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ON NEW PARTICLE SEARCHES

M. Derrick
Argonne National Laboratory
Argonne, IL 60439

Experiments results of searches for new phenomena at PEP are reviewed.

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EHB

1 INTRODUCTION

The Standard Model is a remarkable result of decades of work in particle physics, but it is clearly an incomplete representation of the world. Exploring possibilities beyond the Standard Model is a major preoccupation of both theorists and experimentalists. Despite the many suggestions that are extant about the missing links within the Standard Model as well as extensions beyond it, no hard experimental evidence exists. In particular, in more than five years of experimentation both at PETRA and PEP no new particles have been found that would indicate new physics. Several reasons are possible for these negative results: the particles may be too heavy; the experiments may not be looking in the proper way; the cross sections may be too small or finally the particles may not exist.

A continuing PEP program, at high luminosity will ensure that the second and third reason continue to be addressed. The higher energy e^+e^- storage rings such as TRISTAN and LEP will extend the mass limits. High mass particles can also be produced at the CERN collider and soon with the Tevatron collider.

A concise summary of the mass limits from the PETRA experiments has been given in a recent Mark J publication.[1] The results, shown in Table I, provide a convenient yardstick against which to measure future search experiments.

2 CHARGED PARTICLE SEARCHES

The TPC has placed the best limits[2] on stable fractionally charged particles by measuring the momentum and dE/dx. The limits are somewhat model dependent but are typically $R_q \lesssim 10^{-3}$ for $\frac{1}{3}$, $\frac{2}{3}$ and $\frac{4}{3}$ charged particles.

Unstable charged particles such as technipions or charged Higgs would be revealed by an increase in the R value, the ratio of hadronic to the $\mu^+\mu^-$ pair cross sections. Figure 1 shows a compilation of such measurements. The most

Table I. Lower mass limits (95% CL) for new particles

Particles	Mark J		CELLO	JADE	TASS
	Lower Mass Limit (GeV)	Remarks	Lower Mass Limit (GeV)	Lower Mass Limit (GeV)	Lower M Limit (G
A. QED					
e^*	72	$\lambda = 1$	59	61	61
μ^*	25	$\lambda = 1$	–	22	–
B. Standard Theory					
$L^\pm$	22.5	Lifetime < 10 ns	–	18	15.5
Toponium	46.6	$\Gamma_{ee} B_h < 3$ keV	46.6	–	45.2
Open Top	46.6	–	46.6	35	44
C. Extended Theory					
$H^\pm$ and Technipions	17	$B_r(\tau\nu) > 1/4$	–	14	13
D. SUSY					
$\tilde{\gamma}$	20.5	decay path < 5 cm, $M_{\tilde{e}} = 50$ GeV	13	18	6
$\tilde{e}$	22	–	16.8	25.2	16.6
$\tilde{\mu}$	20	–	16	20.9	16.4
$\tilde{\tau}$	17	–	15.3	–	–
$\tilde{H}^\pm$	22.5	$M_{\tilde{\gamma}} = 4$ GeV	–	–	–
$\tilde{Z}^\circ$	35	$M_{\tilde{\gamma}} < 2$ GeV	–	30	–
		$M_{\tilde{e}} < 40$ GeV	–	–	–
$\tilde{W}^\pm$	25	$M_{\tilde{\gamma}}, M_{\tilde{\nu}} \ll M_{\tilde{W}^\pm}$	–	–	–
E. Scalar					
X	46.6	$\gamma\gamma, \mu\mu, hh$	$\simeq 45$	–	–
	48	$e\bar{e}$	–	–	–

precise results at high energy are:

$$R = 3.96 \pm 0.09 \text{ at } \sqrt{s} = 29 \text{ GeV from MAC}^{[3]}$$

$$\text{and} \quad R = 3.97 \pm 0.05 \pm 0.10 \text{ in the } \sqrt{s} = 12 - 36 \text{ GeV}$$

energy range from JADE.[4] These values may be compared to the expectation of $R = \frac{11}{3}(1 + \frac{\alpha_s}{\pi} + \ldots) = 3.88$.

The production of a scalar charged particle would increase R by 0.25 units which seems unlikely compared to the difference of 0.08 ± 0.07 between the experiment and theory. However the β^3 threshold factor rises very slowly as seen in Fig. 2 and so the production of a pair of charged scalars with mass as low as 10 GeV would still be possible. A pair of spin $\frac{1}{2}$ particles have a much sharper cross section increase above threshold as well as $\Delta R = 1$ and so would have been seen.

A more sensitive technique is to look for specific decay modes. A Higgs particle that preferentially couples to mass would decay to $\tau\nu_\tau$ and to $c\bar{s}$, or $c\bar{b}$ depending on the Higgs mass. A series of experiments at PETRA[5] looking for both leptonic and hadronic decays excludes such a charged Higgs below a mass in the range (14-17) GeV as seen in Fig. 3. Very little else can be said and it is an open question if scalars whose decay modes are not so determined might exist.

The classic search technique is to scan the energy range and look for the appearance of a class of isotropic events as the threshold is passed. This has been done by PETRA at the higher energies in the top quark search but not in the energy range between CESR and PEP. As seen in Fig. 1, essentially no data exists from $\sqrt{s} \simeq 12$ to $\sqrt{s} \simeq 25 GeV$. Here is some unfinished business, although it is clearly a long shot in looking for new phenomena.

A number of searches have been made for excited leptons. These can be produced either directly or as a propagator as in the diagrams of Fig. 4. The direct search looks for an effective mass peak in the lepton-photon system above a continuum coming from radiative events. The MAC result[6] is shown in Fig. 5. The PETRA mass limit[1] for a μ^* is 25 GeV.

For the electron, a better limit comes from the $e^+e^- \rightarrow \gamma\gamma$ reaction. The cross section can be written[7] as:

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{s} \, \frac{1+\cos^2\theta}{\sin^2\theta} \left\{ 1 \pm \frac{s^2}{2\lambda_\pm^4} \, \sin^2\theta \right\} \tag{1}$$

where the first term is the simple QED contribution and the parameter λ is essentially the mass of the hypothesised excited electron e^*. The cross section is large, as seen in Fig. 6, and so most PEP detectors have collected ~ 20 K events. In the central region the modified angular dependance coming from the propagator is small (Fig. 7) so the sensitivity of the experiment depends on how well the systematic errors on the luminosity can be controlled. A cross section comparison between the e^+e^- and $\gamma\gamma$ final states is needed.

The current PEP limits on λ, now the 40–50 GeV range,[8] can be pushed to perhaps 70 GeV with the large data samples now available. This is in the same mass range limit as the Mark J result given in Table I. So in this case the higher energy at PETRA will just be balanced by the higher event rate at PEP. The relative sensitivity goes as $s \; N^{1/8}$, where N is the number of events.

Data on this reaction were used to limit possible explanations[9] of the few radiative Z° decays seen at the CERN collider assuming that the radiative decay went through a new spin zero boson (X) as $Z^\circ \rightarrow X\gamma$ followed by $X \rightarrow e^+e^-$. Such a particle would contribute an isotropic term to the $e^+e^- \rightarrow \gamma\gamma$ cross section. The MAC results shown in Fig. 8 agree with QED and give a limit on the isotropic cross section of < 1.56 pb/sr at 95% C.L. This result plus similar data from PETRA were used to limit the $\gamma\gamma$ width of X as a function of its mass.

3 SEARCH FOR SUSY PARTICLES

This popular extension of the standard model predicts partners of all the known particles with spin differing by one half. In the limit of exact supersymmetry the masses of the particles and their SUSY partners are equal. At what scale the symmetry is broken, and so the masses of the SUSY particles themselves, is unknown. Such particles, if charged, will be produced in e^+e^- collisions at the same rate as the known particles. A simple search can then be made, for example, for $e^+e^- \rightarrow \tilde{e}^+\tilde{e}^-$ followed by the decays $\tilde{e} \rightarrow e\tilde{\gamma}$ where the photino $\tilde{\gamma}$ escapes from the detector. The experiment then consists of looking for acolinear $e^+e^-, \mu^+\mu^-$ or $\tau^+\tau^-$ pairs with no accompanying photons as seen in Fig. 9a. The predominant background comes from radiative events. Such experiments are limited to SUSY particle masses below the beam energy and although PEP experiments[10] quickly ruled out scalar electrons $\tilde{e}$ up to 14.5 GeV as seen in Fig. 10 the higher beam energy at PETRA provided a more stringent limit-in the 20-25 GeV range.

The limit can be pushed beyond the beam energy by searching for single $\tilde{e}$ production via the diagram of Fig. 9b. In this case the scalar electron can be produced almost at rest in the laboratory and the decay gives a single electron of energy $\simeq M_{\tilde{e}}/2$. The result from the Mark II and MAC collaborations are similar.[11] The MAC limit is $M_{\tilde{e}} > 23.4$ GeV. More luminosity would not give significantly better values, higher beam energies are needed. It is a good early experiment for TRISTAN.

A more promising immediate avenue for SUSY searching is to look for the photino. As we have discussed the $e^+e^- \rightarrow \gamma\gamma$ reaction has a large cross section as does the SUSY equivalent $e^+e^- \rightarrow \tilde{\gamma}\tilde{\gamma}$ shown in Fig. 9c. In this case the $\tilde{e}$ appears in the propagator and so one could hope to approach $\tilde{e}$ masses near the 70 GeV limit for the e^* previously discussed. Although many thousands of such events may have been made at PEP they are difficult to observe as a low mass photino is sterile. The signature is to look for a radiative event, such as in Fig.

