SUSY WG
Detector and simulation issues

2005-Aug-25

Snowmass

SUSY mini-plenary

K. Kawagoe / Kobe-U

Talks related to detector and simulation at SUSY session

- Only two talks, Experimentalists have been busy for detector concepts and their R&D studies...
- But they were really excellent:
  - Marco Battaglia
    "Detector and simulation issues of SUSY searches at ILC“
  - Sonja Hillert
    "Physics potential of vertex detector as function of beam pipe radius“
  - See slides on the web for details.

Detector and simulation issues

- Detector coverage
  - Missing P_T measurement (cracks, forward region)
  - Veto $\gamma\gamma$ background (far forward calorimeter)
- Lepton-ID
  - Reconstruction of low momentum tracks
  - Electron/muon identification
  - Tau identification (VTX tag)
  - Full reconstruction of tau decays for detailed stau study
- Jet reconstruction
  - Jet energy resolution with PFA
  - b-tag and c-tag capability
  - Jet charge determination

Benchmark panel: physics processes for detector concept studies

- See Marco's talk at mini-plenary last week
- Draft V2 was distributed yesterday
- Benchmark panel will provide four vectors of benchmark processes
- Each ILC detector concept group will use them for optimization of the detector concept.

SUSY benchmark points

- SUSY points, experimentally and theoretically (cosmologically) well motivated, are selected for detector optimization.

Table I: Model parameters and particle masses for benchmark points taken as points in the mSUGRA model. The spectrum for these points have been computed using ISAJET 7.69 [4]. The benchmark point 5 has $\mu < 0$; all other points have $\mu > 0$. Point 2 has $m_t = 175$ GeV; all other points have $m_t = 178$ GeV.

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]	525	110	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
6	[20]		300	10	0		219						

Taken from draft v2

SUSY

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	$\mathrm{M_{recoil}}$, 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}

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

SUSY (priority)

Process	**V**ertex	**T**racking		**C**alorimetry		**F**wd		**Very** Fwd	**I**ntegration					**P**ol.
	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							

$e^+e^- \to \tilde{e}_R\tilde{e}_R$ 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%.

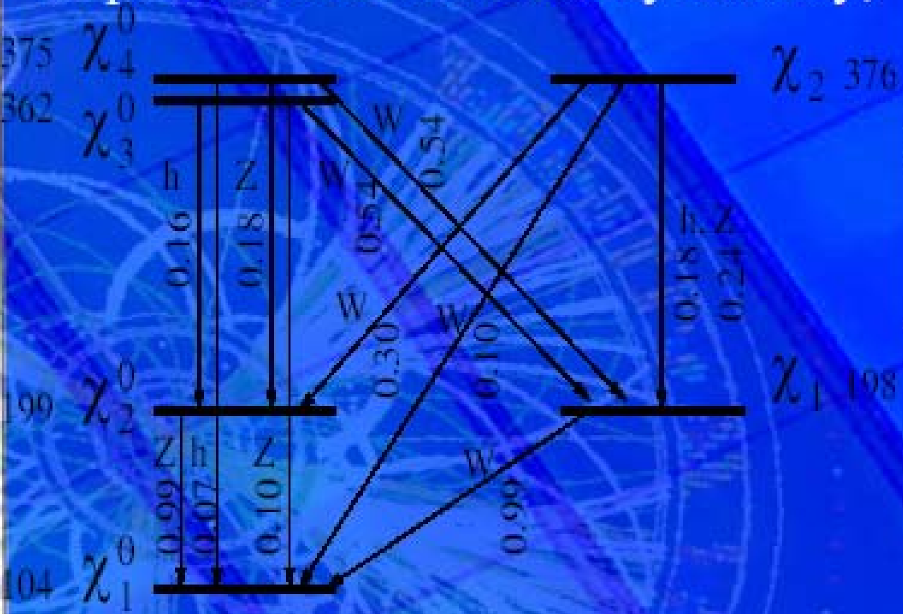
$e^+e^- \to \tilde{\tau}_1\tilde{\tau}_1$, at Point 3 at $\sqrt{s}$=0.5 TeV

