Chargino/Neutralino analysis in SUSY Point 5 scenario with ILD detector

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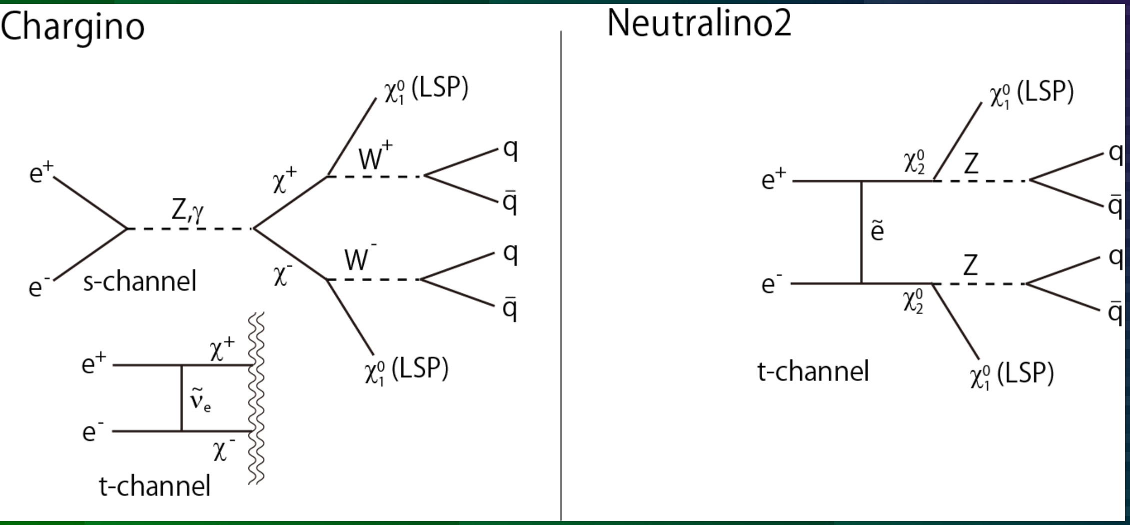
Thanks to all ILD people for various support.

SUSY chi1/ne2-pair process



Final state:
WW/ZZ + DMDM
→jjjj + missing

- Analysis key: W/Z separation by 2 jet mass
  - High energy reso.
- Observables:
  - Cross sections: 1D/2D fit
  - SUSY masses (χ^+_1, χ^0_2 and χ^0_1)

SUSY parameters:
m_0 = 206 GeV, $m_{1/2}$ = 293 GeV,
tan β = 10, A = 0, μ = 375 GeV

Degenerate

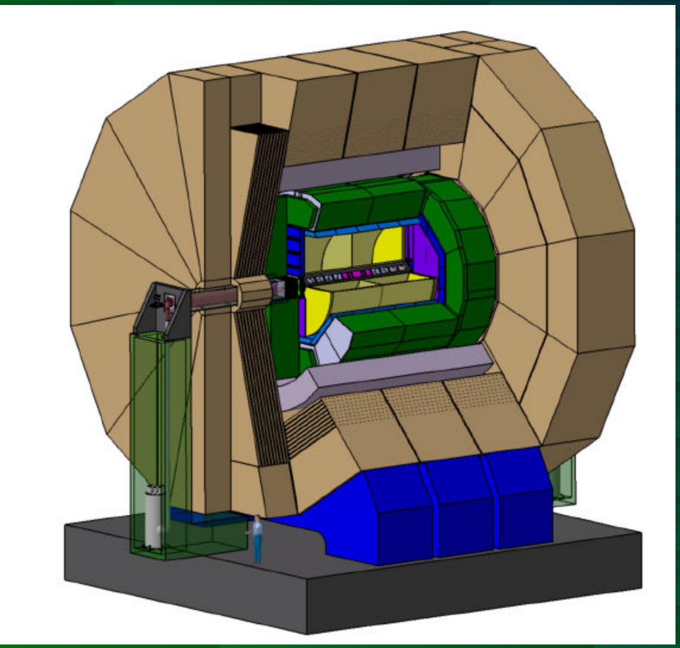
$m(\chi^\pm_1)$ = 216.5 GeV, $m(\chi^0_2)$ = 216.7 GeV
$m(\chi^0_1)$ = 115.7 GeV, Others heavy

