Consistency of New CDF-II W Boson Mass with 123-Model.

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The First Edition of the African conference on High Energy Physics

July 4, 2012 : A Landmark Discovery

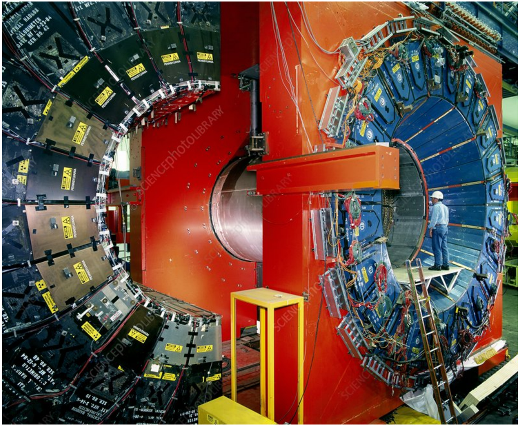
- The Standard Model is one of the most well-tested theories in particle physics

The Standard Model is theoretically incomplete

- It does not unify the Strong and Electro-Weak forces (GUTS ?).
- It ignores Gravity, so does not tell us anything about how it might be unified with the other forces.
- It does not explain Dark Matter and Dark Energy.
- The hierarchy problem.
- Neutrino oscillations can't be explained
- Why is there so much more matter compared to anti-matter.

New CDF II M_w excess $\Longrightarrow$ Open a door BSM physics

The CDF expirement



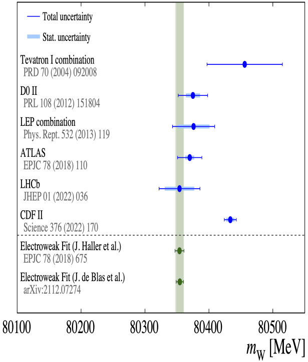
- Multipurpose detector
- Recording data with high efficiency (85%) and making full use of detector capabilities.

SM prediction of the W-boson mass

$$m_W^{SM} = 80.357 \pm 0.006\, GeV$$

Update measurement of the W-boson mass performed by the CDF-II

$$m_W^{CDF} = 80.4335 \pm 0.0094\, GeV$$



CDF-II measurment out of the range of the SM prediction of about 7σ

- **How this excess can be explained BSM ? ? ? ? ?**

123-Model

Motivation

- very consistency with the new CDFII measurement.
- generate neutrino masses.

scalar potential

$$
\begin{aligned}
V_{Higgs} &= \mu_\sigma^2 \sigma^\dagger \sigma + \mu_\phi^2 \phi^\dagger \phi + \mu_\Delta^2 \mathrm{Tr}(\Delta^\dagger \Delta) + \lambda_1 (\phi^\dagger \phi)^2 \\
&+ \lambda_2 \left[\mathrm{Tr}(\Delta^\dagger \Delta)\right]^2 + \lambda_3 (\phi^\dagger \phi) \mathrm{Tr}(\Delta^\dagger \Delta) \\
&+ \lambda_4 \mathrm{Tr}(\Delta^\dagger \Delta \Delta^\dagger \Delta) + \lambda_5 (\phi^\dagger \Delta^\dagger \Delta \phi) + \beta_1 (\sigma^\dagger \sigma)^2 \\
&+ \beta_2 (\phi^\dagger \phi)(\sigma^\dagger \sigma) + \beta_3 \mathrm{Tr}(\Delta^\dagger \Delta)(\sigma^\dagger \sigma) \\
&- \kappa(\phi^T \Delta \phi \sigma + \text{h.c.}),
\end{aligned} \tag{1}
$$

with :

$$
\sigma = \frac{1}{\sqrt{2}}(v_\sigma + R_\sigma + iI_\sigma), \quad \phi = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_\phi + R_\phi + iI_\phi) \\ \phi^- \end{pmatrix}, \quad \Delta = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_\Delta + R_\Delta + iI_\Delta) & \Delta^+/\sqrt{2} \\ \Delta^+/\sqrt{2} & \Delta^{++} \end{pmatrix}
$$