11a, with no other particles in the final state.

This search puts a premium on detecting photons at low transverse momentum, i.e., at small angles to the beam. The background process which presumably does occur is $e^+e^- \rightarrow Z^\circ \rightarrow \nu\bar{\nu}$ and the equivalent W exchange diagram also shown in Fig. 11b. The neutrino pair production rises rapidly with $\sqrt{s}$ and should be simple to observe at TRISTAN as seen in Fig. 12 which is calculated for the conditions of the MAC search. The results from the latter experiment are shown in Fig. 13: one candidate event is found with $E_\perp^\gamma > 3$ GeV which leads to the contours shown in Fig. 14 in the $M_{\tilde{\gamma}} : M_{\tilde{e}}$ space. For $m_{\tilde{\gamma}}$ small and $m_{\tilde{e}_L} = M_{\tilde{e}_R}$ a limit of 37 GeV is found for the scalar electron mass.

A more sensitive experiment (ASP)[12] designed specifically for this search came into operation at PEP this fiscal year and will soon be able to improve this limit. With the good current operation of the storage ring, ASP could place a limit close to 60 GeV as shown in Fig. 15 or indeed discover the photino if it exists and is in this mass range.

As we have discussed, the sensitivity of such an experiment goes as s and as the fourth root of the integrated luminosity so an experiment with ten times the integrated luminosity could push the limit 1.8× higher. Taking data at a higher rate is good for such experiments, assuming that the beam gas backgrounds do not dominate, as the cosmic ray background is relatively supressed and the apparatus needs to be kept in fully calibrated condition for fewer years.

When the neutrino signal is observed, which should occur for an $M_{\tilde{e}}$ limit about 70 GeV, the SUSY experiment loses sensitivity as now a background subtraction will be needed. However the detection of the $\gamma\nu\bar{\nu}$ final state at about the expected level would in itself be an experimental feat and would validate the SUSY search. A major difficulty of all negative results from search experiments is proving that the expected signal would in fact have been seen, if present. The expected limit on the number of light neutrino generations from ASP is ~ 8.

The extension of such experiments into the early 1990s when the width of the Z° will have been measured could be interesting and justified since the two experiments measure somewhat different things. For example both experiments measure the number of light neutrinos but only the lower energy experiment is sensitive to the existence of the photino. By contrast the Z° can decay to $\tilde{H}^\circ$ the SUSY Higgs partner. Scalar neutrino pairs could be produced by both processes depending on the mass of the $\tilde{\nu}$. The cross section ratio $(e^+e^- \to \tilde{\nu}\tilde{\bar{\nu}})/(e^+e^- \to \nu\bar{\nu})$ will be 0.25 times a threshold factor depending on $M_{\tilde{\nu}}$. If the $\tilde{W}$ were much lighter than 83 GeV the scalar neutrino pair production could dominate.

One should not take the SUSY discussion too literally as there is no experimental evidence that the current models have anything to do with the world as seen at present energies. However such complementarity and interplay of results from a lower energy and a higher energy facility has been important in the past, and would justify continuing a PEP physics program even into the SLC/LEP era. In general any particle that couples not to the Z° but to the photon would be much more strongly produced at PEP.

A recent example of such complementary, this time between PEP and the CERN Collider, is provided by the monojet experiments. The results can also be interpreted in SUSY models. Three experiments from PEP[13] and one from PETRA[14] have recently reported similar limits on the production of monojets in e^+e^- annihilation. Table II summarizes the results of the PEP experiments. A monojet is defined as a cluster of energetic particles with unbalanced P_T. Figure 16 shows such an event candidate seen in the HRS. The background comes primarily from annihilations following a catastrophic bremsstrahlung of one of the beam electrons so that the jet resulting from the fragmentation of the $q\bar{q}$ system is balanced by a single photon. If the photon escapes in the small cracks in the shower counters then an apparent monojet will result.

For the MAC experiment the main background comes from $\tau^+\tau^-$ pair production in which one tau decays into a single charged particle going in the backward

Table II. PEP magnet Searches

Group	$\int \mathcal{L}\,dt$ pb^{-1}	Experimental Cuts $\cos\theta^*$	p_T GeV/c	n_{ch}	Candidates	Background	Z° B.R. limit %
HRS	176	0.5	7.2	4	1	3.3 ± 1.5	1.5
Mark II	222	0.67	8.0	2	2	consistent with 2	0.7
MAC	238	0.8	3.0	2	11	13.2	0.5

hemisphere. Such background events are 4 prongs as are all the candidates for this detector. All experiments require more than 2 prongs in the monojet.

The cross section for the reaction $e^+e^- \to Z^\circ \to$ any is given by:

$$\begin{aligned}\sigma &= \frac{G_F M_Z^2 \Gamma_z}{\sqrt{2}(M_Z^2 - s)^2}(1 - 2\sin^2\theta_w + \sin^4\theta_w) \\ &= 6 \text{ pb at } \sqrt{s} = 29 \text{ GeV}\end{aligned} \qquad (2)$$

Hence each PEP experiment has collected more than 1000 such events - more than the detectors at the CERN collider. The monojets from UA1 are about as frequent as $Z^\circ \to e^+e^-$ decays[15] and so would correspond to Z^0 decaying to monojets with a branching ratio of several percent. Therefore if the monojets reported by the UA1 experiment come from anomalous Z° decay each PEP experiment should have seen 10-20 events in clear contradiction to the observation.

A quantitative comparison for the Mark II and MAC experiments is shown in Fig. 17 from which one sees that monojets in the jet mass range from 2 to 10 GeV coming from Z° decay are excluded. This result assumes the reaction $e^+e^- \to Z^\circ \to \chi_1\chi_2$ leads to a final state of two spin zero particles with the corresponding $\sin^2\theta$ angular distribution. If the χ particles are spin $\frac{1}{2}$ heavy leptons with a $(1 + \cos^2\theta)$ angular distribution then the sensitivity is somewhat reduced as shown by the lower curve in Fig. 17a If χ_1 decays to 3ν with a 10%

branching ratio[16] then such a reaction is also excluded for χ_2 masses between 2 and 10 GeV.

The HRS group has also compared their limits to the expectation of a SUSY model. The $\tilde{e}$ exchange diagram of Fig. 18 leads to a cross section, estimated by Haber,[17] of

$$\sigma = 0.61(1 - R^2)(1 + R/2)\lambda^2/r^4 pb$$

where $R = M^2_{\chi 2}/s$, λ^2 is the zino fraction in the $\tilde{H}, \tilde{Z}$ mixing and r is the mass ratio $M_{\tilde{e}}/M_{\omega}$. The production angular distribution goes as:

$$\frac{d\sigma}{d\Omega} \sim (1 + R) + (1 - R)\cos^2\theta\ .$$

The decay of χ_2 could go via $l^+l^-\tilde{\gamma}, q\bar{q}\tilde{g}$ or $q\bar{q}\tilde{\gamma}$. The latter would dominate if the gluino mass is larger than a few GeV and if $M\tilde{q} \sim M\tilde{e}$. If B is the branching ratio of χ_2 to $q\bar{q}\tilde{\gamma}$ then the HRS experiment leads to the contours shown in Fig. 19. Regions to the left of the curves are excluded. This result is more model dependent than the case where $\chi_1 = \chi_2 = \tilde{\gamma}$ discussed previously but gives somewhat higher limits on $M_{\tilde{e}}$ for $\lambda^2 B$ values greater than ~ 0.1.

4 OTHER NEW PARTICLES FROM Z DECAY

The previous discussion of monojets illustrates the capability of an e^+e^- machine that operates well below the Z° mass to study effects that could come from such decays. Although the PETRA measurements show that the charged lepton and the quarks from the fourth generation are above the PEP energy range this may not be the case for the associated neutrino.[18] The ASP experiment may see a few events of $e^+e^- \to \gamma N\bar{N}$ where N is the fourth generation neutrino, but the precision will be insufficient to definitely ascribe the few events expected to generations beyond three.

If the neutrino were to decay then it could be observed as:

a) A jet, perhaps a monojet if the second neutrino escaped the detector,

b) an isolated lX pair from a diagram such as shown in Fig. 20,

c) a group of particles with a vertex well separated from the main vertex, if the lifetime is long.

We have discussed the results of the monojet search. The second kind of event was looked for in the HRS[19] with again a negative result. Six candidates were found, consistent with known backgrounds, and giving limits on σB of 0.08 to 0.2 pb for neutrino masses ranging from 1 to 7 GeV.

The Mark II group has recently reported on a negative search for events with separated vertices.[20] These results are compared with other limits in Fig. 21[21] where the mixing between the fourth and first generations, $|U_{41}|^2$ is plotted against the mass of the fourth generation neutrino, M_N.

The dashed line in Fig. 21 corresponds to $\gamma c\tau$ of 1 m whereas the right hand edge of the region (8), excluded by the Mark II experiment, is $\gamma c\tau$ of a few mm set by the vertex resolution.

The line (7) is the sum of all of the three PEP monojet experiments interpreted in terms of single N production via the reaction $e^+e^- \rightarrow N\bar{\nu}_e$ which proceeds by W boson exchange. The cross section is:

$$\sigma(e^+e^- \rightarrow N\bar{\nu}_e) = |U_{14}|^2 \frac{G_F s}{6\pi}\left(1-\frac{M_N^2}{s}\right)^2\left(1+\frac{M_N^2}{2s}\right)$$

$$\simeq 4.7|U_{14}|^2 pb$$

This limit would fall by perhaps an order of magnitude with a high luminosity PEP. It should also be possible to extend the boundary of the detached vertex search experiment to somewhat higher masses with an optimal vertex chamber.