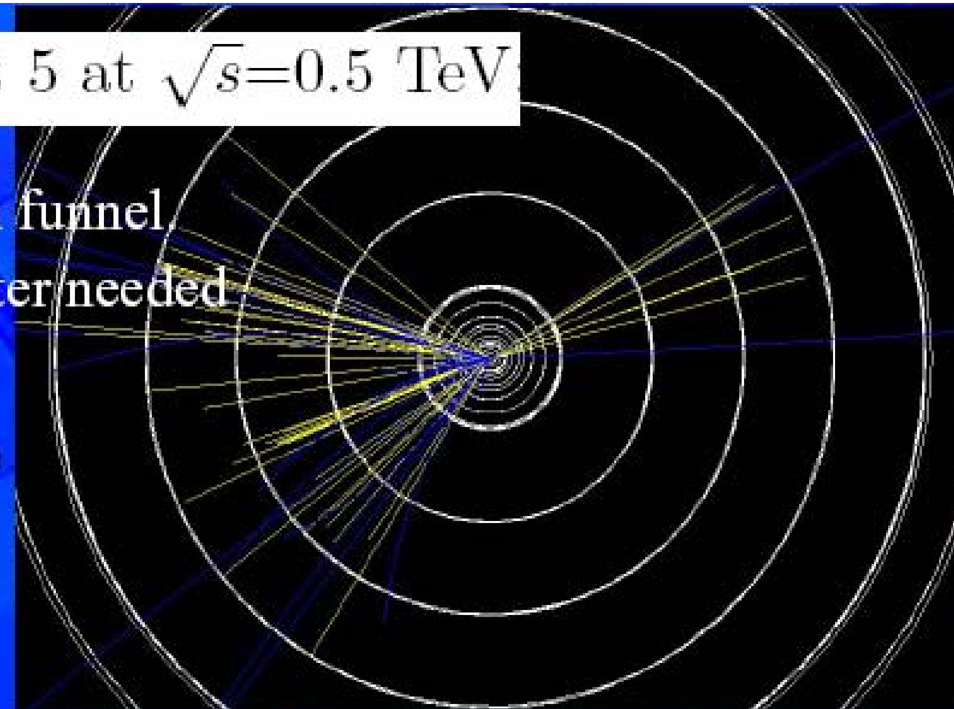
SUSY parameters in co-annihilation region. Target accuracies on the stau and neutralino mass are required to determine DM density to 6% accuracy.
The ee ττ is contaminated by ee -> ee ττ which requires low angle e tagging and, possibly, μ/π id in the very forward instrumentation

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

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.

Simulation of “new” SUSY points

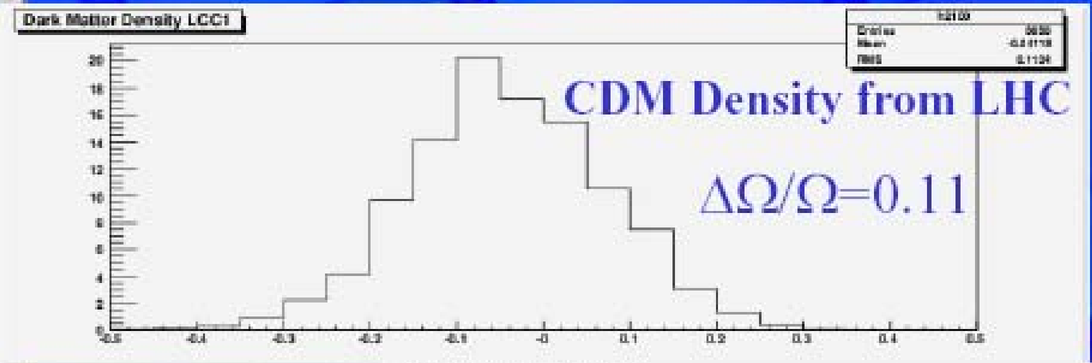
- New SUSY points to be agreed at Snowmass ?
  - For experimentalists, the points should have new and challenging signatures with respect to the old points that have been studied.
- Once the new points are determined,
  - Generate events and perform fast detector simulation with help of simulation WG (Norman Graf et al.)
  - Explore what we can extract from the simulated events:
    - Discovery potential against background
    - Measurement of mass, spin, decay BRs of Sparticles
  - Perform full simulation studies if needed.
- Call for Volunteers !!
- Results → New requests to detector concept studies

Summary

- SUSY points proposed by Benchmark panel
  - Each ILC detector concept group will use them for optimization of the detector concept.
- New SUSY points proposed by SUSY WG at Snowmass
  - Simulation studies should be started soon
  - Need volunteers !

