

# LHCb experimental highlights

**Jiayin Sun**  
**INFN Cagliari**

**on behalf of the LHCb collaboration**

27th March 2023

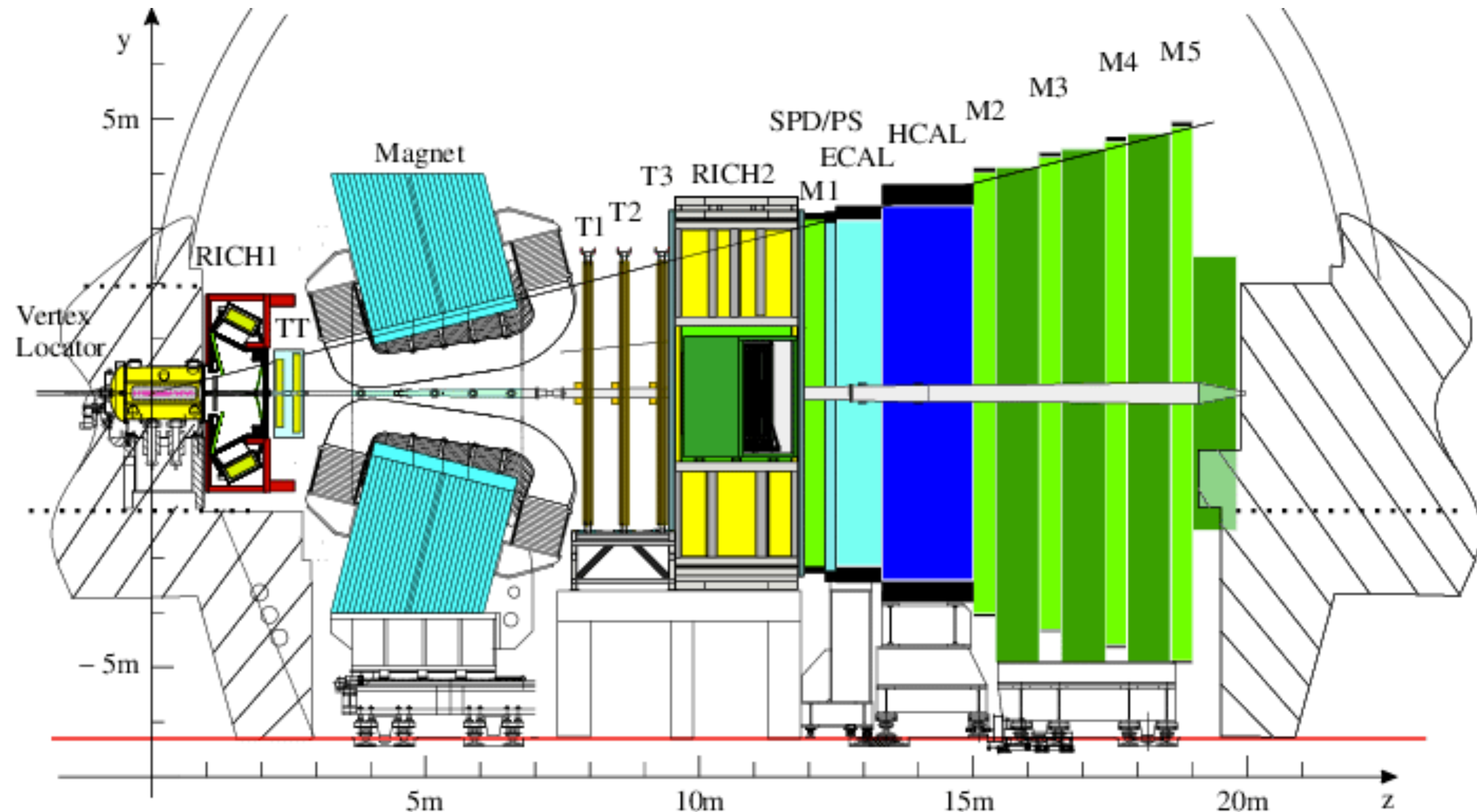


# LHCb detector

- Acceptance:  $2 < \eta < 5$
- Vertex detector (VELO)
  - IP resolution  $\sim 20\mu\text{m}$
- Tracking system
  - $\frac{\Delta p}{p} = 0.5 - 1\%$   
(5-200 GeV/c)
- RICH
  - K/ $\pi$ /p separation
- Electromagnetic + hadronic calorimeters
- Muon system
- Results presented in this talk are based on this configuration

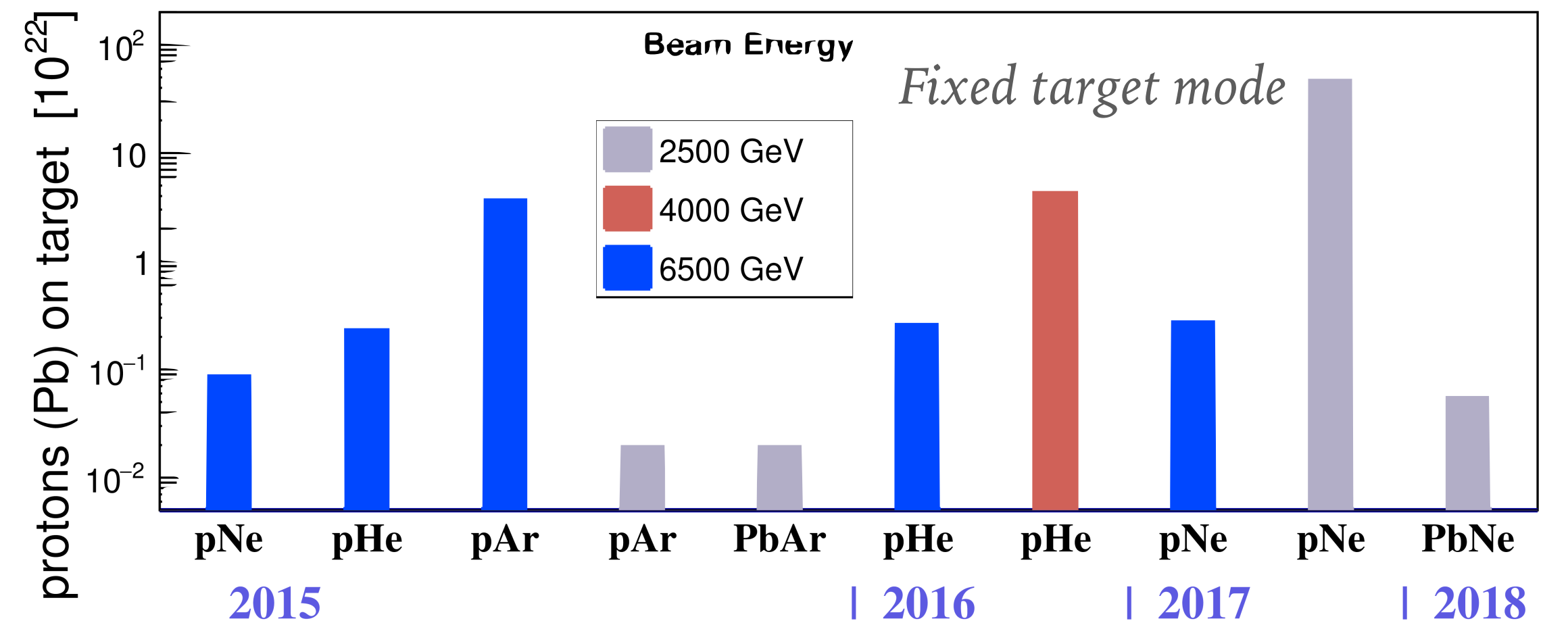
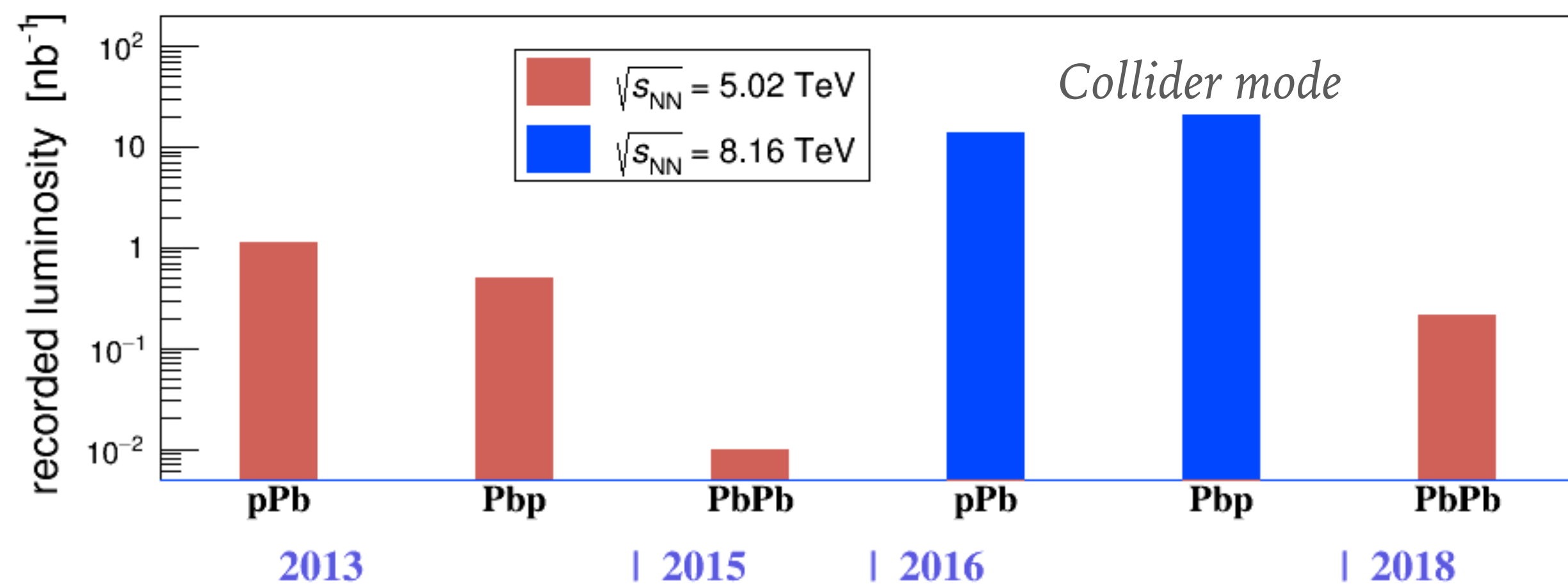
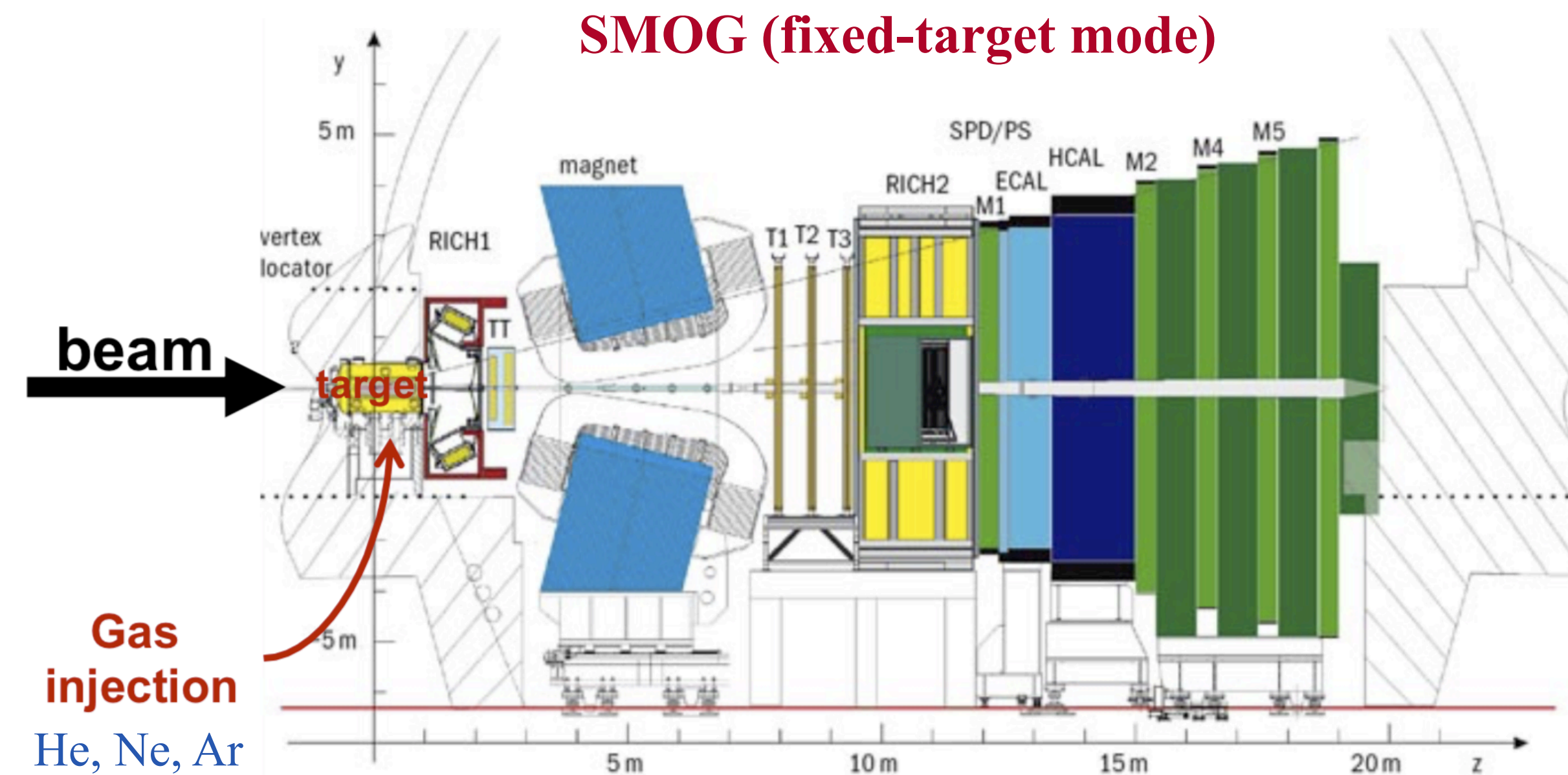
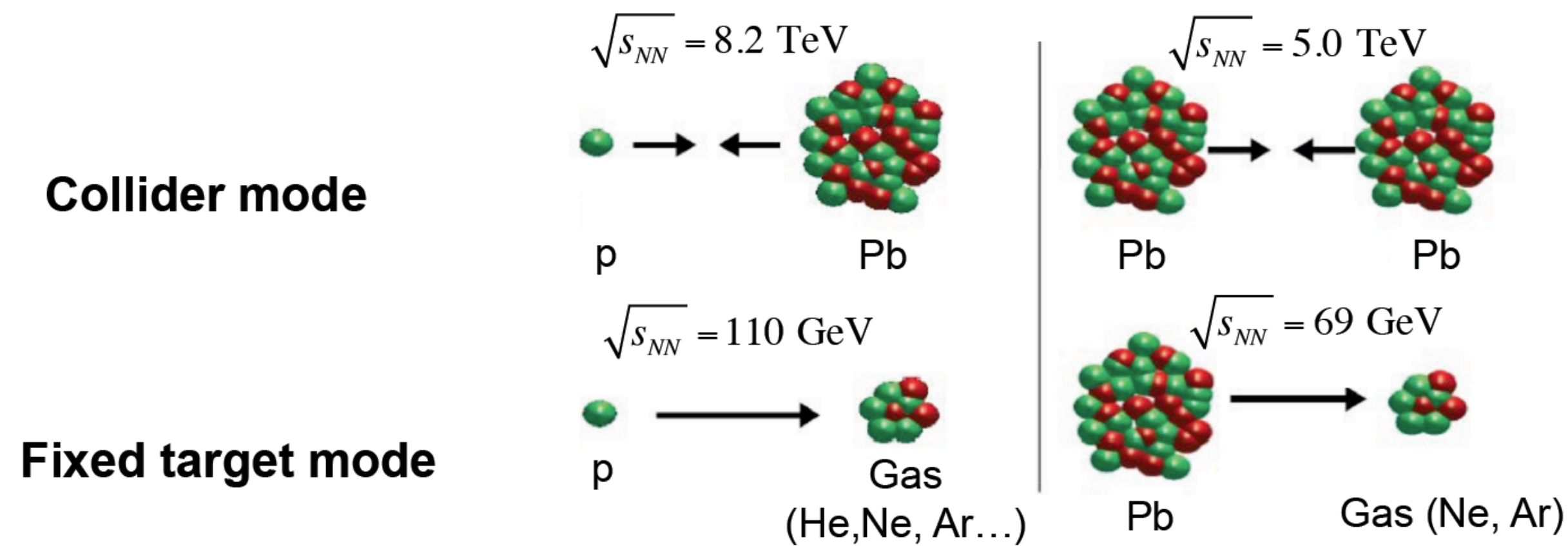
- A single arm spectrometer in forward rapidity, optimized in measuring particles containing  $c$  or  $b$  quark.

