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

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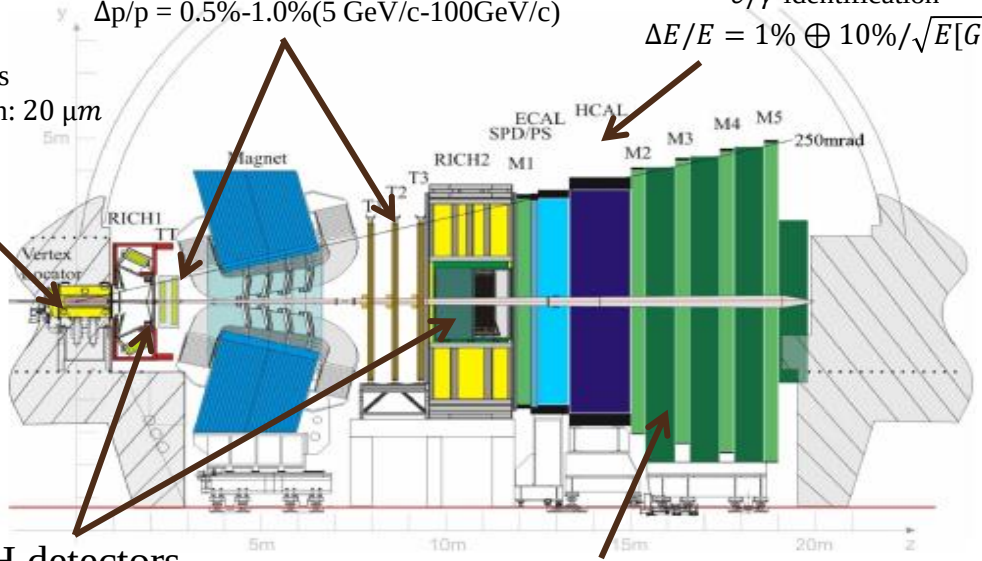
LHCb Detector

- LHCb detector is **a single-arm forward spectrometer** fully instrumented in unique kinematic coverage: **2<η<5**.

Tracking system
Momentum resolution
Δp/p = 0.5%-1.0%(5 GeV/c-100GeV/c)

Vertex Detector
Reconstruct vertices
Decay time resolution: 45 fs
Impact parameter resolution: 20 μm

Calorimeters
Energy measurement
e/γ identification
$\Delta E/E = 1\% \oplus 10\%/\sqrt{E[GeV]}$



- A high precision detector with excellent particle identification, precise vertex reconstruction and high momentum resolution.

RICH detectors
K, π, p separation
$\epsilon(K \to K) \sim 95\%$, mis-ID $\epsilon(\pi \to K) \sim 5\%$

Muon system
μ identification
$\epsilon(\mu \to \mu) \sim 97\%$, mis-ID $\epsilon(\pi \to \mu) \sim 1\text{-}3\%$

