SuperB Polarisation Physics Programme

Michael Roney

University of Victoria

Polarisation Working group discussion

21 September 2009

An Exciting Programme!

- Search for CP and T violation in tau decays
- tau EDM
- Search for LFV – background suppression
- Discover LFV - measure structure of LV process
- low energy window on precision neutral current measurements
  - opportunity to re-visit a lingering 3 sigma effect left over from LEP/SLC: high luminosity + polarization

An Exciting Programme!

- All but the last have been explored, to some extent, and presented at our workshops. These are the ~low risk – high gain studies: 'Wouldn't it be wonderful if…' CPV seen; LFV discovered and studied; etc
- Still work to be done on those
- but the neutral current component is another class of physics that until now hasn't be presented in the context of polarization at SuperB

UVic

$e^+e^- \to f\bar{f}$ Diff. Cross section

$$\frac{2s}{\pi}\frac{1}{N_c^{\rm f}}\frac{d\sigma_{\rm ew}}{d\cos\theta}(e^+e^- \to f\bar{f}) =$$

at LEP: 15M hadronic Z decays, unpolarised
at SLC: 0.5M hadronic Z decays, polarised e-
at SuperB: Z-term ~30M hadronic Z, polarised

$$\underbrace{|\alpha(s)Q_{\rm f}|^2\,(1+\cos^2\theta)}_{\sigma^\gamma}$$

$$\underbrace{-8\Re\left\{\alpha^*(s)Q_{\rm f}\chi(s)\left[\mathcal{G}_{\rm Ve}\mathcal{G}_{\rm Vf}(1+\cos^2\theta)+2\mathcal{G}_{\rm Ae}\mathcal{G}_{\rm Af}\cos\theta\right]\right\}}_{\gamma\text{–Z interference}}$$

$$\underbrace{\begin{array}{c}+16|\chi(s)|^2\left[(|\mathcal{G}_{\rm Ve}|^2+|\mathcal{G}_{\rm Ae}|^2)(|\mathcal{G}_{\rm Vf}|^2+|\mathcal{G}_{\rm Af}|^2)(1+\cos^2\theta)\right.\\ \left.+8\Re\left\{\mathcal{G}_{\rm Ve}\mathcal{G}_{\rm Ae}{}^*\right\}\Re\left\{\mathcal{G}_{\rm Vf}\mathcal{G}_{\rm Af}{}^*\right\}\cos\theta\right]\end{array}}_{\sigma^{\rm Z}}$$

with:

$$\chi(s) = \frac{G_{\rm F}m_{\rm Z}^2}{8\pi\sqrt{2}}\frac{s}{s-m_{\rm Z}^2+is\Gamma_{\rm Z}/m_{\rm Z}},$$

where θ is the scattering angle of the out-going fermion with respect to the direction of the e^-.

UVic

$e^+e^- \to f\,\bar{f}$ Diff. Cross section

$$\begin{aligned} \mathcal{G}_{Vf} &= \sqrt{\mathcal{R}_f}\,(T_3^f - 2Q_f\mathcal{K}_f \sin^2\theta_W) \\ \mathcal{G}_{Af} &= \sqrt{\mathcal{R}_f}\,T_3^f\,. \end{aligned}$$

In terms of the real parts of the complex form factors,

$$\begin{aligned} \rho_f &\equiv \Re(\mathcal{R}_f) = 1 + \Delta\rho_{se} + \Delta\rho_f \\ \kappa_f &\equiv \Re(\mathcal{K}_f) = 1 + \Delta\kappa_{se} + \Delta\kappa_f\,, \end{aligned}$$

the effective electroweak mixing angle and the real effective couplings are defined as:

$$\begin{aligned} \sin^2\theta_{eff}^f &\equiv \kappa_f \sin^2\theta_W \\ g_{Vf} &\equiv \sqrt{\rho_f}\,(T_3^f - 2Q_f \sin^2\theta_{eff}^f) \\ g_{Af} &\equiv \sqrt{\rho_f}\,T_3^f\,, \\ \frac{g_{Vf}}{g_{Af}} &= \Re\left(\frac{\mathcal{G}_{Vf}}{\mathcal{G}_{Af}}\right) = 1 - 4|Q_f|\sin^2\theta_{eff}^f\,. \end{aligned}$$

The quantities $\Delta\rho_{se}$ and $\Delta\kappa_{se}$ are universal corrections arising from the propagator self-energies, while $\Delta\rho_f$ and $\Delta\kappa_f$ are flavour-specific vertex corrections.

