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Exclusive ϒ(1S) photoproduction in PbPb collisions at 5.02 TeV

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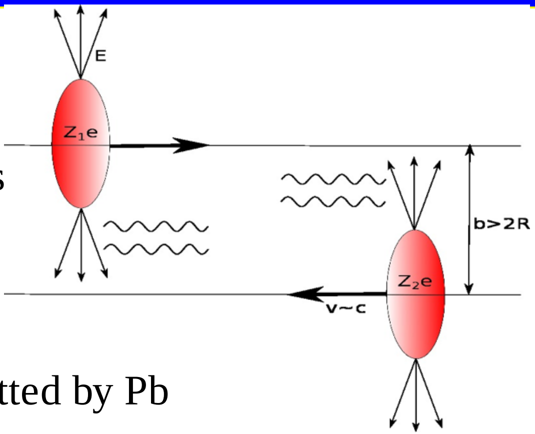
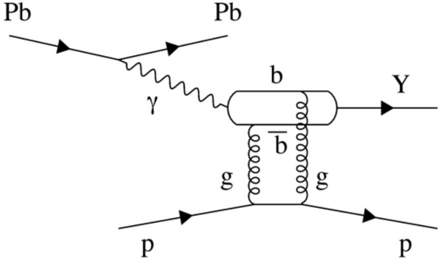
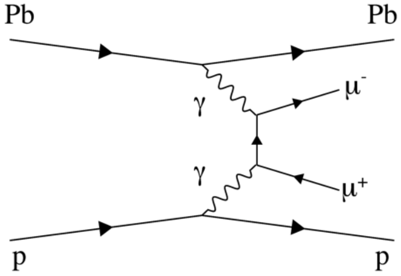
Ultra-Peripheral Collisions

- Impact parameter b >> 2R ($R_A + R_B$)
- Implies electromagnetic interaction by photons
- Photon flux $\propto Z^2$ ($Q^2 < \hbar^2/R^2$)
- Photo-nuclear interaction:
  - Incoherent interaction (dominant): γ emitted by Pb
    Pomeron exchange between $b\bar{b}$ pair and target proton
  - Coherent interaction(small contribution): γ emitted by p
    Pomeron exchange between $b\bar{b}$ pair and target Pb nucleus
- $\gamma\gamma$ QED background → dominant at low dimuon-p_T
- Proton dissociation → dominant at high dimuon-p_T



