GRIDS 2026
Graduate Instrumentation and Detector School

# The ALPHA-g Prototype: radial Time Projection Chamber (TPC)

First release [2023]: A. Capra and P. Giampa
TRIUMF
Update [2026]: G. Smith and A. Capra
TRIUMF

## Contents

# 1) Introduction

The detector to be used in this experiment is the prototype for the ALPHA-g experiment TPC. ALPHA-g is a CERN experiment which is primarily intended to investigate the effects of gravity on antihydrogen. While measuring the gravitational acceleration of antimatter has merits on its own, the scientific collaboration[1] hopes to shed light on the baryon asymmetry problem.

# 2) Experimental Setup

In this section, we review the hardware available for this experiment:

- radial TPC;
- barrel scintillator (scintillator bar with SiPM);
- power supplies and readout electronics.

## 2.1) Radial Time-Projection-Chamber

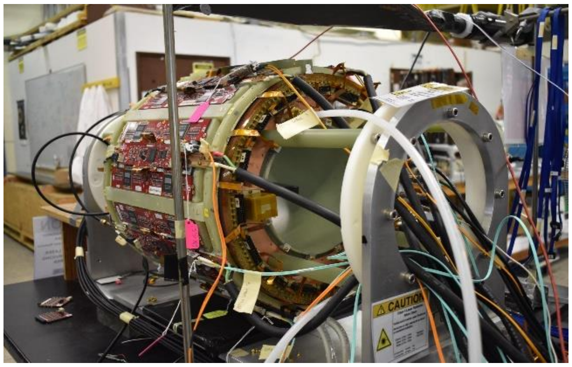


*Figure 1 Instrumented ALPHA-g Prototype TPC.*

The TPC in this experiment (Fig. 1) consists of an inner cathode, shaping wires, readout wires (anodes), and an outer cathode, segmented into pads.

The cathode, located at the center of the cylindrical chamber, creates an electric field that drifts the ionized electrons, produced by charged particles passing through the gas. Shaping wires separate the drift region from the amplification region, where the strong field generated by the sensing wires causes charge multiplication, called an *avalanche*. The avalanches induce a measurable electric signal on the sensing wires. Meanwhile, the segmented cathode serves to locate the position of the avalanche along the detector axis.

---

[1] https://alpha.web.cern.ch/

A schematic representation of the E-B fields in the TPC, as well as a simple representation of drifting charges, are shown in Fig. 2. In a simple formulation, the electron drift velocity can be written as

$$v_d = \frac{e}{m} E\tau$$

where the charge to mass ratio of the electron is $1.7588\times10^{11}$ $C\cdot kg^{-1}$, E is the electric field magnitude and τ is the mean time between collisions.

The radial structure, compared to a more standard cylindrical TPC, was chosen to maximize the tracking performance and minimize the effect of the magnetic field used for trapped antihydrogen atoms.

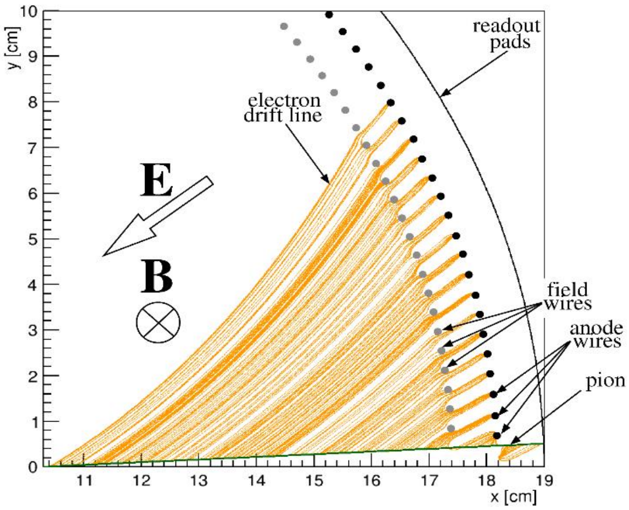
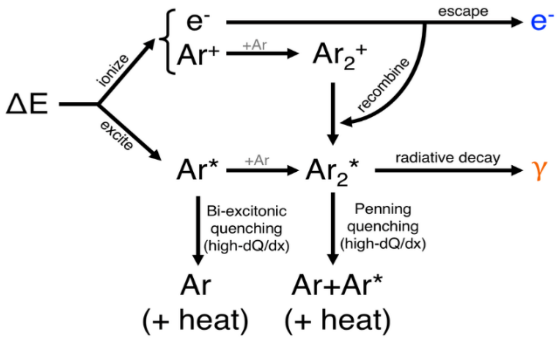


