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SEARCH FOR DOUBLE POMERON EXCHANGE AT THE ISR*

by

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This report summarizes the discussion on our present knowledge and on possible further ISR experiments about double Pomeron exchange, held at CERN on 20 September, 1977 during the second Workshop on Future ISR Physics. The discussion was opened by two talks, one by A. Putzer on the present status and on a possible future experiment with the upgraded Split Field Magnet, and one by A. Kernan on possible experiments with several specialized detectors. The discussion showed a lively interest in further experiments, but at the time of the Workshop there was no specific proposal.

1. Why Search for Double Pomeron Exchange?

The Pomeron is widely used for describing elastic and inelastic diffraction[1)] in a simple t-channel, i.e. exchange, language. But diffraction is not an independent piece of the strong interaction. It is, through s-channel unitarity, a necessary consequence of hadronic absorption, of multiparticle production. This absorption mechanism is described by multi-Reggeon exchange, and if we would have a quantitatively complete description of it, the Pomeron would be completely fixed. In this respect, we do not "need" the Pomeron as an extra piece of exchange dynamics, it is merely the shadow of all Reggeons. All events at very high energies should then fall into two separate categories: absorption with multi-Reggeon exchange (Figure 1A) and diffraction with one-Pomeron exchange (Figure 1B). Is this so, or are there events with more than one Pomeron (Figure 1C)? If events of type C would be identified experimentally, we really "need" the Pomeron, and this Pomeron is then not only the optical shadow of absorption. Double Pomeron exchange has no optical equivalent, its existence is therefore a crucial question on the way to understanding the Pomeron's rôle in the strong interaction.

How to identify events with two Pomerons? One event does not tell anything, it may be due to rare Reggeon exchanges. The probability for a Reggeon exchange depends, however, strongly on the rapidity Δyi over which it is exchanged: The Regge factor $s_i^{\alpha(ti)}$ leads to:

$$\sigma_R \sim e^{-\Delta y_i}$$

if $\alpha(0) = \frac{1}{2}$ and using the relation $\Delta yi \approx \ln \frac{s}{s_i}$. A Pomeron, by definition, ignores the rise of the rapidity gap*:

$$\sigma_P \sim \text{Constant}$$

Rapidity gaps for given topologies increase with increasing energy, therefore the energy dependence of a cross-section like

$pp \rightarrow pp\, \pi^+\pi^-$ with two large rapidity gaps

* The increase in rapidity gap just compensates for the kinematical s^{-1} factor in the amplitude.

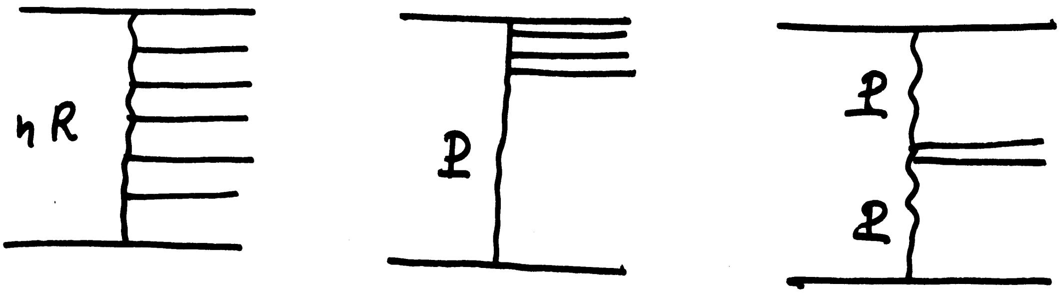

Figure 1 : A Multi-Reggeon exchange
B Pomeron exchange (single diffractive excitation)
C Double Pomeron exchange

