Using electron scattering to constrain the axial-vector form factor

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OUTLINE

I. Introduction/Motivation

II. Parity violating electron-proton scattering

III. Parity violating QE electron-nucleus scattering

I. Motivation

- All neutrino scattering experiments involve nuclear/nucleonic targets. Thus, a good understanding of the neutrino-nucleon/nucleus reaction mechanism is essential to reduce systematic errors in neutrino-oscillation experiments.

- Many of these experiments (MiniBooNE, Minerva, NOMAD, T2K, etc.) are placed at the intermediate energy regime (from hundreds of MeV to a few GeV) where **nucleon form factors** are a main ingredient in the description of the process.

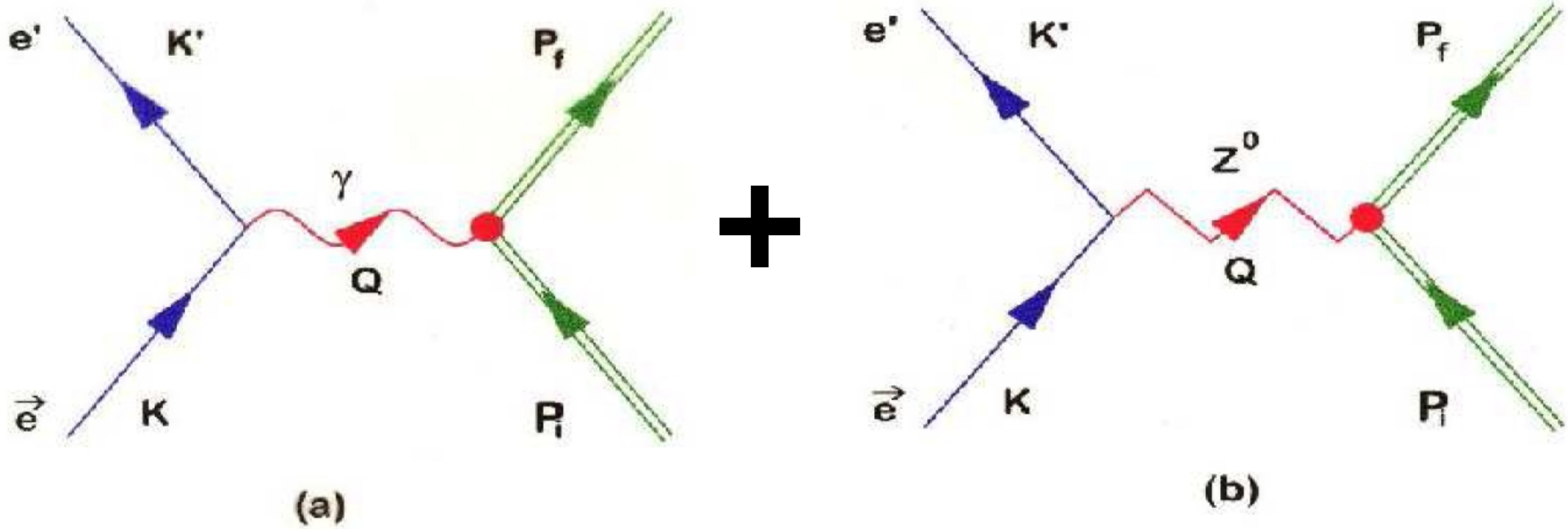
- We aim to show how the electron-nucleon/nucleus scattering reaction can be used as tool to study the **form factors** that enter in the **Weak Neutral Current (WNC)** in the nucleon.

- In particular, we focus on:
  - **Vector strange form factors:** $\langle f|\bar{s}\,\gamma^{\mu}\,s|i\rangle$
  - **Axial-vector form factor:** $\langle f|\bar{q}\,\gamma^{\mu}\gamma^{5}\,q|i\rangle$

Advantages of using electron beams *vs* neutrino beams?

- Easily produced and accelerated
- Easily detected
- Monochromatic beams

II. Parity violating electron-proton scattering



Cross section:

$$\sigma \sim |\mathcal{M}_{EM} + \mathcal{M}_Z|^2 = |\mathcal{M}_{EM}|^2 + 2\mathcal{R}e(\mathcal{M}^*_{EM}\mathcal{M}_Z) + |\mathcal{M}_Z|^2$$

Definition of the parity violating asymmetry

$$\mathcal{A}^{PV} \equiv \left(\frac{\sigma^{+} - \sigma^{-}}{\sigma^{+} + \sigma^{-}}\right) = \frac{\sigma^{PV}}{\sigma^{PC}}$$

$$\sigma^{PC} \sim |\mathcal{M}_{EM}|^{2}$$

$$\sigma^{PV} \sim 2\mathcal{R}e(\mathcal{M}^{*}_{EM} M_{Z}) + \cancel{|\mathcal{M}_{Z}|^{2}}$$

$$\mathcal{M}_{EM} = j^{\mu}_{EM}\left(\frac{-ig_{\mu\nu}}{Q^{2}}\right) J^{\nu}_{EM}$$

$$\mathcal{M}_{Z} = j^{\mu}_{Z}\left(\frac{ig_{\mu\nu}}{M^{2}_{Z}}\right) J^{\nu}_{Z}$$

Vector strange and axial-vector form factors of the nucleon

$$J_Z^\mu = \langle N_f | \left[\widetilde{F}_1 \gamma^\mu + i \frac{\widetilde{F}_2}{2M} \sigma^{\mu\alpha} Q_\alpha + G_A \gamma^\mu \gamma^5 + \frac{G_P}{M} Q^\mu \gamma^5 \right] | N_i \rangle$$

Considering charge symmetry and at tree level:

$$\widetilde{G}_{E,M}^{p,n} = (1 + \sin^2\theta_W) G_{E,M}^{p,n} - G_{E,M}^{n,p} + G_{E,M}^{(s)}$$

$$G_A = G_A^{(T=1)} \tau_3 + G_A^{(s)}$$

NC reactions

CC (isovector) reactions

There exist a large number of PV elastic electron-proton scattering data.

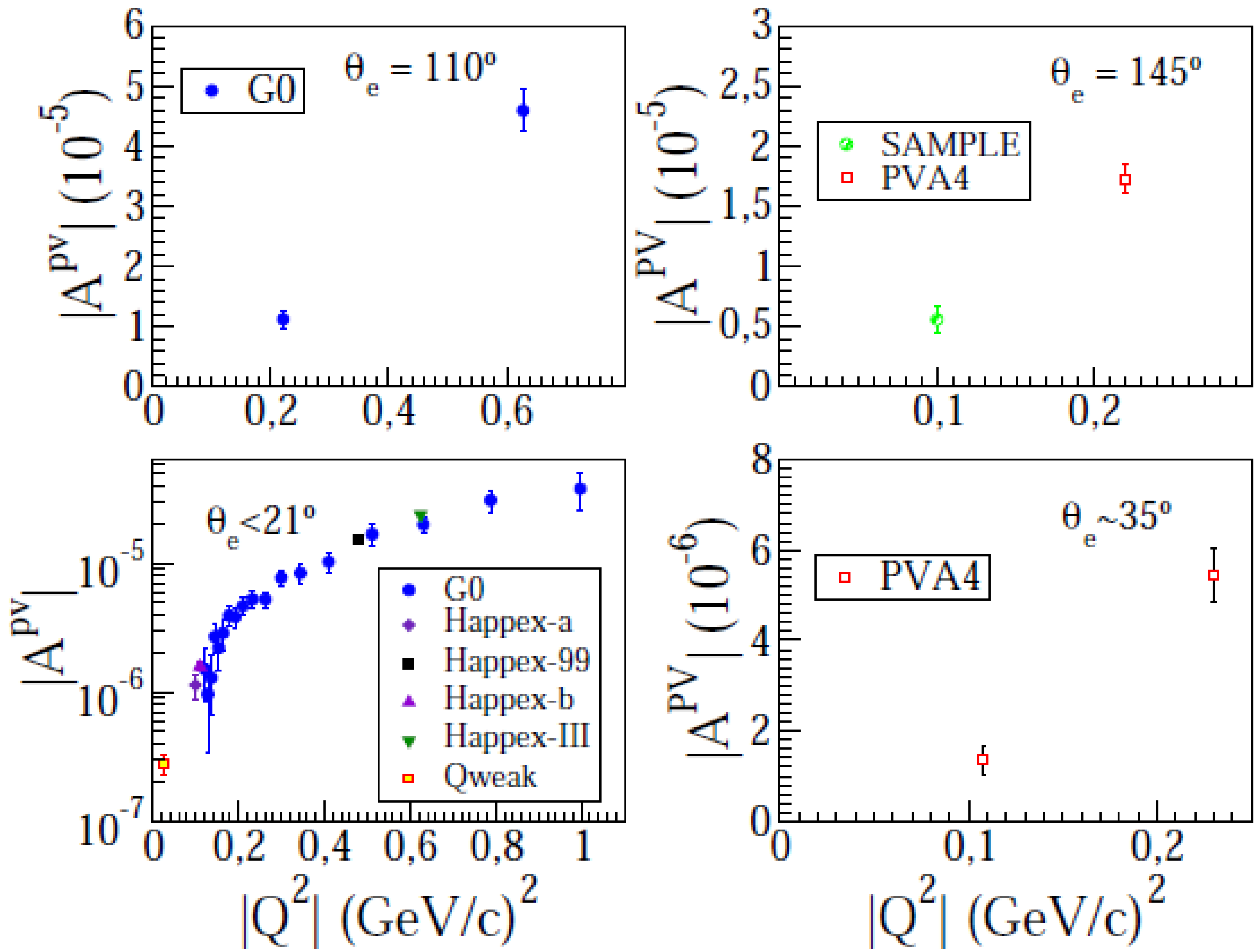


Figure: PV electron-proton asymmetry data. Each panel correspond to a different scattering angle.

