Results of Ultraperipheral Collisions with CMS experiment

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On behalf of the CMS collaboration

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Outline

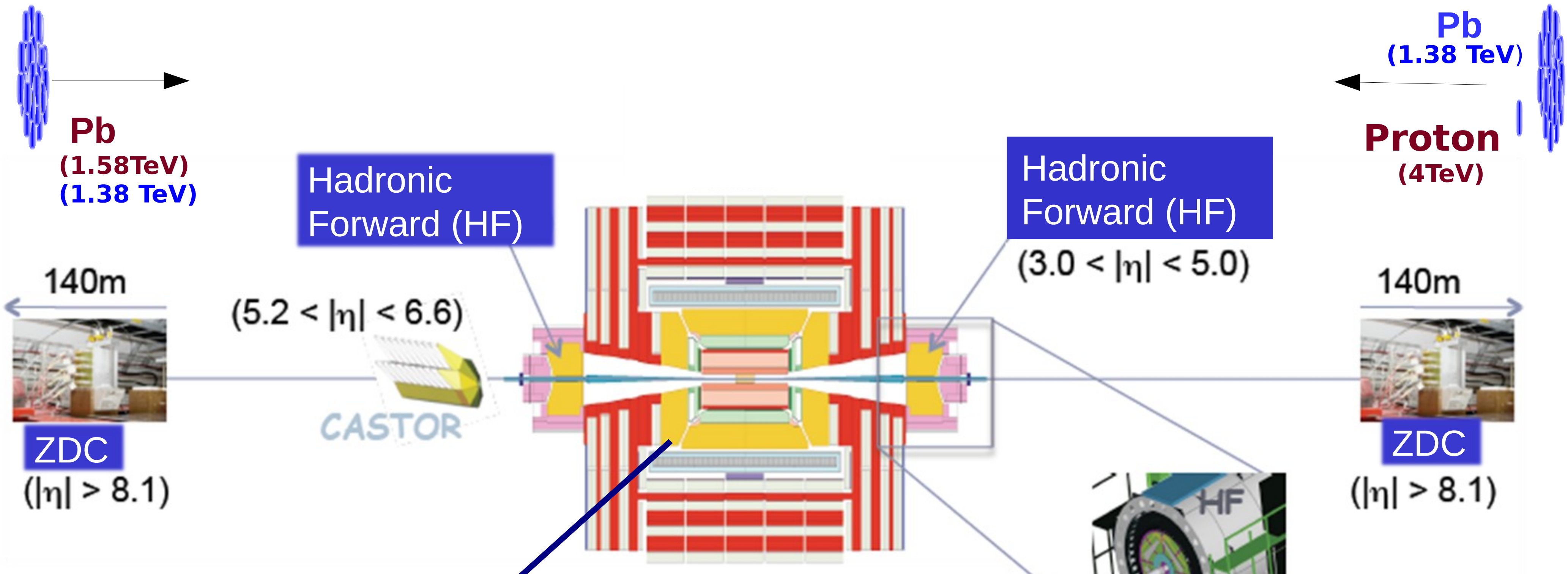
- Inroduction and Motivation

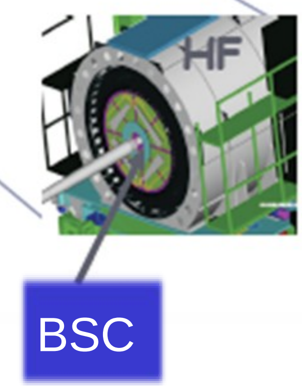
- Exclusive photoproduction of Upsilon in pPb collisions at $\sqrt{s}_{NN}$ = 5.02 TeV
  [CMS-FSQ-13-009, https://cds.cern.ch/record/2147428]
  - estimate the t dependence of the cross-section
  - photonuclear cross-section

- Coherent J/ψ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s}_{NN}$ = 2.76 TeV with the CMS experiment
  [CMS-HIN-12-009: http://cds.cern.ch/record/2154908, http://arxiv.org/abs/1605.06966v1]
  - coherent photoproduction with different nuclear breakup mode
  - nuclear PDF and shadowing

Forward physics results at CMS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ
HIN physics results at CMS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

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:

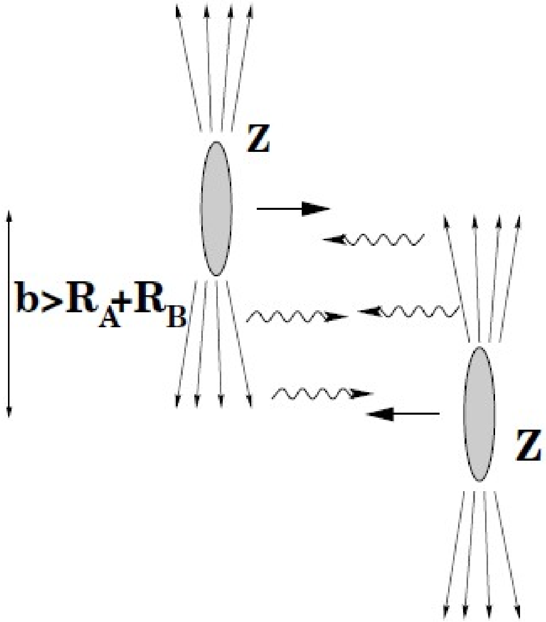
- **HF, hadron forward calorimeter (11m from IP)** **$3 < |\eta| < 5$**
- **BSC, beam scintillator counters (in front of HF)** **$3.2 < |\eta| < 4.7$**
- **ZDC (zero degree calorimeter)** **$|\eta| > 8.1$**

