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 ... made at centre-of-mass ener-
gies of 23, 31, 45 and ... scale of the cross-section
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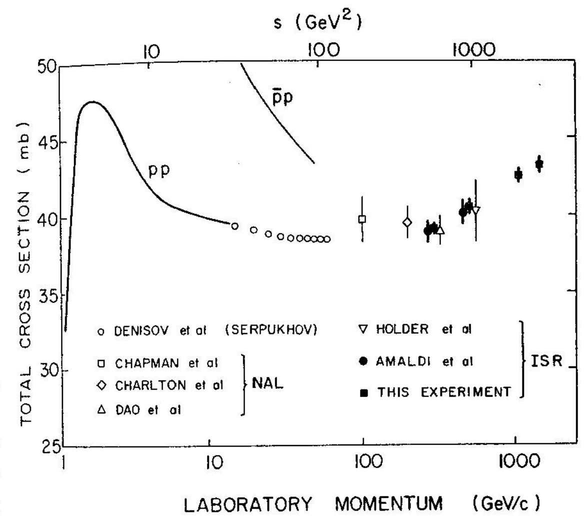
total cross sections we ... n to the forward direction
and by application of ... e studied the proton-proton
total cross-section incr ...



The measurements of t ... e differential cross-section
proton total cross-section ...
ed at the CERN Intersecti ... $\theta = 0$ using the measured θ
methods other than the c ...
technique, which is not di ... from the optical theorem.
beams. In one method σ_t ... sted of small scintillation c
ment of the differential el ... ng elastic scattering and of
by application of the opti ... ge scintillators, detecting in
the total number of proto ... f about 50 mrad, to detern
counted [3]. In appying t ... the beginning of each run
approaches have been use ... d by means of the Van de
the elastic cross-section: measurement of the elastic ... Meer method [4], which may be described as foll
cross-section at very sm ... en the counting rate R
where Coulomb scatteri ... s produced by two bear
absolute value, and dete ... plane, the cross-section
luminosity by the Van ... ts counted by the detec

This letter presents r ... stributions of the store
of-mass energies, $\sqrt{s}$, of ... nd $i_2(z-z_2)$ may be wri
the first method. The v ...
summarized as follows: ... $+ \delta)\,dz$,

a) Measurement of p ... ertical displacement be
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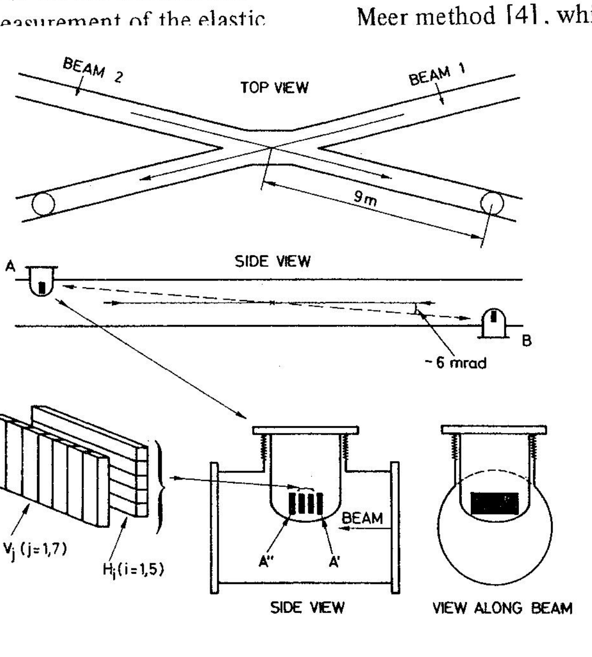

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MEASUREMENT OF THE TOTAL PROTON-PROTON CROSS-SECTION AT THE ISR[☆]

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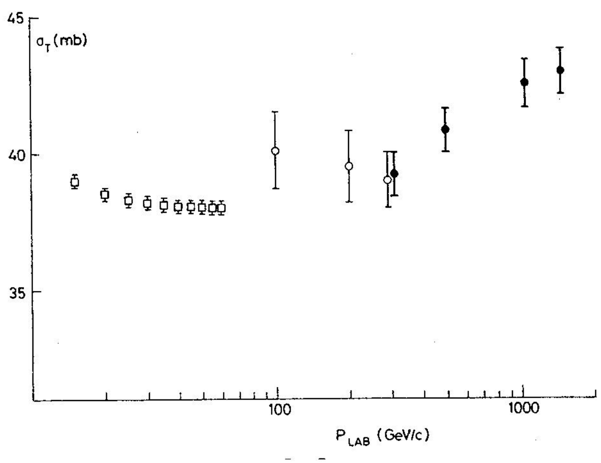
We present the first results of a measurement of the total cross-section σ_T in proton-proton collisions at equivalent laboratory momenta between 291 and 1480 GeV/c at the CERN Intersecting Storage Rings (ISR). The method is based on the measurement of the ratio of the total interaction rate and the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



The simplest and most fundamen size of the proton as observed in ver collisions is the total cross-section. T accelerator data have resulted in the σ_T should remain essentially constar energies, and much of the phenomer tion of strong interactions in the ISF based on the notion that we have ne energy-independent regime of hadro paper we report a measurement of σ and find that there is an appreciable 291 and 1480 GeV/c equivalent labo tum.

