Recommissioning of ASACUSA-CUSP positron system

Oliver Diekmann

August 29, 2019

The ASACUSA experiment plans a high precision spectroscopy of the ground state hyperfine splitting of antihydrogen. With the beginning of LS2 the ASACUSA experiment was temporarily shut down. Within the summer student internship the positron system as well as the CUSP trap were consecutively recommissioned and parameters were optimized accordingly towards performing temperature measurements and cooling of the positron plasma in the CUSP trap.

1 Introduction

The ASACUSA collaboration located at the Antiproton Decelerator (AD) studies the fundamental symmetries between matter and antimatter. The ASACUSA-CUSP experiment aims at a precise measurement of the antihydrogen ground state hyperfine structure as a test of the fundamental CPT symmetry. Three penning-type traps make up the infrastructure for the creation of antihydrogen. Antiprotons are delivered by the AD which slows them down to an energy of 5.3 MeV. They were then further decelerated to 100 keV with a radiofrequency quadrupole decelerator, which is now removed as the newly installed ELENA ring will already provide antiprotons at that energy. Finally, the antiprotons are captured and cooled in the first trap, the MUSASHI trap which consists of a superconducting solenoid and a stack of multiple ring electrodes (MRE). Positrons are provided by a ^{22}Na radioactive source. They are moderated by a solid neon moderator and magnetically guided towards the second trap, a nitrogen based Surko type buffer gas trap. This trap consists of several decreasing potential steps with decreasing nitrogen pressure. Positrons lose energy by excitation of nitrogen molecules and are consequently trapped and accumulated in the potential minimum. After an accumulation time of typically 30 seconds, the positrons are extracted as a bunch from the accumulator and are magnetically guided to the third trap where antiprotons and positrons are mixed. This trap is a dedicated double-cusp trap (CUSP), which is composed of a set of MRE and two sets of anti-Helmholtz coils. Their field gradient exerts a force on the antihydrogen atoms such that it focuses low-field-seeking states while diverging high-field-seekers. By this a spin-polarized beam can be produced. A microwave cavity is used to excite the hyperfine transition, which turns low field seekers into high field seekers. The latter are defocused with a sextupole magnet and by counting the remaining antihydrogen atoms in dependence of the microwave frequency the transition frequency of the hyperfine splitting can be determined.

The collaboration already achieved to detect antihydrogen atoms 2.7 meters downstream from the CUSP trap. However, a measurement of the n-state distribution showed that the rate of groundstate antihydrogen is still not sufficient to perform a spectroscopy experiment. An important parameter for the production rate of antihydrogen in low quantum states by mixing positron and antiproton plasmas is the temperature of the positron plasma. Therefore, a more effective cooling of the positrons and a better knowledge of the temperature is an important step towards successfully performing the desired measurement.

2 Positron moderation

The experiment was not yet operating at the time of my arrival. This gave me the opportunity to document the current state of the positron vacuum system (fig. 1) and subsequently get hands-on experience in operating the corresponding equipment. Since the positrons from the radioactive decay have a broad energy spectrum up to 453 keV they cannot be trapped without further moderation. Due to its comparatively high efficiency a solid neon moderator is used for moderation. Since neon freezes at temperatures below 10 K, the source is mounted on a cryo cold head inside a vacuum chamber. Neon is fed into the vacuum chamber at fixed pressure and for fixed duration. The source is surrounded by coils creating a coaxial field, which guides the moderated positrons towards the accumulator trap. Due to the ongoing construction of the ELENA beamlines in the area the cooling water manifold was repositioned. In the course of reconnecting the cooling water lines a small manifold providing the water connections for the source coils as well as the compressor of the cryocooler was installed (fig. 2) and thereby simplified the previous water connections. Besides the fact that this construction saves one connection to the main manifold it allows monitoring and regulation of the cooling water rates for both circles and has a interlock system that can ensure the flow of cooling water before the high-powered coils of the source are switched on. The moderator growth can be monitored with a CsI scintillator positioned at a closed valve along the beamline seperating the source chamber from the accumulator trap where predominantly moderated positrons annihilate. Over time the efficiency of the moderator decreases which might be explained by an increasing number of crystal imperfections. This growth of the moderator was optimized with respect to the absolute count rate and the stability of the moderator over several hours. In particular, in case of the exclusive presence of neon gas it could be shown that the count rate can be increased by heating up the moderator while staying beneath the sublimation temperature and thereby annealing crystal defects (fig. 3). However, during positron accumulation nitrogen gets to the source and makes up the major part of the degradation, such reducing the lifetime of the moderator to around 8 hours.

