New constraints on nucleon structure from LHCb

Sara Sellam* on behalf of the LHCb Collaboration

XUNTA DE GALICIA
STRONG 2020
MINISTERIO DE CIENCIA E INNOVACIÓN
USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA
IGFAE Instituto Galego de Física de Altas Enerxías
LHCb

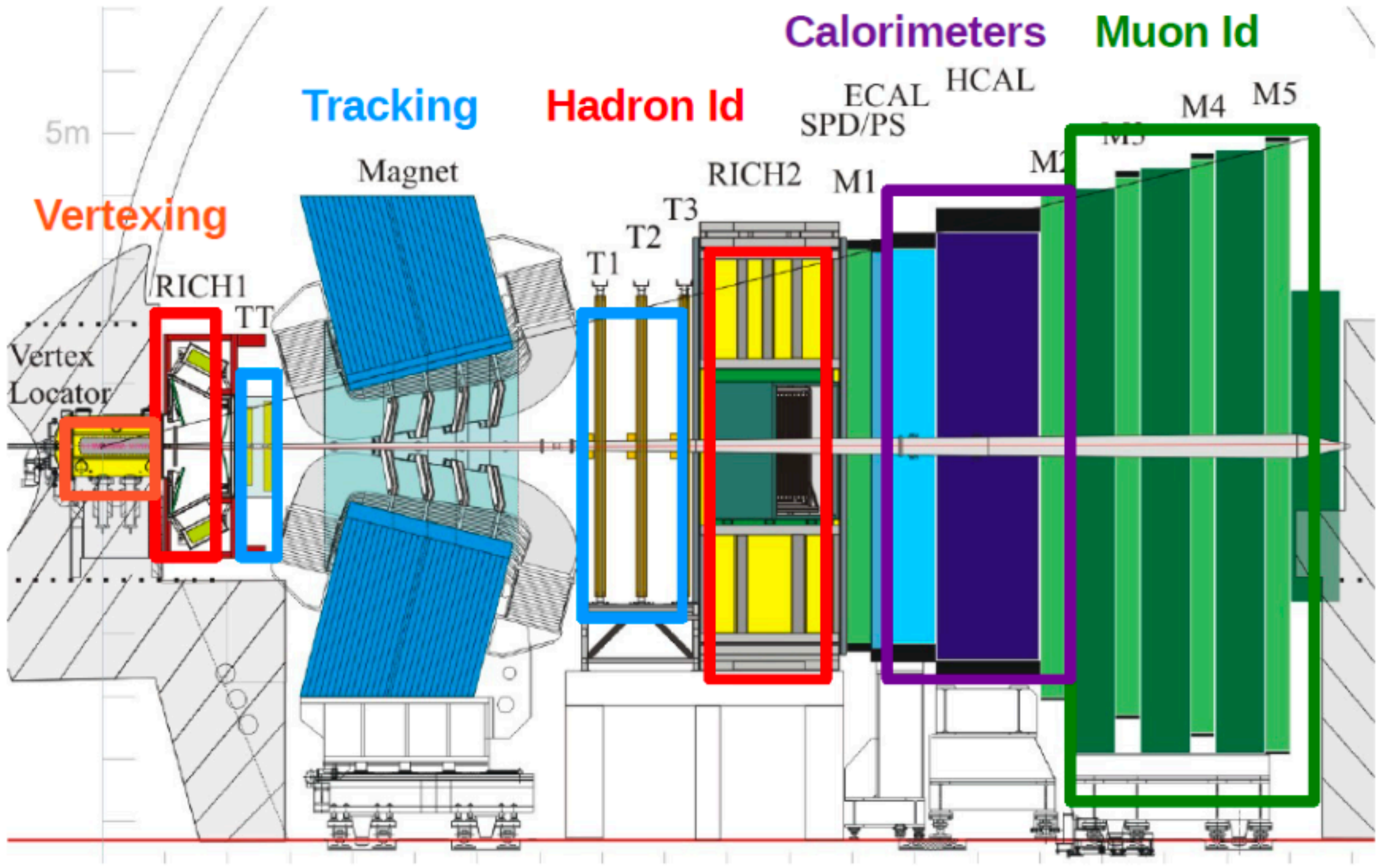
*sara.sellam@usc.es

Topics

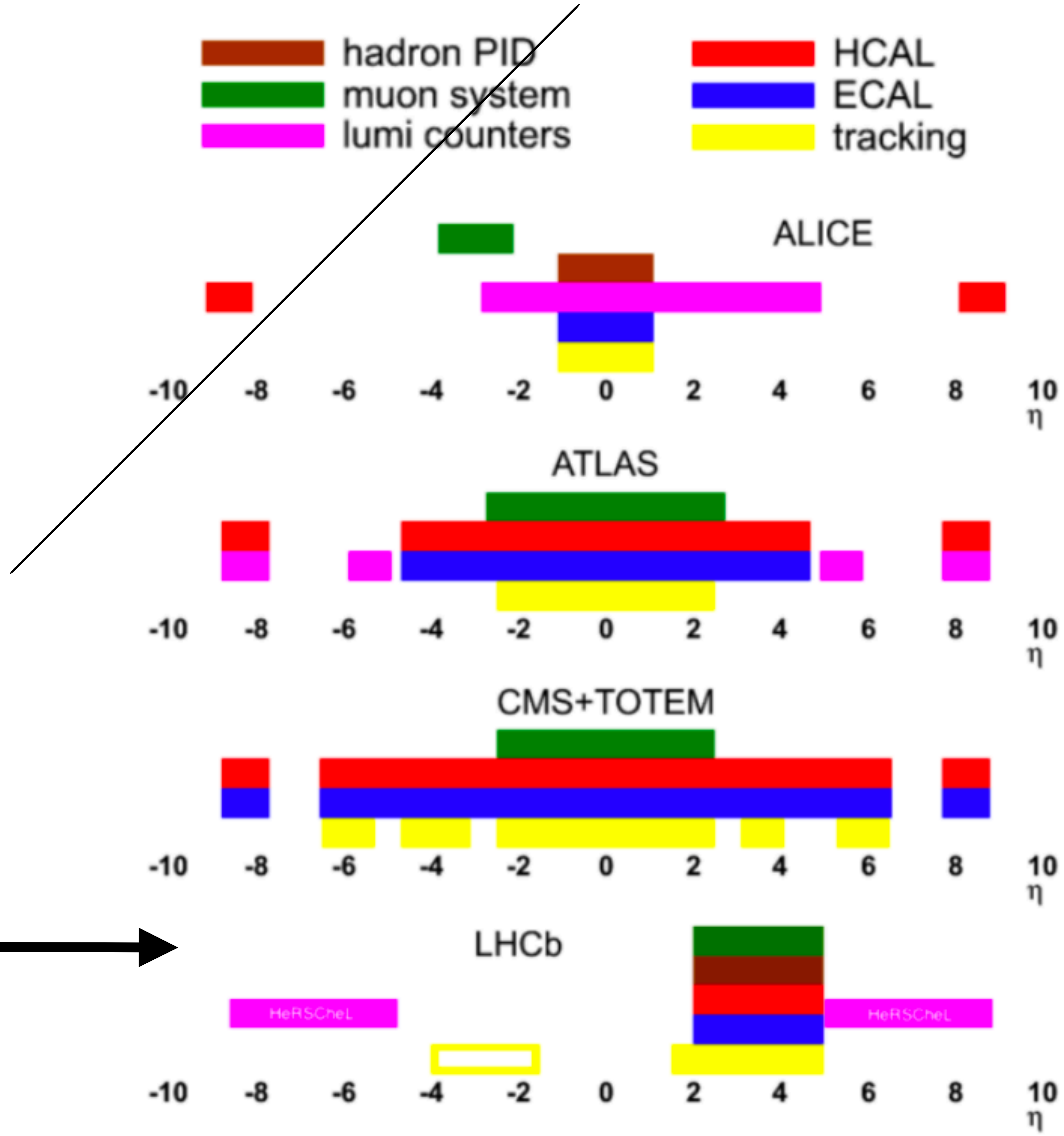
- Neutral pion production in pPb at $\sqrt{s_{NN}} = 8.16$ TeV.
  arXiv:2204.10608 accepted by PRL
- Measurement of Z boson production cross-section in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV.
  arXiv:2205.10213
- Study of Z bosons produced in association with charm in the forward region of pp collision at $\sqrt{s_{NN}} = 13$ TeV. Phys.Rev.Lett. 128 (2022) 8, 082001

LHCb Detector

- From heavy flavour physics to a general-purpose detector in the forward region.
- Forward detector fully instrumented in $2 < \eta < 5$.
- Excellent tracking, momentum resolution, and particle identification.



JINST 3 (2008)S08005



IJMPA 30 (2015) 1530022

Accessible range in the (x, Q^2) plane of LHCb

Q^2 is the momentum transfer between a particle and the incident particle in a collision.

