

# DBD Physics Chapter: Status & Plans

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ILD Workshop, May 23-25 2012  
on behalf of the editors of the DBD Physics Chapter

# Outline of this presentation

## Overview

Purpose & Scope

Structure & Timeline

## Content of the Sections

## Summary

## Purpose of the DBD Physics Chapter

- ▶ present the up-to-date Physics Case of the ILC, especially in view of the LHC results
- ▶ provide material for the European Strategy process (and later others)
- ▶ independent of detector concepts
- ▶ but specific to ILC - make clear that we need to build *and* can build this machine NOW.

## Relation to the detector-specific DBD parts

- ▶ Physics Chapter will *not* describe any analysis in detail
- ▶ Physics Chapter is *not* restricted to full simulation results
- ▶ Physics Chapter will concentrate on  $\sqrt{s} \leq 500$  GeV
- ▶ results important to the physics case (full sim, fast sim, pheno) will be included
- ▶ old (JLC, NLC, TESLA, ?) results will be included where no updates are available
- ▶ new ILD analyses which are not described in detail in the ILD specific part should be written up as note / paper to be “citable”
- ▶ For core topics covered by new full sim analyses (e.g. the Higgs self-coupling, BRs) there *will* be overlap - however PhysChap will just quote result, *not* describe analysis

## Structure — overall editor: Michael Peskin

8 sections with 10-15 pages each:

- ▶ Introduction (Jae Yu, Michael Peskin)
- ▶  $W$  and  $Z$  Boson Physics (Tim Barklow, Jürgen Reuter)
- ▶ Two-Fermion Processes (Yuanning Gao, Maxim Perelstein)
- ▶ Top Quark (Roman Pöschl, Andrei Nomerotski, Andre Hoang)
- ▶ Standard Model Higgs (Keisuke Fujii, Heather Logan)
- ▶ Extended Higgs (Aurore Savoy-Navarro, Shinya Kanemura)
- ▶ Supersymmetry (JL, Howard Baer)
- ▶ Cosmological Connection (Geraldine Servant, Tim Tait)

**order will be changed to have SM Higgs directly after introduction!**

## Timeline

- by June 15: submit the section drafts → still useful as resource to the Le Diberder group writing the common ILC/CLIC physics input to the European Strategy
- until ICHEP: Iterate among editors and with “ILC friendly” referees
- after ICHEP: open draft to public, solicit signatures  
(JL: shouldn't this be coordinated with whole DBD?)
- by July 31: deadline for European Strategy Open Meeting
- until Oct 15: possibility to
  - ▶ adjust to new results (e.g. presented at SUSY 2012,...)
  - ▶ collect further signatures!

# 1. Introduction (Yu, Peskin)

- ▶ Physics at the ILC
- ▶ Advantages of  $e^+e^-$  Colliders
  - ▶ “Cleanliness”: low backgrounds, no trigger, point-like particles
  - ▶ “Democracy”: em coupling roughly the same for all fermions
  - ▶ “Calculability”: LO already precise to  $\mathcal{O}\%$ , with effort subpermille theory predictions
  - ▶ “Detail”: full event reconstruction, polarisation, spin reconstruction in decays
- ▶ Key Physics Explorations at the ILC: Overview of following sections

## 2. $W$ and $Z$ Boson Physics (Barklow, Reuter)

- ▶  $e^+e^- \rightarrow W^+W^-$ 
  - ▶ cross section systematics
  - ▶ measurement of triple gauge boson couplings
  - ▶ Standard Model reference - e.g. in situ polarization measurement
- ▶  $e^+e^- \rightarrow ZZ$
- ▶  $\gamma\gamma \rightarrow W^+W^-$ 
  - ▶ measurement of quadruple gauge boson couplings
- ▶  $WW, ZZ$  scattering at high energy
- ▶ Giga- $Z$ 
  - ▶ measurement of the  $Z$  polarization asymmetry and  $\sin^2\theta_w$
  - ▶ reconciliation of precision electroweak with new particle spectra
  - ▶ other high-luminosity  $Z$  studies



### 3. Two-Fermion Processes (Gao, Perelstein)

- ▶ Systematics of  $e^+e^- \rightarrow f\bar{f}$ : Observables available in  $e^+e^- \rightarrow f\bar{f}$ , polarization and flavor analysis
- ▶  $Z'$  physics
  - ▶ Varieties of  $Z'$  models, and motivations for  $Z'$
  - ▶ Measurement of  $Z'$  couplings
- ▶ Extra Dimensions
  - ▶ Flat Extra Dimensions
  - ▶ Large Extra Dimensions
  - ▶ Randall-Sundrum Warped Extra Dimensions
  - ▶ Relation of Extra Dimensions and Composite Higgs
- ▶ Contact Interactions
  - ▶ Quark and Lepton Compositeness
  - ▶ Other sources of contact interactions