JINST 3 (2008) S08005



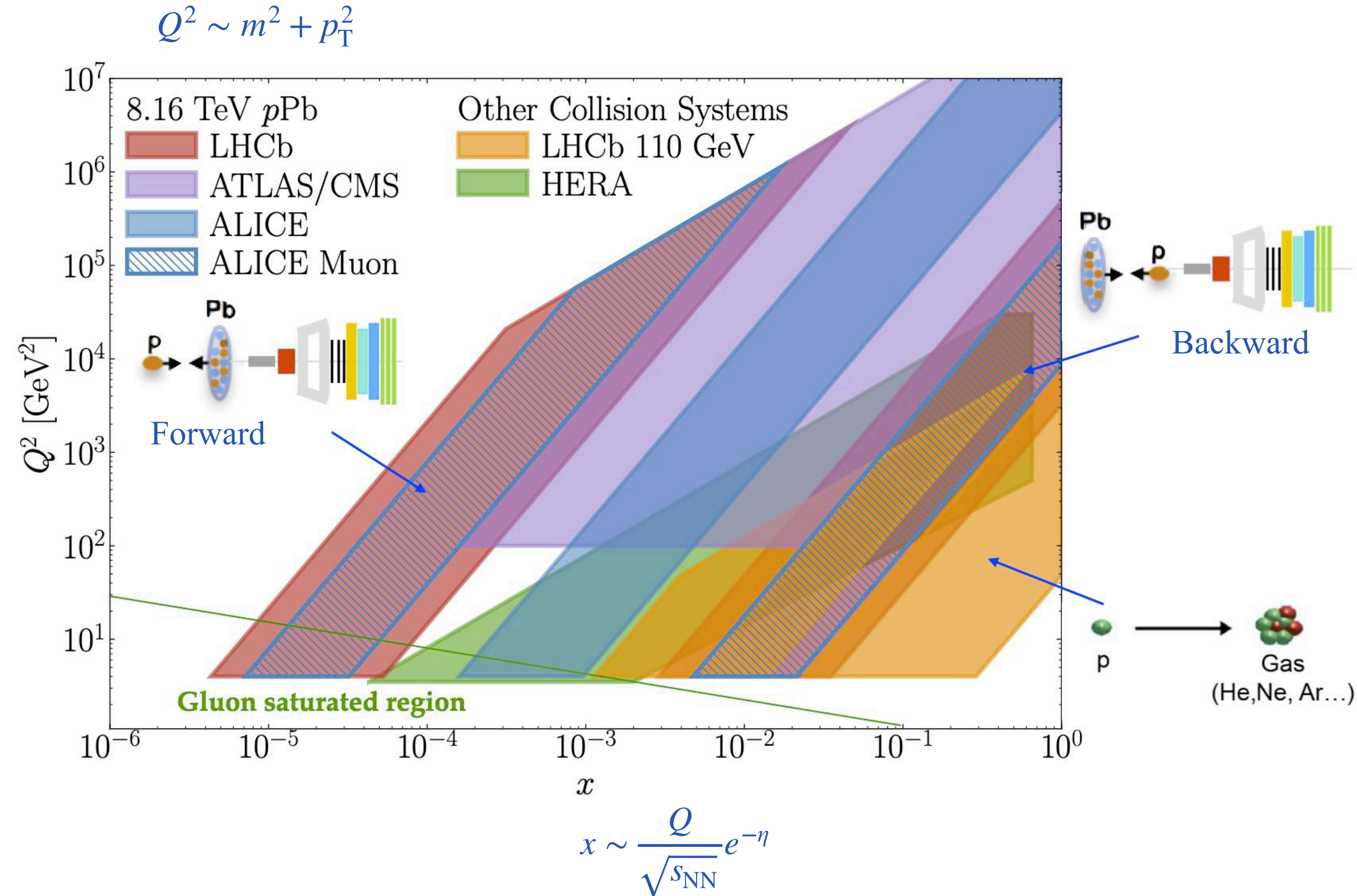
Already upgraded for Run3! more later

# LHCb heavy ion collision modes and datasets



# LHCb in heavy ion physics

- **Excellent for studying  $pp/pPb$  collisions**
  - Constrain nPDF at small and large Bjorken- $x$
  - Probe gluon saturation in low  $x$  and low  $Q^2$  region
  - Test hadronization mechanisms in medium
  - Study final state effects in medium
  - Search for possible QGP droplet formation in small systems
- **Unique opportunities in the fixed-target program**
  - $\sqrt{s_{NN}} = 69-110$  GeV between SPS & RHIC
  - $-3.0 < y^* < 0$
  - Access nPDF anti-shadowing region
  - Probe intrinsic charm content in the nucleon
  - **Inputs to astrophysics**



# Summary of talks and posters

## Initial state effects

- $\pi^0$  production in  $pPb$  collisions at 8.16 TeV
- $Z^0$  production in 8.16 TeV collisions
- Prompt  $D^0$  production in 8.16 TeV  $pPb$  collisions
- Prompt  $D^+$  and  $D_s^+$  production in 5.02 TeV  $pPb$  collisions
- Prompt  $\Xi_c^+$  production in 8.16 TeV  $pPb$  collisions
- Charmonia photoproduction in UPC PbPb at 5.02 TeV
- Bose-Einstein correlations in  $pPb$  collisions at 5.02 TeV

S. Sellam  
Tues. 9:00

R. Litvinov  
Tues. 9:00

Q. Lu  
Tues. 10:50

M. Goncerz  
poster

## Hadronization

- Prompt  $\Lambda_c^+/D^0$  ratio in PbPb collisions at 5.02 TeV
- Prompt  $D_s^+/D^+$  ratio in 5.02 TeV  $pPb$  collisions
- $B_s^0/B^0$  ratio vs. multiplicity in 13 TeV  $pp$  collisions
- $\chi_{c1}(3872)$  production in 8.16 TeV  $pPb$  collisions

C. Gu  
Tues. 17:10

J. Napora  
poster

C. Gomez  
Wed. 11:50

## Fixed-target

- Charm production in  $pNe$  collisions at 68 GeV
- Charm production in  $PbNe$  collisions at 68 GeV

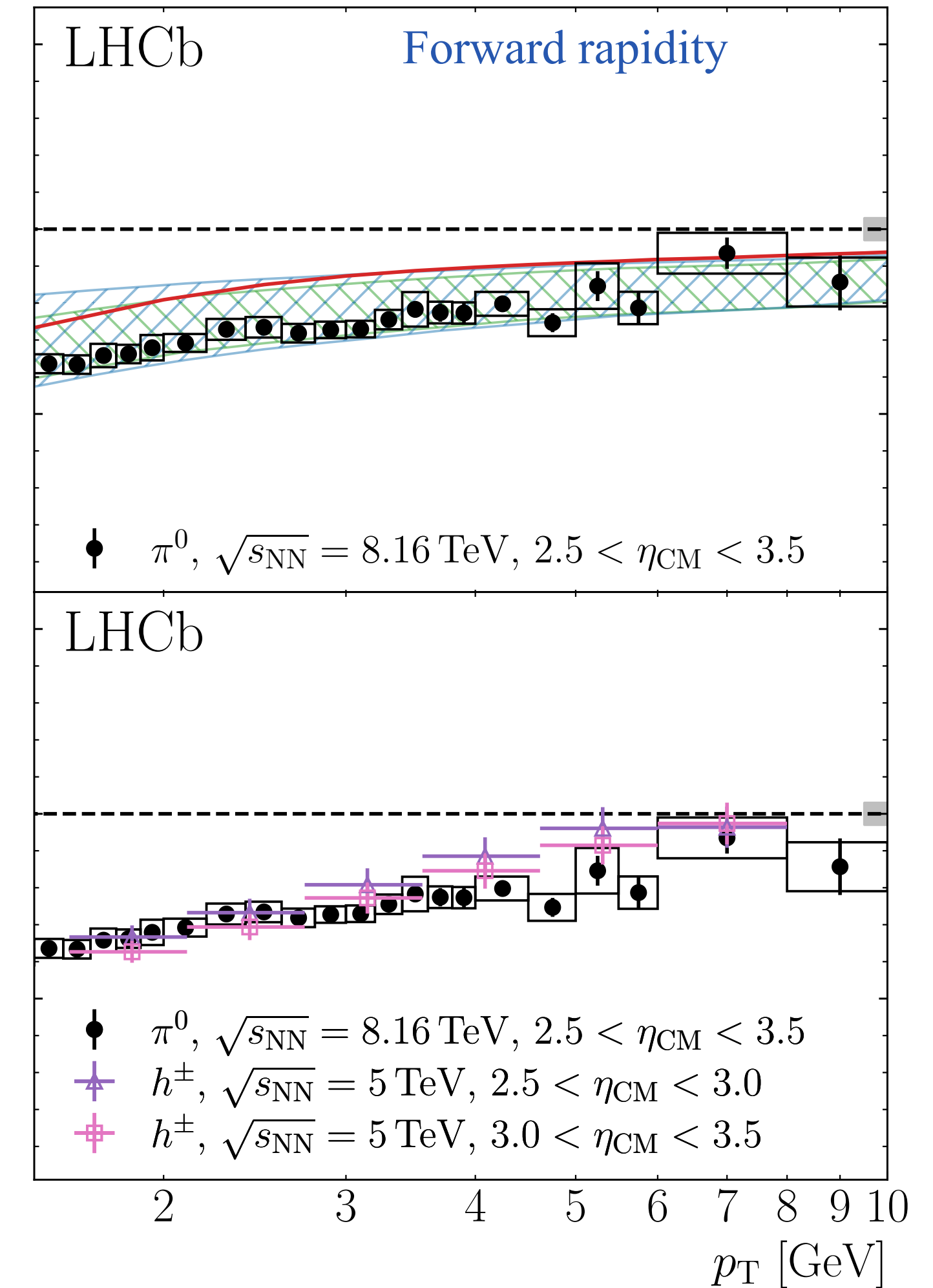
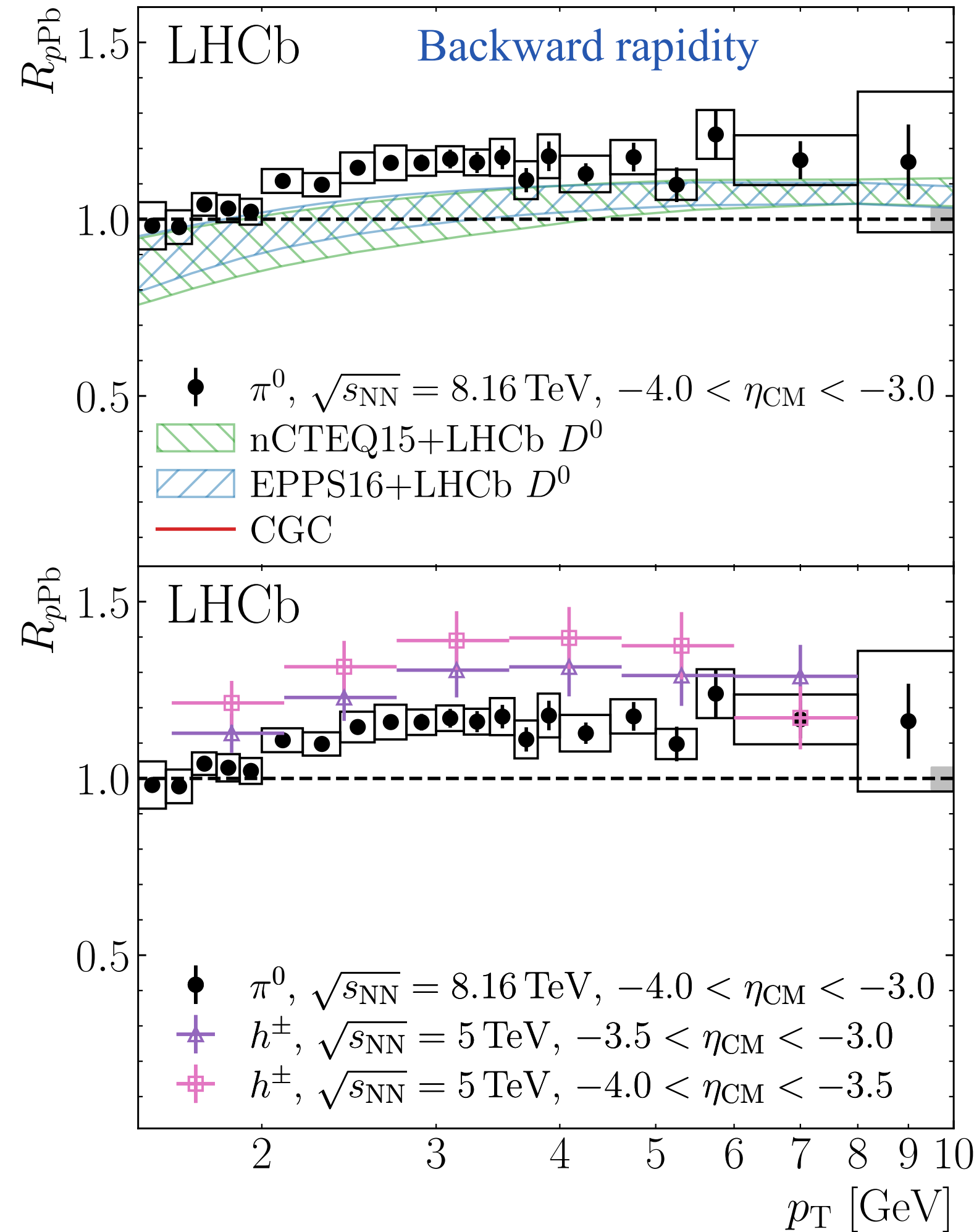
K. Mattioli  
Tues. 15:00

## Run3 upgrade

- First performance results from upgraded LHCb and SMOG II

C. Lucarelli  
poster

- First  $\pi^0$  measurement in forward rapidity at LHC.
- Forward:
  - More precise than nPDF calculations
  - Consistent with charged hadrons
- Backward:
  - Enhancement above nPDF
  - Lower than charged hadrons (mass ordering effect?)
- Gateway to direct photon production measurement



# Prompt $D^0$ production in $p\text{Pb}$ collisions at 8.16 TeV

Roman Litvinov 28/03 Tuesday 9:00

arXiv:2205.03936, accepted by PRL

- Forward:

- Suppression consistent with 5 TeV  $D^0$  result
- Consistent with nPDF and CGC

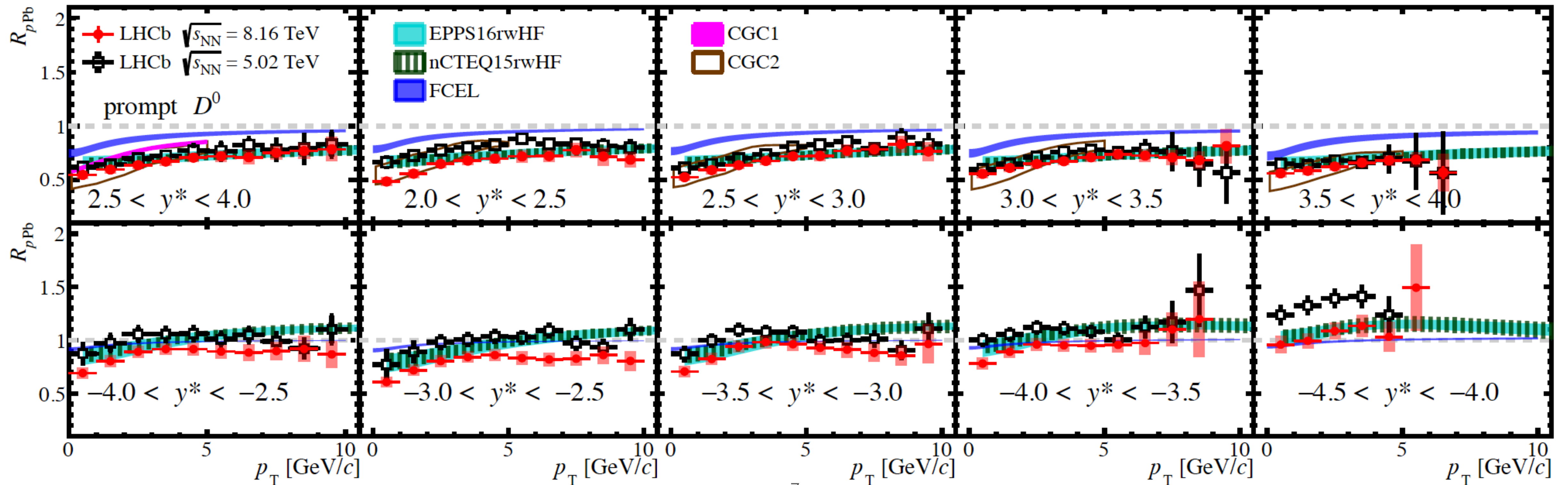
- Backward:

- Data lower than nPDF at high  $p_T$
- Room for additional effects in the backward rapidity

*pp* reference  
from  
interpolation  
between 5&13  
TeV data

JHEP 06 (2017) 147  
JHEP 05 (2017) 074

nPDF calculations do not describe data of  $\pi^0$  and  $D^0$  in the backward



# Prompt $D^0$ production in $p\text{Pb}$ collisions at 8.16 TeV

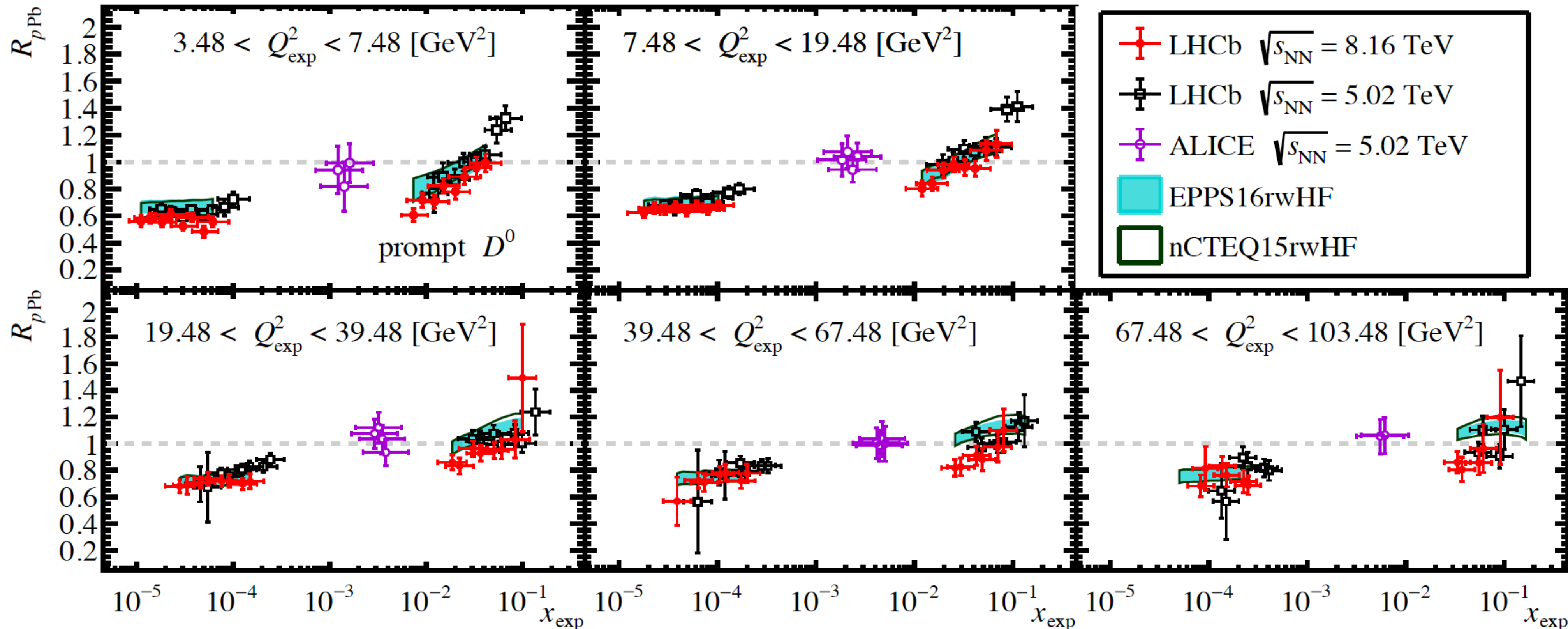
Roman Litvinov 28/03 Tuesday 9:00

arXiv:2205.03936, accepted by PRL

- Experimental proxies for  $x$  and  $Q^2$
- 8 TeV and 5 TeV data consistent with each other
- Forms a continuous trend over a wide  $x$  coverage
- Lower than nPDF at large  $x_{exp}$  and large  $Q_{exp}^2$