3 Positron accumulation

The moderated positrons are guided magnetically towards the positron accumulator. A pair of deflection coils is used to optimize the transfer efficiency, see fig. 4. In order to increase the precision of these corrections proper support structure was designed. The final drawing as done by a colleague can be seen in fig. 5. Once in the buffer gas trap positrons lose energy in collisions with nitrogen molecules and are consequently trapped. The trapping efficiency was characterised by the use of a plastic scintillator or a charge amplifier connected to a multi-channel-plate (MCP) used as a faraday cup. The positron extraction is realized by a high voltage switch temporarily grounding the last electrode and therefore opening the capture potential well. In order to obtain a maximum number of positrons the trap potentials were optimized. The biggest influence is given by the last electrode, which needs a sufficiently high potential to prevent incoming positrons to leave the trap again. Also important is the entrance electrode, which has to be set such that incoming positrons can pass the potential, but positrons having lost energy by a single collision with N2 are already trapped (fig. 6). Furthermore, nitrogen gas pressure within the trap was altered with respect to the positron number. Fig. 7 shows, that the trapping efficiency is increasing with increasing pressure in the buffer gas trap. Nevertheless, a high pressure is not necessarily preferable as the moderator efficiency worsens faster in that case. To simplify the optimization procedure a LabView interface was created that changes several MRE potentials at once and saves the thereby collected data to easily evaluable files.

