EXERCISE IN NOSTALGIA

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This is a subjective and personal view of what I thought were the highlights of a spectacularly rich conference. It is due in a large way to the onset of a new accelerator, PETRA, exploring a new energy range i.e. from 10 to 30 GeV. Tests of QED (just like QCD but instead of gluons you have photons and...) have reached a new level of precision. I grew up on these experiments (hence the nostalgia theme). The new limits represent enormous progress and, in the context of current developments, take on new significance. The results from DESY teach us that the size of the electron i.e. its structure function, can be represented by a cut-off parameter which is approaching ~ 100 GeV. This is point-like indeed. It sets a scale for future experiments that must search for structure inside electrons and quarks. It says such an accelerator must have good luminosity in the energy range of (at the least) many hundreds of GeV in the CM.

It was also the unanimous conclusion of the four PETRA experiments that we still have only five flavors i.e. that the presumed top quark has a mass that exceeds 15 GeV. I found impressive the array of data which point more directly to the existence of gluons and providing striking confirmation of QCD. It was also fun to see the clean signal of the fundamental neutrino-electron elastic scattering as seen in a "small" electronic detector. A series of "indications" added spice and some controversy to the meeting: a bump in the effective mass of a $\psi k\pi$ final state hints at the excitation of bare bottom with 150 GeV pions. A possible final location of the η_c may have been seen in the beautiful gamma spec ctrum obtained by the crystal ball at SPEAR. A suggestive large yield of neutrinos from a CERN beam dump hints at τ-neutrinos. Along the lines of solid achievements there is the measurement of the tau decay "Michel parameter", the observation of charmed baryons in e^+e^- collisions, scaling problems in deep inelastic scattering, curious results on lifetimes of D mesons, important progress, perhaps striking progress, both theoretically and experimentally in the Drell-Yan process, Cabibbo suppressed D decays, very nice demonstration of the helicity and the V-A nature of high energy weak interactions by looking at the polarization of the muon from neutrino scattering experiments, charm changing currents, pion and nucleon structure functions, i.e. photographs of basic particles, charmed baryons at the ISR, and various anomalous lifetimes seen in emulsions. I think this is just a fantastic array of physics; an unusually productive conference.

Let me review some of these subjects briefly. This is nostalgia now, the physics of three days ago.

PETRA came on really impressively and they're to be congratulated on the progress of the machine and the physics they've done in so short a time. Their most spectacular result is the observation of bremsstrahlung of gluons or what somebody called gluestrahlung. To remind you, e^+e^- annihilations into $q\bar{q}$ explained all the data up to 17 GeV but at the higher energies one started to see deviations. Thus in the context of a simple model in which $e^+e^- \to q\bar{q}$, something new was happening. This new thing was anticipated theoretically in the QCD theory.

Quarks are bound by gluons and their presence had already been in evidence in a variety of experiments: in deep inelastic scattering and in the high $p_\perp$ dileptons. At high energy, the hard gluestrahlung can give rise to $e^+e^- \to q\bar{q}\,G$, each constituent fragmenting into a characteristic jet. The results of the four PETRA detectors agree with the predicted three jet structure. It is there pictorially and it is there analytically in detail. Here I might add as an aside that the success of these four experiments is absolutely astonishing. As an experimentalist, I've always hated and feared complicated detectors. Look back at the diagrams of these monstrous spectrometers and we know they never work! In fact of course, they all worked and we will run through the results to show how well.

Fig. 1 is a summary page from TASSO and Fig. 2 is a computer playback of a three-jet event. Fig. 3 and 4 show the same information from JADE. Note especially the three dimensional jet figure obtained by the lead glass cylinder Fig. 5 and 6 show the PLUTO summary and gluon jet data. Finally Fig. 7 and 8 show Mark J results. The agreement of all four detectors is remarkable and give us even more confidence than is necessary in the conclusions. I refer you to Lohrmann's nice summary which I will not summarize.

We now turn to other accelerators and other detectors. A very nice result from this meeting was the VPI, Maryland, National Science Foundation and Peking collaboration. This is another example of exciting physics coming from a collaboration with the Peoples Republic (they also work with the Mark J group). It is an electronic experiment which demonstrates the basic four fermion process:

$$\nu_\mu + e \to \nu_\mu + e$$

The data is shown in Fig. 9 and, for an electronic detector, the elastic peak is very clear. The result is in irritating agreement with the Weinberg-Salam prediction. Note however that whereas the precision is not decisive, this experiment is completely free of uncertainties due to the presence of hadrons.

*Operated by Universities Research Association under contract with the United States Department of Energy.

I remind you that this was carried out by a simple, inexpensive 18 ton detector. To date the best determinations of the Weinberg angle come from the CERN neutrino and SLAC eD scattering. It would be very important, it seems to me, to have ν and $\bar{\nu}$ scattering data from electrons where the overall errors are $\simeq$ 10%. It is not easy!

Another very elegant experiment was carried out at old SPEAR by new crystal ball - a spherical array of conical sodium iodide detectors. The experiment concentrates on good efficiency and resolution for ~ few hundred MeV photons from charmonium spectroscopy (Fig. 10). The single photon spectrum from which π^0 photons have been paired off and subtracted is shown in Fig. 11. The new peak observed in these data indicates the transition

$$J/\psi \to X + \gamma$$

$$E_X = 2980 \text{ MeV}$$

This could very well be the long sought η_c! Notable also is the absence of any evidence for the two levels I show crossed out in Fig. 10. This clean up relieved everyone including Harari.

Fig. 12 presents another "indication" of new physics: a bump of noteworthy but not definitive significance in a final state effective mass of a $\psi K^-\pi^+$. The ψ is seen via its mu pair decay. This possibility illustrates the power of the multiparticle spectrometer (CERN's GOLIATH) as it invades the domain previously reserved for bubble chambers. That this peak is suggestive of exposed bottom (Godiva? see Quigg's report) is indicated in Fig. 13. The bump was observed with 150 GeV pions and the rate compared to Υ is not inconsistent with the ratio of D to J/ψ. However this doesn't make it correct and more data in more channels are needed.

I turn now in my subjective review of highlights to the CERN fine grain neutrino detector. Here they have new results from a beam dump mode i.e. one in which the π and K neutrinos are turned off by rapid absorption. The group acronym is CHARM and the data is shown in Fig. 14. They are looking at "prompt" neutrinos. It is the peak at low energy that is in question. Their summary chart is shown (Fig. 15).

