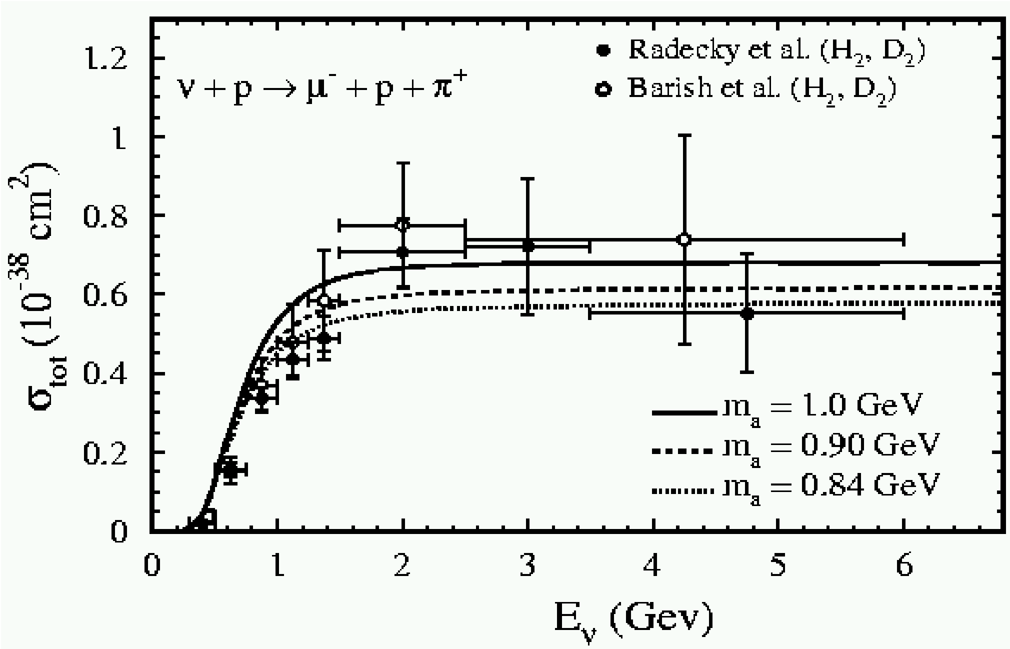
MINERVA

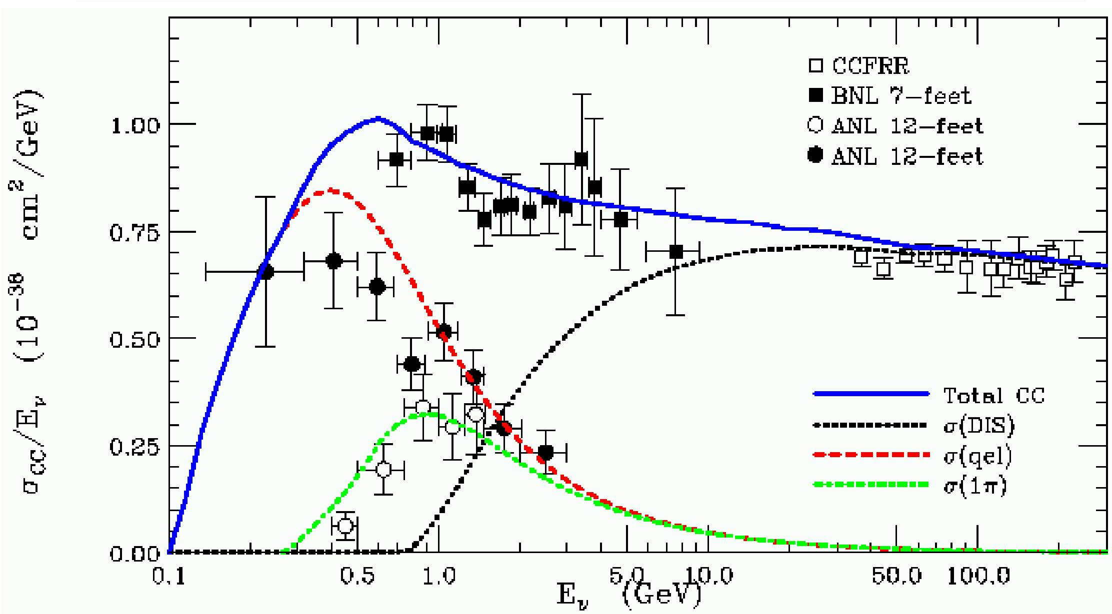
Resonance Production

Not final

Cross Sections

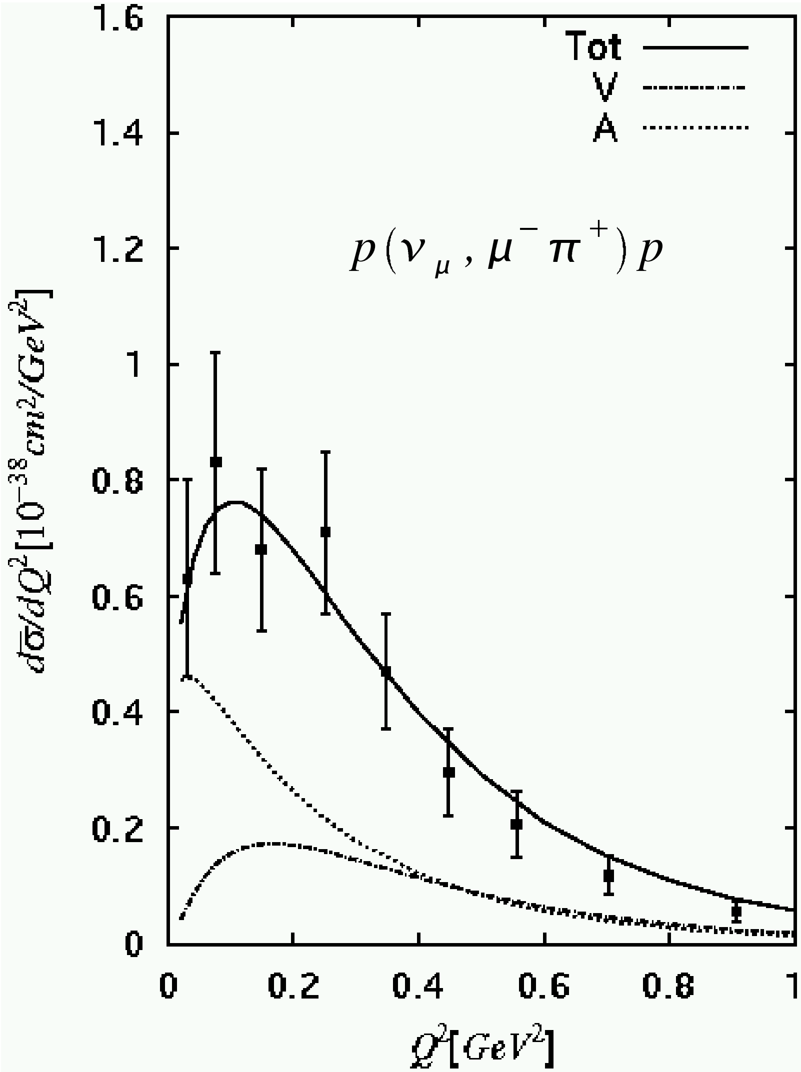


- Total Cross resonance production cross section becomes independent of neutrino energy above 2-3 GeV.
- No shortage of low Q^2 events from high E beam, but such high E neutrinos probably not ideal for resonance production studies.



- At high E total cross section scales with neutrino energy. (Increase of W range)
- But fraction of cross section due to single pion production (mostly Delta), decreases above a few GeV.
- MINERVA beams well matched to region of resonance production importance.

