



South China Normal University



# Charmonia photo-production in ultra-peripheral and peripheral PbPb collisions with LHCb

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on behalf of LHCb collaboration

Institute of Quantum Matter

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# LHCb Detector

Int. J. Mod. Phys. A 30, 1530022 (2015)

➤ LHCb detector is **a single arm forward spectrometer** fully instrumented in pseudo rapidity  $2 < \eta < 5$ .

➤ Constructions:

- Tracker;
- Magnet (4 Tm);
- Calorimeters;
- RICH detector;
- Muon system;

➤ High precision momentum resolution.

➤ Vertex reconstruction.

➤ Particle identification.

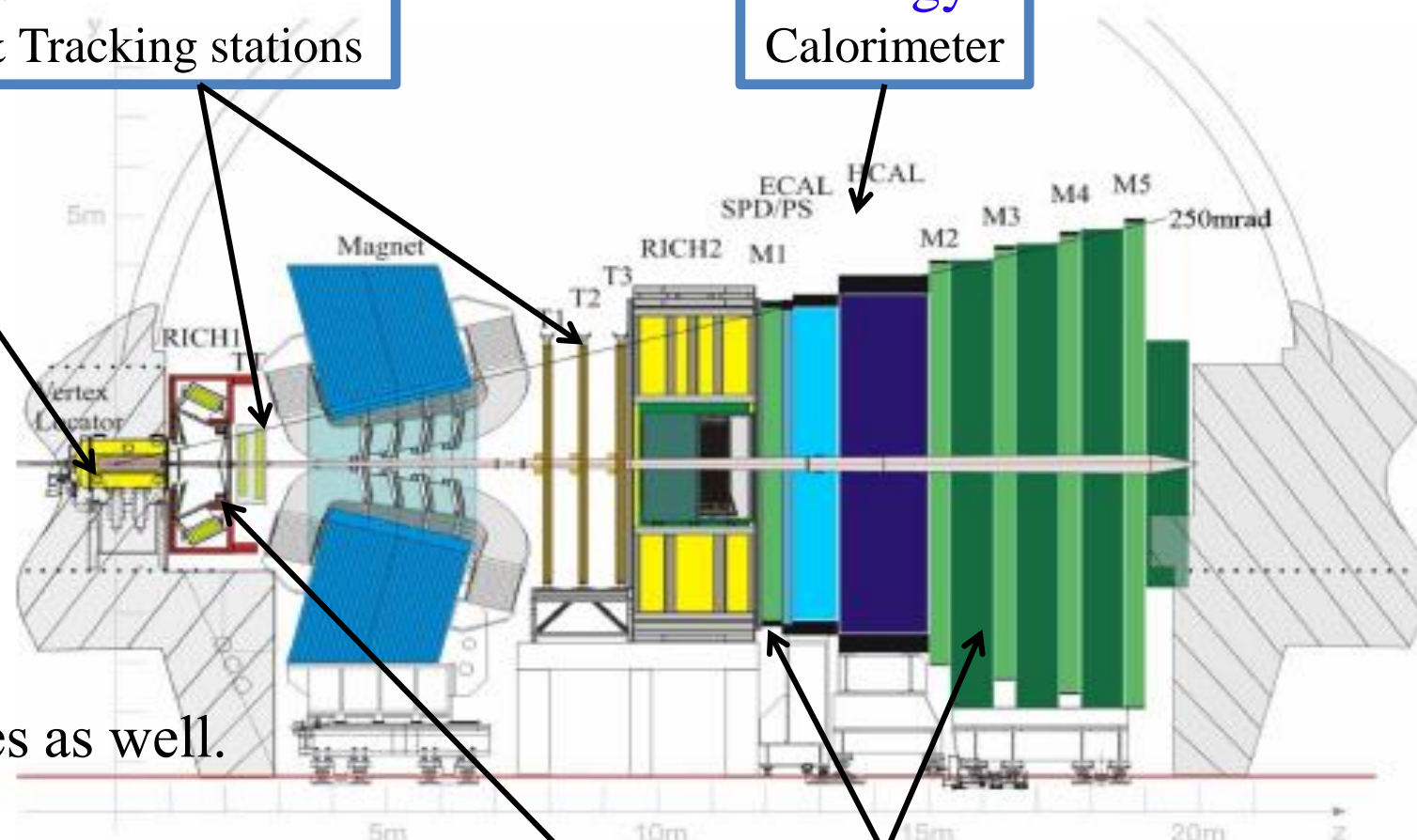
- $e, \mu, \pi, K, p, \gamma$  and secondary vertices as well.

Momentum & Vertices

Vertex locator & Tracking stations

Energy

Calorimeter



RICH detector & Muon stations  
Particle ID

# PbPb collision types

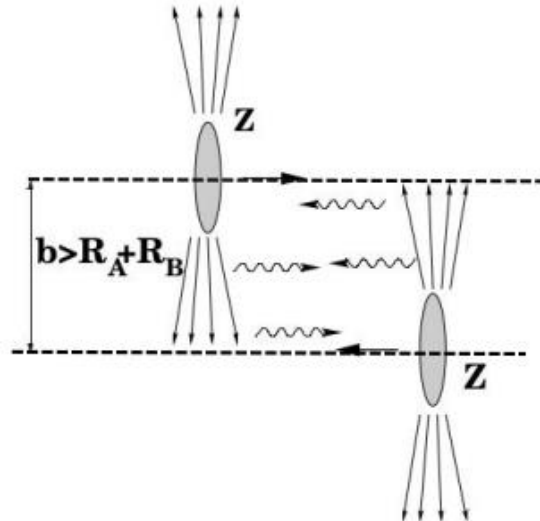
[arXiv:2108.02681]

