Electroweak precision test through single spin asymmetries at the EicC

Yong Du（杜勇）

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Based on

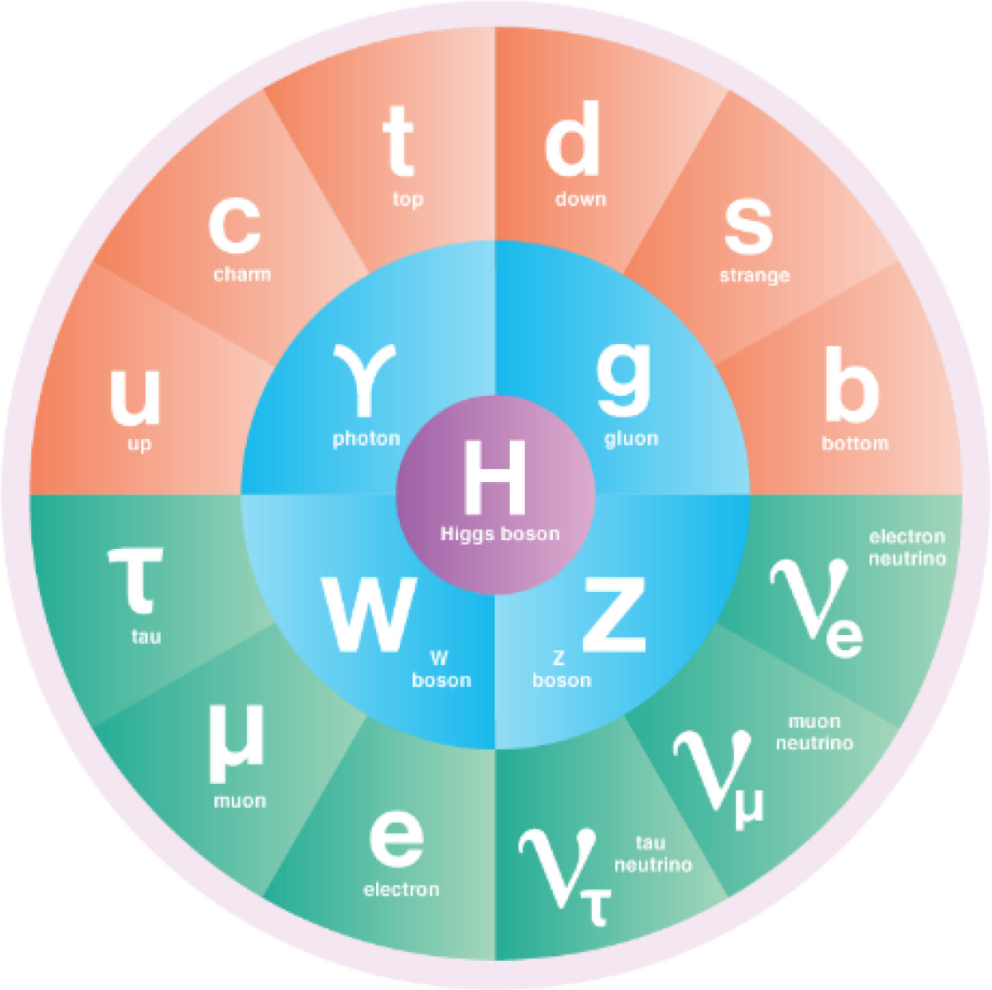
Yong Du, 2412.20469, *Phys.Rev.D* 111 (2025) 11, 116026

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

Introduction

Introduction

The modern picture of our matter world



A gauge theory respecting

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$$

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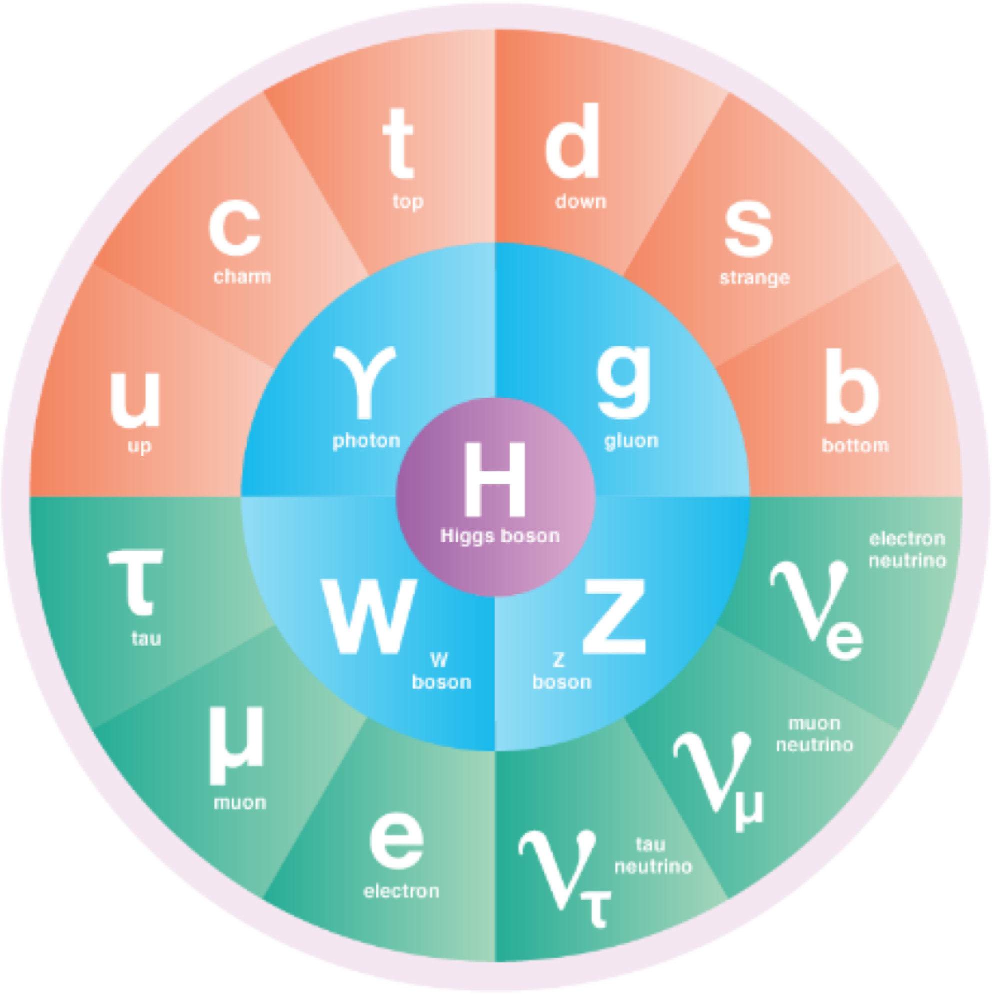

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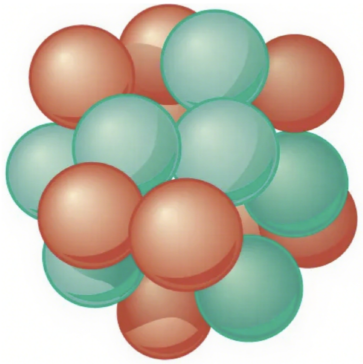
g glues the quarks



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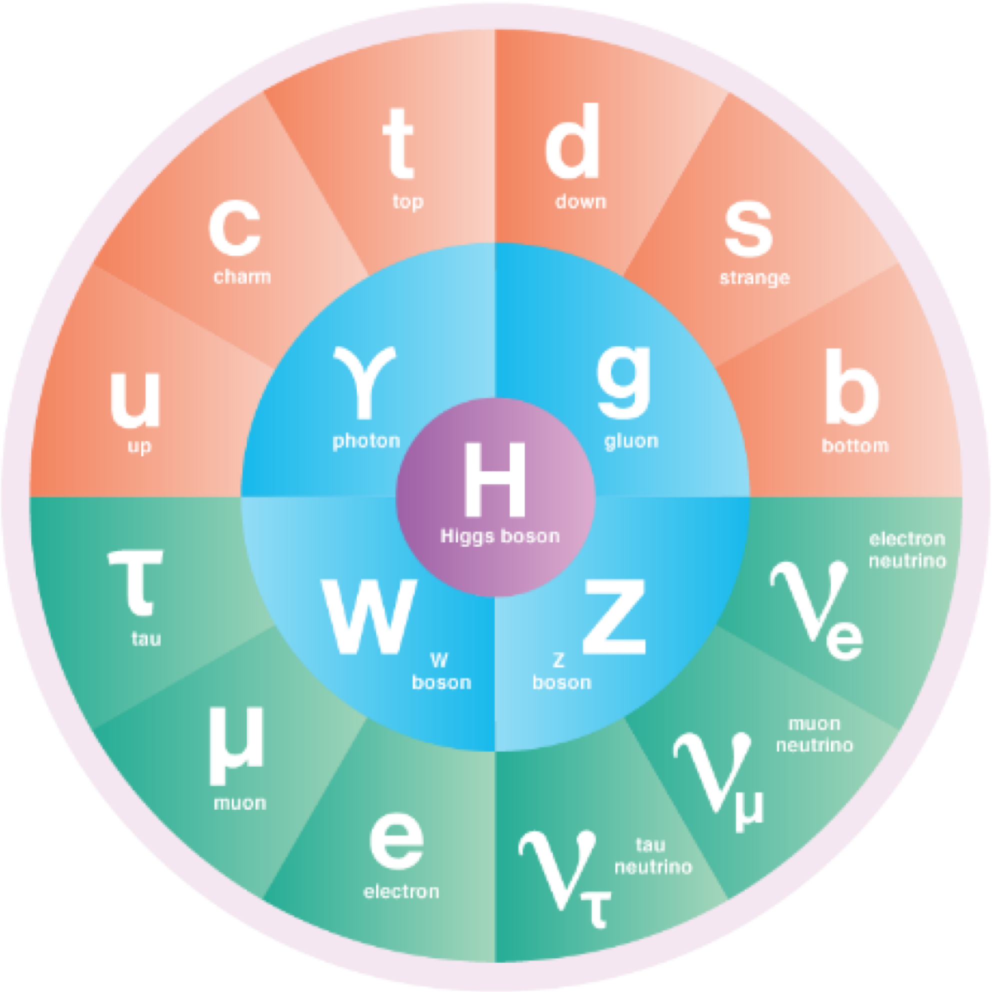

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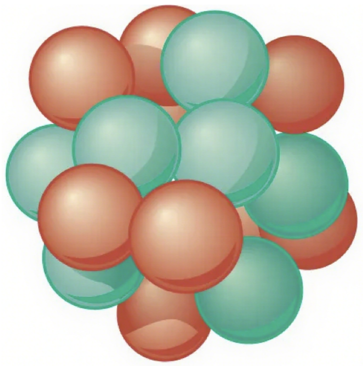

$W^{\pm}/Z$ radiative elements

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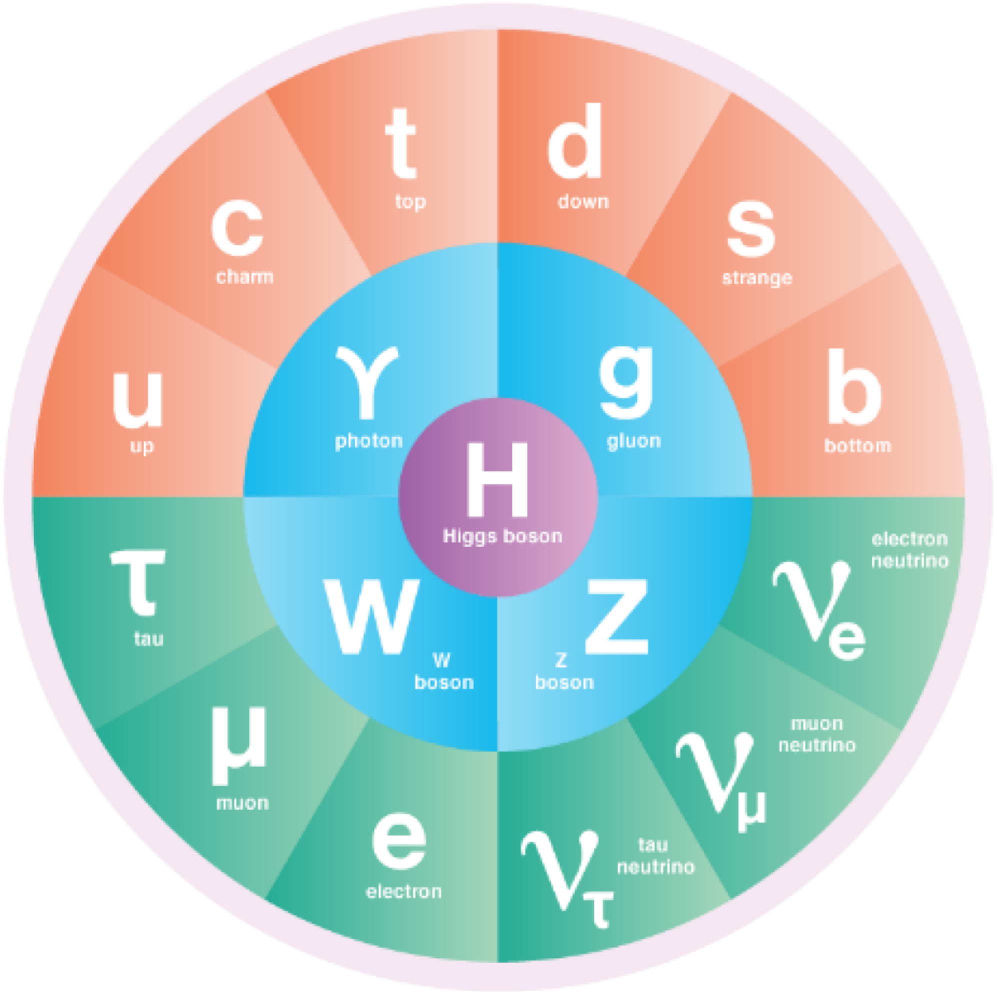