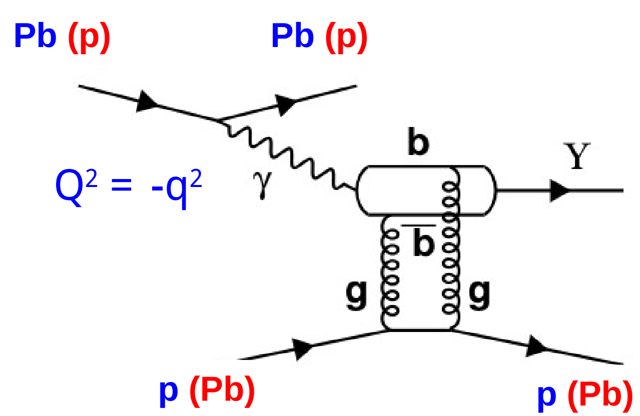
Introduction: Ultra Peripheral Collisions (UPC)

- Collisions between two hadrons (protons, nuclei) at impact parameter $b >> 2R$ (or R_A+R_B)
- Implies no hadronic interaction between hadrons
- Hadrons interact via their cloud of photons, flux α Z^2
- UPC with pPb

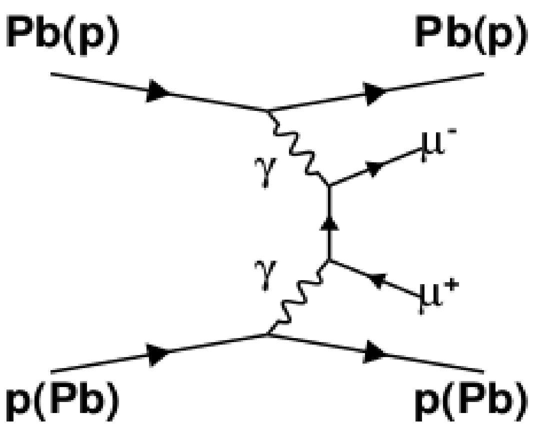
  Photon-nuclear interaction
  - Elastic VM photoproduction

  Photon-photon interaction





Photon-Nuclear Interaction

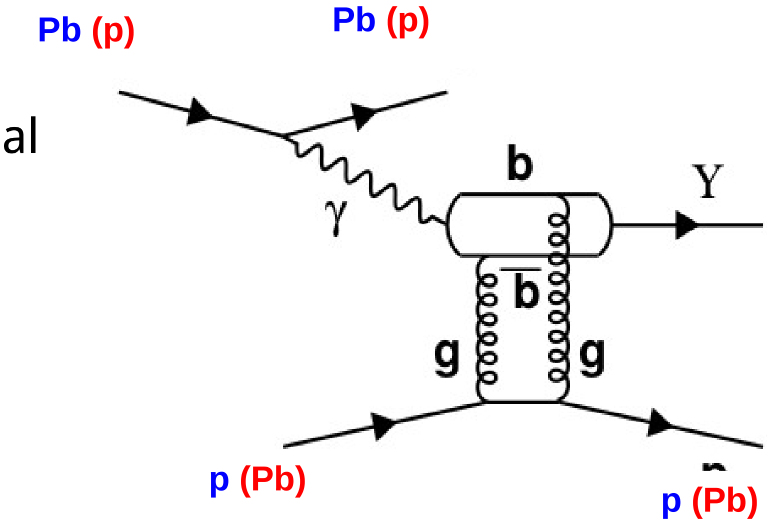


Photon-Photon Interaction

Motivation: Exclusive upsilon photoproduction in pPb

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

- ➔ γ p: Dominant contribution, γ Pb: Small contribution



- ➔ Photoproduction of vector mesons (J/ψ, ϒ) described by the LO pQCD as two gluon exchange between virtual QQbar pair and the target

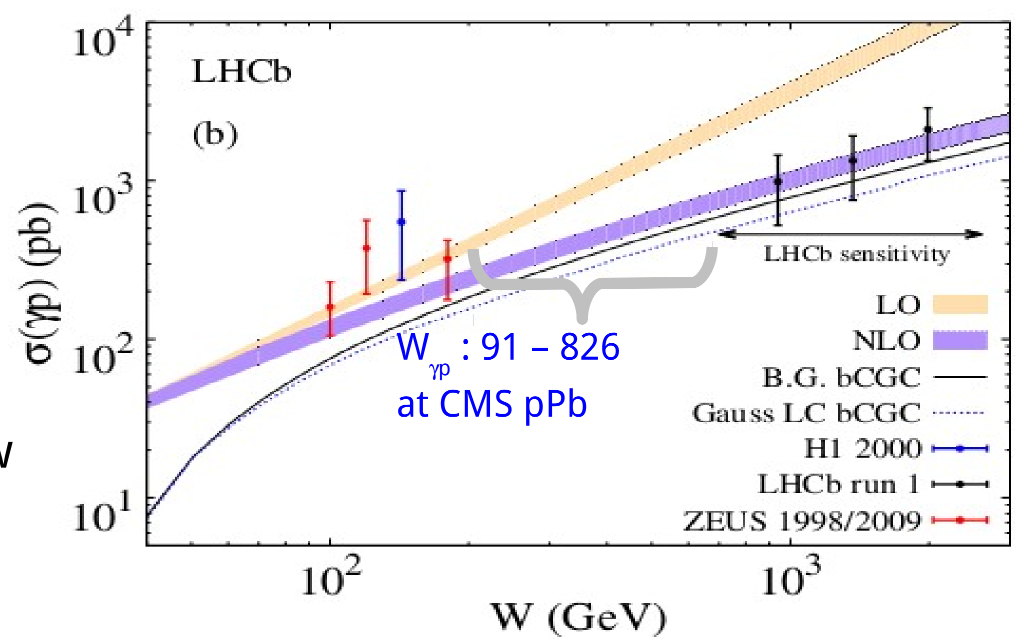
- ➔ Sensitive to the gluon density squared in the nucleon (nucleus)