An experiment with more events or one that searches to greater distances could also fill in the region between contour (5) which comes from the CERN CHARM experiment and the Mark II result.

The cross section (2) for the reaction $e^+e^- \rightarrow Z^\circ \rightarrow$ any is shown in Fig. 22. Since at PEP energies we are working far out on the tail of the resonance the cross section varies only slowly with $\sqrt{s}$. The signal to noise is poor and decreases somewhat faster than s^{-1}. At $\sqrt{s} = 29$ GeV the 6 pb Z° cross section may be compared to a total hadronic cross of ~ 380 pb. With a luminosity upgrade, even if operating at $\sqrt{s} = 24$ GeV, each experiment could collect 1500-2000 Z° events per year. Such rates will be interesting until the new e^+e^- machines, operating at the Z° pole come into operation. A possible scenario is shown in Fig. 23 from which it is clear that a limited window of opportunity exists. The PEP upgrade is overdue if the program is to contribute to Z° physics.

5 PHYSICS WITHIN THE STANDARD MODEL

Although those of us brought up on the V-A, two component theory know that neutrinos are massless this is not the case in many other theories. How it is in nature is an open and important experimental question. A report[22] of a finite result of $M_{\nu_e} \sim 30$ eV from the end point of the $H^3\beta$ decay spectrum gives an added edge to such searches. The current best limit[23] for M_{ν_μ} is 250 KeV at 90% C.L., below the electron mass. The old problem with the rate of neutrino interactions from the sun also stimulated a major experimental activity in searching for neutrino oscillations. Despite a number of false alarms no convincing evidence exists for such effects.[24] The experiments continue. PEP can address such issues through measurements that limit tau neutrino mass. Two recent results[25] from Mark II of 143 MeV from the $\rho' \rightarrow 3\pi^+\pi^\circ$ decay and 157 MeV from the DELCO study of events of the ρ' decay to $KK\pi$, represent the best published values.

Left-right symmetric models[26] such as $SU(2)_L \times SU(2)_R \times U(1)$ give a natural scaling between generations as M_ν/M_l^2 so a 100 MeV tau neutrino mass would correspond to ~ 8 MeV for the electron neutrino which is already much less than the 30 eV measurement.

There are some important constraints coming from astrophysics.[27] The expansion rate of the universe limits the mass of a stable neutrino to $\lesssim$ 100 eV. However neutrinos must then decay with the favored process shown in Fig. 24. The matrix U_{el} connects the flavor eigenstates ν_e with the mass eigenstates ν_i

$$N_l = \sum U_{li}\nu_i \, .$$

The lifetime is given by:

$$\tau \simeq \frac{2.9 \times 10^4}{M_N^5 |U_{li}|^2} \qquad \text{(phase space)}$$

The radiative decays such as $\nu_\mu \to \nu_e\gamma$ are much slower.

The current density of deuterium and helium in the universe limits the possible neutrino lifetimes as decays such as $\nu_\tau \to e^+e^-\bar{\nu}_e$ occurring during nucleosynthesis would give γ rays which in turn would photo-disintegrate the D_2 and He.

These considerations combined with decay and neutrino beam dump experiments rule out the electron decay of the tau neutrino.[27] However a region in the $U_{32} : M_{\nu_\tau}$ space is still allowed. It is therefore important to push the tau neutrino mass limit below the muon mass and so forbid the $\nu_\tau \to \mu e \nu_e$ decay.

The recent observation by the HRS group of the $\tau \to 5\nu^{\pm}\pi^{\circ}\nu_\tau$ decays allows this to be done. The mass spectrum of the 5π and 6π final states is shown in Fig. 25. Fits to these spectra with a number of different models for the final state hadronic system give a 95% C.L. upper limit of the tau neutrino of 89 MeV.[28]

Since the charged particle effective mass resolution for the $5\pi^{\pm}\nu_\tau$ final state is 10-15 MeV in the HRS, the observation of a few events at the kinematic limit of 1784 MeV will limit the tau neutrino mass to the 10-20 MeV range. This can be done with a high luminosity PEP upgrade. The rate of this decay is one observed event every 37 pb^{-1} so 1000 pb^{-1} would give 27 events.

A second, important but very difficult experiment requires a precision check of μe universality in τ decay.[29] The ratio should be given by:

$$R = \frac{BR(\tau \to \mu\nu\nu)}{BR(\tau \to e\nu\nu)} = 1 - 0.027$$

where the 2.7% lower μ decay branching ratio comes from phase space. The current measurements of both the $\mu\nu\nu$ and $e\nu\nu$ final states have errors that are typically 3%.[30] Apart from the general interest in measuring such a fundamental calculable quantity as accurately as possible, a breakdown of μ, e universality could indicate new physics.

A calculation[29] assuming a contribution from a charged Higgs as shown by the diagram of Fig. 26 gives:

$$R = 1 - 0.027 + 0.243 \frac{M_\mu^2 M_\tau^2}{M_H^4} \cot^4 \alpha$$

where α is the vacuum expectation value of the Higgs field. In GeV units this is:

$$R = 1 - 0.017 + \frac{0.0086}{M_H^4} \cot^4 \alpha$$

This is a very small effect unless cotα happens to be large. If $M_H = \cot\alpha$ then an experiment at the 0.5% level is required. As discussed earlier the PETRA limit on M_H is 17 GeV.

Scaling from the present PEP experiments a 1000 pb^{-1} experiments, would yield about 8000 events in each of the e and μ decay modes so the statistical errors could approach 1%. Since one measure a ratio most of the systematic errors would cancel; however, a 1% measurement in a typical e^+e^- spectrometer is difficult.

6 CONCLUSIONS

Although no qualitatively new phenomena have been seen at PEP several search experiments have been done and several more are underway that are as interesting and have as much promise as those of any competitive program.

Whether the CERN and Fermilab colliders will show qualitatively new things beyond the Standard Model is as yet an open question. In any case the advantage of the known electroweak couplings means that search experiments in e^+e^- annihilation are easy to interpret and so can be definitive. By exploring reactions in which new states can appear in the propagator high masses, approaching 100 GeV, can be probed. A window of opportunity exists before the Z° factories come into full operation but the existence of the SLC and LEP projects means that a timely increase of luminosity of PEP is essential. Even after these machines are operating, a lower energy faculty can provide complementary information although operation at energies below 29 GeV is not favored for the search experiments. To fully exploit this physics the detectors should be made hermetic.

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FIGURE CAPTIONS

1. Energy dependence of $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma_{\mu\mu}$.
2. Threshold factors.
3. PETRA limits on mass of charged Higgs as a function of leptonic and hadronic branching ratios.
4. Excited lepton production diagrams.
5. $\mu\gamma$ effective mass spectra compared to QED.
6. Cross section for $e^+e^- \rightarrow \gamma\gamma$.
7. Differential cross section for $e^+e^- \rightarrow \gamma\gamma$.
8. Measured cross section for $e^+e^- \rightarrow \gamma\gamma$ compared to QED predictions.
9. (a) Scalar electron pair production.

   (b) Single scalar electron production.

   (c) Photino pair production.
10. Mass limit for $\tilde{e}^+\tilde{e}^-$ pair production.
11. (a) Radiative photino pair production.

    (b) Neutrino pair production.
12. Cross section for radiative $\tilde{\gamma}\tilde{\gamma}$ and $\nu\bar{\nu}$ production.
13. Transverse energy distribution for MAC experiment.

    (a) 10° veto and (b) 5° veto.
14. contours of excluded region in $m_{\tilde{\gamma}} : m_{\tilde{e}}$ space. The full line assume $m_{\tilde{e}_R} = m_{\tilde{e}_L}$, the dashed line that $m_{\tilde{e}_R} \gg m_{\tilde{e}_L}$.
15. Expected limit from ASP experiment. The dotted line shows the PETRA limit.
16. HRS monojet candidate.

17. (a) MAC limit on scalar pair production ($\chi^{\circ}\lambda^{\circ}$) and fermion pair production ($N\bar{N}$).

    (b) Mark II limit on scalar pair production (SP).

18. SUSY production of $\tilde{\gamma}$ and $\tilde{H}^{\circ}$, $\tilde{Z}^{\circ}$ mixture.

19. Limits on scalar electron mass from HRS monojet experiment.

20. Prompt heavy fermion pair production.

21. Excluded regions in mixing angle $|U_{14}|$: heavy neutrino mass (M_N) space:

    (1),(2) $\pi \rightarrow e\nu$, (3) $K \rightarrow e\nu$, (4),(5) Charm neutrino experiment, (6) universality (7) PEP monojet experiments, (8) Mark II secondary vertex search.

