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MULTIBODY FINAL STATES IN pp COLLISIONS UP TO 500 GEV

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University of California, Los Angeles

It is proposed to expose the 15-foot Hydrogen-filled NAL bubble chamber to a proton beam at several incident momenta up to 500 GeV. A search will be made for new particles by looking for anomalous ionization or trajectories. The film is ideal for discovering new unstable particles with mean free path in the 1 cm - 100 cm range. In the proposed exposure 1 event corresponds to $\sim 10^{-31}$ cm^2. The large number of multi-prong events will be classified and a reasonable fraction measured to determine distributions in multiplicity and transverse and longitudinal momentum. An interesting class of events are those where there is a small momentum transfer to a final state proton or final state Δ^{++}. Results will be compared with various theoretical predictions from models of strong interaction dynamics.

PART I. EXPERIMENTAL ARRANGEMENT

We feel it is important for the physics proposed to do a portion of the run at as high a primary energy as possible. Two charged particle beams are planned for Area 1. The first is an RF separated beam capable of momenta of about 100 GeV/c. A beam designed primarily as a muon beam is also planned to pass through the neutrino shield of Area 1. This beam is planned to reach energies of about 300 GeV/c but as now envisioned will not have the careful intensity control at low fluxes needed for a bubble chamber exposure. In order to fully utilize the highest energies attainable with this accelerator in the NAL bubble chamber, one of the following need be done.

1. The bending magnets of the RF beam must have their capabilities extended to 500 GeV/c. Note that for operation in this unseparated mode the present quadrupoles are adequate even for 500 Gev/c.

2. The muon beam bending magnets should have their capabilities raised to 500 GeV/c. In addition, the inclusion of quadrupoles is necessary for intensity control and beam shaping in the 15' bubble chamber. Preliminary study indicates that a 500 GeV/c beam to the chamber could be constructed using 10 Main Ring B-1 magnets and 2 quadrupoles installed within a 1000' long region and powered with the standard Main Ring power supplies and bus distribution.

We will help investigate which of these alternatives is most efficient in providing a high energy proton beam transport.

Counting Rate and Proposed Exposure

We conservatively assume 3 tracks/picture and a 10-foot fiducial length for rapid scanning. For σ_{tot} = 40 mb, constant with proton energy, 30 feet/picture will give 1.2 events/picture. Of these events approximately three-quarters will be inelastic.

Table I shows our proposed run.

TABLE I

E_{proton} GeV	n_{photos}	n_{events} (inelastic)	μb equivalent	Assumed Accelerator Cycle (No Flattop)	Approximate Running Time
100	50,000	45 K	1.5 events/μb	1.5 sec	30 hrs.
200	50,000	45 K	1.5 events/μb	3 sec	40 hrs.
300	50,000	45 K	1.5 events/μb	4.5 sec	60 hrs.
400	50,000	45 K	1.5 events/μb	7 sec	100 hrs.
500	50,000	45 K	1.5 events/μb	10 sec	140 hrs.
TOTAL	250,000	225 K	7.5 events/μb	-	360 hrs. not including tune up

The exact distribution of pictures among energies and total running time will be determined when more details are available on accelerator operation and chamber schedule. After the run has started, preliminary scanning may indicate it is possible to increase the incident flux.

Advantages Of A Large Chamber

The μ barn equivalent is high and consequently the run is sensitive to new particles and rare very high multiplicity events.

Measurements can be made on the high momentum components of the forward cone. Distance is required for the members of the cone to separate spatially. A typical example is shown in Fig. 1. Average charged multiplicity including protons is about 8 at 500 GeV and according to the theoretical discussion in Section II-C, 1/2 of the particles lie in a forward cone of $\sim$ 4 mrad in the laboratory.

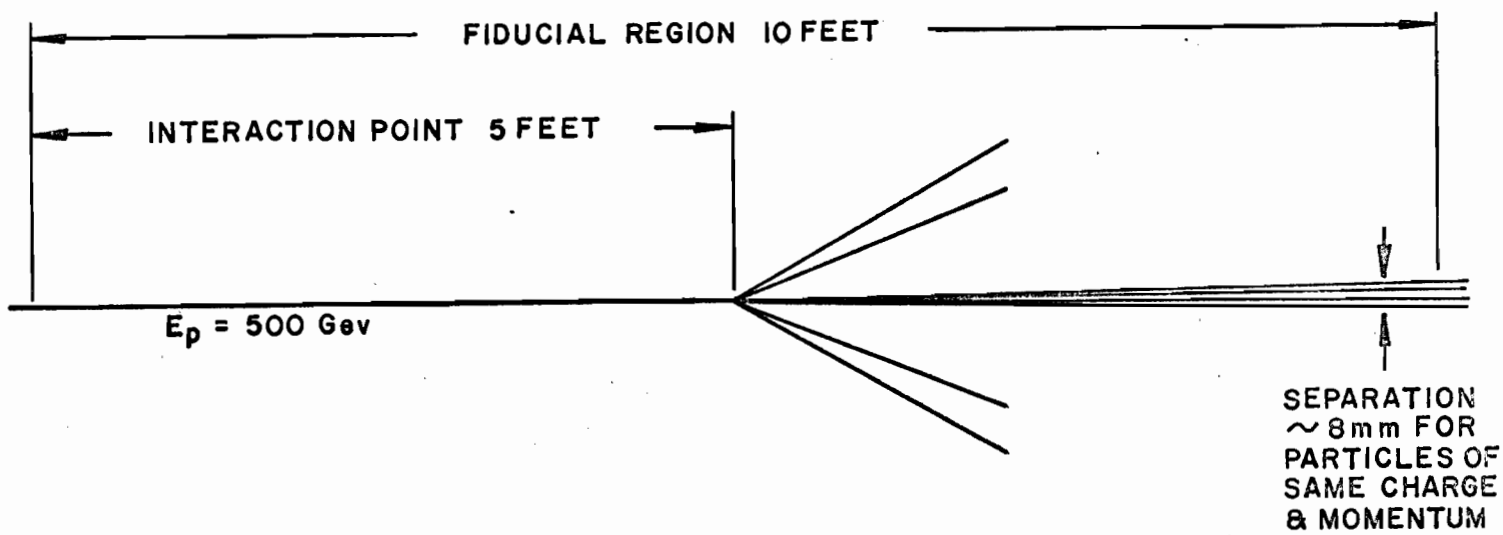


FIGURE I

We have investigated the momentum resolution attainable with the NAL 15' bubble chamber under the assumption of 100μ or 200μ setting errors. The results are displayed in figures 2 and 3. The momentum error contribution from either multiple scattering or measuring error is shown as a function of track momentum and track length. Note, for example, that a 250 GeV/c track requires a length of at least 1 m in order to get a 10% momentum determination with a setting error of 100μ. For the proposed physics program we feel momenta must be determined to at least this precision thus precluding the use of chambers smaller than 2-3 m.

