WORK PROGRAMME

3.1. Research Project

3.1.1. Title

MEASUREMENT OF LEADING NEUTRON PRODUCTION IN ELECTRON-PROTON SCATTERING AT HERA

3.1.2. Objectives

A class of events with a highly energetic forward neutron in the final state has been observed by both the H1 and ZEUS collaborations in electron-proton collisions at the HERA collider at DESY in Hamburg. These events, which account for approximately 6% of the total ep cross-section, are interpreted as being due to the interactions of a virtual photon with a π^+ from the pion cloud surrounding the proton. Their presence allows the scope of the measurements possible at HERA to be extended to include studies of pion structure over a large range of squared 4-momentum transfer (Q^2) and Bjorken-x (x_{Bj}); values of Q^2 far above those accessible at previous fixed target experiments become accessible, as does the region of small $x_{Bj.}$ Furthermore, the first ever measurements of the total $\gamma\pi$ cross-section become possible. These measurements require that the energy and scattering angle of the leading neutron be accurately measured.

In order to improve the accuracy with which measurements can be made at HERA, and to allow the study of rare process, the collider is being upgraded so higher luminosity is achievable. The H1 and ZEUS collaborations are simultaneously improving their detectors to allow full exploitation of the expected larger data samples. As part of the H1 upgrade, a new Forward Neutron Calorimeter (FNC) will be installed which will provide the accurate measurements of leading neutrons necessary for studies such as the above.

The aims of this project are:

- To complete the assembly and installation of the FNC and the associated electronics and data acquisition system.
- To commission, calibrate and monitor the FNC and integrate it into the H1 trigger and data acquisition systems.
- To develop the off-line reconstruction and analysis software to ensure the best possible exploitation of the FNC data in physics analyses.
- To produce large Monte Carlo data samples to enable accurate efficiency and acceptance corrections to be made and to facilitate comparisons with various models describing leading neutron production.
- To extend the range of physics analyses made using the leading neutron data, e.g. to measure the pion structure function F_2^{π} and the total photon-pion cross-section at a range of $\gamma\pi$ centre-of-mass energies.

Funding is requested for three NIS groups in the H1 collaboration to allow their participation in this project.

3.1.3. Background and Justification for Undertaking the Project

The H1 detector is one of the two detectors built around the interaction regions of the electron-proton storage ring HERA at the DESY laboratory in Hamburg, Germany. It provides nearly hermetic coverage allowing the best possible identification and precise measurement of electrons, muons and penetrating neutral particles, together with accurate measurements of jets with high particle densities.

The total ep centre-of-mass energy at HERA of about 320 GeV is an order of magnitude larger than in previous lepton-proton scattering experiments. Since first data taking in 1992, HERA has delivered an integrated luminosity of about $160 \mathrm{pb}^{-1}$. Many important new results have been obtained using these data. Measurements of the structure of the proton and the photon have been made in new kinematic regions. As a result, our understanding of this structure in terms of Quantum Chromodynamics (QCD) has been greatly extended. Valuable results have also been reported in the domains of diffractive and soft interactions, in photoproduction and in the electroweak sector. Searches for phenomena beyond the Standard Model have also been performed.

One of interesting results of HERA experiments is the observation of events with a highly energetic forward (leading) neutron in the final state. These events form approximately 6% of the inclusive ep data sample. According to numerous

theoretical calculations, they can be interpreted as being due to the exchange of a π^+ from the pion cloud surrounding the proton. Measurements of pion structure at HERA thus become possible. The parton distributions of the pion in the region $x_{Bj} > 0.2$ have been constrained by fixed target experiments. Analysis of leading neutron data in DIS at HERA, performed by the H1 collaboration, made possible the first measurement of the pion structure function in the region $10^{-3} < x_{Bj} < 10^{-2}$. A major restriction on the accuracy of this cross-section measurement was the limited energy resolution of the Forward Neutron Calorimeter (~ 20% for neutron energies in the range 300 to 800 GeV).

In the 2000-2001 shutdown, the HERA collider will be upgraded to allow higher luminosity running. This is being achieved by means of dual function magnets, to be added to the HERA lattice close to the ep interaction regions. In order to exploit the expected fourfold increase in luminosity, the H1 and ZEUS experiments are also being improved. The purpose of these upgrades is:

- To greatly enhance the sensitivity to new physics at the highest momentum transfer.
- To obtain larger event samples for low cross-section exclusive processes.
- To run HERA for short periods at different centre-of-mass energies to allow investigation of the kinematic dependence of interesting effects.

The H1 upgrade includes both improvements to present detector systems and the addition of new detectors, for example new drift chambers and silicon detectors are to be added in the forward region.

