The Detection of Low-energy Charged Particles with Particle Identification up to 3.5 GeV/c

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Abstract

A reasonably compact apparatus employing solenoid fields, Cerenkov counters, drift chambers, and time-of-flight capabilities is described. Good particle identification can be obtained through a combination of time-of-flight information and Cerenkov thresholds for π, k, p up to about 3.5 GeV.

I. Central Detector for Momentum Measurement and Identification of Low Momentum Hadrons.

We use here an ordinary solenoid type detector providing a longitudinal field. This will need compensating coils to get a $\int B \cdot d\ell = o$ along the beam. Here the stress is put on low momentum particles with good separation of π, K, P rather than a specially good momentum resolution. This would be needed to make an exact energy momentum balance which, in any case, would be very difficult with a total energy of 30 GeV. Instead of a plain solenoid, one can think of Helmholtz coils, with the difficulty that the field is no longer uniform which makes track recognition more difficult. On the other hand, it provides free space which can be useful for neutral detection.

The set-up, which is described here, (figure 1 and 2), deals with detection of charged particles. One can add a neutral detector outside which would provide a complete determination of the multiplicity over the solid angle. Nevertheless, the inside radius of this detector for neutrals would be 1.4 m which makes it rather expensive.

Anyway, the thickness of the coil has been kept to 0.5 X_o and could be still reduced if one permits increasing the power correspondingly. The magnet covers a solid angle of 87% of 4π (30° to 150°). So it would need an addition towards small angles if one wants to cover as large a fraction of 4π as possible. The magnet was chosen to be conventional with aluminum coils. The field is .5 Tesla. The outer radius is R = .8 m. The useful length to analyze tracks is 1 = .7 m. The length along the beam is 2.4 m.

Position of the tracks is measured by drift chambers which are known to work well with a magnetic field larger than .5T parallel to the wire. Precision in the ϕ (azimuthal angle) direction in the transverse plane can be kept as low as .1 mm. The geometrical precision is

$$\frac{\sigma(P)}{P} = \frac{0.0267\ x\ (\mathrm{mm})\ P_t(\mathrm{GeV/c})}{B(T)L^2(m^2)}$$

where x is the overall precision on the sagitta, which we take also to be .1 mm. So we have

$$\frac{\sigma(P)}{P}_{geom} = 0.011\ P_T\ \mathrm{GeV/c}$$

Take the thickness of the drift chambers to be $2.5 \times 10^{-3} X_o$. One gets for multiple scattering

$$\frac{\sigma(P)}{P}_{ms} = 0.033$$

Overall resolution is plotted in figure 3.

Particle identification is a rather difficult problem. First one can use time of flight at a distance of 1.3 m to separate π, K, P at low momentum. If one assumes a Δt = .5 ns for 1σ, it means that one is able to distinguish π from K with at least 2σ up to 1 GeV/c (figure 4). Above 1 GeV/c π and K are no longer separated.

Then one can use a liguid Cerenkov with an organic liquid of refractive index n = 1.25. This can be the same device used for time of flight. This permits the separation of π and K up to 0.9 GeV/c. (separation being taken at half maximum signal for the K.) A liquid H_z Cerenkov counter along the beam pipe n = 1.11 allows separation up to 1.4 GeV. Above that limit, one has to use gas Cerenkov counter. One takes here gas Cerenkov at around 15 atmosphere with an index of n = 1.019 which gives a threshold for the (half - maximum signal) at 1 GeV/c and provides separation between π and K up to 3.5 GeV/c. The length is 50 cm which, with a light collection efficiency of 0.1 and a photoelectron conversion efficiency of 0.25 gives 12 photoelectrons for half signal, 23 photoelectrons for full signal.

So with time of flight plus liquid and gas Cerenkov counters one obtains particle separation over the low momentum range up to 3.5 GeV/c. Perhaps, an improvement of the technique could come from some types of foams which are presently under development in Saclay, France and which give refractive indexes intermediate between liquids and high pressure gases. It is to be noticed that as long as one goes to non - 90^o polar angle, one improves the time of flight distance as well as the Cerenkov track length, and, of course, the resolution on the momentum.