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

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

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

$$x=(M_\Upsilon/W_{\gamma p})^2\ ,\ W_{\gamma p}^2=M_\Upsilon e^y/\sqrt{s}$$



JHEP 1509(2015) 084

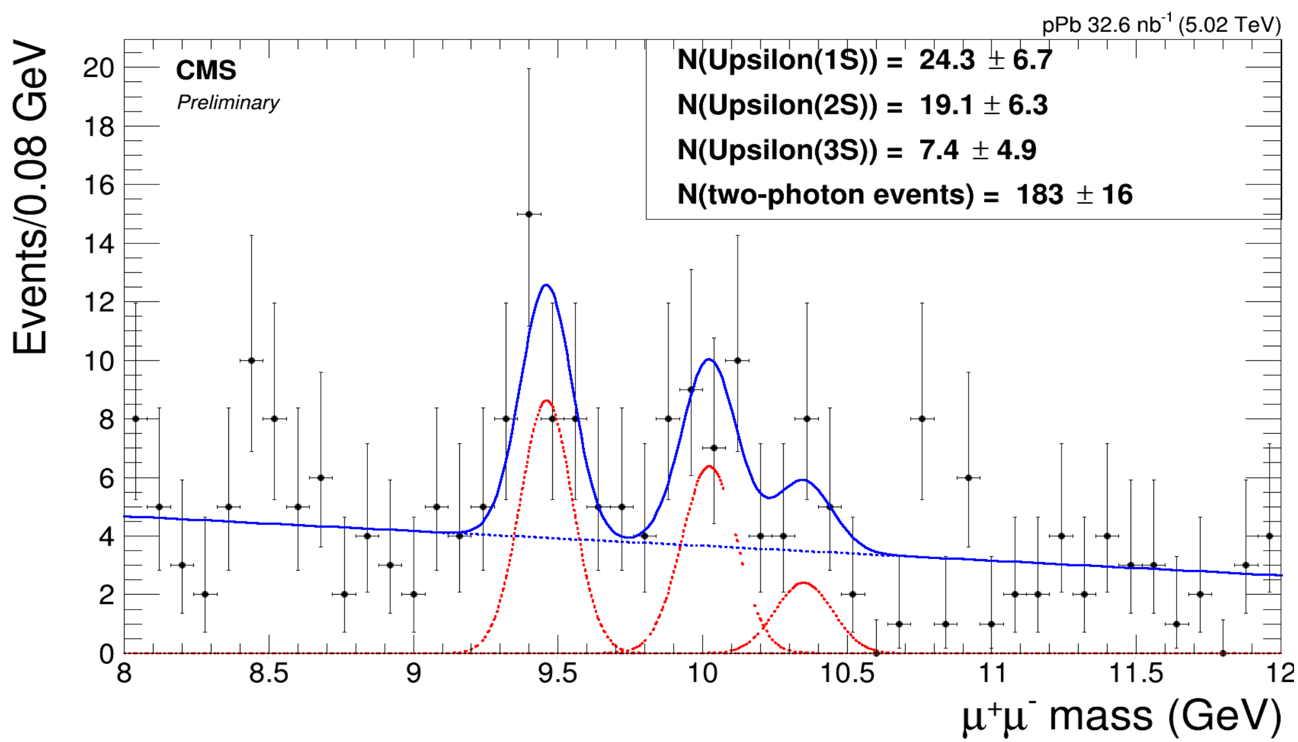
- ➔ Photonuclear cross-section shows power law dependance with $W_{\gamma p}$

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

Exclusive upsilon photoproduction

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

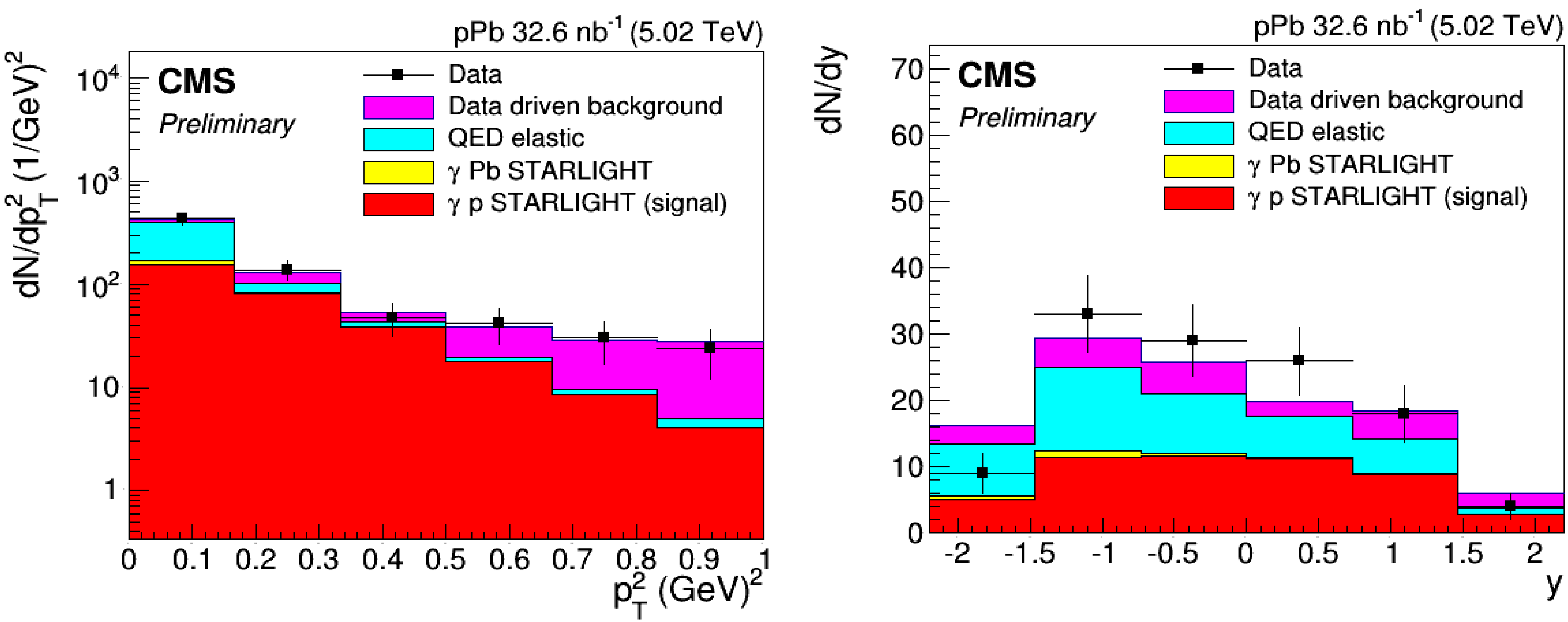
- 2013 pPb data at 5.02 TeV with 32.6 nb^{-1}
- Offline exclusive $pPb \rightarrow \Upsilon(\gamma p) \rightarrow \mu^+\mu^-$ signal selection
  - Invariant mass $(\mu\mu)$: $9.12–10.64$ GeV
  - Opposite-sign $\mu\mu$ pair (final state) originating from commom primary vertex
  - No extra tracks at $\mu\mu$ vertex to suppress non-exclusive background
  - 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)

