Benchmarking SiD: Towards a CDR

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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.

  ⇒ Must strengthen ties with subdetector groups. It would be highly desirable to have more part-time involvement in benchmarking studies from people working in subdetector groups.

- 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.

  ⇒ Due to manpower limitations, only a small fraction of the critical benchmark measurements has been explored so far. Subdetector or global performance optimization not started yet.

- 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.

  ⇒ Must strengthen ties with simulation/reconstruction group.

- New goal: work towards a CDR in ~1.5 years from now.

Main Activities To Date

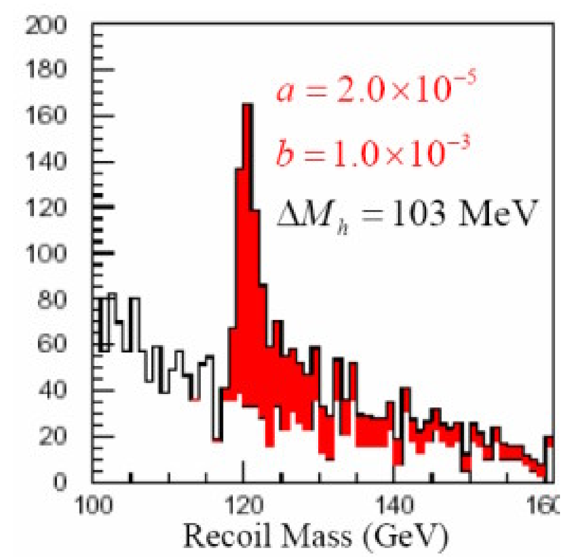
- Perform physics analyses of specific topics to provide "spot checks" of detector performance.

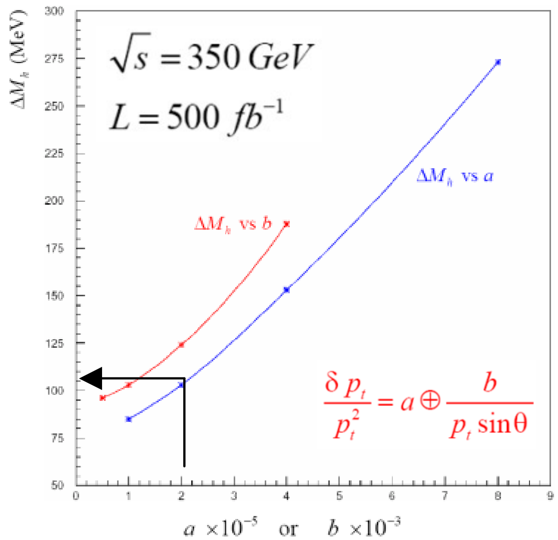
  ⇒ mostly parametric studies focusing on tracker and calorimeter (based on Fast MC)

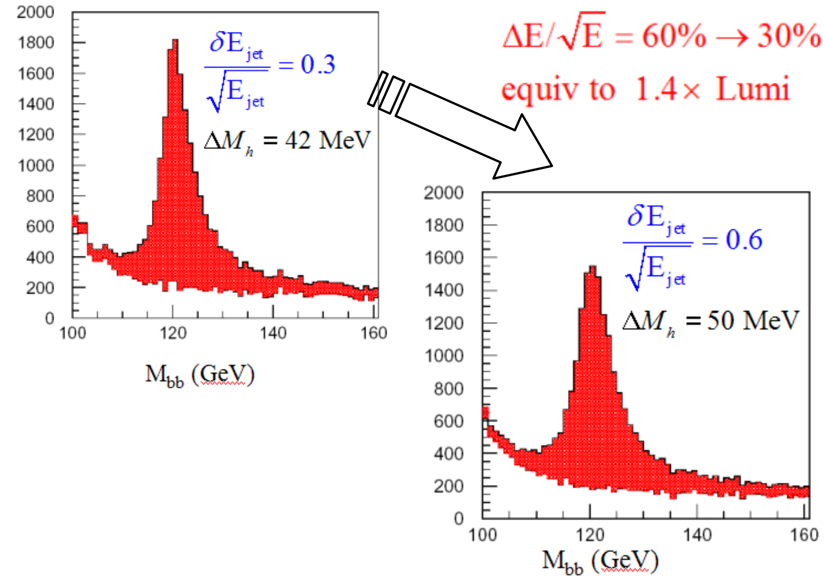
T. Barklow

$$e^+e^- \to ZH \to \mu^+\mu^- X$$

$$e^+e^- \to ZH \to qqb\bar{b}$$







- Evaluate results of individual physics studies for the purpose of developing general conclusions about detector specifications.

