

QWG

Quarkonium photoproduction in nuclear collisions at the LHC

QWG 2022

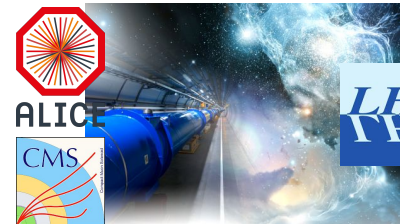
@GSI Darmstadt



South China Normal University

Qiuchan LU,
on behalf of LHCb, CMS, ALICE Collaboration

27th September 2022



UPC as a Υ -p, Υ -Pb collider

Ultra-peripheral collisions:

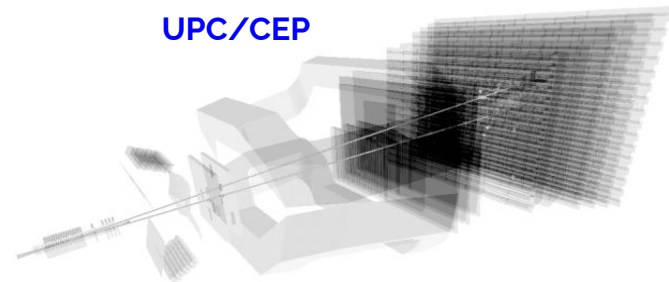
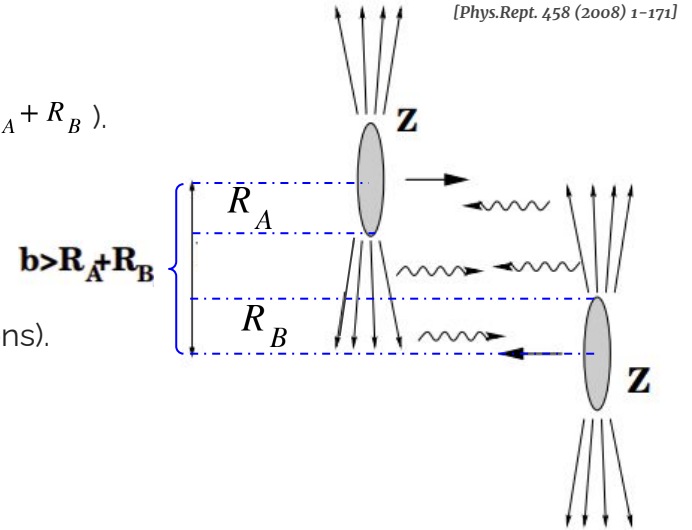
- ❑ Strong EM fields produced by Lorentz-contracted nuclei.
- ❑ Occurs when impact parameter(b) is **larger** than the sum of their radii($R_A + R_B$).
- ❑ Two ions interact via their cloud of virtual photons.

High photon flux:

- ❑ Well described in Weizsäcker-Williams approximation (quasi-real photons).
- ❑ Photon flux proportional to Z^2 .
- ❑ High cross section for Υ -induced reactions.

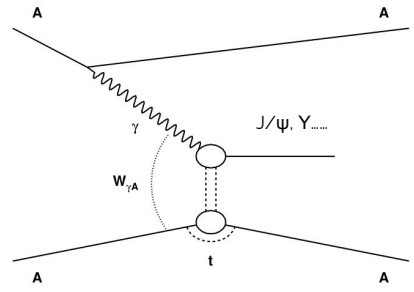
Characteristic properties:

- ❑ Low momentum transfer
- ❑ No additional particle production
- ❑ Hardonic interaction strongly suppressed
- ❑ Heavy ions:
 - ❑ 30 times energy available
 - ❑ multi-photon excitations

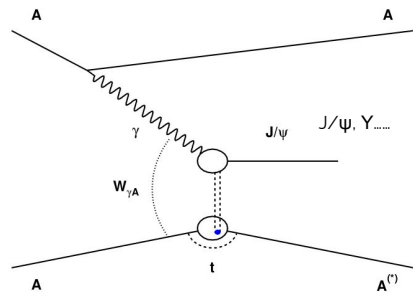


Quarkonia photoproduction in UPC

Test of QCD



a) Coherent photoproduction
 photon interacts with a pomeron emitted by **entire nucleus**
 $p_T^2 \approx 0.001 (GeV/c)^2$



b) Incoherent photoproduction
 photon interacts with a pomeron emitted by **a single nucleon**
 $p_T^2 \approx 0.05 (GeV/c)^2$

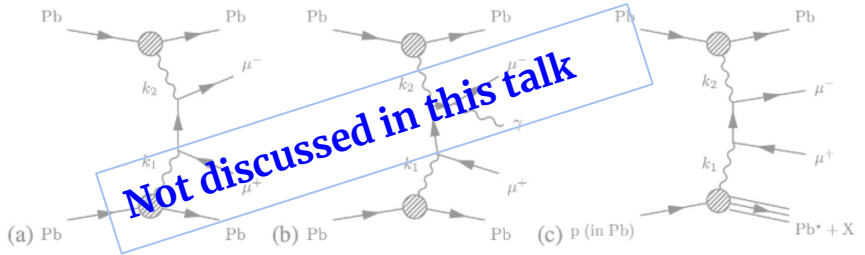
➔ To image the nucleon/nucleus structure:

- ❑ Nucleon and nuclear PDF
- ❑ Gluon shadowing effect, saturation effect
- ❑ Gluon density distributions at low-x

$$x = \frac{\sqrt{m^2 + p_T^2}}{\sqrt{s}} e^{\pm y} \approx 10^{-5} \sim 10^{-2}$$

