EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Measuring the cross-section of anti-deuteron in an aluminum absorber.

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Abstract

The motivation of this project is a precision measurement of the anti-deuteron inelastic cross section within an aluminum target using the HMPID. Here the focus is on the simulation and data analysis in preperation for the data taking with the HMPID and the aluminum absorber in front of it during Run 3 of the LHC. The anti-deuteron arriving at the absorber will be determined using TPC and the TOF. The momentum range used is 0.2GeV/c to 3 GeV/c.

1 Introduction

The anti-deuteron inelastic cross section is going to be measured using a transmission measurement approach. For this two 8cm thick aluminum absorbers have bin installed in front the HMPID chambers, as seen in figures 1 and 2. The dimensions of these plates are 130cm x 130cm x 8cm. The cross section will be calculated by the number of anti-deuteron impinging on the absorber, which will be determined by extrapolating the tracks of the anti-deuteron canditas identified with the dE/dx obtained by the TPC and the expected time of flight compared to the TOF measurement.

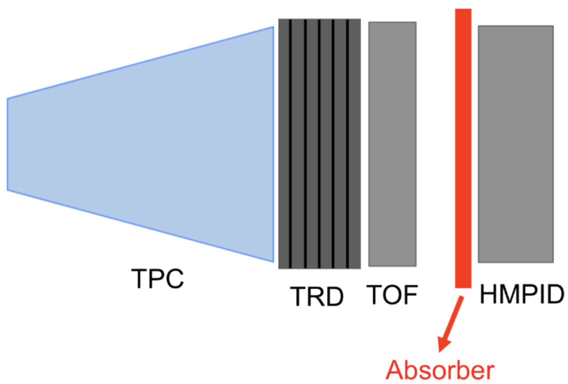

Figure 1: A cross section view of the ALICE detector can be seen with the position of the absorber highlighted.

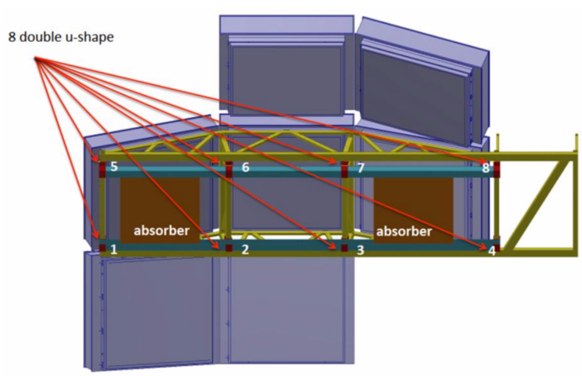

Figure 2: The picture shows a view from the beam pipe on the HMPID(purple) and the two absorber plates(brown) in front of it.

$$N(p - \Delta p_{abs}) = N_0(p) \cdot exp\left(\frac{-\Delta x}{\lambda_I(p_{int})}\right) \quad (1)$$

$$\lambda_l(p_{int})) = \frac{M}{\rho N_A \sigma_I(p_{int})} \quad (2)$$

Solving equations 1 and 2 for σ results in:

$$\sigma_I(p_{int}) = -ln\left(\frac{N}{N_0}\right)\frac{M}{\Delta x \rho N_A} \quad (3)$$

Here $N_0(p)$ denotes the total number of anti-deuteron of momentum p hitting thealuminum absorber of thickness Δx. The amount of anti-deuteron passing through the aborber is given by $N(p - \Delta p_{abs})$, this number can be calculated using 1 and is measured using the HMPID. M and ρ are the molar mass and density of aluminum. N_A is the Avogadro number. σ_I is the cross section and λ_I the hadronic interaction length, which gives the mean distance a particle can travel before interacting. Its value is roughly 16cm (double the absorber thickness) at the higher momenta. [1]

