New measurements on diffractive vector mesons

S. Ragoni for the ALICE and LHCb Collaborations

University of Birmingham, UK
• Introduction to ultraperipheral collisions (UPC) and Central Exclusive Production (CEP)
• Very brief description of the ALICE and LHCb detectors
• J/ψ in Pb-Pb (or better, coherent J/ψ)
• Disentangling low and high Bjorken-x
• UPC potential for tetraquark searches
• Coherent $\rho^0$
Outline

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Introduction to UPC and CEP

- High impact parameter (beyond the reach of the strong interaction)
- Vector meson production
- E.g. $\rho^0, J/\psi, \psi(2S)$

Only QED involved at this vertex!

Hard scale assured by high mass states i.e. $J/\psi, \psi(2S)$

Semi-hard scale for $\rho^0$

- $p + p \rightarrow p + p + X$
- One or two gluon ladders involved (one in photoproduction)

Ryskin: Z. Phys. C 57, 89-92 (1993)
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• Impulse approximation: nucleus as incoherent sum of nucleons

• STARlight: generalised vector meson dominance model + HERA data (~baseline for comparisons)

• EPS09 (GKZ): generalised vector meson dominance model + nuclear shadowing

• ALICE data exhibit moderate nuclear shadowing

Forward analysis

-4.0 < η < -2.5

VETOES and ZDC used as vetoes

Forward
acceptance
and detectors

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
ALICE

Impulse approximation:
- nucleus as incoherent sum of nucleons

STARlight:
- generalised vector meson dominance model + HERA data (~baseline for comparisons)

EPS09 (GKZ):
- generalised vector meson dominance model + nuclear shadowing

ALICE data exhibit moderate nuclear shadowing

Midrapidity analysis

\[-0.9 < \eta < 0.9\]
ALICE

• Impulse approximation: nucleus as incoherent sum of nucleons
• STARlight: generalised vector meson dominance model + HERA data (~baseline for comparisons)
• EPS09 (GKZ): generalised vector meson dominance model + nuclear shadowing
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THE LHCb DETECTOR

\[ 1.5 < \eta < 5 \]
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Coherent $J/\psi$ cross section

- Impulse approximation: coherent sum of nucleons but nuclear effects ignored
- STARlight: Glauber-like model accounting for multiple interactions by a single dipole moving through the nucleus
- EPS09 (GKZ): nuclear shadowing
- ALICE data exhibit moderate nuclear shadowing
Coherent $J/\psi$ cross section

- ALICE in tension with EPS09 at semi-forward rapidity, while LHCb agrees with it.
Coherent $J/\psi$ cross section

- Nuclear suppression factor (easier at midrapidity)
  \[ S_{Pb} = \sqrt{\frac{d\sigma}{dy_{\text{data}}}} / \frac{d\sigma}{dy_{\text{IA}}} \approx 0.63 \]

- IA = Impulse Approximation (no nuclear effects)

- $S(W_{\psi})$ - Nuclear Suppression Factor - provides a way to test the consistency of the data with the available nuclear and nucleon PDFs and to measure the gluon shadowing factor
Coherent $J/\psi$ $t$-dependence

- From $p_T^2$-dependent photoproduction to $|t|$-dependent photonuclear production

$$\left. \frac{d^2 \sigma^\text{coh}_{J/\psi}}{dy dp_T^2} \right|_{y=0} = 2 n_{\gamma\text{Pb}}(y = 0) \frac{d\sigma_{\gamma\text{Pb}}}{d|t|}$$

- Probing the transverse gluonic structure of the nucleus at low $x$
LHCb and ALICE results have already advanced the field

\[ S(W_{\gamma p}) = \left[ \frac{\sigma_{\gamma Pb \rightarrow J/\psi Pb}^{\text{exp}}(W_{\gamma p})}{\sigma_{\gamma Pb \rightarrow J/\psi Pb}^{\text{IA}}(W_{\gamma p})} \right]^{1/2} \]

Guzey, Kryshen, Strikman, Zhalov, Phys.Lett.B 816 (2021) 136202

Talk from Vadim Guzey earlier in this session!
• Introduction to ultraperipheral collisions (UPC) and Central Exclusive Production (CEP)

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Techniques to solve the Bjorken-\(x\) ambiguity

**Neutron emission principle:**
- \(x = \frac{MV_M}{\sqrt{S_{NN}}} \cdot e^{\pm y}\)
- Ambiguity due to sign in the rapidity of the photon emitter \(\rightarrow 10^{-2}, 10^{-5}\) ??
- Additional photon exchanges may lead to neutron emission

