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EXPERIMENTS IN THE FRAGMENTATION REGIONS *

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I. SCOPE OF WORKING GROUP

The fragmentation region is generally defined as the rapidity range where most of the valence partons of the incoming hadrons (or nuclei) are found after normal inelastic interactions. In contrast, the central rapidity region is dominated by hadrons made of sea partons. Shown in Fig. 1 is a schematic representation of the expected rapidity distribution of the net baryon number after an inelastic nucleus-nucleus collision[1] together with the measured rapidity distribution of excess protons in $\alpha\alpha$ collisions at the ISR.[2] As a practical definition, we will define the highest three units of rapidity, i.e., $y_B - 3 < |y| < y_B$ to be the fragmentation region, where y_B is the beam rapidity. This region with a net baryon number greater than 0 is where a baryon-rich quark-gluon plasma would be expected and, especially near $y = y_B$, where exotic nuclear states would be formed. Of course, one of the first experiments to be performed would be to see whether the schematic separation of baryon rich regions as seen in Fig. 1 is in fact found in nucleus-nucleus collisions.

Specifically, experiments in the fragmentation region with 100 GeV per nucleon colliding beams should cover the following range in longitudinal momenta (or rapidity):

$$2.5 \leq |y| \leq 5.7$$

$$5 \leq |p_L| \leq 150 \text{ GeV/c}$$

$$0.05 \leq |x_F| \leq 1.5$$

MASTER

Valence quarks are found to dominate even at lower rapidities in hard interactions (for high p_T), but detailed consideration of such interactions are considered to be outside the scope of this working group in that they can be covered by a central detector.

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The fragmentation region poses some special problems for the design of the beam intersect region as well as for detectors. The large rapidity of the particles of interest means that they are emitted very close in angle to the beam so that long distances must be available to allow for sufficient spatial separation from beam particles. Fortunately the task is somewhat eased because the heavy ion beam rigidity is about a factor of 2 greater than that of singly-charged nucleons with the same momentum per nucleon. It would appear that the narrow angle hall at RHIC is the most suitable location for studies in the fragmentation region.

In the following report the disadvantages of the existing intersection region for fragmentation region studies are discussed and a slightly modified design, which allows study of the fragmentation region, is proposed. The considerations which led to the design of a spectrometer magnet are then outlined and some approaches to specific experiments are detailed. Although we have emphasized a design for stand-alone experiments in the fragmentation region we have envisaged the addition of a more global detector in the central region. In combination with a central detector covering the rapidity range $0 < |y| < 2$ two forward spectrometers for the fragmentation regions would give essentially a 4π detector for investigations aiming at the maximum information on event properties.

II. INTERSECTION REGION DESIGN

In Fig. 2a half of the standard crossing region is shown.[3] The intersect of the beams is at the right of the picture at 0 m. The two bending magnets BC2 serve to bring the two beams from their separate orbits to crossing. BC1 is needed to vary the crossing angle ψ, which for Fig. 2a is $\psi = 0$. The luminosity is largest for the smallest crossing angle, but the penalty is a large longitudinal extent of the intersection diamond (see G. Young's talk in these proceedings). The design in Fig. 2a is optimum if one wants a large free space around the intersect (± 10 m) for a central region detector. However, the high momentum particles of the fragmentation region are emitted at small angles with respect to the beams and will not separate sufficiently from the beam in the space before BC1. For example, a 50 GeV particle with $P_T = 0.5$ GeV/c would separate only 10 cm from the beam at the edge of BC1. The dispersive power of BC1 would help to separate particles with rigidity different from the beam, but its aperture and the distance to BC2 are too small to effectively exploit this feature. Another problem is that although high momentum neutrons and photons come out between the two beam tubes after BC1, the free space between them is too small to fit a useful detector.

A possible solution to overcome these problems is to move BC1 closer to the intersection region (see Fig. 2b). This increases the distance between BC1 and BC2 and allows the following modifications to the standard lattice. There is a larger free space region following the dispersing BC1 and the distance between the two BC2 magnets is increased so as to allow a calorimeter to be placed between the beam tubes prior to BC2 to detect neutrons and/or π°. This solution is not a major modification to the lattice, and it achieves the goal of bringing high momentum particles out of the beam pipe. However, the small aperture of BC1 (20 cm) causes experimental problems for both acceptance and the possibility to analyze low momentum particles, so we turn to a conceptual design of a magnet to replace BC1. We retain the suggested increase of the distance between the centers of two BC2 magnets (about 1 m).