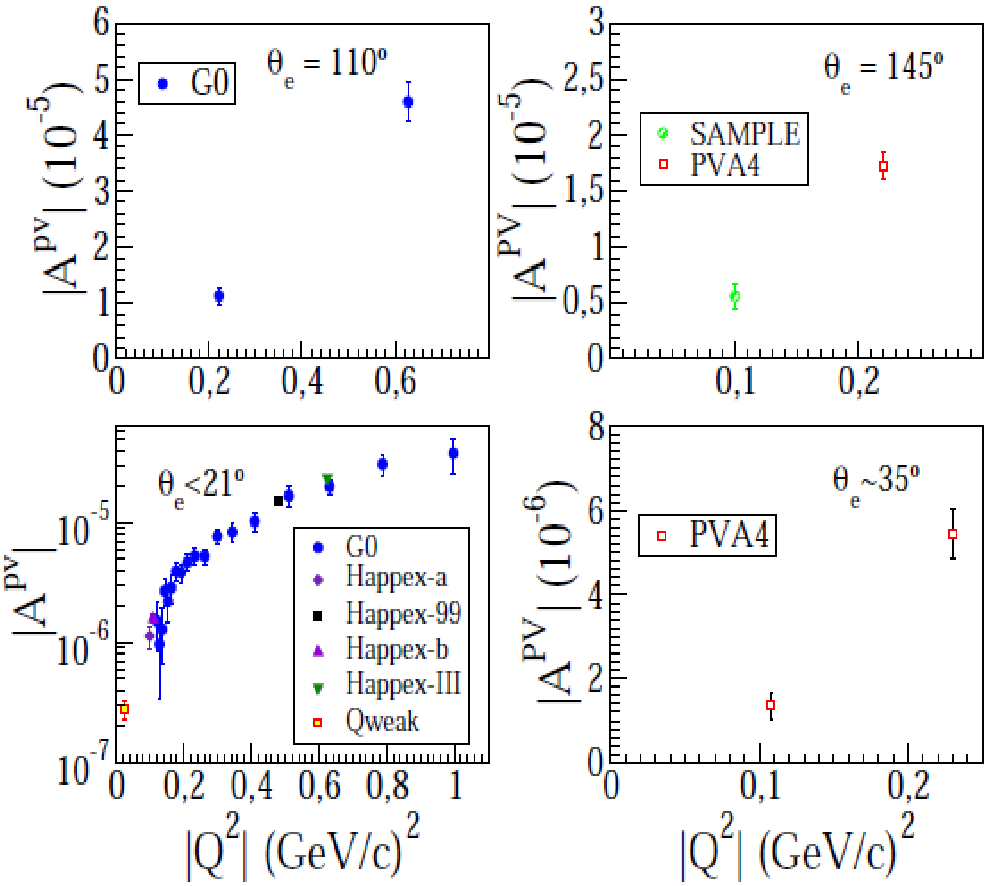
The PVep asymmetry can be written as follows:

$$A_{ep}^{PV}(\theta_e, Q^2) = a\,Q_W^p + b\,Q_W^n + c\,G_M^s(Q^2) + d\,G_E^s(Q^2) + e\,G_A(Q^2)$$

Statistical χ^2-analysis of the full set of exprimental data to estimate the quantities:

- $Q_W^{p,n}$
- $\mu_s = G_M^S(0)$
- $\rho_s \sim \left[dG_E^S/dQ^2\right]_{Q2=0}$
- $G_A(0)$

(dipole shapes assumed)



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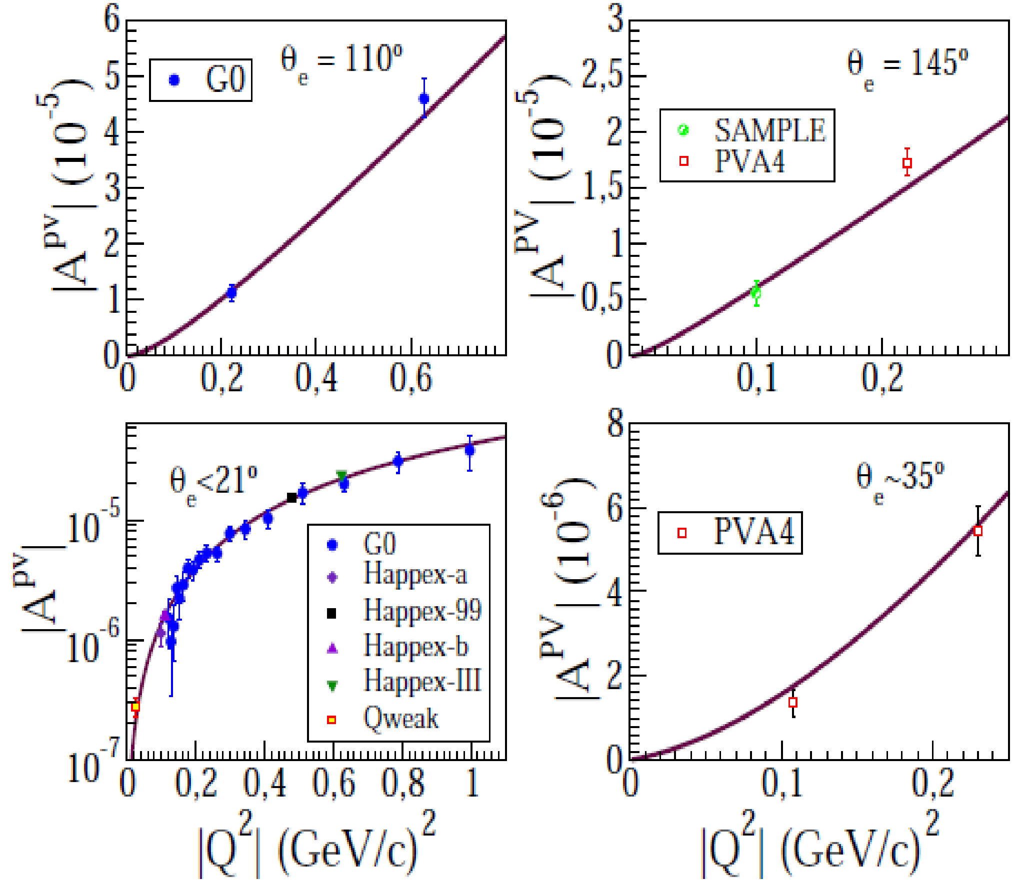
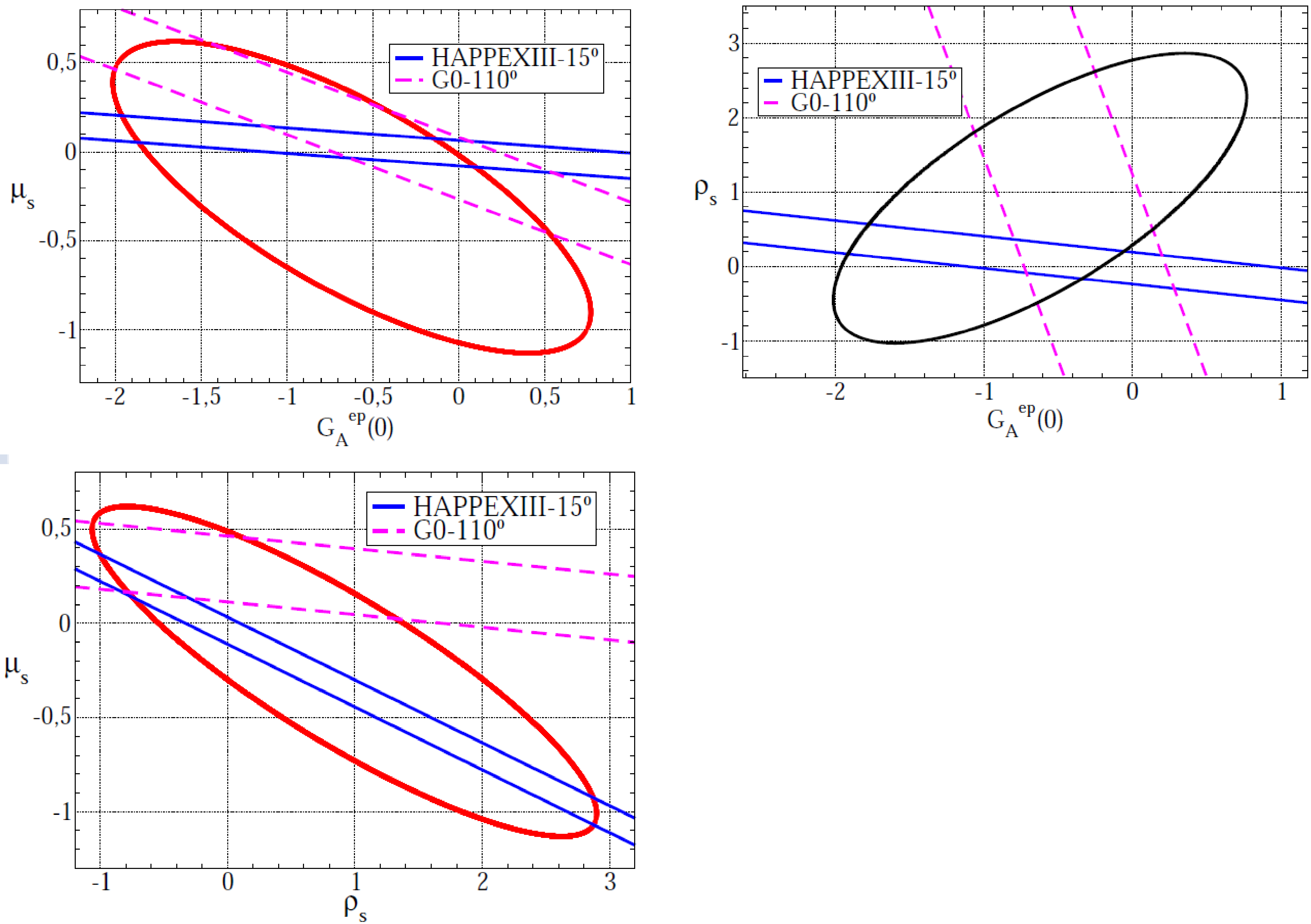


Figure: PV electron-proton asymmetry data. Each panel correspond to a different scattering angle. $\chi^2/dof = 1.30$.