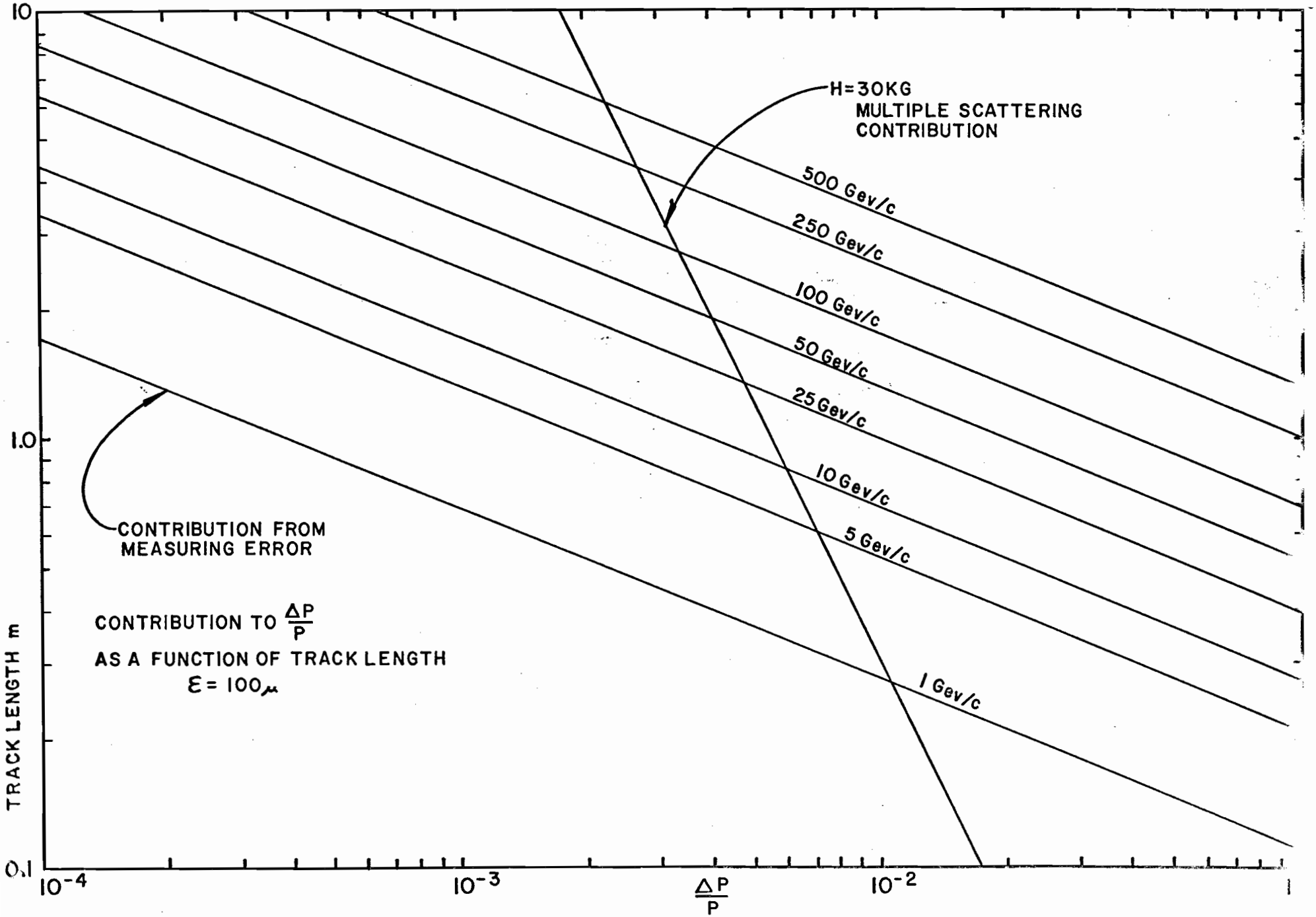

10
1.0
0.1
TRACK LENGTH m
10^{-4}
10^{-3}
10^{-2}
1
$\frac{\Delta P}{P}$
H=30KG
MULTIPLE SCATTERING
CONTRIBUTION
500 Gev/c
250 Gev/c
100 Gev/c
50 Gev/c
25 Gev/c
10 Gev/c
5 Gev/c
1 Gev/c
CONTRIBUTION FROM
MEASURING ERROR
CONTRIBUTION TO $\frac{\Delta P}{P}$
AS A FUNCTION OF TRACK LENGTH
$\varepsilon = 100\mu$

FIGURE 2

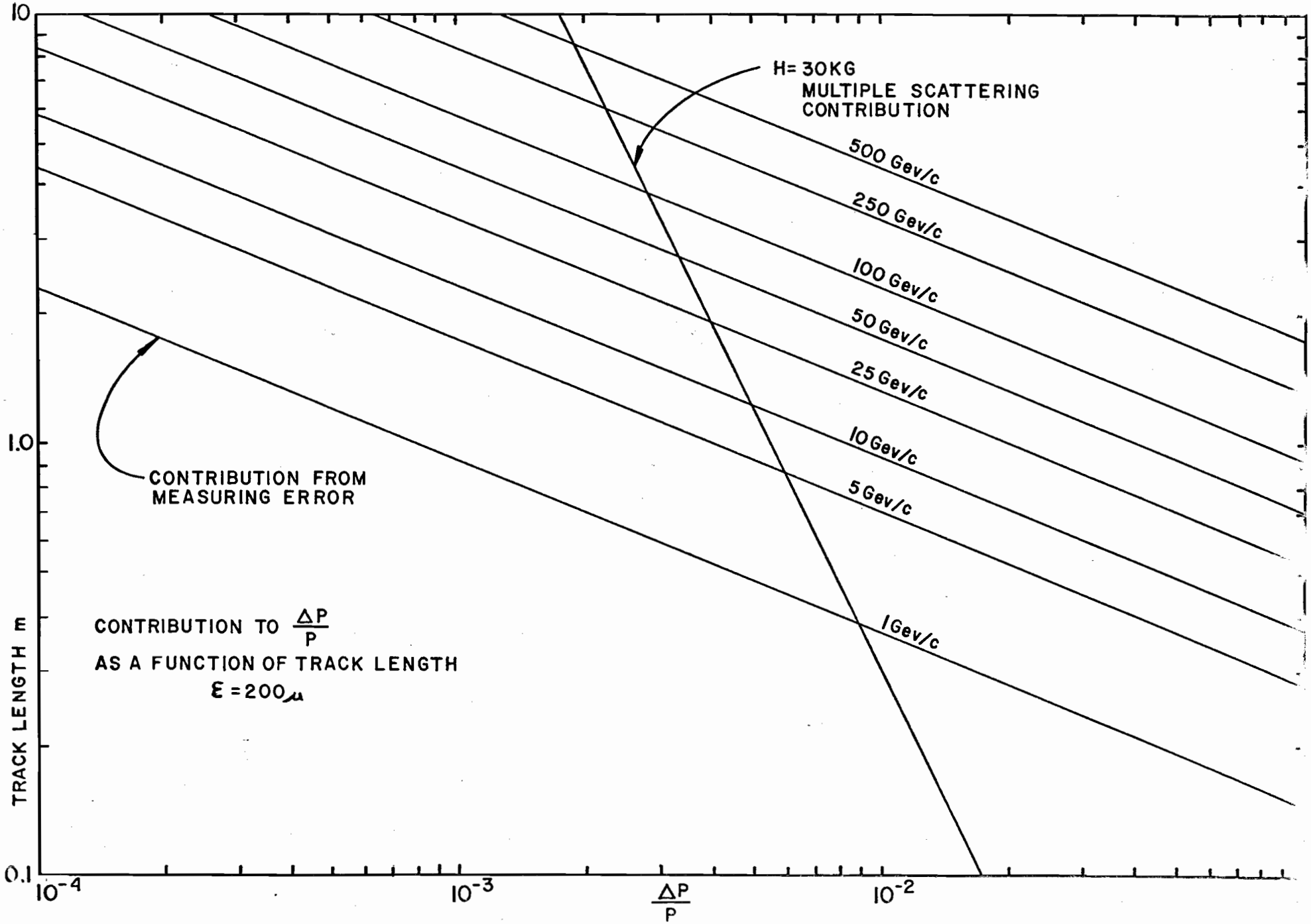

10
1.0
0.1
TRACK LENGTH m
10^{-4}
10^{-3}
$\frac{\Delta P}{P}$
10^{-2}
H= 30KG
MULTIPLE SCATTERING
CONTRIBUTION
500 Gev/c
250 Gev/c
100 Gev/c
50 Gev/c
25 Gev/c
10 Gev/c
5 Gev/c
1 Gev/c
CONTRIBUTION FROM
MEASURING ERROR
CONTRIBUTION TO $\frac{\Delta P}{P}$
AS A FUNCTION OF TRACK LENGTH
$\varepsilon = 200\mu$

FIGURE 3

A large chamber will permit estimates to be made of the number of neutrals created in high multiplicity collisions. This is important for some of the physics described below. Typical conversion probabilities are given in Fig. 4. In some cases the neutron star will clearly point back to the production vertex.

