SLAC-PUB-3234
October 1983
(T/E)

SEARCH FOR HIGHLY IONIZING PARTICLES IN e^+e^- COLLISIONS AT $\sqrt{s} = 29$ GeV*

D. FRYBERGER
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

and

T. E. COAN, K. KINOSHITA† AND P. B. PRICE
Department of Physics and Space Sciences Laboratory
University of California, Berkeley, California 94720

Abstract

The results of the analysis of data taken in the continuation of a previously reported search[1] for highly ionizing particles at PEP are presented. These data were taken in the period from October 1981 to June 1983. Assemblies consisting of Lexan and CR-39 plastic track detectors were exposed in two runs to integrated luminosities of 30×10^{36} cm^{-2} and 150×10^{36} cm^{-2}. The search was sensitive to particles with magnetic charge $20e \leq g \leq 200e$ or electric charge $3 \leq Z \leq 180$. A combined (95% C.L.) upper limit on the production cross section of $\sigma < 3.2 \times 10^{-38}$ cm^2 is obtained, improving the limits in Ref. 1 by more than an order of magnitude.

Submitted to Physical Review D

---

* Work supported in part by the Department of Energy, contract DE-AC03-76SF00515 and by the National Science Foundation, Grant PHY-8024128.

† Present address: Department of Physics, Harvard University, Cambridge, Massachusetts 02138.

The purpose of this paper is to present the results of the analysis of data taken in the continuation of a previously reported search[1] (hereafter referred to as I) for highly ionizing particles at the Stanford Linear Accelerator Center PEP e^+e^- storage ring facility. The new data reported here were all taken in Interaction Region 10 with beam energy $E_B = 14.5$ GeV ($\sqrt{s} = 29$ GeV; the same as in I).

As in I, this search used plastic track detectors comprised of interleaved sheets of Lexan and CR-39. These sheets were 80 μm and 610 - 725 μm thick, respectively, and arrayed in an assembly of stacks as depicted in Fig. 1. A set of holes was drilled in all of the sheets to allow alignment between individal sheets to ≤ 100 μm. The total solid angle Ω subtended by the stacks of sheets in this detector was 0.51 of 4π or 6.4 sr. The full area of the sheets is considered effective for the detection of Dirac magnetic monopoles[2]. As described in I, however, for electrically charged particles, the maximum acceptable zenith angle (the angle between the track trajectory and a vector normal to the plastic surface) is set at 30^o, which in this case reduces the effective Ω to 5.0 sr.

There is a considerable background in IR-10 due to the production of neutrons (see I for discussion) by the (uncaptured) e^- injection beam. This problem was circumvented by mechanically locating the detector assembly in a shielded cave during injection and beam tuning. For the apparatus used to collect the data reported in this paper the mechanical configuration was considerably improved over that of I. The detector assembly used here was mounted on the outer circumference of a wheel of 147 cm diameter. Before each injection, the wheel was rotated by 180^o around its axis, which was parallel to the axis of the beam pipe and 91.5 cm directly below it, carrying the detector assembly into a shielded cave constructed around the lower half of the wheel. A slot in the detector (cf. Fig. 1) permitted it to be moved past the vacuum pipe.[3] The wheel was in the form of a partitioned drum whose sections were filled with a mix of sand and water. This drum was 28.6 cm wide and shielded the retracted detector (with an estimated 150 g/cm^2) from above. Upstream shielding (toward the e^- injection point) consisted of 31.8 g/cm^2 of polyethelene plastic, 138 g/cm^2 of Pb and 425 g/cm^2 of concrete blocks. Downstream shielding consisted of 29.3 g/cm^2 of plastic, 138 g/cm^2 of Pb and 265 g/cm^2 of concrete blocks. This shielding eliminated the problem of neutron-generated background tracks[4] in the detector. At the beginning of each fill, and after injection and tuning was complete, the wheel was rotated back by the 180^o, putting the detector into its data-taking position surrounding the corrugated, 15.2 cm diameter, 200 μm thick[5] stainless steel vacuum pipe at the interaction point. This rotation took about one minute which is $\simeq 1\%$ of the running time allocated to a typical e^+e^- fill.