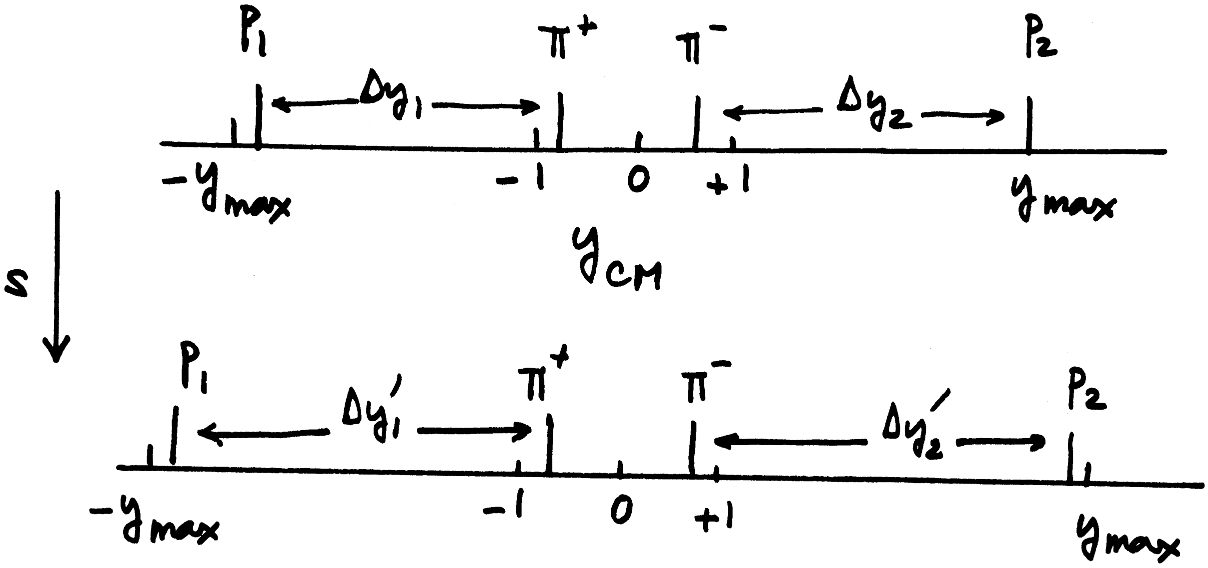

Figure 2 : Rapidity gaps in the exclusive $pp \rightarrow pp\ \pi^+\pi^-$ reaction.
They increase logarithmically with energy

should be suited to look for double Pomeron exchange. This is illustrated in the rapidity plot of Figure 2. If one limits the phase space to

(1) $|y(\pi^+)| < 1, \quad |y(\pi^-)| < 1$

one of the three gaps (the $\pi\pi$ gap) is in a range which does not increase with s, and the two $p\pi$ gaps Δy_i do increase with s. At the ISR, we have with phase-space cuts (1) $\Delta y_{1,2}$ ($\sqrt{s}$ = 23 GeV) = 2.2 and $\Delta y_{1,2}$ ($\sqrt{s}$ = 62 GeV) = 3.2. Events in this phase-space may be produced by RR-, RP- and PP- exchange with always the same (pion-) exchange between the two pions. The cross-section at fixed s depends on seven variables, e.g.

$$t_1, t_2, \phi_1-\phi_2, m_{\pi\pi}, y_{\pi\pi}, \cos\theta, \phi,$$

the momentum transfers to the outgoing protons, the azimuthal angle between the two outgoing protons, and the mass, the rapidity and the two decay angles of the $\pi\pi$ system. Each differential cross-section is built up by the three mechanisms, and one expects for each one the following s-dependence[2)]

$$d^7\sigma = d\ C_{PP} + d\ C_{PR}/\sqrt{s} + d\ C_{PR}/s.$$

And the original question is reduced to: Are there phase-space cells with $d\ C_{PP} \neq 0$? It should be noted that the available rapidity gaps at the ISR are still rather limited. A conclusive answer may eventually only be reached at a machine like ISABELLE or SCISR.* During the discussion it became also clear that it is not very useful to look for higher mass central systems at the ISR, e.g. for $pp \to pp\ (\pi^+\pi^-\pi^+\pi^-)$, where the rapidity gaps $\Delta y_{1,2}$ are still smaller.

2. Present Status on $pp \to pp\pi^+\pi^-$

Experiments at lower energies [3)4)5)] were not conclusive because of the lack of sizeable rapidity gaps. Ref. 5 with phase-space cuts similar to (1) resulted in $\int d^7\sigma_{pp} < 44$ μbarn. The first ISR experiment of Baksay et al.[6)] detected four particles with a magnet-less set-up, two of them forward and two in the centre with a pseudo-rapidity cut

(2) $|\tilde{y}_{3,4}| < 1.5$

The observed number of four-particle events in this topology served as an upper limit for $\sigma(pp \to pp\ \pi^+\pi^-)$, and cross-sections varied from (28 ± 8) μb at $\sqrt{s}$ = 30 GeV to (20 ± 3) μb at $\sqrt{s}$ = 62 GeV. Two further "first generation" ISR

* The $p\bar{p}$ collider at CERN with $\sqrt{s}$ = 540 GeV will give a rapidity interval of 12.6.

experiments were undertaken by two groups using the same detector facility, the Split Field Magnet. The two experiments used different triggers and different acceptance calculations for obtaining cross-sections, but essentially the same programs for reconstructing $pp\pi^+\pi^-$ events. The final fit has four constraints (all momenta being measured), but the particles are not identified. Della Negra et al[7,9] studied differential cross-sections at all five ISR energies in phase-spaces defined by

(3) $|Xp_1| > 0.9$, $|Xp_2| > 0.9$ and (1)

(4) $|Xp_1| > 0.9$ $|Xp_2| > 0.9$ and $\Delta y_1 > 3.0$, $\Delta y_2 > 3.0$.

