



*Benjamin Audurier - Rencontres QGP France - 05/07/2021*

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# LHCb overview

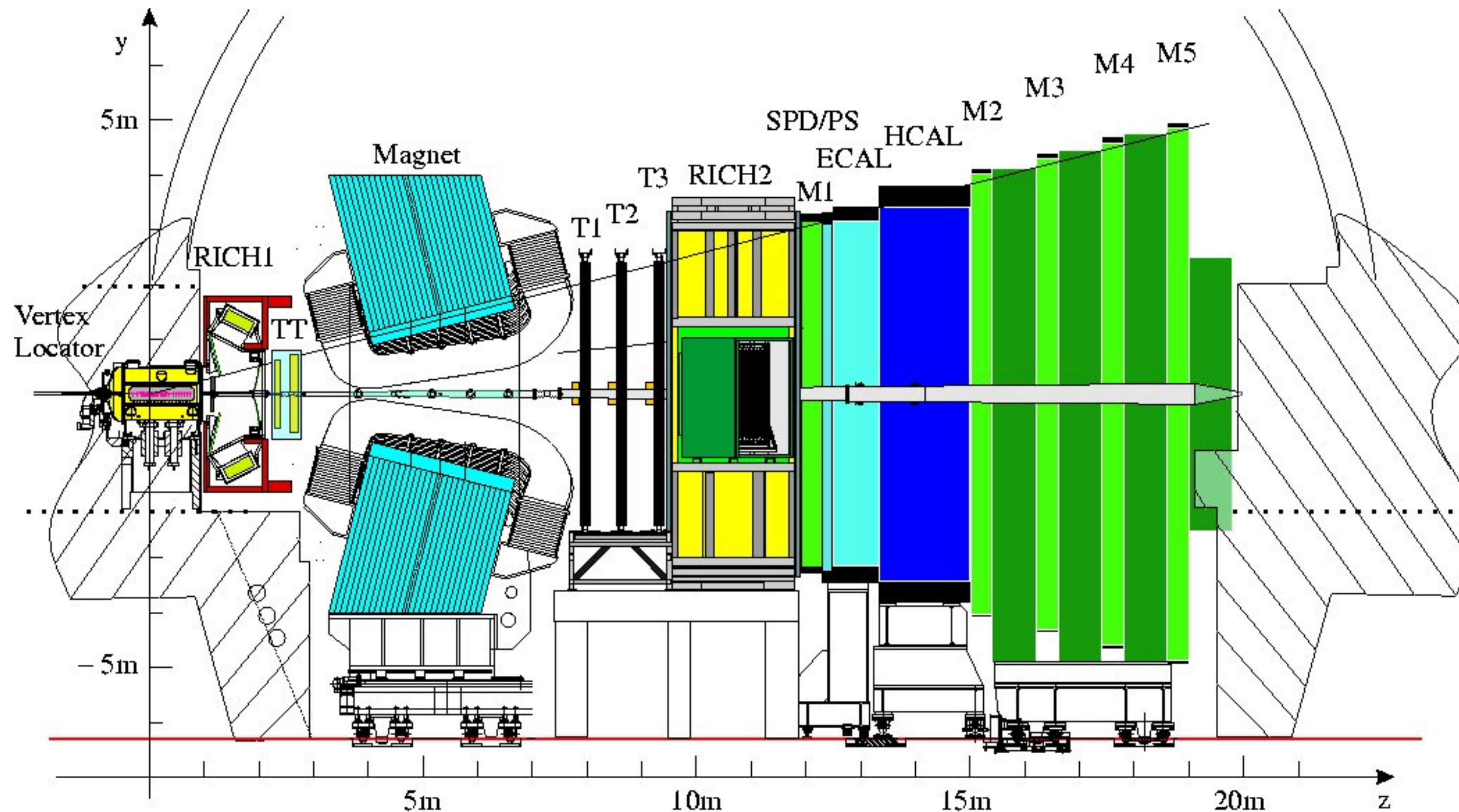
- I. The LHCb detector
- II. Selected recent results
  - 1) Recently published
  - 2) Soon to be published
- III. Conclusion

# The LHCb detector

# The LHCb detector

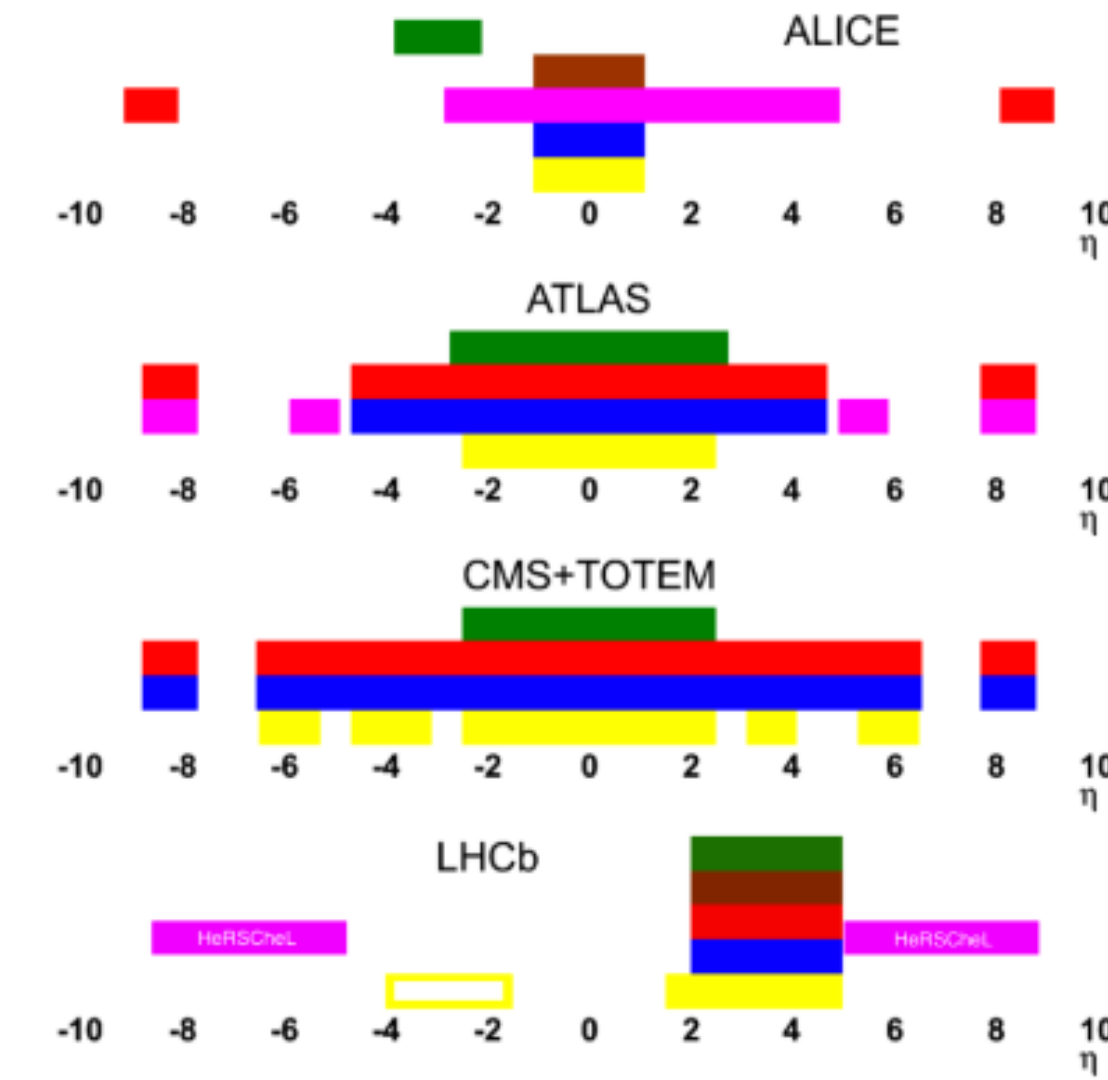
[10.1142/S0217751X15300227](https://doi.org/10.1142/S0217751X15300227)

LHCb : **single arm spectrometer** fully  
instrumented in pseudo-rapidity range  $2 < \eta < 5$



Legend for detector components:

- hadron PID
- muon system
- lumi counters
- HCAL
- ECAL
- tracking



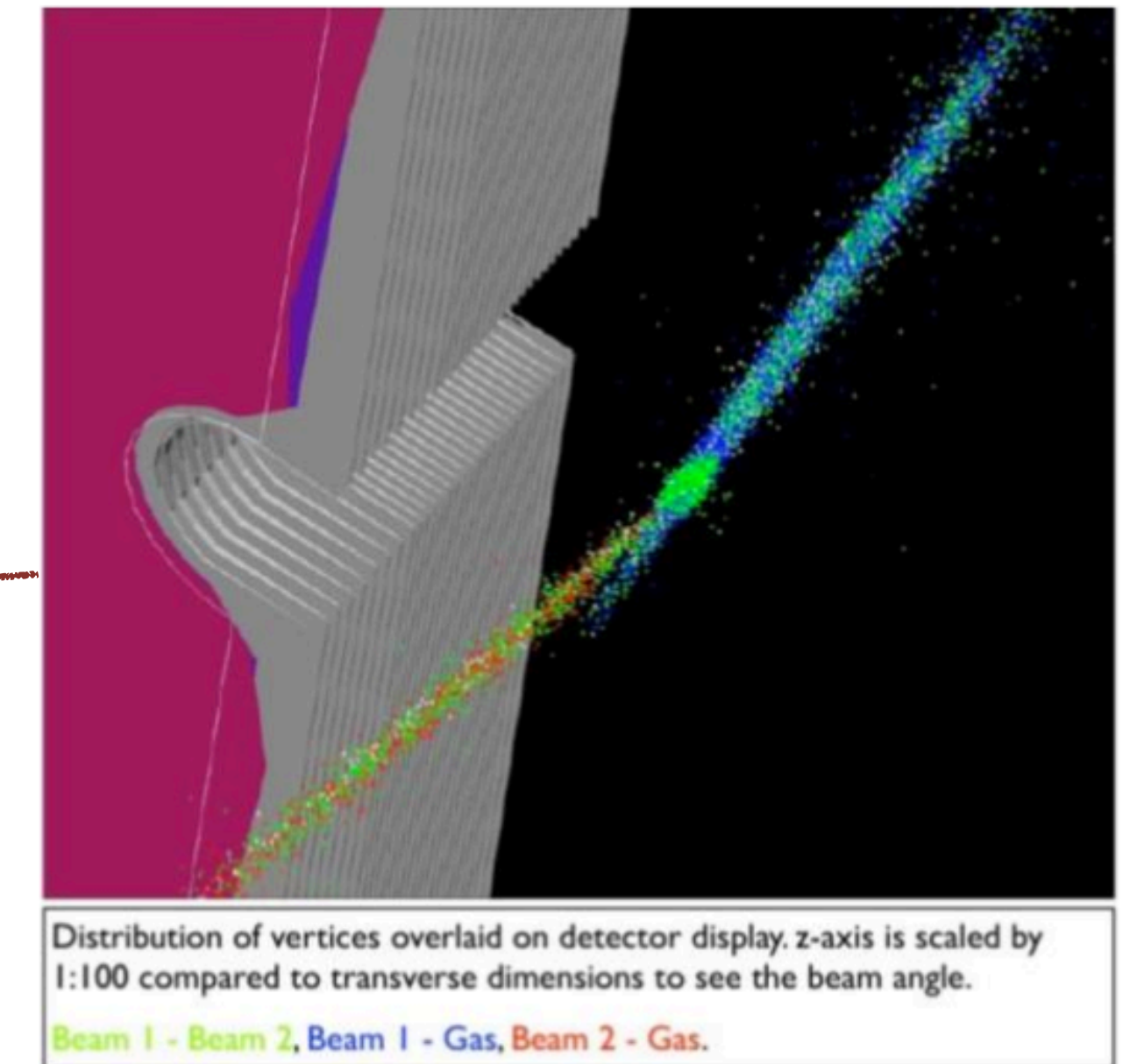
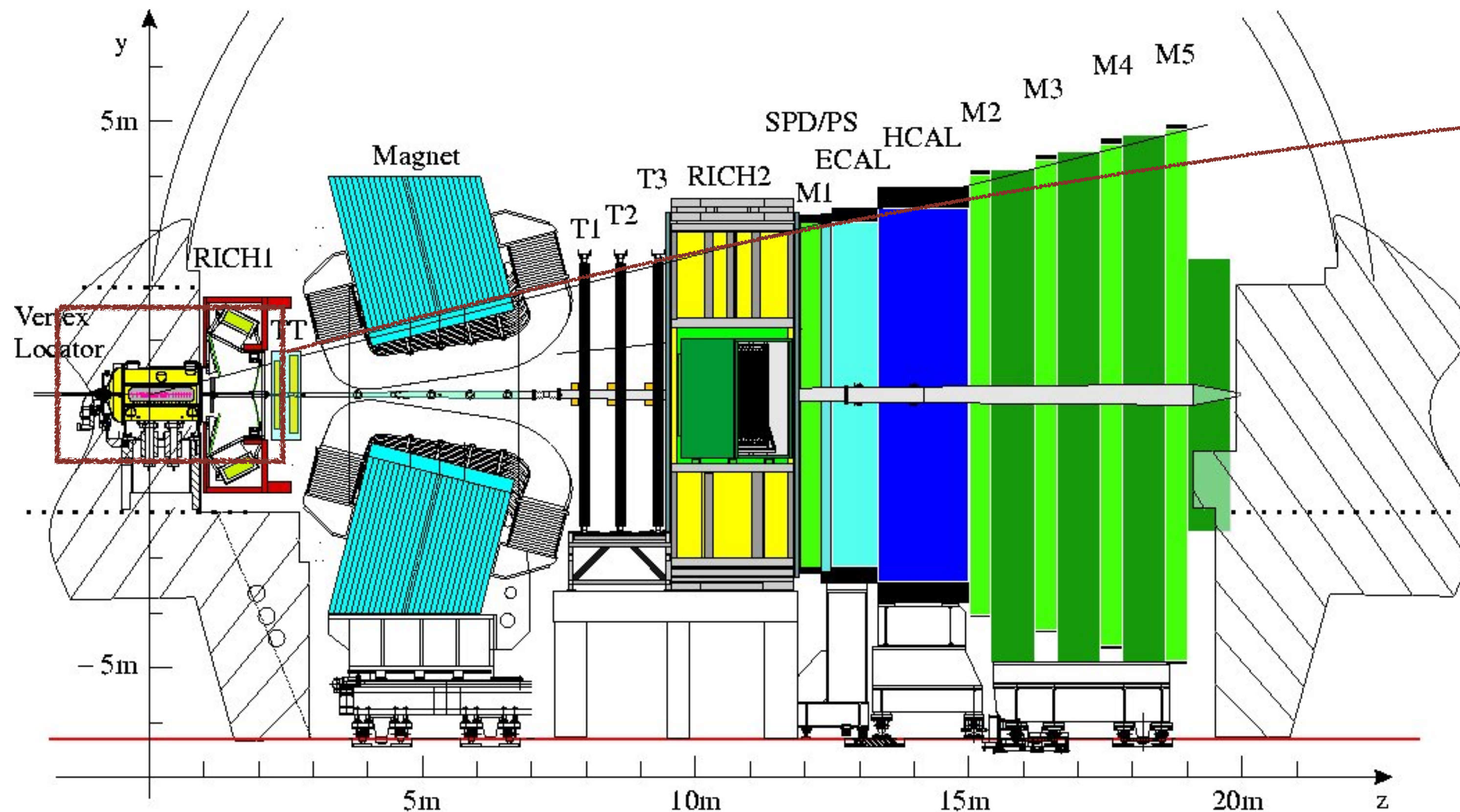
- ❖ Track reconstruction **down to  $p_T = 0$ .**
- ❖ Excellent  **$p_T$  and mass resolution.**
- ❖ Excellent **particle identification.**
- ❖ Precision **vertex reconstruction.**



# The LHCb detector

[10.1142/S0217751X15300227](https://doi.org/10.1142/S0217751X15300227)

Can operate both in pp/pPb/PbPb and fixed-target !



Fixed-target mode: **unique at LHC !**

- Injecting gas in the LHCb VErteX LOcator (VELO) tank.
- **Noble gas only** : He, Ne, Ar
- Gas pressure :  $10^{-7}$  to  $10^{-6}$  mbar



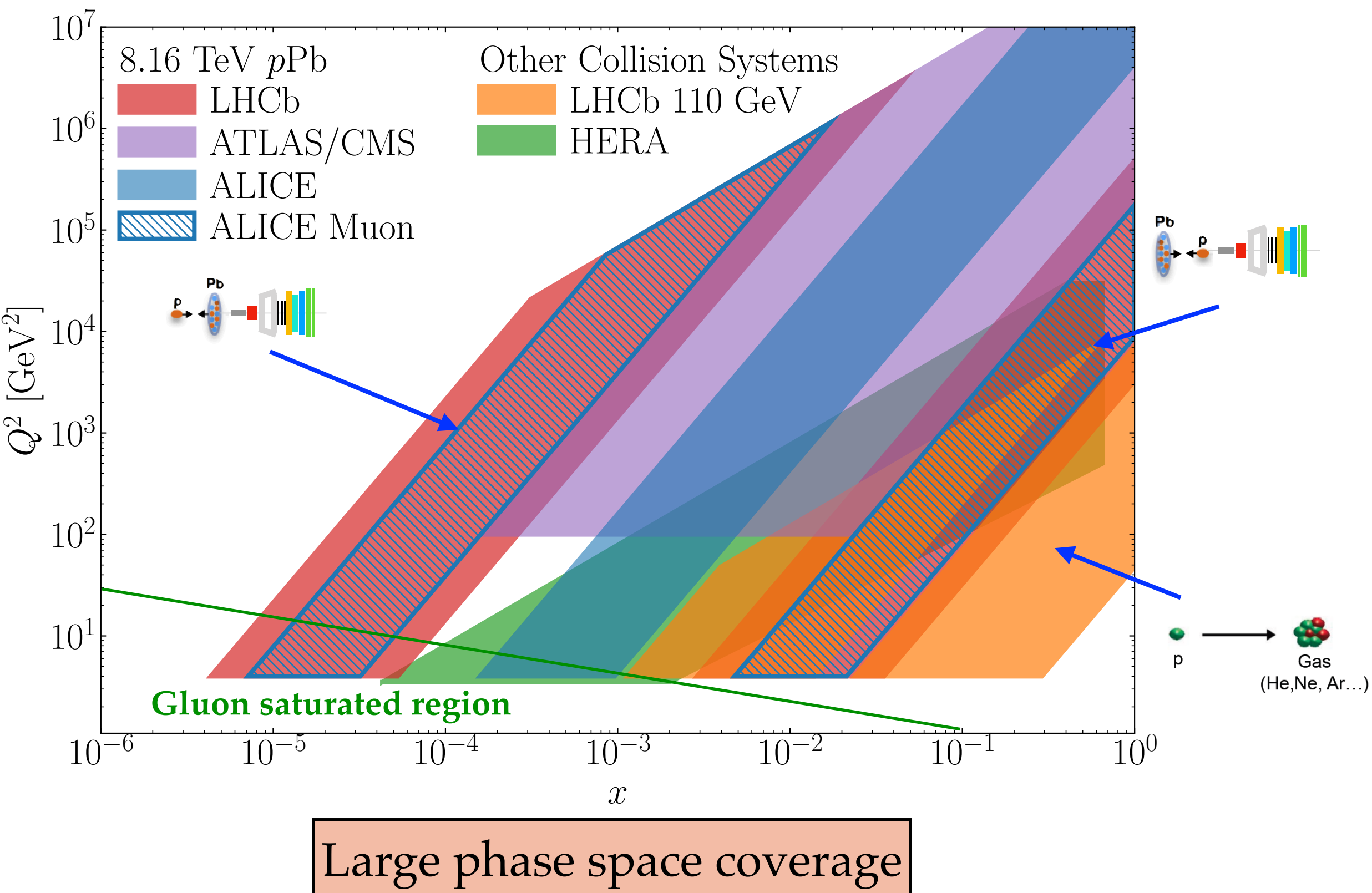
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# LHCb : general purpose detector for heavy-ions

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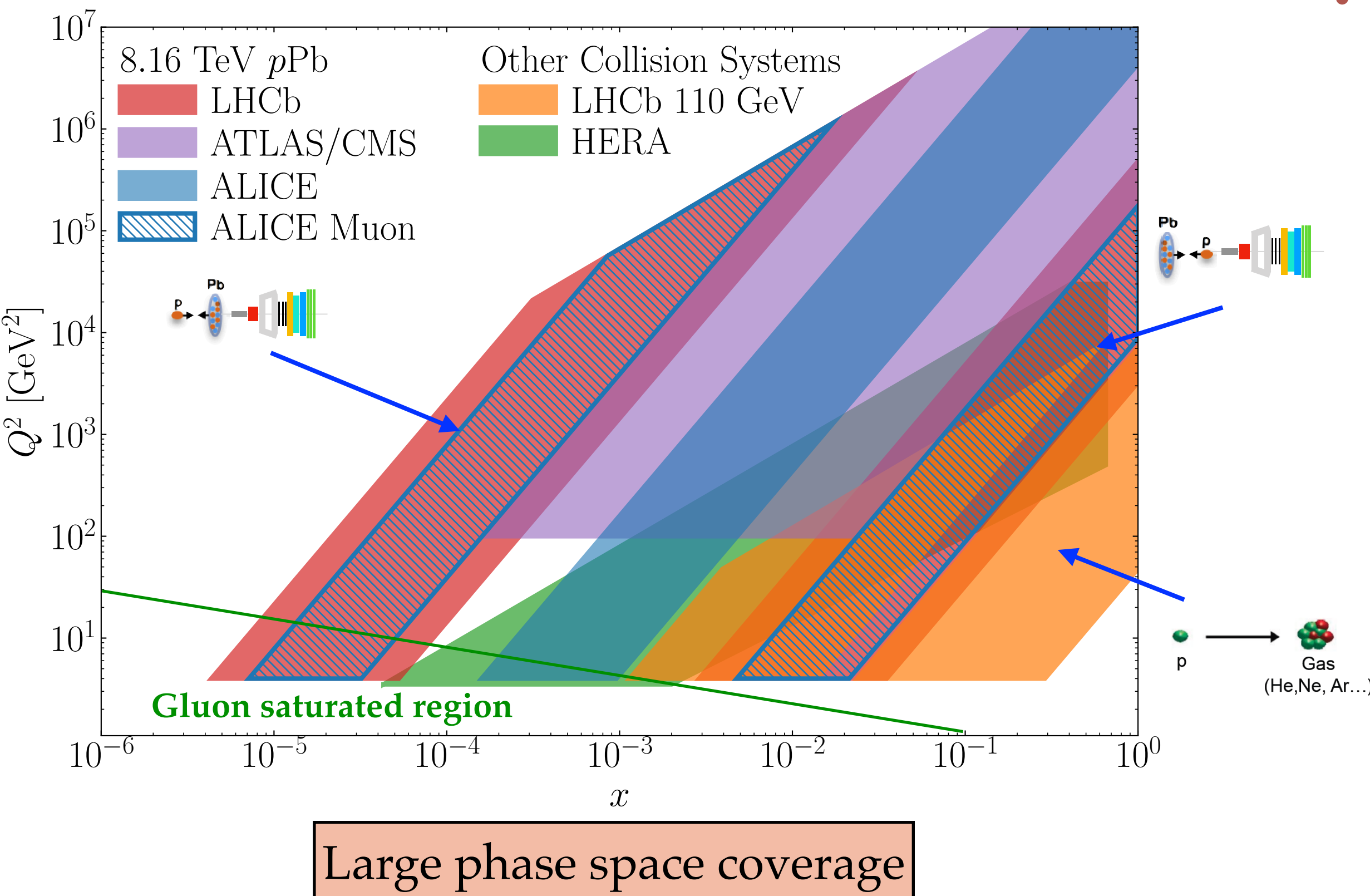
## Hadronic and QGP physics