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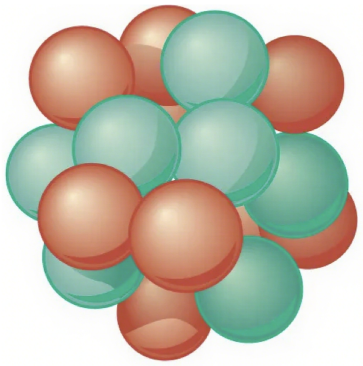
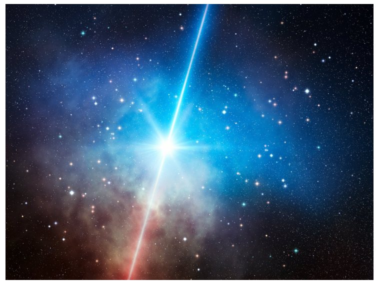


$W^{\pm}/Z$ radiative elements

γ shines lives



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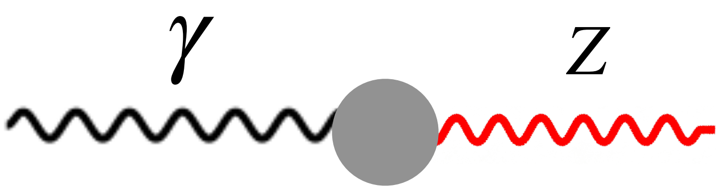
The interesting part of the Higgs mechanism is the introduction of mixing btw $\mathrm{SU}(2)_L$ and $\mathrm{U}(1)_Y$:



This amount of mixing is *purely* determined from the two gauge couplings (at LO)

$$\sin^2\theta_W = \frac{g_Y^2}{g_Y^2 + g_L^2} \approx \frac{1}{4}$$

This number can of course be model dependent

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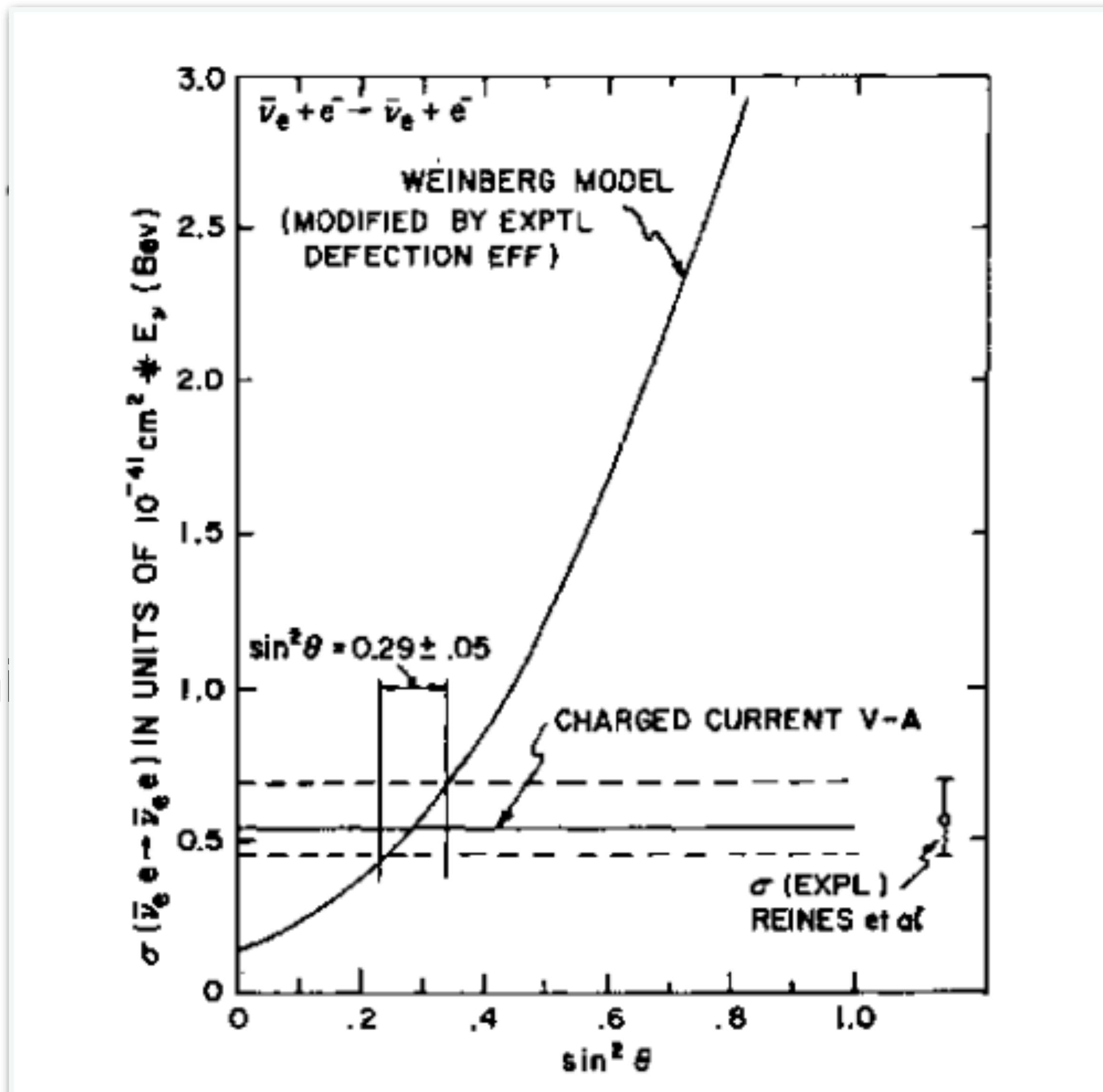
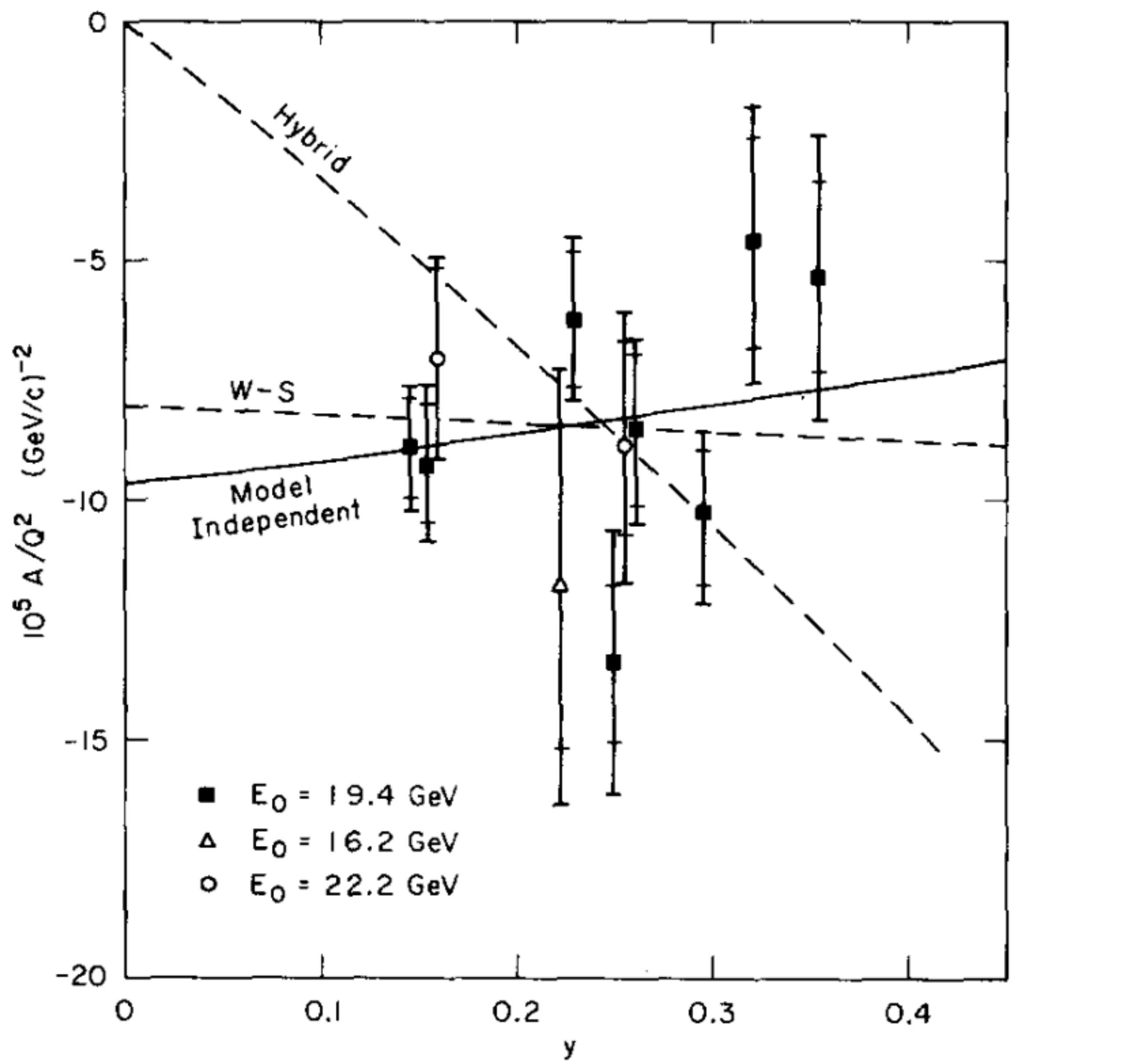


