Proposal 317 - CALICE Status and Update

Birmingham, Cambridge, Imperial, Manchester, UCL

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1 Introduction

This document is a resubmission of the CALICE-UK proposal to the PPRP [1] to participate in the CALICE collaboration, studying calorimetry for a future linear collider (LC). It outlines the changes to the previous proposal, following the comments from the PPRP meeting of 1 July 2002, gives more detail of critical aspects and briefly describes the current status the project. This is done for both the electronics and the simulation work. It finally gives updated lists of the resources and effort needed for this project.

2 The CALICE collaboration

The CALICE collaboration as a whole has expanded both in terms of people and also in terms of the scope of the project.

In recent months, four new institutes have been accepted into the collaboration (Seoul, U. Texas at Arlington, Northern Illinois, Dubna) and three more (Boston, Chicago and Illinois) are currently applying to join. The collaboration now has 138 members from 24 institutes in 8 countries; most importantly, it has membership from all three regions (Europe, US and Asia) involved in the LC program.

These new institutes have allowed new technologies to be considered within CALICE. There are now three options for the digital hadronic calorimeter (HCAL) being actively considered; RPCs, GEMs and small scintillating tiles. These are in addition to the scintillating tile analogue HCAL. The electromagnetic calorimeter (ECAL) work remains concentrated on silicon-tungsten.

The beam test continues to be the major focus of the collaboration work. The aim is for all four HCAL options to be tested so that a meaningful comparison of their performances can be made. All four will be housed within a common mechanical structure containing iron plates, between which the various active layers can be inserted. The different HCAL options are in different stages of maturity; the analogue tile and digital RPC HCALs are likely to be ready by mid 2004, while the other options may be available by the end of 2004. The ECAL is on schedule to be completed early in 2004. The beam test program has therefore been pushed back but extended in scope and length with these new options; rather than the original six months early in 2004, it now looks likely it will continue for around one year, from mid 2004 to mid 2005. With the subsequent analysis of these data, the project will therefore continue into FY05/06.

The location of the beam tests is still not fixed although, given the change in schedule, it is less likely to be at CERN. Fermilab and/or Protvino should both be able to provide beams on this timescale. With regard to the latter, it has now been clarified that there will be no charge for setting up the beam line; hence the £10k budgeted for this possibility in the original proposal is no longer required.

CALICE recently submitted an annual report and gave a presentation to the DESY PRC [2]. This gives a summary of the overall project status. The report was well received and the referee recommended that CALICE proceed to the full beam test as proposed [3].

2.1 The CALICE-UK collaboration

The UK institutes involved have had several changes in personnel since the PPRP meeting and various people have increased their time on CALICE, Manchester have recently appointed S.Soldner-Rembold who has a strong background in LC physics studies, particularly for the TESLA TDR. He will be working 50% on CALICE after he arrives at Manchester next year. D.Miller has significantly increased his time on CALICE; although he is due to retire in 2005, UCL are expected to replace him with a new lecturer full-time on LC work. He has also brought in a UCL postdoc, S.Boogert, who is now splitting his time equally between CALICE and another LC project. This postdoc position will run out before the end of CALICE and we request a one-year extension to this post from the PPRP. D.Ward has obtained a sabbatical for 2003-4 and so can also increase his time on CALICE. Because of these changes, every institute will now have an academic spending at least 50% of their research time on CALICE.

We believe the UK people have already had an important impact within the LC community internationally. D. Miller has been well-known for his LC work for many years and chairs several international committees in this area, in particular the ECFA/DESY LC study [4]. M.Thomson is a convenor of the detector performance working group for these EFCA/DESY studies. P.Dauncey is a convenor of the calorimetry sessions for the international LC workshop meetings [5]. He also presented the CALICE annual progress report to the DESY PRC in October [2].

3 Status of the electronics development

Details of the electronics design can be found at [6].

The ECAL readout electronics went through a conceptual design review (CDR) [7] on 11 October, where the design, schedule, cost, etc., was presented in detail to four external reviewers. This was very productive and there was agreement that the proposed design was sound. Several minor technical issues were raised and solutions found [8].

However, one major item of concern was identified by the reviewers from RAL ID with regard to scheduling the layout of the prototype readout board in the RAL ID drawing office. Due to LHC work, the office is heavily booked for the period when it would be needed.