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

- 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
- STARLIGHT MC : **γPb(small contribution)** and γp contribution reweighted



Good agreement betweem data and MC

Number of signal events estimated by subtracting all background contributions.

Photoproduction cross section as a function of | t |

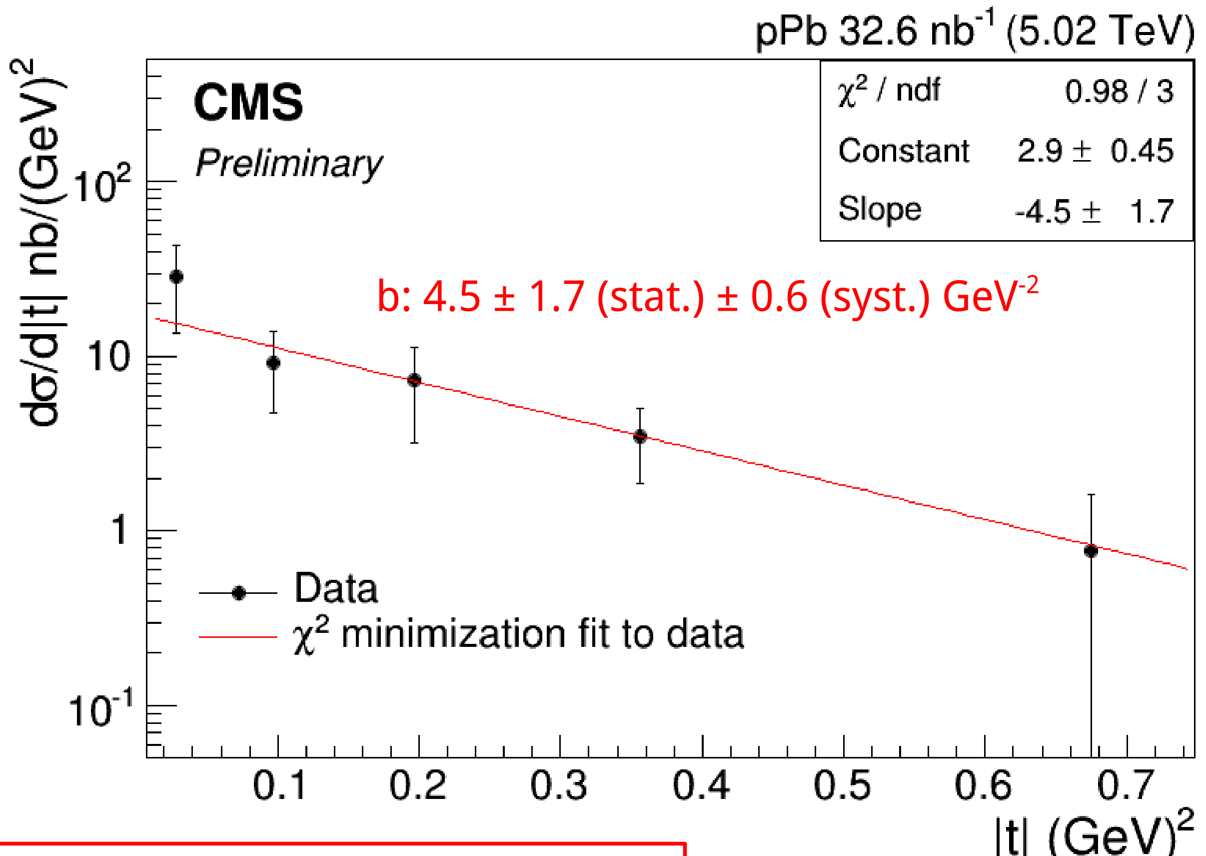
CMS-FSQ-13-009
https://cds.cern.ch/record/2147428

- The differential cross section is calculated 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.

