Hadron production studies with LHCb

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Fixed target experiments at LHC workshop

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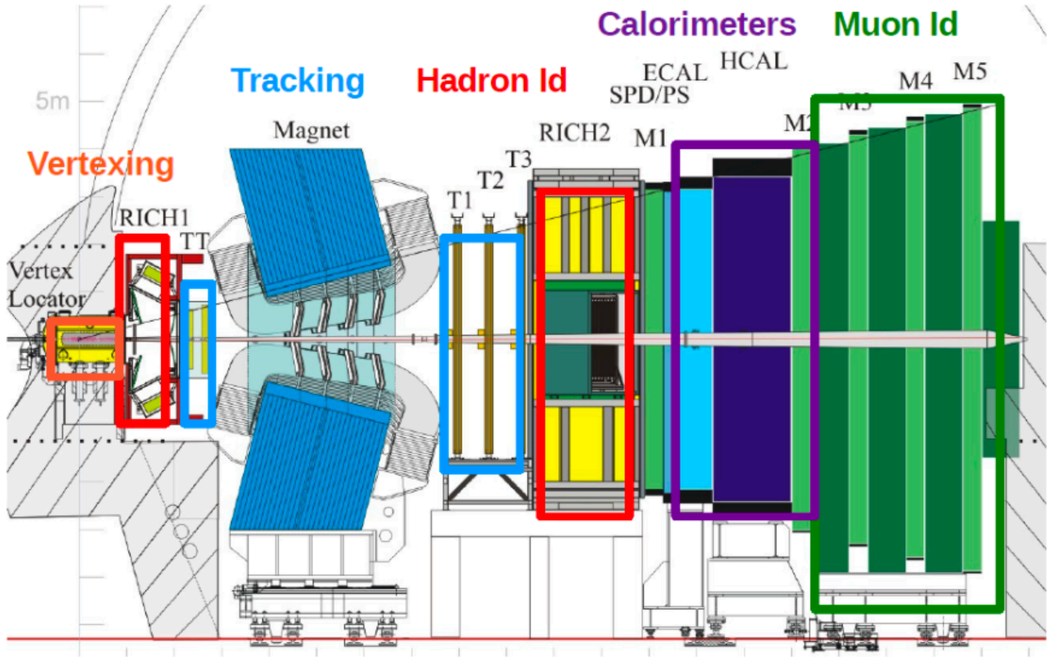
LHCb Detector

- 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.



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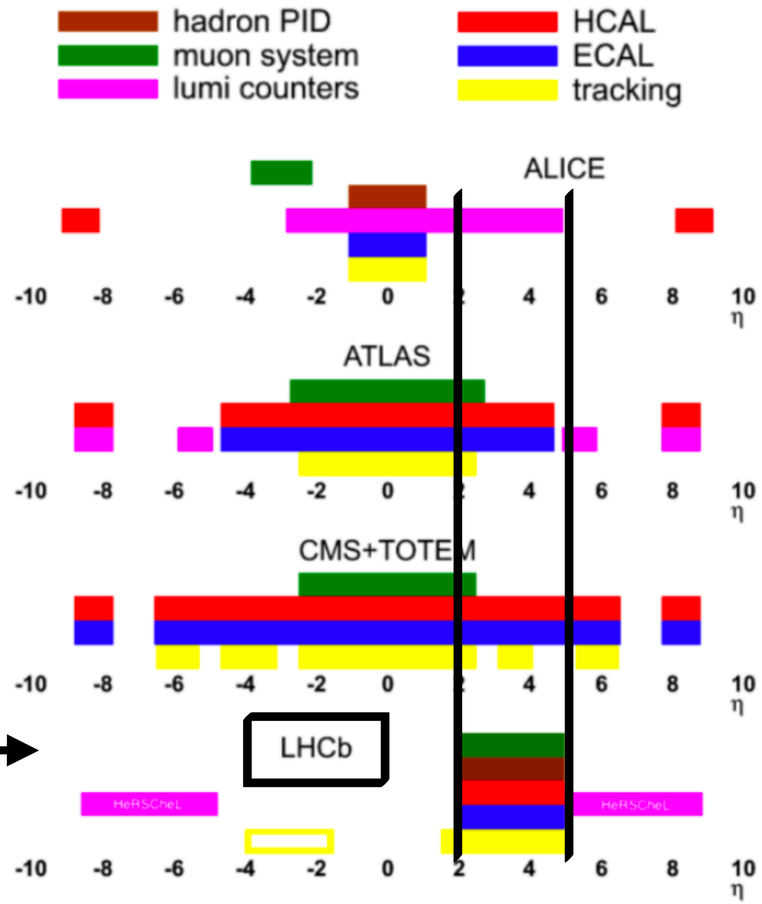
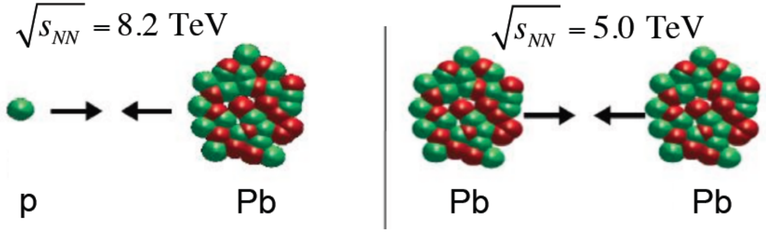


