Standard Model

Electroweak physics with Z^0
bosons

Outline

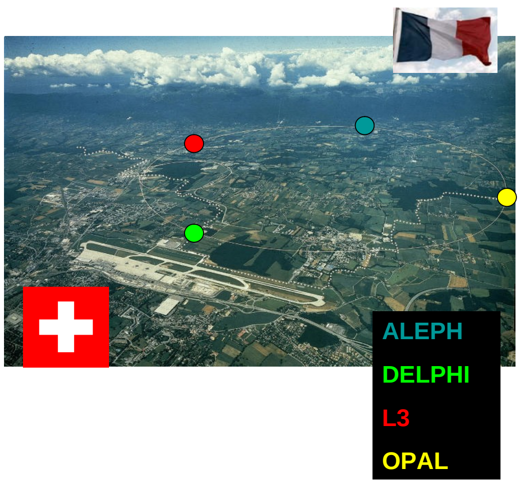
- **Introduction to e^+e^- facilities:**
  - SLC
  - LEP
- **Tests of SM with Z^0 bosons**
  - Z^0 lineshape measurements
    - $\rightarrow$ couplings, $\sin^2\theta_W$
  - Hadronic asymmetries of Z^0 decay products
    - $\rightarrow$ couplings, $\sin^2\theta_W$
- **What this says about top mass**

SLC

- e^+e^- linear accelerator
- 1 experiment
- $\sqrt{s}$ = 91.2 GeV
- Uses polarised electron beams (500 000 Z^0)

LEP

- e^+e^- collider
- 4 experiments
- $\sqrt{s}$ = 91.2 GeV (→1996) (200 pb^{-1})
- $\sqrt{s}$ →210 GeV (2000) (650 pb^{-1})
- nb. Site of LHC pp collider, $\sqrt{s}$ = 14 TeV, 2007→



Tests of SM with Z^0 bosons

- Define set of 5 most uncorrelated observables to test SM:
  - Z^0 mass,
  - Z^0 width,
  - hadronic cross-section,
  - ratio of leptons/hadrons,
  - forward backward asymmetry

Z^0 lineshape

asymmetries

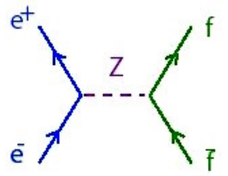
Measure as many observables as possible,

Express observables as functions of unknowns in SM

Fit for unknowns – 1) value of unknowns, 2) test consistency of model

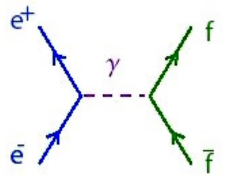
Z^0 production in e^+e^- colliders

2 production processes:



Dominates near M_{Z0}

Depends on $M_Z,\Gamma_Z,\Gamma_e,\Gamma_f$



Small at LEP, SLD

Depends on α

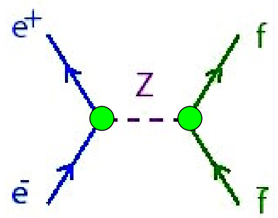
+ interference terms dependent on M_Z,Γ_Z

Z^0 lineshape measurements

Hadronic pole cross-section σ^0 related to total,partial widths of Z^0

$\sigma^0 = (12\pi/M_Z^2)\Gamma_{ee}\Gamma_{had}/\Gamma_Z^2$

Γ_{ee} = partial width for $Z \rightarrow ee$
Γ_{had} = partial width for $Z \rightarrow$ hadrons
Γ_Z = total width for Z^0 decay
M_Z = Z^0 mass (measured)



f = hadrons

Measure σ^0, M_Z, $G_Z \rightarrow \Gamma_{ee}.\Gamma_{had}$

Z^0 lineshape measurements

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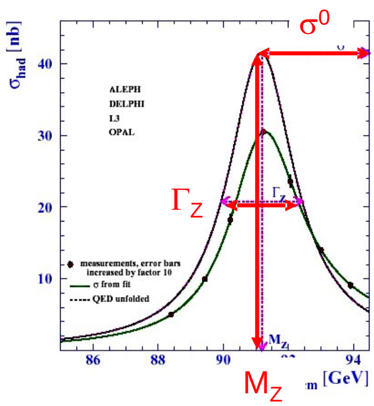
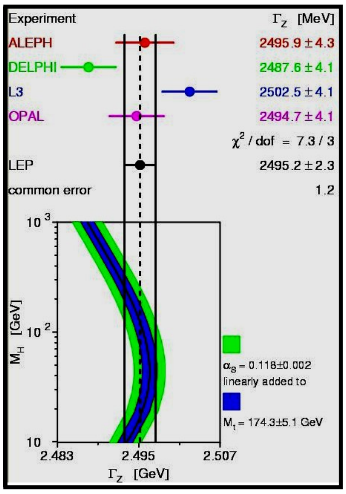