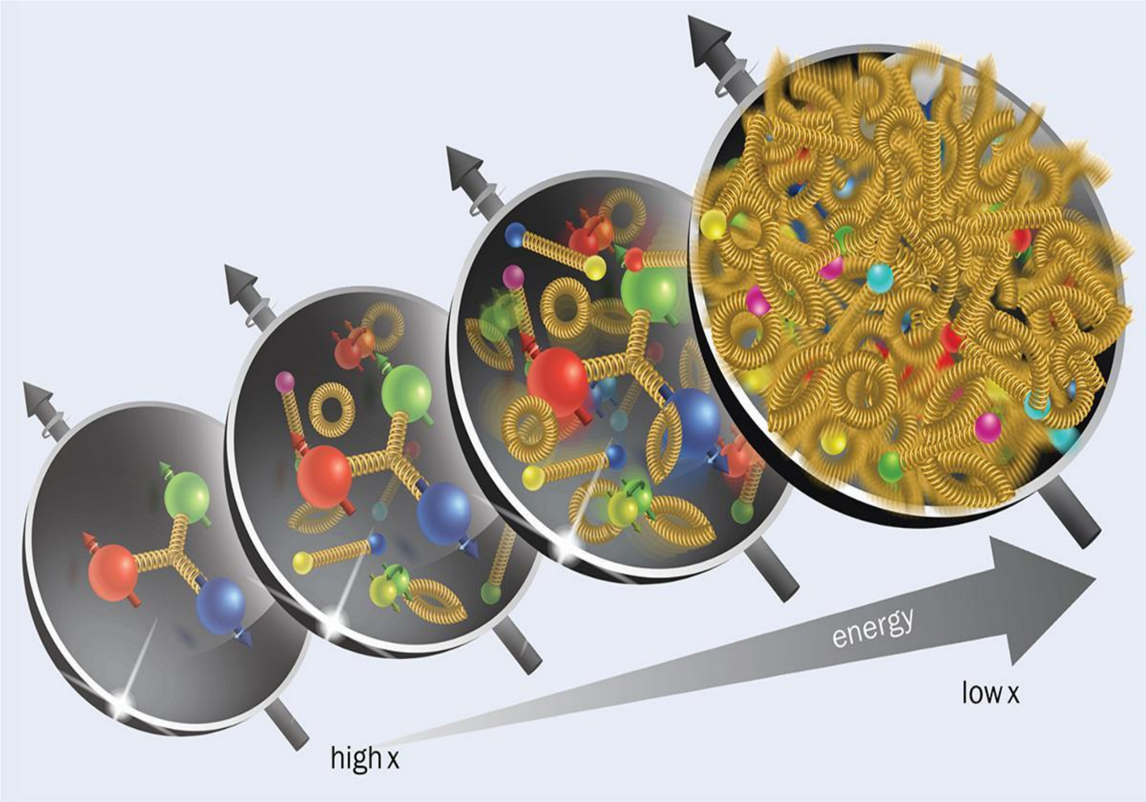


Photon-Nuclear interaction



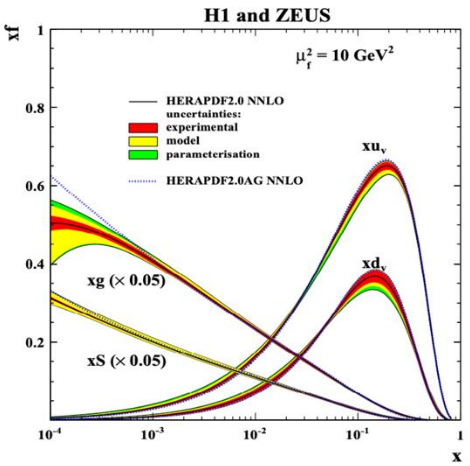
QED interaction

Physics Motivation

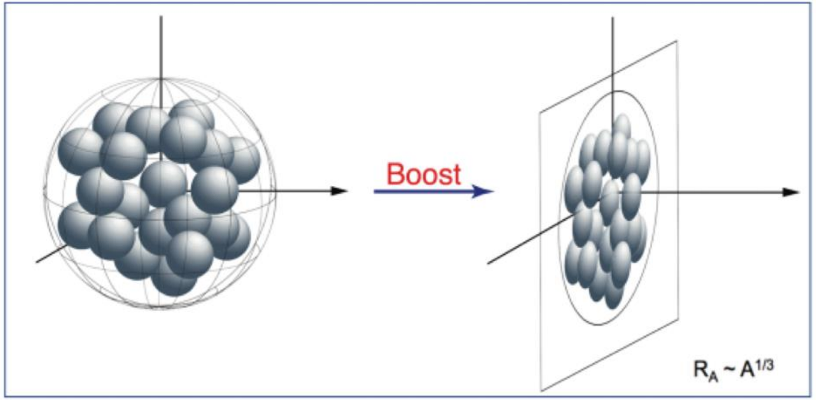


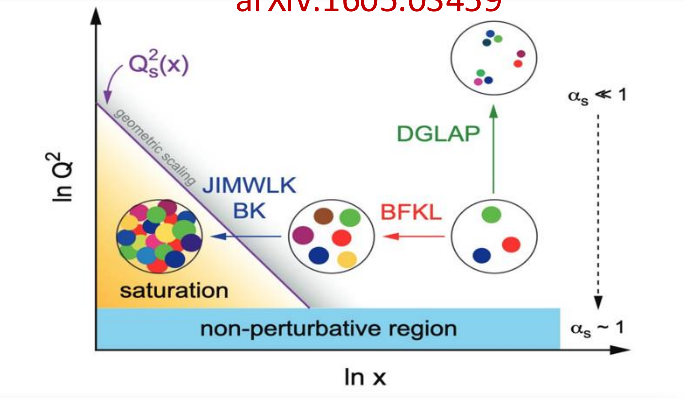
UPCs and Saturation

- Gluons increasingly dominate the proton's structure at high energies (DIS experiments)
- Saturation stage is reached where:
  Gluon Recombination ~ Gluon Splitting
- Conclusive evidence of saturation remains elusive
- Accessing the saturation scale is easier in heavy nuclei
  $Q^2_S(x) \sim (A/x)^{1/3}$



