Results of Ultraperipheral Collisions with CMS experiment

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Outline

Introduction

UPC:Theoretical and Experimental result

Photoproduction of Upsilon @ pPb UPC 5.02 TeV with CMS

CMS-FSQ-13-009, https://cds.cern.ch/record/2147428

Photoproduction of J/ψ @ PbPb UPC 2.76 TeV with CMS

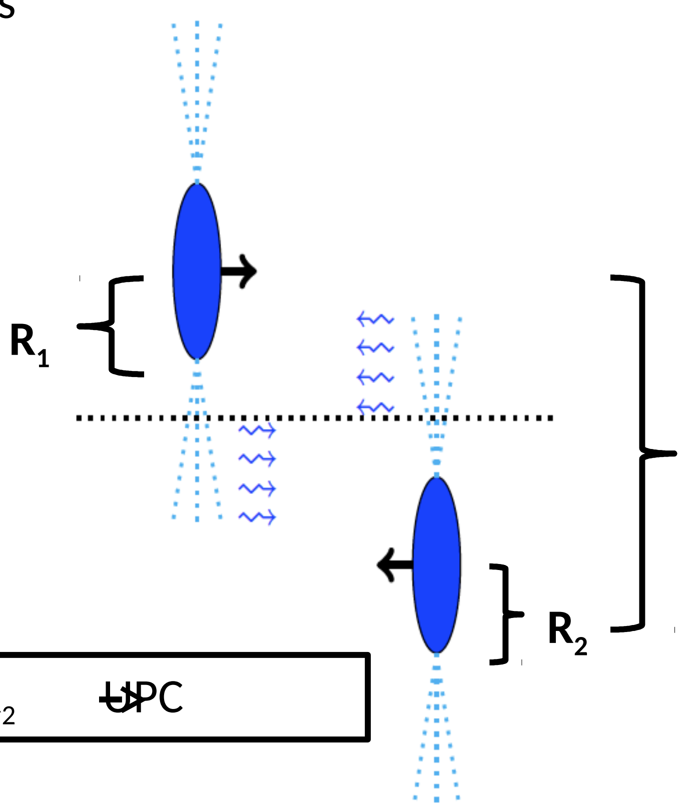
Phys. Lett. B 772 (2017) 489

Light by Light Scattering @ PbPb UPC 5.02TeV with CMS

Conclusion

Ultra Peripheral Collisions (UPC)

The EM field of protons and ions at the LHC can be viewed as a beam of quasi real photons



$b > R_1+R_2 \Rightarrow$ UPC

Note 2:
There are two potential sources, correspondingly two potential targets.

Note3:
The photon is coherently emitted by the source and its virtuality is restricted by the radius of the emitting particle:
$Q^2 \approx (hc/2\pi R)^2$
γ from Pb: $Q^2 \approx (30\ \text{MeV})^2$
γ from p: $Q^2 \approx (250\ \text{MeV})^2$

Note 4:
The flux of the equivalent photon beam is proportional to Z^2

Note1 :
Interactions at large impact parameters (UPC) are of electromagnetic origin, Interaction by cloud of photon, hadronic interactions are suppressed

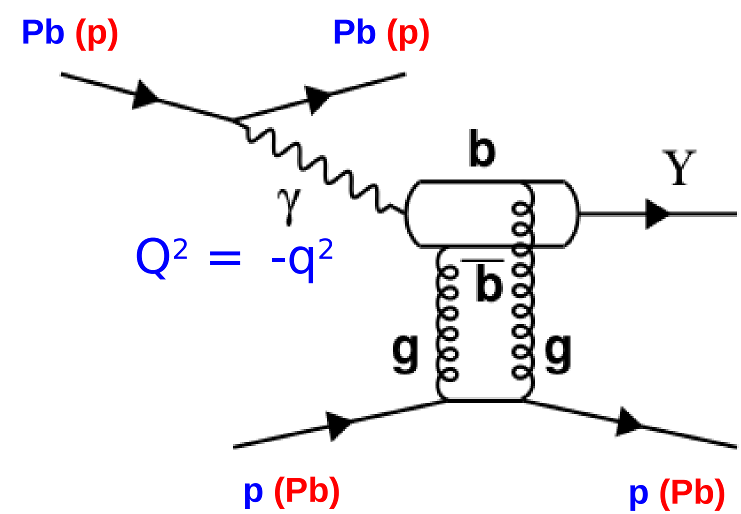
UPC Rev : A. J. Baltz et al. Phys. Rep. 458 (2008)1

Note 5:
The max energy of the photons in the lab system is determined by the boost of the emitting particle
$\omega_{max}=(\gamma_L/R)$, γ_L=Lorentz boost
p: ω_{max} = 950 GeV; Pb: ω_{max} = 50 GeV
In Run2: larger energies possible

Photoproduction of vector meson

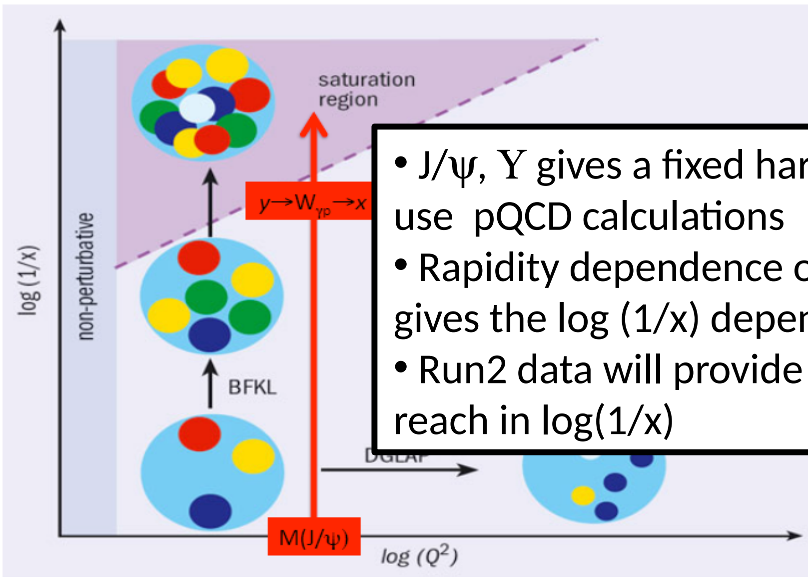
- Photoproduction is convolution of
  - Photon flux
  - Photonuclear cross-section
    - Photoproduction of vector mesons (J/ψ, ϒ) sensitive to the gluon density squared in the nucleon (nucleus)
- Relation between Bjorken x, $W_{\gamma p}$ and rapidity y

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

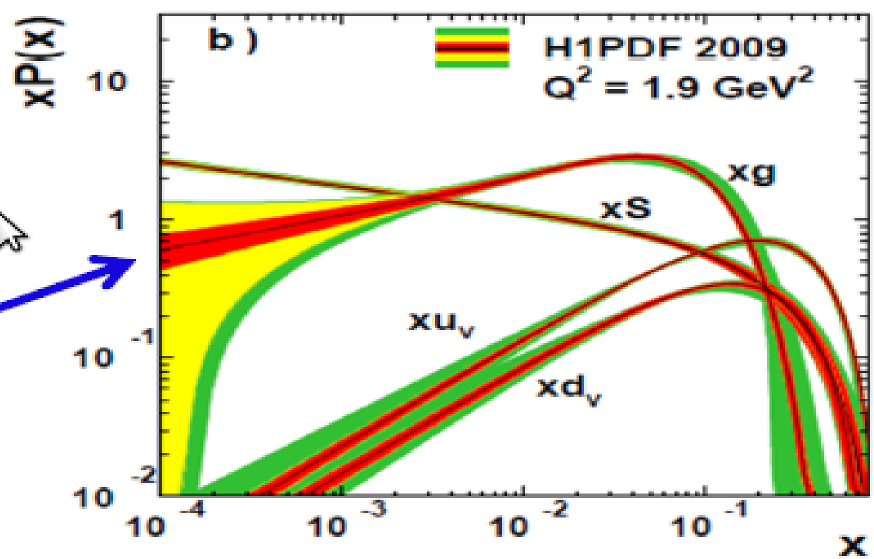


- Probe poorly known gluon distribution in the Proton at low Bjorken x (10^{-4} to 10^{-2}) and search for saturation effects.

$$Q^2 \approx \frac{M_V^2}{4} (2.4 GeV^2 for J/\psi , 22.37 GeV^2 for \Upsilon)$$



- J/ψ, ϒ gives a fixed hard scale to use pQCD calculations
- Rapidity dependence of the ϒ gives the log (1/x) dependence
- Run2 data will provide a larger reach in log(1/x)

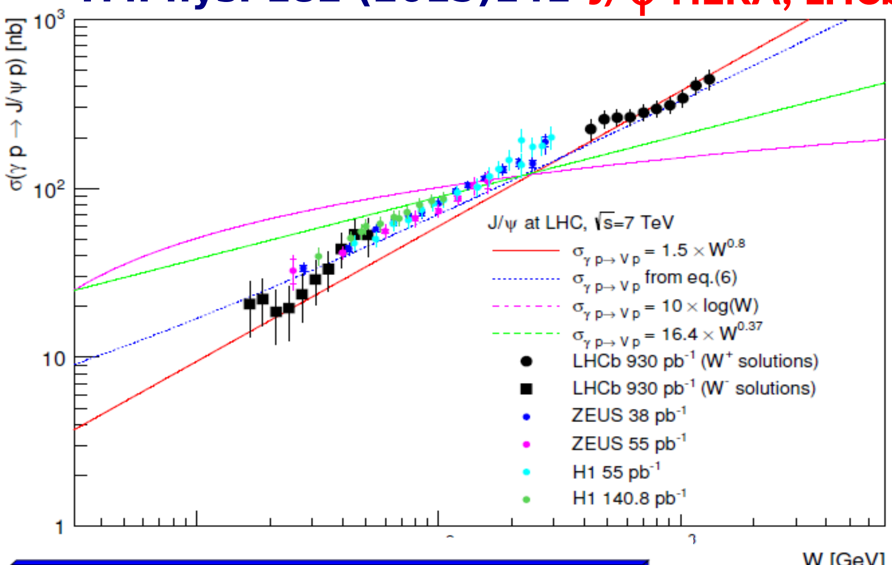


Recent results

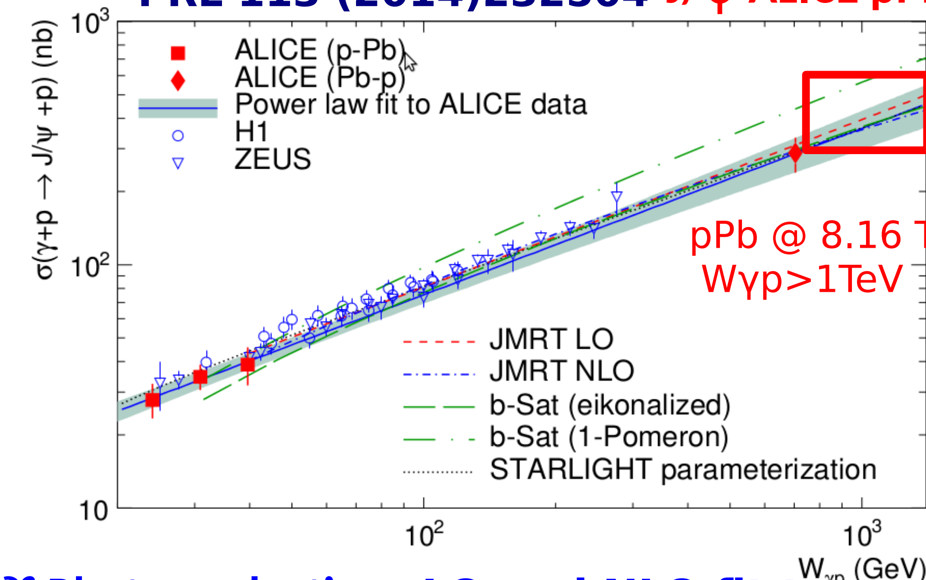
Cross section as a function of photon proton centre of mass energy

