Questions and Answers from PPESP Referees to Proposal "A Fast Track Trigger with High Resolution for H1"

H1 UK Fast Track Trigger Group

November 2, 1999

1 Introduction

This short document contains the questions raised by Jon Butterworth and those summarised from the last PPESP meeting by Neville Harnew to the proposal for a fast tracking trigger for H1. The questions are in italics. Our answers are in standard font. These issues can of course be discussed in more detail at the forthcoming meeting between members of H1 and the referees.

2 Questions from Jon

1) We will need to see names next to the FTE numbers in the table in your two-page UK proposal of work. Are the requested RAL staff specific key individuals? I should warn you that despite some recent recruitment, the staff effort in RAL TD is extremely heavily committed to other projects, and this is especially true for the more experienced staff.

Going through the table in the covering letter from the proposal ...

- **Analogue DCrϕ Daughter Card:** The Manchester effort corresponds to Scott Kolya, Dave Mercer and technicians. The RAL contribution is requested from the Instrumentation Division, where Adam Baird will presumably continue to coordinate the FTT effort.
- **L1 Front End Modules:** We request that the RAL Instrumentation Division Systems Design group effort be led by Adam Baird, who is already spending some of his time working on this aspect of the project. No particular names are requested for the remaining manpower. The RAL PPD effort corresponds to Dave Sankey, who is working in particular on the $Q-t$ algorithm.
- **Coding Track Segment Finding Algorithm:** In contrast to the statement in the proposal, Birmingham University is now also working in this area (Paul Newman with one first year graduate student). An efficient solution to the track segment finding algorithm is essential in order to minimise the number of FPGA chips required by the system and to ensure that the algorithm can be performed sufficiently quickly. The 2 staff years of effort quoted in the proposal is probably an underestimate of the work required here. The basic algorithm concepts are in place after work from DESY and ETH Zürich. Birmingham have now become involved in the further development, testing and tuning of the algorithm using already existing H1 data and a simulation of the FTT. At a later stage, the algorithm must be coded using a language such as VHDL (Varilog Hardware Description Language). This work could also be done in

Birmingham. The final implementation to the FPGA chips is likely to need more specialised manpower, especially if the algorithm pushes the limits of the FPGAs in terms of size or speed. In the UK, we are unable to commit ourselves to this rather crucial aspect of the problem at present, since we are not aware of the existence of the necessary expertise outside the RAL systems design group, which is already known to be over-stretched. It is also felt that support at DESY will be required in this area for the initial stages of operation of the trigger. There is currently a plan to form a group with these sorts of skills at DESY. If this group materialises, it would be ideal for our requirements. The Birmingham graduate student could work on fitting the algorithm to the FPGAs together with such an group.

- **Control Software and Interfaces:** The manpower requested from RAL would best come from the Real Time Systems group, several of whom already have considerable experience with writing this sort of software for applications in H1. The Manchester effort corresponds to Scott Kolya, who has similar experience.

- **L1 Service Module / Trigger Card:** The service module is intended as a joint venture between Birmingham and Manchester Universities and is required to perform a number of miscellaneous tasks. These include the final stages of the L1 trigger algorithm (assuming an L1 trigger proves possible), dealing with the interaction with the H1 central trigger and data acquisition and the distribution of clock signals synchronised to the HERA bunch crossings to other parts of the L1 FTT system. The trigger itself would be based on a single FPGA per card, which would be the responsibility of Birmingham University (Richard Staley and technicians). The remaining parts of the board will be the responsibility of Manchester University (Scott Kolya, Dave Mercer and technicians)

- **Trigger Algorithms and Simulation** Assuming the L1 trigger design option is followed, this would be the responsibility of Birmingham (Paul Newman with a first year graduate student), in collaboration with the people at DESY / Zürich who are developing the track segment finding algorithm. The input information to the L1 trigger would come from the front-end track segment finding algorithm, so it is necessary to finalise that algorithm and the format of its output before work on the trigger can advance beyond the conceptual stage. Significant work on the trigger is thus likely to begin a few months from now. At present, the only effort in this area is in evaluating whether the gains relative to the existing DCrϕ L1 track trigger will make the work worthwhile.

