SuperB Neutral Current Polarisation Physics: Studies with ZFitter &tc

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Frascati

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

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

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

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

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

with:

$$\chi(s) \;=\; \frac{G_F m_Z^2}{8\pi\sqrt{2}}\frac{s}{s-m_Z^2+is\Gamma_Z/m_Z}\,,$$

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

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

$$\mathcal{G}_{\mathrm{Vf}} = \sqrt{\mathcal{R}_{\mathrm{f}}}\,(T_3^{\mathrm{f}} - 2Q_{\mathrm{f}}\mathcal{K}_{\mathrm{f}}\sin^2\theta_{\mathrm{W}})$$
$$\mathcal{G}_{\mathrm{Af}} = \sqrt{\mathcal{R}_{\mathrm{f}}}\,T_3^{\mathrm{f}}\,.$$

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

$$\rho_{\mathrm{f}} \equiv \Re(\mathcal{R}_{\mathrm{f}}) = 1 + \Delta\rho_{\mathrm{se}} + \Delta\rho_{\mathrm{f}}$$
$$\kappa_{\mathrm{f}} \equiv \Re(\mathcal{K}_{\mathrm{f}}) = 1 + \Delta\kappa_{\mathrm{se}} + \Delta\kappa_{\mathrm{f}}\,,$$

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

$$\sin^2\theta_{\mathrm{eff}}^{\mathrm{f}} \equiv \kappa_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}$$
$$g_{\mathrm{Vf}} \equiv \sqrt{\rho_{\mathrm{f}}}\,(T_3^{\mathrm{f}} - 2Q_{\mathrm{f}}\sin^2\theta_{\mathrm{eff}}^{\mathrm{f}})$$
$$g_{\mathrm{Af}} \equiv \sqrt{\rho_{\mathrm{f}}}\,T_3^{\mathrm{f}}\,,$$
$$\frac{g_{\mathrm{Vf}}}{g_{\mathrm{Af}}} = \Re\left(\frac{\mathcal{G}_{\mathrm{Vf}}}{\mathcal{G}_{\mathrm{Af}}}\right) = 1 - 4|Q_{\mathrm{f}}|\sin^2\theta_{\mathrm{eff}}^{\mathrm{f}}\,.$$

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

$e^+e^- \to f\,\bar{f}$ 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

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

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

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

with:

$$\chi(s) = \frac{G_F m_Z^2}{8\pi\sqrt{2}}\frac{s}{s-m_Z^2+is\Gamma_Z/m_Z}$$

where θ is the scattering angle of the ou

$$g_L^{tree} = \sqrt{\rho_0}\,(T_3^f - Q_f\sin^2\theta_W^{tree})$$
$$g_R^{tree} = -\sqrt{\rho_0}\,Q_f\sin^2\theta_W^{tree}\,,$$

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

$$g_V^{tree} \equiv g_L^{tree}+g_R^{tree} = \sqrt{\rho_0}\,(T_3^f - 2Q_f\sin^2\theta_W^{tree})$$
$$g_A^{tree} \equiv g_L^{tree}-g_R^{tree} = \sqrt{\rho_0}\,T_3^f\,.$$

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

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

at SuperB: γ–Z interference term dominates over pure Z-exchange

$$\underbrace{|\alpha(s)Q_f|^2(1+\cos^2\theta)}_{\sigma^\gamma}$$

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

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

Asymmetries at Z-pole from measured cross-sections:

$$A_{\mathrm{FB}} = \frac{\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}}}{\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}}}$$

$$A_{\mathrm{LR}} = \frac{\sigma_{\mathrm{L}} - \sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}} + \sigma_{\mathrm{R}}} \frac{1}{\langle|\mathcal{P}_{\mathrm{e}}|\rangle}$$

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

correcting back to 100% pol

Problematic at SuperB because of pure QED FB asymmetry - requires polarised beam - use ZFitter 6.43 to evaluate impact

