Muon Cooling Studies

MPI f. Physik Project Review 2008

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Muon Group

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Group Activities

- Muon Collider Front-End Simulation
- Frictional Cooling Simulation
- Frictional Cooling Demonstration
  - Simulation
  - Experiment

With help from Hr Tran, Hr Ackermann, and Hr Winklmueller.

Why Build a Muon Collider?

Advantages over the electron

Synchrotron radiation energy loss goes as $m^{-4} \approx 2x10^{9}$ times smaller for muon

Meaning

Higher energies and smaller machines

Advantages over the proton

Muon is a point-like particle

Meaning

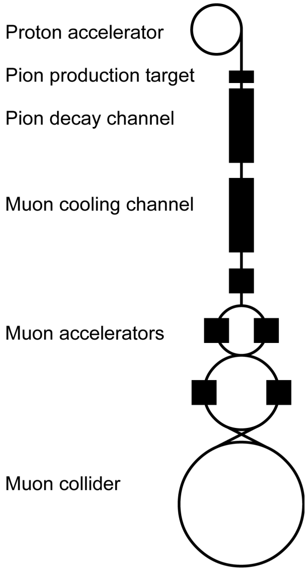
More precise measurements

Disadvantages

Muon decay time (2.2 microseconds)

Meaning

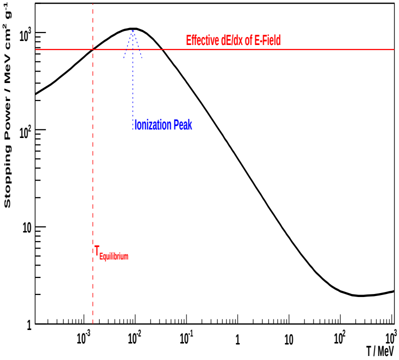
Fast schemes for cooling, bunching, accelerating needed; emittance reduction by a factor 10^{6}



Frictional Cooling Concept

A particle is brought to an equilibrium energy by application of a constant electric field in a retarding medium where energy loss increases with increasing kinetic energy.

Stopping power for muon in helium



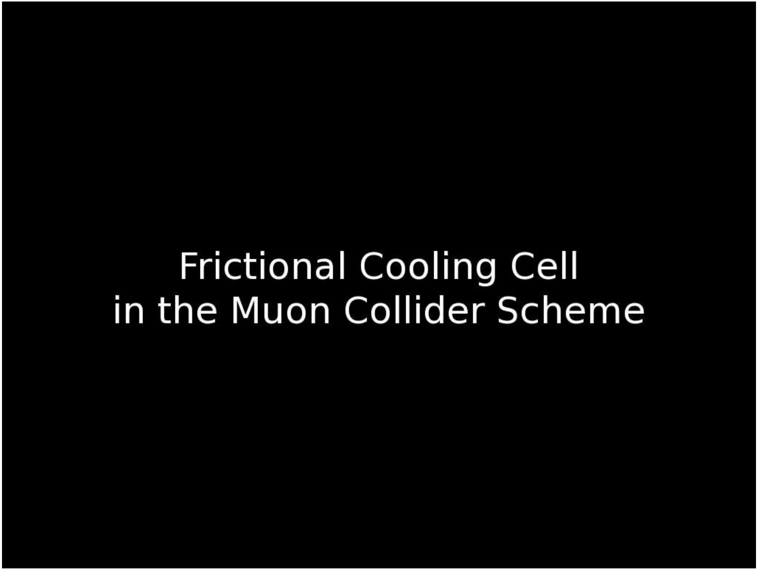
Issues:

High $\rho\, \mathrm{d}E/\mathrm{d}s$ around around equilibrium energy necessitates medium be gas rather than liquid

μ^+capture of $e^-$to form muonium atom necessitates medium be He, where cross section for inverse is larger

μ^-capture by He nucleus and subsequent decay needs to be studied

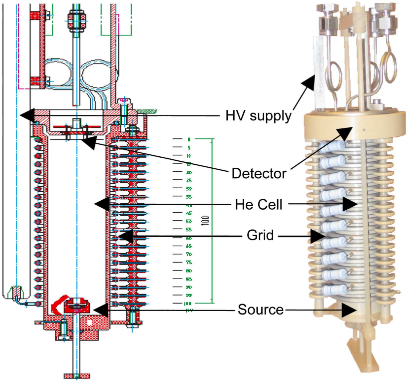
Frictional Cooling Cell



FCD Cell

The proton source and detector are mounted inside the gas cell, eliminating the need for windows in the gas cell.

