Electroweak radiative corrections to neutrino-nucleon scattering at NuTeV

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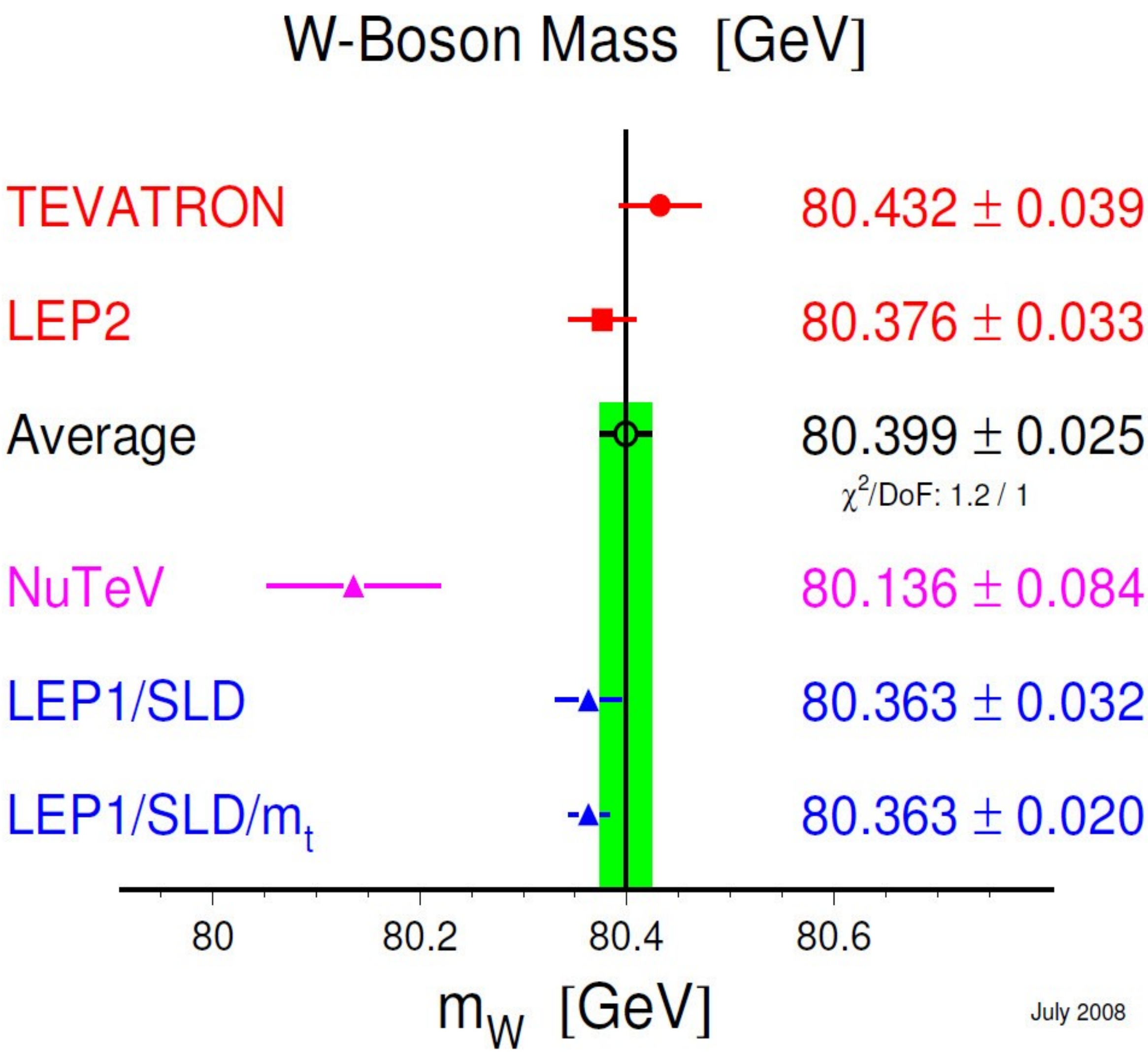
in collaboration with Ulrich Baur and Doreen Wackeroth (SUNY at Buffalo)



$\sin^2\theta_W$

0.2227 ∓ 0.0004

0.2277 ∓ 0.0014 (stat)
∓ 0.0009 (syst)

$\delta \sin^2\theta_W \approx 0.005$

$\sin^2\theta_W$ measured at NuTeV differs from the average by about 3σ (NuTeV anomaly)

LEP EWWG 2008(http://lepewwg.web.cern.ch/LEPEWWG/plots/summer2008)

Possible explanations

► QCD corrections

- Perturbative QCD corrections

  → small

- Uncertainties on Parton Distribution Function (PDF)

  → in future global analysis

  → The NNPDF Collaboration (arXiv:0906.1958)

- Isospin breaking

  → large isospin violation in PDF could explain NuTeV anomaly

► Electroweak radiative corrections

→ This talk

Kevin S. McFarland and Sven-Olaf Moch, hep-ph/0306052

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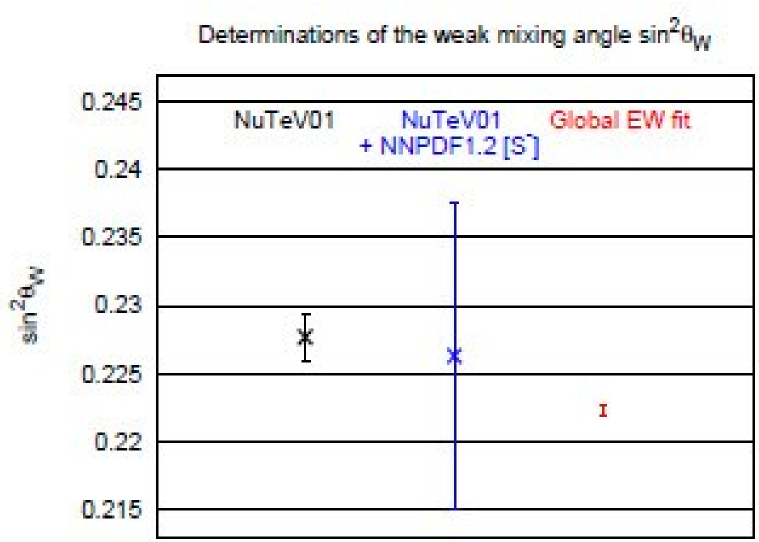