2 Determination of low background momentum range

In the beginning the momentum range that could be used for the measurement had to be determined. For this data measured during Run 2 of the LHC with ALICE was used. Possible anti-deuteron candidates hitting the absorber were identified using the TPC data and the dE/dx method. For these the tracks the time of flight data was evaluated and the difference to the expected time was plotted in a histogram. This can be seen as an example for protons, which provide a significantly better statistic for the fit, in figure 3. The same is done for anti-deuteron (figure 4). The counts of deuteron are smaller by a factor of 10000 compared to the proton data, making a good background more challenging due to higher statistical fluctuation. In the example displayed for anti-deuteron it can be seen that the background is still distinct from the signal area. The Signal area is from -3 to 3 σ TOF, where 0 denotes the expected time for anti deuteron of the given momentum. With increasing momentum the signal and background move closer together and overlap more.

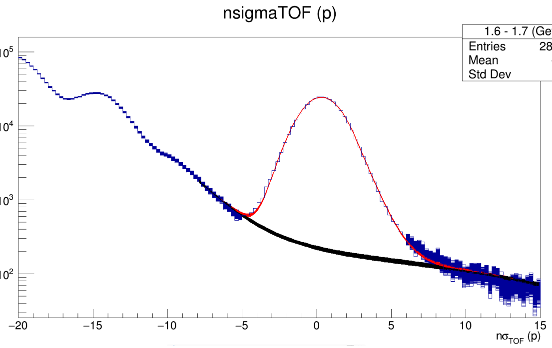

Figure 3: Histogram of the proton candidates(blue). The x axis displays the difference from the expected time of flight in $n{\cdot}\sigma_{TOF}$. On the y axis the counts are displayed. The Signal area is from $-3 < n{\cdot}\sigma_{TOF} < 3$. The red function is the combined signal + background plot and the black lines display the background.

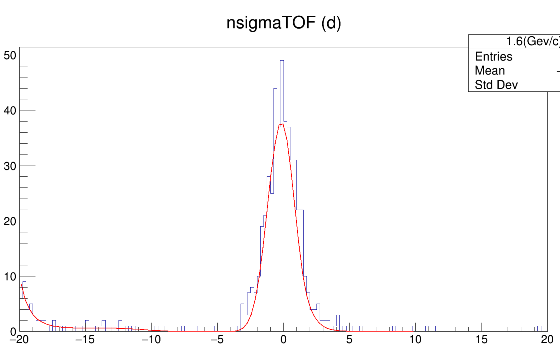

Figure 4: Histogram of the anti-deuteron candidates(blue). The x axis displays the difference from the expected time of flight in $n \cdot \sigma_{TOF}$. On the y axis the counts are displayed. The Signal area is from $-3 < n \cdot \sigma_{TOF} < 3$. The red function is the combined signal + background plot.

To calculate the background in the signal area the a fit of both functions combined was done. The parameters of the background part was then inserted into the function of only the background to generate the black line in figure 3. By integrating this from -3 to 3 the background was determined. Using this the purity of the signal was calculated using:

$$purity = 1 - \frac{background}{totalcounts} \tag{4}$$

This was done for anti-deuteron in the momentum range of 1.5GeV/c to 1.9GeV/c (figure 5). The purity for lower momenta was assumed to be nearly 100% due to the increasing seperation of background and signal with low momentum. As expected the purity decreased towards higher momentum but was still above 97% at the highest evaluated momentum. This lead to the decision to do the simulation described in the next section for anti-deuteron of up to 3GeV/c.