Grid and gas cell construction:

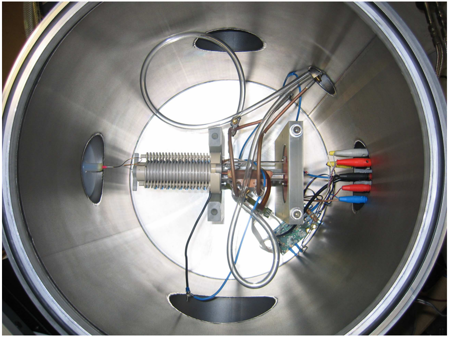


Detector mounted in gas cell flange:

Accelerating Grid Upgrade

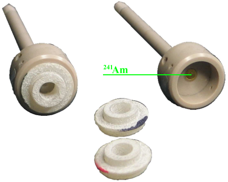
Working with Hr Tran from Elektronik, we upgraded the accelerating grid: the detector flange was modified to better shield the detector from breakdowns in the electric field; the HV connection was completely redone to reduce the chance of breakdowns.

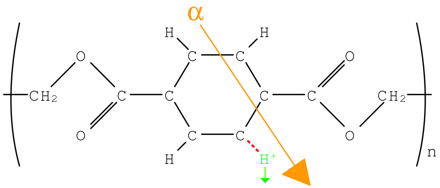
The grid has been operated up to 90 kV, and run stably at 65 kV with the gas cell evacuated, and 40 kV with the gas cell filled with Helium.



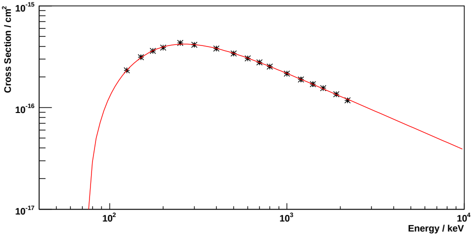
Proton Source Mechanism

Protons created by stripping e^- from H atoms in Mylar



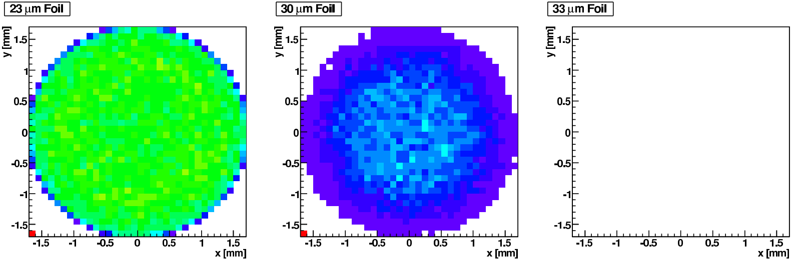


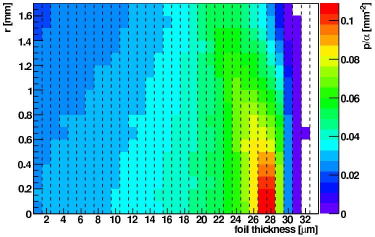
H-C bond ionization cross section

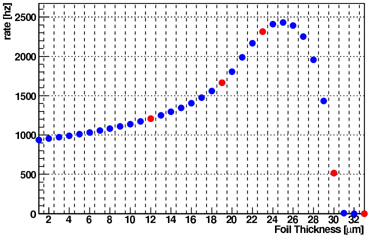


Proton Source Simulation

MC (Geant4) simulation of proton source used to predict spacial distribution of protons.







Proton Source Upgrade

Working with Hr Ackermann and Hr Winkelmuller from Konstruktion, the proton source was recently upgraded:

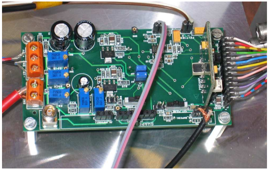
- the ^{241}Am source activity was increased 20X from 74 kBq to 1.5 MBq,
- the Mylar foil was moved closer to the Americium, increasing the acceptance of α's from 6% to 50%,
- the foil window diameter was increased from 3.5 mm to 8 mm, and the foil holder was thinned from 4 mm to 2 mm,
- the construction was made glueless.

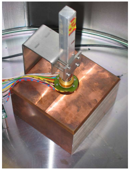
Recent data has shown proton production rates of several kHz.

Detection Upgrades

We upgraded our detector electronics and readout system:

- integrated electronics with a voltage divider replaced several power supplies,
- with the help of Hr Tran, all signal connections were simplified and shielded,
- the ADC was upgraded from 1.25 MHz to 10 MHz





New detector cabling was designed allowing for easier mounting to the detector in the gas cell flange and providing extra shielding to the signal lines.

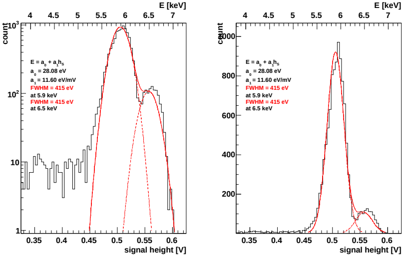
Resolution Improvement

The upgrades in detector readout lead to a large improvement in resolution.

