Electroweak Precision Measurements

Jens Erler

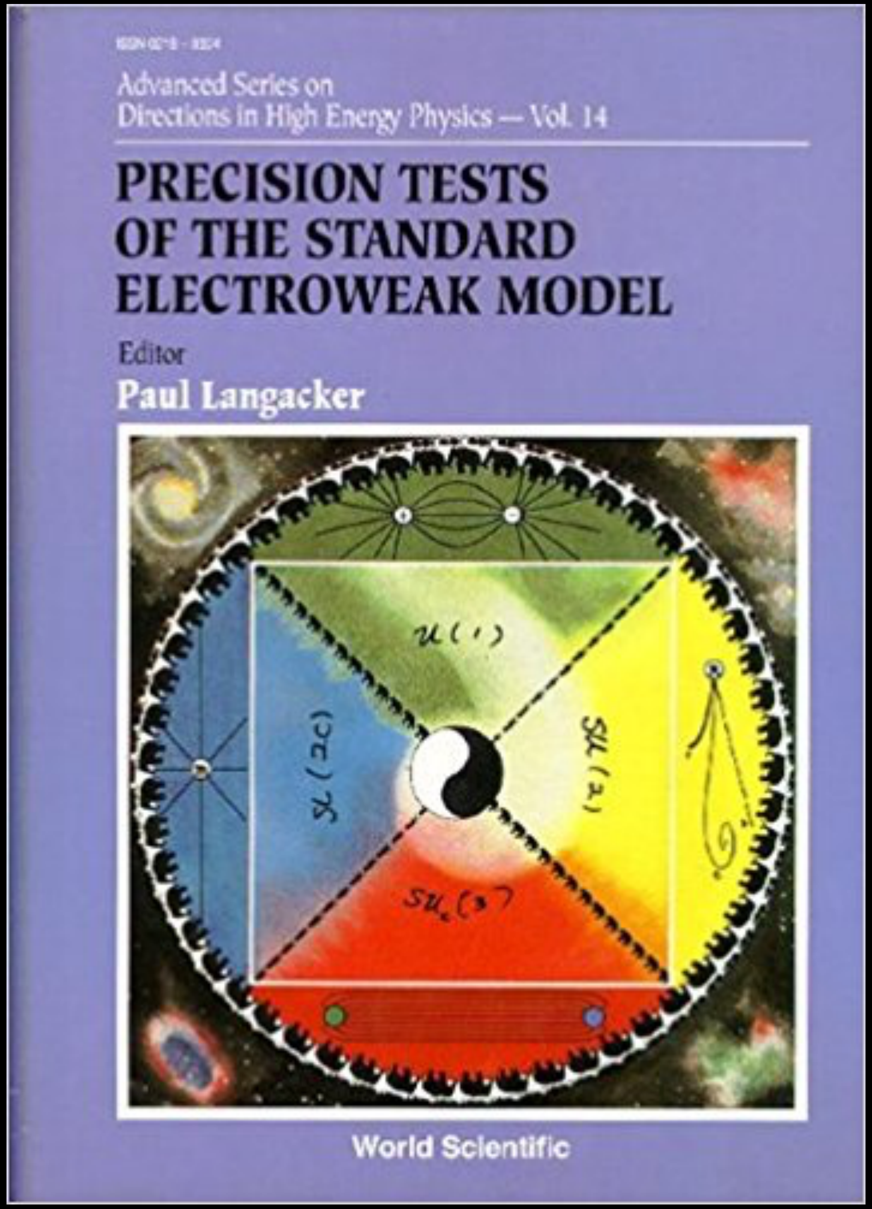
2017 CAP Congress

— Testing Fundamental Symmetries —

Kingston, ON

May 30, 2017

Outline


Advanced Series on
Directions in High Energy Physics — Vol. 14
PRECISION TESTS
OF THE STANDARD
ELECTROWEAK MODEL
Editor
Paul Langacker
World Scientific

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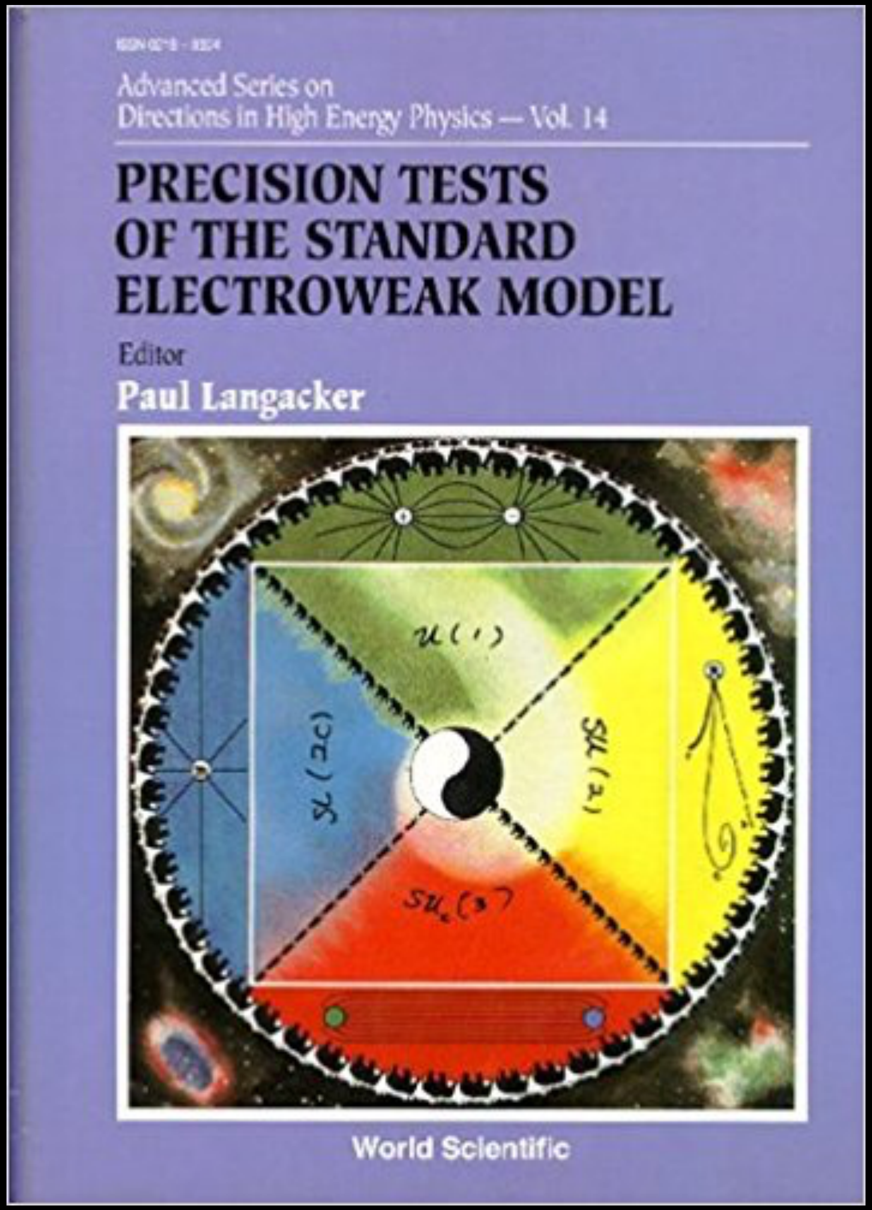
- Introduction:
  Fundamental symmetries, standard model and beyond



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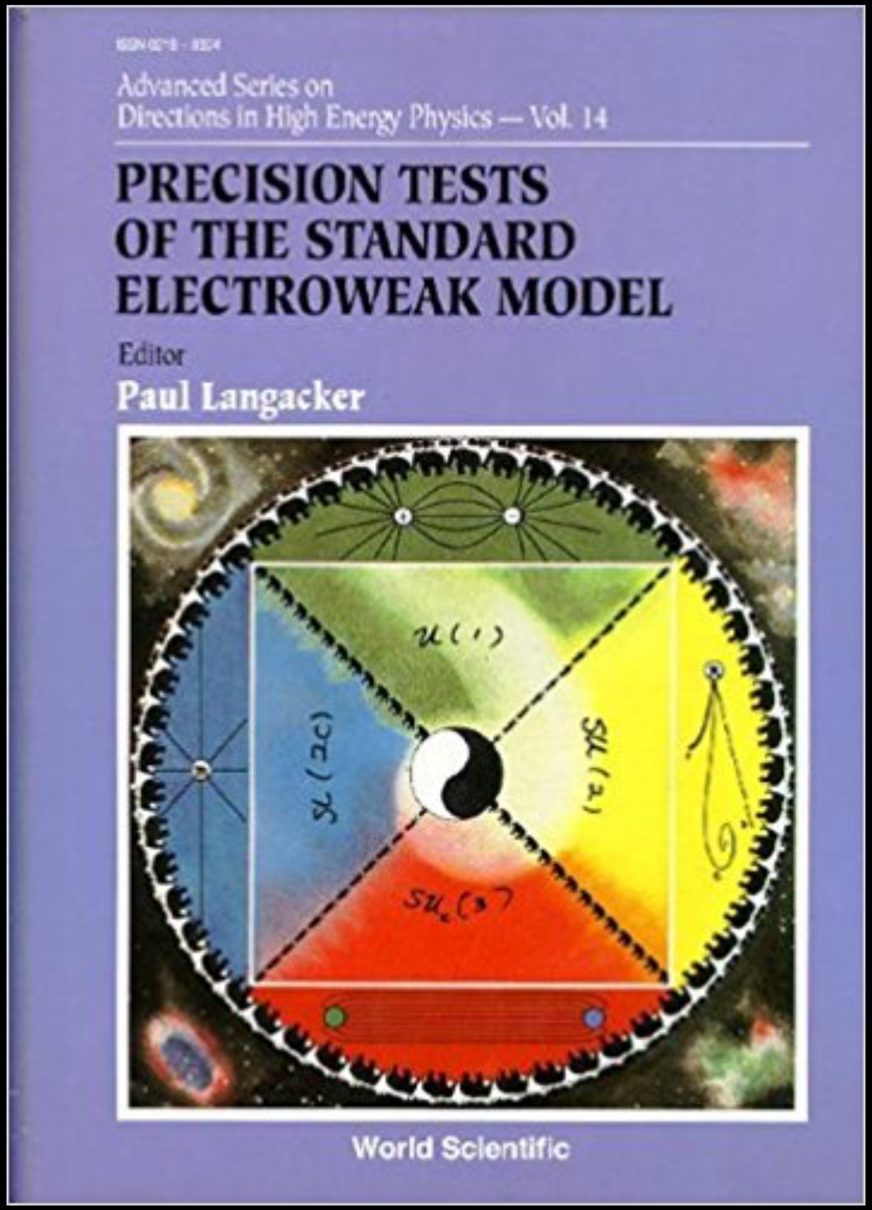

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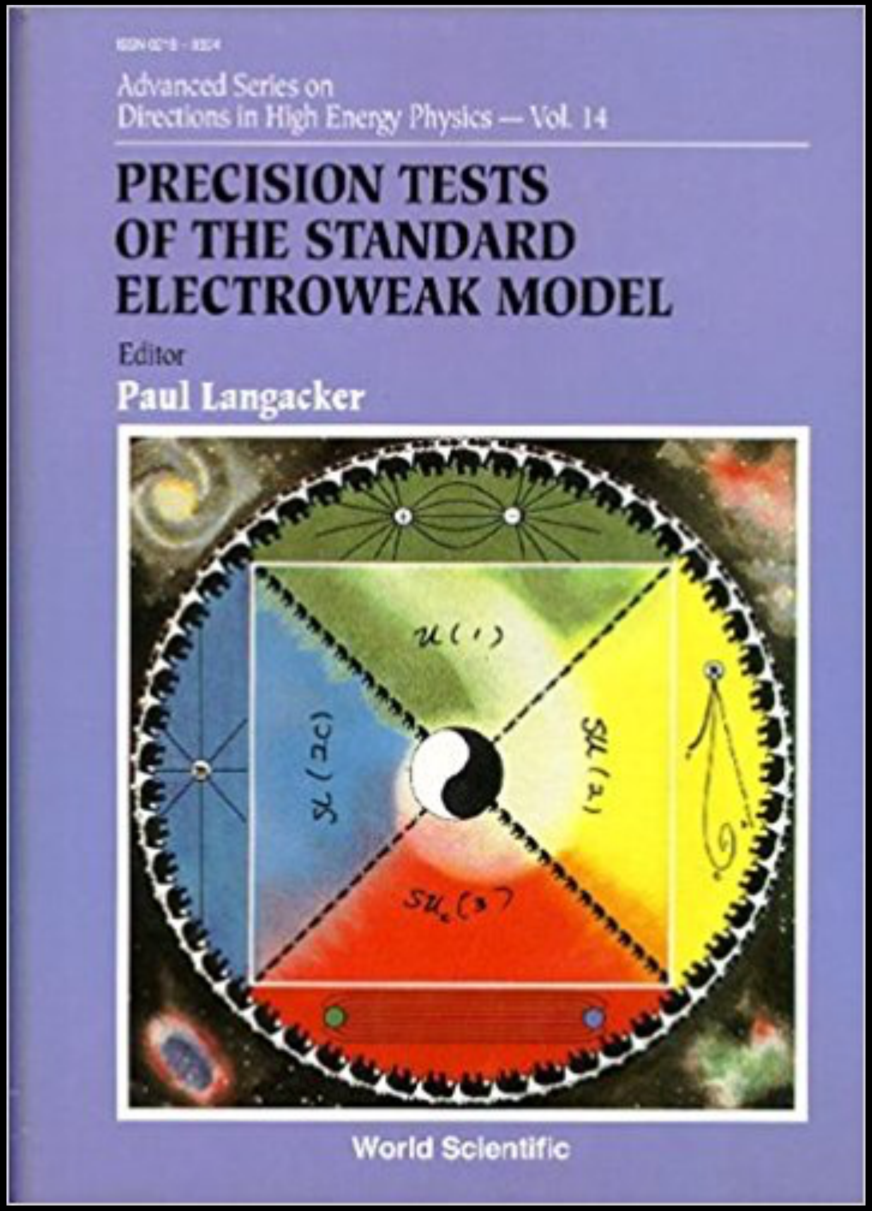

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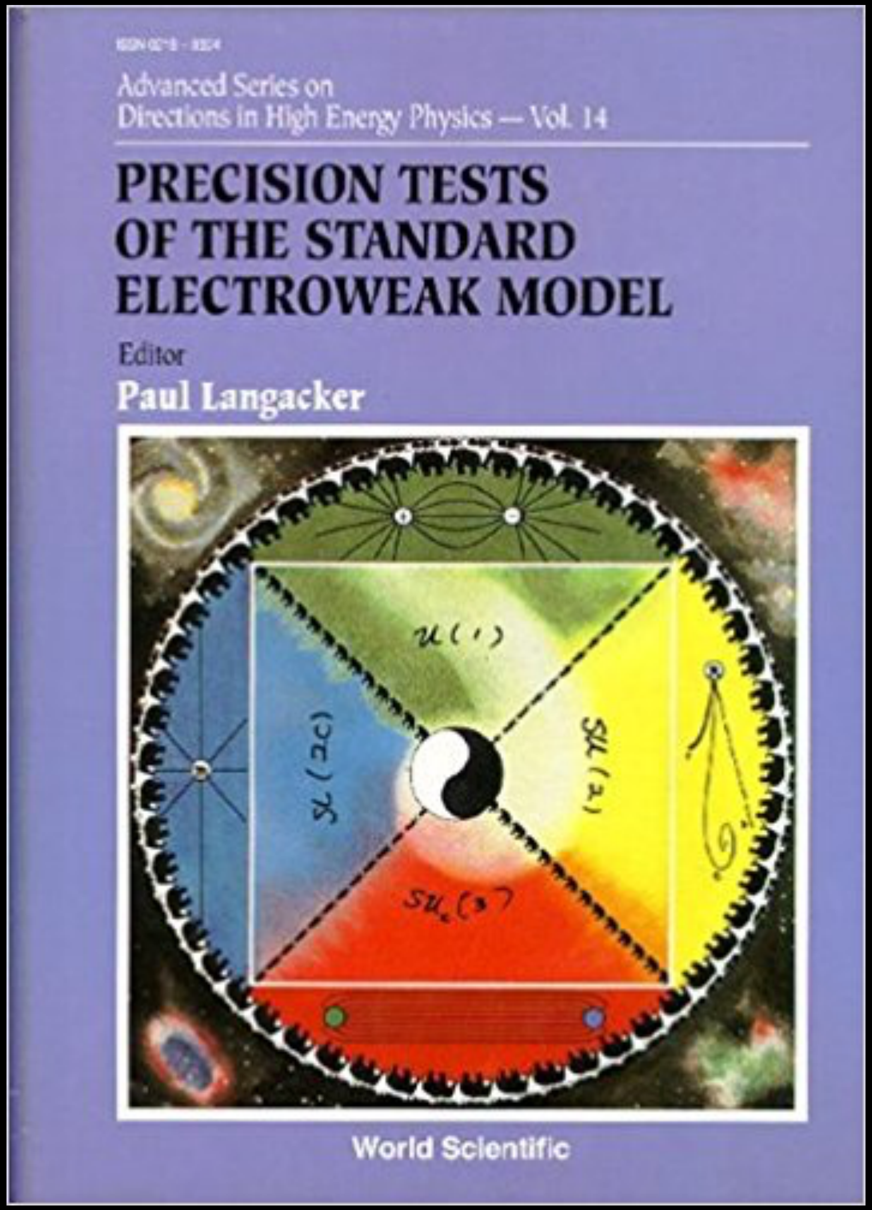

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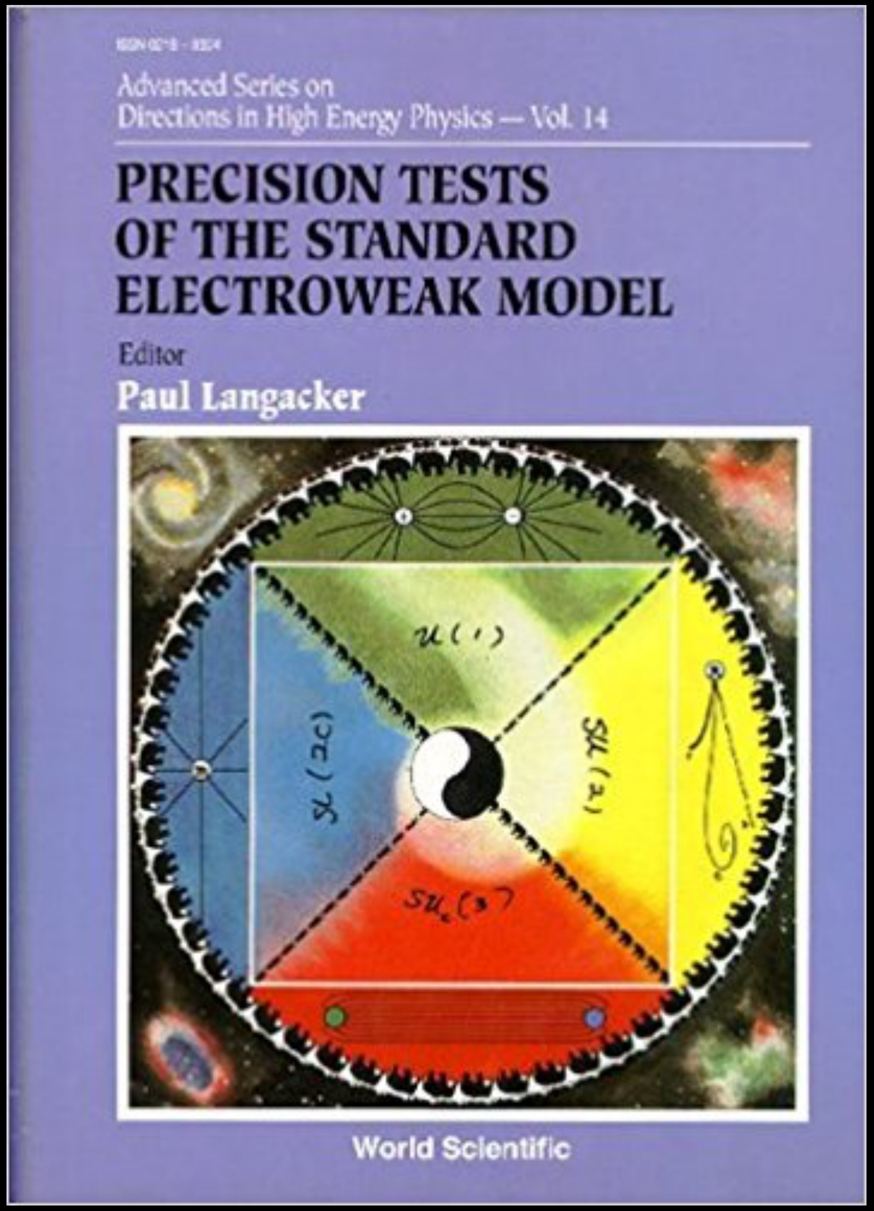