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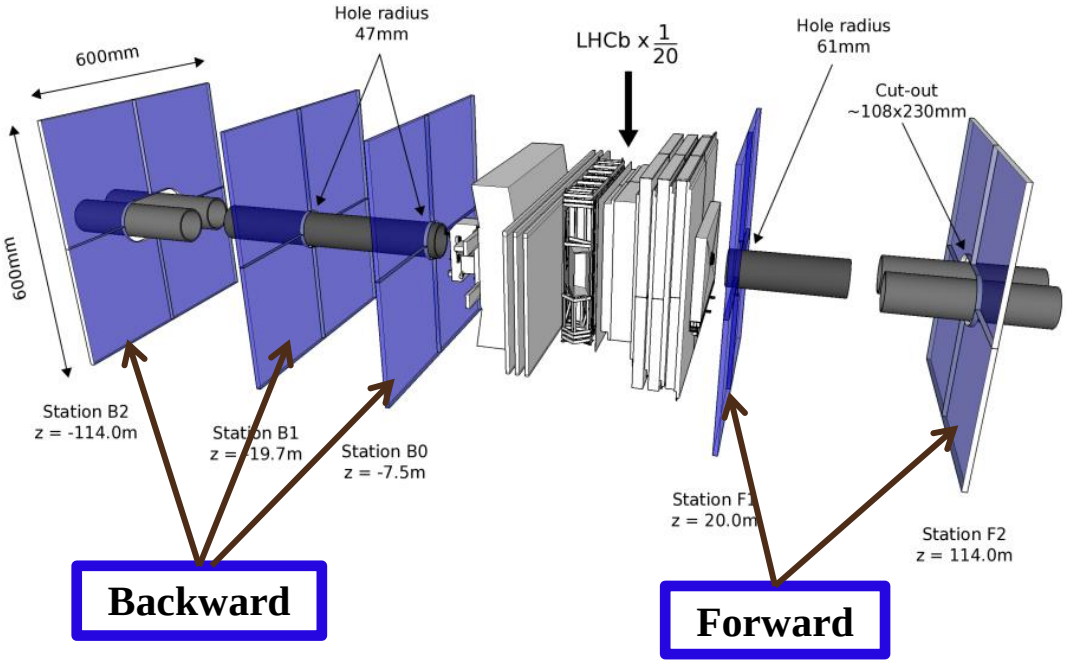
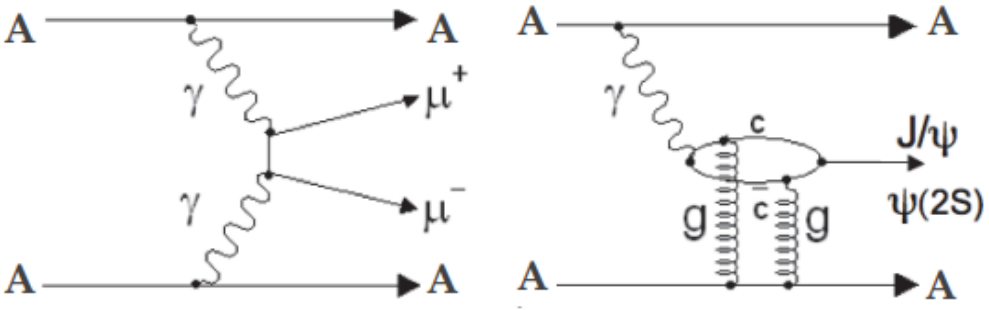
HeRSCheL detector

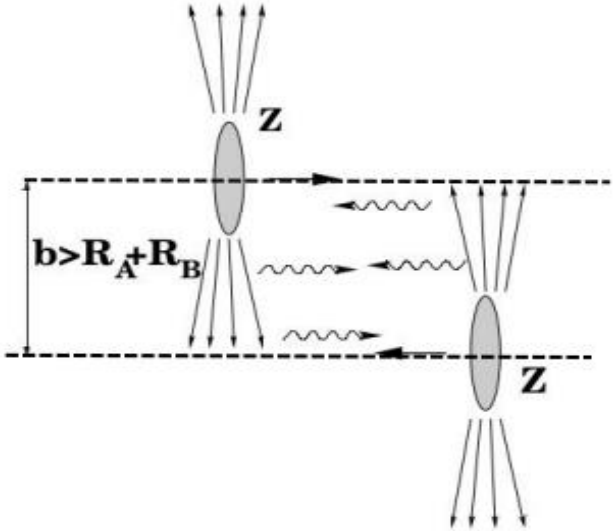
- HeRSCheL(**High Rapidity Shower Counters for LHCb**), is a set of plastic scintillators used in order to detect any activity in high pseudo-rapidity range, typically $\eta \gtrsim 8$.
- Remove background activities close to beam.
- Also used to cut component with large momentum.
- May also cut a small fraction of signal.



Ultra-peripheral PbPb Collisions

- **Ultra-Peripheral Collisions(UPCs):**
  - Occur when two nuclei collide, in which the impact parameter b is greater than the sum of their radii.
  - Reactions in which two ions interact via their cloud of semi-real photons.



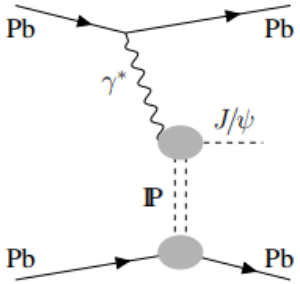


- Photon-induced quarkonium production: A $q\bar{q}$ loop created by the photon interaction with a pair of gluon exchange (pomeron) to produce a quarkonium($c\bar{c}, b\bar{b}$).
- Non-resonant background: $\gamma\gamma \rightarrow \mu^+\mu^-$

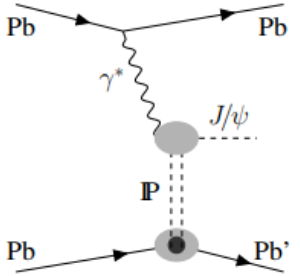
J/ψ production in UPC

- Coherent J/ψ production, the emitted photon interacts coherently with the whole nucleus.
- Incoherent J/ψ production, the photon interacts with one nucleon leading to the break up of the target nucleus.
- J/ψ from the feed-down of coherent and incoherent ψ(2S) production.

