Electroweak Elastic Scattering In Heaven and Earth

Irvine, Dec. 2002

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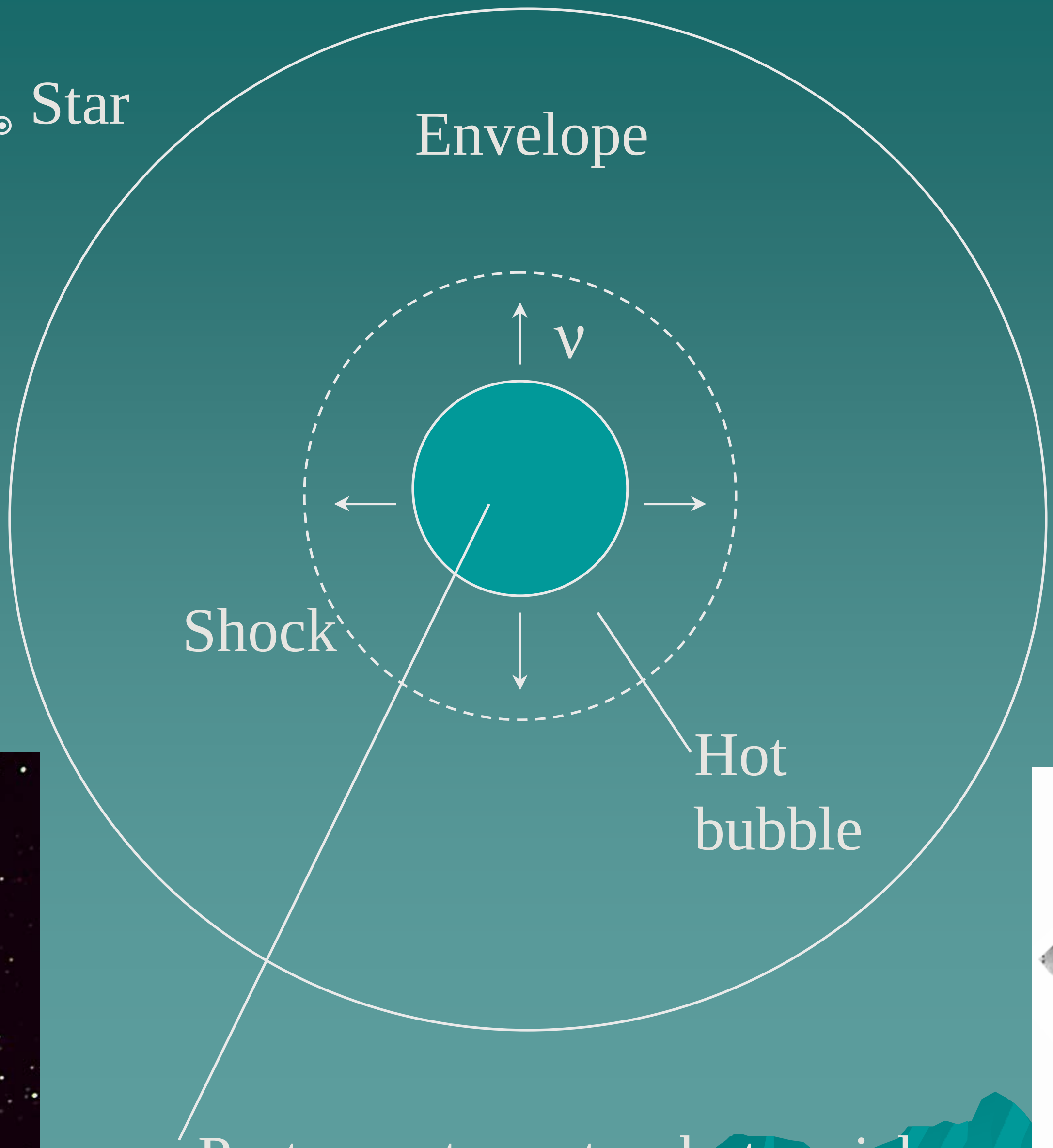
Electroweak Elastic Scattering

- ν interactions in supernovae
  - Opacity dominated by ν-n elastic.
  - ν energies and r-process nucleosynthesis.
  - SN detection via ν-p and ν-A elastic.
- Strange quark content of nucleon
  - Parity violating electron scattering
  - ν-p elastic scattering to determine strange quark contributions to nucleon spin Δs.
  - Measure ratio of neutral to charged current.

