ANTI-DEUTERON SENSITIVITY STUDIES AT LHCb

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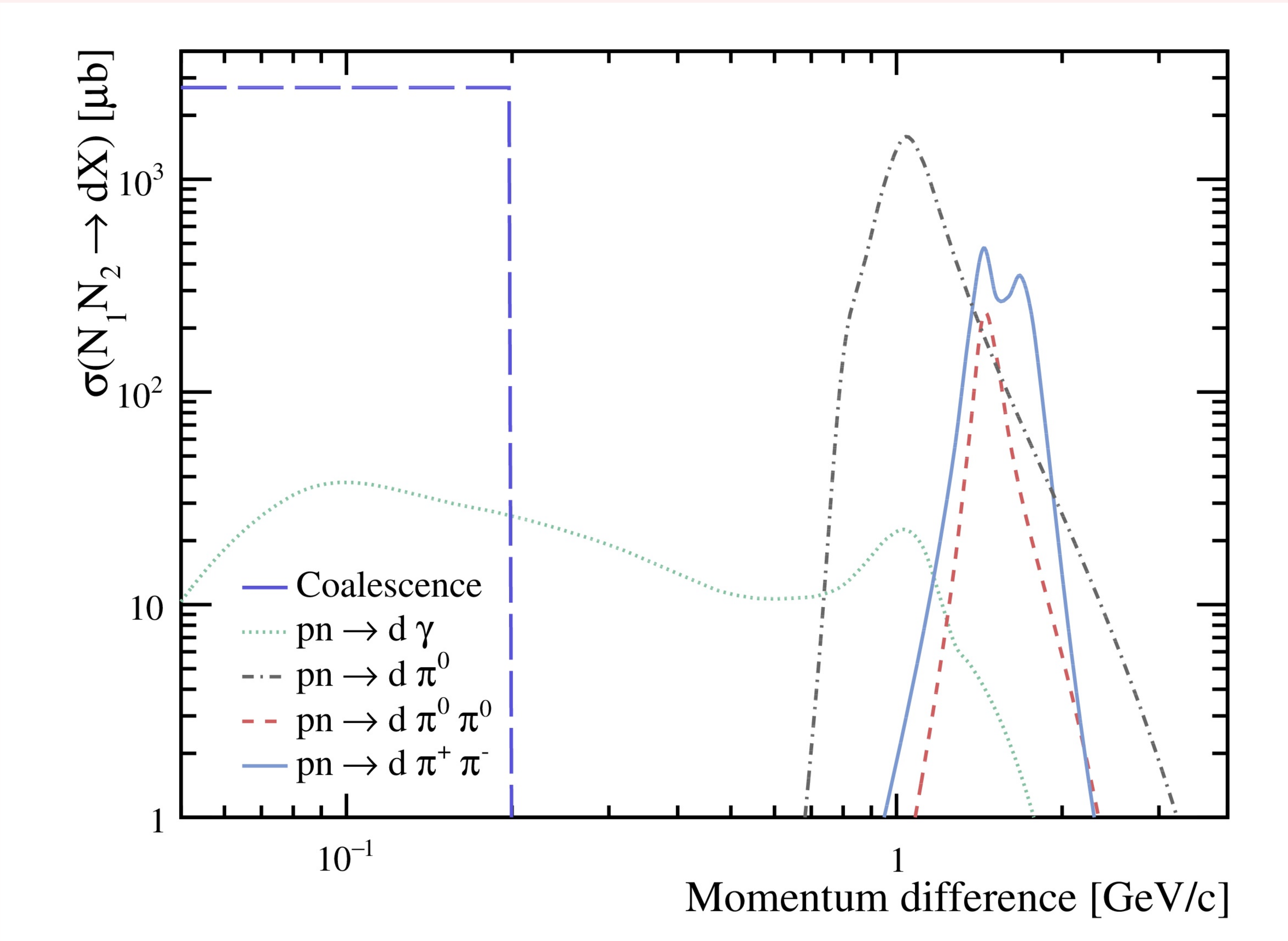
Measurements of anti-deuterons at HEP experiments can help to constrain systematic uncertainties in indirect dark matter searches. These searches look for excess signals of anti-matter in cosmic rays; no conclusive evidence for dark matter has been seen using anti-proton or positron signals, but heavier antimatter, such as anti-deuterons, has lower backgrounds compared to these [1].
The limiting systematics in this search are the propagation of charged particles through the cosmos, as well as the production of secondary anti-deuterons by cosmic rays.

Production models

Coalesence: (1963) protons and neutrons bind when they are close enough in momentum space; a step function with a threshold parameter taken from measurement. Widely and successfully used for many years [2].

Cross-section: (2015) mechanisms for pp, pn and nn to bind into deuterons through multiple channels; uses a probabilistic approach, with normalisation taken from measurement [3].