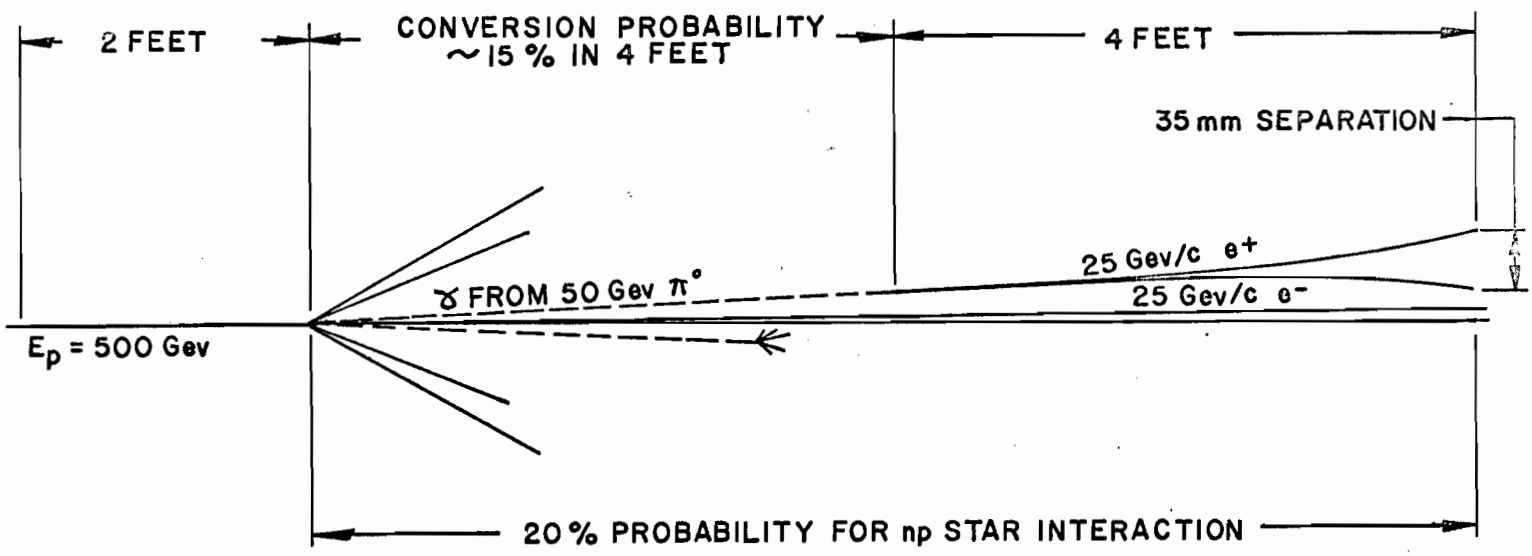


FIGURE 4

An obvious extension of this experiment when preliminary results are obtained from this film is to repeat the exposure when much more effective neutral detection capability, such as a neon blanket surrounding a hydrogen target region, is available.

PART II. PHYSICS JUSTIFICATION

A. Search For New Particles

A search will be made for new particles: unstable particles with mean free path 1 cm - 100 cm, particles with anomalous ionization (quarks), or anomalous trajectories (monopoles). This part of the analysis would not take long since it is basically a scan.

B. Multiparticle Final States

The study of highly inelastic channels in pp collisions confronts the experimentalist on the one hand with the difficult question of what to measure, and the theorist, on the other hand, with the challenge of constructing a model in which one can correlate the large variety and complexity of final states. Our goal in these studies is to improve our understanding of strong interaction dynamics. The analysis would make use of accurate measurements of charged particle multiplicities, laboratory momenta, plus/minus ratio, and inelasticity, as well as approximate measurements on neutral particle production. We should also be able to determine the strange particle production cross sections. The symmetry of the pp system means the high energy strange particles in the forward cone can be inferred by identifying the lower energy strange particles in the backward cone. Thus, cross sections for the production of K_s, Λ^o, $\Sigma^{\pm}$, Ξ^- and Ω^- as well as the corresponding anti-hyperons can be determined.

In the past, two classes of models were developed which bear on this problem, viz, (1) The statistical models of Fermi,[1] Landau,[2] and Hagedorn;[3] (2) The multiperipheral model of Amati, Stanghellini and Fubini.[4] More recently three new classes of models have emerged: (3) The multi-Regge Model, (MRM),[5] (4) Scaling models,[6,7,8] and (5) dual resonance models.[9] We shall emphasize here some of the more recent developments, i.e., (3), (4) and (5) and comment on how they compare with the earlier theoretical work.

C. Multiparticle Final States : Scaling Models and Comparison With Data

Recently, and in part, motivated by the scaling properties observed in deep inelastic electron scattering experiments,[10] Feynman[7,8] and Benecke, Chou, Yang, and Yen[6] have proposed a scaling law referred to by Yang as "The hypothesis of limiting fragmentation".[6] The distributions of fragments in a high energy collision eventually approach a limit independent of the bombarding energy.

More precisely Benecke et al conjecture the distributions $\rho_1(\vec{p})$ $\rho_2(\vec{p}_1,\vec{p}_2);\ldots\rho_i(\vec{p}_1,\ldots,\vec{p}_i)$, approach a non zero limit as the energy E goes to infinity. $\vec{p}_i$ are the three momenta in the laboratory for a particle of mass m_i, and $\rho_i(\vec{p}_1,\ldots\vec{p}_i)\, d^3\vec{p}_1\ldots d^3\vec{p}_i$ are the partial cross sections that a particle of mass m_i, and momentum $\vec{p}_1$, and i - 1 other particles of masses m_i and momentum $\vec{p}_i$ are emitted together with any number of other particles.

Benecke et al.[6] have obtained supporting evidence for their hypothesis for ρ_1 shown in Fig. 5 for the following reactions at 19.2[15] and 30 GeV/c.[16]

$$pp \rightarrow p + \text{anything} \tag{1a}$$

$$pp \rightarrow \pi + \text{anything} \tag{1b}$$

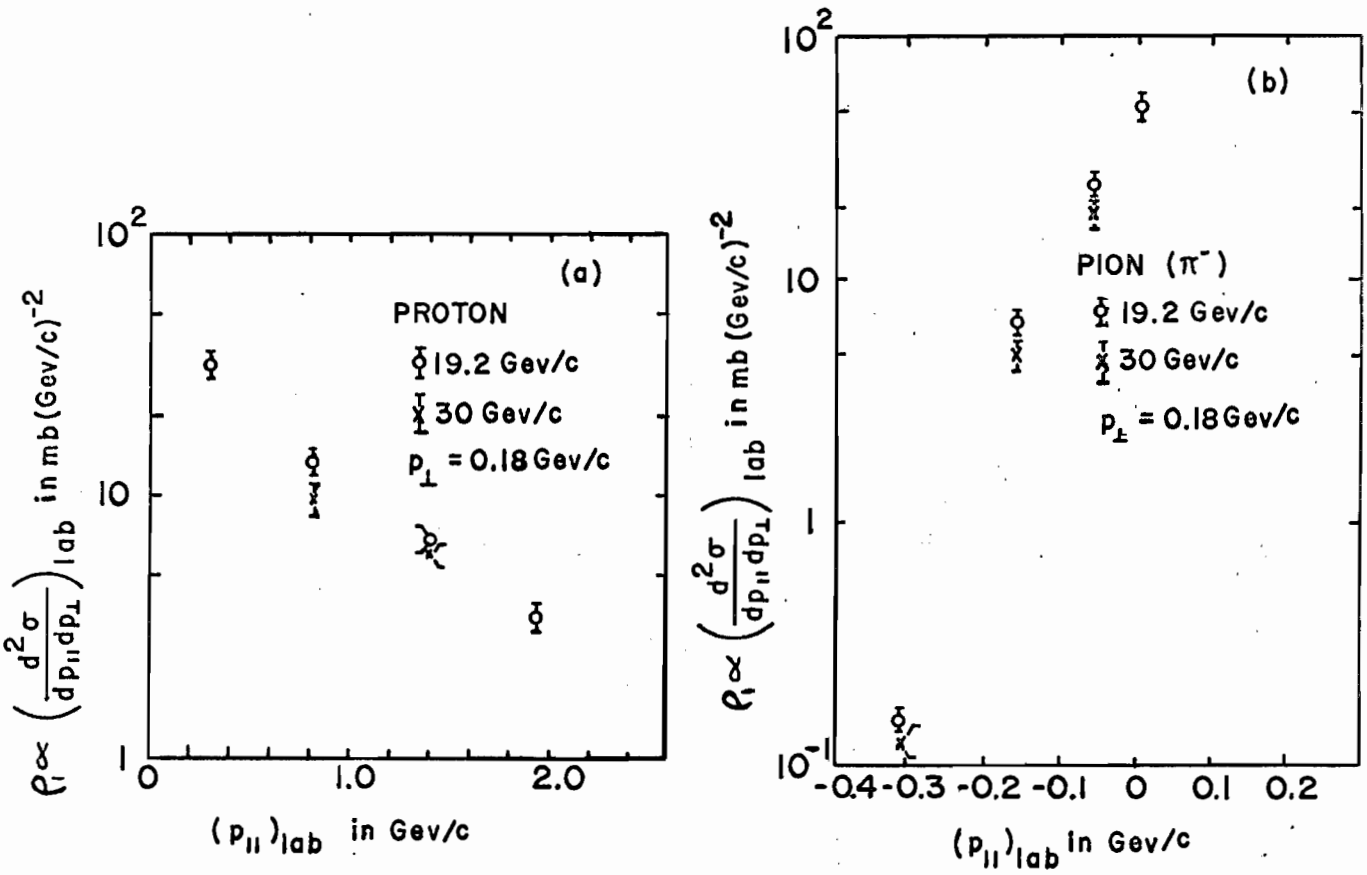


FIGURE 5

We stress here that the distribution ρ_1 is a function of two variables $p_{\parallel}^{lab}$, and $p_{\perp}^{lab}$, and not the usual three variables s, t, and M_x^2. (M_x is the mass of the system excluding the measured particle.) This is an example of scaling.*

