Fermilab

g-2 tracker characterization

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Summary

- The g-2 experiment
- The straw tracker;
- Entries VS High Voltage with different configurations;
- Entries VS threshold with fixed High Voltages;
- Estimation of S/N;
- Test beam data → Fit of signals and fit parameters plots;
- Test beam data → cross-talk;
- Simulation;
- Test beam data → detector efficiency;
- Conclusion.

What is g?

The g-factor dictates the relationship between momentum and spin, telling us something fundamental about the particle itself (and those interacting with it): $\vec{\mu} = g \frac{q}{2m} \vec{s}$

In a classical system g=1; elementary particles such as electrons, as predicted by Dirac, should have g=2.

A large discrepancy between the theoretical prediction and a measurement of the hydrogen hyperfine structure was found out by Schwinger $\longrightarrow$ the classical result differs from the observed value by a small fraction of a percent.

Radiative corrections are due to the fact that space is never empty

$$a = \frac{g-2}{2} \approx \frac{\alpha}{2\pi} \approx 0.0011614$$

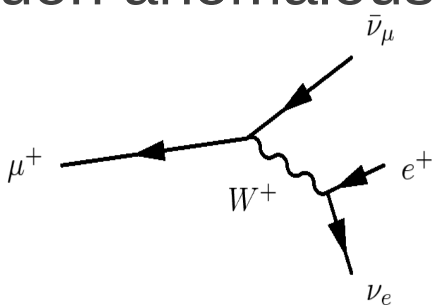
What about muons?

Muons are produced from the interactions between an energetic proton beam and a target. The proton collisions produce pions, which decay into muons. The muon beam produced can be 100% spin polarised.

After an average lifetime of 2.2 μs, a lifetime long enough to guarantee an easy way to make sample production, each muon decays and emits a positron. The decay positrons are preferentially emitted in the muon spin direction.

The prediction for the value of the muon anomalous magnetic moment includes three parts:

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{had} + a_\mu^{EW} + \ldots$$



How to measure g? The g-2 experiment

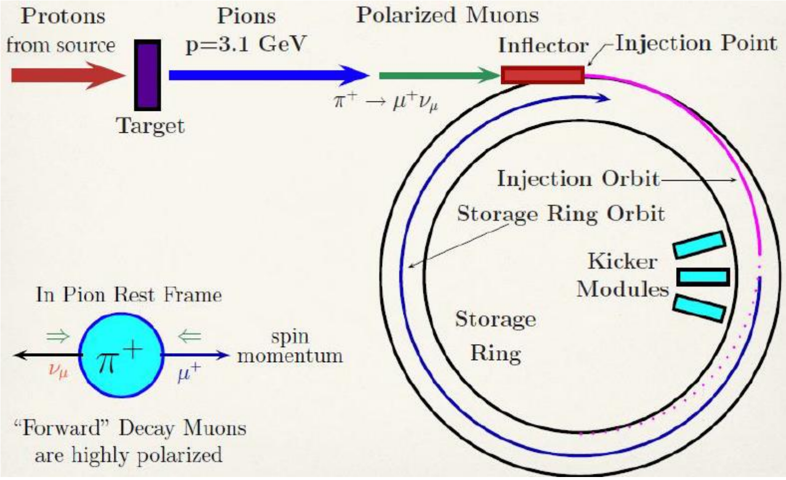
Put polarized muons in a magnetic field and measure precession frequency

Get muon spin direction from decayed electrons.

- a_μ ~ difference between precession frequency and cyclotron frequency

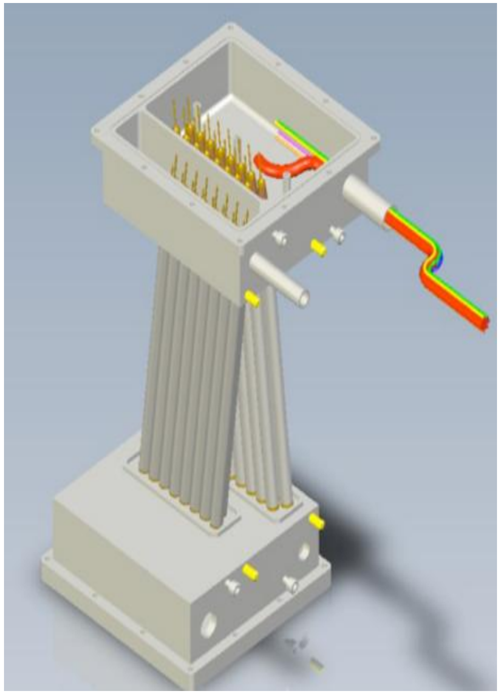
$$\omega_a = \omega_s - \omega_c \longrightarrow \omega_a = a_\mu \frac{eB}{mc}$$

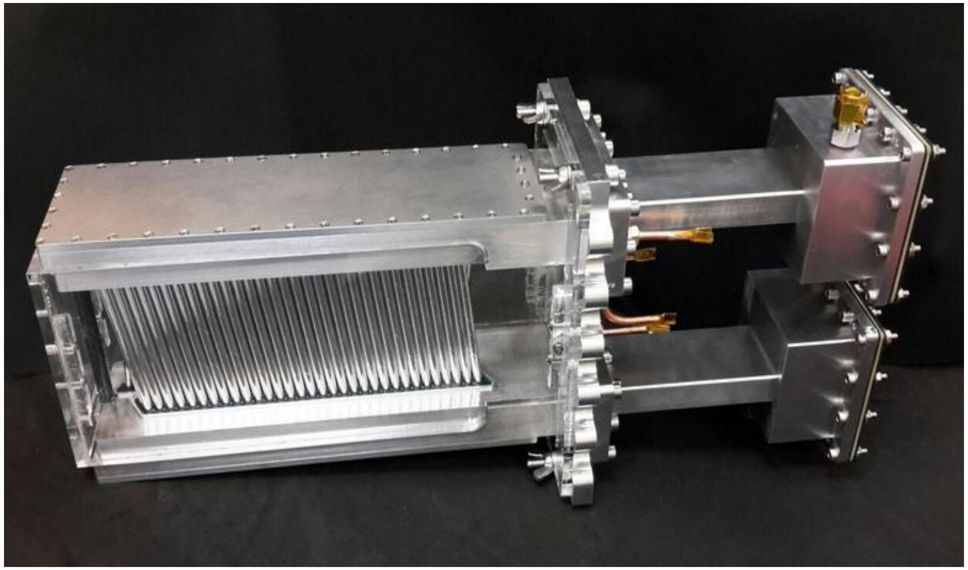
Uncertainty	*Goal [ppb]*
Experiment	*140 (540 BNL)*
Theory	*140*



The straw tracker

- Track the trajectory of the decayed positrons;
- Get information about the muon beam from this trajectory.





The preliminary design is an array of straw tubes with alternating planes oriented 7.5° from the vertical direction.

The straw tracker

We refer to the plane with negative slope as the U plane and the plane with the positive slope as the V plane with respect to the radial-vertical plane.

Straw tubes are constructed with a single anode wire centered in an aluminized plastic tube forming the grounded cathode.

