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PROPOSAL TO MEASURE THE REACTIONS $pp \rightarrow p + n + \pi^+$ AND OTHERS AT THE ISR

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1. GENERAL STATEMENT OF PROGRAMME

We propose a series of measurements at the ISR starting without requiring any magnetic analysing field. The range of reactions studied will be extended if and when such a field becomes available.

Stage		Reaction	No. of Constraints
1) No Magnet	A	$pp \rightarrow p + N^{*}(1470, \text{etc})$, $N^{*} \searrow \pi^{+} n$	1C
	B	$pp \rightarrow n + N^{*++}(\Delta, \text{etc})$, $N^{*++} \searrow \pi^{+} p^{+}$	1C
2) Central Field Only	C	$pp \rightarrow p + p + \text{Boson}$, $\text{Boson} \searrow \pi^{+}\pi^{-}$	2C
	D	$pp \rightarrow n + N^{*++} + \text{Boson}$, $N^{*++} \searrow \pi^{+} p^{+}$, $\text{Boson} \searrow \pi^{+}\pi^{-}$	1C
3) 4π Magnetic Field	E	$pp \rightarrow pp\,\pi^{+}\pi^{+}\pi^{0}$	1C
	F	$pp \rightarrow p + n + \pi^{+}\pi^{+}\pi^{-}$	3C
		etc.	

The method we propose for stage 1 has not to our knowledge been applied previously. We note that we can establish with a high degree of reliability by counter detectors that 3 and only 3 particles are produced in a pp interaction, namely p^{+}, π^{+}, neutron. We can measure the positions and directions of $p^{+}\pi^{+}$ (with 0.25 mm resolution) and the point of interaction of the neutron (with $\pm$ 5 mm resolution). The $p^{+}\pi^{+}$ tracks also determine the pp interaction vertex, and thus we know the direction cosines of all 3 particles. Thus energy, momentum conservation enable us to determine the 3 unknown magnitudes of the particle momenta, <u>and</u> leave us with one constraint, which turns out to be of importance since it permits us to measure the number of spurious events included in our data. The spurious event rate is calculated to be small, and will be observed directly in the experiment.

By this method, Reaction A, the production of baryon resonances with the proton quantum numbers (diffraction dissociation, or Pomeron exchange) is fairly straightforward, without using any magnets. It will be shown that the invariant mass resolution is around ±20 MeV for $N^*(1400)$, which compares favourably with estimates for observing this with various magnet systems. See, for example, calculations of ±55 MeV for $pp \rightarrow p + N^*(\pi^0 p)$ by Hyams, O'Neill[1] and ±20 MeV for $pp \rightarrow p + N^*(\pi^+ n)$ by Winter[2].

Production of states with isospin $3/2$ ($\Delta I = 1$ reactions) appears to be observable, but due to the smaller cross sections is far more difficult.

With a central magnetic field, and none downstream, reactions C, D can be studied if both π^+ and π^- momenta are measured. It is established that reaction D produces ρ^0 mesons with low velocity in the C.M. at 20 GeV/c[3]. So far, reaction C is not known to produce bosons, decaying into $\pi^+\pi^-$, so a neutron detector is very desirable.

We note that there are at least two possibilities for employing existing CERN magnets in the central region, and will propose to do so if no other central field is provided. We remark that the position of compensators becomes a key problem for our detection system.

With a 4π magnet system the range of possibilities increases greatly, but the neutron detector remains a valuable aid in analysis.

We do not consider Reactions C, D, E, F further here.

2. THE REACTIONS $pp \to p + N^{*+}$, $N^{*+} \to n + \pi^+$

i) Scope of measurement

The N* family 1470, 1518, 1688, 2190 (etc.) can be produced by Pomeron exchange - with large cross sections. We propose to measure their differential cross sections $d\sigma/dt$, and alignment. We detect events for $t \geq 0.015\ (\text{GeV/c})^2$ out to wherever the rate limits us. We accept masses up to 3 GeV with $\gtrsim 50\%$ efficiency.