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Poincaré symmetry

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- Quantum Lorentz transformations & translations **Weinberg**

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- no analog for $h = 0 \Rightarrow$ hierarchy problem

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- CPT a tool to access Planck scale physics (tomorrow)

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- Flavor changing charged currents: $B \to D\tau\nu$ (3.9σ high @ BaBar, Belle, LHCb)

The weak mixing angle ($\sin^2\theta_W$)

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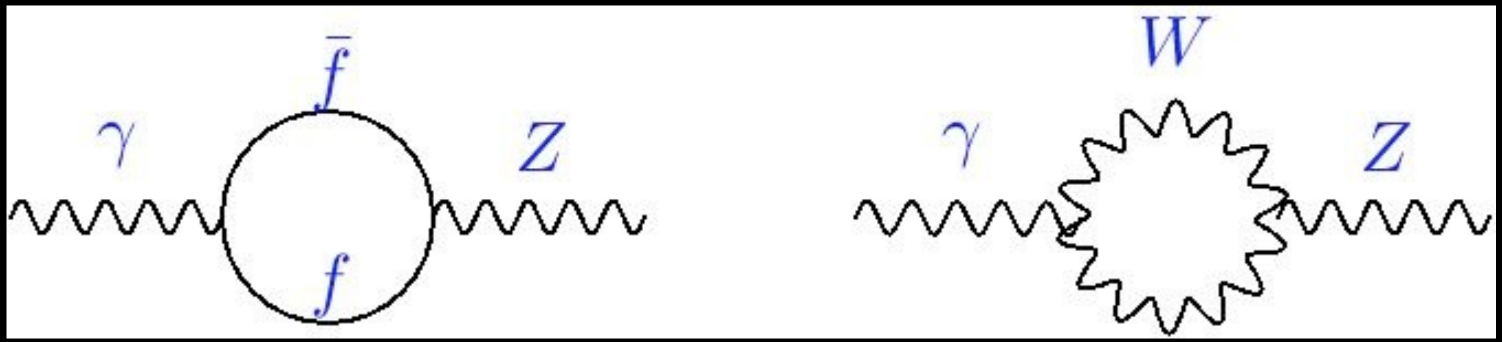
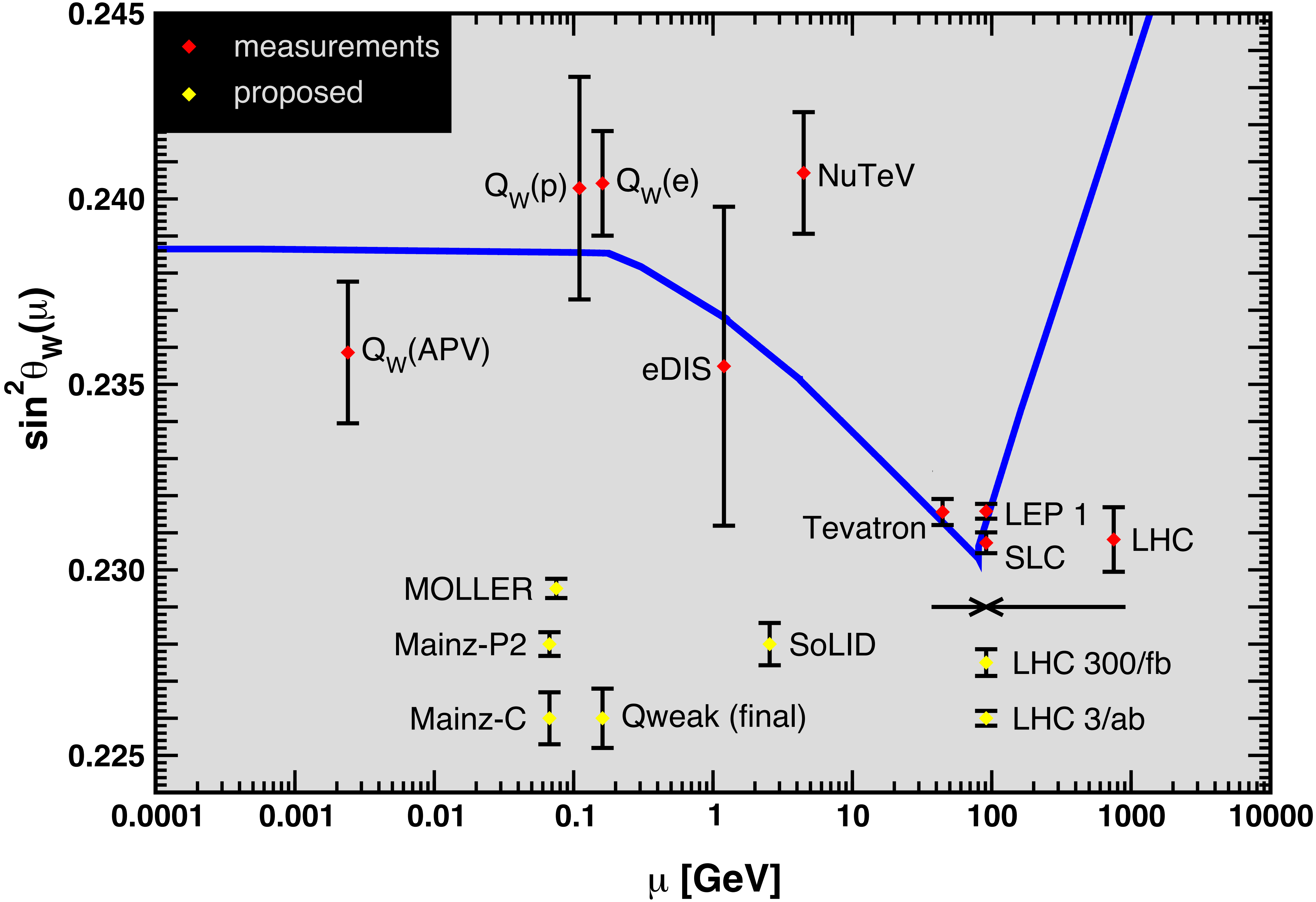
- mixing of $SU(2)_L \times U(1)_Y$
- $W^{\pm} = (W^1 \mp i W^2) / \sqrt{2}$
- $Z^0 = \cos\theta_W W^3 - \sin\theta_W B$ $\quad A = \sin\theta_W W^3 + \cos\theta_W B$

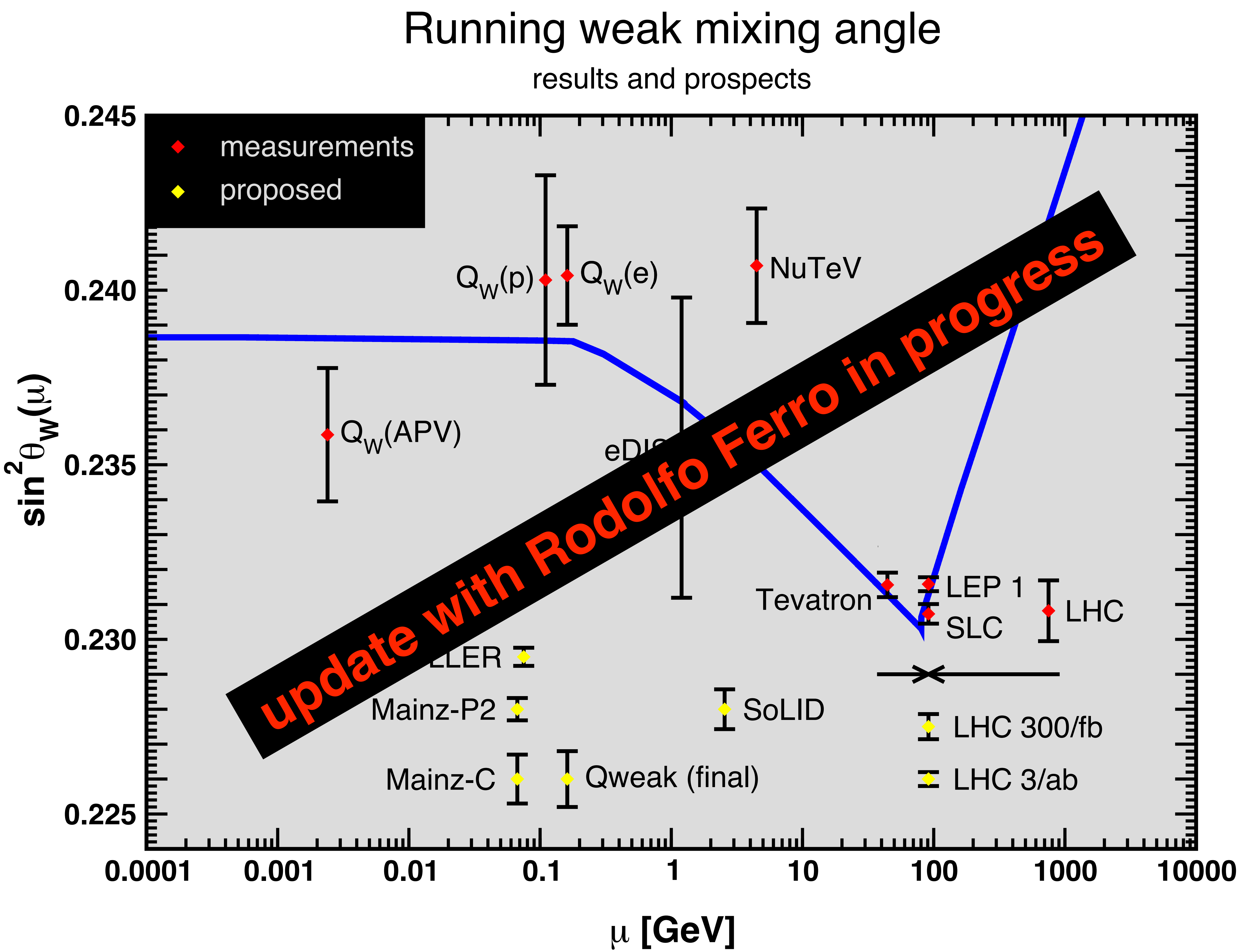


- $M_W = \frac{1}{2} g v = \cos\theta_W M_Z$
- $\sin^2\theta_W = g'^2 / (g^2 + g'^2) = 1 - M_W^2 / M_Z^2$ (tree level)

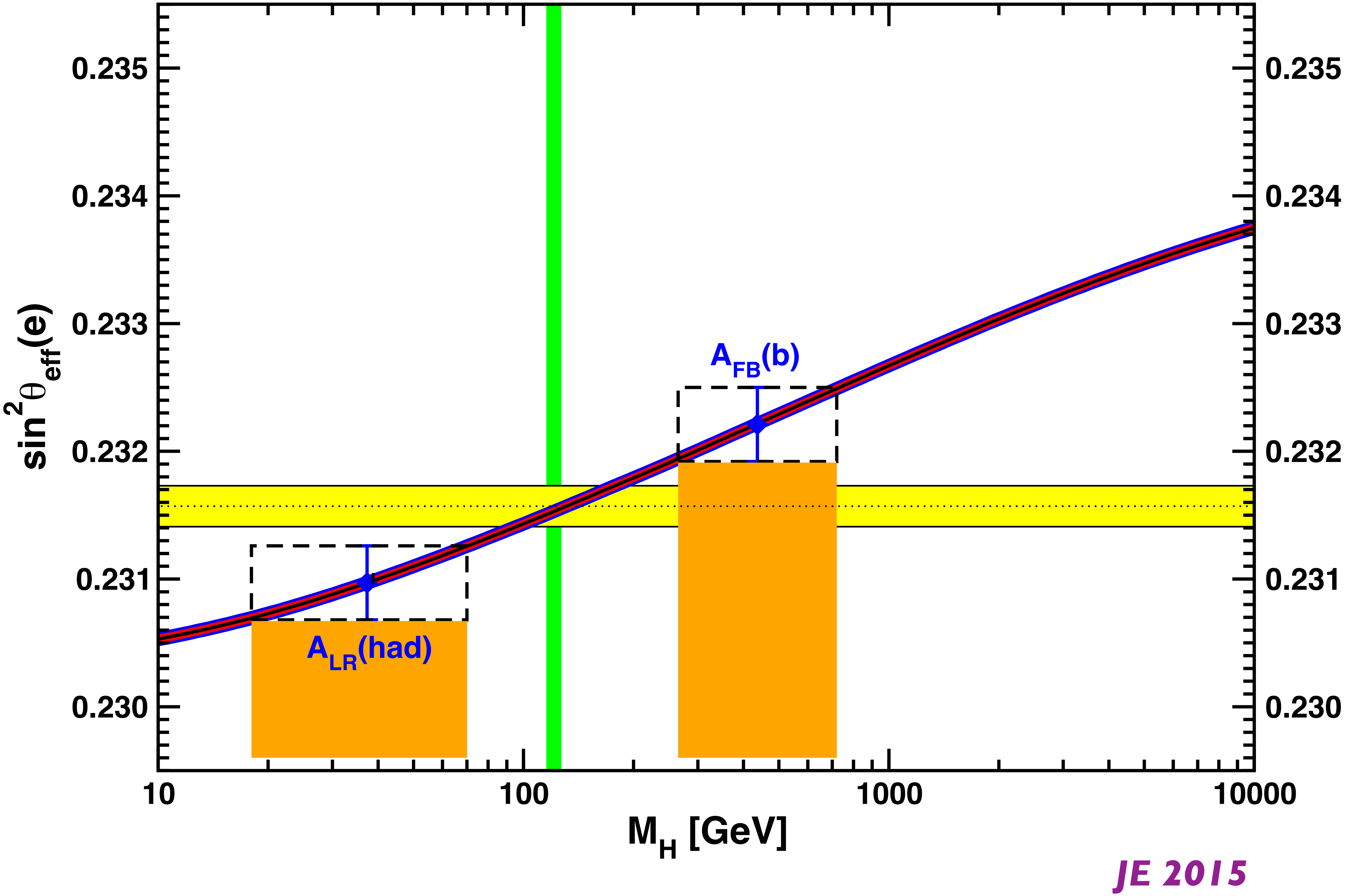
Running weak mixing angle

results and prospects



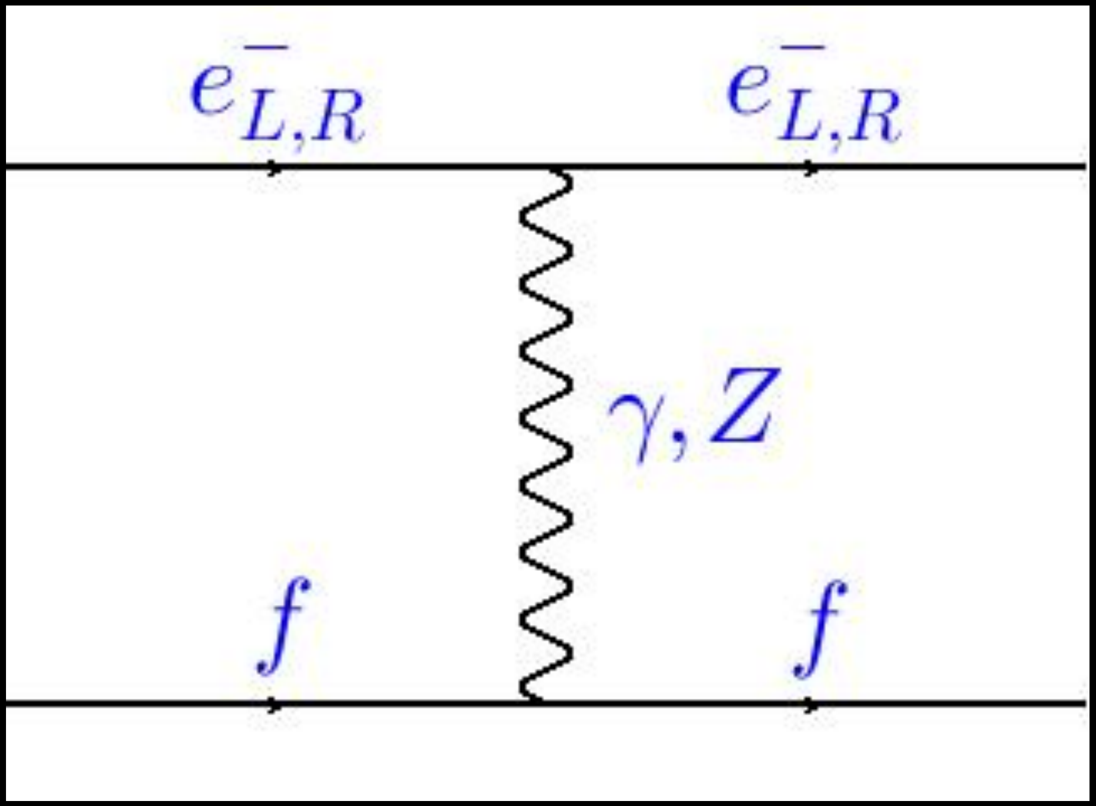


Running weak mixing angle
results and prospects
measurements
proposed
0.245
0.240
0.235
0.230
0.225
$\sin^2\theta_W(\mu)$
$Q_W(p)$
$Q_W(e)$
NuTeV
$Q_W(APV)$
eDI
Tevatron
LEP 1
SLC
LHC
LLER
Mainz-P2
SoLID
LHC 300/fb
Mainz-C
Qweak (final)
LHC 3/ab
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
μ [GeV]
update with Rodolfo Ferro in progress



0.235
0.234
0.233
0.232
0.231
0.230
sin²θ_eff(e)
A_FB(b)
A_LR(had)
10
100
1000
10000
M_H [GeV]
JE 2015

PV experiments



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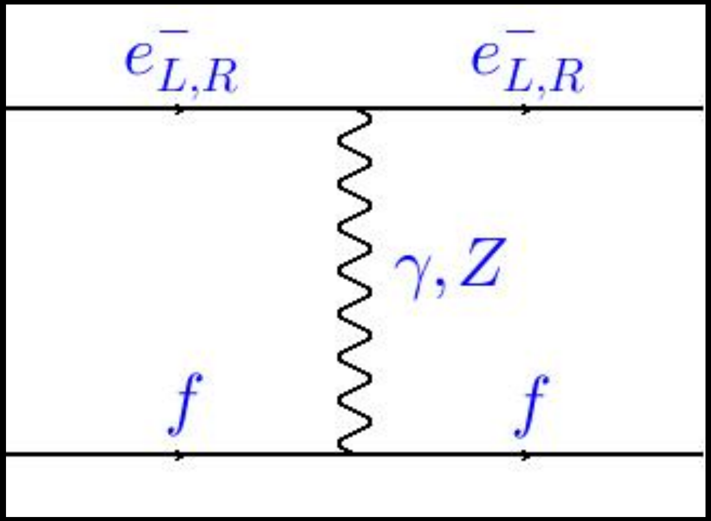

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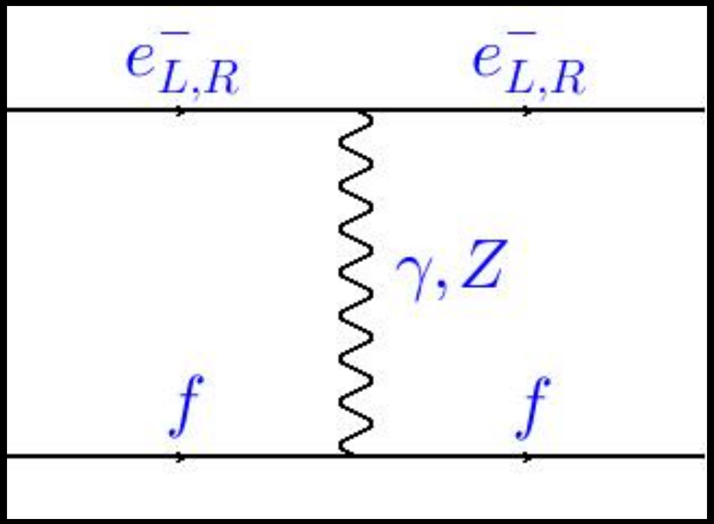