Their data show all the expected properties of double Pomeron exchange, exponential $t_{1,2}$ dependence with $d\sigma \sim e^{b(t_1 + t_2)}$, factorization between the protons (no correlations in ϕ nor in t), low mass enhancement of the $\pi\pi$ system, no ρ signal in the $\pi\pi$ mass, and θ,ϕ angular distributions compatible with spin 0 of the $\pi\pi$ system. For details, the reader is referred to Ref. 9. The integrated cross-sections for phase-spaces (3) and (4) are shown in Figure 3. The cross-section for (3) (essentially $\equiv$ (1)) first falls with energy and then levels off, which is taken as a proof for $\int d\, C_{pp} \neq 1$. Error bars are however big; they originate from statistics and from acceptance uncertainties mainly due to the SFM beam tube which disturbs the outgoing protons at small t strongly.

The second SFM experiment of de Kerret et al.[8] has so far produced differential cross-sections at two energies, $\sqrt{s}$ = 23 and 45 GeV. The agreement with Ref. 9 is not perfect, the slope values b are bigger, the integrated cross-sections lower, and there are definite ϕ correlations between the two outgoing protons. The reader is again referred to the original publication, Ref. 8, and the results, extrapolated to phase space (3), are also shown in Figure 3. The ϕ values being correlated, $d\sigma/d(\phi_1 - \phi_2)$ not being flat, the authors attribute a peak seen at $\phi_1 - \phi_2 \approx 0$ to single diffraction (PR^-) background and impose a cut $|\phi_1 - \phi_2| > 90^o$. Due to limited statistics in both experiments, the ϕ question is far from being settled. The author of this report is convinced that there must be ϕ correlations even in a pure PP-mechanism because phase space (energy-momentum conservation) imposes them. Apart from this detail, the discussion showed up a wider scepticism. The data certainly prefer the existence of double Pomeron exchange with a reasonable cross-section in the order of 10 μb for phase space (1), but most participants would prefer to see more and better data before being convinced.

N.B. Recent developments on the status of $pp \rightarrow pp\pi^+\pi^-$ can be followed in ISR discussion meeting summaries 18 (1976) and 22 (1977)