IJMPA 30 (2015) 1530022

LHCb Dataset

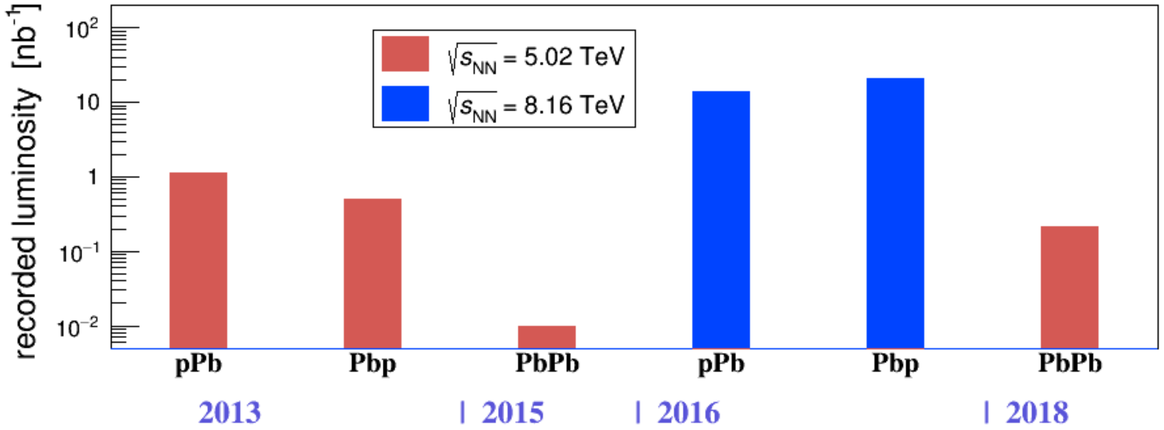
Collider mode

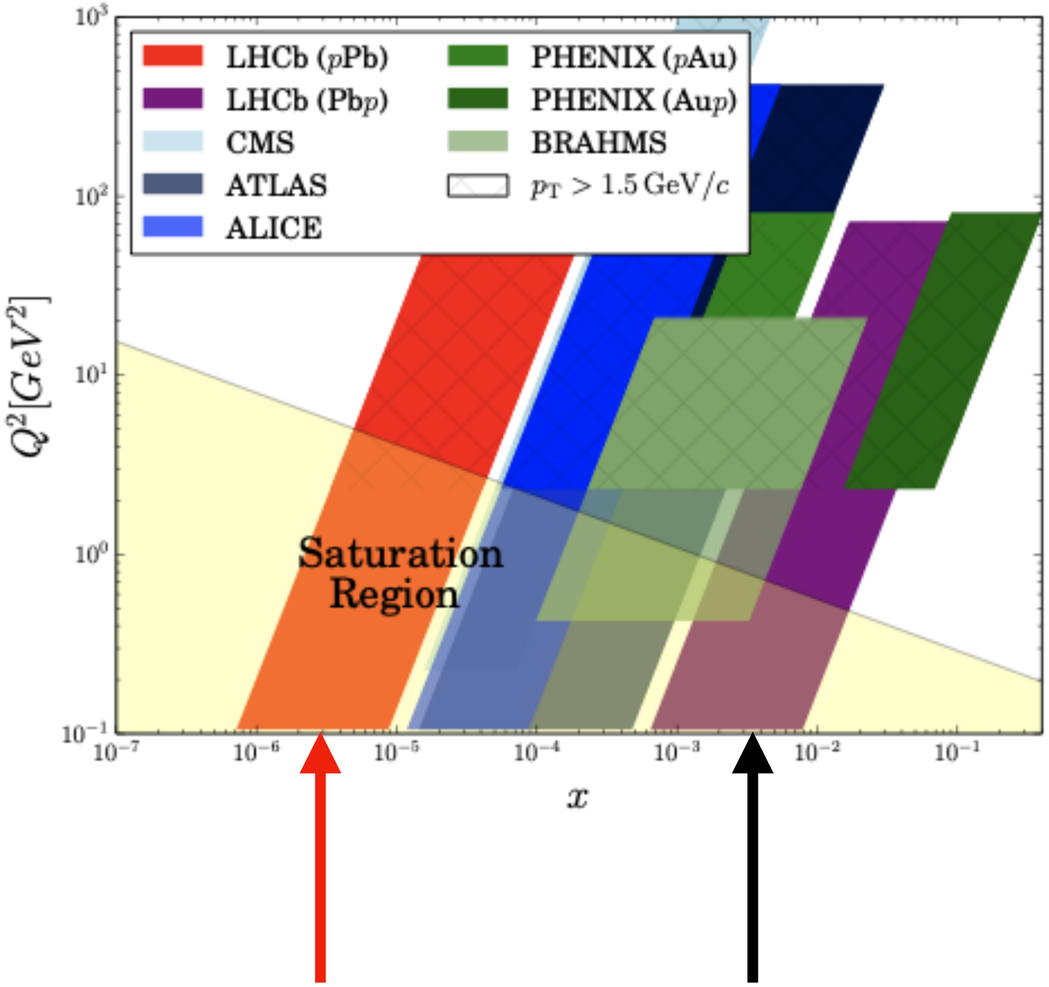


Q^2: exchanged momentum between interacting partons

x: momentum fraction of Pb parton

$$Q^2 \sim m^2 + p_T^2, \qquad x \sim \frac{Q}{\sqrt{s_{NN}}} e^{-\eta}$$





$pPb : 10^{-6} \leq x \leq 10^{-4}$ $\quad$ $Pbp : 10^{-3} \leq x \leq 10^{-1}$

Prompt charged hadron production in *pPb* and *pp* at 5 TeV

Prompt : Any lepton or hadron with a mean lifetime $\tau > 0.3 \times 10^{-10} s$ produced directly in the collision or from decays of shorter-lifetime particles.

Phys. Rev. Lett. 128, 142004

Long lived particles :

$$\pi^-, K^-, p, \Xi^-, \Sigma^+, \Sigma^-, \Omega^-, e^-, \mu^-(+cc.)$$

Datasets at: $\sqrt{s_{NN}} = 5TeV$

Beam	Acceptance	Luminosity
pp	$2 < \eta < 4.8$	$3.49 \pm 0.07\,\mathrm{nb}^{-1}$
pPb	$1.6 < \eta < 4.3$	$42.73 \pm 0.98\,\mu\mathrm{b}^{-1}$
Pbp	$-5.2 < \eta < -2.5$	$38.71 \pm 0.97\,\mu\mathrm{b}^{-1}$

$$R_{p\mathrm{Pb}}(\eta, p_\mathrm{T}) = \frac{1}{A} \frac{d^2\sigma_{p\mathrm{Pb}}(\eta, p_\mathrm{T})/dp_\mathrm{T}d\eta}{d^2\sigma_{pp}(\eta, p_\mathrm{T})/dp_\mathrm{T}d\eta}$$

A=208

$$\left.\frac{d^2\sigma}{dp_\mathrm{T}d\eta}\right|_{p\mathrm{Pb},pp} = \frac{1}{\mathscr{L}} \cdot \frac{N^{ch}(\eta, p_\mathrm{T})}{\Delta p_\mathrm{T} \Delta\eta}$$

N^{ch} : prompt charged particle yield

$\Delta\eta\Delta p_T$: bin size

$\mathscr{L}$: integrated luminosity.

$$N^{\mathrm{ch}} = N^{\mathrm{candidates}} \frac{P}{\varepsilon_{\mathrm{reco}}\varepsilon_{\mathrm{sel}}}$$