*pp* reference  
from  
interpolation  
between 5&13  
TeV data

JHEP 06 (2017) 147  
JHEP 05 (2017) 074

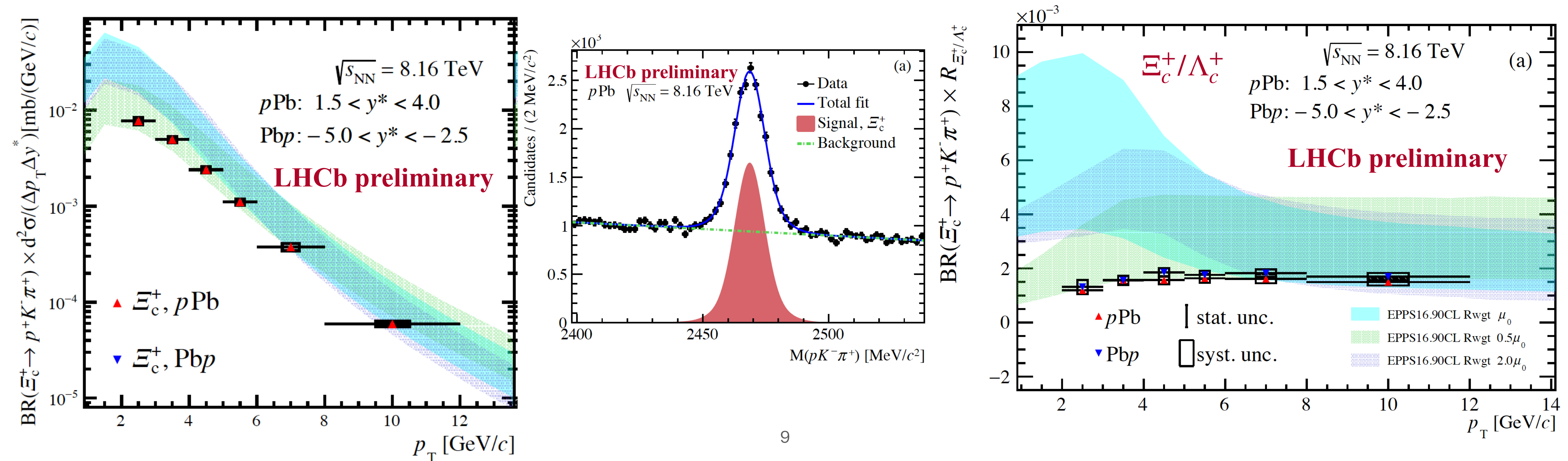


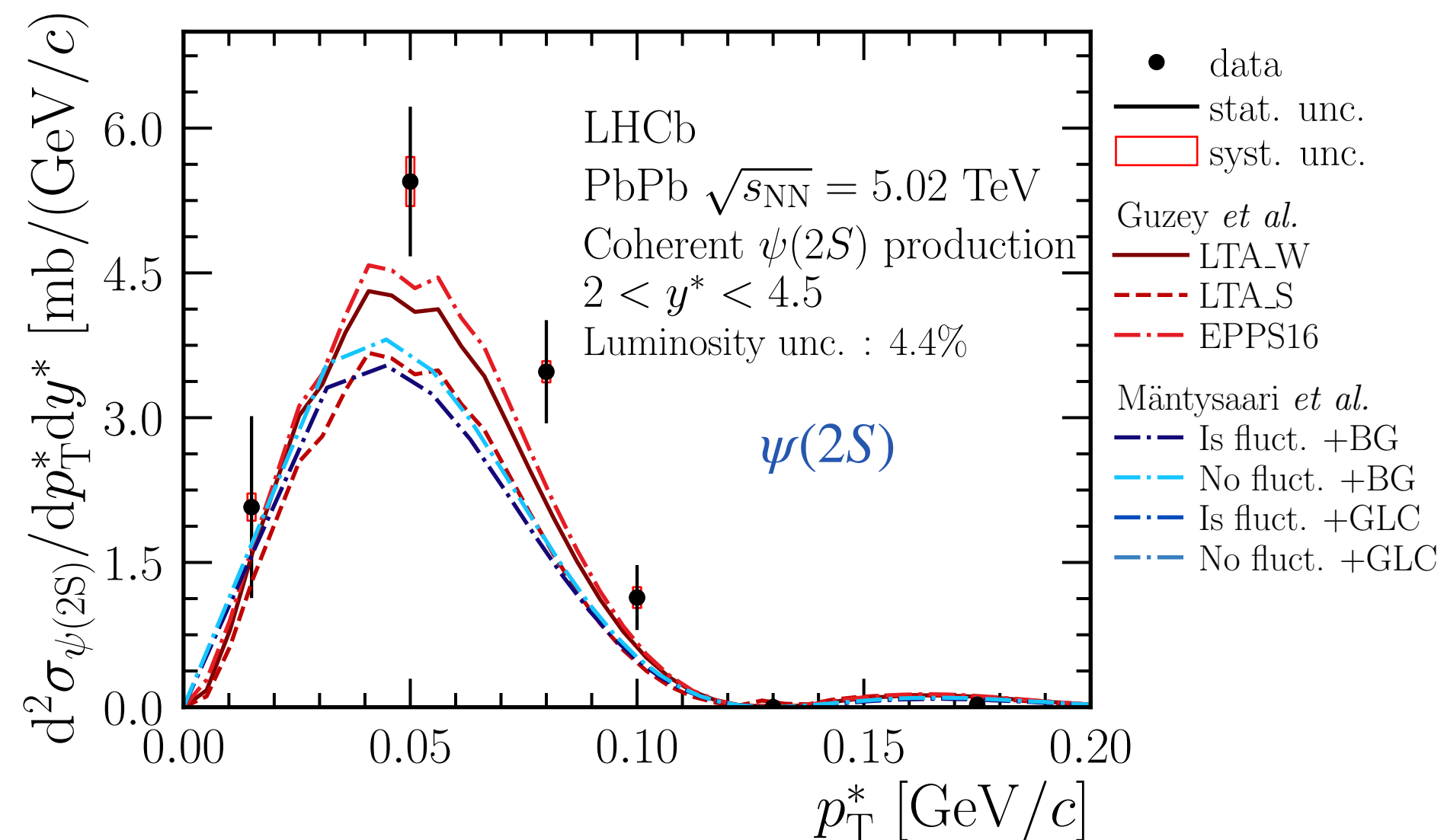
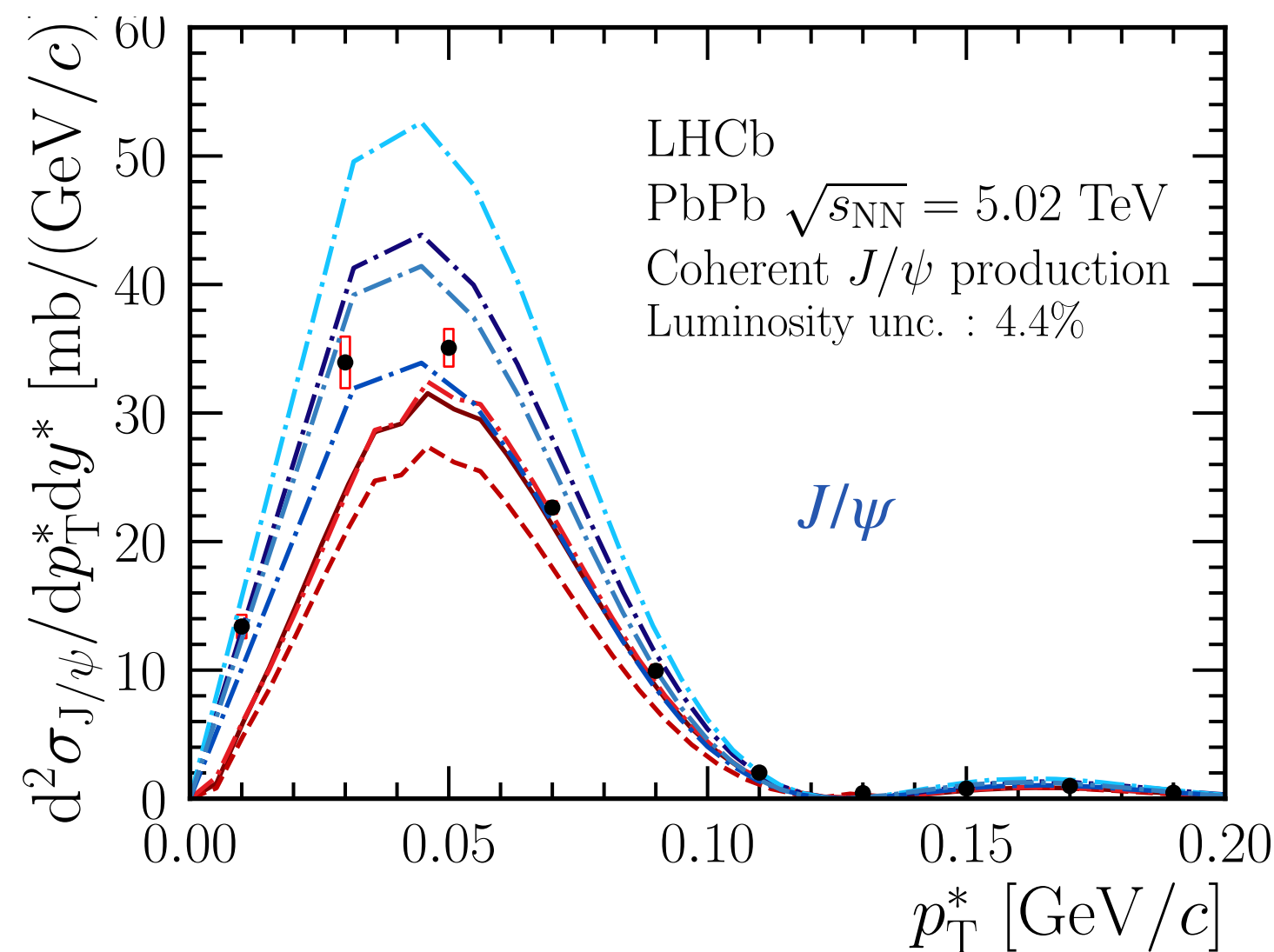
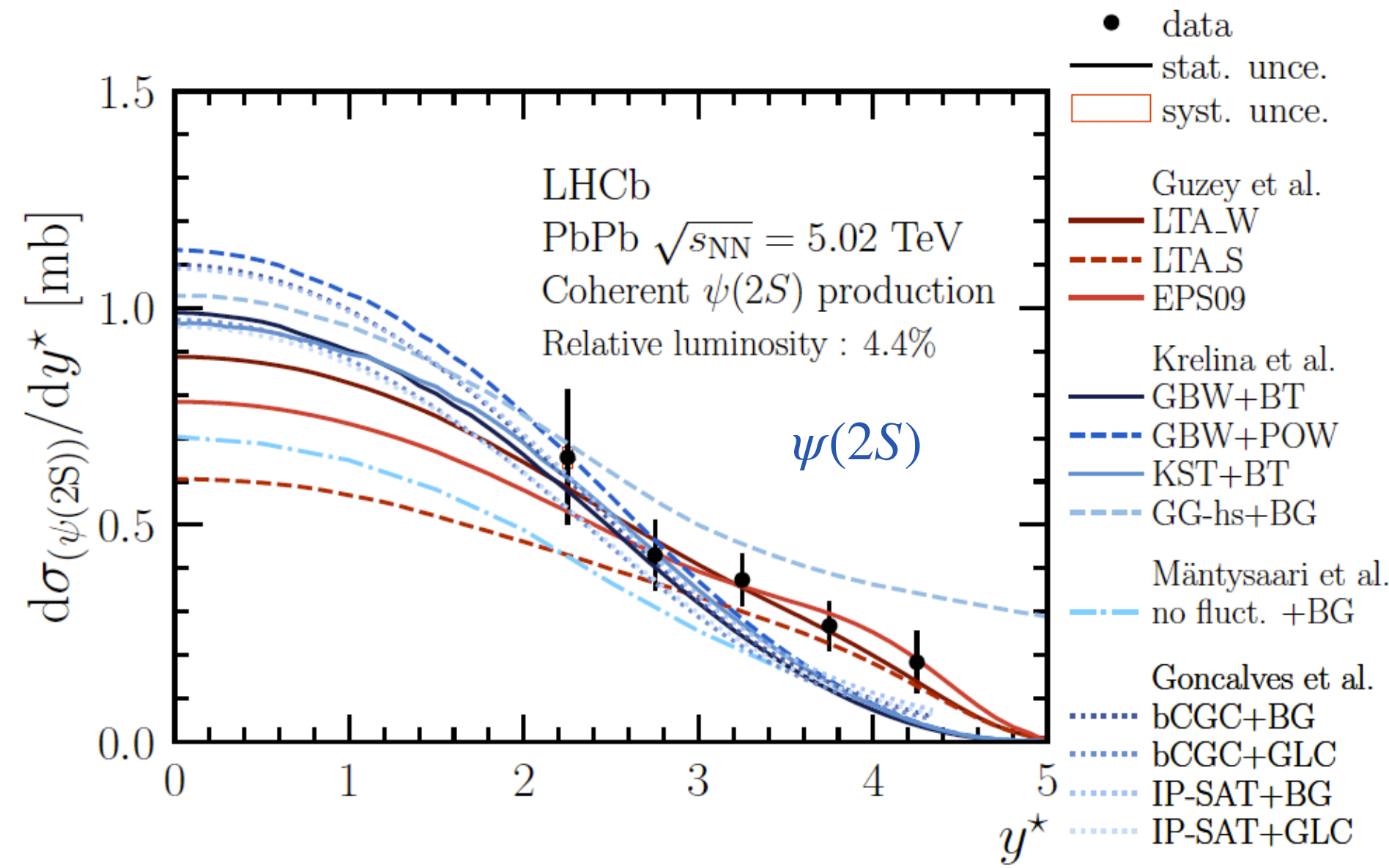
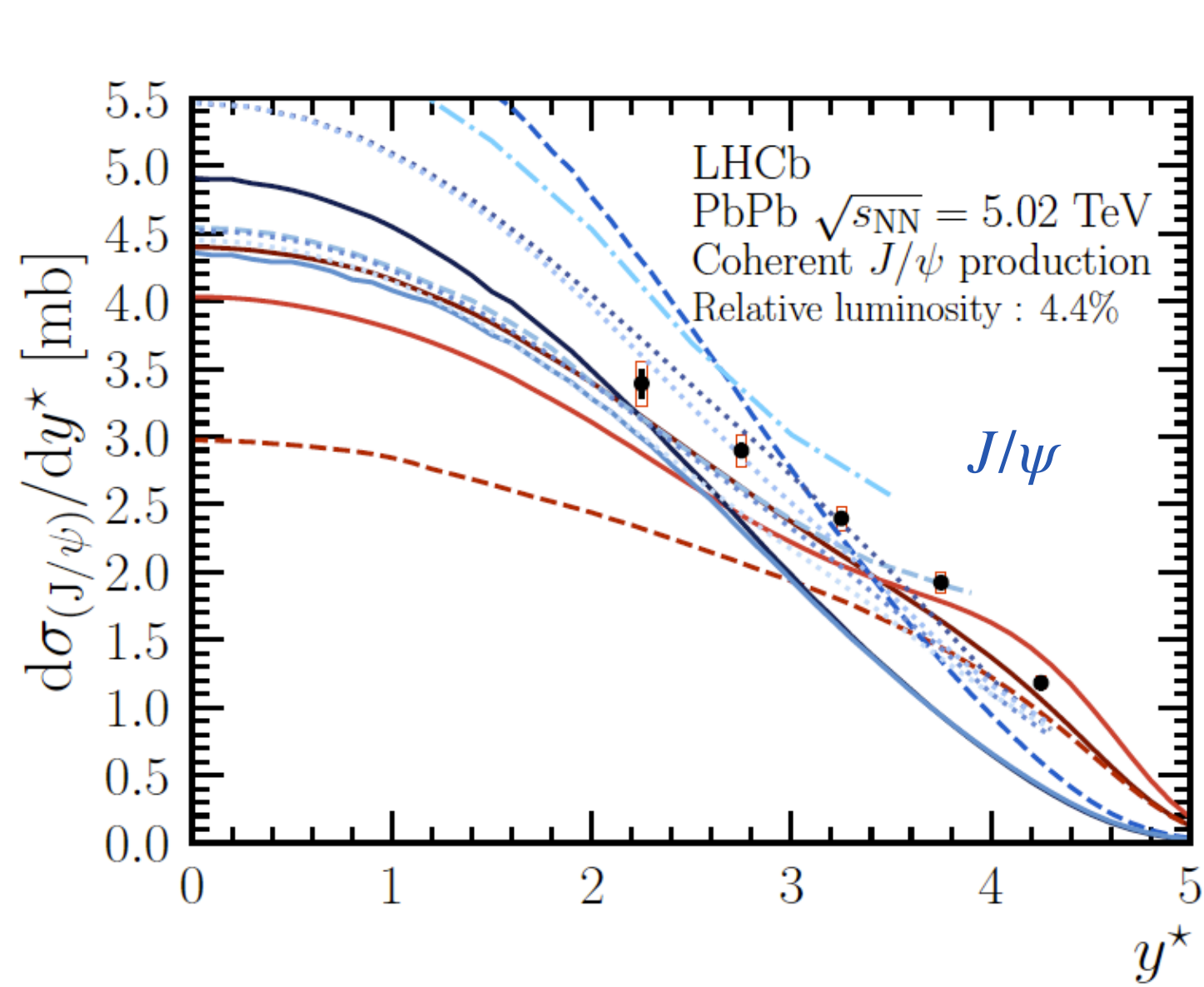
$$Q_{\text{exp}}^2 \equiv m_{D^0}^2 + p_{\text{T}}^2$$

