A_{FB} in the SuperB EW Physics Programme => why we need A_{LR}

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QMUL

Outline

- Reminder of what A_{LR} –the EW programme
- Comments on A_{FB}: what we're measuring, why this isn't the way to get the weak mixing angle
- Reminder of how tau polarisation FB asymmetry gives us precision beam polarization

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EW reminders…

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

$$\mathcal{G}_{\mathrm{Af}} = \sqrt{\mathcal{R}_{\mathrm{f}}}\,T_3^{\mathrm{f}}\,.$$

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.

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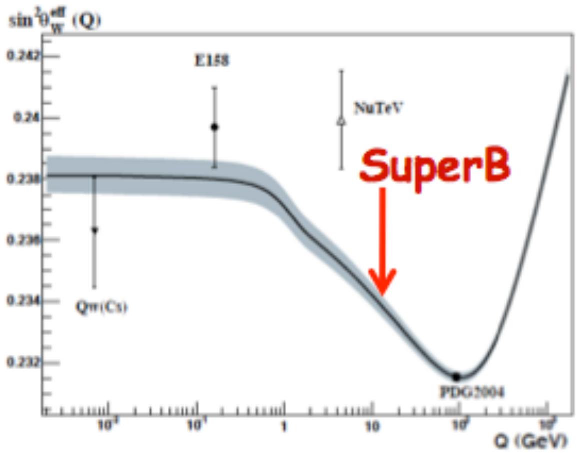
Polarised Beams provide an impressive Precision EW Programme at SuperB

- polarised beam provide measurement of $\sin^2\Theta w(\mathrm{eff})$ of using muon pairs of comparable precision to that obtained by SLD, except at 10.58GeV.



- Similar measurement can be made with taus and charm
- Test neutral current universality at high precision
- Because it depends on gamma-Z interference it is sensitive to Z'
- Measure NC Z-b-bbar vector coupling with higher precision and different systematic errors than determined at LEP with A_{FB}^{b} and at high precision

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

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

σ_{ALR} =5x10^{-6} → $\sigma_{(\sin2\theta eff)}$ =0.00018

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

relative stat. error of 1.1% (pol=80%)

require <~0.5% systematic error on beam polarisation

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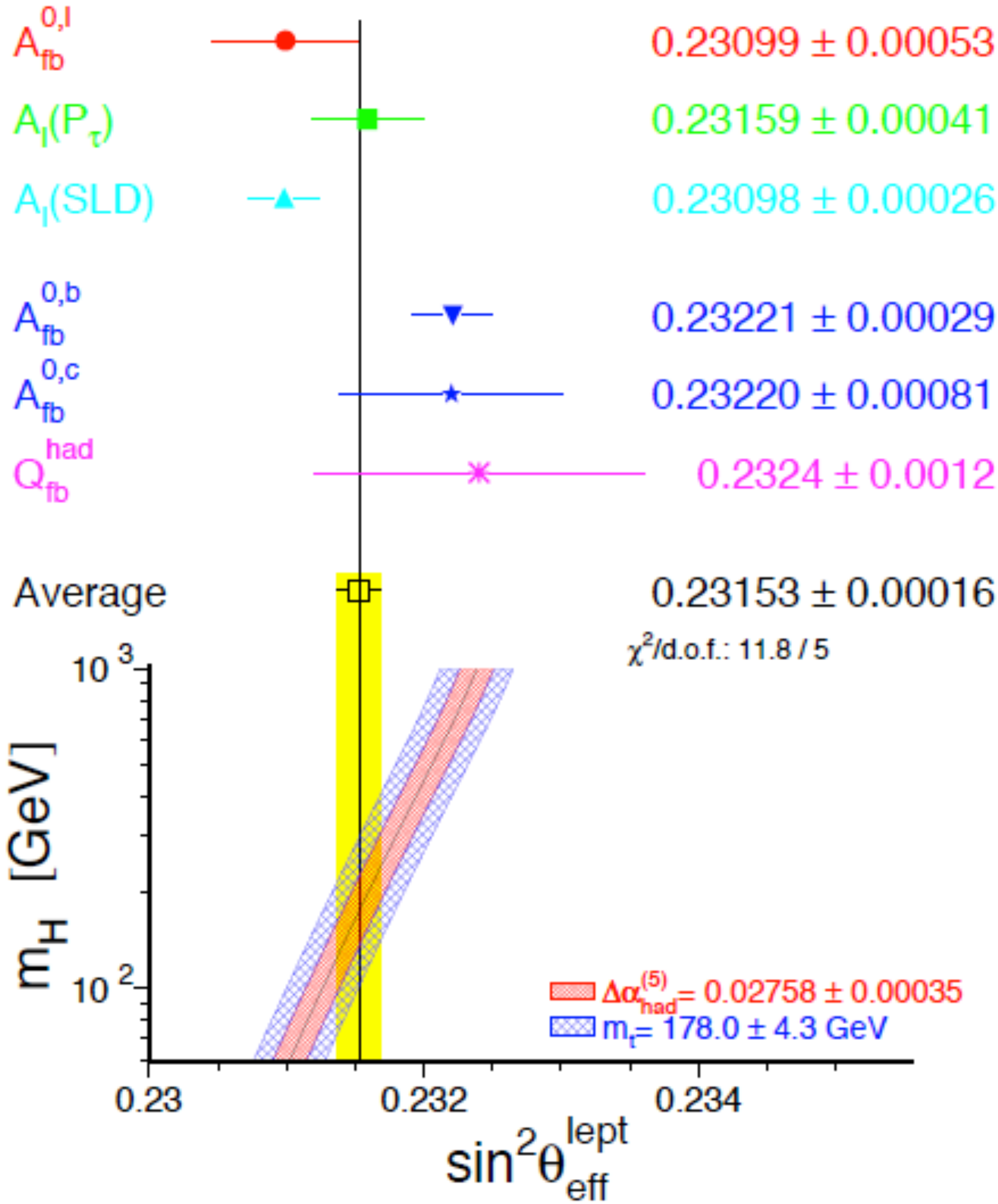
Tau and Charm