- atomic parity violation (most precise: Boulder & Paris)

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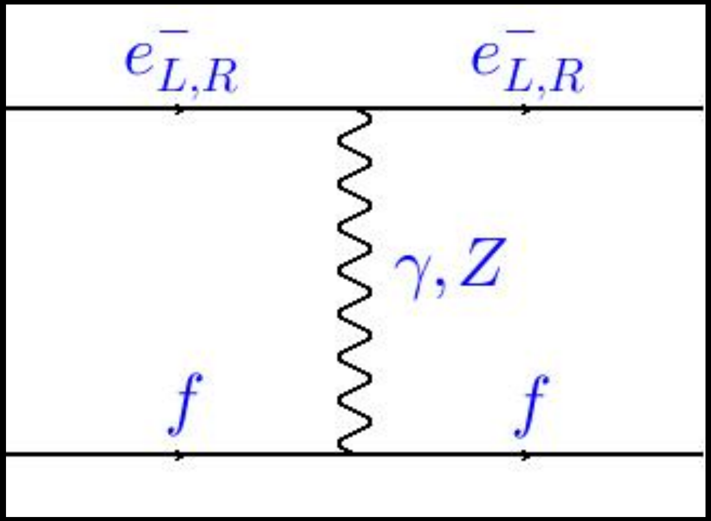

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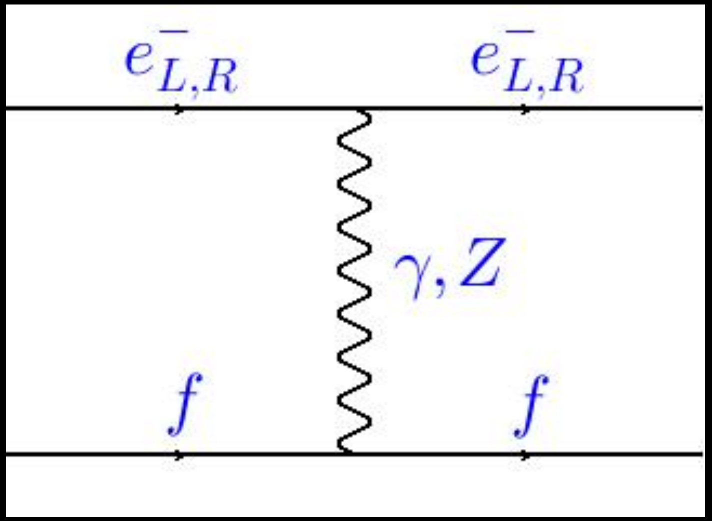

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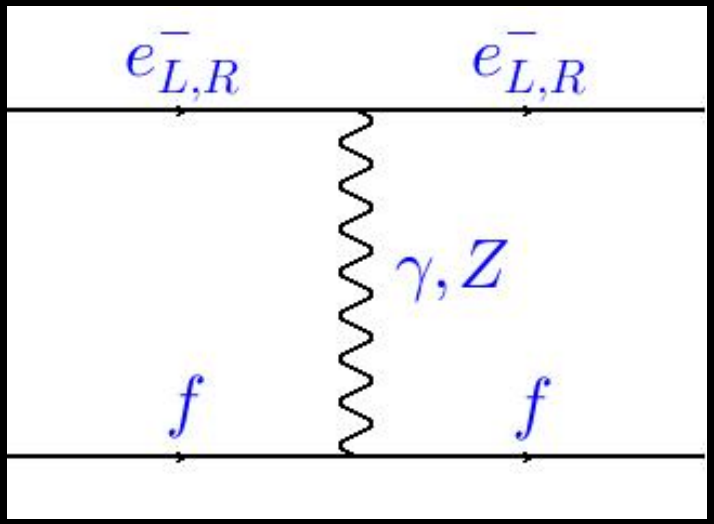

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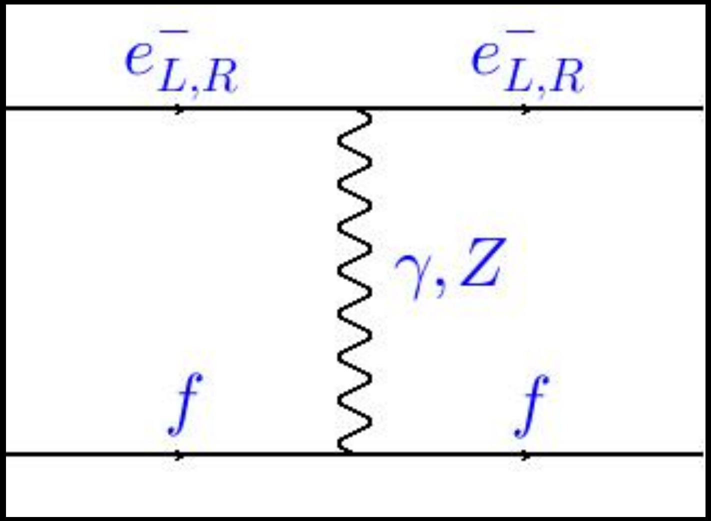

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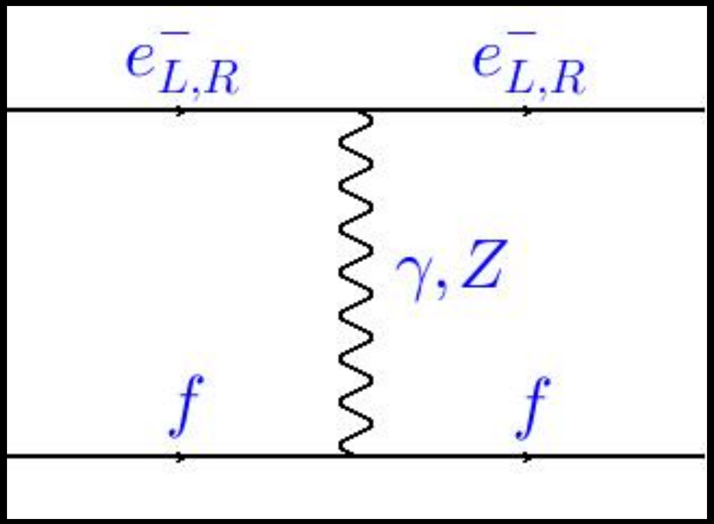

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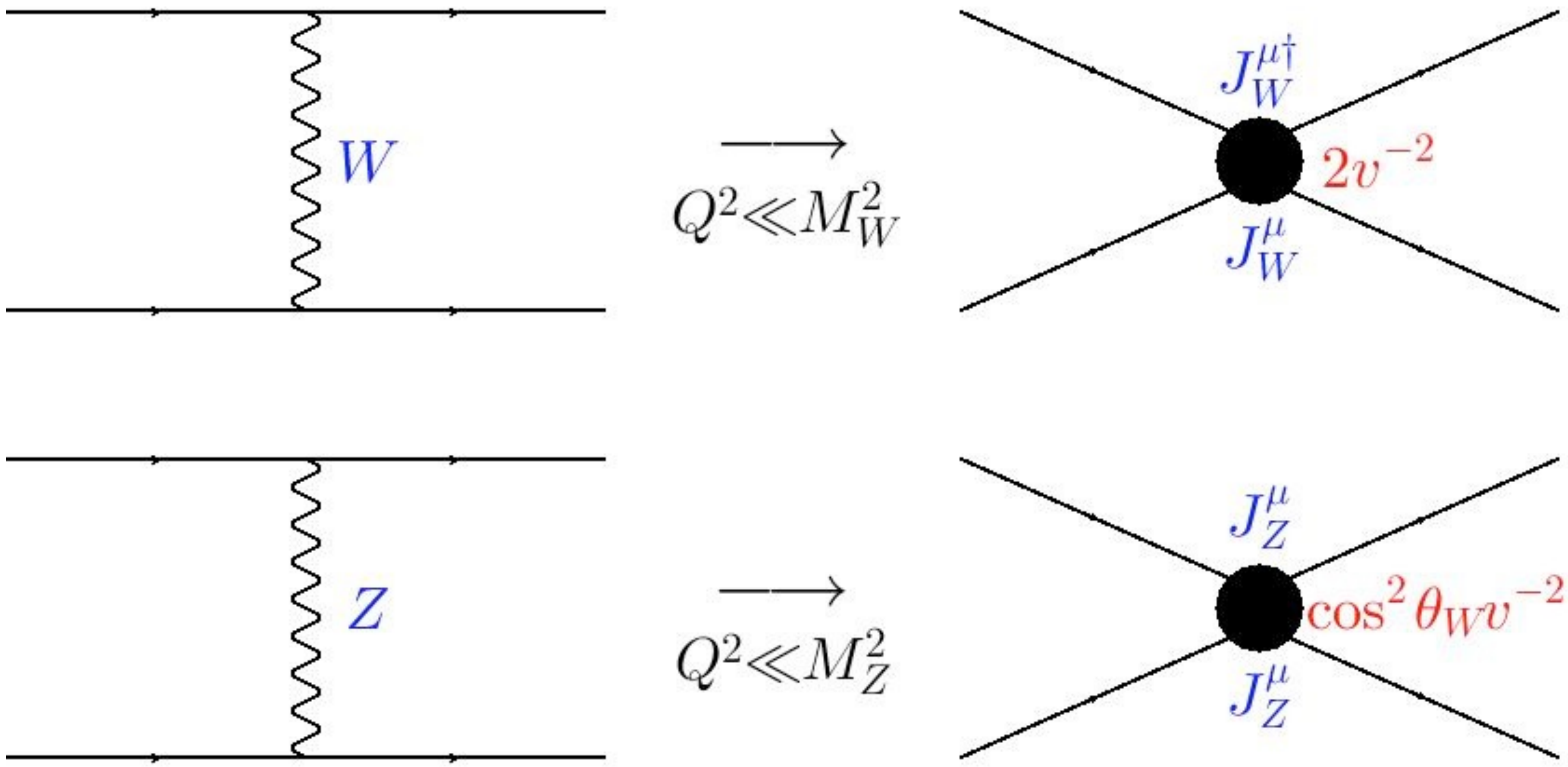
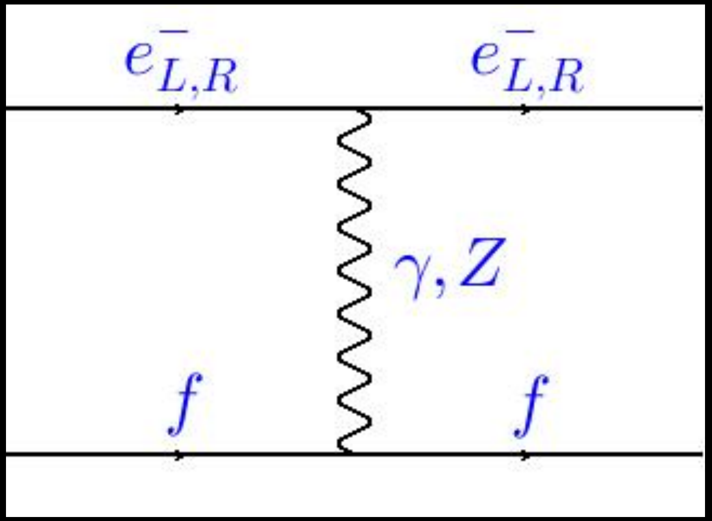
- PV in single trapped Ra ions? (KVI Groningen)

The Low-Energy (Fermi) Limit



$$\mathcal{L}_{\text{eff.}} = -\frac{2}{v^2}\left(J_W^{\mu\,\dagger} J_{W\mu} + \cos^2\theta_W \frac{J_Z^{\mu} J_{Z\mu}}{2} \right)$$

Effective couplings



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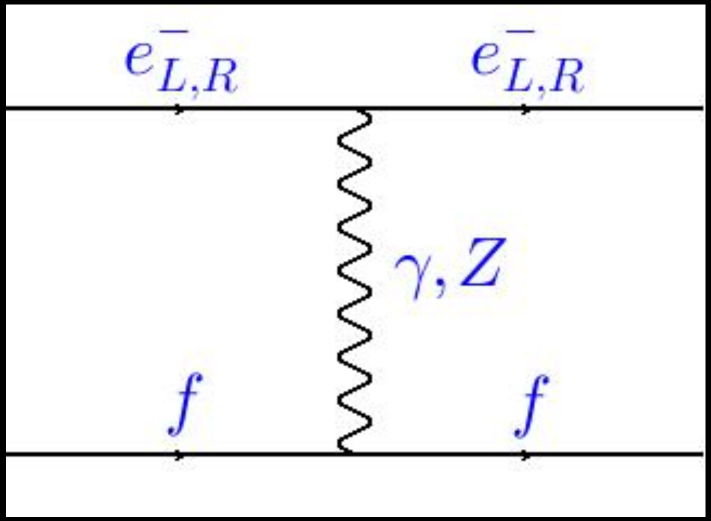

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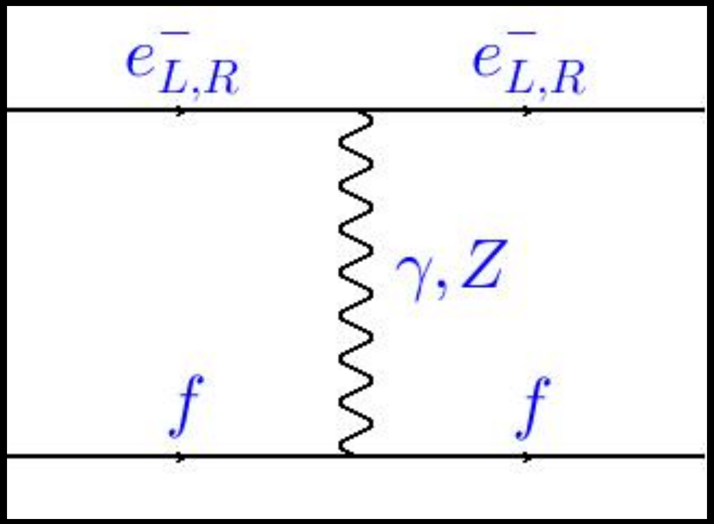

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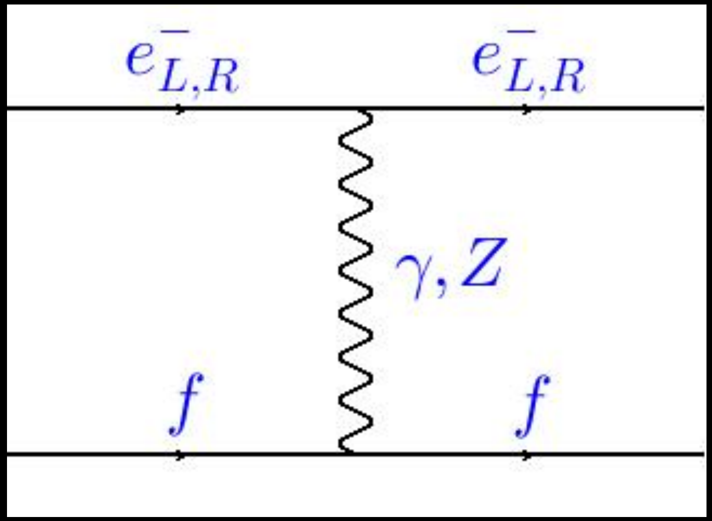

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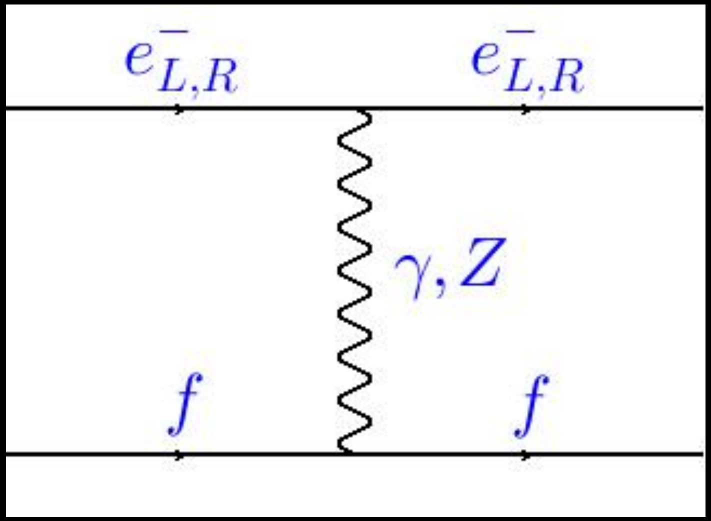

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(compete with ultra-precise Z-pole determinations)

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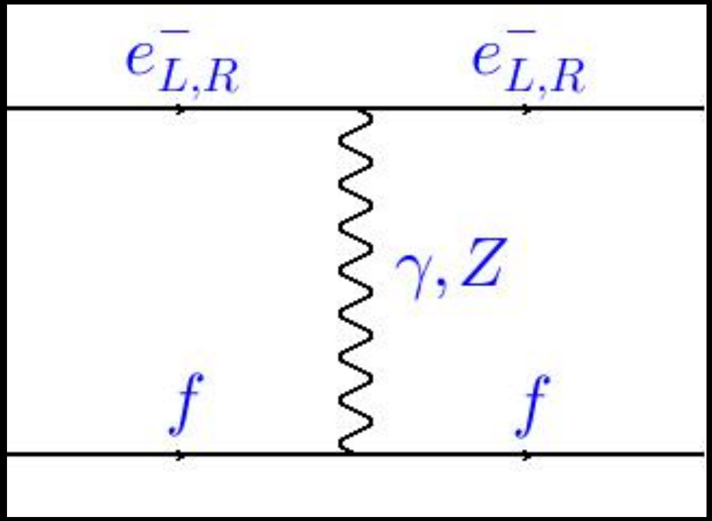

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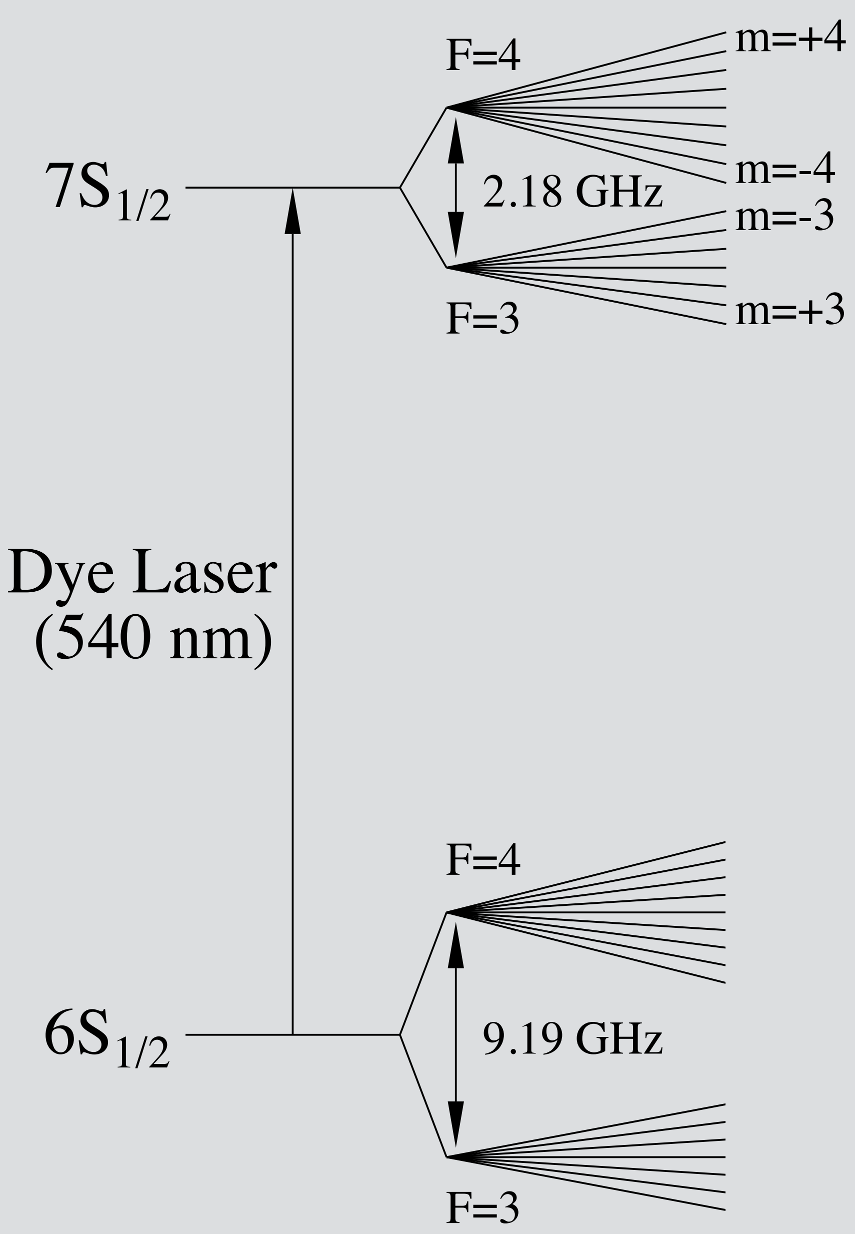
➡ Beyond SM: enhanced sensitivity to Λ_{new}

