Radiatively Generated Isospin Violations in the Nucleon and the NuTeV Anomaly

P. Jiménez Delgado

Theoretische Physik IV
Universität Dortmund

Workshop on Hard Processes
Dortmund, October 11th 2005

M. Gluck, P. J. D. and E. Reya, Phys. Rev. Lett. **95** (2005) 022002.

- NuTeV Weinberg angle $s_W^2 \equiv \sin^2\theta_W \approx 3\sigma$ above world average.
- Among other sources, isospin-symmetry violating pdfs in the nucleon:

$$\delta \overset{(-)}{u}(x,Q^2) = \overset{(-)}{u}{}^p(x,Q^2) - \overset{(-)}{d}{}^n(x,Q^2)$$
$$\delta \overset{(-)}{d}(x,Q^2) = \overset{(-)}{d}{}^p(x,Q^2) - \overset{(-)}{u}{}^n(x,Q^2)$$

- Nonperturbative valence asymmetries due to mass differences $\delta m = m_d - m_u$ and $\delta M = M_n - M_p$ reduce $\approx 30\%$ (Londergan *et al.* within bag model).
- Additional asymmetries from radiative QED effects, at $\mathcal{O}(\alpha)$:

$$\frac{d}{d\ln Q^2}\,\delta \overset{(-)}{u}(x,Q^2) = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\,P\left(\frac{x}{y}\right)\overset{(-)}{u}(y,Q^2)$$
$$\frac{d}{d\ln Q^2}\,\delta \overset{(-)}{d}(x,Q^2) = -\frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\,P\left(\frac{x}{y}\right)\overset{(-)}{d}(y,Q^2)$$

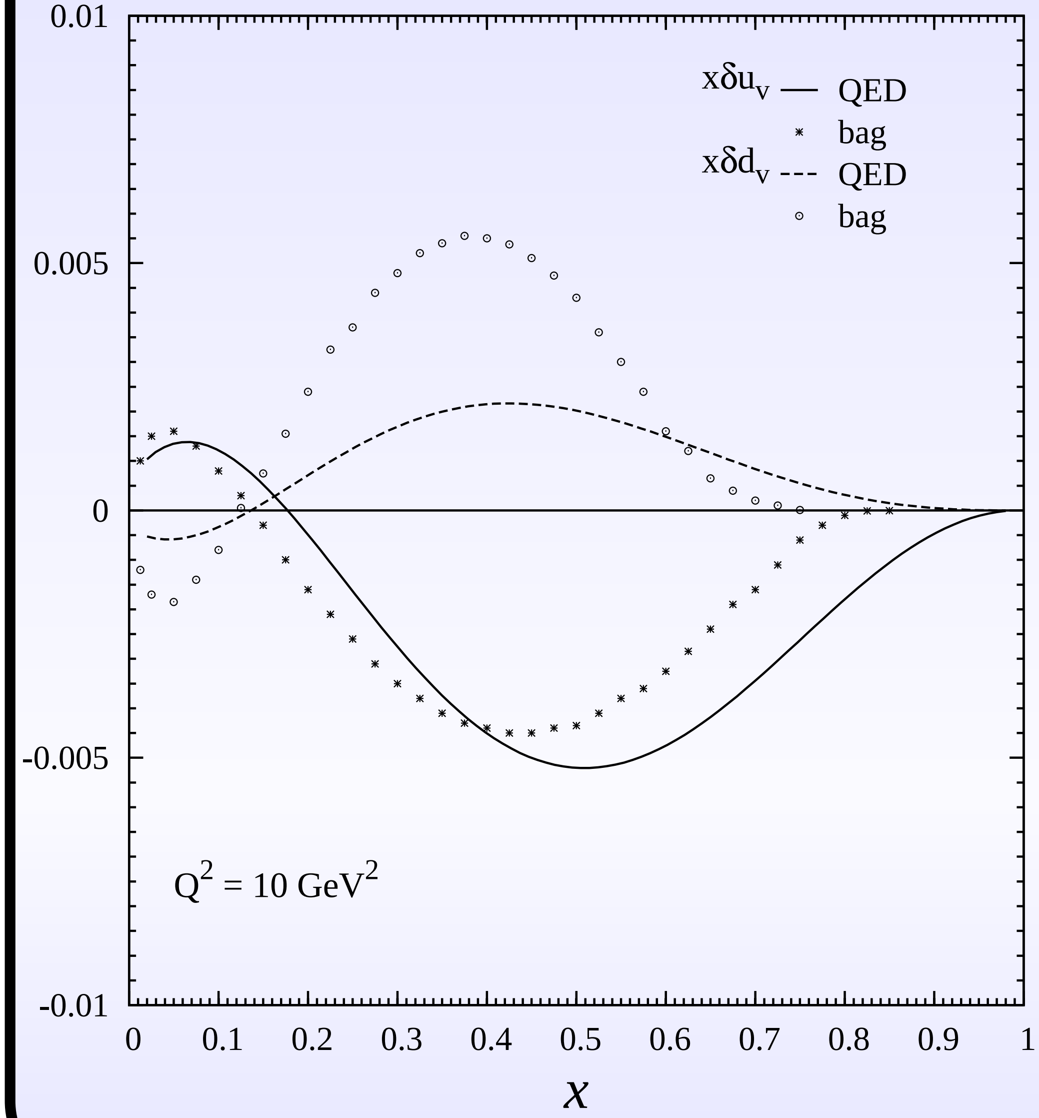
$$P(z) = (e_u^2 - e_d^2)P_{qq}^{\gamma}(z)$$

