ILC/CLIC Benchmark Studies

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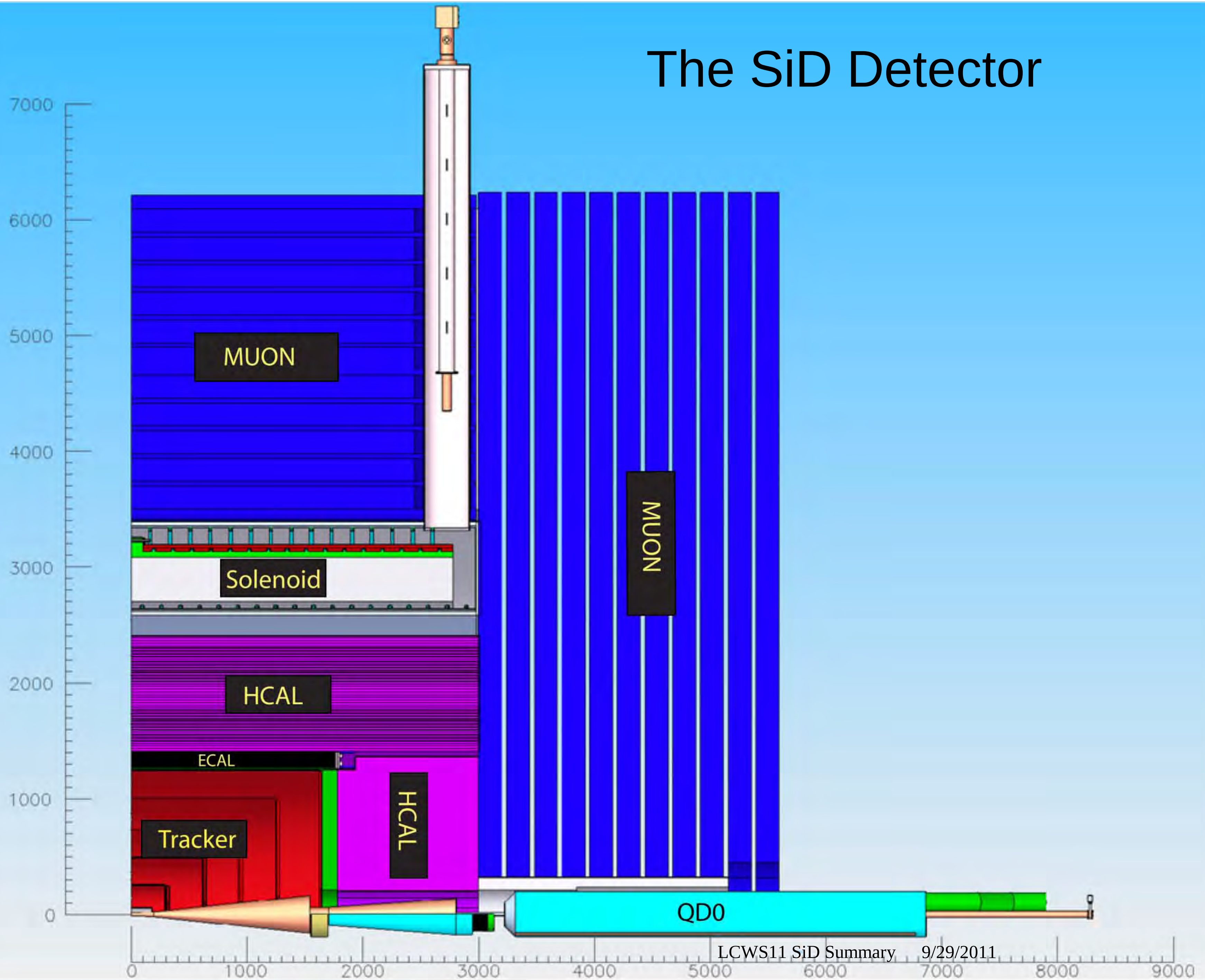
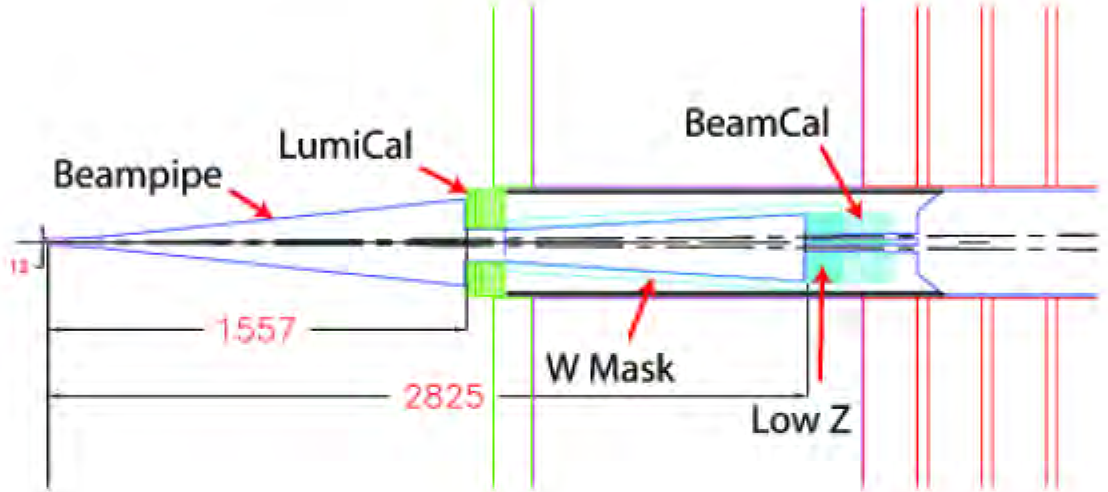
Physics Overview vs. e+e- Energy

$\sqrt{s}$	Topics
91	$\sin^2 \theta_W$
160	M_W
250	$M_H, BR(H \to X), ZH$ threshold
350	$BR(H \to X), t\bar{t}$ threshold
500	$t\bar{t}$ continuum, new particles M<250 GeV,observe interfer. from obj w/ M~ few TeV
1000	$BR(H \to X)$ from $e^+e^- \to \nu\nu H$, new particles M<500 GeV, $t\bar{t}H$, WW scattering
3000	$BR(H \to X)$ from $e^+e^- \to \nu\nu H$, new particles M<1500 GeV, WW scattering

All results shown use GEANT4 simulation of the passage of particles through the detectors described in the 2009 LOI and 2011 CLIC CDR

The SiD Detector





z	158 - 173 cm
Inner radius	6 cm
Outer Radius	20 cm
Fiducial	46-86 mrad
Tungsten thickness	2.5 mm (20 layers), 5.0 mm (10 layers)
Silicon sensor thickness	320 μm
Radial division	2.5 mm pitch
Azimuthal division	36

Table 2.8: LumiCal Parameters

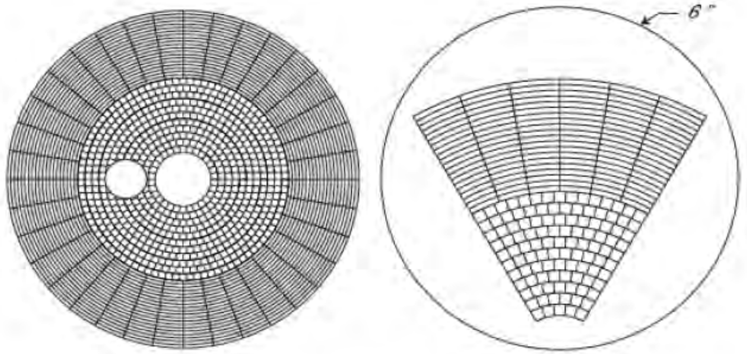
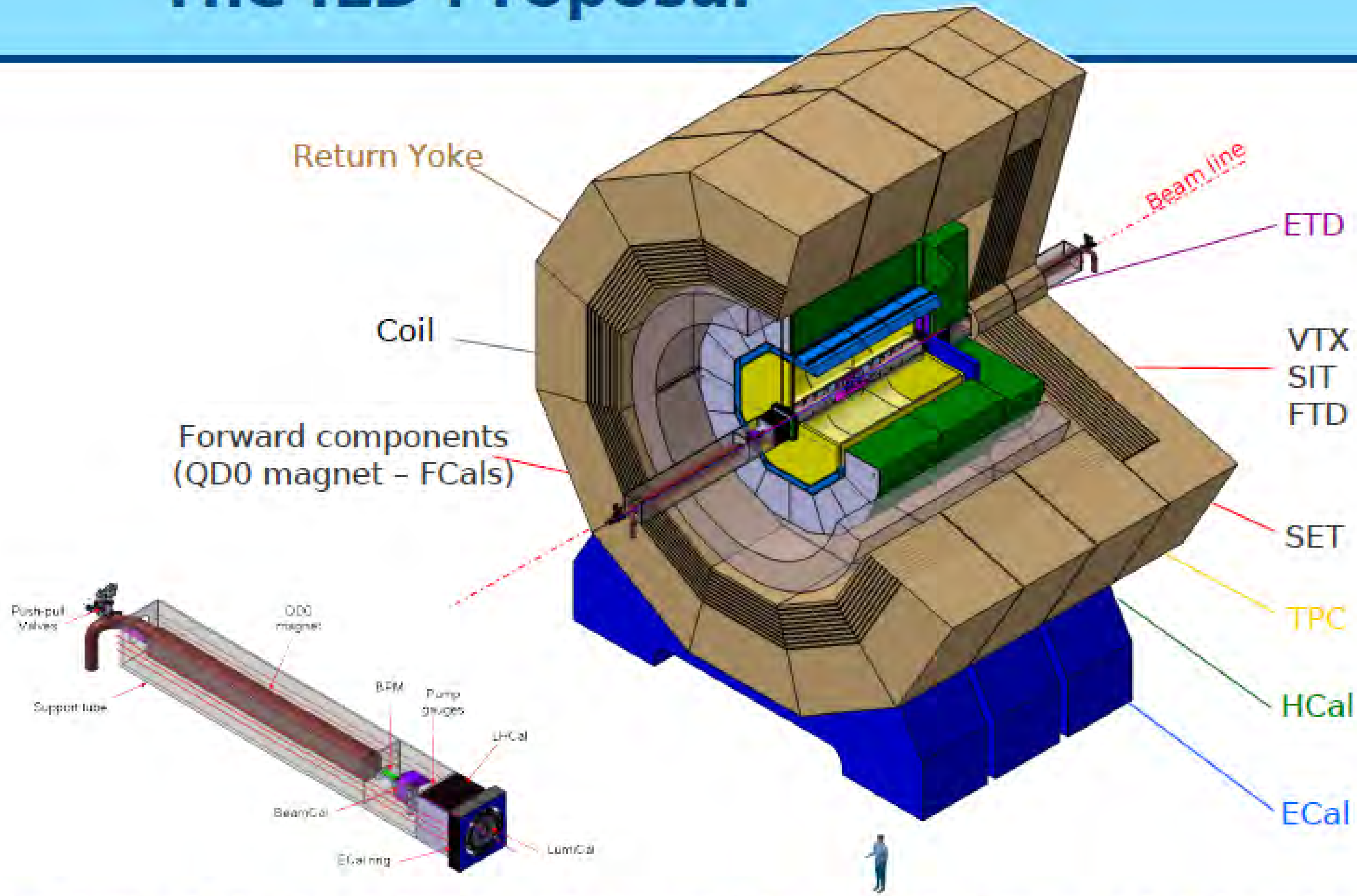


