CMS Results on Ultra-Peripheral Heavy-Ion Collisions

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Overview of CMS Results on Ultra-Peripheral Collisions

- Introduction to UPC physics
- Detector description
- Measurement of coherent J/ψ cross section
- Future prospects
The ultra-peripheral coherent J/ψ photoproduction cross section depends on the nuclear gluon density squared.

The Compact Muon Solenoid

- Calorimeter coverage extending to $|\eta| = 5$ helping to ensure exclusivity
- Muon coverage up to $|\eta| = 2.4$ for triggering and id
- Track $p_T$ resolution of 1-2%
- Efficient triggering collecting about 95% of the delivered PbPb luminosity

Wide muon coverage allows for acceptance of zero $p_T$ $J/\psi$ mesons near $|y| = 2$
2011 PbPb UPC Trigger for J/ψ Analysis

- **L1**: hardware trigger system from calorimeters and muon systems only
  - Loosest muon 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 one pixel track
Neutron Tagging

- Neutron emission can occur through multiple photon exchange in coherent production
- Detected by the ZDCs covering $|\eta| > 8.3$
- Thresholds for one and more neutrons are set from the fits to the zero bias spectrum
**Beam background rejection:** pixel cluster shapes are consistent with the vertex position, timing of hits in the BSCs are consistent with a collisions, and vertex within 25 cm of the nominal interaction point in the beam direction and 2 cm in transverse direction

**Hadronic rejection:** HF calorimeters, $3 < |\eta| < 5$, are empty, a neutron signal in the ZDCs on only one side of the interaction point, and only two reconstructed tracks in the tracker

**Muon quality:** muon track $\chi^2$ per degree of freedom $< 3$, at least 5 hits in the tracker, and matches within $3\sigma$ of hit in muon systems

Restrict reconstructed muons to $1.2 < p_T < 1.8$ GeV/c and $1.2 < |\eta| < 2.4$ to match muon trigger efficiency measurements

517 candidate events with $p_T$ below 1 GeV/c and $1.8 < |y| < 2.3$ after event selection
Extraction of the Coherent $J/\psi$ Signal

207 +/- 18 Coherent candidates with $p_T$ below 0.15 GeV/c from the simultaneous mass and $p_T$ fit
Acceptance and Efficiency Corrections

\[ \frac{d\sigma_{X_{n}^{0n}}^{coh}}{dy}(J/\psi) = \frac{N_{J/\psi}^{coh}}{BR(J/\psi \rightarrow \mu^{+}\mu^{-}) \cdot L_{int} \cdot \Delta y \cdot (A \times \varepsilon)^{J/\psi}} \]

- The combined total correction factor \((Ax\varepsilon)^{J/\psi} = 6\%\)
- The acceptance and reconstruction efficiency are estimated from MC and found to be 12\%.
- The trigger efficiency is measured from data and found to be 50\%.
Systematic Uncertainties on J/ψ Cross Section

Table 1: Summary of systematic uncertainties.

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Neutron tagging</td>
<td>6%</td>
</tr>
<tr>
<td>(2) HF energy cut</td>
<td>1%</td>
</tr>
<tr>
<td>(3) signal extraction</td>
<td>5%</td>
</tr>
<tr>
<td>(4) MC input</td>
<td>1%</td>
</tr>
<tr>
<td>(5) ZDC efficiency estimation</td>
<td>3%</td>
</tr>
<tr>
<td>(6) Tracking reconstruction</td>
<td>4%</td>
</tr>
<tr>
<td>(7) Luminosity determination</td>
<td>5%</td>
</tr>
<tr>
<td>(8) Branching ratio</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11%</strong></td>
</tr>
</tbody>
</table>

- Neutron tagging is the leading systematic uncertainty
  - Several methods are used to define the ZDCs signal and corresponding thresholds
- The sub-leading systematic uncertainty comes from signal extraction
  - The invariant mass fit functions were varied as well as the mass range, which was extended to 8 GeV/c^2
Coherent $J/\psi$ Cross Section in PbPb UPC

- Cross section measured for events with single sided neutron emission, the $X_{n0n}$ break-up mode
- $X_{n0n}$ is the largest cross section available given ZDC trigger requirement

$\frac{d\sigma}{dy}(\text{coh}/X_{n0n}) = 0.37 \pm 0.04(\text{stat}) \pm 0.04(\text{syst}) \text{mb}$
Break-up Modes Ratios