III. SPECTROMETER MAGNET DESIGN

A spectrometer magnet for the momentum range $5 < p < 150$ GeV/c at a hadron collider should not be much different in scale from that employed in fixed target experiments at the CERN SPS or the Fermilab accelerators. It is common in fixed target experiments to have several spectrometer magnets to achieve good momentum resolution and acceptance for low and high momentum particles. However, the multi-magnet concept leads to long spectrometers which generally cannot be accomodated at a collider where there is limited space downstream of the intersection vertex. Likewise, the bending power of the magnet(s) at a collider should be stronger than that at a fixed target facility.

These considerations have led us to propose a single long dipole magnet with a large integrated bending power B•L (similar to that of the standard BC1), but with moderate field strength in order to facilitate momentum analysis in the lower momentum range. For field strengths of 1.8 T the magnet should be about 10 m long so that the beams are bent correctly to continue in the lattice and so high momentum particles will be swept out of the beam tube. The aperture of the magnet is determined by the condition that there is 100% geometrical acceptance for particles at the lower end of the desired momentum range (5 GeV/c). The front end of the magnet is envisaged to be placed 2 m from the intersect so as to allow a central detector to be added. The additional requirement that a 5 GeV/c particle travel 2 m in the magnetic field leads to a vertical gap of about 1 m. The horizontal gap should be somewhat larger.

A magnet with a cross section as sketched in Fig. 3 and a length of 10 m would have the desired properties. The precise dimensions of this L4 magnet (Long, Large aperture, Low field, Long Island) may change according to specific physics goals, money and space constraints, but we have used these dimensions to obtain cost estimates. The requirement on momentum resolution is not severe; we choose $\Delta p/p = 1\%$ which would allow for particle interferometry if desired.[4]

Tracking would be needed in L4, and external spectrometers are needed for particle identification. This is not a problem for the highest energy particles (greater than 25 GeV) because the magnet wall does not interfere, and the narrow angle hall has enough space (Fig. 4). However, in order to identify the lower momentum particles, portals will be needed in the sides of the magnet as shown in Fig. 5.

IV. TRACKING IN L4

The total multiplicity at the entrance of the magnet is expected to be enormous (about 1000 charged particles for Au + Au at 100 GeV/A). The particle density is even more overwhelming, but at that point most particles are still inside the beam tube. The natural divergence of the particles, as well as the bend due to the magnetic field, begins to separate the reaction particles from the beam particles. An example of trajectories for charged particles of momentum $16 \leq |p| \leq 24$ GeV/c is shown in Fig. 6. Cross sectional views at 0, 2, 4, and 6 m distances along the magnet are shown in the figure, and the separation of negatively charged tracks and positively charged tracks is evident. The circle on the figure for 0 m is the beam pipe. It is clear that by the end of the magnet the multiplicity is low enough that tracking should not be a problem. We envision a combination of TPC's (for pattern recognition) and drift chambers (for spatial resolution) to be placed in the magnet volume.

V. EXTERNAL SPECTROMETERS

The expected particle multiplicities in the external spectrometers are similar to those anticipated for the upcoming round of fixed-target relativistic heavy ion experiments, and thus can be handled with similar techniques. There would be two sets of highly redundant drift chambers (with a total of 16 planes) to measure the particle trajectories outside of the magnet. Particle identification would be accomplished with two highly segmented gas Cerenkov counters.

For both cost and space reasons, no more than 2 or 3 of the magnet portals on each side would be instrumented with external spectrometers at any one time. The spectrometers would be designed to move and cover a relatively wide range in momentum.

VI. COSTS

The cost of L4 is given in Table 1 both for a warm magnet and a superconducting one. Because of cost and because the magnet must conform to the other magnets in the lattice, the superconducting design is chosen.

The tracking chamber cost is clearly dependent on the segmentation and type of chambers which are required. If our goal is to track and momentum analyze most of the charged particles in the fragmentation region for Au-Au collisions, we would require an extraordinary amount of information to handle events with the order of 1000 tracks entering the detector. The multiparticle pattern recognition capacity required near the entrance to L4 is beyond the present state of the art, but the necessary two track spatial and momentum resolutions are within conventional ranges (e.g., at the CERN pp collider, the Tevatron, LEP or SLC). As an estimate we assume that we fill the L4 gap with about 100 drift chamber planes. If we further choose a wire spacing of 2 cm we end up with 5000 sense wires. This would be augmented by about 20 TPC planes with 200 channels each (0.5 cm resolution in the coordinate vertical to the drift direction). The cost of such a scheme is estimated in Table 2.