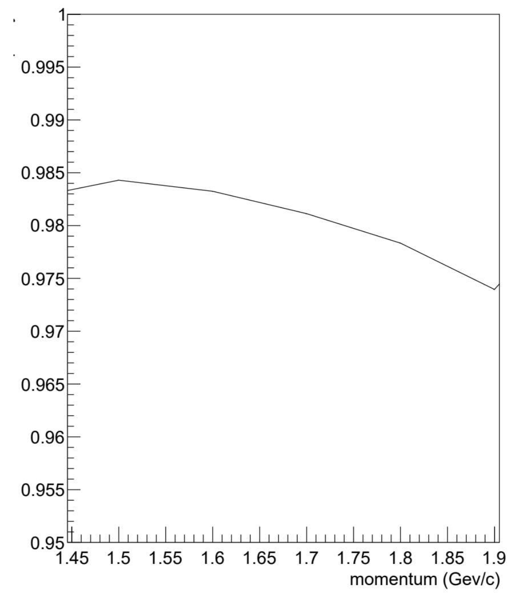

Figure 5: Graph of the purity of the anti-deuteron signal over the momentum p.

3 Simulation of anti-deuteron in the absorber

A simulation based on the Bethe-Bloch formula was carried out to calculate the momentum distribution with which anti-deuterons of different momenta entering the absorber would decay. The simulation was made using the following steps:

1. Generate anti-deuteron with momentum $0.5GeV/c \leq p \leq 3GeV/c$
2. Use Bethe Bloch for energy loss per step
3. After every step calculate the momentum dependent hadronic interaction length (eq. 2)
4. Draw a random number between 0 and 1 and check against absorption probability for decay
5. Save start and decay momentum if particle decayed
6. Repeat until particle decayed or left the absorber

In the beginning this was done for in incident angle $\phi = 90°$ and absorber thicknesses of 4cm and 8cm.

To calculate the hadronic interaction length the current estimation of the absorption cross section was used. The results of the simulation were then plotted in a two dimensional histogram as seen in figure 6. A strong correlation between the initial momentum and the decay momentum can be seen for higher momenta. This is to be expected since faster particles loose less energy inside the absorber and can not decay at vastly lower momentum.

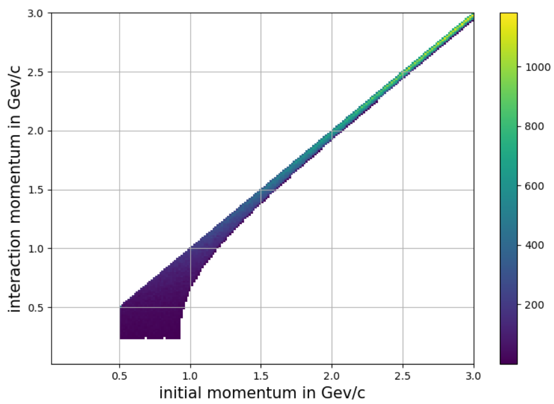

Figure 6: Histogram of the interaction momentum and initial momentum of the decaying anti-deuteron. An 8cm thick absorber and one million particles were simulated.

The next step was respecting the angle dependent thickness of the absorber. For this an angle ϕ at which each particle leaves the beam line was generated. From this the angle at the absorber was calculated using the orbit radius inside the magnetic field of ALICE. The absorber is positioned 4.8m from the beam line, this is visualized in fig. 7. To save computational time only particles that hit the absorber should be generated. This was achieved by another algorithm, that calculated the minimum and maximum angle ϕ possible for each momentum under which the particles still hit the absorber. To not have to do that again for each particle the results were written to a file that was then read during the simulation.

The algorithm has the the structure:

1. Iterate over momenta from $0.5 \leq p \leq 3GeV/c$
2. Calculate radius for given momentum
3. Iterate over all angles from 0 to 2π
4. Determine if that trajectory goes through the absorber
5. Write minimum and maximum angle ϕ to a file

