Charge Symmetry Violating Parton Distributions

Charge Symmetry for Parton Distributions
Inclusion of CSV in phenomenological PDFs
Theoretical Estimates of parton charge symmetry
Experimental Constraints on parton CSV
Implications of parton CSV→ **PV electron asymmetry**
Conclusions

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Charge Symmetry of Parton Distributions:

Charge symmetry = 180° rotation about "2" axis in isospin space

At the partonic level, **charge symmetry (CS) operation** corresponds to: $u(x) \leftrightarrow d(x)$, and $p \leftrightarrow n$.

(a similar relation holds for antiquarks)

- Nuclear physics → CS generally valid to fraction of %
  (in general, isospin effects ~ 3%)

- Until 2003, all phenomenological parton distribution functions (PDFs) assumed charge symmetry
  (reduced # of PDFs by a factor of 2)

We know the origins of parton CSV:

o quark mass difference: $\delta m \equiv m_d - m_u \sim 4\ \text{MeV}$

o Electromagnetic contributions: an important EM effect:

n-p mass difference $\delta M \equiv M_n - M_p = 1.3\ \text{MeV}$

Models for CSV in Valence PDFs

Violation of approximate symmetries: **"window" →** non-perturbative physics

Construct quark models that reproduce qualitative features of PDFs

Examine their behavior under charge symmetry operations

$$\delta m \equiv m_d - m_u; \qquad \delta M = M_n - M_p$$

$$\delta q_{\mathrm{V}} \approx \frac{\partial q_{\mathrm{V}}}{\partial m}\,\delta m + \frac{\partial q_{\mathrm{V}}}{\partial M}\,\delta M$$

Quark models → predict sign, magnitude of valence parton charge symmetry violation

Important to disentangle CSV effects from other isospin violation, flavor symmetry, heavy quarks → **dedicated experiments**

Quantitative Estimates, Valence Parton CSV

Use quark-model wavefunctions for valence parton PDFs:

$$\delta q_{\mathsf{V}}(x) \approx \frac{\partial q_{\mathsf{V}}}{\partial m}\delta m + \frac{\partial q_{\mathsf{V}}}{\partial M}\delta M$$

$$q_{\mathsf{V}}(x) = \sum_X |\langle X|\psi_+(0)|N\rangle|^2 \, M \, \delta(M(1-x)-p_X-E_X)$$

Sather: study variation with nucleon, quark mass: assume w-function is invariant under CS; obtain analytic approximation (appears as derivatives of valence parton distribution)

$$\delta d_{\mathsf{V}}(x) = d^p_{\mathsf{V}}(x) - u^n_{\mathsf{V}}(x) = -\frac{\delta M}{M}\frac{d}{dx}[x d_{\mathsf{V}}(x)] - \frac{\delta m}{M}\frac{d}{dx}d_{\mathsf{V}}(x)$$

$$\delta u_{\mathsf{V}}(x) = u^p_{\mathsf{V}}(x) - d^n_{\mathsf{V}}(x) = \frac{\delta M}{M}\left(-\frac{d}{dx}[x u_{\mathsf{V}}(x)] + \frac{d}{dx}u_{\mathsf{V}}(x)\right)$$

require $\langle \delta q_{\mathsf{V}} \rangle = 0$ (valence quark normalization)

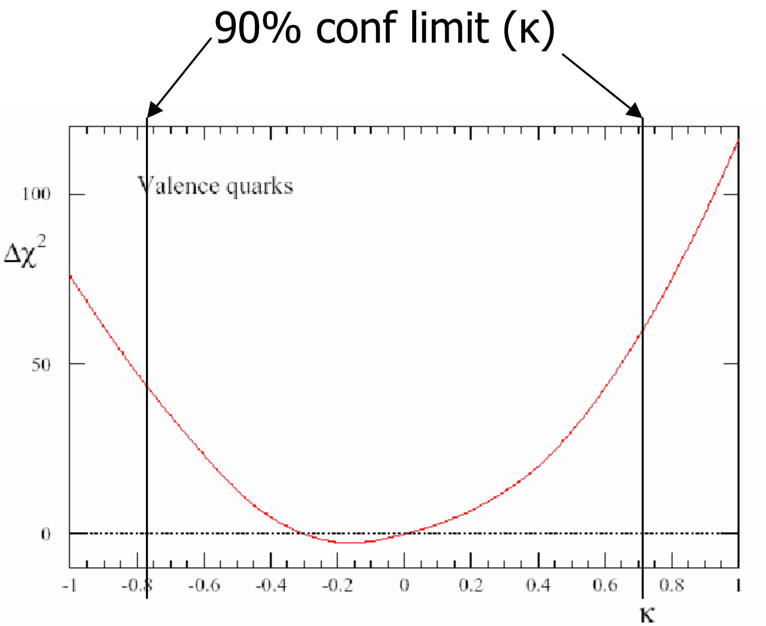
Rodionov etal → quark model CSV calculation;
accounted for quark p_T (neglected by Sather); yet,
CSV PDFs agree to within 20%

