Partonic charge symmetry violation in the nucleon

Ross Young
CSSM & CoEPP
University of Adelaide

INPC 2016
26th International Nuclear Physics Conference,
11-16 September 2016
Adelaide Convention Centre, Adelaide, Australia

Why care about charge symmetry violation in partons?

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nature International weekly journal of science

LETTER

[2014]

doi:10.1038/nature12964

Measurement of parity violation in electron–quark scattering

The Jefferson Lab PVDIS Collaboration*

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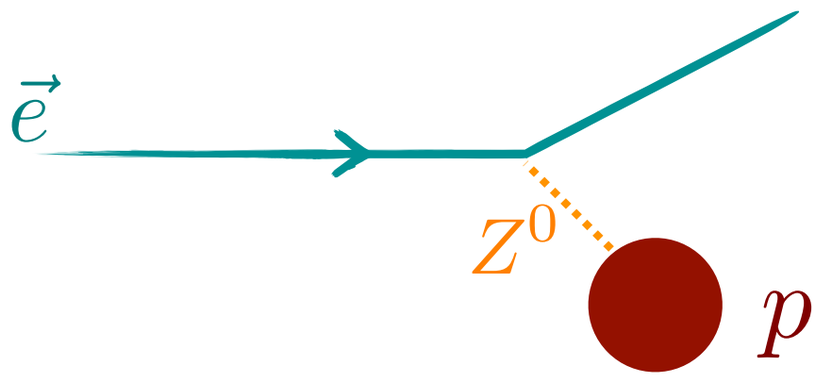
Test of the Standard Model in parity-violating deep inelastic scattering



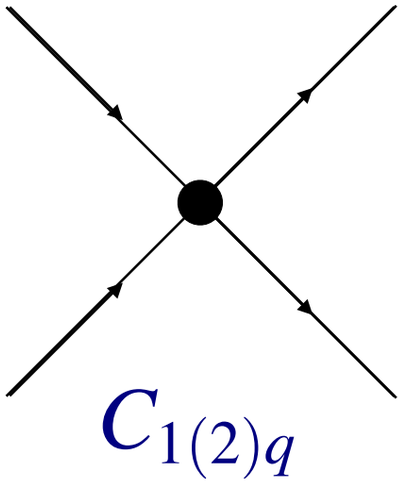
Intermediate momentum transfer

$$\Lambda^2_{\mathrm{QCD}} \ll Q^2 \ll \Lambda^2_{\mathrm{weak}}$$

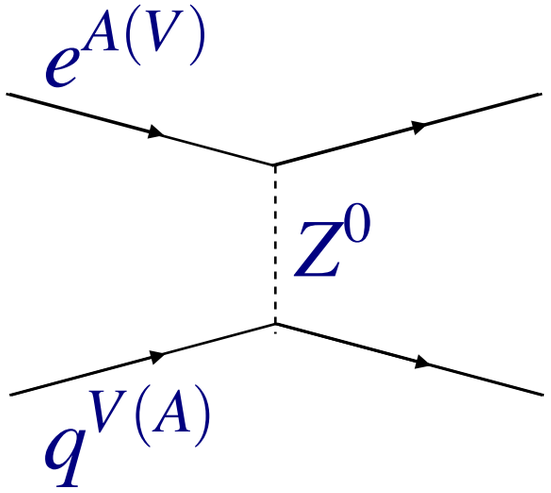
e–*p* scattering in terms of parton degrees of freedom

low-energy effective electroweak interaction

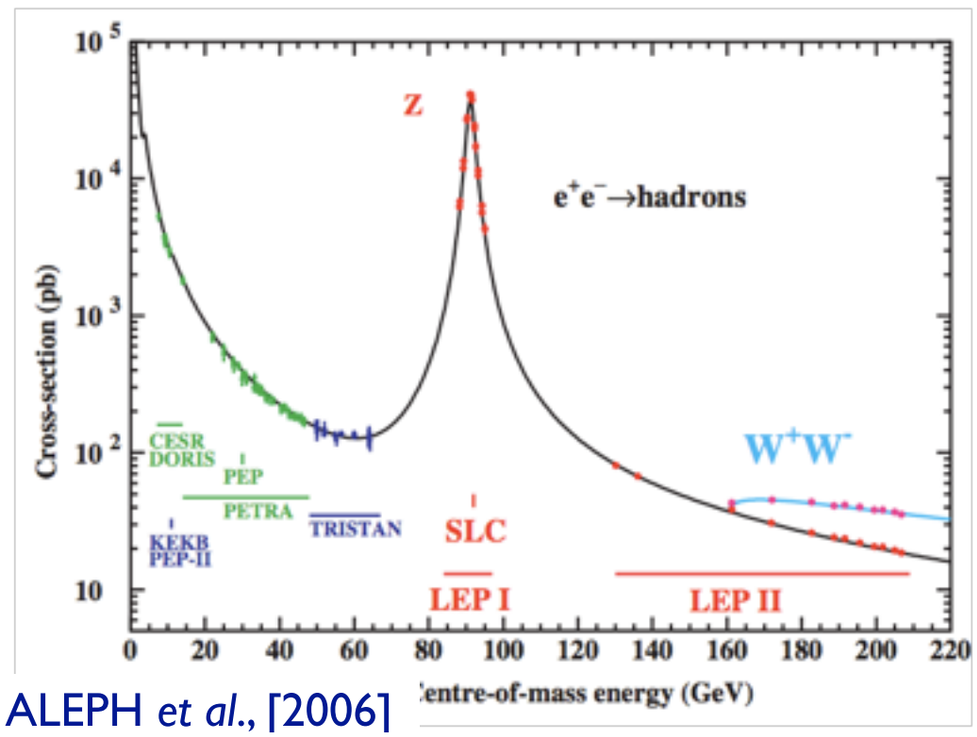
Effective weak interaction



$Q^2 \to 0$



Precision Z-pole measurements [LEP]



ALEPH *et al.*, [2006]

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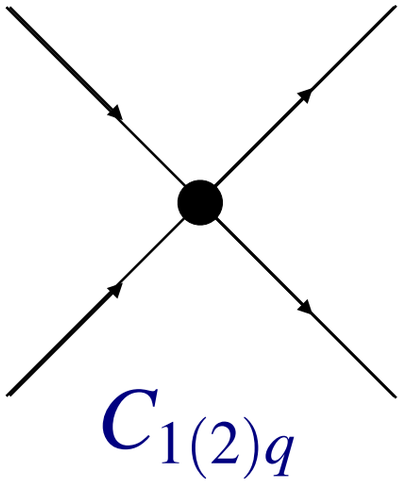

