Detailed characterization of low background
β-delayed proton detector

M. Janasik

mollyjanasik@gmail.com

T. Budner, M. Friedman, C. Wrede

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Abstract

In order to determine the rates of two important reactions, $^{30}\text{P}(\text{p},\gamma)^{31}\text{S}$ and $^{15}\text{O}(\alpha,\gamma)^{19}\text{Ne}$, for the astrophysical rapid proton (rp) capture process, we have built a segmented, low background β-delayed proton detector. A detailed characterization of the detector's Micromegas pad plane was performed using measurements with a radioactive ^{55}Fe x-ray calibration source.
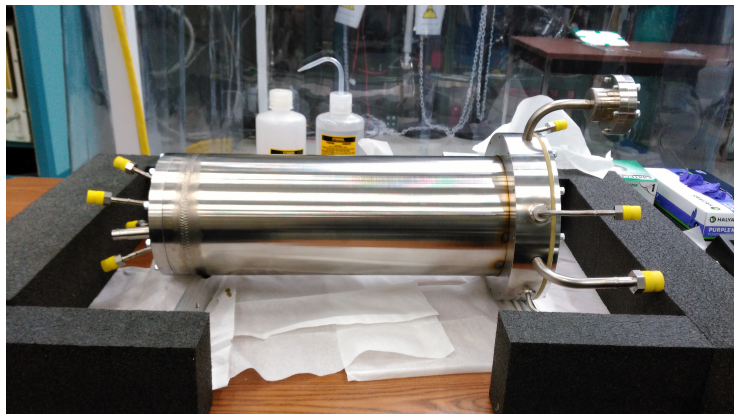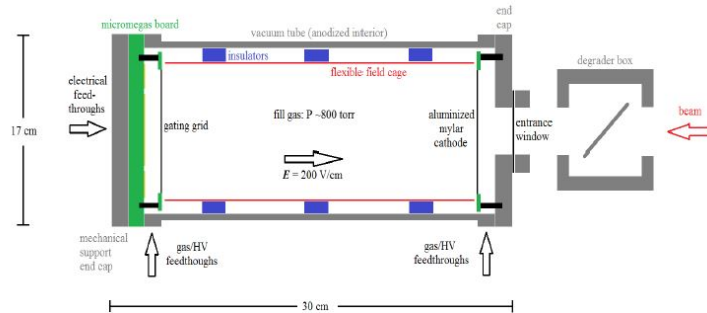
Figure 1: The Proton Detector.

Figure 2: Conceptual design sketch of the proton detector system, circa 2014. While the core concept hasn't changed, the detector was lengthened somewhat during the subsequent mechanical design phase.

1 Introduction

Our research focuses on studying nuclei experimentally to probe astrophysical questions about classical novae and x-ray bursts. We are currently focused on measuring the beta decays of proton-rich nuclides in order to do this. The one of current relevance is ^{31}Cl because in NSCL experiment 12028, we showed that ^{31}Cl β decay populates new astrophysically relevant states in ^{31}S [1]. We have built a detector of beta delayed charged particles. In its current Phase I, the gas–filled detector employs a Micromegas pad plane and will serve as a proton calorimeter to measure the proton branching ratio for the $E_{CM} = 259$ keV ^{30}P(p,γ)^{31}S resonance. In Phase II, the detector will be upgraded into a time-projection chamber with a high-granularity Micromegas board, to enable a sensitive measurement of the alpha-particle branching ratio for the $E_{CM} = 506$ keV ^{15}O(α,γ)^{19}Ne resonance.

