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INTERSECTING STORAGE RINGS COMMITTEE

Preliminary Proposal

INTERSECTING STORAGE RINGS STUDY OF DILEPTONS

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1. INTRODUCTION

The proposal is to study the process

$$p + p \rightarrow \Gamma + e^{+} + e^{-} , \qquad (1)$$

where Γ is any combination of hadron states. In this study the invariant mass of the e^+e^- pair would be measured to a precision $\leq$ 3% via a measurement of the laboratory angles and energy of each electron. The initial thrust is a simple, limited scope survey of the mass range 5-60 GeV/c^2 with a sensitivity of the order of 1×10^{-34} cm^2.

2. MOTIVATION

The spectrum of known and postulated 1^- states is extremely rich, and the observation via lepton pairs provides a sensitive probe of hadronic and electromagnetic structure in a totally unexplored domain.

In a recent AGS experiment*), muon pairs were observed when 29 GeV protons were incident on a uranium block. The data are still being analysed but there was no difficulty in surveying the dimuon mass range from 1-8 GeV/c^2. The dimuon "effect" was ∿ 5%, the background being all randoms. A search for pion-originated background was negative, indicating a great reluctance for pions to associate in pairs of large effective mass. More quantitative data will soon be available.

In a real sense this method provides data complementary to clashing electron-positron beams:

$$e^{+} + e^{-} \rightarrow \text{hadrons} \qquad (2)$$

since the two hadrons must be protons. Thus it is a unique exploration of the high-energy (time-like) hadronic electromagnetic structure, since 3 GeV storage rings are many years away and 30 GeV rings may never exist.

Recent theoretical discussions of formula (2) have emphasized the large continuum contribution (based on crossing symmetry and the recent SLAC data on deeply inelastic scattering), the possibility of infinite

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*) J. Christenson, G. Hicks, L. Lederman, P. Limon, B. Pope and E. Zavattini.

sequences of vector mesons from Regge-pole models, etc. At this writing we can only speculate that there must be a strong connection between formulae (2) and (1), certainly in so far as resonances are concerned, and very likely in the general behaviour of the cross-section with M^2_{ee}.

We can subdivide the area as follows:

2.1 Search for heavy vector mesons

The known particle states ρ, ω, φ, fit well into SU_3 family groups for low-lying states, but fail to account for such important structures as the nucleon form factor.

This and basic experimental curiosity leads to the question of the possible existence of heavier vector mesons and their detectability.

Assuming a leptonic branching ratio of the order 10^{-3} does not seem excessively optimistic, since the many competing strong channels (e.g. pions) are generally suppressed by structure functions $[F_\pi{}^2(M^2)]$. Production cross-sections may go resonantly as $(M_\rho/M_X)^2$ and for $M_X = 30$ GeV/c^2, say, we may have $\sigma B \sim 3 \times 10^{-34}$. This is certainly within the realm of ISR and of this proposal.

2.2 Search for W^0

Ever since the revival of interest in intermediate bosons (the quanta of weak interaction), dating perhaps from the post parity period ∿ 1958$^{1-3)}$, detailed theories have included neutral bosons as well as charged bosons. For more recent theories, see other publications$^{4-6)}$. The primary reason for this lies in the well-verified $|\Delta I| = 1/2$ rule in the decays involving strangeness-changing and non-strangeness-changing currents. A difficulty which then appears is the apparent absence of neutral lepton pairs, e.g. $K^0 \rightarrow \mu^+ + \mu^-$, which would naturally be generated via neutral W^0's. Various *ad hoc* procedures are employed to suppress the coupling to neutral lepton currents. However, it is clear that the W^0 to lepton current coupling constants can in general be dependent on momentum transfer and, in fact, may perhaps be expected to constitute a significant part of the presumed W^0 branching ratio especially if the mass of the W^0 is large. This is due to the large suppression of $W^0 \rightarrow$ hadrons channels by virtue of form factor contributions. For example, see Carhart and Dooher$^{7)}$. See also T.D. Lee$^{8)}$. Good, Michel and de Rafael$^{9)}$ discuss an interesting theory that illustrates our general approach to W^0 and $W^0 \rightarrow$ leptons. The W^0, if it exists and has a decent lepton branching ratio, is a lovely object to find since its mass can be precisely measured. Theoretical estimates of production vary with models from 10^{-32} to 10^{-35}, and the most we can say is that there is some sensitivity in this proposal; certainly the virtues of detection make it comparable to proposals for $W^{\pm}$ searches.

