

THE ENERGY DEPENDENCE OF THE PROTON-PROTON TOTAL CROSS-SECTION FOR CENTRE-OF-MASS ENERGIES BETWEEN 23 AND 53 GeV

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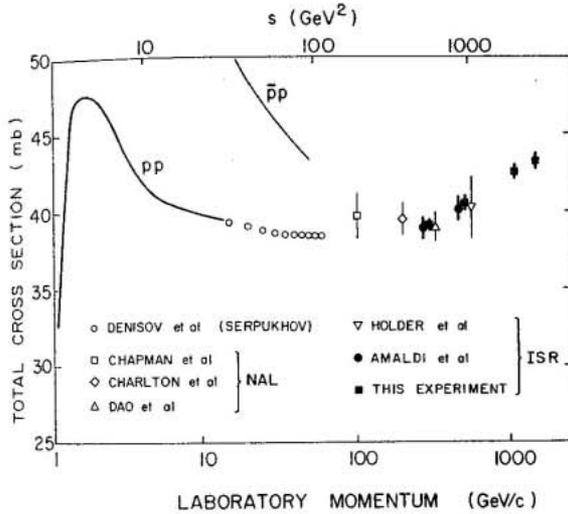
Measurements of p-p cross-sections at centre-of-mass energies of 23, 31, 45 and 53 GeV were established by determining the total cross-sections with the Van der Meer method and by application of the optical theorem. The total cross-section increases with energy.

The measurements of the proton total cross-section were performed at the CERN Intersecting Storage Rings using methods other than the conventional optical theorem technique, which is not directly applicable to the colliding beams. In one method σ_t is determined from the measurement of the differential elastic cross-section by application of the optical theorem. In the other method the total number of protons counted [3]. In applying these approaches have been used the elastic cross-section: measurement of the elastic cross-section at very small angles where Coulomb scattering dominates the absolute value, and determine the luminosity by the Van der Meer method [4].

This letter presents results for centre-of-mass energies, \sqrt{s} , of 23, 31, 45 and 53 GeV. The results are summarized as follows:

- a) Measurement of σ_t at angles θ around 6 mrad
- b) Determination of the luminosity of colliding beams in their rest frame (by the Van der Meer method [4]).

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made at centre-of-mass energies of 23, 31, 45 and 53 GeV. The total cross-section was determined by the Van der Meer method and by application of the optical theorem. The total cross-section increases with energy.

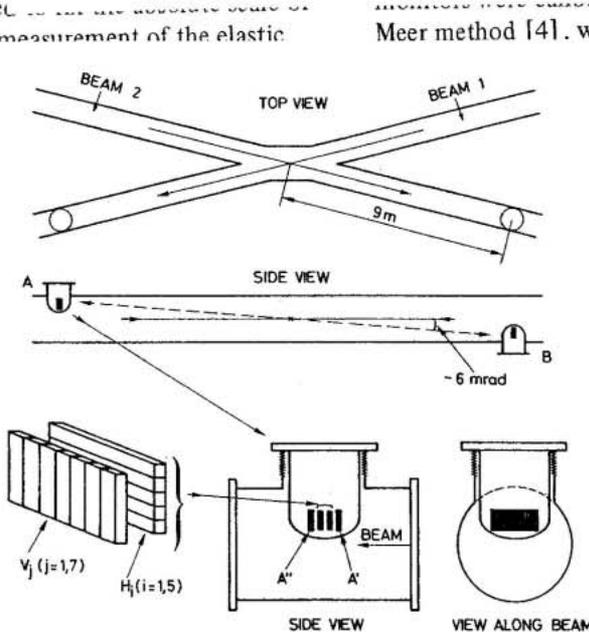
The differential cross-section was measured at $\theta = 0$ using the measured θ dependence of the differential cross-section.

The luminosity was determined from the optical theorem. The total cross-section was determined from the measurement of the differential elastic cross-section by application of the optical theorem.

