Supersymmetric mass precisions for different ILC parameter sets

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In 2002 I was concerned that, if the physics program for ILC were very rich requiring runs at many different energies, the available luminosity would not enable the program to be completed in reasonable time.

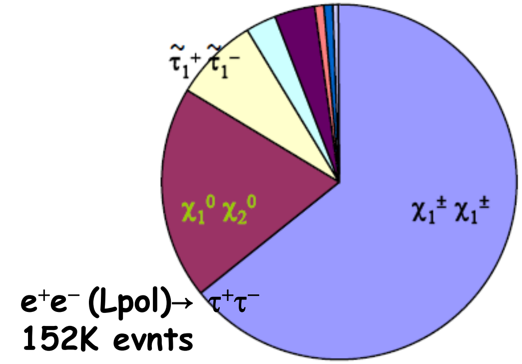
So, I examined the Snowmass SM2 benchmark point (strictly, now disallowed) which had many sparticles accessible to a 500 GeV ILC. I considered final states of 2, 4, and 6 leptons (+ MET) which could often be fed from several different initial sparticle pairs. We focused on sleptons and gauginos and considered e^- polarizations of ±80% and no e^+ polarization.

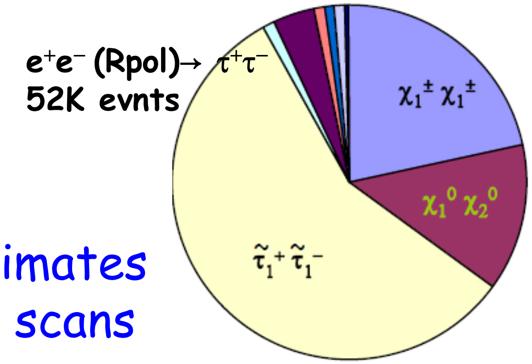
	M	Final state	(BR(%))			
$\tilde{e}_R$	143	$\tilde{\chi}_1{}^0 e$ (100)				
$\tilde{e}_L$	202	$\tilde{\chi}_1{}^0 e$ (45)	$\tilde{\chi}_1{}^\pm \nu_e$ (34)	$\tilde{\chi}_2{}^0 e$ (20)		
$\tilde{\mu}_R$	143	$\tilde{\chi}_1{}^0 \mu$ (100)				
$\tilde{\mu}_L$	202	$\tilde{\chi}_1{}^0 \mu$ (45)	$\tilde{\chi}_1{}^\pm \nu_\mu$ (34)	$\tilde{\chi}_2{}^0 \mu$ (20)		
$\tilde{\tau}_1$	135	$\tilde{\chi}_1{}^0 \tau$ (100)				
$\tilde{\tau}_2$	206	$\tilde{\chi}_1{}^0 \tau$ (49)	$\tilde{\chi}_1{}^- \nu_\tau$ (32)	$\tilde{\chi}_2{}^0 \tau$ (19)		
$\tilde{\nu}_e$	186	$\tilde{\chi}_1{}^0 \nu_e$ (85)	$\tilde{\chi}_1{}^\pm e^\mp$ (11)	$\tilde{\chi}_2{}^0 \nu_e$ (4)		
$\tilde{\nu}_\mu$	186	$\tilde{\chi}_1{}^0 \nu_\mu$ (85)	$\tilde{\chi}_1{}^\pm \mu^\mp$ (11)	$\tilde{\chi}_2{}^0 \nu_\mu$ (4)		
$\tilde{\nu}_\tau$	185	$\tilde{\chi}_1{}^0 \nu_\tau$ (86)	$\tilde{\chi}_1{}^\pm \tau^\mp$ (10)	$\tilde{\chi}_2{}^0 \nu_\tau$ (4)		
$\tilde{\chi}_1{}^0$	96	stable				
$\tilde{\chi}_2{}^0$	175	$\tilde{\tau}_1 \tau$ (83)	$\tilde{e}_R e$ (8)	$\tilde{\mu}_R \mu$ (8)		
$\tilde{\chi}_3{}^0$	343	$\tilde{\chi}_1{}^\pm W^\mp$ (59)	$\tilde{\chi}_2{}^0 Z$ (21)	$\tilde{\chi}_1{}^0 Z$ (12)	$\tilde{\chi}_1{}^0 h$ (2)	
$\tilde{\chi}_4{}^0$	364	$\tilde{\chi}_1{}^\pm W^\mp$ (52)	$\tilde{\nu}\nu$ (17)	$\tilde{\tau}_2 \tau$ (3)	$\tilde{\chi}_{1,2} Z$ (4)	$\tilde{\ell}_R \ell$ (6)
$\tilde{\chi}_1{}^\pm$	175	$\tilde{\tau}_1 \tau$ (97)	$\tilde{\chi}_1{}^0 q\bar{q}$ (2)	$\tilde{\chi}_1{}^0 \ell\nu$ (1.2)		
$\tilde{\chi}_2{}^\pm$	364	$\tilde{\chi}_2{}^0 W$ (29)	$\tilde{\chi}_1{}^\pm Z$ (24)	$\tilde{\ell}\nu_\ell$ (18)	$\tilde{\chi}_1{}^\pm h$ (15)	$\tilde{\nu}_\ell \ell$ (8)

