Department of Experimental Particle Physics F-9

Department research activity is devoted to measurements in the world of elementary particles, revealing the nature of elementary interactions, as well as to the development and applications of technologically advanced particle detectors. Experimental techniques in the field of elementary particle physics have evolved to the point at which scientists from all over the world combine their research efforts in large collaborative programs, centred on a few international laboratories with high-energy particle accelerators.

Head:
Asst. Prof. Marko Mikuž

In order to reveal the ultimate secrets of nature in the world of elementary particles, accelerators with higher and higher energies are needed. Their cost, both in terms of money and human resources, has grown to the level at which they became affordable only as an international, joint enterprise. Thus, future accelerators will be unique facilities of their kind, the first being the Large Hadron Collider (LHC) constructed in the European laboratory for particle physics (CERN) in Geneva. All the researchers in the field will exploit this facility jointly to perform experiments in energy regions as yet inaccessible to humans, but still far from the vast blast of the Big Bang which led to the creation of the Universe.

Researchers from the Particle Physics Department of the Jožef Stefan Institute, together with their colleagues from the Physics Department of the Faculty of Mathematics and Physics of the University of Ljubljana and from the Faculty of Chemistry and Chemical Technology of the University of Maribor, make their measurements in two international centres for particle physics, the European Laboratory for Particle Physics (CERN) in Geneva and the German centre DESY in Hamburg. They are taking part in five experiments, each of which is conducted as an international collaboration,

- ARGUS at the DORIS storage ring at DESY, composed of around 80 researchers from 10 institutions,
- ATLAS at the Large Hadron Collider (LHC) at CERN (1700 researchers, 144 institutions),
- CPLEAR at the Low Energy Antiproton Ring (LEAR) at CERN (120 researchers, 16 institutions),
- DELPHI Large Electron Positron collider (LEP) at CERN (550 researchers, 52 institutions) and
- HERA-B at the HERA electron-proton collider at DESY (310 researchers, 32 institutions).

The lifetime of an experiment is unique to the field of high energy physics. Its duration ranges from five to more than twenty years; in between it goes through the phases of planning, R & D, construction of the apparatus, several years of acquiring data, its analysis in terms of the physics followed by publication of the results. Except for the final phases of construction and data-taking, which necessarily take place at the research centres, the rest of the activities are distributed to the home laboratories of the collaborating institutions. The necessary coordination is achieved through electronic media (World Wide Web, e-mail, video conferencing), although frequent meetings of groups and subgroups still prove to be essential. In larger experiments these meetings almost resemble workshops or even conferences, both in the number of participants and in the level of presentations.

Although the field is devoted to basic research into the nature of the Universe, using the highest energies obtainable, the very existence of a joint endeavour of this magnitude, constitutes an ideal breeding ground for new products and technologies. Developed primarily to make the experiments feasible, many of them find widespread application in other areas. The obvious showcase is undoubtedly the World Wide Web. Conceived at CERN as a communication exchange facility for the big collaborations at the LHC, it has in the past years developed into an indispensable tool in almost every field of human endeavour.

ARGUS Collaboration

Although data acquisition at the ARGUS detector at DESY stopped years ago, parts of the analysis are still in progress. In 1997 two articles were published, one describing the $\gamma\gamma \rightarrow \alpha_2$ contributed by our researchers. The analysis of $\gamma\gamma \rightarrow K^{0*}\bar{K}^{0*}$ was performed by our student as a PhD thesis and these results are being prepared for publication.

ATLAS Collaboration

In June 1996 the Slovenian group became the 148th institution to join the ATLAS collaboration. They will build jointly a general-purpose detector to detect 14 TeV proton-proton collisions at the LHC. The detector is expected to be operational by mid 2005.

