PVDIS: 6 GeV Results and the SoLID Program

Xiaochao Zheng (郑晓超) (Univ. of Virginia)

August 5th, 2015

- PVDIS and electron-quark effective couplings
- The 6 GeV PVDIS experiment
- PVDIS with SoLID

Jefferson Lab

Basics of Electron Scattering on a Fixed Nuclear Target

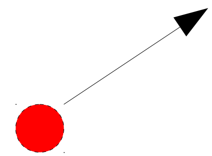
electron beam

$$\lambda = \frac{hc}{6\,GeV} = 0.2\ fm$$

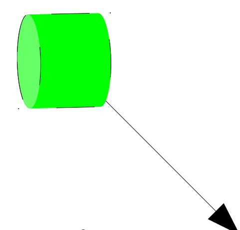
target (at rest)

Before

to detector



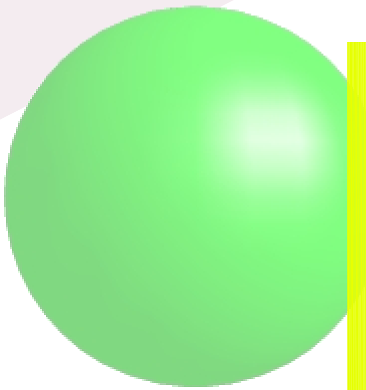
<u>Inclusive</u>: only the scattered electron is detected



recoil

After

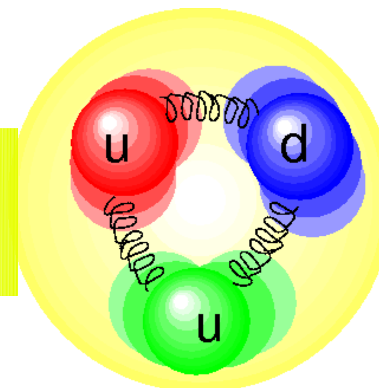
Three Kinematics Regions of Electron Scattering



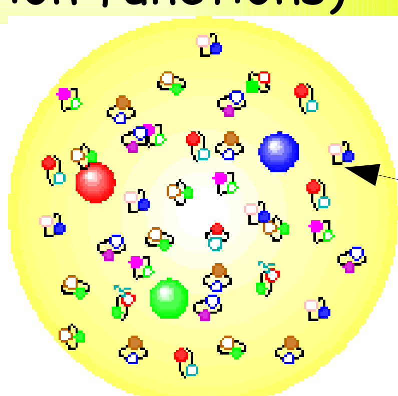
"Elastic": $W=M_t$ or M_p

(form factors – fourier transformation of the charge distribution in the nucleon)

"Resonance": $1<W<2$GeV

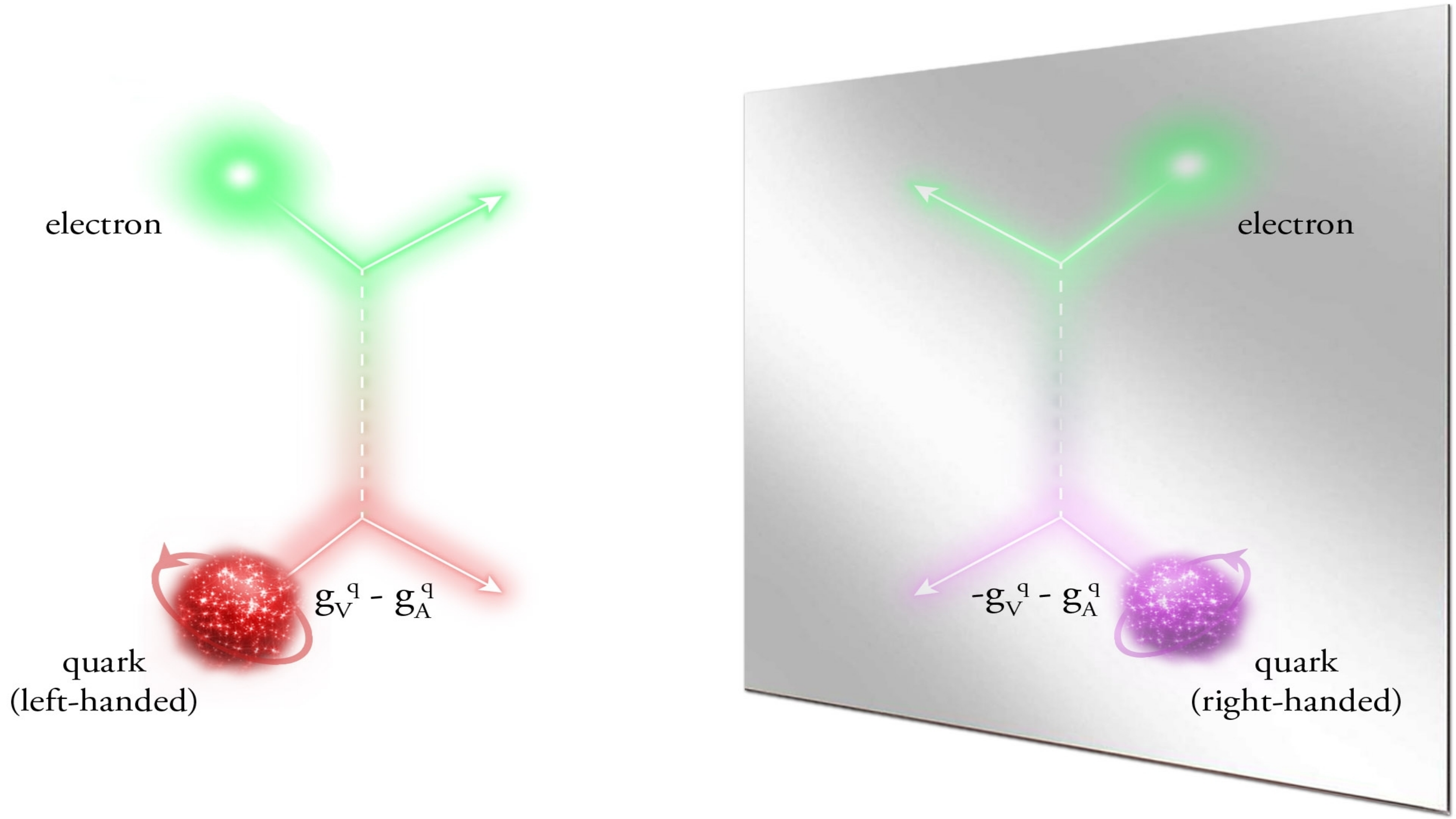


"Deep Inelastic": $W>2$ GeV, (structure functions, parton distribution functions)



10^{-18}m or smaller

Parity Violation in the Standard Model



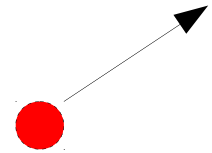
Measuring PVES Asymmetry

electron beam

$$\lambda = \frac{hc}{6\,GeV} = 0.2\ fm$$

target (at rest)

to detector

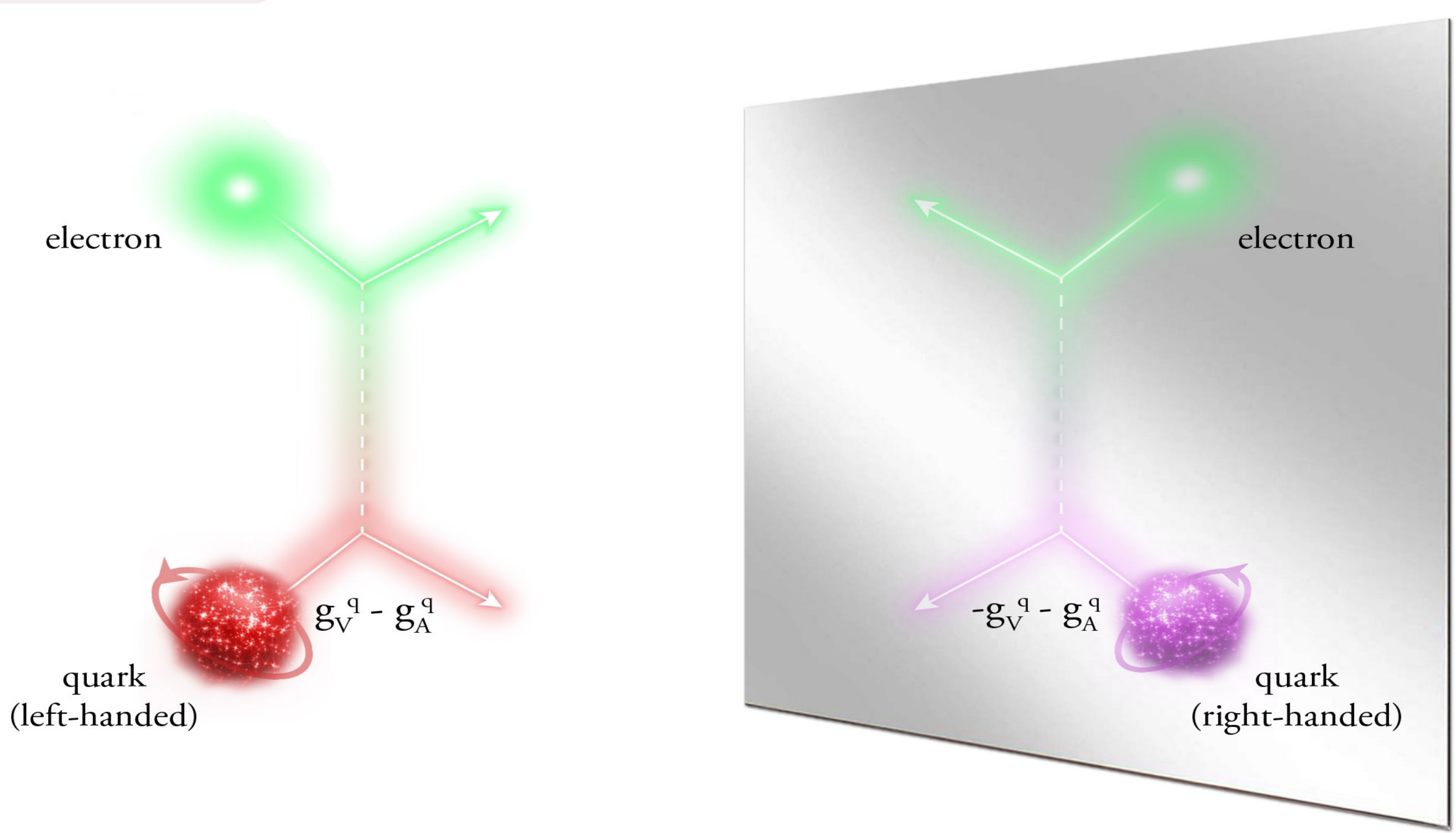


<u>Inclusive</u>: only the scattered electron is detected

change helicity of the electron beam

count how many electrons are scattered, using the same detector system

Parity Violation in the Standard Model



- In weak interaction, all elementary fermions behave differently under parity transformation

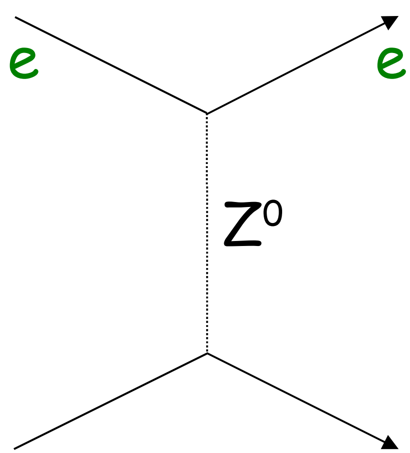
- They have a preferred chiral state when coupling to the Z^0

Parity Violation in the Standard Model

- Unlike electric charge, need two charges (couplings) for weak interaction: g_L, g_R

or "vector" and "axial" weak charges: $g_V \sim (g_L + g_R)$ $g_A \sim (g_L - g_R)$

$$-i\frac{g_Z}{2}\gamma^\mu[g_V^e - g_A^e\gamma^5]$$



fermions	$g_A^f = I_3$	$g_V^f = I_3 - 2Q\sin^2\theta_W$
ν_e, ν_μ	$\frac{1}{2}$	$\frac{1}{2}$
$e-, \mu-$	$-\frac{1}{2}$	$-\frac{1}{2} + 2\sin^2\theta_W$
u, c	$\frac{1}{2}$	$\frac{1}{2} - \frac{4}{3}\sin^2\theta_W$
d, s	$-\frac{1}{2}$	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_W$

Parity Violation in the Standard Model

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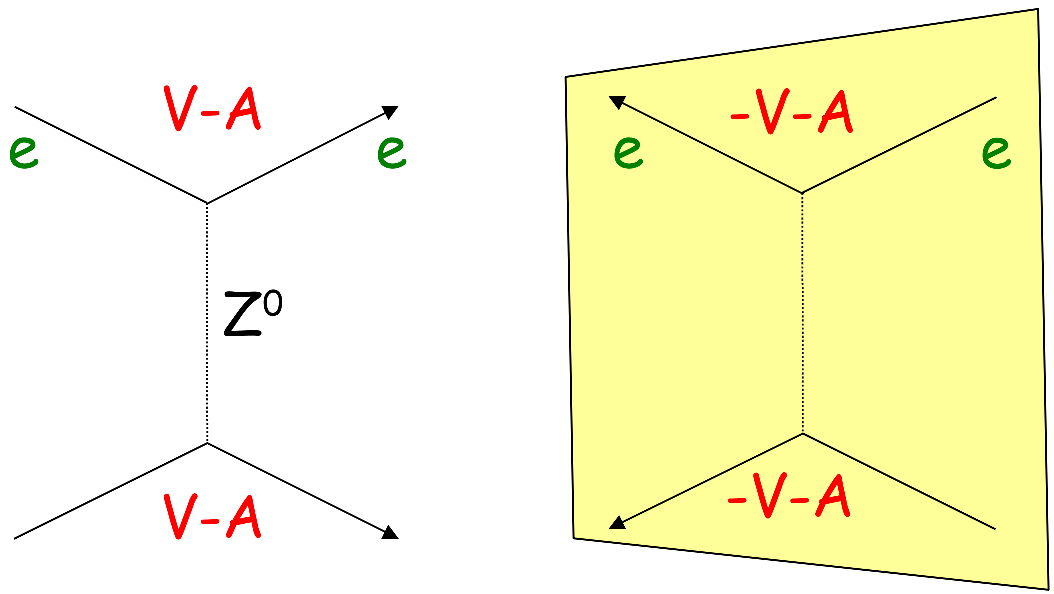
  or "vector" and "axial" weak charges: $g_V \sim (g_L + g_R)$ $g_A \sim (g_L - g_R)$

