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6 Agosto 1979

P. Spillantini and T. M. Taylor: A MULTIPURPOSE CENTRAL DETECTOR USING A TOROIDAL MAGNET.

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1.- INTRODUCTION

At the LEP Summer Study(1) and in following LEP notes(2,3) a "Jet Detector" based on a longitudinal solenoid has been extensively studied and its precision investigated as a function of the design parameters(4). It is apparent from the discussion that even if the general features of the event are recorded, the apparatus is primarily conceived as a "leading particle" detector, i.e. an instrument to identify, and to measure the momentum of the leading charged particles of the event, up to the highest momenta.

It is not the purpose of this note to contest the utility of the Jet Detector, nor the undoubted power of the instrument to resolve the momentum of high energy particles, but to describe a complementary system, using a toroidal magnet, which places more emphasis on the detection of the many charged particles which have considerably less momentum than the leading particles. The choice of this complementary detector structure was based upon the following critique of the Jet Detector:

(1) For more than 90% of the detected particles, multiple scattering in the gas and in the chamber material provides the most important contribution of error in momentum resolution(5); the measurement precision of the track detector only concerns those particles having high momentum (less than 10% of the total, i.e. less than one particle per event, on the average). This is clearly shown in Fig. 1b, where momentum resolution is plotted versus a linear abscissa of expected charged particle production, normalized to 1 at 70 GeV/c.

(2) The high precision of the track detector is such that the iron hadron calorimeter, or even a uranium version, does little to improve the momentum resolution of particles having even the highest momentum (see Figs. 1c and 1d).

(3) On average nearly a quarter of all charged particles (i.e. 3 to 4 particles per event (see Fig.2)) curl up in the track detector, possibly blinding some fraction of it. A further 10% of particles curl up between the track detector and the coil, to intereact with the e.-m. calorimeter(4) and send some low energy products back

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[x] CERN, Geneve (Switzerland).

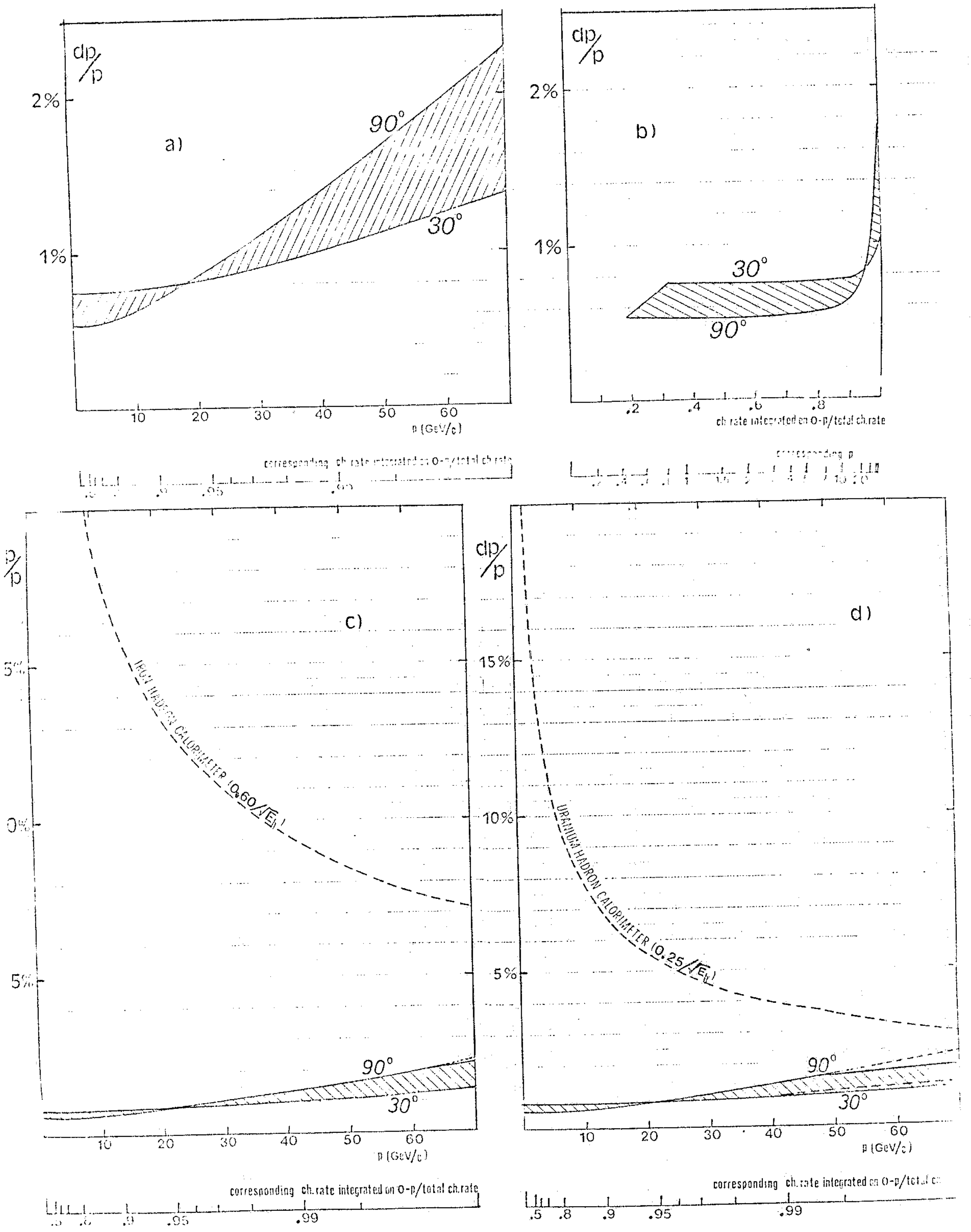


FIG. 1 Momentum resolution of the Solenoidal Jet Detector, making the following assumptions:

- Magnetic field: 1.5 T (uniform)
- Projected track length: 1.7 m
- Sagitta measurement error: ± 0.05 mm (170 points at ± 0.2 mm)
- Gas thickness: 5.2×10^{-2} r.l. (4 atm A + Isobutane).

into the track detector. Ultimately 60% of the charged particles could escape the magnetic field(6), but even then degradation due to interactions in the coil must also be taken into account.

(4) Three-quarters of the charged particles completely traverse the track detector. If we look at the transverse projection, half of these particles exit at an angle of more than 17° to the radial direction(6). In real space, since $p_{\parallel} \neq 0$ in general, the trajectories are even more skew. This complicates the use of the e.-m. calorimeter, and sets serious limits to the granularity and general performance of likely contenders which might replace this system within the coil. Outside the coil the situation is worse.

(5) Some doubt shrouds the feasibility of using high pressure gas in the track detector in order to identify particles by dE/dx measurements(3,7,8). It can be shown that this procedure enables the separation of K's from π's for not more than half of the detected particles, and this at the price of a noticeable deterioration in the momentum resolution of more than two-thirds of the particles(5), not to mention added complication to the track detector.