*Figure 2 Cross-section view of a wedge of the TPC. A pion crosses the ionization chamber (green) and produces e−ion pairs in the gas. The electronics (orange) are drifted toward the anode wires under the influence of a radial electric field and an axial magnetic field (1T).*



In the ALPHA-g proto-TPC detector, the chamber is filled with Argon and $CO_2$ gas, with a nominal mixture ratio of 70%/30%, respectively. As charged particles pass through the gas and deposit energy, argon atoms are either excited or ionized (Fig. 3). Excited atoms form dimers and then disassociate producing VUV light (peaked at 128 nm). However, the fraction of $CO_2$ is used as a quencher, as it highly suppresses the excitation process, thus maximizing ionization when energy is deposited in the gas by a charged particle.

*Figure 3 Schematic representation of the ionization and excitation paths when energy is deposited in the target gas. The CO2 fraction suppresses the excitation path.*

The presence of the electric field prevents the ionized atoms from recombining, thus the electron/ion pairs can be drifted and collected, generating signals strength proportional to the energy deposited. The number of electron/ion pairs per cm, the 1st Towsend coefficient α, can be estimated as

$$\alpha = N\,\sigma_i$$

Where N is the number of molecules per unit volume and σ is the ionization cross-section. The number of pairs at distance x is given by

$$N(x) = N_0 e^{\alpha x}$$

Note that the 1st Towsend coefficient is dependent on the applied field, as typically, the ionization probability increases with the applied electric field. Although we should note that at a certain level, the E-field is too large and induces discharge, hindering the charge readout.

The 256 sensing wires are readout in groups of 16, by dedicated electronics (preamplifier) to amplify the avalanche signal. The analog signal from these cards is extracted with high-density coaxial cables (blue). The pads can also be read out using the same electronics employed with the wires, through an adaptor board.

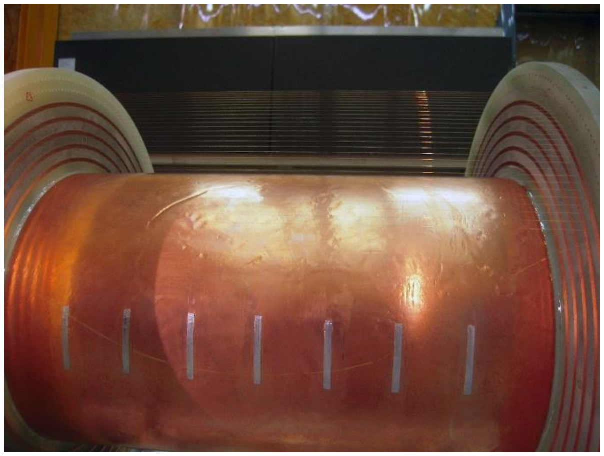


*Figure 4 Inside the TPC "the gas volume". The center cylinder is the cathode and at the edges, we can see the field-shaping and readout wires.*

## 2.2) Barrel Scintillator

The ALPHA-g TPC is surrounded by 64 scintillator bars[2] read out at both ends by an array of six SiPMs[3]. In this setup, there is one bar (Fig. 5), albeit much shorter than the one used in the final setup. When charged particles interact with the bar, the polymer emits light (fluorescence) that is not re-absorbed and travels towards the SiPM. The SiPM are photosensors (i.e., light detectors) that produce a signal that is proportional to the number of impinging photons. The SiPM exploits a common radiation detection mechanism, where a p-n junction is reversed biased to amplify the charge of an electron (or a hole, for shorter wavelength) that results from the interaction of a photon with the material (photo-conversion).

