Electroweak Model and Constraints on New Physics

(Jens Erler and Paul Langacker, 11/09)

- Review of precision electroweak data (with correlations)
  - WNC, Z-Pole (LEPEWWG averages/correlations), LEP 2, M_W, m_t
  - Selected (correlated) flavor physics
    (g_μ-2, $b \to s\gamma$, hadronic τ decay)
- Complete SM radiative corrections
  - MS-bar scheme (GAPP)
    (on-shell awkward for mixed QCD-EW, large m_t, new physics)
- Consistent and optimal theory expressions (with correlations)
- SM fit
  - consistency; $\sin^2\theta_W$, m_H, α_s, m_t, $\Delta\alpha_{had}$
- Beyond the SM fits
  - oblique (ρ; S, T, U), model independent

New for 2010

- Reorganized (section on W and Z physics)
- New data (Tevatron M_W, m_t; $\Delta\alpha_{had}$ constraints)
- Improved theory on hadronic τ decays
    - Lower α_s (better agreement with other determinations)
- Improved many body calculations for atomic parity (Cs)
    - Previous 2.3σ discrepancy resolved
- Theory corrections for NuTeV
    - Initial 3.0σ discrepancy (major effect on BSM fits)
    - A number of corrections/new effects have been identified (may shift central values, increase uncertainties)
    - Preliminary, pending NuTeV reanalysis (need by 9/11 for next PDG)

ν-DIS

- ***NuTeV***: initially 3.0 σ deviation
- $\int dx\, x\, [s - \bar{s}] = 0.0020\ (14)$ ***NuTeV*** $\Longrightarrow \delta s^2_W = -0.0014\ (10)$
- theory: zero crossing too early? $\Longrightarrow \delta s^2_W = -0.0007\ (7)$
- $K_{e3} = 4.82\ (6)\% \rightarrow 5.07\ (4)\%\ (4\sigma) \Longrightarrow \delta s^2_W = 0.0016$
- $m_d - m_u$ (CSV) $\Longrightarrow \delta s^2_W = -0.0015\ (3)$
- QED splitting effects (CSV) $\Longrightarrow \delta s^2_W = -0.0011\ (11)$
- isovector EMC effect (affecting all and not just excess neutrons) ***Cloet, Bentz, Thomas*** $\Longrightarrow \delta s^2_W = -0.0019\ (6) \Longleftarrow$ ***(!)***
- QED radiative corrections ***Diener, Dittmaier, Hollik*** $\sim \mathcal{O}(1\sigma)$