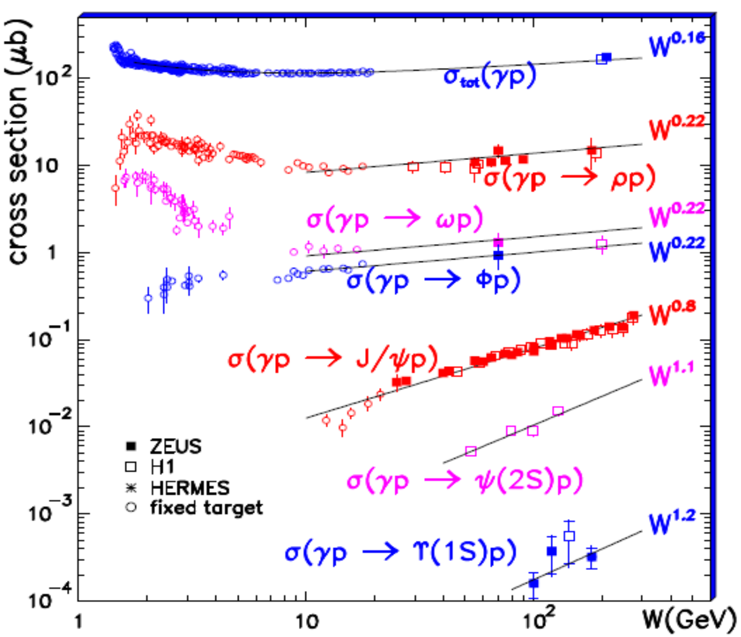
J/ψ photoproduction, LO and NLO fit to H1 , ZEUS, LHCb, ALICE data

TMPhys. 182 (2015)141 J/ψ HERA, LHCb

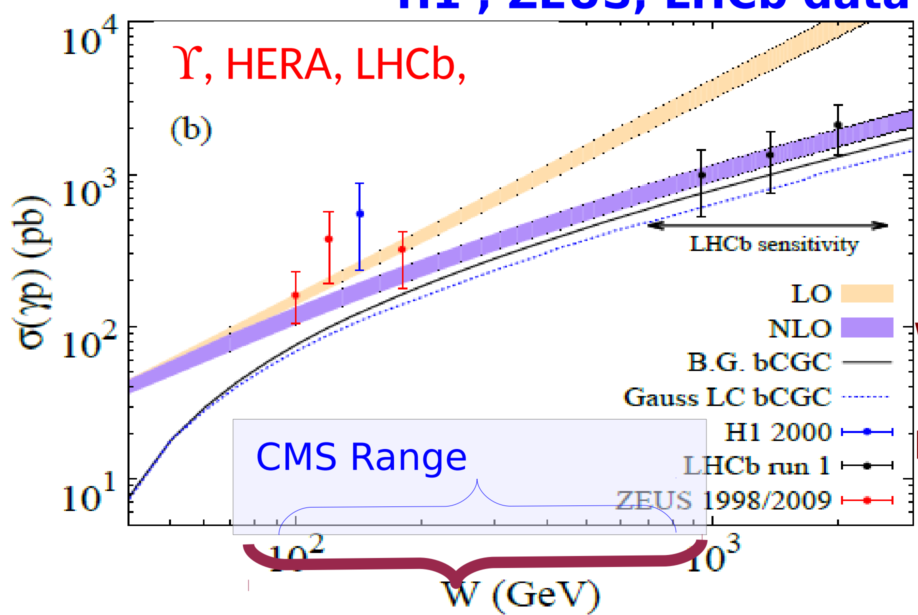


PRL 113 (2014)232504 J/ψ ALICE pPb





Υ Photoproduction : LO and NLO fit to H1 , ZEUS, LHCb data

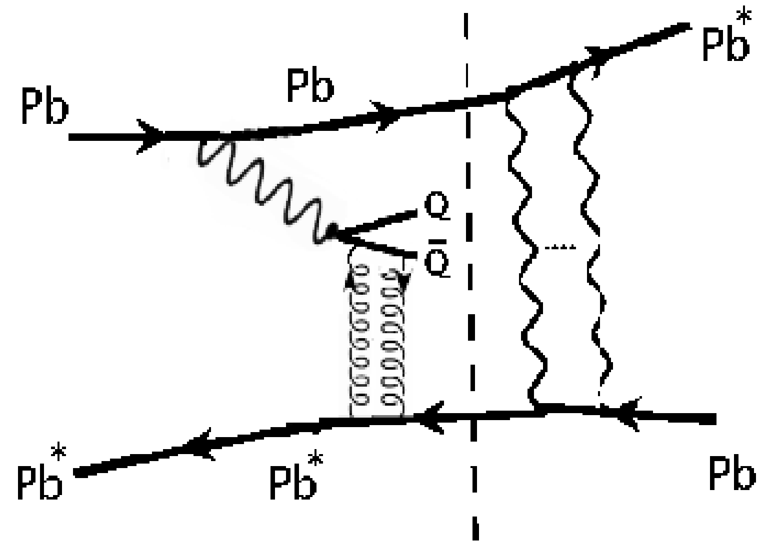


$W_{\gamma p}$: 91 – 826 GeV at CMS pPb @5.02 TeV

$W_{\gamma p}$: 105 –1164 GeV at CMS pPb @8.16 TeV

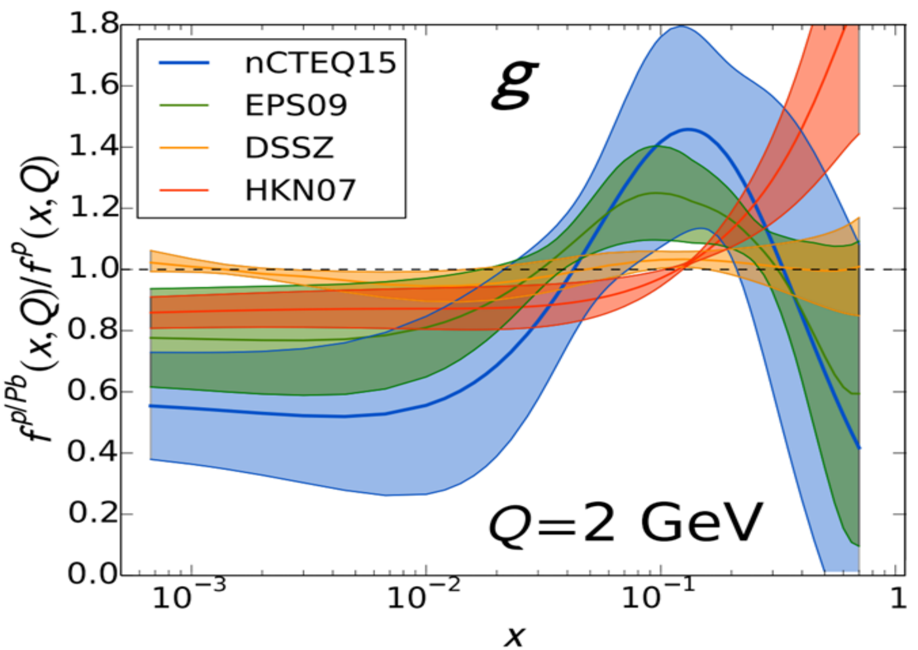
Photoproduction of vector meson in PbPb

- **γPb reactions**
  - Coherent vector meson production
    - Photons couple coherently to allmost all nucleons, ($\omega_{max} \approx \gamma/R$)
    - $\langle p_T \rangle \sim 1/R_{Pb} \sim 60$ MeV/c
  - Incoherent photoproduction,
    - Photon couples to a single nucleon
    - $\langle p_T \rangle \sim 1/R_p \sim 500$ MeV/c
  - Columb nuclear dissociation with coherent photoproduction



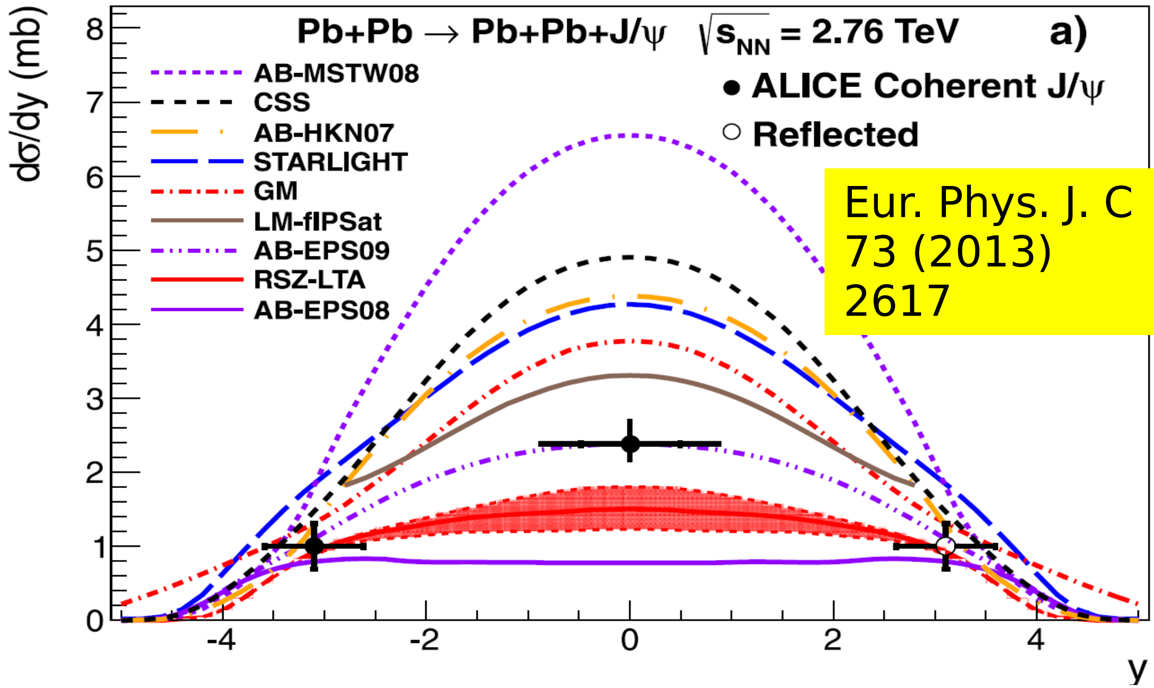
- Coherent J/ψ photoproduction in PbPb is a promising probe to study the gluon PDF and nuclear shadowing at small Bjorken x