---

[2] http://www.ggg-tech.co.jp/maker/eljen/ej-200.html

[3] http://sensl.com/products/j-series/

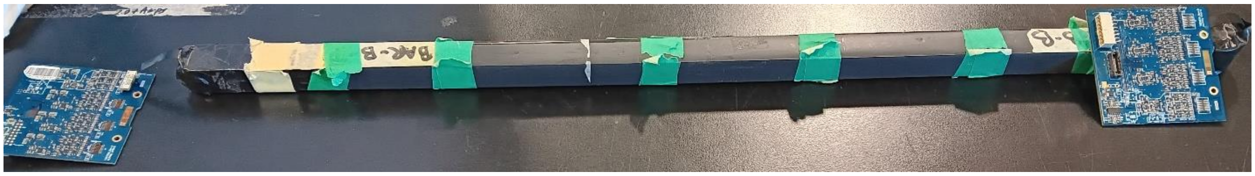


*Figure 5 Scintillator bar used in the ALPHA-g setup with readout cards connected to SiPM at each end.*

## 2.3) Electronics

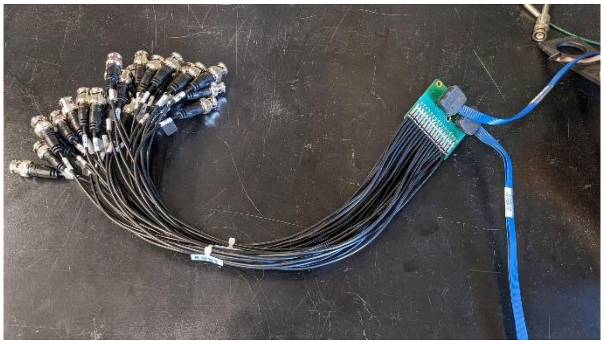


*Figure 6 Connector board, adapting the high-density cables to BNC connections that can easily be readout on a scope*

Each TPC preamplifier is connected on one end to pins that are crimped onto 16 anode wires, and on the other end they are readout with a high-density cable. While the overall experiment is set up to go through a dedicated DAQ, for the scope of this school we will be working with two preamplifiers at a time (limited by the maximum number of channels on the oscilloscope). The connections are done through an adaptor board (Fig. 6), where the high-density cable is turned into BNC connection for an easier readout via scope (or Red Pitaya).

The cathode pads can also be analyzed. To perform said readout, a connector board (Fig. 7) needs to be plugged in on to the chosen pad sector. The output high-density cable can then be connected to the adapter board described above.

*Figure 7 Readout board for the cathode pads with preamplifier, so that the readout is similar to the wires.*

The high voltage to the field-shaping wires, then readout wires, and the cathode is supplied by two HV power supplies: a negative supply BERTAN M1755N for the field-shaping wires and cathode, and a positive supply BERTAN M1755P for the readout wires.
Further instructions on how to use those power supplies can be found in Section 3.

*Figure 8 Adapter card between SiPM preamplifier and oscilloscope.*

The SiPM are readout by a specialized card that performs the sum of the signals of the six photosensors optically coupled to the bar. In this setup we are interested in the analog signals, which can be visualized with an oscilloscope. The connection between the SiPM and the scope is done thanks to an adapter board (Fig. 8).

The SiPM are (reversed) biased using a bench power supply and they are generally operated with a biased voltage between 27 and 30 V (WARNING: never exceed 30V).