- Understand luminosity (L), energy (E) and polarization (P) measurement requirements and evaluate methods to measure L,E,P from physics processes.

Current Benchmarking Tools

- MC Data sets:
  - On SLAC mass storage: stdhep files corresponding to 1 ab^{-1} worth of all SM processes at $\sqrt{s}$=500 GeV for nominal ILC machine parameters and all initial beam polarization states.
  - Will likely also produce a list of samples (signal and main backgrounds) corresponding to higher priority benchmark processes and make it available via ftp.

- Fast MC = Fast Physics Object MC

  Takes as input stdhep files and outputs the same kind of reconstructed particle LCIO objects that full event reconstruction software produces.

  Emulates bottom-line performance of the event reconstruction software in producing the physics objects ($e,\mu,h^{\pm},h^0,\gamma$).
  - Tracker simulation uses parameterized covariance matrices based on tracker geometry and material.
  - Electron, muon, photon and neutral hadron ID given by min energy + overall efficiency.
  - Photon and neutral hadron energies and angles smeared using single particle resolutions.
  - Desired jet energy resolution from PFA simulated by adjusting single particle resolutions.

  $\Rightarrow$ In the near future it will be important to understand limitations of fast MC and improve it.

- A number of analysis tools should be developed in future benchmark studies (e.g. multivariate flavor/charge tagging, constrained kinematic fitting, etc) and made available.

Physics Benchmarks

- WWS formed a committee to develop a physics benchmark list (hep-ex/0603010).

- 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

     $\Rightarrow$ in general well defined target precision

  b) Studies of the SUSY sector

     $\Rightarrow$ in general not so well defined target precision, except for scenarios where measurements at the ILC are supposed to provide critical information to the LHC or match in precision measurements from cosmology.

  c) Precision measurements of:
     - SM processes with indirect sensitivity to New Physics,
     - Luminosity/Energy/Polarization via SM processes.

The 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 $BR_{\mathrm{invisible}}$=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 $(g-2)_t/2 \le 10^{-3}$	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			
$ee \to Zh, h \to b\bar{b}/cc/\tau\tau$	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;

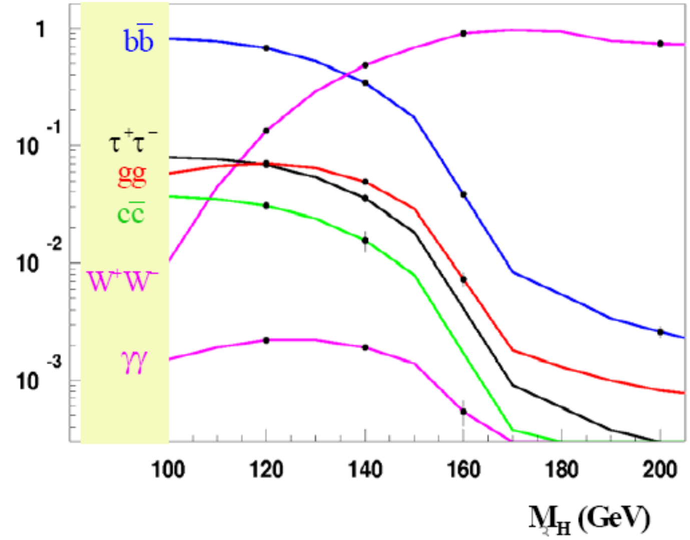
- Largely inspired by it, we have created our own preliminary highest priority list, temporarily dropping measurements which have been so far rather extensively studied (e.g. recoil M_H measurement), and including a few additional ones.

  Goal is to start attaching names to each of them.

- This list is/will be evolving as new priorities replace old ones, and we learn about new challenges that the current list is not addressing.

  JoAnne's talk was very stimulating. Looking into adding benchmarks related e.g. to γ/h+MET or long-lived particles (non-pointing objects) $\Rightarrow$ fine calorimeter granularity, tracking/pattern recognition at large impact parameter, etc.