# LHCb : general purpose detector for heavy-ions

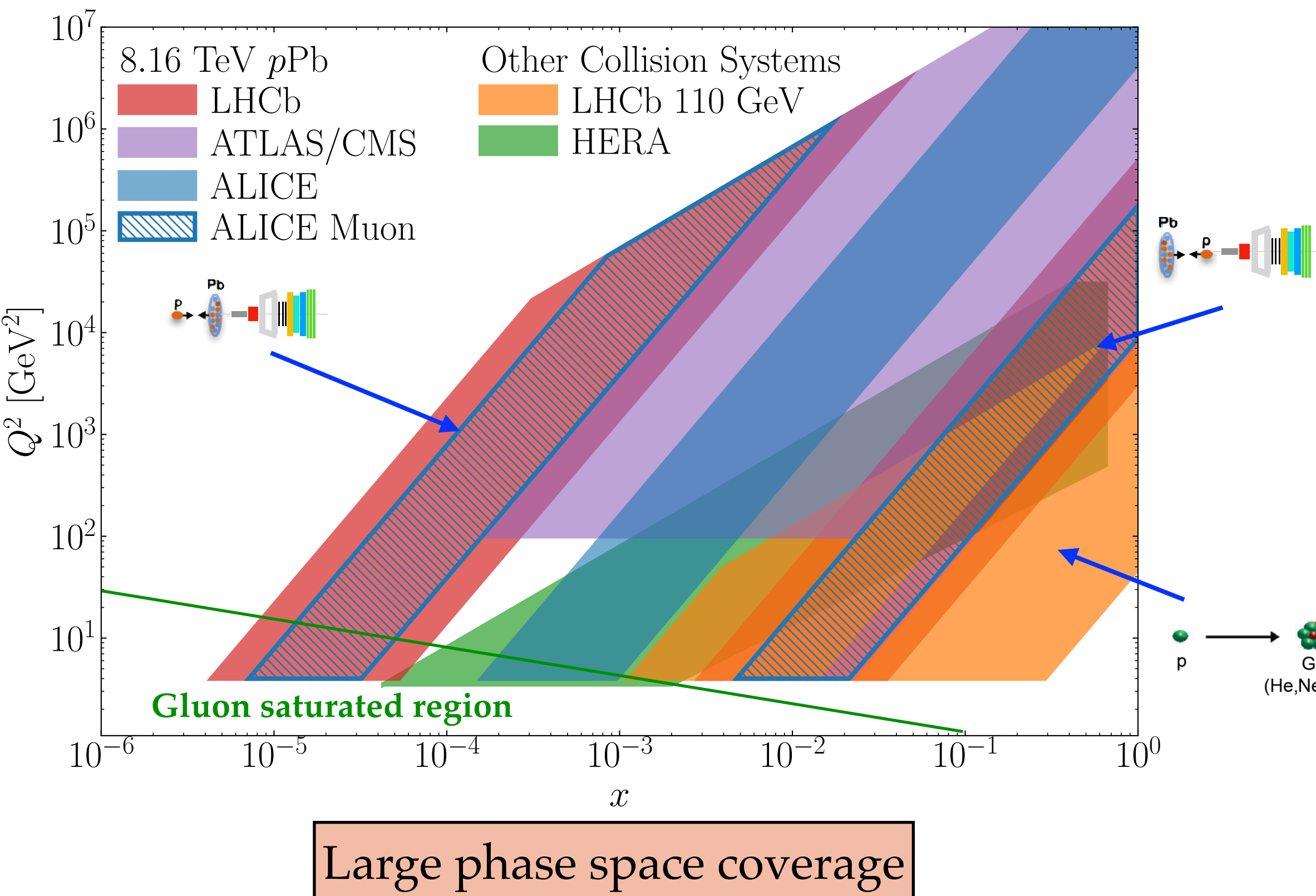
## Hadronic and QGP physics



- Collider mode :
  - Detector is well suited to constrain (n)PDFs.
  - New PbPb dataset reaching 60% in centrality.

# LHCb : general purpose detector for heavy-ions

## Hadronic and QGP physics



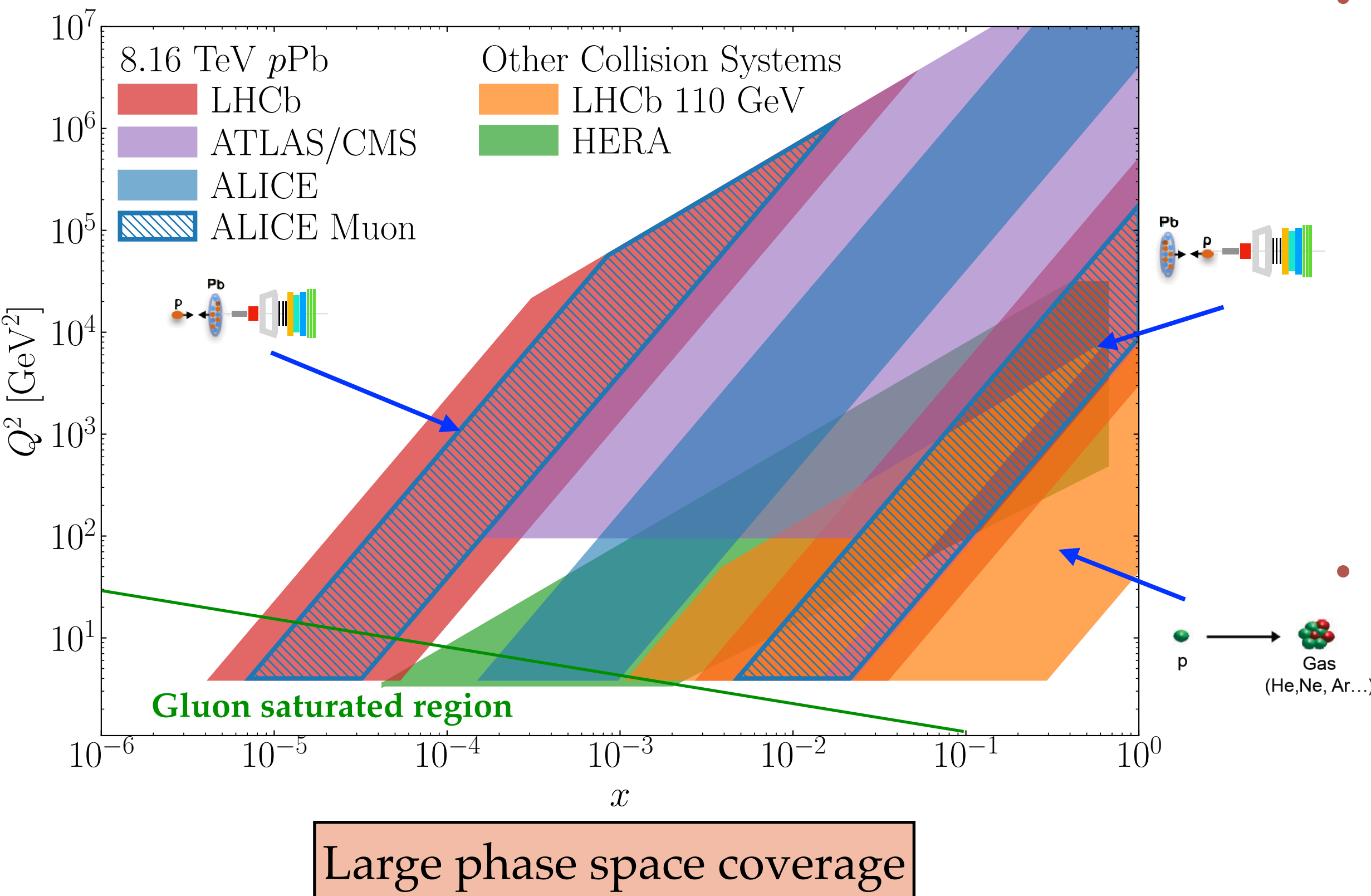
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- Fixed-target program :
  - (n)PDFs studies.
  - Test cosmic physics in laboratory.



# LHCb : general purpose detector for heavy-ions

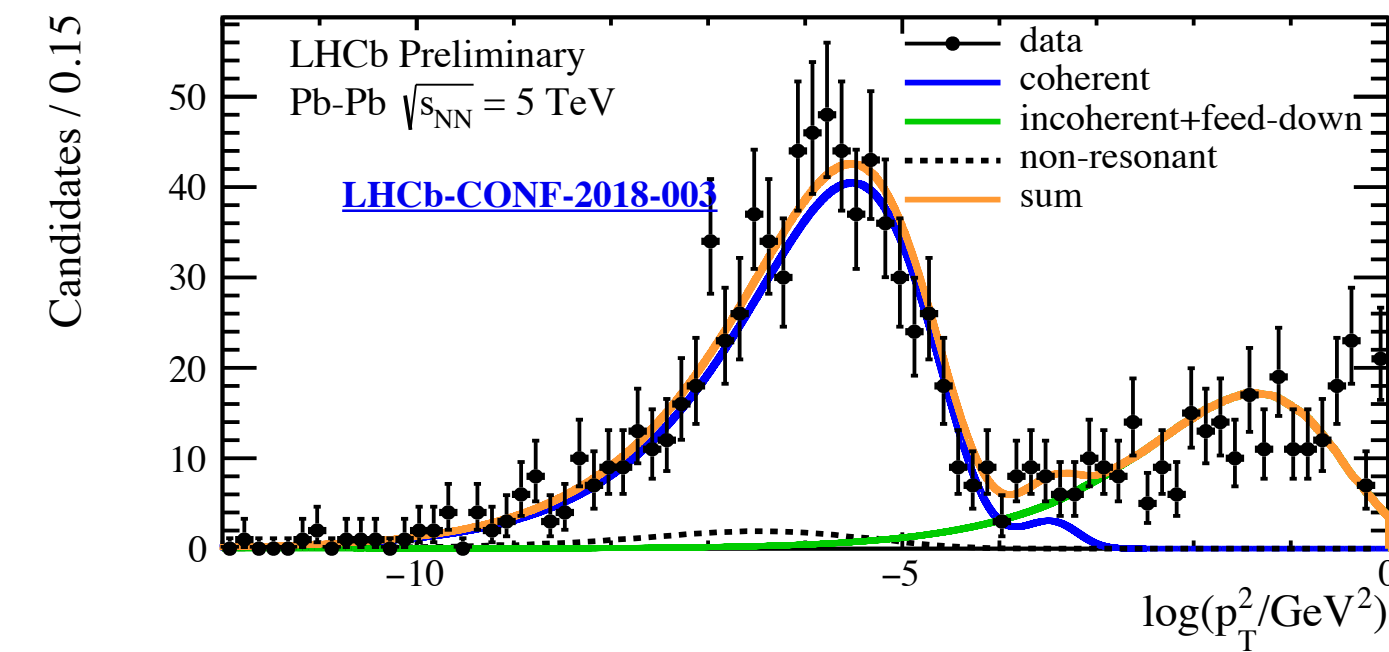
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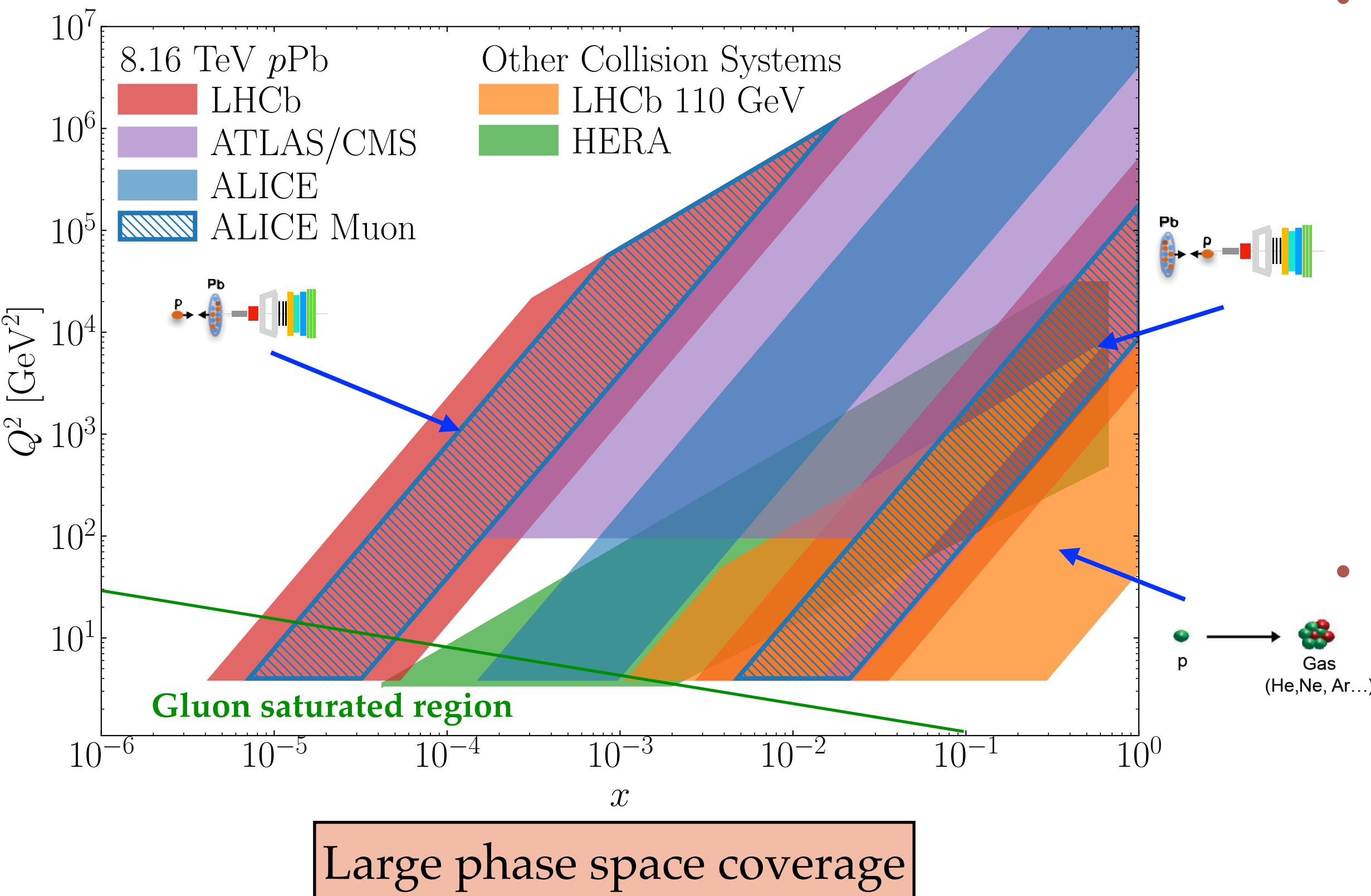
## UPC physics



- $p_T$  resolution : key to ultra-peripheral PbPb collisions.
- UPC physics can be extended to pA and fixed-target.

# LHCb : general purpose detector for heavy-ions

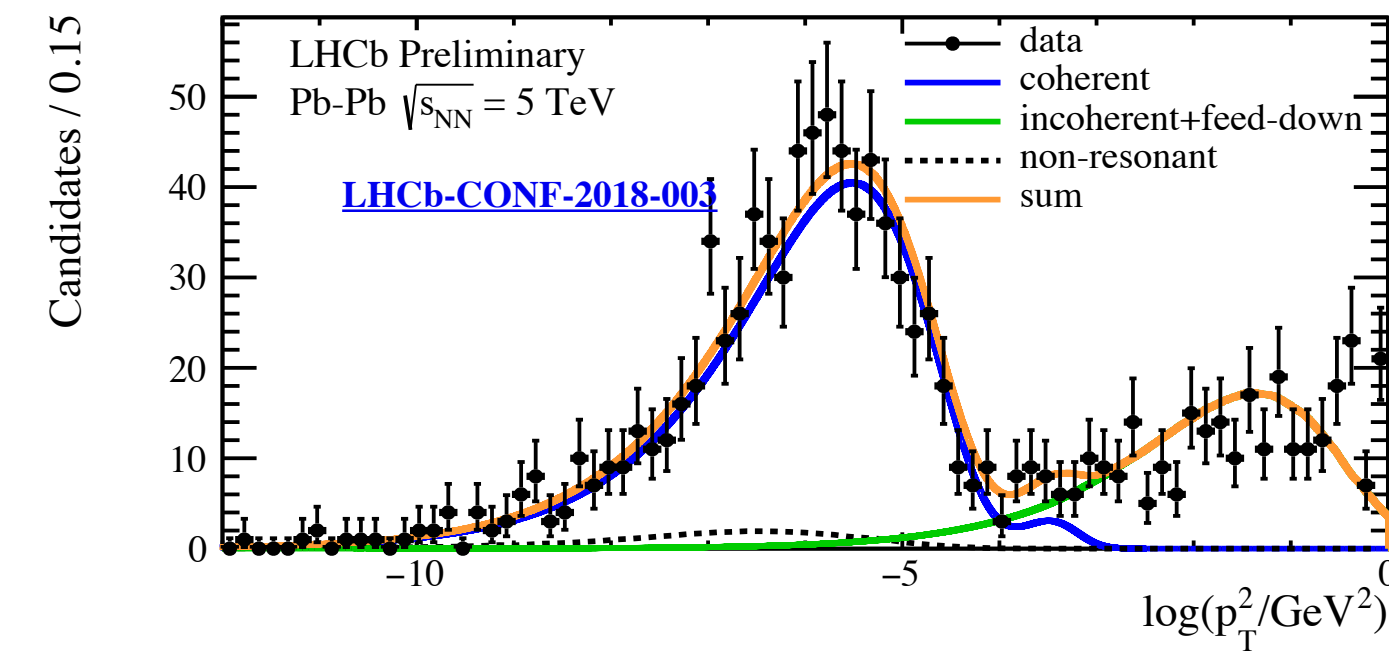
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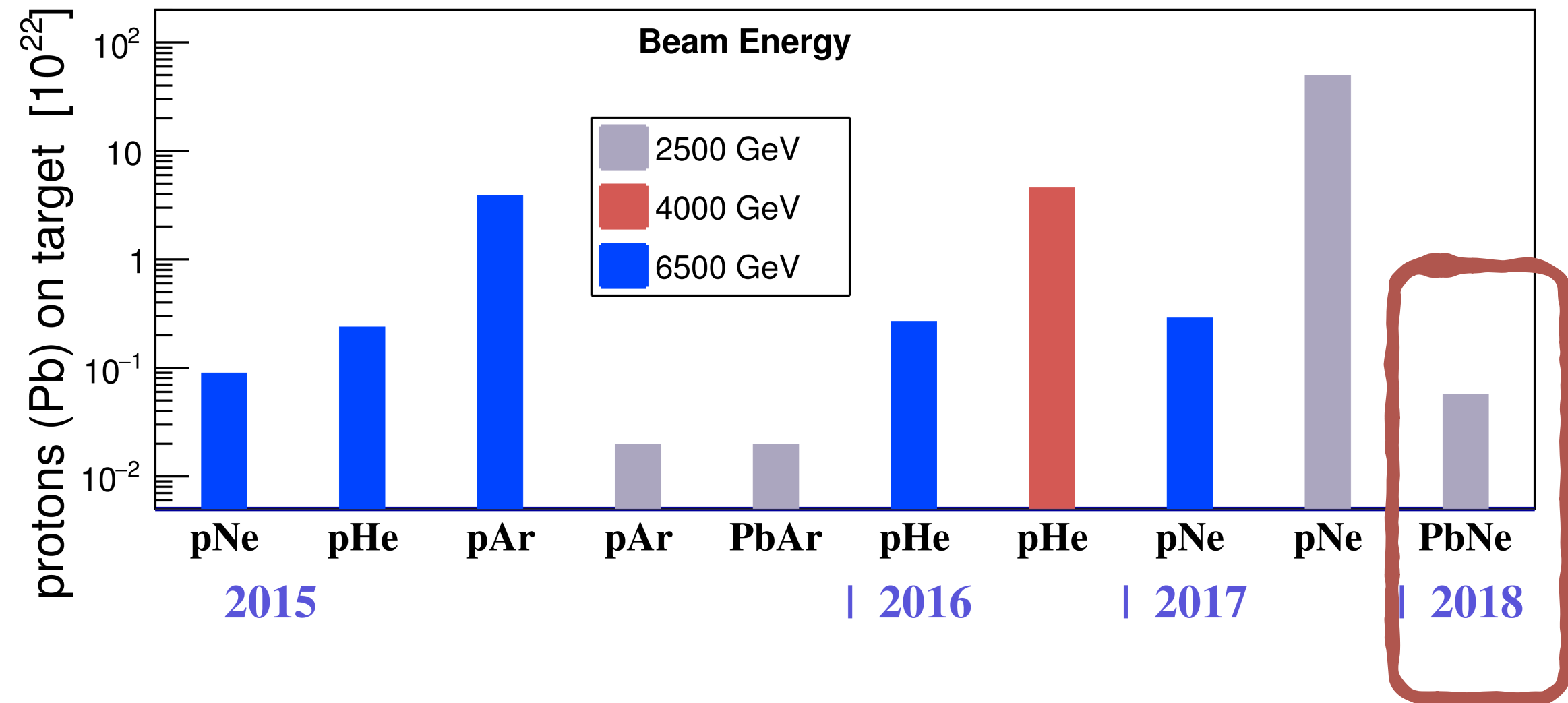
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Large and expanding physics program !

