Light hadron production at the LHCb experiment

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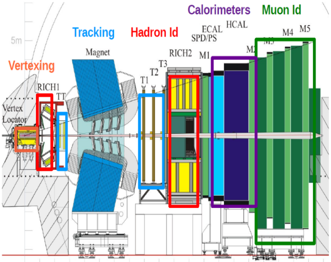
Outline

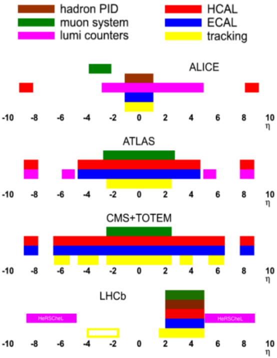
- Particle identification in the LHCb experiment.
- Light hadrons production: goal and perspective.
- Conclusion.

The LHCb detector

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



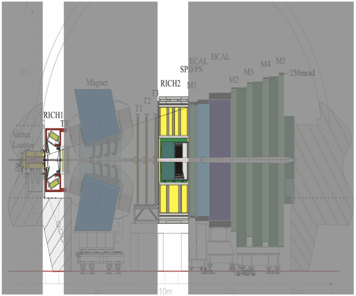
JINST 3 (2008)S08005

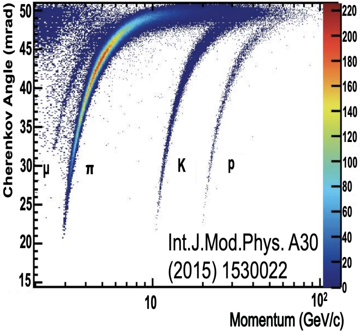


IJMPA 30 (2015) 1530022

PID detectors: RICH

- RICH detectors provide excellent $p/\mathrm{K}/\ \pi$ discrimination in the momentum range 2-100 GeV/c.





JINST 3 (2008) S08005

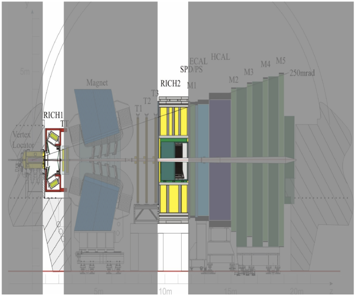
IJMPA30 (2015) 1530022

PID detectors: RICH

- RICH detectors provide excellent $p/K/\pi$ discrimination in the momentum range 2-100 GeV/c.
- Combining the information from the PID sub-detectors, two sets of global PID variables are built.

PID variables

$\Delta \log \mathcal{L}$: sum of the likelihood information of each sub- detector.
ProbNN: built using multivariate techniques created combining tracking and PID information. This results in single probability values for each particle hypothesis.



Calibration samples

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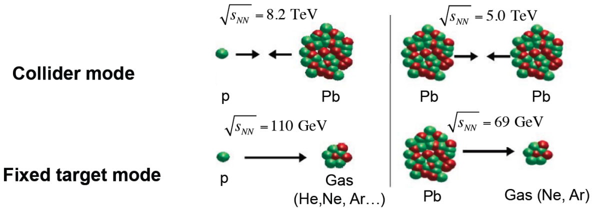
- The PID performance is evaluated with a data-driven approach using dedicated calibration samples, as the PID variables are reproduced with insufficient precision in the LHCb simulation.

Species	Soft	Hard
$e^{\pm}$	—	$J/\psi \to e^+e^-$
$\mu^{\pm}$	$D_s^+ \to \mu^+\mu^-\pi^+$	$J/\psi \to \mu^+\mu^-$
$\pi^{\pm}$	$K_S^0 \to \pi^+\pi^-$	$D^* \to D^0\pi^+$, $D^0 \to K^-\pi^+$
$K^{\pm}$	$D_s^+ \to K^+K^-\pi^+$	$D^* \to D^0\pi^+$, $D^0 \to K^-\pi^+$
$p^{\pm}$	$\Lambda^0 \to p\pi^-$	$\Lambda^0 \to p\pi^-$, $\Lambda_c^+ \to pK^-\pi^+$

LHCb operation modes

In addition to *pp*:



- Fixed-target modes: Noble gases injected in the interaction region thanks to SMOG.
- Unique experiment which allows data taking in fixed target mode.

Prompt light hadron production

- Soft probe of the Quark-Gluon Plasma, specially prompt probes which are directly produced in the Primary Vertex.
- Light hadrons with strange quarks are measured to study strangeness enhancement from pp, pPb and PbPb collisions.
- Clean probe for Cold Nuclear Matter (CNM) effects.

LHCb provide measurements for CNM effects at low p_T and forward rapidities, where nPDFs are poorly constrained.

Production observables

- 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:

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

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

Experimental results

- $R_{p\mathrm{Pb}}$ for p shows a strong Cronin enhancement at around 4 GeV.
- pions and kaons ratio indicates the presence of a little or no nuclear modification at high p_T.