$$x_{\text{exp}} \equiv 2 \frac{Q_{\text{exp}}}{\sqrt{s_{\text{NN}}}} e^{-y^*}$$



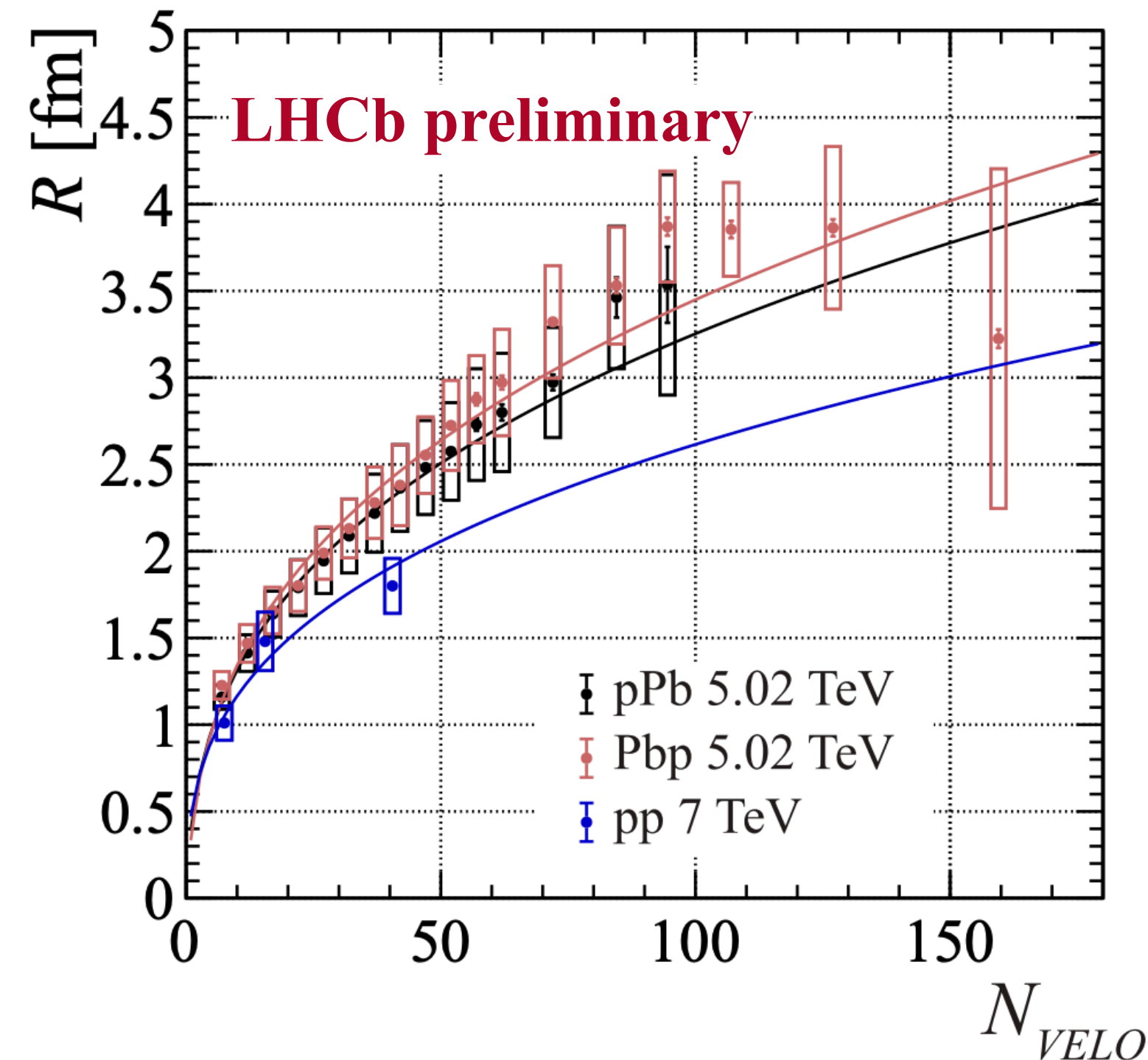
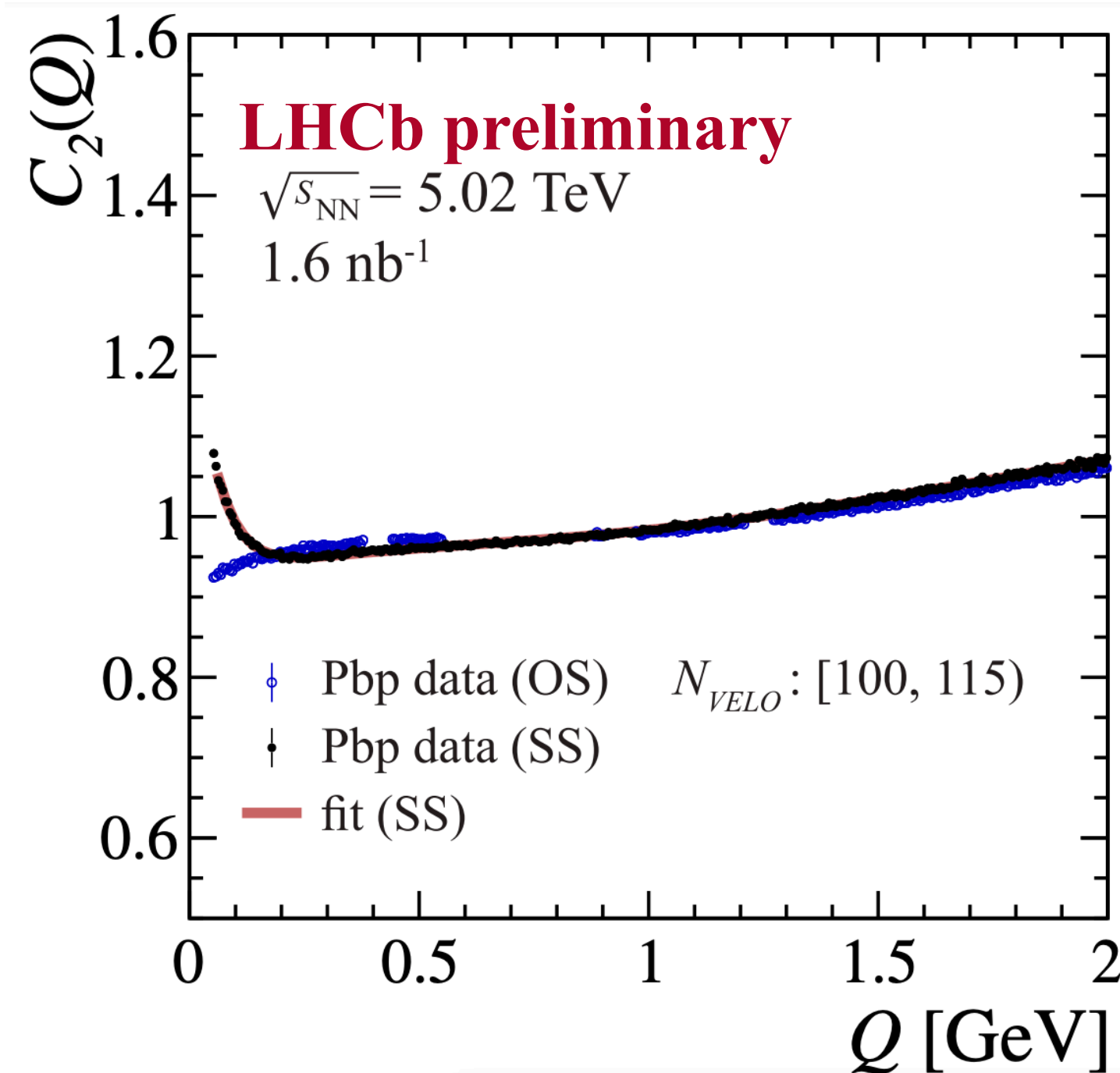
- First measurement of prompt  $\Xi_c^+$  in heavy ion collisions
- Measured via decay channel  $\Xi_c^+ \rightarrow pK^-\pi^+$
- Differential cross-section of prompt  $\Xi_c^+$  production measured as a function of  $p_T$  and rapidity
- $\Xi_c^+/\Lambda_c^+$  ratio constant over  $p_T$



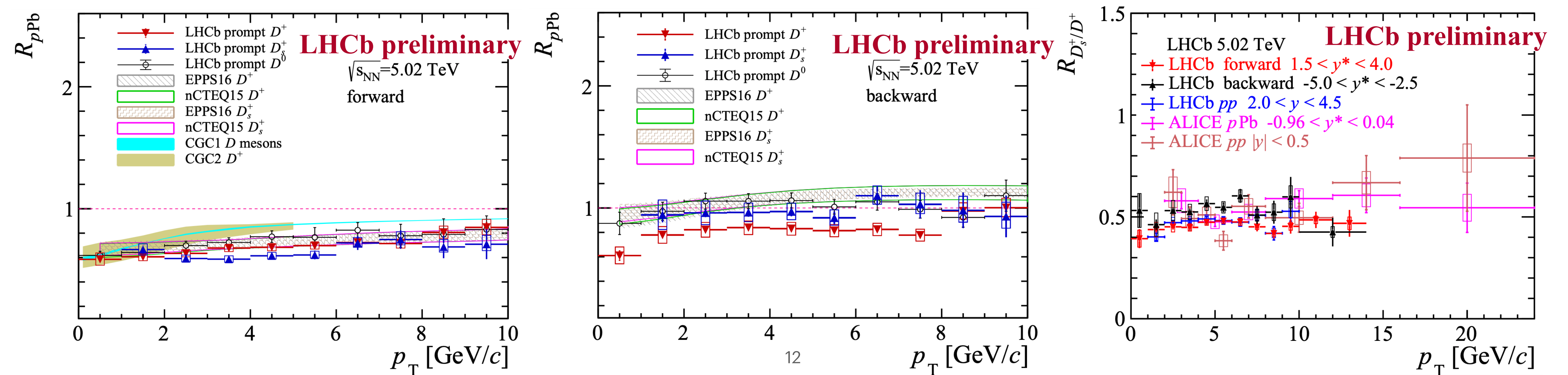


- Coherent charmonia produced by interaction between a photon and a pomeron
- Probe the nuclear gluon distribution functions at a scale  $Q^2 \approx m^2/4$
- First coherent  $\psi(2S)$  measurement in forward rapidities at the LHC
- Precise measurement of coherent  $J/\psi$  cross-section vs.  $p_T$  in PbPb UPC
- Reasonable description of data by models based on nPDF/CGC.
- $J/\psi$  uncertainty much smaller than the spread of theoretical curves

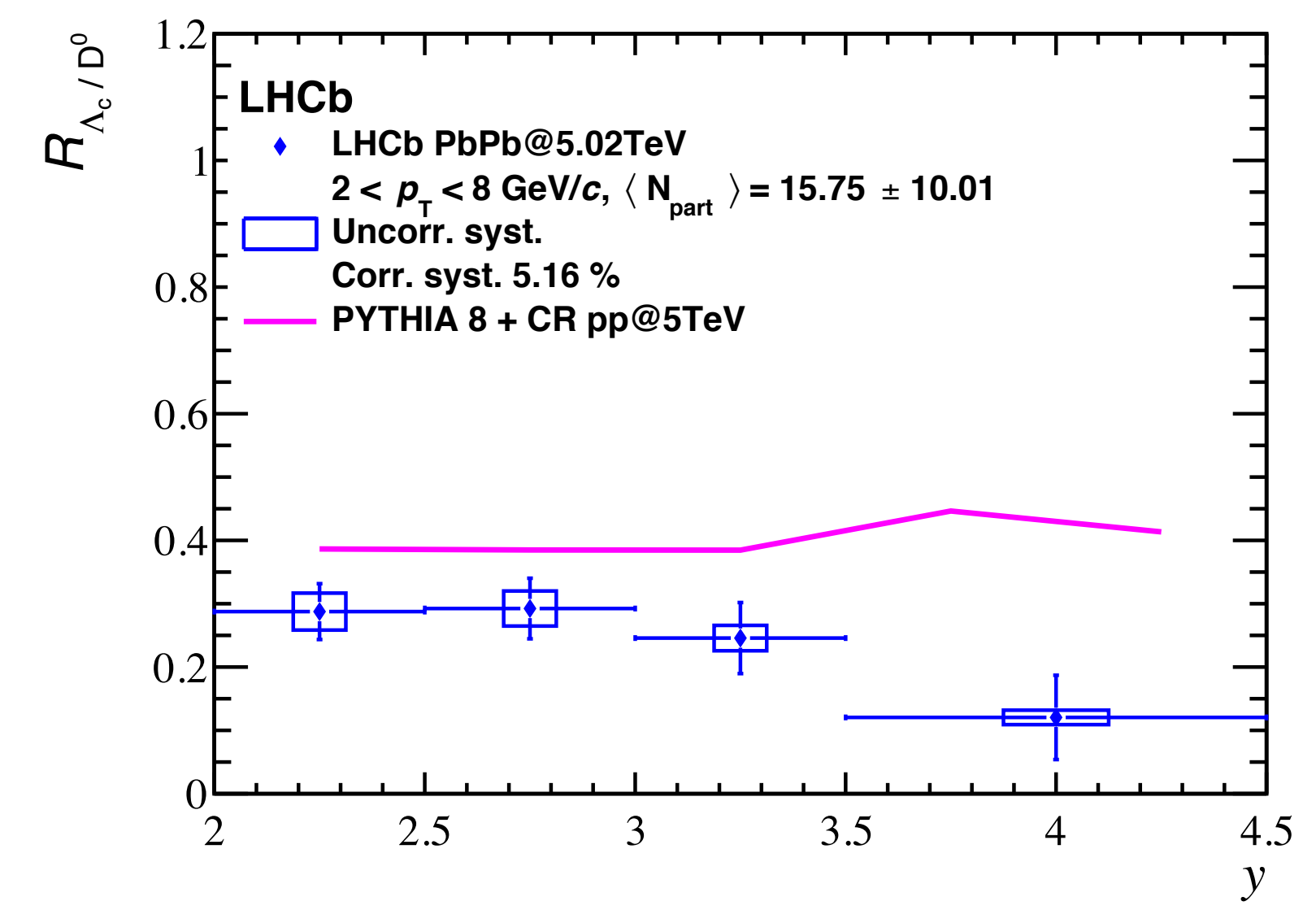
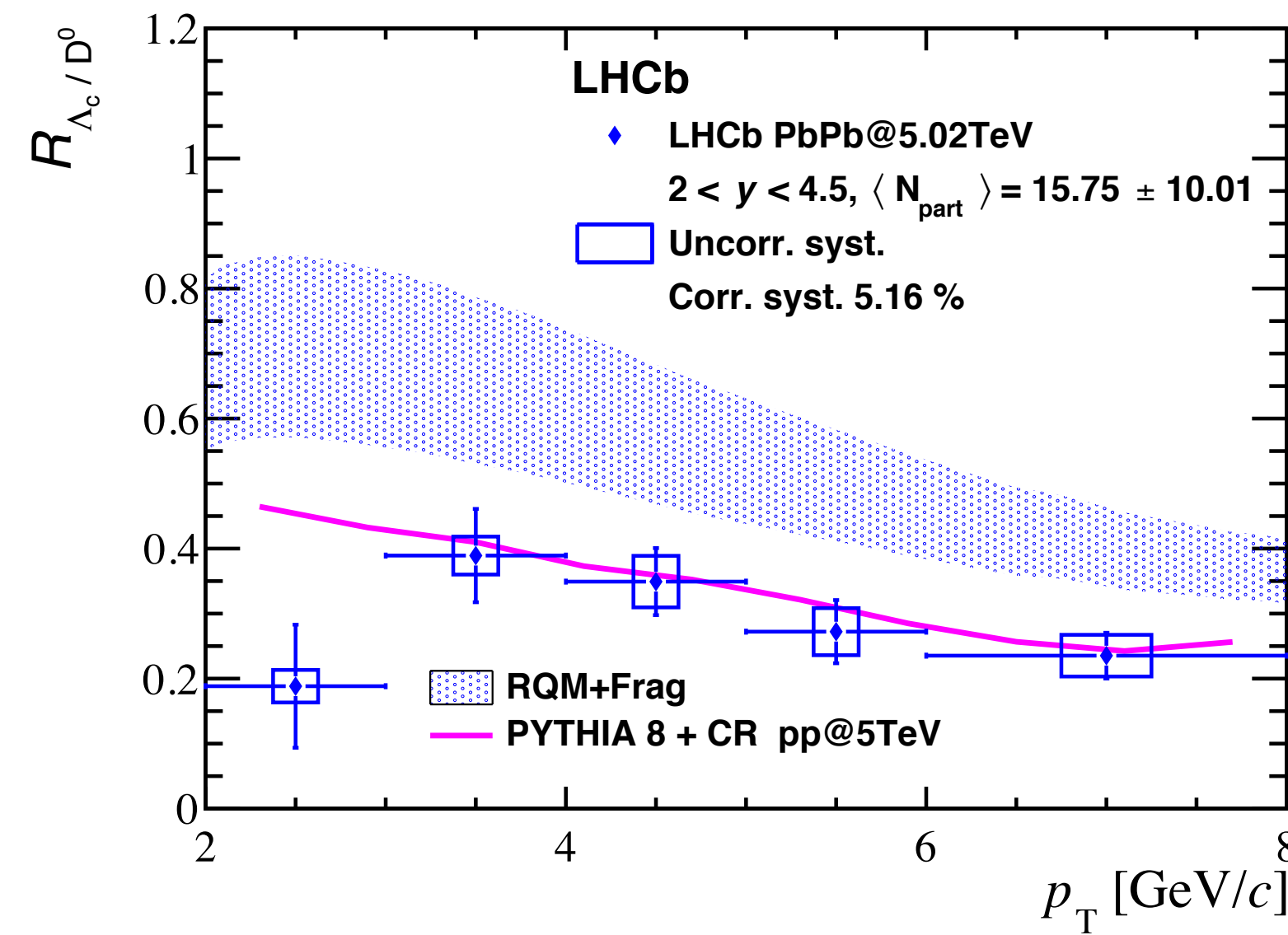
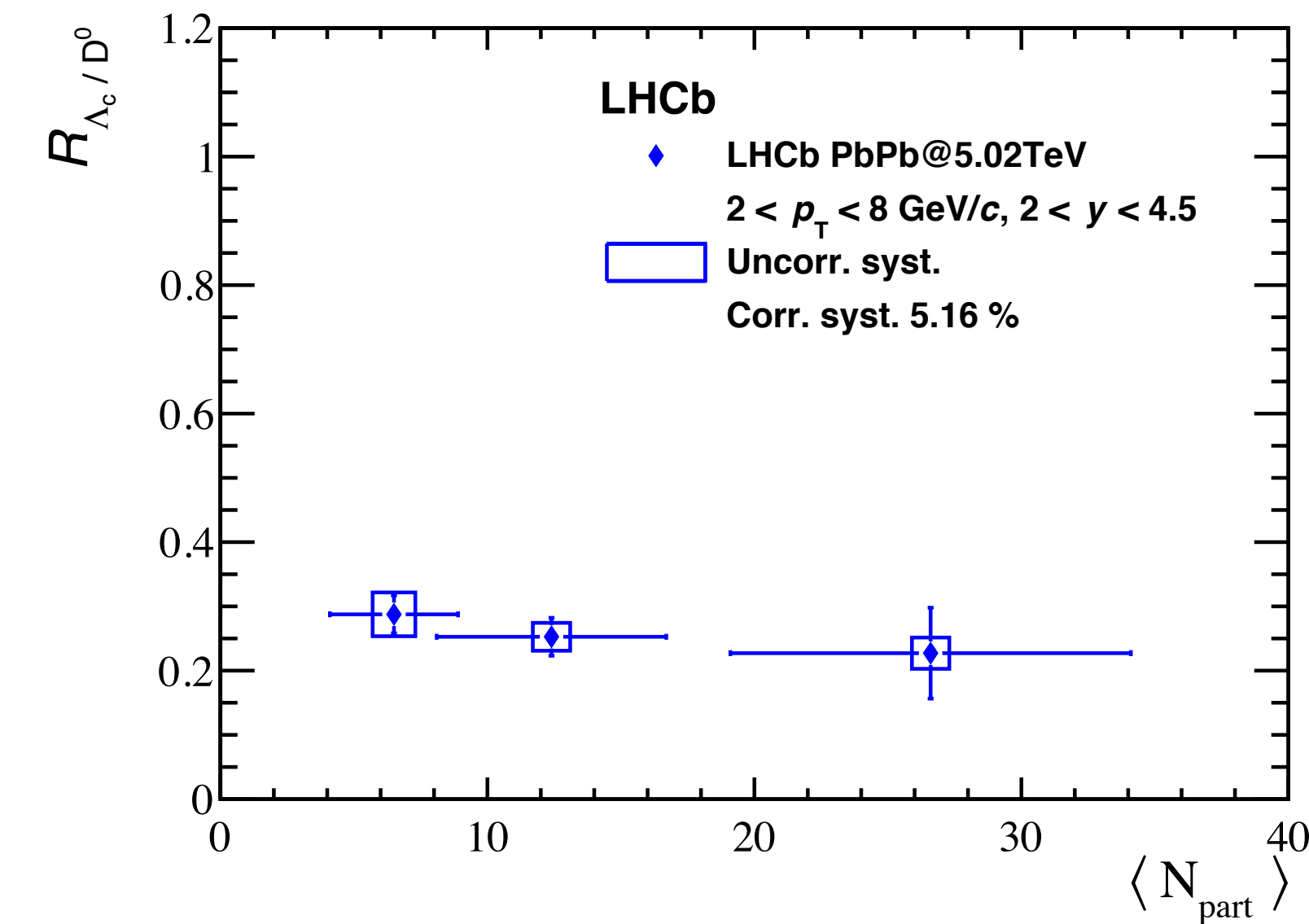
- BEC: enhancement of same-sign charged pions with small four-momentum difference squared
- Insight into the geometrical size of the particle emitting source
- **First BEC measurement in the forward region in  $p$ Pb collisions**
- Correlation radii scale with cube root of the reconstructed charged-particle multiplicity, compatible with hydrodynamic model expectation



- First measurement of prompt  $D^+$  and  $D_s^+$  mesons in forward rapidity in heavy ion collisions
- Forward:
  - significant suppression consistent with nPDFs
  - consistent between  $D^0$ ,  $D^+$  and  $D_s^+$
- Backward:
  - $D_s^+$  consistent with nPDFs
- $D_s^+/D^+$  ratio consistent with LHCb  $pp$  result and ALICE  $pp/p$ Pb measurements in midrapidity