HAPPEXIII-15º
G0-110º
0,5
0
-0,5
-1
-2
-1,5
-1
-0,5
0
0,5
1
μ_s
$G_A^{ep}(0)$
HAPPEXIII-15º
G0-110º
3
2
1
0
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-1
0
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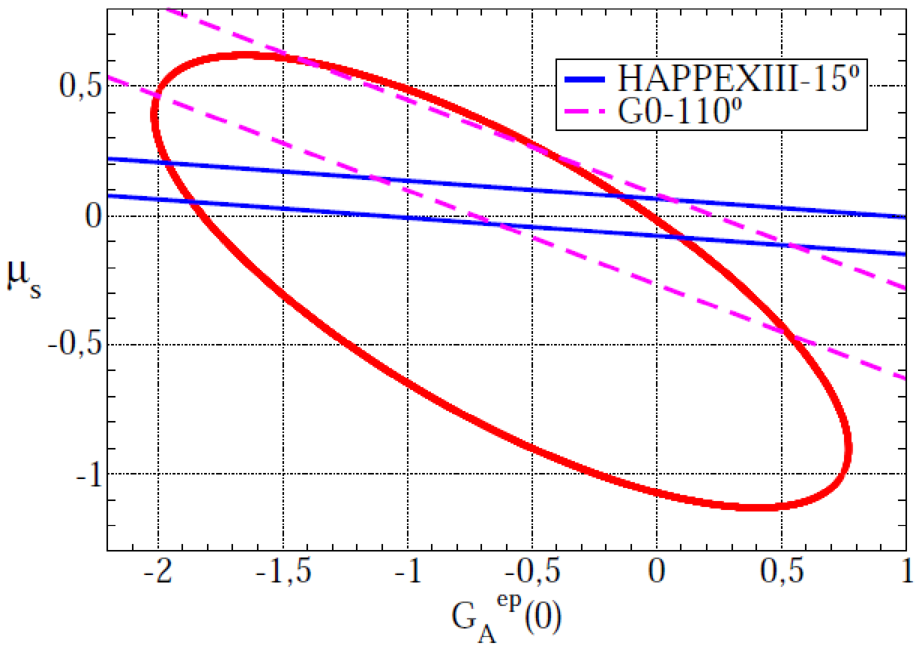
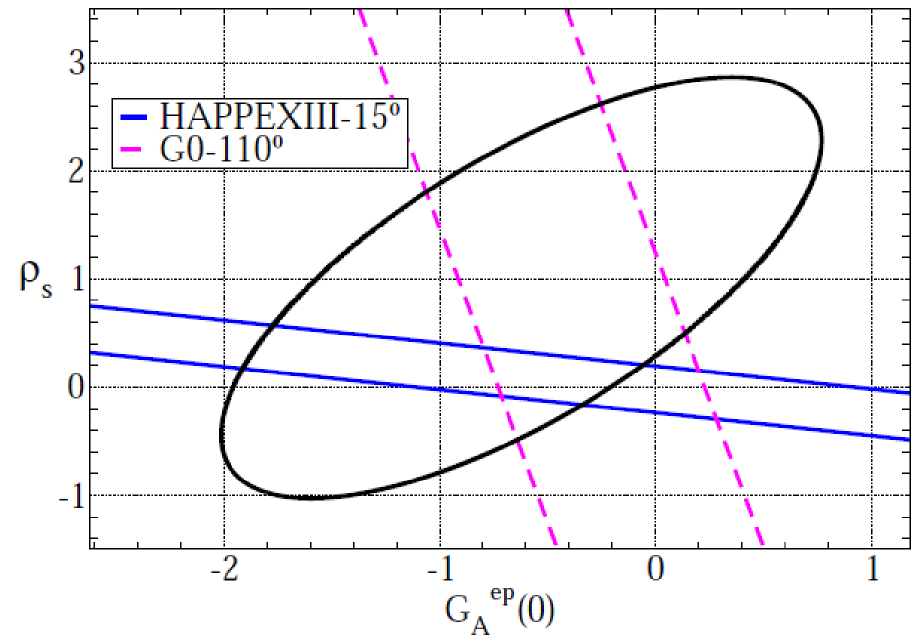
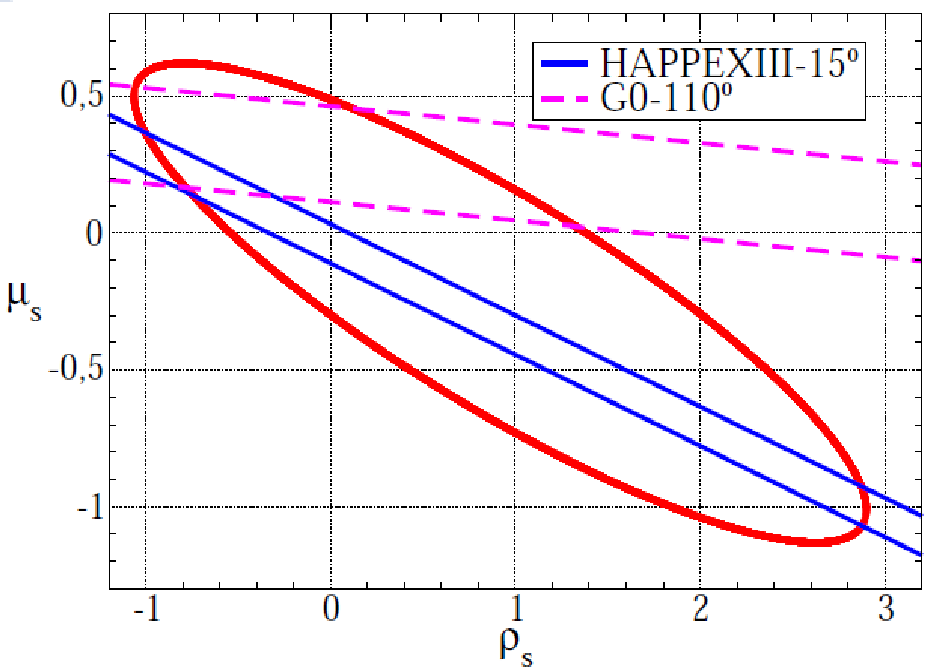
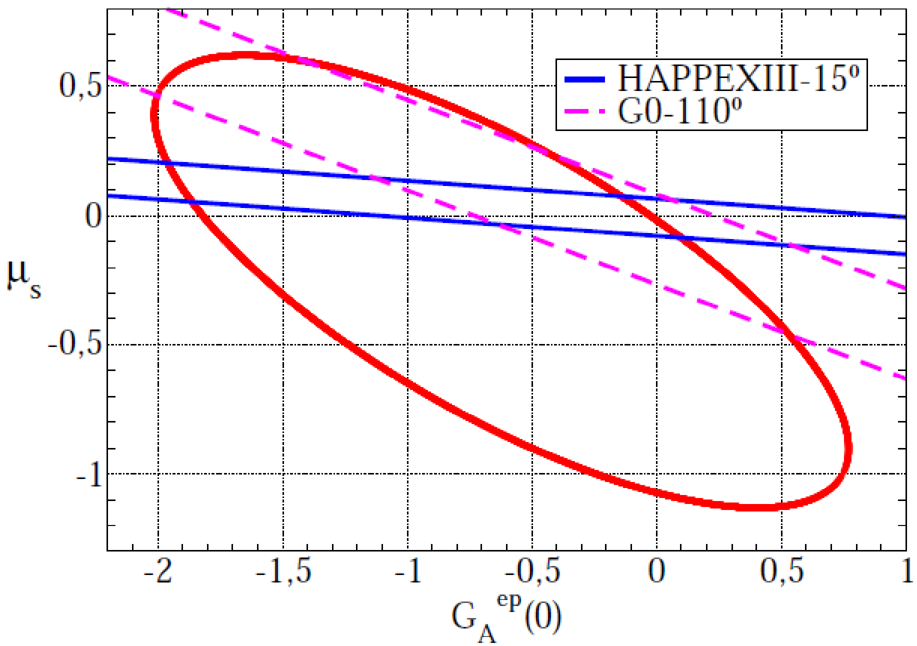
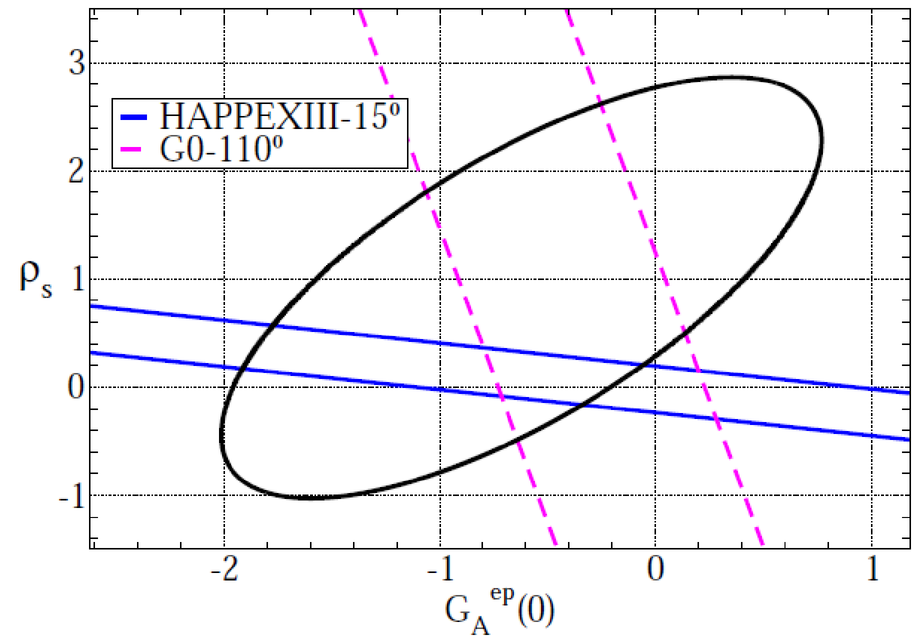


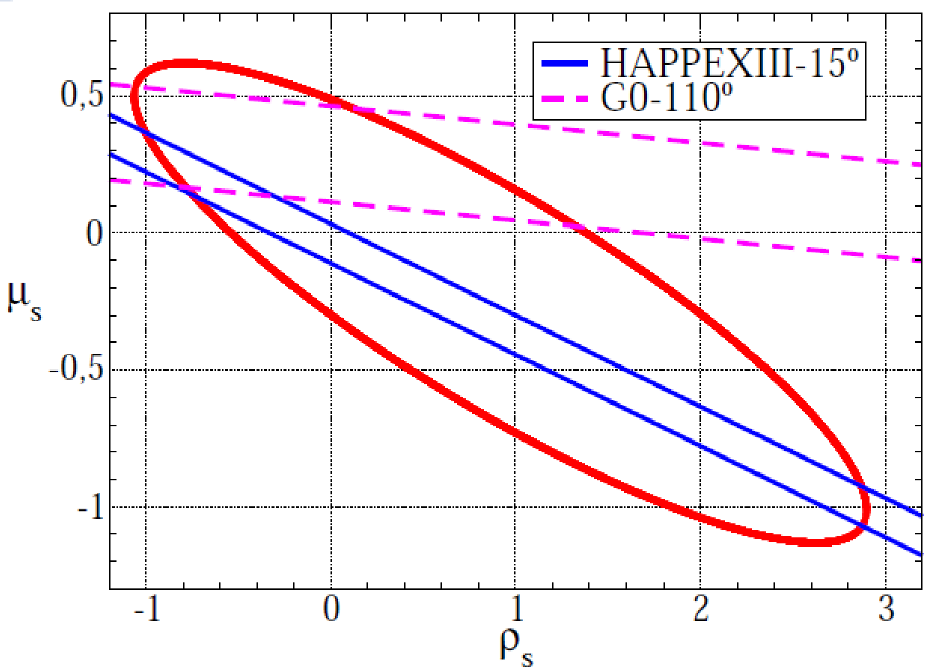




	ξ_V^n	G_A^{ep}	ρ_s	μ_s
ξ_V^p	-0.191	0.0469	0.262	0.162
ξ_V^n		0.392	0.552	-0.775
G_A^{ep}			0.711	-0.749
ρ_s				-0.870