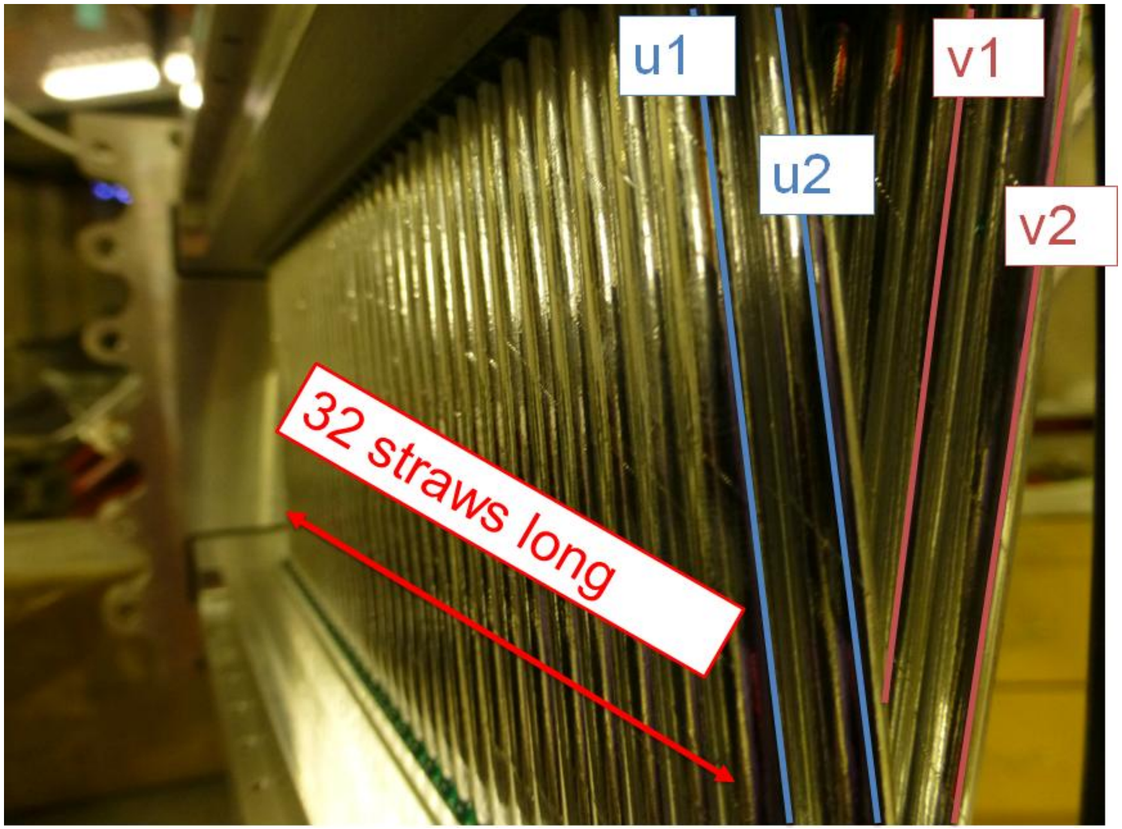
The required number of planes, along with the need to minimize multiple scattering $\longrightarrow$ gas based detector.

The requirement to place the detector in vacuum $\longrightarrow$ straws:

they can hold the differential pressure with minimal wall thickness.

The straw tracker

In order to minimize multiple scattering, g-2 muon storage volume is evacuated



Straw parameters	
Wall Material	Aluminized Mylar
Wall thickness	15μm
Wire Material	Gold plated Tungsten
Wire diameter	25 μm
Straw length	10 cm
Stereo angle	±7,5° from vertical
Operating Voltage	1800 V

Straws are made to work at 1800 V

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The choice of gas mixture

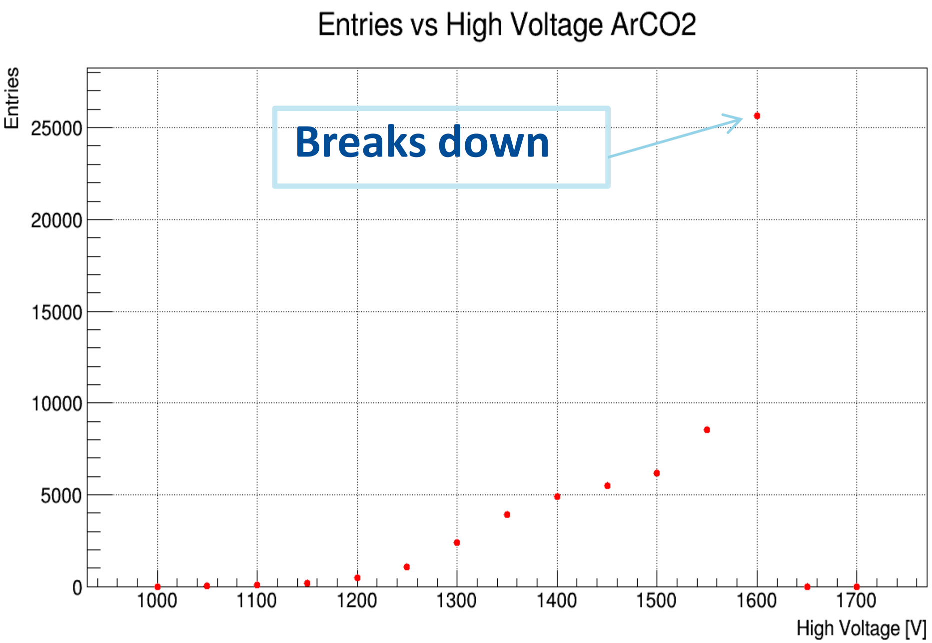
The choice of the drift gas that has to fill the detector, between the wire and the walls of the straw, is guided by gain, efficiency, convenience and economic reasons.

The typical mixture is composed by a noble gas, that is the main component and a quencher, which will of course slightly increase the threshold voltage.

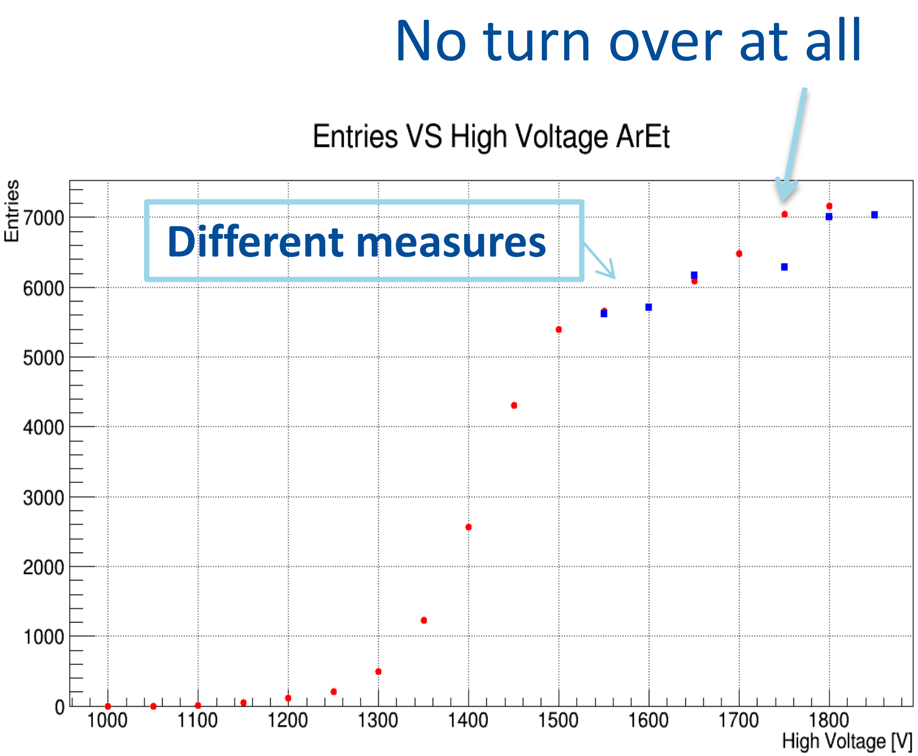
The first one is chosen because avalanche multiplication occurs in noble gases at much lower fields than in complex molecules; the choice naturally falls on Argon.

The second one target is to absorb X rays coming from Argon ions that hit the walls of the straw and excites the atom of the wall.

Gas mixtures: ArCO2 and ArEt plateau curve with ^{90}Sr source



ArEt:
- works better at high gain;
- flammable.