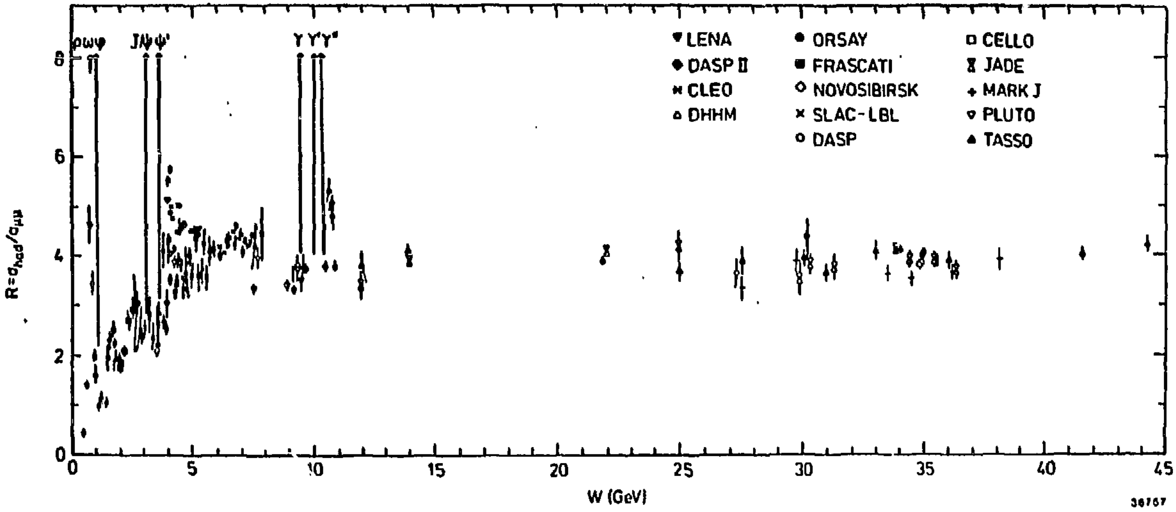
22. Cross section for $e^+e^- \rightarrow Z^{\circ}$.

23. Z° production rates from different storage rings.

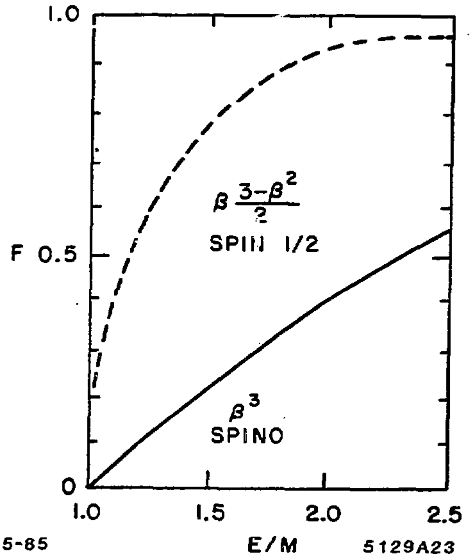
24. Heavy neutrino decay diagram.

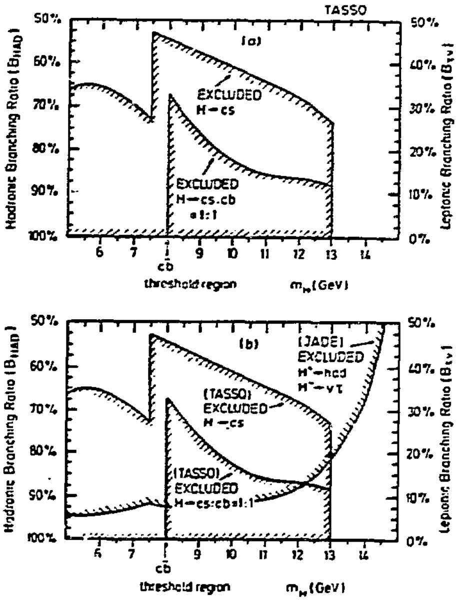
25. Hadronic system mass from 5π and 6π decay of tau.

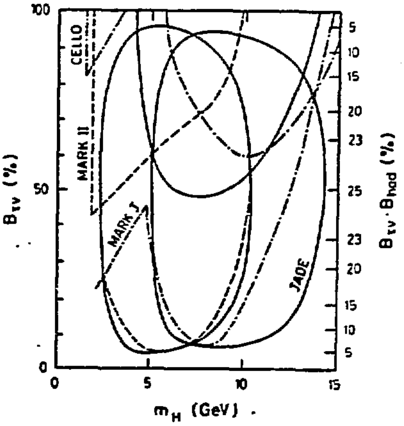
26. Tau decay via charged Higgs.

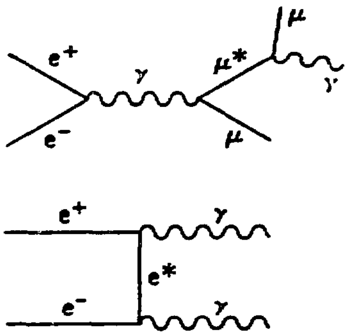


ρωφ
J/ψ ψ'
Υ Υ' Υ''
▼ LENA
◆ DASP II
✖ CLEO
△ DHHM
● ORSAY
■ FRASCATI
◇ NOVOSIBIRSK
× SLAC-LBL
○ DASP
□ CELLO
⧗ JADE
+ MARK J
▽ PLUTO
▲ TASSO
$R = \sigma_{had}/\sigma_{\mu\mu}$
0
2
4
6
8
0
5
10
15
20
25
30
35
40
45
W (GeV)
36767

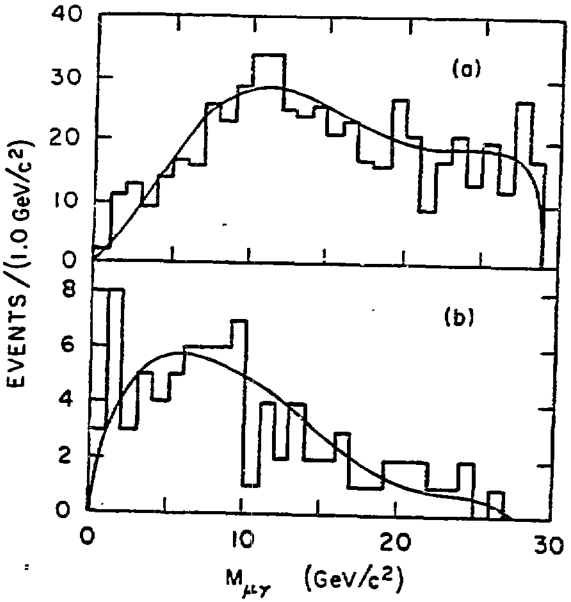

1.0
F 0.5
0
1.0
1.5
2.0
2.5
E/M
$\beta \frac{3-\beta^2}{2}$
SPIN 1/2
β^3
SPIN0
5-85
5129A23

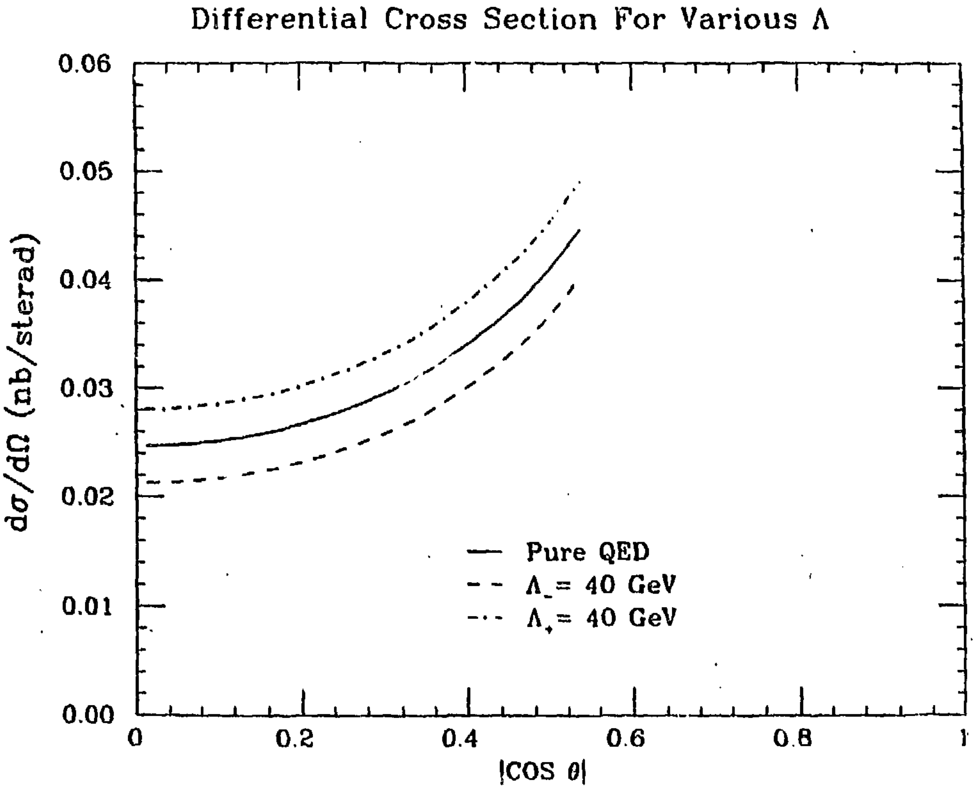

TASSO
(a)
EXCLUDED
H → cs
EXCLUDED
H → cs.cb
≈1:1
Hadronic Branching Ratio (B_HAD)
Leptonic Branching Ratio (B_τν)
50%
60%
70%
80%
90%
100%
40%
30%
20%
10%
0%
6
7
8
9
10
11
12
13
14
cb̄
threshold region
m_H (GeV)
(b)
(JADE)
EXCLUDED
H⁺ → had
H⁺ → ντ
(TASSO)
EXCLUDED
H → cs
(TASSO)
EXCLUDED
H → cs:cb=1:1


