1 Forward Track Detector Upgrade

1.1 Introduction

The proposed upgrade to the HERA *ep* collider [1] at DESY will result in a significant increase in the achievable luminosity. This will enable the HERA experiments H1 and ZEUS to study in detail the high Q^2, large x region of the deep-inelastic scattering (DIS) kinematic plane. Interactions at large x and Q^2 result in the scattered lepton and the produced hadrons travelling in the proton, or forward, direction, so efficient particle detection and measurement in this region becomes particularly important. In the H1 detector, charged particle measurements in this region are made using the Forward Track Detector (FTD). To date, the FTD has been used to study charged particle transverse momentum spectra in low Q^2 DIS events [2], to determine the position of the z vertex [3] in DIS events and as a veto in various studies of the production of heavy quarks [4]. It also played a role in the detection of the positrons in the highest Q^2 events yet recorded by H1 [5]. Further studies involving forward charged hadrons will require improved systematic as well as statistical precision.

As discussed in section 1.2.1, the hadronic track finding efficiency of the present FTD lies between about 50% and 90%, depending primarily upon the stringency of the track quality selection criteria and upon the local track density. Analyses at the lower end of this efficiency scale, requiring high quality well measured tracks, can thus be more susceptible to systematic errors due to the model dependence of the relatively large correction factors required. As statistical accuracy increases with improving luminosity it will become increasingly important to minimise these systematic errors. Likewise, although the FTD has been used in the detection of the scattered lepton at high Q^2, only weak selection criteria could be used to avoid a large reduction in lepton track finding efficiency. This reduction is due to electromagnetic "showering" from the lepton as it passes through the material prior to and within the FTD.

The proposals made in this document address both of the above issues. By increasing the efficiency of the FTD a significant reduction of the statistical and systematic errors associated with the above types of hadronic final state analyses, at both low and high Q^2, can be achieved. In particular, the search for QCD instanton induced events [6] would benefit, as would measurements of the properties of the highest transverse momentum jets observed in DIS to date, studies of the effects of QCD evolution schemes such as those of BFKL [7] and DGLAP [8], the study of charged particles in diffractive events in which the photon dissociates to produce a system with large mass and the study of the forward charged pion cross-section [9]. Determination of the charge of the scattered lepton would become possible in a larger proportion of the highest Q^2 events.

If approved, the modifications proposed here could be made during the HERA shut-down in the year 2000.

1.2 The Current Forward Track Detector

The FTD, illustrated schematically in figure 1, covers the angular range $5^\circ < \theta < 25^\circ$ and consists of, in order of increasing z, a planar module, a multi-wire proportional chamber (MWPC) module, a transition radiator and a radial chamber, this pattern being repeated 3 times in

