List of Benchmark Processes

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Goals of Benchmarking Group

- High level goals:
  - In conjunction with the detector subgroups, to develop a good quantitative understanding of what performance each subsystem must deliver to achieve the physics goals of the ILC.
  - To initiate physics analyses for a series of critical benchmark measurements that document the overall physics performance of SiD, and that can be used in the global optimization of the detector design.
  - To incorporate in the physics analyses as realistic a description of the SiD detector and background processes as possible, and to upgrade analysis results to include full MC simulations as they become available.

- Current tasks:
  - Perform physics analyses of specific topics to provide "spot checks" of detector performance.
  - Evaluate results of individual physics studies for the purpose of developing general conclusions about detector specifications.
  - Perform some analyses with full MC and reconstruction; understand fast MC limitations and improve fast MC.
  - Evaluate effects of machine and beam-beam backgrounds on physics results.
  - Understand luminosity (L), energy (E) and polarization (P) measurement requirements and evaluate methods to measure L,E,P from physics processes.

Physics Benchmarks

- WWS (World Wide Study of Physics and Detectors for the ILC) formed a committee to develop a physics benchmark list.

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Report to the ILC World-wide Study

Physics Benchmarks for the ILC Detectors

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This note presents a list of physics processes for benchmarking the performance of proposed ILC detectors. This list gives broad coverage of the required physics capabilities of the ILC experiments and suggests target accuracies to be achieved. A reduced list of reactions, which capture within a very economical set the main challenges put by the ILC physics program, is suggested for the early stage of benchmarking of the detector concepts.

Physics Benchmarks

- Standard set of physics benchmark processes:
  - help justify the detector R&D goals by the required physics capabilities of the detector,
  - provide focus on specific problems, and promote the development of more realistic simulations,
  - provide guidance to optimize subdetector and integral detector performances to maximize physics capabilities,
  - will eventually allow to compare the relative integral performance of the different concept detectors.

- Basic requirements of a physics benchmark list:
  1) should include the most important reactions that give justification to the ILC,
  2) should be robust, i.e. address issues common to a variety of physics analyses,
  3) the effect of the performance of individual detector components on the physics results should be manifest.

- Relatively long list of physics benchmarks covering:
  a) Studies of the EWSB sector
  b) Studies of the SUSY sector
  c) Precision measurements of:
     - SM processes with indirect sensitivity to New Physics,
     - LEP via SM processes.

