# Luminosity and Energy calibration why do we need them at the same time?

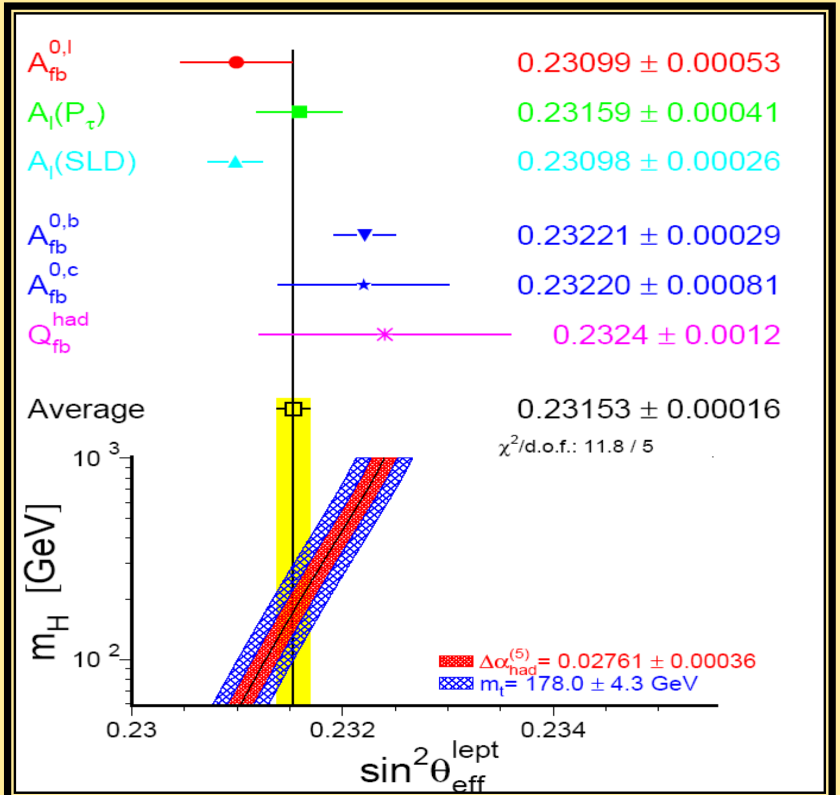
| observable | Physics | Present precision | | FCC-ee stat Syst Precision | FCC-ee key | Challenge |
|---|---|---|---|---|---|---|
| $M_Z$ MeV/c2 | Input | 91187.5 ±2.1 | Z Line shape scan | 0.005 MeV <±0.1 MeV | E_cal | QED corrections |
| $\Gamma_Z$ MeV/c2 | $\Delta\rho$ (T) (no $\Delta\alpha$!) | 2495.2 ±2.3 | Z Line shape scan | 0.008 MeV <±0.1 MeV | E_cal | QED corrections |
| $R_l \equiv \frac{\Gamma_h}{\Gamma_l}$ | $\alpha_s$, $\delta_b$ | 20.767 (25) | Z Peak | 0.0001 (2-20) | Statistics | QED corrections |
| $N_\nu$ | Unitarity of PMNS, sterile ν's | 2.984 ±0.008 | Z Peak Z+γ(161 GeV) | 0.00008 (40) 0.001 | ->lumi meast Statistics | QED corrections to Bhabha scat. |
| $R_b$ | $\delta_b$ | 0.21629 (66) | Z Peak | 0.000003 (20-60) | Statistics, small IP | Hem. correlations |
| $A_{LR}$ | $\Delta\rho$, $\varepsilon_3$, $\Delta\alpha$ (T, S ) | $\sin^2\theta_w^{eff}$ 0.23098(26) | Z peak, Long. polarized | $\sin^2\theta_w^{eff}$ ±0.000006 | 4 bunch scheme | Design experiment |
| $A_{FB}^{lept}$ | $\Delta\rho$, $\varepsilon_3$, $\Delta\alpha$ (T, S ) | $\sin^2\theta_w^{eff}$ 0.23099(53) | | $\sin^2\theta_w^{eff}$ ±0.000006 | E_cal & Statistics | |
| $M_W$ MeV/c2 | $\Delta\rho$, $\varepsilon_3$, $\varepsilon_2$, $\Delta\alpha$ (T, S, U) | 80385 ± 15 | Threshold (161 GeV) | 0.3 MeV <0.5 MeV | E_cal & Statistics | QED corections |
| $m_{top}$ MeV/c2 | Input | 173200 ± 900 | Threshold scan | ~10 MeV | E_cal & Statistics | Theory limit at 50 MeV? |