Measure σ^0, M_Z, $G_Z \rightarrow \Gamma_{ee}.\Gamma_{had}$

Measurements of Γ_Z



Z^0 lineshape measurements

Partial widths $\Gamma_{ee}\Gamma_{had}$ are proportional to ewk Z^0 couplings:

$$\Gamma_{ff} = (G_F\sqrt{2}M_Z^3/12\pi)(g_{vf}^2+g_{af}^2)N_{col}$$

- N_{col} = 1 (leptons), 3 (quarks)
- Effective couplings g_{vf}, g_{af} α $\sin^2\theta_W$:
- **$g_{af} = \pm 1/2$**
- **$g_{vf} = \pm 1/2 - 2\sin^2\theta_W e$**

Fundamental SM parameter

Z^0 lineshape measurements

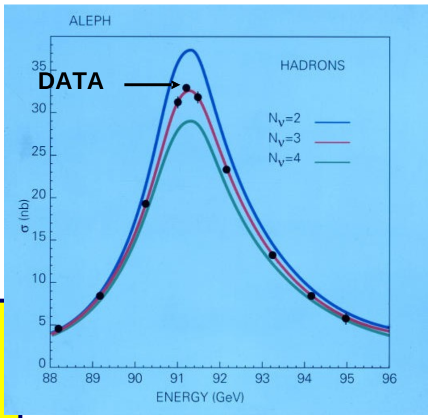
- Can measure ratios of partial width Γ_{ll}/Γ_{had}
  - Compare how often $Z^0 \rightarrow$leptons compared to $Z^0 \rightarrow$hadrons
  - Measure $\Gamma_{ee}\Gamma_{had}$ and Γ_{ee}/Γ_{had}
  - Input G_F, M_Z, extract couplings g_{vf}, g_{af}
  - Extract $\sin^2\theta_W$

No. neutrino species

Input measured Γ_Z, Γuu, Γdd, Γss, Γcc, Γbb, Γee, $\Gamma\mu\mu$, $\Gamma\tau\tau$

Input theoretical $\Gamma\nu\nu$

Calculate $N\nu$



$$\Gamma_Z = \Gamma uu + \Gamma dd + \Gamma ss + \Gamma cc + \Gamma bb + \Gamma ee + \Gamma\mu\mu + \Gamma\tau\tau + N\nu\Gamma\nu\nu$$

$$N\nu = (\Gamma_Z - (\Gamma uu + \Gamma dd + \Gamma ss + \Gamma cc + \Gamma bb + \Gamma ee + \Gamma\mu\mu + \Gamma\tau\tau)) / \Gamma\nu\nu$$

$$= 2.984 \pm 0.008$$

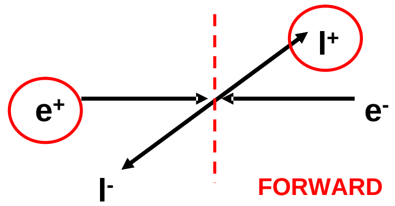
Asymmetries with Z^0 bosons

Measure effective couplings of Z^0 to fermions:

$A^f_{FB} = (N^f - N^b)/(N^f+N^b)$

N^f = number "forward"

N^b = number "backward"



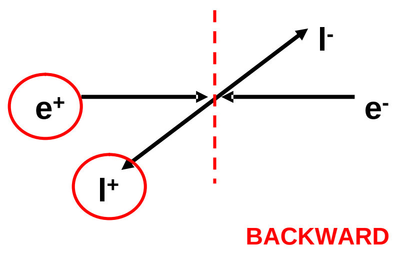
$A^f_{FB} = 3/4 AeAf$

where

$Af = 2g_{vf}g_{af}/g_{vf}^2+g_{af}^2$

$= 2(g_{vf}/g_{af})/(1+(g_{vf}/g_{af})^2)$

And $\mathbf{g_{vf}/g_{af}} \propto \mathbf{\sin^2\theta_W}$



Asymmetries cont.

How do we find Ae?

