This paper is a review of particle production by neutrinos in charged-current inclusive and exclusive channels. In Fig. 1, I have compared the production rates for various particles in neutrino-nucleon interactions at a beam energy of 25 GeV. The mesons are, of course, dominated by pion production. The $\rho^0(760)$ rate is an order of magnitude smaller. Strange and charm pseudoscalar mesons are a further factor of two down in rate. The strange vector mesons are suppressed by more than an order of magnitude relative to $K^0$ production; however, the charmed $D^{++}(2010)$ is only a factor of two smaller in rate than the $D^0(1860)$. With regards to the baryons, most of them are, of course, nucleons. The $\Lambda^0$ and $Y(1385)$ rates are down by one and two orders of magnitude, respectively. The lower limit on the charmed $\Sigma^{++}$ baryon rate is similar to the $Y(1385)$ rate. Finally, the quasielastic and one-pion production exclusive channels have about the same cross section as that of the $D^{++}$; associated production of strange particles in the $\nu N \rightarrow \mu^- K^+ \Lambda$ channel and the $\Delta S = 1 \Delta Q$ process $\nu p \rightarrow \mu^- p K^+$ are down by factors of five and twenty, respectively, compared to the quasielastic cross section.

I will, in order of increasing mass, review the new data available on some of these processes.

**Low Mass Particles**

One-pion production is the only inelastic neutrino process with good data available and corresponding detailed theoretical calculations. Three neutrino and three corresponding antineutrino one-pion production reactions. As shown in Table I, the amplitudes for the reactions can be decomposed into isospin 1/2 and isospin 3/2 components, with $\phi_{13}$ being the relative phase angle between them. One basic physics goal of the experiments is to measure these amplitudes as a function of $\pi N$ mass, the cross section for any observed bumps in the mass spectrum, and some corresponding production and decay angular distributions.

Table II gives a summary of the six recent experiments. The typical experiment has a few hundred events available in any channel.

*Fig. 2* shows the $p\pi^+$ effective mass distribution in the three-constraint process $\nu p \rightarrow \mu^- p \pi^+$ for mean beam energies of 1 and 30 GeV; the data are from the 12-ft* and BEBC** light liquid experiments. At low energy, only the $\Delta^{++}(1236)$...
Table I: One Pion Production Amplitudes

<table>
<thead>
<tr>
<th>One Pion Production</th>
<th>Reactions</th>
<th>Isovector Amplitudes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu p \rightarrow \mu^- p\pi^+$</td>
<td>$\nu n \rightarrow \mu^+ n\pi^-$</td>
<td>$T_{3/2}$</td>
</tr>
<tr>
<td>$\nu n \rightarrow \mu^- p\pi^0$</td>
<td>$\nu p \rightarrow \mu^+ p\pi^0$</td>
<td>$\frac{\sqrt{2}}{3} T_{3/2} - \frac{\sqrt{2}}{3} T_{1/2}$</td>
</tr>
<tr>
<td>$\nu n \rightarrow \mu^- n\pi^+$</td>
<td>$\nu p \rightarrow \mu^+ p\pi^-$</td>
<td>$\frac{1}{3} T_{3/2} + \frac{2}{3} T_{1/2}$</td>
</tr>
</tbody>
</table>

Table II: Summary of Recent One Pion Production Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Bubble Chamber</th>
<th>E (GeV)</th>
<th>Reactions</th>
<th>$\Sigma$ Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACM$^1$</td>
<td>12-foot/D$_2$</td>
<td>0.5 - 6</td>
<td>$\nu N \rightarrow \mu^- N\pi$</td>
<td>600</td>
</tr>
<tr>
<td>ABCED$^2$</td>
<td>GGM/Propane + Freon</td>
<td>1 - 8</td>
<td>$\nu N \rightarrow \mu^- N\pi$</td>
<td>$\sim$ 600</td>
</tr>
<tr>
<td>BMSTL$^3$</td>
<td>GGM/Propane + Freon</td>
<td>1 - 8</td>
<td>$\nu N \rightarrow \mu^- N\pi$</td>
<td>$\sim$ 650</td>
</tr>
<tr>
<td>ABCMO$^4$</td>
<td>BEBC/H$_2$</td>
<td>5 - 100</td>
<td>$\nu p \rightarrow \mu^- p\pi^+$</td>
<td>700</td>
</tr>
<tr>
<td>FMBH$^5$</td>
<td>15-foot/H$_2$</td>
<td>5 - 100</td>
<td>$\nu p \rightarrow \mu^- p\pi^+$</td>
<td>200</td>
</tr>
<tr>
<td>ACMP$^6$</td>
<td>15-foot/H$_2$</td>
<td>5 - 80</td>
<td>$\nu p \rightarrow \mu^- p\pi^+$</td>
<td>130</td>
</tr>
</tbody>
</table>

state is visible. At high energy, there are events at high mass, but no peaks are apparent in the 1700 or 1900 MeV mass regions where several $\Delta_T$ states are known to exist. The $I = 3/2$ $N\pi$ amplitude at high mass is certainly not large.