Suggested Reduced Benchmark List

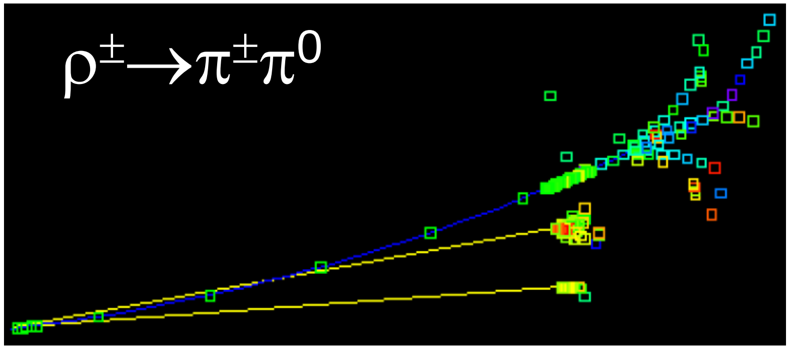


EWSB sector:

One of the highlights of the ILC physics program is the precise and model-independent measurement of Higgs properties, in particular couplings.

1) Studies involving $e^+e^- \rightarrow Zh$ at $\sqrt{s}$ = 350 GeV

- Measurement of B(h→bb,cc): targets vertexing and flavor ID capabilities. Who: orphaned
- Measurement of B(h→WW) with W/Z→jj: targets jet energy resolution to identify/separate Z and W bosons. Who: orphaned
- $h\rightarrow\tau^+\tau^-$:
  - Measurement of $B(h\rightarrow\tau^+\tau^-)$: targets vertexing. Who: orphaned
  - Exploit τ polarization in $h\rightarrow\tau^+\tau^-$ for determination of CP properties of Higgs boson: targets EM calorimeter granularity. Who: orphaned



Suggested Reduced Benchmark List

EWSB sector (cont'd):

dominant

2) Studies involving $e^+e^- \to Zh, \nu\nu h$ at $\sqrt{s}$ = 1 TeV

- Measurement of $B(h \to \mu^+\mu^-)$:
  targets μID and tracker momentum resolution in forward region. Who: orphaned

- Measurement of $B(h \to \gamma\gamma)$:
  targets intrinsic EM calorimeter energy resolution and material in tracker.
  Instrumental background from multijets with jet(s) faking a photon potentially large
  $\Rightarrow$ may provide another motivation for fine EM calorimeter granularity to reject $\pi^0 \to \gamma\gamma$.
  Who: J. Yoh (Fermilab)

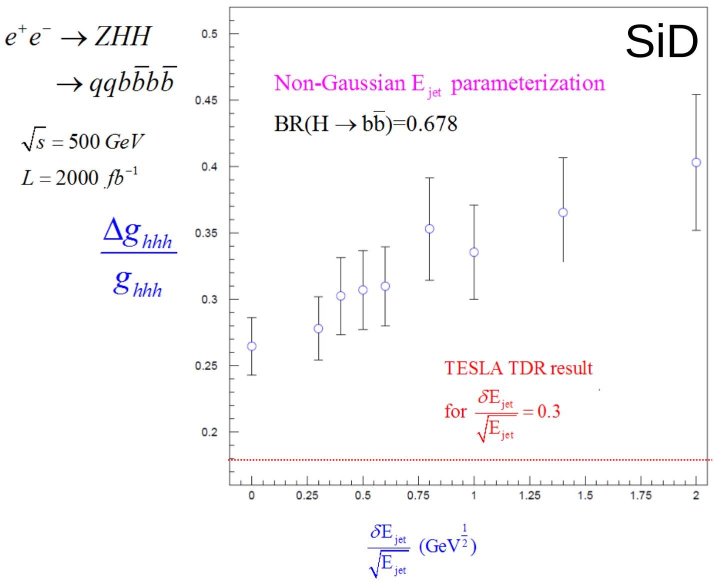
- Measurement of $B(h \to bb, cc)$:
  targets tracking, vertexing and flavor ID capabilities for forward jets, including the impact of material budget in the forward region. Who: orphaned

