Tagging High Energy Photons in the H1 Detector at HERA

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Research

Objectives

The primary objective of this project is to extend the range over which the H1 detector on the HERA electron-proton collider can reconstruct the energy of photons in photoproduction interactions. The goal is to make it possible to tag photons carrying a very large proportion of the incoming electron's energy. This will allow the study of photoproduction interactions at the highest centre-of-mass energies yet observed, and also enhance many aspects of the H1 physics programme. It to be achieved by the addition of a new electromagnetic calorimeter, the Etag8, to the H1 detector. In the interactions the Etag8 is designed to study, the majority of the electron's energy is taken by the photon which interacts with the proton. The energy carried by the scattered electron, measured in the Etag8, is therefore small, making the calorimeter design and operation particularly challenging.

The H1 detector is sited on the electron-proton (ep) accelerator HERA, at DESY, and is designed to measure ep collisions over a large range of squared four-momentum transfer, Q^2. The physics topics covered by H1 include the search for new phenomena and the study of electroweak effects at large Q^2, the study of proton structure over a range of Q^2 about two orders of magnitude larger than accessible before the advent of HERA, the study of virtual photon structure at small and intermediate values of Q^2 and the study of photoproduction, the interactions of quasi-real photons ($Q^2 \sim 0$) with protons.

The Etag8 will contribute to the H1 physics programme in several ways. Searches for new phenomena and the study of electroweak effects at the highest values of Q^2 suffer from the problem that the much more frequent photoproduction interactions can occasionally mimic the signals being sought. The resulting background must be understood, particularly that resulting from highly energetic photoproduction interactions in which the photon carries a large proportion, y, of the incoming electron's energy, as these are the most likely to mimic the signatures of the required events. The electrons scattered in these high y interactions carry only a small proportion of their initial energy, and it is just these electrons that the Etag8 is designed to measure. It is not possible to detect the scattered electrons in all such events; the majority are absorbed in the material of the beampipe and surrounding magnets, but those that fall within the acceptance of the Etag8 can be recorded allowing the definition of a sample of high y photoproduction events. The characteristics of these events can then be compared with those of the signals being sought, whether for new phenomena at the highest values of Q^2 or for electroweak effects, and the resulting contamination determined.

The Etag8 also brings benefits for the study of proton structure. Here, the level of contamination from photoproduction events is one of the significant remaining uncertainties in the measurements. As outlined above, this is a problem that can be addressed with the help of the Etag8.

H1 has performed many interesting studies of photoproduction. For example, inclusive measurements of the photon-proton cross-section have been made at the highest photon-proton energies possible to date. The Etag8 will allow the extension of these measurements to centre-of-mass energies about 50 GeV higher than currently attainable, This figure increases if HERA is able to run with a 920 GeV proton beam in 1998. Other studies require the combination of information from the H1 detector on the hadronic final state in photoproduction events with measurements of the scattered electron. It is then possible to isolate and study events in which the photon-proton collision can be considered to be an interaction between partons from the

proton and partons from the photon. Such events typically lead to the production of two hadronic jets, and the reconstruction of these jets allows the determination of the proportion of the photon's momentum entering the collision, x_γ, which is analogous to the quantity Bjorken-x describing the proportion of the proton's momentum entering the collision. HERA measurements have shown that the structure of the proton in the region of low Bjorken-x is particularly interesting and have made possible studies of photon structure at intermediate x_γ. The Etag8 will allow these latter measurements to be extended to lower values of x_γ than previously attainable.

As described in the following, much progress towards the realisation of the above goals has been made as a result of this project.

Activities

The activities of the group have concentrated largely on the design of the Etag8 calorimeter, the study of the radiation hardness of the optical components of the Etag8, the writing of the Technical Proposal, the construction and testing of a prototype calorimeter and the construction and installation of the Etag8, together with a section of beampipe designed to minimise the amount of material traversed by the electrons subsequently detected in the Etag8. These activities are described in more detail in the following.