CELLO
MARK II
MARK J
JADE
B_τν (%)
B_τν · B_had (%)
m_H (GeV)
0
50
100
0
5
10
15
5
10
15
20
23
25


e+
e−
γ
μ*
μ
γ
μ
e+
γ
e*
e−
γ

4-85 5129A18


40
30
20
10
0
8
6
4
2
0
(a)
(b)
EVENTS /(1.0 GeV/c²)
0
10
20
30
Mμγ (GeV/c²)


Differential Cross Section For Various Λ
dσ/dΩ (nb/sterad)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
0.2
0.4
0.6
0.8
1
|COS θ|
Pure QED
Λ₋= 40 GeV
Λ₊= 40 GeV

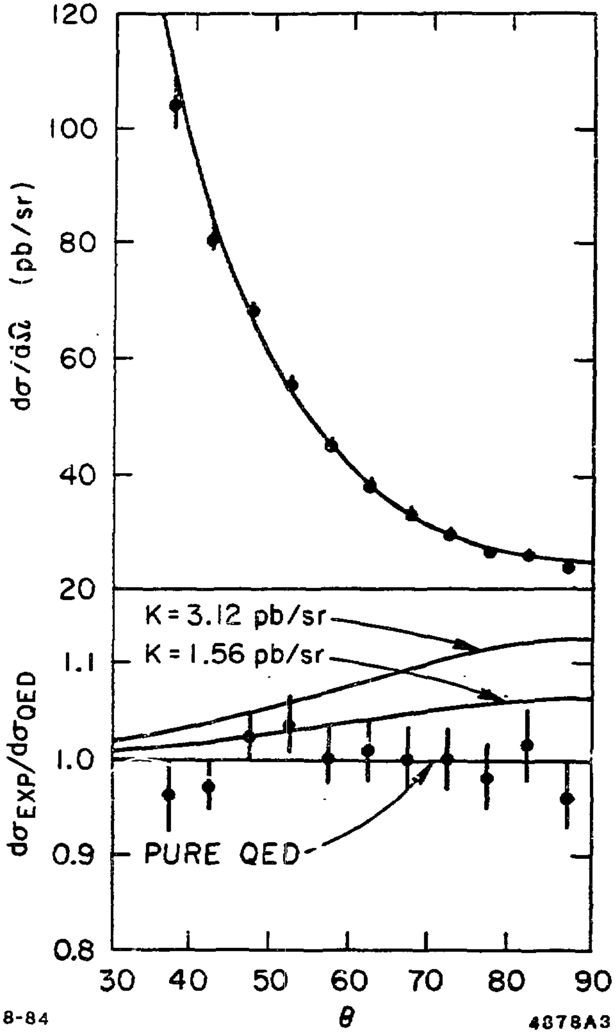
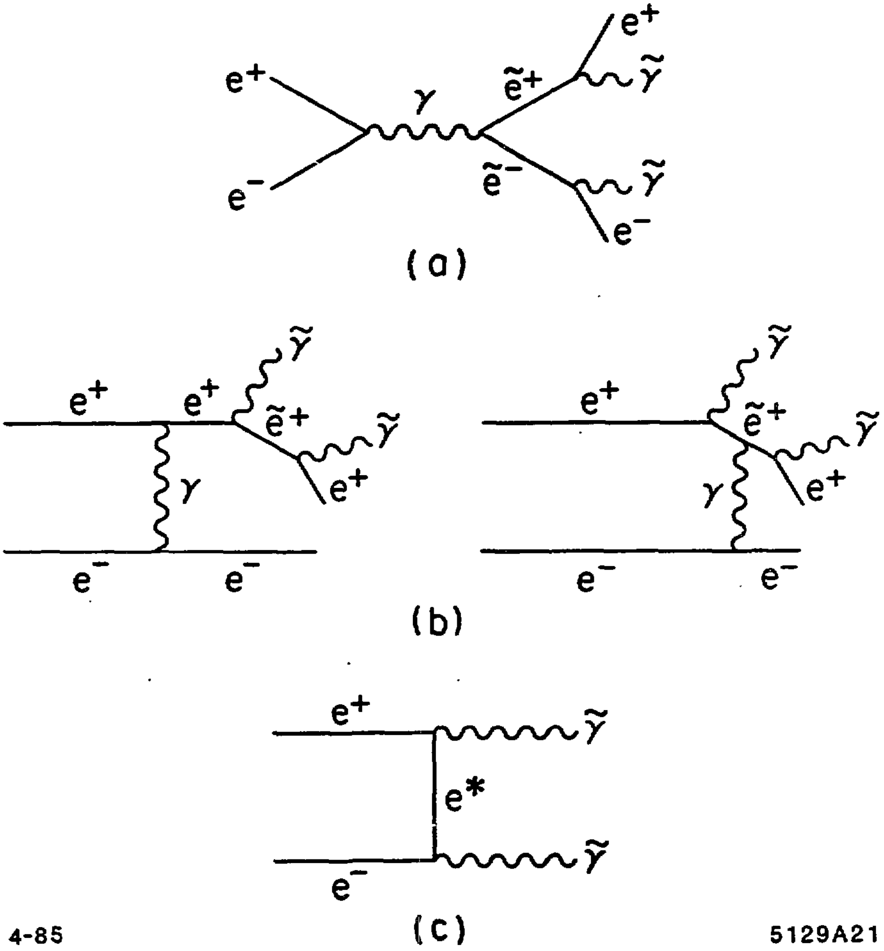

120
100
80
60
40
20
dσ/dΩ (pb/sr)
K = 3.12 pb/sr
K = 1.56 pb/sr
1.1
1.0
0.9
0.8
PURE QED
$d\sigma_{EXP}/d\sigma_{QED}$
30
40
50
60
70
80
90
θ
8-84
4378A3

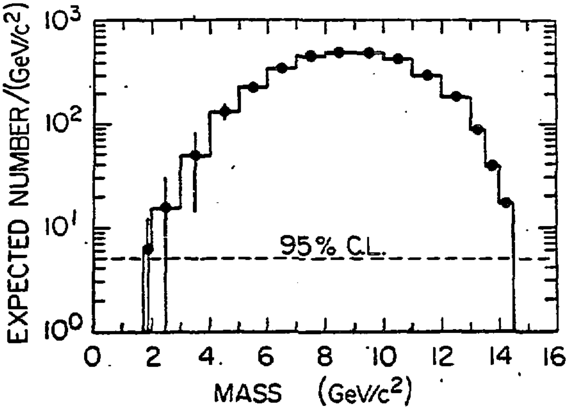
Fig 8



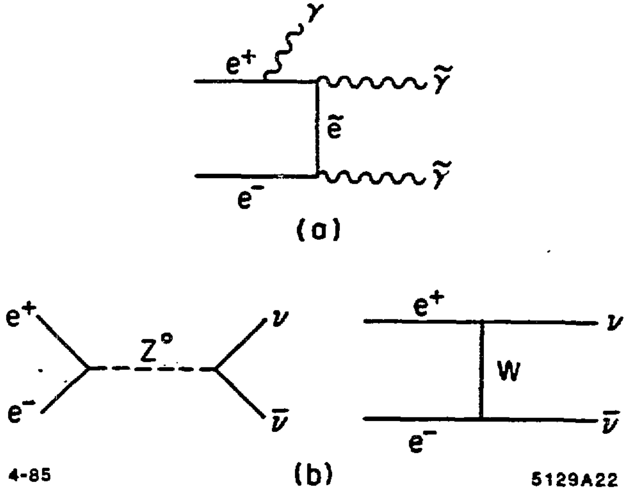
4-85

5129A21

Fig 9



EXPECTED NUMBER/(GeV/c^2)
10^3
10^2
10^1
10^0
95% C.L.
0
2
4
6
8
10
12
14
16
MASS (GeV/c^2)



γ
e^+
$\tilde{\gamma}$
$\tilde{e}$
e^-
$\tilde{\gamma}$
(a)
e^+
Z°
ν
e^-
$\bar{\nu}$
e^+
ν
W
e^-
$\bar{\nu}$
4-85
(b)
5129A22

