PSI Experiment R-05-01 (PEN)

Precise Measurement of the $\pi^+ \to e^+\nu$ Branching Ratio

Progress Report and Beam Request

The PEN Collaboration

17 January 2008

1. Summary of activities in 2007

Subsequent to the approval of the 2007 beam time allocation to the experiment, the PEN collaboration proceeded to implement a number of needed changes. They are summarized below.

- New counters designed and built for the 2007 run:
  - A new active target detector made of fast plastic scintillator with Hamamatsu H2431-50 photomultiplier readout,
  - A compact-design active degrader detector, 5 mm thin, read out by a fast 1 cm–diameter Hamamatsu photomultiplier,
  - An annular active collimator detector ensuring a restrictive pion stop distribution.
- The thin 20-element plastic hodoscope detector (historically labeled PV) was refurbished for the 2007 run with brand new plastic scintillator staves replacing the original ones whose surfaces had become crazed with age.
- A new compact thin upstream beam tag counter was designed to fit inside a vacuum beam pipe, along with a matching lead-tungsten passive collimator, thus allowing us to shorten the initial drift length in the beamline.
- A different compact quadrupole triplet magnet was used for the first time in the experiment. This, along with the new compact beam counter enclosure, enabled us to shorten the in-area beamline by almost one meter from ~ 3.9 m to ~ 3 m, giving us increased ability to use lower pion momenta.
- The CsI calorimeter PMT's and voltage dividers that failed in 2006 were replaced.
- The old LeCroy high voltage system, no longer serviceable and subject to HV drifts that degrade CsI calorimeter energy resolution, was replaced with a new system designed and built at PSI, with much tighter output voltage stability specifications. Ours was the first large-scale in-beam implementation of this system; it was successful.
- New temperature sensors and controller interface were installed.
- A completely new slow control arm of the data acquisition DAQ system was implemented for the 2007 run. This removed one of the obstacles to using the most recent version of the Midas package, and replaced obsolete hardware that had become difficult to service.

- New front-end DAQ electronics was implemented, based on the GE Fanuc VMIVME-7807 VME Controller.
- Two new front-end DAQ computers were implemented, and new code was written to enable simultaneous readout of the Acqiris digitizer along with the Fastbus and Camac DAQ branches, within an up-to-date version of Midas.
- After it was established that modern DAQ hardware and recent versions of Midas are not compatible with direct memory access DAQ mode in the existing Fastbus controller, the latter was upgraded to a newer version which supports the fast DAQ mode.

All of the above changes and upgrades were implemented successfully. A drawing of the central beam region used in the 2007 PEN run is shown in Fig. 1. The drawing shows the geometry and location of the new active target, degrader and collimator detectors, as well as the refurbished PV counters. The active collimator, degrader and target geometry was designed to produce a compact stopping distribution at the expense of pion rate.