- Same approach can be used for taus and charm:
  - identify events as tau or charm
  - for each type, measure A_{LR}
  - Interpret in terms of measurement of vector coupling and $\sin^2\theta^{eff}_W$
  - Can probe universality at unprecedented precision



$A_{fb}^{0,l}$ 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
$\sin^2\theta_{eff}^{lept}$

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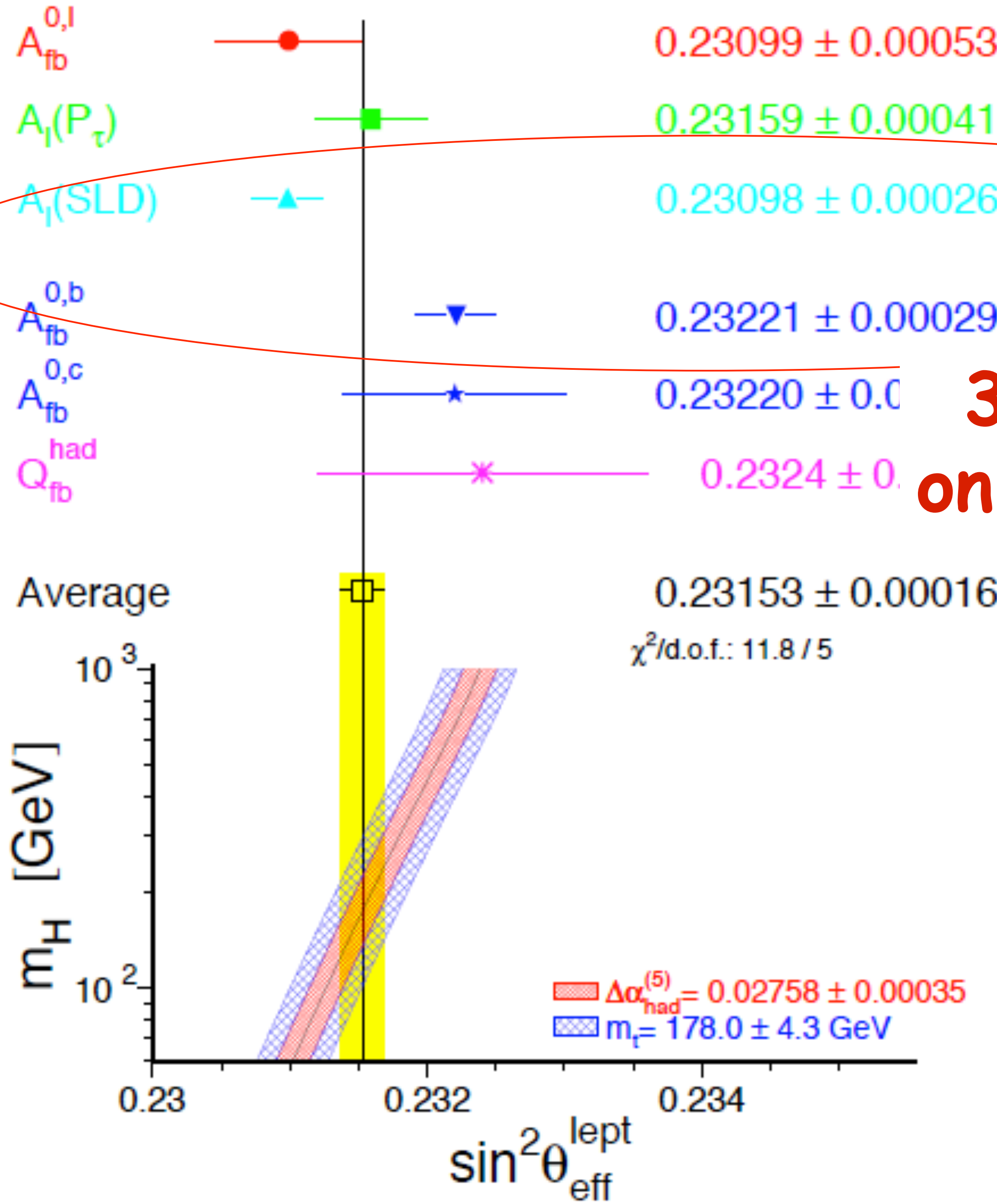