Differential Cross Section



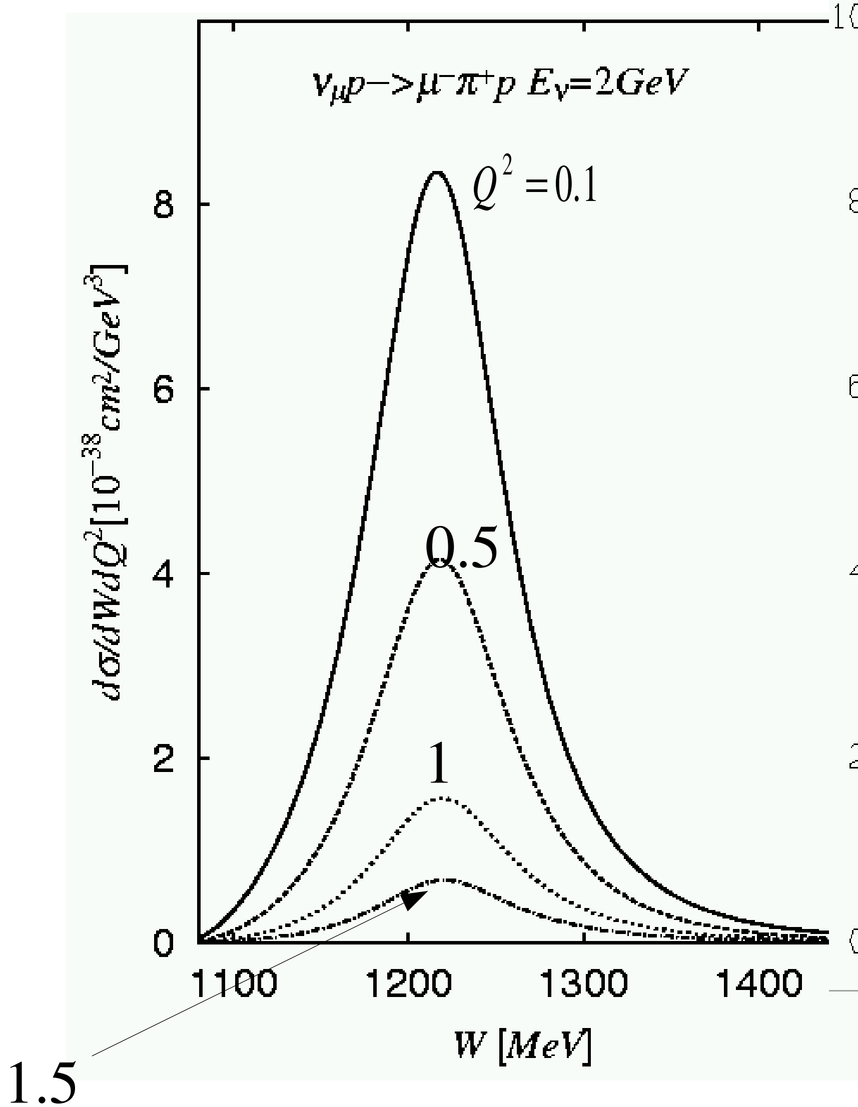
Barish PRD 19, 25231 (1979)