UVic

$e^+e^- \rightarrow f\,\bar{f}$ Diff. Cross section

at LEP: 15M hadronic Z decays, unpolarised
at SLC: 0.5M hadronic Z decays, polarised e-
at SuperB: Z-term ~30M hadronic Z, polarised

$$\frac{2s}{\pi}\frac{1}{N_c^{\mathrm{f}}}\frac{d\sigma_{\mathrm{ew}}}{d\cos\theta}(\mathrm{e^+e^-}\to\mathrm{f\bar{f}}) =$$

$$\underbrace{|\alpha(s)Q_{\mathrm{f}}|^2\,(1+\cos^2\theta)}_{\sigma^\gamma}$$

$$\underbrace{-8\Re\left\{\alpha^*(s)Q_{\mathrm{f}}\chi(s)\left[\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Vf}}(1+\cos^2\theta)+2\mathcal{G}_{\mathrm{Ae}}\mathcal{G}_{\mathrm{Af}}\cos\theta\right]\right\}}_{\gamma\text{–Z interference}}$$

$$\underbrace{\begin{array}{c}+16|\chi(s)|^2\left[(|\mathcal{G}_{\mathrm{Ve}}|^2+|\mathcal{G}_{\mathrm{Ae}}|^2)(|\mathcal{G}_{\mathrm{Vf}}|^2+|\mathcal{G}_{\mathrm{Af}}|^2)(1+\cos^2\theta)\right. \\ \left.+8\Re\left\{\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Ae}}{}^*\right\}\Re\left\{\mathcal{G}_{\mathrm{Vf}}\mathcal{G}_{\mathrm{Af}}{}^*\right\}\cos\theta\right]\end{array}}_{\sigma^{\mathrm{Z}}}$$

with:

$$\chi(s) = \frac{G_{\mathrm{F}}m_{\mathrm{Z}}^2}{8\pi\sqrt{2}}\frac{s}{s-m_{\mathrm{Z}}^2+is\Gamma_{\mathrm{Z}}/m_{\mathrm{Z}}}$$

where θ is the scattering angle of the ou

$$g_{\mathrm{L}}^{\mathrm{tree}} = \sqrt{\rho_0}\,(T_3^{\mathrm{f}} - Q_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}^{\mathrm{tree}})$$
$$g_{\mathrm{R}}^{\mathrm{tree}} = -\sqrt{\rho_0}\,Q_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}^{\mathrm{tree}},$$

or, equivalently in terms of vector and axial-vector couplings:

$$g_{\mathrm{V}}^{\mathrm{tree}} \equiv g_{\mathrm{L}}^{\mathrm{tree}} + g_{\mathrm{R}}^{\mathrm{tree}} = \sqrt{\rho_0}\,(T_3^{\mathrm{f}} - 2Q_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}^{\mathrm{tree}})$$
$$g_{\mathrm{A}}^{\mathrm{tree}} \equiv g_{\mathrm{L}}^{\mathrm{tree}} - g_{\mathrm{R}}^{\mathrm{tree}} = \sqrt{\rho_0}\,T_3^{\mathrm{f}}.$$

UVic

$e^+e^- \to f\,\bar{f}$ Diff. Cross section

$$\frac{2s}{\pi}\frac{1}{N_c^{\mathrm{f}}}\frac{d\sigma_{\mathrm{ew}}}{d\cos\theta}(\mathrm{e}^+\mathrm{e}^- \to \mathrm{f}\bar{\mathrm{f}}) \;=$$

$$\underbrace{|\alpha(s)Q_{\mathrm{f}}|^2\,(1+\cos^2\theta)}_{\sigma^\gamma}$$

$$\underbrace{-8\Re\left\{\alpha^*(s)Q_{\mathrm{f}}\chi(s)\left[\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Vf}}(1+\cos^2\theta)+2\mathcal{G}_{\mathrm{Ae}}\mathcal{G}_{\mathrm{Af}}\cos\theta\right]\right\}}_{\gamma\text{–Z interference}}$$