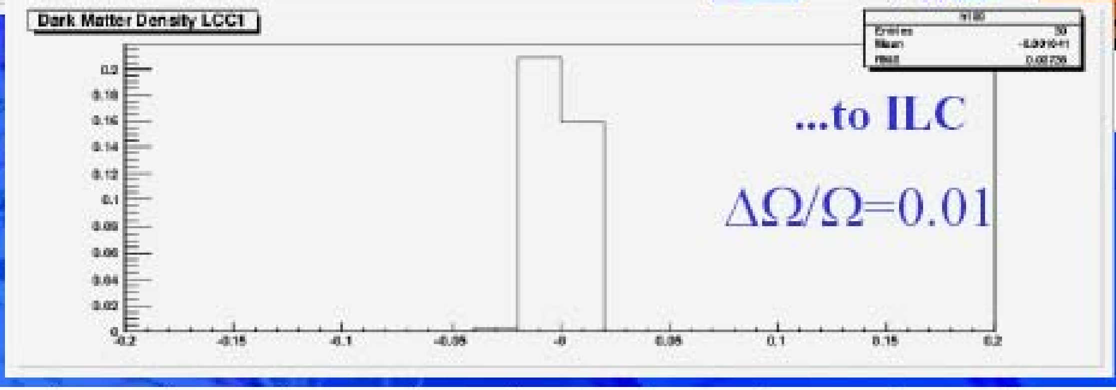
Backup

SUSY Benchmarks and the Cosmology-ILC connection



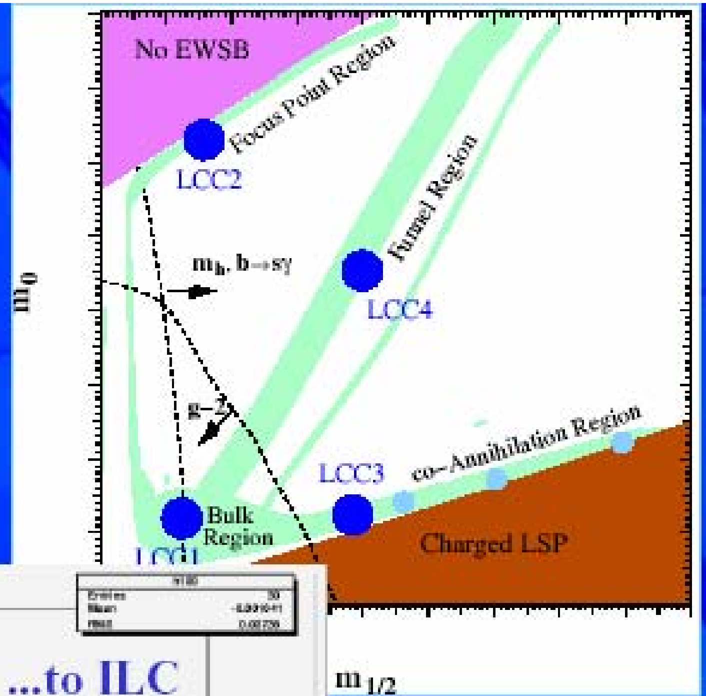
CDM Density from LHC

$\Delta\Omega/\Omega$=0.11



...to ILC

$\Delta\Omega/\Omega$=0.01



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		
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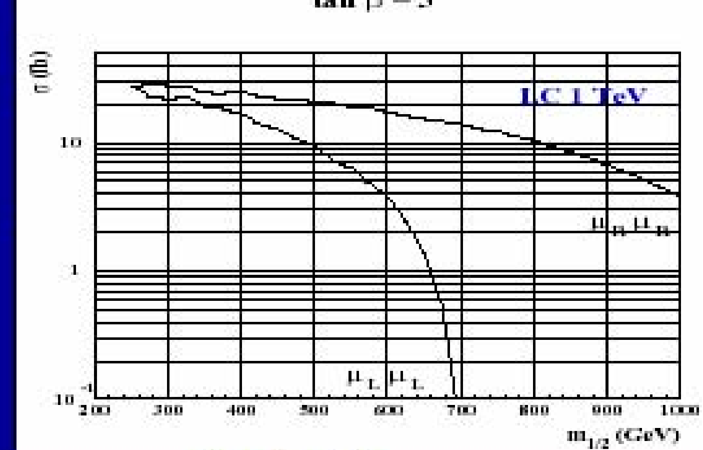
5	-	230	265	37	0	104	220	200	362	254	312	198	376