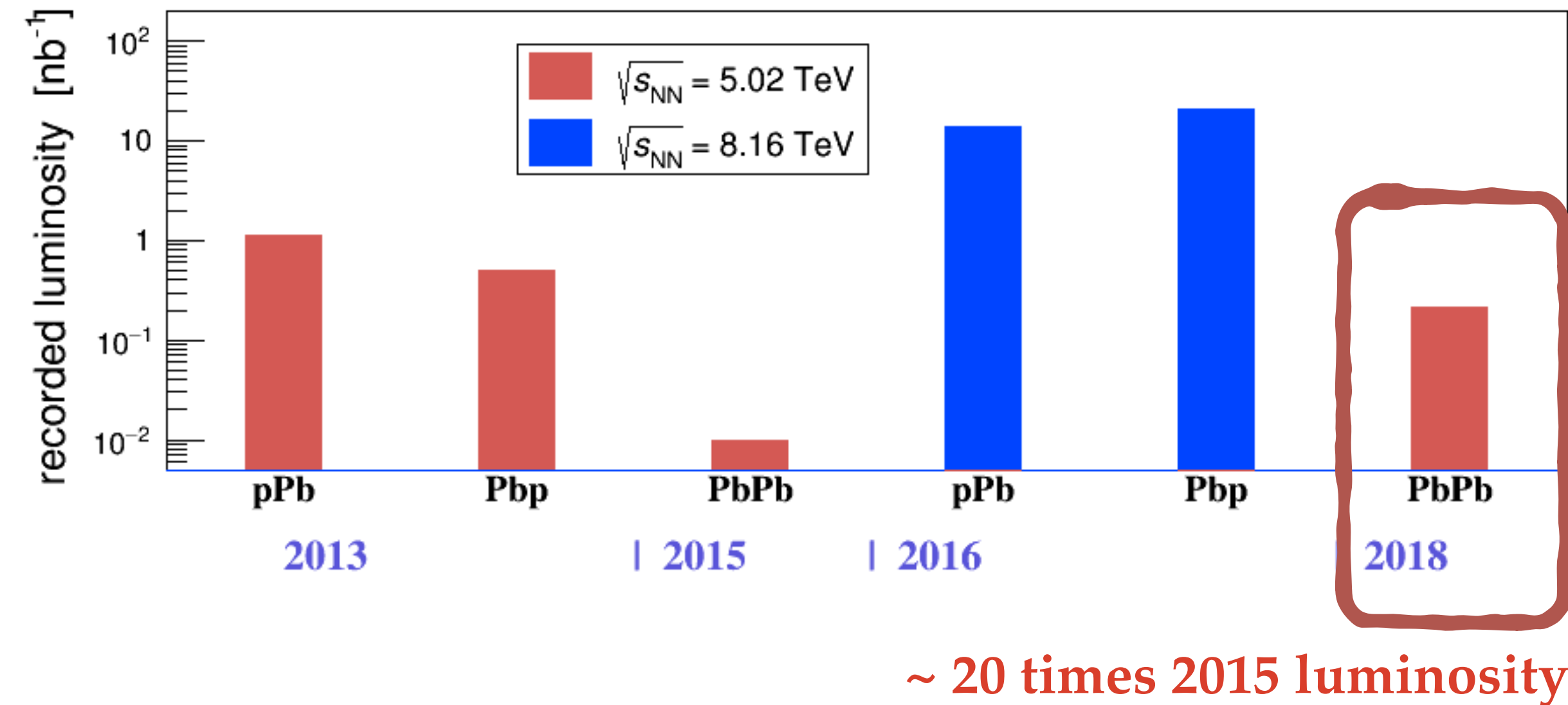


# LHCb physics program

*Fixed-target mode samples*



*Collider mode samples*



- ❖ Large variety of samples to study !
- ❖ Two new samples : PbNe at  $\sqrt{s_{\text{NN}}} = 68.6$  GeV and PbPb at  $\sqrt{s_{\text{NN}}} = 5.02$  TeV

# Results from the LHCb Ion-Fixed-Target group

TITLE	DOCUMENT NUMBER	JOURNAL	SUBMITTED ON
Measurement of prompt-production cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV	PAPER-2020-048 arXiv:2103.07349 [PDF]	Phys. Rev. C103 (2021) 064905	12 Mar 2021
Observation of multiplicity-dependent prompt $\chi_{c1}$ (3872) and $\psi(2S)$ production in $pp$ collisions	PAPER-2020-023 arXiv:2009.06619 [PDF]	Phys. Rev. Lett. 126 (2021) 092001	14 Sep 2020
Observation of enhanced double parton scattering in proton-lead collisions at $\sqrt{s_{NN}} = 8.16$ TeV	PAPER-2020-010 arXiv:2007.06945 [PDF]	Phys. Rev. Lett. 125 (2020) 212001	14 Jul 2020
Measurement of $B^+$ , $B^0$ and $\Lambda_b^0$ production in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV	PAPER-2018-048 arXiv:1902.05599 [PDF]	Phys. Rev. D99 052011 (2019)	14 Feb 2019
First Measurement of Charm Production in its Fixed-Target Configuration at the LHC	PAPER-2018-023 arXiv:1810.07907 [PDF]	Phys. Rev. Lett. 122 (2019) 132002	18 Oct 2018
Study of $\Upsilon$ production in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV	PAPER-2018-035 arXiv:1810.07655 [PDF]	JHEP 11 (2018) 194	17 Oct 2018
Prompt $\Lambda_c^+$ production in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV	PAPER-2018-021 arXiv:1809.01404 [PDF]	JHEP 02 (2019) 102	05 Sep 2018
Measurement of antiproton production in $p\text{He}$ collisions at $\sqrt{s_{NN}} = 110$ GeV	PAPER-2018-031 arXiv:1808.06127 [PDF]	Phys. Rev. Lett. 121 (2018) 222001	18 Aug 2018
Study of prompt $D^0$ meson production in $p\text{Pb}$ collisions at $\sqrt{s}=5$ TeV	PAPER-2017-015 arXiv:1707.02750 [PDF]	JHEP 10 (2017) 090	10 Jul 2017
Prompt and nonprompt $J/\psi$ production and nuclear modification in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV	PAPER-2017-014 arXiv:1706.07122 [PDF]	Phys. Lett. B774 (2017) 159	21 Jun 2017
Study of $\psi(2S)$ production and cold nuclear matter effects in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 5$ TeV	PAPER-2015-058 arXiv:1601.07878 [PDF]	JHEP 03 (2016) 133	28 Jan 2016
Measurements of long-range near-side angular correlations in $\sqrt{s_{NN}} = 5\text{TeV}$ proton-lead collisions in the forward region	PAPER-2015-040 arXiv:1512.00439 [PDF]	Phys. Lett. B762 (2016) 473	01 Dec 2015
Observation of $Z$ production in proton-lead collisions at LHCb	PAPER-2014-022 arXiv:1406.2885 [PDF]	JHEP 09 (2014) 030	11 Jun 2014
Study of $\Upsilon$ production and cold nuclear matter effects in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 5\text{TeV}$	PAPER-2014-015 arXiv:1405.5152 [PDF]	JHEP 07 (2014) 094	20 May 2014
Study of $J/\psi$ production and cold nuclear matter effects in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 5$ TeV	PAPER-2013-052 arXiv:1308.6729 [PDF]	JHEP 02 (2014) 72	30 Aug 2013

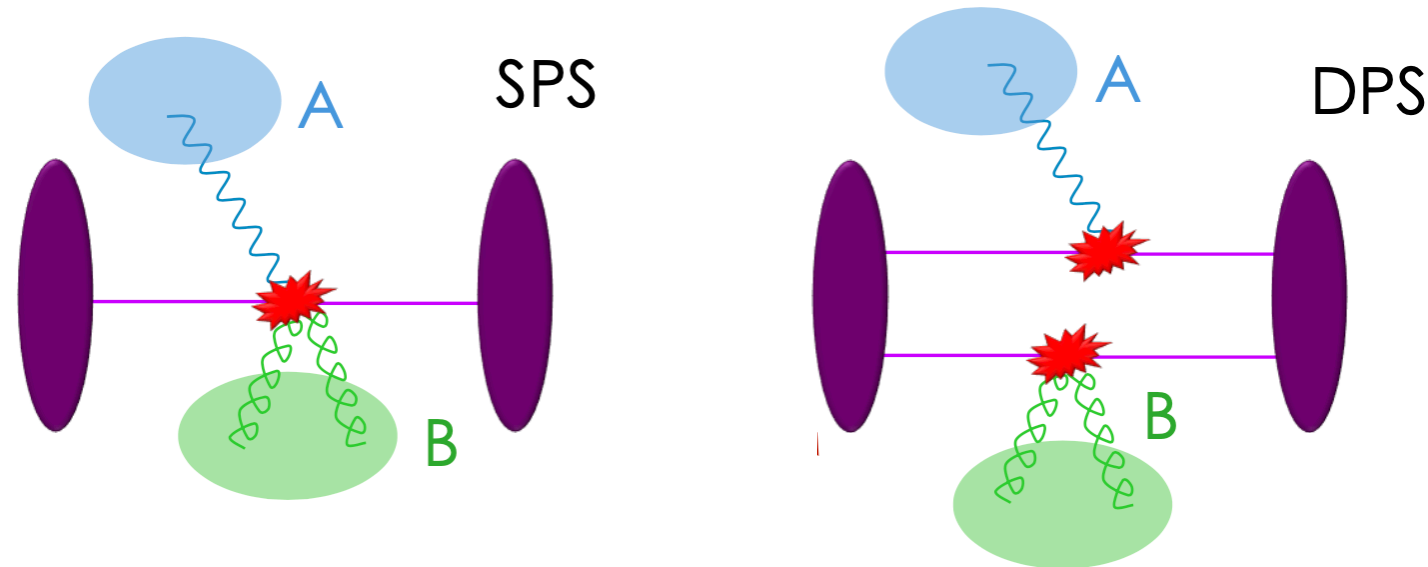
I will focus on these results,  
and others even more recent...

List of published papers available [here](#)



# Selected recent results

# Double charm production in pPb

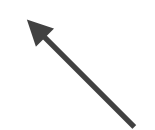


J. Gaunt, Quarkonia as Tools 2020 workshop

## ❖ Why Double Parton Scattering (DPS) ?

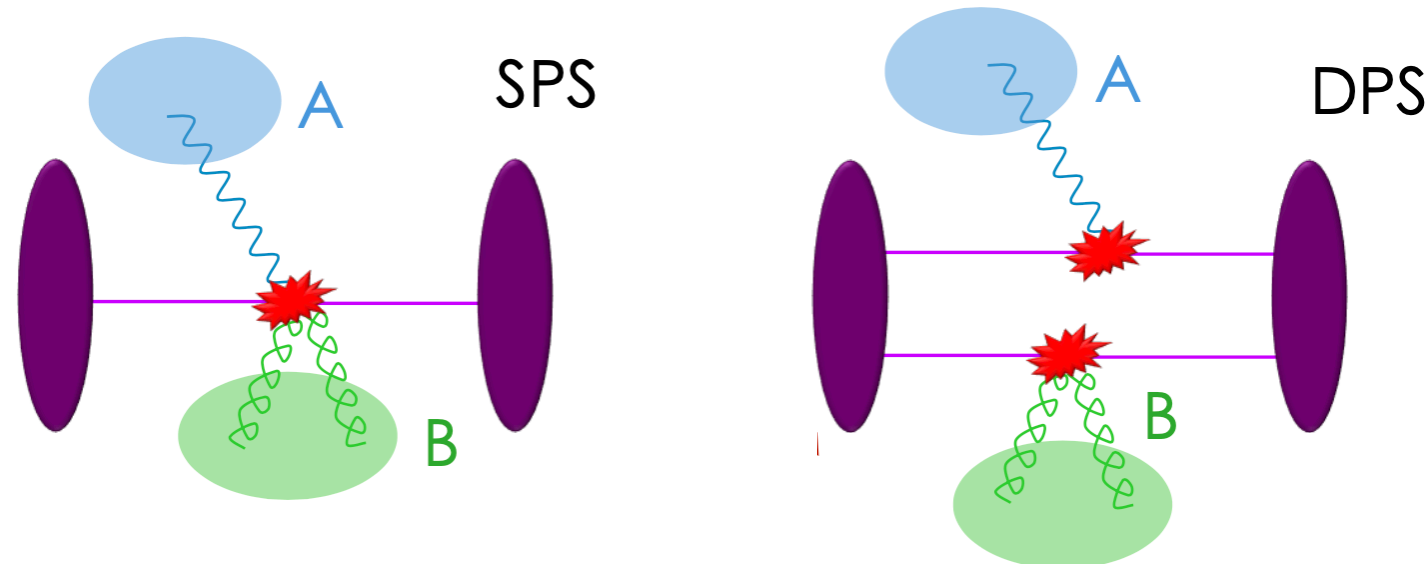
- ➔ To study the underlying event.
- ➔ To access Double Transverse Momentum Dependent Parton distributions (JHEP 1203 (2012) 089).
- ➔ ...

## ❖ DPS cross-section parametrisation, assuming two independent hard collisions :

$$\sigma_{\text{eff}} \propto \frac{\sigma^A \sigma^B}{\sigma_{\text{DPS}}^{AB}}$$


*Related to the geometry of the collision and independent of the final state (?)*

# Double charm production in pPb



J. Gaunt, Quarkonia as Tools 2020 workshop

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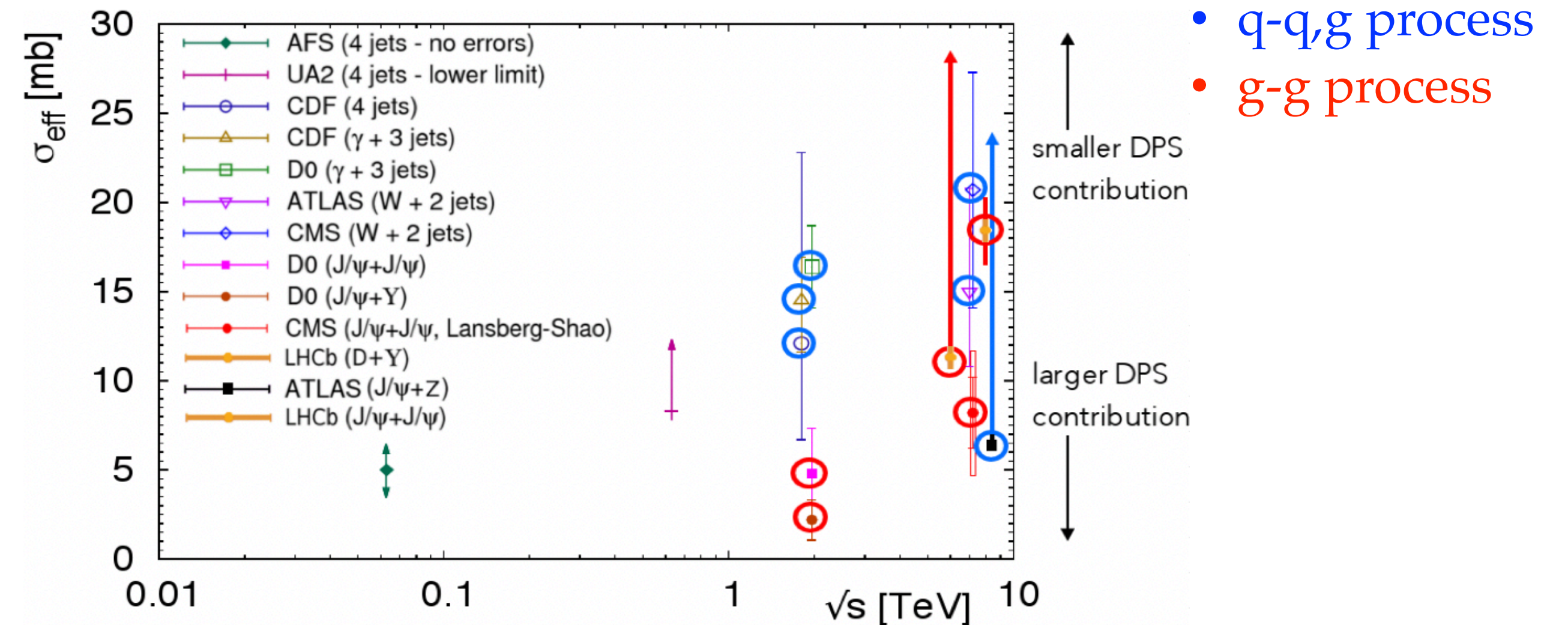
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D.D'Enterria, Quarkonia as Tools 2020 workshop



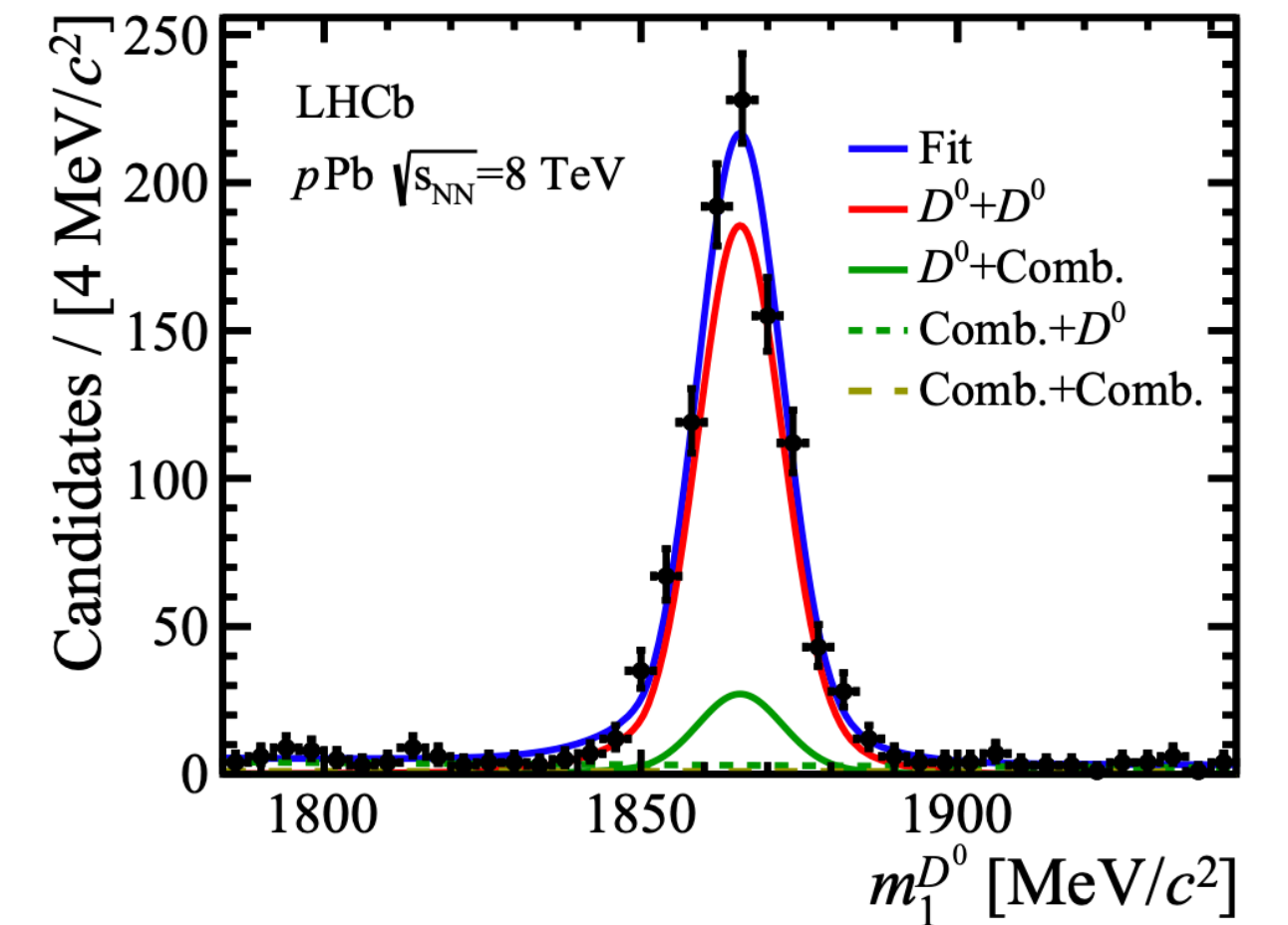
- ❖  $\sigma_{\text{eff}}$  final state dependant ? (mind the large uncertainties).
- ❖ Is  $\sigma_{\text{eff}}$  interpretation correct ?
- ❖  $\sigma_{\text{eff}}$  can also be measured in pA collisions and compared to pp collisions with simple scaling (arXiv:1708.07519).



# Double charm production in pPb

PHYS. REV. LETT. 125 (2020) 212001

- ❖ LHCb has measured prompt double open-charm / open-charm +  $J/\psi$  production in pPb@8.16TeV.
  - ➔ Combined pairs from the same event and corrected from acceptance/efficiency.

