3. THE HERA – B EXPERIMENT

In this chapter we discuss the setup of the HERA – B experiment. We start with an introduction on the design of HERA – B (section 3.1) and a short description of the accelerator (section 3.2). In the detector description (section 3.3) emphasis is put on the components used in the analysis of this thesis. The trigger and data acquisition system is described in section 3.4. The trigger setup actually used in 2000 is discussed in the last section of this chapter (3.5).

3.1 Introduction, design of HERA – B

The HERA – B detector was proposed in 1994 [34] as a fixed target experiment at the 920 GeV proton beam of HERA at DESY. Its primary goal was to search for CP violation in the B system, more precisely in the so called ‘gold plated’ decay \( B^0 \to J/\psi K_S^0 \). It was also designed to study other B decays and quarkonium production.

The measurement of CP violation in the B system has been established by other experiments [35, 36] with a precision not attainable by HERA – B. Therefore, this measurement is no longer its primary goal. However, the aim of collecting a large sample of \( B^0 \to J/\psi K_S^0 \) decays has been the driving force in the design of the detector and trigger.

Figure 3.1 shows a schematic view of the ‘gold plated’ decay in the HERA – B environment. To detect CP violation in the \( B^0 \to J/\psi K_S^0 \) mode, one needs to fully reconstruct the decay and measure the decay rates for \( B^0 \) and \( \bar{B}^0 \) mesons independently. Since both the \( B^0 \) and the \( \bar{B}^0 \) can decay into \( J/\psi K_S^0 \), the initial flavour of a reconstructed B needs to be determined via the other B in the event. This tagging can be done, for example, by determining the charge of a lepton or kaon from the decay of the B. For the separation of kaons and pions, a particle identification device is installed. The \( J/\psi \) is required to decay into two leptons, which is the signature used in the trigger. A vertex detector enables the measurement of the decay length of the B-meson. The typical decay length at HERA – B is about 1 cm. To measure CP violation in the ‘gold plated’ decay, about 1500
3. The HERA-B experiment

![Diagram of B meson decay](image)

**Figure 3.1.** Schematic overview of the 'gold plated' decay $B^0 \rightarrow J/\psi K^0_{S}$. The B-meson has a decay length of about 1 cm. The $J/\psi$ is required to decay into two leptons, a signature used in the trigger. Decay products of the second B in the event are used for tagging.

Reconstructed $B^0 \rightarrow J/\psi K^0_{S}$ decays need to be recorded. HERA-B has to deal with small signal over background ratios. At $\sqrt{s} = 41.6$ GeV, the cross section for $b\bar{b}$ events is about $10^{-6}$ of the total inelastic cross section. The probability of forming a $B^0$ or a $\bar{B}^0$ out of the produced $b\bar{b}$ pair is about 0.8. The branching ratio for the gold plated channel is about $9 \times 10^{-4}$. To collect sufficient $B^0 \rightarrow J/\psi K^0_{S}$ decays, taking into account an estimated trigger and reconstruction efficiency of 0.005, a total of $4 \times 10^{14}$ inelastic interactions must be delivered. The bunch crossing rate of the beam is 10 MHz. Therefore, to measure CP violation in one year ($10^7$ s), HERA-B has to operate with 4 overlapping interactions per event.

The large particle flux, radiation load and event rate posed serious challenges to the design and operation of the detector. The main components of the detector, trigger and readout electronics had to be designed at the forefront of technology. As a consequence, the R&D phase took much longer than expected and the detector was only completed in the spring of 2000; two years later than originally scheduled.

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1 This efficiency includes the branching fraction of $K^0_{S} \rightarrow \pi^+ \pi^-$ and $J/\psi \rightarrow l^+ l^-$, since these are the decay channels that we are reconstructing.
3.2 Hera

The HERA-B experiment is one of four experiments at the HERA (Hadron-Elektron-Ring-Anlage) accelerator of DESY (Deutsches Elektronen Synchrotron). HERA is a storage ring with a circumference of about 6 km in which protons and positrons (or electrons) run in opposite directions in two separate beam pipes (see figure 3.2). The protons are accelerated to 920 GeV, the positrons/electrons to 27.5 GeV. The two beams collide at two interaction points, where the H1 and ZEUS detectors are located. A third experiment, HERMES, uses only the electron beam. HERA-B makes use of the proton beam.

