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ELEMENTARY PARTICLE EXPERIMENTS AT TRISTAN

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ABSTRACT

With the completion of the TRISTAN e^+e^- storage rings at KEK, a new energy frontier has been opened up for elementary particle physics. We give an overview of the experiments successfully conducted at the collision energies of 50 and 52 GeV.

INTRODUCTION

The physics potential at a e^+e^- collider is clear-cut and well known. By the annihilation of pointlike particles (e^+ and e^-) that collide head on, the collision energy turns into a virtual photon/neutral weak boson Z^0 and then a pair of real particles is created. The whole process is just the particle-antiparticle production at a well controlled energy. In addition, as long as kinematically allowed, all species of elementary particles are created in pair with equal weight, only depending on their charges and the number of degrees of freedom. Being the highest energy e^+e^- collider, the TRISTAN contributes to significantly enlarge the mass range to be explored. Furthermore, not only charged particle pairs, but also new neutral particle pairs could be produced via virtual Z^0.

Four experimental apparatus (called AMY, SHIP, TOPAZ and VENUS) now occupy the beam collision areas symmetrically placed along the main ring. One of them (SHIP) is a small-scale special purpose detector and the rest are large detector complex for general purpose experiment. They share the same circulating beams of $2e^+$ bunches and $2e^-$ bunches.

The real experiment very smoothly started from May 31, 1987 with the collision energy of 50 GeV. The energy was soon increased to 52 GeV and the first-round experiment was concluded on July 25. The available beams during this period were efficiently used for data collection, the accumulated luminosity amounting to about $4pb^{-1}$/experiment. The data analysis software had been well prepared in each group, and thus the analyses kept good pace with experiment. In fact, when the experiment came to an end, preliminary physics results were already available for presentation as major topics at international conferences.[1-4)]

At a storage ring like TRISTAN, the beam collision area which is a part of the ring is also an essential part of experimental apparatus. It was therefore indispensable for us to keep close contact with the accelerator staff, and we have enjoyed it.

PHYSICS OBJECTIVES

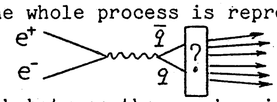
We have come a long way to know that quarks and leptons are elementary particles and that gauge bosons (photon, gluon, weak bosons) exist mediating different interactions between them. However, the number of species already exceeds a few, and they have masses considerably different with each other. Then it would be natural and economical to regard even the quarks and leptons as composites of a small number of more fundamental units. With this possibility in mind, whenever the collision energy goes up, we eagerly search for new interactions and new particle states or, more modestly stating, small deviations from what the pointlike-particle theories predict.

On the other hand, the quarks and leptons are nicely classified to good reasons into 3 families (or generations) of weak-isospin doublets;

Family #	1	2	3	
Quarks	$\begin{bmatrix} u \\ d \end{bmatrix}$	$\begin{bmatrix} c \\ s \end{bmatrix}$	$\begin{bmatrix} \; \\ b \end{bmatrix}$	x 3 colors
Leptons	$\begin{bmatrix} e \\ \nu_e \end{bmatrix}$	$\begin{bmatrix} \mu \\ \nu_\mu \end{bmatrix}$	$\begin{bmatrix} \tau \\ \nu_\tau \end{bmatrix}$	

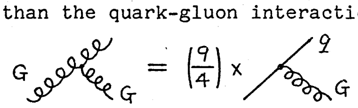
One immediately notices the missing spot in the third quark family, which has long been reserved for the top quark. The currently popular theories need it to exist and its search is one of the important motivations of the TRISTAN project. Its bound state called the topponium, if exists in this energy region, will be the best place to search for the most elusive but important scalar particle, the Higgs. As for the number of quark-lepton families, no theoretical explanation exists. Only the experiment at high energies can tell how many there are in nature. We may then find that the family structure shown above is just a part of larger multiplets. The present family structure implies that the weak interaction is universal among the families. The universality is more closely examined by comparing the weak coupling constants deduced from high statistics data on fermion pairs produced democratically in e^+e^- collision.