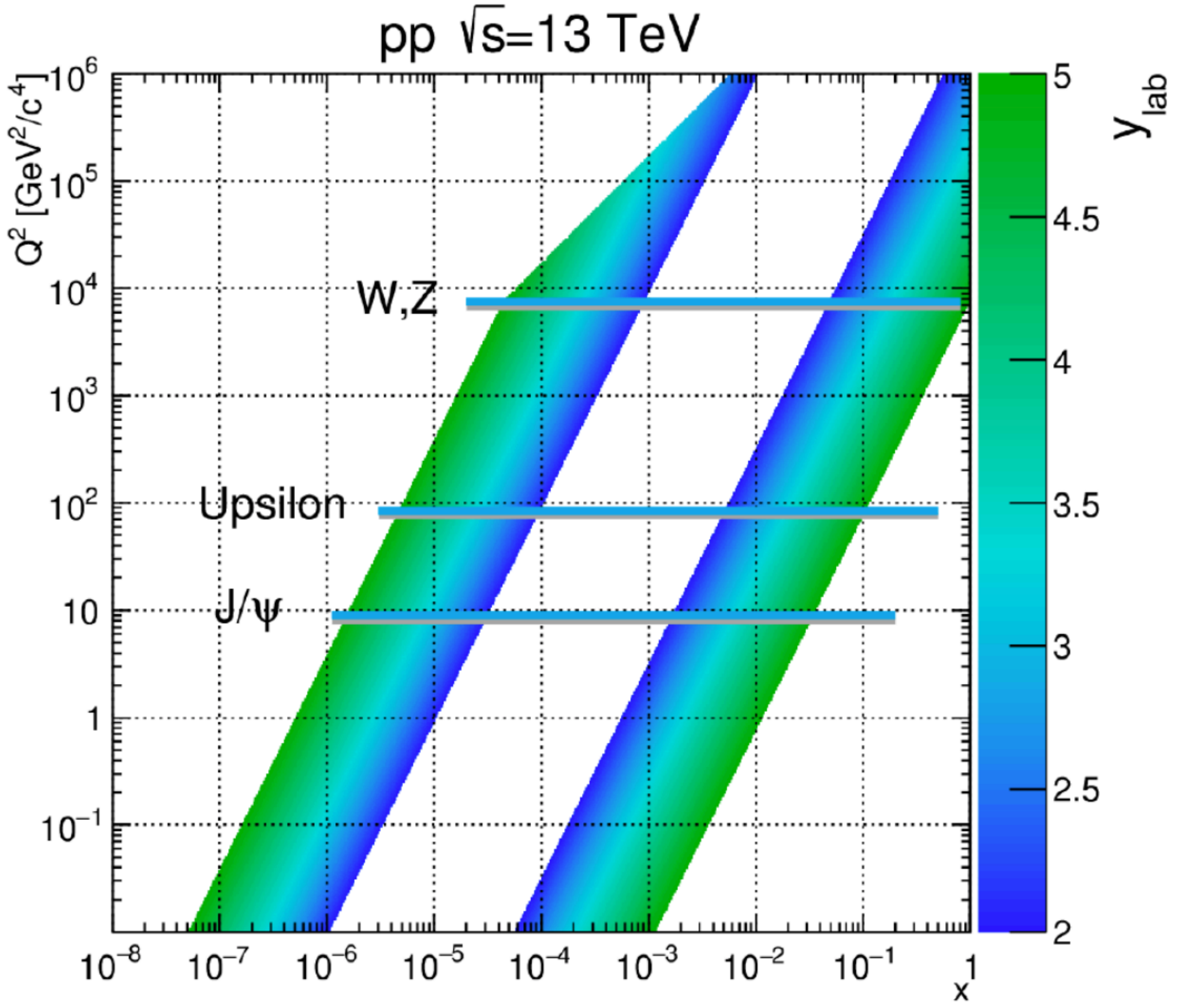
Forward : $10^{-6} \leq x \leq 10^{-4}$

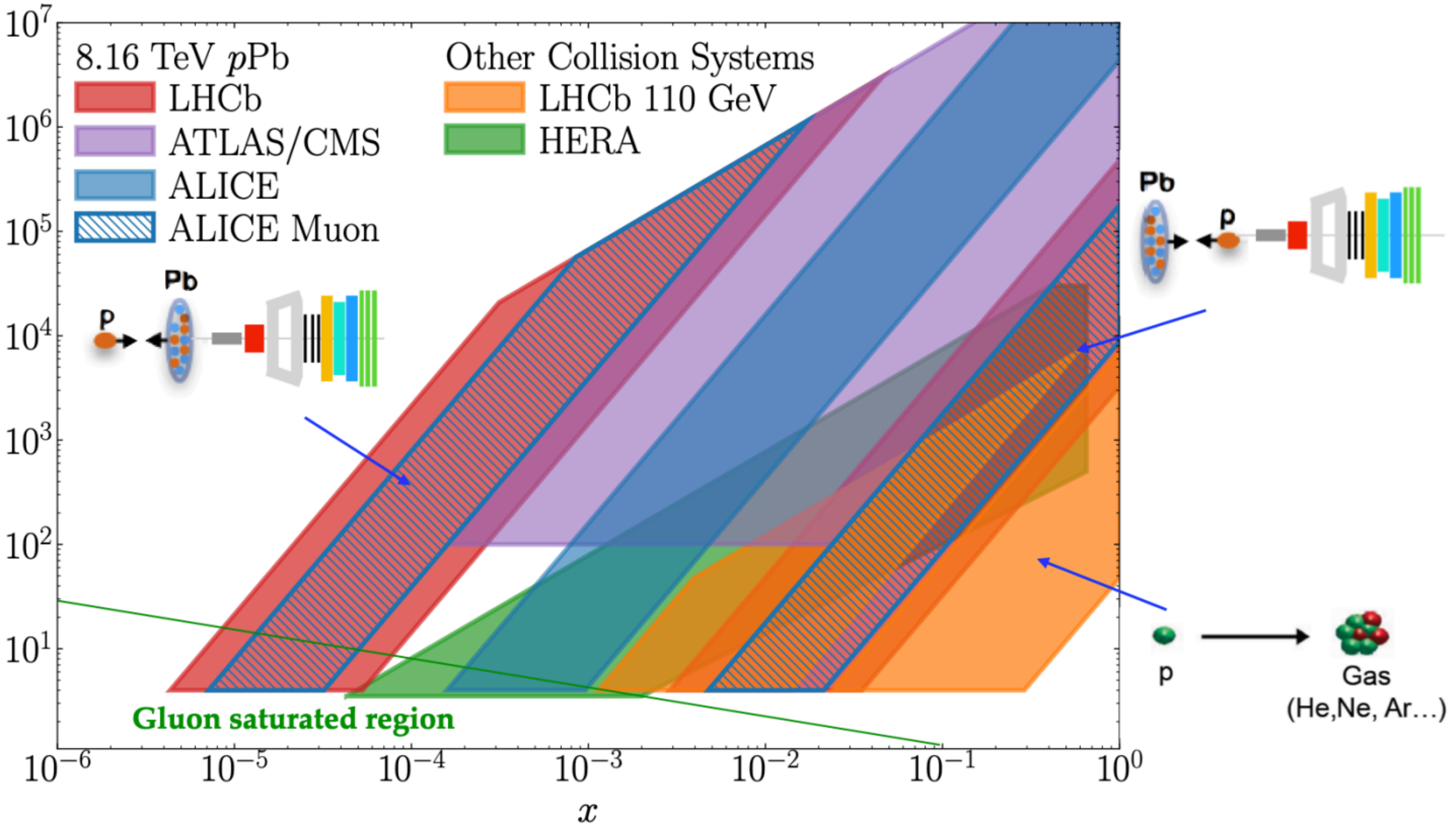
Backward : $10^{-3} \leq x \leq 10^{-1}$