Core collapse supernova

$>8M_{\odot}$ Star



Envelope

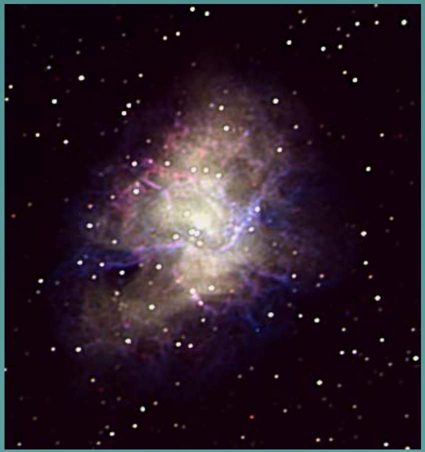
ν

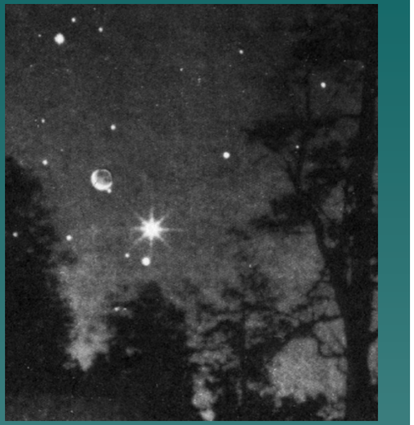
Shock

Hot bubble

Proto-neutron star: hot, e rich

Crab nebula





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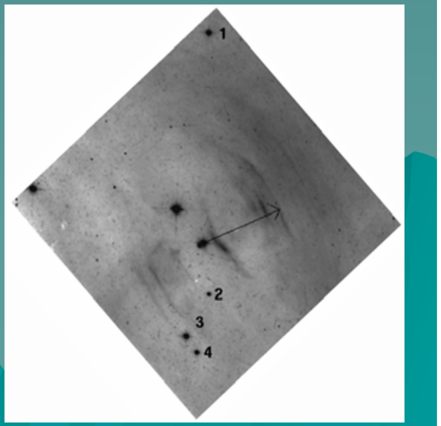


Opacity Dominated by ν-n Elastic

- Energy transport mostly by ν_x ($\equiv \nu_\mu, \nu_\tau$) because twice as many as ν_e and ν_x without charged currents, have longer mean free path.
- Opacity of ν_x mostly from ν-n elastic.
- Incorrect elastic cross sec caused Oak Ridge simulation to explode when it did not with correct one.
- Uncertainty in ν-n cross sec from strange quarks relevant for SN simulations.

