Nuclear modification and exclusive photoproduction of Upsilon in pPb collisions with the CMS experiment

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Motivation

**Upsilon (ϒ)** (Bound state of $b\bar{b}$)
- Produced in initial hard scattering of hadron collisions
- Probe of quark gluon plasma medium
- Sensitive to gluon PDFs

PbPb collision

Quarkonia yields modified cold nuclear matter + hot deconfined plasma.
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Important to distinguish CNM effects and suppression due to QGP, studied in pPb collisions
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PbPb collision

pPb collision

pp collision

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Quarkonia yields modified Cold Nuclear Matter (CNM)

Baseline measurement

Important to distinguish CNM effects and suppression due to QGP, studied in pPb collisions
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Sensitive to nPDFs

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Cold nuclear matter effects:
- Energy loss
- Comover breakup
- Modification of nuclear parton distribution function (nPDF)

\[ R = \frac{f_i/A}{A f_i/p} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}} \]
Cold nuclear matter effects:
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\[ R = \frac{f_i/A}{A f_i/p} \approx \text{measured} \frac{\text{expected if no nuclear effects}}{\text{measured}} \]

- Quarkonia in Ultraperipheral collisions (UPC) probes nuclear and nucleon PDF.
- UPC: No QGP, provides cleaner environment for nPDF
- **UPC (J/Ψ):** Results favor the Leading Twist Approximation (includes gluon shadowing) over the Impulse Approx. (ignores nuclear effects)
Upsilon reconstructed via dimuon decay.
Muon reconstruction: Silicon tracker + Muon sub-detectors
Outline

- Upsilon in pPb and pp collisions at 5.02 TeV
  CMS-HIN-PAS-18-005

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Quarkonia peaks modeled with Crystal Ball function

Background: error function \times exponential function
Nuclear modification factor

\[ R_{\text{pPb}}(p_T, y_{\text{CM}}) = \frac{\langle d^2\sigma/dp_T dy_{\text{CM}} \rangle_{\text{pPb}}}{A \langle d^2\sigma/dp_T dy_{\text{CM}} \rangle_{\text{pp}}} \]

- Sequential suppression of the Y states across entire rapidity and \( p_T \) region
- Indicating modification by cold nuclear matter effects
• $\Upsilon(3S)$ state largely suppressed at low $p_T$ in the Pb going side.
• Different amount of suppression for each $\Upsilon$ state, stronger for higher excited state
• Similarly observed in $\Psi(2S)$ at CMS
• Data compared with comover interaction model (CIM) + shadowing corrections (nCTEQ15 and EPS09NLO)
• Model predictions are in agreement with data within uncertainties.
• Suppression in order of binding energy
  \( R_{p\text{Pb}}(\Upsilon(1S)) > R_{p\text{Pb}}(\Upsilon(2S)) > R_{p\text{Pb}}(\Upsilon(3S)) \)

  \( \Upsilon(1S) \) \( R_{p\text{Pb}} = 0.773 \pm 0.023(\text{stat}) \pm 0.074(\text{syst}) \),
  \( \Upsilon(2S) \) \( R_{p\text{Pb}} = 0.673 \pm 0.039(\text{stat}) \pm 0.083(\text{syst}) \),
  \( \Upsilon(3S) \) \( R_{p\text{Pb}} = 0.514 \pm 0.056(\text{stat}) \pm 0.094(\text{syst}) \).

• Larger suppression in PbPb than in pPb
  \( R_{p\text{Pb}} > R_{AA} \)
\textbf{ϒ in UPC pPb collisions at 5.02 TeV}

- Photon with flux \( \alpha Z^2 \)
- Photon emitted by Pb interacts with p -> γp: dominant contribution
- Photon emitted by p interacts with Pb -> γPb: Small contribution
• Photoproduction $\alpha$ (gluon density)$^2$

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

$$x = \left( \frac{m_Y}{W_{\gamma p}} \right)^2$$

• Centre-of-mass energy of the photon-proton system:

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

• Measure exclusive vector meson $x$-section vs $t$, $t \sim p_T^2$

• Appearance of Diffractive dips are signature of gluon saturation according to b-CGC and IP-Sat model (exclusive $\rho^0$ production).