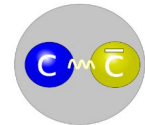
- ❑ Ratio of charmonium indicates the correct vector meson wave function in dipole scattering models [PLB 772 (2017) 832, PRC (2011) 011902]

Test of QED



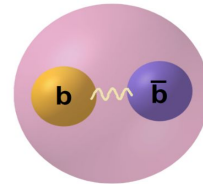
Not discussed in this talk

c) Photon-photon interactions



Charmonium

- ✓ large cross section
- ✗ Sizable regeneration
- ✗ Sizable co-mover dissociation



Bottomonium

- ✓ Negligible regeneration
- ✓ Negligible co-mover dissociation
- ✓ A much cleaner probe
- ✗ Small production cross section

Results from

Ultra-peripheral collision @PbPb

1. Coherent J/ψ photoproduction at forward rapidity in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV @ALICE
[Physics Letters B, (2019) 798:134926]
2. Coherent J/ψ and ψ' photoproduction at midrapidity in ultra-peripheral Pb–Pb collisions at $s_{NN} = 5.02$ TeV @ALICE
[Eur. Phys. J. C 81 (2021) 712]
3. Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{NN}}=5$ TeV
[JHEP 2207 (2022) 117] @LHCb
4. Study of the coherent charmonium production in ultra-peripheral lead-lead collisions
[arXiv:2206.08221] @LHCb

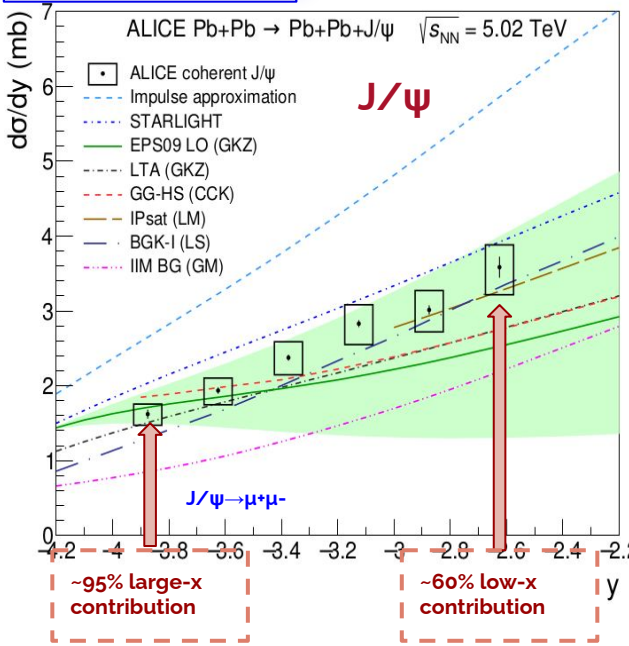


ALICE

Quarkonium UPC PbPb @5.02TeV

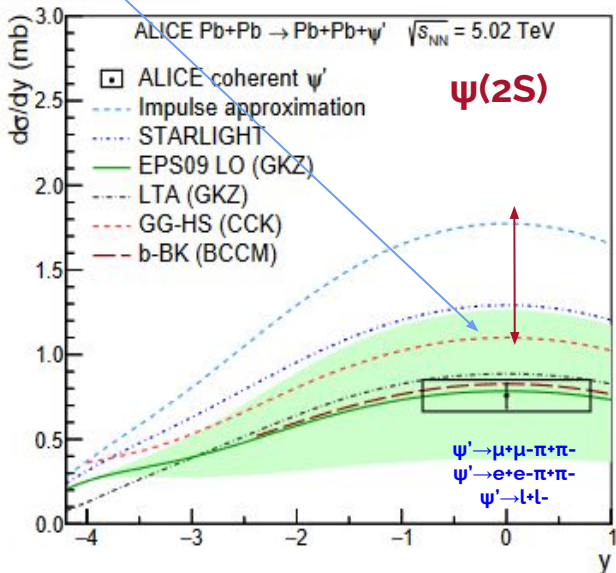
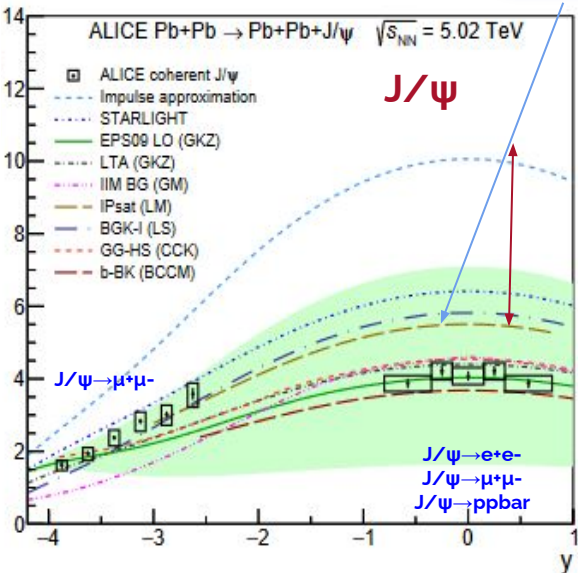
Forward Y

[Physics Letters B, (2019) 798:134926]



Mid Y

[Eur. Phys. J. C 81 (2021) 712]