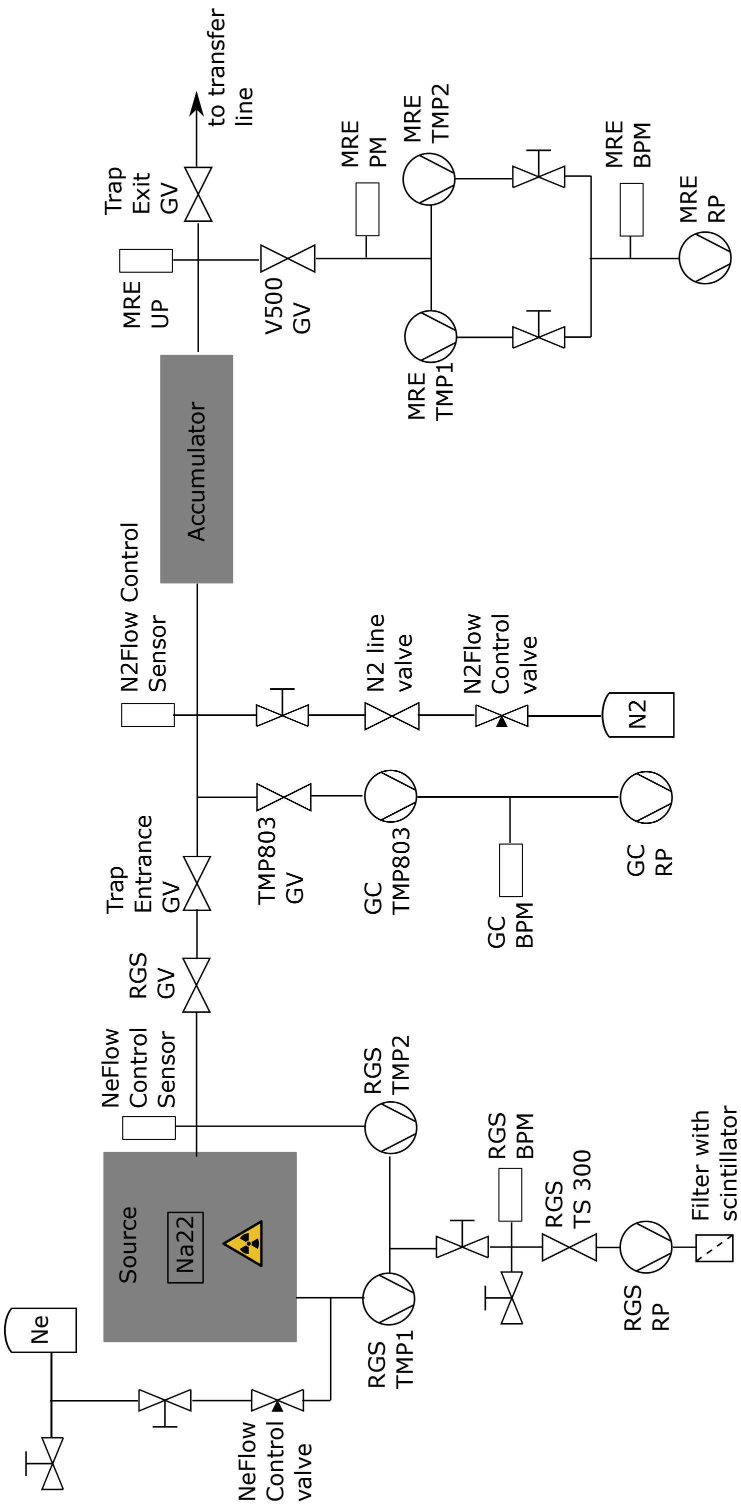

Figure 1: Vacuum scheme of the positron system.

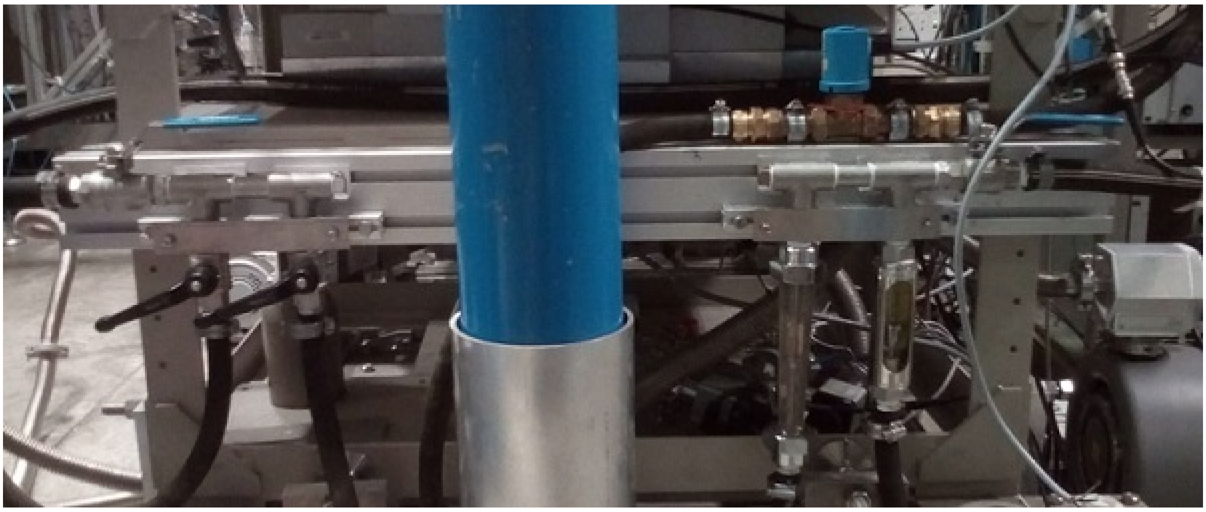

Figure 2: Positron cooling water manifold with flow rate interlock system.