- PVES asymmetry comes from V(e)xA(targ) and A(e)xV(targ)



Effective Couplings in the Standard Model

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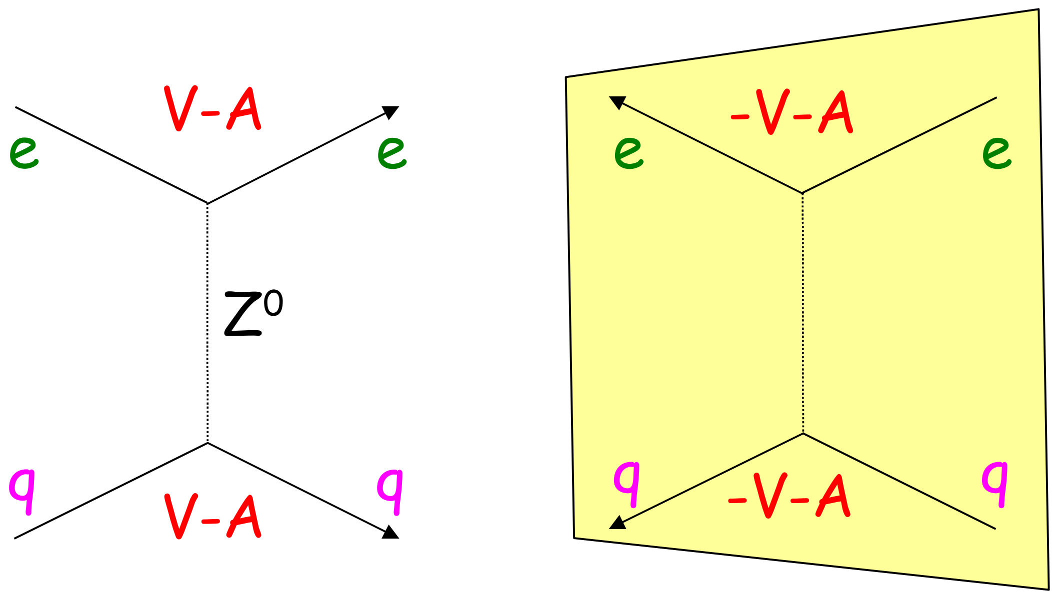
- PVDIS asymmetry comes from: $C_{1q} \equiv 2 g_A^e g_V^q, \quad C_{2q} \equiv 2 g_V^e g_A^q$

"electron-quark effective couplings"



Effective Couplings and New Contact Interactions

- Unlike electric charge, need two charges (couplings) for weak interaction: g_L, g_R

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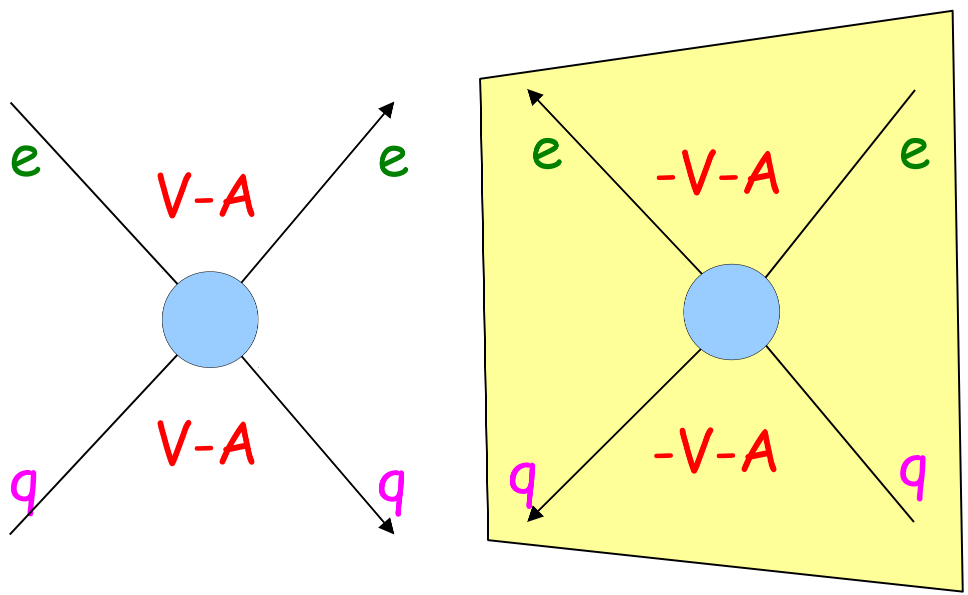
"electron-quark effective couplings"



Effective Couplings and New Contact Interactions

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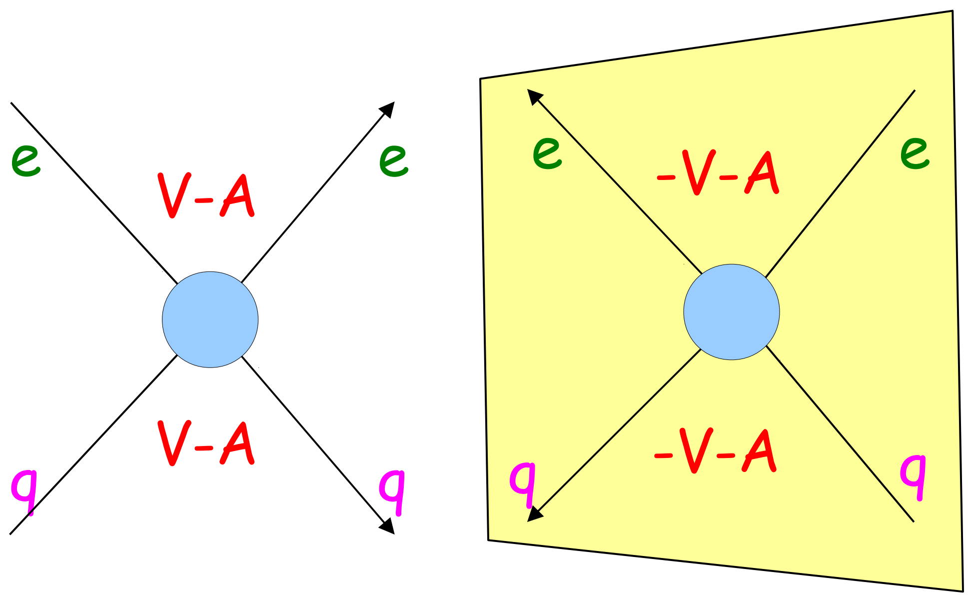


"electron-quark effective couplings"

$$C_{1q} = g_{AV}^{e\ q},\ C_{2q} = g_{VA}^{e\ q}$$

Erler&Su, Prog. Part. Nucl. Phys. 71, 119 (2013)

Accessing $C_{1q,2q}$

- Need electron beam on hadronic target
- In elastic PVES
  - directly probes C_{1q}, electrons' parity-violating property;
  - quarks' parity-violation is represented by the nucleon axial form factor G_A, and extracting C_{2q} from G_A is model-dependent
- Only in PVDIS, electron probes the quark and PVDIS asymmetry depends on C_{2q} directly.

Formalism for Parity Violation in DIS

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + Y(y)\, b(x)\right]$$

$x \equiv x_{Bjorken}$ $y \equiv 1 - E'/E$

$$q_i^+(x) \equiv q_i(x) + \bar{q}_i(x)$$

$$q_i^-(x) = q_i^V(x) \equiv q_i(x) - \bar{q}_i(x)$$

$$a(x) = \frac{1}{2} g_A^e \frac{F_1^{\gamma Z}}{F_1^\gamma} = \frac{1}{2} \frac{\sum_i C_{1i} Q_i q_i^+(x)}{\sum_i Q_i^2 q_i^+(x)}$$

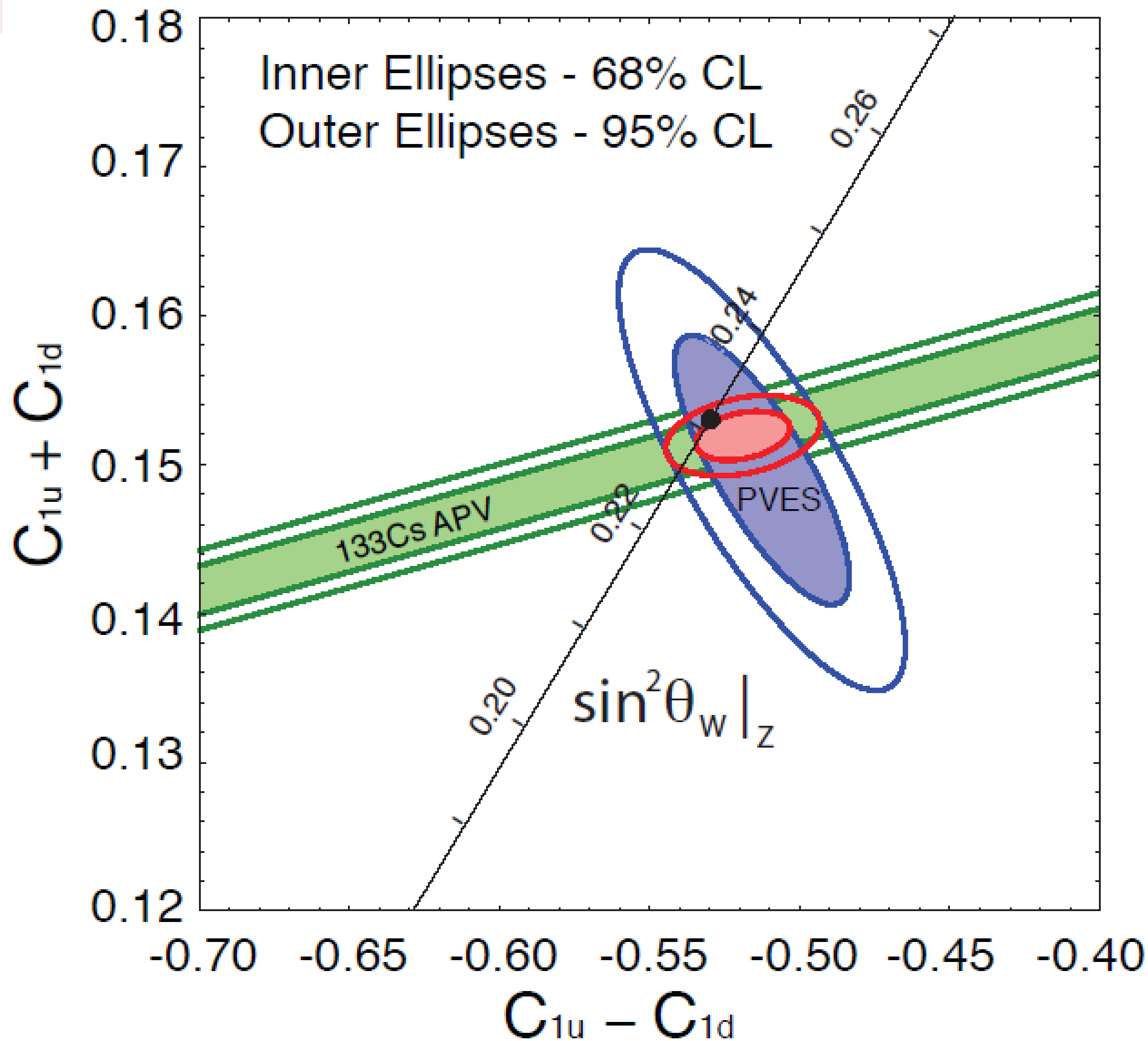
$$b(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^\gamma} = \frac{1}{2} \frac{\sum_i C_{2i} Q_i q_i^-(x)}{\sum_i Q_i^2 q_i^+(x)}$$

For an isoscalar target (^{2}H), structure functions largely simplifies:

$$a(x) = \frac{3}{10}\left(2C_{1u} - C_{1d}\right)\left(1 + \frac{0.6\, s^+}{u^+ + d^+}\right)$$