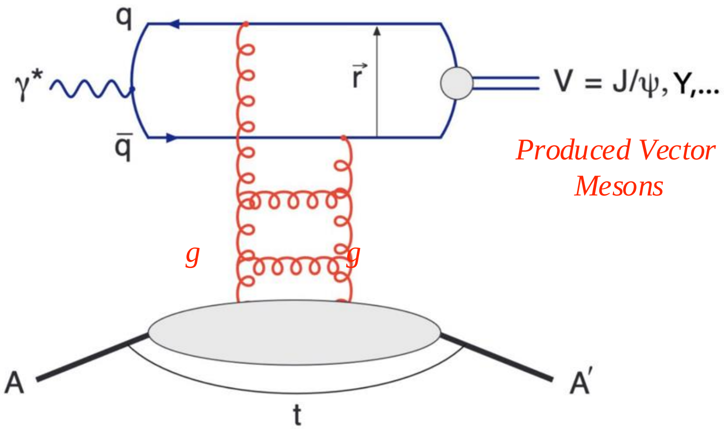
arXiv:1605.03459





Photoproduction of Vector Mesons

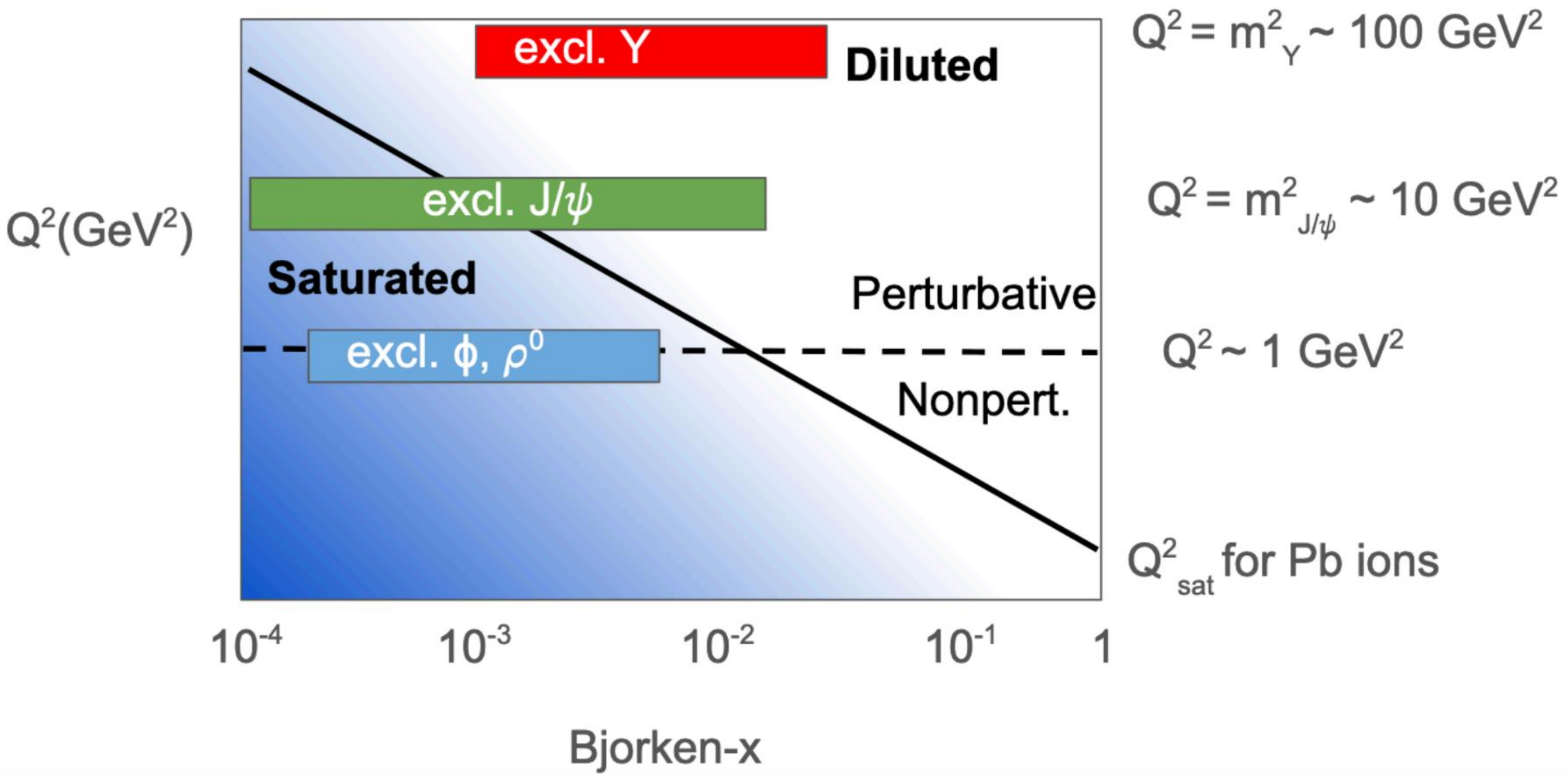
- Photon fluctuate into a quark-antiquark ($q\bar{q}$) pair color dipole
- Dipole interacts with the target nucleus through a t-channel exchange of two gluons
- At first approximation, it is highly sensitive to the gluon density of the target: $\sigma \sim [xg(x, Q^2]^2$
- Heavy quarkonia set sufficiently large scales for perturbative QCD to be valid.
- Lighter VMs (J/ψ, ρ, ϕ,..) are more sensitive to saturation effects (larger color dipoles).
- Υ(1S) constrains the transition to the "diluted" regime.



Produced Vector Mesons

Map out transitions from diluted to saturated regimes

- Different VM states map out the transition to the low-x regime.



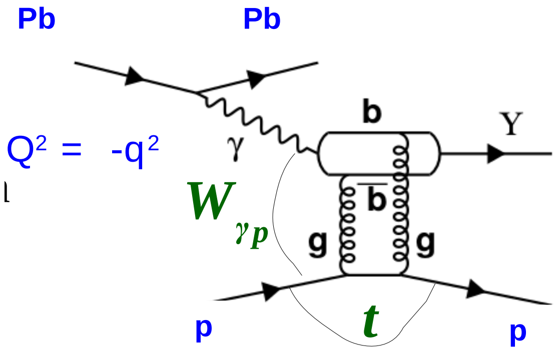
Aim of exclusive Υ photoproduction study in pPb

- In leading logarithmic approximation of pQCD, photoproduction cross-section of Υ is related to the gluon density in proton:

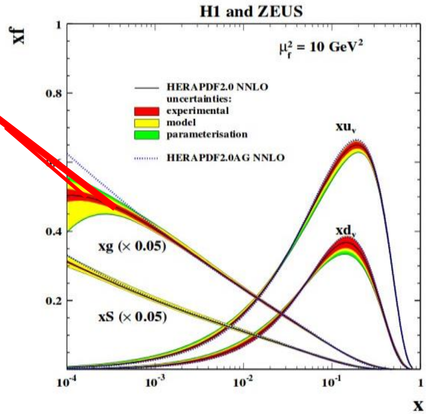
$$\left.\frac{d\sigma_{\gamma p\to\gamma p\Upsilon}}{dt}\right|_{t=0} = C(\mu^2)[xG(x,\mu^2)]^2$$

$$\text{Where } x = (M_\Upsilon/W_{\gamma p})^2,\ \mu^2 = M_\Upsilon^2/4,$$

$$C(\mu^2) = M_\Upsilon^3\Gamma_{\mu^+\mu^-}\pi^3\alpha_s(\mu^2)/48\alpha_{em}\mu^8$$