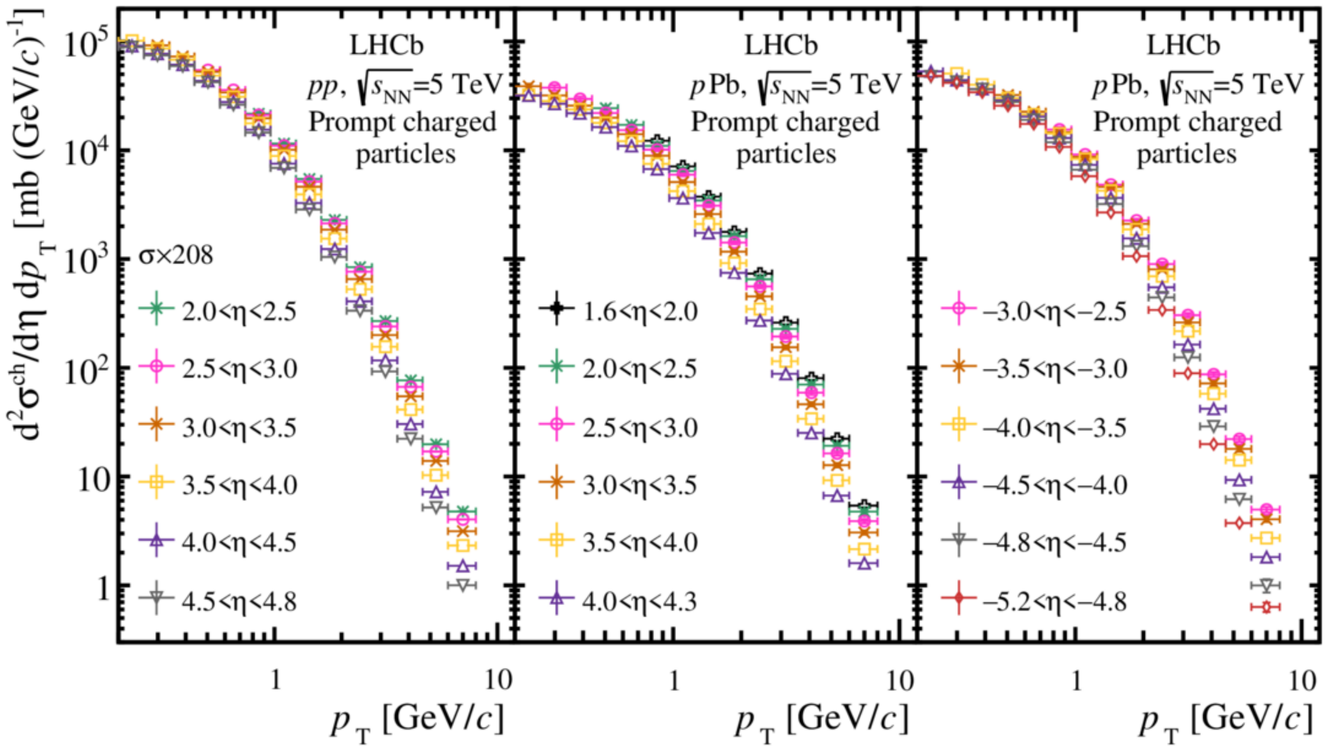
$N^{candidates}$: selected long tracks.
P : purity of the signal.
ε_{reco}: reconstruction efficiency
ε_{sel}: selection efficiency
$\mathscr{L}$: integrated luminosity.

Prompt charged hadron production in *pPb* and *pp* at 5*TeV*

Phys. Rev. Lett. 128, 142004

$$\left.\frac{d^2\sigma}{dp_{\mathrm{T}}d\eta}\right|_{p\mathrm{Pb},\,pp} = \frac{1}{\mathscr{L}} \cdot \frac{N^{ch}(\eta, p_{\mathrm{T}})}{\Delta p_{\mathrm{T}} \Delta\eta}$$

- Precise double differential cross-sections measured in multiple η range.



Nuclear modification factor

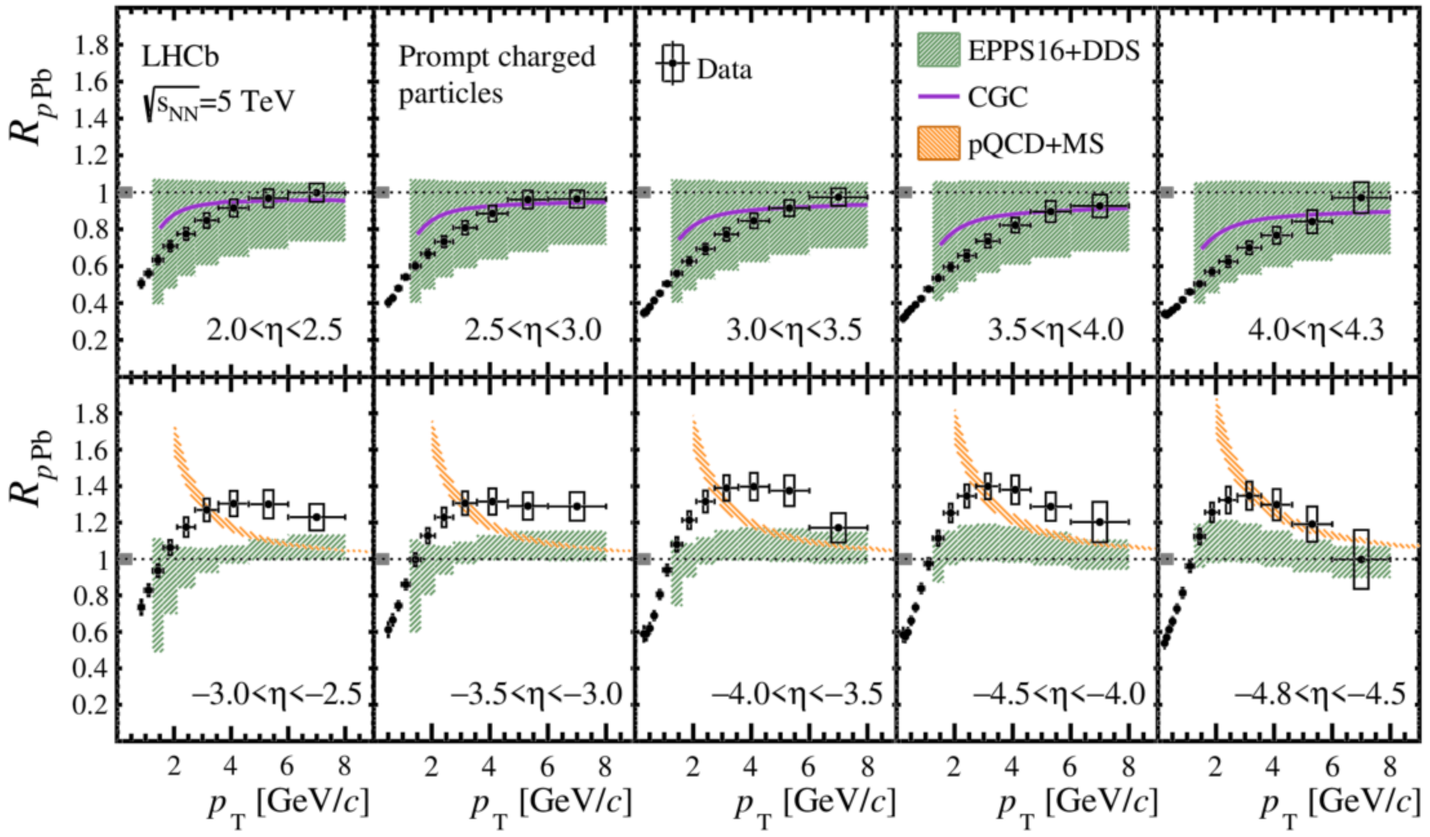
Phys. Rev. Lett. 128, 142004

Forward rapidity:

- Strong suppression at forward rapidity down to ~ 0.3 at low p_T .
- Discrepancy with theoretical prediction is observed at low p_T.