## ➤ Ultra-Peripheral Collisions(UPCs):

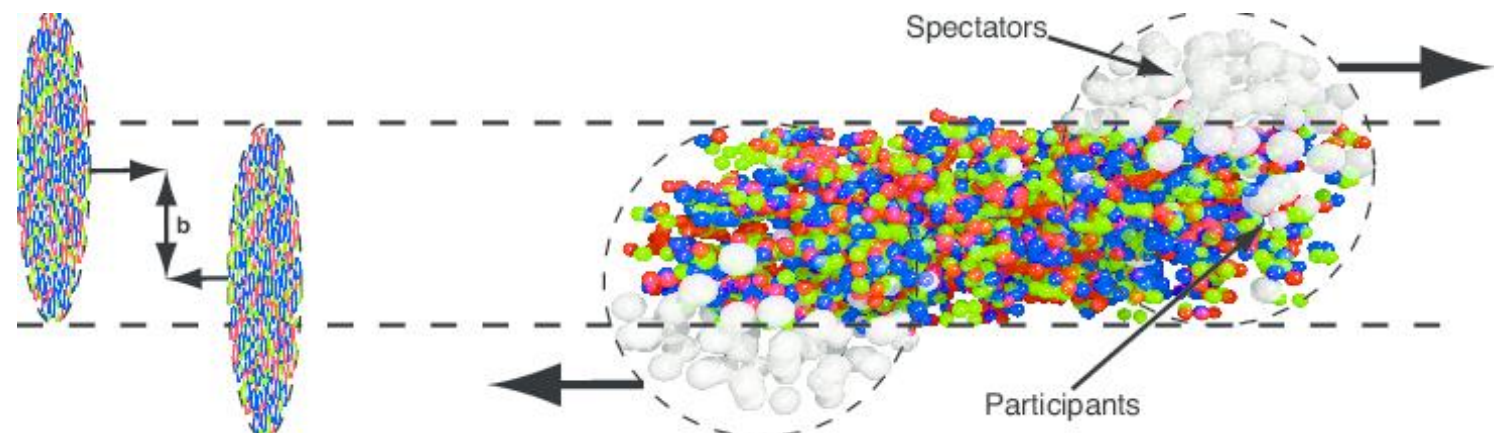
- Two ions interact via their cloud of **virtual photons**.
- Impact parameter  $b$  is larger than the sum of the radii  $R_A$  and  $R_B$  of the two colliding nucleus, hadronic interaction are suppressed, photonuclear interaction dominates.
- Intensity of the electromagnetic field proportional to  $Z^2$ .

## ➤ Peripheral Collisions:

- $b$  is **smaller than** the sum of the radii.
- **Hadronic interaction** and photonuclear interaction.



Ultra-Peripheral Collision

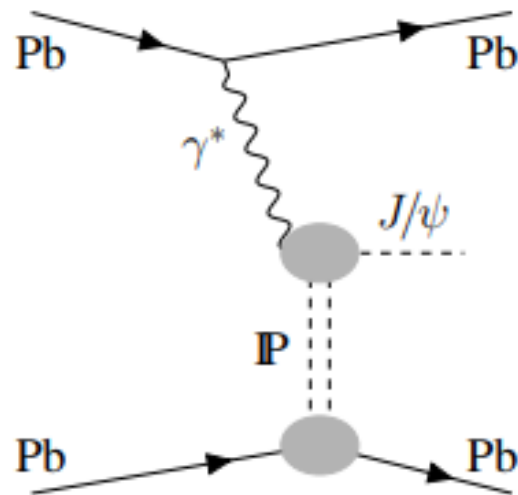


Peripheral Collision

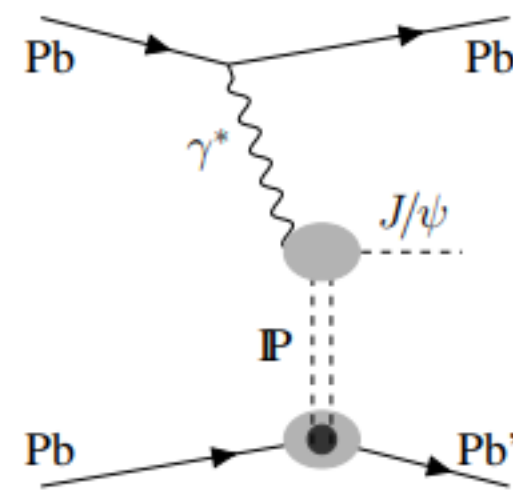
# Coherent $J/\psi$ production in UPC

[arXiv:2108.02681]

- Coherent  $J/\psi$  production constraints the gluon Parton Distribution Functions.
- The  $(J/\psi) / \psi(2S)$  ratio measurement is helpful to constrain the choice of the vector meson wave function in dipole scattering models. [e.g. PLB 772 (2017) 832, PRC (2011) 011902]



Coherent  $J/\psi$  production



Incoherent  $J/\psi$  production



# LHCb latest results



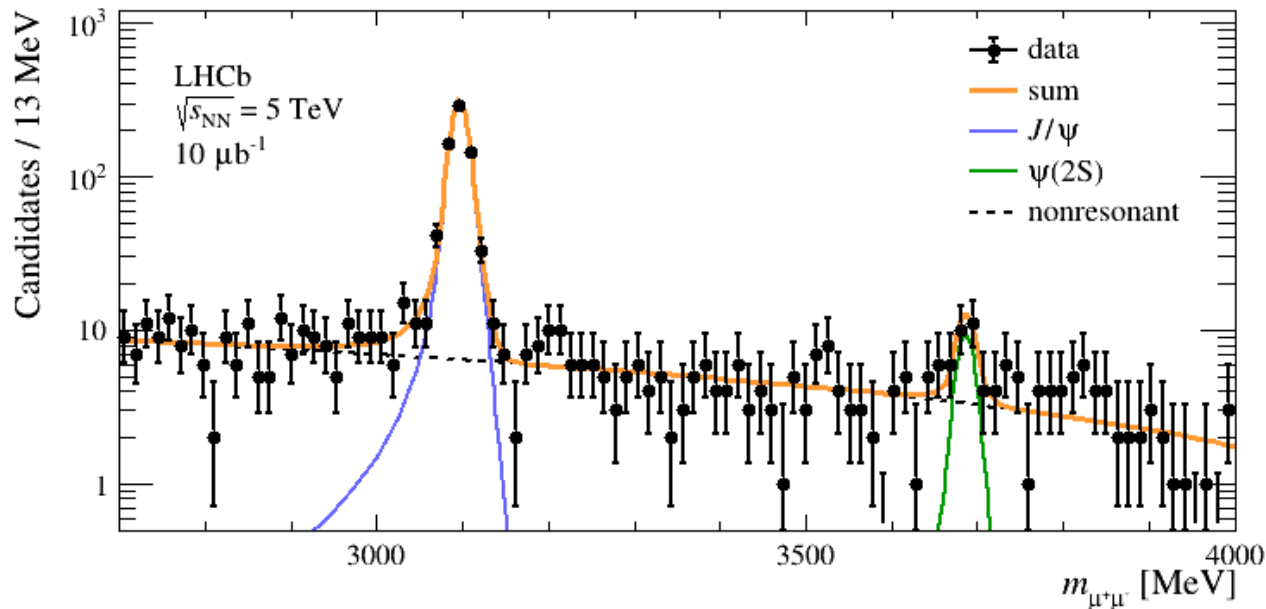
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Study of coherent  $J/\psi$  production in ultra-peripheral lead-lead collisions at  $\sqrt{s} = 5$  TeV

ArXiv:2107.03223

[arXiv:2107.03223]

$J/\psi$  production in PbPb:  $Pb+Pb \rightarrow Pb+Pb+J/\psi$ .



