Benchmarking the ILC Detectors

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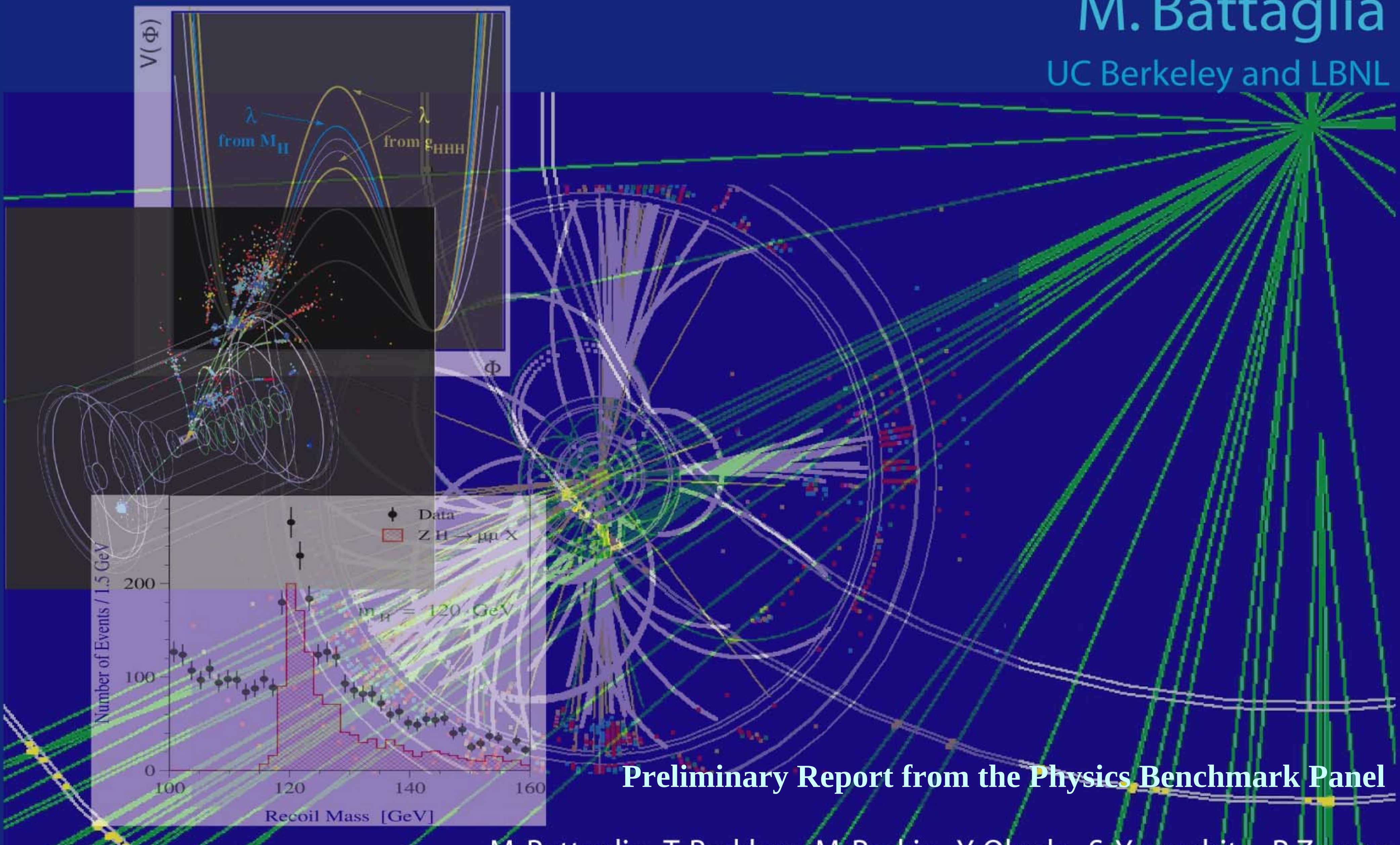

Preliminary Report from the Physics Benchmark Panel

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

With the start of detector concept studies and continuing Intl. sensors and subsystems 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;

Benchmark Parallel session at LCWS05 and related discussion, lead to the set-up of an informal group for a first survey of interesting benchmark processes, study their relation with detector performance and draft a proposal:

Benchmark group consists 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 in May as Benchmark Panel and given detailed charge.

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** so that there is reasonable time before Snowmass workshop 2005. The document will be made available to concept studies and wider linear collider communities by appropriate means. The charge and membership of the panel will be reevaluated at the Snowmass workshop based on wide inputs from the community.

Physics Benchmarks for the ILC Detectors

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This note discusses physics processes in relation to the benchmarking of the performances of detectors at a TeV-class e^+e^- linear collider.

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;**

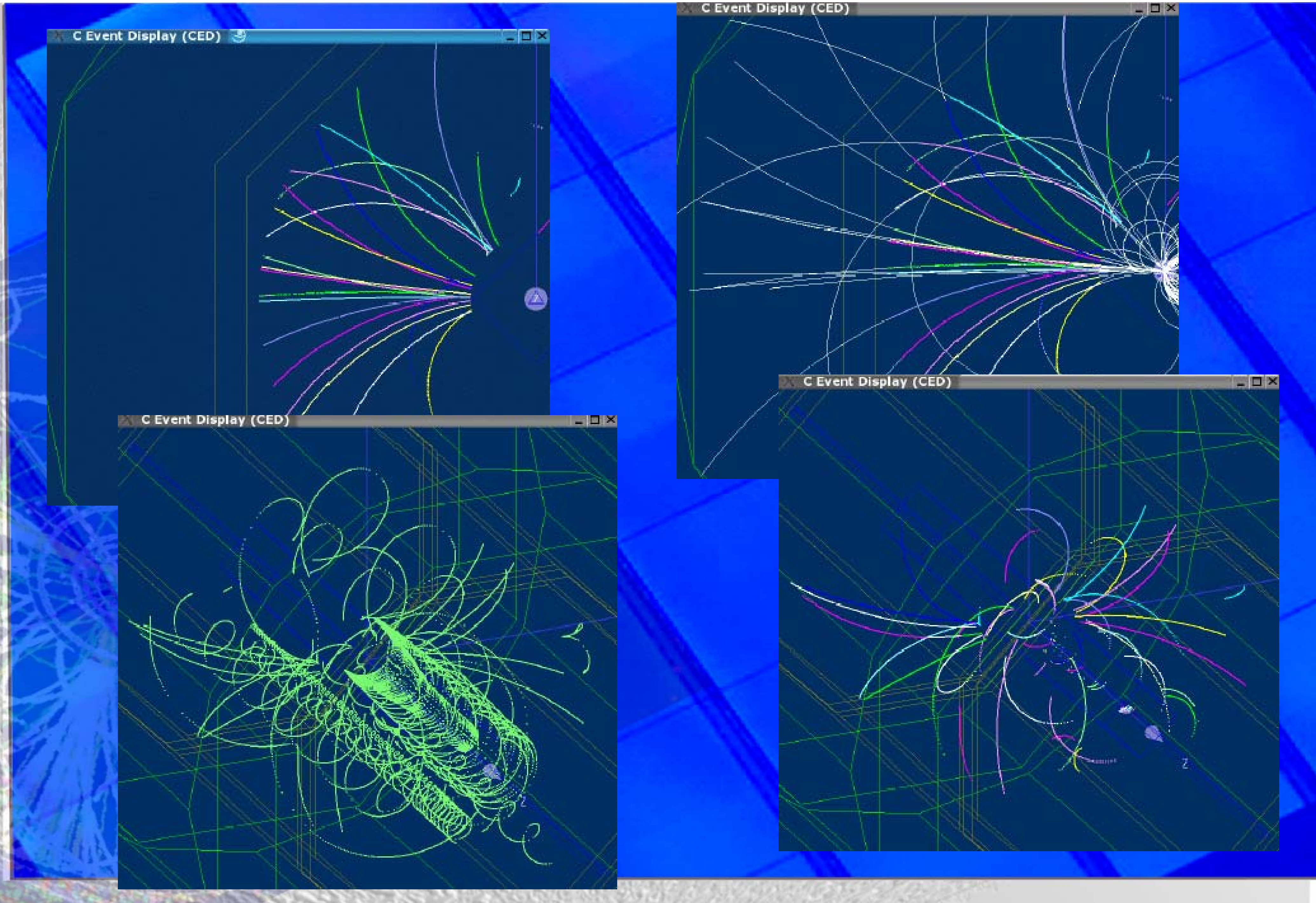
Benchmark target performance motivated by quantitatively well-defined requirements.

