News from the Pb-Pb run and future prospects for UPC from ALICE

O. Villalobos Baillie for the ALICE Collaboration

The University of Birmingham
Plan of Talk

• Introduction
• The ALICE experiment
  • Trigger configurations
• Run 1 results
• Run 2 results and prospects
• Run 3-4 prospects
• Summary
In Ultra-Peripheral Collisions (UPC), the projectiles (Pb-Pb, p-Pb or pp) are at large impact parameters, \( b > R_1 + R_2 \), and so hadronic processes are greatly suppressed.

- Photon flux \( \propto Z^2 \)
- Photon virtuality \( Q^2 = (\hbar c/R)^2 \approx (35 \text{ MeV})^2 \) for \( \gamma \) from Pb
J/ψ Ultra-Peripheral Production

\[ \frac{d\sigma}{dt\gamma_p/Pb}(t=0) = \frac{16G_{ee}\pi^3}{3\alpha_{em}M_{J/\psi}^5}\left\{ \alpha_s(Q^2)xF_{p/Pb}(x,Q^2) \right\}^2 \]

**LEADING ORDER**

- Essentially the same process as ep, except that the photon is emitted by a proton or a nucleus.
- The photon emitted by one nucleus couples to a vector meson.
- At LO, the cross-section is proportional to the gluon PDF squared.
- Hard scale for the J/ψ of \( Q^2 \approx (M_{J/\psi}^2/4) \approx 2.5 \text{ GeV}^2 \)
  - Model dependence for lighter particles (e.g. ρ)

**Exclusive process: we go to very low multiplicities**
ALICE Apparatus

THE ALICE DETECTOR

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14. Muon Trigger
15. Dipole Magnet
16. PMD
17. AD
18. ZDC
19. ACORDE

VZERO-A: $2.8<\eta<5.1$
VZERO-C: $-3.7<\eta<-2.7$

a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD
ALICE Apparatus

FORWARD TRIGGER

V0-A.V0-C.DIMUON

Also AD veto counters in Run 2, extending veto to $\eta \sim 7$

V0-A: $2.8 < \eta < 5.1$

V0-C: $-3.7 < \eta < -2.7$
ALICE Apparatus

**Central Trigger**

\[ V0-A \cdot V0-C \cdot SPD \cdot TOF \]

Also **AD** veto counters in Run 2

- **V0-A**: \(2.8 < \eta < 5.1\)
- **V0-C**: \(-3.7 < \eta < -2.7\)
Central

Pb-Pb Collision
ALICE Apparatus

ALICE Apparatus

NEW - More Later

A-SIDE

(C-ZDC)

ADA

V0-A

SPD

MUON ARM

C-SIDE

(ZDC)

(AD)'

VZERO-A.SPD.DIMUON

NEW - More Later

V0-A: 2.8<\eta<5.1

V0-C: -3.6<\eta<-2.6

Also AD veto counters in Run 2

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ALICE Apparatus

SEMI-FORWARD TRIGGER

\[ V0-A \cdot V0-C \cdot SPD \cdot DIMUON \]

Also AD veto counters in Run 2
Semi-Forward

p-Pb collision
Run 1 Summary
Publications

Pb-Pb 2.76 TeV per nucleon

- ρ⁰ central: J. Adam et al., JHEP **09** (2015) 095

p-Pb 5.02 TeV per nucleon

J/ψ Production-Pb-Pb

STARLIGHT: Klein, Nystrand, PRC60 (1999) 014903
VDM + Glauber approach where J/ψ+p cross section is obtained from a parameterization of HERA data

• GM: Gonçalves, Machado, PRC84 (2011) 011902
colour dipole model, dipole nucleon cross section taken from the IIM saturation model

• AB: Adeluyi and Bertulani, PRC85 (2012) 044904
LO pQCD calculations: AB-MSTW08 assumes no nuclear effects for the gluon distribution, other AB models incorporate gluon shadowing effects according to the EPS08, EPS09 or HKN07 parameterizations