Slepton and gaugino masses in SM2 scenario

1. Full energy running for end points:

We called for substantial running at full energy to get sparticle masses from the end points in energy of visible decay products. The $\mu^+\mu^-$ +ME final state is dominated by smuon pair production. But for the $\tau\tau$ ME final state, many different sparticle pairs contribute. Here one needs to compare (E,θ) distributions of final state τ 1 prongs to disentangle the several initial sparticles.





2. Scans at other energies: After obtaining reasonable estimates of sparticle masses from end points, we asked for threshold scans of some sparticle pairs for more accurate mass determinations.

2002 study assumed $L \sim E_{cm}$

To dramatize the point of ILC flexibility, we also requested one run at E*=580 GeV (trade $\mathcal{L}$ for E) to access $\tilde{\chi}_1^\pm\,\tilde{\chi}_2^\pm$ production, and a run with $e^-\,e^-$ to better measure the $\tilde{e}_R$ mass.

We simply scaled mass resolutions from previous studies to the luminosities of our run scenario, but accounted for mass precision degradation due to the overlapping sources of a given final state.

The 2006 RDR already differed from simple $\mathcal{L} \sim E$ scaling. The new 2010 Strawman Baseline, updated from the 2009 version, (**here called "NB"**) parameter set differs further and has subsets according to whether a travelling focus (TF) at the IP is implemented or not.

For NB the beamstrahlung is large, so we consider both the full delivered luminosity (**totL**) and that delivered within 1% of the nominal energy (**pkL**), since particularly for threshold scans, the lower energy collisions are of less use.

Ecm /	**200**	**250**	**350**	**500**
Ecm scaling	0.80	1.00	1.40	2.00
RDR		0.75	1.20	2.00
NB TF totL	0.50	0.80	1.00	2.00
NB TF pkL	0.50	0.71	0.77	1.44
NB noTF totL	0.50	0.70	0.80	1.50
NB noTF pkL	0.50	0.67	0.70	1.10

$\mathcal{L}$ vs E for different parameter sets (10^{34} cm^{-2} s^{-1})

NB parameters are taken from tdp2_machine_parameters_stamp.pdf at http://ilc-edmsdirect.desy.de/ild-edmsdirect/document.jsp?edmsid=*925325

The original study considered a run of 6 years + 1 more for initial commissioning, giving $\int \mathcal{L}dt$ = 1000 fb^{-1}, where $\mathcal{L}$ is the equivalent luminosity that would have been accumulated if the time were spent at E_{cm} = 500 GeV. $\mathcal{L}^*$ is the actual luminosity delivered at the energy desired (for E_{cm} scaling).

Year	1	2	3	4	5	6	7
$\mathcal{L}$	10	40	100	150	200	250	250

We proposed a set of runs starting with some running at full energy to obtain end point measurements that roughly define the sparticle masses, followed by threshold scans for various sparticle pair productions.

Beams	Energy	Pol.	$\mathcal{L}^*$	$\mathcal{L}$	comments
$e^+ e^-$	500	L/R	335	335	top energy for end point measurements
$e^+ e^-$	M_Z	L/R	10	45	calibrate with Z's (4 times)
$e^+ e^-$	270	L/R	100	185	scan $\chi_1^0\chi_2^0$ and stau1 pair thresholds
$e^+ e^-$	285	R	50	85	scan smuonR pair threshold
$e^+ e^-$	350	L/R	40	60	scan ttbar, selectronR-selectronL and $\chi_1^+\chi_1^-$ thresholds
$e^+ e^-$	410	L	60	75	scan stau2 pair and smuonL pair thresholds
$e^+ e^-$	580	L/R	90	120	sit above $\chi_1^+\chi_2^-$ threshold for χ_2^+ mass
$e^- e^-$	285	RR	10	95	scan with e^-e^- for selectronR mass

Note: this scenario did not provide for Higgs studies at the peak of the ZH cross section, but relied on Higgs samples taken from all energies.

The 2002 study estimated the sparticle mass precisions from both the end point and threshold scans, accounting for the overlap of several sources in a given final state, using the E_{cm} scaling.

Disclaimers:

We do not claim that these uncertainties are fully correct; we bootstrapped from studies available at the time, and made some assumptions on how to disentangle a particular sparticle pair from the several reactions feeding a given final state.

And of course there is no reason to claim that the SM2 benchmark resembles what Nature chooses!