Figure 3(a-b) shows the $p\pi^-$ effective mass distribution in the three-constraint process $\nu p \rightarrow \mu^- p\pi^-$ for mean beam energies of 3 and 25 GeV; the data are from GGM$^3$ and the 15-foot chamber$^6$ experiments. Even at low energy, there is considerable production of events with mass greater than 1.4 GeV. With the energy increased to $\sim$ 25 GeV, the $D^0(1236)$ is hardly visible; the mass spectrum is dominated by the 1400-1900 MeV region. Since we know the $I = 3/2$ amplitude is small for $M_{N\pi} > 1.4$ GeV, the $I = 1/2$ amplitude must be responsible for this broad enhancement.

Figure 4(a) shows the energy dependence of the $\nu p \rightarrow \mu^- \Delta_T^{++}$ cross section from 0.5 to 100 GeV. The data displayed are from three different bubble chambers, $^1,^4,^5$ The neutrino flux was determined by pion and kaon yields for the 12-foot data. The other two experiments have determined the flux by normalizing their inclusive data sample to the measured $\nu N$ total cross section and using the QPM to fix the neutron/proton cross section ratio. The three experiments are in good agreement on the $\mu^- \Delta_T^{++}$ cross section; for $E_\nu > 5$ GeV, $\sigma = (0.64 \pm 0.03) \times 10^{-38}$ cm$^2$. Adler's model$^7$ with $M_A = 1.05$ GeV, and several quark models$^8,^9,^10$ give good fits to the data. Fig. 4(b) shows the energy dependence of the $\nu p \rightarrow \mu^+ \pi^-\pi^+\pi^-$ cross section$^3,^6$ for $M_{\pi^-\pi^+\pi^+} < 1.9$ GeV. This mass selection presumably selects several $N^*$ states along with the $D^0(1236)$. The slow rise of the cross section is due to (1) destructive inter-
In the energy region below 8 GeV, several experiments have extracted the isospin 1/2 and 3/2 amplitudes. Figure 5 compares amplitude results from three low energy experiments using the 12-foot and GGM chambers (see Table II for details). Be-
cause the beam spectra and experimental cuts differ between experiments, some differences in the results are expected. Nevertheless, there seems to be agreement that the $I = 1/2$ amplitude is large even at low $N_\tau$ effective mass, and that the relative phase angle is near 90°. The open points in the figures are predictions of the Fogli-Nardulli quark model where attention was paid to the experimental conditions of each experiment.

The agreement with data is very good in two cases, and only two standard deviations off for the GGM $\nu N$ results. The Adler prediction is also shown for the 12-foot case and the agreement is fine.

Additional information on the $\Delta(1236)$ form factors can be obtained from the production and decay angular distributions. Figure 6 shows the three $\Delta^+(1236)$ decay density matrix elements as a function of $Q^2$ using data from the low energy 12-foot experiment and the high energy BEBC and 15-foot experiments. Also shown is the Adler prediction as calculated for the 12-foot experiment. However, the decay distributions are predicted to be nearly energy-independent so the curves may also be compared with the $\sim 30$ GeV data. The experiments and model seem to be in fairly good agreement. The FMBH group claims to see some "illegal" angular moments in the $\Delta$ decay, implying the presence of non-resonant background in the final state. This effect still needs to be confirmed.

Finally, Fig. 7 shows the $dN/dQ^2$ distribution for the three neutrino reactions at low energy. There is fairly good agreement with Adler's prediction, although one would like better data on the $\mu \pi^0$ channel. Figure 8 shows $d\sigma/dQ^2$ for the $\nu p \rightarrow \mu^- \Delta^{++}$ process at high energy. The 15-foot and BEBC data are in very good agreement. The predictions of Adler with $M_A = 1.05$ GeV and the Fogli quark model (nearly identical) do not agree well with the data. Note that the $Q^2 = 0$ point is constrained by PCAC, and that the high $Q^2$ curve is dominated by the vector amplitudes. One can, of course, change the value of $M_A$ to improve the prediction, but the $\nu \tau$ prediction would then not be as good.