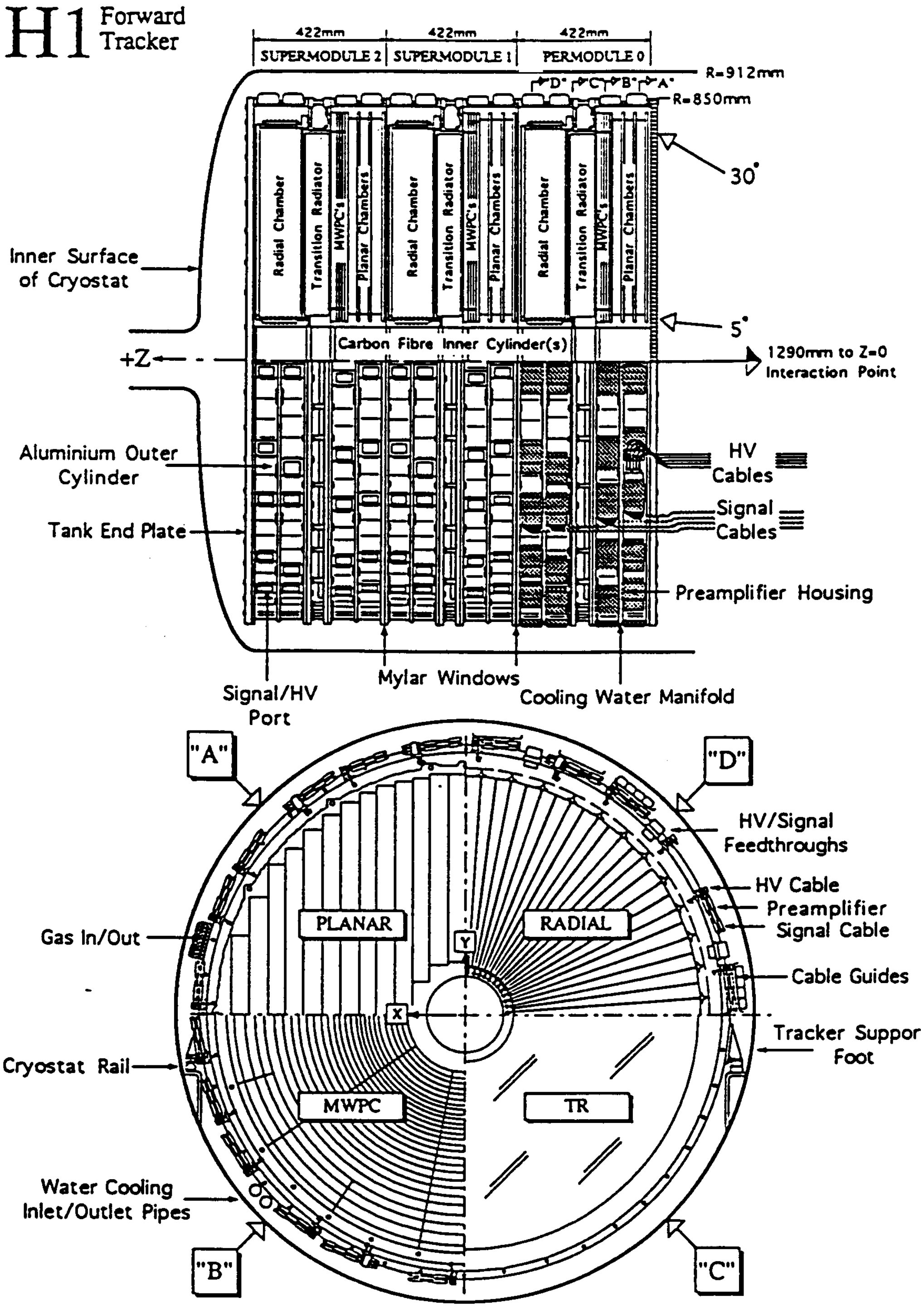

Figure 1: The forward track detector currently installed in the H1 detector showing the planar chambers, the multi-wire proportional chambers, the transition radiators and the radial chambers.

the FTD. The FTD, and the H1 detector of which it is part, are described in more detail in reference [10].

The planar modules are composed of three planar chambers. One quarter of a planar chamber is illustrated in figure 1A. The planar chamber situated closest to the interaction point is made of 32 rectangular cells which each contain 4 vertical sense wires. These are spaced along the z axis with a stagger of $\pm 300\,\mu$m, which aids resolution of the left-right ambiguity. The second chamber, in order of increasing z, is oriented with the wires at $+60°$, the third with wires at $-60°$ to the vertical. As the wires are only read out at one end, each of these orientations defines a plane in space containing the path of any charged particle which passes through the chamber. The combination of two planes defines a line segment on the particle's path, a so-called planar segment. If several particles pass through the chamber, many possible combinations of two planes result and the third plane must be used to resolve these "hodoscope" ambiguities.

The radial chambers, as illustrated in figure 1D, contain radially strung wires, sets of 12 of which are arranged along the z direction in 48 wedge shaped drift cells. The wires in one cell are connected at the inner hub with those in a cell displaced by 105° in ϕ. Each of the wires thus passes through two drift cells. They are read out at both ends. Charge division gives the coordinate along the wire and allows the determination of which of the two cells was crossed by a particle. As the charge division coordinate is considerably less accurate than the drift coordinate, location of the track of a particle requires that a planar segment be associated with the track.

1.2.1 Current FTD performance

As mentioned in the introduction, the efficiency for detection of well measured forward leptons and hadrons could be improved upon.

For both types of particle the most significant factor in reducing the efficiency is a high local background track density. Although the source of these background tracks is different for leptons and hadrons, as described below, they create a large number of "hodoscope ambiguities" in the Planar chambers. The track reconstruction software has been optimised to cope as well as is possible with these ambiguities, but beyond the equivalent of about 25 forward tracks per event the efficiency begins to drop rapidly [11].

Before entering the FTD, a particle from the primary interaction vertex must pass through material equivalent to about 50% of a radiation length ($0.5\,X_0$). This material is concentrated in the end-wall of the Central Jet Chamber (CJC) and in the CJC electronics and cables mounted on it.

Thus for a 200 GeV positron, as observed in H1's highest Q^2 events, the average energy loss before entering the FTD is 75 GeV. The resulting electromagnetic shower contains on average 8 photons of energy 7 GeV and two e^+e^- pairs with a total energy of about 14 GeV. These enter the FTD very close to the primary positron, resulting in a high local track density. The conditions deteriorate further as this shower develops in the material of the FTD itself. A high Q^2 event illustrating these problems is shown in figure 2.

A related problem affects the detection of charged hadrons. In this case the source of background tracks is e^+e^- pair production by conversion of photons. Each charged pion emerging from the primary interaction vertex is accompanied on average by one photon from the decay $\pi^0 \to \gamma\gamma$ and these photons must also pass through the CJC end-wall before reaching the FTD. Pair production in the end-wall then generates a high level of backround tracks entering the FTD and this worsens as resulting showers develop in the material of the FTD itself. The situation is less serious than the positron case because these secondary tracks are not directly correlated with the primary charged hadrons. Nevertheless these unwanted tracks constitute a 25% background in the selected forward tracks of an average DIS event and do degrade the efficiency through increased hodoscope ambiguity.

Background is also increased by the interaction of particles from the proton remnant with material in the beam-pipe and in a small aperture collimator, designed to prevent scattering of synchrotron radiation into the CJC. Interactions in the latter produce secondaries which double the number of tracks in the last third of the FTD. Although none of these background tracks survive the vertex-pointing cuts to reach physics analysis plots, they do significantly increase the hodoscope ambiguities, and thus reduce the efficiency, in that part of the detector.