$$\underbrace{\begin{array}{c}+16|\chi(s)|^2\,[(|\mathcal{G}_{\mathrm{Ve}}|^2+|\mathcal{G}_{\mathrm{Ae}}|^2)(|\mathcal{G}_{\mathrm{Vf}}|^2+|\mathcal{G}_{\mathrm{Af}}|^2)(1+\cos^2\theta) \\ +8\Re\{\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Ae}}{}^*\}\,\Re\{\mathcal{G}_{\mathrm{Vf}}\mathcal{G}_{\mathrm{Af}}{}^*\}\cos\theta]\end{array}}_{\sigma^{\mathrm{Z}}}$$

with:

$$\chi(s) \;=\; \frac{G_{\mathrm{F}}m_{\mathrm{Z}}^2}{8\pi\sqrt{2}}\frac{s}{s-m_{\mathrm{Z}}^2+is\Gamma_{\mathrm{Z}}/m_{\mathrm{Z}}}$$

where θ is the scattering angle of the ou

$$g_{\mathrm{L}}^{\mathrm{tree}} = \sqrt{\rho_0}\,(T_3^{\mathrm{f}} - Q_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}^{\mathrm{tree}})$$
$$g_{\mathrm{R}}^{\mathrm{tree}} = -\sqrt{\rho_0}\,Q_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}^{\mathrm{tree}}\,,$$

or, equivalently in terms of vector and axial-vector couplings:

$$g_{\mathrm{V}}^{\mathrm{tree}} \equiv g_{\mathrm{L}}^{\mathrm{tree}} + g_{\mathrm{R}}^{\mathrm{tree}} = \sqrt{\rho_0}\,(T_3^{\mathrm{f}} - 2Q_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}^{\mathrm{tree}})$$
$$g_{\mathrm{A}}^{\mathrm{tree}} \equiv g_{\mathrm{L}}^{\mathrm{tree}} - g_{\mathrm{R}}^{\mathrm{tree}} = \sqrt{\rho_0}\,T_3^{\mathrm{f}}\,.$$

$e^+e^- \rightarrow f\,\bar{f}$ Diff. Cross section

Asymmetries at Z-pole:

$$
\begin{aligned}
A_{\mathrm{FB}} &= \frac{\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}}}{\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}}} \\
A_{\mathrm{LR}} &= \frac{\sigma_{\mathrm{L}} - \sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}} + \sigma_{\mathrm{R}}} \frac{1}{\langle |\mathcal{P}_{\mathrm{e}}| \rangle} \\
A_{\mathrm{LRFB}} &= \frac{(\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}})_{\mathrm{L}} - (\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}})_{\mathrm{R}}}{(\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}})_{\mathrm{L}} + (\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}})_{\mathrm{R}}} \frac{1}{\langle |\mathcal{P}_{\mathrm{e}}| \rangle} .
\end{aligned}
$$

Problematic at SuperB because of pure QED FB asymmetry - requires polarised beam - still need to evaluate impact

