Brief Update on PSI experiment R-08-01

Muon Capture on the Deuteron - The MuSun Experiment

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1 First Engineering Run

In fall 2008 a first engineering run for MuSun was performed in the πE3 area. The main components for this experiment were as follows:

- Proto-TPC: an existing MuCap TPC operating at room temperature was rebuilt with several newly developed components. A gold coated pad plane was designed from high vacuum, cryo-compatible material, and a kapton based flexible readout board connected the pads with the high vacuum feedthroughs, while minimizing the capacitive cable load. The gas density was 1% of liquid hydrogen density, whereas the final Cryo-TPC will operate at 5%.
- A low noise 16-channel preamplifier unit for reading out signals from the anode plane of the TPC was developed and successfully tested during the run.
- The MuCap isotopic purifier, previously employed to produce ultra-pure protium, was refurbished to produce 2800 liters of isotopically ultra-pure deuterium. This gas was used for the run.
- A high-bandwidth analog readout for the TPC was developed, based on a new analog fan-out and the MuLan 500 MHz waveform digitizers (WFD). During the course of the run half of the 80 TPC channels were instrumented with the new system capable of recording the full untriggered TPC event rate.
- New liquid scintillation detectors, capable of neutron/gamma separation, were built and used to monitor the 2.5 MeV neutrons from the dd fusion reaction in deuterium, which provide essential information for the required understanding of the muon induced kinetics.
- A NaI gamma counter detected muonic X-rays after muon transfer from deuterium to nitrogen in an effort to develop an efficient impurity tag, which is critical considering the ultra-high purity requirements of the final experiment.

The detector system of the test runs served technical as well as scientific goals. On the technical side we wanted to prove the stable operation and excellent resolution of the new TPC operated as an ionization chamber. The chamber operated very reliably during the run. The excellent resolution is required to cleanly identify the muon stop, indentify and separate fusion recoils and identify impurity capture events. With the new chamber design and electronics the resolution figures of the proposal were achieved. Nevertheless, the signals are small as the chamber has no internal amplification, and the tracking algorithm, as well as the pad layout of the final chamber, has to be carefully optimized to minimize potential systematic effects. The test run provided a wealth of data to refine and test the properties of the new chamber design.

As regards physics goals, we wanted to measure the important and poorly known transfer rate from deuterium to nitrogen and, at the same time, optimize our monitoring sensitivity for very low level impurities. The required data was collected in a dedicated TPC filling of deuterium doped with 50 ppm of nitrogen.

2 Development of the Full Setup

The main design of the system (Cryo-TPC itself and cryo-infrastructure) is well advanced. The principal mechanical elements of the Cryo-TPC are:

- Aluminum gas vessel
- Beryllium window
- Flanges with indium sealing. They will be tested at room temperature and at 80K.

Pressure tests have been done up to 26 bar, while the working pressure is 5 bar. Pressure and temperature cycling is being done.

The internal elements of the Cryo-TPC (cathode plane, Macor insulators, grid plane) are in production - the anode pad plane and flat kapton cables are presently being designed, based on the experience with the Proto-TPC. The high voltage vacuum-feedthroughs are in production. They will be tested up to 70 kV at room temperature and as well at cryogenic conditions. The production of two Cryo-TPC units will be finished by May 2009. They will be tested with deuterium at 80K.

The main electronics components include

- The preamplifier card for the TPC, a board of 4 layers in mini-VME standard which will be placed in a crate attached at the vacuum flange. This board was successfully tuned during the test run in December 2008, thus no second iteration is needed. All electronics components have been acquired and we are ready to produce all boards for the 100 channels of the Cryo-TPC. The motherboard for the preamplifiers was also designed and is in production. We made calibration ports for fine turning and noise measurements. This development was the base of a diploma project by a St. Petersburg student.
- Hardware prototypes for the WFD readout chain were successfully tested during the run. We still want to perform the full data analysis, but thus far the design seems ready for production. Integrated laboratory tests of the complete system with the full DAQ load are foreseen for this summer.
- A new module for the slow control system of the Cryo-TPC has been designed. We tested a high-precision 24-bit ADC module for temperature readout, a 32-channel module for readout of the analogue signals, and a two-channel module for the temperature stabilization. For the platinum temperature sensors (type Pt100) in the working range 30K-350K we observed a resolution of about 0.005K.

In addition to the hardware developments, several analysis software improvements took place in the context of the test run to adjust to the new chamber design. Significant effort is still required to optimize the WFD based pulse finding algorithm, which is an important new distinctive feature of MuSun relative to the mainly discriminator based MuCap analysis.

3 Outlook

Originally the collaboration had planned a brief commissioning run of the full cryogenic setup at the end of 2009 and then to continue data taking after the 2010 shutdown. Our current planning is that we systematically build up the complex final setup at PSI during fall 2009, but do not request a beam test in 2009. Most of the required effort is related to chamber development, electronics and cryogenic systems, which can be well tested at PSI without beam. In addition we plan an extended presence at PSI to reassemble the electron wire-chambers into the electron tracker, which have been repaired of broken wires. Such an approach reduces the risk presented by a too tight schedule and also is more compatible with the available human and travel resources of the collaboration. Thus we expect to achieve a working system during 2009, to have sufficient time to commission it in the experimental area during the spring 2010 shutdown and to start production running after the 2010 shutdown.