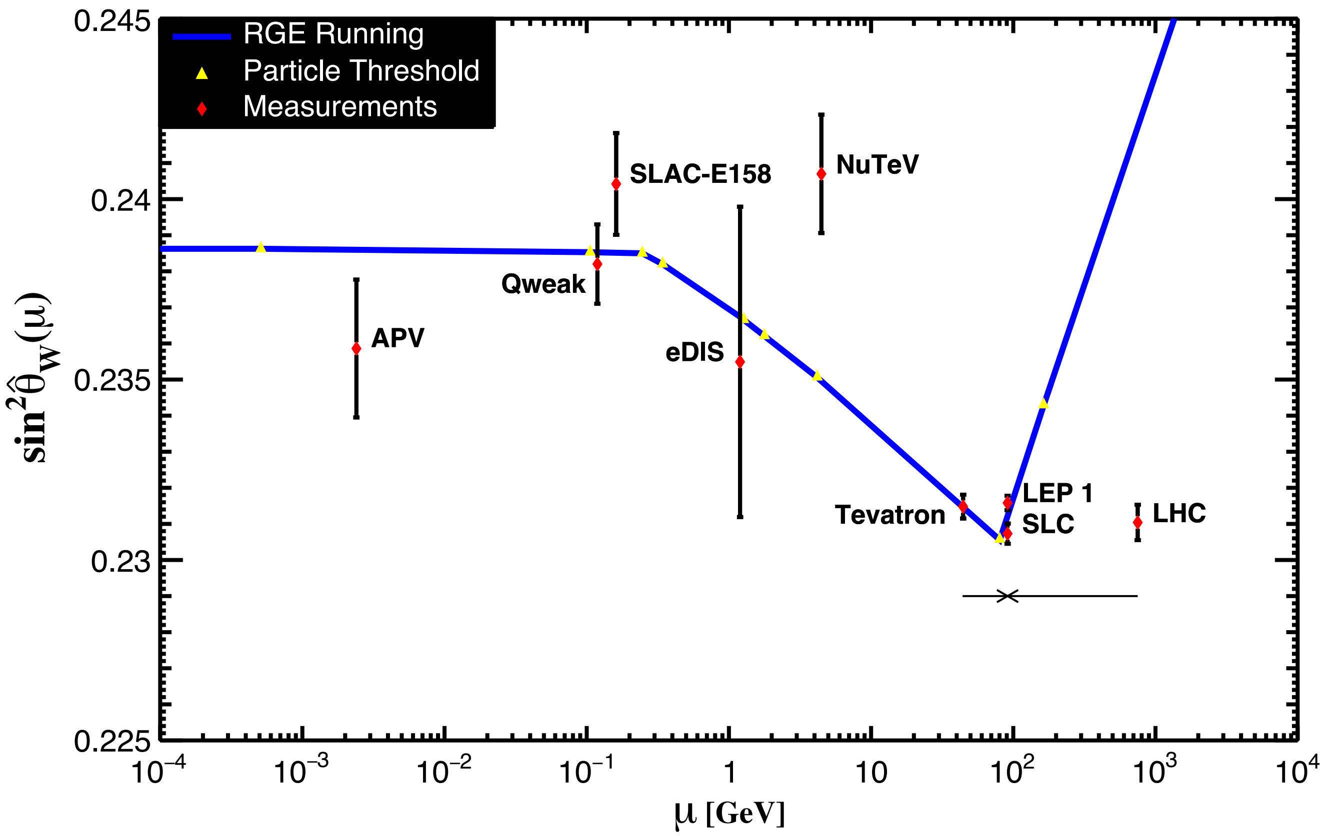
Baltay, Conf.Proc.C 780823 (1978) 882



Prescott et al, PLB 77 (1978) 347, 84 (1979) 524

Introduction

State of the art:



Jens & Michael, 2005

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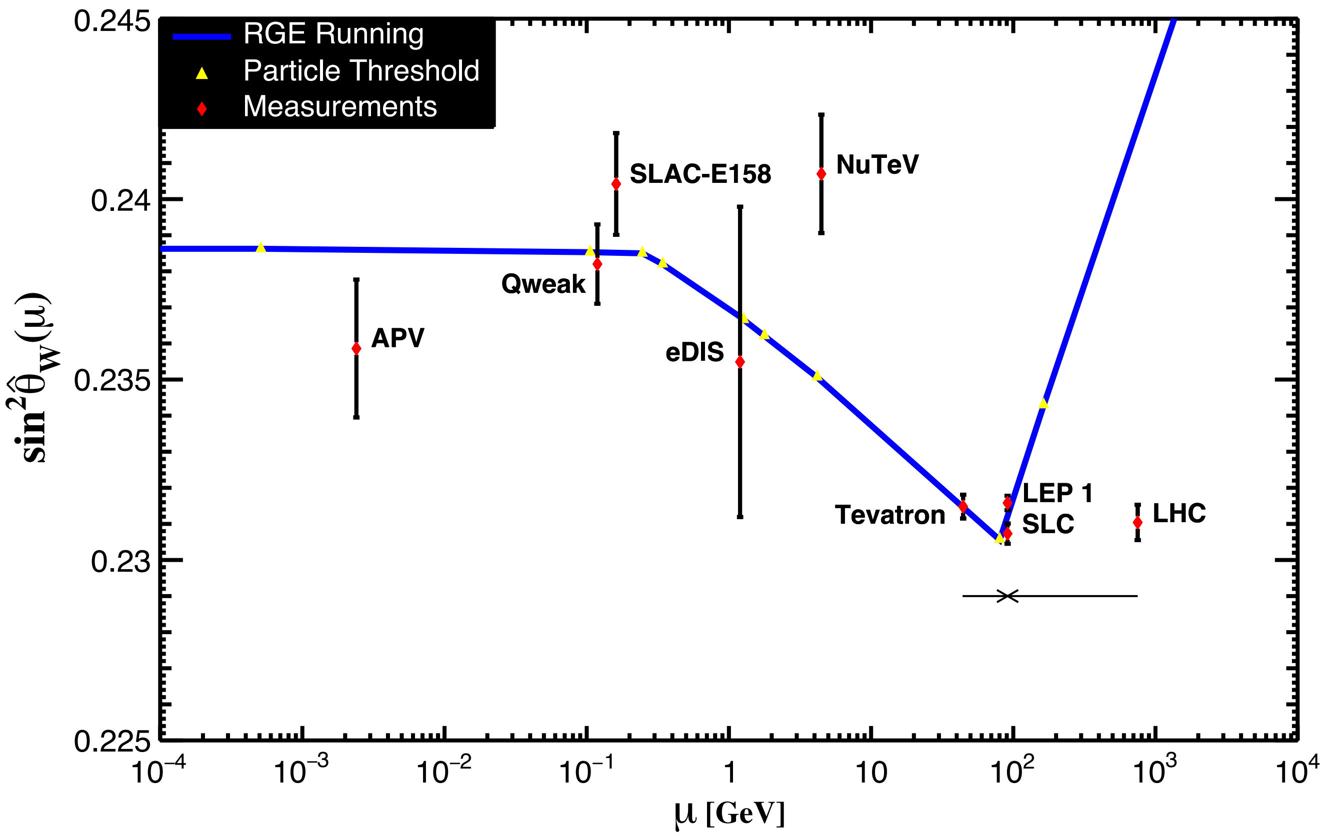

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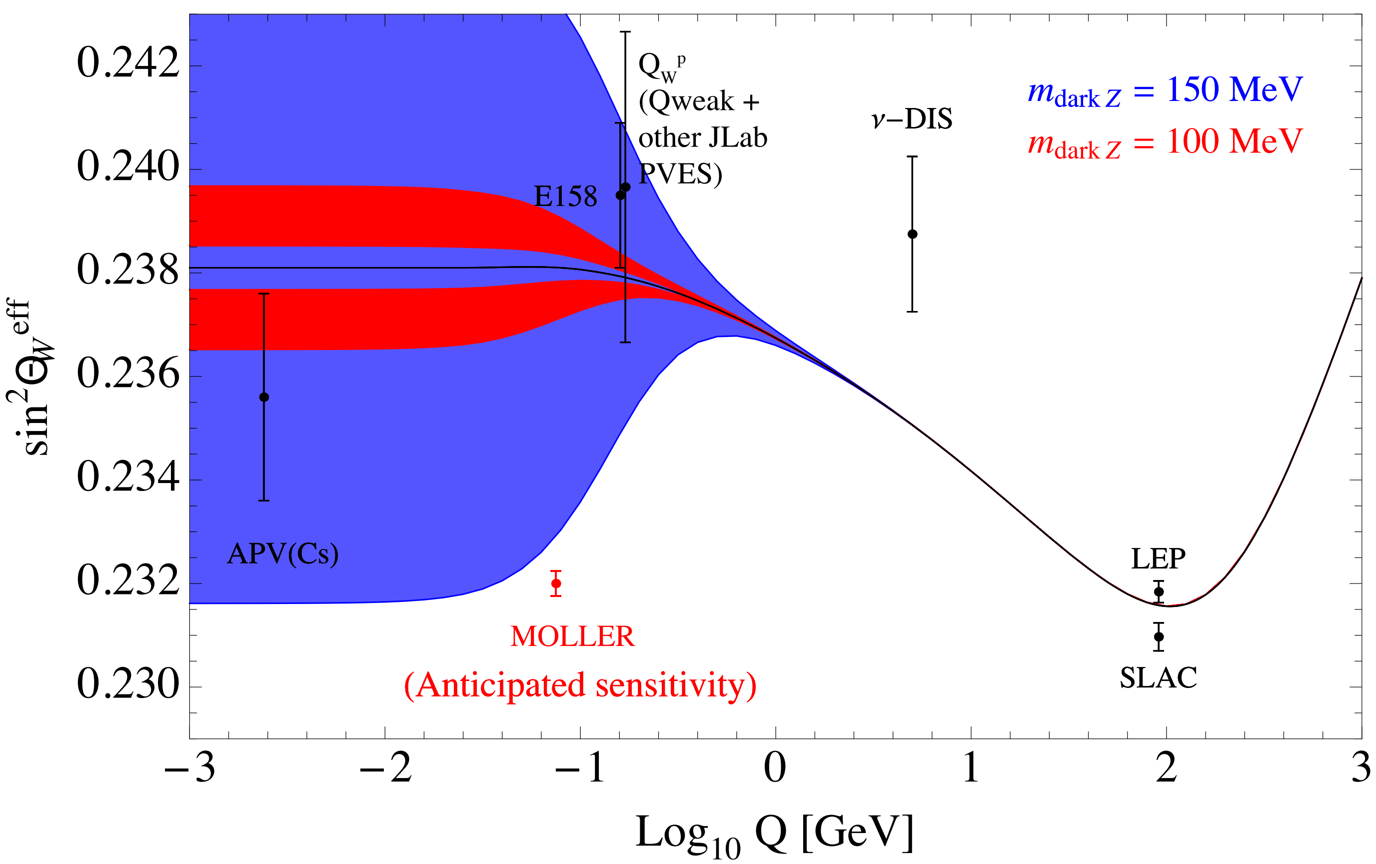

MOLLER Collaboration, 1411.4088

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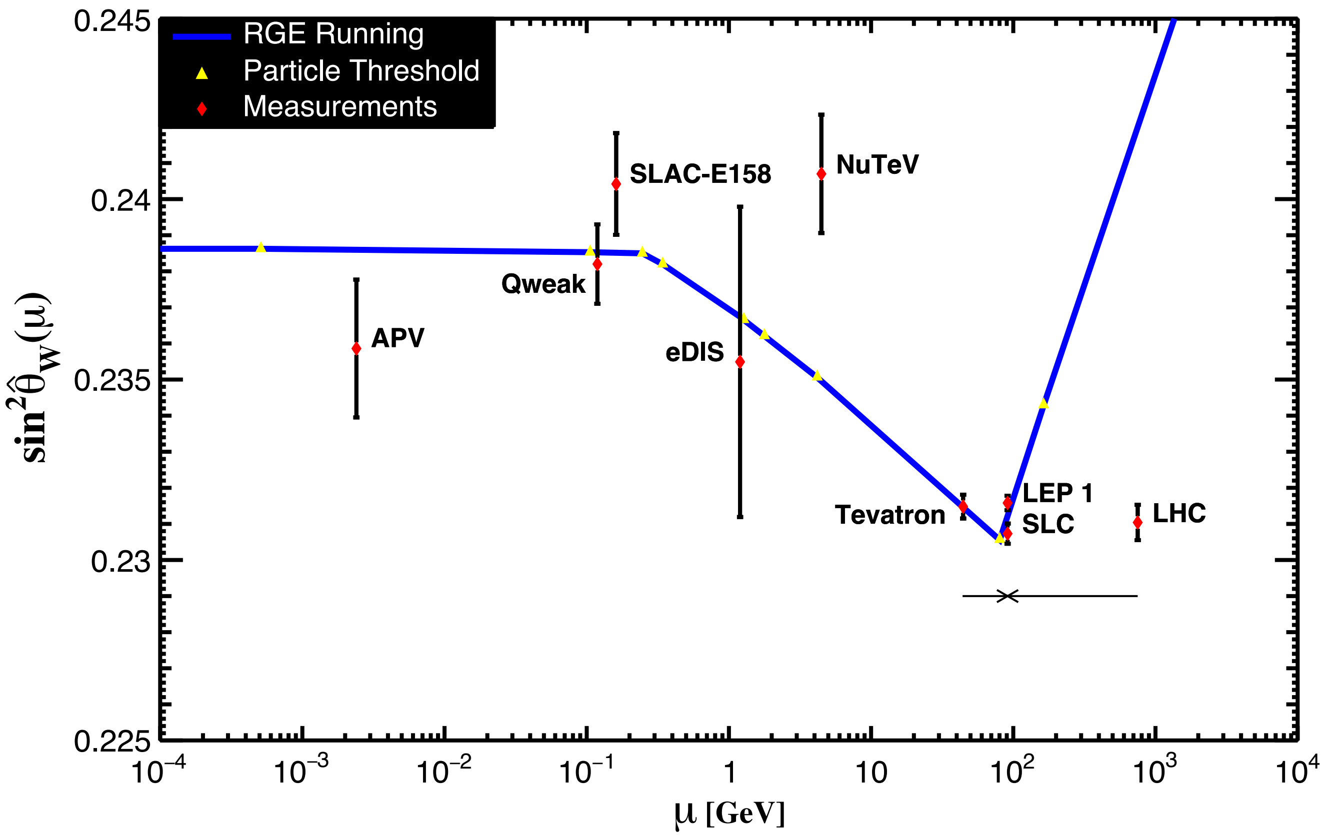