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Existing Calculations

1. Bardin and Dokuchaeva (JINR-E2-86-260 (1986))
   - ► Not include full electroweak $O(\alpha)$ corrections.
   - ► Massless fermion approximation.
   - ► Used in NuTeV analysis.

2. Arbuzov, Bardin and Kalinovskaya.(JHEP **0506**, 078 (2005))
   - ► Include full electroweak $O(\alpha)$ corrections.
   - ► Massless fermion approximation.

3. Diener, Dittmaier and Hollik (Phys. Rev. D **69**, 073005, 2004 ,Phys. Rev. D **72**, 093002 ,2005)
   - ► Include full electroweak $O(\alpha)$ corrections.
   - ► Higher order FSR, unv. 2-loop, γ induced precess
   - ► Massless fermion approximation
   - ► study the dependence on input-parameter scheme.

Motivation for our calculation

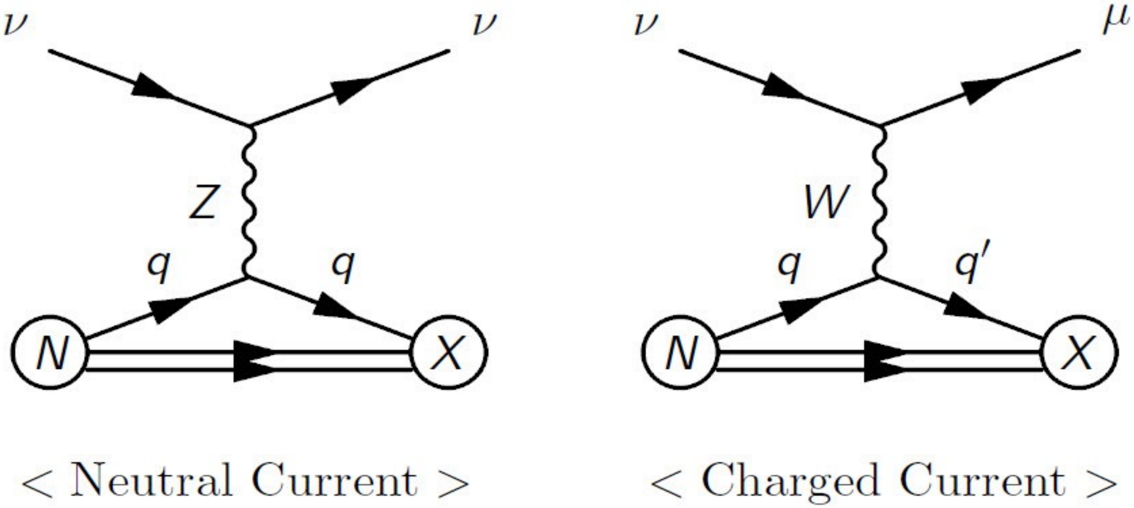
- Include full electroweak $O(\alpha)$ corrections.
- study the effect of fermion mass
- study the effect with realistic, experimental set-up

"Massless" / "Massive"

"Massless" : All fermion masses have only been used to regularize mass singularities, otherwise neglected.

"Massive" : Heavy fermion masses (muon, charm quark) have been taken into account everywhere.

W mass from νN scattering



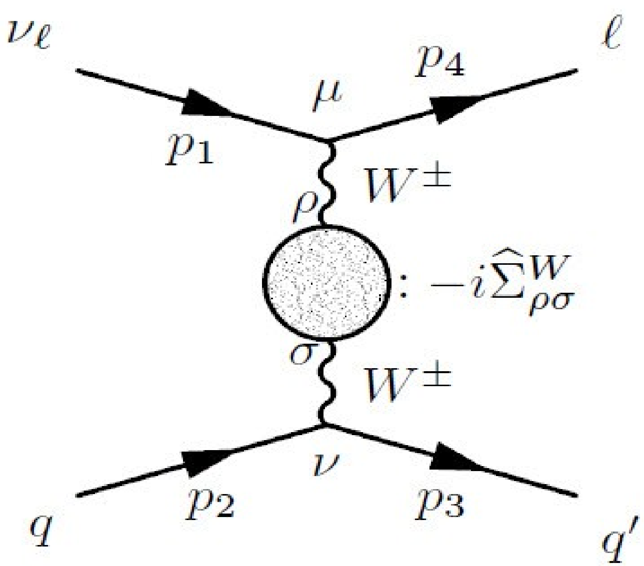
$$R = \frac{\sigma^{\nu}_{NC}(\nu N \to \nu X) - \sigma^{\bar{\nu}}_{NC}(\bar{\nu} N \to \bar{\nu} X)}{\sigma^{\nu}_{CC}(\nu N \to l X) - \sigma^{\bar{\nu}}_{CC}(\bar{\nu} N \to \bar{l} X)} = \rho^2 \left(\frac{1}{2} - \sin^2\theta_W \right)$$