To overcome this problem, the reviewers proposed taking an existing board with a similar architecture and redoing the layout only for the parts which need to be CALICE-specific. The CMS Tracker Front End Driver (FED) [9] was identified as a good starting point. This 9U VME64 board has been developed over several years by groups at Imperial and RAL and first full-specification prototypes are due to be available in December this year.

The architecture of the FED is very similar to the proposed readout board; it has several Front End (FE) FPGA's, each handling an (optical) input cable, and these are controlled and read out using a Back End (BE) FPGA. These have effectively identical functions to the readout board slave and master FPGAs, respectively. The FED is somewhat overengineered for the CALICE application; around 500 will be built for CMS and they will have to operate for around ten years. Hence, there is an emphasis on reliability and operational efficiency, with hot-swap capability, software-loadable firmware updates, resettable fuses, temperature-sensitive, multi-level power-downs, etc. These would not normally be considered as critical for a beam test application and some of the components may not be mounted for CALICE use to save on cost. In addition, the FED has more functionality than needed for the readout board, so the FPGAs are larger and more performant (and hence more expensive) than needed.

The VME interface, BE FPGA and layout up to the FE FPGAs are all usable directly in CALICE, although some BE firmware development will probably be needed. However, the input stage of the FED is completely different. This front 10cm strip of the board will be redesigned

and laid out with the connectors, ADCs and DACs needed for the ECAL readout. However, this is only around 20% of the total board area. Hence, it is feasible for this smaller amount of work to be done in the RAL drawing office early in 2003. The FE firmware to control this will clearly need to be written from scratch.

The FED is 9U rather than the previously proposed 6U boards. This has two implications. Firstly, more connectors can be put on the front panel, so increasing the number of channels per board and so decreasing the number of boards and crates required. Secondly, because of the extra connectors in VME64, there is greater connectivity on the backplane. This will allow all the I/O signals for the trigger board to be brought into the readout board, so the trigger functionality can be implemented in the BE FPGA. This obviates the need for a separate trigger board, at the cost of extra firmware effort needed in the BE.

3.1 Schedule, effort and cost

Overall, the equipment cost is only changed slightly. Using 9U rather than 6U puts up the board and crate cost, as does using the more expensive FED FPGAs. However, only 6 readout boards will now be required, compared to 15 previously, and only one, not two, VME crates will be needed; both these give substantial savings. The total cost is now estimated at £104k?

Layout effort needed is reduced by not having to design the majority of the readout board or any of the trigger board. Reusing most of the BE firmware, compared with designing the master from scratch, will also save some effort. The FE and slave are effectively the same and so this gives no change. The total RAL ID effort needed is now estimated at 18 months.

The impact of not having RAL ID effort available for the last four months has not been negligible. Besides not having the ability to book ahead in the drawing office, the lack of engineering effort has meant the design has developed a little more slowly than originally scheduled. Overall, the project has probably lost two months because of this. This means some costs from this FY will now slip into FY03/04. The original end date of January 2004 will also move back by around two months but will still require no equipment funds in FY04/05. This extra time is now available due to the shifted time of the beam test now being planned; the completed (and tested) electronics must be ready by mid 2004.

4 Status of the simulation work

At their meeting in July, the PPRP indicated the need for a detailed work plan for simulation work in the UK. We outline our plans here, and report briefly on progress to date.

4.1 Plans and timescale

Software activities are taking place at several institutes in CALICE, so in the UK we have endeavoured to identify a program of work which complements existing activities, and matches the manpower at our disposal. The most detailed Monte Carlo for linear collider calorimetry is `Mokka`, based on `Geant4`. Many studies have also been performed using `Brahms`, based on `Geant3`. Our aim in the UK (Cambridge and Birmingham, at present) is to conduct a critical comparison of the physics content of various Monte Carlo programs, particularly the response to hadrons, and to assess the impact of any differences seen on the design and expected performance of linear collider calorimeters. In this way we expect to identify key areas in which results from the CALICE test beam will be essential to test the expected performance of the calorimetry for a future linear collider experiment.

