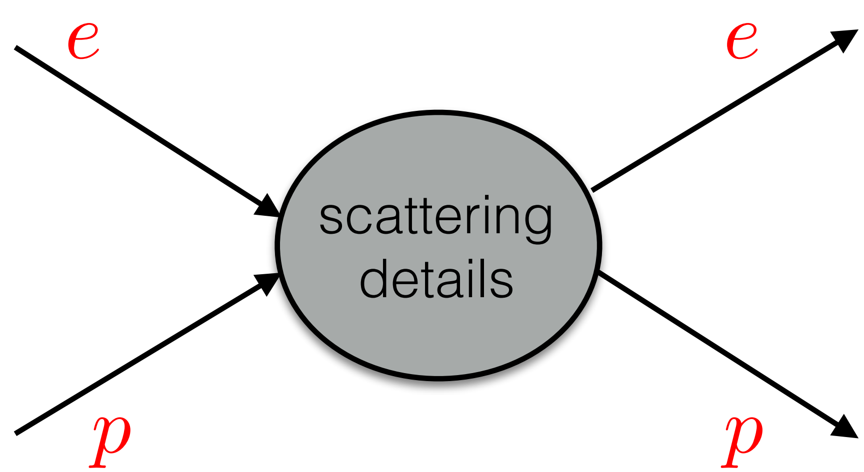
From Parity Violation In e-p Scattering to the Running of the Weak Mixing Angle

Kyle Shiells

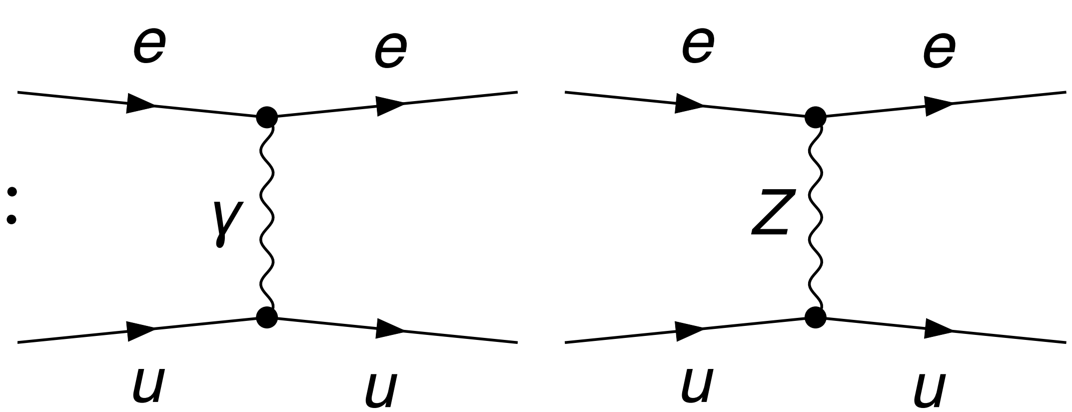
UNIVERSITY OF MANITOBA

PV e-p Scattering:

Process:



Tree Level Diagrams:



1 2

Weak Charge of the Proton <-> Left-Right Asymmetry:

at tree level:

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha} Q_W^{p,LO}$$ very small, but finite

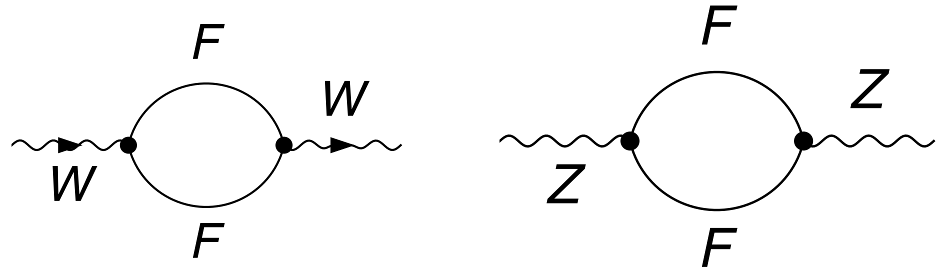
$$Q_W^{p,LO} = 1 - 4\sin^2\theta_W = 0.0688$$