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


C Event Display (CED)
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Physics Benchmarks for the ILC Detectors

	Process and Final states	Energy (TeV)	Observables	Target Accuracy	Detector Challenge
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
	$ee \to Z^0H^0, H^0 \to b\bar{b}/c\bar{c}/\tau\tau$	0.35	Jet flavour , jet $(E, \vec{p})$	δM_H=40 MeV, $\delta(\sigma_{ZH} \times BR)$=1%/7%/5%	V
	$ee \to Z^0H^0, H^0 \to WW^*$	0.35	M_Z, M_W, σ_{qqWW^*}	$\delta(\sigma_{ZH} \times BR_{WW^*})$=5%	C
	$ee \to Z^0H^0/H^0\nu\bar{\nu}, H^0 \to \gamma\gamma$	1.0	$M_{\gamma\gamma}$	$\delta(\sigma_{ZH} \times BR_{\gamma\gamma})$=5%	C
	$ee \to Z^0H^0, H^0\nu\bar{\nu}, H \to \mu^+\mu^-$	1.0	$M_{\mu\mu}$	5σ Evidence for $M_H = 120$ GeV	T
	$ee \to Z^0H^0, H^0 \to$ invisible	0.35	$\sigma_{qqE_{missing}}$	5σ Evidence for $BR_{invisible}$=2.5%	C
	$ee \to H^0\nu\bar{\nu}$	0.5	$\sigma_{bb\nu\nu}$, M_{bb}	$\delta(\sigma_{\nu\nu H} \times BR_{bb}) = 1\%$	C
	$ee \to t\bar{t}H^0$	1.0	σ_{ttH}	δg_{ttH}=5%	C
	$ee \to Z^0H^0H^0$, $H^0H^0\nu\bar{\nu}$	0.5/1.0	σ_{ZHH}, $\sigma_{\nu\nu HH}$, M_{HH}	δg_{HHH}=20/10%	C
SSB	$ee \to W^+W^-$	0.5		$\Delta\kappa_\gamma, \lambda_\gamma = 2 \cdot 10^{-4}$	V
	$ee \to W^+W^-\nu\bar{\nu}/Z^0Z^0\nu\bar{\nu}$	1.0	σ	$\Lambda_{*4}, \Lambda_{*5} = 3$ TeV	C
SUSY	$ee \to \tilde{e}^+_R\tilde{e}^-_R$ (Point 1)	0.5	E_e	$\delta M_{\tilde{\chi}^0_1}$=50 MeV	T
	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (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
	$ee \to \tilde{t}_1\tilde{t}_1$ (Point 1)	1.0		$\delta M_{\tilde{t}_1}$=2 GeV	
-*CDM*	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, $\tilde{\chi}^+_1\tilde{\chi}^-_1$ (Point 3)	0.5		$\delta M_{\tilde{\tau}_1}$=500 MeV, $\delta M_{\tilde{\chi}^0_1}$=500 MeV,	F
	$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$, $\chi^+_1\chi^-_1$ (Point 2)	0.5	M_{jj} in $jj\not{E}$, $M_{\ell\ell}$ in $jj\ell\ell\not{E}$	$\delta\sigma_{\chi_2\chi_3} = 4\%$, $\delta(M_{\tilde{\chi}^0_2} - M_{\tilde{\chi}^0_1})$=500 MeV	C
	$ee \to \chi^+_1\chi^-_1/\tilde{\chi}^0_2\tilde{\chi}^0_3$ (Point 5)	0.5/1.0	$ZZ\not{E}$, $WW\not{E}$	$\delta\sigma_{\tilde{\chi}\tilde{\chi}}$, $\delta M_{\tilde{\chi}^0_2}$ =	C
	$ee \to H^0A^0 \to b\bar{b}b\bar{b}$ (Point 4)	1.0	Mass constrained M_{bb}	δM_A=1 GeV	C
-*alternative*	$ee \to \tilde{\tau}^+_1\tilde{\tau}^-_1$ (Point 6)	0.5	Heavy stable particle	$\delta M_{\tilde{\tau}_1}$	T
SUSY	$\chi^0_1 \to \gamma + \not{E}$ (Point 7)	0.5	Non-pointing γ	$\delta c\tau$=10%	C
breaking	$\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$ (Point 8)	0.5	Soft $\pi^\pm$ above $\gamma\gamma$ bkgd	5σ Evidence for $\Delta\tilde{m}$=200 MeV-2 GeV	F
Precision SM	$ee \to t\bar{t} \to 6$ *jets*	1.0		5σ Sensitivity for $(g-2)_t/2 \leq 10^{-3}$	V
	$ee \to f\bar{f}$ $(f = e, \mu, \tau; b, c)$	1.0	$\sigma_{f\bar{f}}$, A_{FB}, A_{LR}	5σ Sensitivity to $M(Z_{LR}) = 8$ TeV	V
New Physics	$ee \to \gamma G$ (ADD)	1.0	$\sigma(\gamma + \not{E})$	5σ Sensitivity	C
	$ee \to KK \to f\bar{f}$ (RS)	1.0			T
Energy/Lumi	$ee \to ee_{fwd}$	0.3/1.0		δM_{top}=50 MeV	T
Meas.	$ee \to Z^0\gamma$	0.5/1.0			T