The proton detector(see Figure 2) is based on a Micromegas structure at CERN [2][3]. The purpose of this analysis is to test the functionality of the Micromegas using a truncated version of the detector, called the Pancake. The Pancake is comprised of the same Micromegas as the detector, but is smaller in size which allows us to efficiently test just the Micromegas and each of its 13 detecting pads. The pads are organized into three rings and each of the pads were tested for performance and to ensure uniformity across pads of the same ring. The central pad was named pad A with four pads surrounding it: B,C,D, and E with eight pads surrounding them: F,G,H,I,J,K,L,M (see Figure 1). We used a preamplifier to amplify the signal from the Pancake and an XIA digital data acquisition system, or DDAS, to convert that signal into a digital signal we can use. We also used a gas handling system to flow P10 gas through the Pancake.
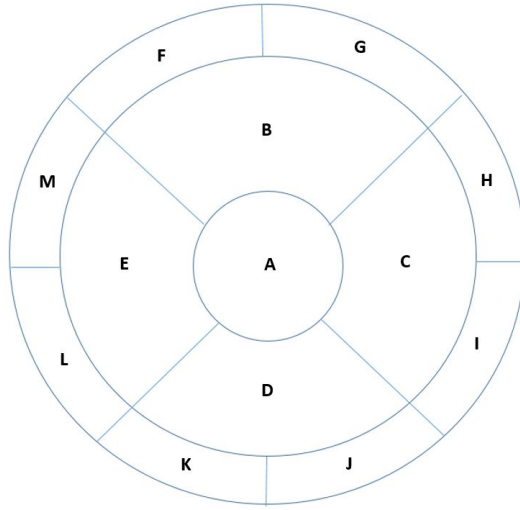
Figure 3: A Drawing of the Pancake with the 13 pads of the Micromegas labeled.

2   Experimental Setup

We assembled the Pancake July 2017 in the clean room. The Pancake's components include, in order: a collimation mask (see Figure 5) that allows x-ray photons to reach only a specific volume of gas corresponding to a specific area of a specific pad and its borders, a thin Kapton window to allow x-rays to enter the Pancake, a high voltage cathode tongue, short drift region with uniform electric field, and Micromegas that is then connected to our readout electronics (see Figure 6). We used P10 gas at about atmospheric pressure, or 778mTorr. The voltage applied on the cathode was -130V and on the MicroMesh was 450V. We then took measurements using an ^{55}Fe x-ray source of 400 µC with two peaks at about 5.9keV with 24% intensity and about 6.5keV with 2% intensity [4] using a source holder at each of the holes on the mask. Each run was about 5 minutes long at the middle of the pad, 10 minutes for a border between two pads, 15 minutes for a border between three pads, and 20 minutes for a border between four pads.

3   Analysis

From taking data on small spots of each detecting pad and their borders of the Micromegas using a collimation mask, I obtained some results about the Pancake. First of all, it works. A basic, but important, result is that the Micromegas functions as expected. Resolution was another important factor we looked at. Resolution was determined by fitting the peaks in the spectrum with a Gaussian function and calculating the full-width at half-maximum, the Gaussian used is seen in Figure 7. The relative intensities and energies were fixed in the fit. The resolution for the central pad is at about 16%, which is much better than the initial tests back in February 2017 at about 20%. This improvement is most likely due to the use of a collimated source and shorter drift field. Resolu-
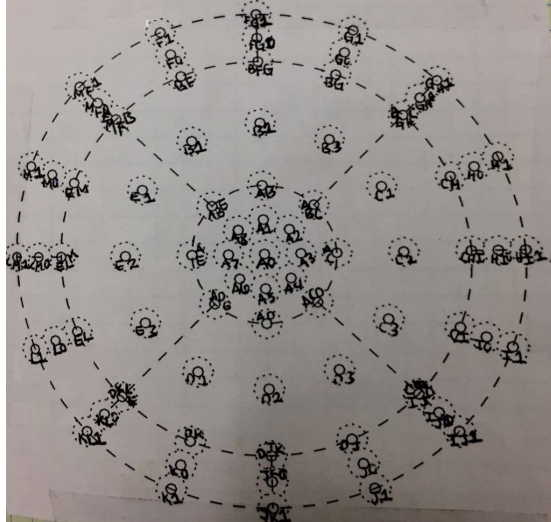
Figure 4: Map of Pancake used to distinguish between mask holes and their locations on the pads

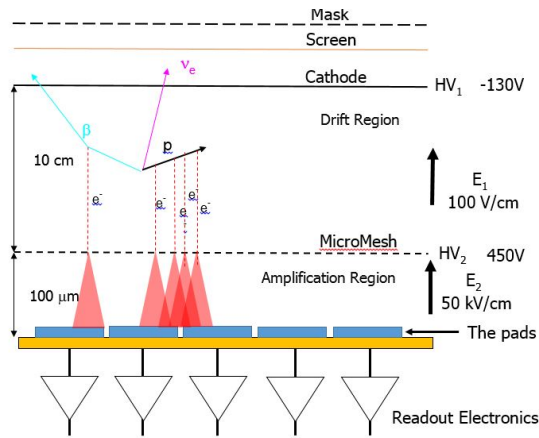Figure 5: A The Pancake (mask side) and source holder

