Precision Study of Electroweak Interactions at the Energy Frontier

Outline of the report of the Snowmass EW study group
updated with workshop results

Ashutosh Kotwal
Duke University

Two main topics:

1) Electroweak precision physics

2) Non-standard interactions of EW gauge bosons in multi-boson processes

1) Electroweak precision physics

1. M_W and $\sin^2\theta_{eff}$: precision measurements and SM predictions - updates
2. EWPOs in the pMSSM- update
3. EWPOs and Z' – planning 4 TeV Z' prediction
4. S,T,U and BSM physics – planning 2HDM with 125 GeV light Higgs

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

$\Delta \sin^2 \theta_{eff}$ [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 analysis presented by Regina Caputo on Sunday -

Experience from ATLAS and CMS analyses will be used to project uncertainties to larger datasets

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

Polarized Threshold Scan Errors

- conservative – viewed from + 14 years ....
- Non-Ebeam experimental error (stat + syst)
  - 5.2 MeV

	Scenario 0	Scenario 1	Scenario 2	Scenario 3
L (fb^{-1})	100	160*3	100	100
Pol. (e- / e+)	80/60	90/60	90/60	90/60
Inefficiency	LEP2	0.5*LEP2	0.5*LEP2	0.5*LEP2
Background	LEP2	0.5*LEP2	0.5*LEP2	0.5*LEP2
Effy/L syst	0.25%	0.25%	0.25%	0.1%
ΔmW(MeV)	5.2	2.0	4.3	3.9

Slide from Graham Wilson's talk on Tuesday: exploring scenarios for MW at ILC with threshold scan

Also exploring methods of reducing beam energy calibration error to ~2 MeV on MW

From C.Schwinn's talk on Tuesday:

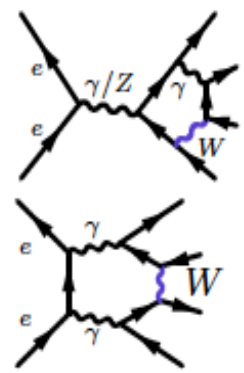
W-pair production

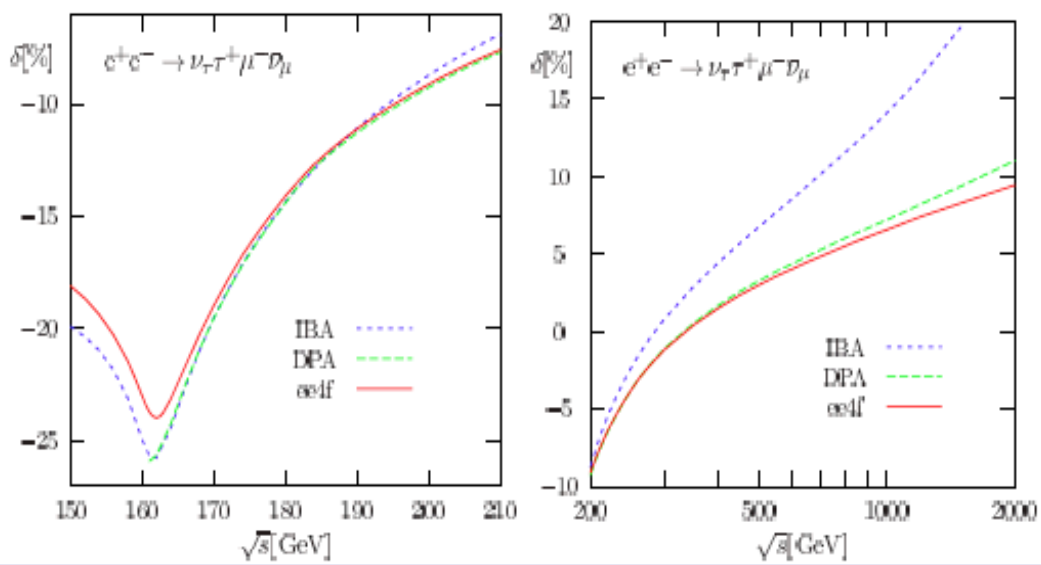
Full NLO calculation for $e^+e^- \to 4f$ (Denner, Dittmaier, Roth, Wieders 05)