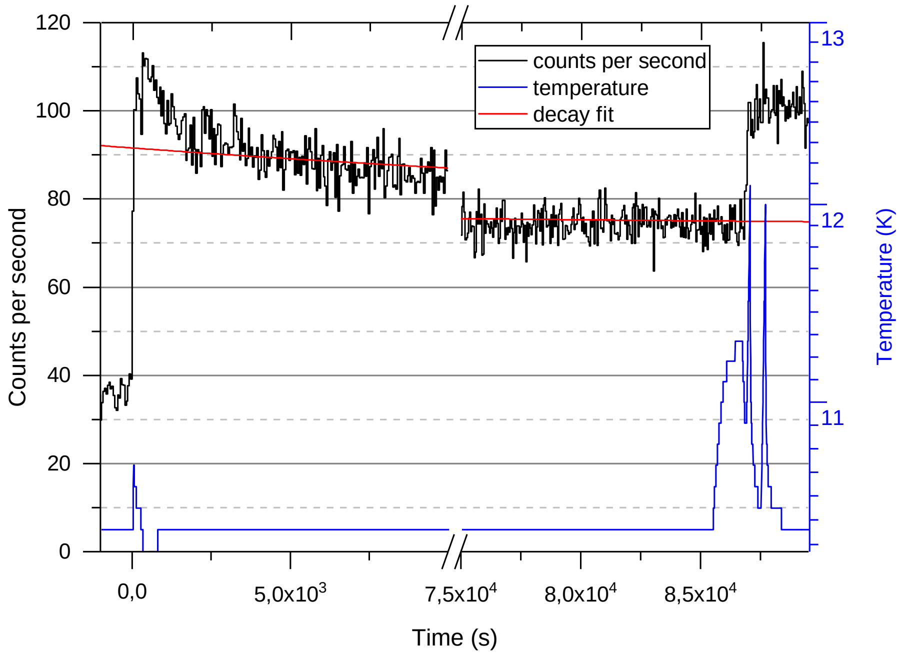

Figure 3: Exponential decay of moderator efficiency without presence of other gases. Several attempts of annealing were performed at the end of the measurement. A maximum temperature of 12.6 K is successful whereas after annealing further annealing does not yield any benefit.

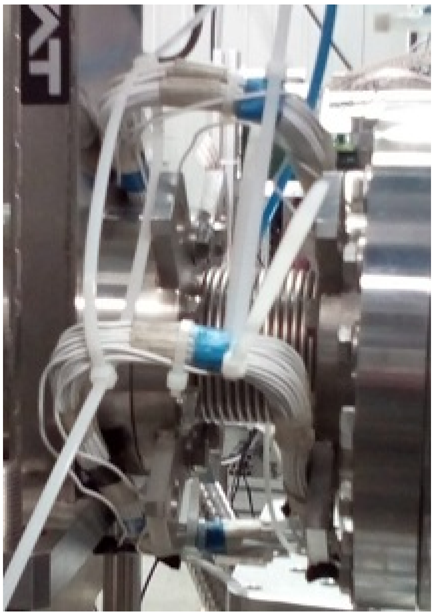

Figure 4: Temporarily mounted deflection coils between source and accumulator.

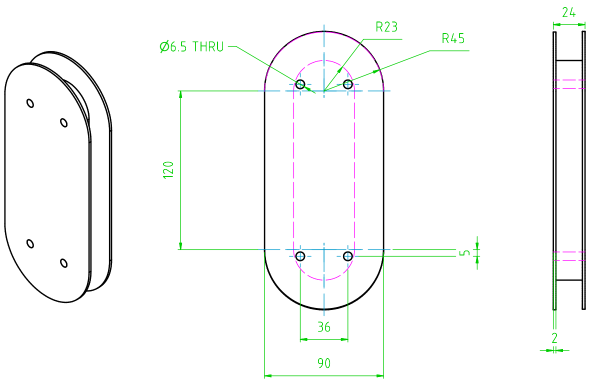

Figure 5: Professionally drawn coil holder for a higher precision of the adjustment.

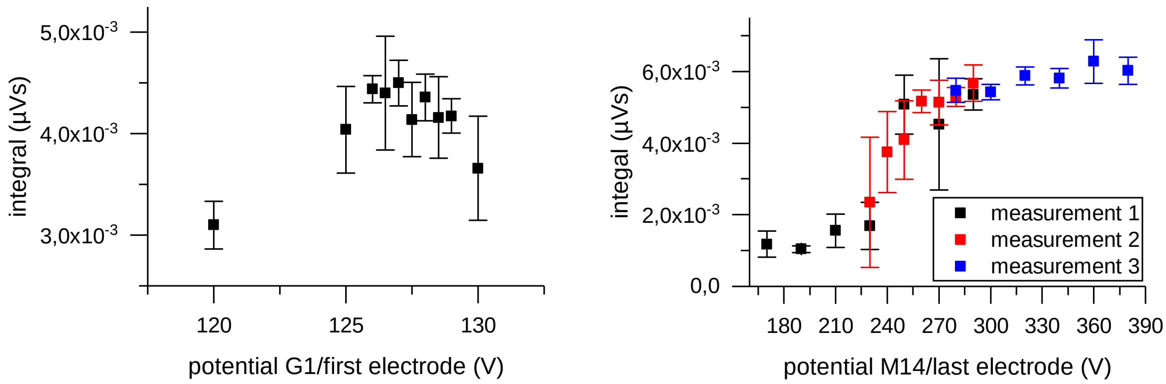

Figure 6: Optimizing MRE potentials of the first (left) and last (right) electrodes with respect to the integrated scintillator signal at the accumulator exit. Measurements are shown with standard deviation.