Phenomenological Parton CSV PDFs

MRST PDFs from global fits include CSV for 1st time:
Martin, Roberts, Stirling, Thorne [Eur Phys J C**35**, 325 (04)]:
Choose restricted form for parton CSV:

$$\delta d_{\mathrm{V}}(x) = -\kappa f(x) = -\delta u_{\mathrm{V}}(x)$$
$$f(x) = x^{-0.5}(1-x)^4(x - .0909)$$

- f(x) has zero first moment (preserves valence quark normalization)
- f(x) similar to valence PDFs at large, small x
- **requires** δd_v, δu_v equal & opposite

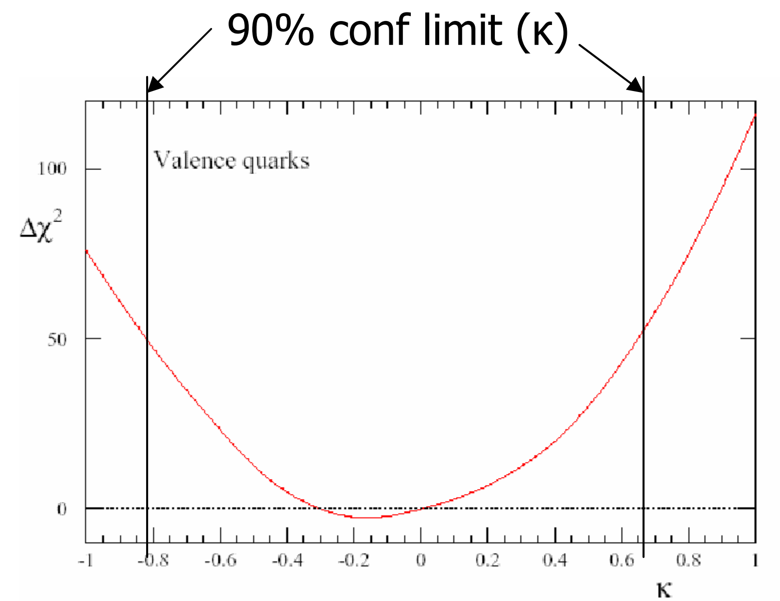


Very shallow minimum found in global fit to HE data
Best fit: **κ = -0.2**, large uncertainty !
90% confidence limit: $-0.8 \leq \kappa \leq +0.65$