- **Characteristics of coherent J/ψ production:**
  - No additional particle production ($Pb + Pb \rightarrow Pb + Pb + J/\psi$).
  - low J/ψ mesons transverse momentum.



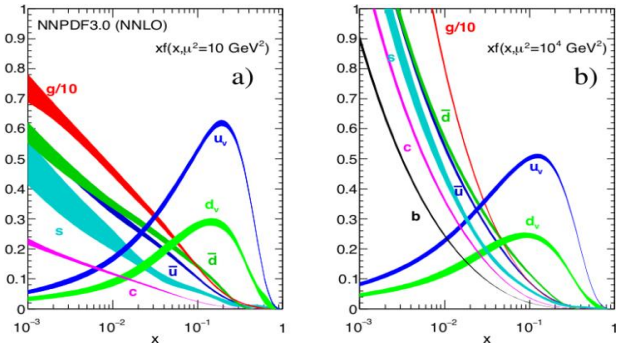
Coherent J/ψ production

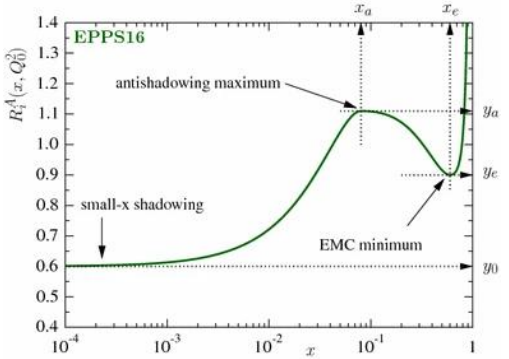


Incoherent J/ψ production

Physics motivation

- Probe gluon distribution at low Bjorken-x and search for saturation effects.
- In gamma-nucleus the vector meson production (such as the J/ψ) is sensitive to the square of the nuclear gluon density at the leading order of perturbation.
- Coherent J/ψ production constrains the gluon Parton Distribution Functions.
- Coherent photoproduction in PbPb is a promising probe to study nuclear shadowing effect at small-x.





Analysis strategy

- Decay channel: $J/\psi \rightarrow \mu^+\mu^-$ events.
- Dataset: lead-lead collisions at $\sqrt{s}$ = 5TeV taken in 2015. Integrated luminosity is $10.12 \pm 1.31\ \mu b^{-1}$.
- Definition of J/ψ cross section:

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

Dimuon mass fits

➢ Using mass fit to determine the yields of background under:

- J/ψ mass window $3032 < m_{\mu^+\mu^-} < 3162$ MeV

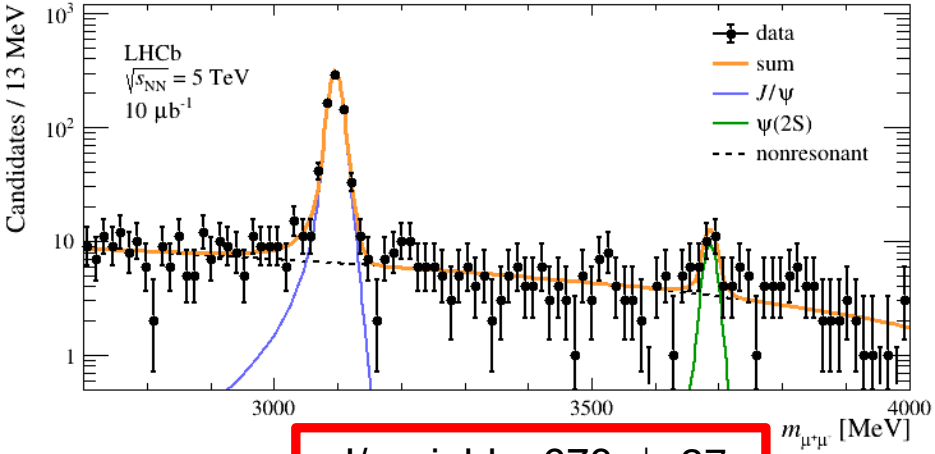
➢ Double-side Crystal Ball function for the mass peaks

