Benchmarking the ILC Detectors

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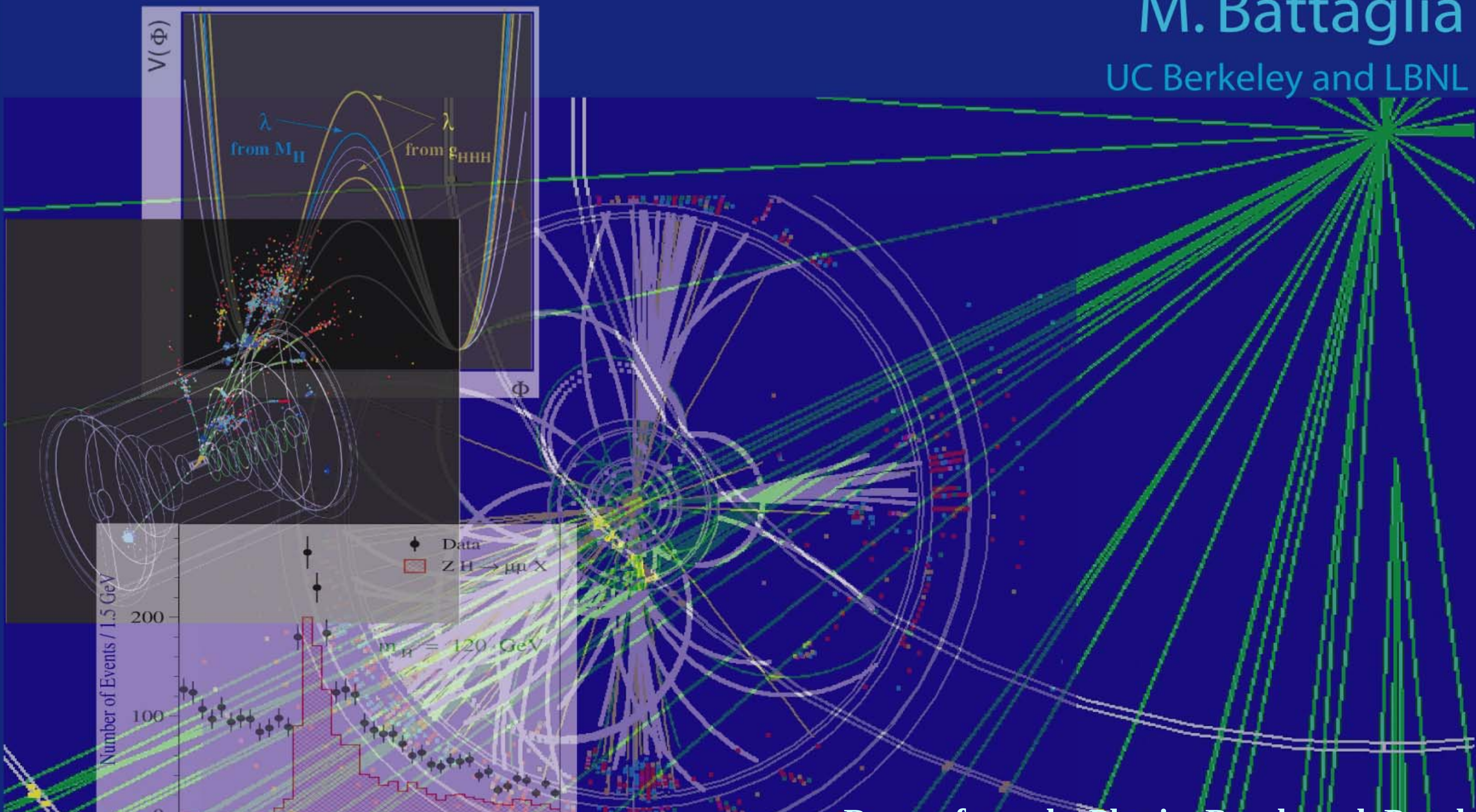

Report from the Physics Benchmark Panel

ECFA ILC Workshop,
Vienna, 16 November 2005

M. Battaglia, T. Barklow, M. Peskin, Y. Okada, S. Yamashita, P. Zerwas

With the start of detector concept studies and expanding R&D, sets of reference benchmark processes become needed to **optimise** each individual design with respect to performance/cost, **justify** and **direct** R&D effort and, eventually, **compare** relative merits;

Detailed studies of leading physics processes, including realistic simulations also help in refining ILC physics potential assessment;

Set up of a Benchmark group at LCWS05 consisting of **three theorists**, representing the **three regions**, (M. Peskin, Y. Okada, P. Zerwas) and **three experimentalists**, representing the **three detector concepts** (T. Barklow, M. Battaglia, S. Yamashita);

Benchmark group recognised by WWS as Benchmark Panel and given detailed charge. Report at Daegu in June, preliminary document submitted to WWS in July and discussed in Snowmass, mandate to benchmark panel extended at Snowmass WWS meeting.

Charge to the Benchmark Panel from the World Wide Study

Detector concept studies for ILC are now moving from basic concepts to optimization of detector parameters. The **aim of the benchmark panel is to aid this process by proposing a minimum set of physics modes that cover capabilities of detector performance** such as vertexing, tracking, calorimetries, muon system, machine-detector interface, and overall issues of particle flow and hermeticity, such **that concept studies can use these modes to evaluate and optimize given detector designs**. For such evaluations to be effective, benchmark panel may suggest important backgrounds to be taken into account and other assumptions used in evaluating the benchmark modes. The **panel is to submit to WWS a document that contains the information as stated above by the beginning of July**. The document will be made available to concept studies and wider linear collider communities by appropriate means.

