Electroweak radiative corrections to neutrino scattering at NuTeV

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In collaboration with U. Baur and D. Wackeroth.

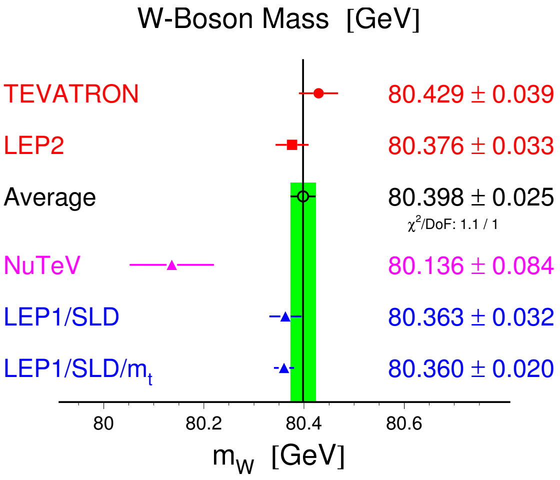
Motivation

Precise W boson mass measurement :

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

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

W boson mass

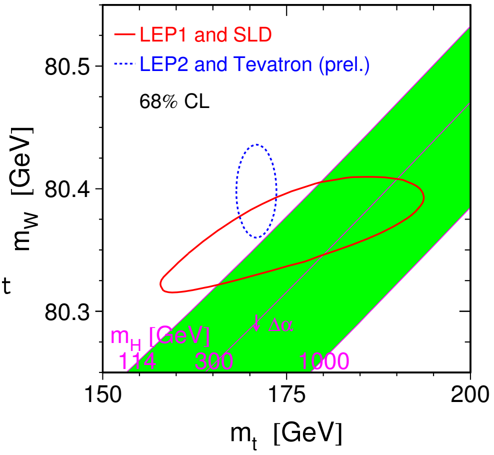


LEP EWWG 2007 (http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2007/)

W boson mass : 80.398 ± 0.025 GeV

$M_t = 170.9 \pm 1.1 \pm 1.5$
$M_h = 76^{+33}_{-24}$ GeV

NuTeV M_w measurement
$\rightarrow$ 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
J.T. Londergan arXiv:hep-ph/0408243

Motivation

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

  $\longrightarrow$ 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.final.gov/ gzeller/nutev.html

Motivation

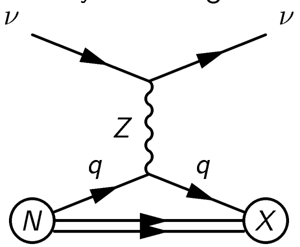
There is the study of the calculation of full Electroweak $\mathcal{O}(\alpha)$ corrections in the paper of Diener,Dittmaier and Hollik, (K. P. Diener, S. Dittmaier and W. Hollik, Phys. Rev. D **72**, 093002 (2005))

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.

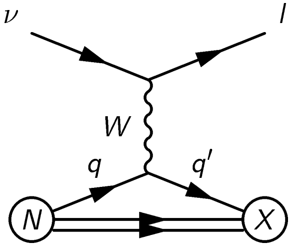
$\rightarrow$ After getting result, Compare with above paper and Study the impact of those corrections with Dr. Kevin McFarland who is one of the NuTeV collaborator

Calculation

Tree-level Feynman diagrams :



< Neutral Current >



< Charged Current >

Calculation

$$R = \frac{\sigma^{\nu}_{NC}(\nu N \to \nu X) - \sigma^{\bar{\nu}}_{NC}(\bar{\nu} N \to \bar{\nu} X)}{\sigma^{\nu}_{CC}(\nu N \to l X) - \sigma^{\bar{\nu}}_{CC}(\bar{\nu} N \to \bar{l} X)} = \rho^2 \left(\frac{1}{2} - \sin^2 \theta_w \right)$$