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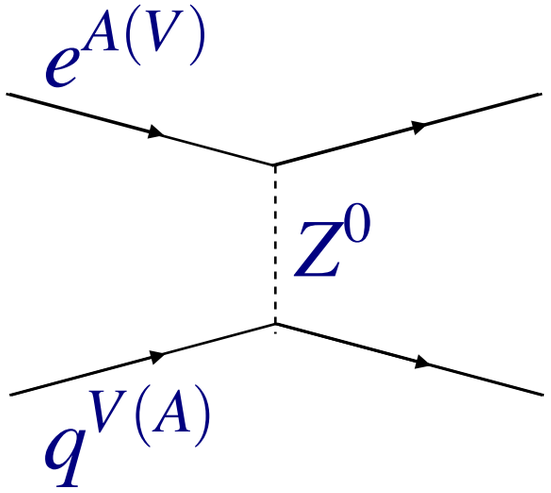
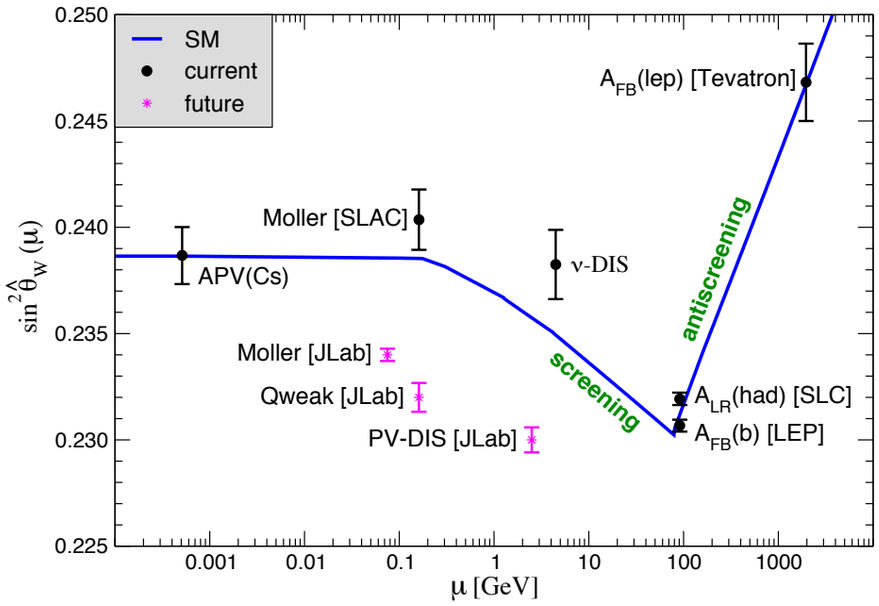
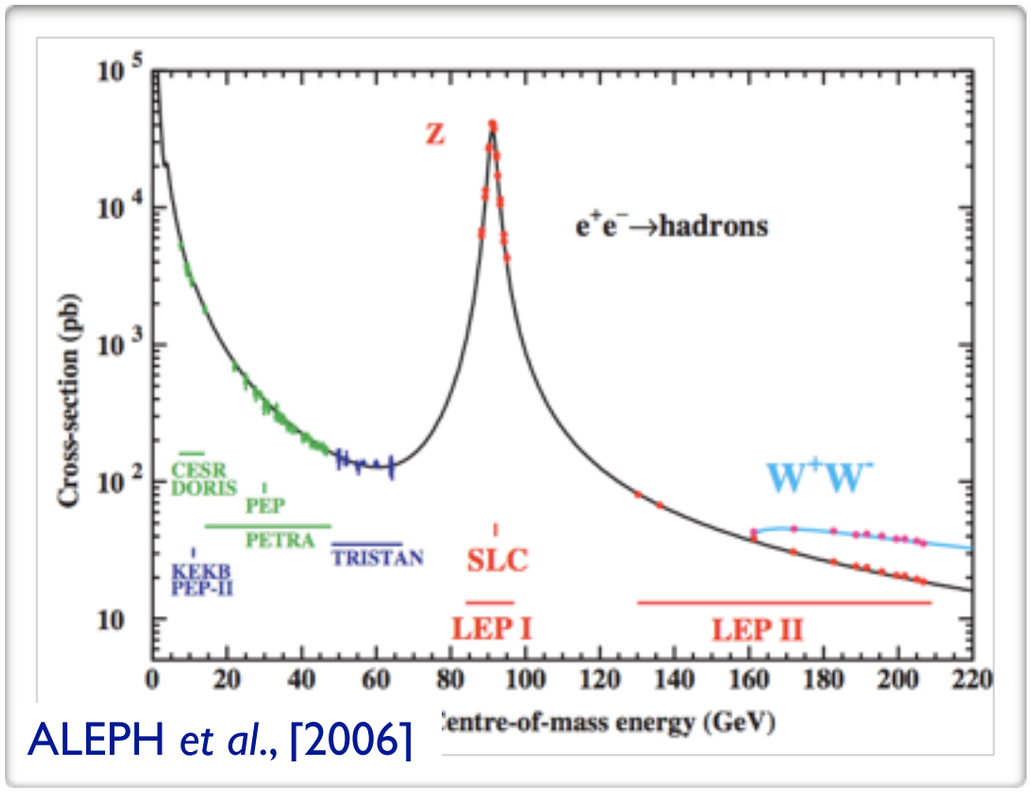




Precision *Z*-pole measurements [LEP]



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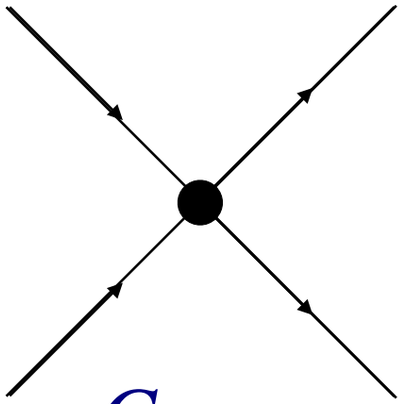
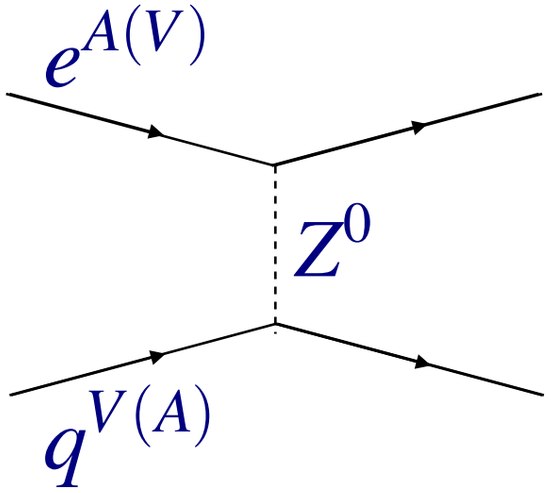
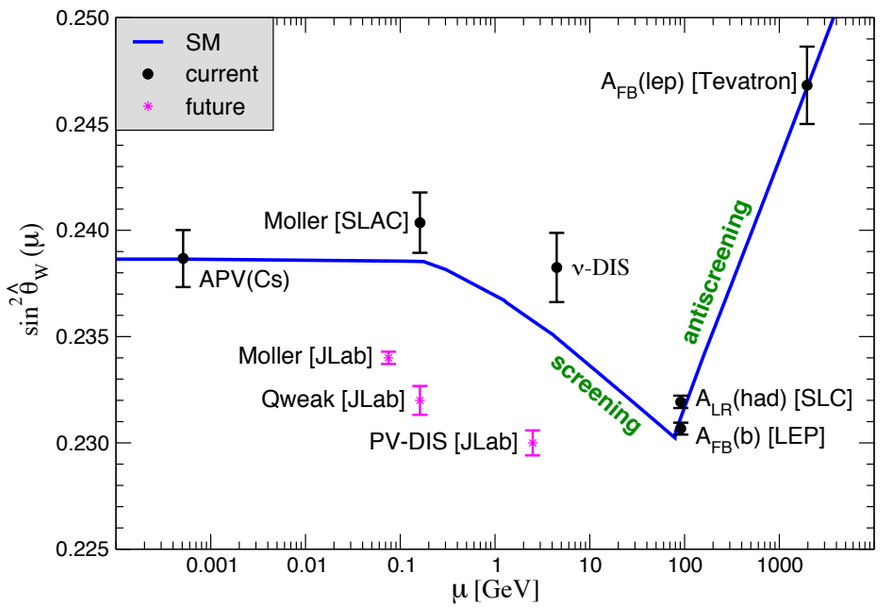


$C_{1(2)q}$

$Q^2 \to 0$



$$\mathcal{L}^{PV}_{(q)} = \frac{G_F}{\sqrt{2}}\left[C_{1q}\bar{q}\gamma^\mu q\,\bar{e}\gamma_\mu\gamma_5 e + C_{2q}\bar{q}\gamma^\mu\gamma_5 q\,\bar{e}\gamma_\mu e\right]$$



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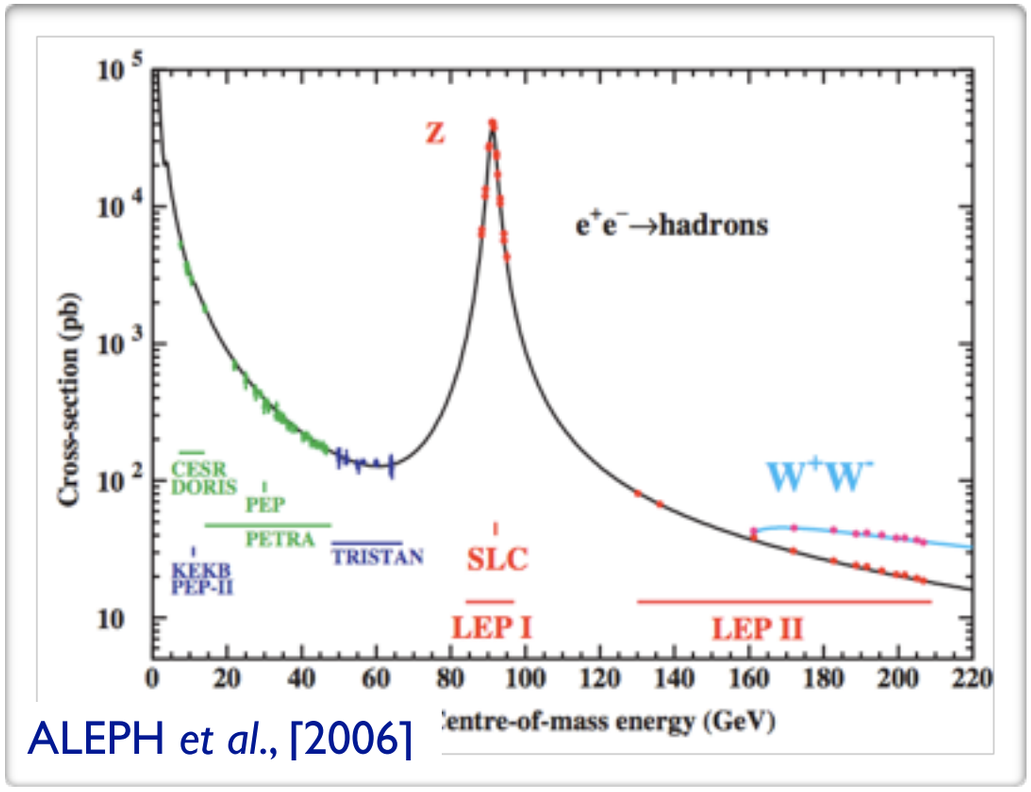