3.2σ comparing only A_{LR} and $A^{0,b}_{fb}$

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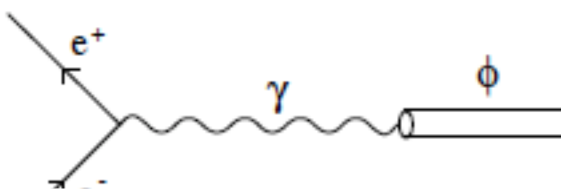
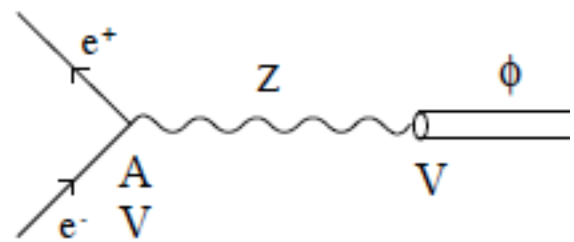
Z-b-bar couplings

- 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)





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

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

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

Z-b-bbar couplings

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

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

$$\langle Pol \rangle = 80\%; A_{LR} = -0.008$$

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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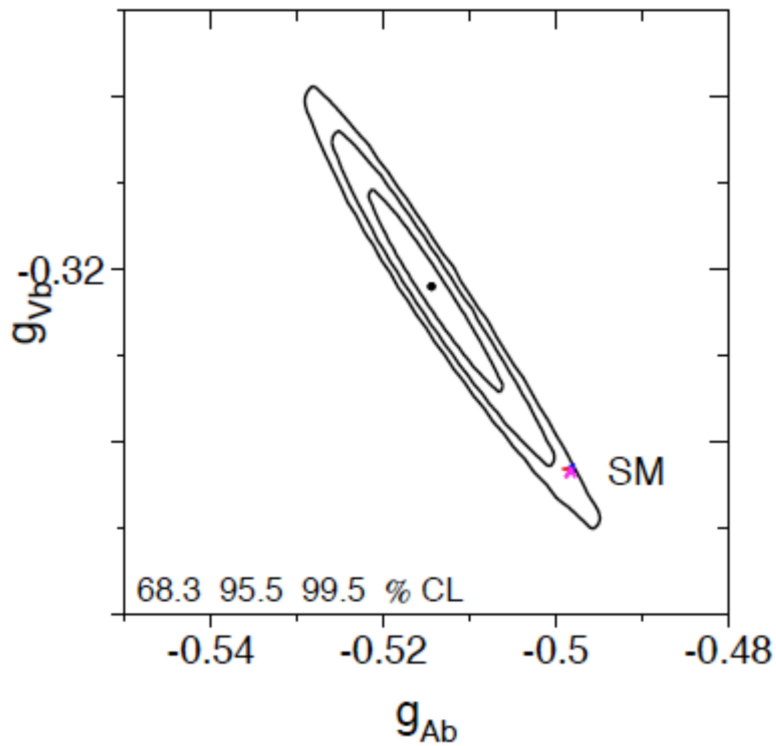
SM expectation & LEP Measurement of g_V^b