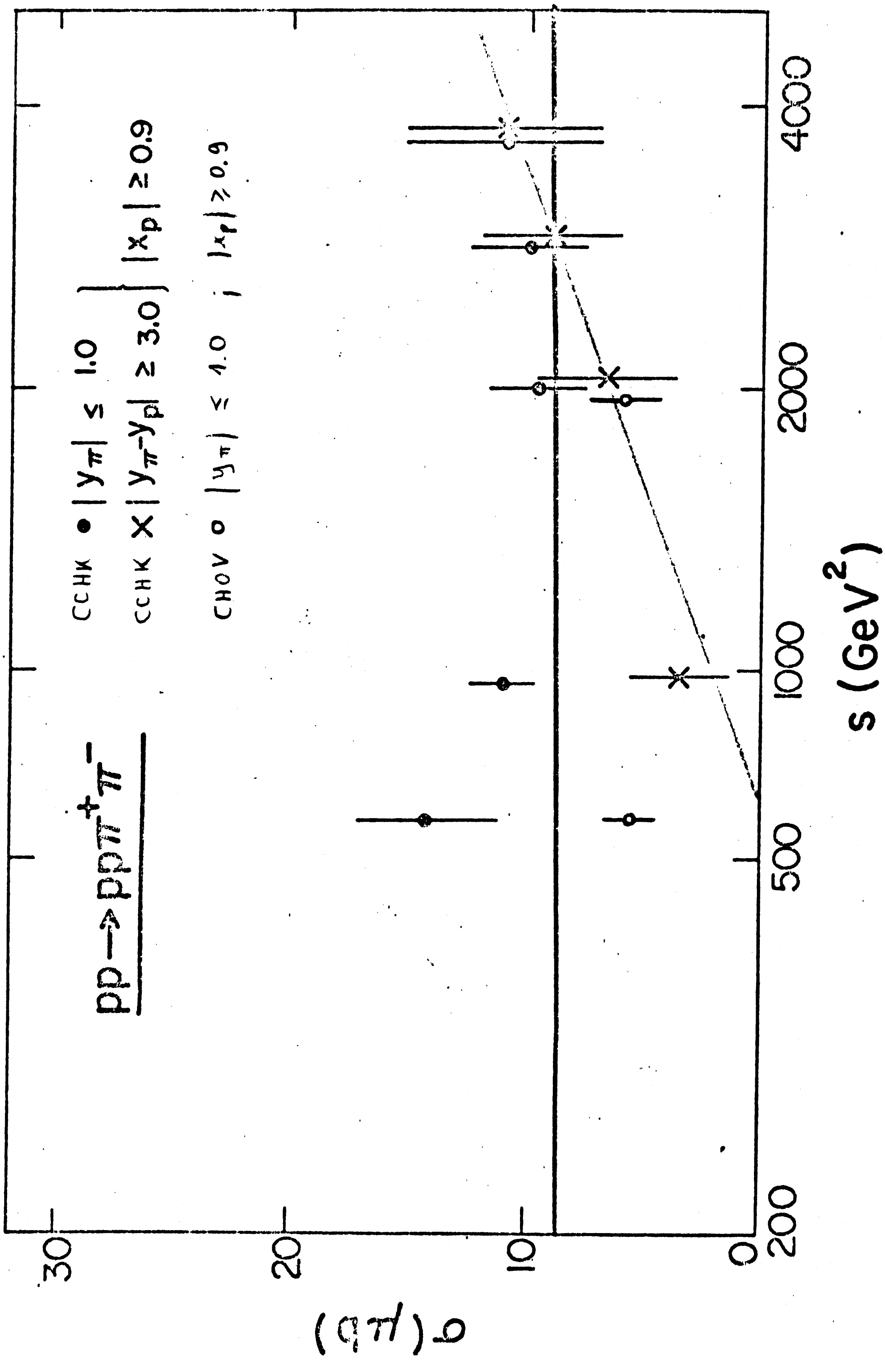

Figure 3 : Cross-section for the reaction pp $\rightarrow$ pp$\pi^+\pi^-$ with different kinematical cuts. See ISR Discussion Meeting summary 18 for a detailed discussion of the effect of the cuts

3. A Possible Experiment with the Upgraded SFM

The Split Field Magnet (SFM) facility has been improved after the end of its first generation of experiments 1973-77. New multi-wire proportional chambers are installed to improve pattern recognition, momentum resolution and acceptance. Figure 4 shows the new configuration. Additional features are a new vacuum chamber (which reduces the absorption of low-t-protons and therefore the acceptance uncertainty by a factor of ≈ 3), Cerenkov counters and a calorimeter at large angles and a time-of-flight measuring scintillator system. Though being constructed and optimized for high-p_t and lepton production physics, this set-up is also better suited for studying double Pomeron exchange than the previous one: less absorption for the forward protons and therefore less acceptance uncertainty, higher (nearer-to-4π) geometrical acceptance and therefore again less uncertainty in converting event numbers into cross-sections, particle identification and therefore the possibility to look e.g. for $pp \rightarrow ppK^+K^-$. Figure 5 shows the particle separation capabilities of the set-up. The capability of triggering for rare topologies has also been improved due to selective readout and on-line track-finding. An estimate of A. Putzer (ACCHKW), based on 10^5 $pp\pi^+\pi^-$ events with $X_p > 0.8$, gives about 8 hours of running time and 50 h of CDC 7600 computing time for a possible new SFM experiment. Due to its limited momentum resolution at small t values ($\Delta p/p \approx 5\%$), the SFM is still not suited for inclusive studies of the type $pp \rightarrow ppX$, but well placed for the study of exclusive channels with 4 kinematical constraints. The constraints are tight enough to exclude background from "neighbouring" channels to the 5% level.

4. Possible Experiments with other Set-ups

The discussion on further possible experiments started from the idea to complement an existing or planned well-suited central detector with a pair of special forward spectrometers. This set-up should then be able to measure $pp \rightarrow pp\pi^+\pi^-$, ppK^+K^- ($pp\pi^+\pi^-\pi^+\pi^-$ is probably of no use, as said before), and also to measure $pp \rightarrow ppX$. A pair of forward spectrometers with high momentum resolution is necessarily of limited solid angle. Therefore, a double Pomeron exchange experiment in the frame of this idea has either to rely on the knowledge of $d\sigma/d(\phi_1 - \phi_2)$ - which is far from being established - or it is limited to specialized questions and not able to measure an absolute cross-section within a wide phase space as given by (1).

A proposed forward spectrometer pair[10)] consists of two (or four) septum magnets 9 m downstream from the intersection (necessity to be in an even intersection) with $\int Bdl = 2$ Tesla-meter and an aperture of 30 x 20 cm^2. With drift chambers of $\sigma x \approx 200$ µm, this would yield $\Delta p/p \approx \pm 0.4\%$ and a missing mass