## Data set

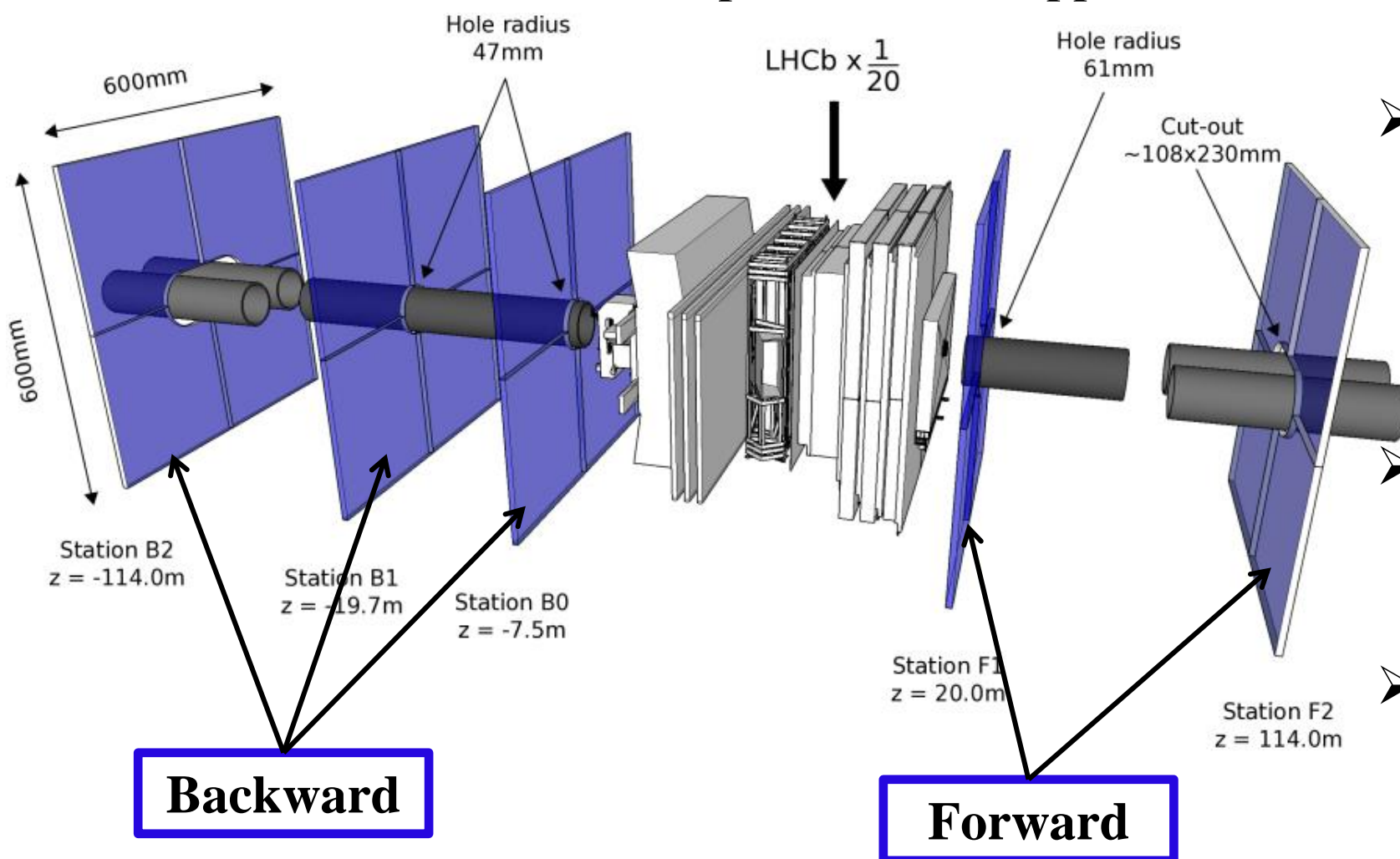
- lead-lead collisions at  $\sqrt{s} = 5$  TeV taken in 2015. Integrated luminosity is about  $10 \mu b^{-1}$ .

## Event selection

- $J/\psi \rightarrow \mu^+ \mu^-$ .
- Each muon  $p_T > 800$  MeV.
- $2 < \eta < 4.5$ .
- Di-muon  $p_T < 1$  GeV.
- Di-muon mass  $m_{\mu^+\mu^-} > 2.7$  GeV.

