NAL PROPOSAL No. 140

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Proposal to Study High Mass States of $\pi^{\pm}$, $K^{\pm}$ and $p^{\pm}$ With Masses Up to 10 GeV

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Abstract

A missing mass spectrometer experiment is proposed to study high mass states, *, of the π, K and p produced in the reactions:

1. $\pi^{\pm}p \rightarrow (\pi^{\pm})^{*}\ p$ (1)
2. $K^{\pm}p \rightarrow (K^{\pm})^{*}\ p$ (2)
3. $p^{\pm}p \rightarrow (p^{\pm})^{*}\ p$ (3)

An existing recoil proton spectrometer system, capable of high data rates (~ 200 events per pulse of 1 sec length), will be used in a variable energy ($10 \leq p \leq 200$ GeV), medium resolution ($\delta p/p \leq 1/4\%$), secondary beam.

The experiment will:

a) Search for new hadron excited states, resonances, in the mass range $2 \leq M \leq 10$ GeV.

b) Measure the s ($40 \leq s \leq 400$ GeV^2) and t ($0.10 \leq t \leq 0.45$ GeV^2) dependences of the production cross sections for well established hadron states such as the $\pi^{*}(1.3)$ (the A_2 meson), and the p^{*} (1.7).

c) Study the s ($40 \leq s \leq 400$ GeV^2), t ($0.10 \leq t \leq 0.45$ GeV^2), M^2 ($0 \leq M^2 \leq 100$ GeV^2), and charged pion multiplicity dependences of the non resonance or background production cross sections.

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1. Physics Justification.

a) Introduction

This experiment proposes to measure, in an as yet unexplored kinematic region, highly inelastic hadron reactions of the type

$$H + p \rightarrow H^{*} + p \qquad (4)$$

where H indicates a stable beam particle ($\pi^{\pm}$, $K^{\pm}$ or $p^{\pm}$) and H^{*} a collection of hadrons i.e. decay products from a hadron resonance or hadrons produced directly in the inelastic collision. The important features of the experiment will be its high sensitivity for detection of resonances (e.g. for π^{*} or p^{*} resonances the sensitivity is $> 10^{4}$ events per 5 μb production cross section per 50 hours of data taking) and its ability to accurately map the dependences of both resonance and non-resonance production cross sections on beam momentum, proton four-momentum transfer, hadron mass and charge multiplicity in a kinematic region where present models can be critically tested.

The overall proven ability of the system proposed to carry out a significant survey of high mass hadron spectroscopy with a modest investment of effort and resources, combined with the complementary nature of this work with respect to other presently planned NAL experiments (for example NAL proposal 110) make this experiment particularly valuable as an experiment to be performed early in the NAL program.

b) Zoology of Hadron Resonances

Almost all present theories which attempt to explain the features of the low lying hadron states predict that high mass ($M \geq 3$ GeV) resonances (or excited states) exist. For example, in the quark model, one expects higher mass $(\pi^{-})^{*}$ states which correspond to the higher orbital (or radial) excitations (above the ground state) of the quark-anti-quark pair that make up the π^{-}. This experiment will determine, with a high level of sensitivity, whether or not high mass objects exist with cross sections large enough to make these objects amenable to detailed (and less general) study using other techniques, i.e. studies to determine their spins, parities and branching ratios. In this sense, this experiment is exploratory and is designed to effectively point the way towards areas (masses and charge multiplicities of decays) where more specific experiments could be designed to study the quantum numbers of the resonances.7)