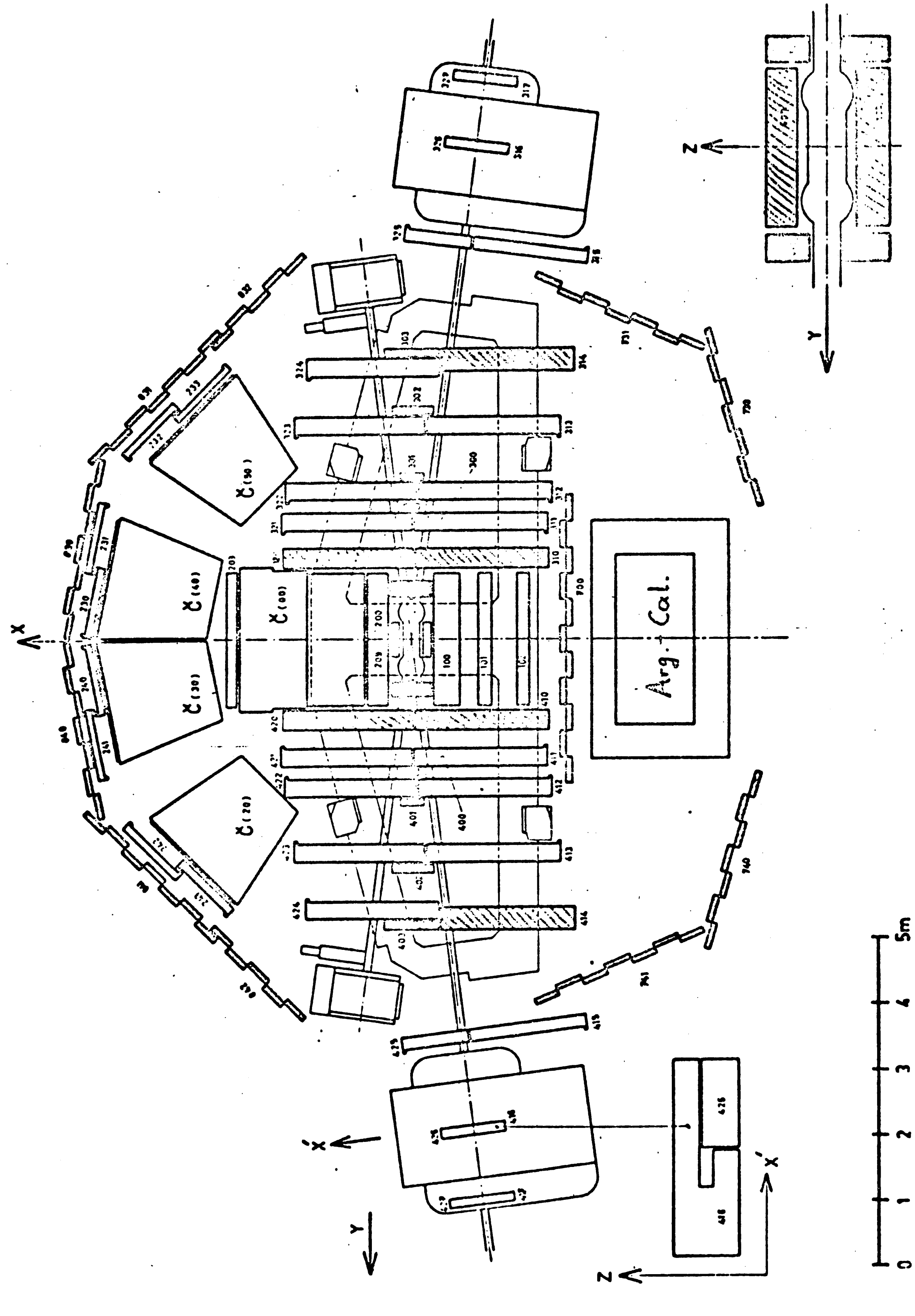

Figure 4 : The Upgraded SFM (see ISR WORKSHOP/2-7 for a detailed description)

resolution in pp→ ppX of Δm_x = 0.07 (0.18) GeV at $\sqrt{s}$ = 23 (62) GeV. θ_{min} would be ≈ 10 mrad, and $\Delta\Omega = 10^{-3}$ sr. The mass range of Mx would be from threshold to ≈ 6 GeV.

The three possible central detectors are I-1, I-7 and the AFM. The I-1 and I-7 detectors do not cover the full azimuthal angle for the central particles. Since a full ϕ range is essential for a good double Pomeron experiment aiming in absolute cross-sections, this report should be limited to a discussion of the proposed Open Axial Field Magnet, AFM[11]. Figure 6.a) shows a schematic view of this detector. Acceptance and resolution are ideal for a double Pomeron exchange experiment. The ϕ acceptance goes all around within a radius of 2.5 m which is covered by special cylindrical drift chambers allowing particle identification. The θ acceptance is $90^\circ \pm 50^\circ$, corresponding to a pseudo-rapidity range $-1 < \tilde{y} < +1$ just adequate for phase space (1). The θ ranges from 15° to 40° and 140° to 165° are without acceptance, but the two forward cones are again free and would allow the installation of a pair of forward spectrometers. Figure 6.b) shows the momentum resolution of the AFS. Particle identification is also very good[11].

