Nuclear Isospin Violation- How it turned out and where it is going

Gerald A. Miller
Univ. of Washington

Happy Birthday James

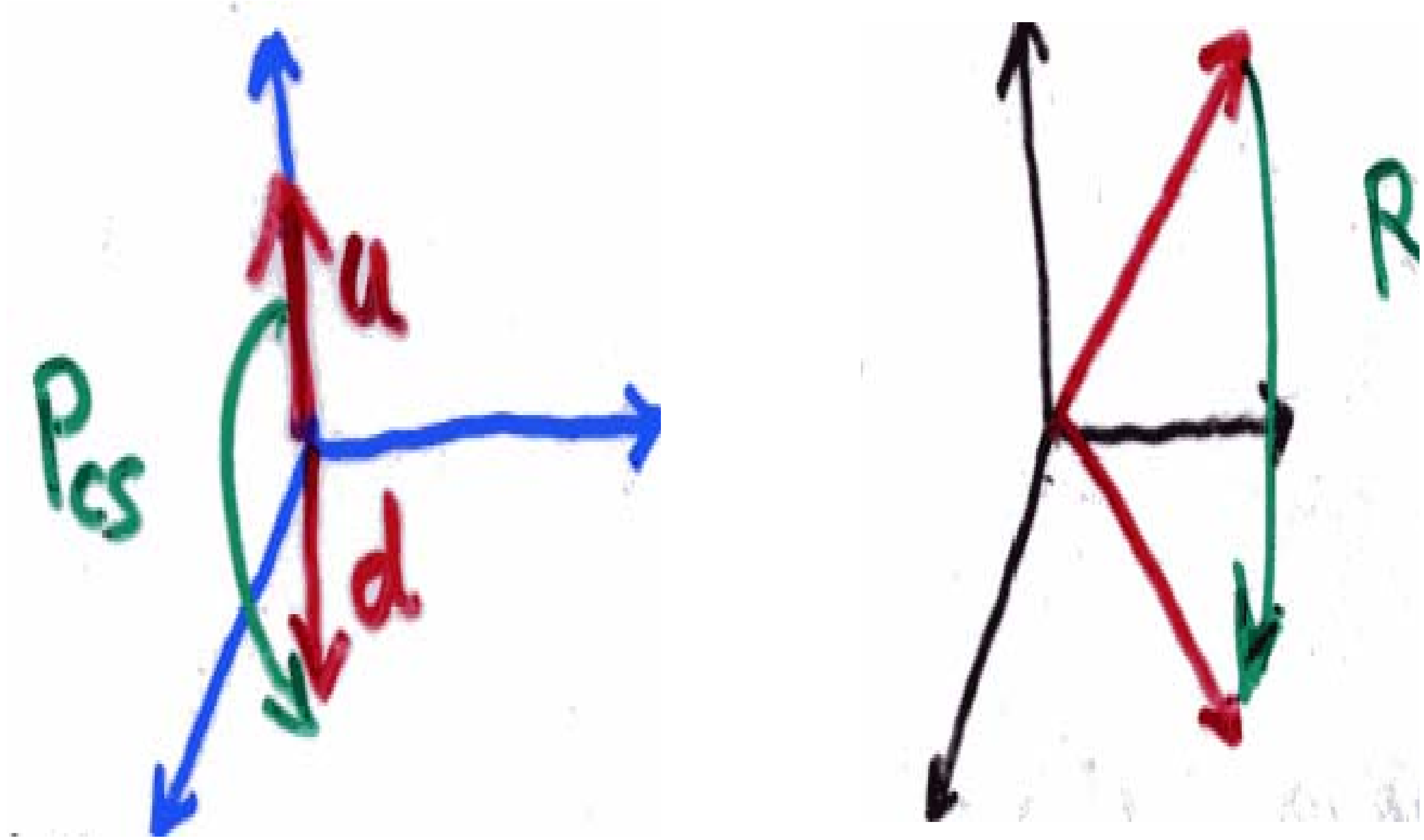
I met James at MIT in the 70's

- I was a grad student, he was a post-doc
- My project- formation/decays of double isobaric analog states in proton heavy-nucleus scattering -couldn't find sizable contribution
- James suggestion: include pairing correlations in Po^{210} -this enhanced matrix element by a factor of 7
- I graduated- I am forever grateful to James

Interest in Isobaric analog states decayed

- focus changed to isospin violating nucleon-nucleon forces & consequences in few body reactions
- Comment- tools discussed at NTSE can lead to much better treatment of nuclear isospin violations than in the old days-super allowed beta decay

Charge Symmetry is invariance under 1 isospin rotation



Isospin invariance $[H,T_i]=0$, charge independence, CS does NOT imply CI

CS is broken slightly by light quark mass difference and E&M

Examples where CS holds, isospin (CI) violated

- **$m(\pi^+) > m(\pi^0)$, electromagnetic**
- **causes charge dependence of $^1S_0$ scattering lengths**
- **no isospin mixing**

Scale of CSB is Smaller than CIB

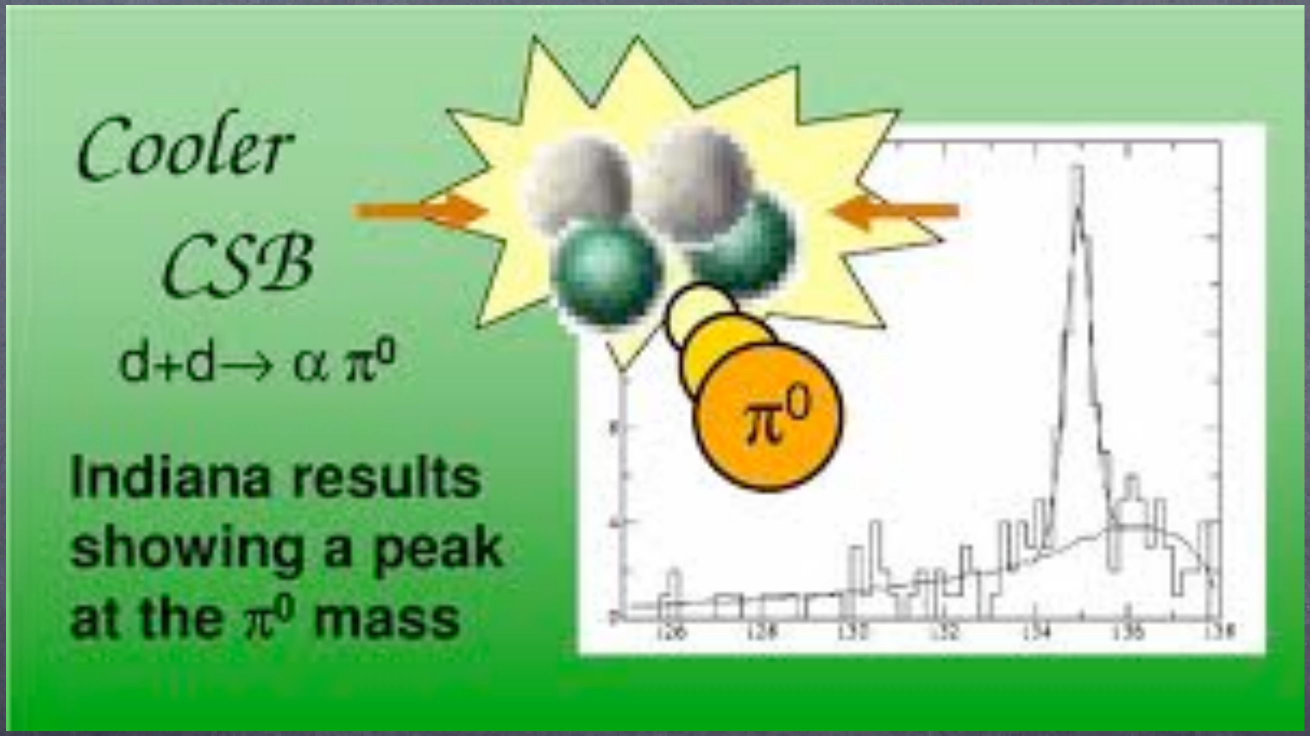
- Scale is ~$(M_n-M_p)/M_p$~ 1/1000
- Much less than pion mass difference effect ~1/27
- NN Scattering- CIB discovered before 1965
- NN Scattering- CSB found after 1976
- Expectation is CSB is a small effect, uncovered only with special effort
- CIB > CSB Natural in Chiral perturbation theory van Kolck, Friar