Physics Benchmarks for the ILC Detectors

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			
$ee \to \nu\nu H$	x	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							
$ee \to ttH$	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			
$ee \to \tilde{e}_R\tilde{e}_R$		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		
$ee \to \tilde{\tau}_1\tilde{\tau}_1$	x	x			x	x	x		x					
$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$														
$ee \to HA \to bbbb$	x	x								x	x			
$ee \to \tilde{\tau}_1\tilde{\tau}_1$, $\chi^0_1 \to \gamma + \not{E}$, $\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$														
$ee \to tt \to 6\ jets$	x		x						x	x	x			
$ee \to ff\ [e, \mu, \tau; b, c]$	x		x				x		x		x		x	x
$ee \to KK \to ff\ [e, \mu; q]$		x									x			
$ee \to \gamma G$				x	x			x						x
$ee \to ee_{fwd}$						x	x	x						
$ee \to Z\gamma$		x		x	x	x	x							

Define an economical set of priority processes which emphasise key aspects of detector performance in terms of vertexing, tracking, calorimetry, very forward instrumentation and integration.

Privilege benchmarks whose analysis preserve a simple relation to the basic detector observables and also emphasise complementarity and extension, that ILC will provide with respect to LHC:

1. 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
2. $e^+e^- \to f\bar{f}$, $f = e$, μ, c, b at $\sqrt{s}$=1.0 TeV;
3. $e^+e^- \to ZH, \to \ell^+\ell^- X$, $M_H = 120$ GeV at $\sqrt{s}$=0.35 TeV;
4. $e^+e^- \to ZH$, $H \to b\bar{b}$, $c\bar{c}$, $\tau^+\tau^-$, WW^*, $M_H = 120$ GeV at $\sqrt{s}$=0.35 TeV;
5. $e^+e^- \to ZHH/HH\nu\bar{\nu}$, $M_H = 120$ GeV at $\sqrt{s}$=0.5/1.0 TeV;
6. $e^+e^- \to \tilde{e}_R\tilde{e}_R$, $\chi^+_1\chi^-_1$ at Point 1 at $\sqrt{s}$=0.5 TeV;
7. $e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1$, $\chi^+_1\chi^-_1$ at Point 3 at $\sqrt{s}$=0.5 TeV;
8. $e^+e^- \to \chi^+_1\chi^-_1/\chi^0_2\chi^0_3$ at Point 5 at $\sqrt{s}$=0.5/1.0 TeV;

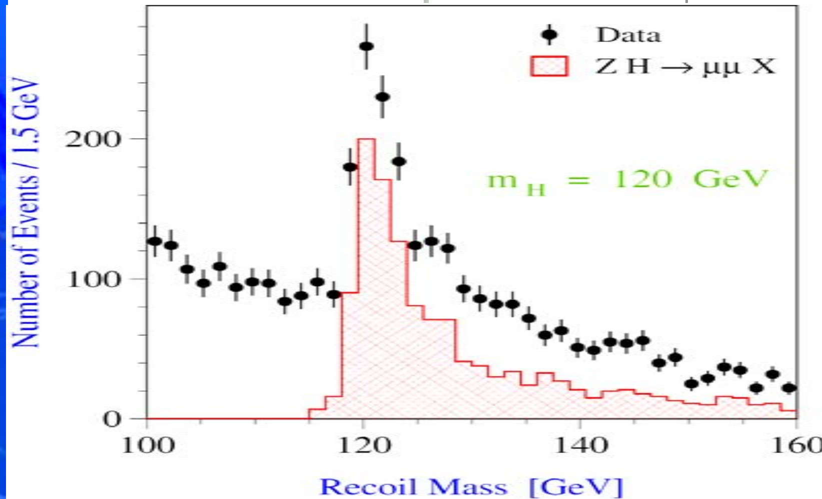
$$\text{Single } e^{\pm},\ \mu^{\pm},\ \pi^{\pm},\ \pi^{0},\ K^{\pm},\ K^{0}_{s},\ \gamma,\ u,\ s,\ c,\ b;\ 0 < |\cos\theta| < 1,\ 0 < p < 500 \text{ GeV}$$

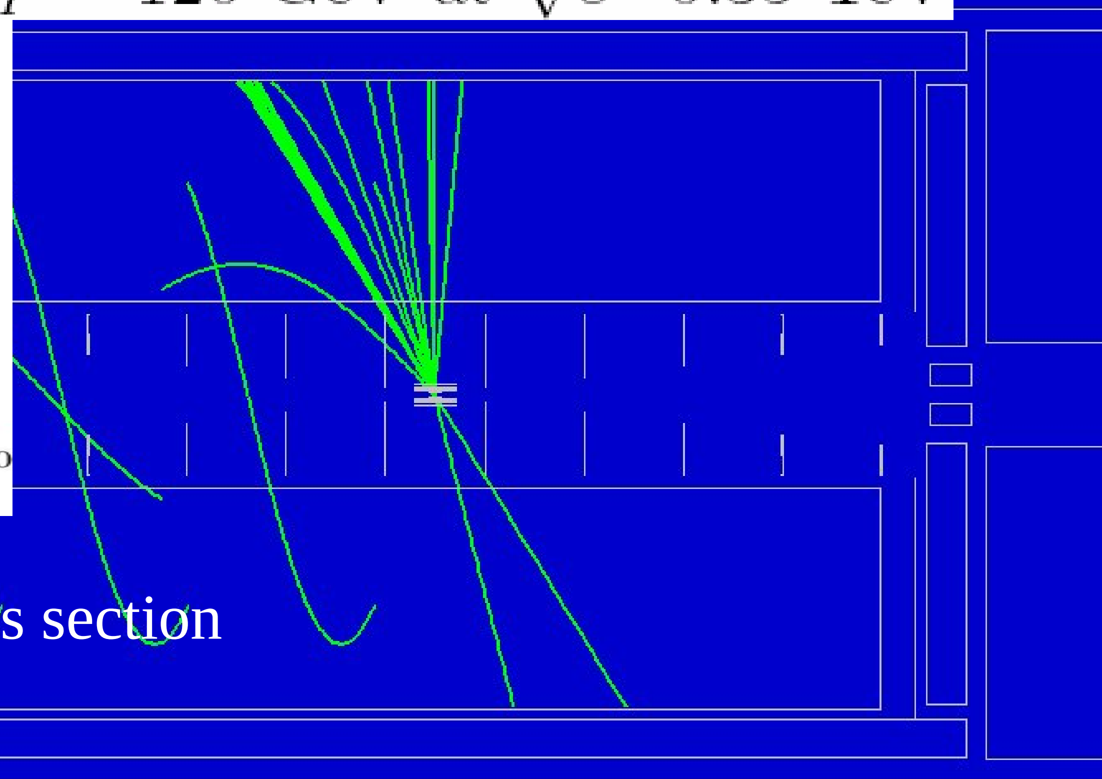
Single particle and jets over full range of polar angles and energies will test reconstruction capabilities in terms of efficiency and resolutions on full simulation;

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.