When a very large momentum kick is given or equivalently when a large momentum transfer is involved in a given reaction, quarks can be treated by the asymptotic freedom as free particles for a limited time duration. Then the hadronization follows and we can observe only a jet of hadrons. In fact, multihadron events resulting from high energy e^+e^- annihilation is interpreted without any doubt as the quark-antiquark production. The whole process is represented as



The missing link between the quark pair and the hadron jets we detect has so far only been described phenomenologically. It is a cascade process involving a very high to low momentum transfers and is crying for more detailed studies on the nature of these jets which is the only information available to us on the parent quarks. A high energy e^+e^- collider offers the best opportunity for this purpose.

One of the very important ingredients of the current theory is that, having the color charge, the gluons can couple to themselves and that this coupling is stronger than the quark-gluon interaction;



But it has not been possible to verify this at low energies. A high collision energy is required to recongnized a jet resulting from the gluon branch. High statistics data at TRISTAN should allow us to contribute in this area through studies on the 3-gluon decay of a topponium if exists or through 4-jet events among multihadron events.

This list of our physics objectives can continue. But, we summarize them all by saying that we intend to investigate into the deepest level all the reactions in this new energy regime.

EXPERIMENTAL APPARATUS

A large number of high energy particles emerges at wide angles as a result of head-on collision of two beam particles. Fig. 1 shows the charged particle multiplicity distribution actually measured at TRISTAN.

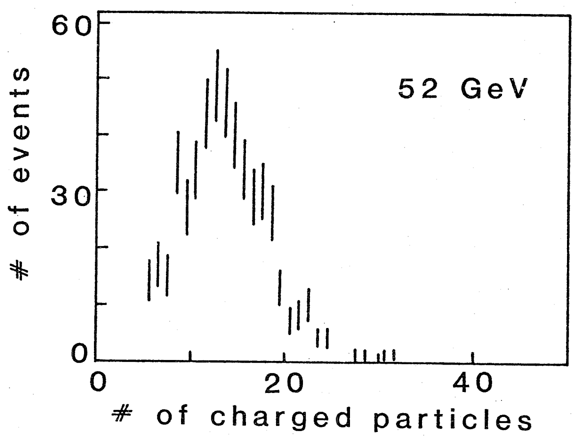


Fig. 1 Charged particle multiplicity distribution at 52 GeV (TOPAZ).

The mean at 52 GeV collision energy is about 16 and the similar number of photons are simultaneously present due mostly to neutral pions. An experimental apparatus aiming for the above physics objectives should be able to measure for all these particles the momentum and the emission angle and to identify the particle species. There is, however, no single detector that can do everything. The apparatus necessarily becomes a large complex of various detectors surrounding the collision point. The central part is a large magnetic spectrometer consisting of high-resolution gaseous position detectors inside a superconducting magnet. The repeated sampling of gas ionization caused by charged particles is the essential technique used in this part. The spectrometer is closed by segmented calorimeters which detect photons and electrons as local cascade showers. The muons, nonshowering particles, penetrate through thick iron slabs which filter out other particles, and are detected by gaseous position detectors.

Aiming at almost the same physics in the same environment, the three general-purpose detectors are similar in configuration. Fig. 2 shows one of the detectors. However, for various reasons, the detectors are considerably different in may aspects. See Table 1.

EXPERIMENTAL ENVIRONMENT

To recognize the occurrence of an interesting event, the trigger logic is formed to require correlated combinations of detector signals.