To this end, we envisage the following core areas of work, with the approximate timescales given:

- Start with the design presented in the Tesla TDR, i.e. a silicon-tungsten ECAL and an iron-scintillator or iron-RPC HCAL, as coded in `Mokka`. Examine the response of the calorimeter to single particles ($e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$ etc.), initially at normal incidence. Compare the standard `Mokka` simulation with alternatives, e.g. `Geant3` [10], `Fluka` [11] and the several alternative hadronic interaction models implemented in `Geant4`. In addition the dependence of the results on tracking cutoffs is being considered. *[Summer/Autumn 2002.]*

- Extend these studies using the geometry envisaged for the test beam prototype, to confirm whether effects seen in the TDR design would also be reflected in the test beam data. *[Early 2003.]*

- Investigate the impact which differences between models would have on the performance of energy flow algorithms for jet energy reconstruction. This work would cover existing algorithms, as used in previous studies, and hopefully also new energy flow ideas being developed in the UK. *[Spring/Summer 2003.]*

- Quantify the relative performance of alternative detector designs, e.g. different longitudinal sampling and transverse segmentation, dead cells. In particular, does this depend on the Monte Carlo simulation used? *[Summer 2003.]*

- Devise a data taking strategy for the test beam (choice of particle types, energies, angles) that will yield the most valuable information about the reliability of the Monte Carlo simulations. *[Autumn 2003.]*

- Prepare software tools for test beam running and ensure that suitable Monte Carlo samples are in hand, so that the UK physicists can play a leading rôle in the interpretation of the data. *[Autumn 2003 – Spring 2004.]*

In parallel, work on physics studies and on energy flow algorithms will proceed as manpower is available. Use has already been made of undergraduate projects, this is continuing and we expect the recruitment of research students and fellows to allow growth in this area.

A complementary program of work is under way at UCL, studying the use of wide angle Bhabha scattering events for monitoring of the beam energy spectrum. This will focus on the use of the calorimetry for the measurement of high energy electrons, and will allow us to ensure that this field is not compromised by any optimization of the calorimetry for jet energy reconstruction.

4.2 Measuring the luminosity spectrum using Bhabhas

The electromagnetic calorimeter will be a crucial component in measuring the luminosity spectrum at the LC. The luminosity spectrum is essential for precision physics, especially for the planned threshold measurements of the top-quark mass with a precision of better than ± 100 MeV (also for sparticle masses, and for the Z lineshape and the W mass to 6 MeV in the GigaZ option). The measurement relies on a high precision determination of the distribution of the acollinearity angle of Bhabha scattering events in the electromagnetic endcap [13]. This angle is a surrogate variable whose sensitivity to beamstrahlung and other effects should enable the true $\sqrt{s}$ distribution to be unfolded with the required precision. The UK groups are using the `Brahms` and `Mokka` simulation software to develop optimised clustering algorithms for this measurement. Within the period of the current bid we will demonstrate whether the current CALICE design is capable of delivering the required efficiency and angular precision.

4.3 Geant3/Geant4 comparisons

These studies have started using the Tesla TDR calorimeter design implemented in `Mokka` (`Geant4`). We have generated samples of e^-, μ^-, $\pi^\pm$, $K^\pm$, K^0_L, protons and neutrons at kinetic energy 2, 5 and 15 GeV, impinging at normal incidence on the barrel calorimeter. `Mokka` provides a facility whereby `Geant3` FORTRAN code describing the geometry can be written out. We have taken this code and implemented it in a `Geant3` Monte Carlo (using the `Brahms` framework), and generated corresponding samples of events. The two programs have been harmonised by the use of a common output format. The digitization process is not simulated – our comparisons are based on "hits", corresponding to the ionization deposited in the sensitive detector volumes; in this way we are making a direct comparison of the physics content of the simulations.

First results from these comparisons, using the purely electromagnetic processes induced by e^- and μ^-, showed many more hits in the `Geant4` simulation than in `Geant3`. This was readily attributable to the different (higher) tracking cutoffs implemented by default in `Geant3`, and a lack of δ-ray creation. When δ-ray production was enabled and the tracking thresholds were reduced to $\sim$ 10 keV, reasonable agreement between `Geant4` and `Geant3` was achieved. Fig. 1 shows that the longitudinal and transverse energy profiles of e^--induced showers agree well between the two models. There is a discrepancy of $\sim 6\%$ in the overall energy scale, which seems quite sensitive to the treatment of the low energy cutoffs, which are implemented in different ways in the two versions of `Geant`. The energy resolution shows good agreement.

