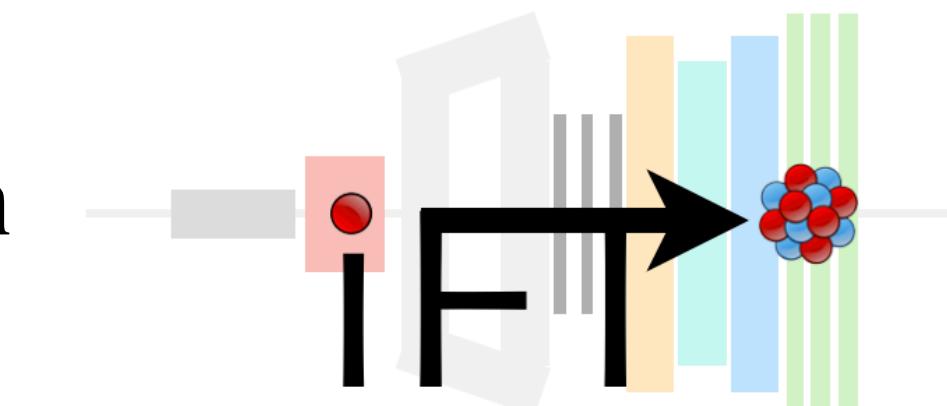


Studies of low- x phenomena and collectivity with the LHCb detector



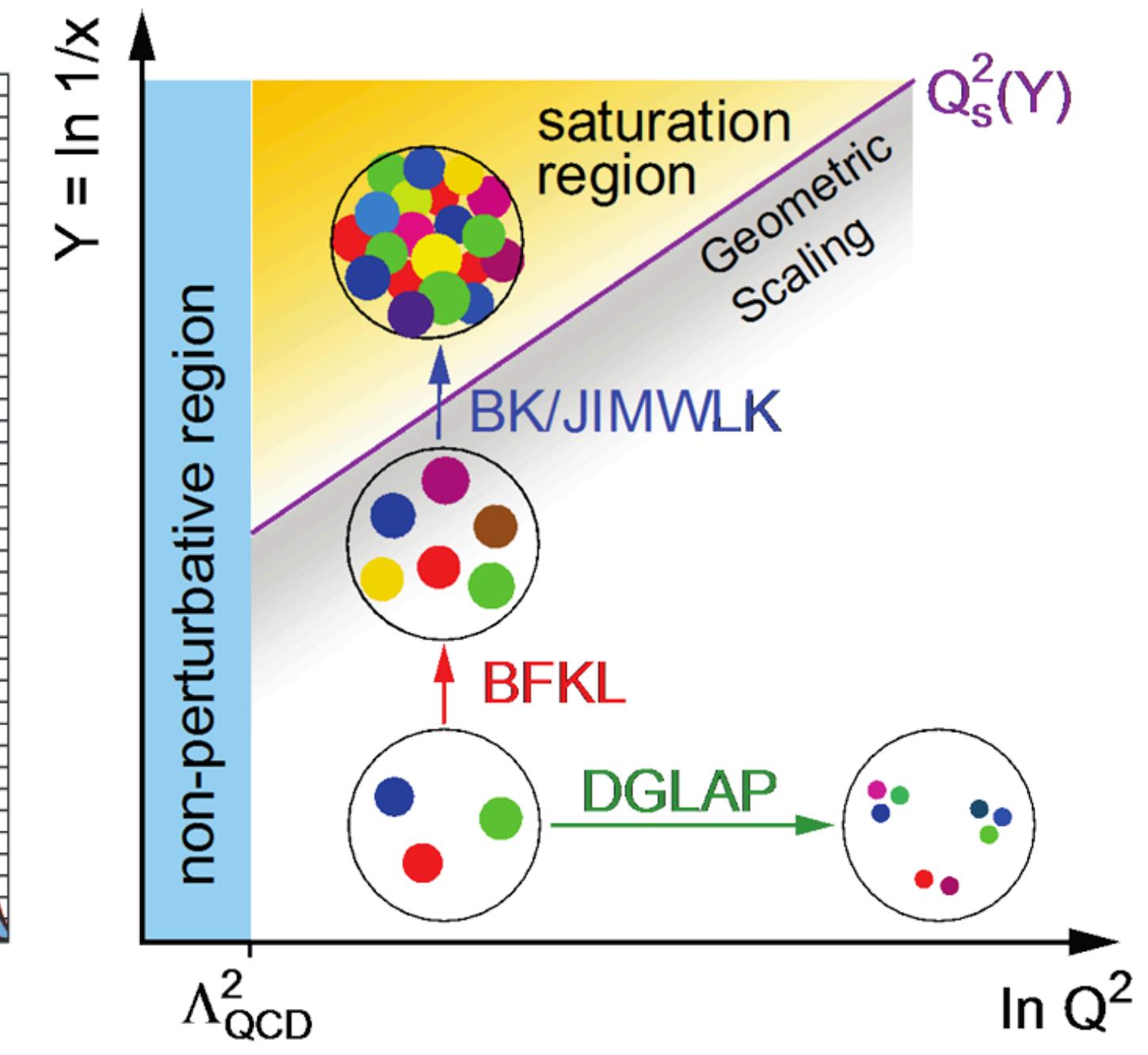
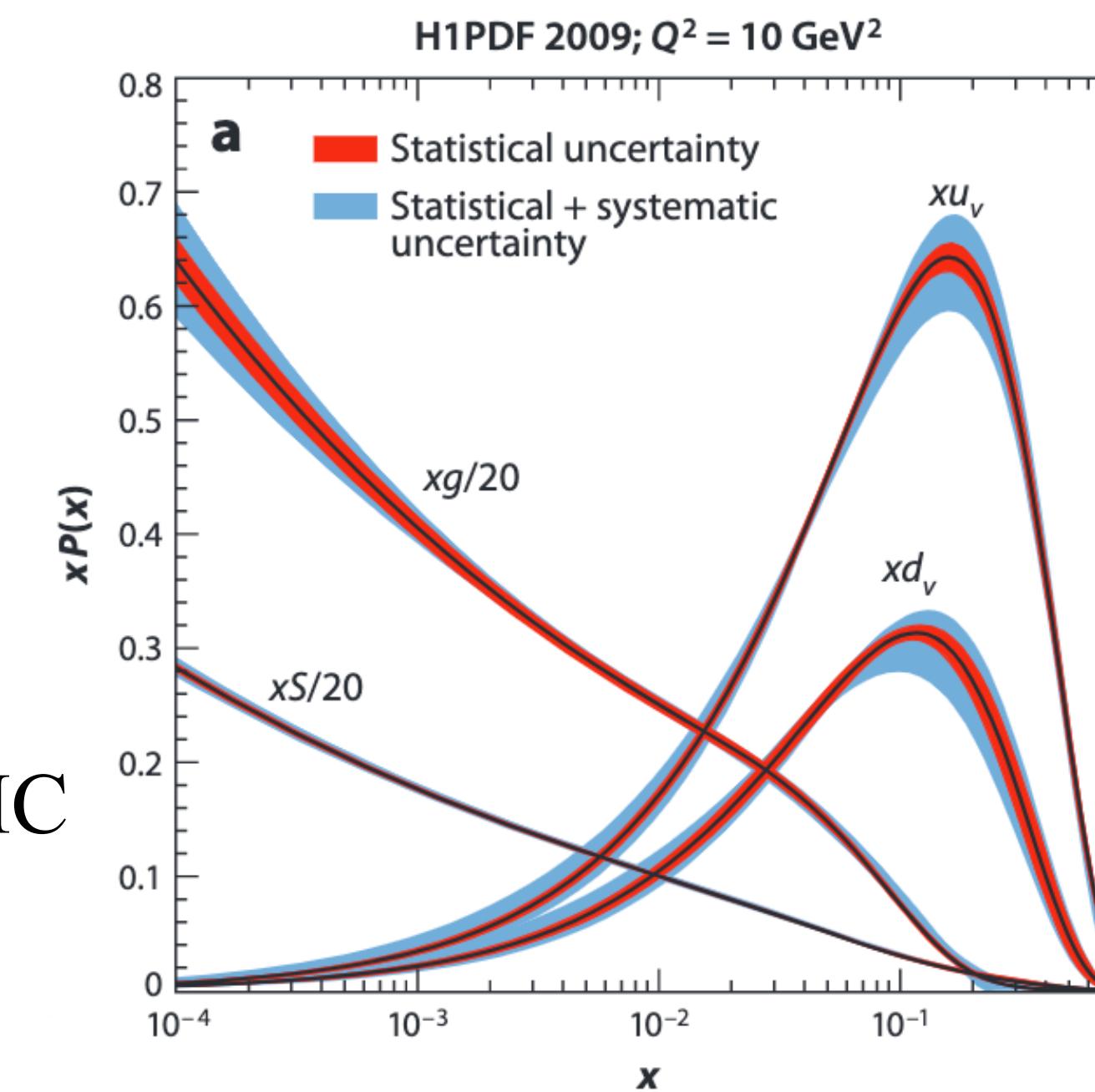
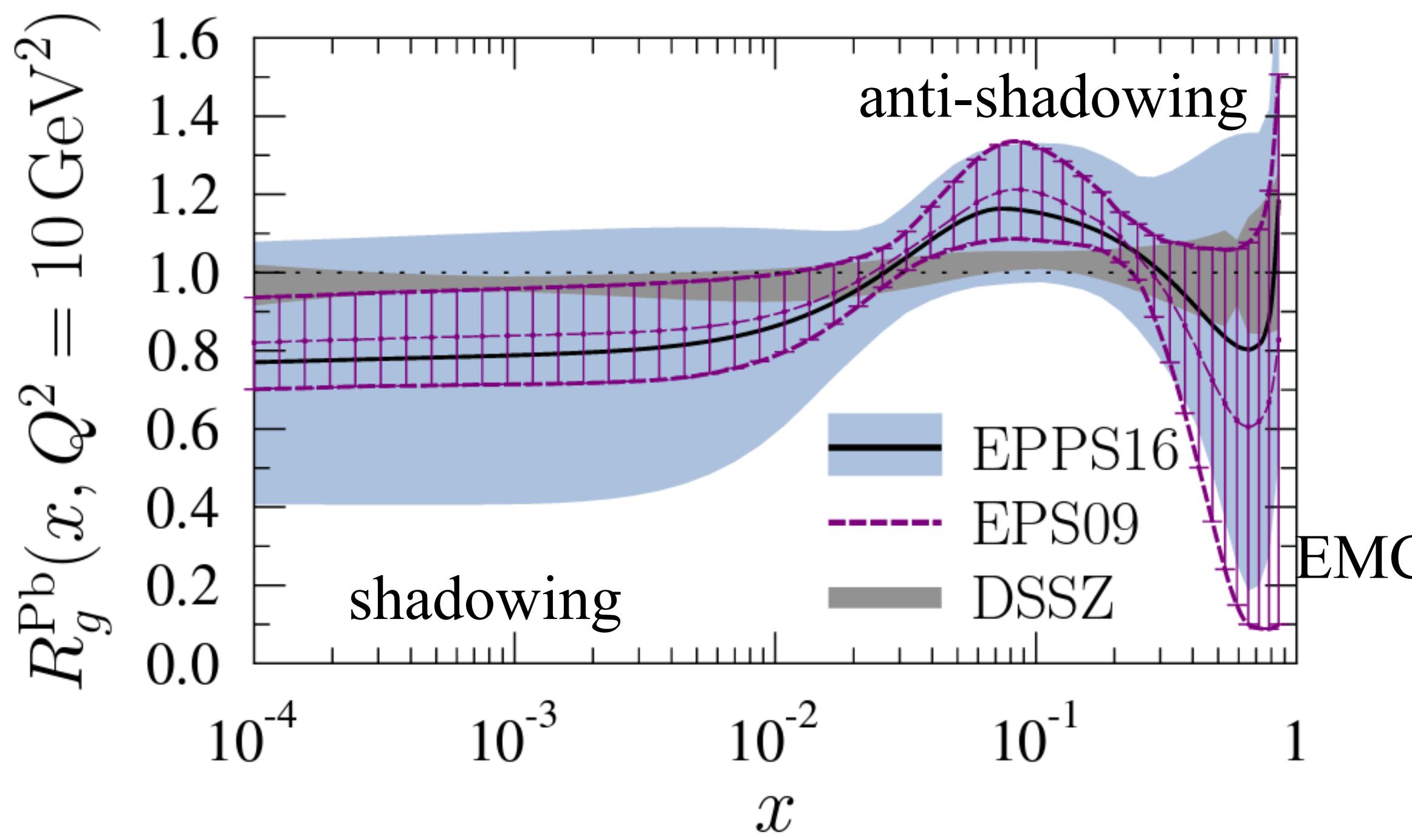
Jiayin Sun
INFN Cagliari
on behalf of the LHCb collaboration