But we can use these results to estimate the **relative** change as we go from E_{cm} scaling to some other parameter set.

	δM (Ecm scaling)		
Sparticle	**endpt**	**scan**	**total**
selectron_R	0.19	0.02	0.02
selectron_L	0.27	0.30	0.20
smuon_R	0.08	0.13	0.07
smuon_L	0.70	0.76	0.51
stau_1	~1-2	0.64	0.64
stau_2		1.10	1.10
sneutrino_e	~1	--	~1
sneutrino_mu	~7	--	~7
sneutrino_tau	--	--	--
chi1^0	0.07	--	0.07
chi2^0	~1-2	0.12	0.12
chi3^0	8.50	--	8.50
chi4^0	--	--	--
chi1^+	~1-2	0.18	0.18
chi2^+	4.00	--	4.00

We have now revisited the mass precisions expected for the RDR and new NB parameters, assuming that the mass precisions scale as

$$\sqrt{\mathcal{L}(E_{cm}\text{ scaling})/\mathcal{L}(\text{new params})}$$

The table shows the total uncertainties (sum in quadrature of the end point and threshold scan uncertainties) and increase relative to the E_{cm} scaling case.

sparticle	Ecm scale	RDR		NB TF totL		NB TF pkL		NB noTF totL		NB noTF pkL	
	δM(GeV)	δM(GeV)	rel to Ecm	δM(GeV)	rel to Ecm	δM(GeV)	rel to Ecm	δM(GeV)	rel to Ecm	δM(GeV)	rel to Ecm
selectron_R	0.02	0.02	0%	0.02	0%	0.02	0%	0.02	0%	0.02	0%
selectron_L	0.20	0.21	3%	0.21	7%	0.25	25%	0.25	22%	0.28	38%
smuon_R	0.07	0.07	3%	0.07	3%	0.08	20%	0.08	18%	0.09	33%
smuon_L	0.51	0.52	2%	0.53	4%	0.62	21%	0.61	19%	0.70	36%
stau_1	0.64	0.82	29%	0.73	13%	0.78	22%	0.78	22%	0.81	26%
stau_2	1.10	1.25	13%	1.25	13%	1.34	22%	1.35	22%	1.39	26%
sneutrino_e	~1	~1		~1		~1		~1		~1	
sneutrino_mu	~7	~7		~7		~7		~7		~7	
sneutrino_tau	--	--		--		--		--		--	
chi1^0	0.07	0.07	0%	0.07	0%	0.08	18%	0.08	15%	0.09	35%
chi2^0	0.12	0.14	13%	0.14	13%	0.15	22%	0.15	22%	0.15	26%
chi3^0	8.50	8.50	0%	8.50	0%	10.02	18%	9.81	15%	11.49	35%
chi4^0	--	--		--		--		--		--	
chi1^+	0.18	0.19	8%	0.21	18%	0.24	35%	0.24	32%	0.25	41%
chi2^+	4.00	4.00	0%	4.00	0%	4.71	18%	4.62	15%	5.41	35%

Comments:

- The mass precisions with the RDR parameter set degrade only a few % relative to E_{cm} scaling (we did not consider the effect of the beamstrahlung for either the E_{cm} scaling or RDR cases).

- For the NB parameters with travelling focus, mass precisions degrade by ~20% relative to E_{cm} scaling (considering only $\mathcal{L}$ within 1% of nominal E).

- For NB parameters with no travelling focus, mass precisions degrade by ~35% relative to E_{cm} scaling ($\mathcal{L}$ within 1% of E_{nom}).

- For the NB parameters, mass precisions using only the luminosity delivered within 1% of nominal energy are degraded by ~15% from those calculated using the total delivered luminosity.

- In the spirit of these rough estimates, the run time for equal mass precision scales as $(\mathcal{L}/\mathcal{L}_{\text{Ecm scaling}})^2$

Supplementary tables (SBmod == NB)

	δM (Ecm scaling)			δM (SBmodified)			δM (RDR)		
Sparticle	**endpt**	**scan**	**total**	**endpt**	**scan**	**total**	**endpt**	**scan**	**total**
selectron_R	0.19	0.02	0.02	0.19	0.02	0.02	0.19	0.02	0.02
selectron_L	0.27	0.30	0.20	0.27	0.35	0.21	0.27	0.32	0.21
smuon_R	0.08	0.13	0.07	0.08	0.15	0.07	0.08	0.15	0.07
smuon_L	0.70	0.76	0.51	0.70	0.82	0.53	0.70	0.79	0.52
stau_1	~1-2	0.64	0.64	~1-2	0.73	0.73	~1-2	0.82	0.82
stau_2		1.10	1.10		1.25	1.25		1.25	1.25
sneutrino_e	~1	--	~1	~1	--	~1	~1	--	~1
sneutrino_mu	~7	--	~7	~7	--	~7	~7	--	~7
sneutrino_tau	--	--	--	--	--	--	--	--	--
chi1^0	0.07	--	0.07	0.07	--	0.07	0.07	--	0.07
chi2^0	~1-2	0.12	0.12	~1-2	0.14	0.14	~1-2	0.14	0.14
chi3^0	8.50	--	8.50	8.50	--	8.50	8.50	--	8.50
chi4^0	--	--	--	--	--	--	--	--	--
chi1^+	~1-2	0.18	0.18	~1-2	0.21	0.21	~1-2	0.19	0.19
chi2^+	4.00	--	4.00	4.00	--	4.00	4.00	--	4.00