- dσ/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

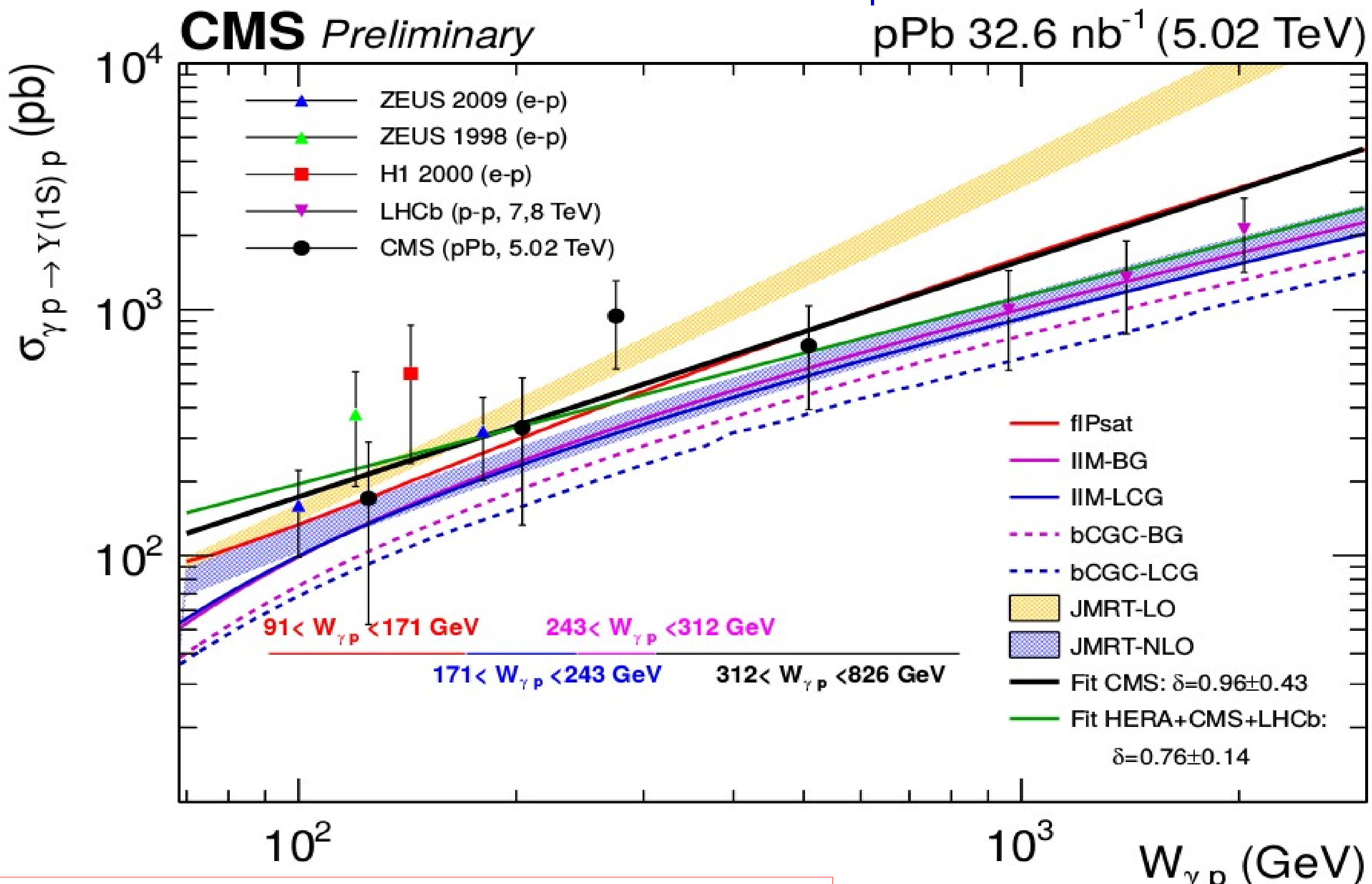
Cross-section as a function of $W_{\gamma p}$

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

- 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+2S+3S) 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

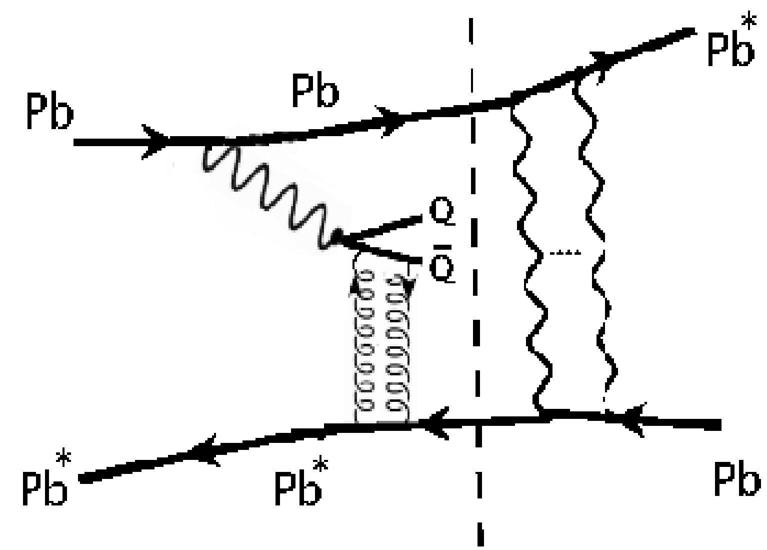


A fit with power-law **A X (W/400)$^{\delta}$** to the CMS data
δ = (0.96 ± 0.43) , A = 655 ± 196
Data compatible with power-law dependence of $\sigma(W_{\gamma p})$, disfavours LO pQCD predictions