## 2.4) NIM Logic Modules

To help in experiment design, some NIM logic modules are provided for your use. The following modules are available, with more possibly available if needed on request:

- 2x 365AL 4-fold logic unit. This unit can be used for logical operations on NIM signals, such as coincidence. Manual: https://wwwusers.ts.infn.it/~rui/univ/Acquisizione_Dati/Manuals/LRS%20365AL.pdf
- 2x 821Z quad discriminator module. This unit compares the input signal to a fixed threshold and outputs a digital pulse when the threshold is exceeded. Manual: https://wwwusers.ts.infn.it/~rui/univ/Acquisizione_Dati/Manuals/LRS%20821.pdf
- 429A fan in fan out module. This module is used for combining and duplicating signals. Manual: https://wwwusers.ts.infn.it/~rui/univ/Acquisizione_Dati/Manuals/LRS%20429A.pdf

*Figure 9 Snapshot of the NIM electronics crate that be used to process the TPC and SiPM signals, next to the high voltage power supplies used for the cathode, anode wires, and field wires.*

# 3) Operation

Note, if in doubt always ask an instructor first. Especially with the HV supplies, do not apply high voltage on any component until you receive the permission of the demonstrator first. Please also remember that you are working in a functioning lab, so be respectful to the people doing research around you.

## 3.1) Gas Flow

As stated above, the experiment uses a mixture of Ar and $CO_2$ as the active medium (gas). Therefore, before powering up the detector, it is important to make sure that gas flows through the chamber and at the appropriate flow rate. This can be checked in the gas shack, ask your demonstrator. Make sure that the gas inlet and outlet are at roughly the same flow rate.

In the gas storage room, before starting any experimental work, we should also confirm the gas mixture. You will need help from the demonstrator to complete this step. The gas is pre-set to a mix of 70% argon and 30% $CO_2$, however, some groups might change that ratio to investigate the impact of the quenching gas on the strength of the ionization signal. Note that the readings from the flowmeters must be corrected to estimate the right gas mixing.

Finally, please check that the gas bottle is not at a low level (yellow or red light). This can be done by checking that the gas line for ALPHA-g has a green light in the main gas panel in the laboratory. If not shown, please ask your demonstrator to show you where the lab the panel can be found.

## 3.2) HV Ramp Up

To set up your experiment and start using the ALPHA-g Prototype, the HV needs to be distributed across the three main field components: field-shaping wires, readout wires, and cathode. The high-voltage power supplies are designed so that, when the current flowing from the wires or the cathode to the power supplies, exceeds a predetermined threshold. When the current exceeds the threshold, the power supply “trips" and is turned off for the safety of the equipment. The threshold is defined by the measurement range knob on the power supply and is set to 80% of this value. Field-shaping wires, readout wires, and cathode have different leakage currents, therefore they have different trip levels. The applied voltage and the current can be more easily read off using the provided voltmeters. They can be connected to probe points on the power supply with LEMO cables. Note that in both power supplies, one does not read directly the high voltage, but rather a scaled voltage, such that the reading on the voltmeter is 1 V = 1 kV. Equally, the currents (very small) are converted into a voltage, and the current reading is scaled to 10 V = 1 mA. The steps are the following:

1) Following Section 3.1, make sure the gas is flowing through the chamber at the desired settings. If you have any questions, please ask the demonstrator.
2) Inspect the power supplies and make sure all HV cables are properly connected. Remember to check the back of the power supplies as well. Feeding HV into the chamber

is a delicate step and it carries some risks to the experiment, so please be extra mindful when operating high voltage power supply.

3) Start by manually bringing the Cathode HV up slowly. The rise in voltage should be very slow, about 0.1kV per second, and, in any case, at such a speed that the needle on the ammeter does not reach 0.8 of the full-scale on the analog display To monitor the voltage, you will need to connect the output lines from the HV supply into two voltmeters (one for the voltage and one for the current readout). The final voltage for the cathode should be set at 4 kV, with a current of ~50 uA.
4) Manually apply high voltage on the shaping wires. Similarly to step 3, ramp-up must be done very slowly, at a rate of about 0.1 kV per second. Do not change the trip threshold. If during the ramping the power supply trips, ask the demonstrator how to proceed. The final voltage for the field-shaping wires should be 400V, with a current of ~150 uA.
5) Lastly, bring the high voltage on the readout wires up slowly, and do not change the trip threshold. Just like 3 and 4, the ramp-up speed should not exceed 0.1 kV per sec. These wires can be set to 3.2 kV to start, although groups can investigate the effect that increasing the fields has on the signal. It’s worth noting that some signals, i.e., some amplification, should be visible on the oscilloscope at 2.8kV, albeit at a reduced rate and height. Moreover, the maximum voltage on the readout wires should never exceed 3.6 kV. Operating at this bias voltage should not be the norm, but it’s ok to explore the pulse heights in this “high gain” region. The current readout should never exceed 1uA in steady state operation (at 3.2 kV) if it does ramp down and discuss with the demonstrator. During the ramp-up stage of the readout wires, the range scale of the ammeter can be set to 10 uA, meaning that the trip threshold is at 8uA. During operation, it’s recommended to lower the trip threshold to 800 nA, since the leakage current is negligible (few nA) at nominal bias.

