Tagging High Energy Photons in the H1 Detector at HERA

Final report on project INTAS-RFBR 95-0679, June 2000.
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Research

Scientific objectives

The primary objective of this project was to extend the range over which the H1 detector on the HERA electron-proton collider can reconstruct the energy of photons in photoproduction interactions to allow the tagging of those photons carrying a very large proportion of the incoming electron's energy. This enables the study of photoproduction at the highest centre-of-mass energies yet observed and also enhances many other aspects of the H1 physics programme. To achieve this objective, it was necessary to design, build, test and install within the H1 detector an electromagnetic calorimeter, the Etag8, with an accompanying trigger system. Further, software was produced to enable the calibration and running of the Etag8, the analysis of the data obtained and the simulation the performance of the calorimeter.

Research activities

The activities of the group concentrated largely on the design of the Etag8 calorimeter, the study of the radiation hardness of its optical components, the measurement of the radiation levels at the location of the detector, the writing of the Technical Proposal, the construction and testing of a prototype calorimeter, 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 and the subsequent operation of both the prototype, which was so successful in was left *in situ*, and the Etag8. These activities are described in more detail in the following.

Detector design

The Etag8 is a calorimeter 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 are used as a veto. Again, readout is via photomultipliers. More details on the construction of the Etag8 are given in the appendix.

The Etag8 is read out as part of the luminosity branch of the H1 data acquisition system. It provides 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 electrons scattered with energies in the required range, $1.4 < E < 4$ GeV, suffers from a high radiation level. Measurements of this level were made during HERA operation by the group and revealed that the Etag8 is 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 does not cause problems in the operation and accuracy 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 experienced at HERA and the continuous monitoring system, allowing correction for changes in the transparency of the optical components of the Etag8, this is not 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 and the subsequent re-establishment of the necessary very hard vacuum would have taken much longer than allowable within the modified HERA schedule.

This set-back resulted in a longer period of running with the prototype Etag8, which was left in place for the 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 have left the prototype *in situ* and continue to operate it in parallel with the Etag8.

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 in 1997/1998. This shutdown was also used to install the section of beampipe with an electron exit window. This ensures that the electrons measured in the Etag8 do not suffer from the large amounts of energy loss and scattering which degraded the measurements made with the prototype.

The software necessary to accurately calibrate the Etag8, to reconstruct the position and energy of the electrons detected by the Etag8 and to monitor and simulate its performance is all in place.

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.

N.N. Lvova
Production of software for physics analysis

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

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 was rectified during the 1997/1998 shutdown and physics studies have commenced.

Results

The main achievements of the project 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 construction of the Etag8.
6. The installation of a new beampipe, equipped with an exit window to allow optimal exploitation of the Etag8.
7. Installation of the Etag8.
8. Surveying of the new beampipe and Etag8 *in situ*.
9. Incorporation of the Etag8 into the H1 trigger system.
10. Incorporation of the Etag8 into the H1 readout.
11. Production of the Monte Carlo simulation software
12. Production of software for the reconstruction of events recorded in the Etag8.
13. Presentation of first physics results using the Etag8.

The above are described in the Lebedev Physical Institute and Liverpool University pre-print attached as an appendix to this report. This will be submitted to Nuclear Instruments and Methods.

The first data with the Etag8 and new H1 beampipe were taken at the end of 1998. Analyses incorporating the Etag8 have started and first results are now available. The preliminary results of one analysis are presented in the appendix.

The papers in production and presentations made as a result of this project are summarised in the following table:

Scientific Output	Published	In press/accepted	Submitted	In preparation
Paper in Int. Journal				√
Abst. in Proc. Of Conf.				
Oral presentation				
Technical proposals	√			

Project Management

Meetings and visits

Several project members spent a large amount of their time working at DESY in Hamburg, the site of the HERA collider and the H1 detector, as detailed below:

Person	Institute	Time working at DESY
V. Andreev	LPI	2 months
A. Fomenko	LPI	2 months
L. Gorbov	LPI	3 months
N. Lvova	LPI	1 month
E. Malinovski	LPI	2 months
A. Semenov	ITEP	1 month
I. Sheviakov	LPI	2 months

Project co-ordination

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.

Co-ordination meetings in Hamburg

Meetings between project participants, the H1 Spokesman and the Technical Co-ordinator of H1 took place at DESY in Hamburg in February, April, October and November 1997. 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). A further meeting at DESY took place in August 1998 at which G.-G. Winter, E.I. Malinovski, T. Greenshaw, P. Biddulph and J.B. Dainton (new Spokesman) were present. G.-G Winter and T. Greenshaw met in March 1999 to discuss the project finances and again in May 1999. G.-G Winter, E.I. Malinoski and T. Greenshaw met in June 1999 .