1.3 Proposed upgrade

The time available for the upgrades proposed here limits the scale of the modifications that can sensibly be attempted. The construction of a new gas tank for the FTD is not possible; it is too complex and large an engineering job to be completed in the time available. Likewise, completely new chamber designs are not feasible; there is insufficient time to design, construct and test prototype chambers. This document thus concentrates on identifying modifications to the existing FTD which will produce the desired performance improvements, will fit in the existing gas tank and which, given our experience with the current FTD, do not require extensive test-beam studies.

The basic strategy of the proposed FTD upgrade is as follows:

- Reduce the amount of material within the FTD as much as is possible.
- Add extra planar chamber orientations to aid resolution of the hodoscope ambiguities.
- Increase the number of sense wires in the planar chambers to aid resolution of the left-right ambiguity and increase the accuracy of the segment measurements.

The addition of extra planar chambers in particular leads to a large improvement in FTD performance.

1.3.1 Reduction of the material in the FTD

The amount of material in the FTD can be reduced by removing the MWPCs, which are unlikely to survive a further 5 to 10 years of luminosity. The MWPCs are currently used to provide the z-vertex trigger [12] for events with only forward tracks and to provide the forward ray trigger, which is used in conjunction with information from the liquid argon calorimeter trigger system. These trigger functions will become largely superfluous when the proposed new central inner multi-wire proportional chambers (CIP) and associated z-vertex trigger are installed [13].

A further reduction in the amount of material can be achieved by removing the transition radiators. The transition radiators and radial chambers allow enhanced electron identification in the forward region [14], but FTD operation with gas mixtures optimised for transition radiation detection has proved unstable, so this option cannot be used for long periods of

HERA running. Hence, the removal of the transition radiators does not represent a serious reduction in the physics capability of the H1 detector.

The amount of material within the planar chambers themselves can be reduced by utilising previously unavailable materials. The amount of material within the radial chambers cannot be significantly reduced.

1.3.2 Construction Of New Planar Chambers

In addition to reducing the amount of material in the FTD, the above measures free space for the major part of the proposed upgrade, the construction and insertion of new planar chambers. Two options are considered here.

A Building one new planar chamber per planar module and rearranging the existing planar chambers so that the sense wires of the four planar chambers in each module are oriented at $0°$, $90°$, $+45°$ and $-45°$ to the vertical, in order of increasing z.

B Replacing all the current planar chambers with new planar chambers and adding an extra planar chamber to each module, the orientation of the sense wires being as above.

Options A and B are described in more detail in the following and the expected resulting improvement in performance evaluated. The costs of the two options are estimated as is the effort required to build and install the new components.

The proposed new planar chambers, illustrated in figure 3, are the same in both the upgrade schemes considered. The design is similar to the current planar chambers, but advantage has been taken of the availability of improved materials to reduce the amount of material in the chambers. In particular the thickness of the double sided G10 used on the inner faces of the chamber's honeycomb end plates has been reduced, as has the thickness of the copper cathodes and HV distribution bus. Studies of the desirability of using paper-epoxy rather than G10 are underway. The thickness of the G10 and copper cathode planes between cells has also been reduced. Consideration was given to using wire cathode planes in place of these, but this idea was abandoned as the loss of mechanical stability of the structure then required that the thickness of the honeycomb at the front and rear faces of the chambers be increased. The material advantage of the wire cathodes is thus less than might be expected and considerable extra man-power is required to string the cathode wires. The net effect of the efforts to minimise the material in the new planar chambers is to approximately halve the number of radiation lengths they present to a particle traversing the FTD; each new chamber has a thickness of $1\% X_0$.

A further improvement is that the number of wires per orientation is increased from the current four to six. This enhances the segment finding capabilities of the planar modules in two respects: the number of cases in which the left-right ambiguity cannot be resolved is reduced and the accuracy of the determination of the position and orientation of the planes that make up a segment is increased.

The new planar chambers are of 5.6 cm smaller radius than the current design and thus contain 30 drift cells rather than the current 32. This enables the insertion of the chambers in the reduced radius sections of the gas tank, at the positions currently occupied by the transition radiators. Option A above then leads to an upgraded FTD as shown in figure 4, and option B to that illustrated in figure 5. In both cases, the redundancy the new planar chambers provide allows the resolution of more of the ambiguities in finding planar segments. Particularly in the case of option B, pattern recognition is further aided by the proximity of the radial and planar chambers. It is no longer necessary to project track segments identified in a planar module large distances in attempting to link them with segments measured in the radial chambers.

1.3.3 Forward trigger

The removal of the MWPCs destroys the current forward ray trigger. This will be largely replaced by the new CIP z-vertex trigger, but the very forward region, $\theta < 12^\circ$, will not be covered. We propose to add a scintillator trigger to remedy this situation. The trigger would give fast signals and thus, in addition to its function as a track trigger, would facilitate proton satellite bunch corrections. The fast signal would also aid the testing and calibration of the FTD using cosmic rays. Space for such a trigger is available.

1.3.4 Further minor improvements to the FTD

The 2 lowest z wires of each radial chamber suffer from reduced gain, and hence efficiency, shortly after turn-on due to the build-up of charge on the thin transition radiation window which closes the low z end of the drift cells [15]. Replacement of these with thin paper-epoxy with copper cathodes would solve this problem.