- SM: -0.34372 +0.00049-.00028
- A_{FB}^b: -0.3220±0.0077



- with 0.5% polarization systematic and 0.3% stat error, SuperB can have an error of ±0.0021

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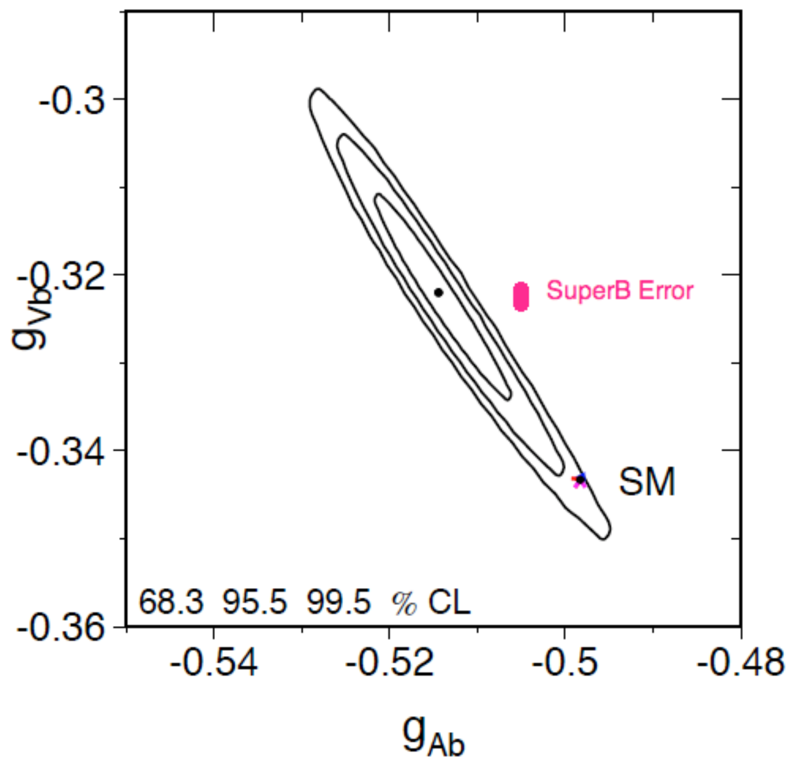

Ratio: A_{LR} (4S)/A_{LR} (mu-pair)

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

Similar as with tau and charm to mu-pair ratios

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A_{FB}

- Without polarization, can we still measure EW effects via the forward-backward asymmetry?

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

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

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

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

with:

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

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A_{FB}

- Without polarization, can we still measure EW effects via the forward-backward asymmetry?

$$\frac{d\sigma(e^+e^- \to \mu^+\mu^-)}{d\Omega} = \left(\frac{\alpha^2}{4s}\right)\left[C_1(1+\cos^2\theta) + C_2\cos\theta\right];$$

θ = angle between μ^- and electron beam direction in CM

$$C_1 = 1 + 8g_V^e g_V^\mu \chi(s)/\alpha + 16\left[\left(g_V^e\right)^2 + \left(g_A^e\right)^2\right]\left[\left(g_V^\mu\right)^2 + \left(g_A^\mu\right)^2\right]\chi(s)^2/\alpha^2$$

$$C_2 = 16 g_A^e g_A^\mu \chi(s)/\alpha + 128 g_A^e g_A^\mu g_V^e g_V^\mu \chi^2/\alpha^2$$

$$g_V^{e,\mu} = T_3 - 2Q_e\sin^2\vartheta_W = -0.5 + 2\sin^2\vartheta_W$$

$$g_A^{e,\mu} = T_3 = -0.5$$

At $\sqrt{s} = 10.58\text{GeV}$ $\quad \chi(s) \approx \frac{-G_F s}{8\pi\sqrt{2}} = -3.7\times 10^{-5}$