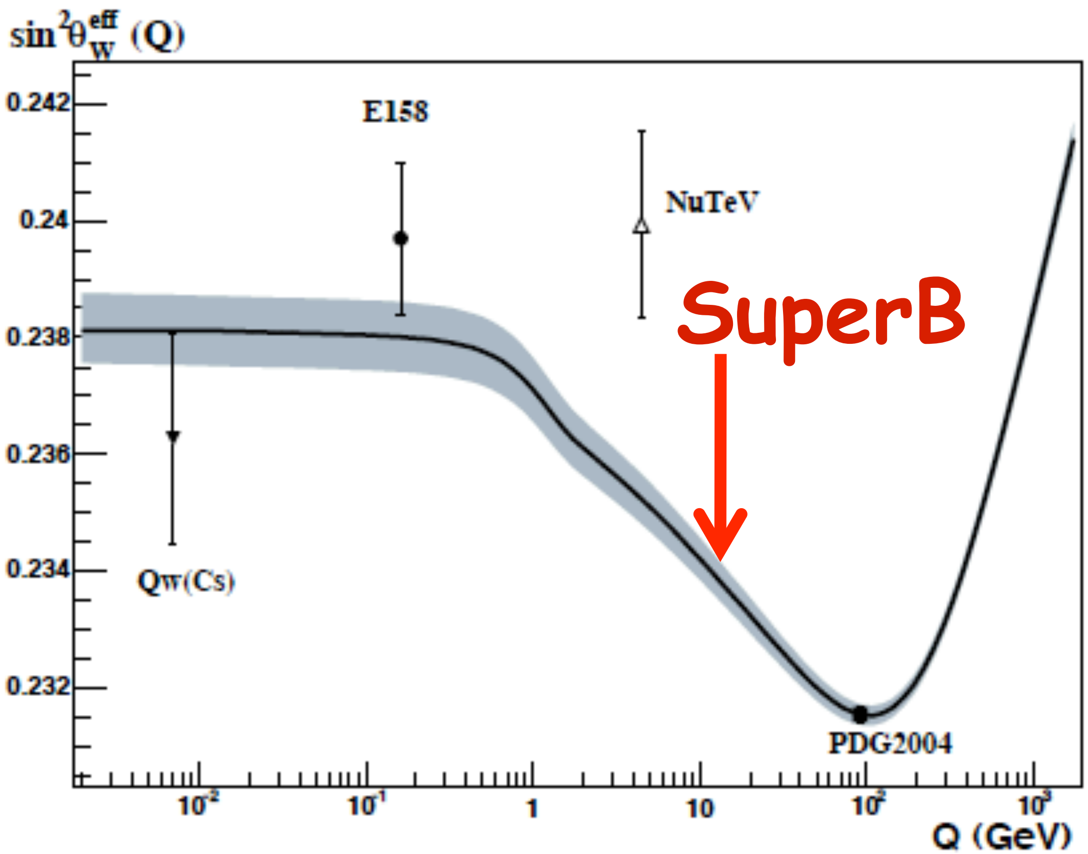
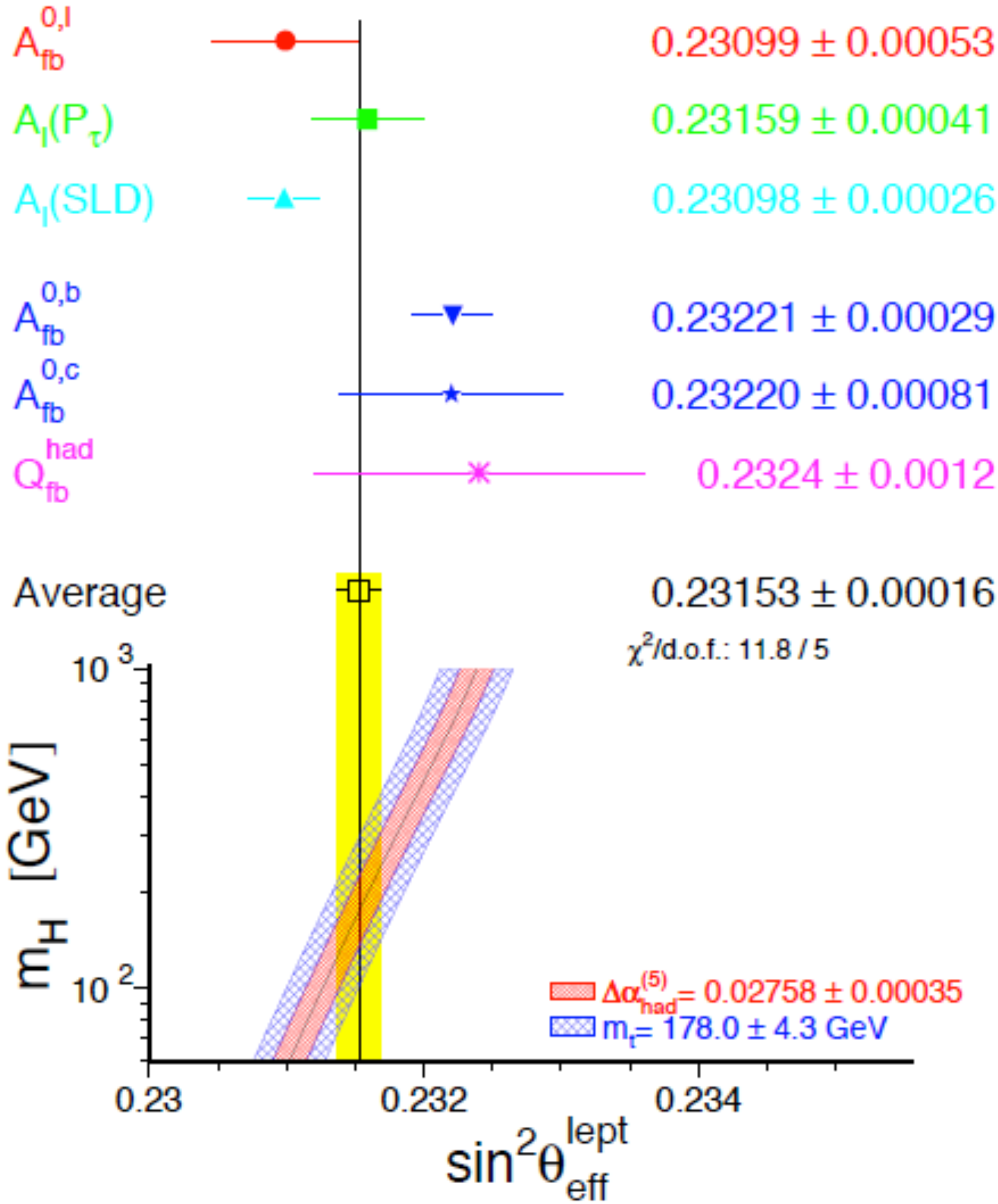