At any one time, between 10 and 20% of the FTD suffers from failures in either the high voltage supply or the signal cabling. This is a result of the extreme complexity of the cabling on the curved surface of the cylindrical FTD gas tank and at the cable distribution area (CDA). In particular, on several occasions following shut-down work, the FTD has been tested and found to be working well, only for the performance to deteriorate following subsequent work at the CDA which resulted in the displacement of FTD cables. We propose to tackle this problem by replacing the connectors with lockable versions.

1.3.5 Expected performance

Monte Carlo studies have been made of the performance of the current and proposed forward track detectors. High Q^2 events were generated using the LEPTO 6.4 program [16] and passed through a GEANT [17] based simulation of the detector.

The efficiency for the detection in the FTD of hadrons originating from the primary interaction depends on the criteria which a track is required to satisfy. Here, it was required that a track be composed of at least two segments. Experience with the current FTD has shown that this is necessary to ensure reasonable momentum resolution and to reduce the contamination due to secondary particles. The segments were required to be unambiguously identified, i.e. to be found in at least three of the planar chambers in each planar module. Using these criteria, the efficiency for hadron detection in the angular region $8^\circ < \theta < 18^\circ$ was found to be $45 \pm 5\%$ for the current FTD. Efficiencies in the two upgrade scenarios were $89 \pm 5\%$ for option A and $93 \pm 5\%$ for option B.

Two aspects of the measurement of the scattered lepton in the FTD were examined: the efficiency with which the scattered lepton could be identified and the frequency with which the identification of the charge is possible. For the former, it was required that three segments be identified on the lepton track. Provided this identification is possible, the lepton's charge can often be determined despite the showering it causes as the photons it radiates are emitted essentially collinearly along its path; the direction of the curvature of the track doesn't change, although its radius of curvature decreases. How often the charge may be correctly identified depends therefore on:

- How often the lepton track may be identified, i.e. how often the track is not masked by other charged tracks which are within the two-hit resolution of the FTD chambers ($\sim 2\,\text{mm}$).
- The resolution achieved for the measurement of the "sagitta" (sagitta is a misnomer here as the projection of the lepton track onto the $x - y$ plane is not a circle). A resolution of 0.3 mm was assumed here. The resolution within a chamber of the current FTD is better than this, being $\sim 180\,\mu$m; the above number allows for some misalignment within and of the FTD.

Only tracks in the angular region $8^\circ < \theta < 18^\circ$ were considered as only in this region do the leptons traverse all three modules of the FTD.

The results on the measurement of the scattered lepton can be summarised as follows:

A Lepton identification efficiency $15 \pm 5\%$.

B Lepton identification efficiency $31 \pm 7\%$.

These figures are to be compared with the scattered lepton identification efficiency of $6 \pm 3\%$ in the current forward tracker. For all the above, given that a lepton track was identified, the charge was correctly determined at the 2σ level in $70 \pm 10\%$ of cases.

1.3.6 Required resources

The costs of the two upgrade options can be summarised as follows:

A DM 730 000 plus 6.25 man-years of technical effort.

B DM 2 300 000 plus 13.5 man-years of technical effort.

A more detailed breakdown of these costs is given in tables 1 and 2, respectively. More information on the scheduling of the various tasks involved is given in figures 6 and 7

The figures for the required technical effort given above are sufficient to complete the project with the installation of the upgraded FTD in H1 in the year 2000 if work starts at the beginning of January 1998. It should be noted, however, that the schedule for option B contains absolutely no slack, but that for option A is more flexible.

Item	Individual cost	Quantity	Total	Comments
Clean room	25 000	1	25 000	$6 \times 4\,\mathrm{m}^2$
Surface tables, jigs etc.	15 000	1	15 000	
New planar chambers	20 000	3	60 000	3 new planars needed
Water and gas system changes	1 000	1	1 000	
New feedthroughs	200	45	9 000	
Shipping costs	8 000	2	16 000	DESY-UK-DESY
Internal cables	5 000	3	15 000	Manufactured complete
External cables	15 000	3	45 000	Manufactured complete
Pre-amplifiers	100	72	7 200	Manufactured complete
HV cables	0	0	0	Re-use MWPC cables
FADCs	0	0	0	Exist
Crates	0	0	0	Exist
Column total			193 200	
Plus contingency			222 180	15%
Plus VAT			261 062	17.5%

Table 1: Break down of costs for option A, construction and installation of 3 new planar chambers and re-orientation of existing planar chambers, units are pounds sterling.

Item	Individual cost	Quantity	Total	Comments
Clean room	25 000	2	50 000	$6 \times 4\,\mathrm{m}^2$
Surface tables, jigs etc.	15 000	2	30 000	
New planar chambers	20 000	12	240 000	12 new planars needed
Water and gas system changes	1 000	1	1 000	
New feedthroughs	200	45	9 000	
Shipping costs	8 000	2	16 000	DESY-UK-DESY
Internal cables	5 000	12	60 000	Manufactured complete
External cables	15 000	12	180 000	Manufactured complete
Pre-amplifiers	100	288	28 800	Manufactured complete
HV cables	0	0	0	Re-use MWPC cables
FADCs	0	0	0	Exist?
Crates	0	0	0	Exist?
Column total			614 800	
Plus contingency			707 020	15%
Plus VAT			830 749	17.5%

Table 2: Break down of costs for option B, construction and installation of 12 new planar chambers, units are pounds sterling.