- First measurement of prompt  $\Lambda_c^+/D^0$  in forward rapidity in PbPb collisions (up to 60% centrality)
- PYTHIA8 + Color Reconnection: compatible with data within  $3\sigma$
- Statistical Hadronization Model is above the data
- Needs better understanding of charm hadronization



- Flat dependence vs.  $\langle N_{part} \rangle$

- Enhancement at intermediate  $p_T$

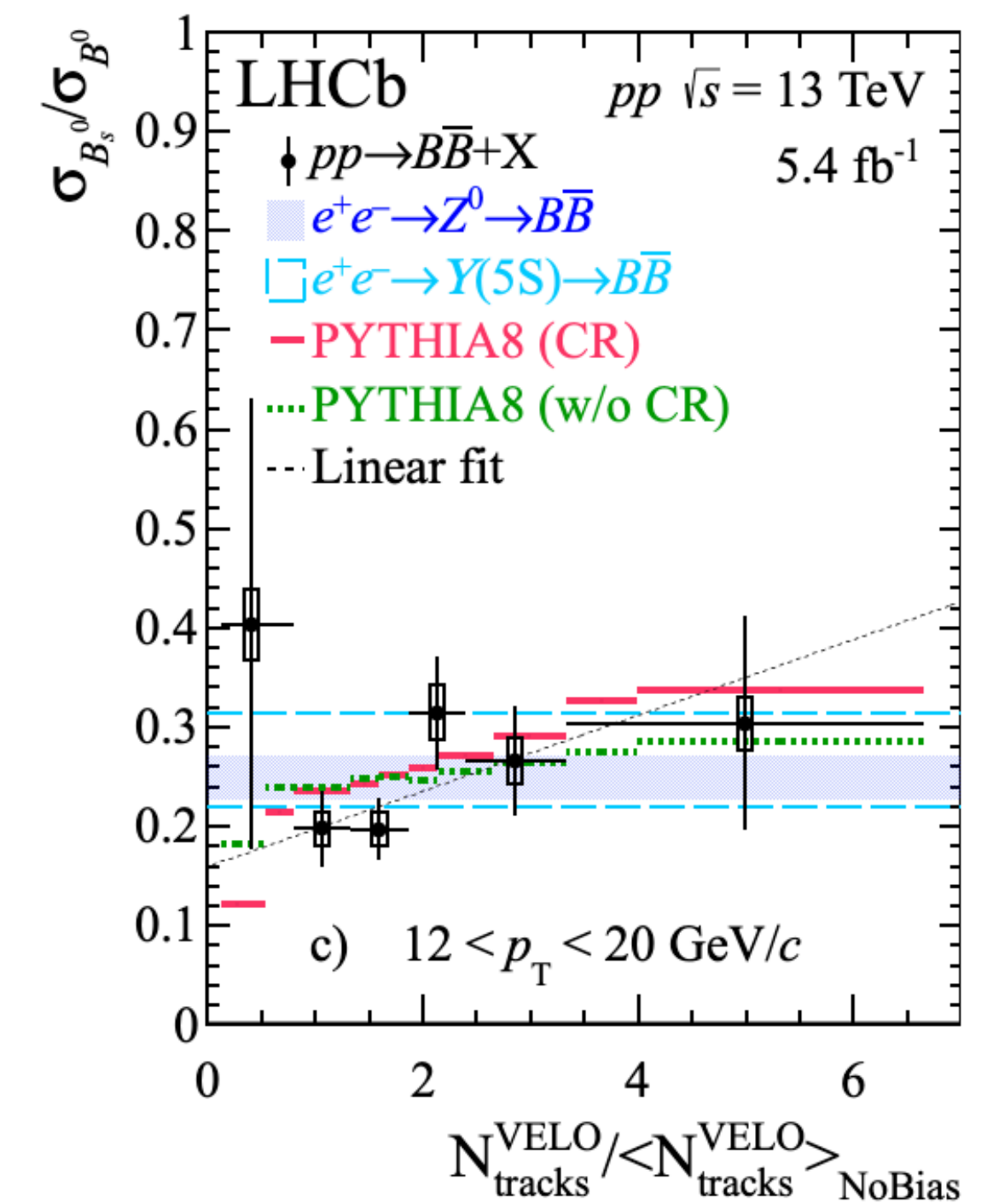
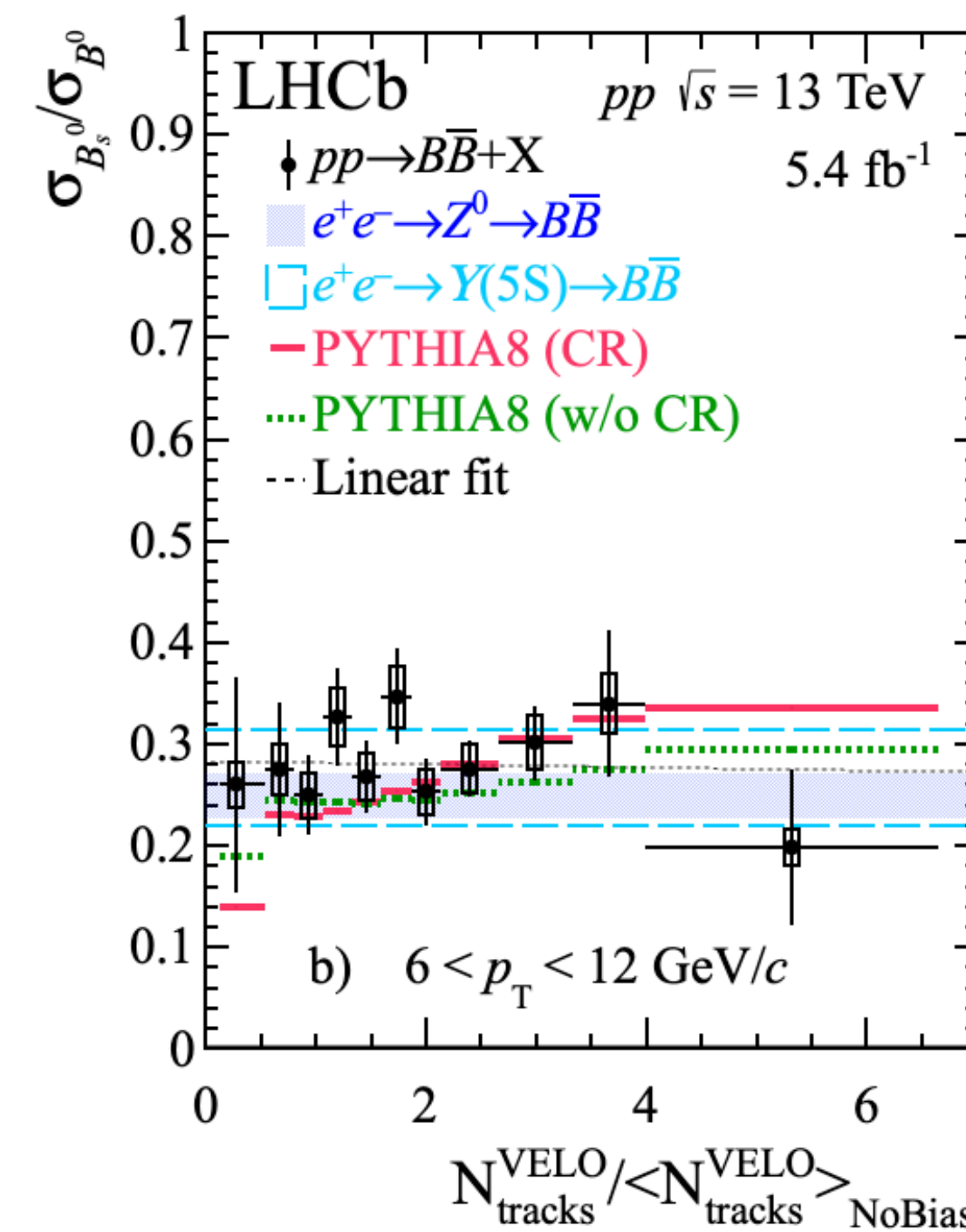
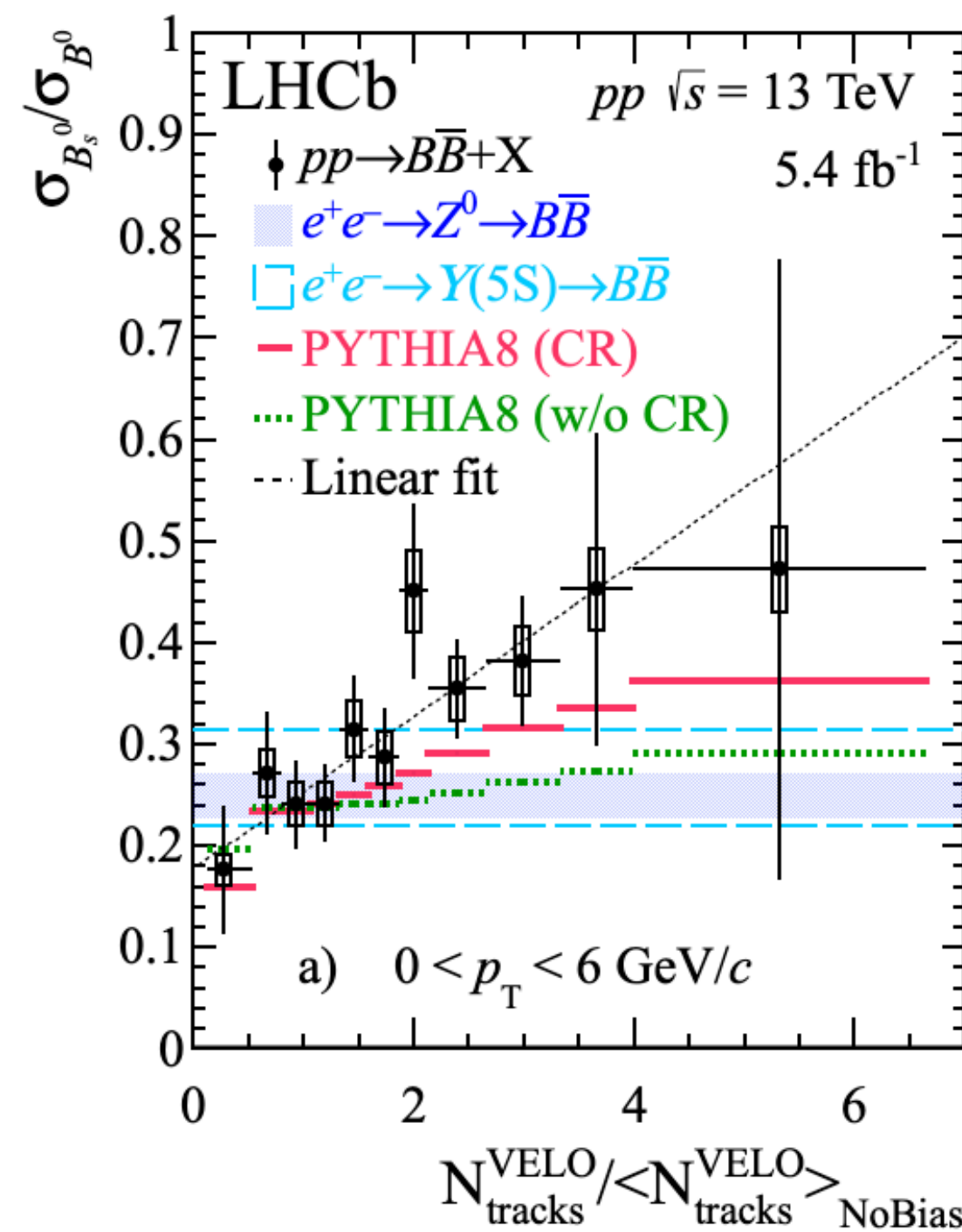
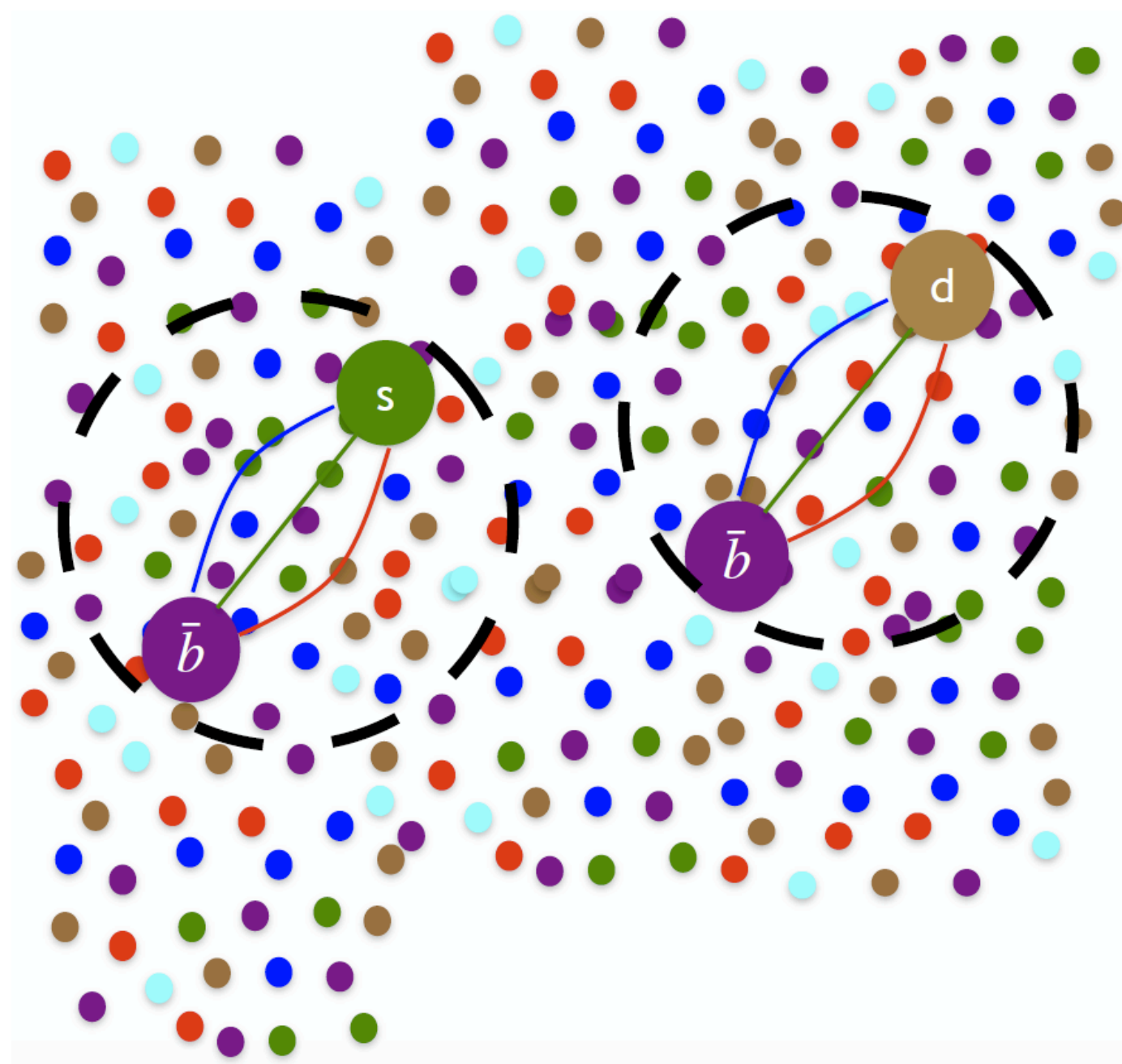
- Compatible with flat dependence vs. rapidity

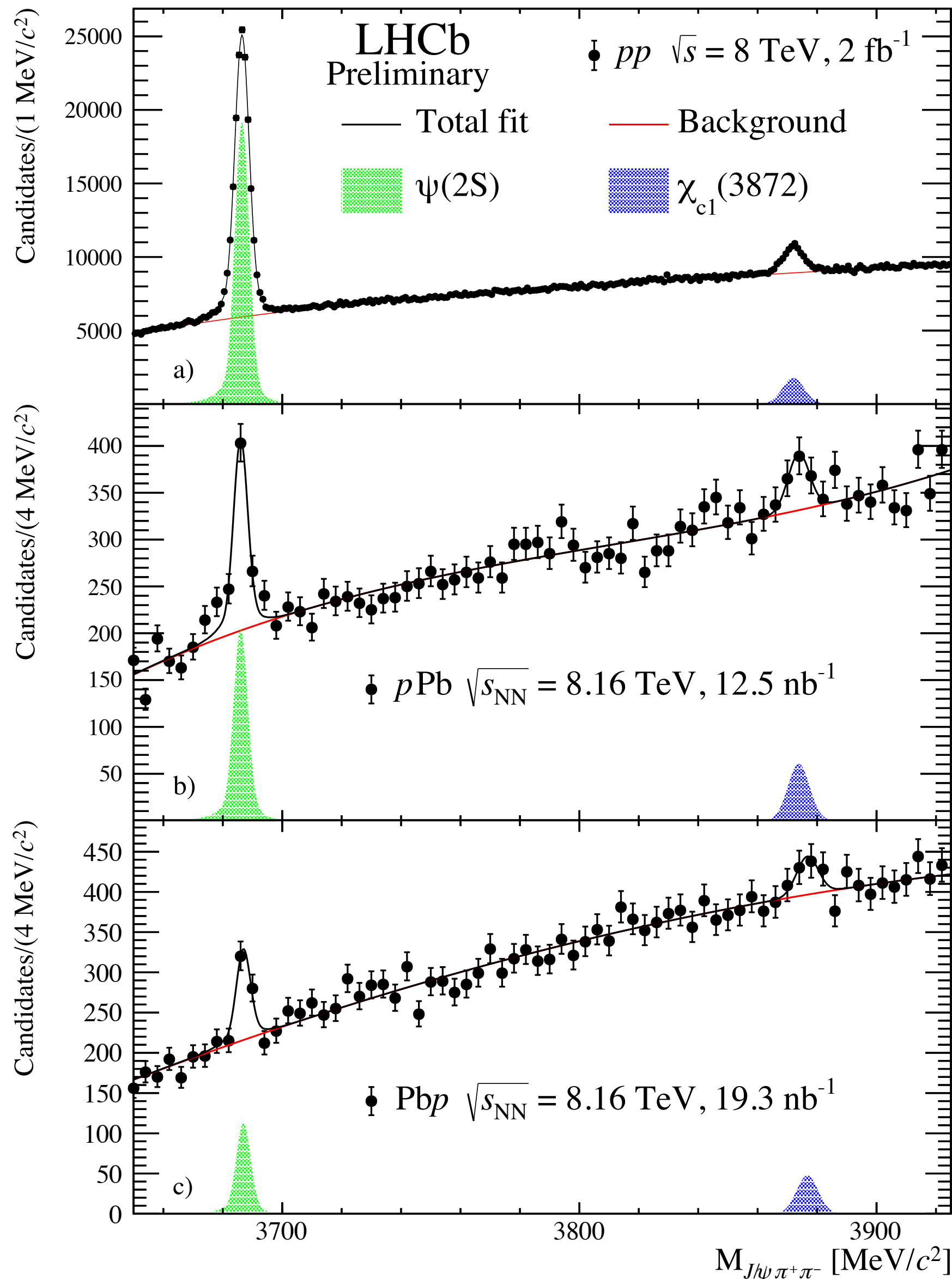
# $b$ hadronization in high multiplicity $pp$ collisions at 13 TeV