• CSS: Cisek, Szczurek, Schäfer, PRC86 (2012) 014905
Glauber approach accounting c̅cg intermediate states

• RSZ: Rebyakova, Strikman, Zhalov, PLB 710 (2012) 252
LO pQCD calculations with nuclear gluon shadowing computed in the leading twist approximation

• LM: Lappi, Mäntysaari, PRC87 (2013) 032201
colour dipole model + saturation

COHERENT

Agreement is best for models incorporating nuclear gluon shadowing.
**J/ψ Production-Pb-Pb**

**MUONS**

\( p_T > 200 \text{ MeV/c} \)

- First measurement in Pb-Pb. Helps to constrain models
- Note photon flux cancels between coherent and incoherent measurements, so ratio coherent/incoherent is also a useful parameter.
- STARLIGHT overshoots both but gets ratio right.
First measurement of $\psi(2S)$ production at LHC energies
Models with moderate shadowing favoured.

Several channels used:
$\psi(2S) \rightarrow \mu^+\mu^-$
$\psi(2S) \rightarrow e^+e^-$
$\psi(2S) \rightarrow J/\psi \pi^+\pi^-; \quad J/\psi \rightarrow \mu^+\mu$
$\psi(2S) \rightarrow J/\psi \pi^+\pi^- \quad J/\psi \rightarrow e^+e^-$

• First measurement of mid-rapidity $dN/dy$ at LHC (consistent with GM (colour dipole) and STARLIGHT)

• Energy dependence consistent with STARLIGHT
Our knowledge of the photon emitter allows us to solve for \( \sigma(W_{\gamma p}) \) using the measured \( d\sigma/dy \)

A power law fit \( (\sigma(W) \sim W^\delta) \) to ALICE data points gives \( \delta = 0.67 \pm 0.06 \).

\[
\frac{d\sigma}{dy}(p + Pb \rightarrow p + Pb + J / \psi) = k \frac{dk}{d\sigma} \sigma(W_{\gamma p})
\]
Our knowledge of the photon emitter allows us to solve for $\sigma(W_{\gamma p})$ using the measured $d\sigma/dy$.

A power law fit ($\sigma(W) \sim W^\delta$) to ALICE data points gives $\delta=0.67\pm0.06$.

$$\frac{d\sigma}{dy}(p + Pb \rightarrow p + Pb + J/\psi) =$$

**ALICE Measurements**

- H1: $\delta=0.67\pm0.03$
- ZEUS: $\delta=0.69\pm0.02$
• Our knowledge of the photon emitter allows us to solve for $\sigma(W_{\gamma p})$ using the measured $d\sigma/dy$

• A power law fit ($\sigma(W) \sim W^\delta$) to ALICE data points gives $\delta = 0.67 \pm 0.06$.
Our knowledge of the photon emitter allows us to solve for $\sigma(W_{\gamma p})$ using the measured $d\sigma/dy$.

A power law fit $\left(\sigma(W) \sim W^\delta\right)$ to ALICE data points gives $\delta = 0.67 \pm 0.06$. 

**References:**

- J/ψ pPb
- ALICE

- Power law fit to ALICE data
- LHCb pp data ($W^+$ solutions)
- LHCb pp data ($W^-$ solutions)

**Figures:**

- Power law fit to ALICE data
- LHCb pp data ($W^+$ solutions)
- LHCb pp data ($W^-$ solutions)

- Phys. Rev. Lett. 113 (2014) 23250

- JMRT S.P. Jones et al., JHEP 1311 (2013) 085
- b-Sat H. Kowalski, L. Motyka and G. Watt. PRD 74 074016
- LHCb A. Aaij et al. J. Phys. G 41 055002

18/12/2018 O. Villalobos Baillie - LHC Forward Physics
Central and semi-forward points added

New configurations confirm original forward spectrometer results

Power law fit ($\sigma(W)\sim W^\delta$) to ALICE data points gives $\delta=0.70\pm0.05$.

