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Optimization of the EAGLE Muon System based on a Fe-Toroid combined with a Central Solenoid

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Abstract

In this note I will describe the present concept of one of the EAGLE muon systems, namely the one which is based on a large 1.8 T Fe-toroid combined with a superconducting 2 T solenoid around the interaction region. In this configuration a resolution dp/p between 2% and 7% can be achieved in the region $|\eta| < 1.8$ for 40 GeV/$c \leq p \leq$ 500 GeV/c rising to 10% and 16% at 1 and 2 TeV/c, respectively.

I will discuss the most recent ideas on the construction of the Fe-toroid and on the concept for the muon tracking chambers. It is argued that the most convenient choice for the muon chambers are drift chambers or drift tubes. A possible geometrical layout of the muon chamber system is presented which minimizes the effect of dead zones at the edges of the chambers.

For our further work it is essential to understand the implication of the muon system on the other components of the detector and vice versa. In this paper I conclude: the central solenoid should have a sufficiently large radius and field to optimize the muon momentum measurement. Therefore it should provide a field of 2 T and be located behind the electromagnetic calorimeter. The hadron calorimeter should be (at least partially) out of magnetic iron in order to return the magnetic flux of the solenoid. It is possible to balance the performance of the toroid against the strength of the solenoid in the "barrel"-region.

This paper should be a base of our future discussions in the Technical and Editorial Board (TEB) to converge towards a letter of intent. I tried to summarize the impact of the muon system on the other detector components. Similarly, constraints of the other detector elements on the muon system should be pointed out to me. For any comments I would be very grateful.

Introduction

Two options for the muon system have been discussed within the EAGLE collaboration: one option consists of the combination of a 2-4 m thick Fe-toroid with a superconducting solenoid of moderate radius, which improves the muon momentum resolution in the central ("barrel") region and also provides a measurement of the charge of electrons. In the second option, the muons are measured outside the hadron calorimeter in a large air volume containing a low(0.5 T) solenoidal field. The forward region is complemented by field shaping coils and optionally also by a toroid.

To enable us to make a choice between these two options, it is necessary to study and to optimize both, so we can understand their performances, the technical efforts and the manpower needed for the two systems. An important aspect is also the impact of the muon systems on the rest of the detector design.

I will concentrate here only on the first option and try to outline the performance we can expect from such a system discussing several possibilities of optimizing the detector. I will argue, that there are some clear conclusions of how the other components of the detector should look like.

The structure of this paper is the following: first the construction of the Fe-toroid is described, then the different possibilities to integrate the solenoid are discussed. In the following section the expected momentum resolution is presented under different assumptions for the magnetic system and the chamber resolution. The next subject is the geometry of the muon chambers and a first discussion on possible chamber techniques and the R&D efforts needed. In the end I will summarize my conclusions.

The Layout of the Fe-Toroid and the Solenoid

One possible layout of an LHC detector based on a conventional Fe-toroid operating at 1.8 T, combined with a superconducting central solenoid is shown in Fig. 1. The technical part of this design has been developed by C. Vollerin and F. Wittgenstein.

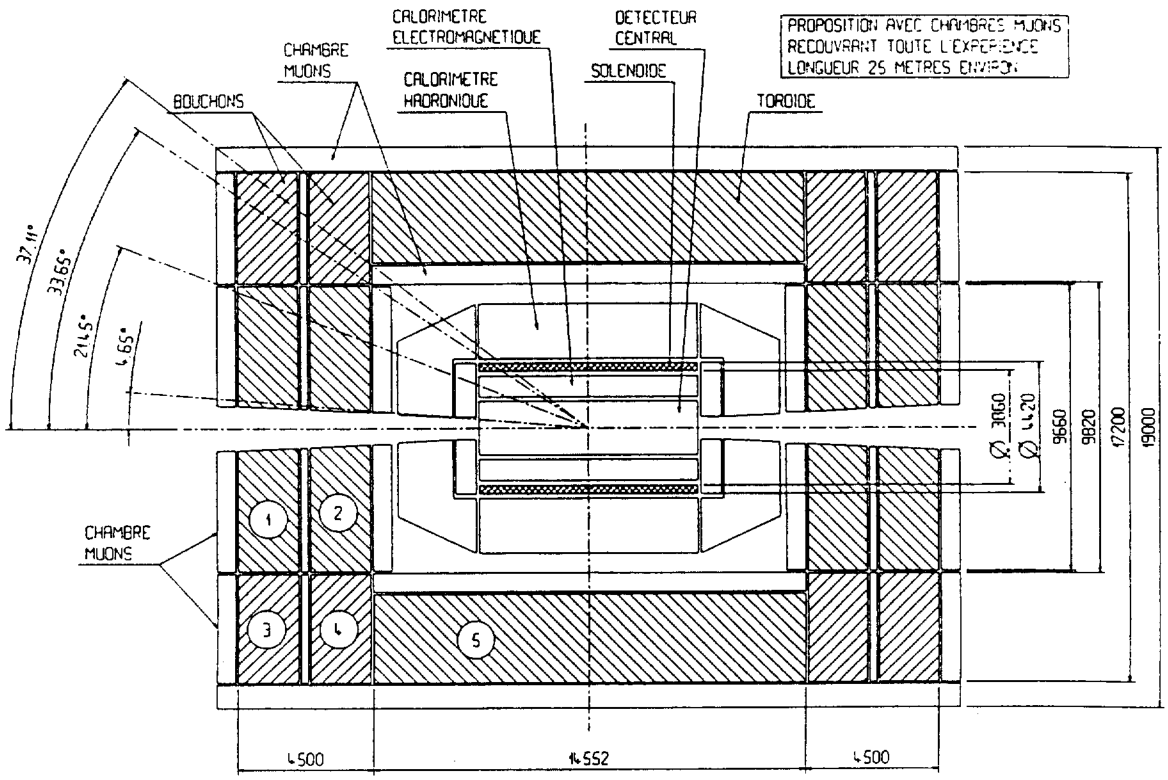

Figure 1: Preliminary layout for an Fe-toroid combined with a central solenoid. The return flux for the solenoidal field is integrated into the hadron calorimeter.

The Fe-Toroid

In the version shown in the figure, already some simplifications have been made: the toroid in the barrel region has no intermediate muon station: that means the momentum of the muon is derived from the measurement of the muon direction before and after the magnetized iron. In this case, no correction can be made for large angle scattering or large catastrophic energy losses in the Fe of the toroid. In addition, all redundancy of the reconstruction has to be achieved by the multi-layer tracking stations outside the iron, in particular in the first planes behind the hadron calorimeter.

The suppression of all intermediate muon stations in the iron is essentially motivated by the construction: Due to the size and the enormous weight of the iron a very simple construction has to be found, minimizing the handling of large heavy units. It turns out, that it is very difficult to build the barrel of a double or a triple layer toroid of the magnitude we are considering here. Not only will there always be a very heavy support structure between the different 1-2 m thick Fe-"layers" restricting the coverage of the chambers, but also is it very difficult to insert, to access and to align any of those chambers in between the iron layers, because they are obstructed by the electric coils surrounding the iron toroid.

Therefore, it was proposed to study first a simpler version of a toroid suppressing the intermediate layers of muon chambers. This led immediately to the construction scheme presented here. If however MC-simulations or other reasons demand a further layer of chambers inside the iron we have to reconsider other possibilities.

In Fig. 2 the present proposal of how to construct the Fe-toroid is illustrated: the whole

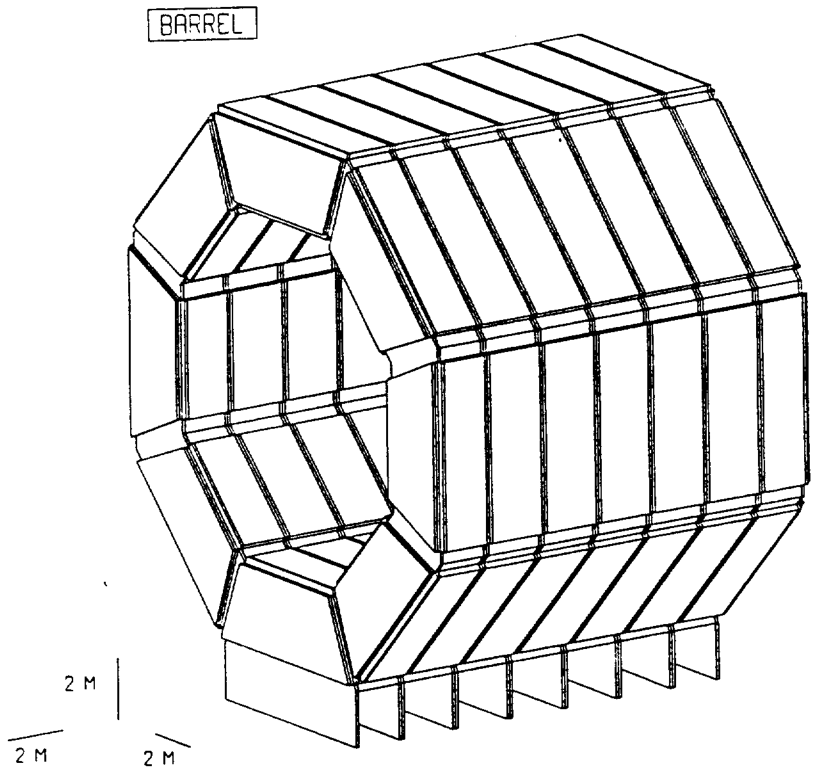

Figure 2: Possible construction of the Fe-toroid out of 2 m thick Fe slices.

magnet is divided into slices or modules of about 2 m thickness. Each slice has a weight of 2000-3000 t, close to the limit of what is possible to move with very heavy lifting devices. The two meter modules are assembled out of 10 cm thick plates (see Fig. 3), which are prefabricated and welded together on site. Two large Fe-plates form the feet of each module, enabling an insertion of muon chambers also at the bottom without too large losses in acceptance.