Highlights since 1972

- 1S0 nn force is more attractive than pp force, $\pi^- d \to nn\ \gamma$
- Nolen-Schiffer anomaly explained using that CSB
- charge symmetry breaking seen in $np \to np$, $np \to d\ \pi^0$, $dd \to \alpha\ \pi^0$

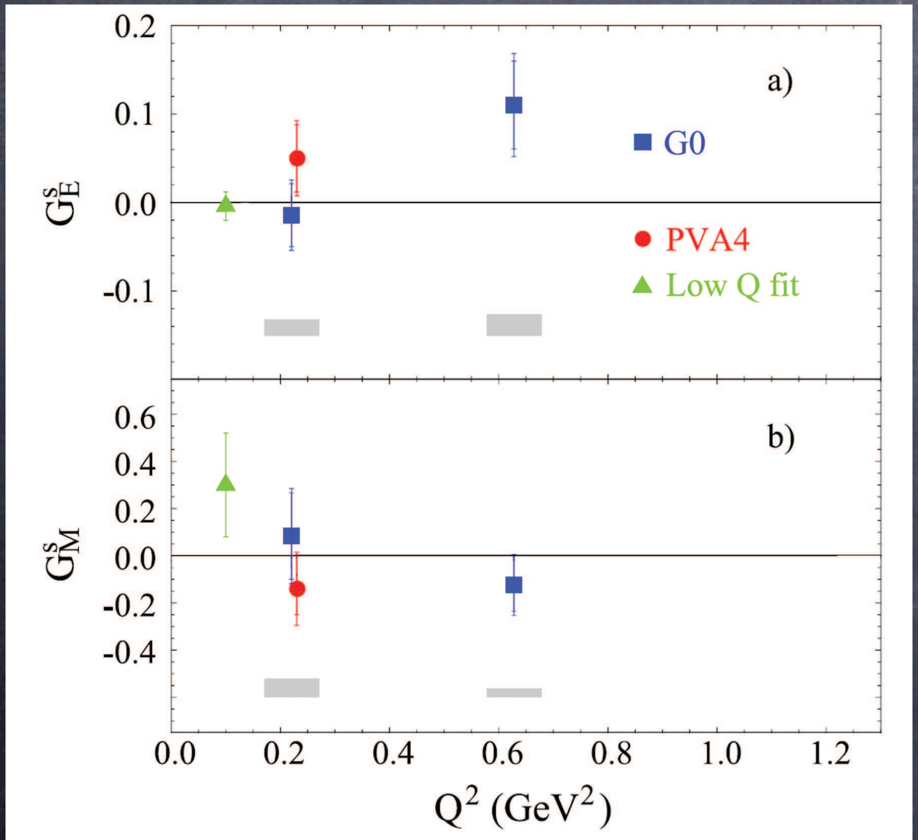
Reviews -Miller, Nefkens Slaus Phys. Rpts. (1990)
Miller, Opper Stephenson ARNPS (2006)

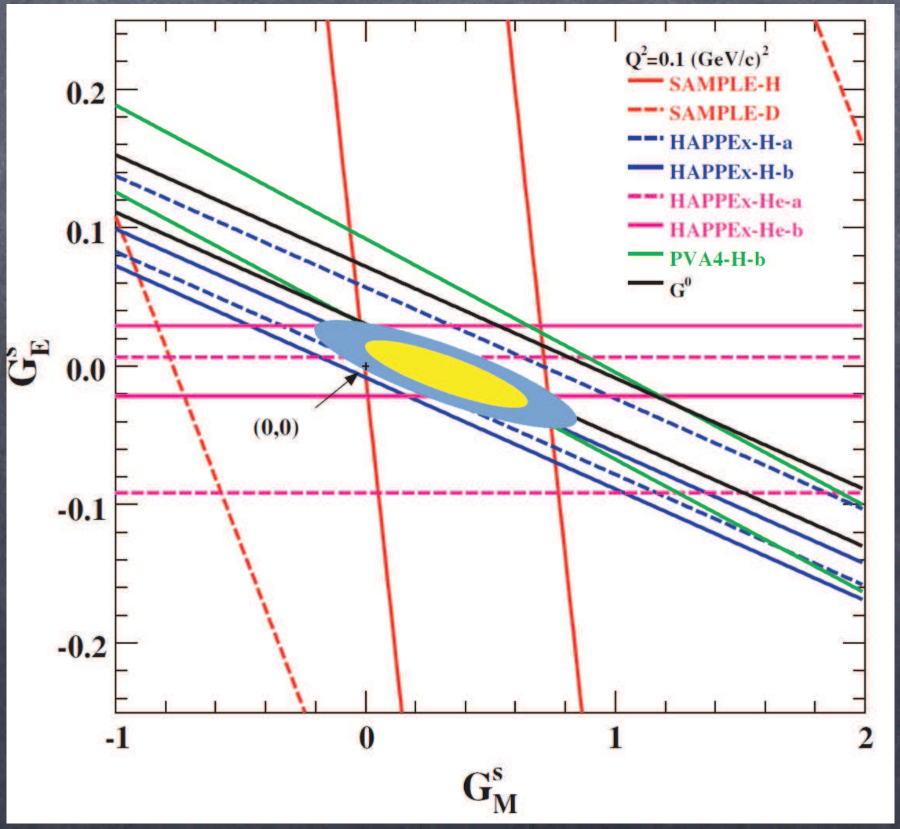
Charge Symmetry Breaking and PV Electron Scattering



Parity Violating Electron Scattering and Strangeness E&M Nucleon Form Factors

- PV electron scattering requires weak neutral form factors
- sensitivity to nucleon strangeness content