Photon-Nuclear Interaction



- Region of interest for PDFs:

  - looking for poorly known gluon distribution in the proton at low-x (10^{-2} to 10^{-4}) and search for new physics (new info on saturation effects)

$$\frac{d\sigma_{pPb\rightarrow pPb\Upsilon}(y)}{dy} = N_{\gamma/Pb}(y)\sigma_{\gamma p\rightarrow p\Upsilon}(y) + N_{\gamma/p}(-y)\sigma_{\gamma Pb\rightarrow Pb\Upsilon}(-y)$$

$Pb\rightarrow \leftarrow p$

LHC @ 5.02 TeV

Photon flux from Pb

Photoproduction cross-section of Υ

Υ rapidity

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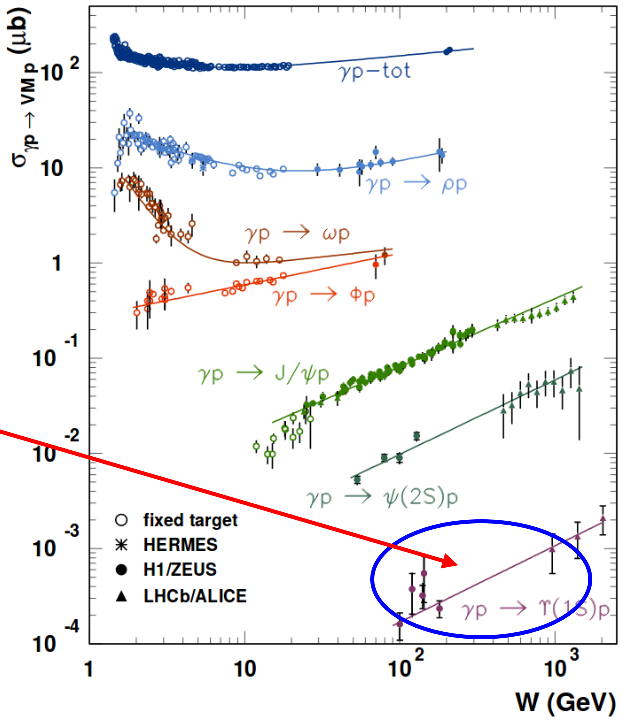


- **Region of interest in CMS**
  - Focusing on small Bjorken-x region.
  - The probe region is the photon-proton center of mass energy $W_{\gamma p}$= 91 - 826 GeV
  - For $x = 10^{-4}$ to 10^{-2}

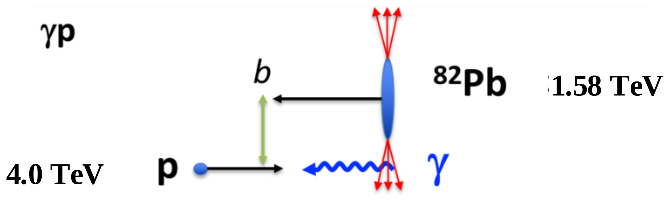
$$x = \left(\frac{M_\Upsilon}{W_{\gamma p}}\right)^2, \quad W^2_{\gamma p} = 2E_p M_\Upsilon \exp(\pm y)$$

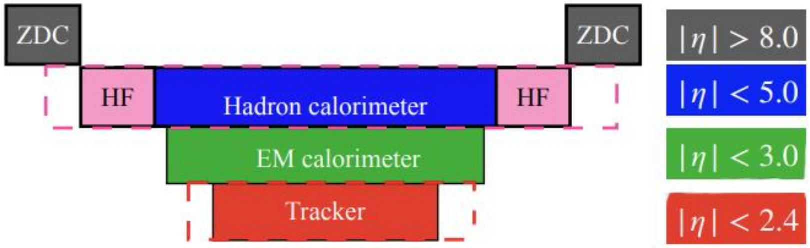
  - Low-mass states with higher rapidity probe low Bjorken x
  - Cross-Section for the Process γ+p→Y+p:

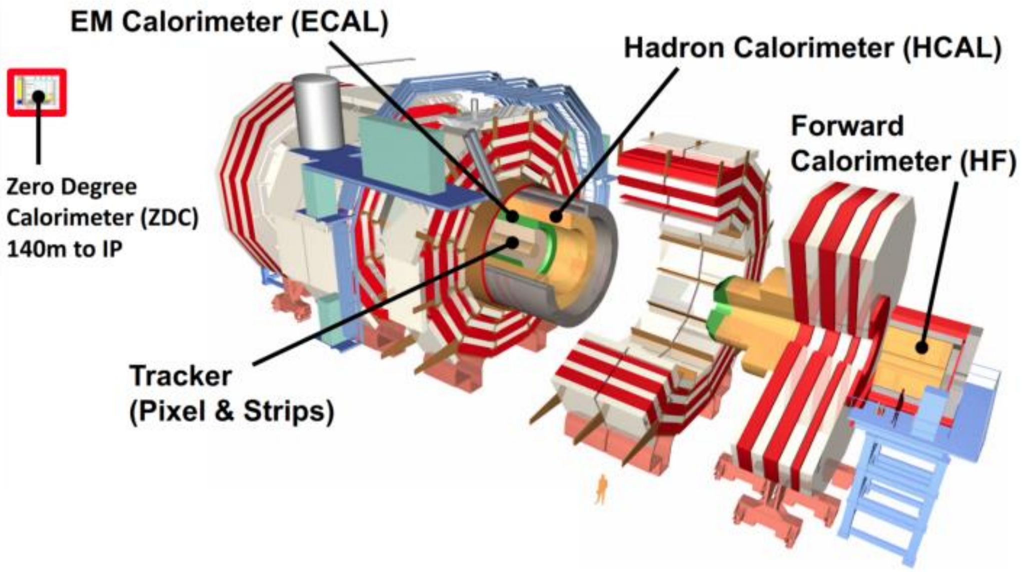
$$\sigma_\Upsilon(W_{\gamma p}) = W^\delta_{\gamma p}$$

The CMS Detector

- HF ensures activity on the proton side while the ZDC calorimeter ensures no neutrons are detected in the intact Pb nucleus side that is the source of the γ flux.