c) Differential Cross Sections of Known Resonances at High Energies

In missing mass experiments in which slow recoil protons have been detected, the most prominent structures in the π^*, K^*, and p^* spectra are the elastic peaks and the $\pi^*(1.3)$, $K^*(1.4)$, and $p^*(1.7)$ peaks. Present phenomenology of cross sections in the beam momentum, P, range $P \leq 20$ GeV suggests that the cross sections for these states will fall slowly ($\sigma \geq$ const./P) with increasing beam momentum. As a result of the large mass acceptance of the apparatus proposed, the differential cross sections for elastic scattering and for these excited states will be measured simultaneously. Thus a highly reliable comparison of the s and t dependences of the inelastic and elastic cross sections will be made. It is expected that the ability of the apparatus to identify the number of charged particles in the final state will provide a clean separation of the elastic and inelastic peaks (specified above) even at the highest beam momentum where the mass squared resolution (FWHM) becomes approximately equal to the separation between the peaks. The behavior of the differential cross sections for these inelastic peaks as well as the non resonance backgrounds1) in the mass region $M \leq 3$ GeV will provide tests of Regge and other predictions for the behavior of the high energy cross sections.

d) Investigation of the Basic Properties of Inelastic Reactions (Non Resonance) at High Energies

In the process of searching for high mass resonances we will collect vast amounts of data (~ 200,000 events per hour) on the s and t dependences of the non resonance production cross sections. Recently there has been much theoretical work$^{2)}$ on so called inclusive reactions which predicts double differential cross sections for one of the final state particles.

Such a reaction is

$$H + p \rightarrow p + \text{"anything"} \qquad (5)$$

in which the cross section $d^2\sigma/dtdM^2$ (M^2 is the squared mass of all the final state particles other than the proton, "anything", and t is the square of the four momentum transferred to the proton) are predicted, for fixed t, to be proportional to $\frac{(s/M^2)^C}{s}$ where C is a constant calculable from a knowledge of the particles exchanged in the reaction. This prediction is derived from a generalized three-particle optical theorem applied to a Regge treatment of inclusive reaction production mechanisms. These predictions are expected to be most reliable for large s and M^2 where the ratio s/M^2 is also large. By collecting accurate data for π, K, and p projectiles, this experiment will test these models and other more phenomenological predictions$^{3)}$.

The measured cross sections $d^2\sigma/dtdM^2$ as a function of the final state charge multiplicity will provide data for testing the validity of the Lorentz Invariant Phase Space Predictions$^{4)}$ and other models for s, t, M^2 and multiplicity dependences of the cross sections.

2) Apparatus

a) Description

A layout of the apparatus in the detector region is shown in Fig. 1.

A high flux (~ 3 x 10^6 particles per pulse) beam impinges on a thin walled 24" L x 0.5" D liquid hydrogen target. A scintillation counter hodoscope placed at the beam's momentum focus measures, for each event, the incident particle's momentum to $\pm$ 0.1%. A Cerenkov counter (disc type) identifies the incident beam particle (π, K, or p). A beam design similar to NAL beams #21 or #25 5), in which the focal properties of the beams at the H_2 target are: spot $\leq (0.3)^2$ in^2 and angular divergences $\leq \pm$ 1 mr is used. Scintillation hodoscopes placed before the target will measure the beam particle's angles and lateral position at the target.

Recoil protons in the kinetic energy, T_p, range $.04 \leq T_p \leq 0.22$ GeV are detected in a proton spectrometer consisting of wire spark chambers, to measure the proton's angles, and scintillation counters, to measure the proton's energy, dE/dx, and time of flight. This proton spectrometer has been used, previously, at the Brookhaven AGS by our group in collaboration with a Stony Brook group. The performance characteristics of this spectrometer are described in detail elsewhere 6).

The decay analyzer, which counts the number of final state charged particles, consists of a cylindrical proportional wire chamber (axis parallel to the beam) and two scintillation counter hodoscopes placed before and after the H_2 target (~ 10 and 60 counters respectively). Since the final state must contain an even number of charged particles, the performance of this analyzer can be easily monitored. (We are currently also studying the feasibility of measuring the number of final state π^o's.)

For each event, all digital information is recorded onto magnetic tape using the Northeastern PDP9 computer and data logging system. This system can record events with less than a 5 m sec dead time and perform crude checks on the performance of the apparatus. The event rate of 200 events per sec does not present any new problems for the spark chambers or data logging system.

b) Performance Characteristics

In determining the performance characteristics of the apparatus we have made extensive use of results of a similar experiment we have carried out at lower energies at the Brookhaven AGS.