- Integrating with $m_q = 10$ MeV lower bound for a photon emited by a quark:

$$\delta \overset{(-)}{u}(x,Q^2) = \frac{\alpha}{2\pi}\int_{m_q^2}^{Q^2} d\ln q^2 \int_x^1 \frac{dy}{y}\; P\left(\frac{x}{y}\right)\overset{(-)}{u}(y,\,q^2)$$
$$\delta \overset{(-)}{d}(x,Q^2) = -\frac{\alpha}{2\pi}\int_{m_q^2}^{Q^2} d\ln q^2 \int_x^1 \frac{dy}{y}\; P\left(\frac{x}{y}\right)\overset{(-)}{d}(y,\,q^2)$$

with:
$$\overset{(-)}{q}(y,q^2) = \overset{(-)}{q}(y,\mu^2)$$
for $q^2 \le \mu^2$

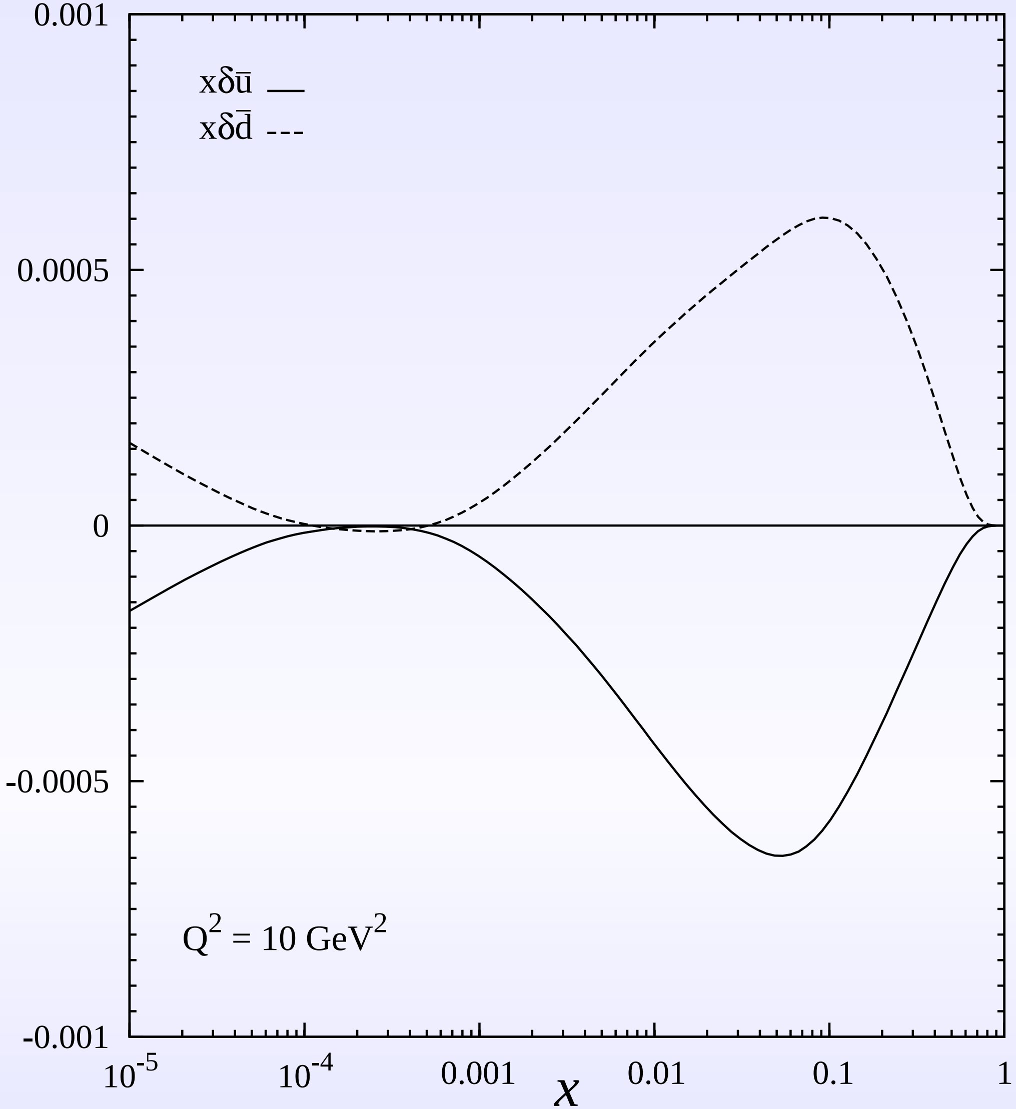
Pedro Jiménez Delgado
Theoretische Physik IV
Universität Dortmund



- LO pdfs of the dynamical (radiative) parton model (GRV98) with $\mu^2 = 0.26$ GeV^2.
- Comparable δu_v but different δd_v than bag model results from δm and δM.
- Similar result as MRST.

Pedro Jiménez Delgado
Theoretische Physik IV
Universität Dortmund

- Considerably smaller than valence asymmetries.
- Similar results obtained for CTEQ4 pdfs which have valence–like sea distributions at the input scale.
- May be tested in precision Drell–Yan and DIS experiments employing neutron as well as proton targets.



Pedro Jiménez Delgado
Theoretische Physik IV
Universität Dortmund

- NuTeV experiment: High precision (anti)neutrino-nucleon DIS. It is measured:

$$R^{\nu(\bar{\nu})}(x, Q^2) \equiv \frac{d^2\sigma_{NC}^{\nu(\bar{\nu})N}(x,Q^2)}{d^2\sigma_{CC}^{\nu(\bar{\nu})N}(x,Q^2)}, \qquad N = \tfrac{1}{2}(p+n)$$

- Assuming $u = d$, $\bar{u} = \bar{d}$ and $s = \bar{s}$:

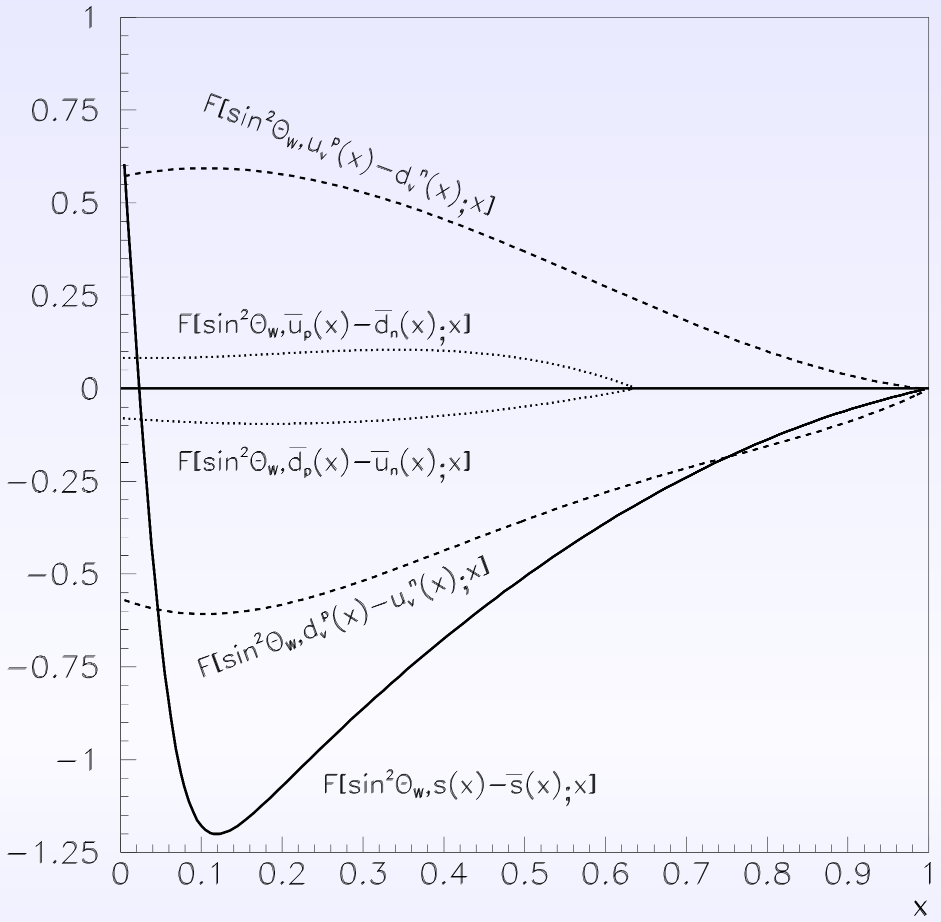
$$R^{\nu(\bar{\nu})} \equiv \frac{\sigma_{NC}^{\nu(\bar{\nu})N}}{\sigma_{CC}^{\nu(\bar{\nu})N}} = g_L^2 + r^{(-1)} g_R^2 \quad \text{with} \begin{cases} g_L^2 = \frac{1}{2} - s_W^2 + \frac{5}{9} s_W^2 \\ g_R^2 = \frac{5}{9} s_W^2 \end{cases}$$

$$\Longrightarrow \sin^2\theta_W^{\text{NuTeV}} = 0.2277 \pm 0.0013 \pm 0.0009$$

- World average of electroweak measurements: $\sin^2\theta_W^{\text{World}} = 0.2228(4)$.
- Analysis includes nonisoscalar target, higher–twists, charm production...
- It is explained considering isospin violations and strange sea asymmetry ($s > \bar{s}$ due to $M_\Lambda > M_K$).

Pedro Jiménez Delgado
Theoretische Physik IV
Universität Dortmund

- Experimental methods/functionals: $\Delta s_W^2 = \int_0^1 F[s_W^2, \delta \overset{(-)}{q}; x] x \delta \overset{(-)}{q}(x, Q^2)\, dx$



- $\Delta s_W^2|_{\mathrm{QED}} = -0.0011$ evaluated using our asymmetries $\delta \overset{(-)}{q}$.