Suggested Reduced Benchmark List

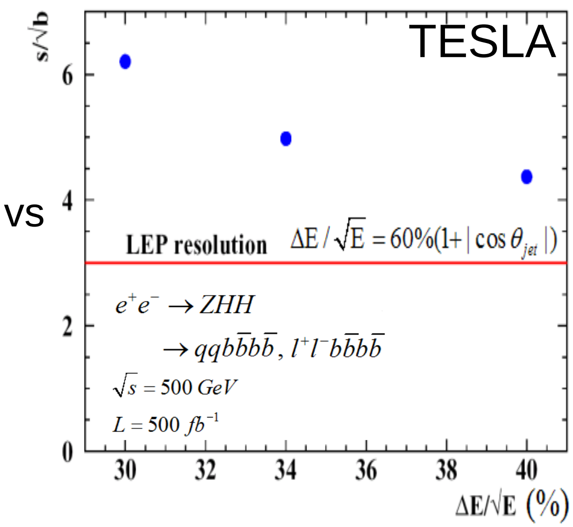
EWSB sector (cont'd):

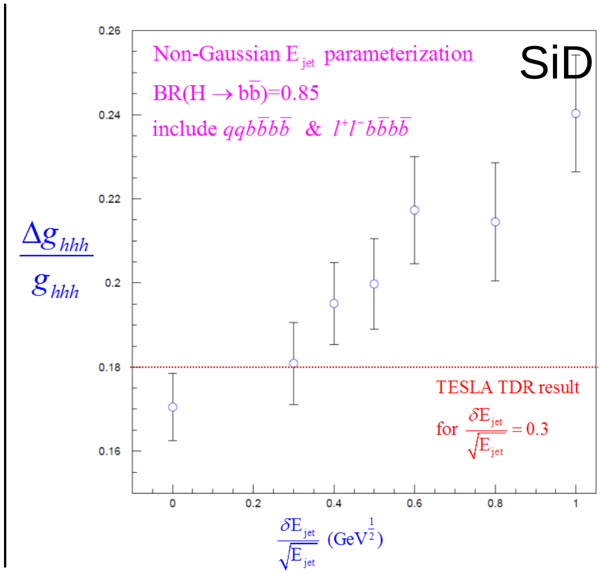
3) Measurement of Higgs self-coupling via $e^+e^- \to Zhh \to 6j$ at $\sqrt{s}$ = 500 GeV:
targets jet energy resolution to identify/separate Z and h bosons. Who: T. Barklow (SLAC)

Discrepancy in luminosity gain between TESLA TDR (x4) and SiD (x1.4) study has been essentially resolved (talk by T. Barklow at yesterday's Benchmarking meeting):



vs





- Data point at "60%/√E" actually corresponded to 100%/√E; S/√B poor measure of $(\Delta g_{HHH})_{stat}$
- Assuming same B(h→bb) and including ZHH →llbbbb channel, SiD analysis can replicate TESLA result.

Conclusion: like previous physics analyses, this one also indicates that ΔE/E=60%/√E → 30%/√E is equivalent to x1.4 luminosity gain.

Suggested Reduced Benchmark List

<u>Caveat of previous analyses</u>: too many b-jets in the final state.

$\Rightarrow$ More physics studies involving direct W and Z production (light-jets dominated) are required before conclusions can be drawn regarding required calorimeter performace.

<u>EWSB sector (cont'd)</u>:

4) Study of Strong Symmetry Breaking via $e^+e^- \to \nu\nu WW, \nu\nu ZZ$ at $\sqrt{s}$ = 1 TeV:

targets jet energy resolution to identify/separate W and Z bosons (no kinematic fit possible).