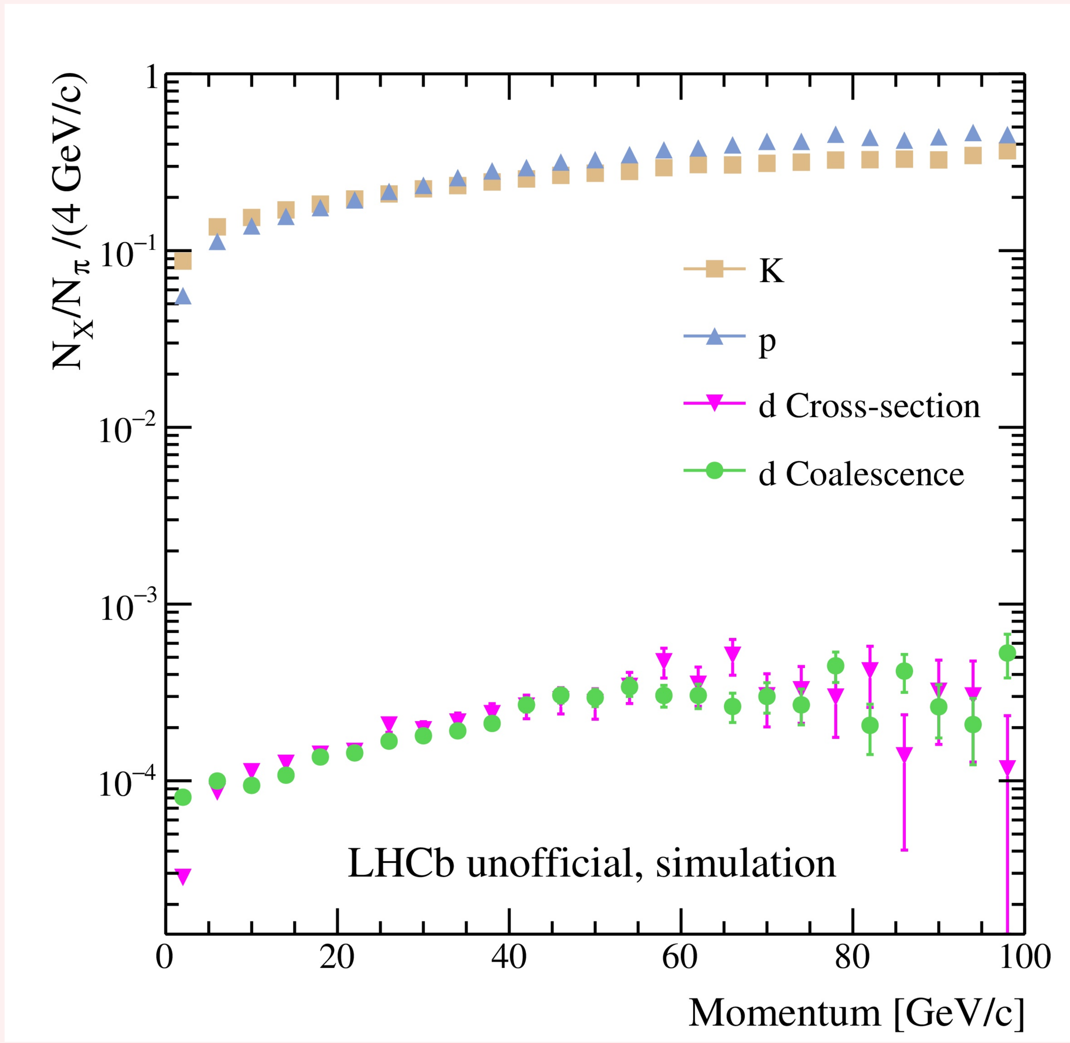


Cross-sections for deuteron production as functions of nucleon-pair momentum difference from the coalescence and cross-section models.

Simulation

Pairs of protons and neutrons from each proton-proton collision are compared; their momentum difference is found, and the chosen model is used to evaluate the likelihood that they bind. If successful, a vertex is added to the Monte Carlo event, with an outgoing deuteron.

The simulation from each of the deuteron production models shows that the deuteron yield will be 10^{-4} the pion yield within the LHCb acceptance.