Atomic parity violation



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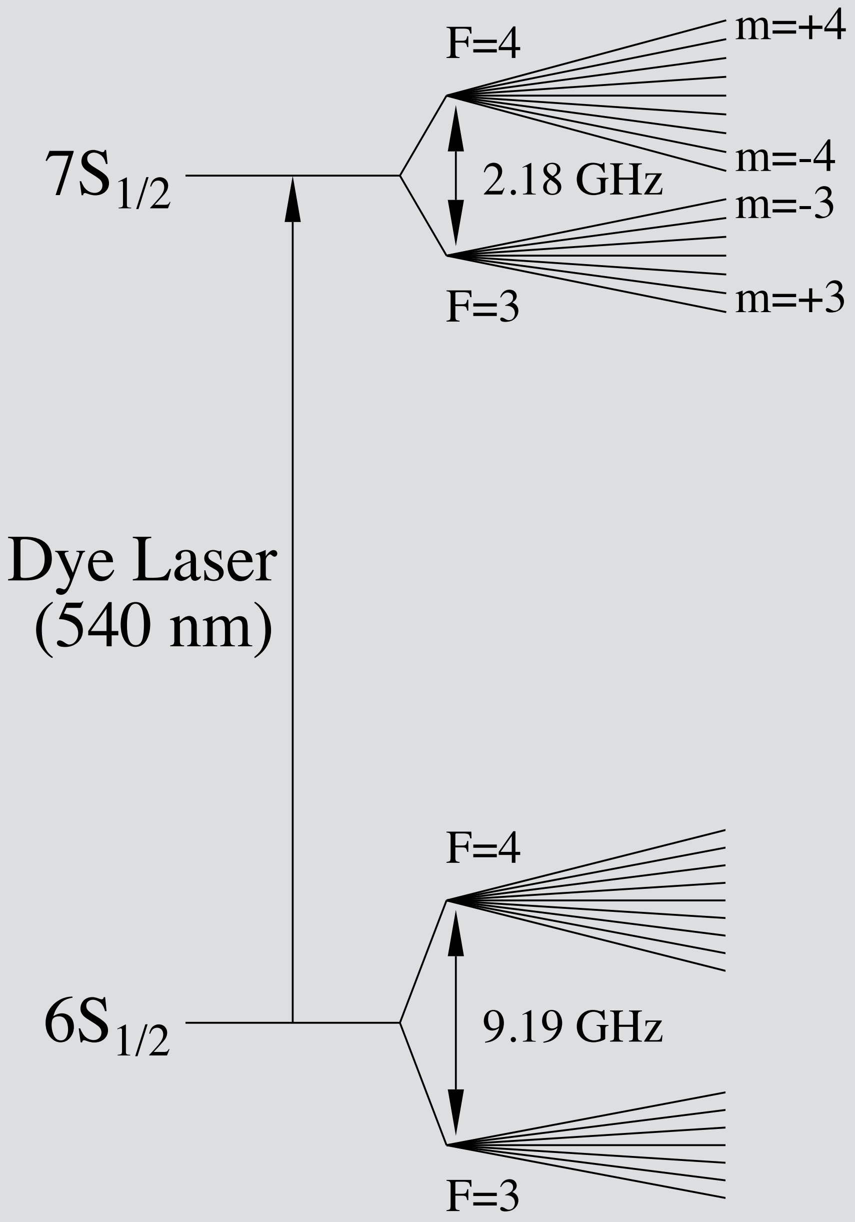
- g^{eq}_{AV} (coherent) Stark induced-Z interference amplitude dominant (spin-independent)



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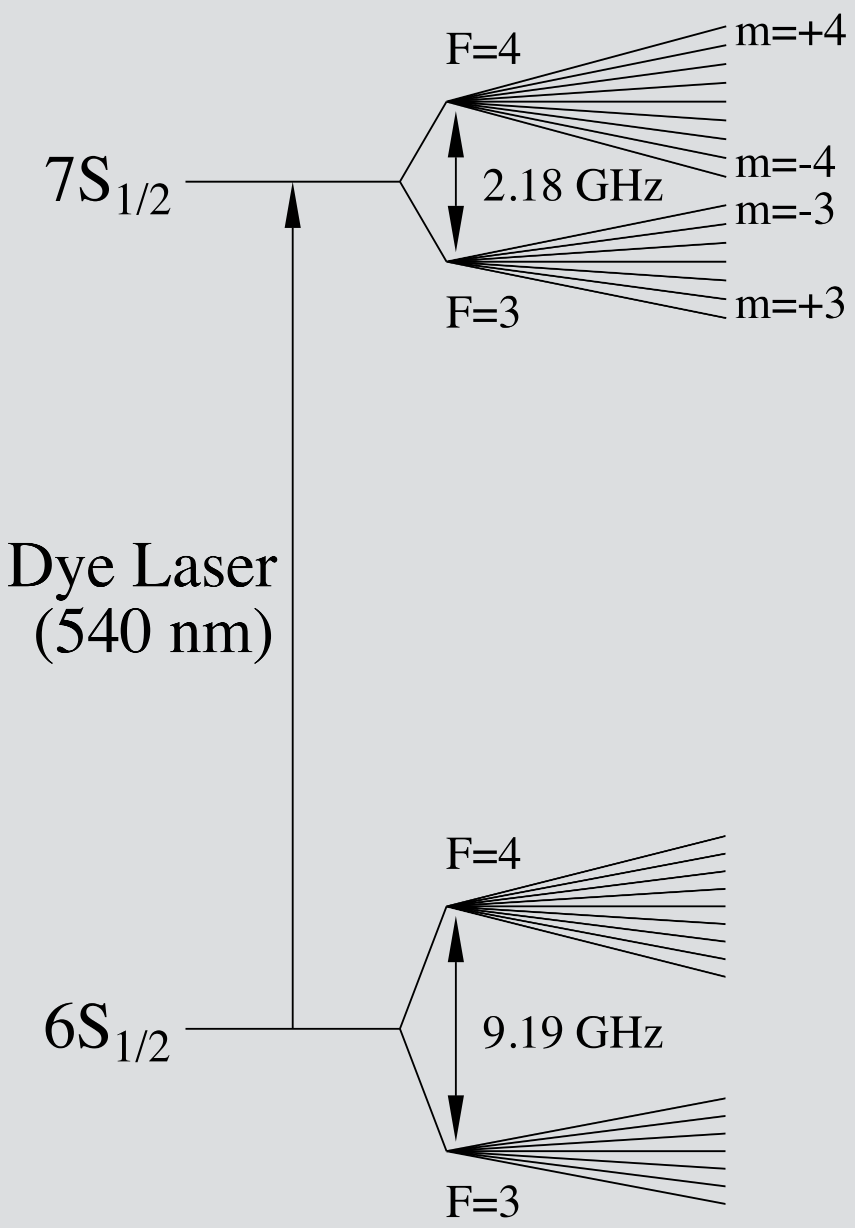

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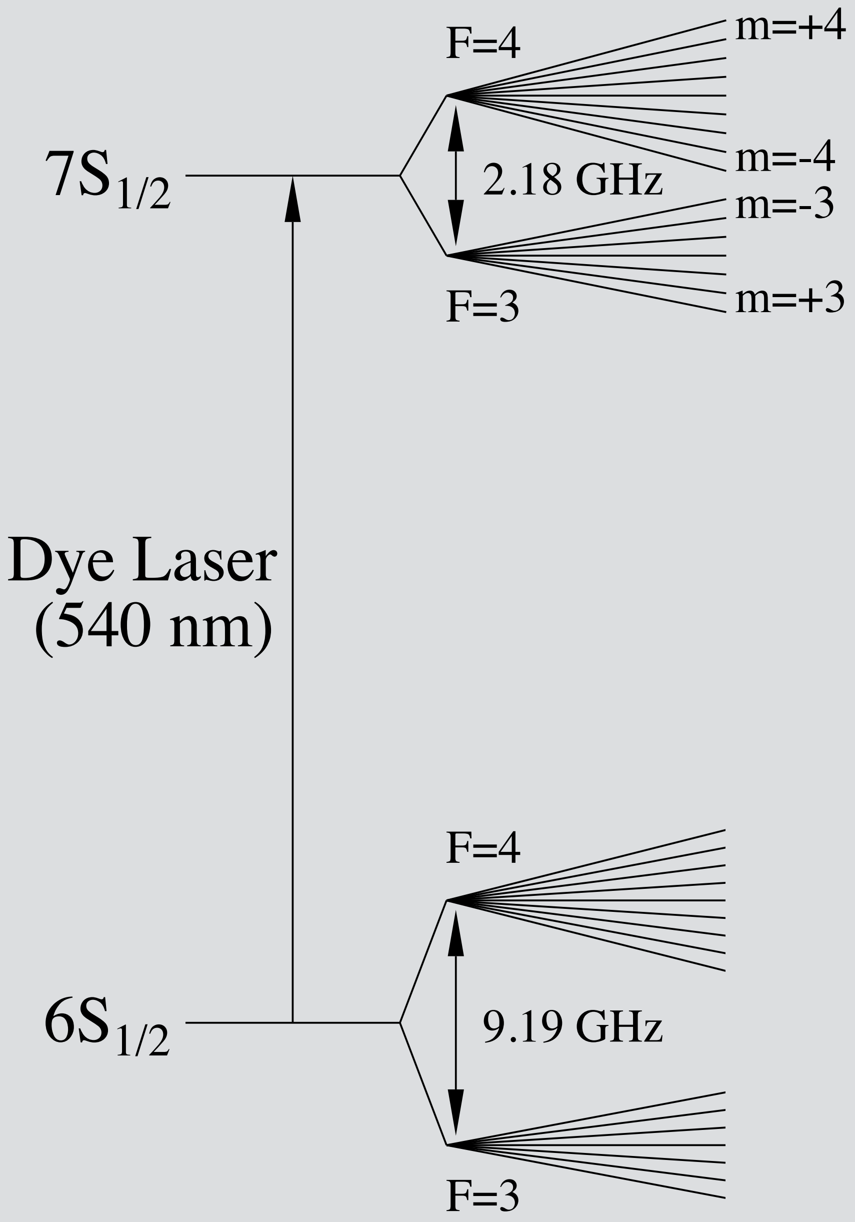
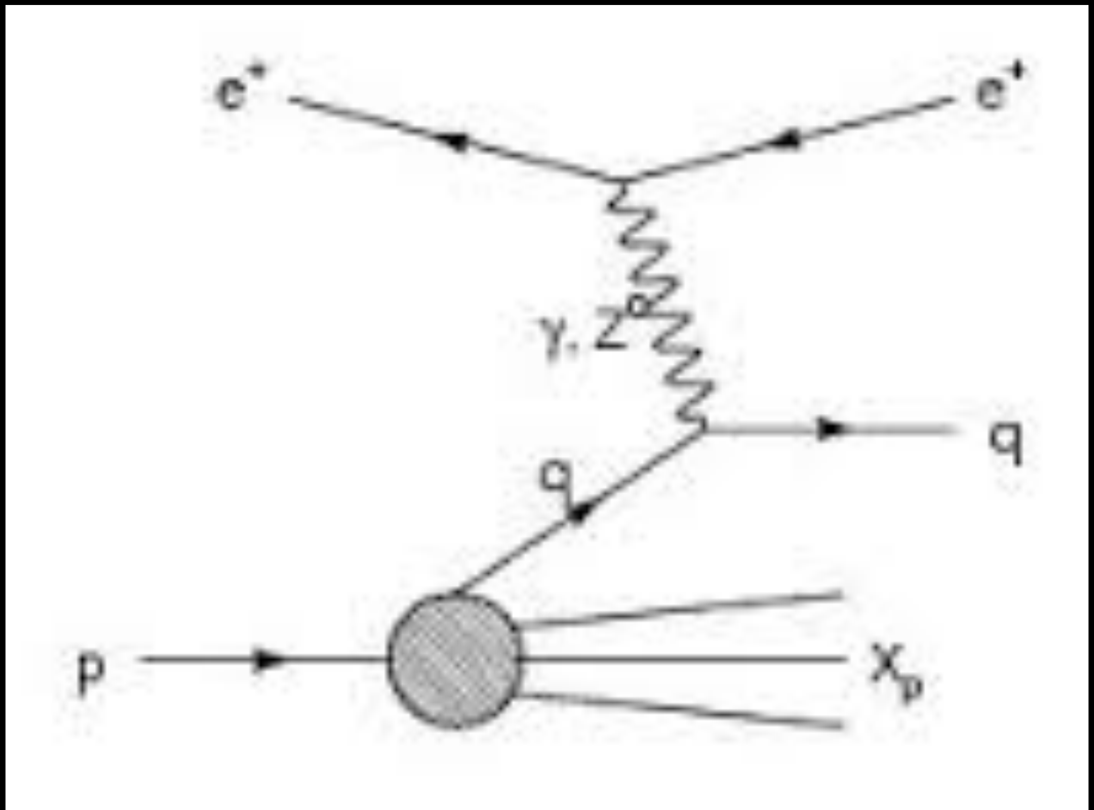
- spin-dependent nuclear anapole moment through difference in hyperfine transitions



Polarized DIS



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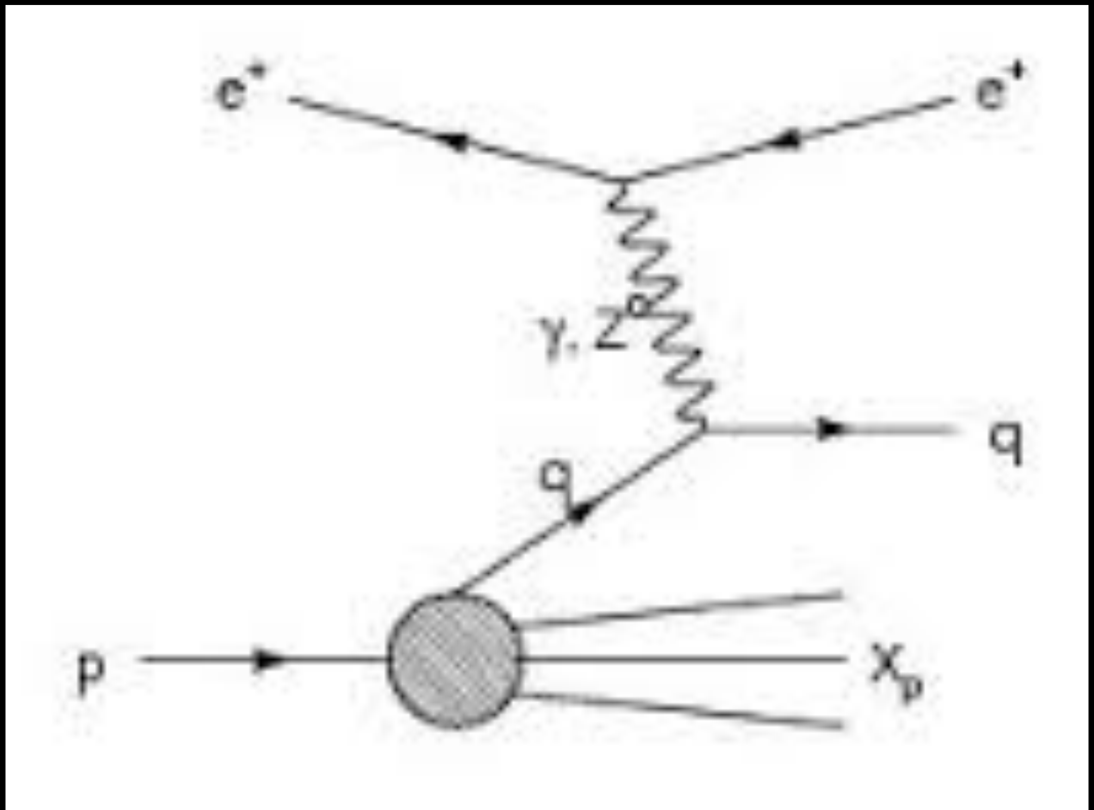

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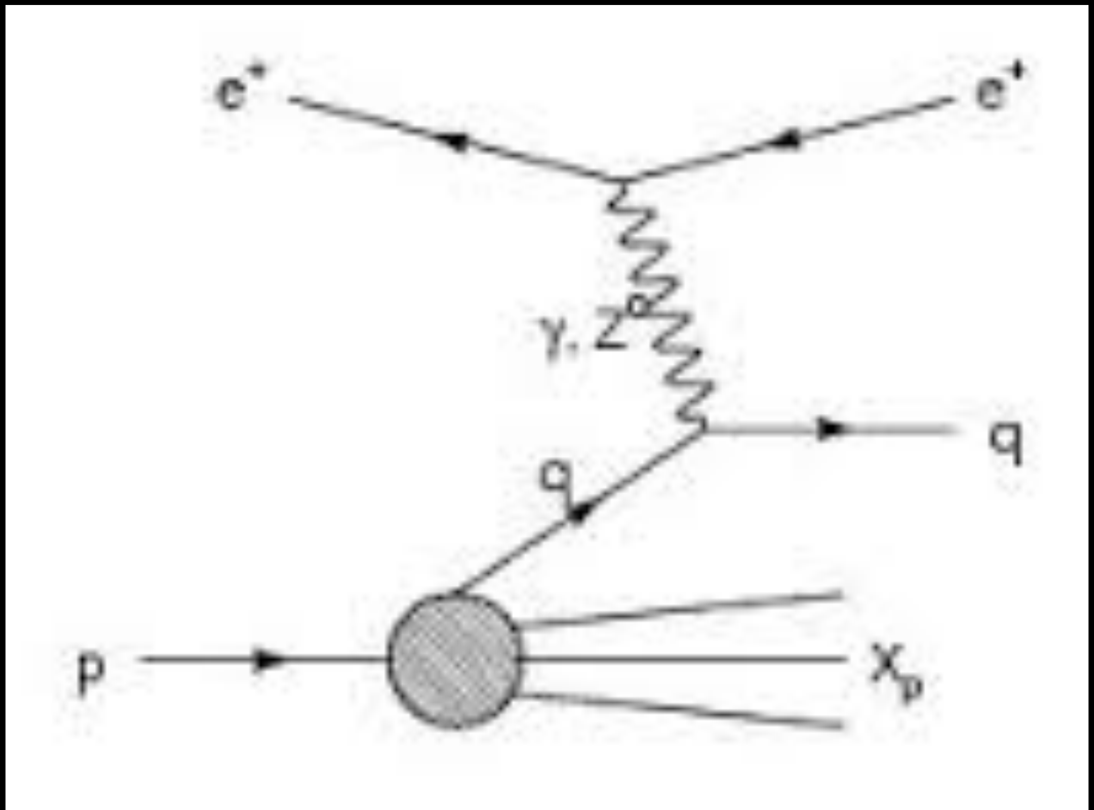