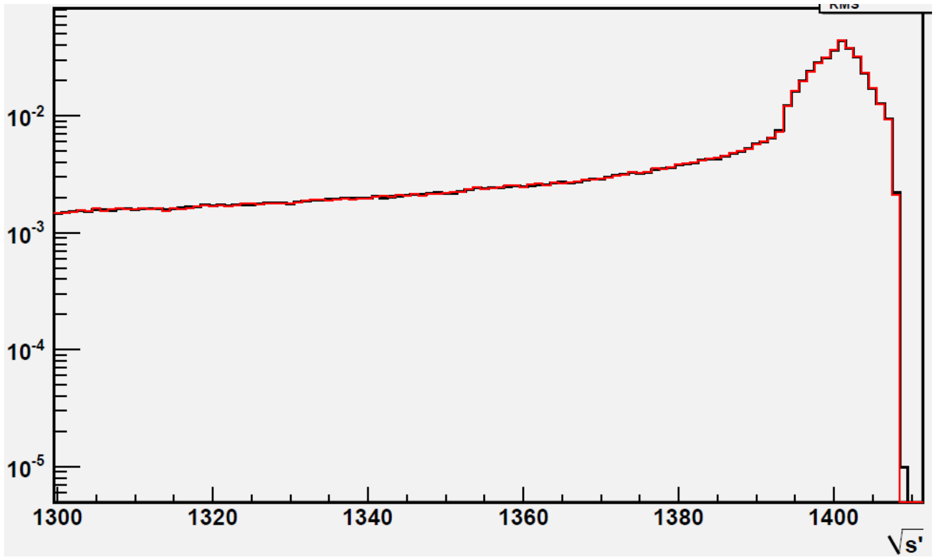
Figure 2.45: BeamCal sensor and segmentation.

The ILD Proposal



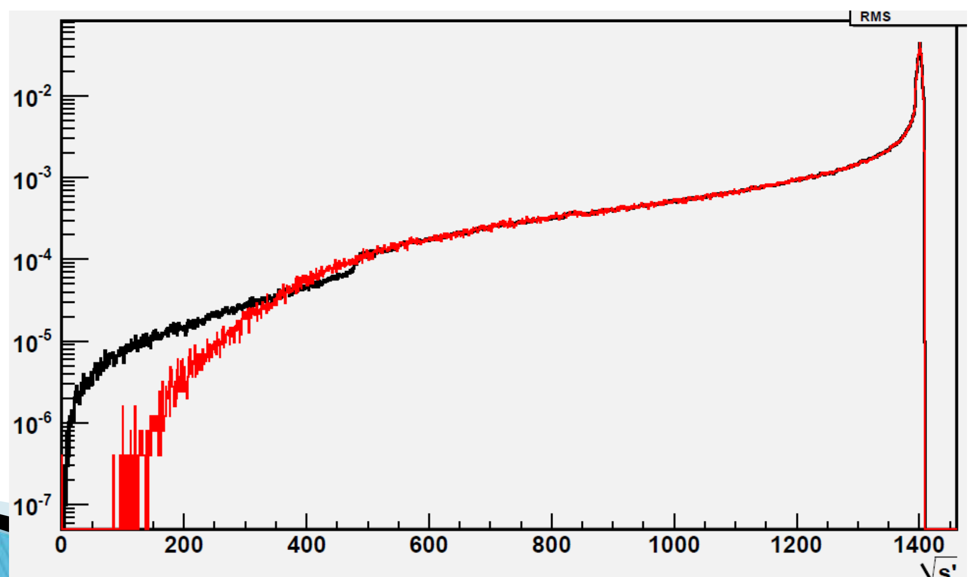
A relatively large detector, designed for particle flow, with a highly granular calorimeter, state-of-the-art gaseous+solid state tracker/vertex detector
Letter of Intent in 2009 – Invited by IDAG to work **towards a DBD for 2012**

Beamstrahlung - CLIC at Ecm=1400 GeV



Guinea-Pig

VEGAS MC Integration



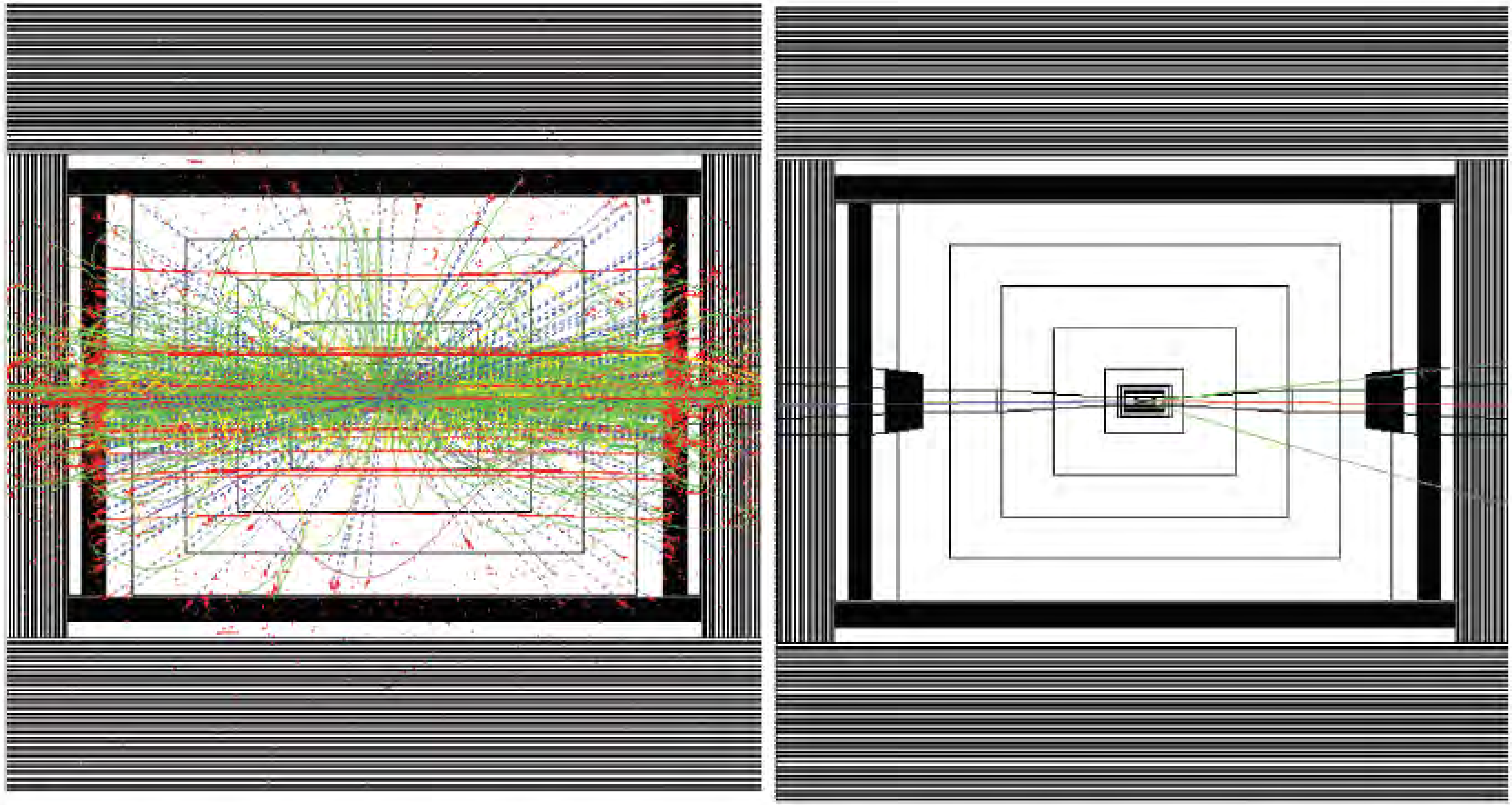


Figure 1.5: Physics backgrounds from $\gamma\gamma$ produced e^+e^- pairs, muon pairs, and hadronic events integrated over 150 bunch crossings (left) and a single bunch crossing (right).

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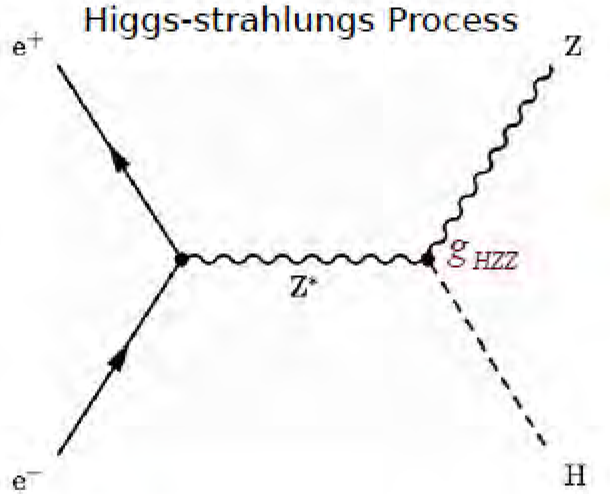
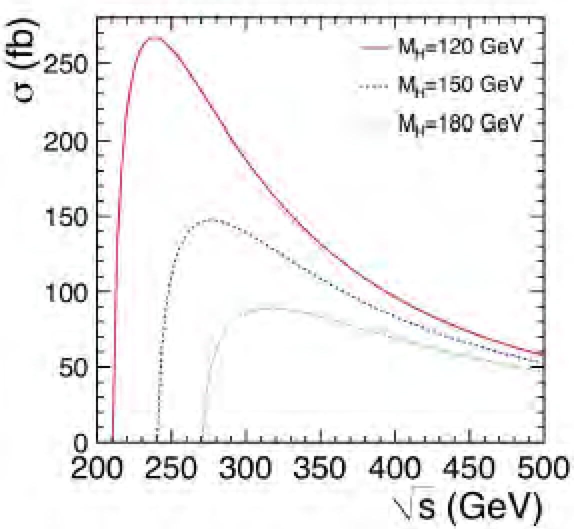
Higgs-strahlung Cross Section and Higgs Mass at the ILC