It should be remembered that there is little previous data on exclusive neutrino reactions for $Q^2 \lesssim 1.5$ (GeV/c)$^2$ and that no neutrino experiment has ever made a quantitative measurement of a form factor. Even for quasielastic scattering, $\nu n \rightarrow \mu^- p$, the available data can be equally well fit by a monopole, dipole, and a quark model-vector dominance shape. This is shown in Fig. 9. So it is not surprising that the low energy models do not correctly predict the shape of the high $Q^2$ distribution.

We can now summarize the one-pion production data:
- the experiments are in reasonable agreement on $M_{N\pi}$, $dN/dQ^2$, $\rho_{MN}$, and $\eta$ measurements.
- the $I = 1/2$ amplitude is large for all $M_{N\pi} < 1.9$ GeV.
The shape of the axial form factor $F_A$ at low $Q^2$ using monopole, dipole, and quark model representations.

- $\Delta$, $N^*$ spectroscopy using neutrino beams is difficult. No individual $\Delta$ or $N^*$ state has a cross section larger than 10% of the $\sigma(\Delta(1236))$.
- the low energy models do describe the new high energy data qualitatively.

Intermediate Mass Particles

The $p^0(760)$ has recently been seen in the inclusive process $\nu \mu \rightarrow p^0 X$ by the Argonne-Carnegie-Mellon-Purdue 15-foot group. Figure 9(a-b) shows the opposite sign and like sign $\pi\pi$ effective mass distributions. A clear $p^0(760)$ enhancement is seen. The rate can be given as $p^0/\nu\mu = 0.20 \pm 0.03$ or $p^0/\pi^- = 0.12 \pm 0.02$. However, the results are strong functions of various kinematic variables. Figure 10 shows the $p^0$ production rate as a function of total hadronic mass. The number of $p^0/\nu\mu$ event quickly rises to 35%. Figure 11 shows the $p^0$ production rate as a function of total hadronic mass. The number of $p^0/\nu\mu$ event quickly rises to 35%. Figur 12 shows the $p^0$ rate as a function of $P_d$, WRT, $Z = E_H/(E_H - E_d)$ and $Y_R = 1/2 \log [(E + P_d)/(E - P_d)]$. It can be seen that (1) the $P_d$ distribution of the $p^0$ is flatter than that of the $\pi^-$, (2) 80% of the $p^0$'s have $Z > 0.5$, which is often called the current fragmentation region, and (3) 70% of the $p^0$'s have $Y_R > 0$, with an apparent peaking for $0.5 < Y_R < 1.0$. Some of these features of $p^0$ production have also been observed in the process $\nu N \rightarrow \mu^+ \mu^-$ by the FMBH group in the 15-foot chamber.

Turning next to $K^0$ production, similar results can be seen. Figure 13 shows the rate of $K^0$ production as a function of $W_{VIS}$ in $\nu N$ interactions as measured by the Columbia-BNL 15-foot experiment. The observed rate is quite similar to that of $p^0$ production. Figure 14 shows the $X_F$ distribution of $p^0(760)$ production in $\nu \mu \rightarrow p^0$ as a function of hadronic mass. The data are from the ACMP 15-ft antineutrino hydrogen experiment.
Fig. 12 In the process $\bar{\nu} p = \mu^+ \rho^0(760)$, the ratios $\rho^0/\pi^-$ as a function of $P_L$, $P_T$, and $Y$. The data are from the ACME 15-R antineutrino hydrogen experiment.

Fig. 13 The rate of $K^0$ production as a function of $W_{VIS}$ in the Columbia-BNL 15-ft neon experiment.

Fig. 14 The $X_F$ distribution of $K^0$s in $\bar{\nu} N$ interactions as measured by the Serpukhov-Fermilab-Moscow-Michigan 15-ft experiment.

Finally, Fig. 15(a-b) displays the fragmentation functions $D(z)$ for $K^0$/$\bar{K}^0$ in $\nu N$ and $\bar{\nu} N$ interactions.12, 13 Their distributions are clearly broader than those of the pion. And it is interesting to note that for $z > 0.5$, $D_{K^0} = D_{K^0}$ and $D_{\bar{K}^0} = D_{\bar{K}^0}$. This is not unexpected since one is observing the fragmentation of the up quark in the case of $\nu N \rightarrow \mu^- X$ and the fragmentation of the down quark in $\bar{\nu} N \rightarrow \mu^+ X$. 