$$Q^2 \sim m^2 + p_T^2$$

$$x \sim \frac{Q}{\sqrt{s_{NN}}} e^{-\eta}$$

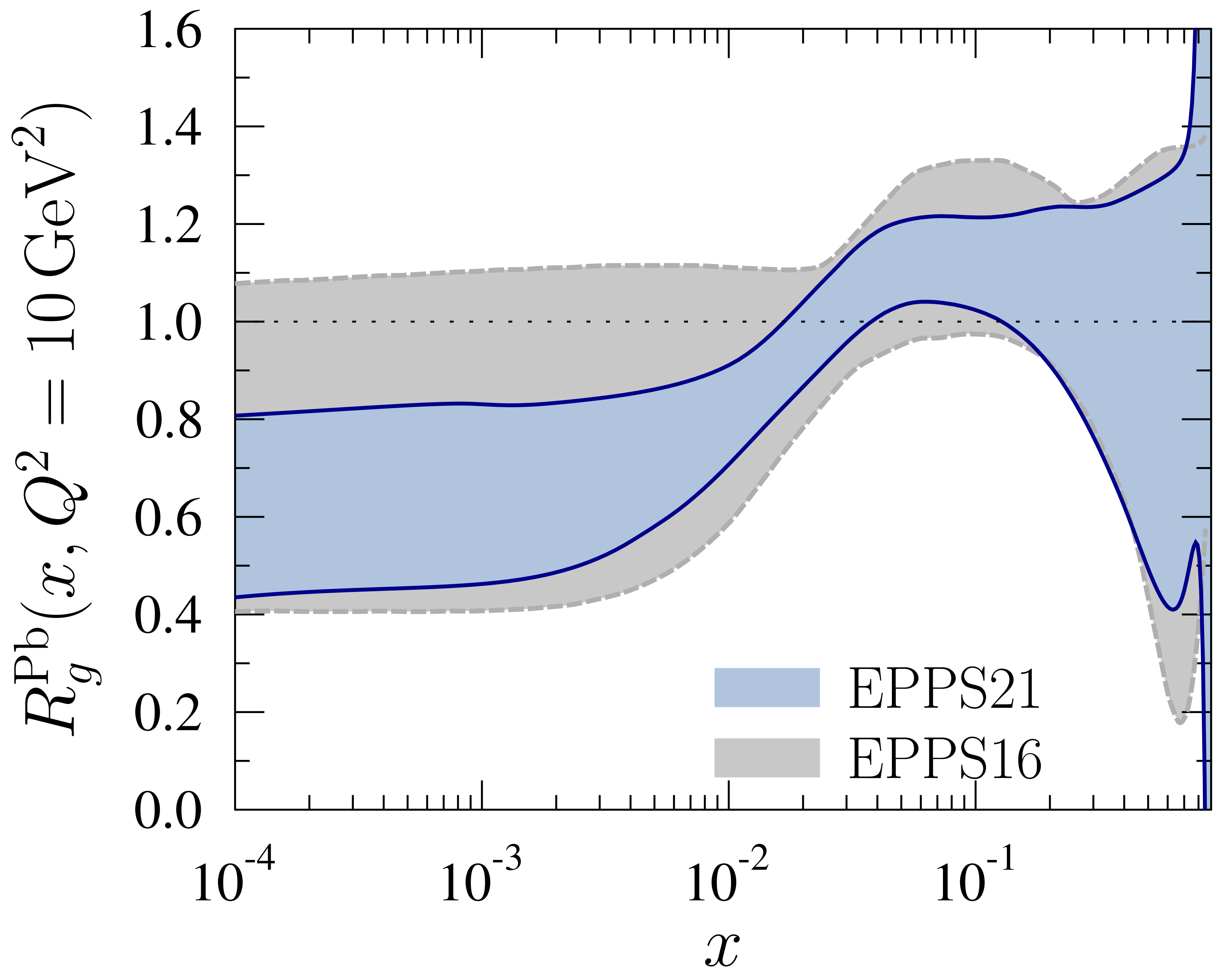
LHCb-PUB-2018-015



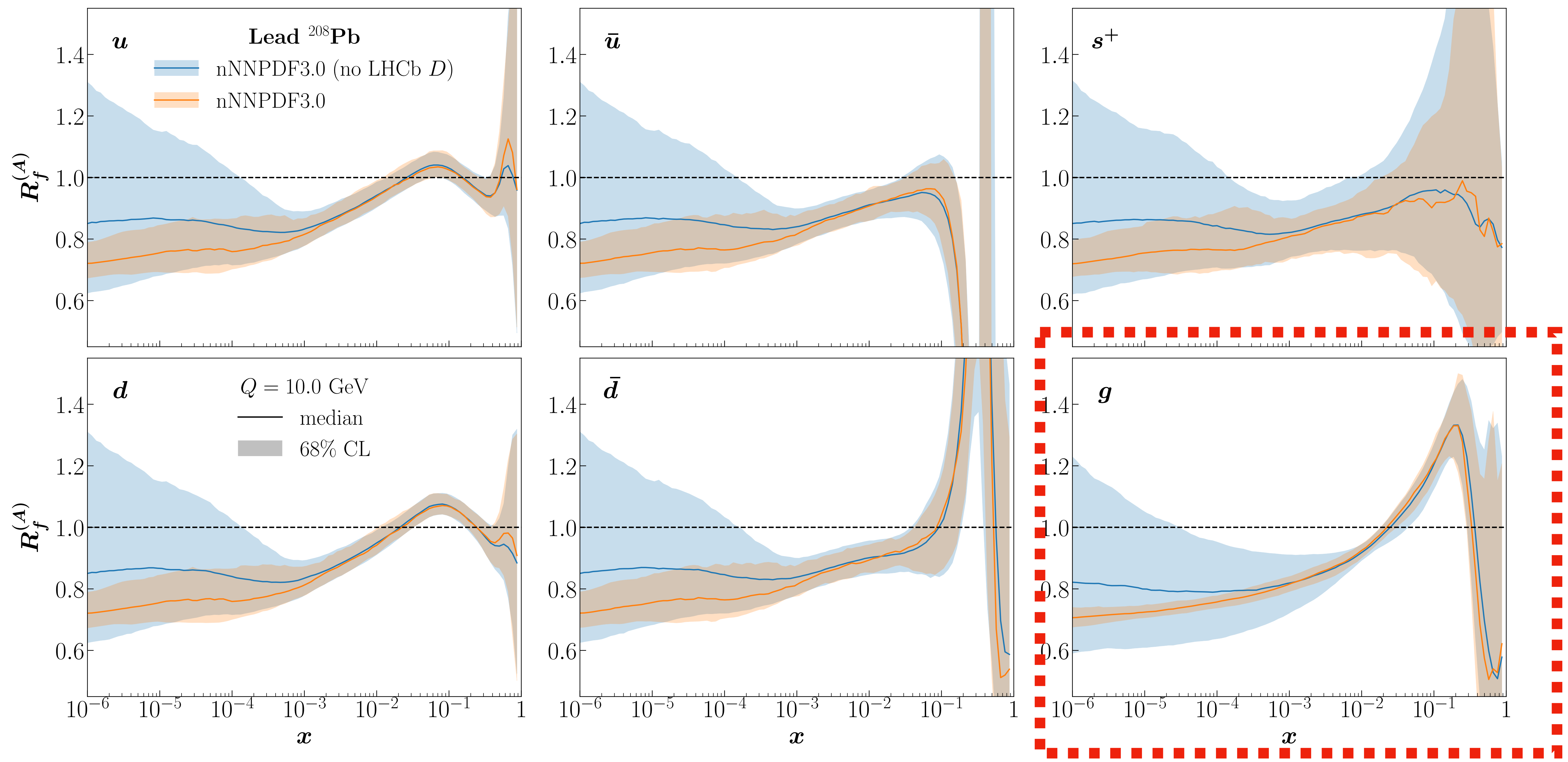


LHCb measurements have a significant impact on nPDFs fits.

EPPS21 [(EPJC 82 (2022) 5, 413)]



nNNPDF3.0 [(EPJC 82 (2022) 6, 507)]



LHCb D^0 meson production in pPb collisions at $\sqrt{s} = 5$ TeV: [JHEP 1710 (2017) 090]

Neutral pion production in pPb at $\sqrt{s_{NN}} = 8.16$ TeV

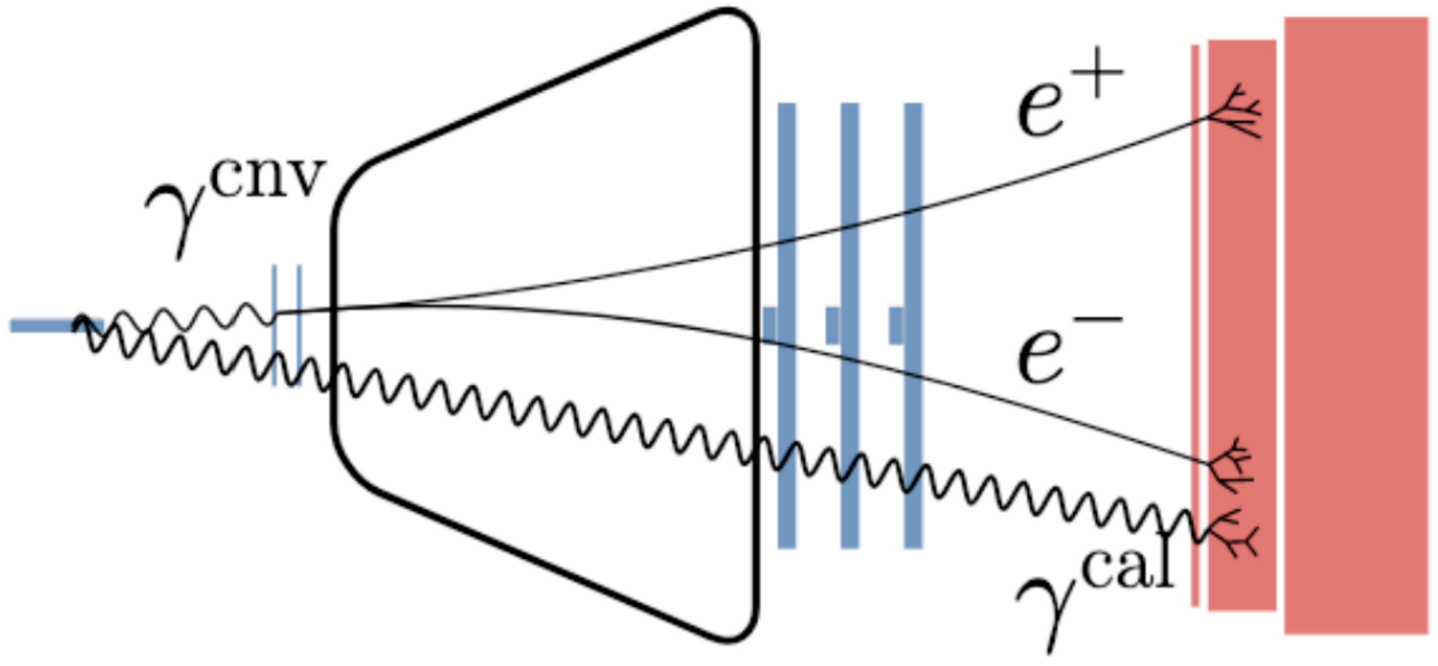
arXiv:2204.10608 accepted by PRL

Motivation :

- π^0 production is particularly sensitive to cold nuclear matter (CNM) effects.
- The Measurement can provide constraints on nPDFs for x between $10^{-6}$and 10^{-1}.

Analysis :

- Neutral pions are reconstructed with one converted photon and one ECAL photon $\pi^0 \rightarrow \gamma^{cnv}\gamma^{cal}$ for better momentum resolution.