Figure 6: Schematic showing how the Pancake works. The detector uses Micromegas as the amplification system. Electrons produced by ionization in the gas drift in a uniform electric field toward the amplification region, where a very strong electric field produces an avalanche multiplication. As opposed to the shown scheme, we did not apply HV2 on the mesh but instead grounded the mesh and applied HV to the pads.
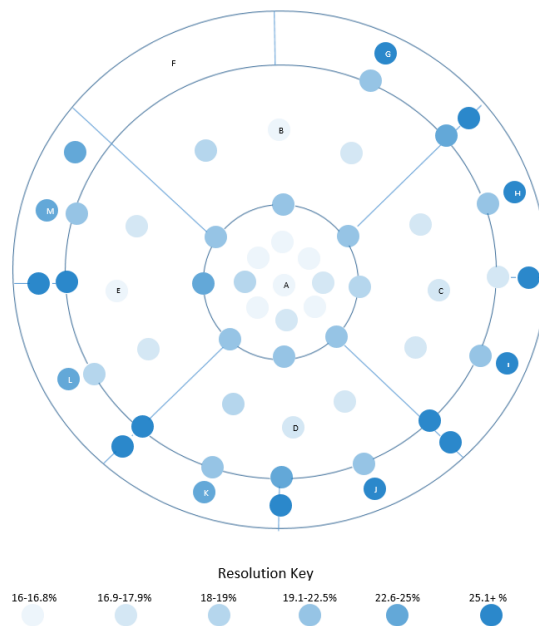

Figure 7: Map of the three rings of the Micromegas pad plane on the Pancake. Small sections of each of the 13 pads and their borders were analyzed for resolution, except for pad F due to the pad not functioning (no signal was detected). Darker blue corresponds to worse resolution, lighter blue corresponds to better.
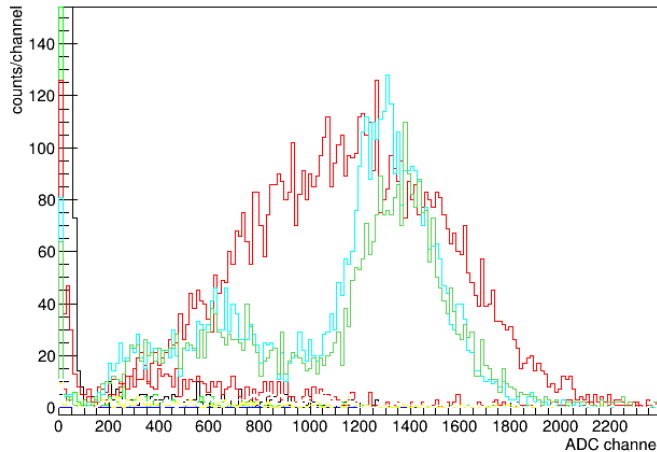
Figure 8: Spectrum showing the pads at the border of pads K (green) and J (blue). Pad B (red) is strangely present as well.

tion is also fairly consistent throughout the Micromegas, which is expected: the deviation is within 2.5% between pads of the same ring and 1.9% within a single pad, see Figure 7. The five central pads are most important and work as they are supposed to. The pads in the outer ring are less important because they are only used to veto high energy protons. High energy protons will deposit only part of their energy in the pads and escape the sensitive region with residual energy. This might cause unwanted background in the spectrum, since we can interpret it as a lower energy event. The outer pads can be used to exclude such events, since this scenario will be detected by one of these pads.

