Part I

Particle Physics

The various groups of the *Physik-Institut* in the fields of particle physics are using for their experiments external accelerators at the large international research institutions PSI (Villigen), CERN (Genf), DESY (Hamburg) and Brookhaven. Further activities in the field of particle physics which are connected to questions of astroparticlephysics and cosmology do not require accelerators or they are carried out at a nuclear reactor.

Most of these experiments are motivated in a broader sense by the fact that the present, highly successful standard model of particle physics cannot be understood as the ultimate truth for several, often cited reasons: There are too many free parameters, the origin of the masses it not known, the nature of the neutrinos is not known, no symmetry is known which leads to the conservation of the lepton number separately for the three generations, the strong force is not yet unified with the electroweak force, the quantization of the gravitational force is unsolved, the question of the existence of other forces is still open.

A test of the standard model can be done by either a search for new particles or states of matter at medium and high energies or complementarily by a search with high precision at low energies for forbidden lepton number violating processes, or a search for the magnetic moment of the neutrino at a reactor power station.

Mainly on the basis of this motivation Part I of the annual report presents the following experiments:

- Search for μ-number violating decays and reactions at PSI
- Meson spectroscopy at LEAR with the Crystal Barrel
- Particle physics at DESY/HERA and Brookhaven
- Search for neutrino masses, mixing and magnetic moment
- Remeasurement of the gravitational constant

Especially the following result should be mentioned:

• The H1-Experiment at HERA has observed at the highest momentum transfers accessible so far a number of events exceeding the standard model expectation. If improved during the coming year these data would be a hint at "new physics" beyond the standard model. At lower momentum transfer the standard model is confirmed. (Chap. 5.4).

1 Search for Lepton Number Violation at PSI

1.1 Search for $\mu \to e$ Conversion in Nuclei

SINDRUM II Collaboration (PSI proposal R87-03)R. Engfer, C. Findeisen, E.A. Hermes, G. Kurz, H.S. Pruys, F. Riepenhausen, F. Rosenbaum, M. Rutsche, A. van der Schaaf and P. Wintzin collaboration with PSI Villigen and III. Phys. Institut B der RWTH Aachen

1.1.1 Lepton-flavor conservation

In the past few years the interest in a possible violation of lepton-flavor conservation (LFC) has further increased after it was realized that LFC violating processes like $\mu \to e\gamma$ and neutrinoless $\mu - e$ conversion have observable rates in large regions of the parameter space of supersymmetric grand-unified theories [1, 2, 3, 4, 5]. Precision flavor tests turn out more sensitive to supersymmetric unification than the electroweak data from LEP and will remain competitive during the next generation of high-energy experiments at LHC. In these theories LFC violation results from CKM type of mixing in the superparticle eigenstates, which are generally not expected to be degenerate. It is the degeneracy of the neutrino states which is responsible for LFC in the standard model.

Triggered by these exciting prospects, more sensitive searches are presently being designed. A search for $\mu - e$ conversion reached the top priority in the future AGS program at the Brookhaven National Laboratory. The feasibility of a $\mu \to e\gamma$ search at PSI is being studied by a number of groups. Both initiatives were discussed at recent workshops [6, 7] and improvements in sensitivity by 2-3 orders of magnitude seem feasible. Our institute considers to join a new $\mu \to e\gamma$ search at PSI, as expressed in a Letter of Intent to be presented at the June 1997 meeting of the PSI Program Advisory Committee.

The SINDRUM II project plans to push the sensitivity to neutrinoless $\mu - e$ conversion in muonic atoms into the region of a few times 10^{-14} in the next few years. Results of first data taking periods at the $\mu E1$ channel at PSI have been presented earlier. During 1996 a search was made in the 1993 data on titanium for $\mu^- \to e^+$ conversion. The results will be presented below. In another section we describe last years progress in the preparations for the final stage of the project and the expectations for the near future.

1.1.2 Test of the conservation of total lepton number in a search for $\mu^- \to e^+$ conversion on titanium

If total lepton number is not conserved processes like neutrinoless double-β decay and $\mu^- \to e^+$ conversion would be allowed. Both require relatively complex mechanisms involving two nucleons. Their close analogy is demonstrated in an example proposed recently (see Fig. 1.1).

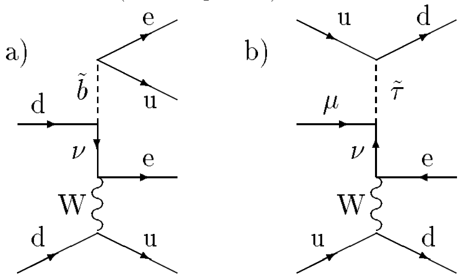

Figure 1.1: Neutrinoless double-β decay (a) and $\mu^- \to e^+$ conversion (b) in the Minimal Supersymmetric Standard Model with explicit R-symmetry breaking [8].

The data sample contains electrons and positrons from the interactions of 3.1×10^{13} μ^- stopping in the target. Details can be found in [9]. Contrary to $\mu^- \to e^-$ conversion, which would leave the nucleus mostly in its ground state, $\mu^- \to e^+$ conversion is expected to lead to (giant resonance) excitations of the daughter nucleus. The emitted positron would no longer be mono-energetic, which has severe consequences for the background discrimination. Fortunately, the intrinsic background is much lower for e^+ than for e^-.