R-process in neutrino driven wind

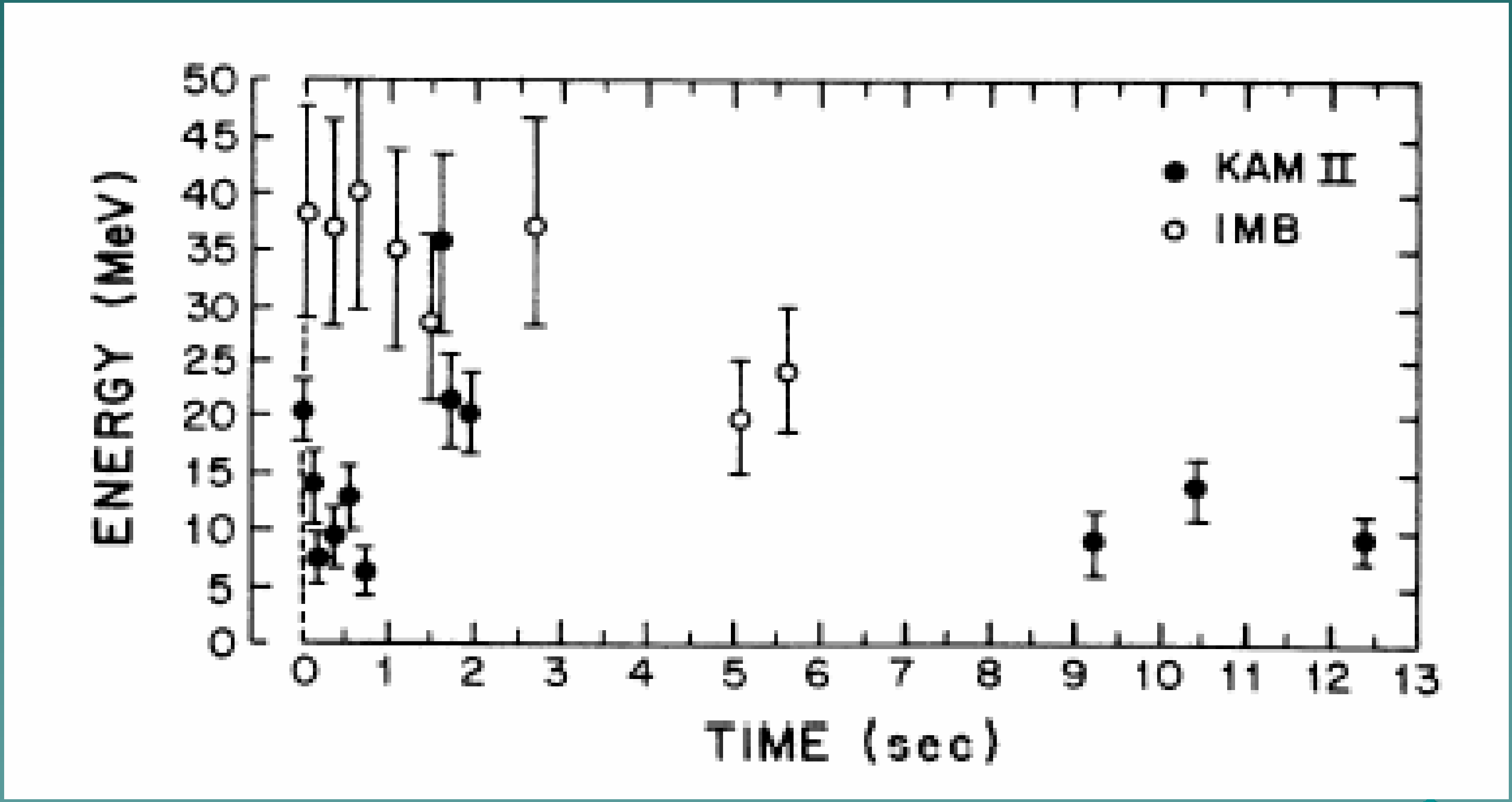
- Half of heavy elements made by rapid neutron capture. Best site is ν driven wind in SN.
- Low density region above proto-neutron star dominated by large ν flux.
- Initial neutron to proton ratio and Y_e in wind set by relative rates:

$$\nu_e + n \rightarrow p + e^- \qquad (1)$$

$$\bar{\nu}_e + p \rightarrow n + e^+ \qquad (2)$$

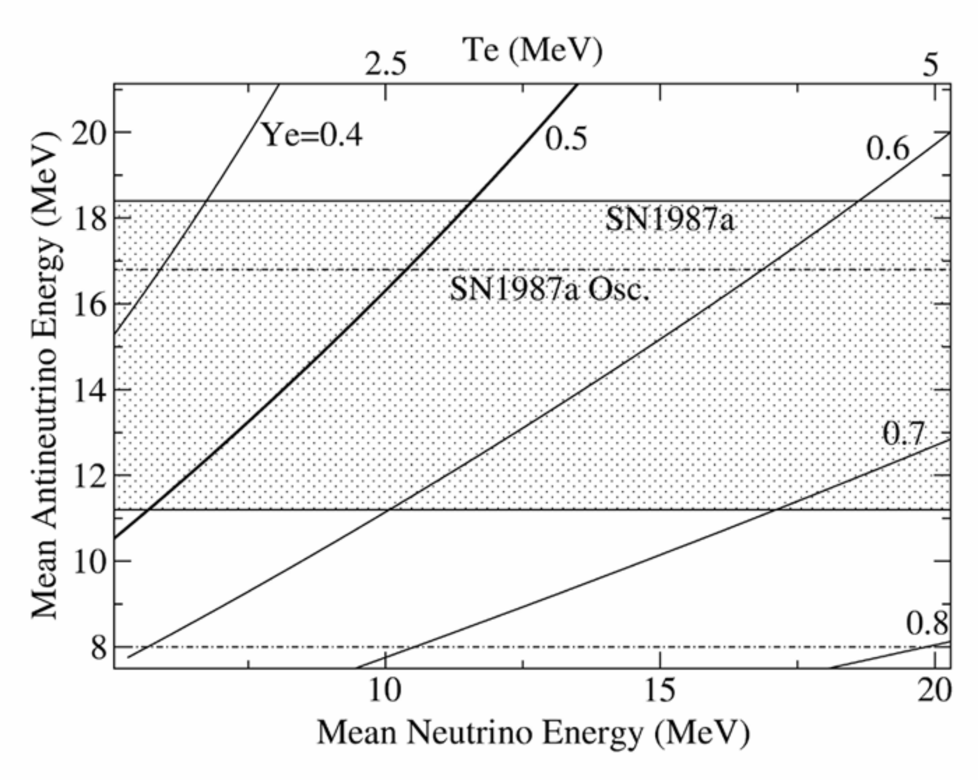
- Cross section for (1) larger than (2) because of n-p mass difference (Q value) and because of weak magnetism. Note, C violating nature of weak interactions insures ν-nucleon cross sections are larger than anti-ν-nucleon.

Historic IMB SN1987A Data



Twenty $\overline{\nu}_e$ detected via $\overline{\nu}_e + p \rightarrow n + e^+$.

n/p ratio in ν-driven wind



For wind to be neutron rich must be above dark Y_e=0.5 line and below solid SN1987A limit line.

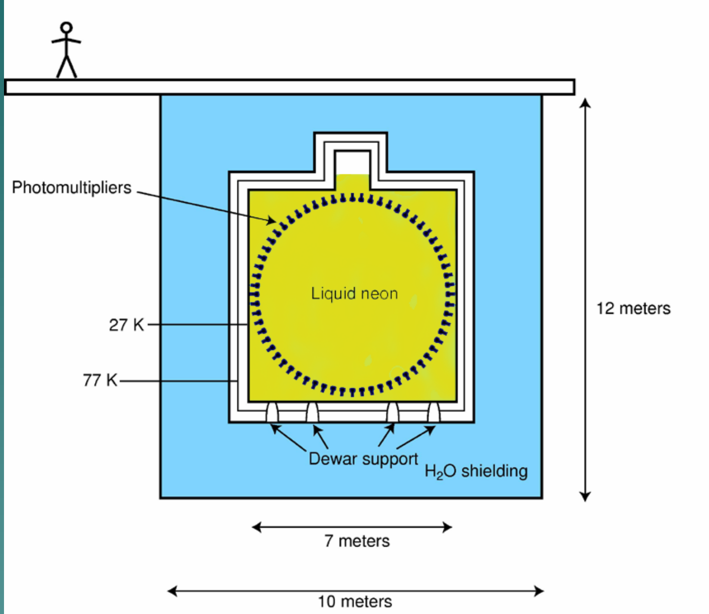
This requires ν_e to be much colder than present simulations.