It is also of interest to test the conjecture for ρ_2, ρ_3 ...etc. It is for these complex distributions in 2i dimensional spaces for i particles that the bubble chamber is particularly well suited. For example to determine $\rho_2\left(\vec{p}_{\perp_1}, \vec{p}_{\parallel_1}, \vec{p}_{\perp_2}, \vec{p}_{\parallel_2}\right)$ from a sample of multiprong events (all multiplicities) in each topology of n-prongs all possible pairs are formed and the resulting distribution normalized by dividing by $\binom{n}{2}$. These distributions are then added together to give $\frac{d^4\sigma}{dp_{\perp_1} dp_{\perp_2} dp_{\parallel_1} dp_{\parallel_2}}$ which is proportional to ρ_2. The statistics expected will allow a study of ρ_2 as a function of E_{lab}. In the 4 dimensional $\left(p_{\perp_1} p_{\perp_2} p_{\parallel_1} p_{\parallel_2}\right)$ space $\sim 10^5$ points will be obtained. Since the distribution in this space is expected to be non-uniform reasonable bin sizes can be formed while maintaining adequate statistics in each bin.

It is instructive to compare the hypothesis of limiting fragmentation to the scaling hypothesis of Feynman.[7,8] For Feynman the fundamental variables are

$$p_{\perp} \text{ and } X = \frac{2p_{\parallel}^{CM}}{\sqrt{s}} \text{ instead of } p_{\perp} \text{ and } p_{\parallel}^{lab} .$$

---

*Another example of a scaling law is[12] $\nu W_2(q^2, \nu) \rightarrow \nu W_2(\nu/q^2)$ in electroproduction.

More precisely, the partial cross section that a particle of mass m is emitted (say a pion) with momentum $\vec{p}_{lab}$ together with any number of other particles is given by:

$$d\sigma = d^3 p^{lab} \rho_1 (\vec{p}_{lab}) \qquad \text{Benecke et al.} \tag{2}$$

$$d\sigma = \frac{d^3 p^{cm}}{E^{cm}} M\left(p_\perp^{cm}, X = \frac{2 p_\parallel^{cm}}{\sqrt{s}}\right) \text{ Feynman} \tag{3}$$

Bali, Brown, Peccei and Pignotti[13] (BBPP) have studied carefully, from the point of view of Feynman scaling, the process $pp \to \pi^\pm$ + anything at accelerator energies (12.2,[14] 19,[15] and 30 GeV/c)[16], and in cosmic rays.[17] They have found that the data can be summarized by the remarkably simple expression

$$\begin{aligned} d\sigma^\pm &= \frac{d^3 p^{cm}}{E^{cm}} G_o^\pm e^{-a^\pm X^2} e^{-b\left(p_\perp^{cm} + \frac{p_\perp^{cm\,2}}{M_p}\right)} \\ &= \frac{d^3 p^{cm}}{E^{cm}} M^\pm\left(p_\perp^{cm}, X\right) \end{aligned} \tag{4}$$

where + refers to π^+ and - refers to π^-, M_p is the proton mass, and $G_o^\pm$, $a^\pm$, and b are constants determined by fitting the data.

In addition to the scaling result, they have observed that the amplitude factorizes into a function of X times a function of $p_\perp$.

BBPP predict.

$$< n^{\pm} > = 1.01 \ln \frac{E_{lab}}{M_p} + 1.3 \qquad (5)$$

where $< n^{\pm} >$ is the average charged particle multiplicity including protons.

In Fig. 6 we have plotted the experimental values for $< n^{\pm} >$, along with the prediction of BBPP,[13] for E_{lab} up to 1000 GeV/c together with accelerator points and the data of Jones,[17] the only cosmic ray data which makes use of a hydrogen target. The agreement is not very good, but it is better than would be expected if scaling were not present.

Data at superhigh energies compiled by Gibbs[18] appears to show a departure from the ln s dependence. Also Dobrotin's[19] points lie systematically higher than those of Jones.

In our proposed experiment the error on $< n^{\pm} >$ at each primary energy will be $\sim \pm 2\%$. This is not sufficient to distinguish a ln s from an $s^{1/4}$ dependence predicted by the statistical model [1,2] <u>unless</u> data from our experiment is combined with other data, e.g., forthcoming data from the I. S. R.[20]

The average transverse momentum, $< p_{\perp} >$ and the average inelasticity, ρ_{π}, defined as the ratio of the total energy that goes into pions to the total available energy, are interesting quantities to investigate.

At accelerator energies $< p_{\perp} >$ appear to increase slowly with energy but is also correlated with mass of the secondaries and with multiplicity.[21]

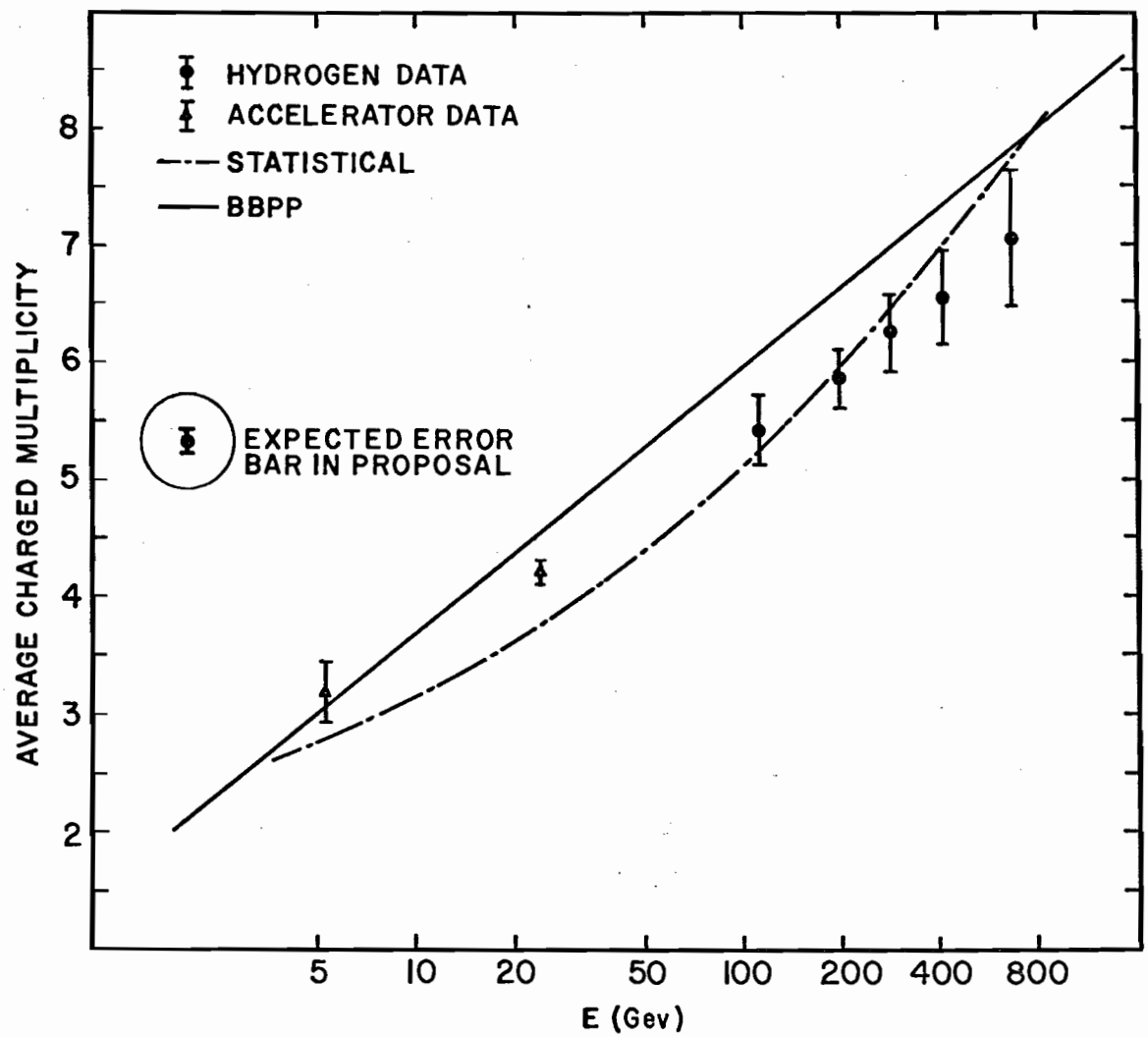

HYDROGEN DATA
ACCELERATOR DATA
STATISTICAL
BBPP
EXPECTED ERROR BAR IN PROPOSAL
AVERAGE CHARGED MULTIPLICITY
2
3
4
5
6
7
8
5
10
20
50
100
200
400
800
E (Gev)

FIGURE 6

Air shower experiments from 10 GeV to 10^5 GeV also show an increase[22] but it is not clear that all the data can be fit by a single expression.

