A PROPOSAL FOR THE DETECTION AND CLASSIFICATION OF BOSONS OF HIGH MASS

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ABSTRACT

An experiment to detect and measure the quantum numbers and decay modes of heavy mass bosons is proposed. The experiment utilizes a large 4π magnet of maximum size $2m \times 2m \times 7.5$ m. Triggering and particle trajectory tracing is done with wire chambers in the magnet and downstream from it. It is shown that counting rates are reasonable for such an effort.

I. INTRODUCTION

There is good evidence[1] that high mass bosons are indeed present in nature. Unfortunately, the paucity of events coupled with the presence of a high background make just their observation difficult, let alone the measurement of their quantum numbers.

The use of a high-energy machine with high-energy pion beams (in the 100-GeV range) may open up a mechanism for cleaner and more copious production of such mesons. The mesons of unnatural parity, π, B(?), A(?), etc., can be produced by Pomeranchuk exchange, i.e., by diffraction production. In that case one can enhance their production by using compound nuclei as the target. One would expect $d\sigma/dt$ for such reactions to be constant with bombarding energy, except that it should grow for production from complex nuclei since the minimum momentum transfer decreases with bombarding energy ($q \sim 1/2\ M_x^2/E$). Thus for a higher bombarding energy one can use larger nuclei for a given particle mass and thereby get the higher A^2 in cross section or one can produce higher mass particles for a given nucleus.

For natural parity particles these could be produced by something like ρ exchange from protons, with a cross section going like s^{-1}, under possibly less favorable signal-to-noise conditions, or else as decay products of the unnatural parity bosons.

II. CHARACTERISTICS OF THE DETECTOR SYSTEM

A. Solid Angle

If one is to measure the spins of decaying bosons it is very important that one capture the full solid angle of the decay products. This is not just for efficiency's sake. At high ℓ values, the difference between $p_\ell^2(\cos\theta)$ and $p_{\ell+1}^2(\cos\theta)$ is in the highest power of $\cos\theta$ and is most evident near $\cos\theta = \pm 1$, i.e. at the extreme decay angles. At these extreme angles the decay particle makes the largest angle with respect to the parent particle trajectory. This angle is given in the relativistic approximation by

$$\tan\theta_{max} = \frac{1}{\gamma}\frac{\beta'}{\sqrt{\beta^2 - \beta'^2}} \simeq \frac{\gamma'}{\gamma} \;(\text{if } \beta \simeq 1).$$

β' and γ' refer to the daughter particle in the c.m. system, β and γ to the parent particle in the lab.

For example, if we consider a 3-GeV particle, with a π meson one of the daughter products in a two-particle decay (e.g. $\pi + \rho$), then $\gamma' = 10$. And if the energy of the 3-GeV mass particle is 100 GeV, then

$$\tan\theta_{max} \simeq \frac{10}{30} = 0.33 .$$

This is a large angle, but we wish to accommodate this decay.

B. Vertex Detection

We will want the capability of measuring the nature, momentum, and angle of the recoil particles for at least two reasons: (1) to distinguish a recoil proton from an N^*, and (2), to use the recoil as a trigger and thereby select the mass range we wish to study. Therefore a magnetic field is required at the target.

C. π^0 Detection

It stands to reason that the final decay particles of a large mass object will be of higher multiplicity than is the case at low mass. We would expect to see at least one or more π^0 mesons, which could be decay products of an intermediate daughter such as the ω^0, η^0, or X^0. If we were to use multiple-plate shower chambers, we could measure the direction of the gamma rays; this reduces the fitting of the event by one constraint so that we could detect three π^0's and still have a 1c fit. It is also conceivable to imagine a set of lead-glass Cerenkov counters placed beyond the last set of detectors beyond the magnet. Such a hodoscope has been built by D. Luckey.[2]

D. Magnet Size

In view of the studies made in SS-86, it appears reasonable to incorporate all magnetic analysis in one magnet. From that study it seems one pays little in extra volume by such a procedure. We therefore suggest a magnet 2 m × 2 m × 7.5 m as very adequate. Further kinematic analysis with constrained fits may indicate a smaller magnet (e.g. 1 m × 2 m × 5 m) to be sufficient.

III. CHARGED PARTICLE DETECTORS

Various detecting schemes have been proposed to trace the charged particles through a spectrometer: (1) bubble chamber at the vertex, spark chamber downstream,[3] (2) streamer chamber (plus wire chambers downstream),[4] (3) proportional chambers,[5] (4) wire-spark chambers alone, and (5) wide-gap chambers.