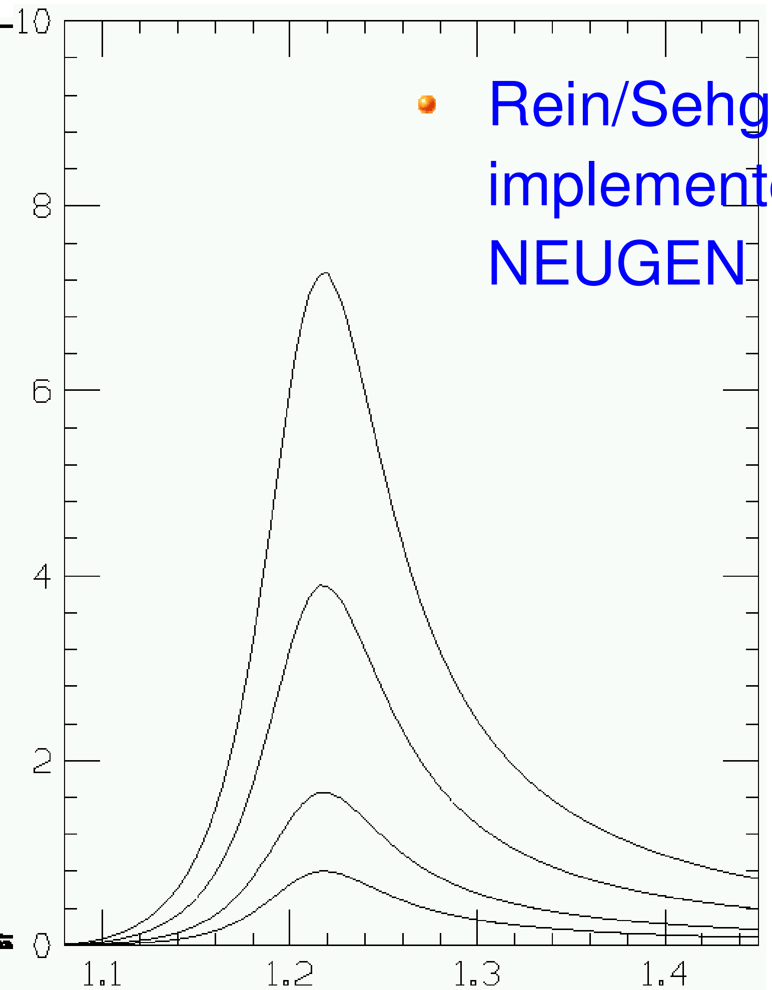
- Differential cross section dsig/dQ^2 is essentially the derivative of the total cross section sigma(Enu). (Enu -> Qmax)
- Highlights uncertainties in data at low Q^2.
- Low Q^2 is where the Axial-Vector coupling is most important and different from the Vector coupling (which we can get from electron scattering).

Models of resonance production

- Early (~1970) analysis of pion production by Adler using CGLN dispersion relations. Some disagreement with data.
- Smith/Moniz model (1972) covers quasi-elastic and delta production in Nuclei.
- Rein Seghal. Feyman-Kisslinger-Ravdal constituent quark model. Includes interferences between resonances and background. Used by (most?) neutrino event generators. Interferences and background not always included in implementations?
- Sato/Uno/Lee extend electro-production model (Sato/Lee 2001). Weak vector currents from EM currents by isospin rotation. N-Delta transition from constituent quark model and electron scattering. Better agreement with data.

Rein/Sehgal – Satu/Uno/Lee comparison





- Rein/Sehgal as implemented in NEUGEN

What it would be nice to do

- Sato/Uno/Lee: “It will be very useful to have sufficient data for performing partial wave decomposition like what have been routinely preformed in (e,e'pi) studies such that the N-Delta form factor can be extracted model independently.
- Would like:
  - Pure hydrogen target
  - Good determination of Q^2, W, charge of pions
  - To measure angular distribution of pi about q vector.

Challenge: Do better than BBC data

- Can't beat tracking in bubble chamber data
- But:
  - Uncertainties in beam flux
  - Existing BBC event sample likely all that will ever exist
- MINERVA
  - High Fluxes
  - Well known neutrino flux
  - Exposure to multiple flux distributions
  - Electronic DAQ
- But:
  - Tracking/resolution pretty depressing for a magnetic spectrometer user.
  - Target CH2, neither free proton nor pure nucleus.

