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PROPOSAL FOR AN EXPERIMENT

MEASUREMENT OF THE $\bar{p}p$ TOTAL CROSS SECTION AT THE CERN ISR

AMSTERDAM [1] - LOUVAIN [2] - NORTHWESTERN [3] COLLABORATION

M.M. Block [3], G.J. Bobbink [1], M. Bosman [2],
R. Campanini [3], F.C. Erné [1], D. Favart [2],
P. Lipnik [2], H. Ludwig [3], P. Macq [2],
D. Miller [3], J.C. Sens [1].

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I INTRODUCTION

A proposal to fill one of the ISR rings with antiprotons has recently been approved [1]. The target date for a first filling is early 1981.

In the following we propose to measure the total $\bar{p}p$ cross section through the ISR energy range and compare the result with the total pp cross section measured at the same energies, with the same apparatus and at close intervals in time.

Total pp cross sections through the ISR energy range have been measured previously [2] in two ways :
1) by a measurement of small angle elastic scattering and application of the optical theorem (CERN-ROME Coll.) and
2) by a measurement of the total rate of interactions (PISA-STONY BROOK Coll.). The results of these experiments are summarized in appendix A.

Our proposal is to obtain $\sigma_{TOT}(pp)$ and $\sigma_{TOT}(\bar{p}p)$ by measuring small angle scattering, using the original CERN-ROME apparatus, consisting of two vacuum vessels and four hodoscopes [*]. It will be shown below that the precision and counting rates which can be reached with this equipment are adequate for measuring $\sigma_{TOT}(\bar{p}p)$ to an accuracy of $\lesssim 1\%$.

Using the original CERN-ROME apparatus virtually eliminates the preparatory stage of constructing equipment, and thus reduces the proposal to a request for permission to re-install the original equipment, and perform measurements of typically a few days at each energy. The main effort of this experiment then lies in the analysis of the data, and in particular of their systematic errors.

We have considered to what extent other features of $\bar{p}p$ collisions (topologies, inclusive particle production) could be measured simultaneously but concluded that this would require either substantial additional equipment or very much longer $\bar{p}$ filling and running times than is envisaged for the σ_{TOT} measurement. We are therefore limiting this proposal strictly to a measurement of the quantities that can be measured with good intensity with the Roman Pots, i.e. the low-t slope, σ_{TOT} and the ratio ρ of the real to the imaginary amplitude at $t = 0$. This then enables us to do the

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[*] We are greatly indebted to the ISR Vacuum Group and the CERN-ROME Coll. for having made available to us the vacuum vessels ("Roman Pots") and all hodoscopes used in this experiment of Ref. 2.

experiment in the early stages of $\bar{p}p$ operation at the ISR.

A letter of intent has been submitted to the ISRC on 13/10/78(CERN-ISRC/78-30). The proposal has been presented in a open ISRC meeting on 9/1/79.

II PRECISION REQUIREMENTS

Fig. 1 shows the expected behaviour of the $\bar{p}p$ total cross section in the ISR energy range, compared to the pp cross section. One can parameterise the pp data as

$$\sigma(pp) = 25.4 + 4.29 \ln \sqrt{s}$$

with $23.5 < \sqrt{s} < 62.7$ and $\sqrt{s}$ in GeV

then if

$$\sigma(pp) = \sigma(\bar{p}p) \text{ at large } s$$

$$\sigma(pp) = \sigma_o + \sigma_+ \qquad \sigma(\bar{p}p) = \sigma_o + \sigma_-$$

$$\sigma_o = A + B(\ln s)^{\alpha} \quad \sigma_{\pm} = C \exp(A \ln p_{lab}) \mp D \exp(B \ln p_{lab})$$

the difference $\sigma(\bar{p}p) - \sigma(pp)$ would be 2.1 mb for 11.8/11.8 GeV and 0.7mb for 31.4/31.4 GeV. If,instead, we extrapolate the downward trend of $\sigma(\bar{p}p)$ linearly into the ISR range we obtain a difference of +2, resp - 2.5 mb :

	Difference $\sigma(\bar{p}p) - \sigma(pp)$ for two extrapolations of $\sigma(\bar{p}p)$ (mb)	
	$\sigma(pp) \approx \sigma(\bar{p}p)$ at $s = \infty$.	$\sigma(\bar{p}p)$ linearly extrapolated.
11.8 / 11.8	+ 2.1 mb	+ 2.0 mb
31.4 / 31.4	+ 0.7 mb	- 2.5 mb

TABLE 1

It thus seems reasonable to require a precision such that $\delta\ \sigma(\bar{p}p) \lesssim 0.5$ mb.