![Figure 3.2](image-url)  
**Figure 3.2.** The HERA accelerator. HERA stores a proton beam of 920 GeV and an electron beam of 27.5 GeV in two storage rings of about 6 km length. Four detectors are installed in HERA, of which HERA-B is one.

The proton beam contains 220 bunches, of which only 180 are actually filled. The filling scheme of the proton bunches is shown in figure 3.3. The bunches are separated from each other by a bunch crossing period of 96 ns, giving the previously mentioned bunch crossing rate of 10 MHz.
3. The HERA-B experiment

Figure 3.3. Filling scheme of proton bunches in HERA. 180 of the 220 bunches are filled in three trains of 60 bunches. The bunches are separated by 96 ns.

3.3 Detector

The HERA-B experiment is a forward magnetic spectrometer with a vertex detector, extensive tracking and particle identification systems [34, 37]. It has a geometric coverage from 15 mrad to 220 mrad in the bending plane and 15 mrad to 160 mrad in the vertical (non bending) plane. A side view of the detector is shown in figure 3.4. We define the $z$ axis as the beam direction, the $y$ axis as the vertical and the $x$ axis as the horizontal direction. The different components of the detector are discussed below.

3.3.1 Target

The target system [38] consists of two stations of four wires each, separated by 4 cm in the direction of the beam. The wires are arranged around the beam axis as depicted in figure 3.5. The wires are made of different materials: carbon, aluminium, titanium and tungsten, yielding an atomic mass range from 12 to 174.

The wire targets are moved into the halo of the beam, such that protons can be extracted without interfering with the data collection of the other experiments at the collider. It is possible to run with all eight wires inserted. The interaction rate and the distribution of interactions per wire can be adjusted by steering the wires individually.

The global interaction rate is measured with a set of scintillator counters. The rate steering is done simply by moving the wires closer to or further away from the beam. The charge produced in each target wire is measured by a charge integrator. In a multi wire run, this information is used to decide which wire should move, to keep the rate on each wire as equal as possible. The rate tuning and equalisation is performed automatically. The positions of the wires are continuously adjusted to obtain the desired rate. Since the target wires effectively ‘scrape’ away protons in the halo of the beam during running, the wires move steadily closer to the beam,
Figure 3.4. Side view of the HERA-B detector.
in order to keep a constant interaction rate.

The triggered data of 2000 was taken with a maximum of two wires operated simultaneously. The two wires were made of Carbon (1000 $\mu$m longitudinally and 100 $\mu$m transversely) and Titanium (500 $\mu$m and 50 $\mu$m, respectively).

![Diagram of target system](image)

**Figure 3.5.** The target system consists of eight wires which can be moved simultaneously into the halo of the beam. The wires are steered in- and outwards, in order to reach the desired interaction rate. The triggered data in 2000 was collected using only the inner 2 (Carbon) and below 1 (Titanium) wires.

### 3.3.2 Vertex detector

The vertex detector [39] (VDS) consists of eight stations of single and double-sided silicon micro-strip detectors. Each station consists of eight modules arranged in four quadrants. Figure 3.6 shows the layout of the detector planes.
The track and vertex resolution are dominated by multiple scattering. Therefore, the amount of material inside the HERA B acceptance is minimised. The first seven stations are mounted on a roman pot system inside a vacuum vessel. They can be retracted during injection and beam steering operations and inserted close to the beam during running. The last station (superlayer 8) is mounted directly behind the 1 mm thick exit window of the vacuum vessel.

The size of the detector planes is $50 \times 70 \text{ mm}^2$. The strips, with a read-out pitch of $50 \mu\text{m}$, are positioned on the planes in four different stereo views. The angles with respect to the vertical axis are $-2.5, 2.5, 87.5$ and $92.5$ degrees.

In 2000, the VDS performed close to design specifications. A hit efficiency better than 97% was obtained for 97 of the 116 detector planes. The stand alone tracking efficiency for tracks with momentum greater than 1 GeV is better than 95%. The

**Figure 3.6.** Schematic picture of the VDS layout. The VDS consists of eight superlayers, of which the first seven can be retracted during injection. Each superlayer consists of eight single or double-sided silicon micro-strip detectors, with strips in four different orientations.
Figure 3.7. Reconstructed primary vertices, eight wire run. All eight wires can be clearly distinguished.