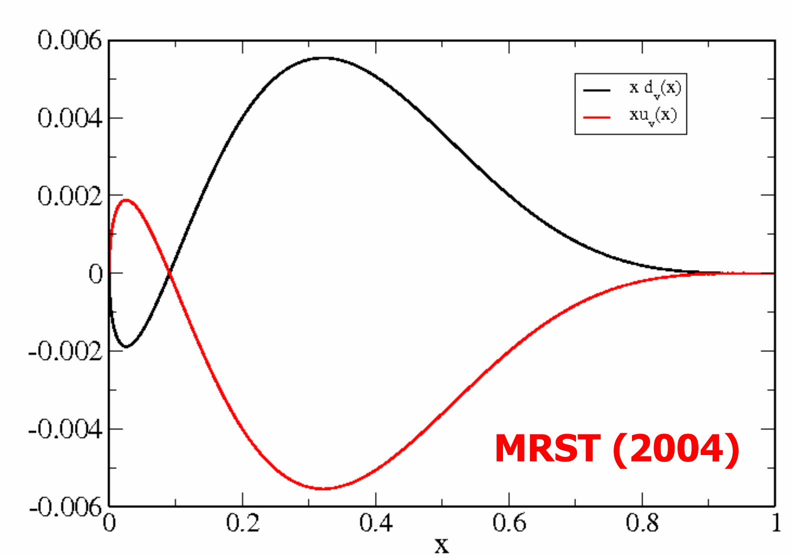
Phenomenological Parton CSV PDFs

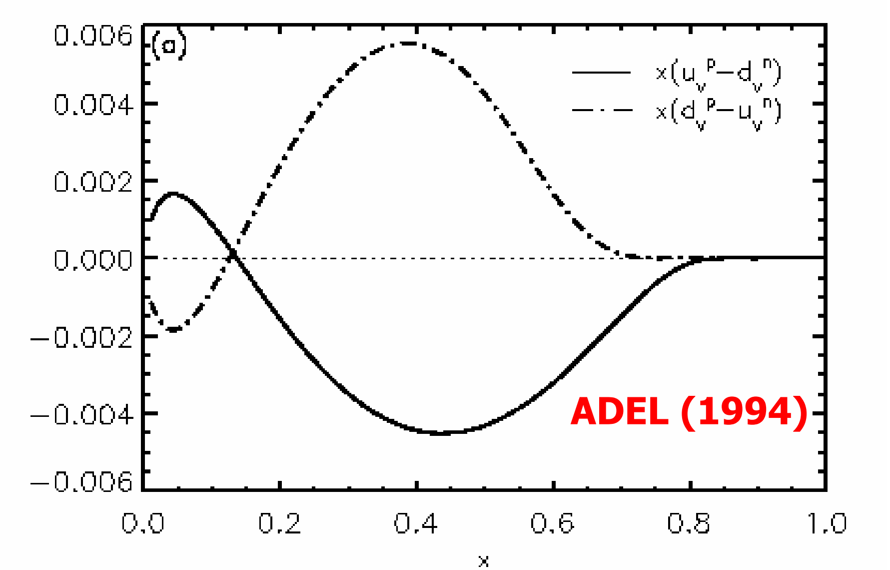
MRST PDFs → global fits including CSV:
Martin, Roberts, Stirling, Thorne [Eur Phys J C**35**, 325 (04)]:

$$\delta d_V(x) = -\kappa f(x) = -\delta u_V(x)$$
$$f(x) = x^{-0.5}(1-x)^4(x-.0909)$$



Best fit: **κ = -0.2**, large uncertainty !
Best fit remarkably similar to quark model CSV calculations





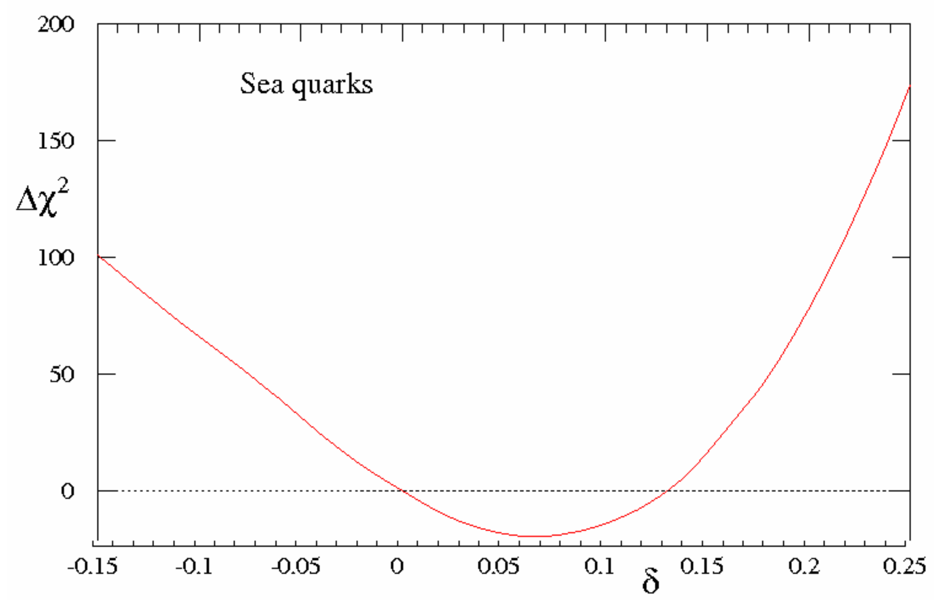
Phenomenological Sea Parton CSV PDFs

MRST also included sea quark CSV term:
Again chose restricted form:

$$\bar{u}^n(x) = (1+\delta)\bar{d}^p(x)$$
$$\bar{d}^n(x) = (1-\delta)\bar{u}^p(x)$$

[momentum carried by sea ~ same for p, n]

Best fit: **$\delta = +0.08$**, surprisingly large!
(corresponds to 8% CS violation in sea)



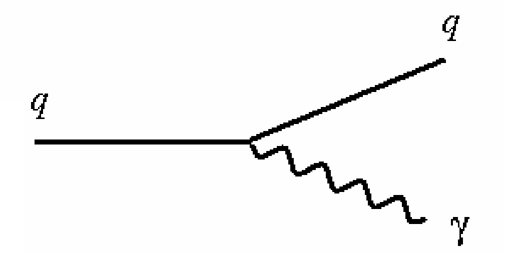
- Minimum in χ^2 substantially deeper than for valence
- Increase in u^n sea → better fit to NMC μ-D data
- Much better fit to E605 Drell-Yan data

Note: for simplicity, MRST **neglect Q^2 dependence of CSV terms**
→ this will affect our estimates of CSV effects.