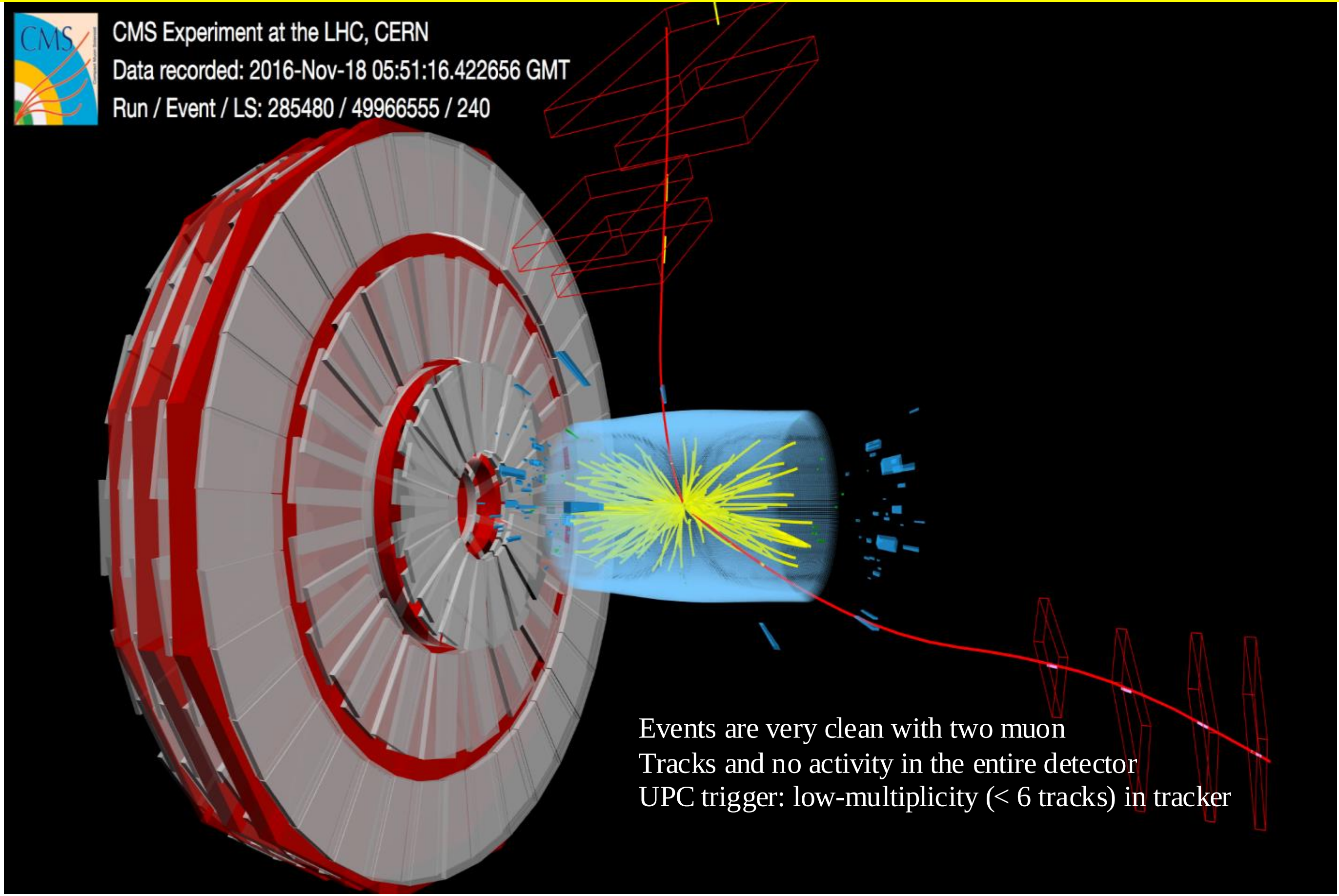
Event Display of muon tracks in CMS

- Quarkonia detected via dimuon decay channel: $Q \rightarrow \mu^{+} \mu^{-}$

- Muon selection:
  - $p_T^{\mu} > 3.3$ GeV/c
  - $|\eta^{\mu}| < 2.2$

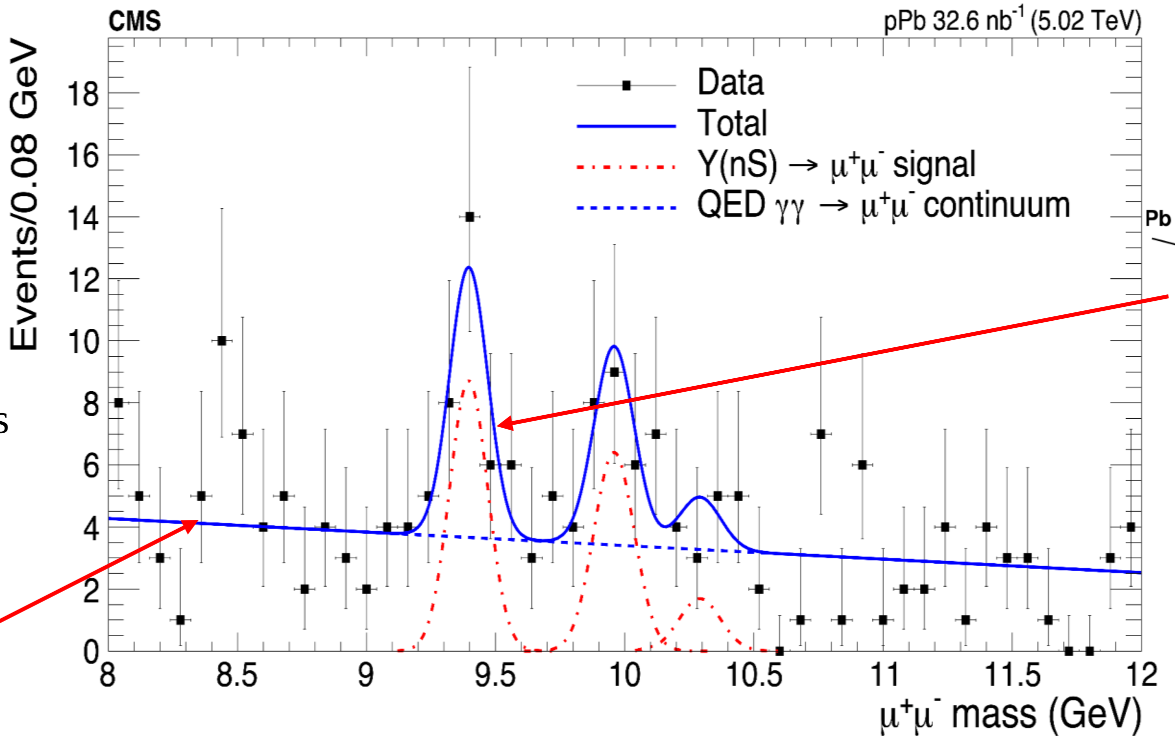
- Upsilon candidate in pPb collision at 5.02 TeV

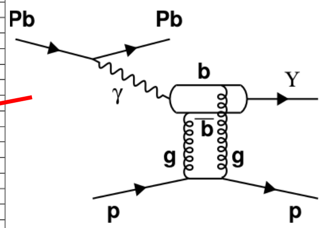
  $|y| < 2.2$

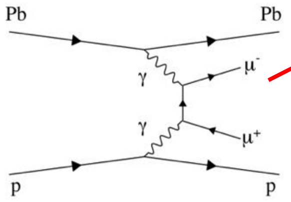


- To describe QED continuum : $\gamma\gamma \rightarrow \mu^{+}\mu^{-}$ linear function as background

- Three Gaussian functions for Upsilon signal peaks Y(1S),Y(2S),Y(3S)







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Differential Cross-section with t

- Estimated for three combined ϒ states
- d**σ**/dt : Fitted with an exponential function N exp(-b|t|)
- Provides information about the transverse profile of interaction region
- Used χ^2 minimization technique
- Slope: b = 6.0± 2.1(stat)± 0.3(syst) GeV^{-2}
- Good agreement with ZEUS results
  - For 60 < $W_{\gamma p}$ < 220 GeV
  - $b = 4.3^{+2.0}_{-1.3}(stat.)^{+0.5}_{-0.6}(syst) GeV^{-2}$