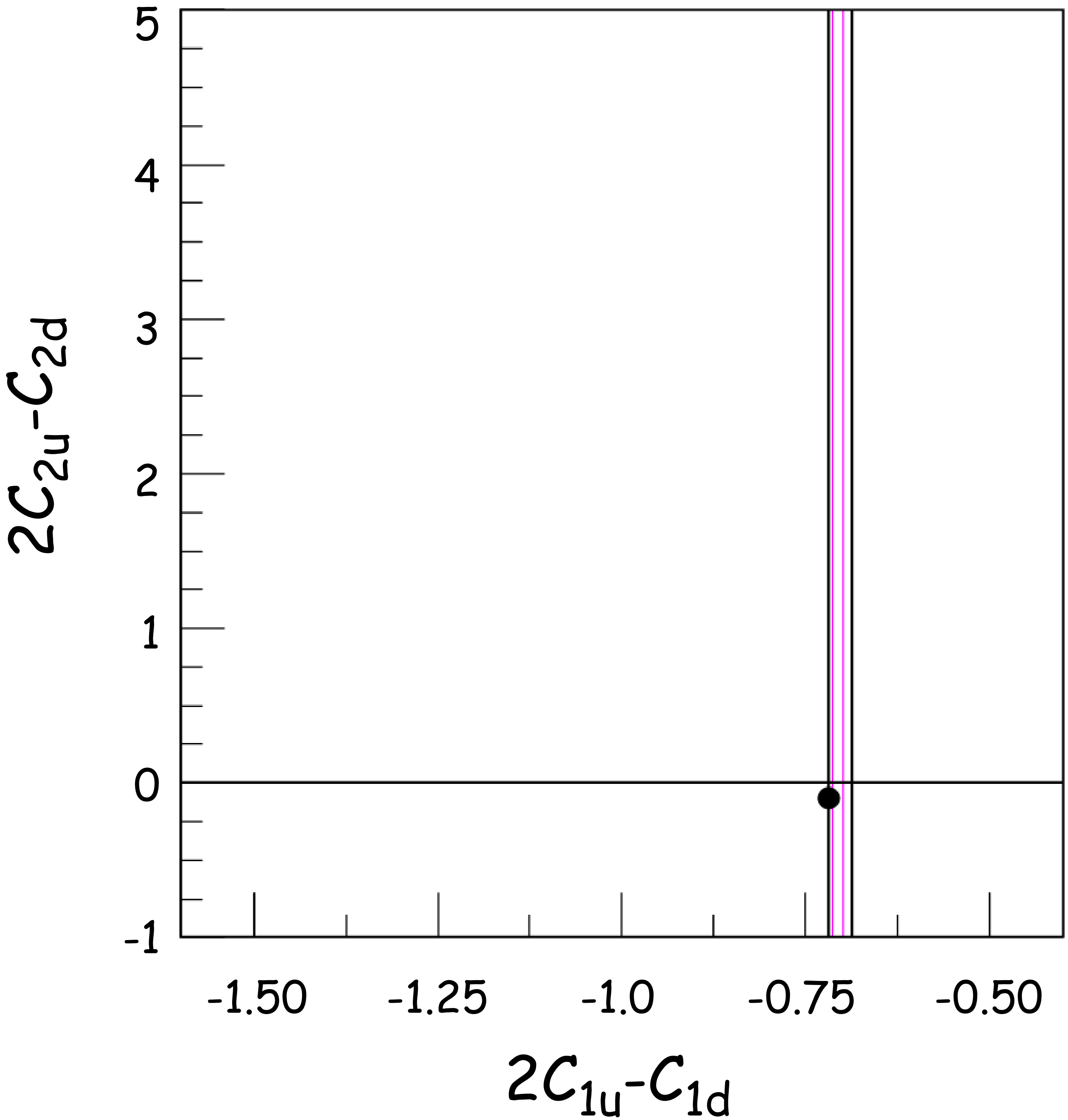
$$b(x) = \frac{3}{10}\left(2C_{2u} - C_{2d}\right)\left(\frac{u_V + d_V}{u^+ + d^+}\right)$$

Best Data on C_{1q} (eq AV couplings) from PVES+APV

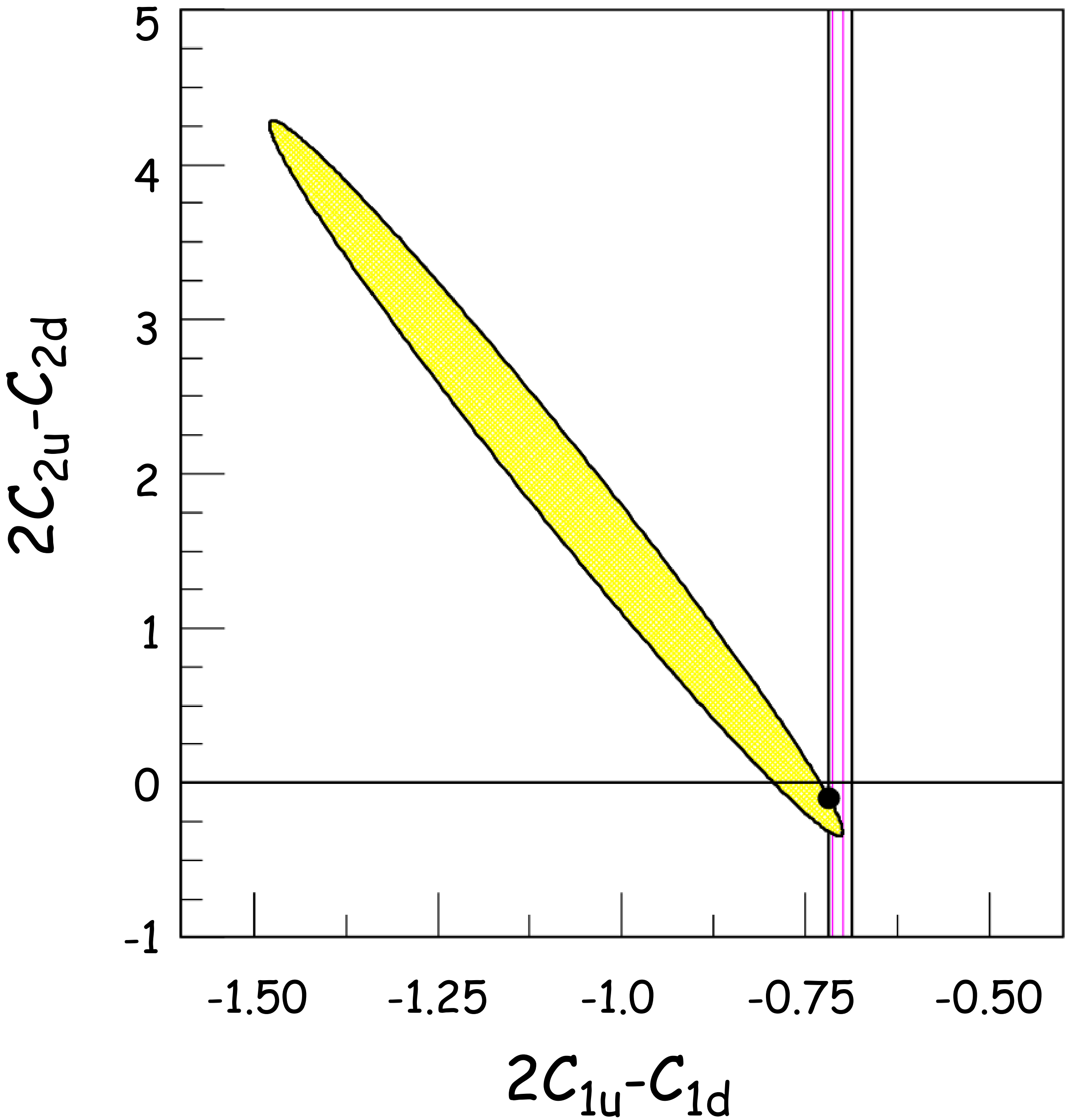


Androic et al., PRL 111, 141803 (2013);

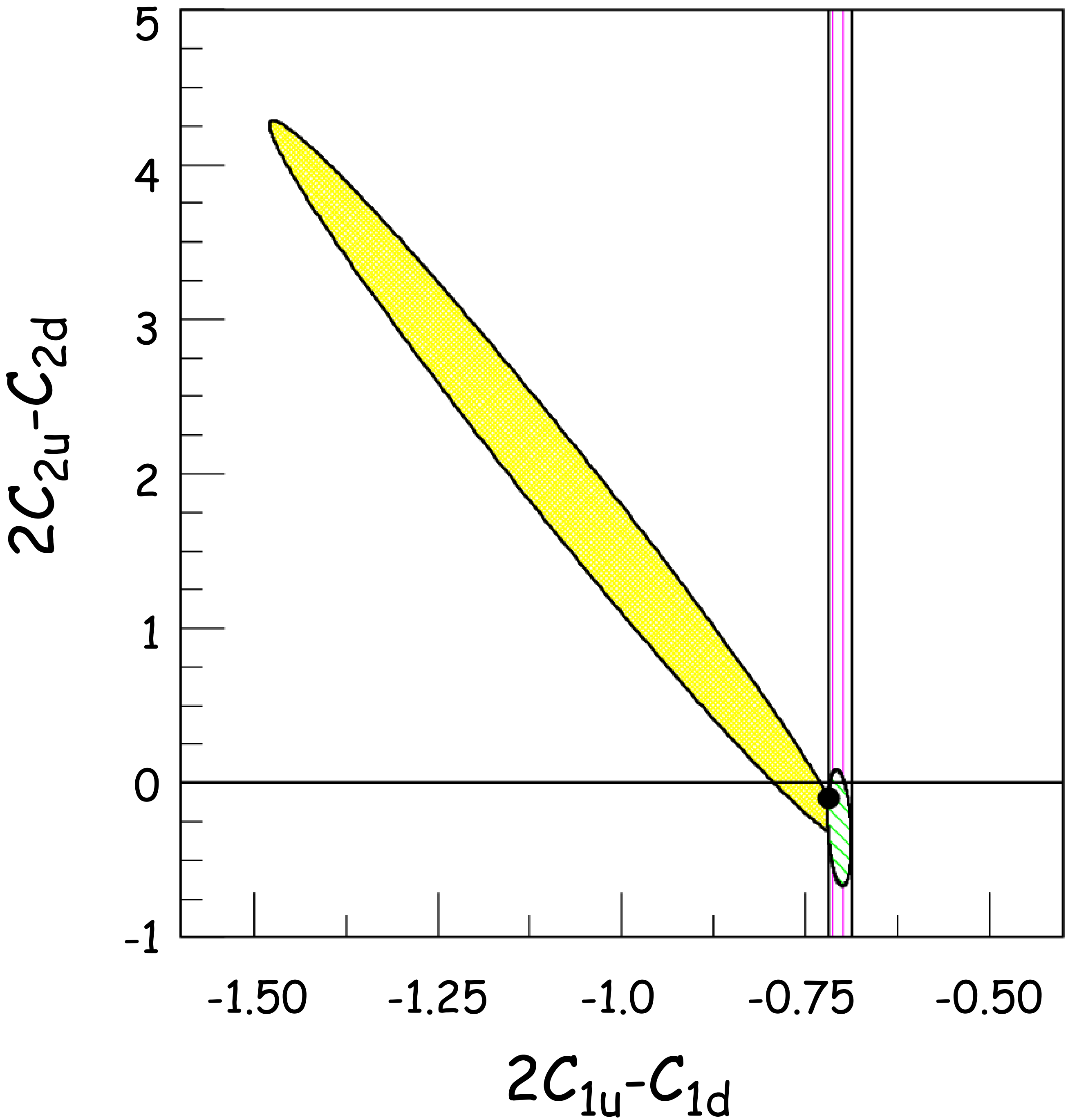
Projecting to C_{1q} vs C_{2q} (e-q AV vs. VA couplings)



