Study to characterize the production of antineutrons in high energy pp and pb–pb collisions through charge exchange interactions

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Introduction

Introduction

- $\bar{p}$ and $\bar{n}$ productions in high-energy collisions should be approximately equal.
- Implicit in the coalescence model[1] calculations used to characterize light anti-nuclei production in high-energy heavy-ion collisions.
- Isotopic effects have recently been proposed[2] to significantly affect this symmetry, resulting in a larger $\bar{n}$ production.
- This led to the inclusion of an $\bar{n}$ / $\bar{p}$ asymmetry parameter, which ranges from 1.2 to 2.0, in the cosmic ray galactic-transport code EPOS-LHC[3].
- Such effect should be measurable in collisions carried out at the main LHC experiments.

[1] M. Büscher, A. A. Sibirtsev, K. Sistemich, Fast deuteron production in proton-nucleus interactions, Zeitschrift fur Physik A Hadrons and Nuclei 350 (2) (1994) 161–166. doi:10.1007/BF01290683.

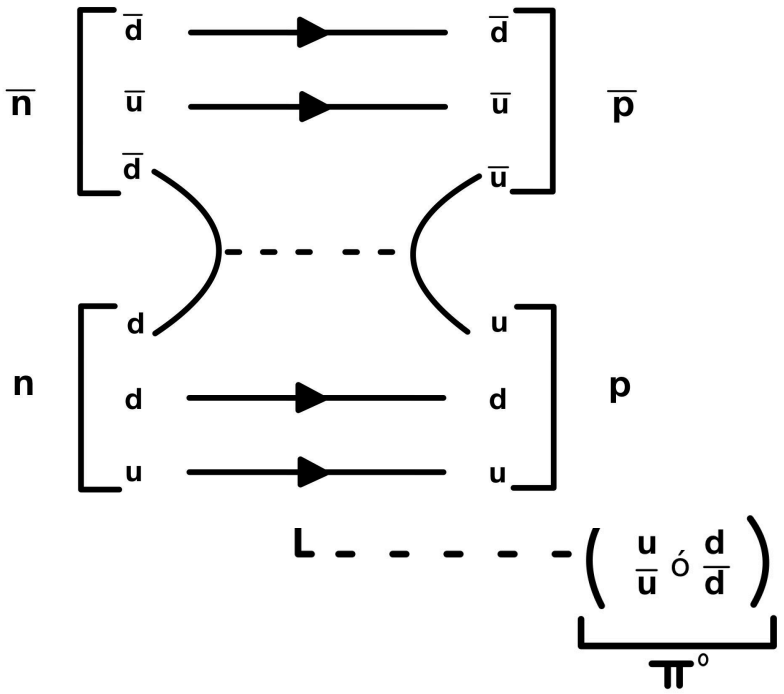
[2] R. Kappl, M. W. Winkler, The cosmic ray antiproton background for ams-02, Journal of Cosmology and Astroparticle Physics 2014 (09) (2014) 051. doi:10.1088/1475-7516/2014/09/051. URL https://dx.doi.org/10.1088/1475-7516/2014/09/051

[3] D.M. Gomez Coral and Arturo Menchaca-Rocha, SM antideuteron background to indirect dark matter signals in galactic cosmic rays, 2020 *J. Phys.: Conf. Ser.* **1602** 012005. doi: 10.1088/1742-6596/1602/1/012005

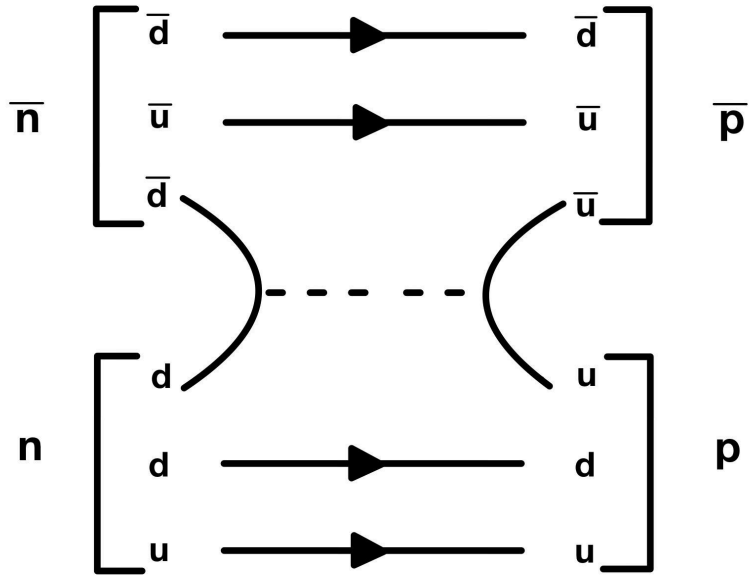
Introduction

- Identifying and reconstructing the kinematic properties of antineutrons produced by LHC experiments via charge exchange interactions (CEX) which can take place in their silicon inner tracking devices.