2) Please provide a schedule with a few milestones relating particularly to the proposed UK work. Who is going to do the planning/project managing for the UK?

The overall UK project manager is Dave Sankey. He is receiving strong support from Adam Baird, who is responsible for the line management in the RAL systems design group, and Paul Newman, who is coordinating the work from the universities on algorithm design.

The expectation within H1 is that the full system will be delivered in time for the beginning of post-upgrade luminosity (March 2001). At present, we think this may not be achievable. A more realistic completion date for the full system is the end of 2001, with the possibility of installing a prototype for testing purposes before the end of the long HERA shutdown. A time schedule on this basis is given below. Understandably, the principal consideration in this is the delivery of the front end module. The time schedule shown here is consistent with previous similar projects delivered by RAL Instrumentation Division and fits well with their staffing profile. It also fits well with a funding profile spread over two years. However, we should stress again that this has not yet been approved within H1 and if it is possible to accelerate this schedule, we would like to do so. A more concrete time schedule will be in place before the PPESP meeting in December.

A delay until December 2001 would have negligible impact on the usefulness of the device, as it is expected that the first few months of post-upgrade luminosity will be dominated by HERA machine tuning and understanding the new background conditions for the experiments. A short shutdown is anticipated for the end of 2001, which would be the intended time of implementation to H1 in this scenario. It should be stressed that it will not be necessary to open or disrupt the existing H1 detector in any other way in order to install the FTT.

Construction of Front End Module

Preliminary design report:	now - 03/00
First design:	03/00 - 06/00
Board layout:	06/00 - 12/00
Prototype manufacture:	12/00 - 01/01
Debug / testing prototype in isolation:	01/01 - 03/01
Installation of prototype at H1:	before 03/01 (end of long shutdown)
Redesign and layout:	04/01 - 06/01
Main production:	06/01 - 12/01

Segment Finding Algorithm for Front End Module

Testing and tuning of $Q-t$ / segment finding algorithm using simulation & H1 data:	now - 04/00
VHDL for segment finding algorithm:	04/00 - 10/00
FPGAs on prototypes programmed:	10/00 - 03/01
Testing and tuning of algorithm in situ at H1:	04/01 - 11/01 (lumi runniing)

DCrϕ Daughter Card

Design:	before 09/00
Production:	before 11/00
Installation:	before 03/01 (end of long shutdown)

Service Module

L1 trigger viability determination:	now - 03/00
L1 trigger algorithm design:	03/00 - 11/00
Design / layout of board:	before 02/01
Prototype service module	before 03/01 (end of long shutdown)
Testing in situ at H1	04/01 - 11/01
Contingency for redesign of service module	06/01 - 09/01
Final production of service module	before 12/01

System Control software

First version of software:	before 03/01 (end of long shutdown)
Testing and refining control software:	04/01 - 12/01 (lumi running)

3) Please clarify the financial contribution from the UK. I presume the DM770 mentioned in the PRC document is an estimate of 250k + 4 CLRC staff years? I presume this 250k is spread over two years? With what spend profile?

The DM770k mentioned in the proposal actually corresponds only to the £260k mentioned in the covering letter to the PPESP (£ to DM exchange rate is around 3.) Assuming the time schedule specified above, the funding would indeed be requested over two years.

The dominant cost in the L1 system is the purchase of the FPGA chips for the front end module. This will mostly be incurred at the production stage, such that the overall spend profile should be weighted to the second financial year. The RAL manpower requests should be approximately flat over the two years from January 2000 (some work is already going into preparing the Preliminary Design Report).

4) In the answers to the PRC you mention the possibility of the FTT providing information to your level one trigger, in which case the existing DCrphi trigger could be completely replaced. How does this impact upon your proposed design? Who is likely to pay the extra DM70k if this proposal is followed up? Have there been any developments in this area?