As part of this programme, the Forward Neutron Calorimeter (FNC), located 107m downstream of the nominal H1 interaction point in the proton direction, will be replaced with a new device. This consists of a pre-shower calorimeter of depth $1.6\lambda_I$ and a lead-scintillator sandwich calorimeter with total depth of $9\lambda_I$. The former is designed to reconstruct the neutron impact point and to separate neutrons from photons resulting from π^0 decays, the latter ensures full containment of the hadronic shower resulting from the neutron impact and allows accurate neutron energy measurement. The new FNC will be integrated into the H1 level 1 trigger and central data acquisition systems.

The improved FNC will be a valuable addition to the H1 experiment. Its improved energy resolution of 3% and position resolution of 2 mm for neutrons with an average energy of 600 GeV, together with the large event samples available after the upgrade, will allow a broad physics programme to be pursued. Some possible topics are listed below:

- The measurements of the cross-section for leading neutron production can be extended to considerably higher values of Q^2 and x_{Bj}. The enlarged kinematic range will allow discrimination between different models for the production of leading neutrons. Measurements at $x_{Bj} > 0.2$ will allow a direct comparison of the neutron data with the pion structure function determined in pion-nucleon scattering experiments.
- Measurement of the t dependence of neutron production in the DIS and photoproduction regimes will allow discrimination between the different predictions for pion distributions in the proton.
- Measurements of high p_T-jet production in photoproduction will provide a sensitive probe of the partonic structure of the pion and the photon and will allow comparisons to be made with different Monte Carlo models and the available parameterisations of the structure functions.
- The total $\gamma\pi$ cross-section can be measured at a range of γp centre-of-mass energies.
- Leading neutrons can be also used to test the DGLAP picture of small-x_{Bj} DIS and hard photoproduction. This picture implies that hadron production in the current and target fragmentation regions is uncorrelated, but may break down if non-linear effects are important in evolution. Such non-linearities could be observed by studying the correlation between forward neutron production and hadron production at central rapidity.

The H1 experiment is operated by an international collaboration consisting of 39 institutes from 13 countries. The institutes and individuals participating in this proposal have been involved in the development and operation of the FNC system, and in the design and construction of the new calorimeter. This proposal will be realized by the groups from the following institutions: the Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany (MPIK); the University of Liverpool, England (UL); the Institute of Theoretical and Experimental Physics, Moscow, Russia (ITEP); the Joint Institute for Nuclear Research, Dubna, Russia (JINR) and the Yerevan Physics Institute, Armenia (YerPhI).

The groups associated with this proposal have agreed to take full responsibility within the H1 Collaboration at HERA for all aspects of the new FNC system.

3.1.4. Scientific and Technical Description

3.1.4.1. Research programme

The research programme is subdivided into the following tasks:

T1: Detector assembly

To fulfil the physics programme described above the FNC must be capable of detecting neutrons produced with scattering angles up to 1 mrad and with energies between 200 and 920 GeV. To measure these neutrons with adequate precision, a lead/scintillator-tile sandwich calorimeter was chosen.

The FNC is 2 m long with a transverse size of ~ 60 x 60 cm^2 and a weight of about 8 tonnes. The total depth of the calorimeter is about $10.5\lambda_I$. The size and weight of the calorimeter, as well as its position in the HERA tunnel, are limited by the available space. Read-out is done via wavelength shifter fibres (WLS) and photomultiplier tubes. The FNC consists of three parts:

- The **main calorimeter**, made of 4 independent longitudinal sections with a transverse size of 60 x 60 cm^2. Each section consists of 25 layers of lead of 14 mm thickness, interleaved with layers of scintillator which are 3 mm thick. Each scintillator layer is made of 8 scintillating tiles with transverse size 20 x 20 cm^2 or 20 x 26 cm^2. This transverse segmentation provides a reasonable spatial accuracy in the transverse direction (~ 2 cm), sufficient to link the cluster reconstructed in the main calorimeter with the cluster in the pre-shower calorimeter.

- The **pre-shower calorimeter**, as used in the previous FNC. This consists of electromagnetic and hadronic sections, each of which is composed of 12 planes. The electromagnetic section is made of thin scintillators (2.6 mm) and lead plates (7.5 mm), and the hadronic section of thicker scintillators (5.2 mm) and lead plates (14 mm). The transverse size of the active elements is 26 x 26 cm^2. With a total depth of about $1.6\lambda_I$, the pre-shower calorimeter allows clear separation of electromagnetic and hadronic showers. The light from each scintillator plane is transmitted by 45 WLS fibres, combined in 9 bundles, to the readout photomultipliers. The pre-shower calorimeter provides a spatial resolution of better than 2 mm in both transverse directions.

- Two layers of **veto counters**, situated 2 m in front of the FNC. These are used to veto charged particles. Each plane is constructed of a 10 mm thick scintillator with transverse size 22 x 24 cm^2, which fully covers the acceptance of the main calorimeter.

In total, the calorimeter has 50 high voltage and readout channels. According to Monte Carlo simulation, the calorimeter is slightly overcompensating (e/h ~ 0.96), the energy resolution $\sigma(E)/E$ is about $22\%/\sqrt{E[GeV]}$ for electromagnetic showers and $42\%/\sqrt{E[GeV]}$ for hadronic showers.

