UC414
LBL-28736

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Physics Division

Presented at the International Conference on
Elastic and Diffractive Scattering,
Evanston, IL, May 2–6, 1989, and
to be published in the Proceedings

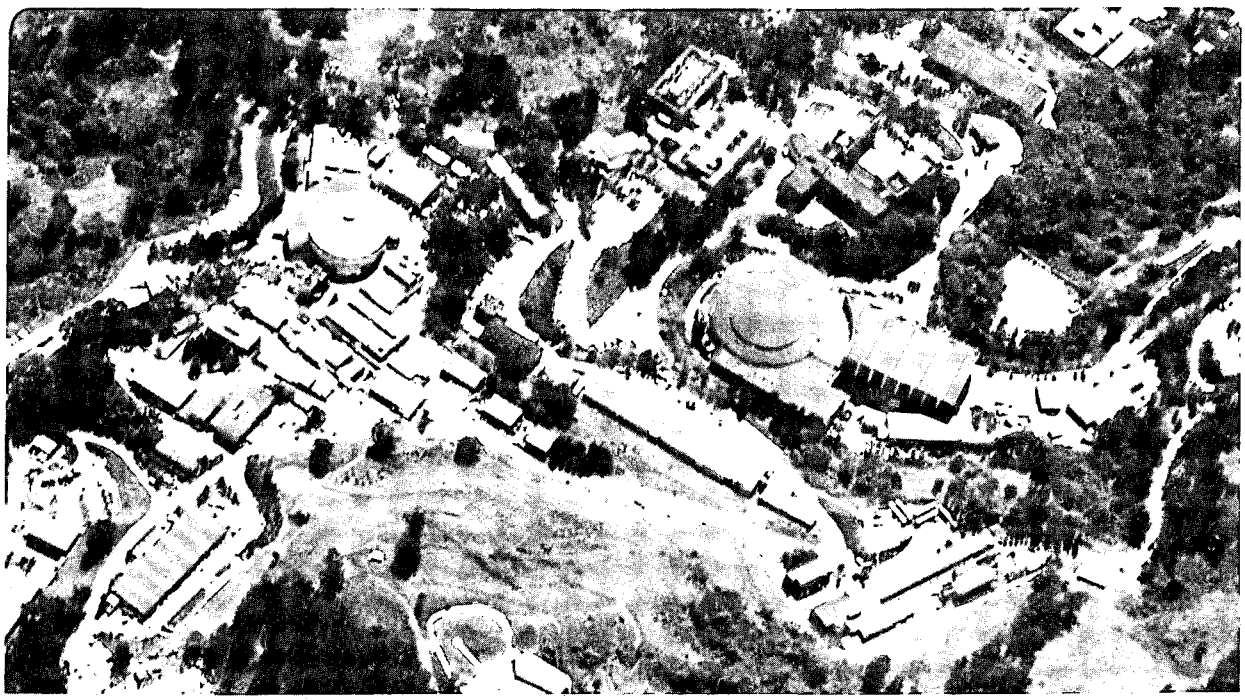
Elastic Scattering and Total Cross Sections

R.N. Cahn

March 1990

For Reference

Not to be taken from this room



LBL-28736
Copy 1
Bldg. 50 Library.

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

March 15, 1990 LBL-28736

Elastic Scattering and Total Cross Sections *

to be published in the
Proceedings of the International Conference on Elastic and Diffractive Scattering
Northwestern University, Evanston, IL
May 2-6, 1989

Robert N. Cahn

Theoretical Physics Group
Physics Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

ELASTIC SCATTERING AND TOTAL CROSS SECTIONS

Robert N. CAHN

Lawrence Berkeley Laboratory, University of California
Berkeley, CA 94720, USA

Summary Talk

This meeting comes at a time of great excitement. There is the excitement engendered by new data and the excitement that comes from the participation of our colleagues from the Soviet Union, who are present in numbers far beyond those of former years. There are, I believe, a number of "schools" of particle physics in general and in the smaller domain of elastic scattering, as well. It is a simplification, but perhaps not a completely inaccurate one, to designate them by nationality. Thus we can identify a British-American pragmatic movement. Its tools include Regge phenomenology. There is, as well, a French school known for its elegance and developed in large part by André Martin. Our Soviet colleagues bring to the field a distinct character, distinguished by powerful calculational technique. The importance of this work is very great for elastic scattering as a discipline must tie itself to QCD if it is to remain an integral part of high energy physics. It is thus especially gratifying to witness the important contributions made by Soviet physicists to this meeting for their continued participation in these meetings will surely be most valuable.

