NAL Proposal 316

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Gargantua: A New Facility for Neutrino Physics at NAL

A large-mass detector employing magnetized iron plates and a novel particle detector, the triangular multi-wire proportional drift chamber, is proposed which would provide several improvements over existing apparatus for the study of neutrino physics at NAL. Modest development work will be required, and it is reasonable to expect operational capability well within two years after approval.

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Introduction

The spectacular new developments in our concept of the weak interaction imply the probable existence of various strikingly new phenomena at sufficiently high energies. It is therefore essential that future experimental facilities reflect in their design the still exploratory state of our understanding of this area of physics.

Significantly, the first and most convincing evidence for the existence of neutral currents comes from the heavy liquid bubble chamber Gargamelle, rather than from the various electronic experiments performed over the years. A new apparatus is needed, which would retain many of the beneficial properties of both bubble chamber and counter techniques, which would provide complementary strength where the NAL bubble chamber will be intrinsically weak, and which would introduce the least theoretical prejudice about the qualitative nature of neutrino interactions in this energy regime.

A new detector, nicknamed Gargantua,[1] is hereby proposed. This apparatus is intended to satisfy the above criteria, and enjoys the additional virtues of being technically and financially feasible.

II. Goals, design considerations, and compromises.

The following list of criteria were selected as important in the design of a new facility.

A. High Statistics. An obvious desideratum, but with the consequence of necessitating a target fiducial volume of the order of several thousand tons to give substantially more than what is available in experiments 1A and 21.

B. Constraints. The understanding of many physical processes and systematic effects is facilitated by a knowledge of the neutrino energy and type. The utilization of a dichromatic beam is therefore the choice over a broad band beam. This choice, in order to compensate for the relatively smaller neutrino flux, also dictates the necessity of a very large mass neutrino target.

C. Muon Identification. Here, one can reasonably ask for close to 100% identification efficiency, independent of the sign of the muon electric charge. In addition, the identification of muons should be effective at low energies like 2 GeV, as well as at the higher energies. Finally, identification of muons should be available over 100% of the kinematically accessible solid angle. To include the possibility of semileptonic decays of "fancy" states as well as totally unexpected phenomena, essentially 4π steradians are needed.

D. "Good" quality of Spatial Information. In addition to the measurement of q^2 and ν, substantial physics content is likely to be carried in the development of the hadronic cascade, for example, in the production and downstream decay of a "fancy" state. The reconstructability of at least the coarse features is a requisite capability. Of course, a bubble chamber is superior to nearly any conceivable electronic device in this latter regard, but a sufficiently fine-grained apparatus should be capable of providing this essential information with adequate resolution.

E. "Reasonably Good" energy-momentum information. Muon momentum determination in magnetized iron is limited by multiple scattering to a resolution of 10 to 15%. This figure is acceptable, and noticeable improvements in this resolution are probably impossible in any high density target.

The measurement of the energy-momentum values of a hadron jet with spectrometer techniques becomes progressively more difficult with increasing energy, and is perhaps intractable in any target environment appropriate for NAL neutrino physics. On the other hand, the resolution obtained with calorimetry techniques improves with energy, and, depending on the sampling frequency and fractional energy loss in the sensitive volume, etc, can be reasonable good, easily 10 to 20%. Nonetheless, in a practical device, energy resolution criteria are likely the most challenging goal to achieve, as costs will reflect very strongly the specified resolution.

III. Gargantua

The concept proposed is shown in Figure 1: neutrinos impinge upon the central region of a "laminated" magnetized iron plate array. Each iron plate is two inches thick and composed of several pieces as shown in Figure 2. A gap of about 2.5 inches is provided between adjacent plates for the introduction of detectors, to be described below. The coil windings circumscribe the entire core, rather than each plate separately.

A. Size. The transverse dimensions reflect primarily the criteria of sec II.c, muon identification. Specifically, a muon borne in the core as illustrated in Figure 3 is likely to enter into the return yoke at some point, where it will experience magnetic deflection in the opposite sense (see Figure 2). Of course, many muons will have a trajectory entirely within the core region. Due to the left-right symmetry, muons of both charge sign have in the statistical sense formally equivalent identification efficiencies, in contrast with toroidal geometries, for which one sign is systematically deflected away from the apparatus. The edge-to-beam center line distance, 1.83 meters, corresponds in iron to approximately 5 interaction lengths minimum; certain pathological cases in which muons emerge somehow at 90° to the beam direction and between the iron plates represent the only and presumably rare exception. Even then, the existence of detectors everywhere in the central and side regions would signify the existence of a particle escaping the gap transversely.

The range of a one GeV muon for a trajectory parallel to the beam line is at least 12 plates or, about 4 interaction lengths. Interference from compenents of the hadronic cascade may raise the threshold for clean muon identification to a few GeV for some events, but should not be a serious problem. Total containment of the hadron cascade, necessary for best energy resolution, also indicates the need for large transverse dimension.

As shown in Figure 2, the central "core" and side sections of the return yoke comprise a square region approximately 3.7 meters on a side. It is proposed to equip the core region of each gap with detectors, thereby providing muon identification, muon momentum measurement, hadron cascade reconstruction, and hadron energy measurement through calorimetry. It is probably sufficient to equip only every fourth or fifth gap of the side yokes with detectors since in these regions only muon identification and muon momentum measurement are needed. Naturally the side yokes could be fully instrumented for calorimetry if found sufficiently interesting. It is not proposed at this time to equip the gaps of the top and bottom yoke pieces.

Referring again to Figure 2, the magnetic field is shown as vertically uniform in the core and side-yokes. This can in fact be obtained in the present case by capitalizing on the unavoidable existence of an air gap between the central region and the top and bottom yoke pieces. Shimming of the air gap would be required to equalize the reluctance integrals for all x values. Sophisticated programs exist at Berkeley and else-

where which can compute the field (including nonlinear permeabilities) for this geometry. The field in the absence of airgaps, as in a filament transformer, would be rather non-uniformly concentrated around the windings. For the purposes of muon momentum measurement, a uniform magnetic field would be a welcome property.

The coil intrudes surprisingly little into the detection-calorimetry process. A one-half inch thick sheet of aluminum (actually broken into many ribbons approximately 3" wide) will drive the iron to 15-20 kgauss with less than a one-third MW power supply (for each module of Garagantua). Furthermore, the symmetry of the magnetic geometry leads to the cancellation of nearly all forces on the coil, simplifying the engineering and construction and minimizing the detector volume taken up by coil support.

