

1 Precision Measurements in Rare Pion Decays

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in collaboration with:

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(PIBETA/PEN Collaboration)

The PIBETA Collaboration performs a research program on rare π and μ decays at PSI. Two decay modes are presently being studied:

- $\pi^+ \rightarrow e^+ \nu_e \gamma$

Data taken parasitically with the $\pi^+ \rightarrow \pi^0 e^+ \nu_e$ experiment showed 20% deviations from the Standard Model prediction in the kinematic region of high E_γ and low E_{e^+} . To clarify the situation a dedicated experiment was performed in the year 2004 and first results became available last year. These new data showed no anomaly and allowed very significant improvements in the determination of the vector and axial-vector form factors F_V and F_A . Using the conserved-vector-current hypothesis (CVC) F_V is connected with the lifetime of neutral pions. The value of F_A is model-dependent.

- $\pi^+ \rightarrow e^+ \nu_e$

This decay mode offers the most sensitive test of lepton universality in charged-current interactions. During 2005 extensive beam studies were performed at PSI. A proposal by the PEN Collaboration to measure the branching ratio with a precision of $O(0.1\%)$ was accepted with high priority by the PSI Program Advisory Committee in February 2006.

1.1 The $\pi^+ \rightarrow e^+ \nu_e \gamma$ decay

The $\pi^+ \rightarrow e^+ \nu_e \gamma$ decay was recorded during $\pi^+ \rightarrow \pi^0 e^+ \nu_e$ data taking (1). This was the first time that this decay mode was studied with a setup with almost complete geometric acceptance. Two decades ago we studied this decay (2) and its Dalitz correction $\pi^+ \rightarrow e^+ \nu_e e^+ e^-$ (3) and more recently the corresponding kaon modes $K^+ \rightarrow e^+ \nu_e e^+ e^-$, $K^+ \rightarrow \mu^+ \nu_\mu e^+ e^-$, and $K^+ \rightarrow e^+ \nu_e \mu^+ \mu^-$. These decays proceed via a combination of inner bremsstrahlung (IB) and two structure dependent (SD^+ , SD^-) amplitudes. Whereas inner bremsstrahlung bears no information of interest the structure dependent contribution allows a determination of meson form factors which, in turn, are an important input into chiral perturbation theory. Figure 1.1 shows the relative contributions to the distribution of photon and electron energies.

In the first data taken with the PIBETA setup 20% deviations were observed in the kinematic region of high E_γ and low E_{e^+} . This kinematic region could not be studied in earlier measurements because of the high level of accidental coincidences with positrons from $\mu \rightarrow e \nu \bar{\nu}$