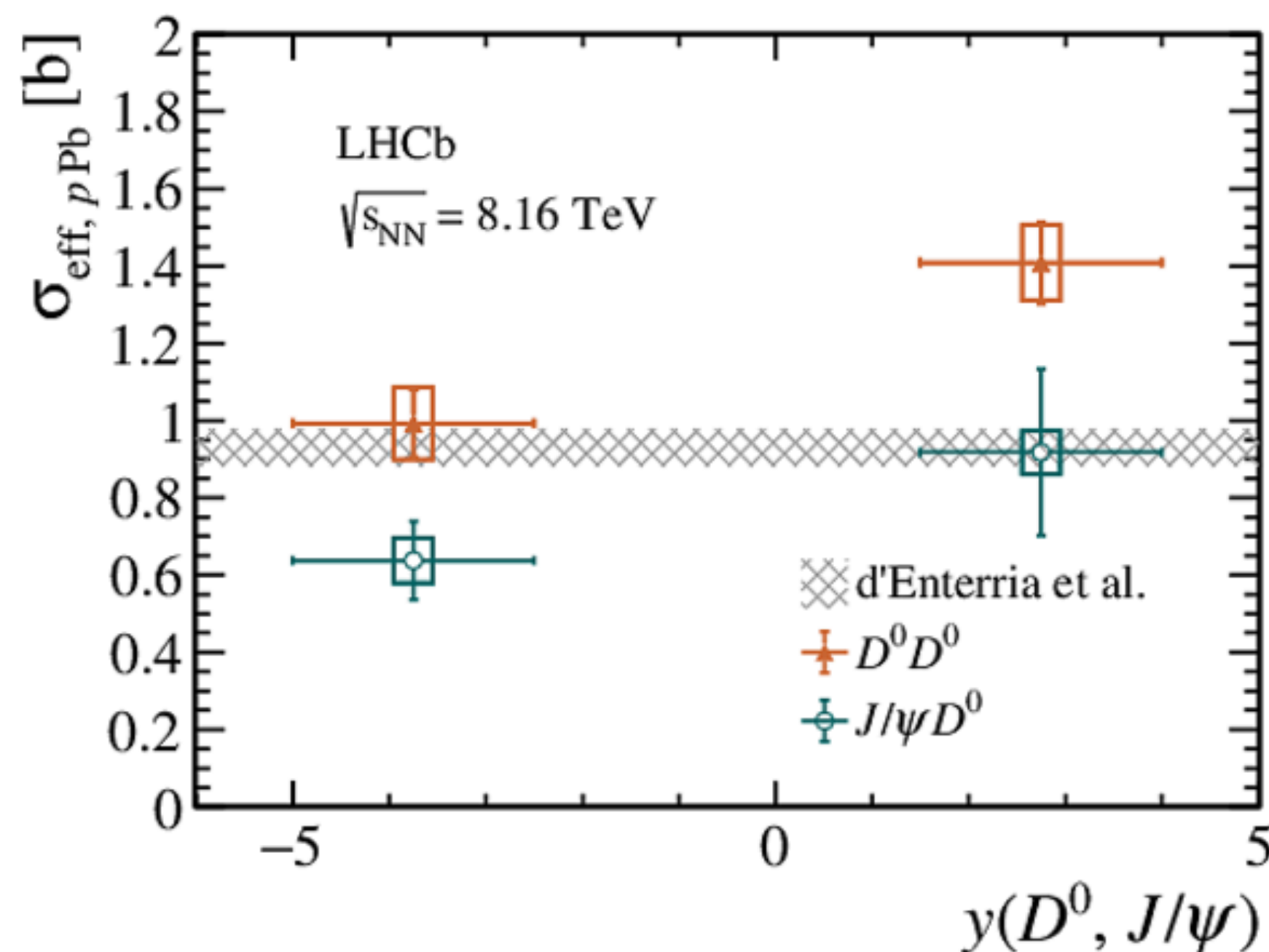
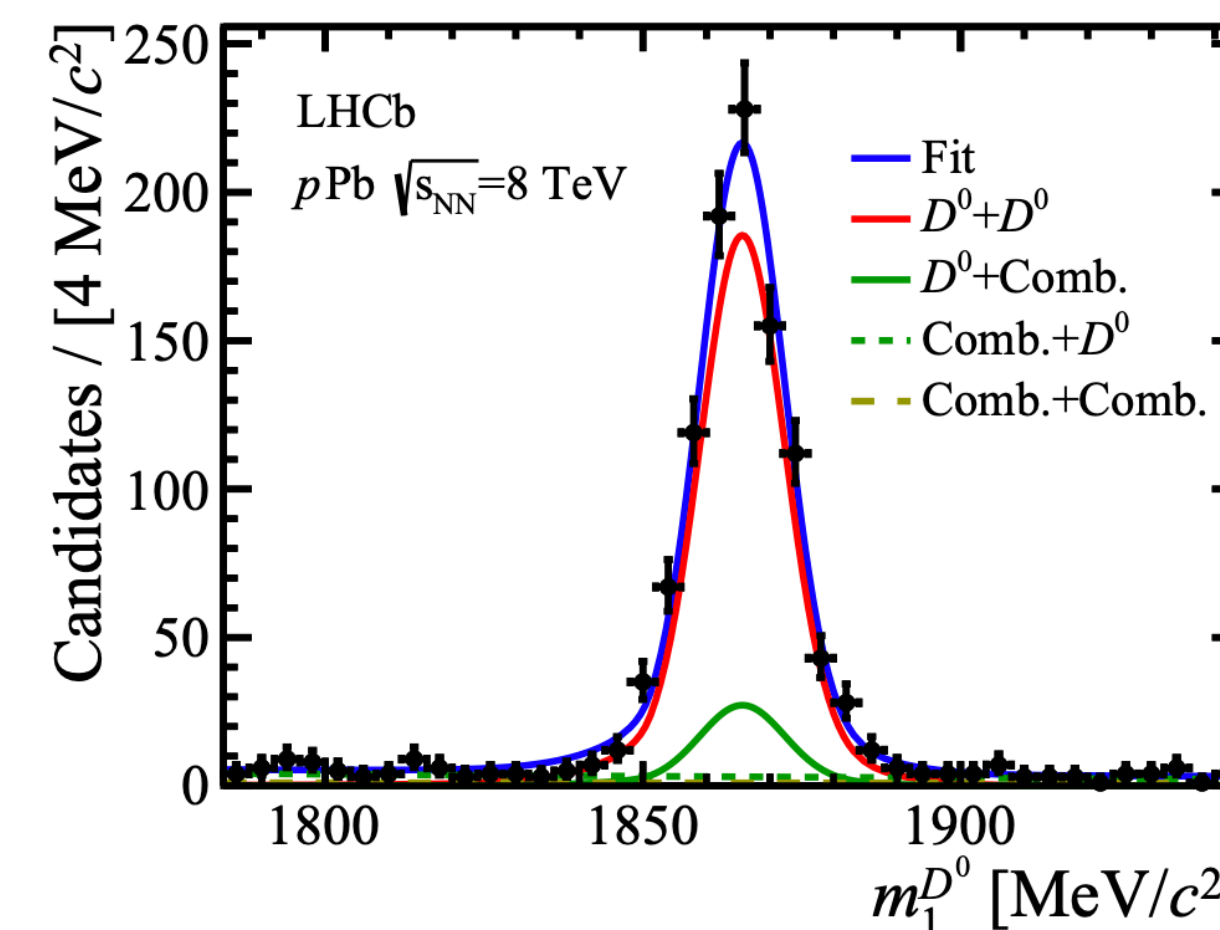


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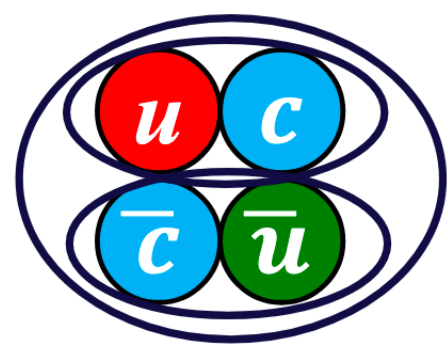


- ❖  $\sigma_{\text{eff,pPb/Pbp}} = 0.9 \text{ b}$  : DPS/SPS enhanced by a factor of 3 compared to pp in agreement with the theory model.
- ❖  $\sigma_{\text{eff,pPb/Pbp}}(J/\psi\text{-}D^0) < \sigma_{\text{eff,pPb/Pbp}}(D^0\text{-}D^0)$  : similar to pp case.
  - Can be due to DPS enhancement / SPS contamination.
- ❖  $\sigma_{\text{eff,pPb}} > \sigma_{\text{eff,Pbp}}$
- ❖ Indication of enhanced DPS for charm production in Pbp compare to pPb.

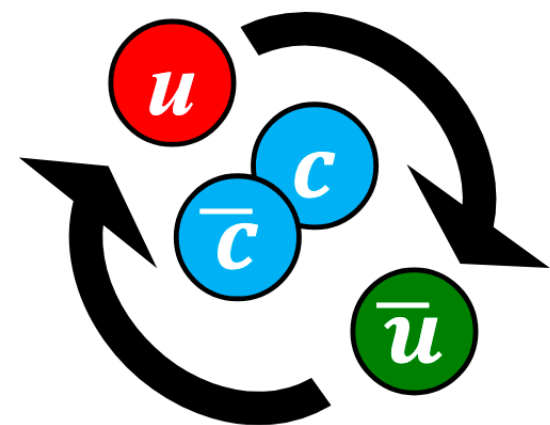
# $X(3872)/\psi(2S)$ in pp/PbPb collisions

- ❖  $X(3872)$  : exotic state still not understood.
  - Tetraquark / hadronic molecule / something else ?
- ❖ Production yield in QCD medium strongly reflects internal structure.

## Compact tetraquark/pentaquark



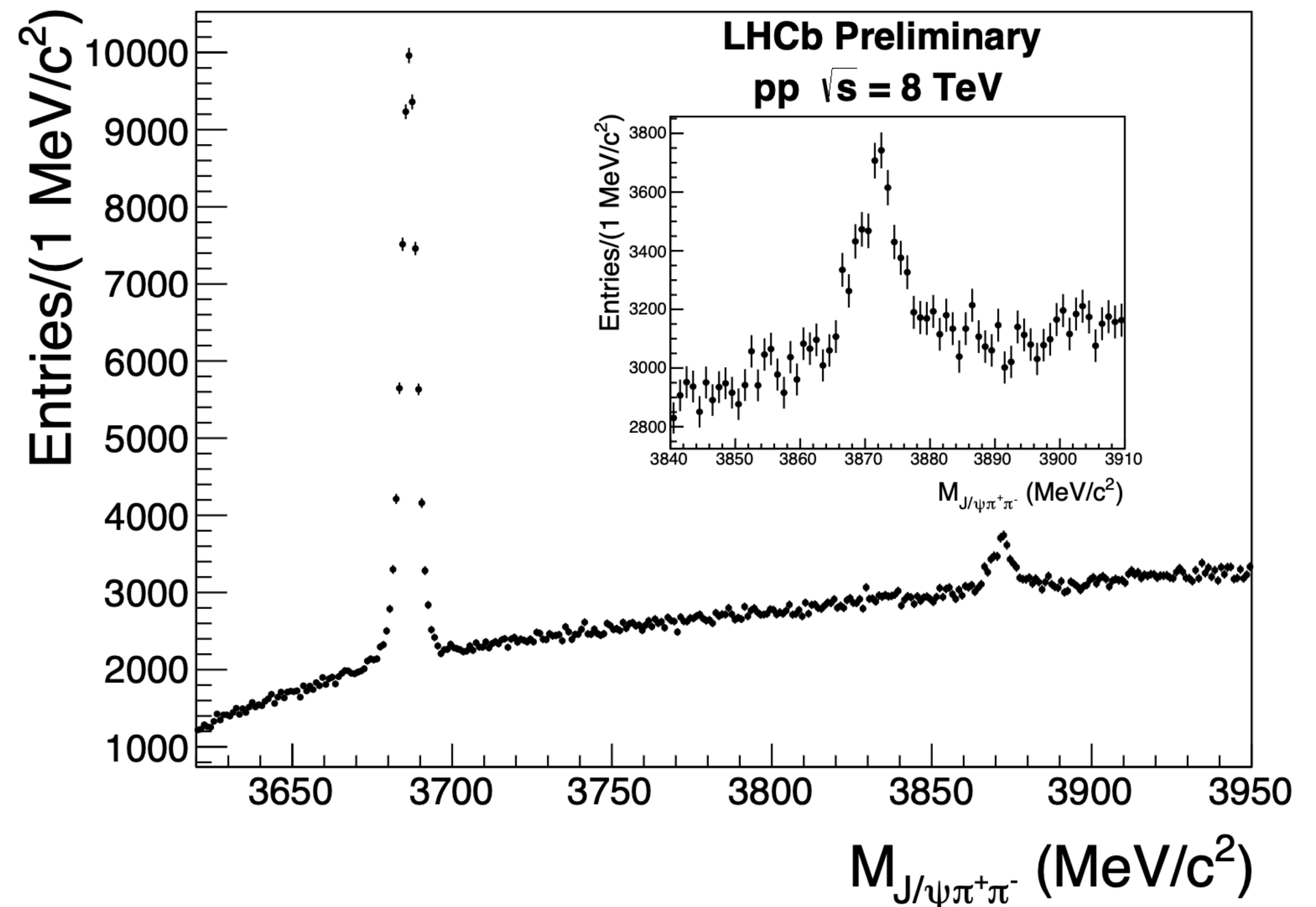
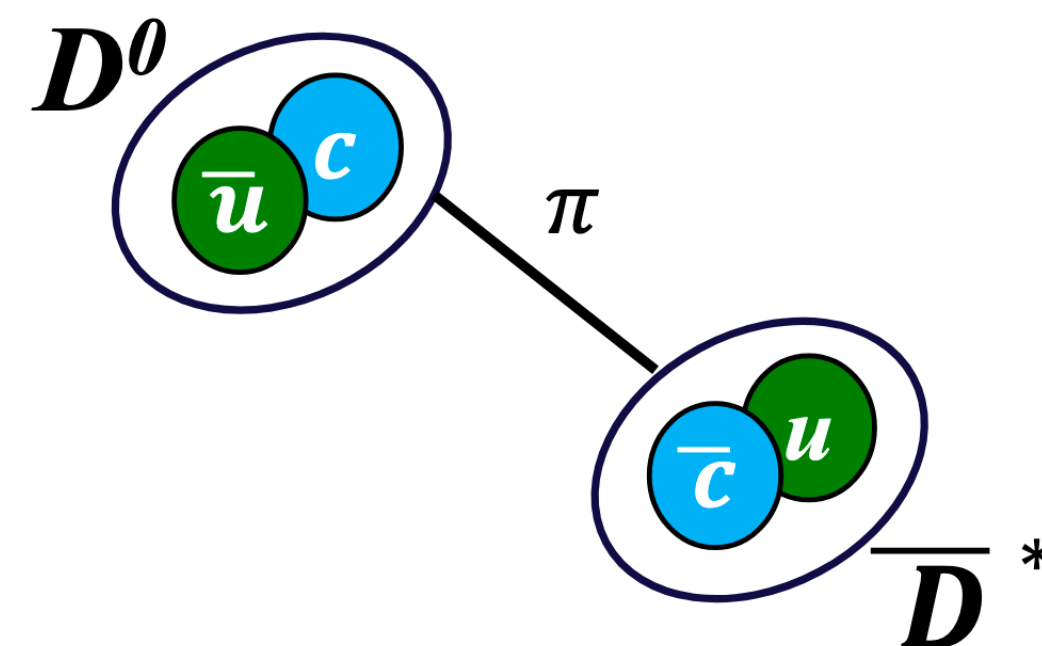
**Diquark-diquark**  
*PRD 71, 014028 (2005)*  
*PLB 662 424 (2008)*



**Hadrocharmonium/  
 adjoint charmonium**  
*PLB 666 344 (2008)*  
*PLB 671 82 (2009)*

## Hadronic Molecules

*PLB 590 209 (2004)*  
*PRD 77 014029 (2008)*  
*PRD 100 0115029(R) (2019)*

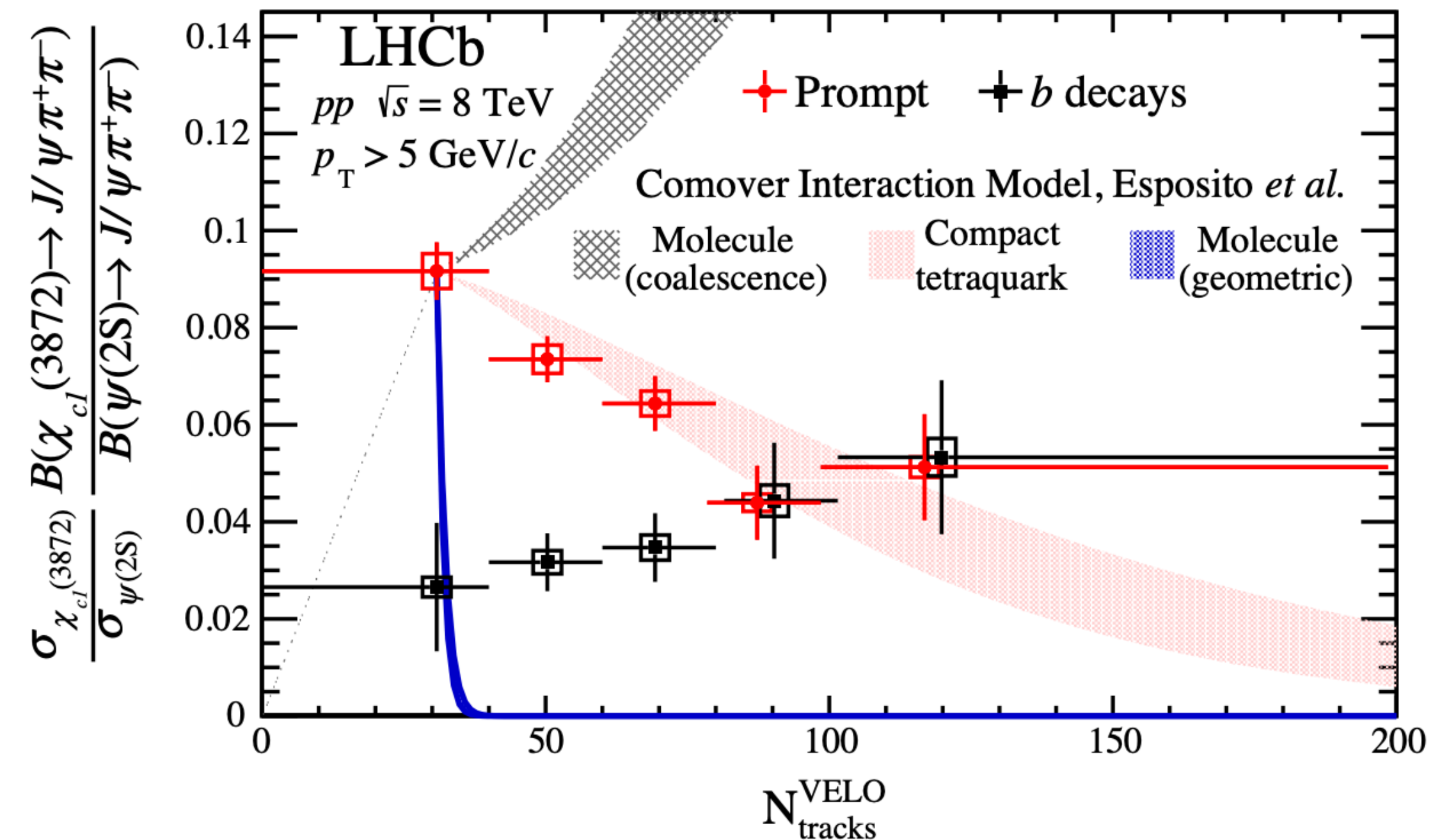




# $X(3872)/\psi(2S)$ in pp PbPb collisions

- ❖  $X(3872)/\psi(2S)$  ratio versus  $N_{\text{tracks}}$  measured in pp collisions at  $\sqrt{s} = 8$  TeV.
  - No significant variation is observed for the non-prompt component
  - **Hint of a relative suppression with event activity for prompt component.**
- ❖ pp results favour tetraquark nature of the  $\chi_{c1}(3872)$ .
- ❖ **Baseline for a future pPb analysis !**

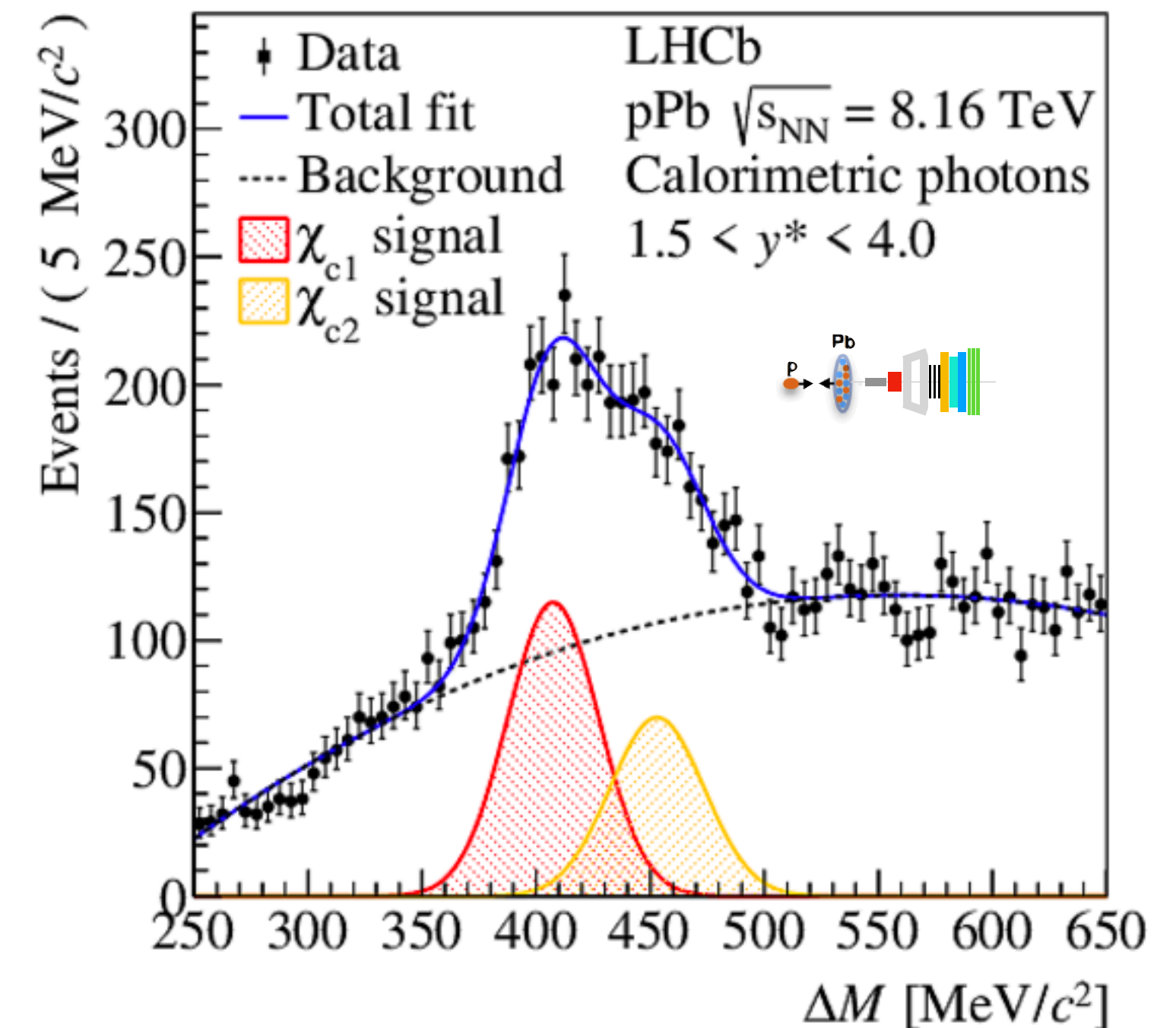
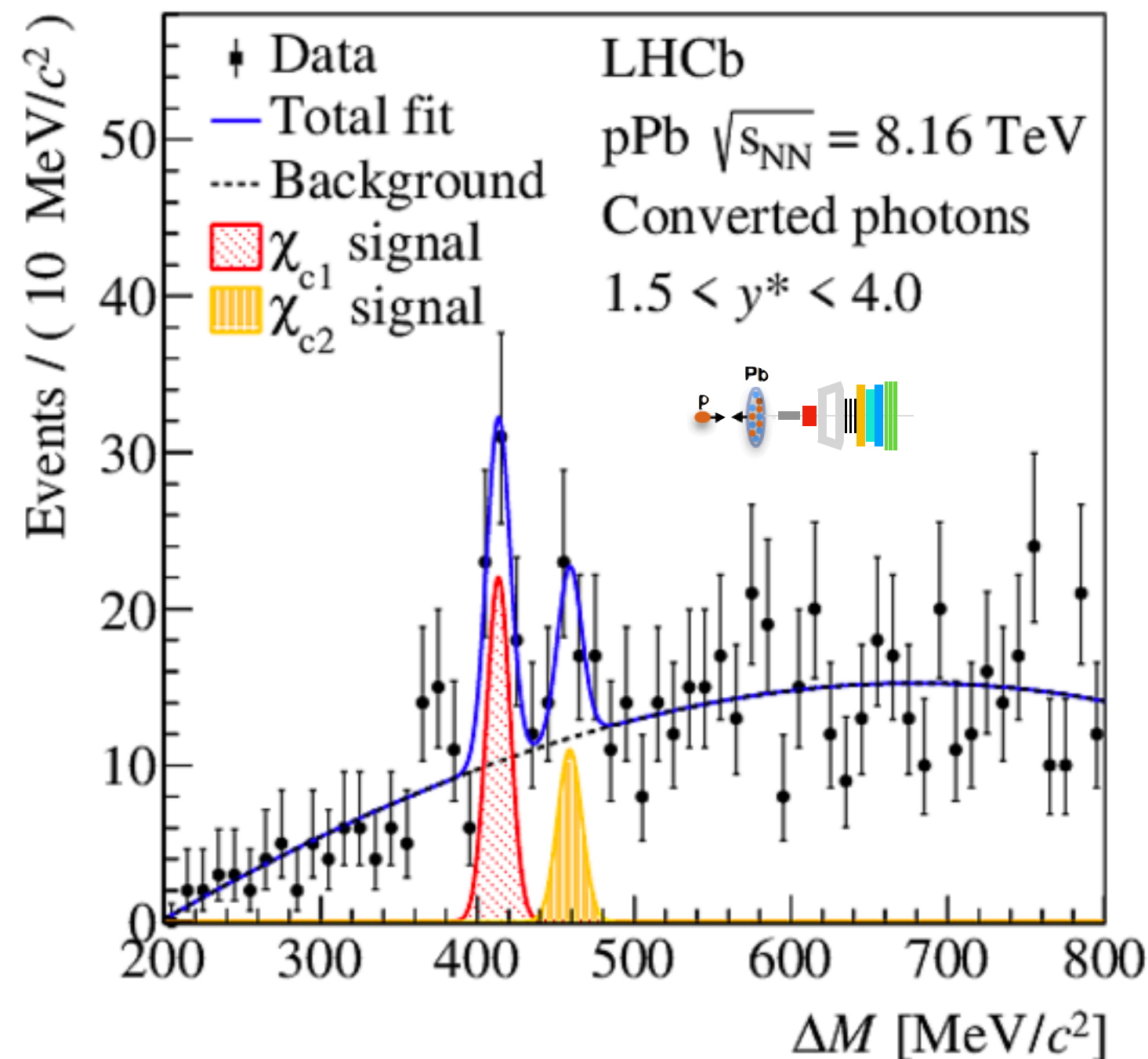
PRL 126 (2021) 092001