2.3 General

It is clear that if a mass peak is observed our troubles, pleasant as they are, just begin. However, a very powerful handle is just the very good mass resolution of $\sim 3\%$ that will permit the identification of broad resonances having strong decay channels. The number of more speculative theoretical candidates is large. One is the old object that makes the electron lighter than the muon. Another is the particle referred to in Lee and Wick$^{10)}$, which damps the electromagnetic propagators. Then there is the vector boson field of Lee and Zumino that couples to the lepton current operator$^{11)}$. One should also be aware of the interest in the continuum as mentioned already and recently (almost) discussed by Drell$^{12)}$, by Sakurai$^{13)}$, and by Berman$^{14)}$.

3. EXPERIMENTAL DETAILS

Figures 1a and 1b show the proposed arrangement. A set of proportional wire chambers defines the angle of each of the observed tracks, say e^+e^- and three pions. This is followed by a wide-aperture freon Čerenkov counter, which is biased to exclude pions of up to 4-5 GeV/c. The freon counter is segmented to render the number of two-track events per segment negligible. In this way the "electron" tracks recorded in the wire chamber system are tagged. The energy of the electron is measured in an array of lead-glass Čerenkov counters of the types now being studied by the Rubbia group at CERN. The maximum energy resolution is determined by this group to be $\sim 3\%$. This counter further serves to discriminate against pions by pulse-height.

Finally, a veto counter follows a wall of ∿ 25 r.l. of lead (15 in the lead-glass Čerenkov counter plus additional lead) to further decrease the pion sensitivity.

The triggering system consists of hodoscopes of small scintillation counters close to the interaction region (to suppress cosmic-ray events) in coincidence with an array after the gas counter with a requirement on the lead-glass pulse-height. All other logical requirements would be imposed in analysis of the tapes, which would contain a record of all counter pulses and relevant pulse amplitudes.

The geometry is variable since the major segments subtend ∿ ±10° and are mobile. The total solid angle would be $\Delta\theta = 120°$ on each side and $\Delta\phi = 1/5$ of the total azimuth. The geometric efficiency is essentially unknowable except for very massive objects (made with very low laboratory velocity). An optimized search would consist of variation of the ISR storage energy, since the ideal situation is to be "not too far" above threshold for exciting the hypothetical new states. Monte Carlo studies of production of massive objects use a variety of models to dispose of the excess energy. The more energy available, the more model-dependent the calculation becomes. In the kind of search proposed here, we optimize the geometry for some intermediate situation, the extremes being (i) production at rest in the c.m. and (ii) all the available energy given to forward (and backward) momentum of the massive state.

4. SENSITIVITY

Our calculations indicate that backgrounds should be either negligible or so unexpected as to be intrinsically interesting. Assuming this, we can estimate here the sensitivity and then give some supporting considerations on backgrounds.

Let us assume of the order of four runs of 100 hours each, and take 1.2×10^5 interactions/sec as standard.

The geometrical efficiency for an isotropic source is 0.18. The correlation of the second lepton varies from 100% for decay at rest to quite small opening angles (again high correlation) for relatively light particles. For our geometry, the worst case is an opening angle $\sim 90°$ where the correlation reduces the efficiency to essentially 0.04. Taking a realistically weighted average and adding in small electronic inefficiencies leads to an over-all efficiency ~ 0.10. Thus, if we consider say 20 events within the mass resolution as constituting a "signal", we have:

$$\frac{\sigma B}{30 \text{ mb}} \times 1.2 \times 10^5 \times 100 \times 60 \times 60 \times 0.1 = 20$$

or

$$\sigma B = 4 \times 10^{-34} \text{ cm}^2 \qquad \text{(100 hour run)} .$$

Several runs under different conditions, each with this kind of sensitivity, could explore the mass range $\sim$ 5-60 GeV/c^2 to a level of $\sim 10^{-34}$ cm^2.

5. BACKGROUNDS

There are two types of background and, of course, combinations of each: electrons from other sources, e.g. pionic, and pions.