Detector design

The design of the Etag8 has been finalised. The calorimeter is of the spaghetti type, using BICRON fibres of 0.5 mm radius embedded in a lead matrix. The lead to fibre ratio is 2.3:1 and the resulting Moliere radius is about 2.5 cm. The calorimeter is placed in the plane of the HERA ring within a few centimetres of the beams. It is built of two separate modules, one above the other, in which the fibres are horizontal and at 90° to the beam. Each module extends over 8.15 cm in the beam direction and has a width of 5 cm and a height of 2.5 cm. In front of the calorimeter are 10 scintillator fingers of thickness 2 mm, height 5 cm and depth 1 cm, placed edge-on to the beam. These allow the determination of the horizontal co-ordinate of an electron entering the calorimeter with an accuracy of about 1 mm. The vertical co-ordinate is also determined with a precision of about 1 mm using the measurement of the relative proportions of the electron's energy detected in the upper and lower modules of the calorimeter. The scintillating fibres and fingers are read out via the appropriate light guides using photomultiplier tubes. To ensure that these are not affected by the HERA magnets, they are shielded against stray magnetic fields. To allow the identification of spurious signals produced by particles traversing the scintillating fibres in the region outside the calorimeter proper, where they are being bundled for attachment to the photomultipliers, this area is surrounded by scintillator plates which can be used as a veto. Again, readout is via photomultipliers. More details on the construction of the Etag8 are given in the appendix.

The Etag8 will be read out as part of the luminosity branch of the H1 data acquisition system. It will also provide a fast (level one) trigger signal, allowing H1 to identify potentially interesting events at the earliest possible phase of the triggering procedure.

Components of the H1 detector which are as close to the beamline as the Etag8 are generally retracted from their operating positions during the HERA injection procedure. This applies, for example, to the Forward Proton Spectrometer and the Very Low Q^2 calorimeter, reducing the amount of radiation to which these detectors are subjected. Unfortunately, the limited space

available in the region of the Etag8 prohibits such a solution. This makes it essential that the materials used in the construction of the Etag8 be sufficiently radiation hard.

Radiation hardness

The region in which the HERA beam optics dictate the Etag8 be placed if it is to detect the electrons in the required range, $0.85 < y < 0.95$, suffers from a high radiation level. Measurements of this level were made during HERA operation and revealed that the Etag8 will be subjected to a yearly dose of about 0.1 MRad. The materials required for the Etag8 were tested for their radiation hardness to ensure they could withstand this dose. The tests were performed at the 1 GeV electron synchrotron of the Lebedev Physical Institute in Moscow. The scintillating fibres, veto scintillators and Plexiglas light guides were all subjected to a dose at least ten times that expected during a year of HERA running. Subsequent studies of the materials showed that the mean free path of the photons in the scintillating fibres decreased from 130 cm to 60 cm. Given the typical length of the fibres in the Etag8, the expected yearly dose of 0.1 MRad and the continuous monitoring and calibration procedures, this will not cause problems in the operation and effectiveness of the Etag8. The transparency of both the veto scintillators and the Plexiglas was also observed to decrease. The former displayed visible yellowing after exposure to a dose of 2 MRad, whereas the latter became brown in colour. The severity of both of these effects was observed to decrease somewhat with time after the exposure. Again, given the doses expected at HERA and the continuous monitoring system, allowing correction for changes in the transparency of the optical components of the Etag8, this will not be a problem for the operation of the system.

Prototype construction and testing

A prototype detector was constructed and installed as close as possible to the position of the Etag8. The prototype was incorporated in the H1 trigger and readout systems and tests were performed during the 1996 and 1997 HERA running period. The prototype calorimeter and the trigger and readout hardware and software functioned extremely well allowing routine operation of the prototype throughout the run period. The data taken were of sufficient quality to enable the testing of the reconstruction software and the development of a calibration procedure plus the necessary software.

The accuracy of the measurements made with the prototype was limited by the amount of material in front of it. We were unable to install the specially developed section of beampipe with an electron exit window during the 1996/1997 HERA shutdown, despite having the completed the design and construction of the apparatus, and thus could not remove the problem for the 1997 running. This situation arose as the HERA schedule was modified, making the shutdown in question very short; HERA resumed operation after a break of only one month. The installation of the new section of beampipe would have required that the vacuum be broken. The subsequent re-establishment of the necessary very hard vacuum would have taken longer than allowable within the new HERA schedule and would have resulted in unacceptable backgrounds in the HERA detectors following the start of HERA running in 1997.