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

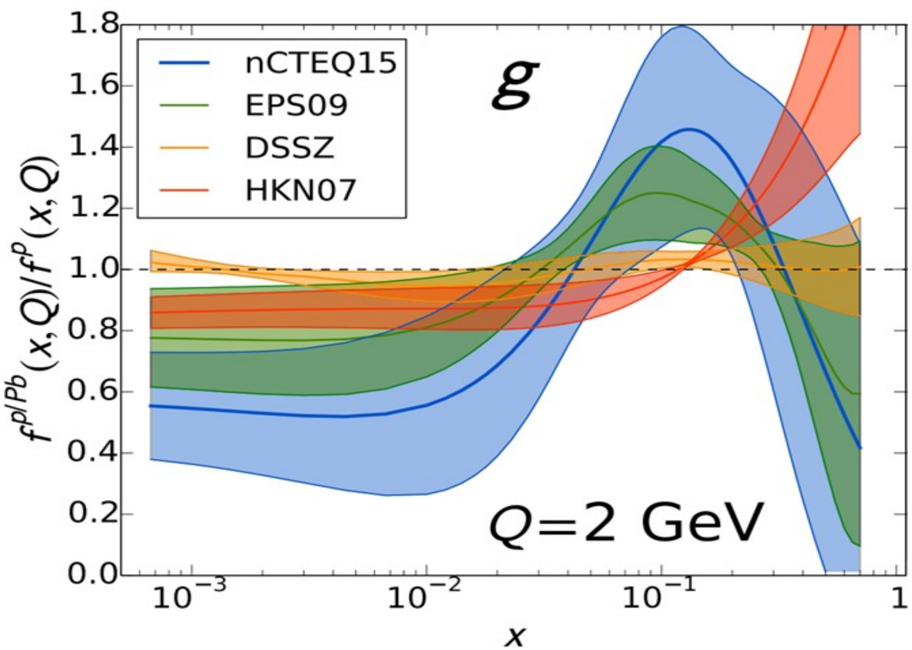
Motivtion: Coherent photoproduction of J/ψ in PbPb

- γPb reactions
  - Coherent vector meson production
    - Photons couple coherently to allmost all nucleons, ($\omega_{max} \approx \gamma/R$)
    - $<p_T>$ 1/R_{Pb} 60 MeV/c
  - Incoherent photoproduction,
    - Photon couples to a single nucleon
    - $< p_T >$ 1/R_p 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



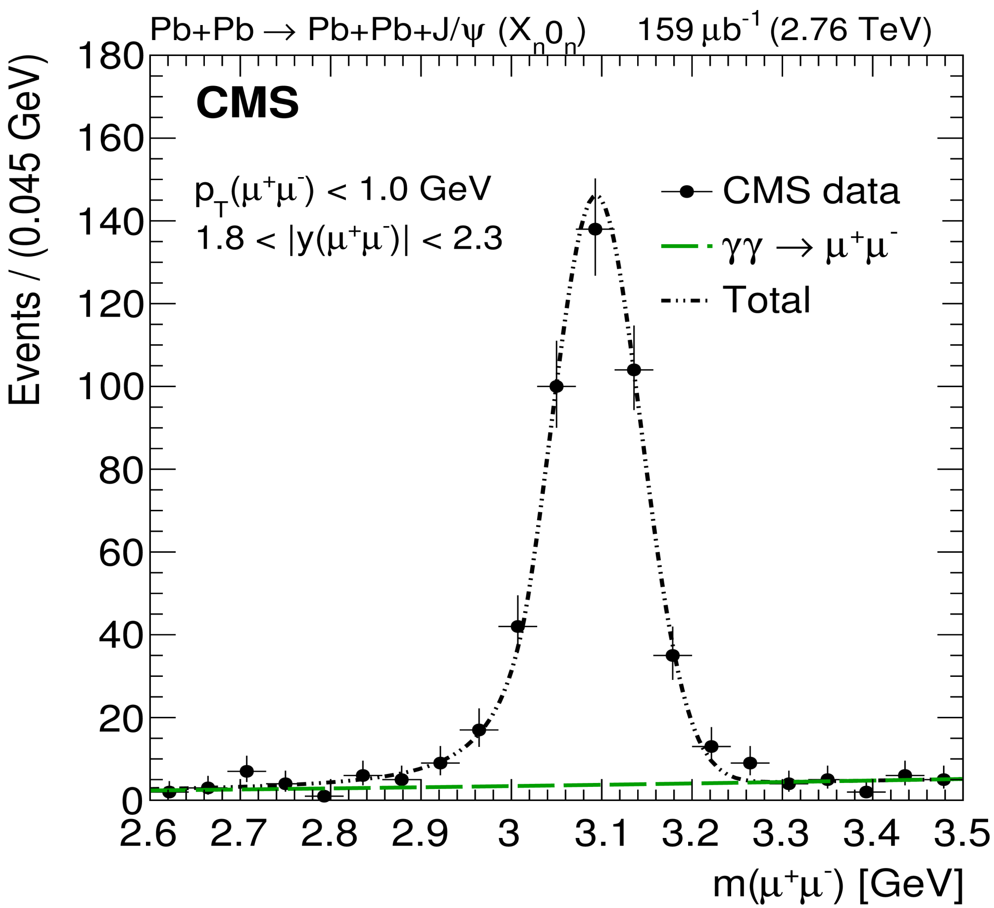
HIN-12-009: http://cds.cern.ch/record/2154908
http://arxiv.org/abs/1605.06966v1