The installation of this "beast" is not yet completely clear: If the solution of large slices is adopted, the toroid modules will be installed first, one by one. After this, the prepared Al-coils will be attached to the iron. They are embedded into large grooves, so the outside of the toroid represents a smooth surface. Then the hadron calorimeter can be inserted, which again is a very delicate operation and depending strongly on the type of calorimeter. Finally the muon chambers and the inner tracking detectors can be added.

By this way of constructing the barrel it is obvious that an intermediate chamber plane is difficult to accommodate. However, in the forward region it is much easier to include intermediate muon chambers within the iron into the design. The total thickness of the iron is chosen to be 4 m, thicker then the barrel part, as here all the muon momentum resolution is obtained by the toroid only.

The Superconducting Solenoid

The presence of the central solenoid improves considerably the momentum resolution for the muons within $|\eta| < 1.8$, if its parameters are dimensioned appropriately.

As we will see in the section on the momentum resolution, a field of about 2 T and a coil radius of about 2 m is desired, to obtain a significant improvement of the momentum resolution

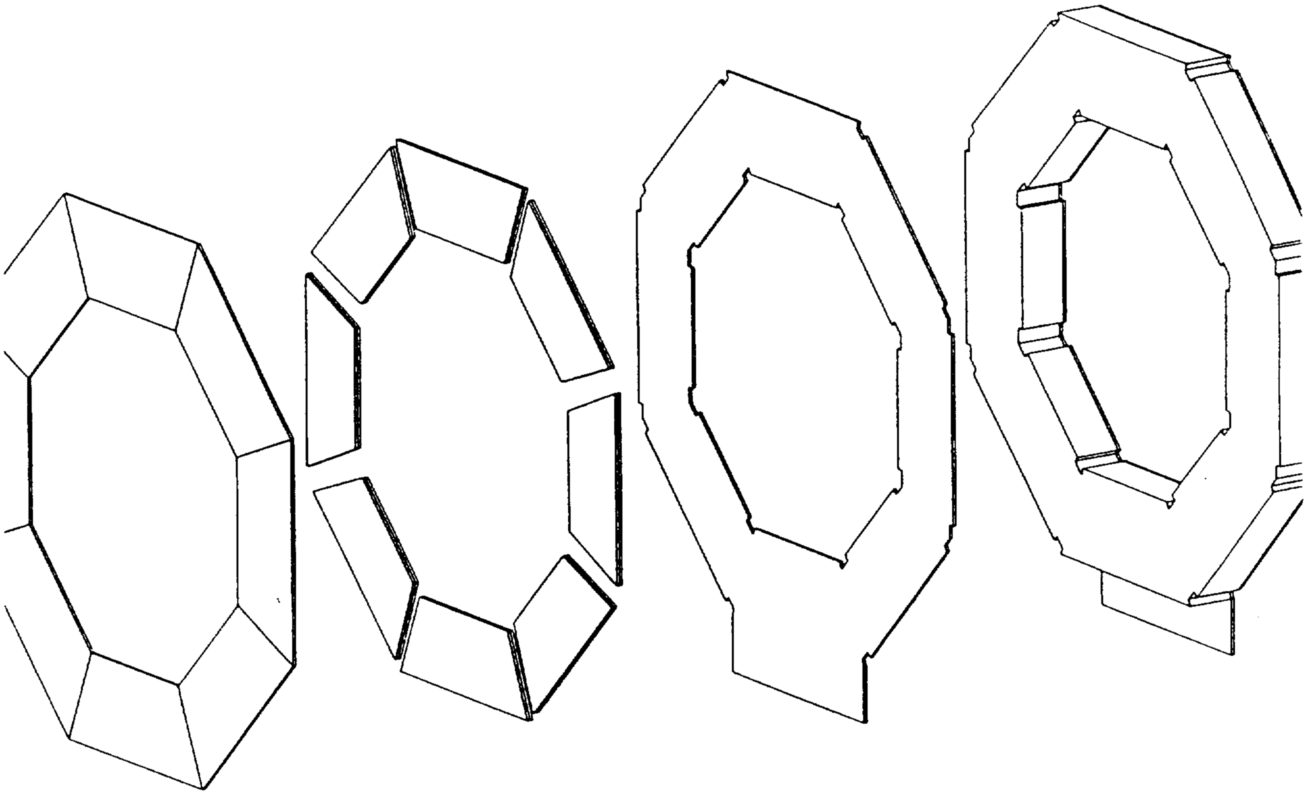

Figure 3: Assembly of the 2 m thick modules out of individual Fe-layers.

by the solenoid. A smaller field will decrease the contribution of the solenoid linearly, whereas a change in diameter of the coil will deteriorate the resolution even quadratically for some cases.

To optimize the muon momentum resolution, it is therefore desirable to place the coil at an as large radius as possible behind the electromagnetic calorimeter.

An important issue for the operation of the muon chambers is the flux return of the solenoid. The most convenient way is to integrate it into the hadronic calorimeter: in this case, all muon chambers can be operated in a region free of any magnetic field (except some small stray fields of the toroid) and all muon tracks will point back exactly to the vertex in the transverse plane (within the limits of energy loss and multiple scattering). Both conditions would not be satisfied if the flux was returned through the iron of the toroid, which is an alternative possibility.

Fig. 4 shows two field calculations carried out by V.I. Klyukhin [1] for the case of a magnetic hadron calorimeter and a separate return yoke. The latter gives also an idea about the field distribution for the case the toroid is used as a flux return.

If a calorimeter technique is chosen, which does not allow to include a magnetic part, a separate return yoke would have to be installed in order to maintain these advantages. This would add to the complexity of the detector.

To minimize the impact of the coil on the calorimetric measurements a very compact construction of the coil is mandatory. In the case of a cryogenic electromagnetic calorimeter like liquid Ar or Kr a combined cryostat of the calorimeter and the superconducting coil seems to be very attractive. To maintain a good electron resolution and photon and pion identification it is essential to minimize the material in front of the first active elements of the calorimeter. The last tracking layer must be close to the cryostat, and high resolution two dimensional active layers should follow it immediately. No separate preshower in front of the cryostat is allowed nor necessary in this scenario. Compare also the various discussions at our DICE-meetings.

The hadronic calorimeter should be magnetic to be used as a return yoke. Only about 50% of its cross-section has to be Fe. The use of a large fraction of iron instead of Pb will

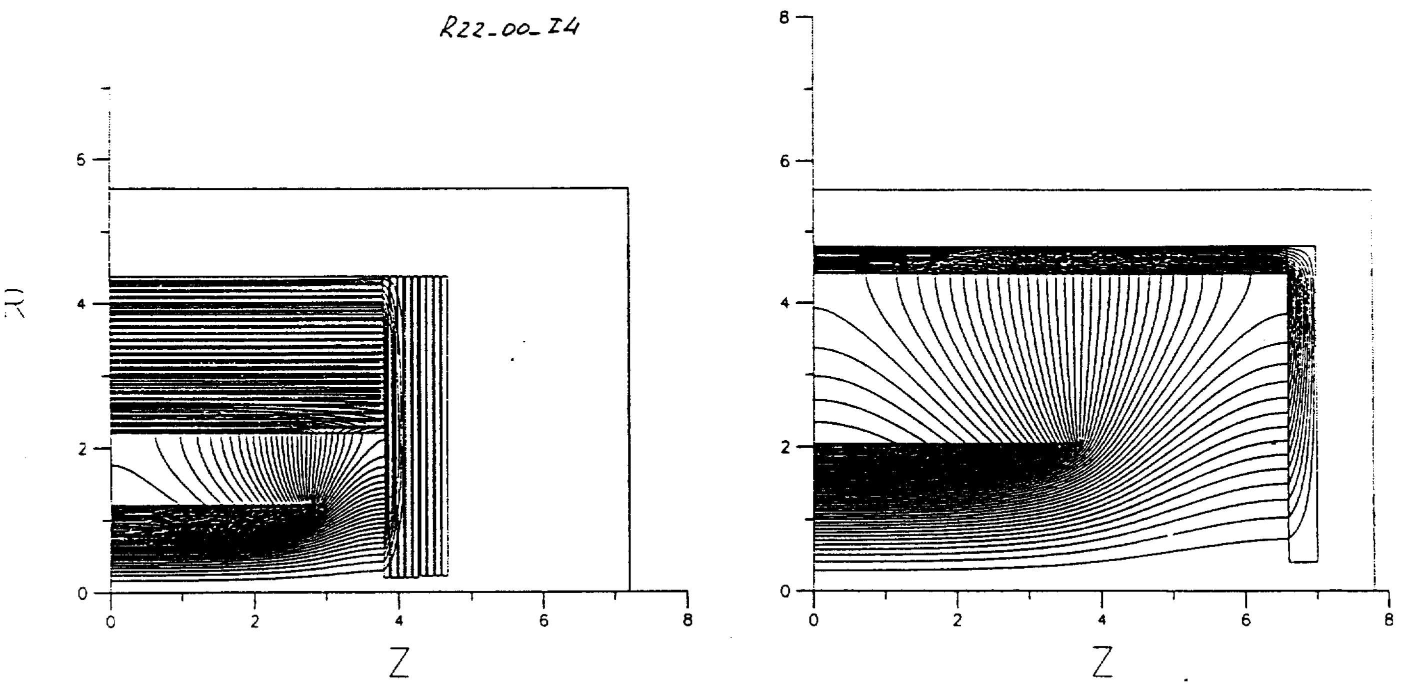

Figure 4: Magnetic field of the solenoid for a Fe hadron calorimeter (a) and an outer Fe-return yoke (b).

also contribute positively to the muon resolution as multiple scattering in the calorimeters is reduced. Likely a deterioration of the hadronic resolution has to be accounted for. Using a non-cryogenic calorimeter technique would probably allow a very hermetic construction and a modular structure, simplifying the installation.