**Peripheral photoproduction:**
- \(b < R_1 + R_2\)
- Hadronic interactions + photoproduction maybe...?
- If so:

\[
\frac{d\sigma_{PbPb}}{dy} = n_P(\gamma, +y) \cdot \sigma_{Pb}(+y) + n_P(\gamma, -y) \cdot \sigma_{Pb}(-y)
\]

\[
\frac{d\sigma_{P'Pb}}{dy} = n_U(\gamma, +y) \cdot \sigma_{Pb}(+y) + n_U(\gamma, -y) \cdot \sigma_{Pb}(-y)
\]

Guzey et al., Eur.Phys.J.C 74 (2014) 7, 2942

J.G. Contreras PRC 96 (2017) 015203

- Simultaneously use UPC and peripheral results to get rid of the ambiguities!

Brez et al.: CPC 253 (2020) 107181
Peripheral J/ψ photoproduction

- First observed with Run 1 data by ALICE
- Now confirmed with Run 2 statistics by both ALICE and LHCb. STAR also reports this

ALICE, EPL (Europhysics Letters), Volume 129, Number 4

STAR Collaboration, PRL 123, 132302 (2019)

DIS talk by Óscar Boente García on behalf of the LHCb Collaboration

LHCb-PAPER-2020-043 in preparation
Peripheral J/ψ photoproduction

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5. UPC potential for tetraquark searches

6. Coherent $\rho^0$
UPC potential for tetraquark discoveries

- LHCb has observed a state interpreted as a tetraquark state $T_{ccar{c}ar{c}}$ in inclusive sample

LHCb, arxiv: 2006.16957[hep-ex]

V. Gonçalves, B. Moreira, Phys. Lett. B 816 (2021) 136249:

UPC potential for tetraquark searches in ALICE and LHCb!
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• Coherent $\rho^0$
Coherent $\rho^0$ in Pb-Pb

- Generally good agreement with models on the market
- A good proof-of-principle while waiting for reduced uncertainties and better agreement between models
- Different neutron emission classes = different impact parameters
- $\langle b_{XN\bar{X}N} \rangle < \langle b_{XN0N} \rangle < \langle b_{0N0N} \rangle$
- Factorization holds
Coherent $\rho^0$ in Pb-Pb

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Coherent $\rho^0$ in Pb-Pb

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- A good proof-of-principle while waiting for reduced uncertainties and better agreement between models
- Different neutron emission classes = different impact parameters
- $\langle b_{XN\pi} \rangle < \langle b_{XN0N} \rangle < \langle b_{0N0N} \rangle$
- Factorization holds

ALICE, JHEP06 (2020) 35
Coherent $\rho^0$ and BDR

- Three collision systems available now ($p$, Pb, Xe)
- First fit to obtain the A dependence!
- Black disk regime (BDR) quite far away
- Models based on Gribov-Glauber shadowing (GKZ) or hot-spots (CCKT) describe the data reasonably well
Summary and a personal wishlist for the future

Shown here:

• Coherent J/ψ: the current state-of-the-art for ALICE and LHCb
• Nuclear suppression factor and how LHCb and ALICE have already helped a lot
• Ways to extract $x \sim 10^{-5}$: neutron emission and peripheral photoproduction
• Coherent $\rho^0$ and how we are still missing the black disk regime
• UPC still have a lot to say!

Questions for a future:

• Neutron emission with coherent $J/\psi \to x \sim 10^{-5}$ with nuclear targets...?
• $\rho^0$ is properly speaking a semi-hard scale... But pQCD works quite well. Could we say something more about this...?
• Increased statistics might lead to higher $|t|$ to improve our knowledge of the transverse gluonic distribution
• Tetraquark searches in UPC?

For all of us feeling nostalgic about CERN!
Backup slides
Coherent vs incoherent J/ψ

• Coherent (dimuon $p_T < 0.25$ GeV/c) cleaner peak – photon couples to entire nucleus coherently
• Incoherent much wider $p_T$ distribution – photon interacts with a single nucleon of the target nucleus

Plots in the dimuon channel (only available channel at forward rapidity)
Coherent vs incoherent $J/\psi$

• Coherent (dimuon $p_T < 0.25$ GeV/c) cleaner peak – photon couples to entire nucleus coherently
• Incoherent much wider $p_T$ distribution – photon interacts with a single nucleon of the target nucleus

Plots at midrapidity
Mass peak for LHCb