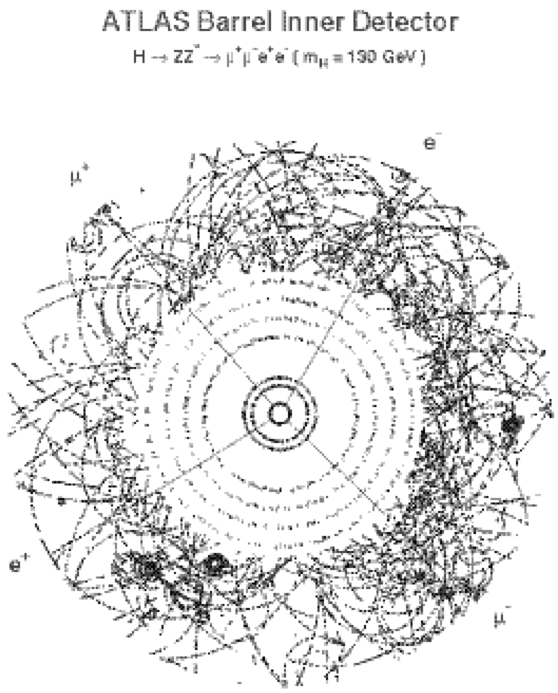

Fig. 1: A simulation of a Higgs boson decay into four leptons as seen by the ATLAS Inner detector. From the centre outwards: three layers of semiconductor pixel detectors, four layers of microstrip detectors and the Transition radiation tracker.

Our researchers are collaborating on the Semiconductor Tracker (SCT) which is part of the ATLAS Inner Detector (Fig. 1). A Technical Design Report on the Inner Detector was submitted in 1997, describing in detail its performance and construction. Our researchers performed a study of the power supply cables to the detectors and electronics. As these cables should provide as small a disturbance as possible to the particles traversing them, a large scale (~ 5 m) flexible printed circuit design on aluminium/kapton laminates was adopted. Electrical and mechanical properties were designed and a production capability study carried out. Preliminary manufacturing results at the ELGO-LINE foundry at Cerknica are encouraging.

The Slovenian group contributed to the radiation hardness programme of silicon detectors.

This was carried out in the scope of the ATLAS SCT effort as well as within a Swiss-Slovenian project with the University of Geneva. A study of the influence of impurities on radiation-induced defects is ongoing in the framework of the ROSE collaboration. We concentrated on the irradiation of strip detectors and *p - i - n* diodes with fast neutrons from the institute's TRIGA reactor facility. A system for cooling and on-line measurement of detectors during irradiation was developed. Two irradiation sites were prepared. The first is located outside the reactor core behind a fission plate and can be used for slow irradiation ($d\phi/dt$ = 2x10^8 n/cm^2) of sizeable samples. The other is a tube at the edge of the core, capable of high fluxes (2x10^{12} n/cm^2), but limited to sample sizes of up to 20 mm.

CPLEAR Collaboration

The CPLEAR collaboration is slowly completing the analysis of the vast amount of data (10 TBy) on strangeness-tagged neutral kaon decays. The extracted parameters on violation of discrete symmetries (CP, T and CPT) represent a new insight into this subject. In 1997, the final results on neutral kaon decays into $\pi^+\pi^-\pi^0$ were published, the Slovenian group having made an important contribution to the analysis. The measured CP violation parameter η_{+-0} and the branching ratio $Br(K_S \rightarrow \pi^+\pi^-\pi^0)$ represent a significant improvement over previous measurements.

The measurement of the kaon regeneration amplitude on carbon, carried out in 1996, was also published. The results, apart from constituting the sole measurement of the amplitude in this energy range, will enable us to halve the systematic error in the measurement of the phase ϕ_{+-} of the CP violation parameter in two charged pion decays.

With the large number of collected K_S decays, CPLEAR is suitable for some rare K_S decay searches. The published result on the branching ratio $K_S \rightarrow e^+e^-$ improved the previous upper limit by a factor of 20 (Fig. 2). This analysis was performed entirely by the Slovenian group.

Using a dedicated trigger, a few hours of data-taking were sufficient to collect enough events to determine the K_SK_S/K_SK_L annihilation ratio and thus the ratio of antiproton annihilations in the *s* and *p* state.

