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SEARCH FOR PRODUCTION OF FRACTIONAL CHARGES, NEW PARTICLES, AND  
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### Publication Date

1985-06-01



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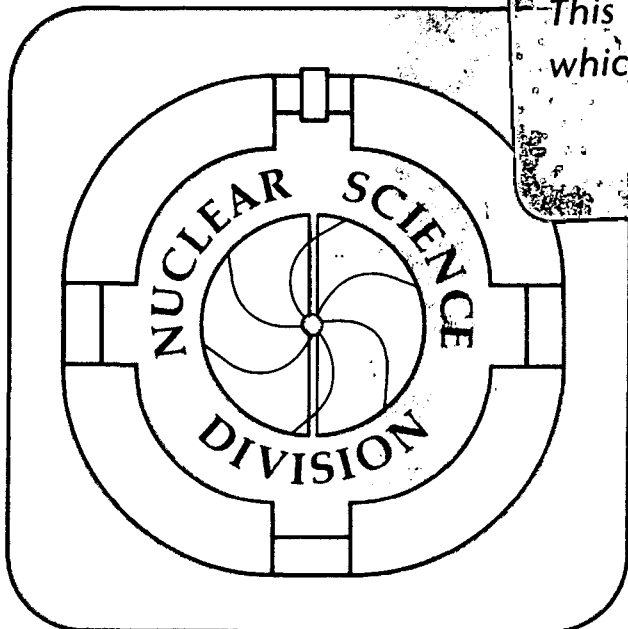
Submitted to Physical Review Letters

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S. Abachi, A. Shor, J. Carroll, E. Barasch,  
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June 1985

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**Search for Production of Fractional Charges, New Particles,  
and "Subthreshold" Antiprotons, in Relativistic  
Nuclear Collisions**

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**Abstract**

A search for production of fractional charges, new long-lived particles, and "subthreshold" antiprotons at  $0^\circ$  in the reaction  $^{28}\text{Si} + ^{28}\text{Si}$  at 2.1 GeV/A has been made at six secondary rigidities. Except for one  $\bar{p}$  candidate, no evidence for such production is found. A summary of upper limits on the yields for charges  $-1/3$ ,  $-2/3$ ,  $-1$ ,  $-4/3$ , and  $-2$  is presented. The results from all six rigidities are combined to yield upper limits of about 1 particle per  $10^4$  to  $10^7$  collisions for the mass range  $0.1 < M < 5.0$  GeV, and one  $\bar{p}$  per  $3.8 \times 10^7$  collisions.

PACS numbers: 25.70.Np, 14.80.Dq, 14.80.Pb

Many attempts have been made to observe fractionally charged particles produced in very high energy  $e^+e^-$ , hadron, or cosmic ray interactions.<sup>1</sup> No evidence for such production has yet been found. Searches have also been performed in matter, where it is hoped to encounter fractionally charged objects left over from the "big bang" or created by extremely high energy cosmic rays. The only positive result reported is that of LaRue *et al.*<sup>2</sup> At the present time the negative results suggest that quarks are confined within hadrons and do not exist as free particles. However, it is conceivable that at higher bombarding energies or under conditions favorable for screening of the color force, they could be liberated.

Slansky, Goldman and Shaw<sup>3</sup> have recently proposed a model in which  $SU(3)^c$  color is spontaneously broken to  $SO(3)^g$  gluon, resulting in imperfect confinement of asymptotic states which are gluon singlets and color nonsinglets. This locally broken symmetry group requires 5 of the 8 gluons to acquire masses of the order of the QCD scale parameter and, therefore, allows quark-quark composites with low masses ( $\sim 1$  GeV) to be created. In particular, this model emphasizes the possibility of di-quark production in heavy ion reactions due to color screening.<sup>4</sup>

Although relativistic heavy ion collisions (RHICs) have been examined for exotic nuclear effects, such as abnormally dense nuclear states and quark-gluon phase transitions,<sup>5</sup> they have not been adequately investigated as possible sources of fractionally charged particles or other new objects at the highest available energies. Such a search, particularly among negative secondaries, offers great sensitivity due to extremely low background.