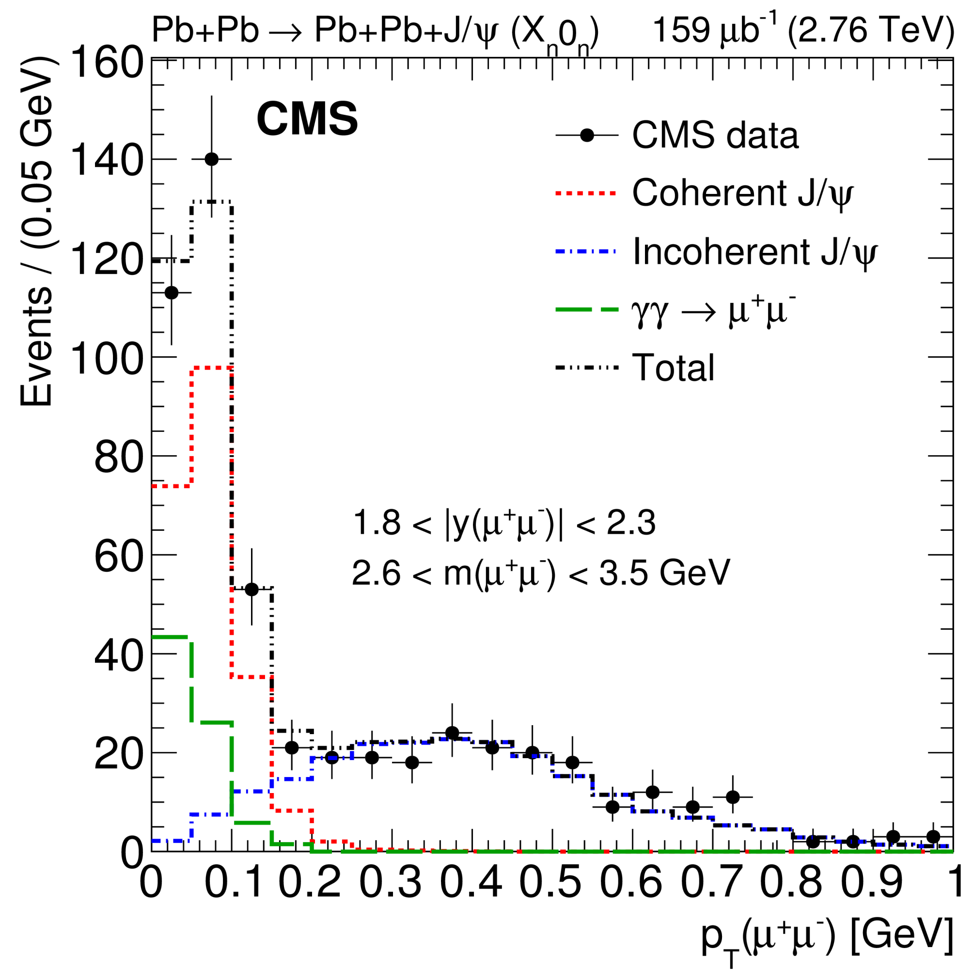
Coherent J/ψ photoproduction in PbPb @ 2.76 TeV

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 to select J/ψ





Nuclear break-up modes with UPC J/ψ

X_n0_n single-sided neutron emission with any number of neutrons
X_nX_n double-sided neutron emission with any number of neutrons
1_n1_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

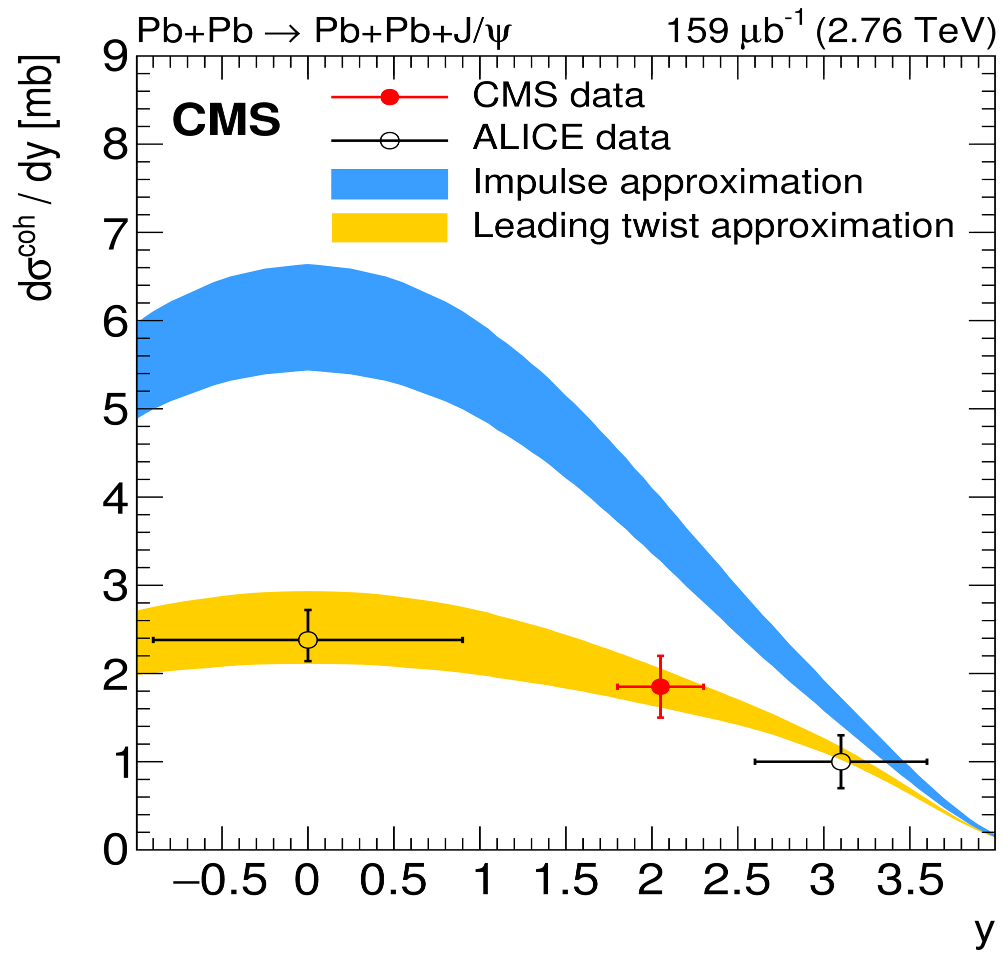
$1_n1_n / X_n0_n$
0.03±0.01
0.02
0.02

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

Rapidity distribution of J/ψ

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

- 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



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

Summary

- Exclusive upsilon photoproduction
  - 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 $d\sigma/d|t|$ is in agreement with earlier measurements

