Sin θ_W at SuperB : a theorist's view

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Why Electroweak Measurements at SuperB ??

Precision EW problems

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$$\sin^2\theta_{eff}^{b,fit} = 0.23293 \pm^{0.00031}_{0.00025}, \quad \sin^2\theta_{eff}^{l,fit} = 0.23149 \pm 0.00016.$$

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$$+\ 0.0004908\ \log\left(\frac{m_H}{100\ \mathrm{GeV}}\right)\ +\ 0.0000343\ \left(\log\left(\frac{m_H}{100\ \mathrm{GeV}}\right)\right)^2$$

$$=\ 0.23110(16) + 0.0004908\ \log\left(\frac{m_H}{100\ \mathrm{GeV}}\right) + 0.0000343\ \left(\log\left(\frac{m_H}{100\ \mathrm{GeV}}\right)\right)^2$$

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$\Delta\alpha_h^{(5)} = 0.02750 \pm 0.00033$, $m_t = (173.2 \pm 0.9)$ GeV, $m_H \simeq 125$ GeV

$$\Downarrow$$

$$\sin^2\theta_{\overline{MS}}(M_Z) = 0.23121(16) \rightarrow \sin^2\theta_l^{\text{eff}}(M_Z) = 0.23149(16)$$

Agree with $\sin^2\theta^l_{eff}$ but 3σ from $\sin^2\theta^b_{eff}$ and g_V^b

$\sin^2\theta_W$ DEFINITIONS

- $\sin^2\theta_W$ pseudo-observable: **NOT** measurable in experiment

- Everything simple at tree-level ...

$$\sin^2\theta_W^0 = \left(\frac{e^0}{g_2^0}\right)^2 = 1 - \left(\frac{M_W^0}{M_Z^0}\right)^2$$

But, at higher orders, masses and radiative corrections different

$\Rightarrow$ Scheme and scale dependent definitions.

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Flavour-dependent “effective” mixing angle from renormalized g_V^f

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$$g_V^f \;=\; T_f \;-\; 2Q_f\,\sin^2\theta_f^{\rm eff}$$

- Definitions related with $\kappa(q^2,\mu)$ form-factors

$$\sin^2\theta_f^{\rm eff}(q^2) \;=\; \kappa^f(q^2,M_Z)\,\sin^2\theta_W^{\rm OS} \;=\; \hat\kappa^f(q^2,\mu)\,\sin^2\hat\theta_W(\mu)$$

- At scale M_Z:

$$\sin^2\theta_f^{\text{eff}} = \sin^2\theta_W^{\text{OS}} + 0.00100 = \sin^2\hat{\theta}_W(M_Z) + 0.00028$$

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- At lower $q << M_Z$:

$$\sin^2\hat{\theta}_W(q^2) \;=\; \hat{\kappa}^{PT}(q^2, M_Z)\,\sin^2\hat{\theta}_W(M_Z)$$

$$\hat{\kappa}^{PT}(q^2,\mu) = 1 + \frac{\alpha}{2\pi\hat{s}^2}\,\ln\left(\frac{m_Z}{\mu}\right)\left[-\frac{1}{3}\sum_i (C_i\,Q_i - 4\,\hat{s}\,Q_i^2) + 7\,\hat{c} + \frac{1}{6}\right]$$
$$+\frac{\alpha}{2\pi\hat{s}^2}\left[-\sum_i (C_i\,Q_i - 4\,\hat{s}\,Q_i^2)\,I_i(q^2) + \left(\frac{7}{2}\,\hat{c} + \frac{1}{12}\right)\,\ln c^2 - \frac{\hat{c}}{3}\right]$$