$$\Rightarrow Q_W^{p,LO} \sim A_{LR}$$ link to measurement as $Q^2 \to 0$

One-Loop Quantum Corrections to Q_W^p

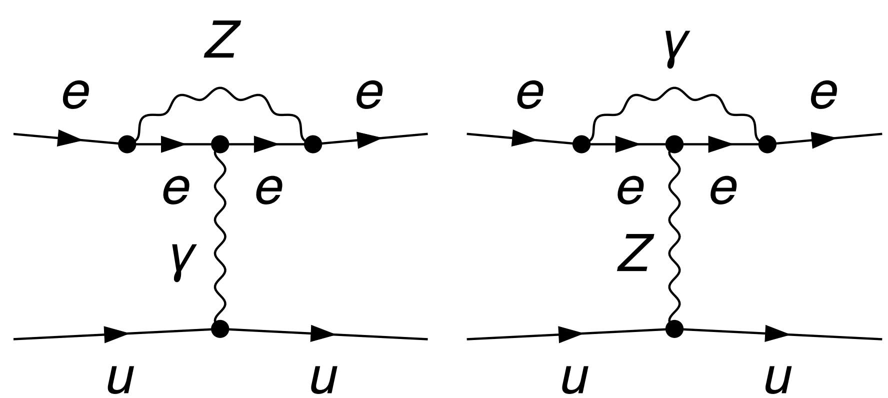
$$Q_W^{p,NLO} = [\rho_{NC} + \Delta_e][1 - 4\sin^2\theta_W(0) + \Delta_e'] + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$

ρ_{NC} :



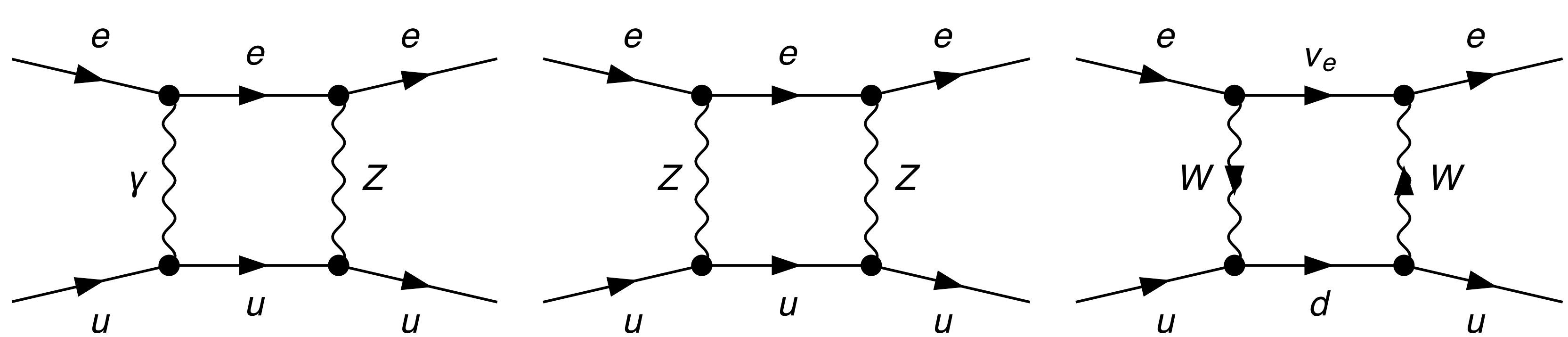
1 1

Δ_e' , Δ_e :



1 2

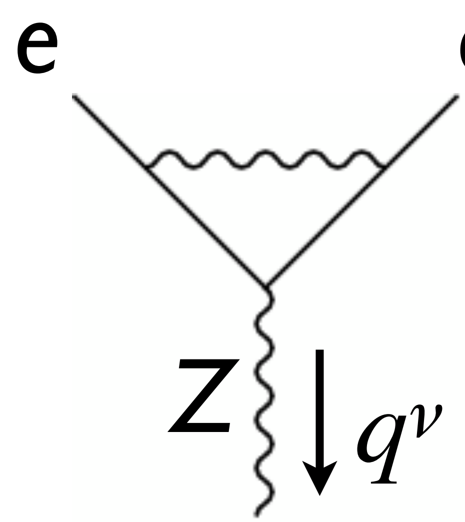
$\Box_{\gamma Z}$, $\Box_{ZZ}$, $\Box_{WW}$:



1 2 3

Vertex correction: $$Q_W^p = (1 + \Delta\rho + \Delta_e)(1 - 4\sin^2\theta_W(0) + \Delta_e') + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}(0)$$

Electromagnetic: $\Delta_e = -\frac{\alpha}{2\pi} \sim 0.00116$ (0.1% of 0.0708)



$$\gamma_\mu \to \gamma_\mu(1 + \delta f_1) + \frac{\delta f_2}{2m_e}\sigma_{\mu\nu}(-q^\nu)$$

$$\gamma_\mu\gamma_5 \to \gamma_\mu\gamma_5(1 + \delta g_1) + \frac{\delta g_2}{m_e}\cancel{\gamma_5(-q_\mu)}$$