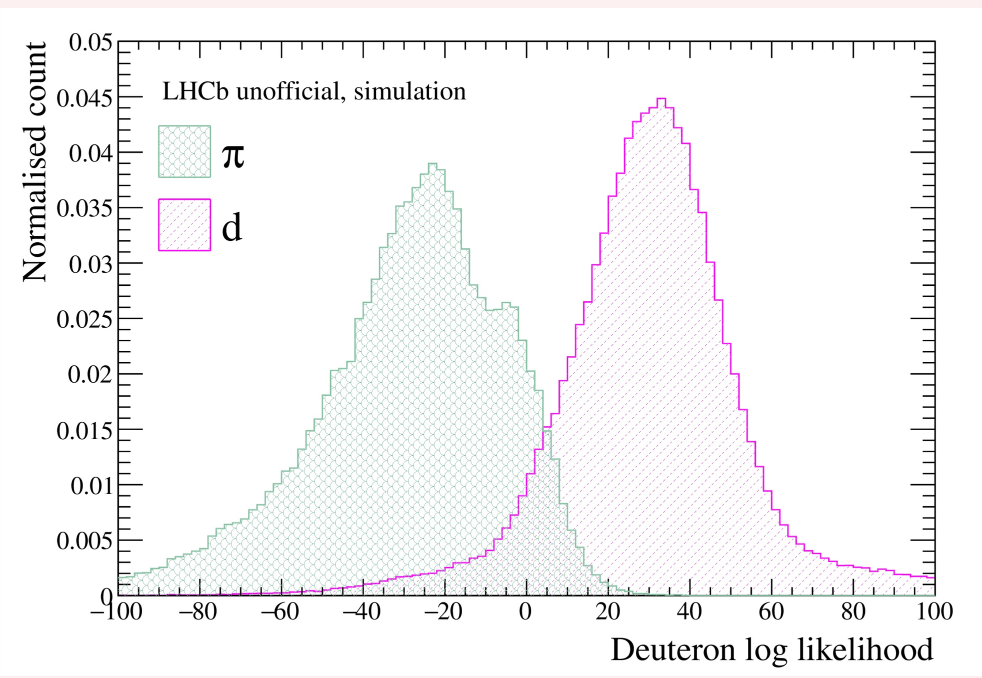


Ratios of deuterons, protons and kaons to pions in bins of momentum within the LHCb acceptance.

Charged particle identification at LHCb

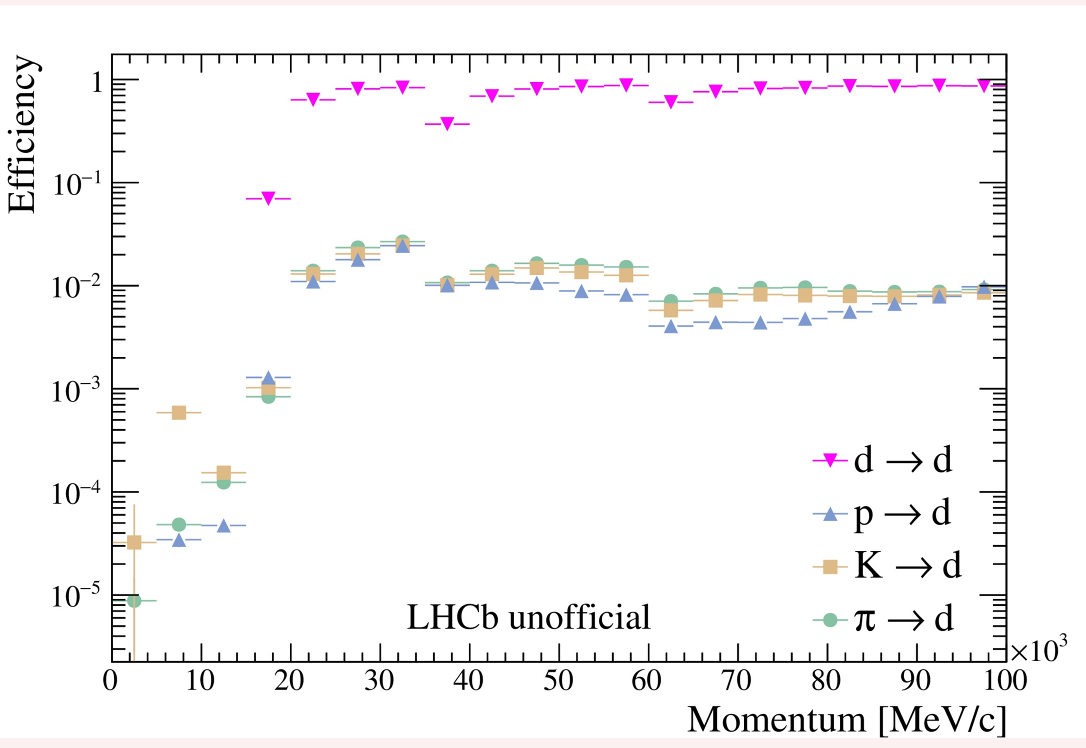
Ring imaging Cherenkov (RICH) detectors and tracking stations are used to ID protons, kaons, pions, muons and electrons [4, 5]. Deuterons can be identified in the same way.