The topics in elastic scattering that have been discussed at the meeting might be placed in three separate categories. The *Sacred* includes analyticity, QCD, and the data. The *Profane* includes Regge phenomenology and the quark-parton model. Finally, the *Heretical* includes the odderon.

Since I am from the Pragmatic school rather than the Elegant school, I am content to summarize in a vulgar fashion part of what analyticity tells about total cross sections. This is vitally important in view of the provocative results from UA-4[1]. We can circumvent dispersion relations, both integral and differential by writing amplitudes that are explicitly analytic[2,3]. A suitable even amplitude is

$$F = F_+ = iAs + iBs\left[\ln(s/s_0) - \frac{i\pi}{2}\right]^2 \tag{1}$$

so

$$\sigma = \frac{1}{s}\Im F = A + B\left[\ln^2(s/s_0) - \frac{\pi^2}{4}\right] \tag{2}$$

Now this really isn't good enough for the ISR region but it will do for our purposes. The minimum of σ occurs at s_0, let say $\sqrt{s_0} = 20$ GeV and

$$\sigma_{\min} = A - B\frac{\pi^2}{4} \approx 40 \text{ mb}. \tag{3}$$

Let's take

$$\sigma(\sqrt{s} = 546 \text{ GeV}) = 62 \text{ mb} = A + B \cdot 41.3 \tag{4}$$

Together these determine $A = 41.3$ mb , $B = 0.50$ mb. Now the phase of the forward scattering amplitude can be measured by observing interference between the hadronic and coulombic scattering amplitudes. The results are expressed as

$$\rho = \frac{\Re F}{\Im F}. \tag{5}$$

For our simple amplitude

$$\rho = \frac{\pi B \ln s/s_0}{A + B\left[\ln^2(s/s_0) - \frac{\pi^2}{4}\right]}. \tag{6}$$

The maximum value of ρ occurs when

$$\ln^2(s/s_0) = \frac{A}{B} - \frac{\pi^2}{4}. \tag{7}$$

For our choice of A and B this gives $\sqrt{s} = 1800$ GeV and $\rho_{\max} \approx 0.173$ Other choices of parameters give very similar results. At $\sqrt{s} = 546$ GeV we actually find $\rho = 0.168$.

The excitement comes from the measurement by the UA-4 collaboration at $\sqrt{s} = 546$ GeV, where they find $\rho = 0.24 \pm 0.04$. Not only is this far above our simple estimate of $\rho = 0.17$, more careful estimates predict $\rho = 0.14$ - 0.15. Of course, the discrepancy is little more than two standard deviations and cynics are entitled to dismiss the whole issue. If, however, we take the reported central value seriously, the consequences are dramatic.

One way to explain the experimental result is to include an odd amplitude that persists at high energies, as discussed by Gauron and by Kang at this conference [4,5], with rather different conclusions. While the data for the difference $\sigma_{pp} - \sigma_{p\bar{p}}$ is consistent with the behaviour $s^{-1/2}$, in principle we can consider contributions of the form

$$F_- = Cs\left[\ln(s/s_0') - \frac{i\pi}{2}\right]^2. \tag{8}$$

	Odderon	Threshold	Cynic
$\sigma_{p\bar{p}}$ (1.8 TeV)	75 mb	95 mb	75 mb
$\rho_{p\bar{p}}$ (1.8 TeV)	0.25	0.17	0.15

Table 1: Alternative expectations for the total cross section and ρ value at the Tevatron[3].

as discussed in much fuller detail by Fischer[6]. This will contribute to σ_{pp} a piece $-\pi C(\ln s/s_0')$ and an opposite amount to $\sigma_{p\bar{p}}$. These must not be large in the ISR region. In addition, $\rho_{p\bar{p}}$ will receive a contribution roughly

$$\Delta\rho_{p\bar{p}} = -\frac{C\left[\ln^2(s/s_0') - \frac{\pi^2}{4}\right]}{\sigma_{p\bar{p}}}. \tag{9}$$

If we somewhat arbitrarily take $s_0' = s_0$ We find $\sigma_{pp} - \sigma_{p\bar{p}} \approx 3.7$ mb at $\sqrt{s} = 546$ GeV and ≈ 5.1 mb at $\sqrt{s} = 1.8$ TeV.

Larger values would result if we required, say, $\Delta\rho_{p\bar{p}} = 0.10$. There is no hope of making a direct measurement of the difference, but a measurement of ρ at the Tevatron should find $\rho_{p\bar{p}} > 0.24$.