Hadronic interactions are notoriously more difficult to simulate correctly, and hence the comparison of hadronic showers is likely to be more interesting. A typical comparison is shown in Fig. 1 for the case of 5 GeV π^+. The longitudinal shower profiles in the ECAL and HCAL show quite good agreement, as does the energy sharing between the two parts of the calorimeter. The transverse shower profiles exhibit some differences, with `Geant3` predicting slightly broader showers, especially in the HCAL. Results for π^-, $K^\pm$ and K^0_L show similar levels of agreement. However, substantial differences were revealed when examining the showers induced by protons or neutrons – the energy deposition in the ECAL and HCAL being greater in `Geant3`. This is illustrated in Fig. 2, which shows, for $\pi^\pm$ and protons the deposited energy in each calorimeter (in Mips, divided by the kinetic energy) for three energies. The discrepancy between `Geant3` and `Geant4` becomes proportionally greater at lower energies, and seems to be largely associated with the low energy baryonic component of the shower. The shower widths are also wider for baryons in `Geant3`.

`Geant4` provides an extensive "toolkit" of possible hadronic interaction models. The `Geant4` authors have recently made available several standard packages of these, to fit standard "use cases". We have started to compare these standard groups, for example one called "LHEP" which provides a parametrized model, and models known as "QGSP" and "QGSC" which implement more detailed descriptions of microscopic low energy cross-sections including resonances. First studies indicate differences between these models for hadronic showers at typically the $\sim 10\%$ level.

We have also recently started to compare the behaviour of hadronic showers in two possible technologies for the HCAL, in which the detection medium could be scintillator or RPCs. First indications are that the detected showers in the HCAL are narrower when RPCs are used, in both `Geant3` and `Geant4`, though there are other significant differences between the two programs. This clearly needs further investigation, and probably evaluation in a test beam, since it could have a significant impact on energy flow performance.

