Outline

- Relativistic Kinematics
  - (4-momentum)2 invariance, invariant mass
  - Hypothesis testing, production thresholds
  - Cross-sections, flux and luminosity, accelerators
  - Particle lifetime, decay length, width
- Classification of particles
  - Fermions and bosons
  - Leptons, hadrons, quarks
  - Mesons, baryons
- Quark Model
  - Meson and baryon multiplets
  - Isospin, strangeness, c, b, t quarks
- Particle Interactions
  - Colour charge, QCD, gluons, fragmentation, running couplings
  - Strong and weak decays, conservation rules
  - Virtual particles and range of forces
  - Parity, charge conjugation, CP
  - Weak decays of quarks
  - Charmonium and upsilon systems
- Electroweak Interactions
  - Charged and neutral currents
  - W, Z, LEP experiments
  - Higgs and the future
- LHC Experiments' Results
- ☹ Future – introduction to accelerator physics ☹

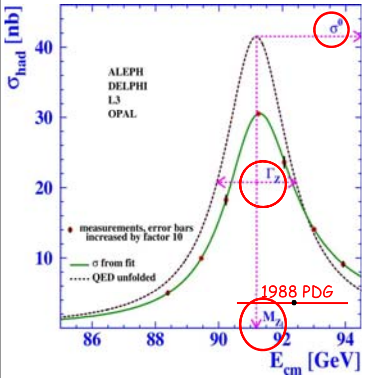
Today

- Lecture 21 (4 slides/page) - Z couplings, decay widths, couplings, Higgs
  - Martin and Shaw, pp. 225-229

Previous lecture

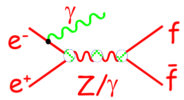
- Lecture 20 (4 slides/page) Weak neutral currents (Z) and experiments
  - Perkins, p317-318;
  - Griffiths, pp. 72-74;

LEP Lineshape: 1989+…final results



Combined measurements, LepI sample

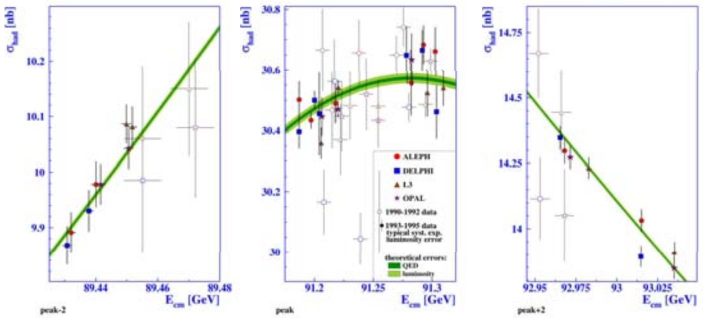
- 3 parameters: m_Z, Γ_Z, σ°_{had}
- Observe



- …EW radiative corrections absorbed in effective couplings
- Deconvolve to Born cross-section
- Obtain
  - m_Z = 91,187.5 ± 2.1 MeV
  - Γ_Z = 2,495.2 ± 2.3 MeV
  - σ°_{had} = 41.540 ± 0.037 nb

Final LEPI "Z^0 lineshape" measurements
See Physics Reports, Vol. 427, Nos. 5-6, May 2006

Details of LepI Cross-Section Data



All 4 LEP experiments and years of LepI

No. of Neutrino Generations

- "Invisible width", $\Gamma_{inv} = \Gamma_Z - \Gamma_{had} - 3\,\Gamma_\ell$
- No. of generations = $\Gamma_{inv}\,/\,\Gamma_\nu^{SM}$ **SM:** $\Gamma_\nu^{SM} = \frac{G_F m_Z^3}{6\pi\sqrt{2}}(c_v^2 + c_a^2)$ **≈166 MeV**
  - **Measure Γ_{inv}**
- c_v + c_a are vector and axial vector couplings of neutrino to Z
- **Direct**: measure $\sigma(e^+e^- \to \nu\bar{\nu}\gamma)$ soft γ + nothing else…challenging!
- **Indirect**: measure m_Z, Γ_Z, R_ℓ, σ°_{had}

$$\sigma^\circ_{had} \equiv \frac{12\pi\Gamma_e\Gamma_{had}}{(m_Z\Gamma_Z)^2}$$

$$\Gamma_{inv}\,/\,\Gamma_\nu^{SM} = \left(\frac{12\pi}{m_Z^2\sigma^\circ_{had}}\right)^{\frac{1}{2}} - R_\ell - 3$$

$\Rightarrow$ $N_\nu = 2.9841 \pm 0.0083$ **for $m_\nu \le \frac{1}{2} m_Z \sim 45$ GeV**

- For N_ν = 3, width from new Z decay modes = -2.7 ± 1.6 MeV
- Still room for heavy or sterile neutrinos

P and T transformations

Observable	Parity transform
Position, **r**	-**r** (vector)
Momentum, **p**	-p (vector)
Spin, σ	σ (axial vector)
Longitudinal polarisation, σ.**p**	-σ.p (pseudoscalar)
Electric field, **E**	-**E** (vector)
Magnetic field, **B**	**B** (axial vector)
Magnetic dipole moment, σ.**B**	σ.**B** (scalar)
Electric dipole moment, σ.**E**	-σ.**E** (pseudoscalar)

Z couplings to fermions

fermion	c_v	c_a
ν_e, ν_μ, ν_τ	½	½
e^-, μ^-, τ^-	$-\frac{1}{2} + 2\sin^2\theta_W$	$-\frac{1}{2}$
u, c, t	$\frac{1}{2} - (4/3)\sin^2\theta_W$	½
d, s, b	$-\frac{1}{2} + (2/3)\sin^2\theta_W$	$-\frac{1}{2}$