Chenxi Gu 28/03 Tuesday 17:10; J. Napora 28/03 Tuesday 18:15

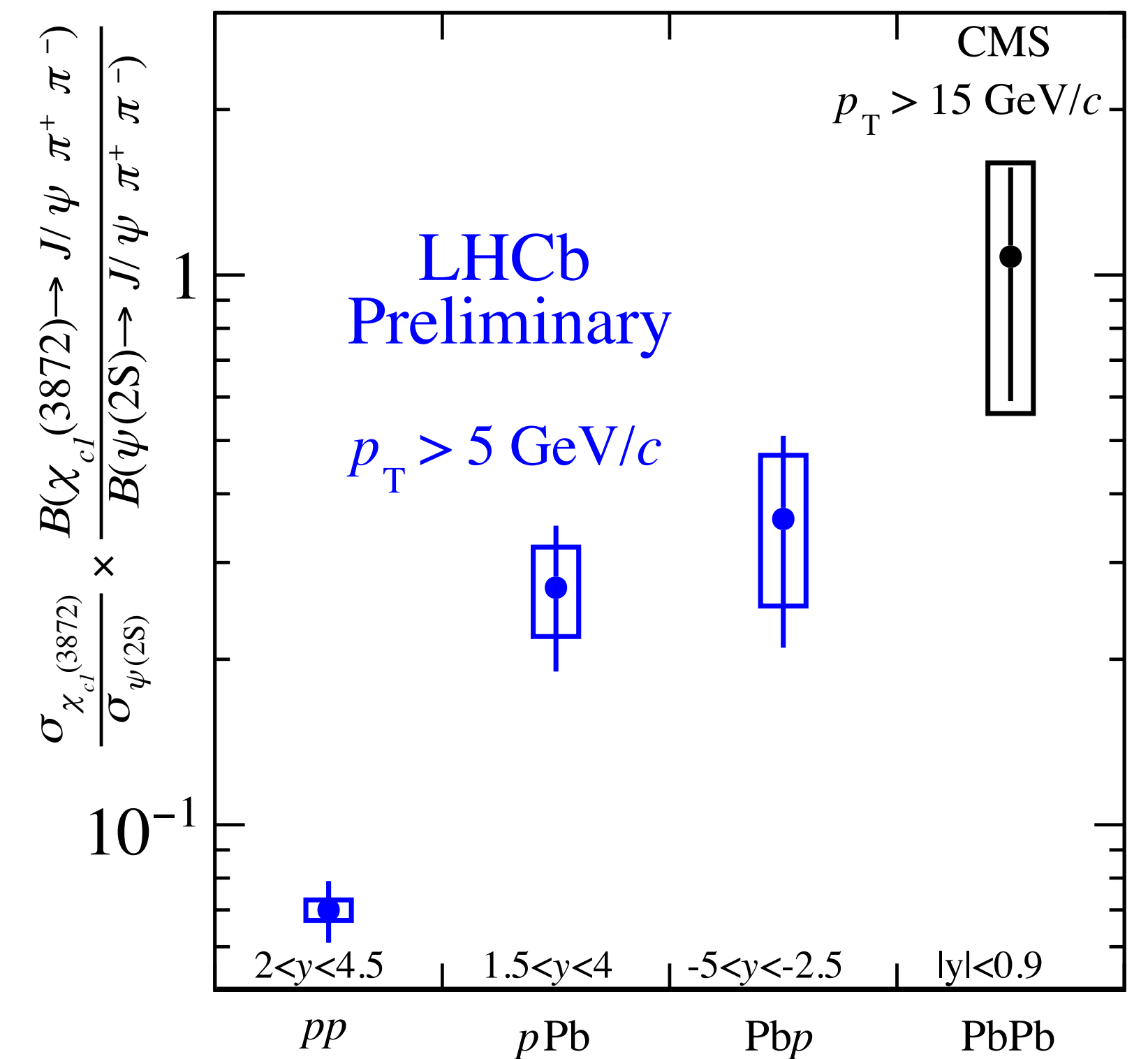
- Production of  $b\bar{b}$  pairs at hadron colliders dominated by hard parton-parton interactions in the initial stages, well described by pQCD calculations
- Enhanced strangeness production in light-quark baryons and mesons observed by ALICE [Nature Phys. 13 \(2017\) 535](#)
- Possible quark coalescence  $\rightarrow$  enhanced  $B_s^0/B^0$  ratio with increasing particle multiplicity, especially at low  $p_T$

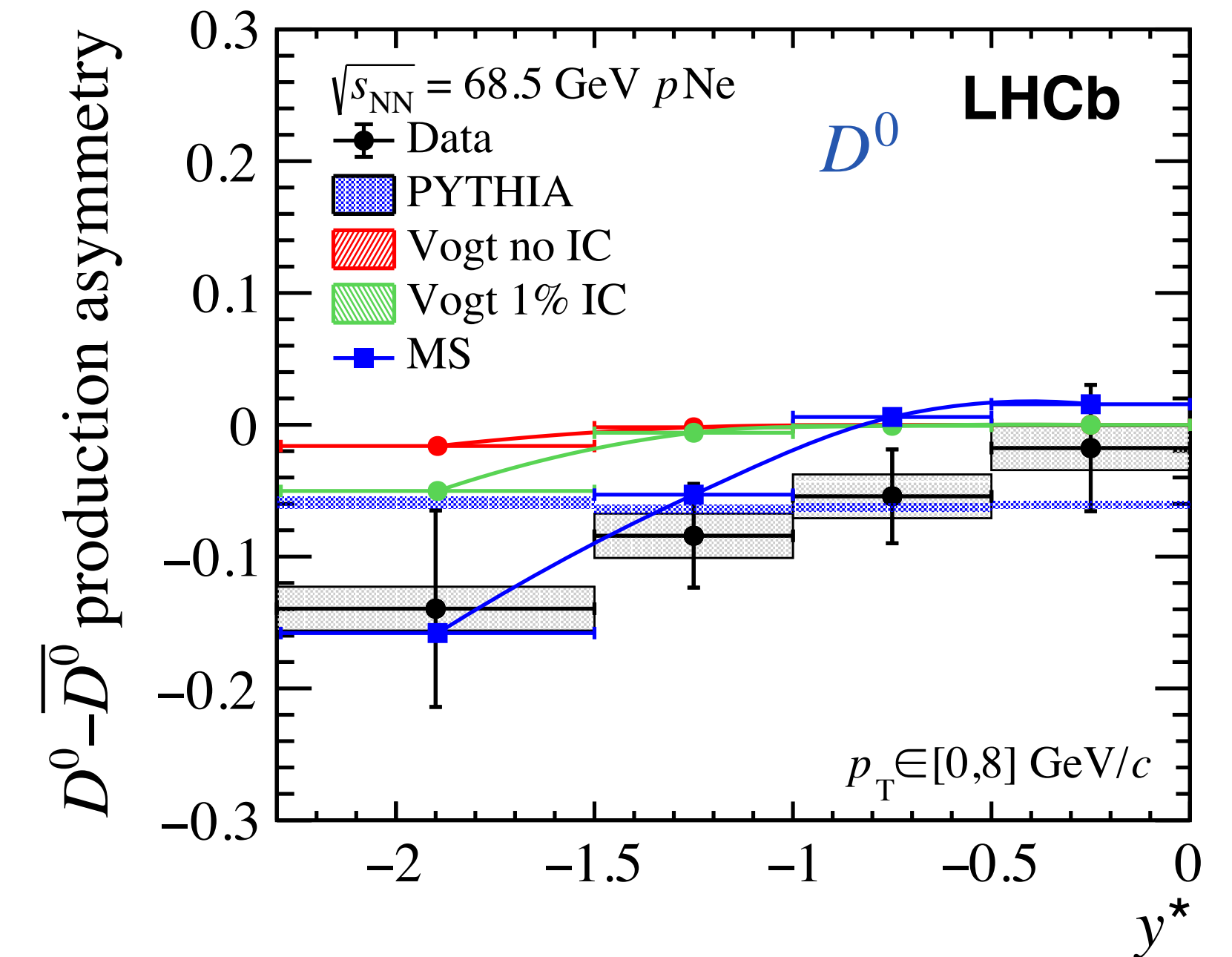
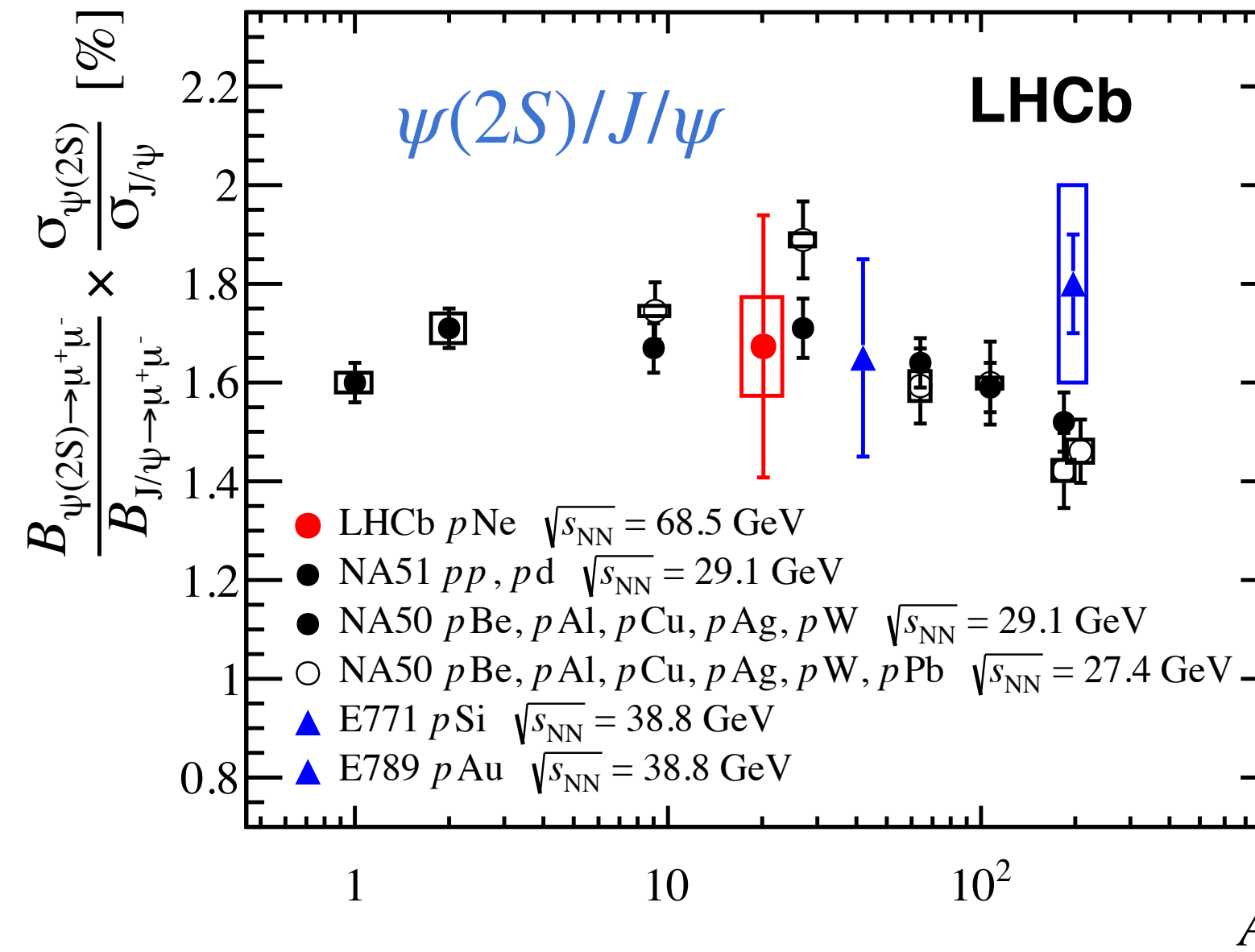
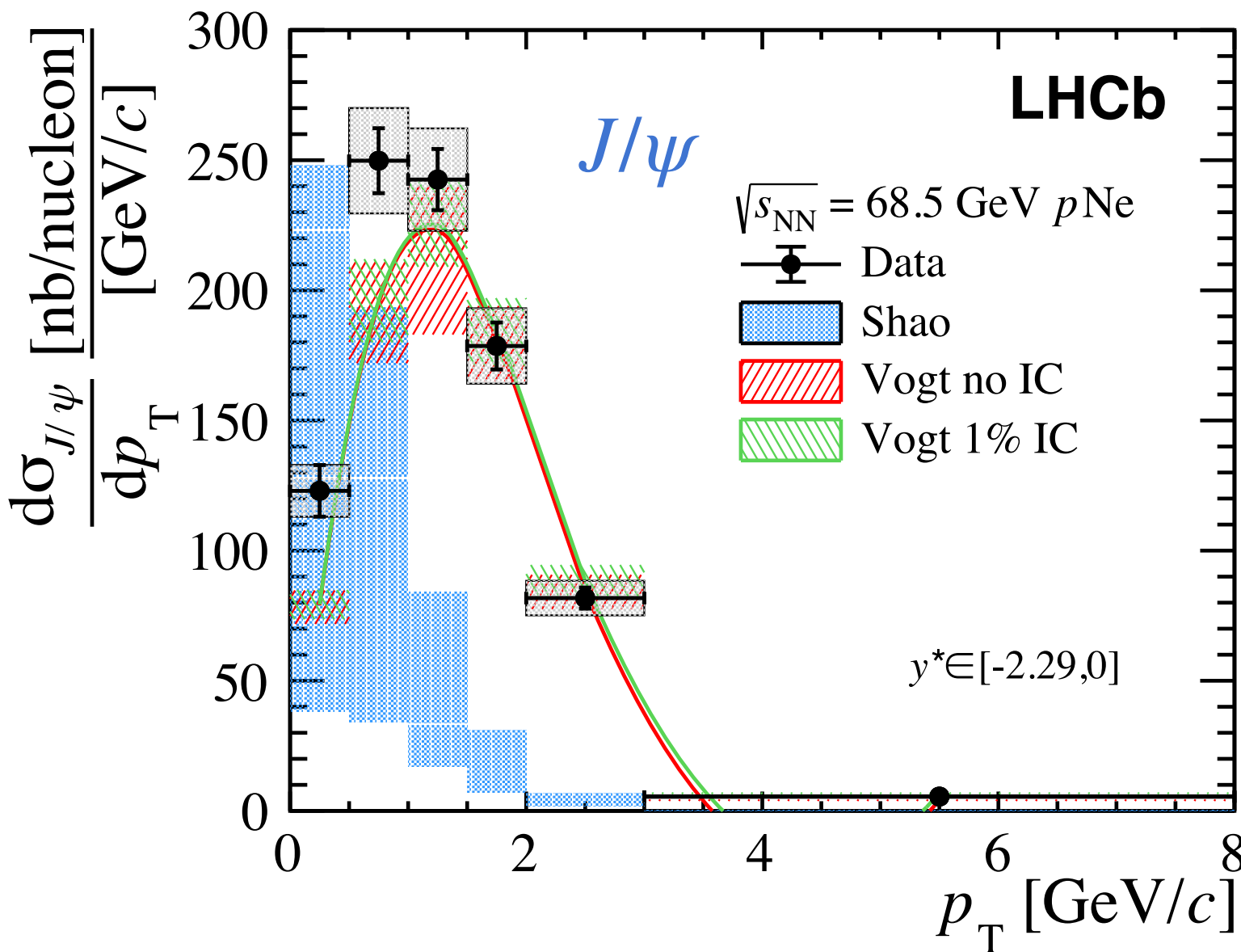
$$B_{(s)}^0 \rightarrow (J/\psi \rightarrow \mu^+\mu^-)\pi^+\pi^-$$



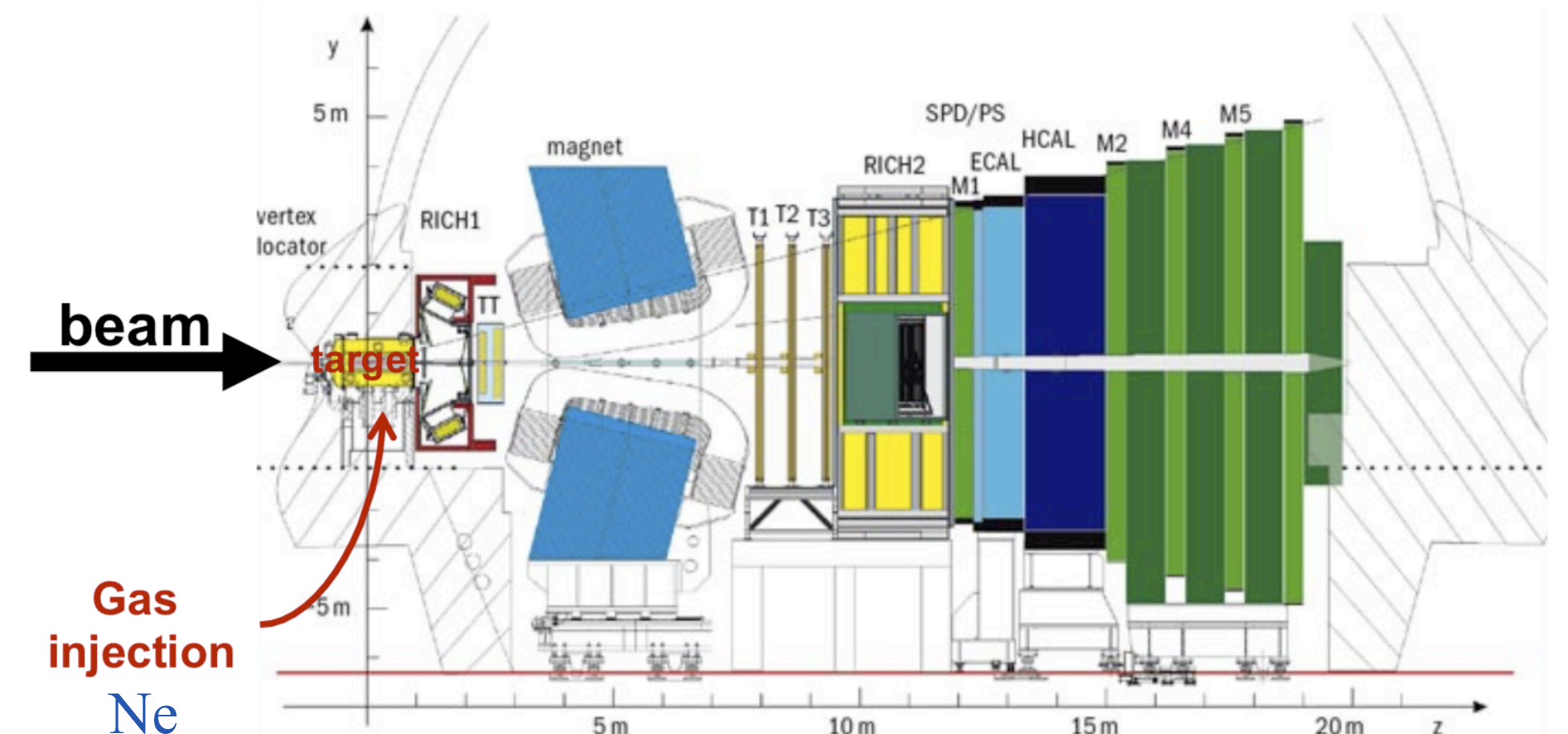


- First  $\chi_{c1}(3872)$  result in  $p\text{Pb}$  collisions
- $\chi_{c1}(3872)$  breaking up in higher multiplicity environment
  - probe inner structure
  - test coalescence with 4 valence quarks
- $\chi_{c1}(3872)/\psi(2S)$  ratio increases with system size
- Coalescence dominates over break-up?