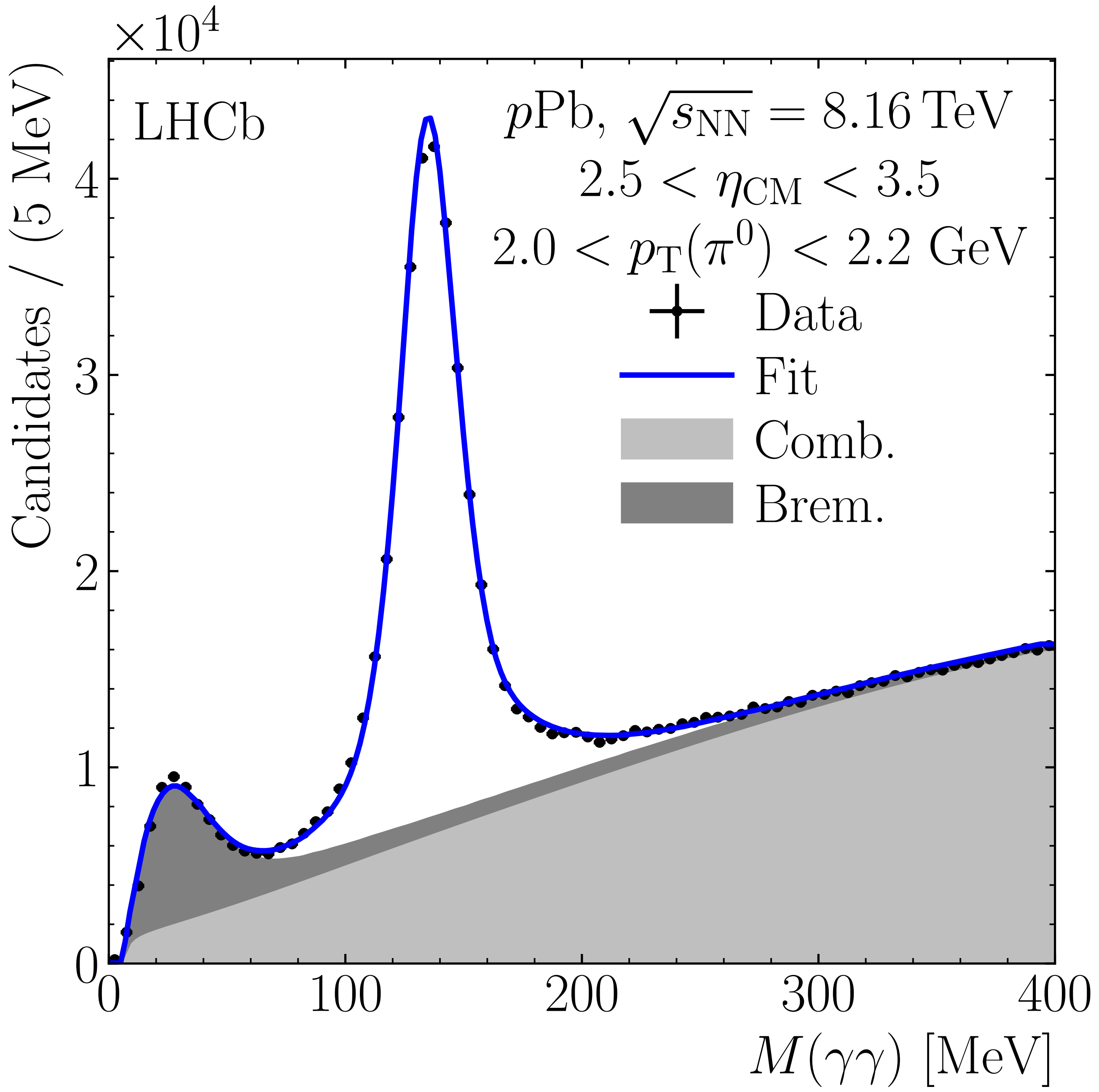


Neutral pion production in pPb at $\sqrt{s_{NN}} = 8.16$ TeV

arXiv:2204.10608 accepted by PRL

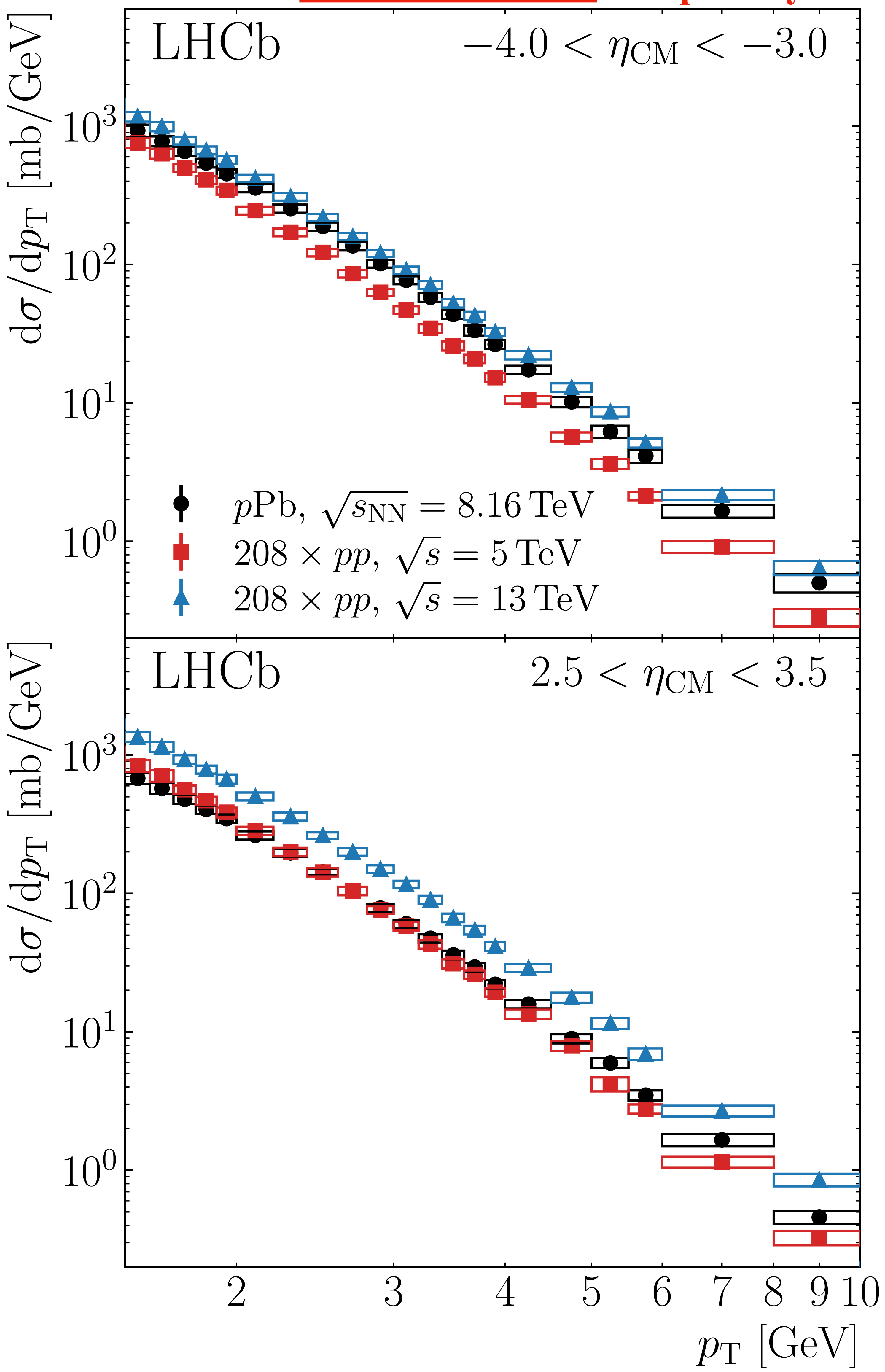
Analysis :

- π^0 yield is reconstructed in p_T and η_{cms} bins.
- The combinatorial background is modelled using charged tracks from MC.
- The peak at the lower mass arises when a converted photon is combined with its own bremsstrahlung radiation.



$$R_{p\rm Pb} \equiv \frac{1}{A}\frac{d\sigma_{p\rm Pb}/dp_{\rm T}}{d\sigma_{pp}/dp_{\rm T}}$$

$$A = 208$$



Neutral pion production in pPb at $\sqrt{s_{NN}} = 8.16$ TeV

arXiv:2204.10608 accepted by PRL

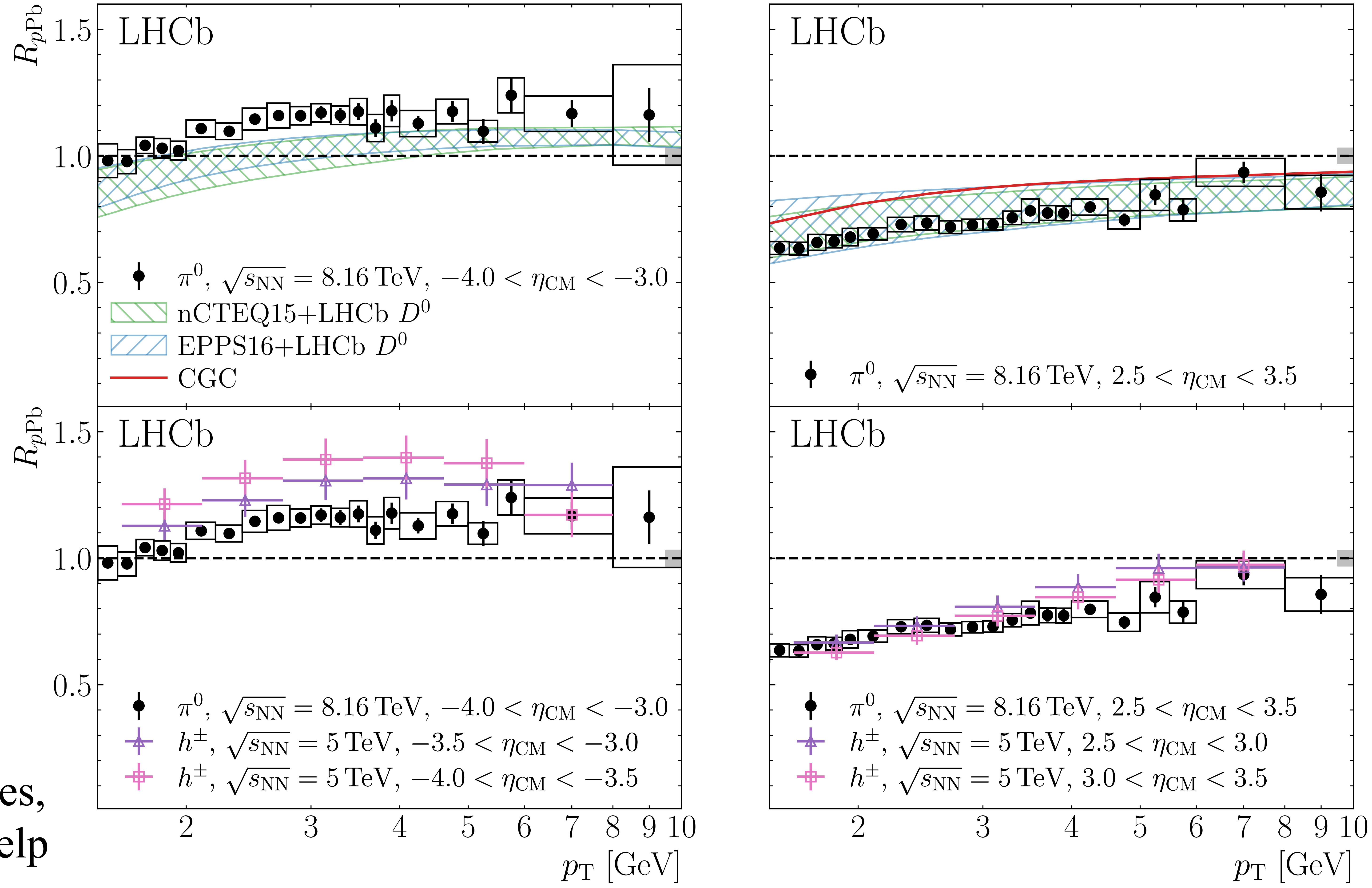
Forward

- The nuclear modification factor shows a strong suppression.
- The measurement is also compared to the charged-particle nuclear modification factor by LHCb.
- The data can provide powerful constraints on nPDF at low x.

Backward

- Enhancement of π^0 production with respect to pp at intermediate p_T.
- The enhancement is smaller than the charged particles, studies of other identified particles $(p, K, \eta^{(\prime)})$ will help clarify the picture .

Backward **Forward**



Motivation :

- Z-boson production carries valuable information in constraining the PDFs and nPDFs.
- Clean probe of the initial state at low- and high-x.

Analysis :

- $Z \to \mu^+\mu^-$ events are reconstructed in a fiducial region with $60 < m_{\mu^+\mu^-} < 120$ GeV.
- The rapidity range in the centre of mass frame (y_Z^*) is :
  - Forward (fw) collision : $1.53 < y_\mu^* < 4.03$
  - Backward (bw) collision : $-4.97 < y_\mu^* < -2.47$
- The Nuclear modification factor $R_{pPb}^{bw/fw}(x)$ and the forward and backward $R_{FB}(x)$ ratio are corrected with a factor $k(x)$ using POWHEGBOX with the proton PDF CTEQ6.1.

