



Heavy-flavour production at LHCb

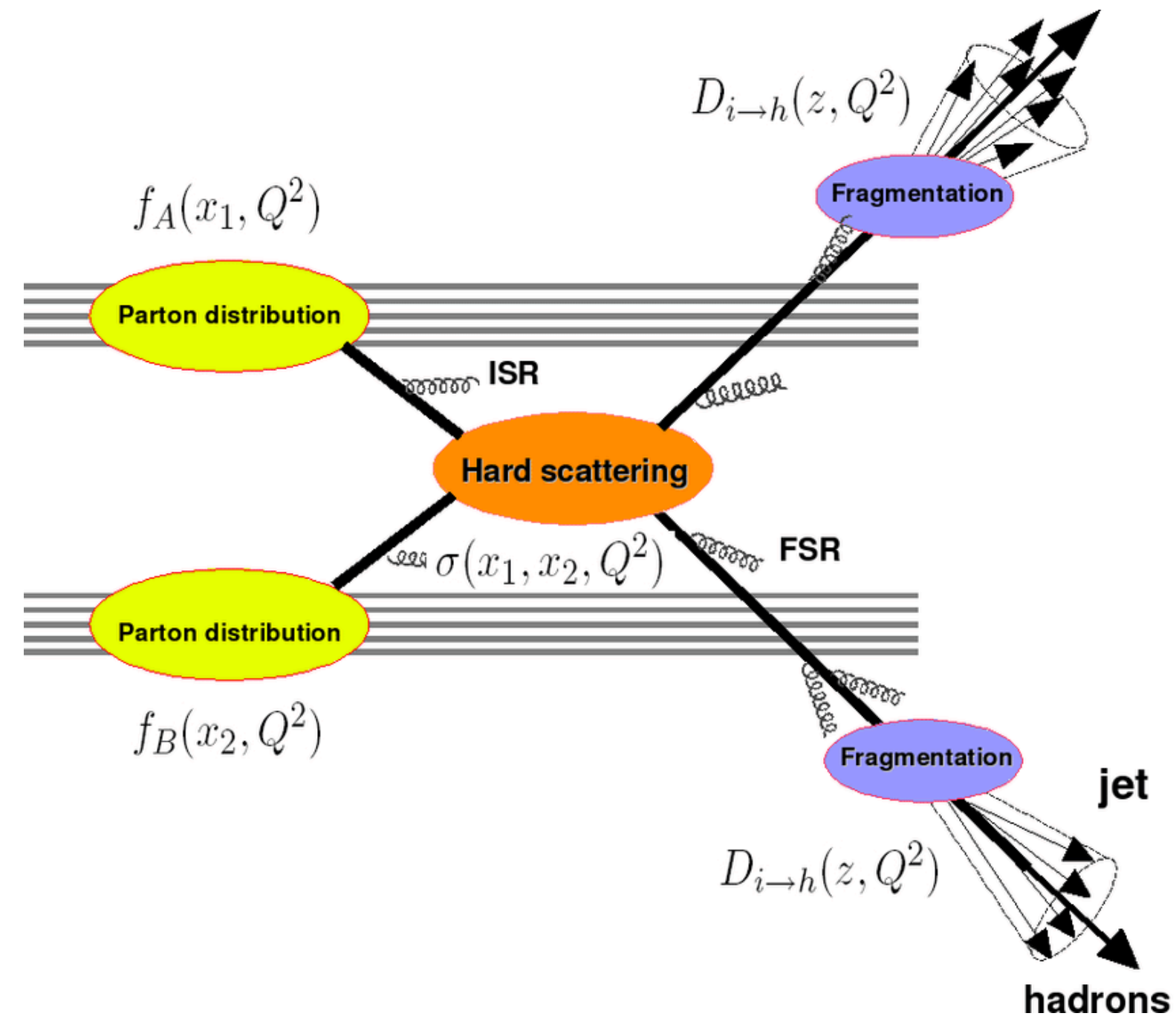
Benjamin Audurier* for the LHCb collaboration



Introduction

Heavy-flavour production

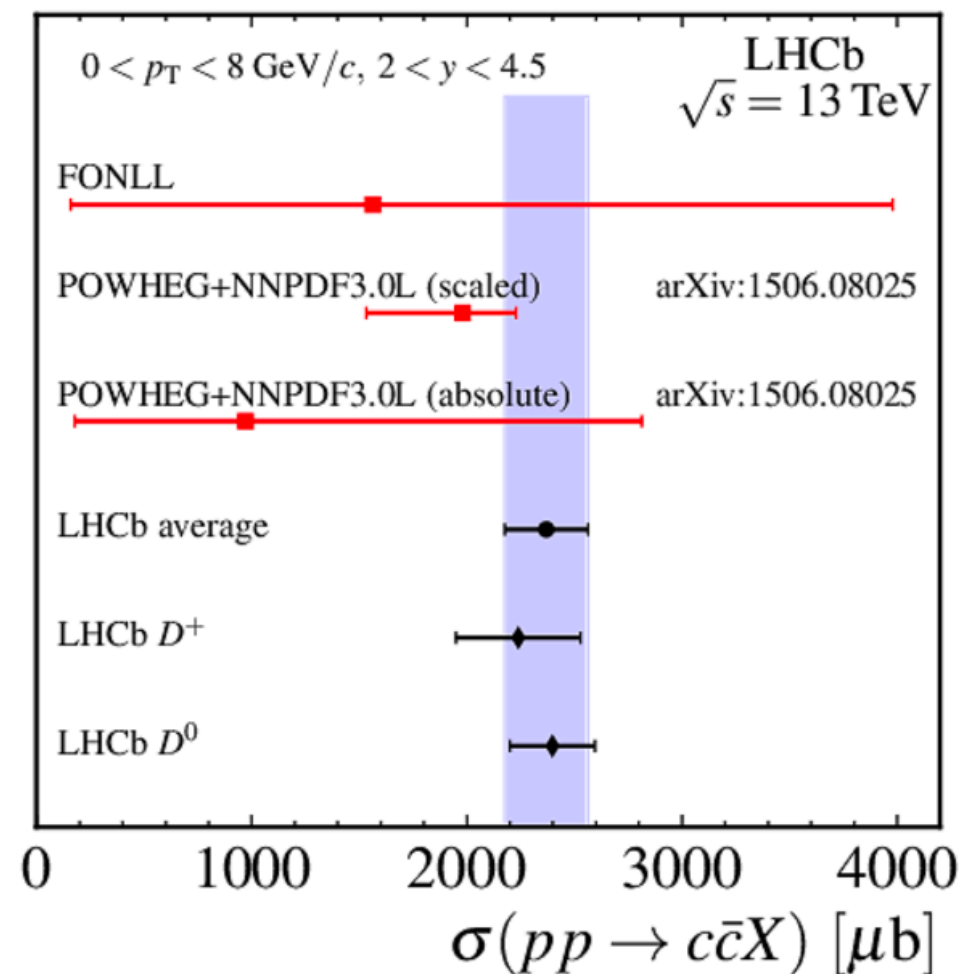
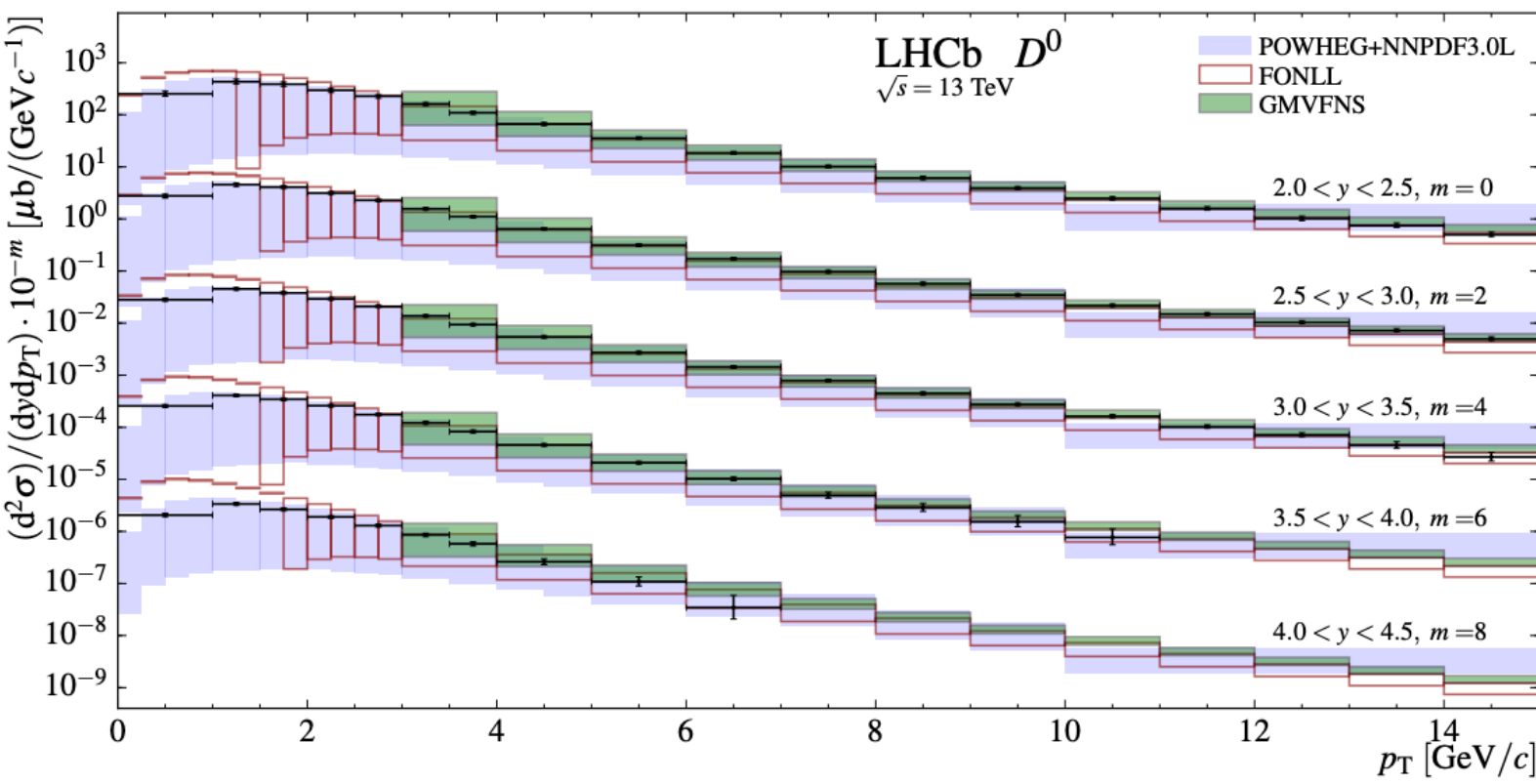
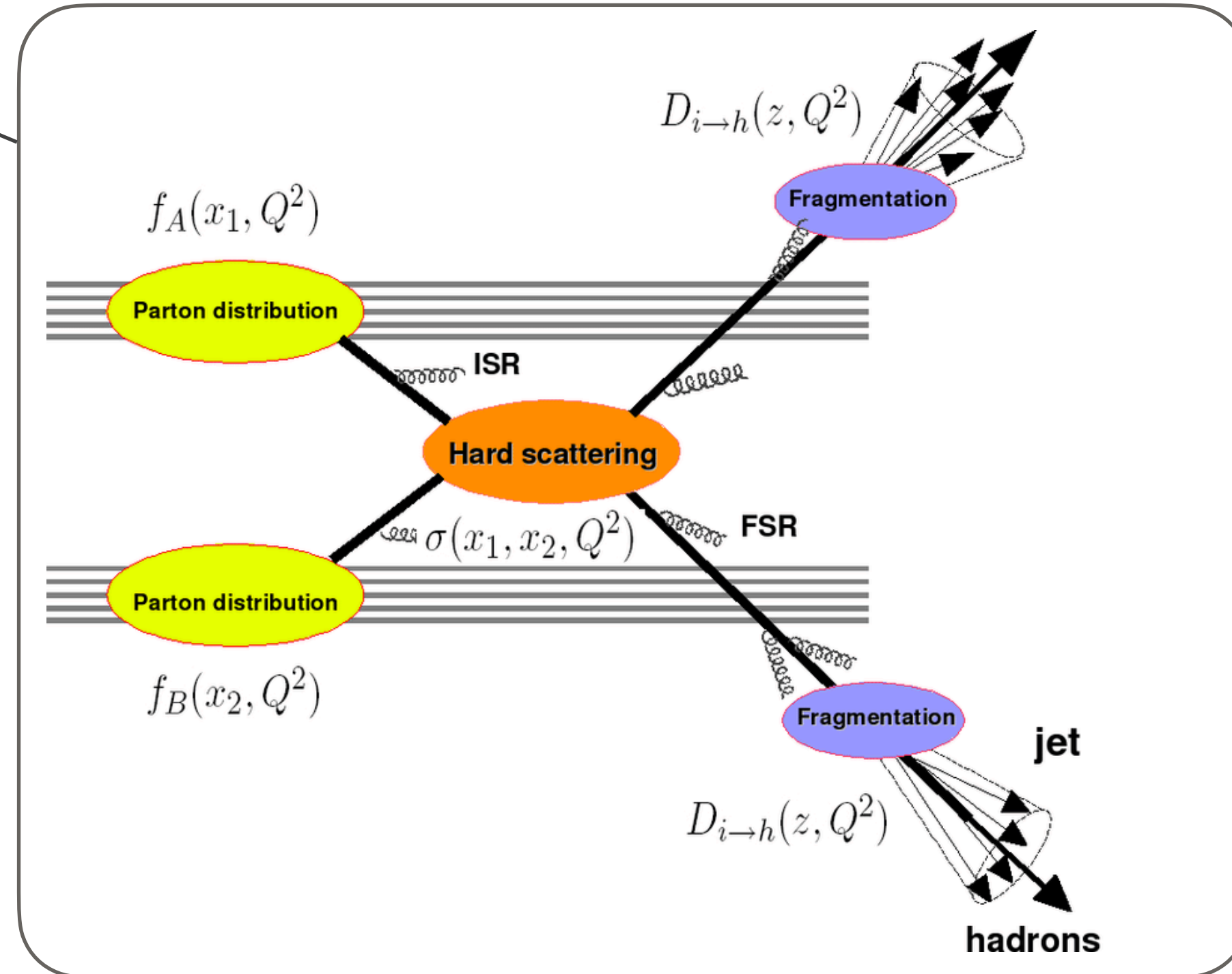
- Large quark mass \rightarrow hard scale for pQCD calculation.



Heavy-flavour production

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- Test pQCD factorisation.



JHEP 05 (2017) 074

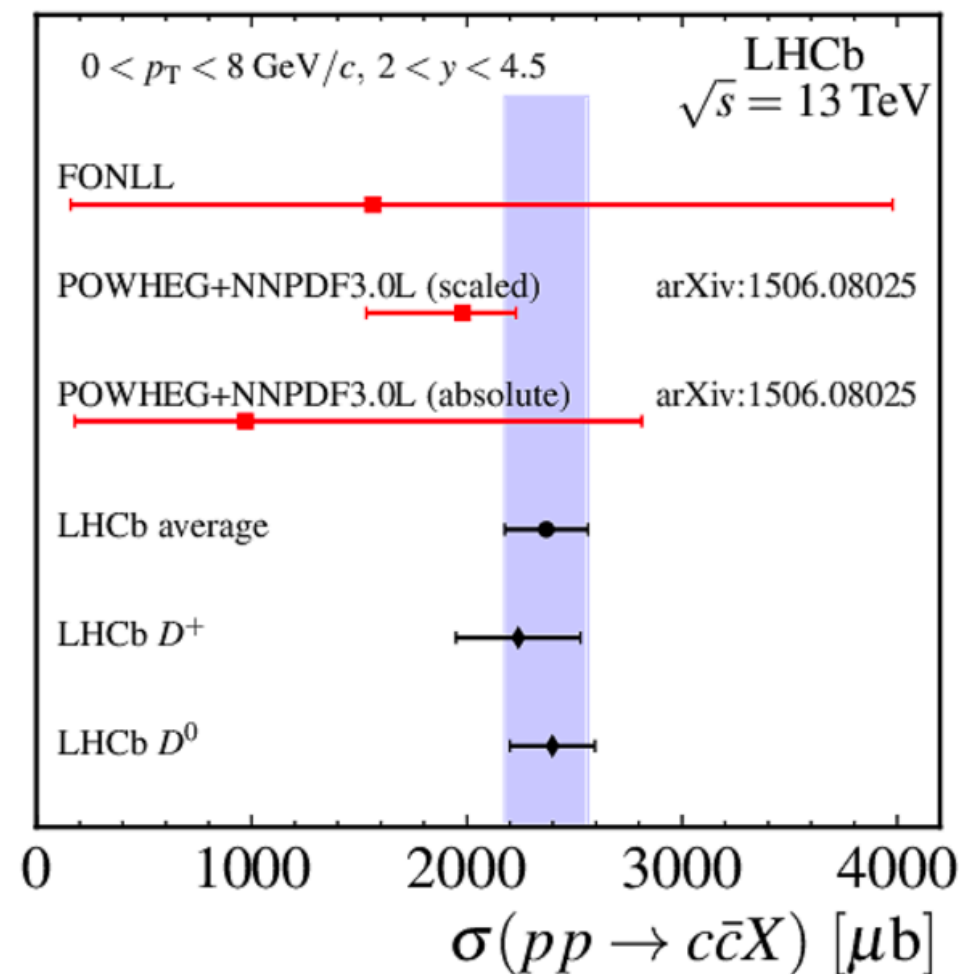
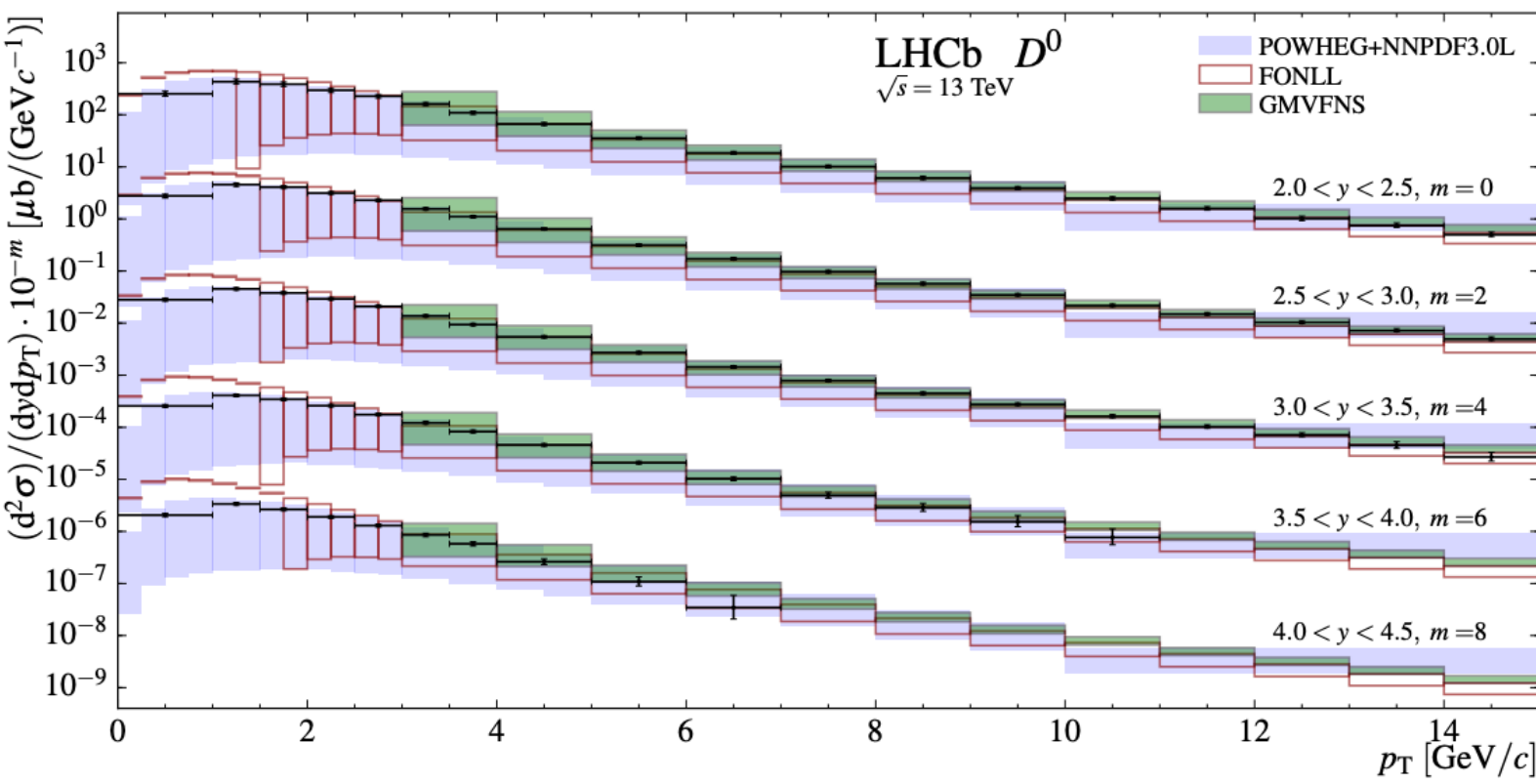
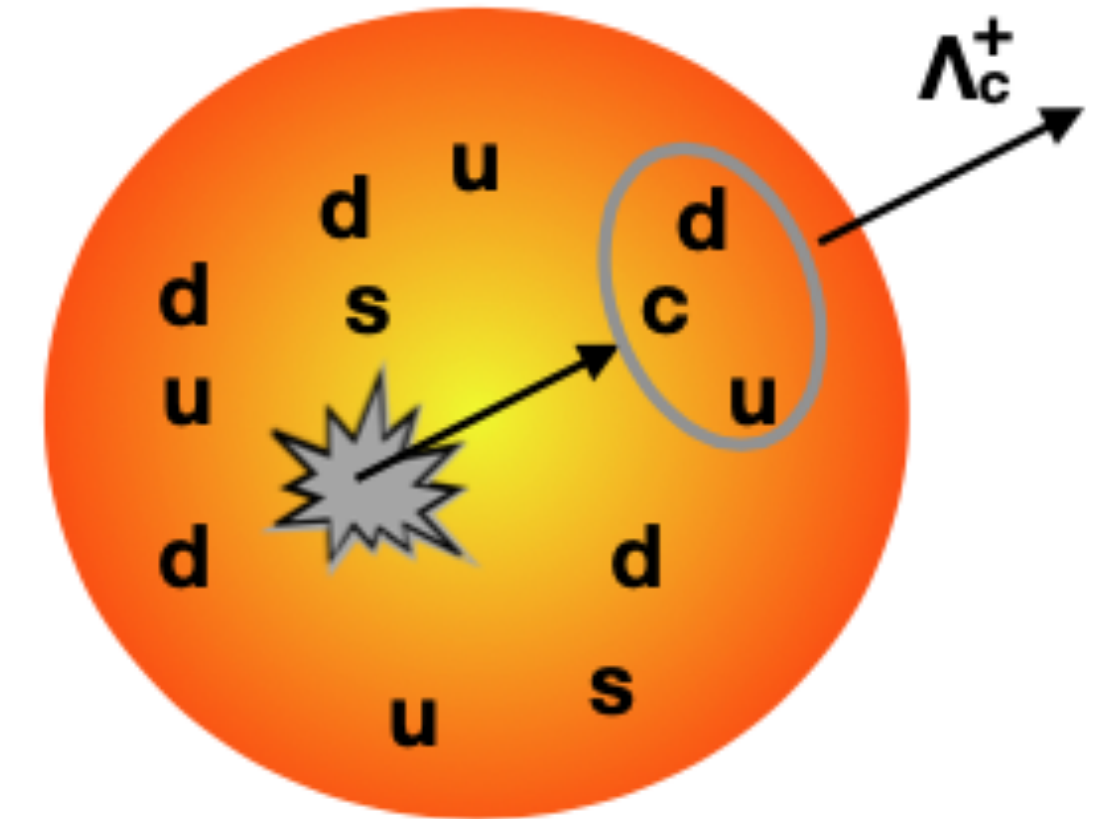
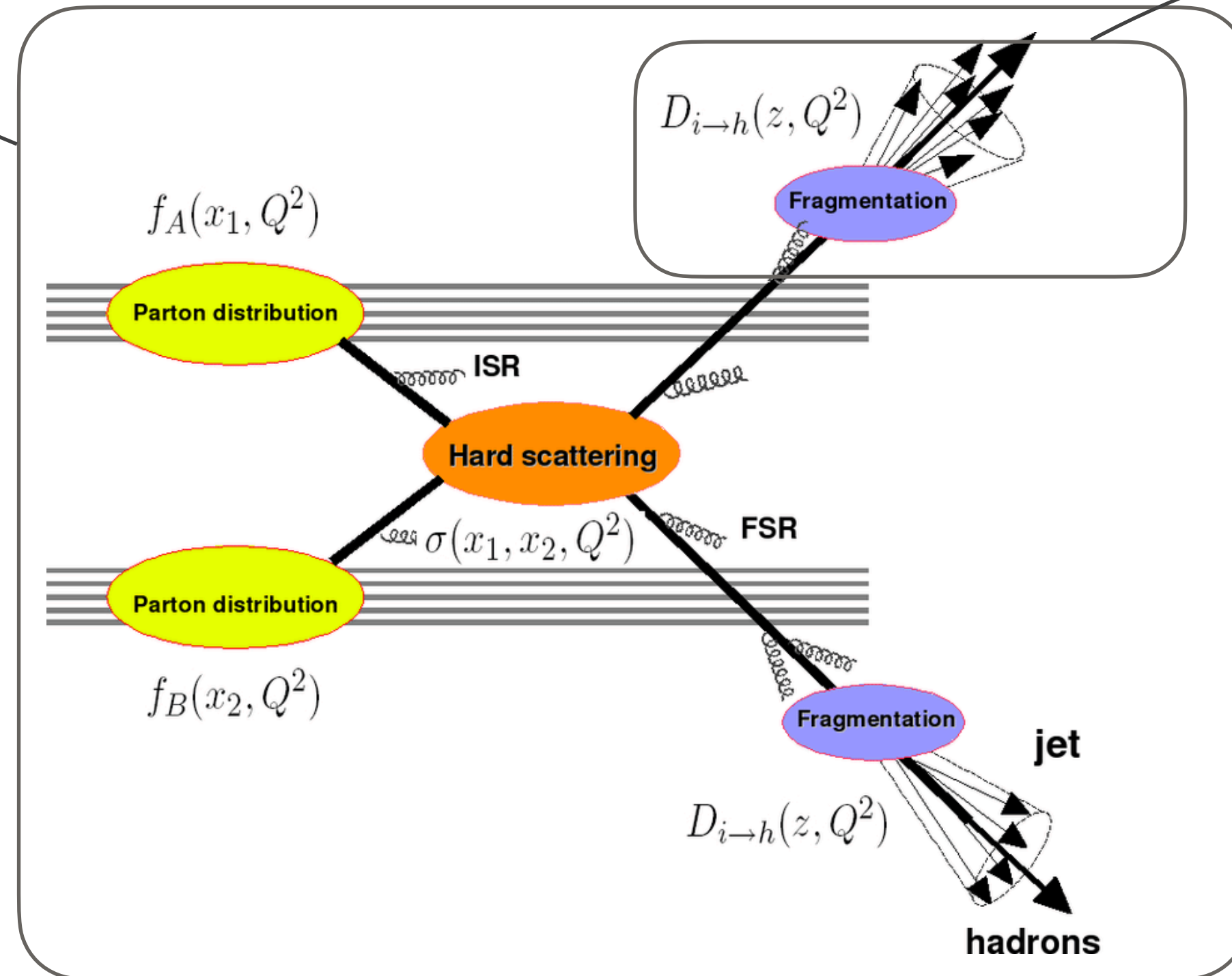
Heavy-flavour production

- Large quark mass \rightarrow **hard scale for pQCD calculation.**

- Test pQCD factorisation.

- Probes the hadronization mechanisms:

- Fragmentation functions.
- Coalescence.



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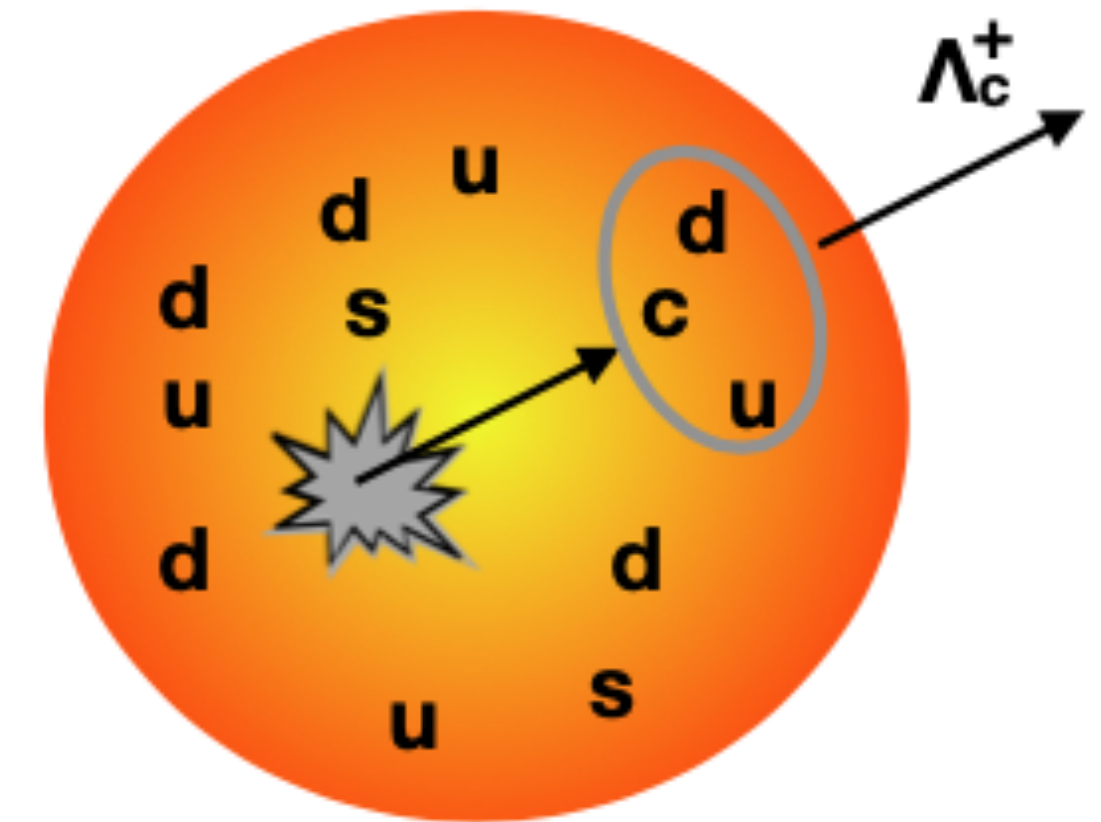
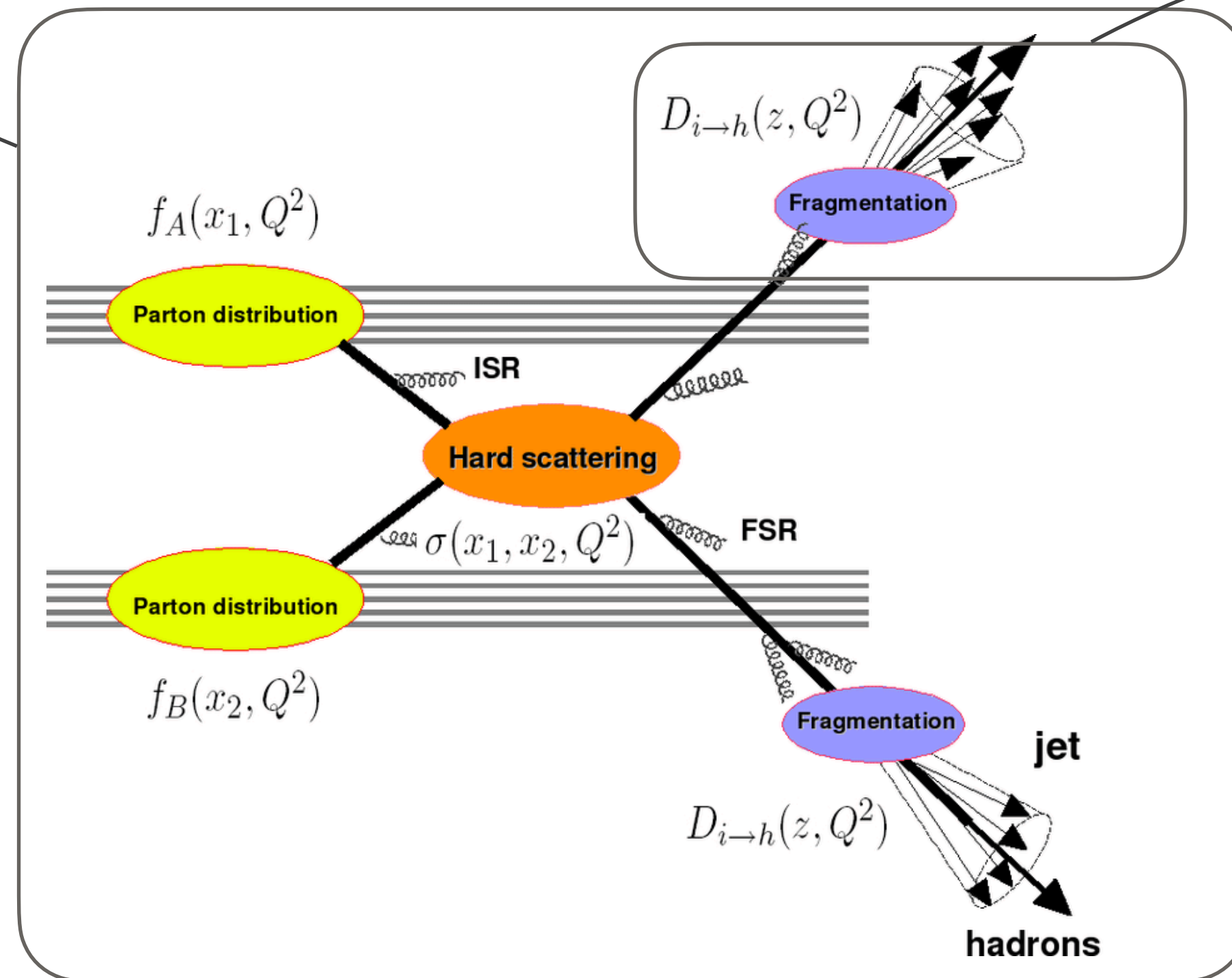
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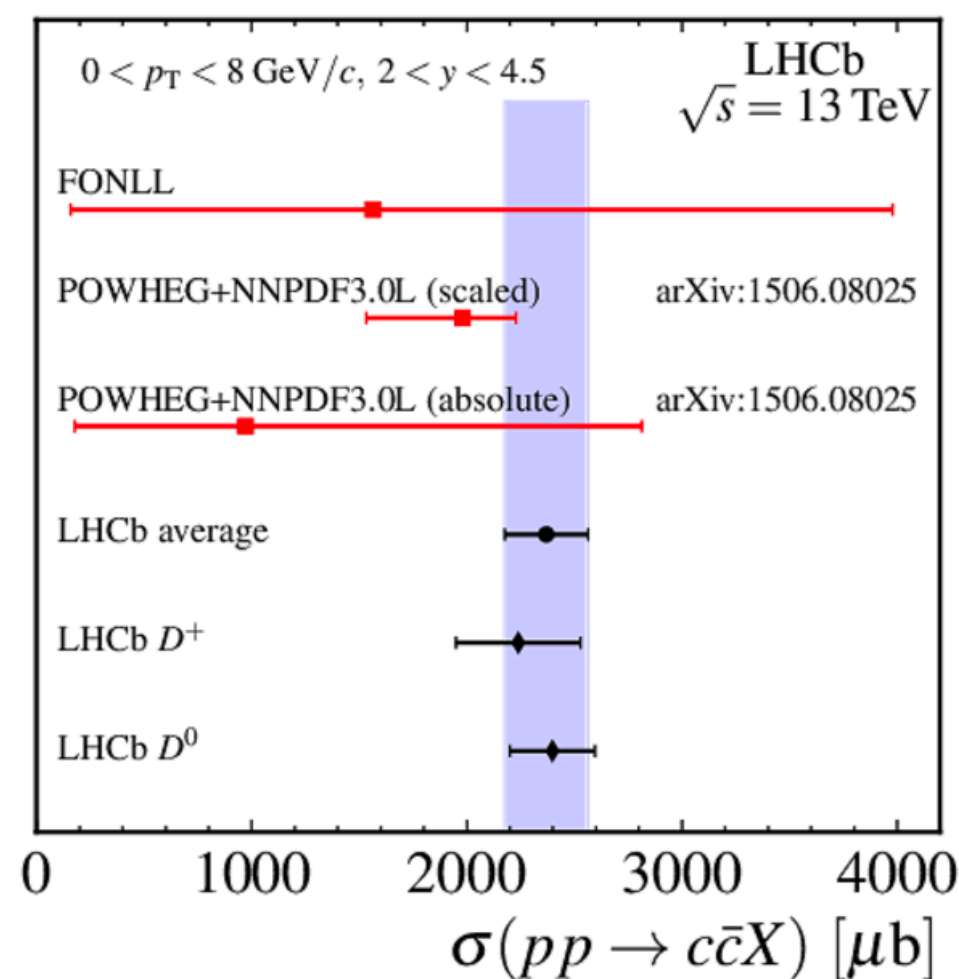
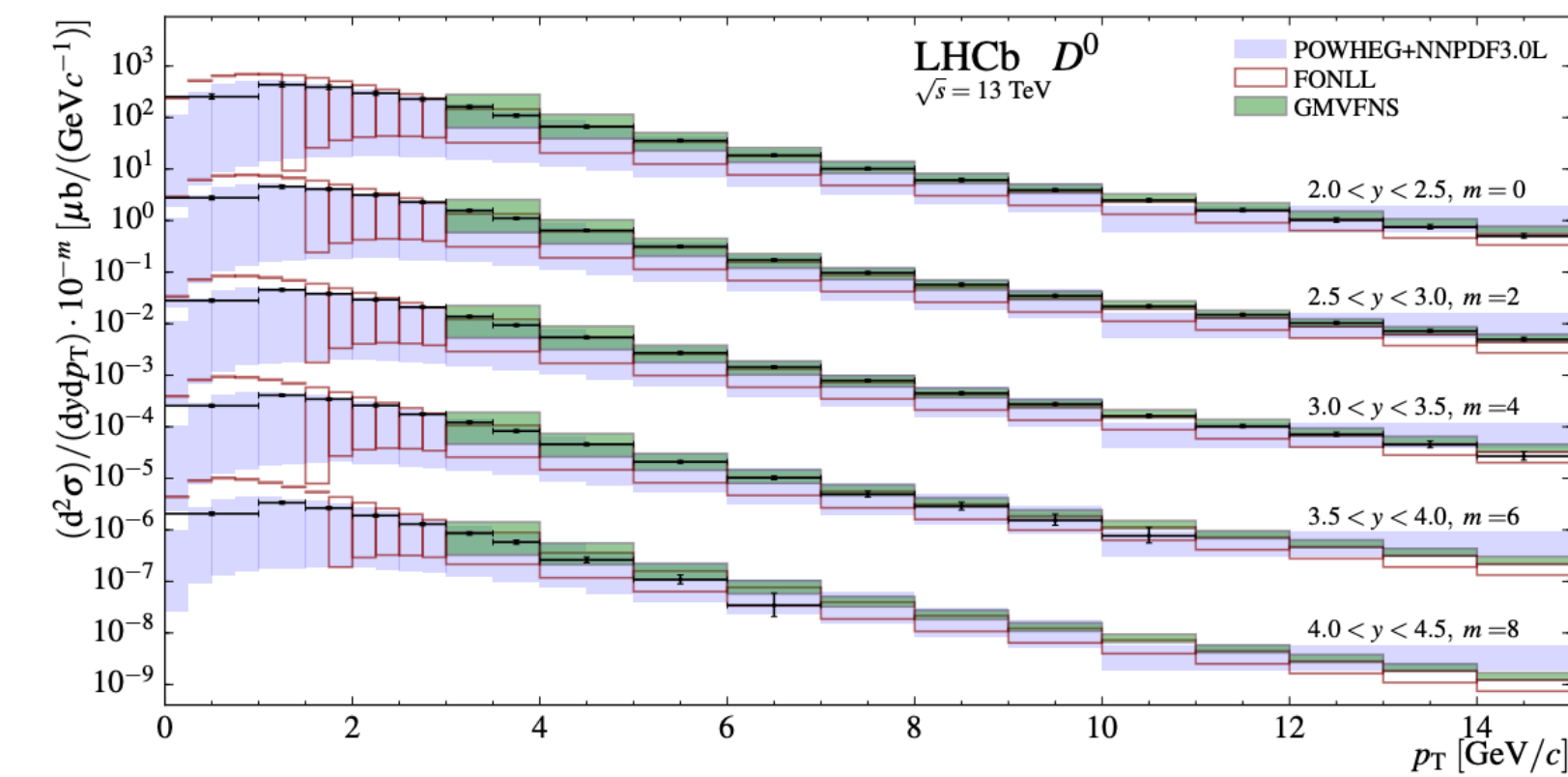
- Probes the hadronization mechanisms:

- Fragmentation functions.
- Coalescence.