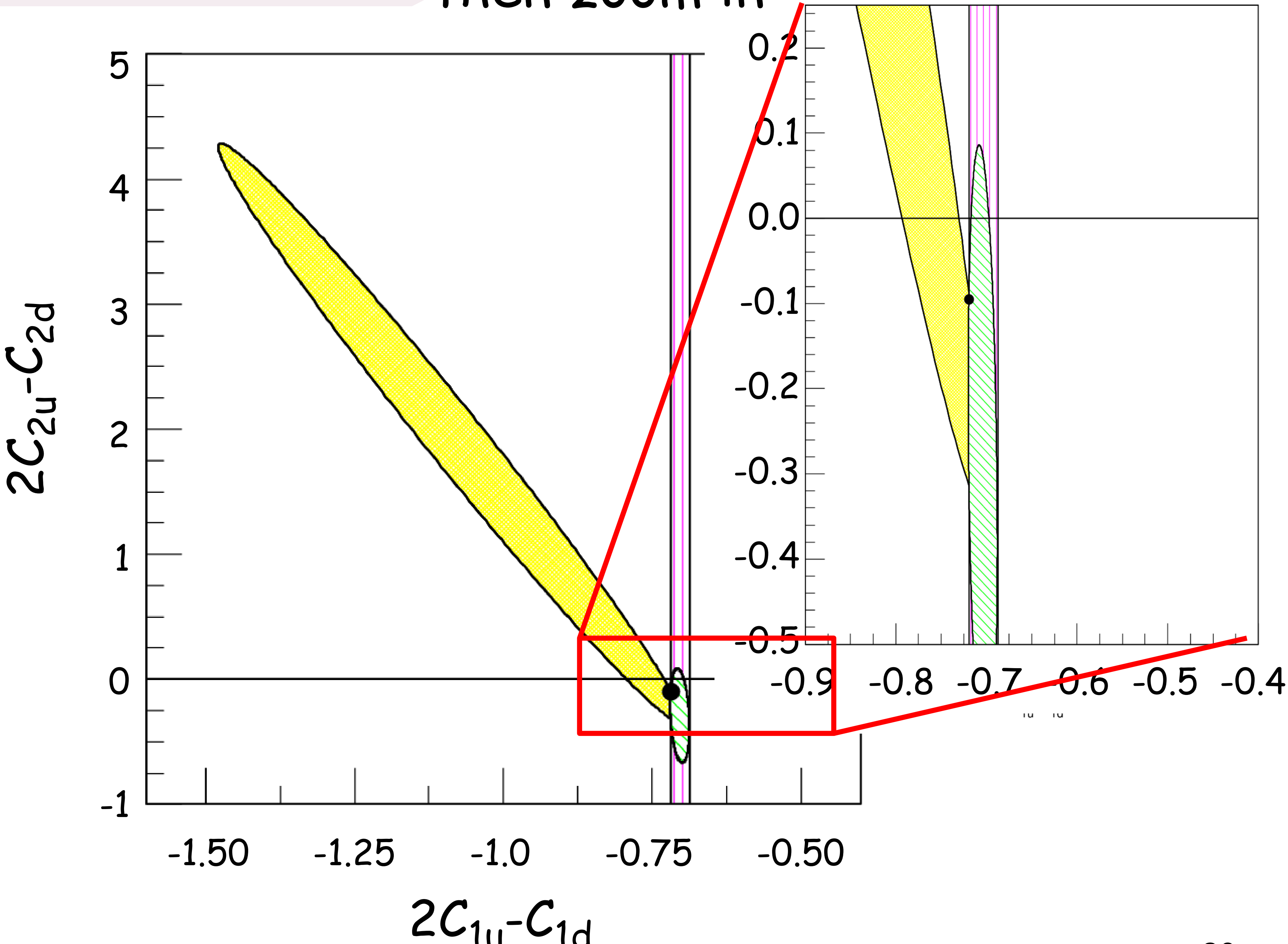
Add E122



and combine them



then zoom in

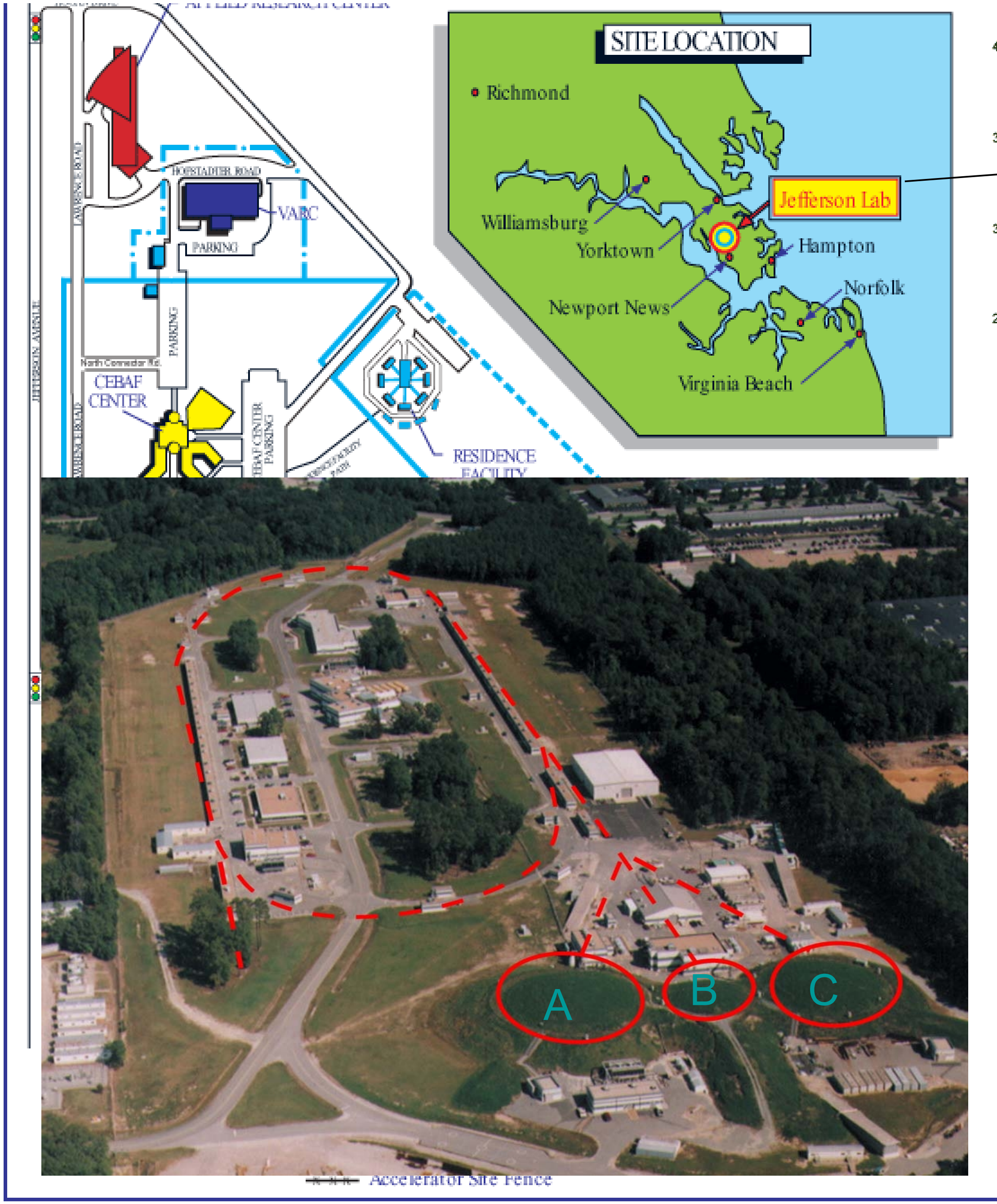


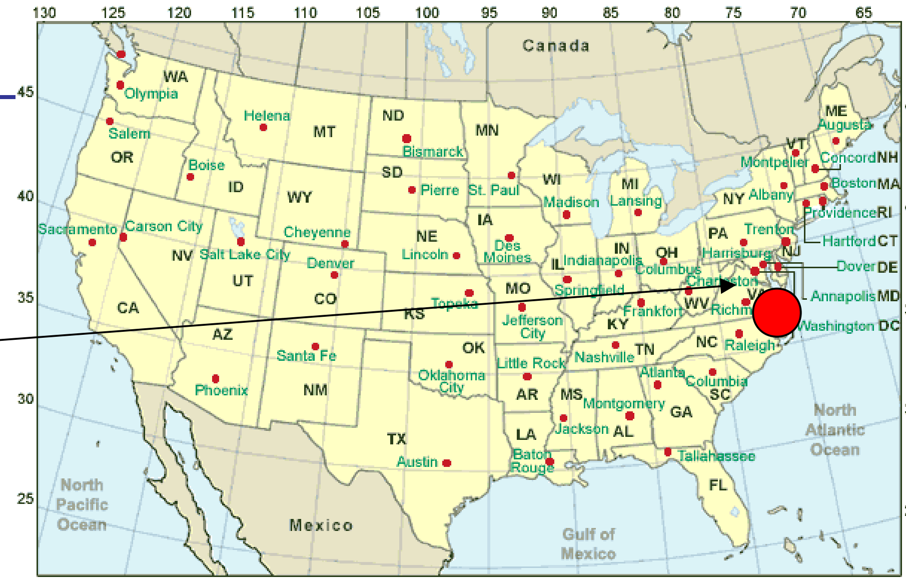
5
4
3
2
1
0
-1
-1.50
-1.25
-1.0
-0.75
-0.50
$2C_{2u}-C_{2d}$
$2C_{1u}-C_{1d}$
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4

PVDIS at 6 GeV (JLab E08-011)

Jefferson Lab

Thomas Jefferson National Accelerator Facility



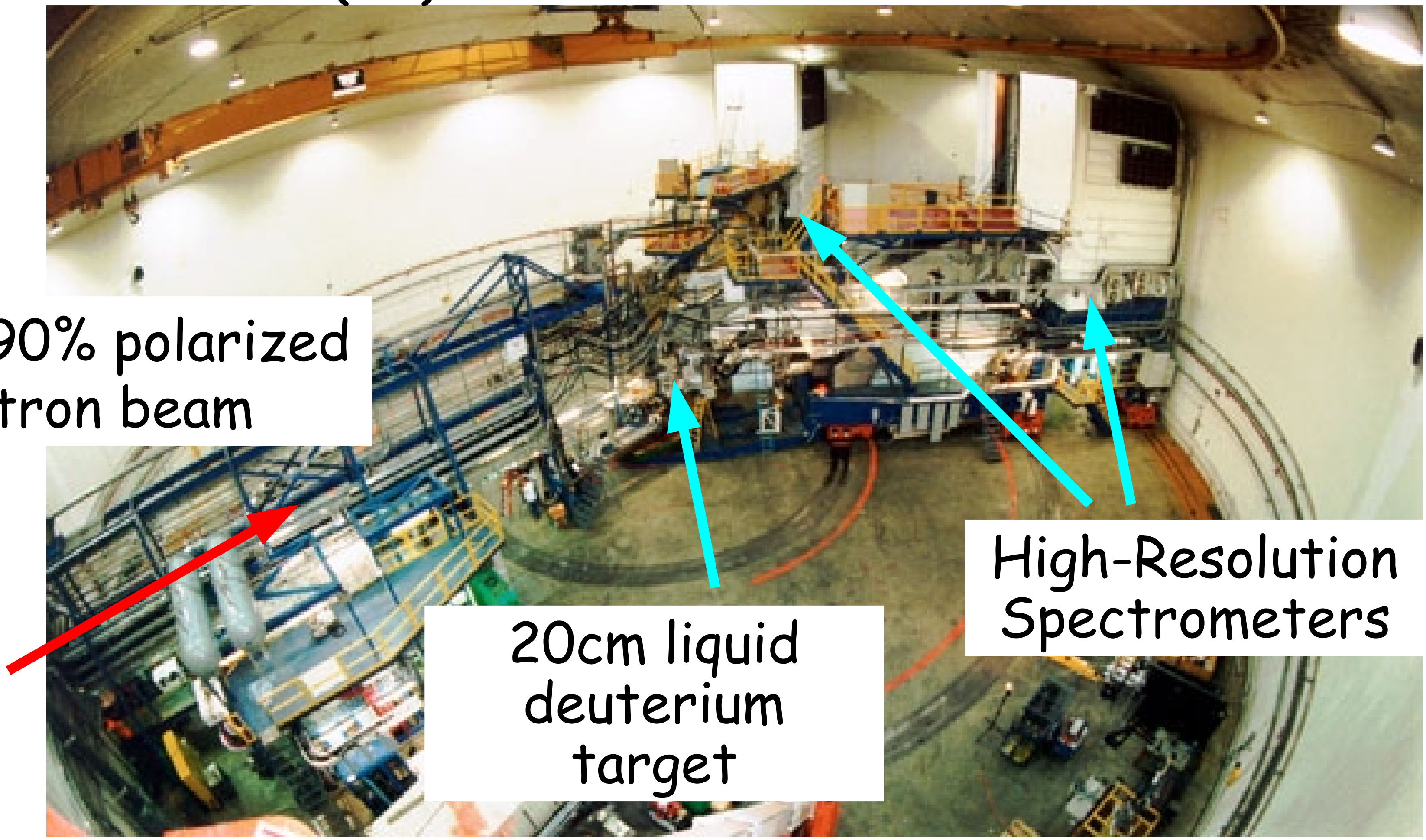


- **Staff: ~700**
- **User community: ~1300**

- Beam first delivered in 10/95
- ~1/3 of US PhDs in Nuclear Physics
- Energy: 6 GeV, 12 GeV ongoing
- **The largest superconducting RF accelerator in the world, the highest polarized luminosity.**

PVDIS at 6 GeV (JLab E08-011, ran in Oct-Dec. 2009)

- Measured two DIS points: Q^2=1.085 and 1.901 $(GeV/c)^2$
- Collected 170 billion (E9) electrons in total



- Students: Xiaoyan Deng, Kai Pan, Diancheng Wang (PhD)
- Postdoc: Ramesh Subedi

From Measured to Physics Asymmetry (Unblinded in 2012)

$$A^{raw}_{Q^2=1.085,\,x=0.241} = -78.45 \pm 2.68 \pm 0.07\ ppm$$

$$A^{raw}_{Q^2=1.901,\,x=0.295} = -140.30 \pm 10.43 \pm 0.16\ ppm\,(L)$$

$$A^{raw}_{Q^2=1.901,\,x=0.295} = -139.84 \pm 6.58 \pm 0.46\ ppm\,(R)$$

- beam polarization
- counting deadtime
- EM radiative correction
- box correction
- target aluminum endcap
- beam depolarization
- beam-normal asym
- Q^2 determination
- pair production
- target impurity
- charged pion background

$$A^{phys}_{Q^2=1.085,\,x=0.241} = -91.10 \pm 3.11 \pm 2.97\ ppm$$

$$A^{phys}_{Q^2=1.901,\,x=0.295} = -160.80 \pm 6.39 \pm 3.12\ ppm$$

Compare to Standard Model?

$$A^{phys}_{Q^2=1.085,\, x=0.241} = -91.10 \pm 3.11 \pm 2.97\ ppm$$

$$A^{SM} = (1.156\times 10^{-4})\left[\left(2C_{1u} - C_{1d}\right) + 0.348\left(2C_{2u} - C_{2d}\right)\right] = -87.7\ ppm$$

$$A^{phys}_{Q^2=1.901,\, x=0.295} = -160.80 \pm 6.39 \pm 3.12\ ppm$$

$$A^{SM} = (2.022\times 10^{-4})\left[\left(2C_{1u} - C_{1d}\right) + 0.594\left(2C_{2u} - C_{2d}\right)\right] = -158.9\ ppm$$