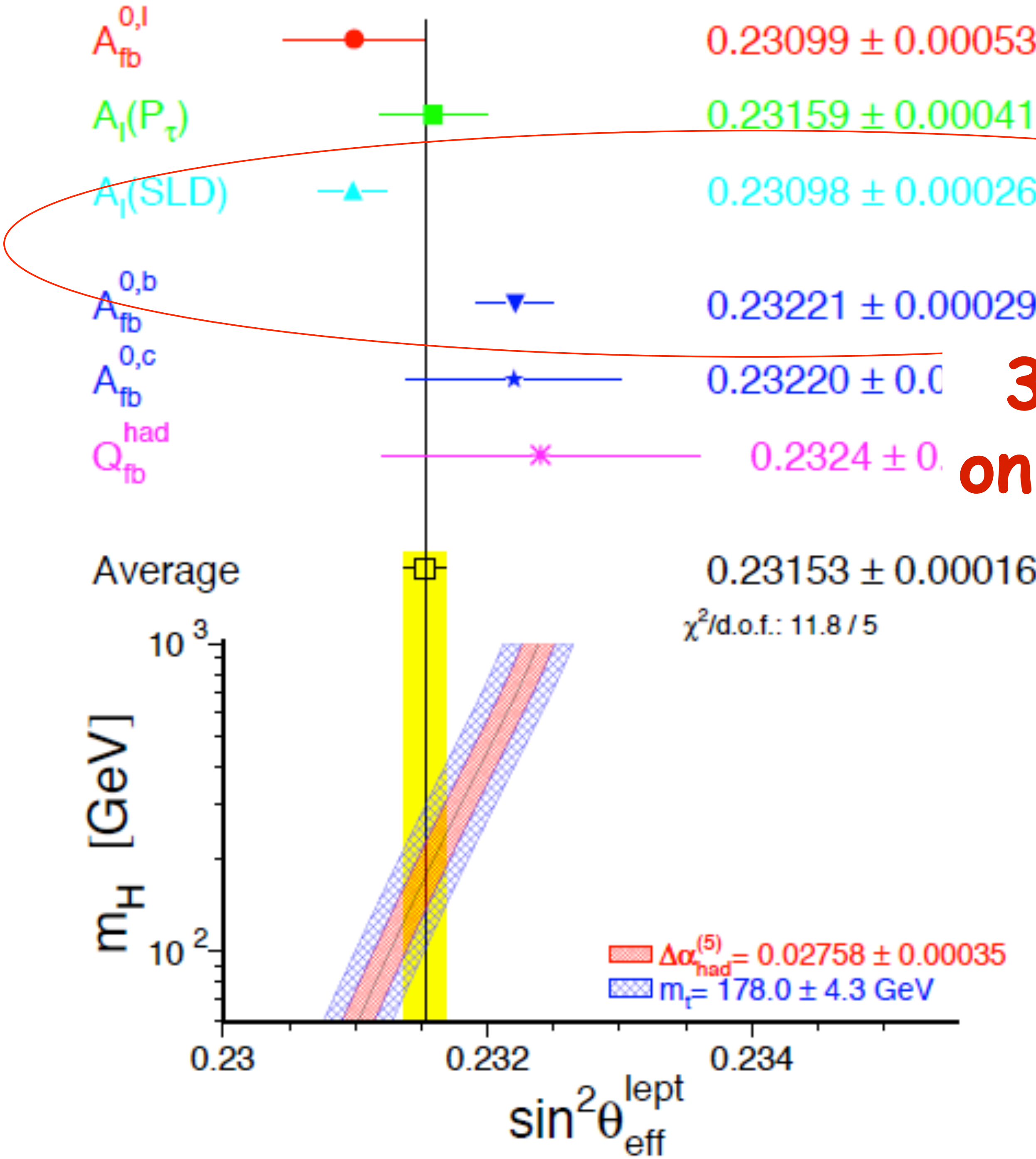
FIG. 2: Predicted variation [18] of $\sin^2\theta_W^{\rm eff}$ as a function of momentum transfer Q (solid line) and its estimated theoretical uncertainty (shaded area). Results of prior low energy experiments [6, 16] (closed triangle, shown at an arbitrarily higher Q) and [7] (open triangle) are overlaid together with the Z^0 pole value [16] (square) and this measurement (circle).