8th July 2022



Phenomena at low Bjorken- x

- Parton densities are modified in nuclei
 - Shadowing: depletion of the effective number of gluons in low- x .
 - Poorly constrained from previous data
- Large number of small- x gluons, leading to a very dense saturated wave function known as the Color Glass Condensate (CGC)
 - Saturation scale $Q_s^2 \propto A^{1/3}$ (Lorentz contraction)
 - Expected in small x and small Q^2 region

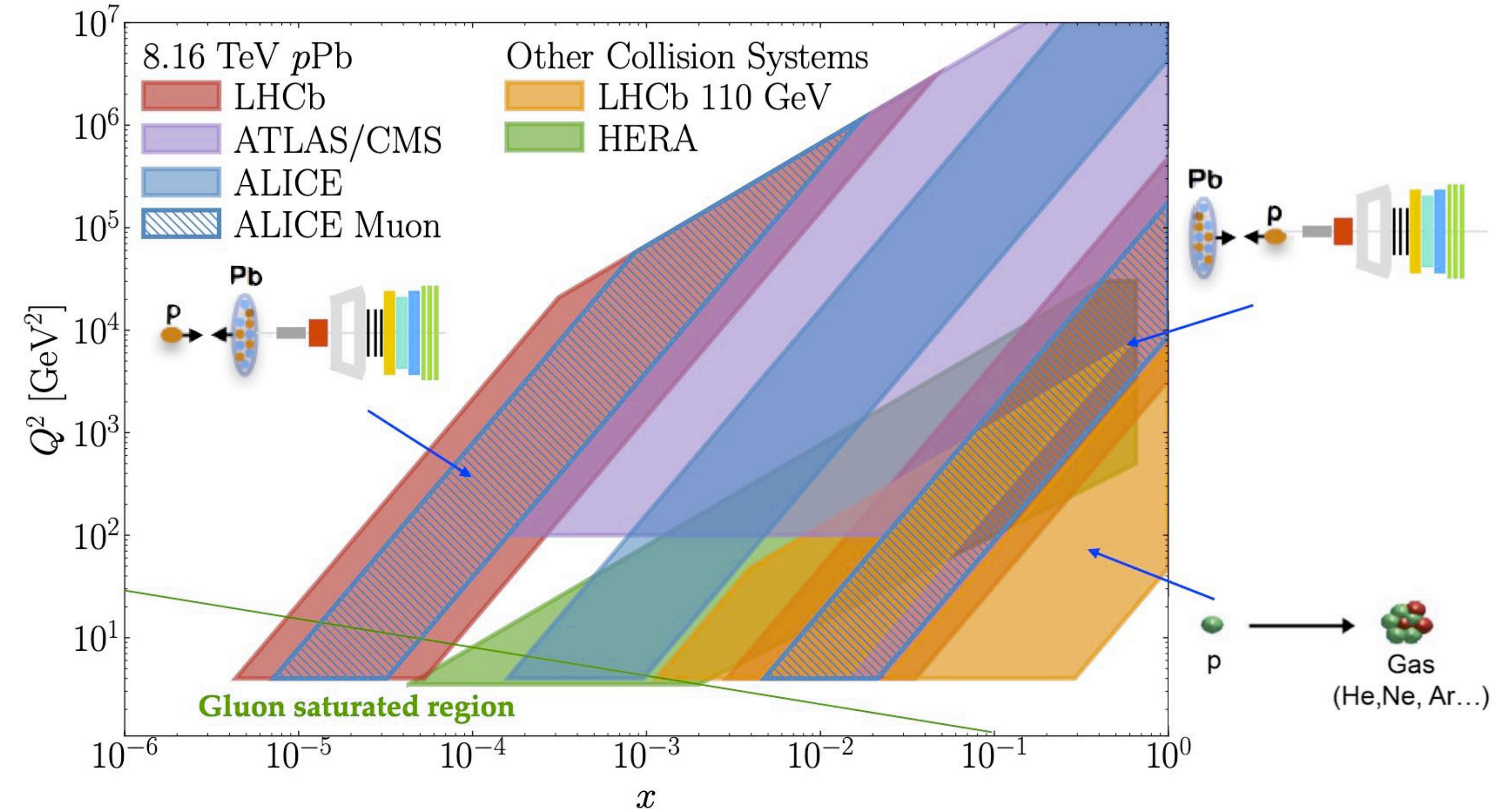
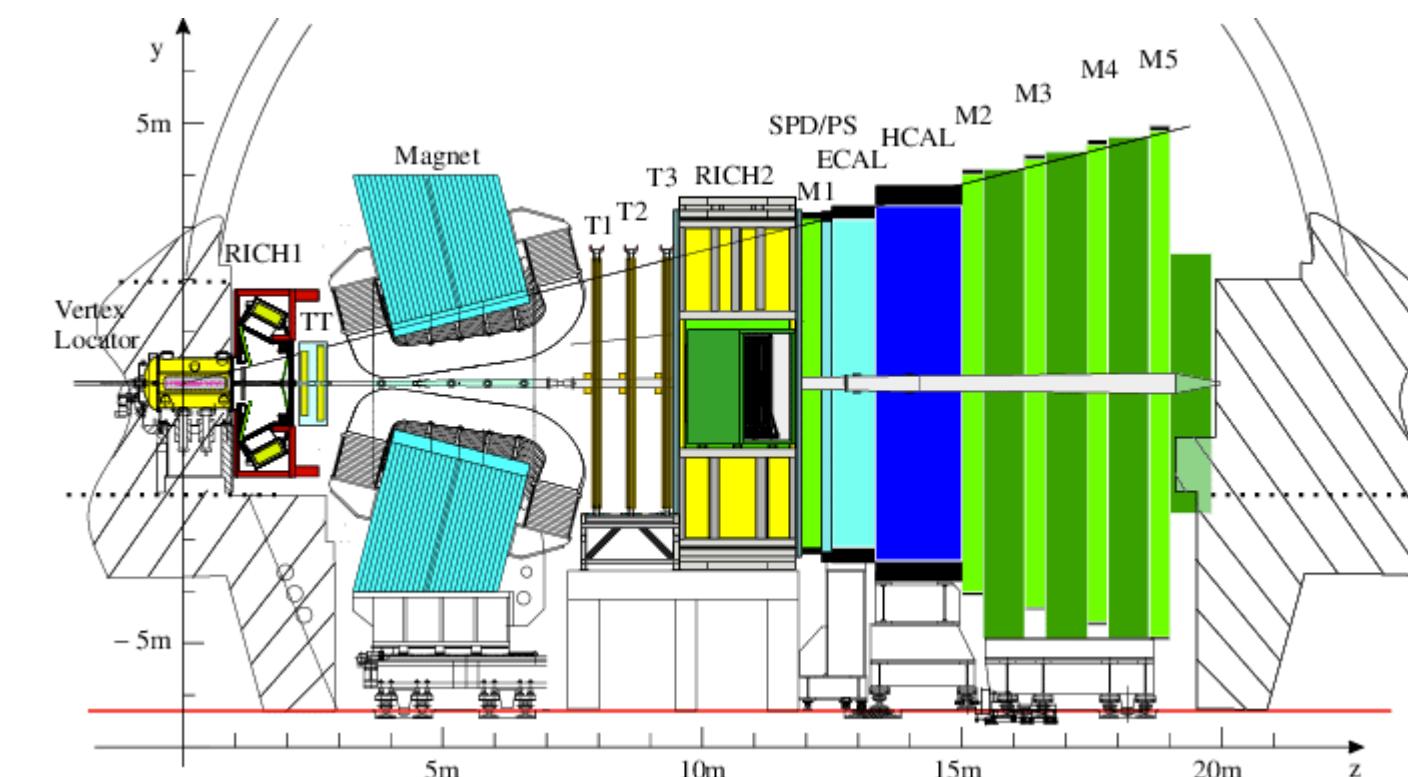