A Long List

TABLE II: Benchmark reactions for the evaluation of ILC detectors

	Process and Final states	Energy (TeV)	Observables	Target Accuracy	Detector Challenge	Notes
Higgs	$ee \to Z^0h^0 \to \ell^+\ell^-X$	0.35	M_{recoil}, σ_{Zh}, BR_{bb}	$\delta\sigma_{Zh} = 2.5\%$, $\delta BR_{bb} = 1\%$	T	{1}
	$ee \to Z^0h^0$, $h^0 \to b\bar{b}/c\bar{c}/\tau\tau$	0.35	Jet flavour , jet $(E, \vec{p})$	δM_h=40 MeV, $\delta(\sigma_{Zh} \times BR)$=1%/7%/5%	V	{2}
	$ee \to Z^0h^0, h^0 \to WW^*$	0.35	M_Z, M_W, σ_{qqWW^*}	$\delta(\sigma_{Zh} \times BR_{WW^*})$=5%	C	{3}
	$ee \to Z^0h^0/h^0\nu\bar{\nu}$, $h^0 \to \gamma\gamma$	1.0	$M_{\gamma\gamma}$	$\delta(\sigma_{Zh} \times BR_{\gamma\gamma})$=5%	C	{4}
	$ee \to Z^0h^0/h^0\nu\bar{\nu}$, $h^0 \to \mu^+\mu^-$	1.0	$M_{\mu\mu}$	5σ Evidence for $M_h = 120$ GeV	T	{5}
	$ee \to Z^0h^0, h^0 \to invisible$	0.35	σ_{qqE}	5σ Evidence for $BR_{invisible}$=2.5%	C	{6}
	$ee \to h^0\nu\bar{\nu}$	0.5	$\sigma_{bb\nu\nu}$, M_{bb}	$\delta(\sigma_{\nu\nu h} \times BR_{bb}) = 1\%$	C	{7}
	$ee \to t\bar{t}h^0$	1.0	σ_{tth}	δg_{tth}=5%	C	{8}
	$ee \to Z^0h^0h^0$, $h^0h^0\nu\bar{\nu}$	0.5/1.0	σ_{Zhh}, $\sigma_{\nu\nu hh}$, M_{hh}	δg_{hhh}=20/10%	C	{9}
SSB	$ee \to W^+W^-$	0.5		$\Delta\kappa_\gamma, \lambda_\gamma = 2 \cdot 10^{-4}$	V	{10}
	$ee \to W^+W^-\nu\bar{\nu}/Z^0Z^0\nu\bar{\nu}$	1.0	σ	$\Lambda_{*4}, \Lambda_{*5} = 3$ TeV	C	{11}
SUSY	$ee \to \tilde{e}^+_R\tilde{e}^-_R$ (Point 1)	0.5	E_e	$\delta M_{\tilde{\chi}^0_1}$=50 MeV	T	{12}
	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (Point 1)	0.5	E_π, $E_{2\pi}$, $E_{3\pi}$	$\delta(M_{\tilde{\tau}_1} - M_{\tilde{\chi}^0_1})$=200 MeV	T	{13}
	$ee \to \tilde{t}_1\tilde{t}_1$ (Point 1)	1.0		$\delta M_{\tilde{t}_1}$=2 GeV		{14}
-CDM	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (Point 3)	0.5		$\delta M_{\tilde{\tau}_1}$=1 GeV, $\delta M_{\tilde{\chi}^0_1}$=500 MeV,	F	{15}
	$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (Point 2)	0.5	M_{jj} in $jj\not{E}$, $M_{\ell\ell}$ in $jj\ell\ell\not{E}$	$\delta\sigma_{\tilde{\chi}_2\tilde{\chi}_3} = 4\%$, $\delta(M_{\tilde{\chi}^0_2} - M_{\tilde{\chi}^0_1})$= 500 MeV	C	{16}
	$ee \to \tilde{\chi}^+_1\tilde{\chi}^-_1/\tilde{\chi}^0_i\tilde{\chi}^0_j$ (Point 5)	0.5/1.0	$ZZ\not{E}$, $WW\not{E}$	$\delta\sigma_{\tilde{\chi}\tilde{\chi}}$=10%, $\delta(M_{\tilde{\chi}^0_3} - M_{\tilde{\chi}^0_1})$ =2 GeV	C	{17}
	$ee \to H^0A^0 \to b\bar{b}b\bar{b}$ (Point 4)	1.0	Mass constrained M_{bb}	δM_A=1 GeV	C	{18}
-alternative SUSY breaking	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$ (Point 6)	0.5	Heavy stable particle	$\delta M_{\tilde{\tau}_1}$	T	{19}
	$\tilde{\chi}^0_1 \to \gamma + \not{E}$ (Point 7)	0.5	Non-pointing γ	$\delta c\tau$=10%	C	{20}
	$\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$ (Point 8)	0.5	Soft $\pi^\pm$ above $\gamma\gamma$ bkgd	5σ Evidence for $\Delta\tilde{m}$=0.2-2 GeV	F	{21}
Precision SM	$ee \to t\bar{t} \to 6$ *jets*	1.0		5σ Sensitivity for $(g-2)_t/2 \leq 10^{-3}$	V	{22}
	$ee \to f\bar{f}$ $(f = e, \mu, \tau; b, c)$	1.0	$\sigma_{f\bar{f}}$, A_{FB}, A_{LR}	5σ Sensitivity to $M_{Z_{LR}} = 7$ TeV	V	{23}
New Physics	$ee \to \gamma G$ (ADD)	1.0	$\sigma(\gamma + \not{E})$	5σ Sensitivity	C	{24}
	$ee \to KK \to f\bar{f}$ (RS)	1.0			T	{25}
Energy/Lumi Meas.	$ee \to ee_{fwd}$	0.3/1.0		δM_{top}=50 MeV	T	{26}
	$ee \to Z^0\gamma$	0.5/1.0			T	{27}

Targeted Subdetector(s)

TABLE III: Table of relations between the benchmark physics processes and parameters of detector subsystems