UVic



$A_{fb}^{0,l}$ 0.23099 ± 0.00053
$A_l(P_\tau)$ 0.23159 ± 0.00041
A_l(SLD) 0.23098 ± 0.00026
$A_{fb}^{0,b}$ 0.23221 ± 0.00029
$A_{fb}^{0,c}$ 0.23220 ± 0.00081
Q_{fb}^{had} 0.2324 ± 0.0012
Average 0.23153 ± 0.00016
χ^2/d.o.f.: 11.8 / 5
m_H [GeV]
10^3
10^2
$\Delta\alpha_{had}^{(5)}$ = 0.02758 ± 0.00035
m_t = 178.0 ± 4.3 GeV
0.23
0.232
0.234
$\sin^2\theta_{eff}^{lept}$

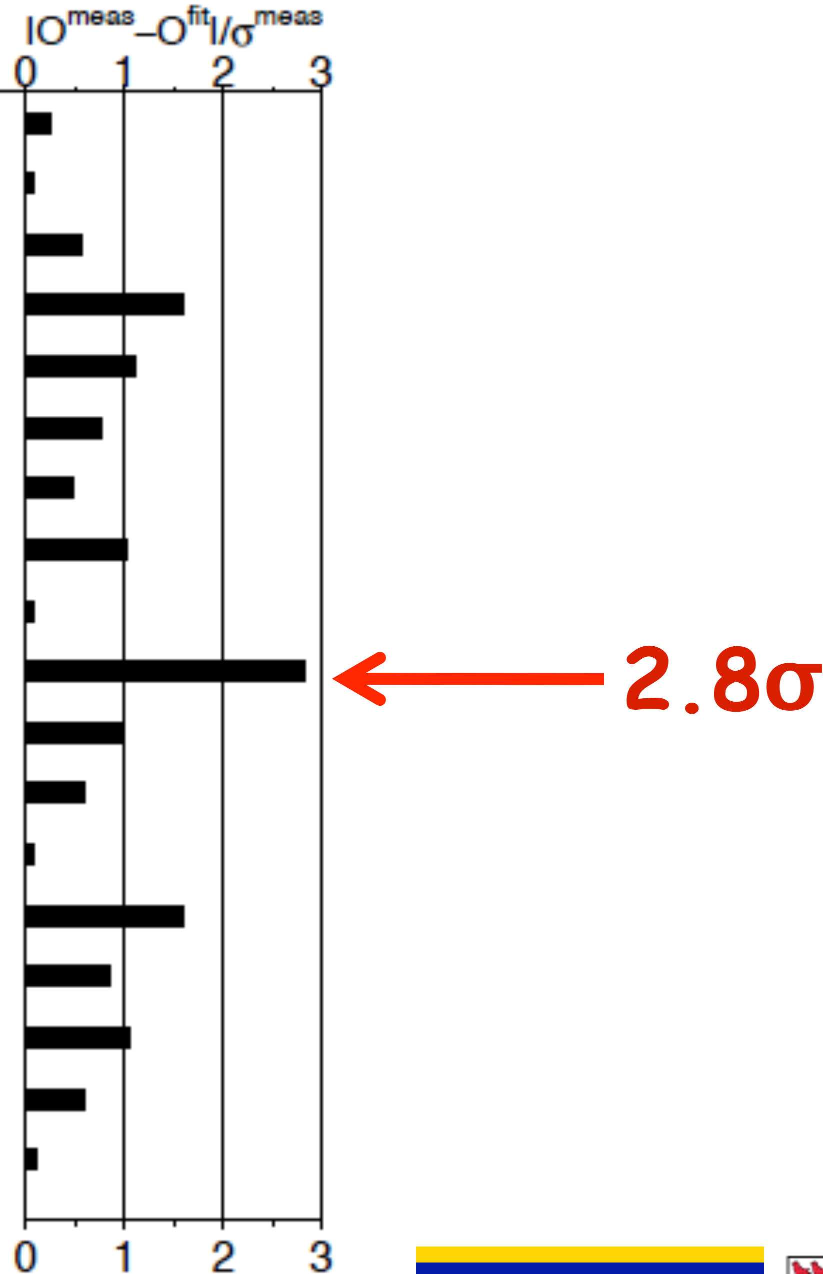
UVic



3.2σ comparing only A_{LR} and $A^{0,b}_{fb}$

UVic

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ^0_{had} [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21562
R_c	0.1721 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.389
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.5



UVic

Lepton universality: where are we now?