All models considered agree with data.
J/$\psi$ pPb with new points

NEW

arXiv:1809.03235

CCT:
- Includes saturation in an energy dependent hot spot model.
- PLB766(2017) 186

JMRT NLO
- DGLAP formalism with main NLO contributions included.
- EPJC76 (2016) 633

Starlight:
- Parameterisation of HERA and fixed target data.
- CPhC 212 (2017) 258

NLO BFKL
- Proton impact factor from F2 HERA data.
- PRD94 (2016) 054002

CGC
- CGC models with saturation.
- PRD90 (2014) 054003

Combines forward, central and semi-forward configurations
Run 2
Run2 Luminosity

<table>
<thead>
<tr>
<th>Pb Pb</th>
<th>Run 1</th>
<th>2015</th>
<th>2018</th>
<th>Run 2</th>
<th>pPb</th>
<th>Run 1</th>
<th>Run 2</th>
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<tbody>
<tr>
<td>Vs</td>
<td></td>
<td>2.76</td>
<td>5.02</td>
<td>5.02</td>
<td>Vs</td>
<td>5.02</td>
<td>5.02</td>
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<tr>
<td>μb⁻¹</td>
<td>μb⁻¹</td>
<td>μb⁻¹</td>
<td>μb⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mid-rapidity</td>
<td>23</td>
<td>94.6</td>
<td>250</td>
<td>mid-rapidity</td>
<td>6.92</td>
<td>2.7</td>
<td></td>
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<tr>
<td>Forward</td>
<td>55</td>
<td>216.8</td>
<td>546</td>
<td>Forward</td>
<td>pPb</td>
<td>3.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Pbp</td>
<td>4.5</td>
<td>11.9</td>
<td></td>
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</tr>
</tbody>
</table>

Run 2 benefits from:-

- (mostly) increased luminosity
- Higher cross section
- More effective triggers
- New Forward Detector (AD)
Forward J/\psi

- Run 2 PbPb2015: ~50 \times run 1 statistics!
- Data consistent with moderate nuclear shadowing

**ALICE Preliminary Pb+Pb \rightarrow Pb+Pb+J/\psi \quad s_{\text{NN}} = 5.02 \text{ TeV}

\begin{itemize}
  \item Impulse approximation: No nuclear effects
  \item STARLIGHT: VDM + Glauber
  \item EPS09 L0: EPS09 shadowing
    (Guzey, Kryshen, Zhalov, PRC \textbf{93} (2016) 055206)
  \item LTA: Leading Twist Approximation
    (Guzey, Kryshen, Zhalov, PRC \textbf{93} (2016) 055206)
  \item CGC GM: color dipole model + IIM/BCGC
  \item CGC LM: Color dipole model + IPSat
    (Lappi, Mantysaari, PRC \textbf{83} (2011)065202; \textbf{87} (2013) 032201)
  \item GG-HS: hot spots with Glauber-Gribov
    (Cepila, Contreras and Krelina, PRC \textbf{97} (2018) 024901)
  \item GS-HS: hot spots with geometrical scaling
    (Cepila, Contreras and Krelina, \textit{ibid.})
\end{itemize}
Extraction of low $x$ and high $x$ contributions

- Kinematics provides $d\sigma/dy$, but this is not uniquely linked to $d\sigma/dx$

$$\frac{d\sigma}{dy} = n(y) \left. \frac{d\sigma_{\gamma\text{Pb}}}{dy} \right|_y + n(-y) \left. \frac{d\sigma_{\gamma\text{Pb}}}{dy} \right|_{-y}$$

High-$x$ \hspace{1cm} Low-$x$

- Flux factors $n(\pm y)$ can be precisely calculated, but still leaves two unknown cross sections.