Process	Vertex	Tracking		Calorimetry		Fwd		Very Fwd	Integration					Pol.
	σ_{IP}	$\delta p/p^2$	ϵ	δE	$\delta\theta$, $\delta\phi$	Trk	Cal	θ^e_{min}	δE_{jet}	M_{jj}	ℓ-Id	V^0-Id	$Q_{jet/vtx}$	
$ee \to Zh \to \ell\ell X$		x									x			
$ee \to Zh \to jjbb$	x	x	x			x				x	x			
$ee \to Zh, h \to bb/cc/\tau\tau$	x		x							x	x			
$ee \to Zh, h \to WW$	x		x		x				x	x	x			
$ee \to Zh,\ h \to \mu\mu$	x	x									x			
$ee \to Zh,\ h \to \gamma\gamma$				x	x		x							
$ee \to Zh, h \to invisible$			x			x	x							
$ee \to \nu\nu h$	x	x	x	x			x			x	x			
$ee \to tth$	x	x	x	x	x		x	x	x		x			
$ee \to Zhh,\ \nu\nu hh$	x	x	x	x	x	x	x		x	x	x	x	x	x
$ee \to WW$										x			x	
$ee \to \nu\nu WW/ZZ$						x	x		x	x	x			
$ee \to \tilde{e}_R\tilde{e}_R$ (Point 1)		x						x			x			x
$ee \to \tilde{\tau}_1\tilde{\tau}_1$	x	x						x						
$ee \to \tilde{t}_1\tilde{t}_1$	x	x							x	x		x		
$ee \to \tilde{\tau}_1\tilde{\tau}_1$ (Point 3)	x	x			x	x	x	x	x					
$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$ (Point 5)									x	x				
$ee \to HA \to bbbb$	x	x								x	x			
$ee \to \tilde{\tau}_1\tilde{\tau}_1$			x											
$\tilde{\chi}^0_1 \to \gamma + \not{E}$					x									
$\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$			x					x						
$ee \to tt \to 6\ jets$	x		x						x	x	x			
$ee \to ff\ [e,\mu,\tau;b,c]$	x		x				x		x		x		x	x
$ee \to \gamma G$ (ADD)				x	x			x						x
$ee \to KK \to f\bar{f}$		x									x			
$ee \to ee_{fwd}$						x	x	x						
$ee \to Z\gamma$		x		x	x	x	x							

Suggested Reduced Benchmark List

- A reduced benchmark list was included in the hep-ex/0603010 report.

0. Single $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, π^0, $K^{\pm}$, K^0_S, γ, $0 < |\cos\theta| < 1$, $0 < p < 500$ GeV
1. $e^+e^- \to f\bar{f}$, $f = e, \tau, u, s, c, b$ at $\sqrt{s}$=0.091, 0.35, 0.5 and 1.0 TeV;
2. $e^+e^- \to Z^0h^0 \to \ell^+\ell^-X$, $M_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;
3. $e^+e^- \to Z^0h^0$, $h^0 \to c\bar{c}, \tau^+\tau^-, WW^*$, $M_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;
4. $e^+e^- \to Z^0h^0h^0$, $M_h = 120$ GeV at $\sqrt{s}$=0.5 TeV;
5. $e^+e^- \to \tilde{e}^+_R\tilde{e}^-_R$ at Point 1 at $\sqrt{s}$=0.5 TeV;
6. $e^+e^- \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, at Point 3 at $\sqrt{s}$=0.5 TeV;
7. $e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1/\tilde{\chi}^0_2\tilde{\chi}^0_2$ at Point 5 at $\sqrt{s}$=0.5 TeV;

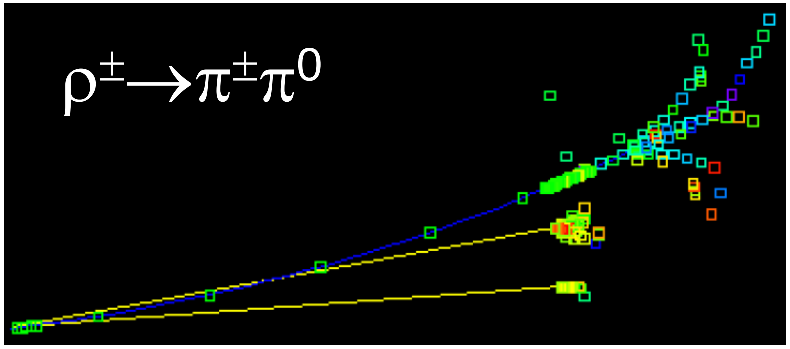
- Largely inspired by it, we have created our own preliminary highest priority list, (temporarily) dropping measurements which have been so far rather extensively studied, and including a few additional ones. After this meeting we would like to start attaching names to each of them.

- Most of these studies can initially be performed using fast MC. Ideally, they should target the reconstructed particle class, so that they can automatically be rerun on full MC as soon as it is appropriate/possible.