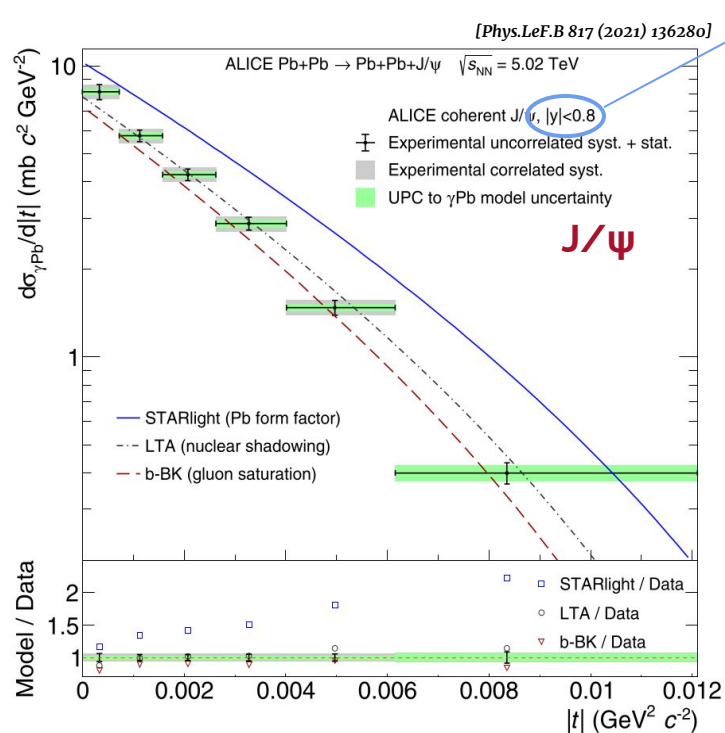
EPS09 LO central set in agreement with data.
 The other majority of color dipole models overpredict the data.
 Nuclear gluon shadowing factor at $x \sim (0.3, 1.4) \times 10^{-3}$:
 $J/\psi = 0.64 \pm 0.04$, $\psi(2S) = 0.66 \pm 0.06$.

STARLight model and **Impulse Approximation** overpredict data.
 The other majority of color dipole models underpredict the data.
 Nuclear gluon shadowing factor at $x \sim 10^{-2} = 0.8$



Quarkonium UPC PbPb @5.02TeV

$|t|$ = square of the momentum transferred between incoming and outgoing nucleus



Bjorken-x ragen (0.3-1.4) $\times 10^{-3}$

Dependence on $|t|$ of the photonuclear cross section for the coherent photo-production of J / ψ off Pb compared with model predictions.

- ☐ Probes the transverse partonic structure of the nucleus
- ☐ Poor description by **STARlight model** (driven by nuclear form factor)
- ☐ Agreement with models including nuclear shadowing (LTA) and **gluon saturation (b-BK)**

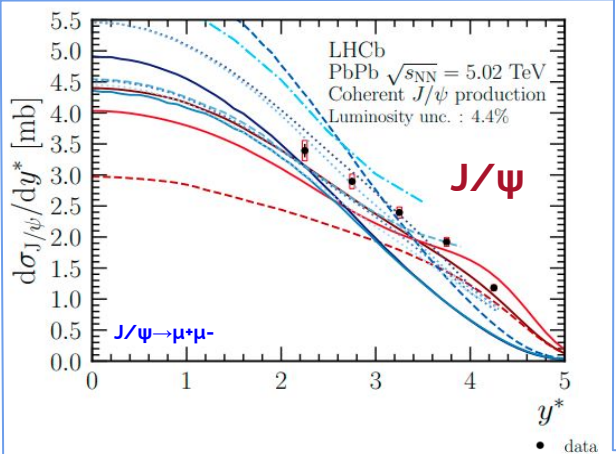
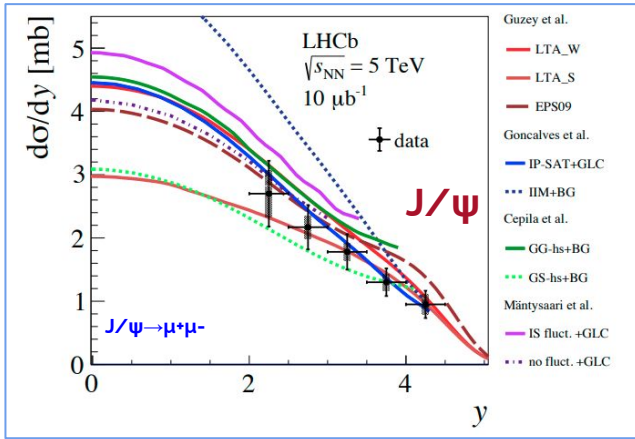
Quarkonium UPC PbPb @5.02TeV

→ LHCb better at low-x region

2015 PbPb

[JHEP 2207 (2022) 117]

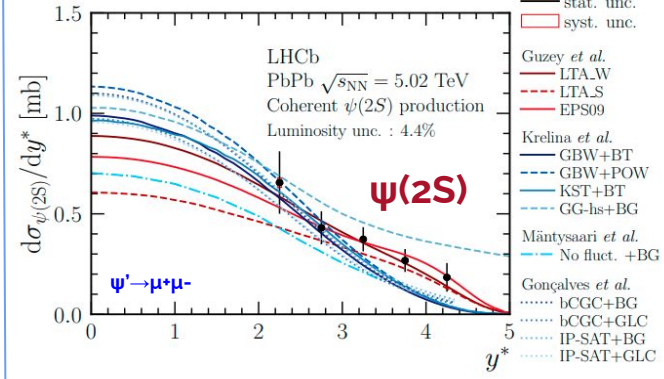
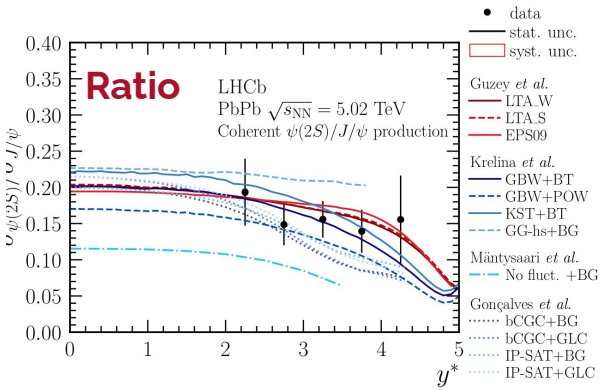
First UPC measurement at PbPb collision at LHCb.
Baseline for LHCb 2018 UPC analysis.



