Study of a Multi-Hadron Facility for 'PEP' Based on Toroidal Field Magnets

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Abstract

A facility based on magnetic fields with toroidal structure is proposed for the study of the e^+e^- annihilation into multi-hadrons. Evaluations are carried out for a scheme with three toroidal superconducting coils (the 'central' coil and two 'small θ' coils) covering a 96%*4π solid angle. Very forward angles are kept free for the possible addition of two other toroidal coils covering down to ~0.7^o. The choice of the geometrical dimensions of the 'central' and 'small θ' coils is discussed. The evaluations are made for two different geometries of the central coil, one 'large' and the other one 'compact'. The weight of the coils is very low (.3-1.5t) while a ~2.5 Tesla maximum field can be obtained (~3.5 Tesla for the 'compact' central coil).

A complete detection apparatus requires for the central coil ('large' version) about 600 drift wires, 1000 proportional wires, 150 photomultipliers, 40 TOF channels; from another proposal the cost of a 'MPWC+ lead glass TAC' γ-detection system can be scaled to $650K or $1100K, depending on the possible inclusion of a high pressure gas cerenkov in the apparatus. Each 'small θ' spectrometer requires ~1/4 of all this. The 'compact' coil reduces the cost for the central spectrometer by a factor of 1.5-2.

With the discussed apparatus the momentum resolution at $\theta=90^o$ goes from 2% to 11% for p = 1-10 GeV/c in the 'large' central spectrometer, and from 8% to 15% in the 'compact' one. In the 'small θ' spectrometers the resolution is very good: at $\theta=10^o$ it goes from .5% to 3% in the same 1-10 GeV/c momentum range.

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I. General Characteristics for a Multi-Hadron Facility*

A list of the physical subjects to be investigated in the e^+e^- annihilation processes into many pions and kaons may be summarized in the following points:

a) δ_{tot}, δ^{ch}_{tot}, $\delta^{\pi o}_{tot}$ for each multiplicity value 'η'
b) <n>, $<n_{ch}>$, $<n_{\pi^o}>$, 'n' distributions
} do not require necessarily magnets

c) inclusive spectra in semi-inclusive approach
d) correlations (jets, clusters, resonances)
} require at least magnets

f) exclusive reactions, at least dominant channels (or for the simplest ones)
} require good 'p' and 'Eγ' resolutions and particle identification

The most relevant features foreseen for these processes can be stated as:

1) The counting rates should not be a problem (10^3 events/day are expected);
2) High multiplicities are expected, distributed with Poissonian law around averages values from ~8 to ~14 in the PEP energy range;
3) Products are expected to have broad distributions in θ and φ (reference system as in Figure 1), with a substantial sharing of total energy among themselves.

The broad angular distribution and the high multiplicities require large solid angles to be covered for any kind of measurement that must be done on the products.

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*This section follows strictly the introduction to chapter 4 of ref. 1

This is the most severe requirement for a detector suited to fulfil a complete investigation on the above listed subjects. Thus, the main experimental requirements for a suitable detector can be ordered in the following items, according to their relevance for the experimental program:

I)	θ_{ch}, ϕ_{ch} measurement on a wide $\Delta\Omega_{ch}$	($\gtrsim$95%*4π)	
II)	θ_{γ}, ϕ_{γ} " " " " $\Delta\Omega_{\gamma}$	($\gtrsim$90%*4π)	
III)	'P_{ch}' " " " " $\Delta\Omega_{p}$	(~80%*4π)	with a good resolution
IV)	$E\gamma$ " " " " $\Delta\Omega_{E\gamma}$	(~80%*4π)	with a good resolution
V)	particle identification on a wide $\Delta\Omega_{id}$	(~80%*4π)	in the whole 'p' range

VI) possible blind angular regions not concentrated at small θ's.

Observations:

The requirements (I)+(II) can be sufficient to cover the first two subjects [2) and b)] of the above list.

The requirements in the dashed area perimeter become necessary if we want to face the exclusive study of some specific reaction channel (subject f) of the list].

Blind angular regions must be nearly completely avoided in $\Delta\Omega_{ch}$ and $\Delta\Omega_{\gamma}$. In fact these solid angles must be very large ($\gtrsim$95%*4π) as we must avoid that, in the average multiplicity region ('n' $\simeq$ 10÷12) the not completely detected channels overcome the sample of the lower multiplicity ('n-1', 'n-2'--) completely detected channels; i.e. the sample of the events completely detected must be substantial ($\gtrsim$10%).

Indeed the last requirement (VI) concerns above all the acceptances for 'p' and Eγ' measurements; it is essential to avoid biases in the completely detected event sample, and it can be useful in the study of other physical processes (e.g. via 2γ events).

All the above requirements are in a way conflicting of one wants to fulfill them simultaneously. For instance the particle identification over a wide $\Delta\Omega_{id}$ poses problems for γ detection and measurement. Another conflicting choice can arise between the two extreme attitudes of a poor momentum resolution ($\Delta p/p \sim 3$-10% in useful 'p' range, $p \lesssim$ GeV/c) over a $\Delta\Omega p \gtrsim 80\% * 4\pi$, or of a better resolution in a smaller solid angle.

II. Comparison of Different magnetic Devices

The direction of a rather poor momentum resolution(*) over a wide $\Delta\Omega p$ seems to be more promising and flexible; moreover good resolution seems to be explicitly required only for the study of exclusive reactions. An analysis according to this attitude of how the various experimental solutions realized or proposed fulfil the above requirements has been performed by the 'SuperAdone Study Group'[1], and some aspects useful to this analysis are summarized in Table I (adopted from page 162 of ref. (1).

III. The Toroidal Magnetic Field Properties

From this analysis it appears that the toroidal field configuration (see Fig. 2) is the most promising for a multi-hadron facility conceived on the basis of the above discussion. The most remarkable advantages are in fact related to (see also ref. (2)):

(1) The possibility of covering a nearly 4π solid angle with systems of toroidal magnets [in fact they can be assembled together in a unique system as they have neither fringing field nor iron return yokes, and moreover the coils can be arbitrarily shaped provided that their cylindrical symmetry is preserved];

(*)By poor momentum resolution is at least intended a resolution such as to allow, for instance, the recognition of nucleon pairs in the final state or the clean reconstruction of ζ masses from the momenta of pairs of pions.

(2) The good transparency of these magnets for γ-rays at any angle;

(3) The structure of the field, which leaves each particle in its original emission plane (see Fig. 3). This last property is particularly remarkable as:

(4) It permits an easy pattern recognition with a minimum number of points (≳3 on each trajectory) measured on a plane, with a fast rejection of background events.

(5) In fact the three-dimensional motion is reduced to a two-dimensional one in the plane ϕ=constant, simplifying considerably the problem of the ambiguities and the design of trigger systems, which can be easily done with $\Delta\phi$ hodoscopes [and any other device built in $\Delta\phi$ sectors works cleanly].

(6) Morever the points can be measured outside the magnetic field, leaving inside of it enough free space for the insertion of gas cerenkov counters or other particle identification devices.

(7) Finally, another favorable situation deals with the optimium use of the bending power of the magnetic field, because the momentum of the particle remains always perpendicular to it.

Other important properties of the toroidal field magnetis are related also to the 1/R behavior of the field:

(8) In fact the total current needed does not depend on the solid angle acceptance, which can be indeed very large.