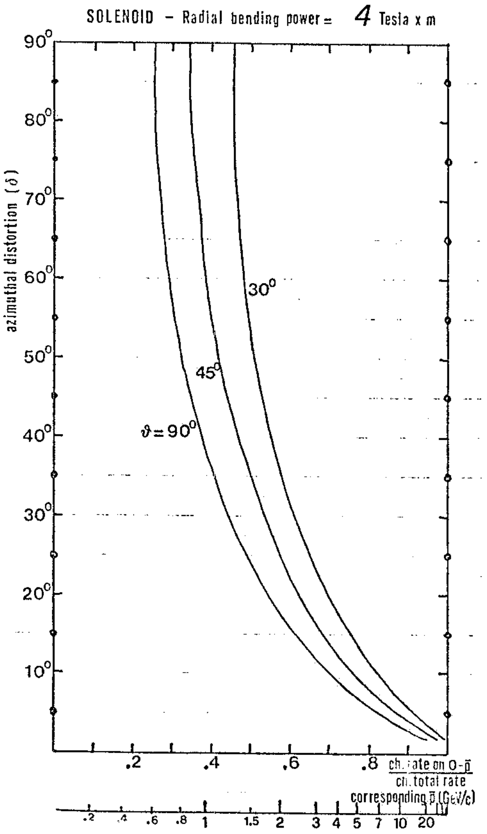


FIG. 2 - The importance of the azimuthal distortion of tracks in the solenoid is clearly seen when this is plotted against expected rate of charged particle production at LEP.

In consideration of the difficulties which may be encountered in getting a complete picture of a complex event, the detector which is described in this note differs fundamentally from the Jet Detector in two ways. Firstly, the measurement of the momentum of the particles having the highest momentum is committed to an optimized hadron calorimeter. And secondly, the magnetic spectrometer provides a relatively weak bending power in order to offer the widest acceptance to the abundant low momentum particle product.

Whereas the technical problem of making a suitable toroidal magnet having a bending power approaching that of the solenoid featured in the Jet Detector may well be insoluble, the feasability of toroid providing a low to medium radial bending power should not be doubted (certainly for a device which does not rely on superconducting technology). In view of the advantages to be gained from using a toroidal field this configuration has been chosen for the detector which will be described in this note. In the following the instrument will be referred to as the "Toroidal Central Detector", as compared to the "Solenoid Jet Detector" discussed at Les Houches.

Following some comments on the "complete" detectionof jets (par. 2), the layout of the Toroidal Central Detector is described (par.3) in terms of the required performane. A possible superconducting toroidal coil is discussed in par. 4, and an attempt is made in par. 5 to evaluate the complexity of the associated track detector. The various efficiencies and figures for the momentum resolution are given in par. 6; the effect of using a simpler (i.e. water-cooled Al) winding for the toroid is discussed in par. 7. Finally, in par. 8, attention is drawn to an important property of a central toroidal magnet regarding γ-detection. The feasibility of the SC toroidal coil is discussed in an appendix.

2.-THE "COMPLETE" DETECTION OF JETS.

The "Leading particle" -orientated nature of the Solenoid Jet Detector was inspired the belief that it is the particles of highest momentum which will carry the most information about the flavour of the primary quark-anti-quark pair created in the $e^+ e^-$ annihilation process.

It may, however, be claimed that for a complete investigation of the phenomena involving the search for associated jets, quantum number correlation, etc., and in particular when a new energy domain is to be explored, the detector should provide the possibility of measuring of momentum, mass and production angle of as many secondaries as possible in order to avoid bias. At LEP the momenta to be measured range from a few hundred MeV/c to some tens of GeV/c. Available devices which can be used to cover large solid angles do not provide comparable relative precision over so wide a momentum band. We note, for example, that the precision attained at high momenta using a large magnet involves the "loss" of many particles carrying low momentum, while hadron calorimeters cannot be expected to provide much useful information in the low momentum region.

3.-THE TOROIDAL CENTRAL DETECTOR: GENERAL LAYOUT.

It is evident that there are some good physics reasons for employing separate detectors for the highest and for the low to medium momentum regions. A natural choice involves the use of an "optimum" hadron calorimeter (present techniques allow $\pm$ 25% $/\sqrt{E_h}$ resolution with uranium) for momentum measurement at high levels, combined with a central magnetic spectrometer designed to measure low to medium momenta (but nevertheless capable of providing a rough measurement (to 10%) at the highest end of the useful range, to complement the calorimeter). The magnet should provide an integrated radial bending power of perhaps 1/4 that of the Solenoidal Jet Detector, to obtain a momenta resolution of better than 10% at p_t = 50 GeV/c$^{(5)}$.

In order to maximize information coverage, sufficient space must be allocated for a good e.-m. calorimeter, in between the magnet spectrometer and the hadron calorimeter. A target specification for this device might be $\Delta E_\gamma / E_\gamma \sim$ a few % in the range $0.5 < E_\gamma < 3$ GeV; an "NaI-like" device is perhaps indicated. However, since only the outlines of the layout are being considered at this moment, no particular hypotheses are made concerning the techniques to be used for the calorimeters, nor on their granularity - which is assumed to be perfect for the purpose of the present study (see note 10 of ref.(5)).

Finally, as the measurement of high momenta is ascribed essentially to a bulky and costly device (a hadron calorimeter built from uranium sheets has to be at least one metre thick), in front of which must be put an e.m. calorimeter which is itself neither small nor inexpensive, there are strong reasons to minimize the external (radial) dimensions of the magnet in order to minimize the volume of the calorimeter. An external radius of about 1.25 m is thought to be a reasonable compromise: this should leave sufficient space to obtain the required bending power, and since the total thickness of the calorimetric system might be of the order of 2 m, to push to reduce the radius still further would not lead to a significant reduction in its volume.

In view of the modest size of the magnetic spectrometer, it is not unreasonable to consider the use of an "equivalent momentum resolution" toroidal structure as a worthwhile alternative to the traditional solenoid. Moreover, such a choice only enhances the complementary nature of the present layout as compared to other proposals. A magnetic field of toroidal geometry does have undoubted appeal$^{(9,10)}$. Particles produced at the interaction move along two-dimensional trajectories on φ = const. planes (see Fig. 3); the φ-pattern of the event is thus conserved, resulting in a considerable simplification of pattern recognition and momentum measurement. Furthermore the field lines are closed on themselves: no flux return path is required and the structure lends itself

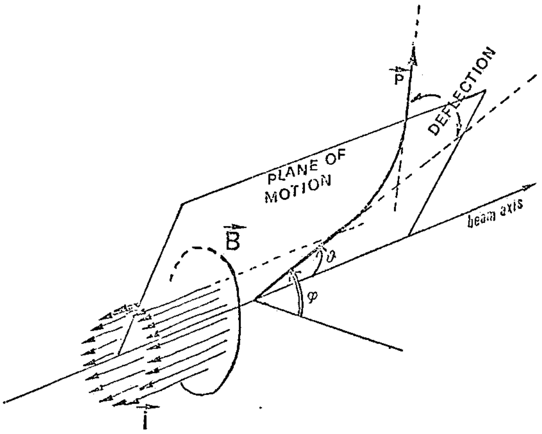


FIG. 3 - The most important feature of the toroidal field: particle trajectories stay in one plane.

nicely to the provision of two large open cones along the beam lines, offering attractive possibilities for $\gamma\gamma$-physics experiments. Another attractive feature of the toroidal magnet is that the volume within the conductor sheet which produced the field is virtually field-free: the electron beams are not perturbed, and even if these conductors are placed at a relatively small radial distance from the axis it is quite feasable to measure the production angles ϑ_{ch} and / φ_{ch} of the charged particles before they enter the magnetic field volume. For a fixed average thickness of the conductors and a given external radius R_{ext} of the toroid, the radial bending power is maximum(11) if the inner radius $R_{int} \cong 1/4\ R_{ext}$. For the case under study we have chosen $R_{int} = 0.30$ m.

The schematic layout shown in Fig. 4 represents an attempt to synthesize an experimental setup based upon the preceding arguments. In this sketch the current return of the toroid is not shown, since its detailed geometry will depend intimately on the choices made for the calorimeter structure.

