Antideuterons at LHCb

Sophie Baker
on behalf of the LHCb collaboration

Imperial College London

Antideuteron 2019
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Antideuterons at the LHC

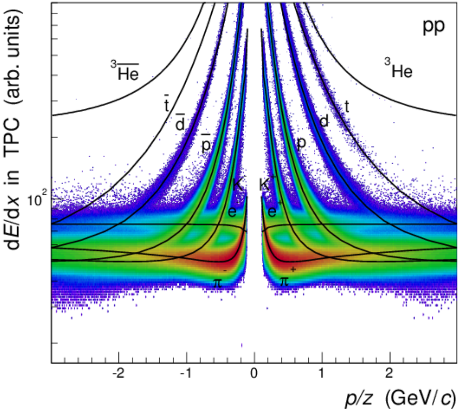
As seen this morning, antideuterons have already been observed in high energy collisions at the Large Hadron Collider by ALICE.

ALICE acceptance: $|\eta| < 0.8$, $p_T < 5\,\mathrm{GeV}/c$

A measurement complementary to this can be made at LHCb.

LHCb acceptance: $2 < \eta < 5$, $2 < p < 100\,\mathrm{GeV}/c$

This measurement will be useful for estimations of secondary antideuterons as the background to indirect dark matter searches.



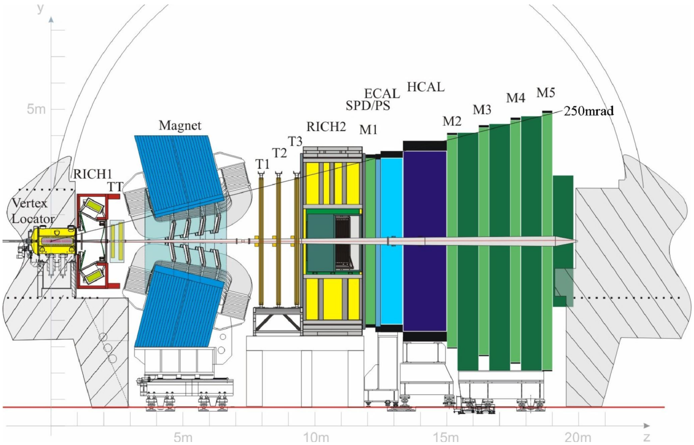
[ALICE Collaboration, Phys. Rev. C 93, 024917 (2016)]

LHCb detector

Forward single-arm spectrometer, measuring collisions of pp collisions at the LHC.

Designed for the study of heavy-hadron decays, precise charged particle identification (PID) is vital.

There is also a program of heavy ion collisions, and fixed-target measurements.



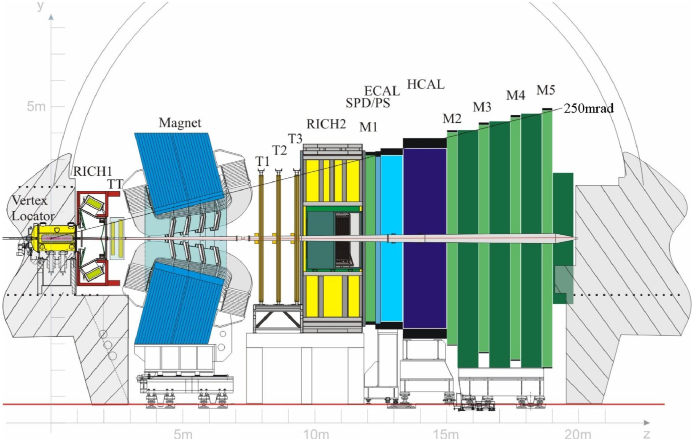
[Int. J. Mod. Phys. A 30 (2015) 1530022]

LHCb detector

Forward geometry of LHCb is chosen for better observing b-hadron decays.

