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Letter of Intent to the SPSSC

Magnetized liquid Argon detector for electron charge sign discrimination

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Abstract

A liquid Argon time projection chamber (TPC) immersed in magnetic field is proposed for systematic study and parameter optimisation in electron/muon charge sign discrimination and muon momentum determination by magnetic deflection. Design criteria and preliminary calculation are described. A proof of principle experiment is proposed using an electron beam of 1-10 GeV/c momentum incident on a prototype liquid argon TPC approximately $0.8 \times 0.8 \times 3.2\ m^3$ that is placed in a 1-T magnetic field.

Introduction

A liquid Argon TPC appears to be an ideal instrument for detection and reconstruction of neutrino interaction events due to its specific measuring capabilities, such as fine-grain 3d-imaging, *dE/dx* tracking and hadron/electromagnetic calorimetric response. See for example the event in Figure 1. While extensive experience has been accumulated[1] on the liquid Argon TPC technique, its performance in magnetic field remains to be demonstrated.

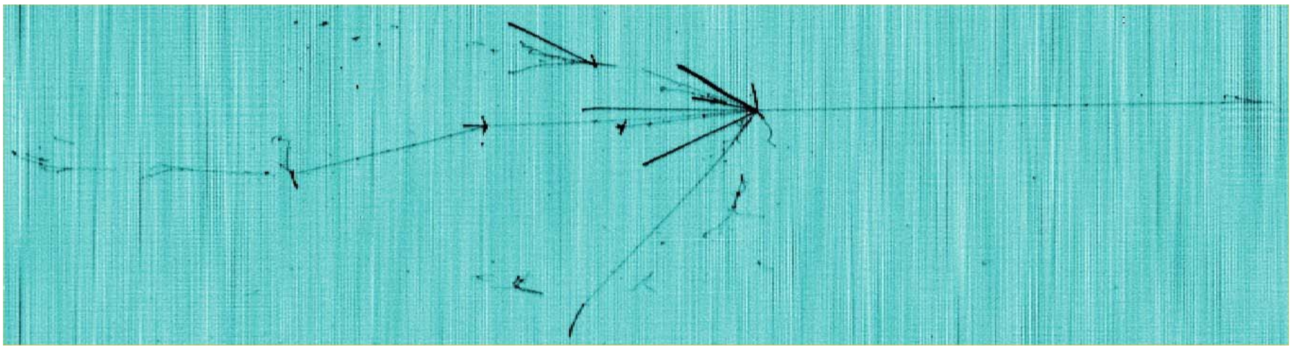

Figure 1: Nuclear interaction recorded in ICARUS T600 during the first setting-up of the detector.

In the case of neutrino beams from neutrino factories based on muon storage rings, the detection of charged current neutrino interactions with leptons (e, μ) with charge sign opposite to that expected from the stored μ sign, is, by itself, a proof of oscillation. Thus, the identification of the charge sign for e's and μ's through magnetic deflection is the qualifying feature of detectors for such physics. For muons of any energy, their long observable path permits deflections (and hence the sign of their charge) to be rather easily detected against the multiple scattering even at field intensities of ~0.2 T. For electrons, the useful tracking is reduced to their path before showering ($1 \div 2 X_o$) and then the charge sign discrimination, at 3-σ, requires a magnetic field intensity of 0.4 T at 1 GeV/c and 1.2 T at 10 GeV/c (see Figure 3). From simulations, it results that, in many cases, the electromagnetic shower axis follows, along several radiation lengths, the path of the primary electron and then the shower itself appears bent, in the range up to its maximum, accordantly with the sign and the momentum of the primary electron.

The electron charge sign identification results then an interesting and intriguing theme to be worked up with a dedicated R&D program. The program is based on a liquid Argon TPC to be tested in a $1 \div 10$ *GeV/c* electron test beam. The active volume should have good shower containment (~$20 X_o$ length, ~$6 R_M$ transverse size). The cryostat is outfitted with a solenoid coil able to generate fields up to ~1 T.

With such a device it will be possible also a systematic study of the operating parameters in the muon momentum measurement by magnetic deflection in a liquid Argon TPC.

[1] ICARUS detector: for a description and a complete reference list visit the sites http://www.aquila.infn.it:80/icarus/index.html and http://pcnometh4.cern.ch.