The proposal to upgrade the FNC calorimeter with the device described above was accepted by the H1 Collaboration in spring 1999. Experts from ITEP and JINR then carried out the necessary mechanical design work. The ITEP group took responsibility for assembling the calorimeter and by June 2000 had completed the mechanical construction of the calorimeter modules. Following tests in the ITEP 10 GeV proton beam, the detector was shipped to CERN for further test-beam studies and from there to DESY.

To complete the construction of the FNC the following tasks must be performed:

T1.1 Installation and testing of LED monitoring system (see also T3)
A light emitting diode (LED) monitoring system is foreseen to monitor the gain variation of the photomultipliers and the light yield of the scintillators. The light from blue LEDs will be distributed by optical fibres to one fifth of the scintillator tiles. This will allow the monitoring of both the optical connections in the whole system and any radiation damage to the scintillators. The gain of the photomultipliers will be permanently monitored by a further independent LED monitoring system with a rate of 1 Hz. This consists of a LED matrix and fibre light-guides connected directly to the photomultipliers.

T1.2 Installation of optical connectors
Light from a LED matrix placed in a monitor box outside the detector will be transferred to the optical fibres of the monitoring system via optical connectors which will be installed on the walls of the calorimeter.

T1.3 Design and assembly of mechanical support structure.
All FNC calorimeter sections will be installed in their working position in the HERA tunnel by a special HERA-tram. For this a mechanical support has to be designed and constructed.

The above will be coordinated by CR3 and performed by CR2 and CR3.
Schedule: months 1 to 4.

T2: Calorimeter energy calibration using the CERN test beam data

Since the absolute energy calibration is crucial for using the FNC calorimeter for physics analysis, calibration runs were taken at the CERN H4 and H6 test beams during June-July 2000. The high voltage setting of each FNC channel was determined by equalizing the energy response. The detector was then exposed to electron and hadron beams of energies in the range 100 to 350 GeV. About 70 Gbytes of calibration data were written to tape. The analysis of this data will provide the required information on the energy and spatial resolution of the FNC and the linearity of its response. This will be used not only in the energy reconstruction and off-line analysis (T7 and T8) but also for tuning the LED monitoring system and DAQ electronics.

CO are responsible for coordinating this task, which will be performed by teams CO, CR2, CR3 and CR4.
Schedule: months 1 to 5.

T3: Design and manufacturing of DAQ, trigger and monitoring systems

The following R&D on the electronics for the FNC DAQ, trigger and monitoring systems must be performed:

T3.1 Data acquisition system
The new FNC calorimeter provides much better energy resolution than the old detector. In order to guarantee that the resolution is not deteriorated by the electronics (noise, cross-talk, etc.), essential changes in the FNC data acquisition system are foreseen. The old 8-bit FADCs will be replaced with a new 100 MHz 12-bit FADC system. Signals from the photomultipliers will be split for the trigger and for the DAQ systems. The data from the FNC DAQ will be transferred to the H1 DAQ via a standard VME/VSB connection. Corresponding modifications of the readout software will be necessary.

T3.2 Trigger system
All H1 subsystems provide signals for the H1 central trigger logic. For the FNC the energy yields in the various channels will be used to calculate energy sums, and signals for the H1 trigger will be provided indicating the presence of a neutron or a photon at different energy thresholds. In addition, a trigger signal from the LED monitoring system will be generated. To meet the technical requirements given by the upgraded H1 central trigger system, new FNC trigger electronics, based on programmable chips, will be designed and manufactured.

T3.3 LED Monitoring system
The LED system described in T1.1 will be controlled by a special electronics board, which will be placed in the tunnel near the detector and steered remotely from the electronics room. The system will monitor and control the light output from the LED matrix and the frequency of LED starts.

CR2 will coordinate the above tasks, which will be performed by CR2, CR3 and CR4.
Schedule: months 1 to 6.

T4: Software development for data acquisition, monitoring and calibration

In the framework of the HERA/H1 upgrade, new strategies are foreseen for FNC data acquisition, on-line monitoring systems and calibration studies:

T4.1 Data Acquisition
The old FNC shared a DAQ branch with the Luminosity and Forward Muon systems. Due to the upgrade of these components, the data transfer from the FNC to the Central DAQ has to be modified. Updated branch protocols and software for data distribution are required.

T4.2 Online monitoring and slow control
Online monitoring and slow control will be managed by an Alpha workstation connected to the FADC crate via a VME/VSB interface. The FNC slow control system connects to the main H1 system via Ethernet. The system needs essential software modifications to cope with the new FNC. Data for FNC calibration purposes will be collected by the H1 Central trigger. This calibration data will be analysed on-line and the extracted calibration constants written to a database and used for on-line reconstruction.