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.

Benchmark panel report sent to WWS and Detector Concepts contacts
and to appear on the LCWS05 proceedings

Criteria for the Benchmark choice

A set of valid benchmark processes should fulfill certain basic criteria:

ILC **physics scenarios broadly covered;**

Benchmarks must be **robust and retain wider scope** being representative of specific scenarios not yet considered;

Detector performance should be **manifest in a direct way;**

Benchmark target performance motivated by quantitatively well-defined requirements.

Program can be carried out by investigating three classes of processes:

i) **Higgs** mechanism and **strong electroweak symmetry breaking**,
ii) **Supersymmetry**
iii) **EW** precision measurements and indirect sensitivity to **New Physics**.

These three classes indeed provide a net of benchmarks that not only address ILC key physics questions but that also determine the detector performance in a robust form.

Balanced choice of different centre-of-mass energies from 0.3 to 1.0 TeV

At Snowmass 2005, updated SUSY points as result of discussion in SUSY WG to converge on set of points common with LHC studies.

	Process and Final states	Energy (TeV)	Observables	Target Accuracy	Detector Challenge	Notes
Higgs	$ee \to Z^0h^0 \to \ell^+\ell^- X$	0.35	$\mathrm{M_{recoil}}$, σ_{Zh}, BR_{bb}	$\delta\sigma_{Zh} = 2.5\%$, $\delta\mathrm{BR}_{bb} = 1\%$	T	{1}
	$ee \to Z^0h^0, h^0 \to b\bar{b}/c\bar{c}/\tau\tau$	0.35	Jet flavour , jet $(E, \vec{p})$	$\delta\mathrm{M}_h$=40 MeV, $\delta(\sigma_{Zh} \times \mathrm{BR})$=1%/7%/5%	V	{2}
	$ee \to Z^0h^0, h^0 \to WW^*$	0.35	M_Z, M_W, σ_{qqWW^*}	$\delta(\sigma_{Zh} \times \mathrm{BR}_{WW^*})$=5%	C	{3}
	$ee \to Z^0h^0/h^0\nu\bar{\nu}, h^0 \to \gamma\gamma$	1.0	$M_{\gamma\gamma}$	$\delta(\sigma_{Zh} \times \mathrm{BR}_{\gamma\gamma})$=5%	C	{4}
	$ee \to Z^0h^0, h^0\nu\bar{\nu}, h \to \mu^+\mu^-$	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 $\mathrm{BR_{invisible}}$=2.5%	C	{6}
	$ee \to h^0\nu\bar{\nu}$	0.5	$\sigma_{bb\nu\nu}$, M_{bb}	$\delta(\sigma_{\nu\nu h} \times \mathrm{BR}_{bb}) = 1\%$	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	$\delta m_{\tilde{\chi}_1^0}$=50 MeV	T	{12}
	$ee \to \tilde{\tau}_1^+\tilde{\tau}_1^-$, $\tilde{\chi}_1^+\tilde{\chi}_1^-$ (Point 1)	0.5	E_π, $E_{2\pi}$, $E_{3\pi}$	$\delta(m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0})$=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, $\delta m_{\tilde{\chi}_1^0}$=500 MeV,	F	{15}
	$ee \to \tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_1^+\tilde{\chi}_1^-$ (Point 2)	0.5	M_{jj} in $jj\not{E}$, $M_{\ell\ell}$ in $jj\ell\ell\not{E}$	$\delta\sigma_{\chi 2\chi 3} = 4\%$, $\delta(m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})$= 500 MeV	C	{16}
	$ee \to \tilde{\chi}_1^+\tilde{\chi}_1^-/\tilde{\chi}_i^0\tilde{\chi}_j^0$ (Point 5)	0.5/1.0	$ZZ\not{E}$, $WW\not{E}$	$\delta\sigma_{\tilde{\chi}\tilde{\chi}}$=10%, $\delta(m_{\tilde{\chi}_3^0} - m\tilde{\chi}_1^0)$ =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*	$ee \to \tilde{\tau}_1^+\tilde{\tau}_1^-$ (Point 6)	0.5	Heavy stable particle	$\delta m_{\tilde{\tau}_1}$	T	{19}
SUSY	$\chi_1^0 \to \gamma + \not{E}$ (Point 7)	0.5	Non-pointing γ	$\delta c\tau$=10%	C	{20}
breaking	$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + \pi^\pm_{soft}$ (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	$ee \to ee_{fwd}$	0.3/1.0		δm_{top}=50 MeV	T	{26}
Meas.	$ee \to Z^0\gamma$	0.5/1.0			T	{27}

Physics Benchmarks - Detector Performance Matrix

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											
$\chi^0_1 \to \gamma + \not{E}$					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							

Useful to define economical subset of priority processes which emphasise key aspects of detector performance: vertexing, tracking, calorimetry, very forward instrumentation and integration.