We also looked at the multiplicity to see how many pads responded to the same event, and the results showed usually only one pad responded to the event. We ran into some problems while performing the tests on the pads of the Micromegas. Pad F was not working so we could not get any signal, and therefore we couldn't analyze the pad's performance. There was also a gain drift due to a leak in the Pancake; this affected gain so we did not include it in the analysis. Results were also very inconsistent and irreproducible due to the leak. An example of this is that an energy peak of pad B, one of the middle ring pads, was seen in almost every run no matter the location of the source, see Figure 8. This was not the case for other tests we conducted before and after this one. This error does not affect resolution or the fact that the Micromegas works.
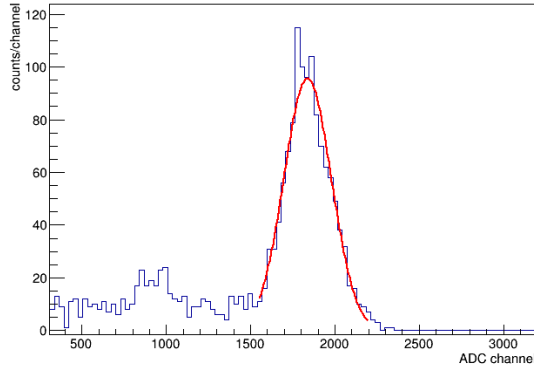
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Figure 9: Spectrum showing the energy spectrum of the central pad when the source is focused at its center. The second peak, left of the larger peak, is the escape peak. The Gaussian fit shown was used to determine the resolution in the Resolution Map in Figure 7. The resolution for this specific location was 18.7 +- 0.6%

4 Discussion and Future Plans

The main takeaways are that the Micromegas and the digital data acquisition work and the resolution is excellent. These tests will later be performed again using new Micromegas boards to be acquired in early 2018.

Looking ahead, we will be running a commissioning experiment on the NSCL beam line in 2018 to test our actual beta delayed proton detector under realistic operating conditions using a strong peak from ^{25}Si decay at $E_{CM} = 401$ keV. Under the optimized settings, we then will perform a test measurement of a known weak low-energy proton peak from ^{23}Al decay at $E_{CM} = 214$ keV.

5 Appendix

5.1 Appendix 1

The data can be found when logged in as protondetector and is in the data/pancake/ directory. The files that can be used are in the format runxx.root. The macro used to do the analysis is named createNanalyze.C and the file that converts DDAS into something we can use is DDAStoROOT. Some gain, efficiency, and resolution comparisons are in this directory as well. There is also a logbook that explains how to find each of the runs' information with the specific pressure, time, etc. of each run. This document is named 'SQL Commands.pdf' and can be found in 5.2.

5.2 Appendix 2

SQL Commands
Created by Pranjal Tiwari
June 27, 2017

To access the database of the logbook, you will have to open a terminal window to start inputting commands. The first thing you need to do is log in as a user for a the protondetectordaq database, this represents data acquisition from the proton detector:

mysql -uprotondetector -p protondetectordaq

Once this has been inputted, you type in the password for the user uprotondetector, which is the same as the password for the machine itself: z8=GrsFi8. Now you are logged into the database and can change the tables within it. The first table in there is the log, to see all the columns that a table contains along with the entries it accepts, use the command:

DESCRIBE log;

Now that you know the columns and data types each column takes, you may want to insert new rows into the table. If you want to see another table, just replace log with the name of another table in the database To do so, you will need the command:

INSERT INTO log VALUES ([column 1 value] , [column 2 value], ...);

There are columns for date and time, to get this from the system, just input CURDATE and CURTIME for the respective column and it will take the system date and time. If you want to see the entire table, just type in

SELECT * FROM log;

If you want a specific value from a column to be present, use:

SELECT * FROM log WHERE [column name] [boolean operator] [value];

Just remember that the semicolons at the end are important. If you want to create a new table, the syntax is:

CREATE TABLE name ([column 1] [data type] , [column 1] [data type] , ...)

These are all the basic ones and the language is very simple to learn, so if you want to do anything more advanced, you can easily look it up and understand what the command is saying by looking at it.

References

[1] M. B. Bennett et al., Phys. Rev. Lett. 116, 102502 (2016)

[2] Y. Giomataris et al., Nucl. Instrum. Methods Phys. Res., Sect. A 376, 29 (1996)

[3] E. Pollacco et al., Nucl. Instrum. Meth. A 723, 102 (2013)

[4] http://www.nndc.bnl.gov/chart/decaysearchdirect.jsp?nuc=55FE&unc=nds