- Coherent J/ψ photoproduction in PbPb collisions
  - First measurement of coherent J/ψ photoproduction in different nuclear break-up mode
  - Rapidity distribution compatible with considerable nuclear gluon shadowing

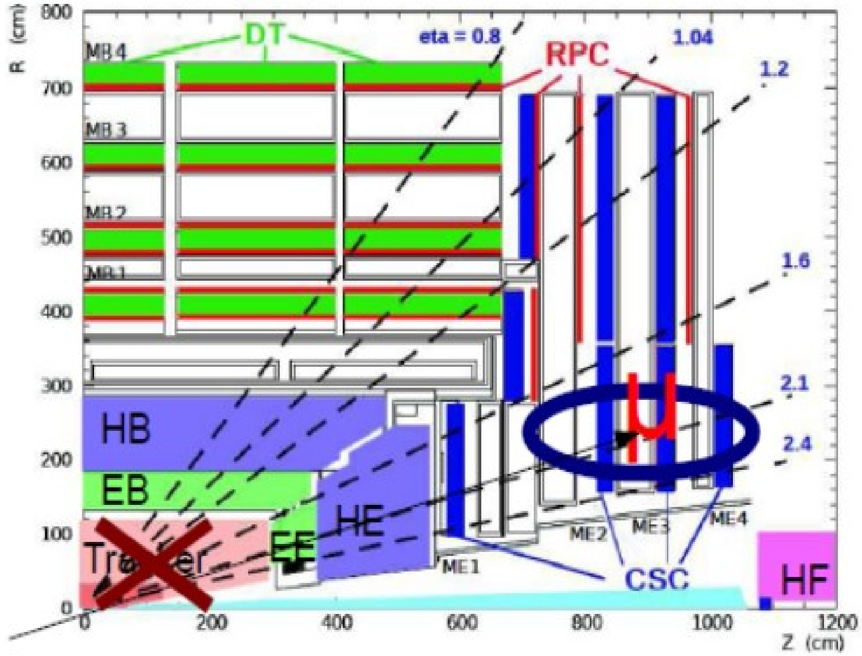
- Probe much lower x vaues with UPC pPb @ 8 TeV and PbPb @ 5.02 TeV collisions
- Expect more exciting results in different exclusive channel (J/ψ,Υ,dijet,light-light) in future, with UPC PbPb @ 5.02 TeV collsions of 2015 and pPb in 2016 .

Thank you

Back up

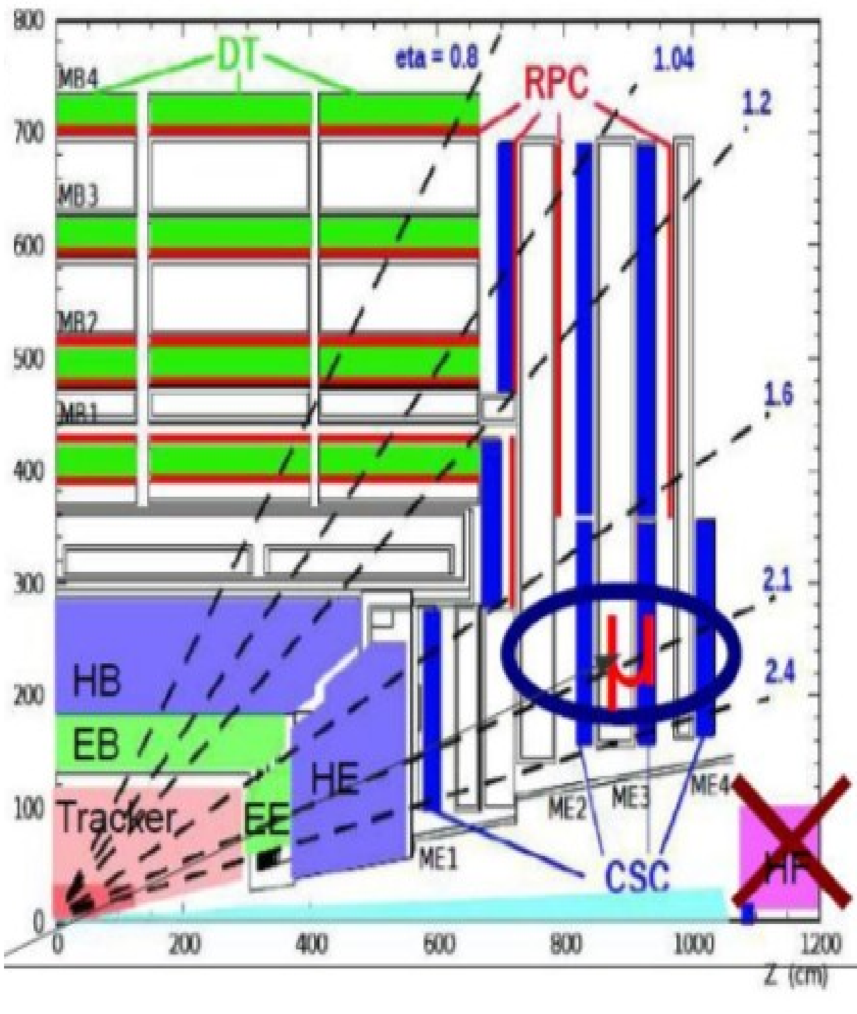
UPC Triggers for 2013 pPb

- 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%