The presence or absence of a L1 trigger does not have a major impact on the rest of the system. A final decision on whether to incorporate such a trigger will be made before, or at the same time as, the preliminary design report for the front end module. If it goes ahead, an L1 trigger would then take input from the Front End Module in a similar format to that passed to the L2 system. It is planned that the processing electronics for the trigger itself will be housed in the service module. Since only two of these modules will be required, no long production phase is foreseen and the design of the trigger electronics can reasonably lag behind that of the Front End Module by a few months.

The figure of 70kDM mentioned in the addendum to the proposal to the PRC was intended as contingency for the overall project. The cost of including a L1 trigger (basically one FPGA in each of the two service modules) is actually lower than this and is already included in the costing in the covering letter to the PPESP under 'L1 service module / trigger card'. The manpower effort will be provided by the University of Birmingham, so no additional funding is required.

We are in the process of evaluating the potential of a level 1 trigger from the FTT. This work is at the stage of conceptual design of algorithms that will work under the tight time constraints, attempts to estimate the resolution in terms of track p_{T} and to determine the accuracy with which tracks can be constrained to the vertex in the $r\phi$ plane. It remains to be seen whether the improvements over the existing DCrϕ trigger will be sufficient to motivate the work required in developing a FTT level 1 trigger.

5) Like the PRC I too was puzzled by the low (3%) $W \to \mu\nu$ efficiency without the FTT, and understand from your reply to them that the H1 efficiency for these events would be much higher when muon and missing ET triggers are used (phew!). I think you should consider what FTT adds to the total H1 trigger efficiency, not what it adds to the standalone track trigger efficiency. This applies to all channels considered. Could you please give some numbers for this kind of gain?

Up until now, track triggering in H1 has been realised with loose requirements at the level 1 stage and refinements at the level 4 filter farm stage. Irrespective of whether the FTT provides a trigger at level 1, it will make refined track trigger decisions possible for the first time at levels 2 and 3. The possibility of rejecting background before the level 4 stage will reduce the need for random downscaling for any process that involves charged tracks. This will be crucial with the large post-upgrade luminosities. The existing level 1 DCrϕ track trigger, though reasonably efficient, is not able to provide a sharp p_{T} threshold and has only a limited ability to recognise whether a track truly originates from the vertex region. Thus for all processes where charged tracks form part of the basis for trigger decisions at level 1, the FTT could also provide sharper trigger thresholds in track p_{T} and improved background rejection even at level 1.

The improved flexibility in trigger decisions offered by the FTT will mean that more complex decisions can be made for certain types of process. For some such processes, the FTT will complement other triggering methods and thus improve the redundancy of the overall H1 trigger. For example, J/ψ photoproduction measurements have been made in the channels $J/\psi \to \mu^+\mu^-$ or e^+e^-,[1] using a variety of muon, electromagnetic calorimeter and tracking detector based triggers. The overall efficiencies are far from perfect (around 50% for e^+e^- and 60% for $\mu^+\mu^-$ in the elastic channels, considerably smaller in the inelastic channels, with large systematic errors arising from the trigger efficiency determination in both cases). Furthermore, the existing triggers already have rather high rates and will thus be downscaled after the upgrade unless additional selectivity is available from the FTT. The J/ψ (and more so for the Υ) decay products typically have rather large p_{T}. With the FTT, trigger selections can be made on the basis of measurements of those p_{T} values at level 1 and 2, with the level 3 vector meson invariant mass selection improving the selectivity still further. The FTT efficiencies quoted in the addendum to the PRC proposal of 12% (inelastic) - 60% (elastic) were based on a $p_{\mathrm{T}} > 0.8$ GeV for both lepton tracks and thus do not completely overlap with the existing triggering methods. Assuming the FTT efficiencies are very well known, the FTT will have an impact on heavy onium physics in terms of reduced trigger systematics as well as enhanced statistics.

The process $W \to \mu\nu$ is the only process listed in the table in the PRC document for which there are real alternatives to using tracking triggers after the upgrade. The process has so far been triggered only on the basis of missing p_{T}.[2] To obtain reasonable background rates, the missing p_{T} threshold is set at 25 GeV. Above this transverse momentum, the efficiency is large $\sim 90\%$, but the 25 GeV threshold cuts heavily into kinematic phase space, such that the overall $W \to \mu\nu$ efficiency is at the 10% level. It is clear that a track trigger which can identify a single high p_{T} track, used in conjunction with a lower threshold missing p_{T} trigger, will enhance the overall process efficiency considerably.