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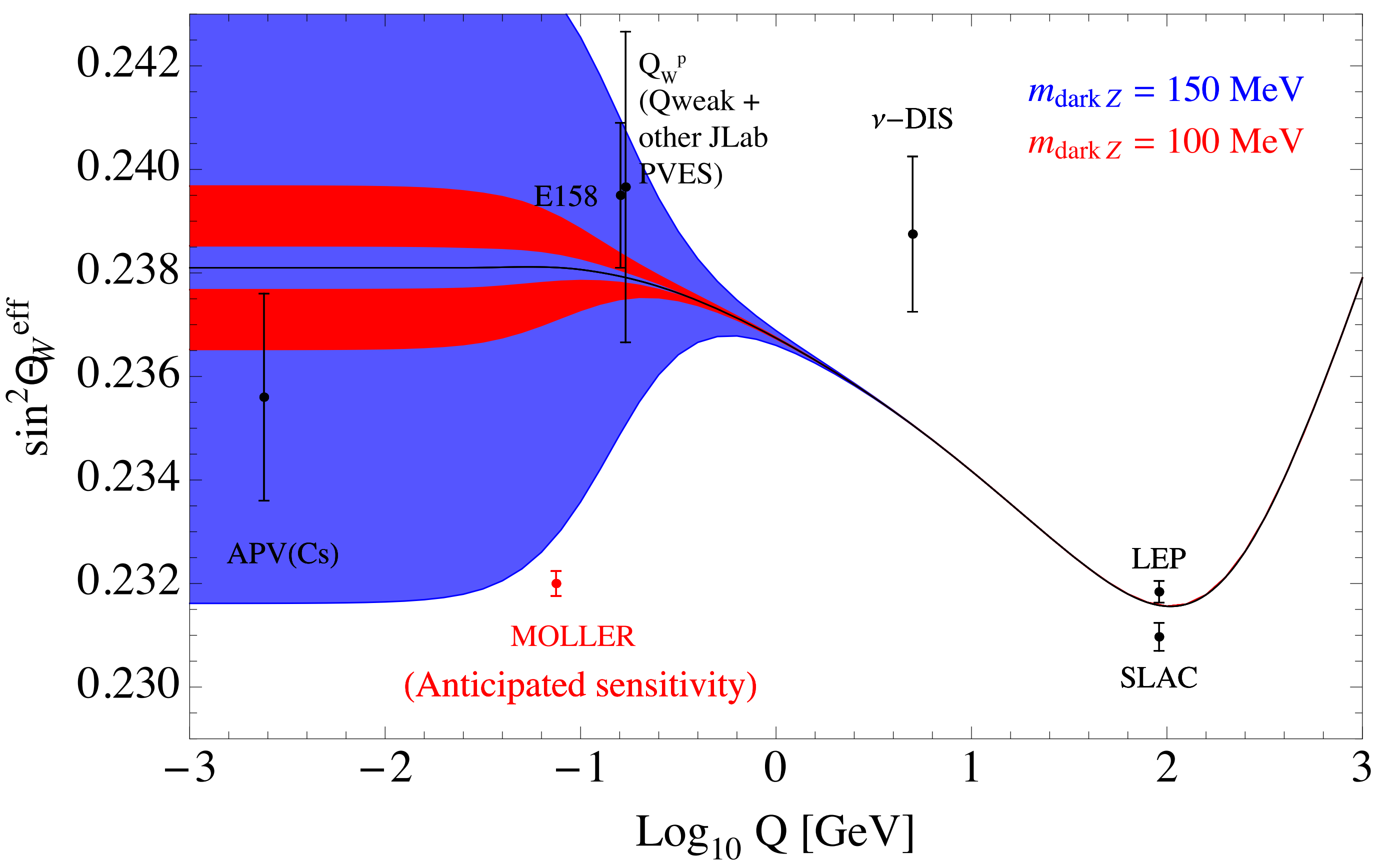

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Good opportunity to discover/falsify light new dofs!

Introduction

New option: the Electron-ion collider in China (EicC)

March, 2025

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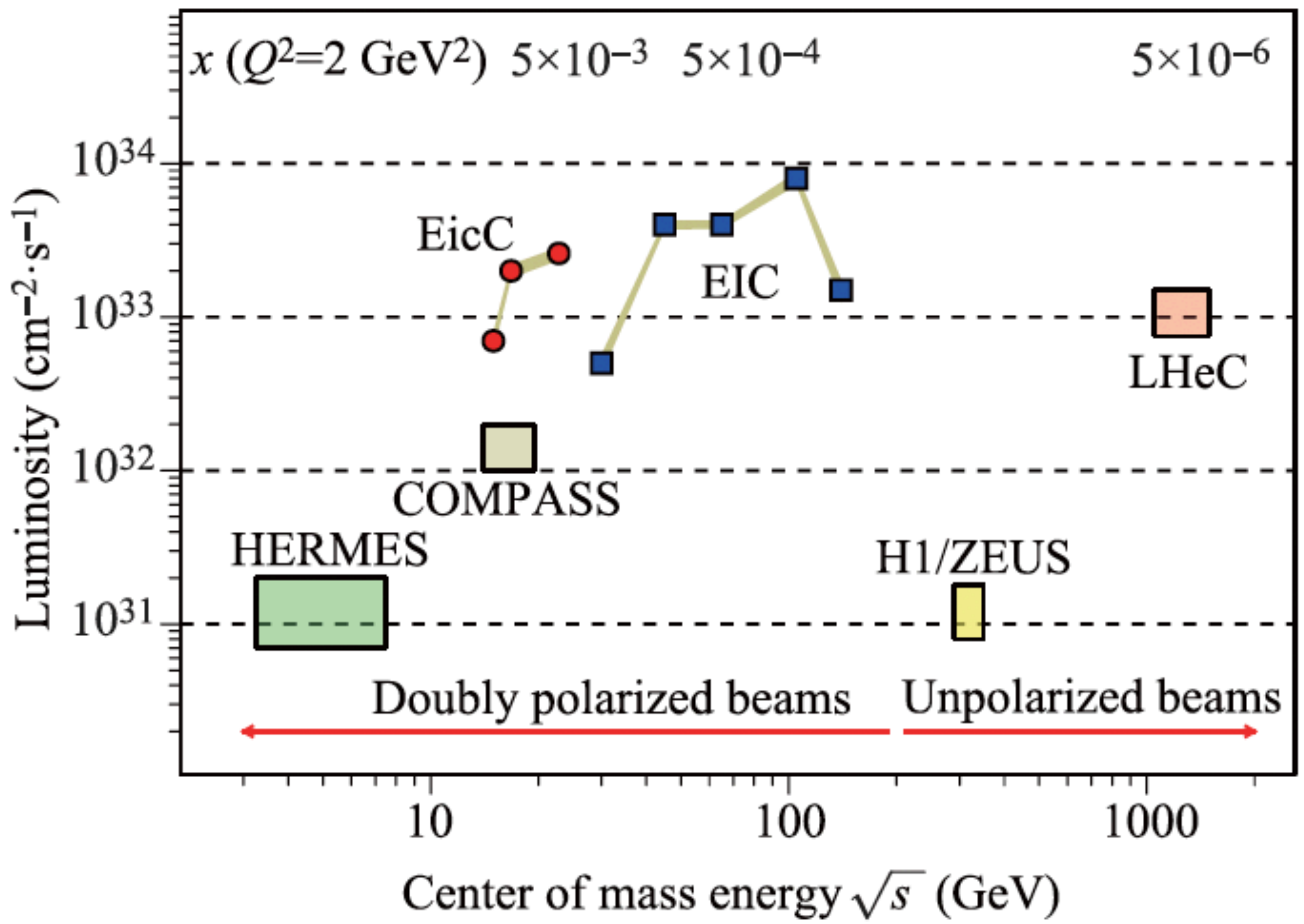

Energy: $E_e = [2.8, 5]\,\mathrm{GeV}$, $P_e = (80 \pm 1.6)\,\%$

Luminosity: $2 \times 10^{33}\,\mathrm{cm^{-2}\,s^{-1}}$ (instantaneous)

COM: $\sqrt{s} = 15 \sim 20\,\mathrm{GeV}$

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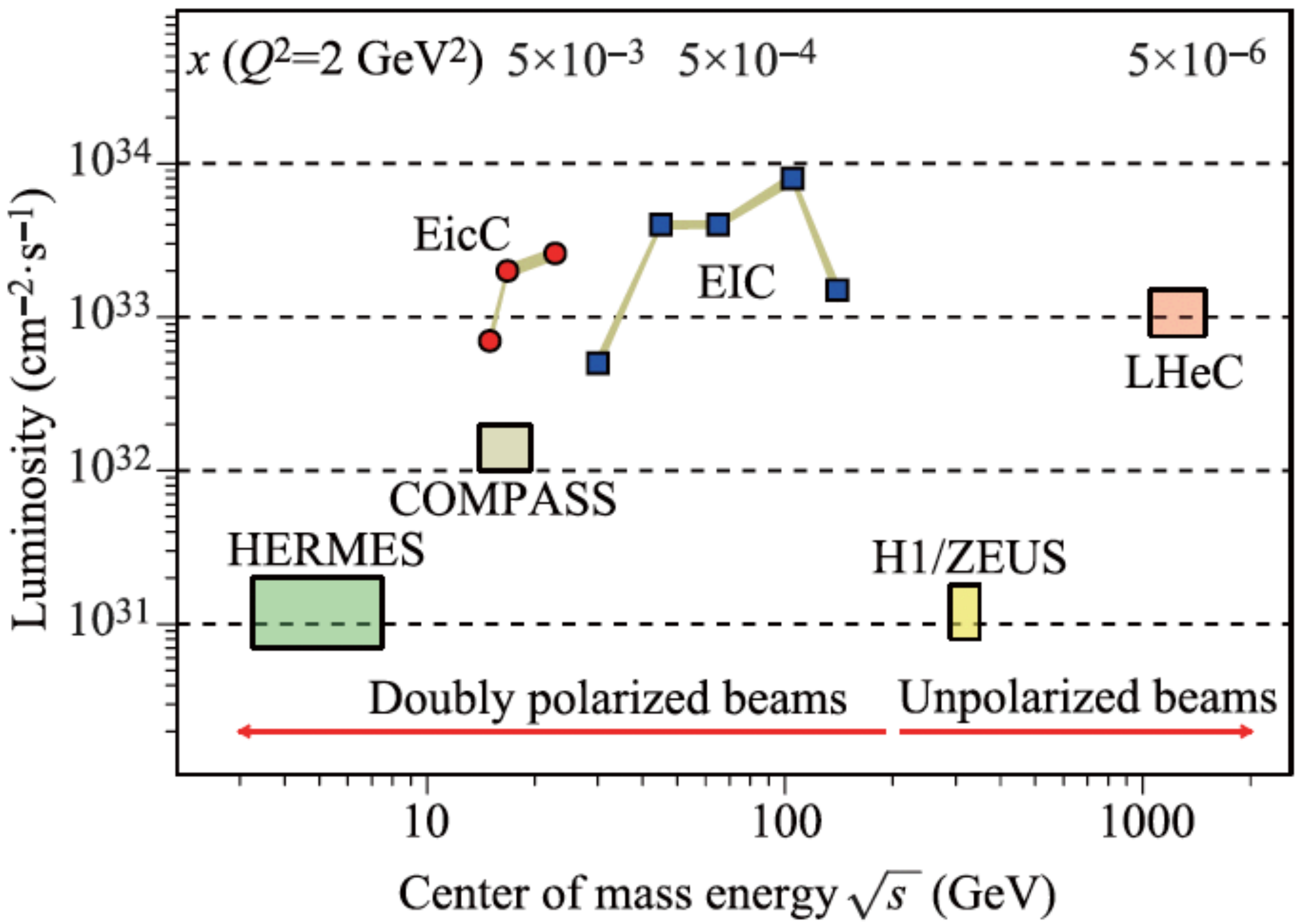