Another objective of this work was to continue the investigation of collective and/or thermal effects in RHICs by studying subthreshold particle production, *i.e.*, production of particles at bombarding energies below the threshold required for their creation in direct N-N collisions. We have already measured the subthreshold production of  $K^-$ 's to be about 20 times larger than what Fermi momentum calculations

predict.<sup>6,7</sup> This enhancement suggests some degree of thermalization or collective behavior among the participant nucleons. However, these results cannot conclusively determine whether it is the *conventional* dynamics of these collisions that is not fully understood, or if we are dealing with a new production mechanism. The search for the production of antiprotons, whose energy threshold for creation is much higher than that for kaons, could help answer this question.

In this paper we report the measurements of upper limits for the production of fractional charges, rare long-lived particles, and subthreshold antiprotons at  $0^\circ$  in the reaction  $^{28}\text{Si} + ^{28}\text{Si}$  at 2.1 GeV/A for six secondary rigidities. Negative secondaries produced in these collisions were rigidity selected and transported along a magnetic beam-line. Three bends, each followed by a detector station, allowed multiple checks on time of flight (TOF) and pulse height information. Each detector area was equipped with Cerenkov counters and an array of scintillation counters, as described elsewhere.<sup>6</sup> Background events, mostly negative pions, were identified by liquid Cerenkov counters for  $p_{lab} < 1$  GeV/c and by high pressure gas Cerenkov counters for  $p_{lab} > 1$  GeV/c. The TOF and  $dE/dx$  information from the scintillation counters, as well as the known rigidity values, were used for particle identification. Secondary rigidities were chosen to be 0.73, 0.90, 0.98, 1.42, 1.95, and 2.37 GeV/cz.<sup>8</sup> To reduce the background we required that the TOF information from various detectors yield a consistent velocity for each event. To include all charges and masses, no pulse height cuts were employed. The beam line acceptance was determined by direct comparison of pion yield in the reaction  $^{12}\text{C} + ^{12}\text{C}$ , with the established cross sections measured by Moeller *et al.*<sup>9</sup>

In Fig. 1 we show the charge identification of events which survived the TOF consistency requirement after removing pions and subthreshold kaons.<sup>10</sup> The ordinate is the weighted sum of the pulse heights in all scintillation counters that were put into coincidence, and the abscissa represents the expected energy-loss per unit charge-squared. Since this quantity is a function of  $\beta$  only, its value is calculated from the

event TOF. The solid curves shown in Fig. 1 were determined using the pulse heights of protons and deuterons from data taken at several momenta for positive secondaries. The curve for  $Z=-1$  was drawn through centroids of the proton and deuteron clusters, and calculated for other charges by assuming that the pulse height was proportional to the square of the charge. The deviation from linearity at higher pulse heights is due to saturation of some of the photo-tubes at the higher voltages required to plateau them for charge  $-1/3$ . The thirteen events appearing in this plot were obtained from a data sample containing  $6 \times 10^6$  pions. It can readily be seen from this graph that there are no candidates for charge  $-4/3$  or higher. Almost all of the surviving events are clustered around the  $Z=-1$  curve. Nine of these were subsequently discarded for having inconsistent pulse heights at different detector stations. The event occurring in the region between  $Z=-1/3$  and  $Z=-2/3$  curves falls into this category. Of the four surviving events, three, belonging to the 0.90 GeV/cz rigidity data, had proper TOFs for antiprotons, but extremely low pulse heights in several of the scintillation counters. The pulse heights of these candidates were studied by the Likelihood Method, which indicated that they had very small probabilities to be antiproton events. (Less than  $1/2\%$  of the antiprotons should possess likelihoods smaller than the likelihood calculated for these events.) The probability that these events were consistent with *any* charge hypothesis between  $-2/3$  and  $-4/3$  was less than 4%.

