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A TOROIDAL MAGNETIC FIELD SPECTROMETER FOR EXPERIMENTATION WITH HIGH ENERGY BEAMS

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1. GENERAL CHARACTERISTICS FOR HIGH ENERGY REACTIONS

General kinematical features of the high energy reactions

I - momenta of the outgoing particles much higher than their masses ;

II - very narrow angular opening in ϑ ;

III - completely open configuration in φ ;

IV - very large average multiplicity of products.

Specific problems created by these features are :

(1) - precise measurement (to some tenth of %) of high momenta ;

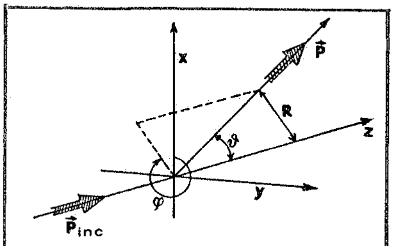
(2) - precise measurement (to ~ 0.1 mrad) of the ϑ angles ;

(3) - difficulty in using the open "φ pattern" after the momentum measurements ;

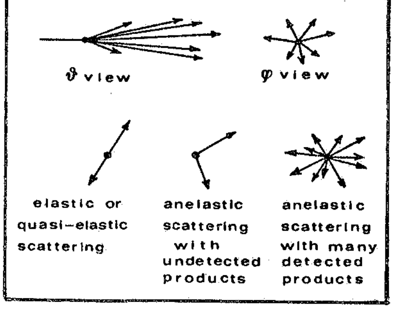
(4) - large solid angular acceptance required, resulting in the following :

(4.1) - a high intensity magnetic field in a large volume ;

(4.2) - difficulty in resolution of ambiguities in the spatial reconstruction of the trajectories.



Laboratory reference frame



2. TOROIDAL MAGNETIC FIELD

First, to solve problem (3) the magnetic field B must always be perpendicular to the momentum p ; this implies a structure of B as in Fig. 1, which can be obtained with a coil as in Fig. 2. B is zero outside, while inside the coil B = constant/R ; a deflected particle remains in its emission plane, φ = constant (see Fig. 3). We will call "toroidal magnet" a magnet that creates such a "toroidal magnetic field".

The main advantages of a toroidal magnetic field for a spectrometer are :

(a) - the field is confined inside the coil, indeed no iron for returning flux is needed ;

(b) - the "analysing power $\Delta p/p$" is only slightly dependent on ϑ at a fixed p^{cm} (Fig. 4) ;

(c) - the simple and open "φ pattern" is conserved after the momenta measurement : the three-dimensional motion is reduced to a two-dimensional one in a plane φ = constant, simplifying considerably the problem of the ambiguities and the design of trigger systems, which can be done easily with $\Delta\varphi$ hodoscopes ;

(d) - the total current needed does not depend on the solid angle acceptance : indeed this can be very large and without loss of "analysing power" (see (b));

(e) - owing to the $1/R$ dependence of B the total current needed increases only linearly with the target-magnet distance : it is indeed relatively easy to get a long free-space for a good ϑ measurement and for an abundant K_o and hyperon decay;

(f) - the complete cylindrical symmetry simplifies experiments with polarized beams and/or polarized target;

(g) - the particle trajectory can be defined without the ambiguities present in conventional spectrometers using a smaller number of points (possibly only 3) for which only one coordinate (the distance R from the z-axis) must be measured;

(h) - the "φ pattern" conservation allows :

(h.1) - simple, versatile and general trigger systems including easily K_o's and hyperons, and conditions to be satisfied by particle momenta;

(h.2) - analysis of particles after the magnet in separate sector ("orange quarter") devices (see Fig. 5).