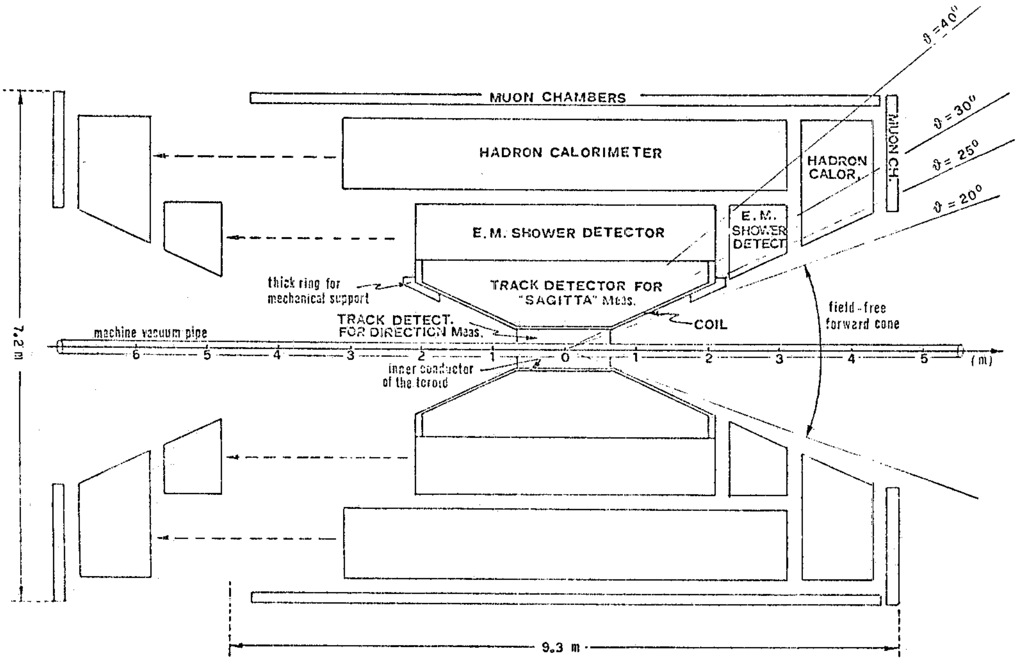


FIG. 4 - Schematic layout of the Toroidal Central Detector.

4. - THE TOROIDAL COIL

For the purposes of discussion it is useful to divide the toroid winding into two distinct parts: (a) the inner conductor which carries the current producing most of the field, and (b) the rest of the coil return which defines the outer dimensions of the field volume (see Fig. 5).

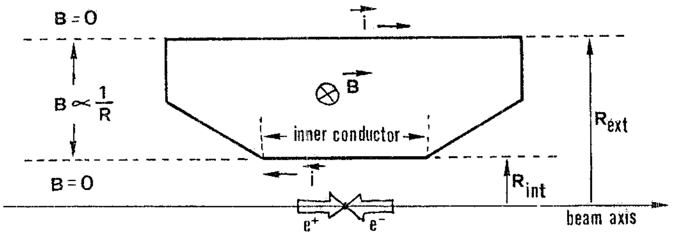
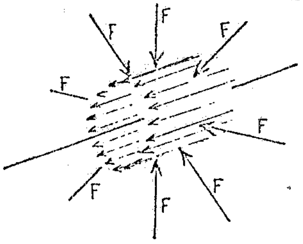


FIG. 5 - Longitudinal cross-section of the toroidal coil.

(a) The inner conductor should preferably be uniformly spread over the inner cylinder of radius R_{int}. In addition to the stress problems associated with the very high fields within lumped inner conductors, the shadows cast by the coils would cover about 30% of the total accceptance$^{(12)}$ making the device unsuitable for the 'complete' coverage desired here. If, on the other hand, the conductor is smoothly distributed over the inner cylinder$^{(10)}$ peak stress in minimized, and the resultant mechanical system can be considered to be analogous to a cylinder supporting external hydrostatic pressure (see Fig. 6).



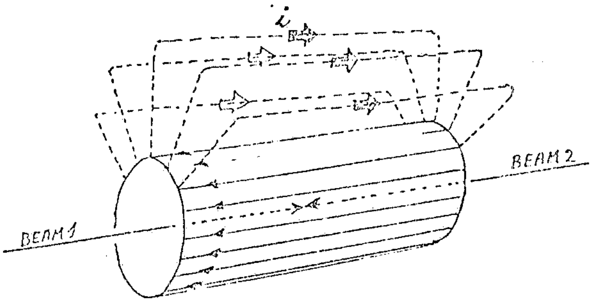


FIG. 6 - The inner cylindrical winding is subject to external magnetic pressure.

It is evident that the inner conductor is the critical part of the coil. It must carry enough current to produce the required bending power, and yet be thin enough to limit the probability of inelastic scattering within its material to perhaps 10% (i.e. an average thickness of $\leq$ 0.5 r.l. of equivalent aluminium). A water-cooled aluminium coil which satisfies these requirements and gives the above-cited bending power would consume in excess of 6 MW. Some attention has therefore been concentrated on a possible superconducting version of this magnet. It should however be stressed that there are a number of identifiable technical problems to be solved regarding the making of a "thin" superconducting toroid, and the ideas presented in this section must be considered as being very preliminary. Before designing an experiment the entire success of which depended on achieving the performance being sought after in the SC toroid, it would be necessary to make a detailed design study, including prototype work. Nevertheless, as we shall see in par. 7, the general setup proposed in this note would still provide very interesting possibilities for physics experiments even if a lower power ($\sim$ 2 MW) water-cooled aluminium coil were to be used, so that the success of a detector embodying these concepts does not hinge on the favorable outcome of a design study for a thin SC magnet.

In order to achieve a total equivalent thickness of the order of 0.5 r.l., it is necessary to push the current density in the conductor to as high a level as possible; the vacuum tank and coil support structure themselves consume a large fraction of the allowance. This excludes the possibility of employing cryostatically stabilized superconductors, as used to date in all successful large superconducting spectrometer magnets, and implies the use of intrinsically stable conductor in a way similar to that presently incorporared in the new generation of 'thin' solenoids (CELLO at PETRA, and TPC at PEP, for example). Prototype work at LBL(13) has given encouraging results for the simple solenoidal geometry. We consider a total current of 4 MA flowing through the inner conductors at radius 0.3 m, to produce a maximum field of 2.66 T at this radius, and giving rise to a pressure of 27 atm on the cylindrical support structure. Summing the contributions of the various components, this would lead to a theoretical equivalent thickness of 0.25 r.l. (see appendix, Fig. A1). In the following we assume a thickness of 0.5 r.l., corrresponding to real values scaled from those achieved in the test coil at LBL. At first sight it appears (Fig. 7) that such a coil would have a clear advantage over a normal aluminium version (but see also par. 7).

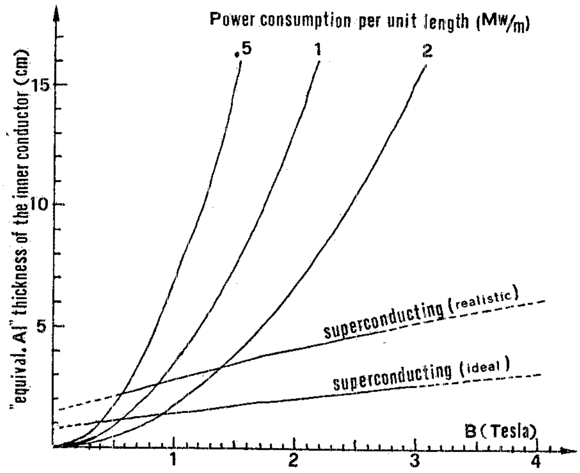


FIG. 7 - For high fields the magnet should be superconducting.