**J/ $\psi$  yields:  $673 \pm 27$**

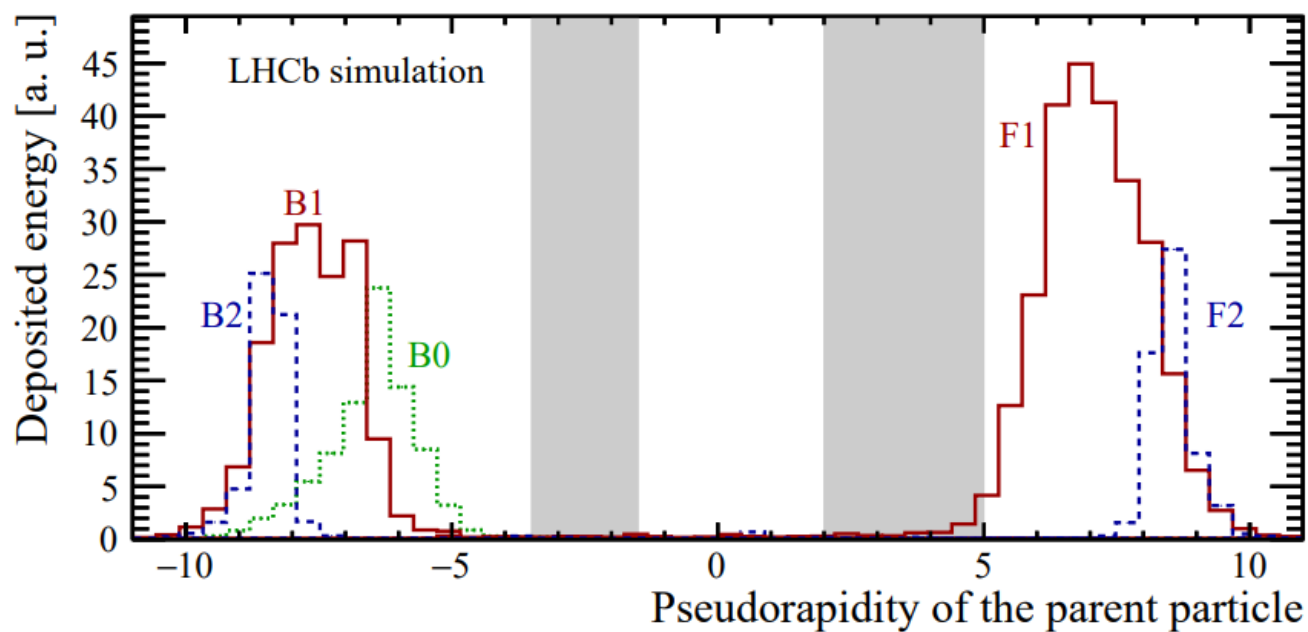
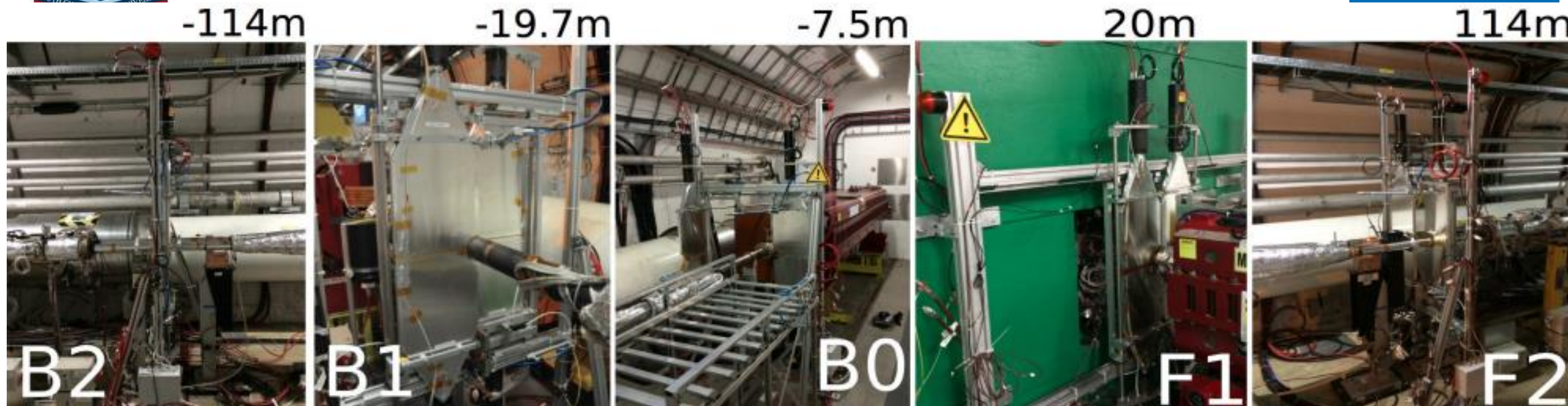
- HeRSChel-**High Rapidity Shower Counters for LHCb**-located in the LHC tunnel on both sides of the LHCb interaction point, which suppressed contamination from inelastic events.



- Five stations:
  - Three backwards
  - Two forwards
  - Four 20 mm thick retractable plastic scintillator plates.
- Pseudo-rapidity coverage:
  - $-8.0 < \eta < -5.0$
  - $5.0 < \eta < 8.0$
- Suppressed background events, whilst maintaining high signal efficiency.



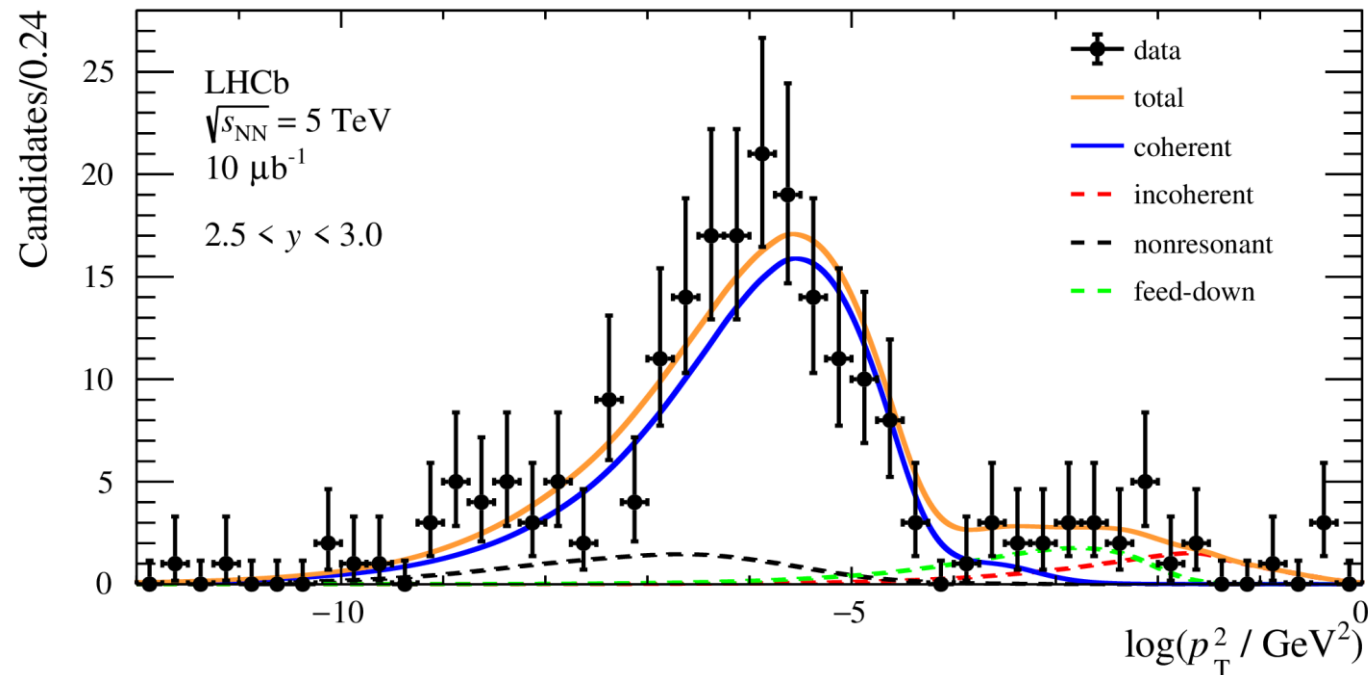
# HeRSChel detector





[arXiv:2107.03223]