"QED Splitting": a New Source of Isospin Violation

MRST, Eur.Phys.J. **39**, 155 (05);
Glueck, Jimenez-Delgado, Reya,
PRL**95**, 022002 (05)

"QED evolution", quark radiates photon
Evolve in Q^2



$$\frac{d}{d\,lnQ^2}\,\delta q_{\mathsf{V}}(x,Q^2) \;\sim\; \pm\frac{\alpha}{2\pi}P\otimes q_{\mathsf{V}}$$

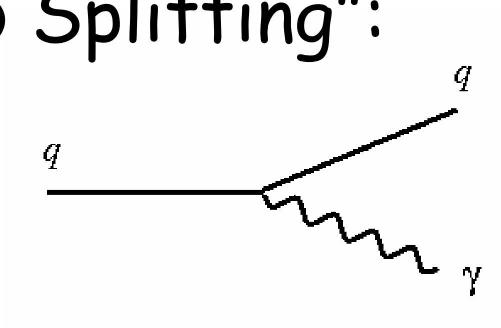
$$P(z) \;=\; (e_u^2 - e_d^2)\left(\frac{1+z^2}{1-z}\right)_+$$

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

- correct to lowest order in α_{QED}
- qualitatively similar to quark model CSV
- QED varied while quarks "frozen"
- contributes even if $m_u = m_d$ and $M_n = M_p$
- evolve from m_q to Q
- for $m_q^2 < q^2 < Q_0^2$, Glueck "freeze" quark PDFs
- (Q_0^2 = GRV starting scale for QCD evolution)

CSV Effects arising from "QED Splitting":

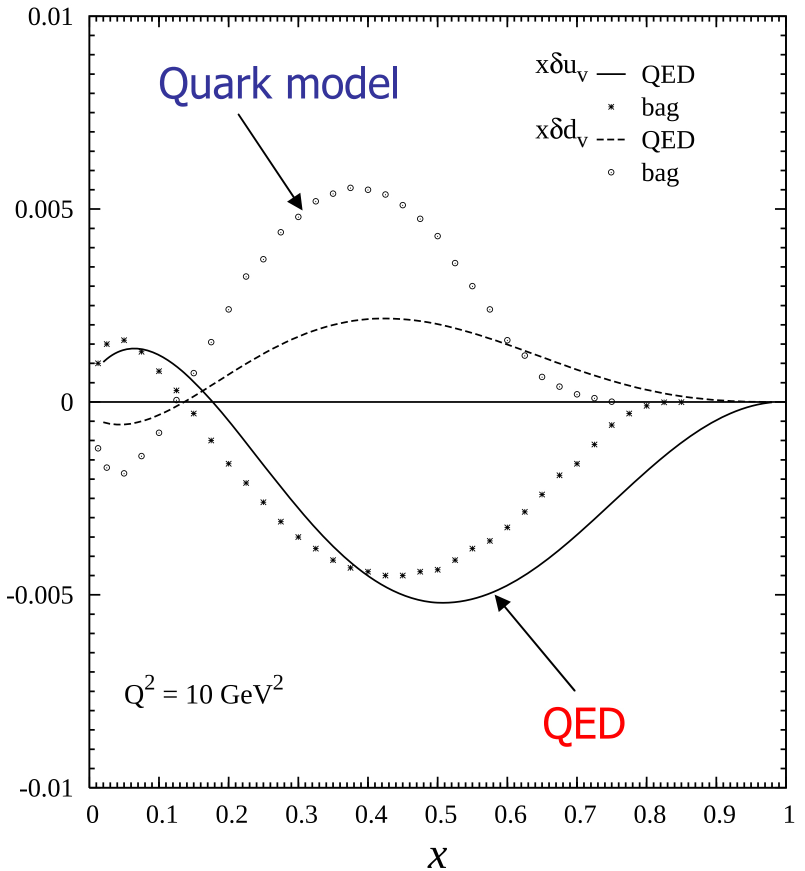
MRST, Eur.Phys.J. **39**, 155 (05);
Glueck etal, PRL**95**, 022002 (05)



$$\frac{d}{d\,lnQ^2}\,\delta q_V(x,Q^2) = \pm\frac{\alpha}{2\pi}P\otimes q_V$$

$$P(z) = (e_u^2 - e_d^2)\left(\frac{1+z^2}{1-z}\right)_+$$

Glueck results:



- **add to** quark model CSV term →
- **increase CSV ~ factor 2**
- MRST incorporate QED splitting with PDFs in global fit to high energy data
- Glueck: CSV effects relatively large at high x

Experimental Limits on parton CSV

- **No direct evidence** for charge symmetry violation in PDFs
- Strongest limits → the **"charge ratio"**
- Compare **F_2 structure functions** from ν, EM DIS

$$R_c(x) \equiv \frac{F_2^{\gamma N_0}(x) + x(s(x) + \bar{s}(x) - c(x) - \bar{c}(x))/6}{5\,\overline{F_2}^{W N_0}(x)/18}$$

$$\approx 1 + \frac{3x\left(\delta u(x) + \delta\bar{u}(x) - \delta d(x) - \delta\bar{d}(x)\right)}{10Q(x)}$$

$$Q(x) \equiv \sum_j x\left[q_j(x) + \bar{q}_j(x)\right]$$

$F_2^{\gamma\, N_0}$ = F_2 structure function for charged lepton DIS on isoscalar target

$\overline{F}_2^{W\, N_0}$ = average F_2 neutrino+ antineutrino CC DIS (isoscalar target)

(sometimes called the **"5/18 rule"**)

Deviation of R_c from 1 → **evidence for CSV in PDFs**

Experimental Measurements of Charge Ratio

New experiments provide unprecedented precision

- Best comparison: NMC mu-D DIS; CCFR nu-Fe CC DIS
- Many corrections must be made in comparison

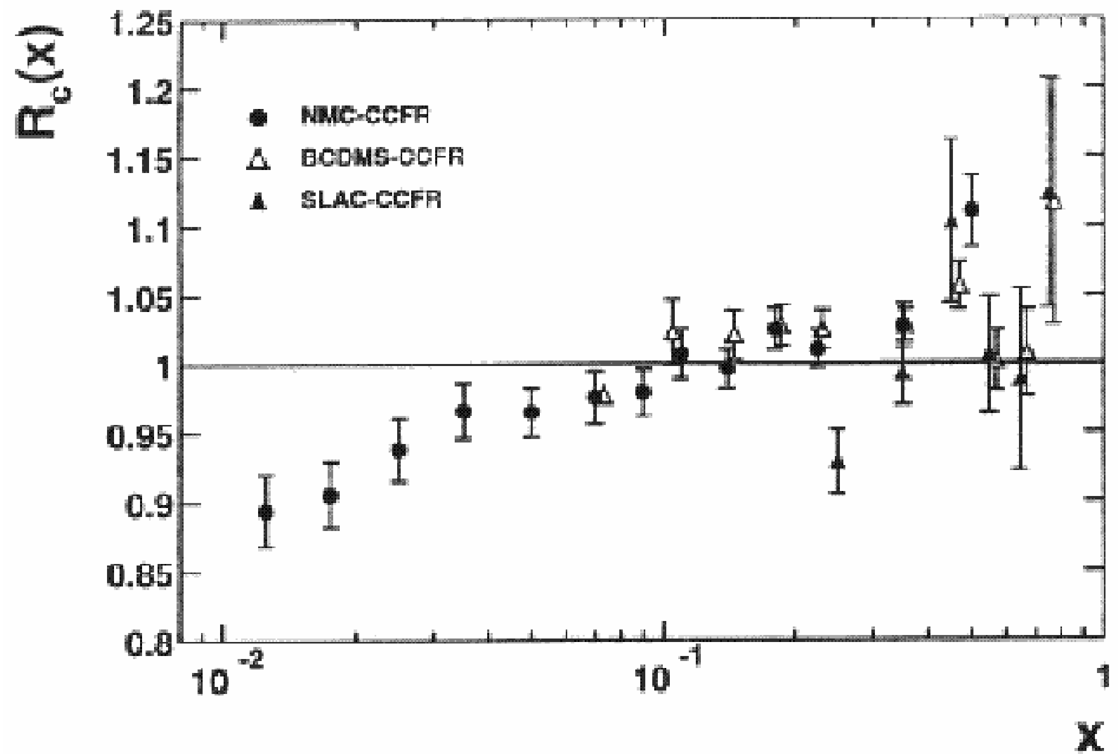
CCFR/NMC (LO) analysis:
Agreement for $0.1 < x < 0.4$
large errors for $x > 0.4$
(nuclear Fermi motion)