## 4. Top Quark (Pöschl, Nomerotski, Hoang)

based on Top Physics workshop in Paris last week, material from S. Heinemeyer, M. Stahlhofen, F. Simon, J. A. Aguilar-Saavedra, M. Vos, K. Ikematsu

### ▶ Introduction

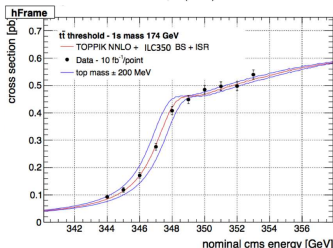
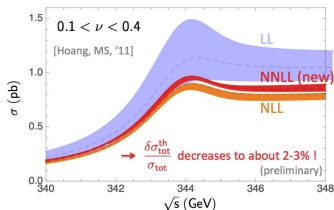
- ▶ guaranteed physics, fundamental SM parameters
- ▶ large mass, especial role in ew symmetry breaking → window to new physics?
- ▶ radiative corrections: non-decoupling effects  $\sim$  powers of  $m_t$   
⇒ need  $m_t$  very precisely to have sensitivity to new physics!

## 4. Top Quark (Pöschl, Nomerotski, Hoang)

- ▶ Top Quark Properties from Hadron Colliders
  - ▶ mass:
    - ▶ systematic limited (JES, MC modelling), getting significantly below 1 GeV is tough
    - ▶ theoretical uncertainties (scheme dependence etc)
  - ▶ width,  $W$  helicity
  - ▶ anomalous moments
  - ▶ Top Yukawa coupling
  - ▶ Top coupling to  $Z$ ,  $A_{\text{FB}}^t$ : tension with SM?

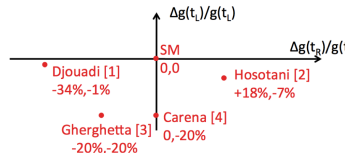
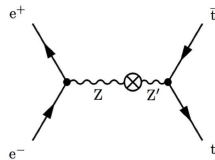
## 4. Top Quark cont'd

- ▶  $e^+e^- \rightarrow t\bar{t}$  at Threshold
  - ▶ Status of QCD Theory, significantly improved cross-section (NNLL, Hoang'11)
  - ▶ Precision measurement of mass (and width): 10 points  $\rightarrow 10 \text{ fb}^{-1} \Rightarrow \delta m_t(\text{stat}) \approx 30 \text{ MeV}$  (F. Simon)
  - ▶ Precision measurement of top quark form factors



## 4. Top Quark cont'd

- ▶  $e^+e^- \rightarrow t\bar{t}$  at 500 GeV and above
  - ▶ Observables of the process
  - ▶ top quark form factors
  - ▶ Measurement of the top Yukawa coupling
  - ▶  $A_{FB}, A_{LR} \rightarrow Z'$  up to 10 TeV
  - ▶ model discrimination, beam polarisation!
- ▶ Models with Top and Higgs Compositeness
  - ▶ Predictions for top quark couplings and form factors
  - ▶ Relevance of the ILC measurements
- ▶  $t\bar{t}H$  (JL: tune with Higgs section!)



Pe- / Pe+ (80% / 0)	ALR	AFBtR	AFBtL	QZtL	QZtR
stat. error	1.3%	1.2%	1.4%	1.0%	1.9%

## 5. Standard Model Higgs (Fujii, Logan; Peskin)

- ▶ The Standard Model Higgs mechanism
  - ▶ SM Higgs mechanism
  - ▶ contrast of the simple SM with other possible models (multiple Higgs, composite Higgs), possibility of multiple symmetry-breaking condensates
  - ▶ overview of the Higgs couplings in terms of the roles of the Higgs; central role of the HWW, HZZ couplings (and sum rule), discussion of the Higgs-fermion couplings
  - ▶ brief discussion of ways these couplings are modified in extended models, to provide motivation for their precision measurement.

## 5. Standard Model Higgs cont'd

- ▶ Status and prospects for Higgs measurements at LHC (JL: realistic number only available after Cracow meeting!)
  - ▶ review Higgs mass, quantum number, and coupling measurement prospects (including theoretical uncertainties)
  - ▶ current LHC running/future run plan (especially related to number of interactions per bunch crossing) and implications for, e.g., VBF
  - ▶ prospects for measurement of the  $Hbb$  coupling
  - ▶ prospects for measurement of the triple Higgs coupling

## 5. Standard Model Higgs cont'd

- ▶ Higgs measurements at ILC at 250 GeV
  - ▶ Mass and quantum numbers
  - ▶ inclusive Higgs cross section and the  $HZZ$  coupling
  - ▶ decay branching ratios in various modes, including invisible,  $H \rightarrow \gamma\gamma$ ,  $H \rightarrow \gamma Z$
  - ▶ coupling extraction, including model-independent techniques
  - ▶ comparison to theo. estimates in non-Standard Higgs models
- ▶ Higgs measurements at ILC at 500 GeV
  - ▶ top Yukawa
  - ▶ triple Higgs coupling
  - ▶ global analysis as of this point