Alternatively, if one does not attempt to detect all particles, but aims for only inclusive measurements in small windows in momentum space it is not necessary to fill the whole L4 gap with tracking devices. It would only be necessary to cover selected regions which would connect with the external spectrometers (section 5). The resulting cost would be considerably less and the job much easier.

The estimated cost of the external spectrometers is also included in Table 2. It is assumed that a total of 6, 3 on each side, would be built.

VII. PARTICIPANTS

Other participants in the working group were: H. C. Britt, Y. Y. Chu, P. Gorodetsky, O. Hansen, R. Ledoux, W. Trautmann and K. Wolf. In the design of the intersection region and the magnet we profited greatly from discussions with S. Y. Lee, H. Hahn, and P. Thompson.

VIII. REFERENCES

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2. W. Bell et al., Zeit. fur Phys. C 27, 191 (1985).
3. RHIC Proposal, BNL 51801 (1984).
4. W. Zajc, Workshop on Detectors for Relativistic Nuclear Collisions, LBL 18225, 1984, p. 121.

Table 1
L4 Design and Costs

Specifications

Length	10 m
Gap	0.8 m
Width	1.2 m
B	2.0 T
$\Delta p/p$	1%

	Warm	Cold
Iron	0.4 M$	0.4 M$
Coils	2.9 M$	0.3 M$
Power Supply	2.8 M$ (11 MW)	0.1 M$ (0.5 MW)
Cryostat	-0-	0.3 M$
Total	6.1 M$	1.1 M$

Table 2
L4 Tracking and Spectrometer Costs

L4	
5000 sense wires @ $150/wire	0.75 M$
400 TPC channels @ $350/ch	1.4 M$
Total	2.15 M$
Spectrometer	
800 sense wires @ $150/wire	0.12 M$
2 segmented Cerenkov counters	0.2 M$
Total	0.32 M$
Total for 6 spectrometers	1.92 M$

IX. FIGURE CAPTIONS

1. (a) Schematic baryon longitudinal rapidity distributions for nucleus-nucleus collisions.[1] (b) Experimental rapidity distributions for all positively charged particles [•] and protons [•] from αα collisions.[2]

2. (a) RHIC standard crossing region design. (b) Possible modifications to allow more space for studies in the fragmentation region.

3. Cross section of the spectrometer magnet, L4.

4. View of L4 in the narrow angle hall at RHIC. The numbered arrows indicate the angles at which particles produced at 0° with the indicated momenta will emerge from L4.

5. Perspective view of L4 showing portals in the sides of the magnet.

6. HIJET-produced distributions in X and Y of charged particles with momenta $16 < p < 24$ GeV/c at 0, 2, 4 and 6 m distance in L4.