100 GeV diff.: decays W/Z + LSP (>95%)

$\sigma(e^+e^- \to \chi^+_1\chi^-_1)$ = 132.2 fb
$\sigma(e^+e^- \to \chi^0_2\chi^0_2)$ = 23.3 fb

5.7 times

ILD Analysis framework



ILD_00 detector model

- Vertex: Si pixel (3x2 layers)
- Silicon Tracker: 4 layers
- TPC(main tracker)
- ECAL/HCAL (5mm/3cm pixel)
- Solenoid (3.5Tesla)
- Muon detector

ILC standard sample (SLAC SM stdhep)

SUSY sample (DESY)

Mass production on grid

ILD standard MC simulation output

SM full processes
(luminosity: 0.1-50 fb^{-1})
SUSY signal: 1000 fb^{-1}

ILD standard reco. output

- Tracking
- Particle Flow
- Flavor tagging etc.

20M events

Analysis code

- An original Marlin processor for kinematic fit and ROOT tree making
- ROOT macros for analysis.

Data Samples

- SUSY point5 signal events generated with whizard (in DESY)
  - 500 fb^{-1} all-SUSY processes in point5
  - Another 500 fb^{-1} $\chi^{\pm}/\chi^{0}$ signal events for template

  NOTE: m_W = 79.8 GeV due to whizard's problem
- SM events (mass production, ~20M events)
  - 20-50 fb^{-1} ee->2/4/6-jet(+lepton) events
  - 0.1 fb^{-1} $\gamma\gamma$/eγ events
  - Additional 500 fb^{-1} $\gamma\gamma$ -> WW events
- All ILD_00 geometry

Cuts for SM suppression

BG suppression cuts

"qqqq + missing"

- 4-jet clustering (Durham)
- # Track >= 20
- 100 < E_{vis} < 300 GeV
- each E_{jet} > 5GeV
- $|\cos\theta|_{jet}$ < 0.99
- each jet has >= 2tracks
- $|\cos\theta|_{miss}$ < 0.8
- no > 25 GeV leptons
- # PFOs/jet > 3
- missing mass > 220 GeV
- Kinematic fit converged

	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to$ hadrons	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to$ hadrons	other SUSY	SM $\gamma\gamma$	SM 6f	SM 4f	SM 2f
nocut	28529	5488	74650	3.66e+09	521610	1.48e+07	2.14e+07
Total # of tracks ≥ 20	27897	5449	24305	3.03e+06	495605	6.68e+06	5.33e+06
$100 < E_{\rm vis} < 300$ GeV	27895	5449	22508	1.06e+06	44394	959805	1.56e+06
$E_{\rm jet} > 5$	27889	5446	20721	908492	44096	916507	1.47e+06
$\lvert\cos(\theta)_{\rm jets}\rvert < 0.99$	26560	5240	19200	350364	41098	678083	874907
$y_{34} > 0.001$	26416	5218	15255	202510	38638	423080	166305
# of tracks ≥ 2/jets	25717	5146	9559	162193	22740	255870	145270
$\lvert\cos\theta_{\rm miss}\rvert < 0.99$	25463	5099	9487	25087	22311	193706	4039
$E_l < 25$	25123	4981	6463	23133	14407	154927	3534
$N_{\rm PFO} > 3$	25029	4975					3518
$\lvert\cos\theta_{\rm miss}\rvert < 0.8$	20144	4079					529
$M_{\rm miss} > 220$ GeV	20139	4079					389
kin. fit converged	20085	4068	4999	626	3649	44577	341