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



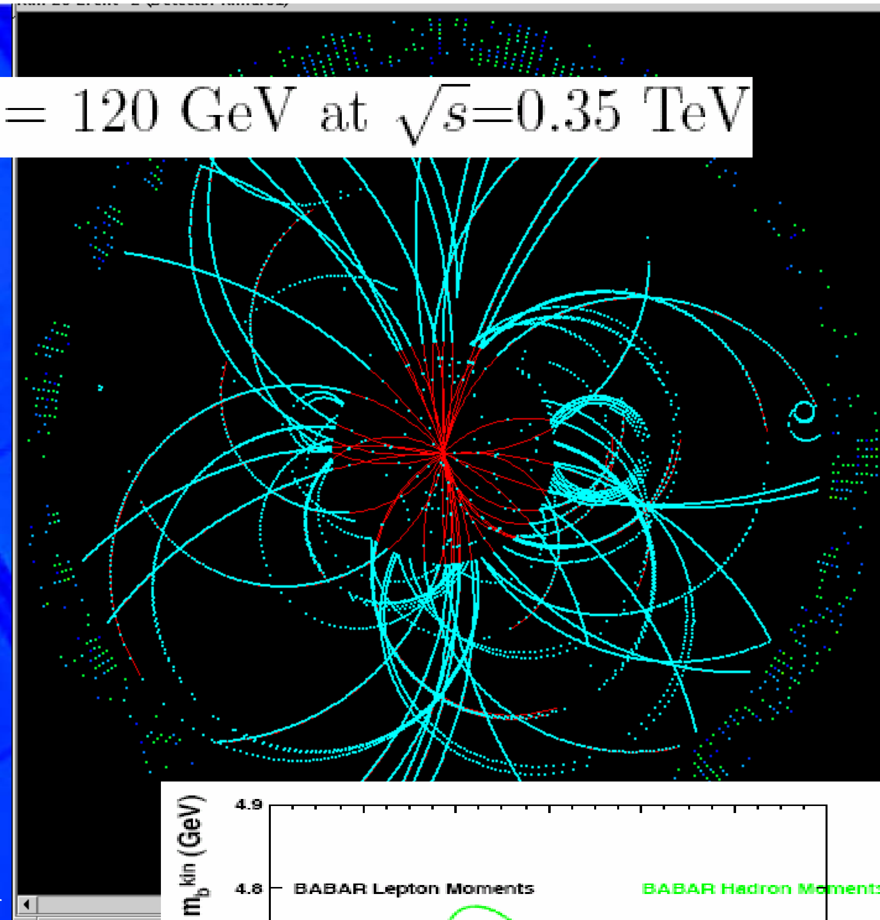


Determine Higgstrahlung cross section to 2.5% accuracy

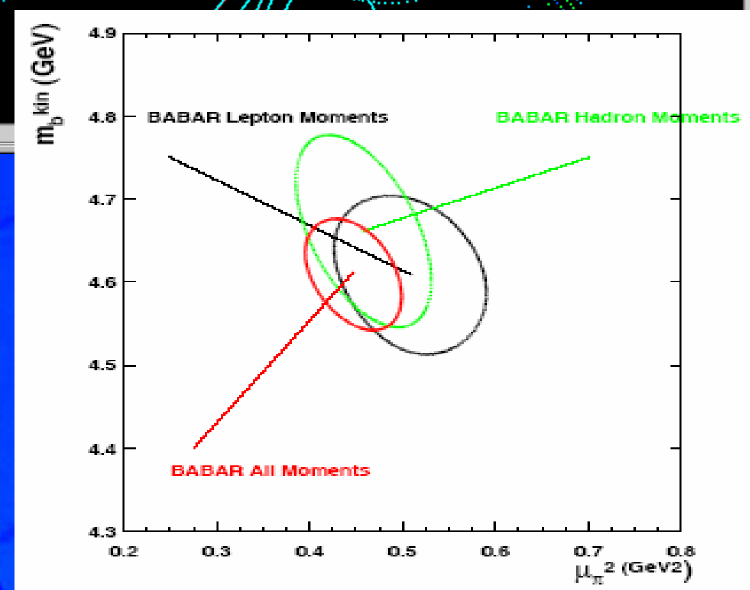
Higgstrahlung provide stringest requirement on single track momentum resolution

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

$e^+e^- \to ZH,\ H \to bb,\ cc,\ \tau\tau,\ WW*,\ M_H = 120\ \text{GeV at}\ \sqrt{s}$=0.35 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

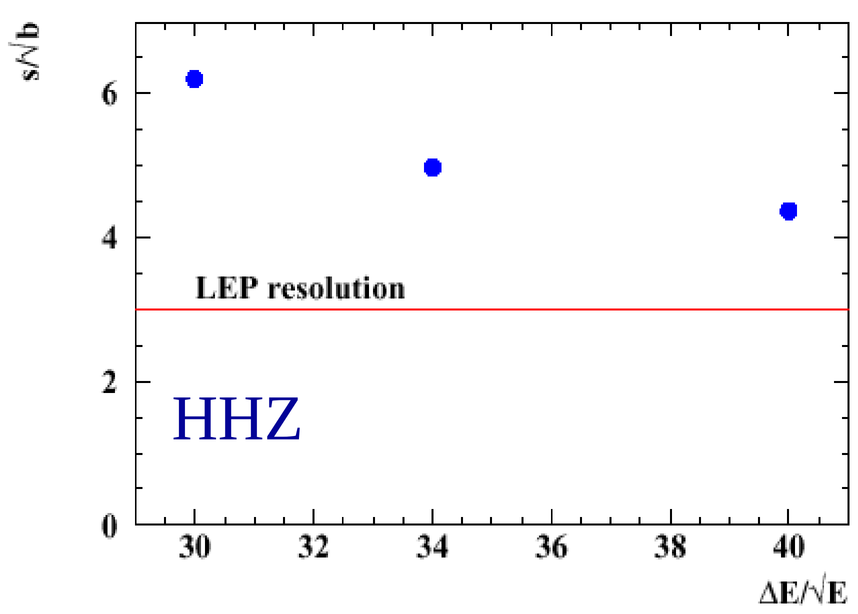
$e^+e^- \rightarrow ZHH$, $M_H = 120$ GeV at $\sqrt{s}$=0.5 TeV