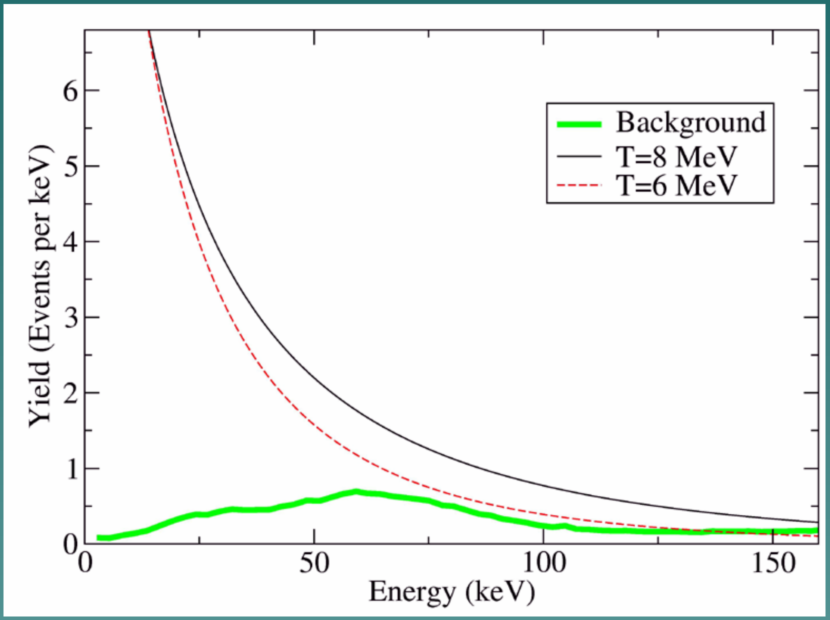
Present simulations are not robustly neutron rich. Where do n come from for r-process?

Supernova Spectra and ν Oscillations

- Expect E of $\nu_e < \overline{\nu}_e < \nu_x$ because ν_x have no charged current and star is neutron rich.
- Difference in E of $\nu_x - \nu_e$ is lever arm for ν osc.
- Active ν osc don’t help r-process. Raising E of ν_e makes problem worse. E of $\overline{\nu}_e$ constrained by SN1987A data.
- Super-K sees E of $\overline{\nu}_e$ well. Need E of ν_x
- Elastic ν-p or ν-A scattering can measure energy of ν_x via recoil spectrum.
- ν-p elastic perhaps in Kamland [J. Beacom]
- ν-A has very large coherent cross section. Yield of a few or more events per *ton* for a Galactic SN.

Supernova at 10 kpc in CLEAN





CLEAN is detector for low E solar ν via ν-e elastic. Monte Carlo for backgrounds , mostly radioactivity in phototubes. -- Dan McKinsey, Kevin Coakley

Green curve is total low energy background in 10 seconds. Black curve is Galactic SN signal of order 400 ν_x events. Can determine ν_x temperature.

Strange quark content of nucleon

$$\langle f \,|\, J^H_\mu \,|\, i \rangle = \bar{u}_f(p') \left[\gamma_\mu F_1(Q^2) + i \frac{\sigma^{\mu\nu}}{2M_p} q^\nu F_2(Q^2) + \gamma_\mu \gamma_5 G_A(Q^2) \right] u_i(p) \,,$$