Additional benefit of large transverse dimension is the capability of studying practically the entire neutrino energy spectrum simultaneously. Since the energy spectrum of the neutrinos is accurately predictable (a straightforward function of radial distance from the beam line for the "dichromatic" beam), this capability adds a new tool for self-consistency checks, in addition to the simple virtue of providing more data per unit running time. The maximum length of the apparatus is determined ultimately by financial and geographical factors, although each module is likely to be about 20 meters long. This figure corresponds to the longest easily transportable straight length,

in this case the aluminun or copper extrusions of the coil. The left-right cross connections at the ends of each module can be made very compact so that modules can be spaced closely together, thereby forming a continuous detector from the standpoint of the physics. Alternatively, substantial gaps occupied by LH_2 or LD_2 vessels could be provided; this configuration however begins to compete, perhaps unfavorably, with the 15' bubble chamber capabilities, and the merit of this possibility will not be defended here.

A module 20 meters long will weigh 1550 tons. The entire structure can be fabricated so that the iron is recoverable without undue difficulty, perhaps to be used as a muon spoiler for future neutrino beams. Another possibility is to reconfigure the iron without the central core, so that a future facility employing LH_2 targets, superconducting coils, etc as proposed by Osborne et al. can be built when feasibility and desirability is established.

B. Detectors. A novel variation of familiar techniques, the triangular multiwire proportional drift chamber,* has been invented for the purposes of Gargantua. This device in intended to provide all of the following capabilities:

1. Detection of the occurence of an event candidate, i.e., self-triggering.
2. Accurate Localization of tracks, i.e., $\lesssim$ 1mm resolution. This is necessary for muon momentum measurement.

*hereinafter referred to as TMWPDC.

3. Measurement of the energy and momentum of the hadronic cascades, through calorimetry (i.e. pulse height) and track-counting plus other spatial criteria.
4. Provide 3-dimensional (i.e. non-projective) spatial information. This capability should enormously simplify reconstruction of the interesting features of the hadronic component due to the absence of the usual ambiguities.

The basic idea is given in Figure 4. A sequence of tubes, each with the cross sectional shape of an equilateral triangle, is formed to provide a row of cells, each with a single wire located at its centroid. The construction methods anticipated for this device are shown schematically in Figure 5, and discussed in fair detail in Appendix A. Since hundreds of chambers are needed, the economy and feasibility of the present proposal hinges substantially on this mundane aspect.

The chambers would be constructed in modules of 26 cells. The wire spacing would be $\approx$ 3.4 cm, and the overall length would be $\approx$ 3.6 meters as shown in Figure 6. A Gargantua module 20M long with contain 175 gaps. The two chamber modules will be needed per gap to fully equip the core region, corresponding to 9100 wires, or 350 chambers. The side-yoke gaps (filling every fifth) will require 70 chambers, or 1820 wires. To provide the y coordinate of muons which leave Gargantua through the side yokes, chambers can be placed along the sides; this would require another 40 chambers, or 1040 wires. The total number of wires per module of Gargantua is a minimum of 11, 960 wiere or 460 chambers.

It is worth noting at this point that the reliability of contemporary solid state electronics is sufficiently high that systems of this size are easily manageable. The CERN split-field magnet facility currently has over 60,000 wires and circuits in routine operation. The authors personal experience with the 5,000 wire Columbia K^0 spectrometer system includes periods of several months running uninterrupted by failures.

A self-evident virtue of the TMWPDC's is their ruggedness, due to the sheet metal construction of the walls and zigzag webbing. As argued in Appendix A, they are expected to be easy to make in an assembly line type of operation, especially since at most two module sizes are needed (discussed further below).

However, the most attractive capability of the TMWPDC's is their intrinsic resolution of the well-known left-right ambiguity, the bête-noire of conventional drift chambers. As indicated in Figure 4, a particle always leaves a track in two of the cells, except for the infrequent case of a trajectory passing through the apex of one of cells. Even then, from the fact that only a single cell gives a count, one knows the trajectory at the apex position. A more pathological possibility is the traversal within the webbing wall, giving no count at all; this defines the trajectory even more precisely! The accurate localization of trajectories is needed mainly for the muon momentum determination, although it is expected that the reconstruction of the hadron cascade will benefit from this capability. To be sure, high multiplicity cascades such as electromagnetic showers from π^0's will defy detailed reconstruction, and in these areas calorimetry information will likely be the only useful datum.

As noted in the beginning of this section, calorimetry information is to be derived from the pulse area information. For the chambers in the core region, it is proposed to record the pulse area individually for each end of each cell. Thus, not only can the local energy deposition be measured, but the position of the discharge along the wire can be determined by the current-division method. Thus each cell would provide a three dimensional spatial datum plus an energy datum. A single TMWPDC plane with two electronic circuits/wire thus provides the equivalent spatial performance of the conventional x,x', y,y, plus inclined u,u' plane system (primes refer to the need for two planes/axis toresolve left-right ambiguities).

The individual cell pulse area information is unnecessary for the chambers outside the core, since muon tracking is the primary goal in the side regions. Therefore only one circuit per wire (measuring drift-time only) is needed for these regions. Thus 18,200 time + pulse area circuits are needed for the central core, and 2860 time circuits for the side regions.

The design of the circuity needed to accomplish these purposes represents the only significant developmental effort. The requirements are technically straightforward, and the main challenge lies not in producing a workable circuit but in keeping the costs low.

Along the wire, however, the resolution obtained by the current division technique may be limited in practice to about 1% of the wire length. In the present case, this would be about 4 cm. Therefore, the quality of the reconstructed image in the yz plane will be poorer than in the xz plane, in which the magnetic bending occurs. This

compromise seems worthwhile, considering the very substantial reduction in complexity of the chambers and data analysis as well as cost, relative to the conventional approach. If higher resolution in the yz plane is found necessary, it is of course possible to have the chambers in the central core region of every fifth or so gap arranged to have horizontal wires. This would require twice as many chambers, each half as long, for these gaps.

The electric field distribution for the basic cell is shown in Figure 7. The drift-time versus distance relationship can be expected to depend on track angle and to display non linear characteristics. However, these same problems exist in nearly all drift chamber designs, the only exceptions being those in which the electric field is very carefully (and expensively) prepared by finely graded potential drops along the high voltage plane. The important consideration is not linearity per se, but that the drift-time vs distance relationship, whatever it turns out to be, can be accurately determined and introduced into a computer. As the magnetic field will be almost entirely contained within the iron, the performance of the TMWPDC's should not be adversely affected. Finally, the triangular configuration adds substantially to the electrostatic stability of the central wire.