1. Event simulation

Montecarlo simulation on electromagnetic showers in a liquid Argon TPC immersed in magnetic field[2] show that, for showers completely contained in the active volume, the calorimetric measure gives the energy and then the expected curvature radius. The sign of the initiating electron can be detected, in many cases, by selecting the best fit of an arc of such a radius to the initial part of the shower, on the left or on the right of its axis.

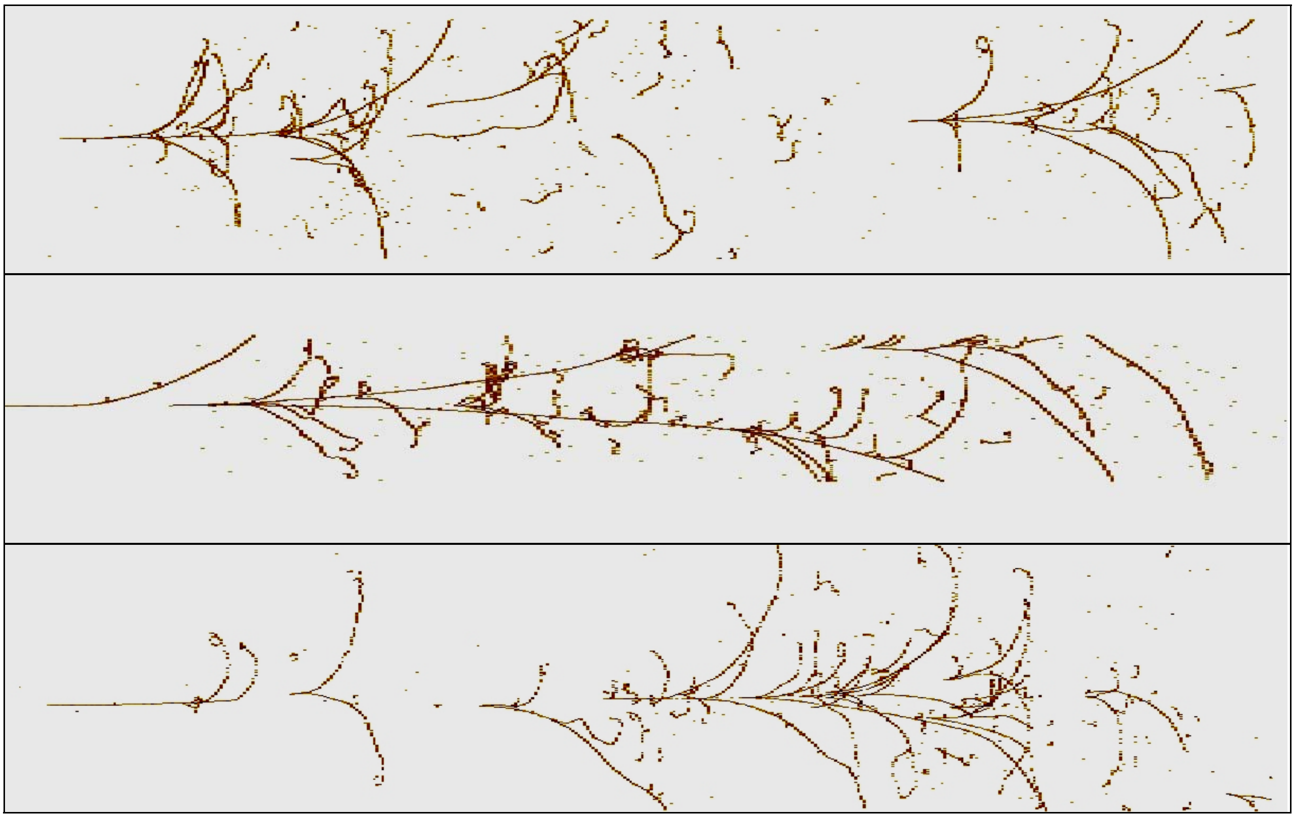

Figure 2: Montecarlo generated electromagnetic showers in a magnetised liquid Argon TPC. $E_{sh} = 2.5\ GeV$, $B = 1\ T$.

In most cases, and in particular when low energy γ–rays are produced in the first 3÷4 radiation lengths, the initial electron continues to appear as the leading particle of the shower for more than one or two radiation lengths and then we can observe an average bending of the shower (statistical sign discrimination).

In other cases, when the initial electron emits a high-energy γ–rays, its momentum and its curvature radius are significantly reduced making easier the sign identification (see, for example, the two lower events in Figure 2).