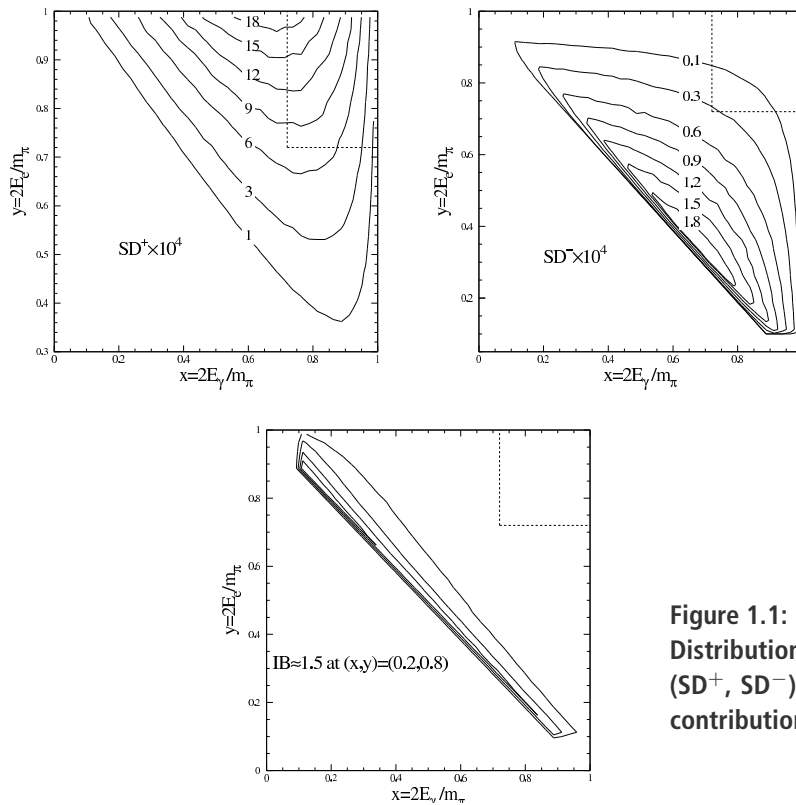


Figure 1.1:
Distributions of the structure dependent (SD^+ , SD^-) and inner Bremsstrahlung (IB) contributions.

decay. To clarify the situation a dedicated measurement (4) was performed at reduced beam intensity for which we contributed an improved active target. Thanks to the improved conditions almost background free data could be collected as is demonstrated in Fig. 1.2.

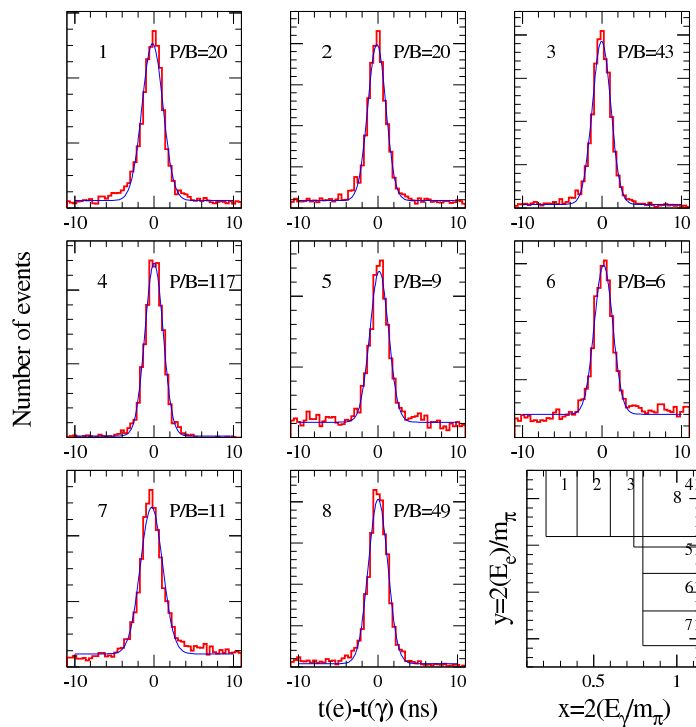


Figure 1.2:
Signal histograms for eight kinematic regions defined in the last panel.

The fit of the form factors to these data resulted in:

$$F_A = 0.0118 \pm 0.0003 \quad (1.1)$$

$$F_V = 0.0262 \pm 0.0015 \quad (1.2)$$

$$a = 0.241 \pm 0.093 , \quad (1.3)$$

where a describes the momentum dependence of the form factors which was never determined before. These results were obtained without any constraints or theoretical hypotheses. Earlier measurements usually resulted in a value for F_A/F_V only. This ratio is directly connected to the pion polarizability α_E defined by: $\vec{p} = \alpha_E \times \vec{E}$ (\vec{p} pion electric dipole moment) through:

$$\alpha_E = \frac{2\alpha}{8\pi^3 m_\pi f_\pi^2} \times \frac{F_A}{F_V} = (2.81 \pm 0.07) \times 10^{-4} \text{ fm}^3 , \quad (1.4)$$

where the numerical value was determined using our new results.

