

Electroweak radiative corrections to neutrino scattering at NuTeV

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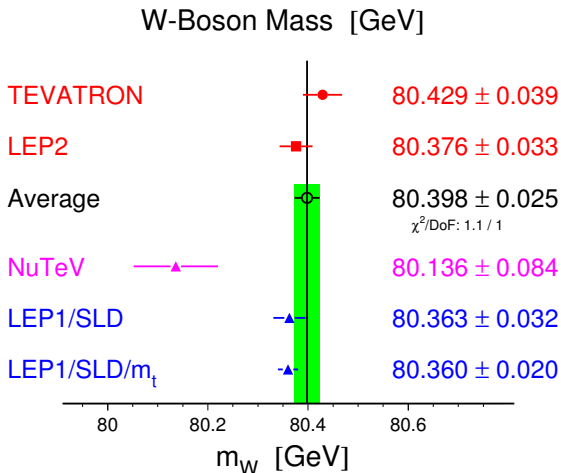
Pheno2007
May 8, 2007

In collaboration with U. Baur and D. Wackeroth.

Precise W boson mass measurement :

- ▶ W mass is an important SM input parameter
- ▶ Together with top mass, W we can predict the Higgs mass.

$$\text{World Average } M_W = 80.398 \pm 0.025 \text{ GeV}$$



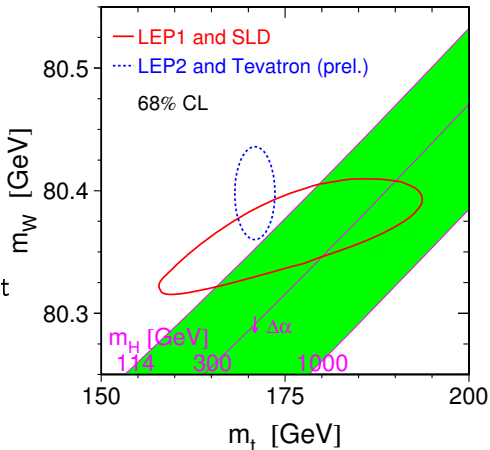
LEP EWWG 2007 (<http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2007/>)

W boson mass : 80.398 ± 0.025 GeV

$$M_t = 170.9 \pm 1.1 \pm 1.5$$

$$M_h = 76^{+33}_{-24} \text{ GeV}$$

NuTeV M_W measurement
→ Heavy Higgs



LEP EWWG 2007 (<http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2007/>)

Possible Reasons for NuTeV discrepancy

- ▶ Electroweak Radiative Correction → this talk
- ▶ QCD Correction
- ▶ Parton Distribution Function
- ▶ Nuclear Structure
- ▶ ...

Kevin S. McFarland and Sven-Olaf Moch [arXiv:hep-ph/0306052](https://arxiv.org/abs/hep-ph/0306052)

J.T. Londergan [arXiv:hep-ph/0408243](https://arxiv.org/abs/hep-ph/0408243)

- ▶ The W boson mass measured by the NuTeV collaboration differs from the world average by about 3σ

—→ How about including the COMPLETE electroweak one-loop corrections ?

- ▶ We can get more precise mass of Higgs boson if we have W boson mass and top quark with higher precision.

Some of Discussion: <http://home.fnal.gov/~gzeller/nutev.html>

Motivation

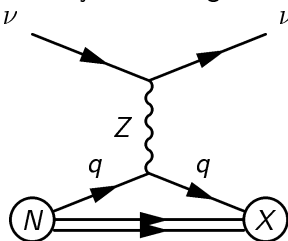
There is the study of the calculation of full Electroweak $\mathcal{O}(\alpha)$ corrections in the paper of Diener, Dittmaier and Hollik, (K. P. Diener, S. Dittmaier and W. Hollik, Phys. Rev. D **72**, 093002 (2005))

However, no study yet of impact of these corrections on M_W measurement in NuTeV and NuTeV analysis still doesn't include whole Electroweak $\mathcal{O}(\alpha)$ corrections.

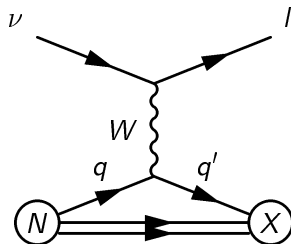
→ After getting result, Compare with above paper and Study the impact of those corrections with Dr. Kevin McFarland who is one of the NuTeV collaborator

Calculation

Tree-level Feynman diagrams :



< Neutral Current >



< Charged Current >

$$\begin{aligned} R &= \frac{\sigma_{NC}^{\nu}(\nu N \rightarrow \nu X) - \sigma_{NC}^{\bar{\nu}}(\bar{\nu} N \rightarrow \bar{\nu} X)}{\sigma_{CC}^{\nu}(\nu N \rightarrow lX) - \sigma_{CC}^{\bar{\nu}}(\bar{\nu} N \rightarrow \bar{l}X)} \\ &= \rho^2 \left(\frac{1}{2} - \sin^2 \theta_w \right) \end{aligned}$$