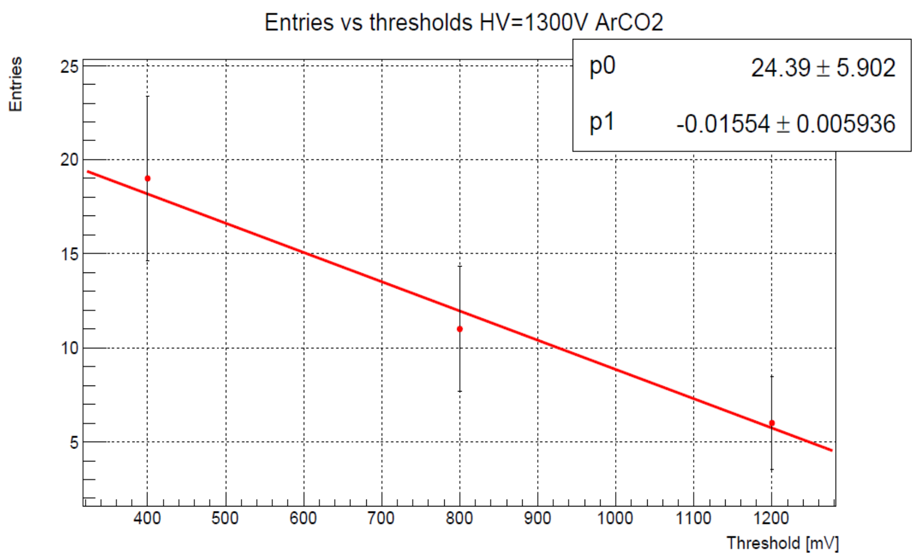


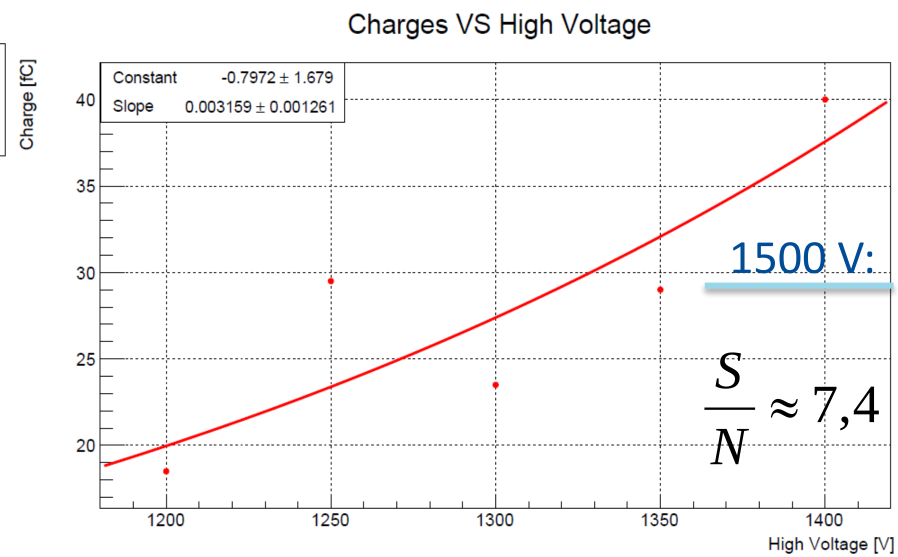
ArCO2:
- not flammable;
- cheaper;
- doesn't work at high gain.

Gas mixture: ArCO2 ; Source: ^{55}Fe $\longrightarrow$ estimation of S/N

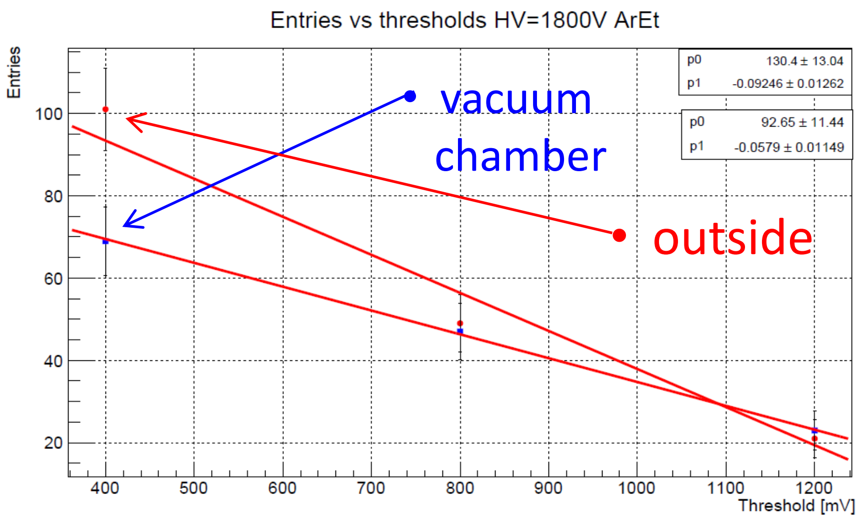
The characterization of the performance of the straw tube detector goes through the estimation of the gain:

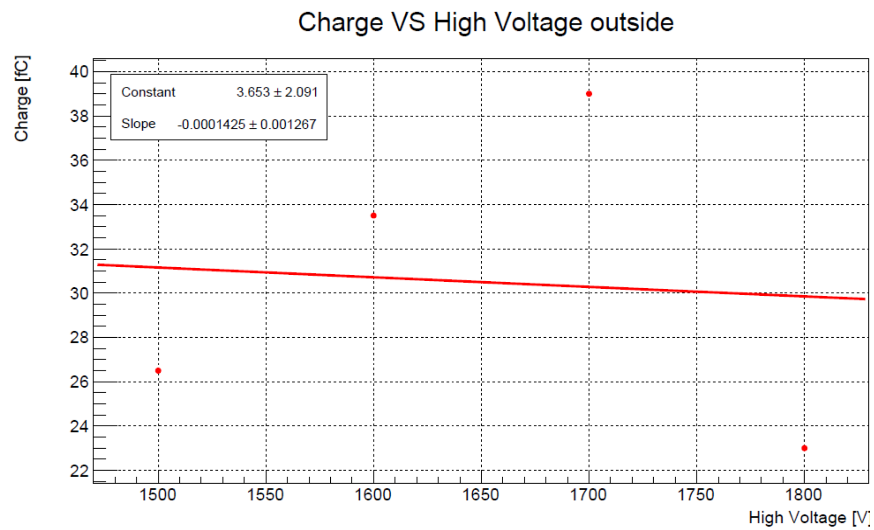
- First step: determination of the threshold that corresponds to half of the rate using the intercept of the fitting line;
- Second step: determination of expected charges using the calibration curve and the extrapolated thresholds (at 50%).