# $\chi_{c2}/\chi_{c1}$ production in pPb

Phys. Rev. C 103, 064905

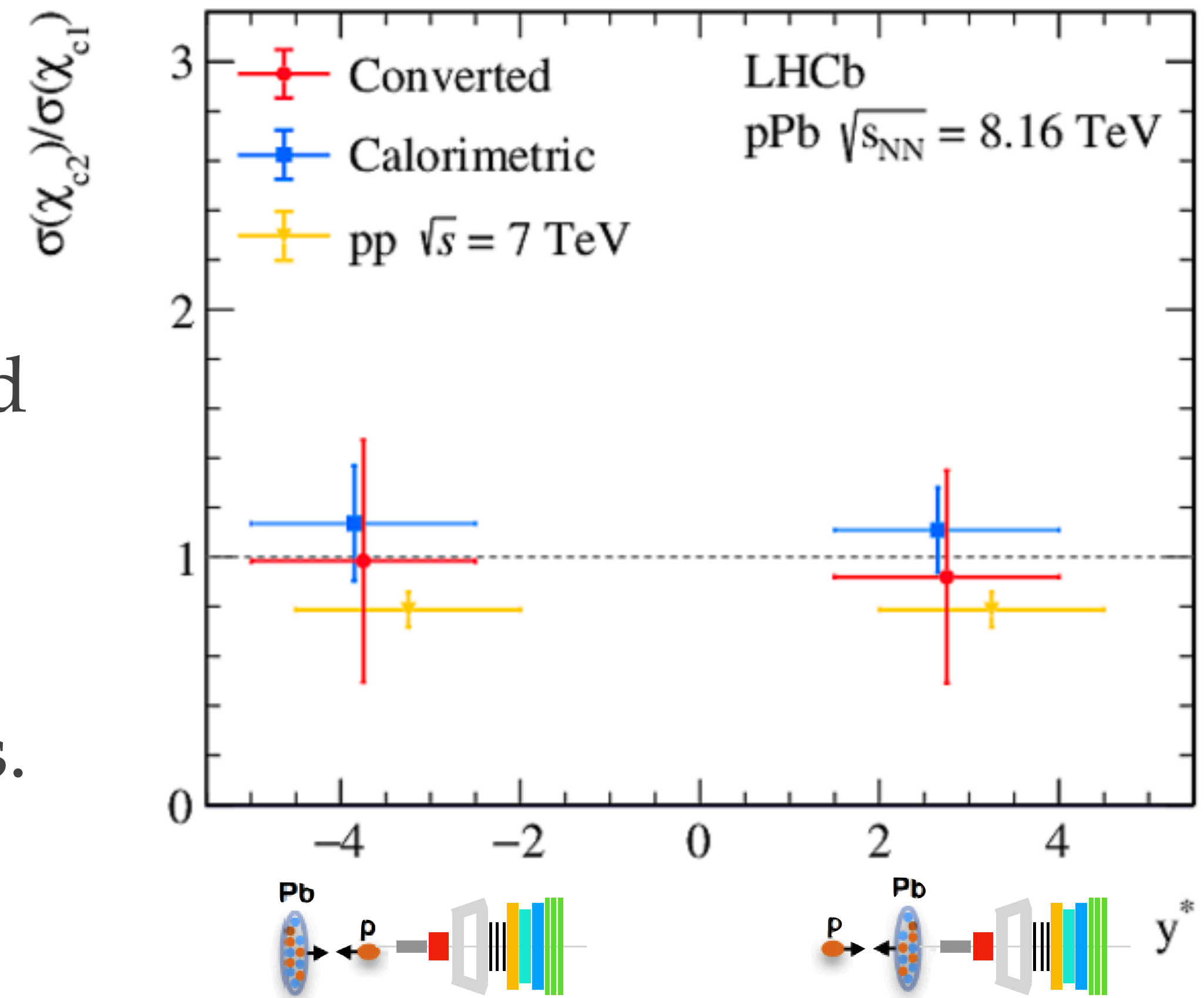
- ❖  $\chi_c$  is a charmonium  $\rightarrow$  same physics motivation as for others  $c\bar{c}$  states.
- ❖ In addition, feed-down from  $\chi_c$  represents  $\sim 30\%$  of the prompt  $J/\psi$  production.
- ❖ Experimentally,  $\chi_c$  measurement is challenging ( $\chi_c \rightarrow J/\psi(\rightarrow \mu^+\mu^-) + \gamma$ )



# $\chi_{c2}/\chi_{c1}$ production in pPb

Phys. Rev. C 103, 064905

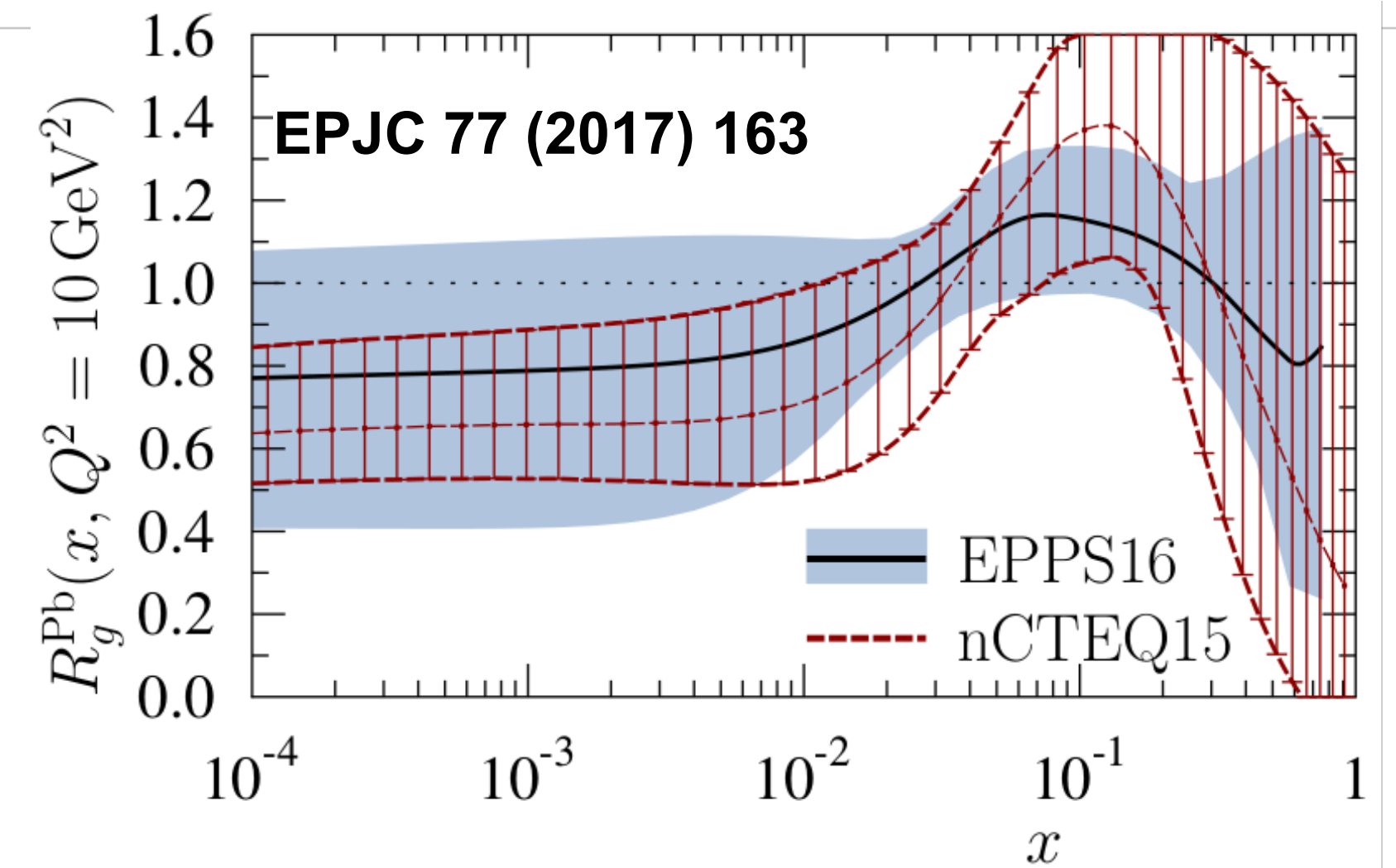
- ❖ **First  $\chi_c$  measurements in heavy-ion data at the LHC.**
- ❖  $\chi_{c2}/\chi_{c1}$  compatible with unity both in pPb and Pb collisions with large statistical uncertainties.
- ❖ pPb results compatible with pp@7TeV results.





# Prompt Charged Particle Production in pPb

- ❖ Prompt charged particle production in pA collisions:
  - Strong constrain to the nuclear PDFs.
  - Prob the saturation region ?
- ❖ LHCb acceptance allow to access:
  - The low Bjorken- $x$  region in pPb collisions ( $x \in [10^{-6}, 10^{-4}]$ ).
  - The large Bjorken- $x$  region in Pbp collisions ( $x \in [10^{-3}, 10^{-1}]$ ).



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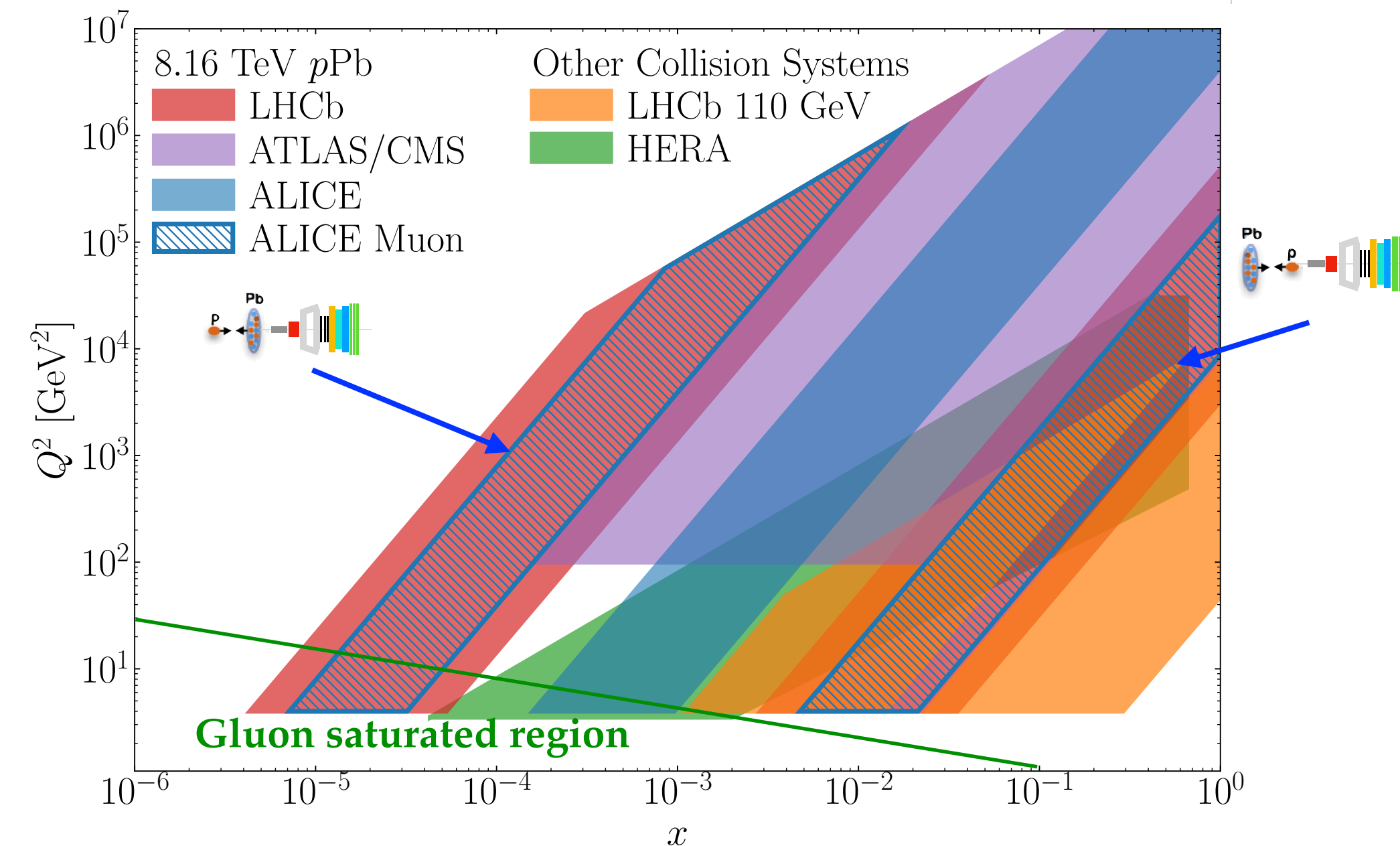
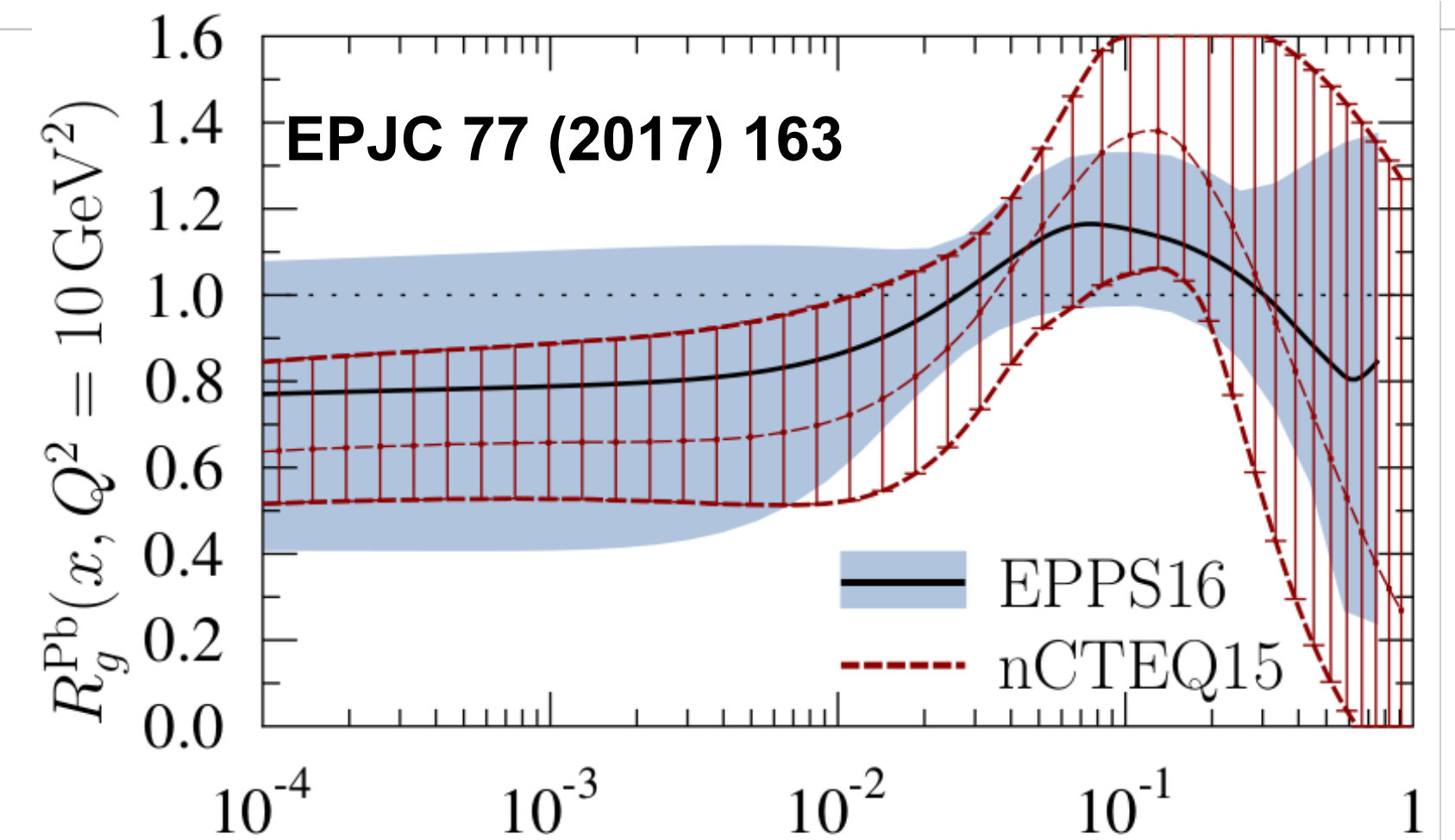
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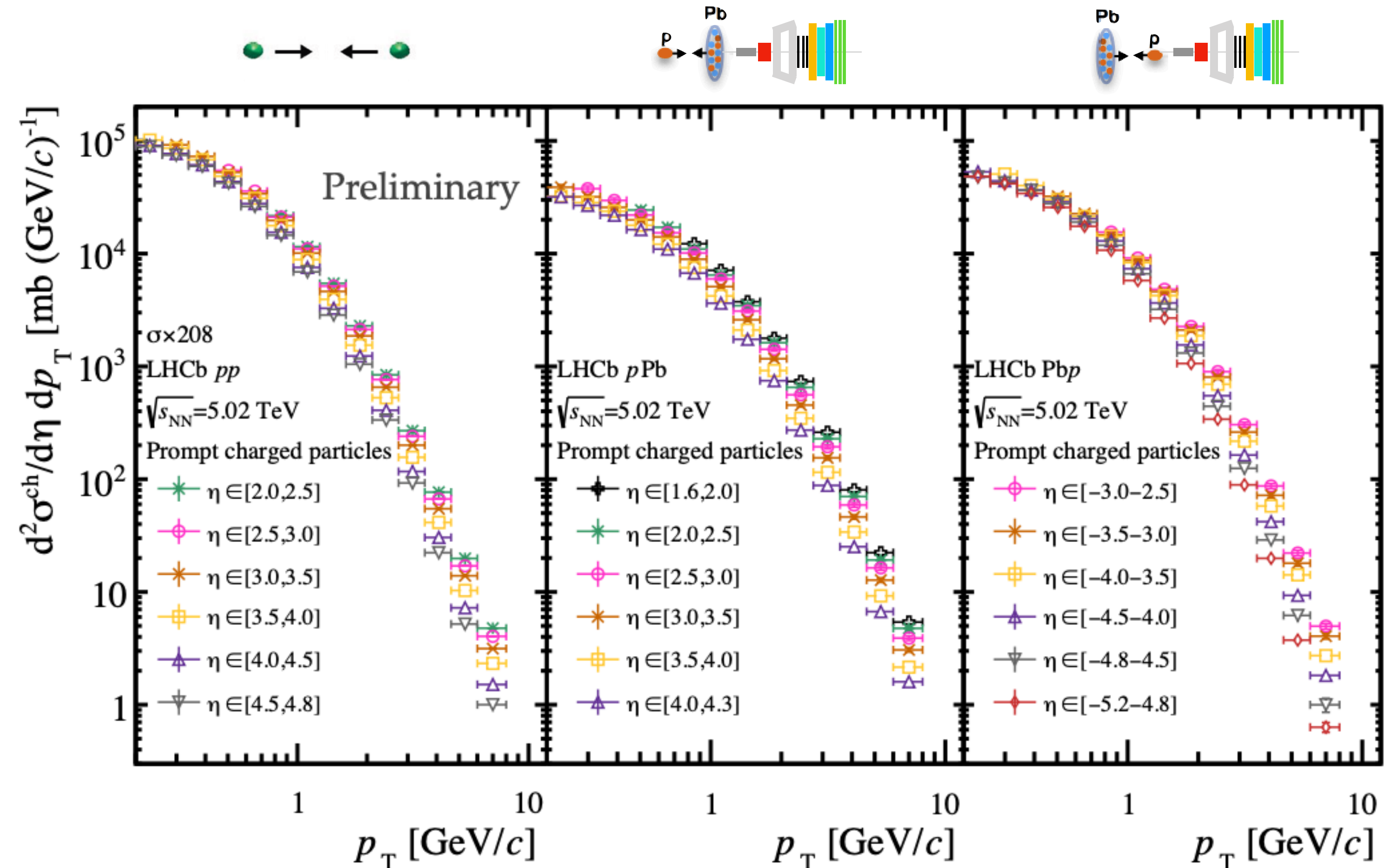
- The large Bjorken- $x$  region in PbP collisions ( $x \in [10^{-3}, 10^{-1}]$ ).