The Muon Momentum Resolution

The resolution in the central rapidity range of $|\eta| < 1.8$ is plotted in Fig. 5, calculated in an analytical approach. The following assumption have been made to obtain this figure. (For

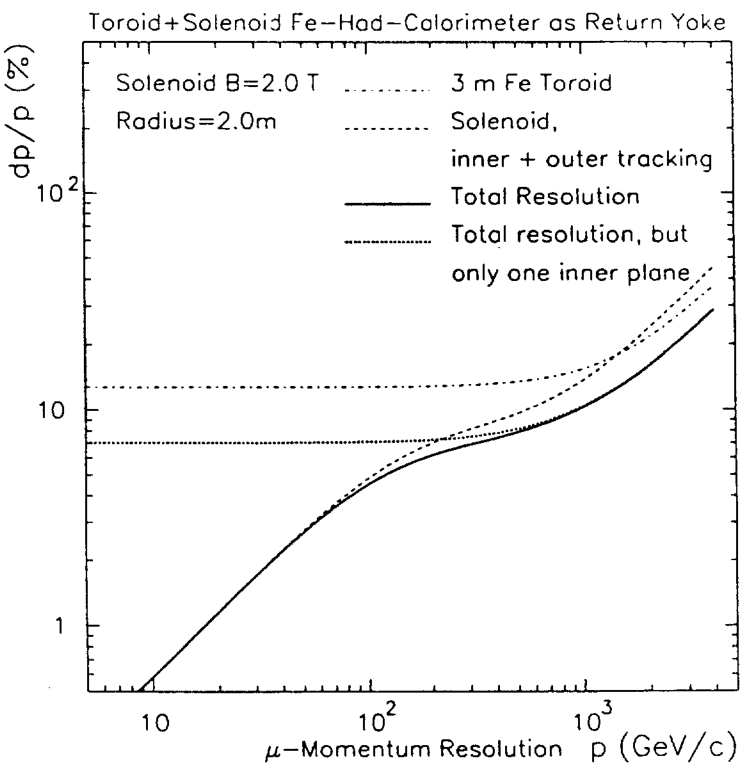

Figure 5: Analytically calculated estimate of the muon momentum resolution at 90^o for a angular resolution of 100 μrad

further details and the explicit formulas see Ref. [2]).

- The central solenoid is located behind the electromagnetic calorimeter.
- The solenoidal field is 2.0 tesla.
- The flux return is inside a pure iron hadron calorimeter of 10Λ.
- The Fe-toroid is 3 m thick.
- The angular resolution is 100 μrad before and after the toroid for the bending angle. This is equivalent to 80 μ position resolution in two pairs of chamber planes, separated by 80 cm.
- In the transverse plane the muon chambers have a resolution of about 0.5 mrad corresponding to 300 μ.
- The inner tracking achieves a resolution of 20, 50 and 75 micron for the vertex, the middle plane and the last plane before the calorimeters, respectively.

In Fig. 6 a cross-section of the detector model used for this calculation is shown. It demonstrates the large volume of the toroid relative to the rest of the experiment.

The toroid resolution is multiple scattering limited for momenta up to 1 TeV/c depending on the chamber resolution. Below 200 GeV/c the solenoid gives a far better resolution, provided an good tracking inside the inner cavity can be achieved and the muon can be uniquely identified. Under the assumption, that the inner tracking is not working for the most inner planes, but only for the planes in the front of the electromagnetic calorimeter, a resolution better than the pure toroidal resolution can be obtained. If the coil is located in front of the electromagnetic

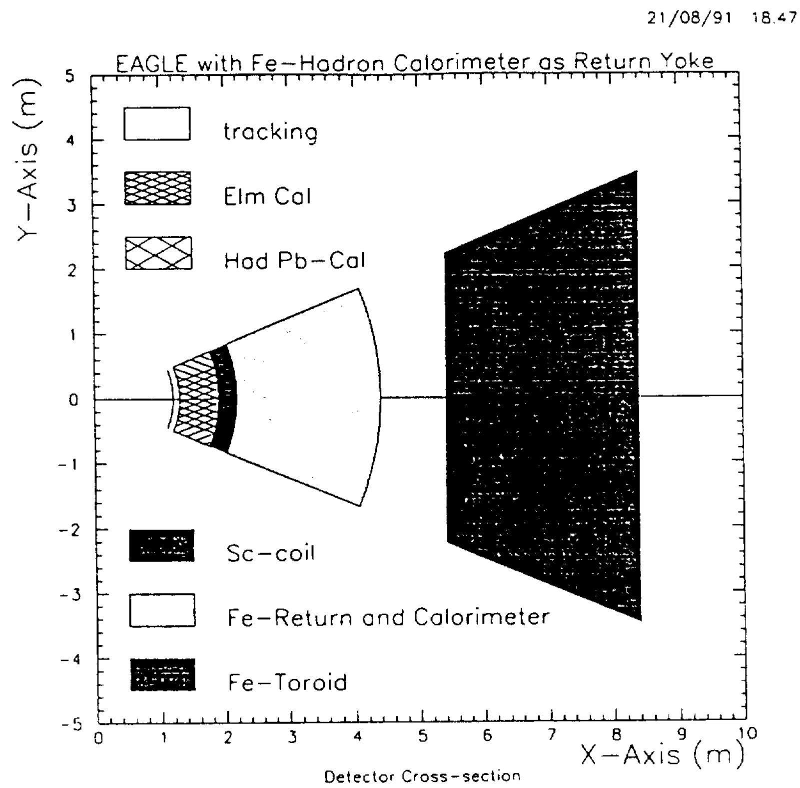

Figure 6: cross-section of the detector model used for the analytical estimate of the muon momentum resolution.

calorimeter this resolution curve quickly deteriorates as it scales with R^2. This is demonstrated in Fig. 7.

In the low momentum region the muon chamber resolution does not enter. It becomes important only at high momenta. The curves are calculated under the assumption, that a 100 and 500μrad angular resolution can be achieved in the chambers in both directions, ϕ and θ, respectively. Assuming that each station consists out of two superlayers separated by about 80 cm on average and assuming further at least two hits in each superlayer we have to achieve a single plane accuracy of 80 μm. A relaxation of this requirement in the θ direction would shift the linear behavior of the resolution proportionally, as we show in Fig. 8.

In the other coordinate the position resolution is less critical as all planes can be averaged. If at least 4 layers are hit before the toroid a chamber resolution of better than 0.3 mm seems to be sufficient. The angular resolution should be better than 0.5 mrad in order not to affect the resolution curves of Fig. 5.

It should be well understood, that this high accuracy of the muon chambers is used only in a very limited momentum range, namely for momenta well above 500 GeV/c! This is the region where we are looking for very rare, non-standard processes. A region of great importance but also at the limit of LHCs discovery potential. At lower momenta and under the assumption that the tracking inside the solenoidal field is working, there would be **no** need for ultra precise muon chambers!

We see that for the barrel region the muon momentum resolution is dominated by the strength of the solenoid and only at very high momenta it is also determined by the toroid. This could lead to the conclusion, that a thinner barrel region would not significantly affect the performance. We show therefore in figure Fig. 9 the resolution for the case of a 2 m thick Fe-toroid.

In fact at high momenta the solenoid resolution scales quadratically whereas the toroid resolution only linearly with its thickness. Much iron can be saved, if the solenoid is dimensioned

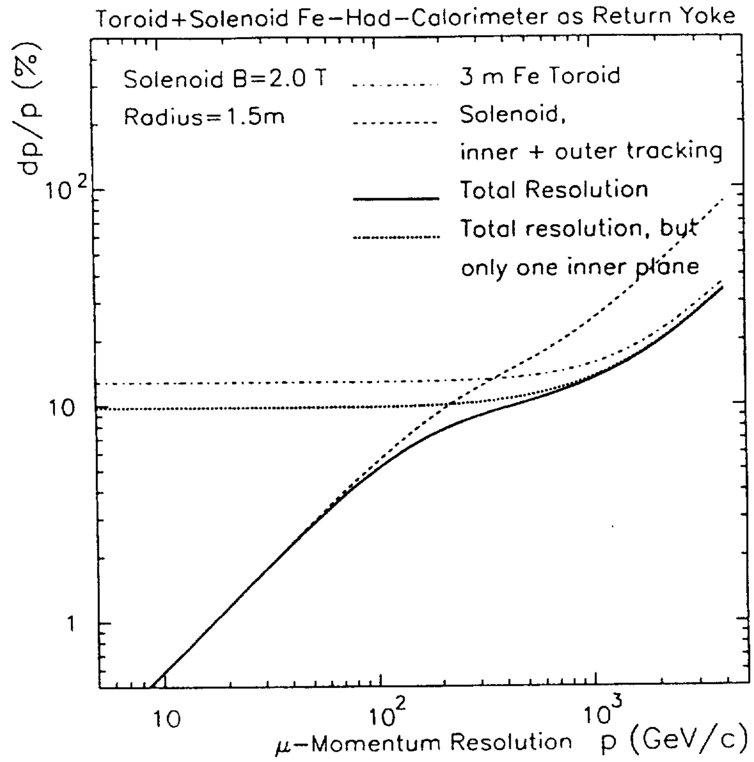

Figure 7: Analytically calculated estimate of the muon momentum resolution at 90°. A small solenoid in front of the electromagnetic calorimeter is assumed in this graph.

properly.

However, the toroid plays an important role in the trigger, so its thickness should not be decreased too far, as has been shown by the studies of the rome group [3].