A single hit resolution of 12 μm provides a two track vertex resolution of 60 μm in the $x-y$ plane and 600 μm in the $z$ direction. Multiple interactions can be well separated, provided they occur on different wires. Figure 3.7 shows the spatial distribution of reconstructed primary vertices in an eight wire run. The images of the eight wires can be clearly observed.

For safety reasons, during running in 2000, the roman pots were not moved as close to the beam as was intended. The detectors were limited to a distance of 15 mm from the beam (design value 10 mm), resulting in a low angle acceptance of 15 mrad (design value 10 mrad). Since the detector covering this area in the main tracking system (the inner tracker) could not be used in the trigger, as will be discussed below, this acceptance loss was not dramatic.

### 3.3.3 Main tracker

The main tracker is divided into a fine grained *inner* (ITR) close to the beam, and a large area *outer* (OTR) tracker further away from the beam, to cope with the strong...
increase in particle flux as the distance to the beam decreases. The tracking system is divided into three parts. The first set of tracking stations, the magnet chambers (MC), is placed in the dipole magnet with an integrated field of 2.13 T·m. It is followed by a second set, the pattern recognition chambers (PC), which is placed between the magnet and the Cherenkov counter (RICH, see section 3.3.5). The third set of tracking chambers, referred to as trigger chambers (TC), is placed just in front of the calorimeter. In total the tracking system consists of 13 superlayers as depicted in figure 3.8. Every superlayer consists of several layers of ITR and OTR chambers with three different wire or strip orientations: 0 mrad, +80 mrad and -80 mrad with respect to the y axis.

**Figure 3.8.** Arrangement of the superlayers of the inner and outer tracker. The inner tracker stations cover the region around the beam pipe (<25 cm), the outer tracker covers the region further away from the beam. There are three sets of tracking stations. The first set of chambers (MC1-MC8 and MS01-MS07) is placed inside the magnet. The pattern recognition chambers (PC1-PC4 and MS10-MS13) are located between the magnet and the RICH and the trigger chambers (TC1, TC2 and MS14, MS15) between the RICH and the ECAL.
The ITR [40] uses micro-strip gas chambers with gas electron multipliers. It covers the distance between 6 and 30 cm from the beam axis. The strip pitch is 300 μm which provides a spatial resolution of 80 μm. Figure 3.9 shows a schematic picture of one ITR module.

In 2000, commissioning of the ITR was not finished. The hit efficiency was about 90%. Due to technical problems in the trigger output, the ITR could not be used in the trigger. The OTR [41] is constructed from honeycomb drift chambers with wire pitches of 5 mm for the region closer to the beam pipe and 10 mm for the outer region. The largest superlayers extend up to 3 m from the beam axis. The honeycomb structure is shown in figure 3.10.
In 2000, the OTR readout suffered from electronic noise related to the interface to the trigger hardware. As a consequence the hit resolution of about 350 \( \mu \text{m} \) and the hit efficiency of about 90\% was poor compared to the design values.

### 3.3.4 Calorimeter

![Diagram of an ECAL module.](image)

**Figure 3.11.** Sandwich structure of an ECAL module.

Behind the last superlayer of the main tracker, 13.5 m from the target, the electromagnetic calorimeter[42, 43] (ECAL) is installed. It measures the energy deposited by particles. It is used to identify electrons and photons. Photons leave no track in the tracker and electrons can be identified since their energy should match the measured momentum \( (E/p \approx 1) \). Hadrons leave on average only a small fraction of their energy in the ECAL \( (E/p \ll 1) \).

The ECAL is a ‘shaslick’ sampling calorimeter with absorbers sandwiched between active layers of scintillator material (figure 3.11). Photons and electrons hitting the absorber will produce a shower of secondary electrons and photons. The light produced by these showers in the scintillators is collected and guided to photo-multipliers located behind the calorimeter using wavelength shifting fibres.

The size of the calorimeter is \( 624 \times 468 \text{ cm}^2 \), covering the full HERA – B acceptance. It is divided into three parts to allow for the differences in particle flux (figure 3.12). The innermost region is equipped with cells of \( 2.24 \times 2.24 \text{ cm}^2 \). For this region the absorber material used is tungsten, while for the middle and outer region the cheaper lead is used. The middle and outer region have cell sizes of \( 5.6 \times 5.6 \text{ cm}^2 \) and \( 11.2 \times 11.2 \text{ cm}^2 \), respectively.
Figure 3.12. Layout of the ECAL. The ECAL is divided into an inner, a middle and an outer part, with different cell sizes. The square in the middle is the hole for the proton beam pipe; the lower right square is the hole where the electron beam pipe passes through.