Fig. 15 The $D(z)$ distributions in $\nu N$ and $\bar{\nu} N$ interactions for $K^0$, $\Lambda$, and $\pi$ as measured in the 15-ft chamber by the Columbia-BNL and SFMM groups.
Very little data has been reported on the production of $K$ and $Y$ resonances. Some rates for $K^*(890)$ and $Y^*(1385)$ exist from the 15-foot broadband $v$ neon experiment, but nothing is known of their production mechanism. While there are detailed models for the production of $p$, $K^0$, $A_1$, $\omega$, $\eta$, ..., they have yet to be confronted with data.

High Mass Particle Production

The expression for the charged hadronic current in the standard QPM contains charm-changing and charm non-changing components:

$$J = \bar{u}[d\cdot \cos \theta + s\cdot \sin \theta] + \bar{c}[-d\cdot \sin \theta + s\cdot \cos \theta].$$

It follows that neutrino beams can produce a charm meson or baryon by interactions off a valence quark in the nucleon, and in association with a strange particle, by interactions off a sea quark. Antineutrino beams, however, can only produce charm mesons by interactions off the sea quarks. In naive quark models, the expected charm particle rate is $5-10\%$ for $\nu N \to \mu^+ N$ and $1-4\%$ for $\bar{\nu} N \to \mu^- N$. These rates are large. Neutrino interactions have always been viewed as a good process for discovering and studying the properties of charm mesons and baryons. In fact, $e^+e^-$ interactions now seem to be the ideal place to study charm mesons. However, $e^+e^-$ experiments have had difficulty in observing charmed baryons, and until this Conference, most of the data on charmed baryons has come from neutrino experiments. The remainder of this paper will be a review of the production rates of charm particles in $\nu N \to \mu X$ and attempts at doing charm baryon spectroscopy. Since dilepton production has been discussed by M. Murtagh at this Conference, I will concentrate on the strange particle tag for charm detection.

There is indirect evidence for charm particles in $\nu p$ interactions as reflected in the inclusive strange particle distributions. Table III shows the expressions for $d^2\sigma / dxdy$, as calculated in the QPM, for various antineutrino processes. Events with no strange particles or with associated production of strange particles are seen to occur mainly at small $y$, with a valence $x$ distribution. Events with charm occur mainly at small $x$, with a flat $y$ distribution. The $\Delta x = -1$ events have a rate similar to that of charm and occur at small $y$ with a valence $x$ distribution. Thus, one would expect that charm production will yield an excess of strange particles at small $x$ and large $y$ as compared to the inclusive sample.

This hypothesis has been tested using $\bar{\nu} p \to \mu^+ \nu^0$ data from the Argonne-Carnegie-Mellon-Purdue 16-foot experiment. The only strange particles detected are $\pi^0$ and $\Lambda$ decays, so to compare with the QPM, it was assumed that $K^+$ and $K^0$ rates are equal and that the $\Lambda$, $\Sigma^+$, $\Sigma^-$, $\Sigma^0$ rates are equal. It was also assumed that the associated production of strange particles in $\nu p$ collisions is given by the measured rate in non-weak lepton-nucleon interactions. And finally, the non-charm quark densities were taken from a popular model.

Figure 16 displays the measured $x$ and $y$ distributions of $\nu$ events in $\bar{\nu} p \to \mu^+$ interactions; the curves correspond to the QPM with and without charm production. It is clear that the QPM hypothesis is favored. A fit to the $x$-$y$ correlation yields $\chi^2/DF = 20/9$ for the prediction with charm and $\chi^2/DF = 60/9$ for the prediction without charm. One can use this data to measure the following ratio of quark densities

$$\frac{\int x \tilde{s}(x) \, dx}{\int x [0.343 u(x) + \tilde{d}(x) + \tilde{s}(x)] \, dx} = 0.050 \pm 0.014$$

for $x > 0.05$ and $0.1 < y < 0.8$. This result is in reasonable agreement with sea quark measurements from dilepton experiments.

The dilepton events and the excess of strange particles at low $x$, high $y$ are the only evidence for charm production by antineutrinos.
The beam experiment last year. The group has now analyzed and effective mass combinations with the following mass values were observed: $M(K^+\pi^+\pi^-) = 2011$ MeV, $M(K^+\pi^-) = 1865$ MeV, $M(K^-\pi^+) = 145.2\pm 0.6$ MeV. There is, of course, background to the event from possible associated production hypotheses; the total background is $10^{-4}$, and therefore the event is a highly probable example of $\nu p - \mu^-pK^-$.