Slepton Signatures at low p_{lepton}

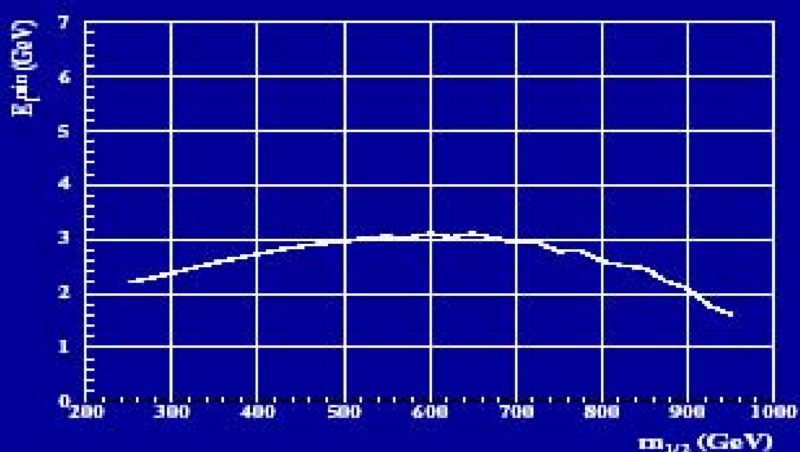
✧ Highest reach in $m_{1/2}$ from $e^+e^- \to \tilde{\ell}^+_R \tilde{\ell}^-_R$: ILC at $\sqrt{s}$=1 TeV covers upper limit in $m_{1/2}$ for $\tan\beta$ = 5 - 10 with $\sigma(e^+e^- \to \tilde{\ell}^+\tilde{\ell}^-) = \mathcal{O}$(1-10 fb);

✧ along WMAP line $\tilde{\ell}_R$ becomes nearly degenerate with χ^0_1: tuning E_{beam} for sizeable σ softens E^{min}_ℓ:

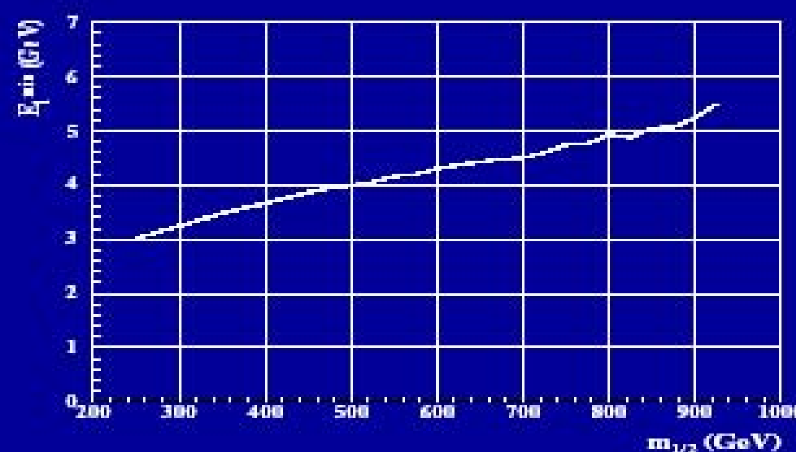
$$E^{min}_\ell = \frac{1}{2} M_{\tilde{\ell}} \left(1 - \frac{M^2_{\tilde{\chi}^0_1}}{M^2_{\tilde{\ell}}}\right) \gamma \left(1 - \sqrt{1 - \frac{M^2_{\tilde{\ell}}}{E^2_{beam}}}\right);$$



tan β = 5



tan β = 10



Slepton Signatures at low p_{lepton}

✧ Lepton id. critical at lower endpoint due to:

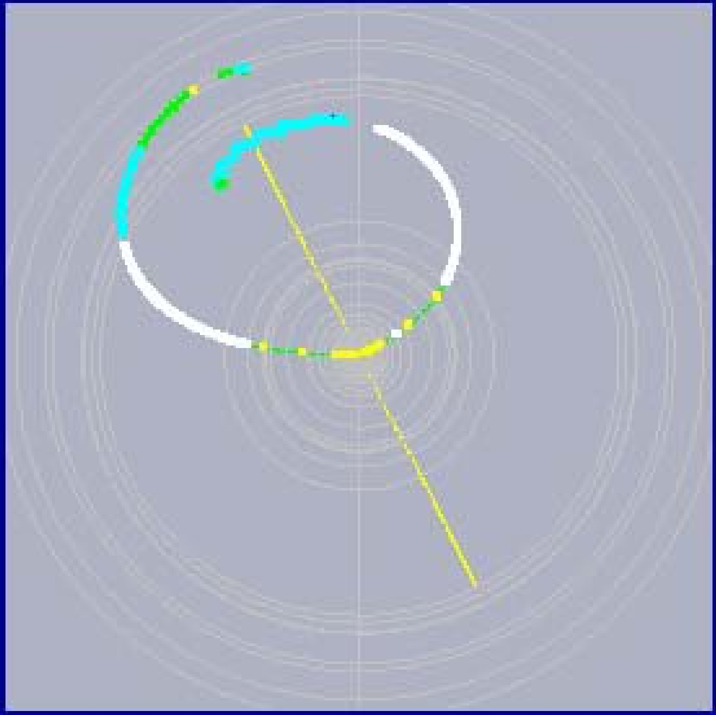
1. Intrinsic Momentum Cut-off
2. $\gamma\gamma \to$ hadrons Background

