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SPECTROMETERS FOR THE STUDY OF 2-BODY INELASTIC PROCESSES UP TO 200 GeV/c

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ABSTRACT

We have looked at some of the problems associated with the study of 2 body inelastic processes up to 200 GeV/c. Such processes are characterised by small cross-sections relative to the elastic scattering. It is important to be able to compare processes initiated by different incident particles. We discuss the construction of a general purpose detection system capable of studying many such processes. The main difficulty (relative to the study of elastic scattering) stems from the need for extremely good momentum resolution, scattered particle identification, and large solid angle acceptance. Most of this report is devoted to a discussion of a forward spectrometer which would fulfil these requirements. The question of an associated wide angle spectrometer is briefly considered.

Physics Possibilities

Apart from elastic scattering, the reactions most easily studied are those involving diffractive production of nucleon resonances eg

$$\pi p \rightarrow \pi N^*$$

$$Kp \rightarrow KN^*$$

$$pp \rightarrow pN^*$$

Because of relatively large backgrounds, and the close spacing in mass of some of these resonances, it is essential that the momentum definition on the forward meson (and incident beam) should be better than for a study of elastic scattering.

Reactions involving meson exchange present a further stage of difficulty because of the rapidly falling cross-sections. For example, one has

$$\frac{d\sigma}{dt}(\pi^+ p \rightarrow K^+\Sigma^+) = \frac{2.5}{p} \; e^{9t} \quad \text{mb}/(\text{GeV}/c)^2$$

(p in GeV/c)

The differential cross sections for elastic π^+p scattering has the same slope as a function of t but a <u>constant</u> forward cross-section of 30mb/(GeV/c)^2. Thus the ratio of this inelastic cross-section to the elastic is $\approx \frac{1}{12p}$.

In general, one has $\left(\frac{d\sigma}{dt}\right)_{t=o} \propto p_{LAB}^{\;b}$, where theoretically $b = 2\alpha(0)-2$. $\alpha(t)$ here refers to the leading Regge trajectory for meson exchange. In general, the experimental values of b (over the very limited range of p_{LAB} so far explored) agree reasonably well with the Regge expectation. Apart from the Pomeron exchange reactions ($b\approx 0$) one finds a range of values from -1.0 (eg for $\pi^+p \rightarrow K^+\Sigma^+$) to about -2.5.

The fall with energy is generally steeper for the u-channel processes ($-1.7 \geq b \geq -4.4$) because of the generally lower lying baryon trajectories

At u=0, $\frac{d\sigma}{du}(\pi^- p \rightarrow p\pi^-) = \frac{1}{10p^{1.6}} e^{4u}$ mb/(GeV/c)^2

The ratio to the forward elastic is thus $\frac{1}{290p^{1.6}}$.

One must therefore aim for large solid angle acceptance and excellent background rejection (since many background processes will, like the total cross-section, be independent of energy.).

Fig. 1 shows the estimated cross-sections for some typical reactions.

One would clearly like to design a spectrometer capable of defining these reactions (and many similar ones) with adequate momentum precision, and with adequate solid angle acceptance. The question of trigger rates and event definition is rather specific and one could expect to see some variation in the details of Cerenkov counters, proportional chambers etc which would be inserted into the basic spectrometer for particular experiments.

Technical Boundary Conditions

We take the point of view that a breakthrough in spatial resolution of maybe 2 orders of magnitude (to say ±5microns) is conceivable within the next few years. This possibility is particularly real in that one would then be discussing detectors for a forward spectrometer of size only ~10cm x 10 cm. In these circumstances one should avoid spending huge sums of money on giant magnet systems which may be rendered redundant.

Magnets which will be needed in any case are dipoles and quadrupoles for beam transport systems. We consider as a working boundary condition the need to use such magnets for all (or at least most) of the spectrometer system. A breakthrough in spatial resolution would not then create any redundant equipment, but merely release a modest number of elements for secondary beam lines.

Fortunately, as we shall show, the standard magnets are quite suitable for the construction of a spectrometer capable of many years of useful operation.

Table I lists the elements we have assumed to be at our disposal, with estimated costs. The lengths are unimportant- what matters is the total length tied up in a given spectrometer design. In addition to the standard elements (Q_1 and D_1), we have allowed ourselves to consider using a few superconducting quadrupoles Q_2, which will be shown to give a greatly improved solid angle acceptance.

We shall furthermore assume that the spectrometer shall be physically fixed in position, and that the required t range would be covered by vertical deflection of the incident beam[1]. A scheme for doing this is shown in Fig. 2. With standard magnets one easily achieves a range in momentum transfer of $2(\mathrm{GeV}/c)^2$. Horizontal deflection may conceivably be useful in special cases, as discussed later.

Fig. 3 shows the effective target size seen by the spectrometer as a function of t. We have assumed a target length of 1m and a beam spot of 2mm x 2mm. A significantly longer target would cause complications because of secondary interactions.

We assume for the present that spatial position is defined to 0.5 mm at any specified measuring plane. Momentum resolution is calculated without considering in detail the effects of multiple scattering, except for the case of the non focussing spectrometer. The insertion of differential Čerenkov counters in the body of the spectrometer may be unacceptable from the point of view of multiple scattering. We assume that the more massive detectors of this type would be located downstream of the momentum measuring spectrometer.

General Requirements

For a large range of 2 body processes, the kinematic variable which is most difficult to measure with adequate precision is the momentum of the forward going particle. For example, consider the process

$$\pi^+ p \rightarrow K^+ \Sigma^+$$

Assuming good Cerenkov identification of the forward K^+, the most serious background comes from

$$\pi^+ p \rightarrow K^+ \quad \Sigma^+(1385)$$

The cross-sections for these two processes are similar. The recoil decay products are

$$\Sigma^+ \rightarrow p\,\pi^0 \quad (\text{or } n\pi^+)$$

$$\Sigma^+(1385) \rightarrow \Lambda\pi^+$$

$$\qquad\qquad\quad \hookrightarrow p\,\pi^- \text{ or } n\,\pi^0$$

Because of the unmeasurably short decay lengths, (not always true for Σ^+) we do not know the hyperon direction before decay. It is impossible to resolve the reaction kinematics by studying just the charged decay products.