DELPHI Collaboration

After producing the first W^+W^- pairs in 1996, the LEP-2 collider is now successfully becoming a W-pair factory. In 1997, at the center-of-mass energy of 183 GeV, each of the four detectors taking data at LEP-2 delivered about 1000 W-pairs. Physicists from Ljubljana have been taking part in measurements at the DELPHI detector.

In 1997 members of the Ljubljana group participated in data acquisition during the five month long run. Apart from on-line quality checking of measured data, they also shared responsibilities for smooth operation and calibration of two sub-detectors of the DELPHI spectrometer, the ring imaging Čerenkov counter and the silicon tracker.

The large number of reconstructed W pairs allowed precise measurement of the W^+W^- production cross-section in e^+e^- collisions. The cross-section value, obtained from data measured in 1997, is in good agreement with the predictions of the Standard Model (SM), the most accurate theory of fundamental particles and interactions in nature. The implications of this measurement are that various extensions of the SM, predicting significantly different total cross-sections or angular distributions of the W bosons, can already be ruled out.

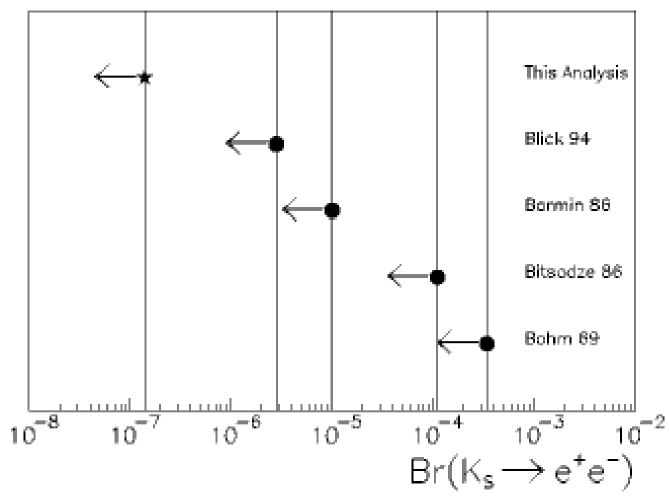

Fig. 2: Time development of the upper limit for the branching ratio $K_S \rightarrow e^+e^-$.

Apart from the cross-section, branching ratios for different decay channels of the W boson were also measured and, as a result, the coupling of W bosons to quarks c and s has been determined. The coupling is parameterised by the V_{cs} element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. Within the achieved precision the measured value of $|V_{cs}|$ supports unitarity of the CKM matrix for three quark generations, incorporated in the framework of the SM.

The missing link in the otherwise consistent SM is the yet unknown mass of the Higgs boson. The latter is of crucial importance, for it is assumed to be responsible for the spontaneous symmetry breaking of the electro-weak (EW) interactions, providing in this way masses to all fundamental particles. With higher beam energy at LEP-2 it is now possible to search for a heavier Higgs boson than at the former LEP-1 collider. Nevertheless, up to now the searches have yielded no results which confirm the existence of a Higgs boson. This sets a lower limit for the neutral Higgs boson mass, which is at present around 80 GeV/c^2. Several extensions of the SM introduce charged Higgs scalars but, as in the case of the neutral Higgs boson, we have found no evidence of their existence in 1997 DELPHI data. Lower limits for their masses vary between 60 and 70 GeV/c^2, depending on the theoretical model predicting the H^+H^- production cross-section.

Apart from direct searches it is also possible to determine the Higgs boson mass m_H from indirect observations. We can make use of the precise measurement of the $W^\pm$ mass or angular distributions of the Z^0 decay products, recorded at LEP-1 between 1990 and 1995. Higher order corrections of the perturbative calculations also include contributions from the virtual Higgs boson exchange and therefore depend on m_H. For example, by comparing forward-backward asymmetries of quarks and leptons from Z^0 decays to SM calculations it is possible to predict the upper limit of m_H to be 450 GeV/c^2. We prepared a new method for measuring the forward-backward asymmetry in $Z^0 \rightarrow bb$ decays by tagging b-quark flavour with fast charged kaons, arising from the $b \rightarrow c \rightarrow s$ quark transitions. The aim of this work is to combine the obtained results with previous measurements and thus to set more stringent limits on m_H.