$$n + \bar{n} \rightarrow p + \bar{p} + \pi^0$$

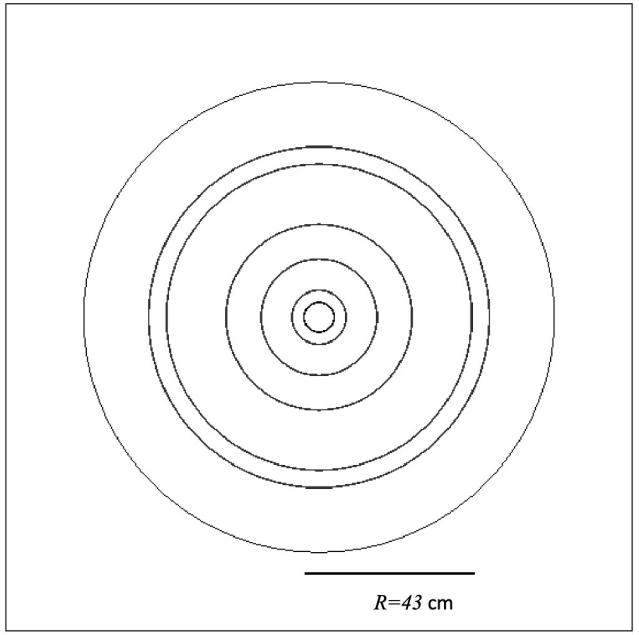


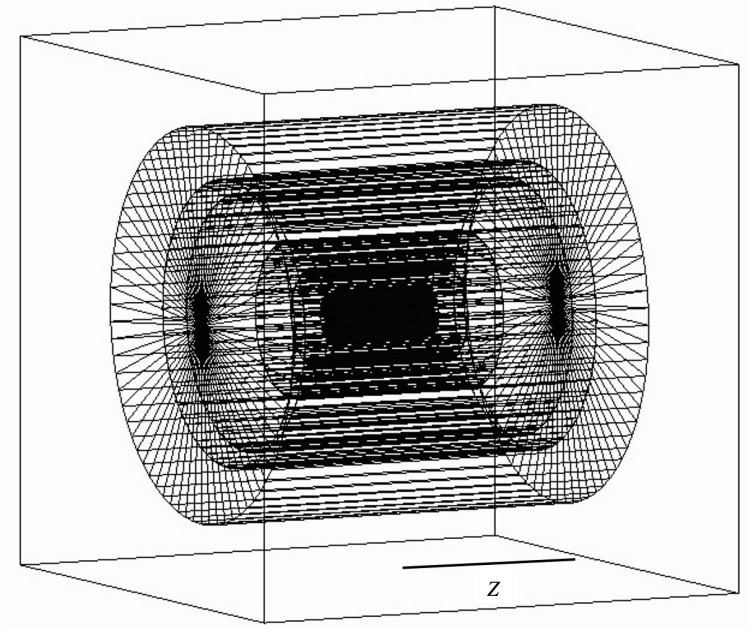
$$n + \bar{n} \rightarrow p + \bar{p}$$



Feasibility Study

Simulation



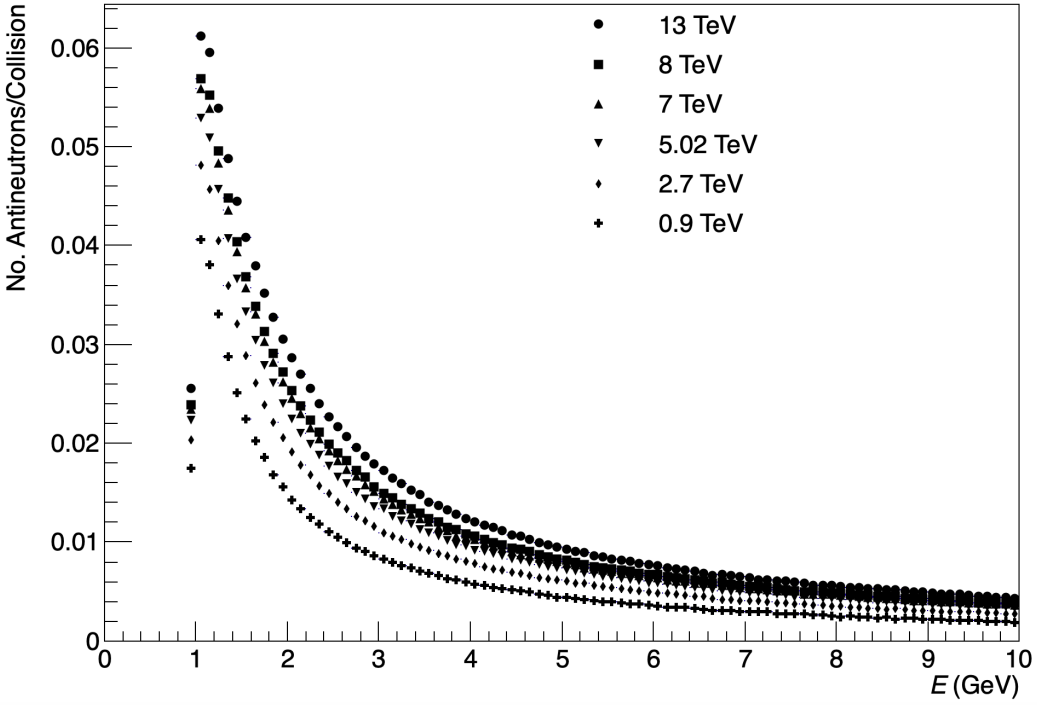


- The technique proposed consists in using the ITS silicon-nuclei neutrons as CEX targets to produce easier-to-identify $p\bar{p}$ pairs.
- The results obtained until now are specifically based on the ALICE RUNs 1 and 2 ITS geometrical configuration.

