Department of
EXPERIMENTAL PARTICLE PHYSICS (F-9)

In order to probe the ultimate secrets of Nature in the world of elementary particles, accelerators with higher and higher energies have been built in a small number of centres for particle physics. Their cost has grown to the level that future accelerators will be unique facilities of their kind, and all the experiments that are performed in them will involve the international collaboration of researchers. Jointly, we shall be exploring an energy region as yet inaccessible to humans - although still far in scale from the vast blast of the Big Bang which created 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, carry out their experimental work 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, all conducted as international collaborations, with the code names

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- *ARGUS* at the DORIS storage ring at DESY, involving around 60 researchers from 10 institutions,
- *ATLAS* at the Large Hadron Collider (LHC) at CERN (1600 researchers, 148 institutions),
- *CPLEAR* at the Low Energy Antiproton Ring (LEAR) at CERN (120 researchers, 16 institutions),
- *DELPHI* at the 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 may range from five to more than twenty years and encompasses the phases of planning, R & D, construction, several years of data-taking, analysis of the experiment in terms of the physics, and, finally, publication of results. Except for the final phases of construction and data acquisition, which inevitably take place at the research centres, the remainder of the activities are distributed to the home laboratories of collaborating institutions. The necessary co-ordination 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 begin to 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 at the level of the highest energies obtainable, the very existence of a joint endeavour of several hundred researchers to take a significant step in a field as yet unexplored, provides an ideal breeding ground for new products and new technologies. Developed initially to make the experiments feasible, many of them find widespread application in other areas. The most obvious showpiece is undoubtedly the World Wide Web. Conceived at CERN as a communication exchange facility for the big collaborations at the LHC, it has developed into a indispensable and exciting tool in almost every field of human endeavour.

The ARGUS Collaboration

Although data acquisition at the ARGUS detector at DESY stopped years ago, parts of the analysis are still in progress. A review article on the ARGUS achievements appeared in 1996, with the two-photon physics chapter contributed by our researchers. In 1996 Slovenian scientists concluded the analysis of the reaction $\gamma\gamma \to \pi^+\pi^-\pi^0$, improved the statistics of $\gamma\gamma \to \rho\rho$, obtained preliminary results on $\gamma\gamma \to K^*K^*$ and started the analysis of two-photon reactions with baryons in the final state.

The ATLAS Collaboration

In June 1996, the Slovenian group became the 148^{th} institution to join the ATLAS collaboration. They will build jointly a general-purpose detector (Fig. 1) to detect 14 TeV proton-proton collisions at the LHC. The detector is expected to be operational in mid-2005. In 1996, the planning and development of the new detector was being completed for inclusion in a Technical Design Report in 1997, prior to approval of construction.

Our researchers are collaborating on the Semiconductor Tracker (SCT) which is part of the ATLAS Inner Detector. For the study of radiation damage in semiconductor materials an irradiation facility at the Institute's TRIGA research reactor was prepared and silicon microstrip detectors were irradiated by fast neutrons. The evaluation of these experiments is under way in the semiconductor laboratory of the department.

Figure 1: Schematic view of the ATLAS detector.

The CPLEAR Collaboration

The final year of LEAR operation was devoted by the CPLEAR collaboration to regeneration measurements of neutral kaons which will substantially reduce the systematic error on some of the CP violation parameters. At the same time, a test of quantum mechanics was carried out by probing the coherence of the two-kaon wave function.

Analysis of data taken in previous years has resulted in significant improvements to the precision of numerous parameters describing CP, T and CPT violation in the neutral kaon system. The CPT test is of special interest. The CPT theorem is regarded as a cornerstone of all field theories, but there are suggestions of CPT-violating effects in the framework of quantum gravity at energies around the Planck mass. The analysis of CPLEAR data has resulted in setting bounds on the parameters of such a model. For one of the parameters the bound already exceeds the Planck mass, thus entering the region of interest. Another, purely phenomenological model assigns all CPT violation to the mass difference between the neutral kaon K^0 and its antiparticle $\bar{K}^0$. CPLEAR results showed the difference between the two masses to be less than 10^{-18}.

Slovene members of the collaboration took part in the analysis of the three-pion and semileptonic decays and set a limit to the rare $K_S \rightarrow e^+e^-$ decay. In addition they actively contributed to regeneration measurements.