- ► $\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$ (On-shell scheme)
- ► Data(σ) + Theory(ρ) → $\sin^2\theta_W$ → M_W

NuTeV G. P. Zeller et al., Phys. Rev. Lett. **88**, 091802 (2002)
E. A. Paschos and L. Wolfenstein, Phys. Rev. **D7**, 91 (1973)

Calculation: Mass effect

Consider self-energy correction:



► Two-point self-energy function:

$$\widehat{\Sigma}^W_{\rho\sigma} = \left(g_{\rho\sigma} - \frac{k_\rho k_\sigma}{k^2} \right) \widehat{\Sigma}^W_T + \frac{k_\rho k_\sigma}{k^2} \widehat{\Sigma}^W_L$$

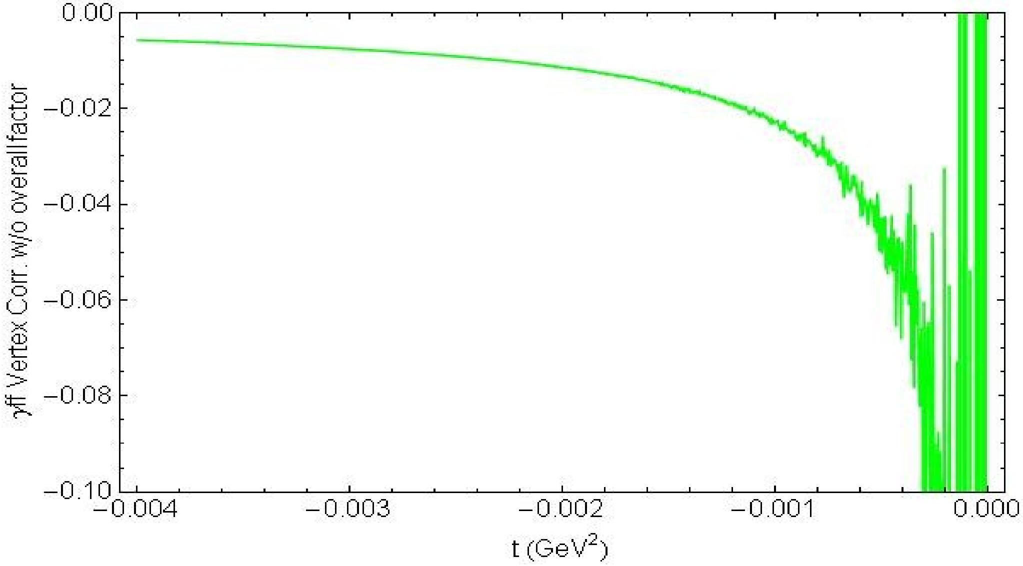
► Contribution to cross section:

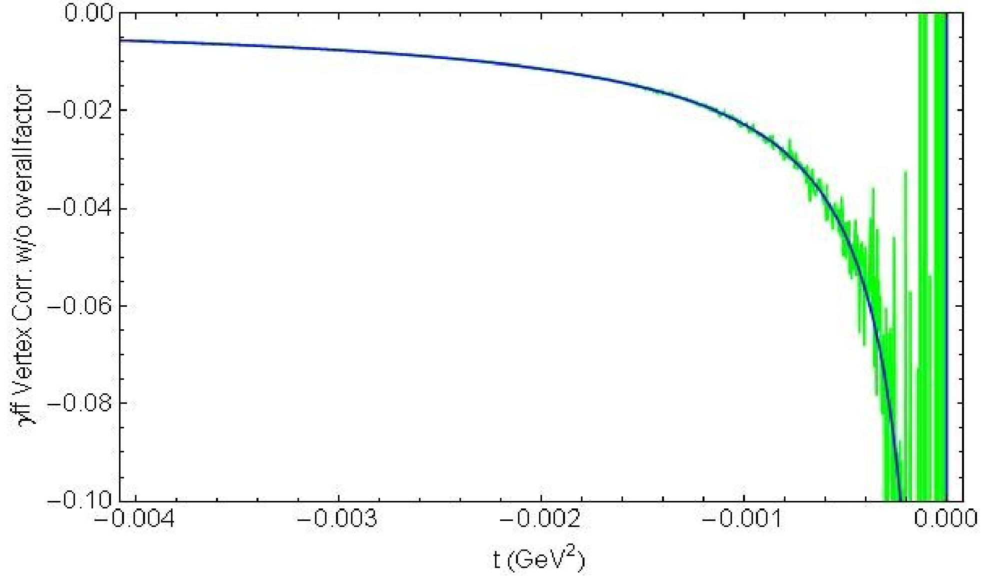
$$\sigma_{se} \sim \sigma_o \left(\frac{2\widehat{\Sigma}^W_T}{t + M_W^2} - \frac{m_\mu^2 m_c^2 u (\widehat{\Sigma}^W_L - \widehat{\Sigma}^W_T)}{4t(t + M_W^2)} \right)$$

where, t and u are Mandelstam variables.