✧ Momentum cut-off p_t^{min} defined by radius R_{det} of ECal, HCal and Muon Chambers and solenoidal field B:

$$p_t^{min}[\text{GeV}] = \frac{R_{det}[\text{m}]}{0.3B[\text{Tesla}]}$$

✧ $\gamma\gamma \to$ hadrons bkg becomes relevant if only one lepton can be tagged

WIRED DISPLAY OF $e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^-$ AT 1 TEV AT LOWER ENDPOINT
$\tan\beta = 5$, $m_{1/2} = 600$, $m_0 = 118$



Lepton Identification

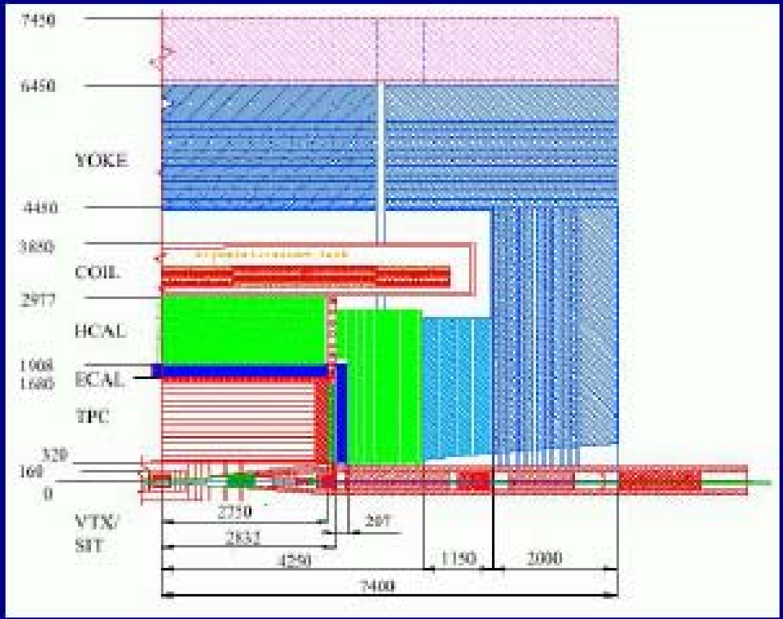
Muons

✧ Identify through hits in Muon Chambers and Energy deposited in HCAL

	Large Det
B [Tesla]	4
	p_t^{min} (GeV)
μ μCh	4.2
μ HCAL	2.0
e ECAL	1.5
e dE/dx	0.7

Electrons

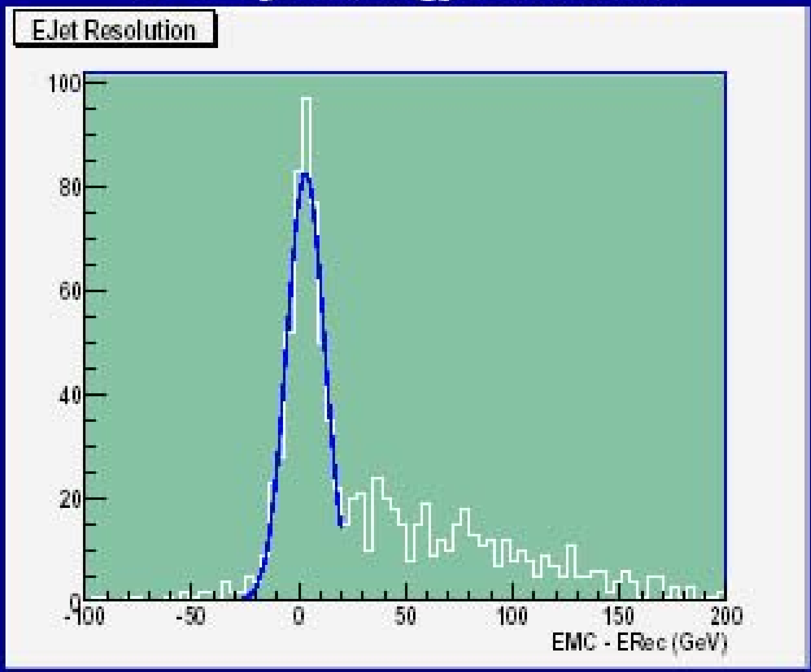
✧ Identify through shower in ECAL and dE/dx in Main Tracker