Backward rapidity:

- Enhancement at backward rapidity for $p_T > 1.5 GeV/c$.
- Pseudo-rapidity-dependent shape.
- Theoretical predictions do not reproduce the data.



Charged hadron R_{pPb} : (x_{exp}, Q^2_{exp}) dependence

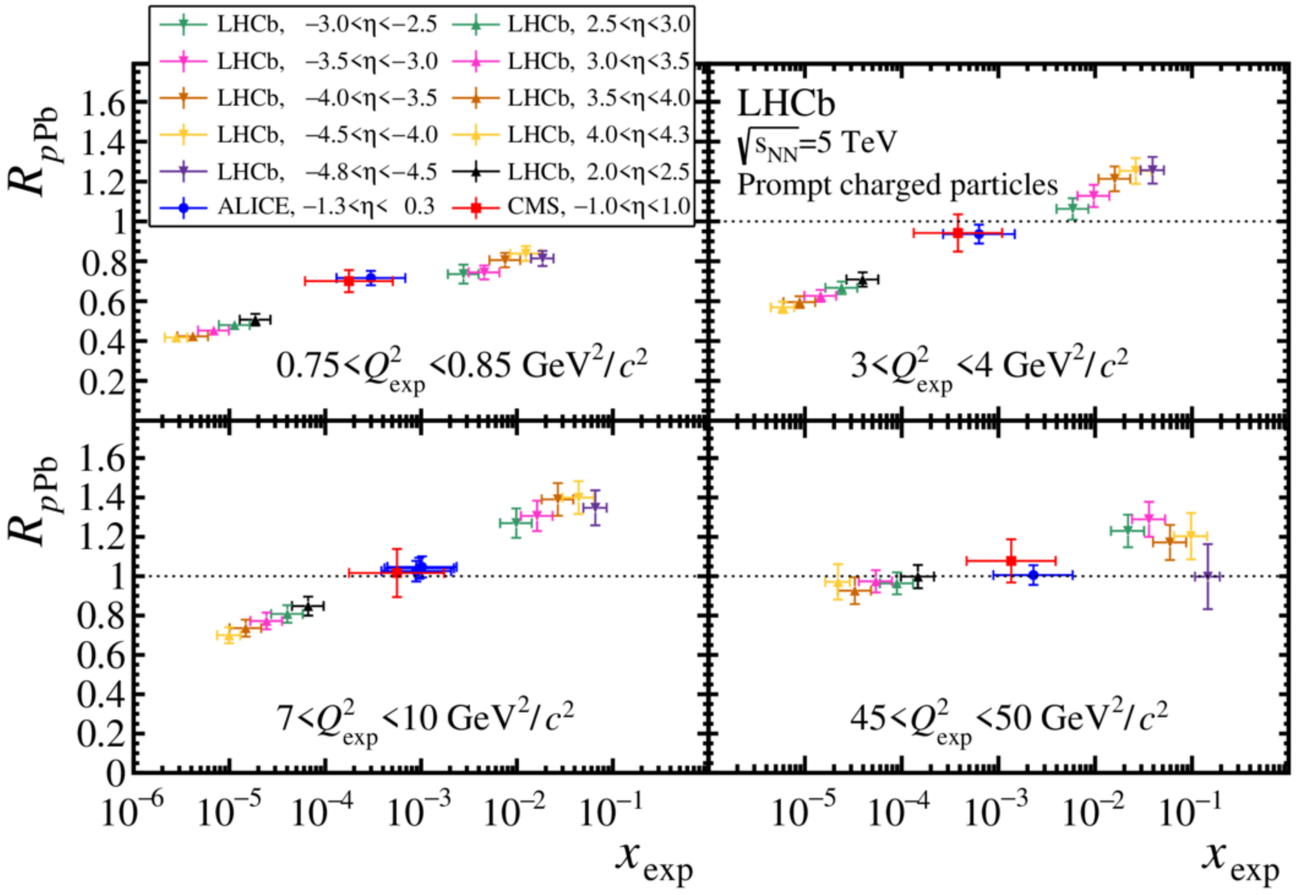
Phys. Rev. Lett. 128, 142004

Approximations to (x, Q^2) :

$$Q^2_{exp} \equiv m^2 + p_T^2 \ , m = 256 \text{ MeV}$$

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

Continuous evolution of R_{pPb} with x_{exp} at different Q^2_{exp} between forward, central and backward η region.



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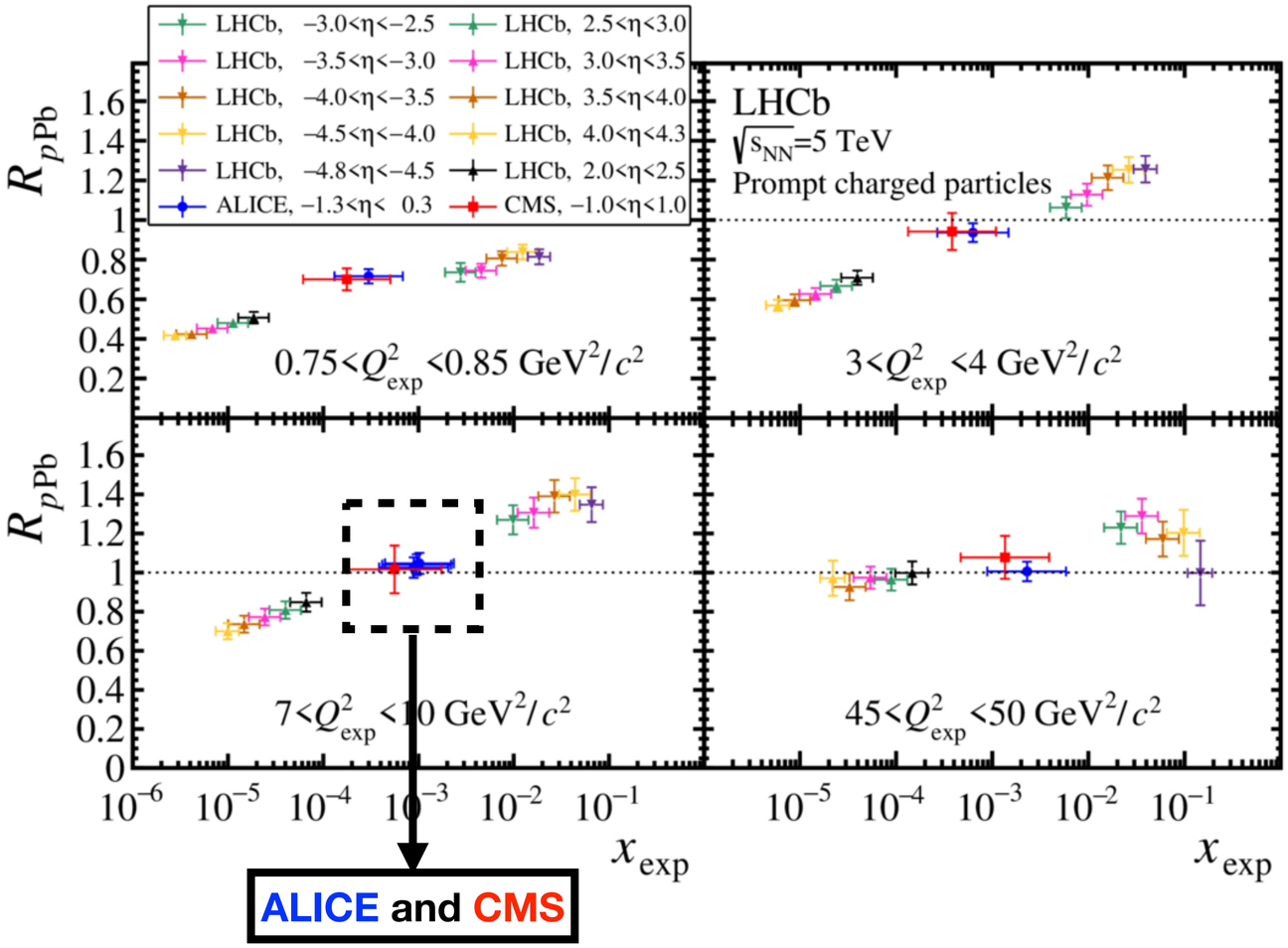