As shown in Figure 4, a particle traversing the chamber liberates charge in the entire 6 cm of gas thickness; all of this charge is eventually collected and amplified at the central wires, although the charge is divided in general between two cells. The energy loss is found by summing the pulse height of apparently related cells. Thus the TMWPDC's make maximum

possible use of the gap between iron plates. However, the energy resolution cannot be as good as the case if the gap were filled with scintillator as fluctuations in energy loss in gas are intrinsically more severe due to the effects of knock-on electrons. Nonetheless, it can be reasonably expected that if the number of samples is large, as assured with the very large energies available at NAL, the effect of the landau fluctuations will be minimized. Unfortunately, reliable experimental results concerning energy resolution at NAL energies and applicable to the Gargantua geometry apparently do not exist, so that some guesswork is involved. The answer is probably in the range of 10 to 15% at higher energies.

The intriguing possibilities of observing tracks with substantially less than minimum ionizing dE/dX, (quarks) or substantially greater dE/dX (??,jets) are included in the capabilities of Gargantua.

An additional benefit of the PH information is that it will allow the removal by computer of the electronic time-slewing caused by pulse height variations. This makes the utilization of slower (and much cheaper) semiconductors feasible. Because of the very large number of circuits required, every economy here is significant. Due to the multiple scattering in the iron, the very high intrinsic resolution obtainable with the drift technique $\approx$ 100 microns, is irrelevant for Gargantua. This relaxes requirements placed on the electronics to a very useful extent, and the circuitry can in many respects resemble that for conventional multiwire proportional chambers, for which figures as low as $2.50/channel have been quoted and substantiated. However the electronics for the present system will more likely be in the $20/channel range.

Calibration of pulse height and circuit performance monitoring can be accomplished by incorporating simple strip lines within the chamber's end regions as shown in Figure 5. A pulse traveling along these lines will capacitively induce a signal on the sense wires; the pulse height and time delay can be computer controlled, and a test can be made between each accelerator pulse. This technique was very successfully employed in the Columbia K^0 spectrometer at the BNL, AGS, although the observed realiability was so high that only occasional checking turned out to be necessary. The gas composition can be continuously monitored by special chambers irradiated with low-energy γ rays (i.e. Fe^{55}) so that the pulse area vs energy deposition ratio can be accurately known. The discussion of the electronic circuitry problem is amplified further in Appendix B. Like the iron, the electronics can be expected to be ultimately reusable in other experiments after work with neutrinos has been completed.

C. Discussion

In attempting to meet the goals listed in Section II, the author has reached the conclusion that a single device, the TMWPDC, is a superior choice compared with more conventional techniques such as optical or wire spark chambers and the associated scintillation counters necessary for triggering and calorimetry purposes. In addition to the advantage of having only one device to construct and understand, the author has been influenced in this choice by the impressively high reliability of the proportional counter in its modern forms.

A prototype cell of the TMWPDC has been constructed and works as expected with any of a large range of central wire diameters, gas mixtures, etc. The drift-time vs. track distance, track

angle relationship will be determined in the near future in a high energy beam.

IV. Physics

In addition to the high statistics study of the charged current, Gargantua should be able to provide comparably clean information about the structure of the neutral current whose existence now seems well established. The large transverse dimension of the sensitive volume will reduce to a very large extent the neutral background contribution due to neutrons entering from the sides. The relatively detailed information obtainable for the hadron cascade will permit the determination of both q^2 and ν with useful resolution, even though the lepton is unseen. The essentially 100% muon identification capability should allow almost completely clean separation of charged and neutral current events.

In the event that the experimental data show evidence of multiple muon production, then the challenging and exhilarating task will be to determine whether the discovery implies the existence of the intermediate rector boson, heavy lepton, or "fancy" hadron states! The understanding of this or other surprising developments is very likely aided by apparatus with the general capabilities of Gargantua.

The possibility may exist that information about purely leptonic interactions may be extractable from the data, although this is by no means assured. Two inches of iron comprise 2.9 radiation lengths, with the result that electromagnetic shower development is essentially certain within one plate. Nevertheless, experience with the data may show that the "background" from neutrino-nucleon interactions can be separated adquately.

A number of other more specific tests appropriate to nuclear targets will not be elaborated here.

V. Summary and Discussion

The concepts of an apparatus designed to provide new capabilities and freedom from systematic biases have been described. Due to the imminent consideration of this class of physics the NAL Program Advisory Committee, this proposal is being submitted for consideration even though some aspects have not been treated. Obviously, collaborators are needed. Emphasis in this preliminary proposal has been placed on technical feasibility and general capabilities.

Only crude cost estimates have been made. Each 20 meter module of Gargantua requires 1500 tons of iron, which will cost about 500 K$. The cost of the chambers plus electronics will be ≥500 K$. Additional miscellaneous expenses will bring the total cost to the level of 1.3 M$ per module. Most of this cost would have to be borne by NAL, or conceivably through supplementary funds provided by the AEC to LBL for this purpose. LBL would design the magnet structure, the electronics, and provide the chambers, at the minimum. Only a modest building and floor crane will be required, although a reinforced concrete floor will be needed to support Gargantua. The initial construction of two modules is regarded as appropriate, considering the potential significance of this area of physics.

References

1. According to Rabelais, Gargamelle, in her eleventh month of pregnancy, gave birth to Gargantua through her left ear after a heavy meal of tripe (from Gargantua and Pantagruel, circa 1534 A.D.)

2. D. Frisch, D. Luckey, L. Osborne, B. Cox, and M. Perl. NAL proposal #256.

Appendix A

Construction Techniques for the TMWPDC

The structural integrity of the device is inherently provided by the triangular webbing. A precision wrinkling machine to make smooth straight 120° bends in sheet metal ~ .030" thickness will be necessary. The engineering and construction of such a machine is a simple task. Spot-welding the three sheets together is one possibility, but may introduce warping and be more time-consuming than gluing with fast-setting resins. Gluing is regarded as more than sufficient as very little mechanical stress will act on the chambers. The sides of the chamber can be solidly sealed by pre-folding the edges of the outer sheets, thereby providing a large area joint (see Figure 5.a). The mechanical tolerances obtainable should be extremely good, as all gluing operations can be jigged, using diagonally placed pinning, etc.