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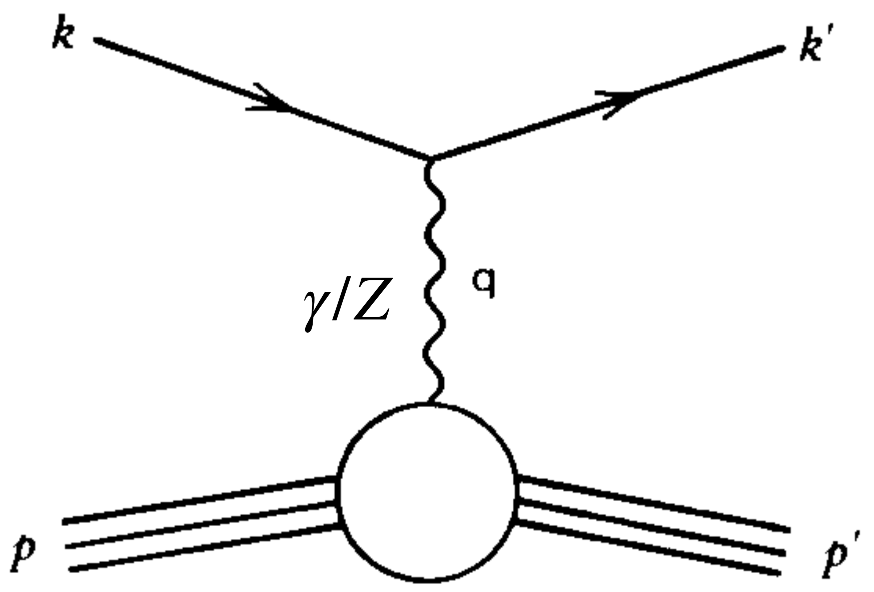
Q: How well $\sin\theta_W$?

Formalism

Formalism



To extract the weak mixing angle, we rely on the interference between Z and γ at tree

Helicity of the electron

Direct current algebra computation leads to

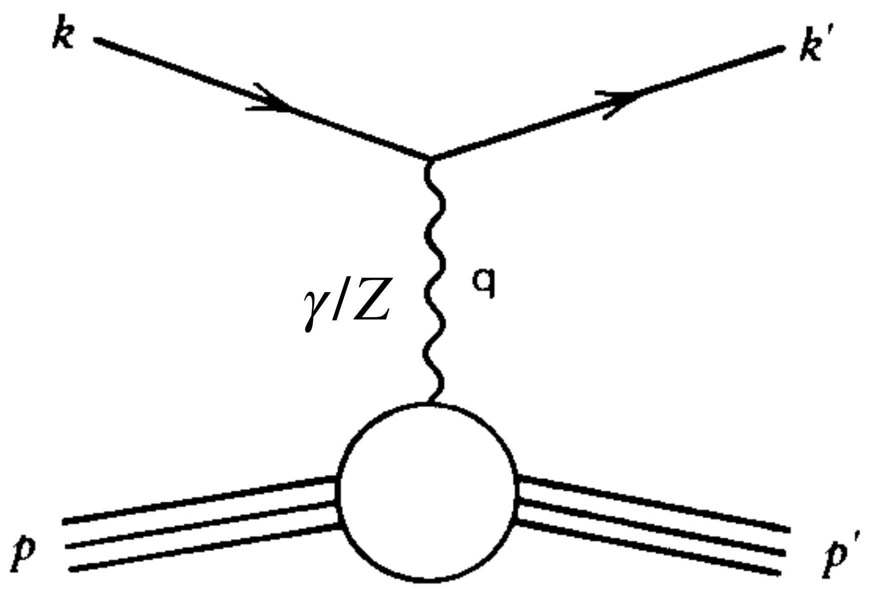
$$\frac{d^2\sigma}{dxdy} = \frac{2\pi y\alpha^2}{Q^4} L_{\gamma\gamma}^{\alpha\beta}\left[\left(\eta_{\gamma\gamma}W_{\alpha\beta}^{\gamma\gamma} + \eta_{\gamma Z}\left(g_V^e - \lambda_e g_A^e\right)W_{\alpha\beta}^{\gamma Z} + \eta_{ZZ}\left(g_V^e - \lambda_e g_A^e\right)^2 W_{\alpha\beta}^{ZZ}\right)\right]$$

$$W_{\mu\nu} = \frac{1}{4\pi}\int d^4z e^{iq\cdot z}\langle p, s\,|\left[J_\mu^\dagger(z), J_\nu(0)\right]|\,p, s\rangle$$

$s_i^\mu = \lambda_i p_i^\mu$ in the relativistic limit

Note that the *leptonic tensor* factorize into the pure photon one + m_e suppressed terms

Formalism



Proton radius $R_p \simeq 1\,\text{fm} \approx \frac{1}{0.8\,\text{GeV}}$

Electron de Broglie wavelength $\lambda_e^{\text{EicC}} \in \left[\frac{1}{2.8}, \frac{1}{5}\right] \frac{1}{\text{GeV}}$

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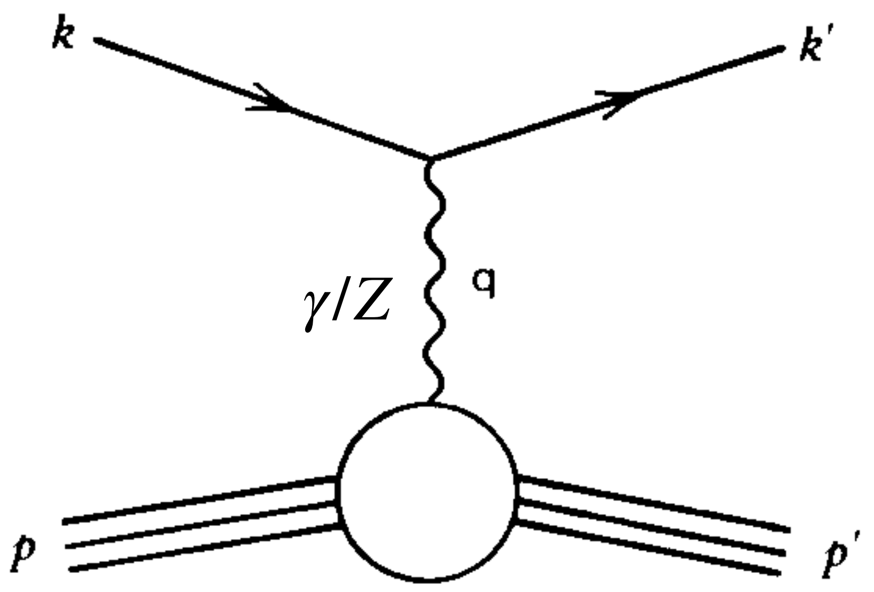

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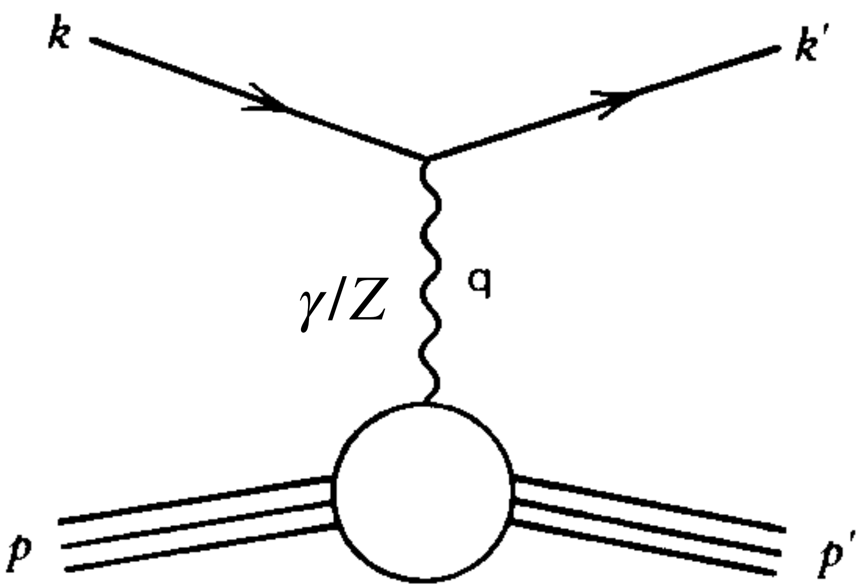
The *hadronic tensor* can thus be reasonably computed within the quark model

$$W_{\mu\nu}^{V_1V_2} = \sum_q \int_x^1 \frac{f_q(\xi)}{\xi} \hat{w}_{\mu\nu}^{V_1V_2}$$

Parton level hadronic tensor evaluated in pQCD

Formalism



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Parton level hadronic tensor evaluated in pQCD

$$W_{\mu\nu}^{V_1V_2} = \left(-g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2}\right) F_1^{V_1V_2}\left(x, Q^2\right) + \frac{\hat{p}_\mu \hat{p}_\nu}{p\cdot q} F_2^{V_1V_2}\left(x, Q^2\right) - i\varepsilon_{\mu\nu\alpha\beta}\frac{q^\alpha p^\beta}{2p\cdot q} F_3^{V_1V_2}\left(x, Q^2\right)$$

$$F_2^{\gamma\gamma} = 2xF_1^{\gamma\gamma} = x\sum_q Q_q^2 (f_q + \bar{f}_q), \qquad F_2^{\gamma Z} = 2xF_1^{\gamma Z} = 2x\sum_q Q_q\, g_V^q (f_q + \bar{f}_q)$$

Callan-Gross relations

Formalism

Obtaining the helicity differential cross section is then straightforward:

$$\frac{d\sigma}{dxdy}\left(\lambda_e,\lambda_p\right)=\frac{4\pi\alpha^2}{xyQ^2}\left[xy^2F_1+(1-y)F_2+\frac{\lambda_e}{2}xy(2-y)F_3\right.$$
$$\left.-\lambda_e\lambda_p xy(2-y)g_1+\lambda_p(1-y)g_4+\lambda_p xy^2g_5\right]$$

From which we can define two types of asymmetries for the extraction of $\sin\theta_W$:

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Double-spin asymmetry:

$$A_{PV}^{ep}\equiv\frac{\sigma_{ep}(P_eP_p>0)-\sigma_{ep}(P_eP_p<0)}{\sigma_0}$$

Reduction in luminosity 🤦

$$=\frac{2\eta_{\gamma Z}\left|P_eP_p\right|\left[g_A^e(y-1)g_4^{\gamma Z}+xy\left(g_V^e(y-2)g_1^{\gamma Z}-g_A^e y g_5^{\gamma Z}\right)\right]+2\eta_{\gamma\gamma}\left|P_eP_p\right|xy(y-2)g_1^{\gamma\gamma}}{\eta_{\gamma Z}\left[-2(y-1)g_V^eF_2^{\gamma Z}+xy\left(2g_V^e yF_1^{\gamma Z}-(2-y)g_A^eF_3^{\gamma Z}\right)\right]+2\eta_{\gamma\gamma}\left((1-y)F_2^{\gamma\gamma}+xy^2F_1^{\gamma\gamma}\right)}$$

Formalism

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$$\frac{d\sigma}{dxdy}\left(\lambda_e, \lambda_p\right) = \frac{4\pi\alpha^2}{xyQ^2}\Big[xy^2F_1 + (1-y)F_2 + \frac{\lambda_e}{2}xy(2-y)F_3$$

$$-\lambda_e\lambda_p xy(2-y)g_1 + \lambda_p(1-y)g_4 + \lambda_p xy^2 g_5\Big]$$

From which we can define two types of asymmetries for the extraction of $\sin\theta_W$:

Single-spin asymmetry:

Our focus today

$$A^e_{PV} \equiv \frac{\sigma_e(P_e>0) - \sigma_e(P_e<0)}{\sigma_0} = \frac{\left|P_e\right|\eta_{\gamma Z}\left[2(y-1)g^e_A F^{\gamma Z}_2 - xy\left(2g^e_A y F^{\gamma Z}_1 - (2-y)g^e_V F^{\gamma Z}_3\right)\right]}{2\eta_{\gamma\gamma}\left((1-y)F^{\gamma\gamma}_2 + xy^2F^{\gamma\gamma}_1\right)}$$

$$A^p_{PV} \equiv \frac{\sigma_p(P_p>0) - \sigma_p(P_p<0)}{\sigma_0} = \frac{\left|P_p\right|\eta_{\gamma Z}\left[-2(y-1)g^e_V g^{\gamma Z}_4 + 2xy\left(g^e_V y g^{\gamma Z}_5 + (2-y)g^e_A g^{\gamma Z}_1\right)\right]}{2\eta_{\gamma\gamma}\left((1-y)F^{\gamma\gamma}_2 + xy^2F^{\gamma\gamma}_1\right)}$$

Results: $A_{PV}^{e,p}$ at the EicC

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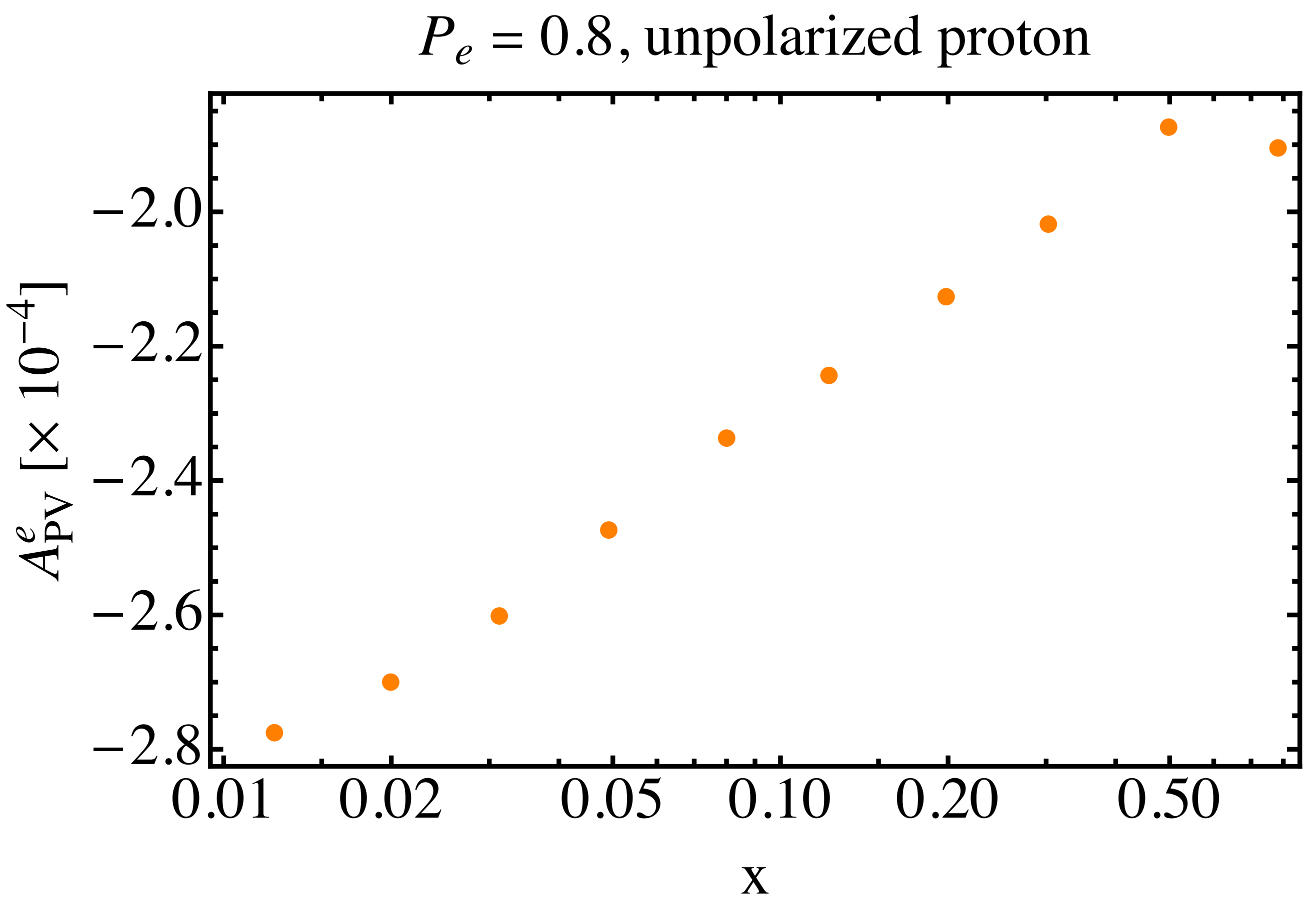
Central values of the asymmetries:

YD, 2412.20469



MMHT2014 PDF

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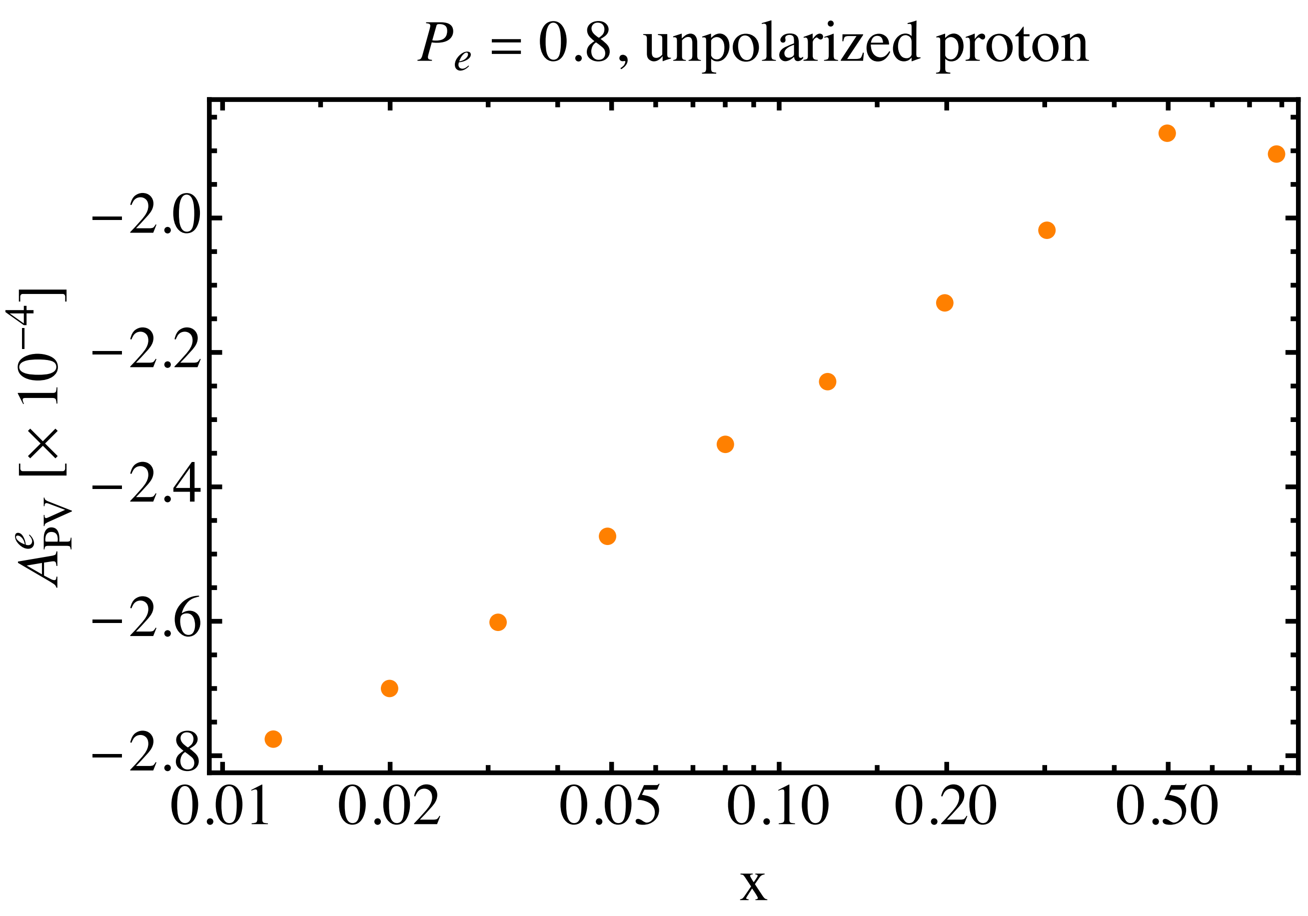
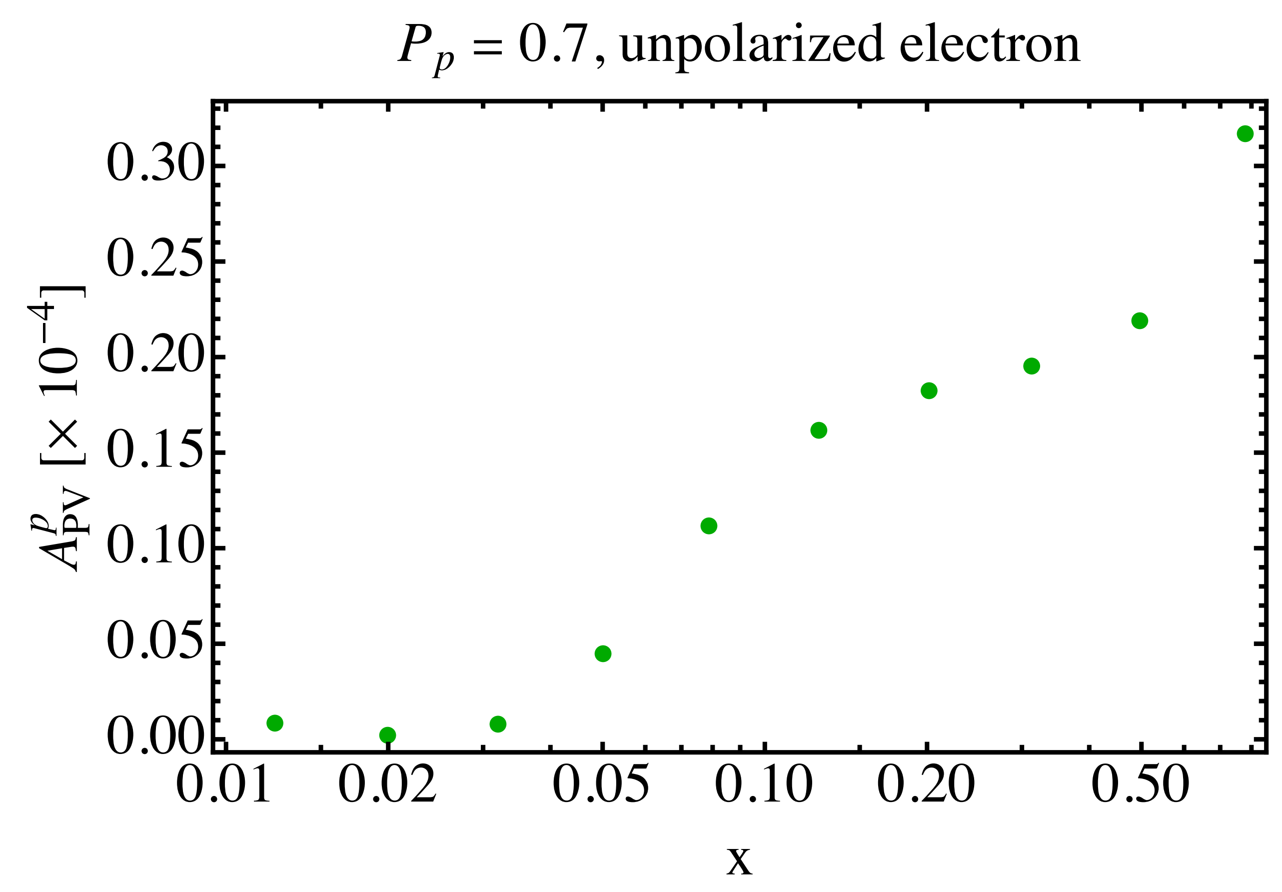