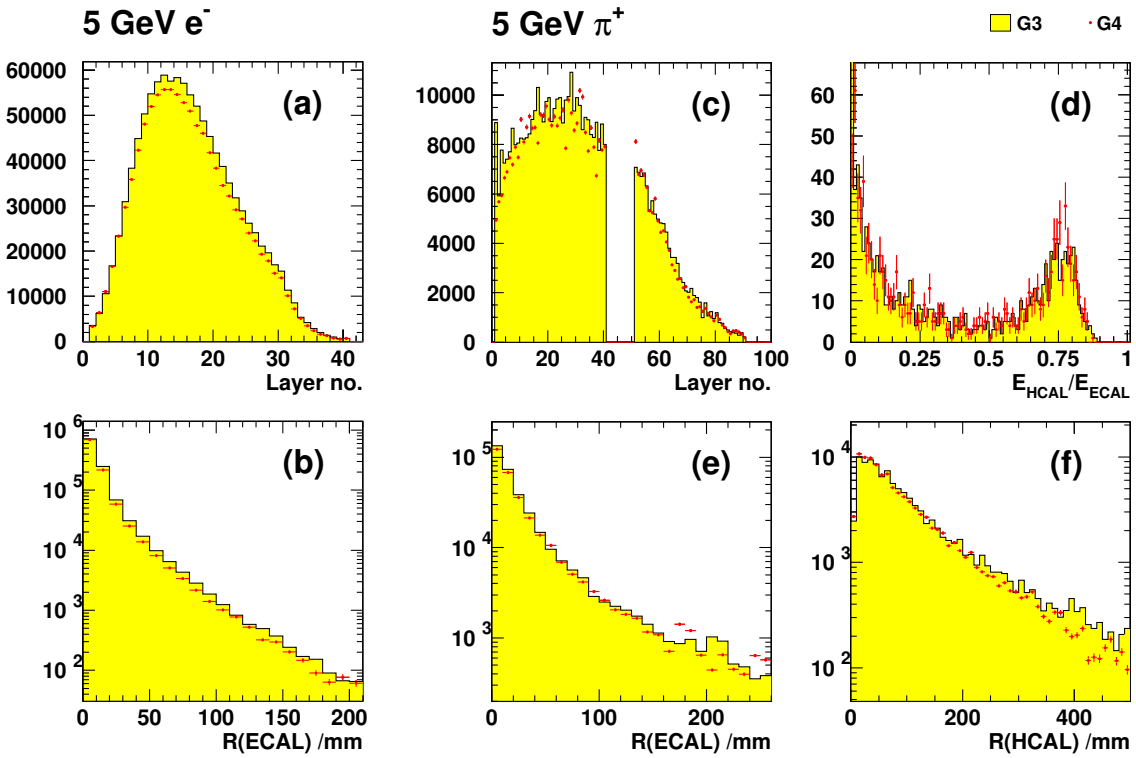

Figure 1: *(a) Longitudinal shower profile (plane number), weighted by energy, for 5 GeV e^- in the ECAL, (b) Transverse shower profile (radius), weighted by energy, for 5 GeV e^- in the ECAL, (c) Longitudinal shower profile (plane number; +50 for HCAL), weighted by energy, for 5 GeV π^+, (d) Fraction of energy deposited in the HCAL, for 5 GeV π^+, (e) Transverse shower profile (radius), weighted by energy, for 5 GeV π^+ in the ECAL, (f) Transverse shower profile (radius), weighted by energy, for 5 GeV π^+ in the HCAL. In all cases the points are* `Geant4` *and the solid histogram* `Geant3`.

4.4 Fluka/Geant comparisons

The `Fluka` Monte Carlo system is reputed to have the most detailed microscopic model of hadronic interactions on nuclei, and is regarded favourably by some LHC experiments. It would therefore be highly desirable to compare `Fluka` with `Geant3` and `Geant4`. An old version of `Fluka` was interfaced to `Geant3`, but this version is now deprecated by the `Fluka` authors. The new version of `Fluka` can not straightforwardly be interfaced to `Geant`, because of differences in philosophy in handling the geometry description as well as differences of programming language.

This difficult issue has been addressed by the LHC experiments in three ways. The first of these is to define the geometry and materials directly in `Fluka`. However, this is potentially inefficient when considering several variations on the detector design. The second approach consists of a "virtual Monte Carlo" system implemented in the ROOT framework and being developed by members of the ALICE collaboration. We chose not to adopt this as it entailed the integration of our existing `Geant3` and `Geant4` simulations with this package in addition to `Fluka`. We chose the third method, which is a direct interface between `Fluka` and the geometry of the detector as described by `Geant4`. This package, called `FLUGG`, has been developed between the `Fluka` authors and ATLAS, and used e.g. by the ATLAS barrel calorimeter group. This method seems to offer the greatest flexibility in terms of ability to study alternative detector configurations. The "hits" information is being output in the same format as the `Geant3` and

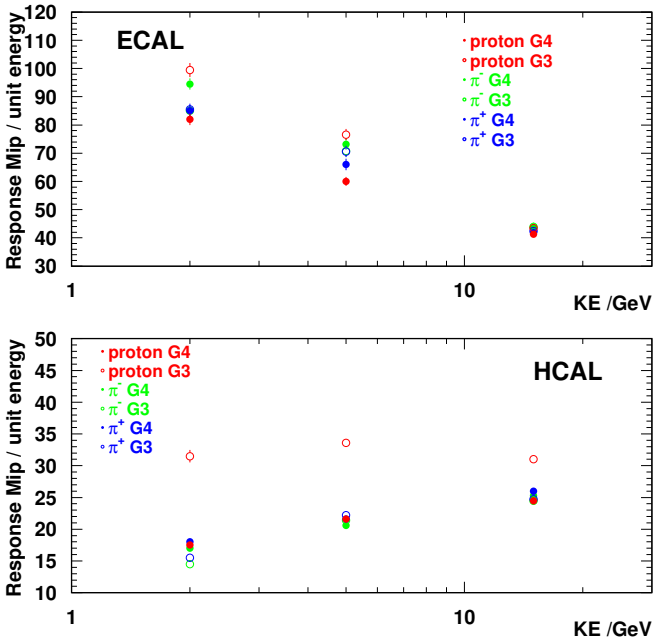

Figure 2: *Average response (in Mips) divided by kinetic energy for* $\pi^{\pm}$ *and protons at three energies, comparing* `Geant3` *and* `Geant4`.

`Geant4` simulations, to facilitate comparisons.