Calculations based on scaling models such as those of BBPP[13] predict a change in average transverse momentum with center of mass energy:

$$< p_\perp > = < p_\perp >_\infty \left(1 - \frac{\lambda}{\ln s}\right) \tag{6}$$

The statistical model (pionization)[23] gives a quite different prediction for $E_p > 100$ GeV.

$$< p_\perp > = 0.4 \left[\frac{E_p}{100 \text{ GeV}}\right]^{1/4} \tag{7}$$

Expression (6) has been fit to accelerator data with $< p_\perp >_\infty = 390$ MeV/c and $\lambda = 0.58$.[13] But this fails to explain data in the region $E_p > 100$ GeV.

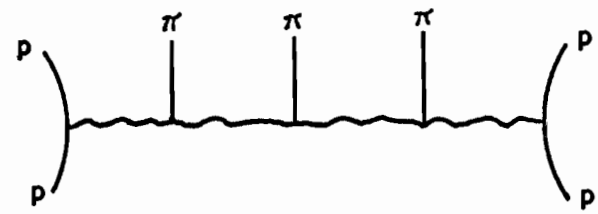
There are difficulties in the comparison of $< n^\pm >$ and $< p_\perp >$ prediction with cosmic ray data: e.g., in Jones' experiment there is an extimated 30% π-contamination[20] in the primary beam and in the very high energy jets.[22] It is uncertain what fraction of the secondaries are π's. In our proposed exposure $< p_\perp >$ will be determined to better than $\pm$ 5 MeV/c at each momentum.

In the scaling models[6,7,8] ρ_π should limit but the data in the 100 GeV - 1000 GeV is too inaccurate to allow definitive statements.

The present situation is confused and clearly more work is needed.

D. Multiparticle Final States: Multi-Regge Models and Experimental Data

The multi-Regge model, (MRM)[5] is based on studying the following diagram:



where the wiggly lines are Regge poles.

Both the multiperipheral model and multi-Regge model [5] lead to

$$< n^{\pm} > \; = \; K \ln s + d \, . \tag{8}$$

For the particle number distribution at a given energy the model of Chew and Pignotti,[25] and also the older multi-peripheral model[5] yield a Poisson form:

$$p_n \sim \frac{(< n >)^n}{n!} \; e^{-<n>} \tag{9}$$

where n = number of mesons produced and < n > = average number of mesons produced (+ - and 0). In Fig. 7 we have plotted the results of Chew and Pignotti[25] for the particle number distribution. For E_{lab} = 25 GeV/c, 50 GeV/c, 100 GeV/c, and 500 GeV/c. Definite predictions can be made concerning the multiplicity distribution for +, -, and neutral particles; these depend on which trajectory appears in the multi-Regge chain.

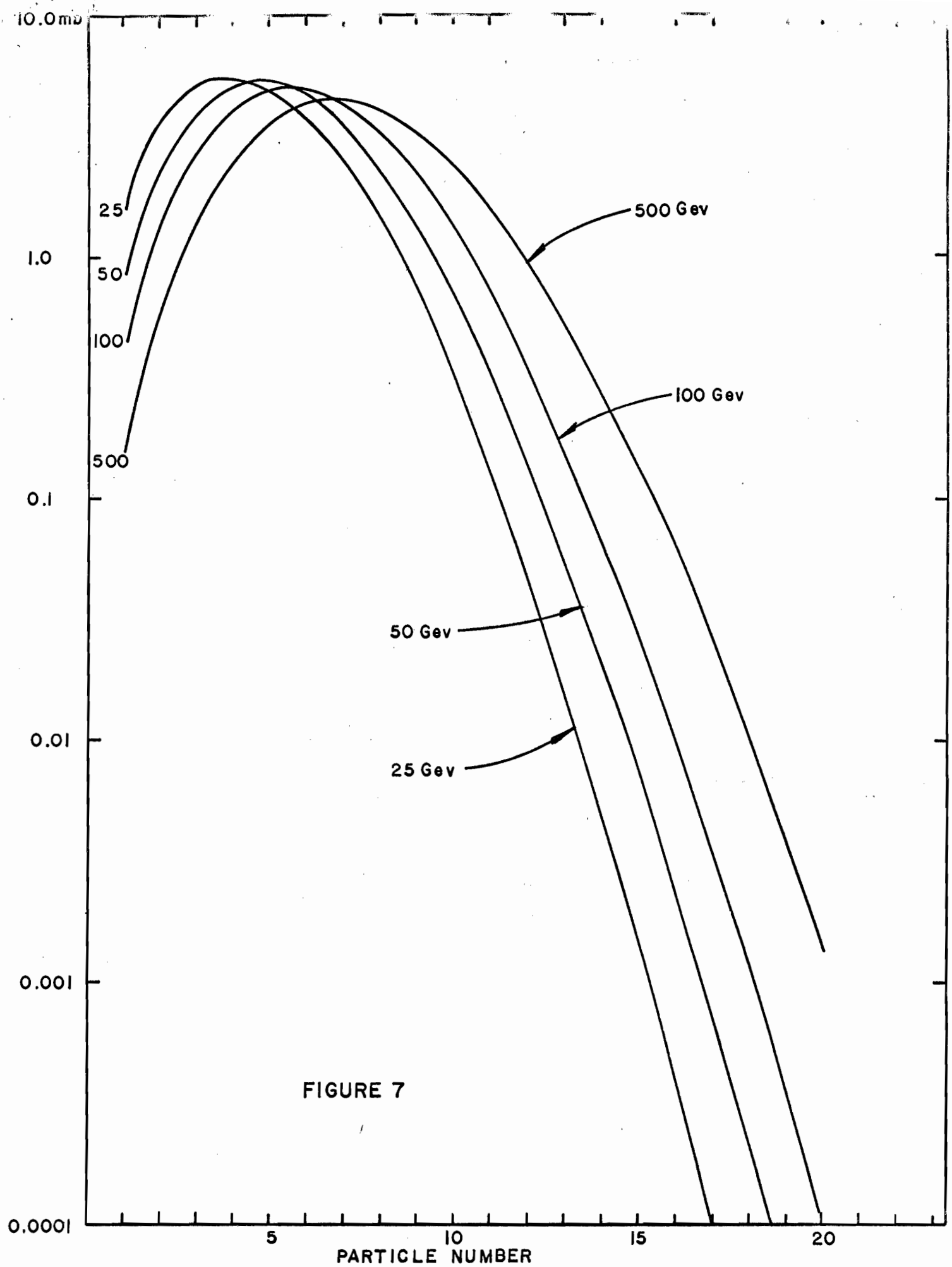

10.0mb
1.0
0.1
0.01
0.001
0.0001
25
50
100
500
500 Gev
100 Gev
50 Gev
25 Gev
5
10
15
20
PARTICLE NUMBER

FIGURE 7

Chew-Pignotti predictions based on equation (9) and combinatorial coefficients calculated assuming alternating I = 0 and I = 1 exchange for our proposed experiment are shown in the following tables:

TABLE II

E_o GeV	E_{cm}	$E_{available}$ $(-2M_p)$	n_π (Maximum Possible)	$< n >$ Average Number of mesons
100	14.2	12.2	87	5.98
200	20.2	18.0	128	6.77
300	24.3	22.3	160	7.22
400	28.3	26.3	188	7.55
500	31.5	29.5	212	7.81
1600 CERN ISR equivalent	57	55	393	9.13

TABLE III

100 GeV PRONG DISTRIBUTION

n_{prong}	σ	n events in 50,000 pictures
2	4.31 mb	6,500
4	9.97	15,000
6	9.20	13,800
8	4.60	6,900
10	1.43	2,100
12	311 μb	470
14	46	70
16	5	8
	~ 30 mb	