ii) Apparatus

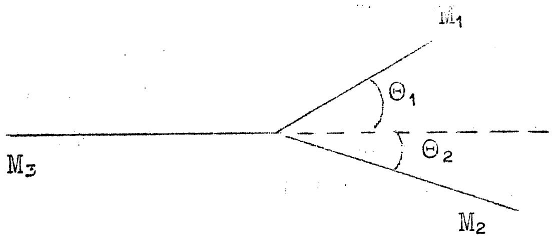
The apparatus is shown in Fig. 1. It uses a 1 mm steel front exit window for forward going particles, to minimize multiple scattering. The proton trajectory is measured on the left with wire spark chambers S. Its trajectory is determined to ± 0.3 mm at points separated by 150 cm. The wire chambers are followed by a threshold gas Cherenkov counter, $\check{C}$, which selects particles with $\gamma < 30$. At the back there is a Pb-scintillator sandwich, γ, to reject events with γ-rays in this solid angle.

The π^+ and neutron are observed on the right. The π^+ trajectory is determined by wire spark chambers as for the proton. The neutrons are detected by a 1-2 cm thick graphite block, followed by scintillation counter and wire chambers. The interaction point of the neutron is localized to ±5 mm. The counter is suitably segmented to count neutrons in the presence of π^+. Events with γ-rays in this solid angle are excluded by a Pb-scintillator sandwich, γ. The absolute efficiency, at various energies, of the neutron counter will be calibrated at the PS, with the aid of a total absorption counter.

The whole solid angle not subtended by the proton and π^+ is covered by a scintillator-Pb shield to exclude charged particles or γ-rays. Thus only K_2^0 and neutrons have a high probability of escaping undetected.

iii) Resolution

It is convenient to have a good simple approximate explicit expression for the invariant mass M of the N^*, in terms of the measured angles.



Such an expression is

$$M^2 = M_1^2 + M_2^2 + \frac{\Theta_1\Theta_2}{(\Theta_1+\Theta_2)^2}\left[p_0^2(\Theta_1+\Theta_2) + M_1^2(1+\Theta_1/\Theta_2)^2 + M_2^2(1+\Theta_2/\Theta_1)^2\right]$$

where $M_1\Theta_1$, $M_2\Theta_2$ are the masses and angles in the C.M., p_0 the initial momentum of the circulating beam. The approximations are for the velocity β, $(1-\beta)^2 \ll 1-\beta$, and $\sin\Theta = \Theta$ for all angles. In this approximation Θ_1, Θ_2 are unchanged in transforming from the Laboratory to C.M. frame.

This explicit expression for the mass has been obtained by eliminating the constraint (the 1C fit) by noting that it may be taken as the check of coplanarity of the 3 outgoing particles in the C.M. frame. With this method of analysis the coplanarity test may be used independently to measure the number of spurious background events.

Using this expression for the mass we include the following errors

ISR momentum spread ± 1%

ISR angular spread ± 0.4 mrad

Detector spatial resolution for π^+, p ± 0.3 mm

Detector spatial resolution for neutron ± 5 mm

Multiple scattering by 1.0 mm steel vacuum chamber front face,

and find the mass resolution shown in Table 1.

Table 1

	Δp(beam) = ± 1%		Δp(beam) = ± 0.2%	
Θ^{π}_{CM}	N*(1470) ΔM(MeV)	N*(2500) ΔM(MeV)	N*(1470) ΔM(MeV)	N*(2500) ΔM(MeV)
25°	30.3	28.8	30.2	26.7
50°	16.5	27.7	15.6	11.4
75°	17.0	36.4	14.2	14.1
100°	20.1	41.3	16.1	17.2
125°	23.8	45.7	19.7	23.2
150°	23.6	54.0	20.6	37.8

iv) Rates.

Using data at 10-30 GeV/c and extrapolating to ISR energies[4)] we estimate a total cross section σ_T = 1 mb for resonance production by diffractive processes.

Our acceptance in t is determined by the vacuum pipe shape and the distance at which we observe the protons. It starts at t = 0.02 GeV/c^2 and is ~ 50% at t = 0.06 GeV/c^2. Therefore our solid angle includes over half the total number of events.

We take a detection efficiency of 10% for the neutron counter, and note that we lose a further factor 2 in rate in taking only left moving protons.