- $J/\psi \rightarrow \mu^+\mu^-$ and $\psi(2S) \rightarrow \mu^+\mu^-$

➢ Exponential function for the background:

- $\gamma\gamma \rightarrow \mu^+\mu^-$

[arXiv:2107.03223]



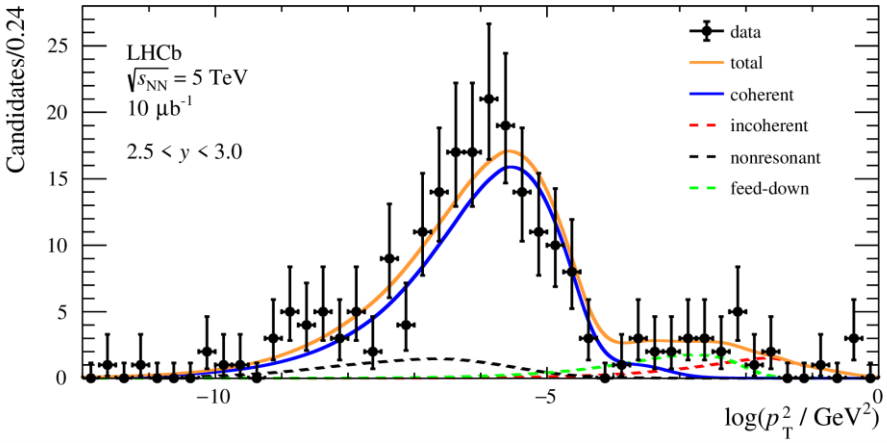
J/ψ yields: 673 ± 27

➢ Selection is defined as:

- Each muon p_T > 800 MeV, 2<η<4.5; Di-muon p_T<1 GeV; Muon $|\Delta\varphi_{\mu^+\mu^-}| > 0.9\pi$;
- Event selection for $\mu^+\mu^-$ in final state with only two long tracks reconstructed: nLongTracks = 2;
- Herschel detector is used to further reduce the multiplicities, applying the herschel cut is very useful to cut the incoherent part in mass window: $ln(\chi^2_{HRC}) < 7$.

$\log(P_T^2)$ fits to extract the coherent component

[arXiv:2107.03223]



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

$$f(log(p_T^2)) = n_{coh} \cdot F_{coh}(log(p_T^2)) + n_{incoh} \cdot F_{incoh}(log(p_T^2)) + n_{feed} \cdot F_{feed}(log(p_T^2)) + n_{non-reso.} \cdot F_{non-reso.}(log(p_T^2)),$$

J/ψ coherent: 489 ± 25

- Fit on the logp_T^2 of J/ψ:
  - Including coherent and Incoherent J/ψ component, ψ(2S) feed down and non-resonant part.
- All signal and background pdfs are estimated using the STARlight generator and the LHCb detector simulation.
- The non-resonant yields are extracted from the di-muon mass fits.

- STARlight is a Monte Carlo generator that simulates two-photon and photon-Pomeron interactions between relativistic nuclei and protons.

in rapidity intervals

- Total and coherent J/ψ yields after the invariant mass and the transverse momentum fits, in J/ψ rapidity intervals:

Rapidity y	Total J/ψ yield	Coherent J/ψ yield
$2.0 - 2.5$	69 ± 9	53 ± 8
$2.5 - 3.0$	208 ± 15	153 ± 14
$3.0 - 3.5$	233 ± 16	176 ± 15
$3.5 - 4.0$	131 ± 12	95 ± 11
$4.0 - 4.5$	32 ± 6	12 ± 5

[arXiv:2107.03223]

