Recent results and prospects on ultra-peripheral heavy ion collisions at LHCb

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Central exclusive production (CEP) and Ultra-peripheral collisions (UPC) in ion collisions

• Two nuclei bypass each other with impact parameter larger than the sum of their radii
• Collisions are ‘elastic’
• Characteristic properties
  • low momentum transfer
  • low transverse momentum
  • no additional particle production

Inelastic collisions

elastic collisions
Central exclusive production (CEP) and Ultra-peripheral collisions (UPC) in ion collisions

- \( \text{Pb} + \text{Pb} \rightarrow \text{Pb} + \text{X} + \text{Pb} \)
- Heavy ions carry a strong electromagnetic field
- EM fields of the ions can interact with each other or the nuclei via photon or ‘pomeron’

Related phenomena where the colourless object creates a particle

(Note: \( J/\psi \rightarrow \mu \mu \) and \( \chi_c \rightarrow J/\psi\gamma \) )
LHCb detector

- LHCb - single armed forward spectrometer, located at LHC
- Acceptance $2 < \eta < 5$
- Proton-proton interaction at up to $\sqrt{s} = 13$ TeV
- Physics goals:
  - Designed for: $CP$ violation in $b$ and $c$ sectors
  - Today: also general purpose physics in forward region

[2008 JINST 3 S08005] [IJMPA 30, 1530022 (2015)]
LHCb recorded data

- **pp collider:** 2010-2018, $\sqrt{s_{NN}} = 2.76, 5, 7, 8, 13$ TeV, $L \approx 9$ fb$^{-1}$
- **pPb collider:** 2013 and 2016, $\sqrt{s_{NN}} = 5.02$ & 8.16 TeV, $L \approx 2$ & 34 nb$^{-1}$
- **PbPb collider:** 2015 and 2018, $\sqrt{s_{NN}} = 5$ TeV, $L \approx 10$ μb$^{-1}$ & 210 μb$^{-1}$

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- **Fixed-target mode:**
  parasitic to collider mode,
  inject noble gas into VELO,
  use non-colliding bunches

**Beam Energy**

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<th>Protons (Pb) on target [10$^{-2}$]</th>
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<td>2500 GeV</td>
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<td>pNe</td>
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<td>pAr</td>
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**Fixed target mode**

- $\sqrt{s_{NN}} = 110$ GeV
- $\sqrt{s_{NN}} = 69$ GeV
UPC in PbPb collisions
UPC in PbPb collisions

- First preliminary result by LHCb on PbPb collisions
- Goal is to study coherent $J/\psi$ production in PbPb collisions at $\sqrt{s(\text{NN})} = 5\text{ TeV}$
- Data set: PbPb 2015, integrated luminosity $\sim 10\ \mu\text{b}^{-1}$
- Muons in acceptance. $\text{Pt}(J/\psi) < 1\ \text{GeV}$. Rapidity $2.0 < y < 4.5$

- Photon-induced $J/\psi$ production cross-section is enhanced by the strong electromagnetic field of the nucleus
- The collisions are either
  - coherent, where the photon couples coherently to all nucleons
  - or incoherent, where the photon couples to a single nucleon
UPC in PbPb collisions

- Invariant mass fit
  - non-resonant: Exponential times straight line \( \propto (a + b m_{\mu+\mu^-} e^{\tau m_{\mu+\mu^-}}) \)
  - \( J/\psi \): Double sided Crystal Ball function
  - \( \psi(2S) \): Double sided Crystal Ball function with all parameters apart from normalisation and mean constrained to be identical to \( J/\psi \)

![Graph showing UPC in PbPb collisions](image)
UPC in PbPb collisions

• Transverse momentum fit
  • non-resonant: STARlight template, normalisation is fixed by Gaussian constraint to the result of the mass fit
  • incoherent $J/\psi$ production: STARlight template, this also accounts for feeddown $\psi(2S) \rightarrow J/\psi X$
  • coherent $J/\psi$ production: STARlight template

• The STARlight templates are from the generated events smeared with a resolution model
UPC in PbPb collisions

• Cross section for coherent $J/\psi$ production at 5 TeV:
  • $\sigma = 5.3 \pm 0.2$ (stat) $\pm 0.5$ (syst) $\pm 0.7$ (lumi) mb,

• Coherent (photon couples to all nucleons) $J/\psi$ production gives constraints to nPDF

• Uncertainty smaller than models spread

• Phenomenological models:
Hershel detector
Rapidity coverage

ALICE

ATLAS

CMS+TOTEM

LHCb

HeRSCHeL

High rapidity detector $5 < |\eta| < 9$
(since 2015)
High Rapidity Shower Counters for LHCb (HeRSCheL)
Different processes compared with the acceptance of the LHCb detector
Separation of coherent and incoherent

- If the nucleus breaks up it will leave debris in $5.0 < \eta < 7.5$
- HeRSCheL extended LHCb to observe this debris
- A reduction of the incoherent background is expected after vetoing significant energy detected in HeRSCheL
Conclusions

• LHCb has measured the cross section for coherent $J/\psi$ production in lead-lead ultra-peripheral collisions using 2015 data
• We have potential to improve the precision of this measurement by using HeRSCheL
• We have prospects for many future analyses with 2018 data
• Stay tuned!
Backups