The one remaining event of rigidity 1.42 GeV/cz was a strong antiproton candidate. Although this candidate had a consistent time of flight in the first two detector areas, it did not register at the third detector station. However this can be attributed to the low beam acceptance ( $\sim 25\%$ ) in this area. In Fig. 2, using the scintillation pulse heights, we compare the likelihood of this event with the likelihood distribution of protons. This figure was produced using the observed pulse height distribution of protons in scintillation counters at positive 1.42 GeV/cz rigidity. We observe that the likelihood of our candidate is near the most probable likelihood.



Table 1 gives the calculated upper limits within the sensitive  $M/|Z|$  range for charges  $-1/3, -2/3, -1, -4/3, -2$ , and for antiprotons, in terms of  $d^2\sigma/d\Omega dR$  ( $R=p/Z$ ) at the 90% confidence level. Except for the  $\bar{p}$  results, we have summarized the upper limits by neglecting any variation of the beamline acceptance due to energy degradation and multiple scattering in the detectors. However, these effects are calculated by Monte-Carlo simulation and are taken into account in the following model calculation.

The large amount of existing particle production data from RHIC experiments demonstrate that the invariant differential cross sections are exponential functions of the CM energy of the produced particles.<sup>11</sup> Motivated by this observation, we assumed an exponential energy spectrum with a slope parameter of 100 MeV, *i.e.*,

$$\tilde{\sigma} = \frac{E}{p^2} \frac{d^2\sigma}{d\Omega dp} \propto e^{-E/T}, \quad T=100 \text{ MeV}, \quad (1)$$

where  $E$  and  $p$  are energy and momentum in the center of mass frame, and  $T$  is the slope parameter. By using relation (1), the estimates of the upper limits at each of the six rigidities were extended to all momenta. This provided us with six separate upper limits at any momentum for any particle mass and charge. It is shown<sup>12</sup> that these six independent upper limits,  $\tilde{\sigma}_1, \tilde{\sigma}_2, \dots$ , and  $\tilde{\sigma}_6$ , may be combined to obtain a smaller upper limit,  $\tilde{\sigma}$ , where

$$\frac{1}{\tilde{\sigma}} = \frac{1}{\tilde{\sigma}_1} + \frac{1}{\tilde{\sigma}_2} + \dots + \frac{1}{\tilde{\sigma}_6}. \quad (2)$$

For antiprotons, if  $E$  is the center of mass kinetic energy, we obtain,  $\tilde{\sigma}^{\bar{p}} = 1.28 \exp(-E/T) [\mu\text{b GeV/sr}(\text{GeV}/c)^3]$ , which expresses the combined upper limit invariant differential cross section as a function of energy. Similar expressions were obtained for various mass and charge assignments. By assuming isotropic production in the center of mass frame these expressions were numerically integrated over momentum and angle to give the combined upper limits in terms of integrated cross sections. To express the upper limits in terms of "number of particles per collision",

these results were divided by the geometrical cross section for  $^{28}\text{Si} + ^{28}\text{Si}$  (1.67 barns). Fig. 3 displays these results (90% confidence level) for charges of interest as a function of mass. The upper limit for antiproton production was calculated to be less than one  $\bar{p}$  per  $3.8 \times 10^7$  collisions. All of the results reported here are calculated for stable particles, and except for  $\bar{p}$ , the absorption in the target and detectors are assumed to be the same as that of pions. We wish to emphasize that these results are not sensitive to the parameter,  $T$ , of the model. For a slope parameter change from 100 to 140 MeV, the antiproton upper limit increased by a factor of 1.2, and for particles with pion mass and charge -1, it decreased by a factor of 1.3.