Privilege benchmarks whose analysis mantains a simple relation to the basic detector parameters and also emphasise key ILC reactions and extended capabilities that ILC will provide with respect to LHC:

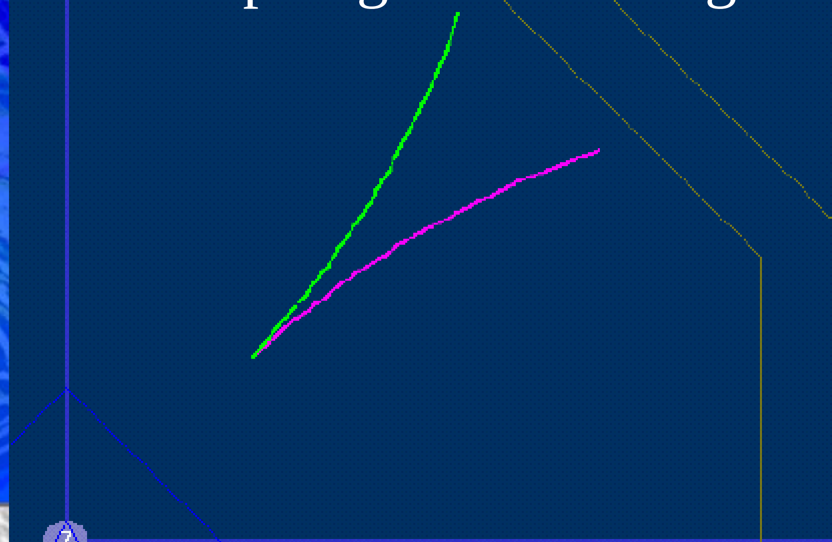
0. Single $e^\pm$, $\mu^\pm$, $\pi^\pm$, π^0, $K^\pm$, K^0_s, γ, u, s, c, b; $0 < |\cos\theta| < 1$, $0 < p < 500$ GeV
1. $e^+e^- \to f\bar{f}$, $f = e, c, b$ at $\sqrt{s}$=1.0 TeV;
2. $e^+e^- \to Zh, \to \ell^+\ell^- X$, $m_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;
3. $e^+e^- \to Zh$, $h \to c\bar{c}$, $\tau^+\tau^-$, WW^*, $m_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;
4. $e^+e^- \to Zhh$, $m_h = 120$ 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. $e^+e^- \to \chi_1^+\chi_1^- / \chi_2^0\chi_2^0$ at Point 5 at $\sqrt{s}$=0.5 TeV;

Single $e^{\pm}, \mu^{\pm}, \pi^{\pm}, \pi^{0}, K^{\pm}, K^{0}_{s}, \gamma, u, s, c, b;\ 0 < |\cos\theta| < 1,\ 0 < p < 500$ GeV

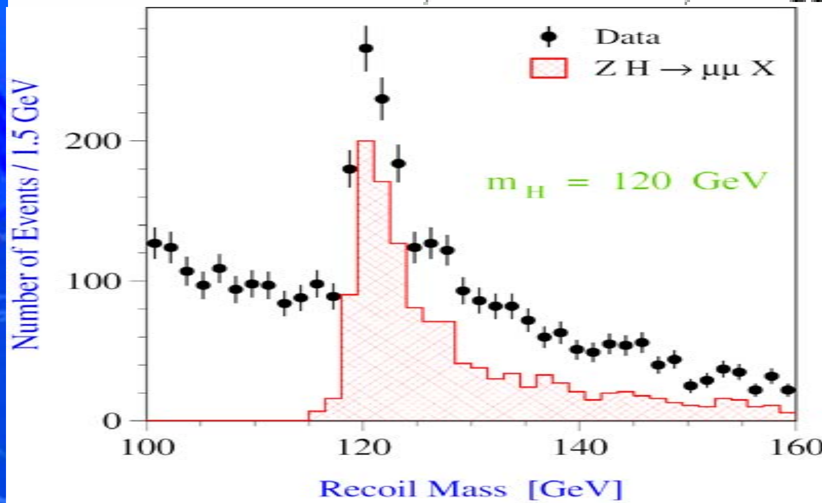
Single particle and jets over full range of polar angles and energies will test reconstruction capabilities in terms of efficiency and resolutions on full simulation;

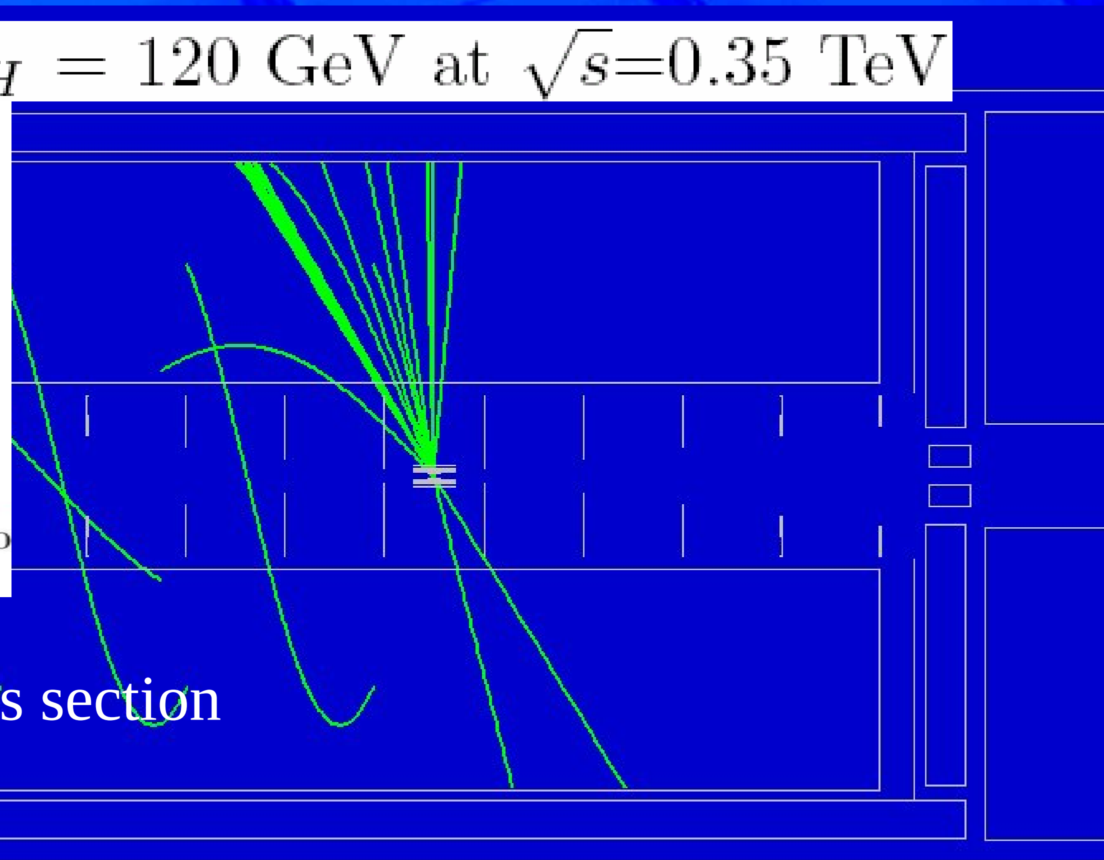
Results can be used for validating fast/hybrid simulation programs to be used in more extensive physics studies;