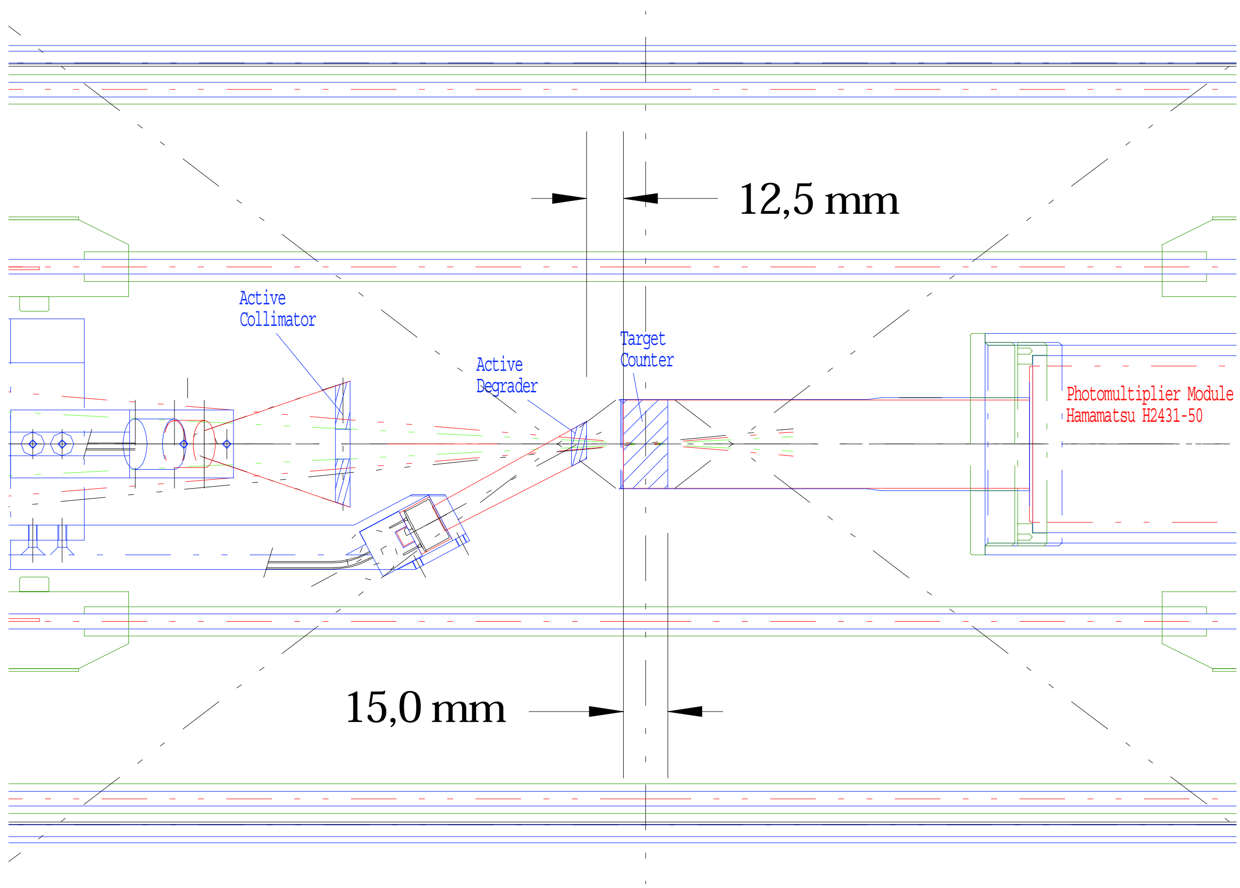

Figure 1: Schematic drawing of the central-region beam detectors redesigned for the 2007 PEN run: the active collimator, degrader, and active target. The upstream Beam tag (not shown here), as well as the thin plastic hodoscope (PV) detectors, were also redesigned and rebuilt for 2007. The PV detectors are the outermost thin bars shown in the figure.

2. Preliminary summary of the 2007 run results

We originally requested and were granted a total of 18 weeks of beam time in 2007 in the PiE1 area, which was to include 3 weeks of basic setup, followed by 15 weeks of detector shakedown and initial data taking. A basic, milestone goal of the run was to acquire a data set that would match the published work of the TRIUMF and PSI groups.

Unfortunately, our allocation of beam time was reduced at the outset by one month due to a change in the accelerator and Hallendienst schedule beyond our control. Thus, we ended up getting only 13 weeks of beam time in the PiE1 area. The key information pertaining to the run is:

- detector was installed on 24 September, followed by 22 days of setup,
- usable data runs started on 16 October; experiment ran until 21 December, for a total of 65 calendar days with 4.46×10^6 s of available beam (availability fraction 0.79),
- our detector system experienced several malfunctions resulting in ~11 % down time, or an availability fraction of 0.89; in addition, because of a failure of the new Fastbus controller which forced us to use the slower old module we lost another ~10 % of data to DAQ dead time,
- we recorded ~280,000 $\pi \to e\nu$ decay events (this result is from a preliminary analysis of the entire data set; known analyzer improvements will yield $\sim 7-8\,\%$ more events, however, more stringent cuts in the final analysis may negate this increase),
- majority of the running was with 68 MeV/c pion momentum, which was increased to 69 and 71 MeV/c during tests toward the end of the run,
- during "production" runs all detector systems behaved as designed, i.e., we do not expect any degradation of the systematic uncertainties in the final analysis that would stem from a malfunctioning subsystem.

The most succinct conclusion of the above summary is that we succeeded in reaching the stated goal of the run. Our statistical uncertainty will be approximately $\delta B/B \simeq 0.2\,\%$, or better, which is competitive with the published results.

More detailed results of the 2007 run will become available as we carry out a more complete analysis of the acquired data, which amount to about 1.6 TB. Below are a few partial results that illustrate the quality of our data.

Fig. 2 shows sample active target waveforms for typical sequences: $\pi_{\rm stop} \to \mu \to e$ and $\pi_{\rm stop} \to e$, as well as corresponding active degrader waveforms. Among notable results of the early analysis are (a) high timing resolution for degrader and target digitized waveforms ($\sigma_{\rm DEG\text{-}TGT} < 80$ ps; Fig. 3, left panel), and (b) the effective suppression of prompt background enabling us to record events cleanly all the way down to $\Delta t = 0$ with respect to the pion stop time (Fig. 3, right panel). At the low pion momenta used in this run, almost all prompt events are associated with protons which are well separated from positrons in both the wire chamber and plastic hodoscope detectors. Finally, Fig. 4 shows the positron energy spectrum for events missing the target muon pulse, presumed to be $\pi_{\rm e2}$ events, demonstrating efficient suppression of the Michel positron events.