The authors conclude that the peak is anomalous, not produced by background of cascading hadrons. A tenable conclusion is that we are seeing evidence for neutrinos associated with τ lepton. If this result is confirmed, it establishes the third neutrino and I experience another pang of nostalgia. The yield of τ-neutrinos will be a very important number to establish if we are to improve our understanding of the tau.

The same group provides much new data on neutral currents, hailing Weinberg-Salam and refining their Parameters:

$$\sin^2\theta = 0.230 \pm .009$$

$$\rho = 1.01 \pm .03$$

$$M_{Z^0} = 88.6 \text{ GeV}$$

This detector, in collaboration with the CDHS group presents another piece of data which brings tears of fond memory to this reviewer - the precession of the spin of muons from ν_μ charged current reactions. Fig. 16. In case there were any doubters, the reaction

$$\nu_\mu + N \to \mu^- + N^* \text{ is V-A!}$$

I come now to the Drell-Yan process i.e. dilepton production in hadronic collisions, (sigh!) named by Feynman after an experiment at BNL by Christenson. Here there is considerable progress in the experimental side with new data on pion induced dileptons from CERN and new ISR data at very high s. On the theoretical side progress took the form of several calculations of dilepton production in QCD - so called next order contributions. You may recall that there is a naive Drell-Yan quark-parton model. (QPM) This has had a very large amount of success in qualitative and semi-quantitative agreement with data. Politzer and others who looked at this process in QCD found that to leading order, the field theory gave the same results as QPM provided certain rules were followed in the correlation of this process with deeply inelastic scattering. Now higher order calculations are in and indicate contributions which approximately double the theoretical cross sections. See the paper of John Ellis for a review. The detailed changes in Q^2 and x are minor compared to the normalization effect except for $x \gtrsim .7$ which is outside of the present observations.

Experimentally, the results that were presented here by Pilcher came largely from his Fermilab work and from the NA-3 experiment at CERN. Pion-induced dileptons are shown in Fig. 17 and there we see a clear Υ peak. More nostalgia. I believe this is the first observation of Υ made by pions. They also looked in detail at many qualitative tests of the quark parton model e.g. the π^+/π^- ratio of dilepton production from isoscalar targets which tells you fundamentally the difference in the quark structure of the π^+ and π^-. The prediction is that when you get away from sea effects the ratio should approach .25. The CERN data does just that. Their conclusions, which are good confirmations of some of the Fermilab pion work, find that the charge asymmetry is correct, the angular distributions of dimuons is correct, and they find that α in the A^α dependence is 1.03 ± .03. In absolute normalization they find a difficulty. If we write:

$$\left(\frac{d\sigma}{dm}\right)_{exp} = K \left(\frac{d\sigma}{dm}\right)_{QPM}$$

They find $K \simeq 2$ both for incident pions and incident protons. The basic result is the photograph of a pion and this is in good agreement with the shape obtained in the Fermilab work. The pion structure, see Fig. 18 is given by the various experiments as:

$$f_\pi\ (x,Q^2) \sim (x)^{.4 \pm .1}\ (1-x)^{0.9 \pm .1} \qquad \text{NA-3}$$

$$\sim \sqrt{x}\ (1-x)^{1.1 \pm 1} \qquad \text{ClP}$$

$$< Q > \sim 7\ \text{GeV}$$

A factor of about 1.6 appears in the comparison of the sea distributions from the Fermilab proton data, (CFS) and the CERN neutrino data. This is illustrated in Fig. 19 where the agreement of the sea as deduced from dileptons and neutrinos would be much improved by this factor. There is a disagreement in the per nucleon normalization of the CERN and Fermilab pion-induced dilepton data. The issue is really in the A-dependence of the D-Y cross section. The Chicago-Princeton-Illinois group find $\alpha = 1.12 \pm .05$ behavior whereas CFS and the CERN NA-3 use $\alpha = 1$. This is a two sigma error but has a big effect on normalization. The curious thing is that the new QCD modifications to D-Y reviewed by Ellis predict just this factor of about 1.8. Curious because there is no guarantee that other non-leading terms will not further modify the simple D-Y result.

Another elegant piece of work in the Drell-Yan sphere is by the Chicago-Illinois-Princeton group in which they studied the angular distribution of dimuons about the quark-antiquark collision axis: Drell-Yan predicted, for spin 1/2 quarks:

$$1 + \alpha \cos^2 \theta$$

$$\text{and} \qquad \alpha = 1$$

The CIP result is shown in Fig. 20 where the deviation from $\alpha = 1$ is large at $x \to 1$. This evidence for longitudinal polarization of the virtual photons - an effect predicted by the QCD calculation of Brodsky and Berger. The point is that very large x corresponds to one of the annihilating quarks being far off mass shell. This is a "moderate Q^2" correction to the simple D-Y process and leads to longitudinal polarization and the appearance of a $\sin^2 \theta$ term.

I would like to proceed briefly with a number of items indicating the "slow, broad advance of the frontier" as opposed to the "bold salient into the unknown". There is progress in the "Michel parameter" of the τ decay i.e. the decay spectrum, $\gamma\gamma$ resonance production, D decays, charmed baryons. The Mark II and DELCO work were reviewed by Luth and Kirkby where "charmed baryon physics is just beginning". These results show that the lower energy i.e. SPEAR e^+e^- machines have lots to do. In hadronic production, Λ_c makes its appearance in several ISR experiments.

A dramatic report on the Fermilab emulsion studies of short lifetimes was made by Voyvodic. The numbers of fitted events in the Fermilab work are now about 10 and these experiments should give good lifetimes soon.

Well, the next subject has to do with nucleon structure functions and there were conclusions from the talk of Para on nucleon structure functions via neutrinos. Williams discussed scaling violations and made a detailed comparison of $F_2(x,Q^2)$ as seen by virtual photons and virtual W's. The data from CERN neutrino scattering (CDHS) and from Fermilab muon scattering, (BFP) are the most precise and are in especially good agreement over a reasonable range of x and Q^2. The newer high Q^2 data are not quite together. Systematic errors must be controlled before QCD predictions can be confronted. How incisive these can be is not at all clear after Ellis' talk where ambiguities are discussed. There is an amusing history to scaling. In 1970 scaling was discovered at low q^2. It had to be discovered, they were told to discover scaling. In 1975 scaling violations were discovered at Fermilab. In 1979 Williams' review teaches us that at low q^2 scaling is violated and at high q^2 there is practically no scaling violations! But not to worry, it is all consistent with the theory.

The official language of this conference is supposed to be English but this is what we hear in theoretical talks:

Gluestrahlung
Rishons
Quinks
Onia
Preons
Maons
Instantons
Solitons

We also hear that we are for the moment topless and we may have naked bottoms. (No wonder we have trouble getting funding!)