Thompson limit ($Q^2 \ll m_e^2$): $\delta f_1 = 0; \quad \delta f_2 = \frac{\alpha}{2\pi}; \quad \delta g_1 = -\frac{\alpha}{2\pi}$

Scattering ($Q^2 \gg m_e^2$): $\delta f_1 \sim \log\frac{Q^2}{m_e^2} \times \log\frac{\lambda^2}{m_e^2}; \quad \delta f_2 \to 0; \quad \delta g_1 \to \delta f_1$

IR divergent
(cancelled by soft photon emission)

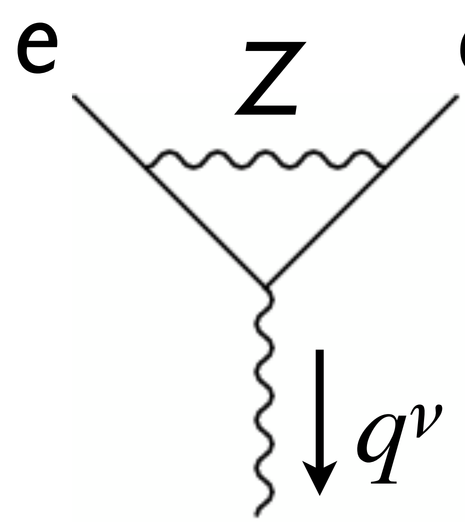
Overall Zee vertex has same (divergent) factor as γee

$\longrightarrow$ Cancels in A_{PV} (or include with standard rad. corr.).

Therefore take $\Delta_e = 0$ for scattering.

Vertex correction: $$Q_W^p = (1+\Delta\rho+\Delta_e)(1-4\sin^2\theta_W(0)+\Delta'_e) + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}(0)$$

Electroweak: $\Delta'_e = -0.0014$ (1.9% of 0.0708)



Thompson limit ($Q^2 \ll m_e^2$): $$\Delta'_e(0) = -\frac{\alpha}{3\pi}(1-4\hat{s}^2)\left(\log\frac{M_z^2}{m_e^2}+\frac{1}{6}\right)$$

Scattering ($Q^2 \gg m_e^2$): $$\Delta'_e(Q^2) = -\frac{\alpha}{3\pi}(1-4\hat{s}^2)\left(\log\frac{M_z^2}{Q^2}+\frac{11}{6}\right)$$

$$\Delta'_e(Q^2) = \Delta'_e(0) + \underbrace{\frac{\alpha}{3\pi}(1-4\hat{s}^2)\left(\log\frac{Q^2}{m_e^2}-\frac{5}{3}\right)}_{+0.0006 \text{ at } Q^2=0.025\ \mathrm{GeV}^2}$$