- Many questions remain on coalescence mechanism:

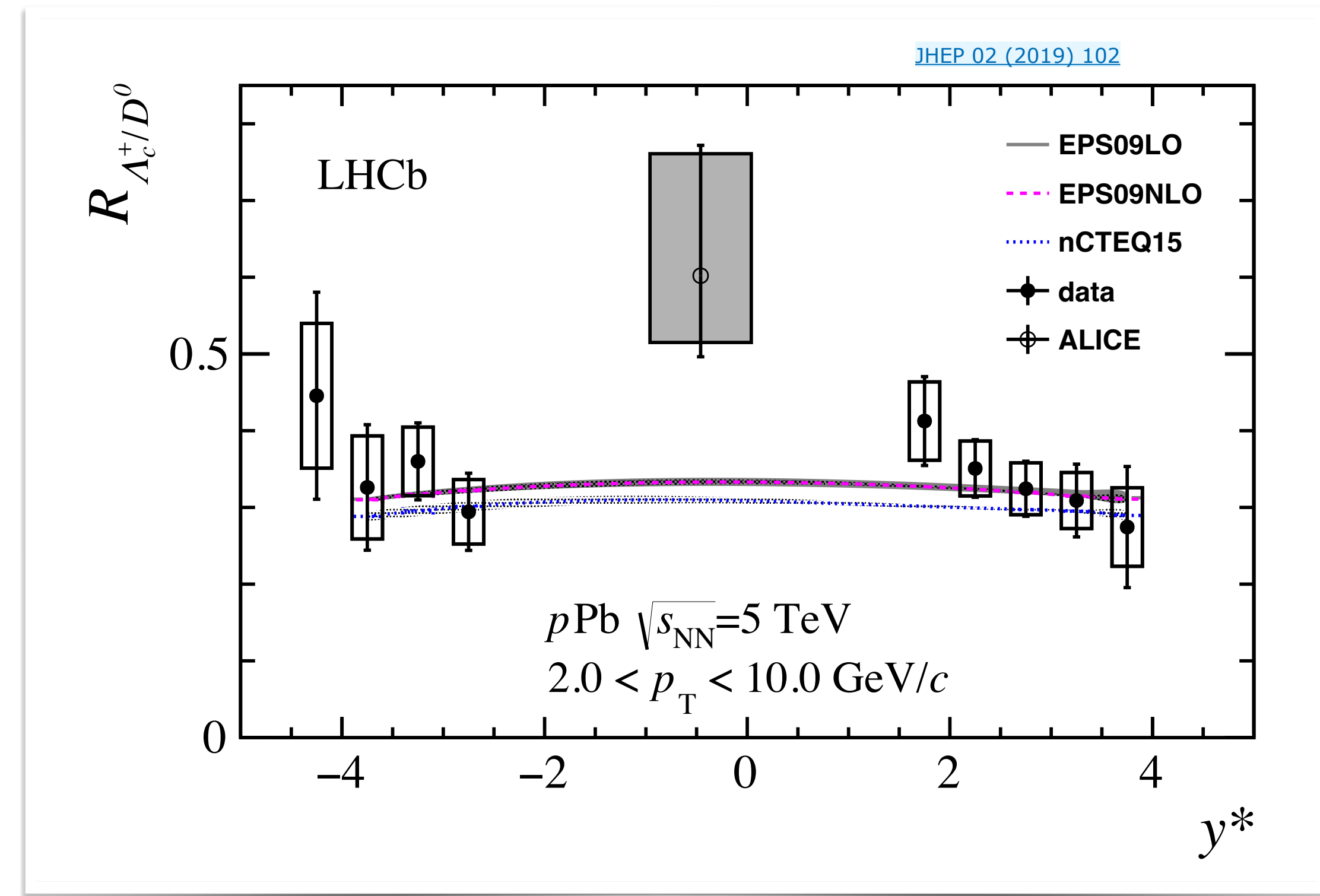
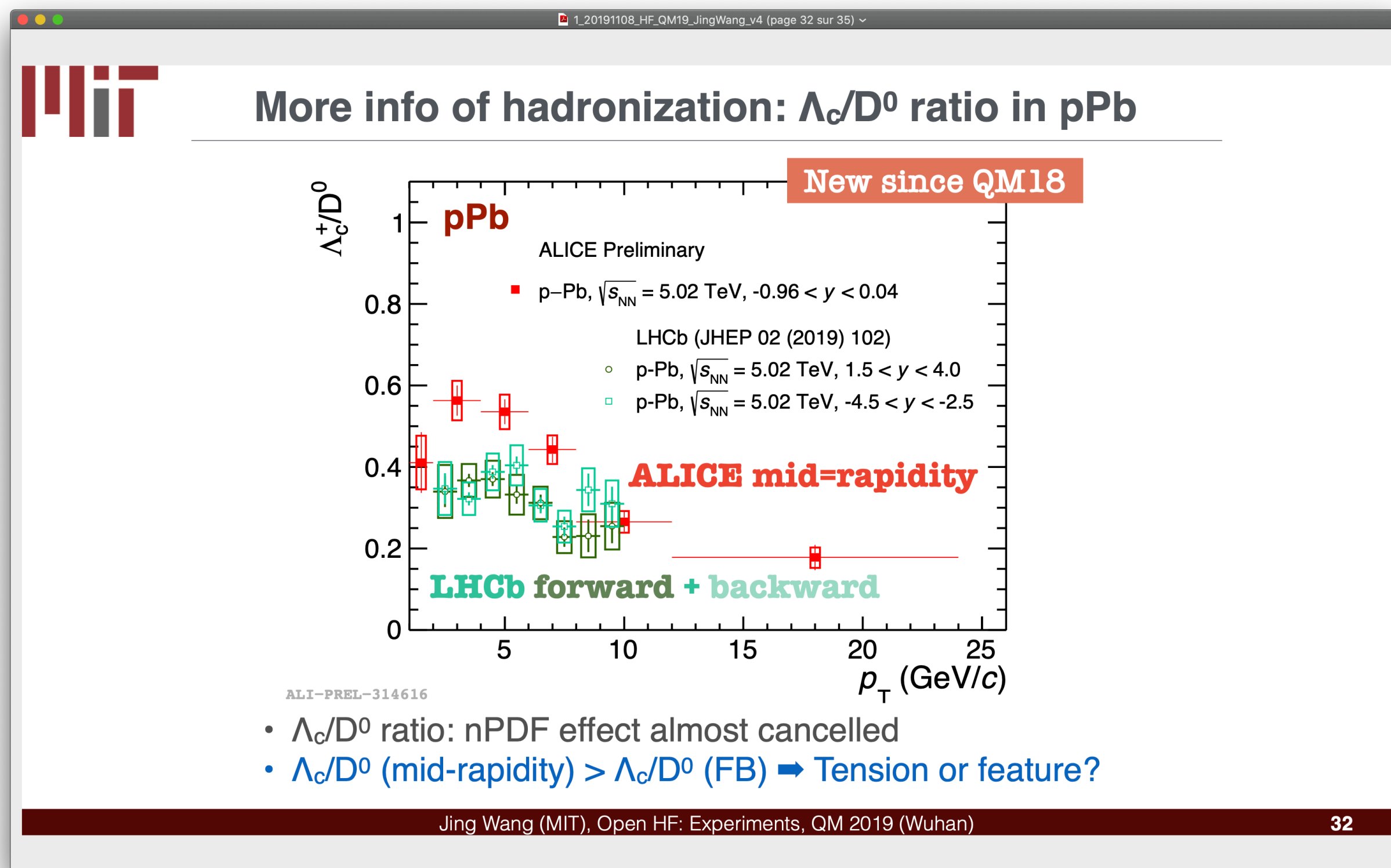
- *Occurring in pp/pA/AA collisions?*
- *Multiplicity dependent?*
- *Probe for medium composition?*



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Open-question at Quark Matter 2019

Slides from Heavy-flavour overview talk at Quark Matter 2019

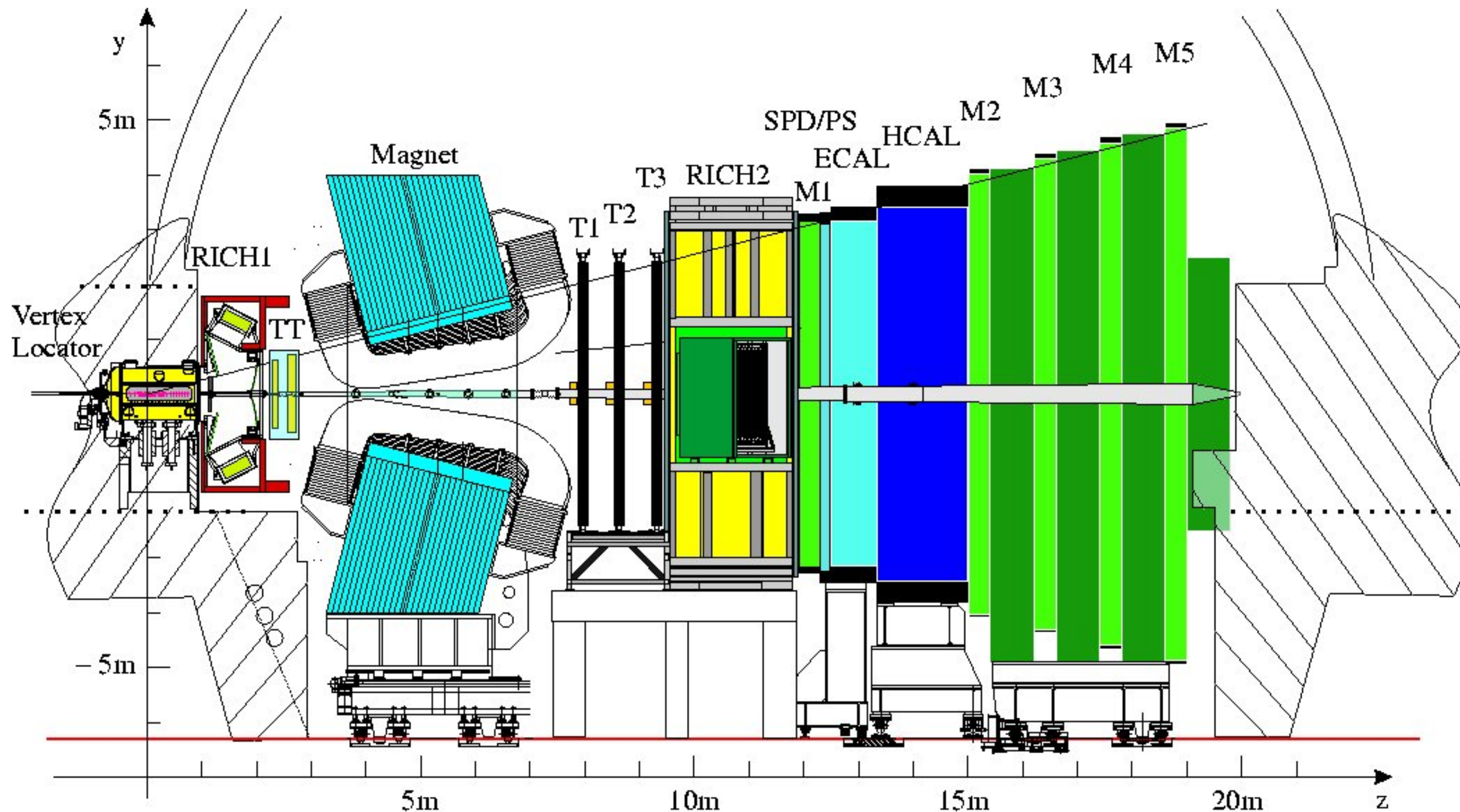


New LHCb PbPb sample might give some insights ?

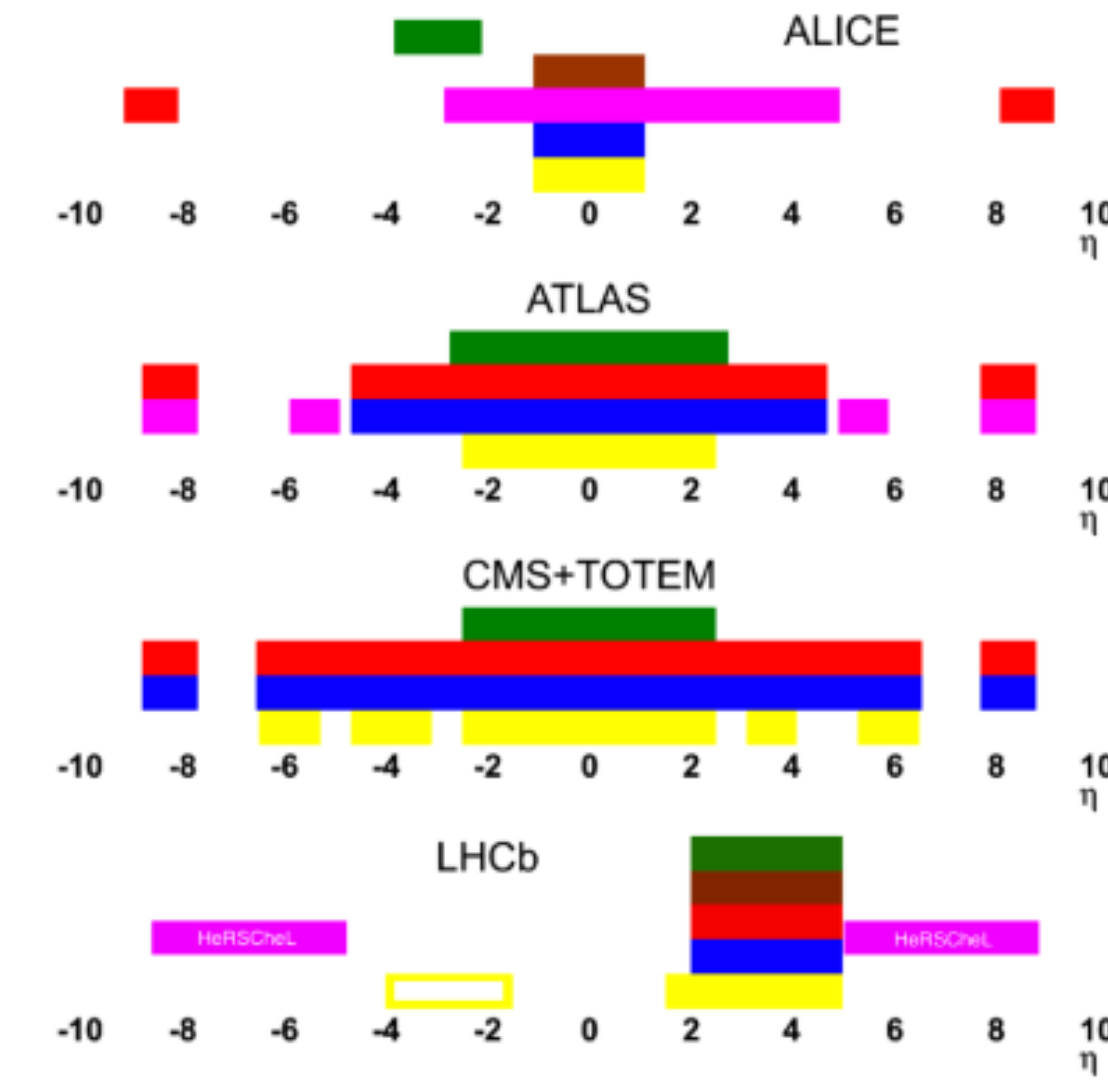
The LHCb detector

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

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



- 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**.

Latest results - pQCD oriented

New

J/ψ production in pp collisions at 5 TeV

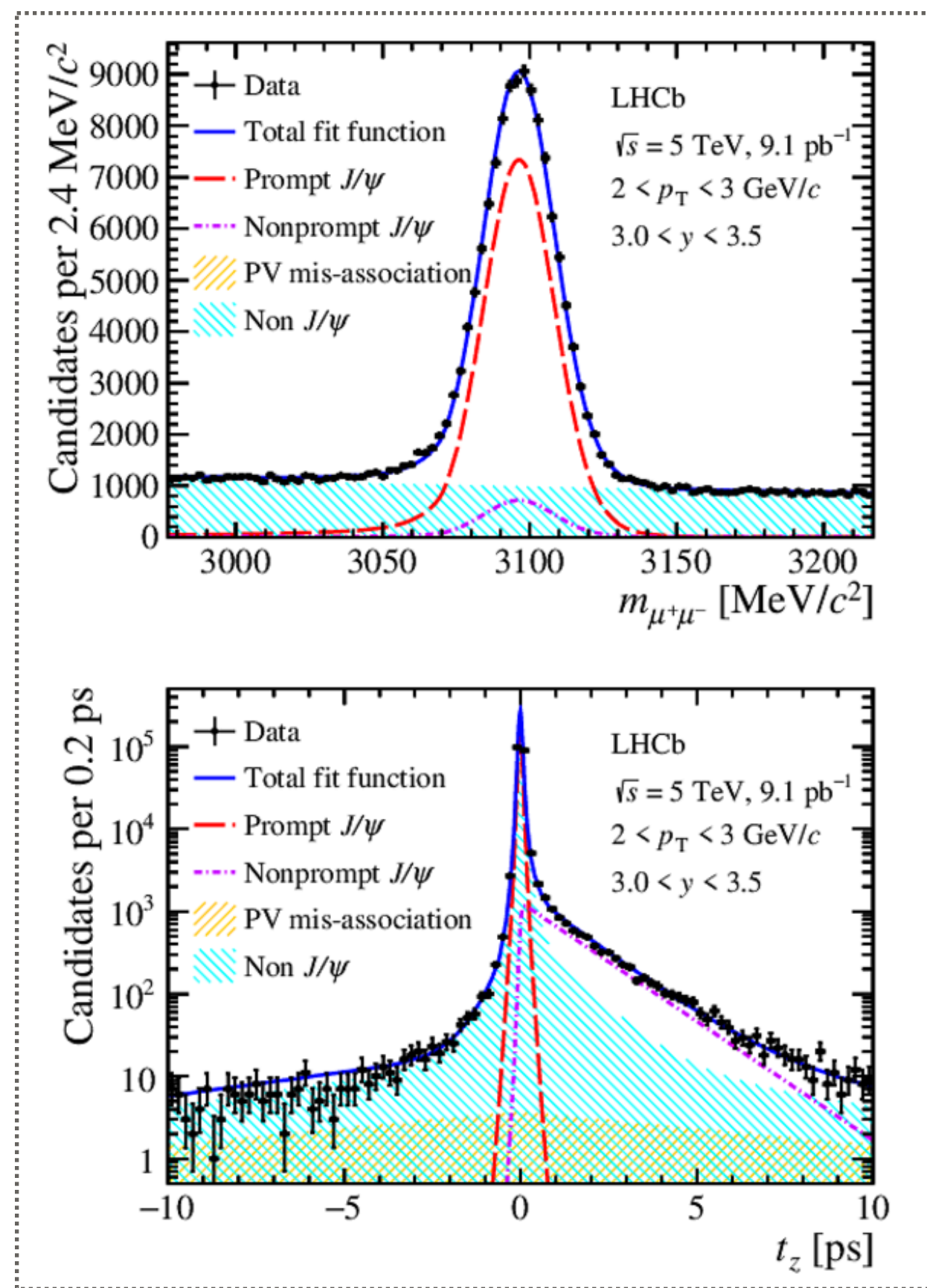
[JHEP 11 \(2021\) 181](#)

New

J/ψ production in pp collisions at 5 TeV

JHEP 11 (2021) 181

Simultaneous fit



$$t_z = \frac{z_{J/\psi} - z_{\text{PV}}}{p_z} \times m_{J/\psi}$$

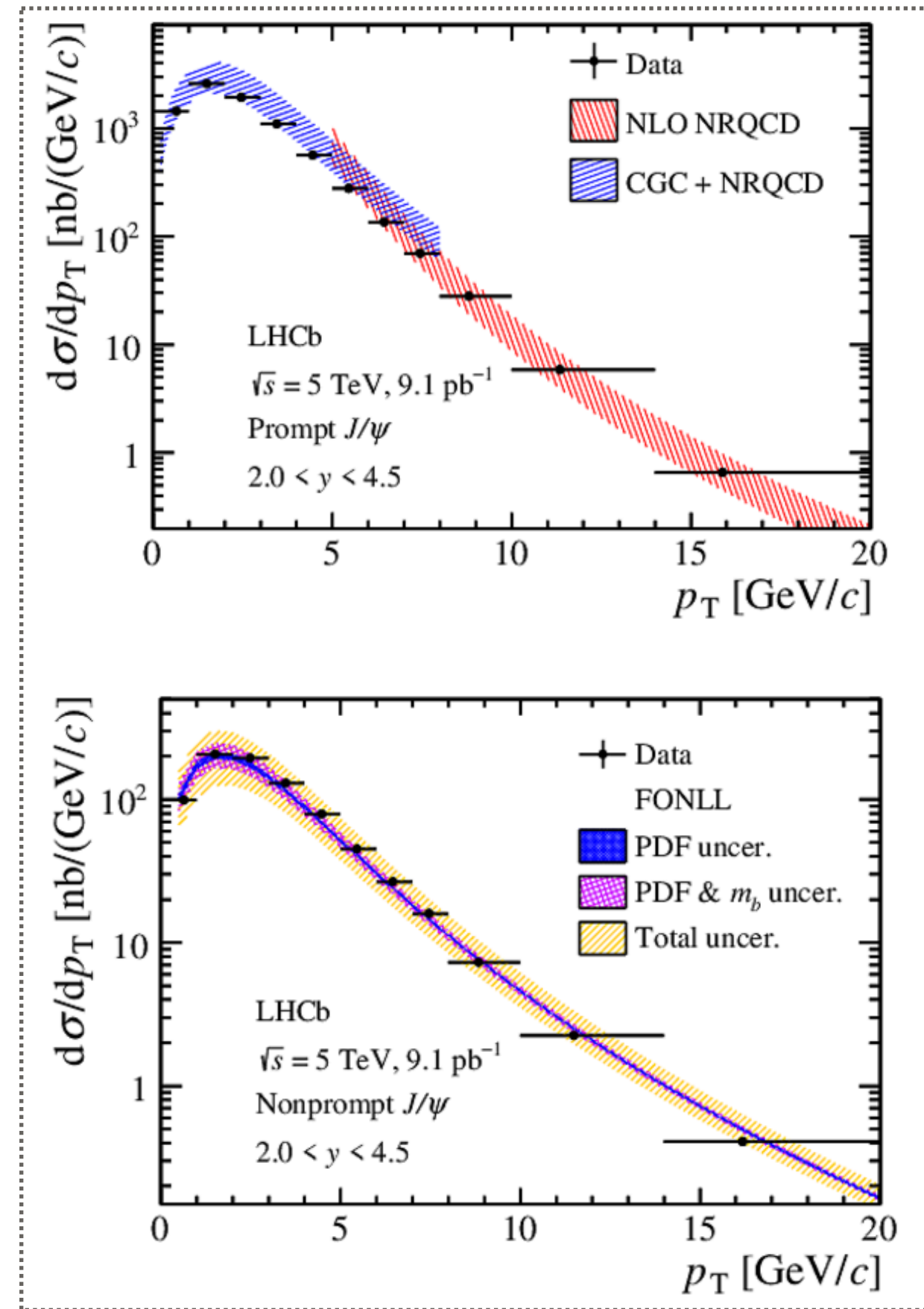
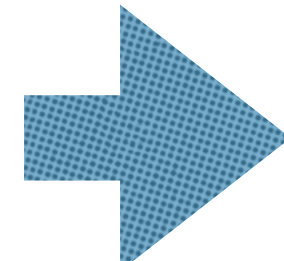
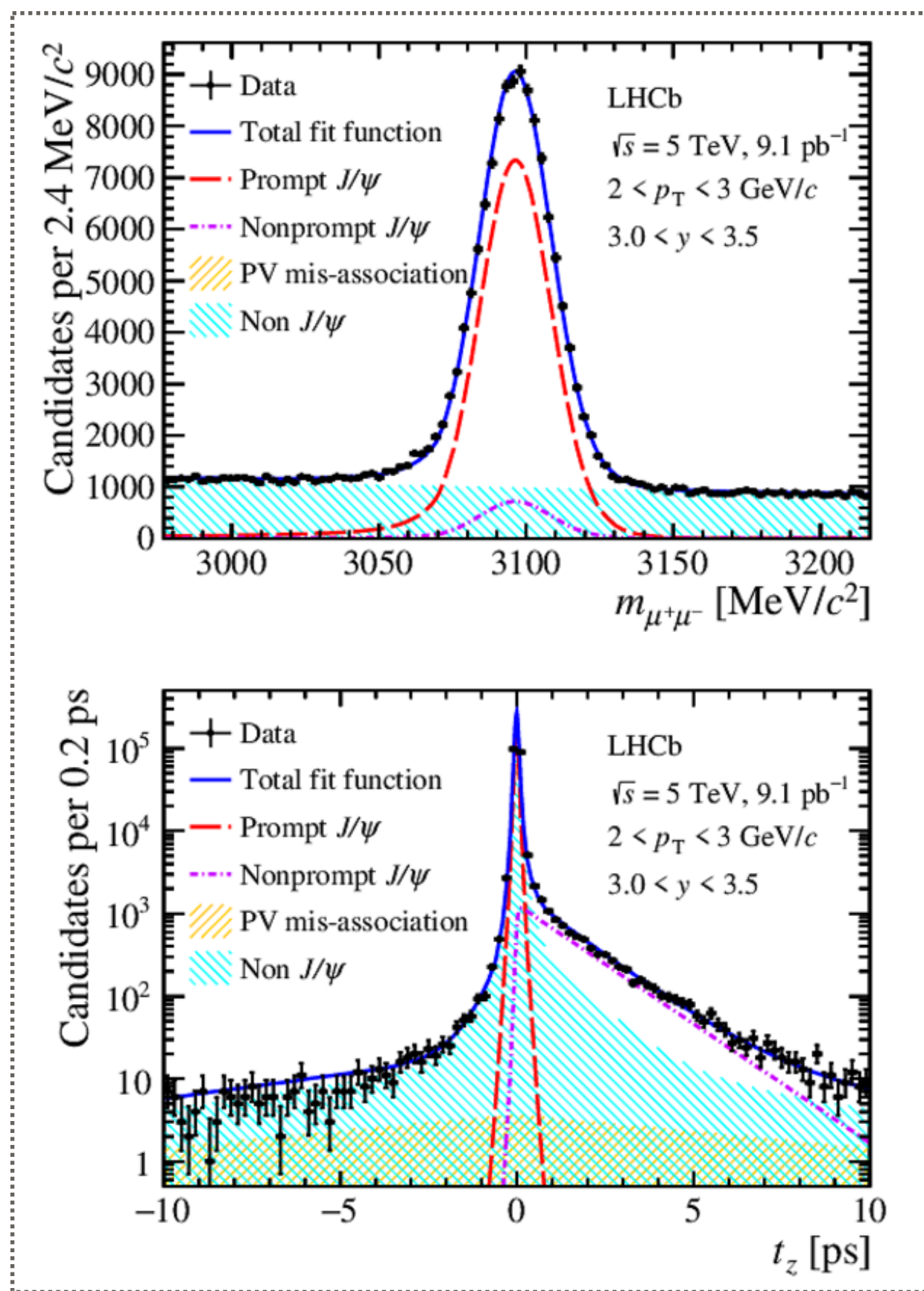
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JHEP 11 (2021) 181

Simultaneous fit

Cross-sections



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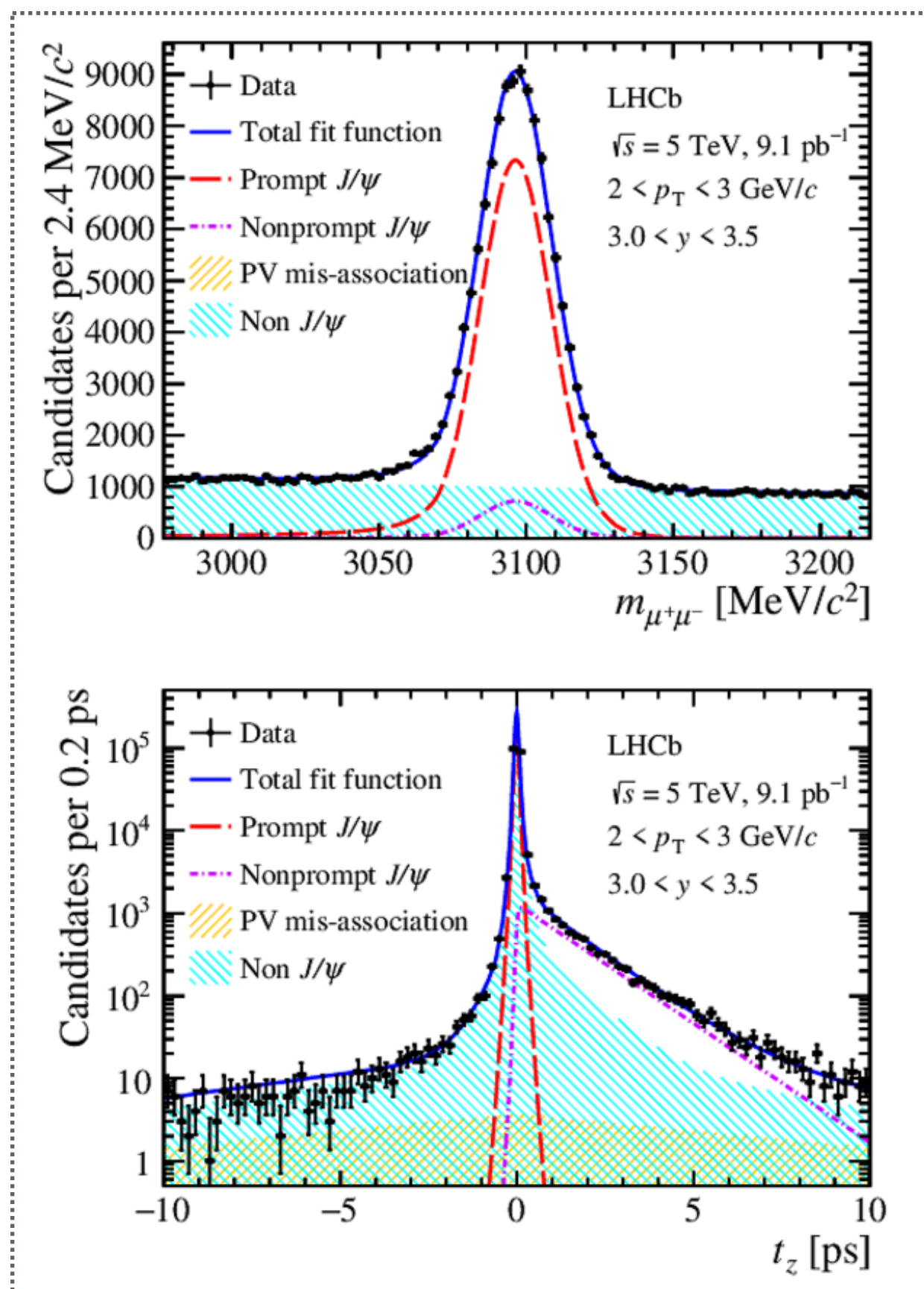
• Agreement between data/NRQCD.