(b) The outer conductor, needed to return the current, can be either lumped or continuous, to be determined partly by cryogenic and mechanical (vacuum tank optimization) considerations, and partly by appraisal of the possible advantages to be gained from using an integrated (cryogenic) e.-m. calorimeter structure.

The toroid sketched in Fig.8 makes good use of the available space and has wide angular coverage. Further discussion on some technical aspects of this coil is given in the appendix.

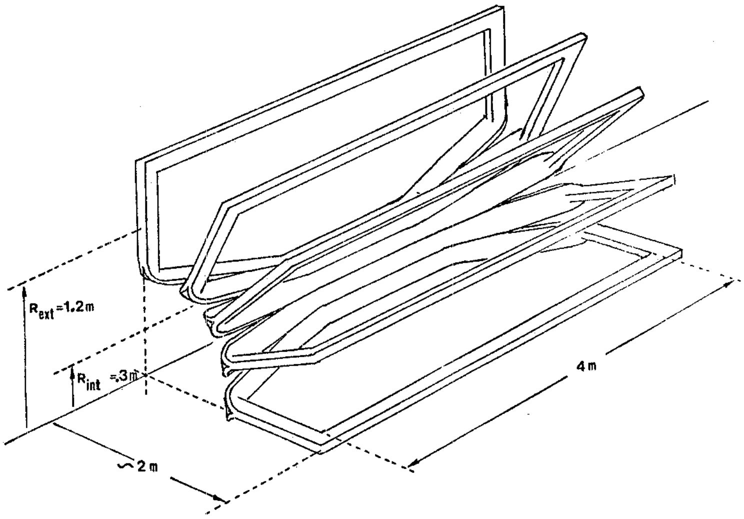


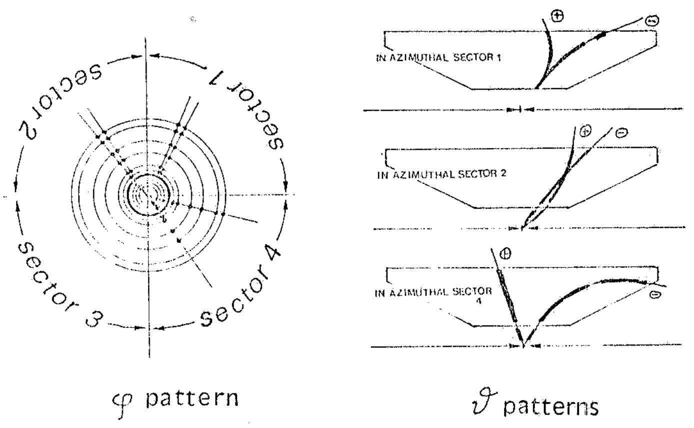
FIG. 8 - Perspective view of the toroidal coil.

5.- THE TRACK DETECTOR

In a toroidal field the measurement device can "factorize" in azimuth (φ) and zenith (ϑ) in a very natural way (see Fig. 9).

The φ-pattern can be recorded by fast detectors (scintillation counters and cylindrical multiwire chambers with their wires parallel to the beams). We might consider, for example,using 8 cylindrical multiwire chambers, having about 12 K wires in total, to obtain $\Delta\varphi \cong 1$ to 2 mrad with ~ 5 mrad resolution in the azimuthal picture: such a system could provide a fast "hardware" preselection of the events.

The momentum measurement could be left to a slower device, able to give good precision and resolution in the longitudinal (z) direction. One might envisage various technical solution based on measurement of drift-time. A straighforward solution would be to use drift chambers with anode wires forming a polygonal approximation to a circle in plane z = constant and centred on the beam line. The dead region at the hooks can be reduced lo less than 1 mm$^{(15)}$, and other mechanical problems become less relevant when one considers a multicell structure using many anode wires per cell (see Fig. 10).



φ pattern

ϑ patterns

FIG. 9 - Factorization of an event in a toroidal field.

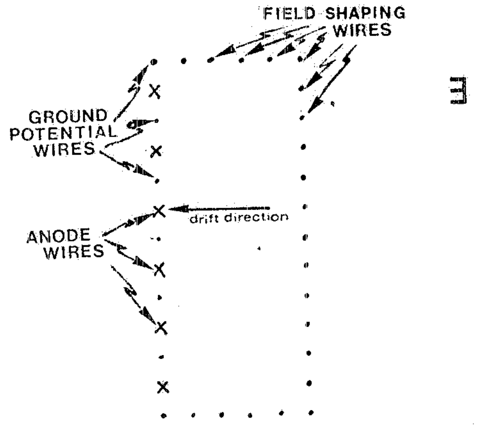


FIG. 10 - Schematic "multicell" wire arrangement.

If we limit the maximum drift space to 5 cm, about 1100 anode wires are necessary for each azimuthal sector in order to record 26 points per track. Assuming the accepted $\sigma = \pm 0.2$ mm resolution, the first 10 points provide us with the ϑ angle of particles in the field-free region inside the inner conductor with a precision of ± 1 mrad and ~ 10 mrad resolution (i.e. only 2 times worse than that obtainable for φ). The other 16 points, measured in three groups of 4, 8 and 4 respectively at the beginning, half way through, and at the end of the path in the useful magnetic field, give a precision of $\sigma_x = \pm 0.1$ mm on the measurement of sagitta$^{(16)}$. In each azimuthal sector it would be necessary to include a certain number of analog read-outs (current division or induced pulse height) to avoid ambiguities.

A more sophisticated device might use (also for ϑ) a wire structure very similar to that normally used for a solenoid, i.e. letting the primary ionization created by the particle drift towards a number of longitudinal anode wires. A rough read-out of drift time is sufficient to match the obtained φ with that given by the multiwire chambers. The estimate of sagitta could be safely committed to the measurement of the centre of gravity of the induced pulse distribution on a row of pads printed on a supporting strip oriented to face some anode wires (see Fig. 11).

This method is in principle very precise, and could improve by a factor of two the resolution at the highest momenta. A very large number of pulse height readouts would however be required. Apparatus of this type, which we shall call the Time Projection Sector (TPS) device, is described in ref. (17).

The main parameters of the two track chamber systems are given in Table I .

Either one of the two devices described could be adapted to permit particle identification by a dE/dx sampling measurement. Adaptation would require some extension to the system and closing it in a pressurized tank. For equal gas pressures the dE/dx resolution is a little worse (3.3 %) than that claimed for the Solenoid Jet Detector (2.5 %). For the polygonal wire device it would be necessary to increase the number of wires by a factor of five, and to read out the pulse height on all of them. For the TPS device several cylindrical chambers (without pad read-out) would have to be added, and another ~ 1 - 2 K anode wires would have to be read proportionally.

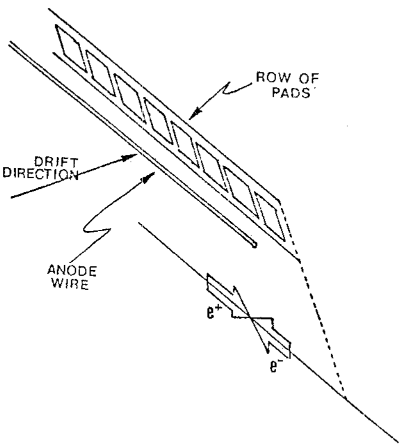


FIG. 11 - Points on the sagitta can be measured by looking at the induced pulse distribution on a row of pads. (See ref. (17)).