Armstrong McKeown ARNPS 2012

convincing signal not seen

.01 =error bar

Relevance of CSB to PV

$$F^{\gamma}_{1,2} \quad = \quad \frac{2}{3}F^{u}_{1,2} - \frac{1}{3}F^{d}_{1,2} - \frac{1}{3}F^{s}_{1,2}$$

$$F^{Z}_{1,2} \quad = \quad (1 - \frac{8}{3}\sin^2\theta_W)F^{u}_{1,2} + (-1 + \frac{4}{3}\sin^2\theta_W)(F^{d}_{1,2} + F^{s}_{1,2})$$

Charge symmetry (u in proton = d in neutron, d in proton = u in neutron)

$$G^{Z,p}_{E,M} = (1 - 4\sin^2\theta_W)G^{\gamma,p}_{E,M} - G^{\gamma,n}_{E,M} - G^{s}_{E,M}$$

CSB and Form Factors

$$Z_\mu = \langle p(\vec{p}\,')\,|\,(1-\frac{8}{3}\sin^2\theta_W)j_\mu^u + (-1+\frac{4}{3}\sin^2\theta_W)(j_\mu^d + j_\mu^s)\,|\,p(\vec{p})\rangle$$

Need to relate $\langle p(\vec{p}\,')\,|j_\mu^{u,d}\,|\,p(\vec{p})\rangle$ to measured form factors

$$|\,p(\vec{p})\rangle = |\,p_0(\vec{p})\rangle + |\,\Delta p(\vec{p})\rangle,\ \ |\,n(\vec{p})\rangle = |\,n_0(\vec{p})\rangle + |\,\Delta n(\vec{p})\rangle,$$

$|\Delta p(\vec{p})\,\rangle$, $|\Delta n(\vec{p})\,\rangle$, caused by $\Delta H \equiv [H, P_{\rm cs}]$

$$G_{E,M}^{Z,p} = (1-4\sin^2\theta_W)G_{E,M}^{\gamma,p} - G_{E,M}^{\gamma,n} - G_{E,M}^s + \langle p_0(\vec{p}\,')|\,\frac{2}{3}j_\mu^d - \frac{1}{3}j_\mu^u|\Delta p(\vec{p})\rangle + \langle \Delta p(\vec{p}\,')|\,\frac{2}{3}j_\mu^d - \frac{1}{3}j_\mu^u|p_0(\vec{p})\rangle$$

Is CSB correction large compared to 0.01?

David Armstrong says

“ I am delighted to hear that you are revisiting the important question of charge symmetry in these processes - the present belief amongst the experimentalists is that the uncertainty attached to charge symmetry is now limiting the ability to push further on the strange form factors, i.e. any more precise experimental results would be hard to interpret cleanly in terms of strangeness or CSV. ”

Does CSB really limit ability to push further?

PHYSICAL REVIEW C VOLUME 57, NUMBER 3 MARCH 1998

Nucleon charge symmetry breaking and parity violating electron-proton scattering

Gerald A. Miller
Department of Physics, University of Washington, Box 351560, Seattle, Washington 98195
(Received 17 November 1997)

The consequences of the charge symmetry breaking effects of the mass difference between the up and down quarks and electromagnetic effects for searches for strangeness form factors in parity violating electron scattering from the proton are investigated. The formalism necessary to identify and compute the relevant observables is developed by separating the Hamiltonian into charge symmetry conserving and breaking terms. Using a set of SU(6) nonrelativistic quark models, the effects of the charge symmetry breaking Hamiltonian are considered for experimentally relevant values of the momentum transfer and found to be less than about 1%.

- 1 % refers to G_E, G_M
- Standard now is << experimental error bar 0.01

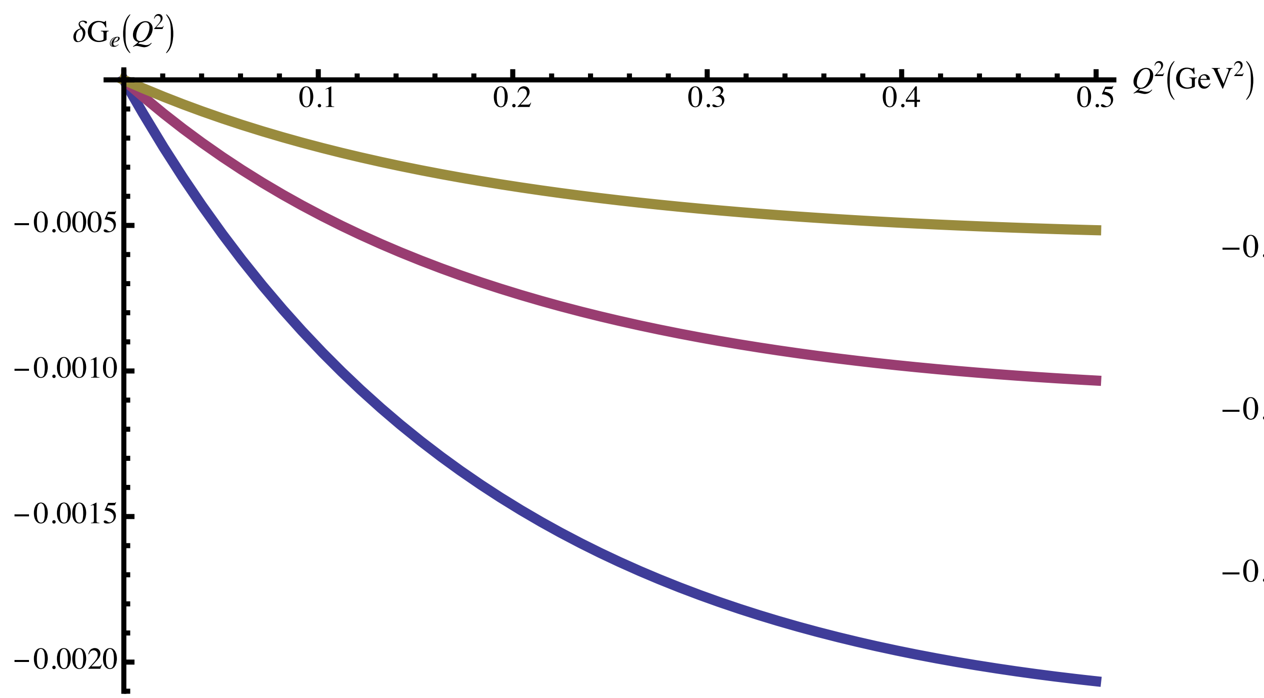
$$\delta Z_\mu(Q^2=\vec{q}^{\,2}) = \langle p_0 | \sum_{i=1}^3 \left(\tfrac{1}{3}+\tau_3(i)\right) \begin{Bmatrix} 1 \\ \frac{\vec{\sigma}(i)}{2m_q} \end{Bmatrix} e^{i\vec{q}\cdot\vec{r}} \frac{\Lambda}{M_p-H_0} 2\Delta H \, | p_0 \rangle$$