Low- x physics with LHCb

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

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

The LHCb detector

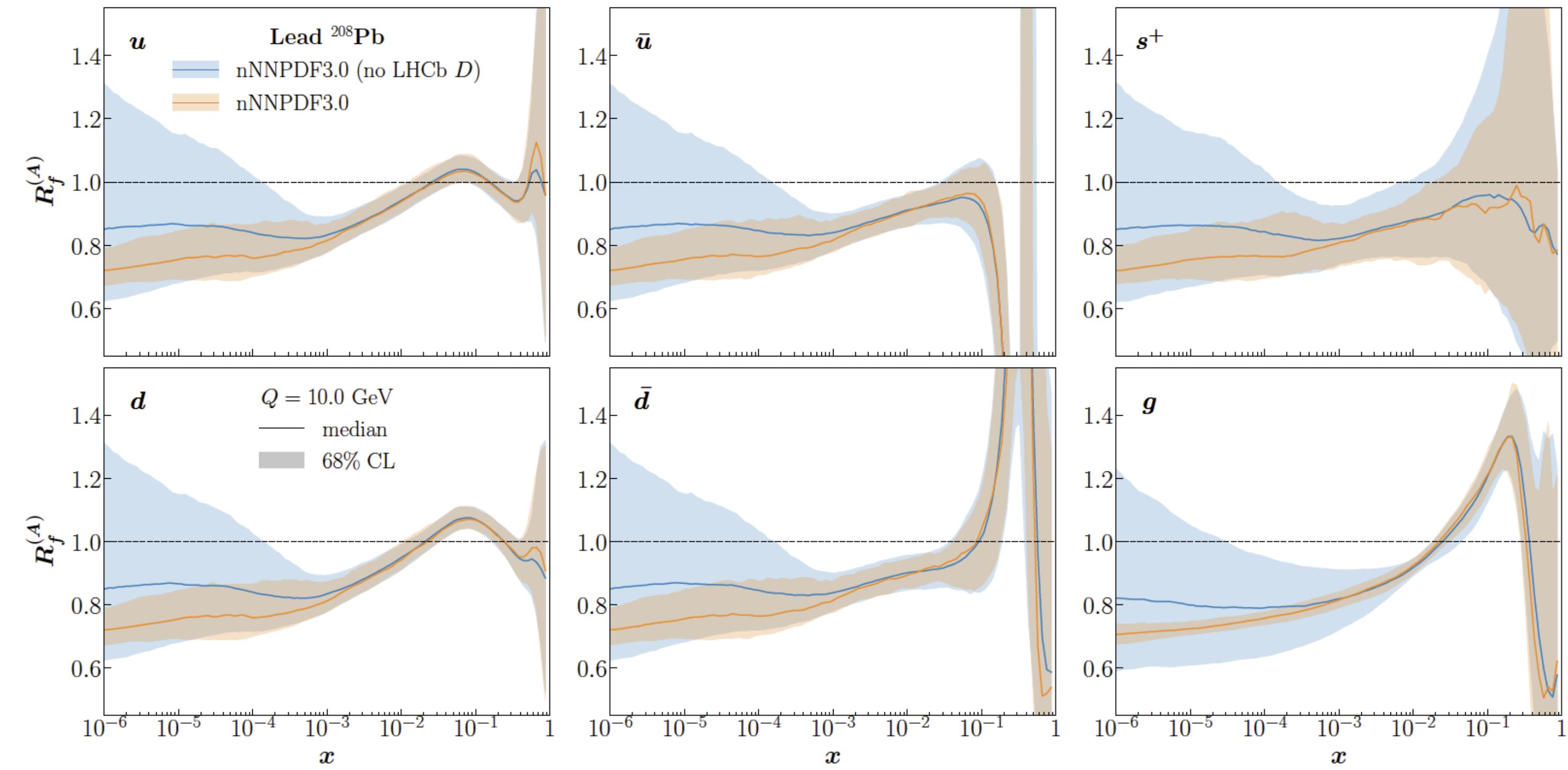
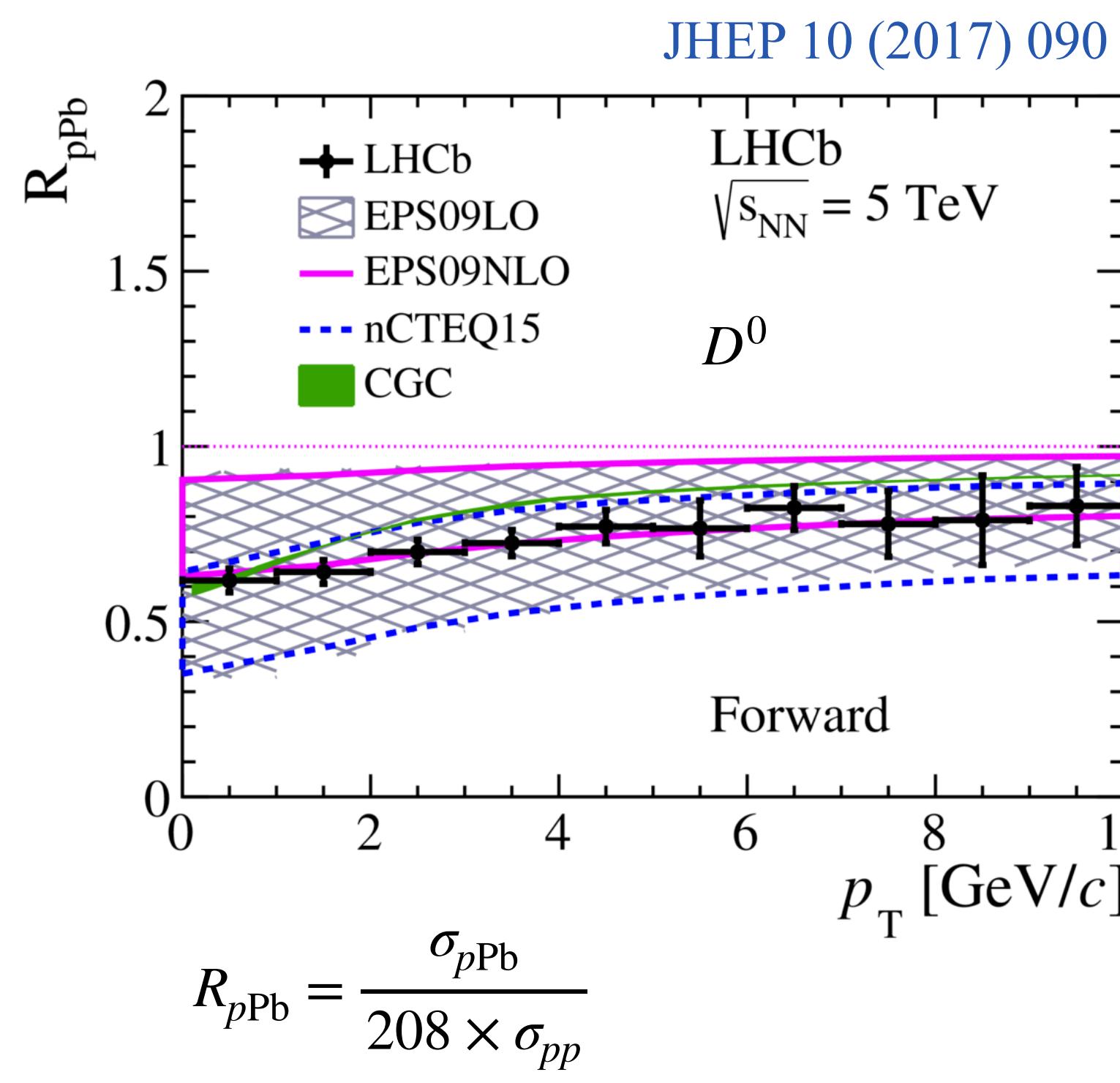


- LHCb kinematic coverage to very low x and low Q^2 !
- Access low Q^2 with light hadrons and direct photons

Constrain nPDF with LHCb data

An example

- nNNPDF3.0 arXiv:2201.12363
- LHCb measurement of prompt D^0 production in $p\text{Pb}$ collisions at 5 TeV makes an impressive impact on reducing nPDF uncertainties down to $x \sim 10^{-6}$

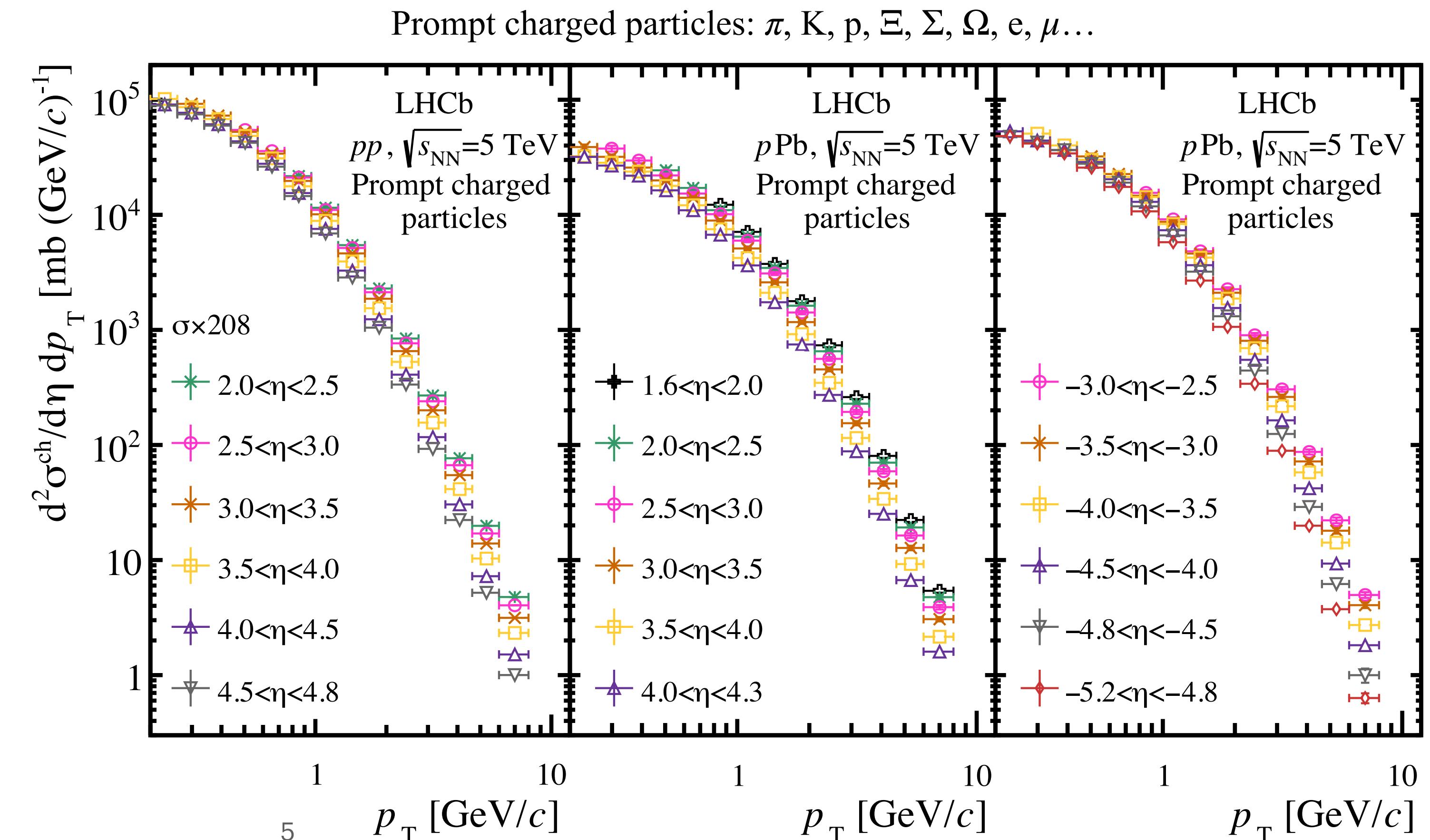


Prompt charged particles in $p\text{Pb}$ and pp collisions at 5 TeV

Differential cross section

PhysRevLett. 128 (2022) 142004

- Inclusive prompt charged particle spectra shed light on the initial state of the collision
- LHCb probes unprecedented Bjorken- x range with forward coverage:
 - Forward: $10^{-6} \leq x \leq 10^{-4}$
 - Backward: $10^{-3} \leq x \leq 10^{-1}$
- Prompt charged particle yields measured with tracking system
- Kinematic coverage:
 - $p > 2 \text{ GeV}/c$, $0.2 < p_T < 8 \text{ GeV}/c$
 - pp : $2 < \eta < 4.8$
 - $p\text{Pb}$: $1.6 < \eta < 4.3$
 - Pbp : $-5.2 < \eta < -2.5$
- Total uncertainty
 - Down to 2.8% in $d^2\sigma/d\eta dp_T$
 - Down to 4.2% in $R_{p\text{Pb}}$