Simulation: PYTHIA

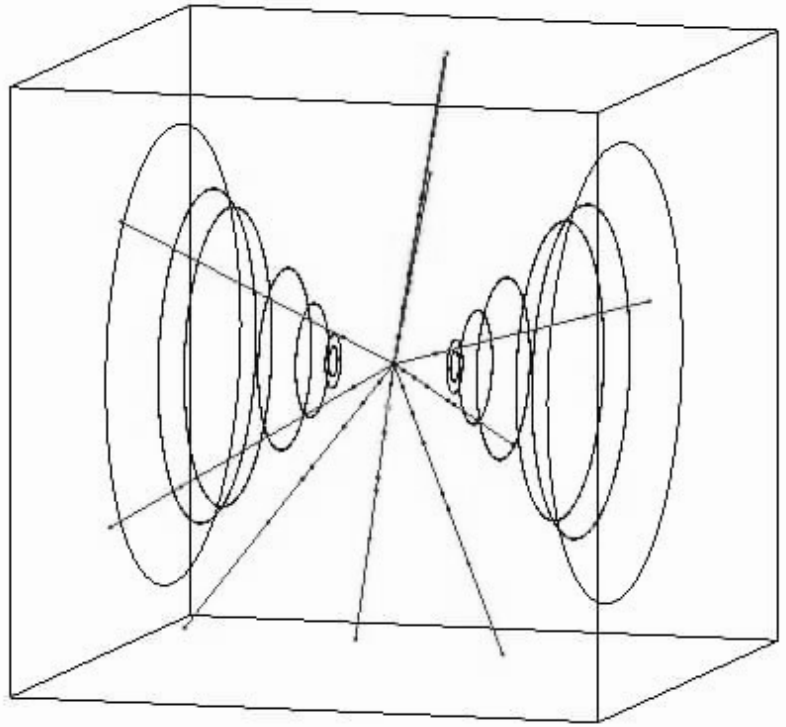
- Three million pp collision events were generated at $\sqrt{S_{pp}}$ = 0.9, 2.7, 5.02, 7, 8, and 13 TeV.
- The number of antineutrons produced per event, as well as their corresponding total energy, were recorded.
- For ALICE Run 2, $\approx 7.2 \times 10^{12}\ \bar{n}$ should be produced in pp collisions at $\sqrt{S_{pp}}$ = 13 TeV.
- $L = 35\ pb^{-1},\ \sigma_{pp} = 68.8\ mb$

$\sqrt{s_{NN}}$ TeV	0.9	2.7	5.02	7	8	13
No. $\bar{n}$/collision pp	0.94	1.44	1.82	2.06	2.17	2.58



Simulation GEANT4

- The present GEANT4 simulations consider an isotropic point source located in the center of a silicon detector, and emitting $\bar{n}$ with a given kinetic energy E_k distribution.
- The simplified version considers the generation of 10^8 fix $E_k = 1$ GeV (i.e., $c\ p_{\bar{n}}$=1.697 GeV) $\bar{n}$ ‘s.
- The second GEANT4 simulation consists of 10^7 events, where the $\bar{n}$'s have the actual 13 TeV PYTHIA energy distribution.



Analysis

- Simulated data were analyzed using ROOT.
- $\bar{p}'$s generated by primary $\bar{n}$'s that left an ionization signal in at least one of the detector layers.
- $n + \bar{n} \rightarrow n + \bar{p} + \pi^{+} (\sigma = 5.76 \pm 0.12$ mb) constitute the only background source to the CEX interaction.
- A π veto was implemented.
- $\sigma_{CEX} = 18.85 \pm 0.11$ mb at $E_k = 1$ GeV
- Identification efficiency of 0.11%. ⟶ ≈ one of every 1000 antineutrons produced could be identified.

Analysis

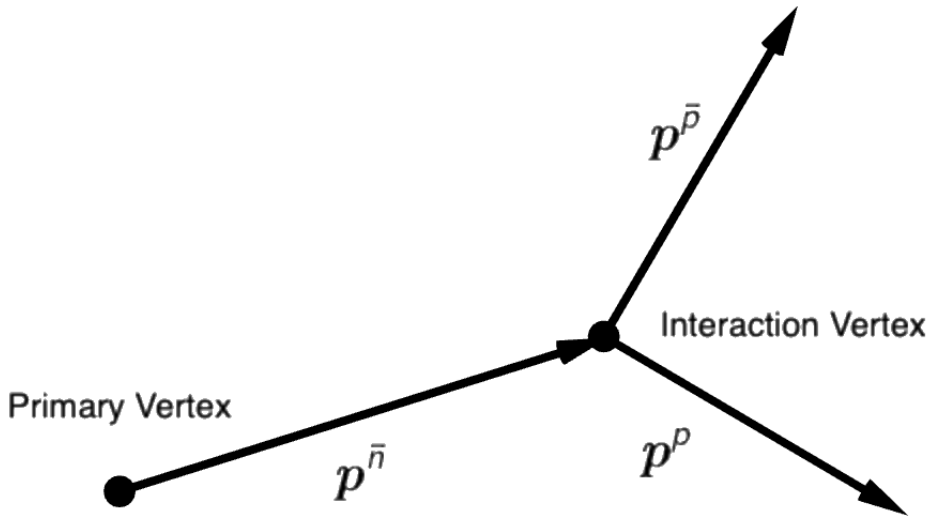
When the reaction takes place, the silicon nucleus breaks and a certain amount of energy is transferred to the nucleus fragments ⟶ An average of 5 protons per event is produced.