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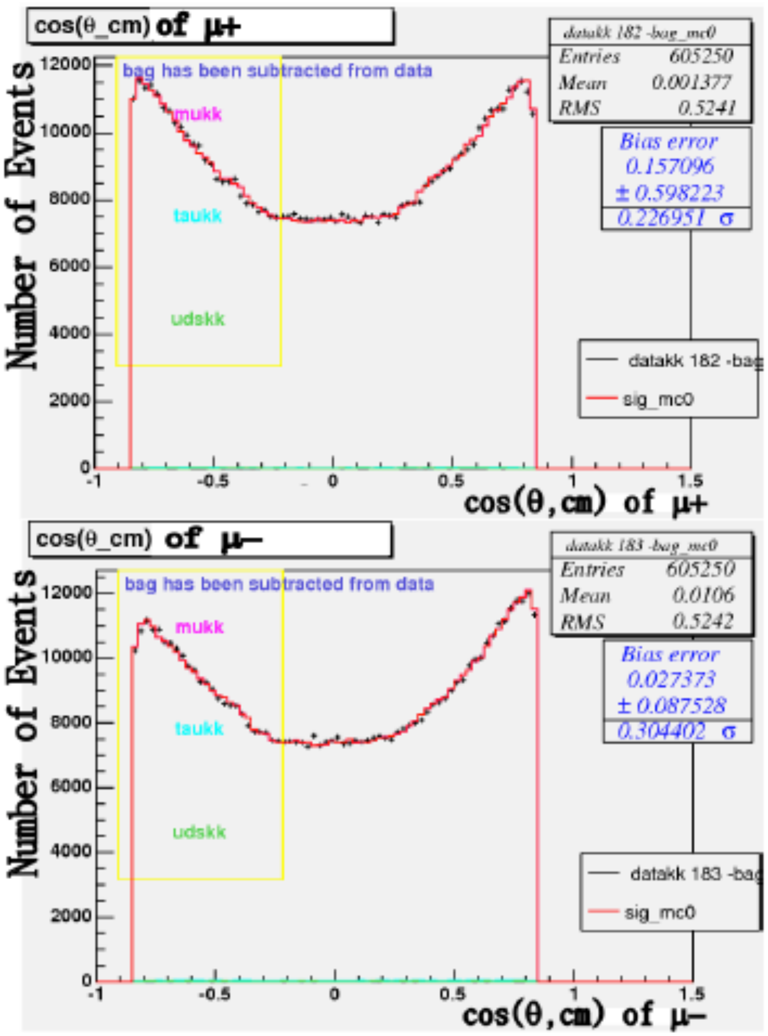
A μ-pair selection in BaBar

- Efficiency = 53.4%
- Purity = 99.6%
- Projected no. of selected mu-pair events at SuperB for 75/ab is 45.6 billion



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$e^+e^- \rightarrow \mu^+\mu^-$ Diff. Cross section $\sqrt{s}$=15GeV (Zfitter has warning below 13GeV – to be investigated)

Diagrams	Cross Section (nb)	A_{FB}	A_{LR} (Pol = 100%)
$\|Z+\gamma\|^2$	0.51	-0.0034	-0.0011
$\|Z\|^2+\|\gamma\|^2$ No interference	0.51	0.0087	-0.00003
$\|Z\|^2$	0.000020	-0.60	-0.71

The interference term is (nearly) everything

UVic

$e^+e^- \rightarrow \mu^+\mu^-$ @ $\sqrt{s}$=10.58GeV
Scales as s

Diagrams	Cross Section (nb)	A_{FB}	A_{LR} (Pol = 100%)
$\|Z+\gamma\|^2$	1.01	0.0028	-0.00051
$\|Z\|^2+\|\gamma\|^2$ No interference	1.01	0.0088	-0.00002

The interference term is (nearly) everything

- interference term ~ $g_A^e\ g_V^\mu$

$e^+e^- \rightarrow \mu^+\mu^-$ @ $\sqrt{s}$=10.58GeV

Diagrams	Cross Section (nb)	A_{FB}	A_{LR} (Pol = 100%)
$\|Z+\gamma\|^2$	1.01	0.0028	-0.00051

expected stat. error on A_{LR} = 4.6×10^{-6}

- relative stat. error of 1.1% (pol=80%)
- So require <0.5% systematic error on beam polarisation