Before a resounding global conclusion, I should comment on the theoretical talks. The reports of Gaillard, Ellis, Veltman and Harari were especially stimulating to me as an experimentalist. Gaillard's discussion of open questions in weak interactions is a primer for those looking for challenging experiments or designing future accelerators. She summarized the reactions which would provide tests of the higher order corrections to what she calls QAD, now a full fledged theory on an equal footing with QED.

The exploration of the Higgs Spectrum culminated in a beautiful graph giving betting odds on where to look. I'm as uncomfortable with these Higgs theories as most experimentalists but know that it will be fun to look. I learned too that there are some ideas which tend to limit the proliferation of fermions and range of masses (there is another graph) and this is the 1979 version of all those nostalgic lectures on the mystery of the muon and the electron. Why does the muon weigh? After reviewing CP violation and decay dynamics, Mary K's conclusion is:

"... there is an honest theory of weak interactions... a major accomplishment of the past decade."

Ellis presents us with the hard work of shaping up a new theory in its useful state: perturbative QCD. There is qualitative progress since the last conference. The data is good and getting better. A large number of processes are discussed in the paper: e^+e^- total cross sections, charmonium, deeply inelastic structure functions, Drell-Yan, jets, real photons at large $p_\perp$ and QCD applied to exclusive processes such as form factors. Ellis concludes: "The theoretical status of QCD calculations is very sound. We still lack convincing proof of the validity of these calculations.... We have to resign ourselves to a long haul of piling up circumstantial evidence...". Veltman is fascinated by the possible richness of high mass phenomena ("we've only seen the tip of the iceberg"). He looks for hints in the data we are getting while grovelling below 30 GeV. There is a threshhold at 1000 GeV: either the Higgs shows up or a new class of strong interactions must be there. He also discusses the (weak) constraints on masses of Higgs and new fermions given by present data. However what interested me most was the more speculative exploration of the possible internal structure of the array of objects usually taken to be elementary: quarks, leptons, W's, Higgs. Enter "quinks". Enter also technicolor, the theory of a new strong force that binds the constituents of the Higgs. The excitement here is that a new spectrum of hadrons could appear and constraints suggest 200 GeV as a threshhold. It just so happens that the Fermilab $\bar{p}p$ collider will be the only accelerator capable of addressing both Veltman threshholds. Harari gave his usual, crystalline review of e^+e^- physics which cannot be served by my comments. Enter rishons.

Now I would have explained to you the papers of Wilchek, Mandelstam and Polyakov but we are rescued by the lateness of the hour so I will instead wish you all a bon voyage and please come again!

Conclusions

1. The ratio R of the total cross section for e^+e^- annihilation into hadrons to the μ pair cross section is constant within errors between c.m. energies of 17 and 31.6 GeV and has a value close to 4.

2. No evidence has been found for the t quark. It appears unlikely that the threshold for continuum $t\bar{t}$ production is below 30 GeV.

3. The multiplicity for charged particles above 10 GeV is found to rise faster than at lower energies.

4. The cross section quantity $s\ d\sigma/dx$ scales for $x > 0.2$ and $W \geq 5$ GeV to within $\pm$ 30%.

5. The shape and magnitude of the total cross section, the observed scaling of $s\ d\sigma/dx$, the occurence of jets and their gross features are in astonishing agreement with the quark hypothesis.

However:

6. The transverse momentum distribution of hadrons relative to the jet axis broadens with increasing energy: $\langle p_T^2 \rangle$ rises rapidly. Hence in the $q\bar{q}$ model the fragmentation function is not energy dependent.

7. The increase of $\langle p_T^2 \rangle$ occurs primarily in only one of the two jets. The distribution of the transverse momentum perpendicular to the "event plane" does not show a pronounced energy dependence while a strong broadening takes place in the event plane at the highest values of $s (= Q^2) \approx 1000\ \text{GeV}^2$.

8. We observe planar events at a rate which is well above the rate computed for statistical fluctuations of the $q\bar{q}$ jets.

9. The planar events when analyzed as three-jet events yield an average transverse momentum of 0.3 GeV/c relative to the jet axis.

10. The planar events establish in a model independent way that a small fraction of the e^+e^- anninilation events proceeds via the emission of three constituents, each of which materializes as a jet of hadrons in the final state.

The data are most naturally explained by hard non-collinear gluon bremsstrahlung, $e^+e^- \to q\bar{q}g$.