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[2] A. Rubbia, *Neutrino Factories: Detector concepts for studies of CP and T violation effects in neutrino oscillations*. Based on an invited talk given at 9th International Symposium on Neutrino Telescopes, Venice, Italy, 6-9 Mar 2001. Published in VENICE 2001, NEUTRINO TELESCOPES, vol. 2, 435-462.

2. TPC in magnetic field

In a TPC, the active volume is immersed in an electric field $\vec{E}_d$ to drift the electrons, generated by an ionising particle, towards a wire chamber anode (*time projection*). In a simple configuration the wire chamber is made by two wire planes, with the wires of the first plane aligned in a direction orthogonal to that of the wire of the second plane. With an electric field $\vec{E}_c \cong (1.2 \div 2) \cdot \vec{E}_d$ established between the two wire planes, drifting electrons pass through the first encountered wire plane (*induction* plane), inducing a negative charge signal on it, when approaching, followed by a positive signal when leaving it. Electrons are then collected in the second wire plane (*collection* plane) generating a negative charge signal on the encountered wires. This mechanism generates a second *geometrical projection* along the coordinates associated with the two wire directions.

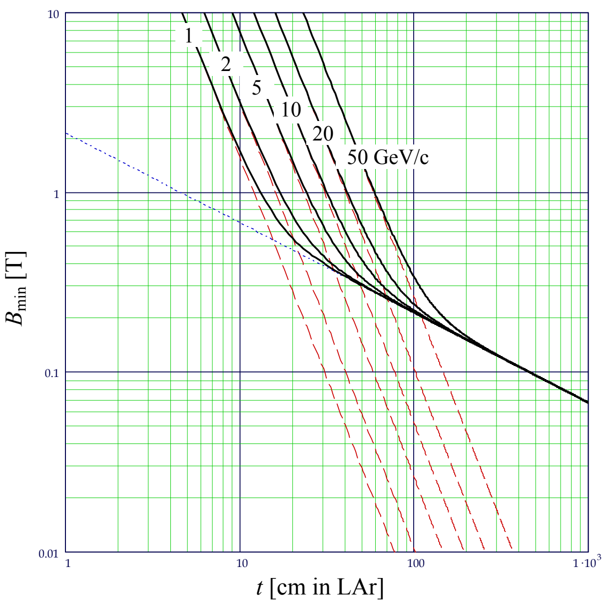


Figure 3: Minimum magnetic field required to discriminate, at 3σ, between positive and negative curvatures vs. track length. Dashed curves: contribution of the detector resolution at momenta 1, 2, 5, 10, 20 and 50 GeV/c. Dotted curve: contribution of the multiple scattering in the range 1÷50 GeV/c. Solid thick curves: combined contribution of detector resolution and multiple scattering in the range 1÷50 GeV/c.

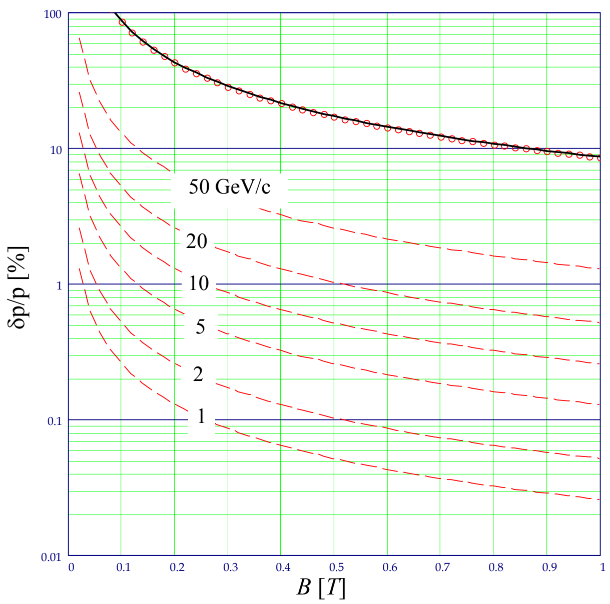


Figure 4: Momentum resolution vs. magnetic field for muons crossing 20 X_o in liquid Argon. Dashed curves: contribution of the detector resolution at momenta 1, 2, 5, 10, 20 and 50 *GeV/c*. Circles: contribution of the multiple scattering not depending on momentum. Solid thick curve: combined contribution of detector resolution and multiple scattering in the range 1÷50 *GeV/c*.