For the more forward rapidities the muon resolution is basically given by the toroid alone, as the effective contribution of the solenoid will decrease quadratically with the angle for $\eta > 1.8$. In Fig. 10, I show the momentum resolution of a 4 m thick Fe-toroid with 100μrad chambers. A resolution of 11% can be maintained up to momenta of about 1 TeV/c.

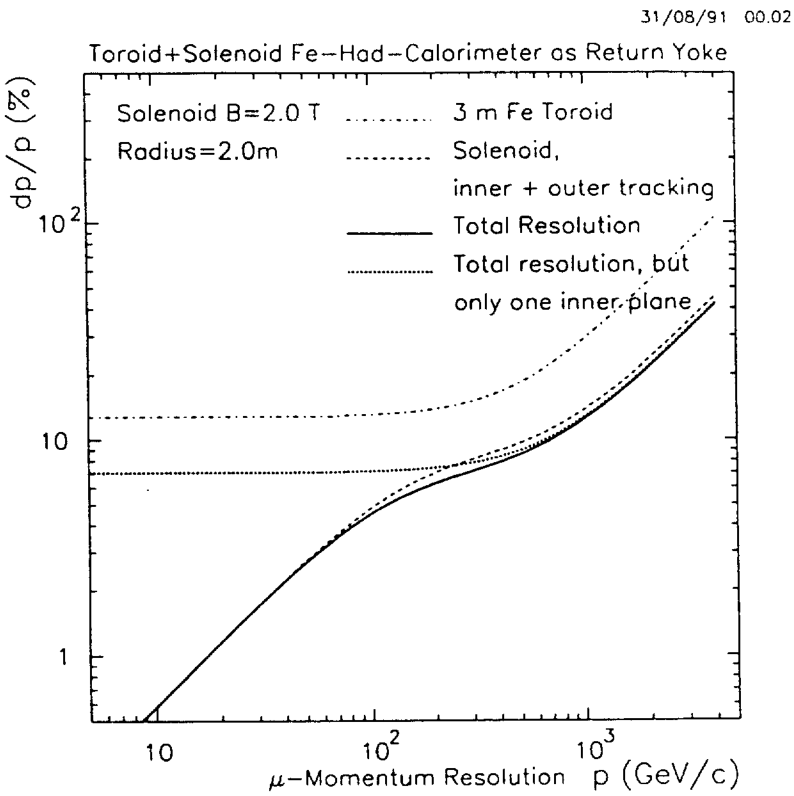

Figure 8: Analytically calculated estimate of the muon momentum resolution at 90°. Like Fig. 5 but for a angular resolution of 300 μrad

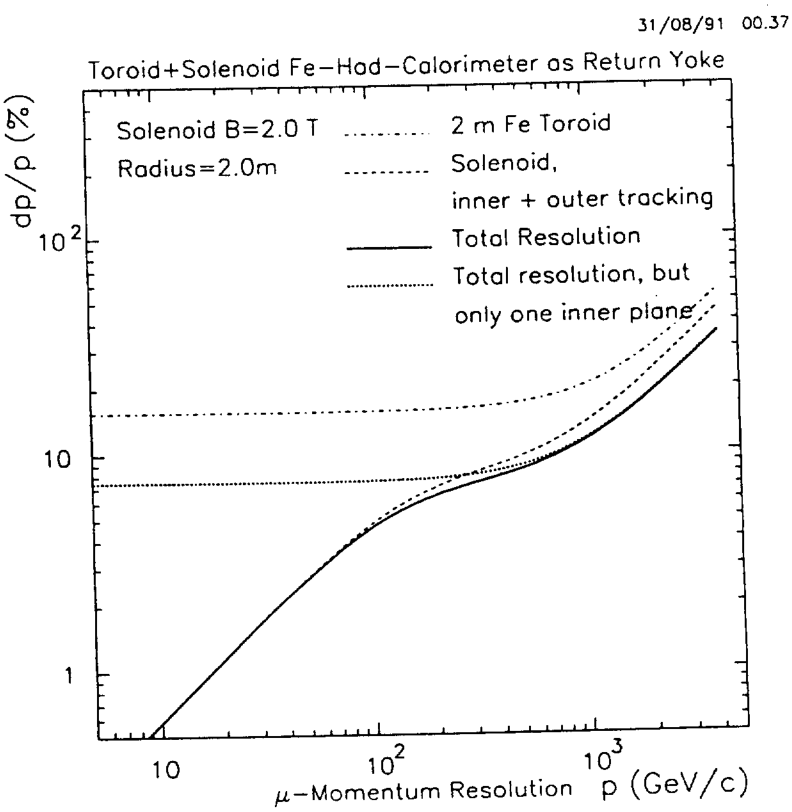

Figure 9: Analytically calculated estimate of the muon momentum resolution for a 2 m thick Toroid. All other parameters unchanged.

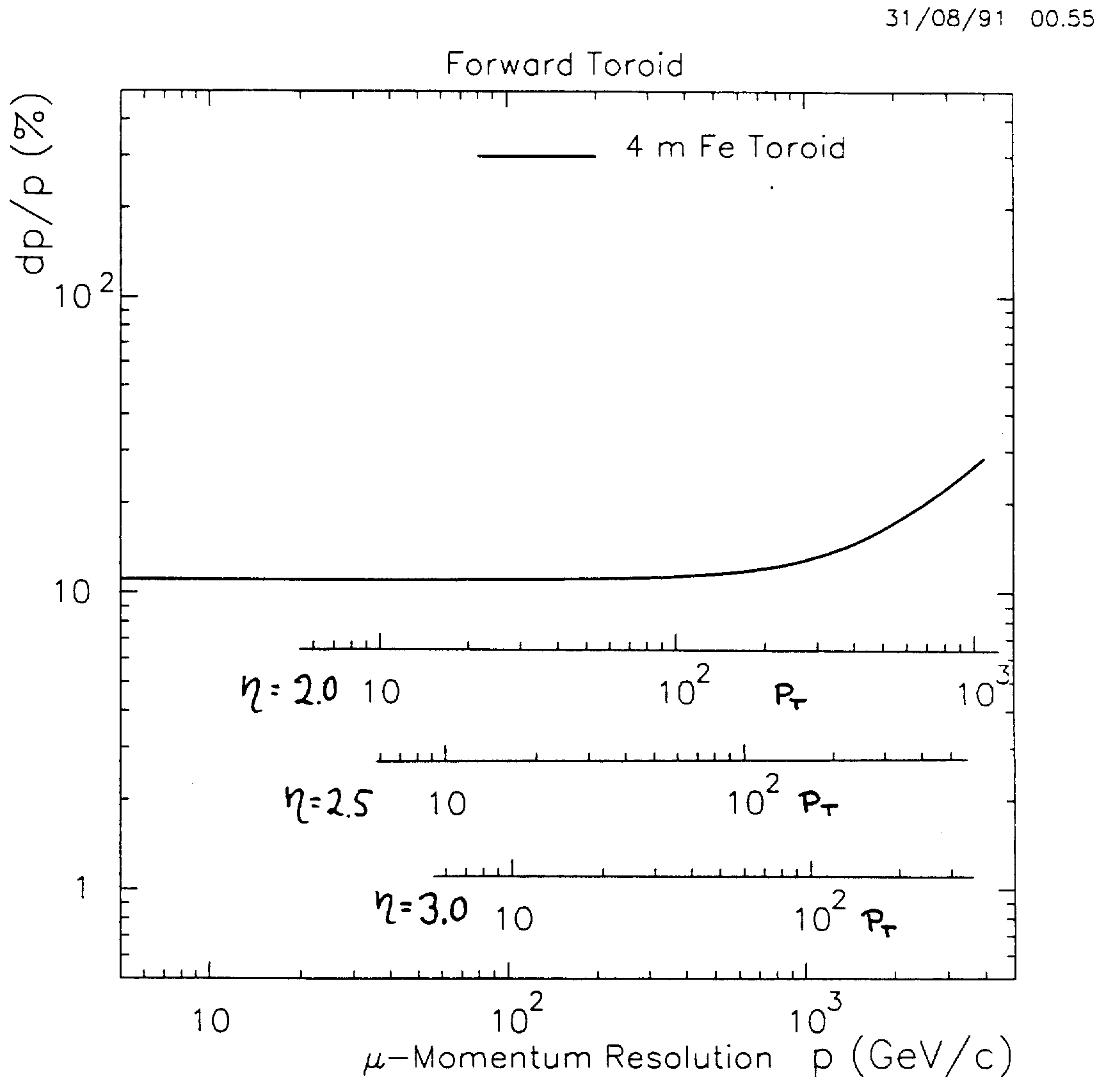

Figure 10: Muon momentum resolution in the forward toroid as a function of the muon momentum. For orientation the corresponding p_T scales for different pseudo rapidities are indicated in the figure.