Prompt charged particles in $p\text{Pb}$ and pp collisions at 5 TeV

Nuclear modification factor $R_{p\text{Pb}}$

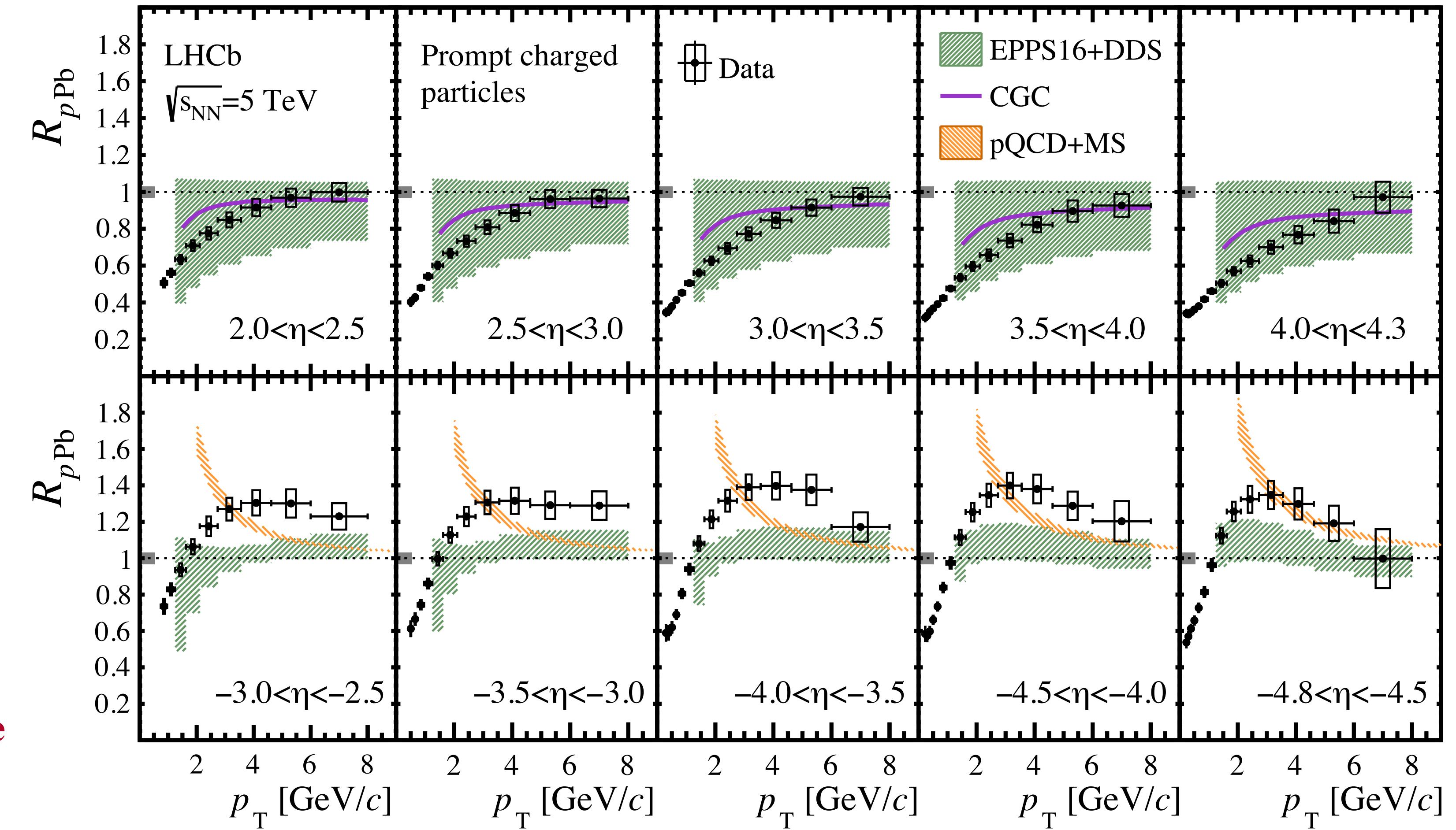
PhysRevLett. 128 (2022) 142004

- Nuclear modification factor:

$$R_{p\text{Pb}} = \frac{1}{A} \frac{d^2\sigma_{p\text{Pb}}(\eta, p_T)/d\eta dp_T}{d^2\sigma_{pp}(\eta, p_T)/d\eta dp_T}$$

$$A = 208$$

- Strong suppression at forward rapidity
- Enhancement at backward rapidity for $p_T > 1.5 \text{ GeV}/c$
- pQCD+Multiple Scattering model can describe PHENIX backward data, but is unable to reproduce backward data from this measurement
- **No model can successfully describe the data across the full rapidity range**



Prompt charged particles in $p\text{Pb}$ and pp collisions at 5 TeV

$R_{p\text{Pb}}$ vs. x_{exp}

PhysRevLett. 128 (2022) 142004

$$Q_{\text{exp}}^2 \equiv m^2 + p_{\text{T}}^2$$

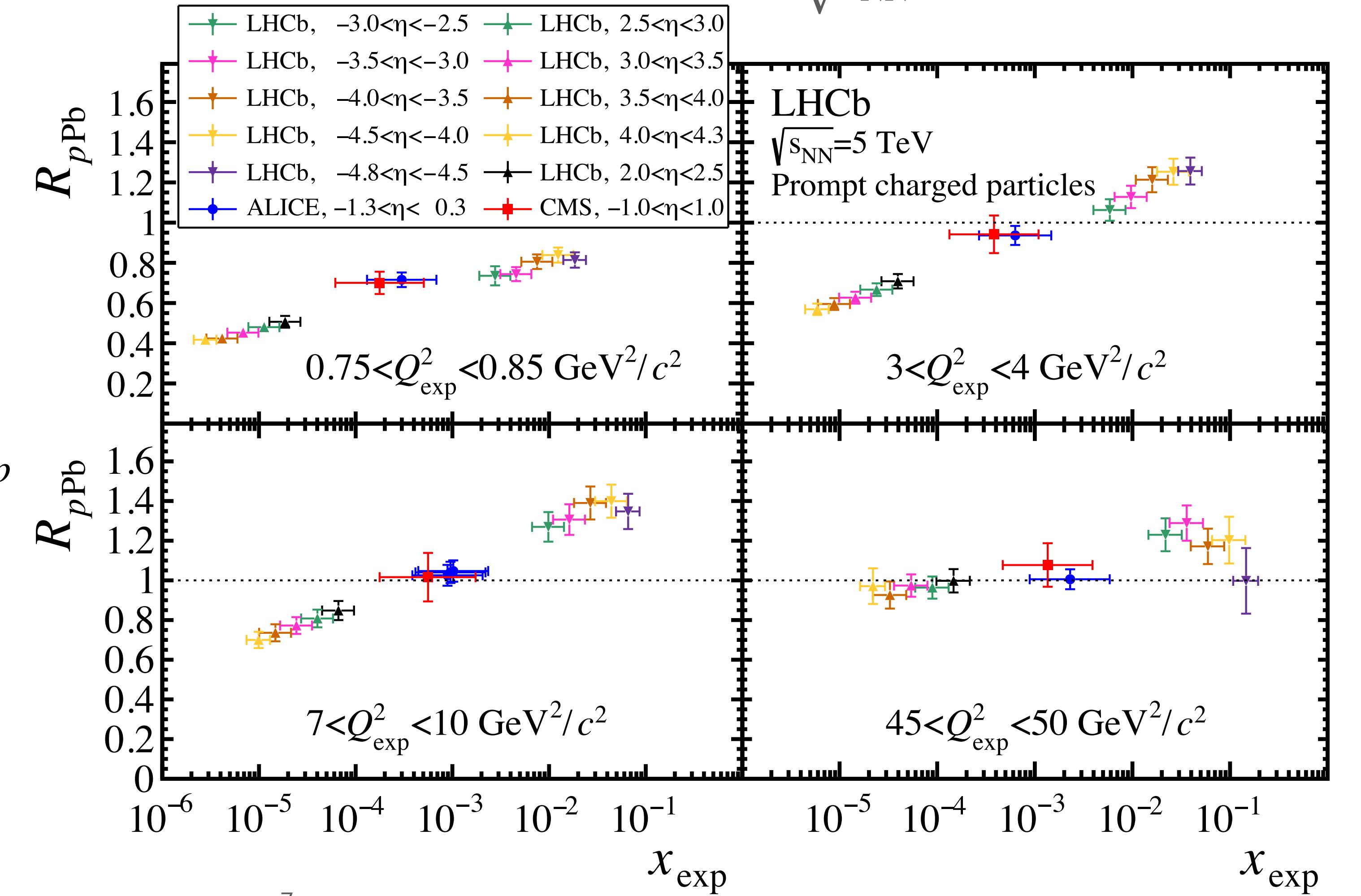
$$x_{\text{exp}} \equiv \frac{Q_{\text{exp}}}{\sqrt{s_{\text{NN}}}} e^{-\eta}$$

ALICE: JHEP1811(2018)013
CMS: JHEP 04(2017)039

► Auxiliary variables x_{exp} and Q_{exp}^2

- η and p_{T} the center of each bin
- $m = 256 \text{ GeV}/c^2$
- Indirect study of the evolution of $R_{p\text{Pb}}$ with x and Q^2

► Continuous trend of $R_{p\text{Pb}}$ with x_{exp} at different Q_{exp}^2 across forward, middle and backward rapidity regions.