Who: orphaned

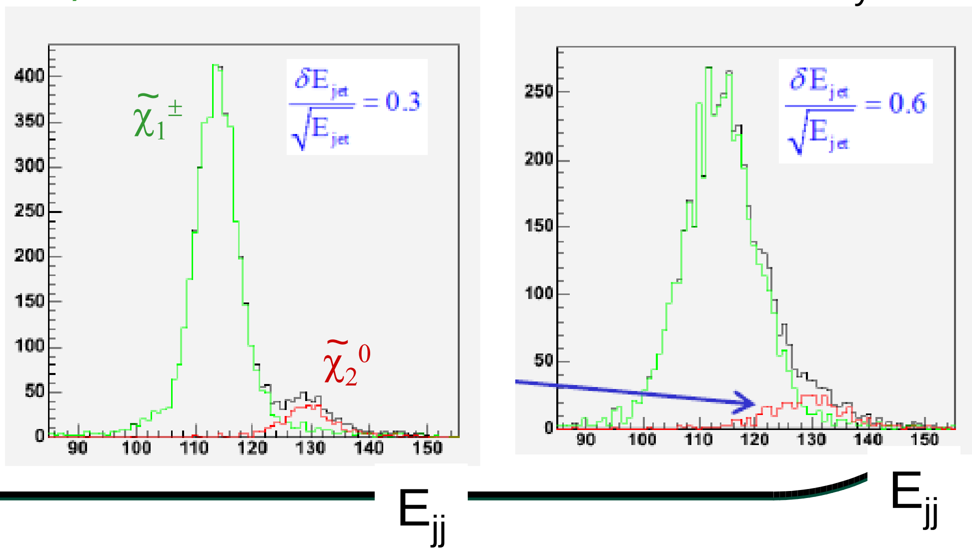
<u>SUSY sector</u>:

5) Measurement of $\tilde\chi_1^\pm,\tilde\chi_2^0$ mass via end-point of W,Z energy spectrum in $e^+e^- \to \tilde\chi_1^+\tilde\chi_1^- \to \tilde\chi_1^0\tilde\chi_1^0 WW$ and $e^+e^- \to \tilde\chi_2^0\tilde\chi_2^0 \to \tilde\chi_1^0\tilde\chi_1^0 ZZ$ (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).

A. Miyamoto

New goal is not only to measure chargino mass, but also neutralino properties under a large chargino background.



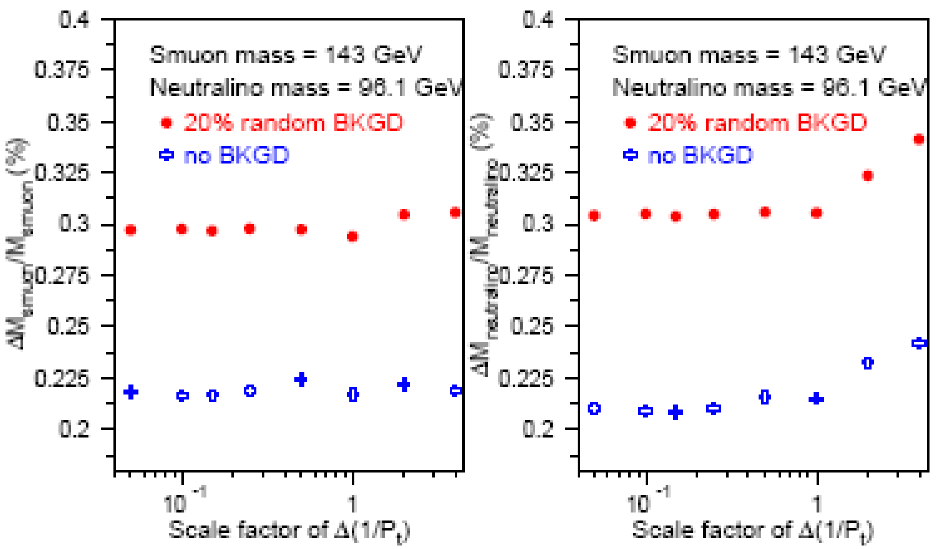
Suggested Reduced Benchmark List

<u>SUSY sector (cont'd)</u>:

6) Measurement of $\tilde{e}$ mass via end-point of electron energy spectrum in $e^+e^- \rightarrow \tilde{e}_R^+\tilde{e}_R^-$ (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).