Golden Plated Channel at e^+e^- Colliders

Sensitive to coupling at HZZ Vertex



Production Cross Section of SM Higgs Boson

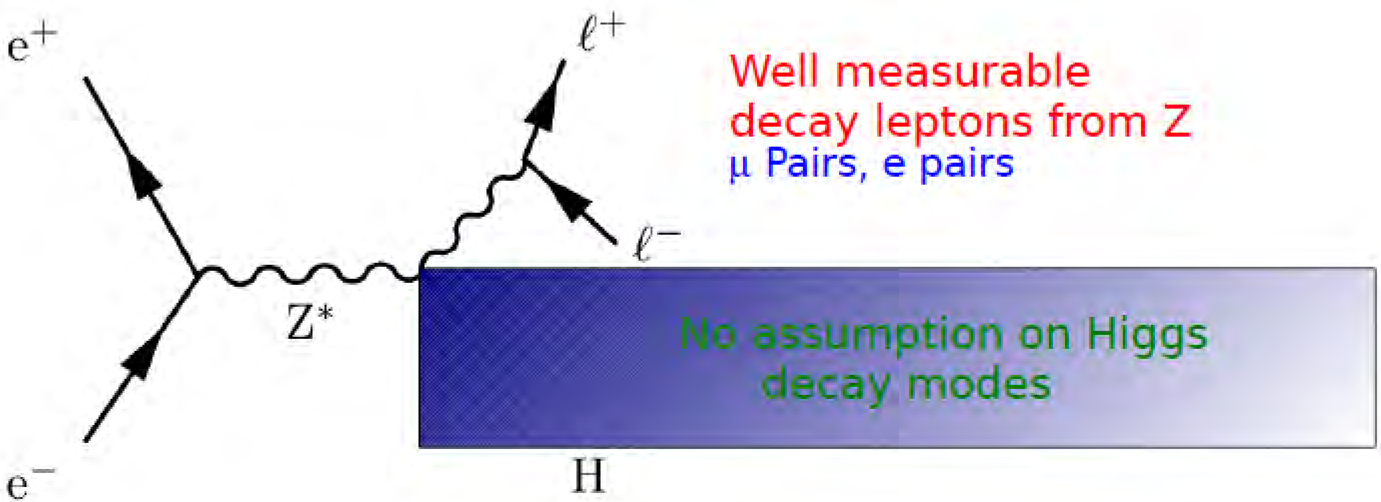
Maximal at HZ production threshold

LOI Benchmark reaction:

Higgs Strahlung at $\sqrt{s}$ = 250 GeV for m_H = 120 GeV

Why golden plated Channel?

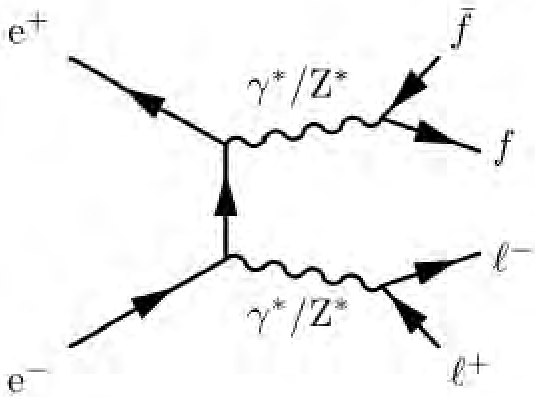
Higgs Mass and ZZH coupling by **Model Independent** measurement

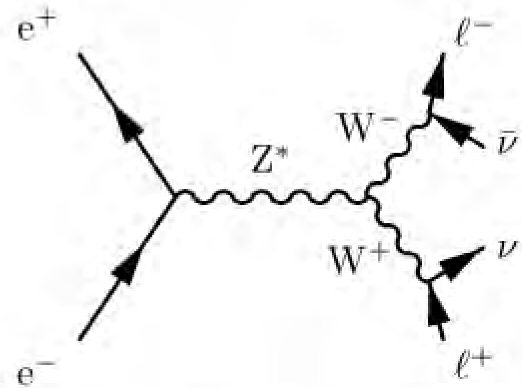


Higgs Recoil Mass: $M_h^2 = M_{recoil}^2 = s + M_Z^2 - 2E_Z\sqrt{s}$

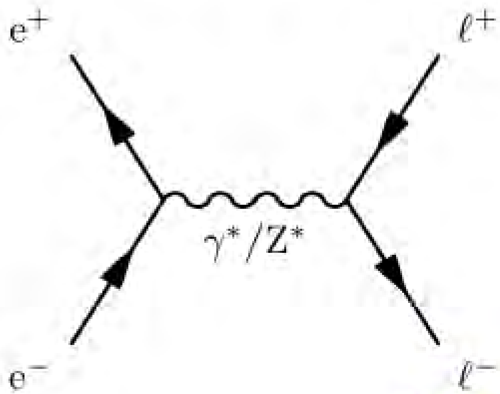
(Main) Background Processes

Boson Pair Production

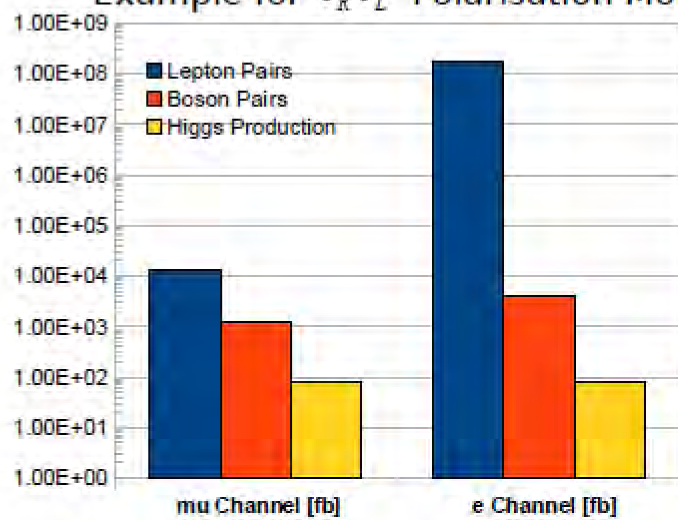




Lepton Pair Production



Example for $e_R^- e_L^+$ Polarisation Mode



Huge Background $\sigma_{signal}/\sigma_{bkgr.}$ ~0

Background Rejection

ILD

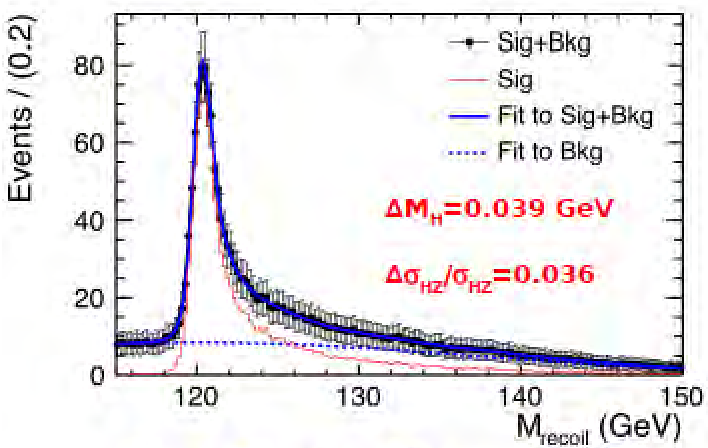
$P_{T,dl} > 20$ GeV
$80 < M_{dl-} < 100$ GeV
$0.2 < acop < 3.0$
$\Delta P_{Tbal.} > 10$ GeV
$|\cos\theta_{miss.}| < 0.99$
$115 < M_{recoil} < 150$ GeV
Dedicated cuts for radiative events
Multivariate Analysis

- Relaxed constraint on dilepton Mass
- Cuts more closely 'tailored' to background

Signal/Background > 30%

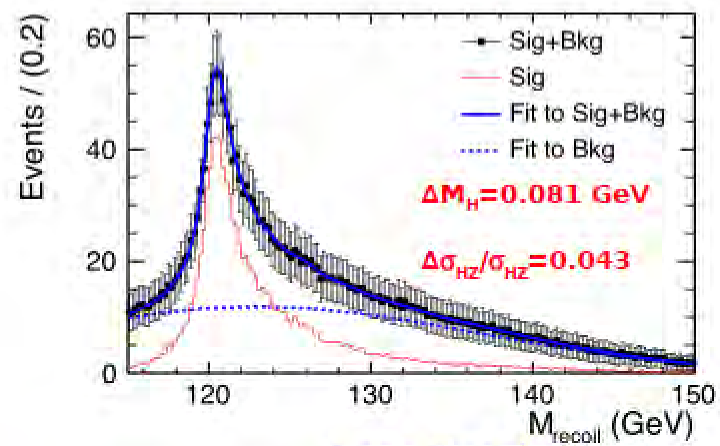
Results (see also LC Note LC_PHSM-2009-006)

Muon Channel



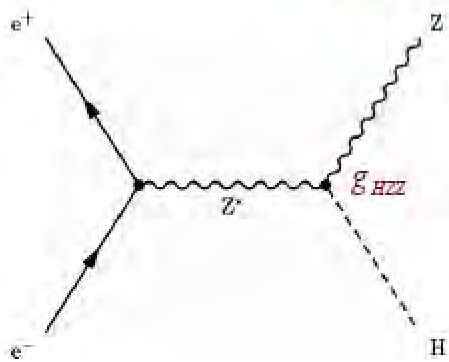
Very Precise Measurement
S/B = 8 in Peak Region

Electron Channel



Less Precise
Bremsstrahlung in detector material

Combined: ΔM_H=0.035 GeV, $\Delta\sigma_{HZ}/\sigma_{HZ}$=0.027



$$\sigma_{HZ} \sim g^2_{HZZ}$$

$\Rightarrow$ Precision in g_{HZZ} coupling 1-2%

Sensitivity to 15% deviations
SM prediction of cross section

$$BR(H \to c\bar{c})\ @\ \sqrt{s} = 250\ \text{GeV}$$

Comparison between ILD and SiD

The analysis results obtained by ILD and SiD are summarized.

LOI

	ILD	SiD
• ZH→ννcc	: 13.8%	10.3%
• ZH→qqcc	: 30.0%	5.8%
• ZH→llcc	: 28.0%	

ALCPG09

	ILD	SiD
• ZH→ννcc	: 13.8%	11.6%
• ZH→qqcc	: 16.6%	8.8%
• ZH→llcc	: 20.8%	

Conclusions

- ZH→ννcc: The result is almost consistent ← OK!
- ZH→qqcc: There are still large difference ← To be checked.
- ZH→llcc/ffμμ: It is preferable to study in both groups.