III THE ELASTIC SCATTERING METHOD

The differential elastic scattering cross section can be written as

$$\frac{1}{\pi}\ \frac{d\sigma}{dt} = \left| \frac{2\alpha}{t}\ e^{i\alpha\phi} + \frac{\sigma_T}{4K}\ (i + \rho)\ e^{-\frac{1}{2}bt} \right|^2$$

$$\left(\frac{2\alpha}{t} \right)^2 + \left(\frac{\sigma_T}{4\pi} \right)^2 (1+\rho)^2 e^{-bt} + \text{Interference}$$

i.e. as the sum of a Coulomb, a Nuclear and an interference term. The Coulomb and the Nuclear terms are approximately equal at

$$t_o = \frac{0.0712}{\sigma_T(\text{mb})}\ \text{GeV}^2 \approx 0.0018\ \text{GeV}^2$$

We thus have 3 regions in t, one where Coulomb scattering dominates, one where the Coulomb-Nuclear interference is strongest and one where nuclear scattering determines the shape of $d\sigma/dt$. These regions, and the corresponding minimum laboratory angles are indicated in table 2 and shown in Fig. 2.

	Minimum Lab Angle (m rad)			
Region	t	11.8/11.8	15.4/15.4	31.4/31.4
Coulomb	$t \lesssim \frac{1}{2}t_c$	2.5	1.9	1.0
Interference (ρ)	$t \approx t_c$	3.6	2.8	1.4
Nuclear(σ_T,b)	$t \gtrsim 3t_c$	6.2	4.8	2.4

TABLE 2

Comparing these numbers to the minimum detectable angle outside the ISR vacuum pipe at the end of an even-numbered intersection, approximately 3 mrad, it is clear that Roman Pot type inserts are required if the measurements are to extend to the highest available ISR energies.

In the past small angle elastic scattering has been measured both with hodoscopes (CERN-Rome)[2] and with multiwire proportional chambers (ARCH GM Collaboration) [3]. Although intrinsically more accurate the latter method has resulted in practice in a distribution in collinearity angle with FWHM $\approx$ 0.3 mrad which is very similar to the FWHM obtained with hodoscopes. Chambers have a smaller and less well known efficiency than counters while the advantage of measuring two tracks whose distance of closest approach can then be computed, rather than measuring two hits is largly offset by applying the Terwilliger scheme which reduces the interaction to an area of $\sim$1 cm^2. This similarity in performance of chambers and hodoscopes is borne out by the errors obtained in the measurements of Refs. 2 and 3 shown in table 3.

Comparison of σ_{TOT} measured with hodoscopes and with chambers		
	Chambers (ARCHGM Coll.Ref 3)	Hodoscopes (CR Coll. Ref 2)
22/22	42.0 ± 0.3	41.45 ± 0.23
26/26	42.8 ± 0.3	42.38 ± 0.27
31/31	43.3 ± 0.4	43.07 ± 0.30

TABLE 3

This table shows that simple-to-operate hodoscopes are adequate and thus to be preferred over the complexity of building wire chambers and installing and operating them inside the Roman Pots.

IV COUNTING RATES, ISR TIME

The counting rates have been calculated assuming

1) The original CERN-Rome hodoscopes, $54 \times 88\ mm^2$ at 9 m covering $3 \leq \Theta \leq 9$ mrad (see fig. 3)
2) One cooled $\bar{p}$ pulse, i.e. a one day $\bar{p}$ fill of 30 mA, against a 1 A proton beam in the other ring, giving $L = 1,5 \times 10^{27} (cm^2 / sec$ [4])

The rates are listed in table 4.

	t_{MIN} $(GeV)^2$ $\times 10^3$	Δt	Rate/sec	Measuring time for 1/4% statistical accuracy (days)
11.8/11.8	1.25	0.0100	0.3	5
15.4/15.4	2.08	0.0166	0.4	$4\frac{1}{2}$
22.4/22.4	4.55	0.0365	0.8	$2\frac{1}{2}$
26.6/26.6	6.37	0.0509	1.0	2
31.4/31.4	8.76	0.0701	1.5	$1\frac{1}{2}$

TABLE 4

Thus, doing 2 measurements at 11.8/11.8 and 3 at all the other energies, the experiment would require 40 days of running time. This would require 14 fills of 1 $\bar{p}$ pulse each, with the Terwilliger scheme on, the low β off and, possibly, the SFM off. Interleaved with, and/or prior to the $\bar{p}p$ runs, we would require several runs with pp at one energy (until the systematics are understood) followed by e.g. two runs at each energy with low ($\sim$1 A) currents.