1. Measure momentum p of charged track
2. Isolate photons within a small angle with respect to the track in the RICH detectors
3. Compare the photon distribution to hypotheses of different charged particles with momentum p
4. Algorithm outputs a difference in log likelihood for each track to originate from each of the charged particle hypotheses
5. Cuts are applied to these log likelihoods to select different particle types



Deuteron-pion separation using the deuteron mass hypothesis log-likelihood for MC pion and deuteron tracks.

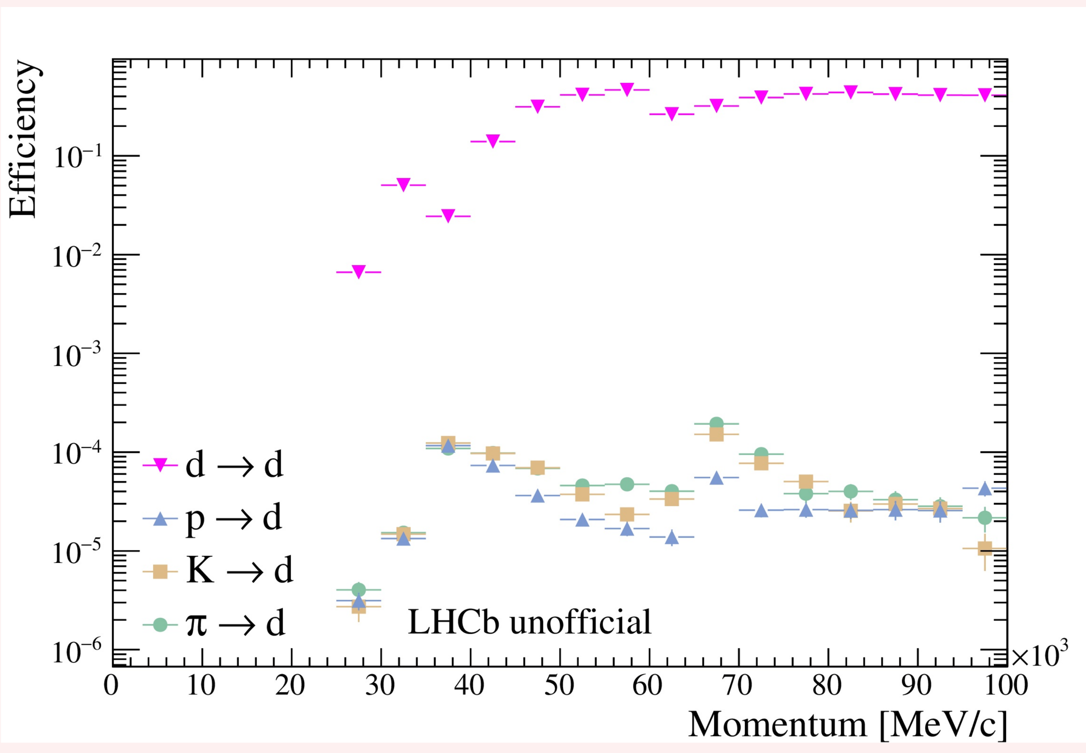
Selection efficiency



Deuteron selection efficiencies with loose (top) and tight (bottom) cuts.

Samples of tracks of known particle type are selected from data in order to determine the efficiency of selections based on the log likelihoods from the RICH. These samples of known tracks are selected kinematically, without use of particle ID variables.

There are no pure data samples for deuterons, so the efficiencies are taken from simulation instead.



In order to reject background from protons, kaons and pions, a combinaton of cuts is applied.

For tight cuts on the RICH log likelihoods, the efficiency for wrongly selecting a pion as a deuteron is at the level of 10^{-4}, which brings the signal and background to similar levels.

Large variations in the efficiencies occur at the momentum thresholds for Cherenkov photon emission in each of the RICH detectors.

Measurement potential

With the high statistics data collected in 2016 and 2017, we expect to be able to measure the cross-section of promptly produced deuterons and anti-deuterons in the LHCb acceptance.

Other particle ID variables could also be used for this search, such as those taken from neural networks, trained to differentiate between particle types. Combining ID techniques will increase the sensitivity and further reduce the backgrounds.

References
[1] Aramaki et al., *Review of the theoretical and experimental status of dark matter identification with comic-ray antideuterons*, Physics Reports 618 1 - 37 (2016)
[2] Kapusta, *Mechanisms for deuteron production in relativistic nuclear collisions*, Phys. Rev. C 21, 1301 (1980)
[3] Dal & Raklev, *An Alternative Formation Model for Antideuterons from Dark Matter*, Phys. Rev. D 91, 123536 (2015)
[4] Adinolfi et al., *Performance of the LHCb RICH detector at the LHC*, Eur. Phys. J. C 73-2431 (2013)
[5] Anderlini et al., *The PIDCalib package*, LHCb-PUB-2016-021 (2016)

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