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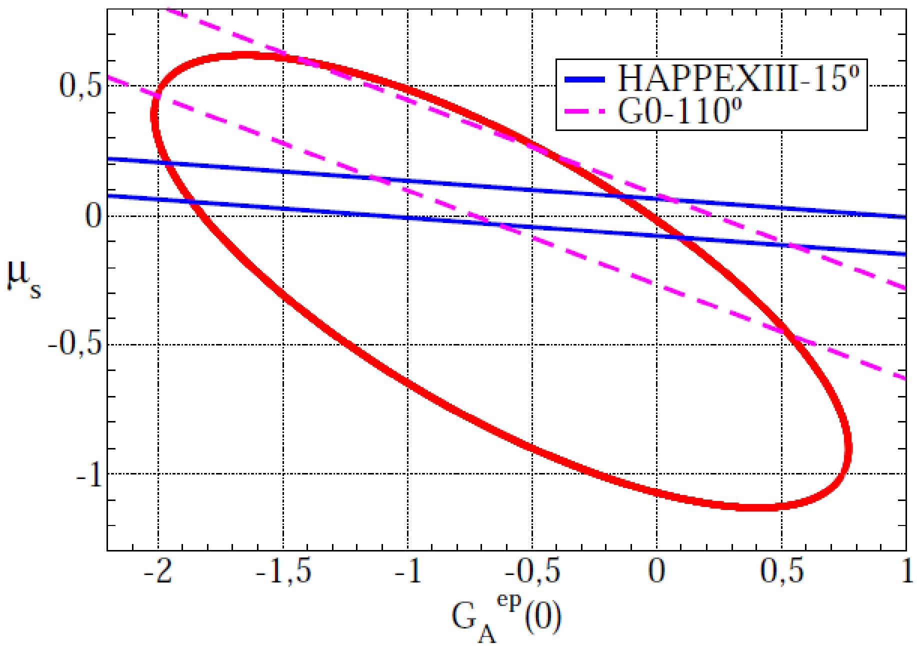

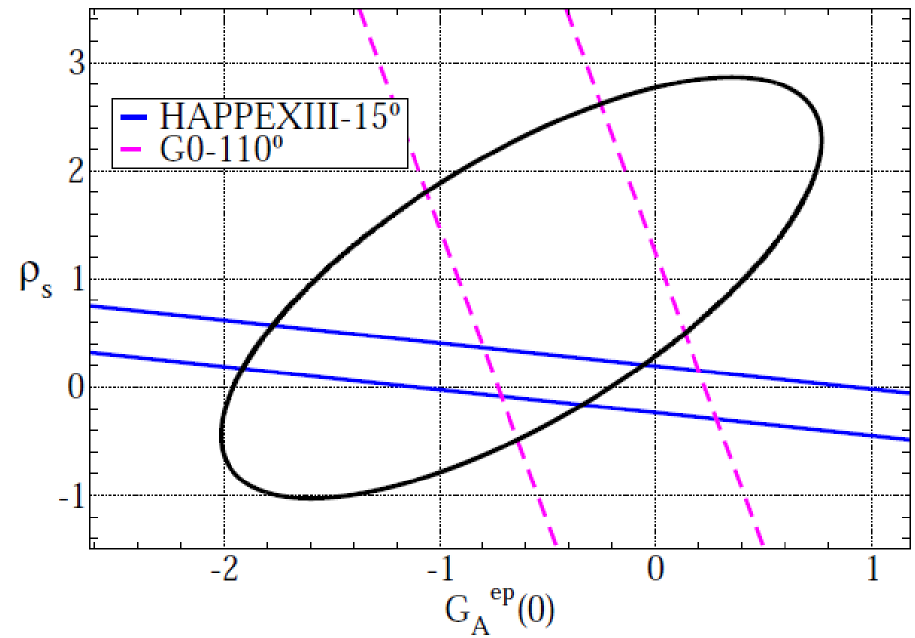

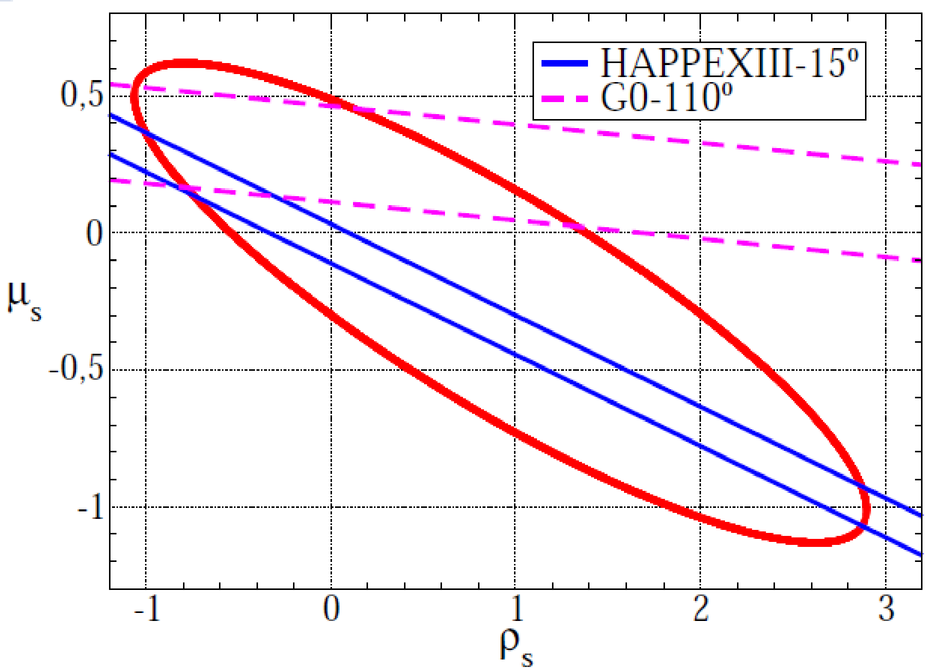

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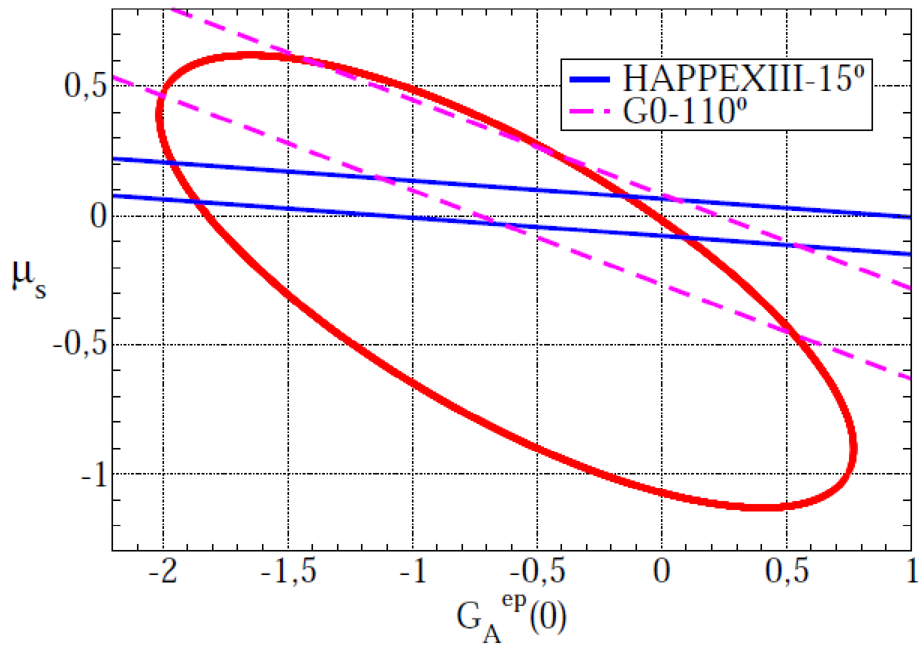