V INSTALLATION, SUPPORT

Both I_2 and I_6 are suitable intersections for this experiment. I_2 would allow an early (summer 1979) installation of the Roman Pots and thus make it possible to do the running-in and the $\sigma_T(pp)$ data taking with the

ISR running at low currents for a modest fraction of the time only. I_6 has the advantage that this collaboration is currently set-up in this intersection, so that cost and effort could be saved by installing the Roman Pots there. It would imply that the installation would have to wait until the end of R607.(R607 is installed since October 1978 but has not yet run at the requested 22/22 GeV). Other factors influencing the choice would be the compatibility of the vacuum systems in I_2 and I_6 with the Roman Pots, and the location of other approved or to-be-approved experiments.

It is our belief that, unlike the more complex experiments, the proposed set-up is sufficiently simple to permit the analysis to be carried out outside CERN. In addition we estimate to need approximately 20 CP HOURS in 1980 and < 30 CP HOURS in 1981 at the CERN CDC's.

Some assistance of the EP-Electronics Loanpool will also be required.

REFERENCES

1) CERN Research Board. CERN/RB/29, 16 Nov.1978, CERN/RB/31 18 Jan 1979.

2) U. Amaldi et al. Phys Lett 62 B (1976) 460; Nucl.Phys B145 (1978) 367; Phys.Lett 66B (1977) 390.

3) L. Baksay et al. Nucl Phys B 141 (1978) 1

4) ISR Operation with Anti-protons. P.J. Bryant (editor) CERN/ISR - BOM/78.18.

FIGURE CAPTIONS

Fig. 1 pp and $\bar{p}p$ total cross section data. The solid line is a fit to the combined pp and $\bar{p}p$ data (see text). The dashed lines indicate the range of values consistent with the fit. Figure taken from ref.2.

Fig. 2 Typical behaviour of the elastic cross sections at 15/15 and 25/25 GeV. Figure from CERN-Rome proposal.

Fig. 3 Layout of the Roman Pots.

APPENDIX A

In this appendix we summarize the results obtained in previous ISR experiments of $\sigma_{TOT}(pp)$.

I MEASUREMENT OF THE TOTAL RATE OF INTERACTIONS

In this method interactions are detected by measuring secondaries in a coincidence between the two hemispheres of a (nearly) 4π hodoscope. The rate R_{int} is related to σ_{TOT} by

$$\sigma_{TOT} = \frac{R_{int}(1+\varepsilon)}{L} + \Delta\sigma_{EL}$$

where L is the luminosity, ε accounts for the combined correction due to diffractive events in the pipe, holes in the 4π detector, inefficiencies, deadtimes etc, and $\Delta\sigma_{EL}$ is the unobserved part of the elastic cross section inside the beam pipe.

In the PISA-STONY BROOK experiment the following results have been obtained (Ref.2).

	Observed $\sigma = R_{int}/L$	ε(%)	$\Delta\sigma_{EL}$	σ(PSB)
11.8/11.8	37.89	1.77	0.24	38.80 ± 0.25
15.4/15.4	38.86	1.80	0.52	40.07 ± 0.24
22.4/22.4	39.82	2.16	1.24	41.90 ± 0.24
26.6/26.6	40.16	2.27	1.66	42.71 ± 0.35
31.4/31.4	39.81	2.49	2.22	42.96 ± 0.38

TABLE A1

We note that :-

1) The observed rise in σ_{TOT} between 11.8/11.8 and 31.4/31.4 is 5.2%, the real rise is 10.9%.

2) The correction $\Delta\sigma_{EL}$ varies by a factor 10 through the energy range and is not a priori known for $\bar{p}p$.
3) A difference between pp and $\bar{p}p$ arises from the fact that in $\bar{p}p$ the final state is neutral. Data on multiplicity distribution suggest that this is a very small effect.