The power required is (for aluminum coil of $.5X_o$) 1.3MW with a current density of 9A/mm which is quite reasonable. If no neutral detection is foreseen, one can go to 1 radiation length thickness and then decrease the power and current density by a factor 2. The iron return yoke has not been sketched, the shape being quite different whether one adds or not a neutral detector.

II. Small Angle Detector:

In order to be able to measure the multiplicity of an event, one needs to go to as small an angle as possible. Besides, it can very well be that strange things happen at small angles (weak interactions coming in...) The smallest angle which can be reached will in fact be determined by background.

We describe here a straight forward and very compact device to measure small angles. This device is only 2m long (figure 1). Of course it can be removed from the interaction point which whould increase the length of the projected track and then allow to go to smaller angles and improve resolution. The field is again solenoidal. Since this apparatus can be added to a central magnetic device, the coils have only been sketched very roughly. If the central detector has also a solenoidal field, one can make use partially of that. Besides, one can very well use Helmholtz coils, and correct for the field inhomogeneities.

The field is assumed to be 0.5 Tesla longintudinal. One uses drift chambers located .5m, 1m, 1.5m and 2m from the interaction point and perpindicular to the beam so as to measure the projected transverse track. The two first ones (starting from the interaction point) covers a θ polar angle of 30 degrees. The two last ones have a .75m radius. If z is the longitudinal length of the useful track, one gets a geometrical resolution:

$$\frac{\delta P}{P} = 0.0267 \, \frac{x(\mathrm{mm})}{B(\mathrm{tesla})Z^2(\mathrm{m})} \, \frac{\sin\theta}{\tan^2\theta} \, P(\mathrm{GeV/c})$$

Where one measures again the sagitta of the projected circle in the transverse plane and where x geometrical precision on the sagitta is taken again as .1mm. One notices that at small angle of given momentum the resolution goes about like $1/\theta$.

To get rid of the multiple scattering in the beam pipe, one will consider the length of track outside the beam pipe, which reduces z and L (the transverse projected track). Taking a radiation length of $2.5 \times 10^{-3}\ X_o$, ones gets the resolution curves given in figure 2. As was said already, at small angles the resolution can be improved by increasing the longitudinal length of analysis.

One can again use time of flight and Cerenkov to identify particles. Putting a time of flight counter at a distance of 4m, and assuming a time separation of 0.5 nsec for σ, provides a separation of 2σ for π and K up to 1.7 GeV/c. Of course, one can also think of neutral detection behind the drift chambers.