Same size as electron contribution from running of $\sin^2\theta_W$

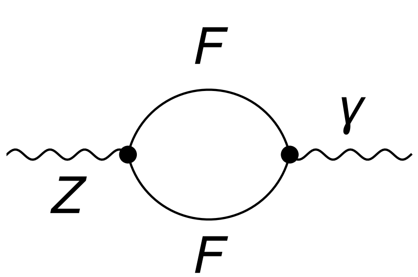
Corrections to $\sin^2\theta_W$

$$1 - 4\sin^2\theta_W(0) = 1 - 4\kappa(Q^2 = 0)\sin^2\theta_W(M_Z^2)$$

comes from all 1-Loop RC's contributing to γZ mixing

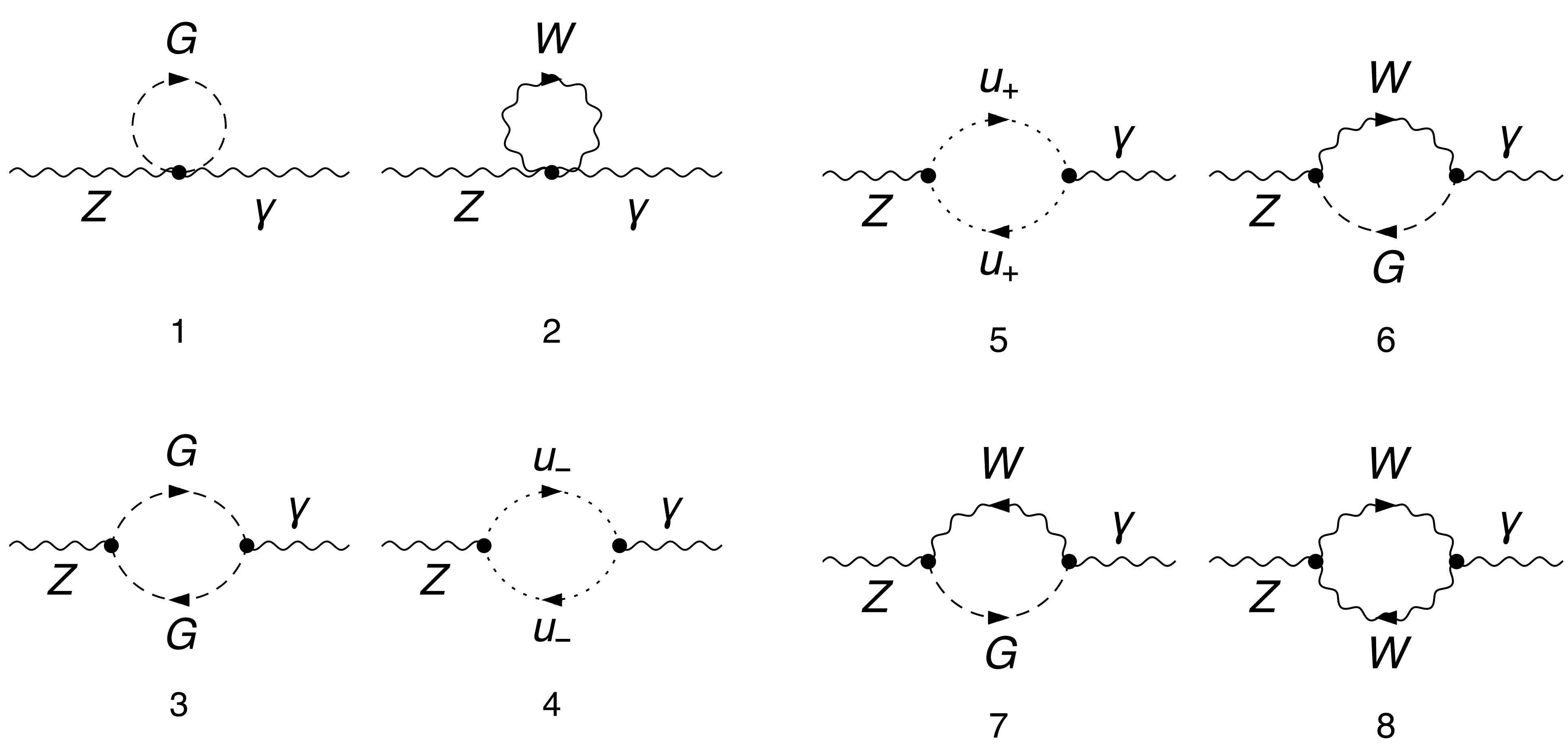
well-measured

Fermonic Loops:



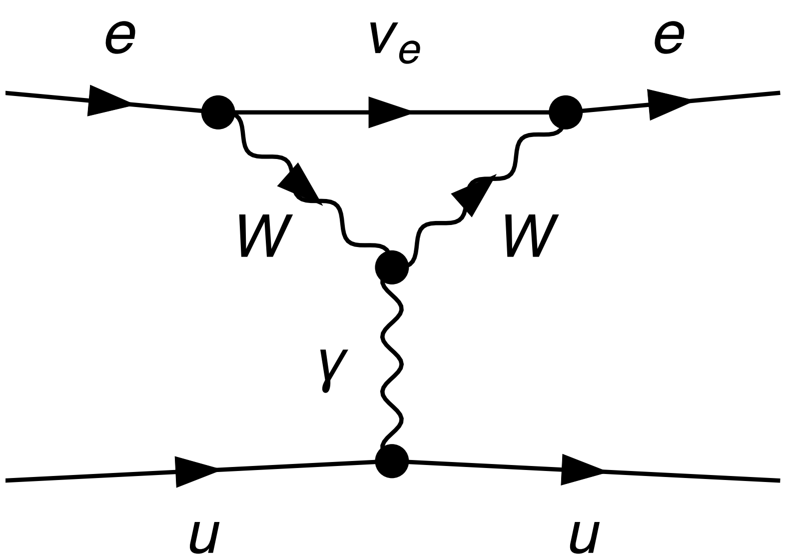
1

Bosonic Loops:



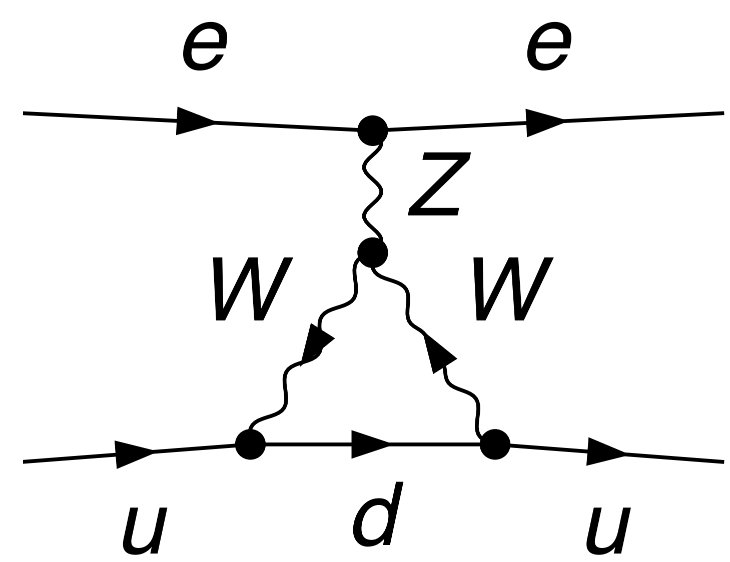
Vertex Contributions to $\kappa^{PT}(Q^2)$

1. Electron's Anapole Moment:



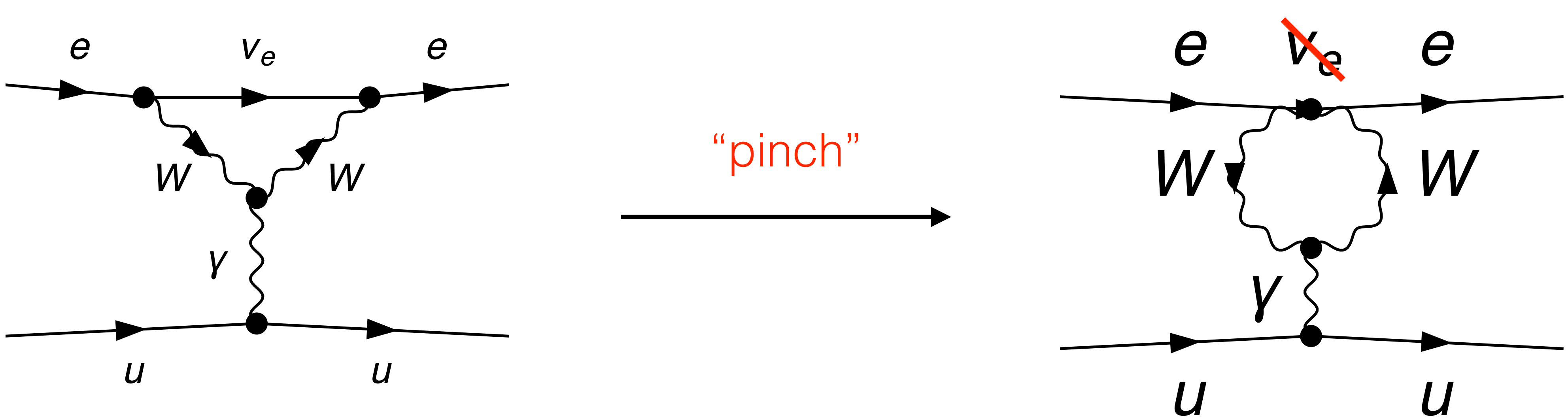
1

2. Proton vertex correction:



1

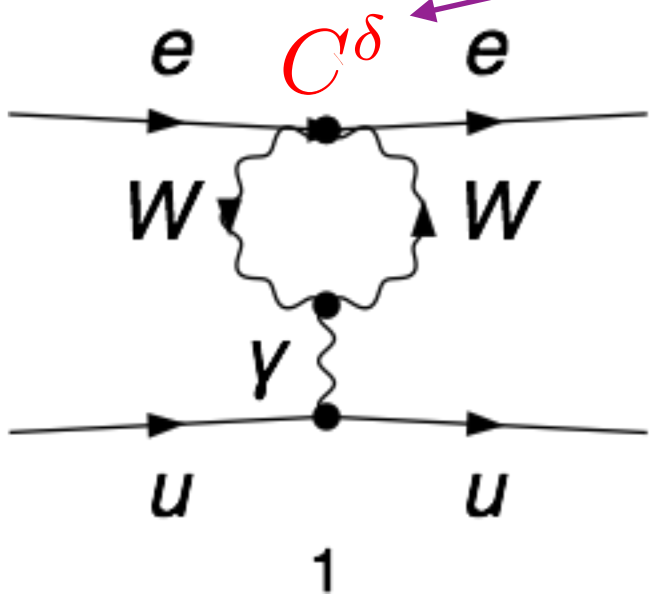
Expanding the γWW vertex gives a term which apparently cancels the neutrino propagator (aka the "Pinch Technique"[G. Degrassi, A. Sirlin, Phys. Rev. D 46, 3104 (1992)])