2 MEASUREMENT OF SMALL ANGLE ELASTIC SCATTERING

Here σ_{TOT} is obtained by extrapolating the differential elastic cross section to 0^o and applying the optical theorem :

$$\sigma_{TOT} = \left[\frac{16\ \pi}{1 + \rho^2} \quad (\frac{d\sigma}{dt})_{0^o} \right]^{1/2}$$

$$= \left[\frac{16\ \pi}{1 + \rho^2} \quad \frac{\pi}{p^2} (1 - \varepsilon_c)\ e^{b|t|} \ \frac{1}{\Delta\Omega} \quad \frac{R_{EL}(t)}{L} \right]^{1/2} = \left[\frac{F}{L} \right]^{1/2}$$

where ε_c is the Coulomb correction. The results of the CERN-Rome experiment are summarized in table A2 (Ref. 3).

	ρ	ε_c	$\bar{b}$	σ(CR)
11.8/11.8	0	0.0574	11.8±0.3	39.01±0.27
15.4/15.4	0.03	0.0141	12.3±0.3	40.38±0.31
21.4/21.4	0.06	0.004	12.8±0.3	41.45±0.23
26.6/26.6	0.07	0.006	13.1±0.3	42.38±0.27
31.4/31.4	0.08	0.007	13.3±0.3	43.07±0.30

TABLE A2

We note that in this method the result is particularly sensitive to the slope of the measured part of the t distribution.