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

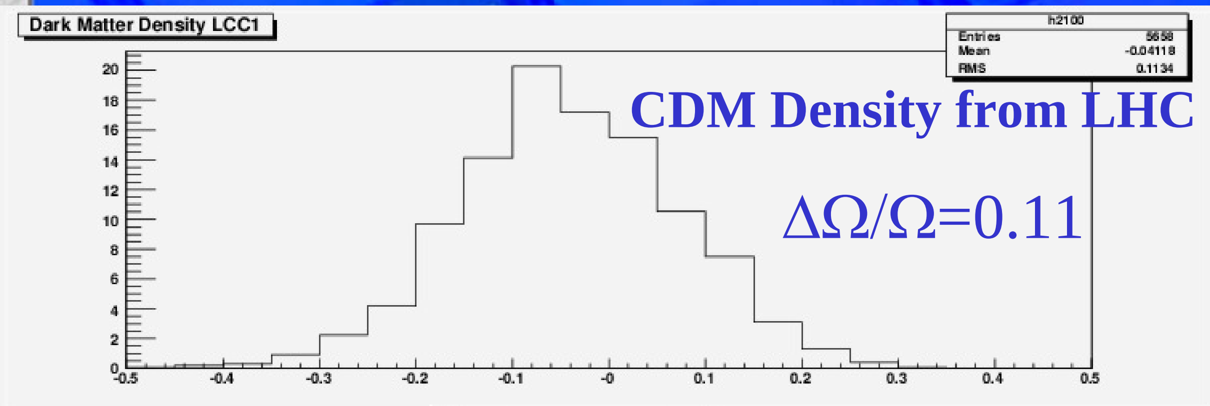
Reconstruction of Higgs potential through study of double Higgs production offer a possibly unique opportunity for ILC

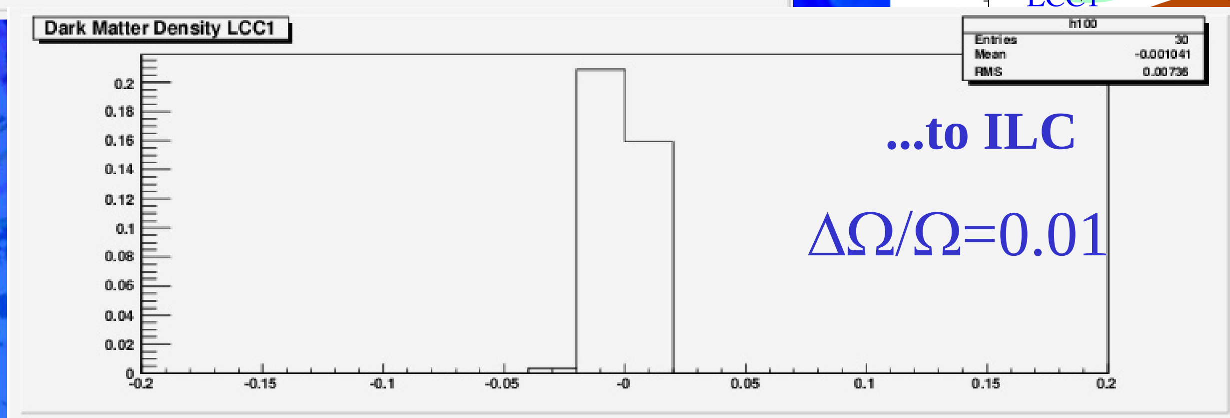
Six jet final state with four b-jets/ four b-jets + $E_{missing}$ and need to reject ZZZ background through di-jet mass analysis, presents important challenges also representative of SUSY Higgs production in SUSY and ttH production;

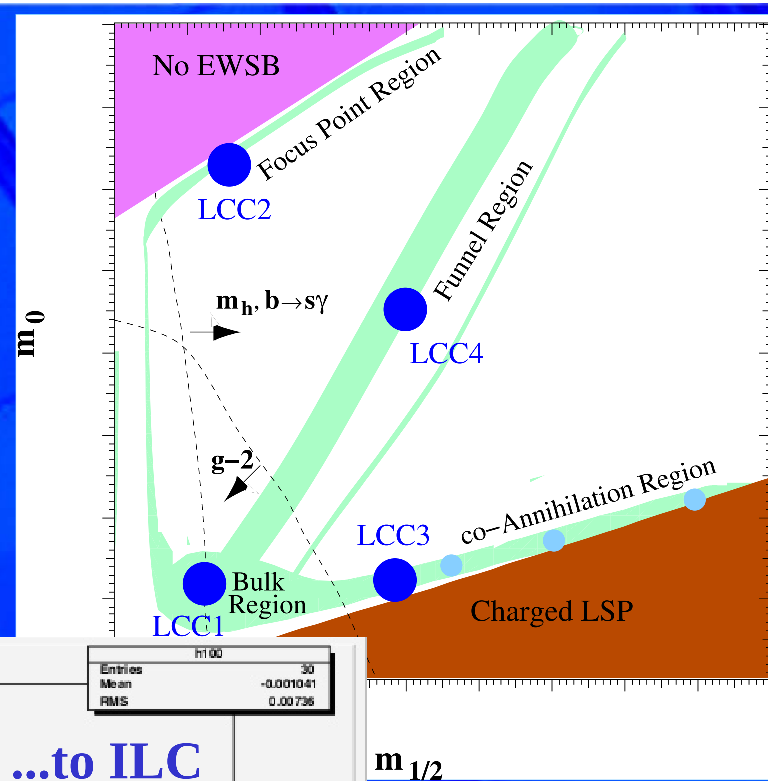
Modest signal cross section and need to reject diagrams not sensitive to Higgs self-coupling for measurement of interesting sensitivity, provide a challenging and well defined performance target