The above tasks will be coordinated by CR3 and performed by CR1, CR2, CR3 and CR4.
Schedule: months 3 to 6.

T5: Installation and integration of FNC into H1

The aims of this task are the installation of the new FNC hardware and its full integration into H1. The task is subdivided into:

T5.1 Detector installation
As soon as the assembly of the FNC hardware is complete and its operation understood, the installation phase of the programme must be performed. The detector will be installed in the HERA tunnel and cabling, testing and surveying performed in the slots foreseen in the HERA and H1 upgrade schedule.

This task will be coordinated by CR2 and will involve all the teams participating in this project.
Schedule: months 5 to 10.

T5.2. Electronic installation
The FNC data acquisition and trigger electronics will require modification (see T3). After installation, the FNC DAQ and trigger have to be integrated into the relevant H1 systems and tests performed to ensure that trigger, on-line monitoring and off-line readout are all correctly handled.

T5.3. Commissioning of FNC
The final tuning of the FNC detector will be done during the optimisation of the H1 detector when first beams are delivered following the HERA upgrade. The necessary tasks include:

- Final tuning of detector HV..
- Tuning of trigger settings.
- Optimisation of FNC and H1 central DAQ.
- Off-line tests of data quality and stability.

The above will be coordinated by CO and will involve all participating teams.
Schedule: months 3 to 14.

T6: Support and maintenance of FNC during H1 data taking

To ensure the FNC data if of high quality, the operation of the detector, the electronics and the DAQ system must be permanently monitored. Servicing of components must be performed as and when necessary.

This above will be coordinated by CR2 and will involve all participating teams.
Schedule: months 14 to 30.

T7: Development of FNC off-line software and integration into physics analysis

The upgrade of the FNC makes necessary significant changes to the existing H1 software packages, in particular to the reconstruction software, the detector simulation and the data analysis tools.

T7.1 Simulation of the forward beam-line and the FNC
Accurate Monte Carlo description of the forward beam-line between the ep interaction point and the FNC (z = 107 m) is crucial for the analysis of FNC data, since the beam-line geometry defines the acceptance of the calorimeter. This task, which requires detailed understanding of the beam-line geometry and of the magnet parameters, necessitates close communication with the HERA experts.

A detailed simulation of the FNC has already been written using the GEANT package. Results form this simulation were used during the detector design, in particular to estimate the expected energy resolution and linearity. The FNC simulation, currently a stand-alone program, has to be integrated into the general H1 simulation program.

T7.2 FNC reconstruction package
The FNC reconstruction program has to be rewritten. Since the reconstruction is the basis for all further off-line analysis, this task has high priority. Experience gained using the old FNC will be used in writing the reconstruction program and integrating it into the H1 reconstruction software.

This task will be coordinated by CR4 and performed by CR1, CR2 and CR4.
Schedule: months 1 to 12.

T8: Off-line data analysis and physics studies

The objective of this project is to use data from the new FNC detector for physics analyses. This requires the following:

T8.1 Monitoring of data quality
The FNC data has to be regularly monitored with regard to both the quality of the calorimeter energy measurement and the efficiency of the triggers. During data taking, the trigger efficiency has to be determined and, if necessary, the thresholds adjusted. Furthermore, the efficiency of the event selection at level 4, the filter farm, has to be continuously monitored and improved as necessary. Analysis tools have to be developed for this purpose.

T8.2 Monitoring of the energy calibration
The short-term variation of gain of the FNC photomultipliers is monitored by the abovementioned LED system (see T1.1 and T3.3). This will be used to determine calibration constants on-line, which will be written to the H1 database. The long-term variation of the light yield of the scintillators (e.g. due to radiation damage) will be regularly monitored by an independent LED system (see T1.1). Moreover, during data taking, calibration constants will be determined every few weeks by comparing the energy spectrum of neutrons observed in interactions between the proton beam and the residual gas in the beam pipe, with the results of a $pp \rightarrow nX$ Monte Carlo simulation based upon pion exchange.

T8.3 Physics analysis
Perhaps the most significant measurement that will be made possible by the new FNC is the determination of the pion structure function in the heretofore unexplored region of low x_{Bj} and high Q^2. Using the old FNC, the H1 collaboration made a first approximate measurement of the pion structure function in the kinematic region $2 < Q^2 < 50$ GeV^2 and $10^{-3} < x_{Bj} < 10^{-2}$. With the improved energy resolution of the new FNC, and the larger data samples following the HERA upgrade, it will be possible to extend this cross-section measurement to considerably higher values of Q^2 and x_{Bj}. The enlarged kinematic range will allow discrimination between different parameterisations of the pion structure function.

The improved spatial and energy resolution of the FNC will also enable measurement of the p_T dependence of leading neutron production and thus make it possible to discriminate between various models of this process. Tagging the scattered electron at low angle also makes possible the study of $\gamma\pi$ interactions. Measurements of the total $\gamma\pi$ cross-section and the cross-section for hard $\gamma\pi$ interactions can be performed.