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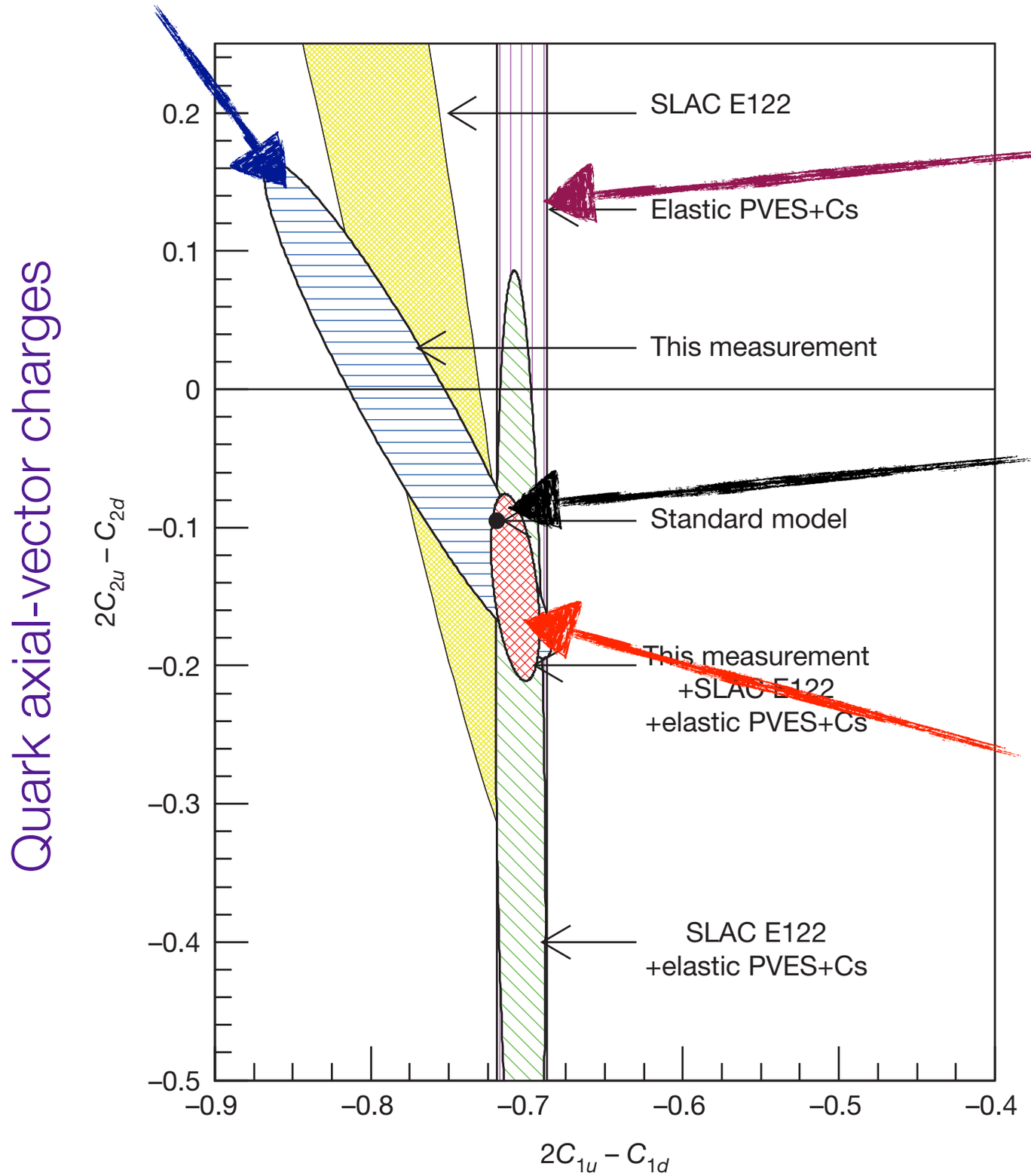
JLab PVDIS

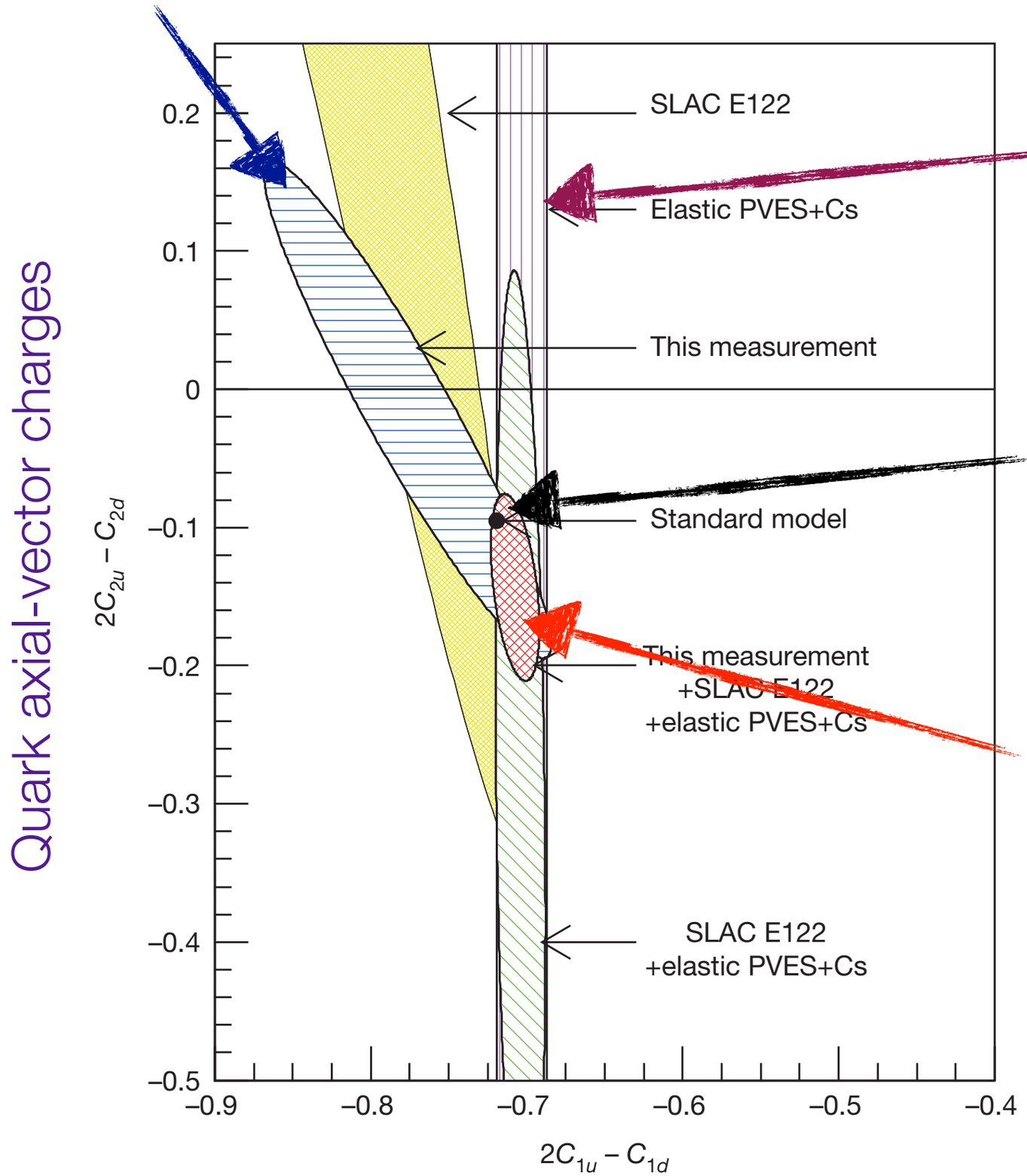


~Q-weak [4%]

Standard Model prediction

ellipse constrains potential new physics: e.g. *Z'*

JLab PVDIS (assuming charge symmetry in nucleon partons)