A magnetic field $\vec{B}$ for charge sign discrimination (and for momentum estimation) is applied orthogonal or parallel to $\vec{E}_d$.

With $\vec{B} \parallel \vec{E}_d$, the maximum bending is obtained for tracks originally contained in a plane orthogonal to $\vec{B}$ and then parallel to the wire plane. Their ionisation electrons arrive then at the same time on the wires, generating degenerate images as straight segments. On the contrary, with $\vec{B} \perp \vec{E}_d$, the maximum bending happens in a plane orthogonal to the wire plane and containing the drift direction. Tracks in the maximum bending plane are then imaged as arc of circle (or ellipse) in at least one of the wire planes.

This justifies the choice of a configuration with $\vec{B} \perp \vec{E}_d$. We propose to evaluate the effect of diffusion enhancing/reduction on the migrating electron clouds by comparing the image definition in the reconstructed ionisation tracks with the two magnetic field orientations and without magnetic field.

For charge sign discrimination, the magnetic bending should be stronger then the multiple scattering and distinguishable against the detector resolution. In both cases, we have to discriminate, between positive and negative curvatures. The Figure 3 shows the minimum magnetic field required to perform this discrimination, at 3-σ. The figure indicates that: *a)* for muons with track lengths over one meter, charge sign discrimination is feasible even at momenta greater than 50 GeV/c, with $B \geq 0.2$ T; *b)* for electrons, assuming $2X_o$ track lengths, an average 3-d detector pixel of 3.4 *mm* and $B = 1$ *T*, charge sign discrimination is possible, at 3-σ, for momenta up to 7.7 *GeV/c*.

Momentum determination through the measurement of the curvature in magnetic field is a precious tool for the total energy evaluation of CC-neutrino interaction events, with muons not stopping inside the active detector volume.

Figure 4 shows that for tracks completely crossing the detector length (~3 *m*) momentum resolutions of 20% at 0.5 *T* and 10% at 1*T* are reachable.

We plan to experimentally proof the above results by registering *e*/μ events in the momentum range 1÷10 GeV/c in a liquid Argon detector immersed in a magnetic field with intensities in the range (-1, +1) *T*.

3. Magnet, experimental area and detector configuration

A full study has been performed to build a newly conceived magnet/cryostat/TPC complex. Resulting that the magnet (plus its power supply and cooling system) is the heaviest item for construction effort and cost, an inquiry on available existing magnets at CERN has been made. The feasibility of the test is also related to the availability of electron/muon beams and of the required area in the experimental hall. With positive answers to the above issues, the cryostat and the detector are then designed by adjusting their sizes and their shapes to efficiently occupy the existing magnetized volume.

The LAr TPC configuration is based on a high voltage cathode plane and a two-plane wire chamber aligned on two vertical planes parallel to the beam direction. A set of equally spaced electrodes (field shaping electrodes), dc-biased at linearly decreasing voltages between the cathode and the ground voltages, surrounds the active volume to maintain the drift field uniform across it. Wires on the first chamber plane are aligned along the horizontal direction while wires on the second plane are aligned along the vertical direction. Wires are individually connected, through twisted pair cables and through a hermetic multi-contacts feedthrough, to the low noise preamplifiers (virtual ground) of the outer electronics.

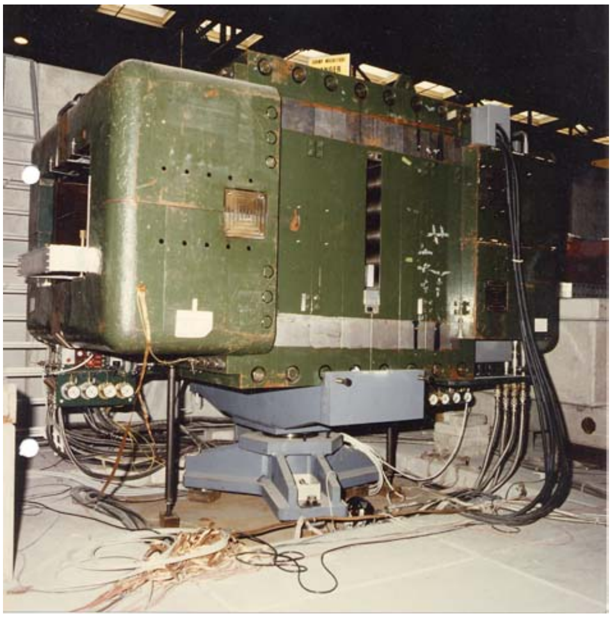
The TPC is housed in a double wall, vacuum insulated and LN_2 cooled cryostat. The cryostat is equipped with flanges and chimneys for HV and signal feedthroughs, in/out for Argon and for LN_2, beam entrance window and vacuum pump.

