UPC physics with ALICE in Run 3

Anisa Khatun (for the ALICE Collaboration)
The University of Kansas

UPC 2023: International workshop on the physics of Ultra Peripheral Collisions
Playa del Carmen
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Ultra-Peripheral Collisions (UPCs) provide a tool to probe the nucleus and nucleons

ALICE is developing a comprehensive physics program [ALICE, arXiv:2211.04384]

Unique in ALICE: Good acceptance for both charged particles, photons at low $p_T$ and excellent particle identification at midrapidity

Run 3 opens a new window to explore novel physics processes

Ions still interact via electromagnetic processes

Photon breaks up target nuclei

No hadronic interaction

Typical exclusive VM production in UPC

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The ALICE experiment in Run 3

FT0-A : $3.8 < \eta < 5.0$
FT0-C : $-3.4 < \eta < -2.3$
FV0 : $2.2 < \eta < 5.0$
FDD-A : $4.7 < \eta < 6.3$
FDD-C : $-6.9 < \eta < -4.9$

ZDC
Zero Degree Calorimeter

ZDC : $4.8 < \eta < 5.7$
MCH : $-4.0 < \eta < -2.5$
MFT : $-3.6 < \eta < -2.5$

FT0-C : $-3.4 < \eta < -2.3$

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The ALICE experiment in Run 3

New common online-offline computing system

- The designed interaction rate was 8 kHz for Pb–Pb and 100 kHz for pp collisions in Run 2.
- To cope up with an increased interaction rate of up to 50 kHz for Pb–Pb, 500 kHz for p-Pb and 1 MHz for pp collisions in continuous readout mode.
- To collect a data sample more than 10 times larger than the combined Run 1 and Run 2 samples.

[Quality control
AO2D
Physics analysis

On-site storage]

BEAM ON: data reduction

BEAM OFF: improved calibration

EPN input data quantum is the "timeframe": 23 ns of continuous readout data. ~10 GB

Progress on UPCs at ALICE

Run 1: ~ 7k events

ALICE Pb-Pb $|s_{NN}| = 2.76$ TeV

$\rho^+(\pi^+\pi^-) < 0.15$ GeV/c

$M_{\pi^+\pi^-}$ (GeV/c$^2$)

$\sigma$ (b/GeV c$^2$) $|y| < 0.5$

- ALICE, stat. errors
- Söding (res.-cont.)
- BW resonance
- Ross-Stodolsky

Low $|y| < 0.9$ 2.5 $|y| < 4$

Run 2: ~ 60k events

ALICE Pb-Pb UPC $|s_{NN}| = 5.02$ TeV

$\rho_1 < 0.2$ GeV/c $|y| < 0.8$

No possible with continuous readout!

Significant increase in statistics in Run 3!

Integrated luminosity:
1 nb$^{-1}$ (Run 2) -> 13 nb$^{-1}$ (Run 3 + Run 4)

CERN Yellow Rep. Monogr. 7 (2019) 1159-1410
**UPC program in Run 3 so far**

- LHC faced cryo incident affected pp data taking
- Despite the issues we were able to collect large sample pp data (see next slides for details)
- LHC faced vacuum incident and postponed pp reference data taking for 2024
- First Pb-Pb data taking with 2 kHz hadronic interaction rate recorded on 26th September
- Data is taken successfully with 45 kHz Hadronic Interaction Rate!

- About 1.5 nb$^{-1}$ of integrated luminosity in 2023
- Collected x40 larger sample of minimum bias events in Run 3 compared to Run 1 + Run 2!
- 1.5 nb$^{-1}$ is x3000 larger than integrated luminosity used in $\rho^0$ analysis of Run 2 data

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**ALICE Performance, 2023**

Pb–Pb, $\sqrt{s_{NN}} = 5.36$ TeV

Recorded: 1535.5 µb$^{-1}$

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As in Run 2, to select an exclusive vector meson UPC event
we require no signal in the FIT and further empty ZDCs
Possible to veto signals in individual detectors in Run 3
More flexibility, possible to select inclusive, semi-inclusive UPC events
Ongoing UPC activity in Run 3

Clear peak of coherent $\rho^0$ and $J/\psi$ in Pb-Pb UPCs at $\sqrt{s_{NN}} = 5.36$ TeV
Both coherent and incoherent are shown in the transverse momentum distribution