# Prompt Charged Particle Production in pPb

LHCb-PAPER-2021-015

- ❖ Prompt charged particle measured with the tracking system.
- ❖ Excellent precision, down to total uncertainty.





# Prompt Charged Particle Production in pPb

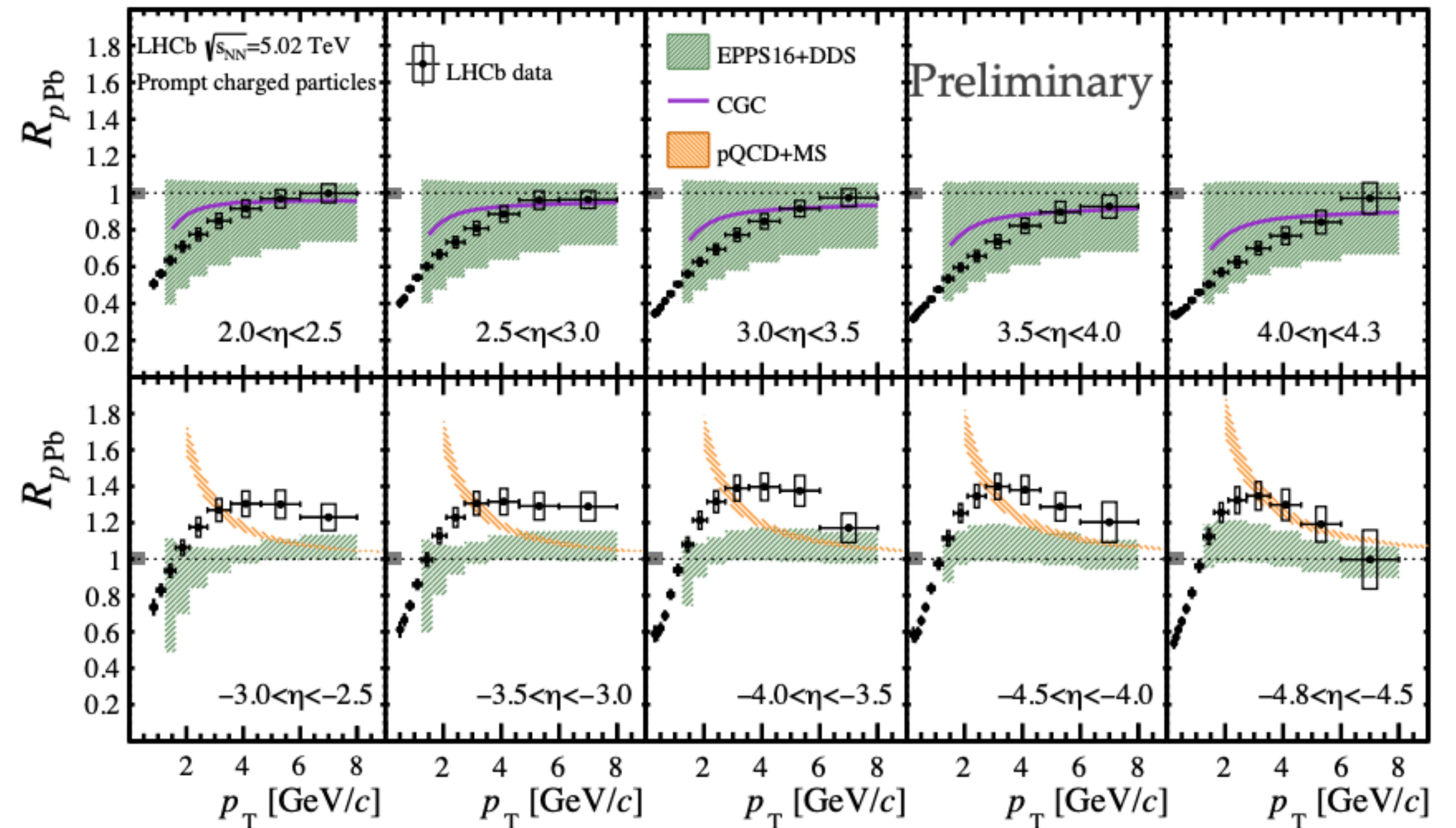
LHCb-PAPER-2021-015

❖ Nuclear modification factor compared to several theory predictions

- EPPS16+DDS JHEP09(2014) 138
- CGC PR D88, 114020
- pQCD+MS PR D88(2013) 054010, PL B740(2015) 23

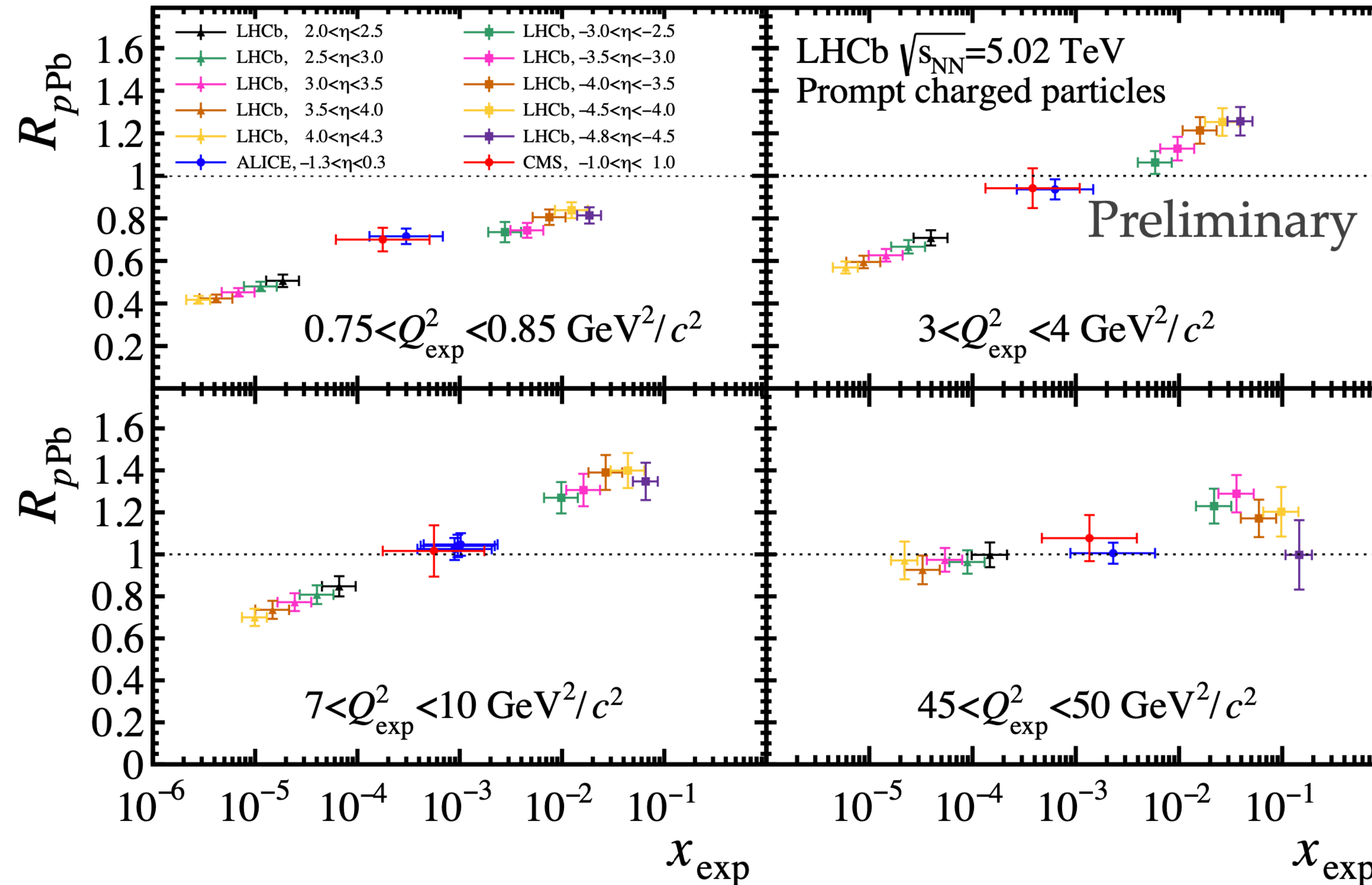
❖ No models can reproduce the backward rapidity results.

$$R_{pPb}(\eta, p_T) = \frac{1}{A} \frac{d^2\sigma_{pPb}(\eta, p_T)/dp_T d\eta}{d^2\sigma_{pp}(\eta, p_T)/dp_T d\eta}, \quad A = 208$$



# Prompt Charged Particles Production in pPb

LHCb-PAPER-2021-015



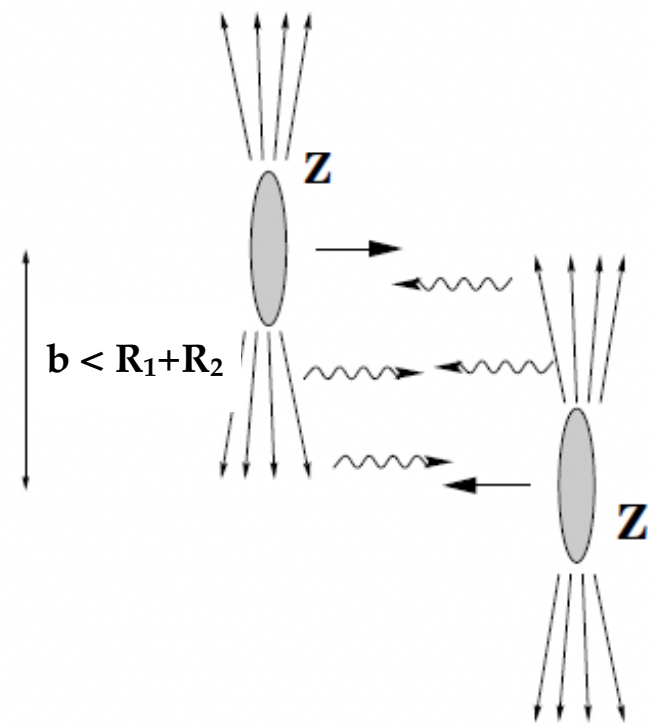
$$x_{\text{exp}} = \frac{Q_{\text{exp}}^2}{\sqrt{s_{NN}}} e^{-\eta}$$

$$Q_{\text{exp}}^2 = m^2 + p_T^2$$

❖ Nice compatibility between ALICE / CMS and LHCb results !

# Quarkonia in AA collisions : photo-production with nuclear overlap

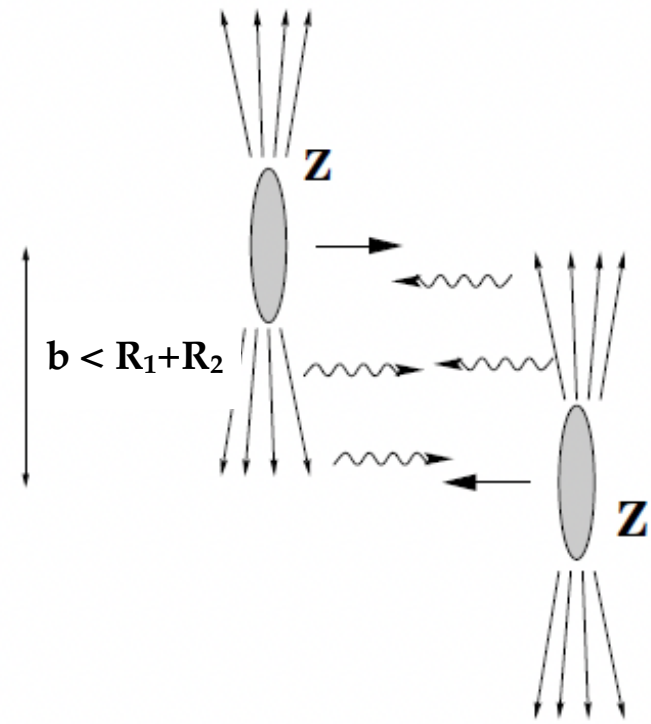
*Peripheral collision*



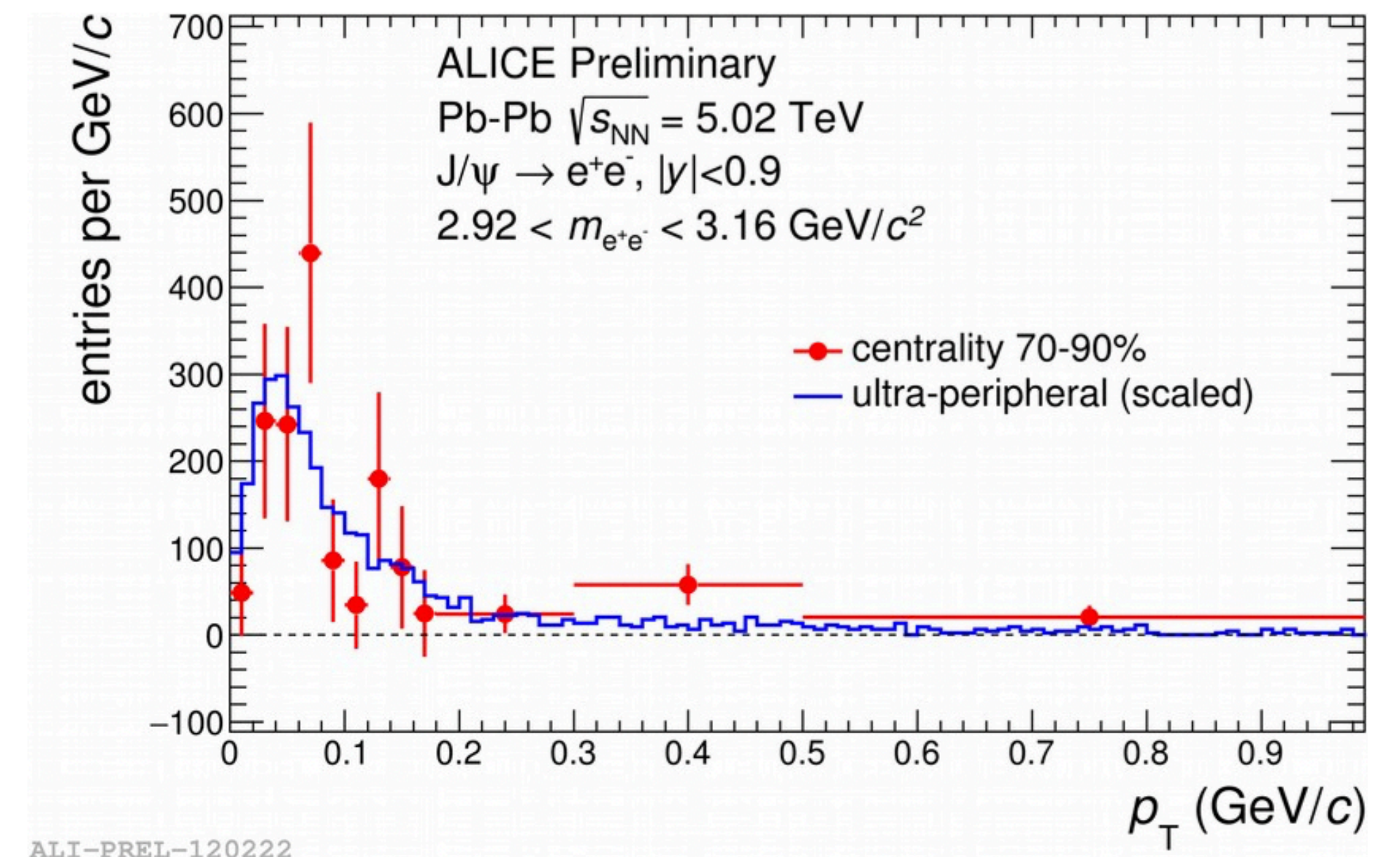
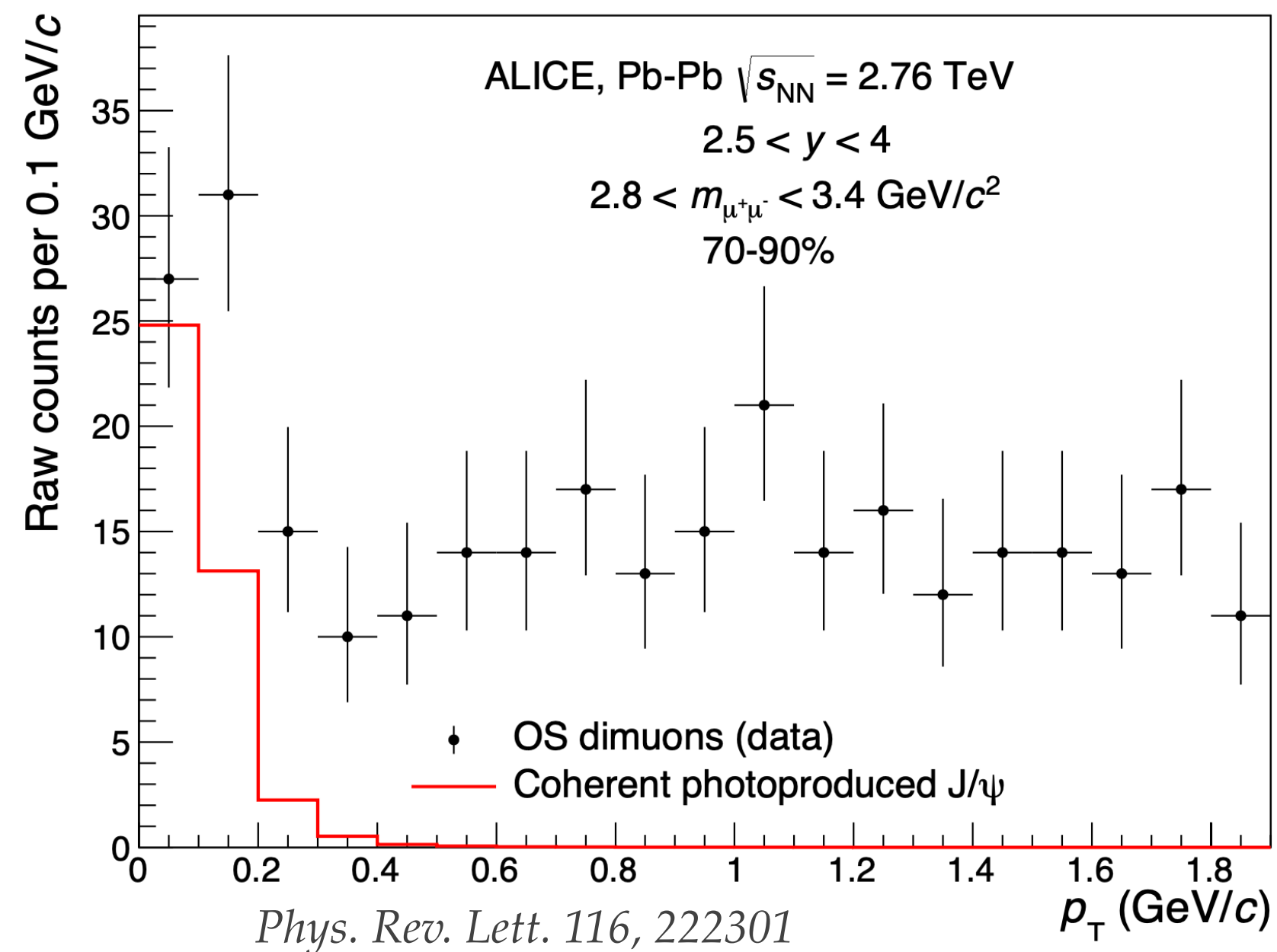


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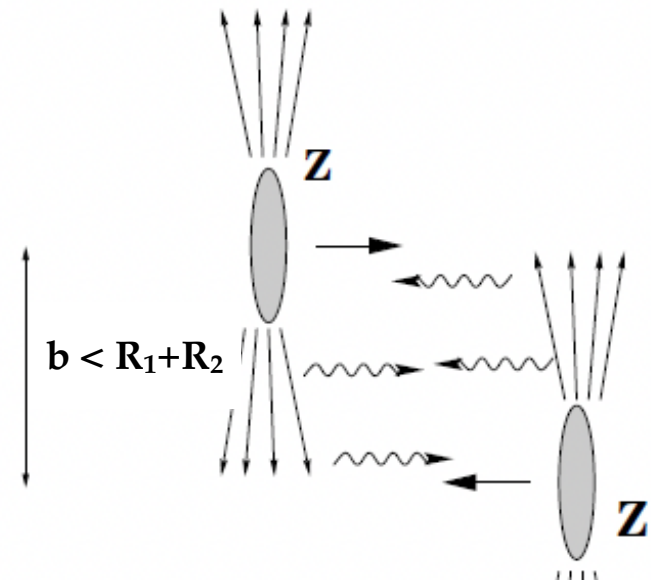
- ❖ Very-low  $p_T$  excess measured by ALICE at LHC
  - ➔ Mostly likely photo-production.