`MMHT2014` PDF



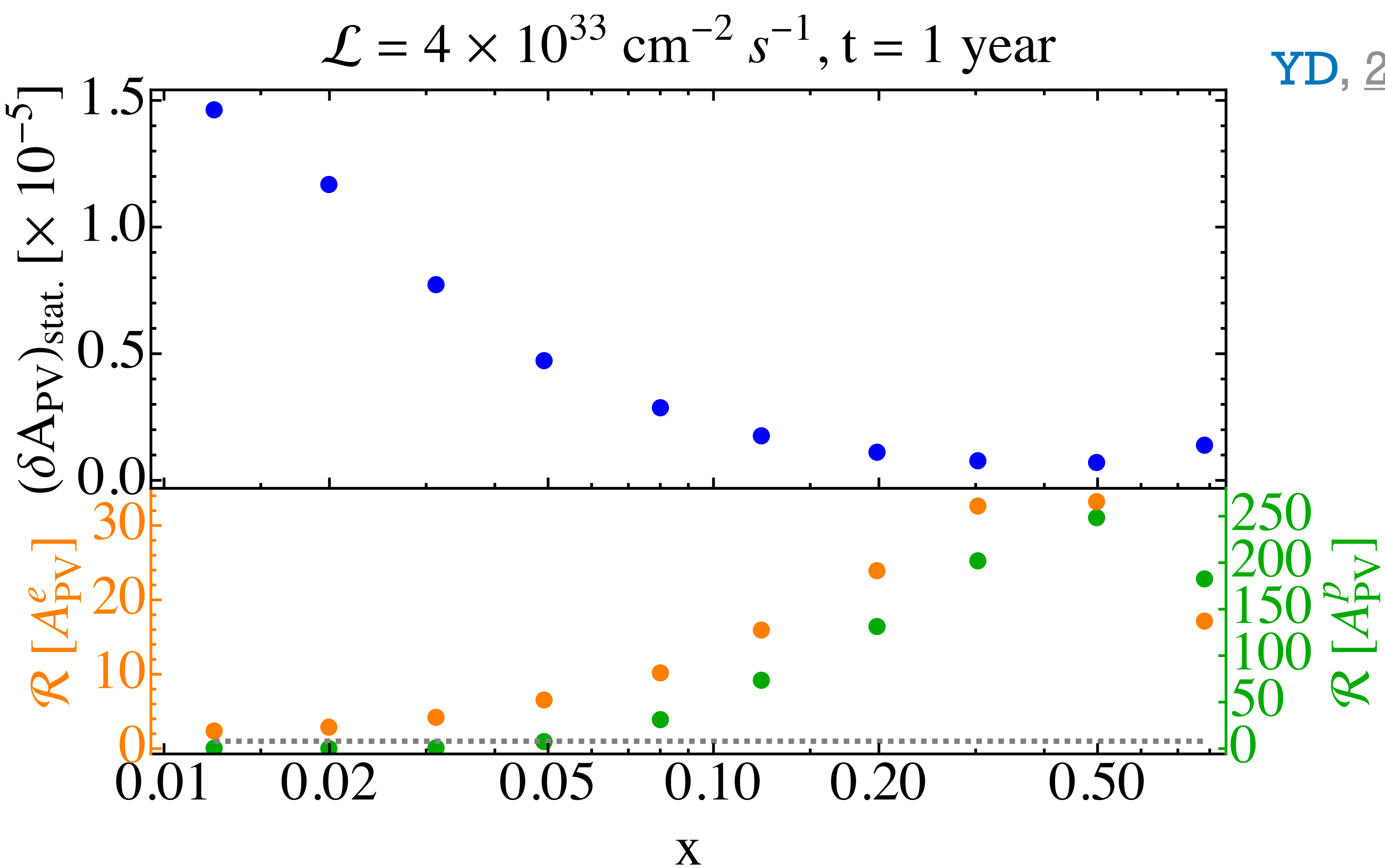
`NNPDFpol1.1` PDF

Roughly, A_{PV}^{p} is about one order of magnitude smaller than A_{PV}^{e}, mainly due to m_Z suppression.

Results: *Uncertainties*

Statistical one $(\delta A_{PV})_{\rm stat.}$: the smallness of $A_{PV}^{e,p}$ tells us that $(\delta A_{PV})_{\rm stat.} = \dfrac{1}{\sqrt{N}}$

For EicC, we adopt a rather conservative detector efficiency being *10%*, and assuming 1-year of running for the following discussions



YD, 2412.20469

Negligible for $x \gtrsim 0.1$

$$\mathscr{R}[A_{PV}^{e,p}] \equiv \left| \frac{A_{PV}^{e,p}}{(\delta A_{PV})_{\rm stat.}} \right|$$

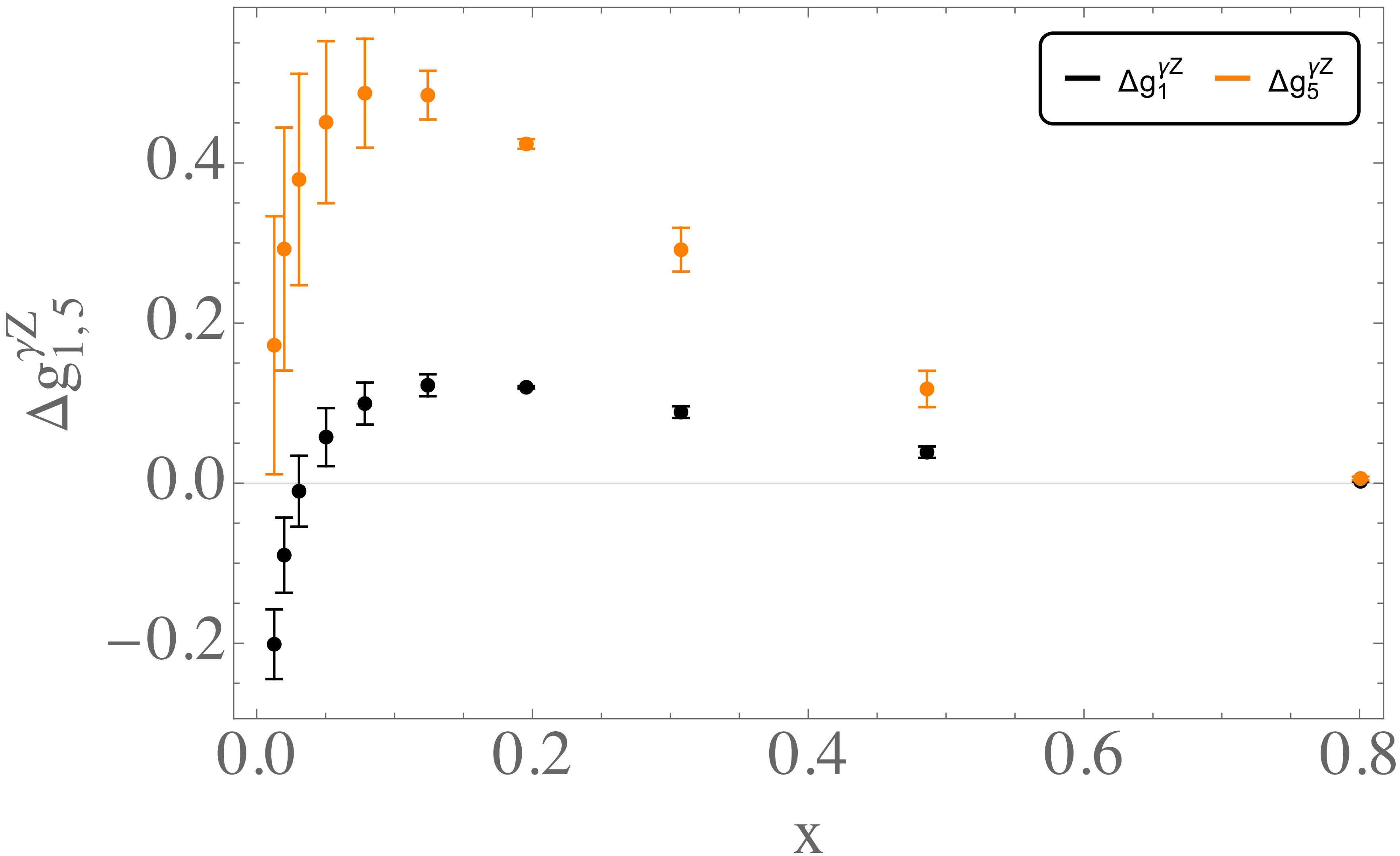
Results: *Uncertainties*

Structure ones or equivalently the PDF uncertainty: $g_{1,5}^{\gamma Z}$ for instance

$$\sigma_f(x,|Q|) = \frac{1}{2}\sqrt{\sum_i \left(x\, q_f^{2i-1}(x,|Q|) - x\, q_f^{2i}(x,|Q|)\right)^2}$$