$J/\psi$  mass window:  $3040 \sim 3165 \text{ MeV}/c^2$ .



- The  $\log p_T^2$  distribution of di-muon candidates in the interval  $2.5 < y < 3.0$ , with  $p_T$  given in GeV.

- The signal yields are extracted from the di-muon mass fits.

Two steps:

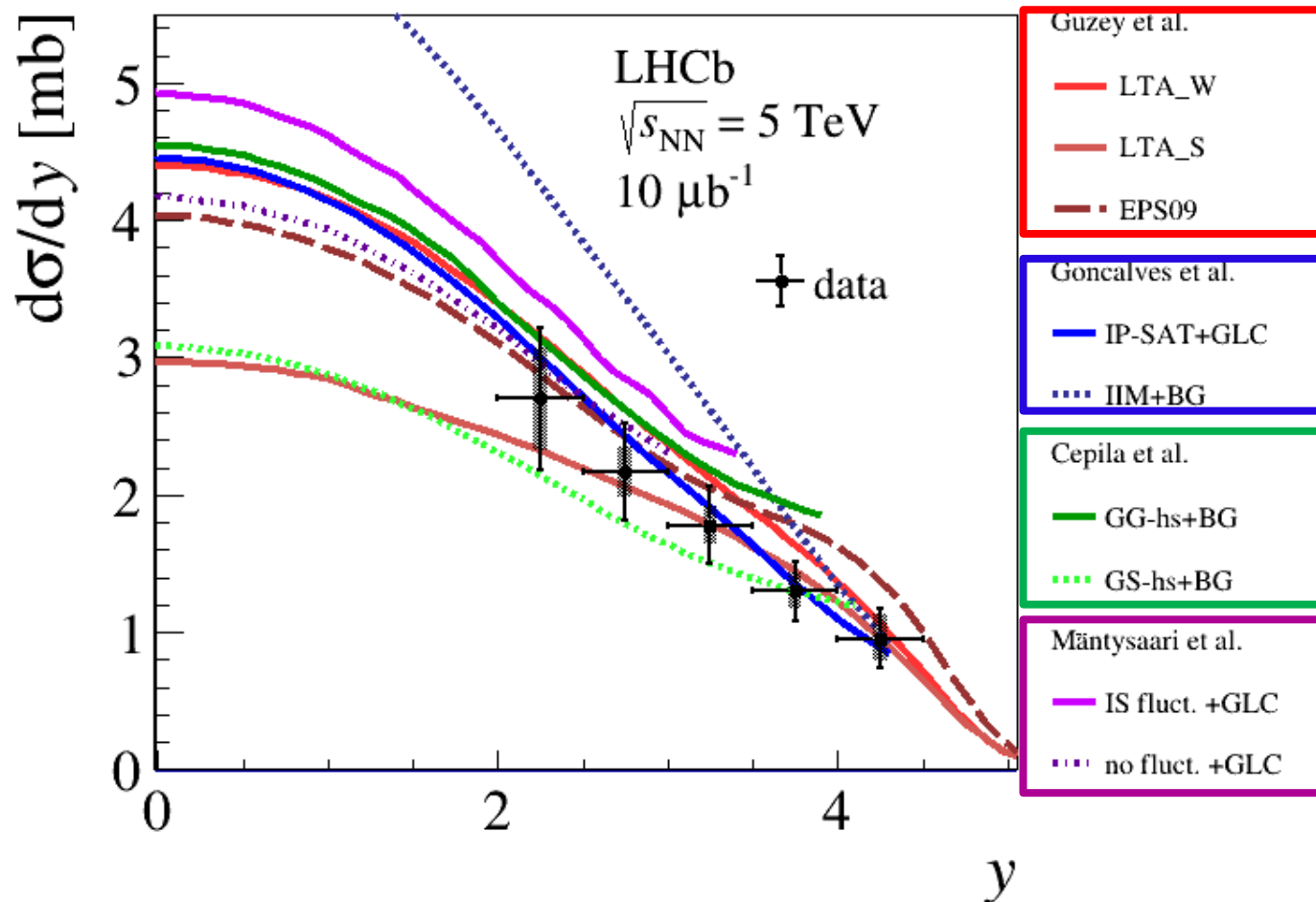
- Fit on the di-muon invariant mass.
- Fit on the  $\log p_T^2$  of  $J/\psi$ .
  - Including  $J/\psi$  coherent and Incoherent,  $\psi(2S)$  feed down.
- Templates are calculated using the STARlight generator and the LHCb detector simulation.