(9) Besides, in the small θ region the total current needed to cover the same solid angle with the same resolution increases only linearly with the 'interaction point-magnet' distance, and not with the square of this distance as it is for the other magnetic field configurations; it is indeed relatively easy to get a long free space for identifying particles before the momentum measurement.

Finally, it must be observed that a good cylindrical symmetry is preserved in the whole θ range.

It is clear that a disavantage of the toroidal scheme is represented by the parallel coil conductors running around the beam line, which in most cases have to be penetrated by the particles before they enter the useful magnetic field. In this respect every effort has to be made in order to reduce the thickness of the conductors to the minimum values consistent with the required high currents. Quantization of the coil in a number of thin pancakes can solve this problem to the extent that their azimuthal encumbrance can be made reasonably low.(3) This requires a detailed study of the possible structures of the pancakes and an optimized choice. For simplicity reasons the quantization of the coil will not be considered in the following evaluations, which will concern indeed only "continuous coils", i.e. coils consisting of rotation surfaces around the toroidal field axis.

IV. A Multi-toroidal Facility

IV.1 General Scheme

A general multi-hadron amihilation facility must be able to cover θ angles as small as 10^{o}-15^{o}; smaller θ's can be covered with some effort and are not of main interest. However, because it can be worthwhile to spend this effort for other reactions, this angular region must be kept free for the possible addition of very forward spectrometers, far away from the interaction point. A toroidal magnet system including also these two forward toroidal spectrometers is sketched in Fig. 4 for a 20m long free straight section: the forward coils can cover down to ~0.7^{o}, while the 10^{o}-170^{o} region is covered by three different spectrometers. This choice avoidshuge detectors and gives a good flexibility to the system, or each spectrometer can be decided, constructed and used separately from the others; moreover the small θ spectrometers can be moved away to cover down to $\sim 3^{o}$ [see dashed position in Fig. 4)], or the forward ones can be brought closer to the interaction region.

The following evaluations will be carried out for a multi-toroidal facility conceived according to this scheme, with all the five coils realized in superconductor (section IV.2). To choose the parameters for the coils some general choices must be made for the detectors (section IV.3). These parameters will be briefly discussed for central coils and small θ coils (section IV.4 and IV.5), and evaluations will be carried out for a particular choice, for which also a tentative detector scheme will be proposed, just to demonstrate to what extent the coils can be well 'dressed' (section IV.6). A possible 'compact' solution for the central spectrometer will be discussed and compared with the previous one (IV.7). Occasionally also some orientative values for the coil of the forward spectrometer will be included in the tables and in the figures.

IV.2 Choices for the Coils

For the central coil the superconducting technique must be certainly preferred, since 'room temperature-water cooled' techniques imply a huge power consumption to obtain the same resolutions with the same material thickness(*) traversed by the trajectories. This option is instead open for small θ and forward coils, since nearly the same resolutions can be obtained in the limit of ~1.5 MW for each coil; however, in spite of the engineering and construction difficulties involved, superconducting technique will be considered also for these coils, as the characteristics of the available superconductors are rapidly developing.

(*) All thickness are always reported to Aluminum radiation lengths.

As the magnetic field in the coils is never too high (~2.5 Tesla at maximum) a 400 Ampere/mm^2 density current in the superconductor can be safely assumed for all the coils. The superconducting wires are assumed to be stabilized in aluminum, as the aluminum-stabilized wire works as well as the copper-stabilized one, although until now it has been used only for small coil construction.

The dewar and the insulation are assumed to occupy at least 3cm around the superconductor winding.

A ≥ 1.5 safety factor has been assumed on the thickness of the material (aluminum) necessary to support the magnetic and atmospheric pressures; the thickness of the cylindrical parts has been evaluated for cylindrical vessels uniform along their length, stressed only radially and not supported by rings or other blocking devices.

IV.3 Choices For The Detectors

The range of choices for the gemetrical parameters of the coils is so wide (internal and external radii, length, shape and thickness can be changed) that some additional guide criteria must be introduced for the detector apparatus, so that it determines these choices.

For simplicity sake and to avoid particle detection losses the θ_{ch} and ϕ_{ch} measurement of charged products is supposed to be performed before they enter the magnetic field, while the γ's are supposed to be detected in the external part, outside the magnetic field. For particle identification the tendency will be to perform it as close as possible to the interaction point; naturally, as it must be performed with a number of different devices, these will be inserted in different parts of the apparatus. In particular a liquid hydrogen cerenkov hodoscope [see in Fig. 2 of ref. (4) a possible structure] is assumed to be inserted very near to the interaction point, in the section devoted to the θ_{ch} and ϕ_{ch} measurement.

The principle of the detection scheme is shown in Fig. 5. Outside the magnetic field, portions are supposed to be measured with drift chambers, and a ±.1mm precision in each point will be assumed. Inside the magnetic field will be assumed a ±.3mm precision.

No special choices will be made for γ-detection and measurement. Only the total surface to be covered by γ-detection and their distances from the interaction point will be given to permit a scaling of the parameters discussed in other PEP projects for similar experimental conditions.

IV.4 The Central Spectrometer

The momentum determination can be done through the measurement of the angular deflection ($\Delta\theta$) of the trajectory or its initial (H_1) or final (H_2) displacement in the magnetic field region (see Fig. 6), or through the sagitta (χ).

For a toroidal field confined between the radii R_1 and R_2, the following expressions are valid to a few precent precision[5], provided that the particle momentum is rather high ($\gtrsim$.5 GeV/c for a 2 Tesla x m bending power):

$$(1)\quad \Delta\theta = 0.06\,\frac{i}{p\sin\theta}\ln\frac{R_2}{R_1} = \frac{K(P)}{\sin\theta}\,f_\theta(y) \qquad [f_\theta(y) = \ln y]$$

$$(2)\quad H_1 = 0.06\,\frac{i\,R_1}{p\sin^2\theta}\left(\frac{R_2}{R_1} - 1 - \ln\frac{R_2}{R_1}\right) = \frac{K(P)xR_1}{\sin^2\theta}\,f_1(y) \qquad [f_1(y) = y - 1 - \ln y]$$

$$(3)\quad H_2 = 0.06\,\frac{i\,R_1}{p\sin^2\theta}\left(\frac{R_2}{R_1}\ln\frac{R_2}{R_1} - \frac{R_2}{R_1} + 1\right) = \frac{K(P)xR_1}{\sin^2\theta}\,f_2(y) \qquad [f_2(y) = y\ln y - y + 1]$$

$$(4)\quad X = 0.015\,\frac{i\,R_1}{p\sin^2\theta}\left(\frac{R_2}{R_1} - 1 - \ln\frac{R_2}{R_1}\right) = \frac{K(P)xR_1}{\sin^2\theta}\,f_X(y) \qquad [f_X(y) = \tfrac{1}{4}(y - 1 - \ln y)]$$

Where the units are m, Tesla, GeV/c, MA, and $y = \frac{R_2}{R_1}$, $K(p) = 0.06\frac{1}{p}$, and i is the total current generating the toroidal field. The behavior of f_θ, f_1, f_2, f_x as function of y (see Fig. 7) shows that the usual preference for a $\Delta\theta$ measurement is the most affected by the multiple scattering in the coil, and only the X measurement is independent of it. Therefore a complete measurement system must combine the X and $\Delta\theta$ measurement, as the X measurement can improve substantially the precision at low momenta.