2018 PbPb

[arXiv:2206.08221]

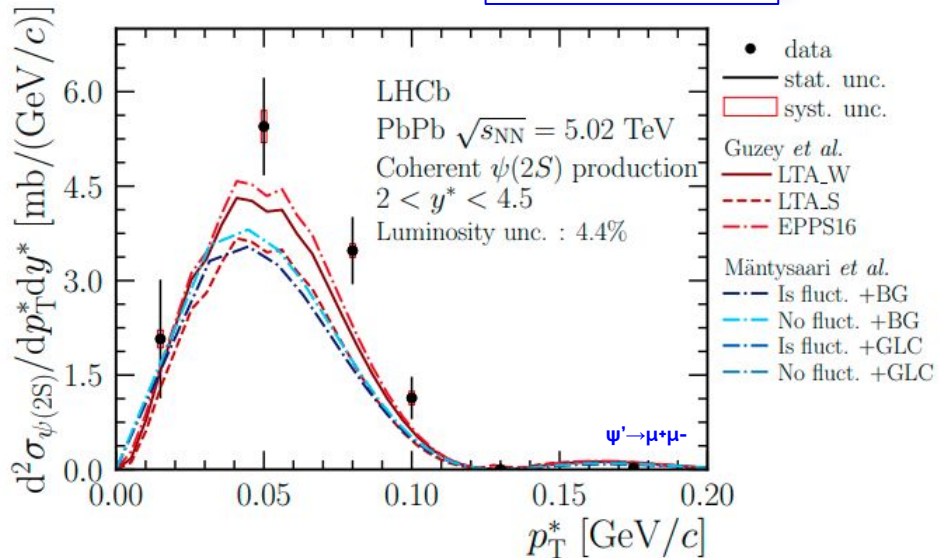
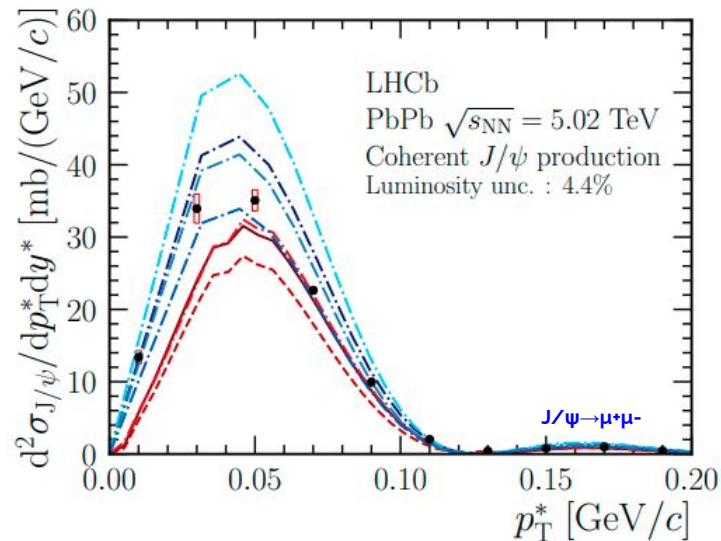
The most **precise** measurement for coherent J/ψ production in PbPb UPC in the forward rapidity to date!
 The **first** coherent $\psi(2S)$ measurement in forward rapidity region at the LHC!



Quarkonium UPC PbPb @5.02TeV

2018 PbPb

[arXiv:2206.08221]



The first and most **precise** measurement of the coherent J/ψ and $\psi(2S)$ production cross-section vs. p_T in PbPb UPC to day.