SOLENOIDAL CENTRAL DETECTOR

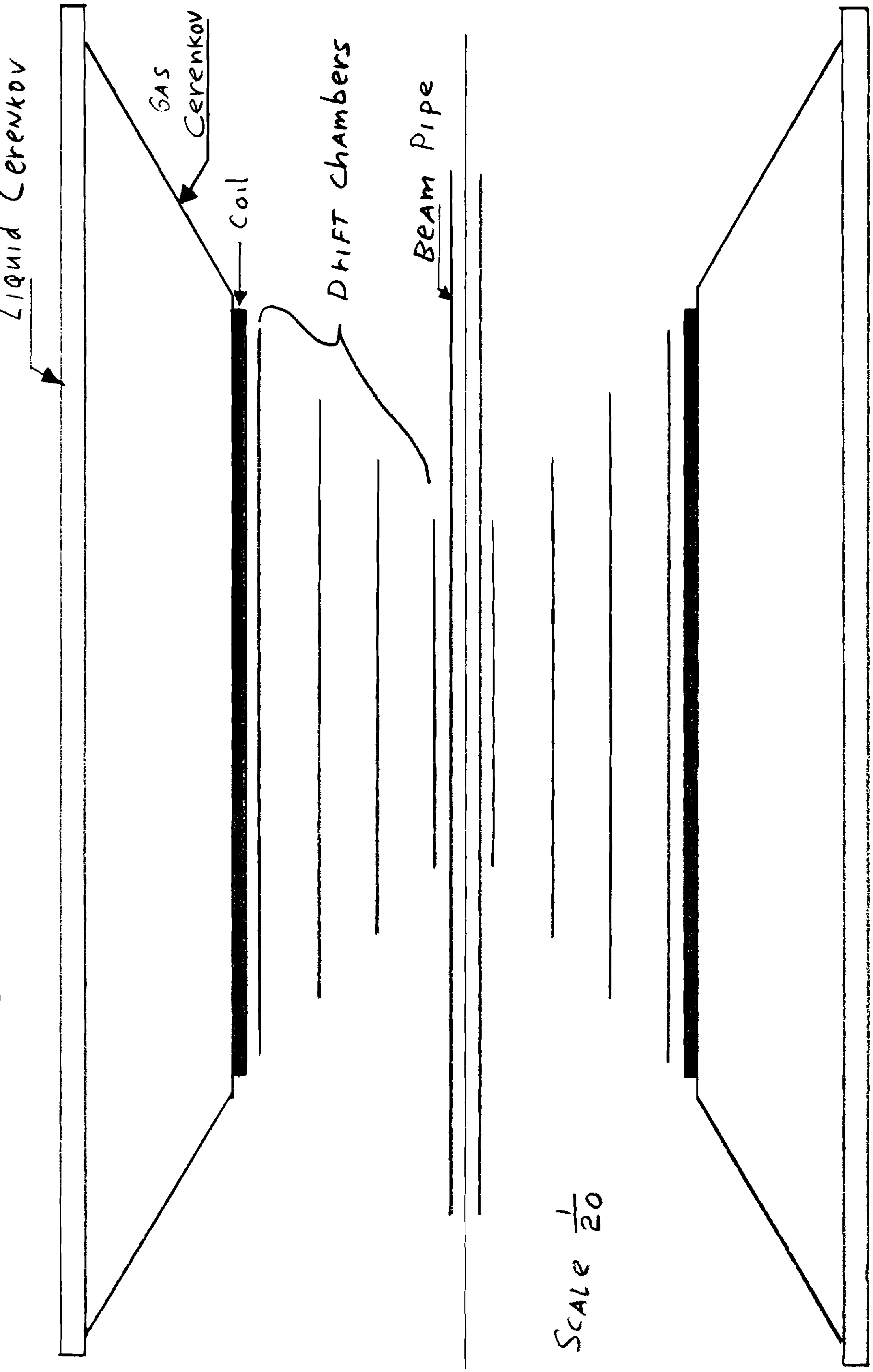


FIGURE I-1

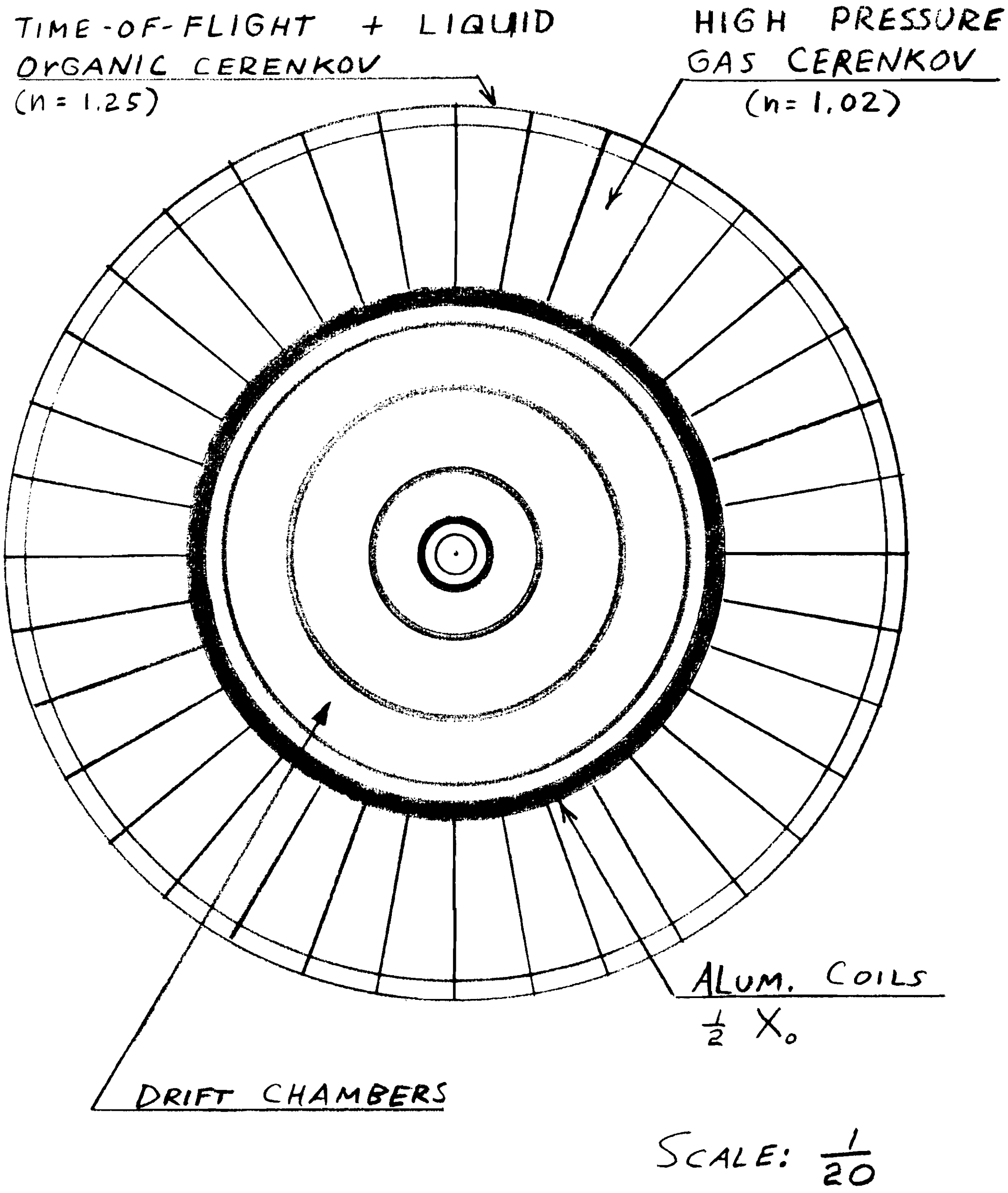

TIME-OF-FLIGHT + LIQUID
ORGANIC CERENKOV
(n = 1.25)
HIGH PRESSURE
GAS CERENKOV
(n = 1.02)
ALUM. COILS
$\frac{1}{2} X_0$
DRIFT CHAMBERS
SCALE: $\frac{1}{20}$