As mentioned above F_A and F_V also give constraints on terms (l_9 and l_{10}) of the Lagrangian of Chiral Perturbation Theory:

$$l_9 + l_{10} = \frac{1}{32\pi^2} \frac{F_A}{F_V} = (1.42 \pm 0.04) \times 10^{-3} . \quad (1.5)$$

[1] **Precise measurement of the pion axial form factor in the $\pi^+ \rightarrow e^+\nu\gamma$ decay,**

E. Frlež *et al.*, Phys.Rev.Lett. **93** (2004) 181804 [arXiv:hep-ex/0312029].

[2] A. Bay *et al.*, Phys.Lett.B 174, 445 (1986).

[3] S. Egli *et al.*, Phys.Lett.B 222, 533 (1989).

[4] **Study of the $\pi^+ \rightarrow e^+\nu\gamma$ anomaly,**

PSI Proposal R-04-01.1, E. Frlež and D. Počanić spokesmen, January 2004.

1.2 A precision determination of the $\pi^+ \rightarrow e^+\nu$ branching ratio

As was discussed in last year's annual report the $\pi^+ \rightarrow e^+\nu / \pi^+ \rightarrow \mu^+\nu$ branching ratio is the best test of μe universality, i.e. the equality of the couplings of $\mu\nu_\mu$ and $e\nu_e$ to the W boson. Two experiments (1; 2) contribute to the present world average (3) for the measured value:

$$R_{e/\mu}^{\text{exp}} = 1.230(4) \times 10^{-4} \quad (1.6)$$

During the years 1999/2001 the PIBETA experiment recorded a huge sample of $\pi^+ \rightarrow e^+\nu$ decays. Although the measurements were not optimized for this decay mode a clear $\pi^+ \rightarrow e^+\nu$ signal was observed with a total systematic error below $\approx 1\%$, i.e. within a factor 2-3 of the dedicated experiments. The main contribution to this uncertainty is in the determination of the number of stopped pions. The statistical uncertainty associated with the number of observed $\pi^+ \rightarrow e^+\nu$ events is totally negligible in this data set.

In Februari 2006 a proposal by the now-called PEN Collaboration (4) was accepted with high priority at PSI. It is planned to take first test data with the new setup this year which will be followed by two years of real data taking. Our group took over the responsibility to develop an ultra-fast beam monitoring system based on 0.6 ns scintillator and microchannel photomultipliers. Waveform digitizers with ≈ 5 GHz sampling rates would be used with the aim of reaching a double pulse resolution $O(1 \text{ ns})$ in the target detector. During a test period