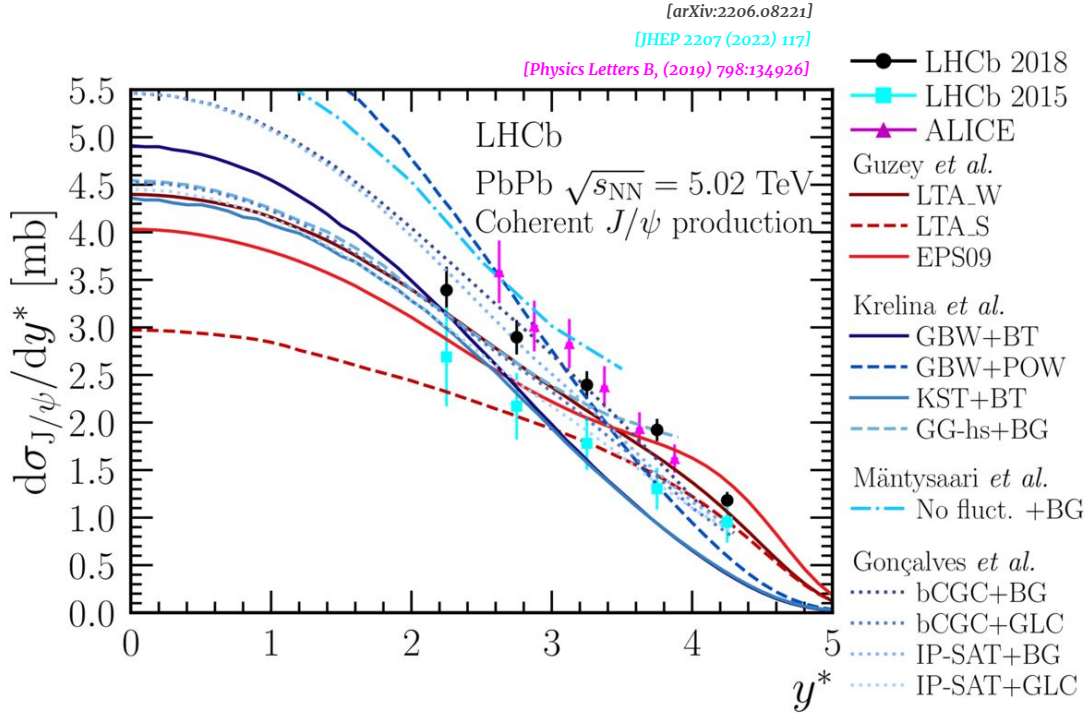
Quarkonium UPC PbPb @5.02TeV



The **LHCb 2018** J/ψ measurement is compatible with **LHCb 2015** and **ALICE** results.

The difference between the **LHCb 2018** and **LHCb 2015** measurement is about **2.0 σ** .

LHCb 2018 is compatible with **ALICE** result.



UPC v.s PC

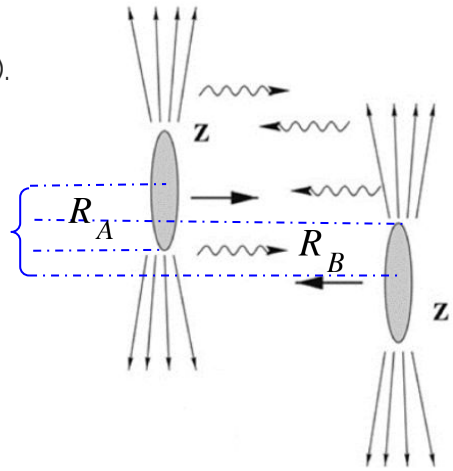
Peripheral collisions:

- ❑ Strong EM fields produced by Lorentz-contracted nuclei.
- ❑ Occurs when impact parameter(b) is **smaller** than the sum of their radii($R_A + R_B$).

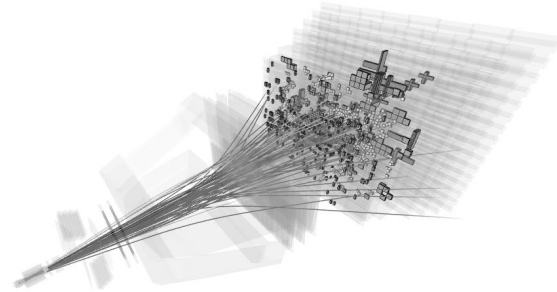
Expected types of interactions:

- ❑ **Photo-produced:**
coherent interaction of the large electromagnetic fields generated by the projectile with the target nucleus.
- ❑ **Hadronic interaction:**
Nucleus breaks up, with larger p_T transferred.

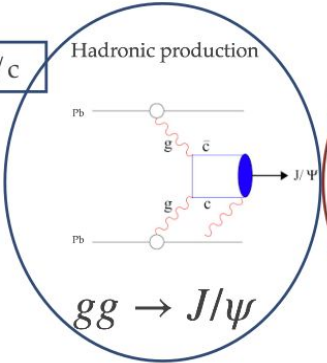
$b < 2R$



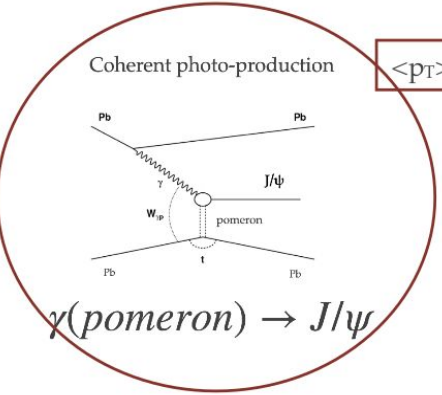
PC



$\langle p_T \rangle \sim 1-2 \text{ GeV}/c$



$\langle p_T \rangle < 300 \text{ MeV}/c$



Results from

Peripheral collision @PbPb

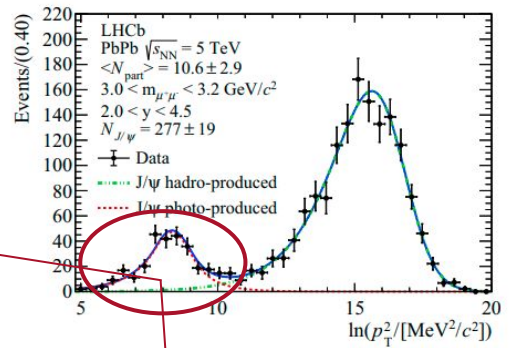
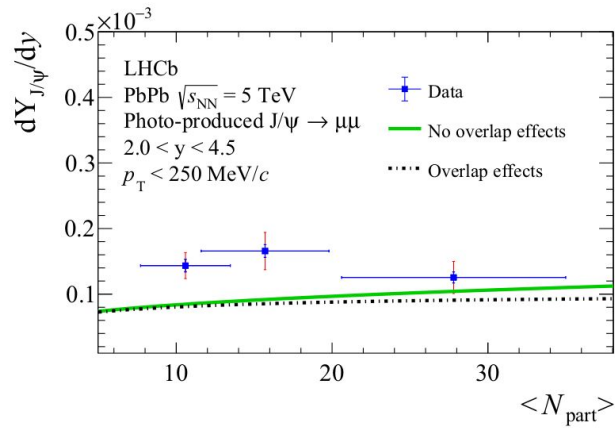
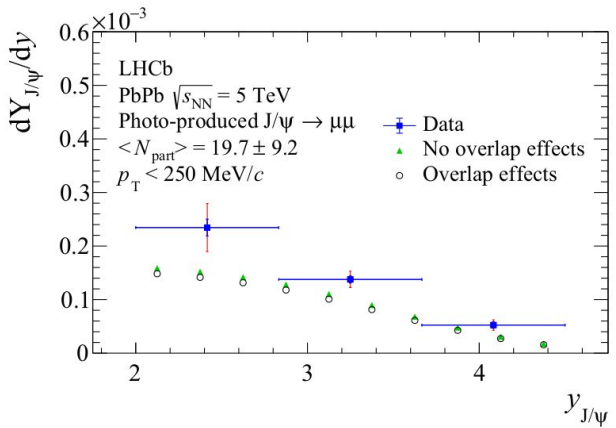
1. J/ψ photoproduction in Pb-Pb peripheral collisions at $\sqrt{s_{NN}} = 5$ TeV @LHCb
[Phys. Rev. C 105, L032201]
2. Photoproduction of low-pT J/ψ from peripheral to central Pb-Pb collisions at 5.02 TeV @ALICE
[arXiv:2204.10684]