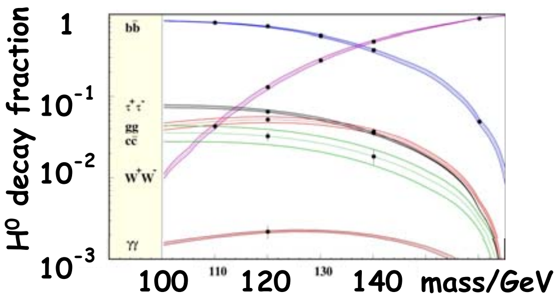
$c_V/c_a = 1\text{-}4Q_f \sin^2\theta_W$

where Q_f is fermion e.m. charge (units of |e|), for all fermion species

θ_W is the "weak mixing angle" (determined experimentally)
Connects weak and e.m. charges by e=g $\sin\theta_W$
Measured value $\sin^2\theta_W$ =0.232
At "lowest order", $M_w = M_Z \cos\theta_W$

Higgs in e^+e^- collisions

- Multi-jets: Higgs spectroscopy,WW/ZZ, tt decays



No ambiguity in predictions.
Precise measurement only possible at lepton colliders.

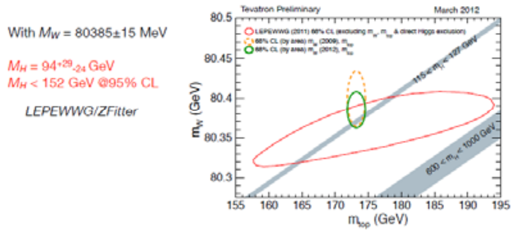
e.g. SM Combined Fits to Data

Consistency of data with SM, illustrated by "pull" values
i.e. for each observable, o_i,
$|(o_i - \text{SM fit}_i)| / \text{error}(o_i)$

See LEP Electroweak Working Group

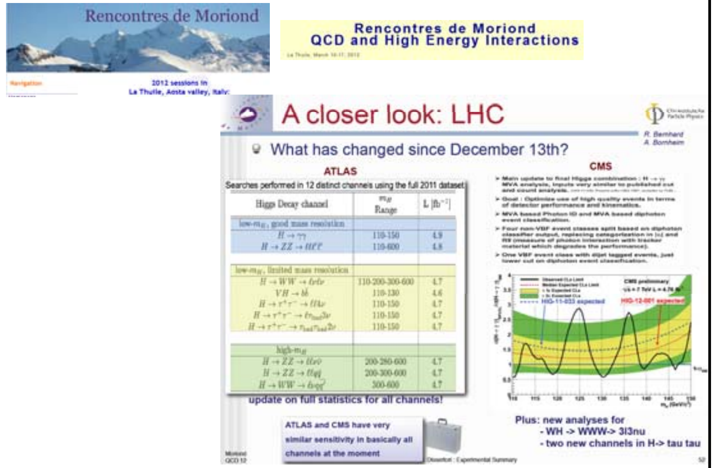
http://lepewwg.web.cern.ch/LEPEWWG/

Now m_W is the most contraining variable in the indirect limit to m_H



When m_H is known it will be time to review implications of influential BSM physics on all EW precision measurements
-- 4th generation
-- SUSY
-- Higgs triplets
-- etc. etc.

Latest updates (17/3/2012)…



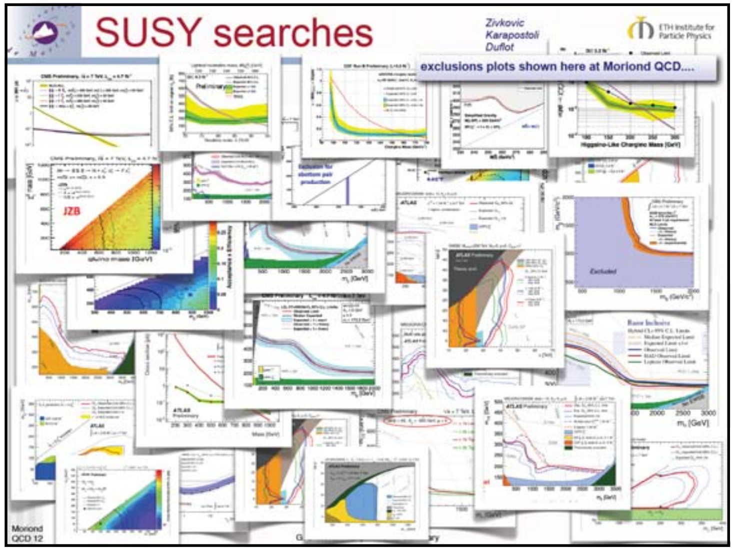
How shall we study X(125)?

At LHC
It is there, and will do it.
The question: with which precision? O(10%) or worse (assume 600fb^{-1})
Effect of pile-up?. Etc. etc.
do we need another machine to study more properties or more precisely?
Performance on couplings self couplings and invisible width?

At a linear collider ?
For 125 GeV Higgs, peak cross-section at ~250 GeV = m_H+m_Z+30 GeV
But.. 250 GV of acceleration and luminosity at that energy still requires a large amount of power and superb alignment. *Cost?*

At a small e+ e- machine? LEP3 in LHC tunnel (see next slides)
Much easier and cheaper than LC but not expandable.

At a muon collider ?
Feasibility study ongoing. Not an easy machine!
Ionization cooling (MICE experiment)
Virtue: s-channel production $\mu^+ \mu^- \to H$, exquisite energy calibration and very small energy spread if needed.



Revision lectures:

- Revsions lecture: 24/4 Poynting SLT
- Please fill in your preferences on poll