In 2000, electronic noise distorted the readout of the ECAL. The energy resolution in the inner ECAL has been measured to be $\frac{\sigma(E)}{E} = 0.22/\sqrt{E} \pm 0.017$. The spatial resolution in the inner ECAL is about 0.2 cm for an electron energy greater than 30 GeV.

3.3.5 Other components

Apart from the subdetectors used in our analysis and discussed above, two other major components should be mentioned: The Ring Imaging Cherenkov Counter (RICH) and the muon system (MUON).

The RICH[44, 45] is used for the separation of kaons and pions. It is located between the PC and TC superlayers of the tracking system. Cherenkov light emitted in the 2.5 m long C\textsubscript{4}F\textsubscript{10} radiator volume is projected by focal and planar mirrors
3.3. Detector

Figure 3.13. Distribution of the square of the Cherenkov angle measured in the RICH, versus the square of the inverse momentum. The bands correspond to different particles.

as a ring image on the photo multiplier plane. The projected ring provides information on the velocity of the particle. The relation between the velocity and the momentum of the particle, as measured in the main tracker, is used for particle identification by the mass of the particle.

Figure 3.13 shows the distribution of the square of the Cherenkov angle versus the square of the inverse momentum. The bands corresponding to different particles can be clearly observed. The RICH provides a 4\(\sigma\) separation of electrons and pions in the momentum range of 3.4-15 GeV/c, for pion and kaons in the range 12 - 54 GeV/c and for kaons and protons in the range 23 - 85 GeV/c.

The muon detector\cite{46, 47} provides tracking for muons with a momentum greater than 4.5 GeV. It consists of four superlayers at different depths in iron loaded concrete absorbers (figure 3.14). The sensitive area is covered by gas pixel chambers for the high occupancy region and tube chambers for the area further away from the beam. The tube chambers are equipped with both wire and pad read out.

The pixel detectors and the pads of the MUON are used for the trigger (see section 3.4.2). In 2000, the hit efficiency of the pad readout was only 70\%, which resulted in a low muon trigger efficiency.
Figure 3.14. The MUON system consists of three hadron absorbers and four superlayers (MU1, MU2, MU3 and MU4). MU3 and MU4 are used to provide an initial trigger signal.
3.4 Trigger

We start this section with a general overview of the trigger design, after which a more extended discussion of the different components will be given. The full trigger system was not ready in the year 2000; only parts of the system were used. The status of the trigger in 2000 will be discussed in the last section of this chapter.

3.4.1 General overview

The selection of interesting events out from the huge amount of background data is the most complicated task of the HERA-B experiment. The fine grained spectrometer has about 500 k channels, for which the information has to be collected for each bunch crossing. It is impossible to store all this data (about 5 TByte per second). A large rate reduction is needed: the 10 MHz rate has to be reduced to a rate of 20-50 Hz of events actually stored on tape. The ratio of $B^0 \rightarrow J/\psi \ K^0_S$ over inelastic events, $10^{-10}$, forces this filtering to be highly efficient. The high multiplicity in the events further complicates this task.

As mentioned before, the signature used in the trigger are the two leptons from the $J/\psi$ decay. Although most of the $J/\psi$ are produced directly in the interaction of the protons with the target and are not the decay product of a $b$ hadron, this signature is sufficient to achieve the desired rate reduction. Furthermore, by only selecting two high $p_T$ leptons, without putting strong constraints on the common vertex or mass, one also selects those events in which two $b$ hadrons both decay semileptonically.

The triggering of events is done in several steps. It is impossible to filter the events in the 96 ns between two bunch crossings. Therefore, the event information has to be buffered. The time available for each trigger step is limited by the number of events that can be buffered at that level. Figure 3.15 shows the four steps in the trigger, their rate reduction and their decision times.