Identification of particles (PID) is done by combining outputs from:

- vertex locator around collision point
- ring imaging Cherenkov (RICH) detectors
- electronic and hadronic calorimeters
- tracking stations
- muon stations



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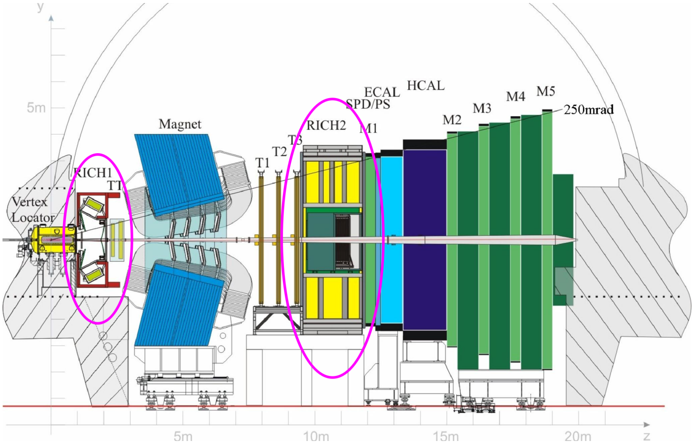
Particle identification at LHCb

High energy charged tracks are identified using two RICH detectors.

Cherenkov thresholds (GeV/c):

	RICH 1	RICH 2
π	2.3	7.0
K	9.3	15.3
p	17.7	29.7
d	35.4	59.3



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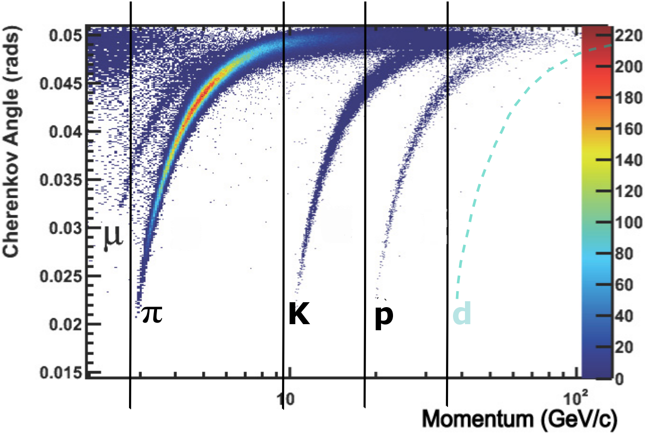
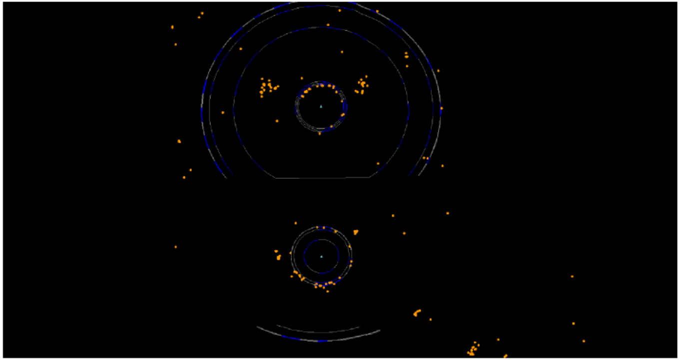


[Eur. Phys. J. C 73 (2013) 2431]

Particle identification at LHCb

Cherenkov angle and track momentum are used in the RICH algorithm to give likelihoods for the track to be a charged particle, *i.e.* e, μ, π, K, p, or d.

Each ring in the detector is compared to hypotheses for rings from different particles, given the known momentum of the track.



[CERN-THESIS-2014-102]

Measurements at LHCb

Antideuterons can be measured at LHCb in *prompt* production in pp collisions, in decays of heavy-hadrons, and in fixed target collisions.

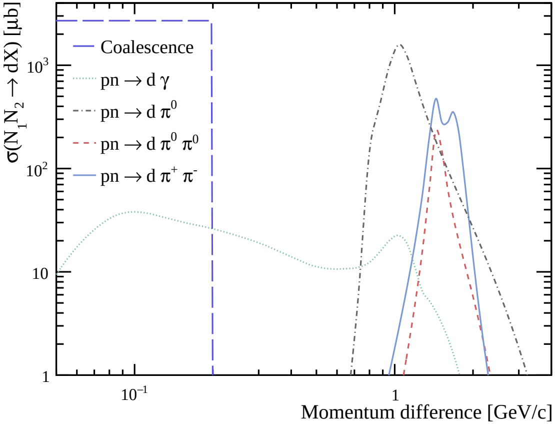
I will focus on measurement of the *prompt* antideuteron cross-section in pp collisions with centre-of-mass energy $\sqrt{s} = 13\,\text{TeV}$.

LHCb can be used to make the first measurement of antideuterons in b-hadron decays, and measurements in pHe collisions will provide unique constraints to the production cross-section in cosmic-rays, similar to the equivalent antiproton measurement, [Phys. Rev. Lett. 121, 222001 (2018)].