6. ON THE MOMENTUM RESOLUTION OF THE TOROIDAL CENTRAL DETECTOR.

Notwithstanding the preceding remarks on dE/dx, we shall, in the following, discuss the performance of a device for which the track detector is operated at atmospheric pressure. Moreover, in order to be independet of the technical solution adopted for the track detector, we simply assume that ϑ and φ are measured with a precision of ± 1 mrad, and the error in the measurement of sagitta is ± 0.1 mm. Chambers and gas are supposed to contribute with 2×10^{-2} radiation lengths to the multiple scattering error on the sagitta measurement. In this manner the results reported in reference (5) can be cited directly.

In the Fig.12 we show how the resolution of the magnetic spectrometer and that of the hadron calorimeter combine to give the overall momentum resolution. In this figure, as in all analogous figures which follow, resolution is plotted both as a function of momentum and of integrated rate. In Fig. 13a the total momentum resolution of the Toroidal Central Detector is compared with that of the Solenoidal Jet Detector. Fig. 13b shows the same comparison if we assume that a $\sigma = 0.1$ mm resolution could be obtained from the track detector (using the Time Projection Sector device for example).

The Toroidal Central Detector starts to look very competitive at all angles, demostrating clearly how efforts to improve track detector performance pay off more than those invested in increasing the strength and volume of the magnet (and indirectly increasing the dimensions and cost of the external calorimeter).

TABLE I

Track detector		Polygonal drift chambers				Time Projection Sectors			
		number of readouts per sector	number of sectors	total no of readouts	type of readout	number of readouts per sector	number of sectors	total no. of readouts	type of readout
between the beams and the inner conductor (θ and ϕ meas.)	ϕ measurement			2.3 K	digital				
	θ measurement	280	4	1.1 K	drift time				
	Ambiguities	100	4	0.4 K	pulse height				
within the magnetic field volume (sagitta meas.)	ϕ measurement			9.9 K	digital	4	48	0.2 K	drift time
	θ measurement	800	4	3.2 K	drift time	2000	24	48 K	pulse height
	Ambiguities	300	4	1.2 K	pulse height	-	-	-	not. neces.
to be added for particle identification		4000	4	16 K	pulse height			1 to 2 K	pulse height

TABLE II

			Charged particles	photons		
				"average"	1st radiator	2nd radiator
track detector	Solid angle covered		91%	91%		
	Total acceptance		80%	81%	(60%)	(21%)
	p_{ch} (E_γ) resolution at the most probable p_{ch} (E_γ) (= 1.5 GeV/c (.8 GeV))	θ = 90°	0.8%	1.2%	(0.6%)	(3%)
		30°	0.1%	0.2%	(0.1%)	(0.6%)
hadron (e.-m.) calorimeter	Solid angle covered		91%	91%		
	E_h (E_γ) resolution		$25\%/\sqrt{E_h}$	$20\%/\sqrt{E_\gamma}$		

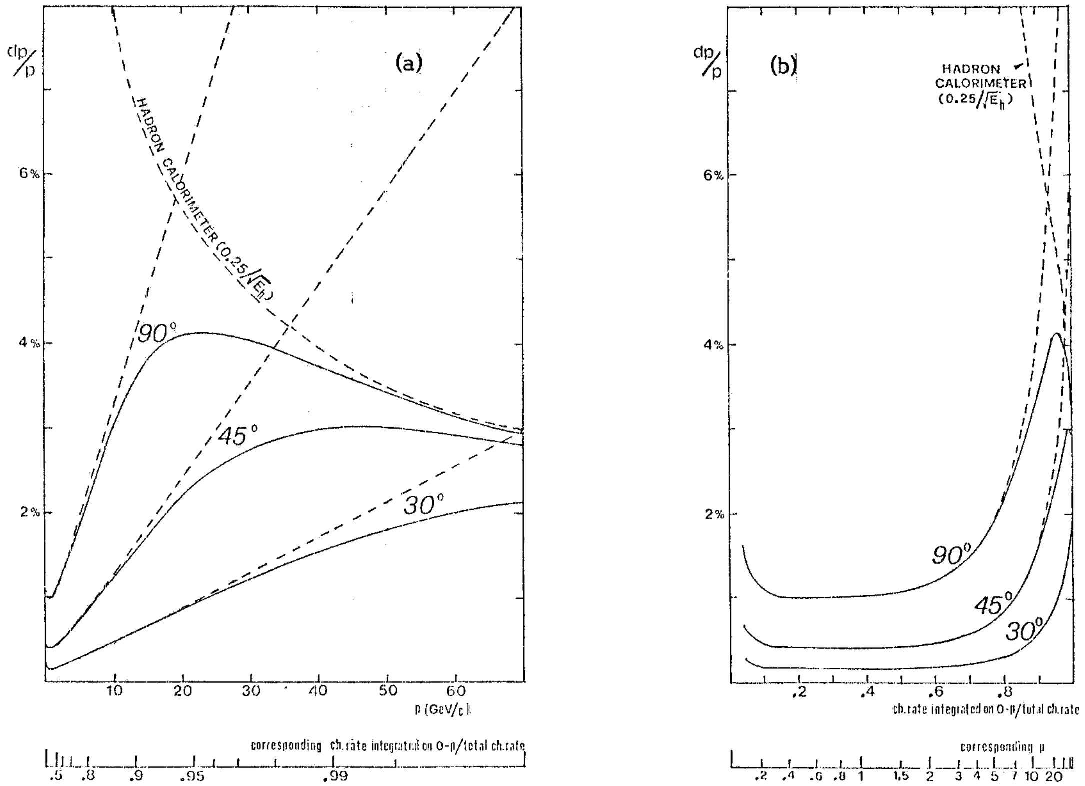


FIG. 12 - Overall momentum resolution of the Toroidal Central Detector together with a calorimeter.

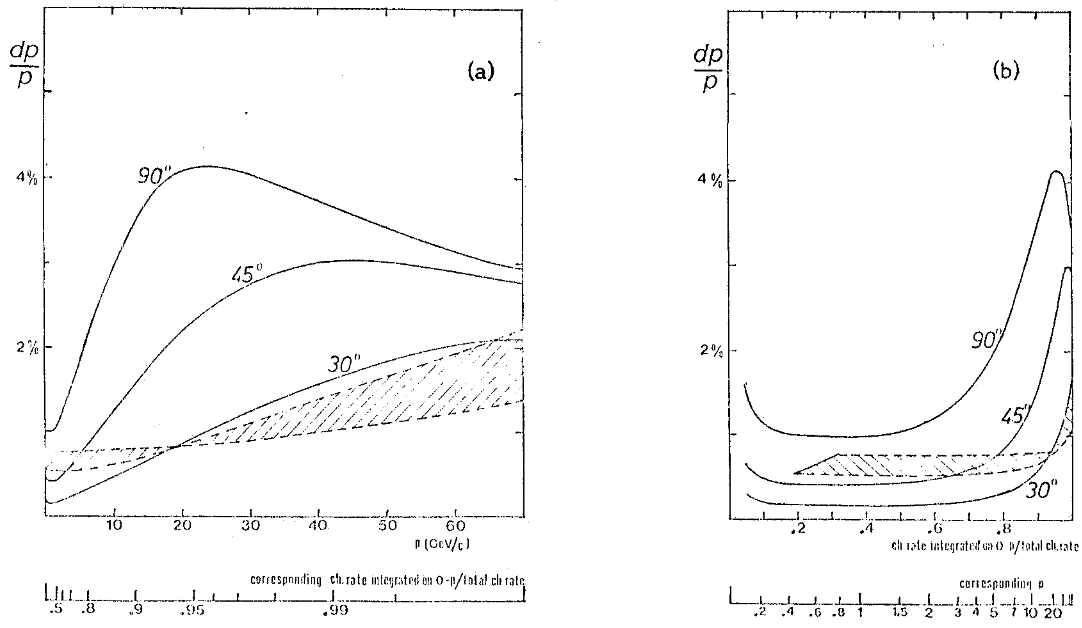


FIG. 13 - The resolution of the Toroidal Central Detector compared to that of the solenoidal Jet Detector. In (a) we assume σ = 0.2 mm for the track detector, in (b) σ = 0.1 mm.