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$$A_{FB} = \frac{\int_0^{+1} d\cos\theta \frac{d\sigma(e^+e^- \to \mu^+\mu^-)}{d\cos\theta} - \int_{-1}^{0} d\cos\theta \frac{d\sigma(e^+e^- \to \mu^+\mu^-)}{d\cos\theta}}{\int_{-1}^{+1} d\cos\theta \frac{d\sigma(e^+e^- \to \mu^+\mu^-)}{d\cos\theta}}$$

$$A_{FB}^0 = \frac{3}{8}\frac{C_2}{C_1} = \left(\frac{3}{8}\right)\frac{16 g_A^e g_A^\mu \chi/\alpha + 128 g_A^e g_A^\mu g_V^e g_V^\mu \chi^2/\alpha}{1 + 8 g_V^e g_V^\mu \chi/\alpha + 16\left[\left(g_V^e\right)^2 + \left(g_A^e\right)^2\right]\left[\left(g_V^\mu\right)^2 + \left(g_A^\mu\right)^2\right]\chi(s)^2/\alpha^2}$$

$$= 6 g_A^e g_A^\mu \chi/\alpha(1 + 8 g_V^e g_V^\mu \chi/\alpha)/(1 + 8 g_V^e g_V^\mu \chi/\alpha + O(\chi^2/\alpha^2));$$

$$\chi(\sqrt{s} = 10.58 GeV)/\alpha \approx -0.0051$$

Recall in SM $g_A^e = g_A^\mu = -0.5; \quad g_V^e = g_V^\mu \approx -0.04 = \text{-}0.5 + 2\sin^2\vartheta_W$

$$\Rightarrow A_{FB}^0 = \frac{6 g_A^e g_A^\mu \chi/\alpha(1 + 8 g_V^e g_V^\mu \chi/\alpha)}{1 + 8 g_V^e g_V^\mu \chi/\alpha + 8(1 - 2\sin^2\vartheta_W + 8\sin^4\vartheta_W)\chi^2/\alpha^2};$$

little sensitivity to $\sin^2\vartheta_W$ as it comes in primarily via pure Z term

Best to consider A_{FB}^0 a measurement of $g_A^e g_A^\mu$ at $\sqrt{s} = 10.58\text{GeV}$

Can we use Zfitter to study this?

- Some have used Zfitter and see an apparent sensitivity to the weak mixing angle via A_{FB} … but it's not so simple
- Input to Zfitter includes fundamental SM parameters (M_z, M_w, M_{top}, M_{Higgs}, α(QED), etc) and Zfitter calculates $\sin^2\theta^{eff}_W$ and outputs expectations of observables such as A_{LR} and A_{FB} etc.
- Zfitter includes higher-order EW loops that contribute to both g_A and g_V

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Can we use Zfitter to study this?

- Variations to inputs that change g_V (and consequently $\sin^2\theta^{eff}{}_W$) typically also change g_A via the EW loops. It is these changes in g_A that naturally leads to a change in A_{FB} .

- Running Zfitter with the EW loop calculations turned off confirms that A_{FB} is giving information about g_A not g_V (and consequently $\sin^2\theta^{eff}{}_W$)

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Tau Polarisation as Beam Polarimeter

$$P_{z'}^{(\tau-)}(\theta,P_e) = -\frac{8G_F s}{4\sqrt{2}\pi\alpha}\mathrm{Re}\left\{\frac{g_V^l - Q_b g_V^b \Upsilon_{1S,2S,3S}(s)}{1+Q_b^2\Upsilon_{1S,2S,3S}(s)}\right\}\left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2g_A^e \frac{\cos\theta}{1+\cos^2\theta}\right)$$

$$+ P_e \frac{\cos\theta}{1+\cos^2\theta}$$

- Dominant term is the polarization forward-backward asymmetry whose coefficient is the beam polarization ->Oscar's slides from Elba
- Measure tau polarization as a function of θ for the separately tagged beam polarization states
- Because it's a forward-backward asymmetry it doesn't use information we'd want to use for new physics studies