At present, we have just finished testing that the FLUGG package faithfully describes the `Geant4` geometry using a lead-scintillator calorimeter configuration [12]. As an example of this, Fig. 3 shows the trajectory of neutrons in the plane transverse to the direction of a 10 GeV π^- entering at normal incidence to the calorimeter. We are now integrating the more complicated Tesla TDR geometry of `Mokka` with FLUGG for direct comparison with the `Geant3` and `Geant4` studies.

4.5 Integrated Detector Design

The aim of the CALICE project is to provide information which will provide guidance in the design of a Linear Collider detector. In the measurement of jets, as well as many other topics, it will certainly be necessary to take an integrated view of the whole detector in considering its overall performance. To this end, the ECFA/DESY series of workshops have recently established a working group addressing these issues, which will be coordinated by a member of UK CALICE (M. Thomson). The UK CALICE groups will have a good understanding of these issues and be in a strong position to influence the detector design by the time an experimental collaboration is formed for a linear collider.

5 Summary

The CALICE collaboration continues to attract more collaborators and its scope is broadening. The UK has continued to be an active part of the collaboration and would like to put our involvement onto a firmer footing.

The electronics work has made good progress. The CME tracker FED has been adopted as the basis of the readout board, which will allow the project to stay on schedule, without any

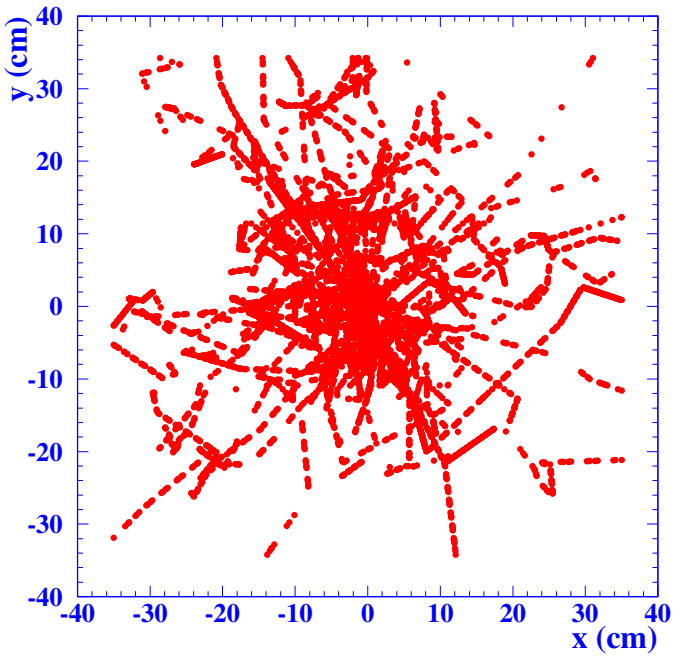

Figure 3: *Neutron trajectories transverse to incident 10 GeV π^- entering at normal incidence to a lead-scintillator calorimeter.*

significant increases in cost or effort.

Simulation studies of differences between `Geant3`, `Geant4` and `Fluka` are being actively pursued and first results have been presented to the collaboration.

References

[1] C.M. Hawkes et al., "Proposal 317 - The CALICE collaboration: calorimeter studies for a future linear collider", submitted to the PPRP meeting, 13 May 2002.

[2] See `http://www.hep.ph.ic.ac.uk/calice/calice/021030prc/docu.ps.gz`

[3] See `???`

[4] See `http://www.desy.de/conferences/ecfa-desy-lcext.html`

[5] See `http://lcws2002.korea.ac.kr/`

[6] See `http://www.hep.ph.ic.ac.uk/calice/electronics/electronics.html`

[7] See `http://www.hep.ph.ic.ac.uk/calice/elecCDR/`

[8] See `http://www.hep.ph.ic.ac.uk/calice/elecCDR/report.ps`

[9] See `http://www.te.rl.ac.uk/esdg/cms-fed/`

[10] For a recent presentation to CALICE on the status of this work, see `http://www.hep.phy.cam.ac.uk/drw/talk_sep24.ps.gz`

[11] For a recent presentation to CALICE on the status of this work, see `http://www.ep.ph.bham.ac.uk/user/watson/calice_sim2_24_09_2002.pdf`

[12] M. Campanella, A. Ferrari, P.R. Sala and S. Vanini, "First calorimeter simulation with the FLUGG prototype", ATL-SOFT-99-004.

[13] ???