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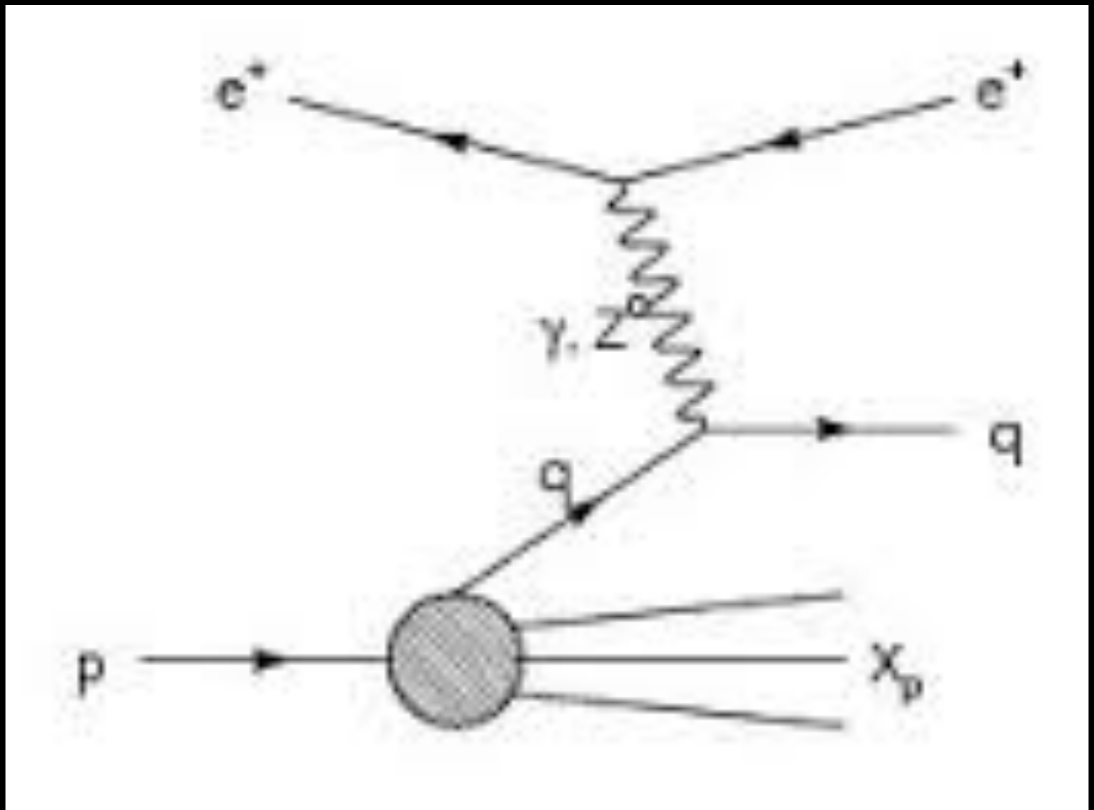

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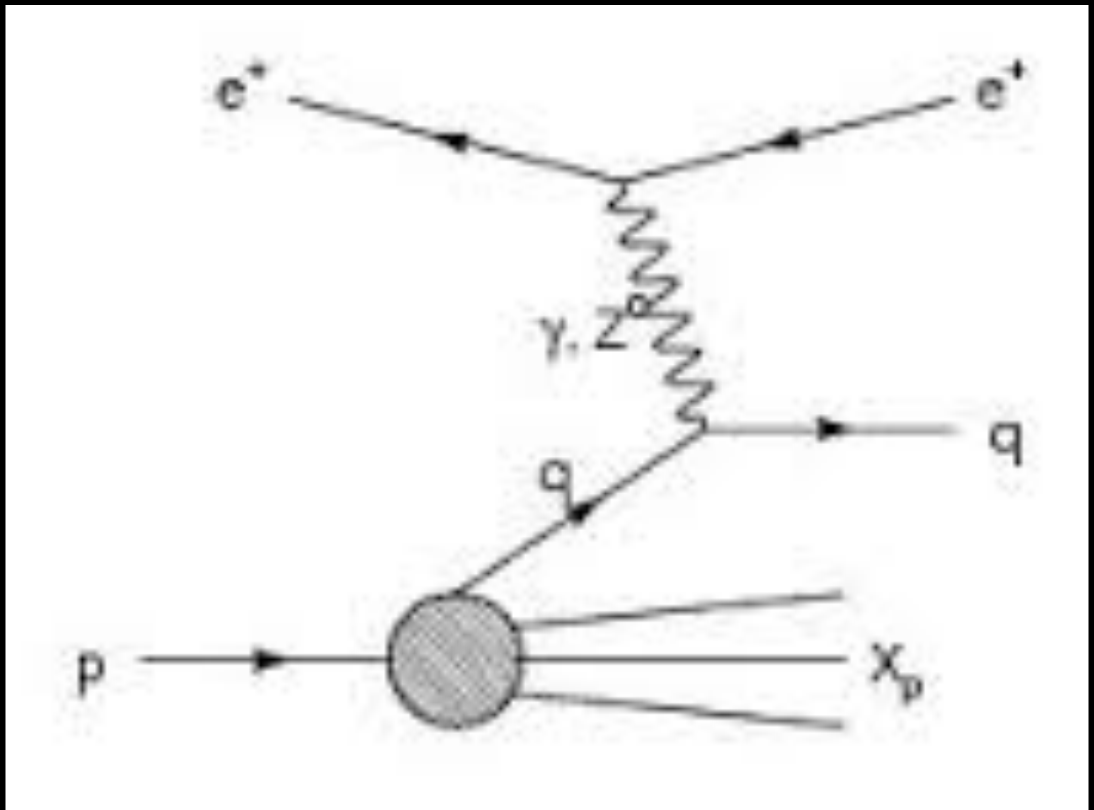
- large y $\Longrightarrow g^{eq}_{AV}$ and g^{eq}_{AV}



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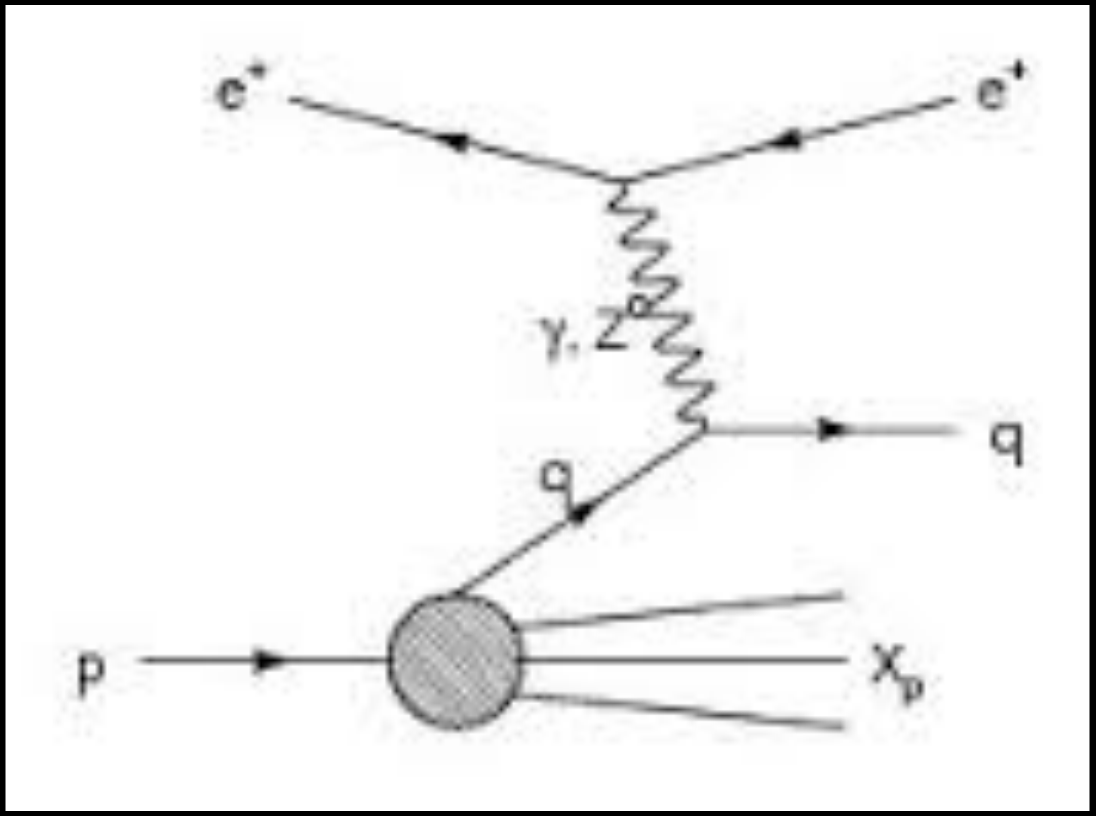
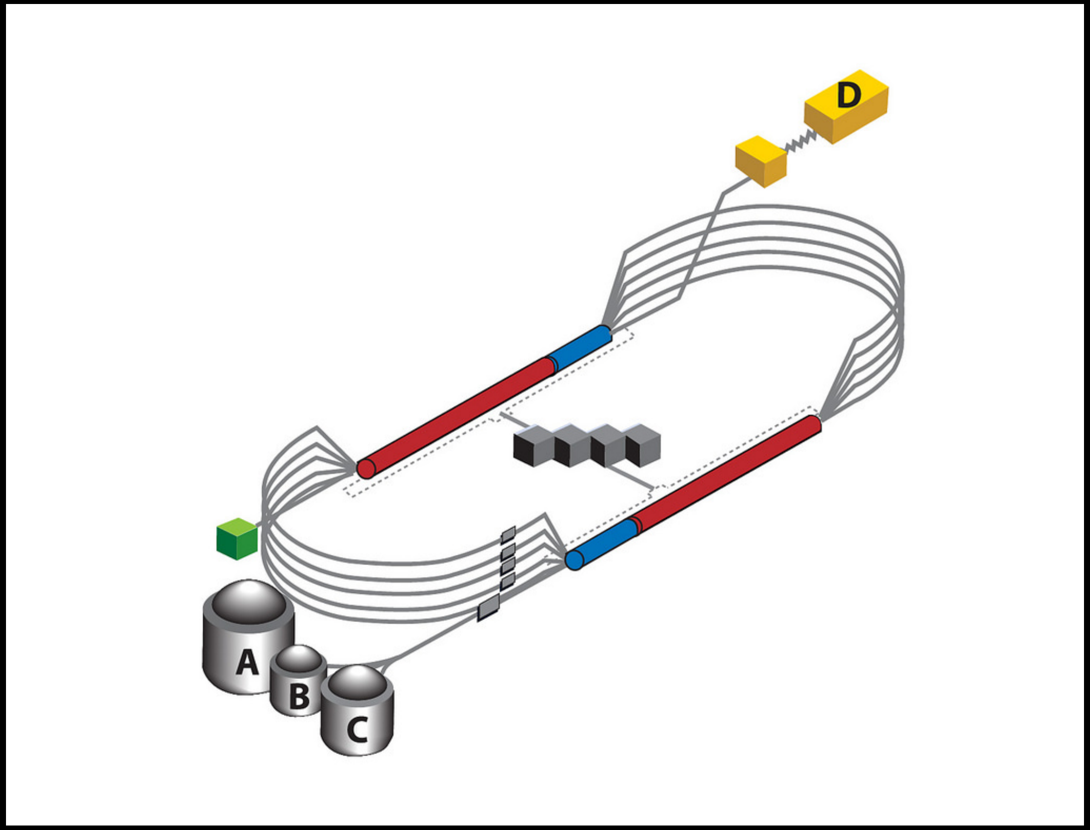
- Q_q weighted
  (γ-Z interference)

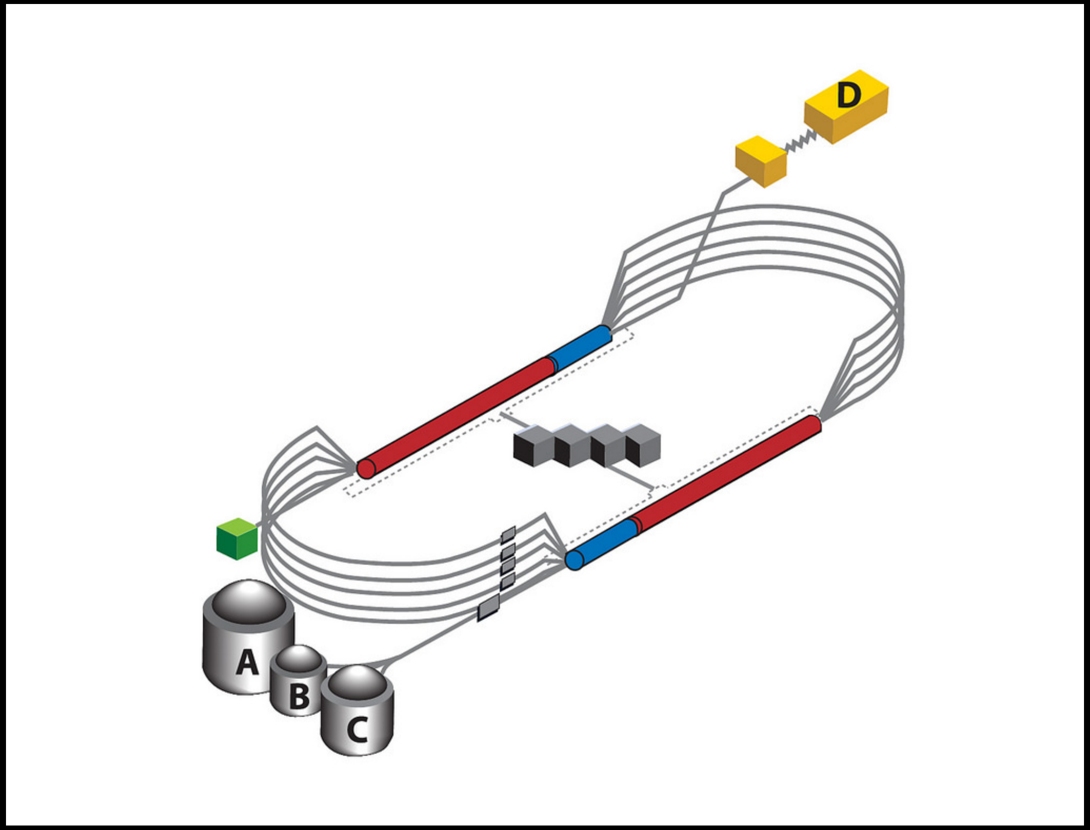


Polarized Møller scattering



Polarized Møller scattering

- $A_{LR} \sim 3 \times 10^{-8}$



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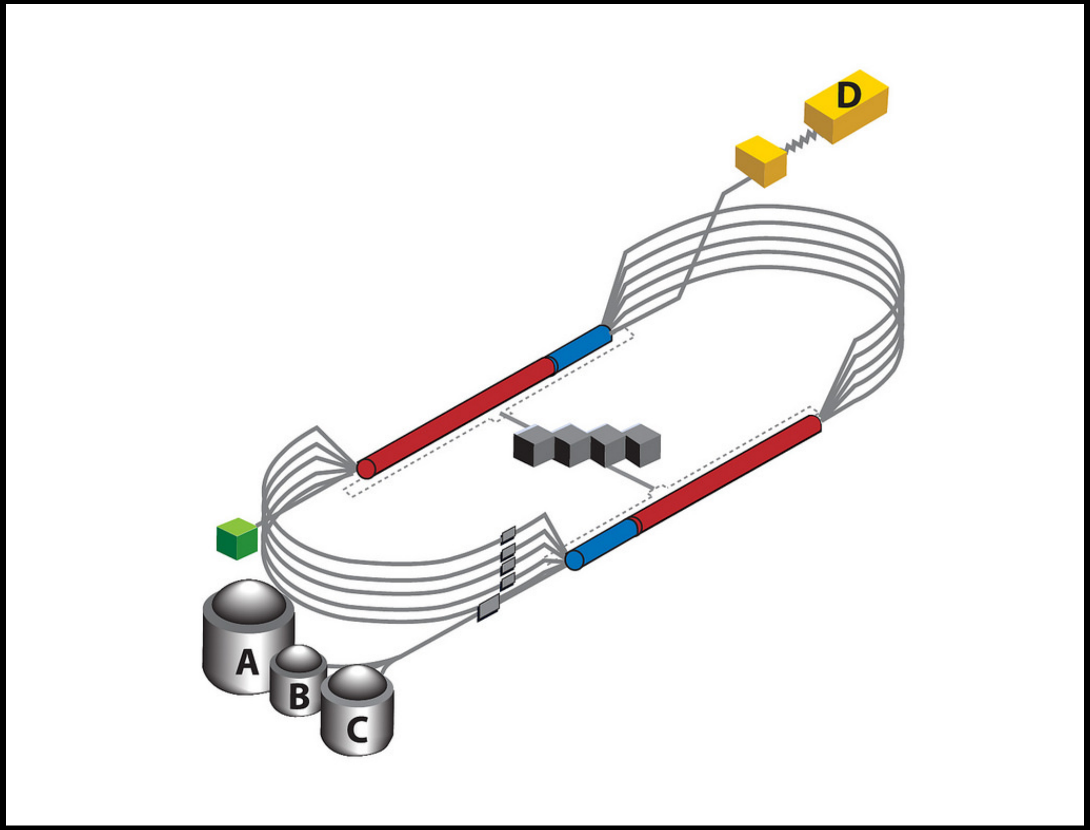
- $A_{LR} \sim 3 \times 10^{-8}$
- purely leptonic



Polarized Møller scattering

- $A_{LR} \sim 3 \times 10^{-8}$
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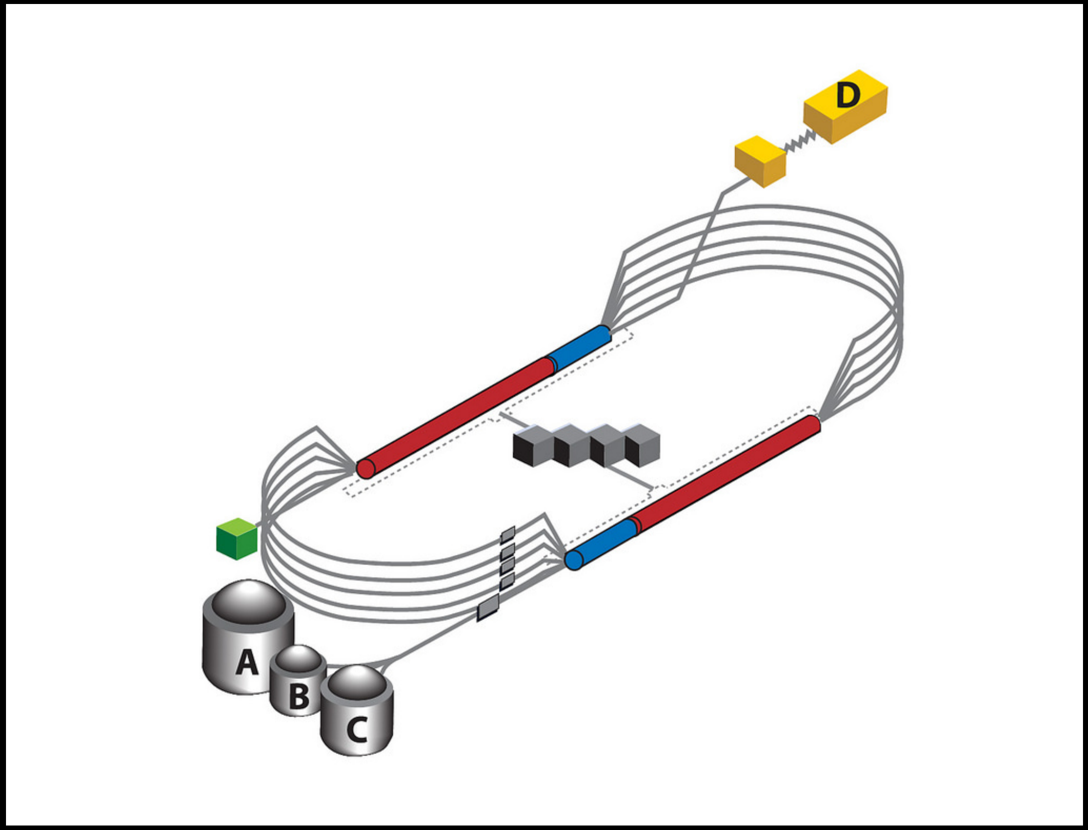
➡ very clean theoretically

