ALICE results on vector meson photonuclear production in Pb-Pb collisions

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on behalf of the ALICE Collaboration

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Beams of quasi-real photons at the LHC
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**Note 5:**
*Interactions at large impact parameters involve photons.*

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Why Pb-ions as source of photons?

The LHC accelerates both protons and Pb nuclei

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→ The intensity is orders of magnitude larger for Pb w.r.t. proton beams.
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It is necessary to separate the collisions of hadrons, for which the LHC and its detectors were optimised, from the collisions involving quasi-real photons.

The strategy is to use the facts that

1. Strong interactions tend to produce particles at all rapidities, while electromagnetic interactions produce large rapidity gaps
2. Pb nuclei are very fragile objects, which break in all hadronic interactions ... and ALICE is able to detect with very high efficiency if a Pb nucleus breaks (by measuring in the very forward direction neutrons from the nuclear fragmentation)

\[ \text{Look for processes with large rapidity gaps and (almost) intact outgoing nuclei} \]
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\[ \text{Look for processes with large rapidity gaps and (almost) intact outgoing nuclei} \]

These are called Ultra-Peripheral Collisions (UPC)
Exclusive photoproduction of vector mesons and ALICE
Shine light in a target and measure the scattered ‘light’, in this case a vector meson...
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Kinematics completely determined:

- Rapidity measures energy of the photon-target interaction
- The square of the transverse momentum of the vector meson is related to \( \Delta \) the momentum transferred in the target vertex.
Exclusive vector meson production

- Shine light in a target and measure the scattered ‘light’, in this case a vector meson ..

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- The production of the vector meson does not break the target

- The transverse momentum transferred, $\Delta$, is very small, being bounded by the size of the target. It is smaller for Pb targets, than for p targets.
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Very clean signature
This interaction probes the QCD structure of the target.

In the colour dipole picture the photon fluctuates into a q-qbar pair, which interacts with the target and produces a vector meson.
The QCD structure of the target

- Measurement of the polar angle of produced vector meson \(\rightarrow\) energy evolution of the QCD structure of target
- Measurement of transverse momentum of produced vector meson \(\rightarrow\) transverse distribution of QCD structure in the target
- Different vector meson masses, in the perturbative regime \(\rightarrow\) different scales for QCD evolution

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In the colour dipole picture the photon fluctuates into a $q$-$\bar{q}$ pair, which interacts with the target and produces a vector meson.

Key words are,
- $p$-$Pb$ ($p$ target): saturation
- $Pb$-$Pb$ ($Pb$ target): shadowing
The QCD structure of the target

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See next talk by Jarda Adam!
ALICE
Magnetic field of 0.5 T in the central region
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Trigger: V0 veto, SPD and TOF signals (with topology)
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Trigger: V0 veto, SPD and TOF signals (with topology)

Trigger: V0A veto, muons in MUON (+signal in V0C)
Particle identification using $dE/dx$

The measurement of $dE/dx$ performed by the TPC allows a clear separation of electrons and muons/pions.
What do we need?

1. To measure the decay products of a vector meson with very low transverse momentum:
   - $\rho$ to $\pi^+ + \pi^-$
   - $J/\psi$ to $\mu^+ + \mu^-$ or to $e^+ + e^-$
   - $\psi(2S)$ to $\mu^+ + \mu^-$, $e^+ + e^-$ or $J/\psi + \pi^+ + \pi^-$

2. To make sure there is nothing else in the detector:
   Large rapidity coverage to veto particles

3. To make sure that the source/target do not break:
   neutron Zero Degree Calorimeters (ZDC)
\( \gamma\text{-Pb: Results from Pb-Pb collisions in Run1} \)
γ-Pb: Results from Pb-Pb collisions in Run1

Four topics:
① Coherent ρ production
② Coherent and incoherent J/ψ production
③ Coherent ψ(2S) production
④ A surprise!
Coherent $\rho$ production

- **Coherent**: photon couples to full nuclei: VM has **very** low transverse momentum
- **Incoherent**: photon couples to one nucleon: VM has low transverse momentum

- 2010 data
- Decay into $\pi^+\pi^-$

Distribution of transverse momentum for coherent $\rho$ is wider in STARLIGHT than in data
To be studied in Run2