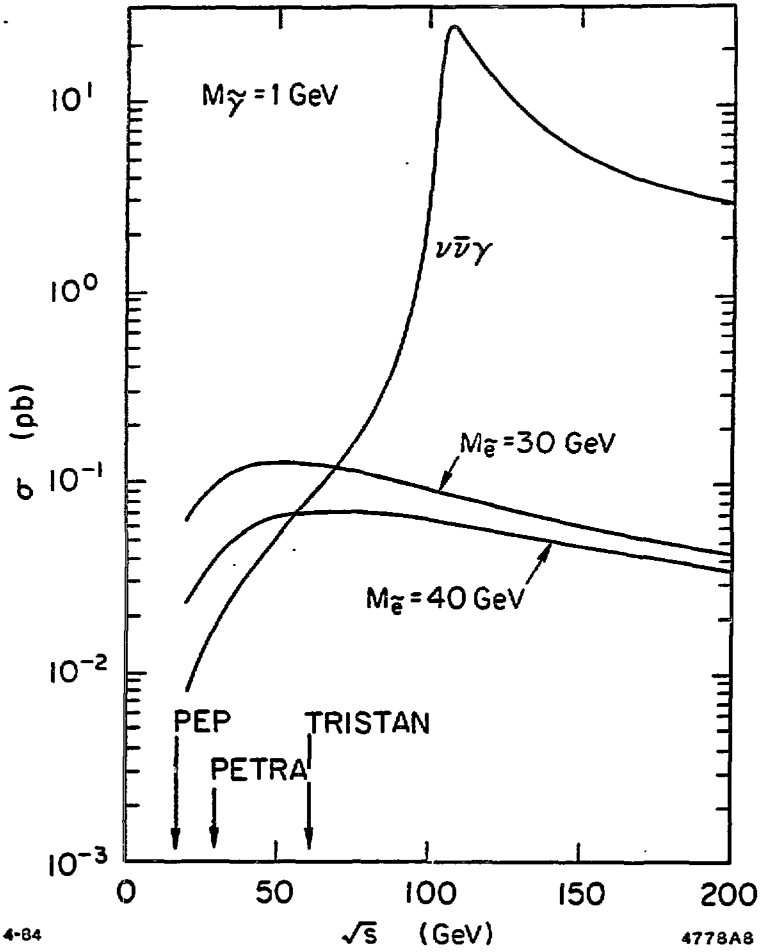
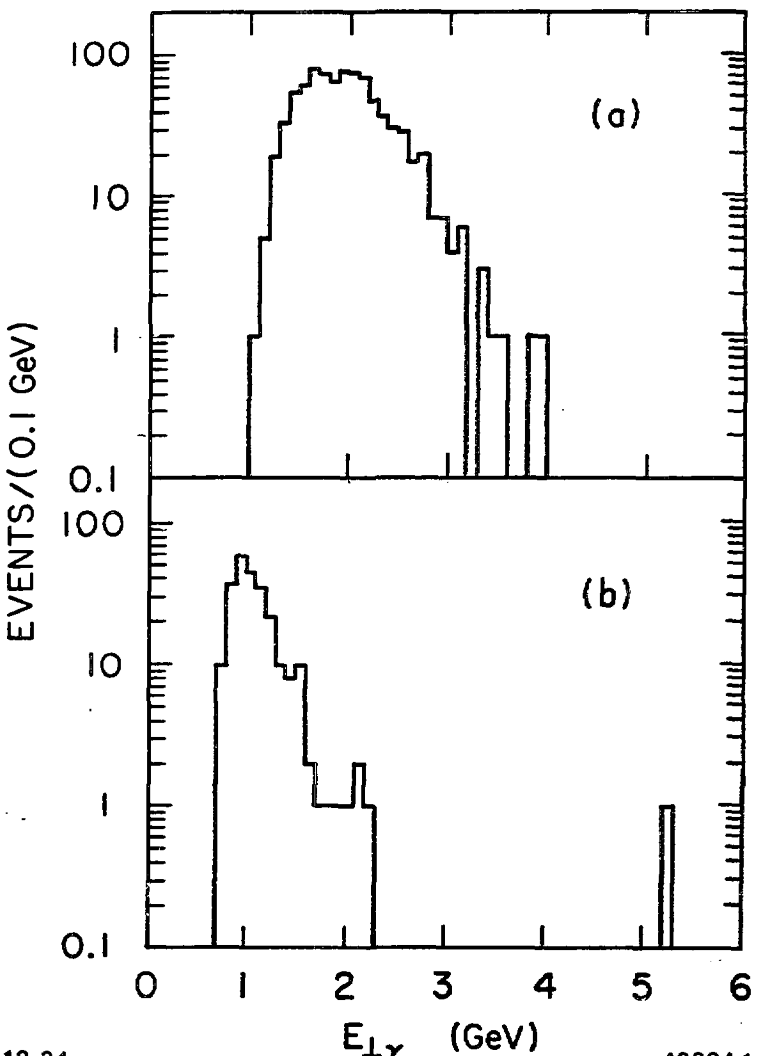

$M_{\tilde{\gamma}} = 1$ GeV
$\nu\bar{\nu}\gamma$
$M_{\tilde{e}} = 30$ GeV
$M_{\tilde{e}} = 40$ GeV
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
σ (pb)
PEP
PETRA
TRISTAN
0
50
100
150
200
$\sqrt{s}$ (GeV)
4-84
4778A8