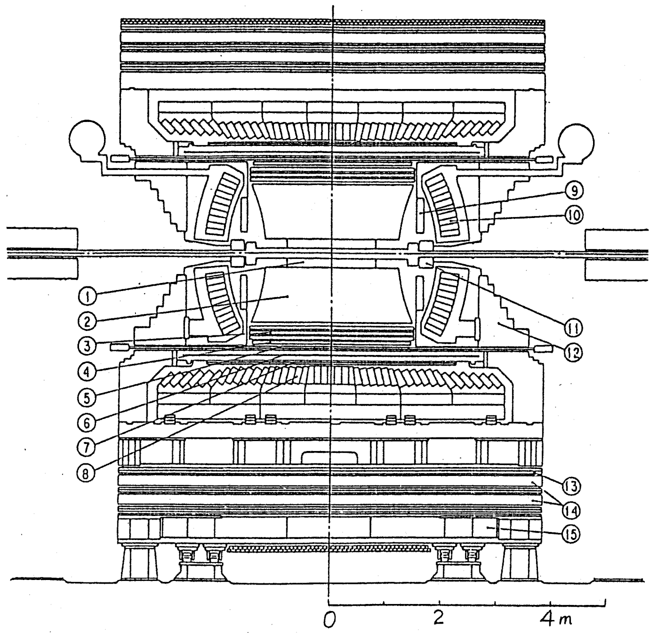


Fig. 2 VENUS detector. (1) and (2) are tracking chambers inside the solenoid (6). They are covered by calorimeters (8) and (10), and by muon detector system (13) and (14).

Multihadron events resulting from q-$\bar{q}$ production are easy to trigger on because there will be many particles as already shown in Fig. 1. The elastic scattering of e^+e^- (called the Bhabha scattering) and the two photon production are even simpler to work with as the collision energy is directly deposited to the calorimeters. Fig. 3 illustrates the detectable energy distribution. The muon-pair production results in two high-momentum tracks, but leaves a tiny amount of energy in the calorimeters. Even worse can be the tau-lepton pair when only two tracks emerge with the rest of energy carried away by neutrinos. To catch all the interesting events efficiently, at least two charged particles should be quickly recognized in the tracking chambers without too much constraints on their energies nor on their spatial correlation. So far, all the detectors at TRISTAN seem to have succeeded in doing this.

The electromagnetic pair production of pointlike fermions such as muons, tau-leptons and quarks is a very small fraction of what the detector sees in association with the colliding beams. Fig. 4 shows

Table 1

Comparison of General Purpose Detectors

	AMY	TOPAZ	VENUS
Collaboration	International	National	National
Strategy	Compact, High Field, Calorimeter inside magnet.	Sophisticated chamber, Particle ID.	Well-established technique, First to roll in.
Mag. field	3.0T	1.0T	0.75T
Central chamber	MWDC	TPC	MWDC
Calorimeters			
Central	Pb/Gas	Pb glass	Pb glass
Ends	Pb/Sc	Pb/Gas	Pb/Liq. Ar.
Particle ID		TOF	TOF
	(Synch. rad.)	dE/dx	(Trans. rad.)
	E/P	E/P	E/P

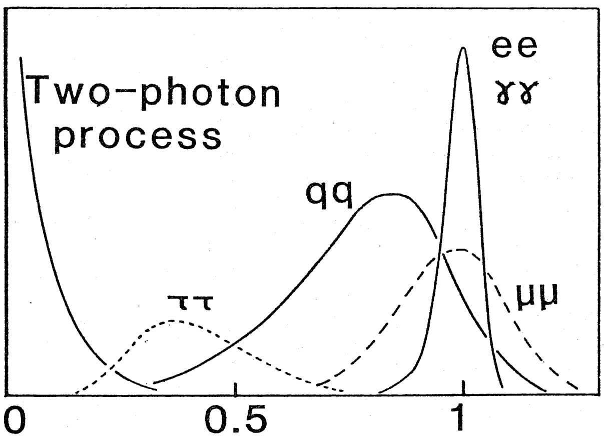


Fig. 3 Illustration of detectable energy distribution for different reactions. Detector resolutions are taken into account.