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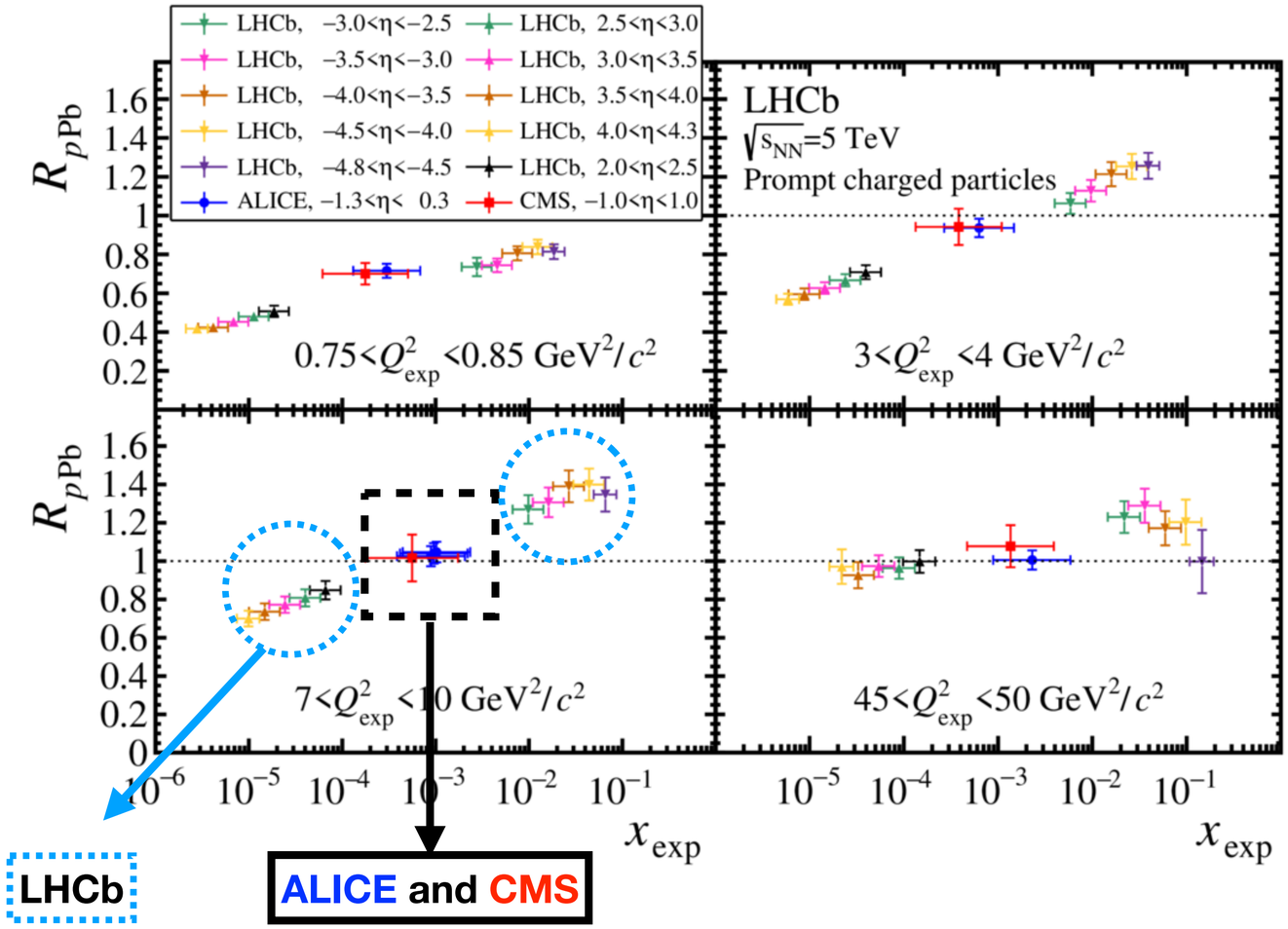


Neutral pion production in pPb and pp

arXiv:2204.10608

- Neutral pion production is sensitive to cold nuclear matter (CNM) effects.
- First π^0 production measurements in the forward and backward.
- Input needed for direct photon production measurement.

Data sets:

pPb and Pbp data at $\sqrt{s_{NN}} = 8.16$ TeV.

pp interpolated between 5 and 13TeV.