Now the ALPHA-g Proto detector should be in a steady state and ready for measuring ionization tracks. Note that in both power supplies the V reading is 1 V = 1 kV and the current reading is set for 10 V = 1mA.

The cathode readout pads do not require any high-voltage bias. They can be directly read out by simply connecting the high-density cable to the adapter. Moreover, it is important to check that the green and red LEDs on the boards attached to the chamber are both on (readout wires and cathode strip-pads). This is the low voltage supply required for the electronics to work, if the off the signal is not properly amplified and it cannot be read out.

Lastly, a very important note about safety. Please keep in mind that this is a prototype detector, therefore please don’t touch any electrical or metallic component that is exposed. The best course of action would be to assume that the chamber should not be modified without checking with the demonstrator first. As stated above, general high-voltage safety procedures apply.

## 3.3) HV Trip Recovery

The LED on the tripped channel is off. When the power supply trips due to an excess current, only the channel involved is turned off, meaning that there is still high voltage on the other elements of the TPC (their LED is on).

1. Connect the voltmeter to the probe points on the tripped channel.
2. Ensure that the voltage reading is 0 or, for the sensing wires, is decreasing.
3. Turn the dial all the way down to ‘0’. For the sensing, now ensure that now the sensing voltage is <0.5kV.
4. Flip the switch “Trip Hold/Auto Reset” to the “Auto Reset” position and ensure that the LED is on now.
5. Flip it back to “Trip Hold”.
6. Repeat the steps of section 3.2

If, during steps 4 or 5 other channels trip (LED off), this procedure must be repeated for all those channels. It’s important that the “Trip Hold” settings are maintained throughout any experiment.

## 3.4) Detectors Signal Readout

The output of the TPC preamplifier (16 wires) is connected to a breakout card (Fig. 6), which accepts two high-density coax cables. The card has 32 BNC cable assemblies for easy connection to an oscilloscope. It’s matter of personal interest whether one wants to look at:

- Two anode wires of the same preamplifier
- Two anode wires of different preamplifiers
- One pad and one wire (note that the pad’s signals are smaller than the wires’ for a given avalanche)
- Two pads from the same of different preamplifier (ask the demonstrator how)

The outputs of the two ends of the scintillator bar are connected to the breakout card (Fig. 7) with high-density coax cables. Please, not here the channels’ configuration is fixed. The MCX to BNC cables can either be connected to an oscilloscope or used to trigger the TPC readout. To reduce accidental trigger, due to the SiPM dark events, it’s advisable to create a coincidence of the two bar ends.

# 4) Possible Measurements

Please note that, as mentioned above, you should consider this an open-ended experiment. Once you understand how the detector works, please feel free to use the experiment for whatever technical or physics measurement you think you might be able to accomplish. Don’t be limited to the suggestions below, think of those as more of a base guideline for your session.

<u>Understanding How TPCs Work</u>

- Compare signals from different readout wires.
- Study the readout wires output signal at different voltage settings.
- Tracks reconstruction with multiple readout wires

- Measure the drift time
- Measure the correlation between the readout wires and the cathode pads
- Investigate induction on nearby wires.

Possible Physics Measurements:

- Tagging cosmogenic activity.
- Study directionality (upward vs downward events).
- Muon tagging in coincidence with a scintillator detector.
    - Use the NIM crate (Fig. 9) with associate electronics to trigger the readout.