Quarkonium PC PbPb@5TeV LHCb

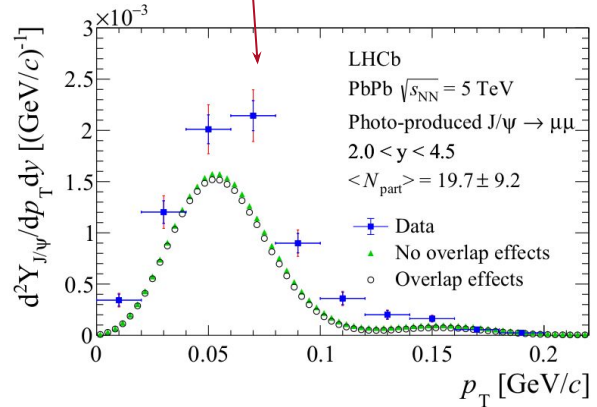
Limited to 60-90% centrality.

[Phys. Rev. C 105, L032201]

First measurement in PbPb hadronic collisions at LHCb



- ☐ Consistent with J/ψ photo-production in PbPb hadronic collisions
- ☐ **Most precise** p_T measurement to date in PC.
- ☐ Results compare with one model with two assumptions:
 - ☐ No overlap effects between the nuclei (UPC-like but small IP)
 - ☐ Overlap Effects
- ☐ [W. Zha et al. Phys. Rev. C97 (2018) 044910 / Phy. Rev. C99, 06901(R)]
- ☐ Trend is consistent, but the data is over above the predictions.

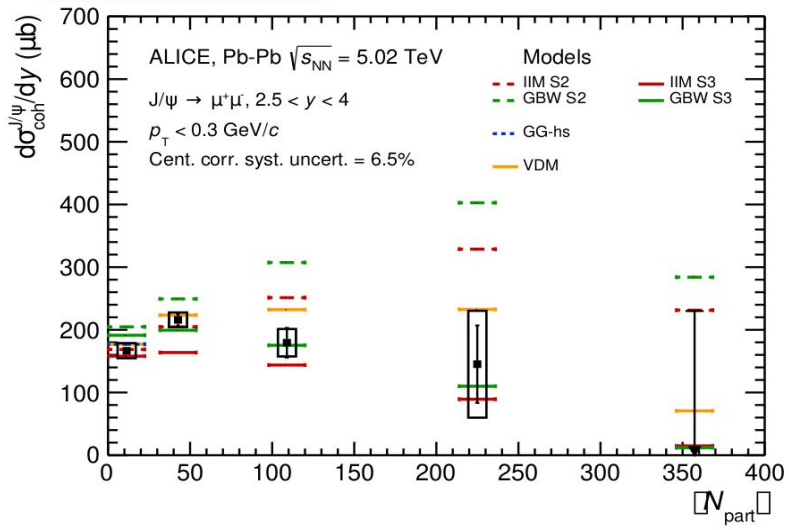


Quarkonium PC PbPb@5TeV Alice



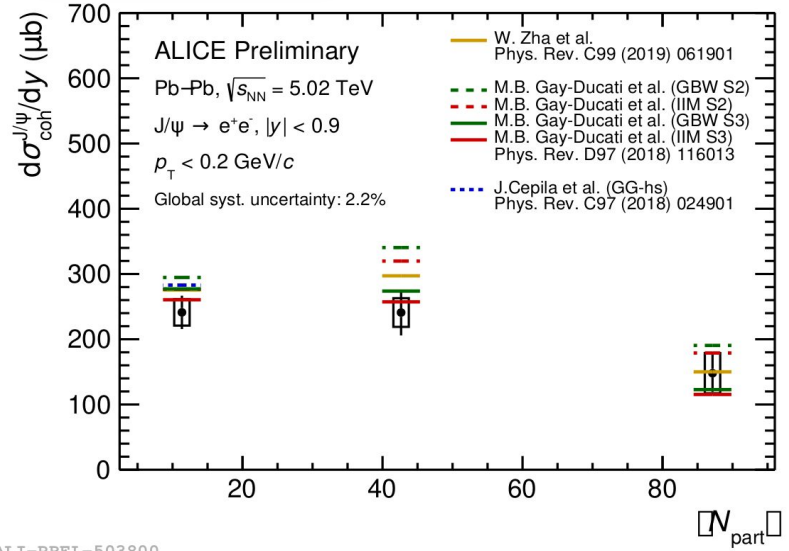
Forward Y

[arXiv:2204.10684]



Mid Y

[ALI-PREL-503800]



ALI-PREL-503800

- **No centrality dependence** of the coherent J/psi photoproduction cross section within uncertainties.
- Effective photon flux for **IIM** and **GBW** S2 and **VDM**:
 - ◆ **VDM** fairly describes data over the full centrality range.
 - ◆ Additional modification of the photonuclear cross section (S3) needed for **IIM** and **GBW** to describe semi-central to central events.
- Effective photon flux and modification of the photonuclear cross section for **W. Zha**: describes mid-rapidity data.
- **GG-hs** valid only for peripheral collisions.