- However, ZDC can help resolve the ambiguity. Look at neutron emission to decouple contributions.
Decoupling of $x$-contributions

- Fluxes including neutron emission can be calculated precisely. So, in notation where $0N0N$ means no emission and (e.g.) $0NXN$ means one sided neutron emission, we have

\[
\frac{d\sigma_{0N0N}}{dy} = n_{0N0N} (y) \frac{d\sigma_{\gamma Pb}}{dy} \bigg|_{+y} + n_{0N0N} (-y) \frac{d\sigma_{\gamma Pb}}{dy} \bigg|_{-y}
\]

\[
\frac{d\sigma_{0NXN}}{dy} = n_{0NXN} (y) \frac{d\sigma_{\gamma Pb}}{dy} \bigg|_{+y} + n_{0NXN} (-y) \frac{d\sigma_{\gamma Pb}}{dy} \bigg|_{-y}
\]

2 equations
2 unknowns
OK
Peripheral collisions

In peripheral Pb-Pb collisions, \( b < R_1 + R_2 \), and hadronic interactions occur. However, the strong fields are still there, so photonuclear interactions can also still take place.

The very sharp low \( p_T \) peak in the peripheral \( p_T \) spectrum indicates this is happening.

The hadronic activity gives an indication of the impact parameter, and again gives us additional flux equations to disentangle the low-\( x \) and high-\( x \) contributions.

\[
\frac{d\sigma_{\gamma\text{Pb}}}{dy} \bigg|_{-y} = \left( n_{\gamma}^P (y) \frac{d\sigma_{\text{PbPb}}^U}{dy} - n_{\gamma}^U (y) \frac{d\sigma_{\text{PbPb}}^P}{dy} \right) / F(y) \\
\frac{d\sigma_{\gamma\text{Pb}}}{dy} \bigg|_{y} = \left( n_{\gamma}^U (-y) \frac{d\sigma_{\text{PbPb}}^P}{dy} - n_{\gamma}^P (-y) \frac{d\sigma_{\text{PbPb}}^U}{dy} \right) / F(y)
\]

J.G. Contreras PRC 96 (2017) 015203

ALICE PRL 116 (2016) 222301
\( \rho^0 \) cross section at 5.02 TeV

- **GKZ:** Gribov-Glauber shadowing. Guzey et al, PLB752 (2016) 51, PRC93 (2016) 055206

\( p \) photoproduction cross section compatible with STARLIGHT but Gribov-Glauber shadowing predictions are still above data
Other results in the pipeline

• We expect to release results on central $J/\psi$, $\psi(2S)$ and $\rho^0$ shortly.
• We are analysing (in particular) the Pb-p 8.16 TeV forward $J/\psi$ data, which will allow us to measure the $\gamma p$ energy spectrum up to higher than 1 TeV.
• Study of $\rho^0$ production in 5.44 TeV Xe-Xe collisions well underway. New handle on system size dependence.
• Data just taken (2018) in 5.02 TeV Pb-Pb promise higher statistics at forward rapidity than 2015 data. Allows more differential studies.
Run 3/4
New readout and detectors

• To cope with the increased collision rate for Run 3 we will have a major upgrade in LS2, in which detectors will prepare for continuous readout.

• Most ALICE signatures are complex and are embedded in very high multiplicity events: not suitable for conventional triggers.

• Instead, in continuous readout, all data are read out and analysed by a huge processor farm, allowing selections to be made on fully processed events.
  • Pb-Pb. Record everything
  • pp, pPb (?) filter in HLT before recording.

• Triggering limited to flagging bunch crossings in which “something happened” as pointers for reconstruction.

• In principle challenging for UPC, as here the minimum bias trigger does not fire.
In runs 1 and 2, VZERO, FMD and SPD were so arranged as to provide continuous rapidity cover in $-3.7 < y < 5.4$.

They will be replaced by a new ITS, and a new Fast Interaction Trigger (FIT) consisting of upgraded V0 and T0 elements, adapted for continuous readout.

This allows us to tag or veto dissociative production in p-Pb, and improve the purity of the exclusive J/ψ sample in Pb-Pb.