New

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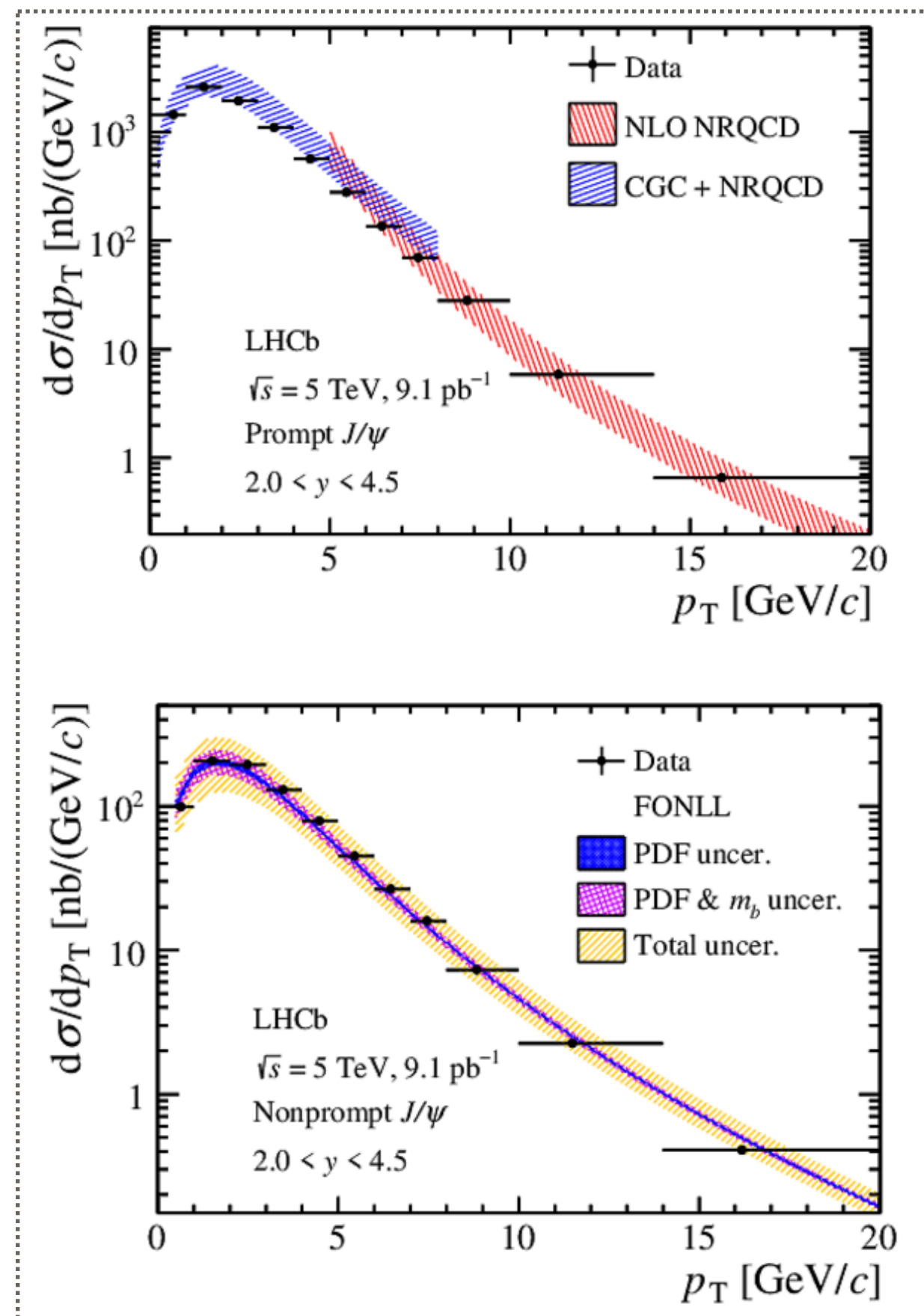
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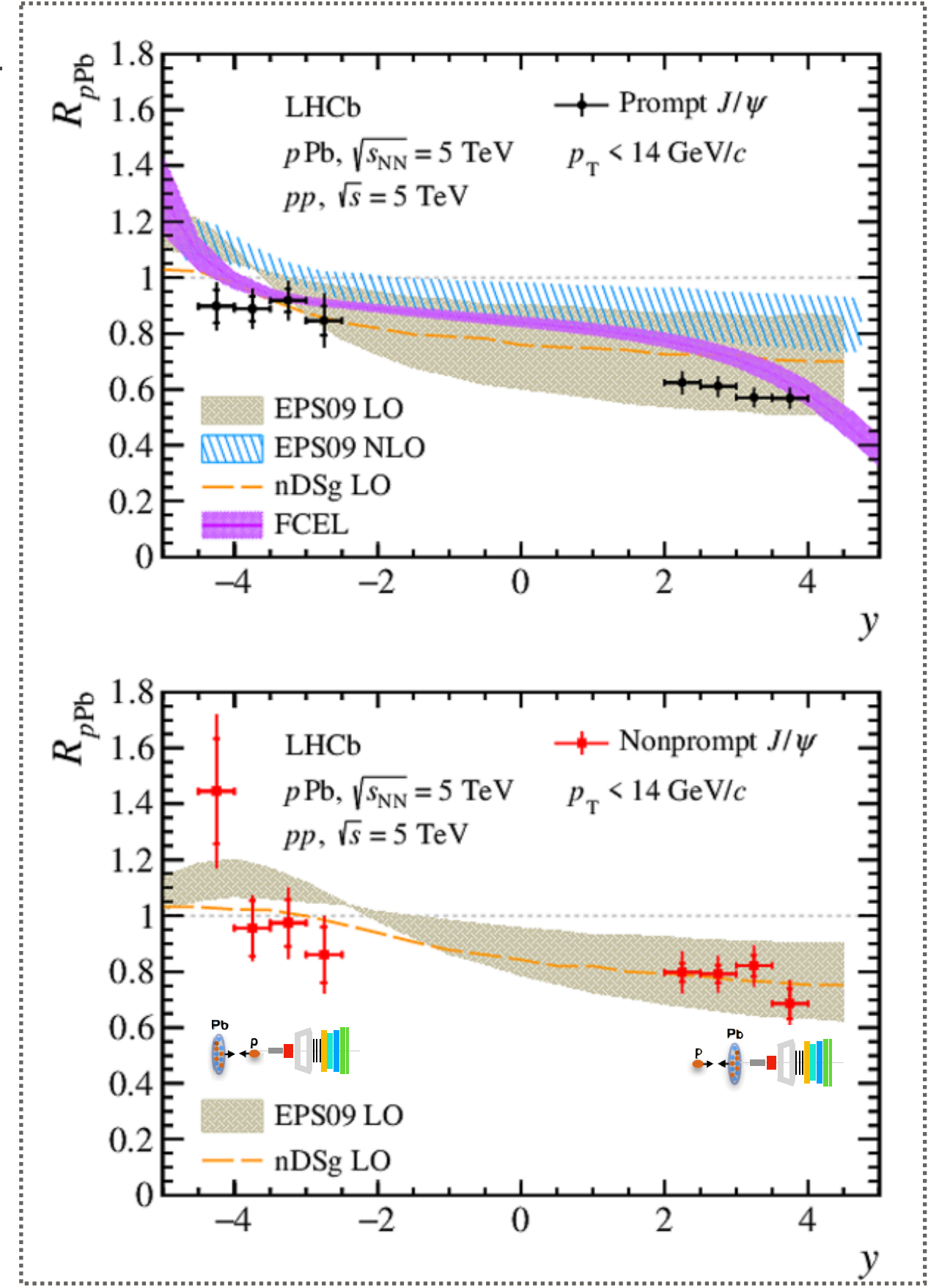
Cross-sections



• Agreement between data/NRQCD.

$$R_{pA} = \frac{\sigma_{pPb}}{208 \times \sigma_{pp}}$$

Nuclear modification factor

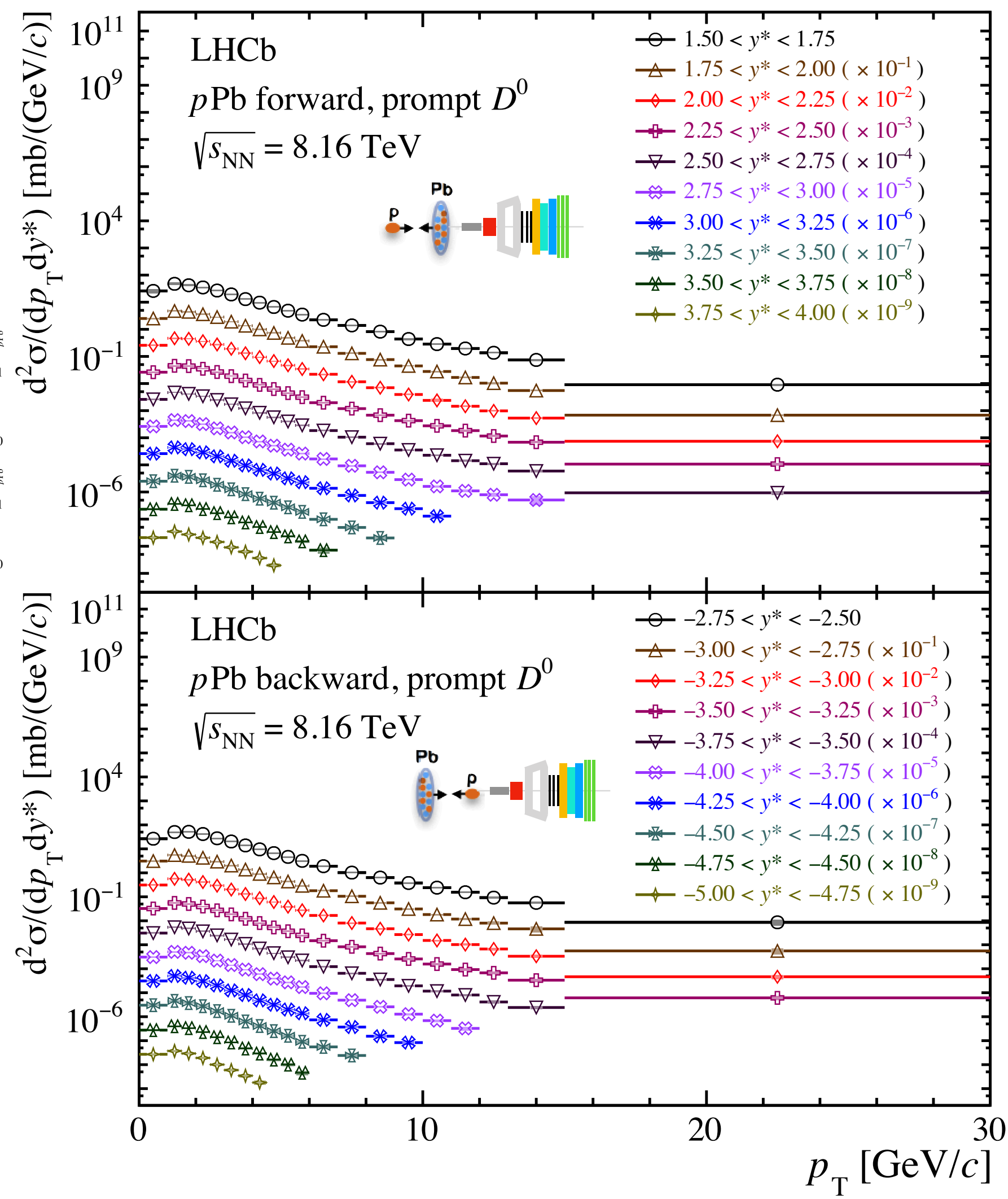


- Updated R_{pA} results with new pp data !
- Good agreement with data/FCEL.
- Tension between data and EPS09 NLO.

New

Open-charm production in pPb collisions

LHCb-PAPER-2022-007

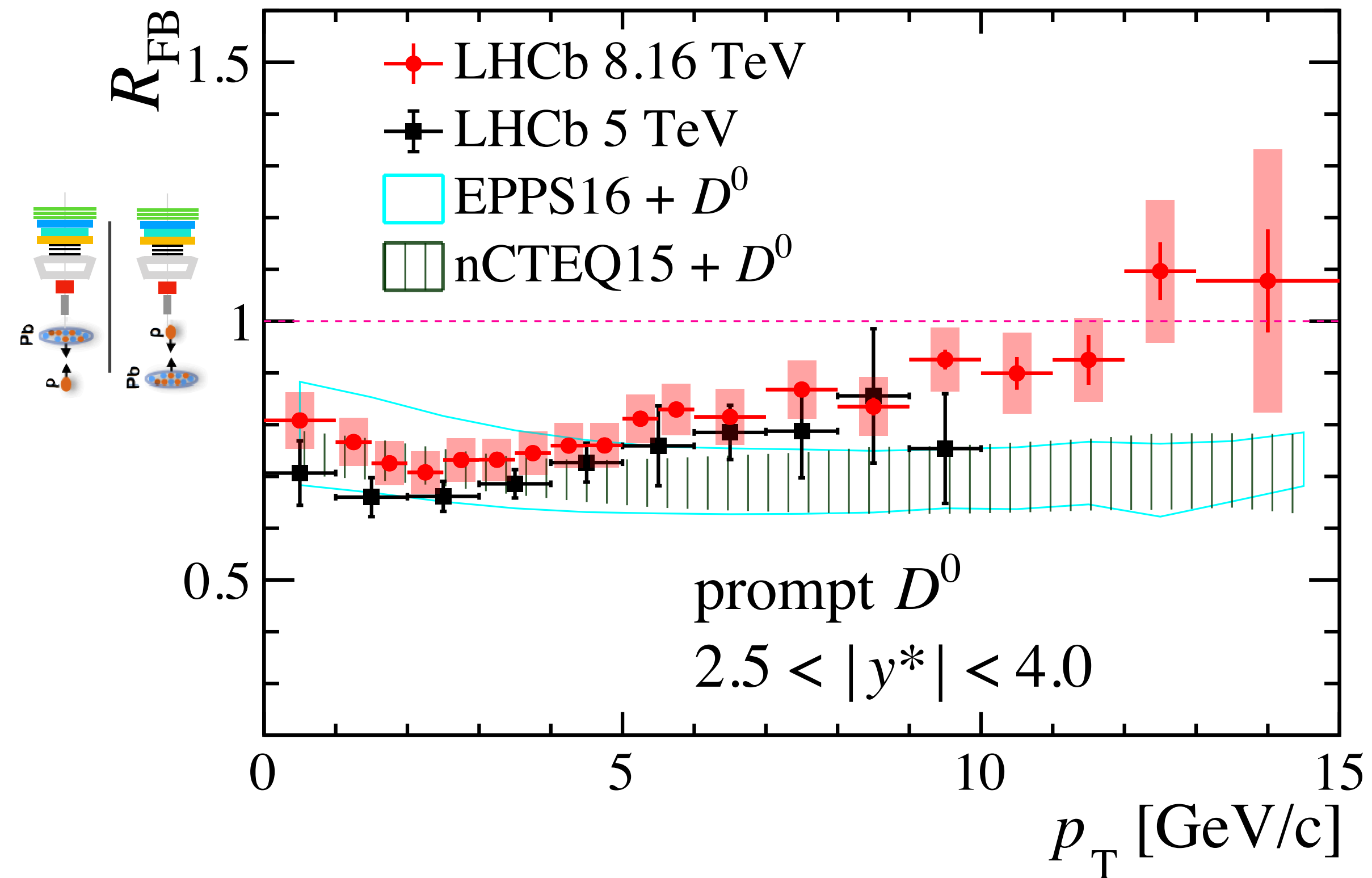
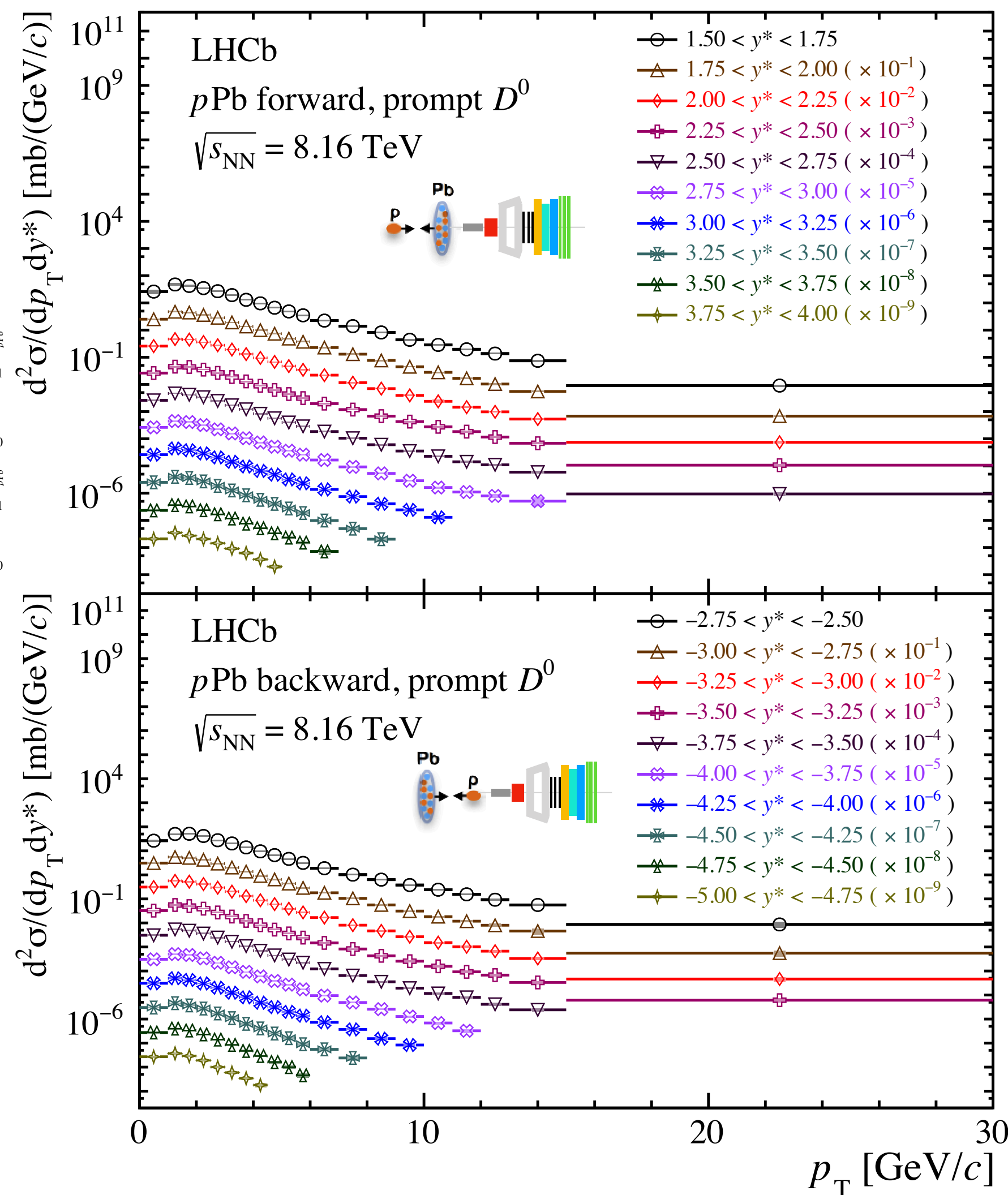


- ❖ **New results for D^0 cross-section** in pPb / Pbp collisions at $\sqrt{s_{NN}} = 8$ TeV up to $p_T = 30$ GeV/c.
- ❖ **Improved statistics** by factor 20 compared to previous LHCb results.

New

Open-charm production in pPb collisions

LHCb-PAPER-2022-007

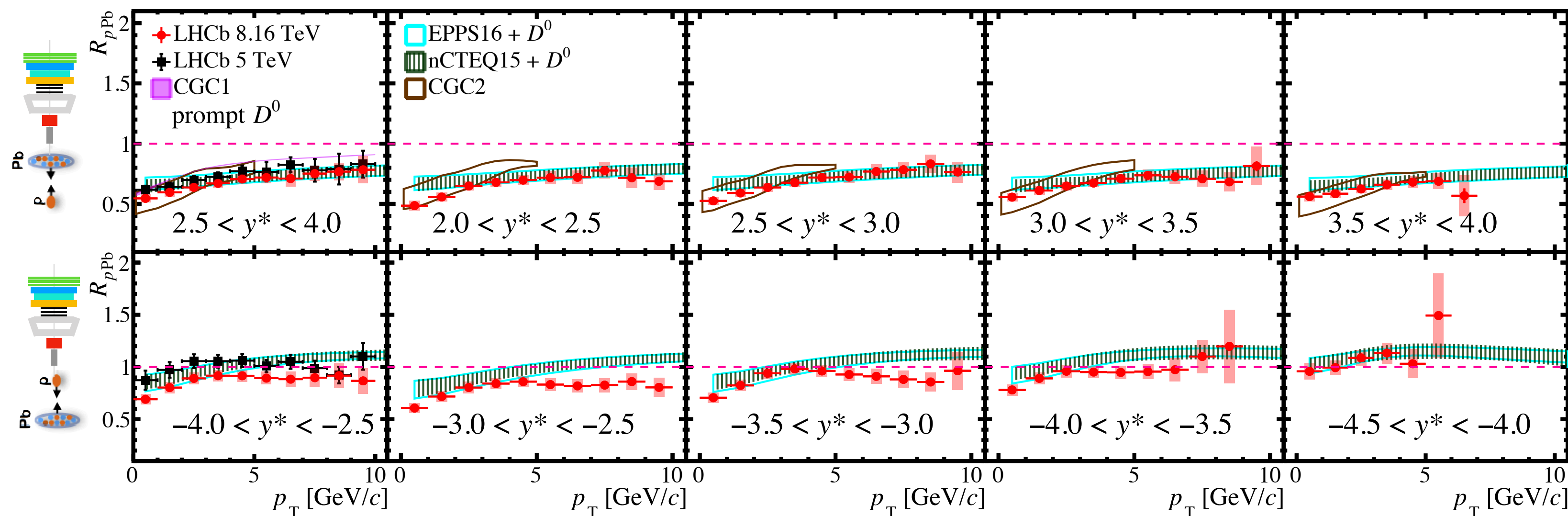
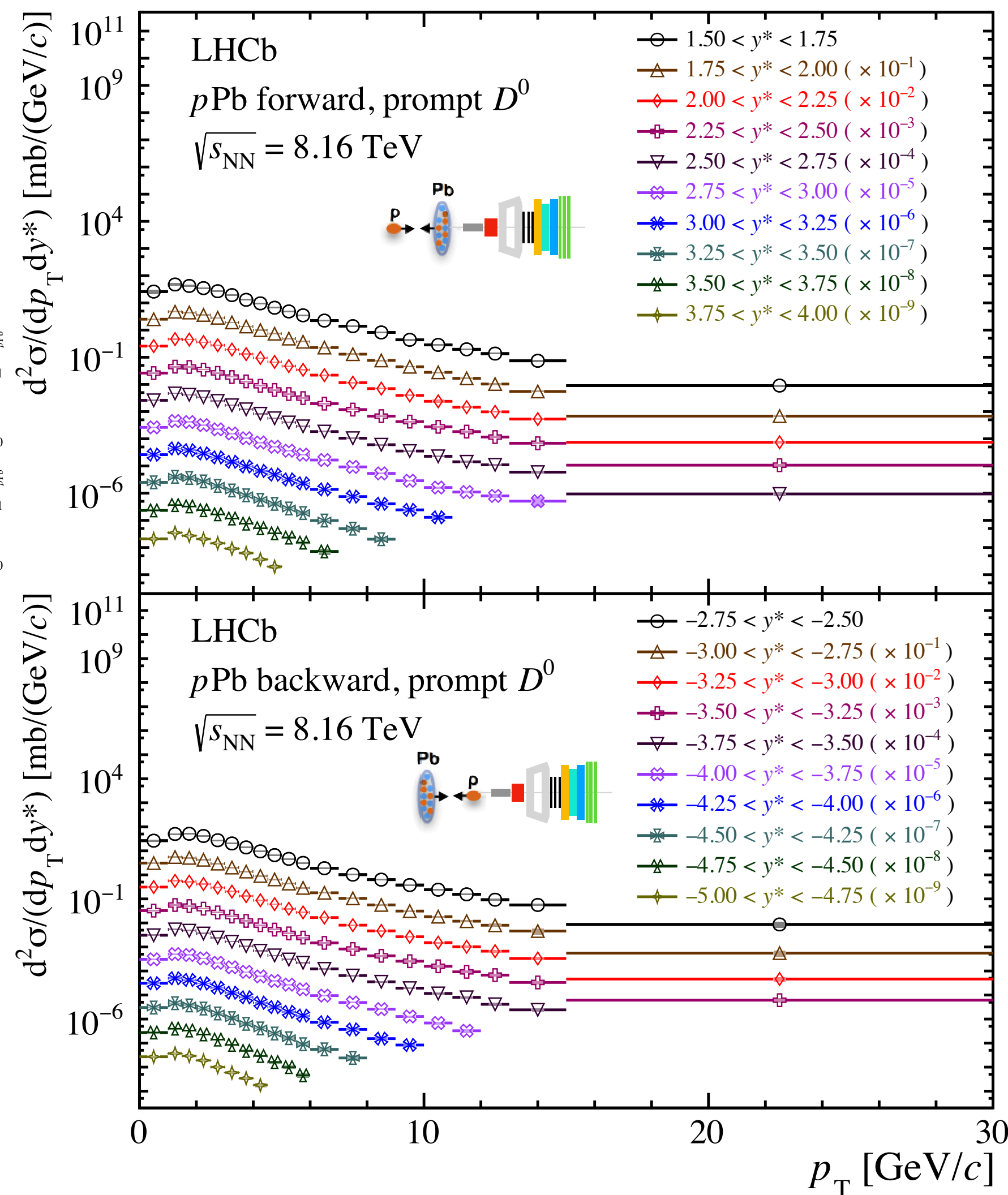


- ❖ Tension between data and theory predictions at high p_T .
- ❖ Additional effect required?

New

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LHCb-PAPER-2022-007



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Latest results - hadronization

Fragmentation fraction ratios in pp collisions

Phys. Rev. D 104 (2021) 032005

- ❖ Fragmentation functions measured with B mesons :

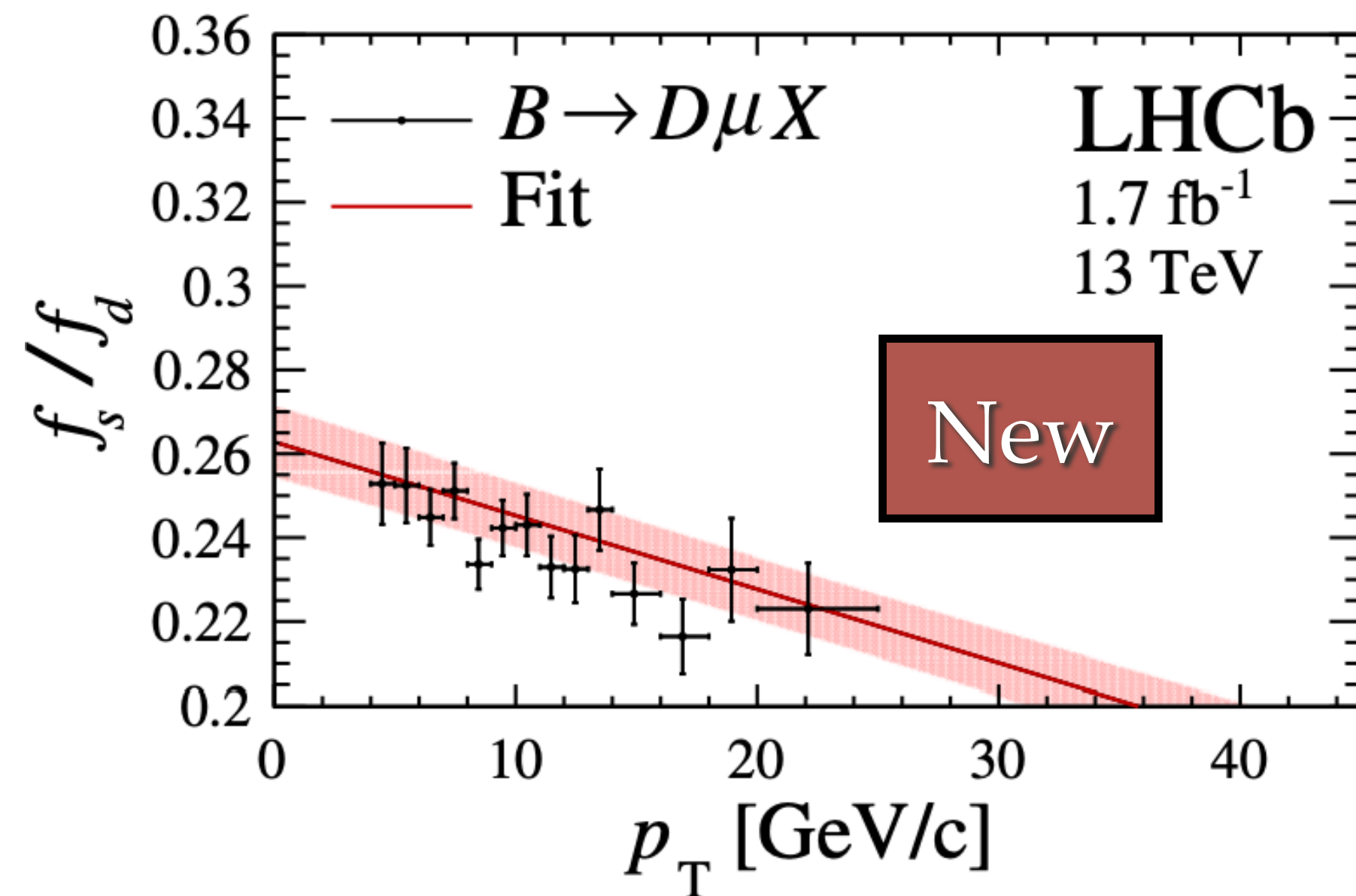
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$$\frac{f_s}{f_d} \propto \frac{n_{corr}(B_s^0 \rightarrow Y)}{n_{corr}(B^0 \rightarrow Z)}$$

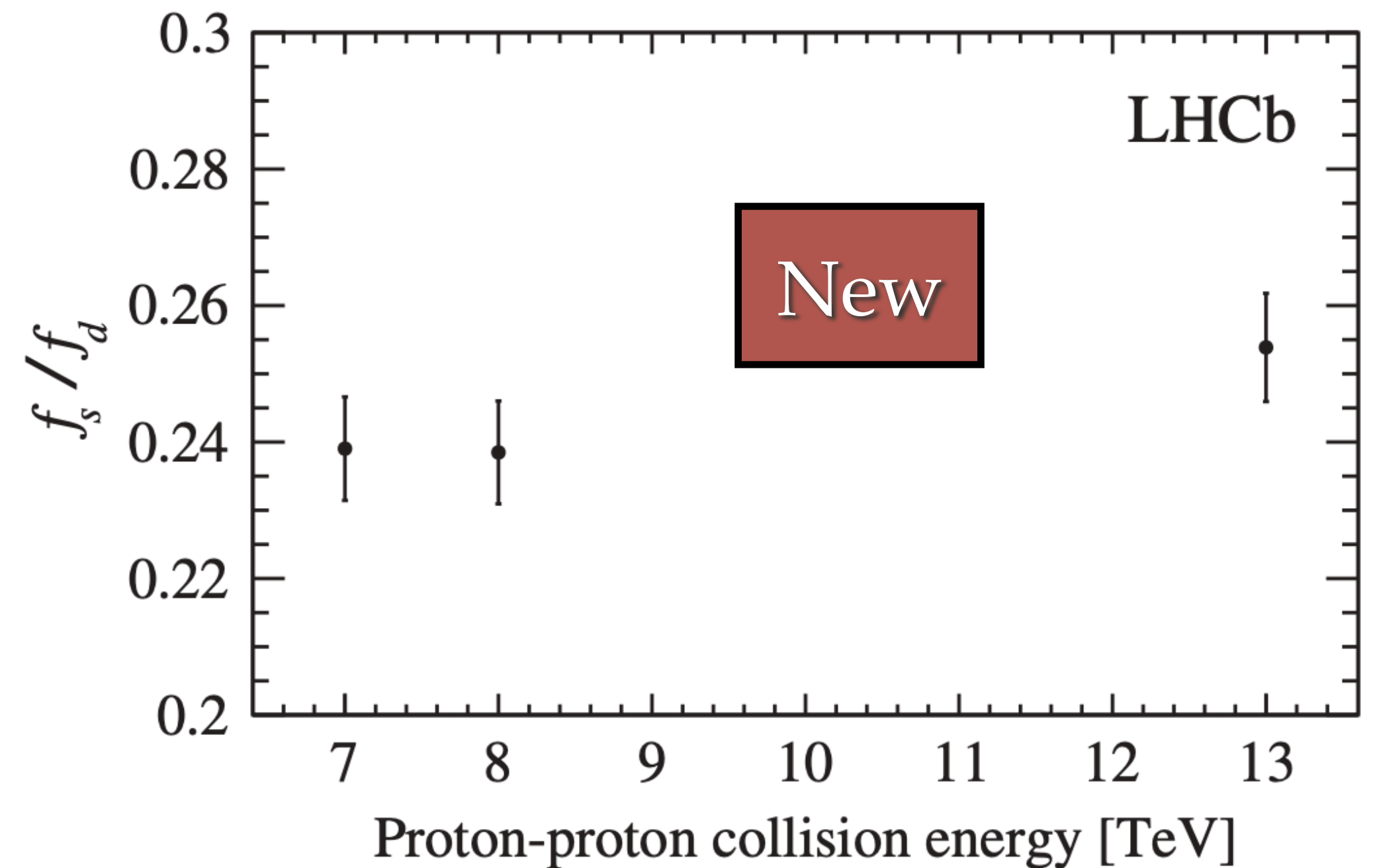
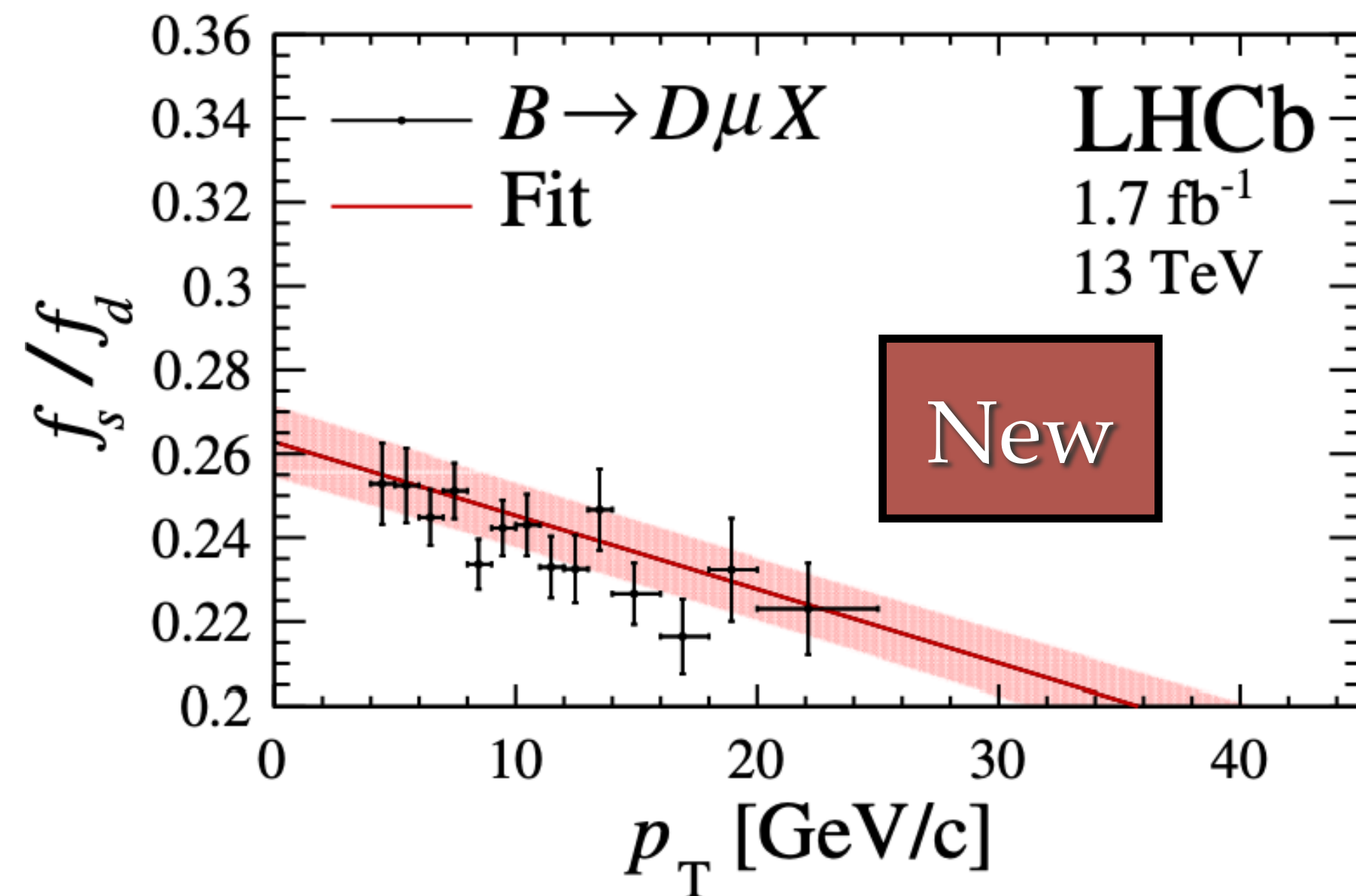