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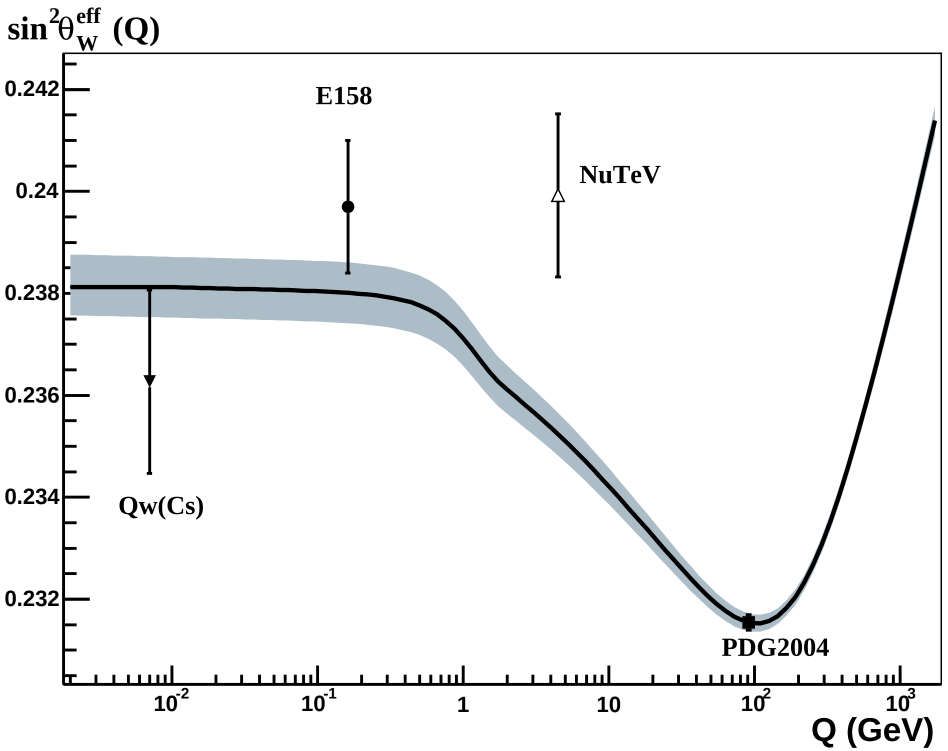

EW Observables

γ-Z interference effects

Subdominant corrections to electromagnetic contributions.

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Subdominant corrections to electromagnetic contributions.

$\Longrightarrow$ **Look for C or P-odd observables**

C-odd

Forward-Backward asymmetry, A_{FB}, is P-even and C-odd.
On the Z-pole:

$$A_{FB}(M_Z) = \frac{g_V^e g_A^e g_V^f g_A^f}{\left((g_V^e)^2 + (g_A^e)^2\right)\left((g_V^f)^2 + (g_A^f)^2\right)}$$

C-odd

But, at 10 GeV:

$$A_{FB}(M_Z) = \frac{3\,G_F\;s}{4\sqrt{2}\pi\alpha}\;\frac{g_A^e g_A^f}{Q_f}$$

$\Rightarrow$ **At SuperB, vector couplings dominated by γ**
only axial couplings . . . , no information on $\sin^2\theta_W$

P-odd

Product $g^e_{A,V}\; g^f_{V,A}$. Two options:

Unpolarized beams	Polarized electron beam
Only τ-polarization	Left-Right asymmetry
	both for leptons and B-mesons

FORWARD-BACKWARD ASYMMETRY

Only possible in leptonic pair production. Not present in $B\overline{B}$:

$$A^0_{FB} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)}$$
$$= -\frac{6}{\sqrt{2}} \left(\frac{G_F s}{4\pi\alpha}\right) \left(\frac{|\vec{p}|p^0}{2(p^0)^2 + m_l^2}\right) g_A^e g_A^l \frac{\mathrm{Re}\{1 + Q_b^2 \Upsilon(s)\}}{|1 + Q_b^2 \Upsilon(s)|^2} .$$

Pure photonic loop corrections also contribute to A_{FB}, (no γ-Z interference).