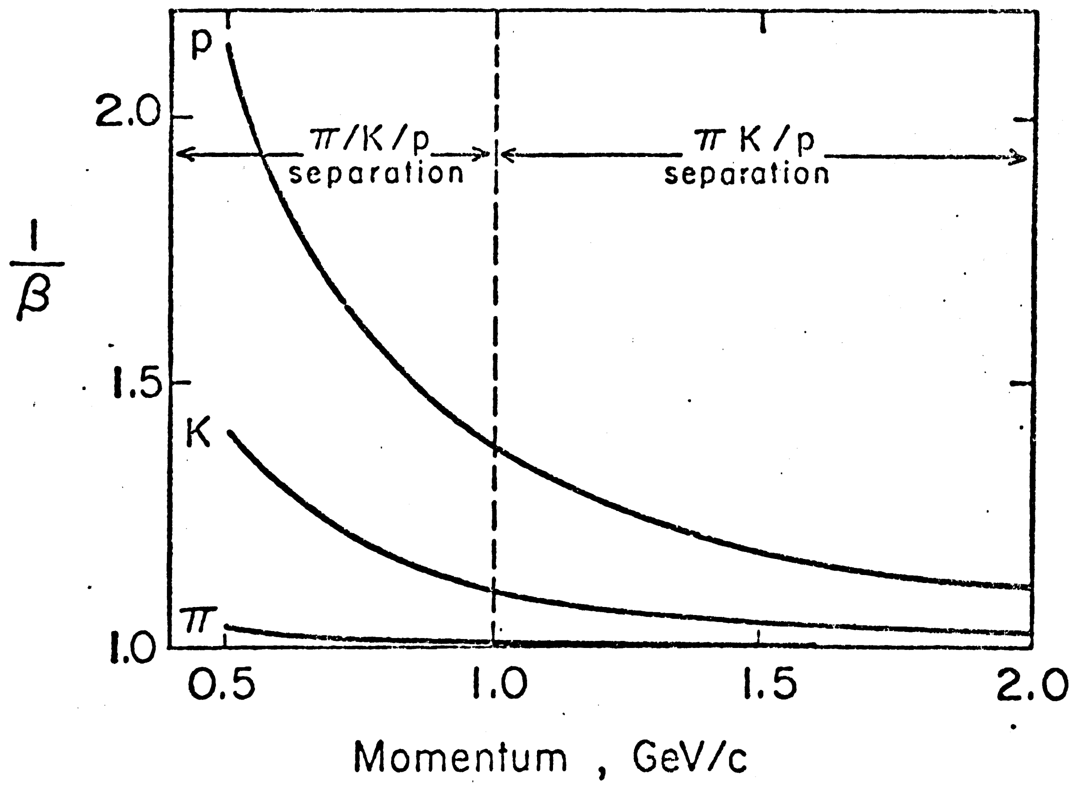

Figure 5 : Particle identification in the upgraded SFM

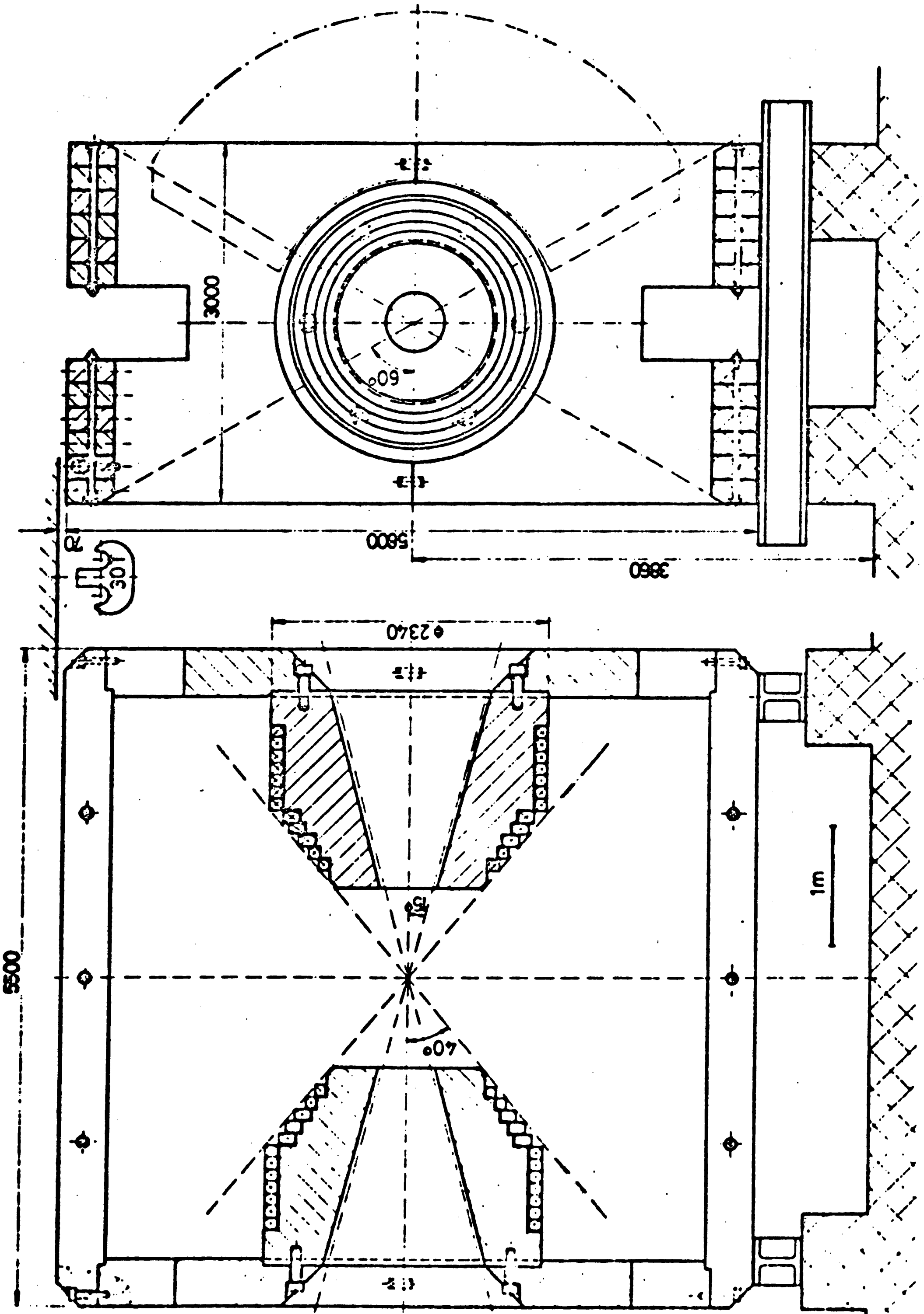

Figure 6.a) : The Axial Field Magnet detector (For a detailed description see ISR Workshop/2-7)