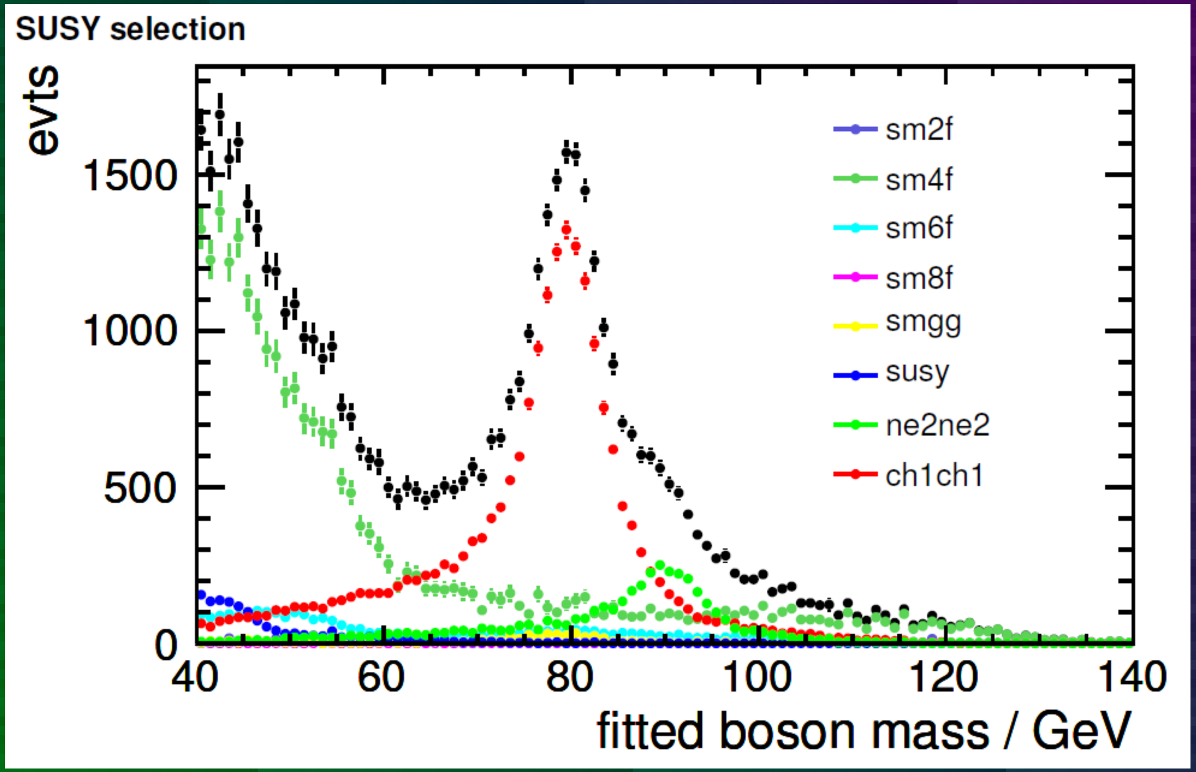
(mass cut is not applied)

Kinematic fit & Jet pairing

- MarlinKinFit processor
  - (Essential) free parameters: Energy and opening angle for each jet(-pair)… NDF=6
  - Constraints:
    - Two di-jet masses are the same – 1C fit
    - Two di-jet masses are m_W / m_Z – 2C fit (W/Z)
- Jet pairing
  - All pairs
  - Best kinematic fit

Obs.	KinFit	Pairing
σ(1D fit)	1C	KinFit
σ(2D fit)	No	All
mass	2C	χ^2 / KinFit

Invariant mass spectrum



- Combination by kinematic fit
- 4f background is small in the signal mass region
- $\chi^{+}_{1}/ \chi^{0}_{2}$ separation can be seen

Cross section – 1D fit

Cross section fitting procedure:

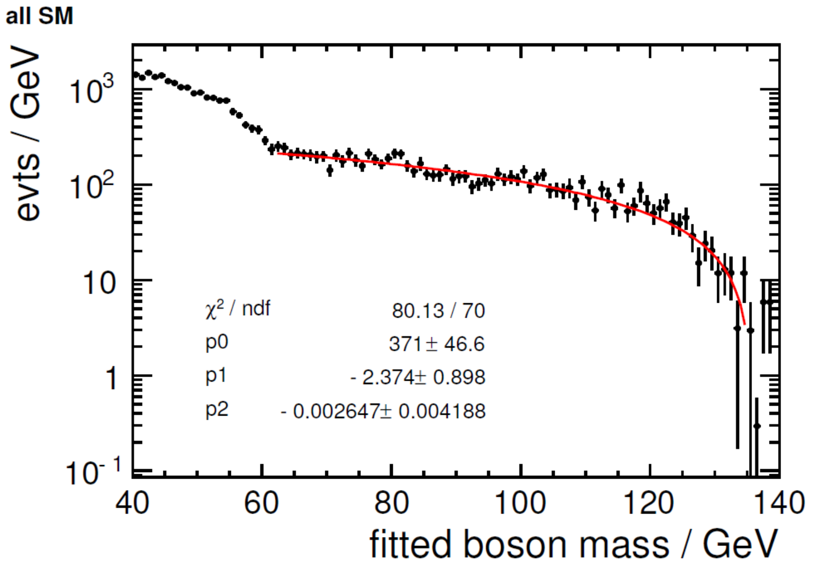
- SM background

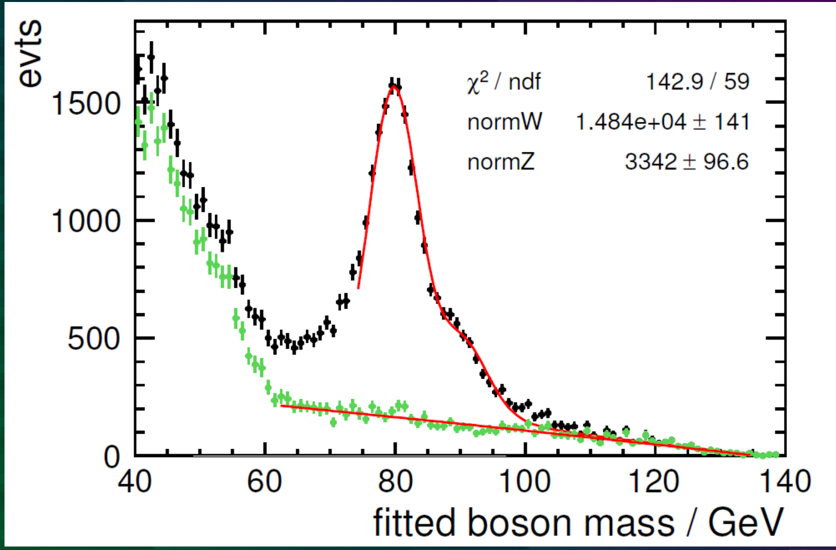
  2^{nd} polynomial fitting separately
- SUSY + SM
  - Gaussian + BW for each W/Z
  - Width and center value fixed, normalization is the only free parameters
  - SM 2^{nd} polynomial fixed

Fit result (σ resolution):

0.95% for $\chi^{\pm}$, 2.9% for χ^0_2.

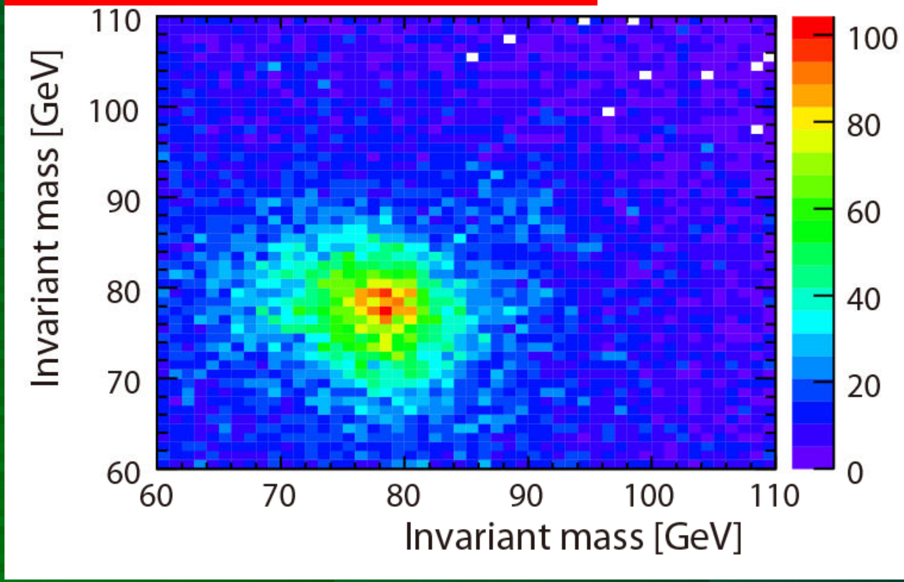
Resolution is a little worse, but less MC info required than 2D fit.