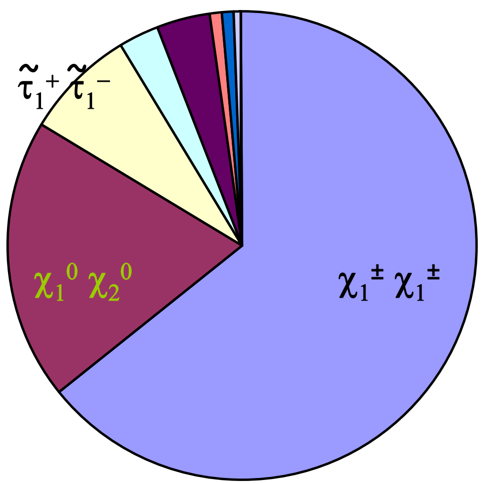
Decomposition of uncertainties from end point and scan measurements

sparticle	Ecm scaling	RDR	SB TF fullL	SB TF peakL	SB noTF fullL	SB noTF peakL
selectron_R	0.02	0.02	0.02	0.02	0.02	0.02
selectron_L	0.20	0.21	0.21	0.25	0.25	0.28
smuon_R	0.07	0.07	0.07	0.08	0.08	0.09
smuon_L	0.51	0.52	0.53	0.62	0.61	0.70
stau_1	0.64	0.82	0.73	0.78	0.78	0.81
stau_2	1.10	1.25	1.25	1.34	1.35	1.39
sneutrino_e	~1	~1	~1	~1	~1	~1
sneutrino_mu	~7	~7	~7	~7	~7	~7
sneutrino_tau	--	--	--	--	--	--
chi1^0	0.07	0.07	0.07	0.08	0.08	0.09
chi2^0	0.12	0.14	0.14	0.15	0.15	0.15
chi3^0	8.50	8.50	8.50	10.02	9.81	11.49
chi4^0	--	--	--	--	--	--
chi1^+	0.18	0.19	0.21	0.24	0.24	0.25
chi2^+	4.00	4.00	4.00	4.71	4.62	5.41

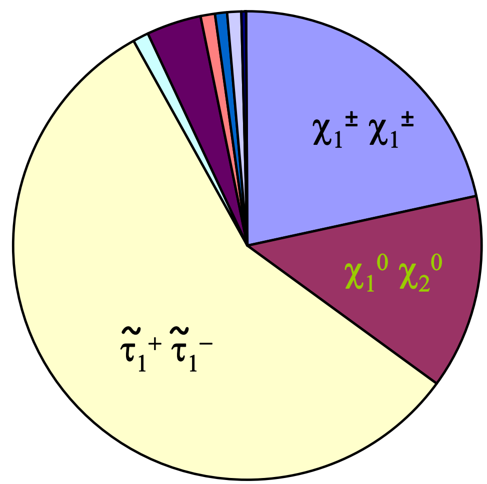
Sparticle mass uncertainties for different ILC parameters

Reaction	$N(e_L)$	$N(e_R)$
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	97,440	11,229
$\tilde{\chi}_1^0\tilde{\chi}_2^0$	29,424	6,846
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	11,792	29,547
$\tilde{\tau}_2^+\tilde{\tau}_2^-$ (via $\tilde{\chi}_1^0\tau$)	5,716	2,027
$\tilde{e}_L^+\tilde{e}_L^-$	3,905	625
$\tilde{\mu}_L^+\tilde{\mu}_L^-$	1,395	428
$\tilde{\tau}_2^+\tilde{\tau}_2^-$ (via $\tilde{\chi}_1^\pm\nu_\tau$)	1,004	356
$\tilde{\tau}_1^\pm\tilde{\tau}_2^\mp$	805	644
$\tilde{\chi}_1^0\tilde{\chi}_3^0$	71	85

Number of events (L and R e^- polztn) in the $\tau\tau$+ME final state from different reactions at 500 GeV (335 fb^{-1})



e^+e^- (left)$\rightarrow \tau^+\tau^-$
152K evnts



e^+e^- (right)$\rightarrow \tau^+\tau^-$
52K evnts