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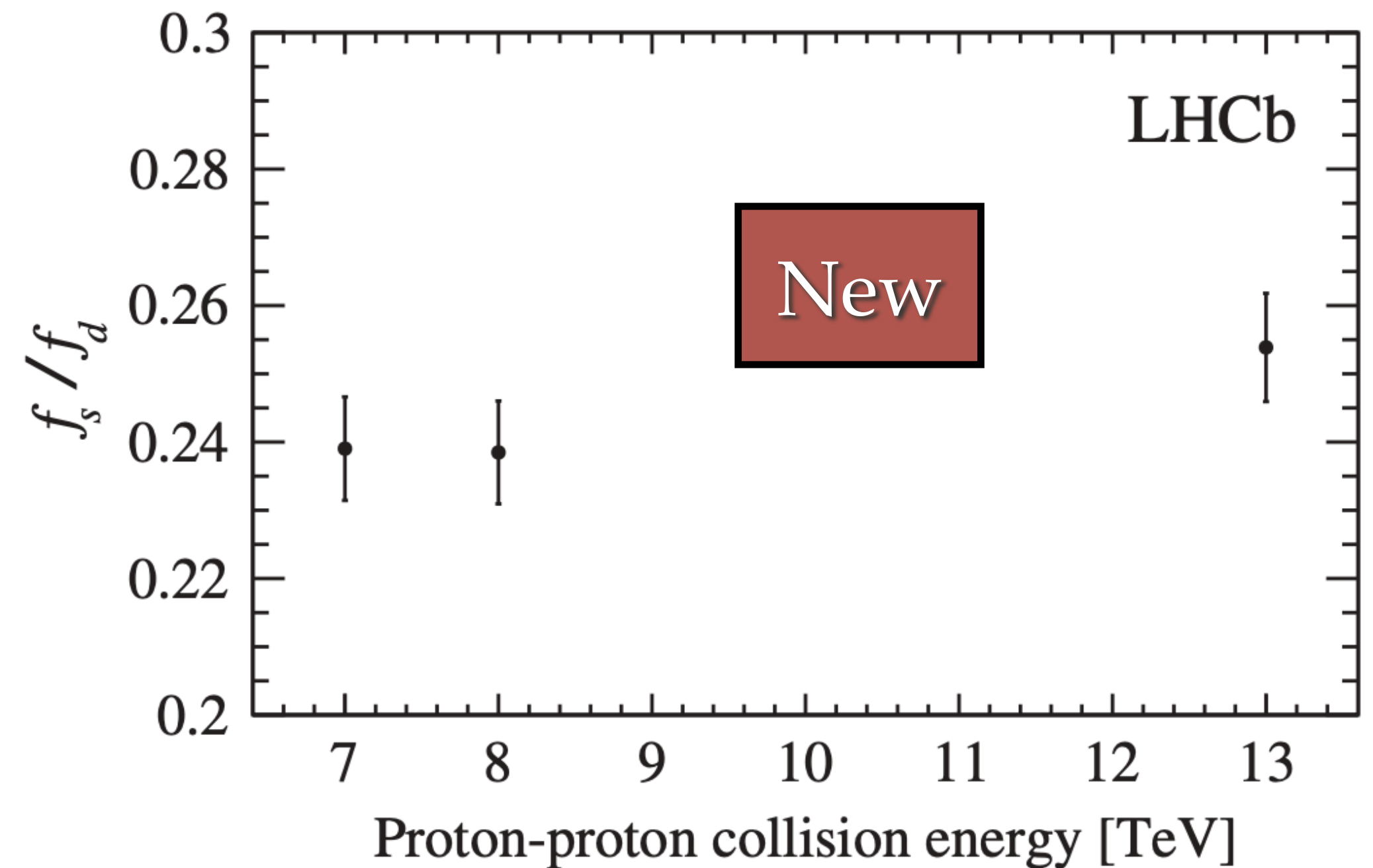
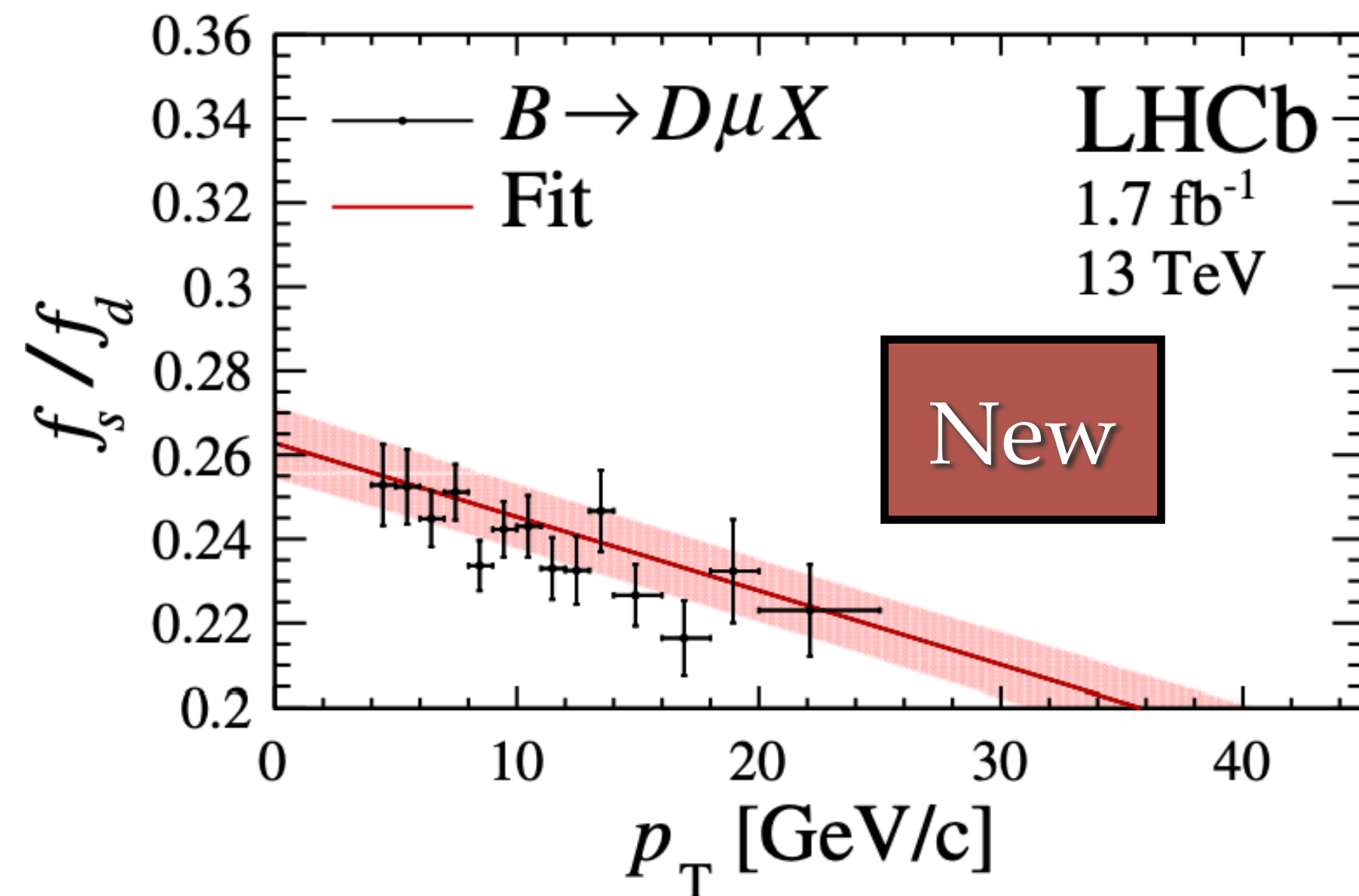


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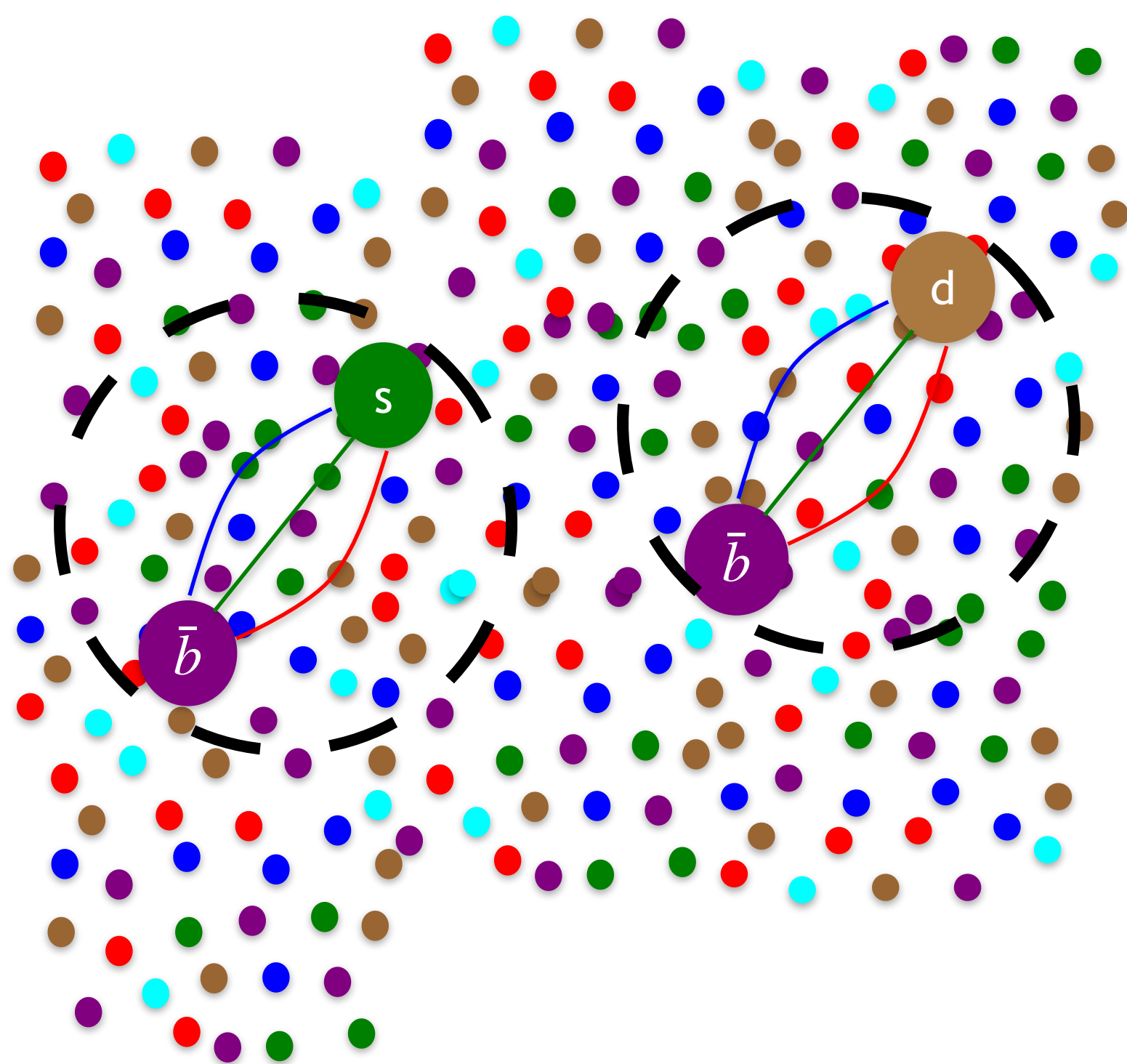


- New paper combined six different decay channels.
- f_s/f_d is observed to **depend on the B meson transverse momentum**.
- No dependence on the collision energy.

B_s^0/B^0 production versus multiplicity in pp@13TeV

[LHCB-PAPER-2022-001](#)

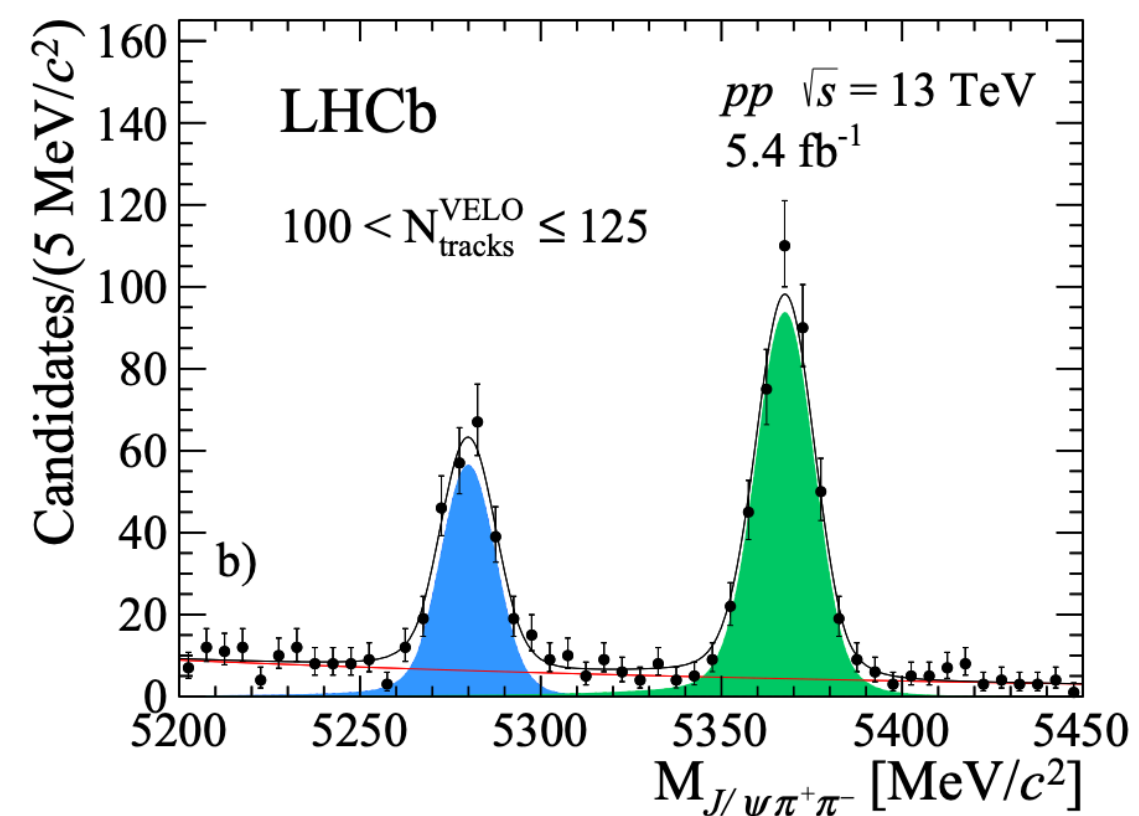
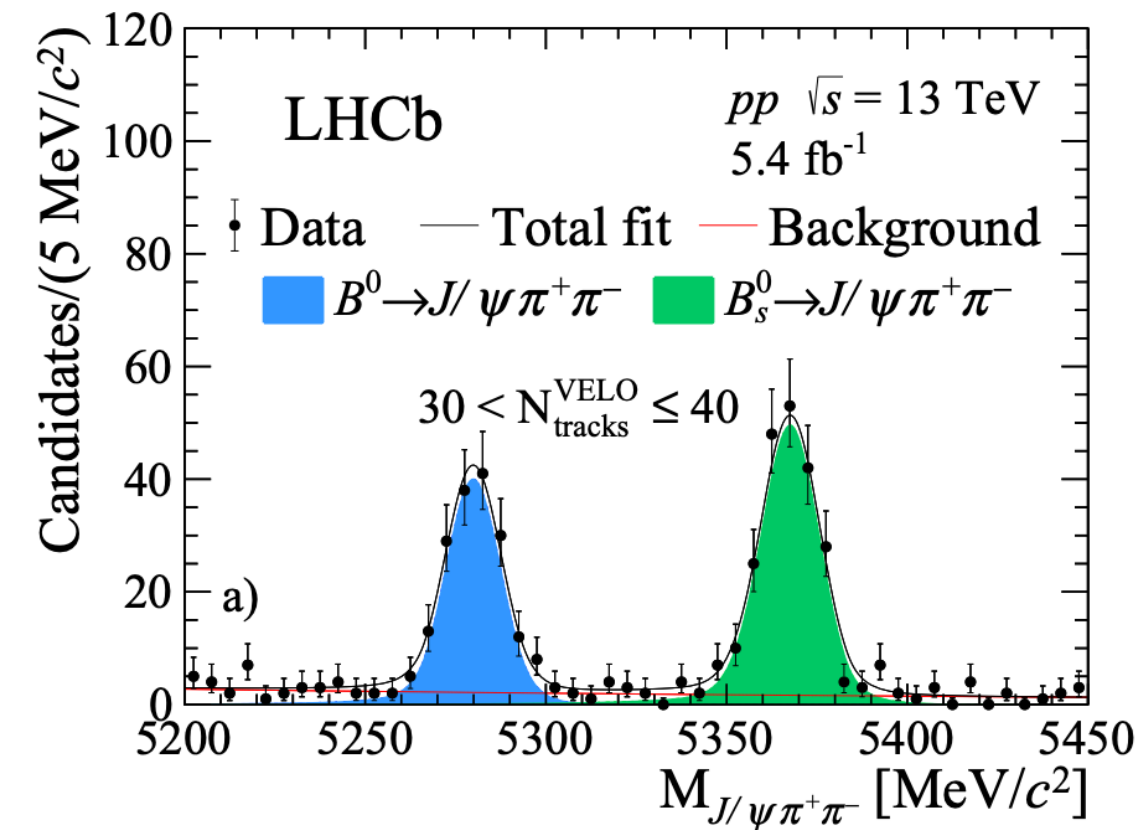
- $\frac{B_s^0}{B^0}$ versus multiplicity:
 - *Probe for local medium strangeness density via coalescence?*
 - *Sensitive to multiplicity?*



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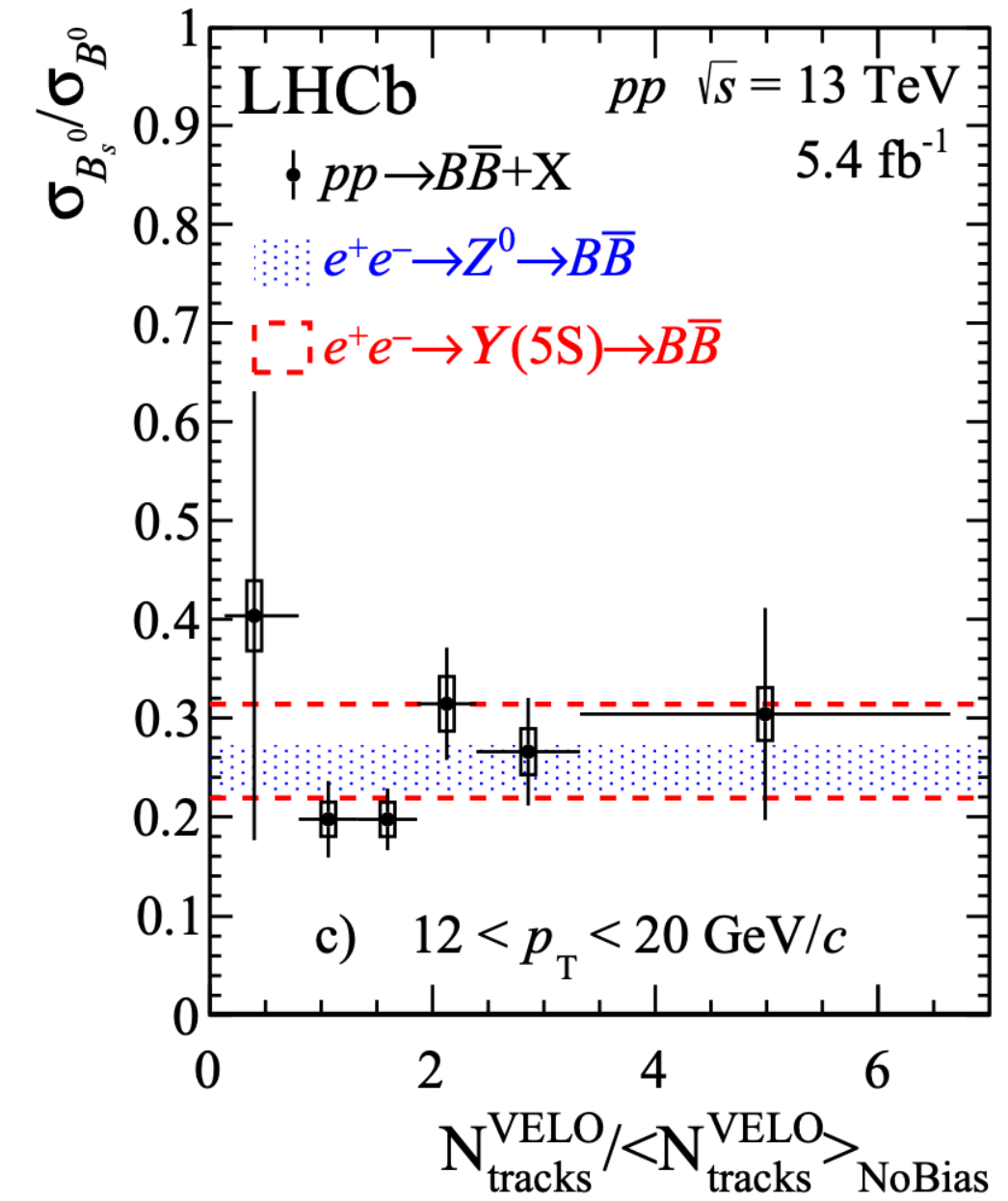
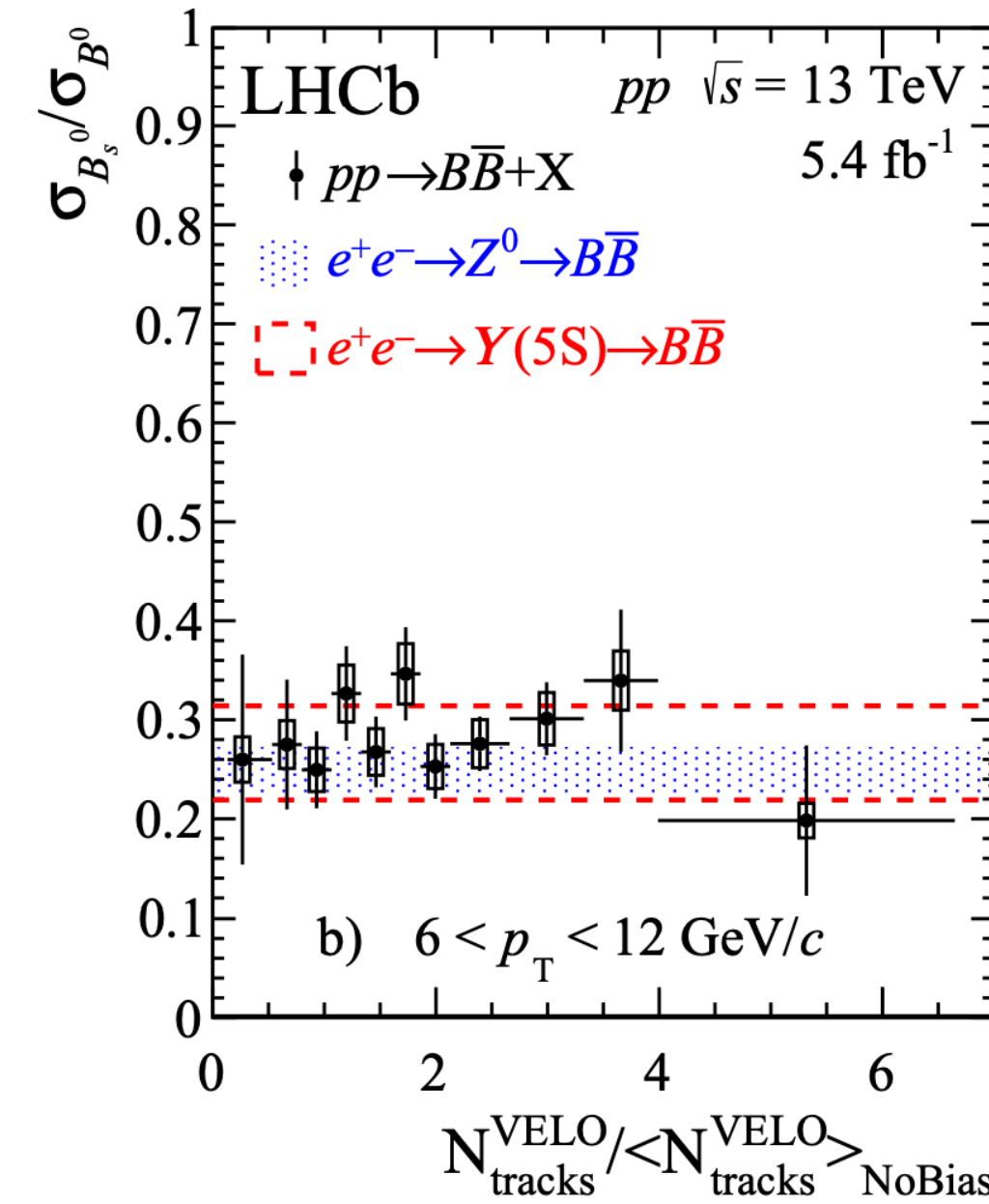
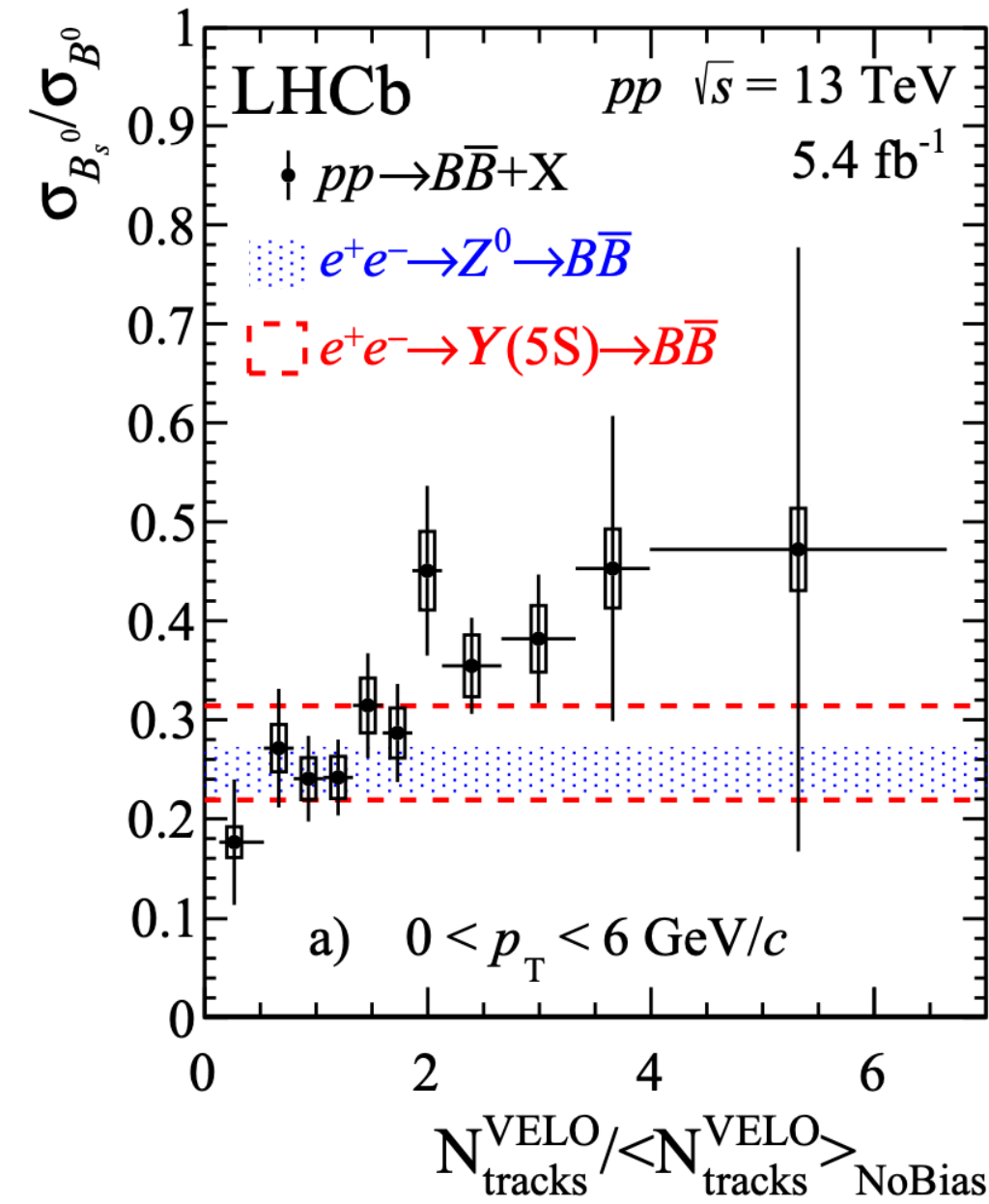
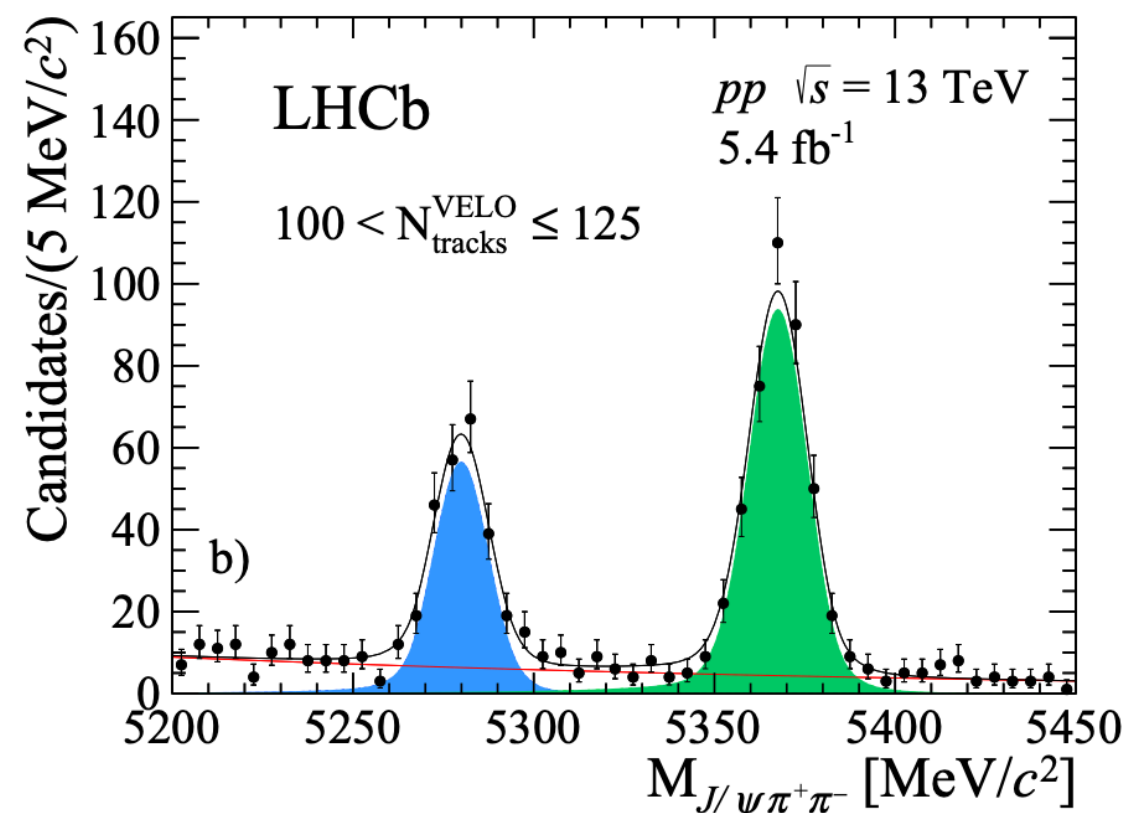
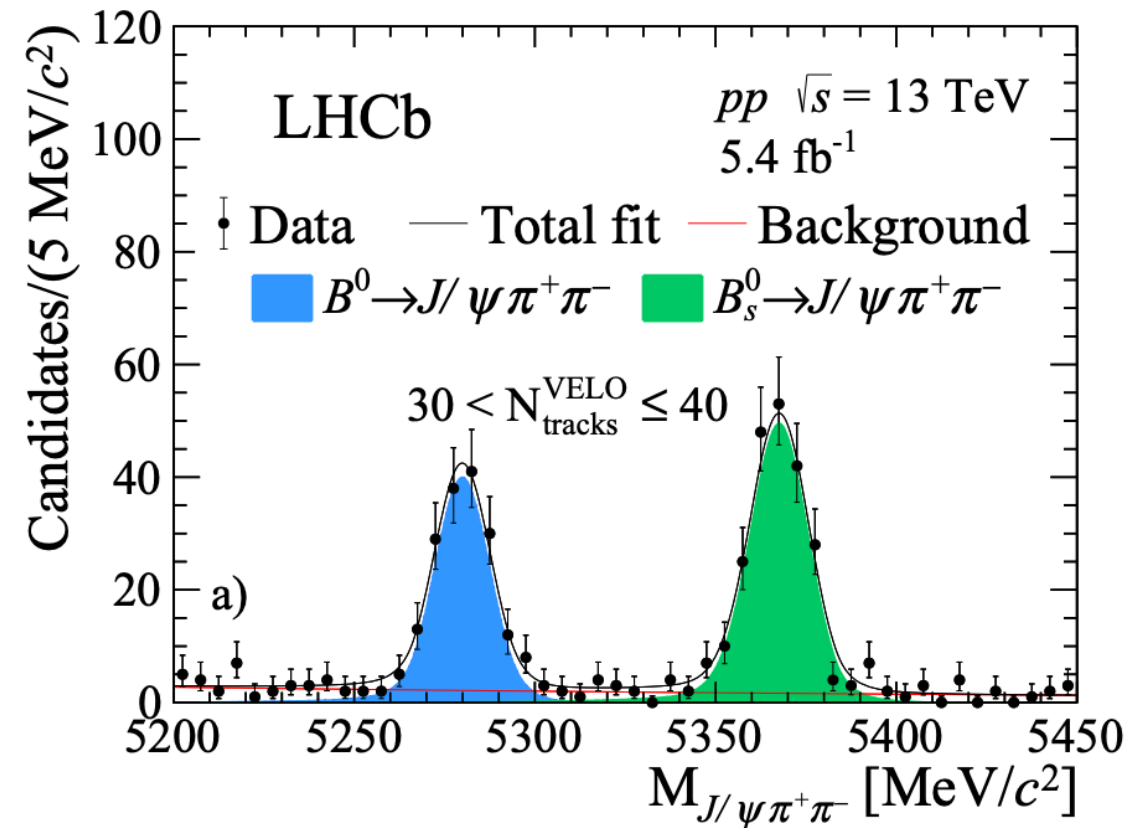
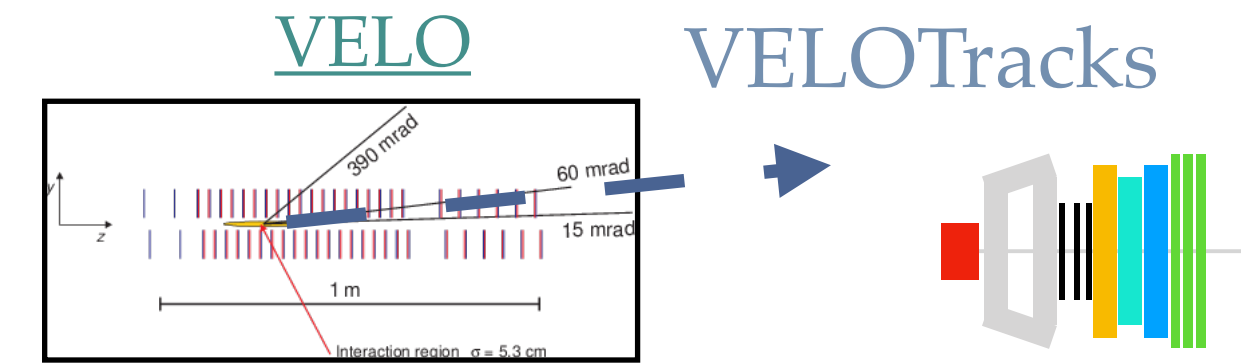