This set-back resulted in a longer period of running with the prototype Etag8, which was left in place for the HERA 1997 running, rather than installing the Etag8 for this run period as originally proposed. Despite the above problem, the results obtained were extremely pleasing. The calorimeter itself functioned as hoped and in fact we will continue to operate the prototype

in parallel with the Etag8. The results of the prototype tests are described in more detail in the appendix.

Construction and installation of the Etag8

As the first tests with the prototype revealed that the calorimeter performed as hoped, construction of the Etag8 went ahead. The detector was completed in time for installation in the 1996/1997 shutdown, but for the reasons mentioned above the installation was not carried out at that time. The Etag8 was finally installed during the long shutdown, now drawing to a close, in 1997/1998. This shutdown was also used to install the section of beampipe with an electron exit window. This will ensure that the electrons measured in the Etag8 when running re-starts will not suffer from the large amounts of energy loss and scattering which degraded the measurements made with the prototype; it will be possible to start precise studies of the physics topics which provided the motivation for the Etag8.

Before the Etag8 can be used for physics analyses, it is essential that accurate calibration constants be determined. Thanks to the work done with the prototype, the necessary software is in place and has been tested so this procedure can be started as soon as stable HERA operation is established. Similarly, the trigger systems, readout and reconstruction have all been extensively tested and we are confident that they will operate reliably from day one of the 1998 HERA running.

Contributions of participants

Participants from Lebedev Physical Institute

V.F. Andreev
Production of Monte Carlo software, determination of Etag8 acceptance, preparation of Technical Proposal.

A.M. Fomenko
Production of on-line and event reconstruction software.

A.S. Belousov
Study of radiation hardness of scintillating fibres, photomultipliers and diodes.

I.P. Sheviakov
Design and construction of front-end and readout electronics.

L.A Gorbov and J.V. Soloviev
Design of Etag8 calorimeter, manufacturing of components, calorimeter assembly.

E.I. Malinovski
Project organisation in Moscow, study of alternative Etag8 designs, preparation of Technical Proposal.

Participant from Institute for Theoretical and Experimental Physics, Moscow

A.V. Semenov
Production of software for physics analysis.

Participant from DESY, Hamburg

G.-G. Winter
Project organisation in Hamburg, design work on new beampipe and beampipe installation.

Participants from Liverpool University

S.J. Maxfield
Preliminary studies of photon structure measurements using the Etag8.

T. Greenshaw
Project co-ordination and preliminary studies of physics potential of Etag8.

Comparison of progress with Work Programme

So far, the research done has been in accordance with the Work Programme agreed at the start of the project, with the exception of the above-mentioned delay in the installation of the section of beampipe close to the Etag8 and the resulting delay in the installation of the Etag8 calorimeter itself. This delay resulted from a change of the operation schedule of the HERA accelerator, making the winter 1996/1997 shutdown too short for the installation of the beampipe. The main effect this has had on the project is to delay the start of physics analyses using Etag8 data; the degradation of the energy measurement using the prototype as a result of the material in front of the calorimeter is too severe to allow the prototype to be used for such analyses. This situation has been rectified during the 1997/1998 shutdown and physics studies can commence as soon as stable HERA operation is established, the calibration of the Etag8 has been completed and a reasonable amount of data has been accumulated. This should be possible before the end of 1998.

Results

The main achievements of the project to date have been:

1. The measurement of radiation levels at the site foreseen for the Etag8.
2. The study of the radiation hardness of the materials to be used in the construction of the Etag8.
3. The design of the new electron tagger for the H1 detector, the Etag8 calorimeter.
4. The construction and testing of a prototype calorimeter.
5. The installation of a new beampipe, equipped with an exit window to allow optimal exploitation of the Etag8.
6. Installation of the Etag8.
7. Surveying of the new beampipe and Etag8 *in situ*.
8. Incorporation of the Etag8 into the H1 trigger system.
9. Incorporation of the Etag8 into the H1 readout.
10. Production of the Monte Carlo simulation software
11. Production of software for the reconstruction of events recorded in the Etag8.