5.1 Electrons

These would come from Dalitz pairs or conversion of π^0 γ's in the small amount of material before the gas Čerenkov counters. To give a high-energy electron requires asymmetric π^0 decay and asymmetric internal or external γ conversion. Allowing 1% for production of electrons and 10% probability for the required asymmetry gives a total suppression given two high-energy π^0's, highly correlated, of $\sim 10^{-8}$ which, considering the rarity of the initial event [say, $p + p \to N^{*+} + N^{*+} \to (p + \pi^0) + (p + \pi^0)$] is small compared to the signal. Further suppression comes from ruling out obvious "pairs" as observed in the wire chambers, i.e. tracks with "zero" opening angle.

5.2 Discrimination against pions

The minimum transverse momentum for counting in this apparatus is $\sim$ 1.5 GeV/c^2, which should remove all but a small fraction of secondary pions. The gas Čerenkov threshold is 4-5 GeV pions. Pulse-height records will further discriminate against pions below $\sim$ 6 GeV. The lead-glass Čerenkov counter provides a further strong suppression of pions. We expect the results to be similar but not so spectacular as the data of Hofstadter in large NaI (see Fig. 2). We can conservatively expect a discrimination of a factor of ∿ 50 for pions below ∿ 8-10 GeV here. Finally, the veto counter adds another factor, which it is recognized may not be independent of the previous factors. The most important process is an early reaction in the lead-glass:

$$\pi^{\pm} + Z \rightarrow \pi^0 + Z^* \qquad (3)$$

with very small excitation. It could be that some ∿ few per cent of pions above 6 GeV will in fact be mistaken for electrons. These will only give difficulty if accompanied by an electron from some π^0 process that satisfies the lead-glass energy requirement, or by another high transverse momentum ≥ 6 GeV pion. Either case implies a dipion mass at least as large as we would then attribute to the electron pair. Although nothing is known about this mass range, we may expect this background to be of the order of the signal being sought. There would be no contribution to a peak from this kind of data, since the lead-glass pulse-height is poorly correlated with pion energy, and the electron carries a variable fraction of the pion energy. The crucial point is that, should there be a significant pion-originated background, this would become immediately evident by the relaxation of one of the three requirements, e.g. for every pion that undergoes process (3) there are 50 or so that would penetrate the veto counter. Thus this background is interesting and knowable.

6. MASS RESOLUTION

The mass of the dilepton is given by

$$M^2 = 2\, P_1 P_2\, (1 - \cos\theta)\ ,$$

where θ is the opening angle of the pair.

Since the error in P_1, P_2 will dominate the mass resolution, we have

$$\frac{\Delta M}{M} = \frac{1}{\sqrt{2}}\,\frac{\Delta p}{p}\ .$$

Now according to the Rubbia group

$$\frac{\Delta p}{p} = \frac{8.6}{\sqrt{p}} \%$$

$$\frac{\Delta M}{M} = \frac{1}{\sqrt{2}} \frac{8.6}{\sqrt{p}} \% .$$

Since $P_{min} = 4$ GeV

$$\frac{\Delta M}{M} \lesssim 3\% ,$$

e.g. for a 20 GeV particle "at rest",

$$\frac{\Delta M}{M} \cong 2\% .$$

Since the continuum and the background will surely peak at low masses, it is clear that the higher the mass, the more sensitive the experiment.

7. IMPROVEMENT POSSIBILITIES

We expect to make extensive calibrations on the AGS and CEA accelerators in the next year. Our collective experience indicates that substantial improvements in arrangement are likely before ISR beam time. The most probable change is the deletion of the gas Čerenkov counters. As the perceptive reviewer has no doubt noticed, it buys only redundancy and a decrease in the threshold mass. The gain in eliminating the gas counters is a factor of 5 in geometrical efficiency for the same cost in lead-glass counters (approximately $200,000) and a considerable contraction and simplification. Clearly more experience with the lead-glass may embolden us to take this step.

Another avenue of investigation is the use of Charpak chambers as indicators of electrons via the relativistic rise in ionization. The main trick would be to improve the statistical significance of the ionization deposited, <u>and</u> at the same time cut the Landau tail by suppression of knock-on electron effects. These techniques are under investigation at Nevis.

8. ISR REQUIREMENTS

A. In order to reduce the conversion of π^0 gammas, the vacuum chamber walls in the interaction region should be $\lesssim 0.1$ cm of steel, which appears not to be a difficult problem (see CERN/ISRC/69-26; Calder, Fisher and Le Normand).