TABLE IV

500 GeV PRONG DISTRIBUTION

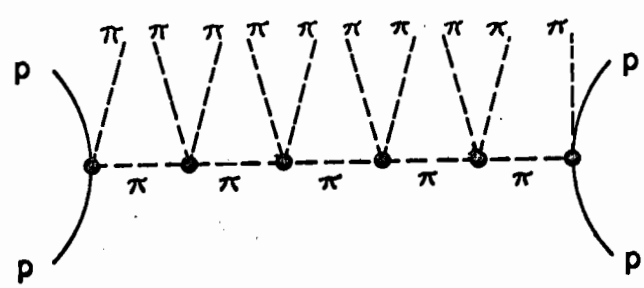
n_{prong}	σ	n events in 50,000 pictures
2	2.04 mb	3,000
4	6.72	10,000
6	9.20	13,800
8	7.04	10,600
10	3.44	5,200
12	1.18	1,800
14	286 μb	430
16	53	80
18	7	11
	~ 30 mb	

In contrast to Chew and Pignotti,[25] Wang[26] considers a statistical model in which a pair of charged pions are produced. Thus in place of Eq. (9), Wang considers,

$$p_n^{\text{Wang}} \sim \frac{\left(\frac{1}{2}\langle n-2\rangle\right)^{\frac{1}{2}(n-2)}}{\left(\frac{1}{2}(n-2)\right)!} e^{-\frac{1}{2}\langle n-2\rangle} \tag{10}$$

In Fig. 8 we show the experimental p_n distribution of Jones[17] compared to the predictions of Chew and Pignotti[25] with an alternating I = 1 and I = 0 exchange and Wang.[26] Perhaps the somewhat better agreement of Wang with the data of Jones is indicative of pion production in pairs along the multiperipheral chain.

Chew, Rogers, and Snider[27] have recently reconsidered the old multipheripheral model of Amati, Fubini, and Stangehellini.[4] They consider such graphs as



Here the dotted lines are elementary pions.

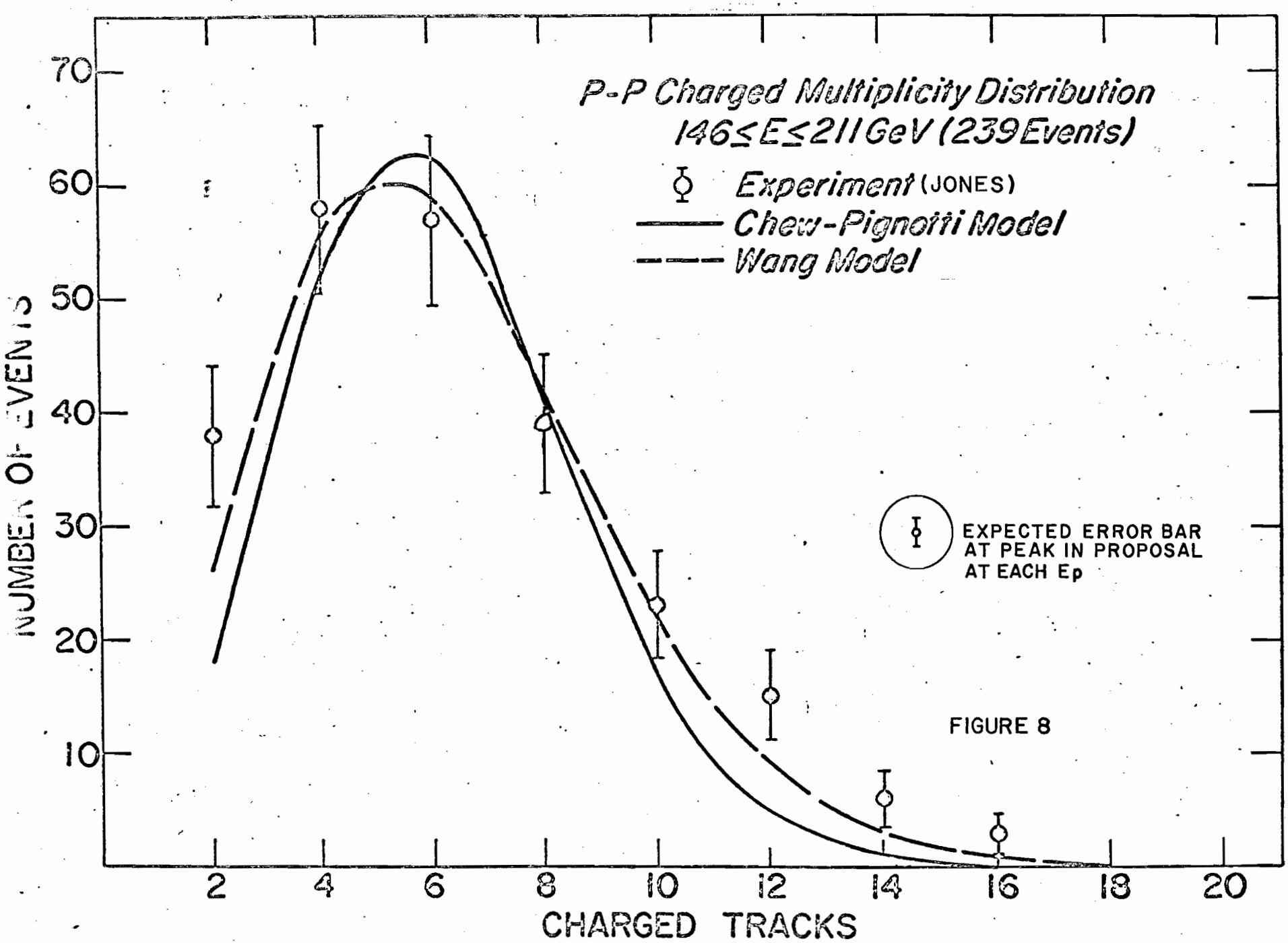

P-P Charged Multiplicity Distribution
146≤E≤211 GeV (239 Events)
Experiment (JONES)
Chew-Pignotti Model
Wang Model
EXPECTED ERROR BAR
AT PEAK IN PROPOSAL
AT EACH Ep
NUMBER OF EVENTS
CHARGED TRACKS
70
60
50
40
30
20
10
2
4
6
8
10
12
14
16
18
20

FIGURE 8

More recently Chew and Snider[28] have speculated on the possibility of complex Regge poles playing a fundamental role in high energy elastic scattering. In particular they were motivated by the apparent up turn in the $\pi^- p$ and $K^- p$ total cross section in recent Serpukhov experiments. A complex Regge pole would lead to a skewed Poisson distribution.

Events with a large number of prongs (≥ 16) will be relatively easy to find in scanning the film. Anylarge excess of those events over the predictions in Tables III and IV would indicate some new mechanism in the collision process.

F. Dual Resonance Models

The dual resonance model (which also has multi-Regge behavior) might be useful in correlating data involving multiparticle final states. Detailed work on 3 body final states has yielded encouraging results.[29] The work of Chang, Freund and Nambu[30] specifically bears on the question of experimental distributions for processes having complicated final states. They have pointed out that dual models predict for the process $A + B \rightarrow C +$ anything

$$\frac{d^2 \sigma}{dt\, dM^2} = A(s, M^2) e^{2\alpha' \ln \frac{s}{M^2}} , \qquad (11)$$

for $s >> M >> 1$.

α' is the slope of the Regge trajectory. Note the expansion of the forward peak as M^2 the mass squared of "anything" increases. Such a phenomena has been observed[31] in the reactions:

$$K^- p \to p\,(K\pi)^- \tag{12}$$

$$K^- p \to p\,(K\pi\pi)^- \tag{13}$$

$$\pi^+ p \to p\,\pi^+\pi^o \tag{14}$$

$$\pi^+ p \to p\,\pi^+\pi^+\pi^- \tag{15}$$

$$\pi^+ p \to N^{*++}\pi^+\pi^- \tag{16}$$

$$\pi^+ p \to N^{*++}\pi^+\pi^-\pi^o, \tag{17}$$

As Caneschi[32] has pointed out Eq. (11) can be obtained from MRM if one assumes, in addition, duality. A comparison of the Caneschi calculation with data for reactions (12) - (17) is shown in Fig. 9.