Thus the effective cross section is ~ 25 μb giving ~ 50 good events accepted sec^{-1}, with full beam. Clearly this experiment is practical at far below full beam intensity.

v) Background.

Random background from 3 unrelated signals is certainly negligible. For example 2 unrelated charged particles coming from upstream, and a stray neutron signal will be recorded less than once in 100 sec with full beam. In analysis very few of these events would give a vertex fit.

The troublesome backgrounds are going to come from physical processes similar to the one sought.

We list in Table II what we think to be the most important sources of background, the rate of triggers they give, and the rate of accepted events they give. This rate of accepted events does not include the rejection to be obtained using the 1C fit. This will entail non-coplanarity from a missing particle with around ~ 200 MeV/c transverse momentum compared with 20 MeV/c measurement errors, and will dilute most backgrounds under the signal by a further factor ~ 10.

vi) ISR Requirements

Intensity

We do not require maximum ISR luminosity. This experiment can be run at currents from I_{max} to $I_{max/30}$ in each ring. There is no great advantage in running at very low intensity as most of the backgrounds vary as I^2.

With ISR currents of 4×10^{13} protons we expect $\sim 10^4$ events in 3 days. So that data collection time will probably be small compared with setting up time.

Vacuum

We can probably work with a vacuum of 10^{-10} Torr at the intersection region, and do not require 10^{-11}. The beam gas backgrounds have assumed 10^4 interaction/sec/meter which is anyhow a very conservative figure.

We do require a vacuum of $\sim 10^{-10}$ Torr upstream and/or shielding from this region.

We do require a special vacuum chamber. It has excellent geometry for pumping, but may pose problems for bake out.

Intersection Region

We need the large downstream drift space, therefore only regions 2, 4, 6, or 8 with inward moving beams can be used.

3. THE REACTIONS $p + p \rightarrow n + N^{*++} \searrow_{p+\pi^+}$

The family of the Δ have been identified from $\Delta(1236)$ to $\Delta(2420)$. They are produced by the exchange of charge one. Existing data[5], and its extrapolation[4] suggest a cross section of $\sim 10^{-4}$ mb for production. Due to this small cross section this is a more difficult reaction to measure than $\Delta I = 0$ processes. However, it still appears to be a feasible experiment with this technique, because all $\Delta I = 1$ processes are expected to be inhibited, and the signature of no charged particle around one pipe, and two around the other rejects $\Delta I = 0$ background efficiently. The detailed design of this experiment is proceeding. However, because it requires full ISR intensity we do not propose to start measuring it as a first experiment.

Table 2

Background rate/Signal Rate

Source of background*	Triggers	After analysis Before 1C fit	After 1C fit	Comments
(beam-beam interaction → $N_a^{*+} + N_b^{*+}$) + $N_a^* \to n\,\pi^+$ $N_b^* \to n\,\pi^+$	~ 1	$\lesssim 1/10$	$\lesssim 1/100$	A missing neutron cannot be identified. We can only guess the cross sections. The Cherenkov signal will be used in analysis, not in anti-coincidence.
(beam-beam interaction → p + p) + 1 proton interacts simulates neutron	$1/30$	$< 1/300$	$\leq 1/3000$	An elastic p-p will be identified.
(beam-beam → $p\,\pi^0 + n\,\pi^+$) π^0 remains in pipe	$1/30$	$1/30$	$\leq 1/30$	
(beam-beam → $p + n\,\pi^+\pi^0$) π^0 remains in pipe	$1/50$	$1/50$	$\lesssim 1/100$	
(beam-beam → $p\,\pi^+\pi^- + \pi^+ n$) $\pi^+\pi^-$ remain in pipe	$1/100$	$1/100$	$< 1/100$	
(beam-beam → $p + p + \pi^0$) 1 γ lost, 1 γ simulates neutron	$1/1000$	$1/1000$	$< 1/1000$	
(beam-gas) + (beam-gas) recoil gas stays in pipe; $\downarrow$ p; $\downarrow$ π+n	$1/50$	$1/500$	$< 1/5000$	The π p vertex test will give a large rejection.
(beam-beam → p + p) + accidental neutron signal	$1/100$	$< 1/1000$	$< 1/1000$	Elastic p-p will be identified.