Deuteron production simulation

The **coalescence** and **cross-section** models for deuteron production are included in LHCb simulation.

Following the work by Dal & Raklev, the threshold for coalescence, and the normalisation of the cross-sections were taken from measurements of deuterons at ALICE in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$.



Based on [Phys. Rev. D 91, 123536 (2015)]

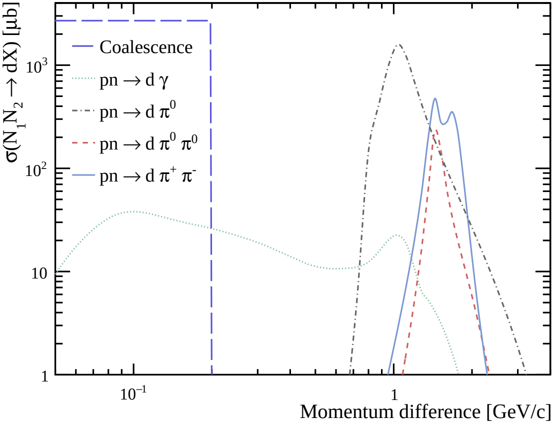
Coalescence model

[Kapusta (1980)] p and n from each pp collision are compared to each other; any pair which flies within a momentum separation cone of $190\,\mathrm{MeV}/c$ will bind.

Assuming that p and n have the same mass and same p_T spectra, d production given by

$$E_d \frac{\mathrm{d}^3 N_d}{\mathrm{d}p_d^3} = B_d \left(E_p \frac{\mathrm{d}^3 N_p}{\mathrm{d}p_p^3} \right)^2 ,$$

where $B_d = \left(\frac{4\pi}{3m_p} p_0^3 \right)$, with p_0 the radius of the momentum sphere for coalescence.



Based on [Phys. Rev. D 91, 123536 (2015)]

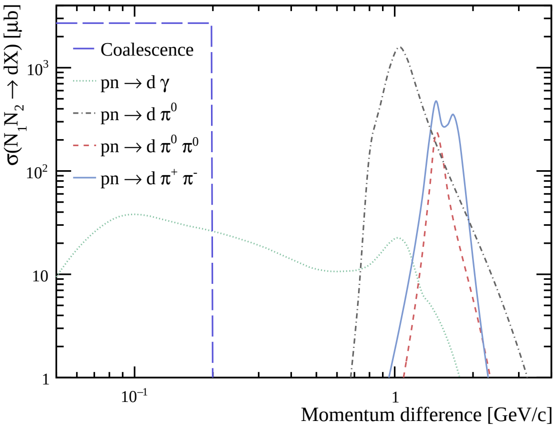
Cross-section model

[Dal & Raklev (2015)] pp, pn and nn pairs from each event are compared; for each possible production channel, the probability that they will bind is found, as a function of momentum separation in their centre-of-mass frame.

Production cross-section as a function of momentum separation in CoM frame, k,

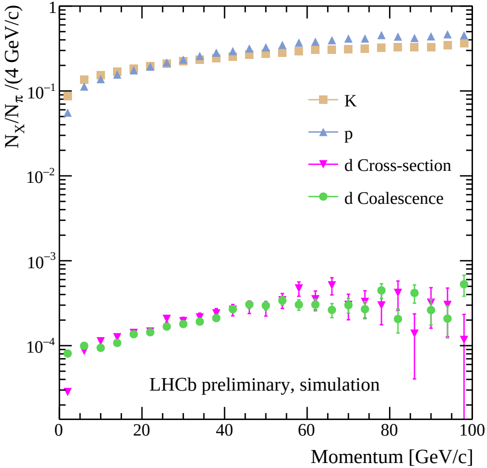
$$\sigma(k) = \frac{ak^b}{(c - \exp(dk))^2 + e},$$

where a, b, c, d, e are best fit parameters given in the paper.



Based on [Phys. Rev. D 91, 123536 (2015)]

Deuteron production simulation



The expected deuteron yield in pp collisions LHCb is low:

$\longrightarrow$ **one deuteron per 10,000 charged pions**

Backgrounds to the measurement will come from p, K and π.

To have a significant deuteron signal, the PID needs to be effective and known to a very high precision.