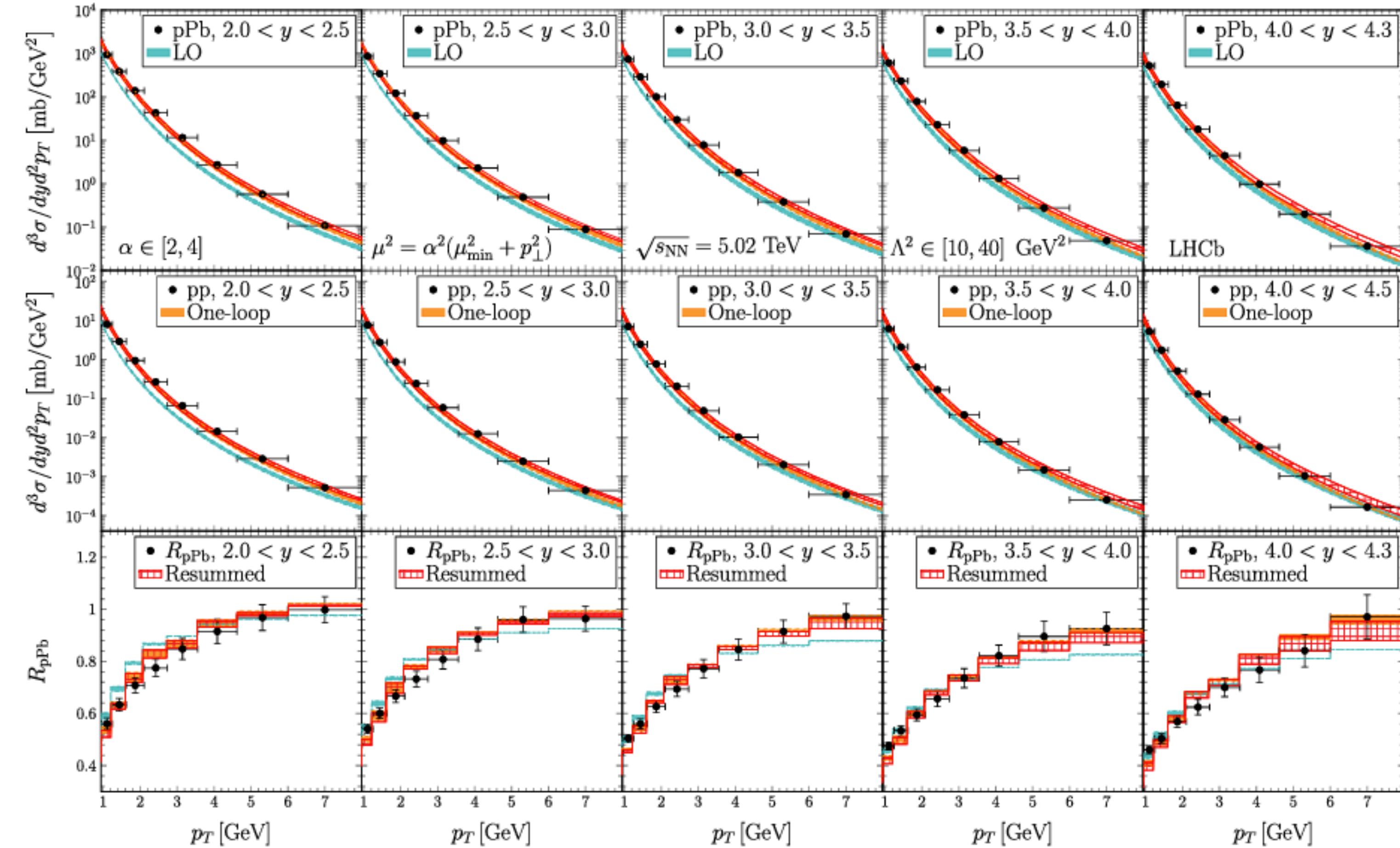


Prompt charged particles in $p\text{Pb}$ and pp collisions at 5 TeV

Theory update

- UPDATE: recent NLO CGC calculation can reproduce LHCb forward data

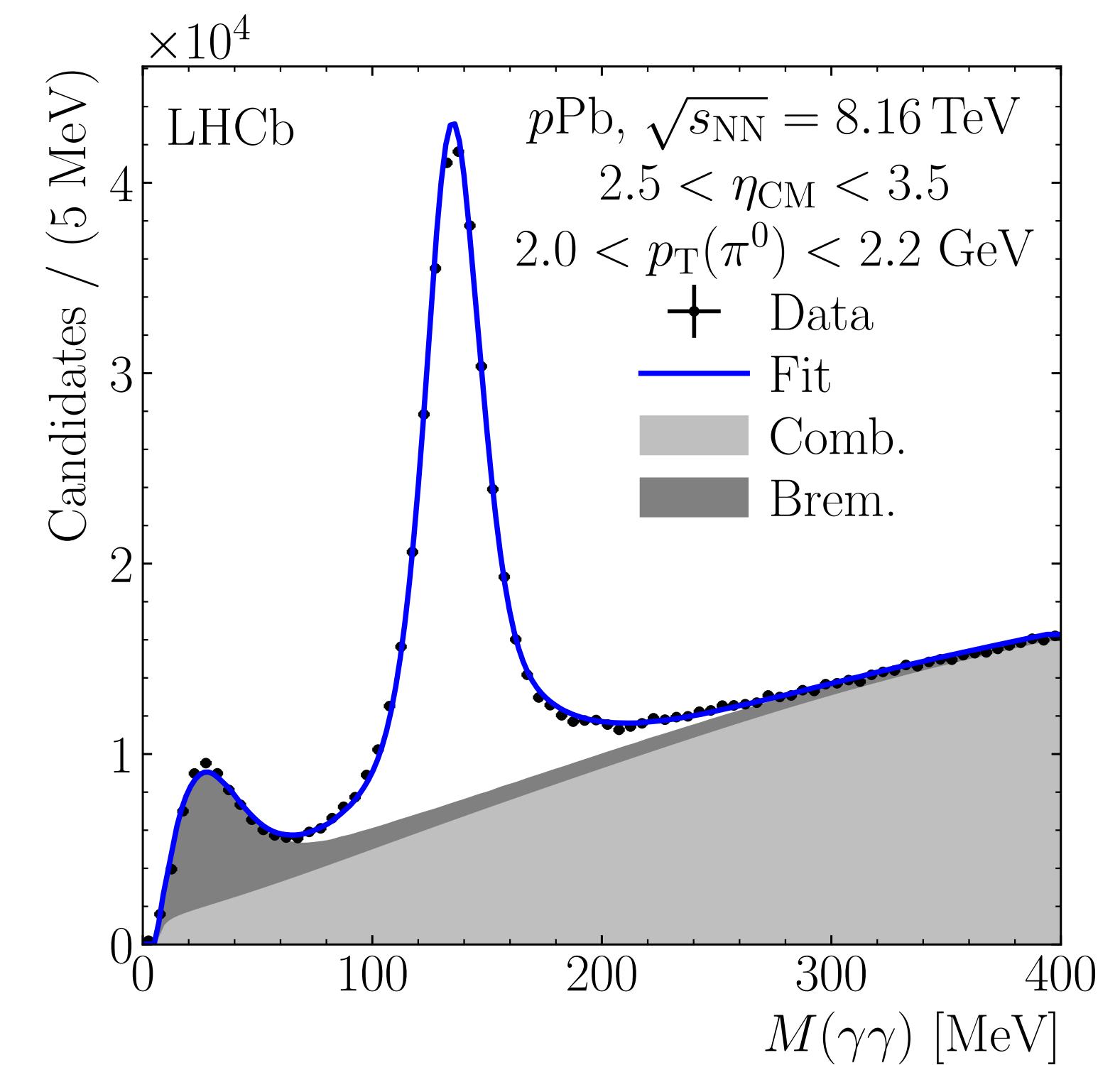
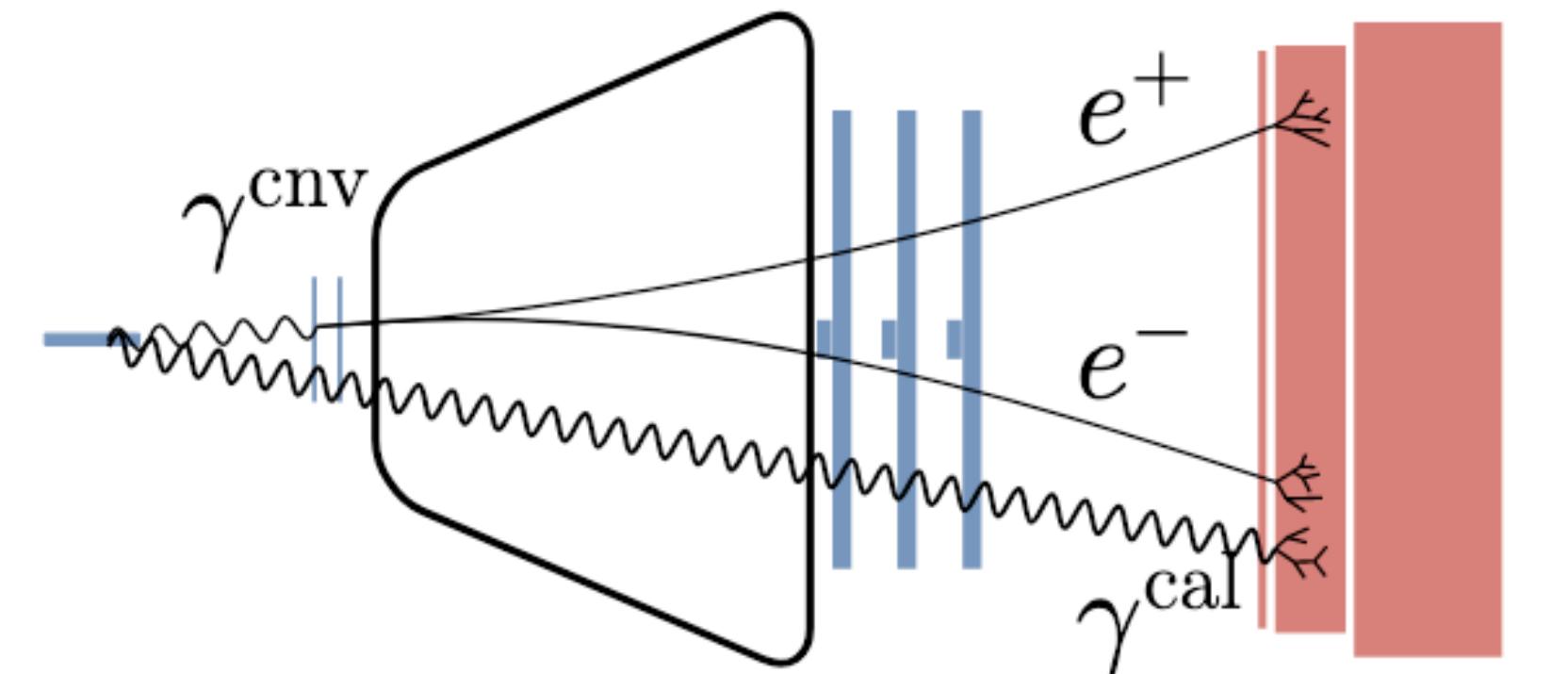
PRL.128.20232(2022)



π^0 production in $p\text{Pb}$ collisions at 8.16 TeV

arXiv:2204.10608
accepted by PRL

- First π^0 result in forward rapidity at LHC.
- π^0 production in $p\text{Pb}$ sensitive to nPDF at low and high x
- By constraining nPDFs, study nuclear effects beyond nPDFs
- Charged hadron in $p\text{Pb}$: large enhancement at backward rapidities
- Disentangle effects from different hadrons, help differentiate between contributions from nPDFs, initial state multiple scattering and final-state effects
- **Gateway to direct photon production measurement**
- Construct $\pi^0 \rightarrow \gamma^{cnv}\gamma^{cal}$
- $1.5 < p_T < 10.0 \text{ GeV}/c$
- $p\text{Pb}: 2.5 < \eta_{CM} < 3.5; \text{Pbp}: -4.0 < \eta_{CM} < -3.0$