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LHCB-PAPER-2022-001

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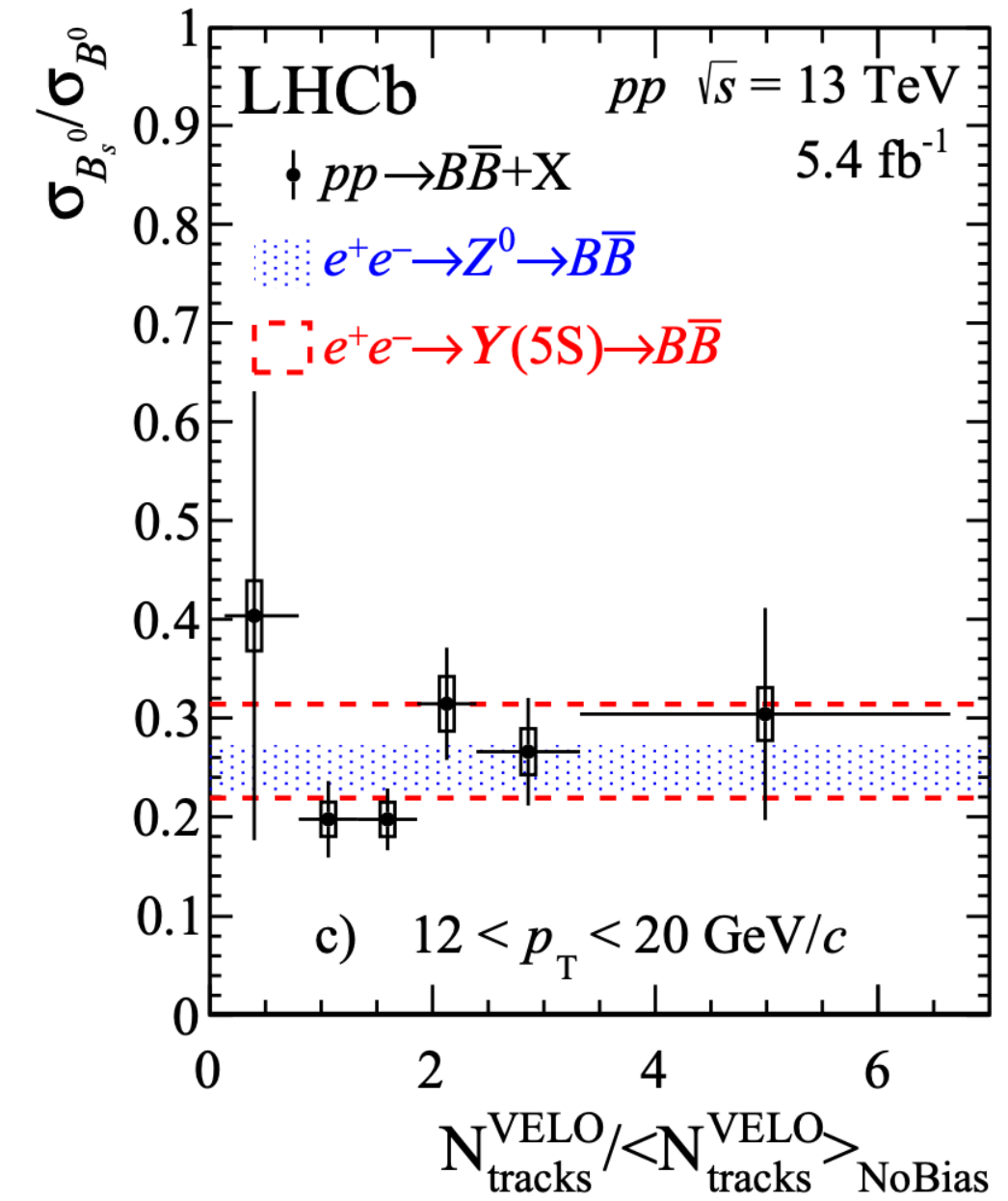
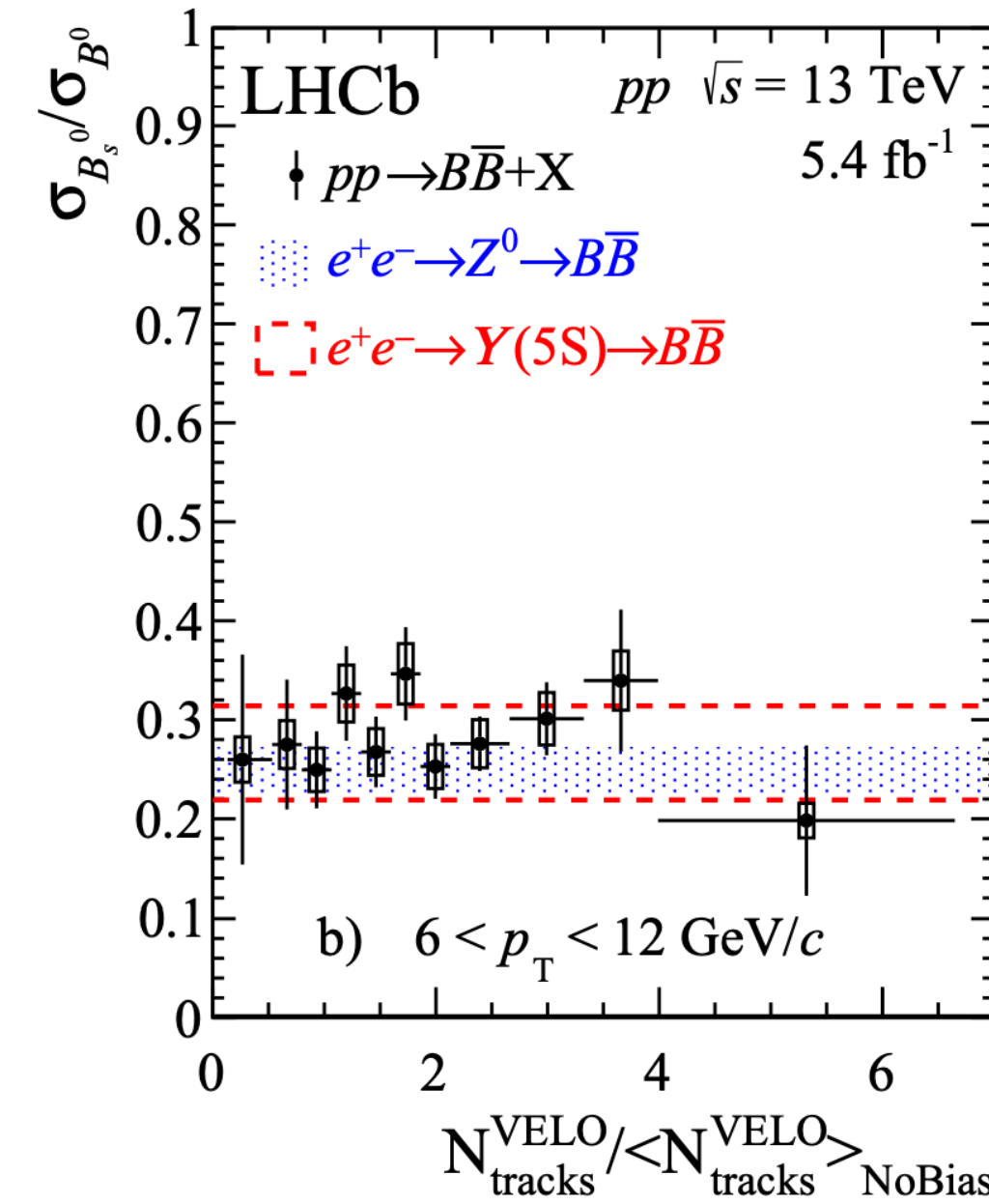
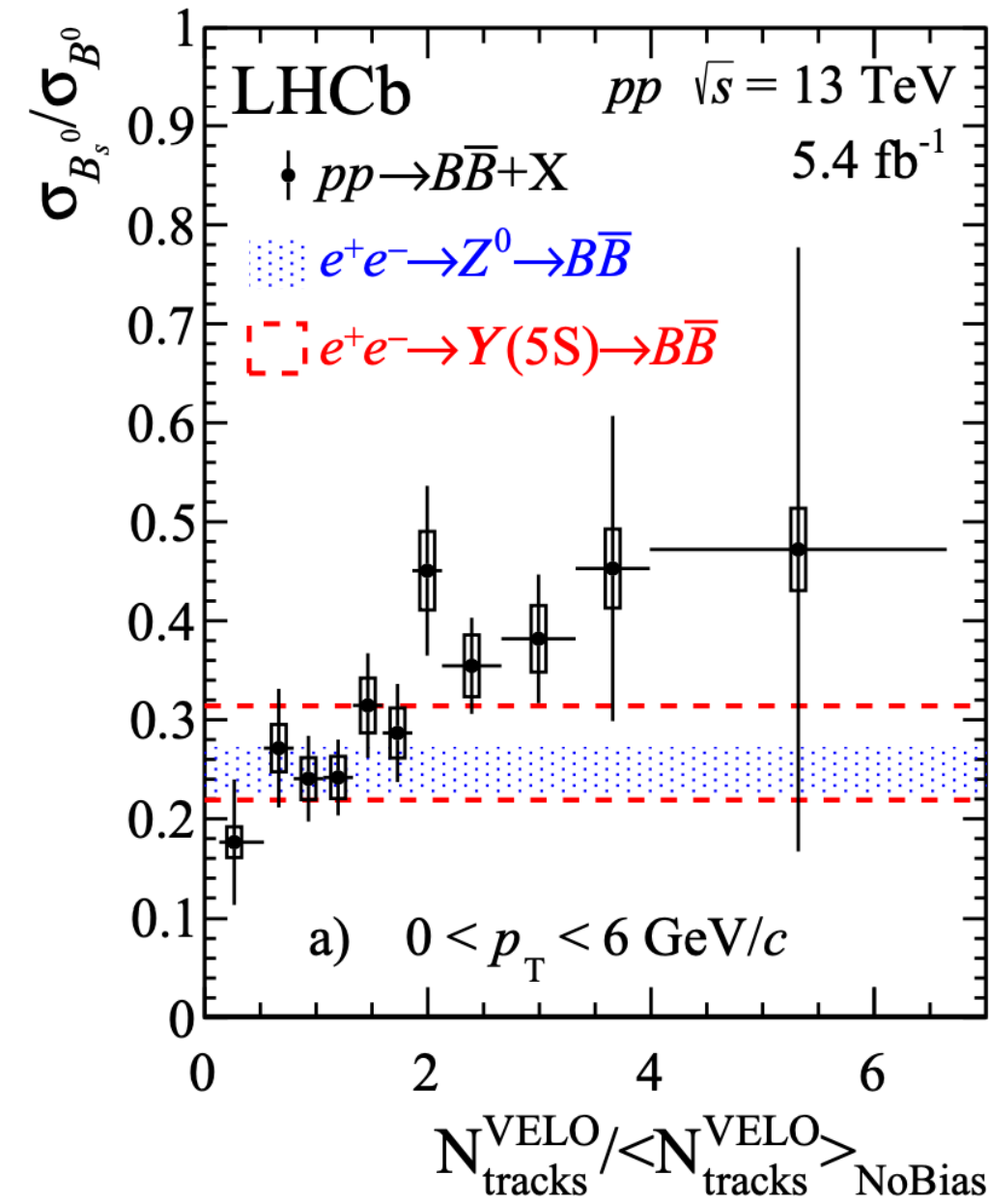
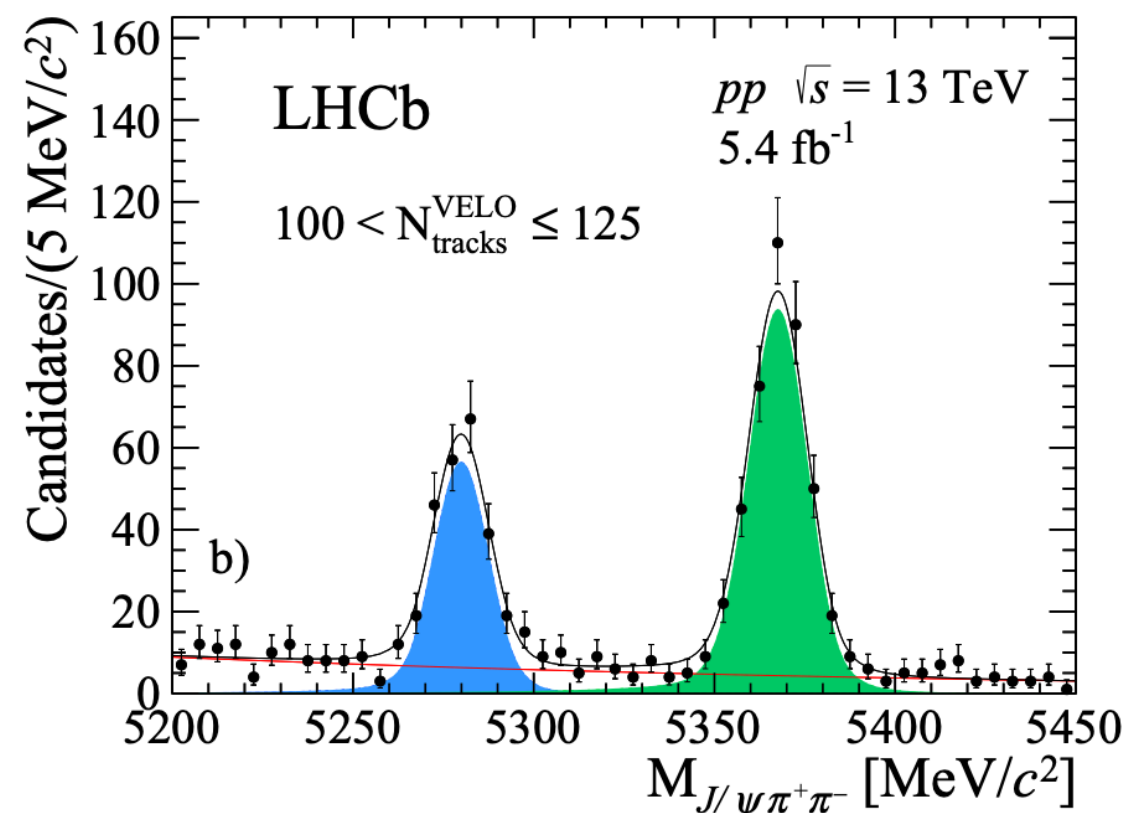
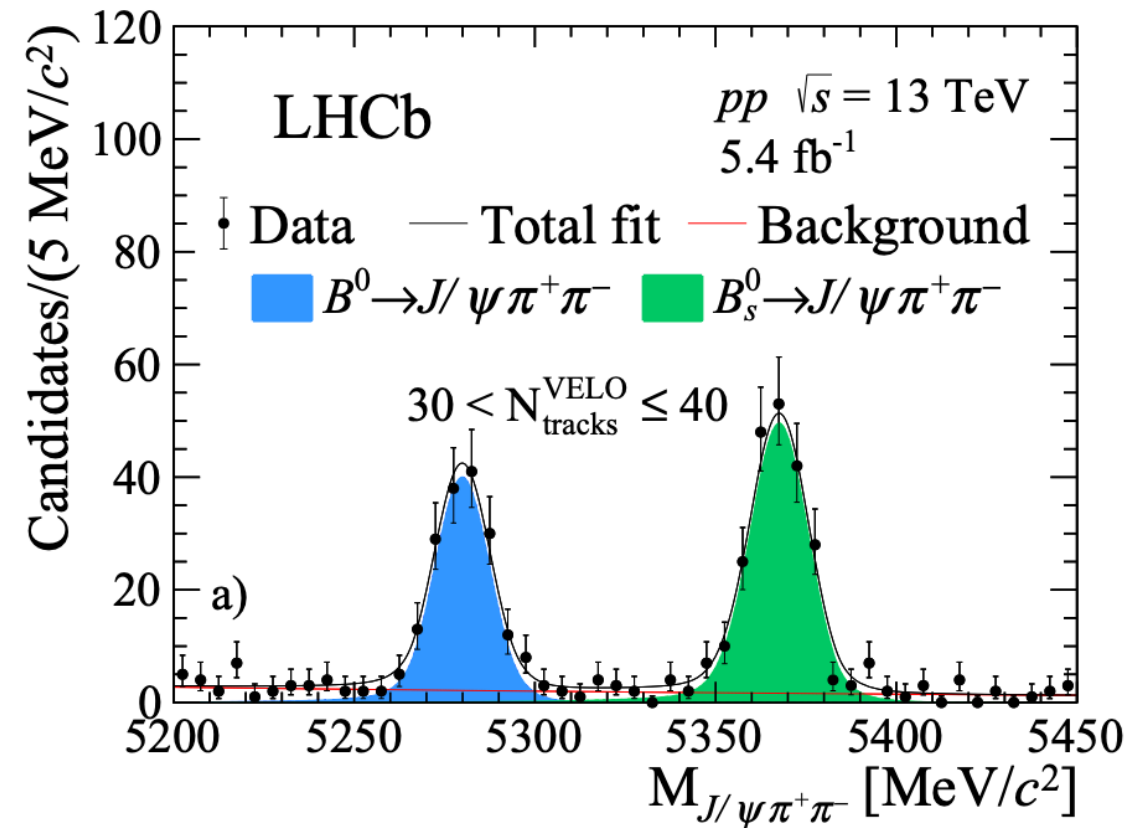
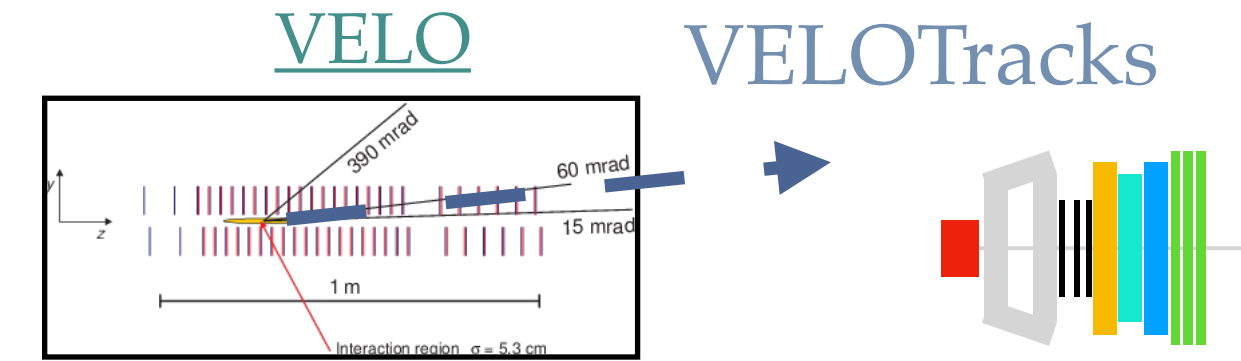


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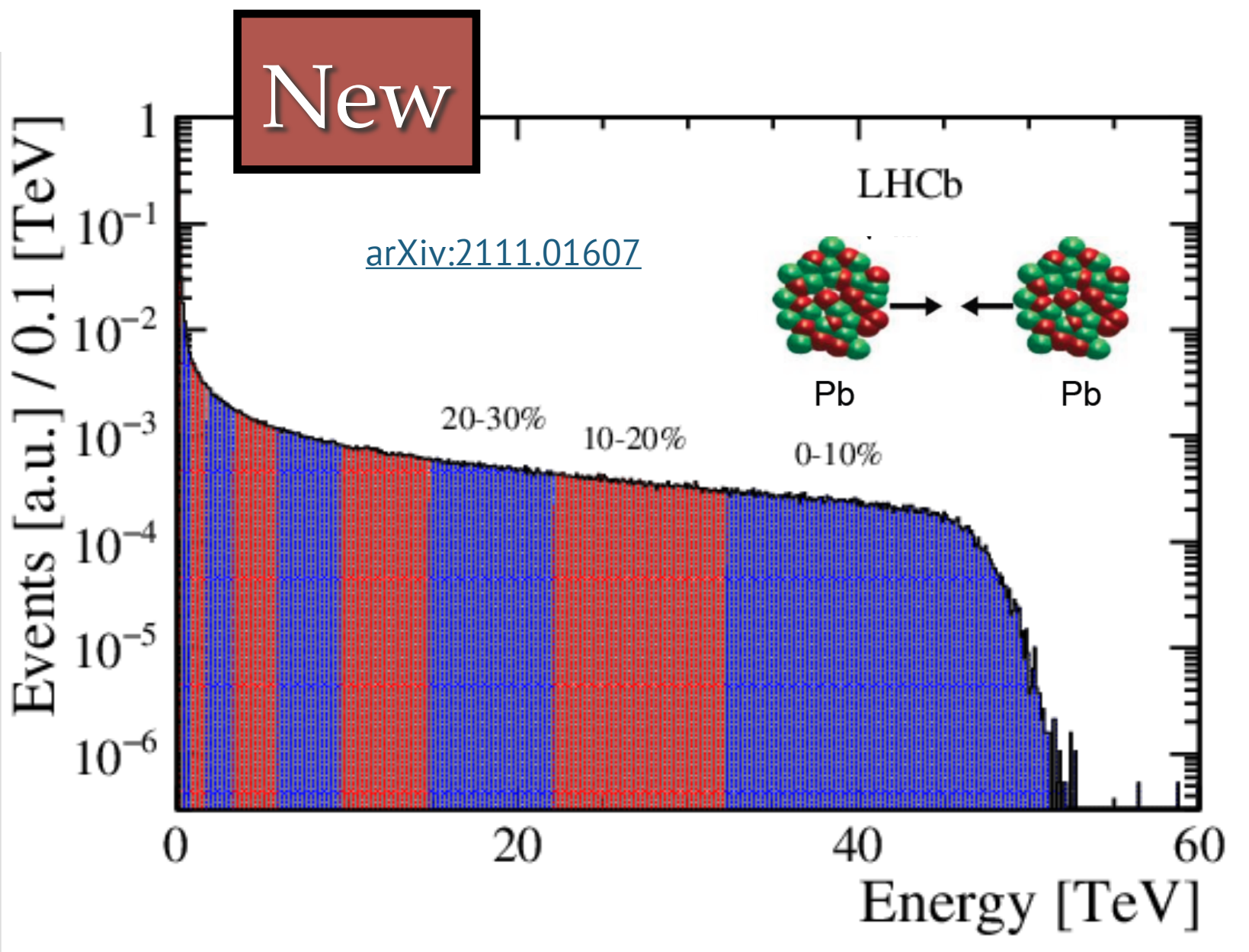
LHCB-PAPER-2022-001

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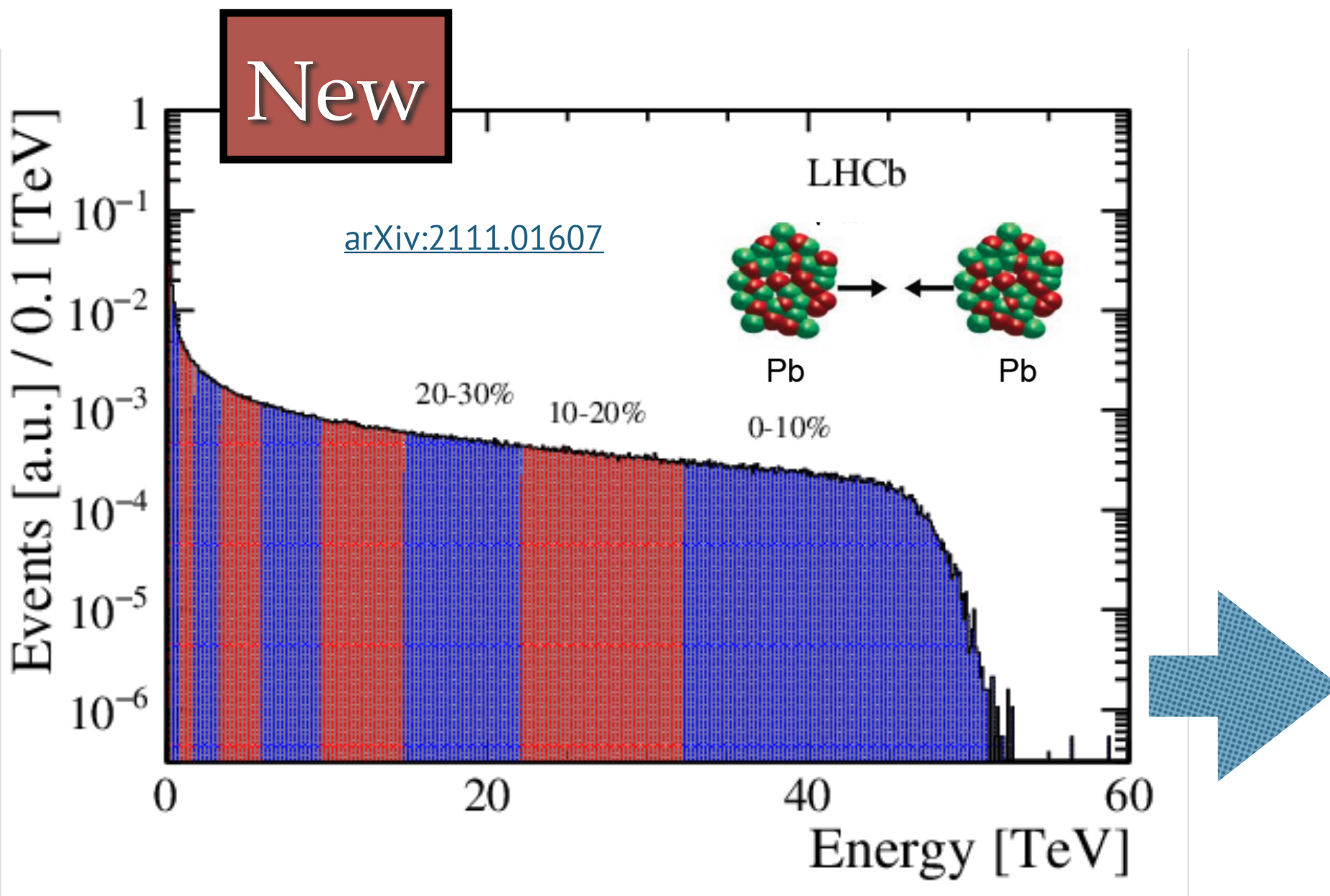
- Increase of B_s^0/B^0 with multiplicity at low- p_T (slope significance = 3.4 sigma).
- No significant dependence on multiplicity at high- p_T , consistent with e^+e^- data.

Λ_c^+ -to- D^0 ratio in peripheral PbPb collisions



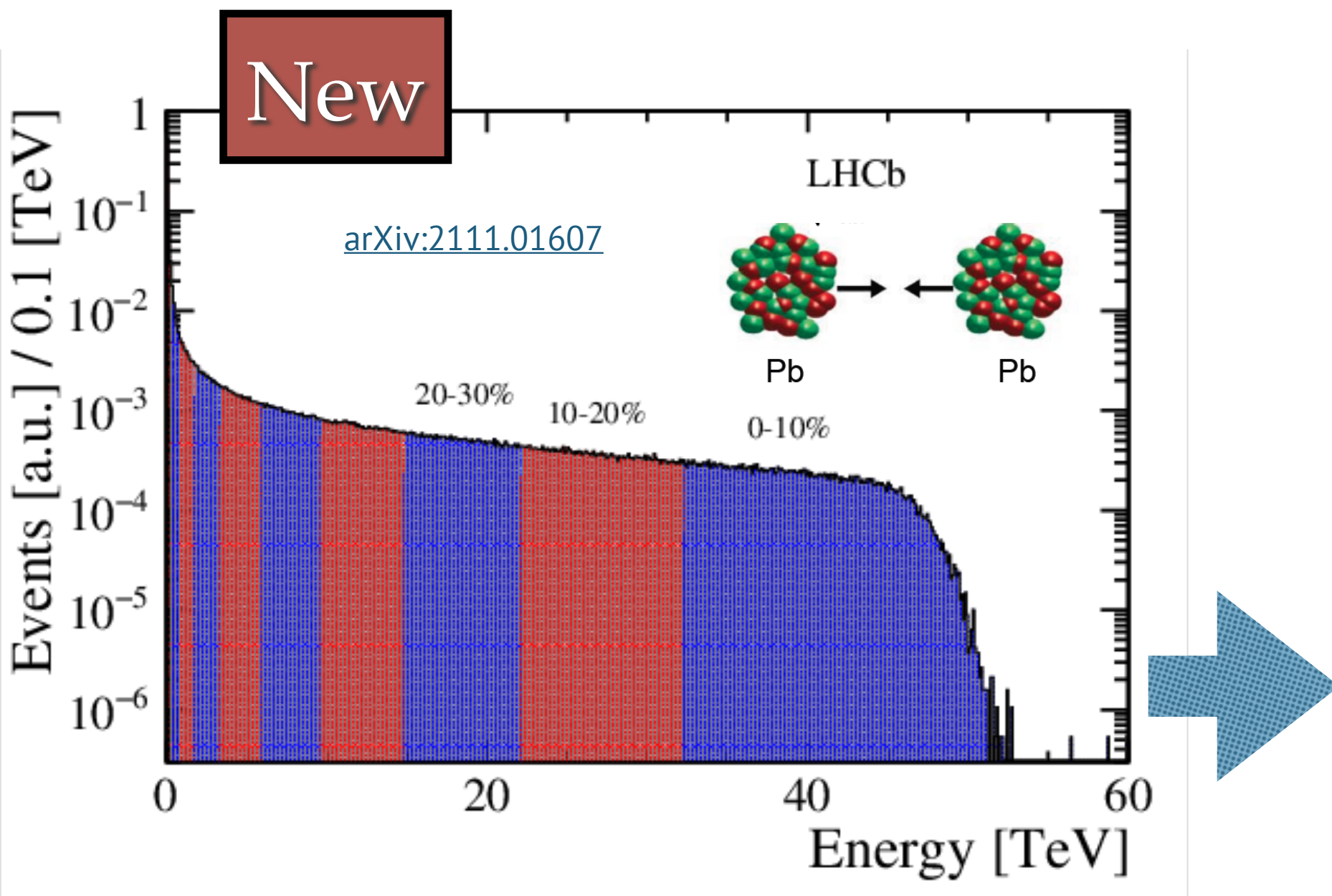
- Centrality measured in 2018 PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.
- Up to 60% centrality reached in hadronic collisions !

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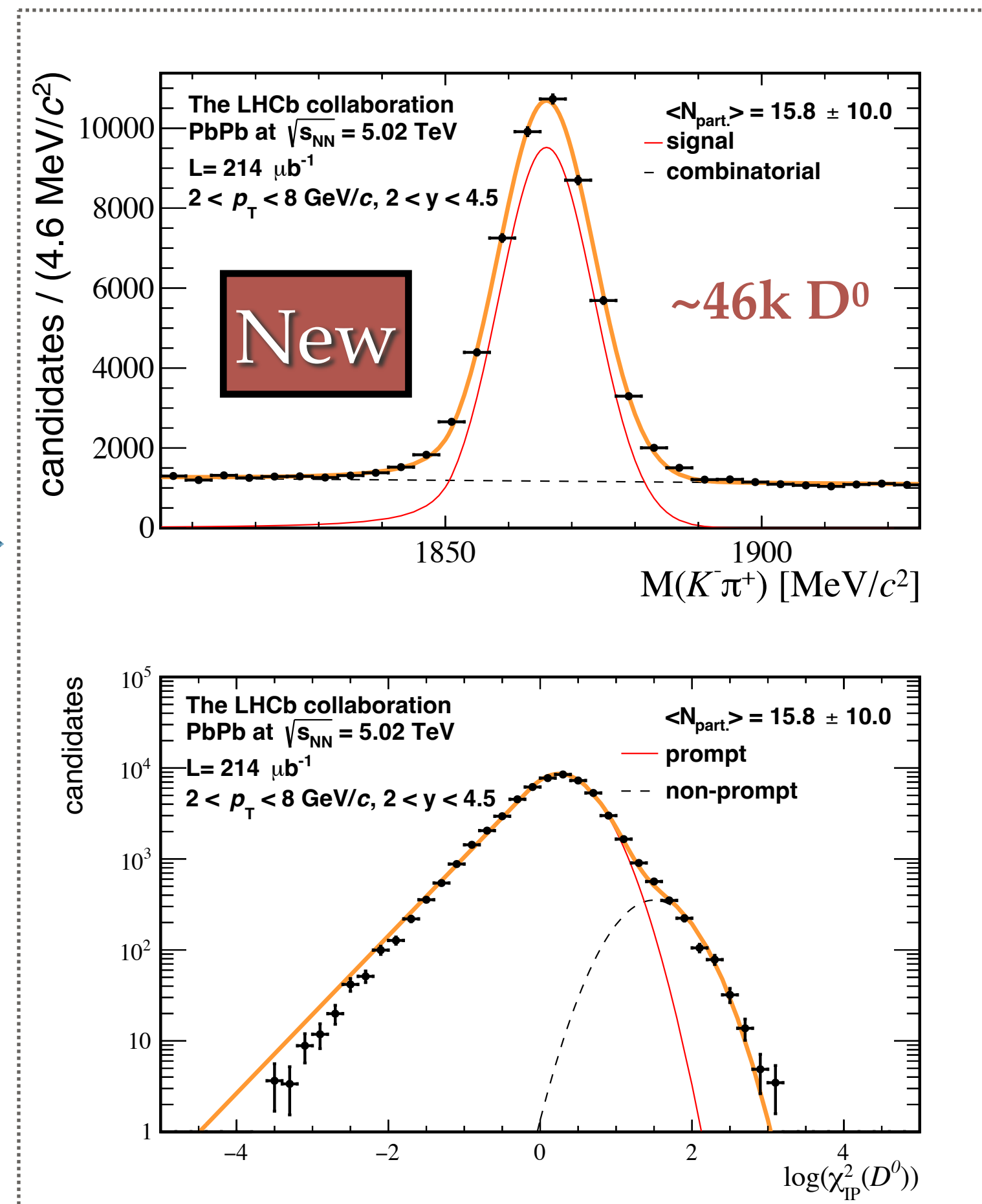


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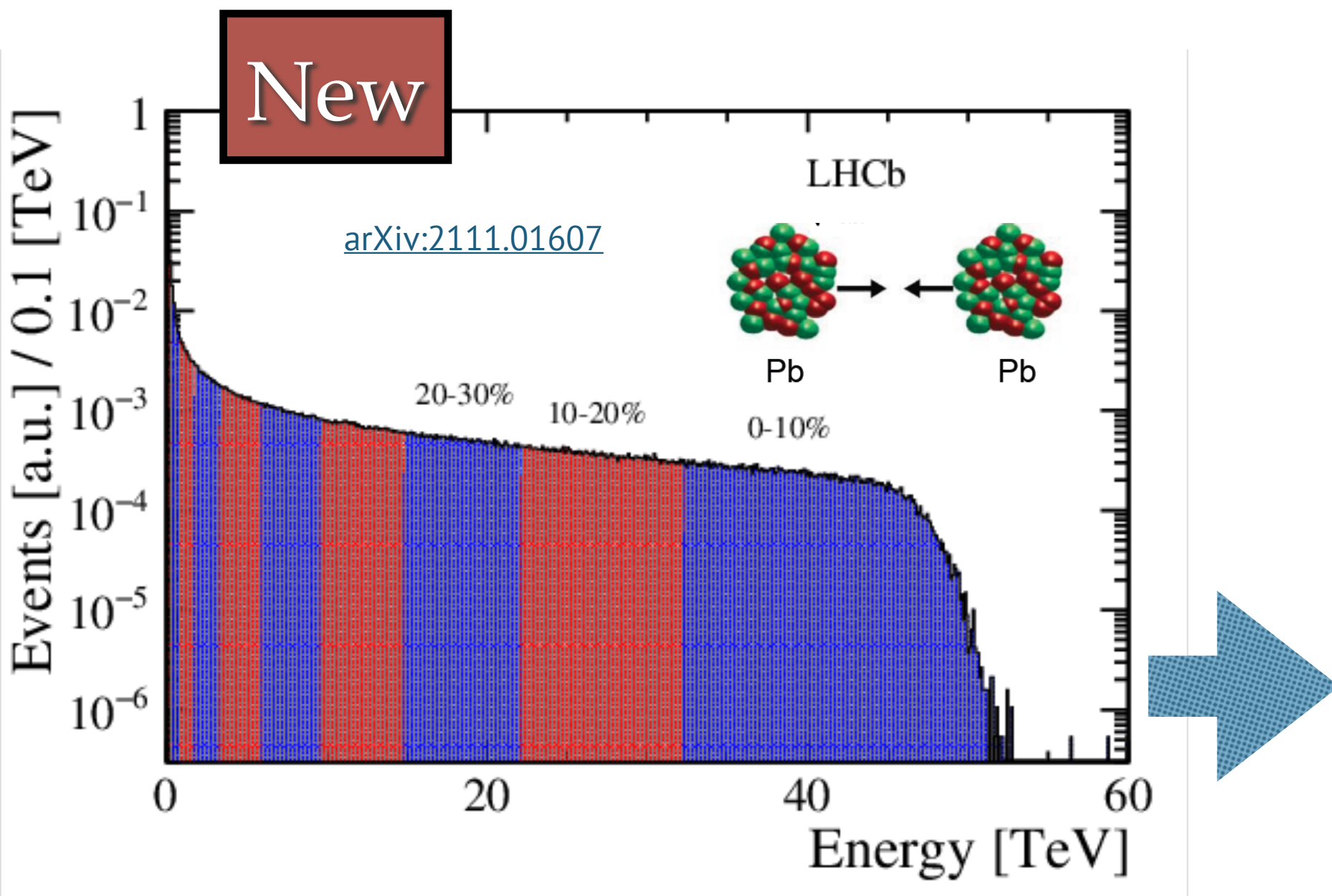