Extracting Effective Couplings

$$A^{phys}_{Q^2=1.085,\,x=0.241} = -91.10 \pm 3.11 \pm 2.97\ ppm$$

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uncertainty due to PDF: 0.5% 5%

uncertainty due to HT: 0.5%/Q^2, 0.7ppm

$$A^{phys}_{Q^2=1.901,\,x=0.295} = -160.80 \pm 6.39 \pm 3.12\ ppm$$

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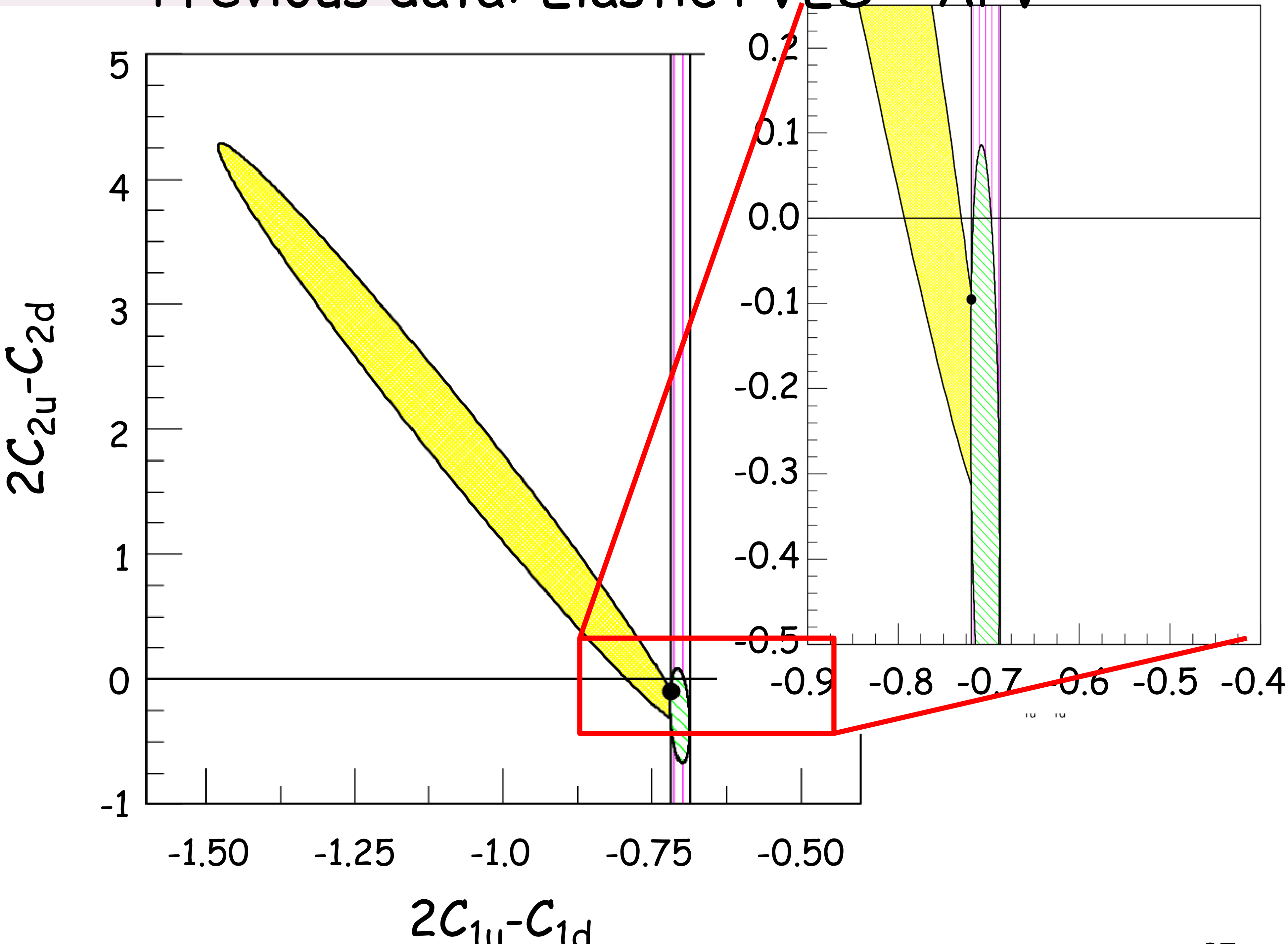
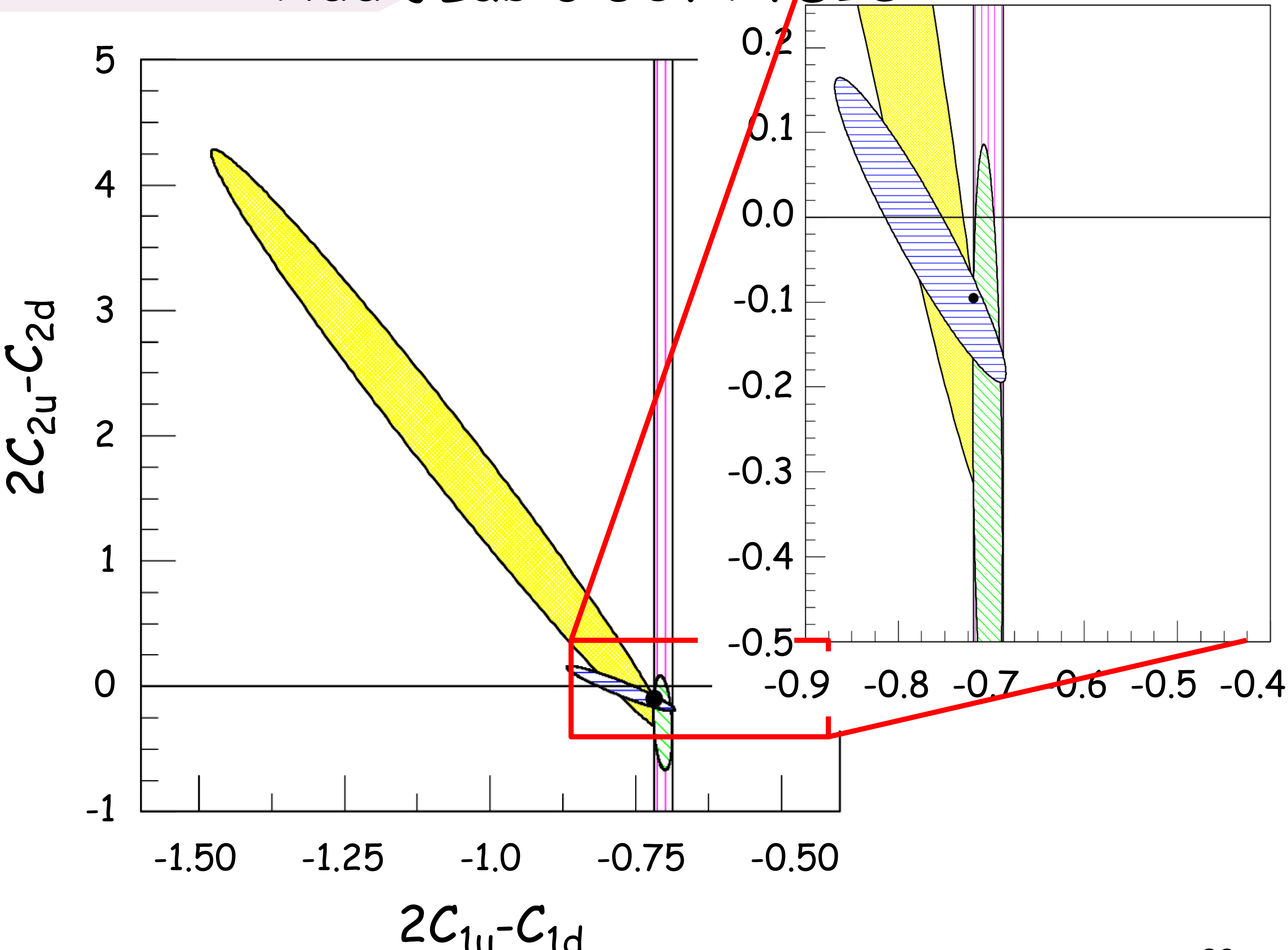
uncertainty due to PDF: 0.5% 5%

uncertainty due to HT: 0.5%/Q^2, 1.2ppm

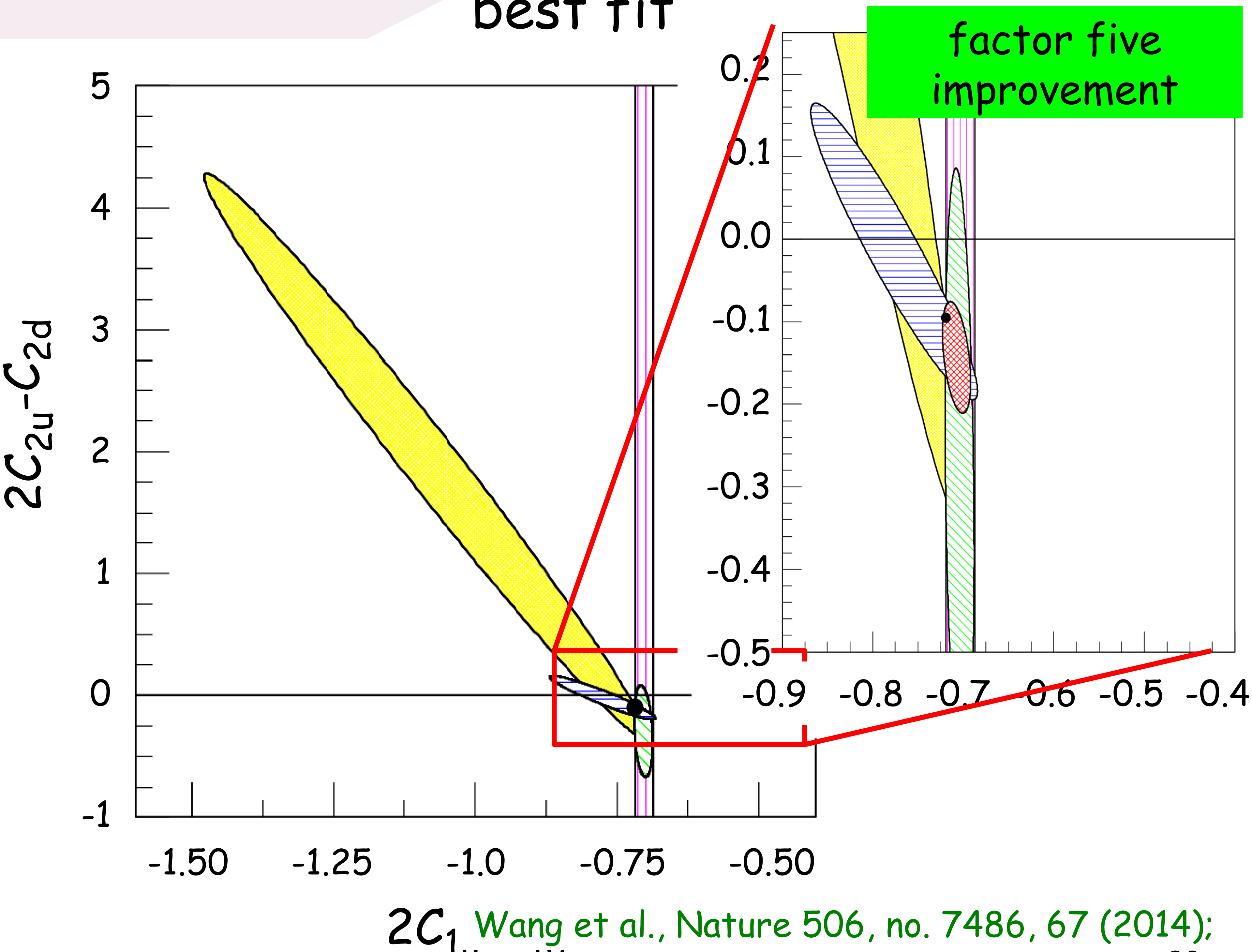
Previous data: Elastic PVES + APV



Add JLab 6 GeV PVDIS

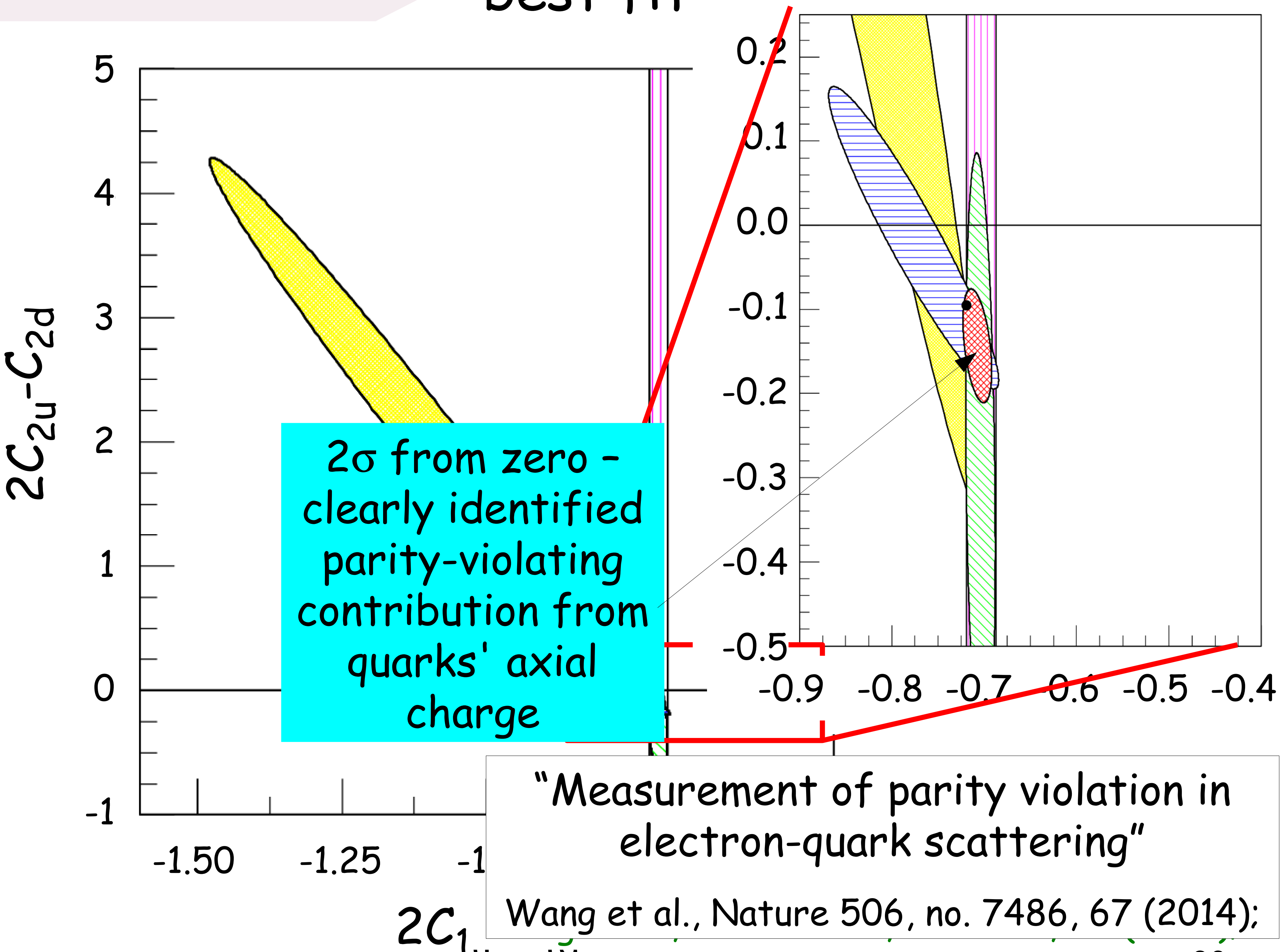


best fit



Wang et al., Nature 506, no. 7486, 67 (2014);