The installation of the cryostat inside the magnet aperture is shown in Figure 9.

3.1. Magnet

The CERN magnet MNP101 (the data below refer to the combination face-to-face of MNP 101/a + MNP 101/b as shown in Figure 5; the Figure 6 describes a single half) seems compatible with our requirements.

The support of the division EP-TA3, (W. Flegel and collaborators), is highly required for the re-assembling, verifying, putting in operation of the MNP101 magnet, its power supply and its cooling system.



Magnetized volume dimensions:	*Gap*	120	*cm*
	Aperture	80	*cm*
	Length	200	*cm*
Field:		1.08	*T*
Power:		1000	*A*
		1200	*kW*
Weight:		100	*tons*
Outline	*Length*	3.8	*m*
	Width	2.1	*m*
	Height	2.4	*m*

Figure 5: The CERN MNP 101 magnet and its main parameters.

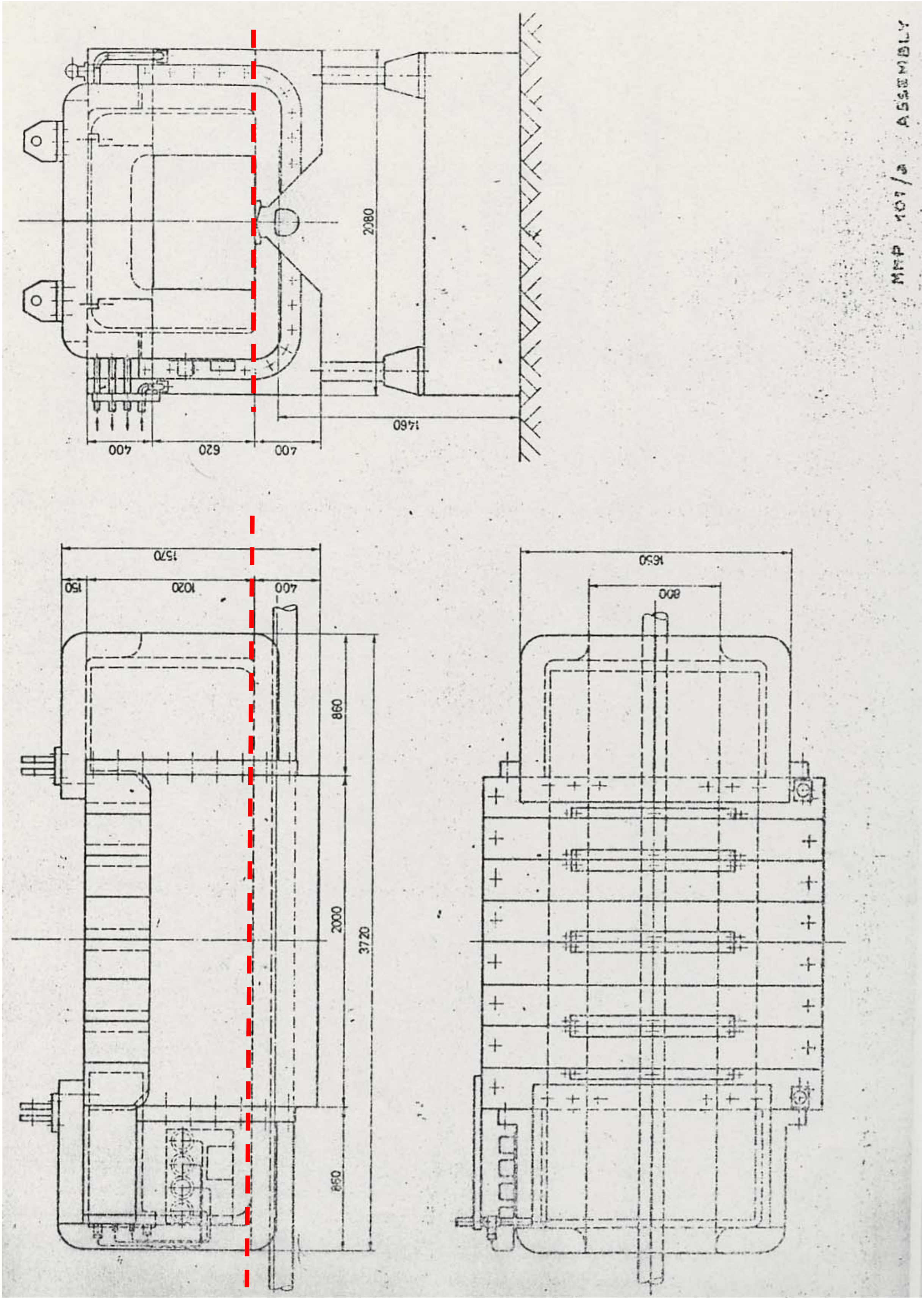


Figure 6: Original assembly drawings for the MNP 101/A/B magnets. The return iron has been dismounted along the dashed lines to allow the combined assembly of the MNP101/A+MNP101/B as in Figure 5.

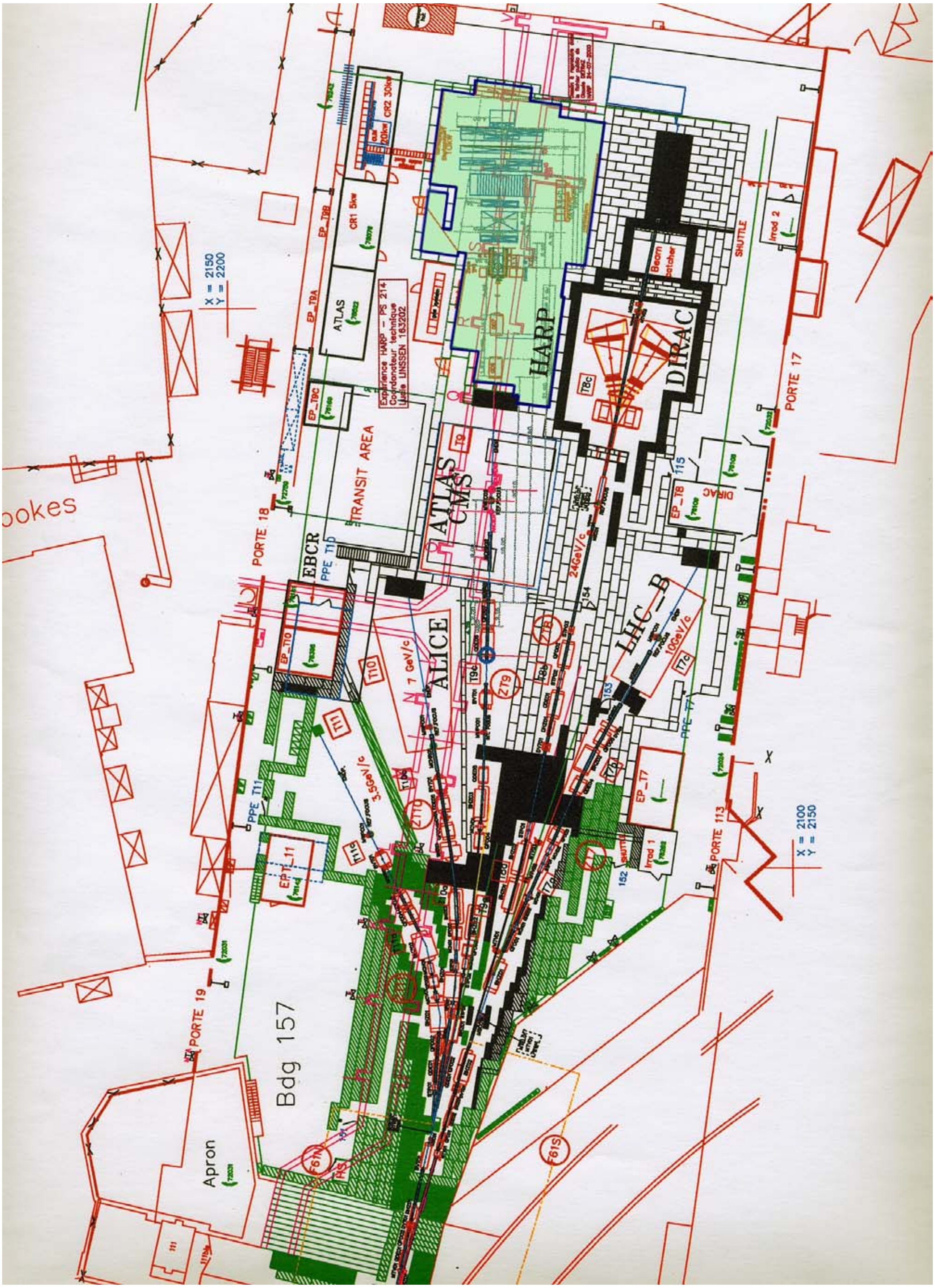


Figure 7: Plan of the East Hall at CERN.