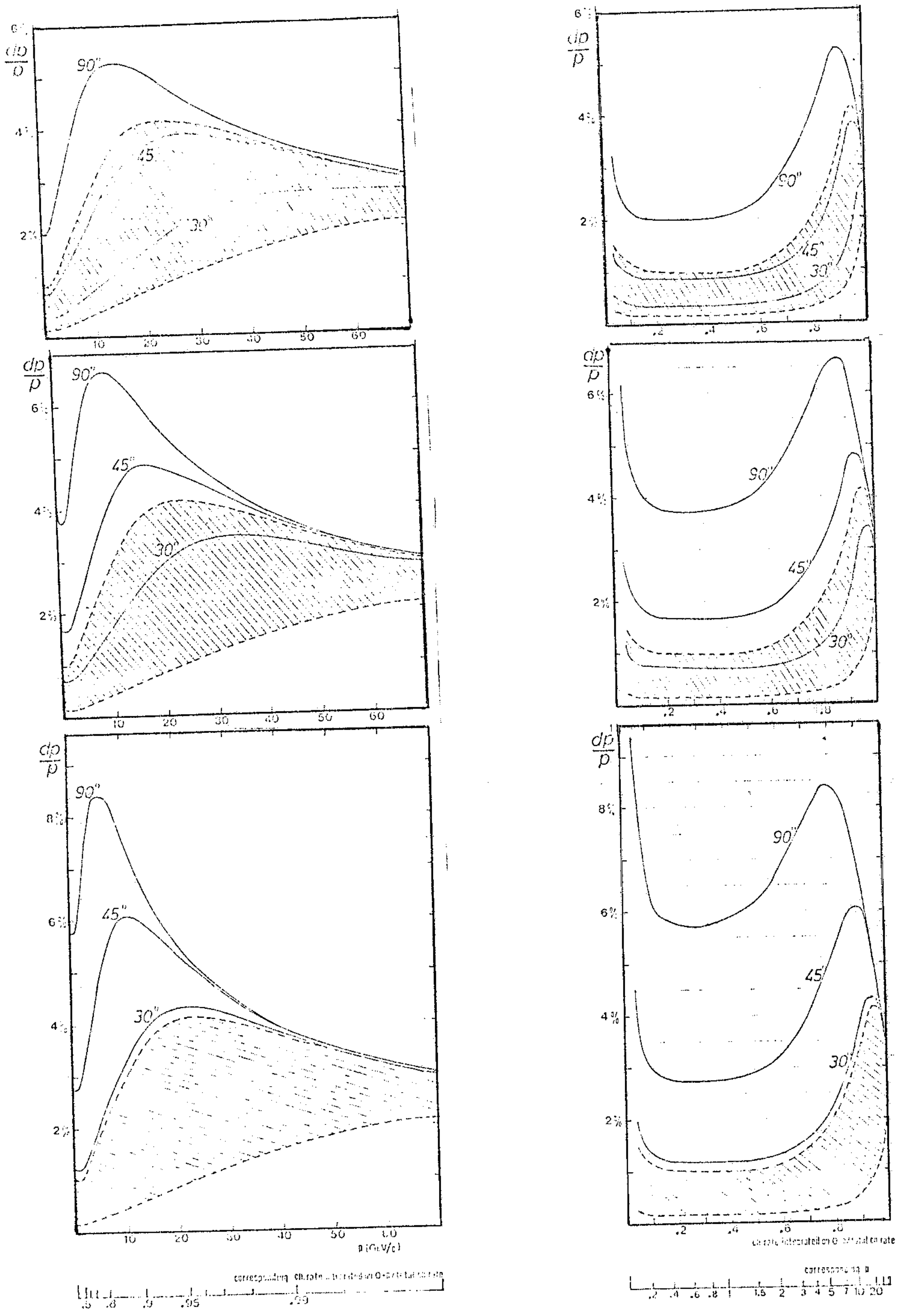


FIG. 14 - The resolution of the detector assuming a 2 MW water-cooled aluminium inner conductor of average thickness 45 mm (a), 10 mm (b) and 3 mm (c), compared to that of the SC version (shaded).

7.- ROOM TEMPERATURE TOROIDAL COILS.

Following the last observation of the previous section, we are naturally led to consider the implifications of reducing the field to a level where a technically straightforward water-cooled aluminium coil could be reasonably considered.

We examine first a coil whose average inner conductor thickness(18) is 0.5 r.l., is equivalent to that of the SC inner conductor discussed above. If this conductor is supplied with a power of 2 MW a current of 2 MA is possible, producing a 1.33 T field at $R_{int} = 0.3$ m. The bending power, and also the momentum resolution, is therefore one half of that of the SC coil. The aluminium coil does not require any mechnanical reinforcement to support the magnetic pressure of 7 atm. (It is assumed that the return (outer) conductor has a considerably larger cross-section in order to minimize the additional power consumption, but as this part of the coil is also longer, it is unlikely that this could be kept to much less than 1 MW.)

Alternatively we could consider sacrificing some of the momentum resolution in favour of cleaner charged particle patterns by dissipating the same 2 MW in an inner Aℓ conductor of average thickness 1 cm. Total current would then be 1 MA, producing 0.67 T at R = 0.3 m.

One could even envisage an ultrathin inner conductor(19): for B = 0.33 T at R = 0.3 m. allowing 2 MW dissipation implies 0.3 cm average thickness (see appendix of ref.(10)). This magnet is indeed 8 times weaker than the original superconducting version, but it is also about 16 times as transparent(18) (including the contribution of a lightweight support structure).

The momentum resolution for these three toroids, together with an 'optimum resolution" hadron calorimeter, is compared with that of the SC coil system in Fig. 14. This reveals the interesting fact that, when the resolution of the hadron calorimeter is included, the average resolution of the combined system degrades at only half the rate at which the magnetic field is reduced (the figure is one third for the leading particle - see Table II of ref.(5)). So a relatively weak magnetic spectrometer remains a valuable complement to a calorimeter-based detector, for solving problems of granularity, for correlation analysis, for correlation for 'decay in flight'(21), for resonance (e.g. ρ) identification, and to provide an abscissa for velocity measurements.

8.- THE TOROID AND γ-DETECTION

About 12 % of the charged particles interact inelastically in the inner conductor of thickness 0.5 r.l. The consequent limitation to the real acceptance is possibly more important than the resulting incertitudes in the φ-patter. However, the presence of this material does carry with it the advantage of converting about half of the γ's in the range $\vartheta = 25°$ to $90°$. The γ produced e^+e^- pair is highly collimated, and the tracks are in general unresolved in φ, but in the zenithal view they open out either because of energy asymmetry or because of low average E_γ. In our setup the energy E_γ can be reconstructed with a very attractive resolution from the momenta of the two members of the pair. This is plotted in Fig. 15a as a function of E_γ, and again (Fig. 15b) as a linear function of expected integrated γ-production normalized to 1 at 70 GeV. The resolution varies within the limits of the bands shown according to the energy asymmetry of the pair. Estimates of resolution for other typical γ-detectors are also shown for comparison.