UVic

$e^+e^- \rightarrow \mu^+\mu^-$ @ $\sqrt{s}$=10.58GeV

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- relative stat. error of 1.1% (pol=80%)
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$\sigma_{ALR} = 5\times10^{-6} \rightarrow \sigma_{(\sin2\theta eff)} = 0.00018$

cf SLC A_{LR} $\sigma_{(\sin2\theta eff)} = 0.00026$

Similar measurement with tau-pairs –

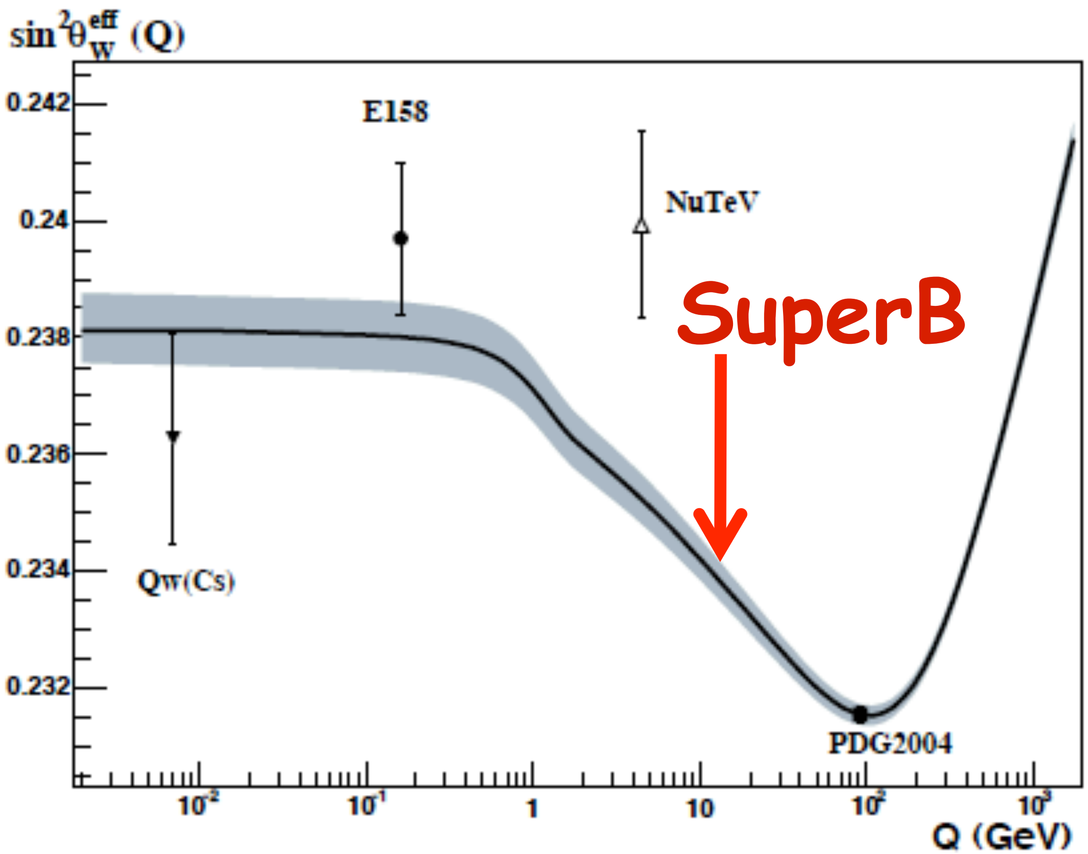
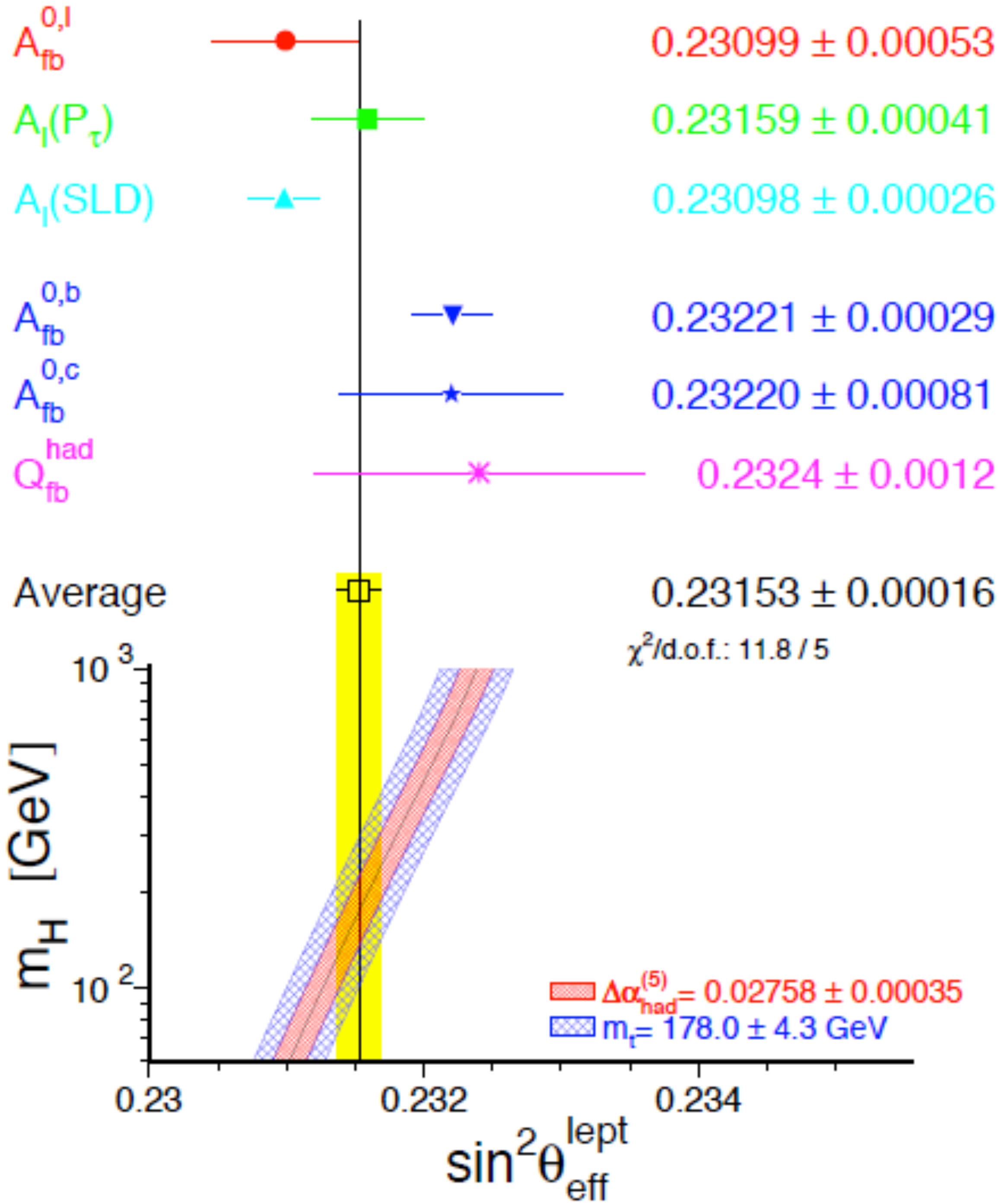