[Link to plots]

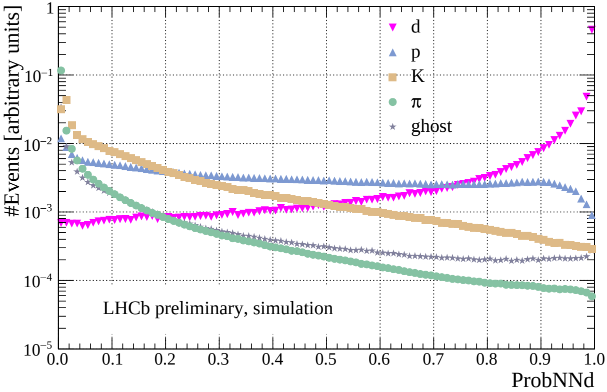
Neural net for deuteron identification

Improved performance of PID using neural nets (NN).

NN inputs: RICH likelihoods, kinematic variables and tracking information

ProbNNd = deuteron neural net variable

Instead of performing a cut-based selection, a template fit can be used to extract the deuteron yield.



Neural net for deuteron identification

Template fit will be performed in bins of track momentum.

Neural net is dependent on momentum, due to the RICH thresholds for Cherenkov light.

Thresholds (GeV/c):

	RICH 1	RICH 2
π	2.3	7.0
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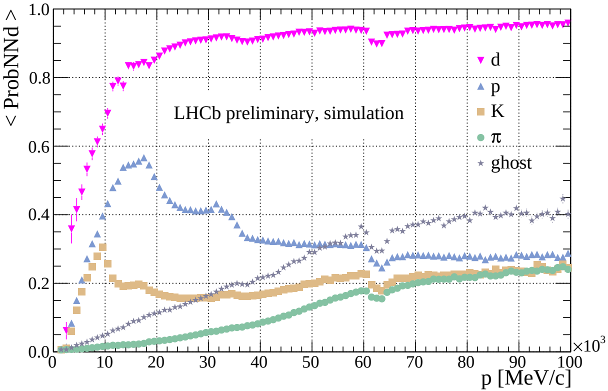
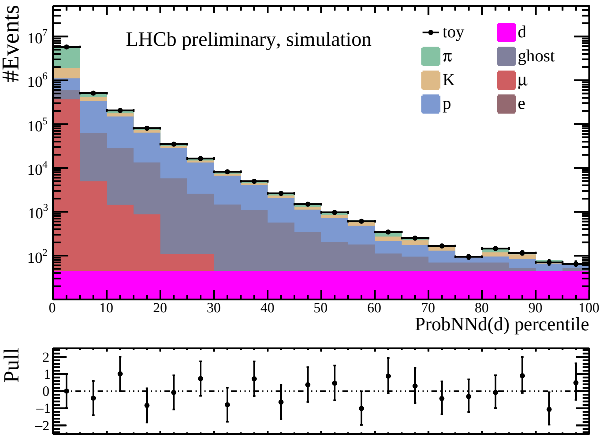


Template fit to ProbNNd

Template shapes for charged tracks will be taken from data samples, and the deuteron and ghost shapes taken from simulation.

The best sensitivity is at very high values of ProbNNd, so the bin boundaries are chosen such that the template for deuterons is flat.



Template fit, $29.7 < p < 35.4\,\mathrm{GeV}/c$

Summary

Measurement of antideuterons at LHCb will provide information about deuteron production at higher energies and more forward pseudorapidities than have been probed at other experiments.

Though LHCb was not designed with this type of measurement in mind, it will be possible due to its excellent PID and the flexibility of the data taking.

Antideuteron measurements in b-hadron decays and in pHe collisions will complement the prompt measurement, and provide contraints for DM searches.

Thanks for listening!

ProbNNd inputs

Kinematic	p, p_T
RICH	Used RICH 1 gas, used RICH 2 gas, above π, K, p thresholds, log likelihood for e, μ, K, p, d hypotheses, log likelihood for being below threshold
Tracking	χ^2_{track}/ndf, track ndf, ghost probability, track fit match χ^2/ndf, track fit χ^2_{VELO}, track fit ndf_{VELO}, track fit $\chi^2_{Tracker}$, track fit $ndf_{Tracker}$
Muon	Muon log likelihood, non-muon log likelihood, #muon shared system hits, binary 'is muon' selection, looser 'is muon' selection, muon system acceptance selection
Calorimeter	EM calorimeter e and μ ID, hadronic calorimeter e and μ ID, preshower e ID, Bremsstrahlung acceptance and e ID