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Tau Polarisation as Beam Polarimeter

- Advantages:
  - Measures beam polarization at the IP: biggest uncertainty in Compton polarimeter measurement is likely the uncertainty in the transport of the polarization from the polarimeter to the IP.
  - It automatically incorporates a luminosity-weighted polarization measurement
  - If positron beam has stray polarization, it's effect is automatically included
- 0.5% systematic error on P_e from tau FB polarization asymmetry can be obtained using only pion decays (0.25% with other modes)
- to get to 1%, we'll need 144fb^{-1}

Tau Polarisation as Beam Polarimeter

- BaBar selection was not optimized for polarisation and would expect more efficient use of data
- See no reason why the tau polarisation forward-backward asymmetry can't be used as a beam polarimeter at SuperB
- At a minimum, it would provide a cross check of the Compton polarimeter measurement
- At best, it may provide the absolute beam polarisation measurement and Compton polarimeter provides time dependence and a cross check

Summary

- We have a very rich EW programme that gives unprecedented precision measurements of the vector coupling via A_{LR} –for mu, tau, charm and b fermions – the best place for b's
- A_{FB}: gives us g_A, but the weak mixing angle
- tau polarisation FB asymmetry gives us precision beam polarization measurement

BACKUP SLIDES

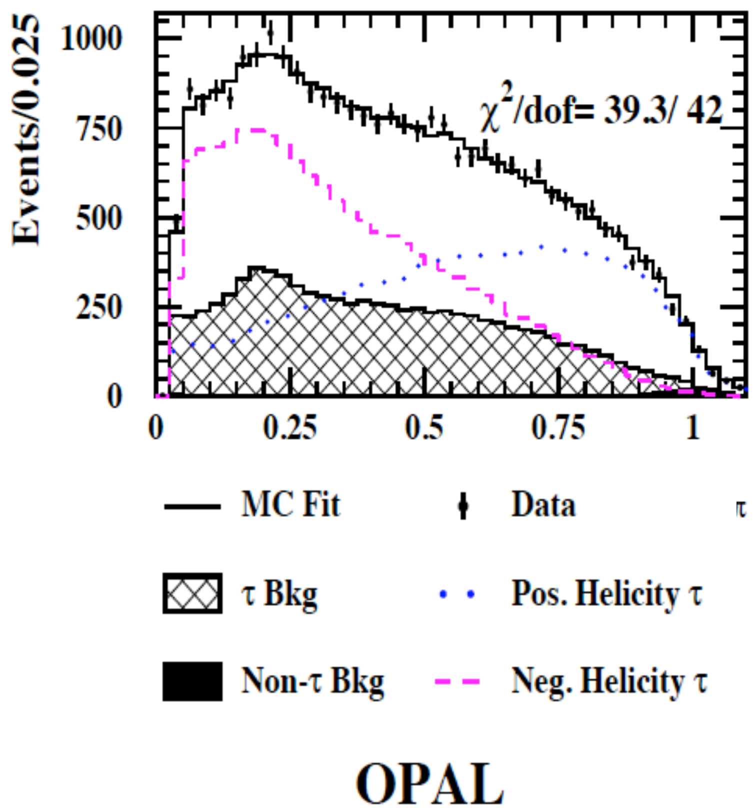
Tau Polarisation as Beam Polarimeter

- OPAL tau->pi nu **Eur.Phys.J. C21 (2001) 1-21**
- Events selected using vetoes against multihadron, dimuon, elec-pair or 2-photon events