A final class of processes, such as $D^* \to K\pi\pi$, $\rho \to \pi\pi$, $\phi \to KK$ etc. can only be triggered using tracking information. In these cases, the numbers in the rightmost column of table 2 in the addendum to the PRC proposal truly reflect the sort of efficiency that can be expected after the upgrade without a FTT.

6) On page 6 of your proposal to the PRC you mention selection on the charge of the tracks at level 2. Don't you need to keep the wrong sign background, since I presume you will not be keeping a control region? If not, how do you evaluate the background under the mass peaks with sufficient accuracy? If you do have to keep wrong sign combinations, how does this affect your rates?

In earlier documents, we have not attempted to address the question of control samples such as this. In general, our intention would be to keep such control samples, but in a downscaled form (for example, retaining one in every ten such events). The choice of downscaling factor would be dictated by the volume of data required for such samples in order to estimate backgrounds with acceptably small statistical errors.

For the $D^* \to K\pi\pi_{\mathrm{slow}}$ process, we are likely to retain a fraction of events for which the K and π have the same charge, opposite to that of the π_{slow}, but where the $K\pi$ invariant mass combination falls inside the D^0 mass window. Studies have shown that taking all such events would increase the overall trigger rate by a factor of approximately two, which may be prohibitively large. However, taking one in ten such events would result in only a 10% increase in rate, which would certainly be acceptable. An alternative and complementary method of estimating the background has been used in previous

[1] See e.g. H1 Collaboration, Nucl. Phys. **B472** (1996) 3.
[2] See e.g. H1 Collaboration, Eur. Phys. J. **C5** (1998) 575.

H1 publications, whereby a 'side-band' with $K\pi$ masses larger than the upper limit of the D^0 mass window is studied to understand the background size and shape. Retaining events of this type may result in smaller rate increases.

The fact that the PPESP has been informed of this proposal so late in the day leads to several comments

7) A large fraction of our money and TD effort is already committed to other projects on your timescale and it is possible that even if we were to wholeheartedly recommend funding, it would not be possible. Please consider what might be the consequences of only a fraction your request being met. Would 1/2 be any use to you? How about 2/3? These are just numbers pulled out of the air by me now, they were not discussed at the panel, so don't put too much weight on them. But I think it would prudent to think about this kind of scenario in advance of the December meeting, since the panel might need to know.

The bid to the PPESP is only a part of the overall costs of the FTT project. The requested funds are necessary in their entirety within the overall funding scheme presented in the addendum to the PRC proposal. Part of the reason for the delay in approaching the PPESP was ensuring that the project was feasible and the costs kept to a minimum. There is thus little scope for reducing the financial requirements of the project other than slipping the delivery date.

Clearly, if the PPESP funding request were only met in part, it would be necessary to make up the shortfall from elsewhere, most likely the collaborating German and Swiss institutes. It is not at all obvious that this would be possible. It would be unlikely that any money could be forthcoming from the UK universities. - Any contingency funds lying around are likely to be taken up in dealing with the consequences of a recent water leak in the Forward Tracker, which is unlikely to be covered by our maintenance and operations budget.

It is very difficult to see where we could find alternative manpower if it were not possible to meet our request for four staff years of effort from the RAL instrumentation division. - Without this effort, the project would be in serious difficulty.

8) Members of the panel were worried that the fact that H1 seems to have come to this late might mean that the physics goals of the FTT are not viewed as high priority within the collaboration. This is not a huge worry of mine knowing the situation at DESY, but I would like to see two things, which I think would also help reassure the panel:

The FTT project has been considered within H1 as highly important since the first discussions on the project in 1996. The delay in coming to a concrete proposal has arisen for technical rather than motivational reasons. Continuous work has been going on in the development of algorithms and other aspects of the project. The project pushes the limits of available technology and it is only comparatively recently that a fully workable scheme has emerged. For example, after considerable investigation, it turned out that our original plans for the track linking were not possible within the 20μs level 2 latency. The emergence of a new generation of high density programmable devices such as the Altera FPGAs and the involvement of the Zürich SCS company (since October 1998) opened up a new direction which we now know can meet the trigger specification. When it became clear that the project was technically viable, considerably increased manpower was committed to the project. It was only once a feasible minimum version of the project design was in place (mid 1999) that it became possible to submit realistic requests to the DESY PRC and the funding agencies.

