8 Particle Physics at DESY/HERA (HERA-B)

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in collaboration with:
the Universities of Heidelberg and Siegen and 31 further institutes from outside Switzerland

(**HERA-B** collaboration)

Originally we started to contribute to the development of microstrip gas chambers, which work well in a high-rate hadronic environment, with a short term and a long term objective.

The long range goal was linked to the participation of our institute in the CMS collaboration at LHC. The technical design report for this planned detector foresaw microstrip gas chambers for the central and forward/backward barrel tracker. Various refereeing committees from outside and inside of the collaboration defined milestones for the acceptance of the reference solutions, which were proposed by the participating institutions. These milestones were met satisfactorily, in particular after the analysis of several test runs at PSI in 1999 was completed. Despite this fact it was decided by the tracker institution board in December 1999 and finally approved by the CMS collaboration board in January 2000 to build an all silicon tracker. The basis for this decision was that a single technology gives the highest chance for delivering a working tracker on schedule. Since our institute is already contributing to the silicon based pixel detector of CMS (see CMS section of this annual report), it was decided to end our involvement with the construction of the forward/backward barrel tracker.

The short range goal was linked to the inner tracker of the HERA-B experiment at DESY, where the rate requirements are similar to those expected for CMS. Here we joined groups from Heidelberg and Siegen and helped building this microstrip gas chamber based detector part. After U. Straumann accepted an offer for a full professorship at our institute and left Heidelberg for Zürich, the Zürich group within HERA-B is now stronger and we decided to continue our participation for a few years on a modest level, i. e. with typically one graduate student and two postdocs. O. Steinkamp from U. Straumann's group had coordinating functions within the outer tracker group of HERA-B and is one of the eight run coordinators of this experiment.

We concentrate in our report mainly on the Zürich contributions to the inner tracker and on our independent measurements concerning the microstrip gas chambers used in that set up, but give also, as last year, a short account of the status of the experiment.

8.1 Microstrip gas chamber development for the inner tracker

During the last year we finalized the design for the support structure of the four inner tracker stations inside and before the HERA-B magnet. The complete set was built in our workshop and successfully installed in the detector before the end of 1999. At IMT-Greifensee the production of substrates for other stations and replacement of faulty chambers continued. The main order was completed and some additional spare plates were produced. We controlled their quality with our test setup at the company. In 1999 we further tested detectors at PSI with a set of three chambers instrumented with the complete readout electronics (see last year's report [1] for a description of the detectors).

8.1.1 The status of the inner tracker

In 1999 a major part of the inner tracking system was completed and installed at the HERA-B experiment. The system consists in total of 10 stations with 184 detectors. Our group was responsible for the design and the construction of the support structure for the four stations in and before the magnet as well as for the necessary infrastructure (gas, electronic patch panels, cabling, etc.). The system contains 40 MSGC-GEM-detectors in total, with four detectors arranged around the beam pipe combined to one active layer (see Fig. 8.1). The first station in front of the magnet has four layers and each of the three stations inside the magnet two layers. The support structure was optimized to keep the material budget as low as possible, while still allowing for precise mechanical positioning of the detectors.

Figure 8.1: *Left: view of one half of the first station in front of the magnet. The special arrangement of the different layers allows for an overlap of the detectors. Right: view along the beam pipe in +z direction in the magnet. One can recognize the three stations which are instrumented with MSGC's because of the small cutout for the beam pipe.*

Presently all efforts are directed towards commissioning of the chambers in the experiment under running conditions. Every detector has to be trained over about a week, before it can be operated under nominal working conditions. This phase is very important and has to be done in a very safe way. As the system comes now into operation all the necessary infrastructure (gas-system, the slow control system - which is crucial to guarantee a save operation) has to be finalized, adapted and often also improved over the original design. In early March tracks were already successfully reconstructed from the information of different layers of a given station. In the next step all the inner tracking stations need to be combined in the analysis. These track segments have then to be linked to the other detectors, which then also allows an alignment of the system.

Table 8.1 summarizes how many substrates were produced at IMT in total. At the beginning of last year the production of type 1 substrates from the main order (40 plates, see also last year's report [1]) was completed. Spares of all types were manufactured in 1999 and tested like all previous ones with the dedicated setup we installed at the company for that purpose.

Table 8.1: Various substrates [1] produced and tested at IMT for the HERA-B experiment.

	Order				
Substrate type	main	second	third	fourth	Sum
1	37		7		44
2	136	32	6	10	184
3	58	7			65
total	231	39	13	10	293

8.1.2 MSGC tests at PSI

Our previous tests of detectors at PSI were mainly devoted to study their radiation hardness and the ageing properties. In last years tests we measured the homogeneity of our rather large detectors. Large differences in the pulse height between different anodes will influence the efficiency of the detectors and finally determine the quality of the tracking system of HERA-B. They could be introduced by mechanical tolerances (non-flatness of the GEM-foils, variations in the thickness of the frames, etc.) and gain variations in the electronics (variation from channel to channel - from chip to chip). The setup is shown in Fig. 8.2.

