Snowmass 2013: Precision Study of Electroweak Interactions

Charge:

- Identify the most important precision observables that can reveal deviations from the standard model.
- Identify the thresholds of precision that needs to be achieved for each of these observables in order to be definitively sensitive to new physics.
- Study the precision that can be achieved at each proposed facility on these observables, and ask what machine and detector parameters are required to reach the discovery threshold.
- Identify the calculational tools needed to predict standard model rates and distributions in order to perform these measurements at the required precision.

Conveners: Ashutosh Kotwal, Michael Schmitt, DW
Webpage:
http://www.snowmass2013.org/tiki-index.php?page=Precision+Study+of+Electroweak+Interactions

EW Precision Observables - Status of theory discussion

- Check of the consistency of the SM by comparing direct with indirect measurements of model parameters, e.g., $m_{top}, M_W, \sin^2\theta_{eff}, M_H$.
  Ayres Freitas (SM), Sven Heinemeyer (MSSM), Alessandro Vicini (M_W)
  NC and CC DY: Simone Alioli, Emmanuele Re, Alessandro Vicini
- Search for indirect signals of Beyond-the-SM (BSM) physics in form of small deviations from SM predictions, yielding exclusions of, and constraints on, BSM scenarios using global fits of EW precision observables:
  Sven Heinemeyer (MSSM), Jens Erler and Paul Langacker (Z'), GFITTER (gloabl fit and S,T,U)
- Sensitive probe of proton structure (PDFs): Alessandro Vicini, Juan Rojo

Multi-boson production - Status of theory discussion

- EW gauge boson pair and triple production directly probes the non-abelian gauge structure of the SM.
- Search for non-standard gauge boson self couplings allowed by Lorentz and gauge invariance provide a unique indirect way to look for signals of new physics in a model-independent way.
- Improved constraints on anomalous triple-gauge boson couplings (TGCs) and quartic couplings (QGCs) probe scales of new physics in the multi-TeV range.
- Important backgrounds to Higgs and BSM searches.
- EFT approach (and relation to anomalous coupling paramaters) implemented in
  Madgraph: Olivier Mattelaer and Celine Degrande
  Oscar Eboli (combined fit to LHC EW and Higgs data)
  Michael Rauch, Barbara Jaeger (multiboson predictions)
  WHIZARD: Jürgen Reuter

Remarks

- There has been tremendous effort and a lot of progress in calculating higher order EW corrections and in understanding enhanced logarithmic corrections of weak origin.
  NLO EW: $pp, p\bar{p} \to W; Z \to l\nu; l^+l^-; VV; Wj; Zj \to \nu lj; l^+l^-j; t\bar{t}$; single top, and $b\bar{b}, jj$ (weak); and for dominant Higgs production processes, e.g., $gg \to H; W/ZH; VBF$.
  EW Sudakov logarithms $\alpha_w^l \log^n(Q^2/M^2), n \leq 2l$: results available for W, Z production, VV, $t\bar{t}$, bb, cc, jj, VBF.
  Photon-induced processes (QED PDFs), real W, Z radiation, multiple photon radiation, interplay of QCD/EW corrections, ...
- Their significance strongly depends on details of experimental definition of observable, specifically which kinematic regime is probed.
- Implementation of EW corrections in publicly available MCs in progress, enabling studies of higher-order mixed QED-QCD effects, has only been done for selected processes.
- Important and difficult task: reliable estimates of theoretical uncertainties due to missing higher-order corrections (work in progress for W/Z observables)

EW Sudakov logarithms $\alpha_w^l \log^n(Q^2/M^2)$, $n \leq 2l$

In the high-energy limit, $\frac{Q}{M_{W,Z}} \to \infty$, EW Sudakov logarithms have been studied in analogy to soft/collinear logarithms in QED,QCD.

- 1-loop: LL and NLL are universal and factorize Denner, Pozzorini (2001)
- Beyond 1-loop: Resummation techniques based on IR evolution equations (IREE) or SCET yield results up to NNLL ($ln^n(\frac{s}{M_W^2})$, $n = 2, 3, 4$).
  - IREE: EW theory splits into symmetric $SU(2) \times U(1)$ ($M_W = M_Z = M_\gamma = M$ for $\mu > M$) and QED regime and effect of EW symmetry breaking neglected. Fadin, Lipatov, Martin, Melles (2000)
  - SCET: At $\mu = Q$ match full theory to SCET($M = 0$), evolve to $\mu = M$ SCET($M \neq 0$), match to SCET with no gauge bosons.
  - SCET and IREE Sudakov form factors are equivalent. Chiu, Golf, Kelley, Manohar (2008); Chiu, Fuhrer, Hoang, Kelley, Manohar (2009); Chiu, Fuhrer, Kelley, Manohar (2010), Fuhrer et al (2011)

Resummation results at LL and NLL confirmed by explicit diagramatic one-loop and two-loop calculations.

Melles (2000), Hori et al (2000), Beenakker, Werthenbach (2000,2002), Pozzorini (2004); Feucht et al (2003,2004); Jantzen et al (2005,2006); Denner et al (2003,2008)

EW Sudakov logarithms $\alpha_w^l \log^n(Q^2/M^2), n \leq 2l$

- Results available for hadronic cross sections for W, Z production, VV, $t\bar{t}$, bb, cc, jj, VBF.
- Best studied so far: $f\bar{f} \to f\bar{f}$
  - up to N^3LL for massless fermions ($a = \frac{\alpha}{4\pi s_w^2}, L = \log(s/M_W^2)$):

$$\frac{\delta\sigma(e^+e^- \to q\bar{q})(s)}{\sigma_{LO}} = a(-2.18L^2 + 20.94L - 35.07) +$$
$$+ a^2(2.79L^4 - 51.98L^3 + 321.20L^2 - 757.35L)$$
$$\approx 2.4\% - 0.4\% \text{ at } 2\,\mathrm{TeV}$$

    Note: only LL at 2-loop: $+3\%$

    Jantzen, Kühn, Penin, Smirnov, hep-ph/0509157

  - up to NNLL for massive fermions Denner, Jantzen, Pozzorini (2008).
  - See also SCET results by Chiu et al, (2008).

Examples: LHC @ 14 TeV

$pp \to Z, \gamma \to \mu^+\mu^-$ at $M_{ll} > 2$ TeV: S.Dittmaier and M.Huber, arXiV:0911.2329 [hep-ph].

	$\delta\sigma/\sigma_B[\%]$		$\delta\sigma/\sigma_B[\%]$
$q\bar{q}$, weak	-11.12	QCD	-11.93
$q\bar{q}$, QED	-12.08	$\gamma\gamma + \gamma q(\bar{q})$	+7.28
$q\bar{q}$, multi-γ	+0.54	h.o. weak	-0.32
h.o. Sudakov	+3.38		

$pp \to W^+W^-$ at $M_{WW} > 2$ TeV: Bierweiler *et al*, arXiv:1208.3147 [hep-ph].

	$\delta\sigma/\sigma_B[\%]$		$\delta\sigma/\sigma_B[\%]$
$q\bar{q}$, EW	-31.3	QCD	+22.8
$\gamma\gamma$	+21.6	WWV	+4.9