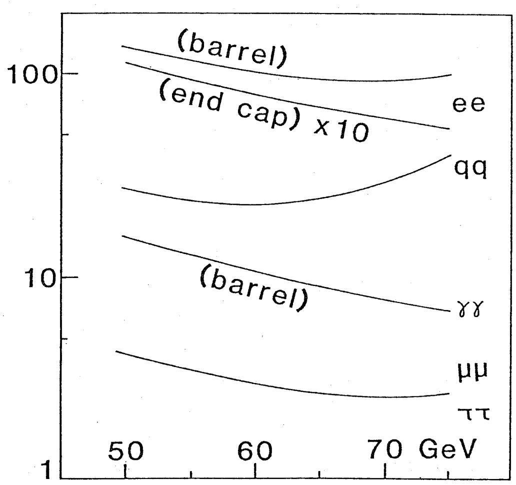


Fig. 4 Counts/day for various reactions for the luminosity of 200 nb^{-1}/day as a function of collision energy.

the rates of interesting reactions for the luminosity of 200 nb^{-1}/day that has been achieved at 52 GeV in the first round of TRISTAN experiment. The sum of them correspond to only 1% or less of the recorded events and are outnumbered by backgrounds. Photons due to the synchrotron radiation in the beam focussing magnets can be multiply scattered into the detector part. Once in the gas chamber, they are detected as randomly distributed points. The famous first VENUS event had this background superposed on the elastically scattered e^+ and e^- tracks. Gradual improvement in beam conditions and, in particular, the insertion of masks substantially reduced this type of background.

More annoying is a spray of low energy particles frequently seen in the chamber volume at small radii. Any beam particle has a chance to radiate in interaction with residual gas atoms, thus going slightly off energy and off central orbit. These particles, when coming close to the collision point, are overfocussed by the focussing Q-magnets and hit the beam pipe, ending up in showers. Some of the shower components, upon entering the detector, generate curling tracks and confuse the trigger logic. Naturally, a high magnetic field of detector magnet helps keeping them near or even inside the beam pipe. It finally turned out that the most effective is the proper shielding around the beam pipe inside the detector structure.

Hard interactions of beam particles with residual gas produce background of different nature. They frequently send higher energy particles into the detector mimicking multihadron events from e^+e^- annihilation. Of course, they occur off the collision point as shown in Fig. 5, and other features are the directionality of the observed tracks and the presence of protons in them. This kind of events should be suppressed as much as possible at the trigger level, but still dominates the recorded data.

Genuine events of our interest is even less frequent than cosmic rays due to the large detector size. It at first surprised us that rather many cosmic muons passed through the beam pipe. They are however distinguishable from the muon-pair production based on the timing information. Those cosmic rays that deposit large energies to the calorimeters satisfy the energy trigger requirement. Lacking proper spatial correlations, they are easily rejected off line and are, anyhow, a small fraction of the total triggers.