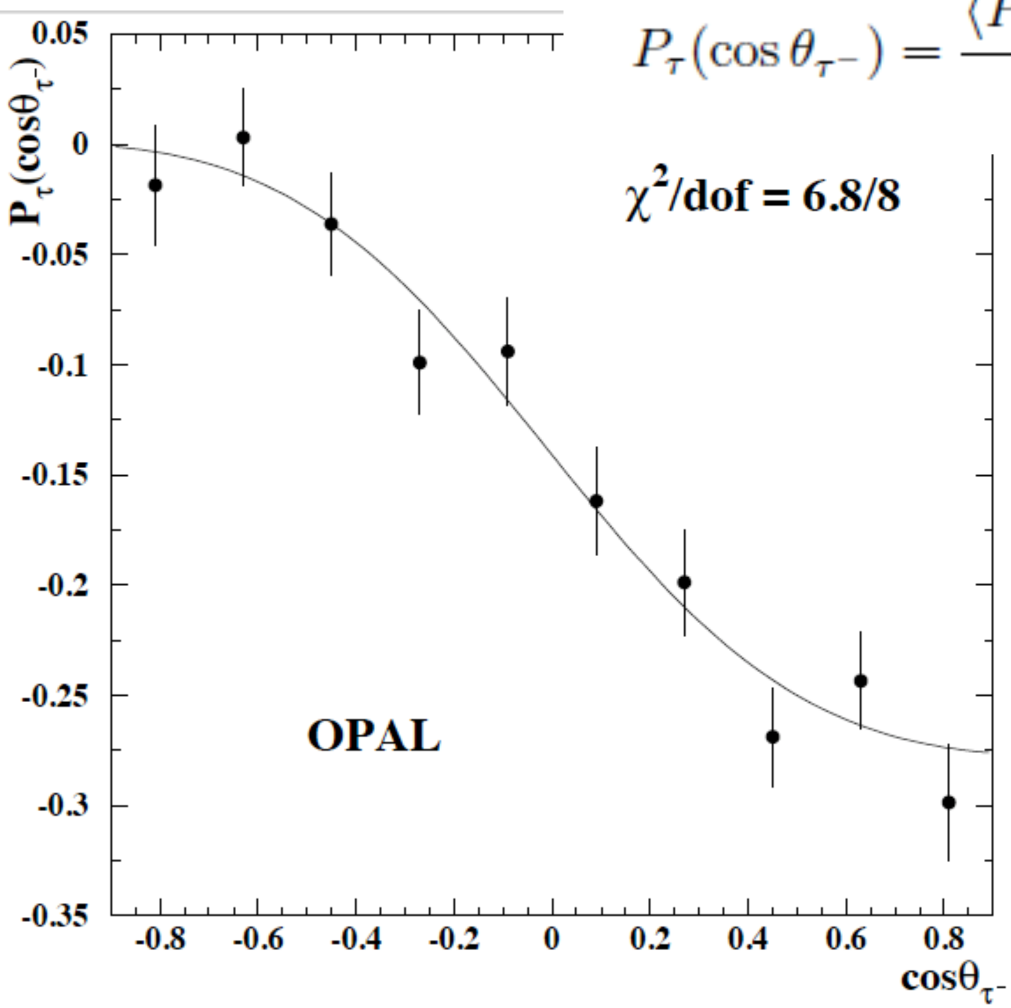
non-tau background (0.2%)

- Nsignal=22526
- Purity=0.74
  - main backgrounds:

    rho(16%);mu(5%);a1(2%)



Tau Polarisation as Beam Polarimeter



$$P_\tau(\cos\theta_{\tau^-}) = \frac{\langle P_\tau \rangle \; (1+\cos^2\theta_{\tau^-}) + \frac{8}{3}\mathrm{A}^{\mathrm{FB}}_{\mathrm{pol}} \; \cos\theta_{\tau^-}}{(1+\cos^2\theta_{\tau^-}) + \frac{8}{3}\mathrm{A}_{\mathrm{FB}} \; \cos\theta_{\tau^-}}$$

$\frac{8}{3} A^{FB}_{POL}$ at OPAL plays role of

P_e at SuperB

Most systematic errors cancel for this FB quantity

Tau Polarisation as Beam Polarimeter

Systematic errors expressed in 0.01 units:

	$\Delta\langle P_\tau\rangle$ and ΔA_{pol}^{FB}											
	e		μ		π		ρ		a_1		Global fit	
Momentum scale/resolution	0.4	0.2	2.1	0.1	0.8	0.1	0.3	0.1	0.4	0.2	0.24	0.13
ECAL scale/resolution	3.2	0.1	0.2	0.1	0.2	–	1.1	0.2	0.3	0.1	0.17	0.11
HCAL/MUON modelling	0.1	–	1.1	0.1	0.5	0.1	–	–	–	–	0.13	0.05
dE/dx errors	0.6	0.1	0.3	0.1	0.3	0.1	0.1	0.1	0.3	0.1	0.12	0.08
Shower modelling in ECAL	0.6	0.1	0.2	0.1	0.4	0.1	0.5	0.2	0.4	0.1	0.25	0.10
Branching ratios	0.1	–	0.1	–	0.2	–	0.2	–	0.2	0.1	0.11	0.02
$\tau \to a_1 \nu_\tau$ modelling	–	–	–	–	–	–	0.4	–	0.5	0.1	0.22	0.02
$\tau \to 3\pi \geq 1\pi^0 \nu_\tau$ modelling	–	–	–	–	–	–	–	–	1.2	0.1	0.11	0.04
A_{FB}	–	0.2	–	–	–	–	–	–	–	–	0.03	0.02
Decay radiation	–	–	–	–	–	–	–	–	0.1	–	0.01	0.01
Monte Carlo statistics	0.7	0.2	0.8	0.3	0.3	0.1	0.3	0.1	0.8	0.2	0.22	0.10
total	3.4	0.4	2.6	0.4	1.2	0.2	1.3	0.3	1.7	0.3	0.55	0.25

Pion systematic error is smallest = 0.002

8/3 factor→translates into 0.005 P_e error

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Tau Polarisation as Beam Polarimeter

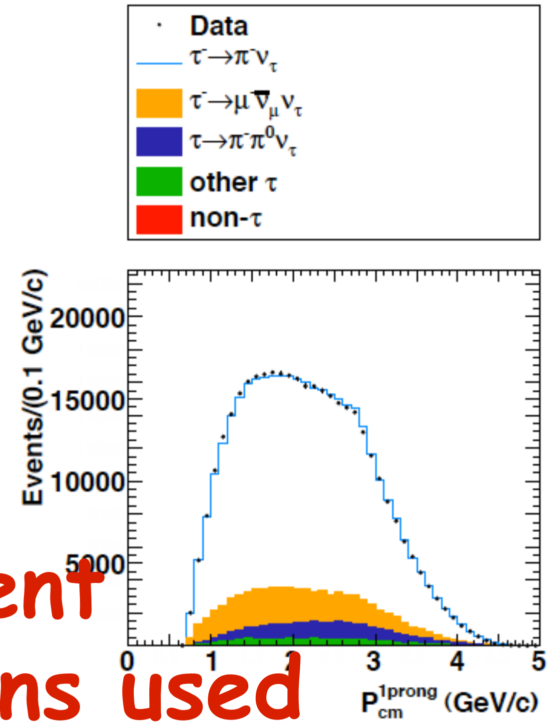
	$\tau \to e\nu_e\nu_\tau$	$\tau \to \mu\nu_\mu\nu_\tau$	$\tau \to \pi\nu_\tau$	$\tau \to \rho\nu_\tau$	$\tau \to a_1\nu_\tau$
Sample size	44,083	41,291	30,440	67,682	22,161
Efficiency	92%	87%	75%	73%	77%
Background	4.6%	3.3%	26%	29%	25%
$\langle P_\tau \rangle$ (%)	-18.7 ± 2.5	-16.3 ± 2.7	-13.8 ± 1.2	-13.3 ± 1.1	-11.6 ± 2.8
A_{pol}^{FB} (%)	-8.9 ± 2.6	-10.6 ± 2.8	-11.5 ± 1.3	-10.6 ± 1.1	-7.1 ± 2.8

Statistical error is 0.013 for 22526 $\tau \to \pi\nu$ signal events

translates into error of 0.035 on P_e
To reach 0.005 error need 1.1M events

Tau Polarisation as Beam Polarimeter

- BaBar tau->pi nu selection from Phys.Rev.Lett. 105 051602 (2010)
- Tag with 3-prong, suppressed non-tau background and trigger efficiency not an issue
- Luminosity=467fb^{-1}
- Nsignal=288,400
- Purity=0.79



Seems ~ 3.6 ab^{-1} is sufficient to get to 0.005 if only pions used

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Additional Thoughts…

- OPAL used 5 channels in a global analysis and achieved a total statistical error on ApolFB of 0.0076 with systematic error of 0.0025 or total error of 0.008, or 8/3*0.008=0.021 for error on P_e. This was with the equivalent of 22526/288400*467fb^{-1} =36fb^{-1} .
- So to get to 1%, we'll need 144fb^{-1}

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