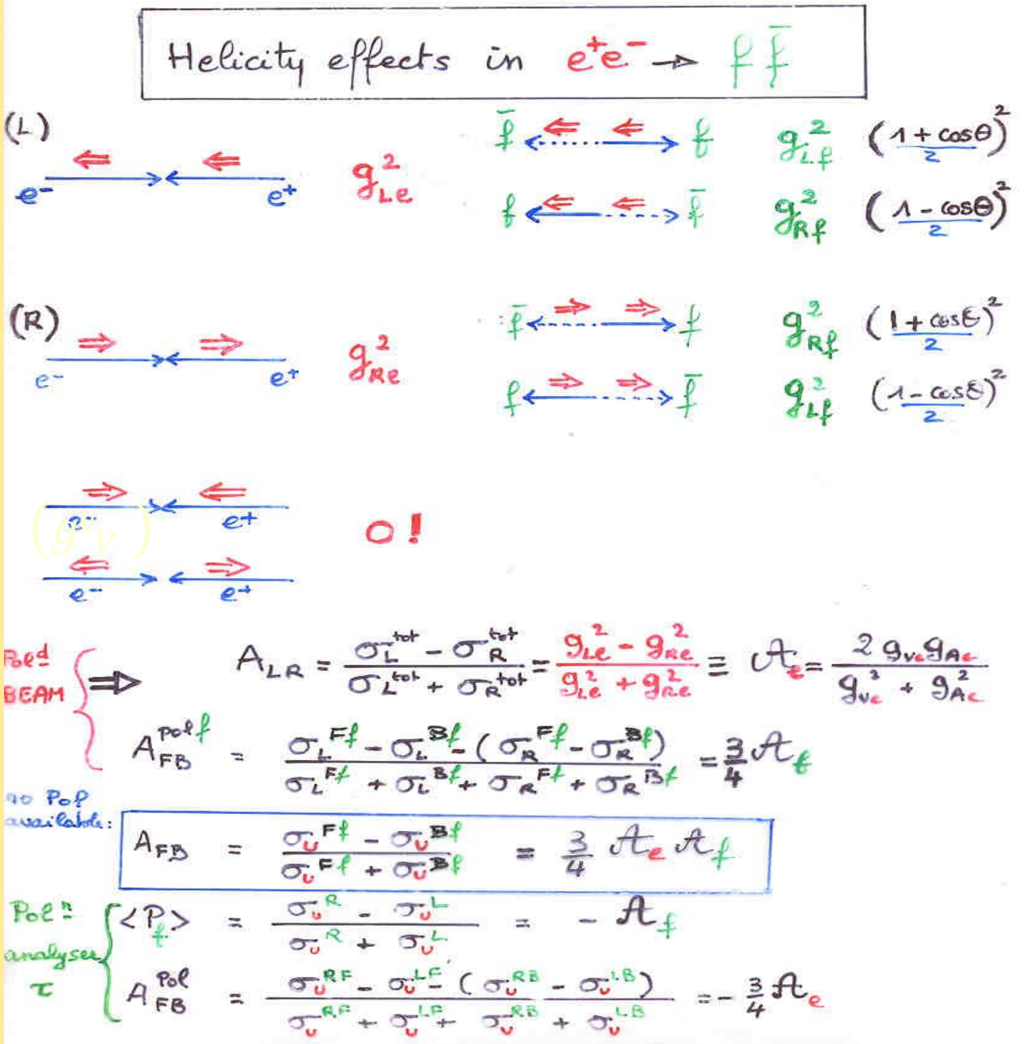
# Measuring $\sin^2\theta_W^{eff}$ $(m_Z)$

