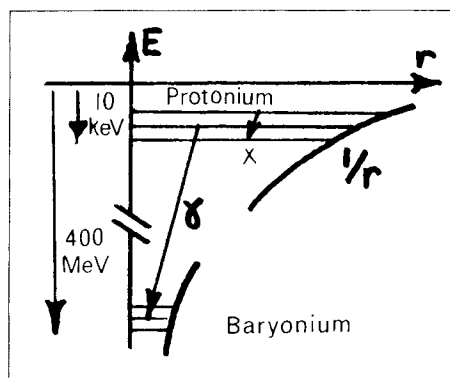




Schematic representation of protonium and baryonium bound states, showing the origin of the observed X-ray and gamma-ray spectra.

system of gamma rays coming from stopped antiprotons in hydrogen. These gamma rays, with energies of 100 to 400 MeV, are emitted when protonium, an atomic system with a first Bohr orbit radius of about 60 fermis, collapses into baryonium, a tightly bound quasinuclear strong interaction state of radius about 1 fermi.

Previous experiments by T. Kalogeropoulos from Syracuse claimed to see discrete gamma-ray spectra in antiproton-deuteron annihilations, but statistics were poor. Now, at CERN, the Basel / Karlsruhe / Stockholm collaboration has carried out a thorough search for gamma transitions in antiproton annihilations in hydrogen. The result is at least four discrete gamma-ray lines in the energy range 100 to 400 MeV.

While this group continues to investigate this gamma-ray spectrum, another group at CERN, a Daresbury / Mainz / TRIUMF collaboration, is looking at the X-ray spectrum seen coming from energy level transitions in atomic protonium.

The idea that the $N\bar{N}$ system can form tightly bound states which would show up as gamma transitions from protonium was suggested by I. Shapiro from ITEP (Moscow). He said that resonant $N\bar{N}$ states should exist as a result of the same meson exchanges which occur in the NN channel. A complementary point of view comes from the quark model, where the discovery of baryonium solves the 'duality' puzzle of baryon-antibaryon reactions which had long been worrying theorists.

In this channel, the deuteron is the only well-known bound state, although evidence now exists for another (see May issue, page 152). However the contributions of mesons with odd G-parity (like the omega), have opposite signs in the NN and $N\bar{N}$ channels. If the relative absence of bound states in the NN channel is interpreted as the result of a repulsion, then there should be a strong attractive force for $N\bar{N}$.

In other words the dearth of bound states in the NN channel could be indicative of a relative abundance of resonances in the crossed channel, and more baryonium states could yet be discovered.

Another heavy lepton sighting?

At Stanford, a Santa Cruz / SLAC collaboration has long been puzzled by a narrow enhancement at 1840 MeV in the muon-rho mass distribution coming from the reaction $\mu N \rightarrow \mu p N$. This signal is defying all attempts to make it go away and could perhaps be related to the heavy lepton seen in electron-positron annihilation experiments at the SPEAR and DORIS storage rings.

Using streamer chamber techniques to pick up the small signals involved, the Santa Cruz / SLAC experiment looks at the interactions of a high quality 14 GeV muon beam producing fast forward muons. For $\pi^+\pi^-$ production reactions, the $\mu\pi\pi$ mass spectrum is unremarkable, but when the $\pi\pi$ events corresponding to rho production are selected out, things begin to happen. Some 30 events are seen at 1840 MeV with a width of 25 MeV.

Far from heralding this discovery as more evidence for a heavy lepton, the collaboration has spent a long time trying to find some alternative explanation for it. Other muon experiments at SLAC do not see it, and the signal is not reproduced in neutrino experiments.

One of the first things the collaboration tried was to repeat the experiment with hadron beams in place of the muons to see if the signal was being faked by contamination of the muon beam. Nothing was seen.

Could the signal be the same heavy lepton seen in the annihilation experi-

ments at SLAC and DESY? One big problem for this viewpoint is the requirement to keep in line with the accurate muon data from the g-2 experiment at CERN. To do this, special couplings between the muon, the rho and any new heavy lepton would have to be introduced.