Because the forward meson is the direct product of the primary interaction, it can be used to fully define the reaction. Kaon identification is of primary importance, because the reactions kinematics is faked by $\pi p \rightarrow \pi \Delta$ etc. Secondly one needs adequate angular and momentum resolution to define the missing mass in $\pi^+ + p \rightarrow K^+ + X$.

To give reasonable background rejection, the standard deviation on measured $(MM)^2$ should be about 0.1 $(\text{GeV})^2$ or better. At 200 GeV/c incident momentum, this implies $\sim$ 0.1 mradian angular resolution and $\sim$ 0.02% momentum resolution. Such figures are typical for 2-body reactions at 200 GeV/c and may be taken as the general requirements for a forward spectrometer. Poorer resolution would of course be acceptable for elastic scattering and some diffraction production processes. There are other reactions which can be studied with a recoil spectrometer alone. These fall outside the scope of this report.

Non Focussing Spectrometer

With fixed magnet aperture and some specified momentum resolution, the best solid angle acceptance is obtained by packing the magnets immediately after the target, with position measurement extending well downstream of the last magnet. Without much loss in solid angle, one can obtain the safer and more commonly used layout in which the particle direction is defined before and after bending. Such an arrangement is shown in fig. 5(a) The rays shown are, in the vertical plane, rays for $y=0$ (continuous) and $y=+1$ cm(broken). In the horizontal plane, rays from $x=0$ and $p=p_o$ (continuous) (the central momentum, shown as straight), and $p= p_o+0.5\%$ (broken). We make the assumption here and in what follows that the target size in the x-direction may be neglected from the point of view of spectrometer acceptance calculation.

Given measuremnts of y at planes V_1 and V_2, and of x at H_1 to H_4, we achieve the desired momentum resolution (0.02%) with $\Delta x=0.5$mm.

Degradation in the momentum resolution is caused by material between H_1 and H_4. We assume that this consists of

a) helium gas at atmospheric pressure.

b) two mylar windows of thickness 0.05 mm each, in position of H_2 and H_3.

c) four wire planes of standard spark chamber type (0.1 mm diameter Cu-Be wires at 1mm intervals) in position of H_2 and H_3.

The implied momentum resolution from multiple scattering in this setup then becomes 0.010% (standard deviation) for particles of 200 GeV/c. Thus the bare spectrometer (free of scintillators and differential Cerenkov counters) does not suffer seriously from multiple scattering effects. The same holds for the focussing spectrometers discussed in the following sections.

The non-focussing spectrometer suffers from the obvious deficiency of very small solid angle acceptance at the target centre ($x=0, y=0$), but this is somewhat offset by the fact that the acceptance is only a slow function of y. Fig. 7 shows the acceptance as a function of y and δp (ie for particles with momentum $p_o+\delta p$). It is clear that one would happily sacrifice some of the y and δp coverage (both of which are far larger than necessary) if one could achieve greater solid angle acceptance at $y=0$, $\delta p=0$. As previously mentioned, target lengths much greater than 1 metre give many complications (including problems with coverage of wide angle particles) so the large y-acceptance of this spectrometer is essentially useless.

These arguments lead us to consider the focussing spectrometer for the forward particles.

Fully Focussing Spectrometer

The general ideas behind the focussing spectrometer may be listed as follows.

a) Set of quadrupoles close to target to obtain good solid angle acceptance and point to parallel optics.

b) Part of parallel optics drift space can be utilized for differential Cerenkov counters where the reduced divergence is very advantageous.

c) The remainder of the parallel optics region carries the particles through a string of dipoles for momentum dispersion.

d) A final set of quadrupoles forms a momentum dispersed image of the source in the focal plane Xp.

e) If the source is sufficiently small (small beam spot; and short target or very small scattering angles), the measurement of momentum may be made purely by using an x hodoscope in plane X_p.

f) The optical properties of the spectrometer then allow one, by suitable x and y measurements downstream of the final quads, to determine all the parameters of the scattered particle viz vertical angle y', horizontal angle x', as well as the momentum p. Thus one eliminates the need for hodoscope planes close to the target, where the intensity conditions may forbid the use of such detectors.

We consider a focussing spectrometer which could utilise some or all of these features.

Wilson[2] has discussed various arrangements of quadrupole doublets and triplets to achieve point to parallel optics in both planes, with maximum solid angle acceptance. Defining α_H and α_V as the horizontal and vertical angular ranges accepted by the quadrupole system, one finds that the doublet generally gives a very asymmetrical acceptance; typically $\alpha_H/\alpha_V \sim 7$ (or 1/7). In contrast, quadrupole triplets can be arranged in several ways to give completely symmetrical acceptance ($\alpha_H = \alpha_V$) and nearly as large a solid angle acceptance as a doublet using the same total length of quadrupole elements. The details of the choice would be dependent on other features of the spectrometer, but a generally useful arrangement would consist of a triplet of equal-length elements, for which the solid angle acceptance can be made equal to 76% of the optimised doublet acceptance. We assume the use of such a triplet in the present discussion.

The use of the drift space for differential Cerenkov counters is an attractive possibility, but one which may be ruled out if the full momentum resolution is needed. The region concerned is the worst in the spectrometer for degrading the momentum resolution by multiple scattering.

In focussing spectrometer, K L Brown has shown[3] that the momentum dispersion in the focal plane is given by

$$D_x(s) = - C_x(s)\int_0^s h(s')S_x(s')d\,s'$$

where s' is the distance from the target along the central trajectory, $h(s') = 1/\rho(s')$ is the curvature of the central ray at s'. $C_x(s')$ and $S_x(s')$ are the first order coefficients in the Taylor's series expansion for the particle trajectory with respect to the central ray; $x(s') = C_x(s')x_0 + S_x(s')x'_0 + D_x(s)\delta p$. C_x and S_x are thus the usual cosine-like and sine-like functions of beam optics.

The formula implies that the bending elements should be located in regions where the sine-like function is near maximal. Thus the parallel region is good, but some or all of the dipoles could be located downstream of the final quadrupoles, if the focal length is not too short.

If one is using the spectrometer with no upstream detectors, the final focal length should not be much longer than the first focal length, or the finite target size will be seriously magnified.

We have considered an arrangement using iron cored quadrupoles (three for each quadrupole triplet) and another arrangement using superconducting quadrupoles. Fig 5(b) shows the arrangement of elements for the latter case, and some typical trajectories. The conventions are the same as for Fig 5(a).