(apparent disagreement $x < 0.1$
→ removed on re-analysis)

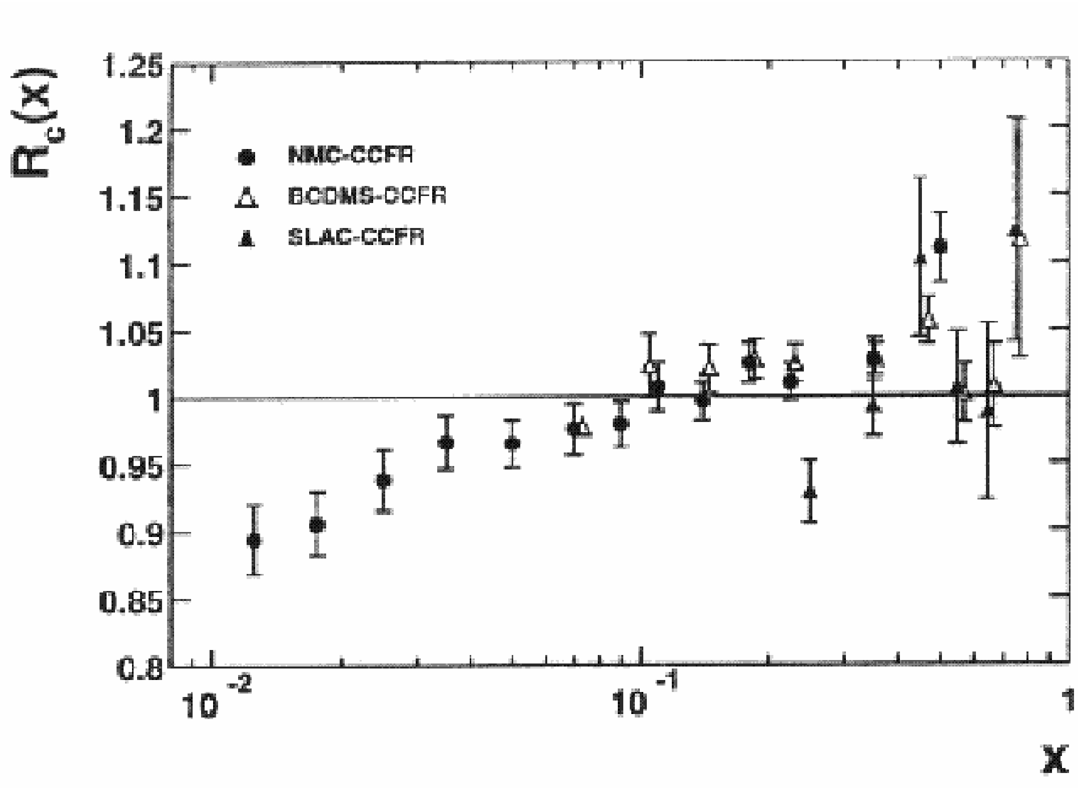
1) ratio R_c ~1 to ~ 2-3 %

$$\frac{\delta q(x)}{Q(x)} = \frac{10}{3}\left(R_c(x) - 1\right)$$

→ parton CSV determined
to ~ 6-9 % level
(includes valence, sea CSV)



Direct Tests of Parton CSV



- Note: no serious limits established for x ≥ 0.4
- Any direct measurement for x ≥ 0.4 would be new
- Current results ≥ 6% on R_c
- This translates to 20% (or larger) limit on CSV

CSV and the Paschos-Wolfenstein Ratio:

Neutrino Total Cross Sections on Isoscalar Target:

$$R^{\nu} \equiv \frac{\sigma\langle \nu\, N_0 \longrightarrow \nu\, X\rangle}{\sigma\langle \nu\, N_0 \longrightarrow \mu\, X\rangle} = g_L^2 + r\, g_R^2$$

$$R^{\overline{\nu}} \equiv \frac{\sigma\langle \overline{\nu}\, N_0 \longrightarrow \overline{\nu}\, X\rangle}{\sigma\langle \overline{\nu}\, N_0 \longrightarrow \overline{\mu}\, X\rangle} = g_L^2 + \frac{1}{r}\, g_R^2$$

$$r \equiv \frac{\sigma\langle \overline{\nu}\, N_0 \longrightarrow \overline{\mu}\, X\rangle}{\sigma\langle \nu\, N_0 \longrightarrow \mu\, X\rangle}$$

$$R^{PW} \equiv \frac{R^{\nu} - r\, R^{\overline{\nu}}}{1-r} = \frac{\sigma\langle \nu\, N_0 \longrightarrow \nu\, X\rangle - \sigma\langle \overline{\nu}\, N_0 \longrightarrow \overline{\nu}\, X\rangle}{\sigma\langle \nu\, N_0 \longrightarrow \mu\, X\rangle - \sigma\langle \overline{\nu}\, N_0 \longrightarrow \overline{\mu}\, X\rangle} = \frac{1}{2} - \sin^2\theta_W$$

Paschos/Wolfenstein: Independent measurement of Weinberg angle
PW ratio → minimizes sensitivity to PDFs, higher-order corrections

NuTeV expt: nu, nubar total X-sections (CC, NC) on Fe target
(weak decays of pi, K from 800 GeV protons at FermiLab)

NuTeV: different cuts, acceptances for $R^{\nu}, R^{\overline{\nu}}$
→ can't simply construct PW ratio:
Monte Carlo procedure (errors differ from PW estimates)

Explanations for NuTeV Anomaly ??

- ✓ "New Physics" – many expt's at Z mass extremely precise
  "new particles" unable to simultaneously fix NuTeV, leave LEP results unchanged

- ✓ Radiative Corrections" to NuTeV measurement??
  unlikely but new calculation → need to include in re-analysis

- ✓ strangeness (diff in momentum carried by s, sbar)
  possible, disagreement between NuTeV, CTEQ

- ✓ parton CSV? **at present, most plausible single explanation for NuTeV anomaly**

- ✓ nuclear effects (shadowing, EMC effect)?
  unlikely – calculations show effect < 20%

Charge Symm Violating Corrections to NuTeV:

Changes in PW ratio from isospin violating PDFs:

$$\delta R^{PW}_{CSV} = \delta\left(\sin^2\theta_W\right) = \frac{\delta U_V - \delta D_V}{2(U_V + D_V)}\left[1 - \frac{7}{3}\sin^2\theta_W + \frac{4\alpha_s}{9\pi}\left(\frac{1}{2} - \sin^2\theta_W\right)\right]$$

$$\delta U_V \equiv \int_0^1 x\left[u_V^p(x) - d_V^n(x)\right]\,dx; \qquad \delta D_V \equiv \int_0^1 x\left[d_V^p(x) - u_V^n(x)\right]\,dx$$

PW Correction → valence parton **charge symmetry violation (CSV)**

- quark models: remove **1σ of NuTeV effect**
- "QED splitting": also remove **1σ of NuTeV effect**
- Phenomenology (MRST): can remove **100% of NuTeV effect** (or make the effect twice as big)

→ CSV sufficiently large to remove NuTeV anomaly would produce **observable effects in certain reactions**

New Expt's to Search for Charge Symmetry Violation ??

- pi-D Drell-Yan Reactions
- SIDIS e-production of pions
- Charge asymmetry in W production

Note: every experiment **has significant challenges**

Expt'l Challenges in Parton Charge Symmetry Searches

- pi-D Drell-Yan Reactions

  need to compare DY for π^+ -D and π^- -D;
  large x for both pi, N
  problem: π^+ mis-identify with protons from initial beam

- electroprod'n of charged pions

  quark fragments to charged pion;
  need factorization to be valid to roughly 2%
  (unlikely to be the case at JLab)

CSV Contribution to PV Asymmetry

PV asymmetry in e-D scattering

$$A_{PV}^{e-D} \sim \frac{F_{1D}^{\gamma Z}}{F_{1D}^{\gamma}}$$

$$\frac{\delta A_{PV}}{A_{PV}} = \left[\frac{3}{10} - \frac{2c_{1u}+c_{1d}}{2(2c_{1u}-c_{1d})}\right] \frac{\delta u(x) - \delta d(x)}{u(x)+d(x)}$$