Calculations of the antiproton production rate have been made using both the fireball model of Hagedorn<sup>13</sup> and the chemical equilibrium model of Olive.<sup>14</sup> Both models overestimate the antiproton yield by at least a factor of  $\sim 14$ .<sup>12</sup> An estimate of the Fermi momentum contribution to subthreshold  $\bar{p}$  production showed a production cross section about three orders of magnitude less than our upper limit.<sup>6,12</sup>

In summary, we find no evidence for the production of fractional charges or new long-lived particles in this experiment. We observed one antiproton candidate at a rigidity of 1.42 GeV/cz. If this candidate is considered to be a legitimate event, it may signal an unusual mechanism for the antiproton production, since the Fermi momentum calculation underpredicts this production by a factor of  $\sim 10^3$ , while the corresponding factor for the subthreshold  $\text{K}^-$  production<sup>6</sup> is only  $\sim 20$ . This will be pursued in a series of experiments with higher sensitivity.

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 contracts DE-AC03-76SF00098 and DE-AC03-76SF00515.

### References

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- <sup>1</sup> See, for example, L. W. Jones, *Rev. Mod. Phys.* 49, 717 (1977).
- <sup>2</sup> G. S. LaRue, J. D. Phillips, and W. M. Fairbank, *Phys. Rev. Lett.* 46, 967 (1981).
- <sup>3</sup> R. Slansky, T. Goldman, and G. L. Shaw, *Phys. Rev. Lett.* 47, 887 (1981).
- <sup>4</sup> G. L. Shaw and R. Slansky, *Phys. Rev. Lett.* 50, 1967 (1983).
- <sup>5</sup> S. A. Chin, *Phys. Lett.* 78B, 552 (1978).
- <sup>6</sup> A. Shor *et al.*, *Phys. Rev. Lett.* 48, 159 (1982), and E. Barasch *et al.*, submitted to *Phys. Lett. B*.
- <sup>7</sup> A. Shor, V. Perez-Mendez, and K. Ganezer, to be published, *Nucl. Phys. C*.
- <sup>8</sup> The 0.98 GeV/cz data (taken in 1981) is not sensitive to charge  $-1/3$ , and to charge  $-2/3$  for  $M < 0.7$  GeV.
- <sup>9</sup> E. Moeller *et al.*, *Phys. Rev.* C28, 1246 (1983).
- <sup>10</sup> Pion and kaon identification is described in Refs. 6 and 12.
- <sup>11</sup> See, for example, S. Nagamiya, in *Proceedings of the 5th High energy Heavy Ion Summer Study*, LBL-12652, Conf-8105104, May 1981, p. 141.
- <sup>12</sup> S. Abachi, thesis, University of California, Los Angeles, 1985 (unpublished).
- <sup>13</sup> R. Hagedorn, *Nuovo Cimento Suppl.* 6, 312 (1968).
- <sup>14</sup> K. A. Olive, *Phys. Lett.* 95B, 355 (1980).

### Figure Captions

FIG. 1 Sum of the observed scintillation pulse heights (weighted by the inverse of the distribution variances) versus expected  $\langle dE/dX \rangle$  per unit charge-squared, for events with consistent TOF (solid dots.) Pions and kaons are removed. The curves for different charges were determined using proton and deuteron pulse heights.

FIG. 2 Likelihood of the antiproton candidate event compared to the likelihood distribution of protons at 1.42 GeV/c momentum.

FIG. 3 Combined upper limit yields for various charges in terms of "number of particles per collision" as a function of particle mass. The rise around the pion mass and the peak at the kaon mass for  $Z=-1$  curve is due to the presence of pions and subthreshold kaons respectively.

### Tables

Tbl. 1 Summary of the upper limit yields in terms of  $d^2\sigma/d\Omega dR$  ( $R=p/Z$ ) at each rigidity for different charges and for antiproton production at the 90% confidence level. The sensitive mass range is given in terms of  $M/|Z|$ . Except for antiprotons, the variation of the acceptance caused by multiple scattering and energy degradation are not taken into account. These effects can increase the upper limits by up to a factor of 3 for large masses.