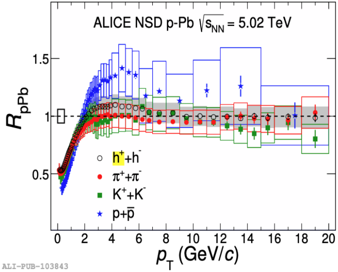


Fig. 1: $R_{p\mathrm{Pb}}$ for different particle species in p–Pb collisions Measured by ALICE.

PLB760 (2016) 720-735

Experimental results

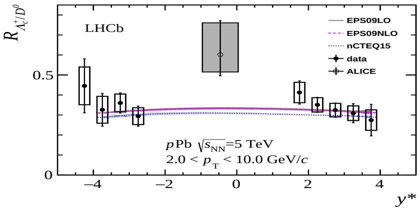


Fig. 2: Λ_c^+ / D^0 The cross-section ratio in p–Pb collisions measured by LHCb

JHEP02 (2019) 102

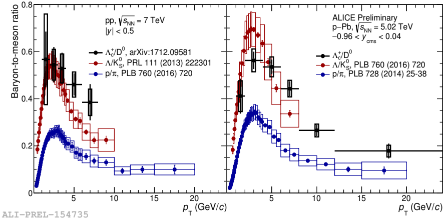


Fig. 3: p/K production ratio in pp and p–Pb collisions in measured by ALICE.

JPCS1137 (2019) 012032

- Λ_c^+ / D^0 ratio exhibits an increasing trend with $|y^*|$.
- Baryon/meson ratio shows an enhancement at intermediate p_T.

The goal of the analysis

Our goal is:

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

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

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

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

LHCb-PAPER-2021-015 (in preparation)

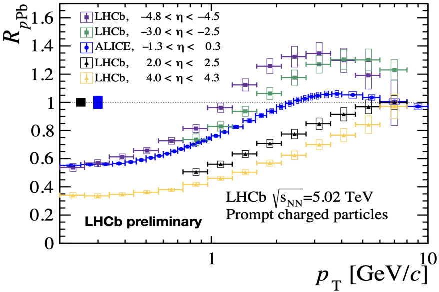


Fig. 4: Prompt charged particle production at 5 TeV

LHCb:DIS (2021)
ALICE :JHEP 1811 (2018) 01

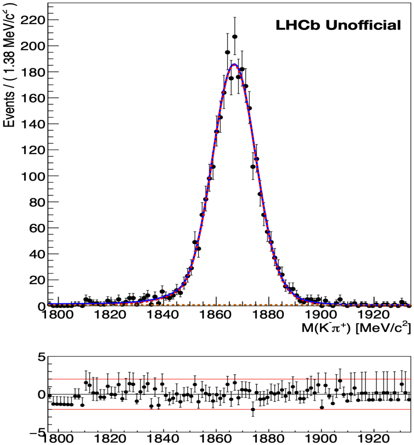
PID efficiency

- ϵ_{PID} is computed for a set of selections in each (p, η) bin that:
  $\rightarrow$ maximise the efficiency map of each Track.
  $\rightarrow$ minimise the mis-id efficiency.

Track type	Selection
π	DLL(K-π) <0
K	DLL(K-π) >0
	DLL(p-K) <0
p	DLL(p-π) >10
	DLL(p-K) >0

Tab. 1: PID selections

$D^*(2010) \rightarrow (D^0 \rightarrow K^+ \pi^-)\ \pi$



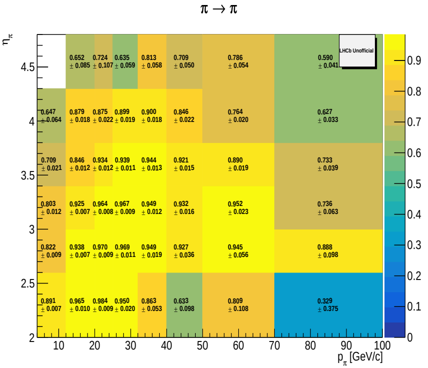
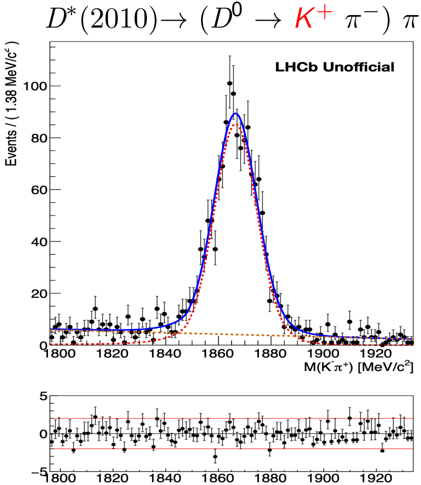