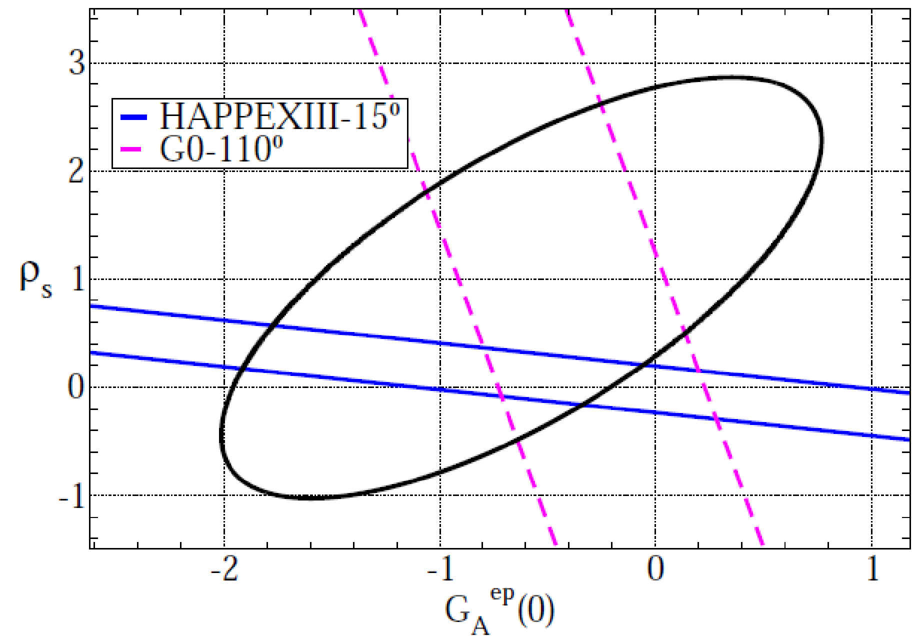

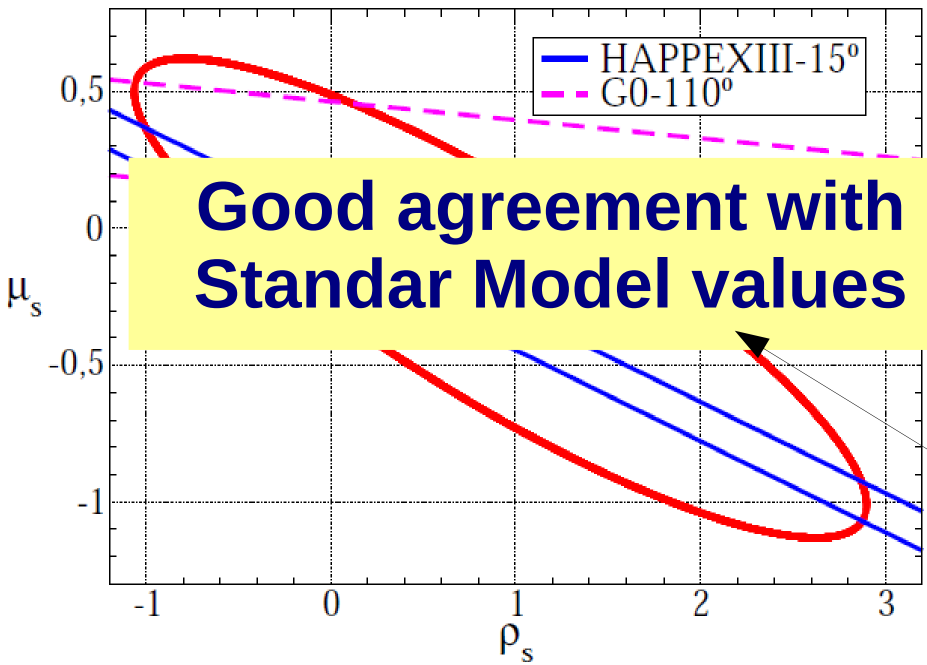

Good agreement with Standar Model values

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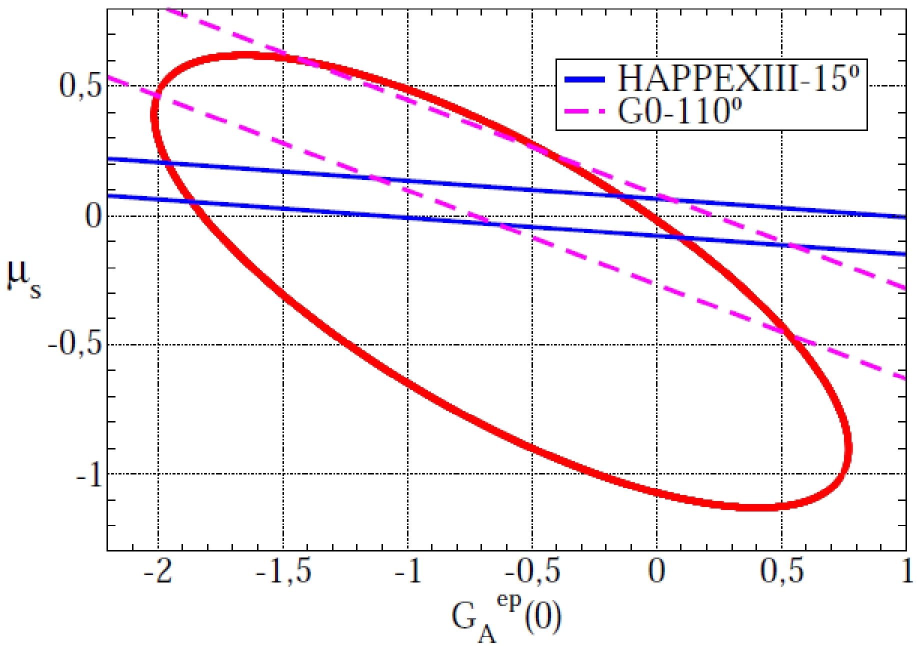

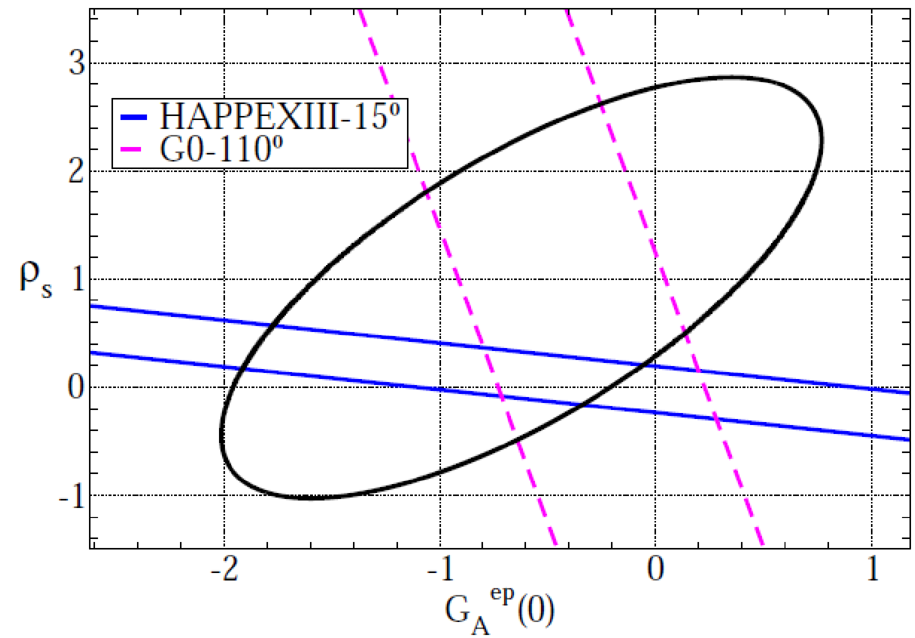

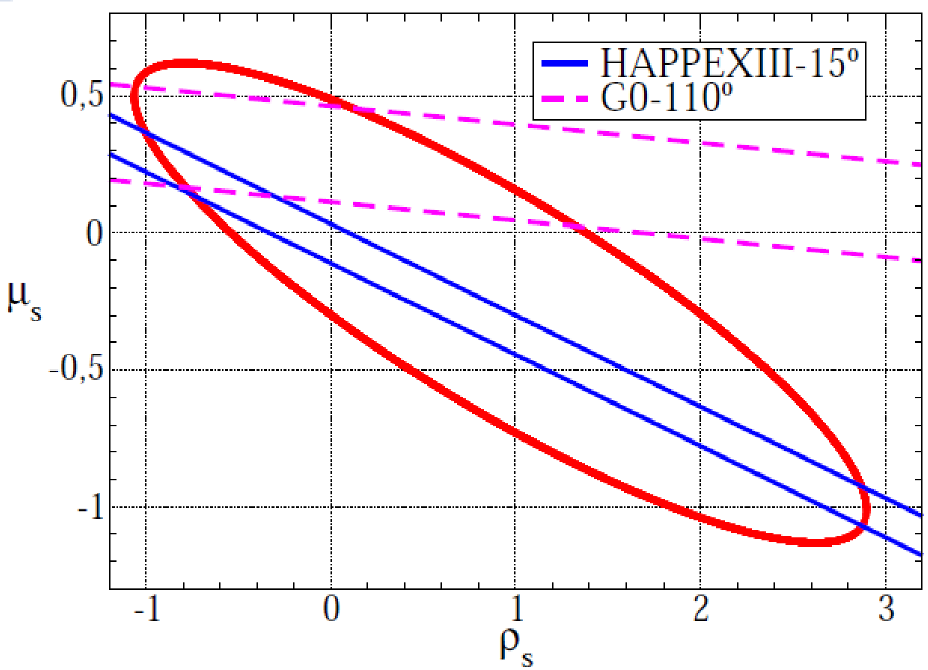

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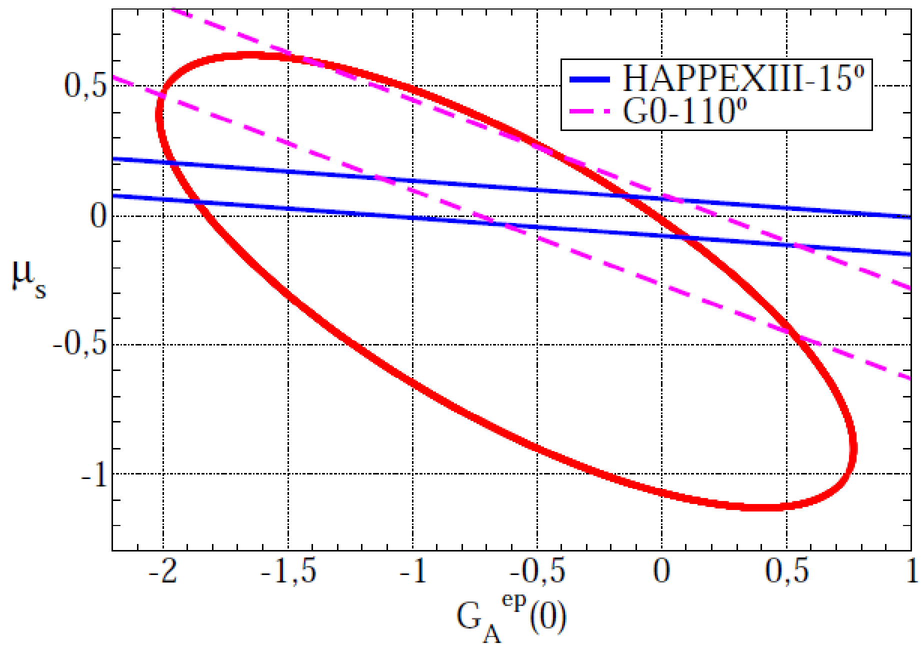