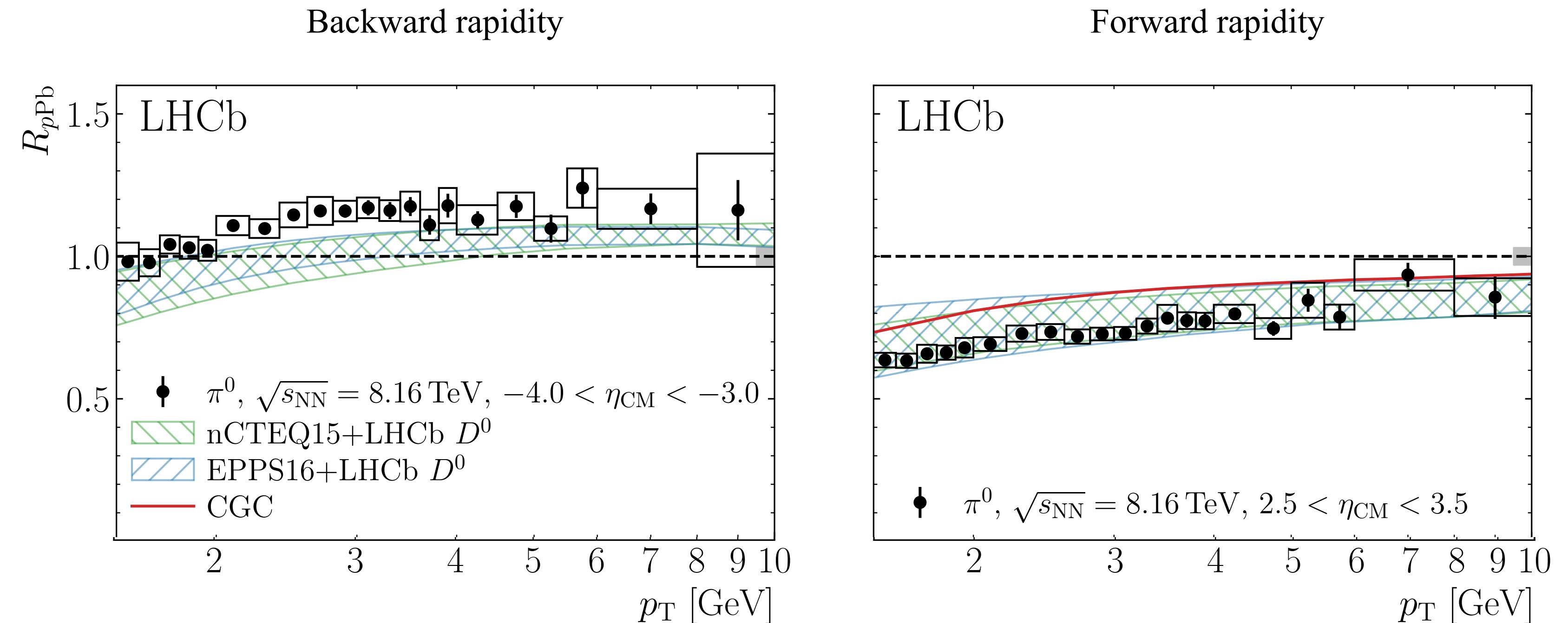
π^0 production in $p\text{Pb}$ collisions at 8.16 TeV

Nuclear modification factor $R_{p\text{Pb}}$

arXiv:2204.10608
accepted by PRL

- pp reference: interpolation between 5 and 13 TeV
- Forward ($p\text{Pb}$):
 - Strong suppression
 - Data smaller uncertainties than the nPDF uncertainties
 - Lower than CGC calculation
- Backward ($\text{Pb}p$):
 - Cronin-like enhancement
 - Larger than nPDF calculations, similar to the charged hadron result

$$R_{p\text{Pb}} = \frac{\sigma_{p\text{Pb}}}{208 \times \sigma_{pp}}$$



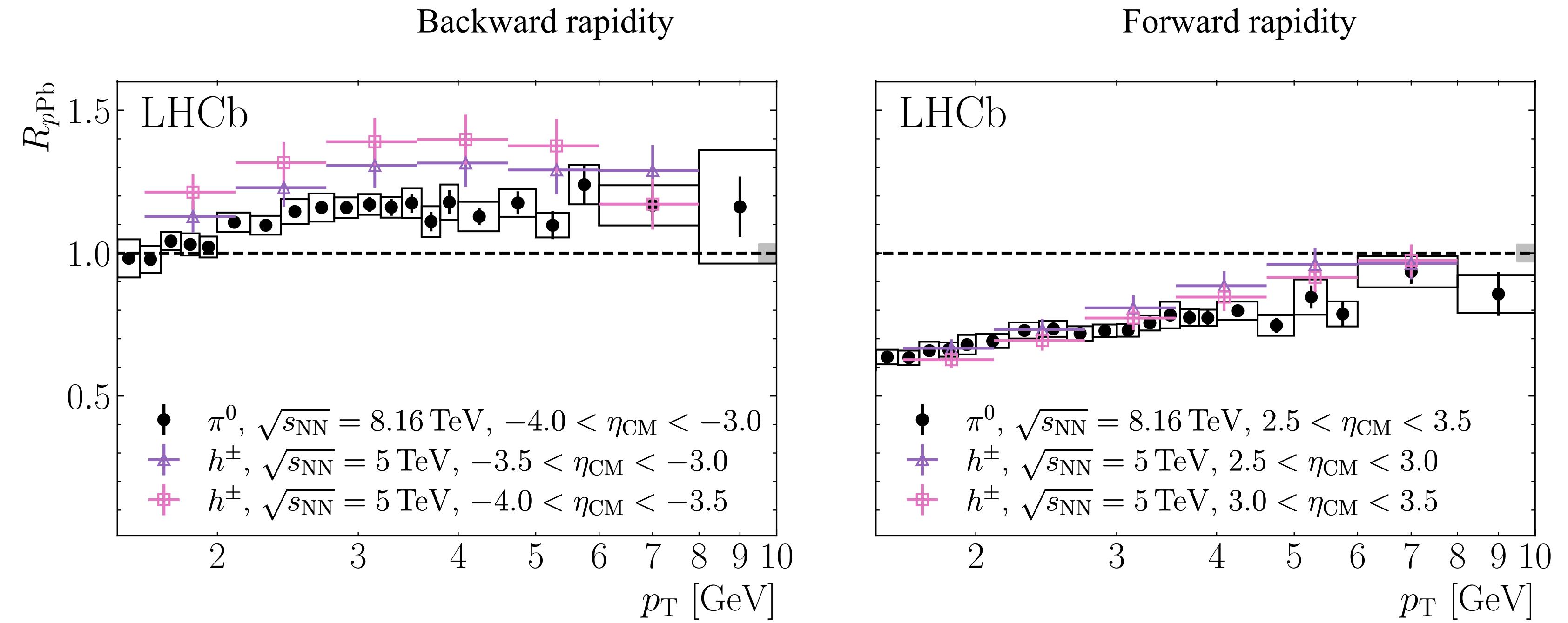
π^0 production in $p\text{Pb}$ collisions at 8.16 TeV