**$J/\psi$  coherent:  $489 \pm 25$**

# Differential cross section

[arXiv:2107.03223]

$$\sigma = 4.45 \pm 0.24(\text{stat.}) \pm 0.18(\text{syst.}) \pm 0.58(\text{lumi})\text{mb}$$



## ➤ Cross-section

$$\frac{d\sigma_{coh.,J/\psi}}{dy} = \frac{N_{coh.,J/\psi}}{\varepsilon_{total} \cdot \mathcal{L} \cdot \Delta y \cdot \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)}$$

➤ The analysis is repeated in bins of half unit rapidity  $y(J/\psi)$

➤ pQCD calculations:

- [PRC 93 (2016) 055206]

➤ Color dipole models:

- [PRD 96 (2017) 094027]

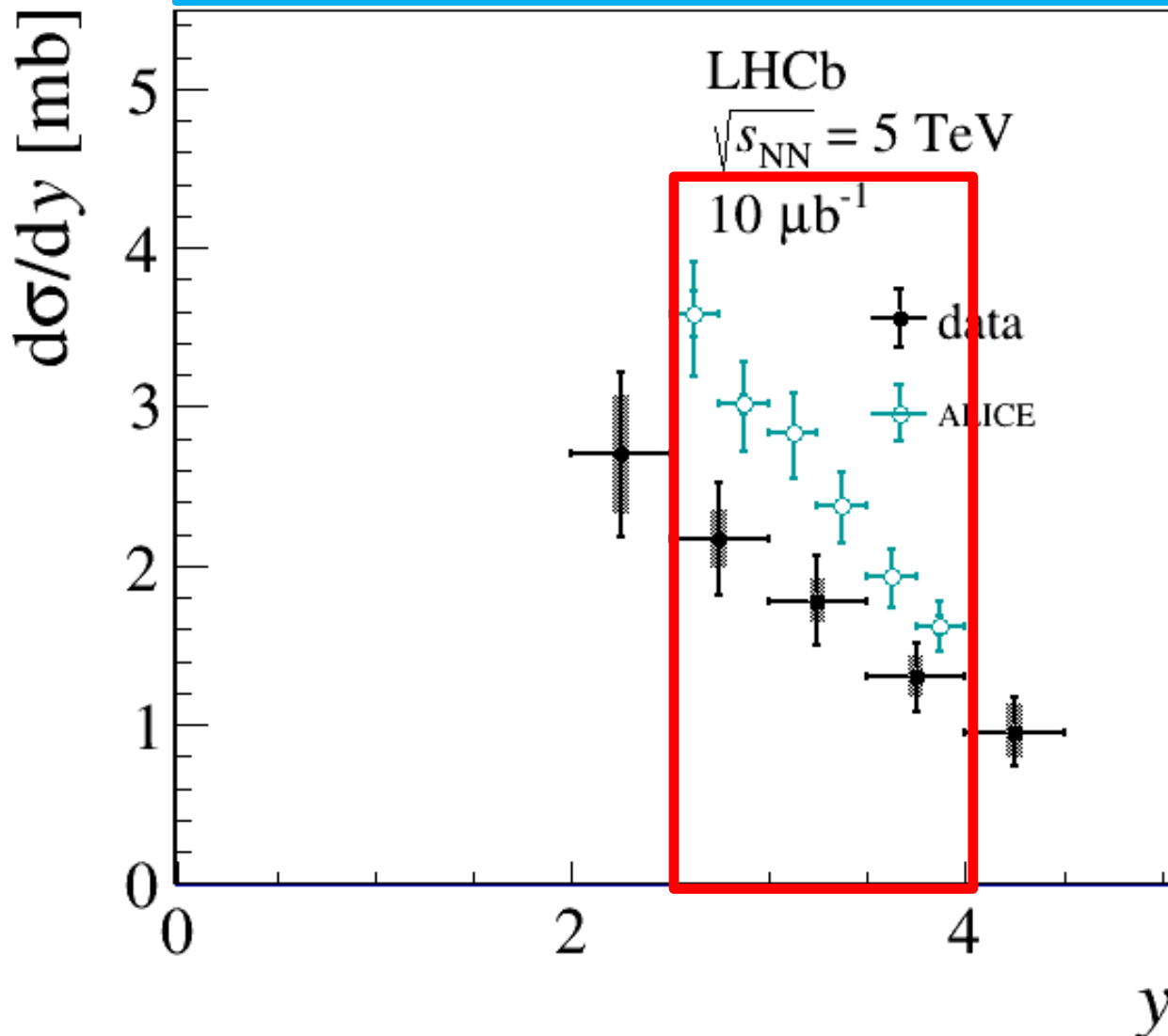
- [PRC 97 (2018) 024901]

- [PLB 772 (2017) 832]

# Result LHCb & Alice

$$\sigma_{LHCb} = 2.04 \pm 0.3(\text{syst.})\text{mb};$$

$$\sigma_{Alice} = 2.549^{+0.209}_{-0.237}(\text{syst.})\text{mb} \quad 2.5 < y < 4.0$$



## Signal definition:

- LHCb: Veto all additional radiation.
- Alice: As well as allows **nuclear excitations**.

## Uncertainty:

- LHCb:
  - Dominant uncertainty arises from the luminosity.
  - Fully correlated.
- Alice:
  - Dominant uncertainty originates from the signal purity estimate.
  - Partially correlated.

$$\frac{\sigma_{Alice} - \sigma_{LHCb}}{\sqrt{\sigma_{\sigma_{LHCb}}^2 + \sigma_{\sigma_{Alice}}^2}} = 1.3$$



# 2018 Data Set



	2015	2018
$\sqrt{s}$	5 TeV	5 TeV
	PbPb	PbPb
$\mathcal{L}$	$10 \mu b^{-1}$	$\sim 210 \mu b^{-1}$