The best one can do is to identify as the p CEX-partner the one fulfilling the following three conditions:

- The most likely p should be that for which the distance from the plane to the primary vertex is minimal.

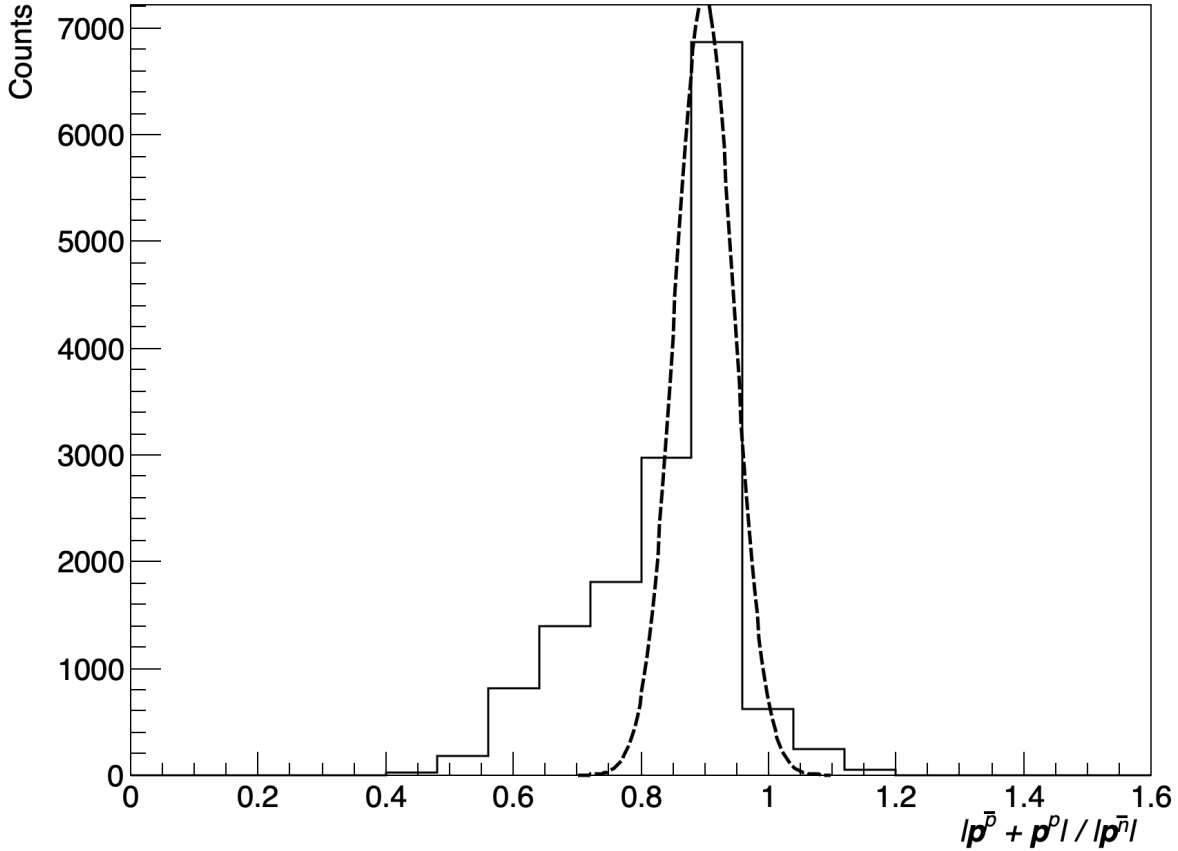
To reduce the uncertainty of kinematic reconstruction, events characterized by a large loss of $\bar{n}$ energy were discarded:

- $E_k^{\bar{p}} + E_k^{p}$
- $\left| c(\boldsymbol{p}^{\bar{p}} + \boldsymbol{p}^{p}) \right|$