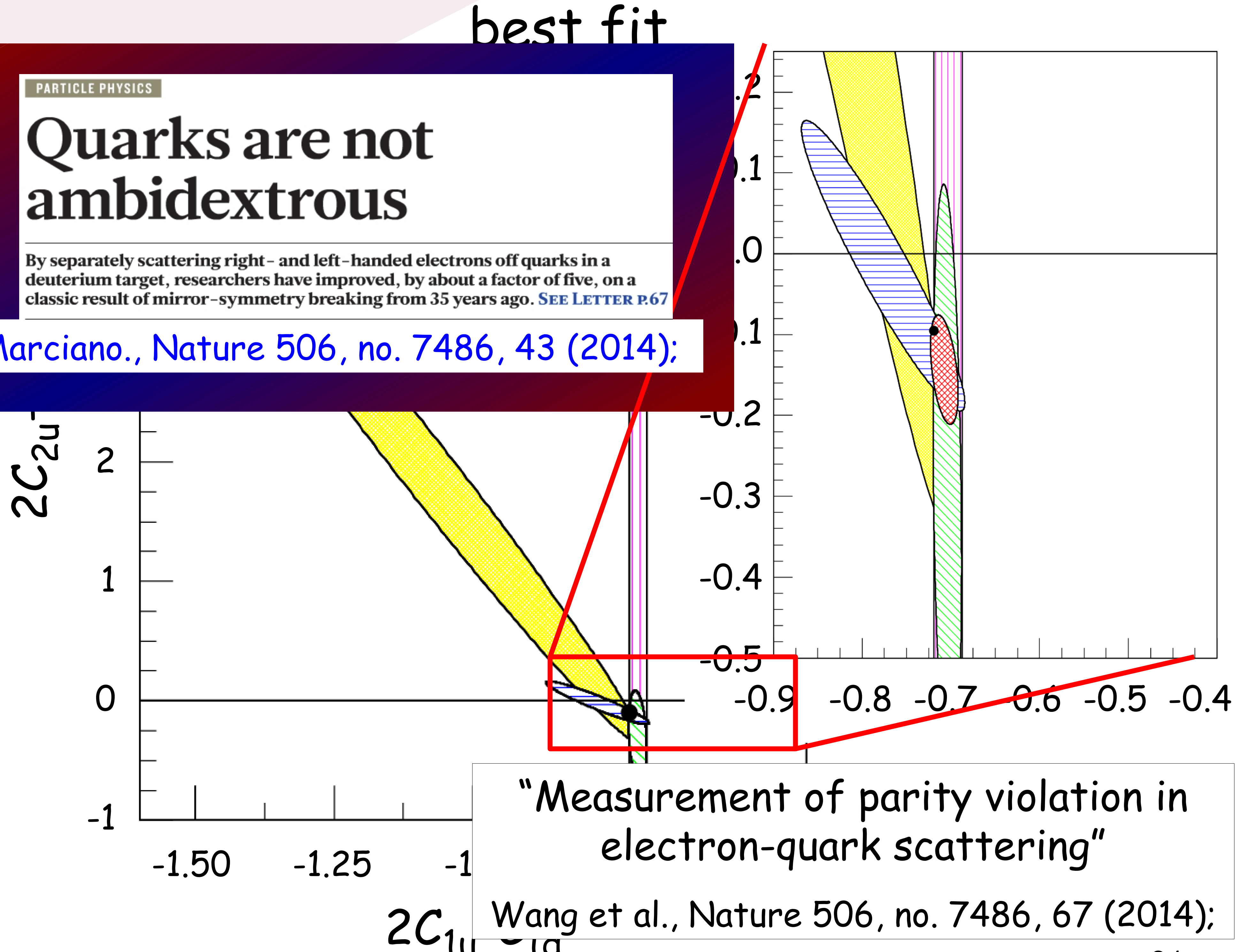
best fit



2σ from zero – clearly identified parity-violating contribution from quarks' axial charge

"Measurement of parity violation in electron-quark scattering"

Wang et al., Nature 506, no. 7486, 67 (2014);



PARTICLE PHYSICS

Quarks are not ambidextrous

By separately scattering right- and left-handed electrons off quarks in a deuterium target, researchers have improved, by about a factor of five, on a classic result of mirror-symmetry breaking from 35 years ago. SEE LETTER P.67

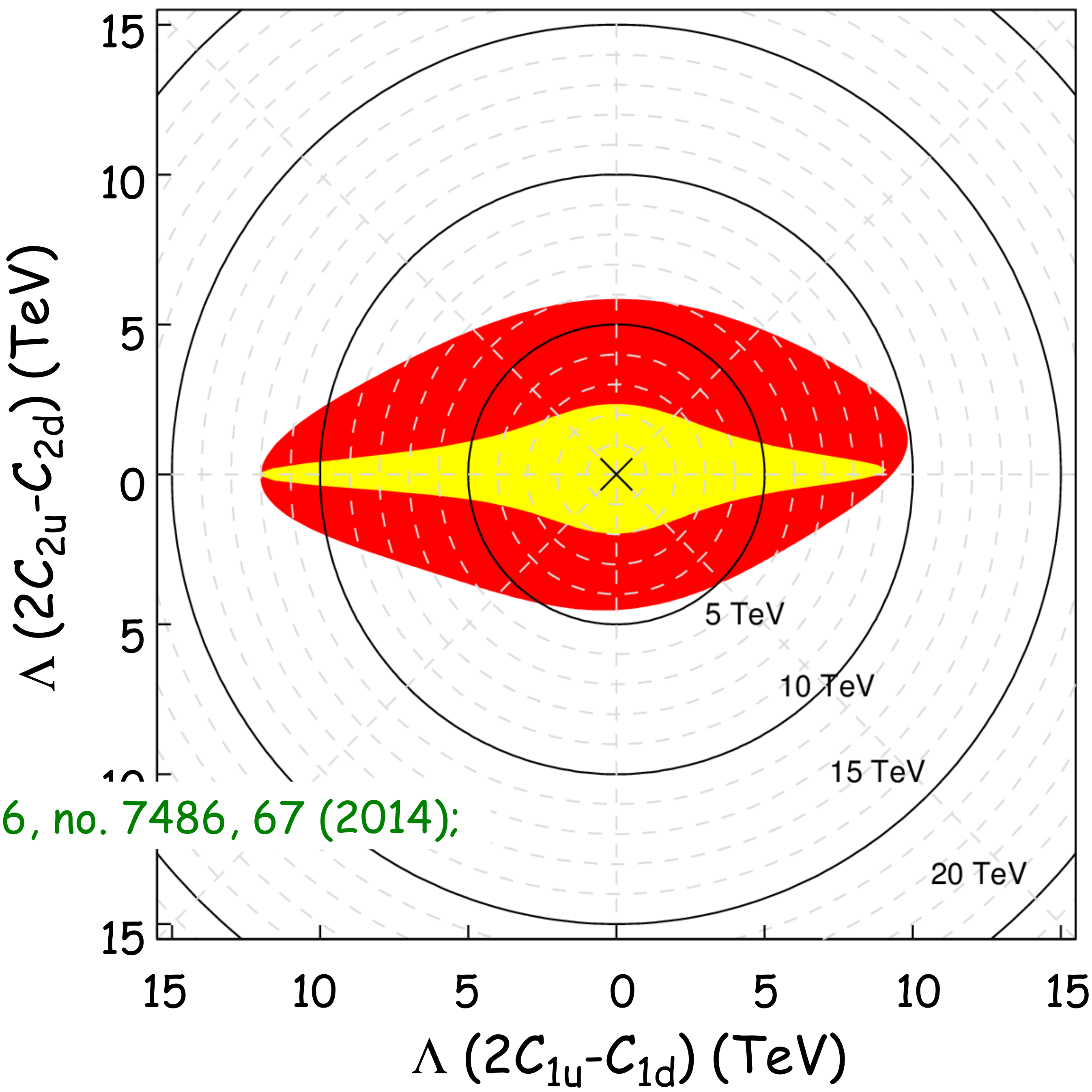
Marciano., Nature 506, no. 7486, 43 (2014);

"Measurement of parity violation in electron-quark scattering"

Wang et al., Nature 506, no. 7486, 67 (2014);

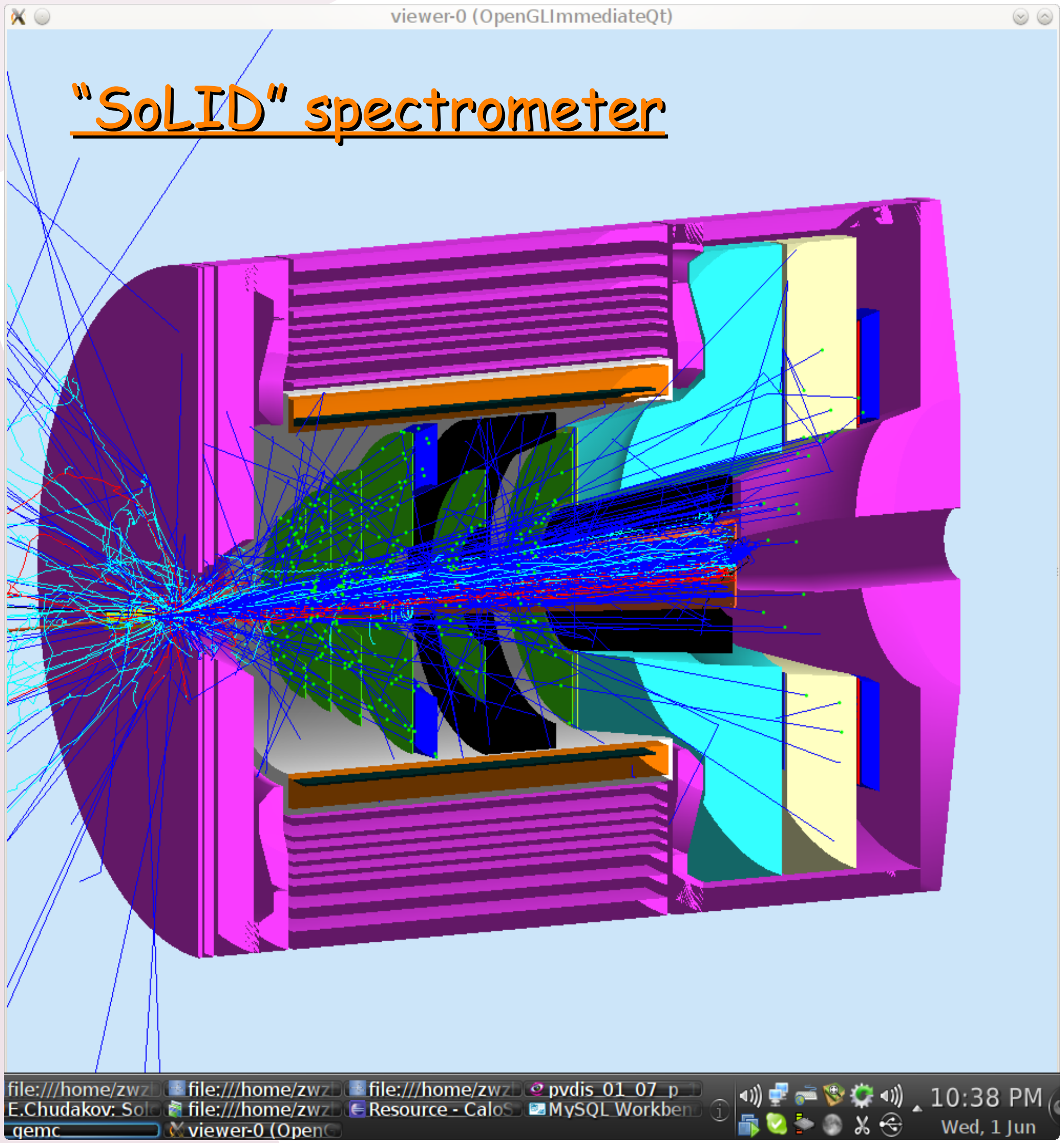
BSM Mass Limit on eq VA contact interaction