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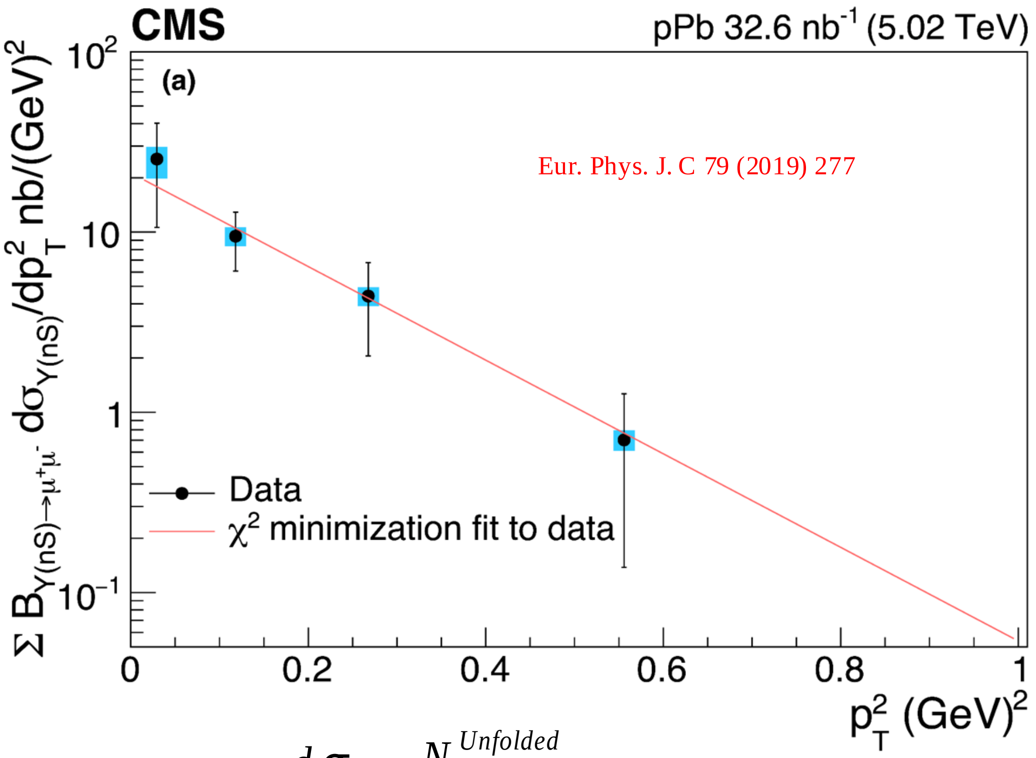


$$\frac{d\sigma_{\Upsilon}}{dt} = \frac{N_{sig}^{Unfolded}}{L \times \Delta t}$$

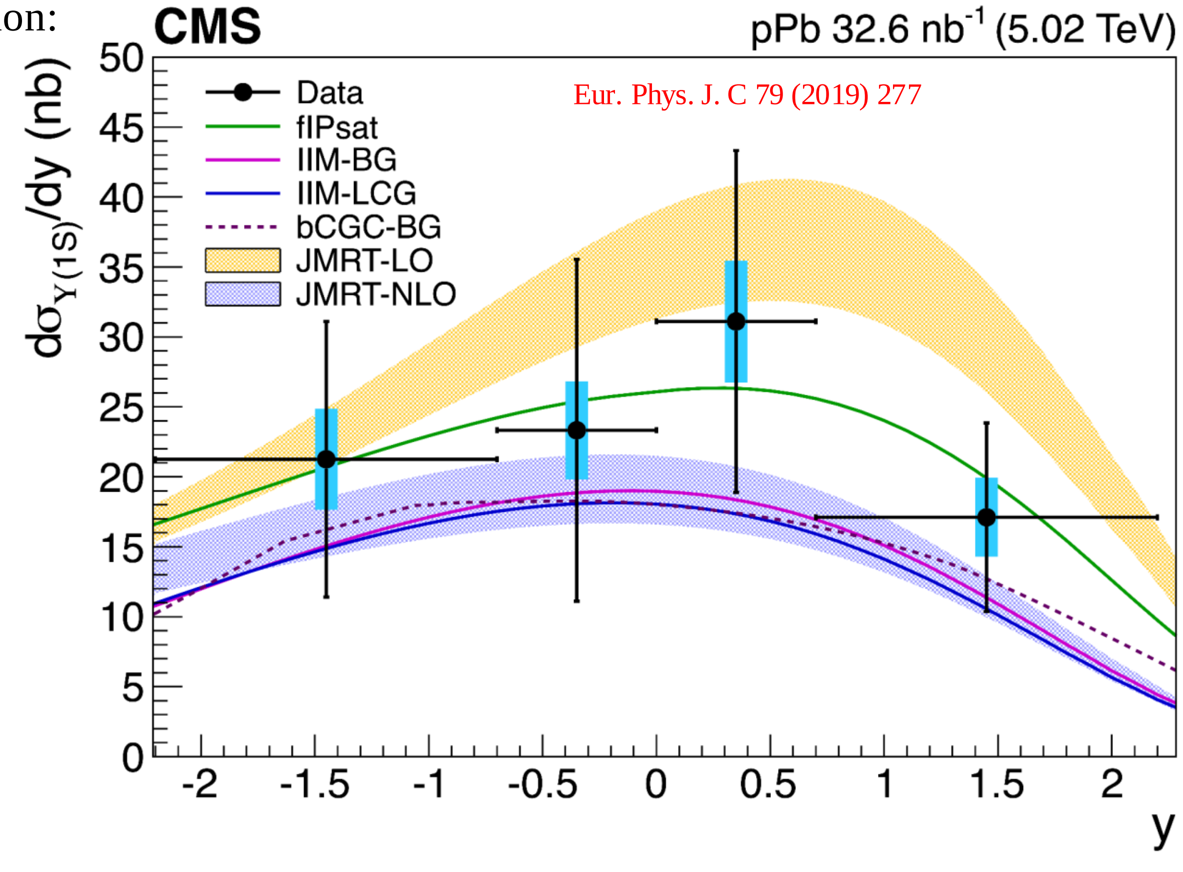
Differential Cross-section with y

- Estimating Differential Cross Section:

$$\frac{d\sigma_{\Upsilon(nS)}}{dy} = \frac{N^{corr}_{\Upsilon(nS)}}{L \times \Delta y}$$