- Vertex and Box Corrections also have similar expression like this
- In small t region, second term is NOT negligible.
- Small t region corresponds to small x region,
  where x is momentum fraction

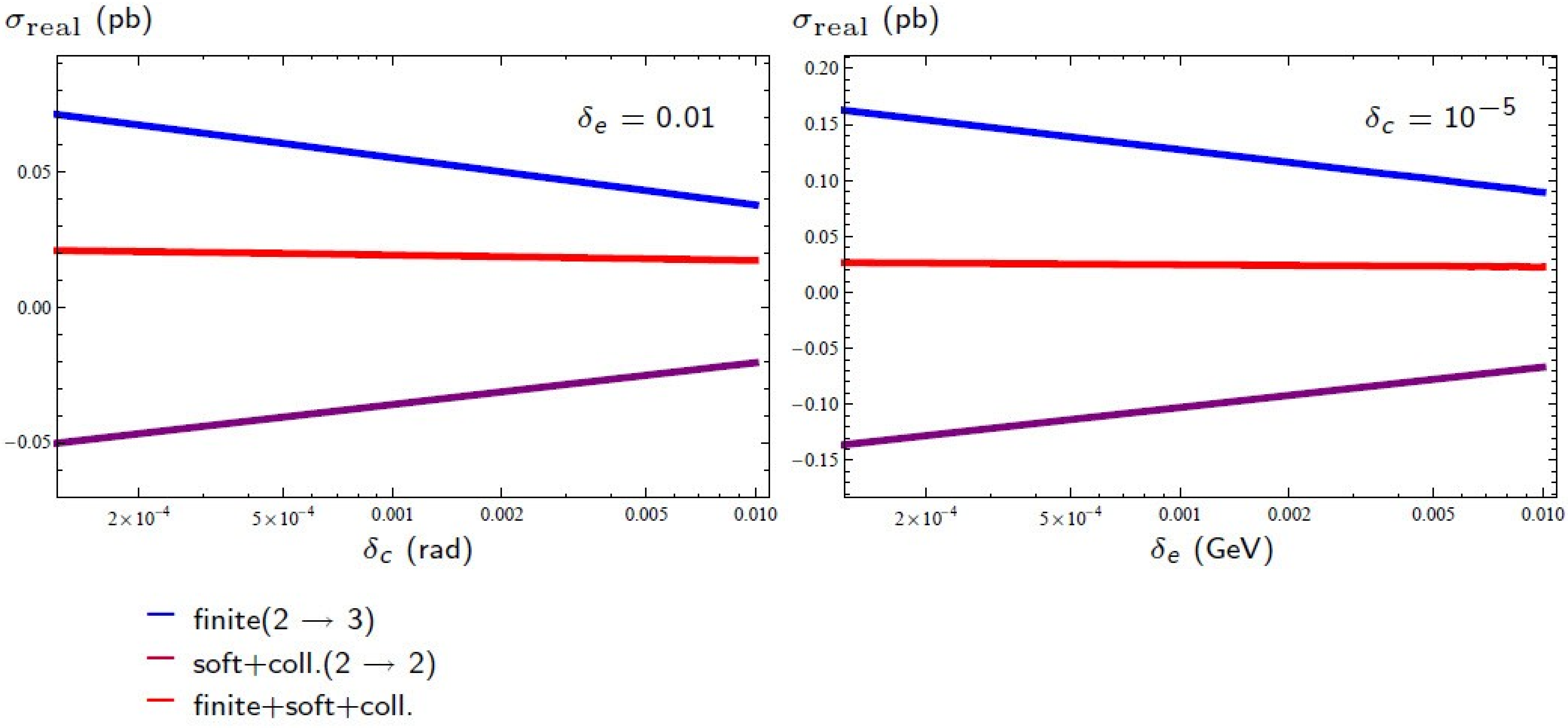
Numerical Instability



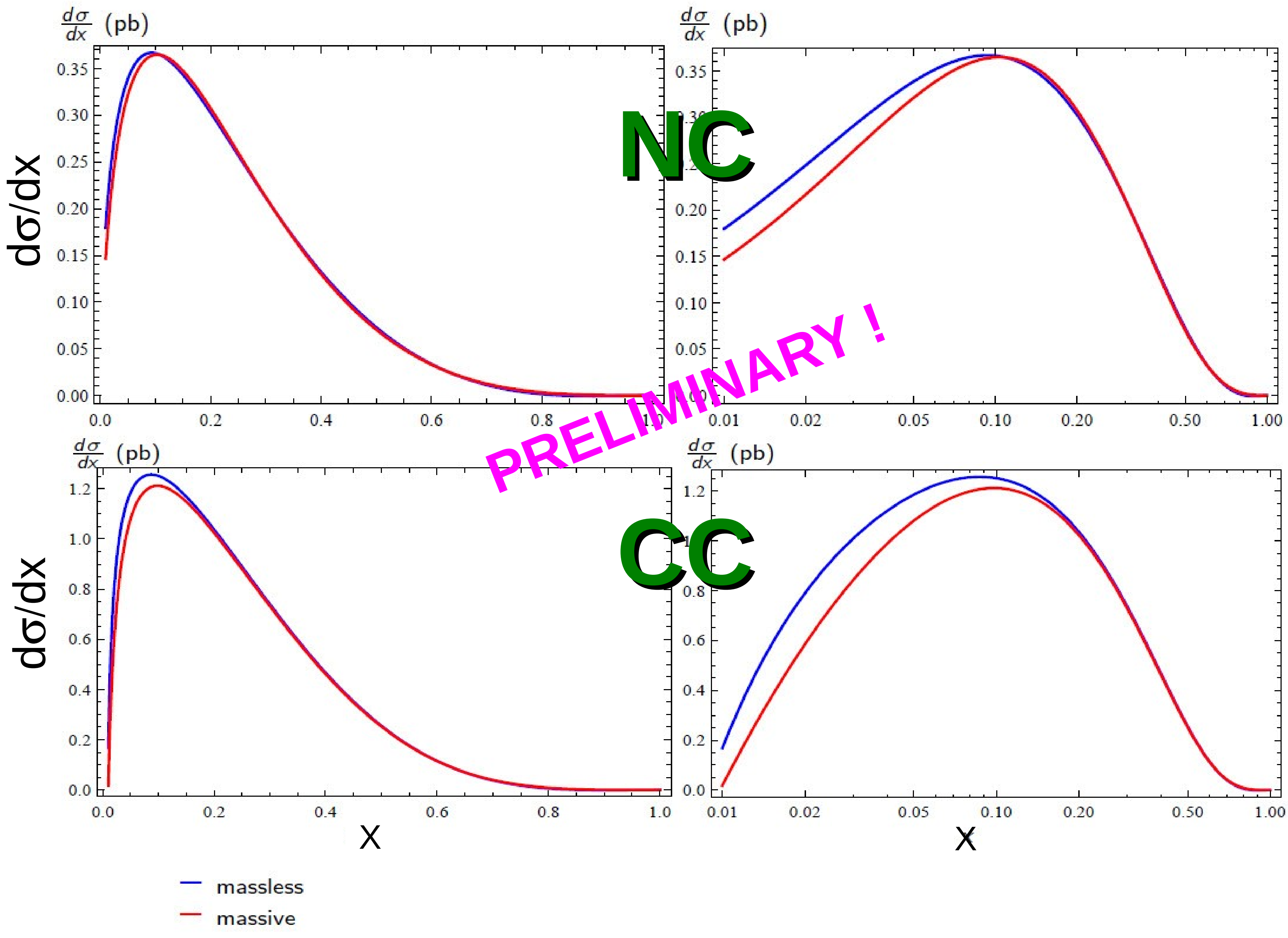


- ► The diagram in which photon is involved, has numerical instability in small Q^2 (=-t) due to t pole (1/t).
- ► We expand those expression up to $O(t^3)$ to fix numerical instability.