3.2. Electron/muon beam and experimental area

A suitable area for the test is on the T9 beam line in the CERN East Hall (see Figure 7). The considered area is at present occupied by the HARP experiment.

We propose to install, at the beginning of the year 2003, the magnet and the detector in a region downstream the HARP area, (not necessarily on the beam line) to perform a test of the magnet and to test the cryogenics and the acquisition electronics of the detector. Once ready and when the activity of the HARP experiment is completed, we propose to occupy the area along the T9 beam and start the data taking. By such program, we could debug all the apparatus off beam and minimise the period on the beam line.

4. The detector

The layout of the detector is based on the following choices:

– Square base parallelepiped active volume with the larger size along the beam line.

– Drift along the horizontal direction, from left to right, perpendicular to the long axis.

– Magnetic field along the vertical direction, perpendicular to the long axis.

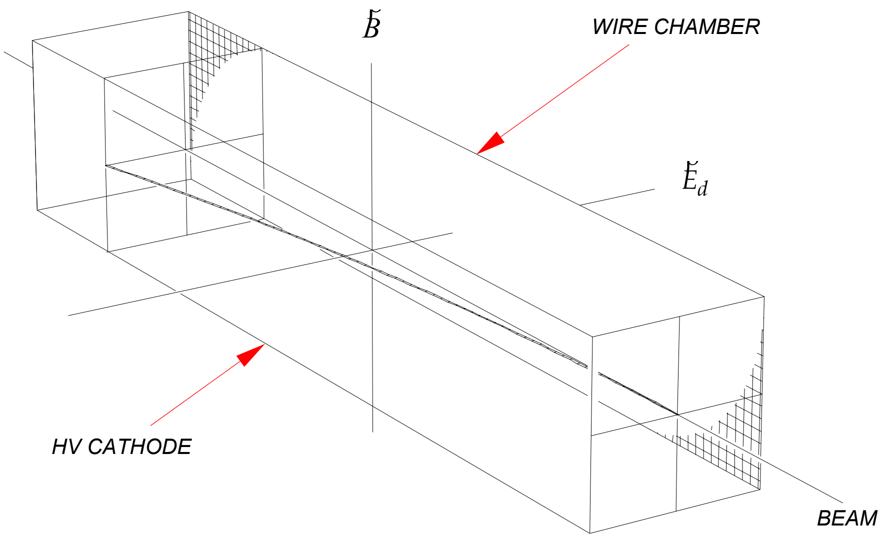


Figure 8: Schematic layout of the chamber geometry.

With this geometry, beam particle tracks are bent in the horizontal plane and projected toward the wire chamber in the right vertical plane (see Figure 8).

5. Set-up area and running time on the test beam

The test requires the use of a low energy (<10 *GeV/c*) electron beam, at very low rates (few hundreds of particles per second). Standard plastic scintillator counters for coincidence and veto will be used to enable the event acquisition.

A possible configuration for beam momentum analysis with a bending magnet, a pair of gas proportional chambers (upstream and downstream the magnet) and the electron beam under vacuum up to the detector should be foreseen for calorimetric calibration.

The area needed to host the magnet with the cryostat has a 4.5×2.5 m^2 size. Some extra square meters are needed for the vacuum pump and LAr and LN_2 dewars, whose location can be arranged depending on the available space.

We plan to take event data with trigger for electrons and for muons with different momenta (1÷10 GeV/c) and at different magnetic field intensities (-1 T ÷1 T). As conservative estimate, a period of about 10 days on the beam line seems required.