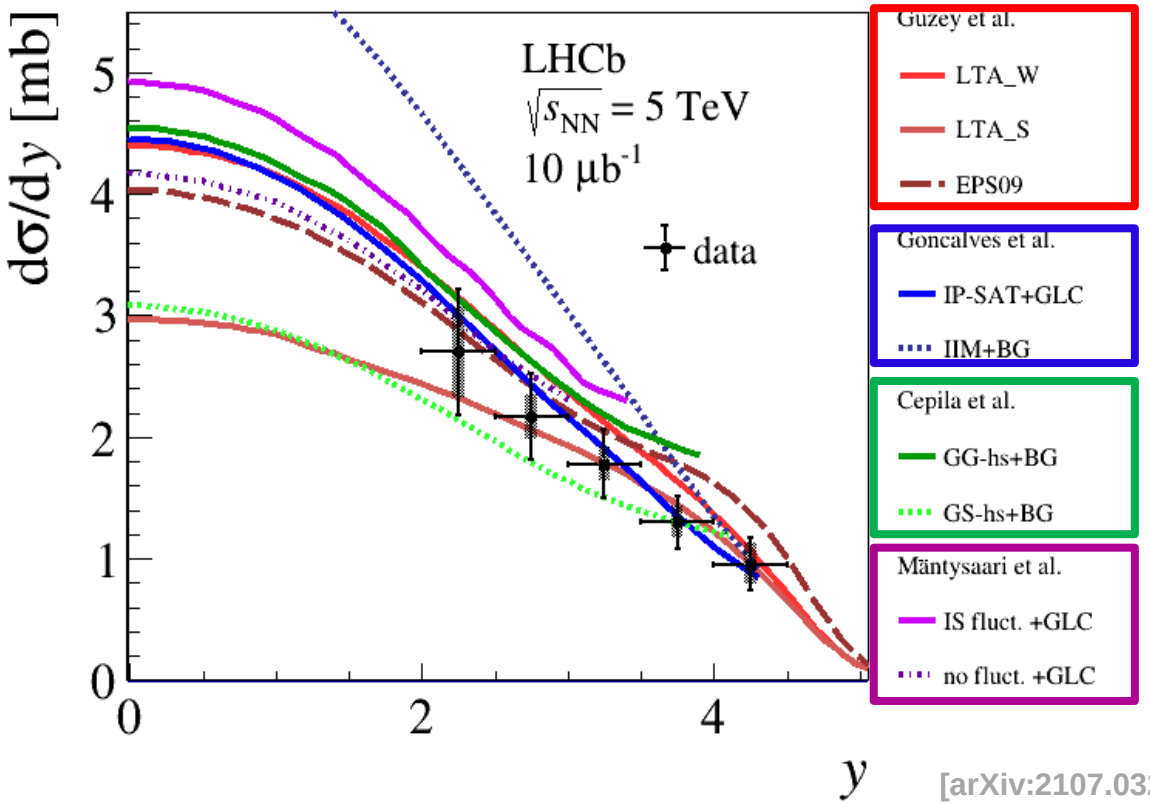
Results of cross section

- Measured cross section with statistical, systematic and luminosity uncertainties measured as a function of the J/ψ rapidity:

y interval	σ [mb]	Stat. [mb]	Syst. [mb]	Lumi. [mb]
$2.0 - 4.5$	4.45	0.24	0.18	0.58
$2.0 - 2.5$	1.35	0.19	0.06	0.17
$2.5 - 3.0$	1.09	0.09	0.05	0.14
$3.0 - 3.5$	0.89	0.07	0.04	0.12
$3.5 - 4.0$	0.65	0.06	0.03	0.08
$4.0 - 4.5$	0.48	0.09	0.02	0.06

[arXiv:2107.03223]

Compare with theoretical predictions



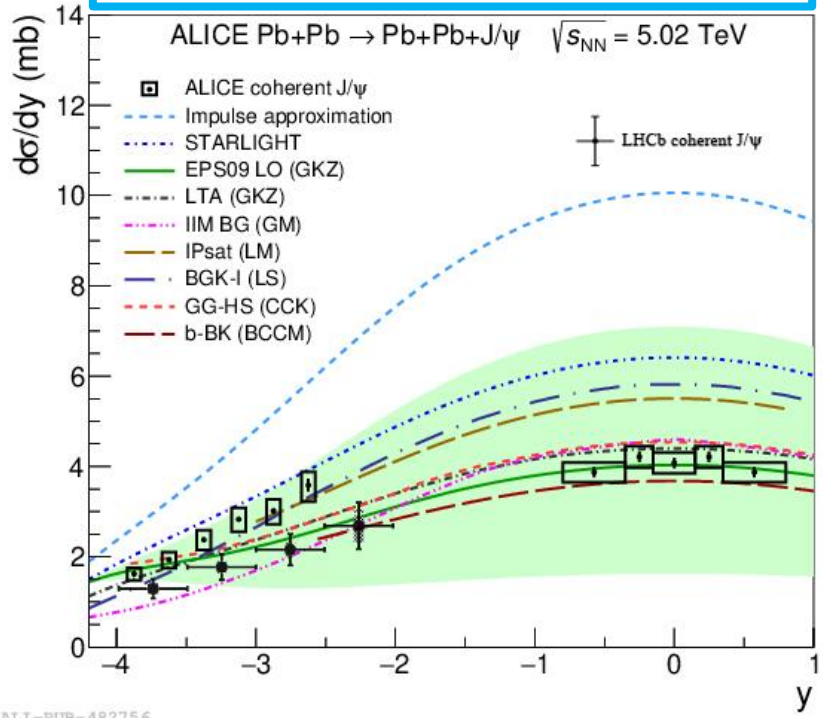
[arXiv:2107.03223]