<table>
<thead>
<tr>
<th>$J/\psi$ with $p_T &lt; 0.15$ GeV/$c$</th>
<th>$X_nX_n/X_n0_n$</th>
<th>$1_n0_n/X_n0_n$</th>
<th>$1_n1_n/X_n0_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>$0.36 \pm 0.04$</td>
<td>$0.26 \pm 0.03$</td>
<td>$0.03 \pm 0.01$</td>
</tr>
<tr>
<td>STARLIGHT</td>
<td>$0.37$</td>
<td>N/A</td>
<td>$0.02$</td>
</tr>
<tr>
<td>GSZ</td>
<td>$0.32$</td>
<td>$0.30$</td>
<td>$0.02$</td>
</tr>
</tbody>
</table>

First measurement of break-up ratios for UPC $J/\psi$

$X_n0_n$ single-sided neutron emission with any number of neutrons

$X_nX_n$ double-sided neutron emission with any number of neutrons

$1_n0_n$ single-sided neutron emission with only one neutron

$1_n1_n$ double-sided neutron emission with only one neutron on each side

The multiple photon-exchange model of nuclear break-up in coherent interactions describes the data reasonably well.
Coherent J/$\psi$ Cross Section in PbPb UPC

- Cross section for $X_{n=0}$ is scaled up to the total cross section using STARLIGHT
- CMS and ALICE results favor the same theoretical models
- ALICE and CMS measurements favor models containing moderate gluon shadowing

CMS: HIN-12-009: http://cds.cern.ch/record/1971267


Prospect for 2015

- Increase in luminosity of a factor of 5-10
- Increase in cross section for coherent $\Upsilon$ of 4 due to increase in energy
- Between 200-1000 $\Upsilon$ candidates expected

2011: 150 $\mu$b$^{-1}$ at $\sqrt{s_{NN}} = 2.76$ TeV

2015: 0.5-1.5 nb$^{-1}$ at $\sqrt{s_{NN}} = 5.1$ TeV

Summary

- UPC quarkonia studies offer a clean probe of the initial state, in particular the nuclear gluon density
- Recent preliminary results from CMS measuring the coherent $J/\psi$ cross section made public
  - Favor same theoretical models as previous ALICE results
  - Cover a new rapidity region
  - Favor theoretical models including nuclear gluon shadowing
  - Break-up ratios are consistent with theoretical models using multiple photon exchange
- The higher energies and luminosities in 2015 PbPb collisions will offer the opportunity to study $\Upsilon$ in UPC events and potentially new objects like dijets

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Backup
Coherent J/ψ Cross Section in PbPb UPC

- Triggering: dedicated UPC triggers rejecting hadronic
- Event selection: rejection of beam background, hadronic interactions, and muon quality requirements
- Neutron tagging: neutron threshold definitions to define break-up modes
- Signal extraction: mass and $p_T$ fits to extract the coherent yield
- Systematic uncertainties: list of systematic uncertainties
- Results: coherent J/ψ cross section and ratios between break up modes
UPC Triggers in pp, PbPb, and pPb

- **L1 trigger**: hardware based trigger using the calorimeters and muon systems
  - **PbPb**: single muon trigger with no $p_T$ threshold, require empty scintillation counters in the forward region, and activity in the zero degree calorimeters
  - **pPb**: single muon trigger with no $p_T$ threshold
- **HLT trigger**: software trigger using the full detector
  - **PbPb**: at least one reconstructed pixel track
  - **pPb**: between 1 and 6 reconstructed online tracks
CMS UPC Analyses

• Preliminary results on coherent J/ψ production made public recently

   HIN-12-009: http://cds.cern.ch/record/1971267

• Analysis of exclusive Υ in pp is underway

• Analysis of J/ψ and Υ underway in pPb
  • Potential to look at γ-p and γ-Pb interactions for J/ψ

Studies of photoproduction of vector mesons in pp, pPb, PbPb can probe both the proton and nuclear gluon densities
The Zero Degree Calorimeters

- Quartz fibers and tungsten absorber Cherenkov detectors
- 140 meters from interaction point on either side
- Total of 18 channels
  - 5 electromagnetic sections each segmented transverse to the beam
  - 4 hadronic sections segmented longitudinally
- Detects neutral particles $|\eta| > 8.3$
Physics Processes in Ultra-Peripheral Collisions

Coherent photoproduction: the photon couples to the nucleus as a whole

Incoherent photoproduction: the photon couples to the nucleons inside

Photon-photon interaction: photons from the two nuclei can interact with each other