Nuclear modification factor $R_{p\text{Pb}}$

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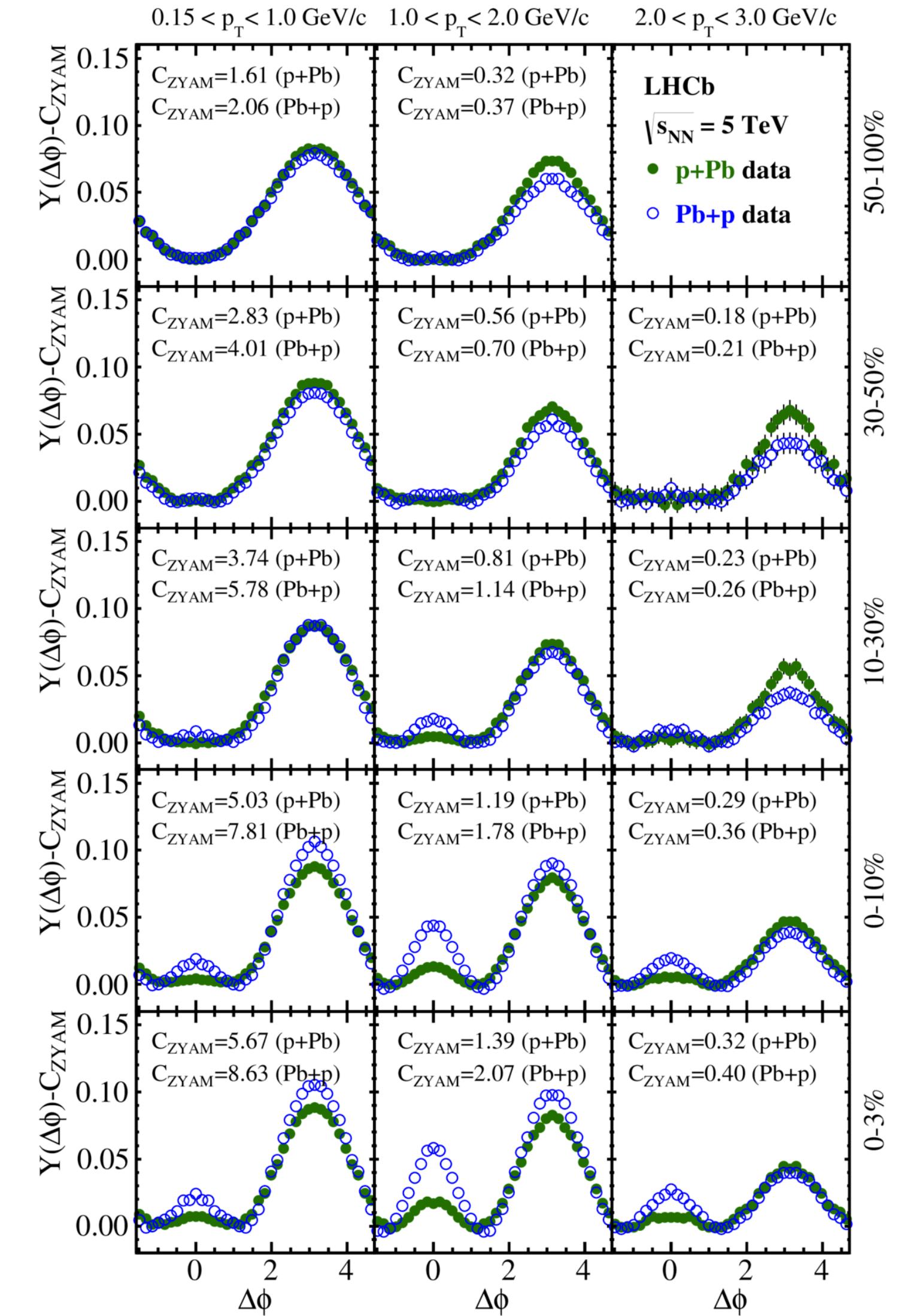
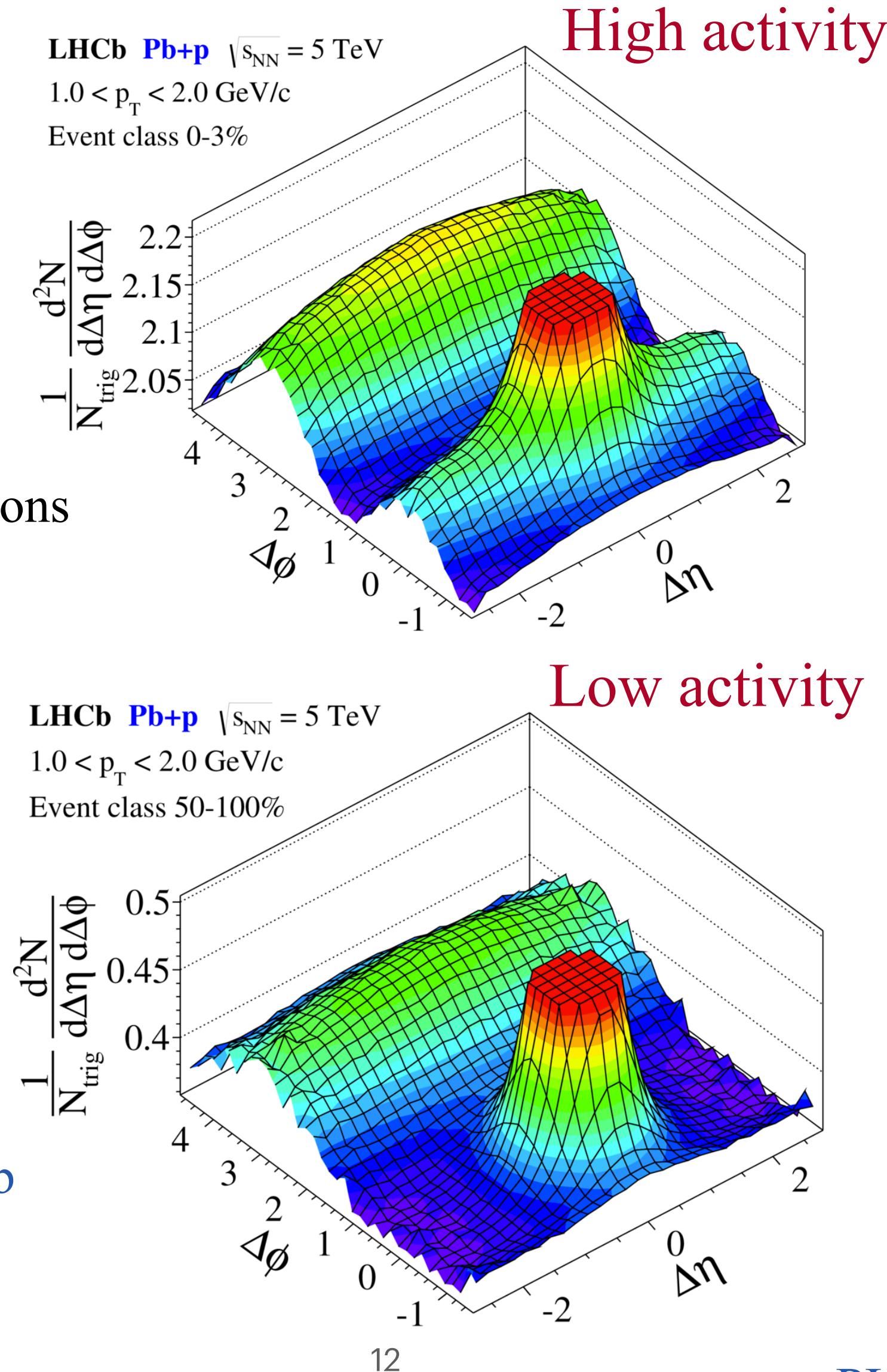
- pp reference: interpolation between 5 and 13 TeV
- Forward ($p\text{Pb}$):
 - Consistent with charged hadron result
- Backward (Pbp):
 - Enhancement less pronounced than charged hadrons
 - Indicating a mass-ordering effect: radial flow, Cronin enhancement...
- Future measurements with identified hadrons highly interesting

$$R_{p\text{Pb}} = \frac{\sigma_{p\text{Pb}}}{208 \times \sigma_{pp}}$$



Charged hadron long-range correlations in $p\text{Pb}$ collisions

- Origin of long-range rapidity correlations under debate:
 - Initial state effects via gluon saturation
 - Hydrodynamic evolution of a high density partonic medium
 - Others...
- LHCb di-hadron correlations in 5 TeV $p\text{Pb}$ collisions
 - First time in the forward region
 - Ridge in high activity events
- Ongoing analyses: **Coming soon!**
 - Charged hadron in 5 TeV PbPb collisions:
 - In the forward rapidity region
 - Includes directed flow
 - Charged hadron and heavy flavor in 8.16 TeV $p\text{Pb}$ collisions:
 - High statistics



Conclusion

Thank you for the attention!

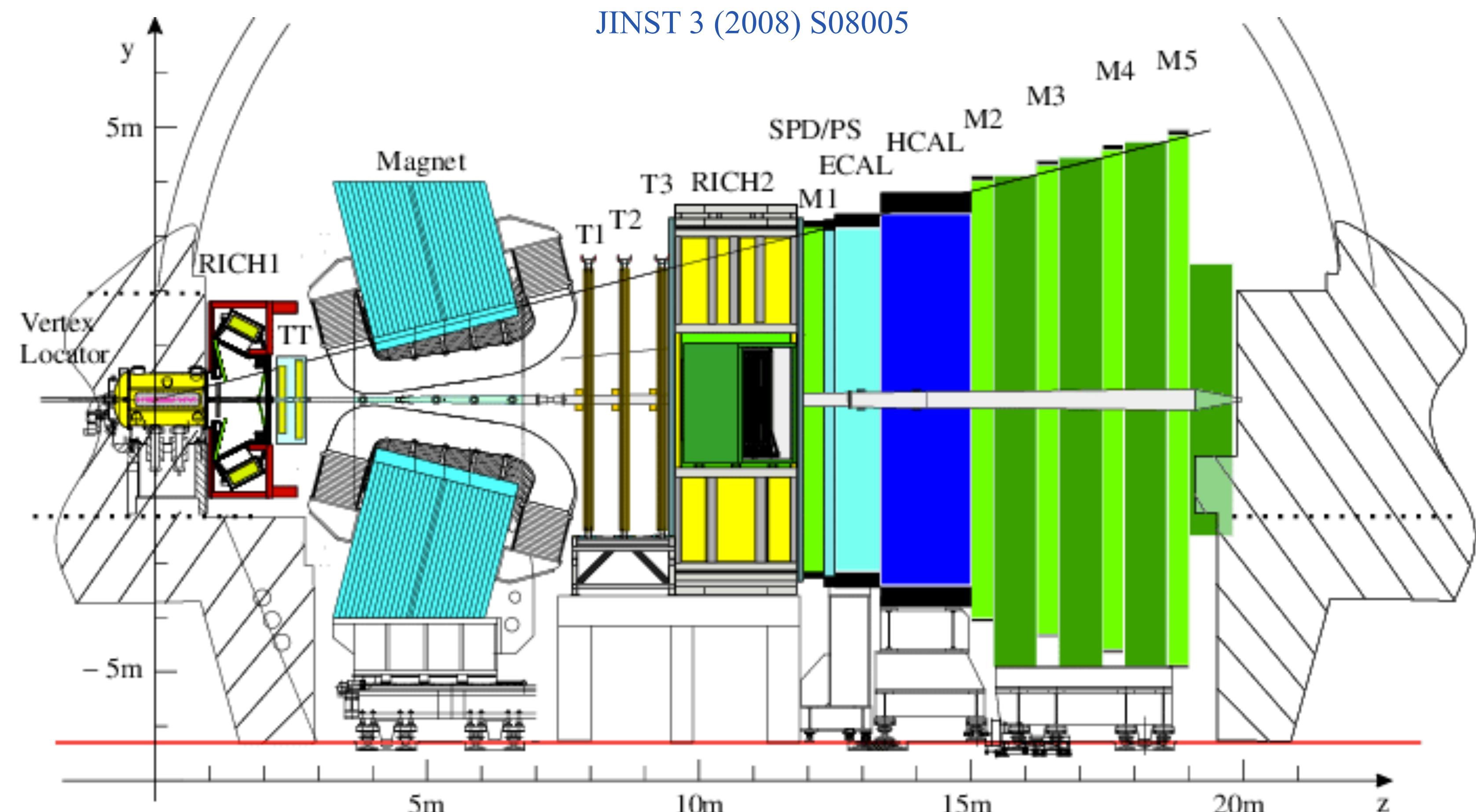
- LHCb has unique capabilities to study phenomena at very low Bjorken- x
- Precision measurements of h^\pm , π^0 production in $p\text{Pb}$ collisions
 - Forward rapidity: precisely pin down nPDF at small x
 - Backward rapidity: models cannot reproduce data, additional effects beyond nPDF
- Collectivity results in forward rapidities coming soon!
- Run3 with a major detector upgrade opens more opportunities
 - Much larger $p\text{Pb}$ sample

