
  - **Dimuon p_T Cut:**
    - -Low p_T cut to have good signal/background ratio, high p_T cut to suppress background from **inclusive Υ** and **Proton Dissociation** (PD)
    - -Dimuon p_T: $0.1 < p_T < 1.0$ GeV/c

$\rho(770)^0$ selection

- **Mass cut: $0.5 < Mass_{\pi\pi} < 1.2$ GeV**
- **Exclusivity Cut:**
  - -Opposite sign 2 tracks of pion in an event ($N_{Tracks}=2$)
  - -Leading tower Energy in HF<3.0 GeV, HE<1.95 GeV
  - -CASTOR<9 GeV, ZDC^+<500 GeV, ZDC^-<2000 GeV
- **Pion selection**
  - **Single pion Cut:**
    - To have good pion efficiency
    - π^+, π^- $p_T^{Leading} > 0.4$ GeV/c and $p_T^{Subleading} > 0.2$ GeV/c, $|\eta| < 2.0$
- **ρ^0 selection**
  - **$(\pi^+\pi^-)$ p_T Cut:**
    - -Low p_T cut to have good signal/background ratio, high p_T cut to suppress background from **inclusive ρ** and **Proton Dissociation** (PD)
    - -$(\pi^+\pi^-)$ p_T^2: $0.025 < p_T^2 < 1.0$ GeV^2/c^2