The data for the analysis reported here were taken using two different loadings[6] of the detector assembly. The first loading was exposed during the period from October 1981 to June of 1982 and the second during the period from October 1982 to June 1983. These two runs yielded integrated luminosity accumulations of 30.3×10^{36} cm^{-2} and 150×10^{36} cm^{-2}, respectively[7].

The plastic sheets from these data runs were analyzed as described in I. Briefly, each CR-39 sheet was etched in 6.25 N aqueous solution of NaOH at 70^oC such that a penetrating track at normal incidence with an average $Z/\beta > 16$ would produce a hole. The ammonia scanning technique was used to search for holes in the etched plastic. Each hole was examined through a stereomicroscope at 15x magnification. This step enables one to eliminate holes due to flaws in the plastic or, if there is an associated track, to determine its orientation. Since the ionization rate of a particle with given electric charge increases with decreasing β (except at the very end of its range), a particle might produce an etchable track above the ammonia detection threshold in one sheet and produce a latent track below the ammonia threshold, but above the etching threshold, $Z/\beta \simeq 8$, in an immediately preceding one. Hence, if any possibly interesting track was found by the ammonia technique, the corresponding area in the previous sheet was also examined through the use of the drilled alignment holes. This coincidence technique discriminates against particles with $Z < 3$. For magnetic monopoles with a given g, the ionization rate decreases as β decreases, so any putative monopole track would have to have an etching signature consistent with this expectation.

Neither data sample produced any candidate for highly ionizing particles produced at PEP.

The formula

$$\sigma < \frac{3}{\Sigma(L_i t_i \Omega_i / 4\pi)} \quad , \tag{1}$$

where Ω_i is the solid angle acceptance and $L_i t_i$ is the integrated luminosity, was used to give the 95% confidence level upper limit on the production cross section.

The results of the three years of data taking are summarized in Table I. For comparison to the limits set here[8], we note that at this energy a generic[9] weak cross section is $\sim 3 \times 10^{-37}$ cm^2, and the QED point cross section is 1×10^{-34} cm^2; our upper limits for monopoles and particles with large electric charge are lower than these cross sections by factors of ~10 to 3000.

We thank the PEP staff for efficient operation and delivery of good luminosity. We thank A. Baumgarten, R. Adamson, D. Nevius and W. Smith for engineering support, T. Jenkins for assistance in the background measurements, and participants in the Free Quark Search Experiment for their cooperation enabling us to install a detector and take data in IR-6. This work was supported in part by the National Science Foundation Grant No. PHY-8024128 and by the Department of Energy contract No. DE-AC03-76SF00515.

References and Footnotes

† Present address: Wilson Synchrotron Laboratory, Cornell University, Ithaca, New York 14850

1. K. Kinoshita, P. B. Price and D. Fryberger, Phys. Rev. Lett. 48, 77 (1982).

2. The assumption of a (back-to-back) pair production process was made in I, which had the effect of doubling the effective solid angle for the 1981 IR-10 configuration (there would be two particles to detect). This assumption did not affect 1981 IR-6 configuration which was symmetrically disposed about the vacuum pipe, and which presumably would detect both particles. The pair production assumption is not made for the 1982 or 1983 data, but rather the more conservation assumption of a general (isotropic) single particle production process. In any case, for the configuration depicted in Fig. 1 there is little practical difference between these two assumptions; the slot in the detector is only $\simeq 20\%$ of the full 2π in azimuth.

3. The diameter of this pipe was 15.2 cm vs 5 cm in the IR-10 configuration of I. The increase in diameter reduced the amount of background generation by scattering both during injection and data collection.

4. The majority of the background tracks were due to knock-on protons. Since these knock-on protons had very low velocity, they registered very short background tracks (more appropriately described as pits) in the plastic track detectors. (Except at the very end of the range, electrically charged particles have a response that increases as β decreases, going like Z/β.) These background tracks, being very short, would not be confused with tracks produced by a highly charged particle emanating from the interaction point.

5. This 200 μm was comprised of 150 μm of corrugated stainless steel, which furnished the mechanical strength, and a 50 μm liner of Cu-plated stainless steel (25 μm s.s. + 25 μm Cu) for the suppression of heating due to higher order mode losses from the circulating beams.