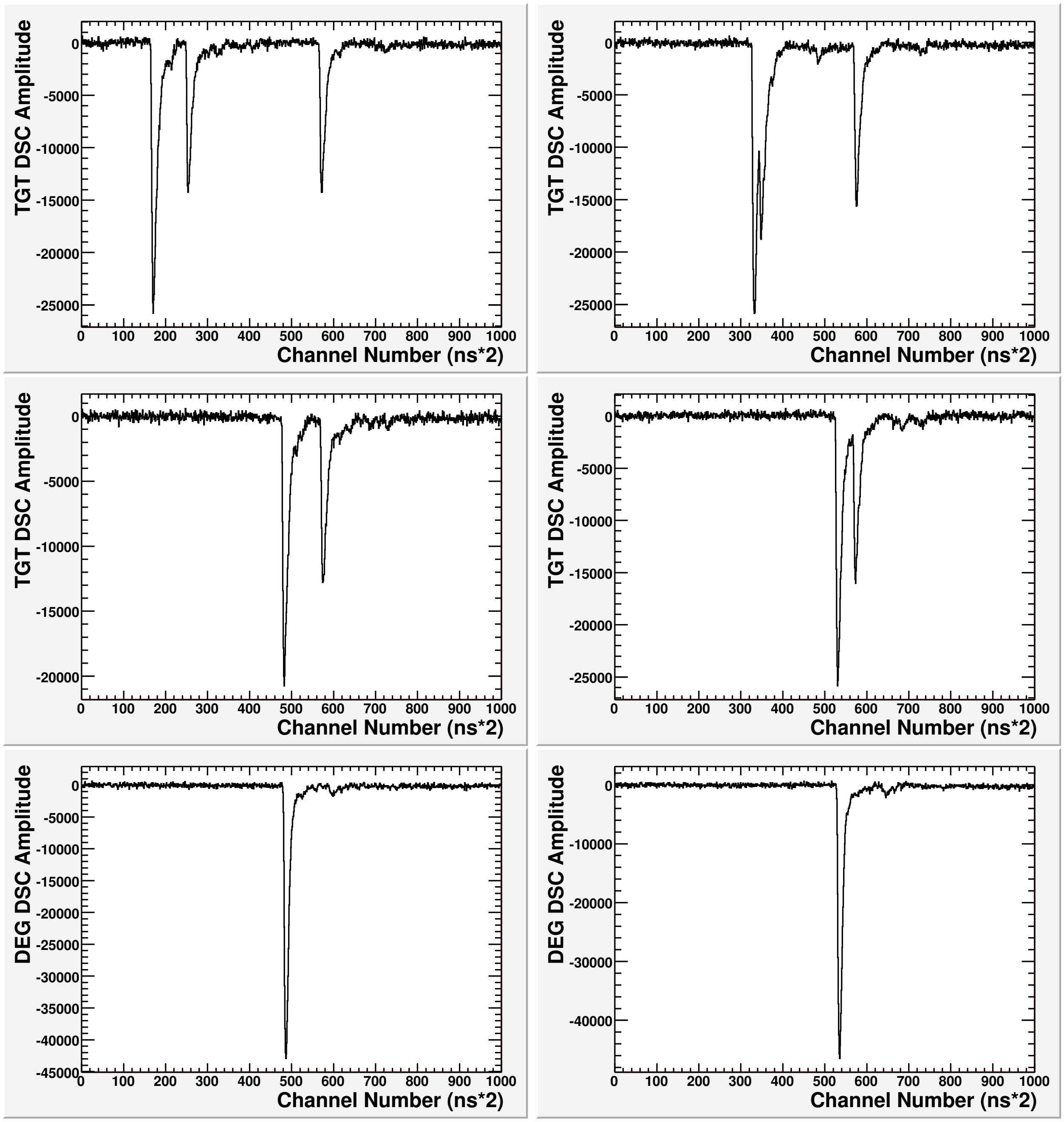

Figure 2: Sample active target waveforms for typical $\pi \to \mu \to e$ (top row) and $\pi \to e$ (middle row) events. Corresponding active degrader waveforms are shown in the bottom row.