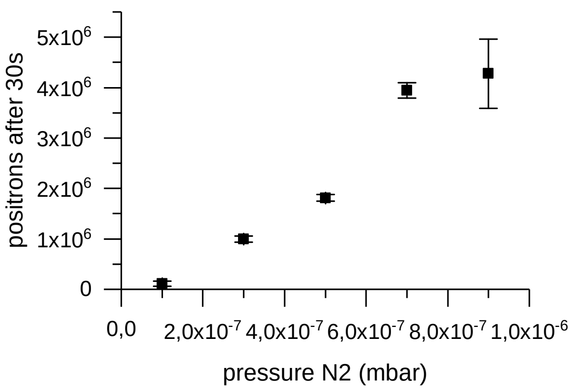

Figure 7: Accumulated positrons after 30 s depending on the nitrogen pressure in the accumulator. Number of positrons was determined with a calibrated charge amplifier and shown with standard deviation.

4 Transfer line

The extracted positron bunches are transfered to the CUSP through pulsed coils which provide a magnetic field sufficient to guide the whole bunch around corners of the beamline. Since the normal conducting magnets of the transfer line undergo large currents these pulses are limited to around four seconds. Within this time the transfer valves are opened and the positron bunch ejected. In order to prevent accidental energization for periods exceeding 10 seconds interlocks were built to electronically and independently limit the pulse duration to roughly 12 s. The core of the interlock device is a timing chip whose switching time is determined by the charging process of a capacitor. The power supply of the timing unit is provided by the voltage applied to the coils. Once the maximum pulse time is exceeded the output of the coil will be switched off and the interlock can only be reset manually with a push button connected to a 9V-battery. The layout, circuit diagram as well as the final interlock box as successfully integrated to the system can be seen in the figures 8, 9 and 10.

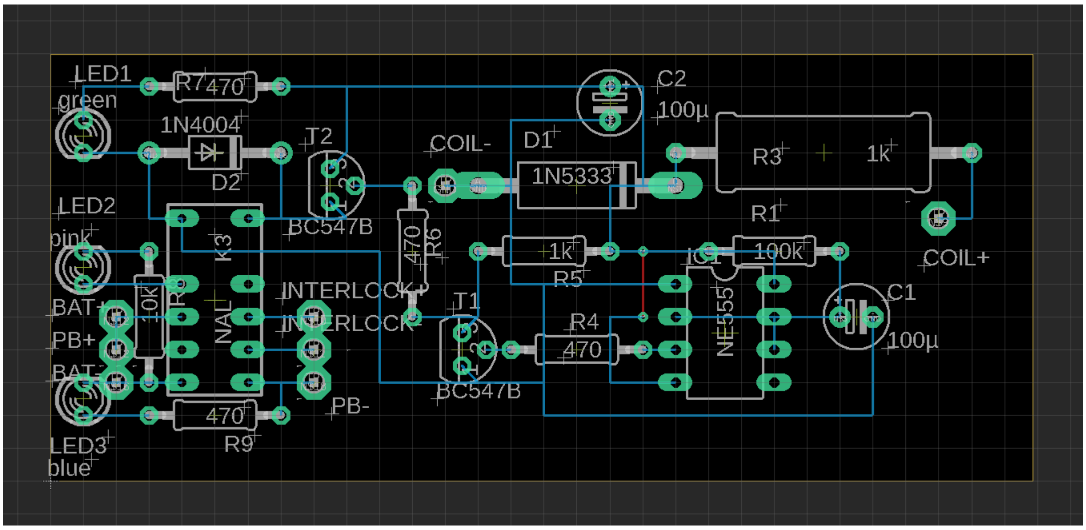

Figure 8: Layout of interlock circuit for pulsed coils.