1.4 Summary

Much physics requiring the efficient detection of charged particles in the forward region of the H1 detector has yet to be studied in detail. The data for such studies will become available following the proposed HERA luminosity upgrade in the year 2000. Simultaneous improvement of the H1 Forward Track Detector (FTD) would allow more efficient exploitation of these data, leading to significant improvements in the statistical and systematic errors of many measurements. Two upgrade programmes for the FTD are outlined in this document. Given the tight schedule, these rely on using chambers similar to those in the current FTD to obviate the need for long test programmes. The options are:

A To add new planar chambers to the FTD and re-orientate the existing planar chambers.

B To add new planar chambers and replace the existing planar chambers.

Option A costs about DM 730 000, option B about DM 2 300 000. The former upgrade yields significantly improved hadron detection efficiency over that achievable with the current detector. The greater expense of the latter option does not bring a concomitant further increase in performance for hadron tracking, but does improve the performance with respect to the measurement of the scattered lepton charge.

Note that, even if no upgrade to the FTD is performed, considerable refurbishment work must be performed on the current FTD if the planar and radial chambers are to continue functioning reliably for a further 5 to 10 years of HERA operation. The cost of this refurbishment is estimated to be DM 140 000 and it will require about 1 man-years worth of technical effort.

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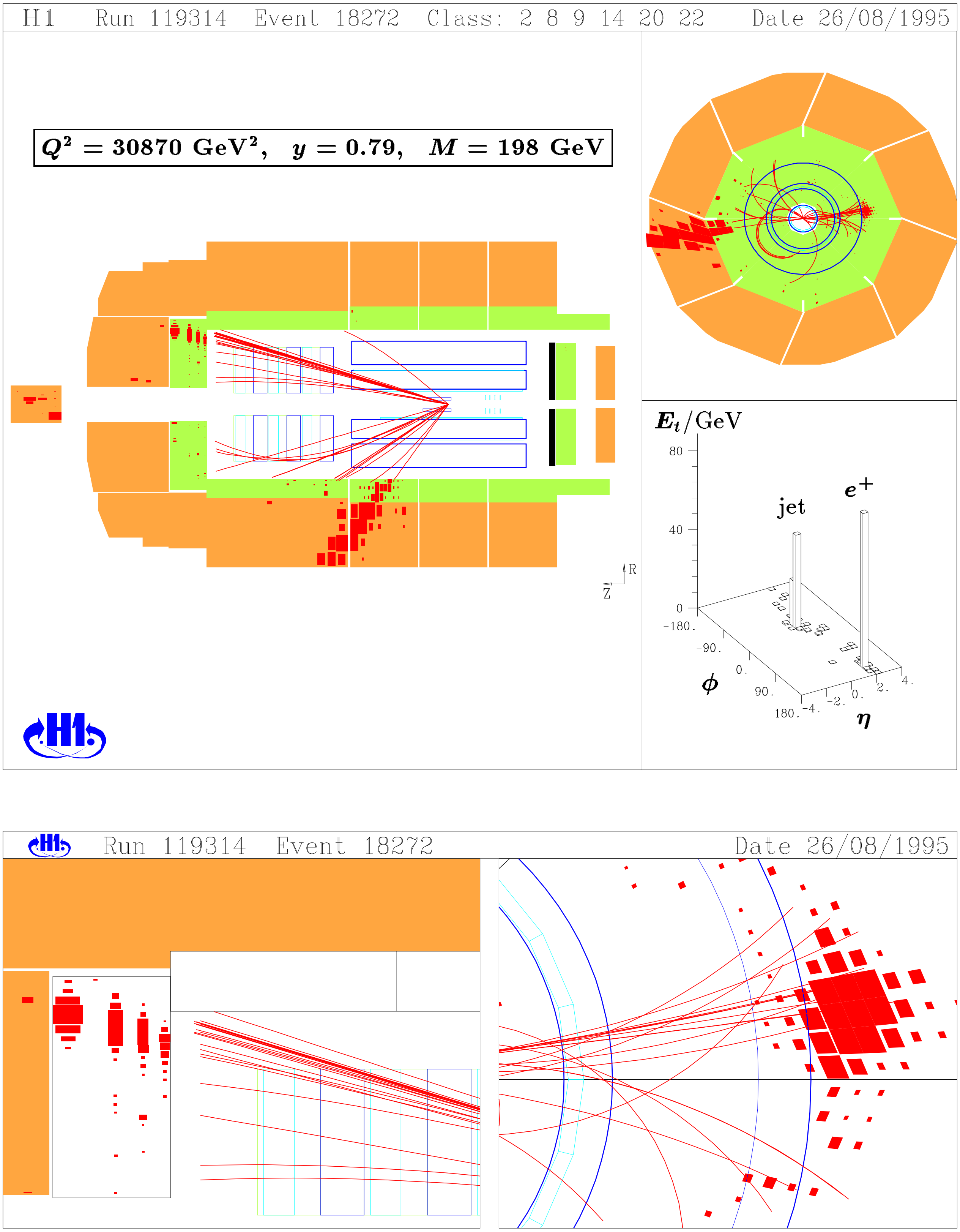

Figure 2: One of the highest Q^2 events recorded to date with the H1 detector; the scattered electron or positron passes through the forward track detector (FTD), but the track it causes cannot be identified as it produces an electromagnetic shower in the material prior to and within the FTD.