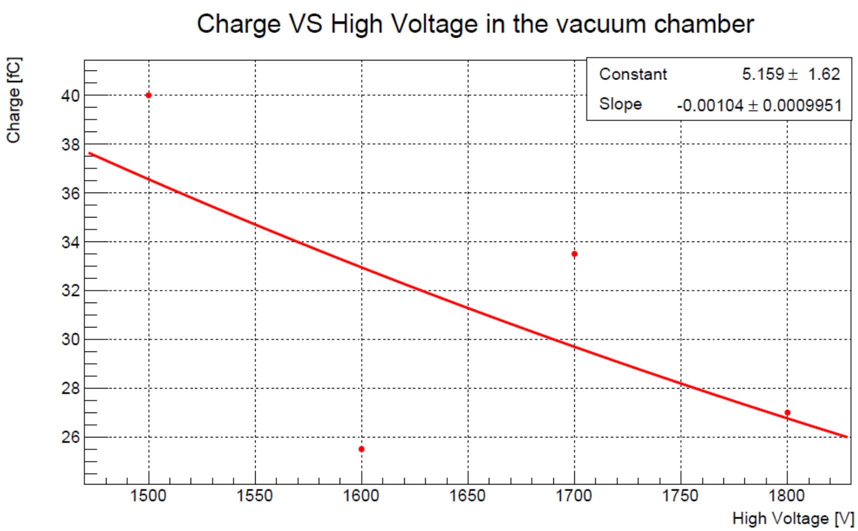




Gas mixture: ArEt ; Source: ^{55}Fe ⟶ estimation of S/N







1800 V:

$$\frac{S}{N} \approx 3{,}3$$ outside

$$\frac{S}{N} \approx 3{,}9$$ vacuum chamber

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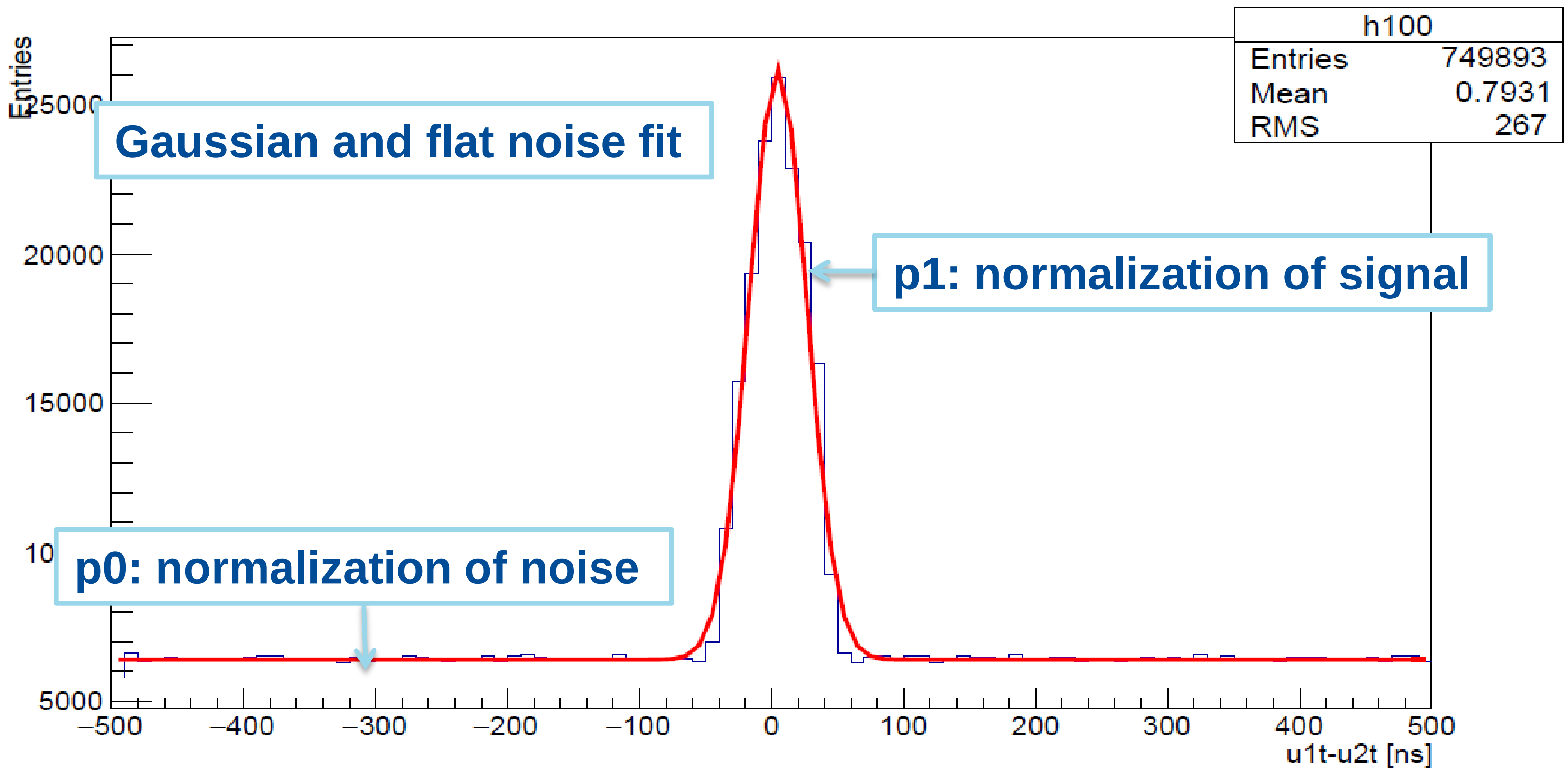
Gas mixture: ArEt ; 120 GeV proton beam, estimation of S/N

The characterization of the performance of the detector goes on with test beam data taken from the 120 GeV proton beam.

The goal of this section is the estimation of the ratio S/N looking at time differences between hits (for the moment we're considering just u1t and u2t).



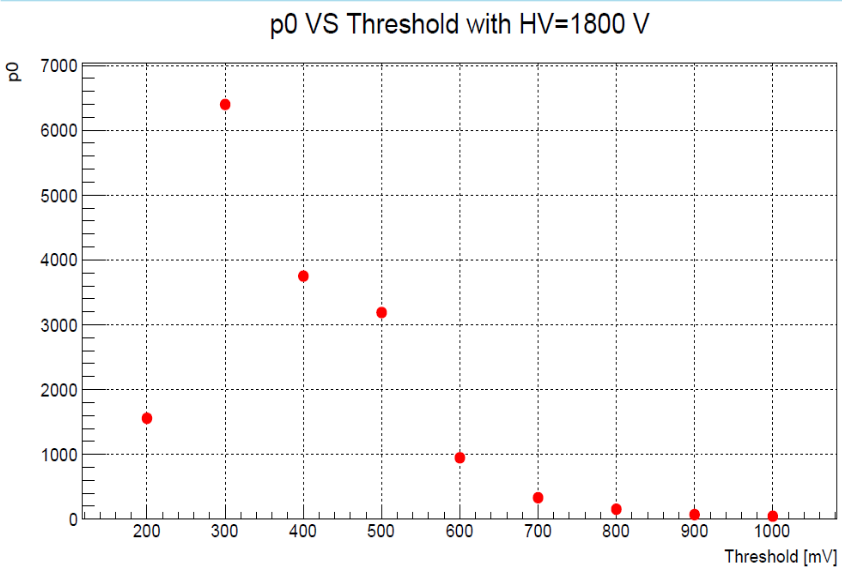
Gas mixture: ArEt ; 120 GeV proton beam, estimation of S/N

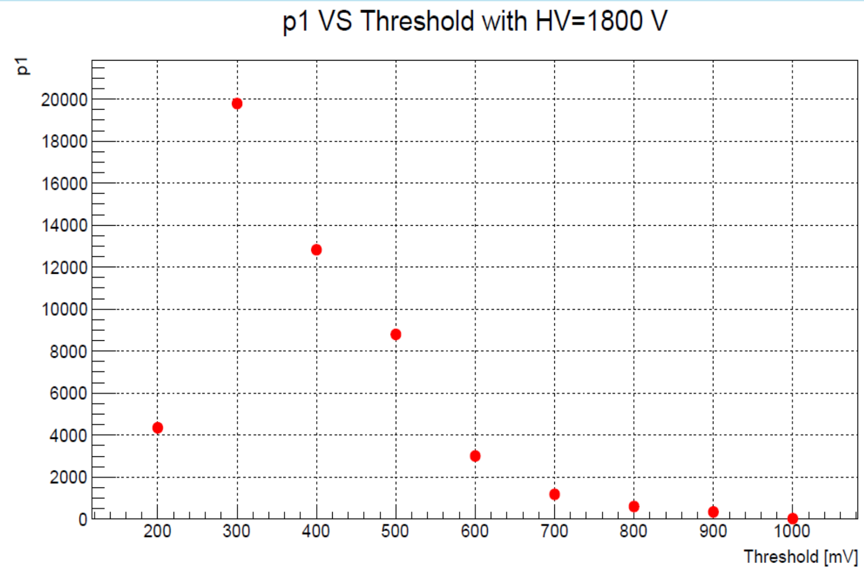
A raw estimation of S/B is given by ArEt HV=1700 V runs, combining a gaussian and a flat fit:

- run 401, thr=1000 mV → $\frac{S}{B} \approx 5$
- run 396, thr=700 mV → $\frac{S}{B} \approx 3,4$
- run 395, thr=600 mV → $\frac{S}{B} \approx 4,6$
- run 392, thr=500 mV → $\frac{S}{B} \approx 4,07$

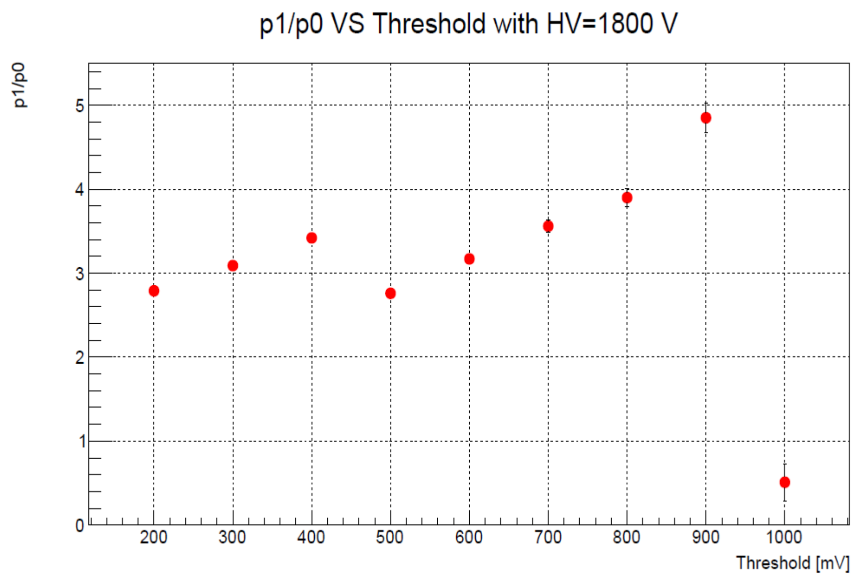
We should underline that these ratios are not really good in comparison with the ideal ratio, but this time we have to consider the fact that we are not using the maximum operating voltage.