B. The detector dimensions require a vertical space of the order of ±2.5 metres with respect to the median plane of the beams, assuming the use of gas Čerenkov counters as in Figs. 1a and 1b. This requires the use of the interaction areas containing a pit. If it appears these are redundant, or if scheduling considerations were dominant, the condensed detector occupies a volume of 1.7 m transverse horizontal × 1.4 m vertical by 4 m along the beam pipes.

C. It would be useful to run the ISR at several energies: perhaps at 10, 20, and 30 GeV/c in order to optimize over a greater range of masses. Clearly we would start at the highest energy and be guided by any suggestions of "bumps".

D. We have no stringent monitor requirements, since absolute cross-sections are secondary in importance. A relative monitor telescope for different runs can eventually be calibrated.

E. Gas-scattered backgrounds, vacuum requirements, etc. are also unimportant in this type of investigation.

9. ORGANIZATION AND TIMETABLE

This is proposed as a BNL, CERN, Columbia collaboration. The apparatus is straightforward and, although large, is modular and easily assembled and dismantled. We consider the absence of a large magnet to be a particularly attractive feature for early ISR exploitation. We expect that we can be prepared about a year after approval is granted. We are prepared to have at least two-thirds of the apparatus constructed in the U.S. and transported to CERN. It is clear that this is not a fully detailed document, but we are prepared to present further details and hope to have a much more elaborate design ready in several months, if there is any encouragement in this enterprise.

REFERENCES

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4) B. D'Espagnat, Phys.Letters 7, 209 (1963).

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6) M. Gell-Mann, M.L. Goldberger, N. Kroll and F. Low, Phys.Rev. (in press).

7) R. Carhart and J. Dooher, Phys.Rev. 142, 1214 (1966).

8) T.D. Lee, Phys.Rev. 168, 1714 (1968).

9) M.L. Good, M. Michel and E. de Rafael, Phys.Rev. 151, 1194 (1966).

10) T.D. Lee and G. Wick (in press).

11) T.D. Lee and B. Zumino, Phys.Rev. 163, 1667 (1967).

12) S. Drell, private communication.

13) J.J. Sakurai, Current propagator and hadron production in electron-positron collisions (in press).

14) S. Berman (private communication) is calculating the nucleon-nucleon production of lepton pairs on the basis of: i) vector dominance; ii) deeply inelastic scattering; iii) and parton or quark models.

Figure captions

Fig. 1a : Vertical section through the detector. Each of the six pie-shaped sectors is independent so that, for example, the arrangement could be split in the centre and folded forward (and backward) along the respective beam pipes to cover, say, 20° to 80° for each of the clashing beams.

Fig. 1b : A section of the detector orthogonal to that of Fig. 1a.

Fig. 2 : Pulse-height distribution obtained with the NaI(Tl) counter in a beam of 10 GeV/c positrons and positive pions. The positron peak is sharp and the pion "peak" is broad and rudimentary. Only a portion of the pion energy is absorbed in this "small" tank counter. A Landau straggling peak for pions lies near the unlabelled peak at the far left but is only partially shown. The data represent unpublished work of E.B. Hughes, and W.L. Lakin, and R. Hofstadter.