- Neutral current universality: a reminder

$g_e^A / g_\mu^A = 0.9981 \pm 0.0013$

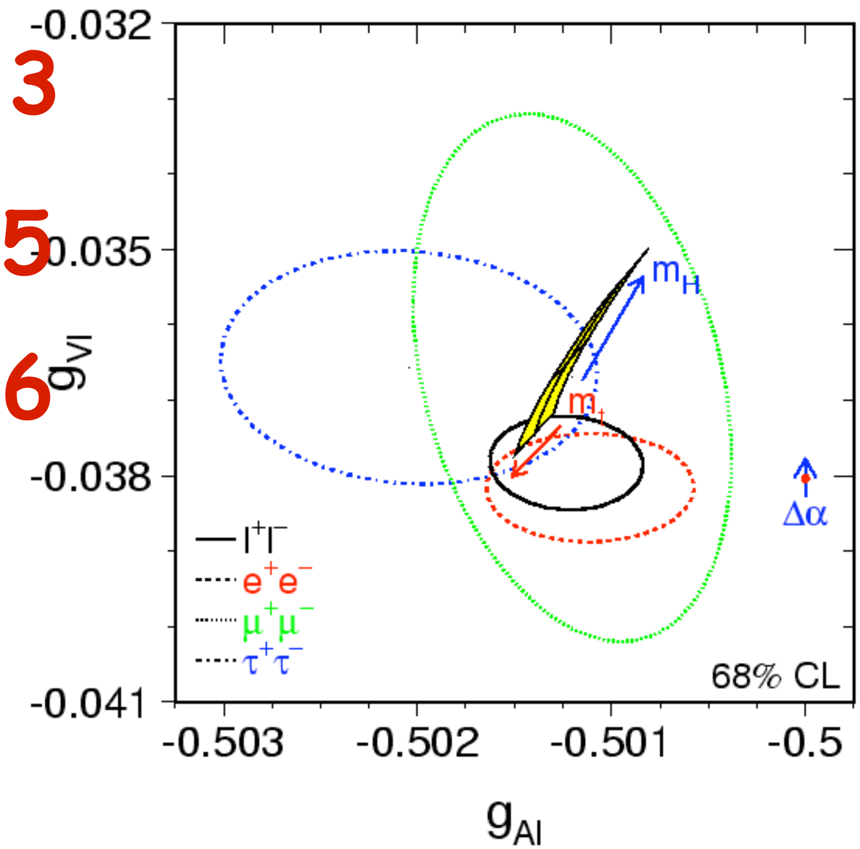
$g_e^A / g_\tau^A = 0.9981 \pm 0.0015$

$g_\mu^A / g_\tau^A = 0.9983 \pm 0.0016$

$g_e^V / g_\mu^V = 1.040 \pm 0.065$

$g_e^V / g_\tau^V = 1.043 \pm 0.030$

$g_\mu^V / g_\tau^V = 1.003 \pm 0.068$



UVic

Neutral Current Physics Programme

- Measure $\sin^2\vartheta^{eff}_W$ at 10.58GeV
  - with muon – probe running, NuTeV result
  - with muons and taus – probe NC universality at low Q2
  - with charm
  - with b's: probe residual 3σ effect from LEP AFB

UVic

Some issues…

- evaluate the sensitivity with 75/ab at SuperB
- need to examine impact of QED AFB
- what are requirements of systematic precision of polarisation

UVic