WG2: Precision electroweak, Status and Plans

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Main topics:

1. SM theory predictions for EWPOs
2. Theory input to fundamental parameter determination
3. Implications for BSM physics from EWPOs
4. Theory and parametric uncertainties for Higgs physics

SM theory predictions for EWPOs

Error estimations:

	LEP/SLC	ILC	FCC-ee	current theory error	theory error with 3-loop†
M_{W} [MeV]	15	3–5	~ 1	4	1
Γ_Z [MeV]	2.3	~ 1	~ 0.1	0.5	$\lesssim 0.2$
R_b [10^{-5}]	66	15	$\lesssim 5$	15	5–10
$\sin^2\theta^{\ell}_{\mathsf{eff}}$ [10^{-5}]	16	1.3	0.6	4.5	1.5

† **Theory scenario:** $\mathcal{O}(\alpha\alpha_{\mathsf{s}}^2)$, $\mathcal{O}(N_f\alpha^2\alpha_{\mathsf{s}})$, $\mathcal{O}(N_f^2\alpha^2\alpha_{\mathsf{s}})$

(N_f^n = at least n closed fermion loops)

$\mathcal{O}(\alpha_{\mathsf{t}}\alpha_{\mathsf{s}}^3)$, $\mathcal{O}(\alpha_{\mathsf{t}}^2\alpha_{\mathsf{s}}^2)$, $\mathcal{O}(\alpha_{\mathsf{t}}^3\alpha_{\mathsf{s}})$, $\mathcal{O}(\alpha_{\mathsf{t}}^4)$ ($\alpha_{\mathsf{t}} = \alpha\frac{m_{\mathsf{t}}^2}{M_{\mathsf{W}}^2}$)

Work in progress/plans:

- Determine what is needed (3-loop + leading 4-loop/5-loop?)
- Agree on method(s) for theory error evaluation
- Connection to low-energy prec. measurements and high-energy RGE evol.?

SM input parameters

- m_{t}: from $e^+e^- \to t\bar{t}$, several sources of theory error
  $\to$ Projected theory error: $\delta_{\mathsf{th}} m_{\mathsf{t}} \sim 50$ MeV

- M_{W}: from $e^+e^- \to W^{(*)}W^{(*)}$, $\delta_{\mathsf{exp}} M_{\mathsf{W}} \sim 1$ MeV
  Current theory error: $\delta_{\mathsf{th}} M_{\mathsf{W}} \sim 3$ MeV
  $\to$ With 2-loop and resummed higher-order terms for $e^+e^- \to WW$
  and $W \to f f'$ expect $\delta_{\mathsf{th}} M_{\mathsf{W}} \sim 1$ MeV

- α_s: from $R_\ell = \Gamma[Z \to \text{had.}]/\Gamma[Z \to \ell^+\ell^-]$, $\delta_{\mathsf{exp}}\alpha_s \sim 0.0001$
  $\to$ Projected Theory error (with 3-loop corrections): $\delta_{\mathsf{th}}\alpha_s \sim 0.0002$

- $\Delta\alpha_{\mathsf{had}}$:
  a) from $e^+e^- \to$ had. using dispersion relation
  Improvement to $\delta_{\mathsf{exp}}(\Delta\alpha_{\mathsf{had}}) \sim 5 \times 10^{-5}$ likely
  b) at FCC-ee from $e^+e^- \to \mu^+\mu^-$ off Z peak: $\delta_{\mathsf{exp}}(\Delta\alpha_{\mathsf{had}}) \sim 3 \times 10^{-5}$
  $\to$ Projected Theory error (with 3-loop corr.): $\delta_{\mathsf{th}}(\Delta\alpha_{\mathsf{had}}) \sim$ few $\times 10^{-5}$

SM input parameters

Work in progress/plans:

- Consistent defintion of all quantities (e.g. $\overline{\text{MS}}$/OS scheme)
- Evaluation of theory error sources and possible ways to avoid them
- Determine what is needed and realistic for future loop calculations

Implications for BSM physics

- In specific physics models
  - Popular models: 2HDM, MSSM, new vector fermions, ...
  - Flavor-dependent models (new bottom/top partners, ...)
  - Physics unobservable at hadron colliders
    (superweak couplings, degenerate spectra, ...)
- Model-independent with EFT framework $\mathcal{L} = \mathcal{L}_{\mathrm{SM}} \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i$

Work in progress/plans:

- More benchmark studies for well-motivated new physics models
- Evaluation of new physics reach including all theory and parametric errors

Measurable properties of $h(125)$:

- **Spin, CP:** already underway at LHC
- **Mass:** direct LHC measurement more precision than SM/MSSM prediction
- **BRs, couplings:** currently $\mathcal{O}(20\%)$, improvement will greatly enhance sensitivity to higher new-physics scales

Englert et al. '14

Target precision of future e^+e^- colliders:

	ILC500	HL-ILC500	FCC-ee
hbb	1%	0.6%	0.4%
htt	2.5%	1.3%	0.7%
$h\tau\tau$	2%	1%	0.5%
hWW	0.4%	0.2%	0.1%
hZZ	0.5%	0.25%	0.05%
$h\gamma\gamma$	8%	4.5%	1.5%
hgg	2%	1%	0.8%

Snowmass Higgs WG '13

Higgs physics

	FCC-ee	current th. err.	param. error
hbb	0.4%	$< 0.4\%$	$\gtrsim 1\%$ (mainly m_b)
$h\tau\tau$	0.5%	$< 0.4\%$	negligible
hWW	0.1%	0.5%	0.2% (mainly M_{H})
hZZ	0.05%	0.5%	0.2% (mainly M_{H})
$h\gamma\gamma$	1.5%	$< 1\%$	negligible
hgg	0.8%	3%	$\lesssim 1\%$ (mainly α_{s})

Theory uncertainty in Higgs production: $\sim 1\%$

Plans:

- Projection for future δm_b (lattice community)
- Determine what is needed and realistic for future loop calculations
  - $\mathcal{O}(\alpha_{\mathsf{s}}^2)$ corrections to $h \to 4f$
  - full $\mathcal{O}(\alpha_{\mathsf{s}}^3)$, leading $\mathcal{O}(\alpha_{\mathsf{s}}^4)$ for $h \to gg$
  - $\mathcal{O}(\alpha^2)$ for $e^+e^- \to h + X$
  - ...

Conclusions

Past activites:

- 1st FCC-ee mini-workshop on Precision Observables and Radiative Corrections, 13–14 July 2015
- FCC-ee Mini-Workshop “Physics Behind Precision”, 2–3 February 2016
- Lots of email communication ...

Next steps:

- Write-up on theory error estimates
- Goal-oriented ”work”-shop
- More input on new-physics implications...

Many opportunities to be involved!