Some mass spectra obtained in the AGS experiment are shown in Figs. 2 and 3. Each of these spectra were obtained with a single angle setting of the proton spectrometer. No piecing together of the separate mass spectra was necessary to examine the large mass intervals shown. This feature makes possible the reliable detection of broad resonances (Γ (resonance) $>$ Γ (experimental) as well as narrow ones (Γ (resonance) $<$ Γ (experimental). In the proposed experiment, the entire mass interval, examined at each beam energy, will be measured with only three separate angle settings of the proton spectrometer. Even with only three settings, good overlap regions between the three spectra will be obtained.

The proton production angle and kinetic energy region in the proposed experiment is the same as that measured in the AGS experiment. In both experiments, for a fixed proton spectrometer angle setting, the detection efficiency as a function of mass, M, depends, to a good approximation, only on the ratio M^2/P (P = beam momentum). Thus, proven methods, already developed for the AGS work, for calculating the mass dependent detection efficiency, are applicable to the analysis of the higher energy data.

Another important property of the apparatus is that at fixed beam momentum the resolution in missing mass squared, δM^2, is approximately independent of M^2. For the several beam momenta, P, $\delta M^2 \alpha P$. Also, as the beam energy is varied, the apparatus always covers a fixed fraction of the total M^2 interval kinematically possible. Since the total cross sections are expected to be approximately constant in the region $10 \leq P \leq 200$ GeV, the data rates observed with the system in the $P < 20$ GeV region have been used in estimating the rates for the $20 \leq P \leq 200$ GeV range.

3) Run Plan

a) Accelerator Time Allotted to Each Reaction, Data Rates etc.

Table I contains a proposed run plan for the experiment and indicates the M^2 ranges covered, M^2 resolutions, data rates expected, and sensitivity to resonances. A total of 950 hours of data taking accelerator time is requested. Beam and proton spectrometer calibration checks, and additional overhead will require an additional 200 to 600 hours of accelerator time. Assuming the beam performance is as expected, approximately three calendar months of accelerator time should be sufficient.

4) NAL Requirements

a) Beam

A high flux unseparated beam will be required as described in Table I. We estimate that the required fluxes will necessitate that the accelerator be run in the 300 to 400 GeV range for approximately 200 hours.

b) Electronics and Electronics Trailers

This experiment will require two 10' x 10' x 60' R.F. shielded electronics trailers (one of which is to be supplied by NU) 150 logic modules (performance characteristics similar to Chronetics 150 series), 20 power supplies and 32 scalers. We feel it most efficient for NAL to supply and maintain this equipment so that it is readily available for other experiments.

c) Beam C Counter

This experiment will require at least one disc type Cerenkov counter. We assume that such counters can be borrowed from another group or will be supplied by NAL.

d) H_2 Target

A 24" L x 0.5" d thin walled target is required (total mylar (or equivalent) material thickness on the proton spectrometer side of less than 0.012"). The target vacuum jacket must be a cylinder of less than 3" d, thin walled, with fill lines on the upstream end of the target. We strongly suggest that this target be built so that it can be filled with deuterium as well as hydrogen.7)

e) Additional Magnets for Beam Performance Verification

Since the proposed apparatus does not have any built in feature for checking the beam momentum resolution, it may be necessary to incorporate additional bending magnets, of small aperture, into the beam or after the H_2 target so that a reliable beam check out can be performed. If this experiment were to be performed in a beam previously verified, such magnets may not be necessary.

f) Floor Space

In addition to the beam line, a detector area of only 20' x 20' on the high momentum side of the beam will be necessary. It is highly desirable that one electronics trailer be placed less than 30' from the detector area and it be possible to connect the two trailers. We also need an additional 1000 sq. ft. of air conditioned laboratory space for storage, light assembly work, etc.

g) Off Line Data Analysis

The experiment can be most efficiently carried out if approximately 500 hours of CDC 6600 time, 50/k core or equivalent computing power were available during the data recording phase of the experiment, for off-line analysis of the data. A turn-around time of one to three hours would be sufficient. In addition, an on-line link between our PDP9 and a PDP10 (50_{10}/k core; 50% CPU usage) or equivalent computer power is desired during beam time. This computer arrangement (PDP9 + PDP10 + CDC6600) is essentially that used by our group during our AGS experiment, and will allow us to carry out the experiment efficiently and on a tight time schedule (6 months from setup to end).

