

Precision Study of Electroweak Interactions at the Energy Frontier

Outline of the report of the Snowmass EW study group

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Two main topics:

- 1) Electroweak precision physics
- 2) Non-standard interactions of EW gauge bosons in multi-boson processes

All projections and conclusions are preliminary and still
under discussion !

1) Electroweak precision physics

1. M_W and $\sin^2\theta_{\text{eff}}^l$: precision measurements and SM predictions
2. EWPOs in the pMSSM
3. EWPOs and Z'
4. S,T,U and BSM physics

1.1) Measurements and Predictions of M_W and $\sin^2\theta_{\text{eff}}$

Current and anticipated uncertainties in the measurement of M_W at the Tevatron:

ΔM_W [MeV]	CDF 2.2 fb ⁻¹	D0 4.3 fb ⁻¹ (+1.1fb ⁻¹)	Tevatron combined	final CDF	final D0	Tevatron combined 10 fb ⁻¹
PDF	10	11	10	5	5	5
QED radiation	4	7	4	4	3	3
$p_T(W)$ model	5	2	2	2	2	2
Other systematics	10	18	9	4	11	4
W statistics	12	13	9	6	8	5
Total	19	26(23)	16	10	15	9

TEV EW WG, TEVEWWG/WZ 2012/01, arXiv:1204.0042

The CDF collab., T.Altoonen et al, PRL108, 151803 (and references therein), arXiv:1203.0275

The D0 collab., V.M. Abozov et al, PRL108, 151804 (and references therein), arXiv:120.:0293

Anticipated uncertainties in the measurement of M_W at the LHC:

ΔM_W [MeV]	LHC 8 TeV, 20 fb ⁻¹	LHC 300 fb ⁻¹	LHC 3000 fb ⁻¹
PDF	5	4	3
QED radiation	4	3	2
$p_T(W)$ model	2	1	1
Other systematics	10	5	3
W statistics	1	0.2	0
Total	12	7	5

- Update on possible improvements in PDF uncertainty on M_W using future improved measurements (with NNPDF).
- Statement on feasibility of calculation of 2-loop QED/QCD and QED to DY
- Projection of improvements in systematic uncertainty based on Tevatron measurement due to higher statistics

Current and anticipated uncertainties in the measurement of $\sin^2 \theta_{\text{eff}}^l$ at the Tevatron:

$\Delta \sin^2 \theta_{\text{eff}} [10^{-5}]$	CDF 2.1 fb ⁻¹	D0 5 fb ⁻¹	final CDF	final D0
PDF		48		
Higher order corrections		8		
Other systematics		38		
Statistical	90	80		
Total	100	101		

V.M.Abazov et al. [D0 Collab.], Phys.Rev D 84, 012007 (2011)
arXiv:1104.4590 [hep-ex]

CDF collab., Note CDF/PUB/ELECTROWEAK/PUBLIC/10952 (2013)

Current and anticipated uncertainties in the measurement of $\sin^2 \theta_{\text{eff}}$ at the LHC:

$\Delta \sin^2 \theta_{\text{eff}} [10^{-5}]$	ATLAS 7 TeV 4.8 fb ⁻¹	CMS 7 TeV 1.1 fb ⁻¹	LHC 8 TeV 20 fb ⁻¹	LHC 300 fb ⁻¹	LHC 3000 fb ⁻¹
PDF	70	130			
H. o. corrections	20	110			
Other systematics	70	181			
Statistical	40	200			
Total	108	319			

ATLAS collab. ATLAS-CONF-2013-043

CMS collab., S.Chatrchyan et al, PRD84, 112002, arXiv:1110.2682 [hep-ex]

Current and anticipated uncertainties in the measurement of M_W and $\sin^2 \theta_{\text{eff}}$ at lepton colliders:

ΔM_W [MeV]	LEP2	ILC/GigaZ	TLEP
systematics	22		
statistical	25		
Total	33	5-6	<1

$\Delta \sin^2 \theta_{\text{eff}}$ [10^{-5}]	LEP/SLC	ILC/GigaZ	TLEP
Total	16	<1	0.2

S.Schael et al, Aleph, Delphi. L3, Opal, LEPEWWG, arXiv:1302.3415 [hep-ex]
 Aleph, Delphi. L3, Opal, SLD, LEPEWWG, HF groups, hep-ex/0509008 (2005)
 TLEP Snowmass white paper (in prep.);
 TLEP aim: A. Blondel, talk at 4th TLEP workshop (see also talk at Seattle meeting)
 ILC TDR vol. 2 (Physics); LC Snowmass white paper (in prep.; see also talk at Seattle meeting)

Summary: Anticipated uncertainties in the measurement of M_W and $\sin^2\theta_{\text{eff}}^l$ at future lepton and hadron colliders:

	LHC 300 fb ⁻¹	LHC 3000 fb ⁻¹	ILC/GigaZ	TLEP
ΔM_W [MeV]	7	5	5-6	<1
$\Delta \sin^2 \theta_{\text{eff}}^l$ [10^{-5}]			<1	0.2

Anticipated conclusion:

- M_W : LHC and ILC/GigaZ can achieve comparable precision of 5 MeV.
- $\sin^2 \theta_{\text{eff}}^l$: For the LHC to reach LEP sensitivity, the PDF error has to be reduced by at least a factor of 7.