Rigidity (GeV/cz)	$\frac{M}{ Z }$ range (GeV/z)  For Z = -1/3, -2/3, -1, -4/3, -2	Upper Limit ( $d^2\sigma/d\Omega dR$ )  ( $\frac{\mu \text{ barn}}{\text{sr. (GeV/cz)}}$ )	
		All Objects	$\bar{p}$ Only
0.73	from 0.30 to 0.80	6.0	1230.0
0.90	from 0.45 to 1.15	4.3	10.8
0.98	from 0.49 to 1.20	2.5 <sup>†</sup>	4.1
1.42	from 0.71 to 1.55	3.8	7.2
1.95	from 0.97 to 2.60	0.9	0.9
2.37	from 1.18 to 3.20	1.0	1.0

† Except for Z=-1/3 and -2/3 (see Ref. 8)

Table (1)

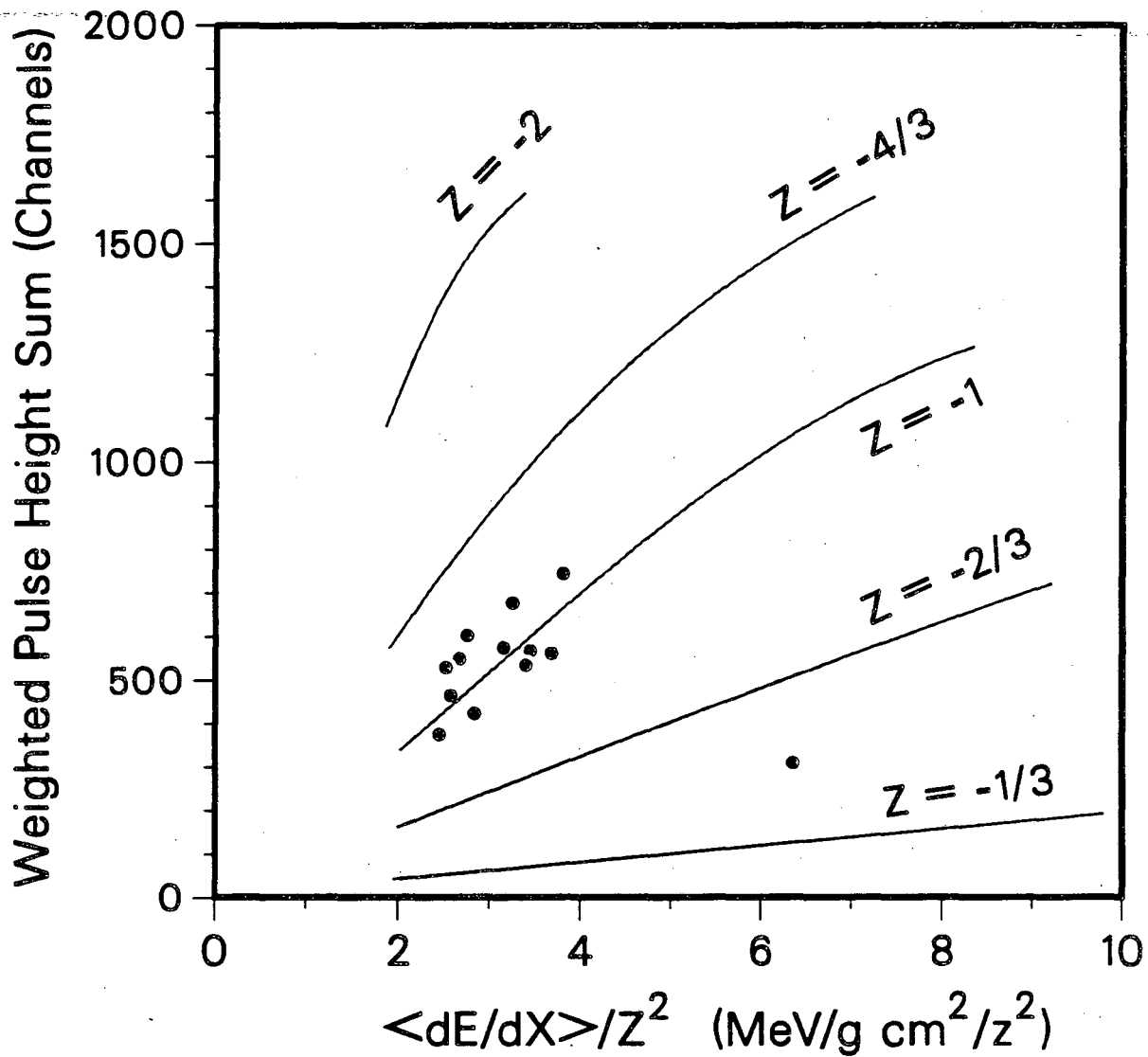


Fig. 1

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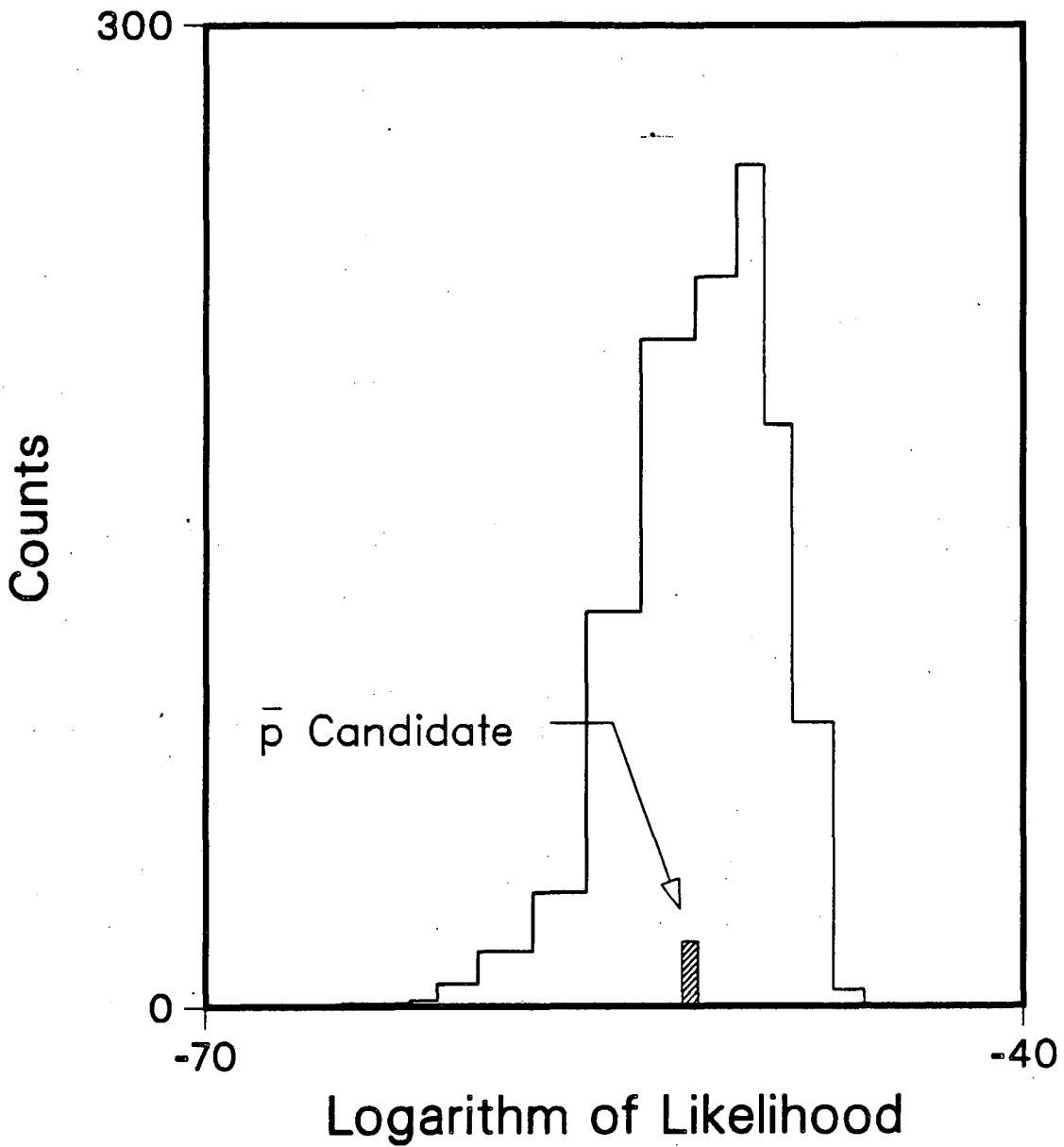