A Appendix

Tables detailing individual effort and costs are given below.

A.1 Individual effort

The fractions of research effort for each person involved are shown in Table 1. The line labelled "New RA" is the post being requested from the PPRP and it is assumed that this will take until April 2003 to get someone for this position.

The new RA is requested to ...

The extension to S.Boogert's post is needed as ...

Institute and Tasks	Name	Funding	FY02/03	FY03/04	FY04/05	FY05/06
Undefined	New RA	PPARC	0.0	1.0	1.0	1.0
Birmingham	C. M. Hawkes	HEFCE	0.1	0.1	0.1	0.1
Simulation studies	N. K. Watson	HEFCE/PPARC	0.7	0.7	0.7	0.7
Cambridge	C. G. Ainsley	Fellow	0.2	0.5	0.5	0.3
Online software	M. A. Thomson	HEFCE	0.2	0.3	0.3	0.3
Simulation studies	D. R. Ward	HEFCE	0.4	0.7	0.6	0.6
Imperial College	D. A. Bowerman	Fellow	0.1	0.2	0.2	0.1
Electronics	W. Cameron	PPARC	0.2	0.2	0.1	0.1
Data acquisition	P. D. Dauncey	HEFCE	0.6	0.6	0.6	0.6
	D. R. Price	PPARC	0.2	0.2	0.0	0.0
	O. Zorba	PPARC	0.2	0.2	0.0	0.0
UCL	S. Boogert	PPARC	0.3	0.5	0.8	0.4
Electronics	J. M. Butterworth	HEFCE	0.1	0.1	0.1	0.1
Simulation studies	D. J. Miller	HEFCE	0.6	0.6	0.6	0.3
	M. Postranecky	PPARC	0.1	0.1	0.0	0.0
	M. Warren	PPARC	0.1	0.1	0.0	0.0
Manchester	R. J. Barlow	HEFCE	0.1	0.2	0.3	0.3
Electronics	I. P. Duerdoth	HEFCE	0.1	0.1	0.1	0.1
Test software	N. M. Malden	PPARC	0.1	0.1	0.1	0.1
Simulation studies	D. Mercer	PPARC	0.1	0.1	0.0	0.0
	S. Soldner-Rembold	HEFCE	0.0	0.3	0.5	0.5
	R. J. Thompson	PPARC	0.0	0.0	0.1	0.1
RAL ID	Engineering	PPARC	0.4	0.8	0.0	0.0
	Drawing office	PPARC	0.2	0.1	0.0	0.0

Table 1: Fraction of research effort per year. All University groups will be involved in analysis of the beam test data, so this task is not listed explicitly here.

A.2 Costs to PPRP and PPARC

The funds requested from the PPRP for each of the four FYs covered by this proposal are shown in Table 2. The new RA is costed at £35k per FTE. RAL ID effort is costed at £68k per FTE.

The travel costs are estimated at £45k per year. This is ...

The differences from the original proposal arise from several sources; the redefinition of what is counted as PPRP funding (this table now includes more than just the equipment and new RA costs), the project now being mainly FY03/04 to FY05/06, the above change in the travel request, the knowledge that there will be no "common fund" expense for setting up the beam line, and the full RA post. Note, from FY04/05 onwards, the travel and effort costs would normally be counted as exploitation, not construction.

	FY02/03	FY03/04	FY04/05	FY05/06	Total
Equipment	30	74	0	0	104
New and extended RA effort	0	35	58	51	144
RAL ID effort	40	62	0	0	102
Travel	17	45	75	55	192
Total Cost to PPRP	87	216	133	106	**542**

Table 2: Requested funding from PPRP per year. Units are FY02/03 £k.

The total cost to PPARC for each of the four FYs covered by this proposal are shown in Table 3. University PPARC personnel are costed using their actual salaries, including all overheads. The main change from the original proposal is the higher rolling grant personnel costs, due to putting more effort into the project as requested. Note, from FY04/05 onwards, the travel and effort costs would normally be counted as exploitation, not construction.

	FY02/03	FY03/04	FY04/05	FY05/06	Total
PPRP Cost	67	204	99	79	449
University PPARC Other Effort	72	72	30	11	185
Total Cost to PPARC	139	276	129	90	**634**

Table 3: Total estimated PPARC cost per year. Units are FY02/03 £k.