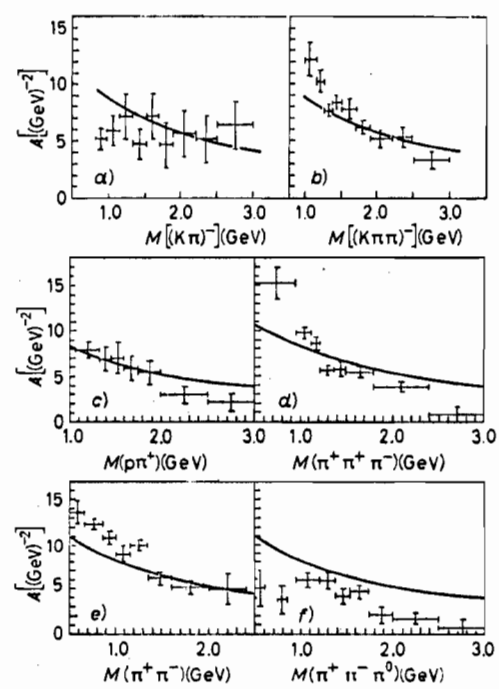


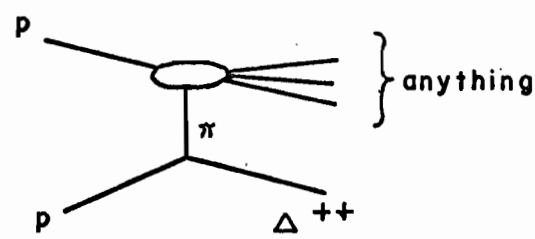
FIGURE 9

If one is optimistic the dual resonance model will develop to the point where it can make definite predictions about particle correlations in these complex events.

G. Peripheral Reactions

Two interesting classes of reactions that can be studied are:

$$pp \rightarrow \Delta^{++} + \text{anything with low } t_{p\Delta^{++}} \tag{18}$$



$$pp \rightarrow p + \text{anything with low } t_{pp}. \tag{19}$$

Figure 10 shows the Chew-Low boundary for these reactions at 100 GeV and 500 GeV.

There is considerable evidence[33,34] that reaction (18) is dominated by pion exchange in experiments at 6.6 GeV/c and 28.5 GeV/c for $t_{p\Delta} < 0.3\ \text{GeV}^2$. E.g., in a 6.6 GeV/c pp bubble chamber experiment,[35] the final states $pp \rightarrow (p\pi^-)\ \Delta^{++}$, $(p\pi^-\pi^o)\ \Delta^{++}$, $(n\pi^-\pi^+)\ \Delta^{++}$ occur with the same relative frequency (for $t_{p,\Delta} < 0.2\ \text{GeV}^2$) as the on-shell π-p cross sections $\pi^- p \rightarrow p\pi^-$, $p\pi^-\pi^o$, and $n\pi^-\pi^+$. Furthermore, a smooth

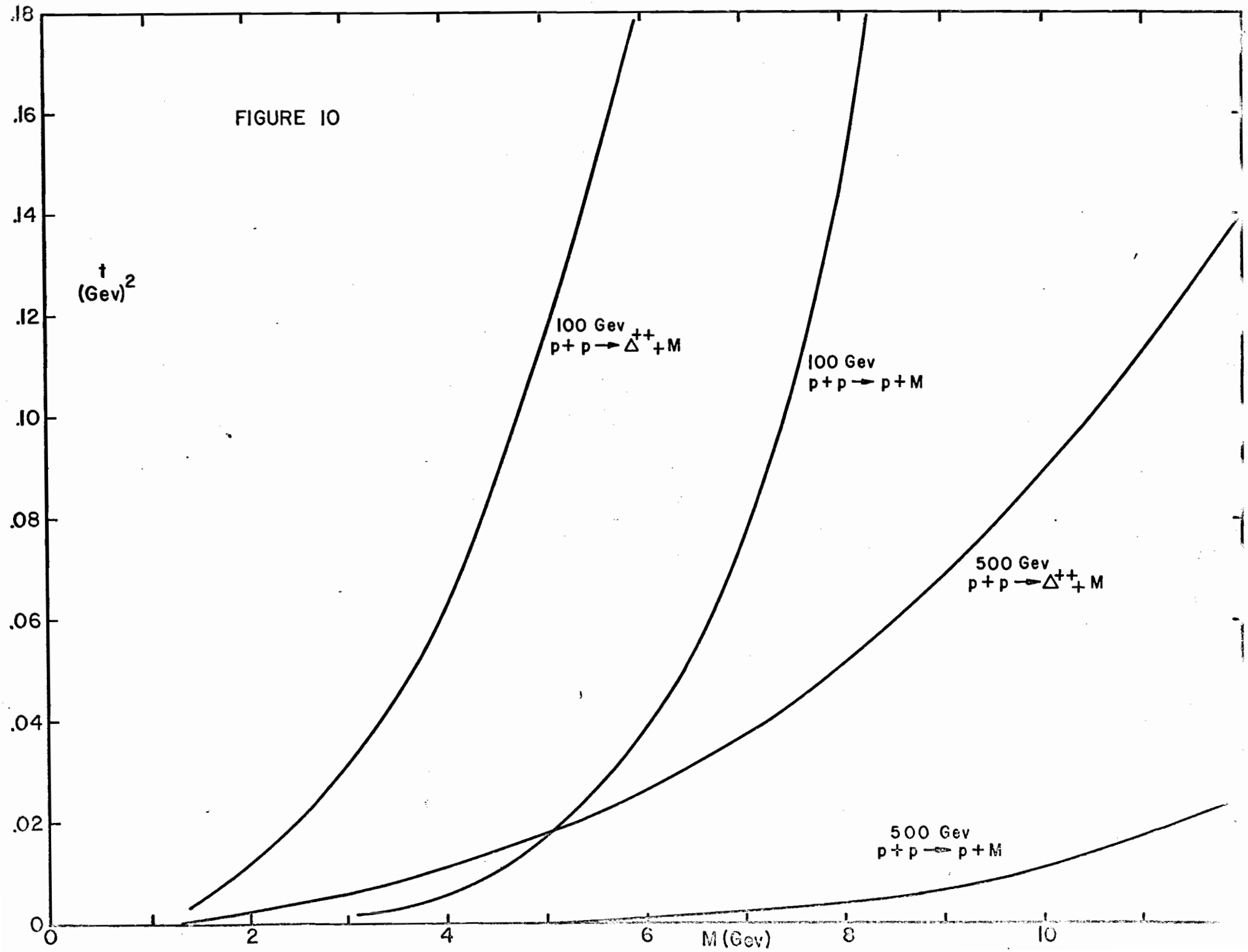


FIGURE 10
t
(Gev)^2
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
0
2
4
6
8
10
M (Gev)
100 Gev
p + p → Δ^{++} + M
100 Gev
p + p → p + M
500 Gev
p + p → Δ^{++} + M
500 Gev
p + p → p + M

extrapolation to the pion exchange pole [31] of $d\sigma/dt_{p,\Delta}$ for fixed $p\pi^-$ mass in $pp \to (p\pi^-)\,\Delta^{++}$ yields the on-shell $\pi^- p \to \pi^- p$ cross section as a function of $\pi^- p$ mass over the entire range of available $m_{\pi^- p}$. Thus agreement between the above mentioned inelastic channels in the physical regions of the Chew-Low plane implies that the extrapolation functions for the different channels must be very similar.

Aside from the kinematic effect due to the Chew-Low boundary changing with laboratory beam momentum p_{lab}, the entire p_{lab} dependence of the differential cross section $d^3\sigma/dt\, dm_{\pi^- p}\, dM_{\pi^+ p}$ is contained in the factor p_{lab}^{-2}. This factor is very small and cuts the low $t_{p\Delta^{++}}$ events down to ~ 10's of μ barns in this exposure. Of course one does not expect this phenomenological description to be exactly correct. The pion Regge trajectory may not be flat. There are technical advantages in being at large p_{lab}. As one moves to higher p_{lab}, there is less ambiguity about whether or not a given π^+ (or p) is a component of a low momentum transfer Δ^{++}. In other words, one can clearly select the low-t Δ^{++} signal in the relative absence of background. Ionization estimates of the p and π^+ decay products of the slow Δ^{++} are still useful. At large p_{lab} a large mass at the upper vertex is kinematically possible when t is small.

Reaction (19) should be energy independent due to Pomeron dominance, and account for a substantial portion of the diffraction dissociation cross section.

Although the expected rates for (19) are larger than (18) there is an experimental difficulty. Small t values close to the boundary ($t \lesssim 0.05\ GeV^2$) are not accessible due to the short range of the recoil proton.