5) Schedules

a) Time and Manpower Schedules for Experimental Setup, Testing and Data Taking

This experiment will require approximately six physicists (of whom at least two are post doctoral research associates) and two technicians full time for a period of six months. With this work force it will be possible to set up and test the equipment in three months and record the final data in an additional three month period. Prior to this six month period an average of three physicists will be required for one year to develop and debug new equipment (proportional chamber, hodoscopes, etc.) and to make improvements in existing data collection and analysis systems (computer programs).

6) References

1. Jiuum-Ming Wang and Luig-Lie Wang, Phys. Rev. Lett. 26, 1287 (1971).
2. C. DeTar, *et al.*, Phys. Rev. Lett. 26, 675 (1971).
3. D. Garelick, Phys. Rev. Lett. 22, 674 (1969).
4. A. Wroblewski, *Proceedings of the XV International Conference on High Energy Physics*, Kiev, U.S.S.R., (1970) (to be published).
5. A. L. Read, NAL report, *Properties of Secondary Beams in Experimental Area #2*, June 25, 1970 (unpublished).
6. D. Bowen, *et al.*, Phys. Rev. Lett., 26, (1971) (to be published), and D. Bowen, *et al.*, *Phenomenology in Particle Physics 1971*, edited by C. Chiu, G. Fox, and A. Hey (California Institute of Technology)(to be published).
7. The ability of our proton spectrometer to function as a deuteron spectrometer has already been checked in studies carried out at the AGS. Resonances seen in the reactions $\pi(K)d \rightarrow \pi^*(K^*)d$ must be $\pi^*(I = 1)$ or K^* $(I = 1/2)$, i.e. deuterium measurements would give indications as to whether or not high mass resonances are exotic.

7) TABLE I. Run Plan.

Beam Particle	Beam Momentum (GeV)	Expected[†] Beam Flux (No. Per Pulse)	M^2 Range[≠] Examined (GeV^2)	M^2 Resolution[□] (FWHM: GeV^2)	Data Collection Time (Hours)
π^-	10	3×10^6	0 - 5	0.1	50
π^-	20	3×10^6	0 - 10	0.2	50
π^-	50	3×10^6	0 - 25	0.5	50
π^-	100	3×10^6	0 - 50	1.0	50
π^-	150	3×10^6	0 - 75	1.5	50
π^-	200[*]	3×10^6	0 - 100	2.0	50
p	20	3×10^5	1 - 10	0.2	50
p	50	1×10^6	1 - 25	0.5	50
p	100	2×10^6	1 - 50	1.0	50
p	150	3×10^6	1 - 75	1.5	50
p	200	3×10^6	1 - 100	2.0	50
π^+	100	2×10^6	0 - 50	1.0	50
π^+	200[*]	3×10^5	0 - 100	2.0	50
K^-	100	3×10^4	0 - 50	1.0	50
K^-	200[*]	3×10^4	0 - 100	2.0	50
K^+	100	3×10^4	0 - 50	1.0	50
K^+	200[*]	3×10^4	0 - 100	2.0	50
$\bar{p}$	100	2×10^4	1 - 50	1.0	50
$\bar{p}$	200[*]	2×10^4	1 - 100	2.0	50

(Table I continued)