σ = 4.45±0.24(stat.)±0.18(syst.)±0.58(lumi)mb

- pQCD calculations:
  - [PRC 93 (2016) 055206]
- Color dipole models:
  - [PRD 96 (2017) 094027]
  - [PRC 97 (2018) 024901]
  - [PLB 772 (2017) 832]

Compare results between LHCb and ALICE

σ_{LHCb} = 2.04 $\pm$ 0.3(syst.)mb;
σ_{ALICE} = 2.549 $^{+0.209}_{-0.237}(syst.)$mb 2.5<y<4.0



Signal definition:

- LHCb: Veto all additional radiation.
- ALICE: Also allows nuclear excitations.

Uncertainty:

- LHCb:
  - Dominant uncertainty arises from the luminosity.
  - All the systematic uncertainty is correlated.
- ALICE:
  - Dominant uncertainty originates form the signal purity estimate.
  - Systematic uncertainty partially correlated.

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

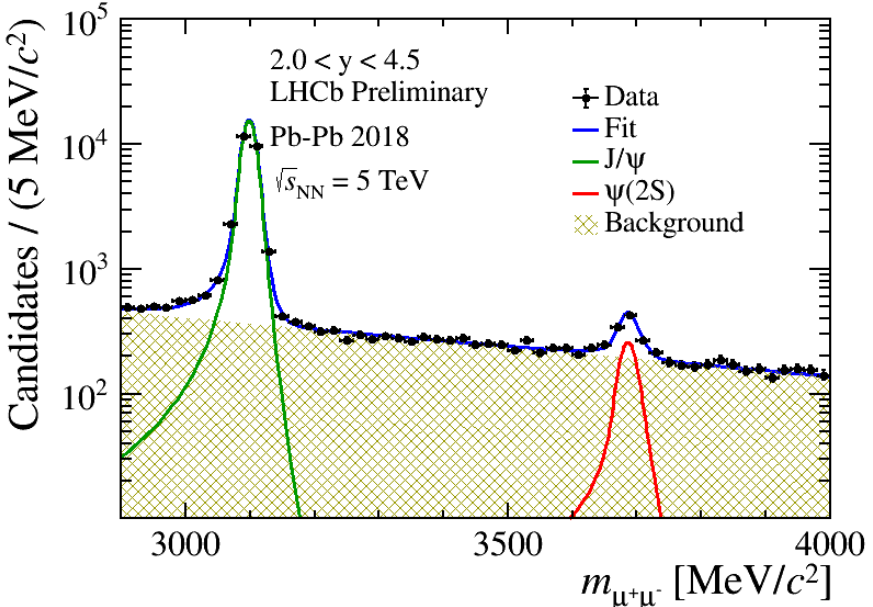
2018 Data Set

	2015	2018
$\sqrt{s}$	5 TeV	5 TeV
	PbPb	PbPb
$\mathcal{L}$	10 μ b^{-1}	~ 228 μ b^{-1}

- About 20 times more statistics in 2015.
- The 20 times higher statistics make it possible to determine the cross-sections of both J/ψ and ψ(2S), as well as in 5 rapidity bins.
- Cross-section ratio:

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

- 2018 data fit



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

summary

- Charmonium production in Ultra-peripheral PbPb collisions is of particular interests to probe gluon parton distribution functions.
- Results based on 2015 PbPb dataset at 5 TeV are presented. [arXiv:2107.03223]
- Higher precision results using 2018 dataset with 20 times higher statistics for both the J/ψ and ψ(2S) cross section are coming soon.

Thanks!

Back up