H. Comparison With π Exposures

An exposure with π^-'s would, of course, be interesting and might well be a logical sequel to this one when the beam is available. Much of the physics overlaps with the proton exposure described.[36] There are, however, the following essential differences:

1. Unlike pp collisions, $\pi^- p$ are asymmetric around 90° in the C.M. The symmetry of the pp collision will be a powerful aid in the analysis since the results from the more easily measured backward hemisphere should equal those obtained from the forward cone. The symmetry is especially useful for measuring hyperons.

2. There are no s-channel resonances in pp in contrast with $\pi^- p$.

PART III. ANALYSIS

Scanning. Scanning of the 15' chamber may require construction of new scanning tables and/or making use of two scanners sitting side by side looking at different portions of the chamber.

During scanning events will be classified by topology. Multiplicities, +/ - ratio and V^o production will be determined as a function of primary energy. Predigitization of the bulk of the film may not be needed if the

common topologies are measured in an automatic scan made.

Measurements

We expect a total of 225,000 inelastic events. However, it will not be clear until analysis starts whether it is worthwhile to measure all of these. Certainly at least for some portion of the film everything will be measured.

It may be decided to select and measure particular classes of events, e.g., 6-8 prongs, or all those events with a possible final state peripheral Δ^{++}.

Even if we decide to measure all the events in the film, it will not overtax the measuring capabilities of the two proposing groups. Both NAL and UCLA have received funding to construct CRT automatic measuring machines. These facilities are expected to be in operation by the time this film would be obtained. Both the NAL and UCLA devices would be capable of providing ionization information for only a small increase of measuring time.

PART IV. CONCLUSIONS

We have chosen to emphasize the type of analysis that can be done on a high statistics sample of complex unfitted events. We feel that besides providing the early 'engineering' information on high energy proton interactions which are so essential for the planning of both counter and future bubble chamber experiments, there are measurable quantities and distributions for which various present day theories make definite statements.

In particular both the multi-Regge models and scaling models lead to definite predictions concerning

1. $\rho_i(\vec{p}_1, \vec{p}_2 \ldots \vec{p}_i)$
2. $< n >$
3. $< p_\perp >$
4. Inelasticity

Moreover, $< n^+ >$, $< n^- >$, $< n^o >$ appear to give some information concerning the Reggeons which appear in the multi-Regge chain. The prong distribution could possibly signal anomolous (complex) trajectories in the multi-Regge chain.

When this bubble chamber data is available it is likely that more detailed theoretical predictions on final state particle correlations will exist. The analysis of complex events is necessarily conducted using a theoretical or phenomenological guide. This is a necessity to guide the analysis through the multitude of possible parameterizations. Historically such analyses have been fruitful in clarifying production mechanisms.

The large liquid hydrogen bubble chamber has shown itself to be a remarkable instrument for the study of the unexpected. In particular its ability to provide an enormous amount of unbiased kinematical information about a single event will insure its value as we enter this new energy realm. With the use of such an instrument in the early phase of the National Accelerator Laboratory's research program we can not only test the validity of our current conjectures at higher energies but also seek out those phenomena which are unique to this new energy range.

REFERENCES

1. Fermi, Progr. Theor. Phys. 5, 570 (1950); Phys. Rev. 81, 683 (1951).
2. Landau, Izv. Akad. Nauk SSSR, Ser. Fiz., 17, 51, 1953.
3. See e.g. R. Hagedorn, Nuovo Cimento 56A, 1026 (1968).
4. D. Amati, A. Stanghellini, S. Fubini, Nuovo Cimento 26, 896 (1962).
5. N.F. Bali, G. F. Chew, and A. Pignotti, Phys. Rev. 163, 1572 (1967). For a more complete list see Ref. 1 of Ref. 25.
6. J. Benecke, T.T. Chou, C.N. Yang, and E. Yen, Phys. Rev. 1[illegible] 2159 (1969).
7. R.P. Feynman, Phys. Rev. Letters 23, 1415 (1969).
8. R.P. Feynman, Third International Conference on High Energy Collisions, State University of New York, Stony Brook, Septermber 5-6, 1969.
9. See e.g., Chan Hong-Mo's Royal Society Lectures CERN preprint TH 1057.
10. MIT-SLAC, M. Breidenbach et al., Phys. Rev. Letters 23, 935-8 (1969).
11. C.N. Yang, Professor of the Month Lectures NAL, 1970.
12. J.D. Bjorken, Phys. Rev. 179, 1547 (1969).
13. N.F. Bali, L.S. Brown, R.D. Peccei and A. Pignotti, University of Washington preprint, the constants $G_o^{\pm}$, $a^{\pm}$ are:

at p_{lab} = 12.2 GeV/c, $G_o^+ = 36$ mb/GeV^2, $G_o^- = 19$ mb/GeV^2
$a^+ = 8.2$, $a^- = 11.5$,

at p_{lab} = 19.2 GeV/c $G_o^+ = 44$ mb/GeV^2, $G_o^- = 25$ mb/GeV^2
$a^+ = 8.5$, $a^- = 10$,

at p_{lab} = 30.0 GeV/c $G_o^+ = 37$ mb/GeV^2, $G_o^- = 29$mb/GeV^2
$a^+ = 7.4$, $a^- = 12.1$,

and b = 2.55.

14. J.L. Day, et al., Phys Rev. Letters 23, 1055 (1969).

15. J.W. Allaby, et al., Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna (Austria) 1968.

16. E.W. Anderson, et al., Phys. Rev. Letters 19, 198 (1967).

17. L.W. Jones, Proceedings of the International Conference on Expectations for Particle Reactions At the New Accelerators, Madison, Wisconsin, April, 1970. Note ~ 30 percent of incident particles are π's. Jones' distribution should go down ~ 10 percent if this is done. (Peccei - private communication.)

18. R. Gibbs, University of Washington, as quoted by N. Bali, Proceedings of the International Conference on Expectations for Particle Reactions at the New Accelerators, April 1970, Madison, Wisconsin.

19. N.A. Drobrotin and S.A. Slavatinsky, Proceedings of the Tenth International Conference on Cosmic Rays, p. 416, Calgary, Canada, June 19 - 30, 1967.

20. B.R. French, "Reflections on the Study of High Multiplicity Interactions and the Reaction $pp \rightarrow pp X^{o}$ at the I.S.R.", CERN Report ISR, 1968 (unpublished).

21. As summarized by F. Turkot, Third International Conference on High Energy Collisions, State University of New York, Stony Brook, September 5-6, 1969.

22. Kiel group, See Trumper, Rapporteur paper on Extensive Air Showers, Eleventh International Conference on Cosmic Rays, Budapest, 1969.

23. M. Koshiba, Rapporteur talk, Tenth International Conference on Cosmic Rays, June , 1967, Calgary, Canada.

24. K. N. Erikson (Colorado). Technical Report of University of Michigan, UM HE 70-4.

25. G. F. Chew, A. Pignotti, Phys. Rev. 176, 2112 (1968).

26. C. P. Wang, Physical Rev. 180, 1463 (1969).

27. G. F. Chew, T. Rogers, D. R. Snider, preprint UCRL - 19457, Jan. 1970.

28. G. F. Chew, D. R. Snider, preprint UCRL - 19409, November 1969.

29. We mention here the study by Chan Hong - Mo et al., of the reactions $K^+ p \rightarrow K^o \pi^+ p, K^- p \rightarrow \overline{K}^o \pi^- p$, $\pi^- p \rightarrow K^o K^- p$, December 1969, CERN preprint, TH- 1111.

30. L. N. Chang, P. G. O. Freund, Y. Nambu, Phys. Rev. Letters 24, 628 (1970).

31. Aachen -Berlin-CERN-London (I. C.)- Vienna, Phys. Letters, 27B, 336 (1968).

32. L. Caneschi, Letters Nuovo Cimento 2, 122, (1969).

33. See review talk by Peter E. Schlein at The Informal Meeting on Experimental Meson Spectroscopy, University of Pennsylvania, April 26-27, 1968. Published in Meson Spectroscopy, ed. C. Baltay and A. H. Rosenfeld (W. A. Benjamin, Inc., 1968). p. 161.

34. Eugene Colton and Peter E. Schlein, Experimental Validity of One-Pion-Exchange and Prospects for Studying $\pi\pi$ and $K\pi$ Scattering. Proceedings of the Conference on $\pi\pi$ and $K\pi$ Interactions, Argonne National Laboratory, May 14, 1969.

35. Eugene Colton, Peter E. Schlein, Eugene Gellert, and Gerald A. Smith, Phys. Rev. Letters 21, 1548 (1968).

36. See e.g., A. R. Erwin, Proceedings of the International Conference on Expectations for Particle Reactions at the New Accelerators, April, 1970, Madison, Wisconsin.

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