The Geometry of the Muon Chambers

In Fig. 11 we show the general arrangement of the different muon chamber planes around the

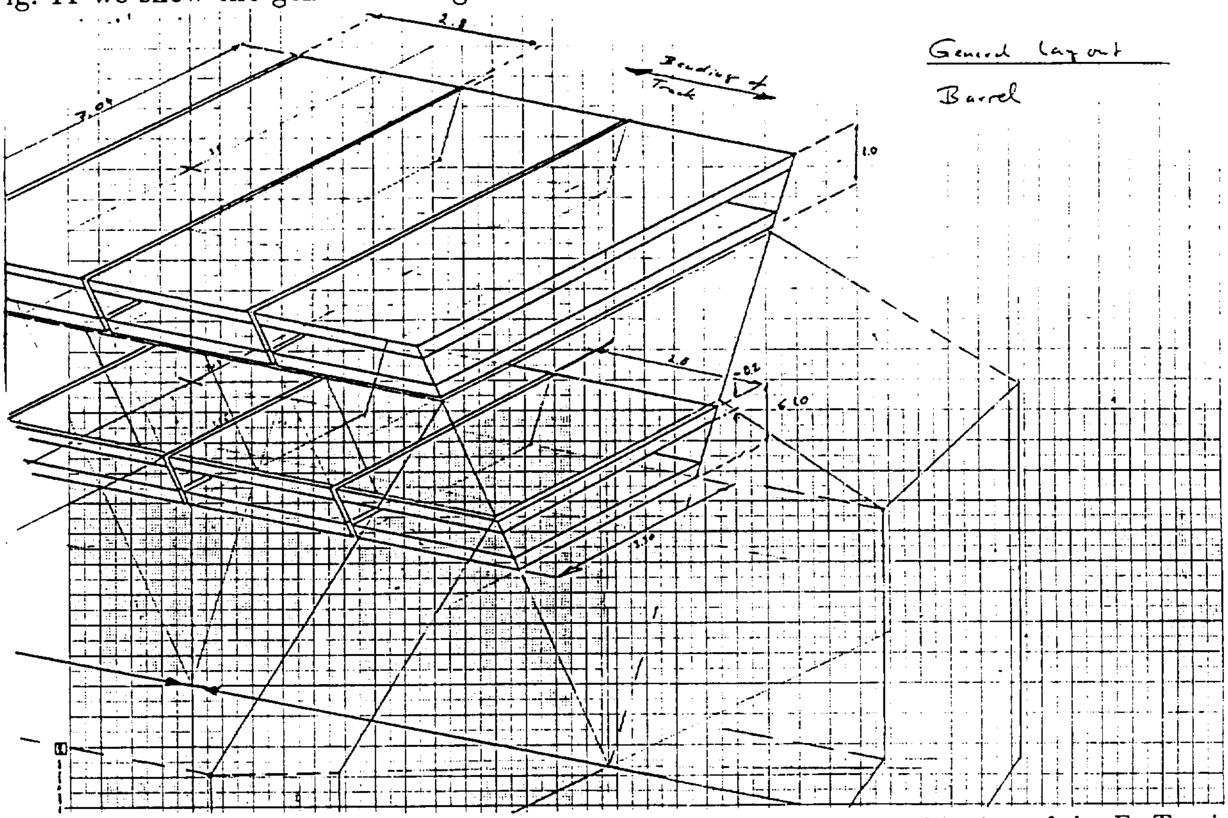

Figure 11: Schematic drawing of the muon chamber positions in the barrel region of the Fe-Toroid.

iron. The total surface of the chambers is about 2580 m^2 per superplane. Two super planes are needed two measure the angle of the muon. Counting at least 4 layers per (super-) plane for redundancy we arrive at a total chamber surface of about 21000 m^2. Care should be taken in the design of the transition region between the barrel and the endcap region. The iron should be continuous with only minor cracks for the coils, cables etc.

Mechanically the main problem is to guarantee the parallelism of the inner and outer planes within a projective geometry. The outer chambers of the barrel should extend to larger z-values than the inner ones and be aligned with them. This might be difficult to do due to access problems.

Fig. 12 presents an arrangement of the muon chambers in azimuth which takes into account small dead zones of the chambers, without affecting the angular coverage.

The mechanical problems to achieve within each octant a planarity and parallelism of better than 100 μrad should be well appreciated. The two muon chamber planes have dimensions of 7×20 m^2 and are separated by 2-3 m of iron. To develop a solution to this challenge is one of the goals of a planned R&D proposal.

Ideally, one would like to establish one large super plane covering all of the surface of 1/8th of the octagon. It has to be investigated if it is possible to maintain the required high stability over this large area. Due to the laminated construction of the Fe-toroid, some mechanical or optical "links" between the inner and the outer modules are possible, as long as they are located between the 2 m thick slices of the toroid construction.

At least two strategies are possible to pursue and are presently investigated.

One approach is to establish the inner and outer planes mechanically separately and to control the stability of their planarity to the required accuracy of 100 μrad. In this case a few

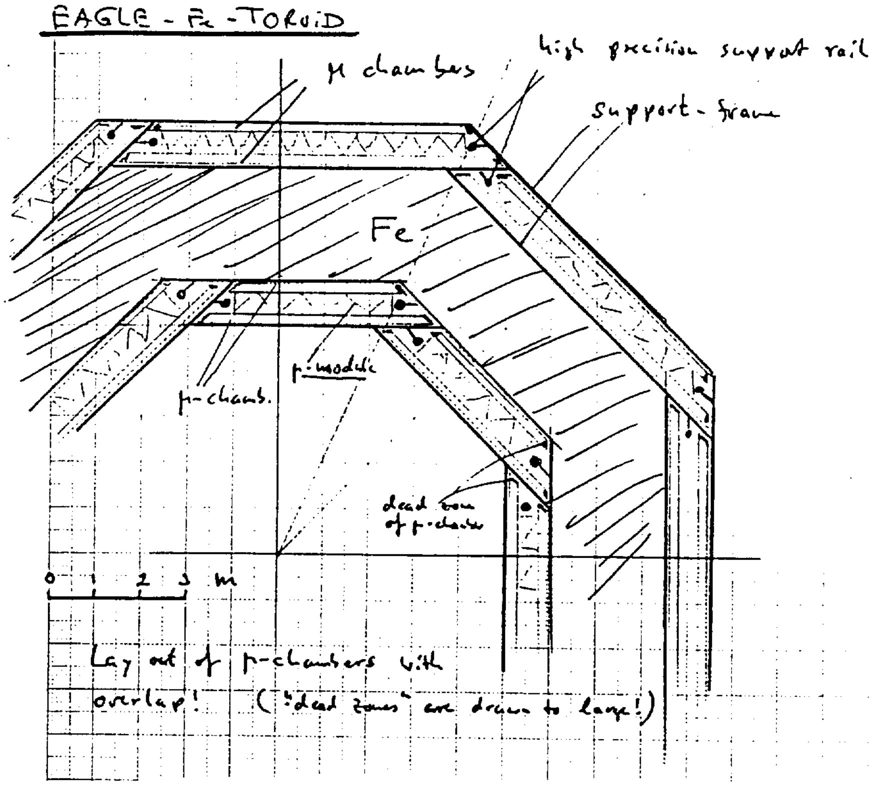

Figure 12: Schematic arrangement of the muon chambers within the barrel octagon of the Fe toroid in which the effect of dead zones in the chambers is minimized. .

measurements of the distance between the inner and outer planes would be sufficient to know their relative orientation. Very long "rails" and reliable supports would have to be developed on which the individual muon chamber modules could be mounted (again with the high accuracy required!). Fig. 13 shows a possible mechanic scheme which could satisfy the requirements and is now under study by CERN-engineers.

We also have to remember, that the different parts of the Fe-toroid move relative to each other by up to a few mm, the precision of the iron sheets, due to the magnetic forces and the settling time of these heavy objects.

The second method is to establish mechanical unities which are sufficiently stable and which connect and support the inner and outer planes. Such connections could be established along the lateral lamination of the iron. However, diagonal reinforcements I find very difficult to implement. One difficulty in this approach is, that the grouping of the front and back planes should be done obeying a projective geometry towards the vertex, which does not coincide with the way the Fe is laminated.

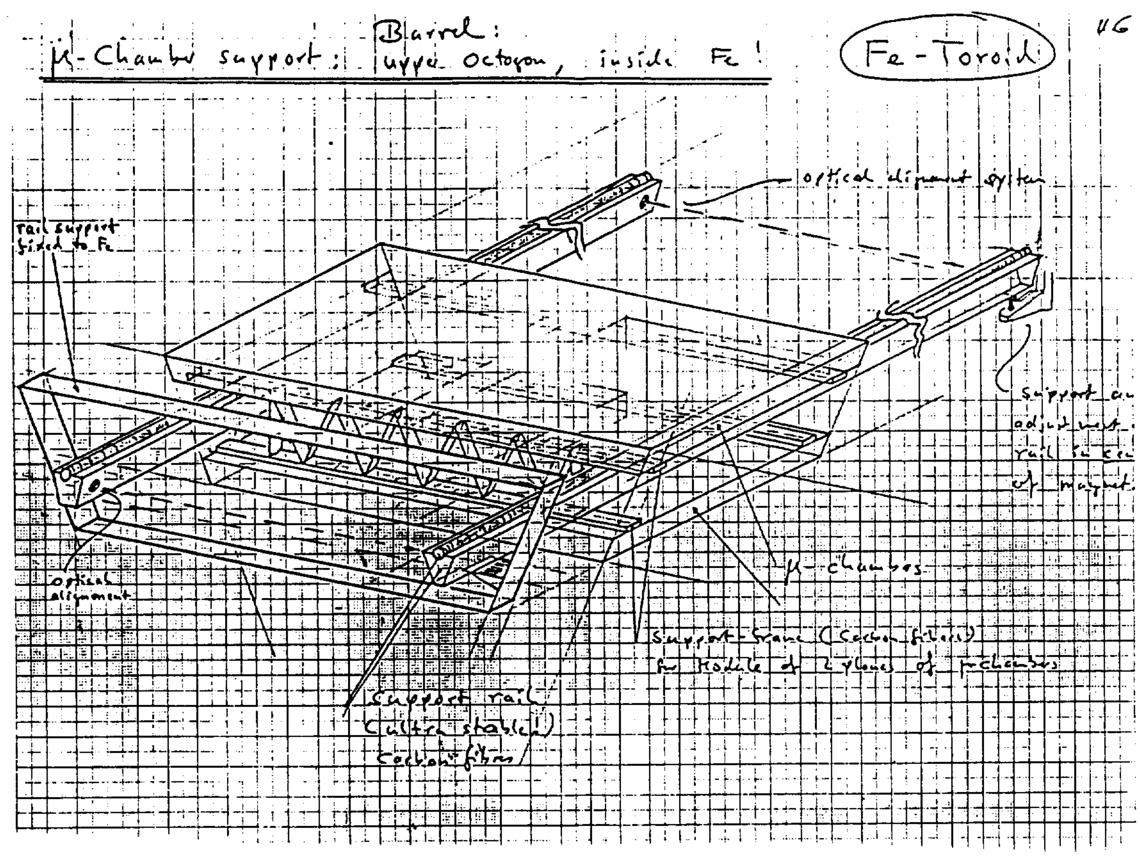

Figure 13: A possible scenario of how to support the muon chamber modules on rails to establish a "perfect" plane.