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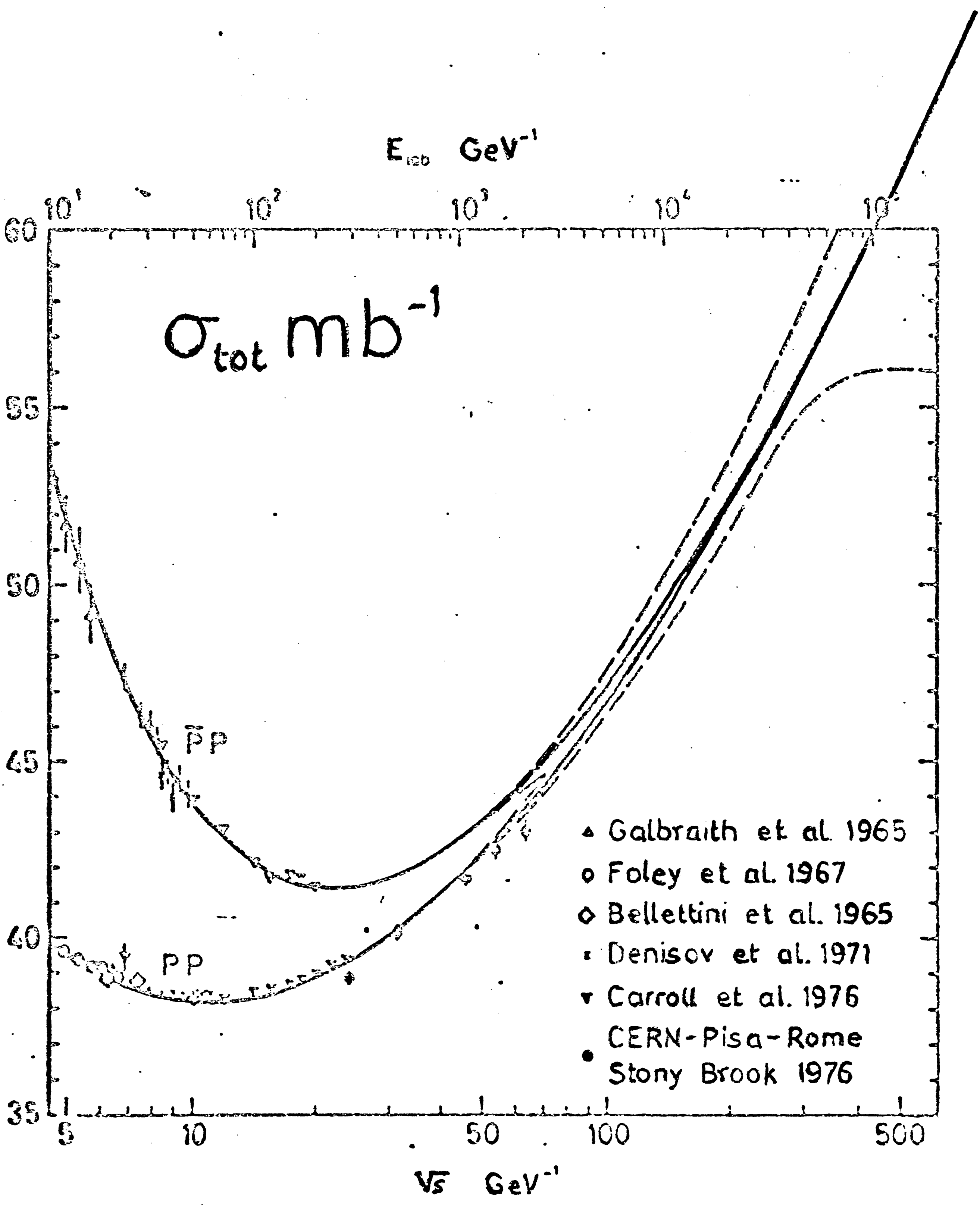
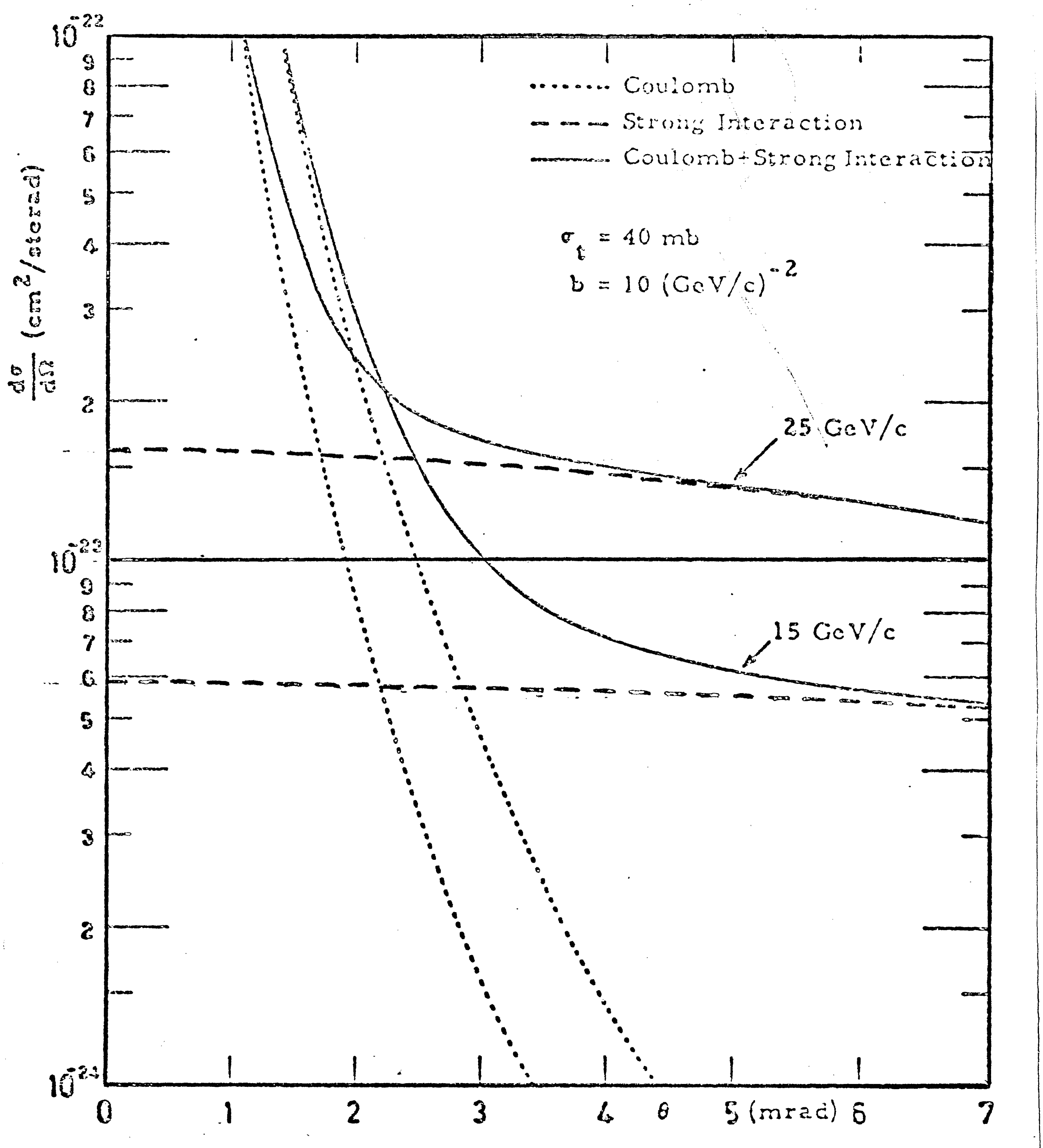