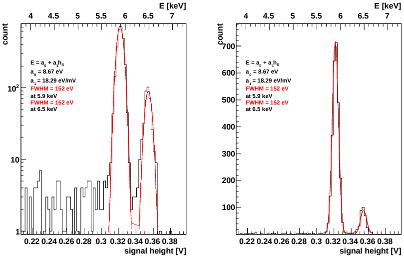
Iron-55 is used to calibrate the detector and measure the resolution. It has X-ray lines at 5.9 keV and 6.5 keV.

Under the best conditions, previously, the best resolution achieved was > 400 eV at 6 keV. Under normal conditions now, resolutions of < 180 eV at 6 keV are achieved.

Before upgrades



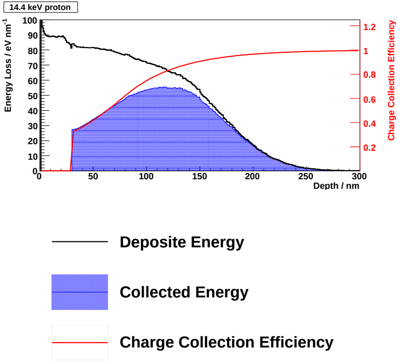
After upgrades

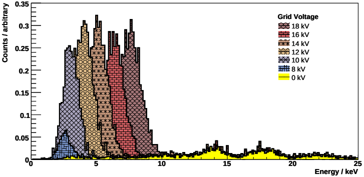


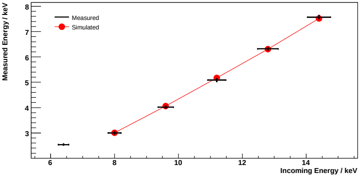
Detector Characteristics

We observe protons with energies between 5 keV and 30 keV. At these energies they deposite all their energy in the first several hundred nanometers of the detector. The detector's dead layers greatly effect how much energy is measured.

The expected proton energies are used to discover the dead-layer characteristics of the SDD.



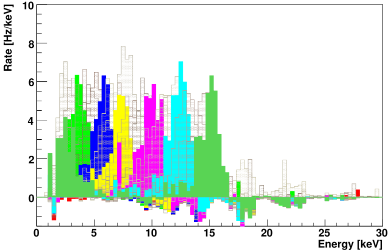


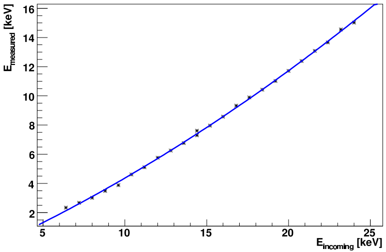


Most Recent Spectra

Proton spectra have recently been taken for energies between 5.6 keV and 24 keV in 800 eV steps. This allows us to characterize the dead layers of the detector very accurately.

The spectra were not taken at the best resolutions possible: since at colder temperatures a new deadlayer freezes onto the surface of the detector, these runs were taken with the detector at temperatures > 5 C.





Simulations

The experiment construction has been successfully commissioned:

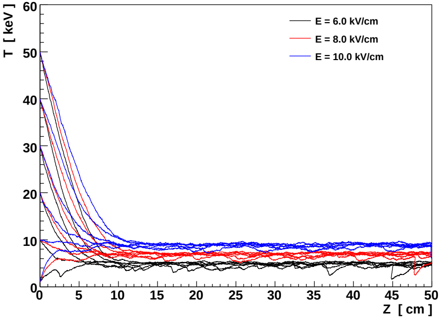
- the accelerating grid can be run reliably, without breakdown up to 40 kV with gas in the cell,
- the gas cell can hold steady pressures of Helium gas from 0.05 mbar to 10 mbar,
- the proton source is constructed and operating,
- the detector dead layer structure is well characterized.

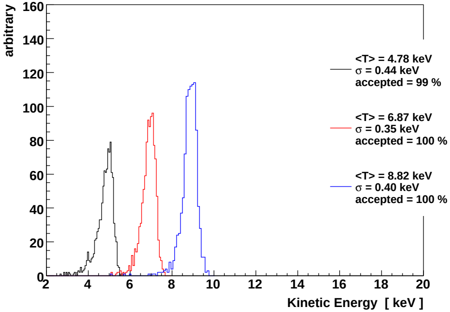
The next step is to measure proton energy spectra for various strengths of the electric field and densities of the gas. These spectra will be compared to those that have been caclculated form Monte Carlo simulations of the FCD experiment.