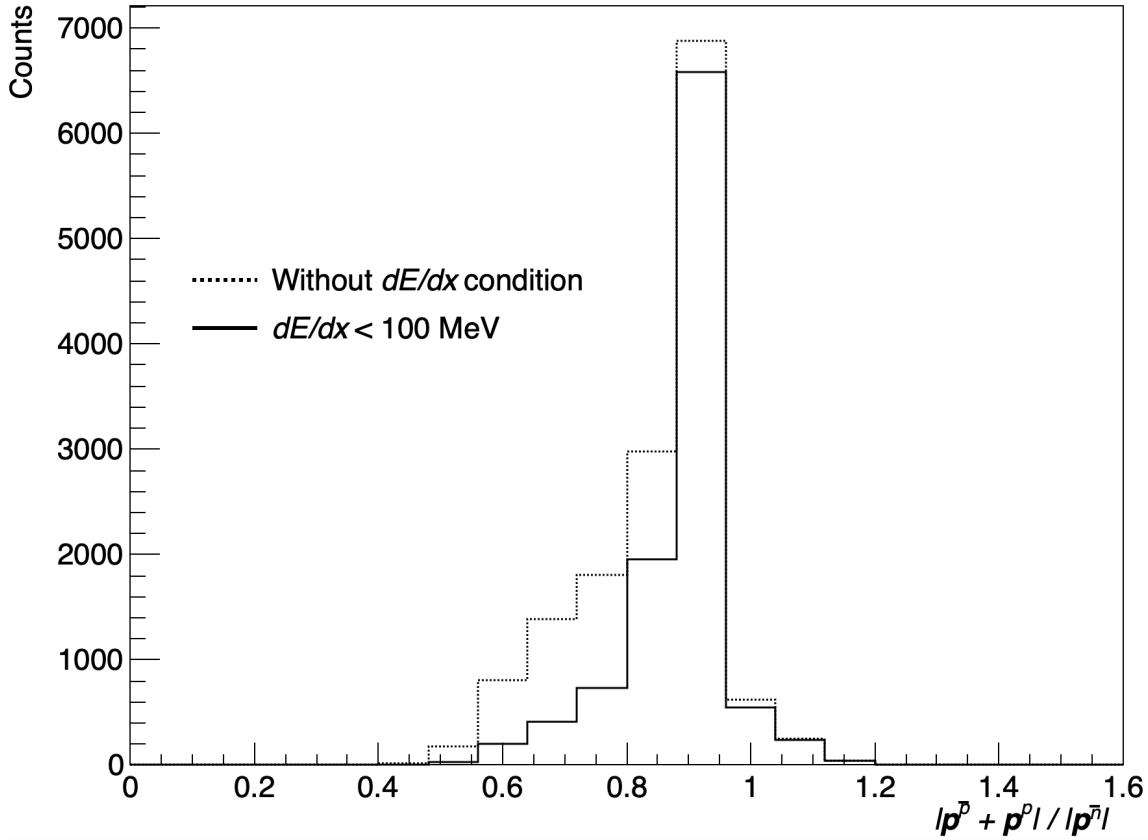
Analysis

- In 0.015% of the mono-energetic data sample the most likely CEX p was identified.
- This simplified exercise already illustrates the feasibility of the technique to identify $\bar{n}$'s, allowing to count $\sim$ 0.1% of them, while being able to reconstruct 90% ($\pm$0.05%) of the momentum for 0.007% of the sample.