~Q-weak [4%]

Standard Model prediction

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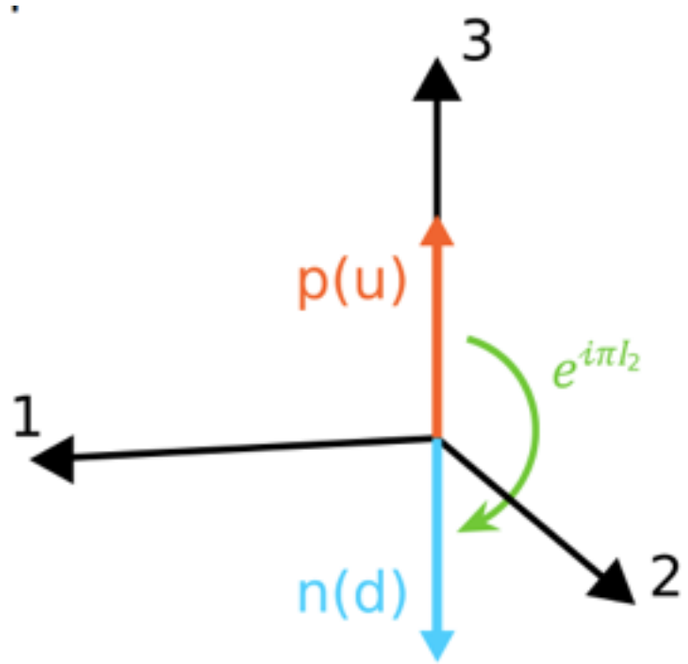
Charge symmetry in partons

- Partonic charge symmetry relations

$$u^p(x) = d^n(x)$$
$$d^p(x) = u^n(x)$$



- Define CSV terms:

$$\delta u(x) \equiv u^p(x) - d^n(x)$$
$$\delta d(x) \equiv d^p(x) - u^n(x)$$

- Two dominant sources of CSV:

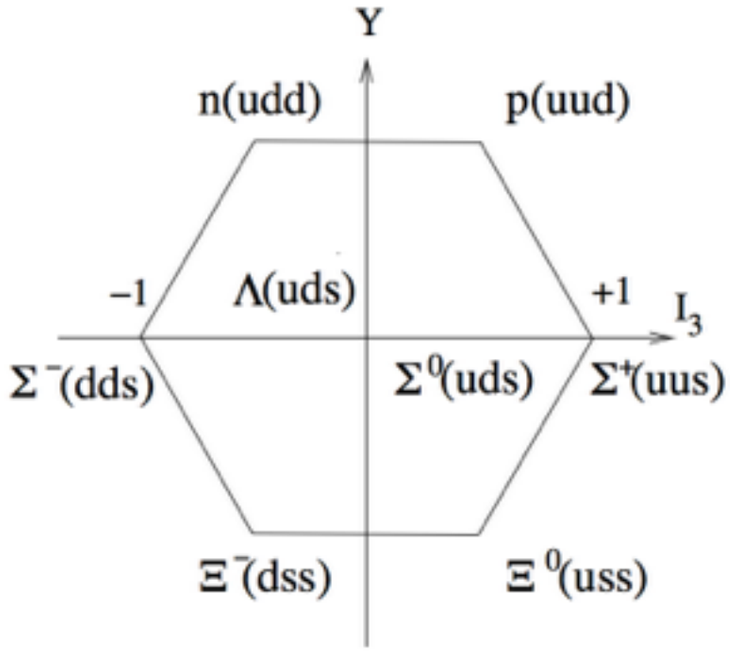
$$m_u \neq m_d$$

Quark masses → Lattice

$$Q_u \neq Q_d$$

QED → photon radiation

Hyperon PDF moments



- Start from **exact** SU(3) symmetric point

$$\langle x \rangle_u^p = \langle x \rangle_u^{\Sigma^+} = \langle x \rangle_s^{\Xi^0}$$

- Determine small perturbations

$$\frac{\partial \langle x \rangle_u^p}{\partial m_u} \sim \frac{\langle x \rangle_s^{\Xi^0} - \langle x \rangle_u^p}{m_s - m_l}, \qquad \frac{\partial \langle x \rangle_u^p}{\partial m_d} \sim \frac{\langle x \rangle_u^{\Sigma^+} - \langle x \rangle_u^p}{m_s - m_l}$$

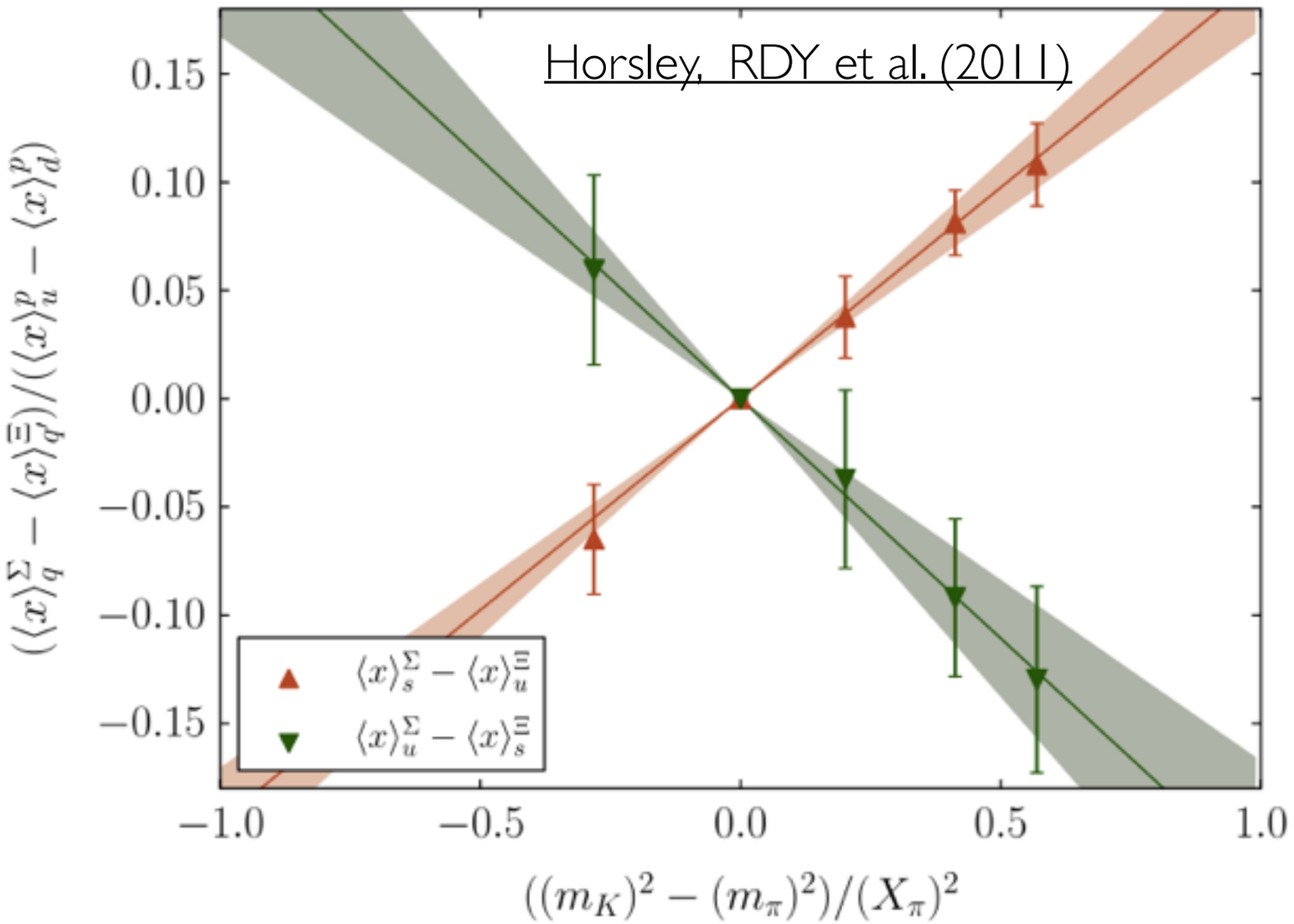
$$\Rightarrow \quad \langle x \rangle_{\delta u} \simeq m_\delta \left[-\frac{\partial \langle x \rangle_u^p}{\partial m_u} + \frac{\partial \langle x \rangle_u^p}{\partial m_d} \right] \simeq m_\delta \frac{\langle x \rangle_u^{\Sigma^+} - \langle x \rangle_s^{\Xi^0}}{m_s - m_l}$$