For choosing the gemetrical parameters of the coil we consider the deflection of a high momentum particle emitted at $\theta = 90^0$.

If s_1 is the thickness of the internal superconductor winding where the current density is δ, then $i = 2\pi R_1 s_1 \delta$, and

$$(5) \qquad \Delta\theta = \frac{0.12\pi s_1 \delta}{p} R_1 \ \ell n\frac{R_2}{R_1}$$

for a fixed δ the bending power depends upon $s_1 R_1 \ell n\frac{R_2}{R_1}$. The R_1 dependence of the term $R_1 \ell n\frac{R_2}{R_1}$ (Fig. 8) shows that a chosen R_2 leaves a wide range of choices of R_1 which give nearly the same $\Delta\theta$. Conversely if R_1 is fixed, R_2 can be chosen over a wide range without a large $\Delta\theta$ variation. According to the scheme of Fig. 5 a R_1~25cm must be assumed, what leaves $R_1 \ell n\frac{R_2}{R_1}$ nearly maximum for R_2 = 50-100cm, with a corresponding $\Delta\theta$ variation of a factor 2. For Fig. 9 the deflection $\Delta\theta$ and the corresponding multiple scattering and measurement errors are shown for different thickness s_1 and for R_2 = 50 and 80cm. The parameters listed on Table II have been used.

For the geometry of the central spectrometer two opposite solutions can be proposed, one which maximizes the geometrical dimensions of the system and indeed its complexity and cost ('compact' solution). Anyway, also for the first choice huge detectors and intractable magnetic pressures must be avoided, so that R_2 = 80cm and s_1 = 5mm are the maximum values advisable. These values will be assumed, while the 'compact' solution will be discussed at the end and compared to the first one.

IV.5 Small θ Spectrometers

At small θ's the formulas (1)-(5) can be conveniently written with the substitution $R = Z\tan\theta$ and approximating $\tan\theta$ with $\sin\theta$ (see Fig. 10):

$$(6)\quad \Delta\theta = 0.06 \frac{i}{p\sin\theta} \ln \frac{Z_2}{Z_1} = \frac{K(p)}{\sin\theta} f_\theta(y)$$

$$(7)\quad H_1 = 0.06 \frac{i}{p\sin\theta} \left(\Delta Z - Z_1 \ln \frac{Z_2}{Z_1}\right) = \frac{K(p)Z_1}{\sin\theta} f_1(y)$$

$$(8)\quad H_2 = 0.06 \frac{i}{p\sin\theta} \left(Z_2 \ln \frac{Z_2}{Z_1} - \Delta Z\right) = \frac{K(p)Z_1}{\sin\theta} f_2(y)$$

$$(9)\quad X = 0.015 \frac{i}{p\sin\theta} \left(\Delta Z - Z_1 \ln \frac{Z_2}{Z_1}\right) = \frac{K(p)Z_1}{\sin\theta} f_x(y)$$

Also in this case, the choice of the geometrical parameters of the coil can be determined by the deflection, which is now written:

$$(10)\qquad \Delta\theta = \frac{0.12\pi s_0 \delta}{p\sin\theta} \left(\tan\theta\, Z_1 \ln \frac{Z_2}{Z_1}\right)$$

For θ and s,δ fixed it has the behavior already discussed (Fig. 8). However, it must be observed that at small θ's the multiple scattering contribution to the error on Δθ overcomes the measurement error, since the basis useful for the angle measurements can be made very long. Indeed it becomes very important to measure the sagitta to avoid the multiple scattering in the coil. This favors a long ΔZ, as the precision on X goes as $(\Delta Z)^2$. In the following, we choose ΔZ = 80cm with s_1 = 5mm. A longer ΔZ is not convenient as the particles begin to be deflected outside the outgoing surface of the coil, and the detectors located behind the coil become too large.

For the small θ spectrometers a 'compact' solution will not be considered, because the gain in detector dimensions, complexity and cost are not substantial.

IV.6 An example of Multi-Toroidal Facility

A schematic longitudinal section of a possible multi-toroidal facility is shown in Fig. 11 a).

The discussion of the coils are those discussed above. The shape chosen for the central coil allows to divide the apparatus in three parts, in principle independent, the central one covering $\Delta\theta = 45^o - 135^o$. In this way the detector surface can be reduced by a factor ~2, and the small θ coils can be brought to a Z_1 ~2m, with a strong reduction of their detector surface.

All the coils are supposed to be divided in a number of identical independent sectors (4 in the present evaluation), each one complete for its part of the apparatus, almost constituting an experimental apparatus as it stands. This avoids any mechanical linking with the machine and gives a good accessibility to the experimental apparatus (see Fig. 12). Moreover the coil can be realized like an open 'fan'(*) (see in Fig. 13 a drawing of this solution for the central coil) to improve the access to the inside.

Just to demonstrate to what extent this coil system can be well 'dressed', an example of detection apparatus must be briefly discussed. The discussion can

(*)But detailed calculations are needed to establish if such a multi-dewar system can work.

be limited to the central spectrometer, as the detection problems in the small θ spectrometers are analogous but easier, as the detectors are flat.

Measuring the charged particle positions outside the magnetic field can be done with a system of 'Drift+MW+MW+Drift' chambers. The drift chambers must have a polygonal structure, with wires perpendicular to the Z axis to get a precise θ_{ch} determination. The MWPC can be polygonal or cylindrical with wires parallel to the Z axis and grouped to build hodoscopes in ϕ_1 of about 200 channels each; on the cathodes must be printed strips at an angle with the wires, to solve ambiguities (see ref. 6). The portions inside the magnetic field can be measured in a MWPC polygonal system (2 layers) with wires perpendicular to the Z axis. An alternative solution can be a system of polygonal or cylindrical MPWC with wires parallel to the Z axis, where the Z coordinate is given by the centers of the pulse height distribution of the pulse introduced on a number of strips printed on the cathodes (ref. 2). This solution can improve ±.3mm precision assumed for the sagitta, but it is very expensive because it requires ~1500 amplitude-number conversions. A storage system and an adressing logic must be developed to reduce the number of conversion devices. However if such a system would be developed in the future, also the drift chambers (necessarily polygonal) external to the coil could be conveniently substituted with MWPC where the Z coordinate is read on the cathodes.

For particles identification a ~3cm thick liquid hydrogen cerenkov hodoscope can surround the vacuum pipe to cover a 90% of 4π with ~2 liters of liquid hydrogen. This device covers well the hole in π/K separation between the T.O.F made in a layer of scintillation counters external to the coil and the β selection on a ~8atm isobutane cerenkov hodoscope (20cm thick) located before the γ detector (see Fig. 14). In 'small θ spectrometers there is a longer free space for a more comfortable T.O.F measurement and also for the insertion of a low pressure gas cerenkov hodoscope to extend the π/k separation in the central spectormeter a low pressure (1-3 atm) device could be located inside the coil. This could be a gas cerenkov filled with isobutane at room temperature, or with H_2 or N_2 gases at a temperature near to their boiling point. This last solution could work well as the temperature can be maintained very low inside the superconducting coil; moreover it could be combined in an unique cryogenic system with the corresponding liquid H_2 and/or N_2 cerenkov hodoscope (see Table III). Particularly attractive are the refraction indices of the 'gas+liquid' helium system which could operate the π/K separation in all the range - = 1 - 10 GeV/c, and could belong to the dewar of the coil, miminizing the added thickness. As the helium scintillates, it is worthwhile to investigate the possibility of a poisoned helium system in which the scintillation light emmission could be suppressed.