Performances also to be used as reference to assess effect of reconstruction in more complicated event topologies and background environments.



$$e^+e^- \to ZH, \to \ell\ell X, M_H = 120 \text{ GeV at } \sqrt{s}=0.35 \text{ TeV}$$



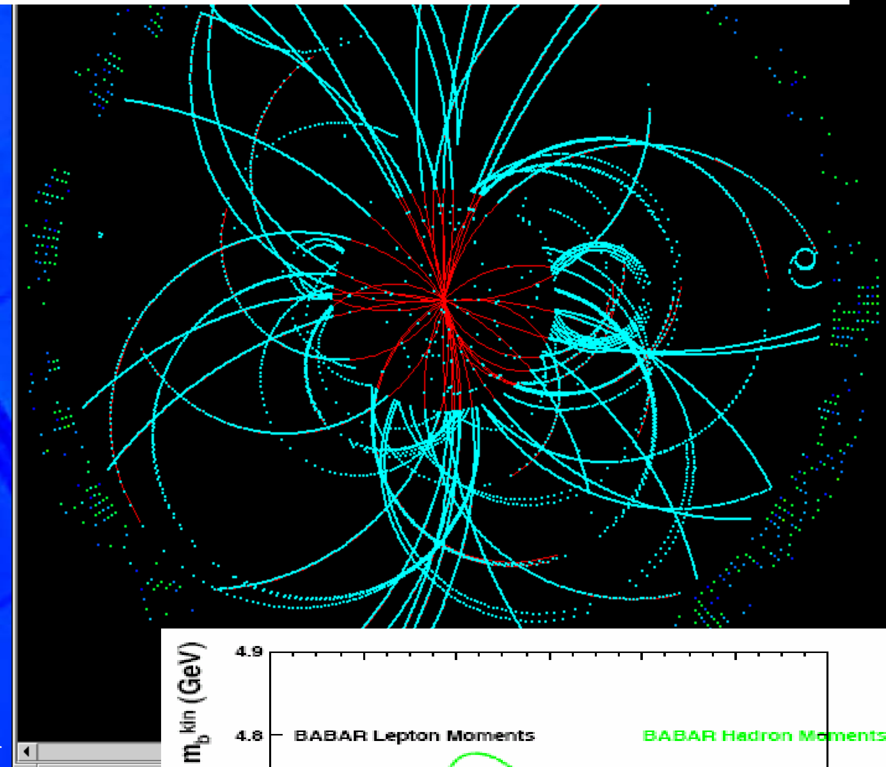


Determine Higgstrahlung cross section to 2.5% accuracy

Higgstrahlung provide stringest requirement on single track momentum resolution

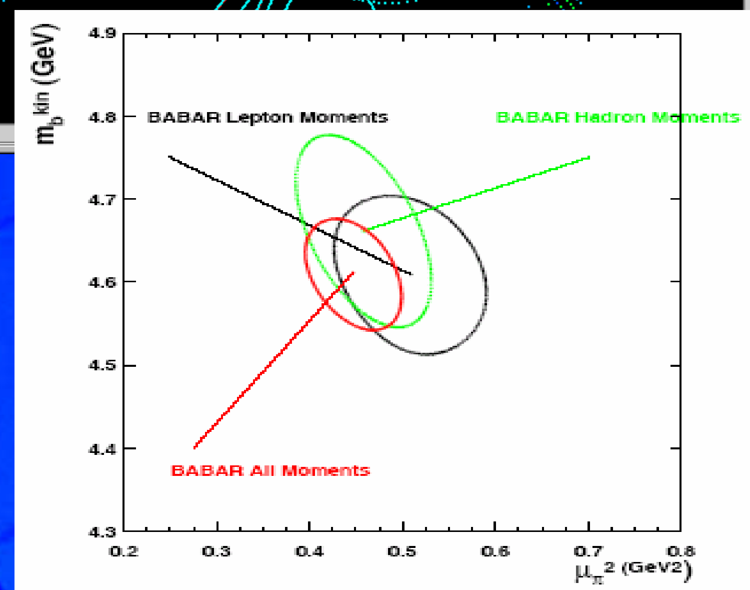
Precision critical in ILC program of Higgs profile study, extraction of bosonic and fermionic couplings, required momentum resolution also important in study of rare Higgs decay

$$e^+e^- \rightarrow Zh,\ h \rightarrow c\bar{c},\ \tau^+\tau^-,\ WW^*,\ m_h = 120\ \text{GeV at}\ \sqrt{s}{=}0.35\ \text{TeV}$$