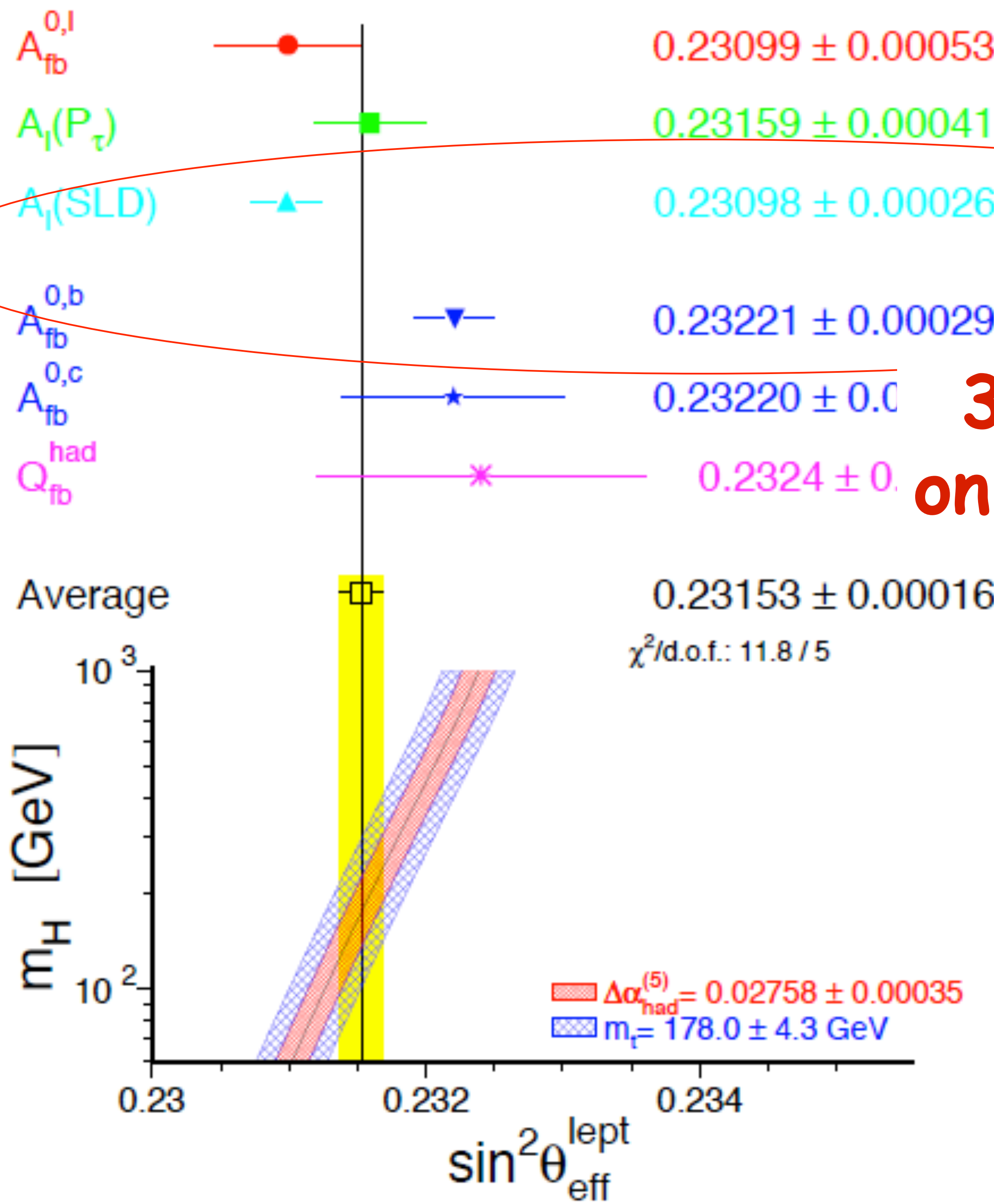
FIG. 2: Predicted variation [18] of $\sin^2\theta_W^{\rm eff}$ as a function of momentum transfer Q (solid line) and its estimated theoretical uncertainty (shaded area). Results of prior low energy experiments [6, 16] (closed triangle, shown at an arbitrarily higher Q) and [7] (open triangle) are overlaid 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
10^3
10^2
m_H [GeV]
$\Delta\alpha_{had}^{(5)}$= 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 $A^{0,b}_{fb}$