The Van der Meer method [4], which may be described as follows: the counting rate R of particles produced by two beams intersecting in the horizontal plane, the cross-section σ is counted by the detector. The distributions of the stored beams $i_1(z-z_1)$ and $i_2(z-z_2)$ may be written as $i_i(z-z_i) = i_i(z_i + \delta) dz$.

The vertical displacement between the two beams. The constant δ is the vertical displacement between the two beams.

The luminosity of the beams at the ISR is $L = N_1 N_2 / A$.



MEASUREMENT OF THE TOTAL PROTON-PROTON
CROSS-SECTION AT THE ISR[☆]

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We present the first results of a measurement of the total cross-section σ_T in proton-proton collisions at equivalent laboratory momenta between 291 and 1480 GeV/c at the CERN Intersecting Storage Rings (ISR). The method is based on the measurement of the ratio of the total interaction rate and the machine luminosity. The data show an increase of about 10% in σ_T in this energy interval.

The simplest and most fundamental size of the proton as observed in various collisions is the total cross-section. Traditional accelerator data have resulted in the σ_T should remain essentially constant at high energies, and much of the phenomenology of strong interactions in the ISR is based on the notion that we have reached an energy-independent regime of hadronic interactions. In this paper we report a measurement of σ_T at 291 and 1480 GeV/c equivalent laboratory momenta and find that there is an appreciable increase of about 10% in σ_T in this energy interval.

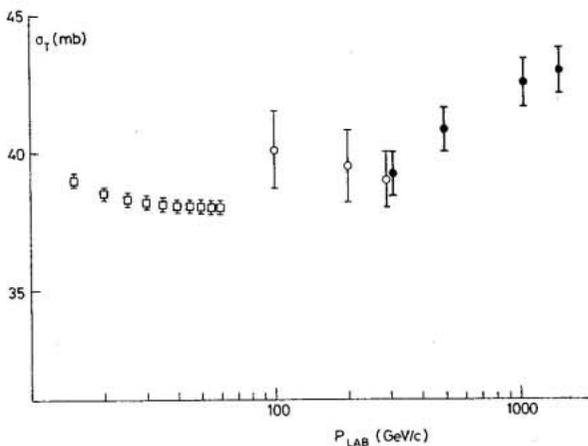
At a machine with two colliding beams the total cross-section σ_T is measured with a traditional transmission method. We instead find σ_T from the detected rate R_T of all interactions through the expression

$$R_T = \sigma_T L, \tag{1}$$

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is. The luminos-
beam fluxes in
the product of
s/cm² in a con-
terms of the

(2)

e is the charge
and α the cross-
section height h_{eff}
direction (ver-
two beams,

as

$$\frac{1}{h_{eff}} = \frac{\int \rho_1(z) \rho_2(z) dz}{\int \rho_1(z) dz \int \rho_2(z) dz} \tag{3}$$

Here ρ_1 and ρ_2 are the beam densities as a function of z , the vertical coordinate. Inasmuch as all parameters in eq. (2) except h_{eff} are known or measured during ISR operation to better than 0.1%, the determination of h_{eff} becomes the most delicate task in measuring L .