Transverse momentum less than 150 MeV/c to reject **incoherent** contribution
Coherent $\rho$ production: cross section

$\text{d}N/\text{d}y$ (mb)

$\text{A}+\text{A} \rightarrow \text{A}+\text{A}+\rho^0$

$\sqrt{s_{NN}} = 2.76$ TeV Pb+Pb $\rightarrow$ Pb+Pb+$\rho^0$

ALICE, JHEP 1509 (2015) 095
Coherent $\rho$ production: cross section


Coherent $\rho$ production: cross section


✓ Agreement with STARLIGHT
✓ Disagreement with GDL model may be explained by inelastic nuclear shadowing

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Coherent and incoherent $J/\psi$ production: cross sections

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$\frac{d\sigma}{dy} (\text{mb})$

$\text{Pb+Pb} \rightarrow \text{Pb+Pb+J/}\psi \quad |s_{NN} = 2.76 \text{ TeV}$

- ALICE Coherent $J/\psi$
- Reflected

$d\sigma/dy (\text{mb})$

$\text{Pb+Pb} \rightarrow \text{Pb+Pb+J/}\psi \quad |s_{NN} = 2.76 \text{ TeV}$

- ALICE Incoherent $J/\psi$

$x \approx 10^{-2}$

$x \approx 10^{-3}$
Coherent and incoherent $J/\psi$ production: cross sections


Coherent and incoherent \( J/\psi \) production: cross sections


\[
\frac{d\sigma}{dy} \left( m_b \right) = 2.76 \text{ TeV} \quad (a) \quad \text{ALICE Coherent } J/\psi \quad \bullet \text{Reflected}
\]

\[
\frac{d\sigma}{dy} \left( m_b \right) = 2.76 \text{ TeV} \quad (b) \quad \text{ALICE Incoherent } J/\psi \quad \bullet \text{ALICE}
\]

\[ x \approx 10^{-2} \quad x \approx 10^{-3} \]

Direct observation of (moderate) gluon shadowing


\[ y = 4 - 2 \cdot 0 \]
Under some assumptions, ALICE measurements can be translated into LO pQCD constraints for gluon shadowing at small $x$. 
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Note: \( R_{\text{Pb}}(x, \mu^2) = \frac{g_{\text{Pb}}(x, \mu^2)}{(A_{\text{Pb}}g_p(x, \mu^2))} \)
Coherent $\psi(2S)$ production
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✓ Measured decay channels:
$\psi(2S) \rightarrow l^+l^-$ and $\psi(2S) \rightarrow J/\psi \pi^+\pi^-$
Coherent \( \psi(2S) \) production

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\( \psi(2S) \rightarrow \ell^+\ell^- \) and \( \psi(2S) \rightarrow J/\psi\pi^+\pi^- \)

![Graph showing the distribution of counts in MeV/c^2](image)

\( \text{Pb+Pb} \rightarrow \text{Pb+Pb+}\psi(2S) \quad \sqrt{s_{NN}} = 2.76 \text{ TeV} \)

\( |y| < 0.9 \)

Counts/30 MeV/c^2

✓ Few signal events with almost no background

To be alongside: ALICE, PLB 751 (2015) 358

\( N_{\psi(2S)} = 17 \pm 4.1 \)
The wave function of excited states present so-called nodes (Nemchik et al., ZPC75 (1997) 71).

These nodes have a negative contribution for large dipole sizes, where saturation effects are expected.

Measure $J/\psi$ and $\psi(2S)$ in the same kinematic region and compare them.
Coherent $\psi(2S)$ production: cross section

$\text{Pb} + \text{Pb} \rightarrow \text{Pb} + \text{Pb} + \psi(2S)$ \quad s_{NN} = 2.76 \text{ TeV}
Coherent $\psi(2S)$ production: cross section

$\text{Pb+Pb} \rightarrow \text{Pb+Pb+}\psi(2S) \quad s_{NN} = 2.76 \text{ TeV}$

Both impulse approximations should be equal ...
Coherent $\psi(2S)$ production: cross section

$\text{Pb}+\text{Pb} \rightarrow \text{Pb}+\text{Pb}+\psi(2S) \quad s_{NN} = 2.76 \text{ TeV}$

- Both impulse approximations should be equal...
- Strong shadowing is disfavoured...