Study of Higgs branching fractions provides compelling case for excellent vertexing capabilities over a wide range from b tagging to charm identification in large b "background" to single track tagging in tau decays

Most recent improvements in determination of b and c quark masses at B factories and perspectives for further reductions in uncertainties underline importance of detector performance matching the decreasing theoretical uncertainty in study of Higgs-fermion couplings



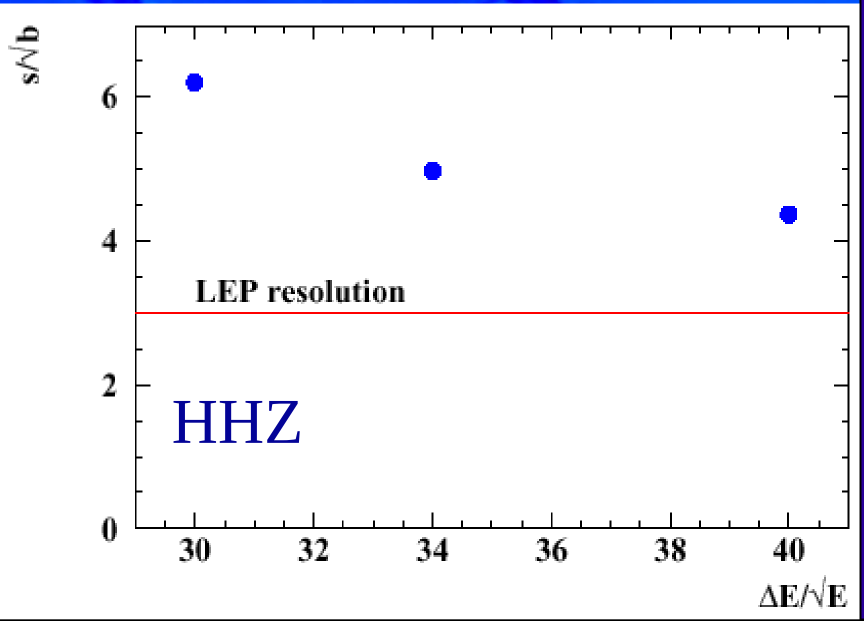
$e^+e^- \to ZHH,\ M_H = 120$ GeV at $\sqrt{s}$=0.5 TeV

Extract g_{HHH} with 10% accuracy by the combination of the two channels using kinematical variables to isolate the HHH vertex;

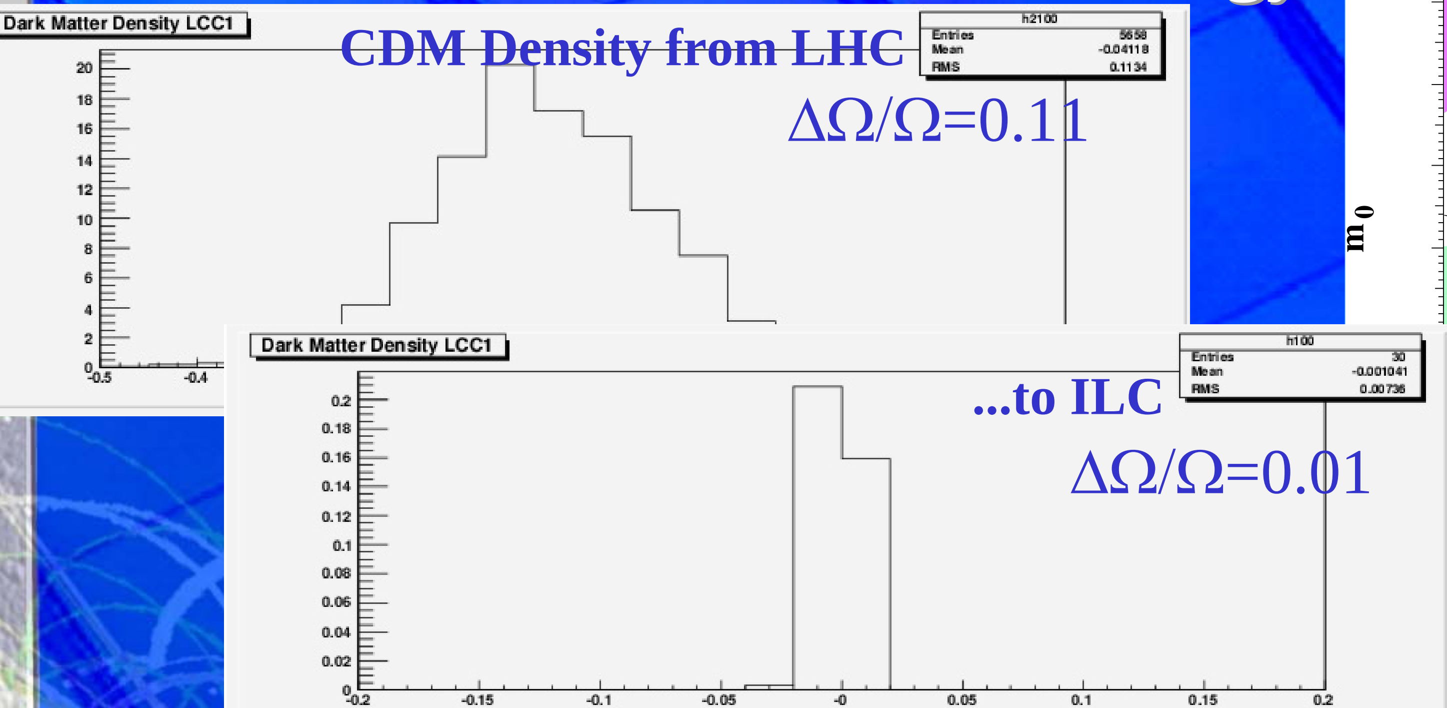
Reconstruction of Higgs potential through study of double Higgs production offer a possibly unique opportunity for ILC