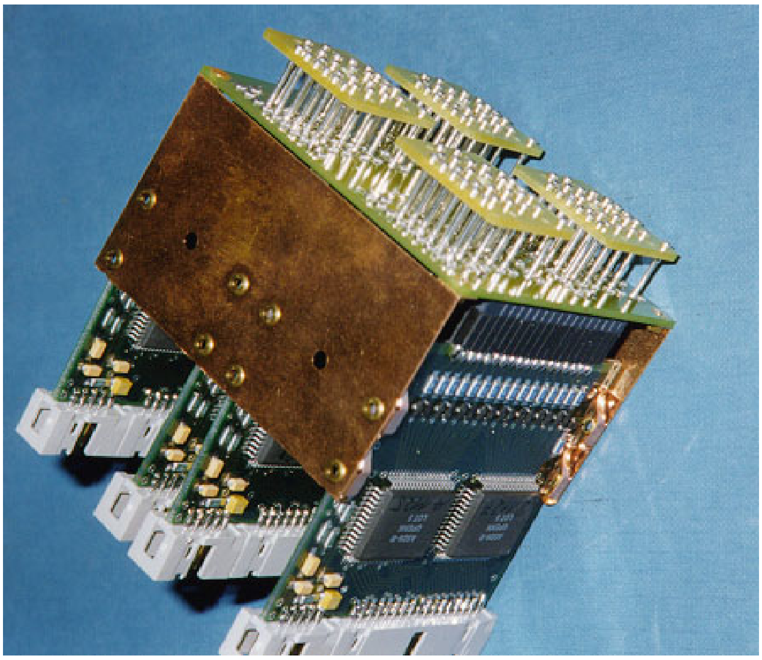

Fig. 3: Basic module of the photon detector for the HERA-B RICH: printed circuit board with four multi-channel photomultipliers, voltage divider and the interface for data acquisition.

HERA-B Collaboration

The construction of the HERA-B spectrometer, an apparatus for studying CP violation in the B system, was continued. In 1997 the design of individual segments of the ring imaging Čerenkov (RICH) counter was finished (Fig. 3). Special care was devoted to preparing the baseboard, a printed circuit which serves as a voltage divider, photomultiplier and readout board support, as well as the photomultiplier-to-readout board interface for signals. In addition, a system for low voltage supply of the electronics readout system was designed, together with the system for preparation and supply of the threshold level with a suitable granularity. It is worth noting that in the development and production of these systems we profited from a very good collaboration with local industry.

As a preparation for the installation of individual components several tests were carried out. A test set-up was prepared where the 2400 multi-anode photomultipliers were tested, and the results were recorded in the form of a database to be used in analysing experimental data. In an electron test beam the prototype of the final version of the supermodule, the basic unit of the photon detector (ten in total cover the photon detector), was tested. The measurements have shown that we can expect 25 photons to be detected per charged track in the HERA-B experiment. This, in turn, is sufficient for a separation between kaons and pions up to momenta of 50 GeV/c. We have also shown that the prototype conforms with all the requirements, i.e. it enables precise positioning of the photomultipliers, it shields well the photomultipliers and the readout system against RF pick-up, and it allows for a reliable supply system. The tests confirmed that the optical collection system used for adapting the granularity of the focal plane to the granularity of the photomultiplier, as well as for reducing the inactive fraction of the photon detector, works as expected.

Two new algorithms were developed for the analysis of data recorded by the RICH counter. The first one enables precise alignment of the mirror segments (80 spherical and 36 planar mirrors) by comparing the detected Čerenkov ring with the prediction given by the tracking system. The second algorithm is an iterative ring search, and was developed by using our experience in the PET image reconstruction.

Development and application of detectors

In the detector development laboratory, applications of high-energy physics techniques to other fields, notably medicine and environmental monitoring, are taking place.