The nuclear modification factor :

$$R_{pPb}^{bw/fw}(x) = k_{pPb}^{bw/fw}(x)\frac{d\sigma(pPb)}{208 \cdot d\sigma(pp)}$$

x can be y_Z^*, p_T^Z or ϕ^*

σ' indicates that this cross-section is calculated theoretically

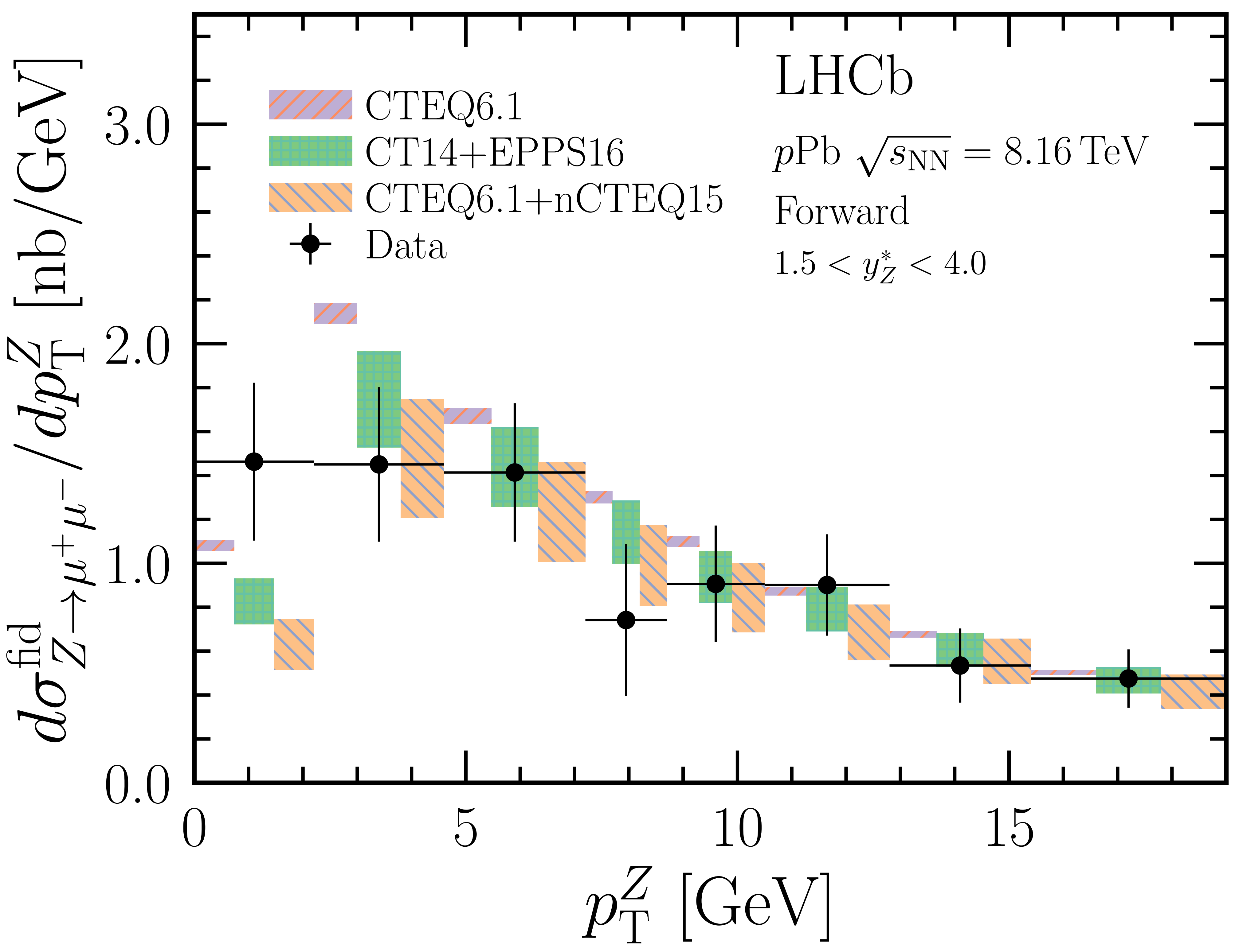
$$k_{\mathrm{pPb}}^{\mathrm{fw}}(x) = \frac{\mathrm{d}\sigma'_{(pp,2.0<y_\mu^*<4.5)}/\mathrm{d}x}{\mathrm{d}\sigma'_{(pp,1.53<y_\mu^*<4.03)}/\mathrm{d}x}$$

$$k_{\mathrm{pPb}}^{\mathrm{bw}}(x) = \frac{\mathrm{d}\sigma'_{(pp,-4.5<y_\mu^*<-2.0)}/\mathrm{d}x}{\mathrm{d}\sigma'_{(pp,-4.97<y_\mu^*<-2.47)}/\mathrm{d}x}$$

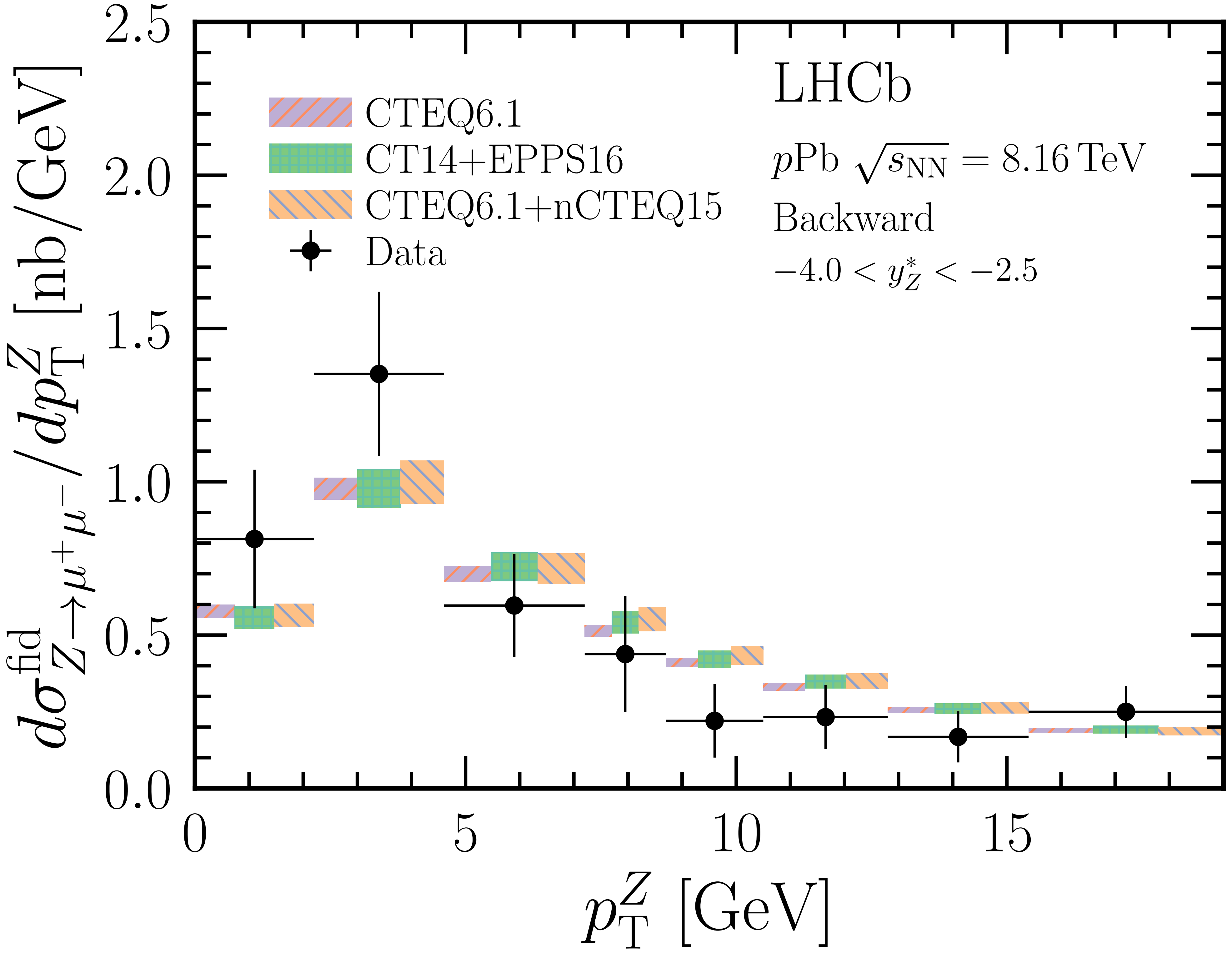
To correct for the different y_μ^* acceptance between pPb and pp collisions