ALICE, PLB 751 (2015) 358
Both impulse approximations should be equal …

Strong shadowing is disfavoured …

Do nuclear effects affect differently 1S and 2S states? Need more precise data!
Pb-Pb collisions for $b<2^*R_A$
Pb-Pb collisions for $b < 2*R_A$

For collisions at impact parameters smaller than the sum of radii of the interacting particles, the nuclei interact **hadronically** and they **break**
Coherent $\text{J}/\psi$ production in peripheral collisions


- ALICE, Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV
- $2.5 < y < 4$
- $2.8 < m_{\mu^+\mu^-} < 3.4$ GeV/$c^2$
- 70-90%

![Graph showing the distribution of raw counts per 0.1 GeV/c vs. $p_T$ (GeV/c)]
Coherent $J/\psi$ production in peripheral collisions

Clear excess in the yield at low $p_T$ for peripheral collisions

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And the excess is clearly from $J/\psi$
Coherent $J/\psi$ production in peripheral collisions


$R_{AA}$

ALICE, Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV
2.5 $< y < 4$

- $0 \leq p_T < 0.3$ GeV/c, global syst = $\pm$ 15.7 %
- $0.3 \leq p_T < 1$ GeV/c, global syst = $\pm$ 15.1 %
- $1 \leq p_T < 8$ GeV/c, global syst = $\pm$ 11.5 %

Common global syst = $\pm$ 6.8 %
Coherent $J/\psi$ production in peripheral collisions

If the excess were from hadronic production, the $R_{AA}$ would reach up to 7!
(Standard expectation is $R_{AA} \sim O(1)$)
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If photoproduction is assumed as the underlying interaction we obtain

<table>
<thead>
<tr>
<th>Centrality class</th>
<th>Cross section ($\mu$b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10%</td>
<td>&lt;318</td>
</tr>
<tr>
<td>10-30%</td>
<td>&lt;290</td>
</tr>
<tr>
<td>30-50%</td>
<td>73$\pm$44$^{+26}_{-27}$</td>
</tr>
<tr>
<td>50-70%</td>
<td>58$\pm$16$^{+8}_{-10}$</td>
</tr>
<tr>
<td>70-90%</td>
<td>59$\pm$11$^{+7}_{-10}$</td>
</tr>
</tbody>
</table>

No theoretical calculations available for coherent photoproduction in peripheral collisions

(A first try is in PRC93 (2016) 044912)
Some comments on Run 2 plans
New for Run2: The AD detector

- Modules of plastic scintillator read out with PMTs
- Time resolution 300 (500) ps in C (A) side, allows one to reject out of time background
- Enlarges ALICE geometric rapidity coverage to
  - $-6.9 < \eta < -4.9$
  - $4.9 < \eta < 6.3$
- It increases ALICE capability to impose a veto on extra activity for exclusive processes in UPC
Run2 expectations for Pb-Pb UPC

- Factor of two increase on the Pb-Pb centre-of-mass energy
  - Increase in the cross section, mainly due to an increase in the photon flux
  - Increase in the kinematic reach: a factor of two lower values of Bjorken x will be accessible

- Improved detector and trigger capabilities
  - Cleaner samples, smaller systematic error
  - Access to other vector mesons, e.g. $\phi$?
  - Better use of detector acceptance

- Increase in the luminosity available for UPC
  - Depending on accelerator and detector conditions we expect a large increase in luminosity

- CMS and ATLAS are joining the party!
ALICE has taken Pb-Pb data in the 2015 period, and the expectations are fulfilled
Central sample $\sim 6x$ larger than in Run1, and
Forward sample $\sim 50x$ larger wrt Run 1!

- Analysis on going
- We will get more data for the Pb-Pb run planned for 2018
The $L\gamma HC$ (and $L\gamma\gamma C$) are delivering very interesting physics

Exciting times are ahead of us, so stay tuned!
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http://inspirehep.net/record/1395296?ln=en
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Coherent rho and J/psi photoproduction in ultraperipheral processes with electromagnetic dissociation of heavy ions at RHIC and LHC,
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   http://inspirehep.net/record/1083333?ln=en

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   JHEP 1311 (2013) 085
   http://inspirehep.net/record/1244687?ln=en

   Exclusive diffractive processes at HERA within the dipole picture
   http://inspirehep.net/record/720153?ln=en