SUSY Benchmarks and the Cosmology-ILC connection

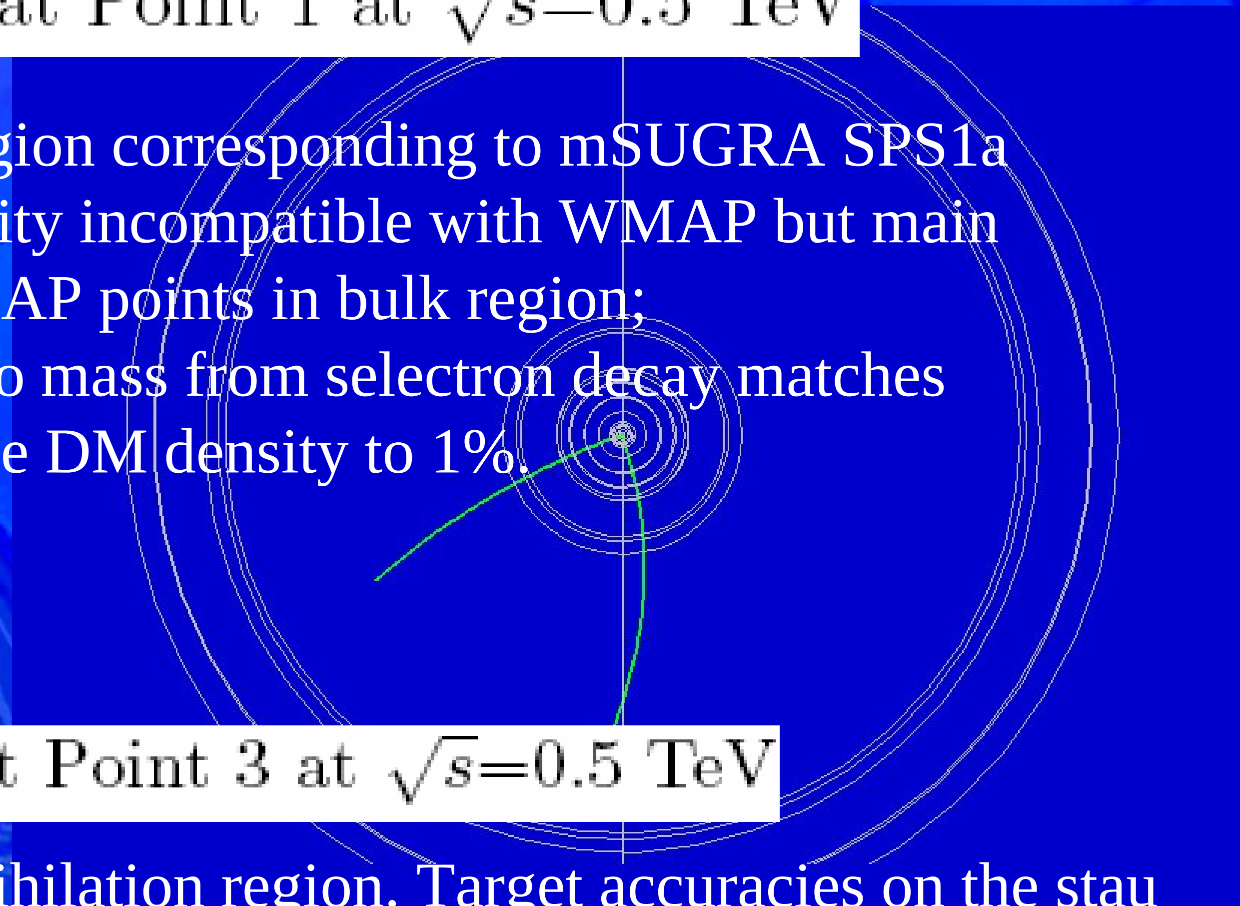






Point	Ref.	m_0 GeV	$m_{1/2}$ GeV	$\tan\beta$	A	$M_{\chi_1^0}$ GeV	$M_{\tilde{\tau}_1}$ GeV	$M_{\chi_2^0}$ GeV	$M_{\chi_3^0}$ GeV	$M_{\tilde{e}_R}$ GeV	M_A GeV	$M_{\chi_1^+}$ GeV	$M_{\chi_2^+}$ GeV
1	SPS1a/LCC1 [15,16]	100	250	10	-100	96.1	133.2	176.4		143	394		
2	LCC2 [16]	3280	300	10	0	107.7		166.3	190	3270	3242		
3	D' [18]	110	525	10	0	220	225	424	655	232	735	424	664
4	LCC4 [16]	380	420	53	0	169.1	195	327	540	412	419	328	553
5	-	230	265	37	0	104	220	200	362	254	312	198	376

$e^+e^- \rightarrow \tilde{e}_R\tilde{e}_R,\ \chi_1^+\chi_1^-$ at Point 1 at $\sqrt{s}$=0.5 TeV



SUSY parameters in bulk region corresponding to mSUGRA SPS1a of LHC/LC study, DM density incompatible with WMAP but main features extends to post-WMAP points in bulk region;
Target accuracy on neutralino mass from selectron decay matches precision needed to determine DM density to 1%.

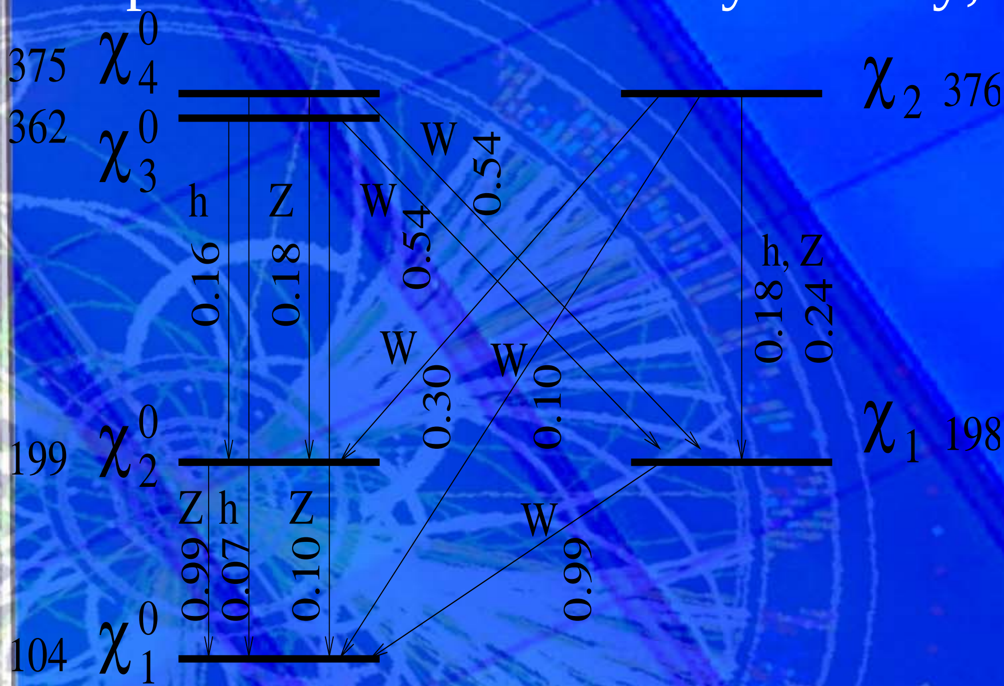
$e^+e^- \rightarrow \tilde{\tau}_1\tilde{\tau}_1,\ \chi_1^+\chi_1^-$ at Point 3 at $\sqrt{s}$=0.5 TeV