Fig. 1

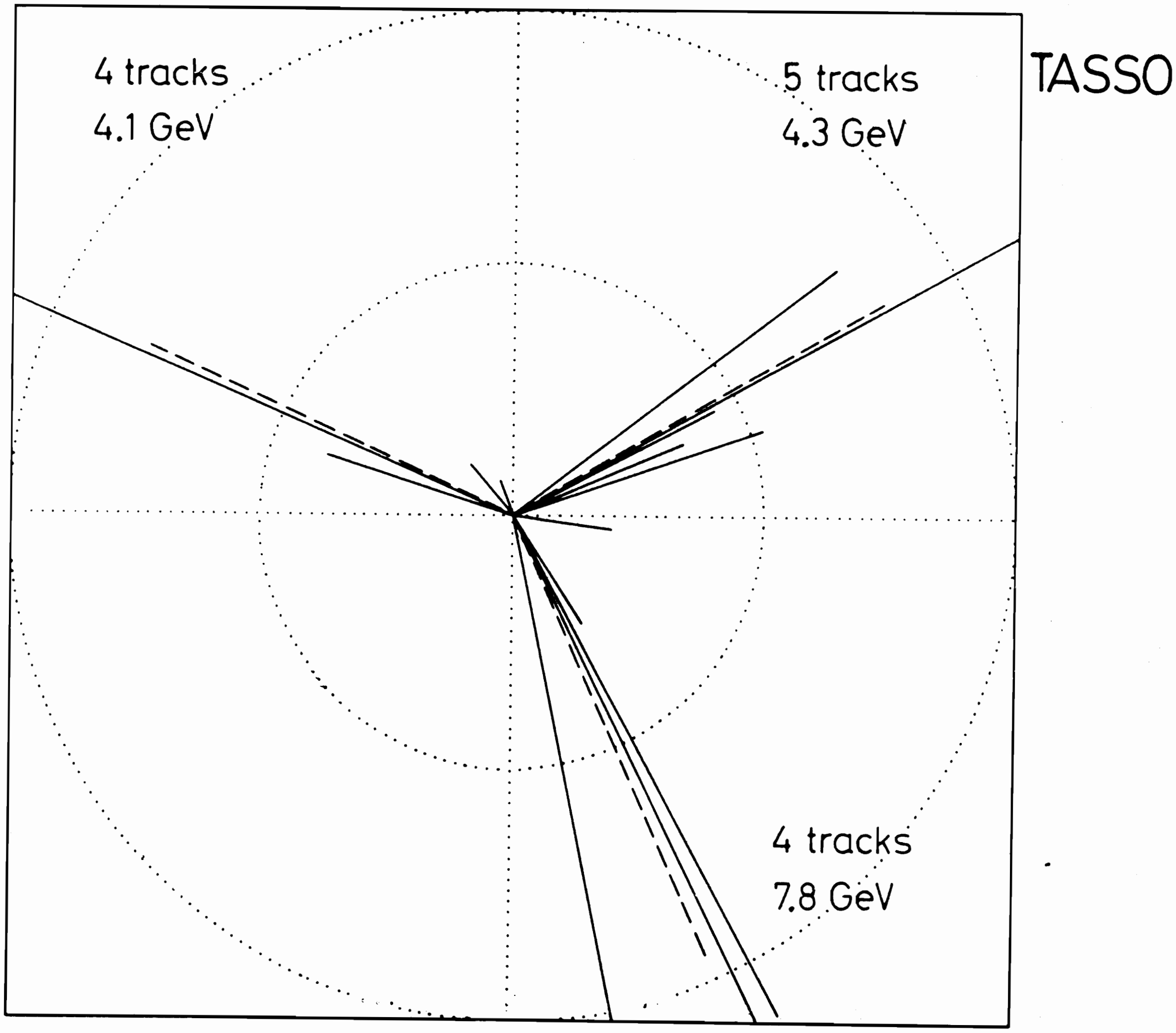


Fig. 2. Another 3-jet event projected into the event plane.

Conclusions

1) Validity of QED and the point-like nature of $e^{\pm}$ are tested to distances of 2×10^{-16} cm.

2) R values (total hadronic cross section in units of the point-like μ pair production cross section) are measured to be about 4 at $\sqrt{s}$ from 22 to 31.6 GeV. This value is compatible with the production of quarks with only the known flavours.

3) No evidence is obtained for events with spherical hadron distribution. Open top production is unlikely at $\sqrt{s}$ below 30 GeV.

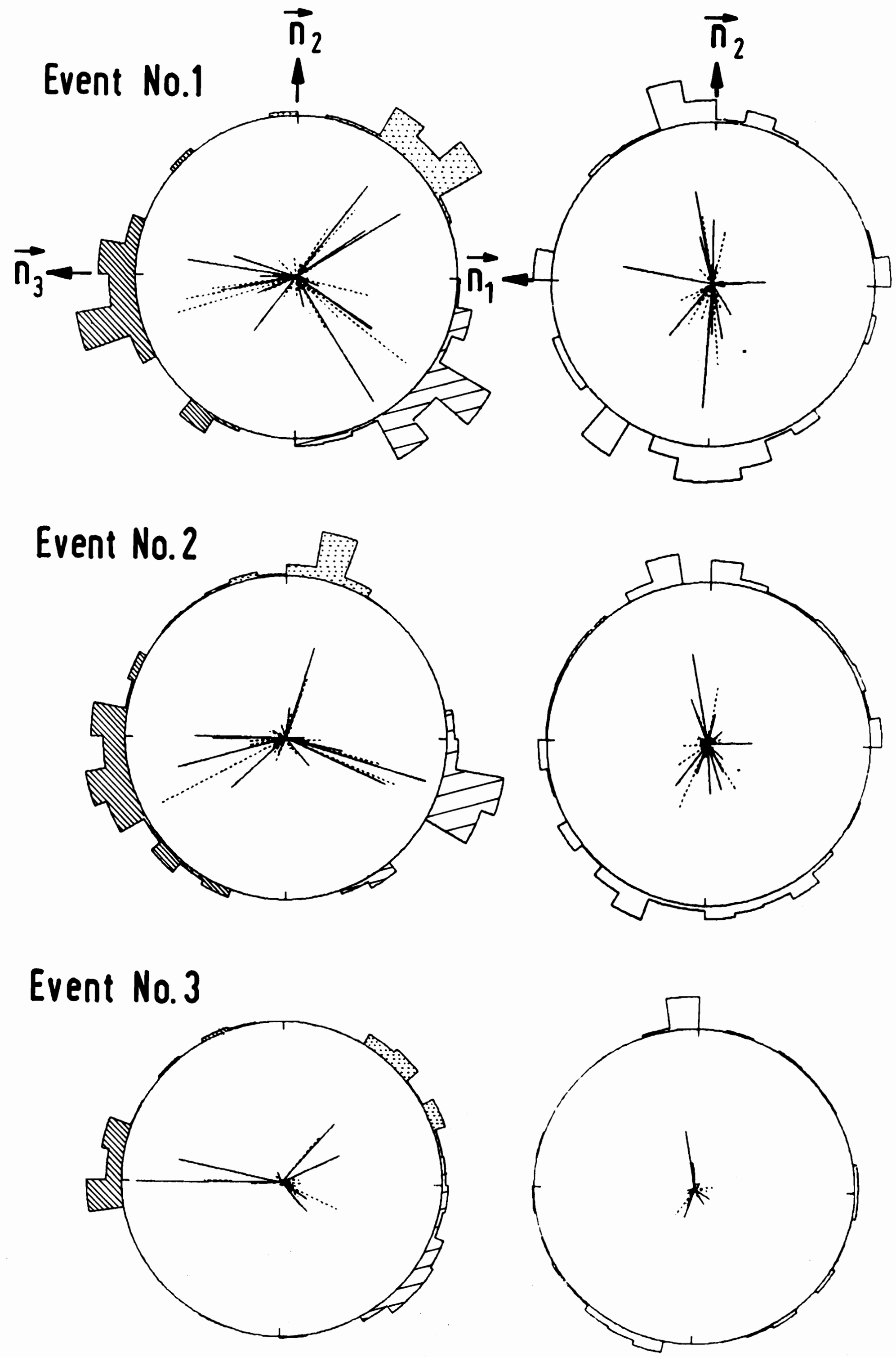
4) Planar events are observed at a level far above the statistical fluctuations of the two-jet process. The planar events exhibit distinct three-jet structure in many cases. This proves that a fraction of the e^+e^- anninilations proceed via a three-body primary process and subsequent fragmentations of the three primary particles.