Input Data

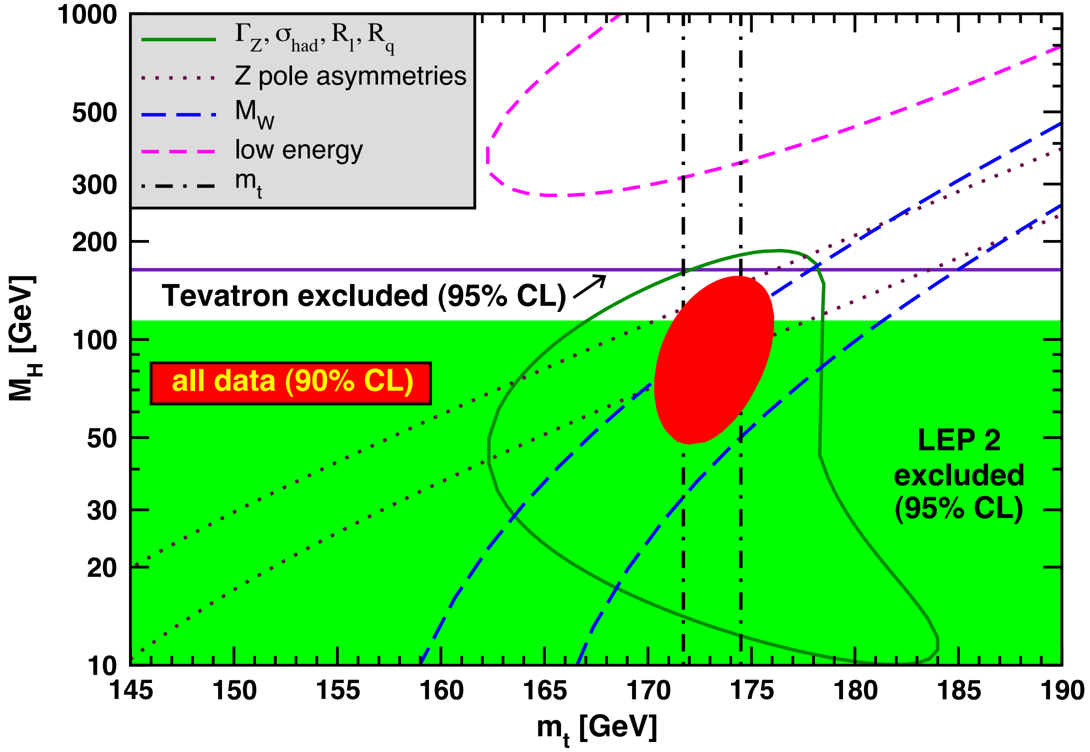
Quantity	Value	Standard Model	Pull	Dev.
m_t [GeV]	173.1 ± 1.3	173.2 ± 1.3	-0.1	-0.5
M_W [GeV]	80.420 ± 0.031	80.384 ± 0.014	1.2	1.5
	80.376 ± 0.033		-0.2	0.1
g_L^2	0.3027 ± 0.0018	0.30399 ± 0.00017	-0.7	-0.6
g_R^2	0.0308 ± 0.0011	0.03001 ± 0.00002	0.7	0.7
$g_V^{\nu e}$	-0.040 ± 0.015	-0.0398 ± 0.0003	0.0	0.0
$g_A^{\nu e}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0	0.0
$Q_W(e)$	-0.0403 ± 0.0053	-0.0473 ± 0.0005	1.3	1.2
$Q_W(\mathrm{Cs})$	-73.20 ± 0.35	-73.15 ± 0.02	-0.1	-0.1
$Q_W(\mathrm{Tl})$	-116.4 ± 3.6	-116.76 ± 0.04	0.1	0.1
τ_τ [fs]	291.09 ± 0.48	290.02 ± 2.09	0.5	0.5
$\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to Xe\nu)}$	$\left(3.38^{+0.51}_{-0.44}\right) \times 10^{-3}$	$(3.11 \pm 0.07) \times 10^{-3}$	0.6	0.6
$\frac{1}{2}(g_\mu - 2 - \frac{\alpha}{\pi})$	$(4511.07 \pm 0.77) \times 10^{-9}$	$(4509.13 \pm 0.08) \times 10^{-9}$	2.5	2.5

Quantity	Value	Standard Model	Pull	Dev.
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1	0.0
Γ_Z [GeV]	2.4952 ± 0.0023	2.4954 ± 0.0009	−0.1	0.1
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7418 ± 0.0009	—	—
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.69 ± 0.07	—	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	84.005 ± 0.015	—	—
σ_{had}[nb]	41.541 ± 0.037	41.484 ± 0.008	1.5	1.5
R_e	20.804 ± 0.050	20.735 ± 0.010	1.4	1.4
R_μ	20.785 ± 0.033	20.735 ± 0.010	1.5	1.6
R_τ	20.764 ± 0.045	20.780 ± 0.010	−0.4	−0.3
R_b	0.21629 ± 0.00066	0.21578 ± 0.00005	0.8	0.8
R_c	0.1721 ± 0.0030	0.17224 ± 0.00003	0.0	0.0
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01633 ± 0.00021	−0.7	−0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.4	0.6
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5	1.6
$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1034 ± 0.0007	−2.7	−2.3
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0739 ± 0.0005	−0.9	−0.8
$A_{FB}^{(0,s)}$	0.0976 ± 0.0114	0.1035 ± 0.0007	−0.6	−0.4
$\bar{s}_\ell^2(A_{FB}^{(0,q)})$	0.2324 ± 0.0012	0.23146 ± 0.00012	0.8	0.7
	0.2316 ± 0.0018		0.1	0.0
A_e	0.15138 ± 0.00216	0.1475 ± 0.0010	1.8	2.2
	0.1544 ± 0.0060		1.1	1.3
	0.1498 ± 0.0049		0.5	0.6
A_μ	0.142 ± 0.015		−0.4	−0.3
A_τ	0.136 ± 0.015		−0.8	−0.7
	0.1439 ± 0.0043		−0.8	−0.7
A_b	0.923 ± 0.020	0.9348 ± 0.0001	−0.6	−0.6
A_c	0.670 ± 0.027	0.6680 ± 0.0004	0.1	0.1
A_s	0.895 ± 0.091	0.9357 ± 0.0001	−0.4	−0.4