6. The specific stack content for the 1982 detector was two initial sheets of Lexan followed by eleven to thirteen (depending upon the specific module) sheets of CR-39. Analysis of the data from this detector indicated that the improved configuration of shielding and vacuum pipe obviated the need for the redundancy furnished by $\sim$ a dozen CR-39 sheets. Thus the stack content of the 1983 detector was set at an initial sheet of Lexan, two sheets of CR-39 and a final sheet of Lexan. During the etching process two CR-39 sheets (from different modules) suffered damage from the stirring paddle. The redundancy furnished by the second CR-39 sheet in these modules enabled the maintenance of track sensitivity over the detector solid angle, the calculation of which is described in the text.

7. The total PEP integrated luminosity for the FY 1983 operations was recorded (in the "official" IR-12 luminosity monitor) as 157×10^{36} cm^{-2}. For the purpose of Eq. (1) this total was rounded down to 150×10^{36} cm^{-2} to account approximately for the detector insertion time plus other minor systematic effects.

8. It is also relevant to note here that there are two recently published searches using Kapton detectors at storage ring interaction points. A search using e^+e^- collisions at PETRA [P. Musset, M. Price and E. Lohrmann, Phys. Lett. 128B, 333 (1983)] reports an upper limit on the pair production of monopoles of 4×10^{-38} cm^2 (95% C.L.) in the range of $67e \leq g \leq 337e$ and masses up to 10-16 GeV/c^2. A search using antiproton-proton collisions at the CERN SPSC [B. Aubert, P. Musset, M. Price and J. P. Vialle, Phys. Lett. 120B, 465 (1983)],

reports upper limits between 10^{-32} and 10^{-31} cm^2 depending upon monopole mass, which ranges as high as ~ 250 GeV/c^2. Representative plots of limits are given for monopole charges $g = g_0$ and $g = 3g_0$.

9. Estimated on dimensional grounds by the equation $\sigma_{\text{weak}} \sim (\hbar G E_B / 2\pi c^3)^2$, where $G = 10^{-5}/m_p^2$ is the universal Fermi constant. This estimate is within a factor of two of a calculated $\sigma(e^+e^- \to Z \to \mu^+\mu^-)$ at $E_B = 14.5$ GeV. See, e.g., C. Quigg, *Gauge Theories of the Strong, Weak, and Electromagnetic Interactions* (The Benjamin/Cummings Publishing Company, Inc., Reading, Mass., 1983), p. 126.

Table I

Summary of Experimental parameters and (95% C.L.)

upper limits to production cross sections. $E_B = 14.5$ GeV.

		1981 IR-6	1981 IR-10	1982 IR-10	1983 IR-10	Combined Limit
	$L_i t_i$ (10^{36} cm^{-2})	6.1	8.4	30.3	150	
	pipe thickness (μm)	200	100	200	200	
Magnetic Monopole	mass limit (GeV), $g = g_0$	13.7	14.0	13.7	13.7	
Magnetic Monopole	$g = 2g_0$	9.5	11.5	9.5	9.5	
Magnetic Monopole	solid angle (sr)	4.6	2.0	6.4	6.4	
Magnetic Monopole	$\sigma(10^{-36}$ cm$^{-2})$	< 1.4	< 2.3	< 0.19	< 0.039	< 0.032
Electric, $Z/\beta > 20$	solid angle (sr)	1.7	1.7	5.0	5.0	
Electric, $Z/\beta > 20$	$\sigma(10^{-36}$ cm$^{2})$	< 3.7	< 2.7	< 0.25	< 0.050	< 0.041

$g_0 \equiv e/2\alpha = 68.5e$, the Dirac charge.

[N.B. QED point cross section = 10^{-34} cm^2 at $\sqrt{s} = 29$ GeV].

Figure Caption

Fig. 1. Schematic depiction of the assembly of Lexan and CR-39 plastic track detectors used in this search for highly ionizing particles. Each of the seven sides contained a stack of interleaved sheets of Lexan and CR-39. The sheets were 31.8 cm long with widths as indicated (11.8 and 14 cm). The eighth side of the octagonally shaped detector was missing so that, prior to injection and beam tuning, the detector assembly could be rotated away from the beam pipe into a shielded cave located near the floor level.