High-y OK

Fermilab bubble chamber experiments and the Caltech/Fermilab counter group, together with two major collaborations at the CERN SPS — the CERN / Dortmund / Heidelberg / Saclay counter experiment and the Aachen / Bonn / CERN / London / Oxford / Saclay group using the BEBC bubble chamber — have obtained comprehensive statistics for neutrino interactions. Taken together, they are free of the anomalies suggested by earlier results which would have called for major upheavals in the underlying theory.

Neutrino-nucleon interactions at high energy are usually interpreted in terms of the parton model which treats the target nucleon like a box of small, hard scattering centres. Evidence for such small scattering centres deep inside the nucleon was first seen in electron-proton experiments at Stanford. The quark model postulates constituents inside the proton and results from neutrino experiments led to an amalgamation of the two ideas, showing that quark-like objects were indeed responsible for the effects seen in high energy lepton-nucleon scattering experiments.

The quark / parton model makes definite predictions about the way the leptons should transfer their energy to the proton constituents, and these spectra, known in the trade as 'y-distributions', should have one form for neutrinos and another for anti-neutrinos.

The variation of the ratio of antineutrino to neutrino cross-sections with energy as measured by the CERN/Dortmund/Heidelberg/Saclay counter experiment at the SPS ('This Expt'), showing that the anomalous behaviour (the high- γ anomaly) previously reported is not confirmed.

Contributing to the latest results on high energy neutrino interactions are experiments in the 3.7 m European bubble chamber, BEBC. They gathered 280 000 pictures with neutrinos generated by a 200 GeV SPS beam and have 520 neutrino and 250 antineutrino photographs. The chamber is performing

efficiently (over 95% during the first operating period) and giving pictures of good quality.

1. The typical complexity of the interactions seen in BEBC by the Aachen / Bonn / CERN / London / Oxford / Saclay collaboration when a high energy neutrino interacts in the chamber liquid.