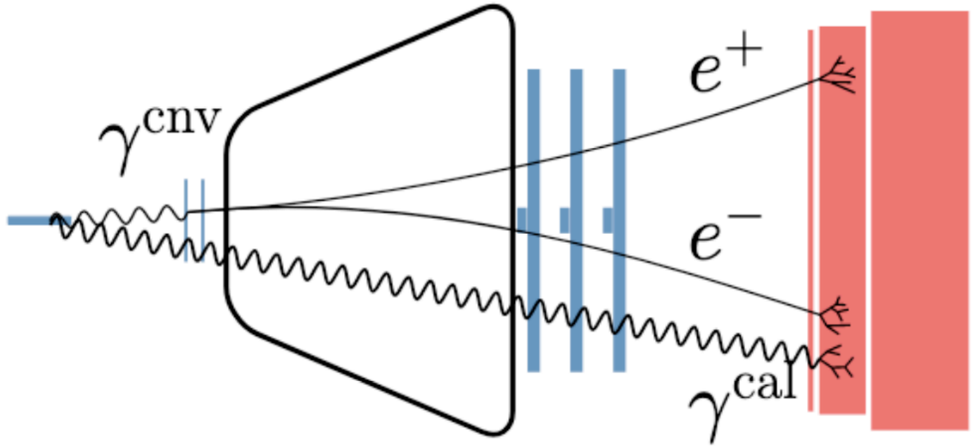
Kinematic coverage:

$1.5 < p_T < 10$ GeV/c

$2.5 < \eta_{cms} < 3.5$

$-4 < \eta_{cms} < -3$

- Neutral pions are reconstructed from to pairs of photons: $\pi^0 \rightarrow \gamma^{cnv}\gamma^{cal}$



Neutral pion production in pPb and pp

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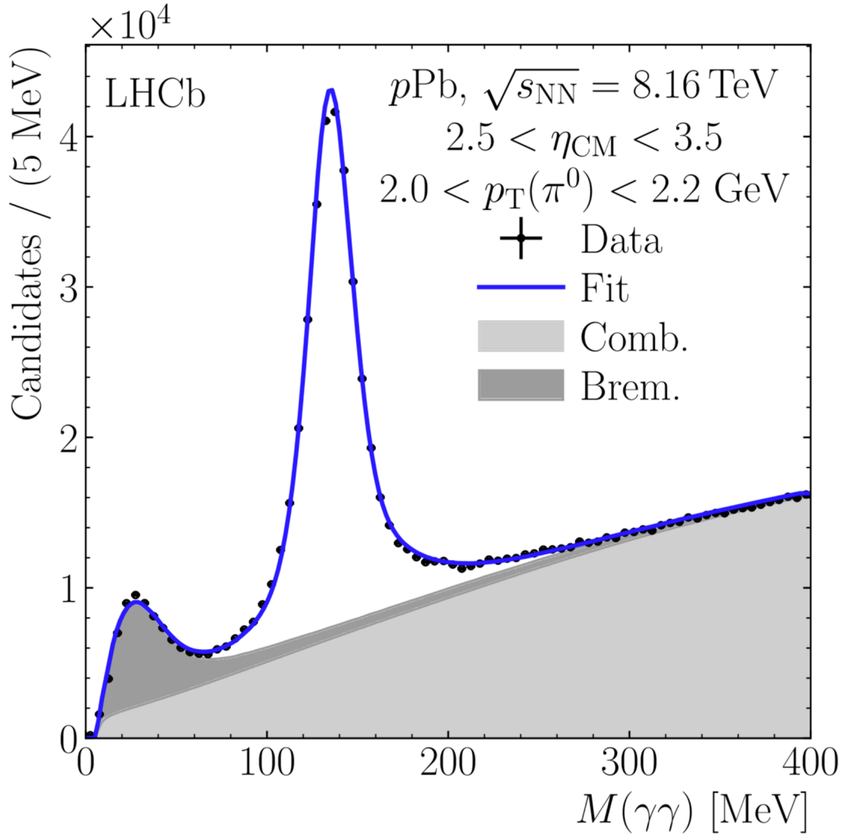
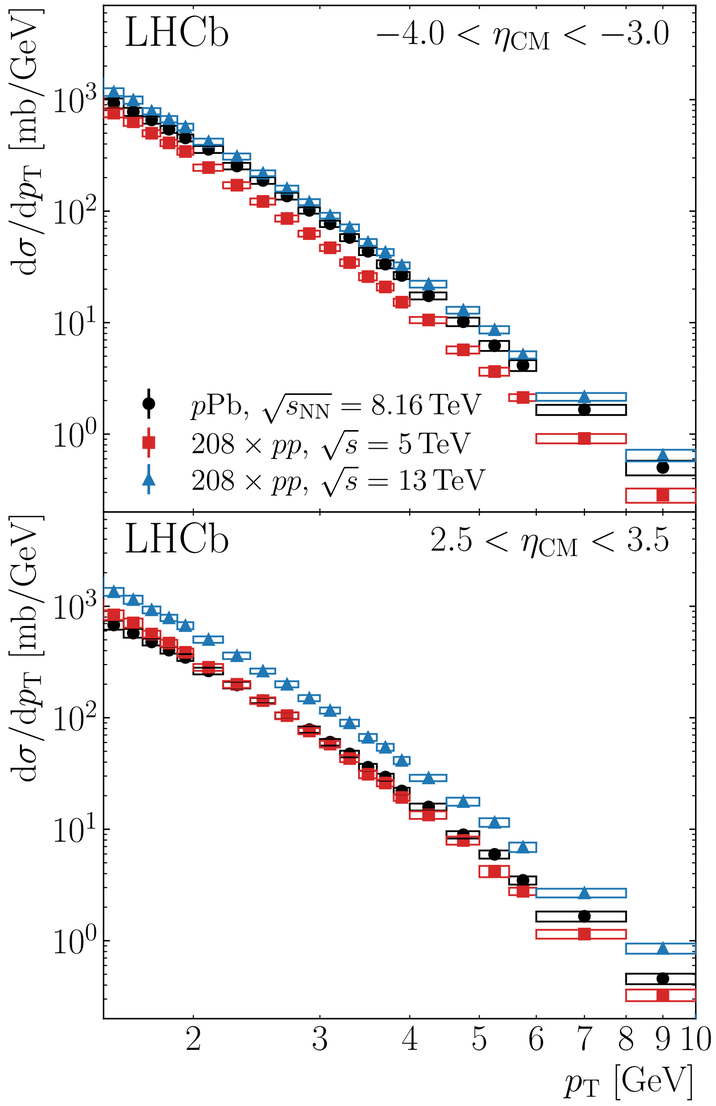
- Signal yield is fitted with a two-sided Crystal Ball function.
- Bremsstrahlung : Combination of converted photons with bremsstrahlung radiation.
- Combinatorial background: constructed with a proxy sample of charged tracks.



- Yields are then corrected by detector effects using simulation.



Neutral pion production in pPb and pp

arXiv:2204.10608

$$R_{\mathrm{pPb}}(\eta, p_{\mathrm{T}}) = \frac{1}{A} \frac{d^2\sigma_{p\mathrm{Pb}}(\eta, p_{\mathrm{T}})/dp_{\mathrm{T}}d\eta}{d^2\sigma_{pp}(\eta, p_{\mathrm{T}})/dp_{\mathrm{T}}d\eta}$$

Forward rapidity:

- Strong suppression of π^0 production.
- Results are compatible with prompt charged particles measurements.
- R_{pPb} is in agreement with nPDFs calculations.