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



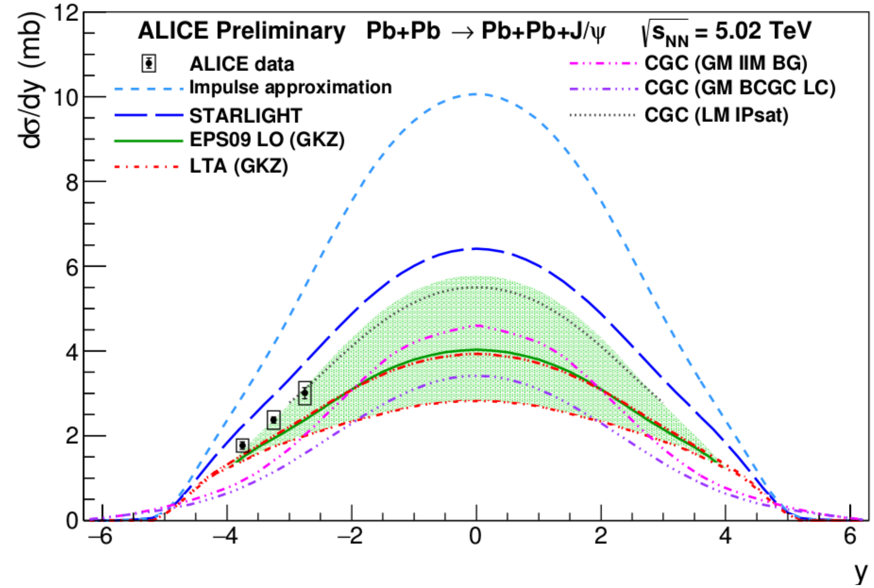
HIN-12-009: http://cds.cern.ch/record/2154908
http://arxiv.org/abs/1605.06966v1

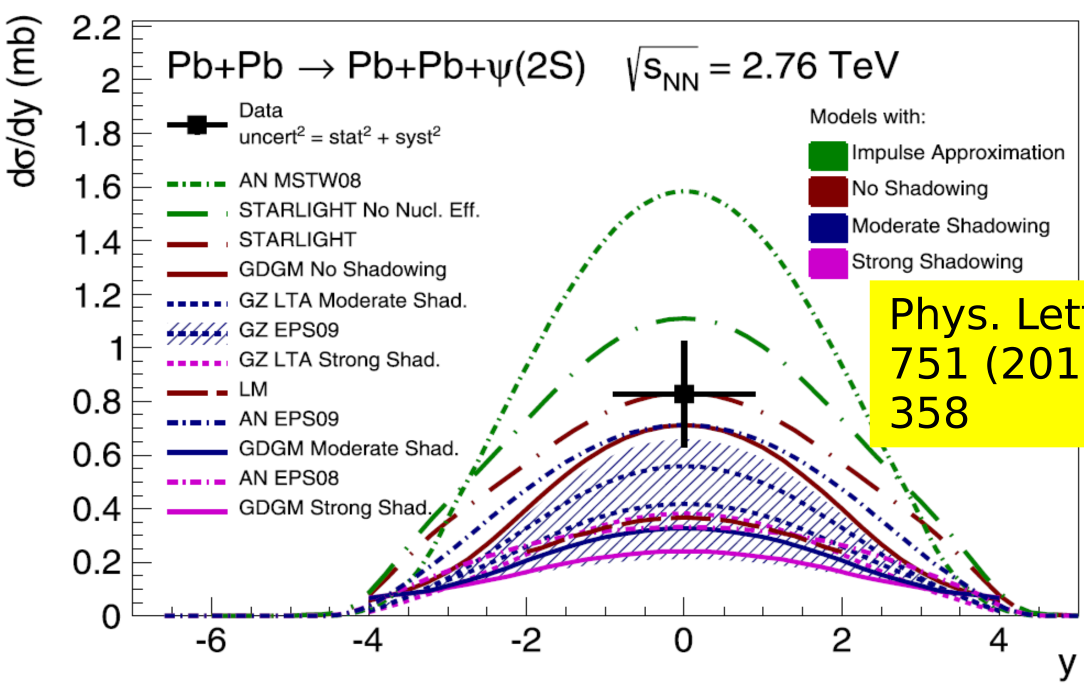
Recent results



Eur. Phys. J. C 73 (2013) 2617

arXiv:1710.03417

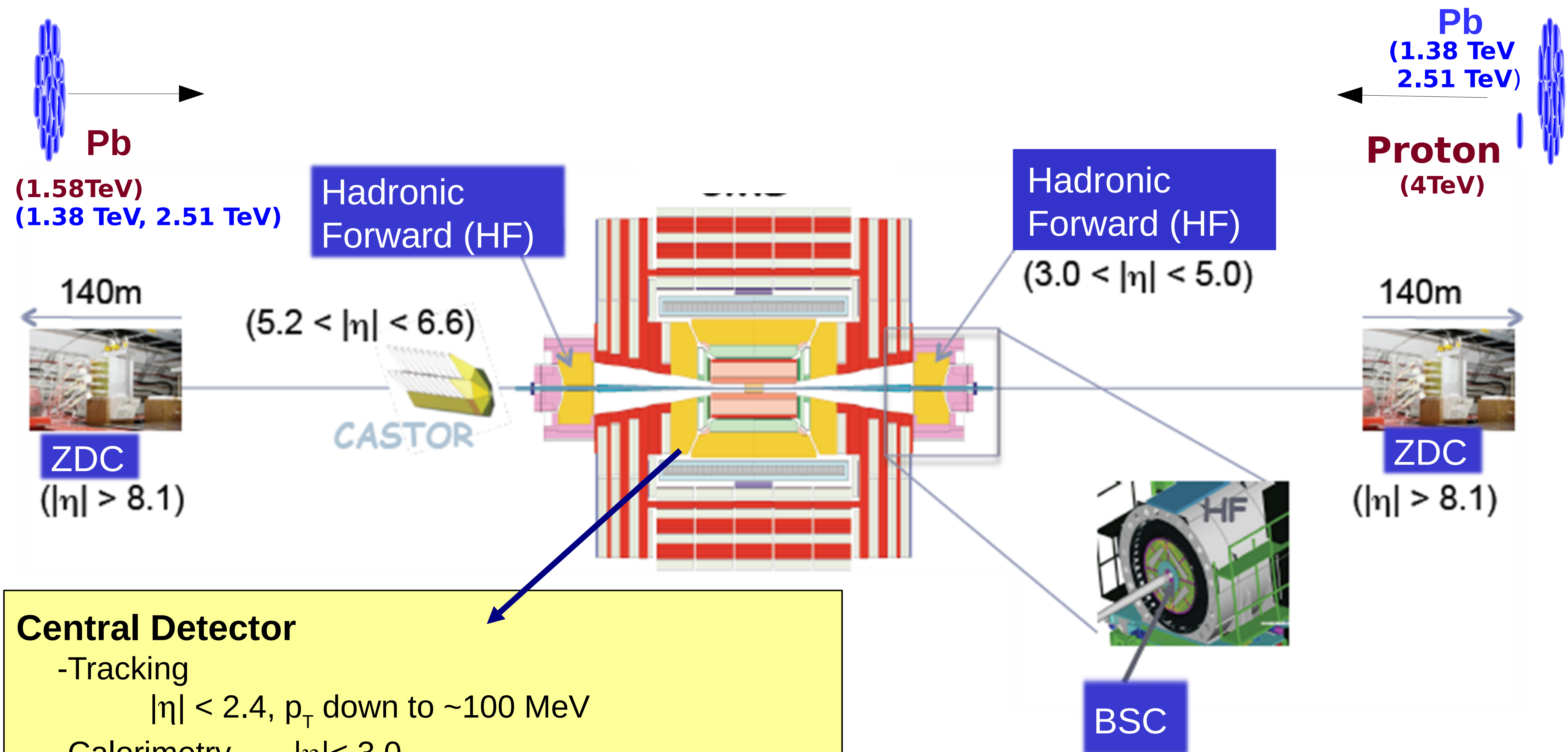




Phys. Lett. B 751 (2015) 358

- ALICE result consistent with models which include moderate shadowing of gluons in nuclei.
- Models with strong nuclear shadowing disfavoured

The CMS Experiment



Central Detector

- -Tracking
  - $|\eta| < 2.4$, p_T down to ~100 MeV
- -Calorimetry $|\eta| < 3.0$
- -Muon Chambers $|\eta| < 2.4$

Forward detectors:

- **HF, hadron forward calorimeter (11m from IP)** $3 < |\eta| < 5$
- **BSC, beam scintillator counters (in front of HF)** $3.2 < |\eta| < 4.7$
- **ZDC (zero degree calorimeter)** $|\eta| > 8.1$

LHC Runs:

Pp 0.9, 2.76, 7, 8, 13 TeV

pPb 5.02 TeV, 8.16 TeV

PbPb 2.76 TeV, 5.02 TeV

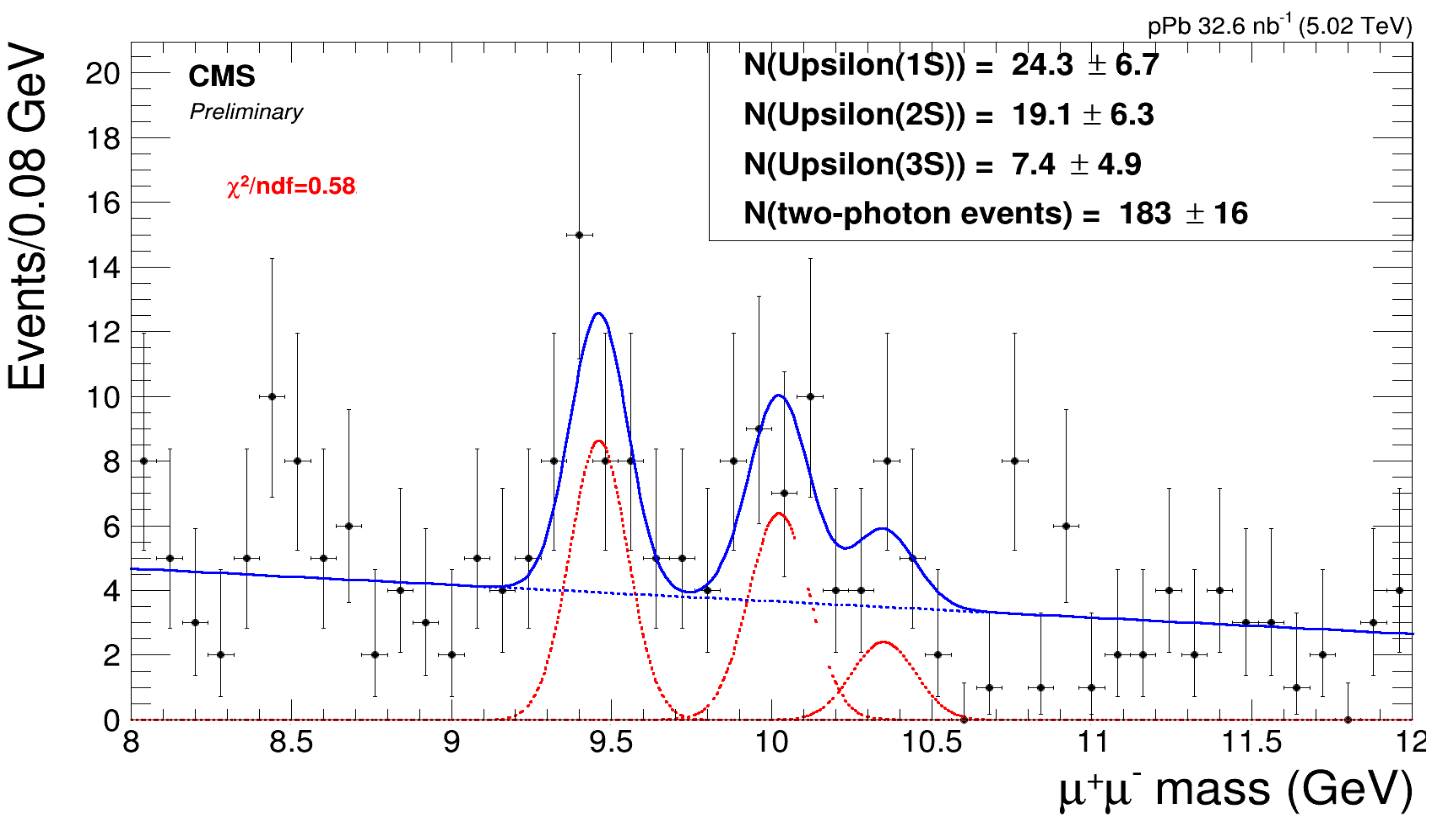
Exclusive upsilon photoproduction in pPb @ 5.02 TeV

CMS-PAS-FSQ-13-009,
https://cds.cern.ch/record/2147428

Exclusive upsilon photoproduction

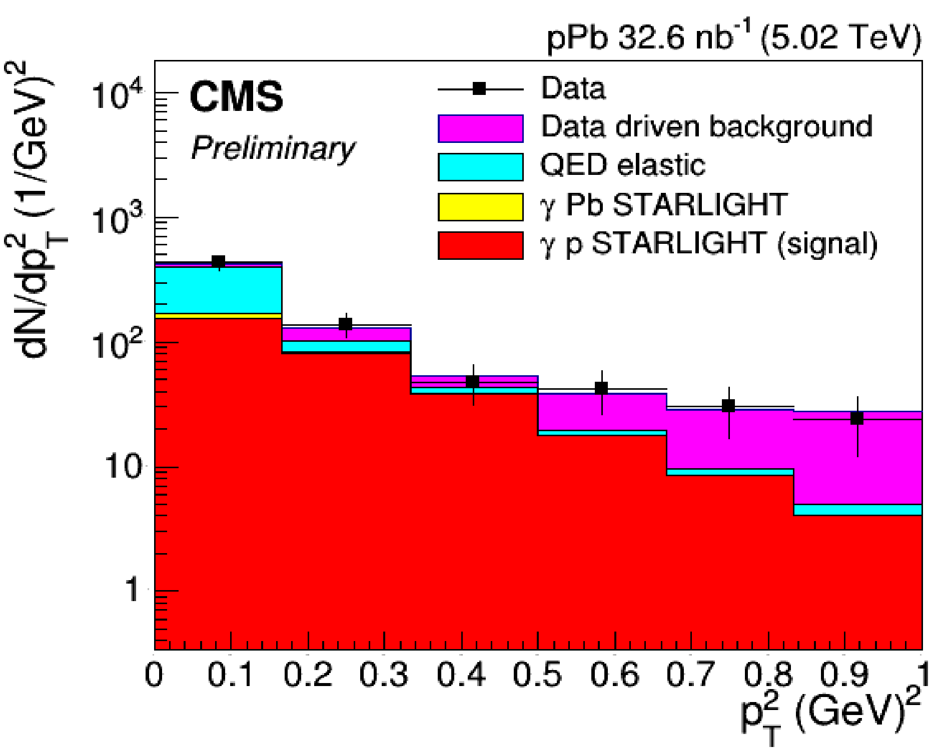
CMS-FSQ-13-009
https://cds.cern.ch/record/2147428

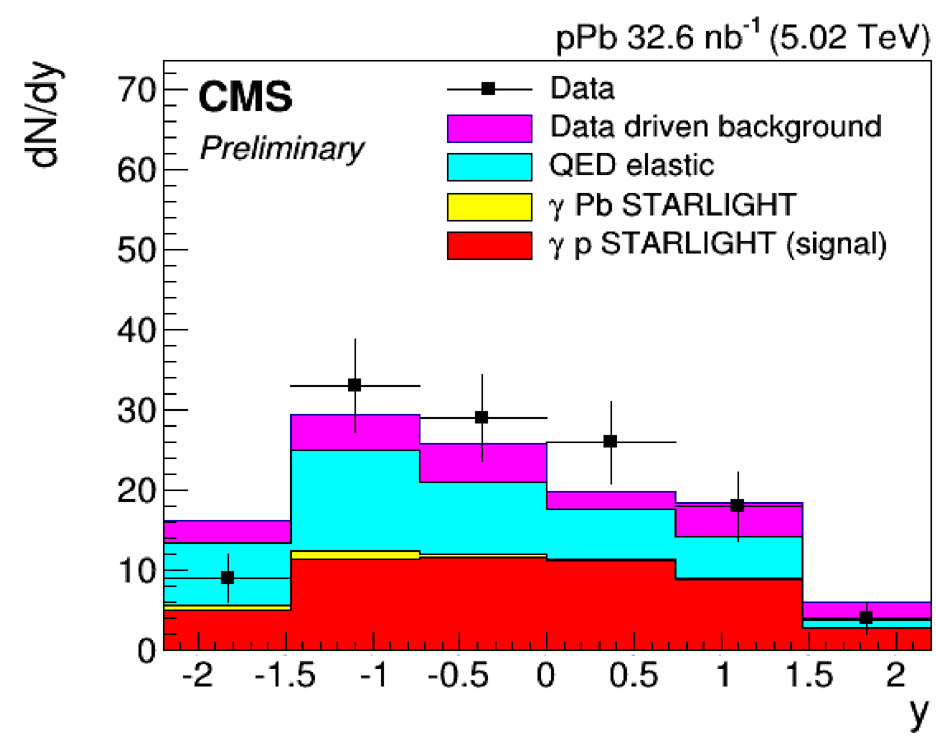
- 2013 pPb data at 5.02 TeV with 32.6 nb^{-1}
- Offline exclusive pPb → Υ (γp) → $\mu^+\mu^-$ signal selection
  - Invariant mass ($\mu\mu$) : 9.1-10.6 GeV
  - Opposite-sign $\mu\mu$ pair (final state) originating from commom primary vertex
  - No extra tracks at $\mu\mu$ vertex to suppress non-exclusive background
  - Single muon p_T : >3.3 GeV and |η|< 2.2 high muon finding efficiency
  - Upsilon p_T : 0.1-1 GeV to suppress QED and non-exclusive background
  - Upsilon |y| < 2.2 high muon finding efficiency



Exclusive upsilon photoproduction (data/MC)

- Data compared to simulation (contains different contribution)
- Low p_T: **QED** elastic background, estimated by STARLIGHT
- High p_T : Non-exclusive background (DY+ incl. Υ + p diss. γp) estimated from data





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

CMS-FSQ-13-009
https://cds.cern.ch/record/2147428

Photoproduction cross section as a function of p_T

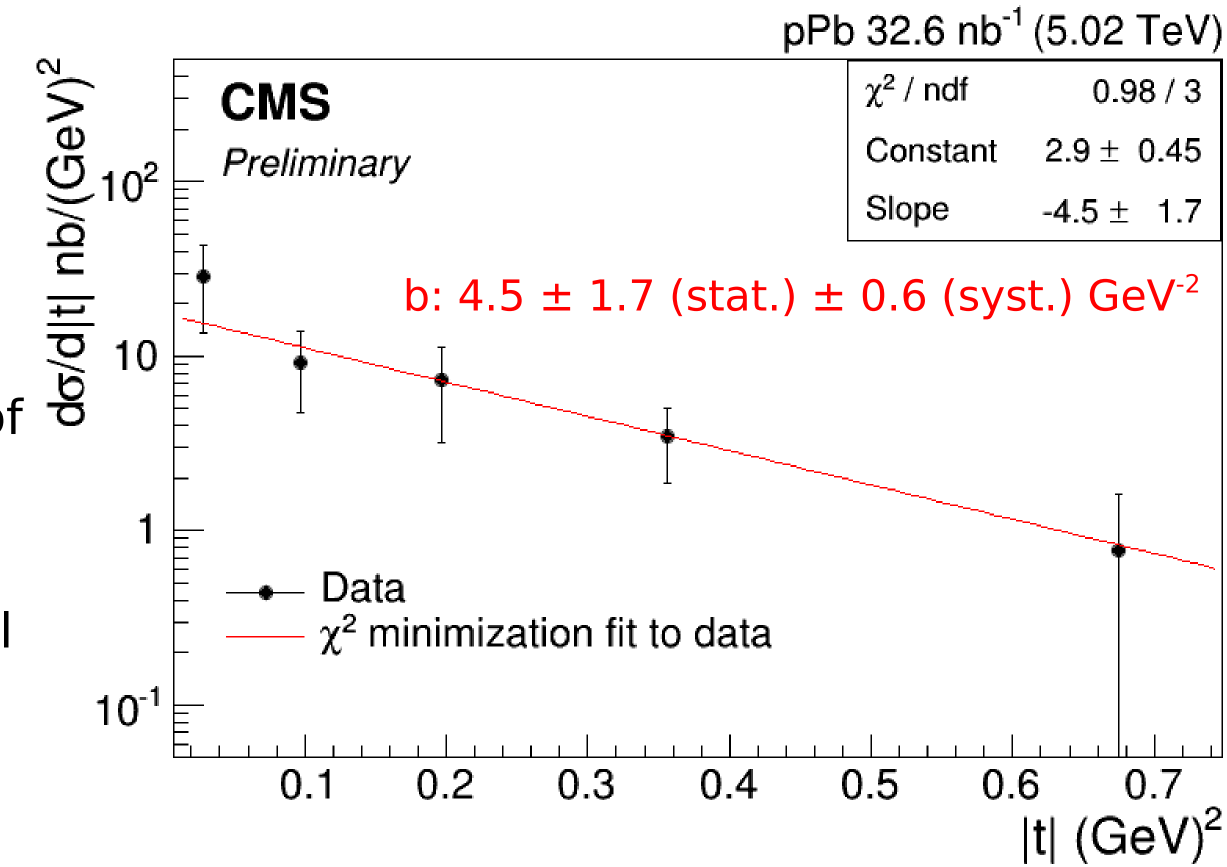
CMS-FSQ-13-009
https://cds.cern.ch/record/2147

- The differential cross section is calculated according to

$$\frac{d\sigma_{\Upsilon(nS)}}{dp_T^2}\cdot B=\frac{N^{corr}_{\Upsilon(nS)}}{L\times\Delta p_T^2}$$

- $N^{corr}_{\Upsilon(nS)}$, the background subtracted, unfolded and acceptance corrected number of upsilon (1S+2S+3S) events in each p_T^2 bin.