Figure 8.2: *View of the experimental setup used at PSI with the chambers mounted on an x, y-table for beam scans.*

To guarantee, that the radiation does not influence and eventually damage the detector a very low rate pion beam was used during the homogeneity measurement. The beam was horizontally (x-direction) defocused to illuminate the whole detector. To determine the vertical position (y-direction, parallel to the detector strips) of the tracks we used two scintillators. The width of these counters (25 mm) determined the position resolution for our scan in vertical direction. Two standard HERA-B MSGC-GEM-detectors and one further detector where the GEM-foil was stretched in a way to guarantee a more precise flatness were available for this test. All three detectors were equipped with the complete standard HERA-B readout chain. Figures 8.3 and 8.4 show some typical results from these studies, which will be described in detail in the thesis of T. Walter [2].

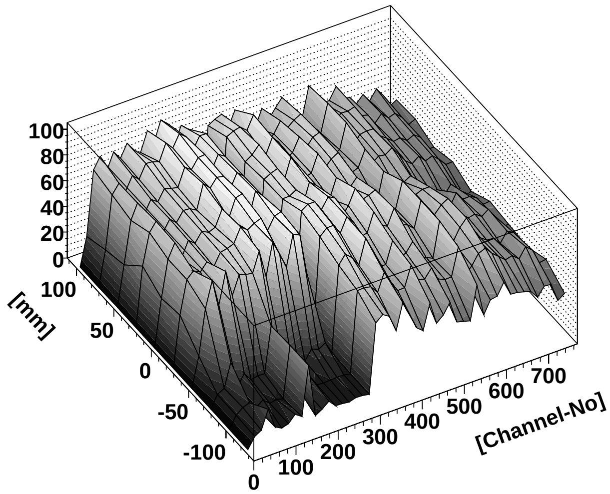

Figure 8.3: *The measured charge distribution of chamber 1 in function of the position. The hole in the lower corner results from the beam pipe cutout.*

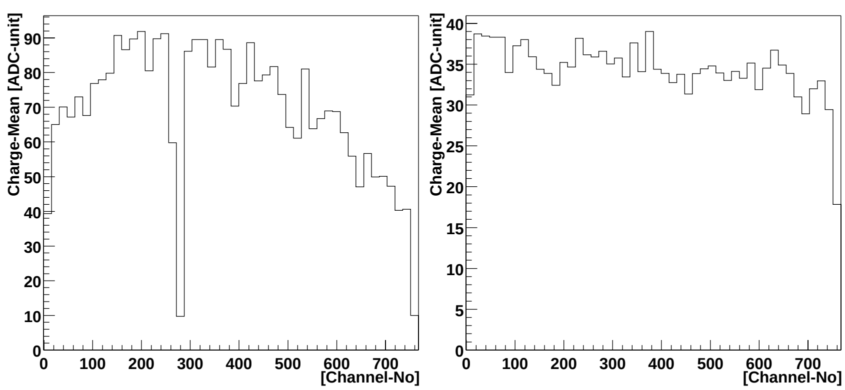

Figure 8.4: *Measured mean charge versus strip number for two different chambers. One channel corresponds to an anode strip. The bins are 20 strips wide.*

8.2 Status of the HERA-B Experiment

8.2.1 Comparison with other B projects

The HERA-B experiment at DESY has been designed to measure CP-violation parameters in the system of neutral B mesons, especially in the so-called golden decay channel $B^0_d \rightarrow J/\psi K^0_s$. The construction of the experiment is nearing completion, the targets and large parts of the detector are routinely operated. Commissioning of the first-level trigger has commenced and defines the critical path for the startup of physics data taking, which should begin in spring 2000. For a recent summary of the HERA-B experiment we refer also to O. Steinkamp's presentation at the Taipeh conference [3].

The standard model of particle physics predicts sizeable CP violating asymmetries in many different decays modes of B and $\overline{B}$ mesons. Measurements of these asymmetries will put a stringent test on the Standard Model. The golden decay channel is one of the theoretically cleanest and experimentally easiest accessible. Analyses from the LEP experiments Opal and Aleph, and from the CDF collaboration at Fermilab give indications for an asymmetry in this decay channel but the statistical error on these measurements are large.

HERA-B is one of several upstarting experiments that are going to produce large enough samples of B mesons to establish CP violating effects and test Standard Model predictions.

BaBar and Belle are experiments at asymmetric e^+e^- colliders at SLAC and KEK, respectively. Both are entering the data taking phase, while the CDF and D0 experiments at the Fermilab Tevatron are undergoing major detector upgrades that will allow them to study B-meson physics.