In the ideal case where x_o is negligible, the relevant trajectory parameters are given uniquely by position measurements in suitably placed downstream hodoscope planes:

y_o by measurement of y at V_1
y'_o by measurement of y at V_2
δp by measurement of x at H_1
x'_o by measurement of x at H_2

The arrangement shown gives a momentum dispersion of 0.1% per mm at H_1.

The use of exclusively downstream measuring planes has a disadvantage in making the system very tight with regard to quadrupole and dipole aberrations. At the highest energies where intensities are low, so that upstream detectors may certainly be used, they would provide the double advantage of allowing long targets and reducing the seriousness of aberrations. These advantages may be important since it is at the highest momenta that the best momentum resolution is needed.

There are possible problems associated with the location of differential Cerenkov counters in the parallel region. Not only are there multiple scattering problems, but there are possibly high rates of false flagging because of the large number of particles (from high multiplicity events) which may traverse these counters simultaneously. Such effects are to be reduced in the NAL spectrometer by the use of a sweeping magnet immediately after the first set of quadrupoles. This problem forms part of the general question of producing an adequately selective trigger. It is clear that one should not try to go very far towards solving it at present, but learn from experience, studying first the channels with larger cross-sections. It may eventually prove necessary to extend the spectrometer with a second point-to-parallel stage, for downstream location of differential Cerenkov counters. One would in any case expect to use threshold counters upstream and downstream of the momentum focus.

A worrying feature of the focussing spectrometer is the dumping of the beam in the front quadrupoles. It would be very desirable to design them so that the beam could pass thrugh, possibly to be subsequently pulled away with a septum magnet.

It has been pointed out by Ritson[1] that one may reach secondary beam intensities where only differential Cerenkov counters can be used in the region of the beam. Then the definition of incident particle momentum becomes a serious problem, which could be overcome by running the beam in a mode to produce a momentum dispersed (rather than recombined) image at the experimental target. The focussing spectrometer could then produce a momentum recombined image, and particles with reduced momentum as a result of scattering processes would appear in the plane H_1 in a position (x) directly related to their momentum loss. One could then consider running on say incident K^- with an impossibly hot negative beam by normal standards.

In Fig. 8 we plot the solid angle acceptance for the focussing spectrometer with superconducting quadrupoles (continuous curve) and iron cored quadrupoles (broken curve). The iron cored quads give about 16 times the solid angle acceptance of the non focussing spectrometer, and the superconducting quads give a factor 4 above that.

In Fig 4 we plot the acceptance relative to the kinematic bands. The advantage of the triplet relative to the doublet configuration is clear.

The fall in acceptance with y or δp (Fig.8) is reasonably well matched to the requirements from the incident beam and projected target size (Fig.3).

However, it is necessary to consider not only the spread in beam momentum, but also the momentum shift through the angular range covered due to the kinematics of the process being studied. For high energy scattering processes off hydrogen at small $|t|$ one has

$$p_s \approx p_{so} - |t|/2$$

where p_s = lab momentum of forward scattered particles

p_{so} = momentum for scattering at 0°.

$|t|$ = 4-mom transfer squared (substitute $|u|$ for u-channel processes)

If the spectrometer acceptance is over an angular range $\delta\theta$ at some angle setting θ ($\gg \theta$), the above equation leads to a momentum variation Δp_s through the spectrometer aperture of

$$\frac{\Delta p_s}{p_s} \approx p_s \, \theta \delta\theta$$

If the spectrometer optics are held constant as the incident momentum is increased, this indicates that the relative momentum spread of particles within the angular acceptance will <u>increase linearly with momentum</u>. At some stage $\frac{\Delta p_s}{p_s}$ will match the acceptance $\frac{\delta p}{p}$ of the spectrometer, and thereafter the solid angle acceptance for events of interest will fall rapidly.

Notice that if the selected scattering angle θ is decreased as the momentum is increased so as to hold the selected <u>momentum transfer</u> constant ($p\theta$=constant) then the "kinematic momentum spread" $\frac{\Delta p_s}{p_s}$ is independent of momentum ($\frac{\Delta p_s}{p_s} = \sqrt{|t|} \, \delta\theta$)

In the spectrometer considered here, we have $\delta\theta \approx 10^{-2}$, and $\frac{\delta p}{p} \approx \pm 10^{-2}$, so that the effect of kinematic momentum spread becomes significant only for $|t| \gtrsim 1 (\mathrm{GeV}/c)^2$.

It is clear that the focussing system with superconducting quadrupoles provides excellent acceptance for the study of very low cross-section processes at the highest energies. For example, suppose that the SPS eventually produces 2×10^6 π^+/second at 200 GeV/c. We could measured $\pi^+ p \rightarrow K^+ \Sigma^+$ with a 1m target out to large $|t|$ values. eg in a bin of $\Delta t = 0.2$ $(GeV/c)^2$ at $|t| = 1 (GeV/c)^2$ the cross-section might be 3×10^{-34} cm^2. This would give a rate in the spectrometer of about 50 events/day.

The spectrometer would be of great value in the study of u-channel processes at high energy.

For purposes of visualization, a scale layout of the fully focussing spectrometer is shown in Fig. 6. A striking advantage of the device is the very compact distributions at the measurement planes. For example, the entire spectrometer could operate with a wire chamber system of $\sim 10^3$ wires (as against several times 10^4 wires for a comparable spectrometer for 10 GeV/c).

It should ne noted that we have so far considered the spectrometer as a fixed optics device, independent of momentum. In practice one would like to use a string of short quadrupoles at the front end whose function could be changed (including turning them off) as the momentum is reduced. In this way the solid angle acceptance could be progressively increased at lower momenta.

Partially Focussing Spectrometer

In Fig 5(c) we illustrate a possible hybrid arrangement where the front quadrupoles alone are used to give the needed solid angle acceptance, but beyond that it consists of just a series of dipoles. The solid angle acceptance (Fig.9) is very similar to that of the focussing device.

This arrangement has the advantage that (apart from the effect of momentum dispersion) the nearly parallel optics is preserved after the momentum determination. This would facilitate the provision of downstream threshold and differential Cerenkov counters.

Wide Angle Detection System

For some processes (particularly those corresponding to 2-body diffraction scattering) it is expected that the forward spectrometer alone will be adequate.