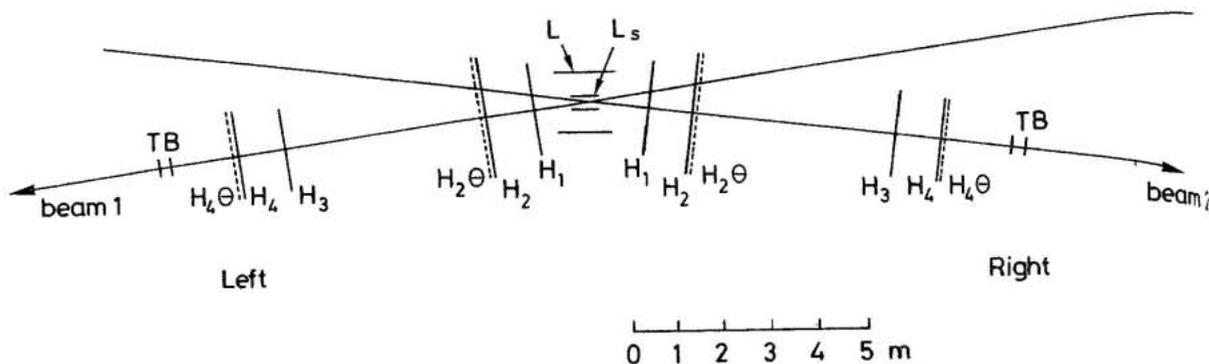


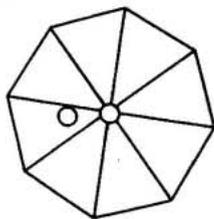
Fig. 1. Schematic layout of the experiment. H_1, \dots, H_4 , counter hodoscopes, binned in ϕ -octants. $H_{2\theta}, H_{4\theta}$, counter hodoscopes comprising four quadrants split into θ -bins. L , double-layer counter hodoscope box (four planes of scintillator/lead/scintillator sandwich). L_s , small counter box (four counters) surrounding the intersection. TB, scintillation counters leaving minimum clearance for the beam pipes. Some additional monitor counters are not shown in the figure.

In the present letter, a brief description of the experimental apparatus and most relevant information on the procedure followed to measure σ_T are given. More details, both on the detectors and on the data reduction, can be found in a forthcoming paper [1].

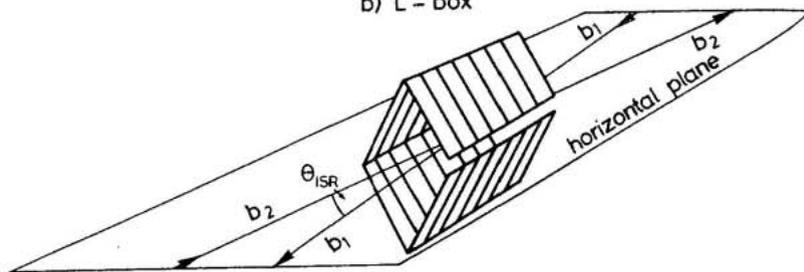
The general layout of the experiment is shown in

fig. 1. The basic trigger requires at least one charged particle in cones surrounding each beam emerging from the interaction region. Each arm of the apparatus consists of hodoscopes H_1, H_2, H_3, H_4 . Hodoscopes H_1 and H_2 are in coincidence and detect particles produced at angles $4^\circ \lesssim \theta \lesssim 30^\circ$. In a similar way

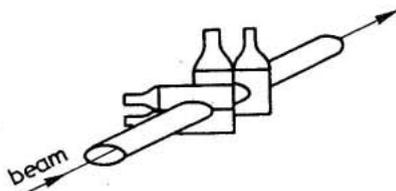
a) ϕ -hodoscope



b) L - box



c) TB counters



d) θ - hodoscope

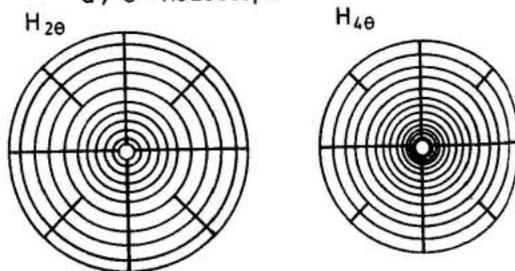


Fig. 2. Schematic drawing of hodoscope counters. a) H_1 hodoscope. Hodoscope H_2 is similar, but the ϕ -bins are rotated by $\pi/4$. Hodoscopes H_3 and H_4 are like H_1, H_2 , but with no off-centre hole. b) L-box. Only the first layer is shown. The second layer is behind it, with a lead plate in between. c) TB counters. d) θ -hodoscopes. The outer rings are split into octants, the inner rings to quadrants.

A PRIMER ON DETECTORS IN HIGH LUMINOSITY ENVIRONMENT

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I. History

The following remarks are relevant to the problem of balancing luminosity versus energy in new HEP construction.