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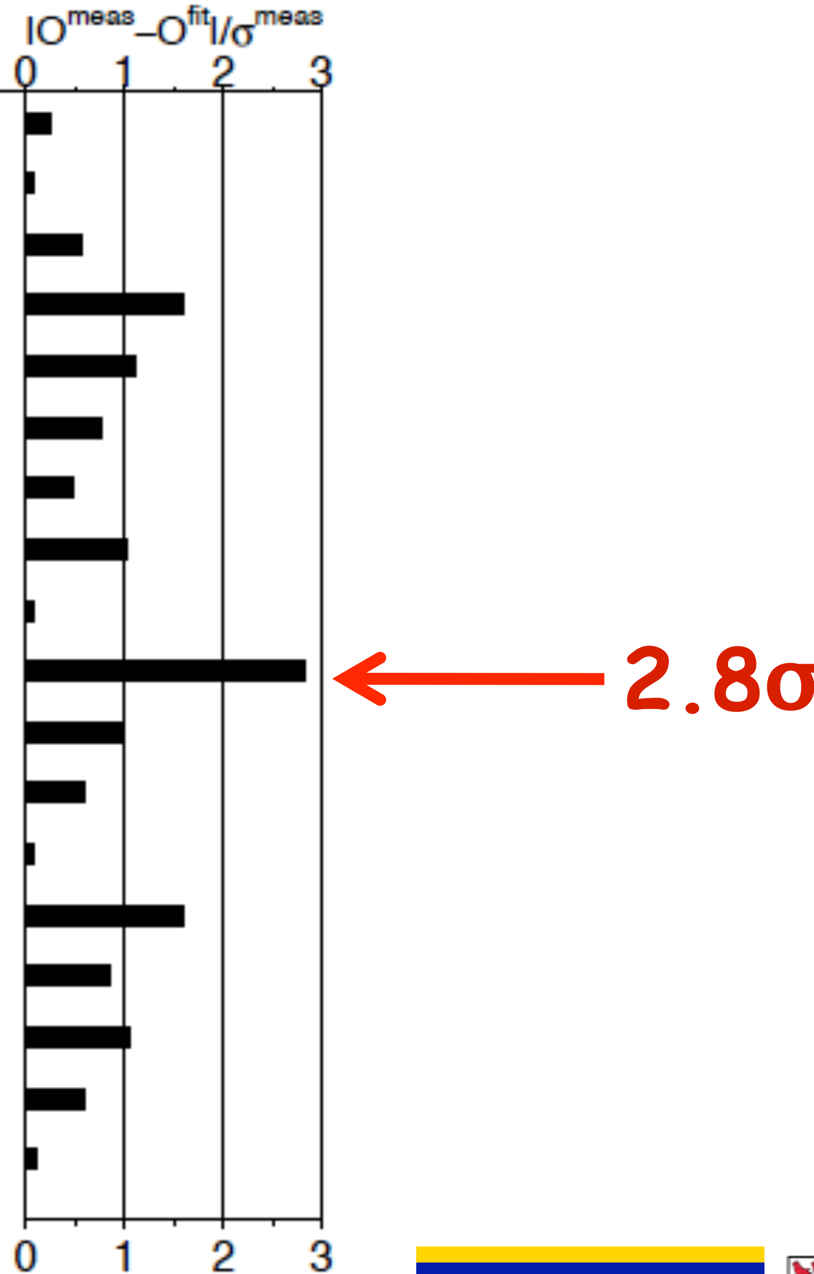
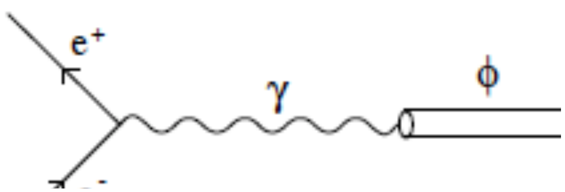
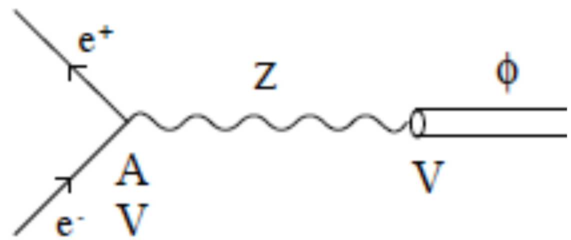
	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ^0_{had} [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	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