For triggering and timing it is sufficient to have a layer of a small number of scintillation counters located near to the interaction region. The MPWC's inserted in the different position could be used to build hodoscopes in ϕ to count the charged prongs and to provide also a fast selection on the particle penetration (essentially against the background). The external scintillation counters planned for the T.O.F measurement can be possibly used in the trigger and fast logic too.

For detecting and measuring the γ's on the whole solid angle covered by the central spectrometer ($\Delta\Omega_{e\gamma} \simeq \Delta\Omega\gamma \simeq \Delta\Omega p$) a ~24 m^2 surface must be covered at an average distance of 1.3m from the interaction point. If a 'MWPC+lead glass TAC' system is used, the total cost given by the "Minimag" group (see the reports of this 'Summer Study') for a similar experimental situation scales in our case to ~\$1100K, to which a ~15% must be added for each of the small θ spectrometers. Eliminating the external high pressure cerenkov, this figure decreases to ~\$650K.

The main parameters of the coils and of the detectors, fixed according to the above discussions are summarized in Table IV.

Assuming these values the momentum resolution are those shown in Fig. 15.

IV.7 'Compact' solution for the central spectrometer

For obtaining a very compact gemetry the liquid H_2 cerenkov can be moved inside the coil, to reduce R_1 to ~20cm; the corresponding external radius can be chosen R_2 ~40cm. In fact the same aluminum thickness can support a double pressure (as the length and the radius of the inner winding decrease both of ~20%) and the field can be increased by a ~1.4 factor without modification of the figures assumed for the previous evaluations. Correspondingly the angular deflection decreases only of a factor 1.47, but the global resolution at low momenta is worse since with this geometry the sagitta measurement is unusable. However the 'compact' solution remains interesting because the detection apparatus becomes very simplified and reduced, as is evident from Fig. 11 b) and from the last column of Table IV.

The momentum resolutions for the 'compact' solutions are reported in Fig. 16, and compared to the previous resolutions in Fig. 17.

References

(1) INFN+LNF, SuperAdone design study, March 1974

(2) P. Spillantini: Internal Report LNF 72159 (1972) and Status Report of the ECFA working parties CERN/ECFA 72/4. Vol. I, page 337; Report CERN/ECFA/WG73-5 (1973); 1973 International Conference on Instrum. for High Energy Physics, Frascati, May 1973, proceedings page 673.

(3) D. Boyd et al: Nucl. Instr. and Meth., 111, 315 (1973).

(4) P. Spillantini, Internal Report LNF 74/6(P) (1974), to be published in Nucl. Instr. and Meth., 119 (1974).

(5) For a simple deduction of these formulas see: P. Spillantini, Internal Report LNF 72/16 (1972)

(6) H. Mehrgardt et al., 1973 International Conference on Instrum. For High Energy Physics, Frascati, May 1973, proceedings page 287.

(7) G. Charpak et al., Report CERN 73-11 (1973).

TABLE I - Comparison of Different Magnetic Devices

	Magnetic Device	Interaction with Mach.: Magnetic	Interaction with Mach.: Mechanical	γ measurement outside ?: in ΔΩp	γ measurement outside ?: out of ΔΩp	Identification Possible ?: in ΔΩp	Identification Possible ?: out of ΔΩp	$\frac{\Delta\Omega p}{4\pi}$ (geom)	$\frac{\Delta p}{p}$ $\left(\begin{matrix}p=1\ GeV/c\\ \theta=30^o\end{matrix}\right)$	∫Bdℓ θ=90° (Tesla-Meters)	Length x width x height (m)	Power (MW)	Total Weight: Coils	Total Weight: iron
longitudinal	Solen. SPEAR	Yes	Yes	~Yes	No	No	No	.70	.020	.6	4.3.3	2.4	7.5	130
longitudinal	Pluto (Doris)	Yes	Yes	~Yes	No	No	No	.70°	.029	1.2	2.4.3	S.C.		120
longitudinal	Zeus(Doris)	Yes	Yes	Yes	No	~Yes	No	.94	.015	1.5	5.6.4	2.6	57	700
longitudinal	Split Solen (S.A.)	No	No		~	No	No	.86°	.008(+)	.8	6.3.3	5	31	32
longitudinal	Solen (S.A)	Yes	Yes	~No	No	No	No	.92	.010(+)	1.0	5.3.3	5	32	121
transverse	Solen. (Adone)	Yes	No	~Yes	No	No	No	.44	.02 (+)	.3	3.4.3	2	3	90
transverse	SFM(ISR)	Yes	No	~Yes	No	Yes	~No	~.80Δ	<<.01 (+)(**)	12(**)	10.3.7	6	42	840
toroidal	Orange (Doris)	No	No	Yes	No	Yes	No	.29	.022(+)	1.0	4.3.3	?	90	
toroidal	Oktupus(Doris)	No	No	Yes	~No	Yes	No	.60	.009(+)	2.9	4.9.9	S.C.	30	No
toroidal	Composed(S.A.)	No	No	~Yes	Yes	Yes	Yes	.96	.02 (+)	.38	5.2.2	5	4	No
toroidal	SuperC. (S.A.)	No	No	~Yes	Yes	Yes	Yes	.96°	.08 (+)	.39	2.2.2	S.C.	.3	No

(+) Evaluation with ±0.2mm error in the sagitta meas. (or equivalent in deflection)
(**) " at θ=0°
o ~2cm AL on the trajectories
Δ small angles (~5°) can be covered
//// dashed areas indicate not favorable qualities

TABLE II

for	$R = R_1 = 25cm$				$R = R_2 = 50cm$			$R = R_2 = 80cm$		
Superc. Winding Thickness (mm)	Total Current (MA)	B (Tesla)	Equivalent Aluminum Thickness (mm)		B (Tesla)	Equivalent Aluminum Thickness (mm)		B (Tesla)	Equivalent Aluminum Thickness (mm)	
			Superc. Wind	Other		Superc. Wind	Other		Superc. Wind	Other
1	.63	.5	2	8	.25	1	6	.12	.6	6
3	1.88	1.5	6	8	.75	3	6	.37	1.9	6
5	3.14	2.5	10	10	1.25	5	8	.62	3.1	6
10	6.28	5.0	20	20	2.50	10	10	1.25	6.2	8

TABLE III

	Liquid (1atm)			Gas(Tboil, 1atm)			Gap in π/K Separation in a liquid+gas system (GeV/c)
	Refrax. Index	Cerenk. Threshold at 1/2 of the maximum (β=1) (GeV/c)		Refrax. Index	Cerenk. Threshold at 1/2 of the maximum (β=1) (GeV/c)		
		P_π	P_k		P_π	P_k	
H_e	1.02	.94	3.40	1.0025	2.8	10	NONE
H_2	1.11	.40	1.45	1.0020	3.0	11	1. 1.45-3.0
N_2	1.21	.29	1.0	1.0011	4.1	15	1.0 -4.1