Response Functions

- Fully differential cross section can be written as:

$k_c, \theta_\pi, \phi_\pi$

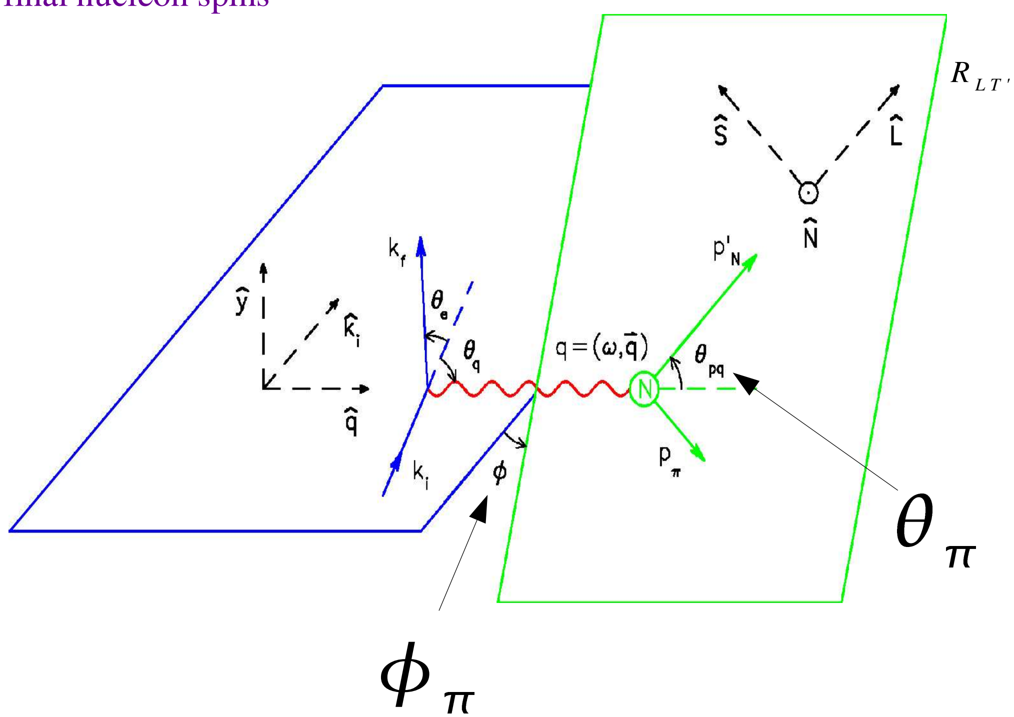
Pion momentum and angles relative to q in pi – N CM frame

$$\frac{d\sigma^5}{dE_l\, d\Omega_l\, d\Omega_\pi} = \frac{G_F^{\,2}\cos^2\theta_c}{2}\frac{|p_l|}{|p_\nu|}\frac{|k_c| m_N}{(2\pi)^5 W}$$

$$\times\left(\frac{1}{2}\sum\left[R_T + R_L + R_{LT}\cos\phi_\pi + R_{TT}\cos 2\phi_\pi + R_{LT'}\sin\phi_\pi + R_{TT'}\sin 2\phi_\pi\right]\right)$$

Sum over initial and final nucleon spins

Need Polarized Beam



$$\begin{aligned}
R_T &= \frac{Q^2}{1-\epsilon}\left[\frac{|j_c^x|^2+|j_c^y|^2}{2} \mp \sqrt{1-\epsilon^2}\,\mathrm{Im}(j_c^x j_c^{y*})\right],\\
R_L &= \frac{Q^2}{1-\epsilon}\epsilon\frac{Q^2}{|\boldsymbol{q}_c|^2}|\bar{j}_c^0|^2,\\
R_{LT} &= \frac{Q^2}{1-\epsilon}\sqrt{\frac{2\epsilon(1+\epsilon)Q^2}{|\boldsymbol{q}_c|^2}}\left[-\mathrm{Re}(\bar{j}_c^0 j_c^{x*}) \pm \sqrt{\frac{1-\epsilon}{1+\epsilon}}\mathrm{Im}(\bar{j}_c^0 j_c^{y*})\right],\\
R_{TT} &= \frac{Q^2}{1-\epsilon}\left[\frac{\epsilon(|j_c^x|^2-|j_c^y|^2)}{2}\right],\\
R_{LT'} &= \frac{Q^2}{1-\epsilon}\sqrt{\frac{2\epsilon(1+\epsilon)Q^2}{|\boldsymbol{q}_c|^2}}\left[\mathrm{Re}(\bar{j}_c^0 j_c^{y*}) \pm \sqrt{\frac{1-\epsilon}{1+\epsilon}}\mathrm{Im}(\bar{j}_c^0 j_c^{x*})\right],\\
R_{TT'} &= \frac{Q^2}{1-\epsilon}\left[-\epsilon\,\mathrm{Re}(j_c^x j_c^{y*})\right],
\end{aligned}$$

$$\epsilon = \frac{1}{1+\frac{2|\boldsymbol{q}|^2}{Q^2}\tan^2\frac{\theta_l}{2}}$$