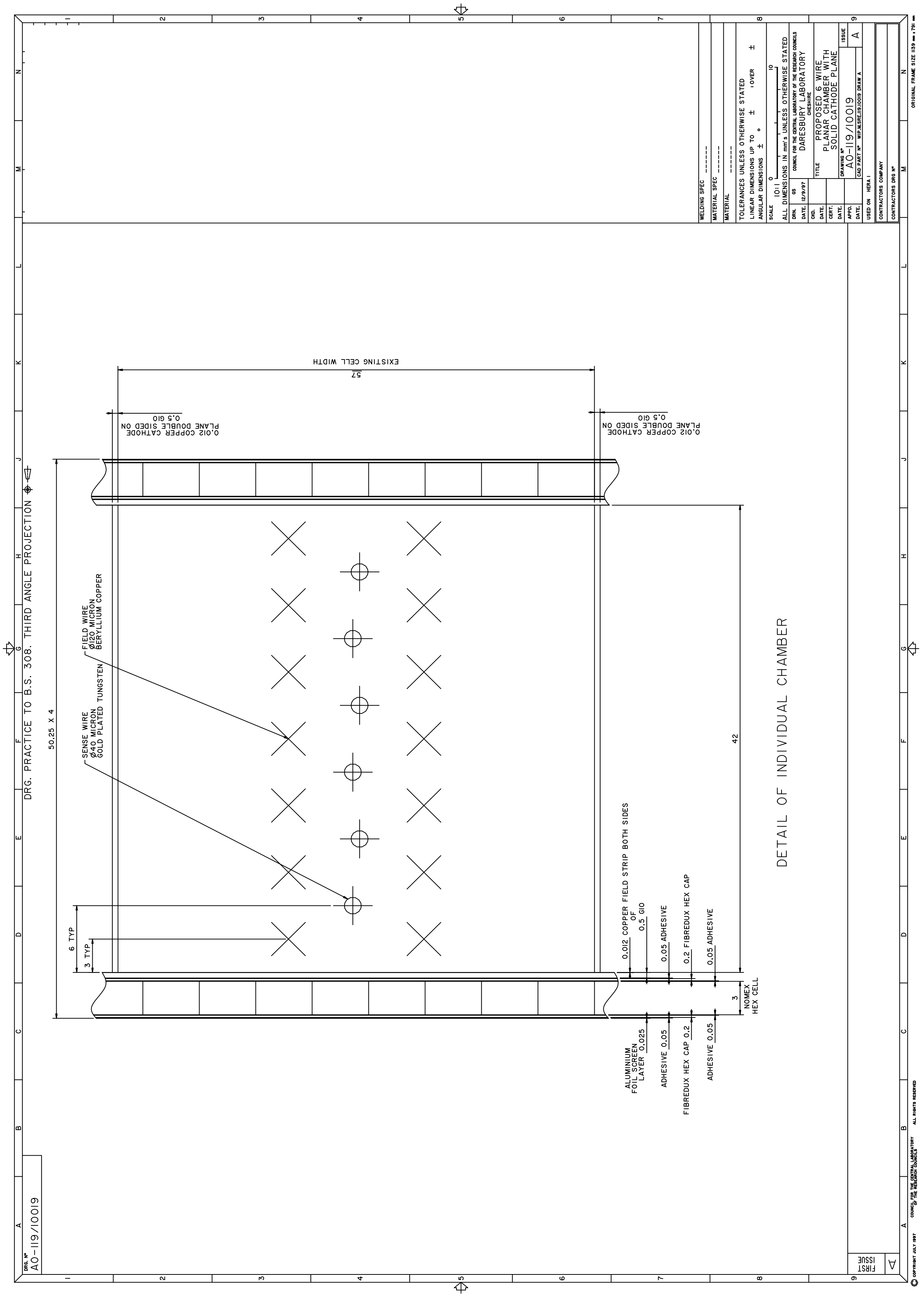

Figure 3: A section through one of the cells of the proposed new planar chambers.