There are predictions that dissociative photoproduction might be sensitive to gluon saturation in the proton (Cepila, Contreras and Tapia Takaki, PL B766 (2017) 186)
UPC events in Run 3

• Look in time intervals with primary vertex formed from two tracks, and follow them to TOF to look for associated hit, which gives bunch crossing of collision. Require at least one match.

• Verify that vetoes are satisfied for specified bunch crossing.

• ADVANTAGE – Reduced trigger efficiency losses

• ADVANTAGE – No competition with other signatures of interest for bandwidth. We collect everything.
Potential for measurement

• In ALICE, the yields are to be calculated on an expected run 3-4 integrated luminosity of

  13 nb\(^{-1}\) (Pb-Pb); 1 pb\(^{-1}\) p-Pb; 6 pb\(^{-1}\) (pp 5.5 TeV); 200 pb\(^{-1}\) (pp 14 TeV)

(latest figures)

• All signatures for heavy vector mesons (forward, central, semi-forward).

• Next slides show potential yields estimated using STARlight, adjusted for nuclear shadowing
  • No correction for acceptance or reconstruction efficiency beyond enforcing rapidity coverage.
  • Branching ratios taken into account
## Expected yields – Pb-Pb

For comparison, in run 2 we collected about 6K \( \psi \) events in the “Forward 1” interval (\( \mathrm{PbPb2015} \))

### Table: Expected yields – Pb-Pb

<table>
<thead>
<tr>
<th>Meson</th>
<th>( \sigma )</th>
<th>All</th>
<th>Central 1</th>
<th>Central 2</th>
<th>Forward 1</th>
<th>Forward 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Total</td>
<td>Total</td>
<td>Total 1</td>
<td>Total 1</td>
</tr>
<tr>
<td>( \rho \to \pi^+\pi^- )</td>
<td>5.2b</td>
<td>68 B</td>
<td>5.5 B</td>
<td>21 B</td>
<td>4.9 B</td>
<td>13 B</td>
</tr>
<tr>
<td>( \rho' \to \pi^+\pi^-\pi^+\pi^- )</td>
<td>730 mb</td>
<td>9.5 B</td>
<td>210 M</td>
<td>2.5 B</td>
<td>190 M</td>
<td>1.2 B</td>
</tr>
<tr>
<td>( \phi \to K^+K^- )</td>
<td>0.22b</td>
<td>2.9 B</td>
<td>82 M</td>
<td>490 M</td>
<td>15 M</td>
<td>330 M</td>
</tr>
<tr>
<td>( J/\psi \to \mu^+\mu^- )</td>
<td>1.0 mb</td>
<td>14 M</td>
<td>1.1 M</td>
<td>5.7 M</td>
<td>600 K</td>
<td>1.6 M</td>
</tr>
<tr>
<td>( \psi(2S) \to \mu^+\mu^- )</td>
<td>30 ( \mu ) b</td>
<td>400 K</td>
<td>35 K</td>
<td>180 K</td>
<td>19 K</td>
<td>47 K</td>
</tr>
<tr>
<td>( Y(1S) \to \mu^+\mu^- )</td>
<td>2.0 ( \mu ) b</td>
<td>26 K</td>
<td>2.8 K</td>
<td>14 K</td>
<td>880 K</td>
<td>2.0 K</td>
</tr>
</tbody>
</table>

CERN-LPCC-2018-07

\[ \text{13 pb}^{-1} \text{ Pb-Pb} \]
Expected yields – pPb

Central 1: $|y|<0.9$; Central 2: $|y|<2.4$; Forward 1: $2.5<y<4.0$; Forward 2: $2<y<5$