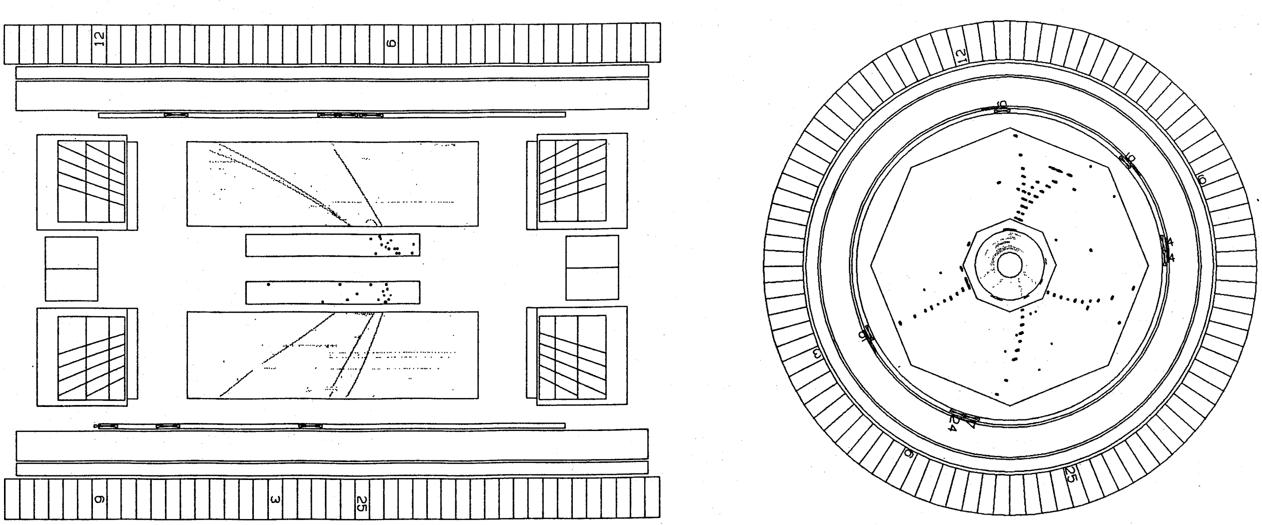


Fig. 5 An example of beam-gas event (TOPAZ).

The beam collision rate, called the luminosity, is monitored by recording the small angle Bhabha scattering, i.e. the glancing collision of e^+ and e^-. To get a high rate, this measurement has to be performed at small enough angles, around 50 mrad, where the beam associated backgrounds described above are a serious problem. With a pair of calorimeter units placed close to the beam pipe, a back-to-back pair of electron-like particles is detected in coincidence. This system has worked well only after imposing tight correlations in time and in energy.

EXPERIMENTAL RESULTS

The experimental groups collected and analyzed data corresponding to the following integrated luminosities [pb^{-1}];

	AMY	SHIP	TOPAZ	VENUS
50 GeV	0.69	0.70	0.46	0.71
52 GeV	4.0	3.9	3.5	3.0

Here we briefly summarized the preliminary results reported in the end of August.[2-4] Each group has just begun submitting their papers for publication. It should be mentioned here that we have been in close collaboration with the theory working group on the radiative corrections in e^+e^- reaction and that owing to the group's activity we were able to get useful results in a short time.

Differential cross sections were obtained for the Bhabha scattering and the two-photon production. In the present energy region, they are expected to closely follow the pointlike electromagnetic theory except at large scattering angles for the Bhabha and it is what we see. The obtained limits on any deviation from this standard picture are already nearly the same or beginning to exceed those set by high statistics data at PEP/PETRA. This in turn implies that we do not see any sign of a possible scalar boson once postulated as a partner of the composite Z^o nor of an anomalous electron propagator.

Lepton pair production such as muon or tau pair is very sensitive to the electroweak effect. Although each group collected less than 100 events for each channel due to their lowest cross sections, we clearly see an increasing contribution of non-electromagnetic effect. When the measured differential cross sections are converted into the forward-backward asymmetries, the result is as large as 20% and is consistent with the expectation. Since the asymmetry is predicted to grow fast with energy, it is very important to continue this study to higher energies with much higher statistics.

A special attention was focussed on multihadron candidates such as shown in Fig. 6 since any new heavy particle is likely to show up there. Firstly, when a new-particle production threshold is passed, there must be a jump in the yield of such events. The cross section was deduced by each group for the multihadron events due to e^+e^- annihilation. For the sake of this talk, we combined the three independent results by treating the statistical and the systematic error on an equal footing. The result normalized to the electromagnetic muon pair is plotted in Fig. 7 in comparison with the three predictions; no new quarks, a new charge 2/3 quark or a new charge -1/3 quark. It agrees very well with the 5-quark case, thus denying the production at 52 GeV of the new 2/3 quark (presumably the top quark). There is a marginal difference from the case with an extra -1/3 quark (called the b'). While giving negative result on new

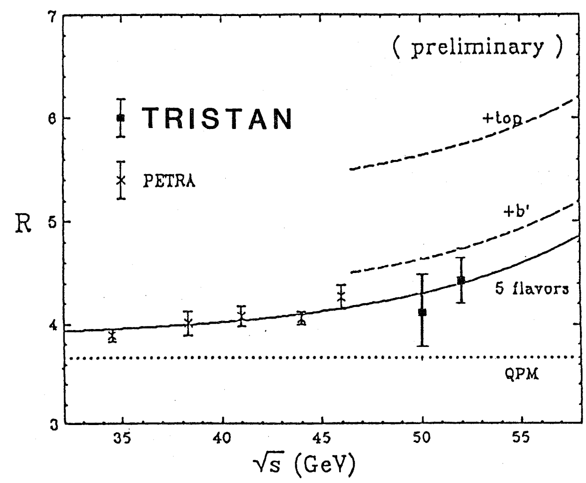


Fig. 7 Total cross section for multihadron production due to e^+e^- annihilation (normalized by electromagnetic muon-pair cross section). The results of 3 groups were statistically combined for simplicity.