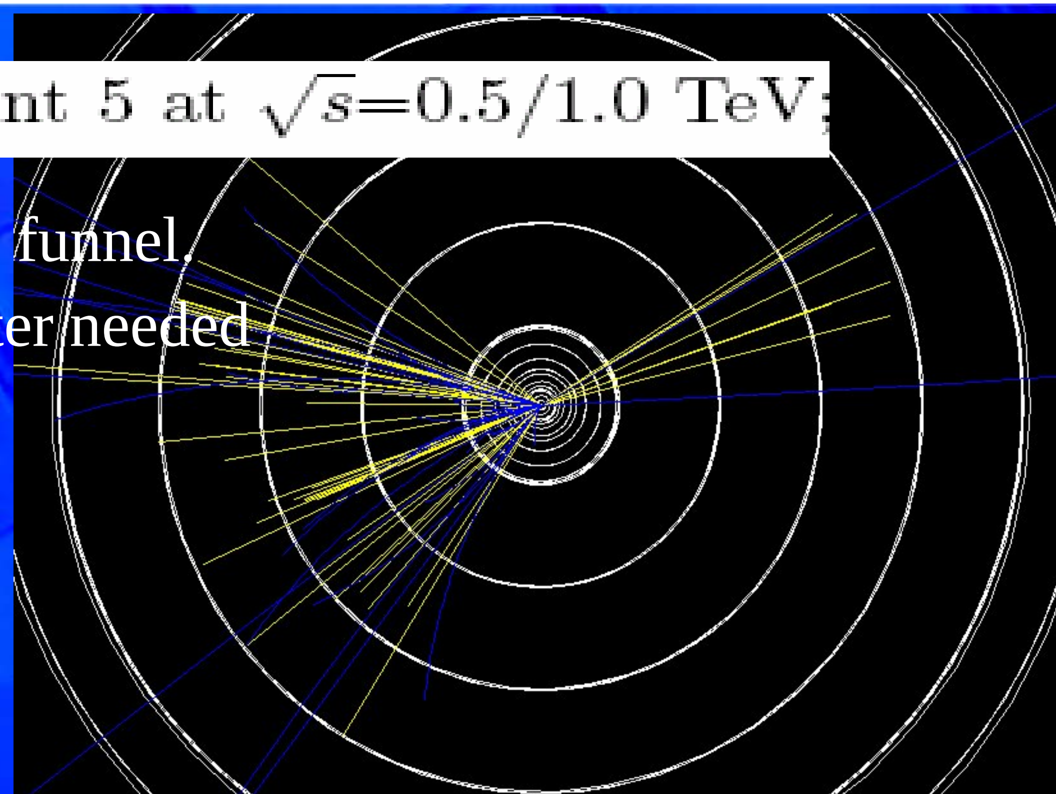
SUSY parameters in co-annihilation region. Target accuracies on the stau and neutralino mass are required to determine DM density to 6% accuracy.
The ee $\tau\tau$ is contaminated by ee -> ee $\tau\tau$ which requires low angle e tagging and, possibly, μ/π id in the very forward instrumentation

$e^+e^- \to \chi_1^+\chi_1^- / \chi_2^0\chi_3^0$ at Point 5 at $\sqrt{s}$=0.5/1.0 TeV;

SUSY parameters in A^0 annihilation funnel.

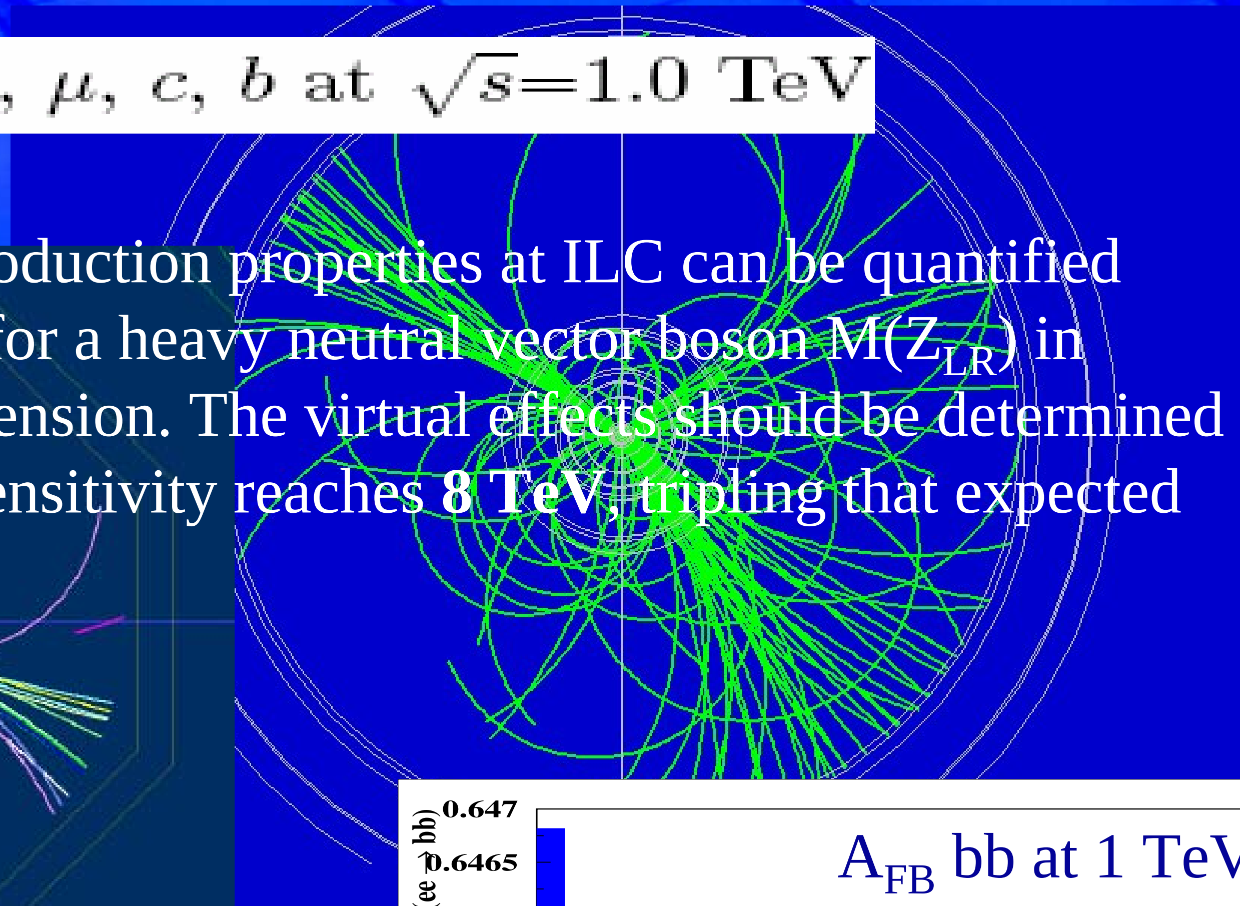
Accurate determination of μ parameter needed to predict relic DM density reliably;