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ILD

Summary of current Higgs study

BR precision	Ecm	250 GeV (LOI)	350 GeV	250 GeV	1 TeV (DBD)
H decay	BR	Mh120 GeV	Mh120 GeV	Mh130 GeV	Mh120 GeV
H→bb	66.5%	vvH, qqH, llH	vvH, qqH, llH	To be update	Required vvH
H→cc	2.9%	vvH, qqH, llH	vvH, qqH, llH	To be update	Required vvH
H→gg	8.2%	vvH, qqH, llH	vvH, qqH, llH	To be update	Required vvH
H→WW*	13.6%	vvH, 4j	No	vvH, 4j	Required vvH
H→μμ	0.02%	for DBD	No	No	Required vvH
H→ττ	6.8%	To be done	No	No	No
H→ZZ*	1.5%	start vvH, 4j	No	No	No
H→γγ	0.2%	Constantino	No	No	No
H→Zγ	0.1%	Constantino	No	No	No

Need to do with qqH for WW, ZZ, ττ...
Recoil mass study should also be tested with several masses

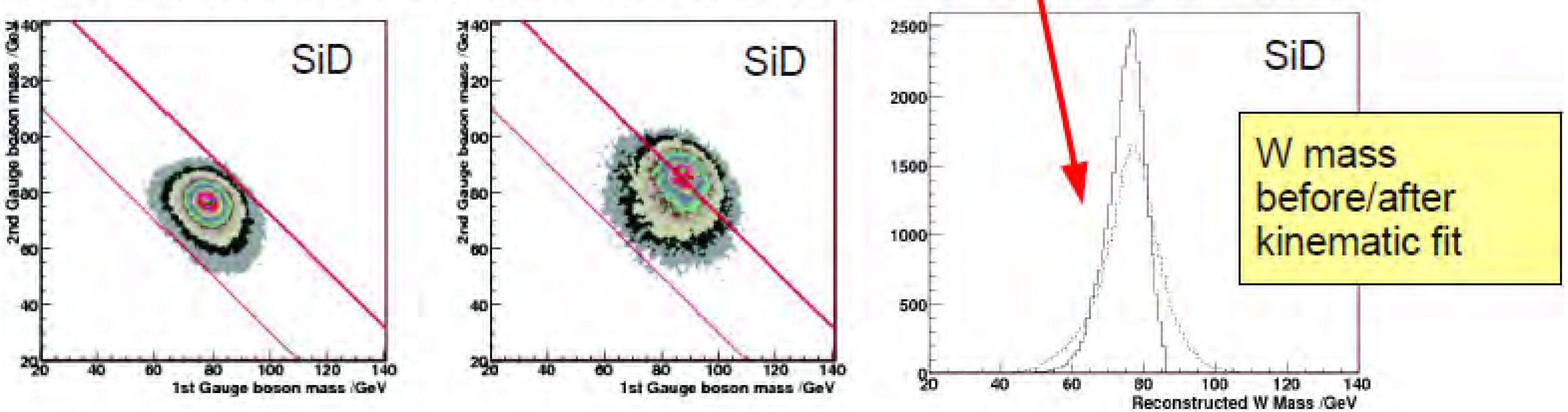
BSM in LoIs: Overview

- benchmarks:
  - NUHM "Point 5"
  - strong EWSB : WW / ZZ
- beyond benchmarks:
  - $\tilde{b} \rightarrow b\, \chi^0{}_1$
  - non-pointing photons from $\chi^0 \rightarrow \gamma\, \tilde{G}$
  - heavy gauge bosons in Little Higgs Models
  - $\tilde{\tau}$ with small mass difference to χ^0 and $\chi^0{}_2 \rightarrow \mu\, \mu\, \chi^0{}_1$
  - radiative WIMP production

"Point 5"

SiD & ILD LoIs

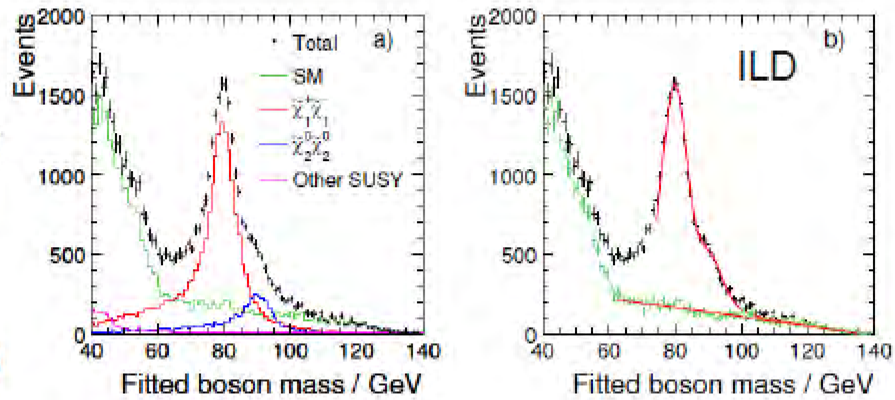
- non-universal soft SUSY-breaking contributions to the Higgs masses
- M_0 = 206 GeV, $M_{1/2}$ = 293 GeV, tanβ = 10, A_0 = 0, μ = 375 GeV
- => $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ mass degenerate (216.5 GeV), decay into $W^{\pm}\tilde{\chi}_1^0$ and $Z\tilde{\chi}_1^0$, respectively (M_{LSP} = 115.7 GeV)
- detector challenge: fully hadronic decay mode 4j + missing 4-mom.
- due to the 2 escaping LSPs, impact kinematic fitting is limited
  => this tests jet energy reconstruction in particle flow calorimetry



Point 5: Cross-sections

SiD & ILD LoIs

- ...and now with backgrounds (SM + SUSY!)
- separate $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ according to di-jet masses
- subtract background measure cross-section
  - event counting (SiD):
    $\delta\sigma$ = 1% ($\tilde{\chi}_1^{\pm}$)/ 4% ($\tilde{\chi}_2^0$)
  - 1D di-jet mass fitting (ILD):
    $\delta\sigma$ = 1% ($\tilde{\chi}_1^{\pm}$)/ 3% ($\tilde{\chi}_2^0$)
  - 2D di-jet mass template fitting (ILD):
    $\delta\sigma$ =0.6% ($\tilde{\chi}_1^{\pm}$)/ 2% ($\tilde{\chi}_2^0$)



- => analysis technique matters!
- don't forget ZZ $\tilde{\chi}_1^0\tilde{\chi}_1^0$ $\rightarrow$ qqll $\tilde{\chi}_1^0\tilde{\chi}_1^0$: lower statistics, but
  - much less background (no chargino bkg!)
  - excellent mass/energy resolution from leptonic Z!

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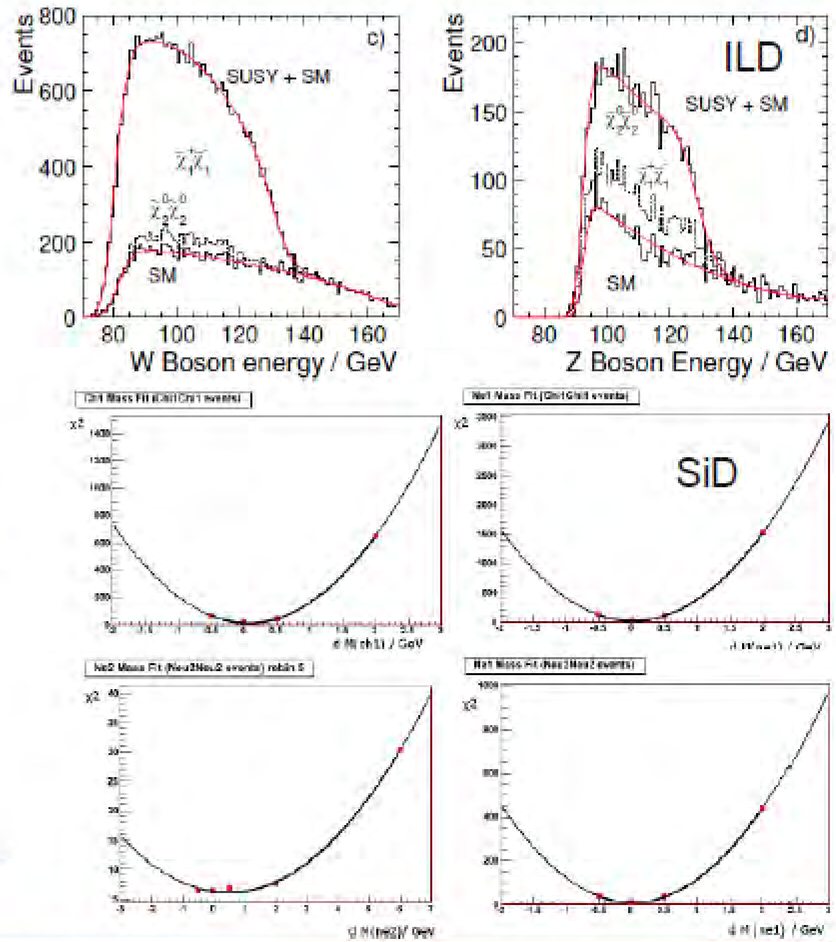
Point 5: Masses

SiD & ILD LoIs

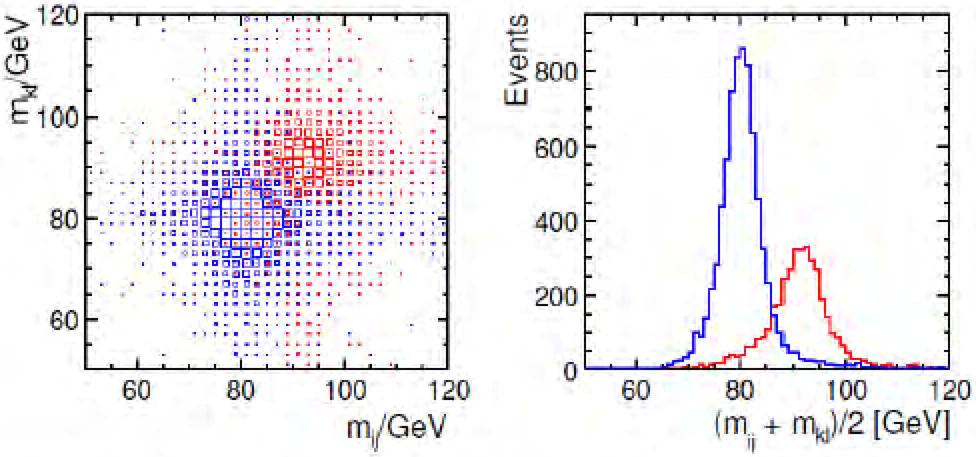
- fitting the edges of the W/Z energy spectrum:
  => edge positions to 0.2....0.7 GeV
- using these to determine all three masses simultaneously (ILD):
  δM($\tilde{\chi}^0_1$) = 0.8 GeV
  δM($\tilde{\chi}^\pm_1$) = 0.9 GeV
  δM($\tilde{\chi}^0_2$) = 2.4 GeV
- correlations are substancial:
  if other 2 masses were known (SiD)
  δM($\tilde{\chi}^0_1$) = 0.2 GeV
  δM($\tilde{\chi}^\pm_1$) = 0.5 GeV
  δM($\tilde{\chi}^0_2$) = 1.0 GeV
- kinematic fitting (constraining the vector boson masses) still helps:
  w/o kin. fit, mass resolution is worse by 0.5...1.1 GeV !



Strong EWSB

ILD LoI

- test $W^+W^- \to W^+W^-$ and $W^+W^- \to ZZ$ vertices by
  $e^+e^- \to \nu_e\overline{\nu}_e q\overline{q}q\overline{q}$ at 1 TeV (1ab^{-1}, P=(0.3,-0.8))
- di-jet mass reconstruction:



- Quartic gauge couplings (SM=0) can be limited to:

$$-1.38 < \alpha_4 < +1.10 \qquad -0.92 < \alpha_5 < +0.77$$

Sleptons with Small Mass Differences

Introduction

What can be done at ILC if SUSY exists, and is "next to LEP", and we use a real detector ? And if the LSP-NLSP difference is small ?