- $\Delta s_W^2|_{\mathrm{bag}} = -0.0015$
  Londergan, Rodionov, Thomas, Sather, etc.

- $\Delta s_W^2|_{\mathrm{strange}} = -0.0017$
  J. Alwall and G. Ingelman.

- Total shift $\Delta s_W^2|_{\mathrm{total}} =$
  $= \Delta s_W^2|_{\mathrm{QED}} + \Delta s_W^2|_{\mathrm{bag}} + \Delta s_W^2|_{\mathrm{strange}}$
  $= -0.0043$

$\sin^2 \theta_W^{\mathrm{NuTeV}} = 0.2277(16) \longrightarrow \sin^2 \theta_W = 0.02234(16)$ agrees with

$\sin^2 \theta_W^{\mathrm{World}} = 0.2228(4)$

Pedro Jiménez Delgado
Theoretische Physik IV
Universität Dortmund

- For simplicity: Corrections to $R^-_{\rm PW}$ instead of $R^{\nu(\bar\nu)}$:

$$R^- \equiv \frac{\sigma^{\nu N}_{\rm NC} - \sigma^{\bar\nu N}_{\rm NC}}{\sigma^{\nu N}_{\rm CC} - \sigma^{\bar\nu N}_{\rm CC}} = R^-_{\rm PW} + \delta R^-_I + \delta R^-_s \ \text{ with } \begin{cases} R^-_{\rm PW} = \frac{1}{2} - s^2_W \\ \delta R^-_I \simeq \left(\frac{1}{2} - \frac{7}{6} s^2_W\right) \frac{\delta U_v - \delta D_v}{U_v + D_v} \\ \delta R^-_s \simeq -\left(1 - \frac{7}{3} s^2_W\right) \frac{S^-}{U_v + D_v} \end{cases}$$

where $\delta\, Q_v(Q^2) = \int_0^1 x\, \delta\, q_v(x, Q^2)\, dx$, $S^- = S - \bar{S}$, etc.

- This overestimates the corrections by $\approx$ 20%–40%:

$$\delta R^-_I|_{\rm QED} = -0.0021 \ \text{ instead of } \ \Delta s^2_W|_{\rm QED} = -0.0011$$
$$\delta R^-_I|_{\rm bag} = -0.0020 \ \text{ instead of } \ \Delta s^2_W|_{\rm QED} = -0.0015$$
$$\delta R^-_s = -0.0021 \ \text{ instead of } \ \Delta s^2_W|_{\rm strange} = -0.0017$$

- $\delta R^-_{I,s}$ should be avoided and Δs^2_W evaluated according to NuTeV functionals (sensitivity of their observables to cuts, etc.)

Pedro Jiménez Delgado
Theoretische Physik IV
Universität Dortmund

Summary

- We evaluate modifications $\delta \overset{(-)}{q}(x, Q^2)$ to standard pdfs due to QED $\mathcal{O}(\alpha)$ photon bremsstrahlung within the dynamical (radiative) parton model.
- The NuTeV Anomaly is removed considering the impact of:
  + these isospin asymmetries (QED).
  + nonperturbative isospin asymmetries: quark and target mass differences.
  + strangeness asymmetry ($s \neq \bar{s}$).
- Naive corrections to the PW relation overestimate Δs_W^2.

Research Status

- Working on NLO $\overline{\mathrm{MS}}$ global analysis (radiatively generated, valence-like).
- Working on factorization scheme dependence of pdfs: DIS scheme analysis.

Pedro Jiménez Delgado
Theoretische Physik IV
Universität Dortmund

Δs_W^2	δu_v	δd_v	$\delta \bar{u}$	$\delta \bar{d}$	total
QED	-0.00071	-0.00033	-0.000019	-0.000023	-0.0011
bag	-0.00065	-0.00081	—	—	-0.0015