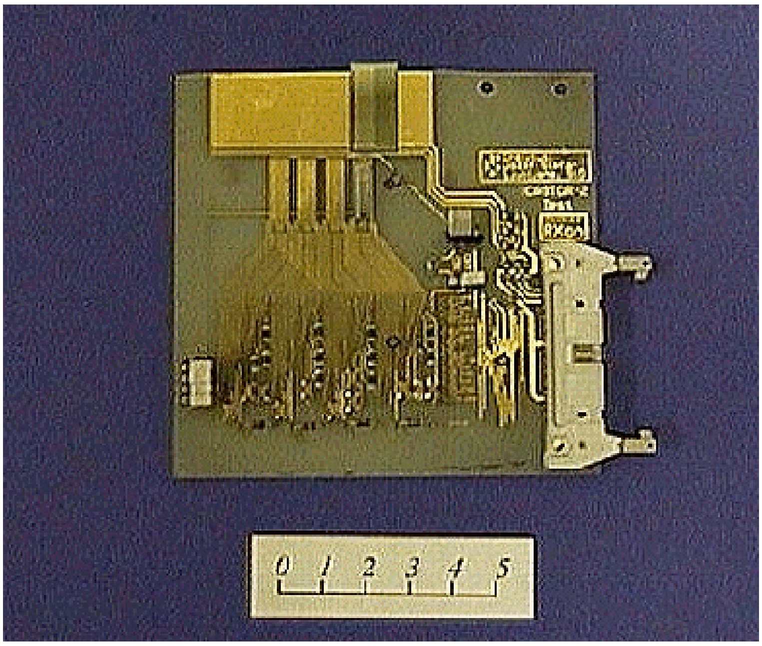

Fig. 4: An X-ray imaging detector: a printed circuit board with a silicon mini-strip detector and the CASTOR read-out chip (scale in cm)

In 1997 we have continued work on improving the scintillator and photomultiplier based apparatus for positron emission tomography and on adapting the computer programmes for reconstructing the tomographic image. Preparations for the production of ^{18}F and for the synthesis of fluoro-deoxy-glucose have also been made.

A feasibility study on the application of silicon detectors for X-ray imaging has been started. Mini-strip detectors with 200 μm pitch and a thickness of 300 μm were evaluated. X-rays impact to the side of the detector, yielding an effective pixel structure with dimensions of 200x300 μm^2. Photon counting was performed using a custom chip CASTOR developed in Strasbourg. A test system was set up (Fig. 4) and images of simple objects taken.

Some outstanding publications in the past three years:

1. *CPLEAR Collaboration: R. Adler, A. Filipčič, I. Mandić, M. Mikuž, D. Zavrtanik et al. (95 co-authors),*
   Tests of CPT symmetry and quantum mechanics with experimental data from CPLEAR
   Phys. Lett. B364 (1995) 239-245
2. *DELPHI Collaboration: P. Abreu, B. Boštjančič, V. Cindro, B. Golob, D. Zavrtanik, D. Žontar et al. (549 co-authors),*
   Observation of orbitally excited B mesons
   Phys. Lett. B345 (1995) 598-608
3. *ARGUS Collaboration: H. Albrecht, G. Kernel, P. Križan, E. Križnič, T. Podobnik, T. Živko et al. (72 co-authors),*
   Determination of the Michel parameters $\overline{\xi}$ and $\overline{\delta}$ in leptonic $\overline{\tau}$ decays
   Phys. Lett. B349 (1995) 576-584
4. *P. Križan, S. Korpar, M. Starič, A. Stanovnik, M. Cindro, G. Močnik, D. Škrk, M. Zavrtanik, A. Bulla, E. Michel, P. Weyers, W. Schmidt-Parzefall, T. Hamacher, R. Schwitters,*
   The RICH detector for HERA-B
   Nucl. Instr. and Meth. in Phys. Res. A371 (1996) 295-299
5. *DELPHI Collaboration: V. Cindro, B. Eržen, B. Golob, T. Podobnik, S. Stanič, D. Zavrtanik, D. Žontar et al. (544 co-authors)*
   Measurement and interpretation of the W-pair cross-section in e^+e^- interactions at 161 GeV
   Phys. Lett. B397 (1997) 158-170