All these analyses will require large Monte Carlo data samples for efficiency and acceptance calculations. Most available Monte Carlo generator programs do not include pion exchange processes, or the implementation is over-simplified (e.g. POMPYT, RAPGAP). In order to achieve a reasonable description of the data, these generators must be improved and tuned. The generators, plus the necessary H1 database, detector simulation and reconstruction software, will be installed on the Liverpool Monte Carlo Array processor (MAP) to facilitate production of large Monte Carlo data samples. Software will be written to allow user-friendly access to MAP and to facilitate the production and analysis of the Monte Carlo data.

Software tools for the analysis of data and Monte Carlo events will also be developed and integrated into the H1 physics analysis environment.

The outcome of this effort will be physics results such as measurements of the pion structure function F_2^{π}, the $\gamma\pi$ cross-section and the total cross-section for events with leading neutrons. These will be presented at international physics conferences and workshops and published in physics journals.

The above will be undertaken by all project members and coordinated by CO.
Schedule: months 5 to 30.

3.1.4.2. DELIVERABLES, EXPLOITATION AND DISSEMINATION OF RESULTS

Two major steps are distinguished in this proposal:

Stage 1, months 1 to 12.
At the end of this stage, timed to coincide with the start of the operation of the upgraded HERA collider, the FNC will be fully operational. A report will be given to INTAS summarizing the progress in the first part of the research programme and in the commissioning of the new FNC. Regular status and progress reports will be given to, and discussed by, the H1 collaboration. The results obtained will lead to publications in H1 internal notes and technically oriented physics journals (e.g. Nucl. Inst. Meth.).

Stage 2, months 13 to 24.
During this period, the detector software and off-line analysis tools will be improved as experience is gained of H1 operation with the upgraded HERA collider. The data and Monte Carlo analysis will be carried out. The results of physics analyses will be discussed in meetings of the H1 physics working groups and in H1 physics meetings. Once accepted by the collaboration, these results will be presented at physics conferences and workshops and will lead to publications in physics journals. The proposed investigations will also form projects for student's Ph.D. theses. A final report will be sent to INTAS at the end of project.

3.1.5 Description of the Consortium

3.1.5.1 Research Teams

All teams involved in this project have experience in the operation of the H1 experiment, detector development, data taking and physics analysis, and, in particular, with construction and operation of the FNC and related physics analysis.

Team 1: (CO) Max-Planck-Institute of Nuclear Physics, Heidelberg, Germany.

The group from MPI-Heidelberg has played an essential role in several experiments at CERN, FERMILAB and DESY, e.g. WA89, HERMES, SELEX, COMPASS. This group initiated the original FNC project and was responsible for the installation and operation of the old FNC as well as for physics analysis using FNC data. It has also made a large contribution to the design and prototyping of the new FNC.
The tasks of this group include detector installation and tests, software development and physics analysis.
Scientific official responsible for the project: Prof. Dr. B. Povh.
Team List:

1. B. Povh.
2. S. Scheloske.
3. T. Schneider.

Team 2: (CR1) University of Liverpool, UK.
The group from the University of Liverpool has contributed to many aspects of H1. It constructed the radial chambers, part of the H1 Forward Track Detector (FTD), and is responsible for the upgrade of the FTD. It has also made, and continues to make, major contributions to physics analysis on H1. The team is part of the University of Liverpool High Energy Physics group in which there is a strong technical base for the design, construction, and operation of large detectors and which has pioneered the use of a 300 PC processor farm for rapid production of large Monte Carlo data samples. Task allocations for the team include detector installation and tests, large-scale Monte Carlo production and physics analysis.
Scientific official responsible for the project: Dr. T. Greenshaw
Team list:

1. T. Greenshaw.
2. D. Milstead.
3. J. Phillips.

Team 3: (CR2) Joint Institute for Nuclear Research, Dubna, Russia.
This group is currently engaged in the operation of, and software development for, the Forward Neutron Calorimeter. They have experience in the design, operation and analysis of various types of detector for high energy physics including, hadron calorimeters, trigger scintillator hodoscopes, fibre detectors and tracking chambers working at Serpukhov, Saclay, CERN and DESY. This group will work on the design, construction and commissioning of the detector hardware and electronics as well as software development and physics analysis.
Scientific official responsible for the project: Dr. L. Lytkine.
Team List:

1. L. Lytkine.
2. R. Koutouev.
3. V. Dodonov (30 years old).

Team 4: (CR3) Institute for Experimental and Theoretical Physics, Moscow, Russia.
The ITEP group was involved in the construction of several of the H1 subdetectors, including the liquid argon calorimeter, instrumented iron and muon chambers and the lead/scintillating SPACAL calorimeter, and has contributed to various aspects of H1 software development and physics analysis. The group has made a major contribution to the design and construction of the new FNC calorimeter. It includes 4 technicians who have been and will continue to be involved in the detector construction and final assembly and installation.
The ITEP group will take on a large part of the responsibility for the construction and commissioning of detector hardware and electronics, as well as software development and physics analysis.
Scientific official responsible for the project: Prof. V. Efremenko.
Team List:

1. V. Efremenko.
2. A. Uraev (22 years old).
3. V. Nagovitsin.
4. S. Chechelnitski.
5. V. Vinogradov.
6. A. Alekhin.
7. A. Baldov.
8. N. Khrapov.