Events in Mass Histograms[‡]	Estimated Sensitivity for Resonances[Δ]	
	Event Per 5 μb:	Signal/Noise:
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
5×10^6	5×10^3:	1/20
2×10^6	2×10^3:	1/20
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
1×10^7	1×10^4:	1/20
5×10^6	5×10^3:	1/20
5×10^5	5×10^2:	1/20
5×10^5	5×10^2:	1/20
5×10^5	5×10^2:	1/20
5×10^5	5×10^2:	1/20
3×10^5	3×10^2:	1/20
3×10^5	3×10^2:	1/20

* For these beam energies the proton accelerator will probably have to be run in the 300-400 GeV range. The particle fluxes in the NAL report, reference 5, beam #25, are used in these estimates.

† Past experience with the apparatus has shown that the spark chambers become background limited at rates of $\sim 3 \times 10^6$ particles per sec through the 24" H_2 target. At a flux of 3×10^6 particles per pulse, there are $\sim 10^3$ triggers per pulse. The system dead time is $\sim 5 \times 10^{-3}$ sec, i.e. ~ 200 events per pulse can be recorded. The total data rate does not decrease until the flux falls below $\sim 10^6$ particles per pulse, but the flexibility in examining a particular small t interval, or particular charge multiplicity, or any highly selective trigger, becomes less.

≠ This mass range will be covered in three angle settings of the proton spectrometer (65°, 55°, and 45°).

Δ In these calculations we assume that the number of events per unit M^2 is approximately constant, in agreement with our results (see Fig. 3). An accelerator repetition rate of 15 pulses per minute is also assumed. The signal to noise estimates have been made for narrow resonances, i.e. resonances where Γ (experimental) $>$ Γ (resonance). For resonances decaying predominantly with a fixed charge multiplicity (e.g. $\pi^- \pi^0$), the signal to noise should be significantly improved by making a charge selection cut to the data.

□ These resolution figures are based on the proton angular and energy resolutions actually achieved in the AGS experiment. With the small beam spot obtainable at NAL, it may be possible to improve the resolution.

8) Figure Captions

Fig. 1 Detector Arrangement

The beam enters the detector region from the left after traversing a Ĉerenkov counter for particle identification, and two hodoscopes used in determining the beam particle's momentum and angles. S1 is a beam defining scintillation counter.

Fig. 2 Missing Mass $(MM)^-$ Spectrum for $\pi^- p \rightarrow (MM)^- p$ at a Beam Momentum of 7 GeV ($0.20 \leq t \leq 0.29$ GeV^2), plotted vs. $(MM)^-$ squared.

The calculated detection efficiency versus mass squared is plotted as a dashed line (for details see reference 6). The detection efficiency correction in the region of the π peak is only approximate. For purposes of clarity, the spectrum in the region of the π peak has been scaled by 1/150.

Fig. 3 Missing Mass $(MM)^-$ Spectrum for $\pi^- p \rightarrow (MM)^- p$ at a Beam Momentum of 13.4 GeV ($0.12 \leq t \leq 0.30$ GeV^2), plotted vs. $(MM)^-$ squared.

The dashed line represents the detection efficiency.