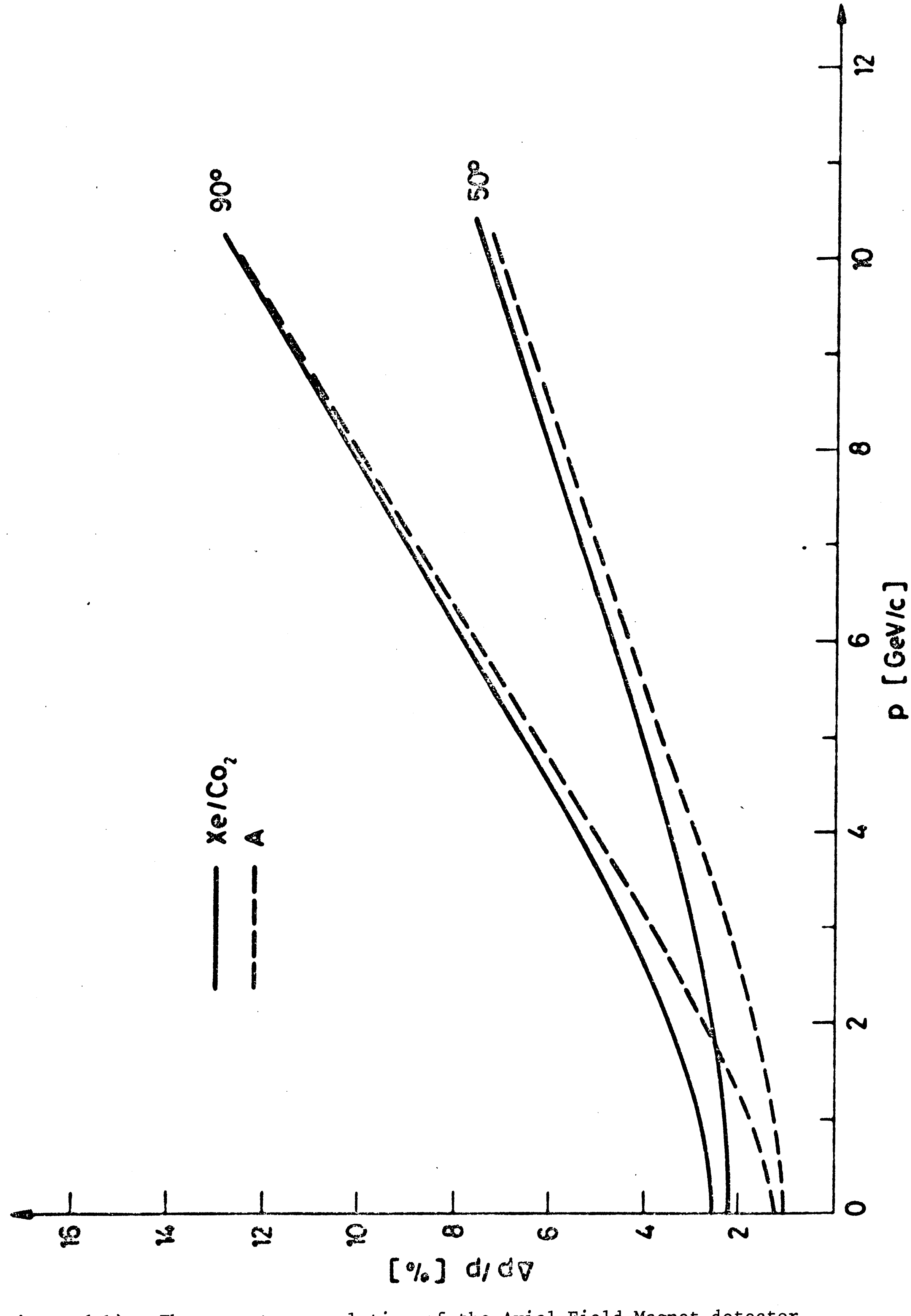

Figure 6.b) : The momentum resolution of the Axial Field Magnet detector

5. Conclusion

In the framework of a Regge description, double Pomeron exchange has to be searched for in the energy dependence of the absolute cross-section of an exclusive channel with certain phase space cuts. At the ISR, the most abundant channel is $pp\pi^+\pi^-$, and an appropriate cut is $|y(\pi^+)|$ and $|y(\pi^-)| < 1$. Present experiments favour the existence of double Pomeron exchange, because the found energy dependence is inconsistent with Pomeron-Reggeon ($\alpha = \frac{1}{2}$) exchange. However, systematic errors (10 - 20%) are too large for a convincing conclusion and the statistics (some 100 - some 1000 events) are too small to study differential cross-sections in 7 variables. A future good experiment on $pp \rightarrow pp\pi^+\pi^-$ is needed. Since the order of magnitude of the cross-section is 10 μb, the running time of this experiment could be short (some days). It is therefore not appropriate to construct special apparatus but rather use an existing one. Two pieces of apparatus would be well suited, the SFM as it is and the AFM complemented with two forward arms. Both have advantages and disadvantages, listed in the table below:

	SFM	AFM
y central	all	$-1 < y < +1$
ϕ central	$\sim 0.8 \times 2\pi$	all
θ forward	$\gtrsim 10$ mrad	$\gtrsim 10$ mrad*
$\Delta p/p$ forward	$\sim$ 5%	$\sim$ 0.5%*
ϕ forward	$\sim 0.5 \times 2\pi$	**
X forward	depending on the trigger for both	

* depending on the forward spectrometers