So what about b-Z couplings?

- hep-ph/9512424 (Bernabeu, Botella, Vives)
  - γ-Z interferometry at the Phi factory
  - Assuming only resonance production
  - Same arguments for ϕ ➔ Υ(4S) (ignoring non-4S open beauty)





$$\sigma(P) = \sigma(P=0)\left[1 + \frac{16}{4\sqrt{2}} \left(\frac{G_F q^2}{4\pi\alpha}\right) \left(\frac{g_A^e g_V^s}{Q_s}\right) P\right]$$

$$A_{LR} = -\frac{3}{\sqrt{2}} \left(\frac{G_F q^2}{4\pi\alpha}\right) g_V^s\, P$$

$Q_b = Q_s = -1/3;\ g_A^e = 0.5$

So what about b-Z couplings?

$$A_{LR} = -\frac{6}{\sqrt{2}}\left(\frac{G_F M^2_{Y(4S)}}{4\pi\alpha}\right) g_A^e g_V^b \langle Pol \rangle$$

Q_b=-1/3; g_A^e=0.5

$$\langle Pol \rangle = 80\%; A_{LR} = -0.010$$

1 billion reconstructed Y(4S) decays gives A_{LR} to 0.3% stat.

Currently value:

$$g_V^b = -0.3220 \pm 0.0077 (2.4\%)$$

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Ratio of A_{LR} mu-pair:A_{LR} Υ(4S)

This ratio probes the ratio of the vector couplings of leptons to b-quarks with the polarisation systematic errors cancelling

Still need to understand impact of non-resonant BBbar production at the 4S

Similar approach for Charm

- Gives charm neutral current vector coupling
- Operate at a ccbar vector resonance above open charm threshold psi(3770) ?
- If we want to get charm, need to have polarization at lower energies with sufficient luminosity

Lepton universality: from LEP/SLC

- Neutral current universality: a reminder

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

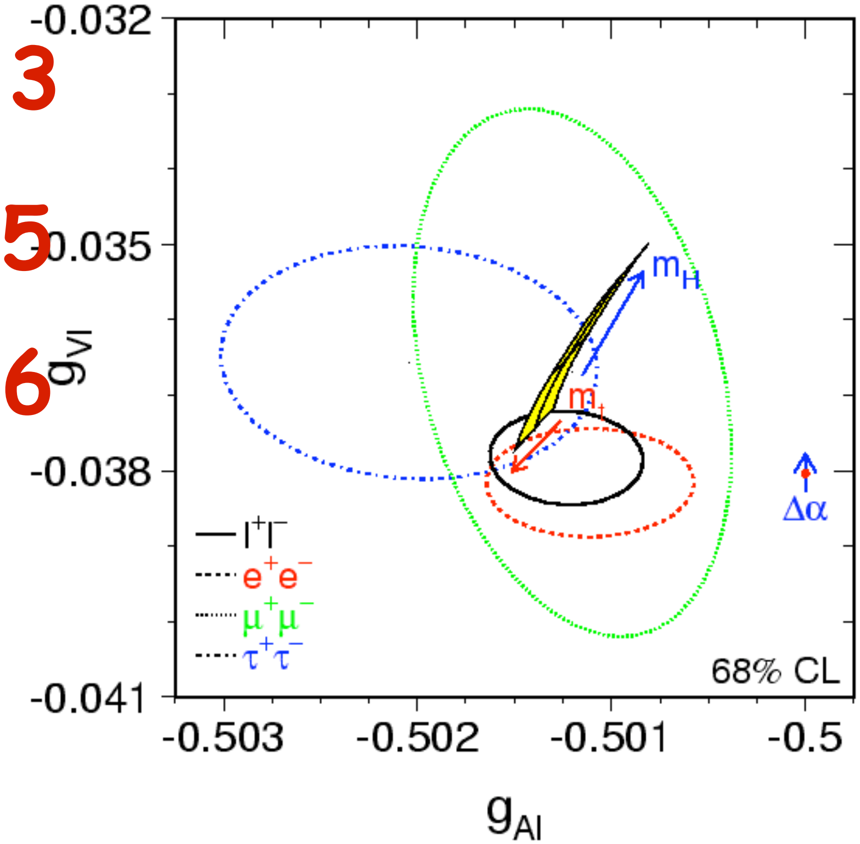
$g_e^A / g_\tau^A = 0.9981 \pm 0.0015$

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

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

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

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



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Neutral Current Physics Programme

- Measure $\sin^2\vartheta^{eff}_W$ at 10.58GeV
  - Competitive precision EW measurements
  - 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

Some issues…

- need to examine impact of AFB (dominated by QED)
- need to examine impact of non-resonant production at 4S
- polarization measurements of ~0.5% are sufficient for absolute measurements
- evaluate charm potential