FIGURE I-2

FIGURE I-3

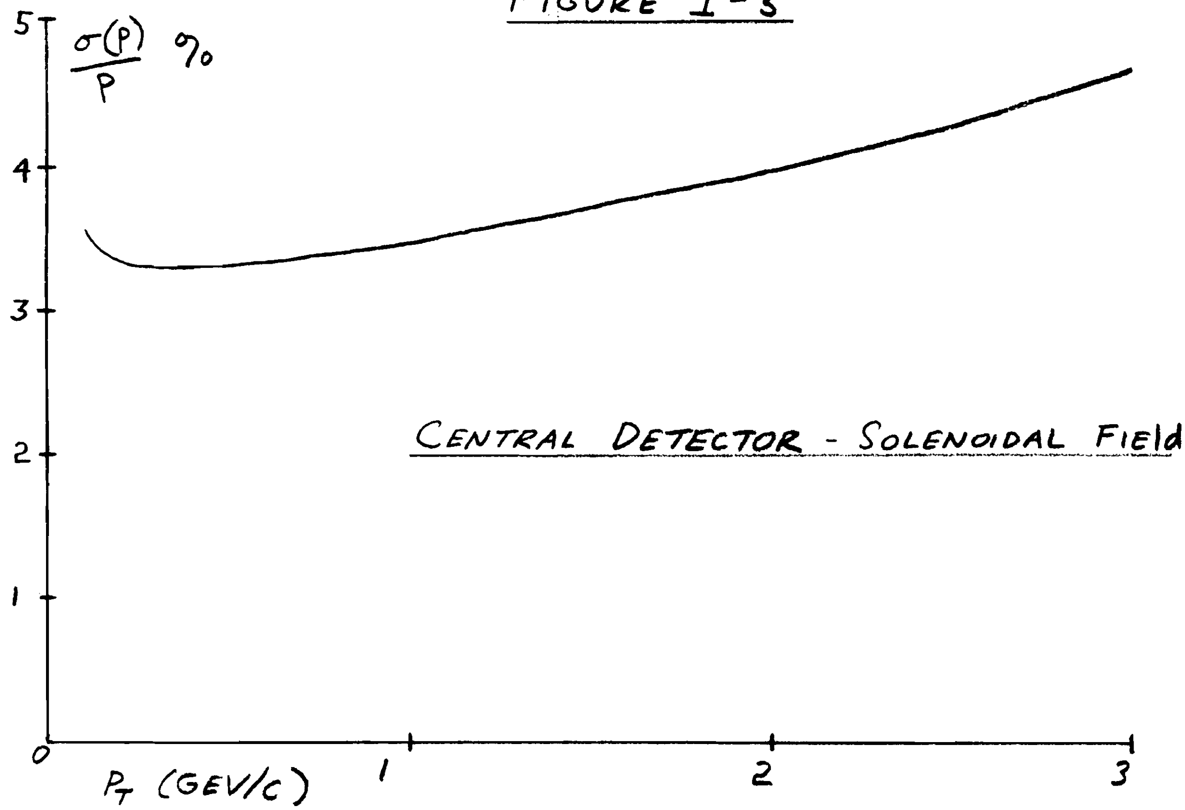