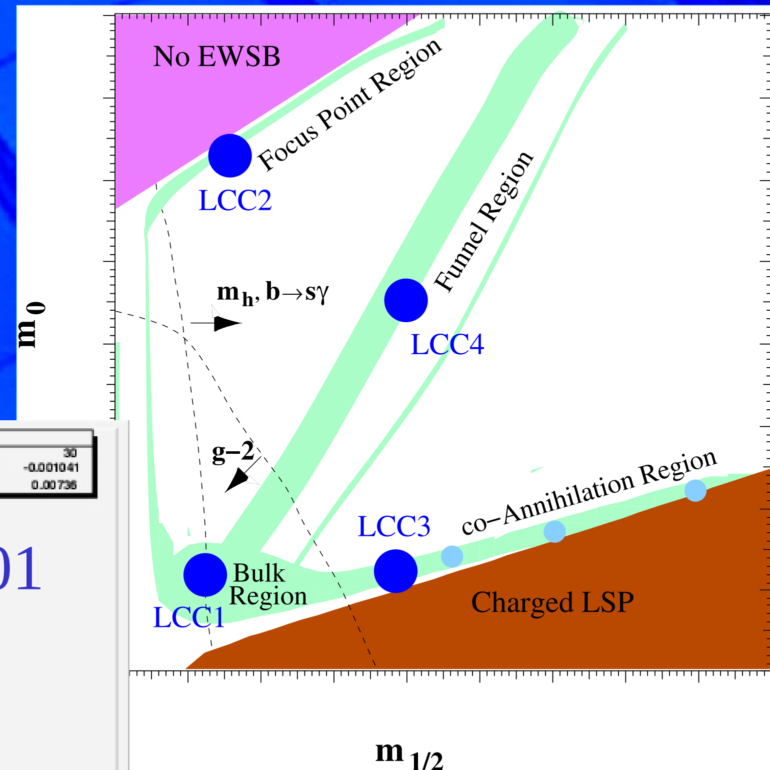
Six jet final state with four b-jets/ four b-jets + $E_{missing}$ and need to reject ZZZ background through di-jet mass analysis, presents important challenges also representative of SUSY Higgs production in SUSY and ttH production;

Modest signal cross section and need to reject diagrams not sensitive to Higgs self-coupling for measurement of interesting sensitivity, provide a challenging and well defined performance target