Complementary to LHC results on the mass limit of eq contact interactions



Wang et al., Nature 506, no. 7486, 67 (2014);

Coherent PVDIS Program with SoLID @ 11 GeV

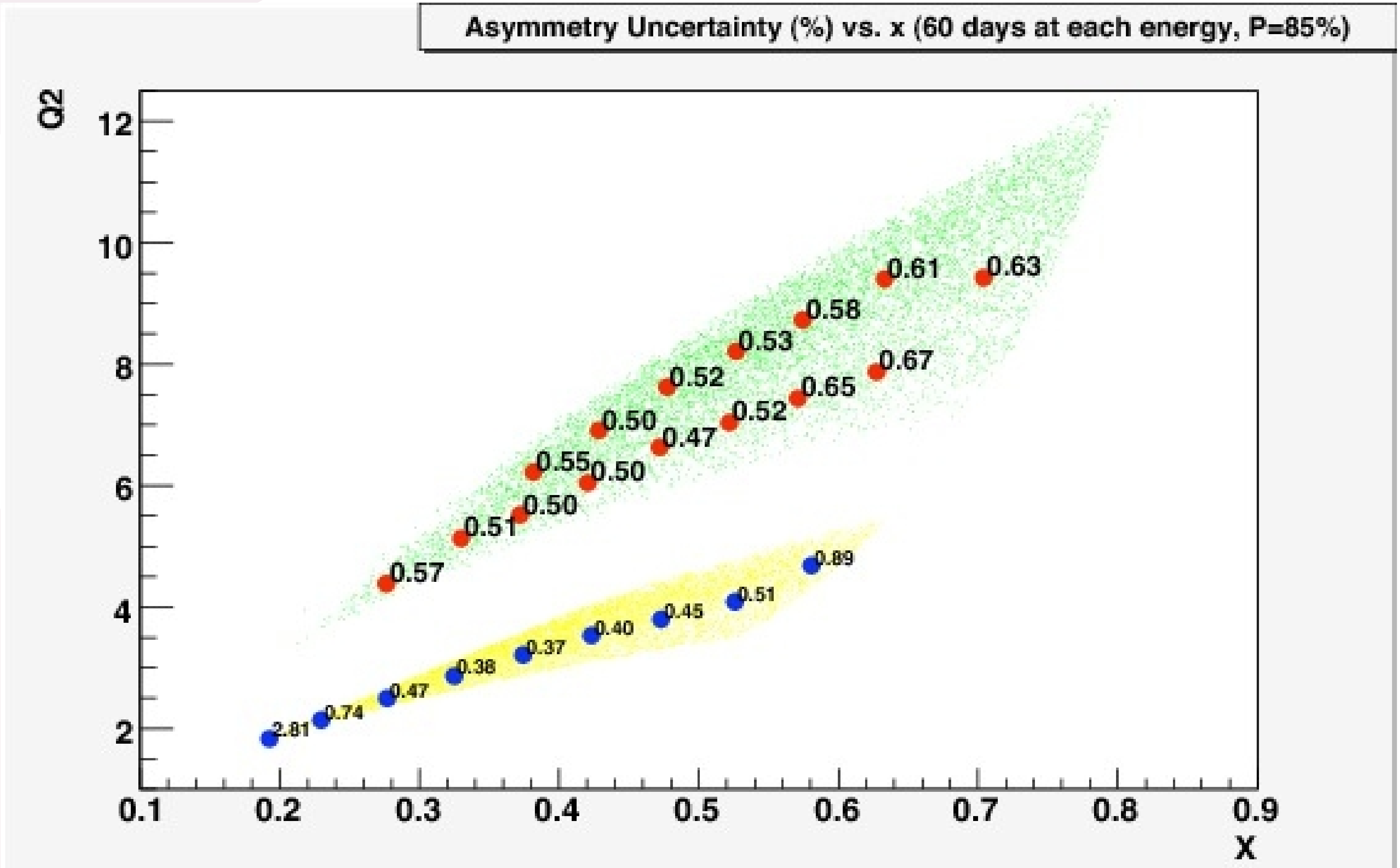


SoLID Physics topics:

- PVDIS
- SIDIS
- J/ψ

X. Zheng, Hadron 2015

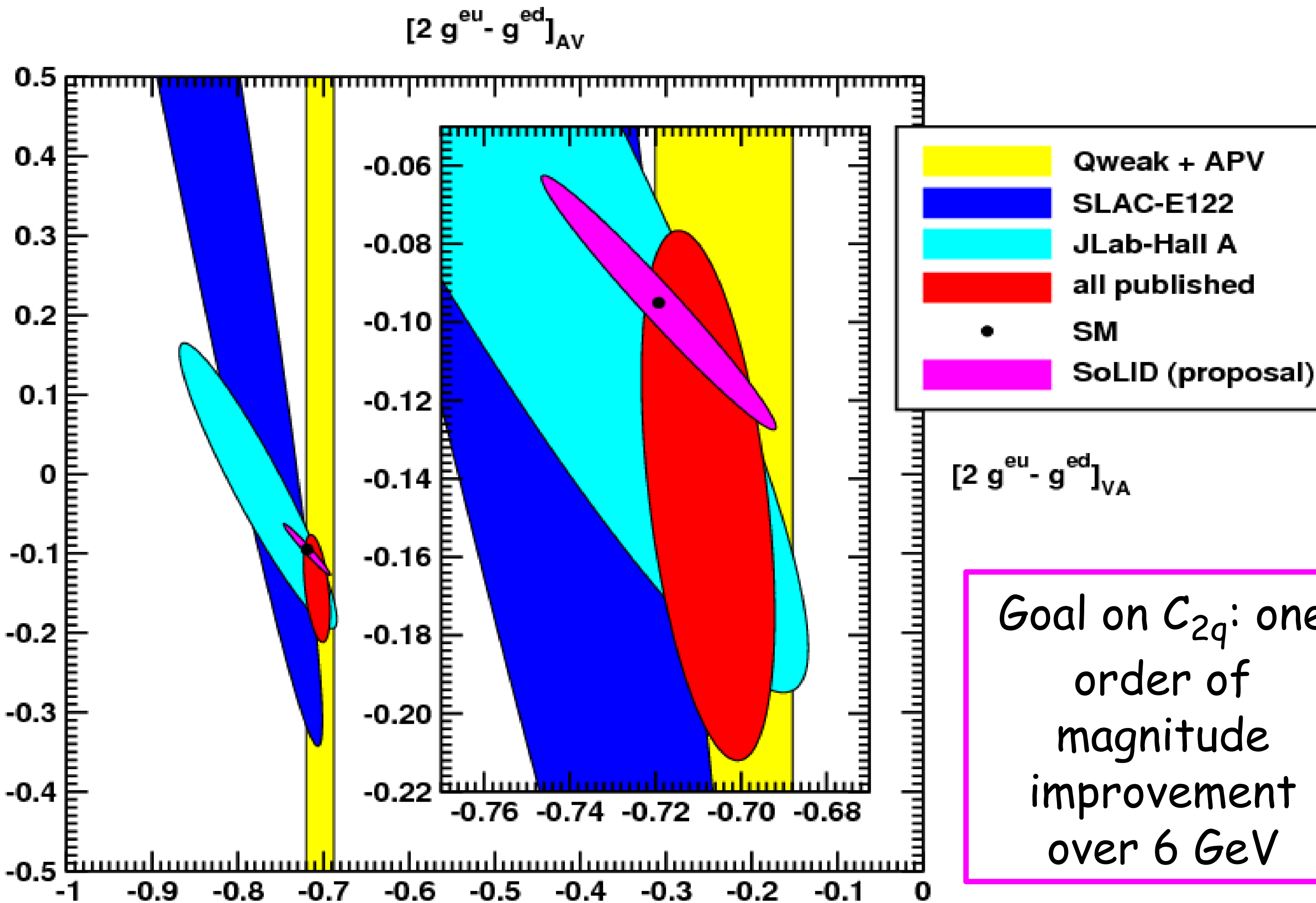
Coherent PVDIS Program with SoLID @ 11 GeV



Goal on C_{2q}: one order of magnitude improvement over 6 GeV

X. Zheng, Hadron 2015

Coherent PVDIS Program with SoLID @ 11 GeV



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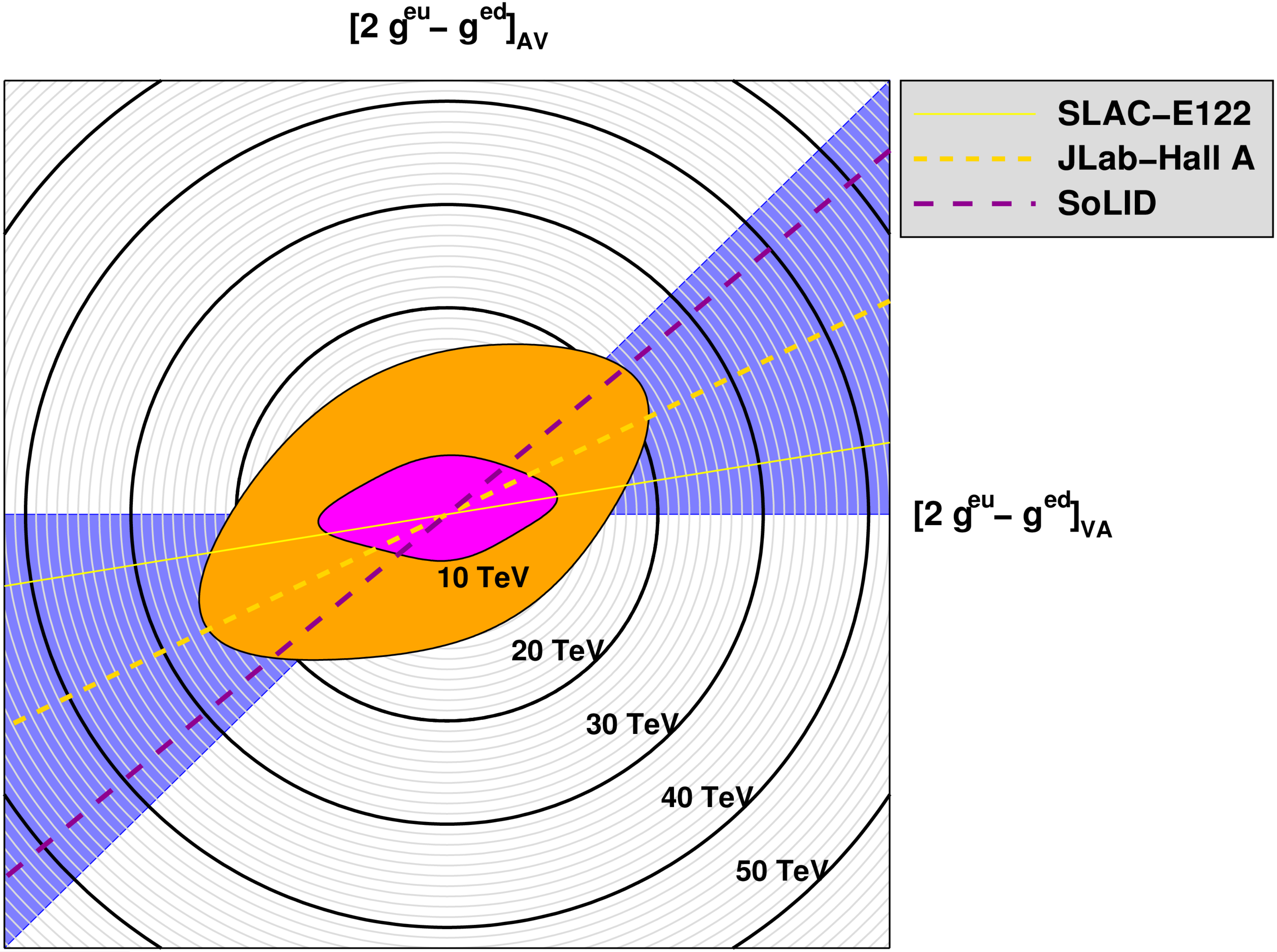


X. Zheng, Hadron 2015

What do you expect a biologist to get from reading your paper?

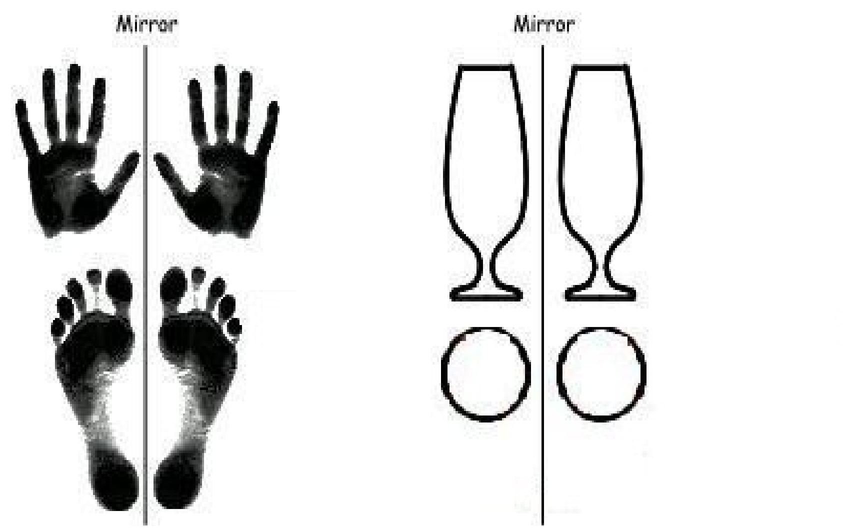
Wang et al., Nature 506, no. 7486, 67 (2014);

Marciano., Nature 506, no. 7486, 43 (2014);

Disclaimer: The following slides are for promoting curiosity and new ideas ONLY.