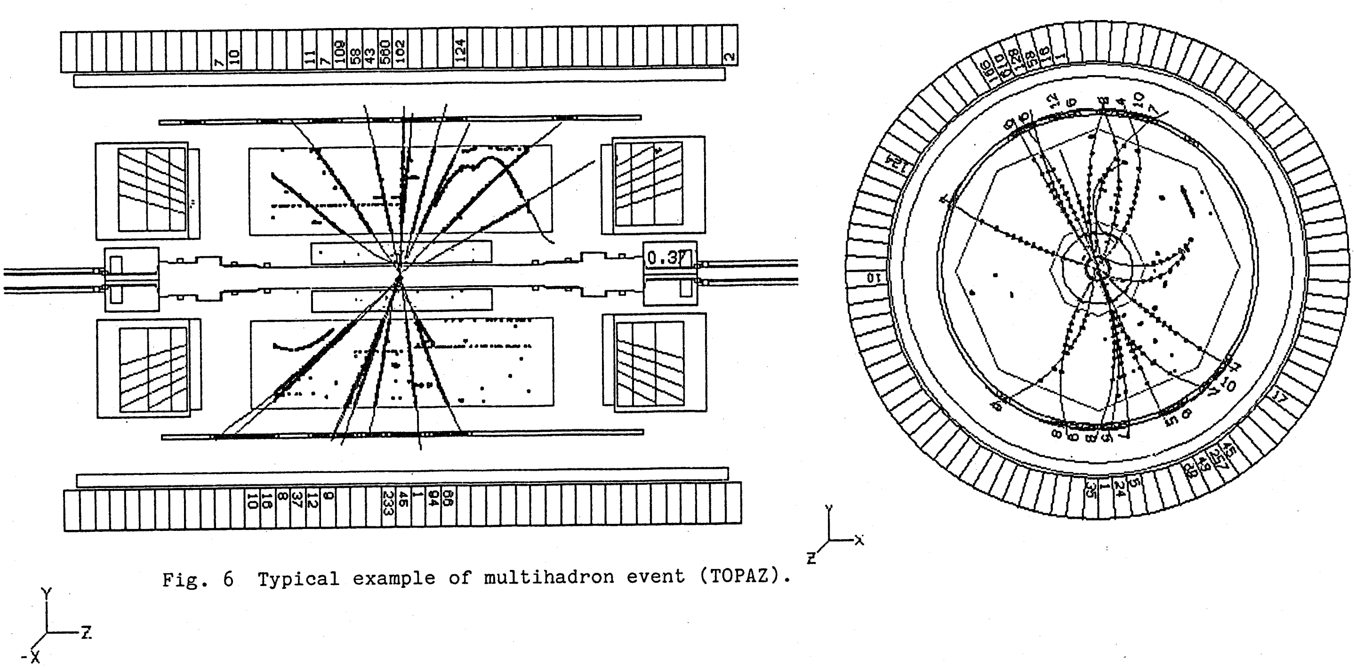


Fig. 6 Typical example of multihadron event (TOPAZ).

particle production, the good agreement with the 5-quark case at this new energy has important implication. It proves the combined prediction of the quark-gluon dynamics and the electroweak theory, and show that the quarks still look like point particles. The same conclusion is reached when a hadron distribution in momentum space is examined on the same data sample. The point here is that hadrons resulting from a heavy quark should look much less jet-like. Fig. 8 shows an example of such a comparison, where we clearly find the data points in good agreement with 5-quark production.