Look at the mSUGRA point SPS1a':

$M_{1/2} = 250\ \mathrm{GeV}, M_0 = 70\ \mathrm{GeV}, A_0 = -300\ \mathrm{GeV}, \tan\beta = 10, \mu > 0$
Just outside what is excluded by LEP and low-energy observations.
Compatible with WMAP, with $\tilde{\chi}^0_1$ Dark Matter.

- All sleptons available.
- No squarks.
- Lighter bosinos, up to $\tilde{\chi}^0_3$ (in $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_3$)

and use:

- Full ILD simulation.
- Full background: SUSY, SM, machine.

SPS1a'

- In SPS1a', the $\tilde{\tau}_1$ is the NLSP.
- $M_{\tilde{\chi}_1^0}$ = 97.7 GeV/c^2, $M_{\tilde{\chi}_2^0}$ = $M_{\tilde{\chi}_1^\pm}$ = 184 GeV/c^2.
- $M_{\tilde{\tau}_1}$= 107.9 GeV: low ΔM. $M_{\tilde{e}_R}$= $M_{\tilde{\mu}_R}$=125.3 GeV
- $M_{\tilde{\tau}_2}$= 194.9 GeV, $M_{\tilde{e}_L}$= $M_{\tilde{\mu}_L}$= 189.9 GeV$>$ $M_{\tilde{\chi}_2^0}$ and $M_{\tilde{\chi}_1^\pm}$: cascades
- For $\tilde{\tau}_1$: $E_{\tau,min} = 2.6$ GeV, $E_{\tau,max} = 42.5$ GeV: $\gamma\gamma$ background.
- For $\tilde{\tau}_2$: $E_{\tau,min} = 35.0$ GeV, $E_{\tau,max} = 152.2$ GeV: $WW \rightarrow l\nu l\nu$ background.
- For $\tilde{e}_R$or $\tilde{\mu}_R$: $E_{l,min} = 6.6$ GeV, $E_{l,max} = 91.4$ GeV: Neither $\gamma\gamma$ nor $WW \rightarrow l\nu l\nu$ background severe.
- $\tilde{\tau}$ NLSP $\rightarrow \tau$:s in most SUSY decays $\rightarrow$ SUSY is background to SUSY.
- For pol=(-1,1): $\sigma(\tilde{\chi}_2^0\tilde{\chi}_2^0)$ and $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-)$ = several hundred fb and BR(X$\rightarrow \tilde{\tau}$) $>$ 50 %. For pol=(1,-1): $\sigma(\tilde{\chi}_2^0\tilde{\chi}_2^0)$ and $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-) \approx 0$.
- For pol=(-1,1): $\sigma(\tilde{e}_R\tilde{e}_R)$ = 1.3 pb !

Extracting the $\tilde{\tau}$ properties

Use polarisation (0.8,-0.22) to reduce bosino background.

From decay kinematics:

- $M_{\tilde{\tau}}$ from end-point of spectrum = $E_{\tau,max}$.
- Other end-point hidden in $\gamma\gamma$ background: Must get $M_{\tilde{\chi}_1^0}$ from other sources. ($\tilde{\mu}$, $\tilde{e}$ ...)

From cross-section:

- $\sigma_{\tilde{\tau}} = A(\theta_{\tilde{\tau}}, \mathcal{P}_{beam}) \times \beta^3/s$, so
- $M_{\tilde{\tau}} = E_{beam}\sqrt{1 - (\sigma s/A)^{2/3}}$: no $M_{\tilde{\chi}_1^0}$!

From decay spectra:

- $\mathcal{P}_\tau$ from exclusive τ decay-mode(s): handle on mixing angles $\theta_{\tilde{\tau}}$ and $\theta_{\tilde{\chi}_1^0}$.

Topology selection

$\tilde{\tau}$ properties:

- Only two τ:s in the final state.
- Large missing energy and momentum.
- High Acolinearity, with little correlation to the energy of the τ decay-products.
- Central production.
- No forward-backward asymmetry.

+ anti $\gamma\gamma$ cuts (see backup)

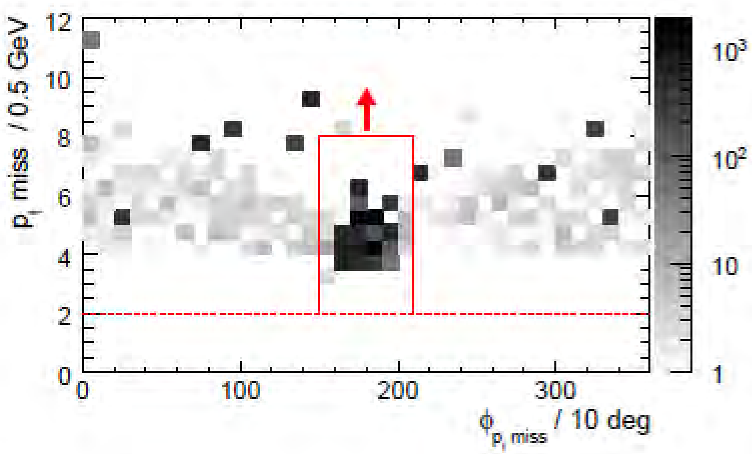
Select this by:

- Exactly two jets.
- $N_{ch} < 10$
- Vanishing total charge.
- Charge of each jet = ± 1,
- $M_{jet} < 2.5\ \mathrm{GeV}/c^2$,
- $E_{vis} < 300\ \mathrm{GeV}$,
- $M_{miss} > 250\ \mathrm{GeV}/c^2$,
- No particle with momentum above 180 GeV/c in the event.

$\gamma\gamma$ suppression

$\Delta(M) = 10.2\ \mathrm{GeV}/c^2 \rightarrow \gamma\gamma$ background ...

- Correlated cut in ρ and θ_{acop}: $\rho > 2.7 \sin\theta_{acop} + 1.8$. ($\rho = P_T$ of jets wrt. thrust axis, in x-y projection.)
- no significant activity in the BeamCal
- $\phi_{p\ miss}$ not in the direction of the incoming beam-pipe.



Results for $\tilde{\tau}_1$

$M_{\tilde{\tau}_1} = 107.73^{+0.03}_{-0.05}\ \mathrm{GeV}/c^2 \oplus 1.3\Delta(M_{\tilde{\chi}_1^0})$.
The error from $M_{\tilde{\chi}_1^0}$ largely dominates.

Results for $\tilde{\tau}_2$

$M_{\tilde{\tau}_2} = 183^{+11}_{-5}\ \mathrm{GeV}/c^2 \oplus 18\Delta(M_{\tilde{\chi}_1^0})$.
The error from the endpoint largely dominates.

Results from cross-section for $\tilde{\tau}_1$

$\Delta(N_{signal})/N_{signal} = 3.1\% \to \Delta(M_{\tilde{\tau}_1}) = 3.2\ \mathrm{GeV}/c^2$

Results from cross-section for $\tilde{\tau}_2$

$\Delta(N_{signal})/N_{signal} = 4.2\% \to \Delta(M_{\tilde{\tau}_2}) = 3.6\ \mathrm{GeV}/c^2$
End-point + Cross-section $\to \Delta(M_{\tilde{\chi}_1^0}) = 1.7\ \mathrm{GeV}/c^2$

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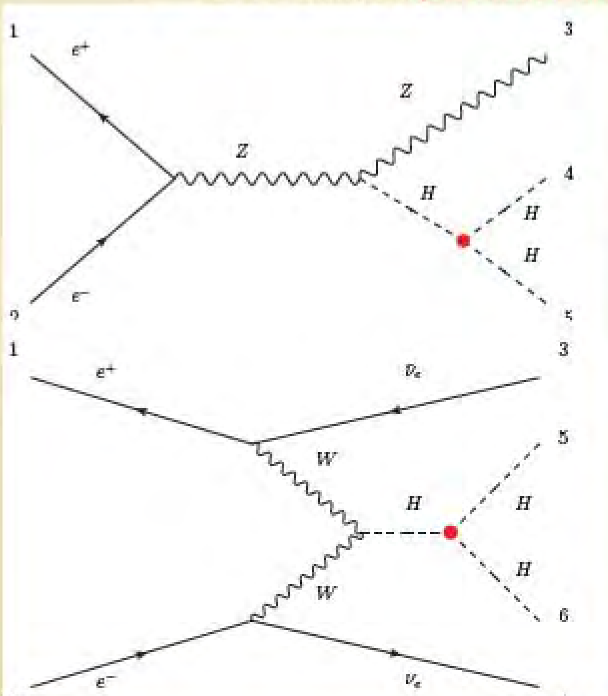
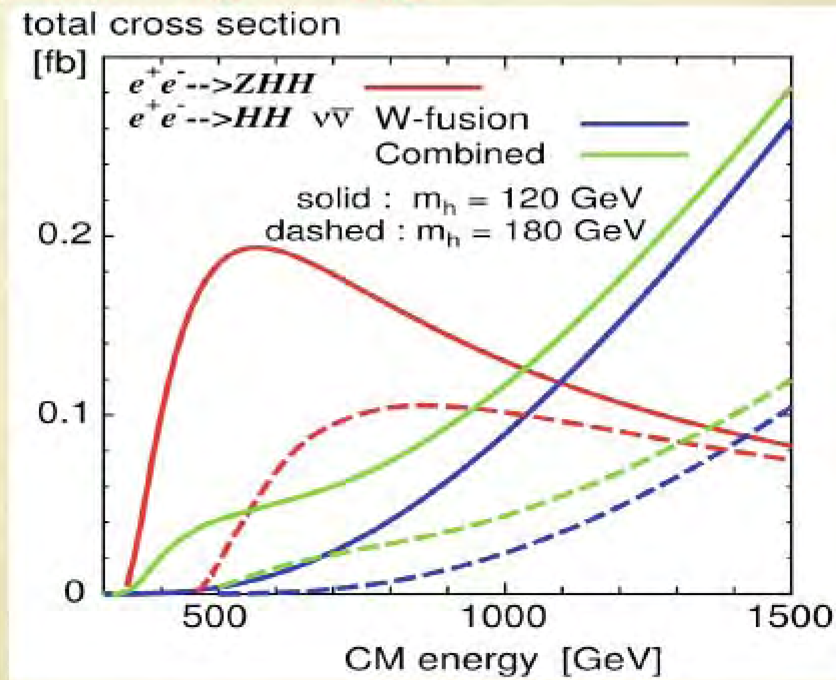
Measurement of the trilinear Higgs self-coupling @ ILC

- double Higgs-strahlung (dominate at lower energy)
- WW fusion (become important at higher energy)