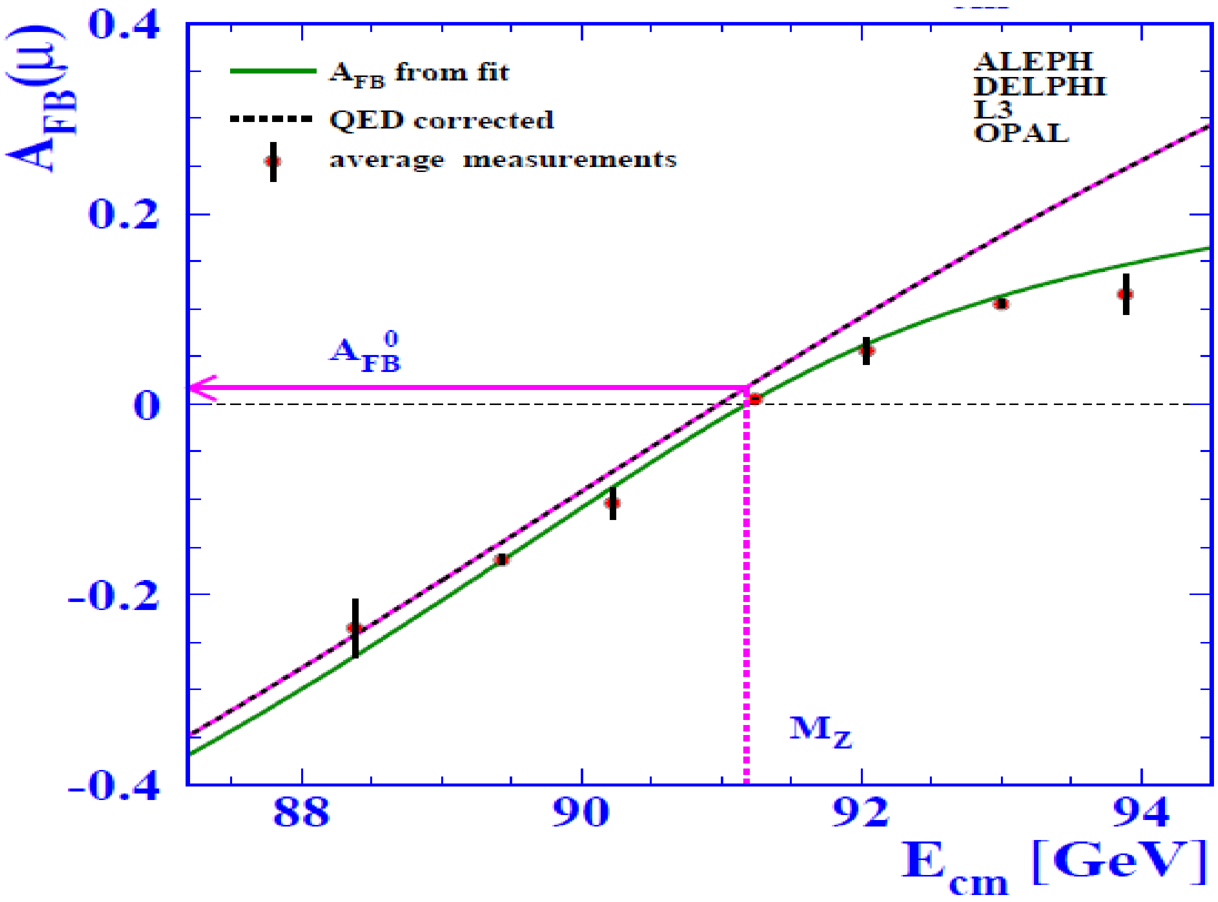
$$\sin^2\theta_W^{eff} \equiv \frac{1}{4}\,(1 - g_V/g_A)$$

$$g_V = g_L + g_R$$

arXiv:0509008





$A_{FB}(\mu)$
0.4
0.2
0
-0.2
-0.4
$A_{FB}$ from fit
QED corrected
average measurements
ALEPH
DELPHI
L3
OPAL
$A_{FB}^{0}$
$M_Z$
88
90
92
94
$E_{cm}$ [GeV]