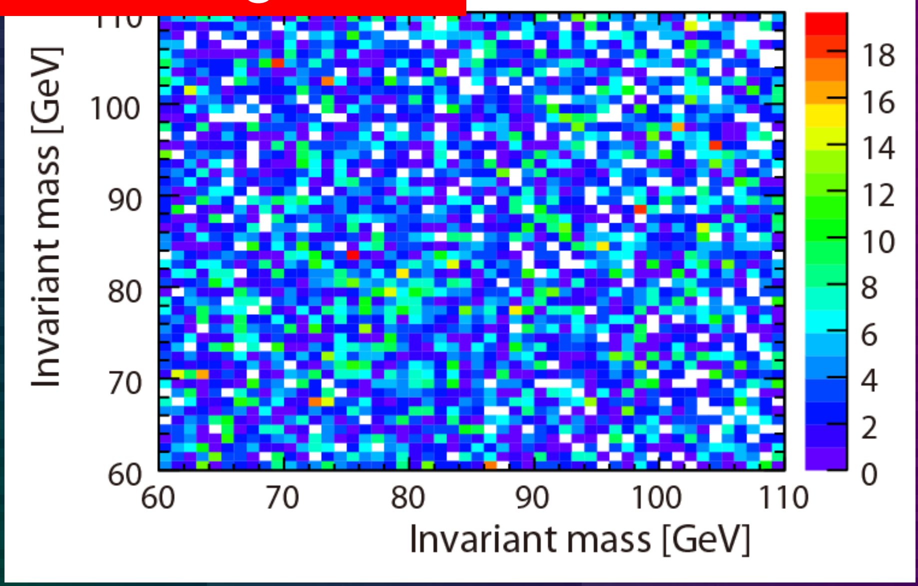


Cross section – 2D fit (1)