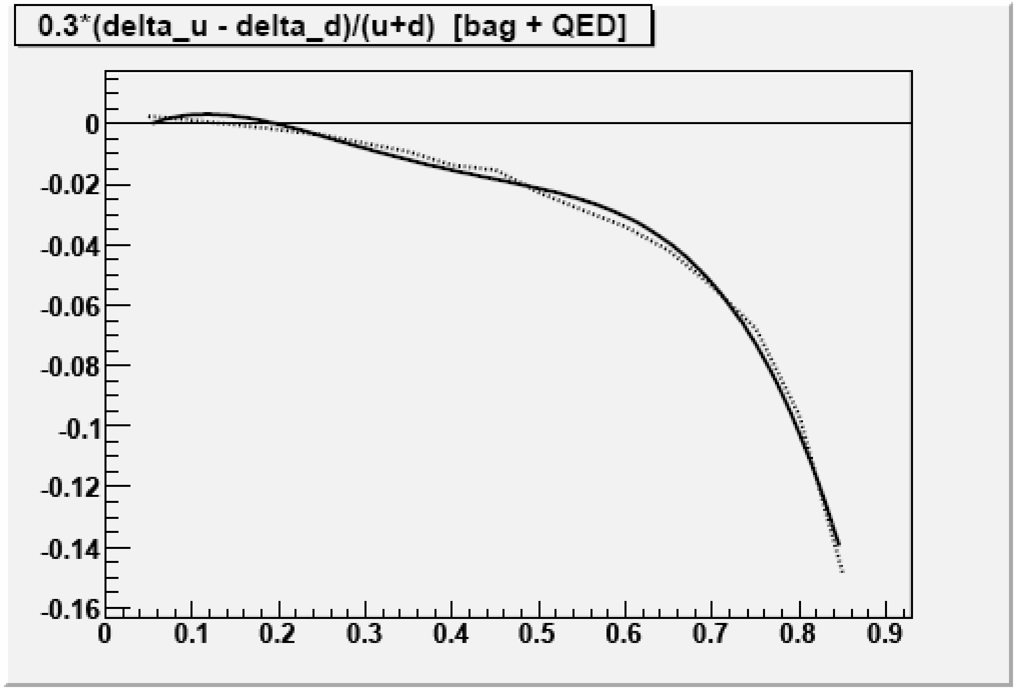
$$\approx 0.28\, R_{CSV}(x)$$

We have assumed the following:

- b(x) << a(x)
- for larger x dominated by valence quark PDFs
- (dominated by **CSV in denominator**)
- factor 0.28 → is CSV large enough to be observed??

Predicted CSV with Glueck PDFs

- CSV same sign as MRST
- significantly larger effects, particularly at large x
- at x= 0.7, CSV asymm is about 6%
- predicted effect grows very rapidly with x
- uncertainty in d/u at large x account for this?
- Note – for x > 0.7, Fermi motion effects become significant (W Melnitchouk)



x

Prospects for Measuring PDF CSV Effects:

- ✓ Can parton CSV be measured in PV DIS asymm at 12 GeV JLab?
- ✓ **QED + QCD models:** valence parton CSV asymm a few % at large x
- ✓ **Asymm measurements at the 1% level should see effect**
  (assuming validity of Glueck + QCD calculations!)
- ✓ Can this be interpreted as CSV? Probably not by itself
  (uncertainty in d/u – need to combine D, H measurements)
- ✓ **Fermi motion effects set in at sufficiently large x**
- ✓ **Warning – calculations are preliminary !**
- ✓ **Any "direct" measurement, even upper limits, for large x**
  would be unique (current limits highly indirect)

Predicted CSV with MRST PDFs

- Predicted CSV is negative (same as for Glueck)
- significantly smaller than Glueck prediction
- seems to arise from **strong cancellation** between valence, sea CSV in MRST → artifact of MRST construction
- currently under investigation
- **No way to tell** which is more accurate – but Glueck seems better motivated theoretically

Conclusions:

✓ **Theoretical models** suggest magnitude, sign of valence parton CSV

✓ **"Charge ratio"** → few % limits on magnitude of CSV, **$x \leq 0.4$**

✓ **"QED splitting"** → new I-spin violating (Q^2 dependent) effect

✓ **First phenomenological CSV PDFs** (MRST 04):
valence CSV – weak evidence, remarkable agreement w/models
sea CSV – roughly 8% effect; improved fit, NMC, E605 data

✓ "I-spin Corrections" to NuTeV measurement of $\sin^2\theta_W$
(most likely single explanation of NuTeV anomaly)

- suggested experiments to measure CS violation
- need excellent precision, dedicated experiments; difficult!

✓ PVDIS exp't → **possibly test CSV at large x**
(MRST → marginal; GRV → large enough to test?)