Backup

LHCb detector

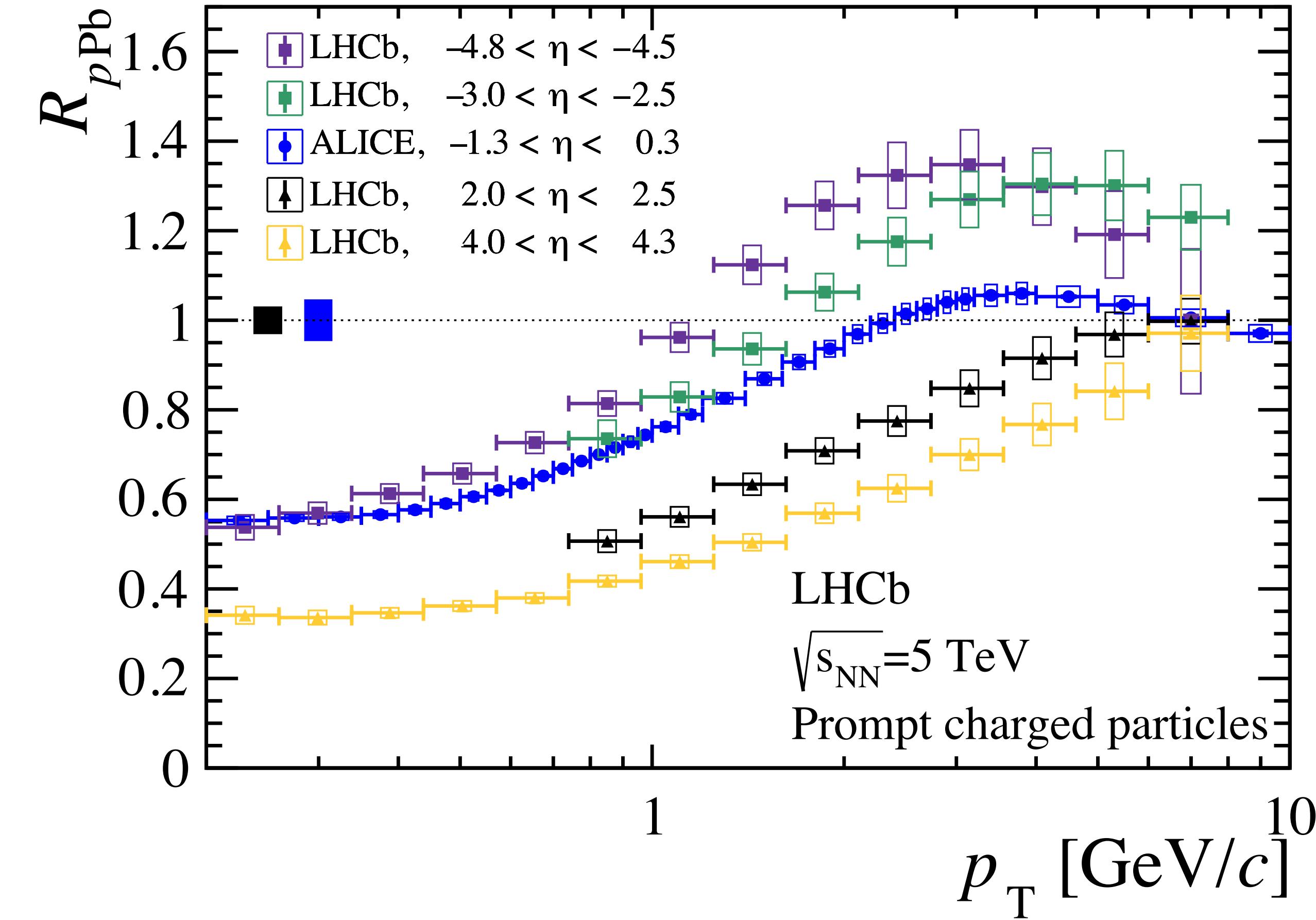
- Acceptance: $2 < \eta < 5$
- Vertex detector (VELO)
 - IP resolution $\sim 20\mu\text{m}$
- Tracking system
 - $\frac{\Delta p}{p} = 0.5 - 1\%$
(5-200 GeV/c)
- RICH
 - $K/\pi/p$ separation
- Electromagnetic + hadronic calorimeters
- Muon system
- Results presented in this talk are based on this configuration

Already upgraded for Run3! more later



Prompt charged particles in $p\text{Pb}$ and pp collisions at 5 TeVNuclear modification factor $R_{p\text{Pb}}$

PhysRevLett. 128 (2022)142004



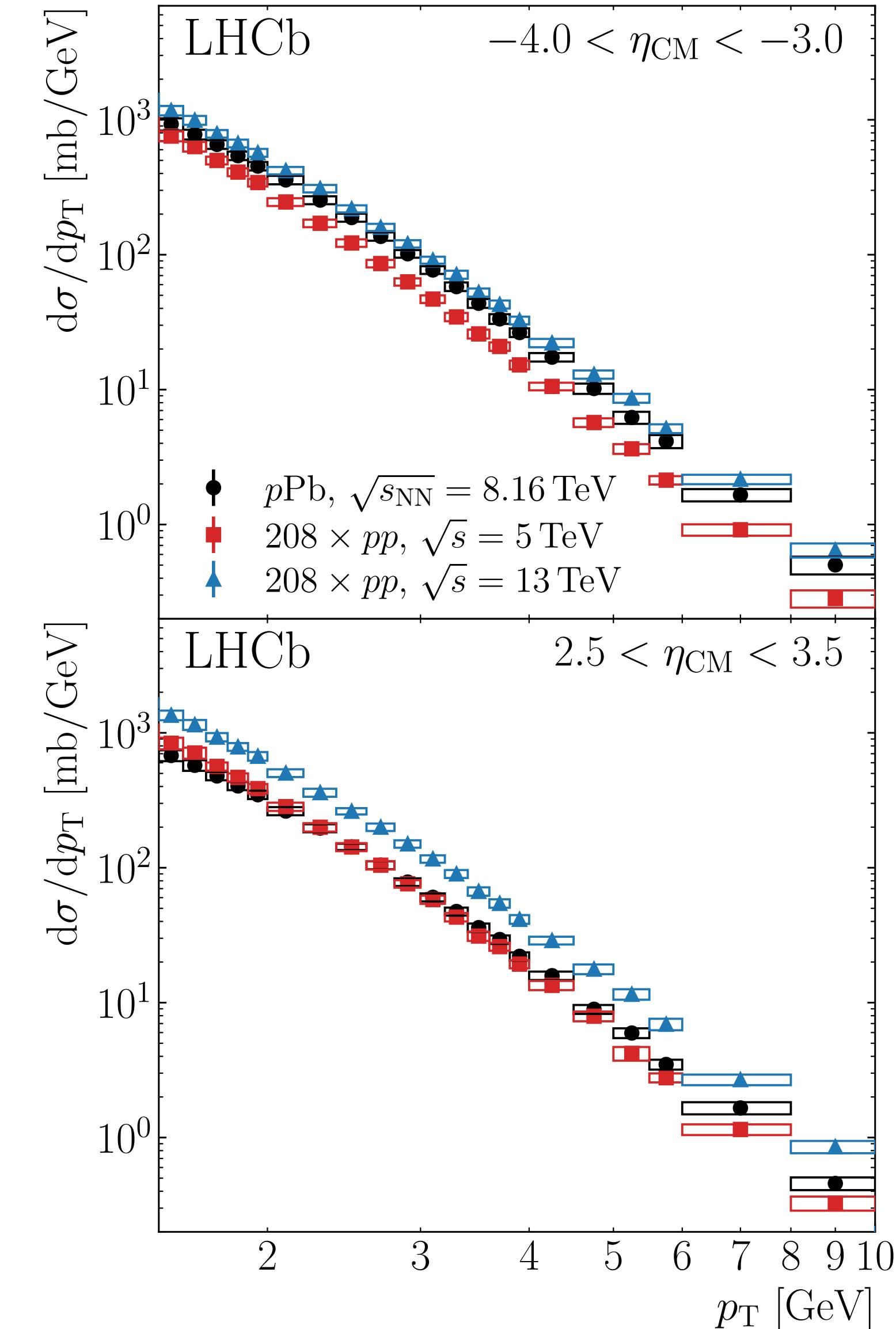
π^0 production in $p\text{Pb}$ collisions at 8.16TeV

π^0 differential cross-sections

arXiv:2204.10608
accepted by PRL

- pp reference for $R_{p\text{Pb}}$: interpolation between 5 and 13TeV

$$R_{p\text{Pb}} = \frac{\sigma_{p\text{Pb}}}{208 \times \sigma_{pp}}$$



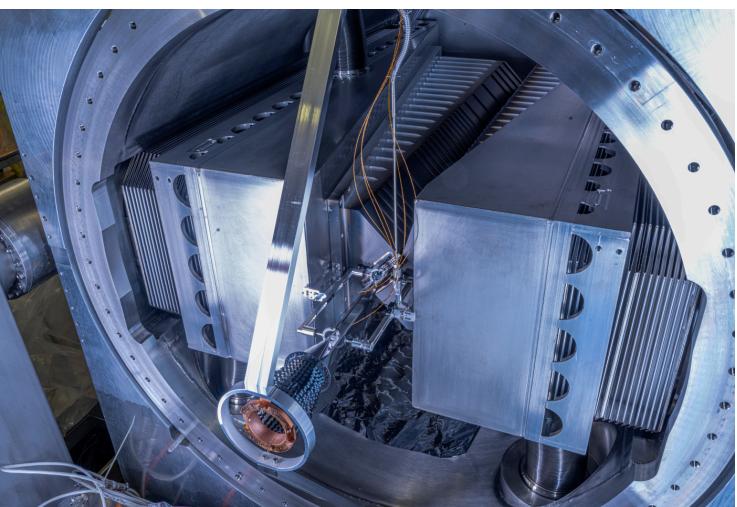
LHCb phase-I upgrade

Full software trigger

- Remove L0 hardware triggers
- Read out full detector at 40MHz
- $p\bar{p}$ requirements: 40MHz collision rate, pile-up factor ~ 5

New Pixel VELO

SMOG2



New tracking systems:

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

Side View

Magnet

RICH1

UT

SciFi
Tracker

RICH2

ECAL HCAL

ECAL

HCAL

M4 M5

M2

M3

18 New RICH optics and photodetectors

20m

z

y

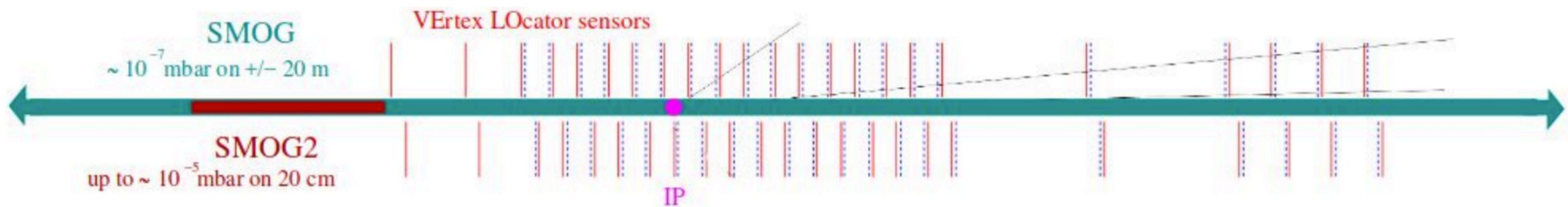
5m

18m

20m

z

SMOG2

Talk by S. Mariani
7 July 10:10

- SMOG2: Storage Cell for the gas upstream of the nominal IP (z in $[-500, -300]$ mm) and precisely calibrated Gas Feed System.
 - Gas density increased by up to two orders of magnitude → much higher luminosity
 - More gas targets: H₂, D₂, He, N₂, O₂, Ne, Ar, Kr, Xe
- beam-beam and beam-gas separate luminous regions:
 - simultaneous pp -SMOG2 data-taking
 - large statistics
- Physics:
 - Intrinsic heavy-quark
 - p-Gas collisions: nPDFs, gluon anti-shadowing at large x , cold nuclear matter effects
 - Pb-Gas collisions: QGP formation, rapidity scan at lower energy
 - Astrophysics

LHCb-PUB-2018-015

No centrality limitation!