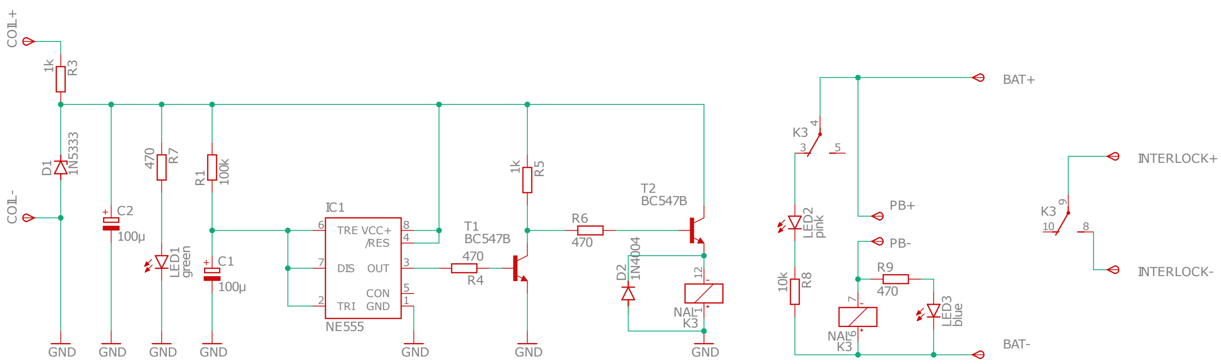

Figure 9: Circuit diagram of interlock circuit for pulsed coils.

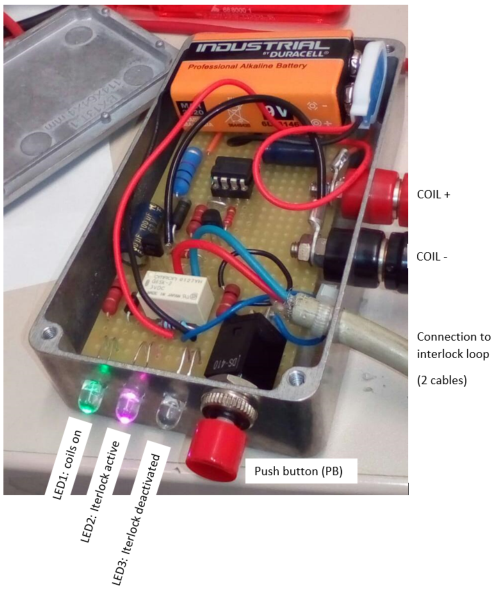

Figure 10: Finalized interlock box as connected to pulsed coils with description of connectors.

A successful transfer of positrons towards the CUSP can be monitored by inserting another MCP into the beamline at the CUSP entrance and monitoring the corresponding charge or annihilation signal. A exemplary comparison of a scintillator signal at the exit of the positron accumulator compared to the corresponding signal at the CUSP entrance is depicted in figure 11. A clear increase in width can be seen after the positron bunch traversed the transfer line. This behaviour is given by the energy spread within a bunch of positrons. The final potential well in the accumulator (fig. 12) as well as its depth (fig. 13) and the overall potential of the accumulator (fig. 14) were optimized with respect to the minimum width at highest positron number.

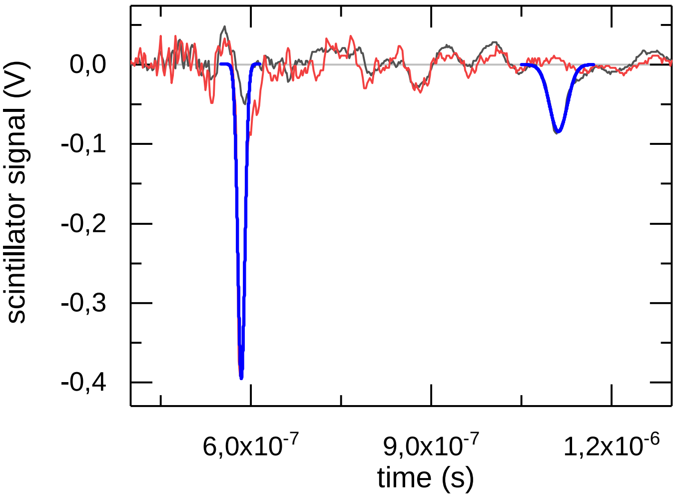

Figure 11: Scintillator signals for annihilation at the positron accumulator exit and CUSP entrance. Signal heights are not necessarily comparable because of different scintillator positions.