Team 5: (CR4) Yerevan Physics Institute, Yerevan, Armenia.
The YerPhI team has contributed to various aspects of the H1 experiment and is currently involved in the operation and upgrade of the time-of-flight and slow control systems. They have also made a significant contribution to H1 software development and physics analysis, in particular to the analysis of processes with leading neutrons in the final state, including those in which hard scattering is observed.
The tasks allocated to the group include design, construction and commissioning of the trigger and DAQ electronics, software development and physics analysis.
Scientific official responsible for the project: Dr .A. Bunyatyan.
Team List:

1. A. Bunyatyan.
2. A. Beglarian.
3. E. Avetisyan (26 years old).

3.1.5.2 Scientific References

Team 1 (CO, MPIH).

1. B. Kopeliovich, B. Povh and I. Potashnikova, DEEP INELASTIC ELECTROPRODUCTION OF NEUTRONS IN THE PROTON FRAGMENTATION REGION, Z. Phys. **C73** (1996) 125.
2. H1 Collaboration, MEASUREMENT OF LEADING PROTON AND NEUTRON PRODUCTION IN DEEP INELASTIC SCATTERING AT HERA, Eur. Phys. J. **C6** (1999) 587.
3. H1 Collaboration, PROPOSAL FOR A FORWARD NEUTRON CALORIMETER FOR THE H1 EXPERIMENT AT DESY, H1 Internal report, 1995.
4. SELEX Collaboration, TOTAL CROSS SECTION MEASUREMENTS WITH π-, Σ- AND PROTONS ON NUCLEI AND NUCLEONS AROUND 600-GEV/C, Nucl. Phys. **B579** (2000) 277.
5. B.Z. Kopeliovich, I.K. Potashnikova, B. Povh and E. Predazzi, NON-PERTURBATIVE GLUON RADIATION AND ENERGY DEPENDENCE OF ELASTIC SCATTERING, Phys. Rev. Lett. **85** (2000) 507.

6. G.T. Garvey, B.Z .Kopeliovich and B. Povh, BARYON NUMBER FLOW IN HIGH ENERGY COLLISIONS, submitted to Comments on Mod. Phys, hep-ph/0006325

Team 2.(CR1, University of Liverpool)

1. T. Greenshaw, RECENT RESULTS FROM H1, in Proc. of the 6th International Workshop on Deep Inelastic Scattering and QCD, DIS98, Brussels, April 1998.
2. J. Phillips, DIFFRACTION AND QCD AT HERA, QCD99 Euroconference, Montpellier, France, July 1999.
3. D. Milstead, FRAGMENTATION AND POWER CORRECTIONS, XXIXth International Symposium on Multiparticle Dynamics, ISMD99, Brown University, Rhode Island, August 1999.
4. H1 Collaboration, DEEP INELASTIC SCATTERING EVENTS WITH A LARGE RAPIDITY GAP AT HERA, Nucl. Phys. **B429** (1994) 477.
5. H1 Collaboration, INCLUSIVE MEASUREMENT OF DIFFRACTIVE DEEP-INELASTIC EP SCATTERING, Z. Phys. **C76** (1997) 613.
6. H1 Collaboration, FORWARD JET AND PARTICLE PRODUCTION AT HERA, Nucl. Phys. **B538** (1999) 3.

Team 3 (CR2, JINR)

1. G. Bitsadze, L. Lytkin et al. RECONSTRUCTION OF THE COORDINATE AND ENERGY OF THE ELECTROMAGNETIC SHOWER IN THE LEAD GLASS HODOSCOPE CALORIMETER AT DIFFERENT ENTRANCE ANGLES OF 5 GEV POSITRONS, Nucl. Inst. Meth. **A311** (1992) 472.
2. D. White, L. Lytkin et al. SEARCH FOR THE DECAYS ETA $\rightarrow$ MU E AND ETA $\rightarrow E^+ E^-$, Phys. Rev. **D53** (1996) 6658.
3. H1 Collaboration, MEASUREMENT OF LEADING PROTON AND NEUTRON PRODUCTION IN DEEP INELASTIC SCATTERING AT HERA, Eur. Phys. J. **C6** (1999) 587.
4. H1 Collaboration, PROPOSAL FOR A FORWARD NEUTRON CALORIMETER FOR THE H1 EXPERIMENT AT DESY, H1 internal report, 1995.
5. H1 Collaboration, MEASUREMENT OF DIJET CROSS SECTIONS WITH LEADING NEUTRONS IN PHOTOPRODUCTION AT HERA, contributed paper to XXXth International Conference on High Energy Physics, Osaka, Japan, 2000: http://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-00-015.long.html
6. I. Vasilevsky, R. Kutuev et al. THIN AND LARGE SIZE SCINTILLATOR PLATE AS A COORDINATE DETECTOR FOR CHARGED PARTICLES (in Russian) JINR-P13-98-272 (1998), submitted to Prib. Tech. Exsp.
7. I. Boyko, V. Dodonov et al. PRESSURISED DRIFT TUBE RESPONSE TO PHOTONS OF ENERGIES FROM 6-KEV TO 1-MEV, JINR-E1-99-55 (1999), submitted to Nucl. Instr. Meth. **A**.