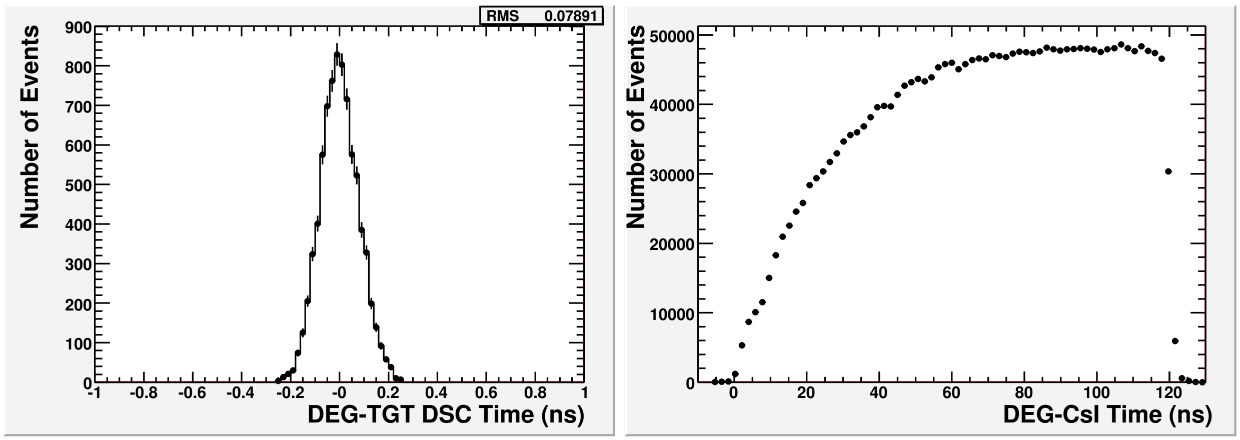

Figure 3: Left plot: degrader–target time difference for stopping beam pions; rms of the distribution is under 80 ps. Right plot: time difference distribution in the target between the pion stop and positron pulses in the $\pi \to \mu \to e$ decay sequence. Time differences all the way down to zero are detectable with no appreciable contamination from prompt background. Both plots reflect a small subset of the 2007 data set.

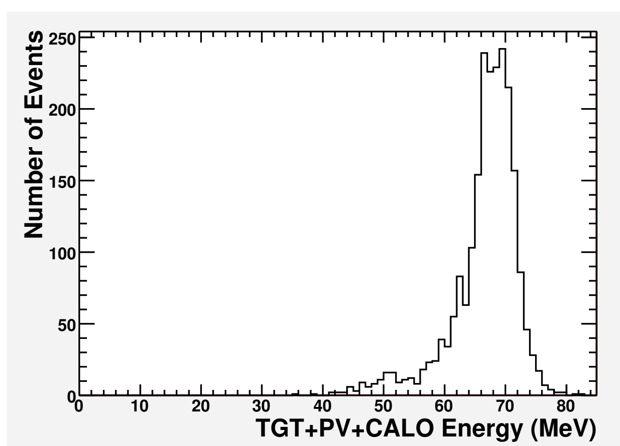

Figure 4: Energy spectrum (sum of target, plastic hodoscope and CsI calorimeter energy) for events lacking the 4.2 MeV muon pulse in the target, for a small subset of the 2007 high-threshold trigger data set.

The 2007 run was restricted on purpose to about 1,200 pion stops/sec; we ran with ∼3,600 pion stops/sec briefly at the end of the run. Relaxing the geometrical restrictions of the beam counters will yield approximately 10,000 pion stops/sec. Due to the short time since the end of data taking, we still need to perform a full evaluation of these results. Appropriate modifications of detectors and DAQ system are planned, and are under way for the 2008 beam period. Additional improvements in DAQ speed may be achieved during the 2008 run that would enable a straightforward further increase in the pion stop rate. However, such changes must be made gradually, monitoring important systematics, and making sure that data quality is not compromised.

3. Resources and beam request

We request 17 weeks of beam time in the πE1 beam area, which includes two weeks for set-up and calibration, and 15 weeks of data taking. Under the circumstances outlined above, this amount of beam time would let us acquire $\sim 4-5\times 10^6$ $\pi_{\rm e2}$ decay events, or statistical uncertainty $\delta B/B \simeq 5\times 10^{-4}$, or better. Given the state of our detector readiness, we request that this period begin with the inception of the 2008 beam delivery at the PSI Ring Accelerator.

There are no major costs associated with the requested run. The main expenditures are the material costs of operating the detector (MWPC gas, supplies, consumables), and modest amounts to support certain local expenses at PSI for collaborators from former socialist countries, similar to the 2007 budget.