$\leftarrow$ proposed by Paschos and Wolfenstein

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

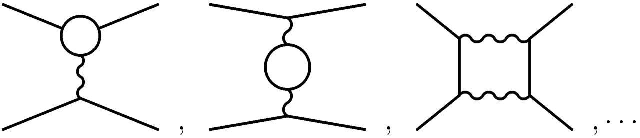
NuTeV result : $\sin^2 \theta_w = 0.22773 \pm 0.00135(\mathrm{stat}) \pm 0.00093(\mathrm{syst})$

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

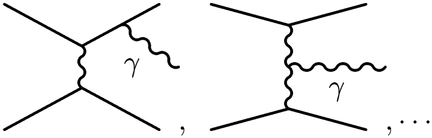
Some details of the Calculation in $\mathcal{O}(\alpha)$ corrections

Examples of Feynman diagrams :

Virtual :



Real :



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

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

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

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

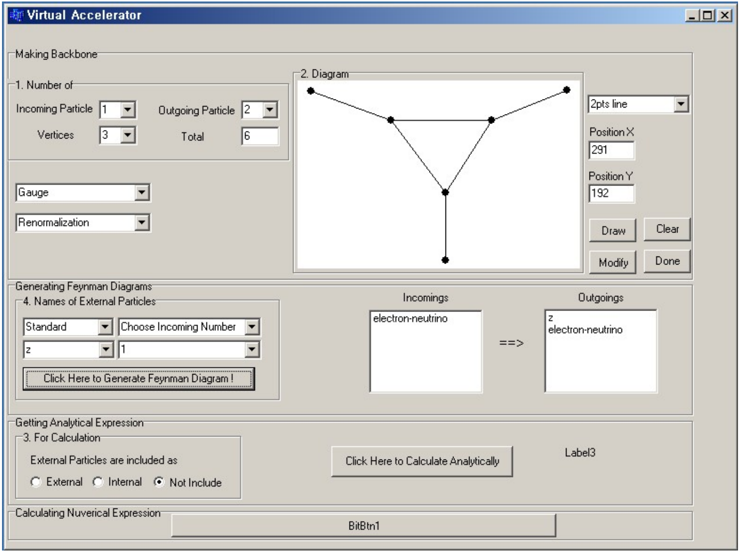
- Feynman - t'Hooft gauge
- On-Shell renormalization scheme
- Soft and collinear singularities is regularized by using fictitious γ mass and fermion masses

Introducing the newly developed computational tool - *"Virtual Accelerator"*

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

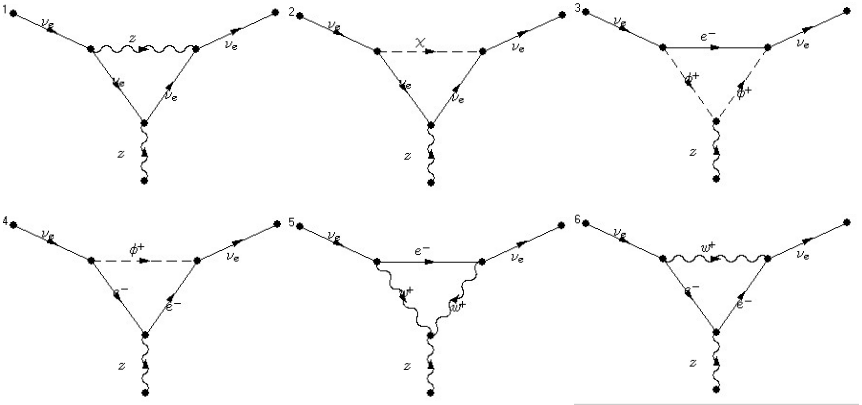
- User friendly interface
- User interactive tool
- Showing 8 calculation steps
- Gauge choice - Landau, Feynman
- Renormalization scheme - On-Shell,Minimal substraction(MS).
- Ease to add other models - QCD,SUSY,...
- Generating diagram images and LaTeX files

Screen Shot of "Virtual Accelerator"



