

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
 - ▶ Charmionium 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 ©

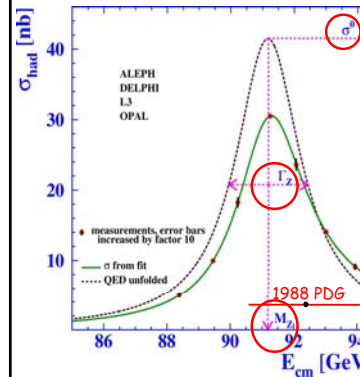
Today

• 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

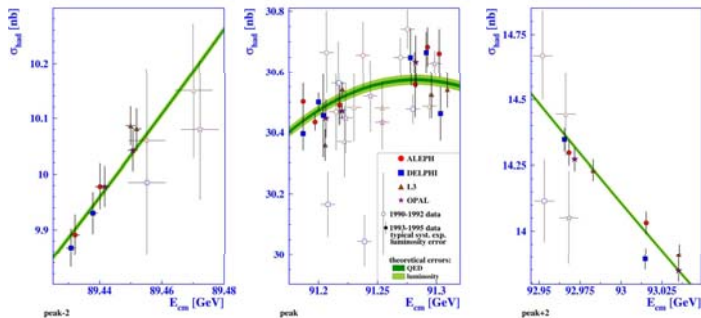


- 3 parameters: $m_Z, \Gamma_Z, \sigma_{had}^0$
- Observe $e^+e^- \rightarrow Z/\gamma \rightarrow f\bar{f}$
- ...EW radiative corrections absorbed in effective couplings
- Deconvolve to Born cross-section
- Obtain $m_Z = 91,187.5 \pm 2.1 \text{ MeV}$
 $\Gamma_Z = 2,495.2 \pm 2.3 \text{ MeV}$
 $\sigma_{had}^0 = 41.540 \pm 0.037 \text{ nb}$

Combined measurements, LepI sample

Final LepI "Z⁰ 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: $\Gamma_\nu^{SM} = \frac{G_F m_Z^3}{6\pi^2} (c_v^2 + c_a^2) \approx 166 \text{ MeV}$
 ▶ Measure Γ_{inv}

- $c_v + c_a$ are vector and axial vector couplings of neutrino to Z
- Direct: measure $\sigma(e^+e^- \rightarrow \nu\bar{\nu}\gamma)$ soft γ + nothing else...challenging!
- Indirect: measure $m_Z, \Gamma_Z, R_\ell, \sigma_{had}^0$

$$\Gamma_{inv} / \Gamma_\nu^{SM} = \left(\frac{12\pi}{m_Z^2 \sigma_{had}^0} \right)^{\frac{1}{2}} - R_\ell - 3$$

$$\sigma_{had}^0 \equiv \frac{12\pi \Gamma_e \Gamma_{had}}{(m_Z \Gamma_Z)^2}$$

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

- For $N_\nu = 3$, width from new Z decay modes = $-2.7 \pm 1.6 \text{ MeV}$
- Still room for heavy or sterile neutrinos

P and T transformations

| Observable | Parity transform |
|--|--|
| Position, \mathbf{r} | $-\mathbf{r}$ (vector) |
| Momentum, \mathbf{p} | $-\mathbf{p}$ (vector) |
| Spin, $\boldsymbol{\sigma}$ | $\boldsymbol{\sigma}$ (axial vector) |
| Longitudinal polarisation, σ_p | $-\sigma_p$ (pseudoscalar) |
| Electric field, \mathbf{E} | $-\mathbf{E}$ (vector) |
| Magnetic field, \mathbf{B} | \mathbf{B} (axial vector) |
| Magnetic dipole moment, $\boldsymbol{\sigma} \cdot \mathbf{B}$ | $\boldsymbol{\sigma} \cdot \mathbf{B}$ (scalar) |
| Electric dipole moment, $\boldsymbol{\sigma} \cdot \mathbf{E}$ | $-\boldsymbol{\sigma} \cdot \mathbf{E}$ (pseudoscalar) |

Z couplings to fermions

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

$$c_V/c_A = 1 - 4Q_f \sin^2\theta_W$$

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

θ_W is the "weak mixing angle" (determined experimentally)

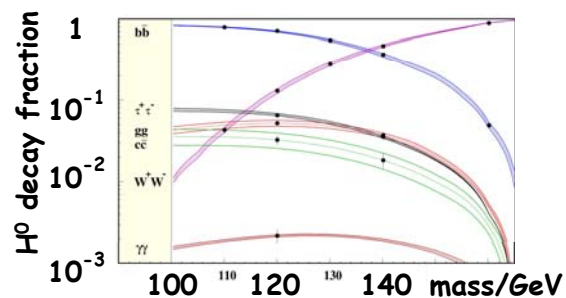
Connects weak and e.m. charges by $e = g \sin\theta_W$