The Muon Chamber Development

This section will briefly summarize the present status on our work concerning the muon tracking chambers.

Rates and Occupancy

As we saw, the total surface of the chambers is very large. However, the occupancies on the chambers are low, so that it is possible to use projective chamber geometries. The average charged particle rates in the chambers are dominated by hadronic punch-through and primary decays of pions and kaons inside the inner cavity before the calorimeters. As an illustration, Fig. 14a,b of Ref. [4] show the charged particle occupancies behind a pure 10 Λ Fe-absorber of a cylindrical shape closed with 16 Λ thick endcaps. The rates are plotted as a function of

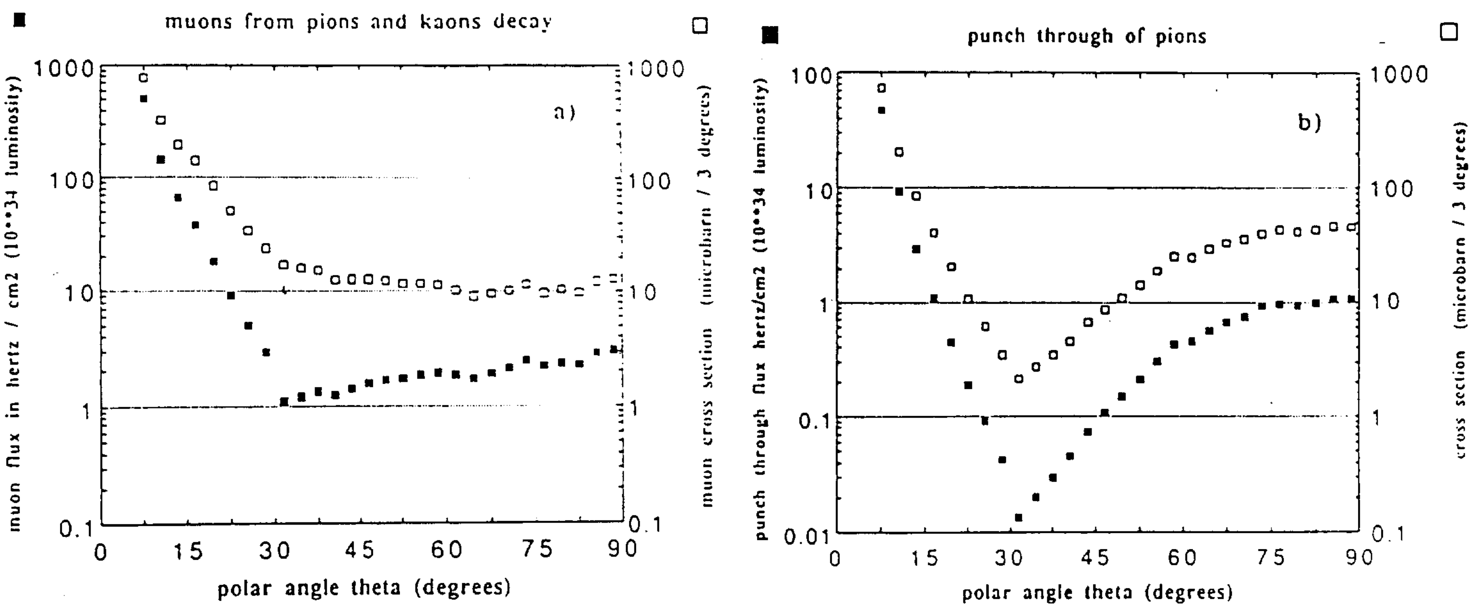

Figure 14: Expected rates from a) $\pi-$K decays and b) hadron punch through as a function of the polar angle. Open squares: cross-sections in microbarns/3°, right scale; full squares: rates in Hz/cm^2 at 10^{34}m cm^{-2}s^{-1} luminosity, left scale.

the polar angle θ: at central rapidities ($\theta = 90^o$) we observe a rate of about a few Hz per cm^2 dominated by π and K decays within the inner cavity of 1.5 m radius. The rate varies only slowly over the "barrel" region, but from 30° onwards it increases rapidly up to 1000 Hz/cm^2 at very forward angles. These values are still small compared to the observed occupancies in the inner tracking devices.

Although these numbers may serve as a guide line, more accurate numbers have to be calculated for our geometry and calorimeter options.

However, it is not sufficient to look just at the average rates in the detector. At LHC we are dealing with muons of very high energy: In Fe, at momenta above 200 GeV/c half of the energy-loss of the muon is caused by electromagnetic showers induced mainly by pair-creation and bremsstrahlung (see Fig. 15a from Ref. [5]). This leads to additional charged particles

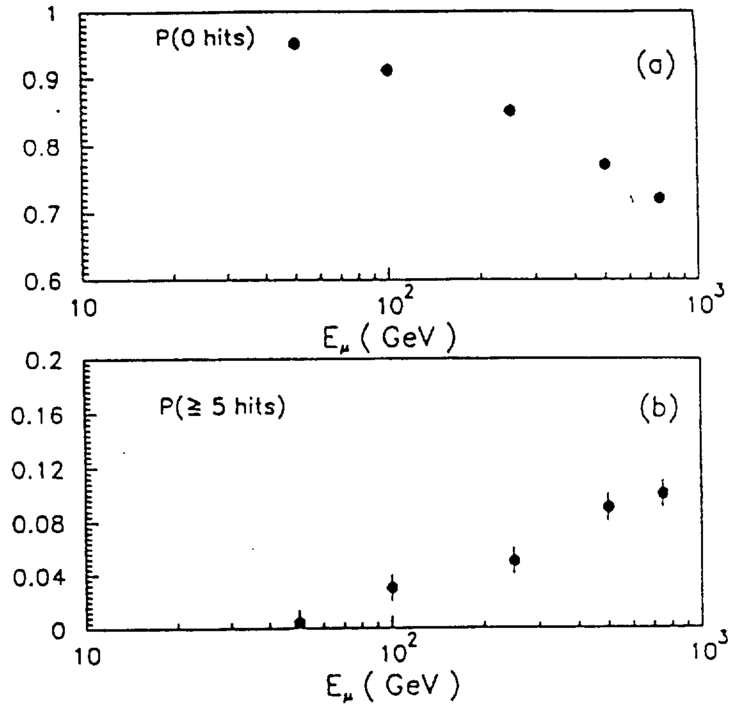

Figure 15: Probability of a clean hit in a detector after 2m of iron; (a) as a function of E_μ. The Probability of detecting more than 4 hits is plotted in (b).

accompanying the muon when it leaves the absorber, as shown in Fig. 15b. As a consequence a reasonable redundancy and multi-hit capability of the muon tracking chamber is mandatory. It should be investigated, if the use of a low Z material in the end of the absorber or the iron could significantly reduce the problem. The R&D proposal RD-5 will investigate this subject and should provide some guidelines for the required redundancy.

Timing and Speed of the Chambers

A problem remaining still open to me is the question of the required speed of the chamber. The most important aspect is the first level trigger: usually it is assumed, that this trigger level has to be ready after 1-2 μsec. This means that the device which provides this information has to have time constants considerable shorter than this value. If the trigger is provided by the tracking chamber itself, shaping and/or drift times should not exceed 100-200 nsec. Otherwise, if a separate system is used for the trigger, like for example RPCs, the maximum collection time is defined by the length of the electronic pipeline.

A different question is the assignment of a given muon track to the exact bunch crossing. It is generally accepted that it is impossible, to distinguish between different events, which occur within the same bunch crossing at high luminosity. It is argued, that the pile-up of minimum bias events will affect the interesting high p_T events only very little. Can this argument be used to average over a few bunch-crossings?? In the case of a drift-chamber, the required final timing resolution will also almost automatically allow the correct assignment to the bunch crossing. It has been suggested to derive the assignment by track segment reconstruction. This needs a generous redundancy of staggered drift cells in order to achieve the necessary timing resolution. An independent fast device might simplify the operation and on-line reconstruction. Again RPCs have been suggested for this purpose [6, 7].

Drift Time Measurement or Cathode-Strip Read-out?

Both methods have their advantages, which have to be studied and weighted against their drawbacks in a given detector lay-out. Cathode strip read-out offers a robust method to determine the position of the track: all mechanical precision is put into the design and manufacturing of the cathode planes only. The precision is not much affected by the exact knowledge of the wires and the gas parameters. A careful job has to be done in the design of the electronic chain.