In Fig. 1.2 the measured e^+ energy spectrum is compared with distributions expected for μ^-Ti$\to e^+$Ca.

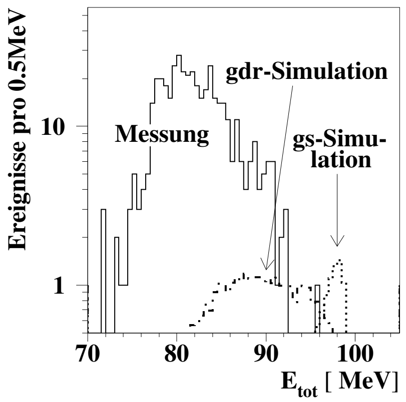

Figure 1.2: Positron energy spectrum from the 1993 data on Ti (a), as compared to the distributions expected for μ^-Ti$\to e^+$Ca assuming no excitation and $B^{gs}_{\mu^- e^+} = 4.3 \times 10^{-12}$ (b) or a 20 MeV giant resonance excitation and $B^{gr}_{\mu^- e^+} = 8.9 \times 10^{-11}$ (c).

The events below 93 MeV can be described by radiative muon capture, followed by $\gamma \to e^+e^-$ production in the target [9]. The event above 93 MeV is consistent with the expected background from cosmic rays, which gives an upper limit of 3.4 conversion events at 90% confidence. Given the detection probabilities of 8.3×10^{-2} and 3.8×10^{-3} for ground state and 20 MeV giant resonance excitation, respectively, this corresponds to upper limits of the branching ratio for the $\mu^- - e^+$-conversion (at 90% confidence) of:

$$B^{gs}_{\mu^- e^+} \leq 1.7 \times 10^{-12} \text{ (ground state)}$$
$$B^{gr}_{\mu^- e^+} \leq 3.6 \times 10^{-11} \text{ (giant resonance excitation)},$$

which is a factor 2.5 below the previous limits [10].

1.1.3 Status of the experiment

Unfortunately, technical problems with the 8.5 m long superconducting PMC magnet have stretched the time table of the experiment by two years. Meanwhile the magnet has reached superconductivity, but it was not yet possible to raise the magnetic field to the required 1.2 T.

Most critical for the success of the experiment are the background levels from radiative π^- capture and μ^- decay in flight. Since these backgrounds are more dangerous for a heavy target, where the large muon binding energy lowers the energy of the hypothetical conversion electrons by roughly 10 MeV, it was decided to start the measuring program with a gold target. An additional complication of a measurement on a heavy target is the potential background from muons stopping in light materials, since the spectrum of muon decay in orbit in these elements reaches beyond the signal region. Dictated by the characteristics of the new beamline and the special requirements of the heavy target the set-up had to be modified as shown in Fig. 1.3.

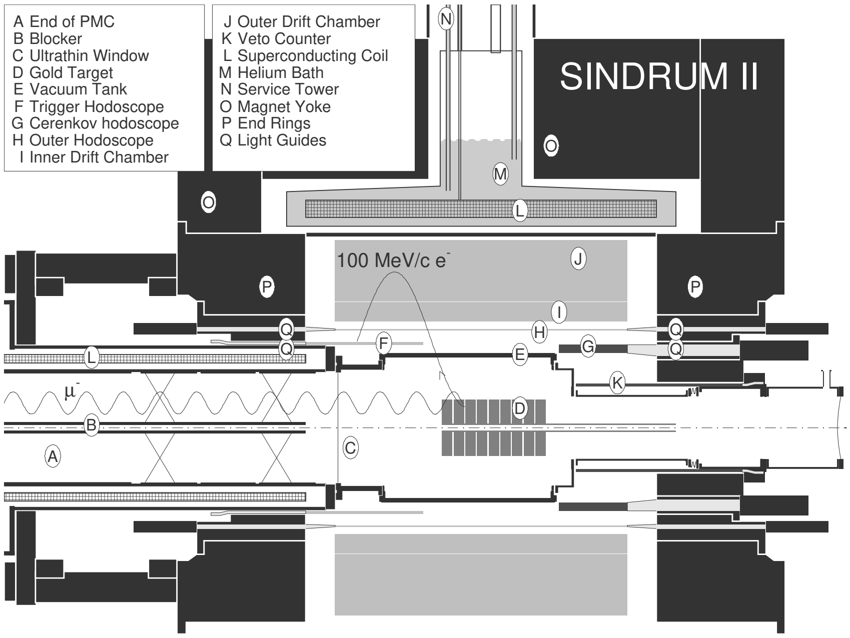

Figure 1.3: Layout of the experiment for the future measurement on gold.