| | $A_{FB}^{\mu\mu}$ @ FCC-ee | | $A_{LR}$ @ ILC | $A_{LR}$ @ FCC-ee |
|---|---|---|---|---|
| visible Z decays | $2 10^{12}$ | visible Z decays | $10^{9}$ | $5.10^{10}$ |
| muon pairs | $10^{11}$ | beam polarization | 90% | 30% |
| $\Delta A_{FB}^{\mu\mu}$ (stat) | $3\ 10^{-6}$ | $\Delta A_{LR}$ (stat) | $4.2\ 10^{-5}$ | $4.5\ 10^{-5}$ |
| $\Delta\ E_{cm}$ (MeV) | 0.1 | | 2.2 | ? |
| $\Delta A_{FB}^{\mu\mu}$ ($E_{CM}$ ) | $9.2\ 10^{-6}$ | $\Delta A_{LR}$ ($E_{CM}$ ) | $4.1\ 10^{-5}$ | |
| $\Delta A_{FB}^{\mu\mu}$ | $1.0\ 10^{-5}$ | $\Delta A_{LR}$ | $5.9\ 10^{-5}$ | |
| $\Delta \sin^2\theta^{lept}_W$ | $5.9\ 10^{-6}$ | | $7.5\ 10^{-6}$ | $6\ 10^{-6}$ +? |

NB: the error on E_CM is the same as that on the Z mass and this should probably lead to some cancellation.

All exceeds the theoretical precision from $\Delta\alpha(m_Z)$ ($3 10^{-5}$) or the comparison with $m_W$ (500keV)

**$\Delta \sin^2\theta^{lept}_W$ ~ $\Delta\alpha(m_z)$ /3**

**But this precision on $\Delta \sin^2\theta^{lept}_W$ can only be exploited at FCC-ee!**

arXiv:1512.05544v3 [hep-ph] 25 Jan 2016

# Direct measurement of $\alpha_{QED}(m_Z^2)$ at the FCC-ee

**Patrick Janot**
*CERN, PH Department, Geneva, Switzerland*

ABSTRACT: When the measurements from the FCC-ee become available, an improved determination of the standard-model "input" parameters will be needed to fully exploit the new precision data towards either constraining or fitting the parameters of beyond-the-standard-model theories. Among these input parameters is the electromagnetic coupling constant estimated at the Z mass scale, $\alpha_{QED}(m_Z^2)$. The measurement of the muon forward-backward asymmetry at the FCC-ee, just below and just above the Z pole, can be used to make a direct determination of $\alpha_{QED}(m_Z^2)$ with an accuracy deemed adequate for an optimal use of the FCC-ee precision data.

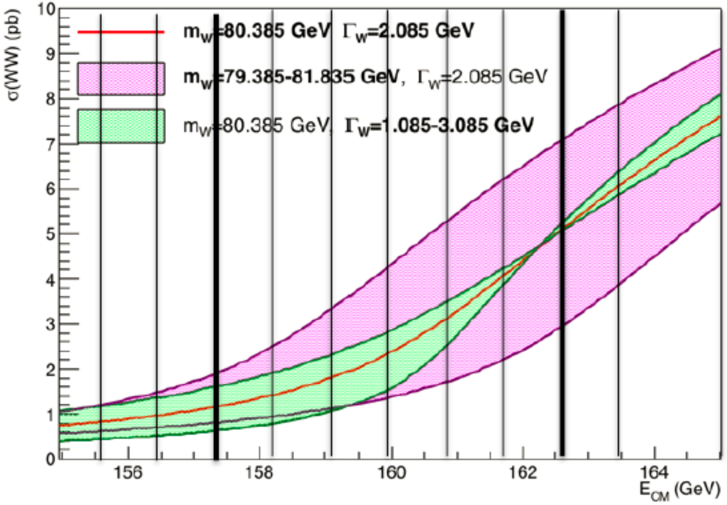
This is unique and allows us to make a complete and powerful investigation of 10-100 TeV scale with precision measurements