* All the isobars considered are supposed to be produced with $\Delta I = 0$ exchange - and 1 mb cross section.

REFERENCES

1. B. Hyams, G.K. O'Neill, "A Momentum Analysis System for ISR Reactions", February 1968.
2. K. Winter, "Isobar Production", June 1968.
3. K. Hansen, Private Communication of data from 19 GeV/c p - p hydrogen bubble chamber results.
4. D.R.O. Morrison, Phys.Letters 22, 528 (1966).
5. P.L. Connolly et al., "Study of pp interactions at 28.5 GeV/c in Two- and Four-Prong Final States", Third Topical Conference on Resonant Particles, Ohio University, Athens, Ohio. November 1967.

FIGURE CAPTION

S	Wire spark chambers and scintillation counters
Č	Cherenkov counter
γ	Pb-scintillation γ-ray detector
A	Pb-scintillation Anti-coincidence counter for charged particles and γ-rays
n	neutron detector 2 cm Č and scintillation counters and wire spark chambers.

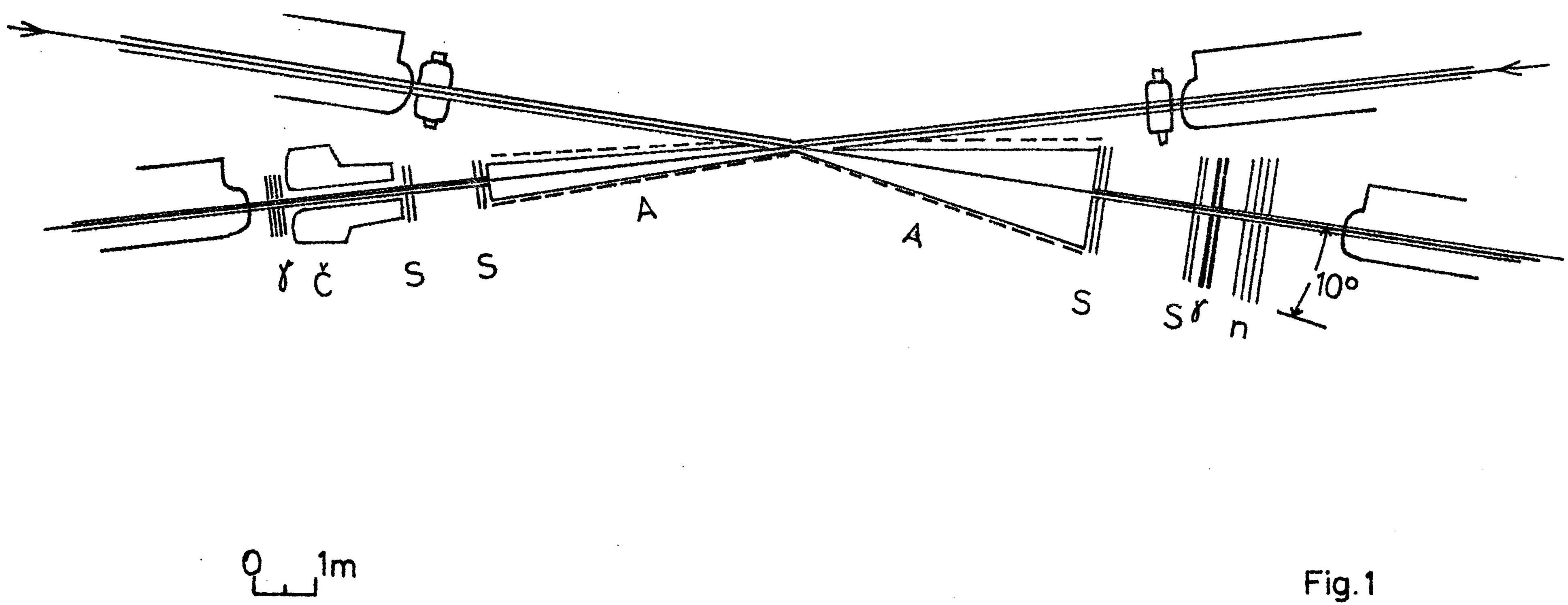


Fig.1