An alternative explanation of a large value of ρ is that there is a sudden threshold beyond which the total cross section grows rapidly. A very large increase is necessary if it is to explain $\rho = 0.24$.

The cynic's response to all this excitement is to remark that the UA-4 result is only 2.5 σ away from the canonical expectation: just wait and the ρ value will decrease. The three explanations are summarized in Table 1[3]. A preliminary report at this meeting from Fermilab experiment E710 indicated a cross section of 85.5 ± 6.4 mb at $\sqrt{s} = 1.8$ TeV[7]. Further refinement of the analysis leads to a slightly lower value, near 79 mb[8]. This favors the cynics and the *odderonistes*.

If we cannot be certain that ρ is rising dramatically, we certainly do know that the total cross section rises substantially between ISR energies and collider energies. An attractive explanation is that at high energies the proton contains more quark-antiquark pairs and gluons and these additional constituents result in a larger cross section, as discussed for example, by Kluit[9]. Of course it is not enough to identify a component of the total cross section that rises. Even if there is inevitably an increase, as the total energy rises, in the cross section to produce jets with a transverse momentum greater than some fixed

amount, it doesn't necessarily follow that the total cross section rises, as was emphasized by Landshoff and Nikolaev[10,11]. The cross section for events without such jets might drop. Only a theory that some how unitarizes can hope to explain the matter. Models using eikonalization were discussed by Durand and by Margolis[12,13]. Both groups were generally successful in reproducing the available data, though not surprisingly their values for ρ were lower than the report UA-4 value. Whether an eikonalized approach is truly justified is another matter, as stressed by Ryskin and by Bartels[14,15].

The proton - proton total cross section is surely one of the most fundamental experimental quantities of our discipline at we must our theory, QCD, with this data, but how? The Pragmatists start from a phenomenological approach. The most pragmatic approach is that of Landshoff[10], who is unafraid of the Froissart bound and boldly fits data to a form increasing as a small power of s. His undeniable success in fitting the data with extremely simple forms provides one front for the necessary assault on elastic scattering. The other front is being established by the brave souls using the weapons of QCD[14,15,16].

The vitality of this program depends on the quantity and quality of new data. We are beginning to see the achievements of E710 at Fermilab[7]. Results on ρ will be of especially great interest. Measuring ρ at the very nearly forward direction is a real *tour-de-force* and even the theoretical analysis requires some care[17].

New results will invigorate the field, just as they did when data from the CERN collider became available. By themselves, however, they will be insufficient to bring elastic scattering to a position of central importance in particle physics. That will happen only when we make some real advance in understanding the non-perturbative aspects of QCD that lie at the heart of the soft phenomena in elastic scattering. I expressed this conviction at the 1988 Fermilab Workshop on Proton-Antiproton Collisions in these terms[3]:

> Discussions of total cross sections and the like often fail to excite audiences of high energy physicists. This is not, I believe, because the subject is intrinsically uninteresting but because we are too ignorant. One day we may wake up and learn that Ed Witten has abandoned strings and has just discovered an ingenious approximation that makes possible predictions to 1% for non-perturbative QCD. Extra dimensions will evaporate before our eyes and everyone from Gordy Kane to Sidney Coleman will be calculating pp total cross sections.

Until that day, the best we can do is to continue to make measurements and to seek an

incremental understanding of these most basic phenomena.

References

[1] UA-4 Collaboration, Phys. Lett. **B198**, 583 (d87).

[2] M.M. Block and R.N. Cahn, Rev. Mod. Phys. **57**, 563 (85).

[3] R. N. Cahn, *Proc. 7th Topical Workshop on Proton-Antiproton Collider Physics*, Ed. R. Raja, A. Tollestrup, and J. Yoh, World Scientific, 1989.

[4] P. Gauron, these Proceedings.

[5] K. Kang, these Proceedings.

[6] J. Fischer, these Proceedings.

[7] R. Rubinstein, these Proceedings.

[8] Experiment E710, private communication from M. M. Block.

[9] P. M. Kluit, these Proceedings.

[10] P. V. Landshoff, these Proceedings.

[11] N. N. Nikolaev, these Proceedings.

[12] L. Durand and H. Pi, these Proceedings.

[13] M. M. Block et al., these Proceedings.

[14] M. Ryskin, these Proceedings.

[15] J. Bartels, these Proceedings.

[16] A. White, these Proceedings.

[17] E. Leader, these Proceedings.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720