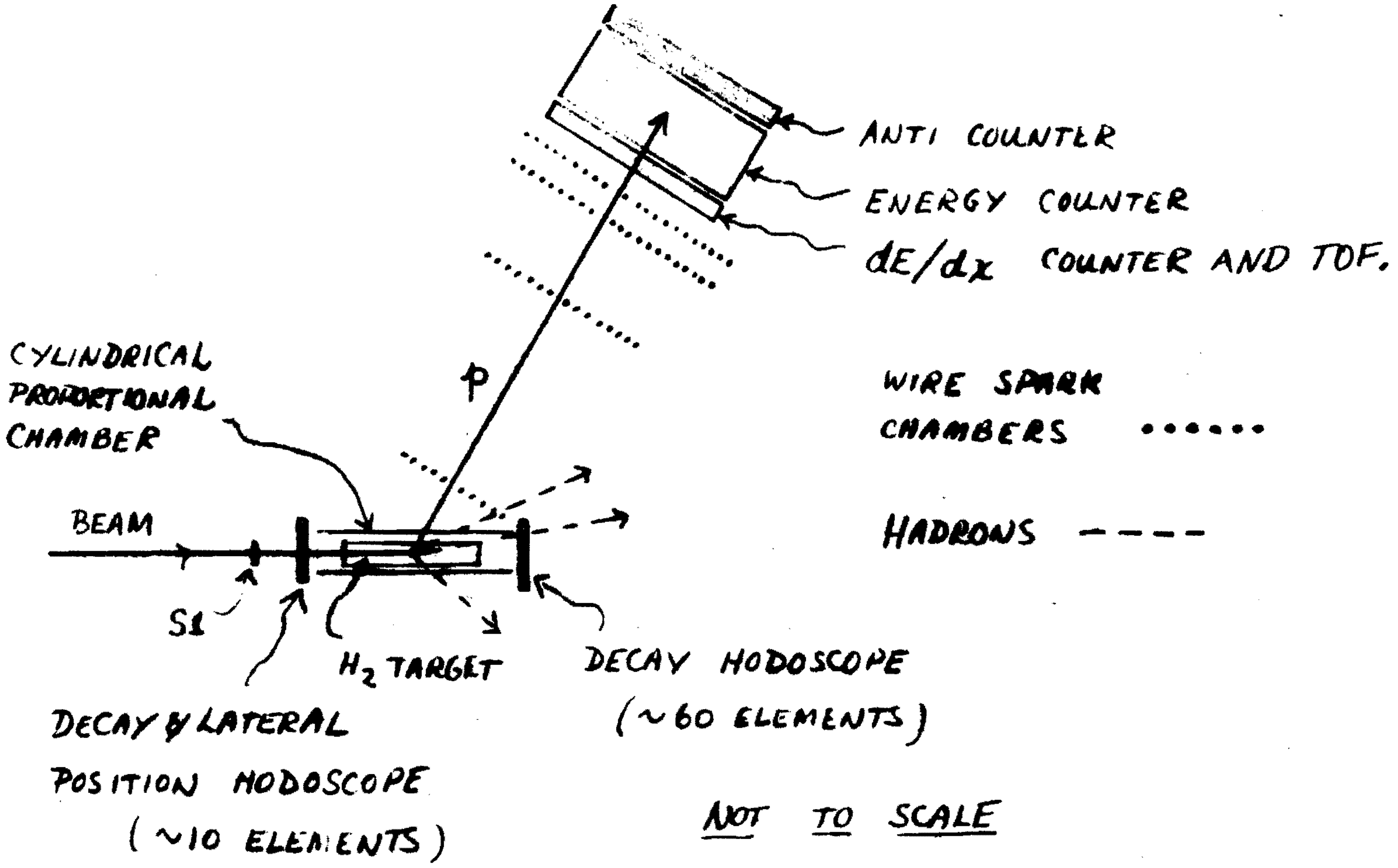
ANTI COUNTER
ENERGY COUNTER
dE/dx COUNTER AND TOF.
P
CYLINDRICAL PROPORTIONAL CHAMBER
WIRE SPARK CHAMBERS ......
HADRONS ----
BEAM
S1
H$_2$ TARGET
DECAY HODOSCOPE (~60 ELEMENTS)
DECAY & LATERAL POSITION HODOSCOPE (~10 ELEMENTS)
NOT TO SCALE