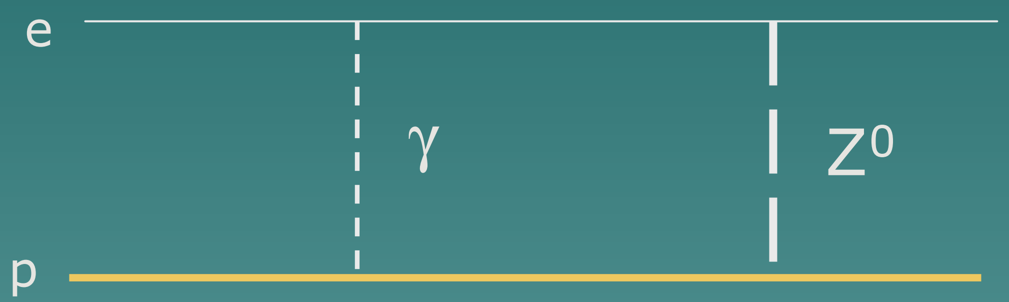
- Three form factors
- F_1^s, F_2^s, G_a^s
- Low Q limits:
  - $F_1^s(0)=0$, dF_1^s/dQ^2 → strangeness radius ρ_s,
  - $F_1^s=(\rho_s+\mu_s)\,Q^2/4M^2$ for small Q^2
  - $F_2^s(0)=\mu_s$ strange magnetic moment,
  - $G_a^s(0)=\Delta s$, fraction of nucleon spin carried by s

Parity Violating Electron Scattering

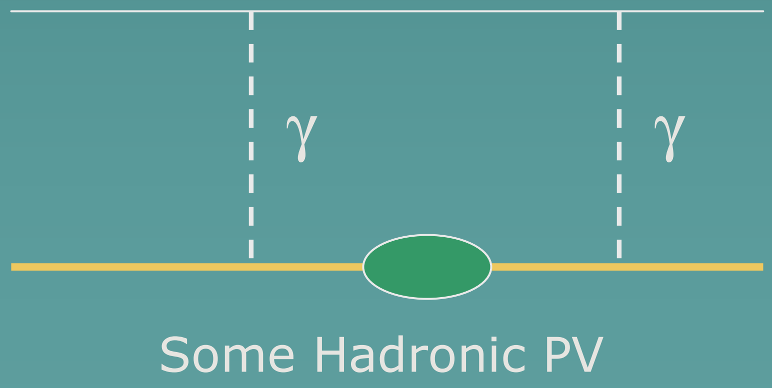
- Measure asymmetry in cross section of right handed versus left handed electrons. $A \approx 1$ ppm
- Sensitive to interference between Z^0 and γ exchange.
- Forward angles: F_1^s, back angles F_2^s
- Little sensitivity to G_a^s because of small vec. weak coupling of electron (and radiative corrections). PV can't get Δs