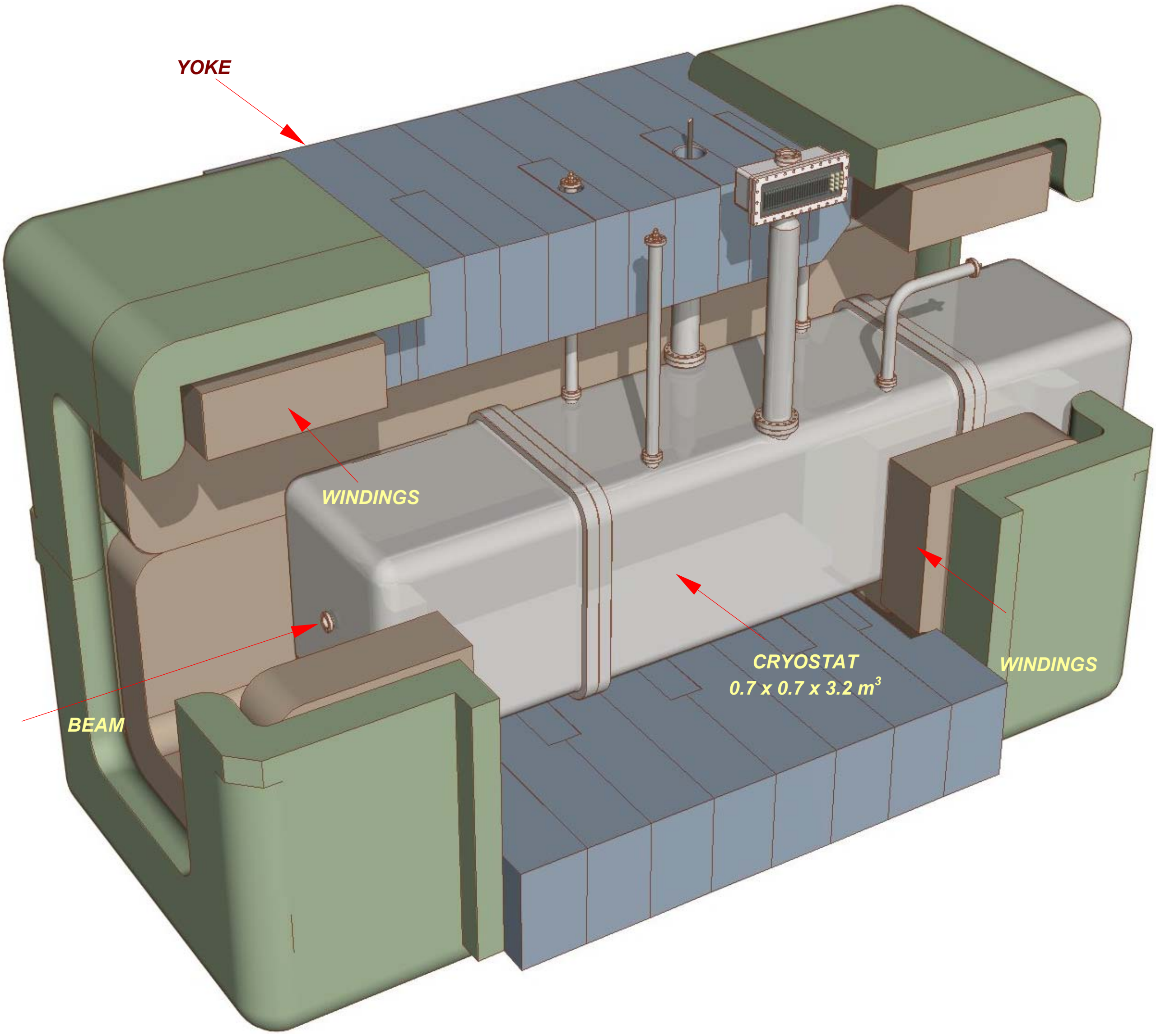


Figure 9: The proposed LAr TPC cryostat installed inside the MNP101 magnet.

6. Conclusions

The proposal for a new configuration of a liquid Argon TPC immersed in a magnetic field has been described. Its main purpose is to investigate the resolving power for the sign of the electron charge up to 10 GeV, and to study the effect of magnetic field on the image quality. This document aims to verify the possibility to perform this research at CERN during the year 2003. A full proposal, including a detailed design of the detector, matched to an existing magnet, will be provided in case of a favourable reception.

We would like to thank J.P. Riunaud, L. Durieu and M. Hauschild for their suggestions as to possible siting of the experiment in the East Hall. We also acknowledge the kind collaboration of W. Flegel for his advice on potential use of the MNP101 magnet.