$$m_\delta \equiv (m_d - m_u)$$

Consider hyperon moments about SU(3) symmetric point

Partonic charge symmetry violation

- Lattice results for quark-mass dependence of hyperon momentum fractions



Slopes determine CSV at SU(3) symmetric point

Partonic charge symmetry violation

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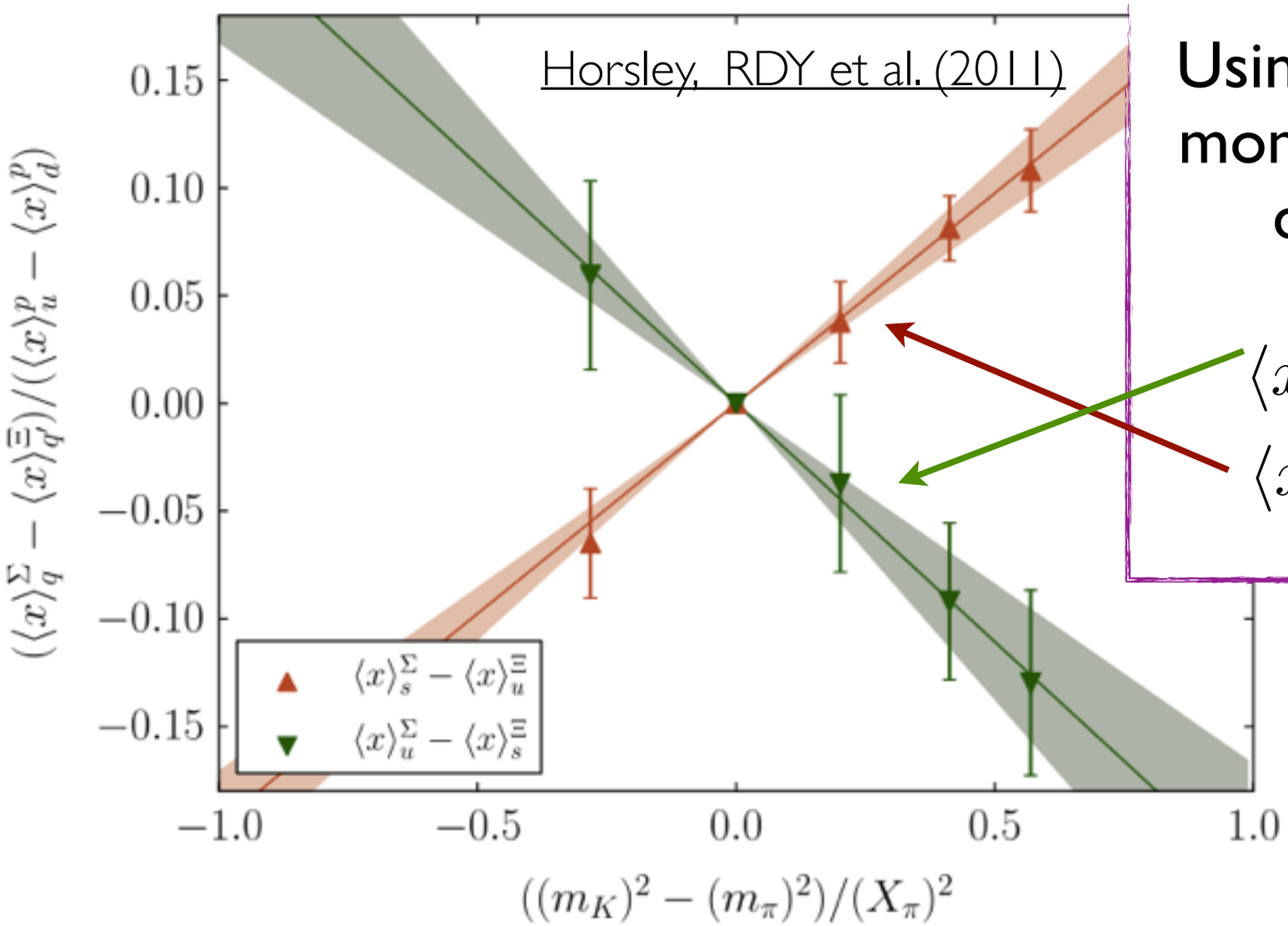


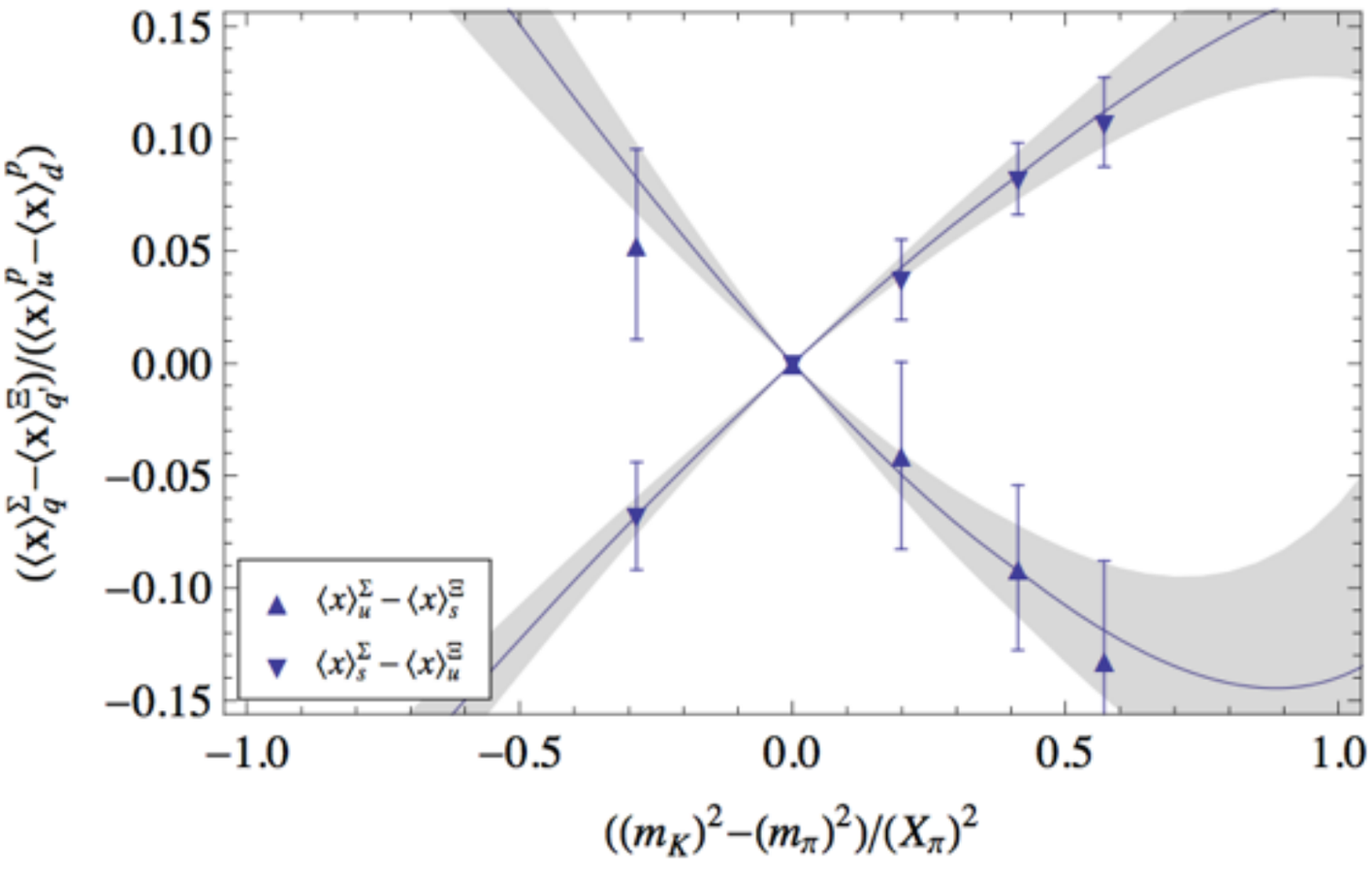
Using phenomenological momentum fraction and quark mass ratio:

$$\langle x\rangle_{\delta u} = -0.0012(3)$$
$$\langle x\rangle_{\delta d} = 0.0010(2)$$