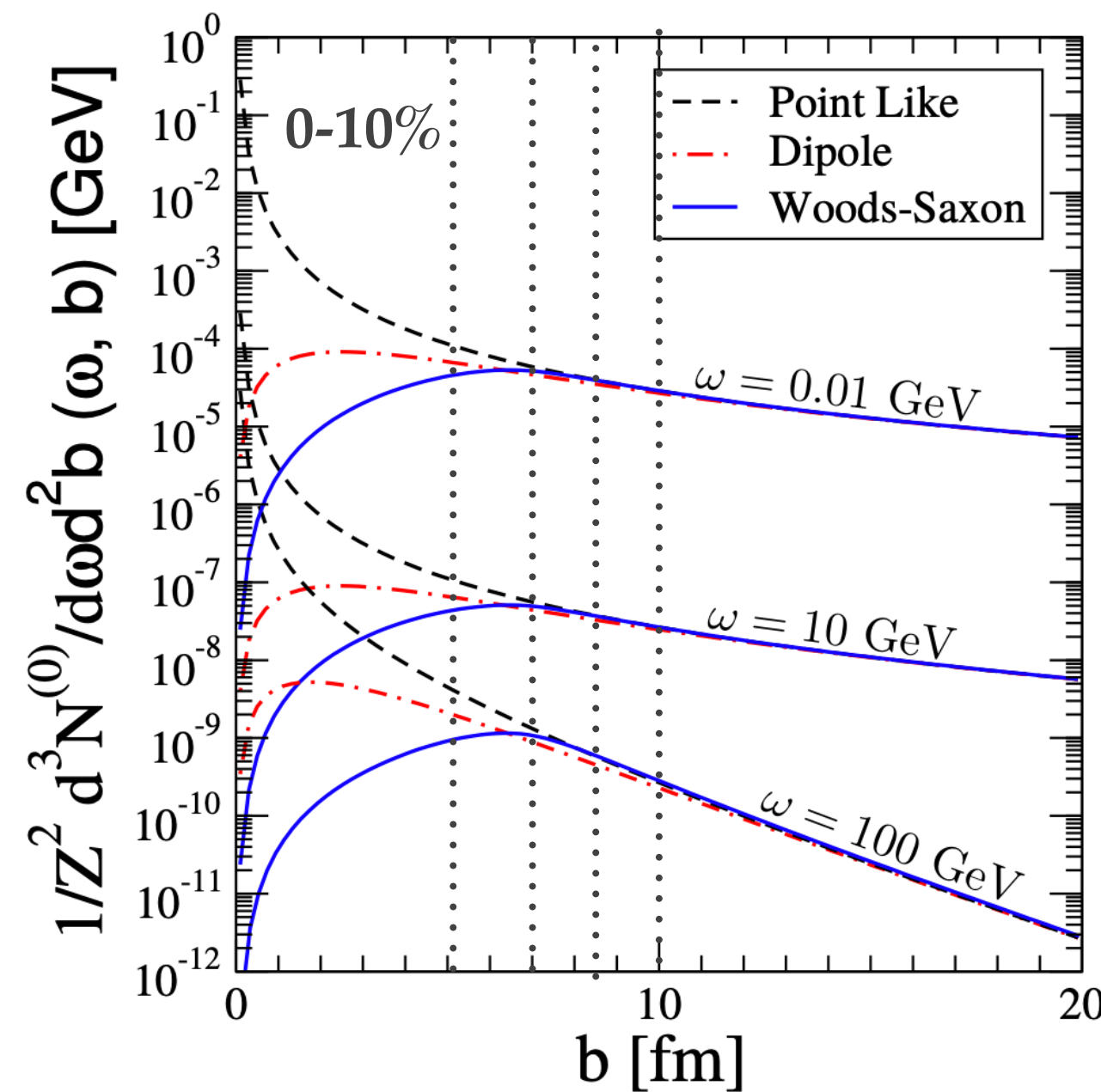


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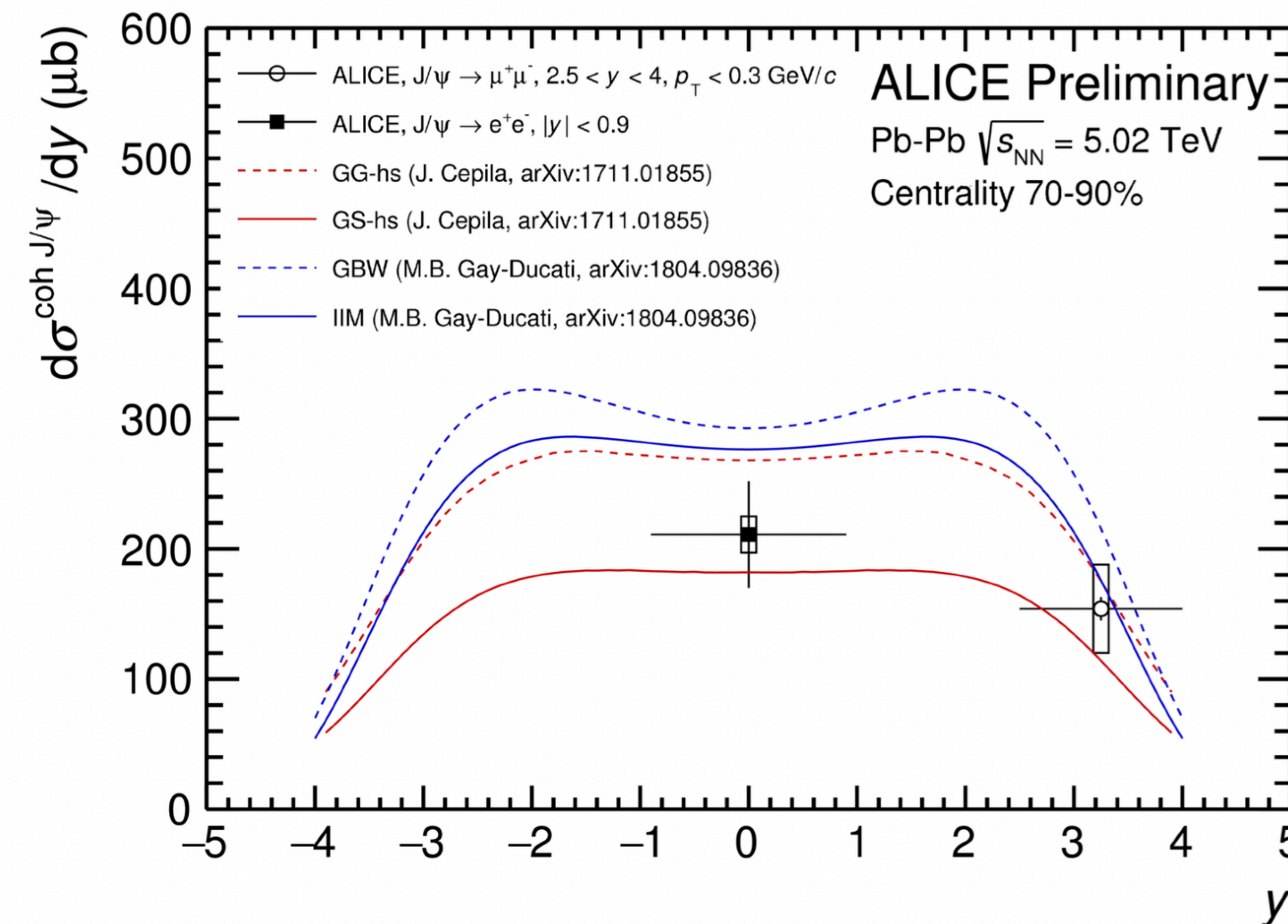


- ❖ Very-low  $p_T$  excess measured by ALICE at LHC
  - ➔ Mostly likely photo-production.
- ❖ Prob for the **photon flux** and **the geometry** of the collisions

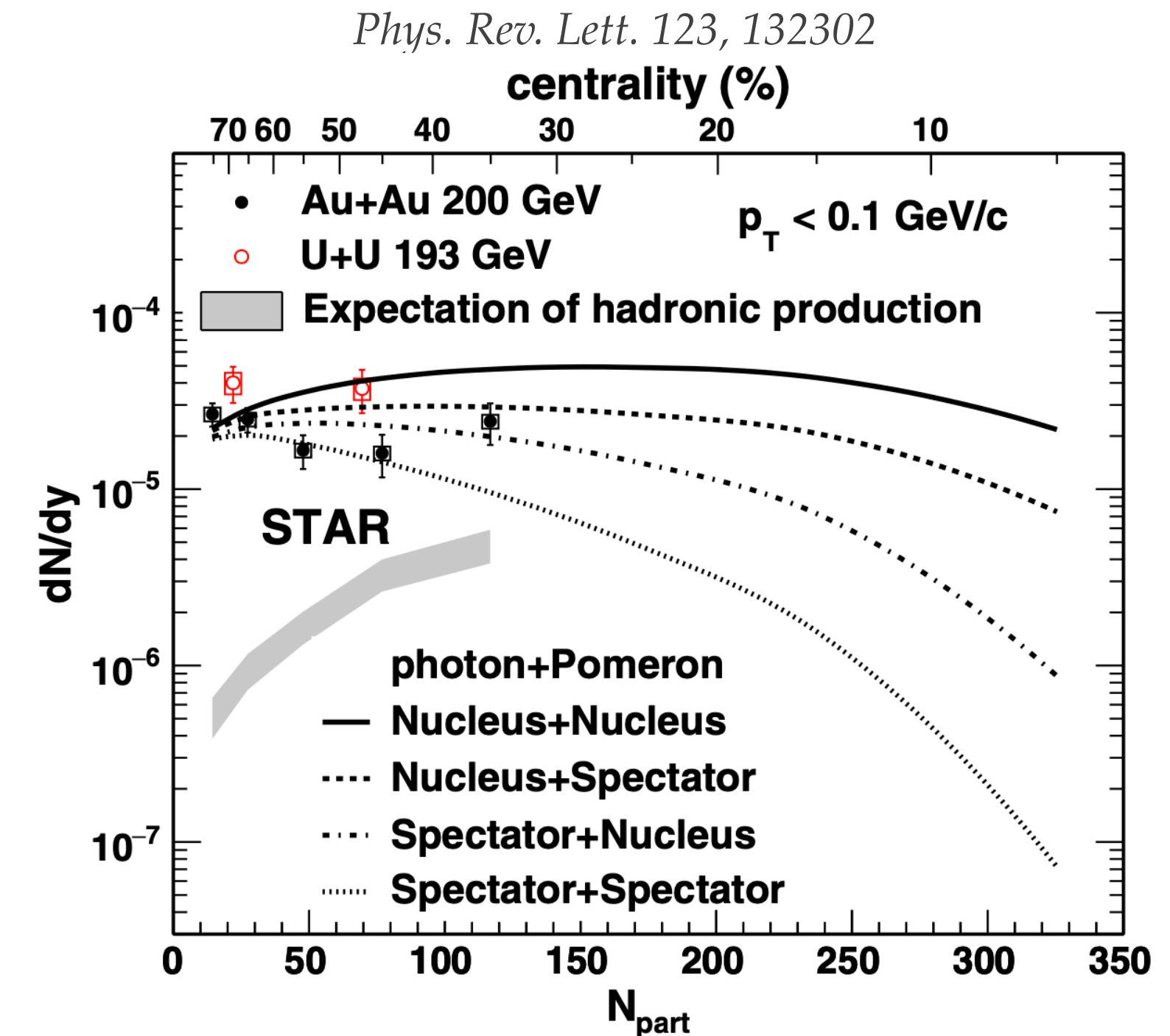


*Phys. Rev. D* 96, 056014 (2017)

FIG. 1: The  $b$ -dependence photon flux distribution for the different form factors of the lead nuclei.



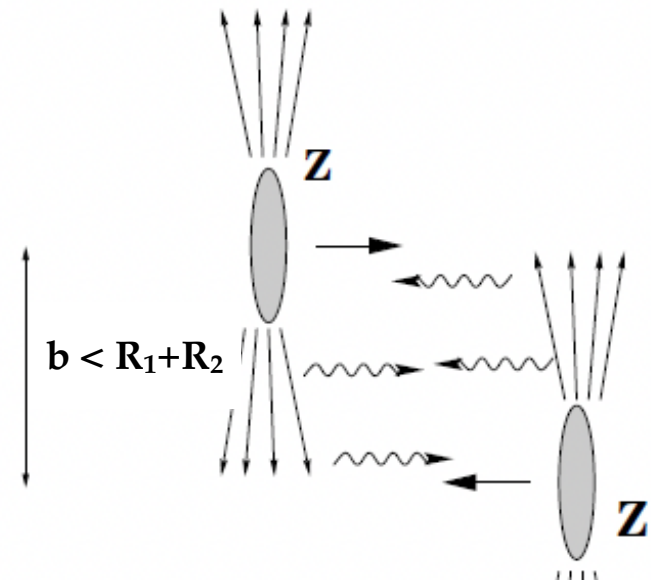
ALI-PREL-309948





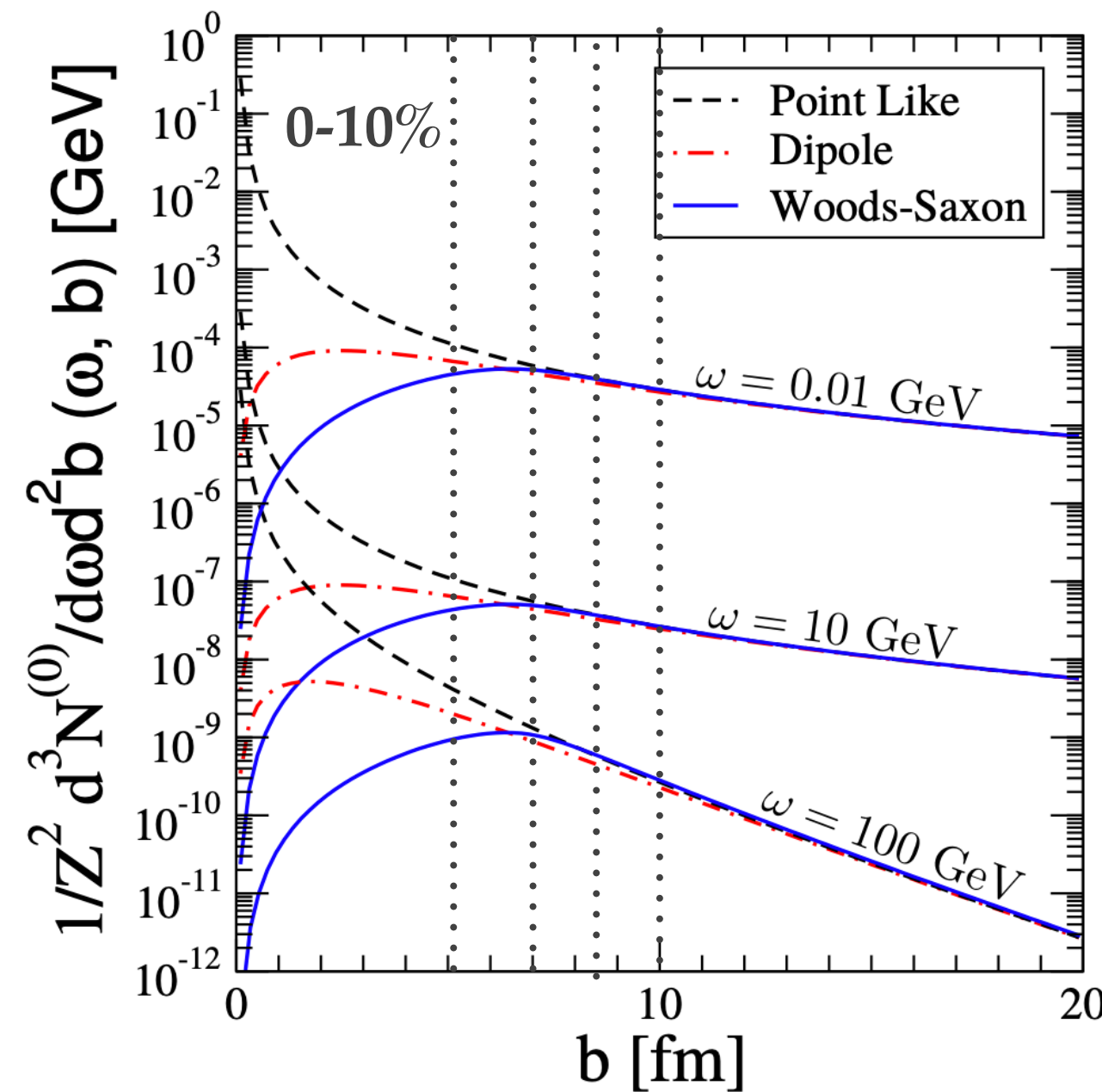
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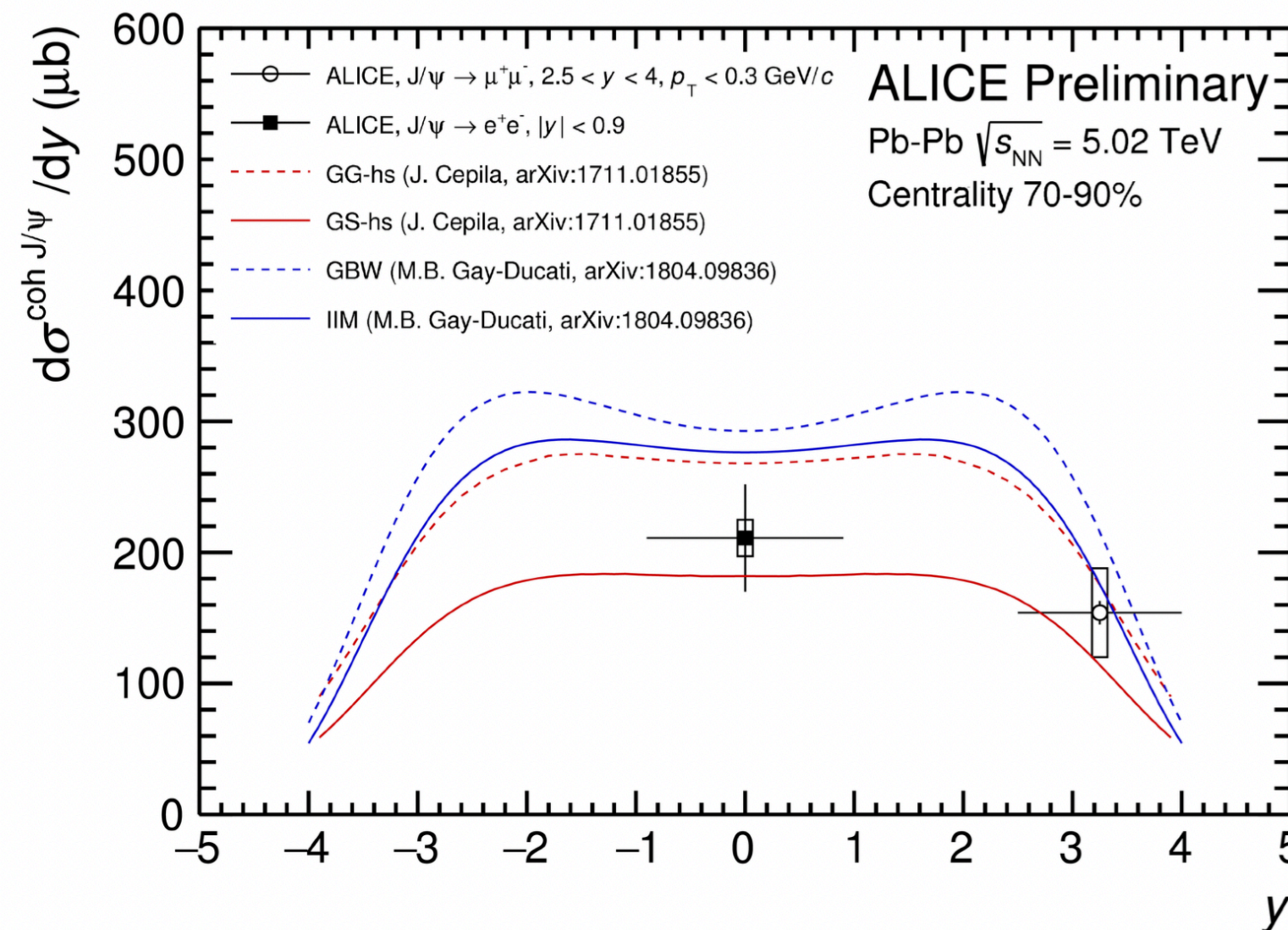
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  - ➔ Mostly likely photo-production.
- ❖ Prob for the **photon flux** and **the geometry** of the collisions
- ❖ Open-question : Could it be useful for QGP studies ?

*Phys. Rev. Lett. 123, 132302*

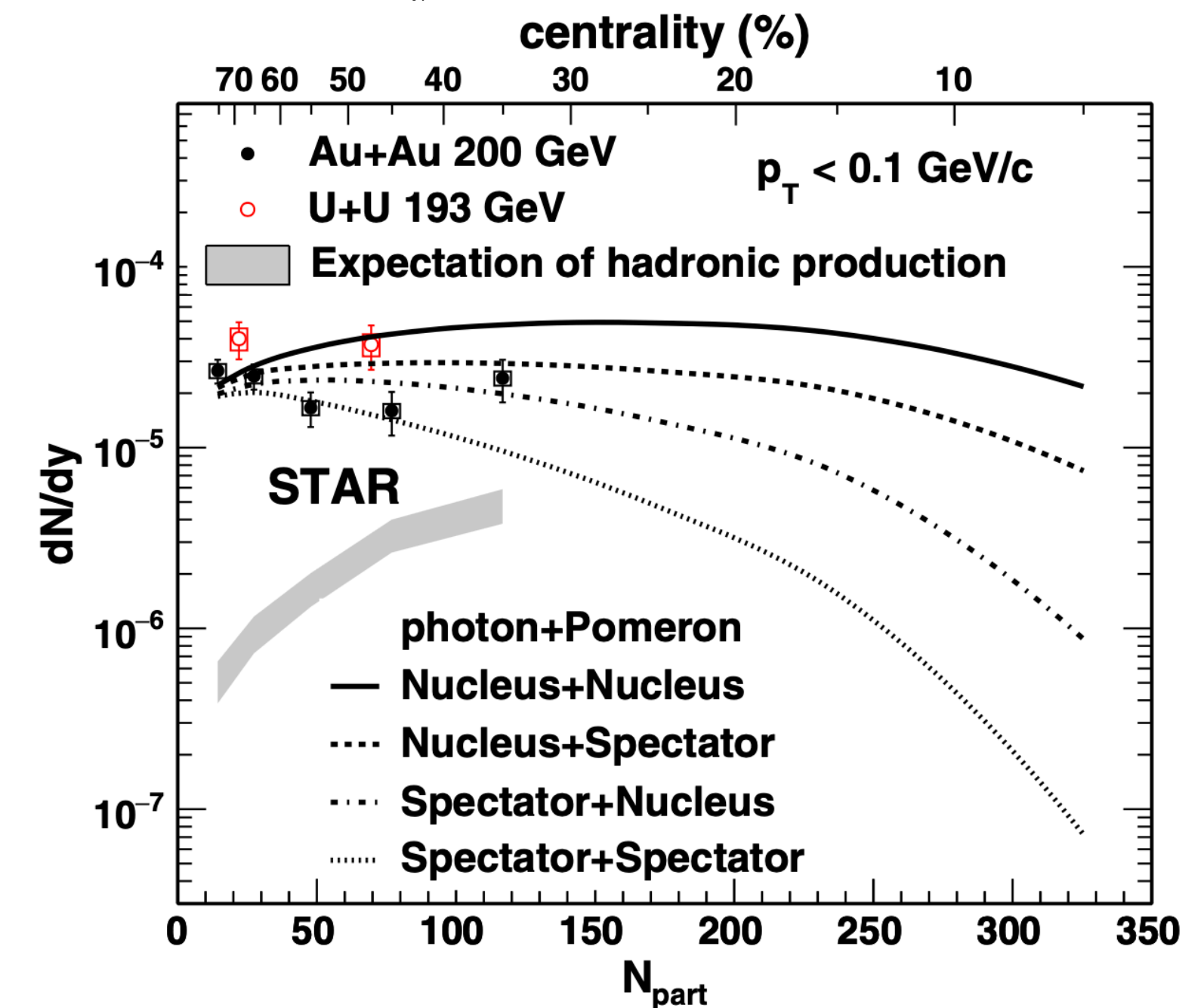


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FIG. 1: The  $b$ -dependence photon flux distribution for the different form factors of the lead nuclei.