1

1

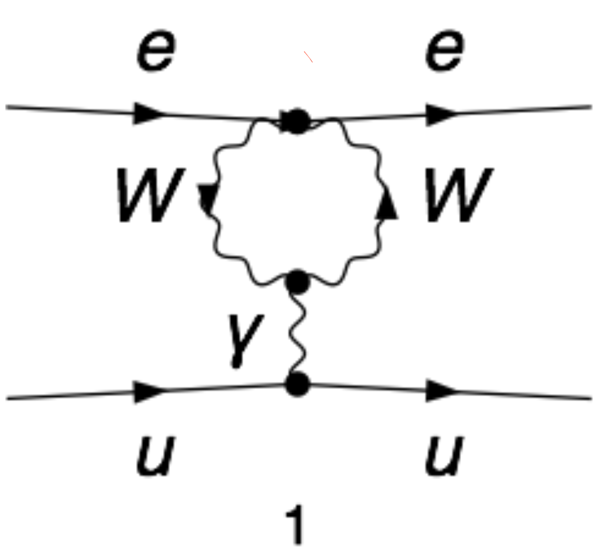
Pinched Diagram



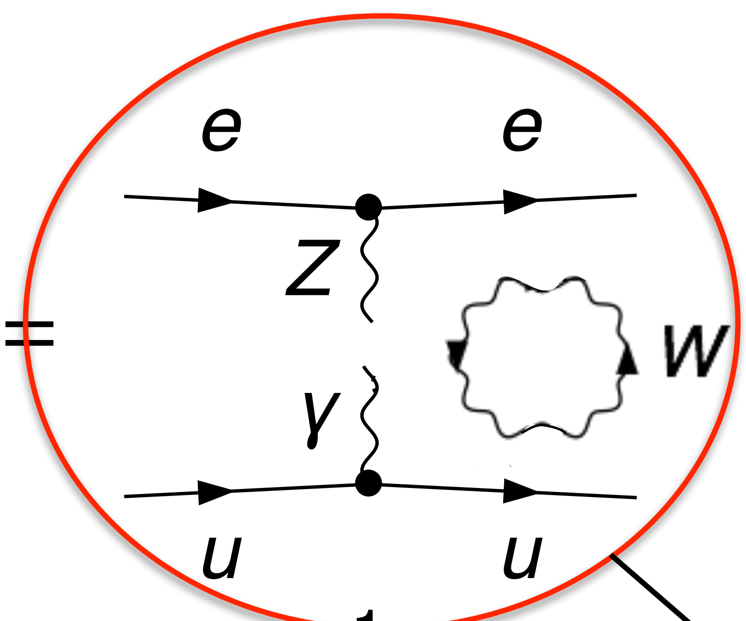
This is not a physical vertex in EW theory, but some "effective" vertex given by: $C^\delta = \gamma^\delta(1-\gamma_5)$

Solution: rewrite this effective vertex as a superposition of physical vertex factors with the Z and γ bosons:

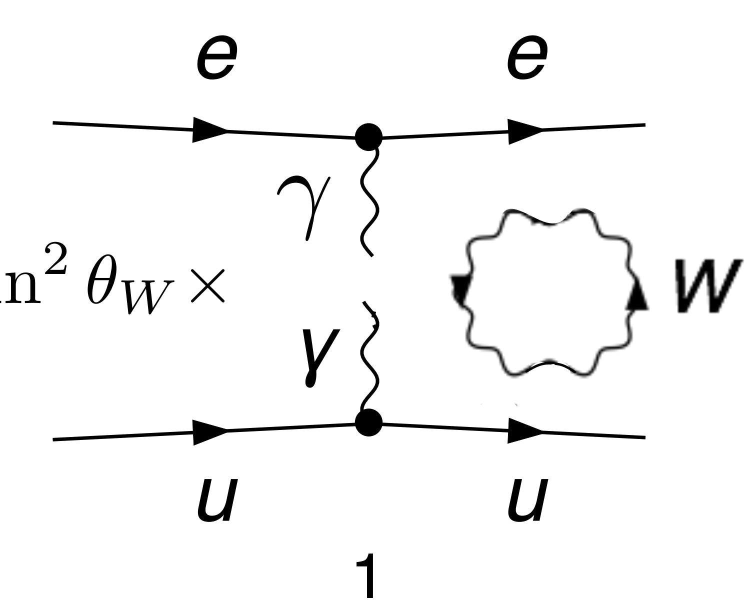
$$C^\delta = V^\delta_{Zee} + 4\sin^2\theta_W V^\delta_{\gamma ee}$$



=



$+ \; 4\sin^2\theta_W \times$



this part contributes to $\sin^2\theta_W$!