Suggested Reduced Benchmark List

EWSB sector:

1) Studies involving $e^+e^- \rightarrow Zh$ at $\sqrt{s}$ = 350 GeV
   - Measurement of $B(h\rightarrow cc)$: targets vertexing and flavor ID capabilities. Who: orphaned
   - Measurement of $B(h\rightarrow WW)$: targets calorimeter performance, especially jet energy resolution. Who: orphaned
   - Exploit τ polarization in $h\rightarrow\tau^+\tau^-$ for determination of CP properties of Higgs boson: targets EM calorimeter granularity. Who: orphaned



2) Studies involving $e^+e^- \rightarrow Zh, \nu\nu h$ at $\sqrt{s}$ = 1 TeV
   - Measurement of $B(h \rightarrow\mu^+\mu^-)$: targets μID and tracker momentum resolution in forward region. Who: orphaned
   - Measurement of $B(h \rightarrow\gamma\gamma)$: targets intrinsic EM calorimeter energy resolution and material in tracker. Who: orphaned
   - Measurement of $B(h\rightarrow cc)$: targets tracking, vertexing and flavor ID capabilities for forward jets, including the impact of material budget in the forward region. Who: orphaned
3) Measurement of Higgs self-coupling via $e^+e^- \rightarrow Zhh \rightarrow 6j$ at $\sqrt{s}$ = 500 GeV: targets jet energy resolution to identify/separate Z and h bosons. Who: T. Barklow (SLAC)
4) Study of Strong Symmetry Breaking via $e^+e^- \rightarrow \nu\nu WW, \nu\nu ZZ$ at $\sqrt{s}$ = 1 TeV: targets jet energy resolution to identify/separate W and Z bosons (no kinematic fit possible). Who: orphaned

Suggested Reduced Benchmark List

SUSY sector:

5) Measurement of $\tilde{e}$ mass via end-point of electron energy spectrum in $e^+e^- \to \tilde{e}_R^+\tilde{e}_R^-$ (Point 1) at $\sqrt{s}$ = 500 GeV: targets tracker momentum resolution and material effects. Who: previous study by H. Yang and K. Riles (U. Michigan) and B. Schumm (UCSC).

6) Measurement of $\tilde{\tau}$ mass via end-point of tau energy spectrum in $e^+e^- \to \tilde{\tau}_1^+\tilde{\tau}_1^-$ (Point 3) at $\sqrt{s}$ = 500 GeV: targets very forward detector, in particular the capability to reject $\gamma\gamma$ backgrounds. Who: previous study P. Bambade et al, hep-ph/0406010.

7) Measurement of $\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ mass via end-point of W,Z energy spectrum in $e^+e^-\to\tilde{\chi}_1^+\tilde{\chi}_1^-\to\tilde{\chi}_1^0\tilde{\chi}_1^0WW$ and $e^+e^-\to\tilde{\chi}_2^0\tilde{\chi}_2^0\to\tilde{\chi}_1^0\tilde{\chi}_1^0ZZ$ (Point 5) at $\sqrt{s}$ = 500 GeV: targets jet energy resolution to identify/separate W and Z bosons (no kinematic fit possible). Who: T. Barklow (SLAC) and A. Miyamoto (KEK).

Suggested Reduced Benchmark List

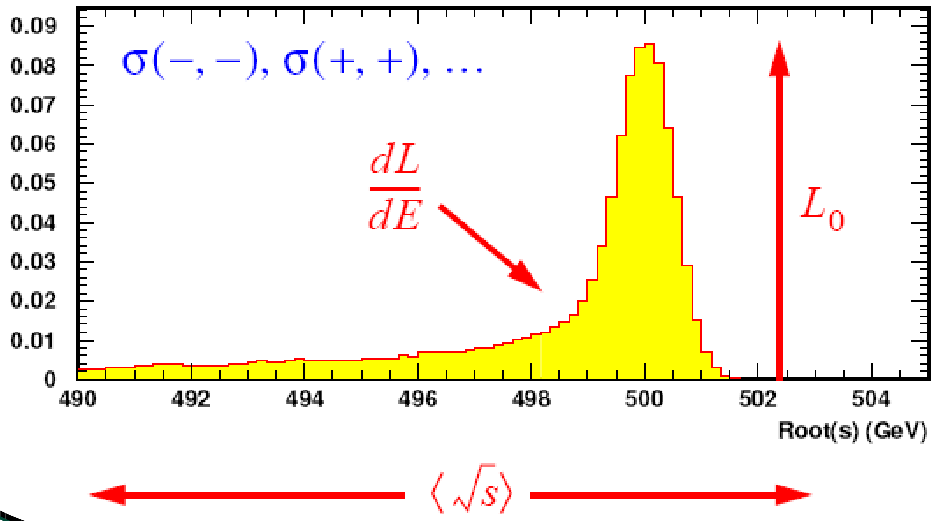
Precision measurements:

8) Measurement of the couplings of a multi-TeV Z' boson in $e^+e^- \rightarrow \tau^+\tau^-$ at $\sqrt{s}$ = 1 TeV exploiting tau polarization: targets EM calorimeter granularity. Who: orphaned

9) Measurement of forward-backward and left-right asymmetries in $e^+e^- \rightarrow$bb,cc at $\sqrt{s}$ = 91, 350, 500 GeV and 1 TeV: targets tracking and vertexing via vertex charge performance. Who: orphaned

10) Determination of LEP using physics measurements:

- Luminosity spectrum via acollinearity in Bhabha: targets forward tracker. Who: orphaned
- Center-of-mass energy via $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$: targets forward tracker. Who: R. Frey (U. Oregon)
- Polarization via $e^+e^- \rightarrow W^+W^-$: targets forward tracker. Who: orphaned



Suggested Reduced Benchmark List

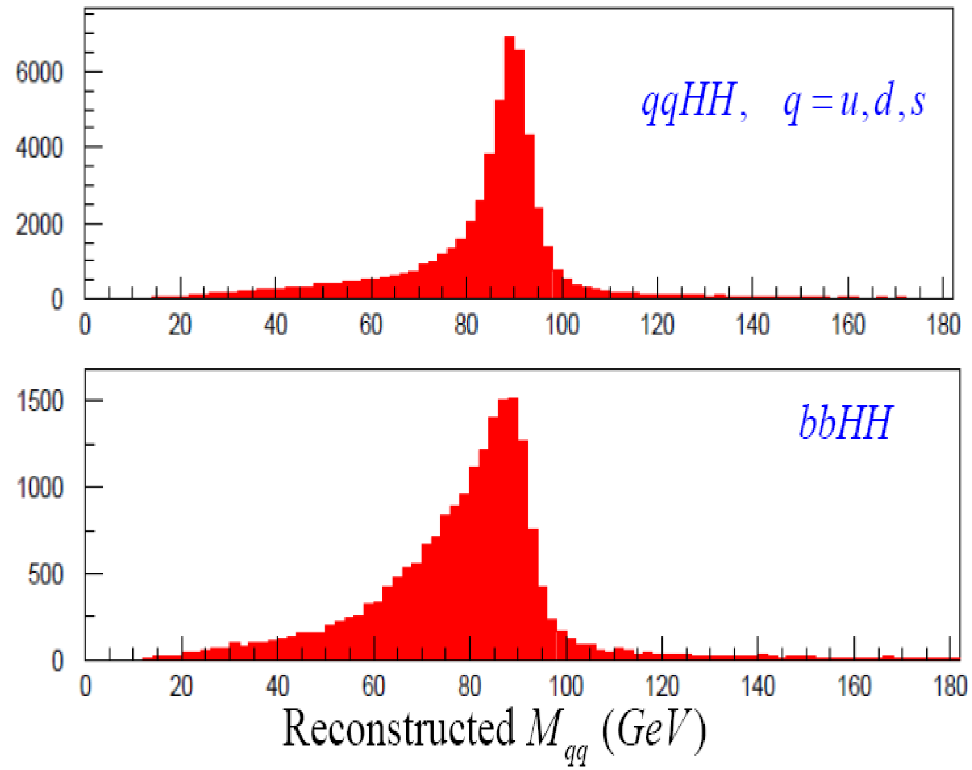
<u>Additional studies</u>:

11) Determine required particle ID performance (efficiency/purity, resolution vs. E, θ,..) for different species: e, μ, τ, $\pi^{\pm}$, π^0, K_S^0, γ.
$\Rightarrow$ in addition to having dedicated single particle studies, we would like, whenever possible, to have required ID performance assessed within each individual analysis.

12) Study how to improve b jet energy resolution, in particular for semileptonic decays.
Who: orphaned

$$e^+e^- \to qqHH, \quad \frac{\delta E_{jet}}{\sqrt{E_{jet}}} = 0.3$$

non-Gaussian Parameterization



T. Barklow

Conclusions

- We have produced a list of high priority benchmarking studies for SiD.
- We anticipate every analysis will involve multiple iterations over time, as we keep providing feedback to the detector design (resulting in configuration changes which will have to be re-evaluated) and as we keep improving the degree of realism of the simulation (e.g. moving from fast to full MC).
- This is the minimum we would like to do. If we can do more, even better!

- Essentially all of us are part-time on this.

  An experienced and/or motivated person can have a big impact!

- Please volunteer to work, preferably on one of the suggested topics, but also on any of the topics in the long list!!