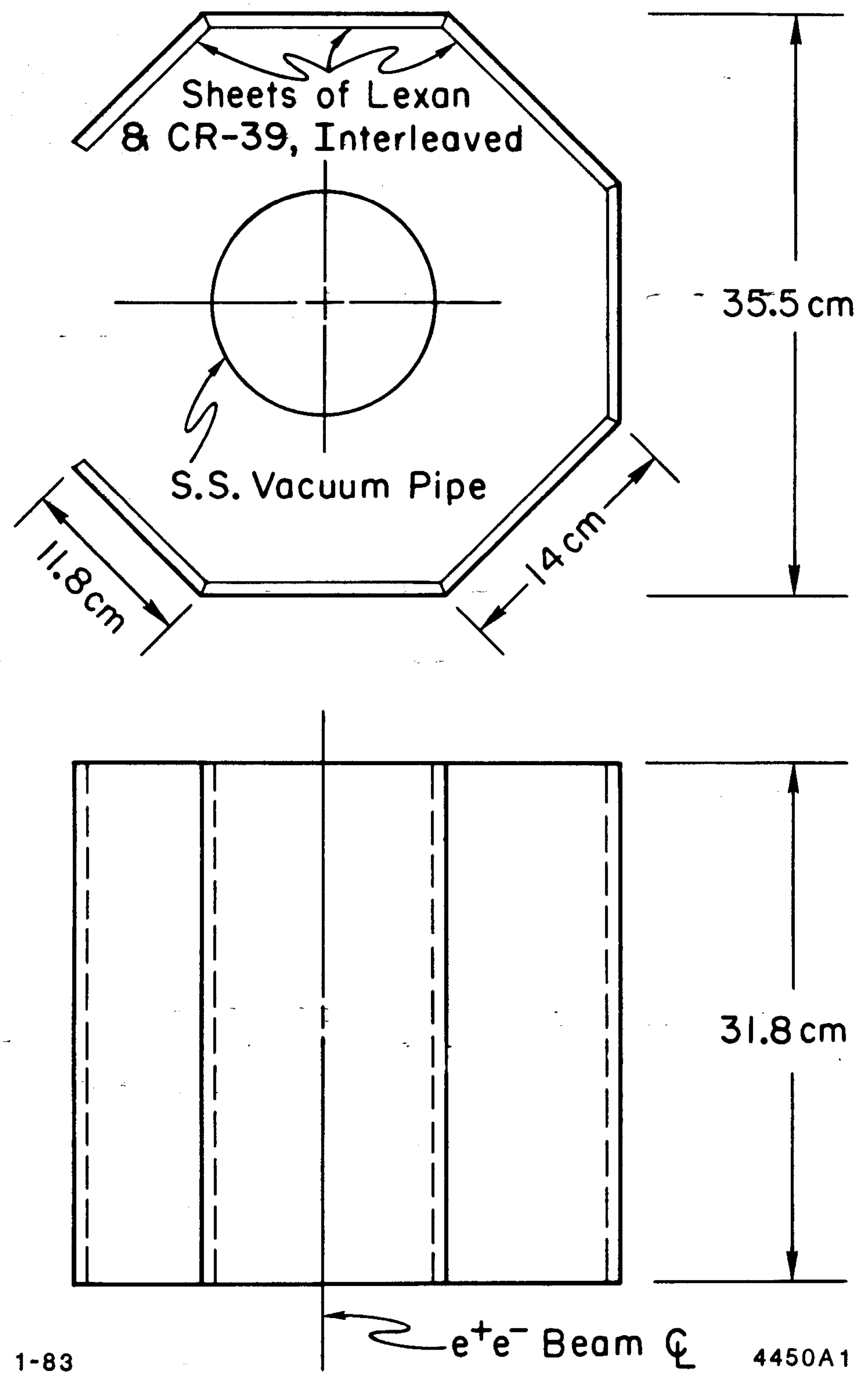
Sheets of Lexan
& CR-39, Interleaved
S.S. Vacuum Pipe
35.5 cm
11.8cm
14 cm
31.8 cm
e+e− Beam ℄
1-83
4450A1

Fig. 1