TABLE IV - The Most Relevant Parameters of the Multi-Toroidal Facility

			CENTRAL	SMALL θ	FORWARD	CENTRAL (COMPACT)
Spectrometers:						
Coil:	external length	(cm)	166	86	106	166
	maximum external radius	(cm)	83	143	153	43
	minimum " "	(cm)	22	29	8	17
	covered Δθ (geometrical)		$27^{o}/153^{o}$	$10^{o}/23^{o}$	$0.7^{o}/8.5^{o}$	$27^{o}/153^{o}$
	covered ΔΩp/4π (geometrical)		89%	3.3%	0.6%	89%
	thickness of inner superc. winding (at the θ in parenthesis)	(mm)	5(at 90^{o})	5(at 10^{o})	5(at 1^{o})	7(at 90^{o})
	total thickness of the trajectories (in+out) (at the θ in parenthis)	(Alr.l.)	29(")	.44(")	.39(")	.43(")
	total current	(MA)	3.19	4.84	1.62	3.52
	maximum magnetic field	(tesla)	2.5	2.7	3.6	3.5
	weight: total	(t)	.4	1.5	1.0	.3
	" : superconductor only	(t)	.17	.24	.06	.15
charged particle detectors	Z development to be measured to ±.1mm (all the 4 sectors)	(m)	29	6		20
	" " " " " " ±.3mm (" " " ")	(m)	13	3		--
	Number of channels in the ϕ hodoscopes (groups of prop. wires)	(m)	1200	500		800
	" " " for the ambiguity resolution		1000	500		600
	" " photomultipliers for the trigger counters		24	6		24
photon detectors	total surface to be covered	(m^2)	24	6		17
	at the average distance from the interpoint	(m)	1.3	3		1
particle identific.	number of photomult. for the T.O.F counters		48	12		24
	" " T.O.F. channels		36	6		12
	" " photomult. for the liquid H_2 cerenkov's		24	6		24
	" " " " " low pressure gas cerenkov's		--	6		--
	" " " " " high " " "		48	6		24
	[" " " " " cryogenic gas cerenkov's]?		[24]	--		--

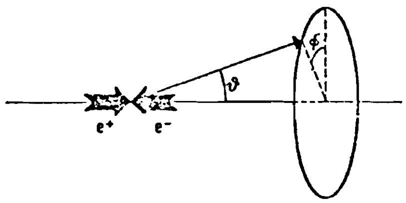
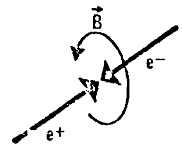
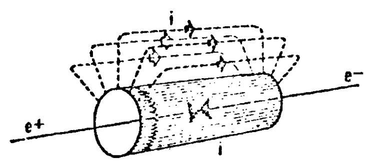


Fig 1 - Reference frame

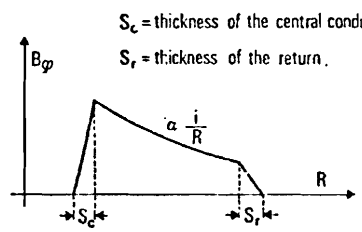
Fig 2



a) toroidal field scheme



b) - Toroidal magnetic field current generating system



c) - Toroidal field radial distribution.