Gas mixture: ArEt ; 120 GeV proton beam, estimation of S/N



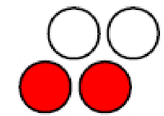
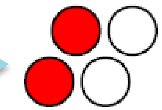


p0, p1 fit parameters

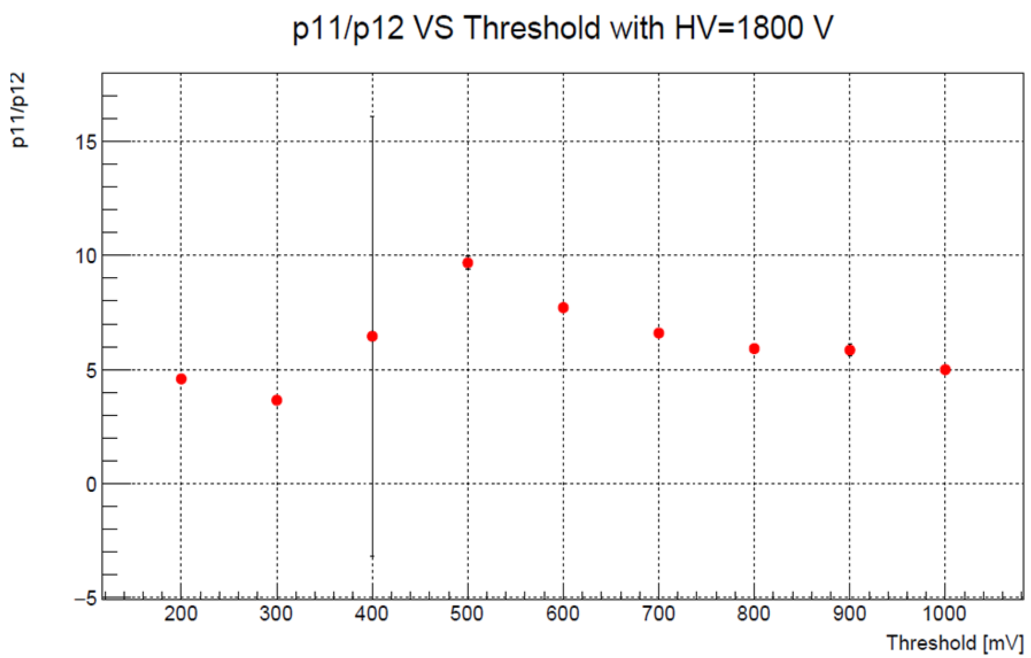


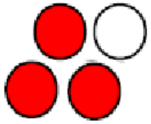
Gas mixture: ArEt ; 120 GeV proton beam, cross-talk

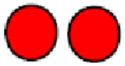
The further step was the research of cross-talk between electronics channels, that is the cross-talk between near capacitors. We should analyse two different cases:

- adjacent straw of the same layer 
- adjacent straw of different layers 

We estimated fit parameters in two different configurations:

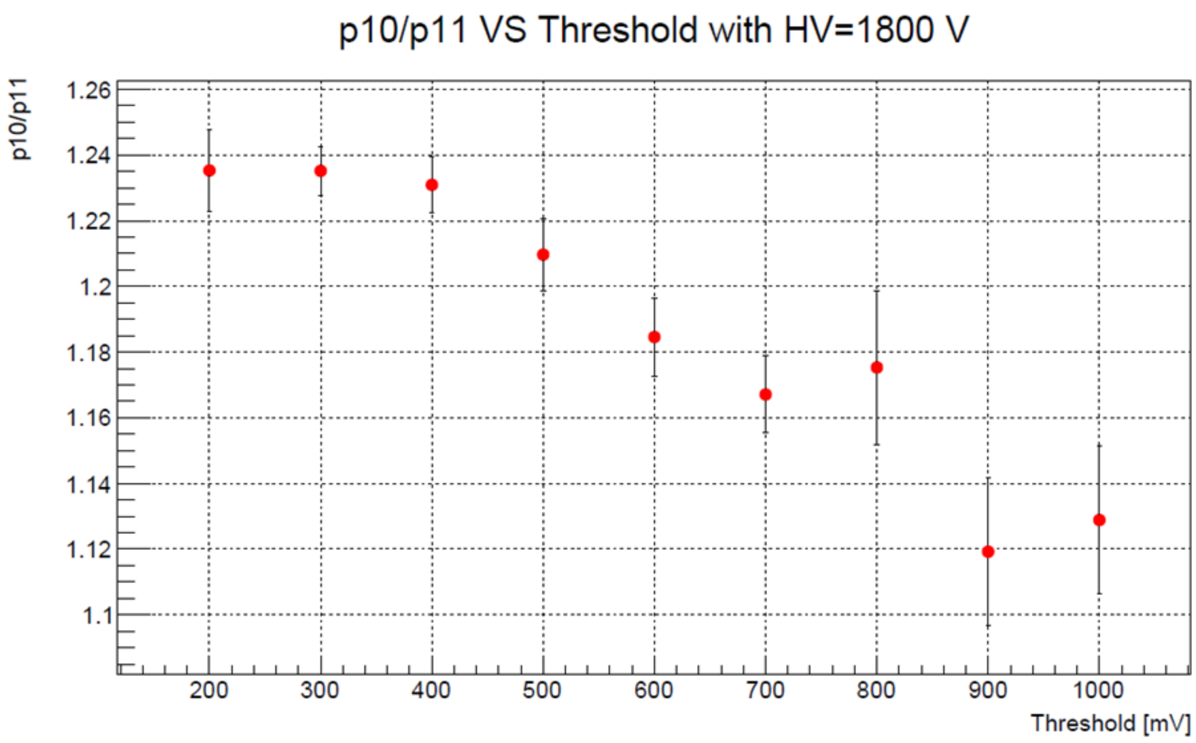


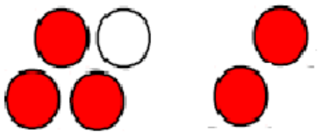




Gas mixture: ArEt ; 120 GeV proton beam, cross-talk

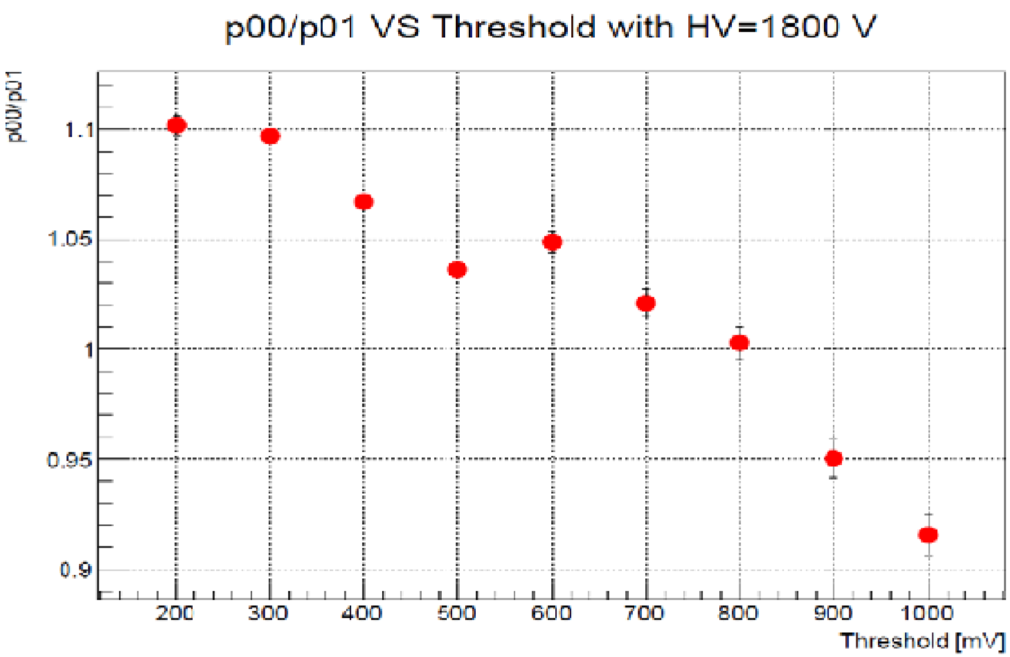
Since these ratios are almost constant, within their uncertainty, we can conclude that, despite of a high occupancy in the beam, there is no real indication or evidence of cross-talk.

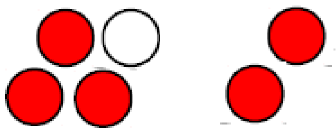




Gas mixture: ArEt ; 120 GeV proton beam, cross-talk

If we consider the normalizations of the noise, p00/p01, we have to note that the background goes down when we increase the threshold; so we can assert that we have noise in both straws but they are not correlated; this could be an indication of the fact that background is really background: our data represent real particles.