Similarly, the proton vertex correction must be pinched in this way

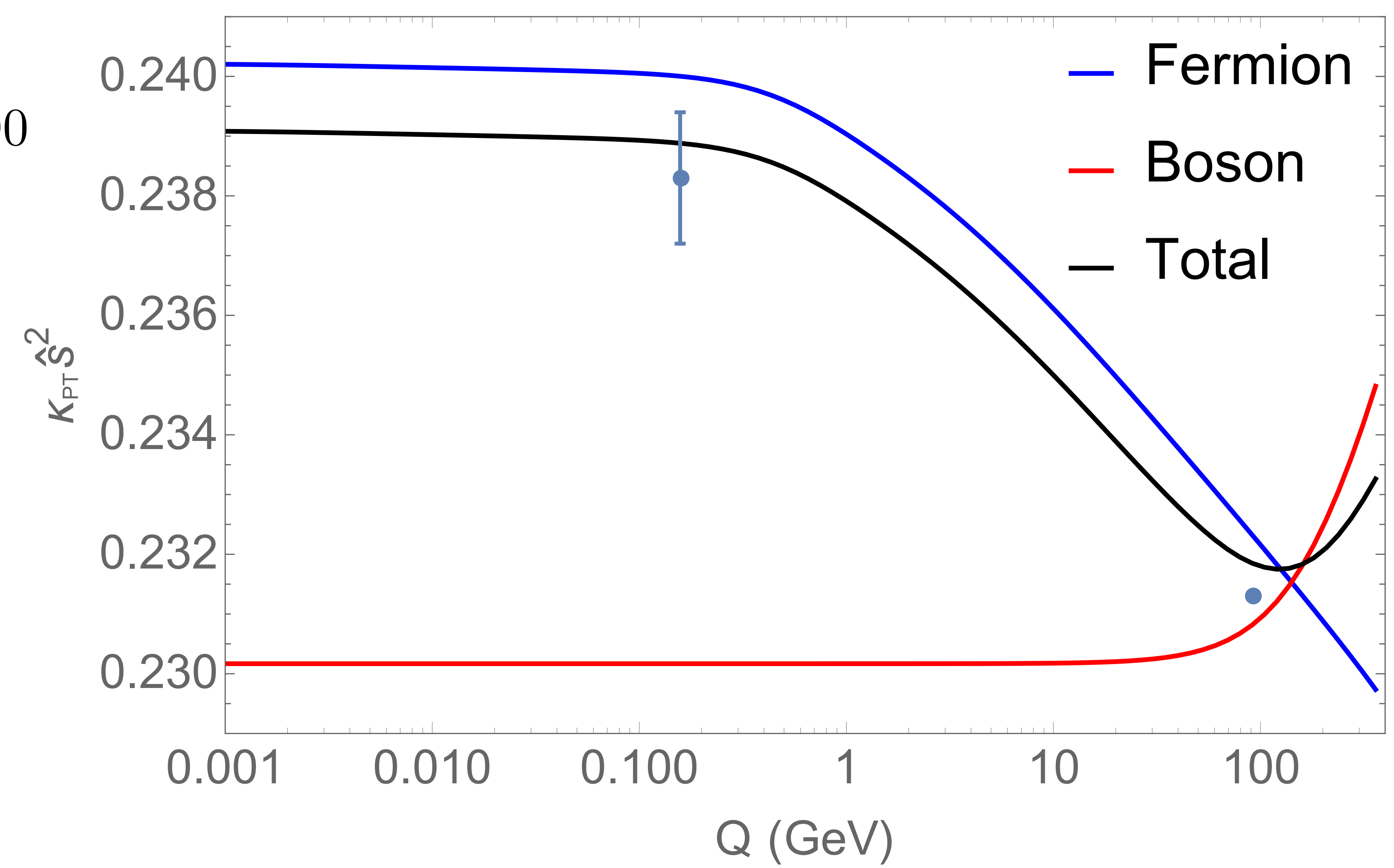
Revised expression

$$Q_W^p = \rho\left(1 - 4\kappa^{\mathrm{PT}}(0)\hat{s}^2 + \Delta_e' + \Delta_W\right) + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z} \qquad \Delta_W = \frac{8\alpha}{9\pi}$$