## 5. Standard Model Higgs cont'd

- ▶ Higgs measurements at ILC at 1000 GeV (JL: include here 800 GeV?)
  - ▶ Higgs coupling to  $\mu^+\mu^-$
  - ▶ top Yukawa
  - ▶ triple Higgs coupling
- ▶ Conclusion: the complete phenomenological picture of the Higgs as generated at the ILC

## 6. Extended Higgs Sectors (Savoy-Navarro, Kanemura)

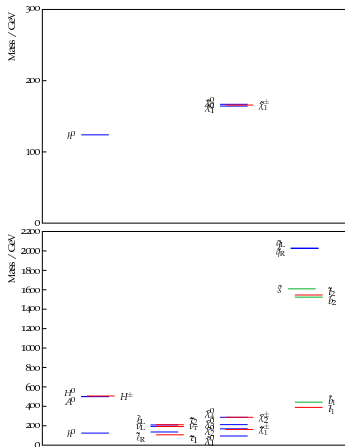
- ▶ Structure of 2-Higgs Doublet Models
- ▶  $e^+e^- \rightarrow H^+H^-, H^0A^0$
- ▶ Singlet Higgs Bosons
- ▶ Measurement of  $\tan\beta$

## 7. SUSY (JL, Baer)

- ▶ motivations for SUSY
- ▶ summary of Higgs and SUSY searches at the LHC
- ▶ discussion of options in SUSY parameter space, especially of
  - ▶ “life beyond the cMSSM”
  - ▶ naturalness and “natural SUSY”
  - ▶ the independence of Higgsino, gaugino, slepton, squark, sfermion 3rd generation subsectors.
  - ▶ the implications of indirect constraints.
  - ▶ the implications of a 125 GeV Higgs, contributions from extended Higgs sector
  - ▶ possibilities for Dark Matter (cf cosmo section)
- ▶ presentation of spectra of  $\sim 3$  different SUSY models not excluded at LHC

## Possibilities for example spectra

1. light Higgsinos optionally with one additional sparticle ( $\tilde{\tau}, \tilde{t}$ )  
→ “focus point”-like, e.g. Natural SUSY / Hidden SUSY / non-min GMSB
2. light sleptons / gauginos with small mass differences (sim SPS1a', but heavy 1.+2.gen squarks & gluinos)
3. NMSSM ? Kallosh-Linde (mixed AMSB - moduli mediation)? RPV? ...



## 7. SUSY cont'd

- ▶ ILC  $\leq 500$  GeV measurements: for each discuss precision on masses, polarised cross-sections, BRs from continuum and/or threshold
  - ▶ Electroweakinos: decay via gauge bosons, decay via sleptons, 3-body-decays, meta-stable
  - ▶ Sleptons
  - ▶ Stops and Sbottoms: decay via top, decay to charm
- ▶ Model discrimination / parameter determination, incl. specific measurements at 1000 GeV
  - ▶ Rich ILC scenarios: Sleptons, Electroweakinos, Stop
  - ▶ Only Electroweakinos
  - ▶ Electroweakinos + Stop or Stau
  - ▶ CPV
  - ▶ bRPV

## 7. SUSY cont'd

- ▶ Conclusion: SUSY is far from excluded, many interesting possibilities remain, they feature important measurements in the SUSY-electroweak sector that can be done at the ILC 500.

## 8. Cosmological Connections (Servant, Tait)

- ▶ Baryogenesis at the Electroweak Scale
  - ▶ Testing the nature of the EM phase transition: implications of 125 GeV Higgs
  - ▶ New sources of CP violation: status of constraints
  - ▶ what more could we learn with the ILC
- ▶ Dark Matter and the ILC
  - ▶ Status of dark matter: SUSY searches, effective theories, direct / indirect detection
  - ▶ Prospects for ILC determination of dark matter parameters (WIMPs)
  - ▶ Nonstandard WIMP dark matter: e.g. super-WIMPs, asymmetric dark matter, non-thermal production

## Summary

- ▶ DBD Physics Chapter is underway
- ▶ will present the ILC specific physics case
- ▶ first complete draft by June 15
- ▶ publicly available after ICHEP
- ▶ finalize and collect signatures until October 15 (JL: for whole DBD probably longer? Coordination?)
- ▶ have a look at:

<http://www.slac.stanford.edu/~mpeskin/PhysicsChapter.html>

....and keep fingers crossed for a  $5\sigma$  Higgs signal by the end of the year – or even an additional surprise!