Radiative Corrections

- Lowest order matrix elem. squared



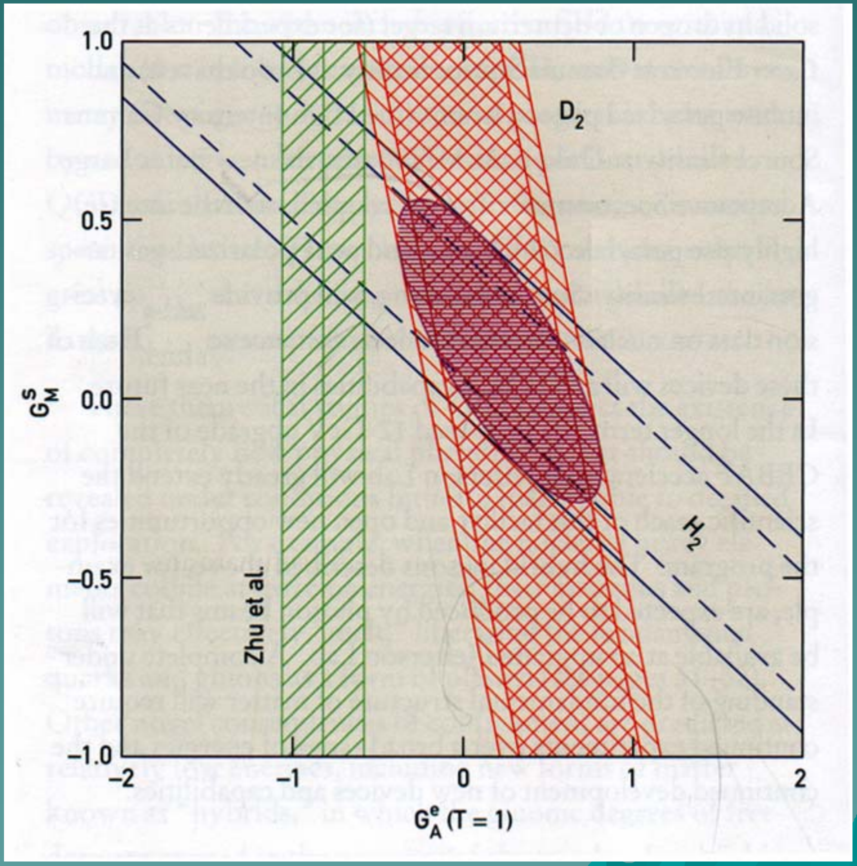
- Radiative correction



Example: photon couples to pion loop which has parity violating weak coupling to nucleon

Sample Results

- PV on H and D give both radiative corrections and μ_s.
- $G_M{}^s$ (or μ_s) consistent with zero but large errors.
- Radiative corrections larger then expected.



Other PV Experiments

- **HAPPEX**: PV from H at forward angle, $Q^2=0.5$ GeV^2. $G_E^s+0.4G_M^S=0.02\pm0.03\pm0.02\pm0.03$
- **G_0** will measure PV from H and D at front and back angles over large Q^2 range. Also PV in Delta production.
- **A4** in Germany, H at intermediate angles.
- **HAPPEX II**: PV from H at more forward angle $Q^2=0.1$ GeV^2.
- Low Q^2 **^{4}He** experiment isolates F_1^s
- Elastic PV from **Pb** will measure neutron radius. [Weak chage of n $\gg$ p].
- **Q_{weak}** PV from H at low Q^2 as standard model test. Also PV e-e exp. at SLAC.

Bring Me the Head of a Strange Quark

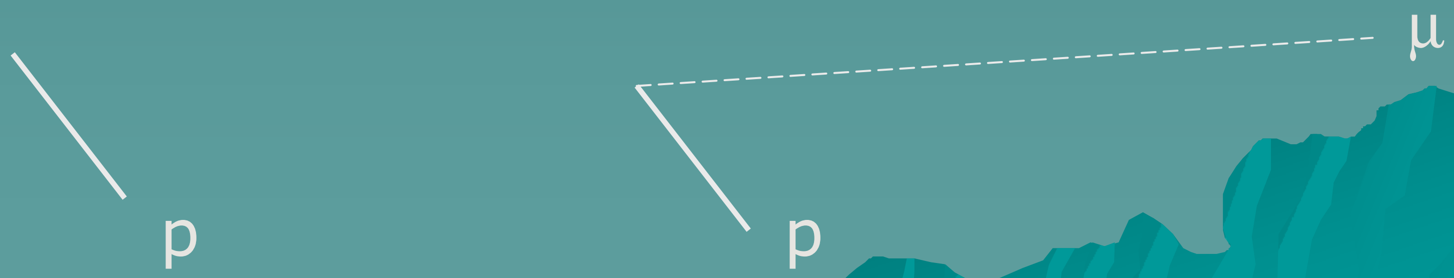
- Can one find a significantly nonzero strange quark signal with PV electron scattering?
- It may be very hard to improve significantly on the systematic errors of SAMPLE and G_0.

Neutrino-Nucleon Elastic Scattering

- Measure strange quark contributions to nucleon spin Δs
- Radiative corrections small.
- Also can measure with antineutrinos.
- Attractive neutrino fluxes at oscillation beam lines.
- Need to control systematic errors.