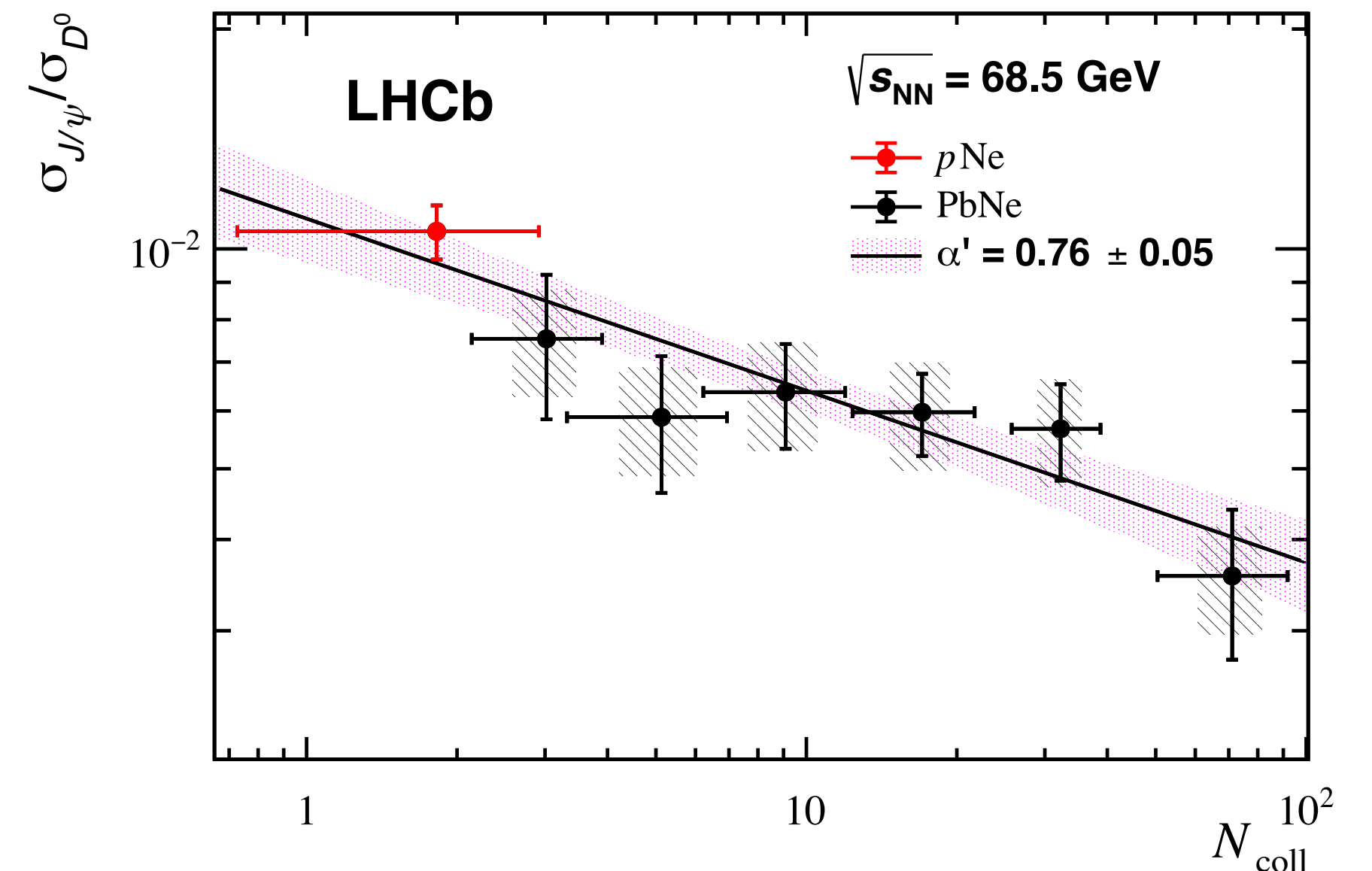
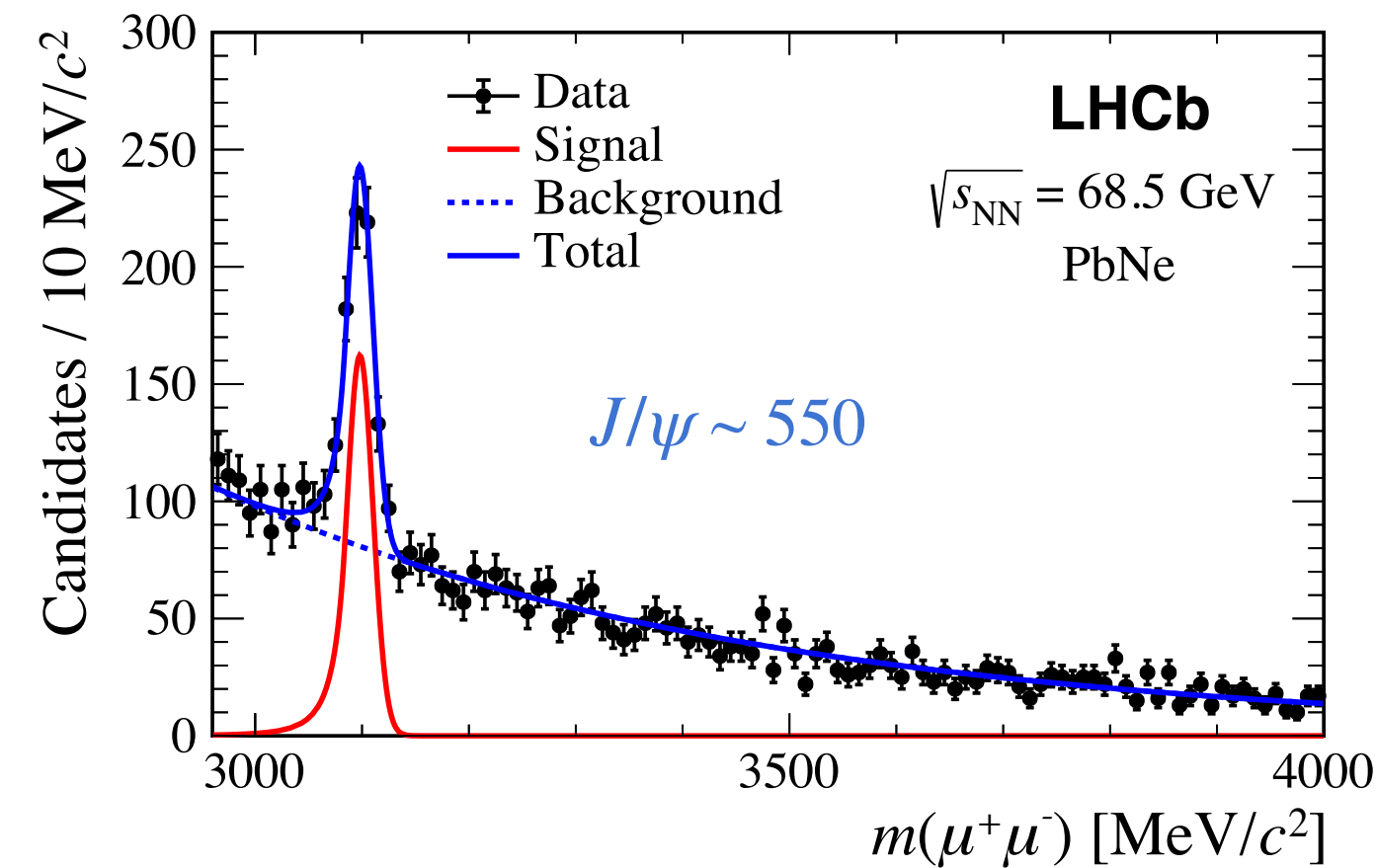
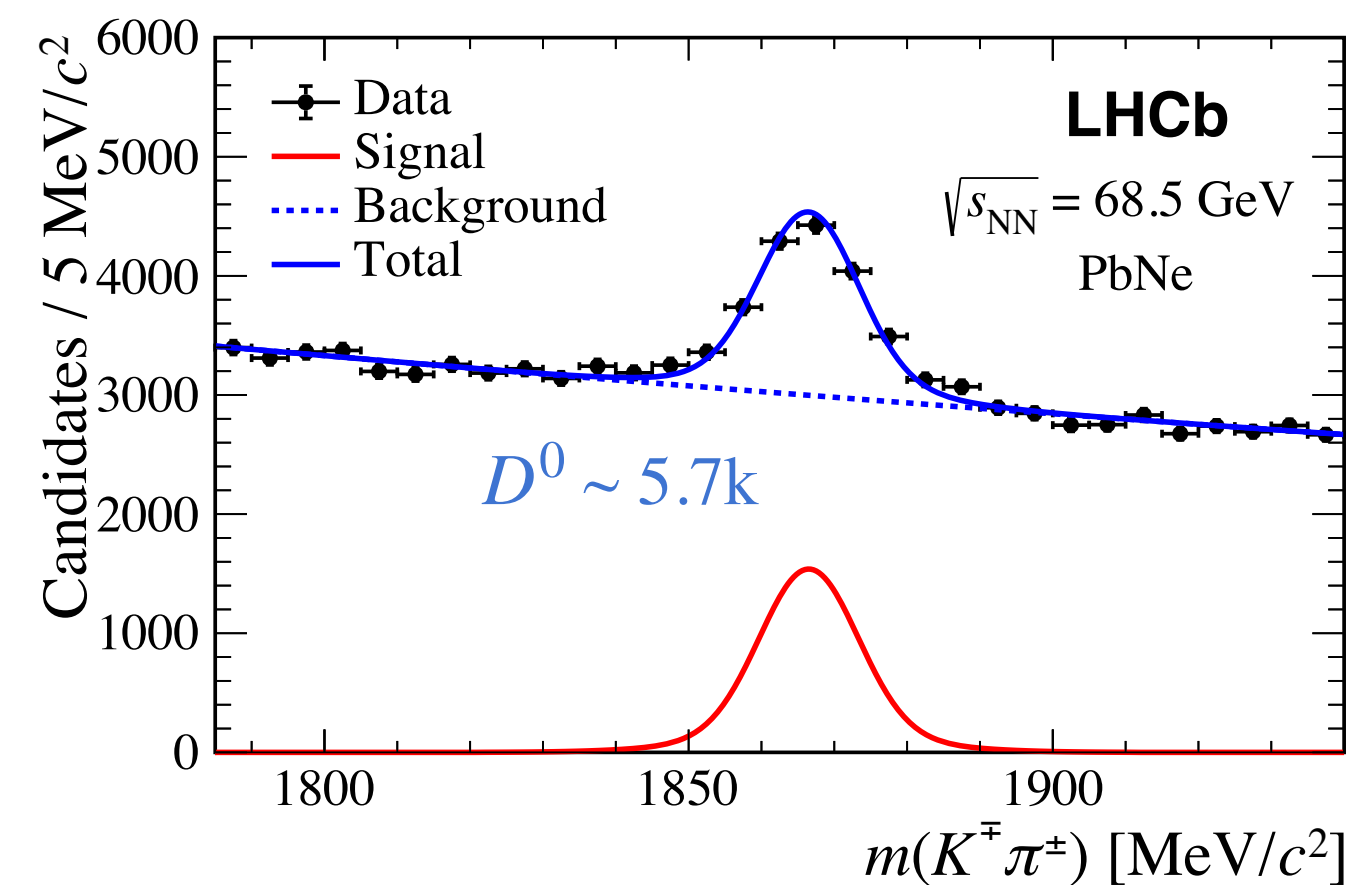
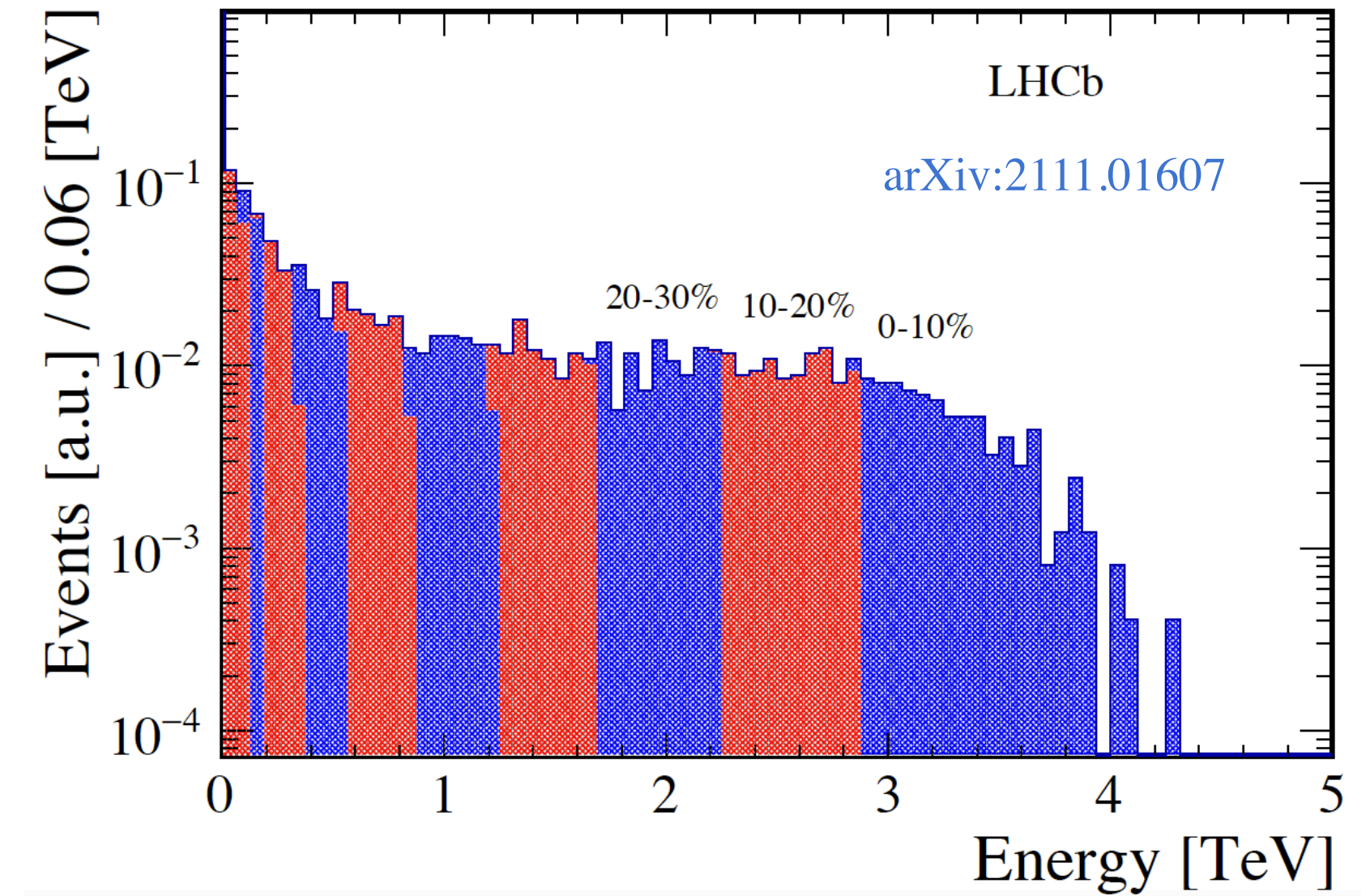


- Differential  $J/\psi$  cross-section measured, agrees with NLO pQCD model with and without intrinsic charm contribution
- $\psi(2S)$  to  $J/\psi$  ratio in good agreement with other proton-nucleus measurements at small values of target atomic mass number  $A$ .
- Largest  $D^0$  asymmetry  $\sim 15\%$  at  $y^* \sim -2.29$ , consistent with MS model (1% Intrinsic Charm + 10% recombination).
- **The first measurement of  $\psi(2S)$  with SMOG**





- **The first measurement in fixed-target nucleus-nucleus collisions at the LHC, a milestone for the SMOG program**
- Search for the potential formation of quark-gluon plasma. Look for the onset of the transition from ordinary hadronic matter to the QGP.
- Additional suppression of  $J/\psi$  compared to  $D^0$  in central collisions
- $J/\psi/D^0$  vs.  $N_{coll}$  slope agrees with measurements from proton-nucleus collisions by NA50 Phys. Lett. B 410 (1997) 337
- **No anomalous  $J/\psi$  suppression is observed that could indicate the formation of QGP**