The above are described in the Lebedev Physical Institute and Liverpool University pre-print attached as an appendix to this report. This is to be submitted to Nuclear Instruments and Methods following the inclusion of results from the Etag8 with the beampipe equipped with an exit window.

The first data with the Etag8 and new H1 beampipe will be taken in August 1998. Analyses incorporating the Etag8 will then become possible and, as understanding of the detector develops, topics such as the study of the structure of the photon at small x_γ, will be pursued.

Project Management

Project Co-ordination and Co-operation

The project was co-ordinated via electronic mail and the use of the WWW. In addition, co-ordination meetings were organised as outlined below.

Co-ordination meetings in Moscow

Regular meetings of the project participants (and other LPI members of H1) were organised. The people present at these were A.S. Belousov, L.A. Gorbov, N.N. Lvova, E.I. Malinovski, A.M. Fomenko, I.P. Sheviakov, and V.F. Andreev from LPI and A.V. Semenov from ITEP. The meetings took place on 13/1/97, 17/3/97, 12/5/97, 11/8/97, 22/9/97, 8/12/97, 12/1/98 and 2/2/98.

Co-ordination meetings in Hamburg

Meetings between project participants, the then H1 Spokesman and the Technical Co-ordinator of H1 took place at DESY in Hamburg on 12/2/97, 14/4/97, 13/10/97 and 17/11/97. Present were E.I. Malinovski, T. Greenshaw, L.A. Gorbov, J.V. Soloviev, V.F. Andreev, G.-G. Winter, A.V. Semenov P. Biddulph (Technical Co-ordinator) and R. Eichler (Spokesman, current Spokesman is J.B. Dainton)

A further meeting at DESY is planned for August at which at least G.-G. Winter, E.I. Malinovski, T. Greenshaw, P. Biddulph and J.B. Dainton will be present. We are discussing the possibility of a final meeting in Moscow to coincide with the end of the project at which we hope to consider how best to exploit the achievements of the project and possible future collaborative work.

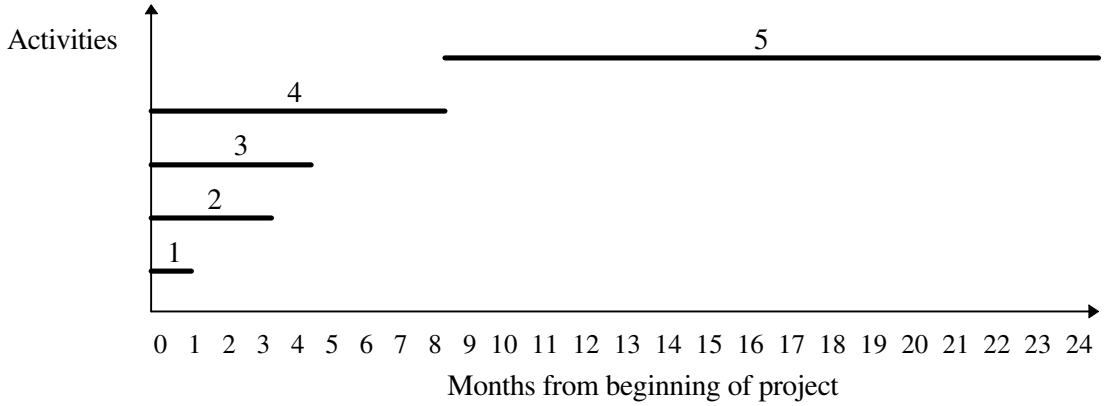
Levels of co-operation

The levels of collaboration between the various institutes may be summarised as below:

	High	Rather high	Rather low	Low
W $\leftrightarrow$ E		x		
E $\leftrightarrow$ E	x			
E $\leftrightarrow$ W		x		
W $\leftrightarrow$ W		x		

Project schedule

The original schedule for this project, taken from the Work Programme, is reproduced below:



Legend

1) Measurement of the radiation conditions at the position of the Etag8. Studies of radiation hardness of materials, choice of detector type and detector design. Monte-Carlo studies of proposed designs. Writing of Technical Proposal.
2) Manufacture and assembly of the detector components and test beam calibration of the entire detector.
3) Design and construction of a new section of beam-pipe and installation thereof.
4) Commissioning of front-end electronics and data acquisition systems, modification of H1 trigger.
5) Etag8 fully incorporated into H1 detector, data taking and analysis with Etag8.