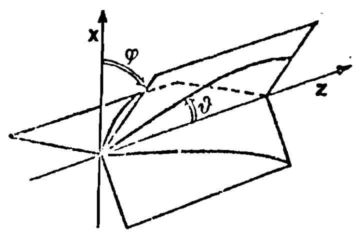


Fig. 3

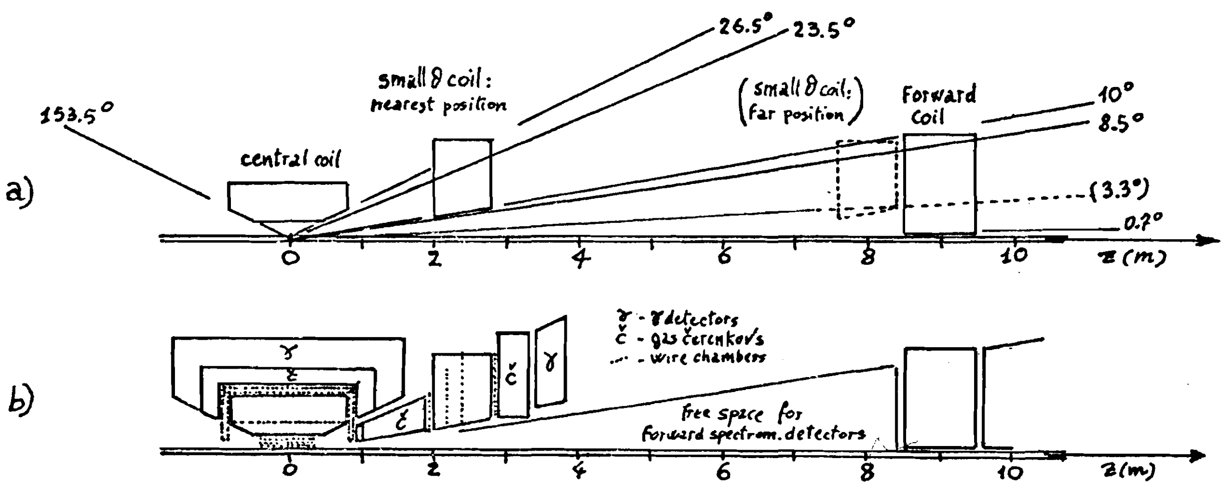


Fig. 4 - Multi-toroidal facility scheme : a) only coils ; b) coils & detectors

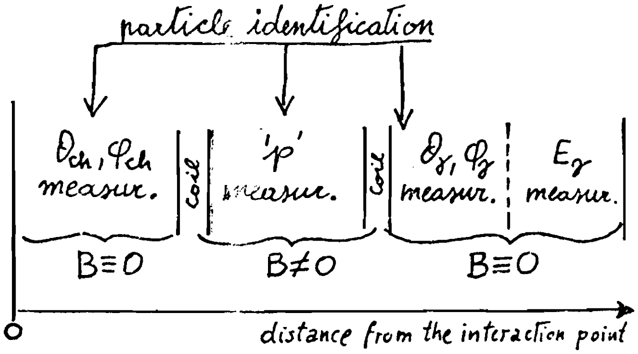


Fig 5 : detection scheme

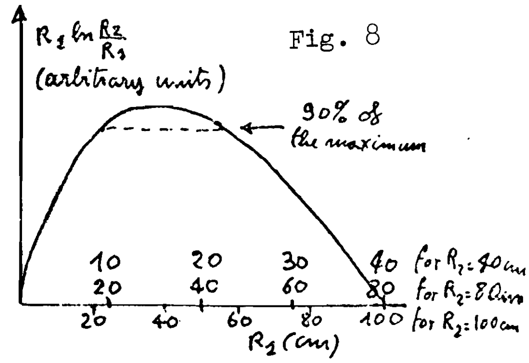


Fig. 8

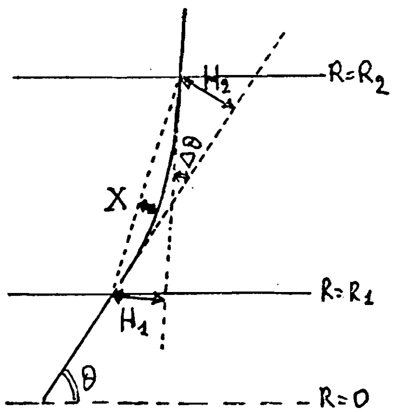


Fig. 6

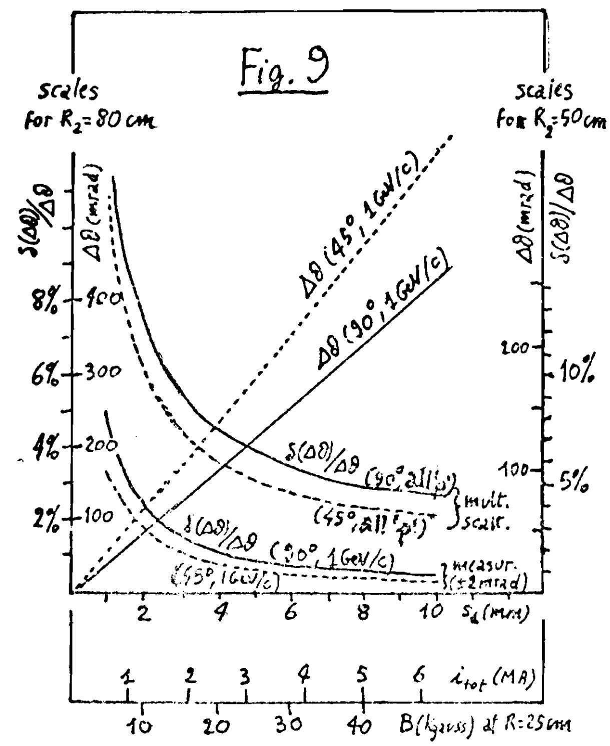


Fig. 9

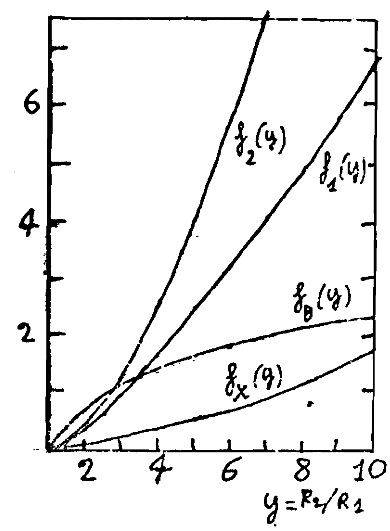


Fig 7

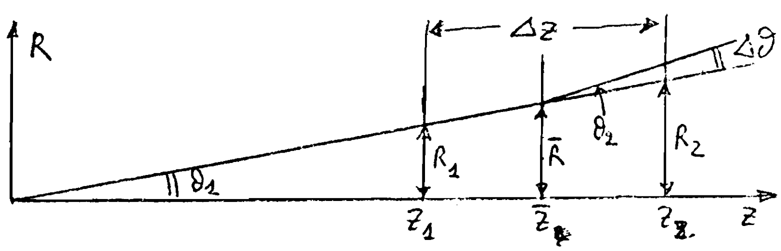
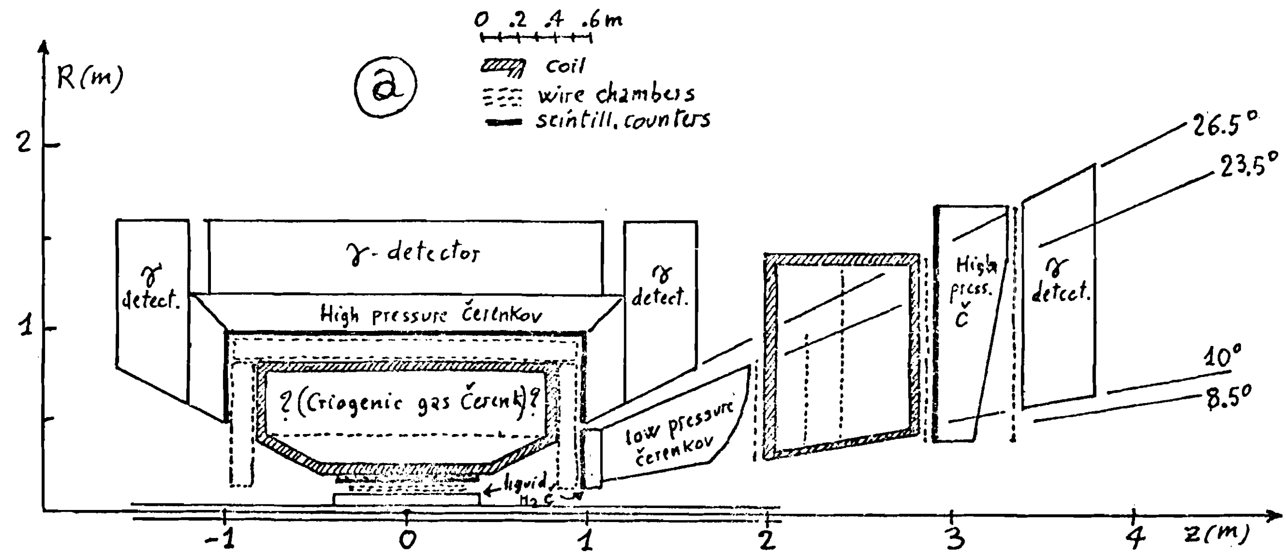


Fig 10



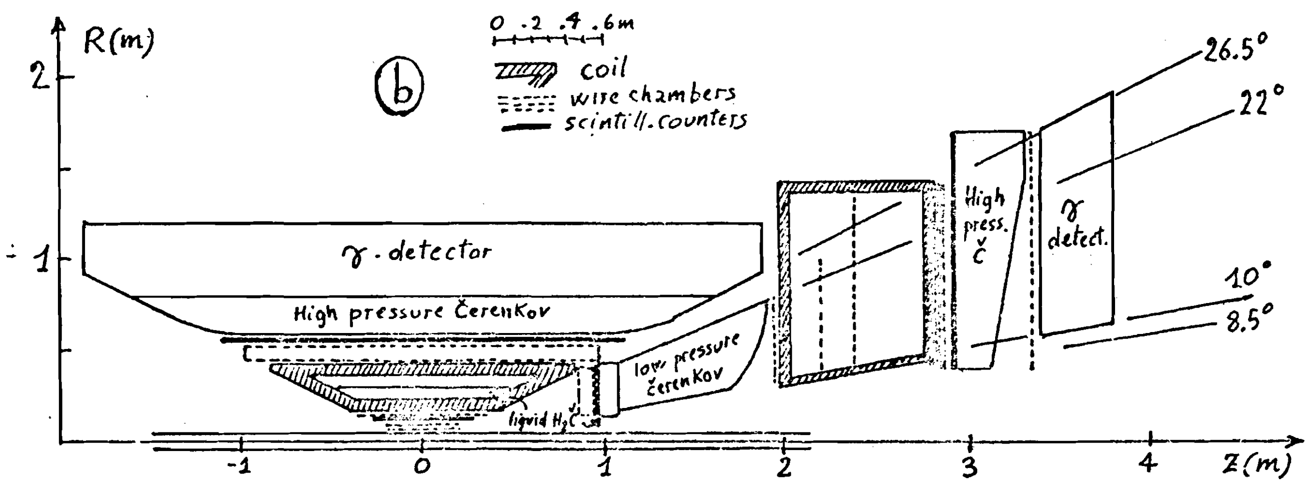


Fig. 11 Multi-toroidal Facility
a. with large central coil
b. with compact central coil