The main limitation arises from the great sensitivity to the inclination of the incident track: Fig. 16 gives for a strip chamber [8] the dependence of the position resolution as a function of the

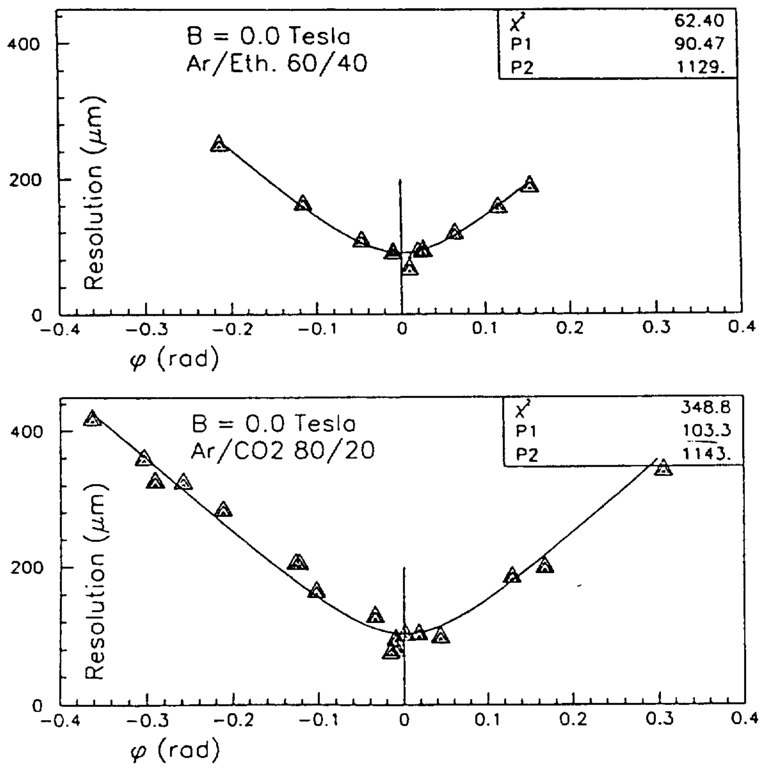

Figure 16: The angular dependence of the resolution in a proportional chamber with cathode strip read-out for the case of the "Honey-comb-chamber".

incident angle: already for relative small angles of 150 mrad (8.6°) the resolution deteriorates by a factor 2!

Drift chambers also have a dependence of the resolution on the direction of the track, if the primary ionization clusters are not distributed along isochronous lines. In carefully designed and oriented drift cells this effect can be minimized. Using high gains and low noise electronics sensitive to the first arriving electrons is another method to circumvent this problem. The latter is essential when drift-tubes are used, which are have a cylindrical symmetry but are extremely non-isochronous.

Nevertheless, both for drift-tubes and isochronous drift-cells superb resolutions have been obtained in small chambers, as demonstrated in Fig. 17a,b taken from Ref. [9, 10]. As already pointed out above, redundancy and a good two track resolution might be an important issue: In this respect narrow drift cells like in ref. [9], in which the positive charge of the ions is removed fast are more advantageous than drift tubes of a radius corresponding to the same total drift time.

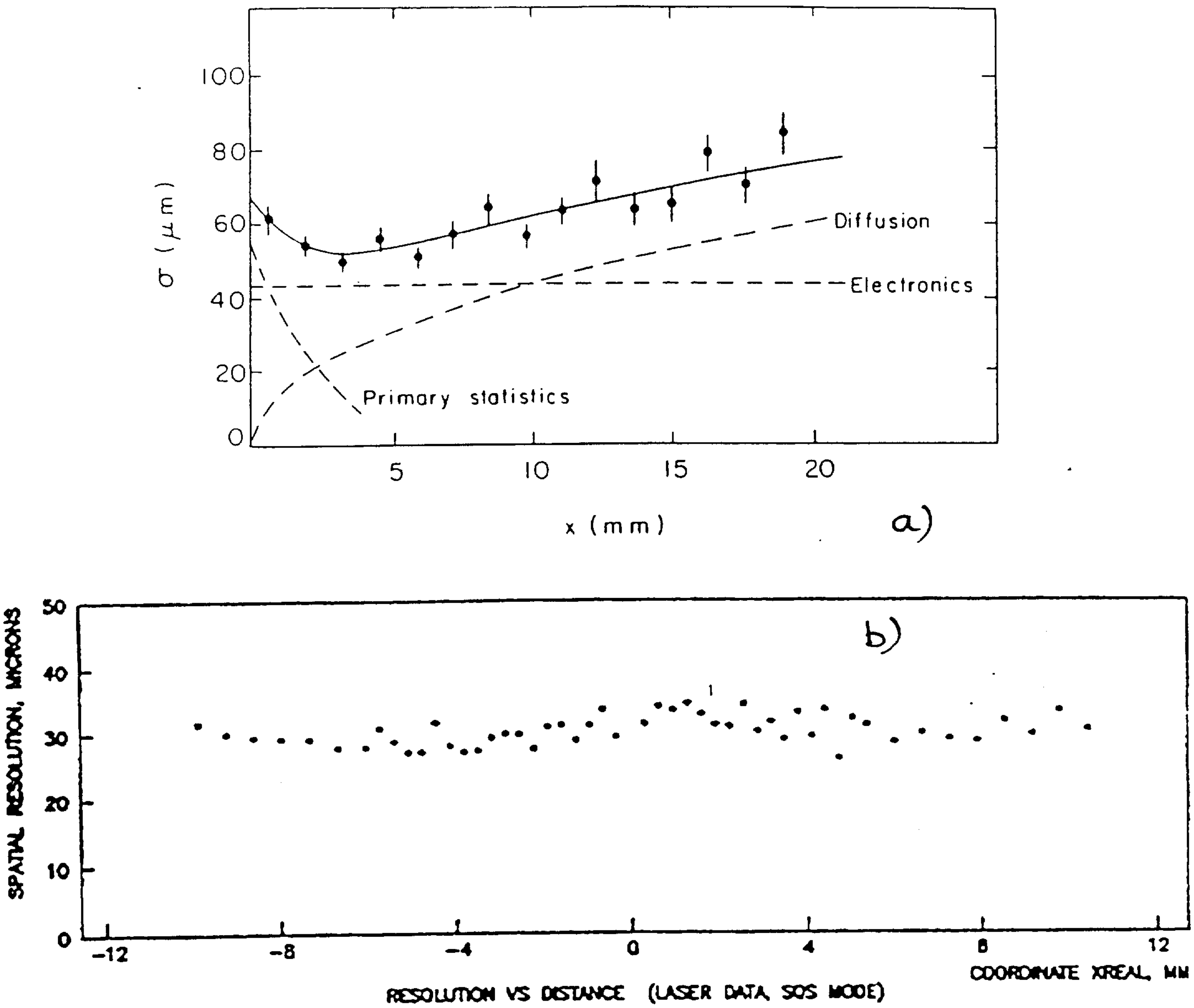

Figure 17: Position resolution achieved in a isochronous drift cell (a) [9] and in a set-up of rectangular drift tubes (b) [10].

The Choice of the Chamber Technique

The choice of the chambers is determined by the desire of a high accuracy to cover the high momentum range of muons with an appropriate momentum resolution. As it is obvious from the geometry of the chamber planes for an iron toroid, large angles up to 1 radian between the plane of the chamber and the muon track have to be encountered for. As a consequence we cannot use cathode strip read-out chambers to measure the bending direction of the muons. However, it seems not to be excluded to consider this technique for the orthogonal coordinate, where the angles are less than 0.4 rad and the required precision is smaller.

This leaves for the precise track coordinate determination basically the method of drift time measurement. This technique is also of course sensitive to the direction of the incoming track, as discussed above, but suitable geometries can be developed. We are looking in the technique of drift tubes, maybe pressurized, as well as in a design with isochronous drift cells.

For the barrel part, the wires will run perpendicular to the beam axis along the octagon surface. For the inner chamber it is probably possible to use one wire to span the complete length of the chamber. However for the outer modules, which are nearly twice as long, spacers or the division into two or more chambers has to be discussed.

The rate on the wires does not lead to any limitation in the layout.: for the barrel region the rates on a single wire assuming a drift distance of ± 1 cm are in the order of 7 kHz per wire increasing to about 100 kHz in the most forward parts of the endcaps.

The Muon Trigger

L. Nisati et al. [3] have shown on several occasions that an appropriate trigger based on the Fe-toroid can be constructed with trigger elements (strips) of the size of 3 cm. In their study RPC chambers were assumed as they provide a very fast signal.

The algorithm is illustrated in Fig. 18 for the case of three trigger planes, before, inside and

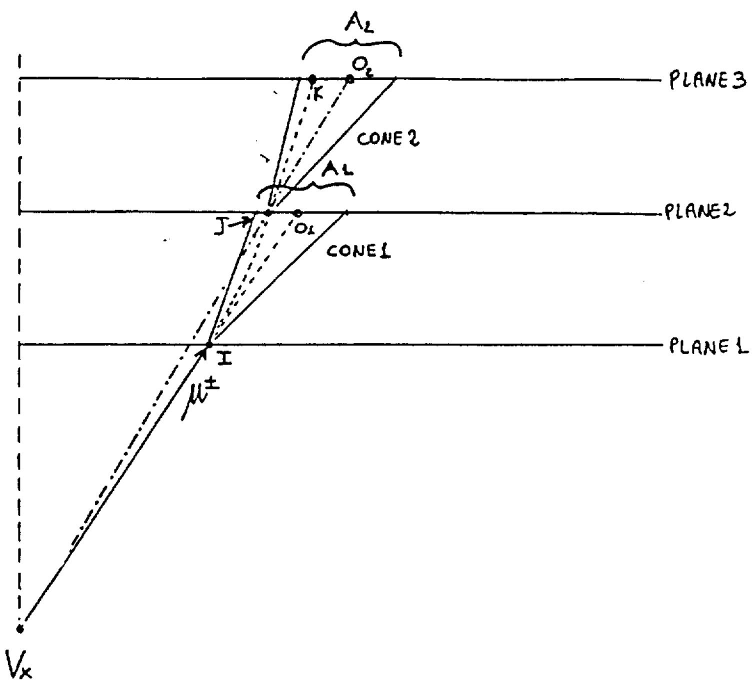

Figure 18: Trigger algorithm using three planes of 3 cm wide strips

after the iron of the Toroid. However, also a scheme with no plane inside the iron, relaying on two stations behind the iron instead, was investigated. This would be the case for the barrel region of the layout presented in this note. The resulting trigger threshold curve is reproduced in Fig. 19 for a threshold value (95%) of 20 GeV/c. A total dimuon trigger rate of 25 Hz ($\mathcal{L} = 10^{34}\text{cm}^{-2}\text{s}^{-1}$) within $|\eta| \leq 2.0$ was estimated to be compared to 14 Hz for a infinite sharp threshold.