← proposed by Paschos and Wolfenstein

$$\sin^2 \theta_w = 1 - \frac{M_w^2}{M_Z^2}$$

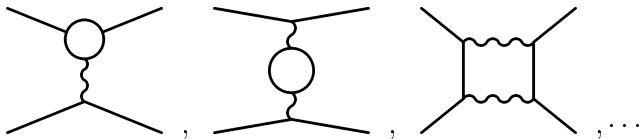
NuTeV result : $\sin^2 \theta_w = 0.22773 \pm 0.00135(\text{stat}) \pm 0.00093(\text{syst})$

NuTeV paper references, <http://www-e815.fnal.gov/webSPACE/e815intr/e815intr.html>
G. P. Zeller *et al* [NuTeV Collaboration], Phys. Rev. Lett. 88 (2002) 091802

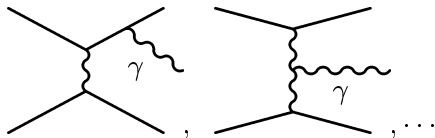
Some details of the Calculation in $\mathcal{O}(\alpha)$ corrections

Examples of Feynman diagrams :

Virtual :



Real :



Some details of the Calculation in $\mathcal{O}(\alpha)$ corrections

$$\begin{aligned}\text{Parton Level : } d\hat{\sigma}_{NC,CC} &= dp \cdot \bar{\Sigma}_{spin,color} |\mathcal{M}|^2 \\ &= dp_{2 \rightarrow 2} \left\{ |\mathcal{M}_{tree\ level}|^2 + 2\text{Re}(\mathcal{M}_{virtual}\mathcal{M}_{tree\ level}^*) \right\} \\ &\quad + dp_{2 \rightarrow 3} |\mathcal{M}_{real}|^2\end{aligned}$$

Hadronic cross section is obtained
by convoluting $d\hat{\sigma}$ with parton distribution function

Some details of the Calculation in $\mathcal{O}(\alpha)$ corrections

- ▶ Feynman - t'Hooft gauge
- ▶ On-Shell renormalization scheme
- ▶ Soft and collinear singularities is regularized by using fictitious γ mass and fermion masses

Introducing the newly developed computational tool - "Virtual Accelerator"

There are several tools such as FeynArts, FeynCalc, LoopTools, Grace...

- ▶ User friendly interface
- ▶ User interactive tool
- ▶ Showing 8 calculation steps
- ▶ Gauge choice - Landau, Feynman
- ▶ Renormalization scheme - On-Shell, Minimal subtraction(MS).
- ▶ Ease to add other models - QCD,SUSY,...
- ▶ Generating diagram images and \LaTeX files

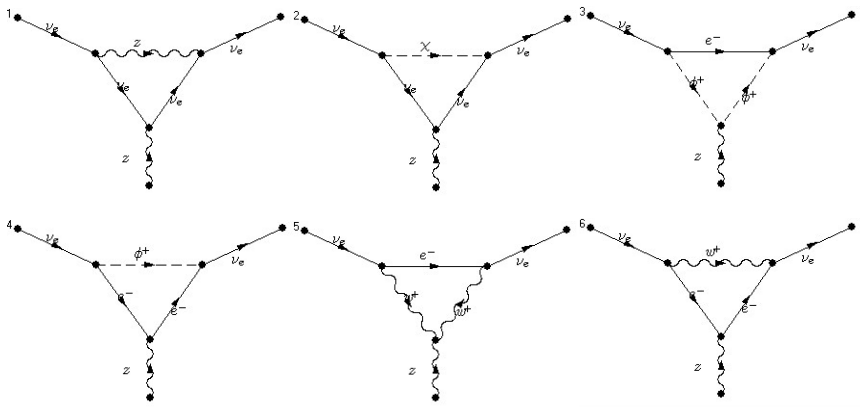
Screen Shot of "Virtual Accelerator"

The screenshot displays the "Virtual Accelerator" software interface, which is used for generating Feynman diagrams and calculating their analytical and numerical expressions. The interface is divided into several sections:

- Making Backbone:**
 - 1. Number of:** Incoming Particle: 1, Outgoing Particle: 2, Vertices: 3, Total: 6.
 - 2. Diagram:** A central window showing a Feynman diagram with 6 vertices and 6 lines. The diagram consists of a top horizontal line, a bottom horizontal line, and two diagonal lines connecting the top and bottom vertices. A vertical line extends downwards from the bottom vertex.
 - 3. Parameters:** Gauge: [Dropdown], Renormalization: [Dropdown].
 - 4. Position:** Position X: 291, Position Y: 192. Buttons: Draw, Clear, Modify, Done.
- Generating Feynman Diagrams:**
 - 4. Names of External Particles:** Standard: [Dropdown], Choose Incoming Number: [Dropdown], z: [Dropdown], 1: [Dropdown]. Button: Click Here to Generate Feynman Diagram!
 - Incomings:** electron-neutrino
 - Outgoings:** z, electron-neutrino
 - Arrow: ==>
- Getting Analytical Expression:**
 - 3. For Calculation:** External Particles are included as:
 - External
 - Internal
 - Not Include
 - Button: Click Here to Calculate Analytically
 - Label: Label3
- Calculating Numerical Expression:** BitBn1

Example of Diagram - ν_e, ν_e, Z Vertex

"Virtual Accelerator" create following images:



+ ..

Example of Calculation - ν_e, ν_e, Z Vertex

“Virtual Accelerator” produce analytic expression:

$$\mathcal{M}_{\text{virtual}} = \cdots \bar{u}(F_V \gamma_\mu + F_A \gamma_\mu \gamma_5) v \cdots$$

1 : $-24\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_1$ (1284)	
2 : $-24\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{12}$ (1266)	
3 : $-24\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{11}$ (1260)	
4 : $-8\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_1$ (1218)	
5 : $-8\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{12}$ (1182)	
6 : $-8\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{11}$ (1176)	
7 : $6\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_1d$ (918)	
8 : $6\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{12}d$ (908)	
9 : $6\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{11}d$ (904)	
10 : $2\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_1d$ (882)	
11 : $2\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{12}d$ (864)	
12 : $2\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{11}d$ (860)	
13 : $8\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_1$ (1440)	
14 : $8\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{12}$ (1422)	
15 : $8\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{11}$ (1416)	
16 : $24\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_1$ (1224)	
17 : $24\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{12}$ (1206)	
18 : $24\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{11}$ (1200)	
19 : $-2\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_1d$ (1002)	
20 : $-2\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{12}d$ (992)	
21 : $-2\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{11}d$ (988)	
22 : $-6\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_1d$ (886)	
23 : $-6\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{12}d$ (876)	
24 : $-6\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{11}d$ (872)	
25 : $-4\gamma_{18}p_{113}a(\nu_e)^3C_{22}m_{\nu_e}$ (1430)	
26 : $-8\gamma_{18}p_{113}a(\nu_e)^3C_{12}m_{\nu_e}$ (1418)	
	32 : $2\gamma_{18}p_{113}a(\nu_e)^3C_{22}dm_{\nu_e}$ (996)
	33 : $4\gamma_{18}p_{113}a(\nu_e)^3C_{12}dm_{\nu_e}$ (990)
	34 : $2\gamma_{18}p_{113}a(\nu_e)^3C_{11}dm_{\nu_e}$ (986)
	35 : $10\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_2dm_{\nu_e}$ (888)
	36 : $6\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_{22}dm_{\nu_e}$ (880)
	37 : $12\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_{12}dm_{\nu_e}$ (874)
	38 : $6\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_{11}dm_{\nu_e}$ (870)
	39 : $4\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_0d$ (824)
	40 : $6\gamma_5p_{113}a(\nu_e)^3C_1dm_{\nu_e}$ (816)
	41 : $4\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_0d$ (772)
	42 : $10\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_1dm_{\nu_e}$ (764)
	43 : $-16\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_2$ (688)
	44 : $-16\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_2$ (484)
	45 : $-12\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_0$ (392)
	46 : $-16\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_1$ (368)
	47 : $-4\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_0$ (286)
	48 : $-16\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_1$ (258)
	49 : $-6\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)a(\nu_e)^2C_1m_{\nu_e}$ (542)
	50 : $-6\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)a(\nu_e)^2C_{12}m_{\nu_e}$ (522)
	51 : $-6\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)a(\nu_e)^2C_{11}m_{\nu_e}$ (516)
	52 : $-2\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)^3C_1m_{\nu_e}$ (486)
	53 : $-2\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)^3C_{12}m_{\nu_e}$ (452)
	54 : $-2\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)^3C_{11}m_{\nu_e}$ (446)
	55 : $8\gamma_{18}\gamma_{13}p_2^{18}v(\nu_e)a(\nu_e)^2m_{\nu_e}C_1$ (533)
	56 : $12\gamma_{18}\gamma_{13}p_2^{18}v(\nu_e)a(\nu_e)^2C_{12}m_{\nu_e}$ (521)

Status of my calculation

- ▶ Getting complete of Diagrams up to one-loop ····· ✓
- ▶ Getting Analytical Expression for Matrix element ····· ✓
- ▶ Getting Numerical Expression to $\Sigma |\mathcal{M}|^2$ ····· I am here !
(→ working on Box Diagram)
- ▶ Getting physical observables such as partonic and hadronic cross section to neutral and charged current processes