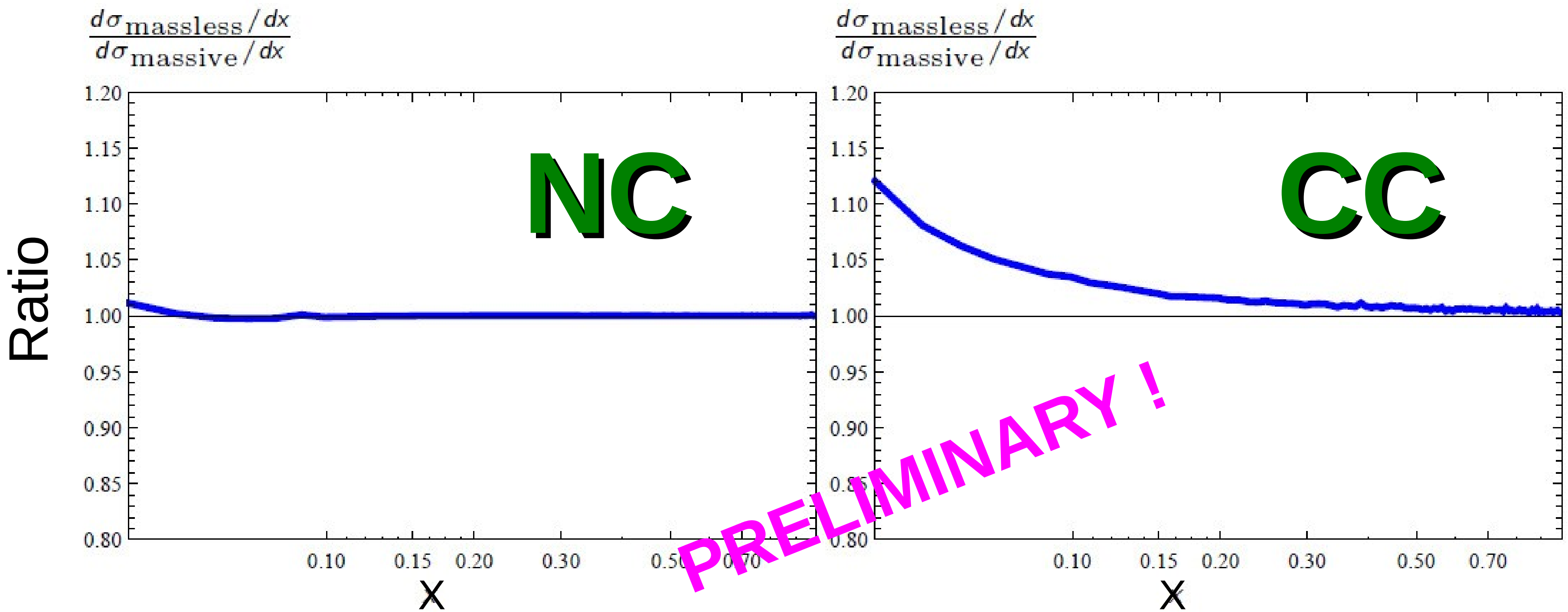
Numerical Results: Independence on phase space slicing parameters



Effect of Mass at small x



Numerical Results: massless vs massive



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$$= \rho^2 \left(\frac{1}{2} - \sin^2 \theta_W \right)$$

Numerical Results: Other dependence

$\Delta \sin^2\theta_W$ is sensitive to the choice of PDF, cuts, final photon treatment, isospin symmetry and so on.