The first step is to glue the plastic T-sections onto the outer sheets. These commercially available items will be equipped with slotted inserts whose locations are jig-bored (prior to gluing) to correspond to the desired wire positions.

The second step will be to introduce an entire array of sense wires, spaced properly to fit the slotted inserts. The wires are then soldered and glued in under tension. (See Figure 5.b). The inserts will be inexpensive custom-made molded units.

Next, the webbing is jig-glued onto one of the outer sheets. Then the other outer sheet (with wires) will be jig-glued on, (since the wires and the sheet metal have similar temperature coefficients, no sagging or stretching over a long time period is expected).

Then the seam formed by the two T sections can be sealed to provide a gas tight unit. The space under the T sections provides a channel for gas flow. (See Figure 5.c)

Next, thin sheet of plastic will be glued on the outside to provide high voltage insulation. Finally, the electronics board can be soldered to the inserts. Wire breakage, if it occurs, can be easily field repaired by removing the inserts to give access to the broken cell.

The maximum length of the TMWPDC is in practice limited by the maximum length of commercially popular sheet metal: 12 feet, or 3.7 meters, Fortunately, this turns out to match the requirements of neutrino physics.

Appendix B

Possible Electronics For the TMWPDC

Only one scheme will be discussed here, a relatively brute force method. Figure 8 gives an outline of the basis idea. A low impedance charge-sensitive amplifier located at the chamber drives a cable connected to the main electronics area. The amplifier must provide a fair dynamic range although linearity is not required.

The main electronics station will in fact be distributed along one side of the apparatus, so that cabling costs can be minimized. Pulses are received and integrated on a capacitor C. The voltage on C is quiescently clamped by diode D and constant current I. As soon as voltage on C exceeds the threshold of the comparator, Flip Flop 1 is set, and the status of the 12 timing lines are latched. The on-gate and clock driving the 12 timing lines are started just prior to the fast beam extraction. Thus the information in Latch 1 contains the drift-time data. The 12 bits provide a maximum sensitive time of 160 microseconds, whereas the fast spill should take less than 20 microseconds (25 MH_z clock rate).

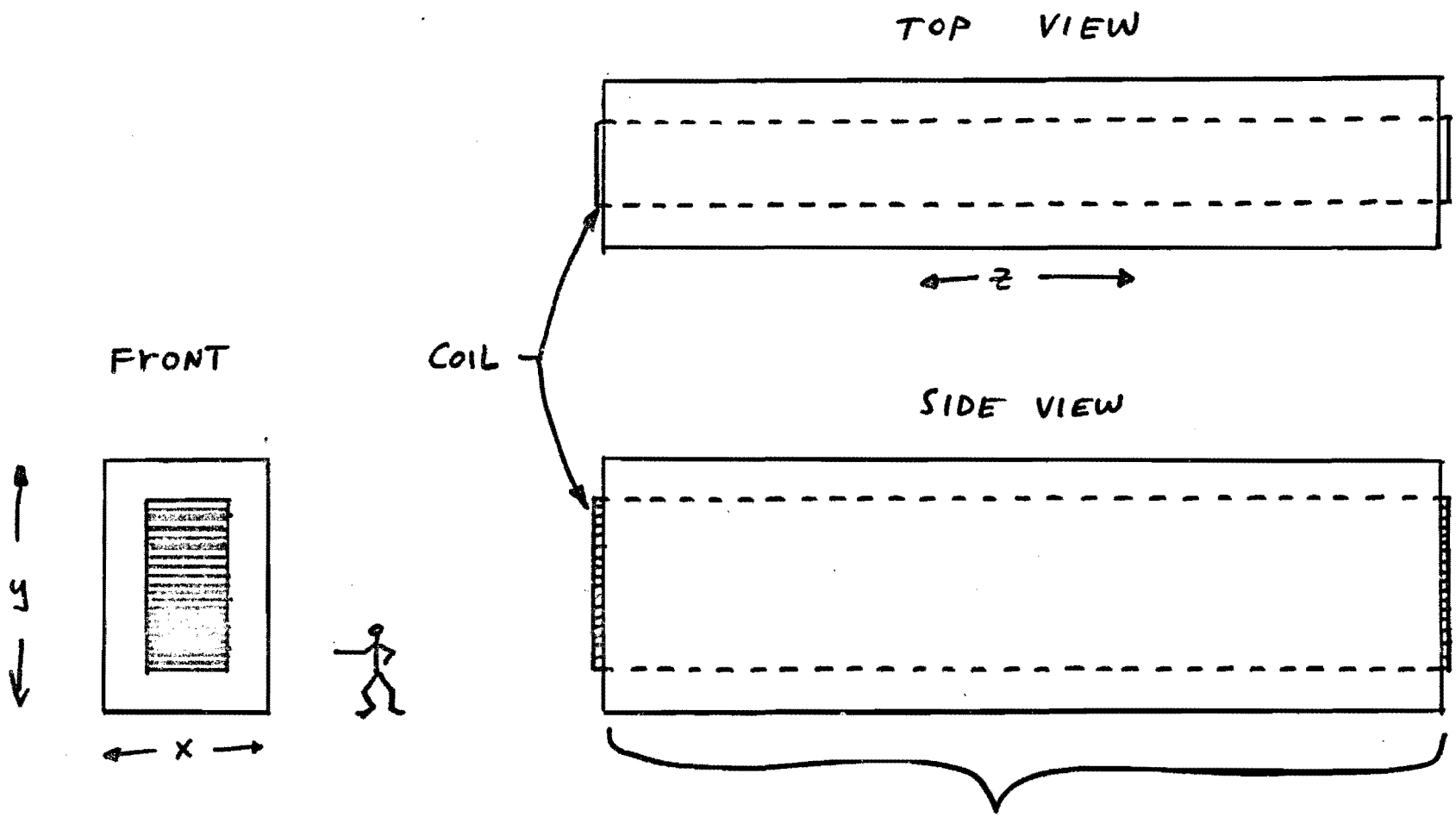
When Flip-Flop 1 is set, the gate for 12 bit latch 2 is activated, but not set until the voltage on C return to threshold. The difference of the times will be proportional to the total charge integrated during that interval. Linearity is not required, but each circuit should have nearly the same response within an overall calibration factor.