Current uncertainties in the predictions of M_W and $\sin^2\theta_{\text{eff}}$:

	$\Delta m_{\text{top}} =$ 0.9 GeV	$\Delta(\Delta\alpha_{\text{had}}) =$ $1.38(1.0) \times 10^{-4}$	ΔM_Z $= 2.1$ MeV	missing h.o. corr.	Total
ΔM_W [MeV]	5.4	2.5(1.8)	2.6	4.0	7.6(7.4)
$\Delta \sin^2 \theta_{\text{eff}}$ [10^{-5}]	2.8	4.8(3.5)	1.5	4.7	7.4(6.7)

$\Delta\alpha_{\text{had}} = 0.027626 \pm 1.38 \times 10^{-4}$: Hagiwara et al, J.Phys.G 38, 085003 (2011) [arXiv:1105.3149]

$\Delta\alpha_{\text{had}} = 0.02757 \pm 1.0 \times 10^{-4}$: Davier et al, Eur. Phys. J.C 71, 1515 (2011)[Erratum: C 72, 1874 (2012)] [arXiv:1010.4180 [hep-ph].

M_W : Awramik et al, Phys.Rev.D 69, 053006 (2004)[hep-ph/0311148].

$\sin^2\theta_{\text{eff}}$: Awramik et al, JHEP 0611, 048 (2006)[hep-ph/0608099].

Anticipated uncertainties in the predictions of M_W and $\sin^2\theta_{\text{eff}}$:

	$\Delta m_{\text{top}} =$ 0.3 GeV	$\Delta(\Delta\alpha_{\text{had}}) =$ 5.5×10^{-5}	ΔM_Z =2.1 MeV	missing h.o. corr.	Total
ΔM_W [MeV]	1.8	1.0	2.6	2.0	3.9
$\Delta \sin^2 \theta_{\text{eff}}$ [10^{-5}]	0.9	1.9	1.5	2.0	3.3

GigaZ/ILC: $\Delta M_Z = 1.6$ MeV

TLEP: $\Delta M_Z < 0.1$ MeV

Anticipated conclusion:

Precision of prediction of M_W is comparable with experimental goals at the LHC and ILC/GigaZ, provided presently missing higher order calculations are available (3 loop).

1.2) EWPO in the pMSSM

Impact of improvements in knowledge of EWPOs, in particular M_W and $\sin^2 \theta_{\text{eff}}$, on their ability to distinguish between the SM and MSSM and to constraint MSSM parameters in a number of MSSM scenarios (taking into account all known constraints), including scenarios where there is sensitivity even when no new physics is found at the LHC.

See, e.g., talk by S.Heinemeyer at BNL Snowmass workshop:
[https://indico.bnl.gov/getFile.py/access?
contribId=71&sessionId=10&resId=0&materialId=slides&confId=571](https://indico.bnl.gov/getFile.py/access?contribId=71&sessionId=10&resId=0&materialId=slides&confId=571)

1.3) EWPO and Z'

- Limits on $M_{Z'}$ and mixing angle $\sin\theta_{ZZ'}$ from global EW fits taking into account all known constraints and in view of future improvements in EWPOs.
- Comparison with limits from direct searches for Z'

1.4) S,T,U and BSM physics

- Update of previous studies to take into account a Higgs mass of 125 GeV. Discussion of constraints on a number of BSM models from S,T,U in view of future improvements in the measurement of S,T,U.
- Are there scenarios where there is sensitivity even when no new physics is found at the LHC ?

See, e.g., Updated Status of the Global Electroweak Fit and Constraints on New Physics by GFITTER collab., <http://arxiv.org/abs/1107.0975>.

2) Non-standard EW interactions in multi-boson processes and scales of new physics

1. Theory tools for studies of non-standard gauge boson interactions (Snowmass white paper)
2. Review of existing constraints on aTGCs and aQGCs
3. Multi-boson processes at the 14 TeV LHC: new studies for VBS and tri-boson production at 300 fb^{-1} , 3000 fb^{-1} ([ATLAS public document ATLAS-PHYS-PUB-2013-006](#))
4. Multi-boson processes at hadron colliders: new studies for VBS and tri-boson production at 300 fb^{-1} , 3000 fb^{-1} , 33 TeV and at 100 TeV (Snowmass white paper)
5. Multi-boson processes at lepton colliders: new studies for muon collider and review of literature on ILC, CLIC, and TLEP
6. AQGCs and new resonances; illustrations of how EFT operators can be related to specific UV-complete theories (e.g., 2HDM).
7. ATGCs from global fits and Higgs data

2.1) Theory tools for studies of non-standard gauge interactions

Snowmass white paper (in prep.)

Outline:

- Parametrizations of non-standard electroweak interactions

Description of effective Lagrangian and effective field theory approach; relation between anomalous coupling parameters and coefficients of higher-dim. operators; unitarization and new resonances.

- Predictions for multi-boson production with non-standard couplings

Brief overview of calculations and MCs relevant for studies of non-standard gauge couplings. Emphasis on description of implementations in MADGRAPH, WHIZARD and VBFNLO, ie tools that are being used for the Snowmass study.

- Tuned comparison of predictions for multi-boson production with WHIZARD, VBFNLO and MADGRAPH

2.3) and 2.4) Non-standard interactions in multi-boson processes

Snowmass white paper (in prep.)

Studies based on Effective Field Theory (EFT) higher dimension operators as implemented in Madgraph. The focus is on dim. 8 operators that do not affect Higgs properties.

Anticipated conclusion:

Comparison of sensitivity of these dim. 8 operators between different colliding beams, collider energies and luminosities.