Results from

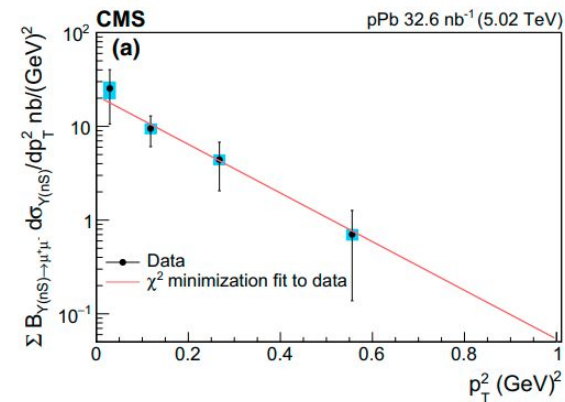
Ultra-Peripheral collision @pPb

1. Measurement of exclusive Υ photoproduction from protons in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV @CMS
[Eur. Phys. J. C (2019) 79:277]

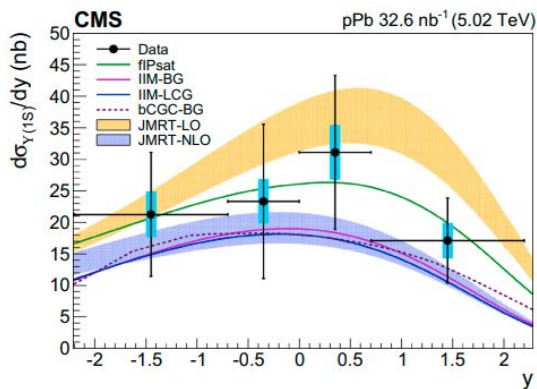
Y(1S) UPC pPb@5.02TeV CMS



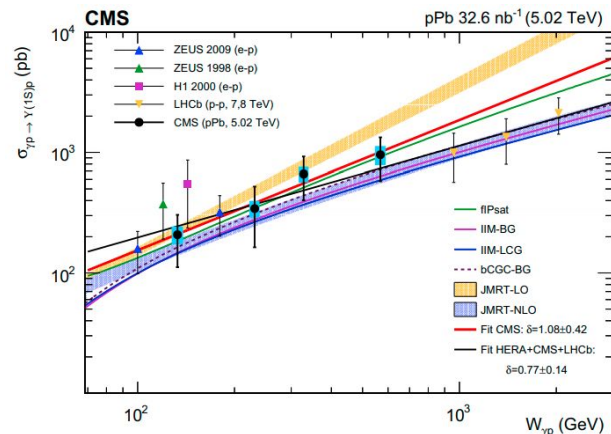
[Eur. Phys. J. C 79 (2019) 277]



- Data points are placed along the abscissa following the prescription of χ^2 minimization fit. [0168-9002(94)01112-5]
- Solid line is an exponential fit of the form $e^{-bp_T^2}$



- Most theoretical predictions are consistent with the data, within the relatively large experimental uncertainties, with the **JMRT-LO** results being systematically above the data points as well as all the other calculations.



- The data are compared to the predictions of the **JMRT** model, including **LO** and **NLO** corrections.
- A fit with the power-law function in the entire W_{pp} range of the data yields $\delta = 1.39$ and $\delta = 0.84$ for the **LO** and **NLO** calculations, respectively.
- LO**: steeper increase
- NLO**: measured rise

Summary

Resent the results of quarkonium photo-produced production in nucleus collision(pPb, PbPb) at LHC:

In PbPb collison:

UPC physics:

Coherent J/ψ photoproduction at **forward rapidity** in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV @ALICE

Coherent J/ψ and ψ' photoproduction **at midrapidity** in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV @ALICE

- Moderate gluon shadowing in nucleus
- $|t|$ dependence sensitive to transverse parton distribution in nucleus
- Described by models with shadowing or saturation

Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{NN}} = 5$ TeV @LHCb

Study of the coherent charmonium production in ultra-peripheral lead-lead collisions @LHCb

- The most precise measurement for coherent J/ψ production in PbPb UPC in the forward rapidity to date
- The first coherent $\psi(2S)$ measurement in forward rapidity region at the LHC

PC physics:

Measurement of photo-produced J/ψ in peripheral PbPb collisions @LHCb

Photoproduction of low- p_T J/ψ from peripheral to central Pb–Pb collisions at 5.02 TeV @ALICE

- No centrality dependence of the coherent J/ψ photoproduction cross section within uncertainties.

In pPb collison:

UPC physics:

Measurement of exclusive Υ photoproduction from protons in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV @CMS

- Cross section as a function of Y , p_T , $W_{\Upsilon p}$ are measured and compared with models.