The second event is an example of $\nu p - \mu^-pK^-$ at 21.3 GeV neutrino energy. The $K^-$ is identified by means of a secondary matter. The following mass values were observed:

$M(K^-\pi^+\pi^-\pi^+\pi^-) = 2013\pm 4$, $M(K^-\pi^+\pi^-\pi^-\pi^+) = 1868\pm 4$, and $\Delta M = 145.2\pm 0.6$ MeV. There is, of course, background to the event from possible associated production hypotheses; the total background is $10^{-4}$, and therefore the event is a highly probable example of $\nu p - \mu^-pD^{*+}\pi^+\pi^-$. These two events establish that the $D^*(2010)$ rate is finite and possibly large since the above-mentioned analysis is sensitive to only exclusive channels with no missing neutrals. To get a better estimate of the true $D^0$ rate, the experiment exploits the fact that the mass resolution in $M(D^{*+}) - M(D^0)$ is $3$ MeV. The mass difference is calculated for the combinations $(K^-\pi^+)\pi^+$, $K^-\pi^+\pi^+\pi^+$, and $K^-\pi^+\pi^-\pi^+$ whenever $M(K\pi\nu) = 1865\pm 25$ MeV. For the first two of the above combinations, all negative tracks are called $K^-$ even if they cannot be identified as $K^0$ by means of energy loss, ionization, etc. Fig. 17 shows the measured $\Delta M$ distributions. There is a possible signal in each combination. From the summed distribution, one obtains 7 $4 D^*+\rightarrow D^0$ events (where 2 of the 7 are the exclusive events). Correcting for $K^0$, $D^0$, and $D^*$ detection efficiencies and branching ratios, the experiment obtains the rate $\nu p - \mu^-X |W > 2.9$ GeV.

Charm Baryons: Two light liquid bubble chamber experiments have observed the $\Lambda_c^+(2260)$ in exclusive final states. As always in these kind of studies, one is restricted to events giving three-constraint kinematic fits with no missing neutrals. The first neutrino-induced $\Lambda_c^+$ event was seen by the BNL group in the 7-foot chamber in 1975. It is an example of $\nu p - \mu^-K^+\pi^+\pi^-\pi^+$.
Fig. 17 The $\Delta M = M(D^{*+}) - M(D^0)$ distributions for various $D^0$ decay modes as measured by the ABCMO experiment using BEMBC.

energies above the $\Lambda_c^+$ threshold energy. Correcting for $K^0$ and $\Lambda$ detection efficiency, but not for the unknown $\Lambda_c^+$ branching ratios, one obtains a rate for $\Lambda_c^+$ production with no missing neutrals of $0.9 \pm 0.7\%$ for $E_\nu \geq 4$ GeV.

The second experiment\cite{21} to see exclusive charm baryon events is the Tohoku-ILT-Maryland-Stonybrook-Tufts (TIMST) $\nu\cdot D_2$ experiment in the 15-foot chamber at Fermilab. This new experiment used a broad-band neutrino beam of $\sim 25$ GeV. They have reported preliminary results from 150,000 of the 328,000 pictures. In 10,000 charged-current events, all events with an associated $K^0_S$ or $\Lambda$ decay were processed and fits tried to $\Delta S = -\Delta D$. The probability of a missing $K^0_S$ in the final state is only $5 \times 10^{-3}$. Thus the event is a solid $\Lambda_c^+$ production candidate.

The other three candidates in the experiment are not as clean since associated production hypotheses cannot be excluded with high probability. However, they are useful to look at since they do provide an indication of rates. Event 2 is possibly a second example of $\nu d - \mu^- \Lambda_c^+ \pi^+\pi^- (p_s)$ at 14.4 GeV beam energy. The relevant mass values are $M(\pi^+\pi^-\pi^-) = 2509 \pm 13$ and $M(\Lambda_c^+\pi^-) = 2256 \pm 12$ MeV. However, the event also fits the hypotheses $\nu d - \mu^- \Delta K^+\pi^-\pi^-\pi^-$ and, furthermore, the probability of a missing $K^0_S$ is 6%.

