Precision Measurement of Singlet μp Capture in Hydrogen

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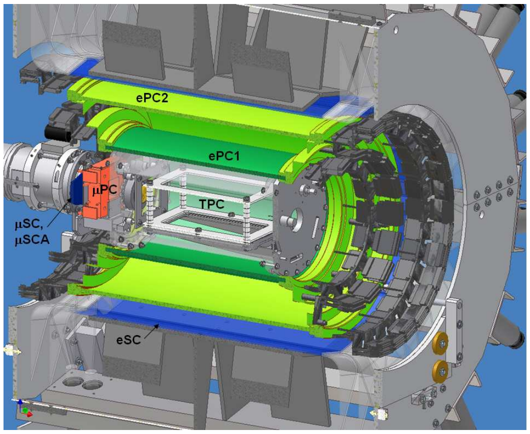

FIG. 1: Solid model of the μCap detector.

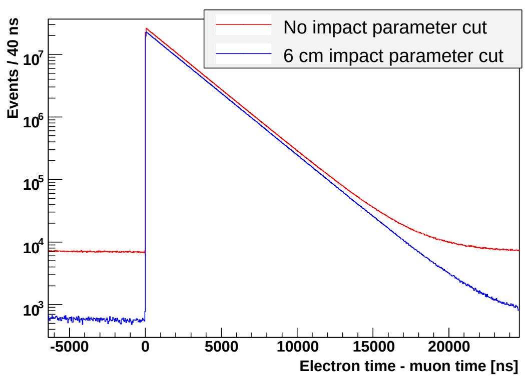

FIG. 2: Electron time distribution in the 2004 data, requiring only a single muon within $\pm$ 25 μs.

The μCap experiment at the Paul Scherrer Institute (PSI) measures the rate Λ_s of muon capture on the proton, $\mu^- + p \rightarrow n + \nu_\mu$, from the 1$s$ state of the muonic hydrogen atom. From this rate, the proton's weak induced pseudoscalar form factor g_p may be computed. A theoretical prediction for this quantity has been made using chiral perturbation theory, with an estimated uncertainty of $2-3\%$. However, the experimental situation remains quite confusing: most published measurements of muon capture were made in liquid hydrogen targets, where the high density leads to significant formation of molecular muonic hydrogen ($p\mu p$), from which the muon capture rate is quite different from its atomic value. Furthermore, the rates of muon capture from the ortho- and para-molecular states differ from each other by a factor of 2.5, and the transition rate λ_{op} from the ortho- to the para- state is poorly determined. Our experiment reduces molecular formation by using a 10 atm hydrogen gas target at room temperature, which has 1% of the density of liquid hydrogen. Our goal is a determination of g_p to 7% precision, which requires a measurement of the capture rate Λ_s to 1%. The capture process provides an additional disappearance channel for negative muons relative to positive muons, which can only decay. Consequently, we measure the effective lifetime of negative muons in our target and compute the capture rate $\Lambda_s = 1/\tau_{\mu^-} - 1/\tau_{\mu^+}$.

In 2005, significant progress was made in two complementary areas. First, the analysis of the data collected in fall 2004 was initiated. These data include approximately 2×10^9 μ^- decay events, permitting a measurement of g_p to approximately 20% precision. Second, a new data set was collected, with an additional 3×10^9 μ^- decays as well as 1×10^9 mu^+ events for comparison. The majority of the new 2006 data was collected with a pulsed "muon on demand" beam structure.

The 2004 data set was the first to include a second cylindrical wire chamber layer in the electron detector (labeled as "ePC2" in Figure 1), permitting decay electrons to be tracked back to the muon stopping point in the time projection chamber (TPC). If we require a small impact parameter between the electron track and the muon vertex, the level of the accidental background is reduced, but the sensitivity to muon diffusion is enhanced. Because there is a deep minimum in the $\mu d - p$ elastic scattering cross section near 7 eV, the amount of diffusion is strongly dependent on the residual deuterium concentration (estimated as $\sim$ 1.4 ppm) in the target gas. Important analysis issues include corrections for this time-dependent diffusion as well for higher-Z impurities. Also, the algorithm that defines a clean muon stop in the TPC must be carefully tuned to minimize the sensitivity to both muon scattering events and fragmentary electron tracks. The analysis should be complete by fall 2006; the electron time distribution is shown in Figure 2.

The μLan experiment at PSI, which aims to measure the positive muon lifetime to 1 ppm precision, has developed a fast electrostatic kicker that switches the muon beam either into the experimental apparatus or into an absorber by application of a $\pm$12.5 kV potential to plates mounted in the beam pipe. For μCap, we configured the kicker control logic to close off the beamline for 25 μs after each muon that was observed in the entrance counter. The reconstruction of the muon track depends on having a single, unambiguous muon entrance time for each TPC drift interval of 25 μs, so this time structure in the beam allows data collection at the maximum useful rate.

Beyond the kicker, there were several other refinements in the 2005 run. The typical TPC operating voltage was increased from 5.0 to 5.4 kV, where it should be possible to observe the final-state 5.3 MeV muons from muon-catalyzed $p-d$ fusion events, providing a way to monitor the deuterium concentration in the target gas *in situ*. Also, the reliability of the CHUPS recirculation system that cleans the hydrogen of higher-Z impurities was improved.