5) Quantitative as well as qualitative properties of the planar three-jet events agree in detail with the predictions based on the gluon bremsstrahlung process $e^+e^- \to q\bar{q}g$ and the subsequent fragmentations. This strongly suggests hard gluon bremsstrahlung as origin of the planar three-jet events.

6) No evidence is seen for fractionally charged or heavy stable particles produced together with multihadrons.

7) The angular distribution of the jet axes indicates a transverse polarization of the beams at $\sqrt{s}$ = 30 GeV.

Fig. 3.



Typical three jet events projected onto the $(\vec{n}_3,\vec{n}_2)$ and $(\vec{n}_1-\vec{n}_2)$ planes. The full and dotted lines represent the momentum vectors of charged and neutral particles respectively. The energy flow is shown by the histograms plotted on a circle around each event.

The three energy clusters obtained from a three-jet analysis are indicated in the $(\vec{n}_3,\vec{n}_2)$ projection of each event. Note that the momentum and energy scales are different for the three events.

Fig. 4

Conclusions

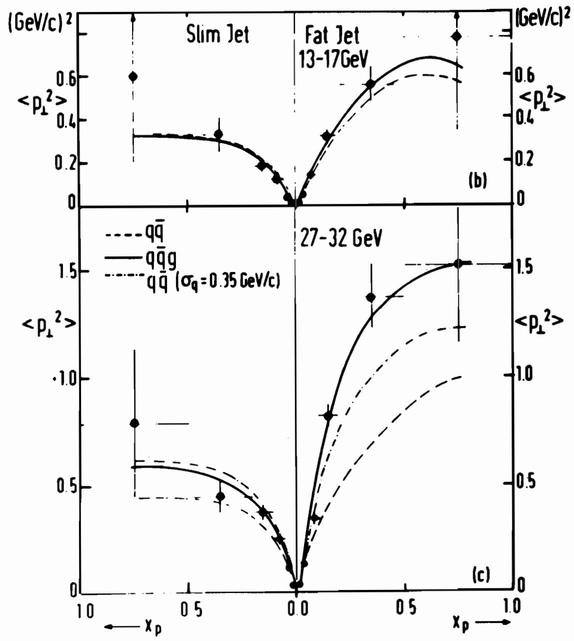
QED is valid down to very small distances ($\approx 3.10^{-16}$ cm)

It is very unlikely that the continuum for $t\bar{t}$ production is below 30 GeV center of mass energy.

There is evidence for gluon bremsstrahlung. Jet broadening and triple jet production rate agree with QCD predictions.

The cross section for hadron production via 2γ interactions agrees with Regge assymptotic behaviour at high CM energies. At low energies there is room for pointlike contributions.

Fig. 5



Seagull plots - $\langle p_\perp^2\rangle$ of charged particles as function of x_p for slim and fat jets at low and high energies. The solid and dashed lines are $q\bar{q}g$ and $q\bar{q}$ predictions, respectively.

Fig. 6

Summary of Mark J Results

1. e, μ, τ pointlike to $\approx 2 \times 10^{-16}$ cm
   $\Lambda \approx 100$ GeV
   $e^+e^- \to e^+e^-\mu^+\mu^-$ in good agreement with QED
2. R values and thrust distribution $\to$ no charge 2/3 quark threshold up to 31.6 GeV
3. Energy flow is in good agreement with QCD. Flat events disagree with naive $Q\bar{Q}$ model.

Fig. 7

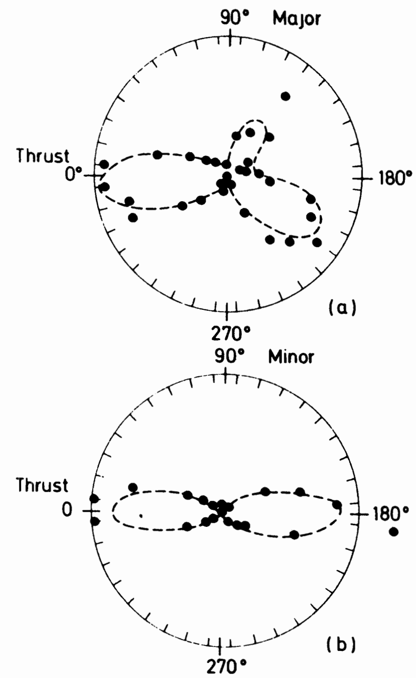


Fig. 8

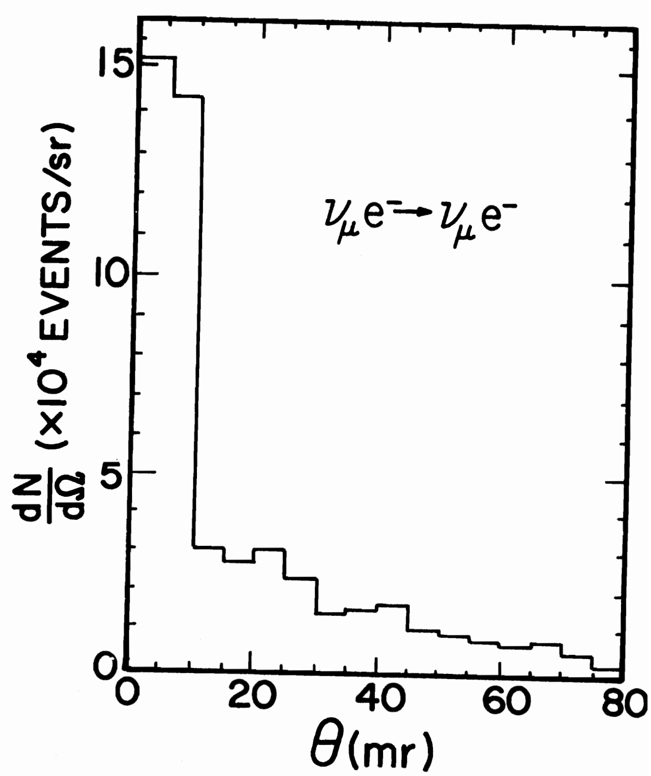
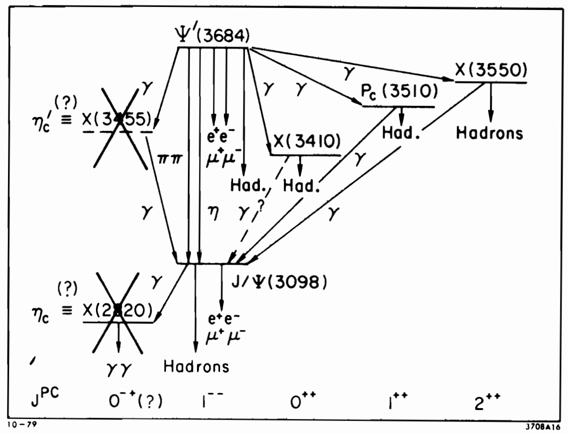
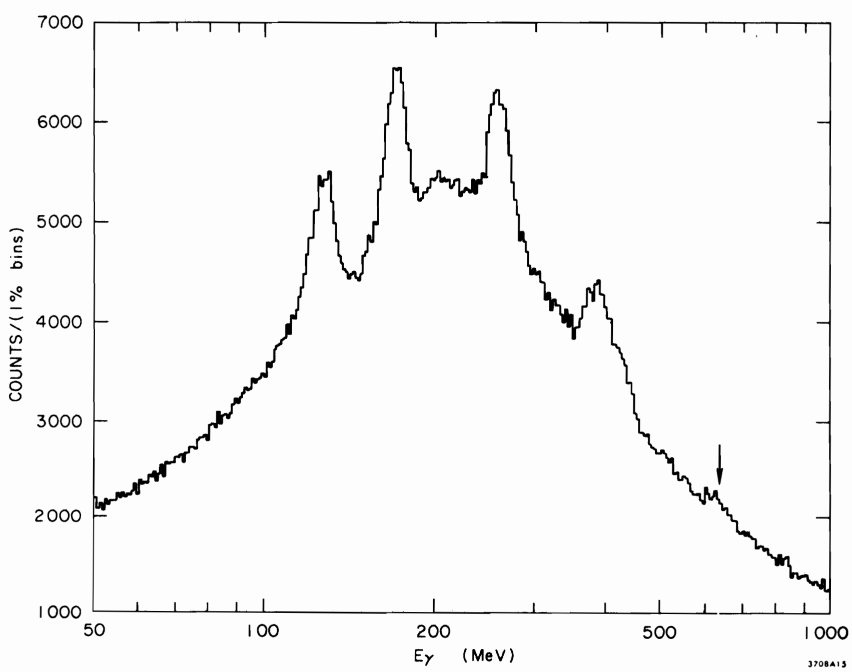