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

| | Measurement | Fit | $\frac{ O^{meas} - O^{fit} }{\sigma(O^{meas})}$ |
|---------------------------------------|-----------------------|-----------|---|
| $\Delta m_{\nu_e, \nu_\mu}^2 (m_e^2)$ | 0.02758 ± 0.00039 | 0.02769 | 0.2 |
| m_Z [GeV] | 91.1875 ± 0.0021 | 91.1874 | 0.1 |
| Γ_Z [GeV] | 2.4952 ± 0.0023 | 2.4959 | 0.3 |
| σ_{had}^0 [nb] | 41.540 ± 0.037 | 41.479 | 1.6 |
| R_b | 20.767 ± 0.025 | 20.742 | 1.0 |
| $A_b^{(1)}$ | 0.01714 ± 0.00095 | 0.01645 | 1.5 |
| $A_b^{(2)}$ | 0.1465 ± 0.0032 | 0.1481 | 0.5 |
| R_b | 0.21629 ± 0.00066 | 0.21579 | 0.7 |
| R_c | 0.1721 ± 0.0030 | 0.1723 | 0.1 |
| $A_b^{(3)}$ | 0.0992 ± 0.0016 | 0.1038 | 2.8 |
| $A_b^{(4)}$ | 0.0707 ± 0.0035 | 0.0742 | 1.2 |
| A_b | 0.923 ± 0.020 | 0.935 | 0.6 |
| A_c | 0.670 ± 0.027 | 0.668 | 0.1 |
| $A_f(SLD)$ | 0.1513 ± 0.0021 | 0.1481 | 1.5 |
| $\sin^2\theta_{eff}^l (C_{23})$ | 0.2324 ± 0.0012 | 0.2314 | 0.8 |
| m_W [GeV] | 80.399 ± 0.023 | 80.379 | 0.5 |
| Γ_W [GeV] | 2.085 ± 0.042 | 2.092 | 0.2 |
| m_t [GeV] | 173.3 ± 1.1 | 173.4 | 0.1 |

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/)

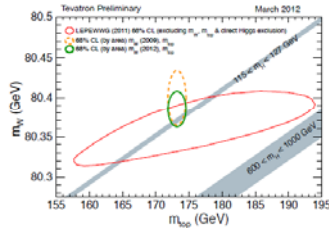
<http://lepewwg.web.cern.ch/LEPEWWG/>

Now m_w is the most constraining variable in the indirect limit to m_H

With $M_W = 80385 \pm 15$ MeV

$M_H = 94^{+20}_{-24}$ GeV
 $M_H < 152$ GeV @95% CL

LEPEWWG/ZFilter



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.

Moriond EW2012 EXP Summary -- Alain Blondel



Latest updates (17/3/2012)...

Rencontres de Moriond
 QCD and High Energy Interactions
 La Thuile, March 16-21, 2012

3012 sessions in La Thuile, Aosta valley, Italy

A closer look: LHC

What has changed since December 13th?

| Higgs Decay channel | μ_{sig} Range | $L [fb^{-1}]$ |
|---|-------------------|---------------|
| low- m_H good mass resolution | | |
| $H \rightarrow \gamma\gamma$ | 110-150 | 4.9 |
| $H \rightarrow ZZ \rightarrow H^0\bar{H}^0$ | 110-600 | 4.8 |
| low- m_H limited mass resolution | | |
| $H \rightarrow W^+W^- \rightarrow \ell^+\ell^-$ | 110-200-300-600 | 4.7 |
| $YH \rightarrow b\bar{b}$ | 110-150 | 4.6 |
| $H \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^-$ | 110-150 | 4.7 |
| $H \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^-$ | 110-150 | 4.7 |
| $H \rightarrow \tau^+\tau^- \rightarrow \tau_{had}^+\tau_{had}^-$ | 110-150 | 4.7 |
| high- m_H | | |
| $H \rightarrow ZZ \rightarrow 4\ell$ | 200-280-600 | 4.7 |
| $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ | 200-300-600 | 4.7 |
| $H \rightarrow WW \rightarrow \ell\nu\ell'$ | 300-600 | 4.5 |

update on full statistics for all channels!

ATLAS and CMS have very similar sensitivity in basically all channels at the moment

Plus: new analyses for $W \rightarrow WW \rightarrow 3l\nu$ - two new channels in $H \rightarrow \tau\nu$

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 $\mu^+ \mu^- \rightarrow H$, exquisite energy calibration and very small energy spread if needed.

Moriond EW2012 EXP Summary -- Alain Blondel



SUSY searches

Zivkovic Karapostoli Dufflot ETH Institute for Particle Physics

exclusions plots shown here at Moriond QCD...

Moriond QCD 12

Revision lectures:

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

Y3 PP revision topics

108 votes | 1.3 | 2 hours ago

Where: Revision week

Please read before choosing

Choose either:

(A) maximum 3 topics from the list, or

(B) a single past paper (see for going through one paper would take most of a lecture)

Please read before choosing

Table view

Advanced search

Most popular option Summer 2008 exam (Close poll)

| | | | | | | | | | | | | | | |
|--|---|-------------------------------------|--|--|-----------------------------|----------------------------------|--|--------------------|-----|----------------------|--------------------------------|------------------------|--|--|
| Concept introduction in Particle Physics | Relativistic mechanics and four momenta | Particle decay and spin experiments | Fuel target and colliding beam experiments | Introduction to quantum field theory and second quantisation | Light and quantum mechanics | Neutron and neutron multiplicity | Scattering cross-section and colour charge | Special relativity | QED | Quantum field theory | Particle physics and cosmology | Quantum chromodynamics | High energy physics and particle detectors | Identifying particles and interactions |
|--|---|-------------------------------------|--|--|-----------------------------|----------------------------------|--|--------------------|-----|----------------------|--------------------------------|------------------------|--|--|

3 participants