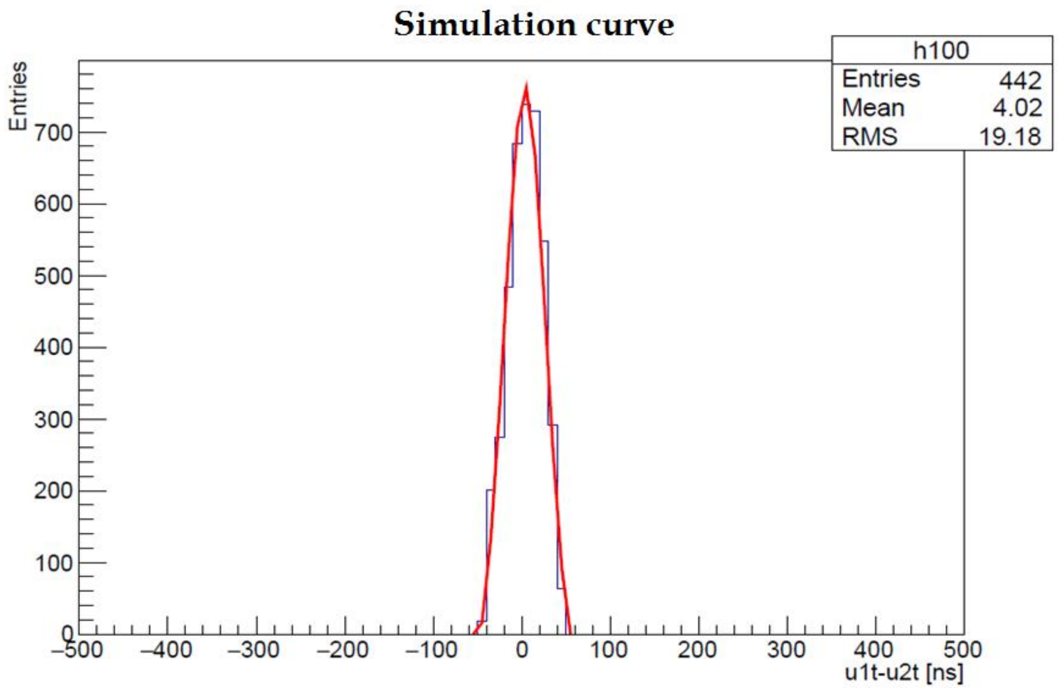


Gas mixture: ArEt ; 120 GeV proton beam, simulation

In order to understand if our results were good, we used the tracker test beam simulation that is characterized by:

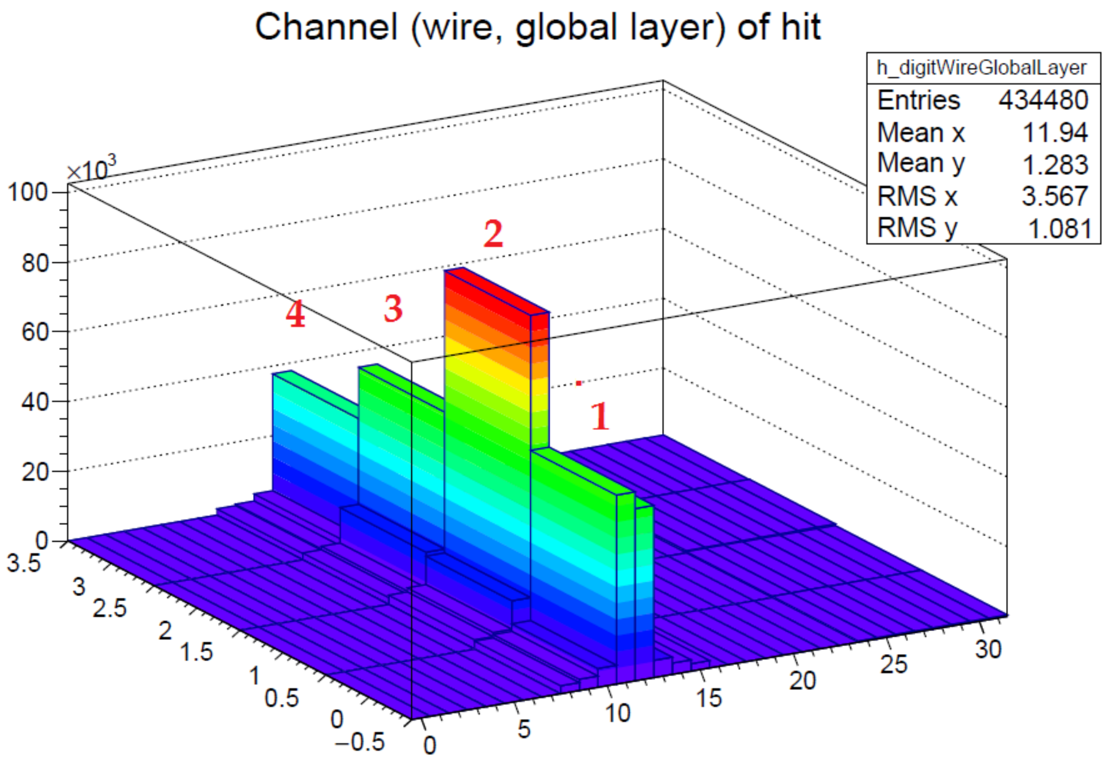
- aim to use same tools as for the real experiment;
- setting up analyses and reconstruction in art for use on both simulation and real data.

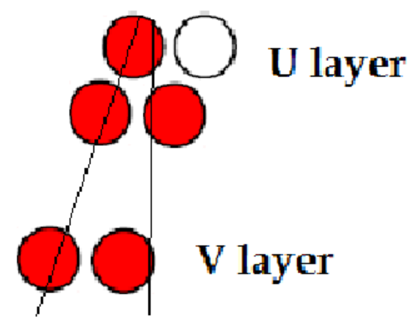
The straw track reconstruction consists of setting up a track finding algorithm for the tracking stations.



Gas mixture: ArEt ; 120 GeV proton beam, detector efficiency

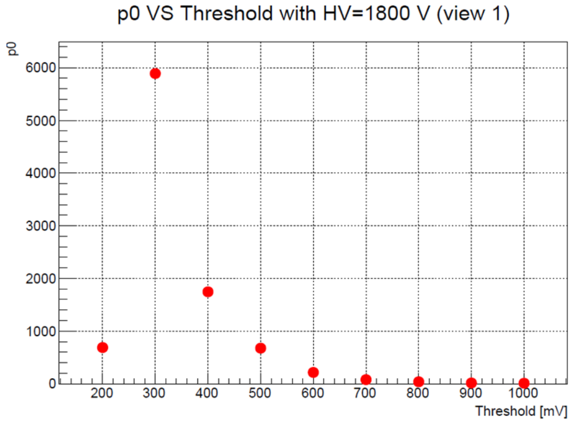
The first point we have to consider to evaluate detector efficiency is that we should have data in all our layers; data quality looks good and we have data in all devices.

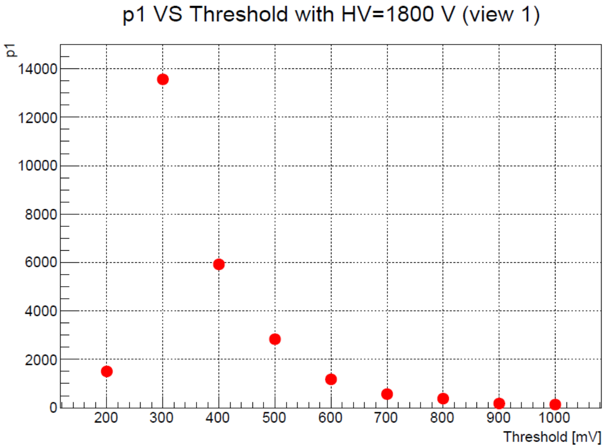


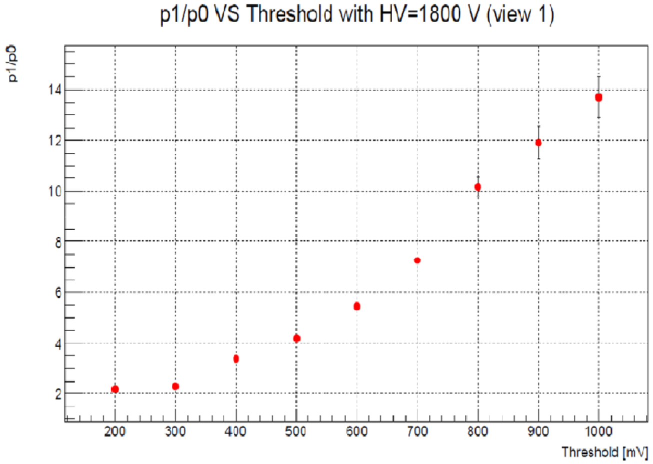


Gas mixture: ArEt ; 120 GeV proton beam, detector efficiency

The plot on the bottom, p1/p0 plot, looks really good because its meaning is that we are killing more noise than signal.