$m_l = 0$ Limit. Very similar to electro-production

Extracting Response Functions

$$\frac{d\sigma^5}{dE_l\, d\Omega_l\, d\Omega_\pi} = \frac{G_F^2 \cos^2\theta_c}{2} \frac{|p_l|}{|p_\nu|} \frac{|k_c| m_N}{(2\pi)^5 W}$$

$$\times\left(\frac{1}{2}\sum \left[R_T + R_L + R_{LT}\cos\phi_\pi + R_{TT}\cos 2\phi_\pi + R_{LT'}\sin\phi_\pi + R_{TT'}\sin 2\phi_\pi\right]\right)$$

- RLT, RTT, RLT', RTT' sensitive to interesting things like deformation in N->Delta transition
- RL, RT need “Rosenbluth” Separation. RLT is an asymmetry forward and backward of q. Require good systematics in q direction.
- RTT is asymmetry between in and out of plane pion production
- RLT' is asymmetry between pions above and below scattering plane. (Current buzzword is “Single Spin Asymmetry”.
- We should have good sensitivities to RTT, RLT' and RTT' (as ratios to cross section)
- Minor wild worry/oportunity: Protons can be polarized. C and H are good analyzers. This either messes up tracks or is an oportunity to measure polariztion response functions. Probably neither.

Rates

- Using Jorge's LE, ME, HE files, as is, and Rein Sehgal subroutine from NEUGEN, estimate event counts for W < 1.4 and 1.4 < W < 2.0 in Q^2 bins of 0.2. Counts/bin/"year"

Rates are only for scattering off free protons in 1000kg CH2 target!

	LE Beam		ME Beam		LE Beam	
Q^2	W < 1.4 GeV	1.4 < W < 2.0	W < 1.4 GeV	1.4 < W < 2.0	W < 1.4 GeV	1.4 < W < 2.0
0 – 0.2	730	1831	2282	4955	3474	7036
0.2 – 0.4	617	1383	1828	3604	2713	5015
0.4 – 0.6	458	958	1325	2451	1945	3377
0.6 – 0.8	335	667	954	1684	1390	2306
0.8 – 1.0	248	474	698	1186	1009	1616
1.0 – 1.2	187	345	520	857	748	1164
1.2 – 1.4	144	257	397	634	566	859
1.4 – 1.6	113	195	308	480	437	648
1.6 – 1.8	90	151	243	370	343	499
1.8 – 2.0	73	119	195	290	273	390

Ways to extract free proton events

That probably won't work

- Assume resonance production on free proton known, use data to test resonance production and pion absorption/transparency models used by neutrino event generators.
- Alternate slabs of CH2 and Carbon, do subtraction
  - Enough rate for total sigma and dsig/dQ^2 improvements
  - Reduction in active volume will hurt resolution
- Alternate layers of proton rich and proton poor scintillator. (Can H fraction be varied??)
- Require total transverse momentum to be zero to reject nucleons with Fermi motion.

Transverse momentum

For scattering on free proton

Other Reactions

Conclusions and Questions

- Data at multiple beam energy distributions, including more narrow band off-axis beams may help sort out resonance cross sections. If off-axis beams turn out to be useful for resonance studies, make sure we spend enough time in those beams.
- Resolutions. PMT's on scintillator essential for tracking and TOF.
- Will RTT, RLT', RTT' on bound protons survive nuclear effects?
- Big Thank you to Thia Keppel.