	R_o^ν	δR_{NC}^ν	δR_{CC}^ν	$\Delta \sin^2\theta_W$
DDH I	0.31766	0.0582	-0.0758	-0.0082
BPW I	0.30638	0.0527	-0.0916	-0.0182
DDH III	0.31167	0.0668	-0.0365	-0.0142
DDH II	0.30455	0.0562	-0.0840	-0.0130
BPW II	0.30471	0.0527	-0.0877	-0.0183

NuTeV Anomaly: $\delta \sin^2\theta_W \approx 0.005$

BPW I, II: calculation by Baur, K. Park and Wackeroth

DDH I, II, III : calculation by Diener, Dittmaier and Hollik (Phys. Rev. D **69**, 073005 (2004,2005))

Definition of DDH I,II,III and Massless I,II

DDH(I): CTEQ4L, y < 0.125,

$$y = E_{had}^{LAB} / E_{\nu}^{LAB} = \frac{-\hat{s}}{\hat{t}}$$

DDH(II): MRST2004QED, $E_{had+phot}^{LAB} < 20.$

DDH(III): MRST2004QEDx(switched off O(α) corr.),

$E_{had+phot}^{LAB} < 20.$

BPW(I): MRST2004QED, y < 0.12

BPW(II): MRST2004QED, y< 0.22

DDH: Diener, Dittmaier and Hollik (Phys. Rev. D **69**, 073005, 2004 ,Phys. Rev. D **72**, 093002 ,2005)

BPW : Baur, Park and Wackeroth (in preparation)

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Dependence on PDF and Isospin Symm.

$\Delta \sin^2 \theta_W$ is sensitive to the choice of PDF, cuts, final photon treatment, isospin symmetry and so on.

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DDH I : CTEQ4L, y_{cut}=0.125 ,
Isospin symmetry.

BPW I: MRST2004QED , y_{cut}=0.12 ,
Isospin breaking.

(see also DDHII)

Numerical Results: Other dependence

$\Delta \sin^2 \theta_W$ is sensitive to the choice of PDF, cuts, final photon treatment, isospin symmetry and so on.

	R_o^{ν}	δR_{NC}^{ν}	δR_{CC}^{ν}	$\Delta \sin^2 \theta_W$
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Dependence on photon treatment

DDH II : MRST2004QED, Isospin breaking. $E^{LAB}_{had+phot} < 20,$

BPW II: MRST2004QED , Isospin breaking. $E^{LAB}_{had} < 17.6,$

DDH (I*): CTEQ4L Isospin symmetry. $E^{LAB}_{had+phot} < 10,$

	R^{ν}_{o}	δR^{ν}_{NC}	δR^{ν}_{CC}	$\Delta \sin^2 \theta_W$
DDH II	0.30455	0.0562	-0.0840	-0.0130
BPW II	0.30471	0.0527	-0.0877	-0.0183
DDH(I)	0.31766	0.0582	-0.0758	-0.0082
DDH(I*)	0.31766	0.0589	-0.0842	-0.0118

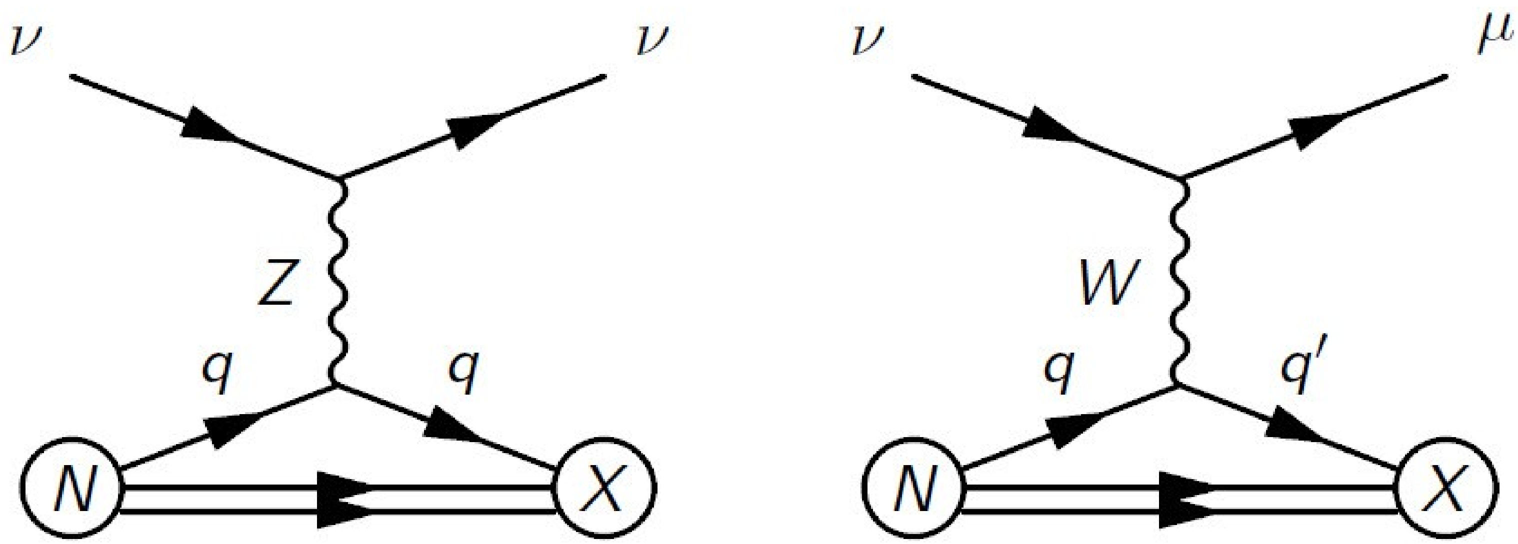
More realistic study is needed in coll. with NuTeV (in progress...)