Fig. 2

XBL 856-2732

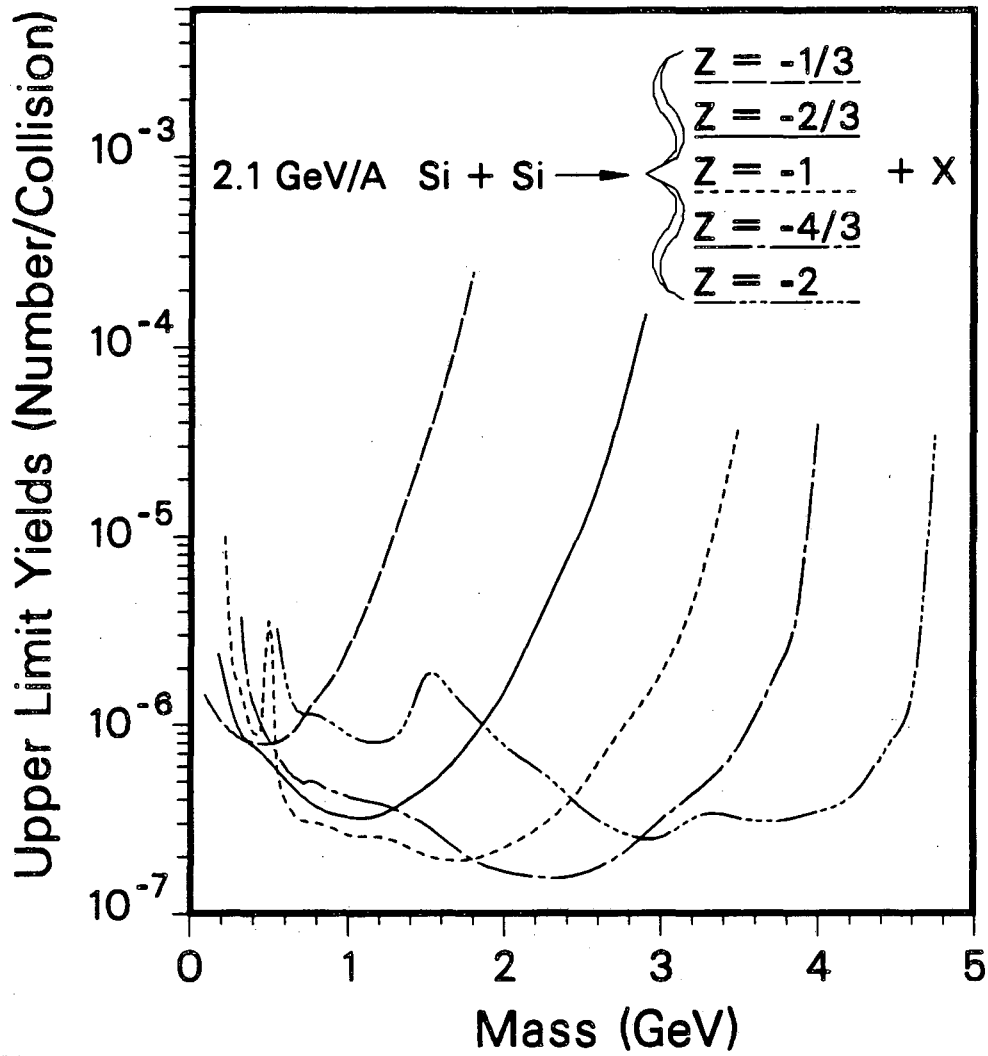


Fig. 3

XBL 856-2730



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