SUSY Benchmarks and Cosmology

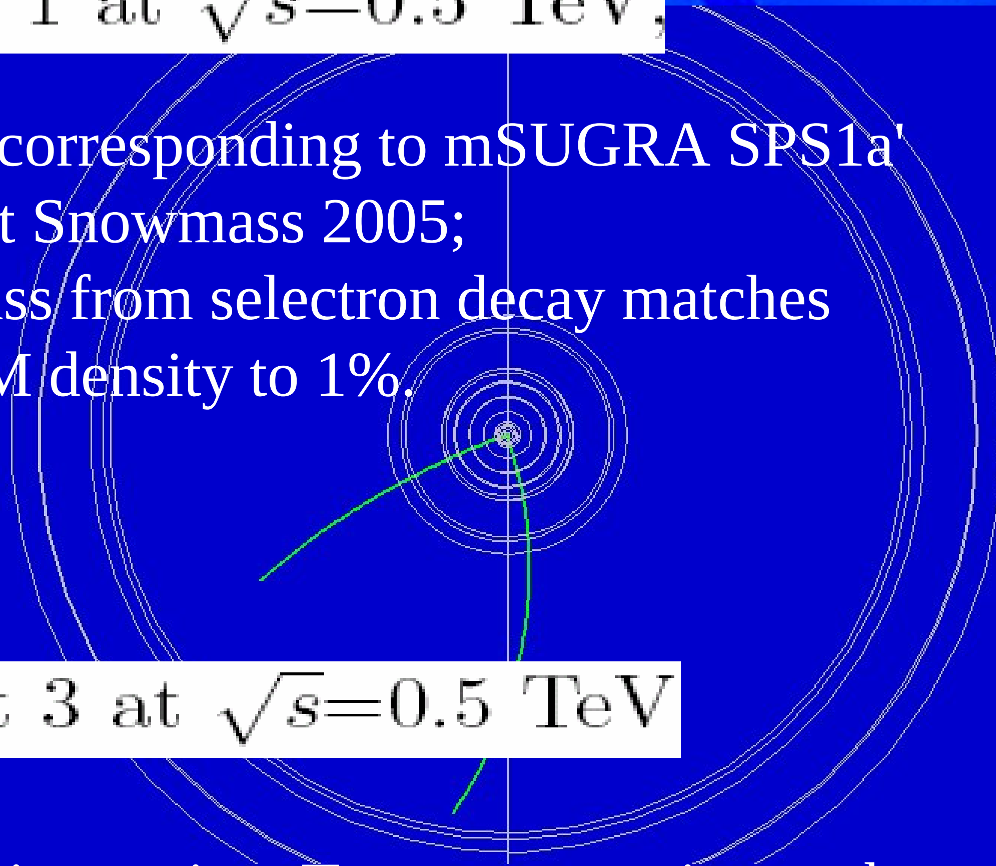




Point	Ref.	m_0 GeV	$m_{1/2}$ GeV	$\tan\beta$ GeV	A	μ GeV	m_{top} GeV	$m_{\chi^0_1}$ GeV	$m_{\tilde{\tau}_1}$ GeV	$m_{\chi^0_2}$ GeV	$m_{\chi^0_3}$ GeV	$m_{\tilde{e}_R}$ GeV	m_A GeV	$m_{\chi^+_1}$ GeV	$m_{\chi^+_2}$ GeV
1	SPS1a' [19, 20]	70	250	10	-300	389	175	96.1	109.2	185	393	124	421	185	408
2	LCC2 [20]	3280	300	10	0	178	175	107.7	3251	166	190	3270	3242	159	287
3	D' [22]	110	525	10	0	654	175	211.3	220.8	408	658	228	744	409	671
4	LCC4 [20]	380	420	53	535	178	0	169.1	195	327	540	412	419	328	553
5	α [23]	206	293	10	0	375	178	113	213	215	380	216	265	215	399
6	ϵ [23]	20	440	15	-25	569	178	175	153	339	574	171	622	340	587

$$e^+e^- \rightarrow \tilde{e}_R\tilde{e}_R \text{ at Point 1 at } \sqrt{s}\text{=0.5 TeV;}$$

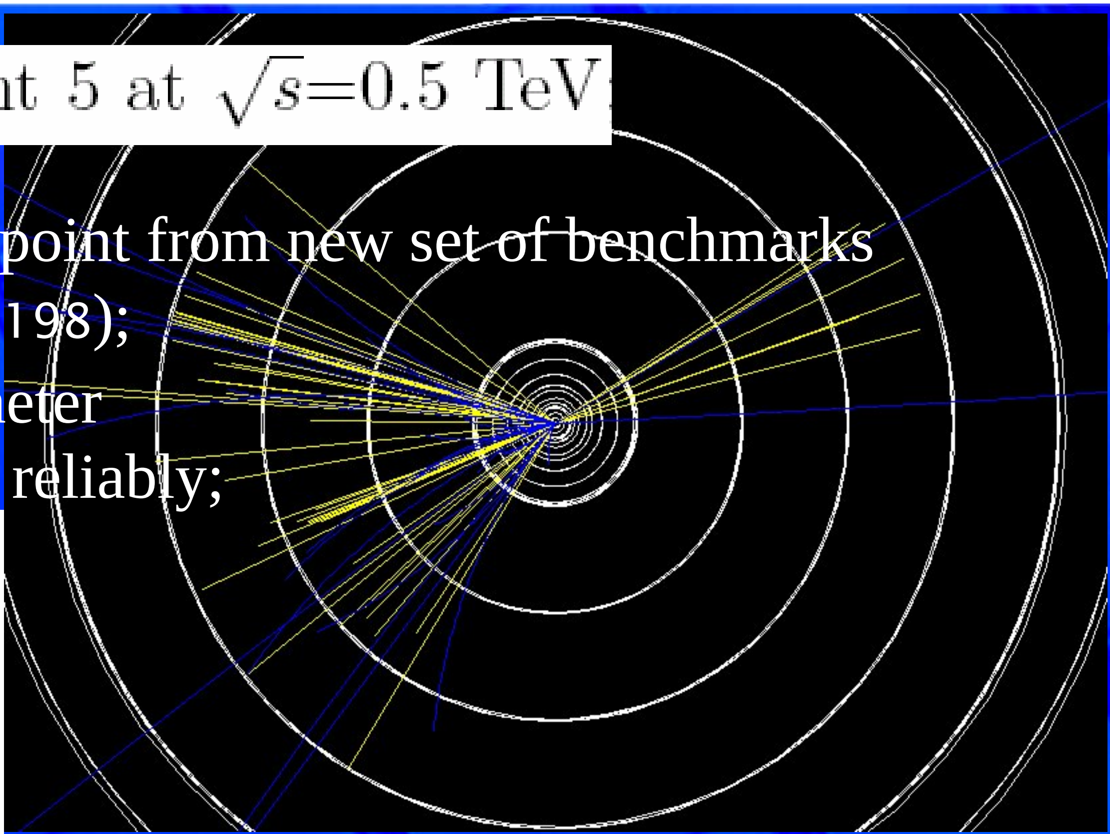
SUSY parameters in bulk region corresponding to mSUGRA SPS1a' revised from of LHC/LC study at Snowmass 2005;
Target accuracy on neutralino mass from selectron decay matches precision needed to determine DM density to 1%.



$$e^+e^- \rightarrow \tilde{\tau}_1\tilde{\tau}_1, \text{ at Point 3 at } \sqrt{s}\text{=0.5 TeV}$$