- More than 1000 1-loop diagrams
  5-point, 6-point loop integrals

$\Rightarrow$ new methods for six-point diagrams

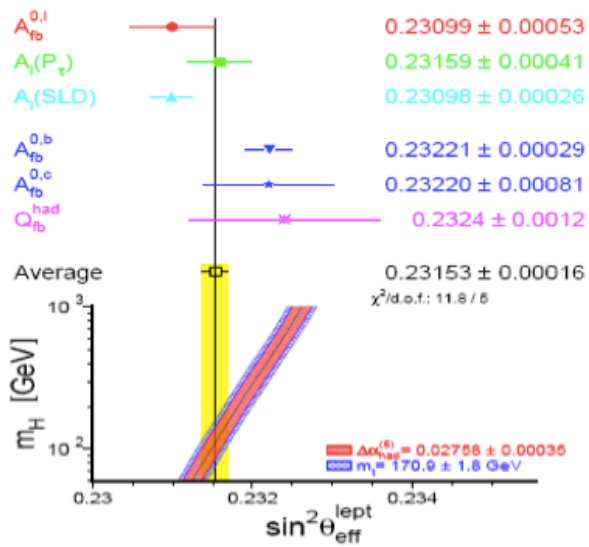
- fully differential calculation
- complex mass scheme: replace $M^2 \to M^2 + \mathrm{i}M\Gamma$,
  everywhere, e.g. $\cos\theta_w = \frac{M_W}{M_Z}$





Slide from G.Moortgat-Pick's talk on ILC physics on Sunday:

Higgs story has just started … $\sqrt{s}$=91 GeV



LEP:

$\sin^2\theta_{eff}(A_{FB}^b)$= 0.23221±0.00029

SLC:

$\sin^2\theta_{eff}(A_{LR})$= 0.23098±0.00026

World average:

$\sin^2\theta_{eff}$ = 0.23153±0.00016

Goal GigaZ: $\Delta\sin\theta$=1.3 10^{-5}

→ factor of 10 better than LEP/SLC

- **Uncertainties from input parameters: Δm_Z, $\Delta\alpha_{had}$, m_{top} ,…**

Δm_Z=2.1 MeV:	$\Delta\sin^2\theta_{eff}^{para}$~1.4x$10^{-5}$
$\Delta\alpha_{had}$~10 (5 future) x 10^{-5} :	$\Delta\sin^2\theta_{eff}^{para}$~3.6 (1.8 future)x$10^{-5}$
Δm_{top}~1 GeV (Tevatron/LHC):	$\Delta\sin^2\theta_{eff}^{para}$~3x$10^{-5}$
Δm_{top}~0.1 GeV (ILC):	$\Delta\sin^2\theta_{eff}^{para}$~0.3x$10^{-5}$

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Quote from TLEP presentation by Alain Blondel on Sunday:

Words of caution:

1. TLEP will have 5.10^4 more luminosity than LEP at the Z peak, 5.10^3 at the W pair threshold.
Predicting achievable accuracies with statistical errors decreasing by 250 is very difficult. The study is just beginning.

Given enormous statistics, TLEP has potential which needs careful study to quantify:

Possibilities:

R_b improved by factor of 10 beyond LEP
A_{LR} depends on longitudinal polarization
M_W approaching/surpassing 1 MeV using threshold scan
...