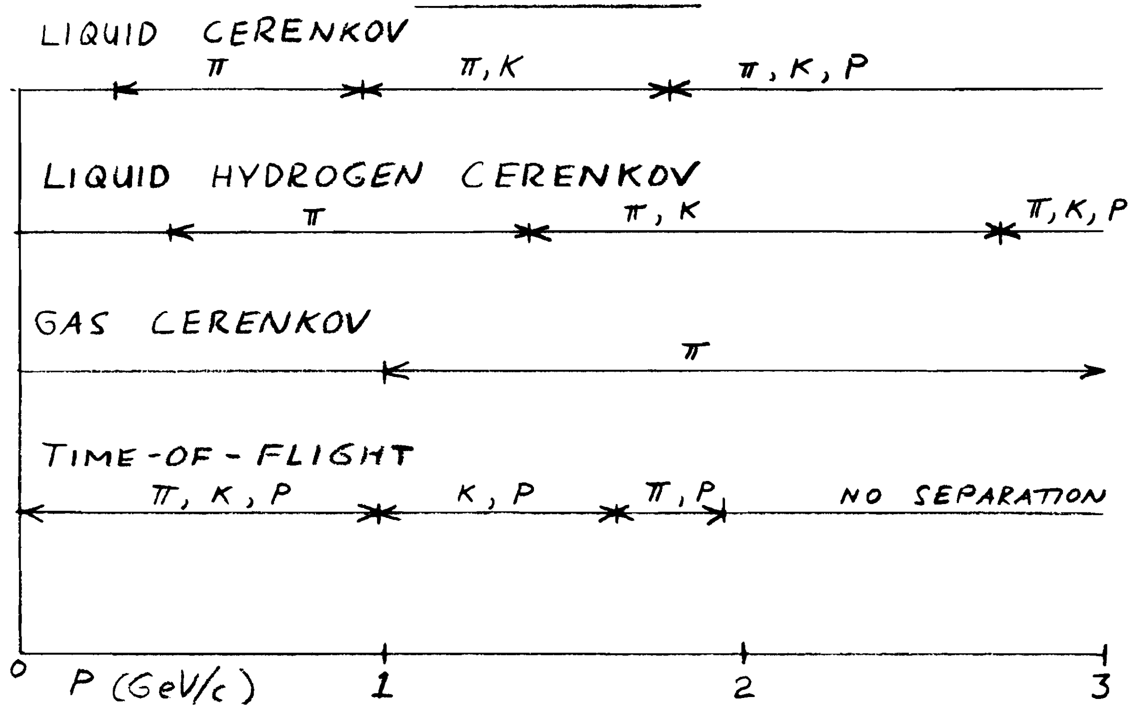
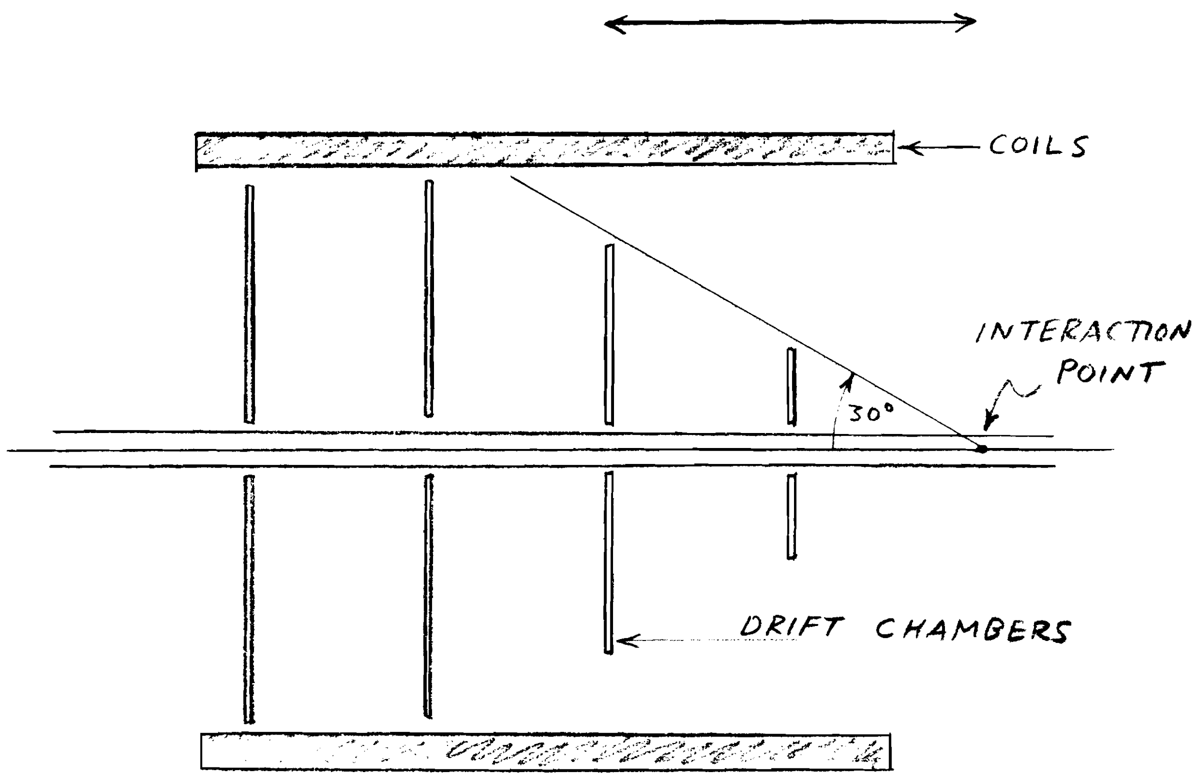