At a machine with two colliding b measure σ_T with a traditional transm ment. We instead find σ_T from the detected rate R_T of all interactions through the expression

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

ns. The luminos- beam fluxes in he product of ts/cm^2 in a con- terms of the

(2)

e is the charge nd α the cross- ve height h_{eff} direction (ver- two beams, as

$$\frac{1}{h_{\mathrm{eff}}} = \frac{\int \rho_1(z)\rho_2(z)\,\mathrm{d}z}{\int \rho_1(z)\,\mathrm{d}z \int \rho_2(z)\,\mathrm{d}z}. \tag{3}$$

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.

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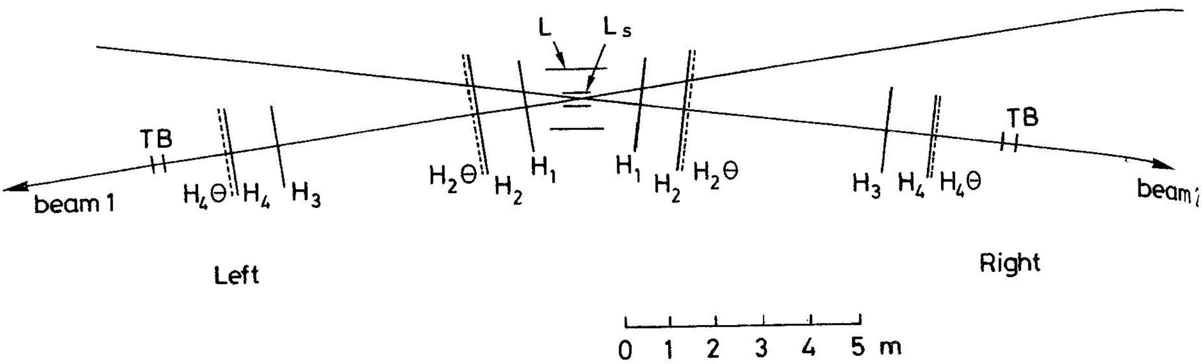

Fig. 1. Schematic layout of the experiment. H_1, ..., H_4, counter hodoscopes, binned in ϕ-octants. $H_2\theta$, $H_4\theta$, counter hodoscopes comprising four quadrants split into θ-bins. L, double-layer counter hodoscope box (four planes of scintillator/lead/scintillator sandwich). L_s, small counter 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 $4° \lesssim \theta \lesssim 30°$. In a similar way

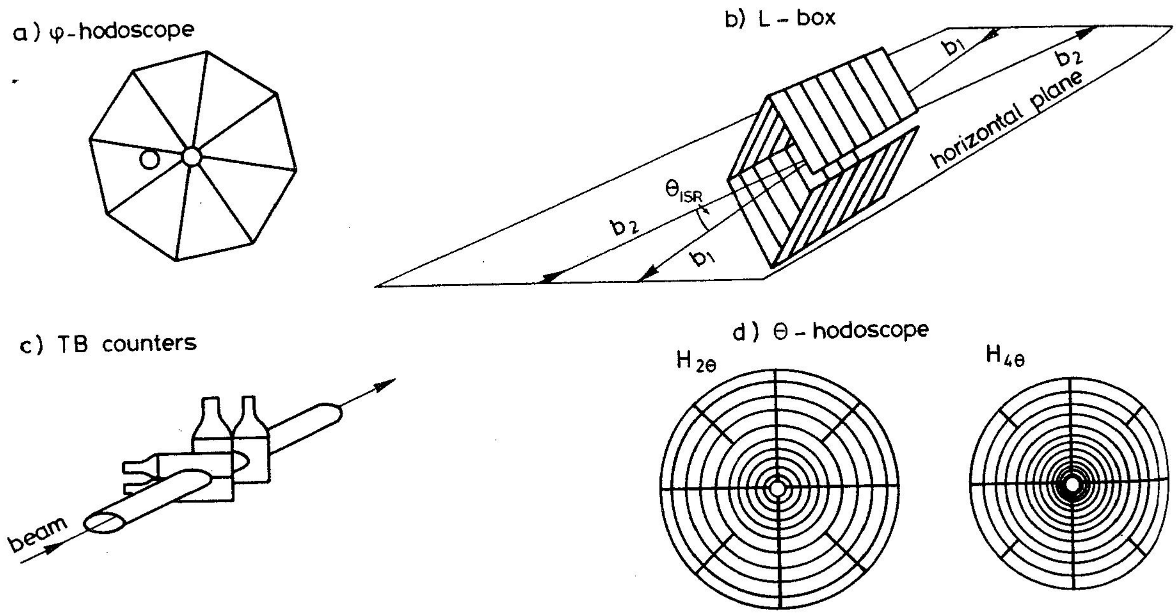

Fig. 2. Schematic drawing of hodoscope counters. a) H_1 hodoscope. Hodoscope H_2 is similar, but the ϕ-bins are rotated by $\pi/8$. Hodoscopes H_3 and H_4 are like H_1, H_2, but with no off-centre hole. b) L-box. Only the first layer is shown. The second layer is behind it, with a lead plate in between. 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 $10^{33}cm^{-2}sec^{-1}$ 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, $\overline{M}$ 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 $\overline{M}$ particles is one quarter that of having $\overline{M}$ particles. A track detector that integrates over, say, N events (with its integrating time of $\geq$100ns) 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 $10^{33}cm^{-2}sec^{-1}$, ±100ns integrates over an average of 10 events. If each event generates an average of 30 charged[3] 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 UA1[3] 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 ±200ns. 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 ~$5x10^{11}$ accumulations of twenty random events! If each charged particle generates a transverse energy of 500 Mev[3] 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

*Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

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 $\bar{p}p$ 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 ~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.[7] 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.