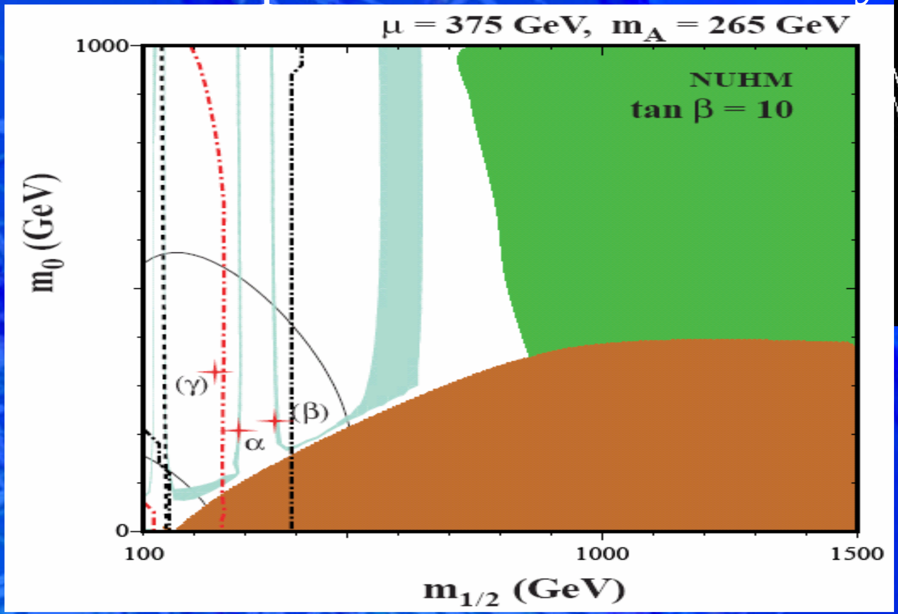
SUSY parameters in co-annihilation region. Target accuracies on the stau and neutralino mass are required to determine DM density to 6% accuracy.
The ee ττ is contaminated by ee -> ee ττ which requires low angle e tagging and, possibly, μ/π id in the very forward instrumentation

$e^+e^- \to \chi_1^+\chi_1^- / \chi_2^0\chi_2^0$ at Point 5 at $\sqrt{s}$=0.5 TeV



Non Universal Higgs Mass SUSY point from new set of benchmarks being studied at LHC (hep-ph/0508198);

Accurate determination of μ parameter needed to predict relic DM density reliably;

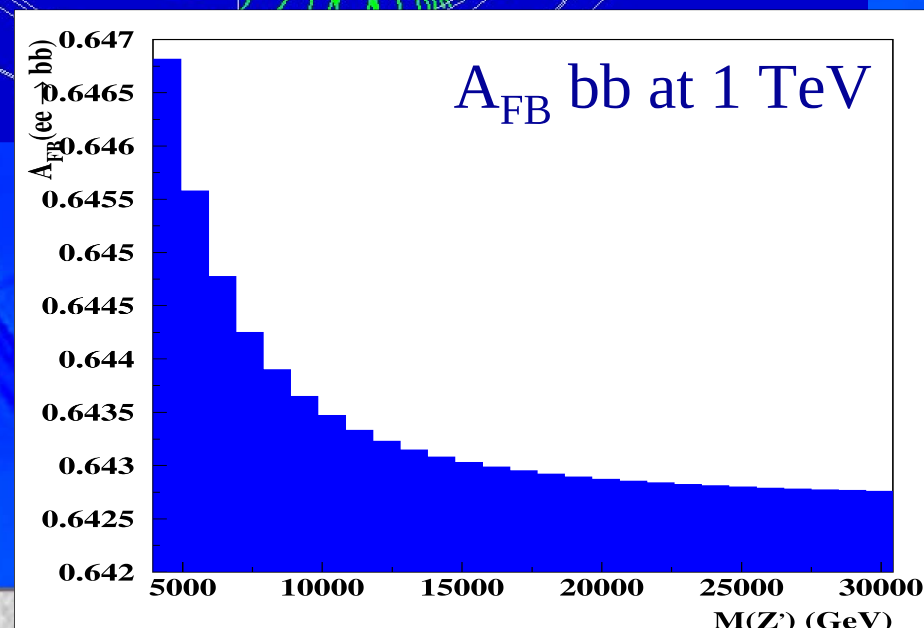


Point 5 produces similar phenomenology to other WMAP-compatible mSUGRA points but requires running at 1 TeV to get full gaugino spectrum and has real W and Z bosons produced in gaugino cascade decays.

$e^+e^- \to f\bar{f}$, $f = e, c, b$ at $\sqrt{s}$=1.0 TeV

Accuracy in fermion pair production properties at ILC can be quantified by studying the mass reach for a heavy neutral vector boson $M(Z_{LR})$ in left-right symmetric SM extension. The virtual effects should be determined well enough that the mass sensitivity reaches **8 TeV**, tripling that expected at LHC;

Since the most sensitive observable at edge of sensitivity range is A_{FB}, this study is particularly sensitive to jet and vertex charge reconstruction



The Next Steps

Final Benchmark report being completed and
will be submitted to WWS and hep-ph within one week;

StdHep samples of events of signal and major backgrounds are being generated for prority processes and will be made available;

Template analyses will be developed, ensuring that applied to simulated events will result in accuracies better or equal to those indicated as target performance;

Benchmark panel will remain in charge to assist Detector Concepts in implementation of analysis of benchmark processes.