In a 1973 Isabelle Summer study,¹ it was stated that the only experiment that would succeed at a luminosity of $10^{33} \text{cm}^{-2} \text{sec}^{-1}$ was one in which the apparatus was shielded from the collision region by massive quantity of steel. In 1981, this opinion was confirmed by an authority no less than S.C.C. Ting.² It may be instructive to review the progress of collider detectors over the past decade. In 1973, the time resolution or, better, the integrating time of tracking detectors was ~ 100 ns. In 1982, this time has remained the same since PWC's are still the fastest tracking devices available. The fundamental limit is the saturated drift velocity of electrons in gases. Better resolution and three dimensional properties have led to the choice of drift chambers and TPC's which have considerably longer integration times. A new characteristic of 1982 detectors is the increasing pervasiveness of calorimeters which have become indispensable devices for measurement of electromagnetic and hadronic energy, especially at momenta where magnetic measurements become imprecise. Calorimeters, because of their innate geometric dimensions set by the nuclear mean free path and their distance from the interaction point have integration times of ~ 200 - 1000 ns. Of course this is the present state of the art which depends on the properties of BBQ, gas chambers, liquid argon, lead glass, etc.

The conclusion is that things have only gotten worse since 1973.

II. Integration Time - Tracking

What are the implications of long integration times? We are facing collision energies so high that the charged and neutral multiplicities, \bar{M} average about 60 particles near 1 TeV. These typical multiplicities have surprisingly large fluctuations, such that Gaussian or Poisson statistics do not apply.³ For example, the probability of having $2\bar{M}$ particles is one quarter that of having \bar{M} particles. A track detector that integrates over, say, N events (with its integrating time of >100 ns) must add N times the average multiplicity to the number of particles in the triggering event. If this is a typical hard collision it may well have a track multiplicity many times higher than the average multiplicity.³ At $10^{33} \text{cm}^{-2} \text{sec}^{-1}$, ± 100 ns integrates over an average of 10 events. If each event generates an average of 30 charged³ particles (and ~ 30 neutral particles) one must add an average of 300 particles to the trigger induced event. Not all of these will conveniently stay in the beam pipe. (See typical events attached.) According to UA1³ an average of 50 particles enter the central calorimeter at $\sqrt{s} = 540$ GeV in minimum bias events. Many others will strike flanges, supports, pole pieces, etc. and shower with very high multiplicities, the end products of which give rise to noise or albedo, i.e., single hits in detectors or random tracks. This has severe implications for

tracking efficiency; there is in fact a fair likelihood that these high multiplicities will render any of the tracking devices, as we now understand them, inoperable. PWC's have operated at ambient singles rates of 10 Mcps with fairly simple track configurations. However, experience with 20-30 tracks, e.g., at the ISR's Split Field Magnet or at various multiparticle spectrometers suggest a CDC 7600 CPU analysis time per event of hundreds of milliseconds up to ~ 5 sec! To contemplate the functioning of a track chamber with several hundreds of tracks, many of low and "curling" energies (even given scintillation tagging) clearly requires a major advance. As a dramatic example, look at Fig. 1 and imagine superposing 2, 3 or 5 such events in a single trigger.

We should note that before one can reject tracks for pointing incorrectly one must be able to do the pattern recognition. A more quantitative tabulation of the influence of finite integrating time is presented in Tables I and II.