Slopes determine CSV at SU(3) symmetric point

Chiral extrapolation of CSV

- SU(3) chiral EFT formalism to extrapolate to physical quark masses



Shanahan, Thomas & RDY, PRD(2013)094515

Chiral extrapolation of CSV

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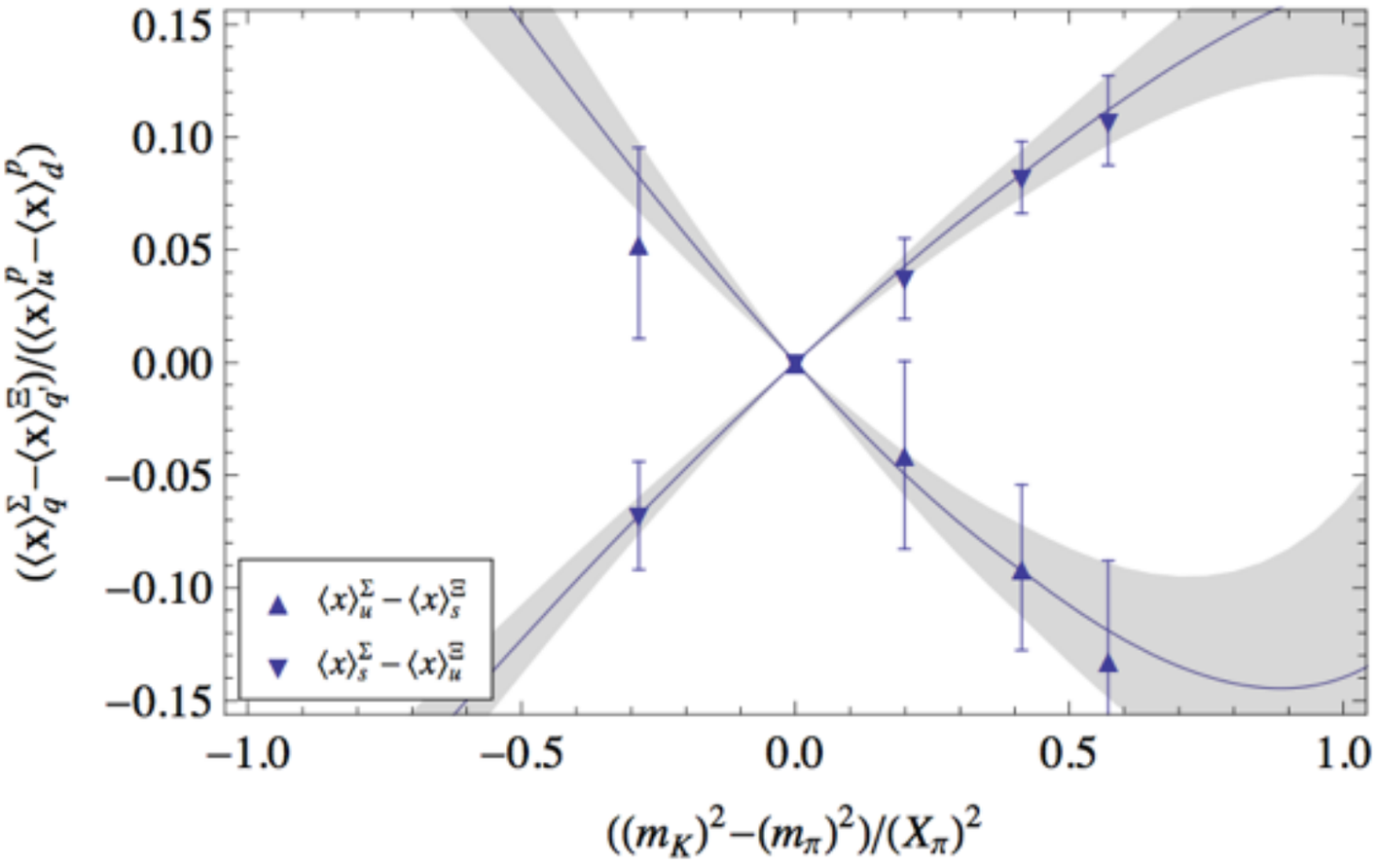


Our result

$$\langle x \rangle_{\delta u} = -0.0023(7)$$

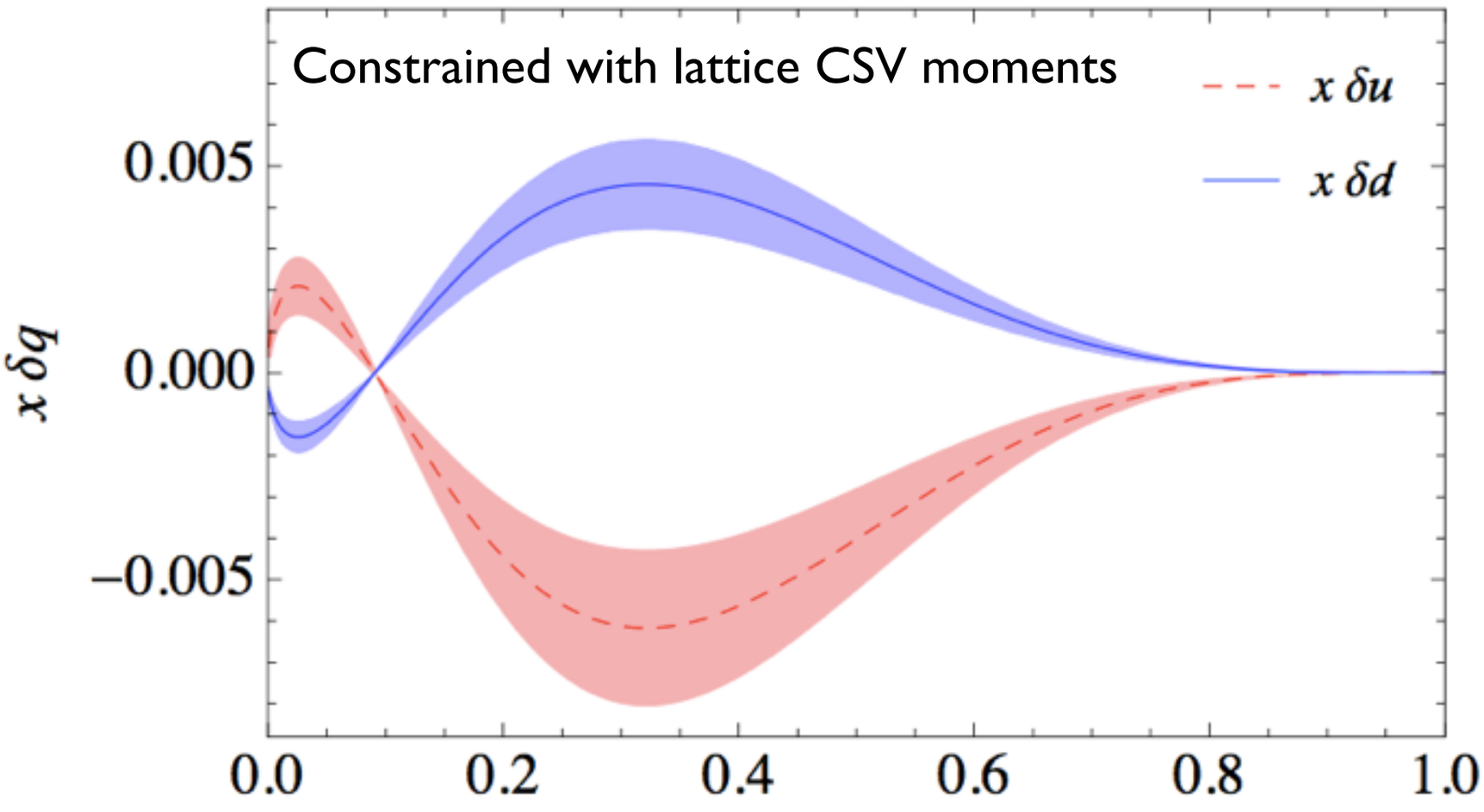
$$\langle x \rangle_{\delta d} = 0.0017(4)$$