Original distribution



SM background

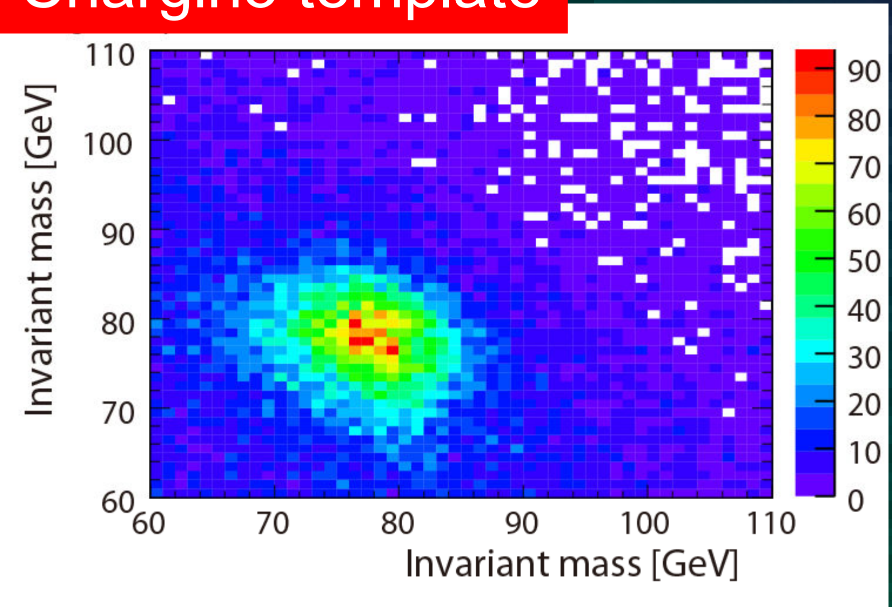


Procedure

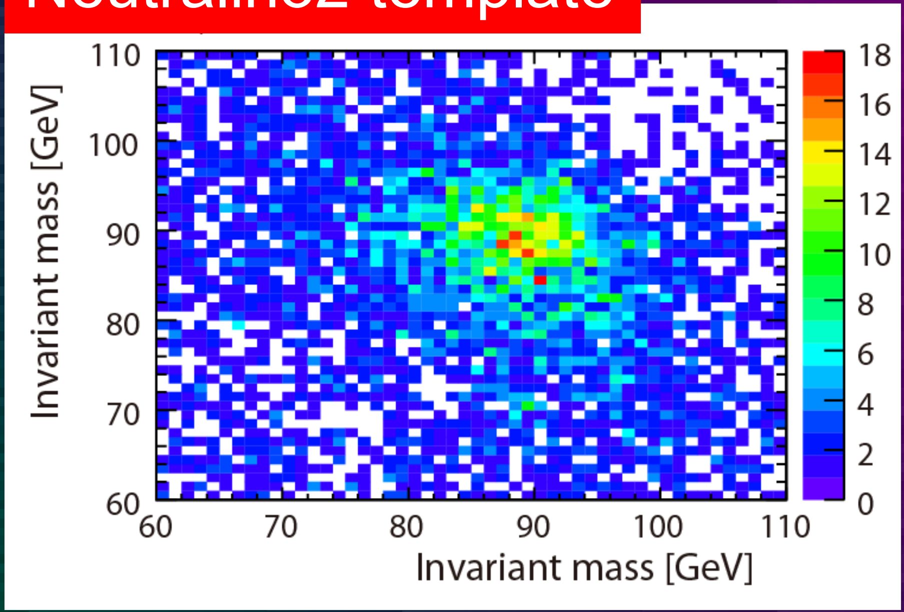
1. Make di-jet-mass-pair distribution with 500fb^{-1} statistics. (left figure)
   – SUSY and SM combined, SM weighted.
   – All combinations are used (3 entries/event)
2. SM background (right figure) is subtracted from the distribution considering statistical fluctuation.

Cross section – 2D fit (2)