Other processes, though of very low cross-section, may be easily isolated because of some characteristic features . For example, u-channel processes having a super-momentum forward baryon and a meson going backwards in the laboratory, give a very clear signature. In such cases momentum analysis of the recoil particle may be unnecessary, and the target region may simply be equipped with spark chambers, scintillation counters, large threshold Cerenkov counters etc; the usual arrangment for studying u-channel processes.

Nevertheless it is clear that a wide aperture magnet for momentum analysis of the recoil particles will be essential for many experiments. At this stage one begins to be embarassed by the fact that in the proposed arrangement with vertical beam deflection the coplanar events at finite $|t|$ or $|u|$ have recoil particles which on average travel vertically upwards. The obvious way to avoid this is to obtain the desired angular range by horizontally deflecting the incident beam, rather than vertically. The first objection to this (increased projected target length horizontally, leading to worse momentum resolution) disappears if one is able to measure the position of the forward particle just downstream of the target. However, even in this case, there is a complication because the loss of acceptance from finite projected target lengths now takes place in the same plane as the loss due to the momentum spread. Thus if these effects separately are near the limit of acceptance, they will combine to give a considerable loss in this case, in contrast to the situation where the effects are separated into the vertical and horizontal planes.

These comments suggest that the incident beam on the target should be left as flexible as possible, maybe with the small deflecting magnets capable of being mounted to give either vertical or horizontal deflection. The optimum arrangement for any experiment will depend on several factors, including the recoil particle detection system.

Regarding the choice of magnet for the recoil spectrometer, it is clear that the large aperture magnets currently in common use would be quite adequate for most purposes. They satisfy the requirement of reasonable solid angle coverage for targets of $\sim$1m length. Momentum resolution which can be achieved with normal detectors is entirely adequate for the low momentum particles picked up at wide angles.

Conclusions

The results of this study show that the low cross-section 2-body processes would be best studied at high energy using some form of focussing spectrometer. The system described would allow the study of many such processes over a wide momentum transfer range. The argument for using superconducting quadrupoles is strong, but they would not be essential in the early days of 300 GeV exploration.

The possible advantage of the fully focussing spectrometer over the half-focussing spectrometer, given by the elimination of upstream detectors, may not be very strong. However, there would be an advantage in the intermediate energy region where intensities should be extremely high. The fully focussing spectrometer would be even further enhanced in this situation if used in the momentum loss mode.

The cost of the spectrometer described here would be about 14 MSw.Fr. A more modest setup using iron cored quadrupoles could be built for about 6 MSw.Fr, but such a system might not be adequately competitive with the NAL system. Currently the NAL spectrometer has an acceptance of only 5 μster at 200 GeV/c, due to poor quality quadrupoles, but it may well be improved before the SPS is operational. Regarding these cost estimates, it should be emphasized that the spectrometer consists of general purpose elements which would be used beyond the life of the spectrometer as a whole.

We would advocate the construction of the most flexible possible system, which would consist of a fully focussing spectrometer of this type, if possible with superconducting quadrupoles. Such a device should be reinforced by various wide angles detection systems as demanded by different experiments. As such it should have a useful life of many years. A question which should be actively pursued is the arrangement of Cerenkov counters in or downstream of the spectrometer. It is conceivable that one should build a further point to parallel stage for Cerenkov counters after the momentum focus.

Acknowledgements

We gratefully acknowledge discussions with David Ritson and John Litt regarding the NAL focussing spectrometer system, and with Alan Carne

regarding details of superconducting quadrupoles.

References

1. D M Ritson, private communication, and NAL proposal No. 96.
2. E J N Wilson CERN/ECFA 67/16 Vol. II (30 May 1967) p.256 & 279.
3. K L Brown, SLAC/TN-64-18, 1964.

TABLE I   SPECTROMETER ELEMENTS

Element	Symbol	Useful Diameter	Aperture HxV	Length	Max Field(T) or Gradient(T/m)	Cost
		cm	cm	m		MSwFr
Iron Cored Dipole	D_1		10x10	5	1.5	0.60
Iron Cored Quadpole	Q_1	10		3	20	0.24
Superconducting Quadrupole	Q_2	10		3	80	1.50

The lengths assumed are purely nominal.

The cost figure includes power supplies and cooling for the iron cored magnet, and refrigeration for the superconducting quadrupole. However, cost estimates for superconducting elements are rather tentative at this stage. In particular, refrigeration becomes much cheaper if it is adopted on a large scale. Also, the cost of constructing iron cored magnets in Europe seems to fluctuate up and down by a large amount from year to year.

FIGURE CAPTIONS

FIG 1 Estimated cross-sections for various reactions at $\theta_{LAB}=0$, as a function of incident lab momentum.

FIG 2 Possible Dipole layout to provide a momentum transfer range of 2 $(GeV/c)^2$ for the spectrometer.

FIG 3 Effective target size seen by the spectrometer for various settings of the selected momentum transfer.

FIG 4 (a) Kinematic bands corresponding to different t values for p_L = 50 GeV/c. Also shown is the solid angle acceptance of the superconducting triplet (in the configuration tunable for 200 GeV/c operation) and a corresponding iron cored triplet of quadrupoles. (b) Equivalent plot for p_L=200 GeV/c.

In addition to the superconducting triplet acceptance, we show the case of a doublet arranged for maximum acceptance.

FIG 5 (a) Layout and particle trajectories for a non-focussing forward spectrometer. (b) and (c) show similar plots for the fully-focussing and half-focussing spectrometers.

FIG 6 Scale layout of the fully focussing forward spectrometer.

FIG 7 Solid angle acceptance for the non-focussing spectrometer as function of y (for $\delta p/p=0$) and of $\delta p/p$ (for y=0). Both curves refer to x=0.

FIG 8 Equivalent curves for the fully focussing spectrometer. The solid curve relates to superconducting quadrupoles, the broken curve to iron cored quadrupoles.

FIG 9 Equivalent curves for the half-focussing spectrometer with superconducting quadrupoles.