- $d\sigma/dt$ fitted with an exponential function, provides the information on the transverse profile of the interaction region.



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

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

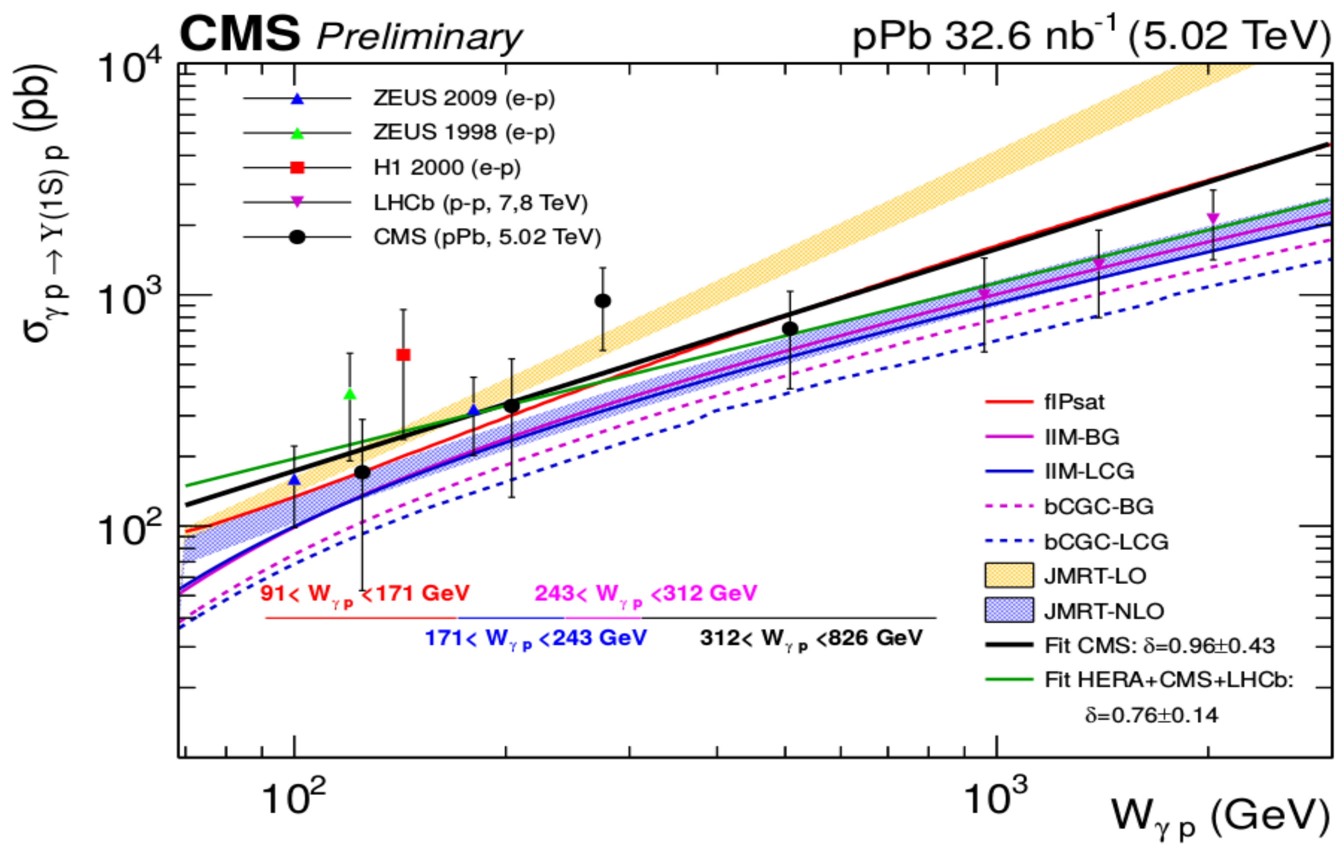
Cross-section as a function of $W_{\gamma p}$

CMS-FSQ-13-009
https://cds.cern.ch/record/21474

- The cross-section is estimated by

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

- Rapidity distribution of Υ(1S) is used to estimate $\sigma_{\gamma p}$(1S) vs $W_{\gamma p}$
- The cross-section is corrected for muonic branching ratio, feed-down, upsilon (1S) fraction



A fit with power-law **A X (W/400)$^{\delta}$** to the CMS data

δ = (0.96 ± 0.43) , A = 655 ± 196

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

ZEUS
δ = 1.2 ± 0.8
Phys.Lett. B680 (2009) 4-12

Coherent J/ψ photoproduction in PbPb @ 2.76 TeV

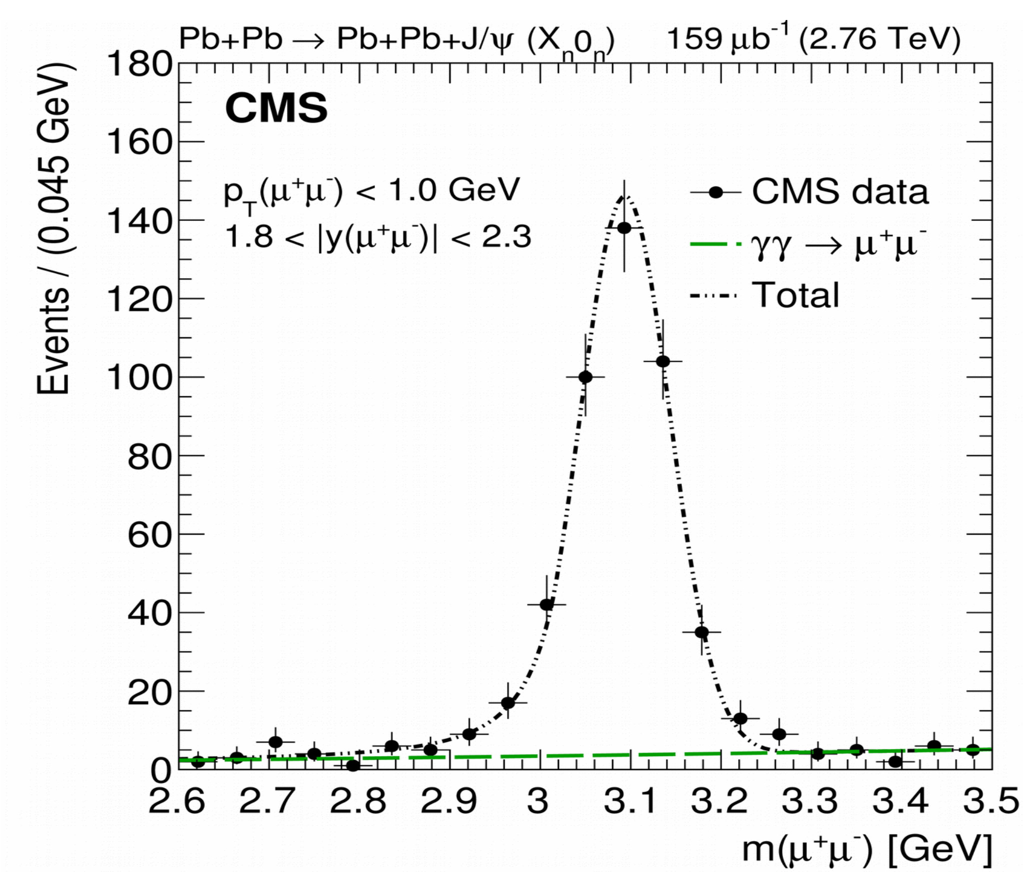
HIN-12-009: http://cds.cern.ch/record/2154908
http://arxiv.org/abs/1605.06966v1
Phys. Lett. B 772 (2017) 489

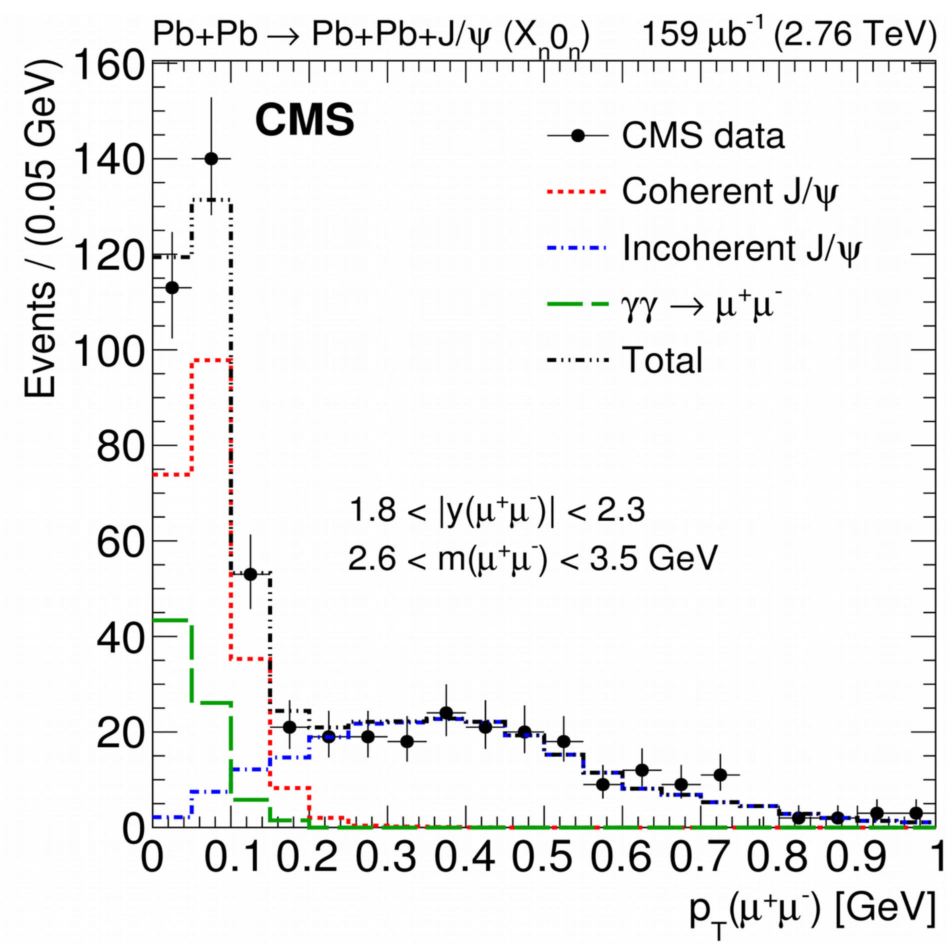
Coherent J/ψ photoproduction in PbPb

HIN-12-009: http://cds.cern.ch/record/2154908
http://arxiv.org/abs/1605.06966v1

Event Selection :