FIG 1

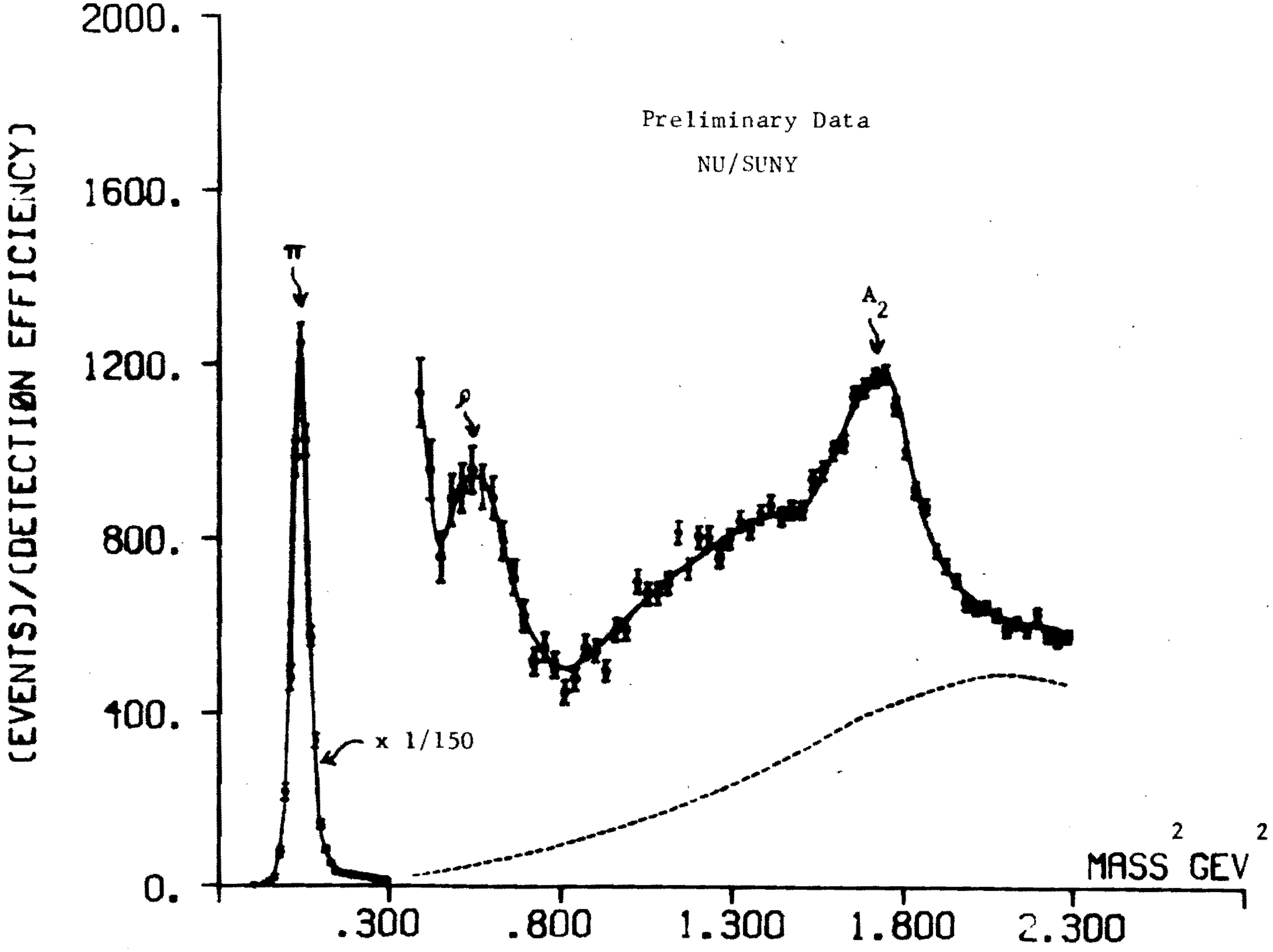
Preliminary Data
NU/SUNY
2000.
1600.
1200.
800.
400.
0.
(EVENTS)/(DETECTIØN EFFICIENCY)
π
ρ
A_2
x 1/150
.300
.800
1.300
1.800
2.300
MASS^2 GEV^2