Team 4 (CR3, ITEP).

1. H1 SPACAL Group (R.-D. Appuhn, V. Efremenko et al.) HADRONIC RESPONSE AND E/PI-SEPARATION WITH THE H1 LEAD/FIBRE CALORIMETER, DESY Report 95-250.
2. H1 SPACAL Group (R.-D. Appuhn, V. Efremenko et al.) H1 BACKWARD UPGRADE WITH A SPACAL CALORIMETER: THE HADRONIC SECTION, DESY Report 96-013.
3. H1 SPACAL Group (R.-D. Appuhn, V. Efremenko et al.) PERFORMANCE OF AN ELECTROMAGNETIC LEAD/SCINTILLATING-FIBRE CALORIMETER FOR THE H1 DETECTOR, Nucl. Inst. Meth. **A374** (1996) 149-156.
4. H1 SPACAL Group (R.-D. Appuhn, V. Efremenko, et al.) THE H1 LEAD/SCINTILLATING-FIBRE CALORIMETER, DESY Report 96-171.
5. H1 SPACAL Group (R.-D. Appuhn, V. Efremenko, et al.) SERIES TESTS OF FINE MESH PHOTOMULTIPLIER TUBES IN MAGNETIC FIELDS OF UP TO 1.2 TESLA, Nucl. Inst .Meth. **A386** (1997) 397-408.
6. H1 SPACAL Group (R.-D. Appuhn, V. Efremenko, et al.) THE ELECTRONICS OF THE H1 LEAD/SCINTILLATING-FIBRE CALORIMETER, DESY Report 98-054
8. H1 Collaboration, MEASUREMENT OF LEADING PROTON AND NEUTRON PRODUCTION IN DEEP INELASTIC SCATTERING AT HERA, Eur. Phys. J. C6 (1999) 587.

Team 5 (CR4, YerPhI).

1. R. Mirzoian, A. Beglarian et al. THE FIRST TELESCOPE OF THE HEGRA AIR CERENKOV IMAGING TELESCOPE ARRAY, Nucl. Inst. Meth. **A351** (1994) 513-526.
2. H1 Collaboration, MEASUREMENT OF DIJET CROSS SECTIONS WITH LEADING NEUTRONS IN PHOTOPRODUCTION AT HERA, contributed paper to XXXth International Conference on High Energy

Physics, Osaka, Japan 2000; http://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-00-015.long.html.
3. A. Bunyatyan, MEASUREMENT OF DIJET CROSS SECTIONS WITH LEADING NEUTRONS IN PHOTOPRODUCTION AT HERA, talk given at Photon 2000 International Conference, Ambleside, England, 2000.
4. A. Bunyatyan, JETS IN DIFFRACTIVE PHOTOPRODUCTION", in Proc. of the 6th International Workshop on Deep Inelastic Scattering and QCD, DIS98, Brussels, Belgium, p.418.
5. H1-Collaboration, DIFFRACTIVE DIJET PRODUCTION AT HERA, Eur. Phys. J. **C6** (1999) 421.
6. H1-Collaboration, JETS AND ENERGY FLOW IN PHOTON-PROTON COLLISIONS AT HERA, Z. Phys. **C70** (1996) 17.

3.1.6 MANAGEMENT

This project forms an important part of the H1 Collaboration's investigations at HERA and will be managed within the structures in place within the Collaboration. Regular project meetings will be organized at DESY and in the institutes of the project teams for which minutes will be produced and posted on the H1 WWW pages. Reports concerning the progress of the project will be given to H1 meetings at DESY and at other institutes as requested by the H1 Technical, Software and Upgrade Coordinators. Physics analyses will be discussed in the meetings of Physics Working Groups and H1 Physics Meetings.