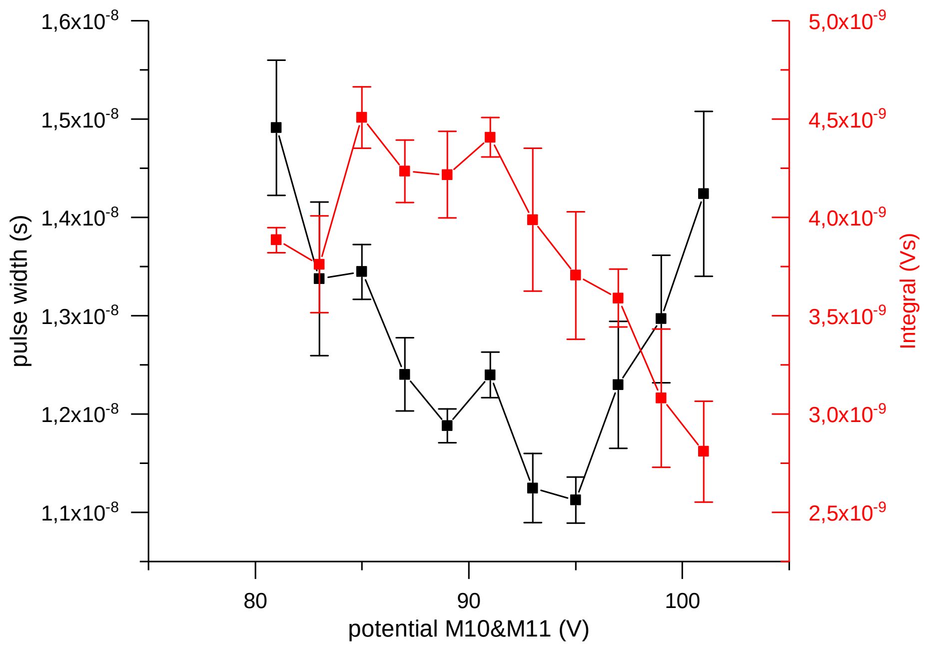

Figure 12: Optimization of the depth of the final accumulation potential with respect to the annihilation signal on the scintillator..

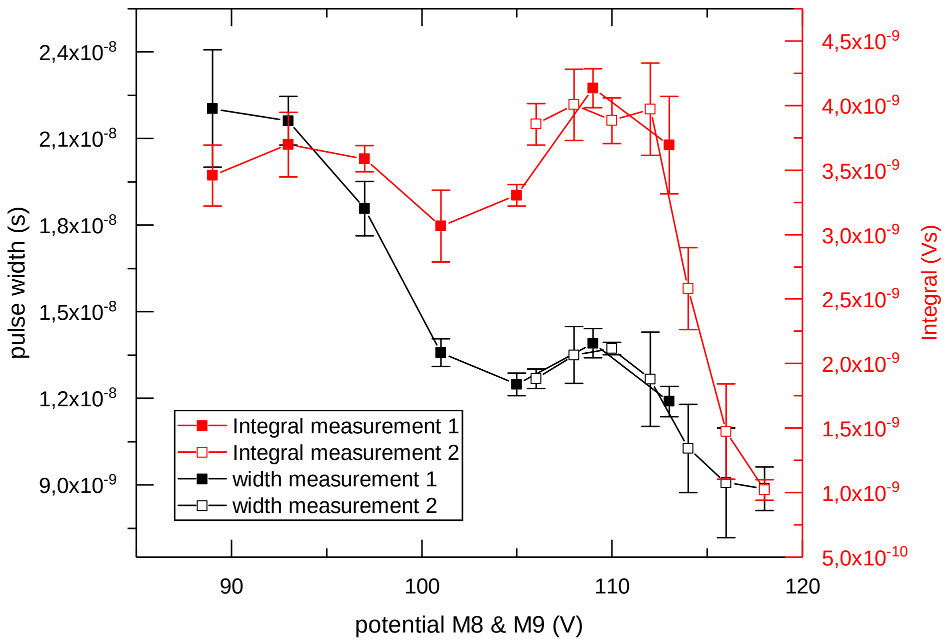

Figure 13: Optimization of the width of the final accumulation potential with respect to the annihilation signal on the scintillator.