Thus, the conventional run-down circuit can be applied here in a relatively inexpensive way. For comparison, the front end analogue

part needs are similar to the conventional MWPC except for increased dynamic (albeit nonlinear) range. The digital parts, i.e., the gates, memory, readout etc. instead of one bit will require a 12 bit data bus. This is not a very substantial extrapolation of present techniques. Because of the modest performance specs TTL can be used, saving a factor 3 in cost relative to MECL. The price of $20/channel for the necessary volume is therefore not likely to be a serious underestimate.

Another possibility is to store the charge temporarily on a capacitor and sequentially multiplex actuated channels to a common ADC. This possible approach may also prove feasible, but has not been considered at this time.

Fig. 1 BASIC GARGANTUA MODULE

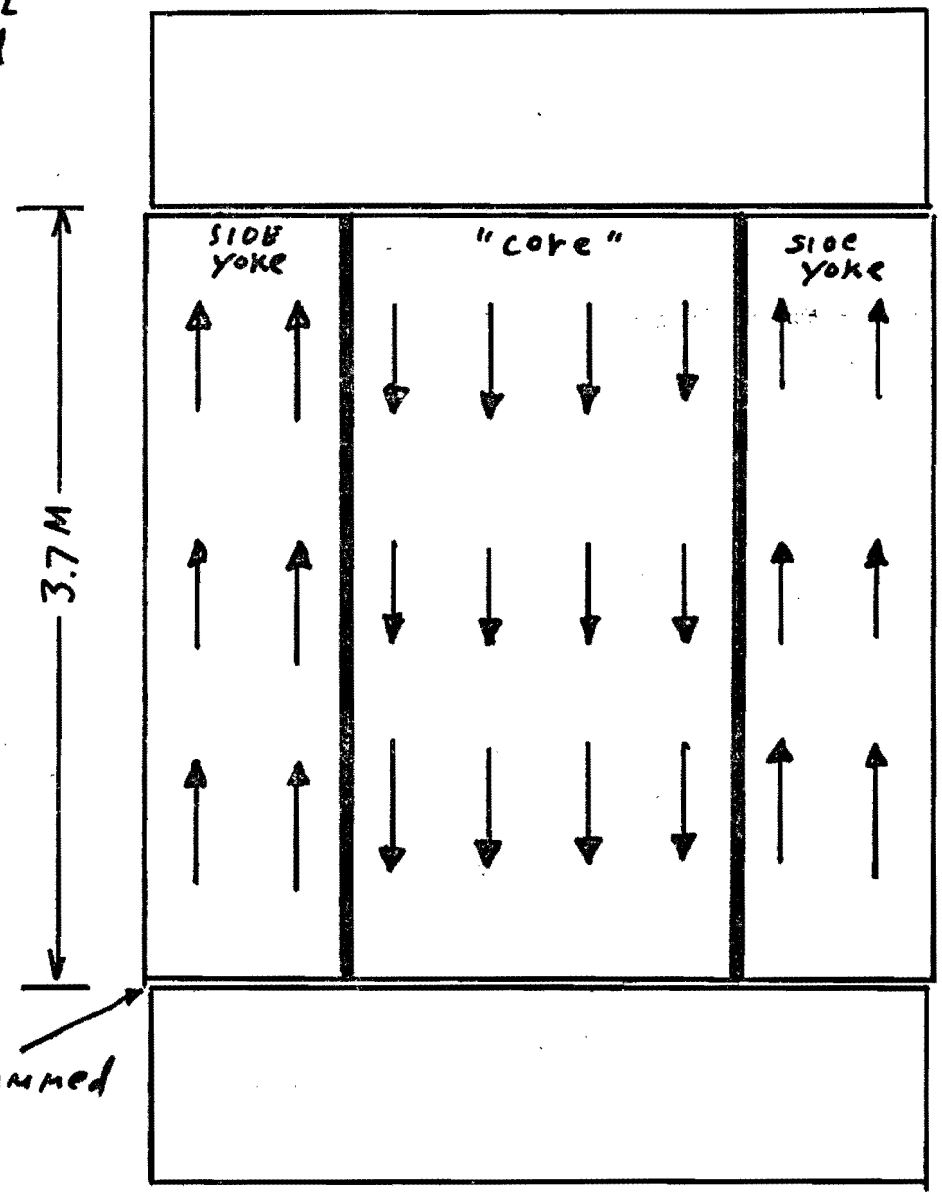


Length along x : 3.7 M
Length along y : 5.5 M
Length along z : 20 M

175 iron plates 2" thick
175 gaps 2.5" thick for detectors

Figure 2. IRON PLATE DETAIL AND MAGNETIC FIELD

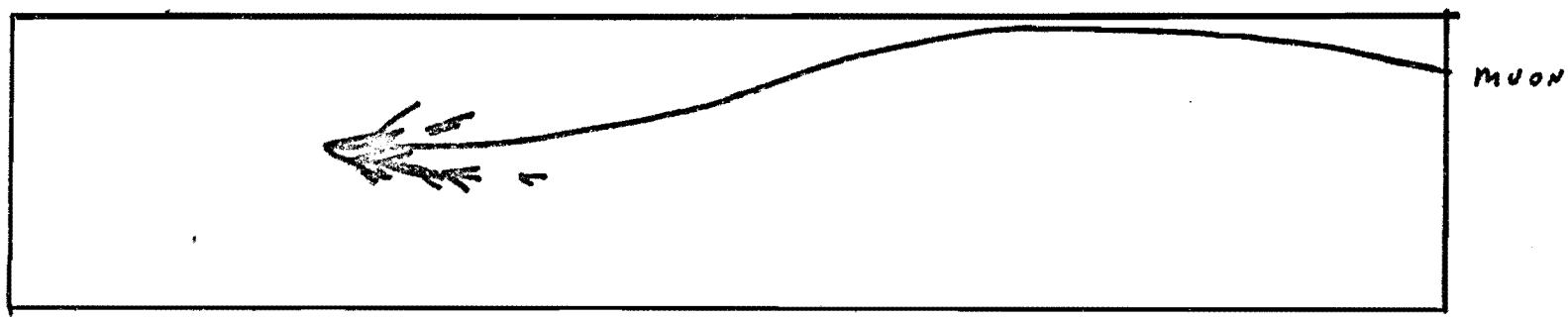
Sensitive volume is the central square region defined by side-yokes and core. Top and bottom yokes can be instrumented



Air gaps, to be shimmed for uniform field.