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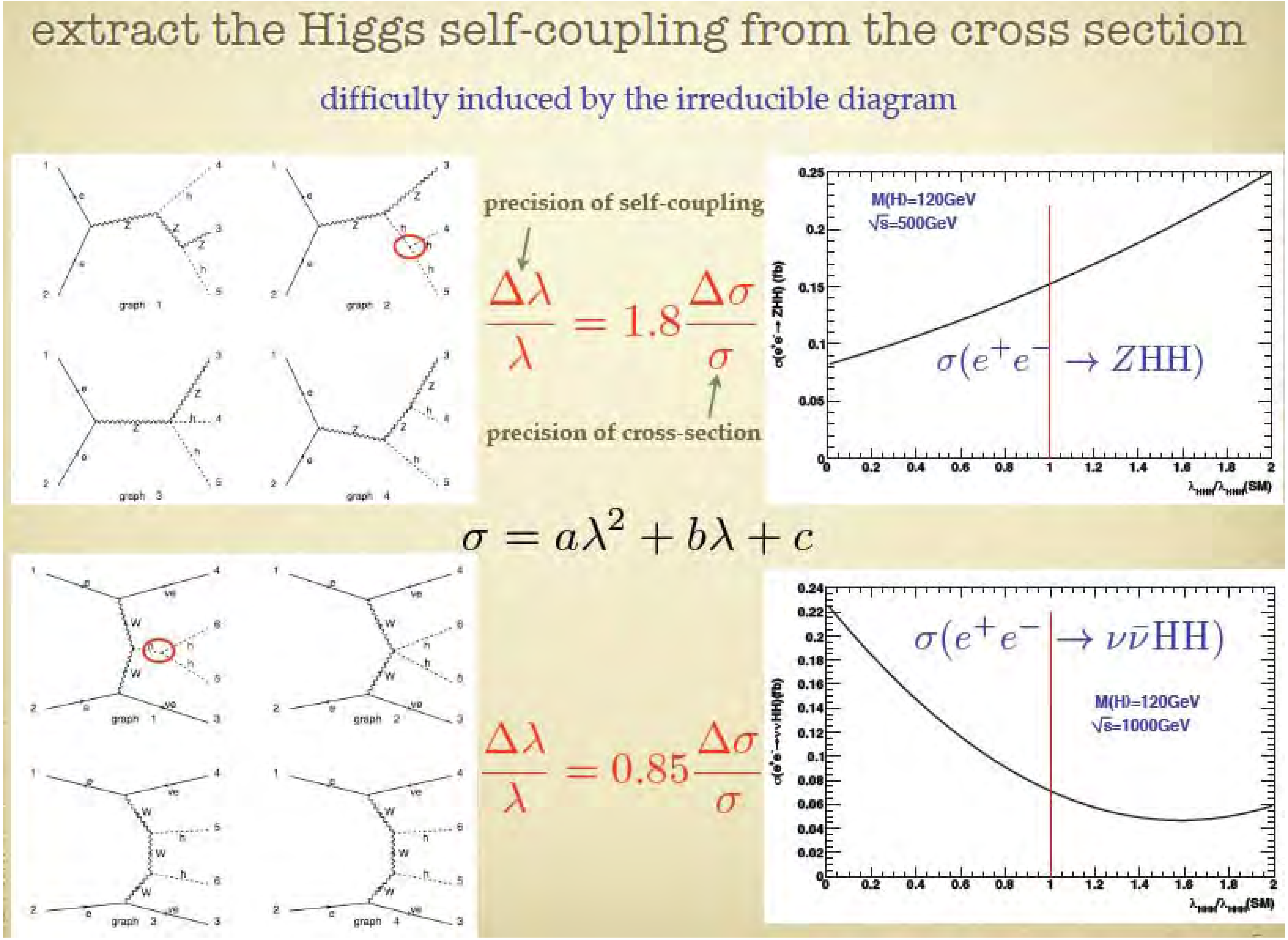

extract the Higgs self-coupling from the cross section
difficulty induced by the irreducible diagram
precision of self-coupling
$\frac{\Delta\lambda}{\lambda} = 1.8\frac{\Delta\sigma}{\sigma}$
precision of cross-section
M(H)=120GeV
√s=500GeV
$\sigma(e^+e^- \to ZHH)$
$\sigma = a\lambda^2 + b\lambda + c$
$\frac{\Delta\lambda}{\lambda} = 0.85\frac{\Delta\sigma}{\sigma}$
$\sigma(e^+e^- \to \nu\bar{\nu}HH)$
M(H)=120GeV
√s=1000GeV

extracting the cross section of ZHH

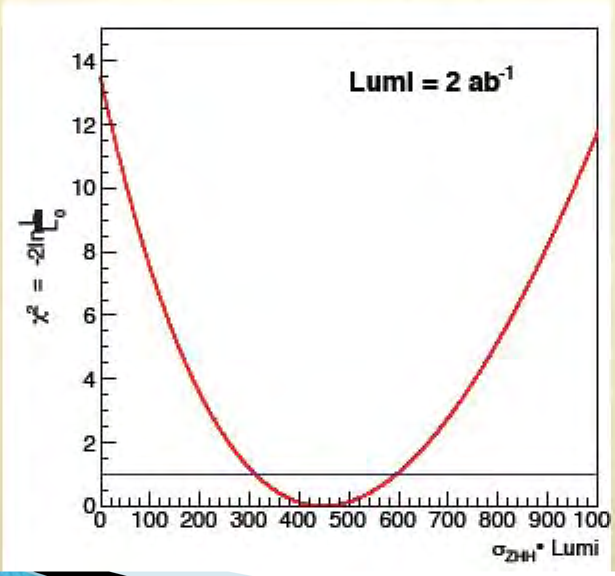
$$L_{s+b} = \Pi_i \frac{e^{-(s_i+b_i)}(s_i+b_i)^{n_i}}{n_i!}$$

b_i: expected background number (known from MC)
n_i: number of observed events (known from Experiment)
s_i: parameter related with the cross section

$$s_i = (\sigma_{ZHH} + \sigma_i) \cdot \mathrm{Lumi} \cdot \mathrm{Br}_i \cdot \mathrm{Eff}_i$$

σ_i: fusion contribution (negligible at 500 GeV)

$$\chi^2 = -2ln\frac{L}{L_{max}}$$



$$\sigma_{ZHH} \cdot \mathrm{Lumi} = 448^{+145}_{-137}$$

$$\sigma_{ZHH} = 0.22 \pm 0.07 \quad \mathrm{fb}$$

precision of cross section: **32%**
precision of Higgs self-coupling: **57%**

recalling $\frac{\Delta\lambda}{\lambda} = 1.8\frac{\Delta\sigma}{\sigma}$

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Conditions at CLIC

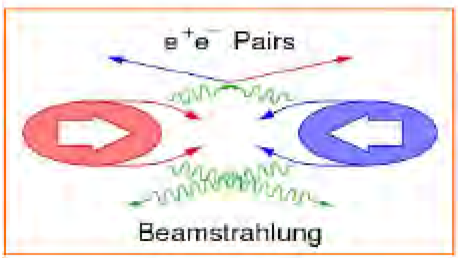
	CLIC at 3 TeV
L ($cm^{-2}s^{-1}$)	5.9×10^{34}
BX separation	0.5 ns
#BX / train	312
Train duration (ns)	156
Rep. rate	50 Hz
σ_x / σ_y (nm)	≈ 45 / 1
σ_z (μm)	44

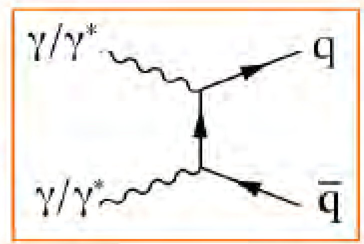
Drives timing requirements for CLIC detector

very small beam size

Beam related background:

- Small beam profile at IP leads very high E-field
  - **Beamsstrahlung**
    - Pair-background
    - γγ to hadrons





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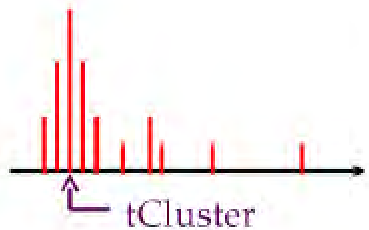
Background Suppression I

Triggerless readout of full bunch train:

Subdetector	Reco. window
ECAL	10 ns
HCAL Endcaps	10 ns
HCAL Barrel	100 ns
Silicon Detectors	10 ns
TPC	full train

1) Identify t_0 of physics event in bunch train
   - Define reconstruction window
   - All hits and tracks in this window are passed to the reconstruction
     $\rightarrow$ Physics objects (PFOs) with precise p_T and cluster time information



2) Apply cluster-based timing cuts
   - Cuts depend on particle-type (charged, neutral and photons), p_T and detector region

$\rightarrow$ Protects physics objects at high p_T

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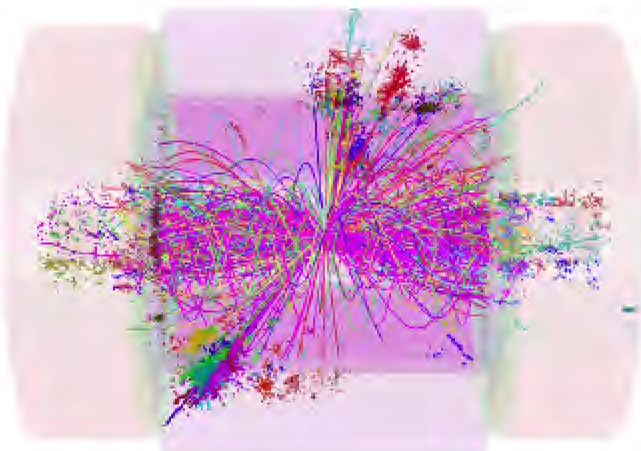
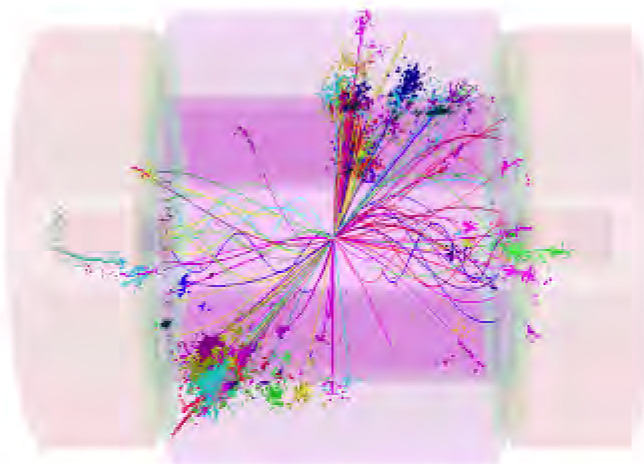
Background Suppression II

$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t}$ (8 jet final state)