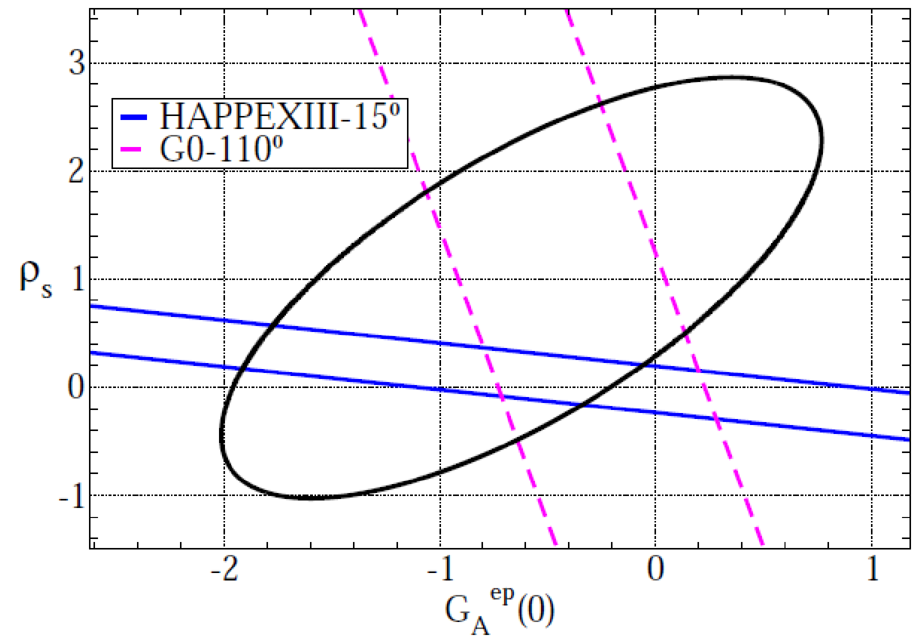

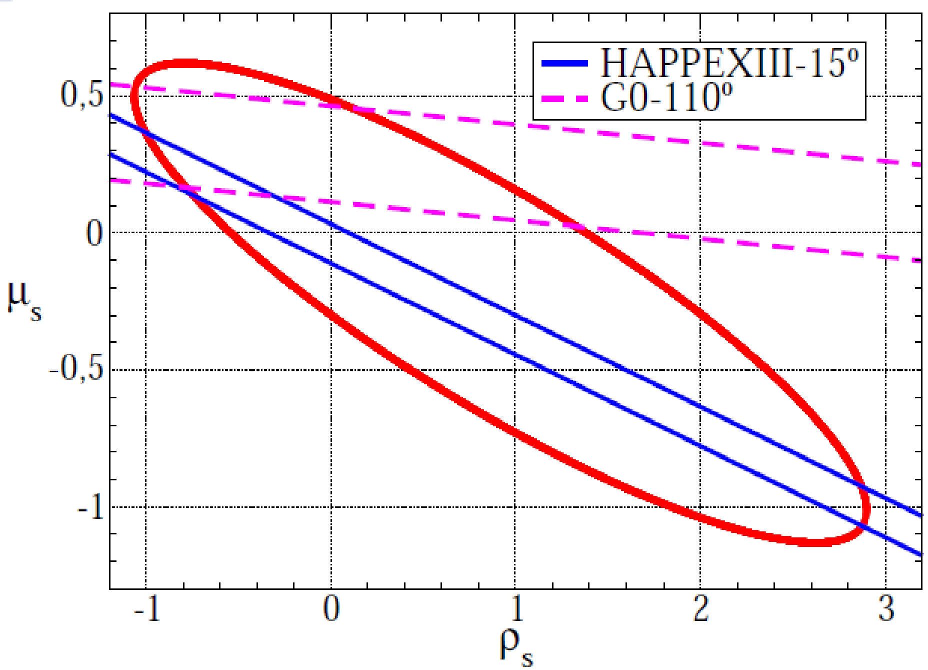

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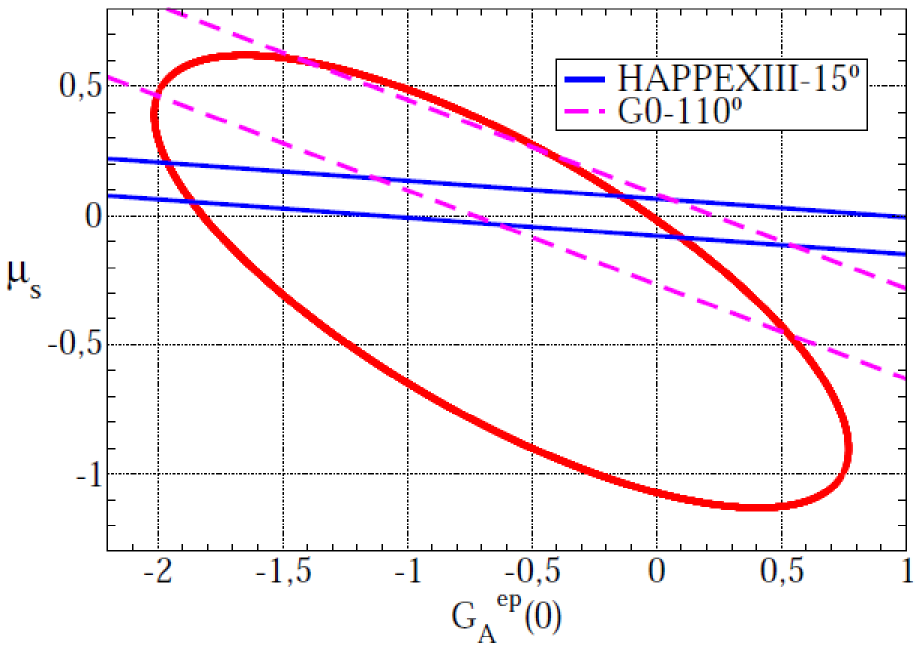

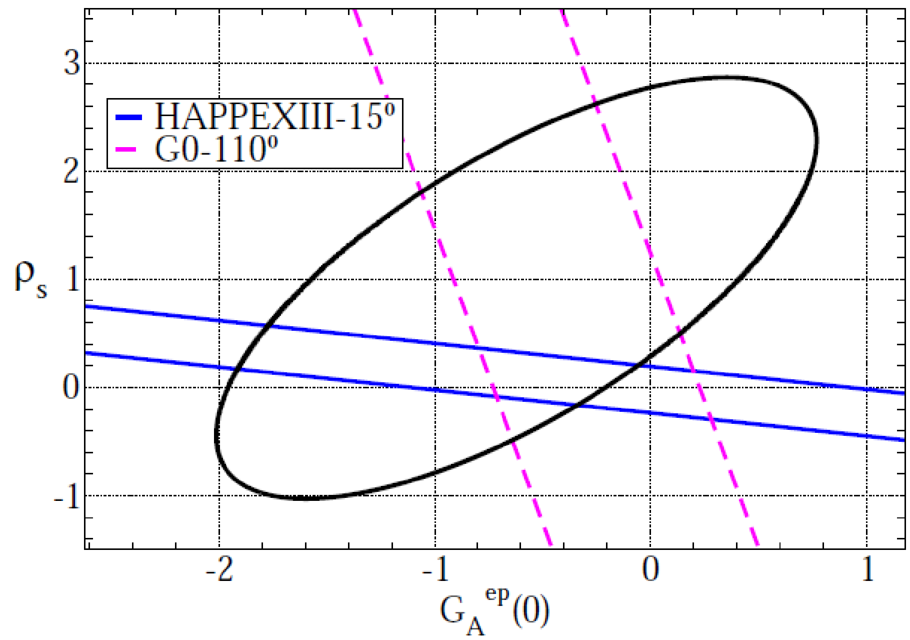

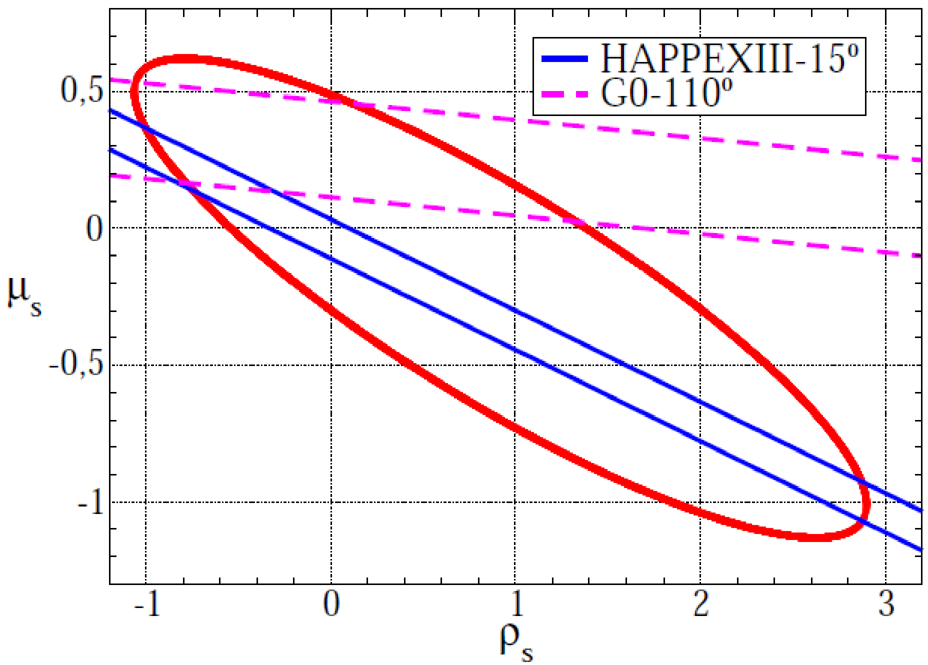

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ξ_V^p

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Can we extrapolate these results to neutrino reactions?

At tree-level (first order), the axial-vector form factor reads:

$$G_A = \left[G_A^{(T=1)} \tau_3 + G_A^{(s)} \right] G_D^A(Q^2)$$

If one considered Radiative Corrections (RC, higher order contributions):

$$G_A^{eN} = \left[(1 + R_A^{T=1}) G_A^{(T=1)} \tau_3 + R_A^{T=0} G_A^{(8)} + (1 + R_A^{(s)}) G_A^{(s)} \right] G_D^A(Q^2)$$

It is assumed that RC are small in neutrino induced reactions where only weak couplings are involved.

However, for electron induced reactions these RC could be of great importance:

$$G_A^{(T=1)} \equiv g_A = -1.27 \xrightarrow{R_A^{T=1} = 0.258 \pm 0.34} (1 + R_A^{T=1}) G_A^{(T=1)} = -1.04$$

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RC could modify G_A in more than 20%

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However, for electr… …ance:

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Summary

- PV elastic electron-proton scattering is an excellent tool to study the WNC form factors, in particular, the vector strange form factors.

- **Strong correlation** between μ_s, ρ_s and $G_A(0)$.

- Unexpectedly **small value of $G_A(0)$**. This suggests:

  + Alternative prescriptions of the Q^2 dependence of the axial-vector form.

  + Strong effects of Radiative Corrections.

- More studies on “Radiative Corrections” in the axial-vector sector of the current are essential to solve the problem.