The proportional chambers seen to have a great attraction but are unfortunately the least developed of the above techniques. At the present time they also seem rather expensive. I would like to suggest, without being explicit, a mixture of proportional and wire-spark chambers, where the former would be used for triggering decisions. Wire chambers have the attraction that, unlike visual techniques, only small holes are needed in the magnet to remove data. This would simplify construction and improve the homogeneity of the magnetic field. In addition, a wire-chamber system is inherently capable of very high data rates. Indeed the data rates are sufficiently high that one would probably place a high selectivity on the trigger.

IV. DATA RATES

A. Needed Event Rates

We will take as a rough criterion for needed rates the desire to measure the ℓ value of a particular resonance "bump" sitting on a background α times larger than the bump. This is very reminiscent of the manner in which J values for baryon resonances have been measured. One expands the angular distribution in powers of cos θ at bombarding energies below, at, and above the resonance; one then looks for the highest power of cos θ which shows a "bump."

Imagine the decay of a particle produced near $\theta = 0$ by a diffraction process into two spinless particles. Our job is to distinguish the distribution, $p_\ell^2(\cos\theta)$, and $p_{\ell+1}^2(\cos\theta)$. We use the approximation

$$p_\ell(\cos\theta) \simeq J_0\left[\left(\ell + \frac{1}{2}\right)\theta\right] \qquad \ell >> 1,\ \theta << 1$$

$$\simeq 1 - \frac{1}{4}\left(\ell + \frac{1}{2}\right)^2 \theta^2 .$$

$$\Delta n(\theta) = N_0 \frac{2\ell + 1}{2} \left[1 - \frac{1}{4} \left(\ell + \frac{1}{2} \right)^2 \theta^2 \right]^2 \Delta(\cos\theta).$$

Δn is the number of events in the $\cos\theta$ interval, $\Delta(\cos\theta)$. Let

$$Y_i = \left[\frac{\Delta n}{\Delta \cos\theta} \frac{1}{N_0} \right]^{1/2} = \sqrt{\ell + \frac{1}{2}} \left[1 - \frac{1}{4} \left(\ell + \frac{1}{2} \right)^2 \theta_i^2 \right].$$

N_0 is the total sample of events in the resonance.

In effect we concentrate on those events at the extreme angles $\theta < 1/\ell$ and $\pi - \theta < 1/\ell$. The slope of the plot Y_i vs θ_i^2 gives $1/4\,(\ell + 1/2)^{5/2}$. To get a rough measure of statistical accuracy we divide the data into two bins, Y_1 and Y_2, with n_1 and n_2 events in each bin.

$$\frac{1}{4} \left(\ell + \frac{1}{2} \right)^{5/2} = \left(Y_1 - Y_2 \right) / \left(\theta_2^2 - \theta_1^2 \right)$$

$$\frac{5}{8} \left(\ell + \frac{1}{2} \right)^{3/2} \Delta\ell = \frac{1}{\theta_2^2 - \theta_1^2} \left[\left(\Delta Y_1 \right)^2 + \left(\Delta Y_2 \right)^2 \right]^{1/2}$$

$$\Delta Y = \frac{1}{4} \left[\frac{1}{N_0 \Delta\theta^2} \right]^{1/2} \frac{\Delta n_i}{n_i^{1/2}}.$$

With no background the uncertainty in n_i is $n_i^{1/2}$. With background, $\Delta n_i = \sqrt{2\alpha n_i}$. Taking $\theta_1 = 1/4\ \ell$, $\theta_2 = 3/4\ \ell$, and $\ell >> 1$

$$\Delta\ell = \frac{1}{5}\, \ell^{3/2} \sqrt{\frac{2\alpha}{N_0}} = 0.25 \text{ (arbitrarily)}.$$

As an example take $\ell = 4$, $\alpha = 3$ (background = 3 × resonance),

$$N_0 = 3600 \text{ events.}$$

This number is somewhat optimistic: (1) We have assumed a simple two-body decay into spinless particles. There are other decay modes and these modes may have particles with spin. (2) The background may interfere with the resonance angular distribution.

We note, however, the general behavior that $N_0 \propto \ell^3$. The number of events is not inconsistent with experimental experience.