-4 < $\eta_p$ < -2.5
2.85 < $M_{\pi\pi}$ < 3.25 GeV/c²

Counts (20 MeV/c²)
Precision study of vector meson photoproduction in UPCs with significant increase in integrated luminosity

Uncertainties for nuclear suppression factor are expected to be at the level of 4% [CERN Yellow Rep. Monogr. 7 (2019) 1159-1410]. Double vector meson photoproduction

UPC bottomonia production [arXiv:2303.03007v1]

Exclusive $\phi$ production in the dikaon channel (currently done with Run 2 data in ALICE [arXiv:2311.11792] - See talk by Minjung Kim)

Exclusive production of a much wider range of particles, including excited vector mesons and searches for exotica- e.g. X(3872)
UPC Physics prospects in Run 3 and beyond: Exclusive vector meson photoproduction with FoCal

- FoCal: Part of ALICE upgrade for Run 4 (starting from 2029)- See talk by Ionut Cristian Arsene
- Positioned 7 m from IP2 (A-side), covering $3.4 < \eta < 5.8$
- Dissociative $J/\psi$ in Run 3 with FOCAL acceptance in Run 4

- Exclusive $J/\psi$ and $\psi(2S)$ ($+\text{Run 4 with Focal acceptance}$) in p-Pb UPCs


Measurement of $\tau$ anomalous magnetic moment

$\gamma\gamma$ interaction in UPC: Measuring light-by-light scattering in Pb-Pb and looking for resonances in the invariant mass distributions -> Axion Like Particles (ALPs) [ATLAS, JHEP 11 (2021) 050]

Axions are likely lighter particles, ALICE can potentially push down the search to 1 GeV with focus on low invariant masses [PRD 99 (2019) 9, 093013]

Tetraquarks: $\gamma\gamma \rightarrow T_{4c} \rightarrow 4l$ [PLB 816 (2021) 136249]

Inclusive/semi inclusive UPCs e.g. inclusive J/$\psi$, jets in UPCs

What one could possibly do in ALICE? A personal wish list!
Study of diffraction reactions (exchange of colourless objects)

- **$\gamma\gamma$ interaction**
  - Final state: $l^+l^-$, meson or photon pairs (light-by-light scattering)

- **Double-pomeron exchange**
  - Final state: enhanced production of gluon-rich final states

- **$\gamma$ pomeron interaction**
  - Final state: vector mesons or dijets

- CEP events are studied using double-gap topology in ALICE central barrel at mid rapidity
- The tracks are selected within central barrel having no signal at the FIT detectors
- About 29 pb$^{-1}$ of integrated luminosity recorded in pp collisions at $\sqrt{s} = 13.6$ TeV in 2022 and 2023. (We collected ~8 pb$^{-1}$ in Run 2!)

ALICE Performance, Run 3, pp, $\sqrt{s} = 13.6$ TeV
Recorded: 29.0 pb$^{-1}$
Central Exclusive Production (CEP) at ALICE

- Particle Identification carried by TPC down to low $p_T$ based on specific energy loss (pion, kaon hypothesis)
- The events are selected with two opposite charge tracks
- Visible resonance in raw invariant mass distributions of opposite-sign pions and kaons
- It will be possible to study strangeness in double gap events with $\phi(1020)$ and $f_2(1525)$ states

ALICE performance
Run 3 pp $\sqrt{s} = 13.6$ TeV
Luminosity = 0.28 pb$^{-1}$

Fraction of $\pi^+\pi^-$ candidates

Visible resonance in raw invariant mass distributions of opposite-sign pions and kaons

2% of 2022 pp data
KK-pairs DG events

ALI-PERF-551097
ALI-PERF-545710

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Conclusion and Outlook

- Exciting time for UPCs in Run 3 and Run 4
- ALICE already collected interesting data in both Pb-Pb and pp collisions. Also prospects for p-Pb data in the near future
- Precision measurements, new resonances as well as new physics!
- Strangeness, heavy-quarkonia (Upsilon), open charm in UPCs
- New physics searches: ALPs, Tetraquarks
- Inclusive UPCs
- New analysis framework capable of handling the event rates expected during Run 3 and beyond!
- Work and development in progress, stay tuned!
Gracias!