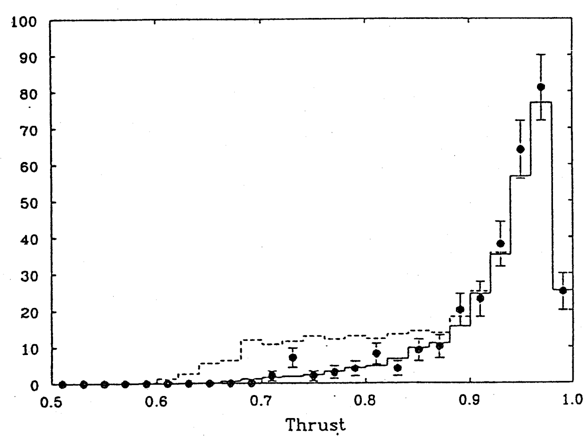


Fig. 8 Thrust distribution for multihadron events (VENUS). The solid and the dotted histogram are expected ones for 5- and 6-quark production, respectively.

In the known 3 quark-lepton families, the leptons are always much lighter than the corresponding quarks. We thus expect the same to hold for the fourth family. The new charged lepton, sequential to the tau, will decay with high probability into a neutrino and a group of hadrons. The candidate of the new charged lepton pair production is those having two acoplanar hadron jets with large missing energy due to the neutrinos. We have found no evidence for them.

A high energy lepton not closely accompanied with other particles is usually a signal of a heavy particle production. A possible evidence at the highest PETRA energy (about 47 GeV) had been reported by two groups for the onset of new phenomena, i.e. an excess of events showing an isolated muon with widely spread hadrons.[5] Unfortunately the PETRA was shut down leaving this very interesting result inconclusive. However, TRISTAN was there to immediately follow PETRA in both time and energy, and was internationally assigned the role to show what is really happening. A search was made and our result, as shown in Fig. 9, came out to be negative.

In contrast to others, the SHIP is a very small detector constructed by a small team of Japan-USA collaboration. It uses a number of plastic (CR-39) sheets surrounding the collision point. Though small in every aspect, their aim is big. They are searching for traces of heavily ionizing particles, magnetic monopoles of charge 137e/2 in particular. Useful upper limits on the mass and the cross section are already obtained.

Much more studies are underway in all the groups on the data in hand. We will soon restart experiment at a higher energy.

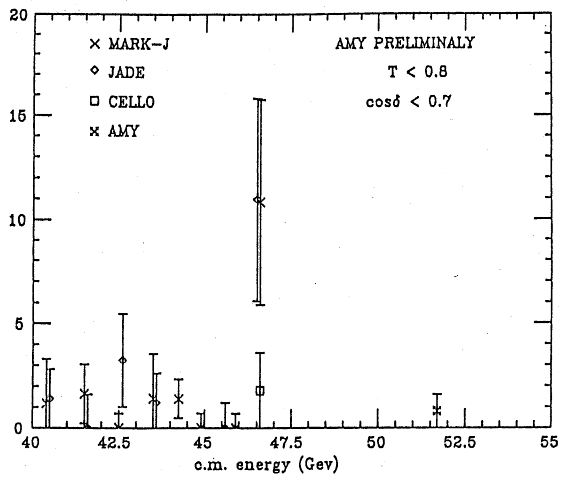


Fig. 9 Cross section times energy^2 (nb·GeV^2) for isolated muon events accompanied by uncollimated hadrons (AMY).

ACKNOWLEDGMENTS

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REFERENCES

1. F. Takasaki, Invited talk at Int. Lepton-Photon Symp. (July 1987, Hamburg).
2. K. Amako (VENUS collab.), Invited talk at Seventh Int. Conf. on Quark-Lepton Phys. in Collision (Aug. 1987, Tsukuba).
3. A. Miyamoto (TOPAZ collab.), ibid.
4. Y. Sakai (AMY collab.), ibid.
5. See for example, CERN Courier, No. 7, Vol. 27 (1987).