Fig. 5: π efficiency in Pbp

PID efficiency in Pbp



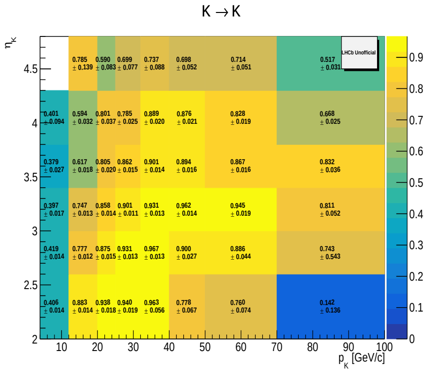
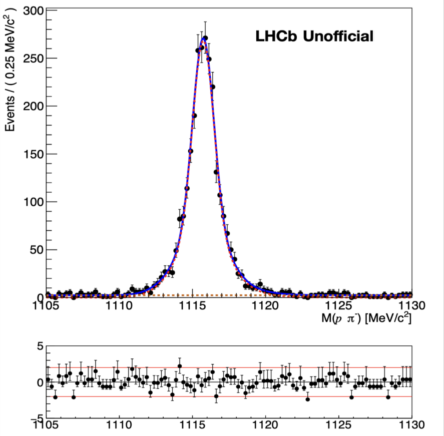


Fig. 6: K efficiency in Pbp

PID efficiency in Pbp

$\Lambda^0 \rightarrow p\ \pi^-$



$p \rightarrow p$

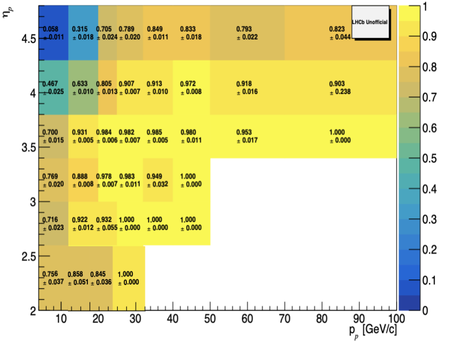
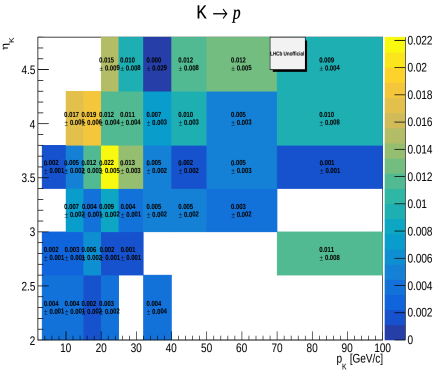
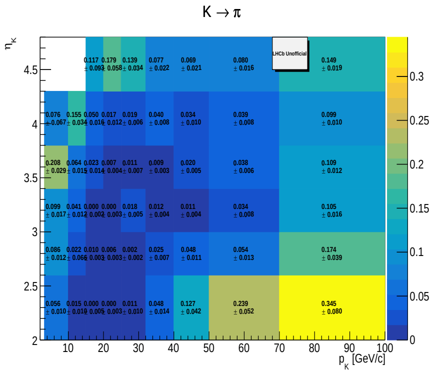


Fig. 7: p efficiency in Pbp

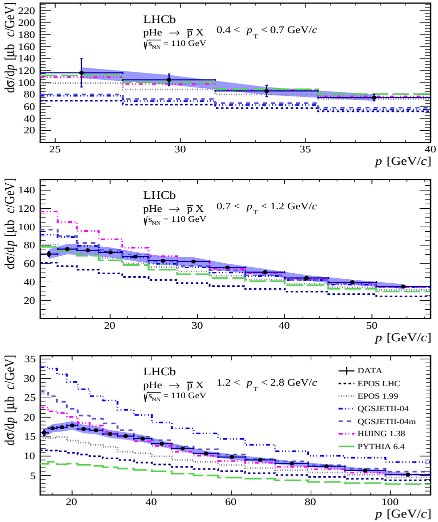
mis-ID efficiency in Pbp





Fixed Target at the LHCb

- First Measurement of $\bar{p}$ production cross section per He at $\sqrt{S_{NN}}$ =110GeV providing precise result on $\bar{p}$ / p ratio prediction.
- An excess of the $\bar{p}$ / p ratio for high energy cosmic rays can be an indirect signal of dark matter.
- Many physics opportunities are being explored.
  LHCb-PUB-2018-015



PRL121 (2018)

Conclusion

- Just the beginning of the analysis much more results to come.
- Hadron production in p-Pb probe for Cold Nuclear Matter effects, their understanding needed for QGP interpretation.
- More and more precise results to come from latest Run 2 and future Run 3 data
- Rich physics program with heavy ions and fixed-target ahead for LHCb.