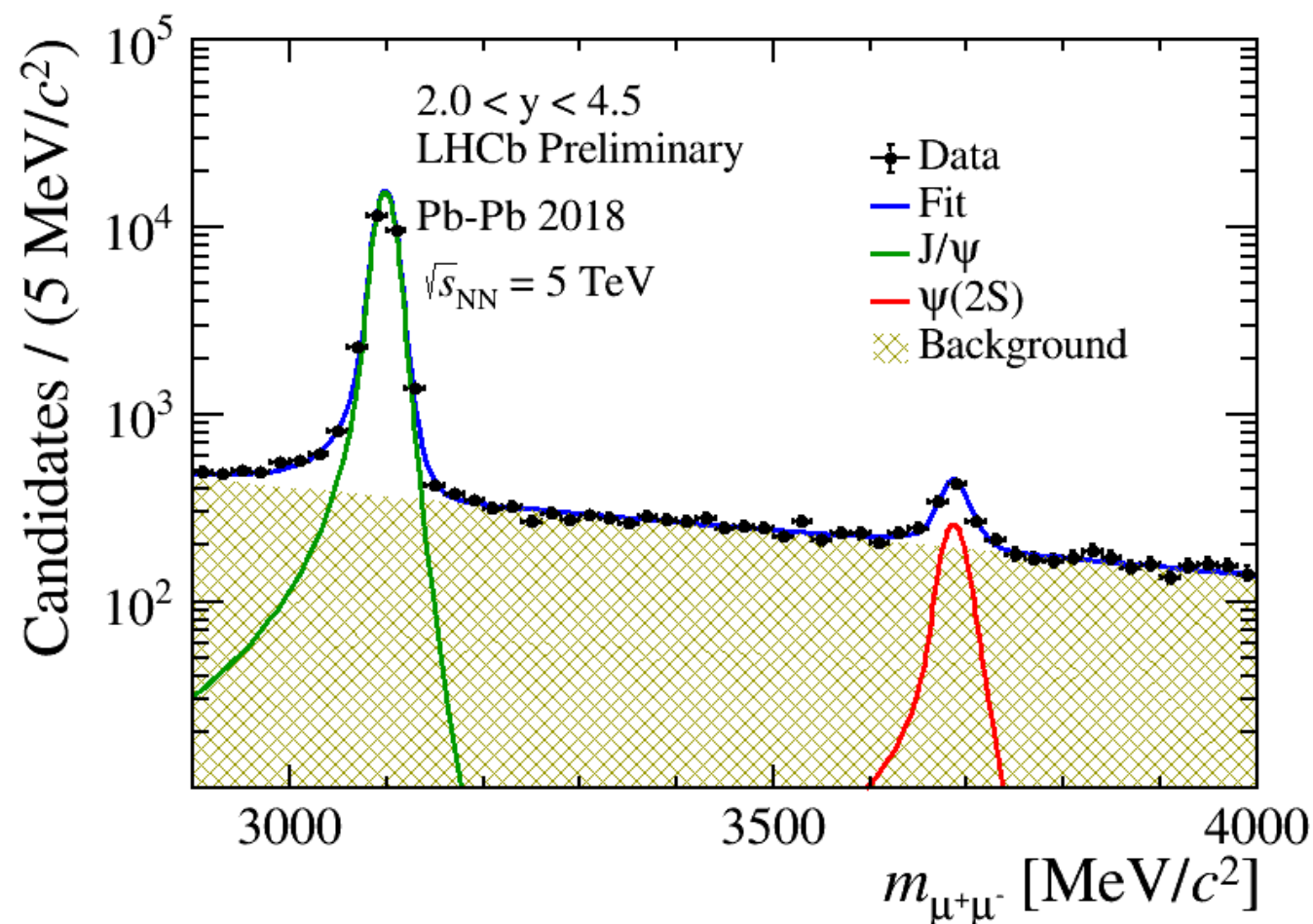
➤ About 20 times more statistics in 2018.

➤ The 20 times higher statistics make it possible to determine the cross-sections of both  $J/\psi$  and  $\psi(2S)$  simultaneously in 5 rapidity bins.

➤ Cross-section ratio:

$$\frac{\sigma_{coh.,J/\psi}}{\sigma_{coh.,\psi(2S)}} = \frac{N_{J/\psi} \cdot \epsilon_{total} \cdot \mathcal{B}(J/\psi \rightarrow \mu^+ \mu^-)}{N_{\psi(2S)} \cdot \epsilon_{total} \cdot \mathcal{B}(\psi(2S) \rightarrow \mu^+ \mu^-)}$$

➤ 2018 data fit



【 <https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlotsQM2019> 】



# LHCb latest results



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Study of  $J/\psi$  photo-production in lead-lead peripheral collisions at  $\sqrt{s} = 5$  TeV