Simultaneous fit

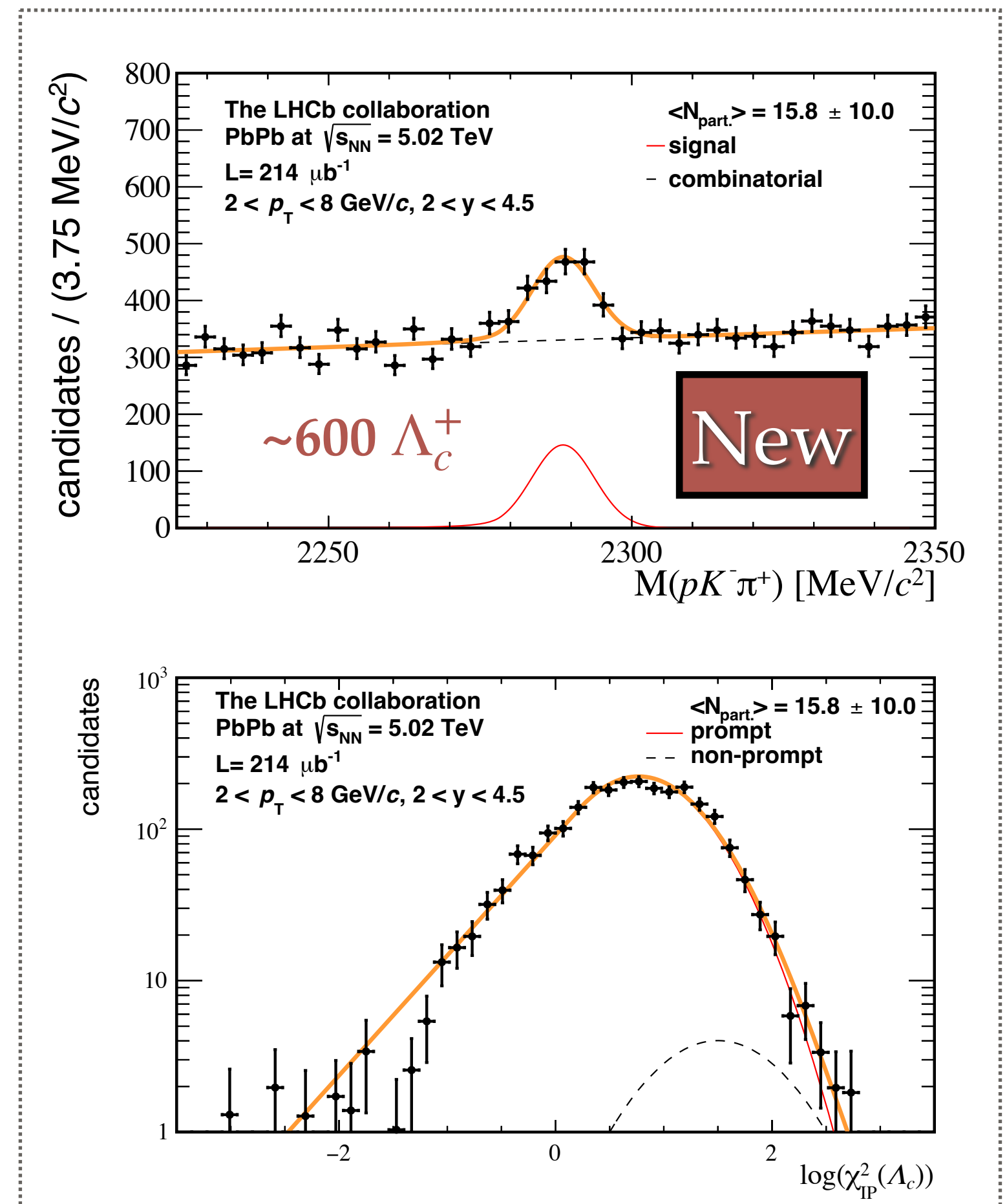
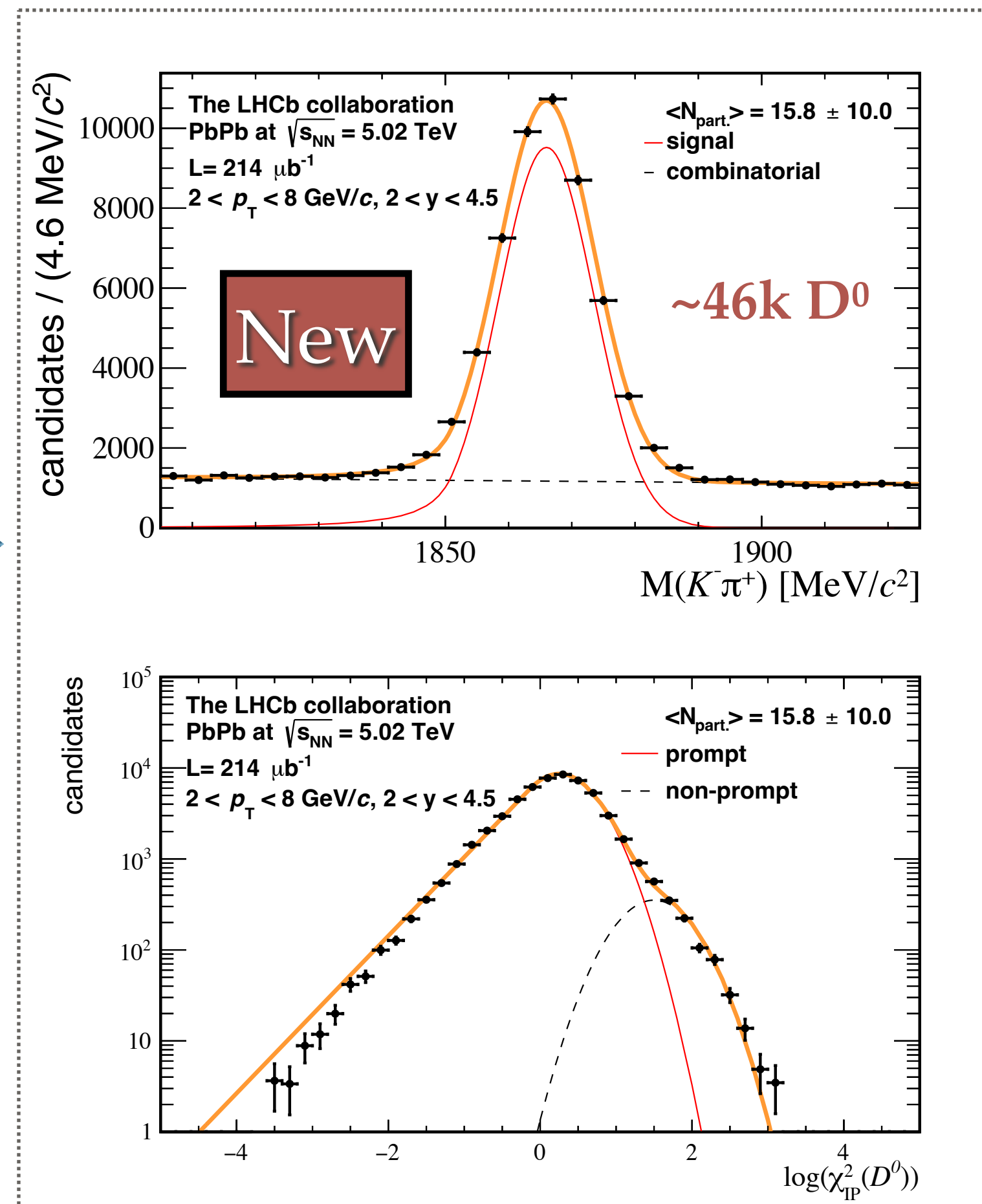


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New

Λ_c^+ -to- D^0 ratio in peripheral PbPb collisions

[LHCB-PAPER-2021-046](#)

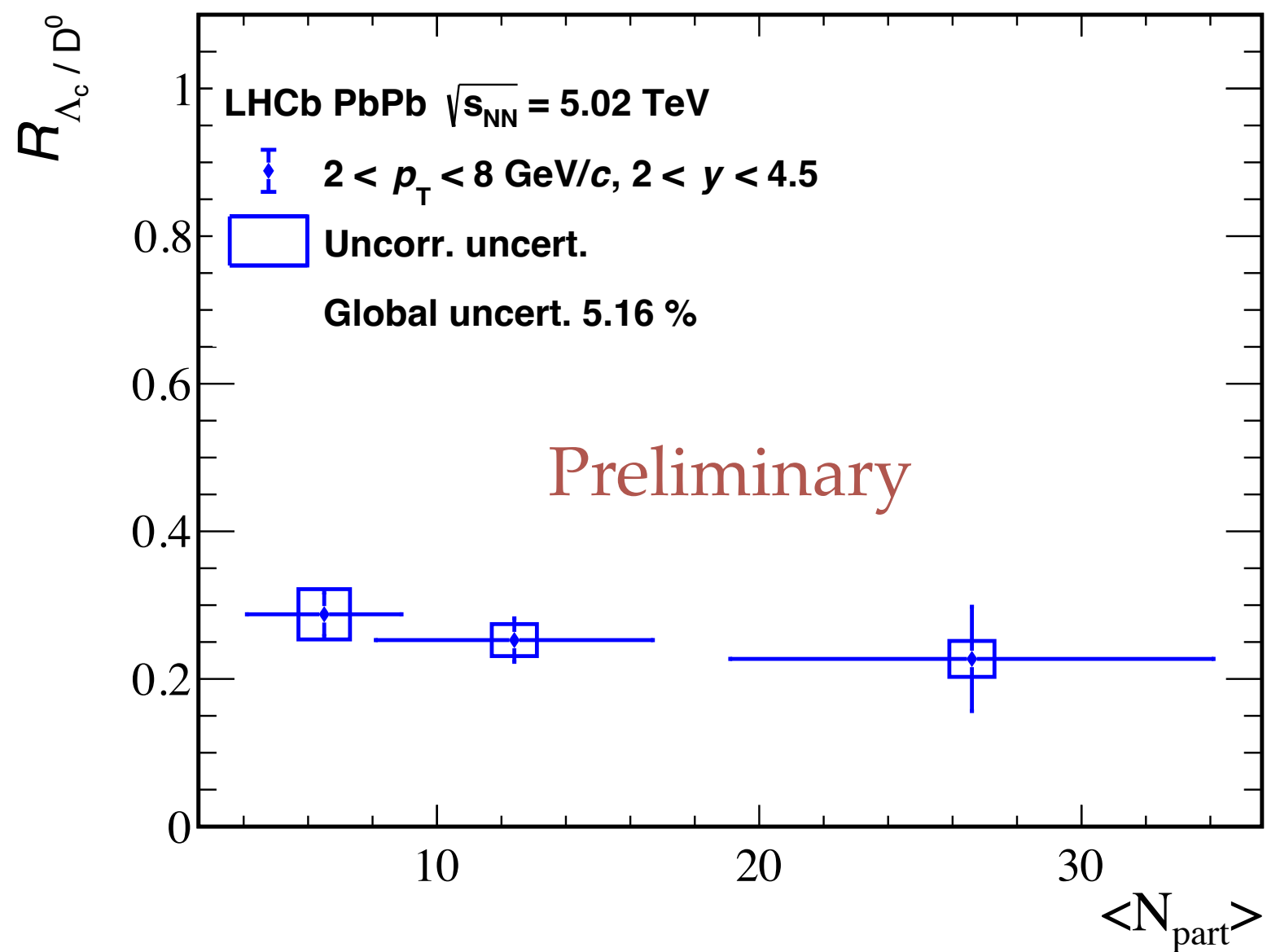
First Λ_c^+ -to- D^0 production ratio measured in peripheral PbPb collisions at forward rapidity.



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LHCB-PAPER-2021-046

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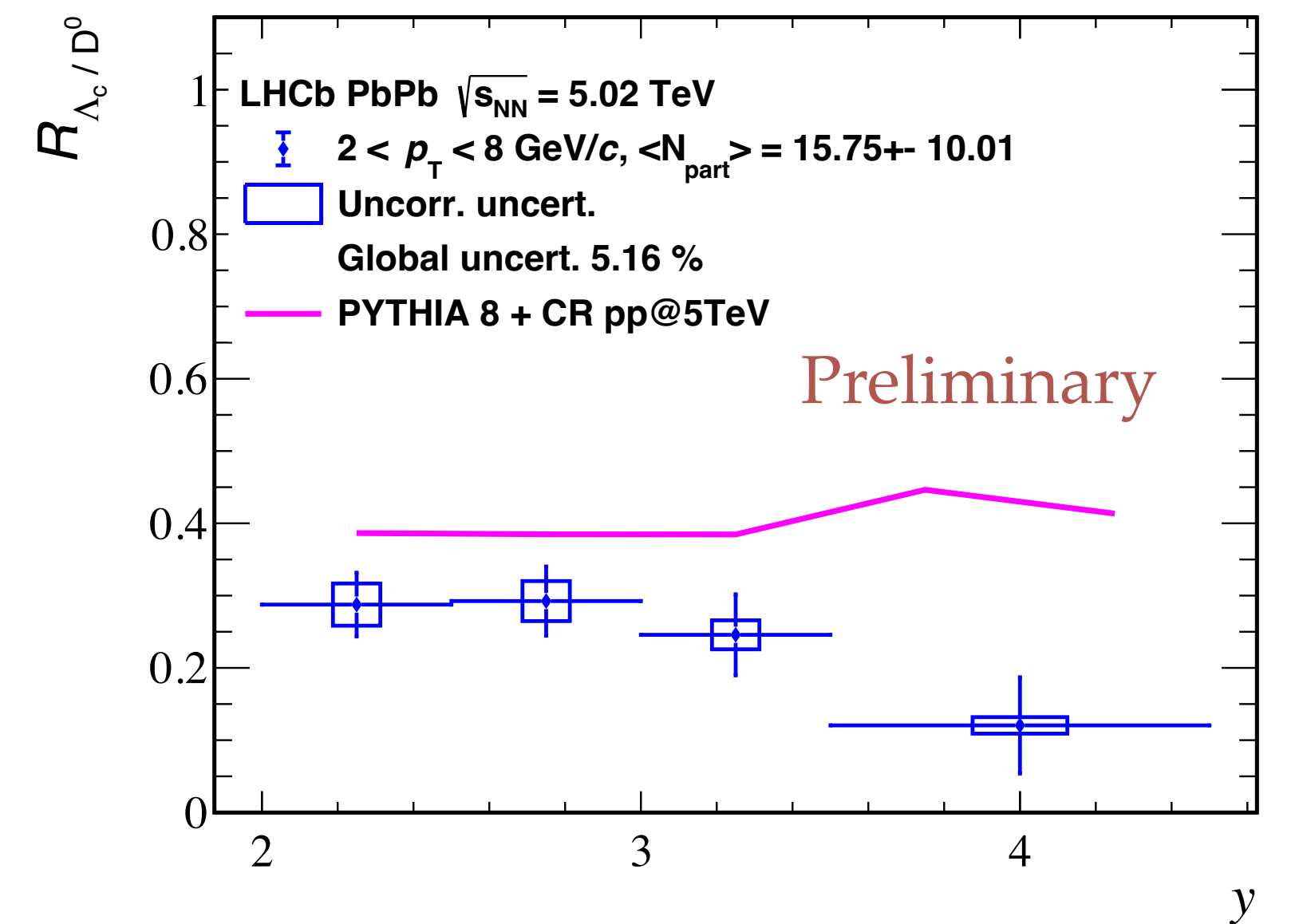
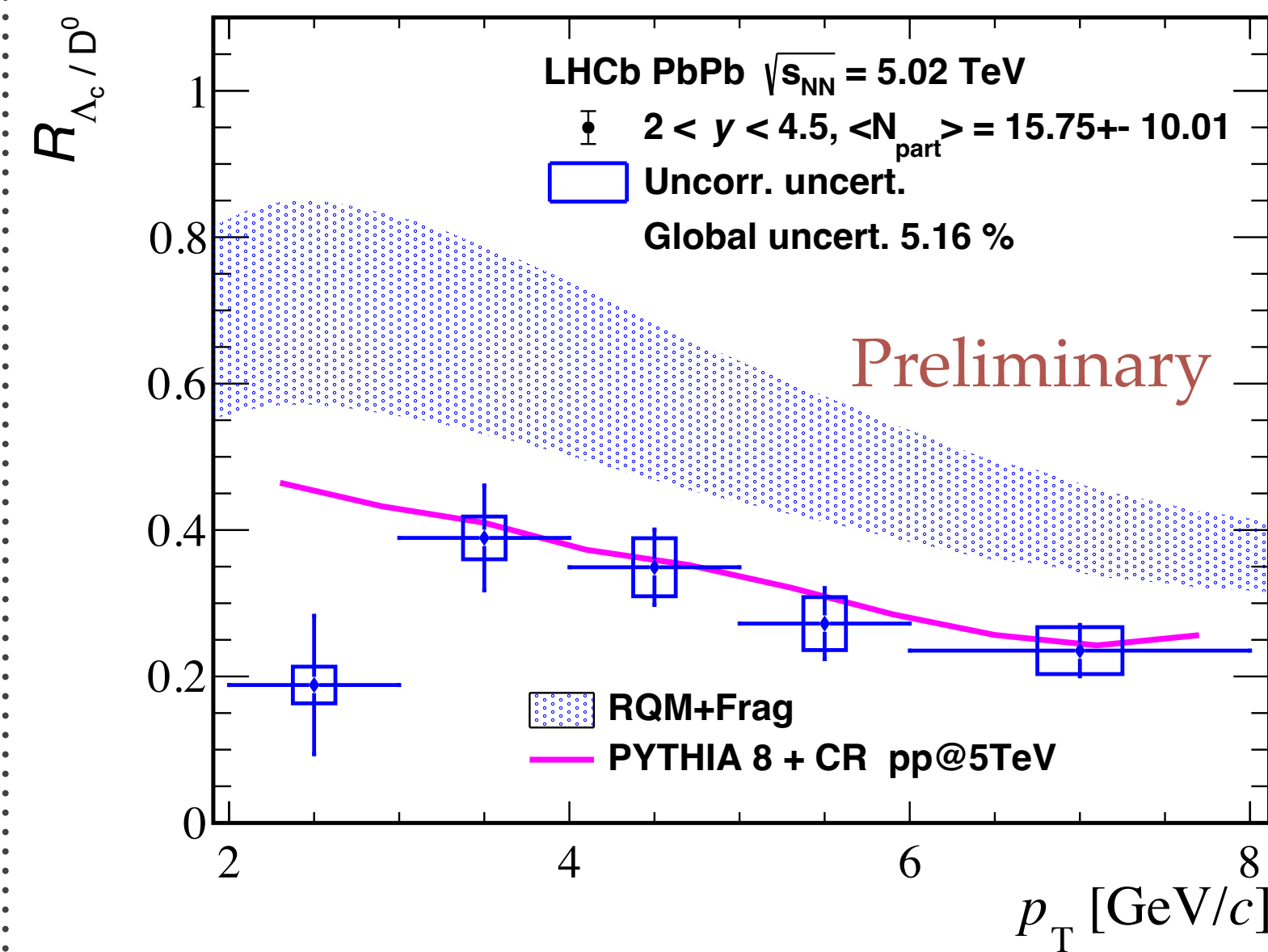
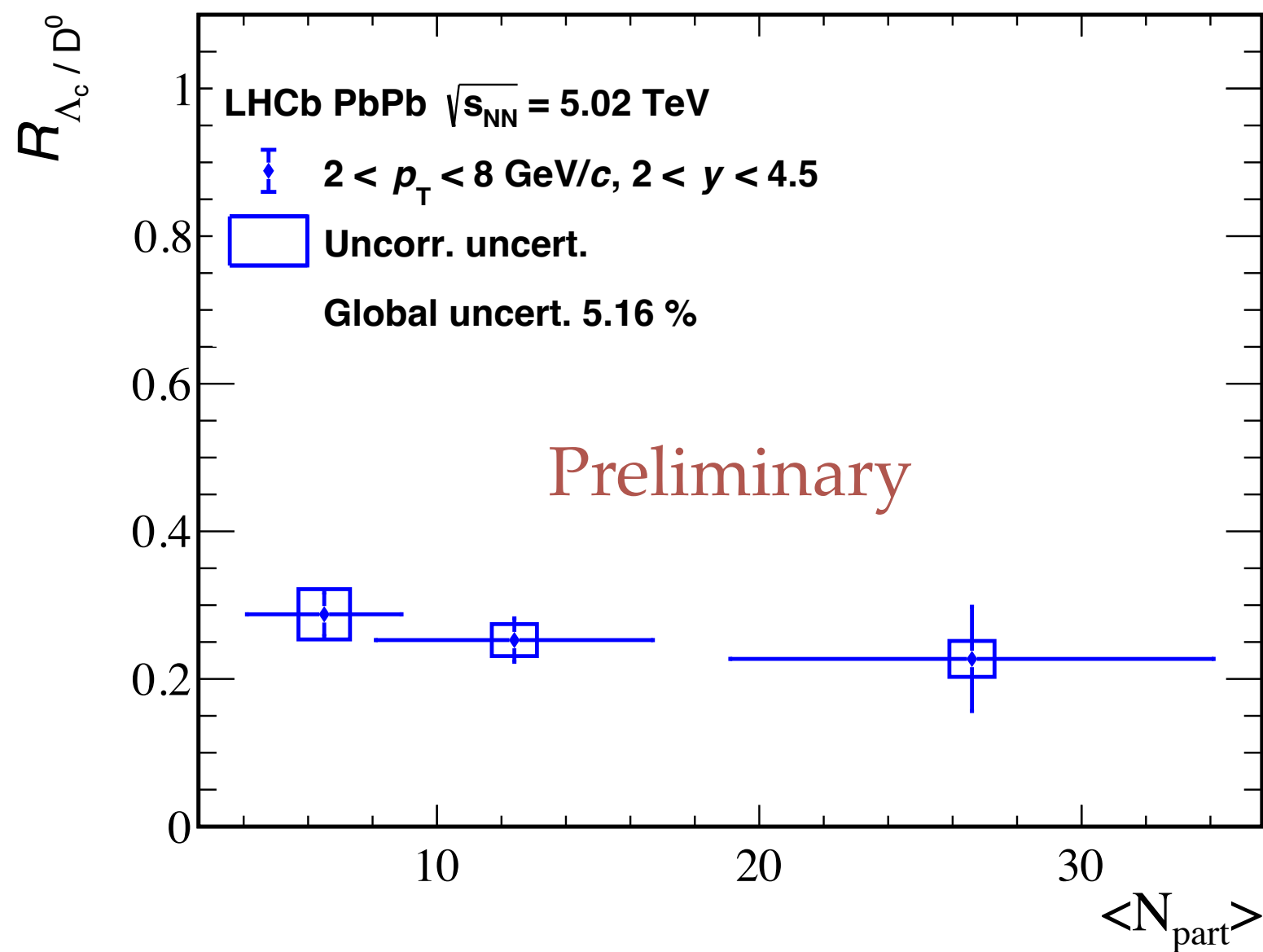


- Flat dependence versus $\langle N_{part} \rangle$.
- $\langle R_{\Lambda_c^+/D^0} \rangle \sim 0.27$

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LHCB-PAPER-2021-046

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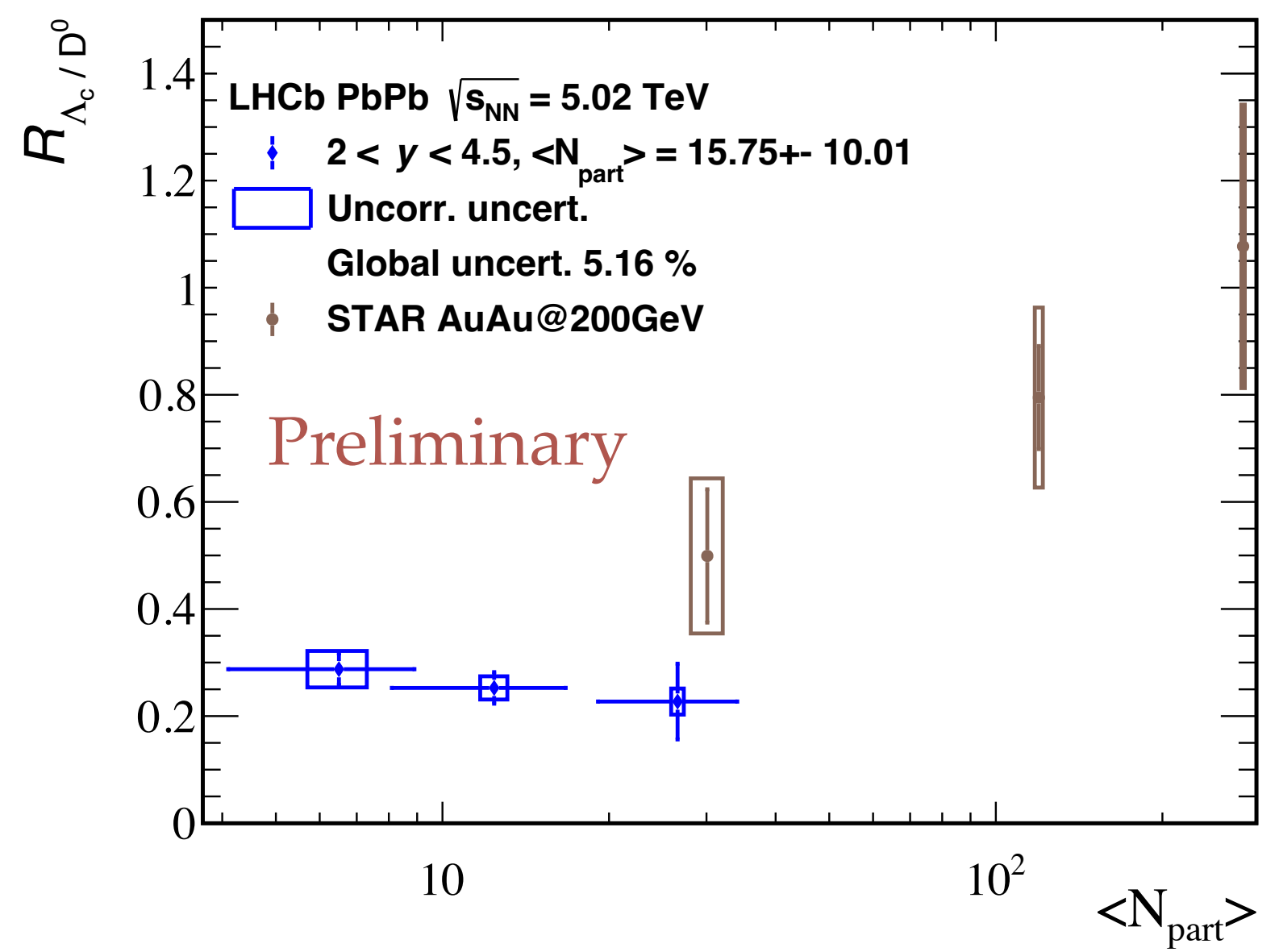
- p_T dependence compatible with a relative enhancement at intermediate p_T .
- Compatible with flat rapidity dependence.
- Comparison to theory predictions:
 - PYTHIA 8 + Colour Reconnection: compatible with data within 3σ .
 - Standard Hadronization Model do not reproduce the data.

New

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LHCB-PAPER-2021-046

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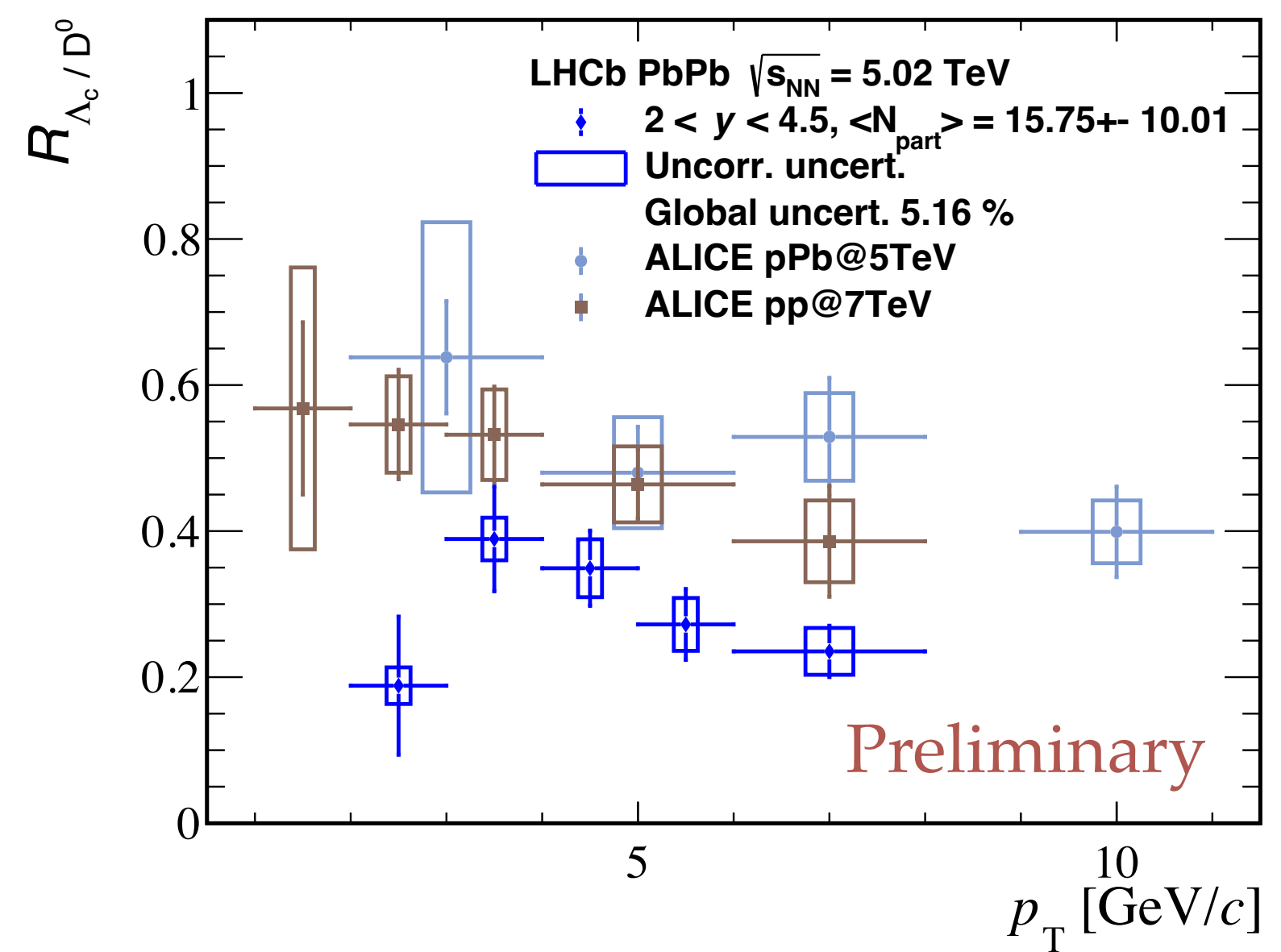
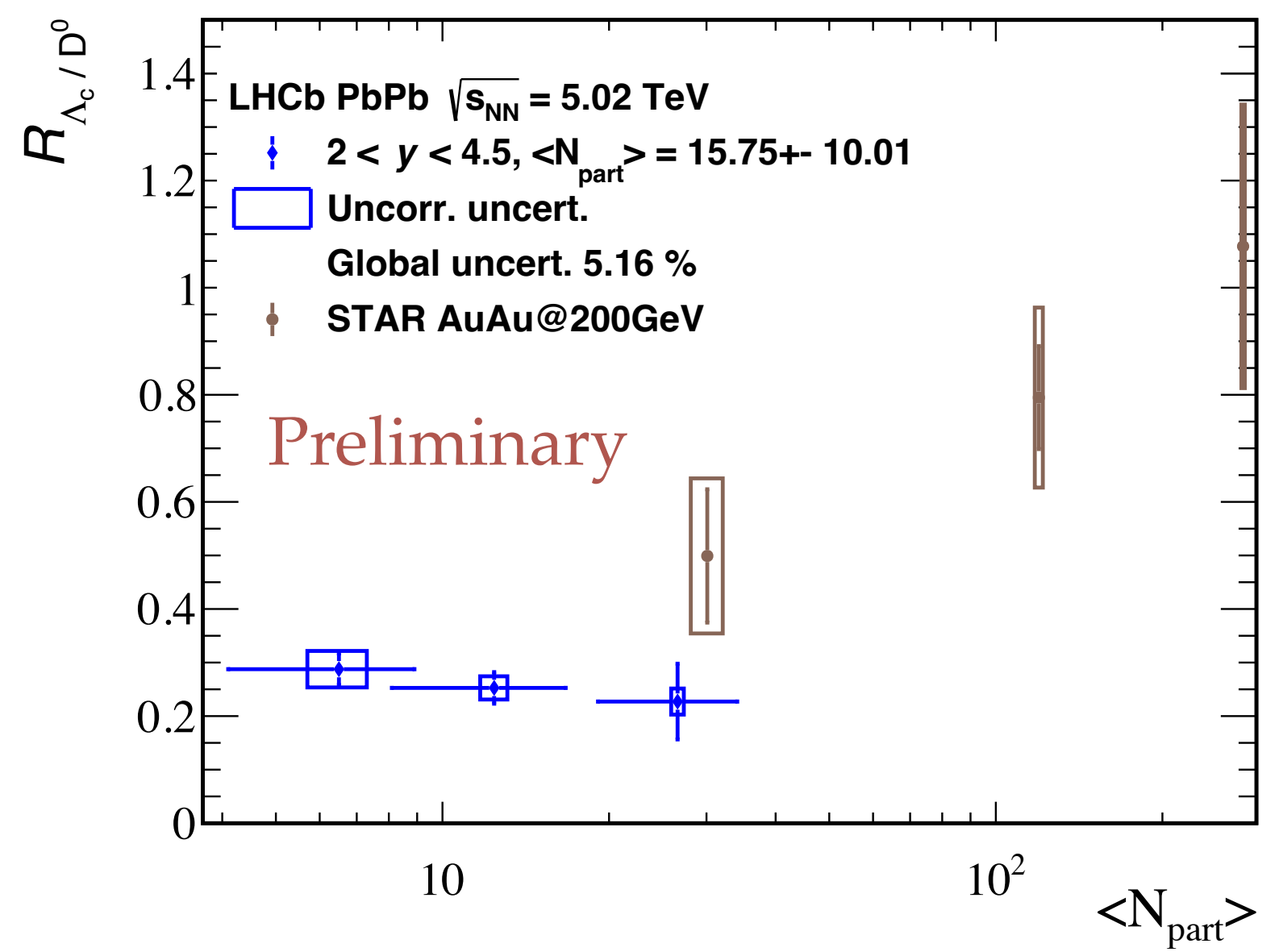
- Most central point compatible with STAR measurements.
- Rising trend ?