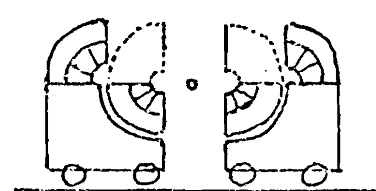


Fig.12

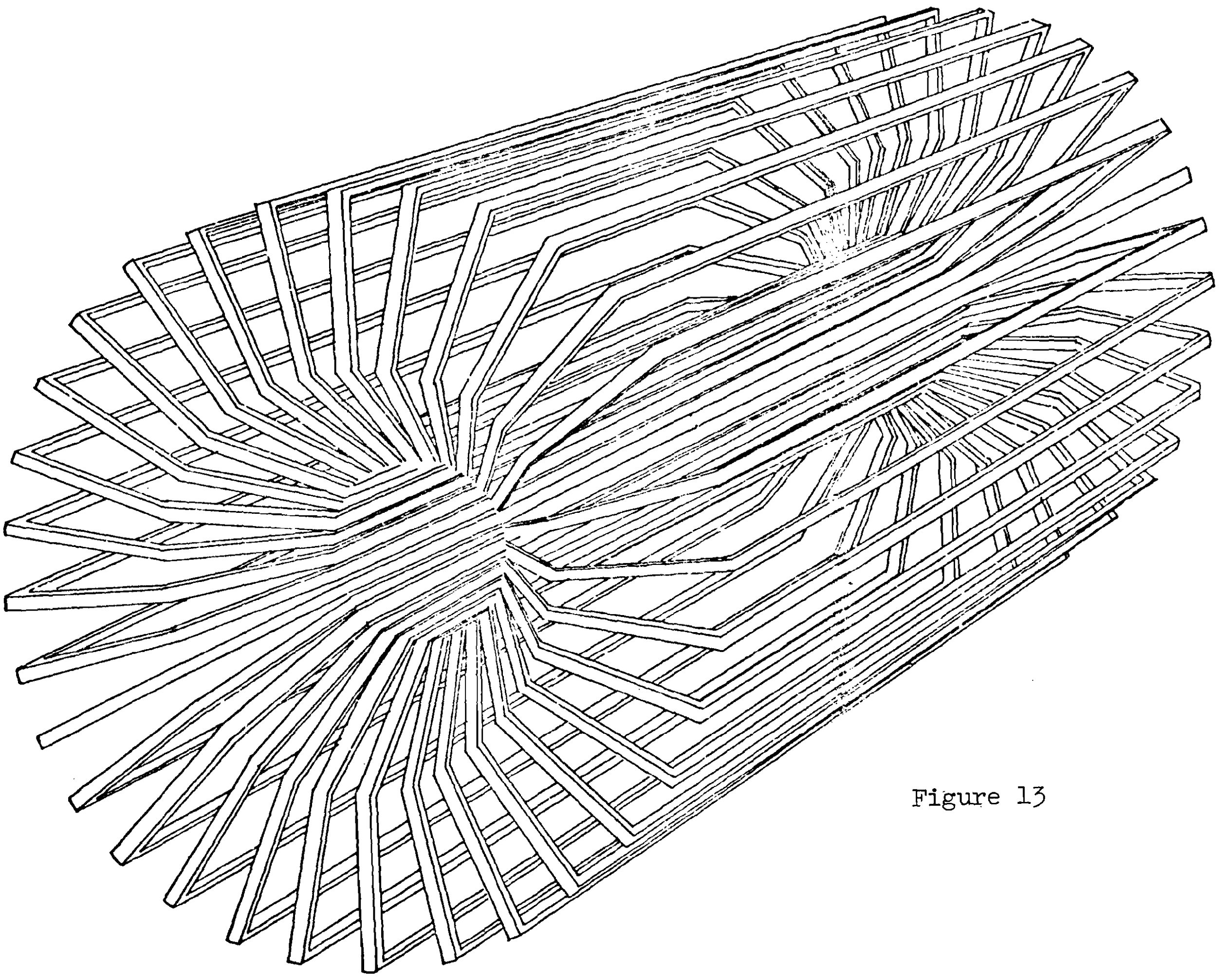


Figure 13

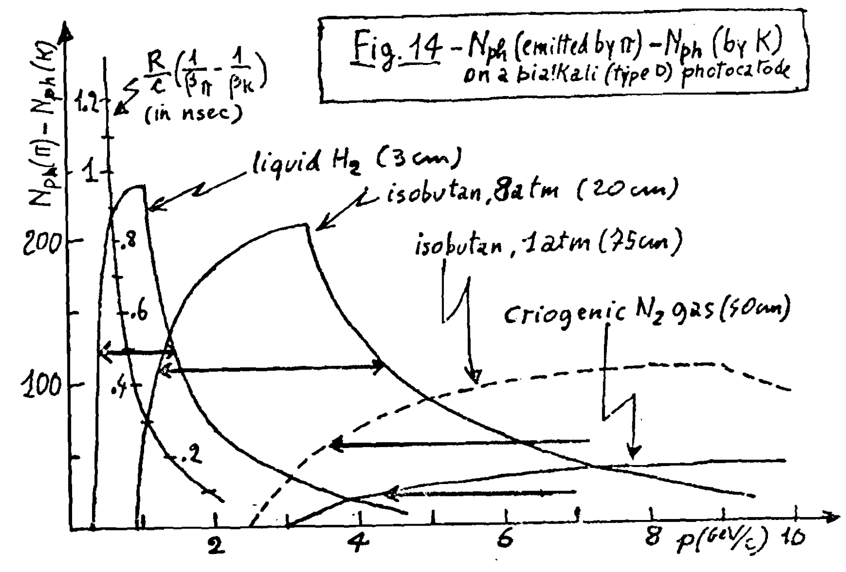


Fig. 14 - N_{ph} (emitted by π) - N_{ph} (by K) on a bialkali (type D) photocatode