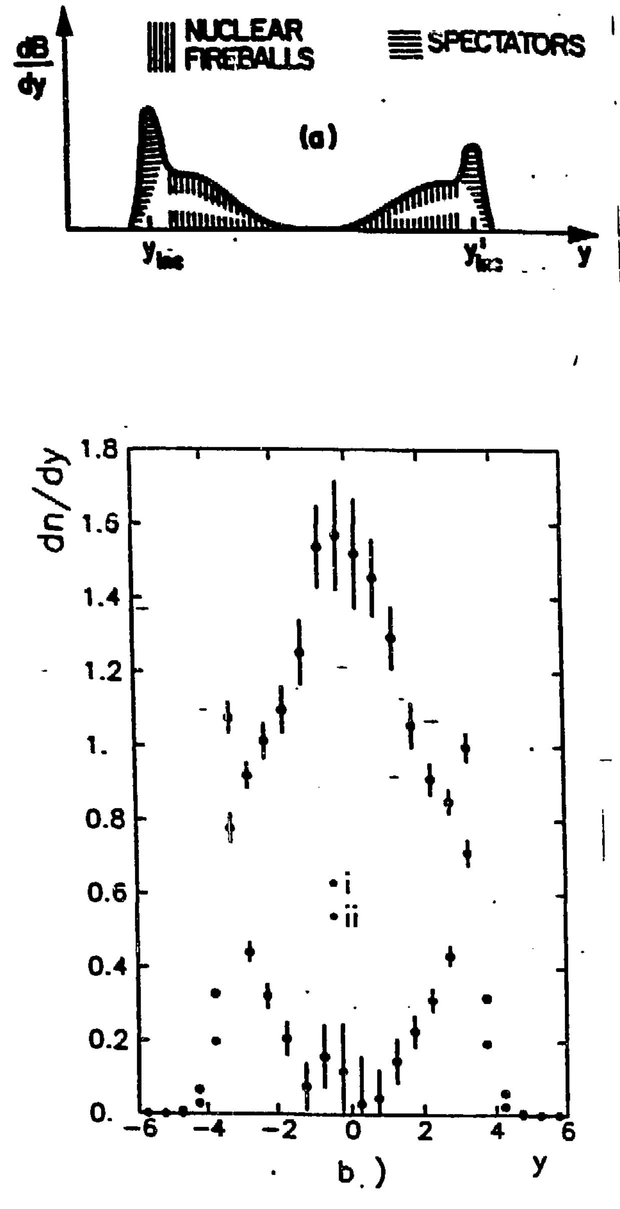

Figure 1

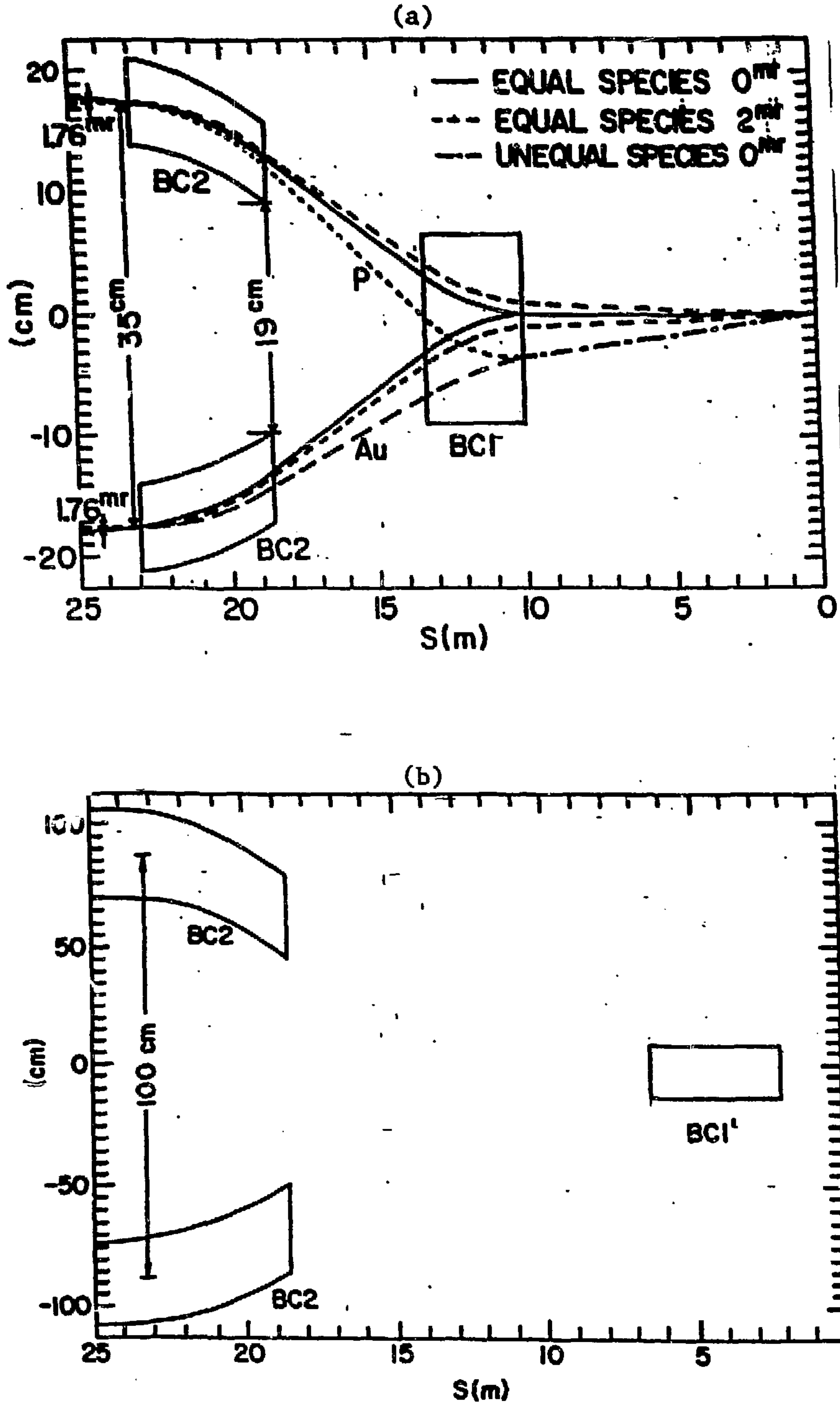
(a)
EQUAL SPECIES 0 mr
EQUAL SPECIES 2 mr
UNEQUAL SPECIES 0 mr
1.76 mr
BC2
35 cm
19 cm
P
Au
BC1
(cm)
S(m)
(b)
BC2
100 cm
BC1
(cm)
S(m)