1.2 TeV
background in the
reconstruction window



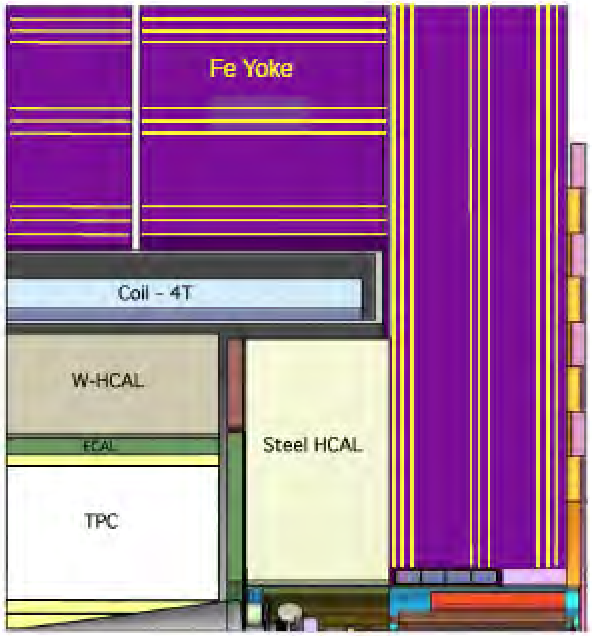
100 GeV
background after
(tight) timing cuts

for 60 BX of $\gamma\gamma \Rightarrow$ hadron background

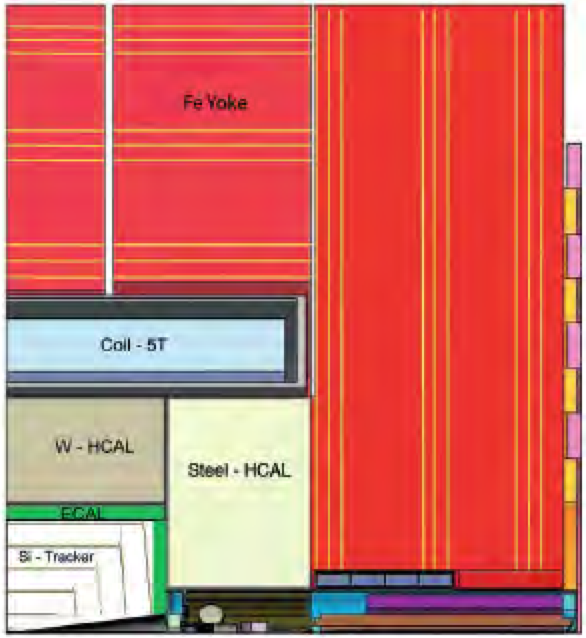
Detector Models

Based on validated ILC designs, adapted and optimized to the CLIC conditions:

- Denser HCAL in the barrel (Tungsten, 7.5 λ)
- Redesign of the vertex and forward detectors (backgrounds)



CLIC_ILD



CLIC_SiD

Chargino/Neutralino: Production (CLIC_SiD)

SUSY model II:

$m(\chi_1^\pm)$=643 GeV, $m(\chi_1^0)$=340 GeV, $m(\chi_2^0)$=643 GeV

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to W^+\tilde{\chi}_1^0 W^-\tilde{\chi}_1^0$$
$$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to h^0(Z^0)\tilde{\chi}_1^0 h^0(Z^0)\tilde{\chi}_1^0$$

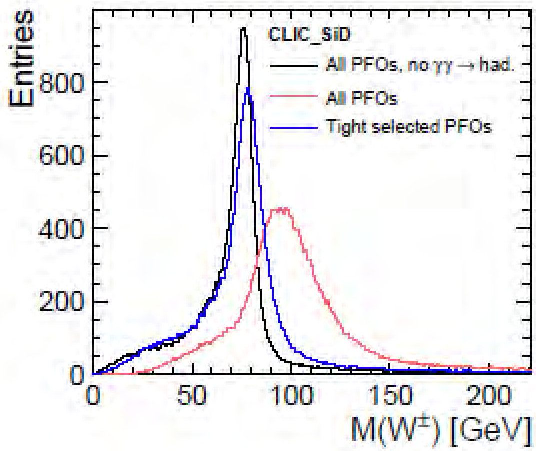
Type	Process	Cross section [fb]	Referenced with
Signal	$\tilde{\chi}_1^+\tilde{\chi}_1^-$	10.6	Chargino
	$\tilde{\chi}_2^0\tilde{\chi}_2^0$	3.3	Neutralino
Background	$\tilde{\chi}_2^+\tilde{\chi}_2^-$	10.5	SUSY
	$\tilde{\chi}_1^+\tilde{\chi}_2^-$	0.8	
	$\tilde{\chi}_1^+\tilde{\chi}_1^-\nu\overline{\nu}$	1.4	
	$\tilde{\chi}_2^0\tilde{\chi}_2^0\nu\overline{\nu}$	1.2	
	$q\overline{q}q\overline{q}\nu\overline{\nu}$	95.4	SM
	$q\overline{q}h^0\nu\overline{\nu}$	3.1	
	$h^0h^0\nu\overline{\nu}$	0.6	

Key detector performance aspects

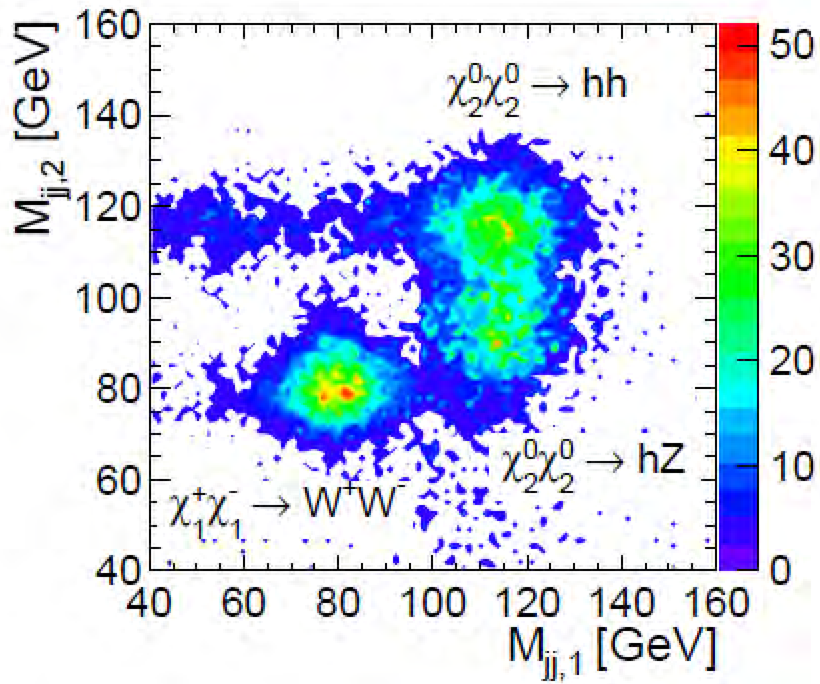
- Jet energy and missing energy reco in high energy decays
- Di-Jet mass reco and separation of hadronic Z, W and h decays

Chargino/Neutralino: Analysis

Background rejection with a Boosted Decision Tree



- Efficiency Charginos: 33%
- Efficiency Neutralinos: 25%
- Purity both: 56%



Application of timing cuts important in addition to jet reco to recover correct mass spectrum.

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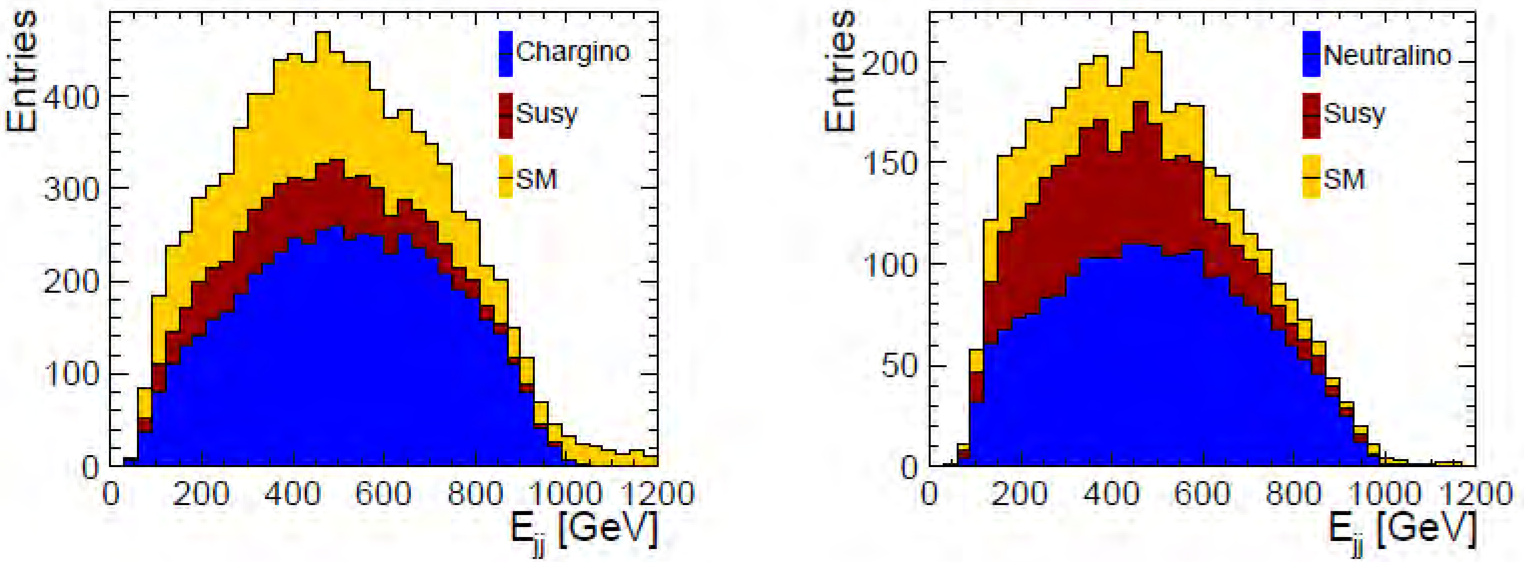
Chargino/Neutralino: Results

Mass and cross section from template (fully simulated) and least squares fits



Parameter 1	Uncertainty	Parameter 2	Uncertainty
$M(\tilde{\chi}_1^{\pm})$	6.3 GeV	$\sigma(\tilde{\chi}_1^{+}\tilde{\chi}_1^{-})$	2.2%
$M(\tilde{\chi}_1^{0})$	3.0 GeV	$\sigma(\tilde{\chi}_1^{+}\tilde{\chi}_1^{-})$	1.8%
$M(\tilde{\chi}_2^{0})$	7.3 GeV	$\sigma(\tilde{\chi}_2^{0}\tilde{\chi}_2^{0})$	2.9%

consistent results with least squares fit

CLIC CDR benchmark results (1)

Table 12.19: Summary table of the CLIC benchmark analyses results. All studies at a centre-of-mass energy of 3 TeV are performed for an integrated luminosity of 2 ab^{-1}. The study at 500 GeV assumes an integrated luminosity of 100 fb^{-1}.