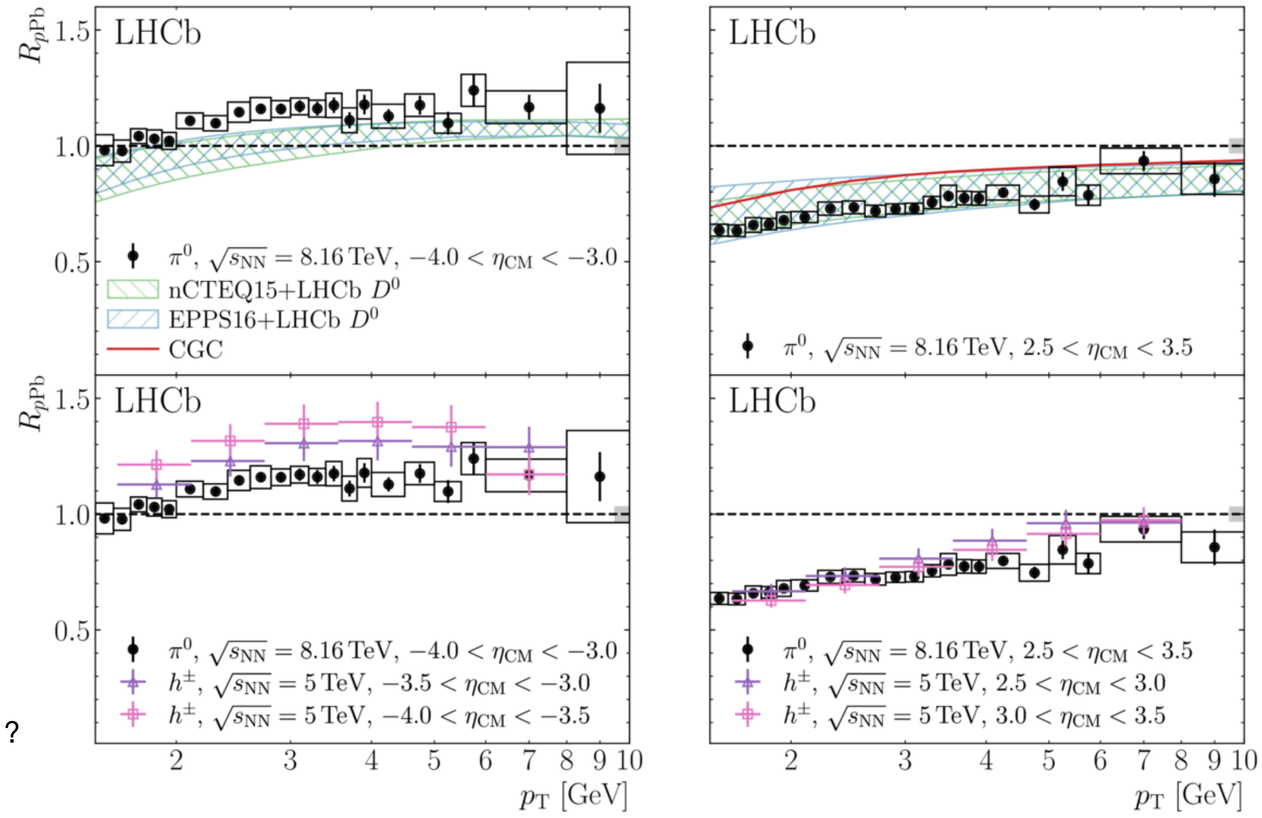
Backward rapidity:

- Enhancement of π^0 production in p_T.
- R_{pPb} Less pronounced than in charged particles :

=> Might Indicates that there is a brayon enhancement, as observed in other experiments.

- Excess over reweighted nPDFs predictions => contribution from additional effects ?

Backward rapidity | **Forward rapidity**



Nuclear modification of prompt π, K and p at 5 TeV

- This analysis is based on the R_{pPb} of prompt charged particles at 5 TeV.

Phys. Rev. Lett. 128, 142004

The goal is to measure :

Nuclear modification factor Effects of nuclear matter:

$$\mathrm{R}^{h}_{p\mathrm{Pb}}(\eta_{cms}, p_T) = \frac{1}{A}\frac{\mathrm{d}^2\sigma^{h}_{p\mathrm{Pb}}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}{\mathrm{d}^2\sigma^{h}_{pp}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}$$

Forward-to-backward ratio:

$$\mathrm{R}^{h}_{FB}(\eta_{cms}, p_T) = \frac{\mathrm{d}^2\sigma^{h}_{p\mathrm{Pb}}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}{\mathrm{d}^2\sigma^{h}_{\mathrm{Pb}p}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}$$

Baryon-to-meson ratio:

$$\mathrm{R}_{B/M}(\eta_{cms}, p_T) = \frac{\mathrm{d}^2\sigma_{Baryons}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}{\mathrm{d}^2\sigma_{meson}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}$$

$$h = \pi, \mathrm{K}, p$$

Nuclear modification factor

$$\mathrm{R}^{h}_{p\mathrm{Pb}}(\eta_{cms}, p_T) = \frac{1}{A}\frac{\mathrm{d}^2\sigma^{h}_{p\mathrm{Pb}}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}{\mathrm{d}^2\sigma^{h}_{pp}(\eta_{cms}, p_T)/\mathrm{d}p_T\mathrm{d}\eta_{cms}}$$

N^h	number of prompt charged hadrons.
$\mathcal{L}$	is the luminosity.
η_{cms}	is the pseudo rapidity in the cms frame
ϵ_{reco}	is the reconstruction efficiency
ϵ_{sel}	is the selection efficiency
ϵ_{PID}	is the PID efficiency
ϵ_{TM}	is the Truth Matching efficiency
P	is the Purity

$$\left.\frac{\mathrm{d}^2\sigma^{h}}{\mathrm{d}p_T\mathrm{d}\eta_{cms}}\right|_{pp,p\mathrm{Pb},\mathrm{Pb}p} = \frac{1}{\mathcal{L}}\frac{N^h(\eta_{cms}, p_T)}{\Delta p_T \Delta\eta_{cms}}$$

$$N^h = N^h_{cand}\frac{\mathrm{P}^h}{\epsilon_{reco}\epsilon_{sel}\epsilon_{\mathbf{PID}}(1/\epsilon_{TM})}$$

$$h = \pi, \mathrm{K}, p$$

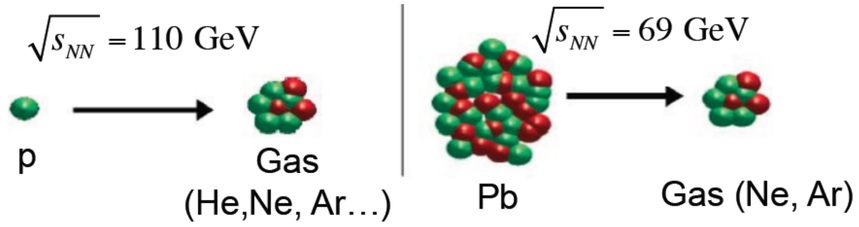
$$P^h = 1 - (f^h_{fake} + f^h_{sec} + f^h_{misID})$$