E lab GeV⁻¹
10¹
10²
10³
10⁴
10⁵
σtot mb⁻¹
60
55
50
45
40
35
p̄p
pp
Galbraith et al. 1965
Foley et al. 1967
Bellettini et al. 1965
Denisov et al. 1971
Carroll et al. 1976
CERN-Pisa-Rome
Stony Brook 1976
5
10
50
100
500
√s GeV⁻¹

Fig. 1



Coulomb
Strong Interaction
Coulomb+Strong Interaction
σt = 40 mb
b = 10 (GeV/c)^-2
25 GeV/c
15 GeV/c
dσ/dΩ (cm²/sterad)
θ (mrad)
10^-22
10^-23
10^-24
0 1 2 3 4 5 6 7

Fig. 2

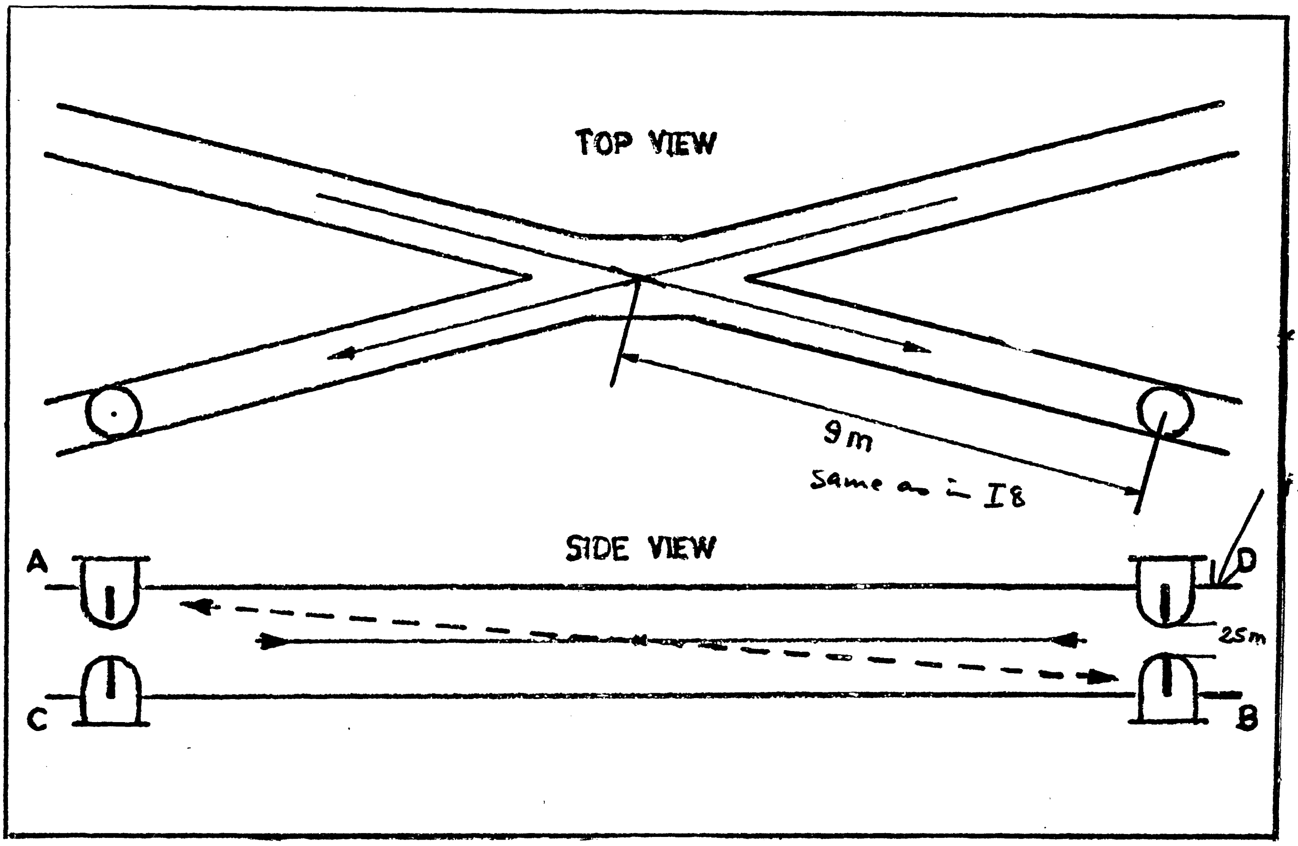


Fig. 3