Brief Reports

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Recent cosmic-ray work and the high-energy real part of the $\bar{p}p$ amplitude

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We suggest that a new large photonuclear interaction at very high energy, as postulated in connection with the "muon excess" problem in cosmic rays, could also induce the large real part of the elastic proton-antiproton amplitude reported from the CERN collider.

Recent reports[1] have strengthened the case for very-high-energy point sources in cosmic rays, as well as for the more controversial but very interesting possible muon excess in the air showers associated with them.[2]

Although the most natural description of the radiation from the point sources is that it is photons, photon-initiated showers contain few pions and so are expected to be muon poor.[3] Hence if the muon excess indeed exists, and the primary particles are photons, no explanation seems to be available in the present framework of conventional physics.

Some time ago, we speculated that an explanation could perhaps be found in the very-high-energy behavior of photonuclear cross sections.[4] If the photonuclear interaction around or above the Fermi (TeV) scale became "strong," a photon entering the atmosphere would have an almost geometric "black disc" cross section on an air nucleus. It then has nearly the same chance for starting a hadronic cascade as for producing an e^+e^- pair. The initial stages of a photon-induced cascade in the atmosphere thus have a hadronic character and can give muons. (This would be particularly so if a particle associated with the new threshold—e.g., "a strongly interacting Z meson"—decays directly to muons).

In this Brief Report we would like to point out a possible connection with another experimental anomaly of recent years (which, like the muon excess, needs further experimental confirmation): the large real part of the proton-antiproton elastic forward-scattering amplitude found at the CERN collider.[5]

In the traditional picture of elastic-scattering amplitudes at high energy, diffractive processes dominate and the real part of the elastic amplitude should become negligible relative to the imaginary part. This follows from analyticity in the form of the dispersion relations and the physical assumption that the difference in total cross sections

$$\sigma_- = \frac{\sigma(\bar{p}p) - \sigma(pp)}{2}$$

goes to zero at high energy. This later assumption, although very plausible in a diffractive picture, remains an assumption, and one of the hypotheses that may be entertained to explain a large real part is that the assumption fails at TeV energies in the center of mass.[6]

Now, it is interesting to remark that the "strongly interacting photon" invoked for the cosmic-ray problem could produce precisely such an effect through the interference of electromagnetic and strong amplitudes. The interference between the new interaction and the usual strong interaction must start by being linear in e; and thus being sensitive to the sign of the beam, will induce a difference in $\bar{p}$ and p cross sections.

For example, consider a process as discussed in Ref. 4, where in $\bar{p}p$ scattering a quasireal photon from the equivalent-photon beam carried by the antiproton (or its quarks) interacts on the proton to produce an arbitrary final state. Let the energy be high enough so that for a significant part of the quasireal-photon spectrum the photon-proton c.m. energy is above the presumed new threshold. Then the amplitude for the photon to be present with sufficient energy is $\approx e$. Since the photon-absorption amplitude will be like that for a hadron it is not unreasonable to assume that the amplitude for this process could be substantially in phase with that for the analogous purely hadronic processes. Upon summing and squaring with these purely hadronic amplitudes to the same final states, we then expect an interference term $\delta\sigma(\bar{p}p) \approx 2eF[\sigma(\gamma p)\sigma(\bar{p}p)]^{1/2}$. The factor F essentially represents the degree of overlap or coherence among the final states reached by the photon processes and by the conventional processes.

Repeating the argument for pp scattering gives the same expression with the opposite sign (from the opposite sign of the photon-emitting vertex), thus giving, for σ_-,

$$\delta\sigma_- \approx \pm 2eF\sqrt{\sigma(\gamma p)\sigma(\bar{p}p)} \ .$$

Thus even if conventional hadronic processes give a negligible σ_-, this mechanism can lead to a nonzero difference of cross sections. In various analyses it is found[7] that about -2 to -5 mb for σ_- in the TeV range could suffice, via the dispersion relations, to induce the large real part. Since $e \approx 0.08$ is not terribly small it is not impossible that with $\sigma(pp) \approx 60-80$ mb and with the "strongly interacting photon," $\sigma(\gamma p) \approx$ many tens mb, that the required $\delta\sigma_-$ can be obtained. The great unknown of course is the overlap factor F, which must not be allowed to be very small; i.e., the photon-induced reactions must be largely coherent with the hadronic ones. (For this reason we do not include very high impact-parameter photon-induced processes.) Unfortunately without a detailed model our suggestion does not imply any particular sign, nor is it possible to say what happens at even higher energy, well beyond the TeV scale.

Although the reasons which might be adduced for the hypothesis of a large increase in the photonuclear cross section, such as "parton proliferation,"[8] do not seem particularly strongly motivated, it is an intriguing possibility, and one that is subject to experimental test. We would especially like to recall that in Ref. 4 it was explained how a colliding beam experiment dedicated to very small momentum transfer could be used[9] to look for an anomalous high-energy photon total cross section.

I would like to thank K. Goulianos for extensive discussions on the current status of the real part problem.

[1]B. L. Dingus *et al.*, Phys. Rev. Lett. **61**, 1906 (1988); G. L. Cassiday *et al.*, *ibid.* **62**, 383 (1989).

[2]M. Samorski and W. Stamm, Astrophys. J. Lett. **268**, L17 (1983); in *18th International Cosmic Ray Conference, Bangalore, India, 1983, Conference Papers,* edited by N. Durgaprasad *et al.* (Tata Institute of Fundamental Physics, Bombay, 1983), Vol. 11, p. 244.

[3]A number of reports on current work were given in *Proceedings of the XXIV International Conference On High Energy Physics,* Munich, West Germany, 1988, edited by R. Kotthaus and J. H. Kühn (Springer, Berlin, 1988). An overview of the current situation may be found in B. Schwarzschild, Phys. Today **41** (No. 11), 17 (1988).

[4]W. Ochs and L. Stodolsky, Phys. Rev. D **33**, 1247 (1986).

[5]D. Bernard *et al.*, Phys. Lett. B **198**, 583 (1987).

[6]E. Leader, Phys. Rev. Lett. **59**, 1525 (1987). For many analyses of these and related questions see *Proceedings of the Second International Conference on Elastic and Diffractive Scattering,* Rockefeller University, 1987, edited by K. Goulianos (Editions Frontieres, Gif-sur-Yvette, France, 1988). As a purely mathematical possibility ("the odderon") this was considered long ago; see the contributions by Nicolescu and by Kang to this conference.

[7]See the table given in Leader's summary talk in *Proceedings of the Second International Conference on Elastic and Diffractive Scattering* (Ref. 6).

[8]M. Drees and F. Halzen, Phys. Rev. Lett. **61**, 275 (1988); see a more detailed discussion in M. Drees, F. Halzen, and K. Hikasa, Phys. Rev. D **39**, 1310 (1989). One might also consider, for example, a "new strong U(1)": S. Dimopoulos and G. Starkman (private communication).

[9]Should the new physics have a pointlike character one might also expect effects in very high transverse momentum photon production. This is discussed by J. Rosner and L. Stodolsky, Phys. Rev. D **40**, 1676 (1989).