➔ tomorrow Patrick will make a proposal for a scan based on half integer spin tune data points. (from $\nu_s$ = 99.5 to 107.5)

**These are the beam energies for the W threshold measurement**

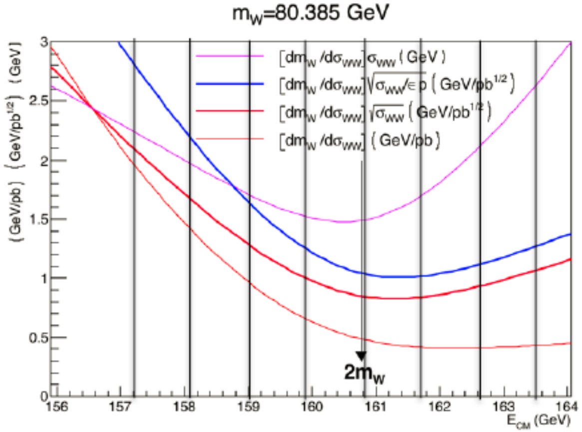
# with half-integer spin tunes

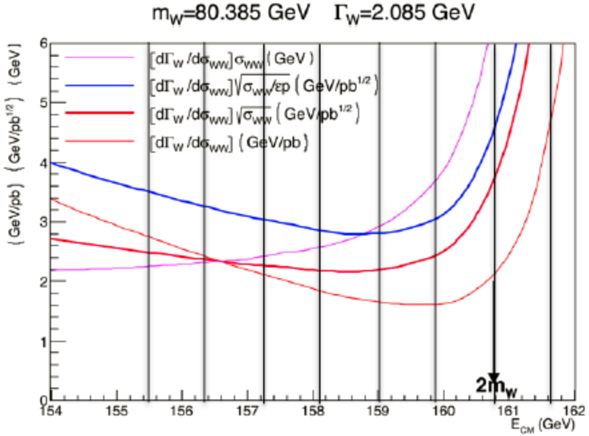
limiting data taking points to
$E_{CM} = (2n+1)*0.4406486$ GeV




min $\Delta m_W + \Delta\Gamma_W$

with $E_1$=**157.3** GeV $E_2$=**162.6** GeV f=**0.4**
**$\Delta m_W$=0.65 $\Delta\Gamma_W$=1.6 $\Delta m_W$=0.60 (MeV)**




~10% loss of stat precision

# Extracting physics from $\sin^2\theta^{lept}_W$

## 1. Direct comparison with $m_Z$

$$\sin^2\theta_W^{eff}\cos^2\theta_W^{eff} = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}\,G_F\,m_Z^2}\,\frac{1}{1+\Delta\rho}\,\frac{1}{1-\frac{\varepsilon_3}{\cos^2\theta_W}}$$

Uncertainties in $m_{top}$, $\Delta\alpha(m_z)$ , $m_H$ , etc….

**$\Delta\sin^2\theta^{lept}_W$ ~ $\Delta\alpha(m_z)$ /3 = $10^{-5}$ if we can reduce $\Delta\alpha(m_z)$ (see P. Janot)**