Well, the whole biological world is chiral

Chirality



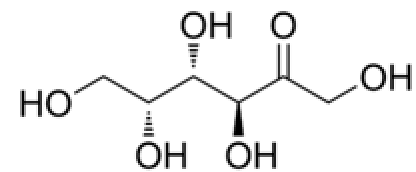
An object that cannot be superimposed on its mirror image is called chiral

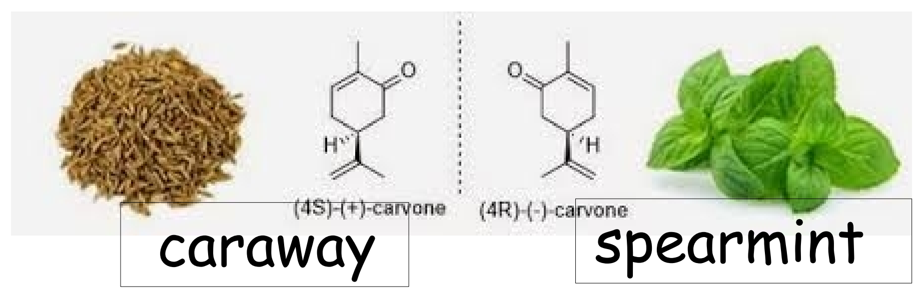
For physicists: do you know the difference between chirality and helicity?

All living organisms contain almost only 'left-handed' amino-acids and 'right-handed' sugars

(Only spider-man has left-handed DNAs)

Natrulose (left-handed sugar) – blessing or curse?

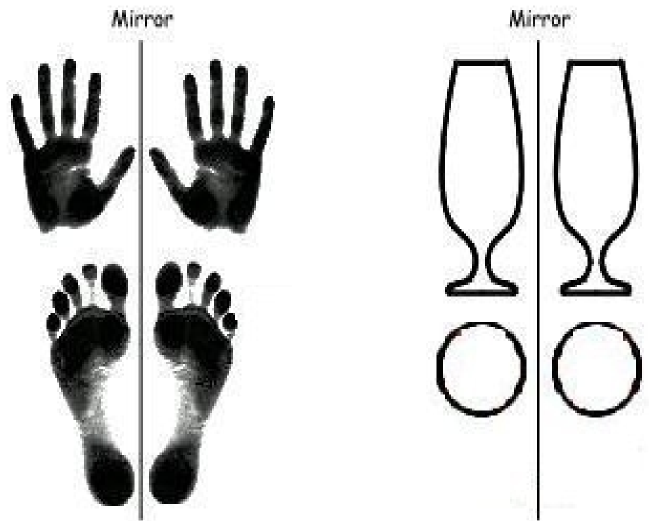




pharmaceuticals must be chirally correct to work.

Well, the whole ~~biological~~ world is chiral

Chirality



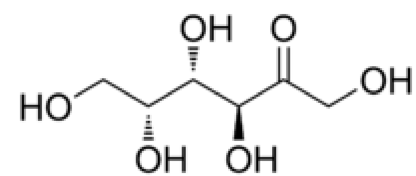
An object that cannot be superimposed on its mirror image is called chiral

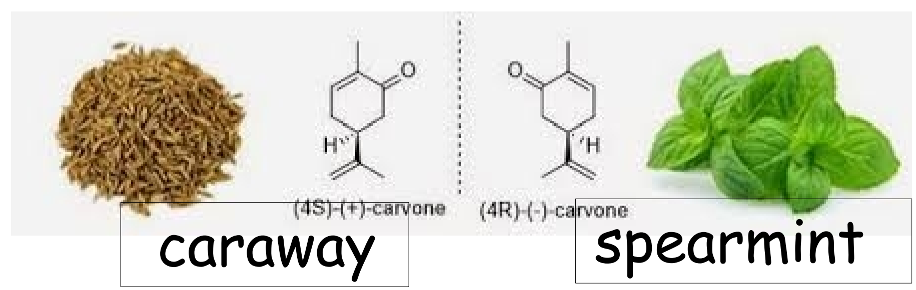
Physicists are studying the same thing – chirality of elementary particles!

All living organisms contain almost only 'left-handed' amino-acids and 'right-handed' sugars

(Only spider-man has left-handed DNAs)

Natrulose (left-handed sugar) – blessing or curse?





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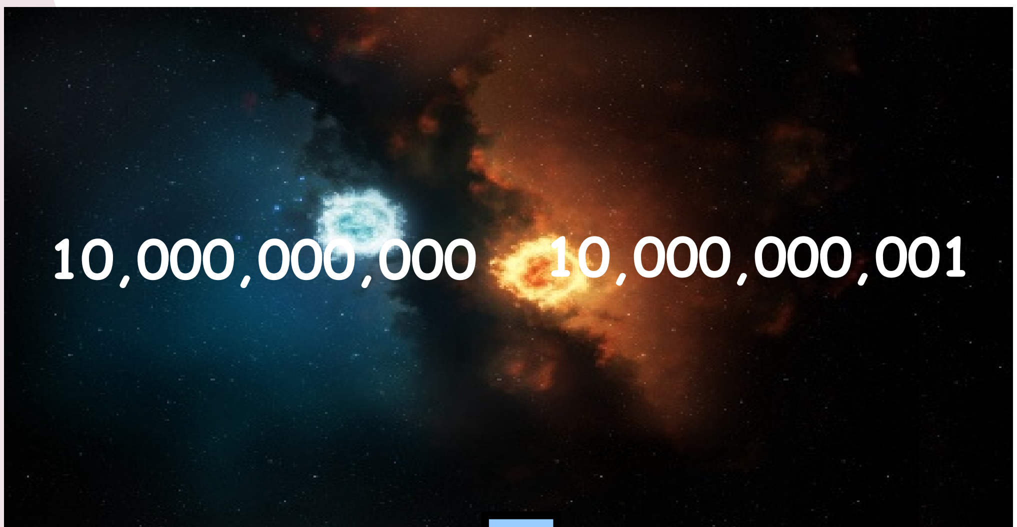
X. Zheng, Hadron 2015

Why is the whole world chiral?

How does parity violation “show up” in the macroscopic world?

CP violation

?



The existence of our universe

X. Zheng, Hadron 2015

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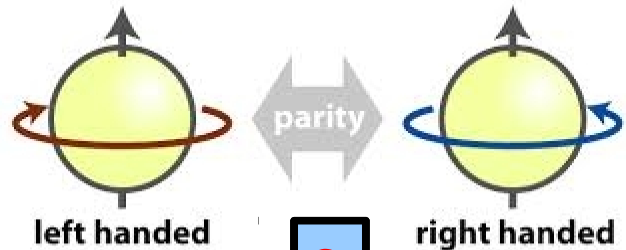
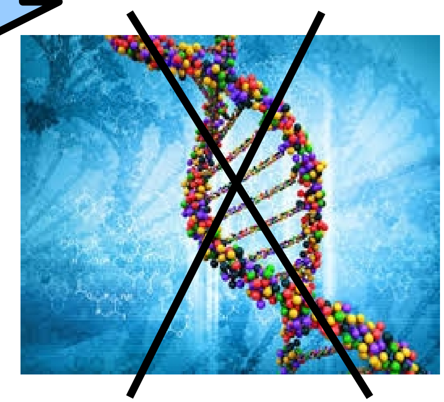
How does parity violation “show up” in the macroscopic world?

Parity violation

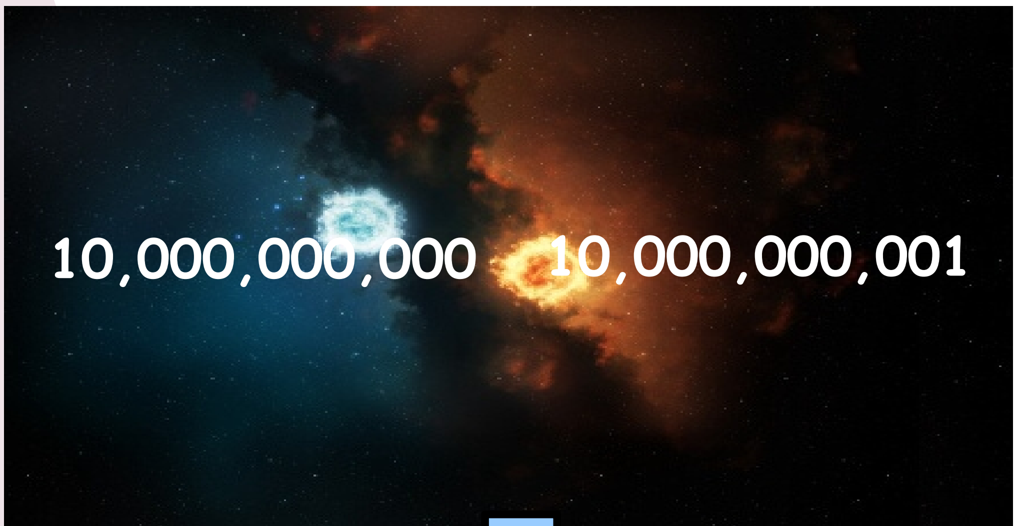


?



CP violation

?



The existence of our universe

X. Zheng, Hadron 2015

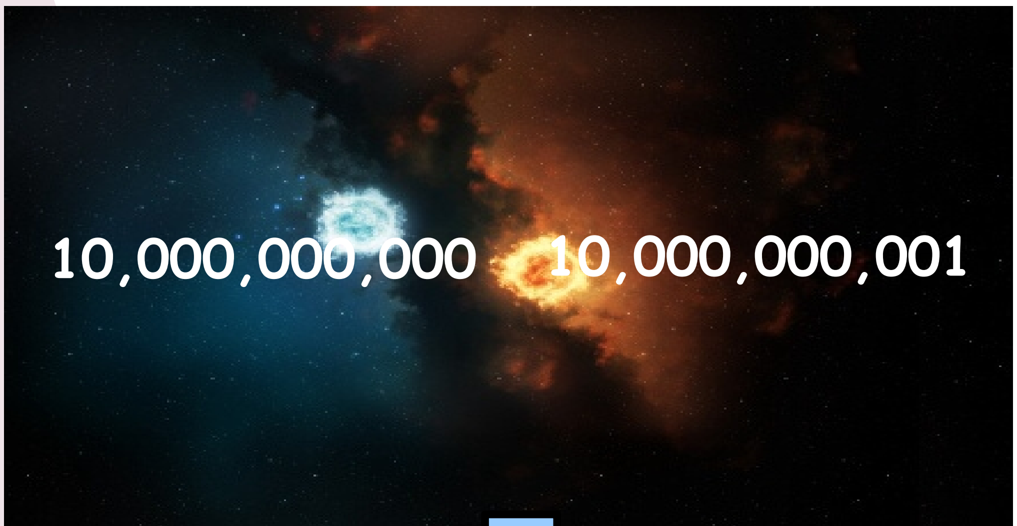
Chirality contributes to complexity of molecules, which is essential for the origin of life.

Why is the whole world chiral?

How does parity violation “show up” in the macroscopic world?

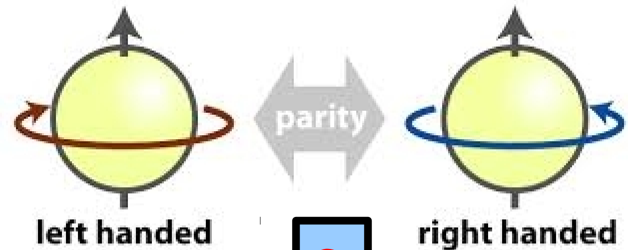
CP violation

?



The existence of our universe

Parity violation



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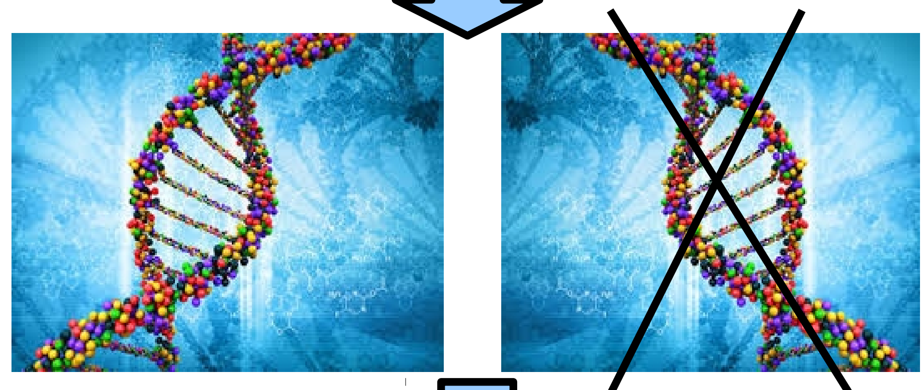

The existence(?) of life?

X. Zheng, Hadron 2015

Symmetry in the macroscopic world comes from symmetry in the underlying building blocks and interactions. So what is the cause of the chiral structure of our biological world? Could it be explained from physics? Could it come partially from parity violation?

How does parity violation affect the macroscopic world?

Summary and Perspectives

The 6 GeV PVDIS from JLab:

- Improved world data on the eq VA effective coupling term $2C_{2u}$-C_{2d} by factor of five
- agrees with the SM
- showed $2C_{2u}$-C_{2d} is 2σ from zero – indicating a nonzero contribution to PVDIS asymmetry due to quark's chirality preference
- BSM mass limits complimentary to collider experiments.

"New construction" experiments at JLab 12 GeV:

- Will improve C_{2q} by another order of magnitude.

Subedi et al, NIM-A 724, 90 (2013); Wang et al., PRL 111, 082501 (2013); Wang et al., Nature506,no.7486, 67 (2014); long paper accepted by Phys. Rev. C.