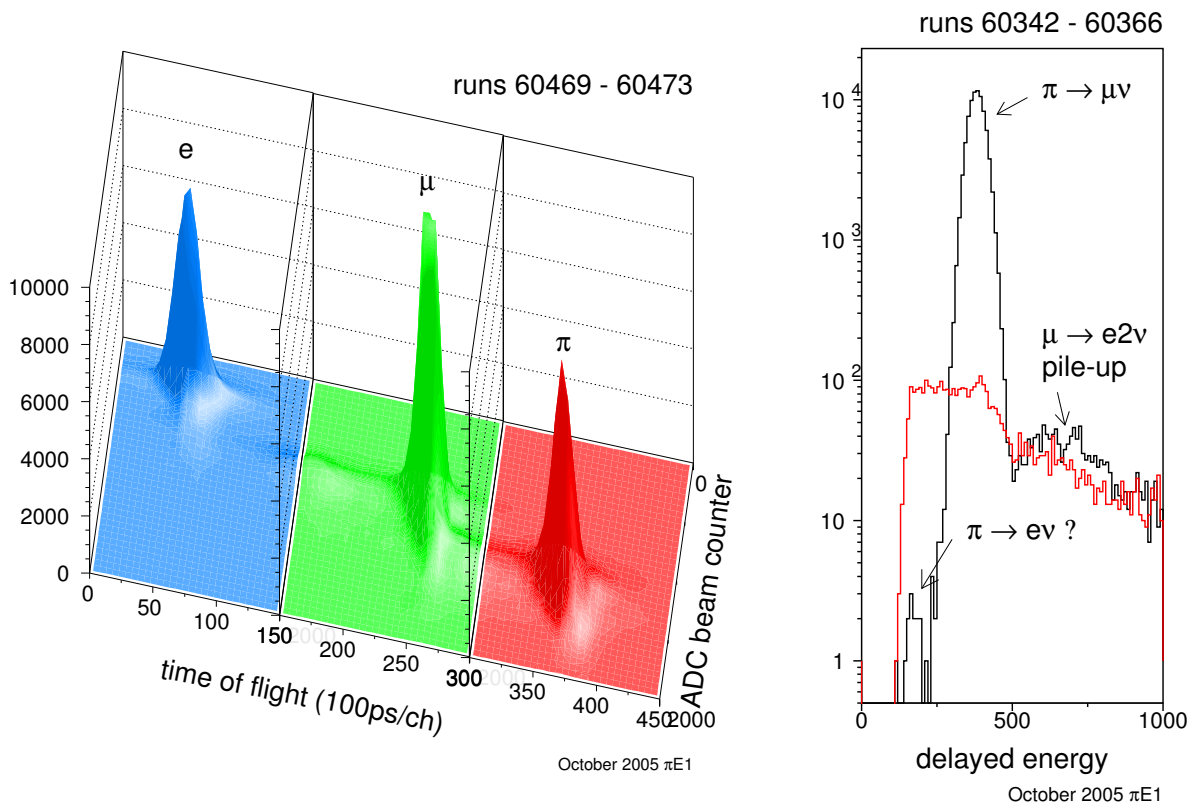


Figure 1.3: Distribution of flight time along the last ≈ 4 m of the π E1 beamline and energy loss in a moderator counter. Results from our 2005 tests at PSI. Pions, muons and electrons are clearly separated. This information will be crucial in estimating the contribution from pion decay in flight in the final data. The time of flight will also allow a precise determination of the pion momentum.

Figure 1.4: Secondary (black) and tertiary (red) target signals. The secondary signals are totally dominated by muons from pion decay at rest. The very low background left of the peak is close to the level expected from $\pi \rightarrow e\nu$.

of several weeks at PSI we learned, however, that these novel photo-detectors are very fast indeed but show a strong ringing after the signal. For this reason it was decided to use very fast (0.7 ns risetime) standard photomultipliers instead. During the tests at PSI we also tried to tune the beam to the lowest possible momentum (≈ 70 MeV/c as compared to ≈ 120 MeV/c for PIBETA running). At these lower momenta the range straggling is much reduced leading to a better definition of the pion stop distribution. At the other hand, because of the 26 ns pion lifetime the pion rate at the exit of the π E1 channel drops quickly towards lower momenta where the beam contains orders of magnitude more electrons and muons. This problem could be solved by inserting a thin degrader halfway the channel. After the degrader pions have lower momenta than the other particles which can be exploited to suppress electrons and muons. As can be seen from Fig. 1.3 the selected beam contains similar amounts of π , μ and e which can be easily distinguished on the basis of their velocity and dE/dx .

The $\pi \rightarrow e\nu$ decays are distinguished from $\pi \rightarrow \mu\nu$ decays followed by $\mu \rightarrow e\nu\bar{\nu}$ on the basis of the different positron energy distributions and the different decay time distributions. A major source of systematic errors is the uncertainty in the low-energy tail of the $\pi \rightarrow e\nu$ decay caused by shower leakage in the electromagnetic calorimeter and nuclear interactions producing neutrons. For this reason it is important to be able to measure a $\pi \rightarrow e\nu$ spectrum with as little $\pi \rightarrow \mu\nu$ contamination as possible. For this reason we checked during the tests

at $\pi E1$ the ability to distinguish $\pi \rightarrow e$ events from $\pi \rightarrow \mu \rightarrow e$ events on the basis of target signals alone. Here one exploits the fact that muons from pion decay at rest are non-energetic, have a range of only 2 mm and deposit their full kinetic energy in the target. As is demonstrated in Fig.1.4 it is possible to distinguish the two components in the amplitude distribution for secondary particles observed in the target shortly after a pion stop.