Ideal Cooling Cell Simulation

Simulation of an ideal cooling cell (uniform magnetic and electric fields) was undertaken to investigate various aspects of the frictional cooling principle, specifically:

- effects of nuclear scattering and multiple scattering
- the rate of μ^-capture and muonium formation
- the role of effective charge
- the effects of impurities in the Helium gas

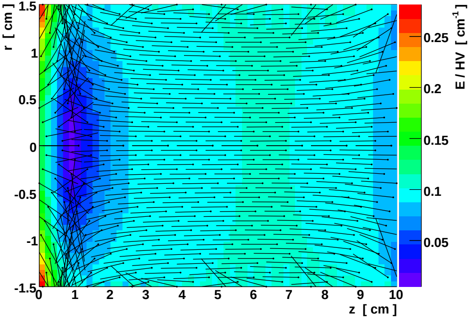


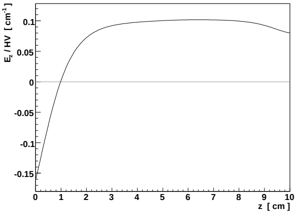


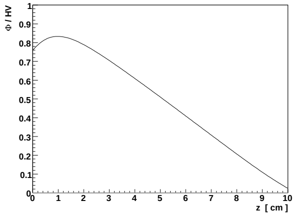
FCD Cell Simulation

A simulation of the gas cell used in the Fricional Cooling Demonstration experiment is used to predict the energies we will measure when running the experiment.

The electric field calculated from the actual accelerating grid construction is used in the simulations of the FCD cell.

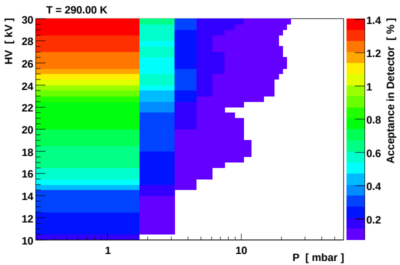


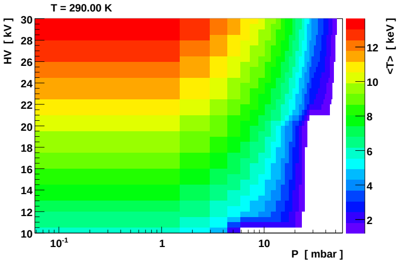




FCD Cell Simulation

These simulations predict acceptance rates and mean proton energy as a function of both the electric field (here represented as a high voltage placed on the first ring of the accelerating grid) and Helium gas pressure.



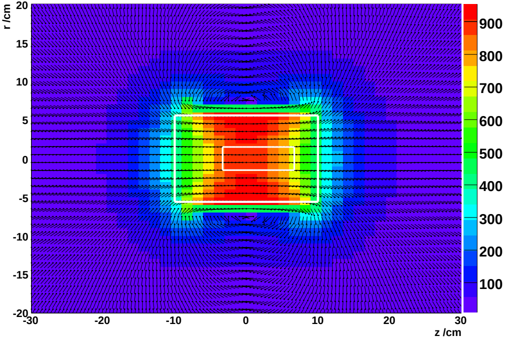


Superconducting Magnet

A superconducting magnet is used to provide a collimating magnetic field, along the central axis of the cooling cell. The field strength has been modeled for use in simulations.

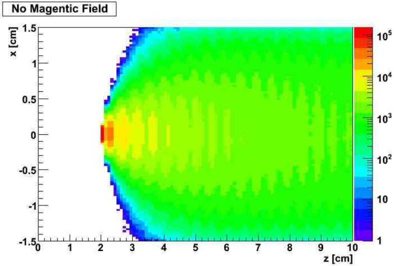
Magnet Core

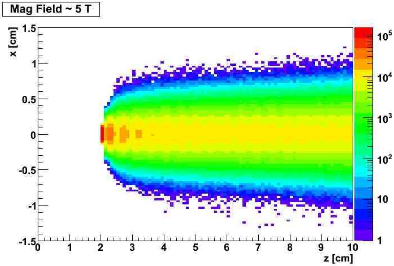
Magnetic Field

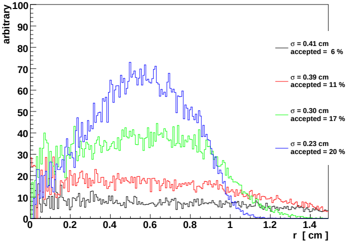


FCD Cell Simulation

These simulations have shown the strong effect of the collimating magnetic field.







Future

- Simulate new source construction
- Expand cooling cell simulation to full muon collider front-end
- Investigate using frictional cooling to increase efficiency of the muon beam at the Paul Scherrer Institut
- Investigate detector quirks
- Run with gas in the gas cell and match results to the simulations
- Adapt new accelerator grid construction for use in the magnet core
- Publish demonstration of frictional cooling