- **UPC trigger**: (i) at least one neutron in either ZDC and no activity in both side BSC
- **Offline**: No HF activity, Muon 1.2 < | η | < 2.4 and 1.2 < p_T < 1.8 GeV/c, $p_T(m^+m^-)$< 1.0 GeV, 2.6 < M (m^+m^-) < 3.5 GeV t Phys. Lett. B 772 (2017) 489





Nuclear break-up modes with UPC J/ψ

$X_n 0_n$ single-sided neutron emission with any number of neutrons
$X_n X_n$ double-sided neutron emission with any number of neutrons
$1_n 1_n$ double-sided neutron emission with only one neutron on each side

J/ψ with p_T <0.15 GeV/c	X_nX_n / X_n0_n
Data	0.36±0.04
STARLIGHT	0.37
GSZ	0.32

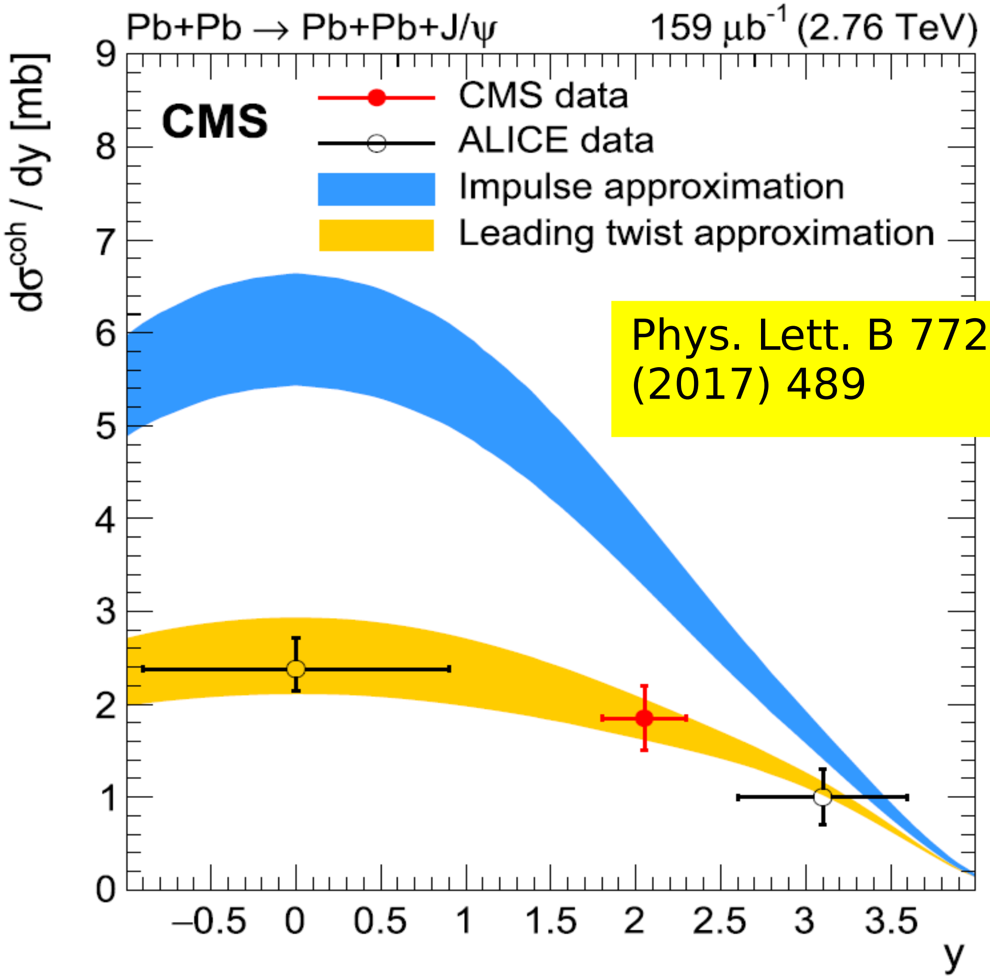
$1_n1_n / X_n0_n$
0.03±0.01
0.02
0.02

HIN-12-009: http://cds.cern.ch/record/2154908
http://arxiv.org/abs/1605.06966v1

Rapidity distribution of J/ψ

$$\frac{d\sigma^{coh}_{X_n 0_n}}{dy}(J/\psi) = \frac{N^{J/\psi}_{coh}}{BR(J/\psi \to \mu^+\mu^-) \cdot \mathcal{L}_{int} \cdot \Delta y \cdot (A \times \varepsilon)^{J/\psi}}$$

- Coherent yield in X_n0_n mode for $p_T < 0.15$ GeV/c
- Cross section for X_n0_n is scaled up to the total cross section using STARLIGHT
- CMS and ALICE, show good agreement with theoretical models which include considerable nuclear gluon shadowing



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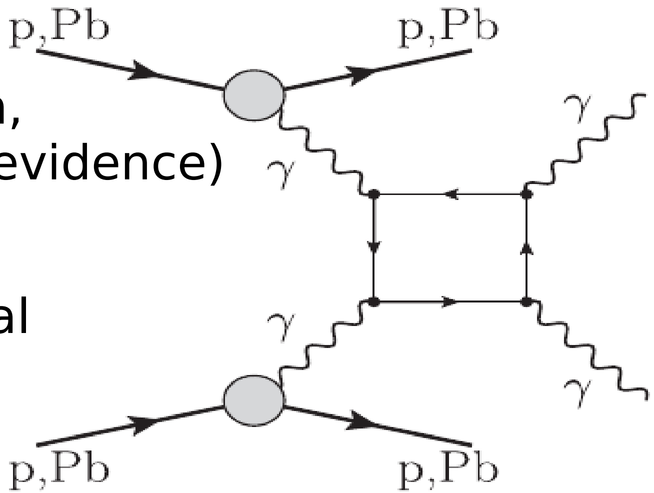
HIN-12-009: http://cds.cern.ch/record/215490
http://arxiv.org/abs/1605.06966v1

Light by Light Scattering in PbPb Collisions @ 5.02 TeV

Light-by-light scattering in PbPb collisions

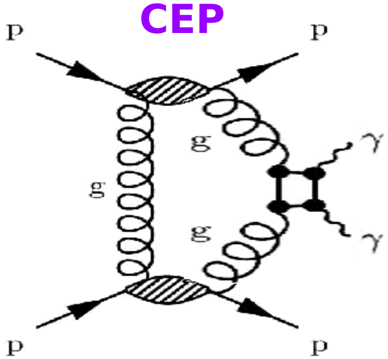
- Elastic light-by-light (LbyL) scattering, fundamental quantum-mechanical process with a tiny cross section, experimentally unobserved so far (*recent ATLAS 4σ evidence)

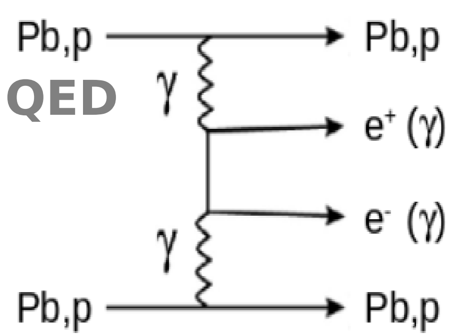


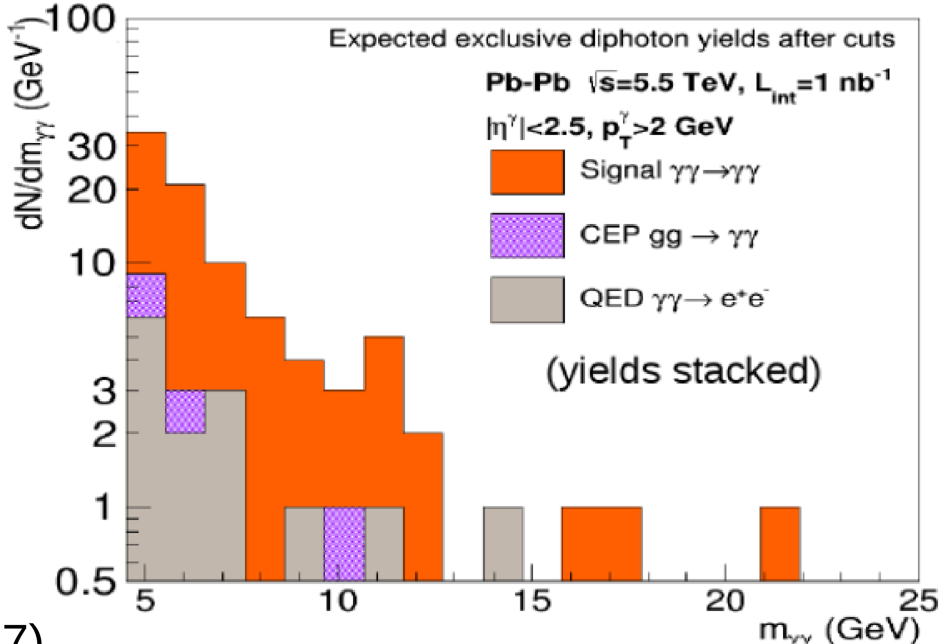
[D.d'Enterria, G.G. daSilveira PRL111(2013)080405]

- Study of $\gamma\gamma \rightarrow \gamma\gamma$ at high invariant mass: Neat channel to study anomalous gauge couplings, search for virtual contributions from BSM charged particles (SUSY, monopoles, axions,...)
- **LbyL** signal events generated with MADGRAPH 5: **N** $_{\gamma\gamma\text{-}\gamma\gamma}$ **~ 70** expected in PbPb at 5.5 TeV (1 nb^{-1})
- **Central exclusive production** generated with SUPERCHIC: N $_{\text{CEP-gg}}$ ~ 6 counts expec.
- **QED** generated with STARLIGHT, **N** $_{\text{QED ee}}$ **~ 15** expected after all cuts