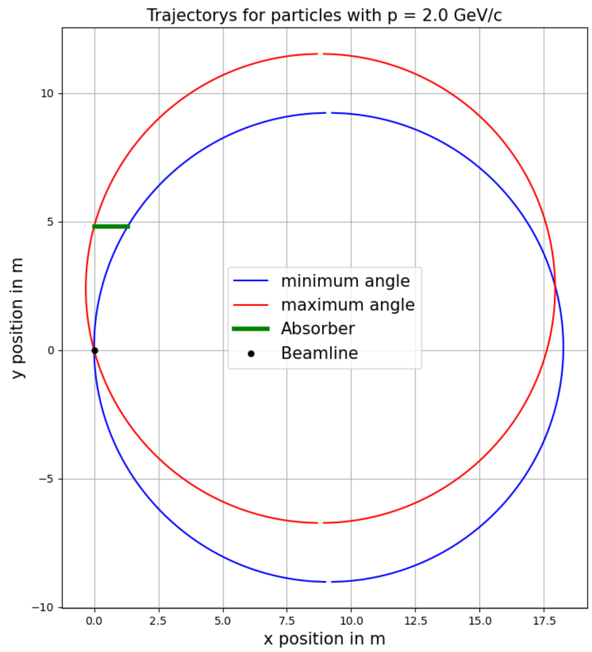

Figure 7: Plot showing the trajectory of an anti-deuteron with the minimum and maximum angle to the x axis inside the ALICE magnetic field. The angle is calculate at the beam line (0/0). On the x axis and y axis the position in meter is shown.

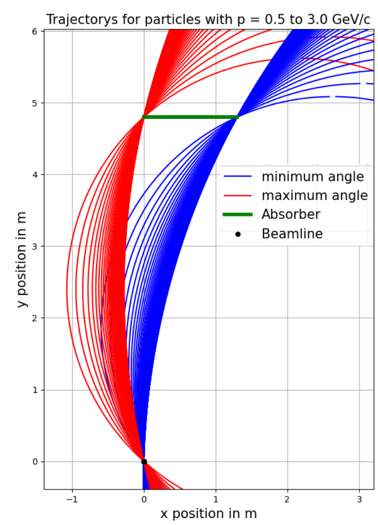

Figure 8: Zoomed in version of fig. 7 showing 50 trajectories from 0.5GeV/c to 3.0GeV/c.

The simulation would then only generate particles with trajectories between the red and blue lines of the corresponding momentum(fig 8). Running it again with this adapted absorber thickness leads to a broadening of the distribution and especially a of the momentum range in which particles can be stopped by the absorber. This can be seen in figure 9 compared to figure 6

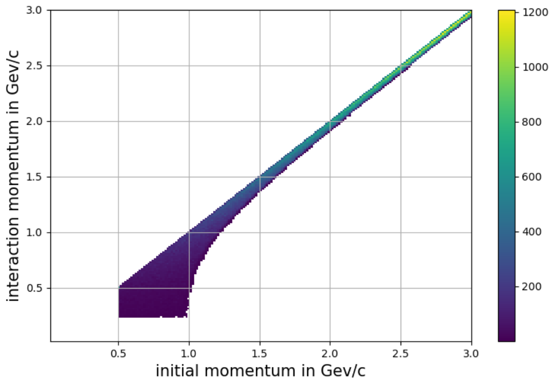

Figure 9: Same plot as fig. 6, using a random angle between Phi min and max for the particles and angle dependent absorber thickness.

4 Cross section calculation

The last step of the project was attempting to calculate the cross section of anti-deuteron from simulated data. Figure 10 shows a simulated template of the anti-deuteron passing through the absorber(blue) and the ones being absorbed(red). The x axis shows the distance from the measured position to the one obtained by extrapolating the track through the absorber into the HMPID. It can be seen that interacting particles have a higher positional displacement compared to the ones passing through, whose displacement is mainly caused by coulomb interaction with the absorber. The purity of anti-deuteron compared fragments is plotted in figure 11. This was obtained using the templates as well as applying a cut at the 3/4 of the mean value of the displacement ΔR. Then the templates were fitted to the simulated data (fig. 12). The fit was done using ROOTs TFractionFitter, which returns the proportion each template contributes the data. This was done for every momentum bin. With the fraction of anti-deuteron that passed through the absorber the cross section was calculated using equation 3.