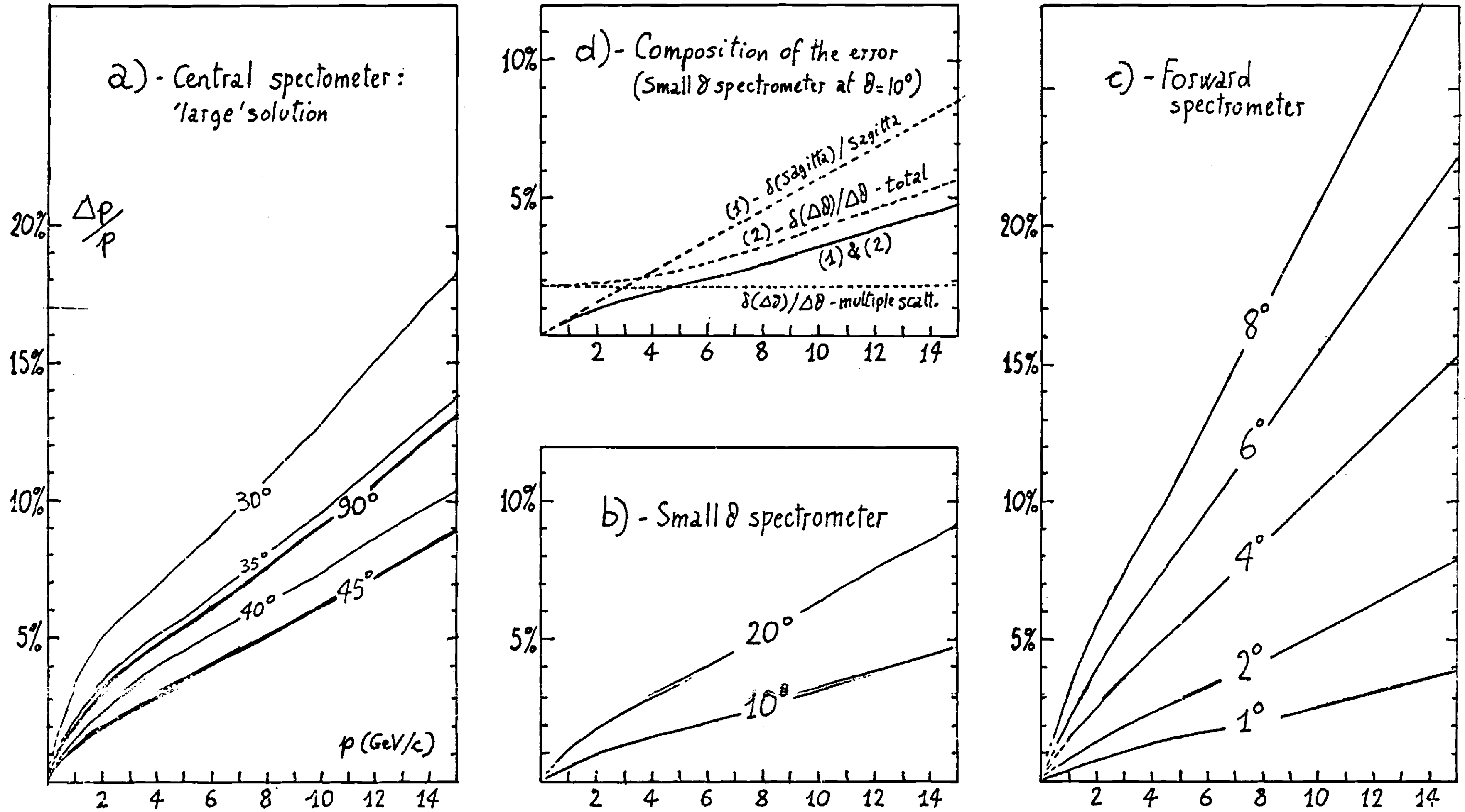
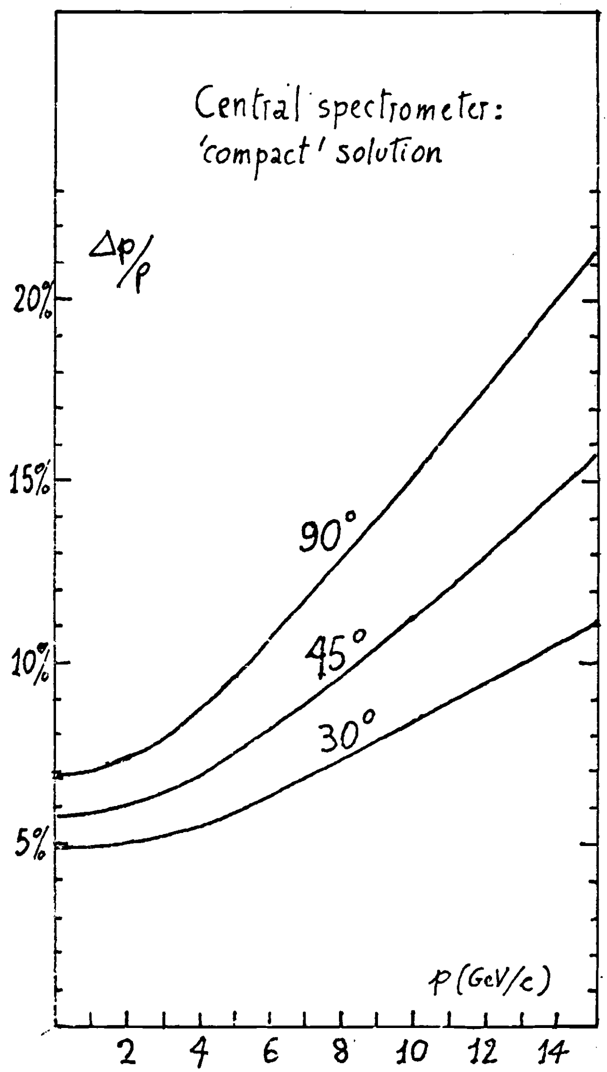


Fig. 15.- Momentum resolutions at some θ angles in the various toroidal spectrometers. The quoted resolutions result from the composition of the error on the 'sagitta' and the error on angular deflection, as shown in the graph d). For the sagitta measurement a ±0.3 mm precision was assumed and no multiple scattering considered.



. Fig 16 - Momentum resolutions at some θ angles in the 'compact' central spectrometer.

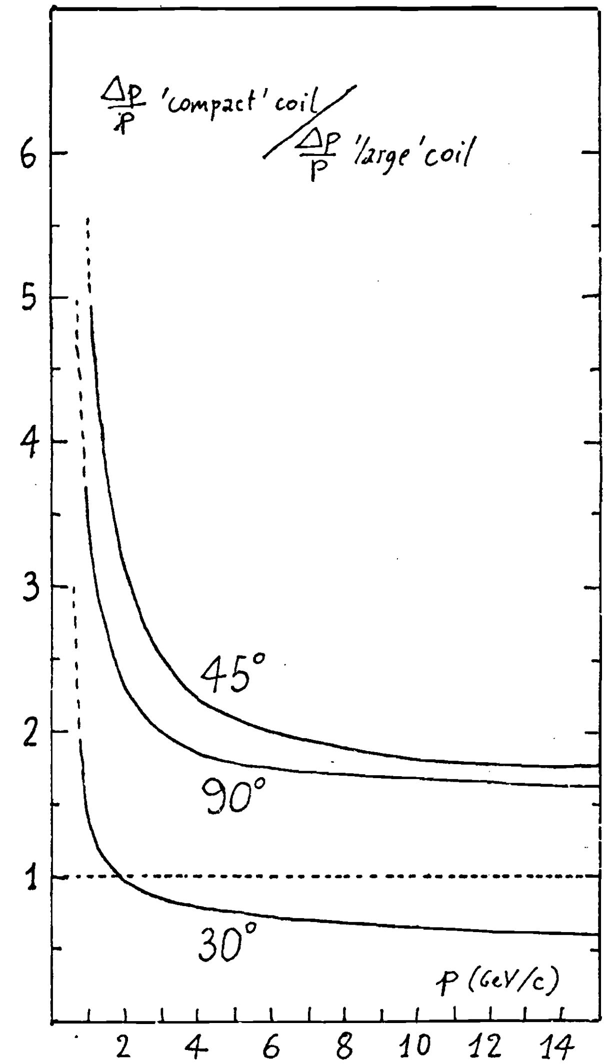


Fig 17 - Ratios of the momentum resolutions in the 'compact' central spectrometer to the resolutions in the large one for some θ angles.