Measure Δs via Ratio of Neutral to Charged Current Scattering

- Ratio of protons from: $\nu + p \rightarrow \nu + p$ to protons from: $\nu + n \rightarrow \mu^- + p$.
- Note, both are quasielastic scattering from an N=Z nucleus such as ^{12}C.
- Very simple observable: ratio of protons of a given E without muons to those with muons.



Example: E_ν=0.8 GeV, Q^2=0.5

- Neutral to CC ratio R $\approx$ 0.14
- Error in extracted

Error in extracted	Δs
– 5% measurement of R	0.04
– ±0.03 GeV uncer. in M_A	0.01
– ±0.3 uncer. in μ_s	0.07
– ±2 uncer. in ρ_s	0.002

[Assume $G_a^s=\Delta s/(1+Q^2/M_A^2)^2$]

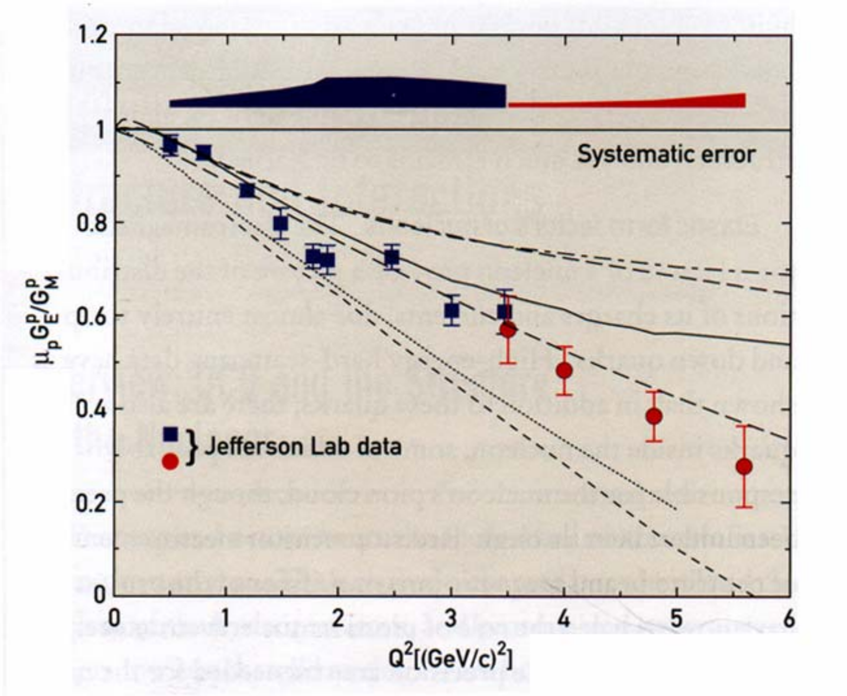
- 5% ratio sensitive to Δs at ±0.04
- Determine one combination of Δs and μ_s from ν and another from anti-ν.

Experimental Considerations

- Many systematics, such as absolute flux, proton efficiency, cancel in ratio.
- Need to identify pions to separate elastic from inelastic events. [This may require a segmented detector.]
- Possible backgrounds from neutrons and multiple nucleon knockout.
- Many nuclear structure issues also cancel in ratio, however don't go too low in Q^2 . Want proton recoil energy to be large compared to giant resonances T_{lab}>50-100 MeV (can use more calculations).
- Note, more counts and closer to $Q^2=0$ limit for Δs at low Q. Tradeoff in Q^2 choice.

Measurement of Charged Current Axial Form Factor, $g_A/(1+Q^2/M_A^2)^2$

- Needed to control systematic errors for extraction of Δs.
- Accurate determination of M_A possible with charged current quasielastic events.



  - ❑ Search for non dipole behavior? Look at large Q2 range: 0.5-2+GeV^2. How to control systematic errors??

FINESE: Fermi Lab Intense ν Scattering Experiment

- Proposed near detector on MiniBooNE beam line.
- Measure Δs via ratio of neutral to charged current.
- See Rex Tayloe
- Also Jorge Morfin's proposal for NUMI