Photon-hadron and photon-photon collisions in ALICE

Rainer Schicker
for the ALICE Collaboration

Phys. Inst., Heidelberg

June 18, 2015
Photon-photon collisions

Photon-hadron collisions

The ALICE experiment

Results Run I

Plans Run II

Summary and outlook
The electromagnetic field of a moving charge

- Fields represent plane polarized radiation moving in z-direction
- Equivalent Photon Approximation (EPA)
  - E. Fermi (1924)
  - C.F. Weizsäcker, E.J. Williams (1934)
- \[ dn_\gamma(\omega, b) = \frac{Z^2_1 \alpha}{\pi^2} \frac{d\omega}{\omega} \frac{d^2 b}{b^2} \text{ (lead. log approx.)} \]
Photon-photon collisions

The ALICE experiment

Results Run I  Plans Run II  Summary and outlook

Photon-photon cross sections

hadron induced photon-photon processes in EPA-formalism

\[ \sigma_{pp\rightarrow pp X}^{EPA} = \int \int d\omega_1^{\gamma} d\omega_2^{\gamma} \sigma_{\gamma\gamma\rightarrow x}(\omega_1 \omega_2) \]

\[ \sigma_{PbPb\rightarrow PbPb X}^{EPA} = \int \int d\omega_1^{\gamma} d\omega_2^{\gamma} \sigma_{\gamma\gamma\rightarrow x}(\omega_1 \omega_2) \]

photon-photon luminosity in EPA formalism

\[ \frac{dL}{dWd\omega_{dy}} = \frac{2}{W} \frac{dL}{d\omega_1 d\omega_2} = \frac{2}{W} \frac{dn(\omega_1)}{d\omega_1} \frac{dn(\omega_2)}{d\omega_2} = \frac{4Z^4\alpha^2}{\pi^2(\omega_1 \omega_2)^{3/2}} \log\left(\frac{\omega}{R\omega_1}\right) \log\left(\frac{\omega}{R\omega_2}\right) \]

\[ W = \text{invariant mass of two-photon system} = 2\sqrt{\omega_1 \omega_2} \]

\[ y = \text{rapidity of two-photon system} = \frac{1}{2} \log\left(\frac{\omega_1}{\omega_2}\right) \]

Photon-hadron and photon-photon collisions in ALICE  June 18, 2015  4 / 17
Photon-hadron cross sections

- Photon of electromagnetic field of one nucleus interacts with nucleus of the other beam

- Cross sections for exclusive vector meson production show energy dependence of hadronic cross sections

\[
\frac{d\sigma}{dt} (\gamma^* p \rightarrow J/\psi p) \bigg|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48 \alpha} \left[ \frac{\alpha_s(Q^2)}{Q^4} x g(x, Q^2) \right]^2 \left( 1 + \frac{Q^2}{M_{J/\psi}^2} \right)
\]

\[Q^2 = (Q^2 + M_{J/\psi}^2)/4, \quad x = (Q^2 + M_{J/\psi}^2)/(W^2 + M_{J/\psi}^2).\]

- Cross section proportional to (gluon dens.)\(^2\), \(\sigma \sim (xg)^2\), hence \(\sigma \sim x^\lambda\)

The LHC collider - 7 experiments

<table>
<thead>
<tr>
<th>year</th>
<th>syst.</th>
<th>$\sqrt{s}$</th>
<th>int. lumi.</th>
<th>year</th>
<th>syst.</th>
<th>$\sqrt{s_{NN}}$</th>
<th>int. lumi.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>p-p</td>
<td>7 TeV</td>
<td>45 pb$^{-1}$</td>
<td>2010</td>
<td>Pb-Pb</td>
<td>2.76 TeV</td>
<td>$\sim 10 \mu b^{-1}$</td>
</tr>
<tr>
<td>2011</td>
<td>p-p</td>
<td>7 TeV</td>
<td>6 fb$^{-1}$</td>
<td>2011</td>
<td>Pb-Pb</td>
<td>2.76 TeV</td>
<td>$\sim 0.15 nb^{-1}$</td>
</tr>
<tr>
<td>2012</td>
<td>p-p</td>
<td>8 TeV</td>
<td>23 fb$^{-1}$</td>
<td>2013</td>
<td>p-Pb</td>
<td>5.02 TeV</td>
<td>$\sim 30 nb^{-1}$</td>
</tr>
</tbody>
</table>
The ALICE experiment