FIGURE I-4





Solenoid Field Small Angle Detector

FIGURE II - 1

Small Angle Detector Resolution

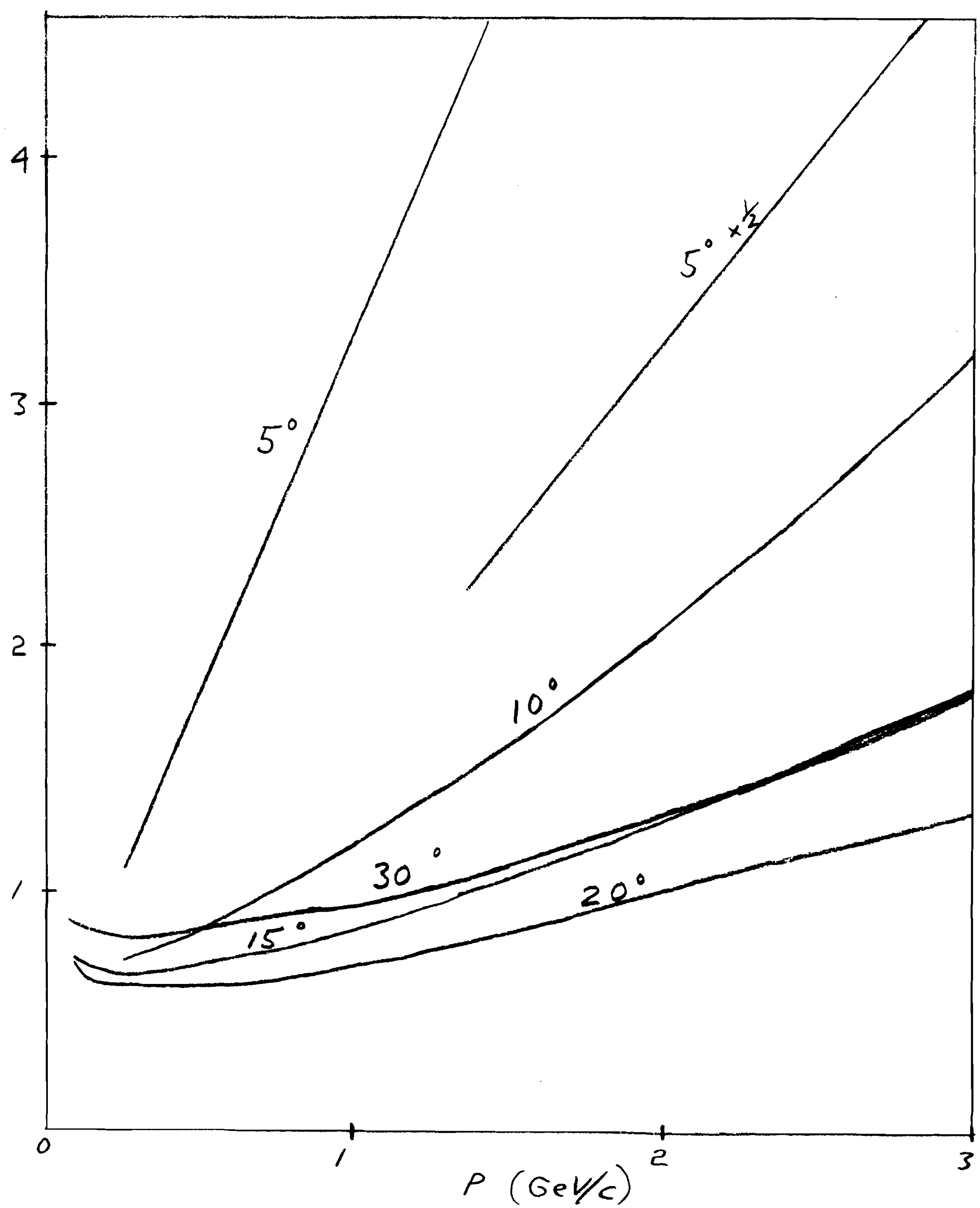


FIGURE II-2