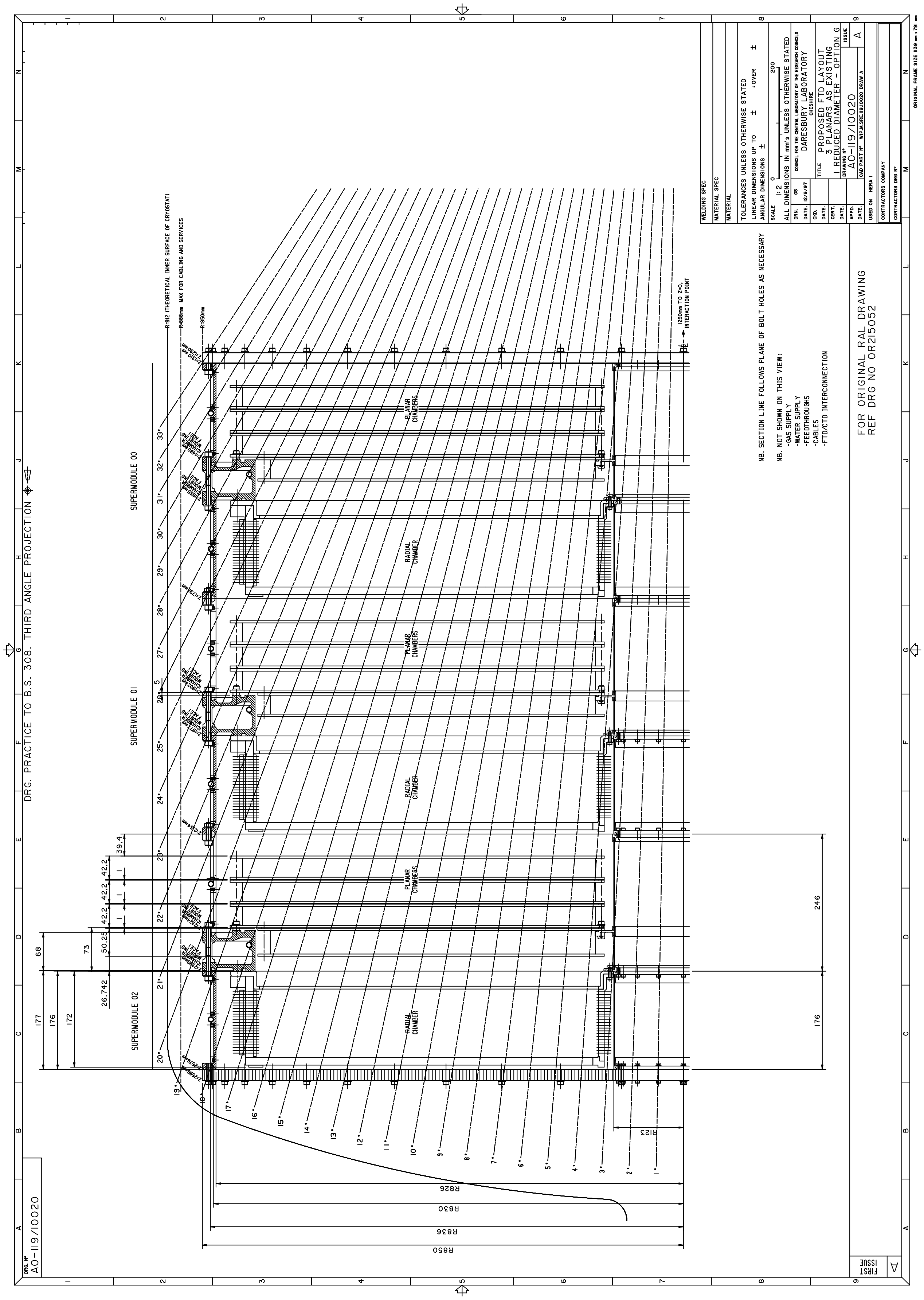

Figure 4: The proposed forward track detector, option A, with three new planar chambers designed to fit into the position currently occupied by the transition radiators, the re-orientated old planar chambers and the radial chambers.

