CHOICE OF MAGNETIC FIELD FOR 25-FT CHAMBER

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ABSTRACT

We have examined in some detail the importance of a high (40 kG) field for the study of strong interactions in the 25-ft bubble chamber filled with H_2 or D_2. For this application a lower field (say 25-30 kG) appears to be completely adequate.

We recommend that the choice between a high field and some other desirable parameter (larger volume, less cost?) be based on the requirements of the neutrino program and not on the requirements of the strong-interactions program.

I. INTRODUCTION

In reading reports [1-5] of the 1968 and 1969 Summer Studies, one is impressed by the recurrence of the statement that a high magnetic field is important for strong-interaction studies in the large (25-ft) bubble chamber at NAL. A careful reading of these reports fails to reveal the factual basis of this statement. In this session several people have tried to pin down parameters for possible multi-particle spectrometers (streamer and wire chambers). All have independently reached the conclusion that a field higher than ~ 20 kG is not essential. In view of this startling unanimity it seemed worthwhile to review the usefulness of a high field for strong-interaction studies in the large HBC.

How can a high magnetic field not be a good thing? It is clear that errors in momenta decrease as $1/B$ (for moderate turning angles), regardless of the source of these errors. This is obviously not in question; what may be in question is the relative importance of momentum errors and other errors. If other sources of error dominate, there is no point in pushing to a high field regardless of cost and possibly at the expense of other parameters. As far as we have been able to determine in situations we have analyzed, it appears that other errors do tend to dominate so that a case for a 40-kG field does not appear to exist for strong-interaction studies in a H_2 (or D_2)-filled chamber. A lower field, say 25-30 kG, seems completely adequate for this purpose.

The errors which appear to limit the resolution in most cases seem to be angle errors on fast tracks and angle errors (due to multiple scattering) on non-relativistic protons (deuterons, hyperons).

We sketch briefly the arguments and come back later to more specific examples.

It seems intuitively obvious that momentum errors and angle errors are matched when turning angles are comparable to relevant production (or decay) angles. This is easily shown to be the case for the simple example of a two-body decay ($X^o \rightarrow A^+ + B^-$). Angle errors and momentum errors make equal contribution to the error in M_x when the turning angle of A and B is equal to the opening angle (we are considering explicitly the 90°-cm decay).

This occurs when $BL/M_x \sim 30$ kG-m/GeV/c^2. We note

1. The result is independent of the setting error, ϵ, since all errors scale equally with ϵ.

2. If the accuracy is limited by multiple scattering rather than by measurement errors, the relative importance of momentum errors is decreased.

3. If we are dealing with a resonance carrying a substantial fraction of the incident momentum, and produced in a 4c event, the use of fitted variables reduces considerably the contribution from momentum errors.

This means that the BL required to reduce the contribution of momentum errors to be less than or equal to the contribution of angle errors is often less than 30 M_x.

To decide on this basis whether we should have a field of 40 kG or 20 kG or 5 kG implies, of course, that we know the masses of important resonances to be discovered at NAL and their width. It seems, nevertheless, reasonable to assert that a 40 kG field cannot reasonably be justified and that 25 or 30 kG seems completely adequate.

The second limitation may seem somewhat paradoxical, but it seems to arise in any situation where we try to apply energy balance to a high-energy interaction (we can, of course, do this only with events with no more than one missing neutral). To be specific, consider a high-energy interaction in which several relativistic particles and one non-relativistic particle (proton, deuteron, etc.) come out. The main source of error on the energy balance is easily shown to be almost invariably the angle error for the slow particle. The error is clearly due to multiple scattering, is clearly independent of magnetic field, and, in fact, of any and all chamber parameters. The only way to reduce it is to give up the liquid H_2 chamber in favor of a less dense target. If it were not for this circumstance it would be just as easy to apply energy balance to sort out hypotheses at very high energy as at lower energies.*

*This remark minus the unfortunate qualifier, has been made by Trilling.[3]

We now proceed to summarize more detailed considerations of specific examples.

II. CAN WE DO 1c EVENTS AT HIGH ENERGIES?

This problem has been considered by Trilling,[3] who came to a fairly optimistic answer, and by Walker,[6] who came to a rather pessimistic answer. In this report, we have no intention of settling the issue; we would simply like to point out that whatever is feasible with a 40-kG field is equally feasible with a lower field and whatever looks hopeless at a lower field is still hopeless at 40 kG.

Trilling[3] in his report asserts that one can expect errors on the missing mass square, δM_x^2, around 0.04 GeV^2 (60-GeV incident beam). We would like to point out that in fact the error is likely to be quite different for missing neutrons and for different π^o energies.

1c With Missing Neutron

Consider for definiteness the important case of a relatively slow neutron:

$$\delta M_x^2 = 2E_x \delta E_x - 2\vec{p}_x \delta \vec{p}_x \simeq 2E_x \delta E_x \simeq 2M_x \delta p_{\parallel}$$

i.e.,

$$\delta M_x \simeq \delta p_{\parallel} .$$

Whatever one's opinion about the likely precision of the 25-ft chamber, it seems that this is a hopeless case at 40 kG. If so, not much is lost by making it somewhat more hopeless by lowering the field.