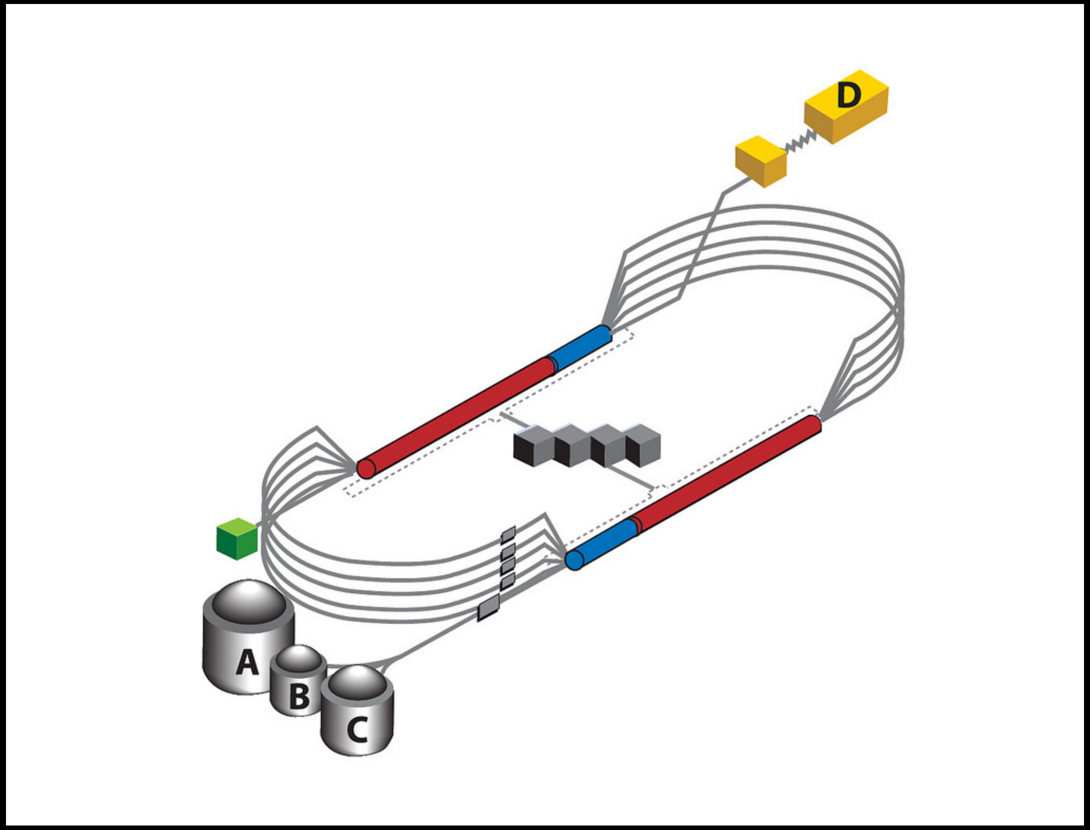


Polarized Møller scattering

- $A_{LR} \sim 3 \times 10^{-8}$
- purely leptonic

➡ very clean theoretically

➡ ultra-high precision



Polarized Møller scattering

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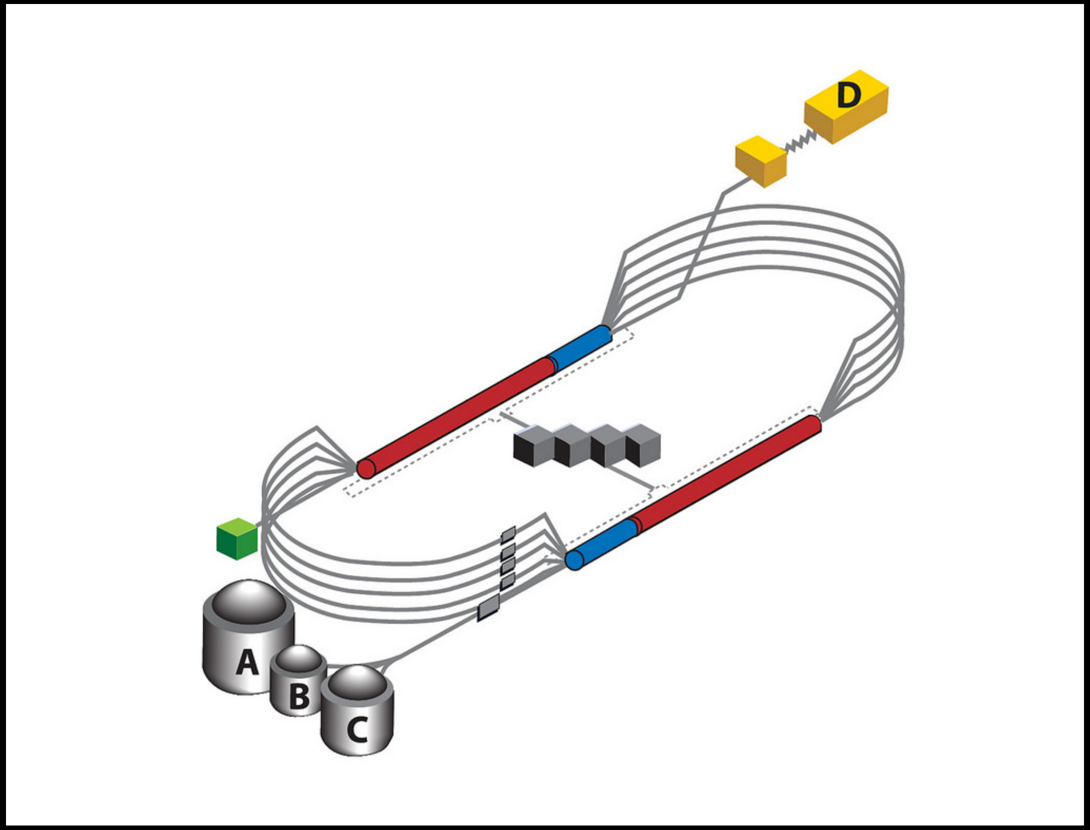
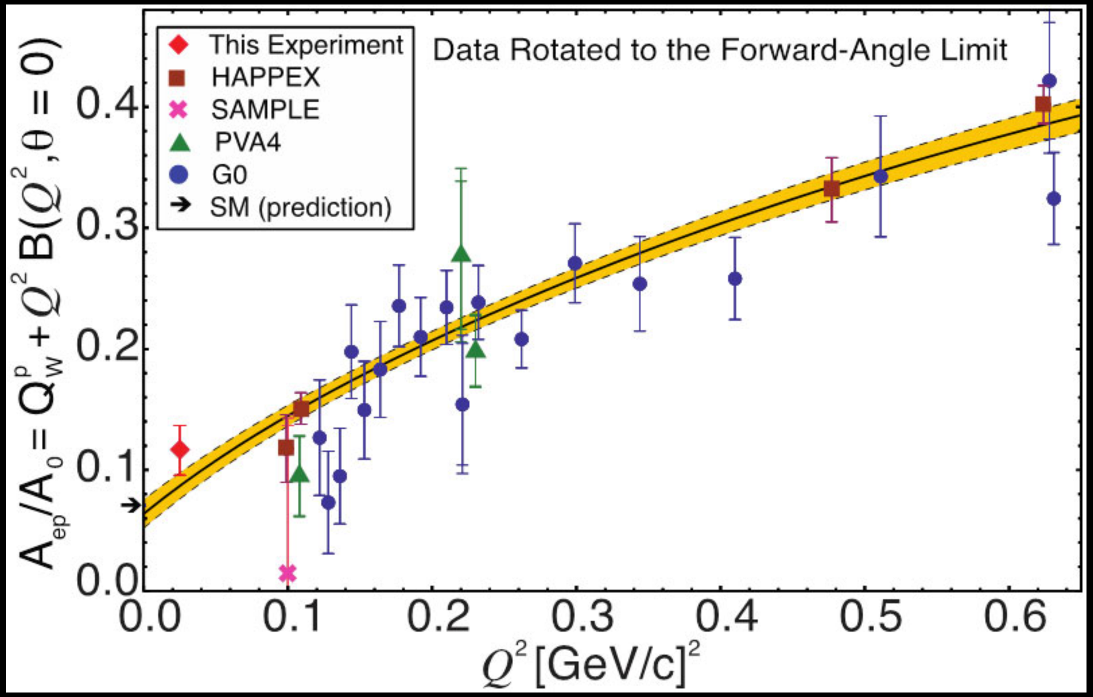
➡ very clean theoretically

➡ ultra-high precision

➡ need at least one 2-loop electroweak calculation
S. Barkanova & A. Aleksejevs (Memorial University of Newfoundland)

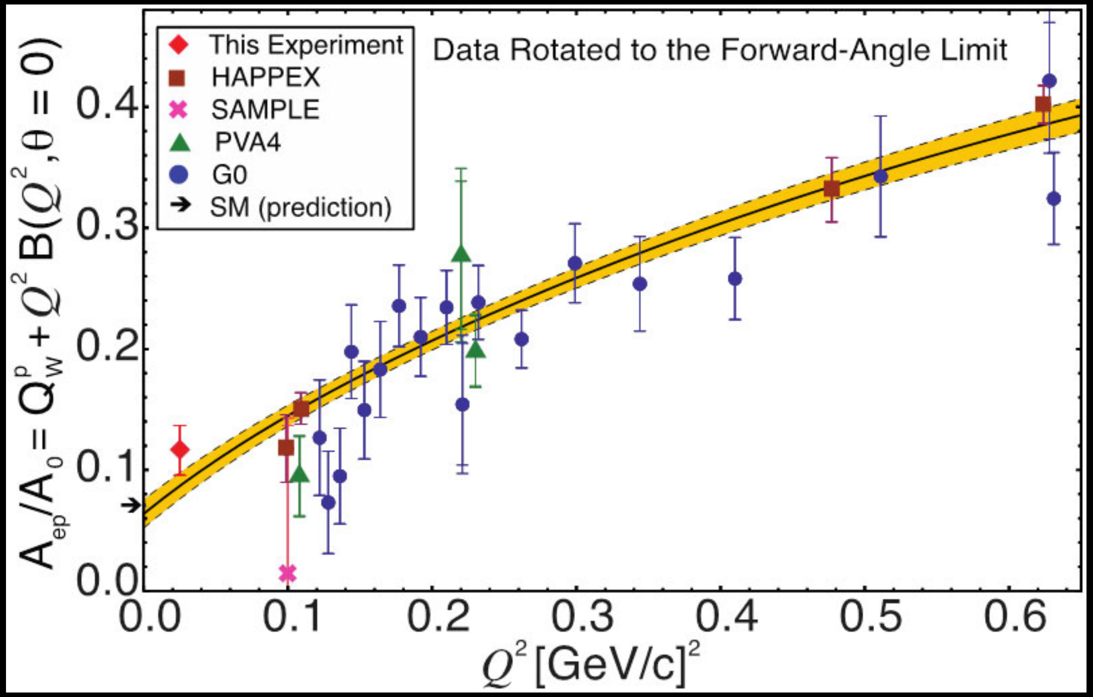


Polarized elastic scattering



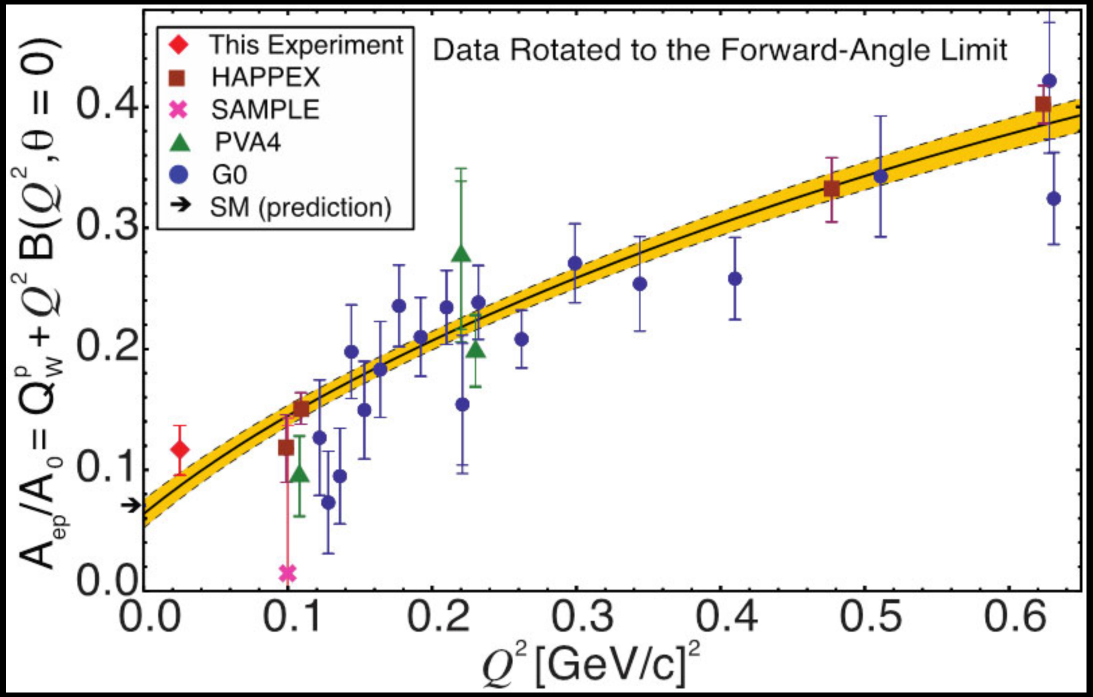
Polarized elastic scattering

- $A_{LR} \propto Q_W(p) + Q^2 B(Q^2, \theta)$



Polarized elastic scattering

- $A_{LR} \propto Q_W(p) + Q^2 B(Q^2, \theta)$
- Qweak: $Q^2 = 0.025\ \text{GeV}^2$



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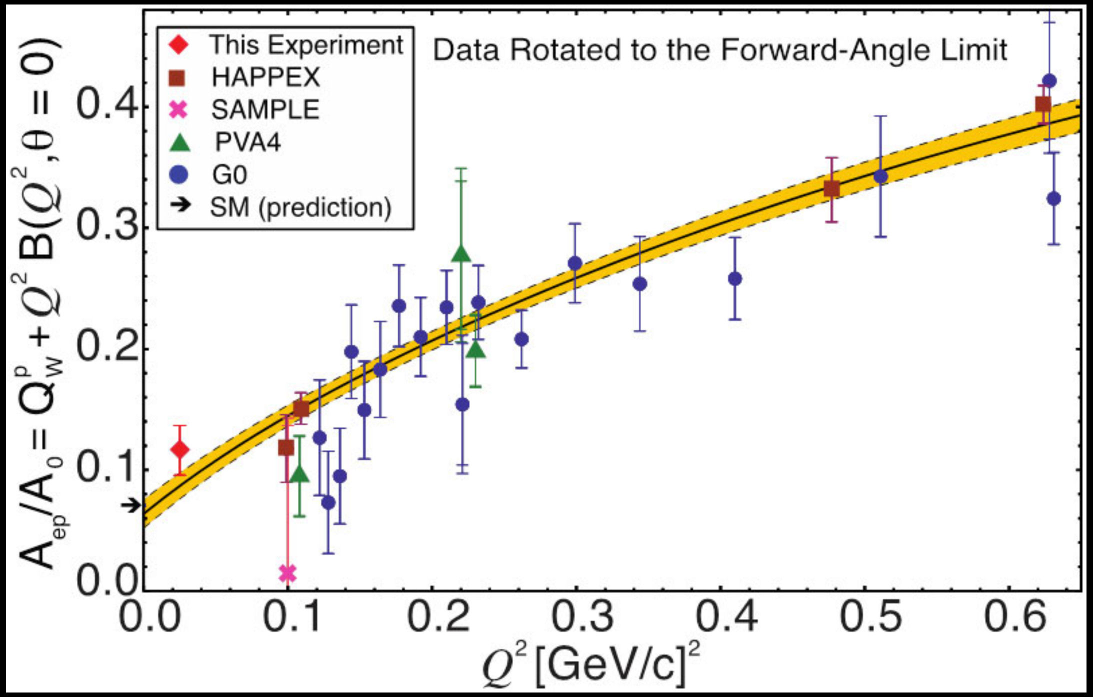
  - extrapolation to $Q^2 = 0$



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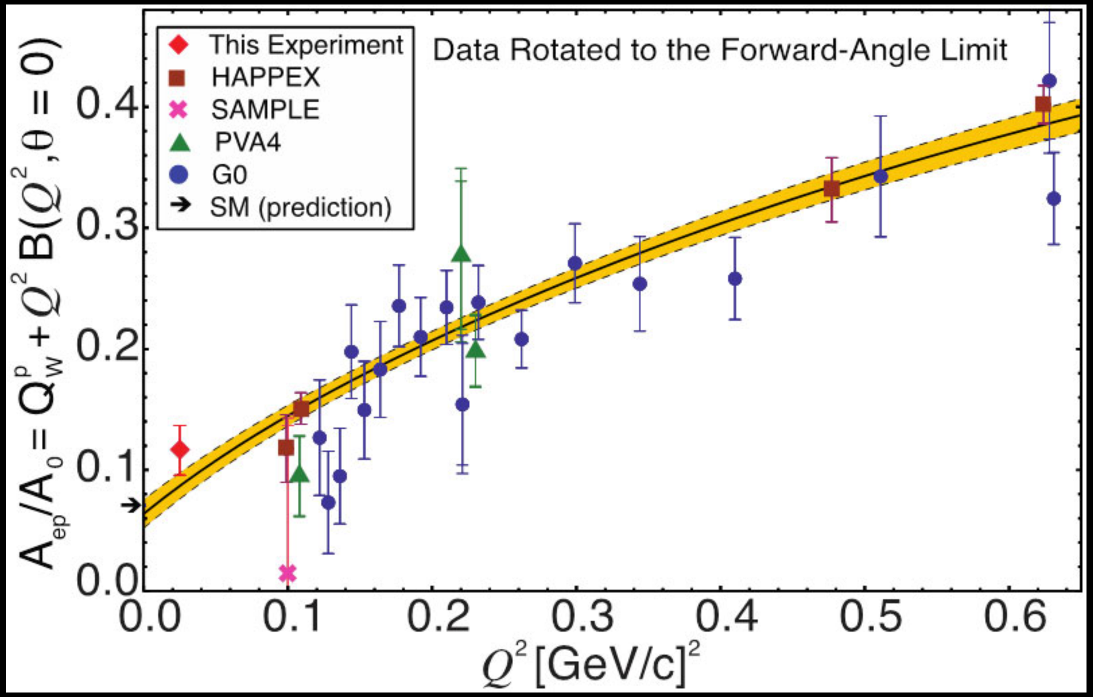
  - large γ-Z box **Gorchtein, Horowitz, Ramsey-Musolf; Rislow, Carlson; Hall, Blunden, Melnitchouk, Thomas, Young**



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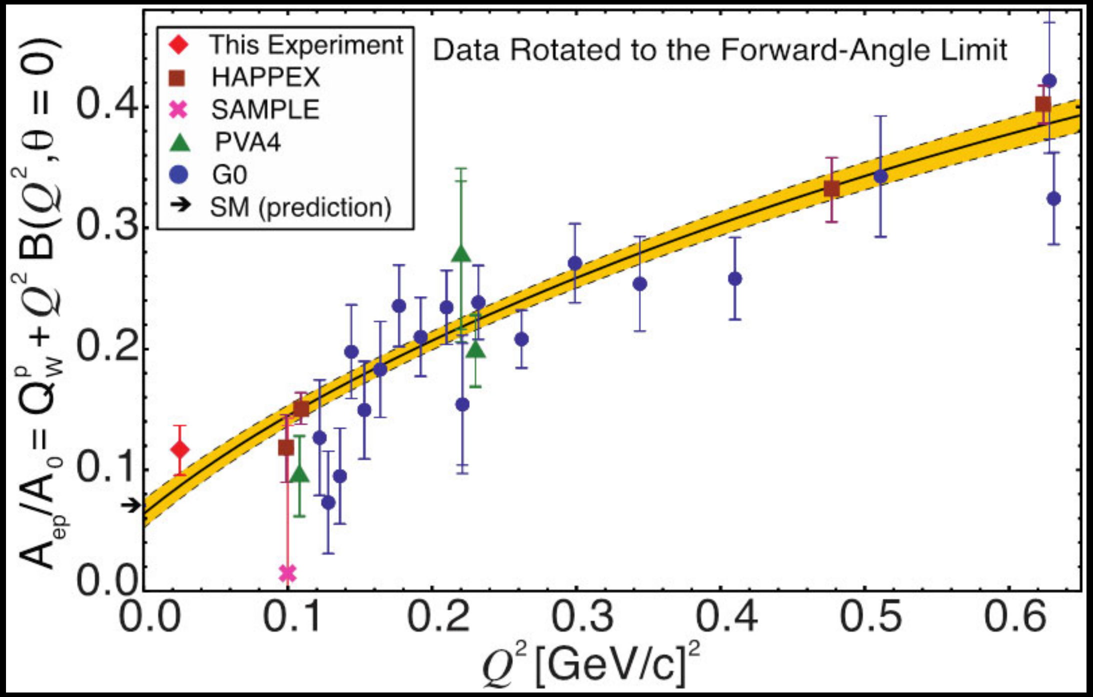