Fig. 2

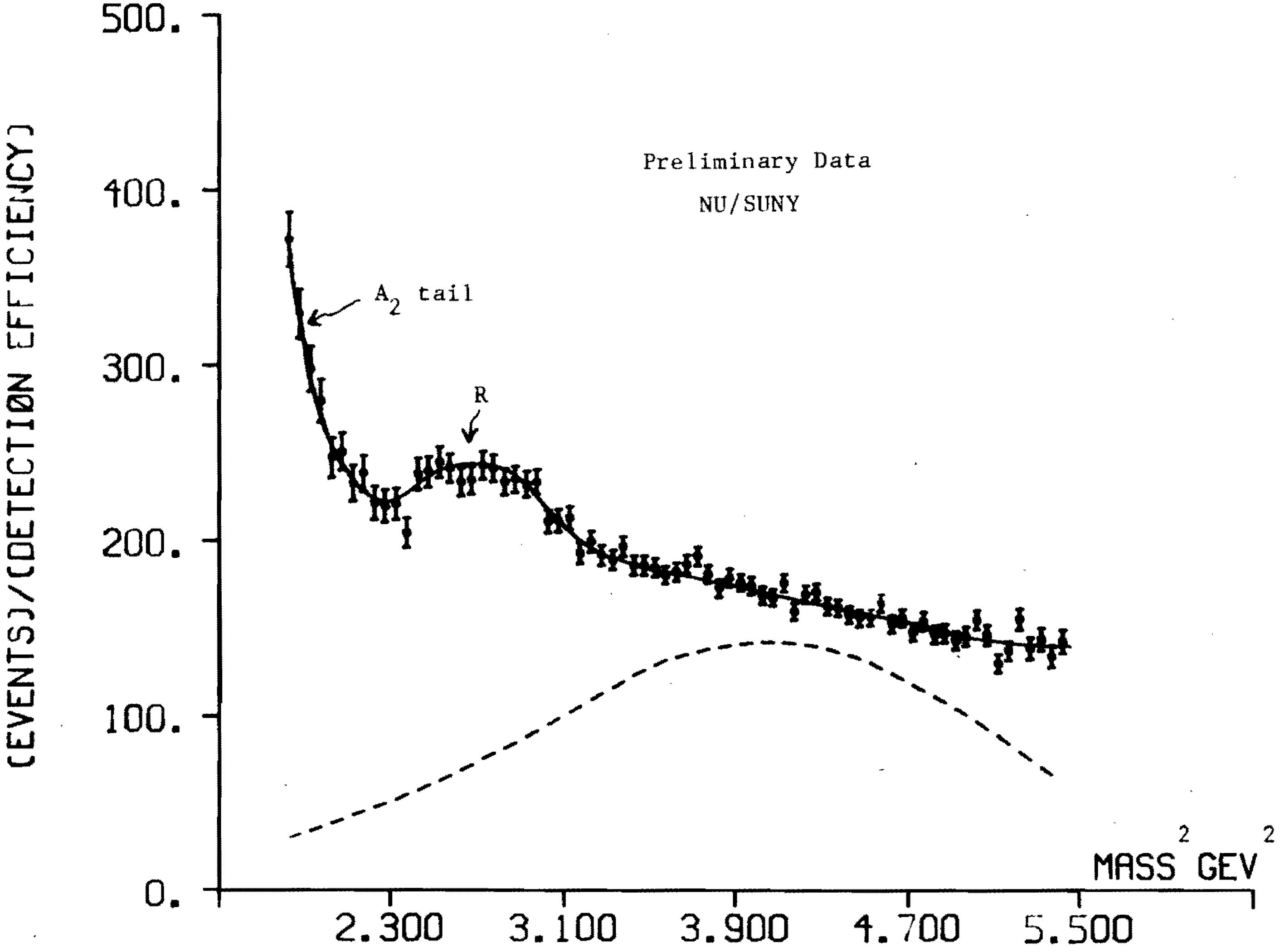
500.
400.
300.
200.
100.
0.
(EVENTS)/(DETECTION EFFICIENCY)
Preliminary Data
NU/SUNY
A_2 tail
R
MASS^2 GEV^2
2.300
3.100
3.900
4.700
5.500

Fig. 3