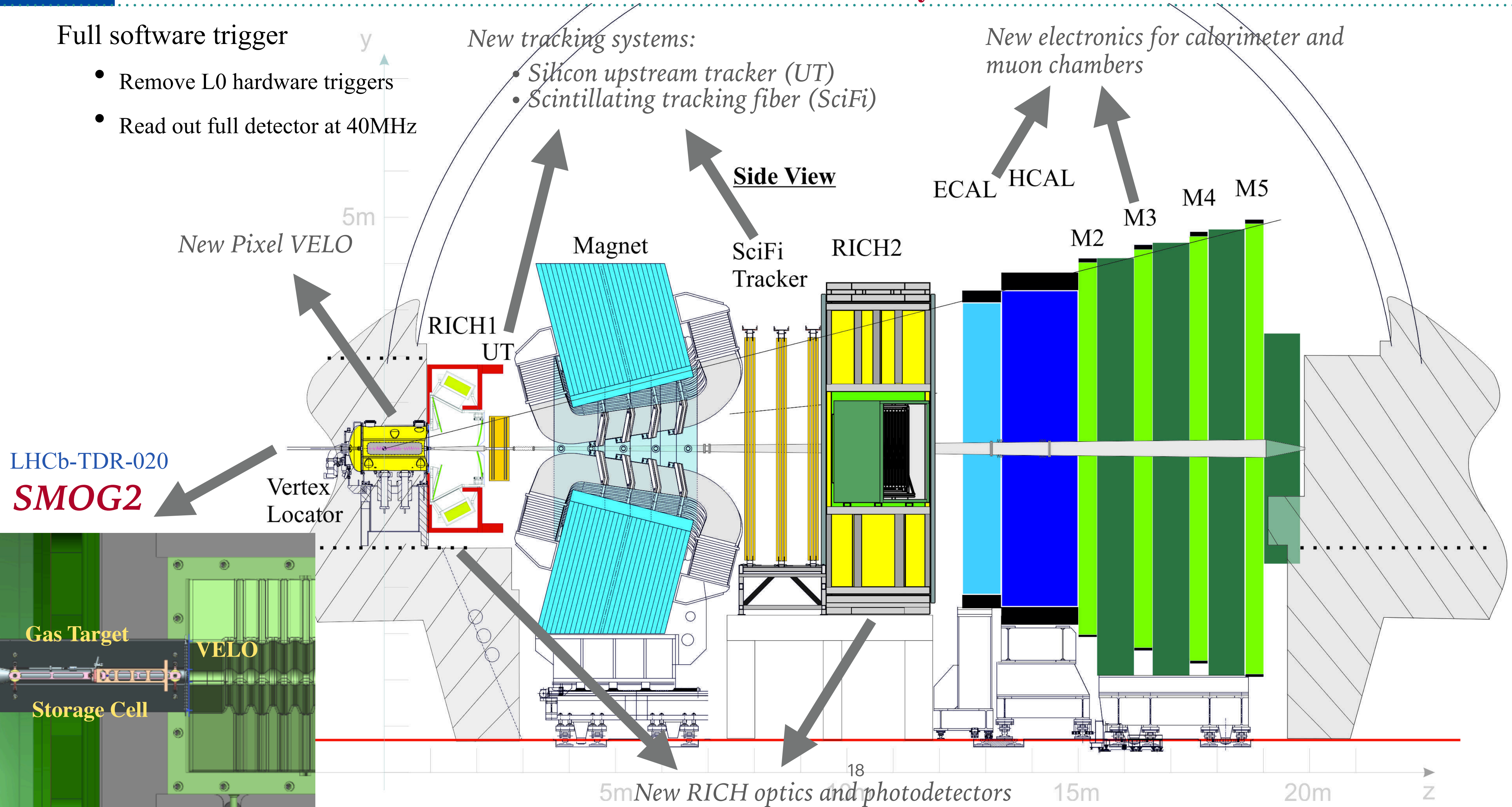
## Full software trigger

- Remove L0 hardware triggers
- Read out full detector at 40MHz

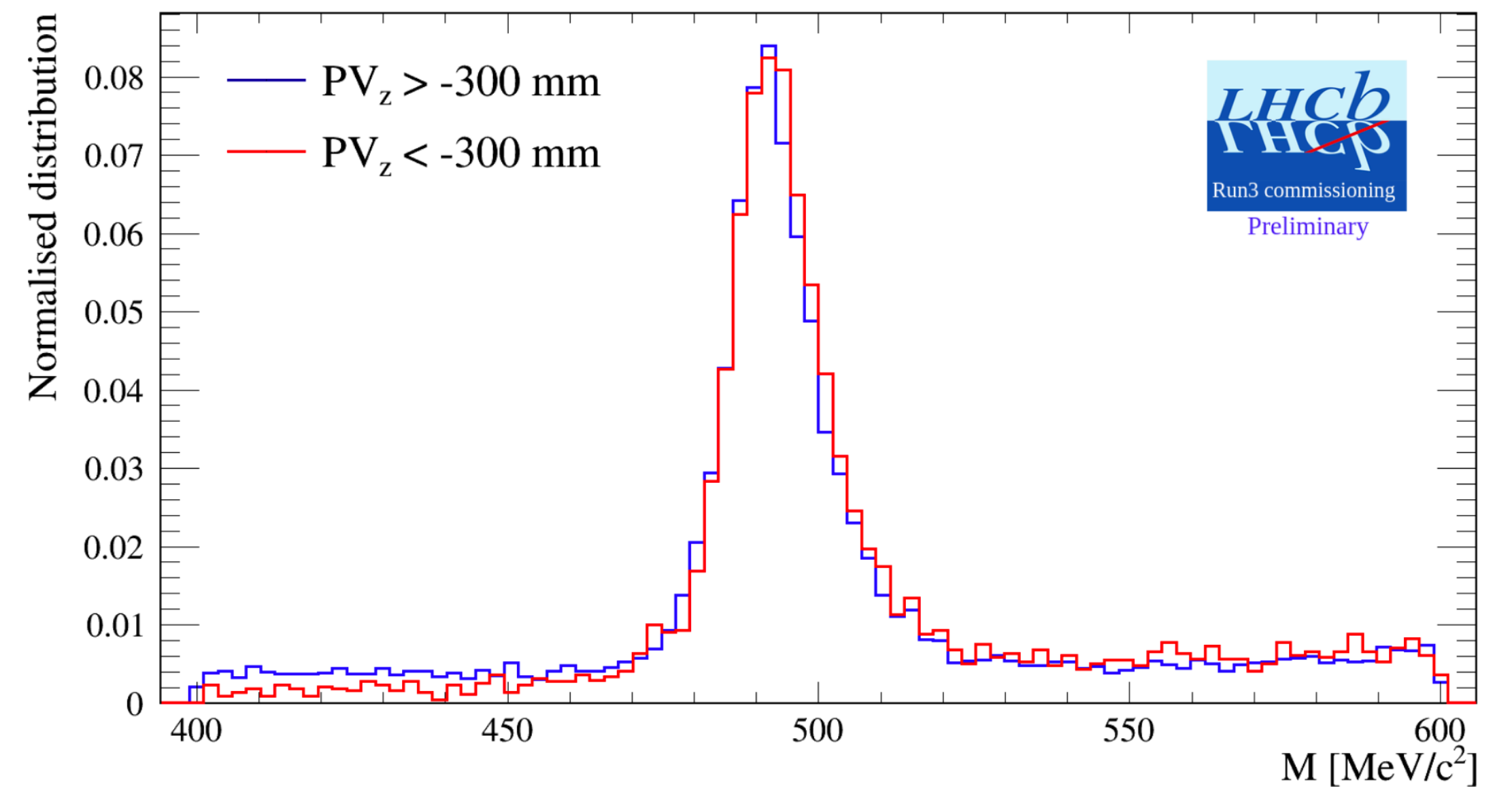
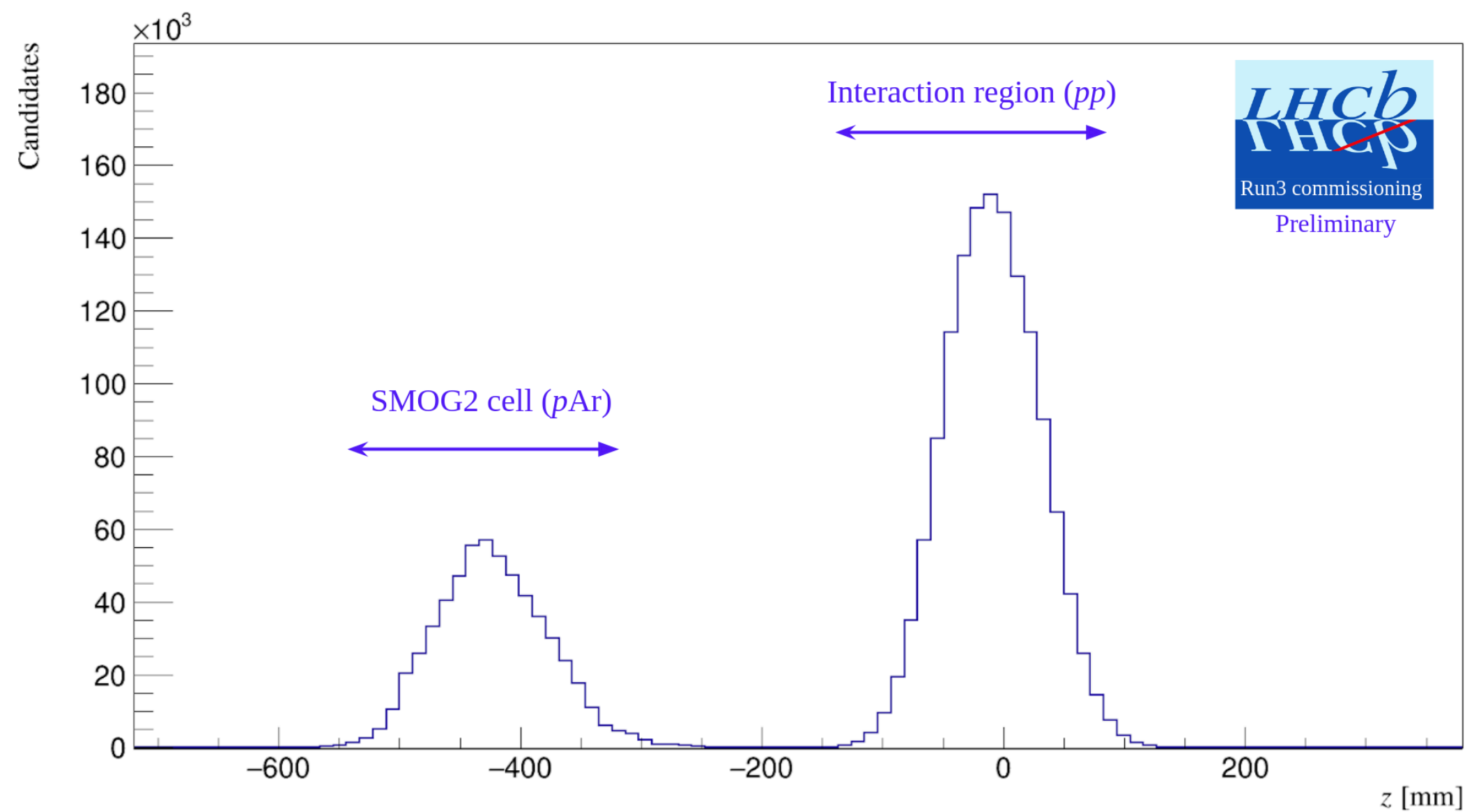
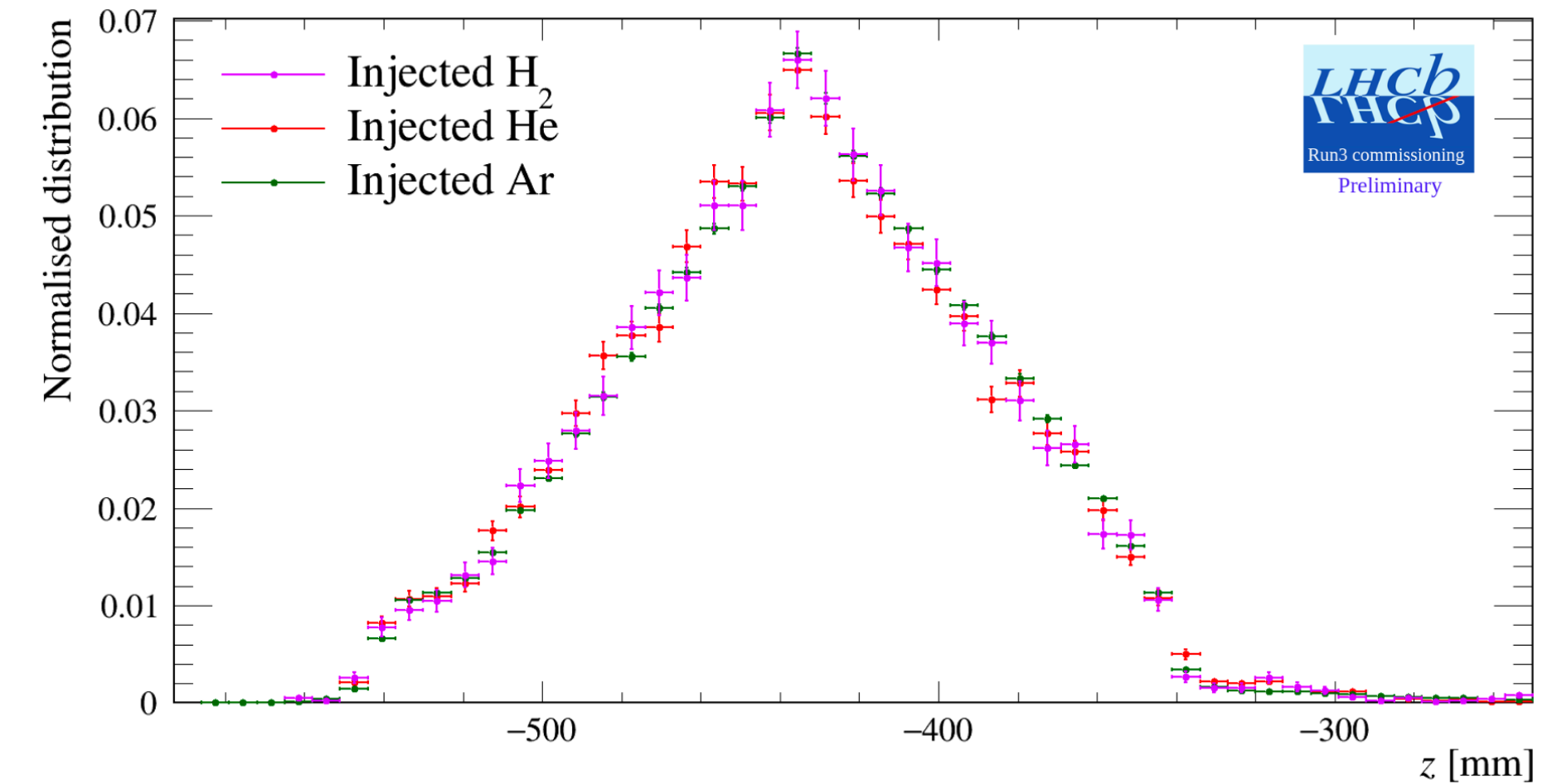
## New tracking systems:

- Silicon upstream tracker (UT)
- Scintillating tracking fiber (SciFi)

## New electronics for calorimeter and muon chambers



- Simultaneous data taking: clear separation of  $pp$  and  $p\text{Gas}$  vertices
- First injection of  $\text{H}_2$  gas.
- Similar mass resolution of  $K_s^0$  in  $pp$  and  $p\text{Ar}$



# Conclusion

## A few highlights

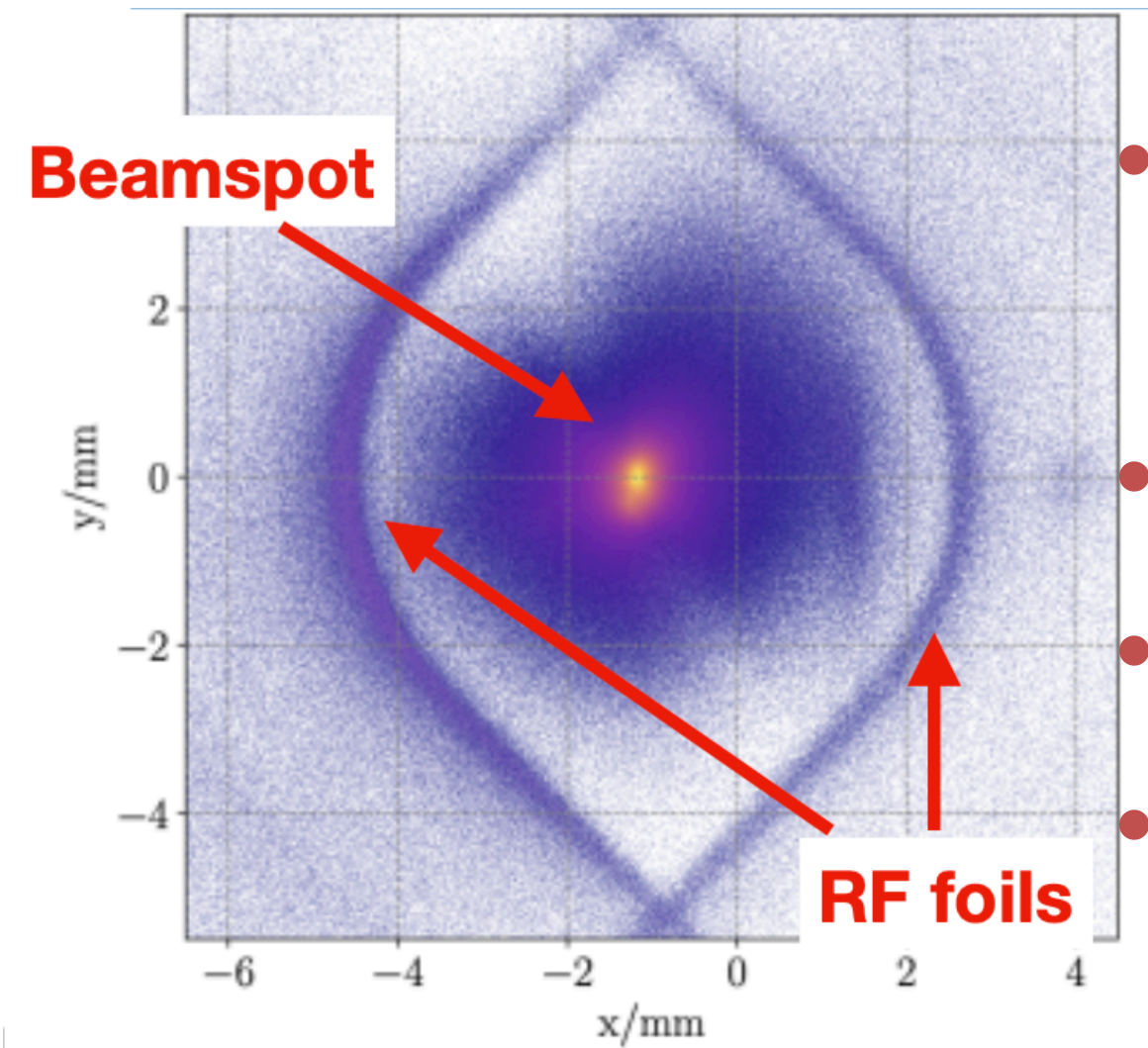
- Precision measurements of  $\pi^0$  and  $D$  mesons in  $p\text{Pb}$  collisions Sara Sellam, Tues. 9:00, Roman Litvinov Tues. 9:00  
Chenxi Gu Tues 17:10
  - Forward rapidity: significant suppression
  - Backward rapidity: models cannot reproduce data, additional effects beyond nPDF
- First  $\Xi_c^+$  measurement in heavy ion collisions Roman Litvinov, Tues. 9:00
- $\Lambda_c^+/D^0$  ratio in PbPb Chenxi Gu Tues 17:10
- Enhanced  $B_s^0/B^0$  ratio in high multiplicity  $pp$  collisions Chenxi Gu Tues. 17:10, Julie Napora Tues 18:15 (poster)
- First exotic  $\chi_{c1}(3872)$  measurement in  $p\text{Pb}$  collisions Clara Landesa Gomez Wed. 11:50
- Precise measurement of coherent charmonia in UPC PbPb collisions Qiuchan Lu, Tues. 10:50
- Bose-Einstein correlations in  $p\text{Pb}$  collisions in forward rapidity Mateusz Goncerz, Tues. 18:15 (poster)
- First SMOG nucleus-nucleus result! Kara Mattioli, Tues. 15:00
  
- Successful commissioning of upgraded LHCb detector, SMOG2 in particular Chiara Lucarelli, Tues. 18:15 (poster)
  - Many new exciting physics opportunities awaiting!



# Backup

- Damage of the RF box between VELO and Primary Vacuum 10/1/23

RF foils imaged in 2022



- multiple equipment failures resulted in a build up of pressure beyond specification between VELO and beam volumes
- RF foils have been deformed. VELO modules do not show damage
- Foil to be replaced in shutdown, current or year end
- Physics programme significantly affected in 2023

## Talks

- Open heavy flavor production in  $p\text{Pb}$  and  $\text{PbPb}$  collisions at LHCb
  - ▶ Roman Litvinov Tues. 9:00
- New constraints on nucleon structure from LHCb:
  - ▶ Sara Sellam Tues. 9:00
- Quarkonia production in ultraperipheral  $\text{PbPb}$  collisions at LHCb
  - ▶ Qiuchan Lu Tues. 10:50
- Quarkonia and exotic hadrons in  $p\text{Pb}$  collisions at LHCb
  - ▶ Clara Landesa Gomez Wed. 11:50
- Modification of heavy quark hadronization in high-multiplicity collisions
  - ▶ Chenxi Gu Tues. 17:10
- New measurements in fixed-target collisions at LHCb
  - ▶ Kara Mattioli Tues. 15:00

## Posters

- Collectivity at LHCb
  - ▶ Mateusz Jacek Goncerz Tues. 18:15
- First performance results from upgraded LHCb and SMOG II
  - ▶ Chiara Lucarelli Tues. 18:15
- Modification of  $b$  quark hadronization in high-multiplicity  $pp$  collisions at LHCb
  - ▶ Julie Napora Tues. 18:15