• First measurement of exclusive $\rho(770)^0$ in pPb UPC

**UPC Trigger:** at least 1 muon + number of tracks < 5

**Upsilon selection in UPC:**
Exactly 2 muons + No tracks or activity in Forward calorimeter $|\eta| < 5.2$

$p_T^{\mu} > 3.3$ GeV, $|\eta^{\mu}| < 2.2$

No additional activity in $|\eta| < 5.2$

$p_T^{\mu\mu} : 0.1-1$ GeV
UPC Trigger: at least 1 muon + number of tracks < 5

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$\mu^+\mu^-$ mass (GeV)

Exclusive upsilon states observed for the first time in UPC pPb collisions.
Background processes:

CMS pPb 32.6 nb⁻¹ (5.02 TeV)

- Data
- γσ → Y(μ⁺μ⁻) signal (STARLIGHT)
- QED γγ → μ⁺μ⁻ bkg (STARLIGHT)
- Proton dissoc. μ⁺μ⁻ bkg (data)
- Incl. Y → μ⁺μ⁻ bkg (data)
- γPb → Y(μ⁺μ⁻) bkg (STARLIGHT)

Background processes:

Proton dissociation: Non-exclusive background
- Estimated from data by requiring activity in HF toward proton going side.
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**Proton dissociation:** Non-exclusive background
- Estimated from data by requiring activity in HF toward proton going side.

**QED (γγ → µ⁺ µ⁻):** Non-resonant elastic background
- Estimated from STARLIGHT MC.

**Upsilon from γPb:** Small contribution
- Estimated from STARLIGHT MC.
\( \gamma \) photoproduction cross-section

- \( \frac{d\sigma}{dp_T^2} \) fitted with an exponential function 
\[ \exp(-|b|p_T^2) \]

- CMS Results: \( b = 6.0 \pm 2.1 \text{ (stat.)} \pm 0.3 \text{ (syst.)} \text{ GeV}^{-2} \)

- ZEUS for \( \gamma(1S) \): \( b = 4.3^{+2.0}_{-1.3} \) (stat)


- Data is in agreement with ZEUS & pQCD predictions.

\[ \chi^2 / \text{ndf} = 0.35 / 2 \]

\[ \text{Constant} = 3.06 \pm 0.45 \]

\[ \text{Slope} = -6.0 \pm 2.1 \]
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- Data is in agreement with ZEUS & pQCD predictions.

- Exclusive \( \Upsilon(1S) \) cross-section vs. rapidity is estimated
- Most theoretical predictions are consistent with data within large experimental uncertainties.

\[ \chi^2 / \text{ndf} = 0.35 / 2 \]
Constant: \( 3.06 \pm 0.45 \)
Slope: \( -6.0 \pm 2.1 \)

Data is in agreement with ZEUS & pQCD predictions.
• Exclusive $\Upsilon(1S)$ cross-section is estimated from the rapidity distribution of $\Upsilon(1S+2S+3S)$

$$\sigma_{\gamma p \rightarrow \Upsilon(1S)p} \left( W_{\gamma p}^2 \right) = \frac{1}{\phi} \frac{d\sigma_{\Upsilon(1S)}}{dy} , \quad \phi = \text{Photon flux}$$

• Power-law fit to CMS data $A \times (W_{\gamma p} / 400)^\delta$, $\delta = (1.08 \pm 0.42)$, $A = 690 \pm 184$

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

• Evolution consistent with previous HERA/LHCb results
• Sequential suppression of upsilon states
  \[ R_{pPb}(\Upsilon(1S)) > R_{pPb}(\Upsilon(2S)) > R_{pPb}(\Upsilon(3S)) \]

• Larger suppression in PbPb compared to pPb
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• First measurement of exclusive upsilon in pPb UPC.

• Studied previously unexplored kinematic region sensitive to gluon saturation in proton


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