Fig. 9



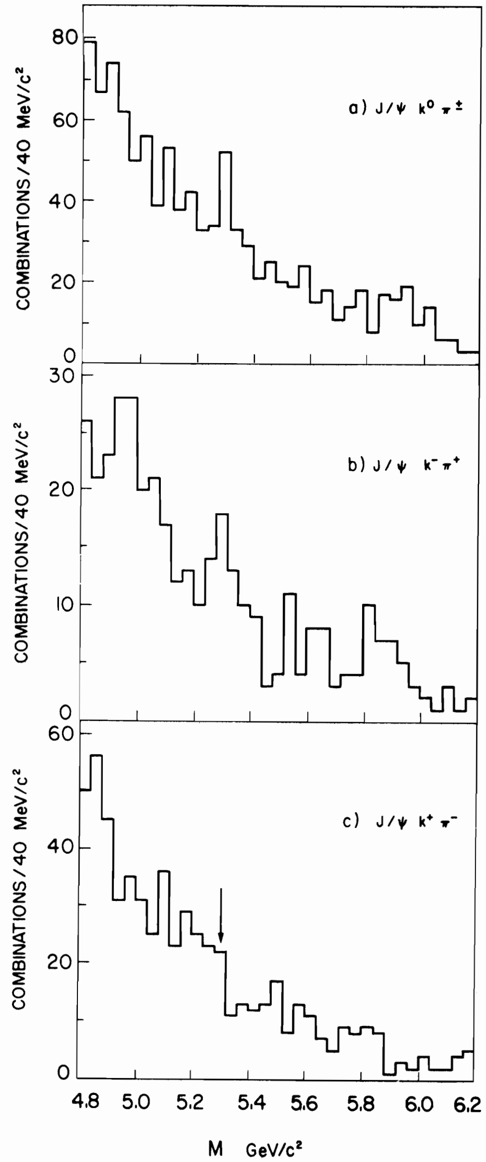
The state of knowledge of the psionium system, as interpreted by the charmonium model, at the last lepton photon conference (minus crosses). The crosses are some of the contributions of the Crystal Ball herein reported.

Fig. 10



Preliminary inclusive photon spectrum generated from 800K ψ' events. The cuts which are used to produce this spectrum are given in Table VII. The well-established states $\chi(3555)$, $\chi(3510)$ and $\chi(3410)$ are clearly evident starting on the left. The next bump to the right is the second cascade photons from $\chi(3555)$ and $\chi(3510)$. The last little bump (under the arrow) is a new state U(2.98 ± 0.02).

Fig. 11



a) $J/\psi K^0\pi^{\pm}$ mass spectrum.
b) $J/\psi K^-\pi^+$ mass spectrum with $p_T(K) > 0.5$ GeV/c^2.
c) $J/\psi K^+\pi^-$ mass spectrum with $p_T(K) > 0.5$ GeV/c^2.

Fig. 12

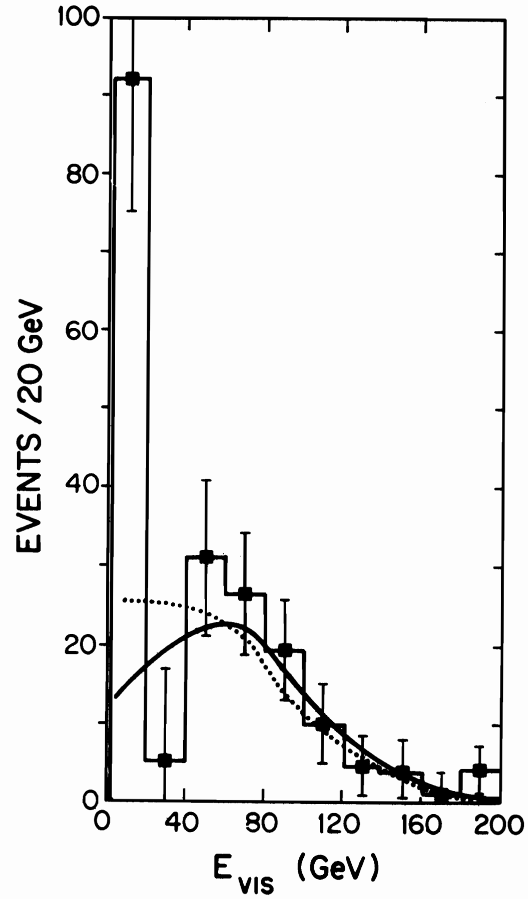


Fig. 14

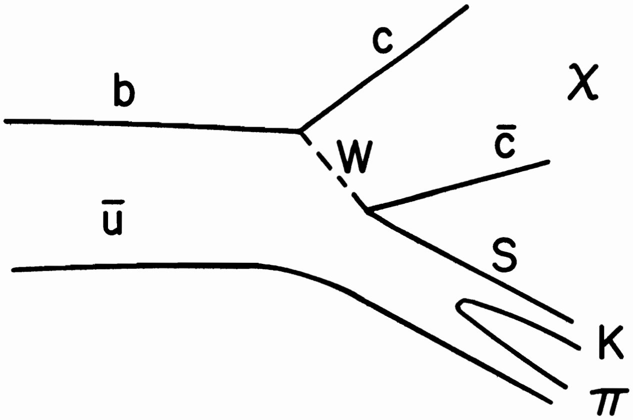


Fig. 13. Naked bottom decay $B \to \chi\pi K$.