The DELPHI Collaboration

Until October 1995 the energy of electrons and positrons in the LEP collider was tuned to 90 GeV for copious production of Z^0 bosons. Since then, the energy has been gradually increased and, from the middle of 1996, it has been possible to produce pairs of W^+W^- bosons. The first W^+W^- pair ever observed was detected in the DELPHI spectrometer and its striking image is shown in figure 2. The availability of higher energies opened up a new area of research, dedicated mainly to tests of the Standard model and to the search for particles and phenomena beyond it. Among the more important issues is the precise measurement of the mass of the $W^\pm$ boson. The preliminary result of the invariant mass spectrum for pairs of jets is shown in figure 3, where a prominent peak at the $W^\pm$ mass can be seen.

The involvement of Slovenian scientists in 1996 can be divided into two categories according to the collision energies involved: analysis of data, recorded in previous years, from studies of the production and decays of the Z^0 boson, and analysis of data taken at collision energies of 130 - 170 GeV, together with on-line monitoring and calibration of the spectrometer.

In the first category, members of the department were active in b-quark physics. The partial decay width for the decay of Z^0 to a pair of $b\bar{b}$ quarks was measured. Optimal separation of b decays from those into lighter quarks was obtained by a method based on neural networks. With partially reconstructed semileptonic decays, the lifetime of the B^0_S meson was measured and the precision of the result makes this among the best estimates of the quantity.

Figure 2: A three-dimensional reconstruction of the first W^+W^- pair ever observed. The event was recorded on July 10, 1996 in the DELPHI spectrometer. Both W^+ and W^- bosons decayed into a pair of quarks, which produced four jets of particles in the detector. The $W^\pm$ bosons are produced nearly at rest, so the jets are back-to-back and have an energy equal to half of the $W^\pm$ boson mass, namely 40 GeV each.

Figure 3: Invariant mass of pairs of jets, produced in collisions of electrons and positrons at a centre-of-mass energy around 170 GeV. The peak in the spectrum results from decays of $W^\pm$ bosons. Data originate from the DELPHI spectrometer.

At higher energies, special attention has been given to a feasibility study on measuring the coupling, V_{CS}, between the c and s quarks. In the Standard model this coupling is an element of the Cabbibo-Kobayashi-Maskawa matrix describing the mixing between quark generations. The coupling value is directly reflected in the number of c- quark pairs produced in decays of $W^{\pm}$ bosons. From data acquired in 1996, the accuracy of the coupling matches that of the world average. With the improvement in statistics expected in subsequent years, this measurement could provide one of the more direct tests of the Standard model.

The upgrade of the silicon microstrip detector, involving active collaboration from the department's researchers, was completed in 1996 and the detector was installed in the DELPHI spectrometer. It is composed of 48 modules with a total of 2000 readout channels (Fig. 4). During data acquisition the system showed stable behaviour, with high efficiency and a good signal-to-noise ratio (35:1 for minimum ionising particles).

The HERA-B Collaboration

The construction of HERA-B, an apparatus designed to measure CP violation in the B-meson system, was continued at the HERA ring at DESY in Hamburg in 1996. B mesons will be produced in collisions of 800 GeV protons with a thin copper wire target. The trigger will accept only a well-defined final state $B \rightarrow J/\psi\ K^0_S \rightarrow l^+l^-/\pi^+\pi^-$. In 1996 part of the spectrometer was installed and tested, including tracking chambers, electromagnetic calorimeter, muon chambers and the silicon vertex detector. With this basic configuration, system tests and background level measurements were performed.

Three types of photodetectors were evaluated for the use in the Ring Imaging Cherenkov counter. Due to ageing problems of the other two, a multi-anode photomultiplier was chosen in early 1996 as the final solution. The rest of the year was devoted to the design and testing of an optical adapter to match the granularity requirements in the focal plane of the detector to those of the photomultiplier. An adapted readout module of the tracking system was used to process the signals and such a configuration showed adequate behaviour during tests.

Figure 4: One half of the assembled silicon microstrip vertex detector before installation in the DELPHI spectrometer. From left to right: detectors of the barrel part (dark plates), their readout electronics on hybrids (blue), forward detectors (dark gold plates) partially covered by hybrids (blue and gold, one marked B-25), electronics drivers and supplies. The forward detector hybrids were produced at IJS.

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. In 1996 a scintillator based positron emission tomograph was refurbished. The response of a 32 X 32 cm^2 gamma ray detector based on multiwire chambers and a converter was evaluated.

Refurbishing the tomograph involved a new data-acquisition system which packs co-ordinates of the two concurrent gamma rays into a single 16-bit data word (4 bits per co-ordinate) and a system to control and detect movements of the rotating detector arms. The apparatus was tested with point sources and phantoms. The resolution obtained is adequate for imaging larger human organs.