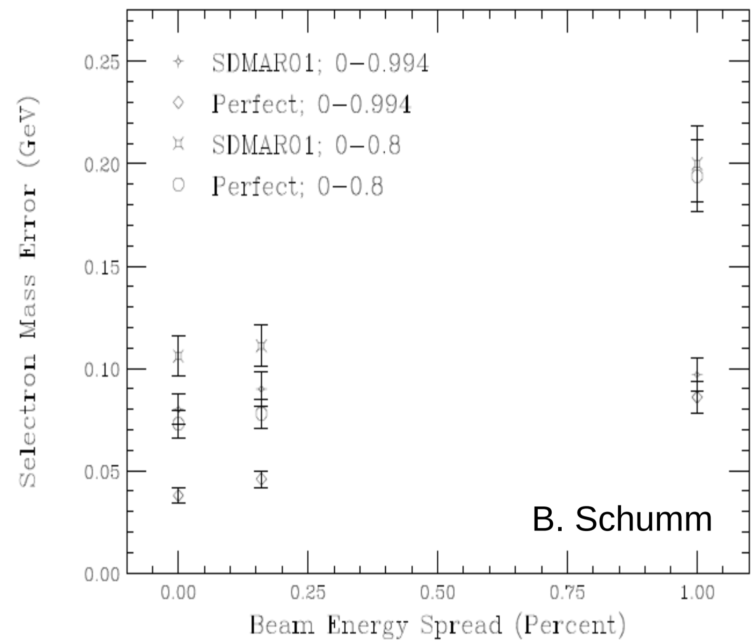
$$M^2_{\tilde{\mu}^\pm_R} = E^2_{cm} \bullet \frac{E_{min} \times E_{max}}{(E_{min} + E_{max})^2} \qquad M^2_{\tilde{\chi}^0_1} = M^2_{\tilde{\mu}^\pm_R} \bullet \{1 - 2\frac{E_{min} + E_{max}}{E_{cm}}\}$$

ILC500-SDMAR01, 50 fb^{-1}, pt > 15 GeV, abs(cosΘ) < 0.9



H. Yang and K. Riles

$\sqrt{s}$=1 TeV, 115 fb^{-1}
$M_{selectron}$=143.1 GeV
$M_{neutraline}$=95 GeV (assumed known)



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

Suggested Reduced Benchmark List

<u>Precision measurements</u>:

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

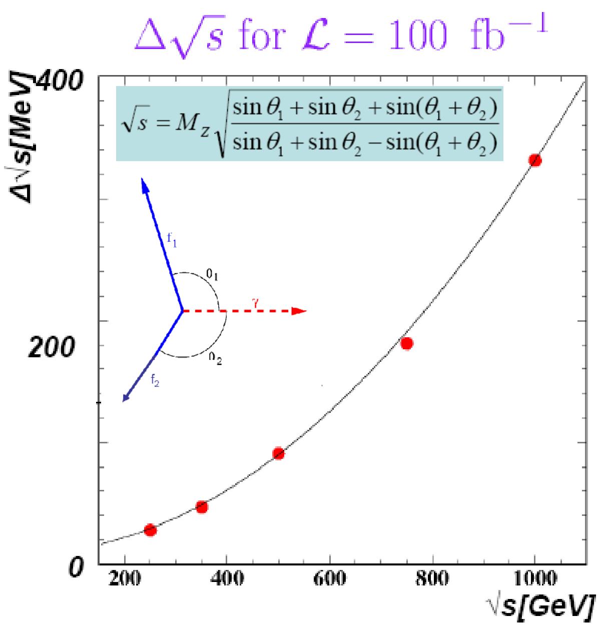
9) Measurement of forward-backward and left-right asymmetries in $e^+e^- \rightarrow$ bb,cc at $\sqrt{s}$ = 91, 350, 500 GeV and 1 TeV: targets tracking and vertexing via vertex charge performance. Who: orphaned

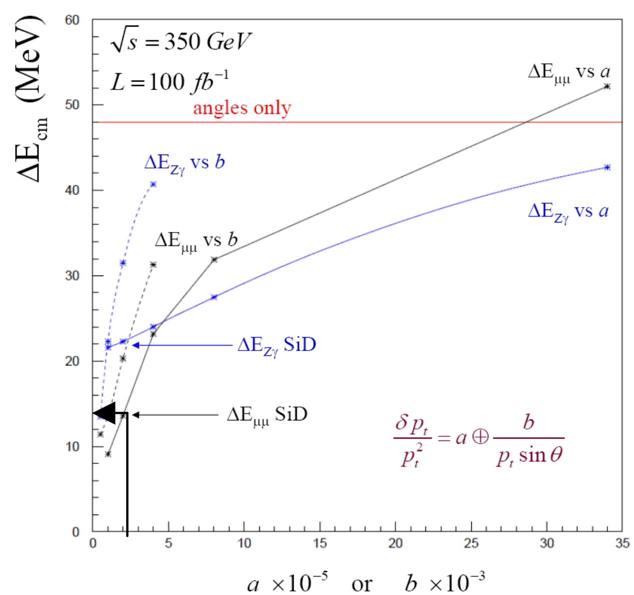
10) Determination of LEP using physics measurements:

- 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)?