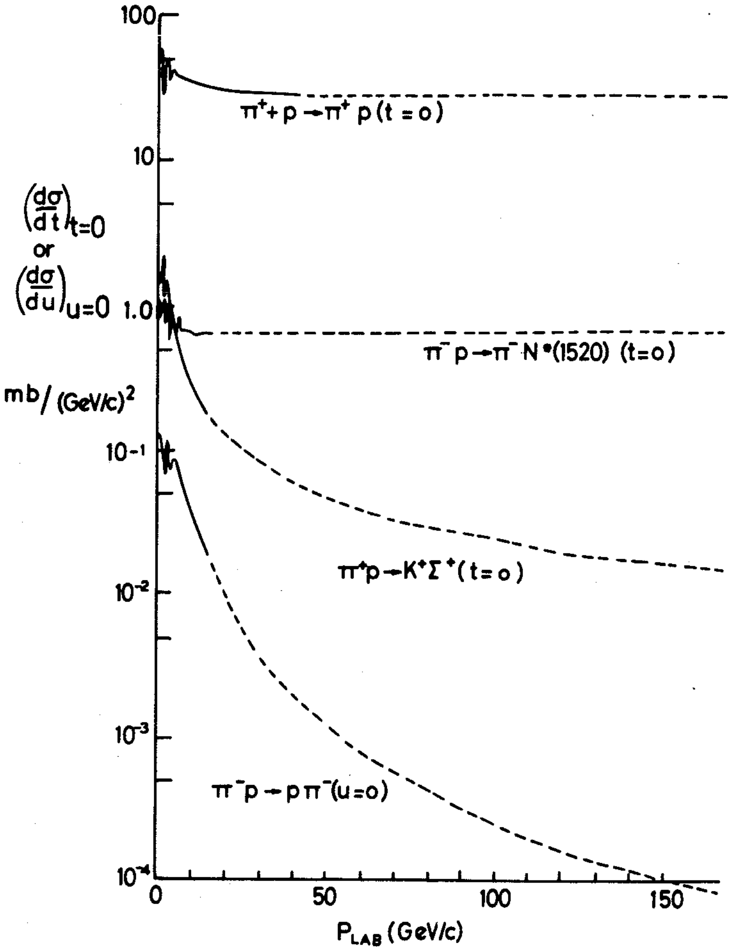
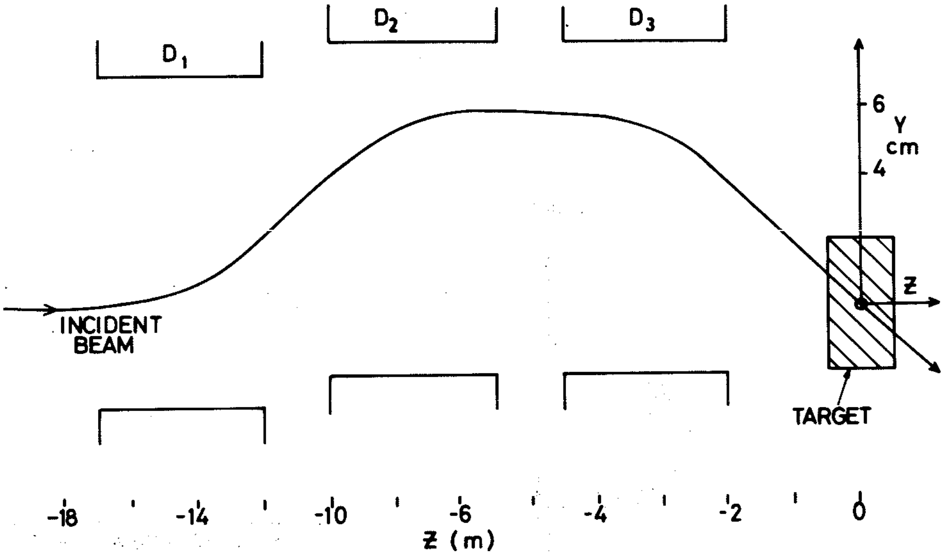

100
10
1.0
10-1
10-2
10-3
10-4
$\left(\frac{d\sigma}{dt}\right)_{t=0}$ or $\left(\frac{d\sigma}{du}\right)_{u=0}$
mb/(GeV/c)^2
$\pi^+ + p \to \pi^+ p$ (t = o)
$\pi^- p \to \pi^- N^*(1520)$ (t=o)
$\pi^+ p \to K^+ \Sigma^+$ (t = o)
$\pi^- p \to p \pi^-$ (u=o)
0
50
100
150
P_{LAB} (GeV/c)