Chargino template



Neutralino2 template

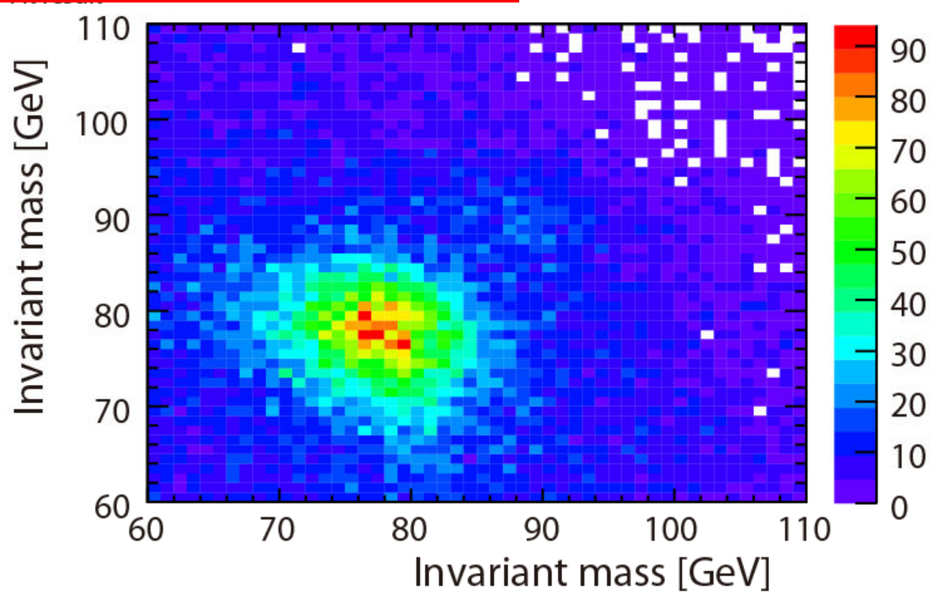


Procedure

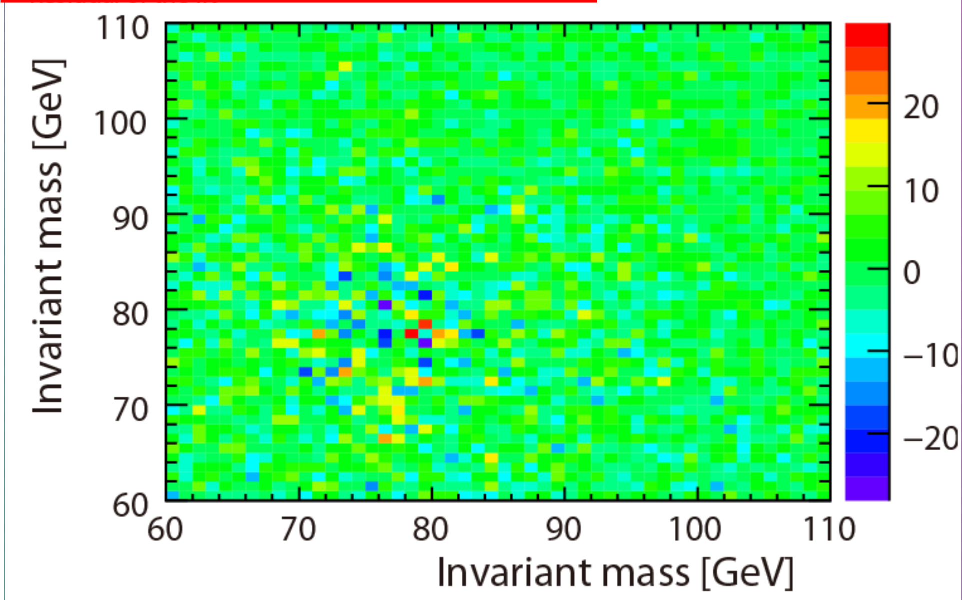
3. Using another 500 fb^{-1} $\chi^{\pm}$/ χ^0_2 data, template distribution for both $\chi^{\pm}$ and χ^0_2 are produced.
4. Fit the distribution obtained in 2. with
   c_1 x (chargino dist) + c_2 x (neutralino2 dist).
   (c_1 and c_2 are free parameters)
5. Repeat 10000 times with SUSY and SM fluctuated.

Cross section – 2D fit (3)

Fitted distribution



Residual (data – fit)



Fit result (10000 average)

$c_1 = 99.97 \pm 0.84$ %, $c_2 = 97.50 \pm 2.75$ %

corresponding to (500 fb^{-1})

$\sigma(e^+e^- \to \chi^+\chi^-) = 124.80 \pm 1.05\ fb^{-1}$ (MC 124.84)

$\sigma(e^+e^- \to \chi^0_2\chi^0_2) = 21.90 \pm 0.62\ fb^{-1}$ (MC 22.46)

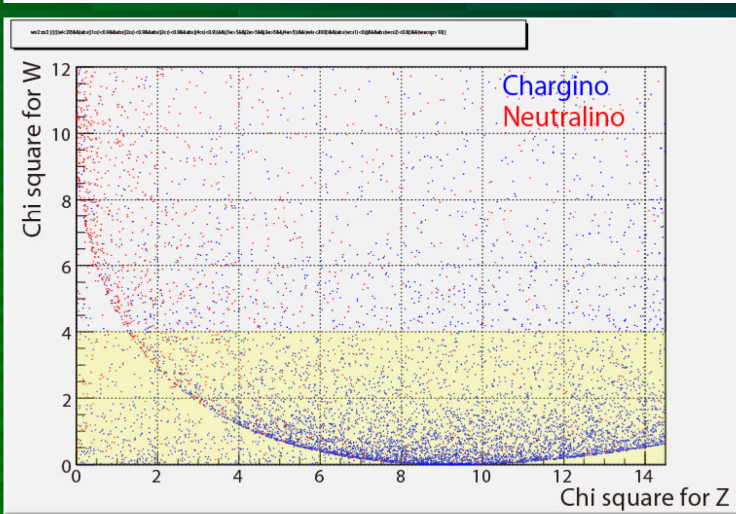
W/Z separation for mass fit

Paring by Kinematic fit probability and cut by χ^2 are applied.