Event 3 is a candidate for the reaction $\nu d - \mu^- \Lambda_c^+ (p_s)$, with $\Lambda_c^+ \rightarrow \Lambda \pi^+$. The beam energy is 22.8 GeV and $M(\Lambda^+\pi^+) = 2266 \pm 8$ MeV. The event also fits the hypothesis $\nu d - \mu^- \Lambda K^+ (p_s)$. In fact, there are 14 events in the experiment which fit that associated production reaction; if the $K^+$ track is called a $\pi^+$ in each event, then there is no other resulting $\Lambda^+\pi^-$ effective mass within 100 MeV of $M(\Lambda_c^+)$. So Event No. 3 must be viewed as a serious $\Lambda_c^+$ candidate, but one must await more detailed background calculations. The final candidate, Event 4, is consistent with the hypothesis $\nu d - \mu^- \Lambda_c^+ (p_s)$ with $\Lambda_c^+ \rightarrow K^0\rho^+\pi^-\pi^-$. The beam energy is 18.3 GeV and $M(K^0\rho^+\pi^-\pi^-) = 2246 \pm 6$, $M(K^0\rho^+\pi^-) = 914 \pm 5$, and $M(p_s) = 1211 \pm 5$ MeV. So there is a suggestion that the following cascade has occurred: $\Lambda_c^+ \rightarrow K^0\rho^+\pi^-\pi^-$. But once again, it is not possible to exclude all associated production hypotheses.

One concludes that the 15-foot $\nu D_2$ experiment has observed between 1 and 4 events of $\Lambda_c^+$ production in 10,000 events, with three of the candidates being off a neutron target. Thus the rate of exclusive channel charm production is very low; one will need $10^5$ event experiments to do detailed studies of charm reactions.

Since exclusive charm rates are so small, one next turns to the inclusive mode in hope of detecting a larger signal. Figure 18 shows the inclusive $\Delta S = -\Delta D$ mass distribution from the TIMST experiment.\cite{22} To enhance any $\Lambda_c^+$ signal, a selection was made that
The $\Lambda^{+}$ distributions for various $\Lambda^{+}$ decay modes as measured by the Columbia-BNL 15-ft experiment.

Fig. 18 The $\Lambda^{+}$ effective mass distribution with the selection $\cos \theta_{\Lambda^{+}} > -0.75$ as measured in the Tohoku-IIT-Maryland-Stony Brook-Tufts collaboration neutrino-deuterium experiment.

$\cos \theta_{\Lambda^{+}} > -0.75$ where $\theta$ is calculated in the $\Lambda^{+}$ rest frame with respect to the $\Lambda^{+}$ line of flight. A possible enhancement is seen at $\sim 2260$ MeV. After the remainder of the group's 328K pictures are processed, this distribution could contain a quite significant $\Lambda^{+}$ signal above a fairly low background.

A clear inclusive $\Lambda^{+}$ signal is certainly seen by the Columbia-BNL 15-foot hydrogen-neon experiment. They do not see any convincing mass peaks for the $\Lambda^{+}$ in uncut distributions, but they see evidence for the decay chain $\Sigma^{+} \rightarrow \Lambda^{+}\pi^{+}$, $\Lambda^{+} \rightarrow (\Lambda + \text{charged pions})$ or $(K \Xi + \text{charged pions})$. They select $\Lambda^{+}$, $K^{0}_{\Lambda}$, $\Sigma^{+}\Xi^{+}\pi^{-}$, $K^{0}_{\Lambda}\pi^{+}\pi^{+}$ particle combinations, with $2235 < M < 2285$ MeV, when there is another $\pi^{+}$ in the event. Then the corresponding mass differences are histogrammed, as shown in Fig. 19(a, c, d); an enhancement is present near 166 MeV. The resolution is $\pm 3$ MeV. Fig. 19(b) shows the $\Lambda^{+}\pi^{+} - \Lambda^{+}\pi^{+}$ mass difference when $M_{\Lambda^{+}\pi^{+}} = M_{\Lambda^{+}}$ and no enhancement is evident. Selecting events with $\Delta M = 166 \pm 6$ MeV, Fig. 20(a, c, d) shows the corresponding effective mass combinations with the quantum numbers of the $\Lambda^{+}$. A total of 14 events over a background of 6 are seen at 2260 MeV in Fig. 20(d). Fig. 20(b) again is a control region where $\Delta M = 154 \pm 6$ or $178 \pm 6$ MeV; no peaking is present in the 2200-2300 MeV region. Table IV gives the $\Sigma^{+} - \Lambda^{+}$ event rates in each of the four decay modes considered; the probability of the enhancement in Fig. 20(d) being a statistical fluctuation is $10^{-5}$.

Note that the $K_{\Sigma^{0}}^{*} \Delta^{++}$ decay mode of the $\Lambda^{+}$ is apparently small; at least one model for $\Lambda^{+}$ branching fractions has predicted that this two-body resonance channel would be quite large compared to other detectable modes.