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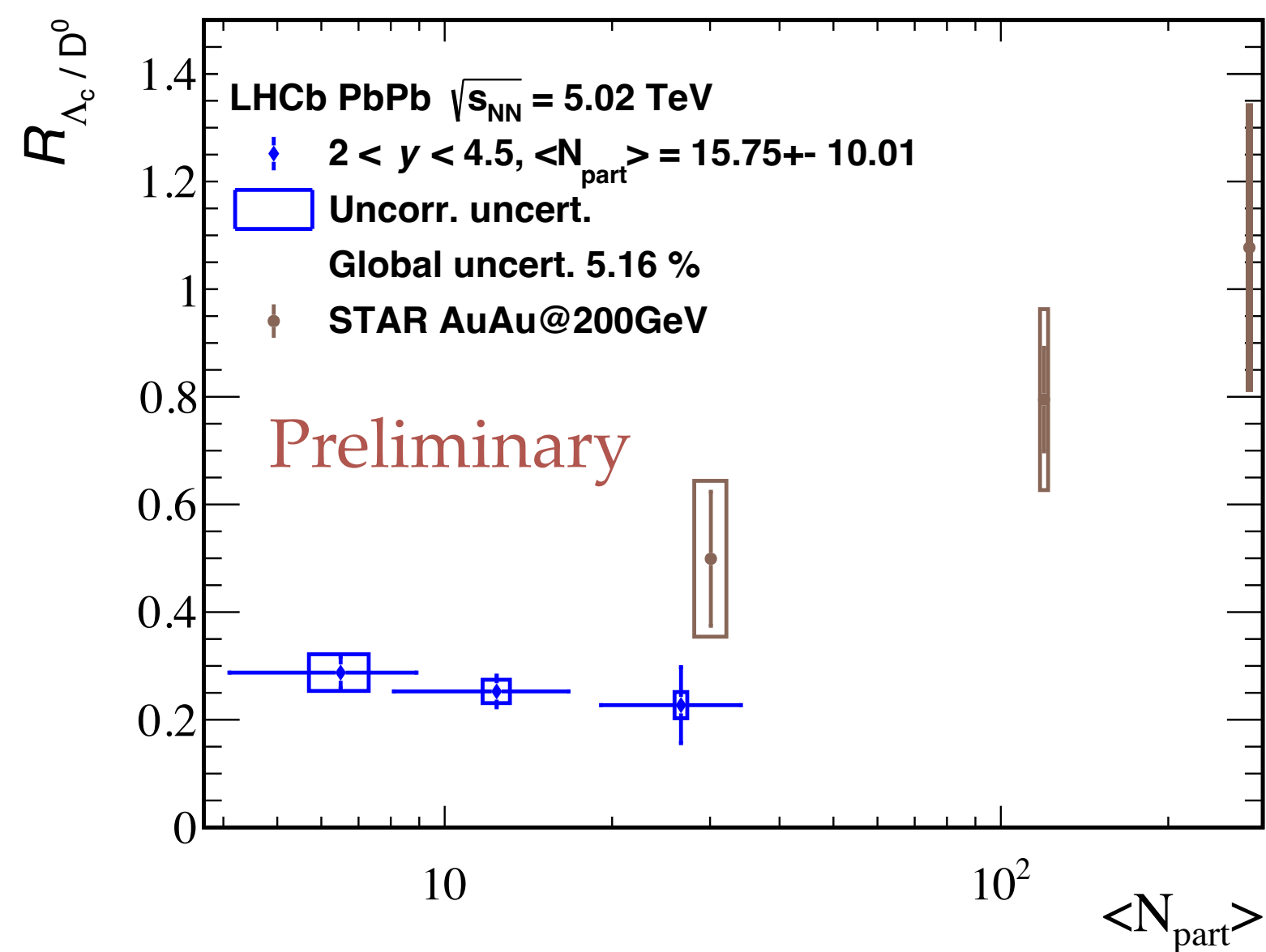
- Similar p_T trend between ALICE and LHCb for $p_T > 4$ GeV/c.

New

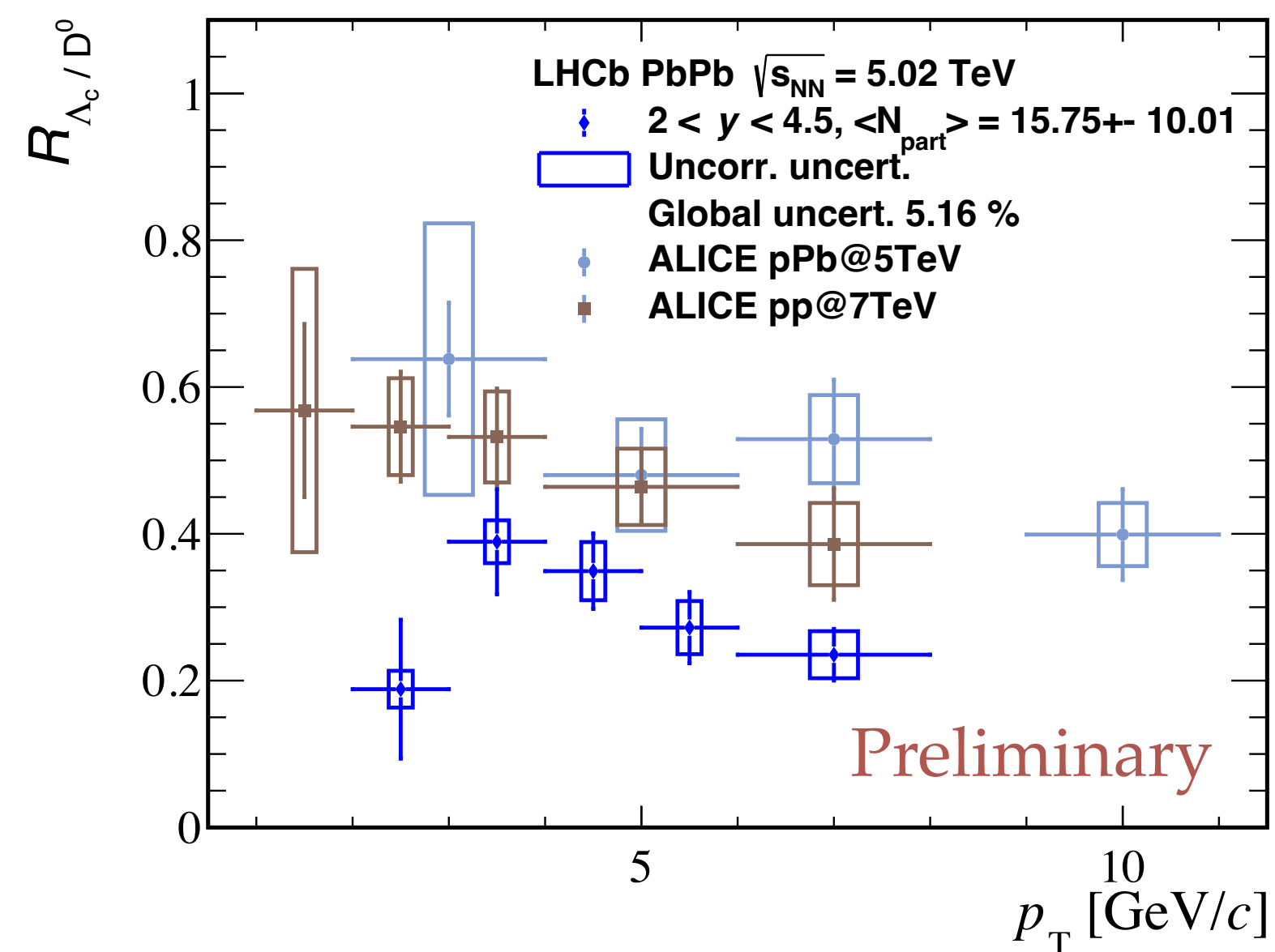
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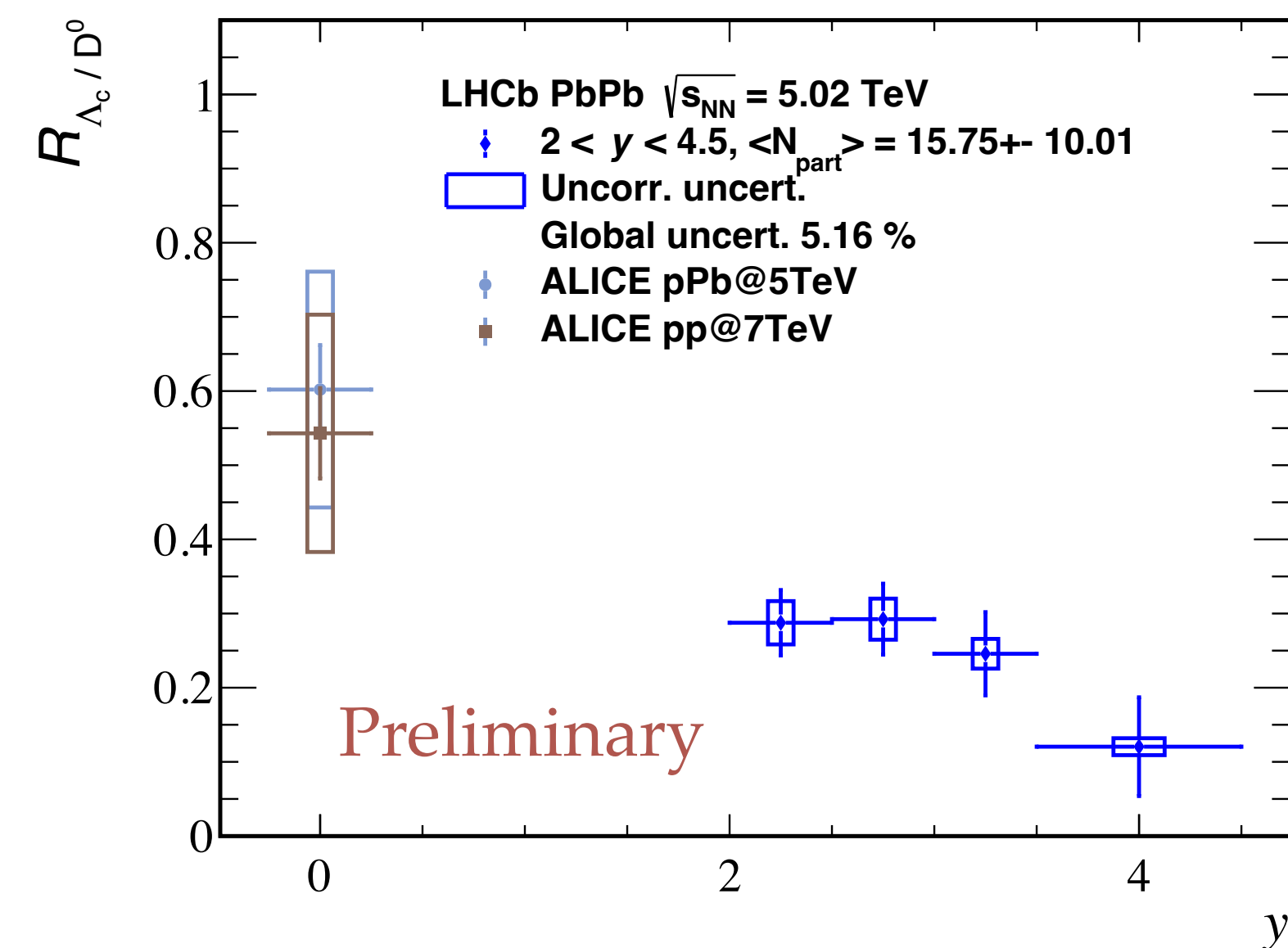
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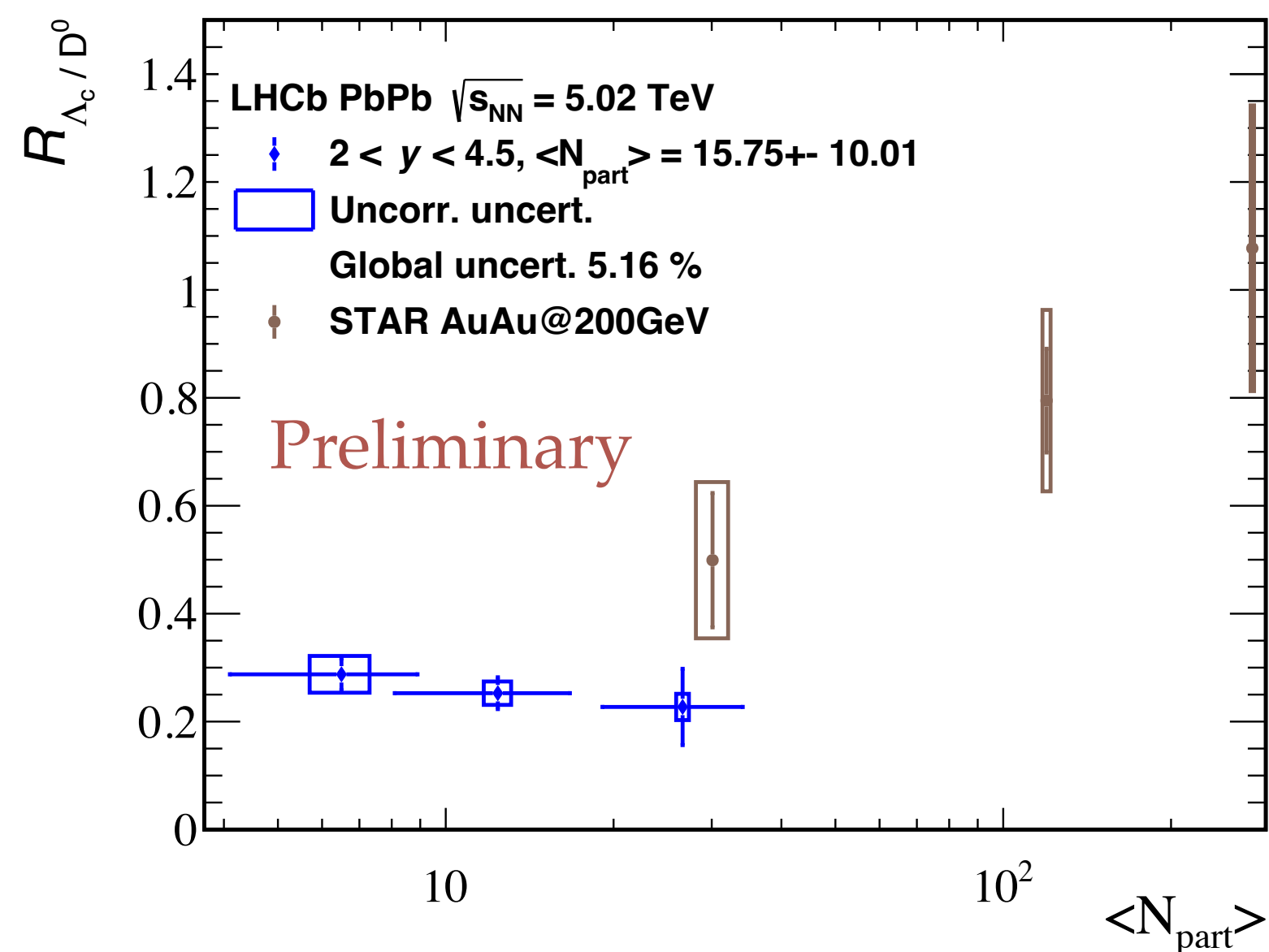
- Difference between LHCb and ALICE data versus rapidity.

New

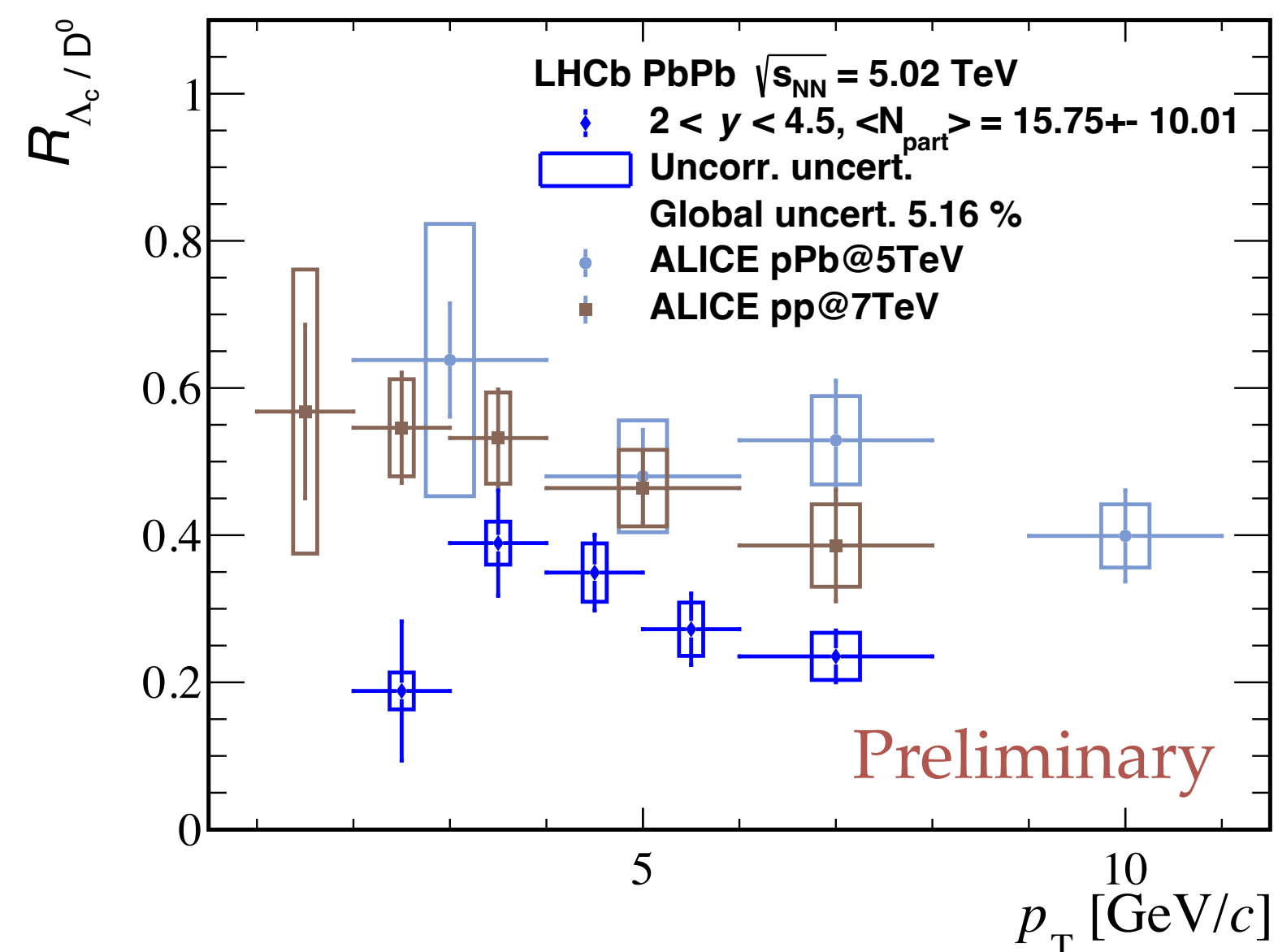
Λ_c^+ -to- D^0 ratio in peripheral PbPb collisions

LHCB-PAPER-2021-046

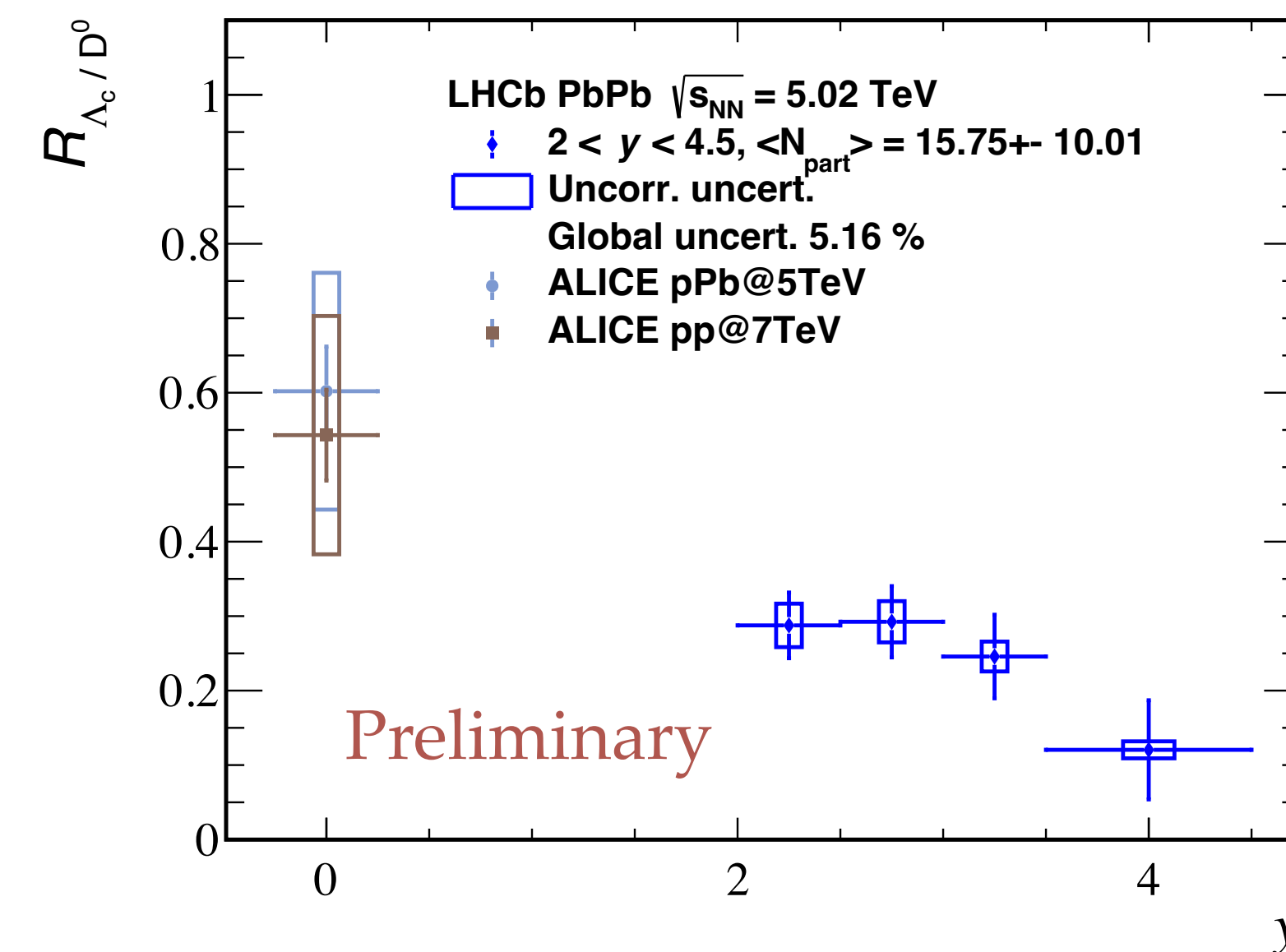
First Λ_c^+ -to- D^0 production ratio measured in peripheral PbPb collisions at forward rapidity.



- Most central point compatible with STAR measurements.
- Rising trend ?



- Similar p_T trend between ALICE and LHCb for $p_T > 4$ GeV/c.



- Difference between LHCb and ALICE data versus rapidity.

Systematically lower Λ_c^+ -to- D^0 ratio in LHCb compared to ALICE due to different rapidity range confirmed?

Conclusion

❖ **LHCb: a pQCD experiment.**

- Large catalogue of HF measurements, from pp to pA and AA collisions.
- Precise data add constrains on pQCD models:
 - PDFs, nPDFs, hadronization mechanisms ...

❖ **New results presented in this talk:**

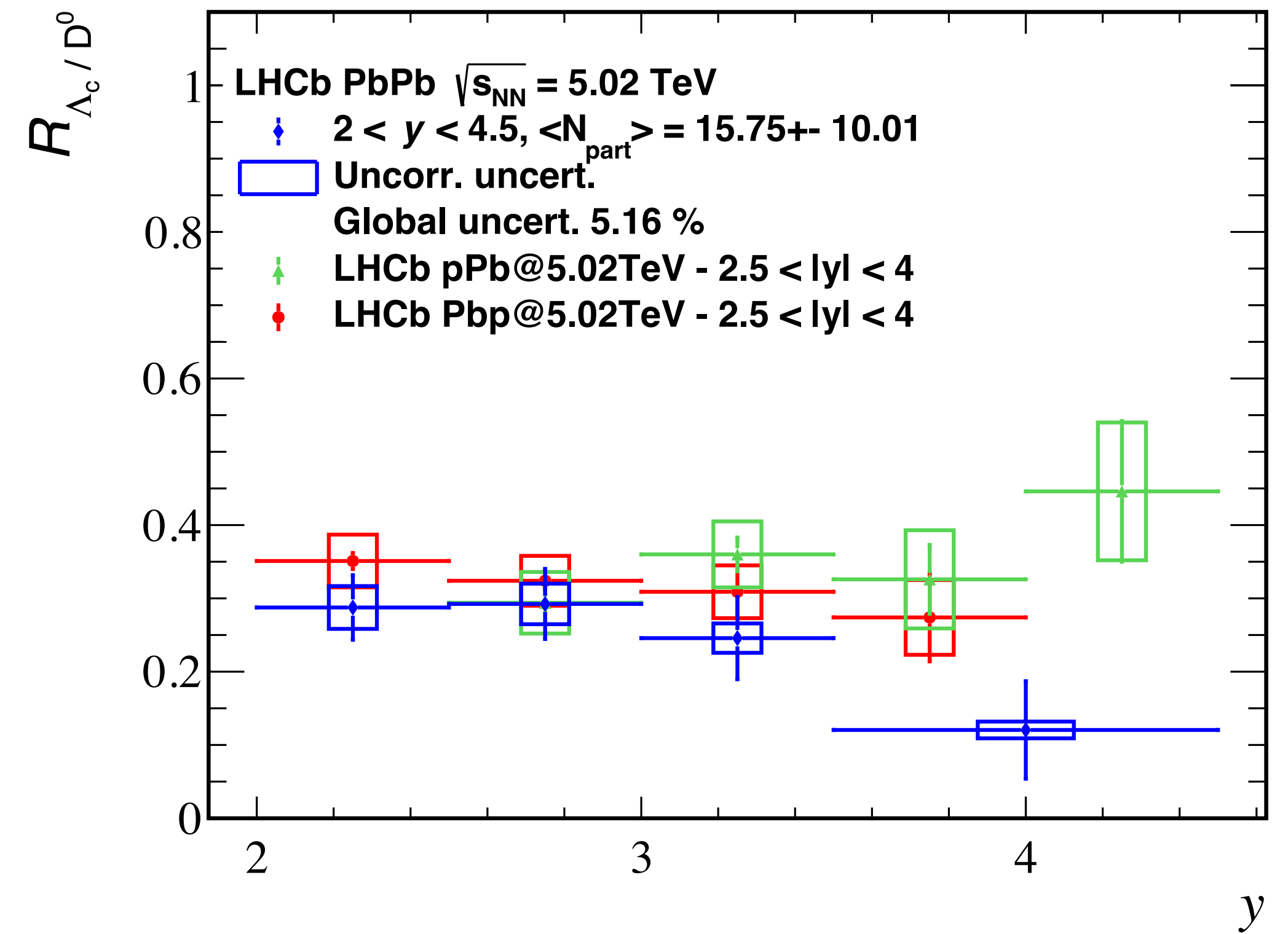
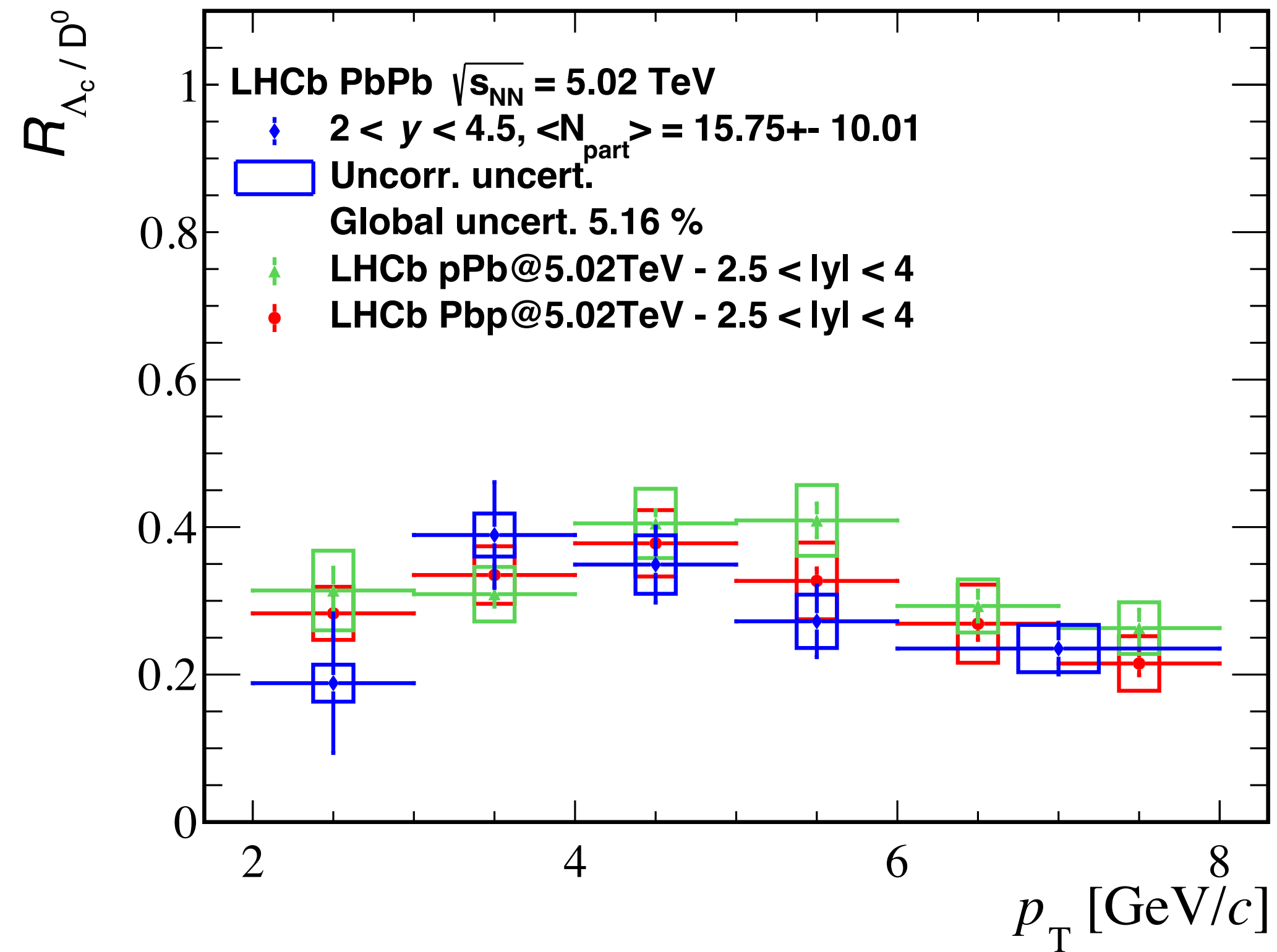
- J/ψ production in pp collisions - JHEP 11 (2021) 181
- Open-charm production in pPb collisions - LHCb-PAPER-2022-007
- Fragmentation fraction ratios in pp collisions - Phys. Rev. D 104 (2021) 032005
- B_s^0/B^0 production versus multiplicity - LHCb-PAPER-2022-001
- Λ_c^+ -to- D^0 ratio in peripheral PbPb collisions - LHCb-PAPER-2021-046

❖ **Striking observations in the results:**

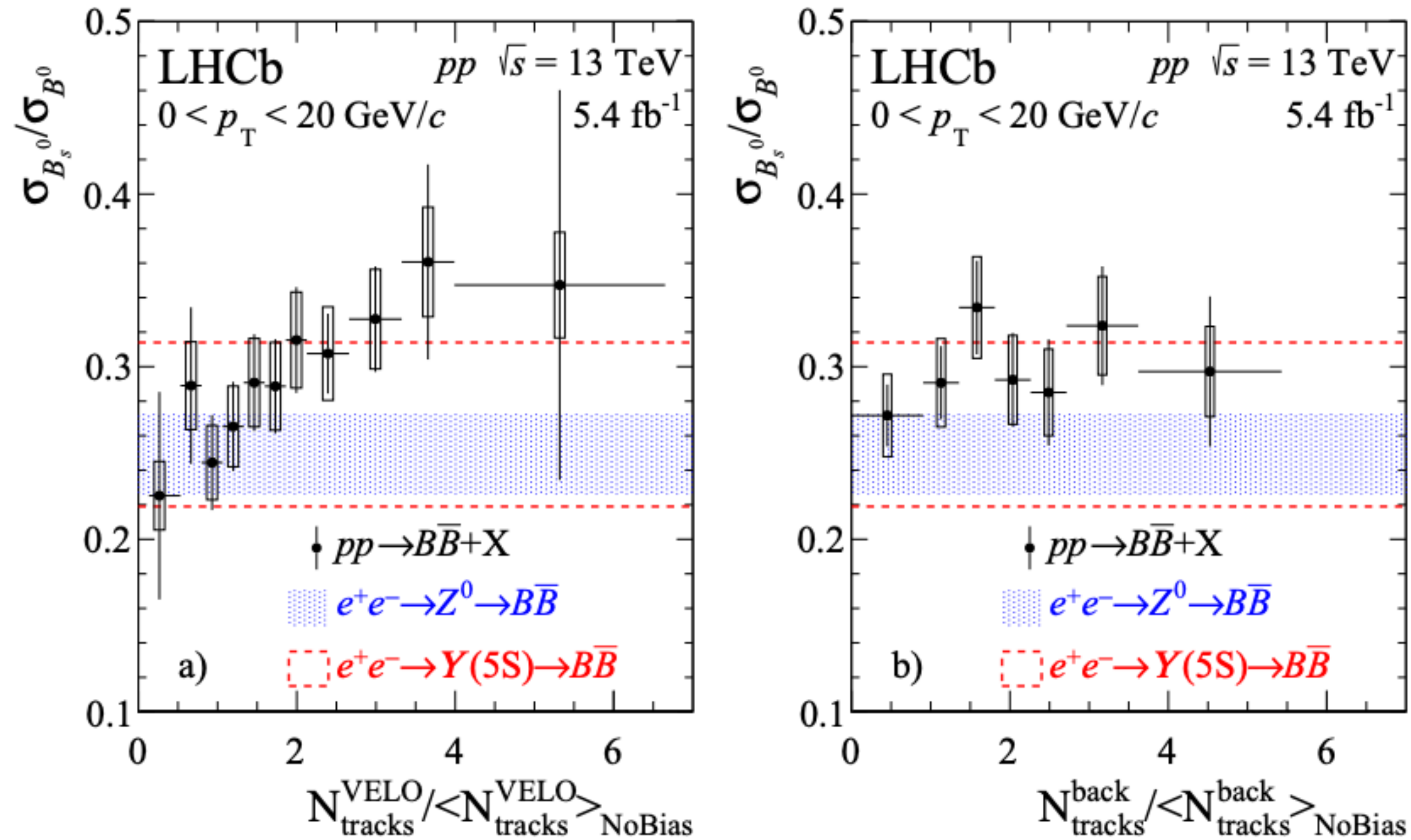
- F_s/f_d dependence on the B transverse momentum.
- Increasing B_s^0/B^0 production ratio versus multiplicity.
- Tension between data and theory predictions at high p_T for D^0 production in pPb collisions.
- Λ_c^+ -to- D^0 ratio in peripheral PbPb collisions compatible to similar measurement in pPb collisions made by LHCb → difference with ALICE remains.