Light-by-light signal is clearly observable over the background



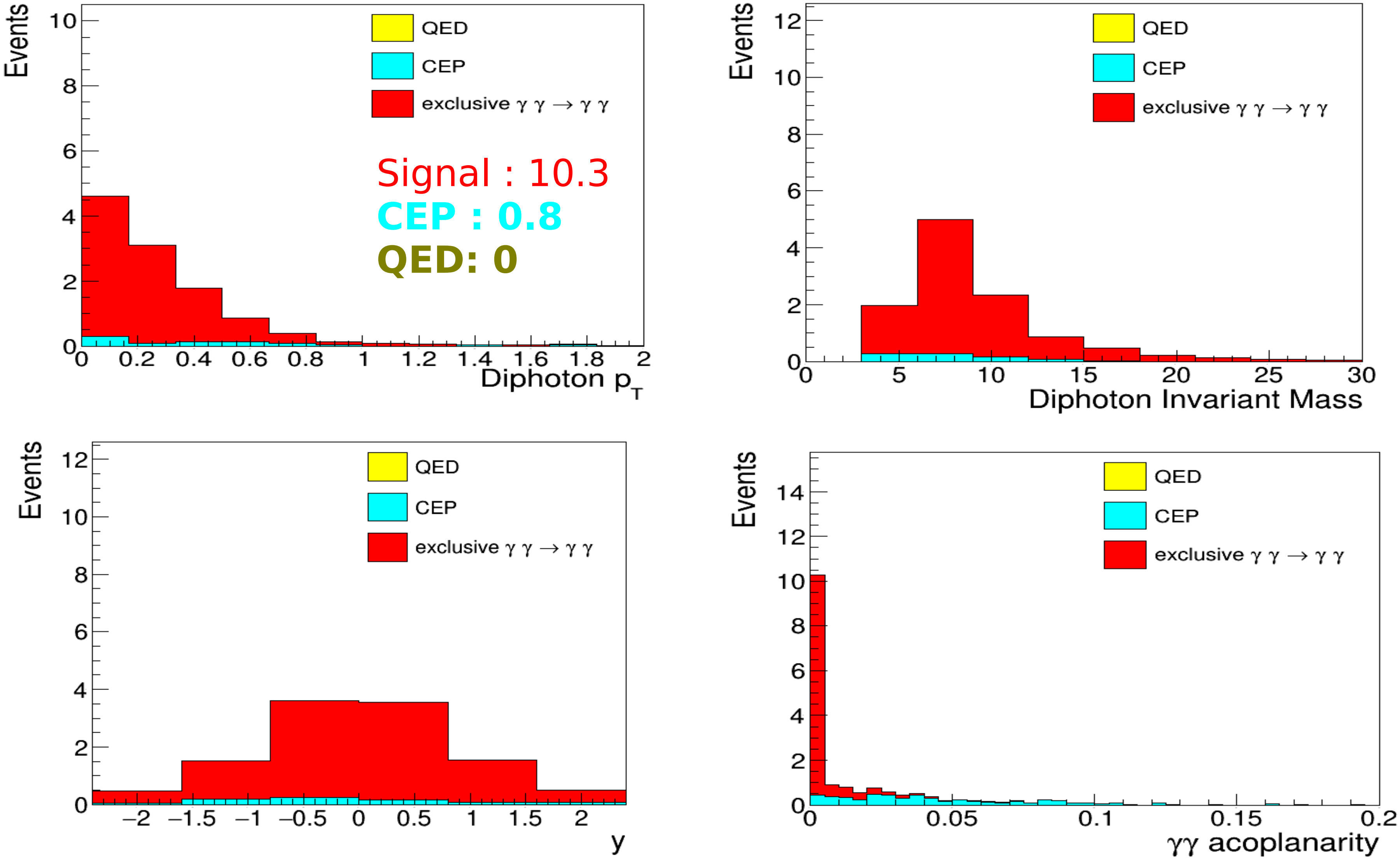




*Nature Physics 13 852 (2017)

Light-by-light MC expectations after cuts

Event selection: $p_T(\gamma) > 2$ GeV, $p_T(\gamma\gamma) < 2$ GeV, aco < 0.01



With current luminosity, we expect ~10 exclusive photon pairs, on top of small QED+CEP backgrounds. Data analysis ongoing.

Theoretical predictions

Theoretical prediction of Upsilon photoproduction

- Photoproduction is convolution of
  - Photon flux
  - Photonuclear cross-section

$$\frac{d\sigma_{AB\to ABY}}{dy} = \underbrace{N_{\gamma/A}(y)}_{\text{Photon flux}}\,\underbrace{\sigma_{\gamma B\to YB}(y)}_{\text{Photonuclear cross-section}} + N_{\gamma/B}(-y)\,\sigma_{\gamma A\to YA}(-y)$$

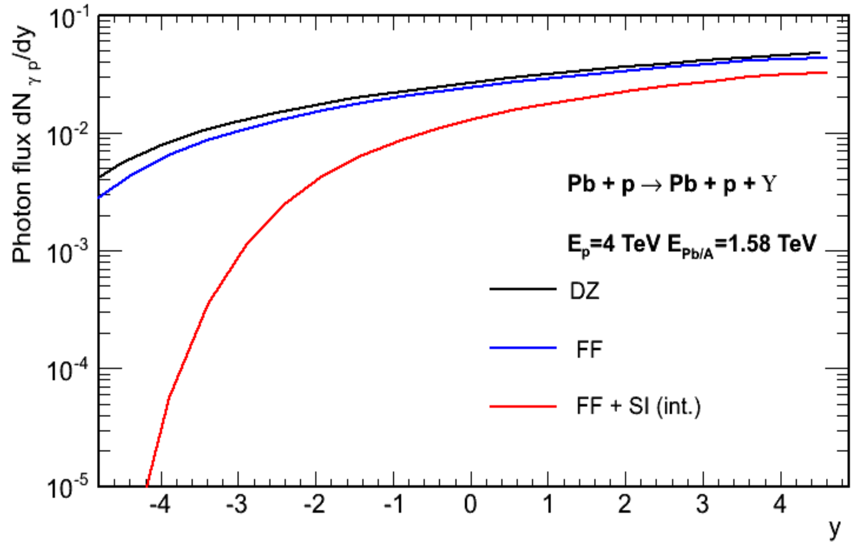
$$\sigma_{\gamma H\to YH}(y) = \left.\frac{d\sigma_{\gamma H\to YH}}{dt}\right|_{t=0} \int dt\,|F_H(t)|^2$$

Forward scattering amplitude

Form factor

$$\frac{d\sigma_{\gamma H\to YH}(W_{\gamma p}, t=0)}{dt} = C\cdot|xG_H(x,Q^2)|^2$$

Gluon distribution in proton or Nucleus



$$N_{\gamma/Z}(\omega) = \int_0^\infty d^2\vec{b}\;\Gamma_{pA}(\vec{b})\;N_{\gamma/Z}(\omega,\vec{b})$$

$$\int dt\,|F_p(t)|^2 \approx \frac{1}{b_V}$$

For proton

$$\int dt\,|F_A(t)|^2 = \Phi_A(t_{min})$$

For Pb ion

The photon flux of the proton (nucleus) of charge Z can be expressed as the convolution over the impact parameter b

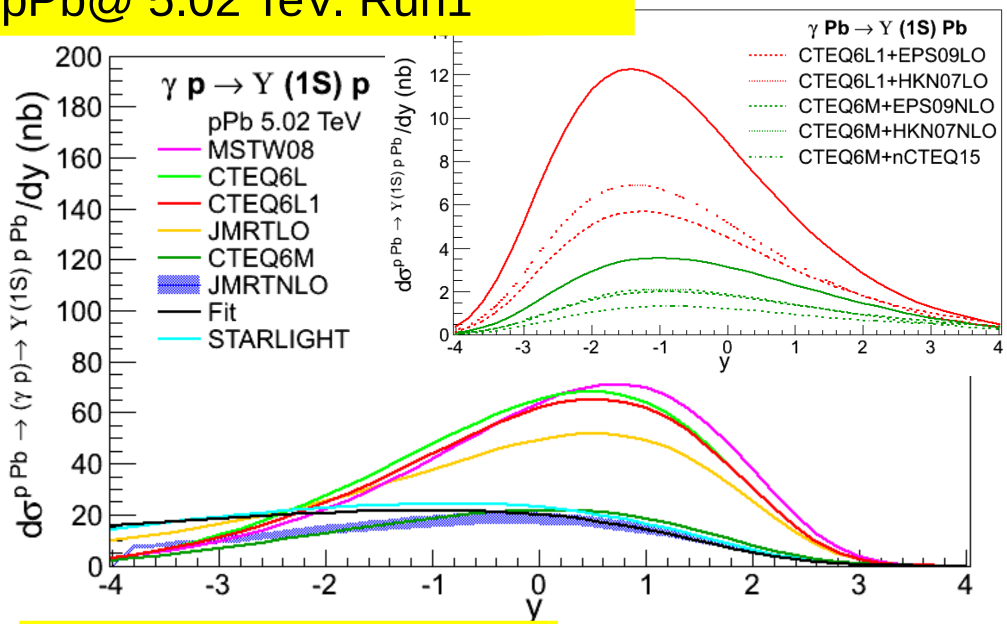
suppression of the flux due to the strong interaction between colliding particles considered

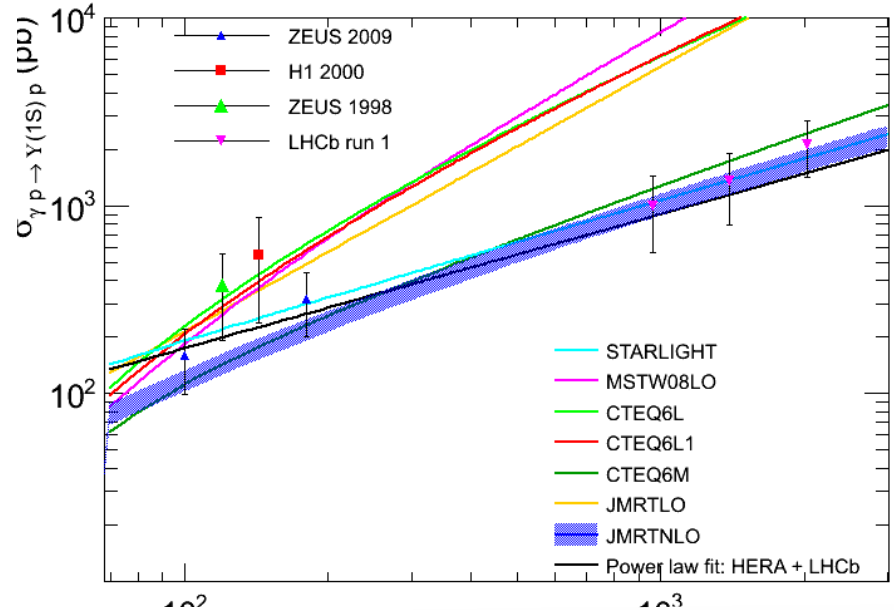
Ref. V. Guzey and M. Zhalov, JHEP 1402, 46 (2014); A. Adeluyi and C. A. Bertulani, Phys. Rev. C 85, 044904(2012), S. R. Klein and J. Nystrand, Phys. Rev. Lett. 92, 142003 (2004)