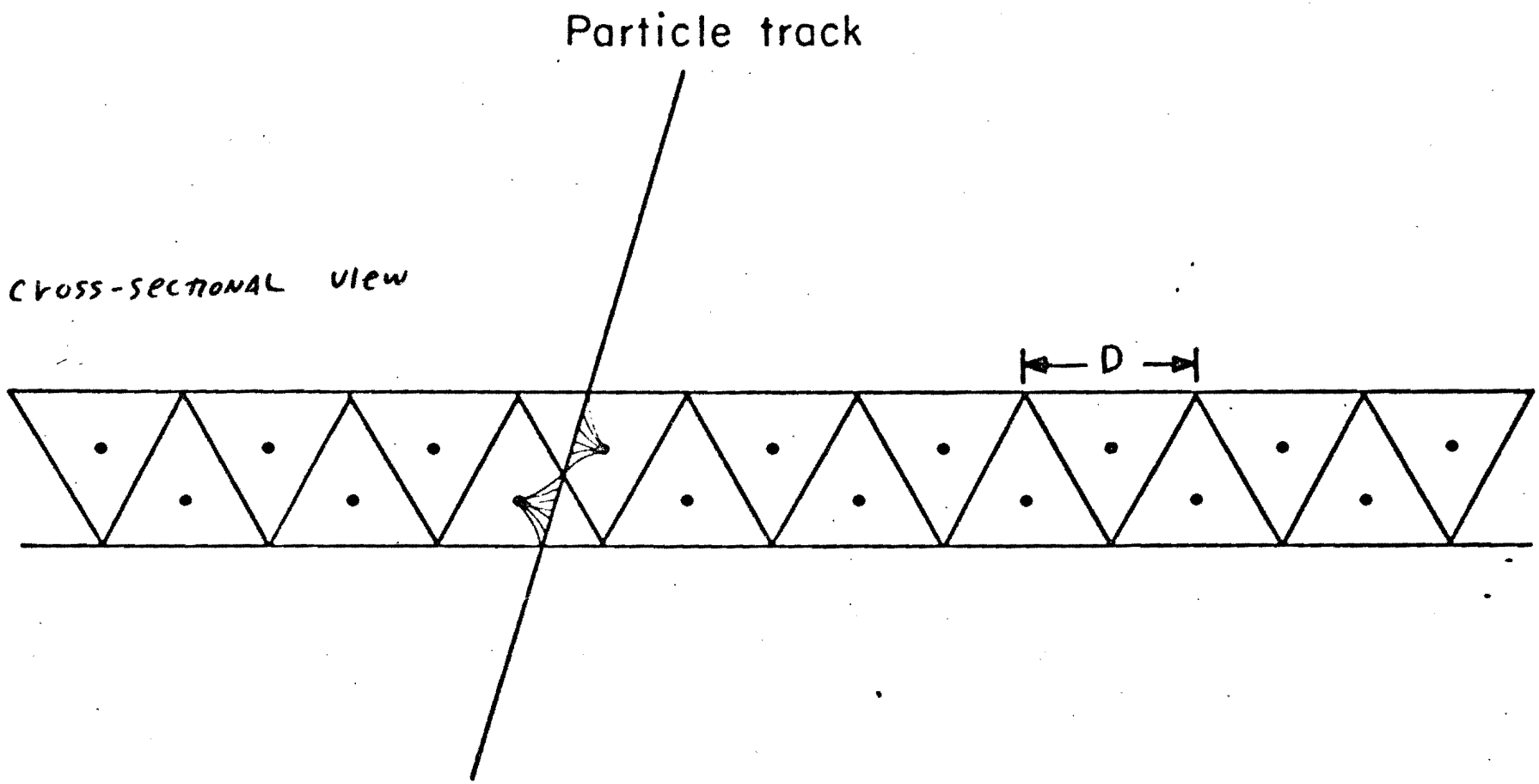
Figure 3. "TYPICAL" EVENT

TOP VIEW



MUON SHOWN HERE IS CREATED NEAR THE CENTER. OTHER MUONS WILL BE AT LARGER ANGLES, REQUIRING SIDE YOKE DETECTORS FOR EFFICIENT IDENTIFICATION.

Figure 4. The triangular multiwire proportional drift chamber



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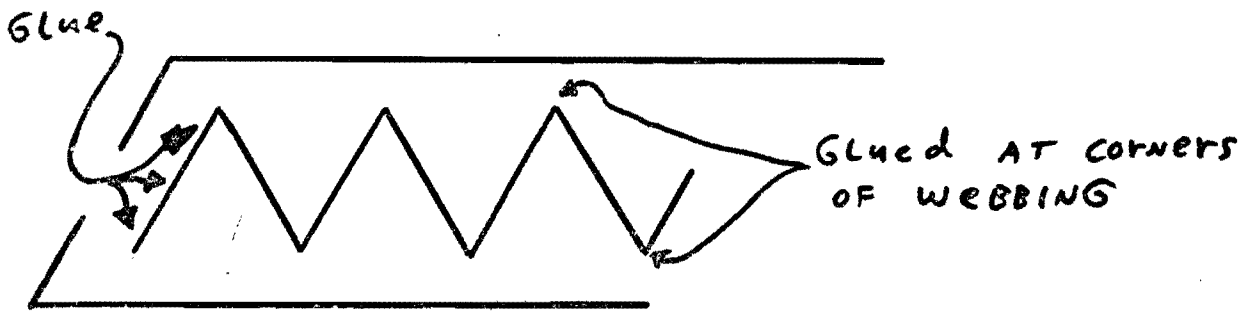
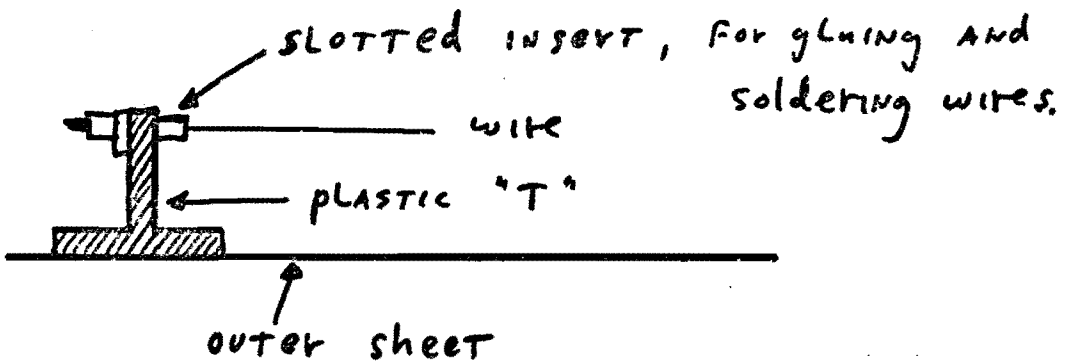
D = 6.8 cm.