- Give a brief list of H1 upgrades (including those with no direct UK involvement) underway or planned on the timescale of the HERA upgrade, along with their dates of presentation to the DESY PRC.

- Presumably the H1 UK collaboration envisages actually doing some of the measurements mentioned in the proposal. If you could indicate which ones, who, and at what institutes, it would be helpful.

PROJECT	PRC Proposal	Date
ϕ Strips for Backward Silicon Tracker	PRC 98/01	Jan 98
Inner Central Tracker MWPC / vertex trigger upgrade	PRC 98/02	Jan 98
Luminosity System Upgrade	PRC 98/05	Jun 98
Forward Track Detector Upgrade	PRC 98/06	Jun 98
New Forward Silicon Tracker	PRC 99/01	Jan 99
Liquid Argon Calorimeter Jet Trigger	PRC 99/02	Jan 99
Upgrade and Merging of L4 / L5 triggers	PRC 99/03	Jan 99
Fast Track Trigger	PRC 99/06,07	Jun 99

Obviously plans for physics analysis shouldn't be prescribed by the PPESP, but we do need to see that the UK intends to exploit the proposed investment.

Certainly the UK plans to exploit the FTT as fully as possible in order to maximise the return on our proposed manpower and financial investments. It is not possible to give a detailed analysis plan at this point, but a number of possibilities are sketched out below.

One UK PhD student (Birmingham) has recently begun working on the design of the FTT. If funding is forthcoming, it is hoped that he will eventually become involved in the analysis of the first data from the device. In the coming years, it is expected that further graduate students will be committed to the exploitation of FTT data.

There is already considerable interest within the UK university groups in several physics analysis areas to which the FTT will contribute. Since the beginnings of H1, the Birmingham and Manchester groups have been heavily involved in both elastic and inelastic J/ψ and $\psi(2S)$ physics. The FTT will improve the prospects for this activity after the upgrade.

Expertise in D^* physics already exists in Birmingham and Manchester, where the analysis of diffractive open charm production has taken place. This expertise could be used, either to extend the diffractive D^* measurements using the statistical improvements after the upgrade, or else to study D^* production in other types of interaction. There are also plans in Liverpool to become involved in the study of charm in the proton using high Q^2 data.

A large fraction of the analysis effort and leadership in H1 diffractive physics in general has come from the UK (Birmingham, Liverpool, Manchester). It is expected that this effort will continue after the upgrade, with the potential to use the FTT for new studies of light and heavy vector meson production, diffractive open charm production etc.

The Liverpool group has dominated the H1 investigations of virtual photon structure, through the study of jets at low Q^2. One possible course of action would be to use the expertise obtained in this area to extend the analysis to the study of D^* events where the p_{T} of the D^* is larger than Q^2. This would help, for example, to unfold the quarks from the gluons in the parton densities of the virtual photon. From the jet data analysed thus far, it is only possible to measure effective parton densities, corresponding to a mixture of quarks and gluons weighted by their colour factors.

9) I presume there is a non-negligible chance that the FTT is not fully operational on day one of the post upgrade running? Is it easy to add it in later?

No technical problems whatsoever would arise from late installation of the device. As discussed in answer to the question on time schedules above, a possible delivery time is the short shutdown planned for the end of 2001. It would also be possible to implement the FTT during a period when H1 is taking luminosity, as the device is entirely 'parasitic' to H1, and can be installed without the removal of any existing part of the detector or its electronics. As stated in the time schedule above, the aim would be to install the DCrϕ daughter cards during the long shutdown. Once they are in place, the remainder of the system can be installed at any time.