Figure 2

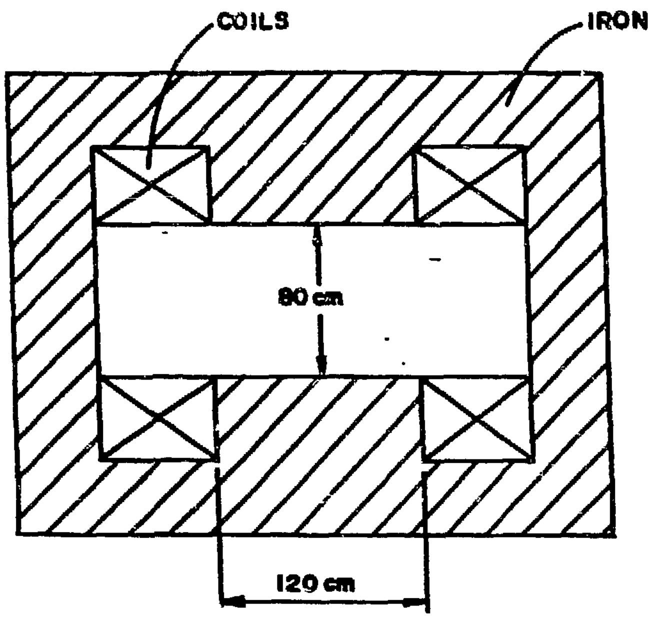

Figure 3

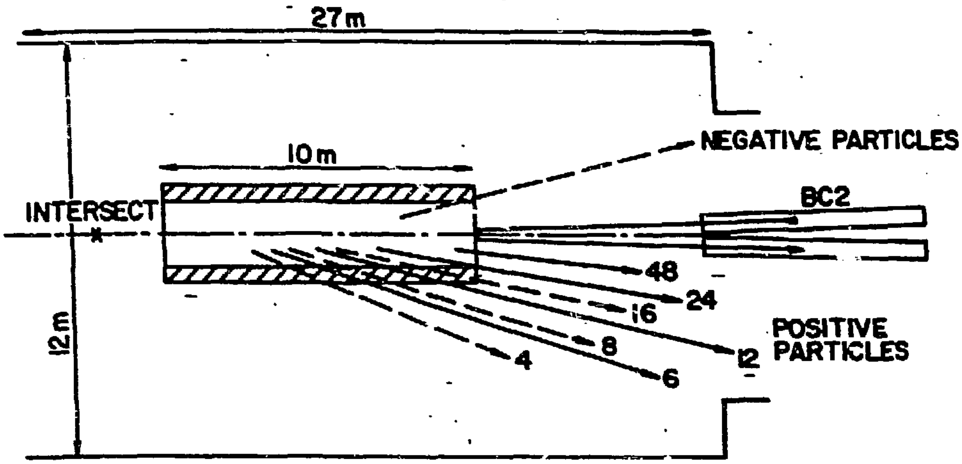
27m
10m
INTERSECT
12m
NEGATIVE PARTICLES
BC2
48
24
16
12
8
6
4
POSITIVE
PARTICLES