Shanahan, Thomas & RDY, PRD(2013)094515

CSV Distributions

- We only have one moment from the lattice 
- Simple parameterisation: MRST2004

$$\langle x \rangle_{\delta q} = \kappa_q \, x^{-1/2}(1-x)^4(x-1/11)$$

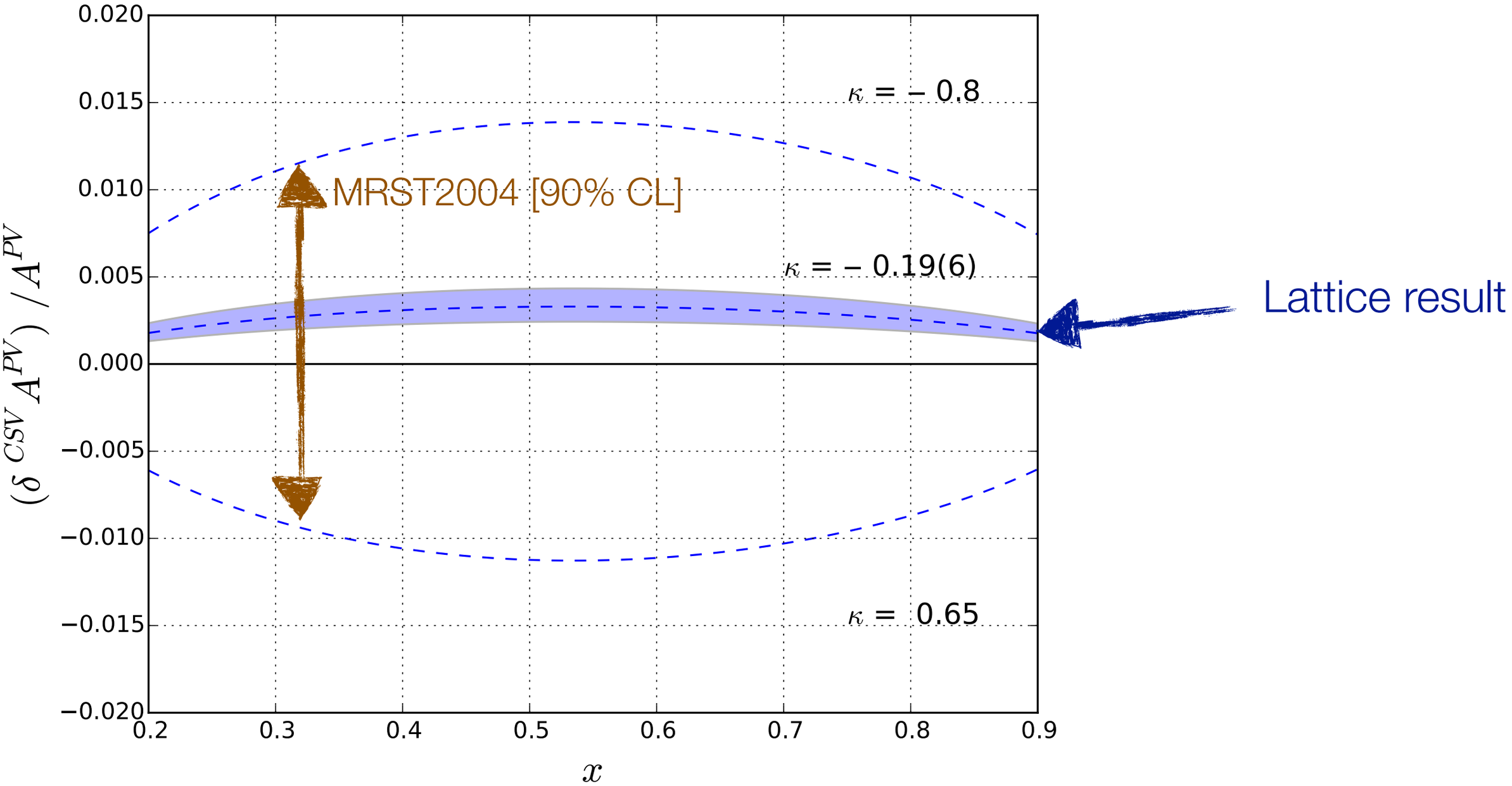


RY, Shanahan & Thomas, 1312.4990[nucl-th]

PVDIS Asymmetry

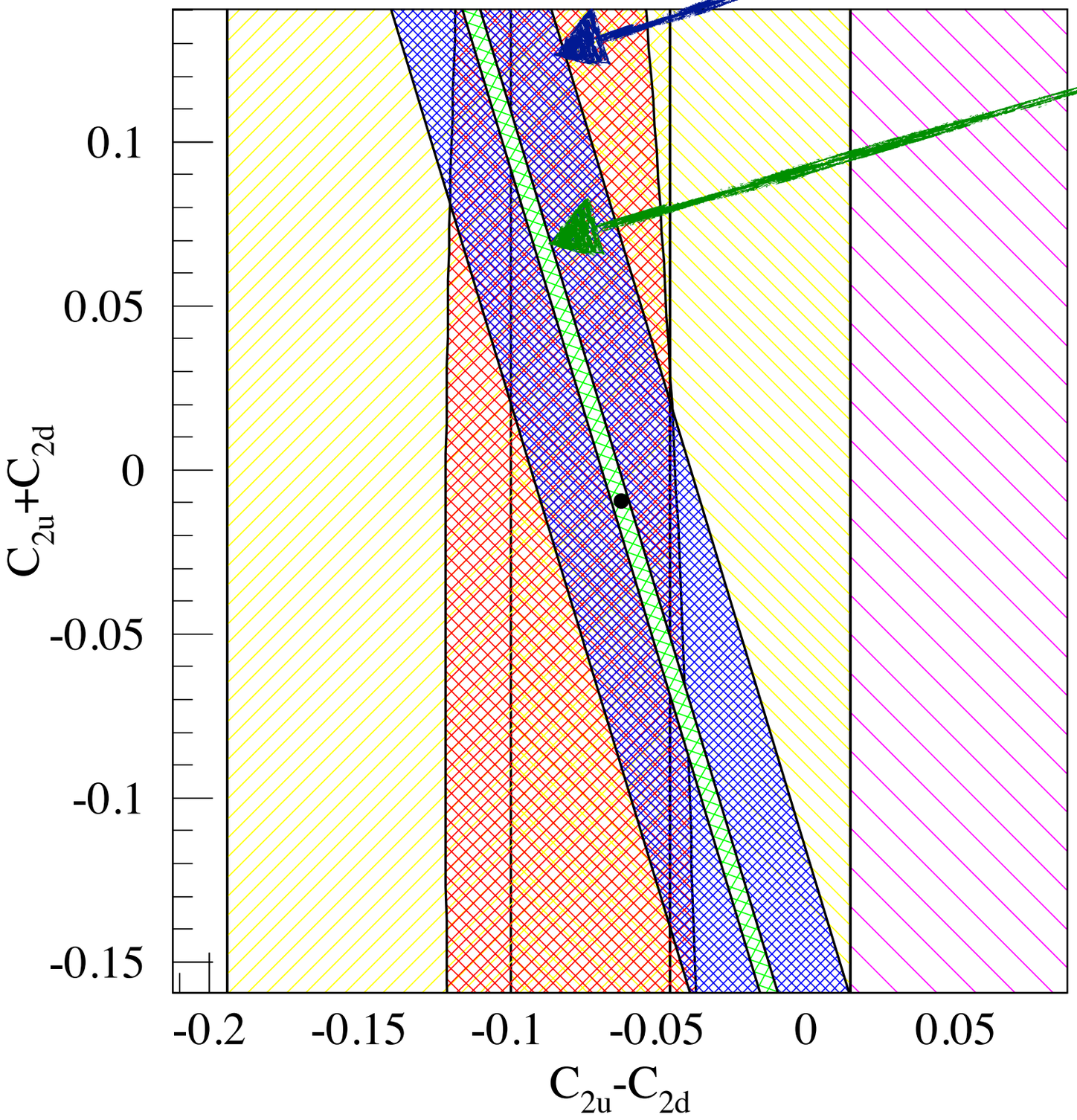
$$A_{\rm PV} = -91.1 \pm 3.1 \pm 3.0\,{\rm ppm}, \quad [Q^2 = 1.085\,{\rm GeV}^2, \overline{x} = 0.241];$$
$$A_{\rm PV} = -160.8 \pm 6.4 \pm 3.1\,{\rm ppm}, \quad [Q^2 = 1.901\,{\rm GeV}^2, \overline{x} = 0.295].$$

$$\pm 4\text{–}5\%$$



CSV is small compared to present experimental precision

Contact interactions

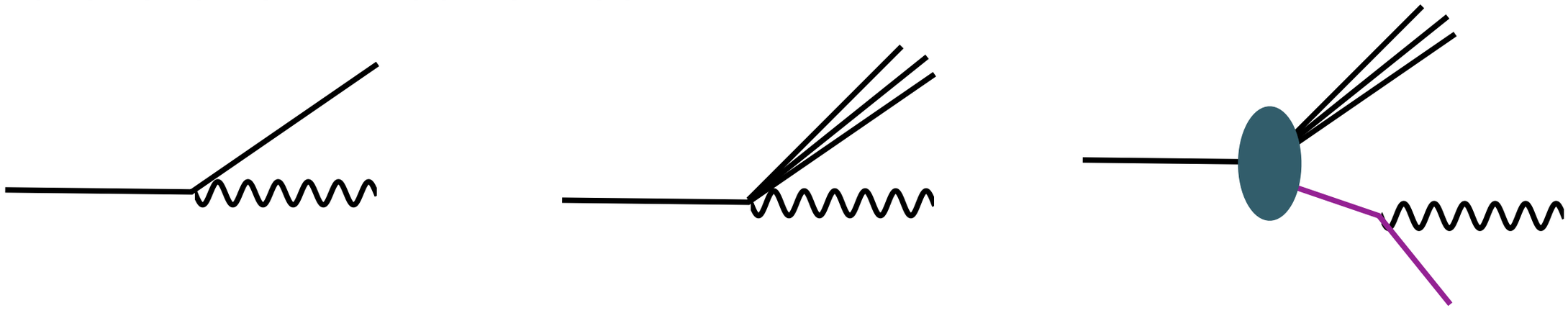


Control of CSV will be essential for robust test of the Standard Model

QED contribution & photon radiation?