Conclusion

- We calculated the complete eletroweak $O(\alpha)$ corrections to neutrino-nucleon scattering processes based on the massless fermion approximations (used in the NuTeV analysis) and with the full fermion mass dependence.
- The calculation is implemented in a Monte Carlo program
- The detailed study of fermion mass effect is in progress. Also updated study on PDF uncertainty including isospin breaking effect will be available soon !
- Although more deteailed studies are needed with more realistic setup, results from previous and this study shows that
  - Theoretical uncertainties due to EW corrections need to be carefully included into NuTeV analysis.
  - The effect of isospin breaking may be NOT negligible
  - An updated study of PDF uncertainty is necessary

BackUp Slides

Calculation: Leading Order



< Neutral Current > < Charged Current >

- ► Cross section, σ can be derived from the multiplication of leptonic(L^{μ}) and hadronic(H_{μ}) currents
- ► L^{μ} and H_{μ} are function of fermion masses:

$\sigma_{NC} \sim L^{\mu}(m_{\nu}, m_{\nu}, \ldots) H_{\mu}(m_{\nu}, m_{\nu}, \ldots)$ — massive terms vanish (NC)

$\sigma_{CC} \sim L^{\mu}(m_{\nu}, m_{\nu}, \ldots) H_{\mu}(m_{\nu}, m_{\mu}, \ldots)$ — massive terms survive (CC)