Table IV gives the $\Sigma^{+} - \Lambda^{+}$ event rates in each of the four decay modes considered; the probability of the enhancement in Fig. 20(d) being a statistical fluctuation is $10^{-5}$.

Note that the $K_{\Sigma^{0}}^{*} \Delta^{++}$ decay mode of the $\Lambda^{+}$ is apparently small; at least one model for $\Lambda^{+}$ branching fractions has predicted that this two-body resonance channel would be quite large compared to other detectable modes.

-300-
Finally, it is of interest to note that only one of the above discussed \(14 \Sigma^+_c \rightarrow \Delta^+_c \pi^+\) events is a serious candidate for the quasielastic process \(\nu p \rightarrow \mu^- \Sigma^+_c\). The observed \(\Sigma^+\) decay mode is \(\Delta^+_c \rightarrow \Sigma^+ \pi^+\). All three of its positive tracks are pions from range, energy loss, or ionization. There are no associated \(K^0\) or neutrons in 2.5 interaction lengths of neon; and there are no associated gammas in 7 radiation lengths. The event balances transverse momentum to 70 MeV/c. The group concludes that the probability that the event is associated production is only \(\sim 3\%\).

The only detailed theoretical predictions for charm baryon production by neutrinos are for exclusive channels. Table V gives cross section predictions, at 10 GeV beam energy, for \(\nu n \rightarrow \mu^- \Sigma^+_c\) and \(\nu p \rightarrow \mu^- \Sigma^+_c, \Sigma^{*+}\) as calculated by four models. 24-27 There are rather large differences in the predictions. It is difficult to compare the available data (\(\sim 3\) events) with these numbers because the \(\Lambda^+_c\) branching ratios are not known. If one assumes a \(\Sigma^{*+}, \Sigma^{*++}\) detection efficiency of 10\%, then the combined \(H_2/D_2\) data from the 7-foot, 15-foot, and BEBC give \(\sigma(\nu p \rightarrow \mu^- \Sigma^+_c, \Sigma^{*+}) \sim 1 \times 10^{-4} \text{ cm}^2\) and the Columbia-BNL 15-foot event in neon corresponds to \(\sim 0.4 \times 10^{-4} \text{ cm}^2\). It is clear that unless there are few \(\Lambda^+_c\) decay modes with no \(\pi^0, K^0\) or neutrons, the exclusive channel cross sections are smaller than many people had expected.

Summary of Charm Production: One can use the eight \(\Delta S = -\Delta \Omega\) exclusive candidates to study the production kinematics of charm particles. Fig. 21 shows the \(x, y,\) and \(Q^2\) distributions for the eight events. They have the expected valence \(x\) distribution. And since the events are generally quasi two- and three-body final states, it is not surprising that they are at fairly low \(Q^2\) values.

To determine the mass of \(\Lambda^+_c\), I have averaged the mass values from the four "best" (lowest background) \(\Delta S = -\Delta \Omega\) exclusive events: the two 7-foot events, the \(\nu D_2\) 15-foot event, and the \(\nu\) neon 15-foot event. The result is \(2259 \pm 7 \text{ MeV}\). The Columbia-BNL inclusive \(\Lambda^+_c \rightarrow \Lambda \pi^+\) events yield the value of \(2257 \pm 10 \text{ MeV}\).

Table VI is a comparison between experiments that observe a charm particle signal and those that do not. Inclusive \(\Delta^0 = K^+\pi^-\pi^0\), exclusive \(\Delta^0 = \Lambda \pi^+\), exclusive \(D^+\), and exclusive \(\Lambda^+_c\) rates are compared by giving the observed raw, uncorrected rates, and the number of events one expects in the other experiments. Note that the two BNL 7-foot \(\Lambda^+_c\) events are seen in a fairly low energy experiment; to compare

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<table>
<thead>
<tr>
<th>(\Lambda^+_c) Decay Mode</th>
<th>Events</th>
<th>Background</th>
<th>Corrected Signal</th>
<th>(\sigma \cdot \mathcal{B}/\sigma_{cc})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Lambda^+_c)</td>
<td>8</td>
<td>1.5</td>
<td>17.6</td>
<td>(1.8 \pm 0.8 \times 10^{-4})</td>
</tr>
<tr>
<td>(K^0)</td>
<td>7</td>
<td>2.0</td>
<td>25.5</td>
<td>(2.7 \pm 1.6)</td>
</tr>
<tr>
<td>(\Sigma^{*+} \pi^+)</td>
<td>4</td>
<td>1.5</td>
<td>12.4</td>
<td>(1.5 \pm 1.4)</td>
</tr>
<tr>
<td>(\Sigma^{*+} \pi^+)</td>
<td>1</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>6.0</td>
<td>55.5</td>
<td>(6 \pm 2.3 \times 10^{-4})</td>
</tr>
</tbody>
</table>
Table V: Exclusive Charm Baryon Rates