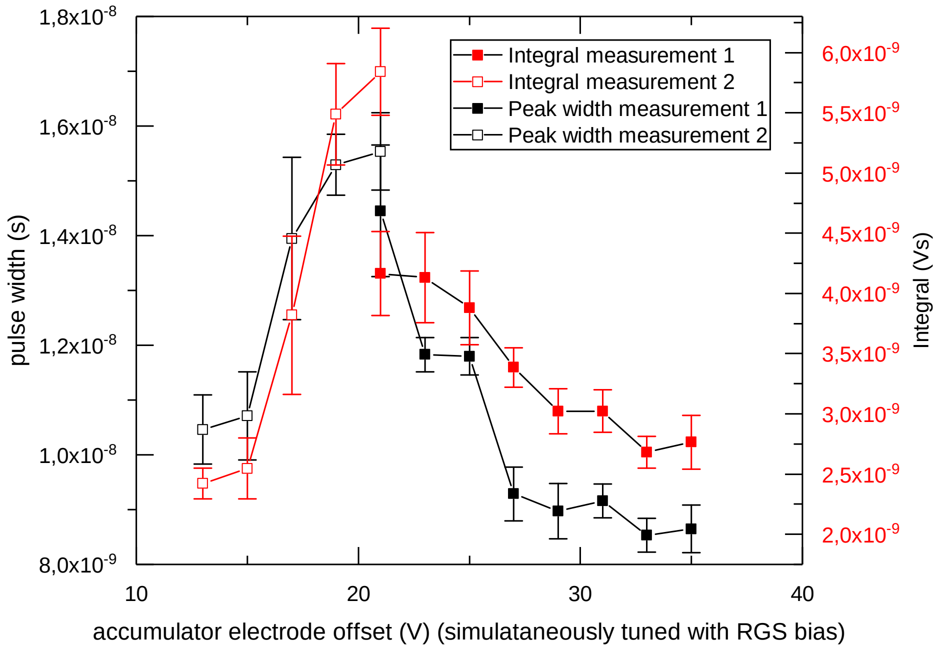

Figure 14: Optimization of overall potential difference between accumulator and CUSP while relative differences between single potentials remain constant. In particular, the potential of the source was altered with the whole accumulator offset.

5 CUSP

Upon the arrival of transfered positrons the axial potential of the CUSP trap is closed with a fast HV switch connected to the entrance electrode. This closing pulse has to be precisely timed with the arrival of the positron bunch inside the CUSP trap. The main parameter which has to be tuned is the delay time between positron ejection from the accumulator and the high voltage switch of the entrance electrode. Other important parameters optimized are the overall potential difference between the CUSP trap as well as the height of the capture pulse. Since one bunch of positrons from the accumulator is not sufficient to perform antihydrogen creation bunches of positrons are stacked in the CUSP trap. This is possible due to the fast cooling of the positron plasma already confined within the trap through cyclotron radiation which prevents these positrons from leaving the trap when the fist electrode is opened again for another bunch.

6 Manipulation in the CUSP

The CUSP entrance is equipped with an electron gun which is used to provide electrons for antiproton cooling. It can be used to test the plasma manipulation and temperature measurement schemes with a significant higher number of particles. The CUSP allows axial manipulation of the plasma by the MRE as well as radial manipulation by two four-times segmented electrodes, e.g. the rotating wall

(RW) technique, i.e. the application of a rf field to compress the plasma. Furthermore, the plasma can be extracted on a MCP with a connected phosphor screen which is monitored by a CCD camera and allows to directly image the integrated radial shape of the plasma. A corresponding image of a compressed electron cloud is shown in fig. 15. Optimizing these parameters a constant and high number of extracted electrons were obtained. This allows us to perform different extraction schemes, e.g. a slow extraction, which finally paves the way towards the measurement of the positron temperature.

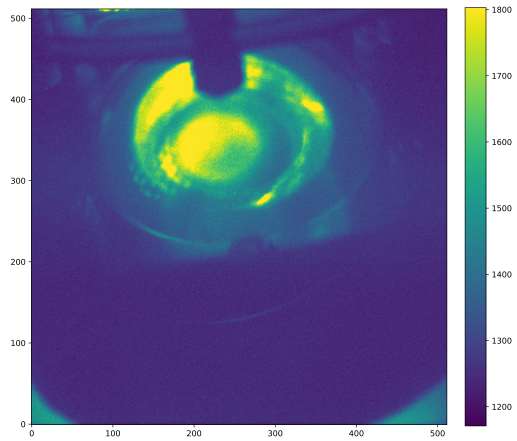

Figure 15: CCD image of a RW-compressed electron cloud extracted on the MCP and subsequent phosphor-screen.

7 Conclusion

The positron system of the ASACUSA-CUSP experiment was recommissioned to stable conditions and a point where first temperature measurements could be performed and correspondingly the cooling process of the positron plasma is about to be monitored. Further work is to be done in the field of different cooling mechanisms.