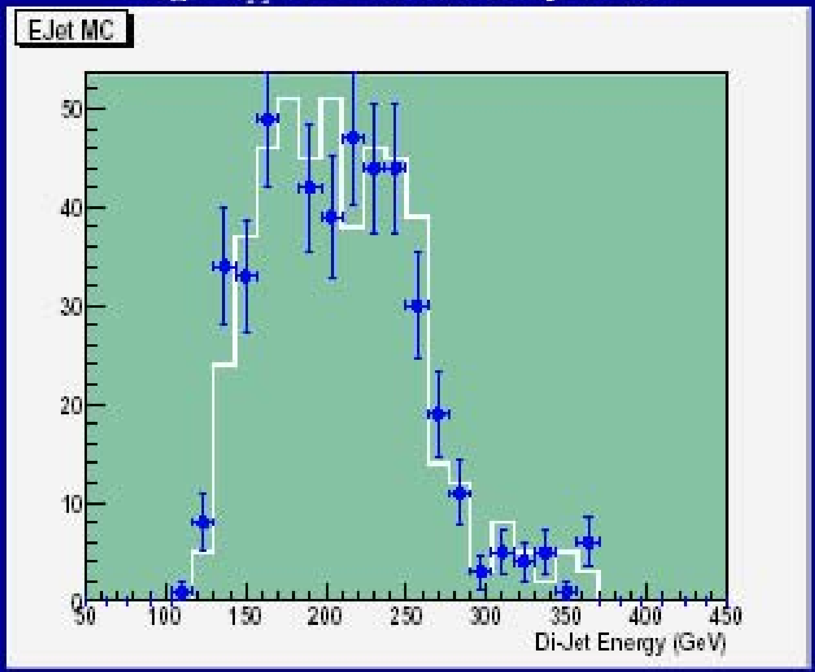
Jet Energy Resolution

- Study $\tilde{\chi}^0_{3,4} \to Z^0 \tilde{\chi}^0_1$ at LCC4 in funnel region;
- Significant decay branching fractions to real Z^0, requires reconstruction of E_{Z^0} to determine the χ_3 and χ_4 mass and the μ parameter, which is essential in the determination of $\Omega_\chi h^2$;
- Fast simulation of decays with $Z^0 q\bar{q}$, `Simdet 4.0` whith $\delta E_{jet}/E_{jet} = 30\%/\sqrt{Ejet}$;

Z^0 Di-jet Energy Resolution



$E_{Z^0 \to q\bar{q}}$ for Gaussian portion



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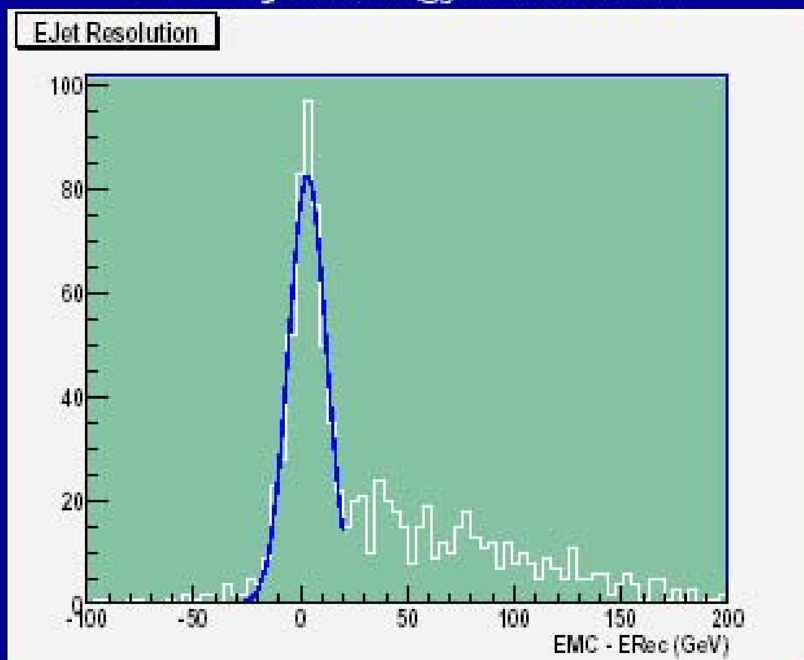
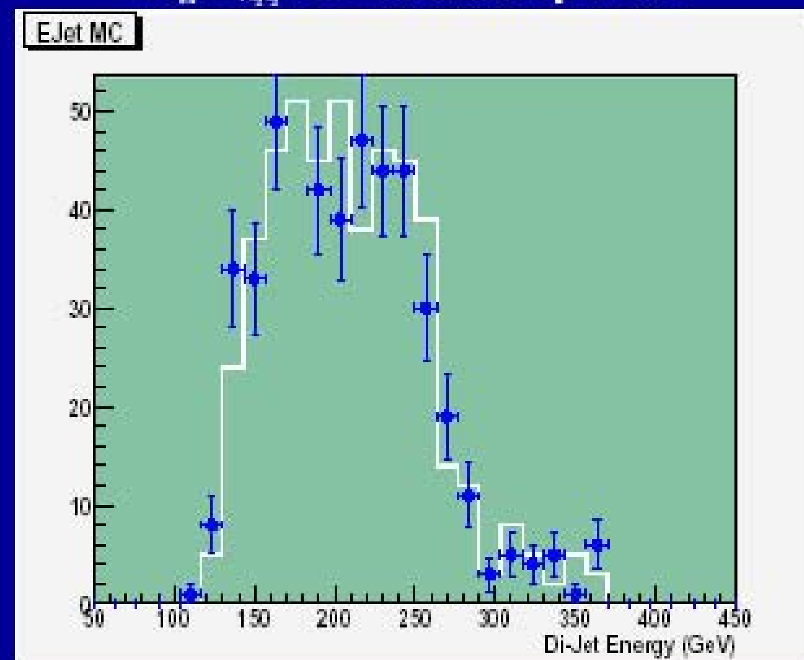
Z^0 Di-jet Energy Resolution