Back-up

Λ_c^+ -to- D^0 ratio in peripheral



B^0_s/B^0 production versus multiplicity in $pp@13\text{TeV}$



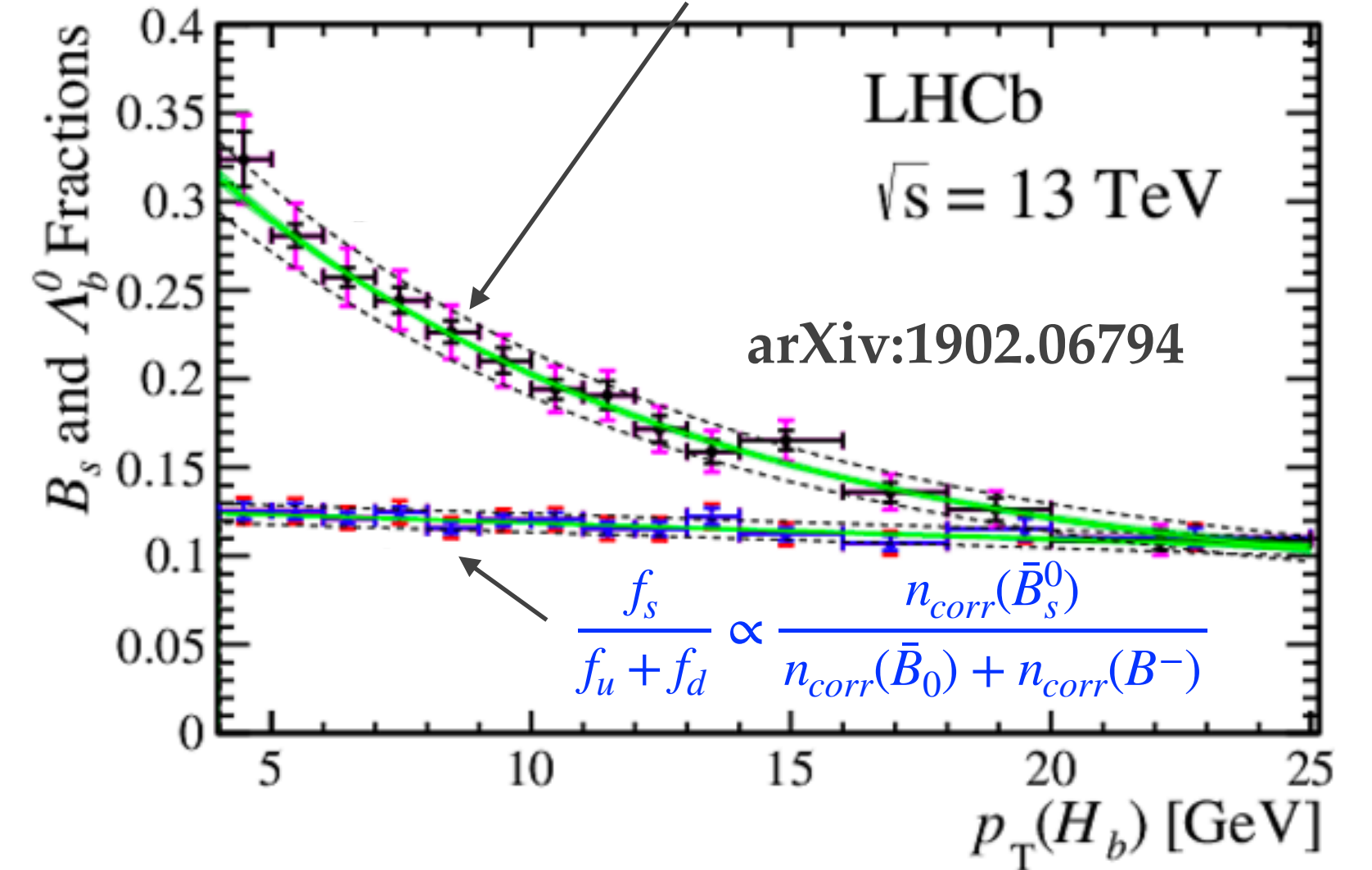
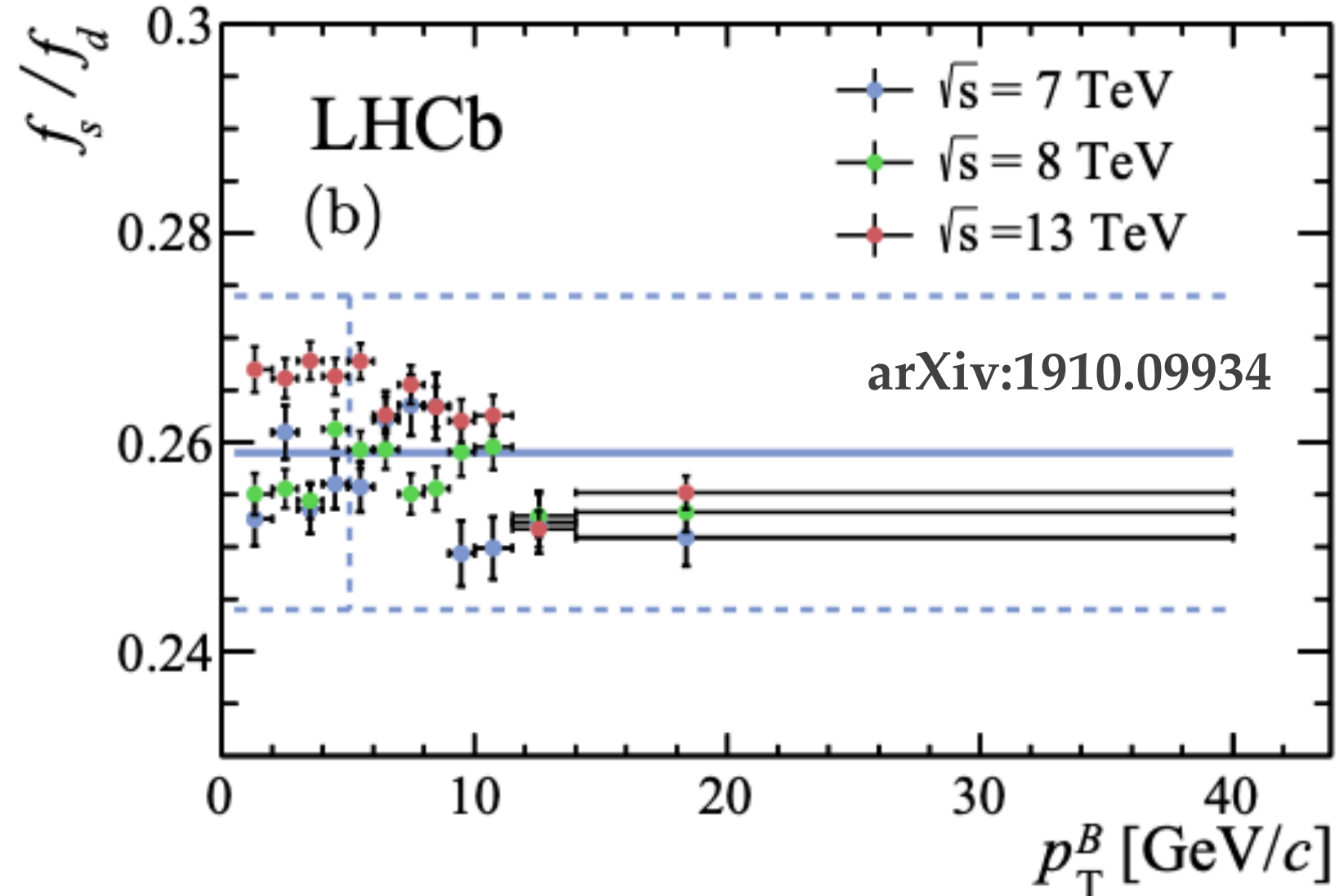
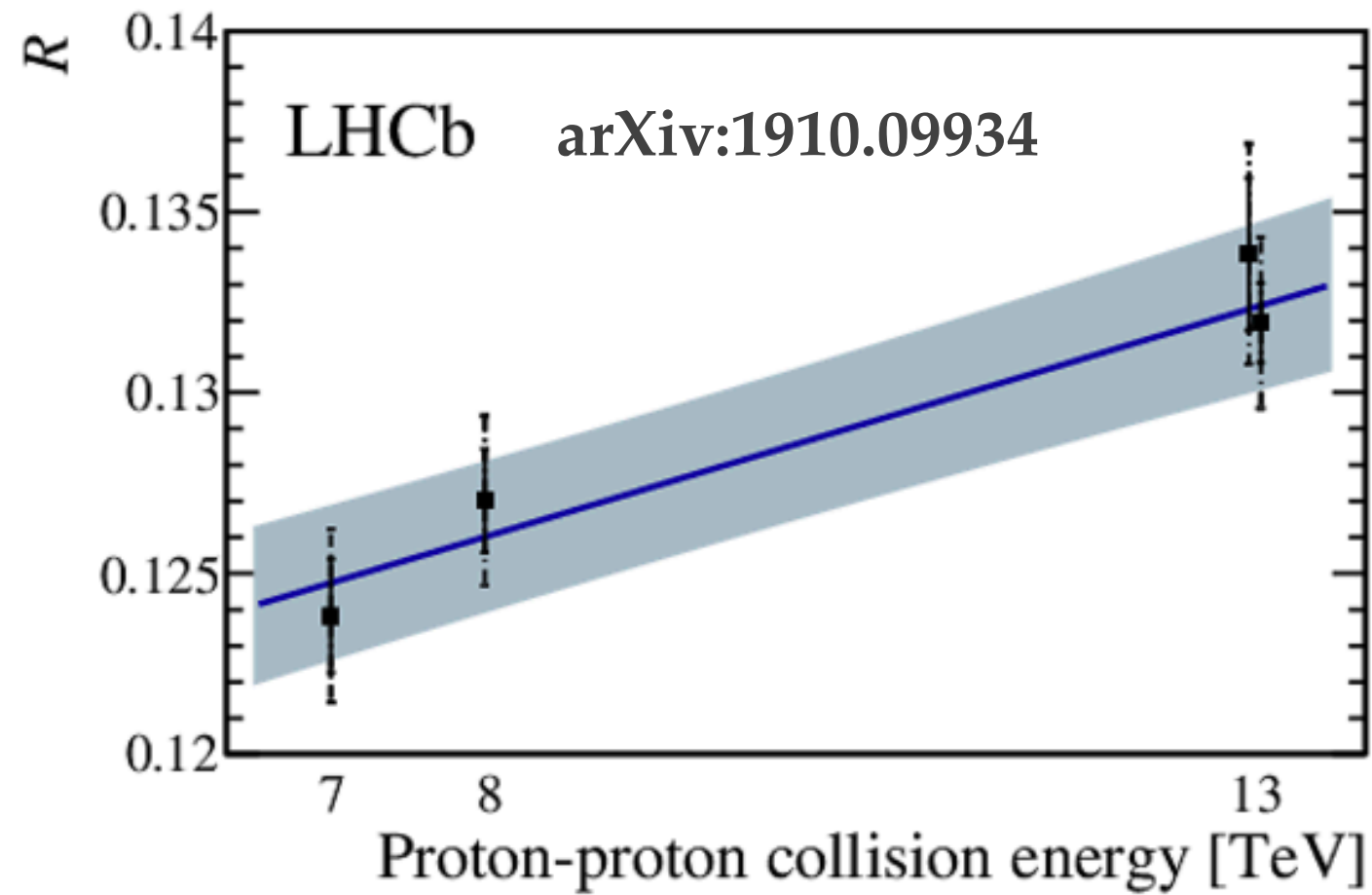
Fragmentation fraction ratio

❖ Fragmentation functions measured with B mesons :

$$R \propto \frac{f_s}{f_u} \propto \frac{n_{corr}(B_s^0 \rightarrow J/\psi\phi)}{n_{corr}(B^+ \rightarrow J/\psi K^+)}$$

$$\frac{f_s}{f_d} \propto \frac{n_{corr}(B_s^0 \rightarrow D_s^- \pi^+)}{n_{corr}(B^0 \rightarrow (D^- K^+ | D^- \pi^+)}$$

$$\frac{f_{\Lambda_b}}{f_u + f_d} \propto \frac{n_{corr}(\Lambda_b^0)}{n_{corr}(\bar{B}_0) + n_{corr}(B^-)}$$



- **4.8 σ evidence** is seen for an f_s/f_u dependence on the collision energy.
- f_s/f_u is observed to **depend on the B meson transverse momentum**.

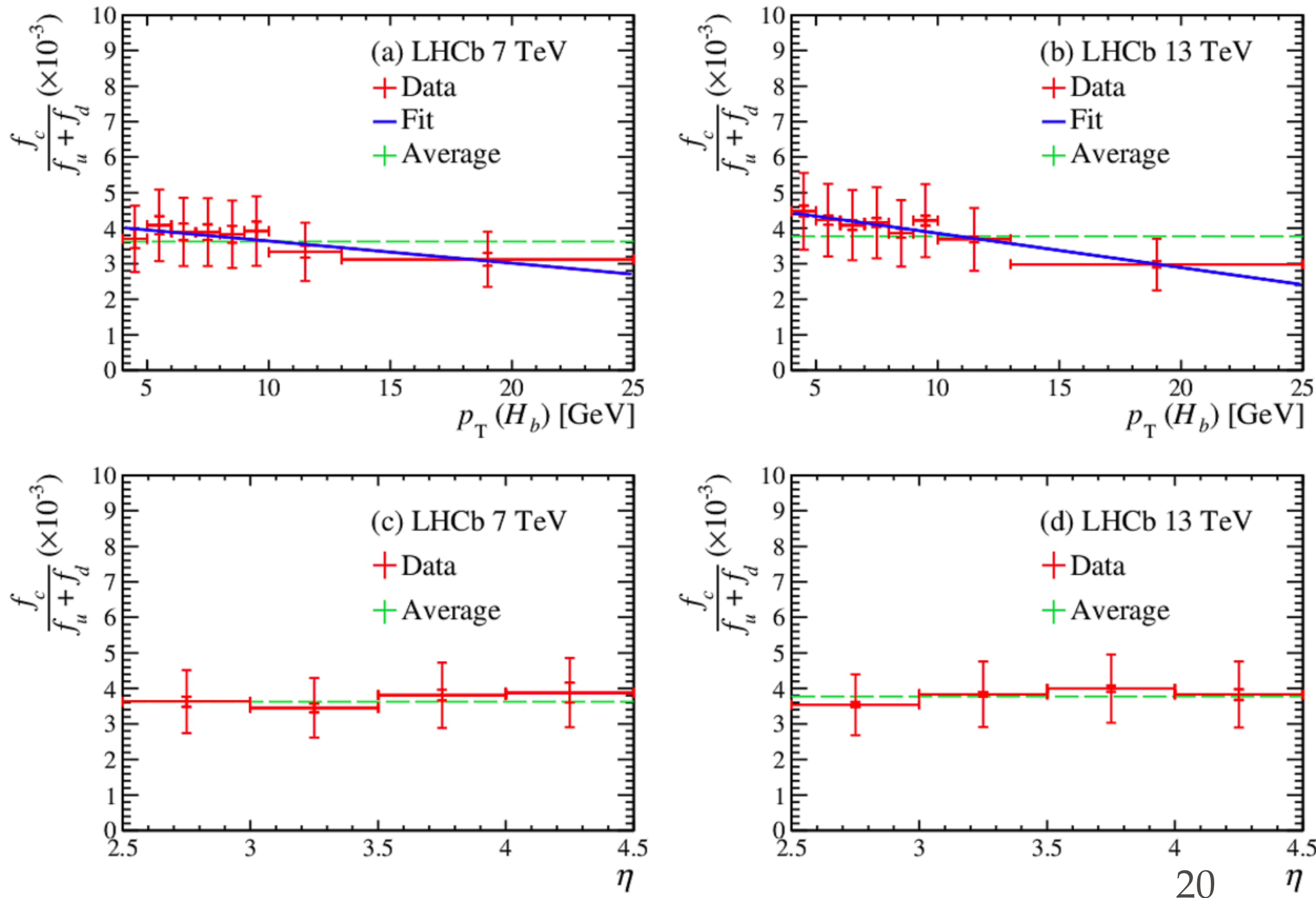
- f_s/f_d is observed to depend linearly with p_T ($> 3\sigma$).
- No rapidity dependence observed.

- $f_{\Lambda_b}/(f_d+f_u)$ is observed to **depend on p_T**
- No rapidity dependence observed.
- pp@13TeV results are consistent with previous results pp@7 TeV.

Fragmentation fraction ratio

PHYS. REV. D100 (2019) 112006

❖ Fragmentation functions measured with B mesons :



$$\frac{f_c}{f_u + f_d} \propto \frac{n_{corr}(B_c^- \rightarrow J/\psi \mu^- \bar{\nu})}{n_{corr}(B_0 \rightarrow D^0 X \mu^- \bar{\nu}) + n_{corr}(B^+ \rightarrow D^+ X \mu^- \bar{\nu})}$$

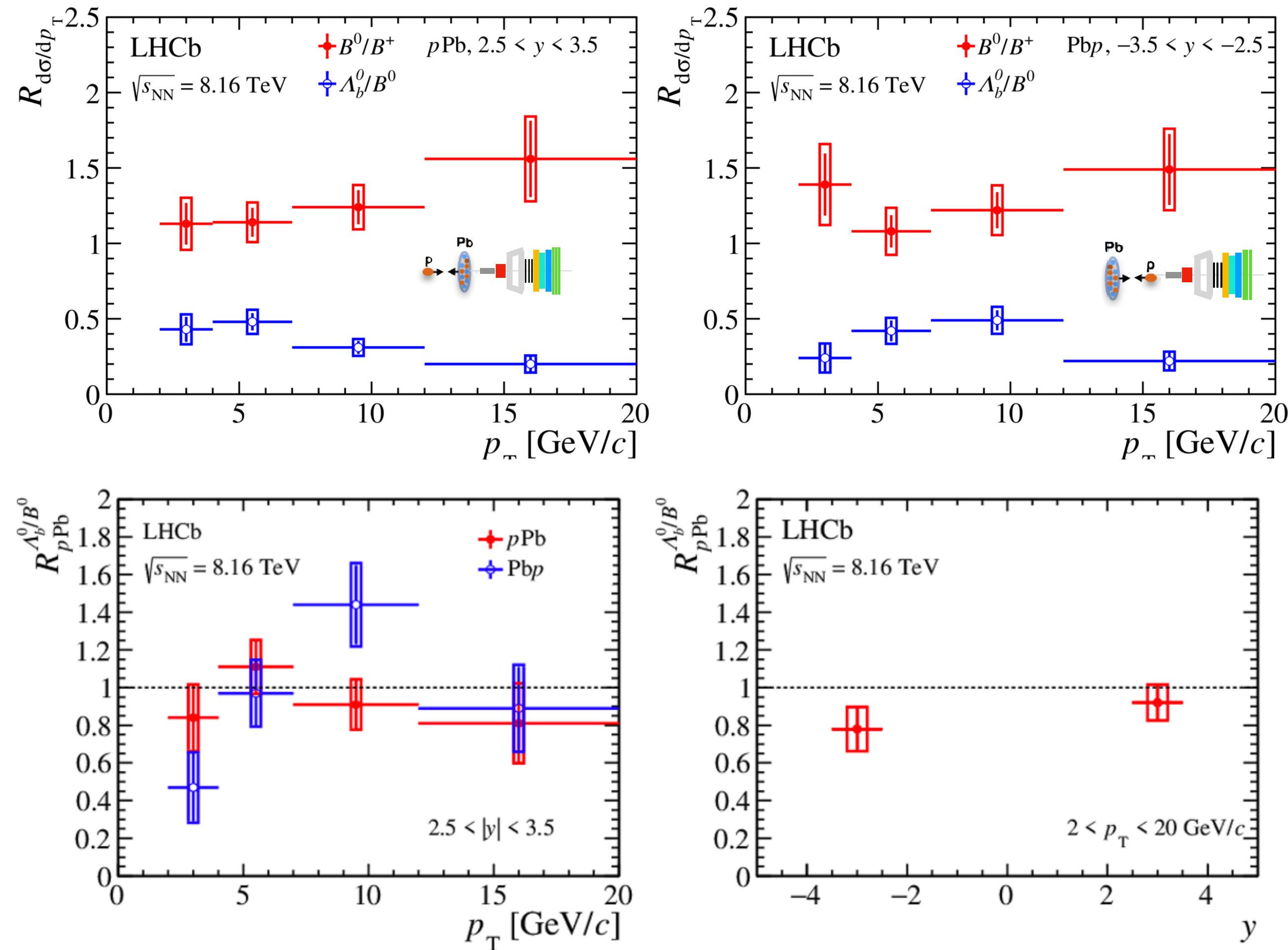
❖ Results are consistent with no increase of the B_c^- fraction between the two collisions energy :

$$R(\text{pp@13TeV} / \text{pp@7TeV}) = 1.02 \pm 0.02 \pm 0.04$$

❖ Average asymmetry in $B_c^- - B_c^+$ production is consistent with zero assuming no CP violation.

Baryon-to-meson ratio in pPb collisions

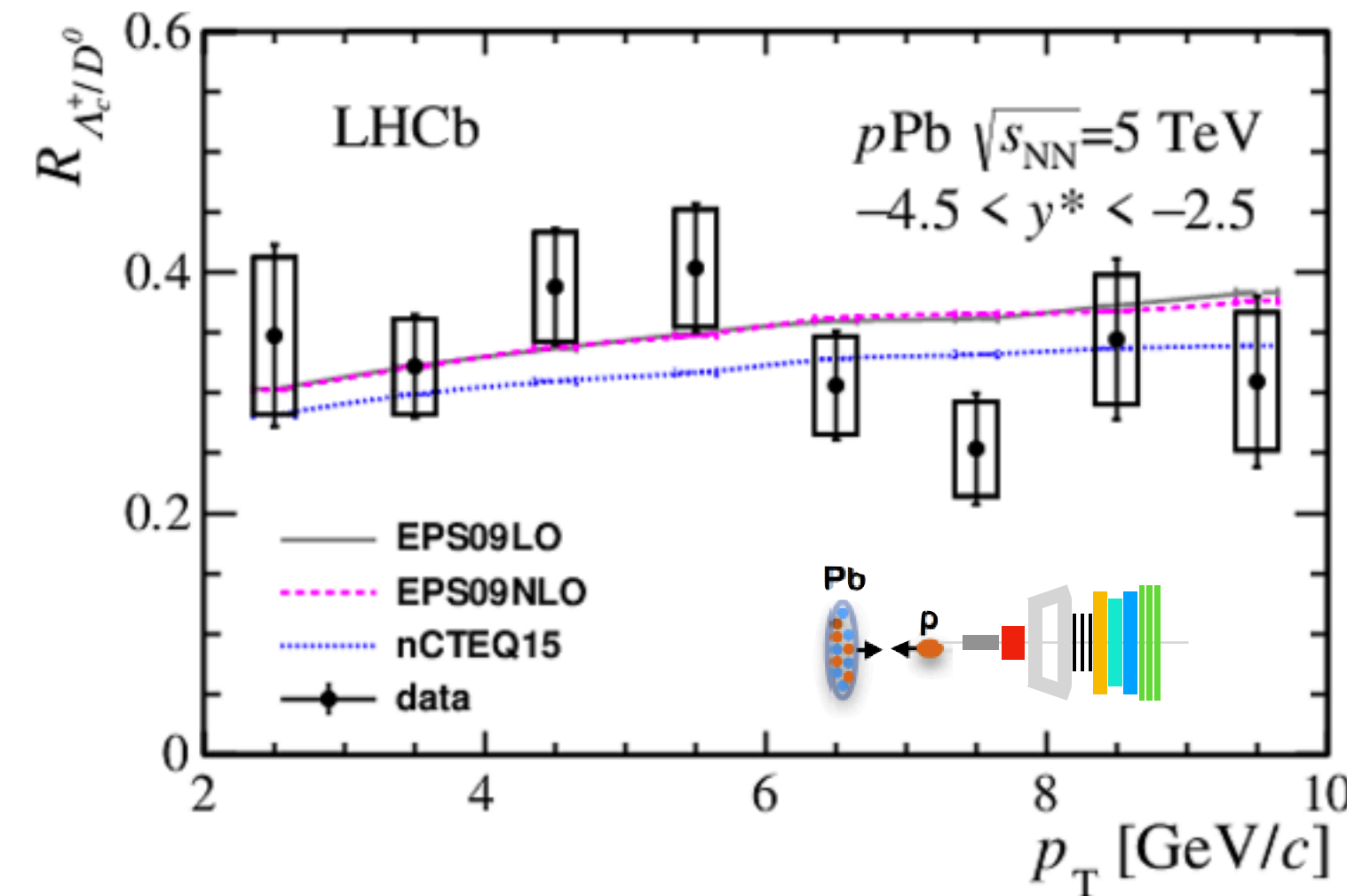
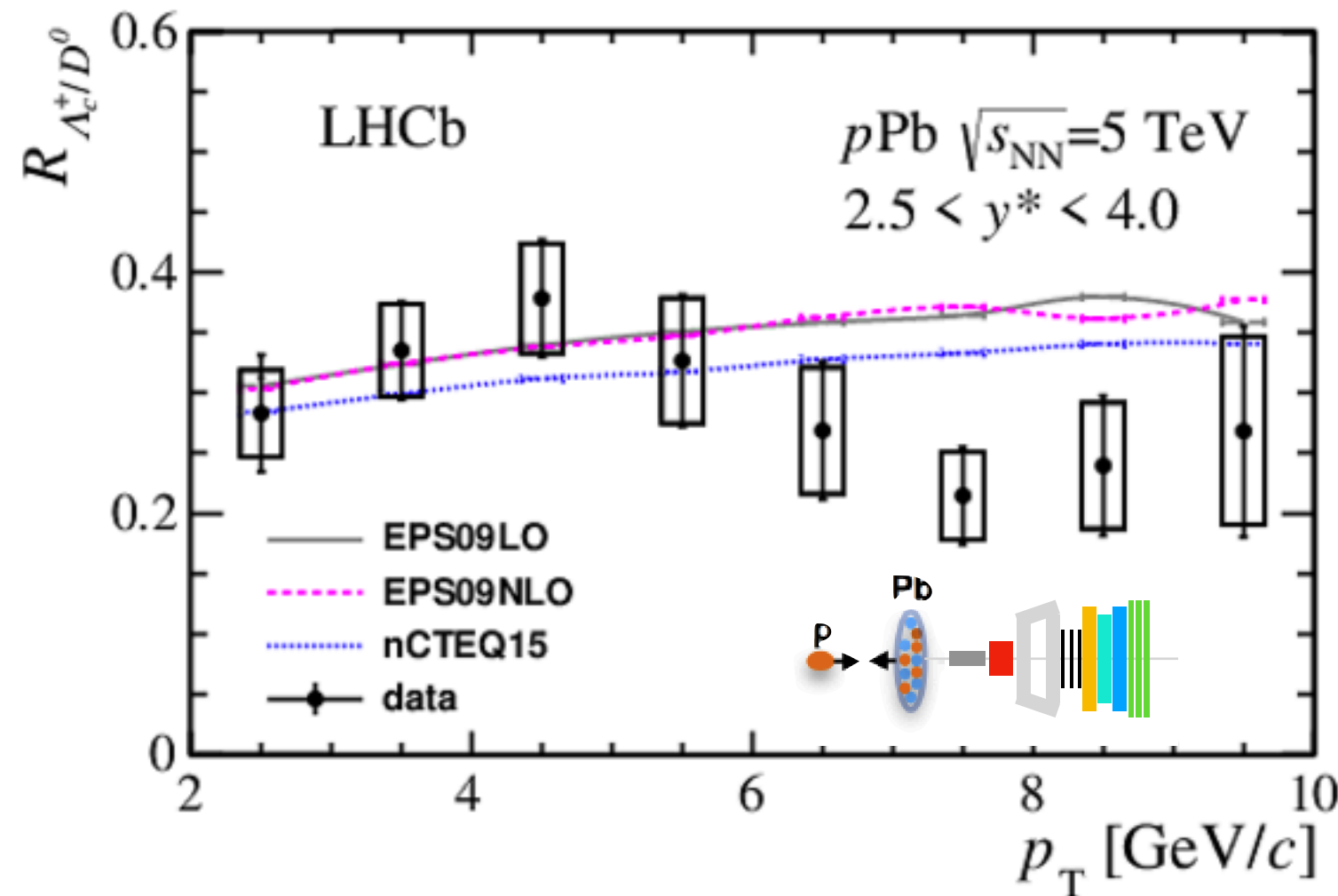
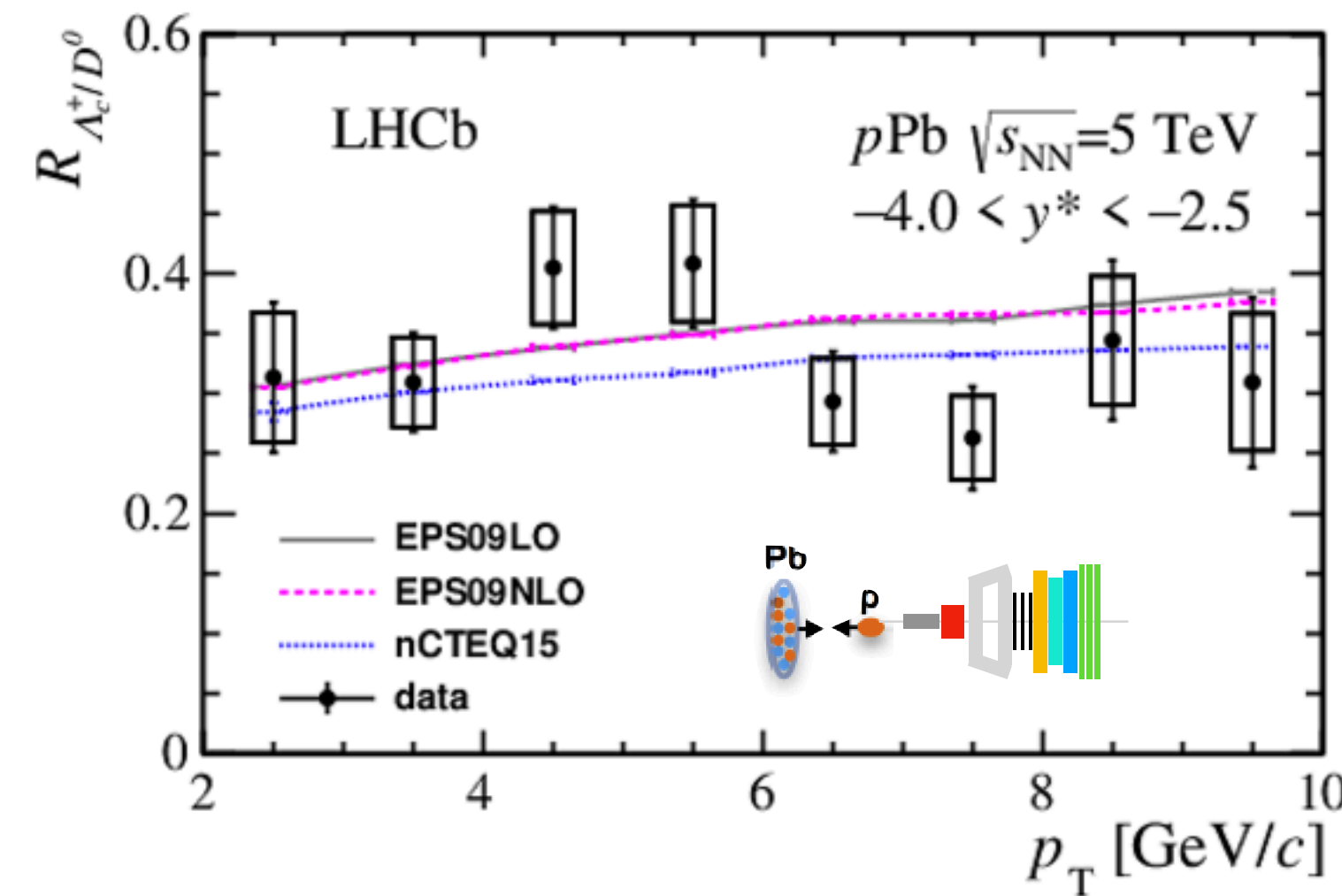
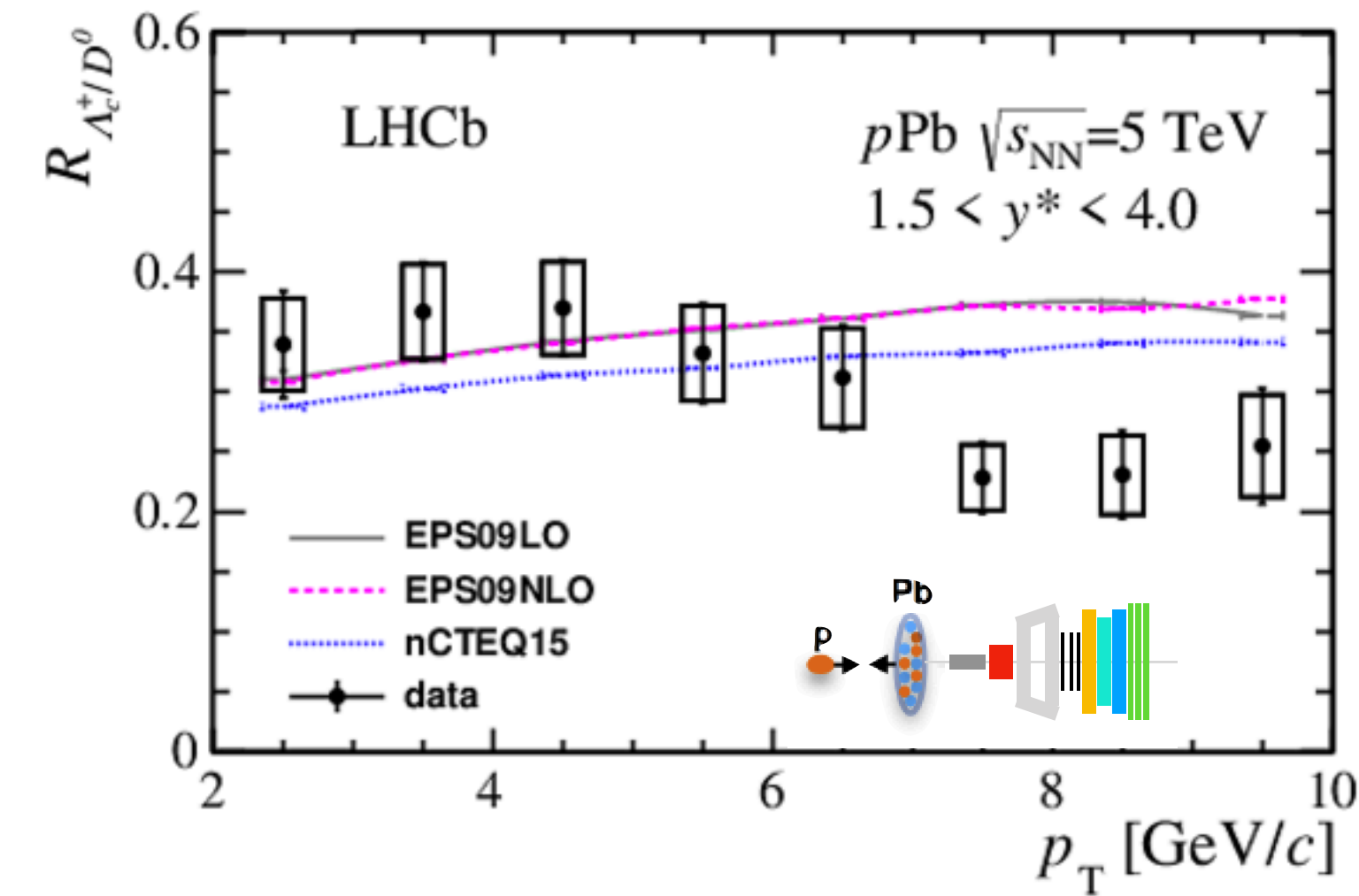
Phys. Rev. D 99, 052011



- ❖ **Beauty mesons and baryon measured in pPb/Pbp collisions at $\sqrt{s_{NN}} = 8$ TeV.**
 - Flat $\sigma(B^0)/\sigma(B^+)$ ratio versus p_T .
 - p_T dependance observed for the $\sigma(\Lambda_b^0)/\sigma(B^0)$ ratio.
 - Hint of a relative Λ_b^0/B^0 suppression in Pbp collisions compared to pp ?
- ❖ Extensive studies show **good agreement** between data and HELAC-onia predictions with several sets of nPDFs.

Baryon-to-meson ratio in pPb collisions

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- ❖ **Charm mesons and baryon measured in pPb/Pbp collisions at $\sqrt{s_{NN}} = 8$ TeV.**
- ❖ No strong dependence of the relative Λ_c^+/D^0 ratio is observed versus p_T and rapidity.
 - ➔ **Decreasing trend versus p_T** in pPb.
- ❖ **Good description of the nuclear modification factors and forward-to-backward ratios** with various nPDFs sets.
 - ➔ within large model uncertainties ...
- ❖ **Tensions between models and data** at higher p_T in pPb collisions.
 - ➔ Data fluctuation ?
 - ➔ Limitation of the hadronization part in the model ?
 - ➔ Additional effect ?