arXiv:2205.10213

Cross section in the forward region



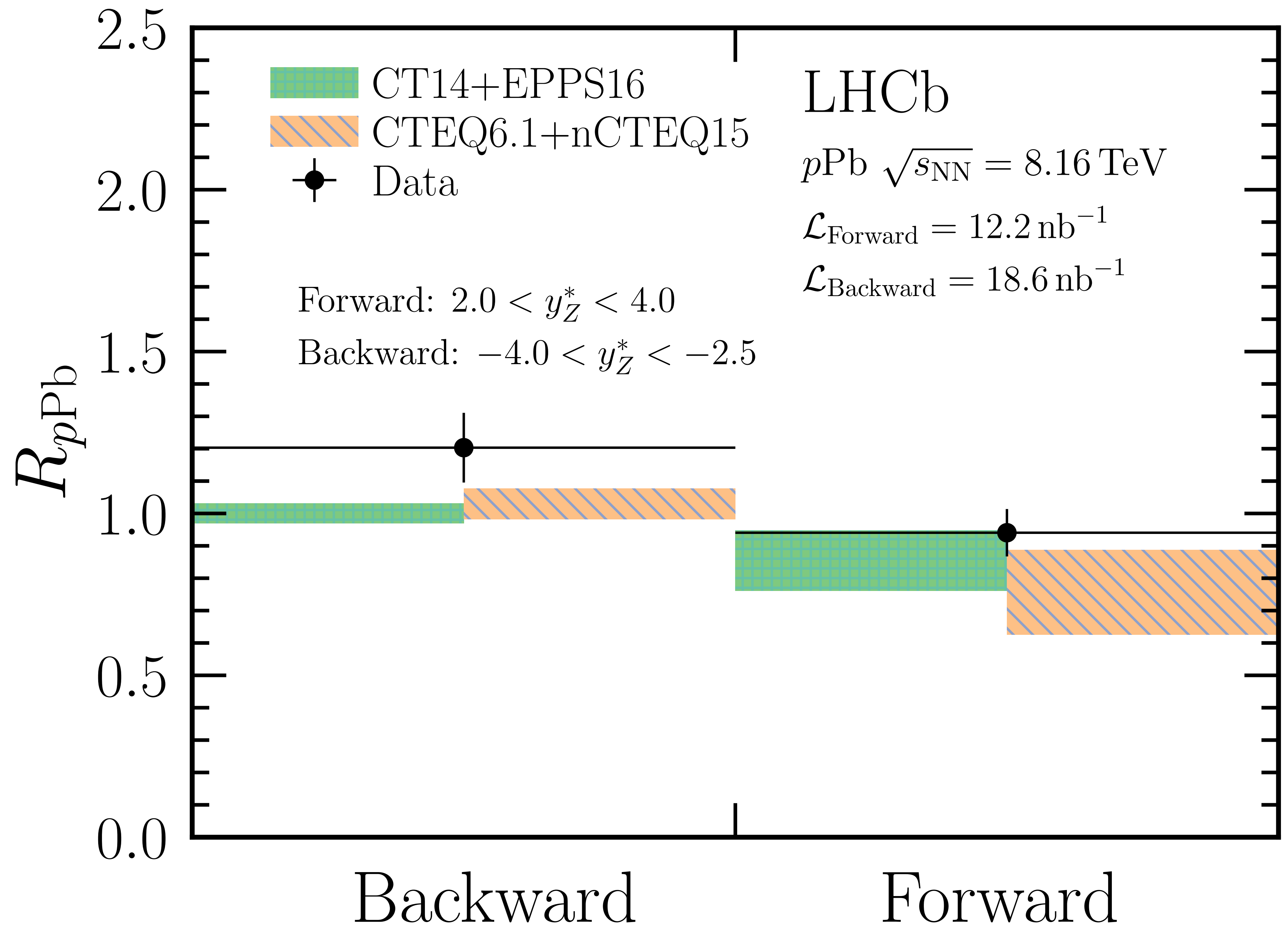
Cross section in the backward region



NLO pQCD calculations agree with the data within uncertainties

- The nuclear modification factor in the forward region is well described by the theoretical predictions.

- The backward region is slightly higher but statistically compatible with the theory's predictions.



Phys.Rev.Lett. 128 (2022) 8, 082001

Motivation :

- The existence of intrinsic heavy quarks within the proton wavefunction remains a subject of ongoing debate and has not been definitively established. Phys.Lett.B 93 (1980) 451-455

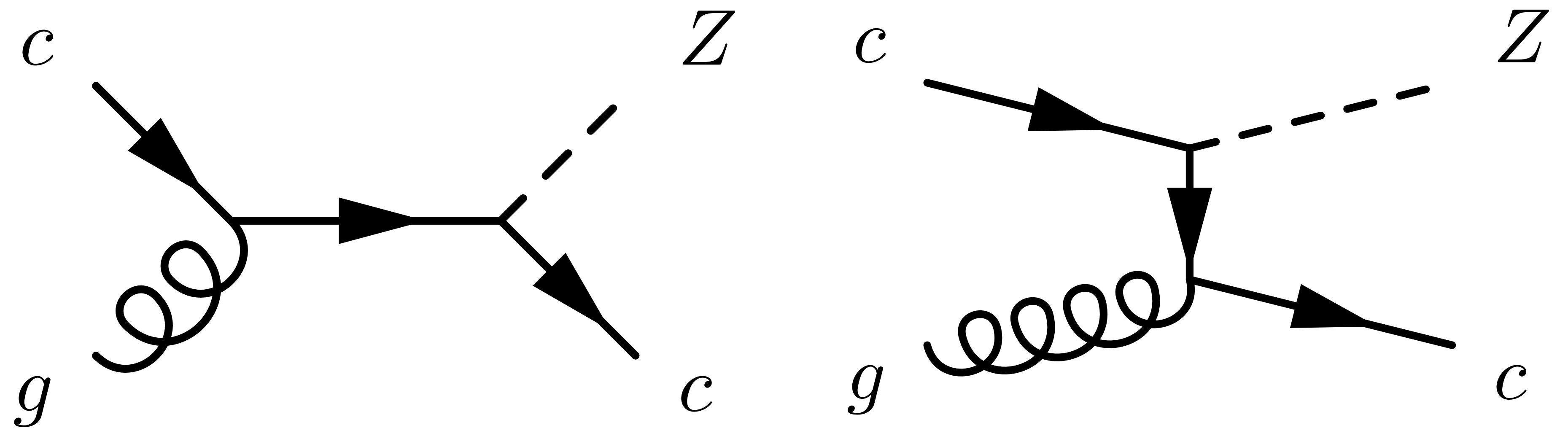
- Non-perturbative IC manifests as valencelike charm content in the PDFs.

Ideal probe

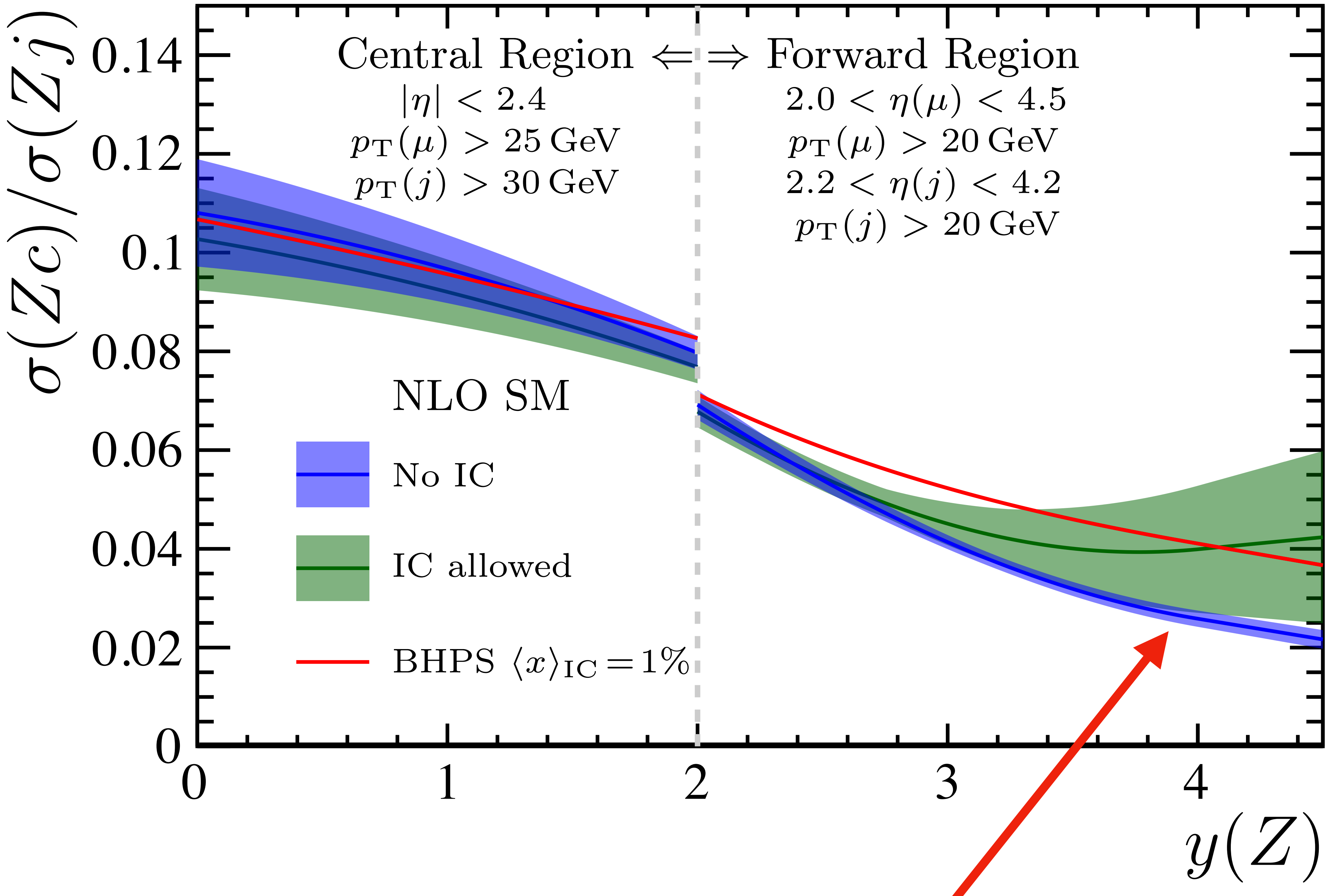
1. Direct sensitivity to the large-x charm PDF.
2. Q is large enough such that hadronic and nuclear effects are negligible

Z+jet events where the jet originates from a c quark

$gc \to Zc$



$$\mathcal{R}_j^c \equiv \sigma(Zc)/\sigma(Zj)$$



IC contribution produces a clear enhancement in $\mathcal{R}_j^c$ for large y(Z).

- Jet reconstruction was performed using anti-k_T clustering algorithm.
- The c jet yields are determined using a c-tagging algorithm that looks for a displaced vertex (DV) inside the jet.
- Two properties: m_{cor}(DV) and $N_{\rm trk}$(DV) are used to separate charm jets from beauty and light jets.

m_{cor}(DV) : The corrected mass of a displaced vertex.