Numerical Results: Input parameters

$\alpha(0) = 1/137.03599911$

$M_W = 80.425 \;\; GeV$

$M_Z = 91.1876 \;\; GeV$

$M_H = 115 \;\; GeV$

$m_e = 0.51099892 \;\; MeV$

$m_\mu = 105.658369 \;\; MeV$

$m_u = 66 \;\; MeV$

$m_d = 66 \;\; MeV$

$m_c = 1.2 \;\; GeV$

$m_s = 150 \;\; MeV$

$m_t = 178 \;\; GeV$

$m_b = 4.3 \;\; GeV$

$V_{ud} = 0.9754$

$V_{us} = 0.2205$

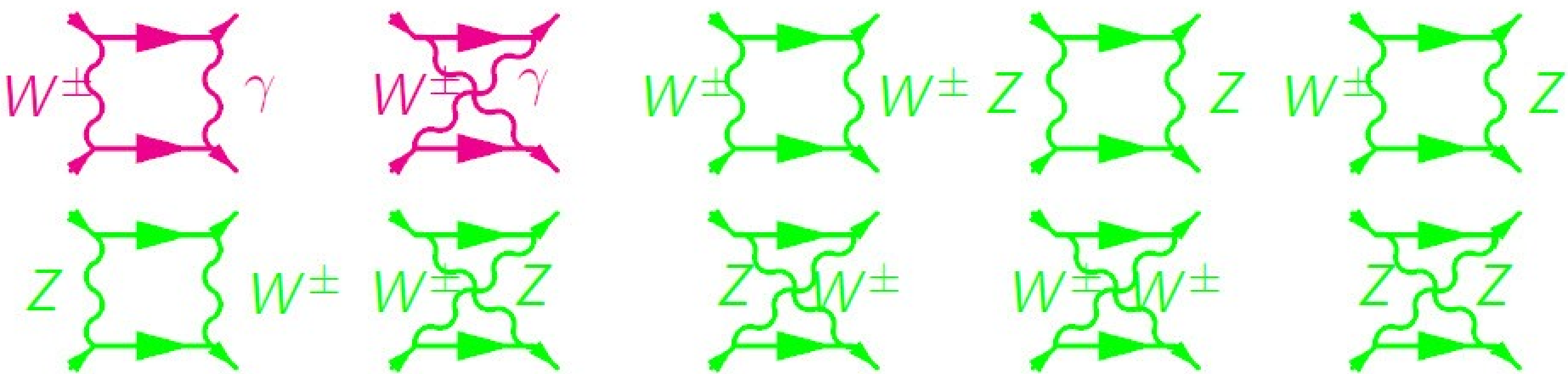
$V_{cd} = 0.2205$

$V_{cs} = 0.9754$

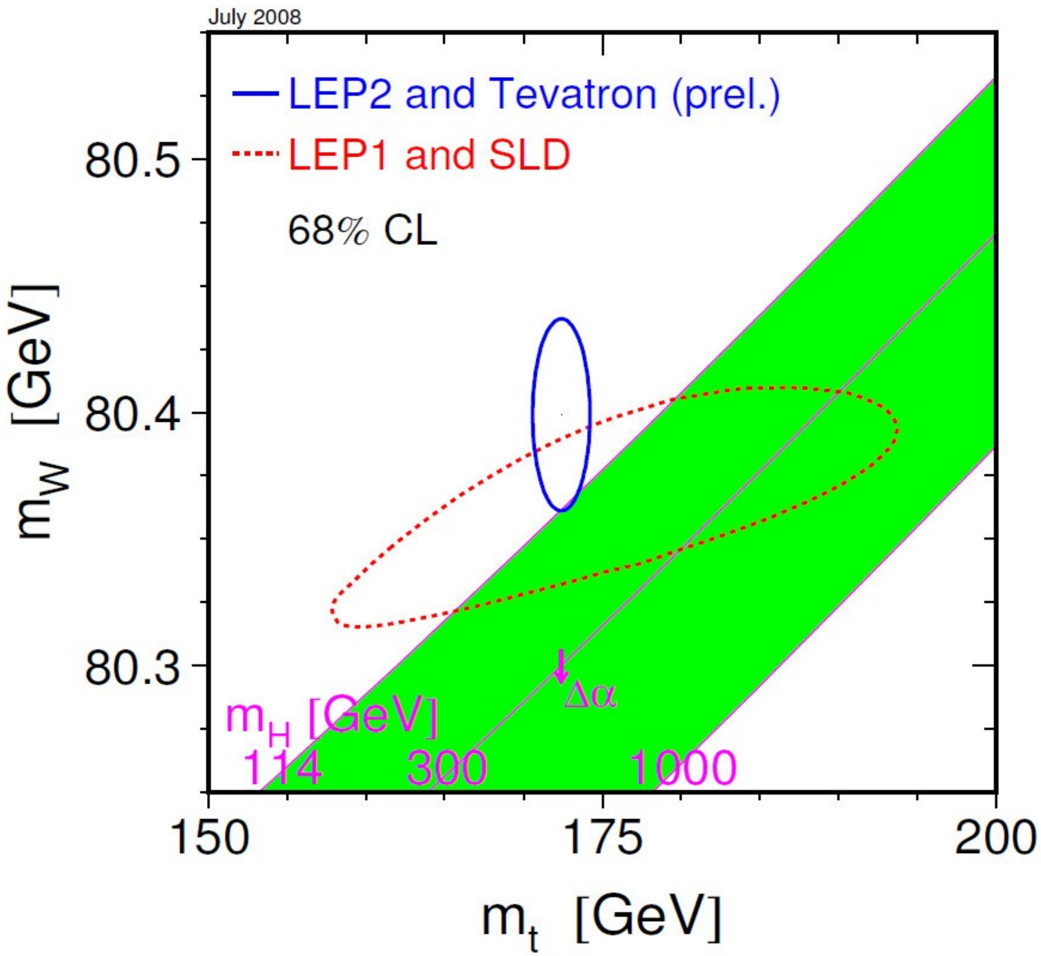
Existing Calculations I

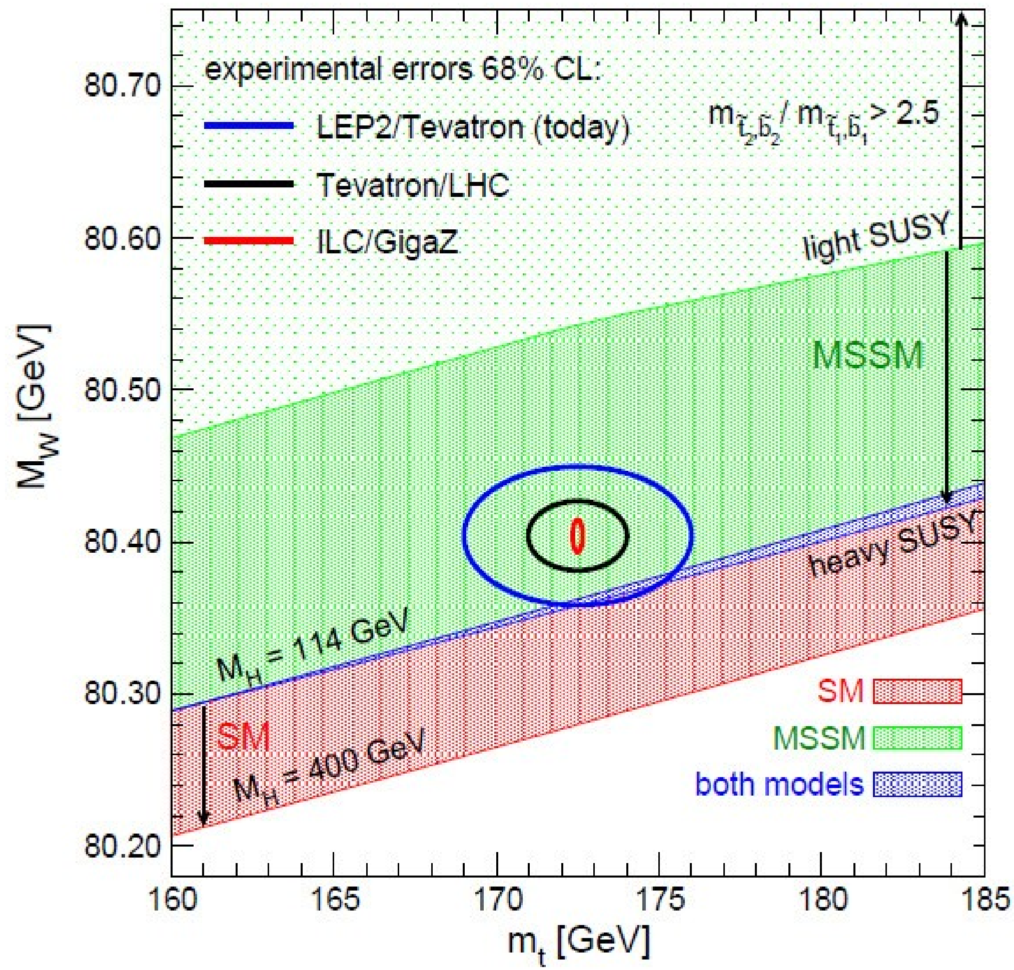
1. Bardin and Dokuchaeva (JINR-E2-86-260 (1986))

► Not include full electroweak *O*(®) corrections.
→ They did include QED but not WEAK boxes.



► Used in NuTeV analysis.





$$M_H = 84^{+34}_{-26}\ \mathrm{GeV}$$

LEP EWWG 2008(http://lepewwg.web.cern.ch/LEPEWWG/plots/summer2008)
S. Heinemeyer et al., hep-ph/060417(www.ifca.unican.es/heinemey/uni/plots/)