- [1] G. Czapek *et al.*, Phys.Rev.Lett.70, 17 (1993).
- [2] D.I. Britton *et al.*, Phys.Rev.Lett.68 (1992) 3000, D.I. Britton *et al.*, Phys.Rev.D 49, 28 (1994).
- [3] S. Eidelman *et al.*, (Particle Data Group), Phys.Lett.B 592, 1 (2004).
- [4] **Precise Measurement of the $\pi^+ \rightarrow e^+\nu$ Branching ratio**,
D. Pocanic and A. van der Schaaf spokesmen, PSI Proposal R-05-01.1.

2 Electronics Workshop

W. Fässler, Hp. Meyer, P. Soland and K. Szeker

In the reporting period a lot of repair and maintenance work was done for the different research groups at the institute. Almost all components of an ESR spectrometer had to be fixed. Triggered by a damaged power supply the whole electronic chain was finally affected and several devices had to be replaced. In this particular case it was very difficult to find suppliers for some older components. Despite of this we developed and built different components used in the laboratories at the physics institute, for other institutes of the university and for experiments at outside labs where members from our institute do there research work. For the demonstration experiments in the lecturer halls again different devices and experimental setups were improved and supplemented in collaboration with L. Pauli and J. Seiler, who are responsible for the preparation of the experiments. Different seminars and courses were attended to keep track of the latest developments. The main focus was on the application of micro controllers and the lead-free soldering process. In the future all assemblies will be produced with lead-free components and lead-free alloys used for the soldering so we acquainted ourselves with this technology. The electronic workshop maintains also a small supply store with the most necessary items, which we upgrade and adapt continuously. In this period we renewed and unified the cable stock. We supplemented also the electronic equipment in the laboratory with a modern spectrum analyzer. It is an extremely lightweight and compact spectrum analyzer that is ideal for a large number of applications in development, service and production. Despite its compact size, it offers a wealth of functions. The instrument features a tracking generator up to 3 GHz and can demodulate signals with a bandwidth of 20 MHz. The main functions of the spectrum analyzer are directly accessible by fixed-assignment function keys, with additional functions accessed using softkeys and tables. This shortens the learning curve for new users as well as for users who operate the instrument only rarely. The spectrum analyzer is ideal for fast, easy measurements during production.

In collaboration with members of the institute of physiology (Research group Prof. N.G. Greef) we developed and built the control electronics for an optical shutter (Fig. 2.1) which is used in a fluorescence microscope with laser illumination. To investigate the operation of ion channels they detect the fluorescence light of a fluorophore, a component of a molecule which causes a molecule to be fluorescent with a CCD camera. These fluorophores suffer damages from the intense illumination. To minimise the exposure time the shutter interrupts the laser beam synchronized to the camera control and hence maximises the lifetime of the fluorophore. Ion channels are membrane proteins, found in virtually all cells, that are of crucial physiological importance.

We also supported a group of high school students from the Kantonsschule Wettingen in performing their "Maturitätsarbeit", which is required as a part of the exam they have to pass. With the help of Kurt Bösiger, Peter Robmann and Stefan Steiner they constructed, built and programmed a robot which can make drawings on a standard blackboard used in class

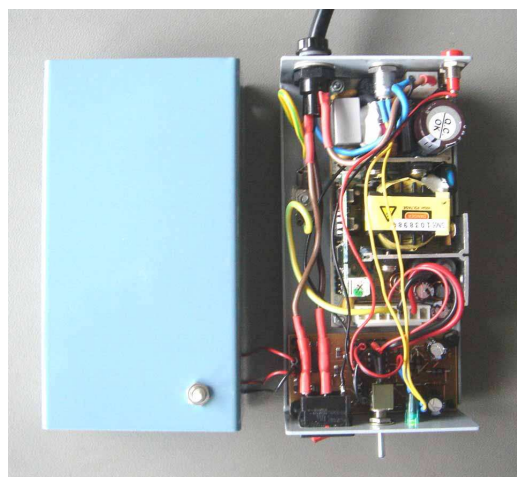


Figure 2.1: Shutter control electronics for the fluorescence microscope.