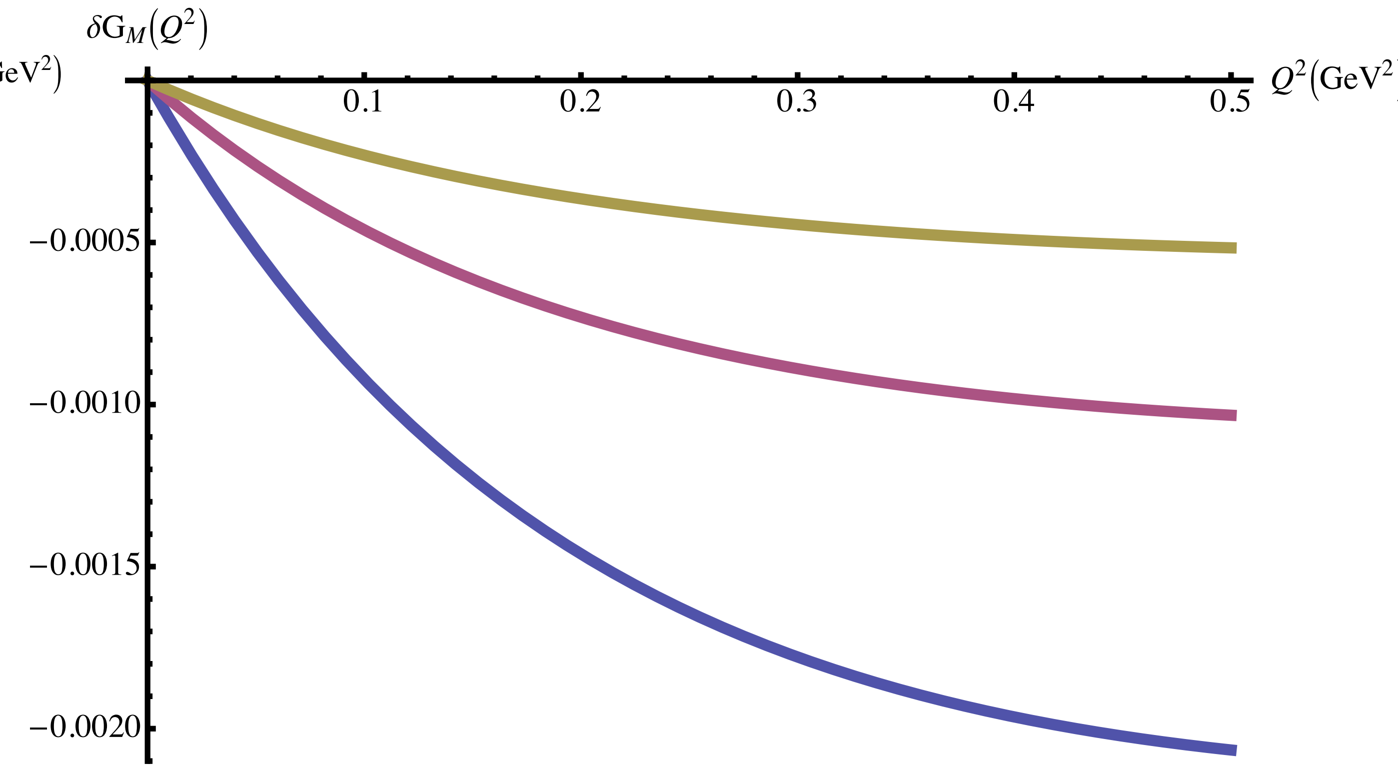
ΔH : $m_d - m_u$ in kinetic energy & one gluon exchange, + one photon exchange

Λ projects out of ground state, if $\vec{q}$=0, $\delta Z_\mu(0)=0$ (ΔH does not excite the Δ)

Effect must be small at low values of Q^2

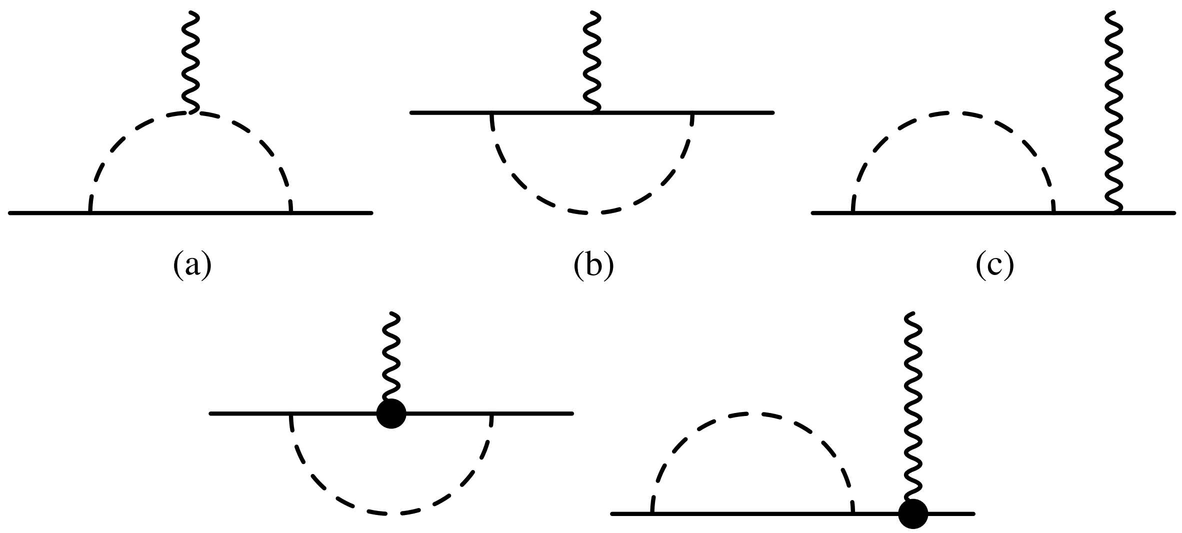
Three Non-Relativistic Models: one gluon exchange causes 0.8, 0.67, 0.33 of Δ N Splitting- same M_n-M_p





CSB Effect is negligible at low Q^2 in these models

Effect I left out - pion cloud- proportional to M_n-M_p



(a) (b) (c) (d) (e)

PHYSICAL REVIEW C **74**, 015204 (2006)

Isospin violation in the vector form factors of the nucleon

Bastian Kubis[1,*] and Randy Lewis[2,†]

[1]*Helmholtz-Institut f¨ur Strahlen- und Kernphysik (Theorie), Universit¨at Bonn, Nussallee 14-16, D-53115 Bonn, Germany*