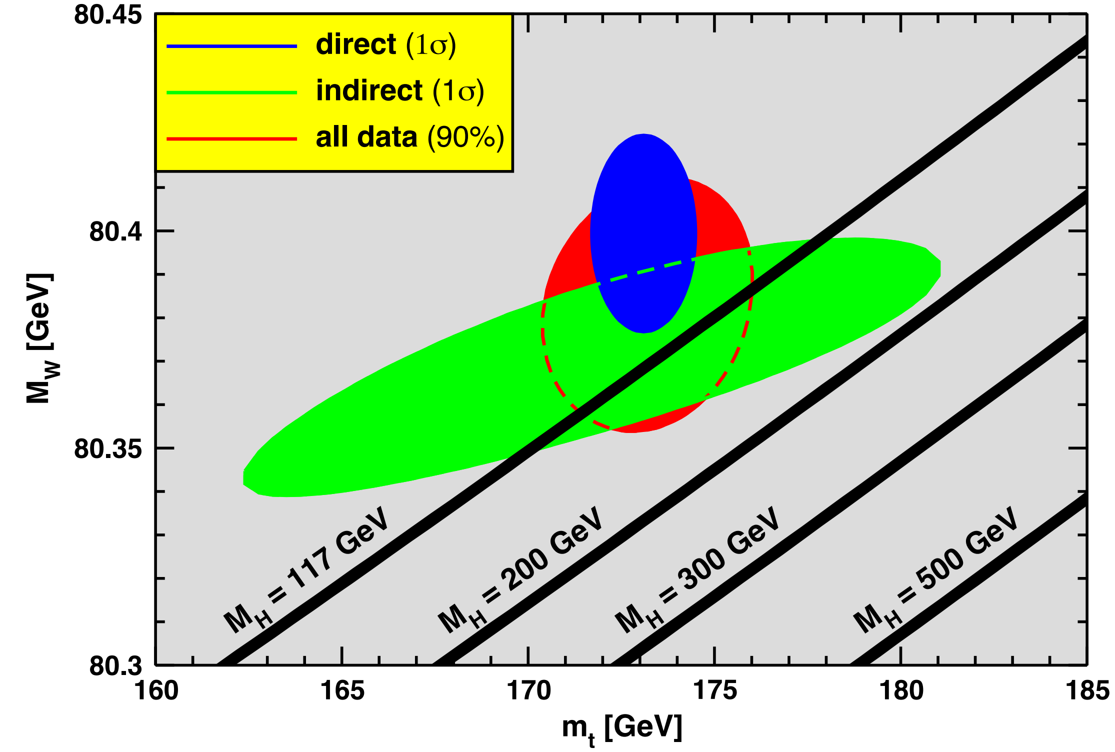
SM fit results

M_Z	91.1874 ± 0.0021	1.00	−0.01	0.00	0.00	−0.01	0.00	0.12
$\widehat{m}_t(\widehat{m}_t)$	163.5 ± 1.3	−0.01	1.00	0.00	0.00	−0.10	0.00	0.39
$\widehat{m}_b(\widehat{m}_b)$	4.198 ± 0.023	0.00	0.00	1.00	0.25	−0.04	0.01	0.04
$\widehat{m}_c(\widehat{m}_c)$	$1.266^{+0.031}_{-0.036}$	0.00	0.00	0.25	1.00	0.08	0.02	0.12
$\alpha_s(M_Z)$	0.1183 ± 0.0015	−0.01	−0.10	−0.04	0.08	1.00	0.00	−0.04
$\Delta\alpha^{(3)}_{\mathrm{had}}(1.8\ \mathrm{GeV})$	0.00574 ± 0.00010	0.00	−0.01	0.01	0.02	0.00	1.00	−0.18
M_H	90^{+27}_{-22}	0.12	0.39	0.04	0.12	−0.04	−0.18	1.00