<table>
<thead>
<tr>
<th>Model</th>
<th>(\sigma(E_{\nu} = 10 \text{ GeV}) \times 10^{-40} \text{ cm}^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\nu_n - \mu^+ \Lambda_c^+)</td>
<td>(\nu_p - \mu^+ \Sigma_c^+), (\mu^+ \Sigma_c^+)</td>
</tr>
<tr>
<td>Lee-Shrock(^{24})</td>
<td>23</td>
</tr>
<tr>
<td>SU(4) Symmetry for Couplings</td>
<td></td>
</tr>
<tr>
<td>D(^q) Dominated Dipole Form Factors</td>
<td></td>
</tr>
<tr>
<td>Amer et al.(^{25})</td>
<td>3.2</td>
</tr>
<tr>
<td>Quark Model + SU(4) Breaking</td>
<td></td>
</tr>
<tr>
<td>Finjord-Ravndal(^{26})</td>
<td>1.2</td>
</tr>
<tr>
<td>Quark Model + &quot;Nucleon&quot; Form Factors</td>
<td></td>
</tr>
<tr>
<td>Avilz-Kobayashi-Könner(^{27})</td>
<td>30</td>
</tr>
<tr>
<td>QM: 1977 (m_c = m_d)</td>
<td></td>
</tr>
</tbody>
</table>
| 1979 \(m_c 
eq m_d\) | 7.5 | 2.5 |

Table VI: Comparison of Raw (uncorrected) Charm Rates
High Energy \(\nu\) Bubble Chamber Experiments; All Rates Have Errors in 20-80\% Range

<table>
<thead>
<tr>
<th>Chamber</th>
<th>BEBC</th>
<th>15-foot</th>
<th>7-foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid</td>
<td>(H_2)</td>
<td>(H_2)</td>
<td>(H_2/\text{D}_2)</td>
</tr>
<tr>
<td>CC Events &gt; 4 GeV</td>
<td>6000</td>
<td>2560</td>
<td>100,000</td>
</tr>
<tr>
<td>(&lt;E_{\nu}&gt;)</td>
<td>30</td>
<td>25</td>
<td>30</td>
</tr>
</tbody>
</table>

| Observed Inc. \(D^0 - K^0\Sigma^+\pi^-\) | No | No | No |
| Expected/BG Events | 6/20 | 3/2 | 8/26 |

| Observed Inc. \(\Lambda_c^{++} - \Lambda_c^{++}\) | No | No | No |
| Expected Events | \(<1\) | \(<1\) | \(<1-2\) |

| Observed Exc. \(D^+\) | (\(R = 3 \times 10^{-4}\)) | No | --- |
| Expected Events | \(<1\) | | |

| Observed Exc. \(\Lambda_c^+\) | No | No | \(\sim 2\) events |
| Expected Events if \(R = 4 \times 10^{-4}\) | 2 | \(<1\) | (\(R = \)?) |
| Expected Events if \(R = 3 \times 10^{-3}\) and \(\sigma \Lambda_c^+\) Constant \(> 4\) GeV | 5 | 2 | (\(R = 3 \times 10^{-3}\)) |

with the high energy data, I have assumed an exclusive channel cross section independent of beam energy above 4 GeV. Overall, there are no serious conflicts between the five experiments. But there is no inclusive or exclusive rate that has been confirmed by a second experiment.

It is clear that charm baryon spectroscopy is difficult with present day neutrino beams and detectors. As suggested by the dilepton data, much of the neutrino flux in the broad-band beams is at energies where the charm rate is slowly rising from threshold. The use of a much higher energy beam from the Tevatron would be of great value to charm spectroscopy.

This research was supported by the U.S. Department of Energy.

References
Questions

F. Messing
Carnegie-Mellon

I have more a comment than a question. There was a question raised earlier about the helicity of charmed particle production. I'd just like to point out that the rise in strange particle production with $\gamma$ makes an inescapable conclusion that there is a strong left-handed component in charmed particle production. If you assume a full strength charmed particle production, then the size of the $s$ sea agrees with that measurement in the dileptons.

G. Snow
Maryland

I have a question about what can one say about single strange baryon production, not charmed baryon production, just the simple Cabibbo antineutrino nucleon goes to a single strange baryon.