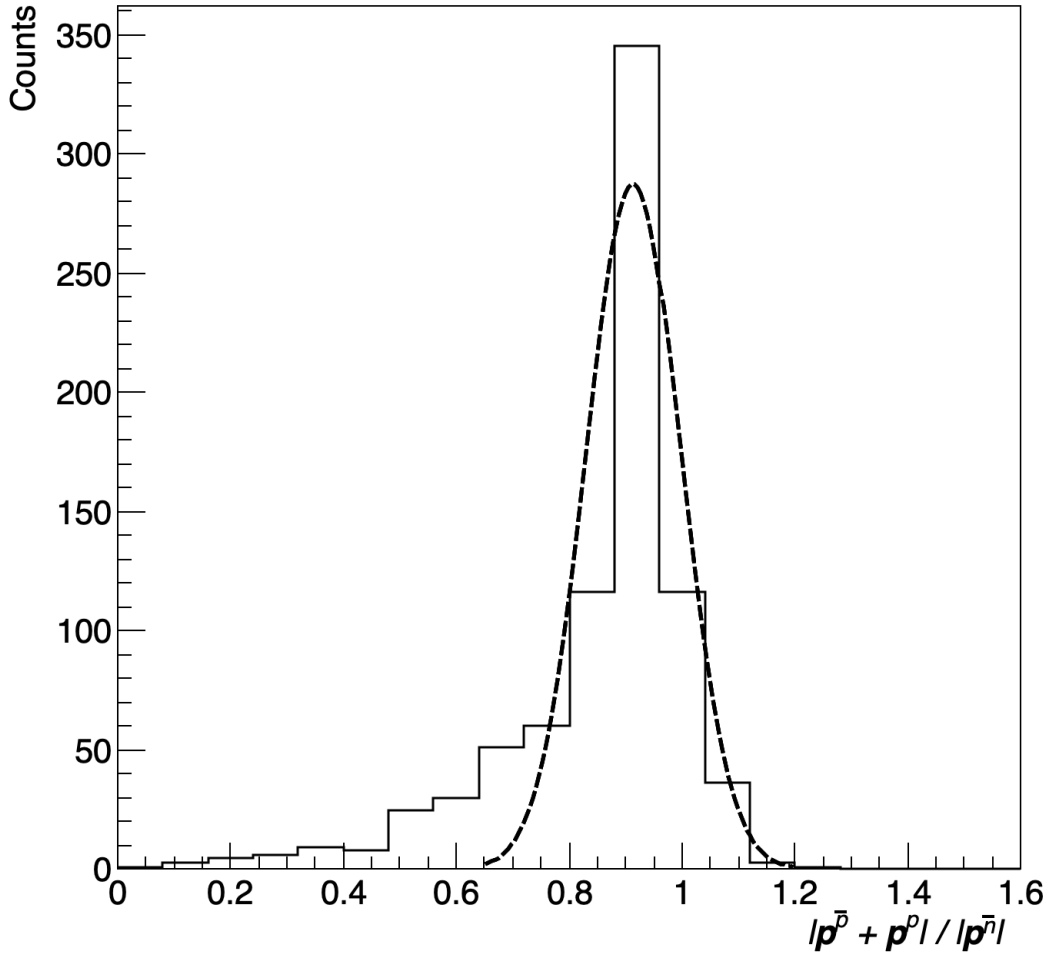
Analysis

- It was empirically determined that selecting events with $\mathrm{dE/dx} < 100$ MeV improved the kinematic reconstruction.
- The percentage of energy that can be reconstructed increased from 84% to 89%.
- An improved uncertainty of ± 0.04.
- The percentage of events in which the CEX proton can be identified, and this condition is satisfied, is 0.011%.
- 20% resolution improvement but there is a 26% yield loss.



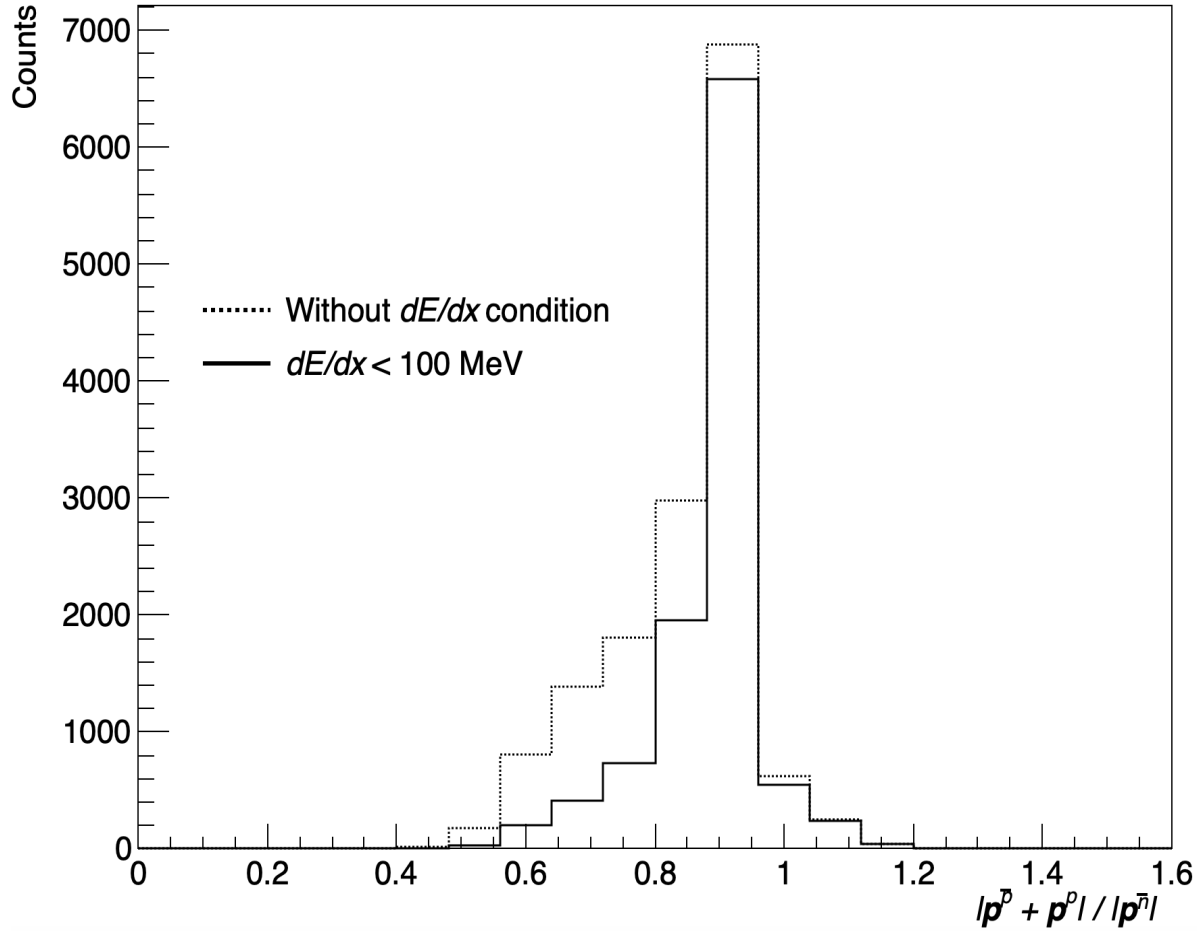
Analysis

- PYTHIA 13 TeV energy distribution between 0 and 10 GeV.
- The corresponding efficiencies were 0.06% for antineutron identification and 0.008% for kinematic information reconstruction.
- A Gaussian fit to the peak of this distribution yields a standard deviation value of 0.08.



Analysis

- The same $dE/dx < 100$ MeV condition was used:
- ➢ The percentage of energy that can be reconstructed increased from 85% to 89%.
- ➢ The fit yielded an improved uncertainty of 0.06.
- ➢ The percentage of events where the most likely CEX proton can be identified and satisfy the $dE/dx < 100$ MeV condition is 0.006%.