A scheme for a system of trigger processors has been presented which could carry out this algorithm and synchronize it to the bunch crossing. A first test of a muon trigger system based on RPCs will be carried out within the WA92 experiment.

If a unique assignment of track segments or tracking elements to the bunch crossing is obtainable already locally close to the detector and sufficiently fast, a trigger could be formed as well by the tracking device itself, for example a hit in a drift tube or cell. (Compare also the discussion and questions concerning timing in the previous sections). Clearly, this is an area were a lot more work is needed to clarify the border line between tracking and trigger.

The effect of punch through on the muon trigger rate was looked at [11] with the goal to determine the minimal calorimeter thickness needed before the first muon station. The authors concluded that a thickness of 12 absorption lengths would result in an unambiguous muon reconstruction. The increased punch through probability in a much shorter calorimeter (7 Λ) would lead to a contribution to the muon trigger rate due to accidental coincidences at the trigger level. This rate was estimated to be approximately comparable to muons from $b\bar{b}$

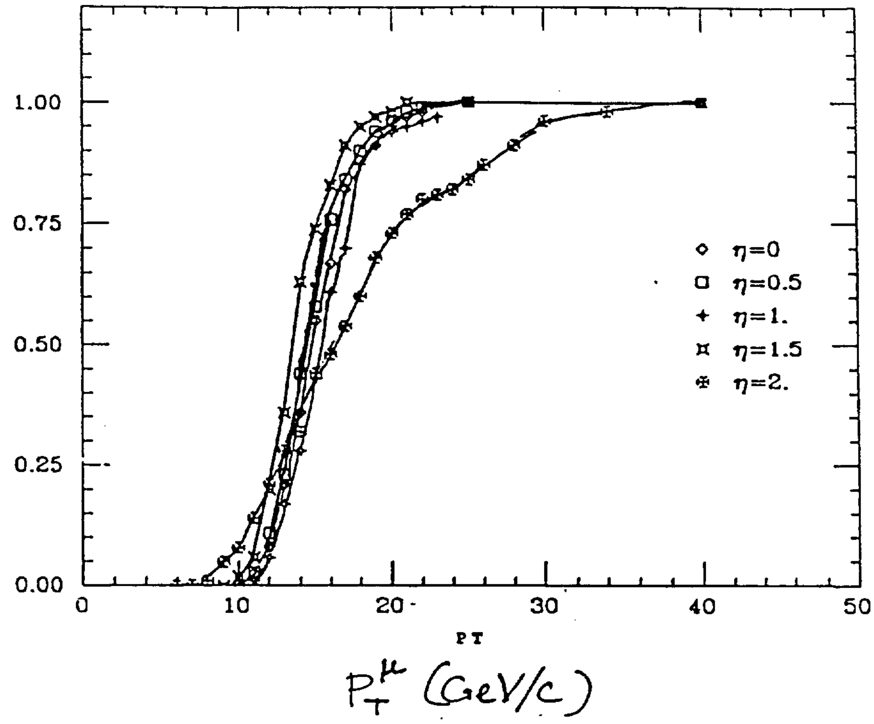

Figure 19: Trigger threshold curve for a 20 GeV/c cut using an algorithm with two planes after the iron of the toroid.

decays. It was argued that the knowledge of the muon momentum would help to resolve that problem.

Conclusions and Open Questions

Several important conclusions can be drawn from the information and arguments presented in this paper:

- The thickness of the barrel toroid can be negotiated against the strength of the central superconducting solenoid.
- The best resolution is obtained with a solenoid of 2 T, the radius of the coil at least 2 m, which means it should be placed between the electromagnetic and the hadronic calorimeter.
- The magnetic flux should be returned in a magnetic Fe-hadron calorimeter. About 50% of the calorimeter cross section has to be Fe to do so.
- The resolution of the muon chambers is important only at high muon momenta above 500 GeV/c.
- To obtain a competitive resolution at 1 TeV/c an angular resolution of the muon chambers of better than 100 μrad is required. This corresponds to about 80 μ position resolution in the bending plane of the toroid.
- The resolution in the other, transverse plane is less critical, it should be better than 0.5 mrad.
- A drift time measurement is the best candidate for a muon chamber due to the geometry of the toroid.
- The efforts on chamber R&D have to be concentrated on large systems: Maintaining a good resolution over a very large area, aligning the chambers and controlling the position and planarity over many square meters.
- The use of a cryogenic electromagnetic calorimeter would offer the attractive possibility to integrate the solenoid coil and the electromagnetic calorimeter into one compact unit, thus minimizing the effect of the coil on the calorimeter resolution. [1]

During the last 6 month many questions could be clarified. The summary of conclusions above proves this statement, although there are several questions still unanswered or disputed. In particular I would like to mention the following topics.

- The timing requirements imposed on the muon chambers are still very badly defined.
- The trigger concept has to be an integral part of any muon chamber R&D.
- The different calorimeter options have to be better specified: This concerns not only the global parameters like weights, dimensions, materials (X_o, Λ, Fe or not) but also installation scenarios and likely or possible support structures (compare Fig. 20).
- The concept of an integrated electromagnetic calorimeter with a superconductive solenoid should be investigated in more detail. Important are again questions of access and support, in particular to the inner tracking chambers.
- Tracking, electron and photon identification in the magnetic field.

[1] In this case, no separate preshower should be in front of the cryostat walls!

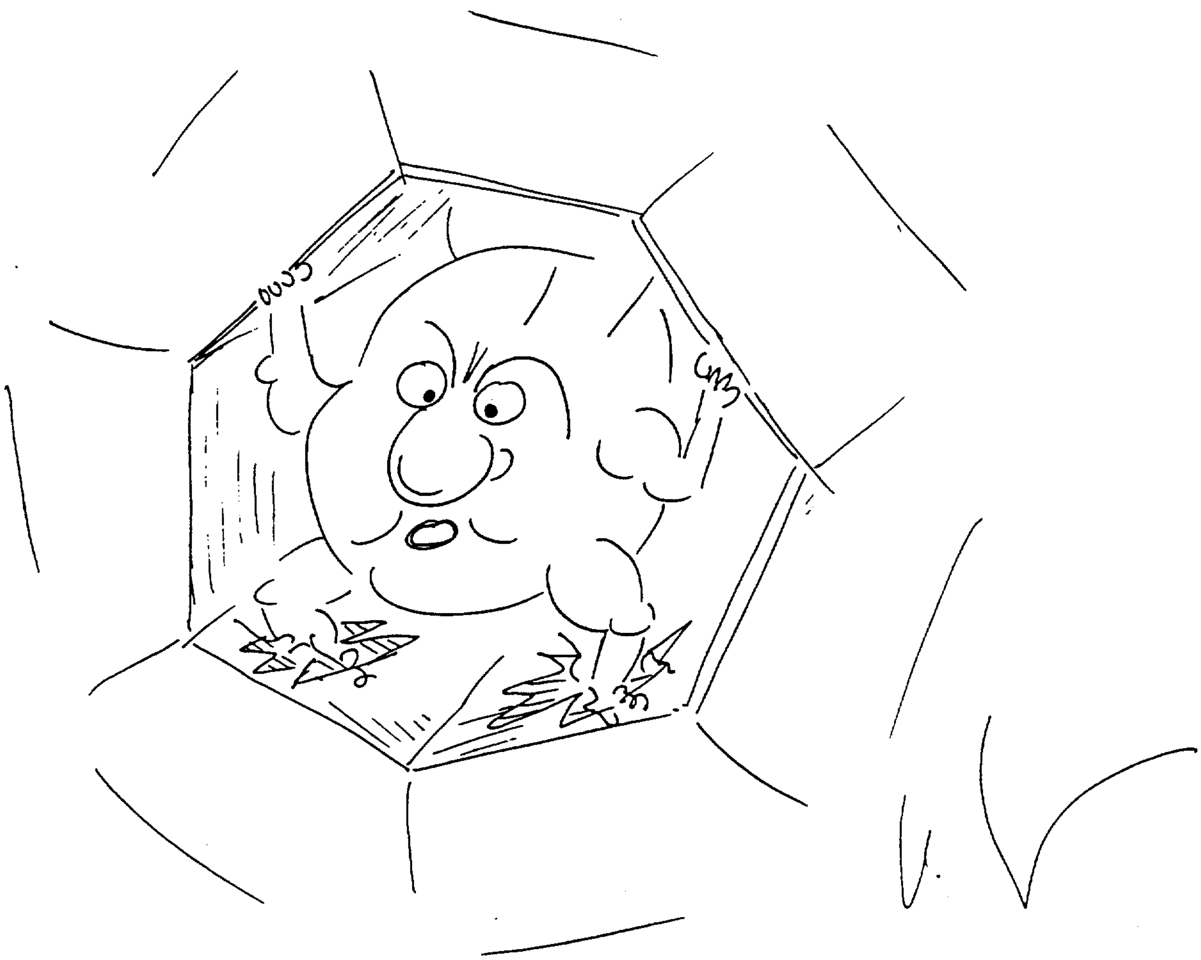

Figure 20: An impossible scenario of a calorimeter support!

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