The first trigger decision, which reduces the rate by a factor of 200, has to be made within 12 $\mu$s. This decision is made by the first level trigger (FLT). The FLT uses information from the TC and PC tracking chambers and from the MUON, to search for tracks. The track search is initiated by the ECAL and MUON pretriggers, which provide a first estimate of the track parameters.

The second level trigger (SLT) includes the information from all the tracking chambers and the vertex detector. Its decision time is about 4 ms and it achieves a rate reduction of a factor 100. The third level trigger (TLT) has an input rate of 500 Hz. At this rate, the data from the complete detector can be used. At the fourth level trigger (4LT) the complete event is reconstructed. No rate reduction
3. The HERA–B experiment

**Figure 3.15.** Overview of the different levels in the trigger.

is needed at this level.

### 3.4.2 Pretrigger

The pretriggers are designed to provide a first estimate of the track parameters to be given as input for the FLT track search. No rate reduction is done at this level. Pretrigger messages can come from high energy clusters in the ECAL or a hit coincidence in the MUON\(^2\). In a single event several pretrigger messages can

\(^2\) A third possibility is the high-\(p_T\) pretriggers. These come from a detector in the magnet especially designed to select hadrons with high transverse momentum. Since this detector was not used in 2000 and will probably not be used in the 2002/2003 run, we do not elaborate on this
be sent to the FLT.

The MUON pretrigger

The MUON pretrigger\cite{48} uses information of hits in the last two superlayers at the very end of the spectrometer (MU3 and MU4). Essentially, only high momentum (> 4.5 GeV) muons can penetrate the absorbers in front of these two layers, such that hits in these layers can be used to separate muons from the hadronic background. In the outer part of the MUON, the superlayers consist of tube chambers with pad readouts. The inner part consists of pixel chambers. For these chambers, blocks of $6 \times 4$ pixel cells are combined into pseudo pads.

![Image](image.png)

**Figure 3.16.** Coincidence scheme used in the MUON pretrigger. For pads there are six possible coincidences; for pseudo pads (pixels) this number is four. An example of a possible coincidence is indicated in gray.

A search for a coincidence of hits is performed in the pads and pseudo pads of MU3 and MU4 according to the scheme shown in figure 3.16. The tracks in the outer part of the detector generally have a lower momentum than tracks in the inner part. Lower momenta mean larger spread in angles due to multiple scattering. Therefore, the pads scheme allows more coincidences than that of the pixels. The positions of the coincidences are sent as pretrigger seeds to the FLT.

The ECAL pretrigger

The ECAL pretrigger\cite{49, 50} is used to identify high momentum electron candidates. The FLT seeds are based on energetic clusters in the calorimeter. For each cell in the ECAL an individual threshold, $E_c$, can be set. If the energy in a cell detector.
exceeds this threshold, a search for a cluster is initiated, using the cell position as seed. Clusters are defined as either nine or five contiguous cells, as depicted in figure 3.17. The central cell must have the highest energy. If the sum of the energies of the central cell and its neighbouring cells exceeds a second threshold, $E_{th}$, a pretrigger seed is generated.

The two thresholds are position dependent. $E_{th}$ is chosen such that effectively a cut on the minimum transverse energy ($E_{T}^{\text{min}}$) of the cluster is applied:

$$E_{th} = E_{T}^{\text{min}} \cdot \frac{\sqrt{x^2 + y^2 + z^2}}{\sqrt{x^2 + y^2}}. \quad (3.1)$$

The standard requirement for $E_c$ is:

$$E_c = \frac{E_{th}}{2}. \quad (3.2)$$

The position of the cluster is determined from the centre of gravity of the cells. The pretrigger seed contains the information about the energy and position of the cluster.

### 3.4.3 First level trigger

The most critical part of the trigger system is the FLT[51]. As said before, the event information can only be buffered for a short time, during which the FLT has to provide a decision. The buffering of the data at this level is done in a pipeline placed in the readout electronics. The pipeline is 128 events deep. With the bunch crossing time of 96 ns, this means that the event information is overwritten after 12.3 $\mu$s. The FLT is a hardware tracking device. It uses the seeds from the pretrig-
3.4. Trigger

Figure 3.18. Overview of the FLT. See text for explanation.
gers to search for tracks from muons or electrons in the main tracker. The track search is performed backwards. Figure 3.18 shows an overview of the FLT track finding.