<table>
<thead>
<tr>
<th>Meson</th>
<th>$\rho \rightarrow \pi^+\pi^-$</th>
<th>$\phi \rightarrow K^+K^-$</th>
<th>$J/\psi \rightarrow \mu^+\mu^-$</th>
<th>$\psi(2S) \rightarrow \mu^+\mu^-$</th>
<th>$Y(1S) \rightarrow \mu^+\mu^-$</th>
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</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>35 mb</td>
<td>870 $\mu$b</td>
<td>6.2 $\mu$b</td>
<td>134 nb</td>
<td>5.74 nb</td>
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<tr>
<td>Total</td>
<td>70 B</td>
<td>1.7 B</td>
<td>12 M</td>
<td>270 K</td>
<td>11 K</td>
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<tr>
<td>Total</td>
<td>3.9 B</td>
<td>65 B</td>
<td>1.0 M</td>
<td>22 K</td>
<td>1.1 K</td>
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<tr>
<td>FW 1</td>
<td>15 B</td>
<td>290 M</td>
<td>5.2 M</td>
<td>110 K</td>
<td>5.4 K</td>
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<td>Total</td>
<td>2.0 B</td>
<td>120 M</td>
<td>6.0 K</td>
<td>18 K</td>
<td>41 K</td>
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<tr>
<td>FW 2</td>
<td>5.5 B</td>
<td>800 K</td>
<td>800 K</td>
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<td>Total</td>
<td>850 M</td>
<td>9.7 M</td>
<td>430 K</td>
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<td>52 M</td>
<td></td>
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</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>BW 2</td>
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<table>
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<tr>
<th>Meson</th>
<th>$\rho \rightarrow \pi^+\pi^-$</th>
<th>$\phi \rightarrow K^+K^-$</th>
<th>$J/\psi \rightarrow \mu^+\mu^-$</th>
<th>$\psi(2S) \rightarrow \mu^+\mu^-$</th>
<th>$Y(1S) \rightarrow \mu^+\mu^-$</th>
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<tbody>
<tr>
<td>$\sigma$</td>
<td>531 $\mu$b</td>
<td>23 $\mu$b</td>
<td>333 nb</td>
<td>8.9 nb</td>
<td>0.43 nb</td>
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<td>Total</td>
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<td>670 K</td>
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<td>Total</td>
<td>83 M</td>
<td>1.3 M</td>
<td>55 K</td>
<td>1.5 K</td>
<td>93</td>
</tr>
<tr>
<td>Total</td>
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<td>7.9 K</td>
<td>460</td>
</tr>
<tr>
<td>Total</td>
<td>20 M</td>
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<td>14K</td>
<td>380</td>
<td>14</td>
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<tr>
<td>Total</td>
<td>44 M</td>
<td>1.7 M</td>
<td>36 K</td>
<td>990</td>
<td>14</td>
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<td>Total</td>
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<td>BW 1</td>
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<tr>
<td>BW 2</td>
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</tbody>
</table>

Lead Emits photon
Proton Emits Photon $\leq 10$

1 pb$^{-1}$ pPb
Summary

• Run 1 harvest of results shows the potential of UPC in heavy ion collisions to study photonuclear processes.
  • Exclusive vector meson production the main route for ALICE
• Run 2 already yields considerably higher statistics. Studies now nearing completion will give more detailed information on production.
• Massive increase in statistics in runs 3 and 4 should allow very detailed differential distributions.
  • Detailed access to low-x region in gluon pdf for protons
  • Big improvement in understanding of nuclear shadowing from A-A collisions.
  • In pPb large sample allows separation of “lead-shine” (dominant) and “proton shine” components, where proton-shine allows new access to low-x Pb-Pb at x~10^{-5}. 

18/12/2018

O. Villalobos Baillie - LHC Forward Physics 40
Backup
\( \rho^0 \) photoproduction in Pb-Pb @ 5 TeV

\[
\frac{d\sigma}{dm_{\pi\pi}} = |A \cdot BW + B + C \cdot e^{i\Phi} \cdot BW|^2 + N \cdot \text{pol6}
\]

- Second diffractive peak clearly visible
- Coherent \( p_T \) distribution from STARLIGHT significantly wider than data

\( \rightarrow \) access impact-parameter dependent shadowing effects (e.g. Guzey, Strikman, Zhalov: PRC 95, 025204 (2017))