As an example, I will use Trilling's estimate $\delta p_{\parallel} \simeq 0.24$ GeV. This is calculated by Trilling[3] for a 60-GeV exposure with the (realistic) assumption that one leaving particle carries away 48 GeV. (He says he uses a setting error of 500μ but is in fact using a setting error of 140μ.) Clearly this is completely inadequate to resolve the neutron peak.

1c With Slow π^o

In this case, again, the dominant error is due to momentum errors, i.e., to $\delta p_{\parallel} > M_{\pi}$, the case looks rather hopeless; even if one can convince oneself that one has, indeed, selected a $1\pi^o$ event, the error of the π^o momentum is ~ 100% or higher. It is not clear how these events will be used to do any physics.

In this case, Trilling's suggestion that detecting one γ is very useful clearly does not apply.

Since this looks quite hopeless with 40 kG, no great loss appears to occur when we go to a lower field.

1c With Fast π^o

In this case, for events with a slow proton, the dominant error appears to be the angle error on the proton recoil:

$$\delta M_x^2 \approx 2p_x p_R \sin \theta_R \, \delta\theta_R .$$

To get a rough idea of the magnitude:

$$\begin{aligned} p_R &\approx 200\text{-}300 \text{ MeV} \\ \sin\theta_R &\approx 1 \\ \delta M_x &\approx 0.01\, p_x \end{aligned}$$

For an energetic π^o this is quite bad (see Walker). Trilling's suggestion that for events with at least one γ ray converting (~49% of events) the additional constraint is sufficient to confirm (or reject) the hypothesis will clearly work. For the purpose of this report, it is sufficient to point out that a reduction in the magnetic field to 25 kG or 30 kG still leaves a very tight constraint. Also, the additional information obtained from the measurement of the γ-ray energy (this cuts down the π^o angle error in one dimension) is almost as good at a lower field. We omit the details which are completely straight-forward and uninteresting.

III. 4c FITS

We see no reason to review the unanimous conclusion that 4c fits are easily identified and that the three momentum constraints are roughly equivalent.[3] It is clear that relaxing one of the three constraints somewhat by decreasing the field will not lose very much.

We would like to review briefly how the situation regarding correct particle identification is changed if the magnetic field is reduced.

It is quite easy to show that nothing is changed with regard to identification by kinematic fitting. The relevant constraint is the energy balance. Its effect is somewhat easier to understand if one subtracts out the longitudinal momentum balance equation:

$$f = (E_{iN} + M_T - p_{iN}) - \Sigma\,(E_i - p_{i\parallel}) = 0.$$

For a relativistic particle emitted at a small angle:

$$E_i \approx p_{i\parallel} + \frac{m_i^2 + p_{i\perp}^2}{2p_i} .$$

This is a small quantity, but the error on it is still a small fraction. If all particles fell in this category, we would have no more problems at higher energy than at lower energies. The difficulty is that a slow non-relativistic particle (proton or other recoil) constitutes a much larger term (effectively this is ~ M_T) giving a much larger error.

For a slow particle the angle error is

$$\delta f = \delta(E_R - p_R \cos \theta_R) \simeq p_R \sin \theta_R \delta\theta_R = 4\text{-}5 \text{ MeV (typically).}$$

To decide whether a change in mass assignment is likely to be detectable or not we have to compare the changes it produces in f with the error in f.

For example $A \leftrightarrow B$

$$\Delta f = \frac{(M_A^2 - M_B^2)}{2} \left(\frac{1}{p_1} - \frac{1}{p_2} \right) \quad \text{(if both particles are relativistic).}$$

The worst case is $\pi \leftrightarrow K$. If for example $p_1 = 1.5$ GeV, $p_2 = 3$ GeV

$$\Delta\delta = \frac{0.29-0.02}{2} \left(\frac{1}{1.5} - \frac{1}{3} \right) = 0.035 \text{ GeV} = 35 \text{ MeV}.$$

It seems that one would have no trouble choosing the correct mass assignment in this case. It seems clear that:

1. The difficulty in choosing whether to call particle A a K and particle B π or vice versa depends on p_A and p_B but not on the beam energy. If p_A and p_B (or at least the lower of the two) is 1 or 2 BeV, the only difficulty arises when $p_A \approx p_B$. Experience with $Kp \rightarrow K\pi\pi p$ at 5.5 GeV shows that this is not a very serious problem.

2. To distinguish between two hypotheses which differ by replacing, for example, a pair of π's by a pair of K's should be relatively easy. If both particles have momenta as high as 20 GeV, $\Delta f \sim 14$ MeV.

3. The above discussion is applicable (with a few complications) to 1c events.

The conclusion appears to be that for fitted events (4c and 1c's) kinematics (energy balance) will resolve most of the ambiguities involving particles with momenta in the range of, say, 1-1.5 GeV. If we reduce the magnetic field, from say 40 to 25 kG, particles with momenta in that range (1-1.5 GeV/c) will not be trapped in the chamber anymore. For fitted events the fact that particles in this momentum range lose their chance to identify themselves by being trapped does not seem at all serious, an identification by kinematics alone is usually possible.

REFERENCES

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