Example of Diagram - ν_e,ν_e,Z Vertex

"Virtual Accelerator" create following images:



$+\cdots$

Example of Calculation - ν_e,ν_e,Z Vertex

"Virtual Accelerator" produce analytic expression:

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

$1: -24\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_1(1284)$
$2: -24\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{12}(1266)$
$3: -24\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{11}(1260)$
$4: -8\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_1(1218)$
$5: -8\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{12}(1182)$
$6: -8\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{11}(1176)$
$7: 6\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_1d(918)$
$8: 6\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{12}d(908)$
$9: 6\gamma_{18}p_2^{18}p_{113}v(\nu_e)a(\nu_e)^2C_{11}d(904)$
$10: 2\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_1d(882)$
$11: 2\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{12}d(864)$
$12: 2\gamma_{18}p_2^{18}p_{113}v(\nu_e)^3C_{11}d(860)$
$13: 8\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_1(1440)$
$14: 8\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{12}(1422)$
$15: 8\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{11}(1416)$
$16: 24\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_1(1224)$
$17: 24\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{12}(1206)$
$18: 24\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{11}(1200)$
$19: -2\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_1d(1002)$
$20: -2\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{12}d(992)$
$21: -2\gamma_{18}\gamma_5p_2^{18}p_{113}a(\nu_e)^3C_{11}d(988)$
$22: -6\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_1d(886)$
$23: -6\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{12}d(876)$
$24: -6\gamma_{18}\gamma_5p_2^{18}p_{113}v(\nu_e)^2a(\nu_e)C_{11}d(872)$
$25: -4\gamma_5p_{113}a(\nu_e)^3C_{22}m_{\nu_e}(1430)$
$26: -8\gamma_5p_{113}a(\nu_e)^3C_{12}m_{\nu_e}(1418)$

$32: 2\gamma_5p_{113}a(\nu_e)^3C_{22}dm_{\nu_e}(996)$
$33: 4\gamma_5p_{113}a(\nu_e)^3C_{12}dm_{\nu_e}(990)$
$34: 2\gamma_5p_{113}a(\nu_e)^3C_{11}dm_{\nu_e}(986)$
$35: 10\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_2dm_{\nu_e}(888)$
$36: 6\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_{22}dm_{\nu_e}(880)$
$37: 12\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_{12}dm_{\nu_e}(874)$
$38: 6\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_{11}dm_{\nu_e}(870)$
$39: 4\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_0d(824)$
$40: 6\gamma_5p_{113}a(\nu_e)^3C_1dm_{\nu_e}(816)$
$41: 4\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_0d(772)$
$42: 10\gamma_5p_{113}v(\nu_e)^2a(\nu_e)C_1dm_{\nu_e}(764)$
$43: -16\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_2(688)$
$44: -16\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_2(484)$
$45: -12\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_0(392)$
$46: -16\gamma_5p_{113}a(\nu_e)^3m_{\nu_e}C_1(368)$
$47: -4\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_0(286)$
$48: -16\gamma_5p_{113}v(\nu_e)^2m_{\nu_e}a(\nu_e)C_1(258)$
$49: -6\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)a(\nu_e)^2C_1m_{\nu_e}(542)$
$50: -6\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)a(\nu_e)^2C_{12}m_{\nu_e}(522)$
$51: -6\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)a(\nu_e)^2C_{11}m_{\nu_e}(516)$
$52: -2\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)^3C_1m_{\nu_e}(486)$
$53: -2\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)^3C_{12}m_{\nu_e}(452)$
$54: -2\gamma_{13}\gamma_{18}p_2^{18}v(\nu_e)^3C_{11}m_{\nu_e}(446)$
$55: 8\gamma_{18}\gamma_{13}p_2^{18}v(\nu_e)a(\nu_e)^2m_{\nu_e}C_1(533)$
$56: 12\gamma_{18}\gamma_{13}p_2^{18}v(\nu_e)a(\nu_e)^2C_{12}m_{\nu_e}(521)$

Status of my calculation

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