D. Dutta, R. Chudasama, arXiv:1711.05999

Theoretical prediction of Upsilon photoproduction

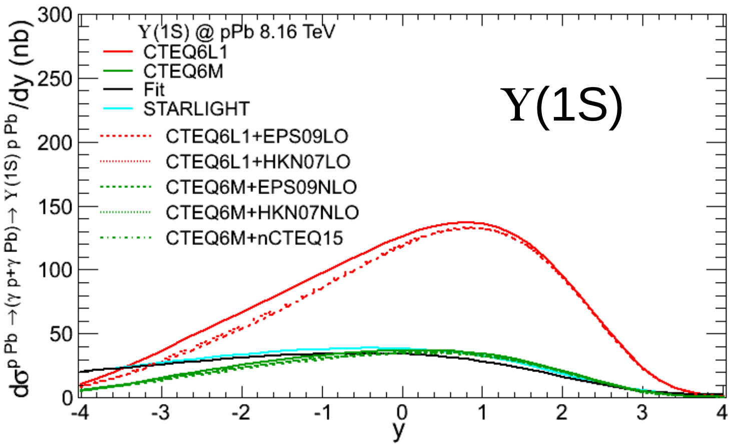
pPb@ 5.02 TeV. Run1

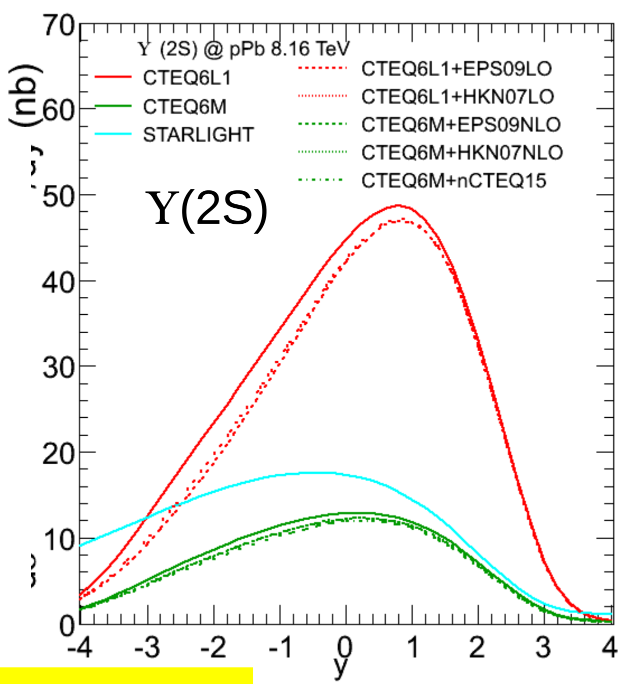


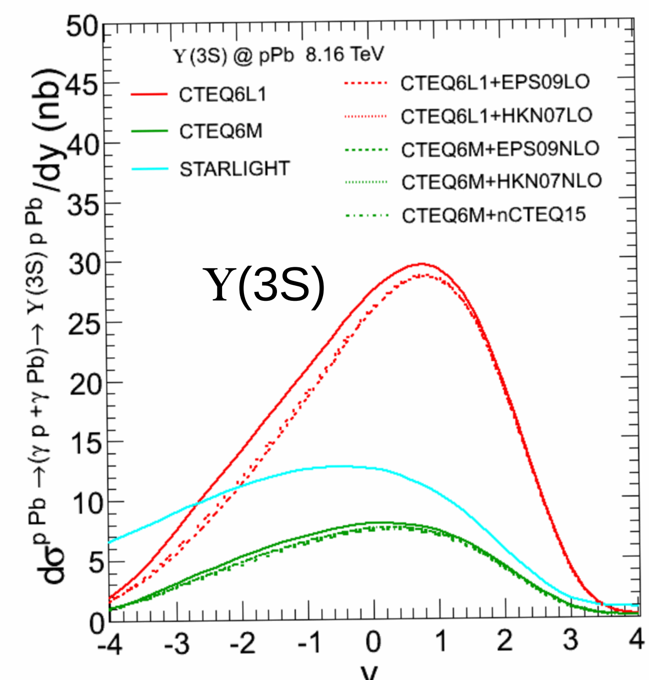


pPb@ 8.16 TeV. Run2

Gluon Shadowing effect included







D. Dutta, R. Chudasama, arXiv:1711.05999

Summary and Outlook

- Exclusive upsilon photoproduction in pPb @ 5.02 TeV (PAS public)
  - The first measurement of exclusive Υ photoproduction in pPb collisions at 5.02 TeV
  - Data compatible with power-law dependence of $\sigma(W_{\gamma p})$, disfavours LO pQCD predictions
  - The differential cross-section $d\sigma/dp_T^2$ is in agreement with earlier measurements
- Coherent J/ψ photoproduction in PbPb collisions @ 2.76 TeV

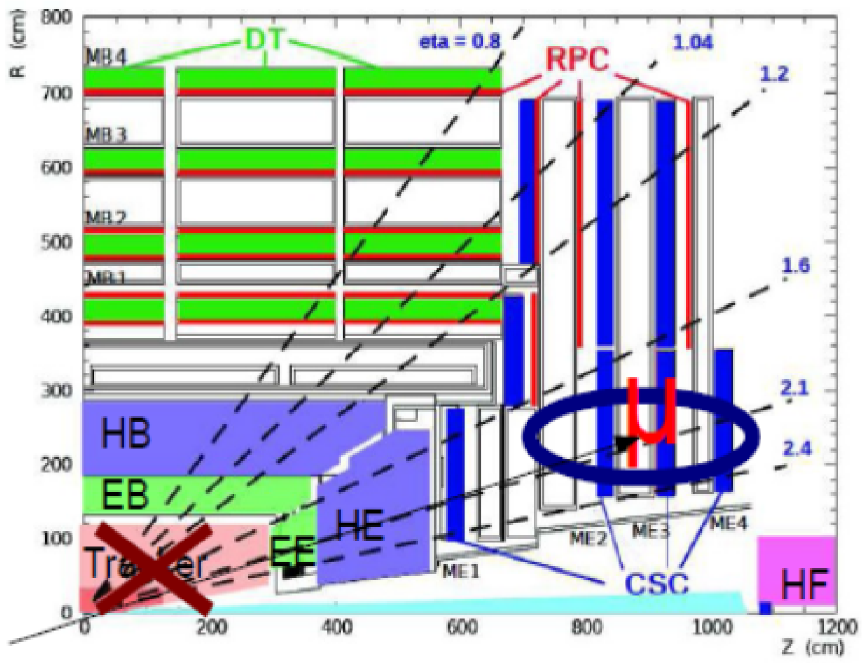
  Phys. Lett. B 772 (2017) 489
  - First measurement of coherent J/ψ photoproduction in different nuclear break-up mode
  - Rapidity distribution compatible with considerable nuclear gluon shadowing
- Light by Light Scattering in PbPb Collisions @ 5.02 TeV
  - Elastic light-by-light (LbyL) scattering, fundamental quantum-mechanical process with a tiny cross section, experimentally unobserved so far (recent ATLAS 4σ evidence)
  - Analysis in very advanced stage, final results expected soon.
- Expect more exciting results in different exclusive channel (J/ψ,Υ,ρ,dijet,light-light..) in future, with UPC PbPb @ 5.02 TeV in 2015 and pPb @ 8.16 TeV in 2016.

Thank you

Back up

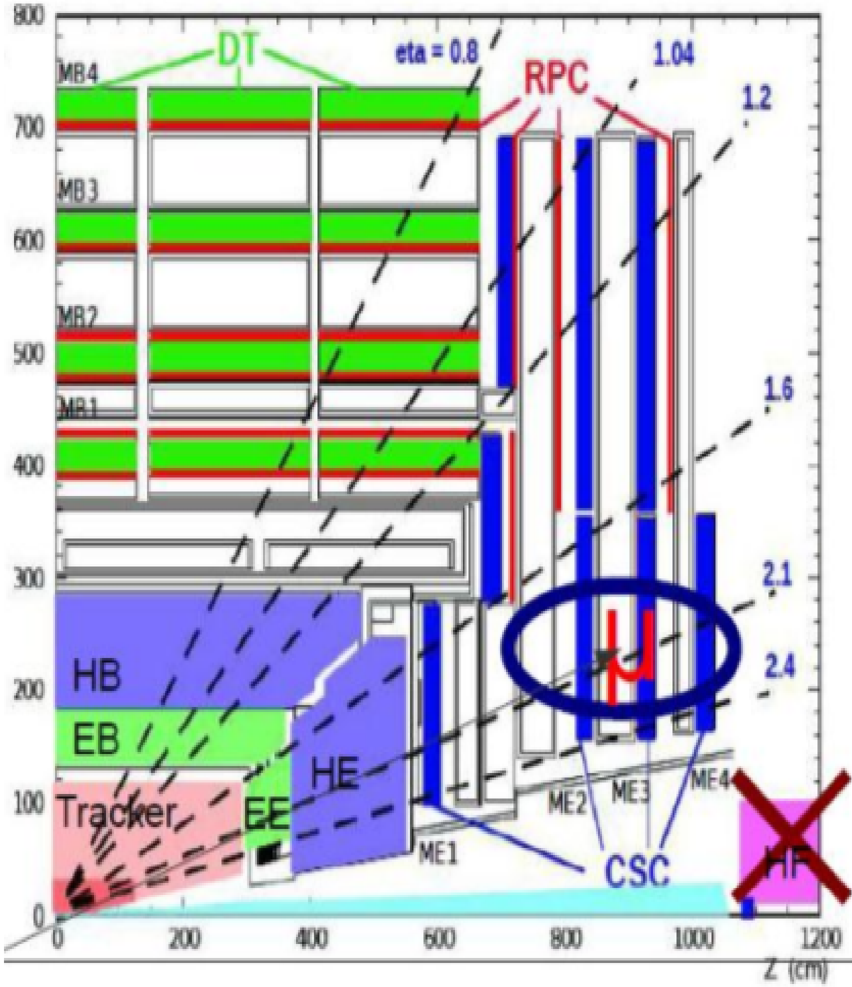
UPC Triggers for 2013 pPb

- L1 required loosest muon or electromagnetic calorimeter triggers only
- More sophisticated HLT



- Higher available L1 bandwidth
  - Removed veto on BSC and requirement of ZDC from the the L1 trigger
- Restrict multiplicity to < 7 tracks in the HLT
- HLT Triggers
  - Require at least one fully reconstruction of dimuon candidate
  - Require < 10 pixel tracks in monitoring path

UPC Triggers for 2011 PbPb



- L1: hardware trigger system from calorimeters and muon systems only
  - Loosest muon trigger and electromagnetic calorimeter trigger
  - At least one ZDC above threshold
  - No activity on both sides of the interaction point in the BSC detectors, $3 < |\eta| < 5$
- HLT: software trigger system using the full detector
  - Require reconstruction of at least on pixel track

Systematic uncertainty for exclusive Υ in pPb @5.02 TeV

Systematic uncertainties on the measurements of the b of the exponential $|t|$ dependence and the $d\sigma/dy$ cross section; individual contributions, as well as the total systematic uncertainty are shown.

Source	b	$d\sigma/dy$
Inclusive background modeling	11%	10%
Exclusive QED background modeling	6%	18%
Muon efficiency (Tag and Probe)	–	11%
Unfolding	2%	1%
MC modeling	2%	7%
Feed-down	–	2%
Branching ratios	–	2%
Luminosity	–	4%
Total	13%	25%

Systematic uncertainty for exclusive J/ψ in PbPb @ 2.76 TeV

Table 1: Summary of systematic uncertainties.

	Uncertainty
(1) Neutron tagging	6%
(2) HF energy cut	1%
(3) signal extraction	5%
(4) MC input	1%
(5) ZDC efficiency estimation	3%
(6) Tracking reconstruction	4%
(7) Luminosity determination	5%
(8) Branching ratio	1%
Total	11%