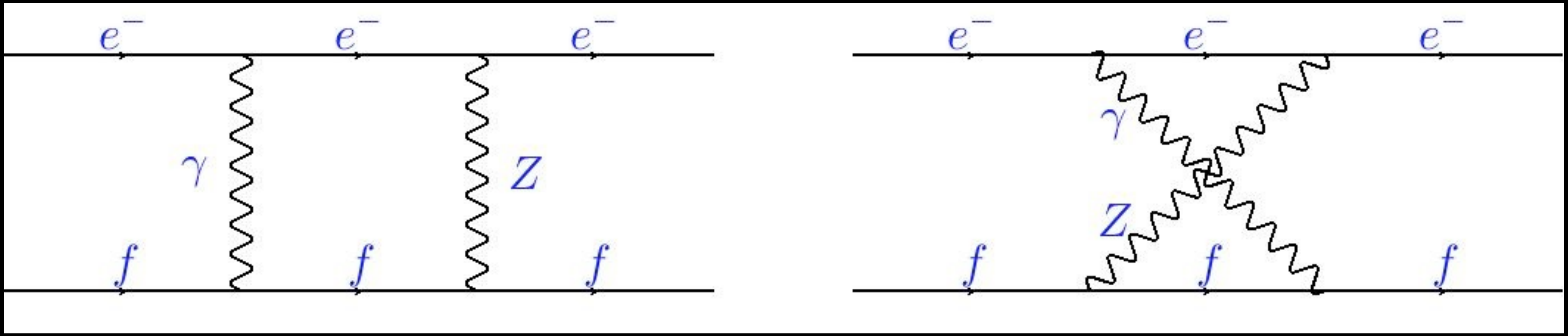

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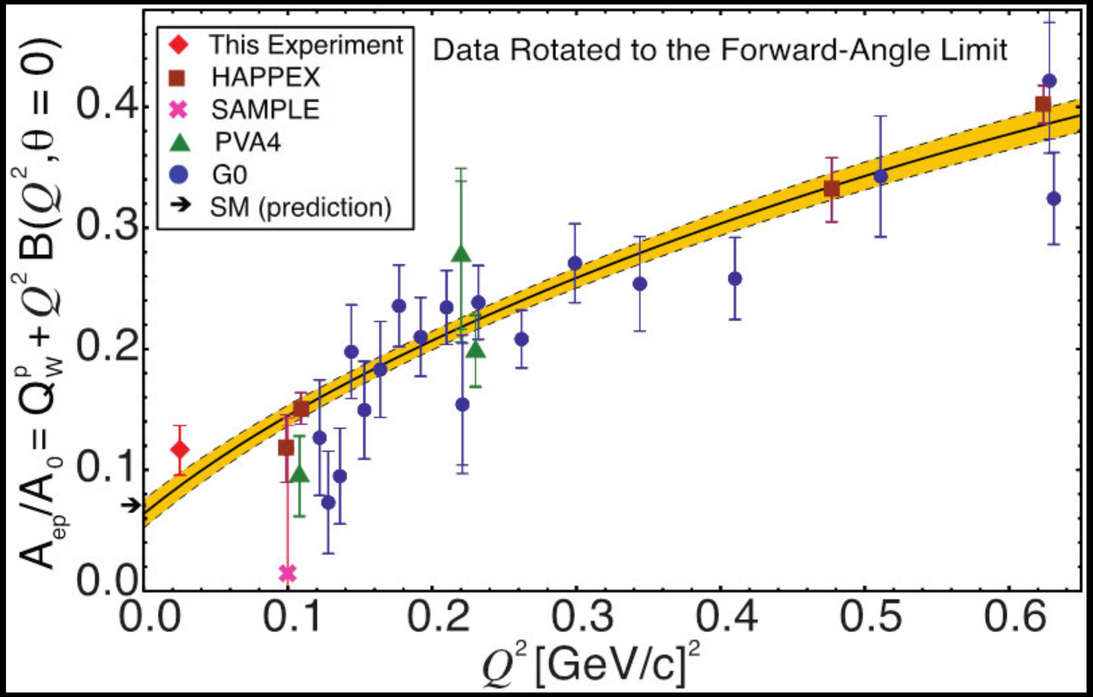
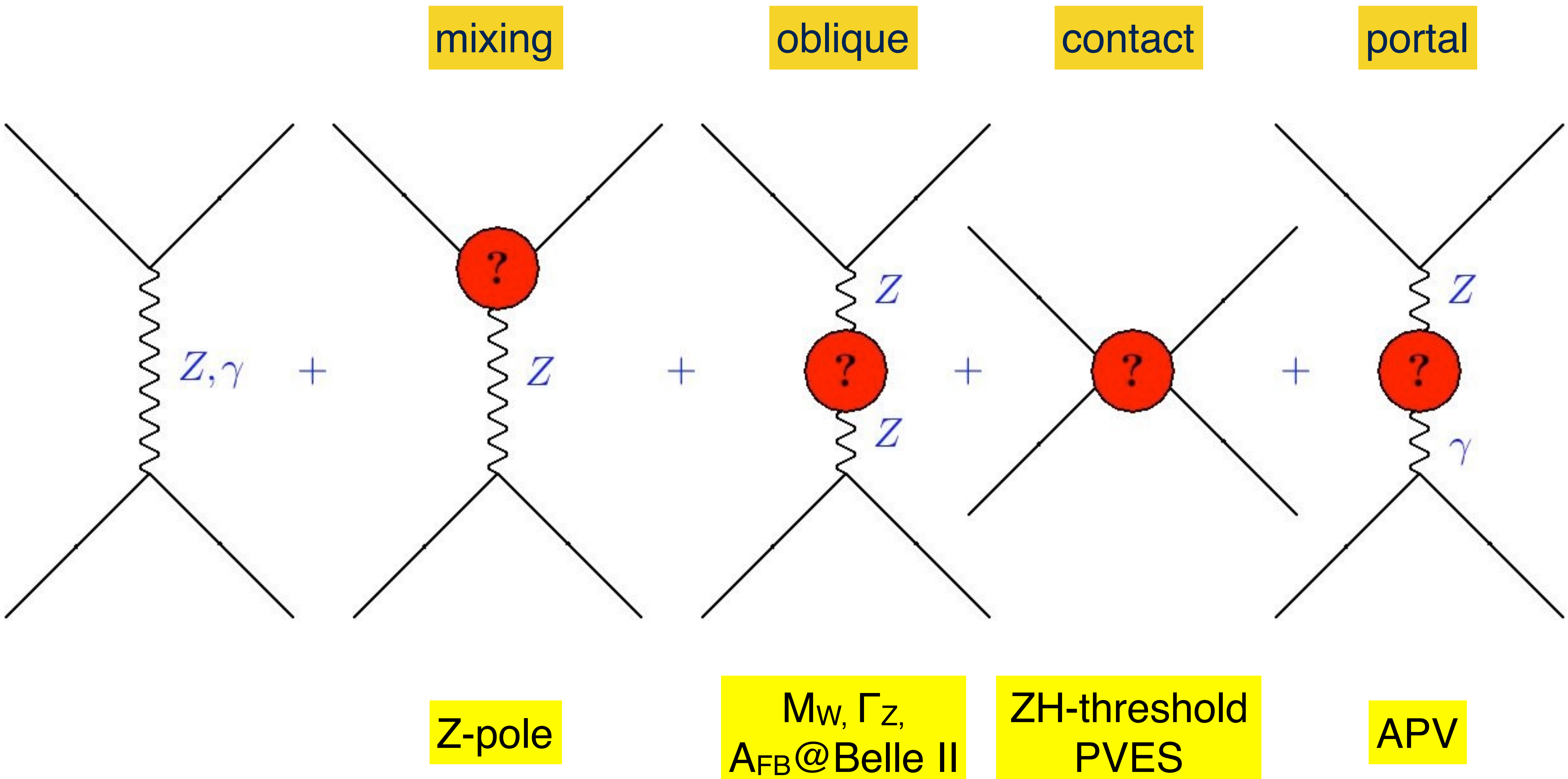


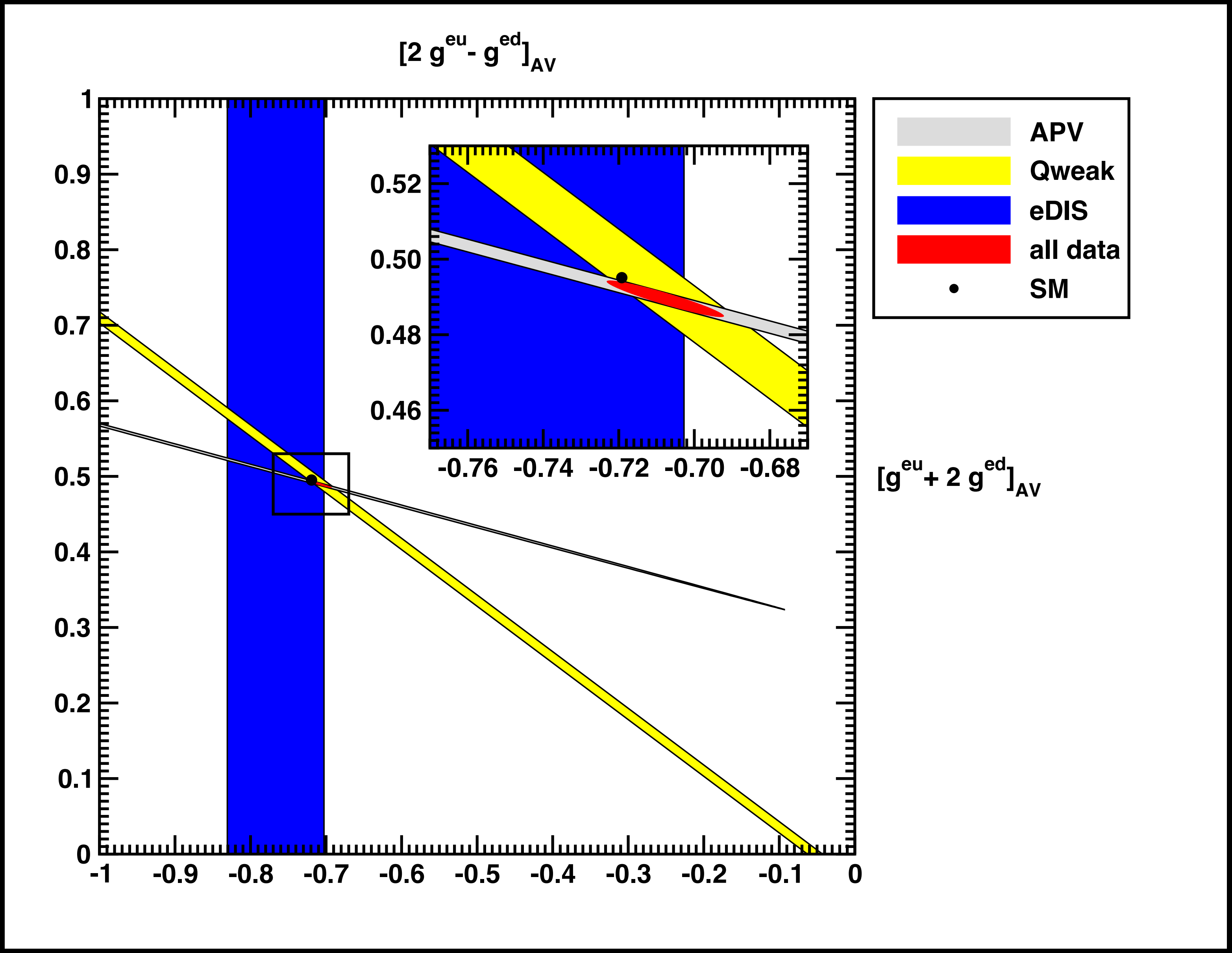
- P2: $Q^2 = 0.0045$ GeV^2 ($A_{LR} \sim 10^{-8}$)
    - γ-Z box correction (error) factor of 8 (5) smaller