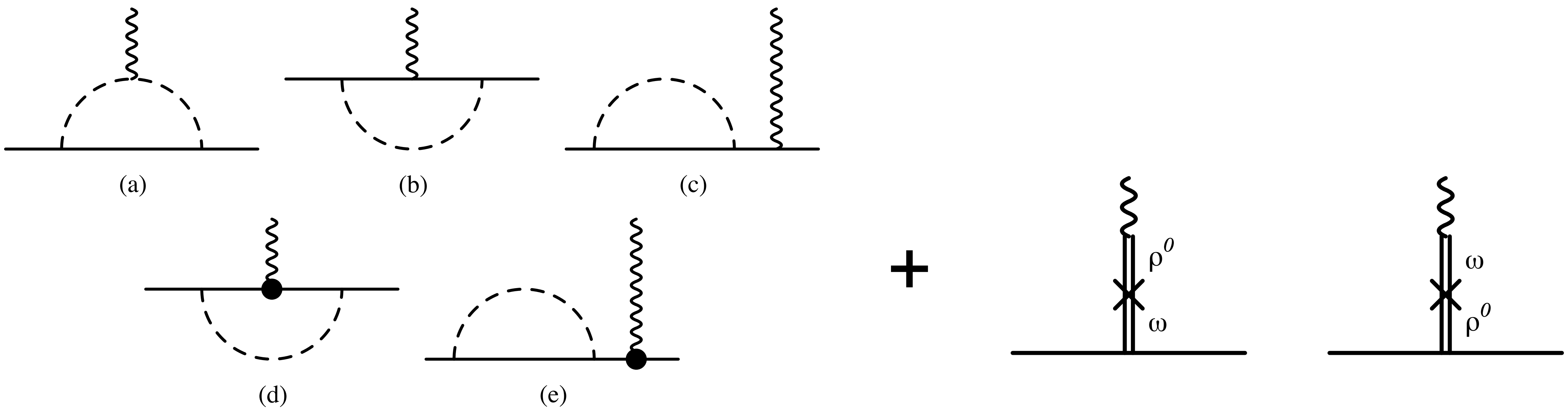
[2]*Department of Physics, University of Regina, Regina, Saskatchewan, Canada S4S 0A2*

(Received 3 May 2006; published 14 July 2006)

A quantitative understanding of isospin violation is an increasingly important ingredient in the extraction of the nucleon's strange vector form factors from experimental data. We calculate the isospin-violating electric and magnetic form factors in chiral perturbation theory to leading and next-to-leading order, and we extract the low-energy constants from resonance saturation. Uncertainties are dominated largely by limitations in the current knowledge of some vector meson couplings. The resulting bounds on isospin violation are sufficiently precise to be of value to on-going experimental studies of the strange form factors.

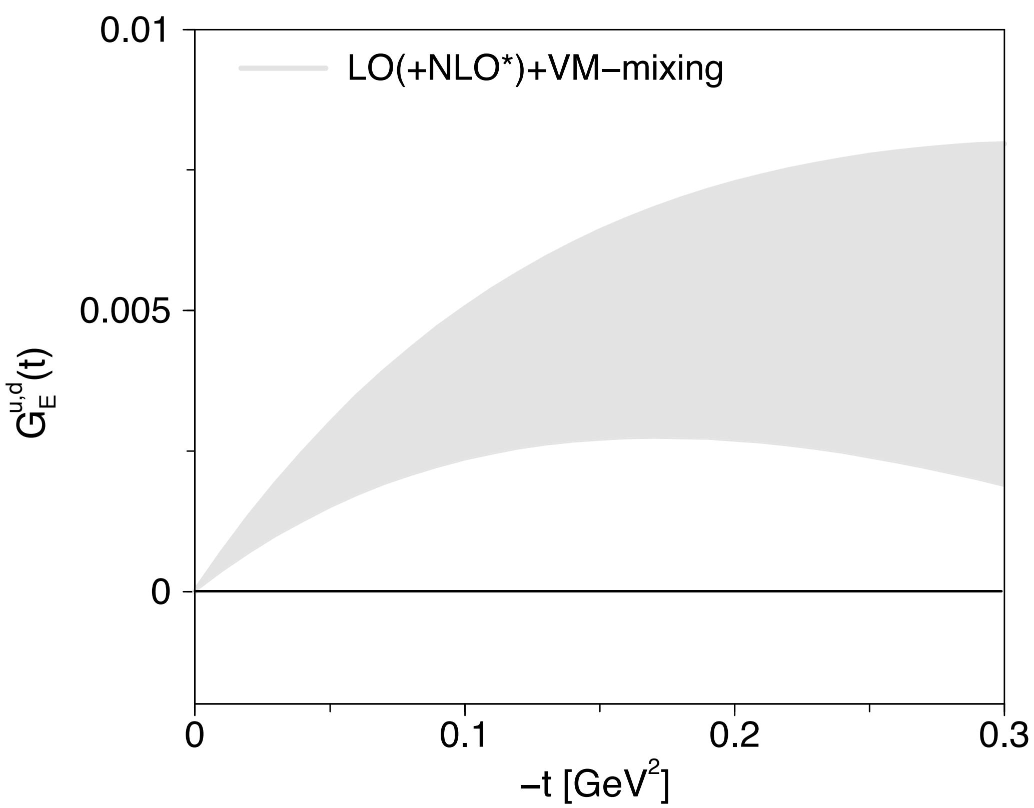
Effects of graphs are not small because of log divergence

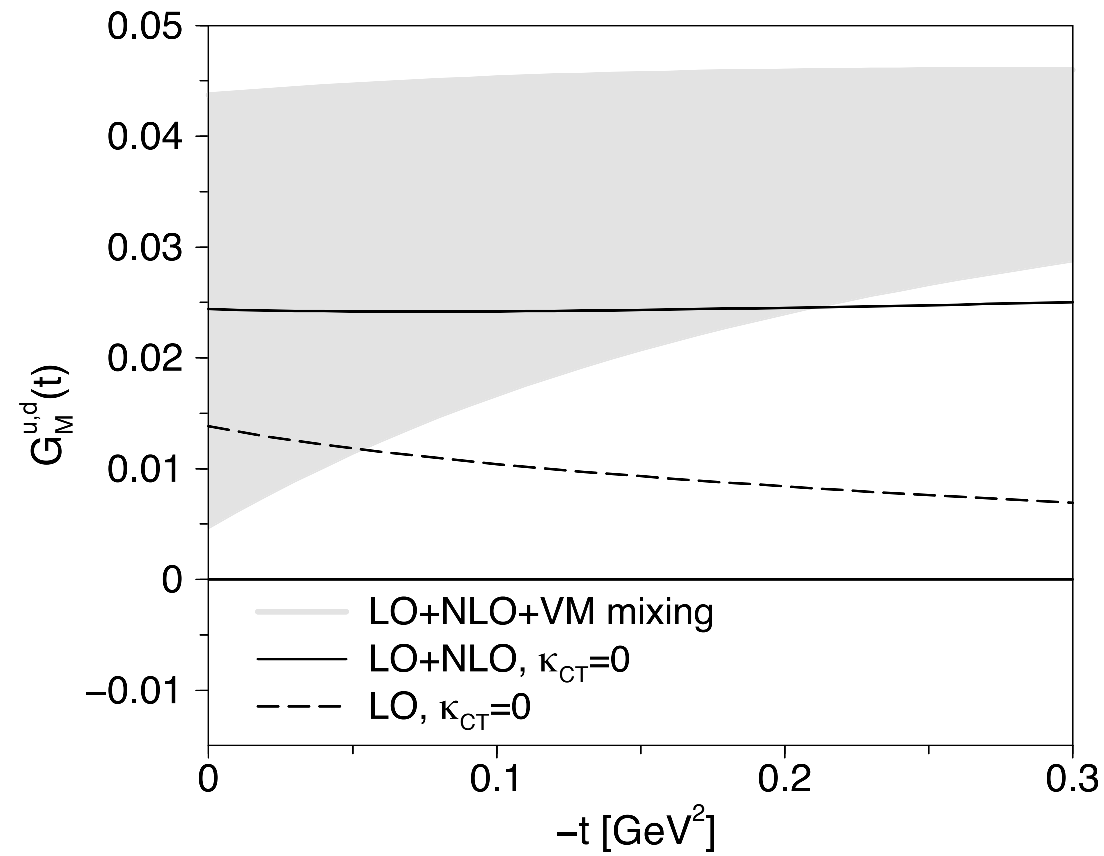
Kubis Lewis procedure-resonance saturation