Angles only

H.J. Schreiber
K. Moning





Both angles and E_μ

T. Barklow

- Polarization via $e^+e^- \rightarrow W^+W^-$: targets forward tracker. Who: orphaned

Suggested Reduced Benchmark List

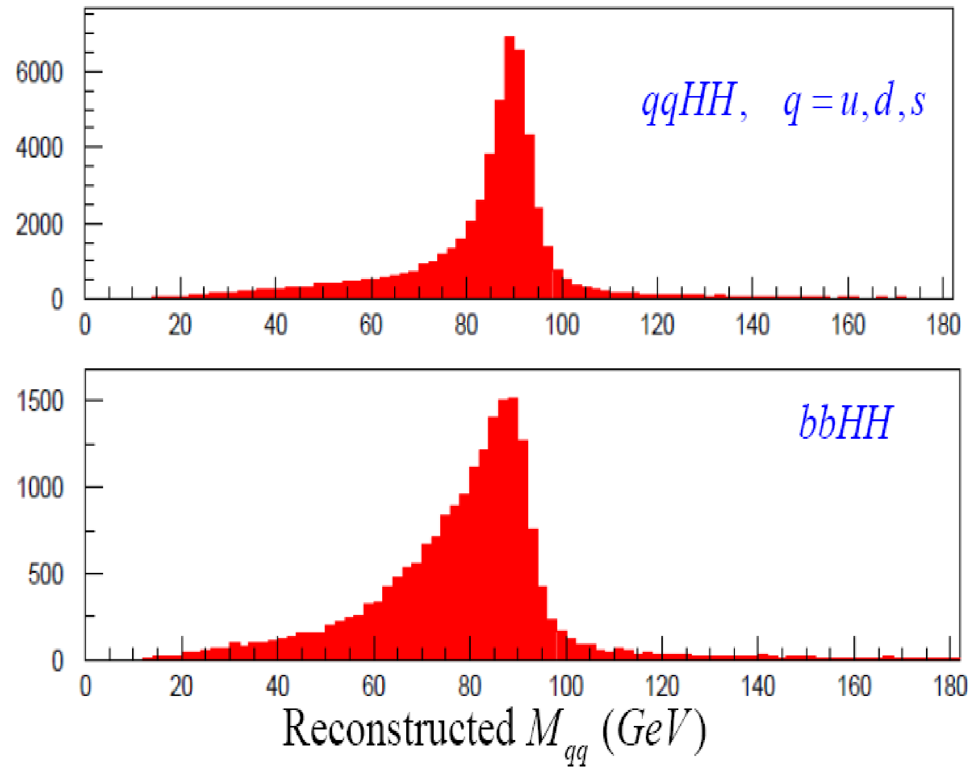
Additional studies:

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

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

non-Gaussian Parameterization



T. Barklow

CDR: The Challenge

Si D

What should CDR be ?

H.Weerts

Simulation & analyzing it, is the foundation for CDR
Need a concept simulation that shows optimization i.e. vary main parameters and convince ourselves that we are at "maximum" in physics performance and "minimum" in cost.

Present one detector with options

- Our goal is to put in place rather extensive collection of physics analyses, most of which will have been developed on fast MC, but which can straightforwardly start being ported to full MC as soon as possible/makes sense.

  Analyses should also evaluate the impact of machine and beam-beam backgrounds.
- Those analyses would be used to start optimizing both subdetectors and well as integral detector performances.

  They will eventually be used to compare the performance among detector concepts.

- First step has been to try to revamp benchmarking effort:
  - create mailing list (69 people subscribed)
  - try to recruit new people
  - establish bi-weekly meetings
  - provide coordination and supervision
  - try to focus effort on most urgent questions

    ⇒ short list of high priority benchmark measurements.

- Starting up slow but we remain hopeful this effort will soon start gaining momentum…