- 3 minimization conditions $\rightarrow$ 9 free parameters

$\lambda_{1,\ldots,5}, \beta_{1,..,3}$ and κ

Parameters that define Δm_W

$$
\begin{aligned}
S &= \frac{1}{24\pi}\left[\left(U_{11}^{H\,2}+U_{12}^{H\,2}+4U_{13}^{H\,2}\right)\ln m_{h_1}^2+\left(U_{21}^{H\,2}+U_{22}^{H\,2}+4U_{23}^{H\,2}\right)\ln m_{h_2}^2\right.\\
&+ 2\left(U_{31}^{H\,2}+U_{32}^{H\,2}+4U_{33}^{H\,2}\right)\ln m_{h_3}^2-\ln m_{h_{\rm ref}}^2+\mathcal{U}_{11}^{H\,2}\hat{G}(m_{h_1}^2,m_Z^2)+\mathcal{U}_{12}^{H\,2}\hat{G}(m_{h_2}^2,m_Z^2)\\
&+ \left.2G(m_{h_3}^2,m_{h_3}^2,m_Z^2)-\hat{G}(m_{h_{\rm ref}}^2,m_Z^2)\right]-\frac{1}{3\pi}\left[\ln\left(m_{H^{\pm\pm}}^2\right)-\frac{(1-2s_W^2)^2}{2}\,\xi\left(m_{H^{\pm\pm}}^2,m_{H^{\pm\pm}}^2,m_Z^2\right)\right.\\
&- \left.\frac{s_W^4}{2}\,\xi\left(m_{H^{\pm}}^2,m_{H^{\pm}}^2,m_Z^2\right)\right], \qquad (2)
\end{aligned}
$$

and

$$
\begin{aligned}
T &= \frac{1}{16\pi m_W^2 s_W^2}\left[F(m_{H^{\pm\pm}}^2,m_{H^{\pm}}^2)+U_{12}^{H\,2}F(m_{H^{\pm}}^2,m_{h_1}^2)+U_{22}^{H\,2}F(m_{H^{\pm}}^2,m_{h_2}^2)+U_{32}^{H\,2}F(m_{H^{\pm}}^2,m_{h_3}^2)\right.\\
&+ 3\,\mathcal{U}_{11}^{H\,2}\left(F(m_Z^2,m_{h_1}^2)-F(m_W^2,m_{h_1}^2)\right)+3\,\mathcal{U}_{12}^{H\,2}\left(F(m_Z^2,m_{h_2}^2)-F(m_W^2,m_{h_2}^2)\right)\\
&+ \left.3\,\mathcal{U}_{13}^{H\,2}\left(F(m_Z^2,m_{h_3}^2)-F(m_W^2,m_{h_3}^3)\right)-3\left(F(m_Z^2,m_{h_{\rm ref}}^2)-F(m_W^2,m_{h_{\rm ref}}^2)\right)\right] \qquad (3)
\end{aligned}
$$

Theoretical and Experimental Constraints

- Unitarity, Perturbativity, Vacuum Stability.
- EW Precision Observables (S,T and U).
- HiggsBounds , and HiggsSignal.

New physics ?

$$\Delta m_W^2 = (m_W^{\text{"123"Model}})^2 - (m_W^{\text{SM}})^2 = \frac{\alpha_0 c_W^2 m_Z^2}{c_W^2 - s_W^2} \left[-\frac{1}{2} S + c_W^2 T \right], \quad (4)$$

$$\Delta \sin^2 \theta_{\text{eff}} = \sin^2 \theta_{\text{eff}}|_{\text{"123"Model}} - \sin^2 \theta|_{\text{SM}} = \frac{\alpha_0}{c_W^2 - s_W^2} \left[\frac{1}{4} S - s_W^2 c_W^2 T \right] \quad (5)$$

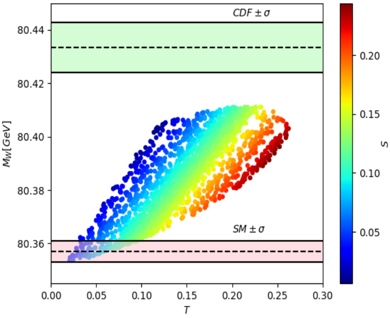
Indicated by "PDG" and "CDF"

$$\text{PDG} : \text{S} = 0.05 \pm 0.08,\ \text{T} = 0.09 \pm 0.07,\ \rho_{\text{ST}} = 0.92$$
$$\text{CDF} : \text{S} = 0.15 \pm 0.08,\ \text{T} = 0.27 \pm 0.06,\ \rho_{\text{ST}} = 0.93,$$