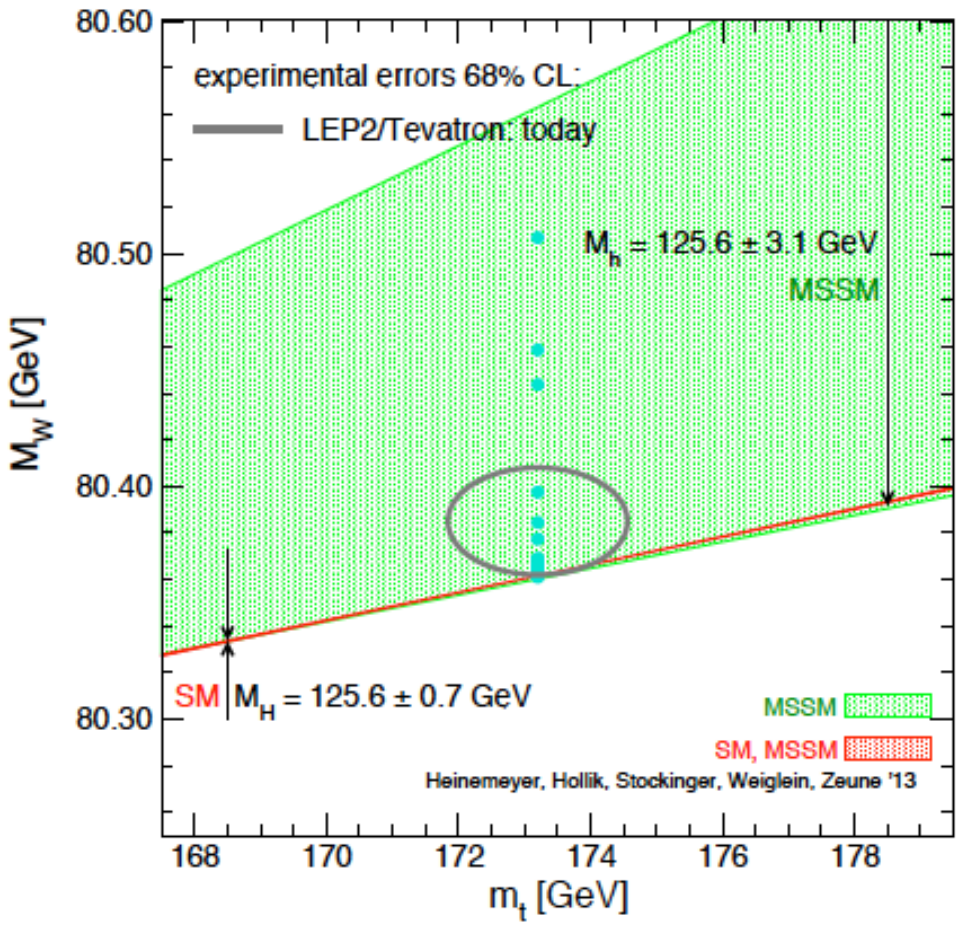
Anticipated uncertainties in the predictions of M_W and $\sin^2\theta_{eff}$:

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

Ayres Freitas' talk on Monday: based on future calculations of 3-loop contributions

[S.H., G. Weiglein, L. Zeune, PRELIMINARY]

Effect of new physics:



Points: 24 Snowmass pMSSM benchmarks

From S.Heinemeyer's talk on Monday

From P. Roloff's talk on Sunday:

Anomalous triple gauge boson vertices

Triple gauge couplings have beed studied in the past using $e^+e^- \rightarrow W^+W^-$ events (hep-ph/0412251):

Table 10: Sensitivity of the real parts of CP-even couplings in units of 10^{-3}, defined and expounded upon in [30]. The integrated luminosities for the 500 GeV, 800 GeV and 3000 GeV stages are assumed here to be 500 fb^{-1}, 1 ab^{-1} and 3 ab^{-1} respectively.

$\sqrt{s}$ [GeV]	$Re(\Delta g_1^L)$	$Re(\Delta\kappa_L)$	$Re(\lambda_L)$	$Re(g_5^L)$	$Re(g_1^R)$	$Re(\Delta\kappa_R)$	$Re(\lambda_R)$	$Re(g_5^R)$
500	2.6	0.85	0.59	2.0	10	2.4	3.6	6.7
800	1.6	0.35	0.24	1.4	6.2	0.92	1.8	4.8
3000	0.93	0.051	0.036	0.88	3.1	0.12	0.36	3.2

→ Improved precision at high-energy

New analysis based on current full detector simulation desirable

30/06/2013 Philipp Roloff Snowmass Energy Frontier workshop 9

Action item: translation between different parameterizations to be included in theory White paper

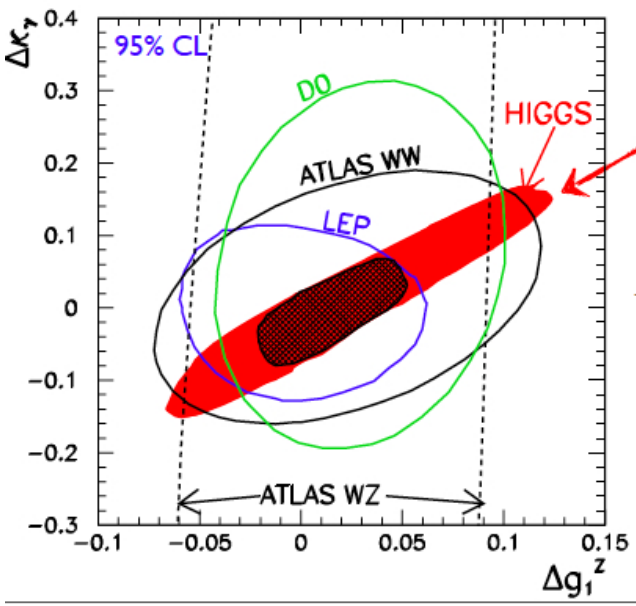
Slide from O. Eboli's talk on Sunday:

Impact on the TGCs

[Campos, Gonzalez-Garcia,Novaes]

- We performed the fitting to Higgs data without TGC data

$$\Delta\chi^2_H(\Delta\kappa_\gamma, \Delta g_1^Z) = \min_{f_g, f_{WW}, f_{\rm bot}, f_\tau} \Delta\chi^2_H(f_g, f_{WW}, f_{\rm bot}, f_\tau, f_B, f_W)$$



nice correlation

$-0.04 \leq \Delta g_1^Z \leq 0.02$,
which imply

$-0.11 \leq \Delta\kappa_\gamma \leq 0.0$
$-0.02 \leq \Delta\kappa_Z \leq 0.$
[68% CL

Study of aQGCs in the presence of resonances at the LHC presented by J. Reuter on Tuesday.

Anomalous coupling sensitivity study of Vector Boson Scattering(VVjj) with Effective Field Theory operators

Shu Li
Duke University

On behalf of
Snowmass EWK VBS/Triboson Group
(C. Degrande, O. Eboli, S. Hsu, A. Kotwal, S. Li, M. Marx, O. Mattelaer, J. Metcalfe, M-A. Pleier, C. Pollard)

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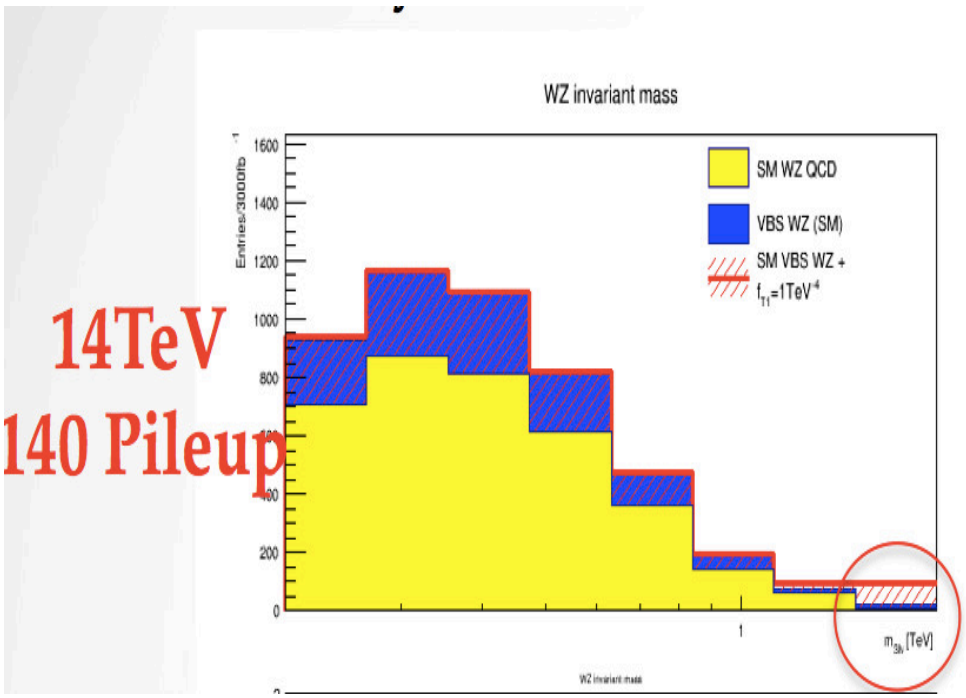
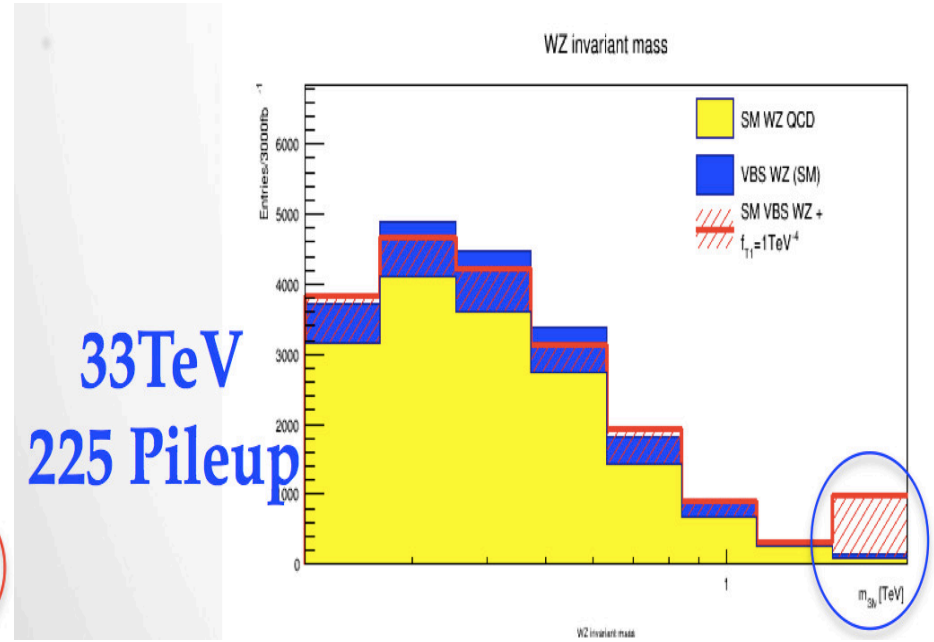
Study of Quartic Boson Coupling in Triboson