III. Calorimetry

To this tale of woe we must add the problem of the calorimeters. Now we have ~ 30 charged and 30 neutral particles incident upon the calorimeter which has an optimistic integrating time of ± 200 ns. This is at ~ 1 TeV. Multiplicities will about double at 10 TeV. It is true that a typical event may add negligibly to a (say) 100 GeV/c transverse momentum trigger. Some fraction of good events would be confused by the integration, but it is also clear that a large enough number of random accumulations of 10 or 20 minimum bias events can generate fake physics. These may provide a background for a large fraction of the anticipated physics signatures. During the interval between real 100 GeV/c jets say (at the rate of 10 per day) there would be $\sim 5 \times 10^{11}$ accumulations of twenty random events! If each charged particle generates a transverse energy of 500 MeV³ and each photon 250 MeV, a minimum bias event produces an average of ~ 20 GeV of E_t . Twenty events yields 400 GeV!! Gating may reduce this to ~ 200 GeV. A patient Monte Carloist can decide how often these will fluctuate and cluster so as to fake a $PT = 100$ GeV/c event. However, this intrepid soul must be sure he is using the correct distribution function for fluctuations around the "typical" minimum bias trigger. This does assume either a breakthrough in tracking or, more likely, ability to see jets without tracks.

IV. Current State of the Art

There is ample data from 1982 experiments that support this pessimism. Charm was discovered in 1975. In spite of eight years and three generations of experiments at Fermilab, ISR, SPS and AGS the total number of clear charm events observed in hadron collisions is about one hundred! Nevertheless, literally millions of charmed particles were produced in the targets of the dozens of experiments looking for charm. It is obviously even worse for bottom mesons. Why? The primary problem is that the hadronic production cross section is less than 0.1% of the total cross section. Then, high (5-10 tracks) multiplicities, combinatorials, backgrounds, i.e., the

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years to handle high rates and get physics out have a very deep respect for these problems.

A pp collider offers the unique feature of factors of 10-100 in potential collision rate over pp at the very significant added cost of an additional ring. This luminosity is strongly motivated by anticipated "new" physics cross-sections. Yet the confidence that these rates are usable is very far from being demonstrated. Before we invest heavily in luminosity, we need a great deal of confidence that the detectors can be dramatically improved. One solution is to use the extra ring money in order to go to higher energy. This tends to raise cross sections for these processes, e.g., Table III, in two different ways and therefore also the signal to noise. Higher energy results in bigger cross sections for masses approaching or exceeding $\sim 10\%$ of \sqrt{s} . Also, since most of the data at very high energy machines are at low x, the QCD effects tend to raise parton flux and therefore effectively again raise cross sections. As we have seen, i.e., Eq. 16, with backgrounds present, we gain with a power of cross section which is larger than one. Since backgrounds increase with multiplicity which scales logarithmically with energy, cuts applied to reduce background are much less likely to injure the physics at higher energy. Of course the strongest drive for high energy is the totally unpredictable phenomena we may see. We should recall that every accelerator that has opened a new energy region in the past thirty years has yielded unanticipated results. It is also at high energy (>10 TeV) where there is some possibility that the 10^{32} luminosities can be profitably utilized. Of course, new physics may very well be nicely explored with modest luminosity. We must go there to see.

The prognosis for instrumental breakthrough is mixed. Serious studies of high luminosity colliders started in 1972. We can look at this as a 15 year program of which 10 years have already been spent. Nevertheless, (and this is the principal motivation of this paper), work must continue on decreasing the integrating time of tracking detectors, preferably without breaking the bank by infinite readout channels. Calorimetry is fundamentally ugly; a cure here would be to improve resolution, decrease integrating time and find a cheap substitute for steel.

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1. L.M. Lederman, Muon Pairs Revisited, Crisp 72-43 and BNL 17 522 (1972) p.406.
2. S.C.C. Ting et al. ISABELLE Summer Study, 1981.
3. UA5 Collaboration - CERN/EP 81-15 3.
UA1 Collaboration - CERN EP/81-155; also presentations at the Paris (Rochester) Conference.
4. T. Akesson et al (Axial Field Spectrometer Collaboration) CERN EP/82 - 139 (1982).
5. F. Paige, BNL Report. G. Kane, Snowmass graphs.
6. One of the authors (LML) has been doing experiments almost exclusively with primary protons since ~ 1964 , including several generations of ISR experiments in the period 1971-1978.
7. This was stressed by T.D. Lee in private communication.

Figure Caption

Typical UA1 events taken at $\sqrt{s} = 540$ GeV and very low luminosity.