Fig 1



CASE SHOWN: $P_L = 50$ GeV/c
$|t| = 2$ (GeV/c)^2

Fig 2

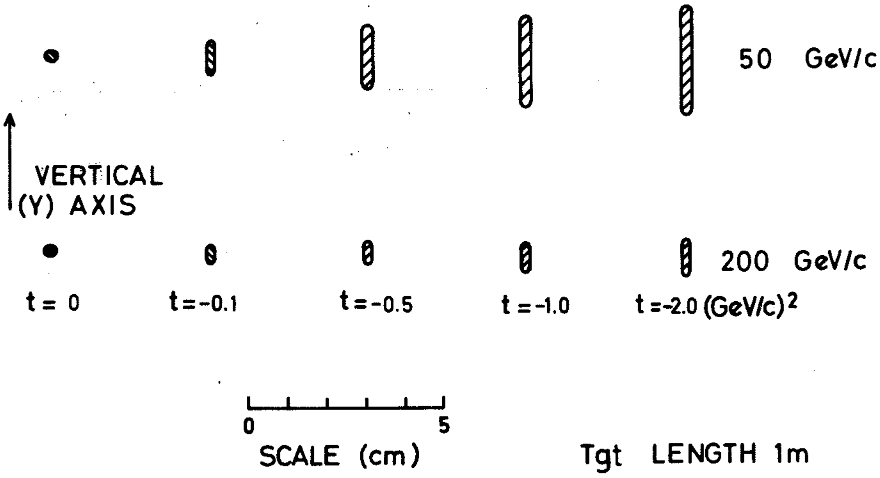


Fig 3

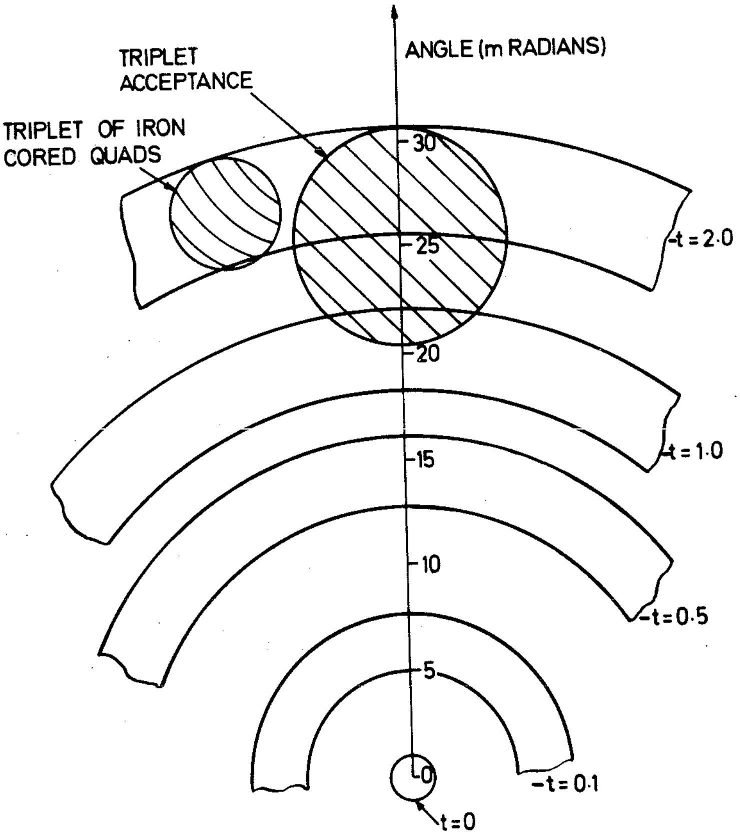

ANGLE (m RADIANS)
TRIPLET ACCEPTANCE
TRIPLET OF IRON CORED QUADS
30
25
20
15
10
5
0
-t = 2.0
-t = 1.0
-t = 0.5
-t = 0.1
t = 0

Fig 4(A)

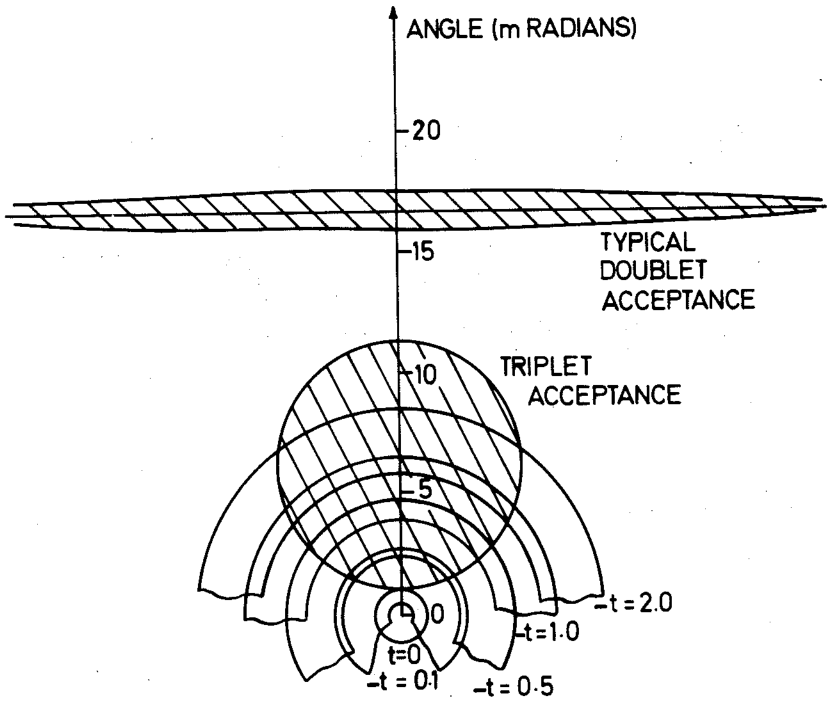

ANGLE (m RADIANS)
20
15
TYPICAL DOUBLET ACCEPTANCE
10
TRIPLET ACCEPTANCE
5
0
-t = 2.0
-t = 1.0
t=0
-t = 0.1
-t = 0.5

Fig 4(B)

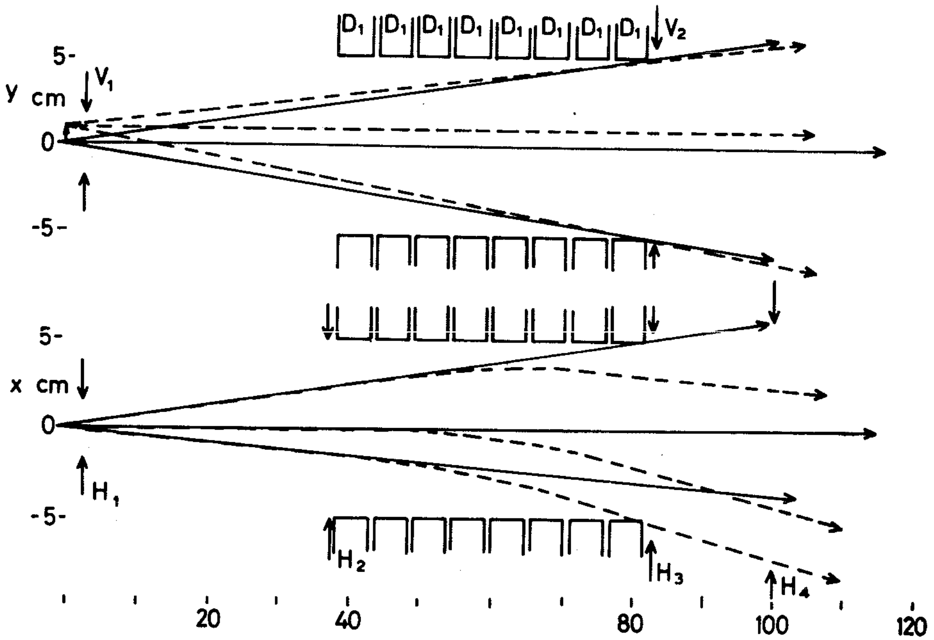

D1
D1
D1
D1
D1
D1
D1
D1
V2
5-
y cm
V1
0
-5-
5-
x cm
0
H1
-5-
H2
H3
H4
20
40
80
100
120
S (m)

Fig. 5(A)