arXiv:2108.02681

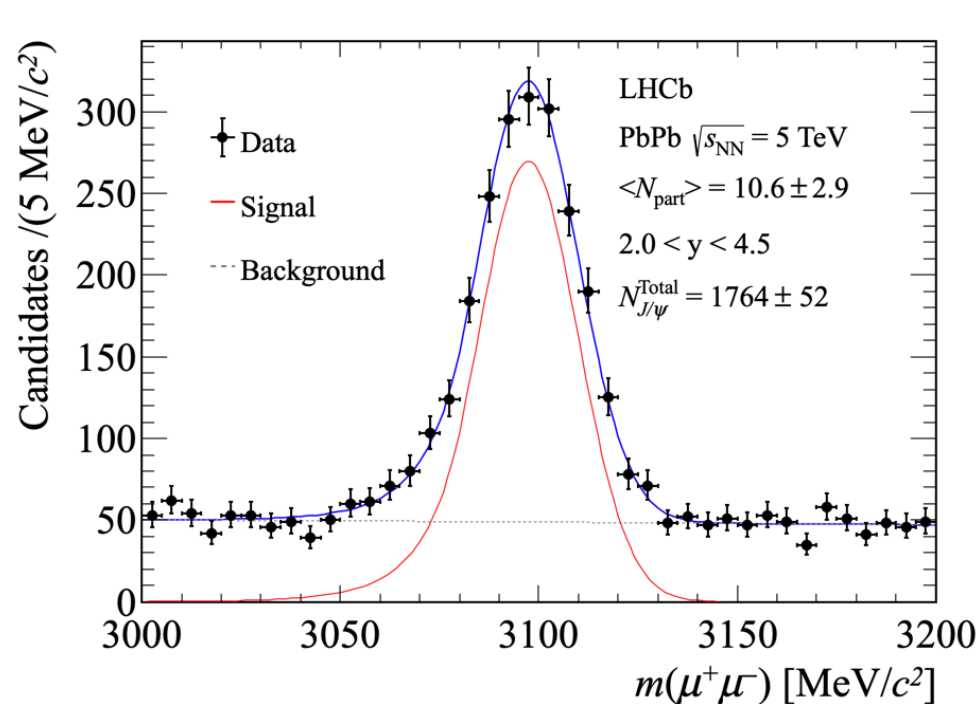


# Peripheral Collisions



**New!**

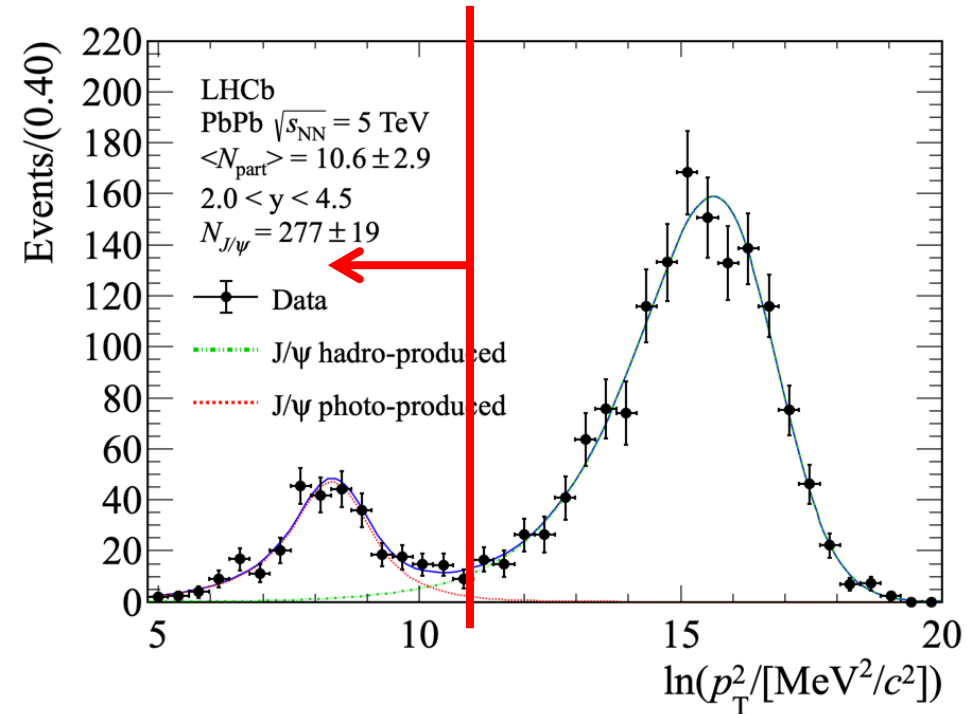
- Data set: Pb-Pb collisions at  $\sqrt{s} = 5$  TeV in 2018
- $J/\psi$  candidates includes photo-produced and hadronically produced,  $\ln p_T^2$  separate them.  
About **20 times** more data than the previous measurement.



One example bin of  $J/\psi$  meson with:

$$p_T < 15.0 \text{ GeV}/c$$

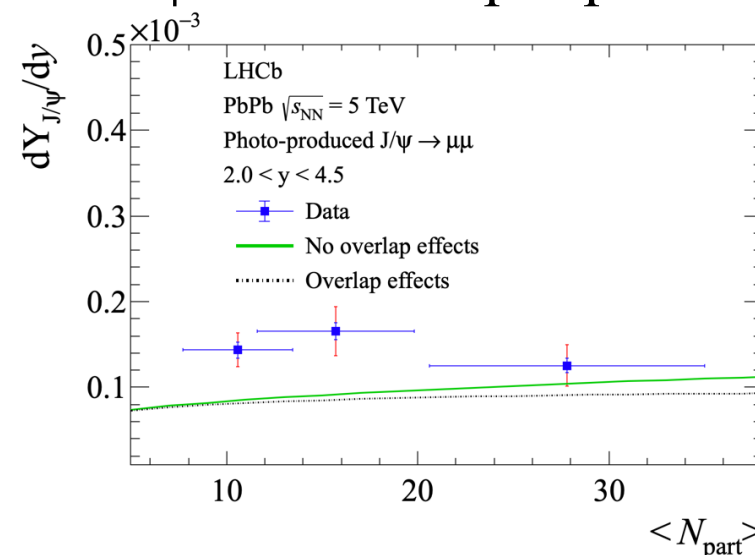
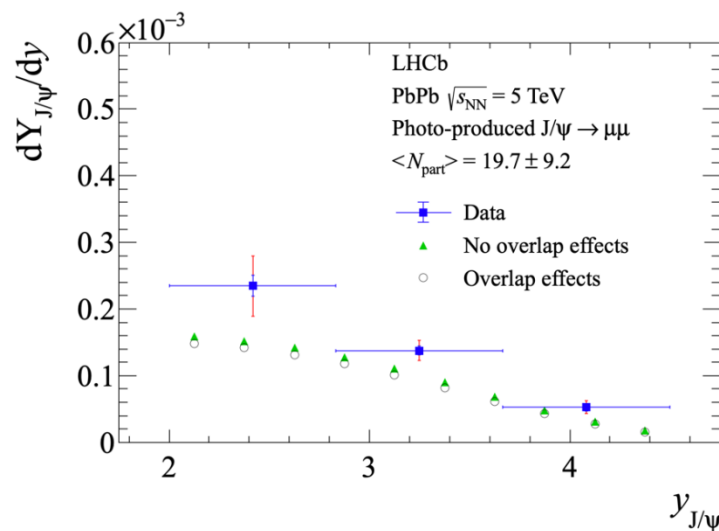
$$\langle N_{part} \rangle = 10.6 \pm 2.9$$



The photo-produced  $J/\psi$  candidates dominate for :  
 $\ln(p_T^2) < 11$

$$\frac{dY_{J/\psi}^i}{dy} = \frac{N_{J/\psi}^i}{\mathcal{B} N_{MB}^i \epsilon_{tot}^i \Delta y}, \quad \frac{d^2 Y_{J/\psi}^i}{dp_T dy} = \frac{dY_{J/\psi}^i}{dy} \frac{1}{\Delta p_T}$$

- Photo-produced  $J/\psi$  yields measured in  $y$  and centrality bins.
- The yield of the coherent  $J/\psi$  production is higher in **low rapidity region**.
- Data are qualitatively reproduced in models with and without overlap effects.
- Confirmation of photo-produced  $J/\psi$  mesons in peripheral hadronic collisions.



W. Zha et. al. Phys. Rev. C97 (2018) 044910  
 W. Zha et. al. Phys. Rev. C99 (2019) 061901



# Summary and Conclusion



- LHCb is a forward general purpose detector with good vertexing, momentum resolution, and particle identification.
- Ultra-peripheral Pb-Pb collisions:
  - Charmonia production in Ultra-peripheral Pb-Pb collisions is of particular interest to probe gluon Parton Distribution Functions.
  - Production cross section  $\sigma = 4.45 \pm 0.24(\text{stat.}) \pm 0.18(\text{syst.}) \pm 0.58(\text{lumi})\text{mb}$ .
  - Higher precision results using 2018 data with 20 times more statistics are coming soon, for both  $J/\psi$  and  $\psi(2S)$  cross section and cross section ratio.
- Peripheral Pb-Pb collisions:
  - Measurement of photo-produced  $J/\psi$  mesons in Peripheral Collisions.





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Thanks for your attention!