Track triggering in the initial phase after the upgrade can continue to be performed using the DCrϕ trigger. Even if it is decided that the FTT should provide an L1 trigger, it is currently planned that the DCrϕ trigger would continue to operate in parallel for an initial period.

3 Further Questions from Neville

Here we either refer to earlier answers, or give a few additional comments where the questions do not overlap with those from Jon.

1) The technical issues are well described in DESY PRC report. However the panel thought that the 2-page UK documentation had many unanswered questions. In particular, the UK planning of the project - who will do what, who will provide the expertise to do it?

See answers to questions 1 and 2 from Jon.

2) Following from above. What is the breakdown of effort in the UK universities ? What are the responsibilities of the individual groups ?

See answer to question 1 above.

3) Who are the people involved at RAL ? What if the RAL effort is not forthcoming ? Would the UK still be able to commit to the project ?

As stated in answer to Jon's question 1, we ask that Adam Baird (RAL Instrumentation Division) should continue to work on the project. Otherwise, we have no special requests for who should be involved. As stated in answer to Jon's question 7, the technical effort from RAL is certainly crucial to the project.

4) The timescale seems very tight, and how can it be achieved as proposed ? Does the track trigger need to be there on day 1 ? When would it be 'too late' to install ?

As discussed in answer to Jon's questions 2, 3 and 9, it is not essential that the FTT be completely ready on day 1 of post-upgrade luminosity. From a technical point of view, it will never become too late to install. However, we obviously would like to deliver the device as early as possible, to maximise the physics output.

HERA anticipates delivering 150 pb^{-1} per year after the upgrade. The numbers of events expected before and after the upgrade in several channels were given in table 1 of the addendum to the PRC proposal. Taking D^* production in DIS as an example, approximately 6500 events are expected per year after the upgrade, which should be compared to around 4000 events expected in total before the long HERA shutdown. Thus if the FTT were available for five years of optimal running after the upgrade, we would expect something like 30000 D^* events, giving a factor of around 10 increase in statistics compared to pre-upgrade yields.[3] Should the FTT only be available for four years after the upgrade, the loss of statistics for D^* analysis would not be critical. Similar arguments apply to the other channels under consideration. Delivery of the FTT more than one year late is an unrealistic scenario, but even then, there would be substantial physics gains from the device.

[3]Note that without the FTT, the post-upgrade D^* efficiency would be at the 1% level - see sections 3.2 and 3.3 of the addendum to the PRC proposal.

5) Why was the request so late to reach the PPESP in its current form ? The project was flagged, but at nowhere near this level of support, when the HERA upgrade was discussed.

As discussed in answer to Jon's question 8, the request comes later than originally planned due to the time taken in convincing ourselves that the project could technically be realised. Once the separate stages in the design fell into place, it became clear that a substantial part of the trigger processing would take place at the level 1 stage. The UK groups saw this extended project as something they wanted to lead and considered the increased costs to be a worthwhile investment.

6) Money. Which other groups are bidding for what towards the track trigger in H1 ? There was some confusion to whether your bid for 260k pounds is consistent with Table 7 in the PRC document, and the statement of 250 DM/institute. It is not clear to us how staff costings are taken account in these PRC figures.

We are sorry if we have presented conflicting information in the various documents as the project has progressed. Please refer to the updated financing scheme in section 5.4 of the addendum to the PRC proposal, rather than the outdated information in the original PRC proposal. In the latter PRC document, the UK contribution is flagged at DM770k, which corresponds to the £260k requested in the covering letter to the PPESP.

The table in the covering letter to the PRC contains separate columns for financial requests and for manpower needs. Of the manpower needs, four staff years of RAL technical effort is requested. This corresponds to 3 staff years for the construction of the front end modules, 0.5 staff years for the construction of the analogue DCrϕ daughter cards and 0.5 staff years for the development of control software and interfaces.

7) What is the status of other UK-funded upgrade projects (have deliverables been met ?). Also the forward tracker.

Apart from the FTT, the only other project with UK funding is the Forward Tracker upgrade. At the present time, this project is on schedule for May 2000.

8) The panel had some questions about the physics benefits - but these will surely come through the referees.

See answers to Jon.