i: number of polarized PDF eigenvectors

Martin et al, 0901.0002



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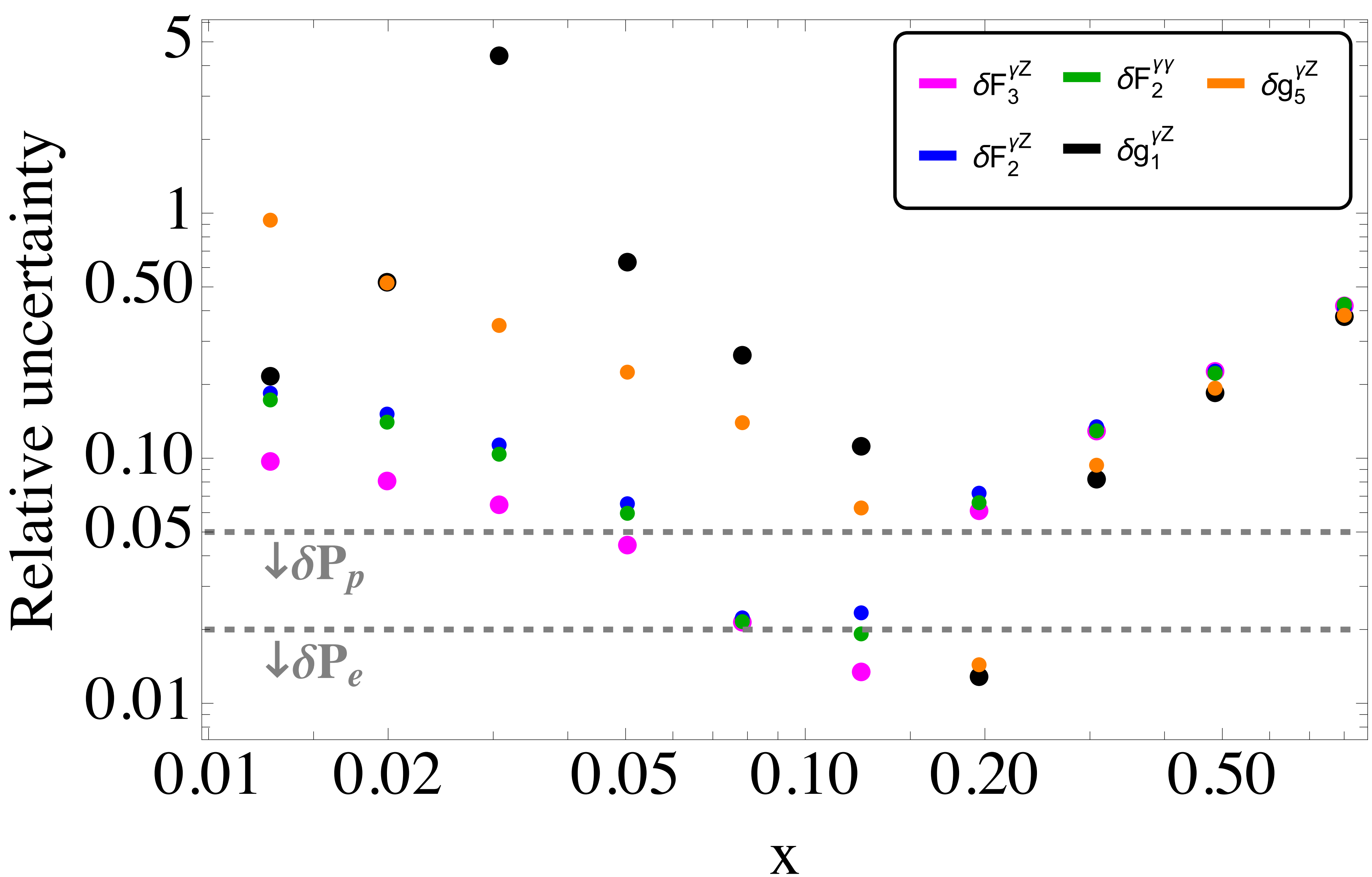
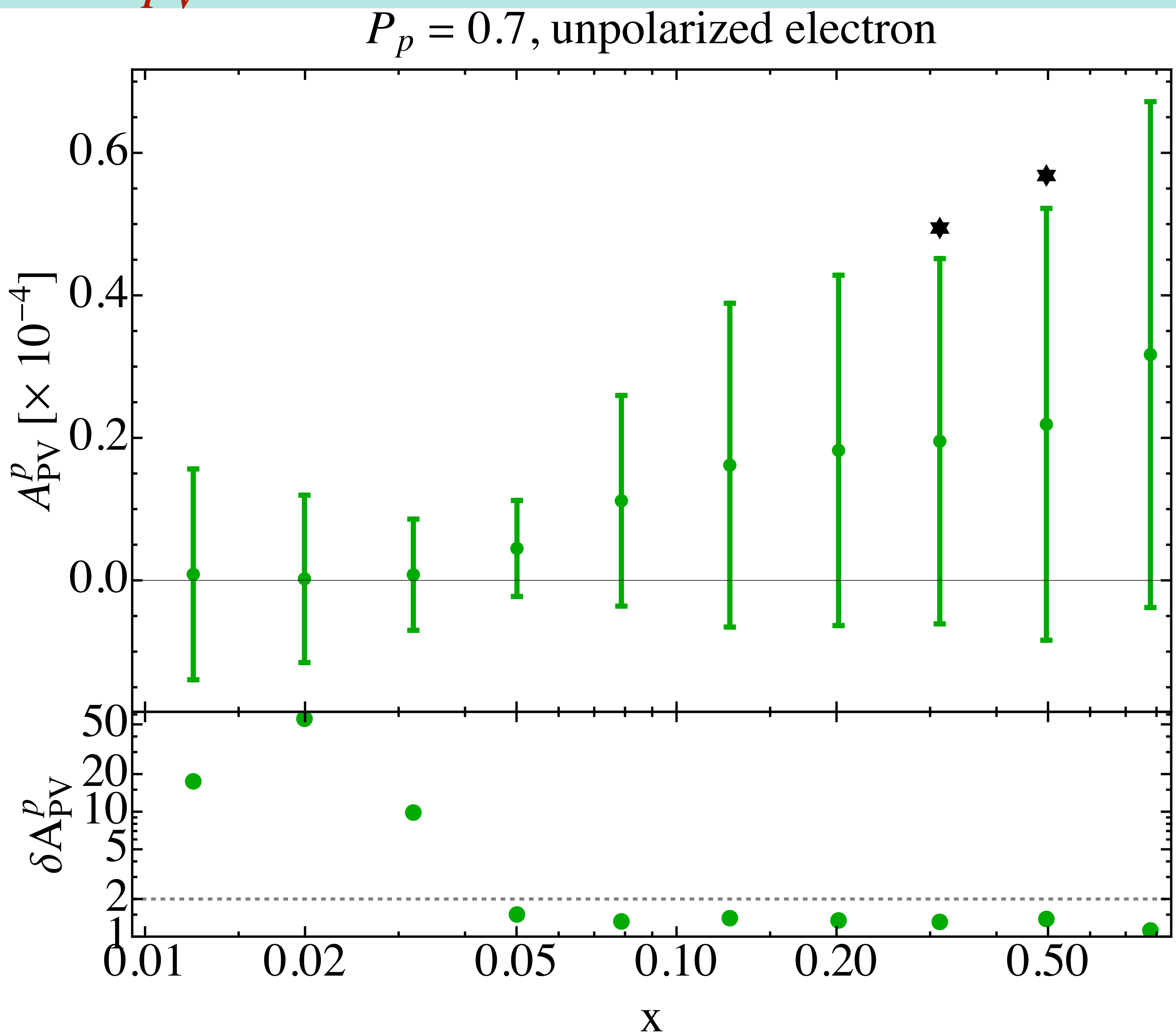


YD, 2412.20469

Results: $A_{PV}^{e,p}$ uncertainties combined



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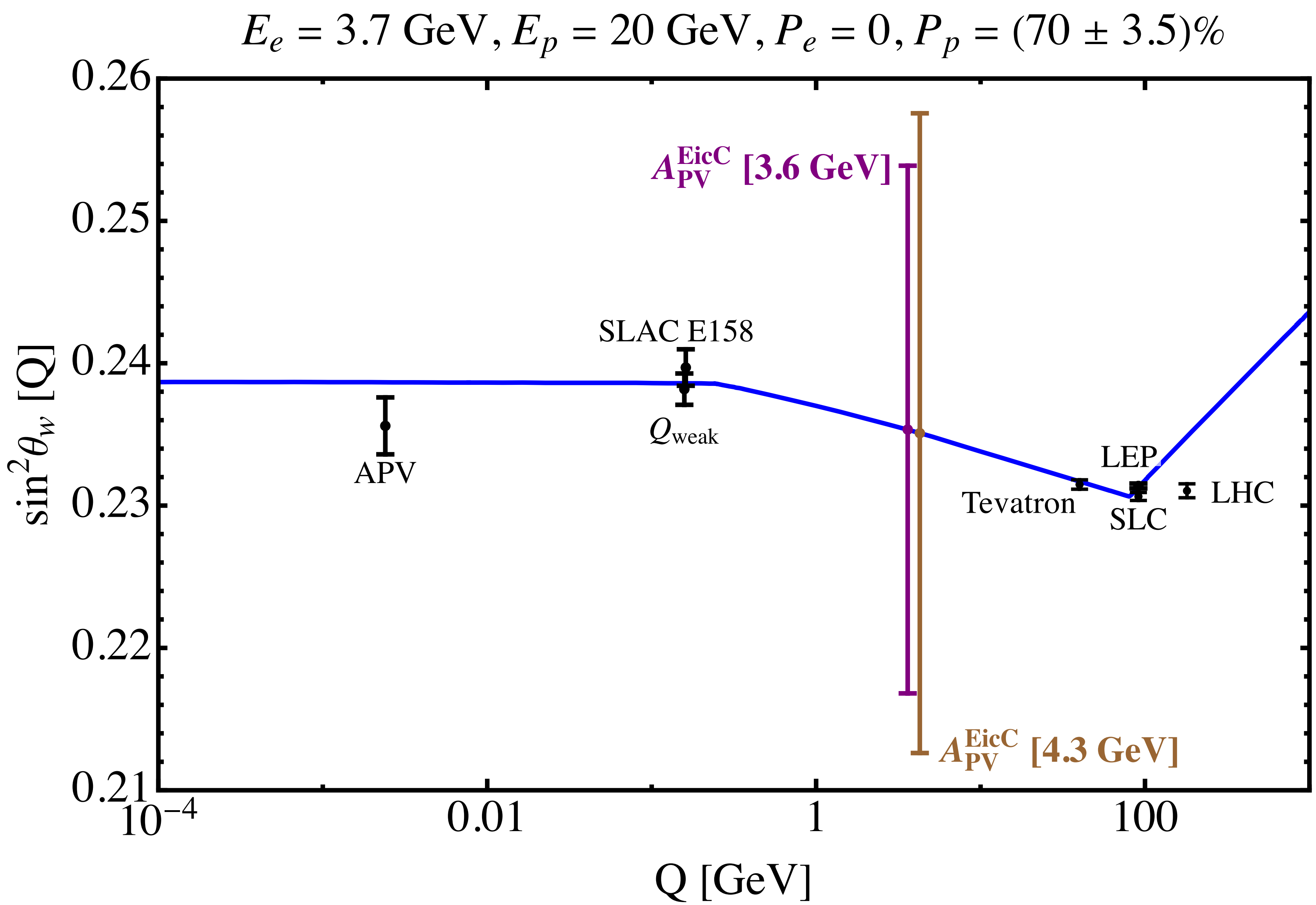
How about the weak mixing angle?



(Would-be)First measurement in this range and base in China!

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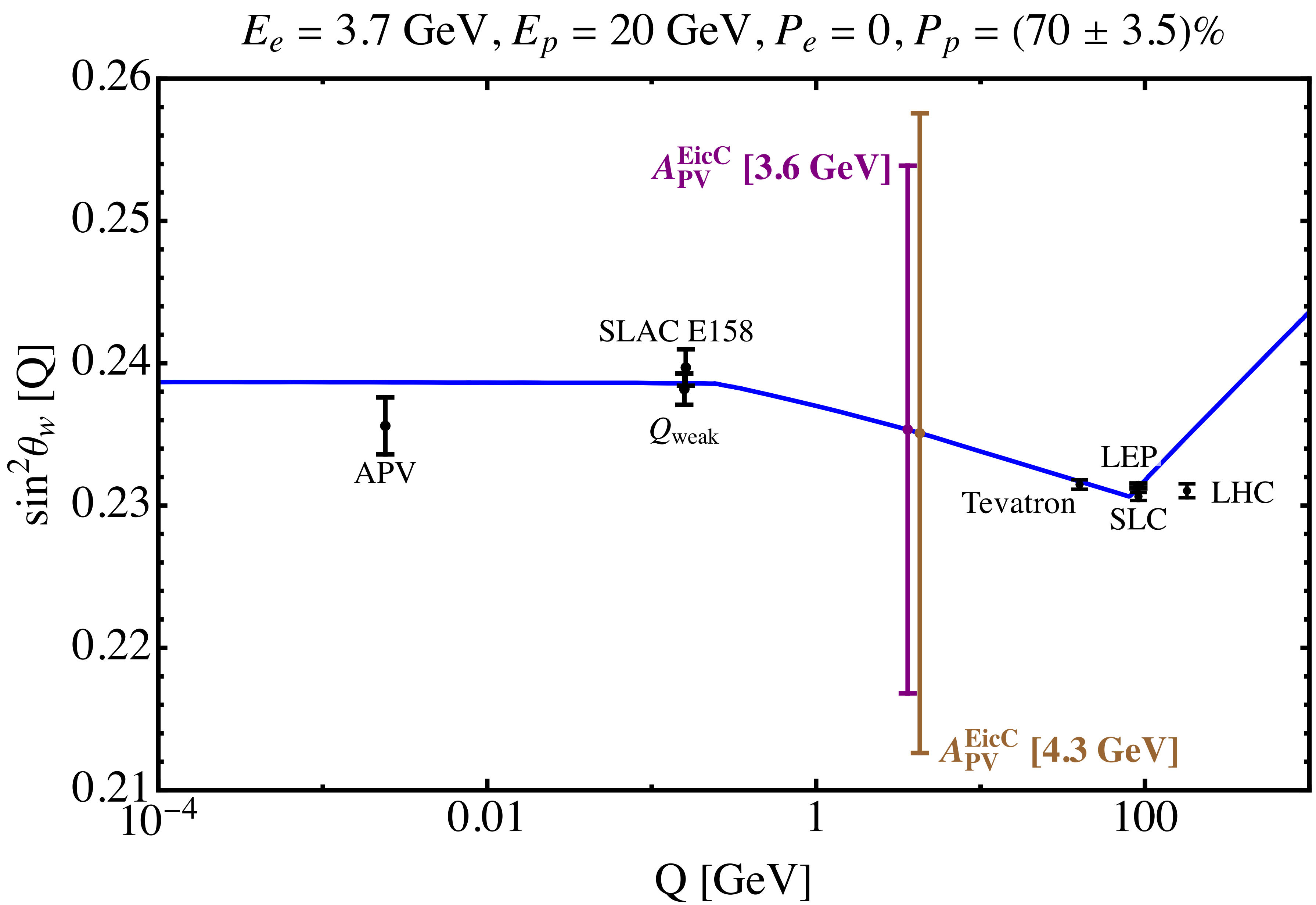

Better than 10%!

(Would-be)First measurement in this range and base in China!

Summary

- We briefly introduced the EicC based on the HIAF in Huizhou, China

- Projections for long. polarized electron or proton beam asymmetry was studied:

  - *Statistical uncertainty largely negligible for* $x \gtrsim 0.1$
  - *PDF uncertainty dominates, which is expected to be further reduced from EIC/ EicC etc*
  - *Polarization uncertainty becomes non-negligible around* $x = 0.1$

- $\sin^2\theta_W$ can be measured with a relative precision *below 10%* at the EicC (*conservative*), and EicC allows a direct test of the RGE running.

Backup