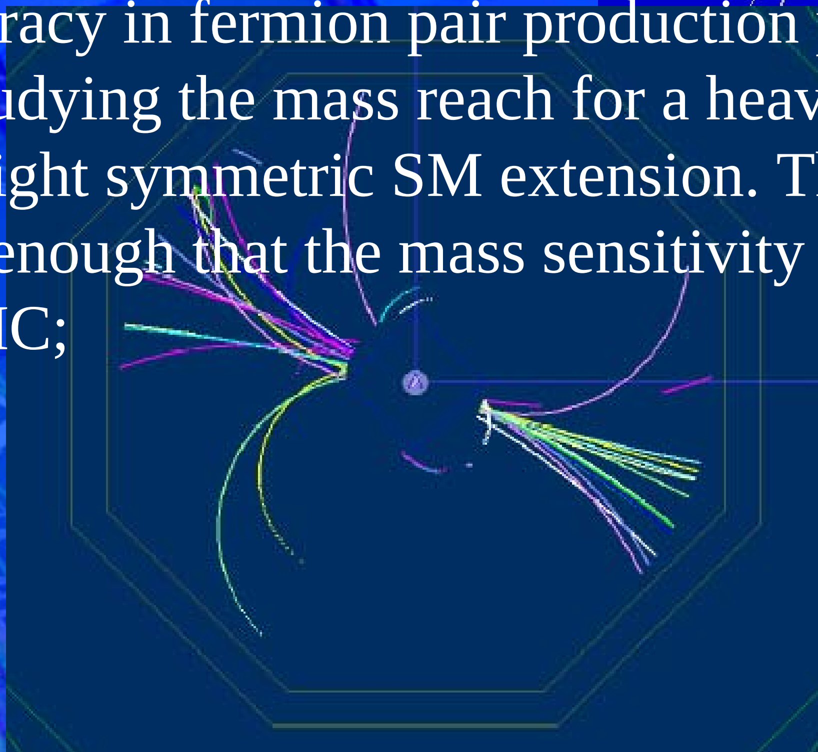




Point 5 produces similar phenomenology to other WMAP-compatible mSUGRA points but requires running at 1 TeV to get full gaugino spectrum and has real W and Z bosons produced in gaugino cascade decays.

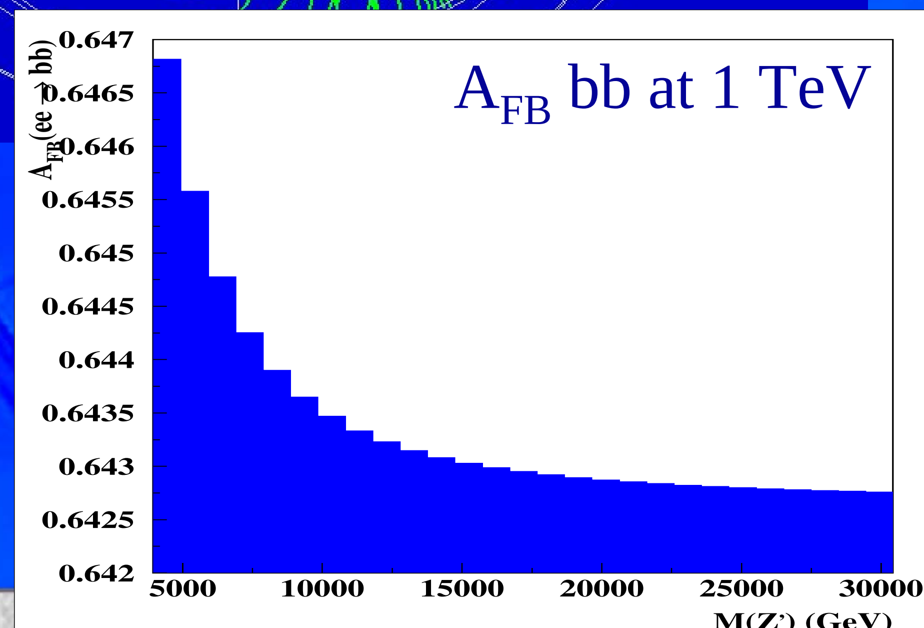
$e^+e^- \rightarrow f\bar{f},\ f = e,\ \mu,\ c,\ b$ at $\sqrt{s}$=1.0 TeV



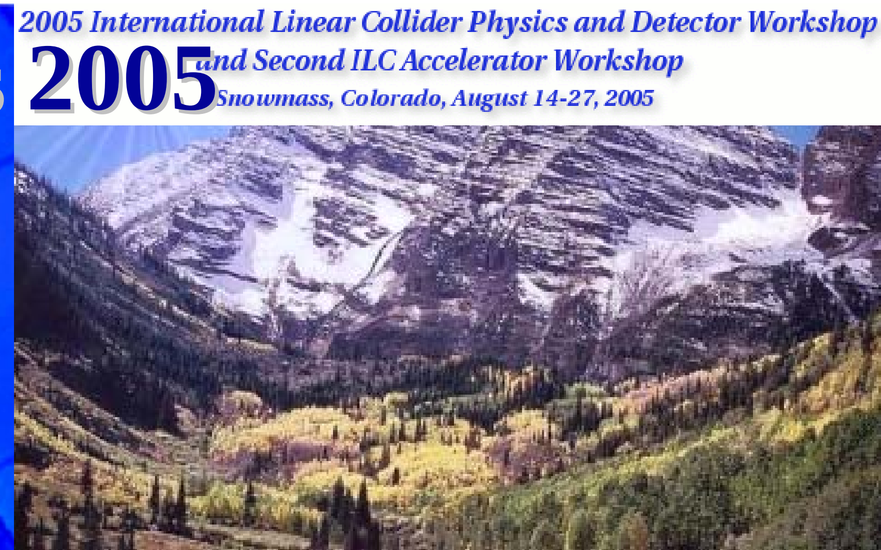


Accuracy in fermion pair production properties at ILC can be quantified by studying the mass reach for a heavy neutral vector boson $M(Z_{LR})$ in left-right symmetric SM extension. The virtual effects should be determined well enough that the mass sensitivity reaches **8 TeV**, tripling that expected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



Benchmarks @ Snowmass



Benchmark Plenary session scheduled on Day-2 (Tuesday) afternoon after Physics Mini-Plenary;

Present final version of Benchmark document, continue discussion with Detector Concept Studies and ILC community on benchmark implementation and plans;

Make available `stdhep` files of selected priority reactions for detector studies;

Discuss future of benchmark panel according to current WWS mandate.

Opening the Discussion

First stage of activity of Benchmark panel nearing completion with the preparation of Benchmark Report in response to WWS charge;

Selection of Physics Benchmarks for the ILC Detectors has generated an "*Embarassment of the Riches*" and choices may need further discussion;

We are seeking suggestions from the ILC community on current choices before finalising the report, which will be distributed ahead of the Snowmass Workshop