## 2. Comparison with $m_w/m_Z$

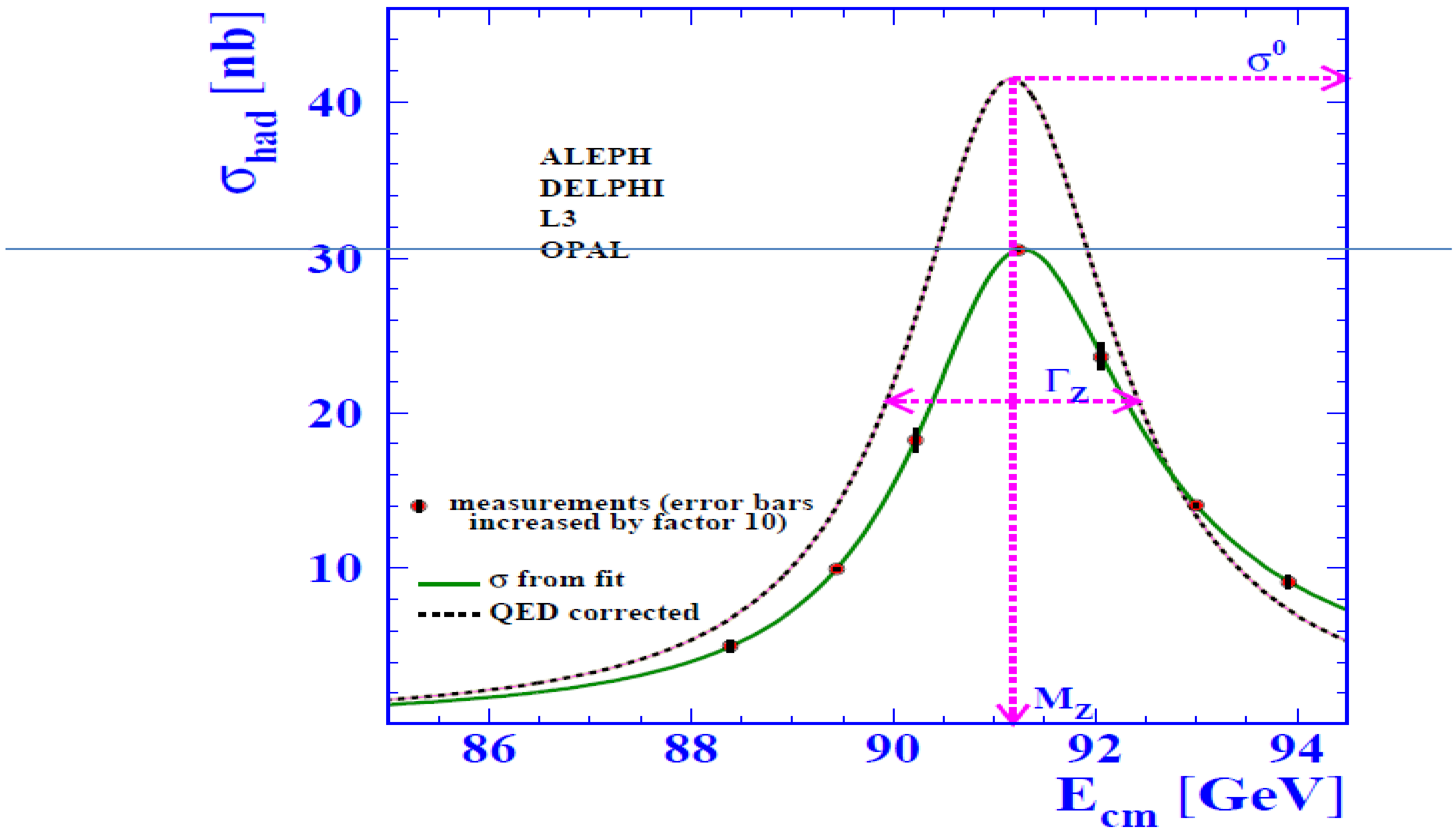
Compare above formula with similar one:

$$\sin^2\theta_W\cos^2\theta_W = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}\,G_F\,m_Z^2}\cdot\frac{1}{1-\left(-\frac{\cos^2\theta_W}{\sin^2\theta_W}\Delta\rho + 2\frac{\cos^2\theta_W}{\sin^2\theta_W}\varepsilon_3 + \frac{c^2-s^2}{s^2}\varepsilon_2\right)}$$

Where it can be seen that **$\Delta\alpha(m_z)$** cancels in the relation.

The limiting error is the error on $m_W$.

For **$\Delta m_W$= 0.5 MeV this corresponds to $\Delta\sin^2\theta^{lept}_W = 10^{-5}$**



$\sigma_{had}$ [nb]
40
30
20
10
ALEPH
DELPHI
L3
OPAL
$\sigma^0$
$\Gamma_Z$
$M_Z$
measurements (error bars increased by factor 10)
σ from fit
QED corrected
86
88
90
92
94
$E_{cm}$ [GeV]