The pretrigger seeds define a region of interest (ROI), through which the track is supposed to have passed, in the first tracking layer used by the FLT. If a hit is found in this region it is used to update the position and direction of the track and a new ROI is defined for the next layer. If more than one hit is found in the ROI, a prediction is made for every hit and the FLT has to search for hits in several ROIs in the next layer. This procedure of hit finding and updating the track parameters is done in 4 superlayers of the main tracker (two upstream and two downstream of the RICH) for electrons, and in three additional MUON layers for muons.

A track said to be found only if hits are found in all superlayers. The tracks are combined into pairs of the same kind. A cut on the two track mass as well as on the $p_T$ of the tracks can be applied at this level.

The FLT makes use of three types of processing units: track finding units (TFU), track parameter units (TPU) and a trigger decision unit (TDU). The TFUs are each connected to a certain part of the tracking layers used in the FLT and operate in parallel. Track candidates are forwarded through the TFU network, as depicted in figure 3.18, where in each step a hit is added to the track. If a track is accepted by one of the TFUs of the last superlayer, it is sent to one of the TPU, which calculates the momentum based on the track parameters given by the TFU. Finally, the TDU collects all accepted tracks, combines them into pairs and calculates the mass. The TDU makes the decision whether or not to accept the event.

### 3.4.4 Second and third level trigger

The SLT[52] is a software trigger, running on a farm of 240 Pentium II PCs. Each node analyses a given event; the nodes work in parallel. The SLT refines the tracks accepted by the FLT. As was the case for the FLT it uses ROIs to search for hits of the tracks. The data of the event accepted by the FLT is stored in the second level buffer (SLB).

Firstly, it is confirmed whether the FLT track candidate is in the tracking layers behind the magnet. The track parameters are calculated by applying a Kalman filter to the hits found. Then the track is propagated backwards through the magnet, using a parameterisation based on the momentum and track slopes, and a search is performed for hits in the tracking layers directly in front of the magnet. The track is then followed through the VDS, again using a Kalman filter. To select B events, it is possible at this moment to require the common vertex to be detached from the target wires, or to select only events in which the reconstructed tracks
3.5. Trigger setup in 2000

have a large impact parameter with the target wires.
Once the event is accepted, all detector information belonging to the event is collected from the SLB by the SLT node[53]. The same node calls the TLT algorithm, which, for the first time, uses the complete detector information. It can do a full track reconstruction in the VDS and determine the positions of primary and secondary vertices. A secondary vertex could indicate a B decay. Apart from confirmation of the dilepton trigger, the TLT can also be used for alternative triggers, such as single high $p_T$ lepton events.

3.4.5 Fourth level trigger

At the 4LT[54], the complete event is reconstructed, classified and logged. The 4LT runs on a second farm consisting of 200 PCs. On this farm online calibration, alignment and data quality monitoring is also done. The final rate with which events are stored is 50 Hz. When the 4LT farm is not being used for data collection, it can be used to reprocess the data.

3.5 Trigger setup in 2000

In 2000, the full trigger system was not ready for data collection. Instead, only part of the system was used to collect the data suitable for physics analysis. The FLT was not yet commissioned in 2000. Technically the system is working, but it is very sensitive to imperfections in the detector. Due to low hit efficiencies in the tracking chambers and alignment as well as technical problems, the system could not be operated at a satisfactory level of reliability.

The SLT and the switching network between the SLT nodes and the SLB did reach design specifications. Being a software trigger, the SLT is much more flexible and the algorithm can be adjusted to the detector and FLT performance. In 2000 the FLT was used in a transparent mode; the TFU network was not used. The TDU was only used to count the number of pretrigger messages. If there were at least two ECAL messages or at least two MUON messages, the pretrigger messages were forwarded to the SLT.

An overview of the SLT algorithm and performance in 2000 can be found in ref. [55]. Here we give a short summary.

The SLT was designed to confirm the tracks accepted by the FLT. For the 2000 run, the algorithm had to be adjusted because of the lack of FLT track information. In the 2000 setup, the SLT was used to search for two tracks (both electron or both muon tracks) in the MUON system, the main tracker and the VDS, using the
pretrigger messages as seeds.

In 2000, two periods of triggered data collection can be distinguished. In the first period (May 2000) only the information from the ECAL and the VDS was used in the trigger. As of June, the MUON pretrigger and the OTR were ready to be included in the trigger as well. Since only the triggered data of the latter period has been used in the analysis of this thesis, we only discuss the SLT algorithms used in this period.