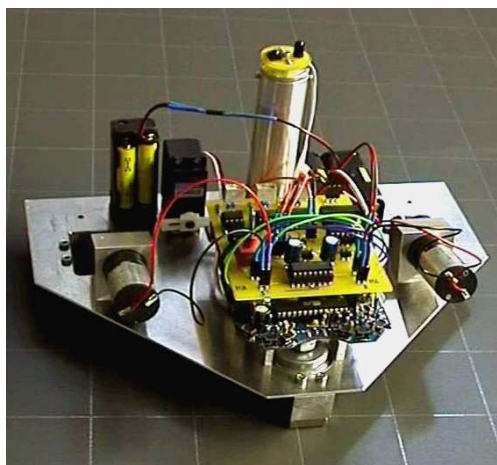


Figure 2.2:
The "Ghostwriter" on the blackboard.



Figure 2.3: Duplexer built for the SCOPES NMR-spectrometers.

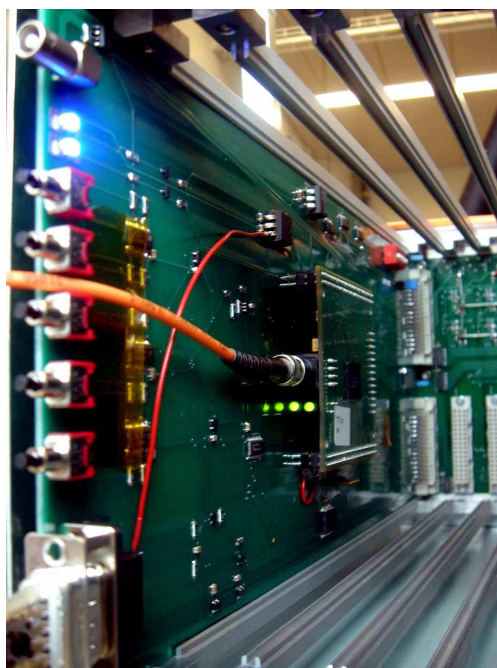


Figure 2.4: Controller card simulator.

rooms. To start with the project a tiny mobile robot developed for educational purposes by DLR, the German aerospace centre was used and adapted to the corresponding needs. The device is very flexible and completely programmable in C. Except for the printed circuit boards only standard parts are utilized and freeware tools can be used for programming. Therefore it is exceptionally suitable as an introduction into processor-controlled electronics, for projects in schools and universities. Special tools, which are freeware for private users, have been used for all electronic development phases and software design, proving that robots can be designed without expensive tools or machines. The robot is equipped with a RISC-processor and an IR-Interface for programming and remote controlling by a PC (Fig. 2.2).

A selection of projects for the different groups is listed below:

- **Physics of Biological Systems (Group Fink, Sec. ??)**
A high voltage heating power supply transformer was modified and improved. The maximum voltage rating was increased from 3.5 kV to 4.5 kV.
- **Superconductivity and Magnetism (Group Keller, Sec. ??)**
Several spectrometers, like the already mentioned ESR spectrometer, had to be repaired. Additional devices for the SCOPES NMR spectrometer were designed and built (Fig.2.3).
- **Particle Physics at DESY/HERA (H1) (Group Straumann and Truöl, Sec. ??)**
The workshop was again involved in the repair and maintenance of the CIP readout electronics for the H1 experiment at DESY in Hamburg.
- **High-precision CP-violation Physics at LHCb (Group Straumann, Sec. ??)**
Several new layouts of printed circuit boards were made and existing ones were adapted. A control card simulator board with a built on micro-controller was developed and built. (Fig. 2.4).