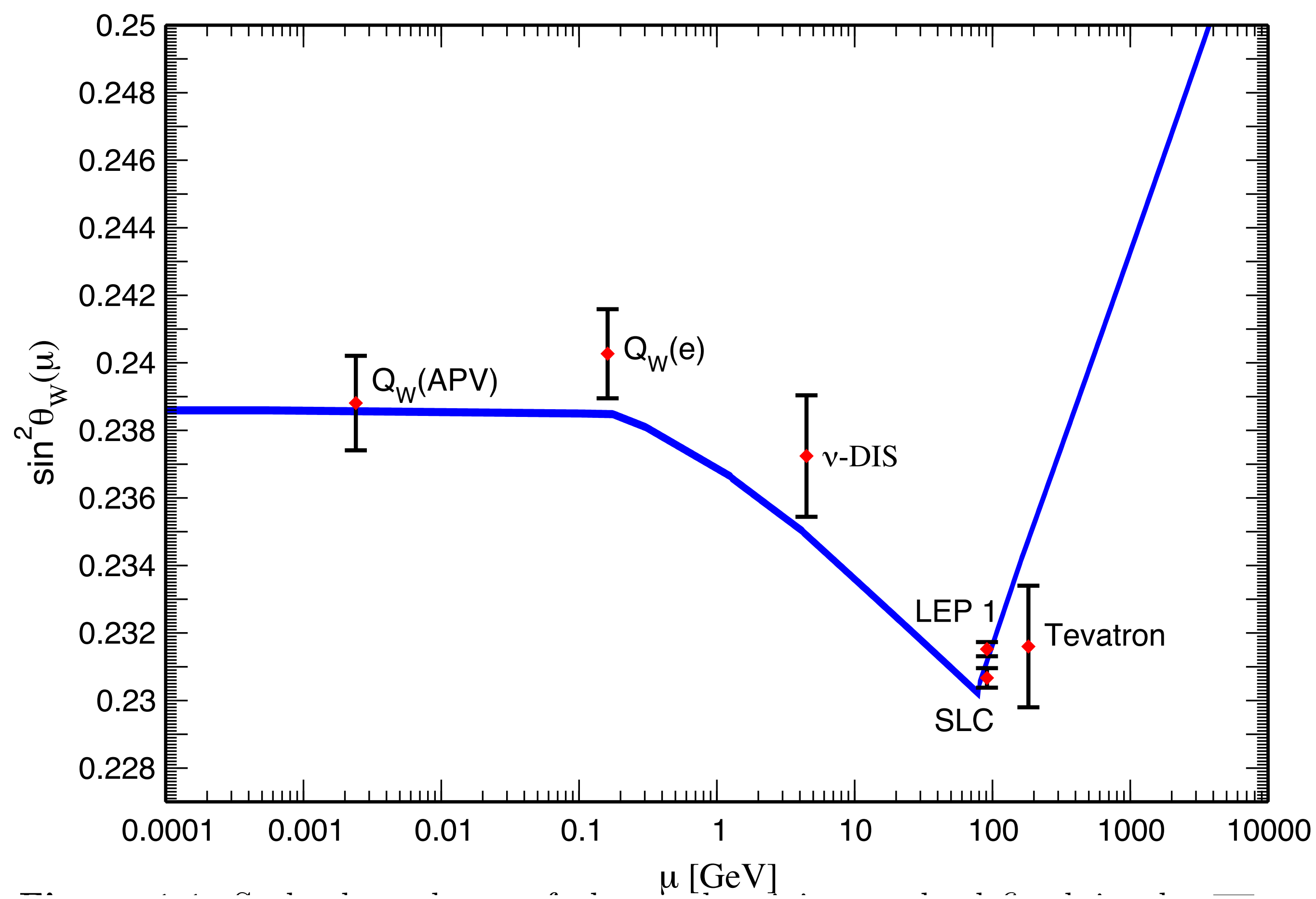
- SM is consistent with data (χ^2/dof=43.0/44)
- m_t (pole)=173.2±1.3 (176.0+8.5-7.0 from indirect alone)
- Including LEP2+ Tevatron M_H limits:
  $M_H \leq$(145, 149, 194) GeV at (90, 95, 99) %
- Consistent with LEPEWWG and GFitter
  (but larger data set; important for BSM)