Conclusions — Charm

i. Observations on prompt ν's from D-meson decays agree with all other experiments.

ii. Excess of 72.1 ± 15.9 (4.6σ) muon-less events cannot be attributed to ν_μ or ν_e interact.

iii. Observation of ~ 6 events with missing p_t^{μ}

iv. Most plausible interpretation tau neutrinos

v. Production mechanism unclear.

Fig. 15

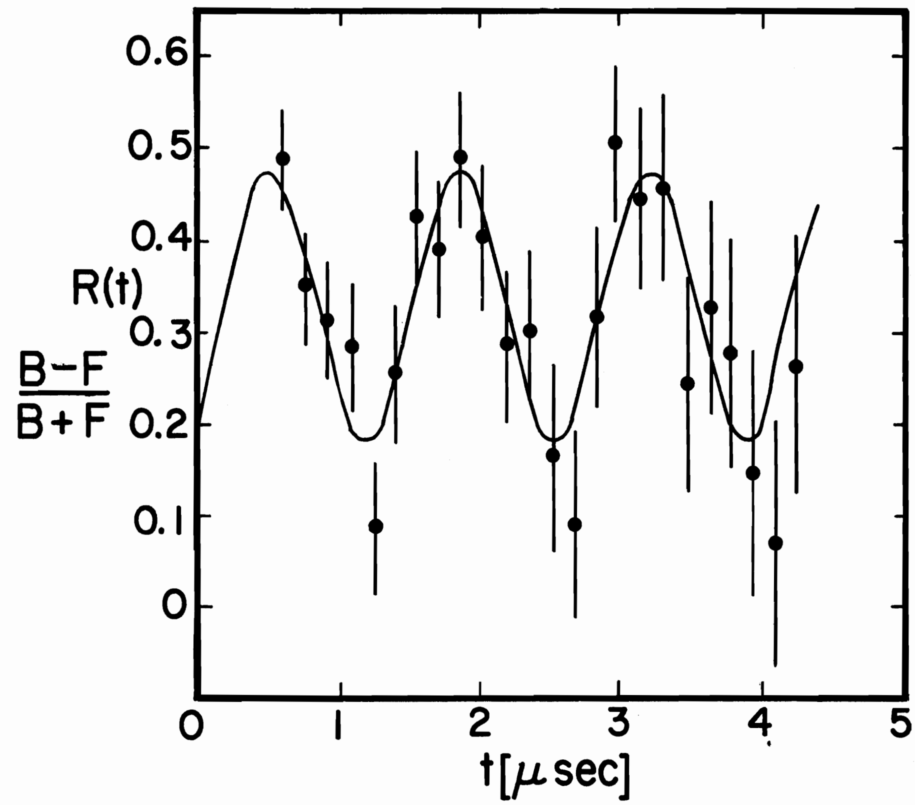


FIG. 16

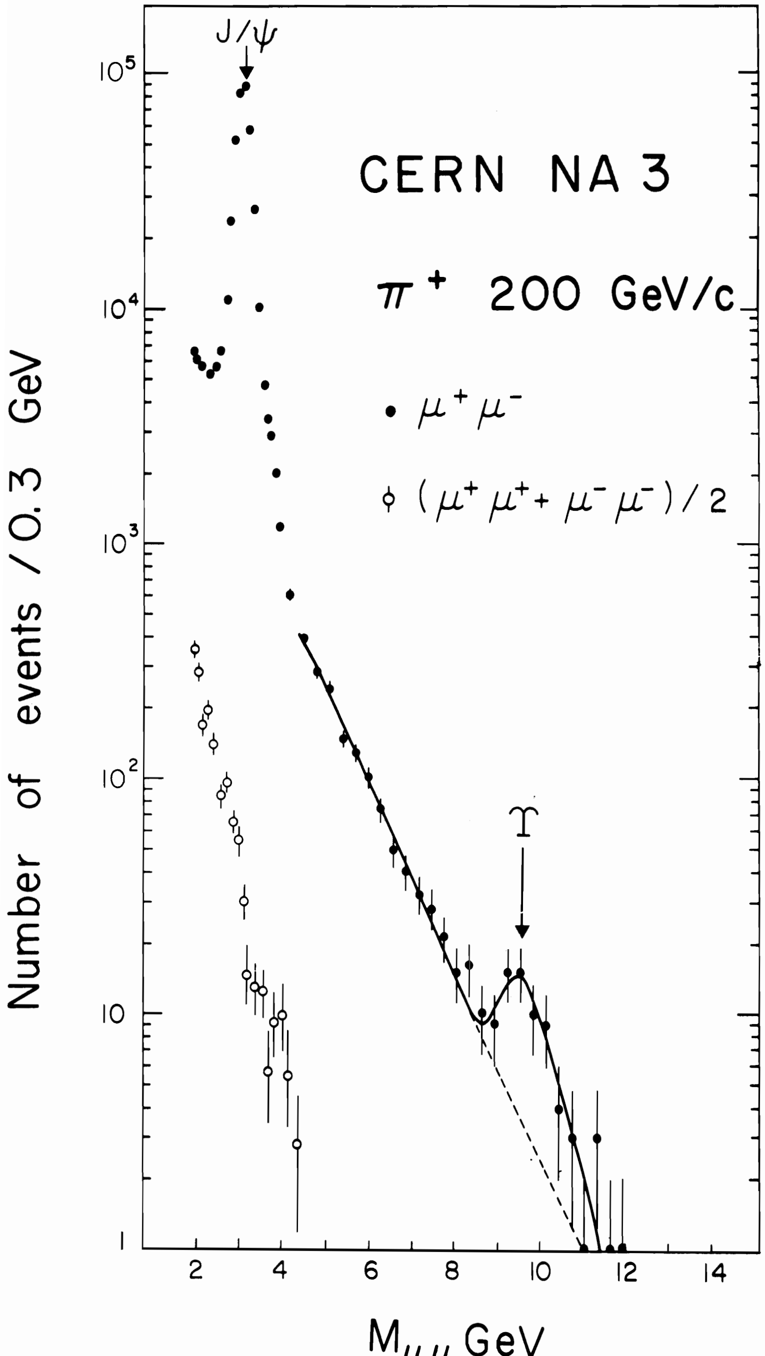


Fig. 17. Di-muon mass distribution for π^+ at 200 GeV/c.