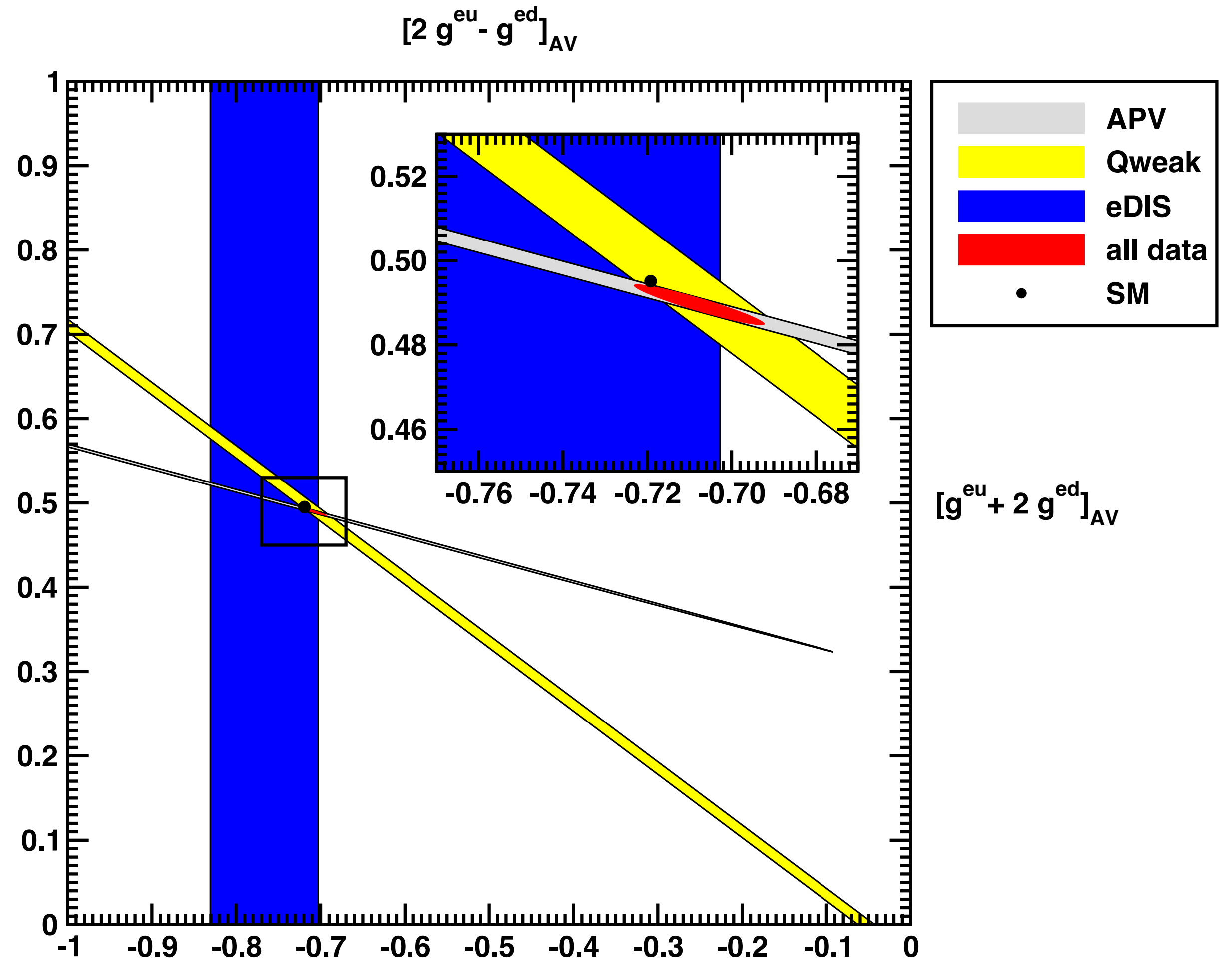
Beyond the Standard Model

New physics discrimination

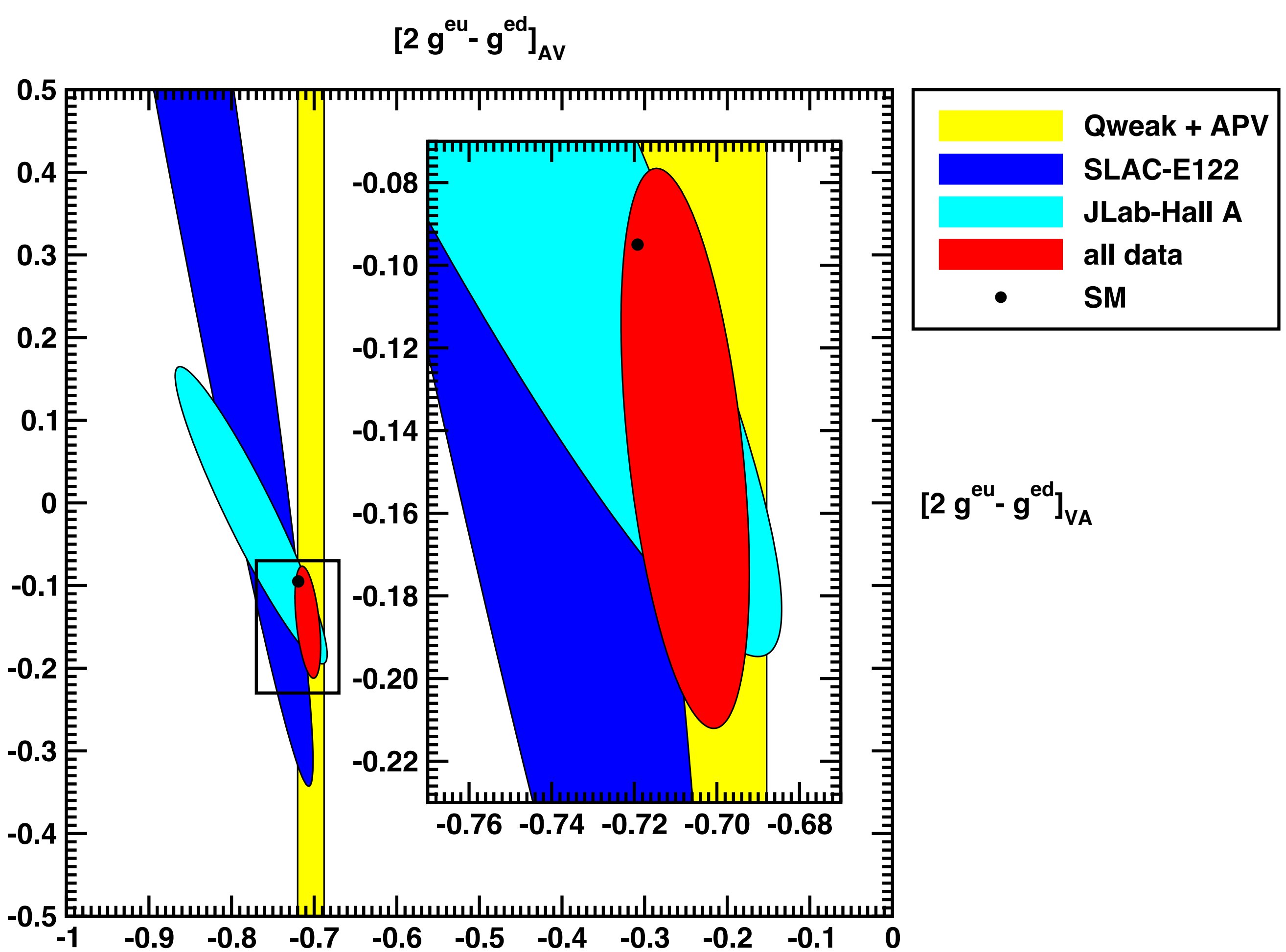


PV (axial)-electron (vector)-quark couplings



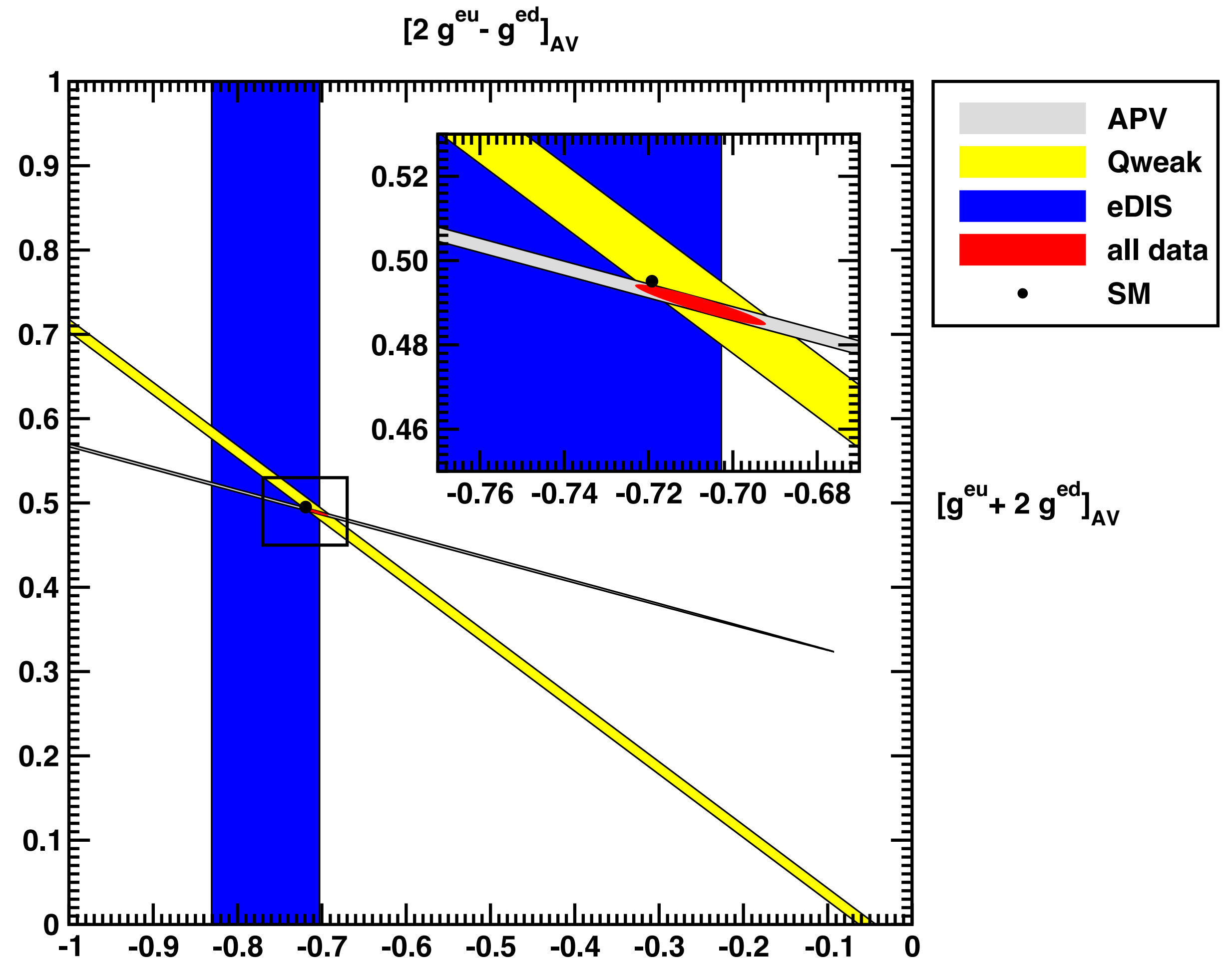


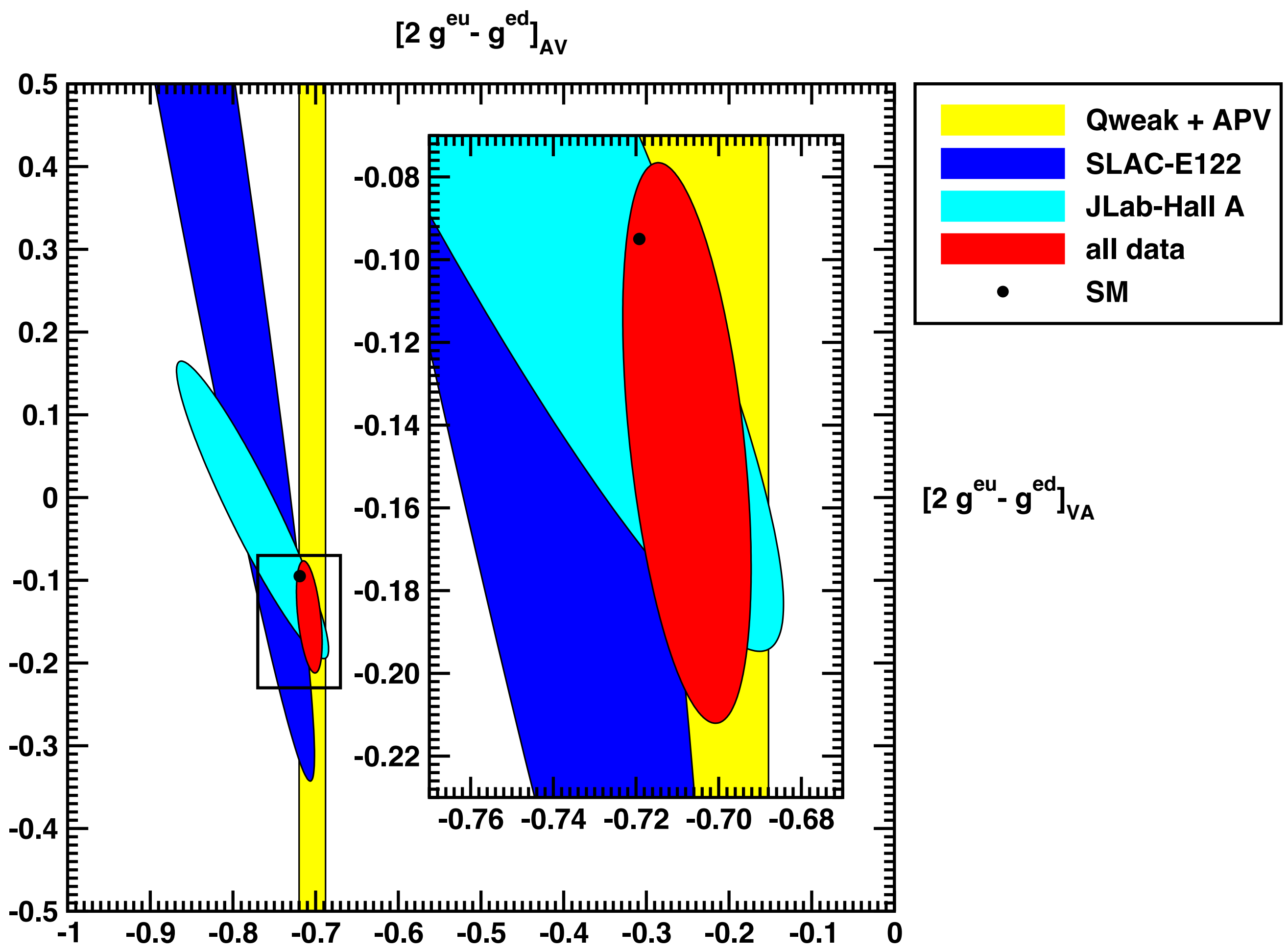
[2 g^eu - g^ed]_AV
APV
Qweak
eDIS
all data
SM
[g^eu + 2 g^ed]_AV

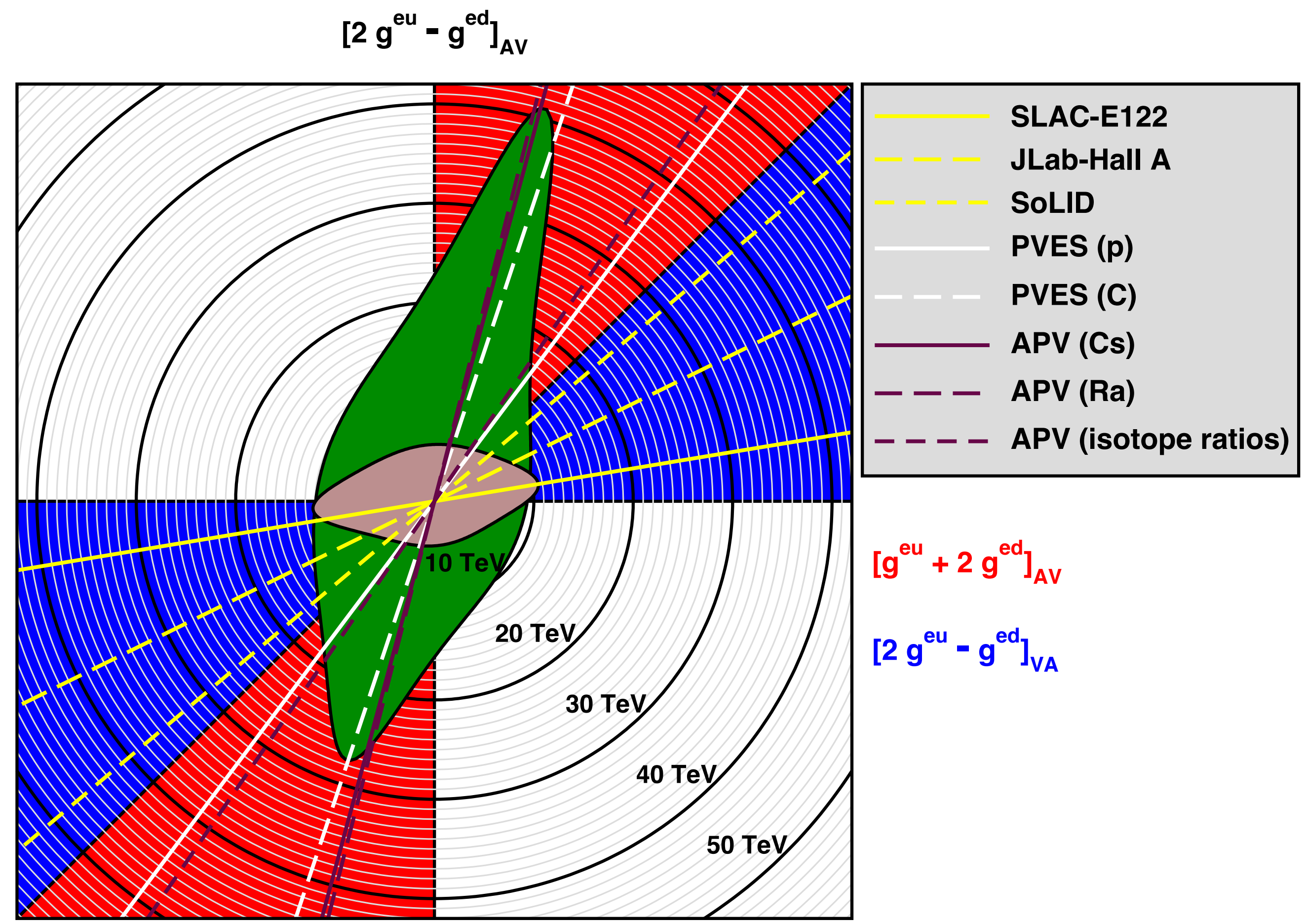


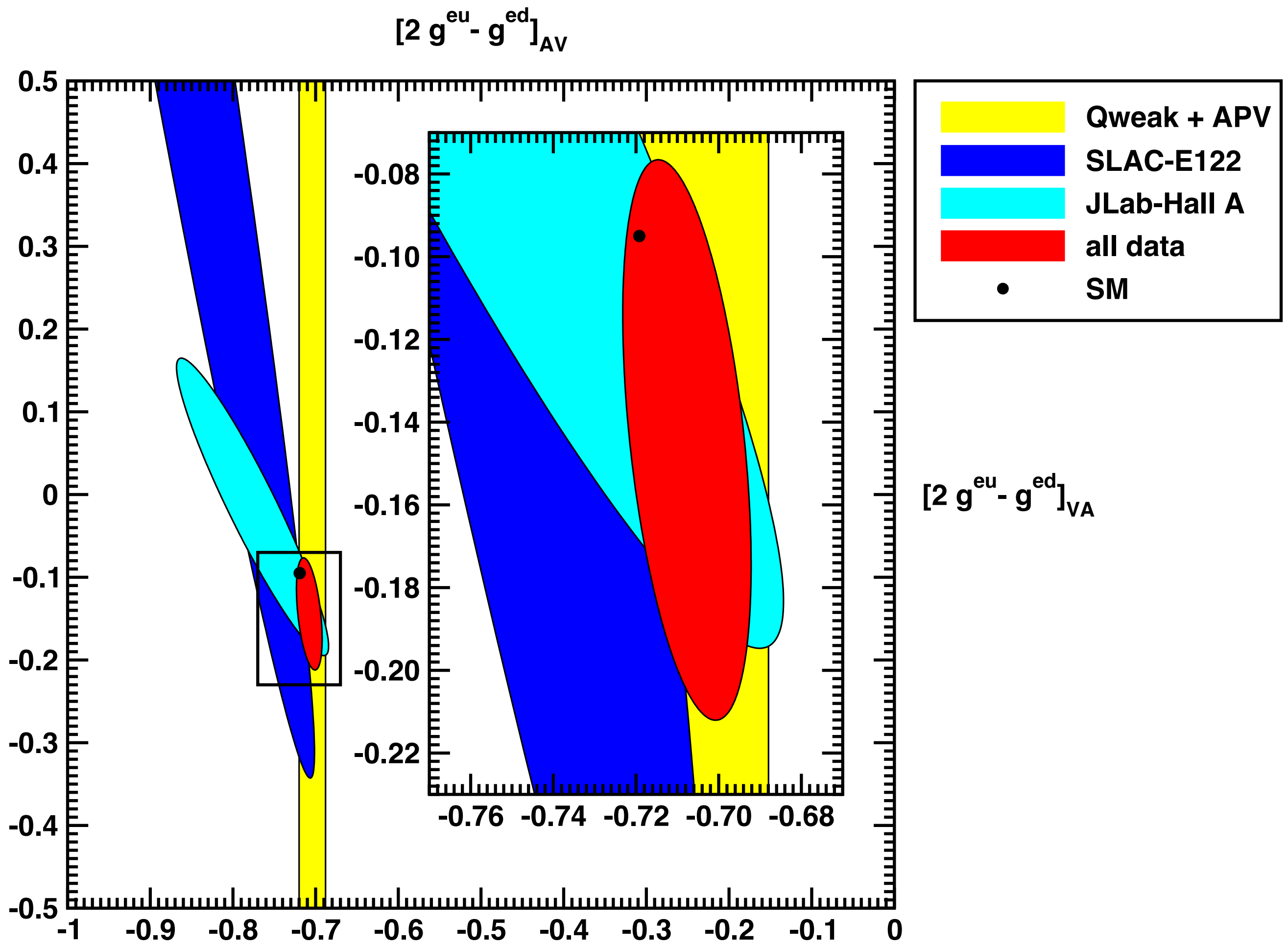
[2 g^eu - g^ed]_AV
Qweak + APV
SLAC-E122
JLab-Hall A
all data
SM
[2 g^eu - g^ed]_VA

Compositeness Scales

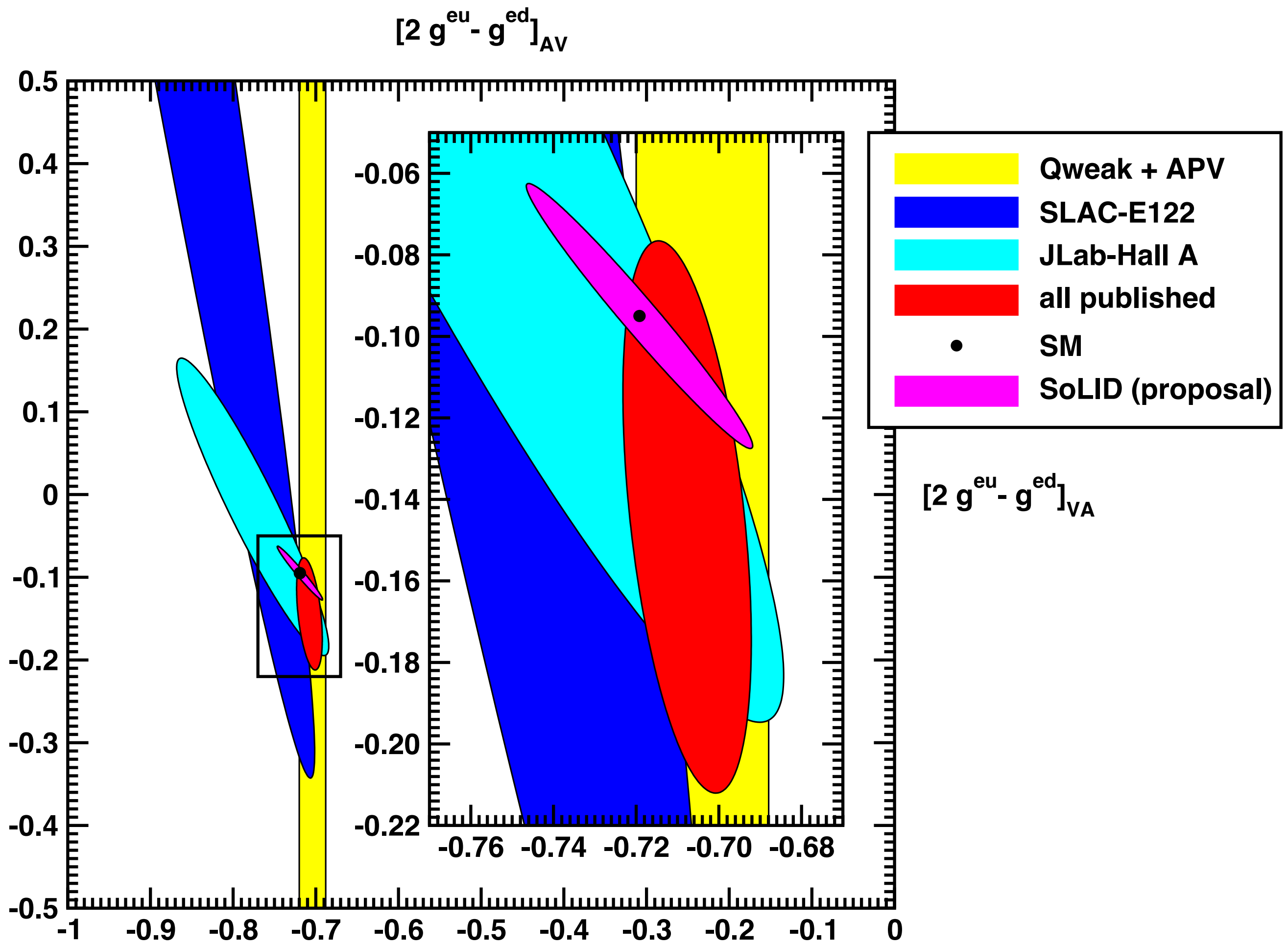








[2 g^eu - g^ed]_AV
[2 g^eu - g^ed]_VA
Qweak + APV
SLAC-E122
JLab-Hall A
all data
SM



[2 g^eu - g^ed]_AV
[2 g^eu - g^ed]_VA
Qweak + APV
SLAC-E122
JLab-Hall A
all published
SM
SoLID (proposal)

Summary

	precision	$\sin^2\theta_W$	Λ_{new}
APV Cs-133	0.58 %	0.0019	32.3 TeV
E158	14 %	0.0013	17.0 TeV
Qweak I	19 %	0.0030	17.0 TeV
PVDIS	4.5 %	0.0051	7.6 TeV
Qweak final	4.5 %	0.0008	33 TeV
SoLID	0.6 %	0.00057	22 TeV
MOLLER	2.3 %	0.00026	39 TeV
P2	2.0 %	0.00036	49 TeV
PVES ^{12}C	0.3 %	0.0007	49 TeV
APV ^{225}Ra	0.5 %	0.0018	34 TeV
APV ^{213}Ra / ^{225}Ra	0.1 %	0.0037	16 TeV

Recent Reviews

Krishna Kumar, Sonny Mantry, William Marciano and Paul Souder

Annu. Rev. Nucl. Part. Sci. 63 (2013) 237–67

Jens Erler and Shufang Su

Prog. Part. Nucl. Phys. 71 (2013) 119–149

Jens Erler and Ayres Freitas

Particle Data Group (2014)

Jens Erler, Charles Horowitz, Sonny Mantry and Paul Souder

Annu. Rev. Nucl. Part. Sci. (2014)