$$A_{FB} = \frac{A^0_{FB} - 4.5\,\alpha/\pi}{1 - 8\,g_V^e\,\chi\,\mathrm{Re}\{\frac{g_V^l + g_V^b\,Q_b\Upsilon(s)}{1 + Q_b^2\Upsilon(s)}\}} \quad \text{with} \quad \chi = \frac{G_F}{\sqrt{2}}\,\frac{M_Z^2}{8\pi\alpha}\,\frac{s}{s - M_Z^2} ,$$

LEFT-RIGHT ASYMMETRY

– With **polarized** electron beam of polarization P, the total cross section to fermion pairs,

$$\sigma(P) \;=\; \sigma(P=0)[1 \;+\; \frac{4}{\sqrt{2}}\,(\frac{G_F q^2}{4\pi\alpha})\,(\frac{g_A^e g_V^f}{Q_f})\;P]\,.$$

– Therefore, the integrated Left-Right asymmetry A_{LR}, for $B\overline{B}$ final states,

$$A_{LR}^b = \frac{\sigma(P)-\sigma(-P)}{\sigma(P)+\sigma(-P)} = \frac{4}{\sqrt{2}}\,(\frac{G_F q^2}{4\pi\alpha})\,(\frac{g_A^e g_V^b}{Q_b})\;P$$

$\Longrightarrow$ Sensitive to g_V^b (or g_V^l for A_{LR}^l) therefore to $\sin^2\theta_W$ in *SM*.

τ POLARIZATION

– $P_{z,x}$ is P-violating, thus sensitive to $g_V \cdot g_A$ (no sensitive to g_v^b at $\Upsilon(4S)$). In the presence of initial beam polarization, P_e, we have:

$$P_{z'}^{(-)}(\theta, P_e) = -\frac{8G_F\ s}{4\sqrt{2}\pi\alpha} \mathrm{Re}\{\frac{g_V^l - Q_b g_V^b \Upsilon(s)}{1 + Q_b^2 \Upsilon(s)}\} \times \left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2\ g_A^e \frac{\cos\theta}{1+\cos^2\theta} \right) + P_e \frac{\cos\theta}{1+\cos^2\theta} \,.$$

– Measurable through the angular distribution of decay products. In the $\tau \to \pi\nu_\tau$ channel, with $\hat{k}$ the pion direction:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\Omega} = \frac{1}{4\pi}[1 + \vec{P} \cdot \hat{k}(\Omega)]$$

$\Rightarrow$

- Proportional to $g_V \cdot g_A$, if $P_e = 0$
- $P_e \neq 0$, additional handle on beam polarization.

Numerical analysis

– With 75 ab^{-1}, $\sim 10^{11}$ lepton and $\sim 10^{9}$ B–$\overline{B}$ pairs at SuperB

$\Downarrow$

Only statistical error $\propto \frac{1}{\sqrt{N}}$:

– Statistical errors in the different asymmetries:

$$A^b_{LR} = (0.03\ P\ g^b_V) \pm 3 \times 10^{-5} \quad \Rightarrow \quad \sim g^b_V\ (10.58\ \mathrm{GeV}) \pm 10^{-3}$$
$$A^l_{LR} = (0.02\ P\ g^l_V)\ \pm 3 \times 10^{-6} \quad \Rightarrow \quad \sim g^l_V\ (10.58\ \mathrm{GeV}) \pm 10^{-4}$$
$$A_{FB} = (0.015\ g^e_A g^l_A)\ \pm 3 \times 10^{-6} \quad \Rightarrow \quad \sim g^l_A\ (10.58\ \mathrm{GeV}) \pm 10^{-4}$$

$\Rightarrow$ SuperB significantly improves error in g^b_V from **LEP/SLC**.

Conclusions

Electroweak measurements possible at **SuperB** with polarized beams.

$\Downarrow$

- In the absence of **beam polarization**, A_{FB} measures only axial couplings, g_A^f
- In the absence of **beam polarization**, only τ polarization can measure, g_V^l and g_V^b.
- With **polarized electron beam**, A_{LR} can measure g_V^l and g_V^b with high precision, at the level of **LEP** measurements.