Γ_Z, σ_{had}, R_l, R_q
Z pole asymmetries
M_W
low energy
m_t
Tevatron excluded (95% CL)
all data (90% CL)
LEP 2 excluded (95% CL)
M_H [GeV]
m_t [GeV]



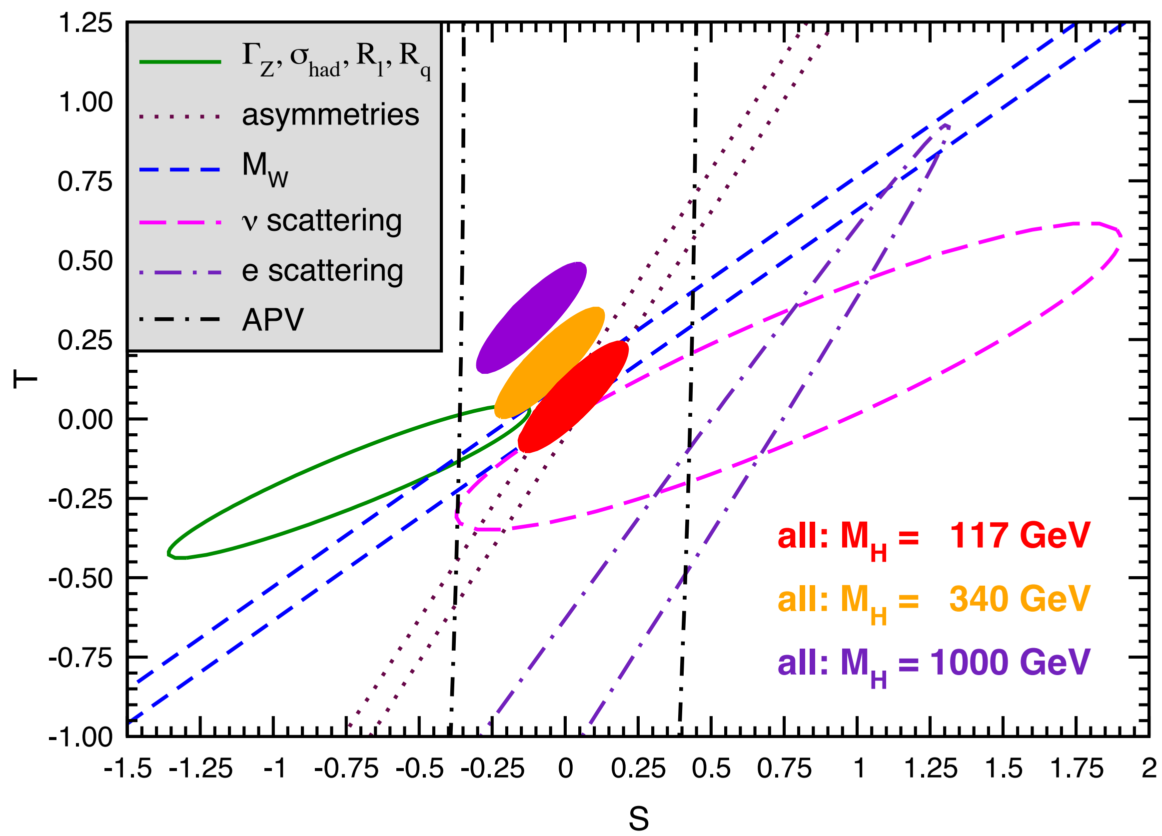
direct (1σ)
indirect (1σ)
all data (90%)
M_H = 117 GeV
M_H = 200 GeV
M_H = 300 GeV
M_H = 500 GeV
M_W [GeV]
m_t [GeV]



Q_W(APV)
Q_W(e)
ν-DIS
LEP 1
SLC
Tevatron
$\sin^2\theta_W(\mu)$
μ [GeV]