B. Expected Event Rates

We take some data from Ref. 1, where they obtained cross sections for R, S, and T meson production of about

$$d\sigma/dt = 30\ \mu b/(GeV/c)^2.$$

We assume that these will hold up in energy and we also assume a "diffractive-type" t dependence, e^{10t}. We obtain a total cross section of 5 μb.

If we take a target of liquid H_2, 20 cm in length (this is a good match to the angular error due to multiple scattering), and a beam of 10^6 π's per second, we get 4.2 events/second. The background will contribute another 12. A simple set of Charpak planes on either side of the target might cut down the ϕ acceptance by 1/2. We obtain then ~ 10^5 real events/day. This should be adequate.

V. TRIGGERING SYSTEM

In an enclosed magnet system one would not have counter triggers defining momentum and direction. A trigger based on a missing mass cut, for example, would be obtained by performing simple arithmetic computation with the outputs of Charpak chambers in binary form. One method that suggests itself is to take the outputs from the wires through emitter followers directly to binary lines and apply the amplification to the binary outputs. This could save in the expense of amplifiers. For example, 64 wires would require 64 emitter followers but only 6 amplifiers. Given such a scheme, one can perform addition and subtraction on these binary numbers with fast logic to obtain a quick measurement of p^{-1}. One can also do the same to get a measurement of production angle. These numbers are compared to prestored limits to decide on a trigger. Other requirements based on secondary particles may be added.

The simplest scheme is to trigger if a recoil proton matches the angle for the "Jacobian peak." A kinematic table for the recoil proton is shown in Table I for a boson mass of 3 GeV.

Table I. Proton Recoil Kinematics.

p (proton), GeV/c	$-t\ (GeV/c)^2$	θ Recoil (degrees)
0.1	0.01	57.5
0.15	0.0225	66.1
0.2	0.04	69.5
0.4	0.16	70.4
0.6	0.36	66.3

An angle limit of 66° to 71° covers an interesting t range for this mass. The mass range is opened up to ±0.3 GeV.

It is amusing to note that a proton of 0.15 GeV/c has a radius of curvature of 25 cm in a 20-kG field; one must plan the logic to expect these particles to spiral around in the wire chambers making more than one traversal through a plane.

VI. EXPERIMENTAL LAYOUT

Figure 1 gives a plan view of the experimental layout. The wire chambers are somewhat denser near the target to measure low-momentum tracks. The outside wire chambers are staggered since the full lever arm is not needed for low-momentum tracks. Gamma shower chambers with wire readout cover all escape avenues from the target. One can also place lead-glass Cerenkov counters behind the shower chambers to get a measure of gamma-ray energy. This is easily done outside the magnet.

VII. ADDITIONAL COMMENTS

Although this magnetic system was devised with a particular experiment in mind, it is clear that it has a great deal of versatility. Since the field covers the π-p scattering ellipse in such a way as to measure Δp to 0.1 GeV, it will then measure all momenta from any reaction to at least this accuracy; momenta from the π-p ellipse are the maximum possible. If one is interested in other processes then it is up to the user to devise the appropriate trigger for that process. It might be mentioned that it is not inconceivable to use this setup for several experiments running concurrently.

ACKNOWLEDGMENTS

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REFERENCES

[1] See, for example, Focacci et al., Phys. Rev. Letters 17, 890 (1966).

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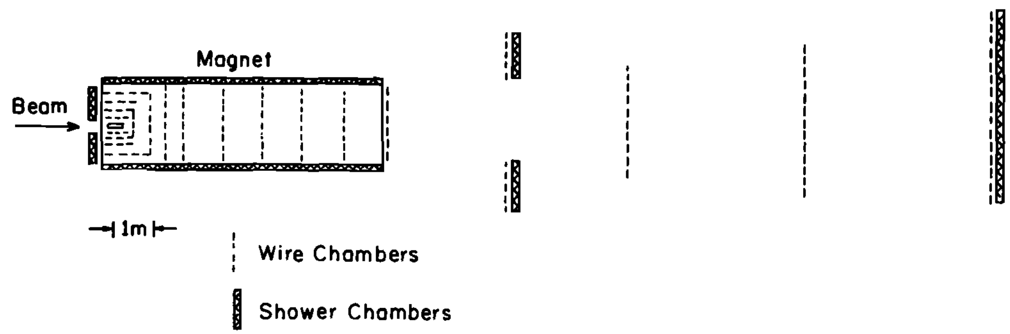

Fig. 1. Proposed experimental arrangement.