This 'bonus' ability to detect γ's could be maintained, even in an improved way, for a weaker toroid with thinner conductor by the addition of a thin lead sheet around the coil to act as a radiator, with only a small increase in the charged particle nuclear scattering.

These considerations bring to mind the possibility of basing γ-detector on the momentum measurement of the first e^+e^- pair produced in the γ-conversion, committing to the e.-m. calorimeter only the determination of

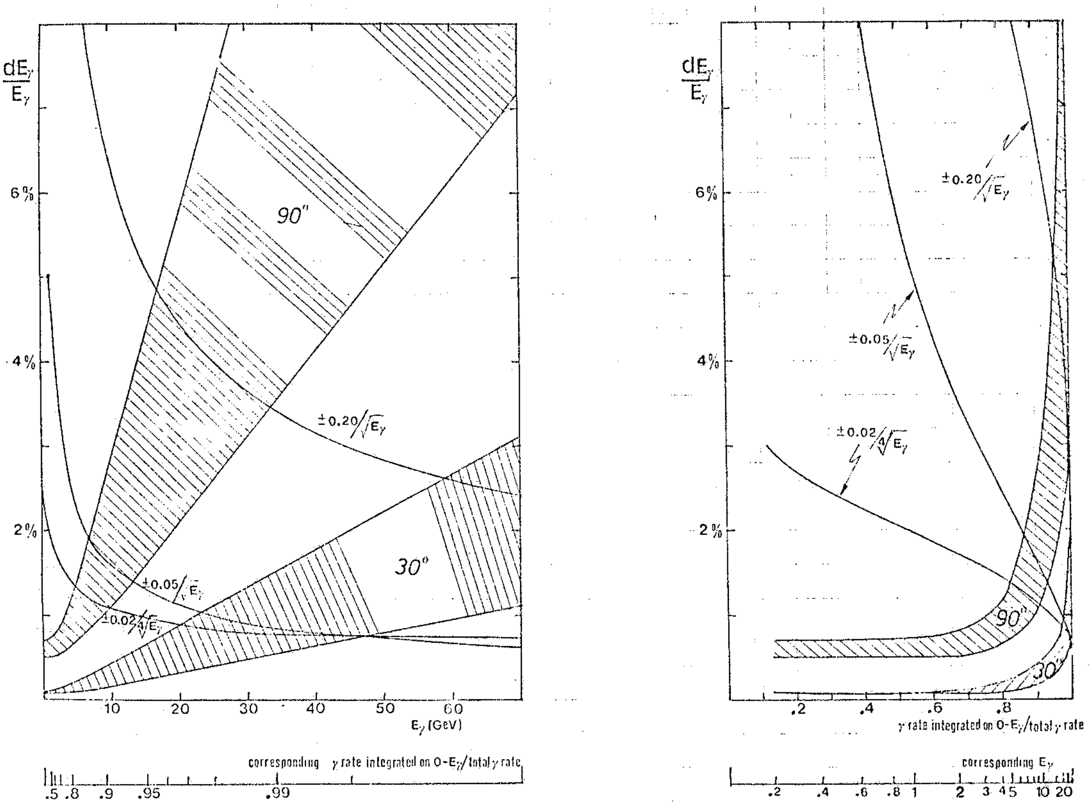


FIG. 15 - Resolution of the toroid when considered as a γ - detector.

the highest E_γ's. Let us consider for example the thin inner conductor dressed with a Pb sheet to give a total equivalent thickness of ~ 0.75 r.l. (i.e. 1 r.l. on average in the zone $\vartheta = 25°$ to $90°$), together with a second Pb radiator ~ 0.75 r.l. thick at R = 1.2 m, followed by a track detecting device capable of measuring the e^+e^- pairs produced in the second radiator (see Fig. 16). This latter device could extend to R = 1.9 m, leaving room for a Pb + scintillator shower detector between it and the hadron calorimeter. The E_γ resolution of such a system is shown in Fig. 17.

We note that the γ-detector is based on the same structure as the hadron detector, and indeed its characteristics are very similar (Table II).

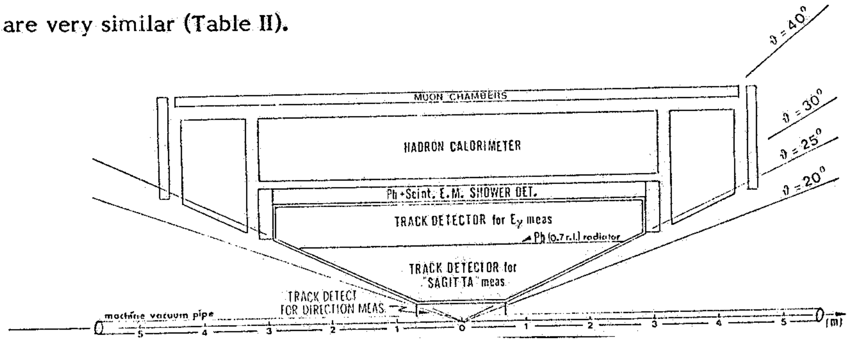


FIG. 16 - Possible layout of a dedicated γ-detector using the thin aluminium toroid.

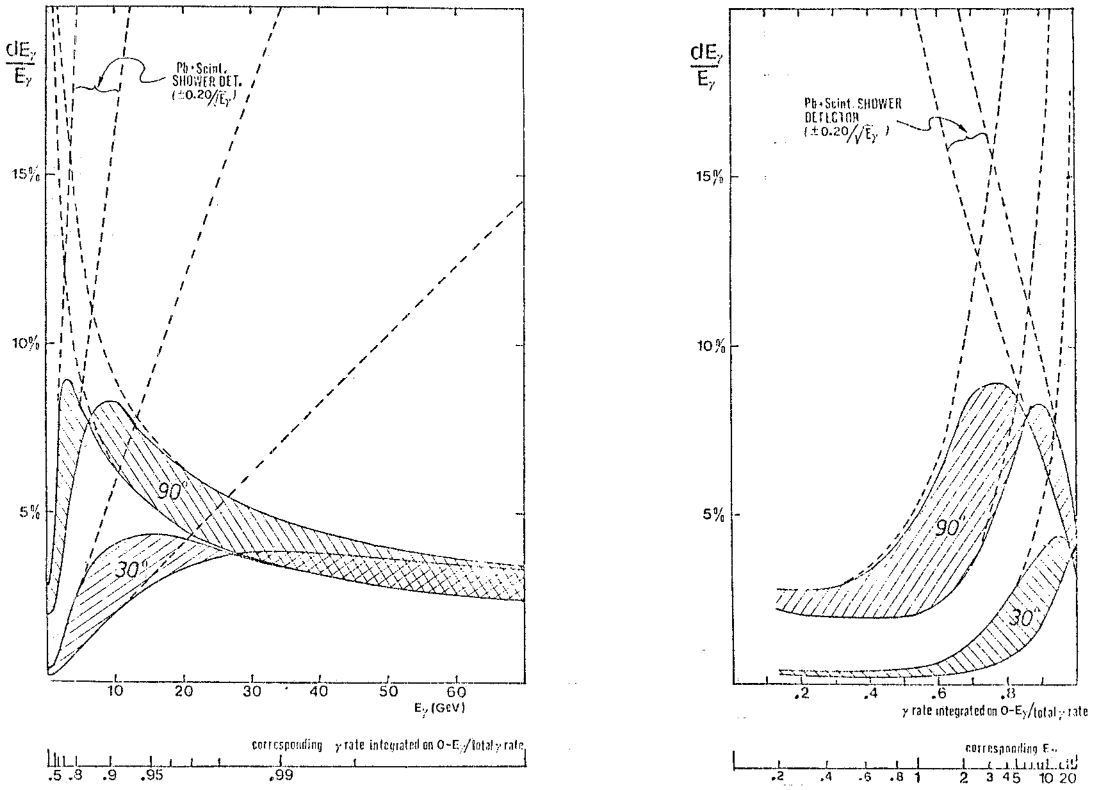


FIG. 17 - Resolution of the dedicated γ-detector of Fig. 16.