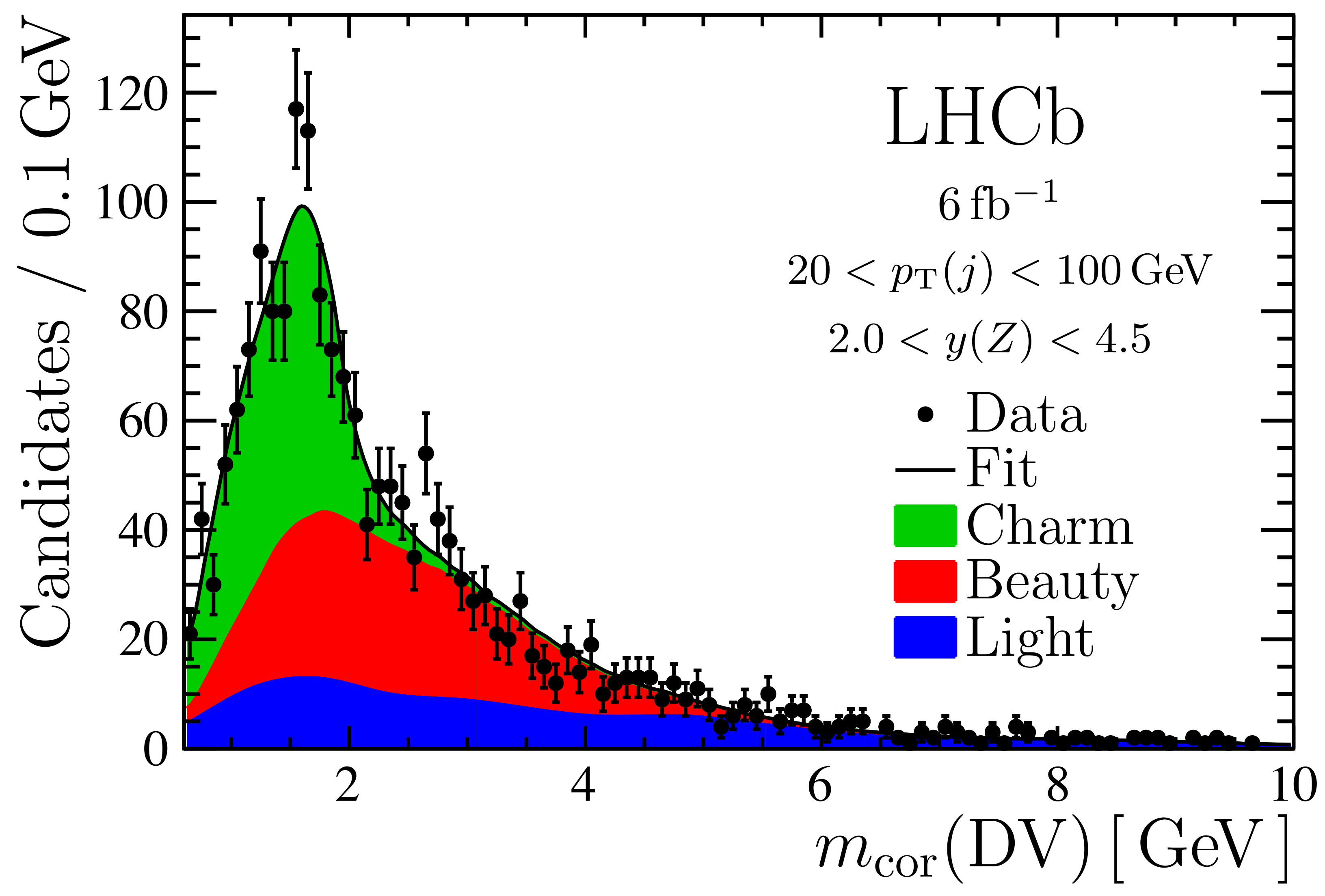
$N_{\rm trk}$(DV) : The number of tracks in the DV.

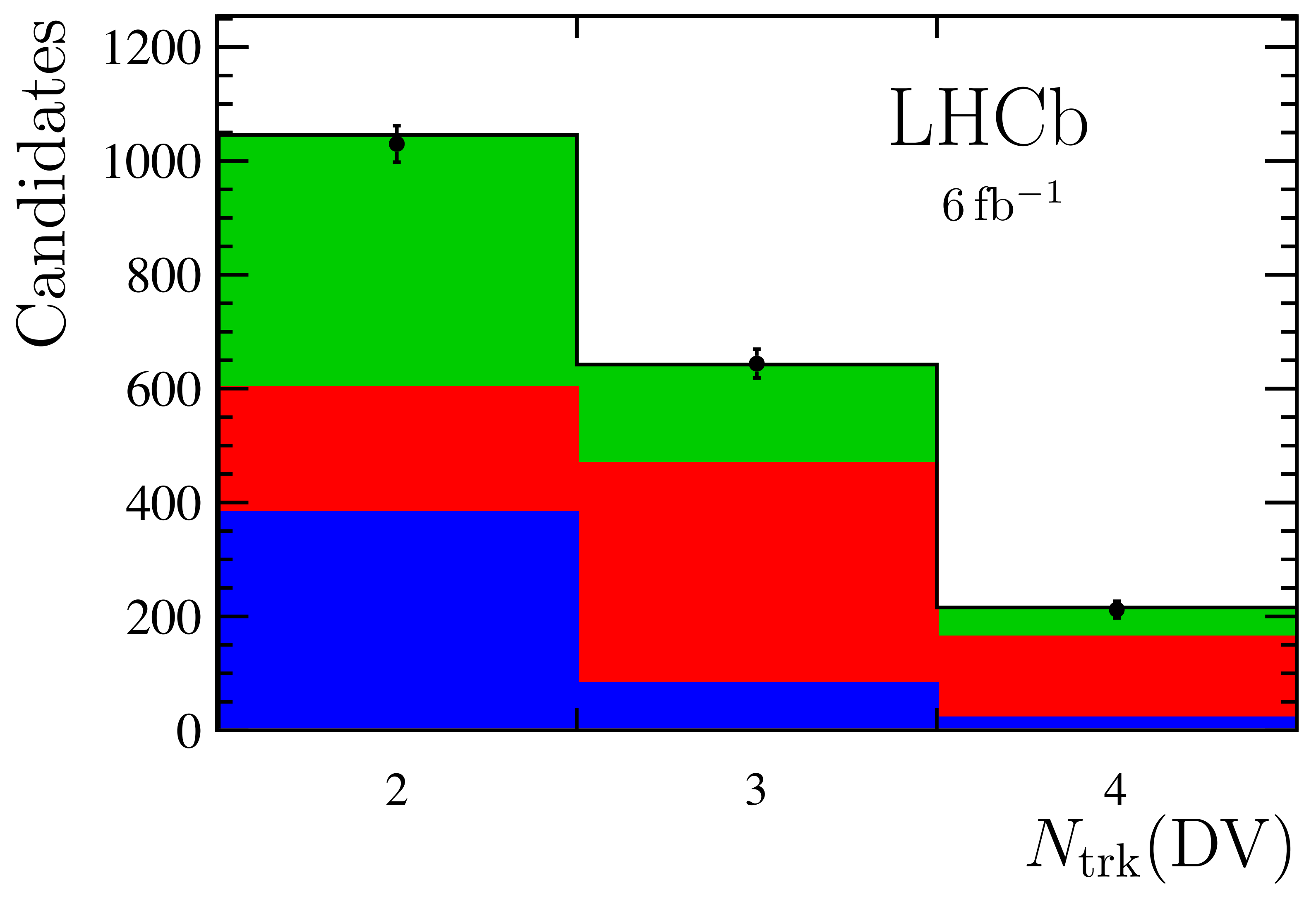
The fiducial region

Z bosons	$p_{\rm T}(\mu) > 20\,\text{GeV},\ 2.0 < \eta(\mu) < 4.5,\ 60 < m(\mu^+\mu^-) < 120\,\text{GeV}$
Jets	$20 < p_{\rm T}(j) < 100\,\text{GeV},\ 2.2 < \eta(j) < 4.2$
Charm jets	$p_{\rm T}(c\ \text{hadron}) > 5\,\text{GeV},\ \Delta R(j, c\ \text{hadron}) < 0.5$
Events	$\Delta R(\mu, j) > 0.5$

$$m_{cor}(\text{DV}) \equiv \sqrt{m(\text{DV})^2 + [p(\text{DV})\sin\theta]^2} + p(\text{DV})\sin\theta$$

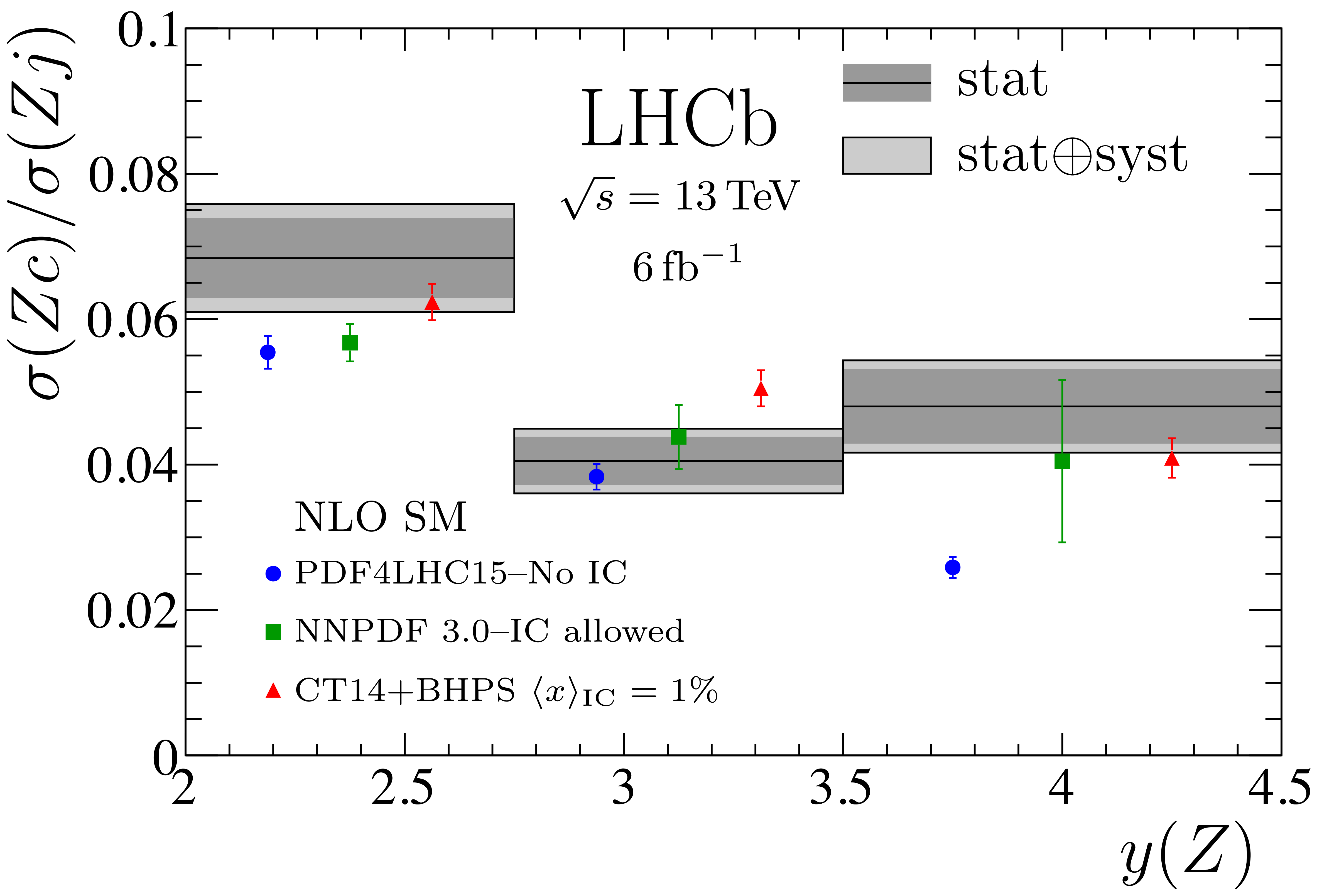
θ is the angle between the momentum and the flight direction of the DV