** depending on the forward spectrometers, but probably very small

The SFM would have the advantage of studying also neighbouring y central regions, say $1 < |y(\pi^\pm)| < 2$, to see their energy dependence and to verify the $\alpha = \frac{1}{2}$ hypothesis of PR-exchange. This point was stressed during the discussion[12], but the CCHK group could do this probably by using their present data. The AFM with appropriate forward detectors would have the capability of studying also inclusive double Pomeron exchange in $pp \rightarrow ppX$. These studies are not well covered by this report, because the author is convinced that a good $pp \rightarrow pp\pi^+\pi^-$ experiment with 5% systematic error and $\gtrsim$10,000 events per ISR energy within phase space (1) should have priority.

References:

1) A recent review is e.g. U. Amaldi et al., Annual Review of Nuclear Science 26(1976) 385.

2) See e.g. A.B. Kaidalov, in ISR Discussion Meeting between Experimentalists and Theorists, Nr. 18 (February 1976).

3) U. Idschok et al., Nucl. Phys. B 53 (1973) 282.

4) D. Denegri et al., Nucl. Phys. B 98 (1975) 189.

5) M. Derrick et al., Phys. Rev. Letters 32 (1974) 80.

6) L. Baksay et al., Phys. Letters 61B (1976) 89.

7) M. Della Negra et al., Phys. Letters 65B (1976) 394.

8) H. de Kerret et al., Phys. Letters 68B (1977) 385.

9) M. Della Negra et al., submitted to the Budapest Conference, June 1977.

10) P. Strolin et al., CERN-ISRC/74-9 and 75-44.

11) CERN-Copenhagen-Lund, CERN-ISRC/76-36.

12) G. Bellettini

The Double Pomeron exchange process is also discussed in the theoretical contribution of A. Schwimmer in ISR WORKSHOP/2-10 which deals more generally with "ℓn s physics". Questions of special interest once the Double Pomeron process has been ascertained are discussed in the contribution by J. Ellis in ISR discussion meeting no. 22 (1977).