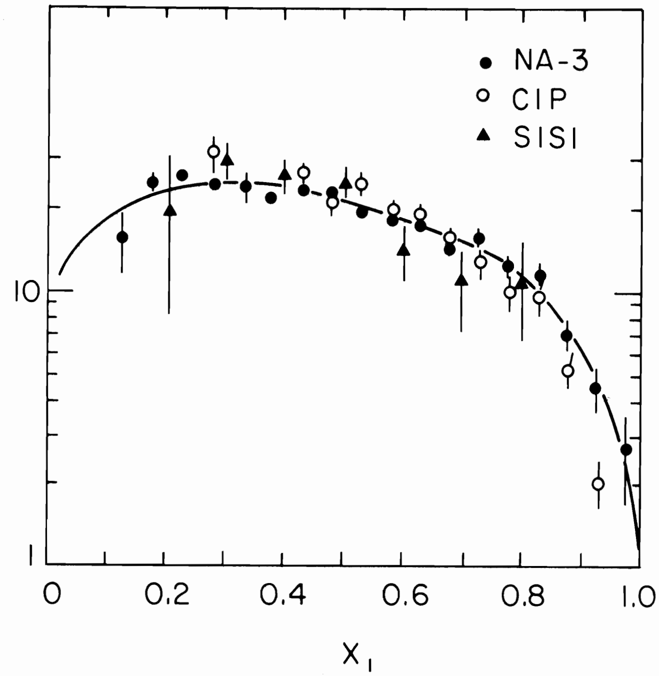


Fig. 18. Shapes of the pion structure function as inferred from a Drell-Yan analysis in three recent high energy experiments. Note that the same normalization has been applied to each experiment.

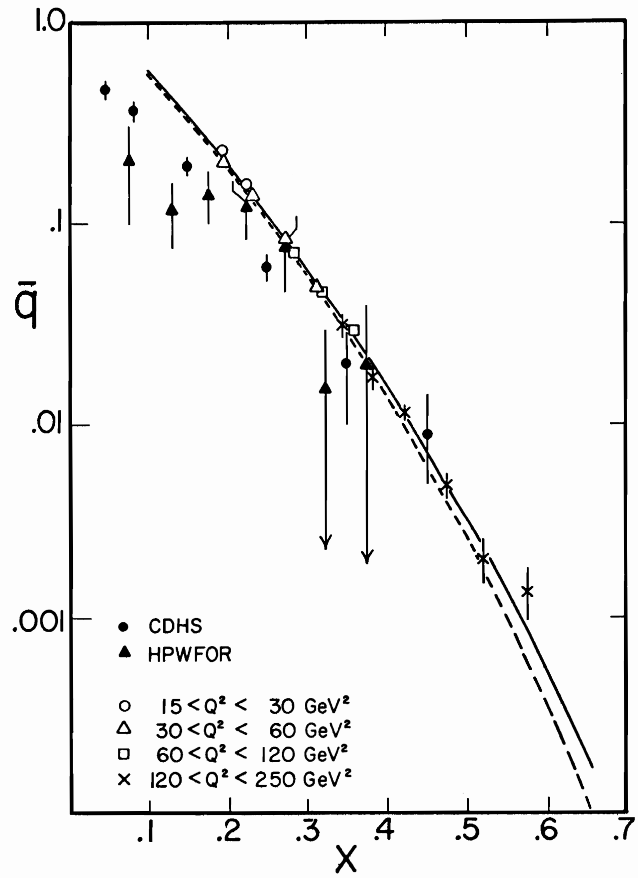


Fig. 19. Comparison of antiquark distribution in the nucleon as determined in deep inelastic neutrino experiments (solid circles and triangles) and in lepton pair production by the CFS group.

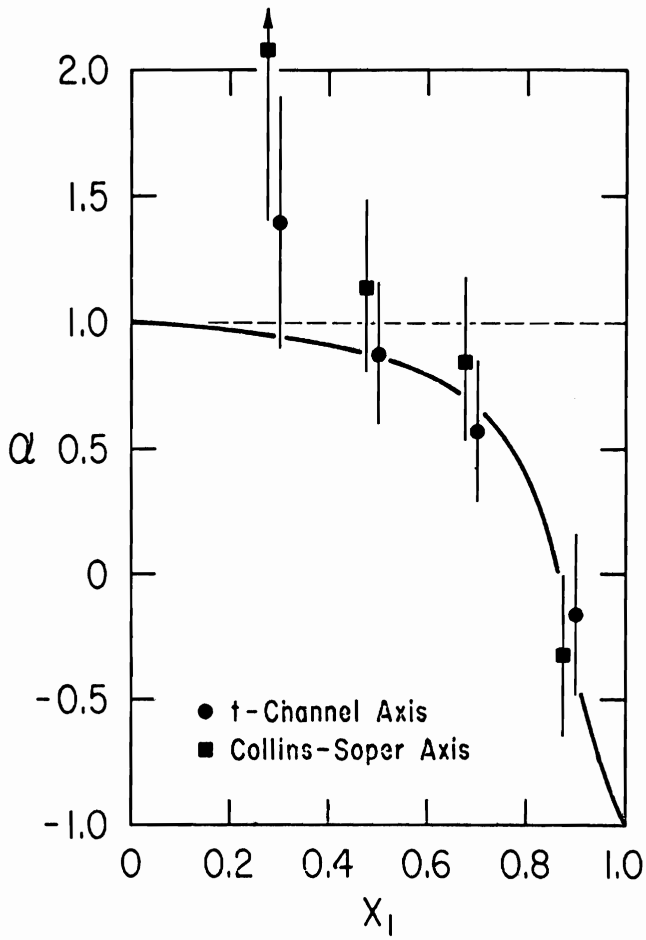


Fig. 20 Results for α from a fit of the helicity angular distribution $dN/d\cos\theta^* \propto 1 + \alpha\cos^2\theta^*$ in different x intervals.