9.- CONCLUSIONS

A device which comprises a carefully dimensioned calorimeter, surrounding a relatively transparent magnetic spectrometer of modest size and bending power, would appear to provide a sound basis from which to probe into the detailed nature of complex events. One suitable geometry for the magnetic field is that of the toroid. Whereas when used with a track detector of average present-day performance it may be desirable to develop a superconducting magnet in order to obtain competitive resolution, a very much simpler water-cooled aluminium toroid would be sufficient if a reasonably more sophisticated track detector were to be chosen.

The possibility of using a thin toroidal magnet as a pair-spectrometer device for γ-detection would also merit further careful study.

APPENDIX :

Discussion on the feasibility of a superconducting toroidal coil having a thin inner conductor.

In order to obtain from a usefully thin ($\lesssim$ 0.5 r.l.) winding, a maximum toroidal field of greater than 1.5 T, it is necessary to use superconductor working in the condition of intrinsic stability. It is proposed to use a structure somewhat similar to that of the LBL test solenoid upon the results of which the TPC coil design has been based. In some respects one might expect the toroidal configuration to be more favorable than that of an equivalent solenoid, because

a) the total stored energy for a given bending is less;

b) the SC wire is in the maximum magnetic field over only 15% of its length,

c) where it is at a maximum, the force due to the magnetic field compresses the winding onto the force supporting structure, ensuring mechanical stability and good thermal contact.

However, the geometry of the toroidal winding makes the design of the support structure considerably more complicated than that of a solenoid, and a detailed design study - probably including construction and testing of prototype windings - would have to be embarked upon without delay if a spectrometer having a magnet of this type were to come into favour .

In order to show how the thickness of the inner conductor sheet, at radius 0.3 m, varies as a function of the maximum toroidal field, plots have been drawn (Fig. A1) making the following assumptions:

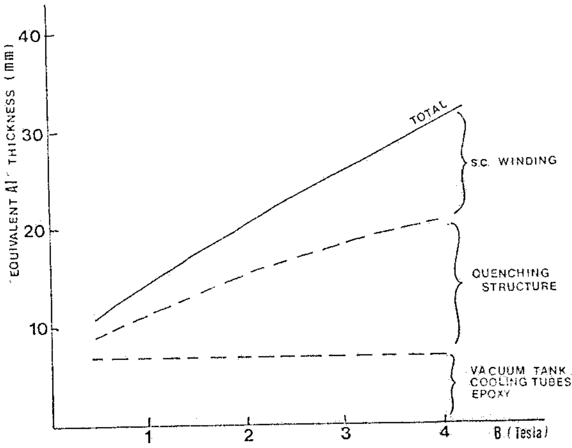


FIG. A1 - Thickness contribution in the SC toroid winding.

1) the superconductor is of a type which is commercially available(14) and conservatively taken to operate on a B/I characteristic obtained by reducing specified field by a factor of 2 and specified current by a factor of 3.

2) The thickness of cooling tubes, insulation and epoxy are taken from those of the LBL test coil.

It is also supposed that the inner conductor sheet, together with its pressure support cylinder and tubular cooling assembly, forms a cylinder which is supported between cylindrical inner and outer vacuum vessel walls.

The current return is thought of as being lumped, to allow easy access, with each coil suspended in its own vacuum tank. The techincal problems associated with joining these thanks to the central tank of concentric cylinders are by no means trivial, but shoud not be insoluble.

It is also interesting to note that the final cryogenic load shoud not be excessive, since most of the magnetic forces are balanced within the cold structure, and the total external surface area of the cryostat is less than 50 m^2 (less than that of an equivalent solenoid).

An artist's view of a single section, with its cryostat open, is shown in Fig. A2, in order to give some qualitative idea of how such a structure might look.

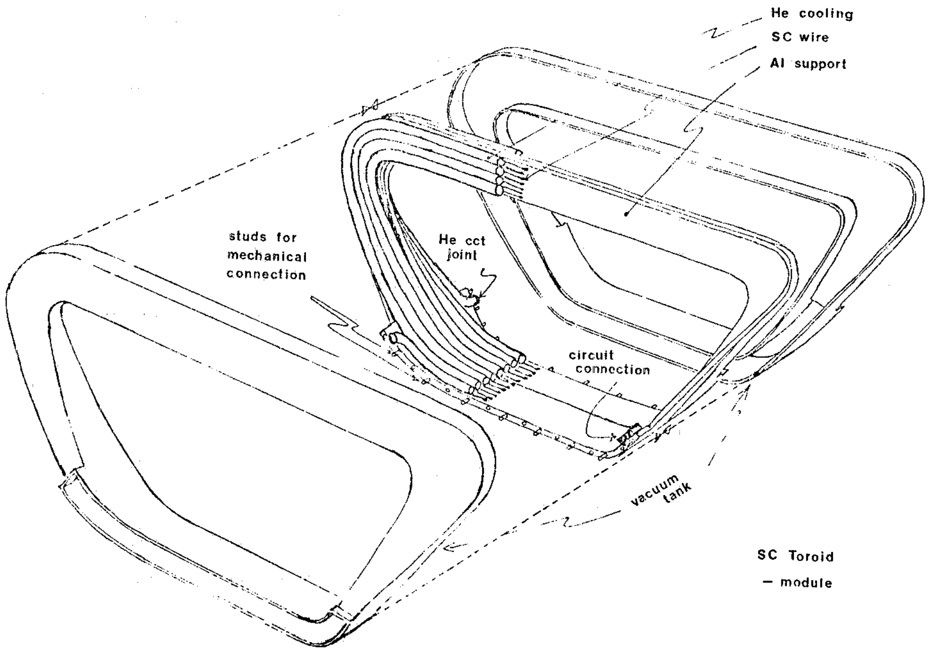


FIG. A2 - Artist's impression of a possible module of the thin superconducting toroid.

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(14) Supercon 252E9. See, for example, M.A. Green, Report LBL-3677 (1975).

(15) Preliminary laboratory results using "nail-head" hooks printed on a fibreglass board give a 0.4 ± 0.1 mm dead space (P. Spillantini, Frascati report LNF-79/52 (1979)). With a suitable design it should be easy to avoid lining up the (small) dead spaces.

(16) In a toroidal field we define as "sagitta" the maximum distance of the trajectory form the straight line joinin the points of entry into and of exit from the field volume.

(17) P.Spillantini; "A Time Projection Sector device for a toroidal central detector", (LNF report in preparation).

(18) The "average inner conductor thickness" referred to in this section is the equivalent radial thickness of aluminium required to carry the current. In reality this will have to be "diluted" with water cooling channels and insulation, and seen as an absorber the coil will be "lumpy". The lumpiness will increase as the average thickness of the winding decreases(20).

(19) This example has been chosen do demonstrate a trend. The technical difficulty of evacuating the heat dissipated in such a thin winding should not be underestimated(20).

(20) T. M. Taylor, Some notes on the choice of magnets for LEP detectors, ECFA/LEP Working Group SSC/13/6 (August 1979).

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