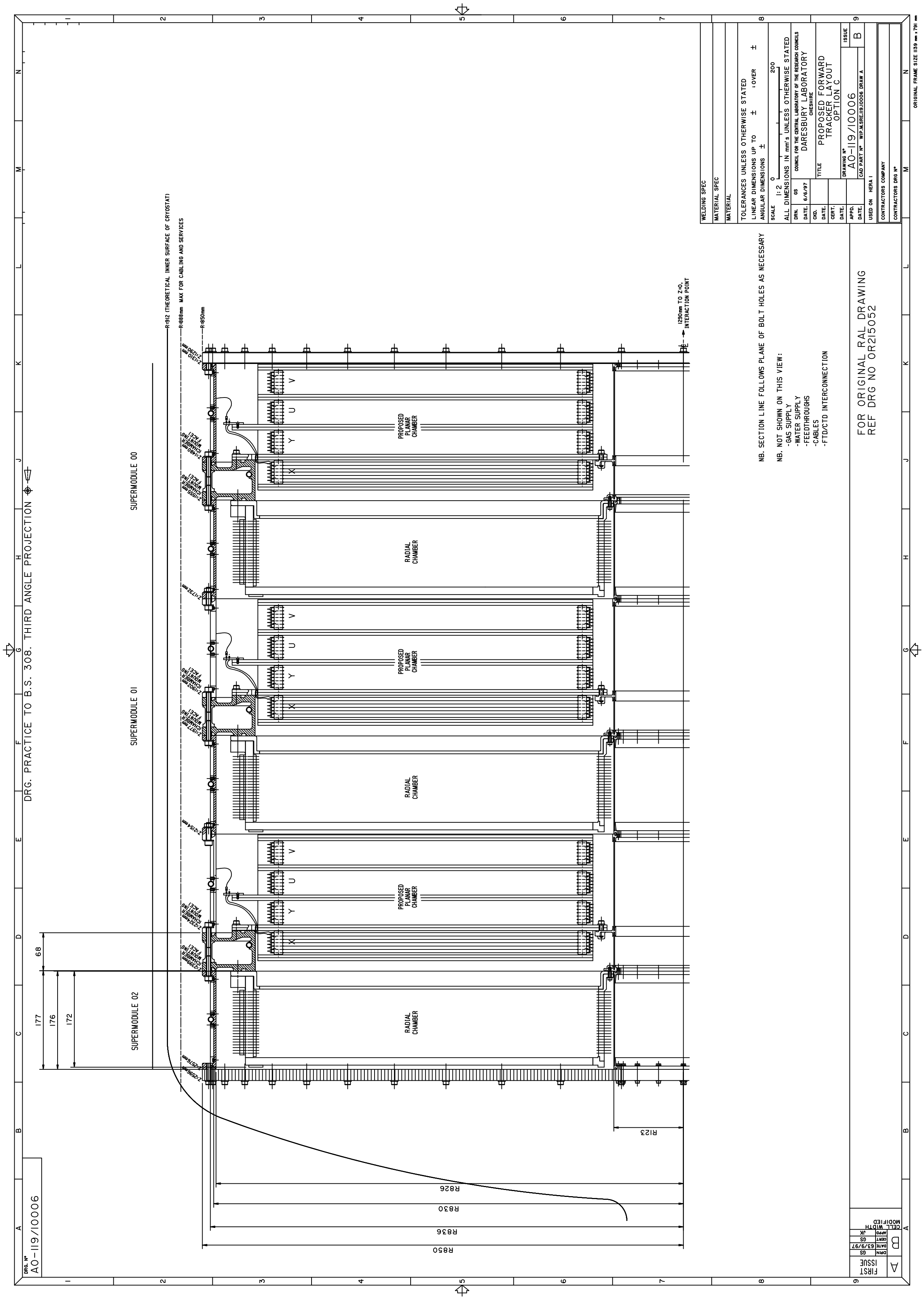

Figure 5: The proposed forward track detector, option B, with twelve new planar chambers designed to fit into the existing gas tank and the radial chambers which are now immediately adjacent to the planar chambers.

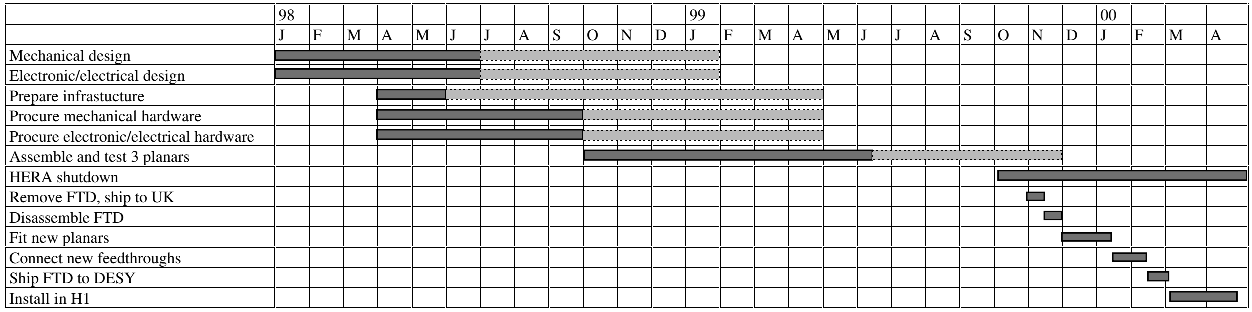

Figure 6: Schedule of work for option A, i.e. disassembly of current FTD, construction and fitting of 3 new planar chambers and re-assembly and installation of FTD.

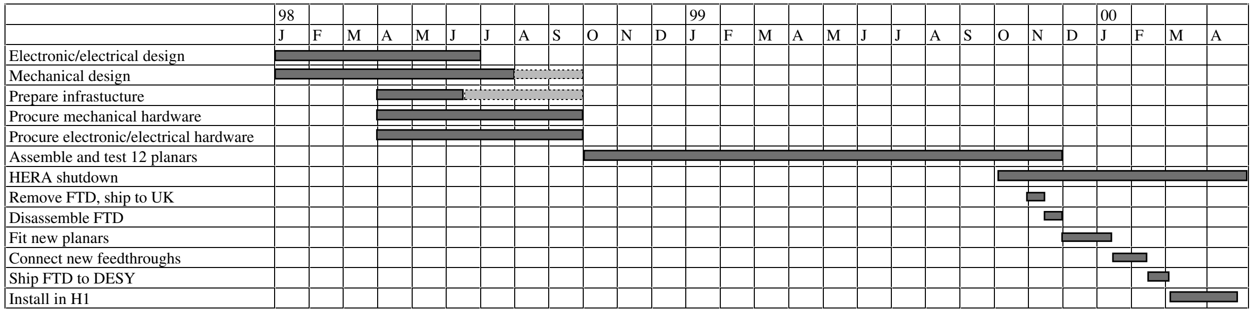

Figure 7: Schedule of work for option B, i.e. disassembly of current FTD, construction and fitting of 12 new planar chambers and re-assembly and installation of FTD.