3. SPECTROMETERS WITH TOROIDAL MAGNET

An evaluation of the main parameters for a general set-up SM123 (see Fig. 6) to be used up to p_{inc} = 200 GeV/c is reported in the Table 1. There are three spectrometers

Table 1

Spectrometer			SM1	SM2	SM3
Magnet (coil in alluminium)	maximum radius	(cm)	116	206	206
	length	(cm)	1002	1002	848
	$B(R = 20$ cm$)$	(kG)	7.5	10	10
	accepted $\|\Delta t\|$ at p_{inc} = 200 GeV/c	(GeV^2)	0.4-14	22-180	220-374
	total current (continuous)	(kA)	754	1005	1005
	absorbed power (c.c.)	(MW)	4.76	3.39	3.90
	total weight of the coil	(t)	13.8	18.5	20.7
	cost of coil + support	(MSF)	0.70	0.95	1.30
	cost of power supply (0.1% stabilization)	(MSF)	0.95	0.65	0.65
Detectors	n^o of gas Cerenkov counters		2	1	1
	total length of "Cerenkov path"	(m)	36.5	4.5	1.5
	n^o of wires (planes) in the logic		7200(12)	5760(10)	8740(14)
	n^o of wires (planes) in the read out		13660(35)	18830(28)	26100(30)

SM1, SM2, SM3 with toroidal magnets M1, M2, M3 (with conventional coil in aluminium cooled by water) covering different and complementary solid angles : such an assembly is possible because of the property (a). The detection apparata consist of wire spark chambers and scintillation counters ; for $\vartheta \lesssim 26.5^{\circ}$ all the particles are also analysed in the gas Čerenkov counters $\check{C}_1$, $\check{C}'_1$, $\check{C}_2$, $\check{C}_3$ which allows a π/K separation up to $p^{cm} \simeq (0.4\text{-}0.5)\, p^{cm}_{max}$ at p_{inc} = 200 GeV/c (for example up to 80 GeV/c in spectrometer SM1) and are absorbed in "total absorbtion" telescopes S1, S2, S3 (of 8-10 collision lengths of thickness), in which only μ's survive ; also neutrons and γ's are detected and measured in these telescopes. The number of wires (and in parentheses the corresponding number of measurement planes) necessary for the complete analysis (ϑ, p and/or E measurements for all charged and neutral particles) is reported in the Table 1 in the hypothesis of $\Delta\varphi = 0.5^{\circ}$ hodoscopes (radial wires in the logic ; see for example moduli "L" in Fig. 7) and of $\pm$ 0.3 mm precision on R coordinate (printed circular wires in the read out ; see for example moduli "R" in Fig. 7).

The obtainable precision $\Delta p/p$ on p measurement is reported in Fig. 8 as a function of ϑ for two values of the magnetic field B(R=20 cm) and for the geometries of the set-up SM123 (geometry 1-lowers scales) and of a set-up where the distances of the magnets M1 and M2 from the target are doubled (geometry 2-upper scales) : in fact each spectrometer can be constructed and used separately and the distances of the magnet from the target can be changed for covering different solid angles.

For $p_{inc} \lesssim 100$ GeV/c the performance of the set-up SM123 becomes very good ; however a set-up of the same kind designed specifically for $p_{inc} \lesssim 100$ GeV/c would result in a much simpler and cheaper arrangement, especially for the detectors.

The use of superconducting or cryogenic magnets, possibly with pulsed power supply, would naturally improve the characteristics of the spectrometers, but a realistic evaluation of such a project depends stronghly on continuous technical progress.

Finally it is important to notice that the incident beam passes undisturbed through all the set-up and can be easly used after by other experiments ; also all of the very low $|t|$ products are undisturbed, so that a large amount of background of this type is avoided in the apparata.

4. PHYSICS

The set-up SM123, in its complete version, provides for considerable part of the physics that "Ω" can do at lower energy, excluding possibly processes with very low $|t|$ products. A single spectrometer of this set-up allows the analysis of particular processes; for example the SM1 spectrometer alone is a good instrument for the study of hyperon physics, of multiplicities and correlations in semi-inclusive processes, of asymmetries (like in μ-nucleon scattering), and in addition the study with high efficiency of elastic or quasi-elastic scattering in the region of intermediate t ($|t| = 0.1\text{-}3.5$ GeV^2 for p_{inc} = = 100 GeV/c) ; on the other hand the SM3 spectrometer is a good instrument for large ϑ recoil, particularly when $p^{cm} \lesssim 0.2\, p^{cm}_{max}$.