- Pion graph cut off at rho mass
- Added rho-omega mixing graphs provide a finite counter term, which is larger than pion loop diagram

Kubis Lewis results- gray band is uncertainty



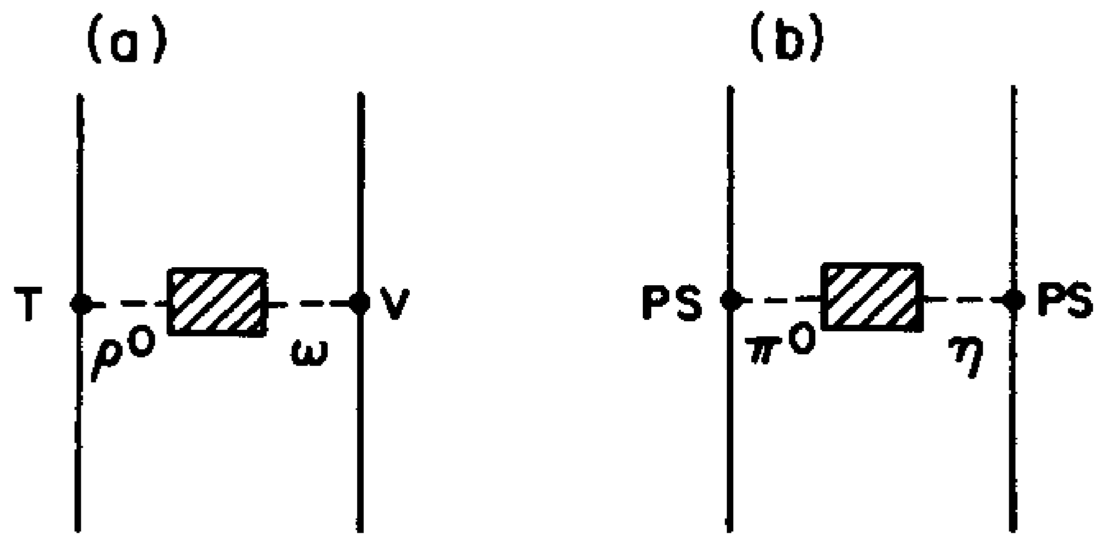


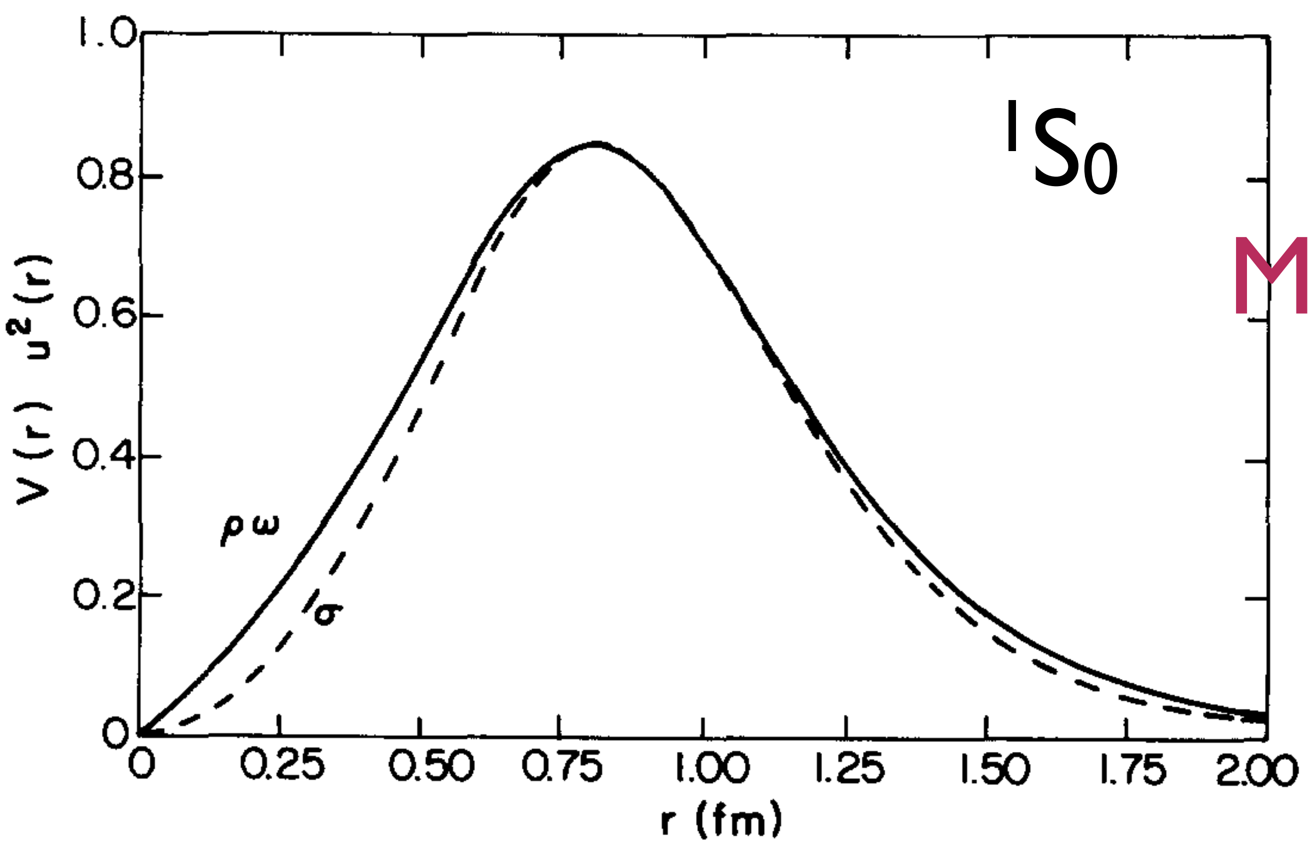
- Results for G_E similar to mine, G_M much larger
- NLO is 100 % correction-calculation NOT converged
- Large spread is caused by uncertainty in strong tensor coupling of omega to nucleon

Kubis Lewis parameters

- KL take strong coupling constants from dispersion analysis of electromagnetic form factors
- Strong coupling constants for omega nucleon MUCH (~7 times) larger than used in NN scattering
- How to tell scientifically ?