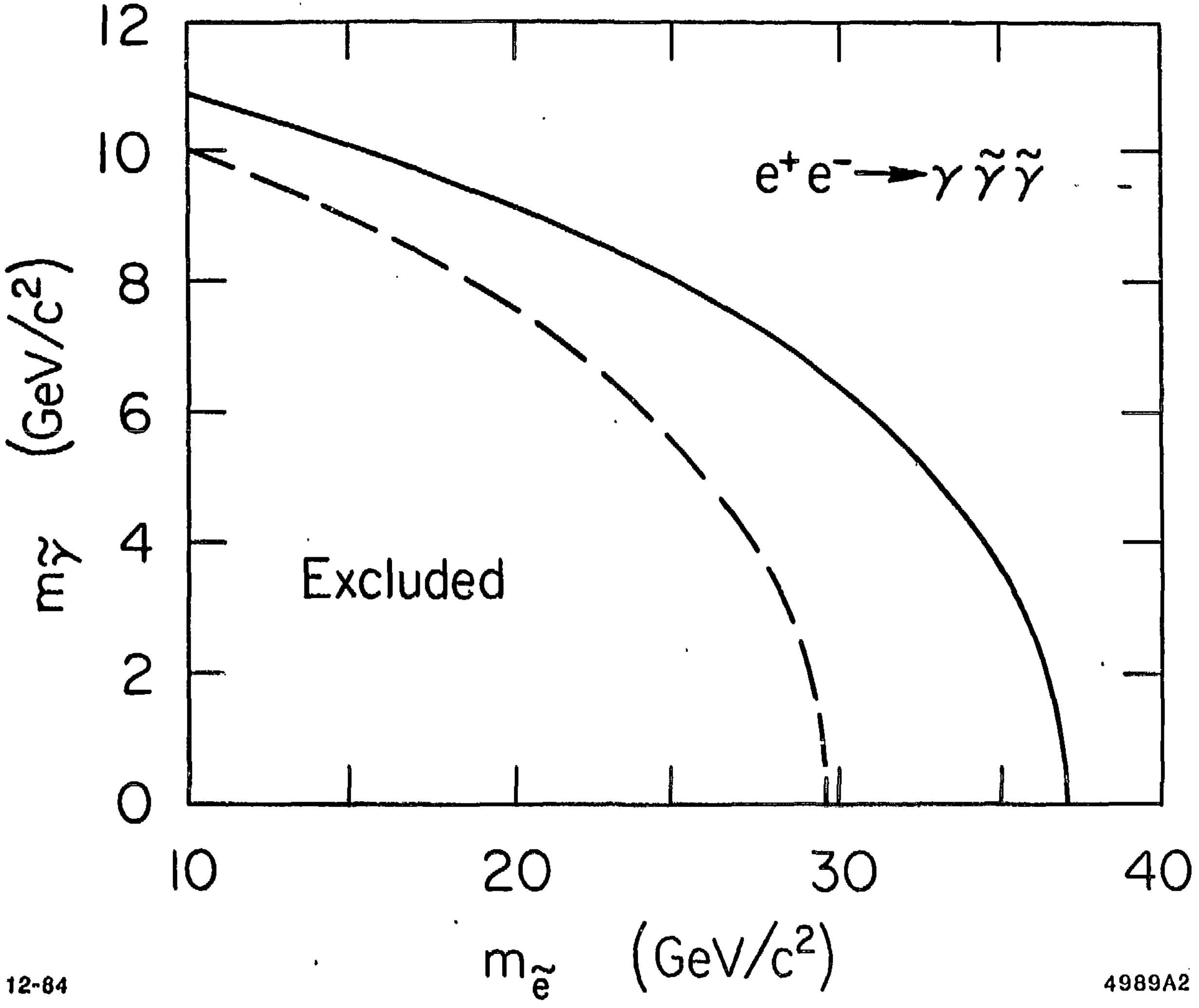
Fig 15

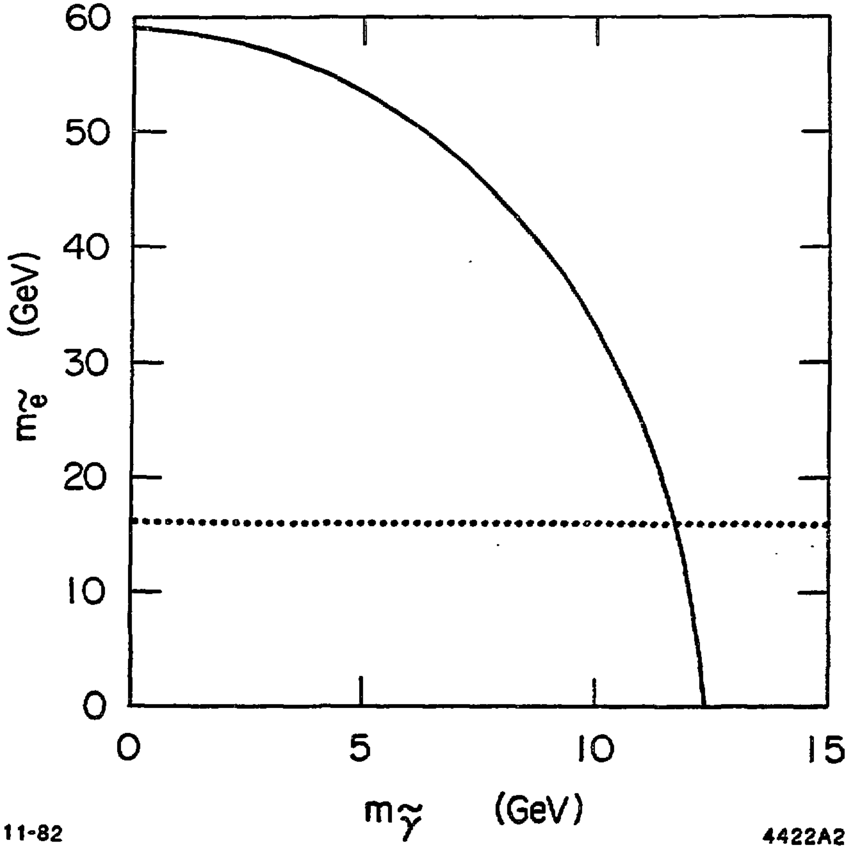


12-84

4989A1

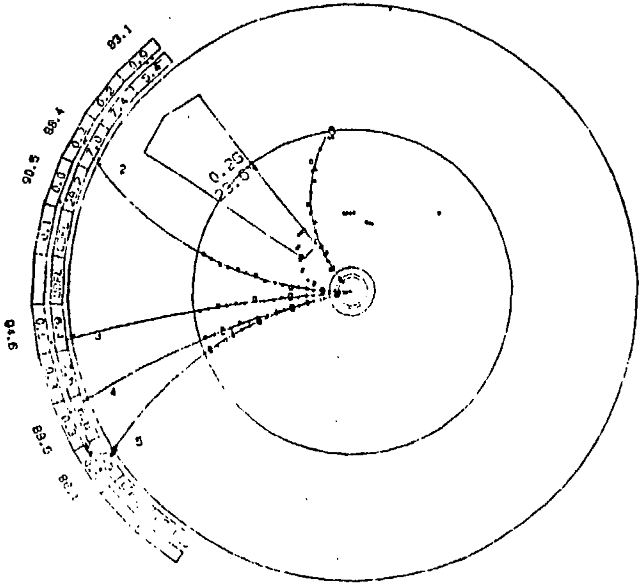
Fig 4


12
10
8
6
4
2
0
$m_{\tilde{\gamma}}$ (GeV/c^2)
10
20
30
40
$m_{\tilde{e}}$ (GeV/c^2)
$e^+e^- \rightarrow \gamma\tilde{\gamma}\tilde{\gamma}$
Excluded
12-84
4989A2



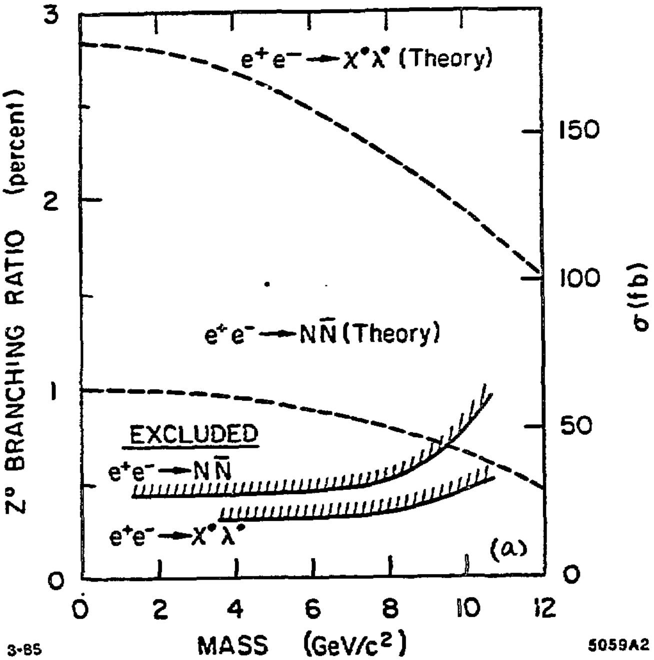
11-82

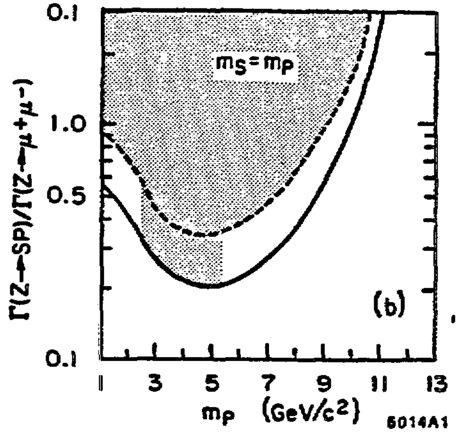
4422A2

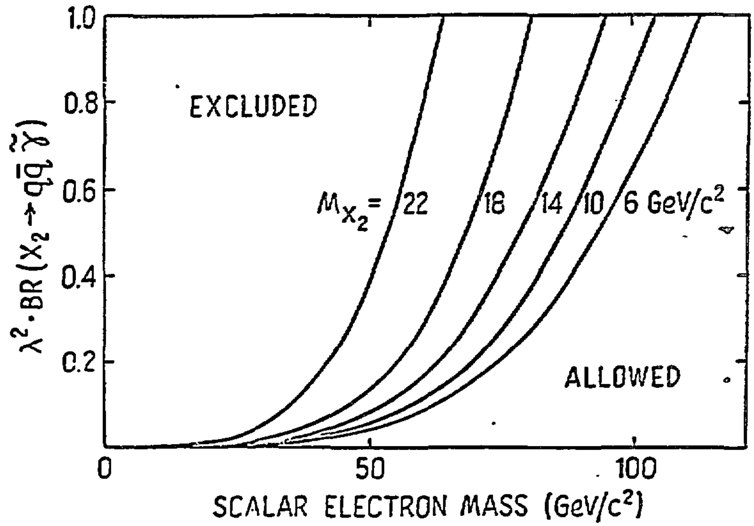


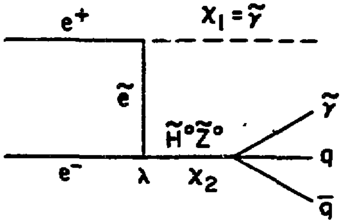
```
H [illegible]  RUN=6106

EVENT=   8692
DCHITS = 138
NPRNG =    6
SH SUM=  3.1 ·   0.2

TRACK MOMENTUM THETA
  2      1.0     85.9
  3     -5.0     94.9
  4     -2.8     87.9
  5     -1.1     89.3
  6      0.5     59.0
```

```
TRIG.= F2 F3 S6 A2 D1 D2.
```

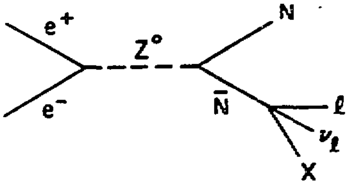

e+ e− → χ° λ° (Theory)
e+ e− → N N̄ (Theory)
EXCLUDED
e+e− → N N̄
e+e− → χ° λ°
(a)
Z° BRANCHING RATIO (percent)
σ (fb)
0
1
2
3
0
50
100
150
0
2
4
6
8
10
12
MASS (GeV/c²)
3-85
5059A2


m_S = m_P
(b)
Γ(Z→SP)/Γ(Z→μ+μ−)
0.1
1.0
0.5
0.1
1
3
5
7
9
11
13
m_P (GeV/c²)
6014A1


1.0
0.8
0.6
0.4
0.2
EXCLUDED
ALLOWED
M_{χ_2} = 22
18
14
10
6 GeV/c²
$\lambda^2 \cdot BR(\chi_2 \to q\bar{q}\tilde{\gamma})$
0
50
100
SCALAR ELECTRON MASS (GeV/c²)