- **Central Barrel**
  - $|\eta| < 0.9$
  - tracking: ITS+TPC
  - trigger detectors: SPD, TRD, TOF

- **Muon spectrometer**
  - $-4.0 < \eta < -2.5$
  - tracking
  - trigger chambers

- **Scintillator arrays:**
  - VZERO-A: $2.8 < \eta < 5.1$, segmented in $\Delta \eta \sim 0.5$, $\Delta \phi = 45^0$
  - VZERO-C: $-3.7 < \eta < -1.7$, segmentation as VZERO-A

- **Zero Degree Calorimeter** for detecting forward neutrons
**J/ψ production at forward rapidity in PbPb-collisions**

- **ALICE Collaboration,**
  - measurement $J/\psi$ production at forward rapidity
  - $J/\psi$ in $\mu^+\mu^-$ channel

- **trigger:**
  - single muon trigger $p_T > 1$ GeV/c
  - at least one hit in VZERO-C
  - no hits in VZERO-A

- not much discriminating power of models at this rapidity, models without nuclear gluon shadowing disfavored
**J/ψ** production at midrapidity in PbPb-collisions

- ALICE Collaboration,
  - ALICE measurement $J/\psi$, $\psi(2S)$ photoproduction at midrapidity
  - $J/\Psi$ identified in $e^+e^-$ and $\mu^+\mu^-$ channels

- trigger:
  - at least 2 hits in SPD
  - number of TOF hits: $2 \leq N^{TOF} \leq 6$
    (2 hits back-to-back)
  - no hits in VZERO-A, VZERO-C

- coherent production
  $<p_T^{J/\psi}> \approx 60$ MeV/c

- incoherent production
  $<p_T^{J/\psi}> \approx 500$ MeV/c
J/ψ production at midrapidity in PbPb-collisions

- **Analysis J/ψ cross section**
  - coherent/incoherent cross section within rapidity $|y| < 0.9$
  - data sample of 23 $\mu$b$^{-1}$
  - $\frac{d\sigma_{coh}^{J/\psi}}{dy} = 2.38^{+0.34}_{-0.24}$ (stat+sys) mb
  - $\frac{d\sigma_{inc}^{J/\psi}}{dy} = 0.98^{+0.19}_{-0.17}$ (stat+sys) mb
- models without gluon shadowing inconsistent with measured cross section
- models with EPS09 gluon shadowing agree well with measurements

- **Analysis $\gamma\gamma \rightarrow e^+e^-$**
  - cross section $\gamma\gamma \rightarrow e^+e^-$ ($m_{e^+e^-} > m_{J/\psi}$) analyzed within rapidity $-0.9 < y < 0.9$
  - good agreement with STARLIGHT event generator
\[\psi(2S)\] production at midrapidity in PbPb-collisions

- **Analysis** \(\psi(2S)\) cross section
- coherent cross section within rapidity \(|y| < 0.9\)
- data sample of 23 \(\mu b^{-1}\)
- identification: \(\psi(2S) \rightarrow l^+ l^-\)
  and \(\psi(2S) \rightarrow \pi^+ \pi^- l^+ l^-\)
- \[\frac{d\sigma_{\psi(2S)}^{coh}}{dy} = 0.83 \pm 0.19 \text{(stat+sys)} \text{mb}\]
- mass spectrum shown for \(\psi(2S) \rightarrow \pi^+ \pi^- \mu^+ \mu^-\)
- similar spectrum for \(\psi(2S) \rightarrow \pi^+ \pi^- e^+ e^-\)
- **cross section ratio** \(\psi(2S) / J/\psi\)
- node in \(\psi(2S)\) radial wave function, smaller \(\psi(2S)\) cross section expected
- GDGM-GM, STARLIGHT models underpredict ratio \(\psi(2S)\) to \(J/\psi\)
**$\rho^0$ production at midrapidity in PbPb-collisions**

- **ALICE Collaboration,**
  arXiv:1503.09177
  - coherent $\rho^0$ photoproduction at midrapidity
  - $\rho^0$ identified in $\pi^+\pi^-$ channel within rapidity $|y| < 0.5$