To define the regions in the tracking chambers from where the hits for the track search should be collected, a first track parameter estimate based on the pretrigger information is performed in the *seeding* step. The seeding differs for ECAL and MUON pretriggers.

For the electron triggered events, the pretrigger $E_T$ threshold is set at 1.0 GeV. If two high $E_T$ clusters are present the event is forwarded to the SLT. At the SLT the high $E_T$ clusters are combined into pairs with an invariant mass larger than 2 GeV/$c^2$. The charge of the two particles is assigned such that that they form an *out bender* pair, i.e. the tracks are pushed apart due to the magnetic field. In the magnetic field configuration of HERA-B this means that the positron has a larger $x$-coordinate at the ECAL than the electron. The momentum of the particles is estimated from the cluster energy, assuming $p = E$. The track direction before the magnet, which is needed for the mass calculation, is calculated assuming a constant $p_T$ kick in $x$ in the centre of the magnetic field. The ROIs for the track-finding algorithm are defined using a parameterisation of the magnetic field instead of the simple $p_T$ kick approximation, and with the assumption that the track originates from the target.

The MUON pretriggers search for hit coincidences in superlayer MU3 and MU4, as described in section 3.4.2. In 2000, the pretrigger system for the pixel chambers was not yet installed and only the pads were used. If two coincidences are present the event is accepted and sent to the SLT. It often happens that if a track passes close to the edge of a MUON pad, two coincidences are recorded for the same track. These false double coincidences are removed by the SLT by simply requiring a minimal distance of 50 cm at MU3 between two coincidences.

The muon tracking requires a pair of hits found in MU01 and MU02, for which the line connecting the hits point to the pad in MU03 that was used for the pretrigger. A cut is applied on the distance in the $x$ direction only ($< 20$ cm).

In contrast to the electron case, for each muon candidate both the negative and the positive charge assumption is made for calculating the ROIs used in the tracking step. Again the target is assumed as origin of the tracks in calculating the ROIs. No mass cut is applied on the muon pairs.
The algorithm used for tracking in the TC and PC chambers of the OTR is the same in the muon and the electron case. First, ghosts are removed by requiring a minimum number of hits (\( > 9 \)) in at least five out of the six OTR superlayers. The tracks are then confirmed by performing a fit in \( x \) and \( y \) independently. Multiple scattering is ignored so that the fit is reduced to a simple least-squares fit of a straight line. The track is accepted if the \( \chi^2 \) of the fit divided by the number of hits on the track is less than five.

Accepted tracks are propagated backwards through the magnet, using a field parameterisation, to obtain the track parameters in the VDS. The tracking in the VDS is done using a simplified Kalman filter and for the \( x \) and \( y \) views independently. The tracks are required to have a minimum of 3 hits in both the \( x \) and \( y \) views, and to have hits in at least two superlayers. Since the suppression by the SLT after the tracking in the OTR and VDS was already large enough, no vertexing was done in the 2000 configuration.

The performance of the SLT depends not only on the efficiency of the algorithms, but also on the amount of data the DAQ is able to handle. Due to the missing FLT, the input rates for the SLT were larger than foreseen. By applying the large \( E_T \) cut to the ECAL pretrigger clusters, the input rate of the ECAL pretriggers of about 6kHz is low enough to be handled by the SLT. This is not the case for the MUON pretrigger rate. Since no \( p_T \) cut can be applied here, the input rate of almost 100 kHz has to be scaled down at the TDU by a factor of four. A major concern for the trigger in 2000 was the dead time, i.e. the percentage of time the DAQ is not ready to treat an event, since it is still blocked by the handling of a previous event. For the 2000 run with ECAL and MUON triggers running simultaneously, the dead time was about 45%. In the 2000 trigger setup the efficiencies, including the pretrigger efficiencies and acceptance, were about 1% for the muon and 2% for the electron channel.

In 2000, there was no need for more suppression beyond that provided by the SLT. Therefore, the TLT algorithm was not used in this running period. A major subject of the physics program in 2002/2003 is charmonium production in the proton nucleon interactions. Therefore, a requirement for detached vertices cannot be used and there are no plans to use the TLT in the 2002/2003 run either.
3. The HERA−B experiment