3.1.6.1 Planning and Tasks Allocation

Tasks	Participants	Months 1-6	Months 7-12	Months 13-18	Months 19-24	Months 25-30
T1.1	CR2,CR3					
T1.2	CR2,CR3					
T1.3	CR2,CR3					
T2	CO,CR2,CR3,CR4					
T3.1	CR2					
T3.2	CR2,CR4					
T3.3	CR2,CR3,CR4					
T4.1	CR2,CR3,CR4					
T4.2	CR1,CR2,CR3,CR4					
T5.1	CO,CR1,CR2,CR3,CR4					
T5.2	CR3, CR4					
T5.3	CO,CR1,CR2,CR3,CR4					
T6	CO,CR1,CR2,CR3,CR4					
T7.1	CR1,CR3,CR4					
T7.2	CR1,CR2,CR4					
T8.1	CR1,CR3,CR4					
T8.2	CO,CR2,CR3,CR4					
T8.3	CO,CR1,CR2,CR3,CR4					

3.1.6.2 Cost Table

Main Cost Table								
INTAS Member Teams								
Team Name	**Status**	**Cost Categories**						**Total**
		Labour Cost	Overheads	Travel and subsistence	Consumables	Equipment	Other cost	Total Euro
MPIH	CO			5000				5000
UL	CR1			5000				5000
SubTotal	**(Euro)**			10000				10000

NIS Teams								
Team Name	**Status**	**Cost Categories**						**Total**
		Labour Cost	Overheads	Travel and subsistence	Consumables	Equipment	Other cost	Total Euro
JINR	CR2	13200	2000	5500	1000	1000		22700
ITEP	CR3	21600	3000	7000	1000	1000		33600
YerPhI	CR4	9200	1500	4000	1000	1000		16700
SubTotal	**(Euro)**	44000	6500	16500	3000	3000		73000

Total	**(Euro)**							83000

NIS Labour Cost Summary Table				
Team Name	**Number of individual grants**	**Cost /month (Euro)**	**Number of months**	**Total Cost (Euro)**
JINR	3	200	66	13200
ITEP	1	250	20	5000
	3	200	65	13000
	4	120	30	3600
YerPhI	2	200	46	9200
Totals	13			44000

3.1.7 SUMMARY

A class of events with a highly energetic forward neutron in the final state has been observed by the H1 and ZEUS experiments at the HERA electron-proton collider at DESY in Hamburg. These events, which form approximately 6% of the total ep cross-section, can be interpreted as being due to interactions of a virtual photon with a π^+ from the pion cloud surrounding the proton. Analysis of these events will allow the study of a wide range of physics processes, e.g. it will be possible to extend the measurements of the pion structure function F_2^π to the regions of high squared 4-momentum transfer, Q^2, and low Bjorken-x, x_{Bj}, and to measure the total $\gamma\pi$ cross-section. Experimentally, such measurements require an accurate determination of the energy and scattering angle of the leading neutron.

The parton distributions in the pion have been constrained by fixed target experiments in the region $x_{Bj} > 0.2$. The analysis of leading neutron data in DIS at HERA performed by the H1 collaboration made possible a first measurement of the pion structure function in the region $10^{-3} > x_{Bj} > 10^{-2}$. A major restriction on the accuracy of this measurement was the limited energy resolution of the calorimeter in which the neutrons were detected.

The HERA collider and experiments will be upgraded to allow higher luminosity running from the year 2001. The aim is to improve the accuracy with which the short distance structure of matter is probed through the interactions of electrons and positrons with protons. As a part of the H1 upgrade programme, a new Forward Neutron Calorimeter (FNC) will be installed 107 m downstream of the ep interaction point in the proton direction. This will provide accurate measurements of the direction and energy of leading neutrons. The improved FNC will be a valuable addition to the H1 experiment. With an energy resolution of 3% and a position resolution of 2 mm for neutrons with energy about 600 GeV, and the large data samples resulting from the HERA upgrade, a broad range of physics problems can be addressed.

The aims of this project are:

- To complete the assembly and the installation of the FNC including the associated electronics, trigger and data acquisition systems.
- To commission, calibrate and monitor the system during operation, and to integrate the FNC into the H1 trigger and data acquisition systems.
- To develop off-line analysis software to allow the best possible exploitation of FNC data for physics analysis.
- To extend physics analysis using the leading neutron data to include for example:
    - measurement of the pion structure function F_2^π at high Q^2 and low x_{Bj};
    - measurement of the total $\gamma\pi$ cross section at various centre-of-mass energies;
    - measurement of the p_T dependence of leading neutron production, allowing discrimination between various models of leading neutron production;
    - the testing of the hypothesis of factorisation of proton and lepton vertices in leading neutron events.

The H1 experiment is operated by an international collaboration consisting of 39 institutes from 13 countries. This proposal requests funding for three of the NIS groups within the H1 collaboration, to ensure their participation in the project.

The proposal will be realized by groups from the following institutions: the Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany (MPIK); the University of Liverpool, Liverpool, England (UL); the Institute of Theoretical and Experimental Physics, Moscow, Russia (ITEP); the Joint Institute for Nuclear Research, Dubna, Russia (JINR); and the Yerevan Physics Institute, Armenia (YerPhI).