ALI-PREL-309948

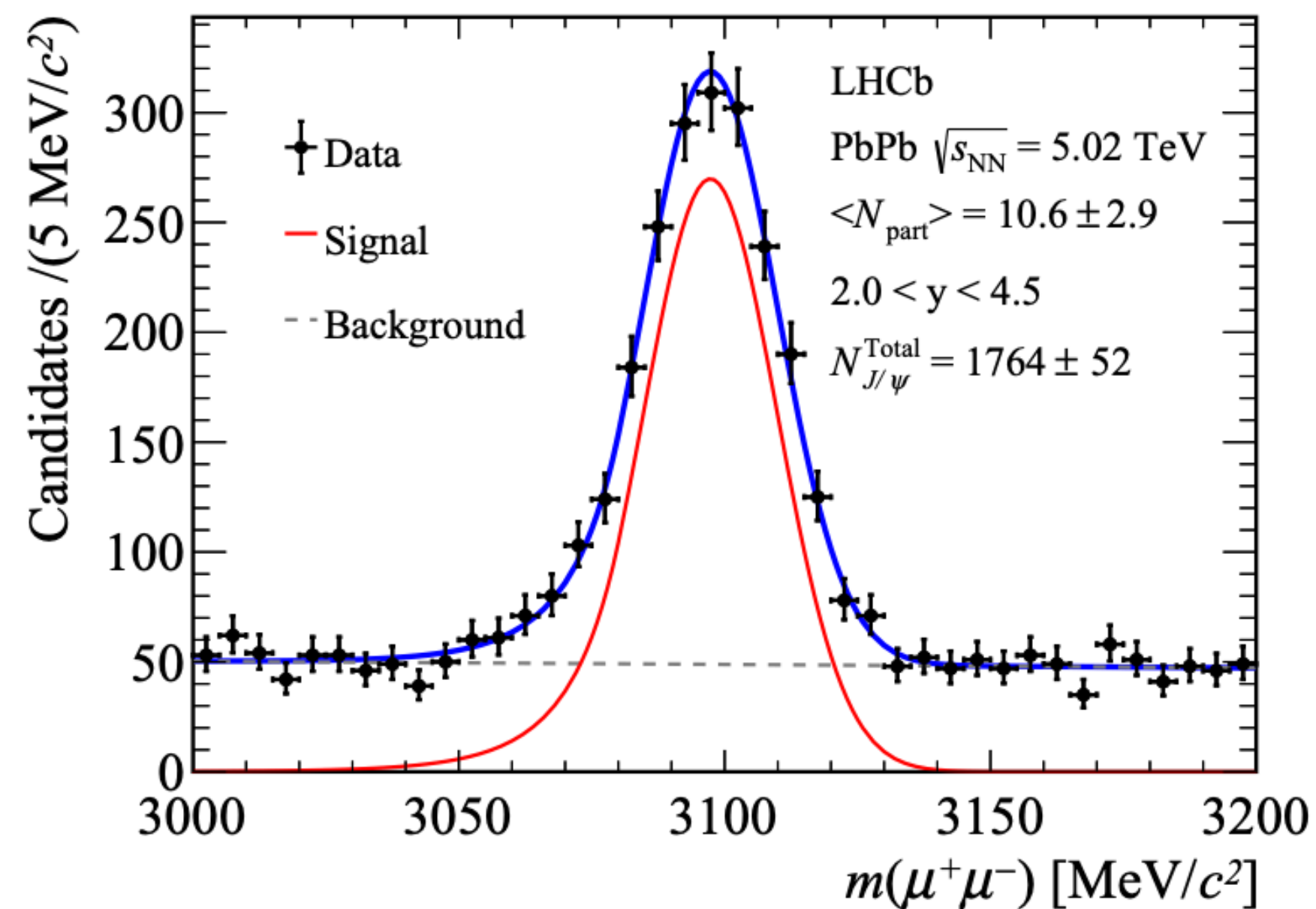




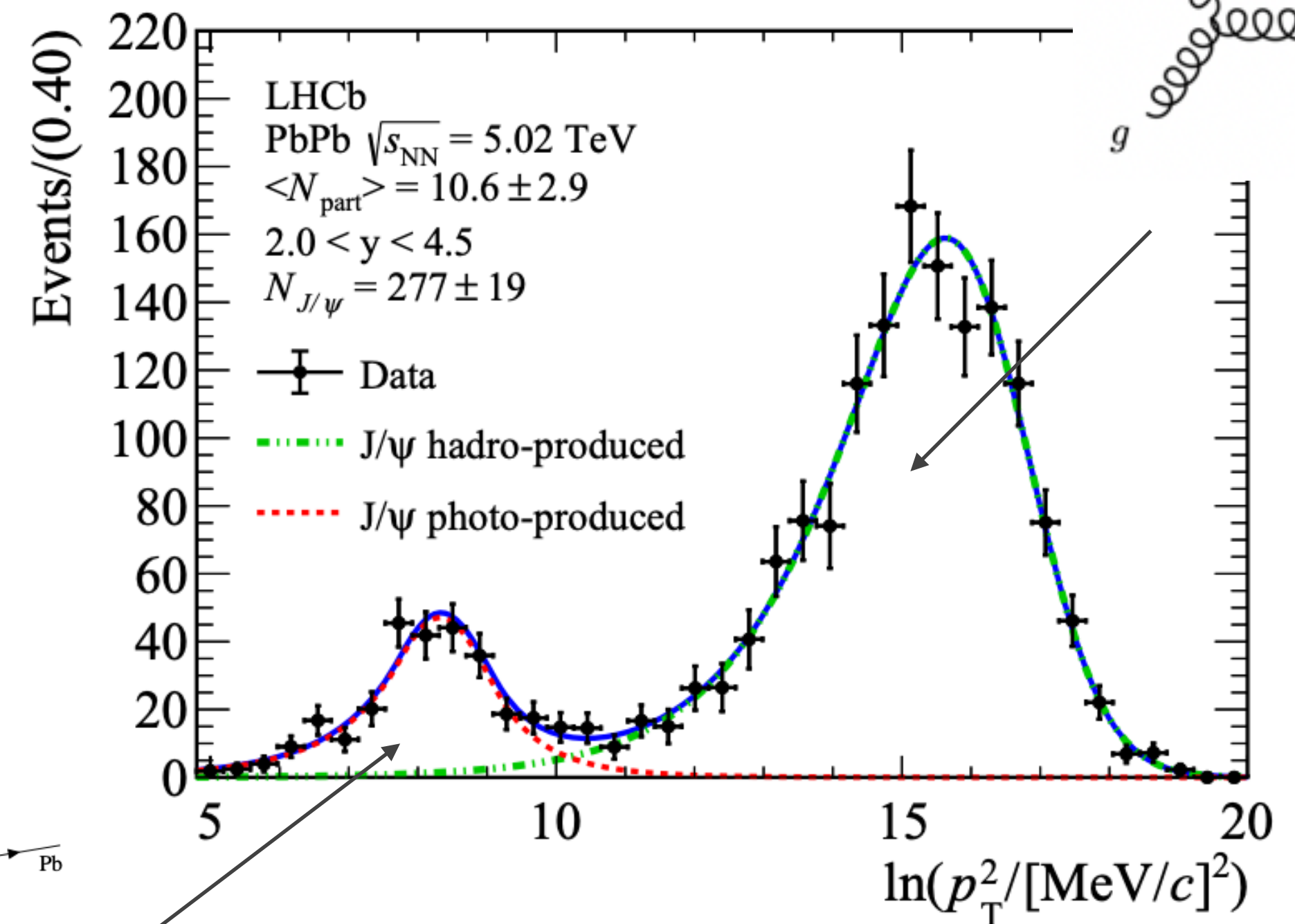
# Quarkonia in AA collisions : photo-production with nuclear overlap

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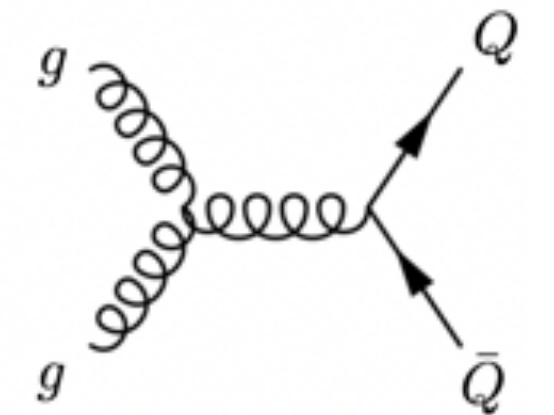
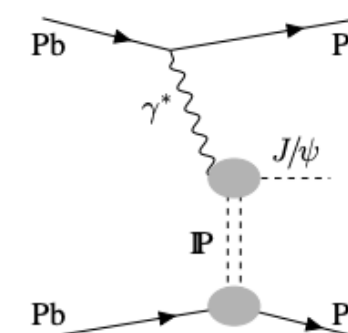
- ❖ In peripheral PbPb collisions, several contributions to the signal.



Combinatorial background removed by invariant mass fit.

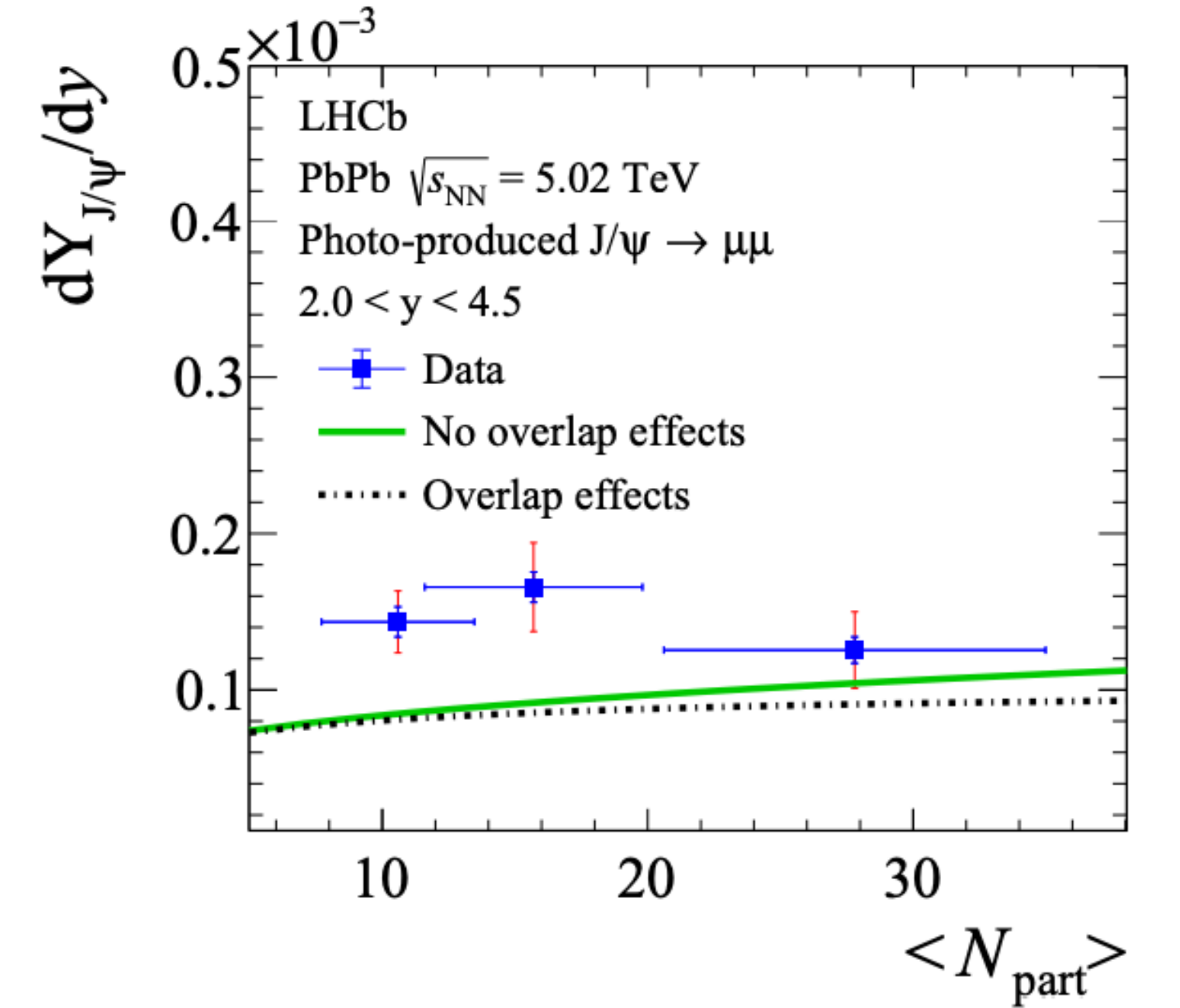
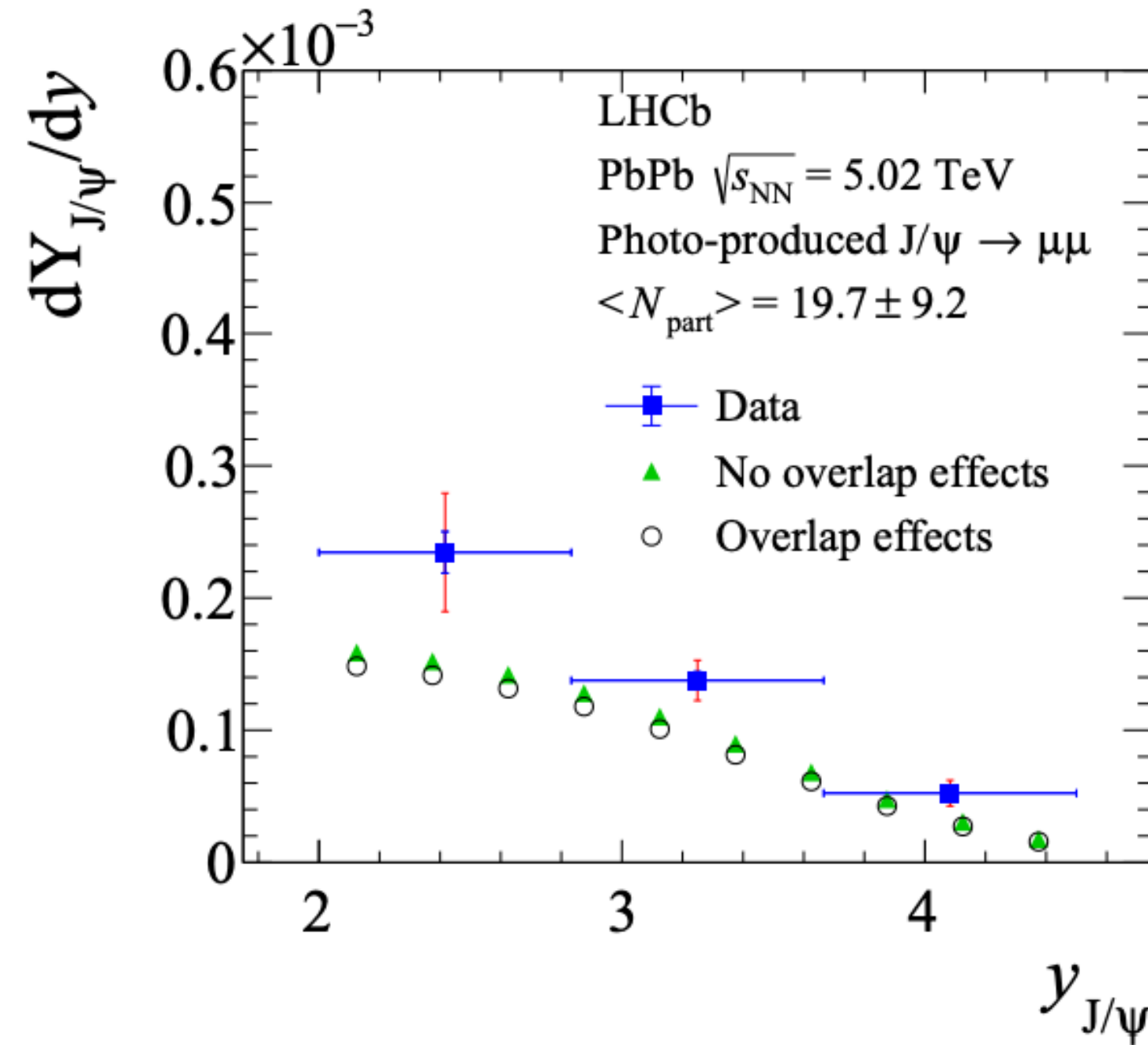
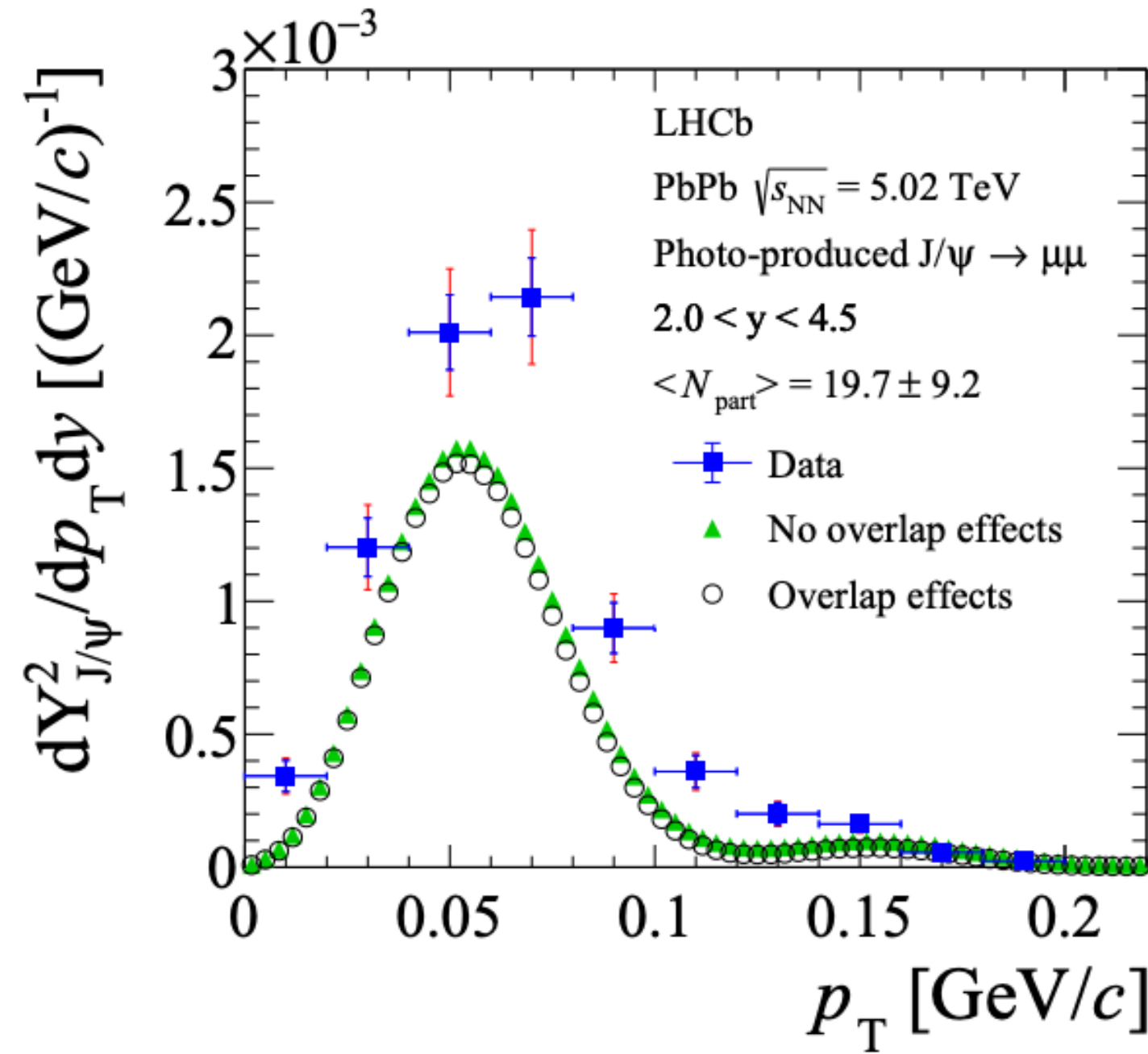


Hadronic production removed by  $p_T$  fit.



# Quarkonia in AA collisions : photo-production with nuclear overlap

LHCb-PAPER-2020-043



- ❖ Latest results show no significant centrality dependence.
- ❖ Two assumptions:
  - No effect of the overlap between the nuclei (UPC-like)
  - Effect of the overlap
- ❖ Shape compatible with model predictions, but the scale is different.

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# Conclusions

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❖ LHCb physics program is constantly expanding with new measurements.

- First  $\chi_c$  measurements in heavy-ion data at the LHC.
- prompt charged particles at forward and backward rapidity.
- Photo-produced  $J/\psi$  in peripheral PbPb collisions.
- ... and many more to come !

❖ LHCb's future is bright

- **New detector** with **new tracking/PID system** driven by pp physics.
- **Improved fixed-target program with SMOG 2.**
- **Better performances expected** for Run 3 in high-multiplicity collisions.

❖ Other LHCb related talks during QGP France 2021:

- Heavy flavour production in fixed target at LHCb - **Felipe Garcia** - Tue. at 11 am.
- Prospectives LHCb U2 - **Michael Winn** - Wed. at 6 pm
- Prospectives LHCb calorimétrie - **Patrick Robbe** - Wed. at 6:30 pm
- Prospectives LHCb tracking - **Stefano Panebianco** - Wed. at 6:50 pm