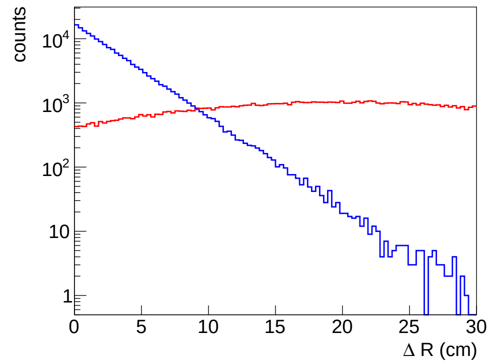

Figure 10: Simulation showing passing anti-deuteron(blue) and interacting ones(red). The x axis shows the difference of the measured position compared to the one extrapolated from the track.

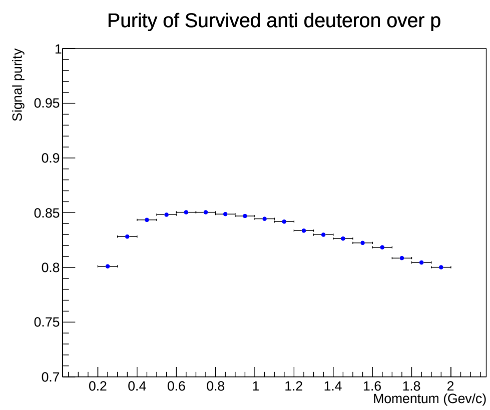

Figure 11: Purity of anti-deuteron in the HMPID behind the absorber.

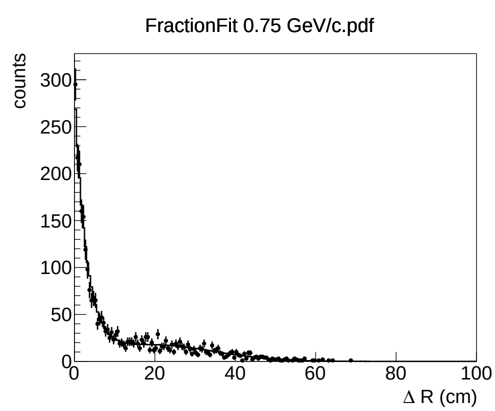

Figure 12: Fit of the two simulated templates (fig. 11)(black line) to simulated data of the HMPID(black dots).

The result of this analysis is shown in figure 13. All the results are a bit below the expected line of the cross section used for the simulation.

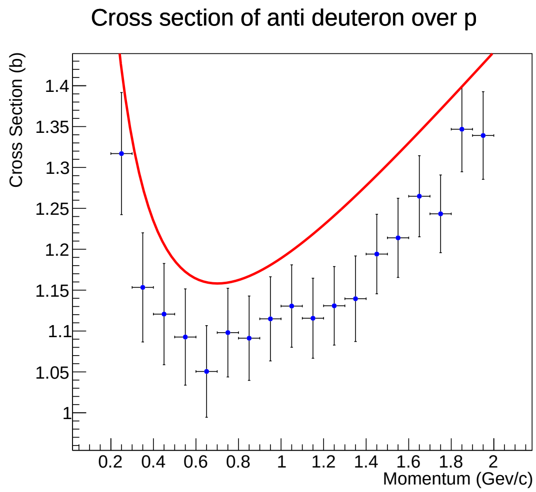

Figure 13: Plot of the GEANT4 cross section(red line) and the calculated cross section from the fit done in figure 12.

5 Outlook

It is likely a factor is wrong somewhere within the code since all calculated values of the crossection from the simulation are below the current theoretical value by a similar amount. This should be corrected. As soon as the real data from the HMPID of LHC Run 3 are available, the measurement can be performed following the same procedure as the cross section calculation, but using the real data instead of the simulated one. This result can then be used to optimise the simulation.

References

[1] Alberto Calivà et al. *Measurement of the (anti-)deuteron inelastic cross section with the HMPID in Run 3*. 2019.