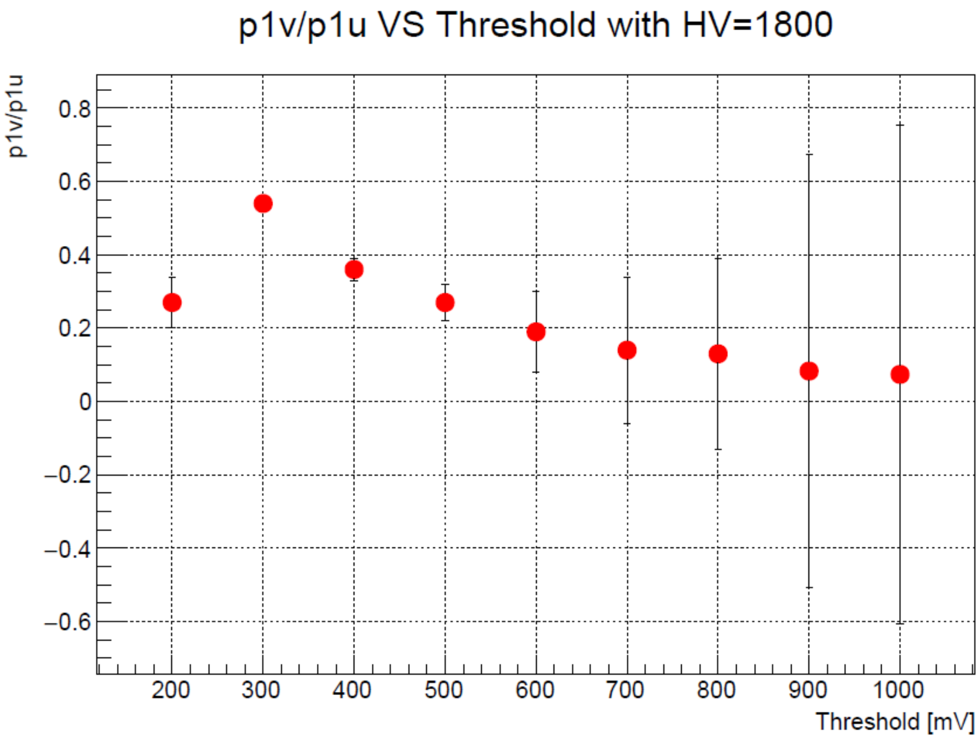


Gas mixture: ArEt ; 120 GeV proton beam, detector efficiency

We want to estimate the efficiency of the detector considering 4 straws; this goal is reached looking at time differences between U layers and V layers.

The value that is estimated through the simulation is $\frac{p1v}{p1u} \approx 1{,}47$

We should underline that the fact that the efficiency is greater than 1 is not a mistake, but it is due to the multiple occupancy of the layers.

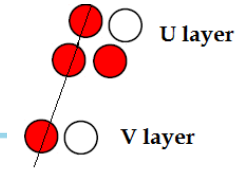


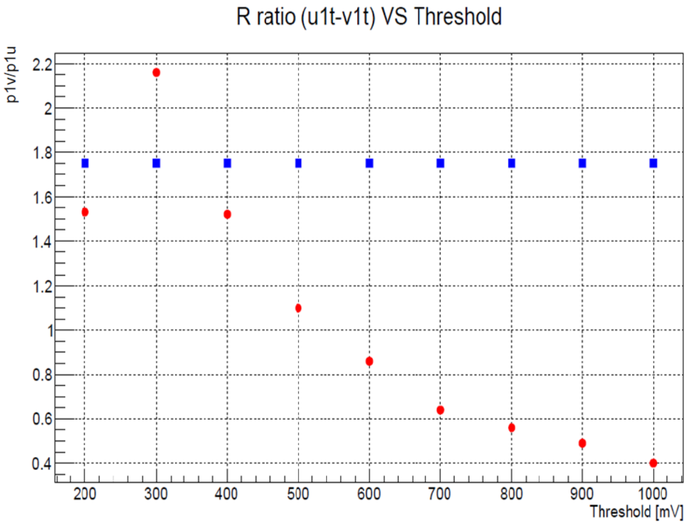
The simulation was set in order to include this phenomenon.

The simulation value is higher than every data parameter:

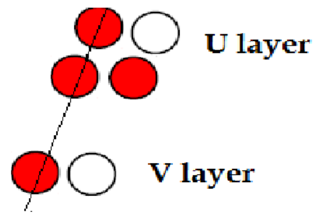
there is something wrong with the layers.

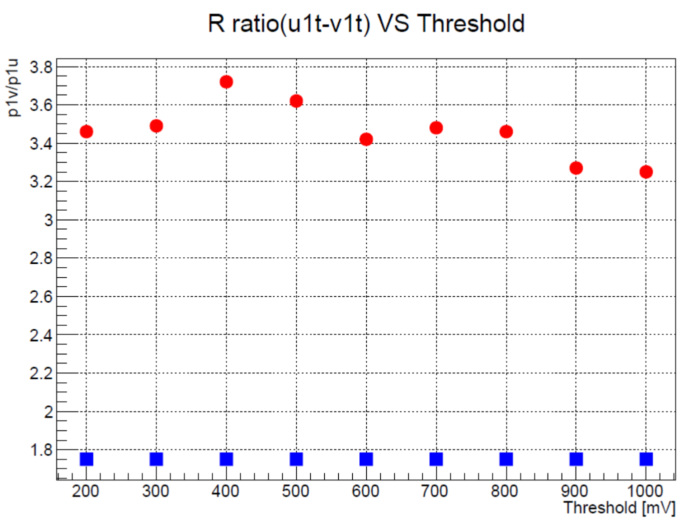
Gas mixture: ArEt ; 120 GeV proton beam, 3 layers



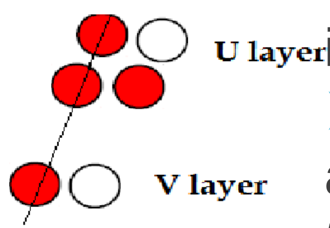


ArEt



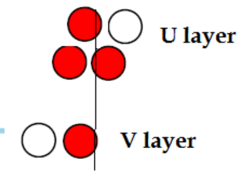


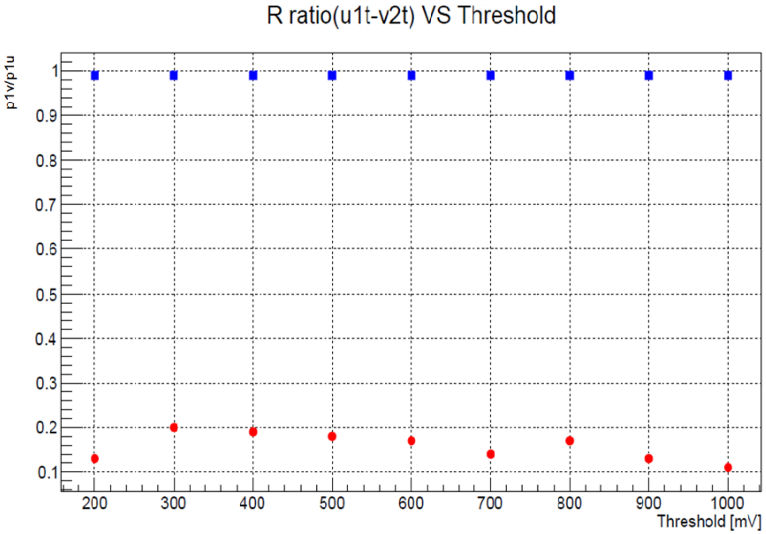
ArCO2

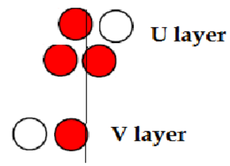


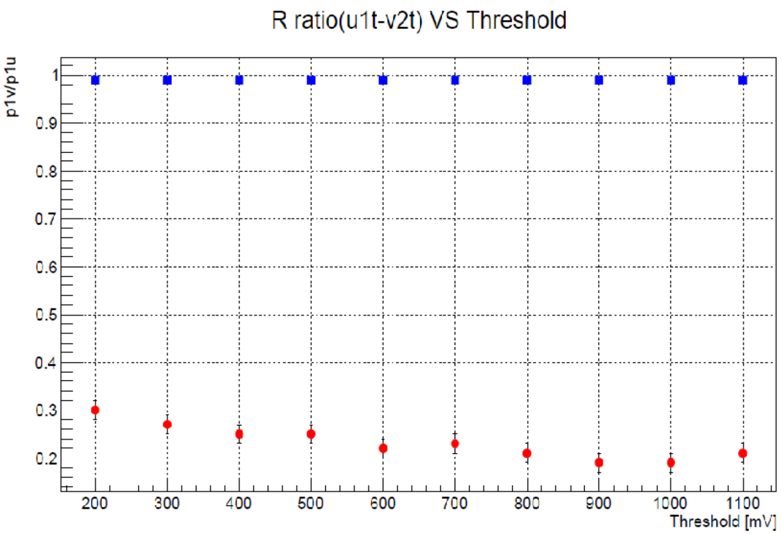
- ArCO2 efficiency is much higher than ArEt one; this feature represents an unexpected behavior and it should be investigated more deeply;
- the fact that the efficiency is greater than 1 is not a mistake, but it is due to the multiple occupancy of the layers;
- it is good that in “ArEt ratio” plot efficiency decreases with increasing thresholds;
- the fact that ArCO2 efficiency is almost constant is probably due to the almost constant number of entries we have with every threshold.