For the reasons mentioned above, i.e. the changes to the HERA schedule, stages 3) and 5) of the project did not take place as planned. Instead extensive tests with the prototype were performed and the software, procedures for incorporating the Etag8 into the trigger and readout etc. were all commissioned using the prototype. Stage 3), the installation of the beampipe, was finally completed earlier this year and stage 5) can now begin as soon as HERA running recommences. No further problems are foreseen with the schedule.

Labour

The total number of people involved with the project to date has been eleven. The participants are listed in the section “Contributions of participants”. In total something of the order of 3000 person-days have been invested in the project, or about 15 person-years using the standard conversion of 204 days of available effort per person per year.

Problems

The major problem which has occurred to date has been mentioned several times in the above, namely the delay arising from the change of the HERA schedule. Fortunately, due to the construction of the prototype calorimeter, this will not lead to severe long-term difficulties, though the production of physics results using the Etag8 has been delayed as a result.

Finances

Breakdown of spending.

The following tables summarise the INTAS money spent to date, units are ECU throughout.

INTAS MEMBER STATE PARTICIPANTS								
Participant	Status	Cost Categories						Total
		Labour	Overheads	Travel and subsistence	Equipment	Consum-ables	Other costs	
1	CO	0	0	0	0	0	0	0
2	CR	0	0	0	0	0	0	0
Subtotal		0	0	0	0	0	0	0

NIS PARTICIPANTS								
Participant	Status	Cost Categories						Total
		Labour	Overheads	Travel and subsistence	Equipment	Consum-ables	Other costs	
3	PI	6240	0	0	0	0	0	6240
4	CR	640	0	0	0	0	0	640
Subtotal		6880	0	0	0	0	0	6880

Total		6880	0	0	0	0	0	6880

The following tables summarise the INTAS money still available for the project, units are ECU throughout.

INTAS MEMBER STATE PARTICIPANTS								
Participant	Status	Cost Categories						Total
		Labour	Overheads	Travel and subsistence	Equipment	Consum-ables	Other costs	
1	CO	0	600	1600	0	0	0	2200
2	CR	0	500	1300	0	200	0	2000
Subtotal		0	1100	2900	0	200	0	4200

NIS PARTICIPANTS								
Participant	Status	Cost Categories						Total
		Labour	Overheads	Travel and subsistence	Equipment	Consum-ables	Other costs	
3	PI	0	3000	16160	8000	500	0	27660
4	CR	0	0	1260	0	0	0	1260
Subtotal		0	3000	17420	8000	500	0	28920

Total		0	4100	20320	8000	700	0	33120

The spending profile has been slower than foreseen as DESY agreed to cover interim costs on the understanding that they would be reimbursed using INTAS funding.

Results

The results of the project to date have been described in some detail in the above. To summarise here, the main result of the groups activities has been the design of an electromagnetic calorimeter to be used as an electron tagger for the H1 detector, the Etag8. The design procedure involved measuring the radiation dose likely to be absorbed by the calorimeter and testing the proposed optical components for their radiation hardness to ensure they could withstand the expected dose. A Technical Proposal was written and approval for the project obtained. A prototype calorimeter was constructed and tested extensively. Trigger and readout hardware and software were produced and the prototype was successfully integrated into the H1 trigger and data acquisition systems. Calibration procedures were developed, the necessary software produced and the prototype calibrated. The reconstruction software was written and was also tested using the prototype.

The project encountered one major unforeseen difficulty; the change of the HERA schedule meant we were unable to install the beampipe with exit window in the 1996/1997 shutdown and the Etag8 calorimeter as planned. Instead the prototype calorimeter was left in position for an extended period and suffered from being screened by a significant amount of material. This material had to be traversed by positrons before they entered the calorimeter, leading to the development of electromagnetic showers and the loss of energy before measurement and hence a significant loss of measurement accuracy. Despite this, some studies of the performance of the calorimeter were possible, as detailed in the appendix. These indicate that the prototype calorimeter performed as required and suggest that the forthcoming HERA running will allow the physics studies for which the Etag8 was designed to commence.