Beyond the Standard Model

- **Oblique** (defined to vanish in SM)
  - ρ=1.0008+0.0017-0.0007 (for S,U=0)
  - S,T, U
  - M_H range expanded
  - Little effect on other SM parameters
- **Discussion of models**
- **Z'**
- **"Model independent"**
  (arbitrary family-universal gauge theory for WNC with V-A for ν)



Z'	electroweak	CDF	DØ	LEP 2	M_H
Z_χ	1,141	892	800	673	171^{+493}_{-89}
Z_ψ	147	878	763	481	97^{+31}_{-25}
Z_η	427	982	810	434	423^{+577}_{-350}
Z_{LR}	998	630	—	804	110^{+174}_{-35}
Z_S	1,257	821	719	—	149^{+353}_{-68}
Z_{SM}	1,403	1,030	950	1,787	331^{+669}_{-246}
Z_{string}	1,362	—	—	—	134^{+299}_{-58}

Quantity	Value	SM	Correlation		
$\epsilon_L(u)$	0.338 ± 0.016	$0.3461(1)$			
$\epsilon_L(d)$	-0.434 ± 0.012	$-0.4292(1)$		non-	
$\epsilon_R(u)$	$-0.174 {}^{+0.013}_{-0.004}$	$-0.1549(1)$		Gaussian	
$\epsilon_R(d)$	$-0.023 {}^{+0.071}_{-0.047}$	0.0775			
g_L^2	0.3025 ± 0.0014	$0.3040(2)$	-0.18	-0.21	-0.02
g_R^2	0.0309 ± 0.0010	0.0300		-0.03	-0.07
θ_L	2.48 ± 0.036	$2.4630(1)$			0.24
θ_R	$4.58 {}^{+0.41}_{-0.28}$	5.1765			
$g_V^{\nu e}$	-0.040 ± 0.015	$-0.0398(3)$			-0.05
$g_A^{\nu e}$	-0.507 ± 0.014	$-0.5064(1)$			
$C_{1u} + C_{1d}$	0.1537 ± 0.0011	$0.1528(1)$	0.64	-0.18	-0.01
$C_{1u} - C_{1d}$	-0.516 ± 0.014	$-0.5300(3)$		-0.27	-0.02
$C_{2u} + C_{2d}$	-0.21 ± 0.57	-0.0089			-0.30
$C_{2u} - C_{2d}$	-0.077 ± 0.044	$-0.0625(5)$			
$Q_W(e) = -2\,C_{2e}$	-0.0403 ± 0.0053	$-0.0473(5)$			

$$-\mathscr{L}^{\nu h} = \frac{G_F}{\sqrt{2}}\,\overline{\nu}\,\gamma^{\mu}\left(1-\gamma^5\right)\nu\sum_i\left[\epsilon_L\,(i)\,\overline{q}_i\,\gamma_\mu\left(1-\gamma^5\right)q_i + \epsilon_R\,(i)\,\overline{q}_i\,\gamma_\mu\left(1+\gamma^5\right)q_i\right]$$

$$-\mathscr{L}^{\nu e} = \frac{G_F}{\sqrt{2}}\,\overline{\nu}_\mu\gamma^{\mu}\left(1-\gamma^5\right)\nu_\mu\,\overline{e}\,\gamma_\mu\left(g_V^{\nu e} - g_A^{\nu e}\gamma^5\right)e,$$

$$-\mathscr{L}^{eh} = -\frac{G_F}{\sqrt{2}}\sum_i\left[C_{1i}\,\overline{e}\,\gamma_\mu\gamma^5 e\;\overline{q}_i\,\gamma^{\mu}q_i + C_{2i}\,\overline{e}\,\gamma_\mu e\;\overline{q}_i\;\gamma^{\mu}\gamma^5 q_i\right],$$

Future

- Incorporate all new data, radiative corrections, theory
- Relevant new LHC, flavor physics, BSM
- NuTeV reanalysis (if available by 9/11)
- LEP 2 results (especially for BSM)
- Integrated Z' analysis (precision, LEP2, Tevatron, LHC)
- Better integration with other reviews
  (e.g., QCD, quark masses, Z')