Conclusions

- Simulations to estimate the identification efficiency, and kinematics-reconstruction precision, in $\bar{n}$ detection using the CEX interactions $n + \bar{n} \rightarrow p + \bar{p}$ and $n + \bar{n} \rightarrow p + \bar{p} + \pi^0$, occurring in silicon nuclei of tracking devices in main LHC experiments, are presented.
- Using the ALICE-ITS detector configuration of RUN ´s 1& 2, two GEANT4 simulations were created:
- Simplified GEANT4 simulation:
  - Develop an $\bar{n}$ identification and kinematics reconstruction protocol.
- PYTHIA 13 TeV $\bar{n}$ energy distribution simulation:
  - Identification efficiency of 0.06% and a 0.008% kinematic reconstruction efficiency.
- For LHC Run 2 pp data, this technique has the potential to identify and reconstruct the kinematics of 4.3×10^8 $\bar{n}$'s, illustrating the feasibility of the method.

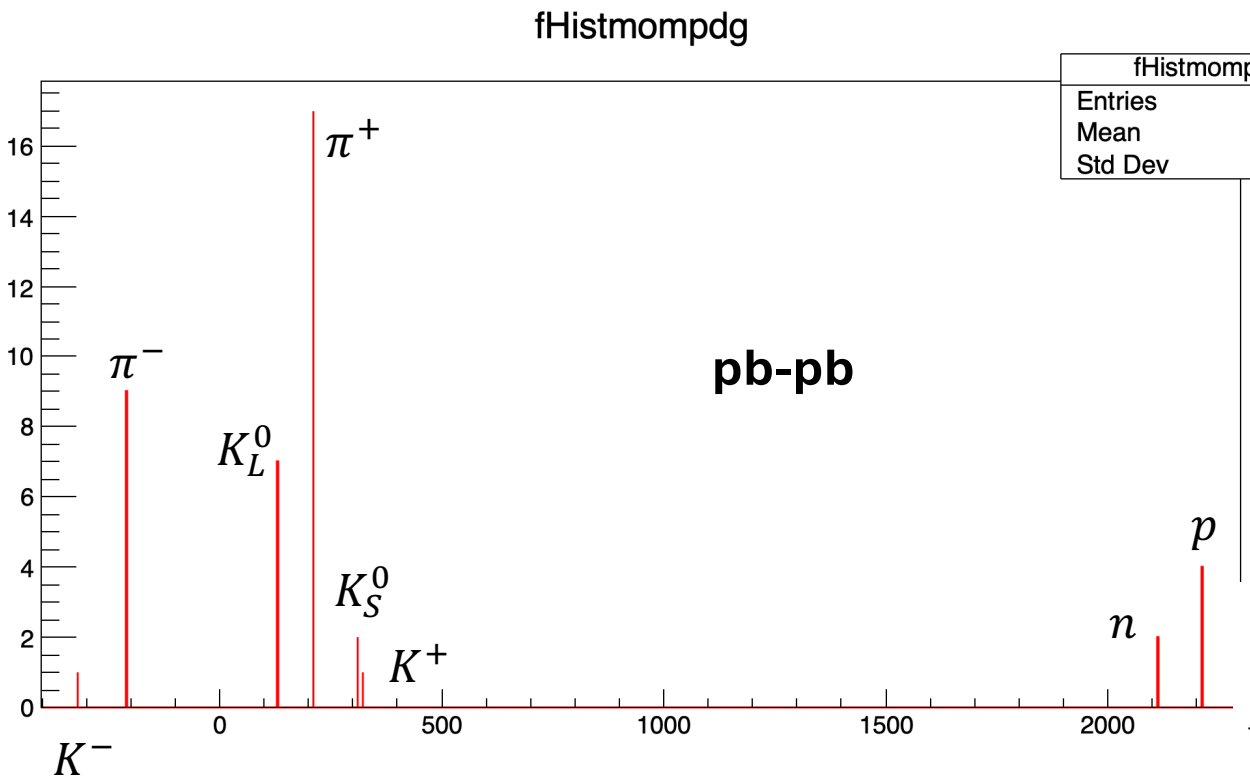
ALICE Monte Carlo Study

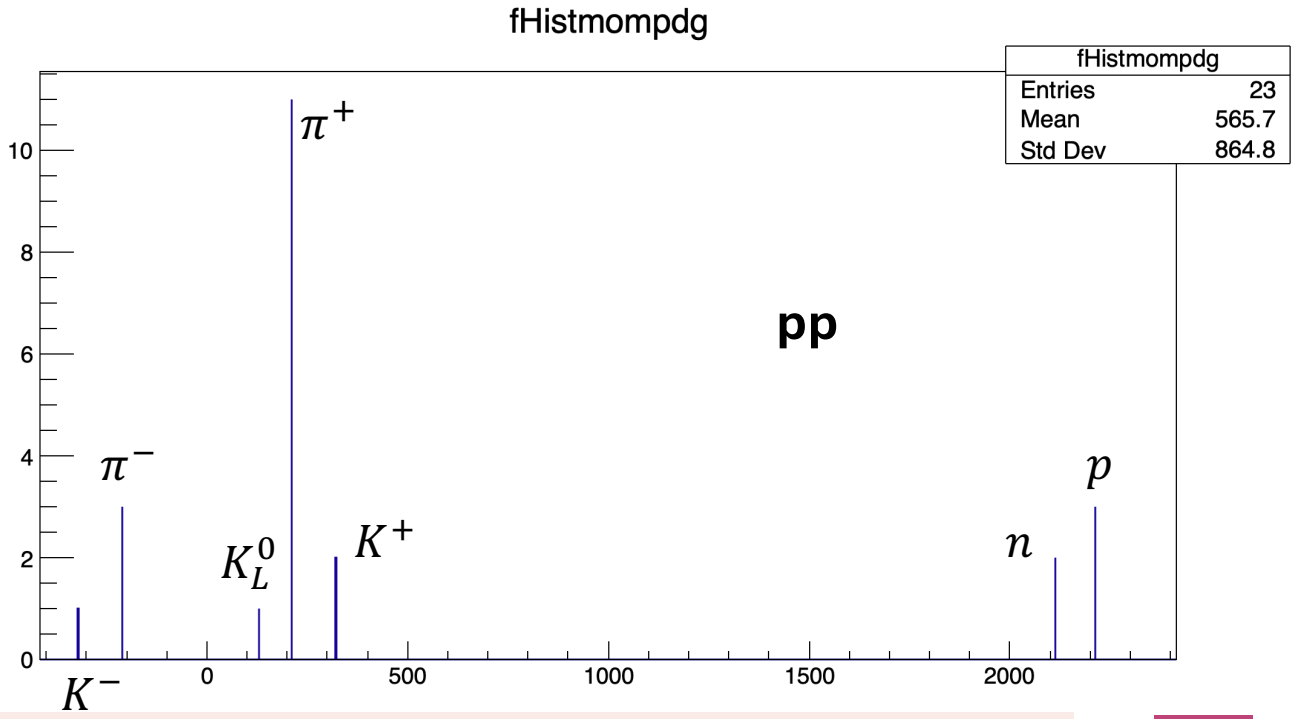
ALICE Monte Carlo Study

- The previous protocol was applied to diferent ALICE Monte Carlo productions
  - pb-pb: LHC16g1 run 244918 ⟶ 10 events ⟶ 2453 $\bar{n}$
  - pp: LHC15a2a run 114786 ⟶ 400 events ⟶ 660 $\bar{n}$
- Due to low statistics only one $p\bar{p}$ pair was selected as produced by CEX interactions.

Background study

- Secondary $\bar{p}$ generated in the material were selected.
- Primary mother particles were studied.
- Most $\bar{p}$ come from other $\bar{p}$ and $\bar{n}$ so that cases were counted in separate histograms.


fHistmompdg
fHistmompdg
Entries 43
Mean 379.3
Std Dev 747
pb-pb
π^+
π^-
K_L^0
K_S^0
K^+
K^-
n
p
0
2
4
6
8
10
12
14
16
0
500
1000
1500
2000


fHistmompdg
fHistmompdg
Entries 23
Mean 565.7
Std Dev 864.8
pp
π^+
π^-
K_L^0
K^+
K^-
n
p
0
2
4
6
8
10
0
500
1000
1500
2000

ALICE Monte Carlo Study

pb-pb:

- 366 (60%) $\bar{p}$ from $\bar{p}$