Visits	Number of project scientists	Number of person days
West → East	0	0
East → West	7	11
West → West	2	1
East → East	8	17

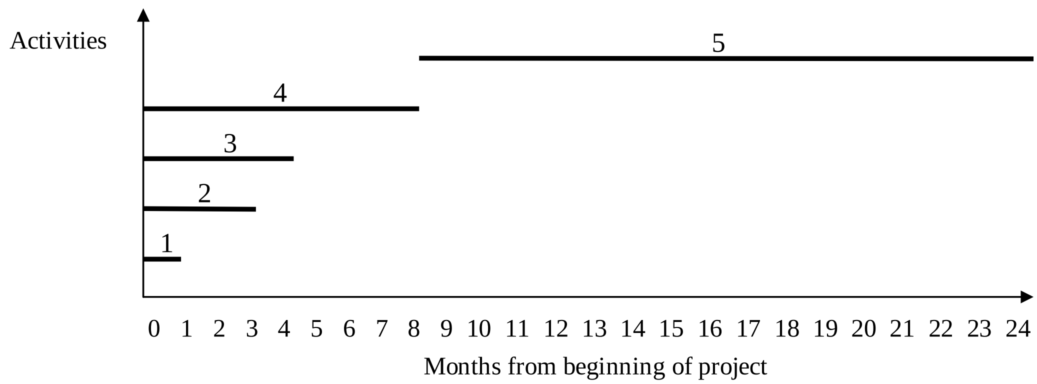
Collaboration

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

Collaboration	High	Rather high	Rather low	Low
W ↔ E		√		
E ↔ E	√			
W ↔ W		√		

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 early in 1998 and stage 5) has been running since then.

Problems encountered

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 did not lead to severe long-term difficulties, though the production of physics results using the Etag8 has been delayed as a result.

A further irritation was the difficulty of transferring funds to Russia, which necessitated the establishment of an account in Hamburg and the transfer of funds through this account. The flexibility of INTAS in this regard was much appreciated.

Problems were also encountered due to the sporadic internet access suffered by the Russian groups in the collaboration. A summary of these problems is presented below:

Problems encountered	Major	Minor	None	Not applicable
Co-operation of team members			√	
Transfer of funds	√			
Telecommunications	√			
Transfer of goods			√	
Other			√	

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	Equip-ment	Consum-ables	Other costs	
1 T. Greenshaw	CO	0	0	0	0	0	0	0
2 G.-G. Winter	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	Equip-ment	Consum-ables	Other costs	
3 E.I. Malinovski	PI	6240	0	16160	0	0	0	22400
4 A. Semenov	CR	640	0	1260	0	0	0	1900
Subtotal		6880	0	17420	0	0	0	24300

Total		6880	0	17420	0	0	0	24300

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	Equip-ment	Consum-ables	Other costs	
1 T. Greenshaw	CO	0	600	1600	0	0	0	2200
2 G.-G. Winter	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	Equipm ent	Consum-ables	Other costs	
3 E. Malinovski	PI	0	3000	0	8000	500	0	11500
4 A. Semenov	CR	0	0	0	0	0	0	0
Subtotal		0	3000	0	8000	500	0	11500

Total		0	4100	2900	8000	700	0	15700

Summary of Results and Key References

Project title

Tagging High Energy Photons in the H1 Detector at HERA

INTAS reference number

INTAS-RFBR 95-0679

Period of project

1st December 1996 to 1st December 1999

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Results

The main result of the group's activities has been the design, construction and installation of an electromagnetic calorimeter for tagging photoproduction in the H1 detector with the attendant level one trigger, readout system and custom built beampipe. This calorimeter, the Etag8, is now being used to make measurements of photoproduction processes in the range $0.85 < y < 0.95$, i.e. at the highest photon-proton centre-of-mass yet observed. The design procedure involved measuring the radiation dose likely to be absorbed by the calorimeter and testing the calorimeter's 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 tested using the prototype. Following a delay due to changes in the HERA schedule, the custom built beampipe was installed and the taking of data useful for the abovementioned measurements of photoproduction in the high y region began. Preliminary results obtained using these data are now available.

Further Information

Further information may be obtained from the group's web site:
http://hep.ph.liv.ac.uk/~green/etag8

Role and Impact of INTAS

The importance of this INTAS grant for this project is summarised in the table below:

Role of INTAS	Definitely yes	Probably yes	Probably not	Definitely not
Would the project have been started without funding by INTAS?			√	
Would the project have been carried out without funding from INTAS?			√	

The main achievements of the project were:

Main achievement of project	Very important	Quite important	Less important	Not important
Exciting science	√			
New International contacts		√		
Additional prestige for my Lab.		√		
Additional funds for my Lab.			√	
Helping scientists in the NIS	√			
Other				

Recommendations to INTAS

The work of INTAS is undoubtedly of enormous importance. There are many talented scientists in the former Soviet Union who would not be able to continue their careers in science, including some of those named above, were it not for INTAS funded projects. My main recommendation would be to increase the number and range of projects funded to maintain the strength of the science base in the former Soviet Union. A pre-requisite for this is of course the availability of the necessary funding. I would also suggest that INTAS continue to try and keep the administrative burden on scientists involved in their projects as low as is possible, commensurate with the requirement to ensure that funds are correctly spent. The persisting difficulties in communication, for example sporadic internet access, make even simple administrative tasks more time consuming than would normally be the case. Transferring money has proved particularly awkward on some occasions. In conclusion, I would also like to express my thanks for the support that INTAS has given this project.