- Rapidity region: |y| < 2.2
- Calculated cross-section of Y(1S) state in 4 rapidity regions

- JMRT-LO results are systematically above the data points and other models

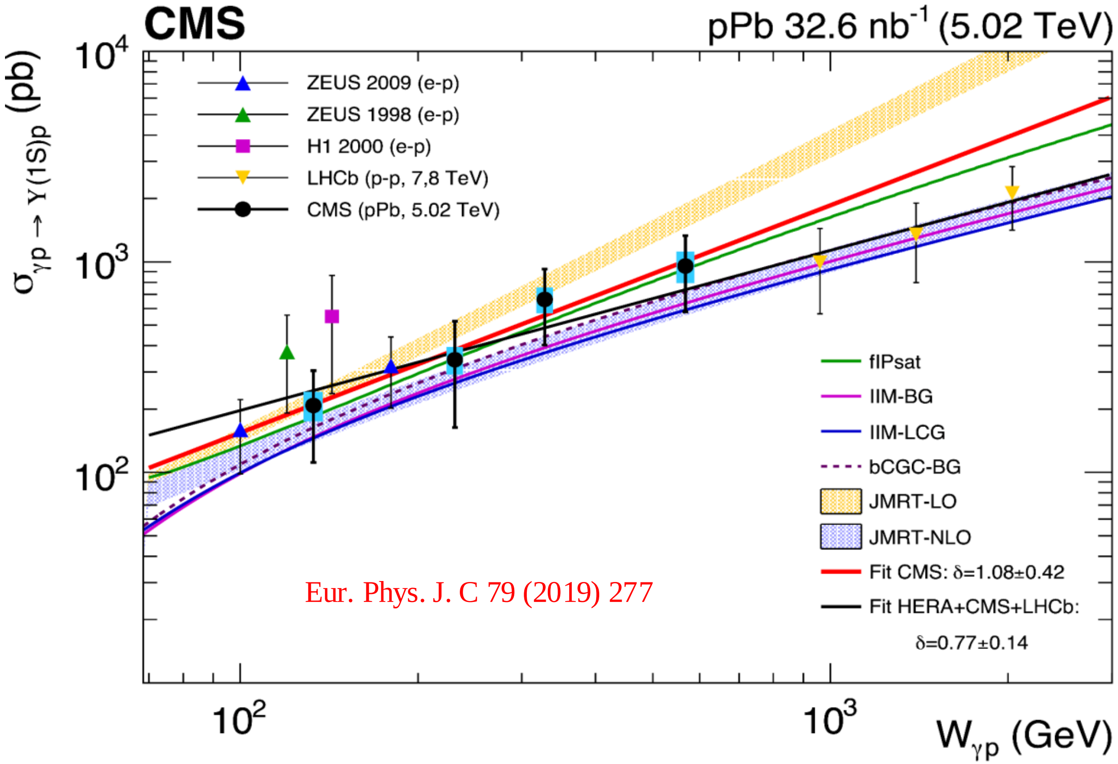


$$W_{\gamma p}^2 = 2E_p M_\Upsilon \exp(\pm y)$$

- Cross Section as a Function of $W_{\gamma p}$

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

- Data is compatible with a power-law dependence of $\sigma(W_{\gamma p})$
- Not in favour of LO pQCD models



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Summary

- 32.65 nb^{-1} of pPb data at 5.02 TeV is analysed
- To extract the dimuon from exclusive Upsilon, proper selection cuts are applied.
- The y and t dependent differential cross sections are compared with various theoretical models
- The exponential slope of the t-dependence is in agreement with the earlier measurements and consistent with predictions based on pQCD models.
- Cross-section is measured as a function of photon-proton centre of mass energy. Our data is compatible with a power law dependence of $W_{\gamma p}$ and disfavours faster rising extrapolations of HERA results (STARLIGHT) and LO pQCD predictions.

On going efforts in CMS for the measurement of exclusive coherent photoproduction of $\Upsilon(1S)$ state in PbPb @5.02 TeV and pPb @8.02 TeV!

Theoretical model

The CMS measurements are compared to the following theoretical predictions:

- The JMRT model , a pQCD approach that uses standard (collinear) PDFs with a skewness factor to approximate GPDs, including LO and NLO corrections, and a gap survival factor to account for the exclusive production.
- The factorized impact parameter saturation model, fIPsat, with an eikonalized gluon distribution function that uses the colour glass condensate (CGC) formalism to incorporate gluon saturation at low x.
- The Iancu, Itakura and Munier (IIM) colour dipole formalism with two sets of meson wave functions, boosted Gaussian (BG) and light-cone Gaussian (LCG), which also incorporate saturation effects.
- The impact parameter CGC model (bCGC), which takes into account the t-dependence of the differential cross section, using the BG wave function.