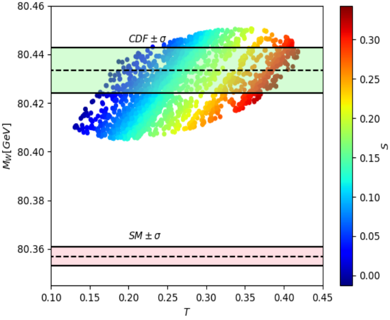
where ρ_{ST} represents the correlation between S and T.

Correction of 123-model W-boson mass

$$\Delta m_W^2 = \frac{\alpha_0 c_W^2 m_Z^2}{c_W^2 - s_W^2}\left[-\frac{1}{2}S + c_W^2 T\right],$$



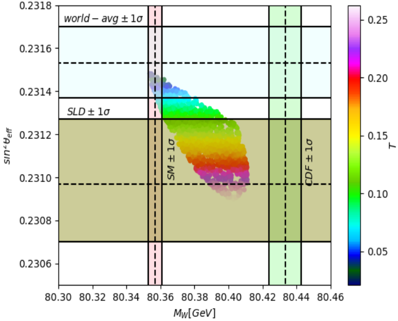
$\chi^2_{STU}(PDG) < 5.99$



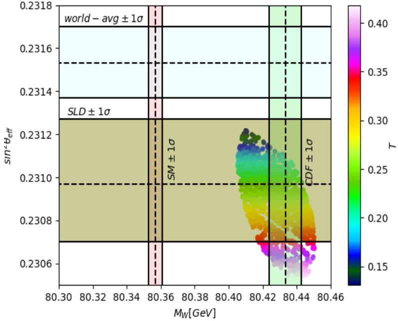
$\chi^2_{STU}(CDF) < 5.99$

Correction 123-model of effective weak angle

$$\Delta \sin^2\theta_{\rm eff} = \frac{\alpha_0}{c_W^2 - s_W^2}\left[\frac{1}{4}S - s_W^2 c_W^2\, T\right]$$

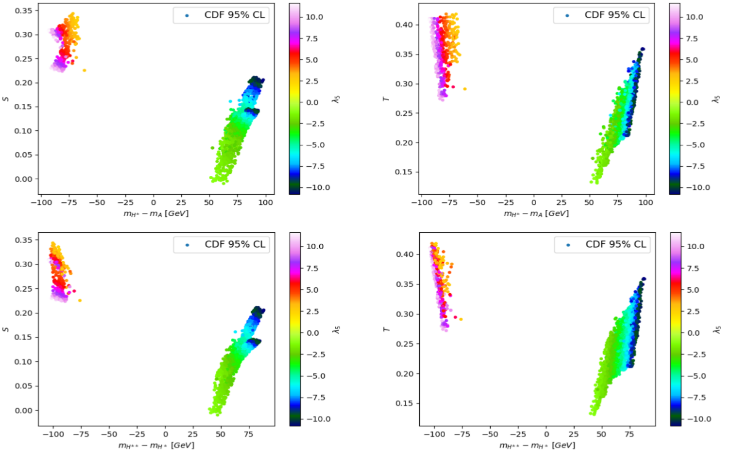


$\chi^2_{STU}(PDG) < 5.99$



$\chi^2_{STU}(CDF) < 5.99$

CDF measurement at 95%



$$\Delta m^2 = m^2_{H^{\pm\pm}} - m^2_{H^\pm} = m^2_{H^\pm} - m^2_A = \frac{1}{2}(m^2_{H^{\pm\pm}} - m^2_A) = -\frac{\lambda_5}{4}\nu^2_\Phi$$

- **-0.82 $<\lambda_5<$2.41 are excluded by 2σ CDF mesurement.**

Thank you

for your attention