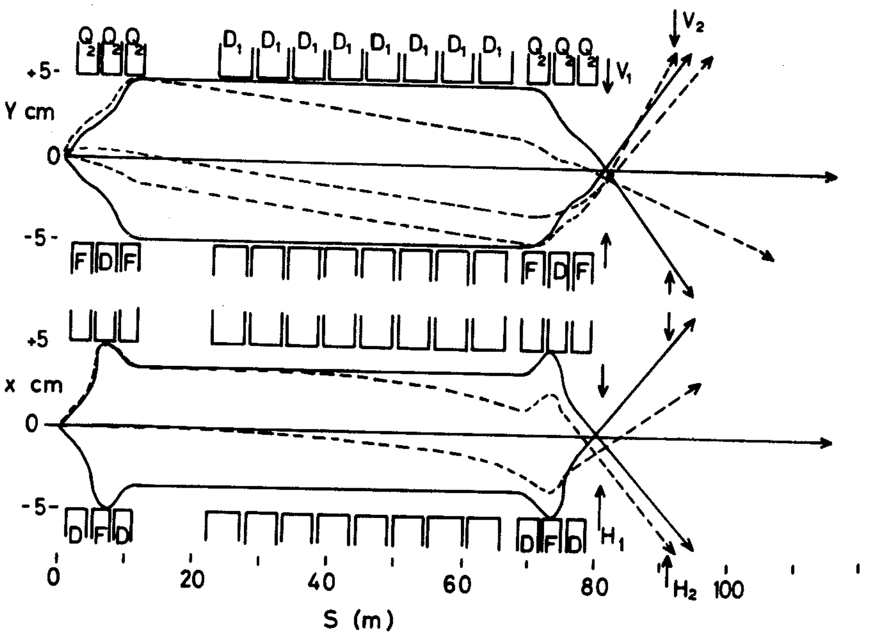
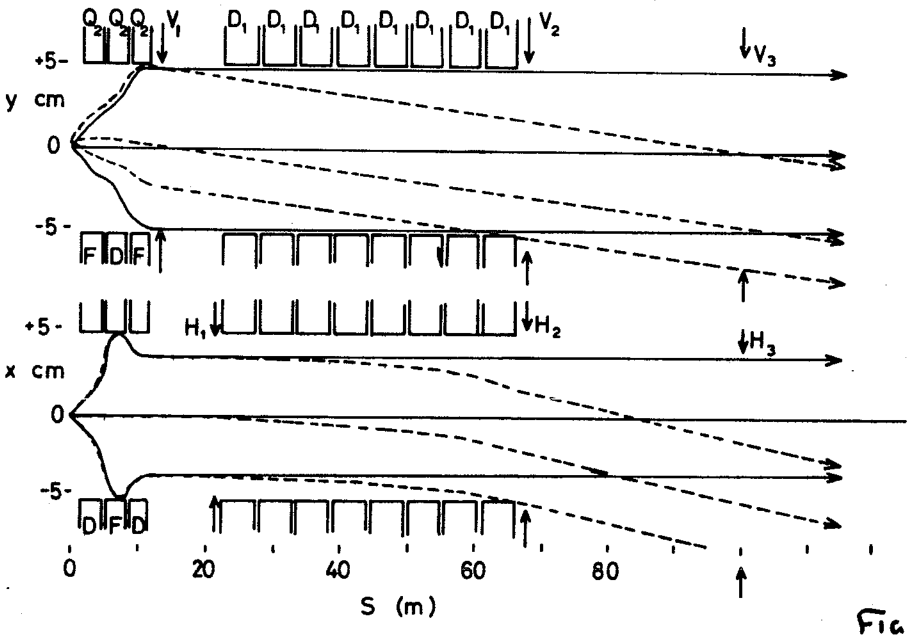
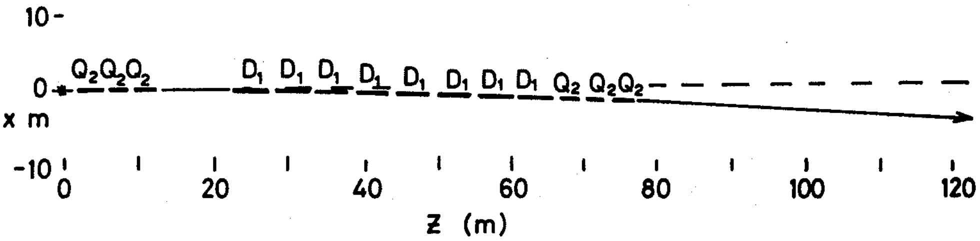

Q2
Q2
Q2
D1
D1
D1
D1
D1
D1
D1
D1
Q2
Q2
Q2
V1
V2
+5-
Y cm
0
-5-
F
D
F
F
D
F
+5
x cm
0
-5-
D
F
D
D
F
D
H1
H2
0
20
40
60
80
100
S (m)

Fig. 5(B)



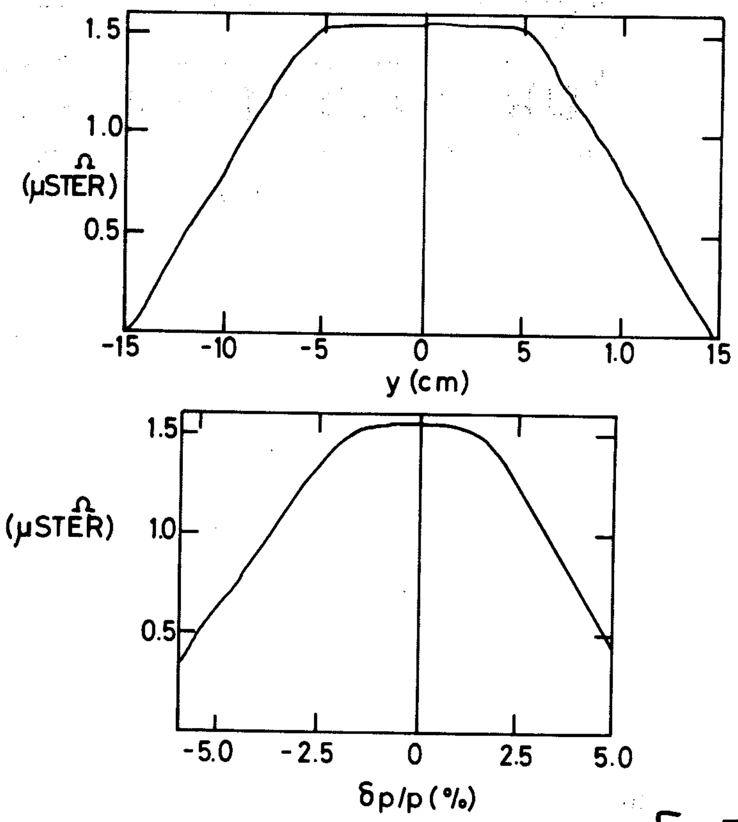
Q2 Q2 Q2
V1
D1 D1 D1 D1 D1 D1 D1 D1
V2
V3
+5
y cm
0
-5
F D F
+5
H1
H2
H3
x cm
0
-5
D F D
0
20
40
60
80
S (m)