- **References: Phys. Rep. 524, 1 (2013)**
  Phys. Rev. D 90, 033002 (2014)

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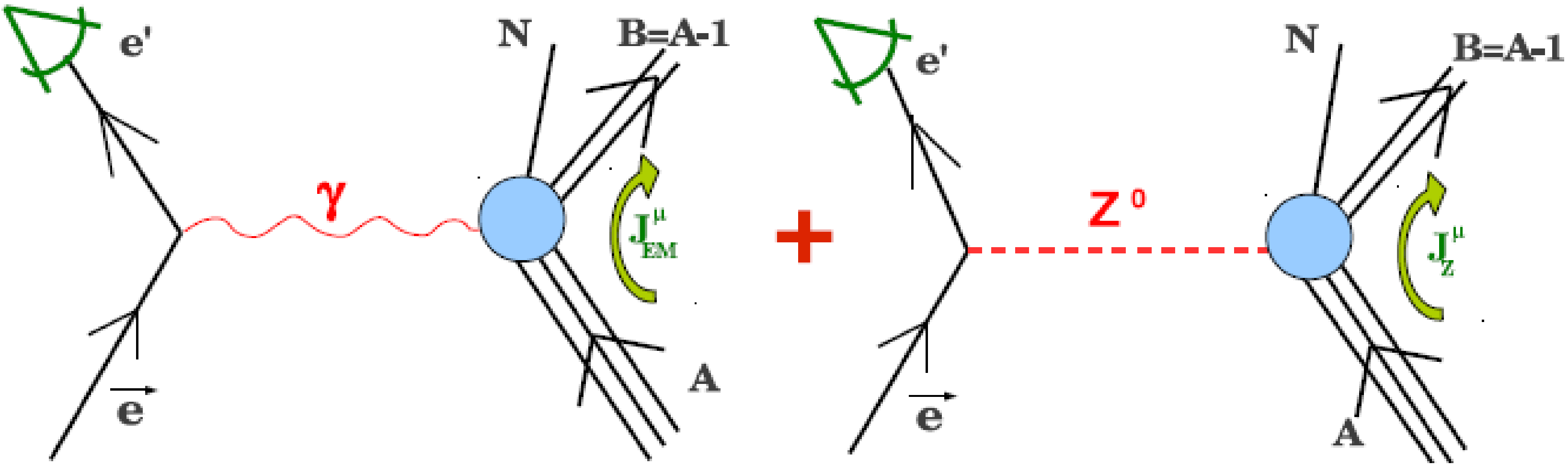
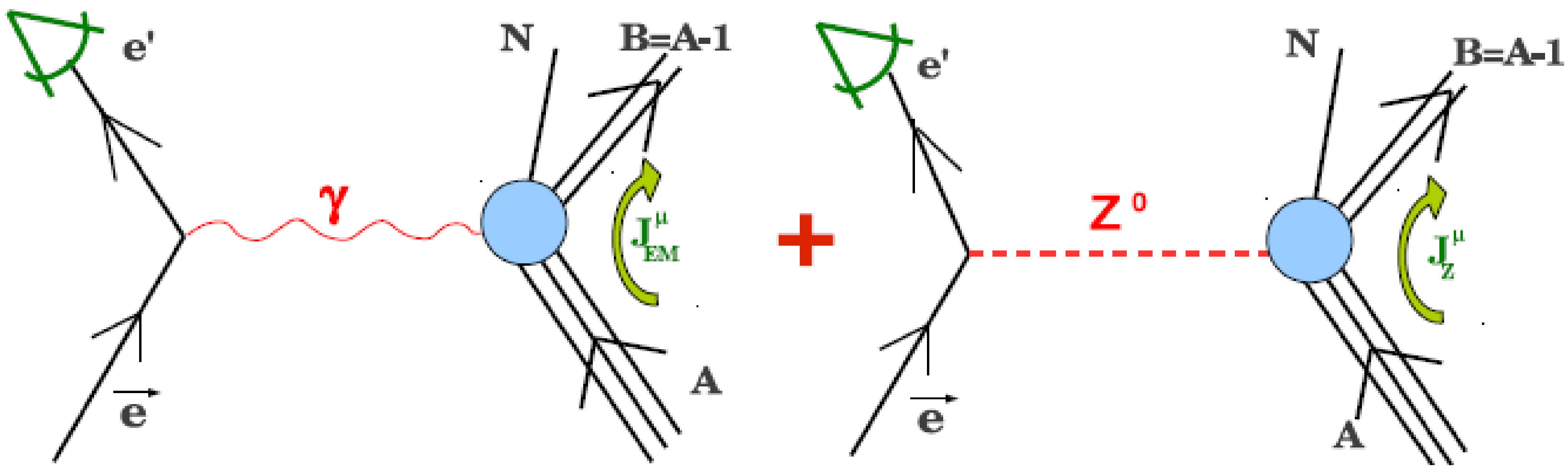


$$\frac{d\sigma}{d\varepsilon_f d\Omega_f} \propto |\mathcal{M}_{fi}|^2 \qquad J_N^{\mu} = \int \mathrm{d}\mathbf{p}\, \overline{\phi}_F(\mathbf{p}+\mathbf{q})\, \hat{\Gamma}_N^{\mu}\, \phi_B(\mathbf{p})$$

$$\mathcal{A}_{QE}^{PV} \equiv \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

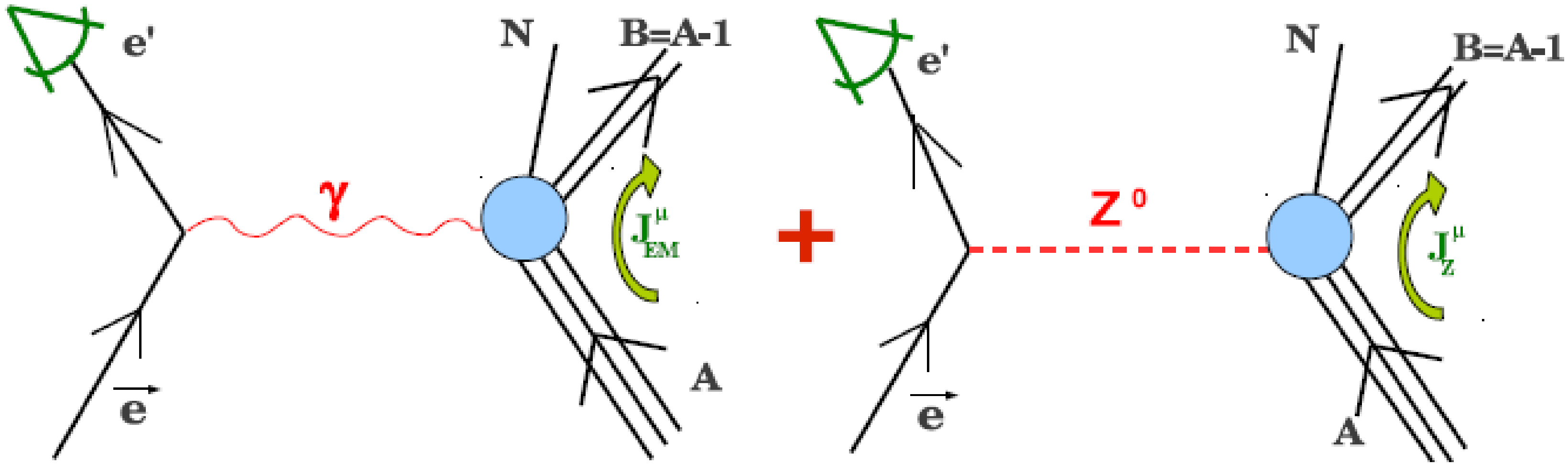
III. Parity violating QE electron-nucleus scattering



Can this process help us?

$$G_A^{eN} = \left[(1+R_A^{T=1})G_A^{(T=1)}\tau_3 + R_A^{T=0}G_A^{(8)} + (1+R_A^{(s)})G_A^{(s)}\right] G_D^A(Q^2)$$

III. Parity violating QE electron-nucleus scattering



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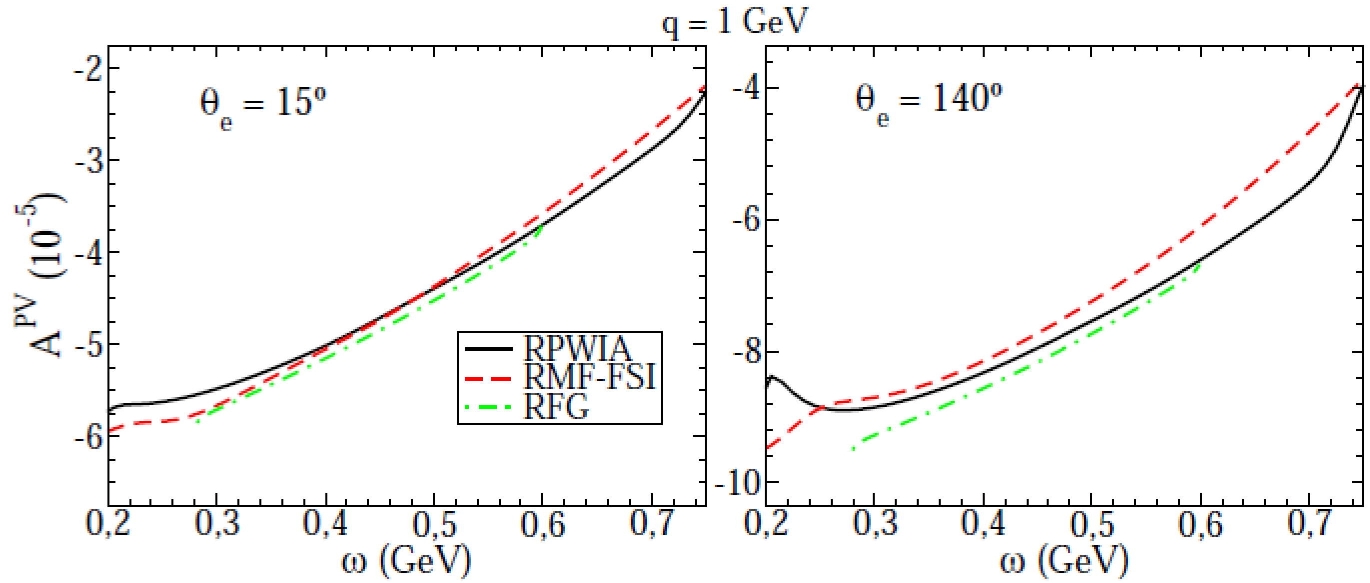


Figure: $\mathcal{A}_{QE}^{PV}$ computed within different models.