In HERA-B, $b\bar{b}$ quark pairs are produced in proton-nucleon interactions on thin wire targets that are introduced into the halo of the HERA proton beam. Different from the e^+e^- collider experiments, all species of B hadrons are produced, giving access to a broader range of observables. Especially the investigation of the oscillation and decays of B_s mesons will give additional constraints on Standard Model parameters. Compared to the general-purpose experiments at Fermilab, the strength of HERA-B lies in its particle identification capabilities. Efficient kaon identification over a wide momentum range is crucial for a large number of measurements.

The main experimental challenge of HERA-B is due to the small $b\bar{b}$ production cross section ratio of $\sigma_{b\bar{b}} / \sigma_{\mathrm{inel}} \approx 10^{-6}$. The experiment must run at a continuous inelastic pN interaction rate of 40 MHz in order to collect in one year of data taking the 1500 reconstructed golden decays that are needed for a competitive measurement of the CP asymmetry in this channel.

Consequently, one of the most challenging systems of HERA-B is the multi-level trigger that must extract the signal channel from the overwhelming inelastic background. In addition, the construction and commissioning of the experiment suffered considerable delays due to various ageing problems discovered in the tracking detectors, that could not withstand the high rates of high-multiplicity hadronic events.

8.2.2 The detector

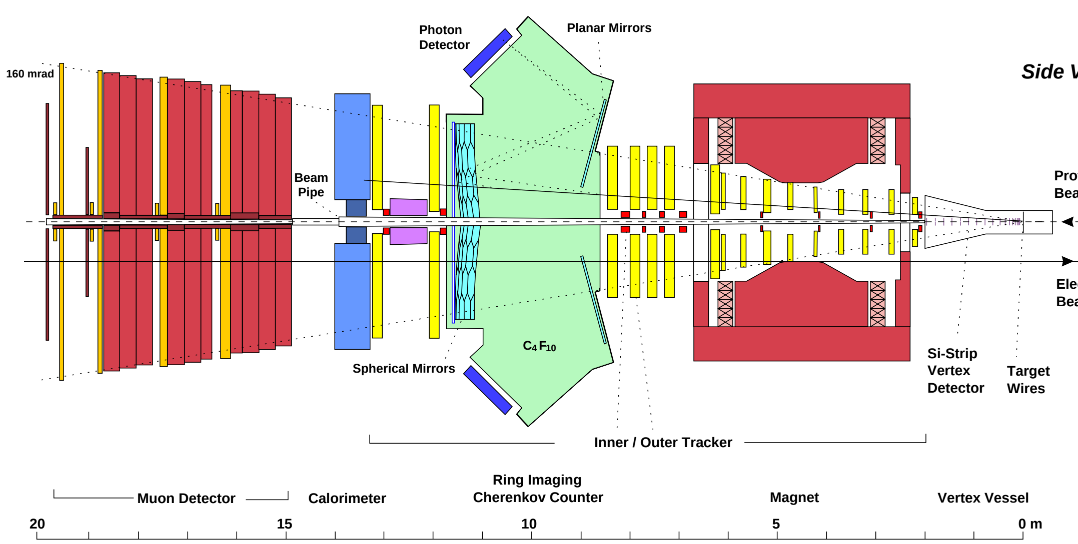

Figure 8.5: *The HERA-B detector*

The experimental apparatus (Fig. 8.5) consists of a large-acceptance forward magnetic spectrometer with a 2.1 Tm normal-conducting dipole magnet, which is complemented by detector elements for vertexing, triggering and particle identification. The main tracking system consists of 13 stations. In each station, the inner tracker (see above) covers the innermost 20 cm around the beam pipe, where particle fluxes are highest. The outer part of the acceptance is covered by up to 4.5 m long honeycomb wire chambers. The first of these detectors that were operated in HERA-B suffered from various ageing problems. It took a considerable R&D program to demonstrate that no major redesign of the detector concept was necessary and that the observed problems could be overcome by different choices of materials and gas mixture, and improved production techniques. The detector has been completed end of 1999, commissioning is in progress.

Just downstream of the target stations, a seven-station silicon strip vertex detector is located in retractable Roman pots inside the HERA vacuum vessel. For data taking, the detectors approach the proton beam to 1 cm, they are retracted during beam insertion. The system is completely installed and routinely operated. It performs well, primary vertex resolutions approach design values.

A gaseous RICH detector mainly serves to identify kaons for tagging purposes. It employs multi-anode photo tubes to detect Cherenkov light produced in a 2.5 m long C_4F_{10} radiator. The detector is fully installed and commissioned, its performance matches design values. An early analysis, comparing measured RICH ring radii with track momenta, shows a clear $p/K/\pi$ separation.