Thanks for your listening

Back Ups

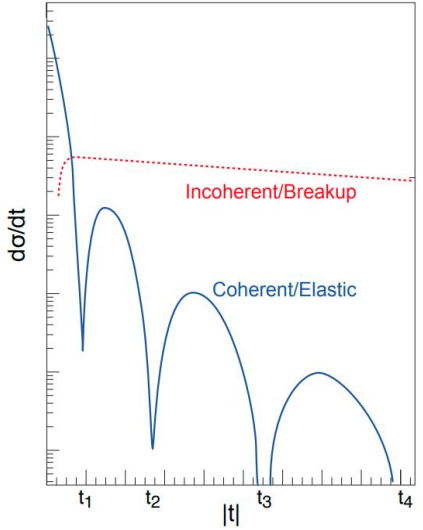
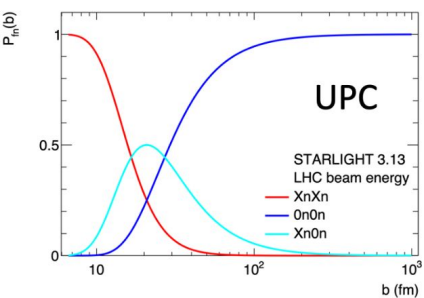
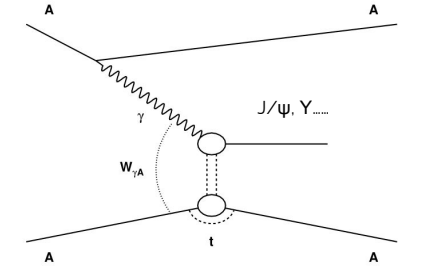


What can photoproduction probes?

➔ To image the nucleon/nucleus structure:

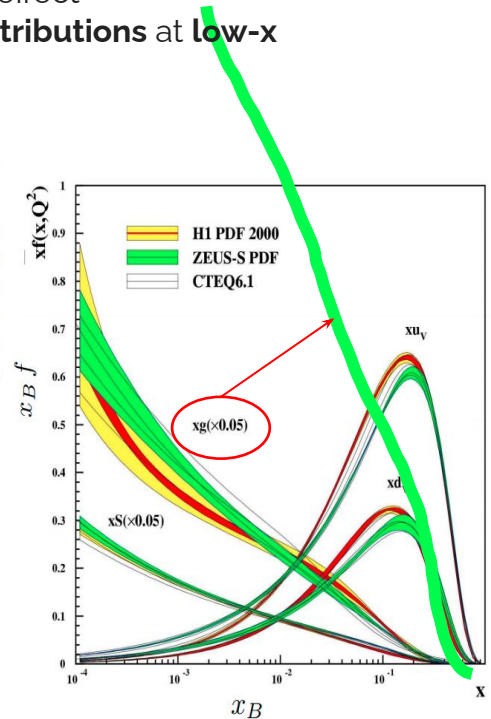
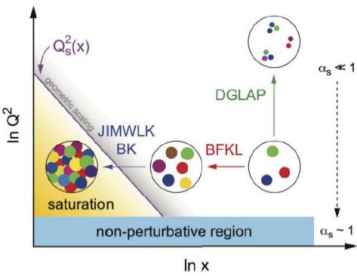
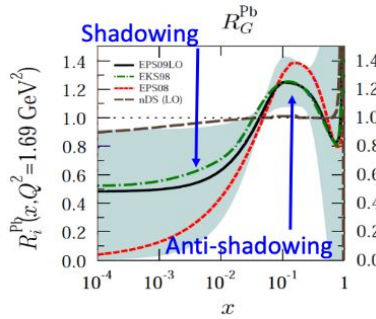
In spatial space:

- ❑ **t** spectrum of coherent photoproduction is related to the **size** of gluon emitter.
- ❑ Control **UPC geometry**
- ❑ ...



In momentum space:

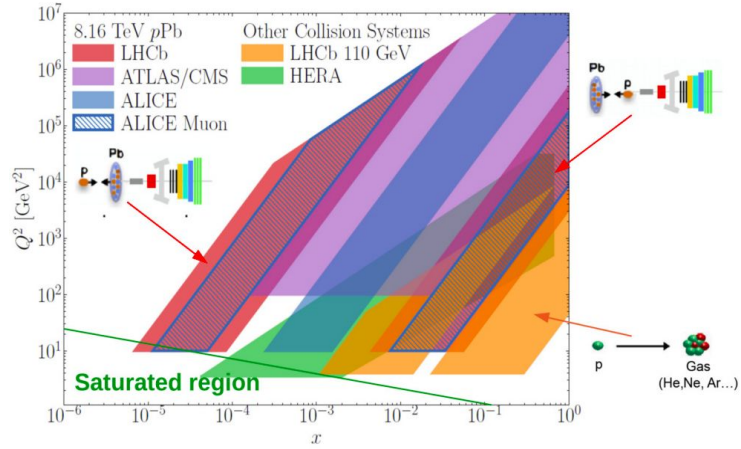
- ❑ Nucleon and nuclear **PDF**
- ❑ Gluon **shadowing** effect
- ❑ Gluon **saturation** effect
- ❑ **Gluon density distributions at low-x**
- ❑ ...



Heavy Ion Collision at LHC

➔ All LHC experiments have joined the LHC HI program

- ❑ Run1 (2010-2013): Pb-Pb@2.76 TeV, pPb@5 TeV
- ❑ Run2 (2015-2018): Pb-Pb@5 TeV, pPb@5TeV, pPb@8TeV, fixed target(@LHCb)
- ❑ Run3 (2021-2024): Pb-Pb@5 TeV, fixed target, SMOG2
- ❑ Run4(2027-2030): TBD...



ALICE: Heavy Ion, Low pT, PID, Open charm, Charmonia...

CMS/ATLAS: Bottomonia, Jets, High pT, EW probes...

LHCb: Fixed target, Low pT, High precision

LHCb as a special detector down to very low-x region