Rho-omega mixing in NN scattering





Medium range potential

Rho-omega mixing in NN scattering

CLASS III:

$a_{nn} - a_{pp} = -1.6 \pm 0.6\,\text{fm} = \Delta a$ ← Coul. removal

nn more attractive

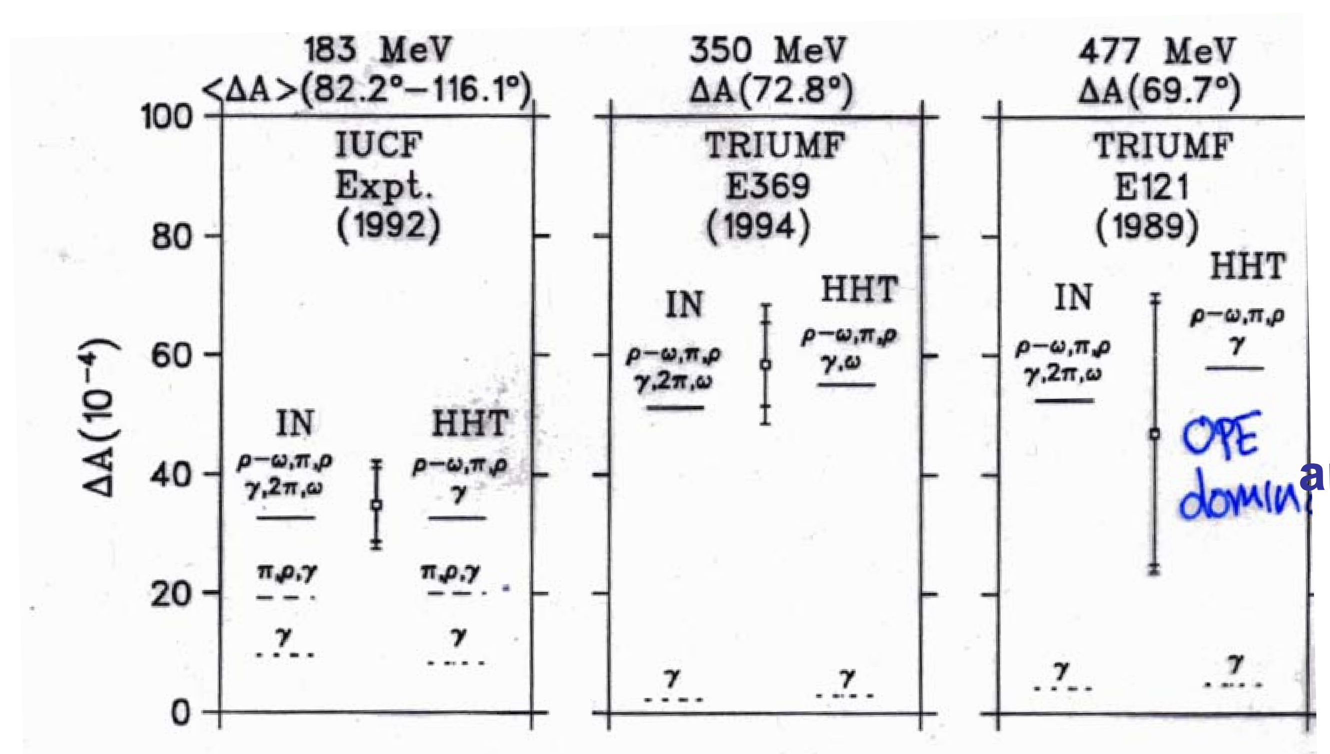
Class IV

$\Rightarrow \Delta a$ Coon & Scadron (OBEP models)

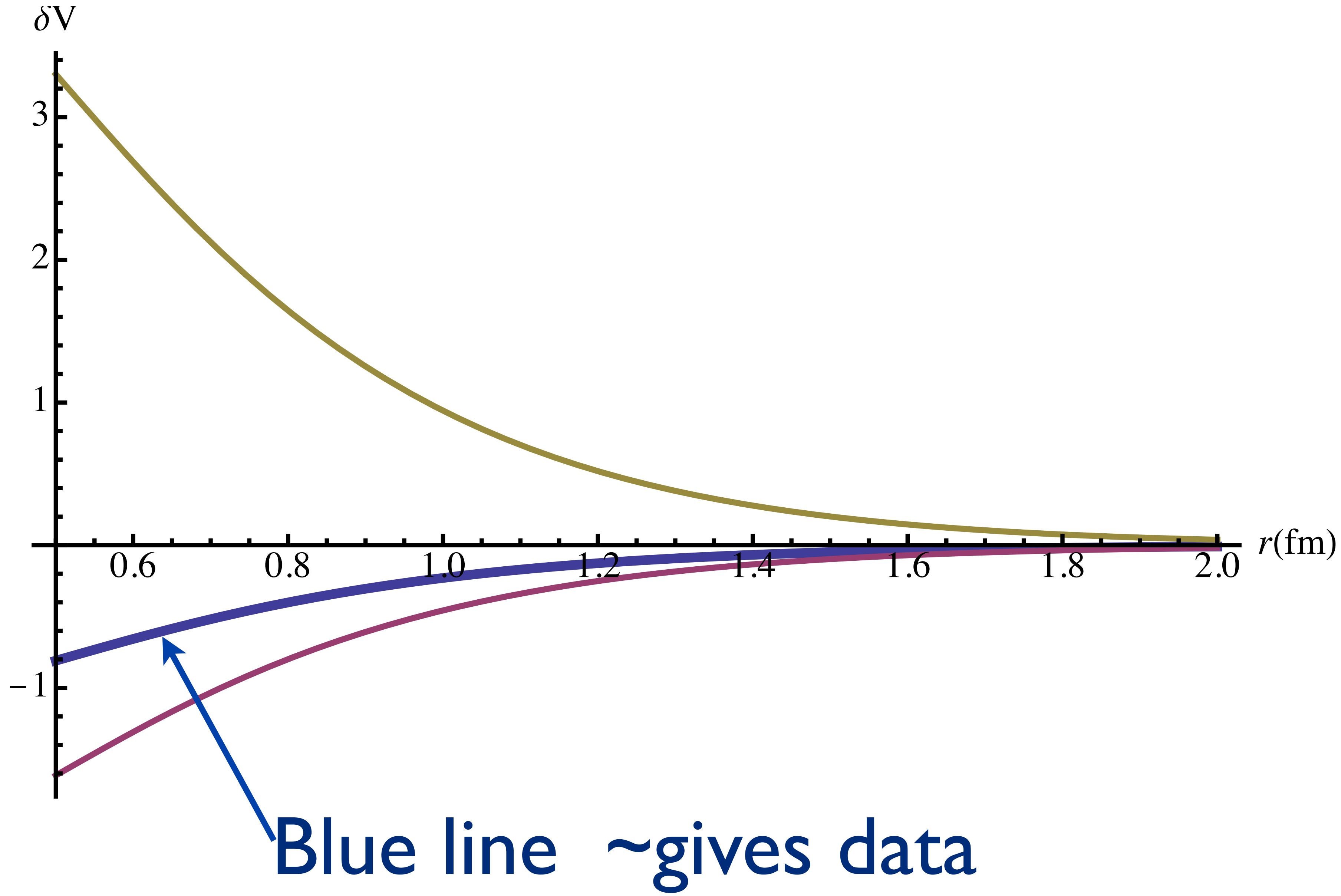
Miller, Nefkens, Slaus 1990

$$V_{IV} = e(\tau_3(1)-\tau_3(2))(\sigma(1)-\sigma(2))\cdot L$$
$$+ f(\tau(1)\times\tau(2))_3\,(\sigma(1)\times\sigma(2))\cdot L$$