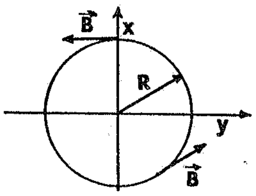


Fig. 1

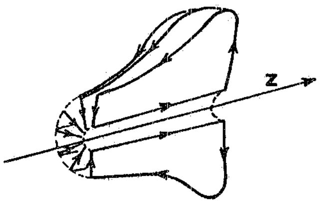


Fig. 2

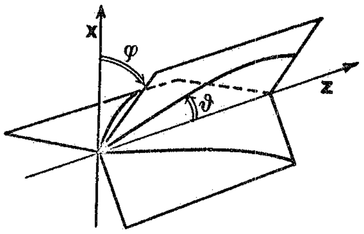


Fig. 3

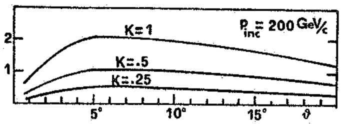
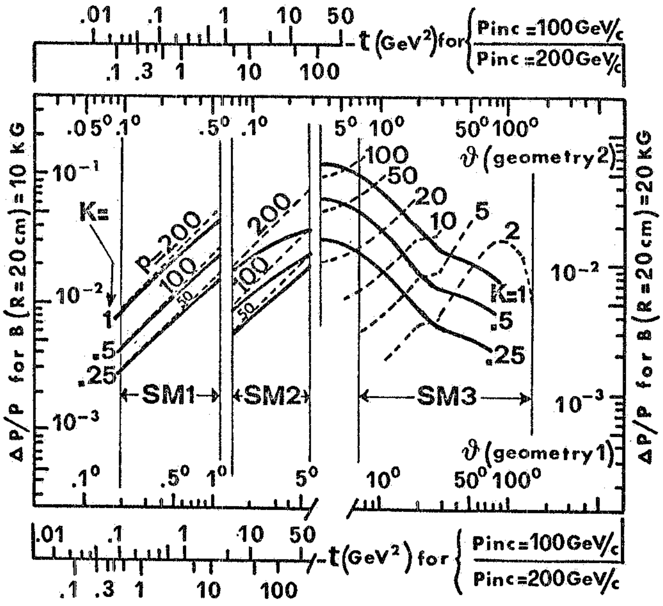


Fig.4– Ratio $\frac{\Delta p}{p}(\vartheta,K)/\frac{\Delta p}{p}(1.43°,K=1)$ – $K=p^{cm}/p^{cm}_{max}$



----- $\Delta p/p$ for some values of p

——— $\Delta p/p$ for some values of $K = p^{cm}/p^{cm}_{max}$

(p_{inc} = 200 GeV/c)

Fig. 8

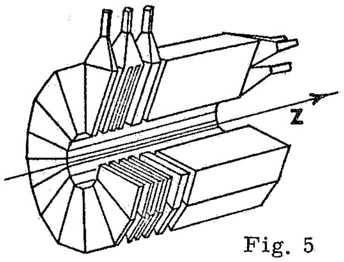


Fig. 5

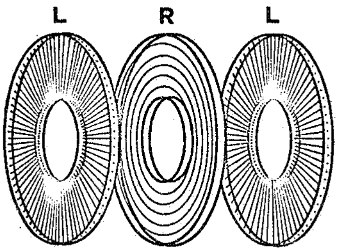


Fig. 7

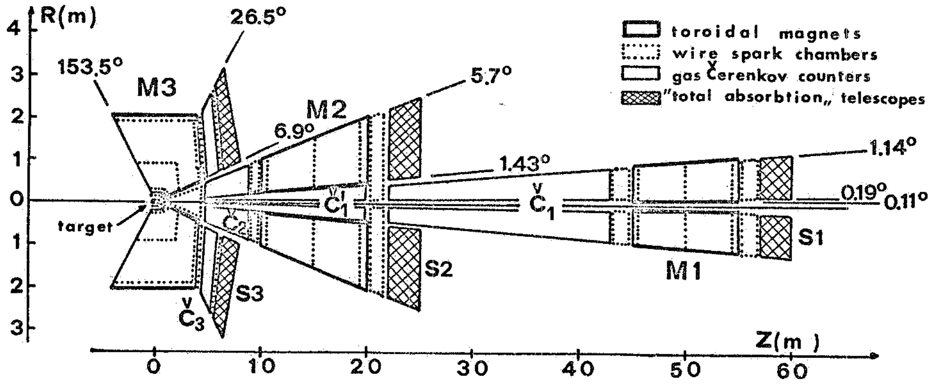


Fig. 6