Shih-Chieh Hsu
University of Washington Seattle
On behalf of the Snowmass EWK VBS/Triboso Group
(C. Degrande, O. Eboli, J.Holzbauer, S.C. Hsu, A Kotawal, S. Li, O. Mattelaer, L.Marx, J. Metcalfe, M.-C. Pleier, M. Rominsky)

Snowmass Energy Frontier All hands-on Workshop
Seattle

VBS WZ -> tri-leptons at HL-LHC and HE-LHC using Snowmass Delphes fast simulation:

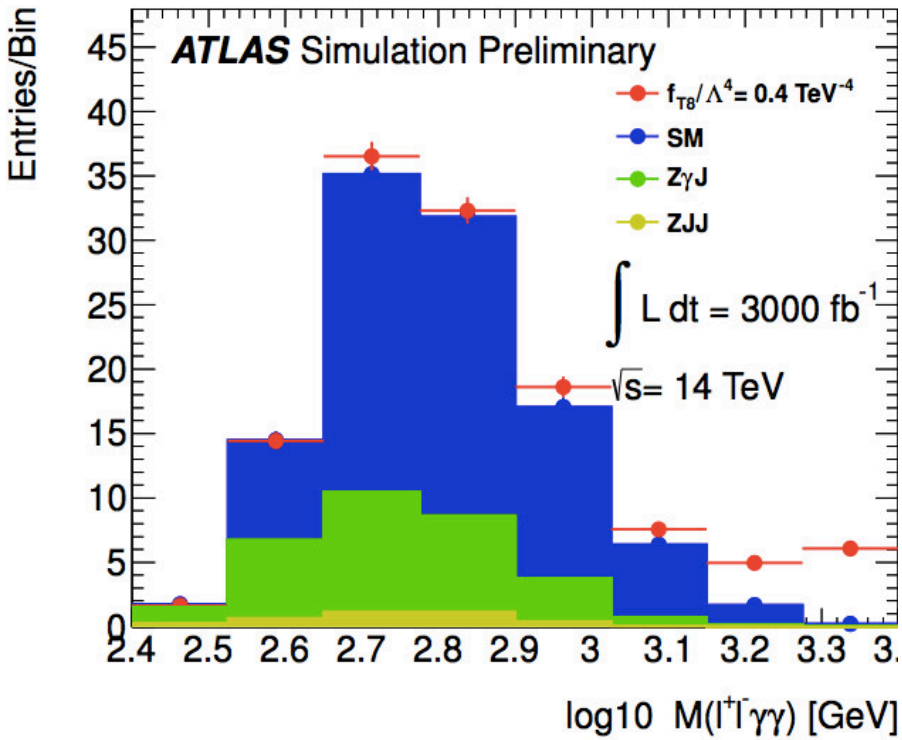




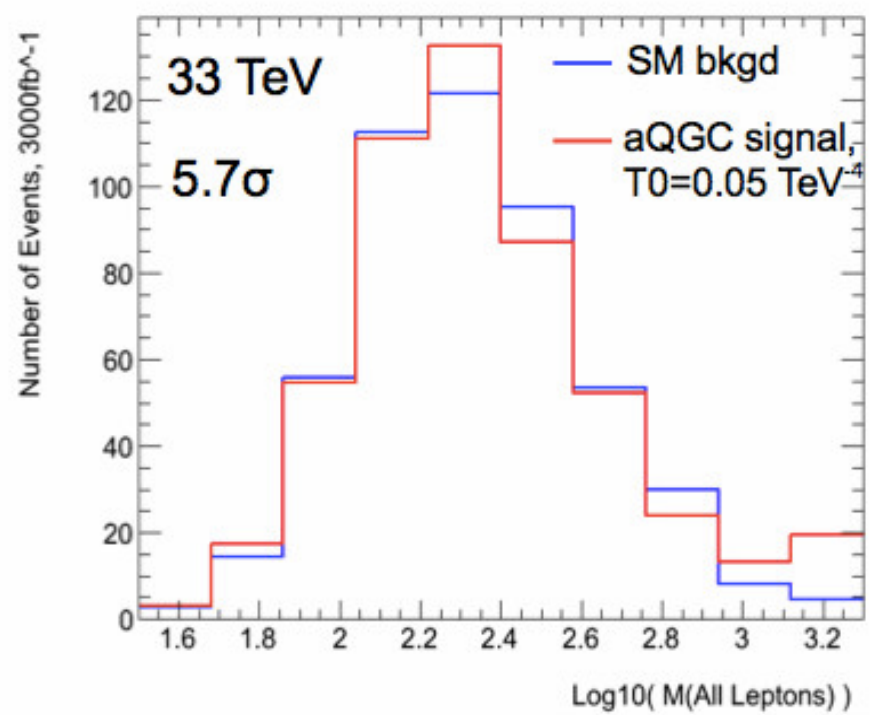
From Shu Li's talk on Sunday

Tri-boson production at HL-LHC and HE-LHC
using lepton-photon final states

Zγγ



WWW



Using Snowmass Delphes

From Shih-Chieh Hsu's talk on Sunday

- A systematic survey of aQGC in multi-boson final states benchmarked with Dim8 operators (ATLAS-PHYS-PUB-2013-006)

Parameter	dimension	channel	Λ_{UV} [TeV]	300 fb^{-1}		3000 fb^{-1}	
				5σ	95% CL	5σ	95% CL
$c_{\phi W}/\Lambda^2$	6	ZZ	1.9	34 TeV^{-2}	20 TeV^{-2}	16 TeV^{-2}	9.3 TeV^{-2}