- In practice, $\kappa^{\mathrm{PT}}(Q)$ is very close to the original Czarnecki-Marciano definition, shifted upward by $2\alpha/(9\pi)=0.00052$ at $Q=0$, and 0.00045 at $Q=M_Z$

$$\kappa^{\mathrm{PT}}(0)\hat{s}^2 = 0.2390$$

Fermion contributions taken from Jegerlehner's dispersive fits to e^+e^- data

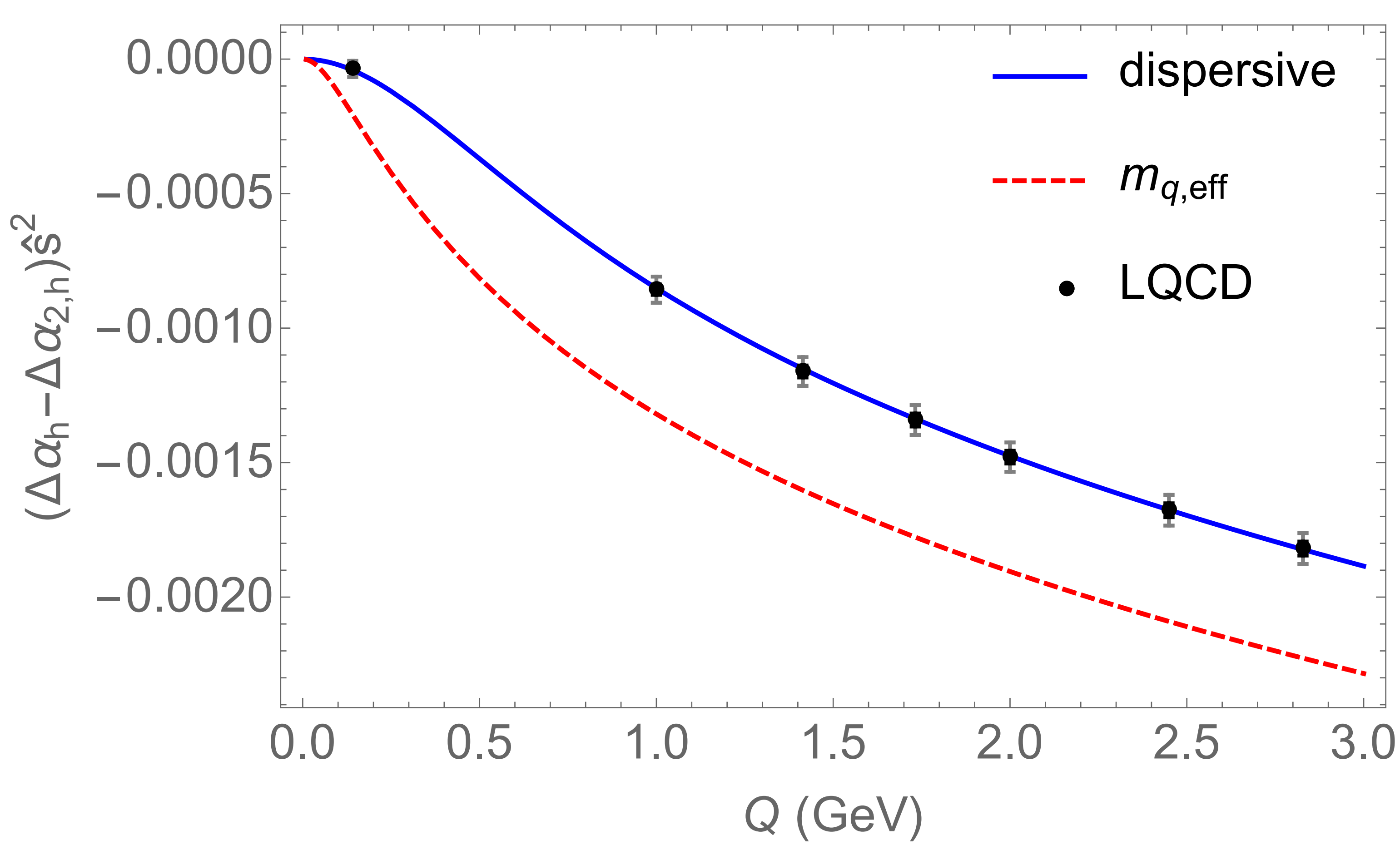


Leptonic & Hadronic Corrections to $\sin^2\theta_W$ at low Q^2

$$\sin^2\theta_W(Q) = \frac{\alpha(Q)}{\alpha_2(Q)} \qquad \alpha(Q) = \frac{\alpha_0}{1-\Delta\alpha(Q)} \qquad \Delta\alpha = \Delta\alpha_{lep} + \Delta\alpha_{had} + \Delta\alpha_{top}$$

$$\delta\sin^2\theta_W(Q) = (\Delta\alpha(Q) - \Delta\alpha_2(Q))\sin^2\theta_W(0)$$

This is the <u>shift</u> in the weak mixing angle from Q^2=0 to finite Q^2



	$\delta\sin^2\theta_W(Q)$	δQ_W^p
leptonic	-0.00015	+0.0006
hadronic	-0.00005	+0.0002
Total	-0.00020	+0.0008

- The shift in Δ'_e is also +0.0006
- It should be included in the Q^2-dependent fits to get Q=0 limit