A sampling electromagnetic calorimeter allows to trigger on high transverse momentum (p_T) electrons and provides offline reconstruction for decays involving photons. It uses a shashlyk design with scintillating fibers in tungsten and lead absorbers. The detector is fully installed. In the absence of tracking information, a preliminary calibration was performed using the $\pi^0 \to 2\gamma$ invariant mass. Clear $\eta \to 2\gamma$ and $\omega \to 3\gamma$ signals are seen.

The muon detector consists of four stations, which are separated by iron/concrete absorbers. The innermost part of each station is covered by gas pixel detectors, the outer part by gas tube chambers. The last two stations are equipped with a pad readout for triggering on high-p_T muons. The detector is fully installed and operational. Observed occupancies and coincidence rates between the trigger layers agree with expectations.

8.2.3 The trigger system

The HERA-B multi-level trigger system is based on the reconstruction of high-p_T tracks, two-particle invariant masses and detached vertices. High-p_T electron, muon and hadron pre-triggers are generated by clusters in the calorimeter, coincidences in two layers of the muon system, or three-fold coincidences from dedicated pad detectors inside the magnet. Any such pre-trigger defines a geometrical region of interest (RoI) which is sent as a message to the first-level trigger. At nominal interaction rates, several such RoIs will be found for each HERA bunch crossing. Almost the full acceptance of the calorimeter is equipped with pre-trigger electronics. The system is in routine operation. Muon pre-trigger electronics are installed on a significant part of the detector and perform according to expectations. Both systems should be completed in March 2000. Installation of the hadron pre-trigger system is expected to begin in March.

The first-level trigger (FLT) must provide a reduction factor of about 200, within a latency of less than 12 μs. Starting from the RoIs defined by the pre-trigger systems, it searches for tracks through four tracking stations downstream of the magnet. Track candidates are passed as messages between custom-made processors, each of which covers part of the acceptance of a station. On reception of a message, the processor searches the corresponding RoI for matching hits and generates an updated message which it sends to the appropriate processors in the next station. A momentum estimate is calculated for tracks that were followed through all stations. The trigger decision is based on single high-p_T tracks and on the invariant mass of track pairs. Most of the FLT hardware has been produced, installation and commissioning are under way. The system is planned to reach full power by April 2000.

The second- and third-level triggers together have to provide a reduction factor of about 1000. The second-level trigger re-processes FLT tracks. It performs a track fit, follows track candidates through the vertex detector and tries to fit vertices. The trigger decision is based on single-track impact parameters or on secondary vertices. The third-level trigger can refine the second-level decision, using full event information. Both trigger levels are integrated with the data-acquisition system on a 240-processor farm of Pentium processors running the Linux operating system, a high-bandwidth switch, and a system of so-called second-level buffers. The hardware is in routine operation, portions of the second-level algorithm have been exercised routinely. Figure 8.6 shows a reconstructed $J/\psi \rightarrow e^+e^-$ signal, where two high-p$_T$ calorimeter clusters with matching tracks in the vertex detector were demanded. A loose vertex cut was made and one of the tracks was required to have an associated bremsstrahlung cluster. No information from the main tracking detectors was used.

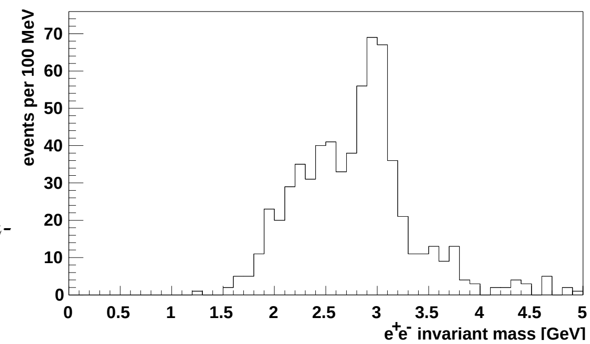

Figure 8.6: *$J/\psi \rightarrow e^+e^-$ signal, reconstructed by the second-level trigger*

The fourth-level trigger is intended for full online event reconstruction. It runs on a 200-node farm of Pentium processors, which is connected via standard Ethernet technology and operates at a data throughput rate of 50 Hz. The farm is complete and routinely in use for data logging, monitoring purposes and partial reconstruction. The full reconstruction code exists and is being tuned for online running.

After significant delays, the HERA-B detector is nearing completion. Large parts of the apparatus have been operated routinely over the last year and have performed up to expectations. The critical path is now defined by the installation and commissioning of the first-level trigger. HERA running will continue until September 2000, when the accelerator will be shut down for several months to allow for a major luminosity upgrade. If routine operation of the first-level trigger can be established, HERA-B should be able to accumulate before this shutdown a solid sample of B decays and possibly contribute to the ongoing effort to establish CP violation in decays of neutral B mesons. After the shutdown, especially the high-p$_T$ hadron trigger will open a wide field of studies in CP violation and heavy-flavour physics.

References

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