Figure 5. Construction details of the TMWPDC.

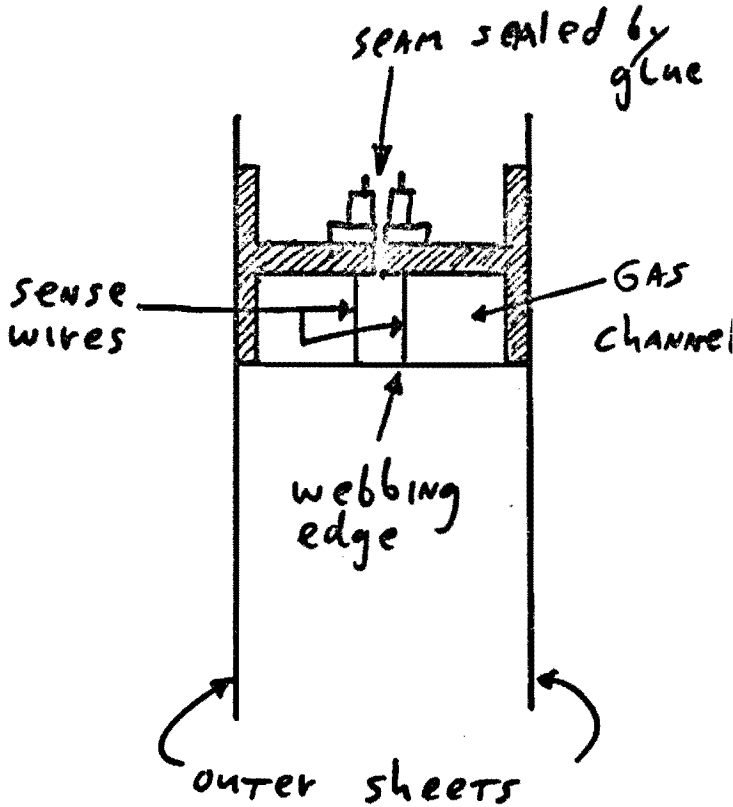
a. Exploded view, end section



b. wire installation, side view

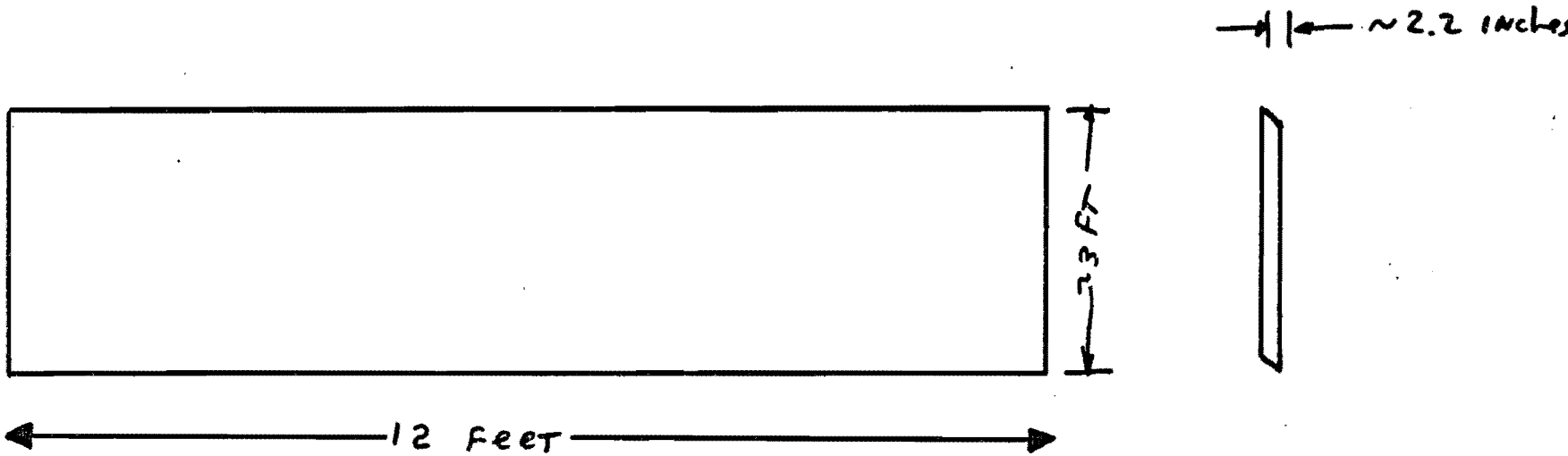


c. Assembled view, side view



wires are naturally staggered; see Figure 4.