- trigger low-lumi runs 2010:
  - number of TOF hits: $N^{TOF} \geq 2$

- trigger higher lumi runs:
  - number of TOF hits: $N^{TOF} \geq 2$
  - at least 2 hits in SPD
  - no hits in VZERO-A, VZERO-C
\( \rho^0 \) production at midrapidity in PbPb-collisions

- \( \pi^+ \pi^- \)-mass spectrum fitted by:
  - in blue: Söding parameterization
  \[
  \frac{d\sigma}{dM_{\pi\pi}} = \left| \frac{A}{M_{\pi\pi}^2 - M_{\rho^0}^2 + iM_{\rho^0}\Gamma(M_{\pi\pi})} \right|^2 \left( \frac{M_{\rho^0}}{M_{\pi\pi}} \right)^k
  \]
  A=Breit-Wigner / B=non-resonant \( \pi^+ \pi^- \) ampl.
  - in green: BW-contr. of Söding fit
  - in red: Ross-Stodolsky parametr.

- comparison to models
  - GDL (Glauber-Donnachie-Landshoff):
    DL model for \( \rho N \) cross sect.
  - STARLIGHT (Nystrand):
    \[
    \sigma(\rho N) = 5.0 \ W_{\gamma N}^{0.20} + 26.0
    \]
    \( W_{\gamma N}^{-1.23} \) \( \mu b \)
\( J/\psi \) production at forward rapidity in pPb-collisions

- ALICE Collaboration,
  Phys.Rev.Lett. 113 (2014) 232504

  - measurement of \( J/\psi \) production at forward/backward rapidity
  - \( J/\psi \) in \( \mu^+\mu^- \) channel

- \( J/\psi \) measured in p-Pb
  - \( 2.5 < y < 4.0, \ 21 < W_{\gamma p} < 45 \) GeV

- \( J/\psi \) measured in Pb-p
  - \( -3.6 < y < -2.6, \ 577 < W_{\gamma p} < 952 \) GeV

- ALICE measurement:
  - cross section compatible with power-law dependence up to \( W_{\gamma p} \sim 700 \) GeV (\( \times \sim 2 \times 10^{-5} \))
  - no change of gluon PDF between HERA and LHC energy
New detectors for Run II

- Run I veto detectors VZERO
  - VZEROA
  - 3.3 m
  - $2.8 < \eta < 5.1$
  - $-3.7 < \eta < -1.7$

- Run II new detectors ADA, ADC:
  - (in addition to VZERO)
  - $4.8 < \eta < 6.3$
  - $-7 < \eta < -4.9$

- Scintillation det. ADA
  - $4.8 < \eta < 6.3$

- Detectors ADC, ADC:
  - extend accept. to lower masses in single/double diffractive dissociation in pp-collisions
  - improve exclusivity condition in pPb and PbPb collisions
  - rejection of beam-gas events
  - ADA/ADC det. taking data

Rainer Schicker for the ALICE Collaboration
**Plans for Run II**

- Run II has officially started!
  First stable proton beams at $\sqrt{s} = 13$ TeV declared on June 3.
- Run II expectations:
  - pp-collisions at $\sqrt{s} = 13$ TeV (maybe higher later in the run), 75-100 fb$^{-1}$ delivered to ATLAS and CMS
  - Pb-Pb at $\sqrt{s} = 5.1$ TeV, 1 nb$^{-1}$
  - p-Pb, $\sqrt{s}$ under discussion:
    - 5.1 TeV (same $\sqrt{s}$ as in PbPb)
    - $\sim 8$ TeV (max. $\sqrt{s}$ available)
Summary and outlook

- a wealth of Run I data available from ALICE collaboration
  - photon-hadron collisions
    - $J/\psi$ production in PbPb collisions at midrapidity
    - $\psi(2S)$ production in PbPb collisions at midrapidity
    - $\rho$ production in PbPb collisions at midrapidity
    - $J/\psi$ production in PbPb collisions at forward rapidity
    - $J/\psi$ production in pPb collisions at forward rapidity
  - photon-photon collisions
    - $\gamma\gamma \rightarrow e^+e^-$ in PbPb at midrapidity
- new detector system ADA, ADC for improved pseudorapidity coverage in Run II