SMOG:fixed-target program

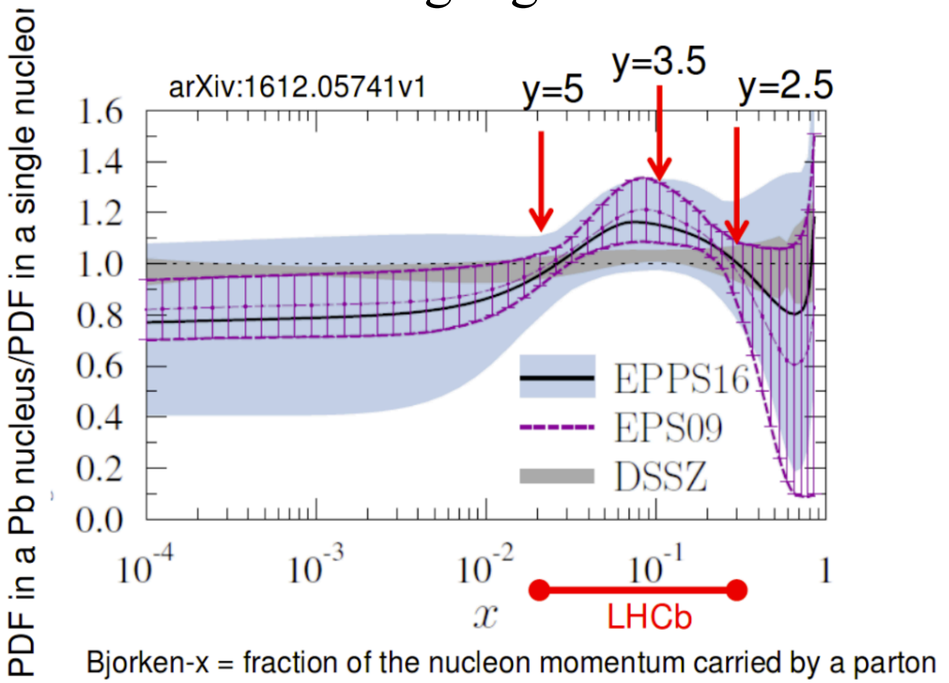
SMOG: System for Measuring Overlap with Gas.

Noble gases at a pressure of $O(10^{-7})$mbar are injected into the VELO.

Fixed target mode



Access nPDF anti-shadowing region:



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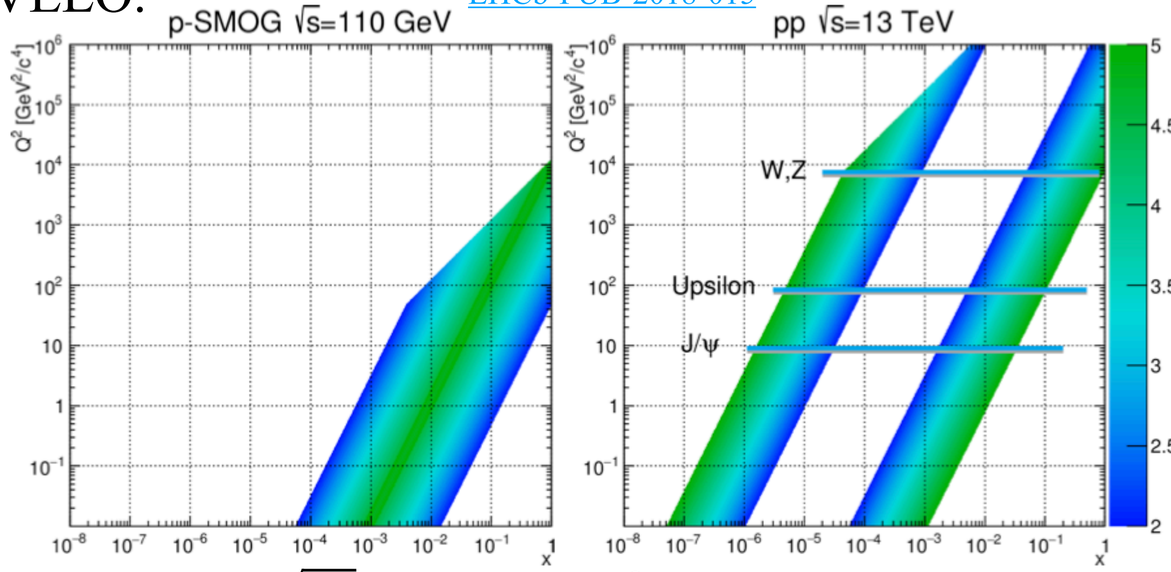
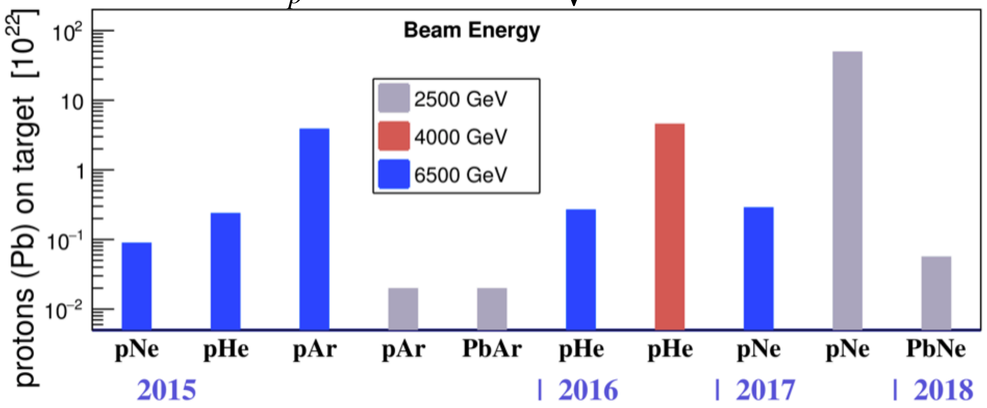


$$y = y^* + ln(\frac{\sqrt{s_{NN}}}{m_p}) \qquad x_F \simeq \frac{2}{\sqrt{s_{NN}}}\sqrt{M^2 + p_T^2} \quad sinh(y^*)$$



Conclusion

- Hadron production in pPb collisions at LHCb provide unique access to the saturation region.
- Future measurements in SMOG will provide a better understanding of the high x saturation region.

  → Nuclear modification factor of light hadrons with SMOG samples for example in pNe/pHe?.

- R_{pA} in SMOG can offer a better understanding of the enhancement observed in the large-x region.