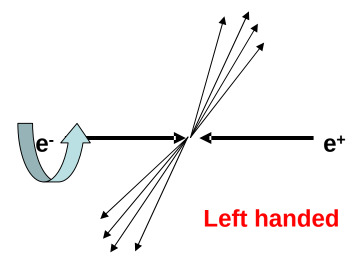
– Measure A_{LR} at SLC

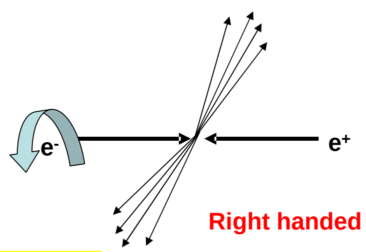
$A^f_{LR} = (\sigma^f_L - \sigma^f_R)/(\sigma^f_L + \sigma^f_R)$

– $\sigma^f_{L(R)}$ = total production cross-section for left (right) handed polarisation of e^- beams

A^f_{LR} = Ae

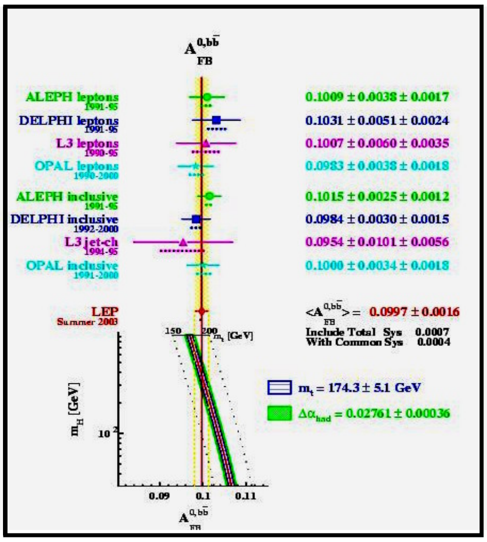
$\propto \mathbf{\sin^2\theta_W}$ **(eff)**





→ lots of independent measurements of $\sin^2\theta_W$

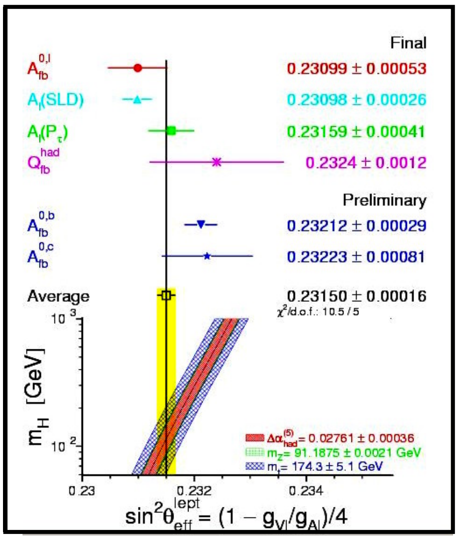
Current A_{FB} measurements



A_{FB} for bb pairs

Many more asymmetries measured …

Current $\sin^2\theta_W$ measurements



SM prediction of top mass

Can combine measurements X_i of lineshape and asymmetries in global fit to SM:

Express each observable X_i as

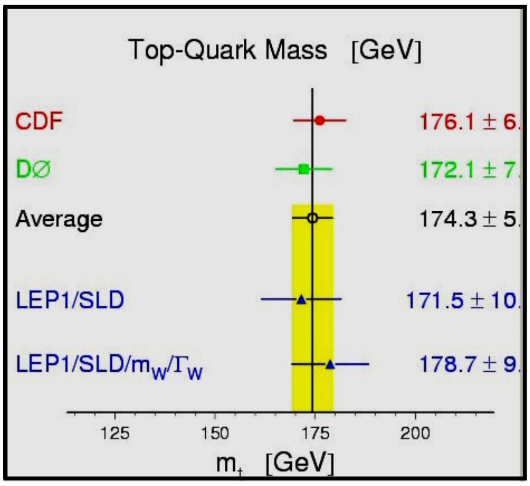
$X_i = X_i(\alpha(M_Z^2), G_F, M_Z, M_t, M_H, \alpha_s(M_Z^2))$

Constrain to measured values

Fixed at 300 GeV, systematically varied

1. Compare observed values to fitted SM values
2. Obtain values for M(top) and $\alpha_s(M_Z^2)$ from fit

SM prediction of top mass



direct

indirect

Indirect measurements told Tevatron where to look for top!

Review

- SM tested extensively in Z^0 sector
  - Cross-section, asymmetries sensitive to $\sin^2 \theta_W$, vector and axial couplings g_{vf}, g_{af}
  - Many independent measurements allow consistency of SM inputs to be tested
- Given experimental inputs of SM parameters, top mass can be predicted.