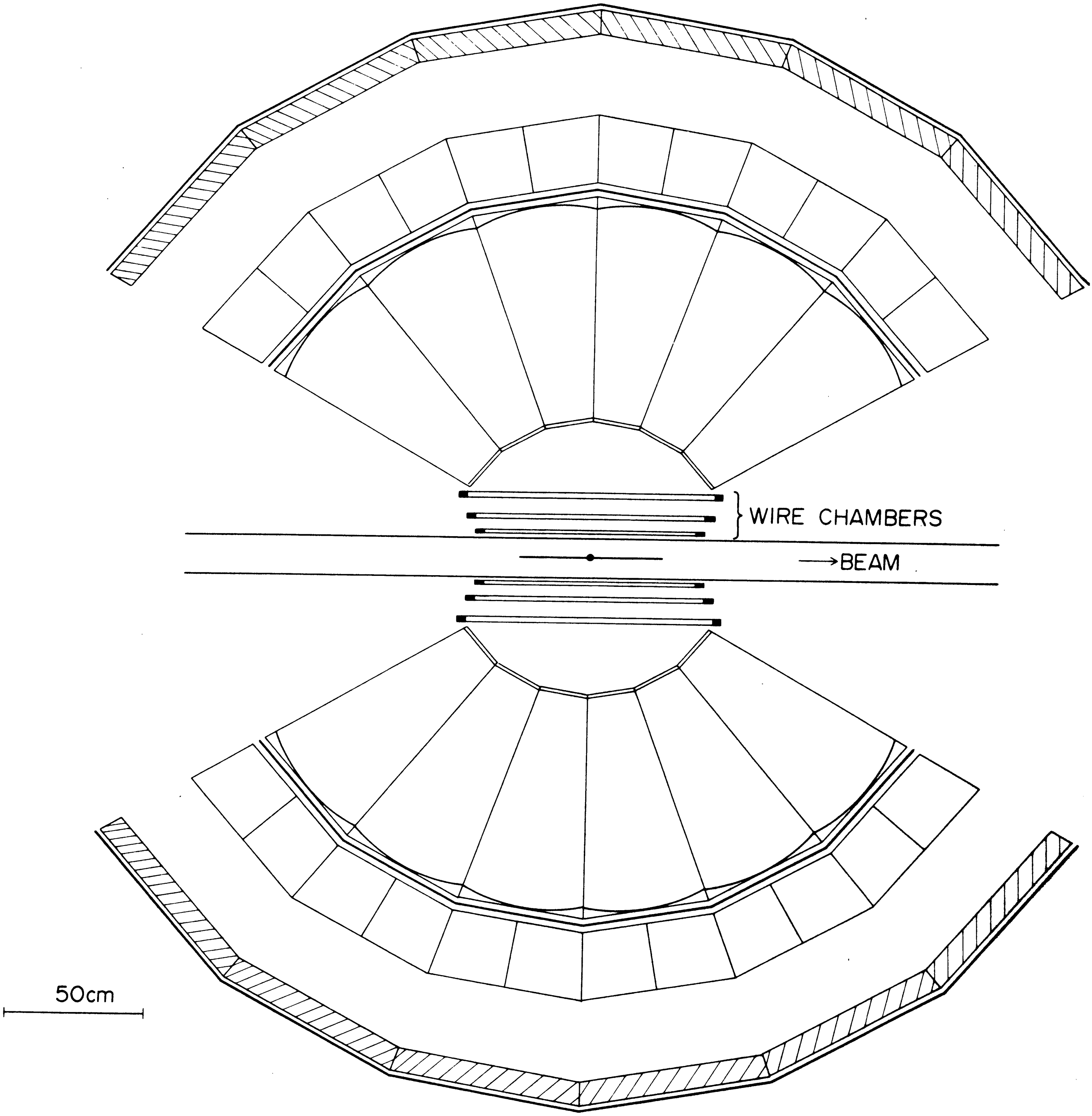

Fig. 1a

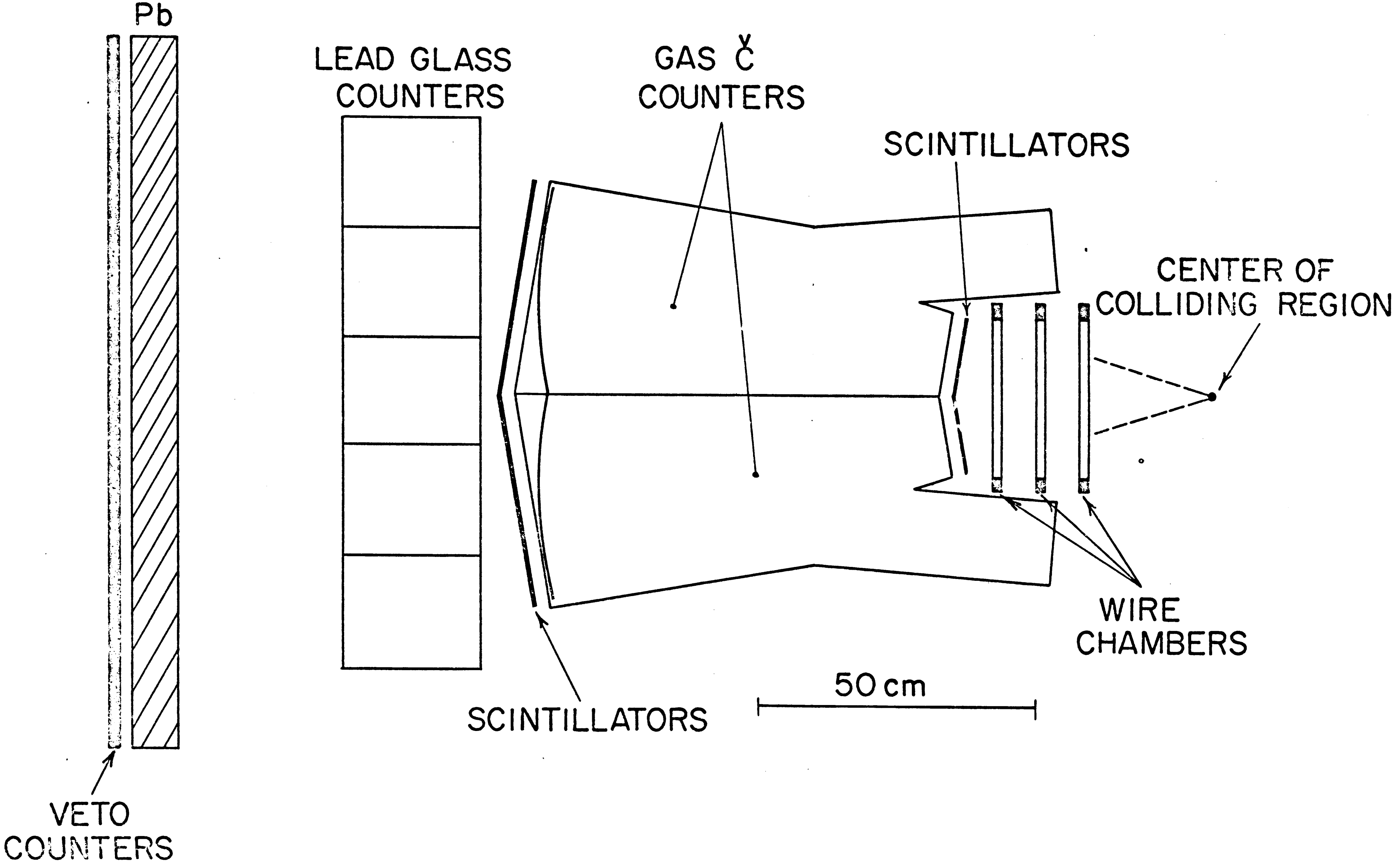
Pb
LEAD GLASS COUNTERS
GAS Č COUNTERS
SCINTILLATORS
CENTER OF COLLIDING REGION
WIRE CHAMBERS
50 cm
SCINTILLATORS