How bright is the proton?

Manohar *et al*. arXiv:1607.04266

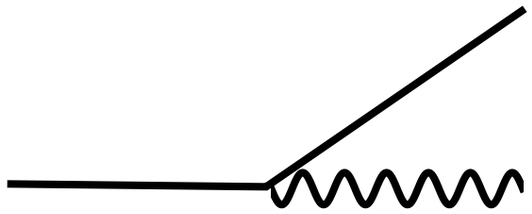


Elastic

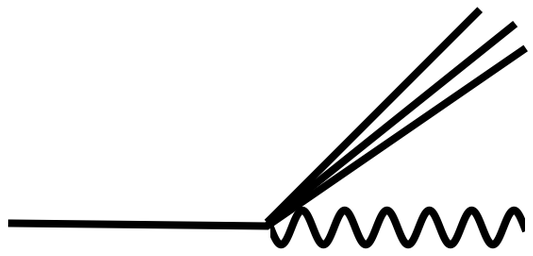
Inelastic

Partonic

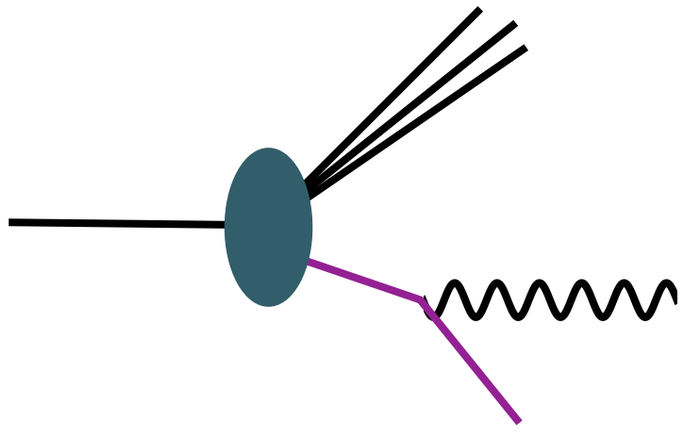
Manohar *et al*. arXiv:1607.04266



Elastic

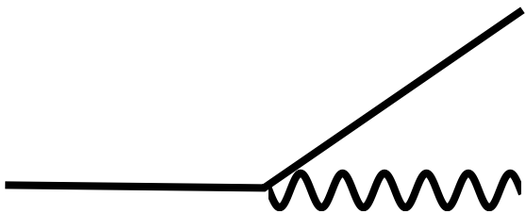


Inelastic

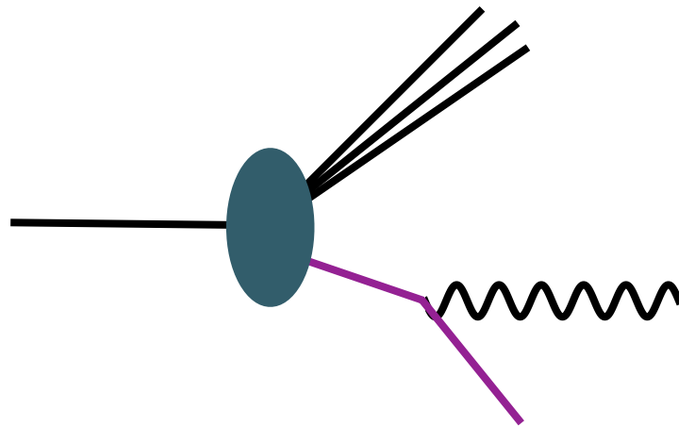


Partonic

Martin & Ryskin, EPJC(2014)

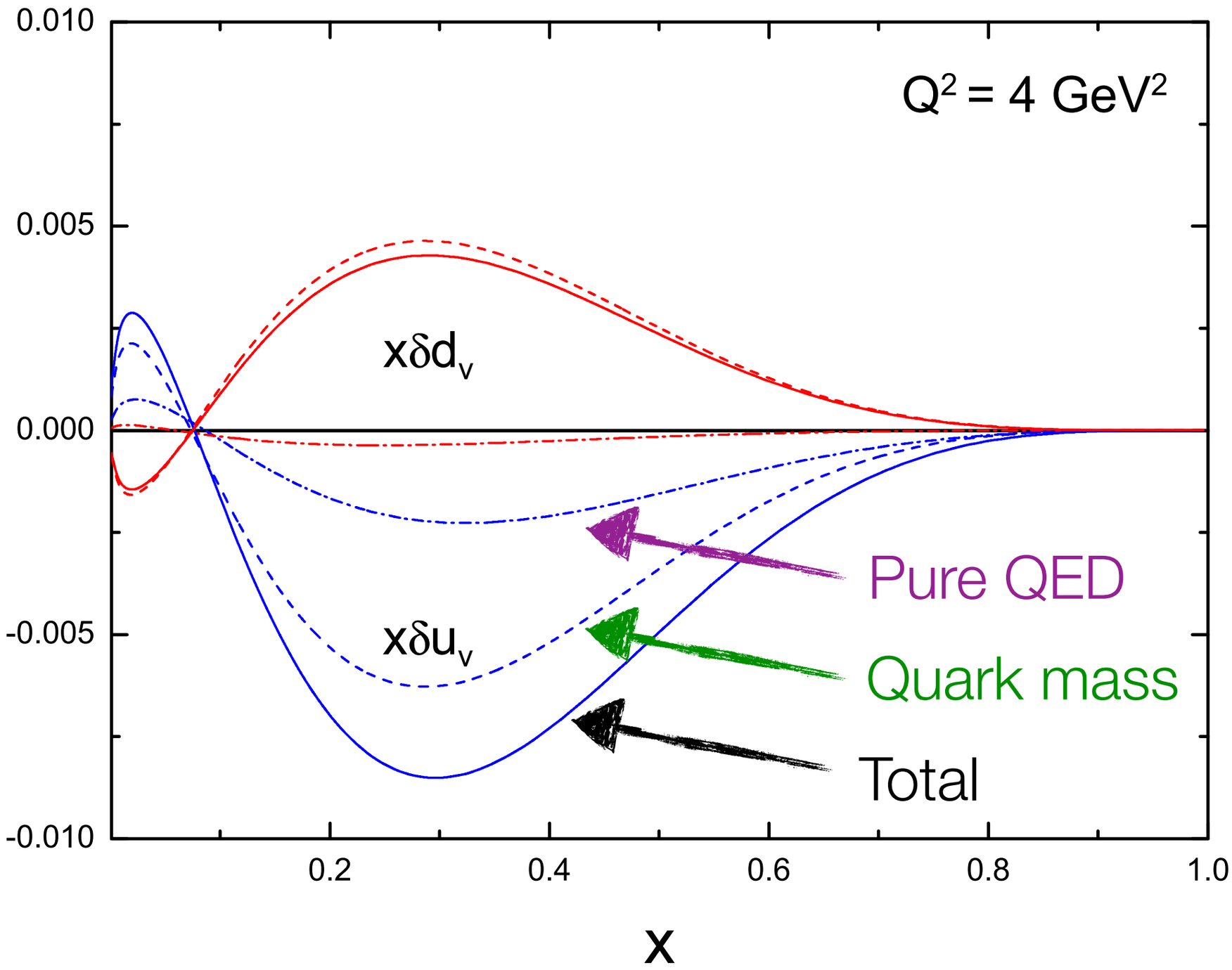


Elastic



Partonic

Including photon radiation in the quark CSV terms



X.-G. Wang, Thomas & RDY, PLB(2016)

Outlook

- Parton charge symmetry violation
  - Quark masses: Lattice QCD
  - QED: photon radiation
- PVDIS@6GeV
  - CSV ok
- CSV likely to become relevant to next generation of precision PVDIS@12GeV
  - Opportunity for theorists to work with experimentalists to improve the sensitivity of SM tests

Acknowledgements

- “Local”
  - J. Crilly, P. Shanahan, A. Thomas, J. Zanotti
- QCDSF-UKQCD Collaborators
  - R. Horsley, Y. Nakamura, H. Perlt, D. Pleiter, P. Rakow, G. Schierholz, A. Schiller, H. Stüben