$E_{Z^0 \to q\bar{q}}$ for Gaussian portion

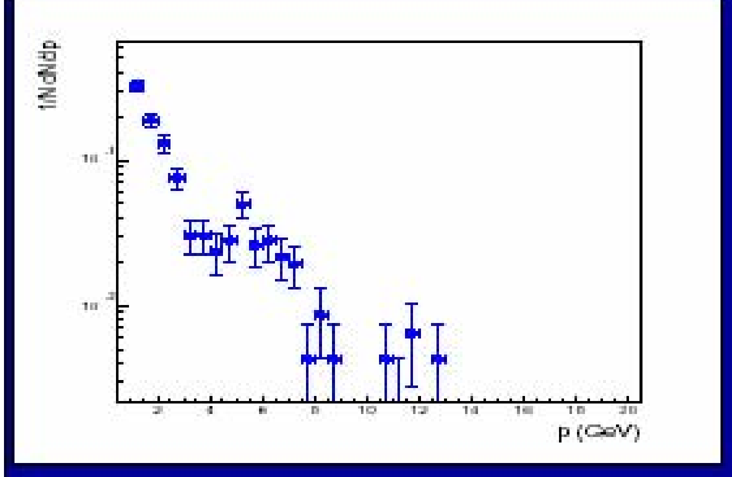


$\gamma\gamma \to$ hadrons **Background**

- Estimate rate from $\gamma\gamma \to \mathrm{hadrons}$ background

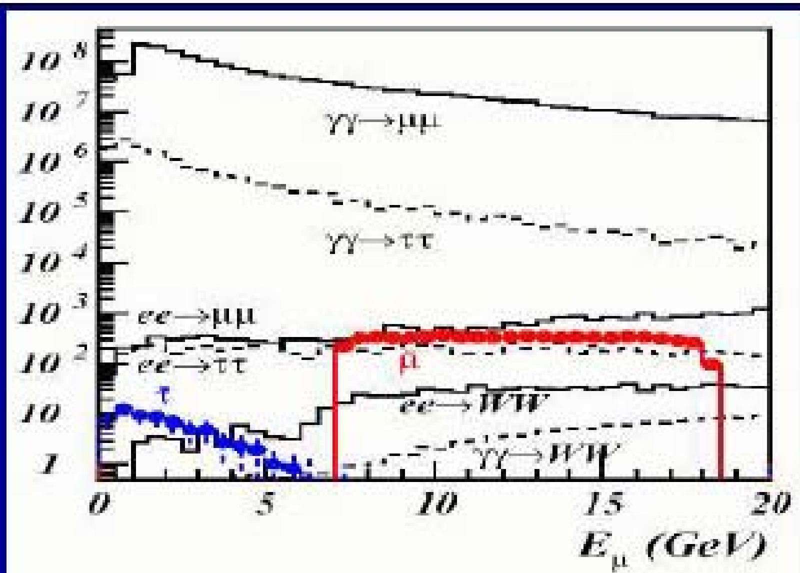
	TESLA 0.8 TeV
$\mathcal{L}$ (fb BX^{-1})	2.7×10^{-9}
$N_{\gamma\gamma}$ BX^{-1}	0.40
$N_{\gamma\gamma}$ 500 fb^{-1}	0.75×10^{11}