- 200 (33%) $\bar{p}$ from $\bar{n}$
- 43 (7%) $\bar{p}$ from other particles
  - 2 $\bar{p}$ from K_S^0 ⟶ 1
  - 7 $\bar{p}$ from K_L^0 ⟶ 0

pp:

- 88 (52%) $\bar{p}$ from $\bar{p}$
- 58 (34%) $\bar{p}$ from $\bar{n}$
- 23 (14%) $\bar{p}$ from other particles
  - 0 $\bar{p}$ from K_S^0 ⟶ 0
  - 1 $\bar{p}$ from K_L^0 ⟶ 0

- Secondary particles of these species also produce secondary $\bar{p}$ in their interactions with the material.
- To filter the background coming from charged particles would be possible with ALICE PID detectors.
- Most $\bar{p}$ from neutral kaons can be discarded by implementing a pion veto.

ALICE Monte Carlo Study

To select CEX events, the following is proposed:

- Use TPC particle identification to select $\bar{p}$.
- Look for $\bar{p}$ that do not leave a signal in the first 2 layers of the ITS (preliminary).
- Implement a pion veto
  - Use TPC particle identification to select pions.
  - Look for pions that do not leave a signal in the first 2 layers of the ITS (preliminary).
  - Produced in the same vertex
- If an $\bar{p}$ fullfils the previous conditions and there are no pions generated in the same vertex, the event is counted as a CEX event.
- CEX p selection
  - We look for p generated at the same vertex, which do not leave a signal in the first two layers.
  - Pevious selection criteria are applied

Conclusions and next work

- Due to low statistics none $\bar{n}$ has been identified.
- Increase the statistics.
- Implement a new task using ALICE O^2 to analyse RUN 3 data.
- F Lugo-Porras *et al,* Feasibility study to characterize the production of antineutrons in high energy *pp* collisions through charge exchange interactions, 2024 *J. Phys. G: Nucl. Part. Phys.* **51** 035005, doi: 10.1088/1361-6471/ad1dc1

THANKS

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