Phys.Rev.Lett. 128 (2022) 8, 082001

- The observed $\mathscr{R}_j^c$ values are consistent with both no-IC and IC hypotheses in the first two $y(Z)$ intervals.
- A sizable enhancement at forward Z rapidities is observed $\longrightarrow$ consistent with the effect predicted by BHPS for a proton with a wave function of $|uudc\bar{c}\rangle$
- The existence of IC is also studied in LHCb's fixed target mode. (see Kara Mattioli's talk: New measurements in fixed-target collisions at LHCb)



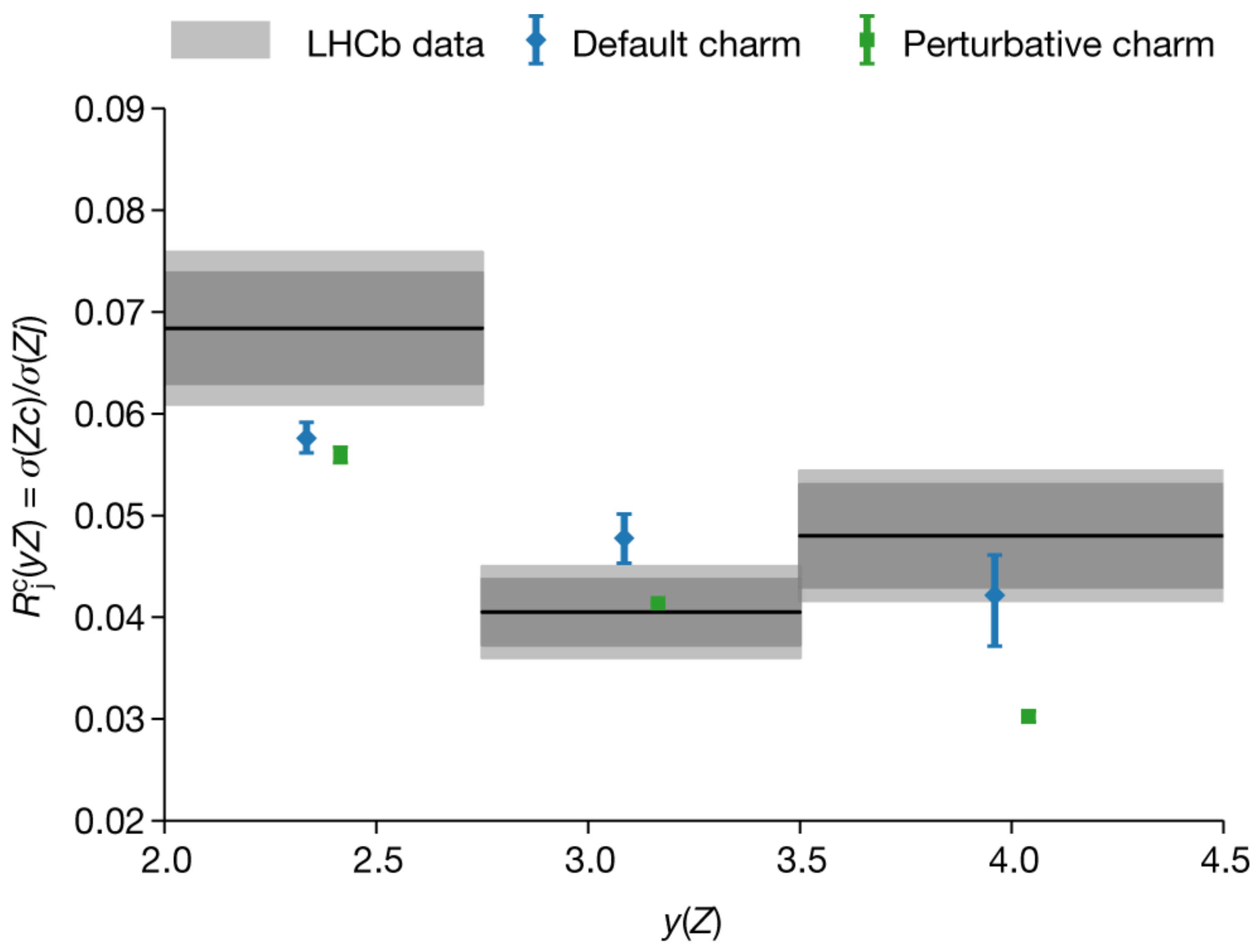
Theoretical predictions

PDF4LHC15-No IC
NNPDF 3.0-IC allowed
CT14+BHPS$\langle x \rangle_{\rm IC} = 1\ \%$

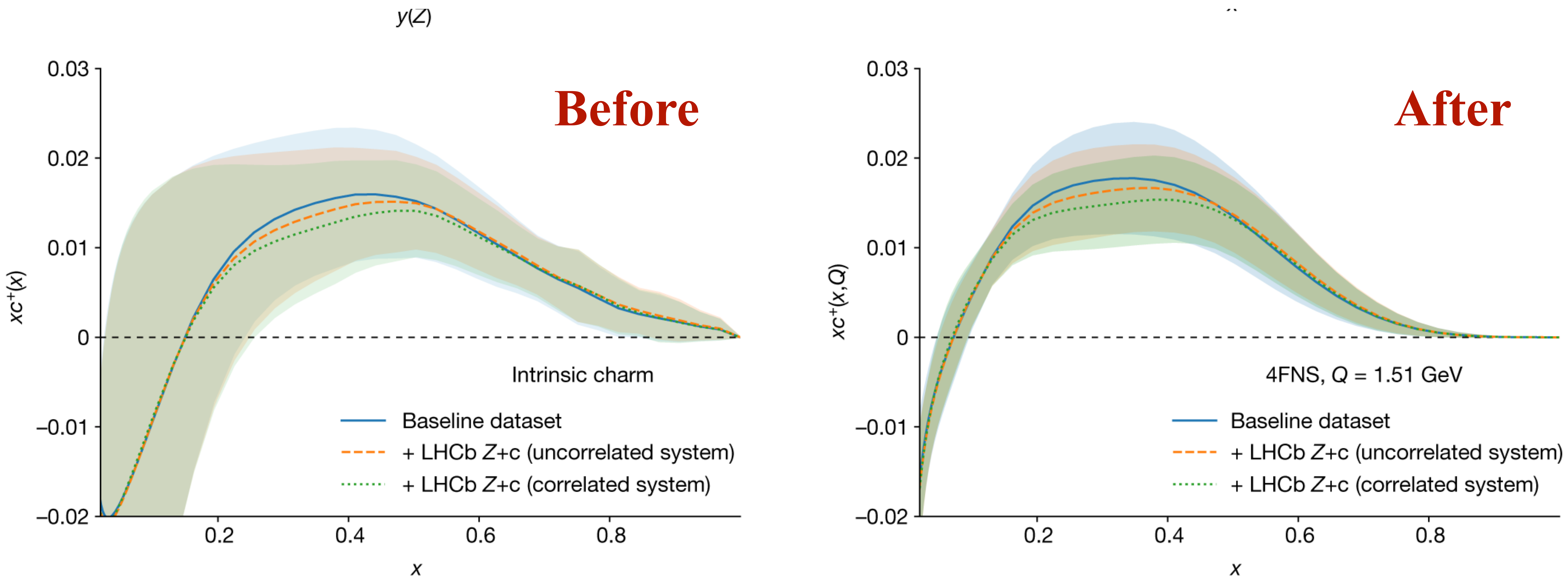
The impact of LHCb Z+charm

Nature 608 (2022) 7923

Default PDFs that include intrinsic charm are compatible with LHCb measurement particularly for the highest-rapidity bin.



Including $\mathscr{R}_j^c$ modularly reduces the uncertainty on the charm PDF.



Conclusion

- The nuclear modification factor for the neutral pion can provide powerful constraints on nPDF at low x in the forward region.
- The cross-section measurement of Z boson in pPb at low transverse momentum can help TMD studies in QCD.
- The ratio $\mathscr{R}_j^c \equiv \sigma(Zc)/\sigma(Zj)$ exhibits an enhancement at forward Z rapidities.
- Future LHCb measurements are coming: identified particles production $(p, K, \eta^{(\prime)})$ will allow us to well constrain the nPDFs.

Backup

Measurement of the Z boson production cross-section in proton-lead collisions at $\sqrt{s_{NN}} = 8.16$ TeV

arXiv:2205.10213

LHCb

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to correct for the different y_μ^*acceptance between pPb and pp collisions

Cross section :

$$\frac{\mathrm{d}\sigma^{\mathrm{fid}}_{Z\to\mu^+\mu^-}}{\mathrm{d}x} = \frac{\rho(x)\cdot f_{\mathrm{FSR}}}{\mathscr{L}\cdot\epsilon^{reco\&sel}(x)\cdot\epsilon^{\mathrm{mon-id}}(x)\cdot\epsilon^{\mathrm{trig}}(x)}\cdot\frac{\mathrm{d}N_{\mathrm{cand}}}{\mathrm{d}x}$$

x can be y_Z^*, p_{T}^Z or ϕ^*

Parameter	Description
N_{cand}	Number of observed candidates after the selection in the fiducial region
ρ	Purity, the fraction of signal events
f_{FSR}	Correction for final state radiation (FSR)
$\mathcal{L}$	Integrated luminosity
$\epsilon^{reco\&sel}$	Efficiency of reconstruction and selection
$\epsilon^{muon-id}$	Efficiency of muon identification
ϵ^{trig}	Efficiency of trigger selection

The nuclear modification factor :

$$R_{pPb}^{bw/fw}(x) = k_{pPb}^{bw/fw}(x)\frac{d\sigma(pPb)}{208\cdot d\sigma(pp)}$$

The forward and backward ratio:

$$R_{FB}(x) = \frac{d\sigma_{fw}/dx}{d\sigma_{bw}/dx}\cdot k_{FB}(x)\Bigg|_{2.5<|y_Z^*|<4.0}$$

$$k_{pPb}^{fw/bw}(x) = \frac{\mathrm{d}\sigma'_{pp}/\mathrm{d}x}{\mathrm{d}\sigma_{pp}/\mathrm{d}x}$$

σ' indicates that this cross-section is calculated theoretically