Figure 6 BASIC chamber module - 26 cells



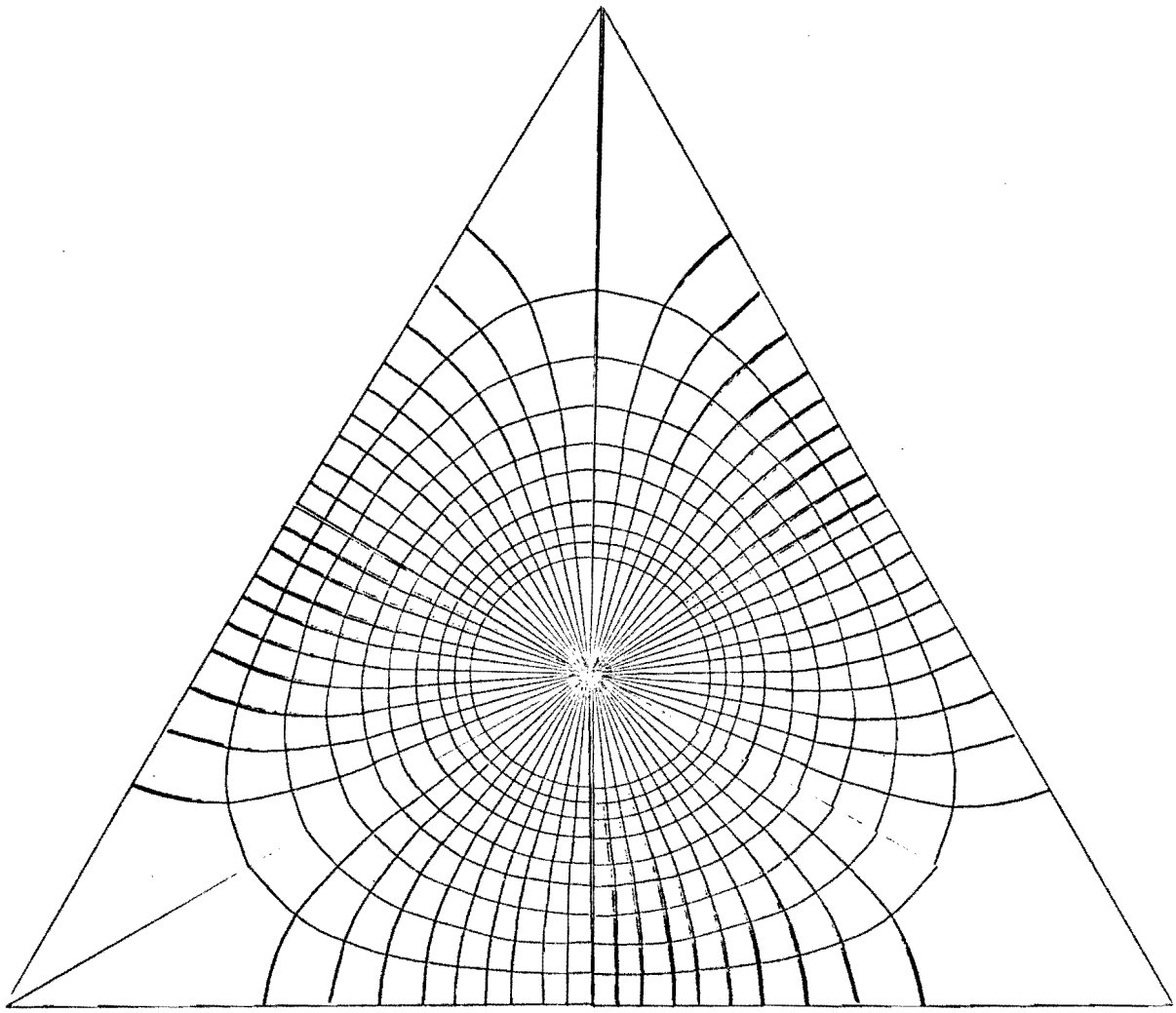


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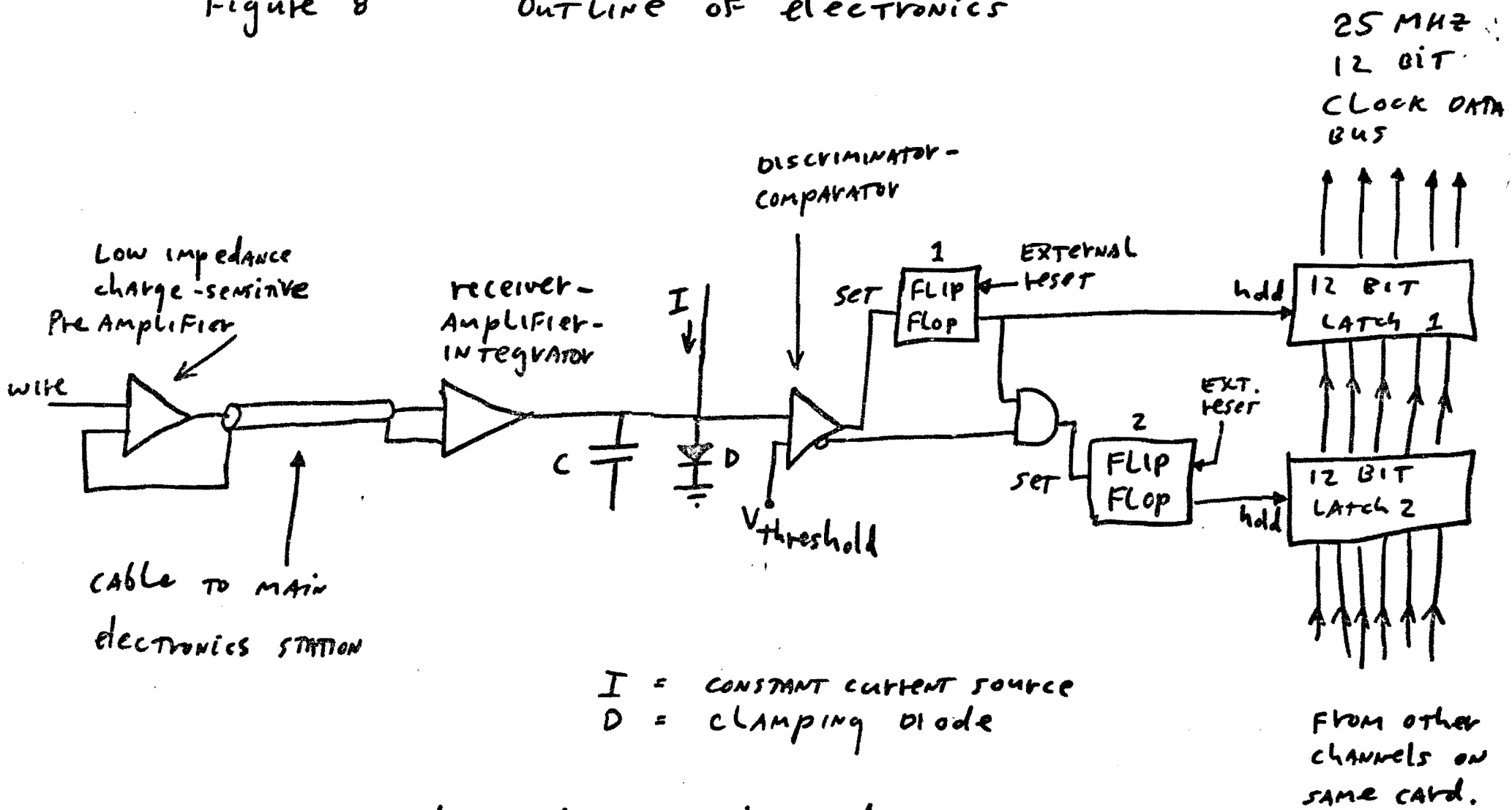
Figure 7

Distribution of equipotentials and field lines for the TMWPDC.

Figure 8 Outline of electronics



After beam pulse, data can be read out on clock bus.