VETO COUNTERS

Fig. 1b

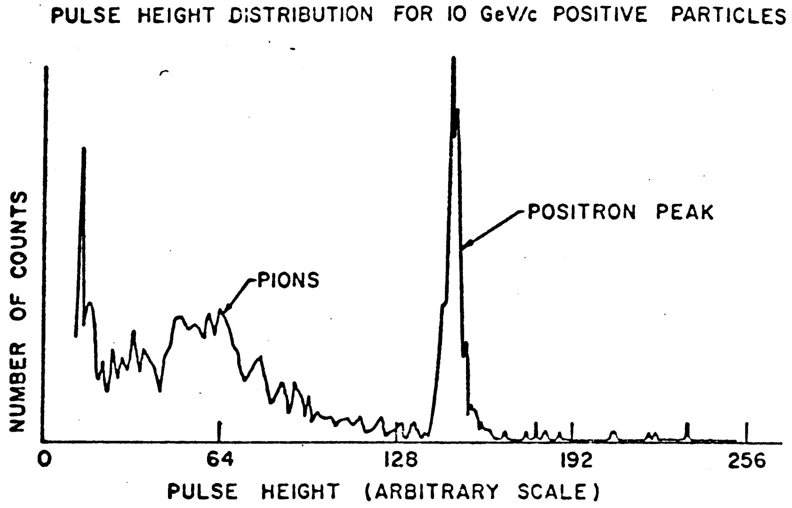
PULSE HEIGHT DISTRIBUTION FOR 10 GeV/c POSITIVE PARTICLES
NUMBER OF COUNTS
PIONS
POSITRON PEAK
0
64
128
192
256
PULSE HEIGHT (ARBITRARY SCALE)

Fig. 2