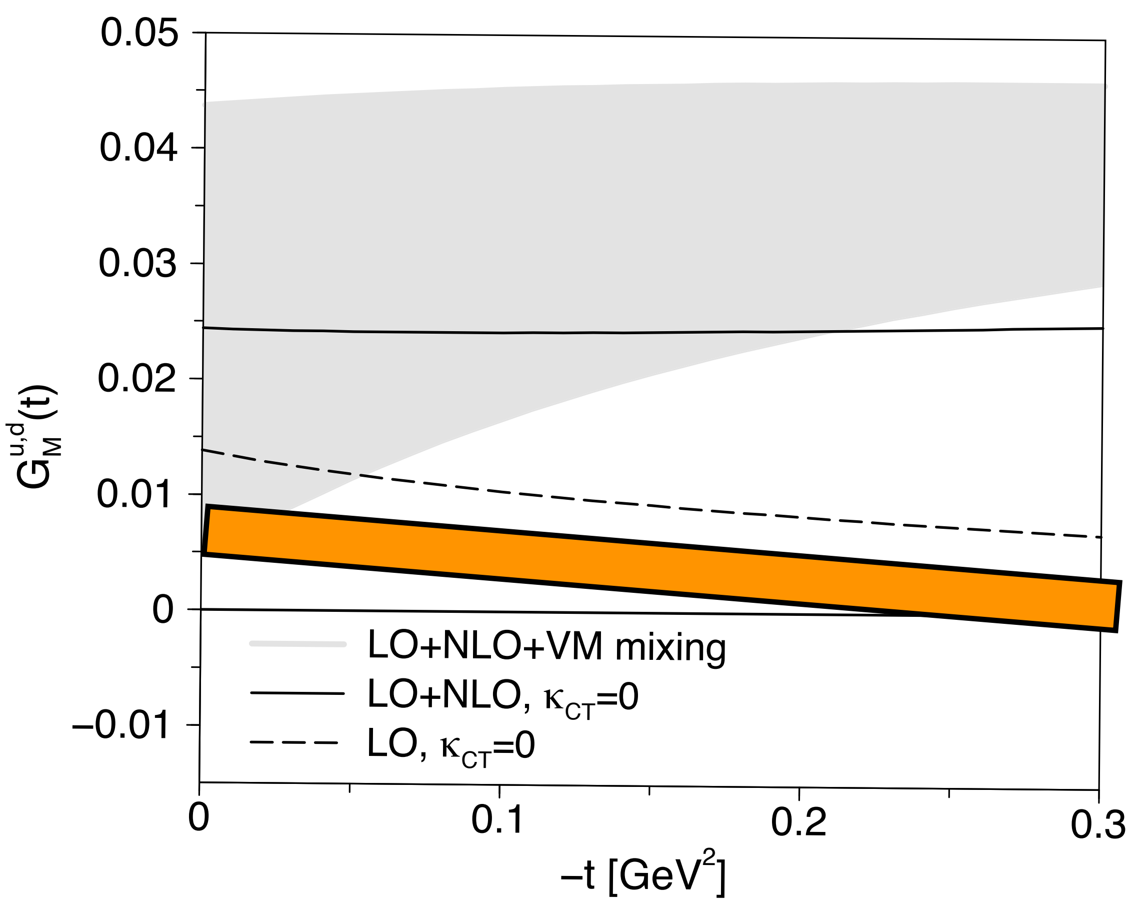
Miller & Van Oers 1994



KL coupling constants in rho-omega exchange



New limits based on CSB in NN scattering +



Preliminary, cautious

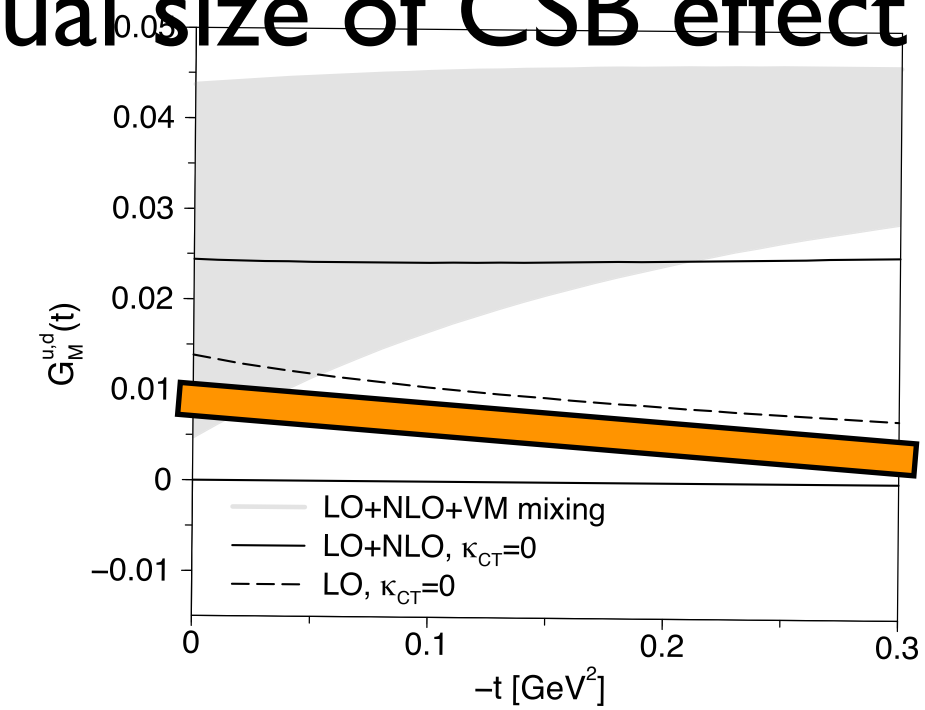
Use of relativistic chiral perturbation theory leads to convergent results

Still to be done

- Model should provide CS form factors that describe data very well
- Use wave functions of those models as basis for CSB calculation
- Relativistic quark model -Cloet Miller 2012
- Bias- quark model vs chiral perturbation theory- if unconstrained counter term needed to evaluate cpt, then model is as good as theory
- can go beyond model and establish rigorous result?

Summary

- Small <0.002 CSB effects, 1998
- Kubis Lewis (not converged) range CSB ~ 0.04 (2006) magnetic
- CSB in NN scattering constrains strong coupling constants in KL resonance saturation
- Actual size of CSB effect probably pretty small



preliminary