f_{S0}/Λ^4	8	$W^{\pm}W^{\pm}$	2.0	10 TeV^{-4}	6.8 TeV^{-4}	4.5 TeV^{-4}	0.8 TeV^{-4}
f_{T1}/Λ^4	8	WZ	3.7	1.3 TeV^{-4}	0.7 TeV^{-4}	0.6 TeV^{-4}	0.3 TeV^{-4}
f_{T8}/Λ^4	8	$Z\gamma\gamma$	12	0.9 TeV^{-4}	0.5 TeV^{-4}	0.4 TeV^{-4}	0.2 TeV^{-4}
f_{T9}/Λ^4	8	$Z\gamma\gamma$	13	2.0 TeV^{-4}	0.9 TeV^{-4}	0.7 TeV^{-4}	0.3 TeV^{-4}

- HL or HE hadron colliders?

Parameter	channel	14TeV 0.3ab-1	14TeV 3ab-1	33TeV 3ab-1
CΦW/Λ2	ZZjj	34 TeV-2	16.0 TeV-2	12.5 TeV-4
fT0 /Λ4	WWW	1.2 TeV-4	0.5 TeV-4	0.05 TeV-4
fT1 /Λ4	WZjj	1.3 TeV-4	0.6 TeV-4	0.3 TeV-4

- Toward Snowmass white paper:

Summary by Shih-Chieh Hsu and Shu Li

Summary

- Many thanks to all contributors!
- Plenty of new work shown and discussed at this workshop.
- Please contact us with comments and suggestions – and send us your contributions to Snowmass Proceedings
- We plan to send the draft to the EW working group mailing list in 2-3 weeks.