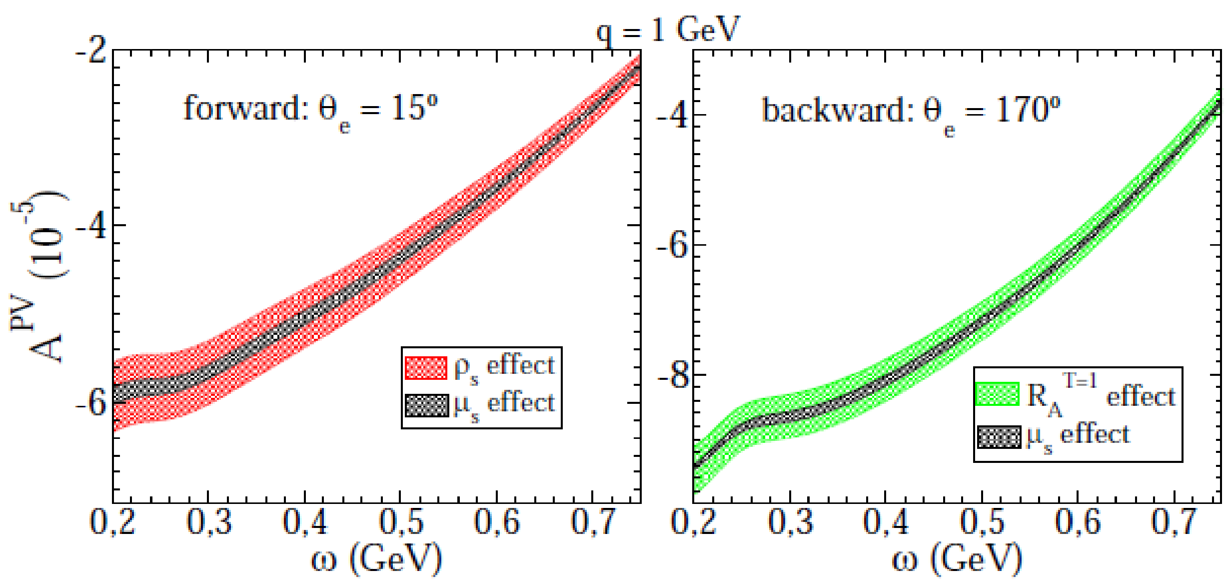


Figure: Effect of μ_s, ρ_s and $R_A^{T=1}$ in $\mathcal{A}_{QE}^{PV}$ at forward (left) and backward (right) scattering angles.

Table: **Impact of nuclear and nucleonic (FF) effects in $\mathcal{A}_{QE}^{PV}$.**

	forward	backward
RPWIA *vs* RMF-FSI *vs* EMA-FSI *vs* RFG	1%	5%
Off-shell effects (CC1 *vs* CC2)	15 – 30%	5%
Magnetic Stangeness	4%	3.5%
Electric Stangeness	13%	tiny
Axial-vector FF ($R_A^{T=1}$)	tiny	10%
MEC, correlation currents (∗)	Very important factor ×2	$< 0.5\%$

(∗) J. E. Amaro *et al*. Phys. Rep. 4 (2002), 368.

Summary

- Study of the sensitivity of the PVQE asymmetry with nuclear and nucleonic effects

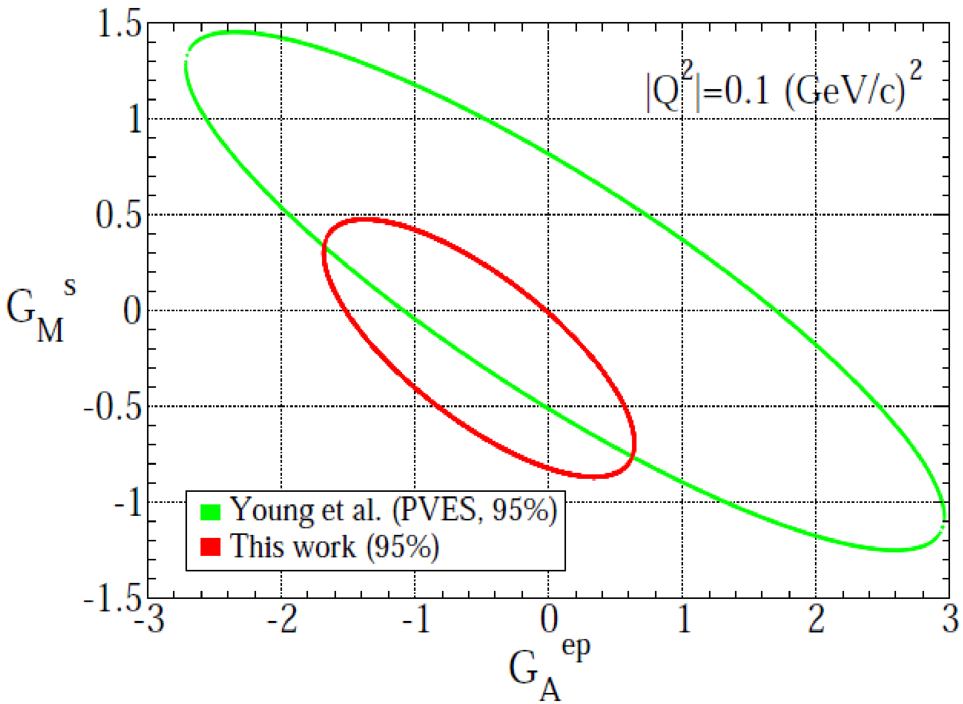
- A measurement of the asymmetry at **backward scattering angles** and momentum transferred around 500-1000 MeV would be very useful to constrain RC that enter in the isovector sector of the axial-vector form factor of the nucleon.

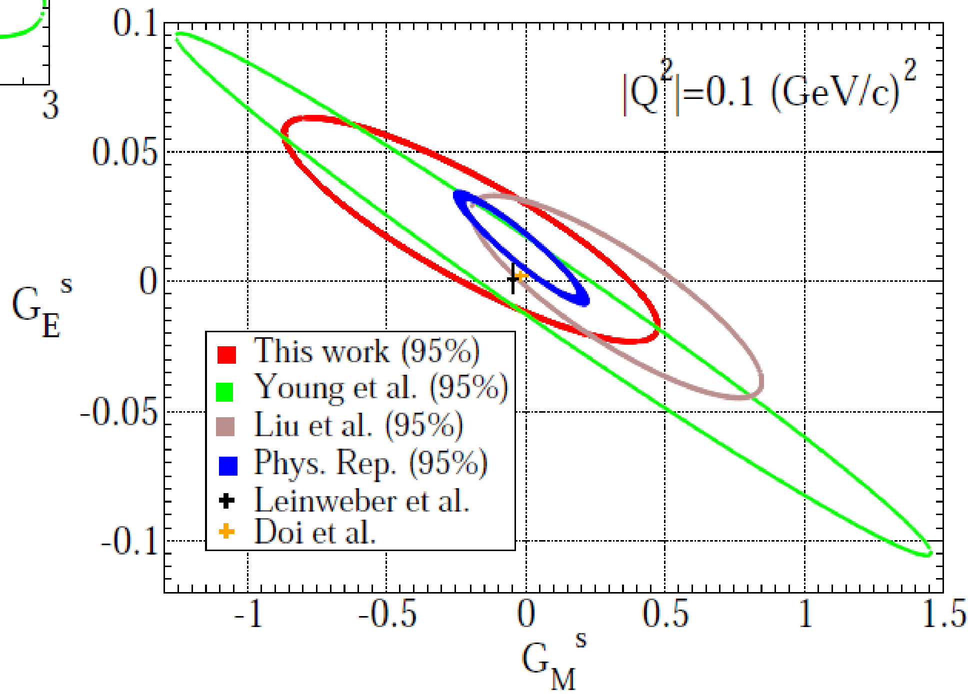
- The determination of these RC would improve significantly the current knowledge on the Weak Neutral Current in the nucleon.

- **References:**
  + "Parity Violation in elastic and quasielastic electron scattering off nucleons and nuclei." Ph.D. Thesis by Raúl González Jiménez, Universidad de Sevilla.
  + Article in preparation.

Than you for your attention!

Backup Slides





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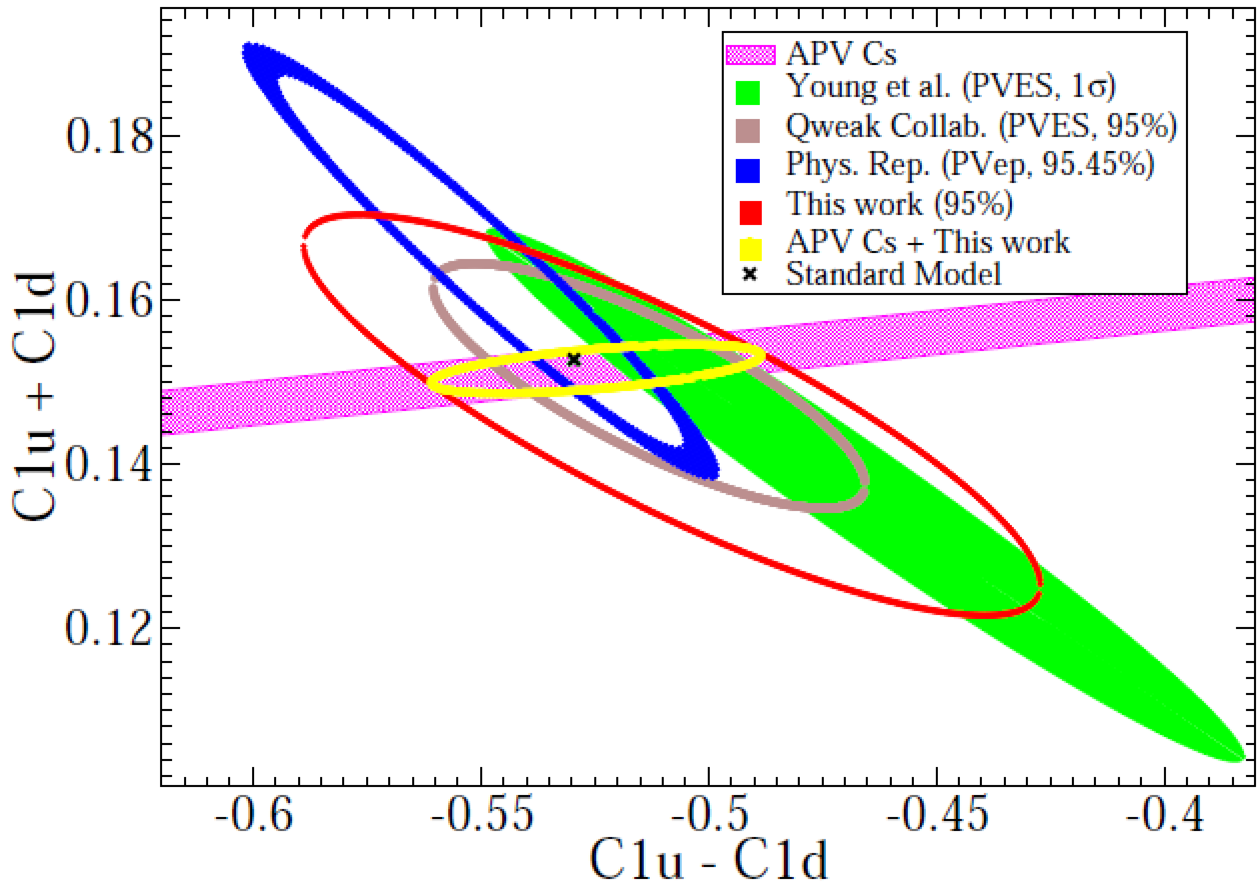

$$C_{1u} - C_{1d} = (\xi_V^n - \xi_V^p)/2\,,$$

$$C_{1u} + C_{1d} = -(\xi_V^n + \xi_V^p)/6$$