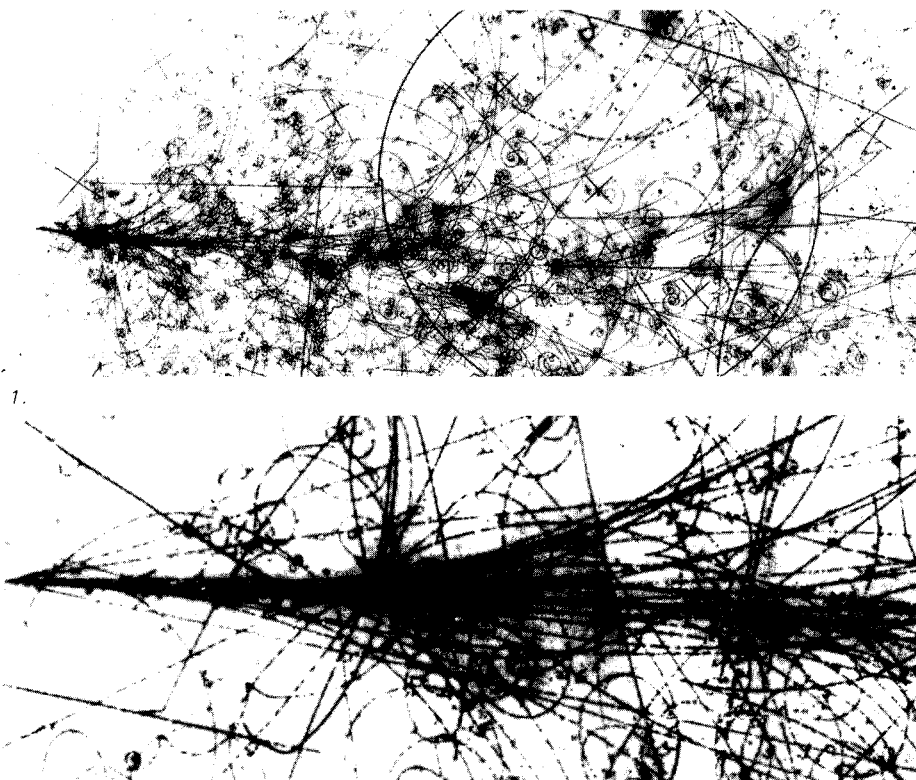
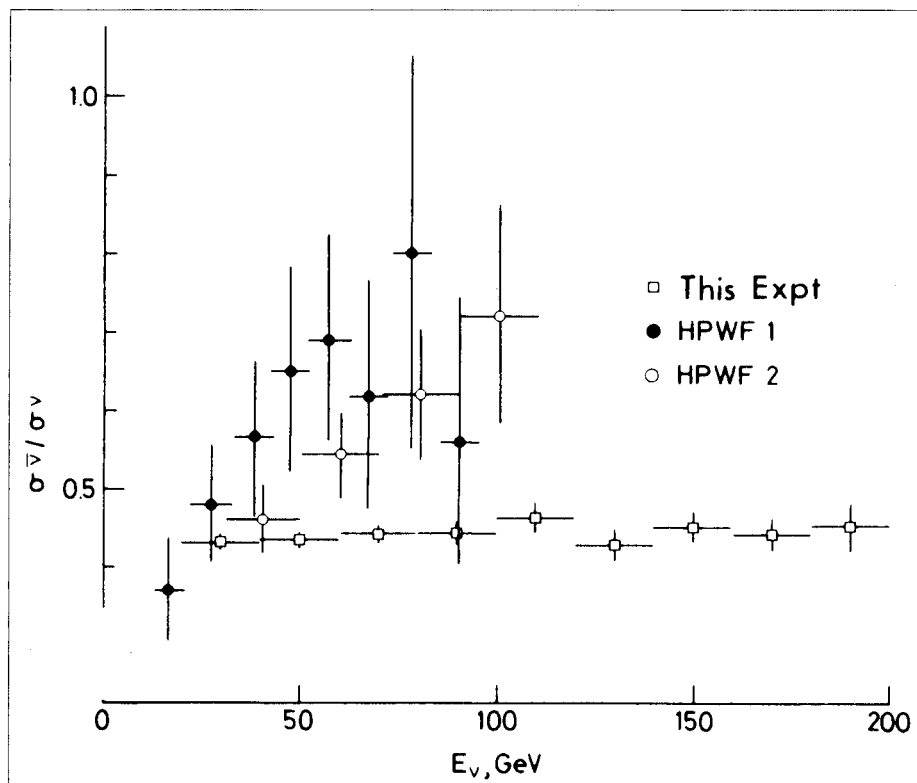
2. An enlargement of the primary interaction area of the above photograph which shows just how well the bubble chamber records this maze of particle tracks.

If the target proton appeared simply as a box containing three quarks, as might be naively assumed from the quark model, then total cross-sections for antineutrinos should be one-third of those for neutrinos. The data gathered at low energies in the Gargamelle bubble chamber at CERN gives a ratio of nearly one-third, but there is a small but systematic deviation from this value. This is attributed to the virtual quark-antiquark pairs which are constantly emitted and absorbed by the proton state. These virtual quark pairs are often termed 'sea' quarks to differentiate them from the permanent or 'valence' quarks.

Investigations at higher energies produced a steady trickle of results from the Fermilab / Harvard / Pennsylvania / Wisconsin group which suggested that the ratio of neutrino and antineutrino cross-sections behaved erratically at high energies, while the antineutrinos did not transfer their energy to the quarks in the predicted way.

Because of the deviation of these spectra from the predicted form, the effects came to be collectively known as the 'high- γ anomaly'. To explain the observations, additional particle production mechanisms for antineutrinos were needed, and the so-called 'bottom' quark with right-handed coupling was brought in to augment the up-down-strange-charm quark family.

The latest experimental results do not show this erratic behaviour. Instead, they all have the antineutrino to neutrino cross-section ratio varying smoothly with energy and obtain statistics compatible with the standard quark / parton predictions. They also have the same fairly gentle deviations from scaling already seen in electron and muon scattering experiments at Stanford and Fermilab. The quark / parton model fits the observed behaviour remarkably well.



2.