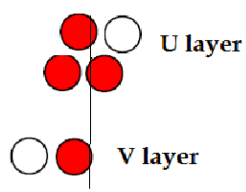
Gas mixture: ArEt ; 120 GeV proton beam, 3 layers











- ArCO2 efficiency is almost equal to ArEt one;
- we really don't understand why the efficiencies are so bad: there should be something wrong with V layers.

Conclusion

The most important purpose of my work was to characterize the performance of the tracker detector testing two different gas mixtures, ArCO2 and ArEt.

ArCO2:

- breaking down point in the plateau curve;
- the S/N ratio is higher than 7:1 → looks pretty good;
- efficiency is much higher than ArEt one (right configuration);
- efficiency is almost equal to ArEt one (wrong configuration).

ArEt:

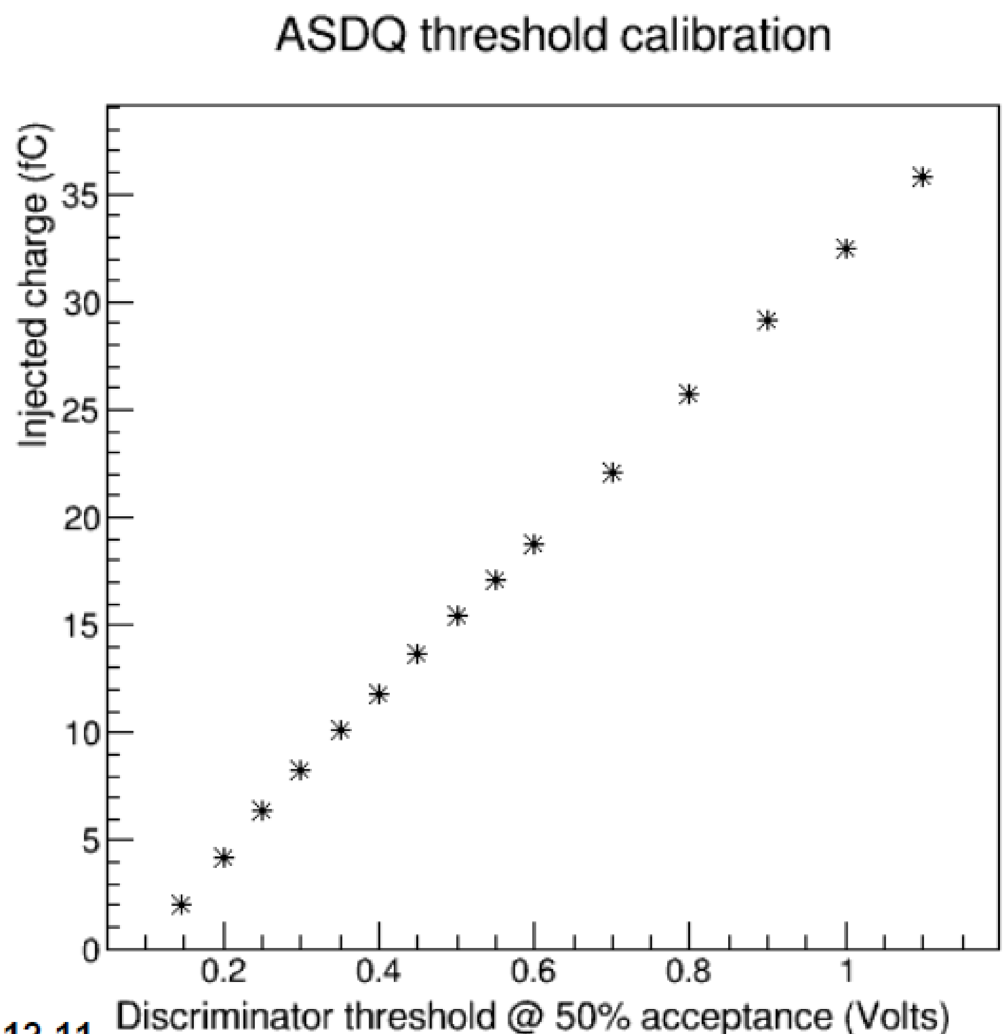
- no turn over at all in the plateau curve;
- although it is good that the ratios S/N outside and in the vacuum chamber are comparable, these ratios are about 3:1 → supposed to be better;
- good that in "ArEt ratio" plot the efficiency decreases with increasing thresholds (right configuration);

There is no real indication or evidence of cross-talk.

Any question?


THANK YOU
for your
ATTENTION!

Backup



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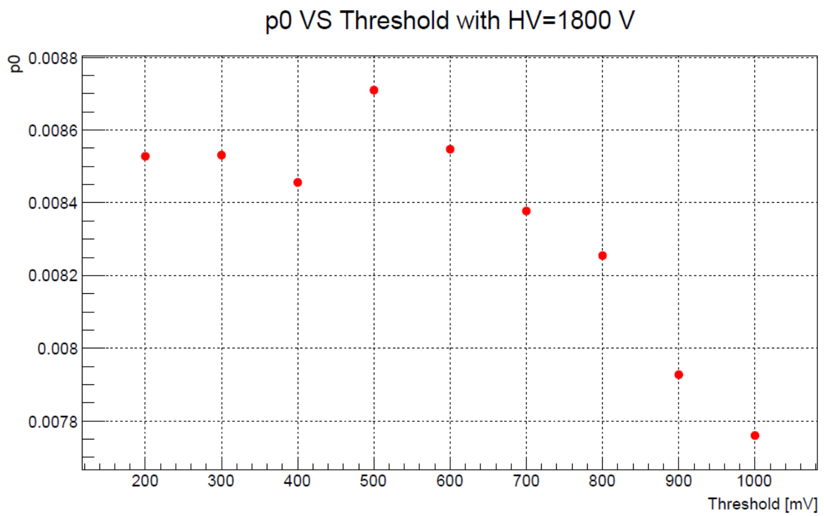
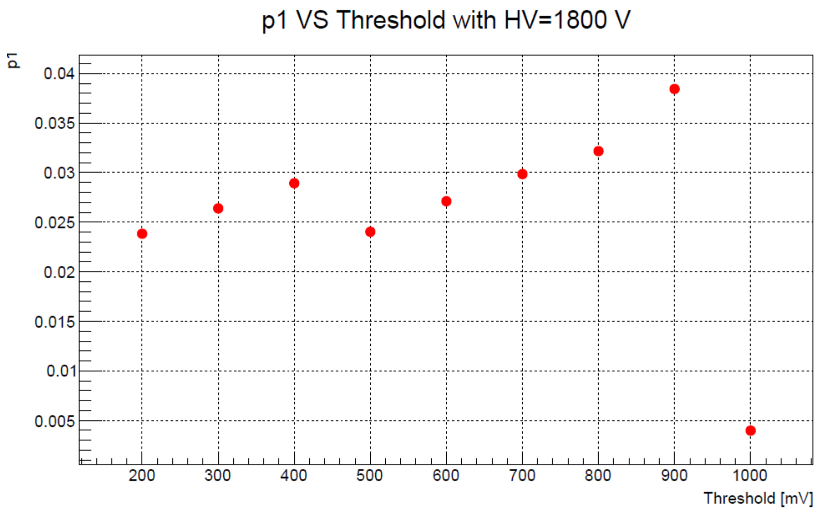
Gas mixture: ArEt ; 120 GeV proton beam, estimation of S/N





Data normalized by the number of entries

p0, p1 fit parameters