Fig 5(c)



10
0
x m
-10
Q2 Q2 Q2
D1 D1 D1 D1 D1 D1 D1 D1
Q2 Q2 Q2
0
20
40
60
80
100
120
Z (m)

Fig 6



1.5
1.0
Ω
(μSTER)
0.5
-15
-10
-5
0
5
1.0
15
y (cm)
1.5
Ω
(μSTER)
1.0
0.5
-5.0
-2.5
0
2.5
5.0
δp/p (%)

Fic 7

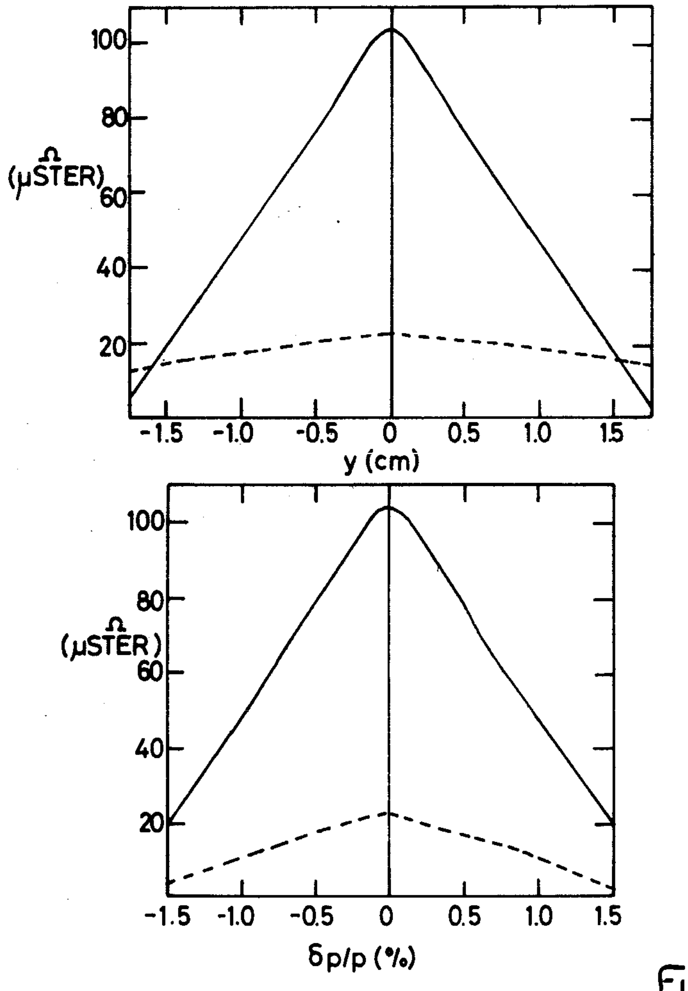

100
80
Ω (μSTER)
60
40
20
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
y (cm)
100
80
Ω (μSTER)
60
40
20
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
δp/p (%)

Fig 8

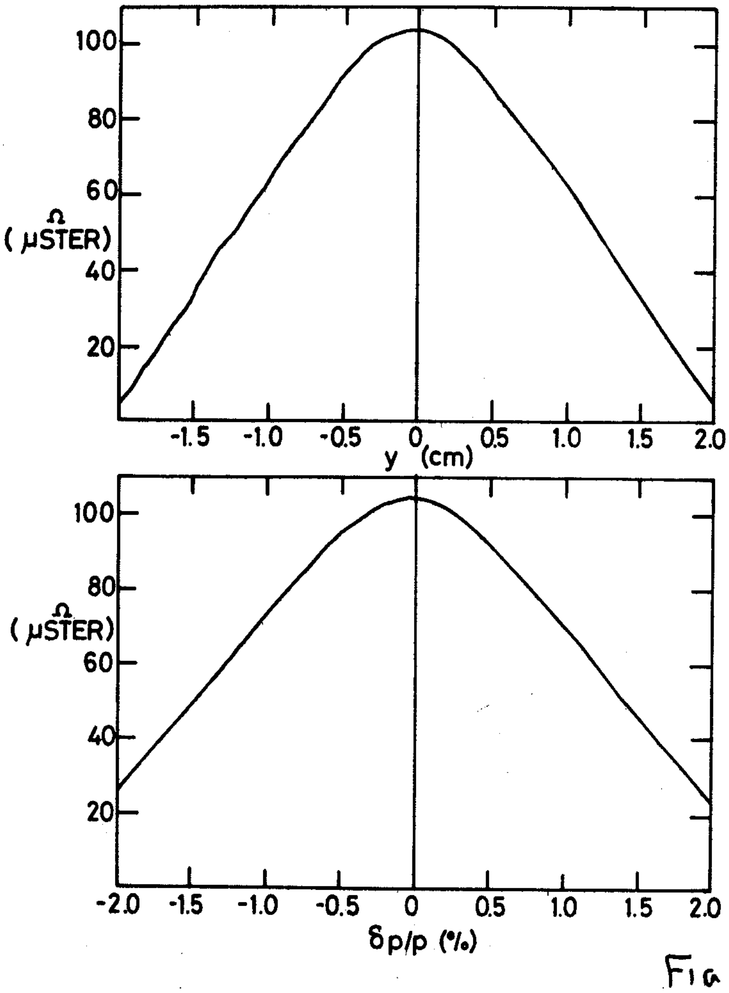

100
80
60
Ω (μSTER)
40
20
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0
y (cm)
100
80
Ω (μSTER)
60
40
20
-2.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0
δp/p (%)

Fig 9