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Observable	Unit	Generator value	Stat. uncertainty
3.0	Light Higgs production	$h \to b\bar{b}$ $h \to c\bar{c}$ $h \to \mu^+\mu^-$		$\sigma \times$ Branching ratio	fb	285 13 0.12	0.22% 3.2% 23%
3.0	Heavy Higgs production	$HA \to b\bar{b}b\bar{b}$	I	Mass Width	GeV GeV	902.4	0.3% 31%
			II	Mass Width	GeV GeV	742.0	0.2% 17%
		$H^+H^- \to t\bar{b}b\bar{t}$	I	Mass Width	GeV GeV	906.3	0.3% 27%
			II	Mass Width	GeV GeV	747.6	0.3% 23%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}^0_1\tilde{\chi}^0_1$	I	Mass σ	GeV fb	1123.7 1.47	0.52% 4.6%

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CLIC CDR benchmark results (2)

3.0	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	σ	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- hh$ $\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- Z^0Z^0$		σ	fb	3.07	7.2%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- W^+W^-$		σ	fb	13.74	2.4%
				$\tilde{\ell}$ mass	GeV	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	GeV	643.2	0.6%
3.0	Chargino and neutralino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h^0/Z^0 h^0/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
0.5	$t\bar{t}$ production	$t\bar{t} \to (q\bar{q}b)\,(q\bar{q}b)$		Mass	GeV	174	0.046%
				Width	GeV	1.37	16%
		$t\bar{t} \to (q\bar{q}b)\,(\ell\nu b)$, $\ell = e, \mu$		Mass	GeV	174	0.052%
				Width	GeV	1.37	18%

2012 DBD Benchmark Studies for ILD and SiD

$$e^+e^- \to W^+W^-\ ,\ \sqrt{s}=1\ \text{TeV}$$

Four Jet Topology

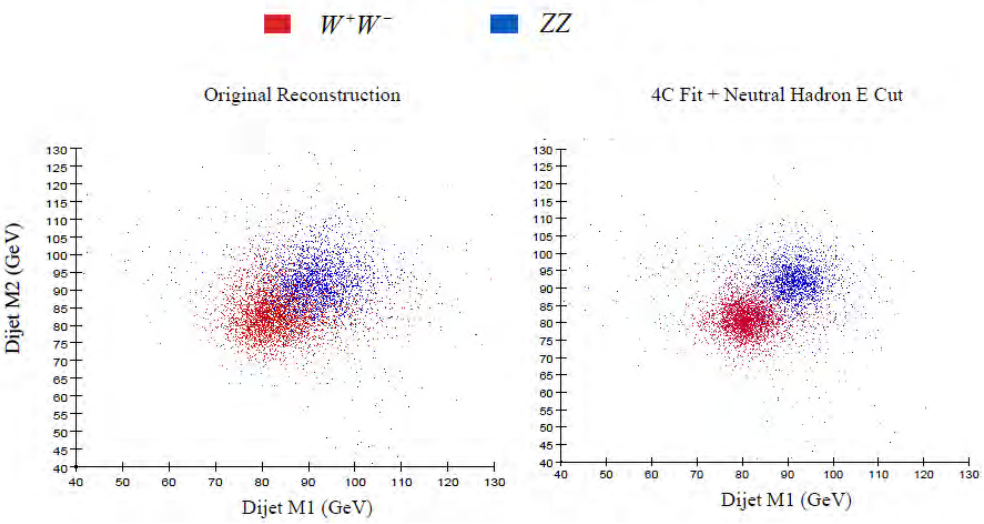
Two Jets Plus Lepton Topology

Beam Polarization Measurement

Triple Gauge Couplings

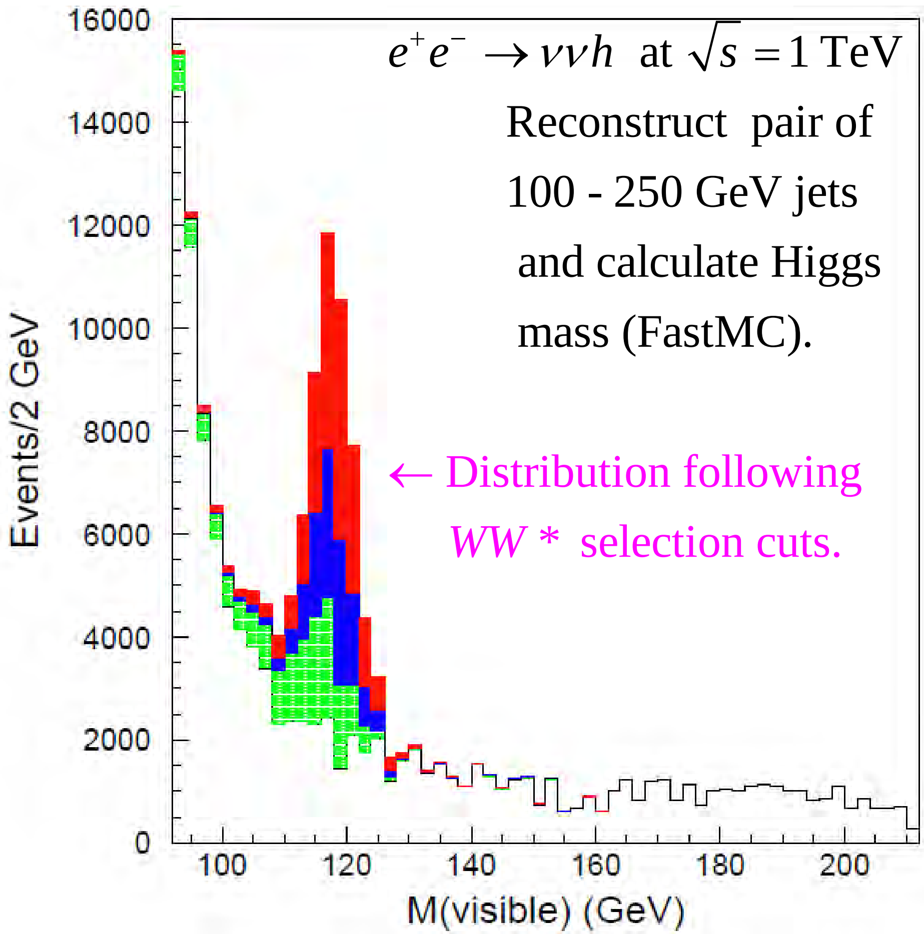
$e^+e^- \to uddu$ at $\sqrt{s} = 1$ TeV

Full energy W^+W^- / ZZ (no ISR)



2012 DBD Benchmark Studies for ILD and SiD

$$e^+e^- \to \nu\bar{\nu}H\,,\ \ H \to \mu^+\mu^-\,,\, b\bar{b}\,,\, c\bar{c}\,,\, gg\,,\, WW^*\ ,\ \sqrt{s}{=}1\ \mathrm{TeV}$$

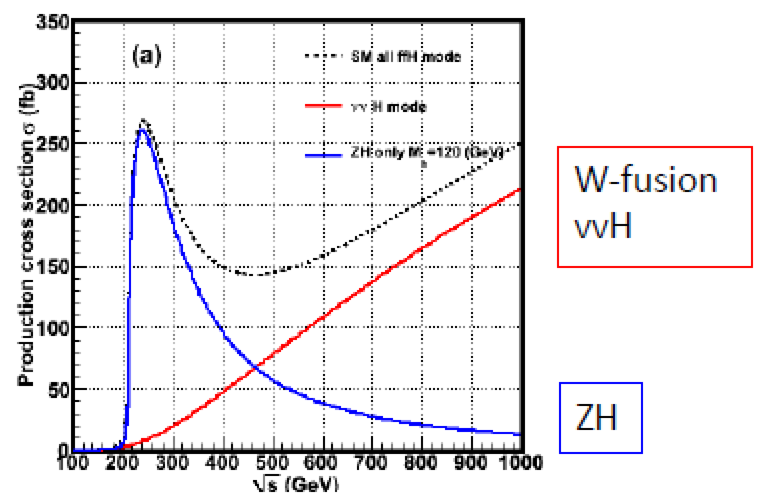


$h \to WW^*$

$h \to gg$

$h \to b\bar{b},\, c\bar{c}$

non Higgs bgnd



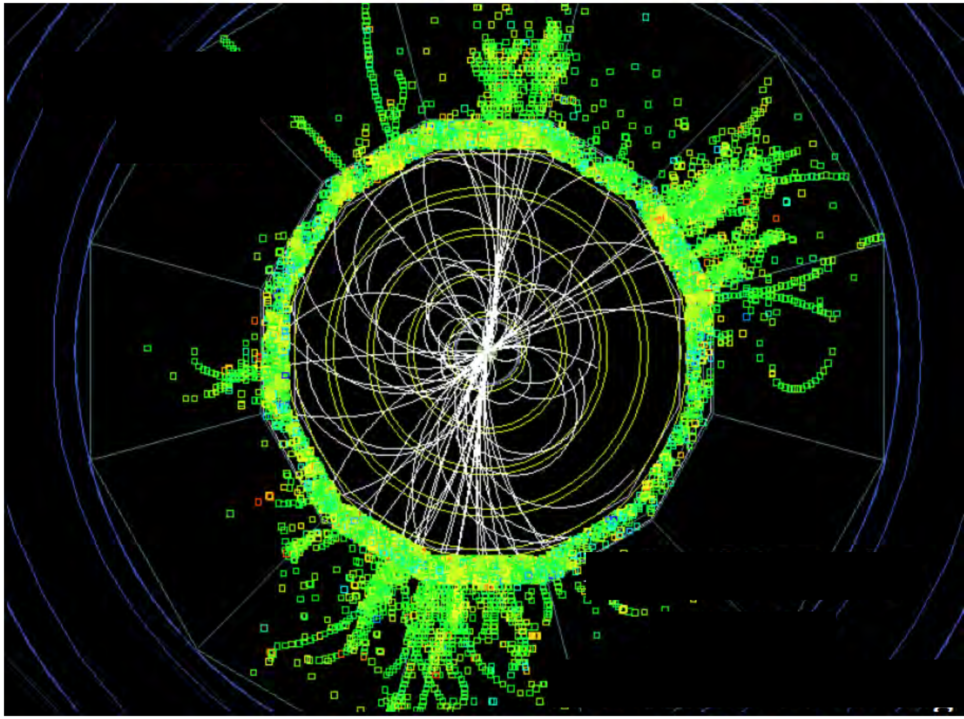
2012 DBD Benchmark Studies for ILD and SiD

$$e^+e^- \to t\bar{t}H\,,\ \sqrt{s}{=}1\ \mathrm{TeV}$$

Eight Jet Topology

Six Jets Plus Lepton Topology

Top Yukawa Coupling Measurement



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Summary

- 2009 LOI Benchmark Studies of ILD and SiD Detectors at Ecm=250 & 500 GeV ILC demonstrate the excellent physics capability of the ILC . Masses and couplings can be measured at the few percent level, processes with small visible energy can be detected, and one can begin to probe the Higgs self coupling
- 2011 CLIC CDR Physics Benchmark Studies demonstrate the strong physics case for CLIC at Ecm=3 TeV. Just like the ILC, masses and couplings are measured at the few percent level. In addition the CDR demonstrated that the large $\gamma\gamma \rightarrow$ hadrons background can be successfully dealt with using timing information and hadron collider jet algorithms.
- 2012 DBD Benchmark Studies of ILD and SiD will demonstrate the physics capablity of the ILC at Ecm=1 TeV and will do so with even more realism incorporated into the detector simulations.