Figure 4

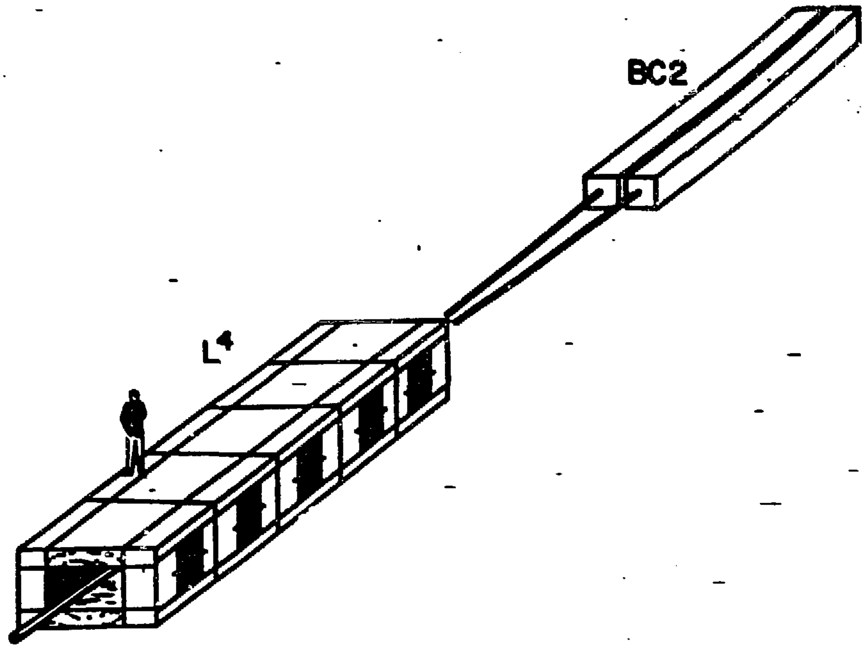

Figure 5

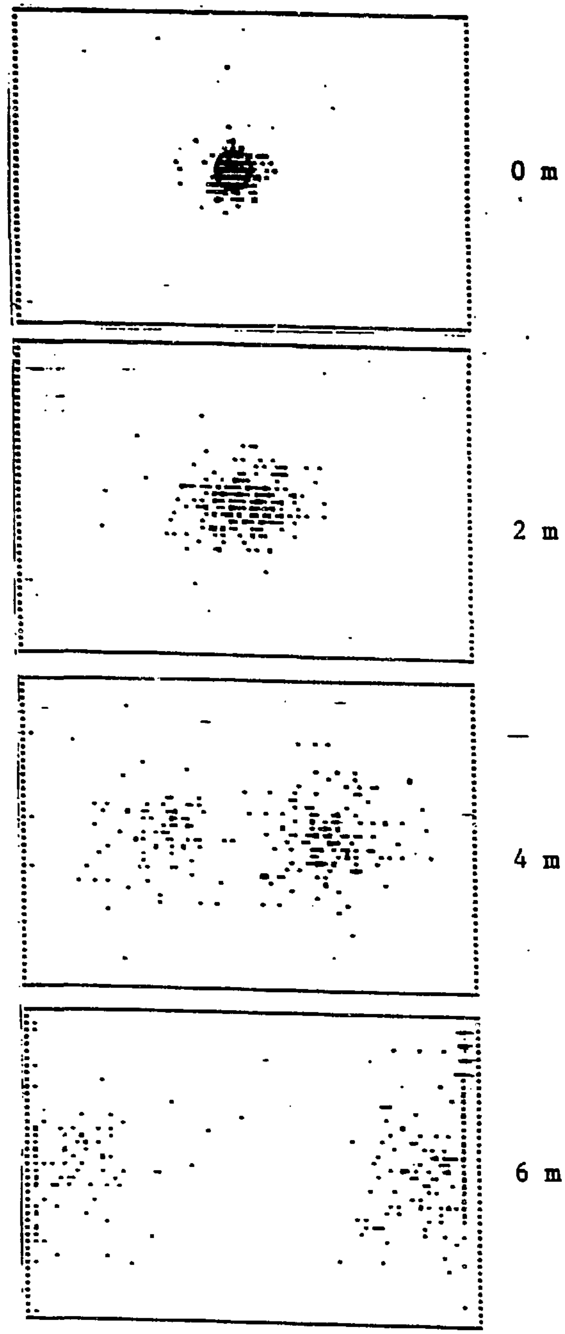

Figure 6