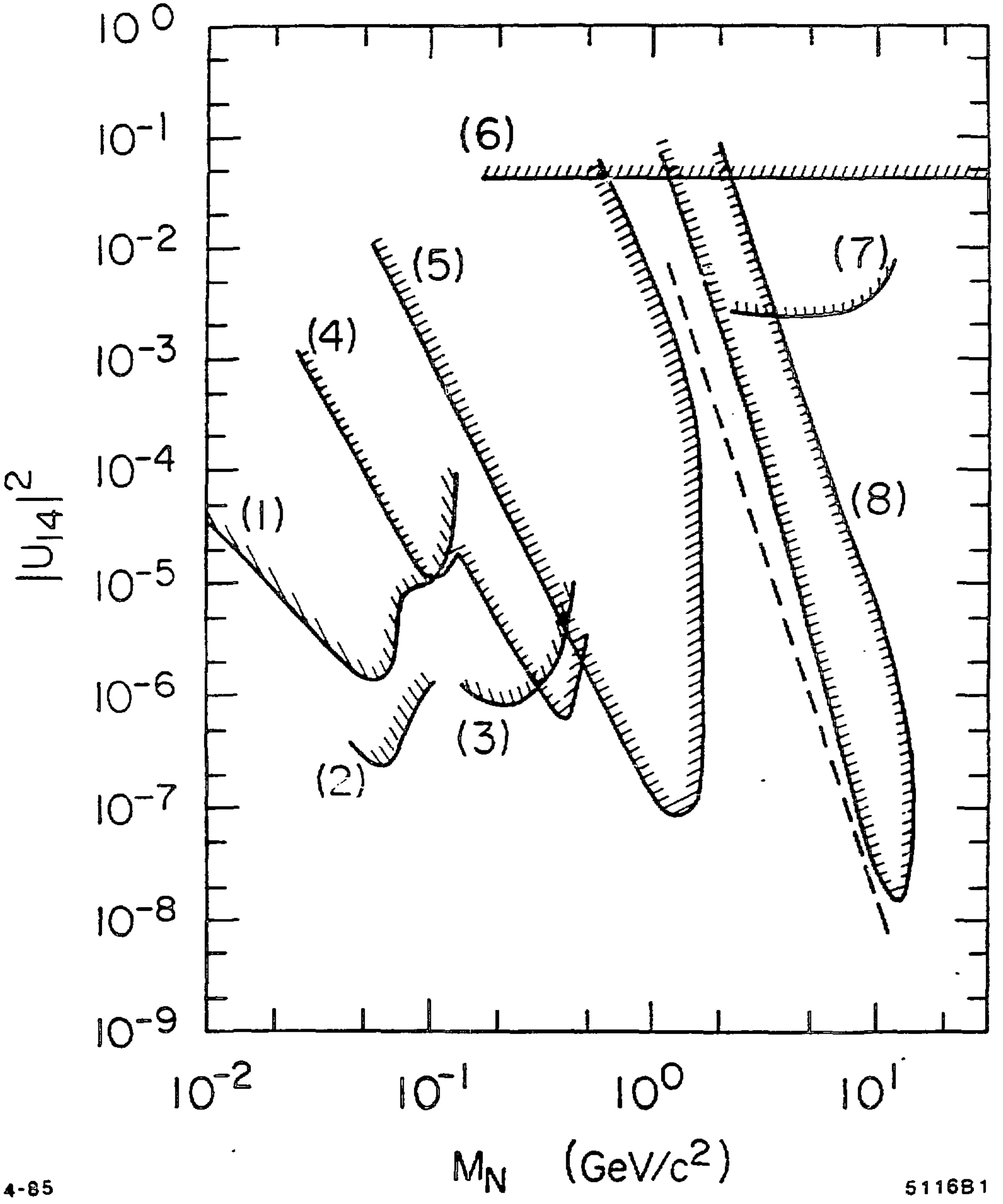

e^+
$\chi_1 = \tilde{\gamma}$
$\tilde{e}$
$\tilde{H}^\circ \tilde{Z}^\circ$
$\tilde{\gamma}$
q
$\bar{q}$
e^-
λ
χ_2

4-85 5129A19



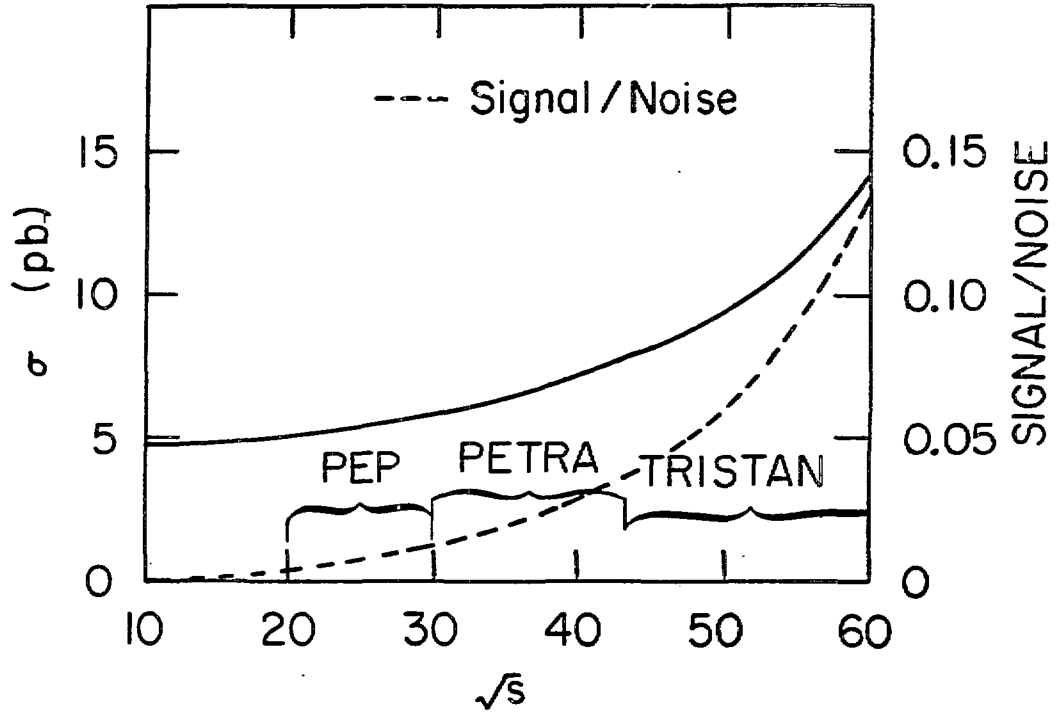
4-85

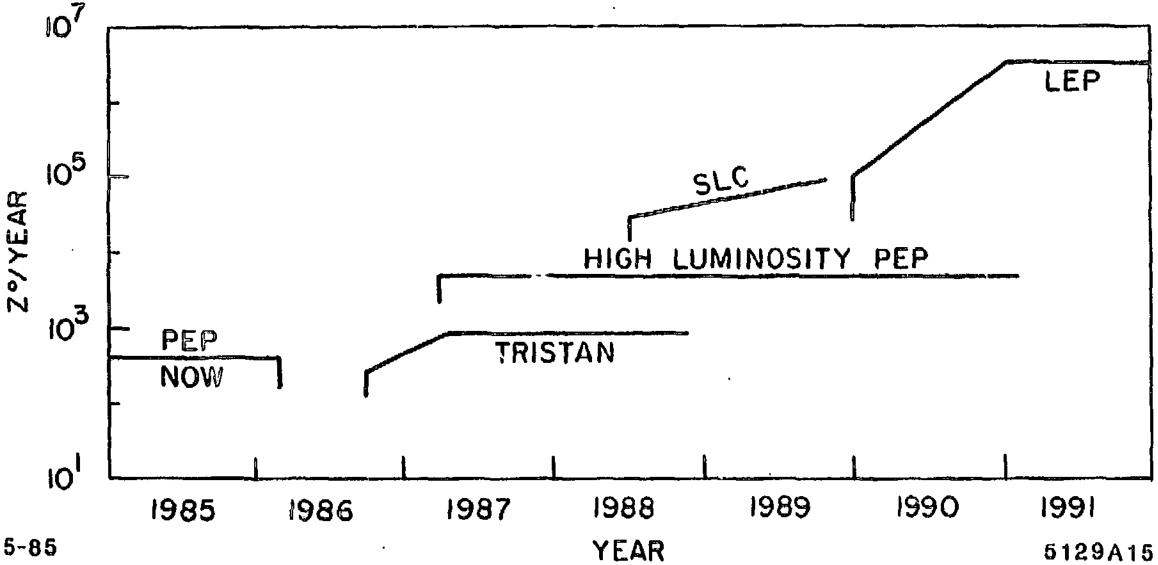
5129A20

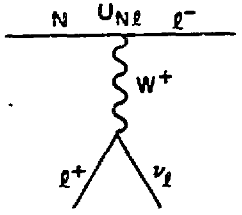


10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
|U14|^2
10^-2
10^-1
10^0
10^1
M_N (GeV/c^2)
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
4-85
5116B1

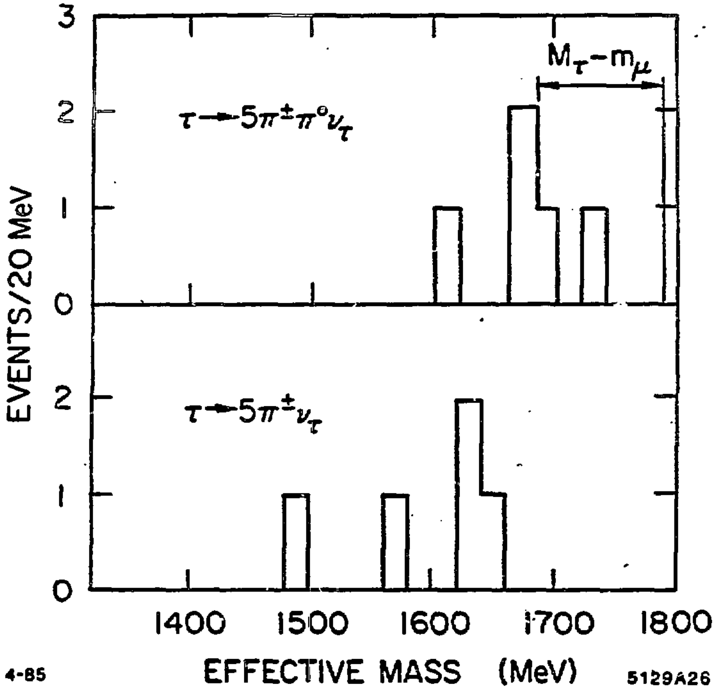
Fig 21


--- Signal / Noise
σ (pb)
SIGNAL / NOISE
15
10
5
0
0.15
0.10
0.05
0
10
20
30
40
50
60
√s
PEP
PETRA
TRISTAN

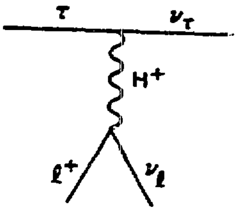
10^7
10^5
10^3
10^1
Z°/YEAR
LEP
SLC
HIGH LUMINOSITY PEP
PEP
NOW
TRISTAN
1985
1986
1987
1988
1989
1990
1991
YEAR
5-85
5129A15



4-85 5129A17



4-85 5129A26



4-85 5129A16