Because of the large beam size with muon trajectories up to 20 cm from the spectrometer axis, the upstream Cerenkov hodoscope had to be replaced by a thin plastic scintillation hodoscope (F in Fig. 1.3). Since the background from scattered electrons is prohibitively large in the forward hemisphere only backward particles will be accepted. The geometrical acceptance was optimized by moving the target slightly downstream. An additional plastic hodoscope (K in Fig. 1.3) will help to recognize background produced by cosmic rays in the magnet iron.

In order to reduce the number of stops in low-Z materials, the beam vacuum was extended to the target region. A novel vacuum pipe (E in Fig. 1.3) was constructed with a mass of only 0.37 g/cm^2. The pipe consists of three concentric layers of carbon fiber separated by Aramid honeycomb. The high-quality PMC vacuum is separated from the target vacuum by a thin foil. About 10 percent of the beam will stop in the downstream flanches of the vacuum chamber. To reduce background these will be lined with lead foil.

It is planned to make first measurements of the backgrounds from radiative pion capture and muon decay in flight in a one month period in summer 1997. Assuming successful operation it is hoped to collect first data on gold during two months towards the end of 1997. This measurement should already bring an increase in sensitivity over our own lead measurement by at least an order of magnitude.

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1.2 Search for Spontaneous Conversion of Muonium to Antimuonium.

M$\overline{\text{M}}$-collaboration (PSI-Proposal R-89-06) Aachen - Dubna - Heidelberg - PSI - Tbilisi - Yale - Zürich

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The M$\overline{\text{M}}$ experiment in Villigen, Switzerland, is a precision experiment, searching for the spontaneous conversion of Muonium ($\text{M} \equiv \mu^+e^-$) to Antimuonium ($\overline{\text{M}} \equiv \mu^-e^+$). This reaction is not forseen in the standardmodel [1, 2, 3], because the separate lepton number conservation for muons and electrons would be violated by 2 units each. However, M$\overline{\text{M}}$ conversions are predicted in various extensions of this model, which are to be investigated by this experiment.

In the experiment a μ^+ beam of 26 MeV/c is stopped in a target of fine silicon dioxide powder. Muonium will be formed by electron capture and eventually diffuses out of the target into the surrounding vacuum region. M$\overline{\text{M}}$ conversion *in vacuo* is observed by the coincident detection of both charged particles from Antimuonium decay. The fast electron from μ^- decay is measured in a magnetic spectrometer, consisting of five concentrical cylindrical proportional chambers surrounded by a scintillator hodoscope. The strength of the magnetic field is 0.1 T. The low energetic positron from the atomic shell of antimuonium is accelerated electrostatically and guided by an energy selective transport system to a positron detector. This positron detector consists of a micro channel plate (MCP) measuring the impact point and time of the positron and a CsI crystal calorimeter for positron identification, performed by observation of at least 1 of the 2 annihilation photons.

In 1995 the experiment was moved from the πE3 beam line to the new πE5 area with improved beam quality. After the detector setup was completed four weeks of beam time had been used to look for muonium – antimuonium conversions. During this period $3 \cdot 10^9$ muonium atoms have been produced in the fiducial volume. Five events with a kinematical signature compatible with typical $\overline{\mathrm{M}}$ decays have been found, but with decay vertices located in the target region. Using an extended Likelihood analysis these events were interpreted as background with high probability.

Therefore assuming an effective (V−A)×(V−A) coupling for the hypothetical interaction only an upper limit for the M$\overline{\mathrm{M}}$ conversion extrapolated to zero magnetic field can be given:

$$P_{M\overline{M}}(B=0) < 3.6 \cdot 10^{-9} \qquad (90\%\ \mathrm{C.L.}). \tag{1.1}$$

This limit means an improvement of the 1993 result [4] by a factor of 2 and a factor of 200 compared with the result of the LAMPF experiment [5].

The upper limit for the coupling constant of the hypothetical interaction is then (in units of the Fermi constant G_F):

$$G_{M\overline{M}} < 1.2 \cdot 10^{-2} G_F \qquad (90\%\ \mathrm{C.L.}). \tag{1.2}$$

For the supersymmetric model of Halprin and Masiero [6] (an (S−P)×(S−P) type of interaction) and the dilepton model of Fujii et al. [7] (with a (V−A)×(V+A) form), the suppression of the conversion process by the magnetic field is less than for a (V−A)×(V−A) type of interaction. The upper limit for the coupling constant is then reduced to

$$G_{M\overline{M}} < 8.0 \cdot 10^{-3} G_F \qquad (90\%\ \mathrm{C.L.}). \tag{1.3}$$

For the supersymmetric model an improved mass limit for the τ sneutrino mediating the M$\overline{\mathrm{M}}$ conversion can be given (using equal couplings as the authors of the model)

$$m_{\tilde{\nu}_\tau} \geq 158\, GeV/c^2 \qquad (90\%\ \mathrm{C.L.}). \tag{1.4}$$

Similar for the dilepton model a limit for the mass of the double charged dilepton can be derived:

$$\frac{m_{X^{\pm\pm}}}{g_{3l}} \geq 1.5\, TeV/c^2 \qquad (90\%\ \mathrm{C.L.}). \tag{1.5}$$

These limits are expected to improve substancially once the analysis of the data taken in a subsequent period of 16 weeks is completed.

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