- Sample generated with `GuineaPig` + `Pythia` for TESLA at 800 GeV;
- Suppress $\gamma\gamma \to \mathrm{hadrons}$ bkg using event shape and kinematical variables;
- Assume $\epsilon(\pi \to \ell) \simeq 0.10$ at low p (M. Piccolo)

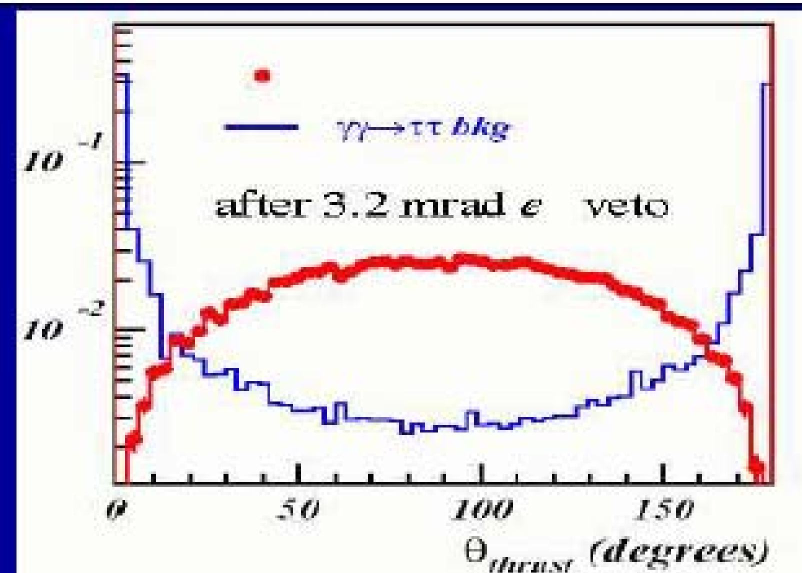


Evts/500 fb^{-1}	1.5 - 2.5 GeV	2.5 - 5 GeV
$2\ \ell + E_{miss}$	$\sim$ 22k	$\sim$ 7 k

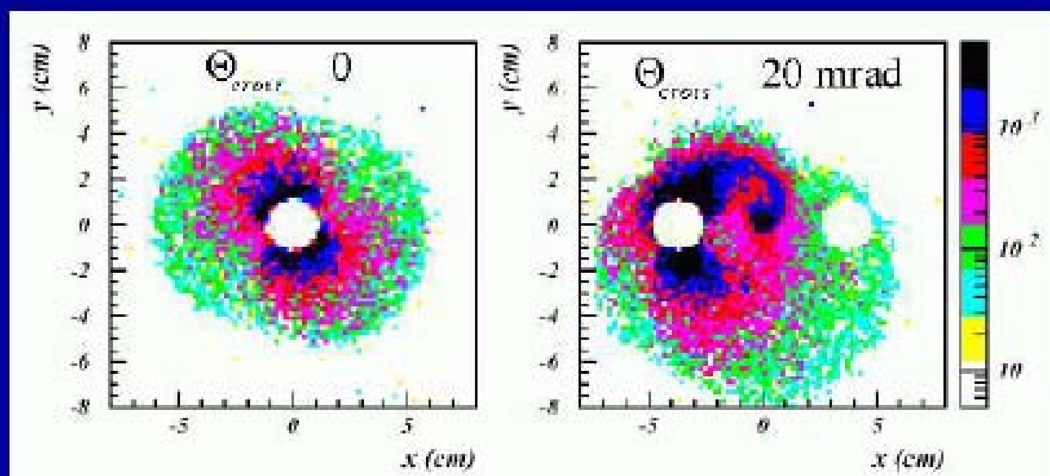
- Important to tag fwd electrons down to small angles to suppress $\gamma\gamma \to \mathrm{hadrons}$.



$\gamma\gamma \to \mu\mu$
$\gamma\gamma \to \tau\tau$
$ee \to \mu\mu$
$ee \to \tau\tau$
μ
τ
$ee \to WW$
$\gamma\gamma \to WW$
E_μ (GeV)



$\gamma\gamma \to \tau\tau$ bkg
after 3.2 mrad e veto
Θ_{thrust} (degrees)



Θ_{cross} 0
Θ_{cross} 20 mrad
y (cm)
x (cm)