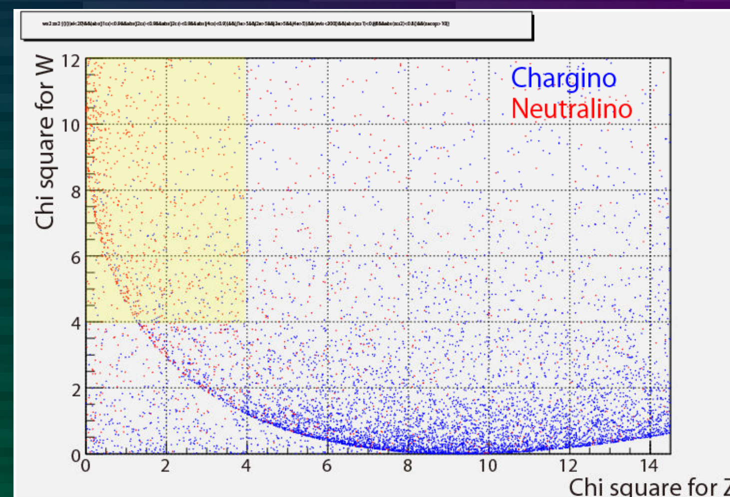
$$\chi^2_W(m_1, m_2) = \frac{(m_1 - m_W)^2 + (m_2 - m_W)^2}{\sigma^2}$$

$$\chi^2_Z(m_1, m_2) = \frac{(m_1 - m_Z)^2 + (m_2 - m_Z)^2}{\sigma^2}$$

- $\chi^2_W < 4$ for $\tilde{\chi}^\pm_1$ mass fit.
- $\chi^2_W > 4$ & $\chi^2_Z < 4$ for $\tilde{\chi}^0_2$ mass fit.



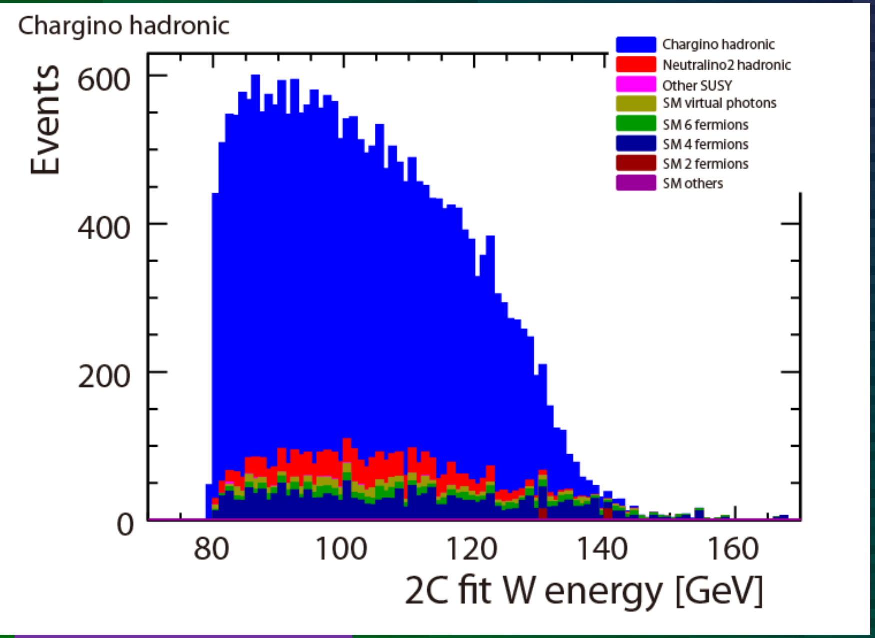
Chargino selection (no SM)

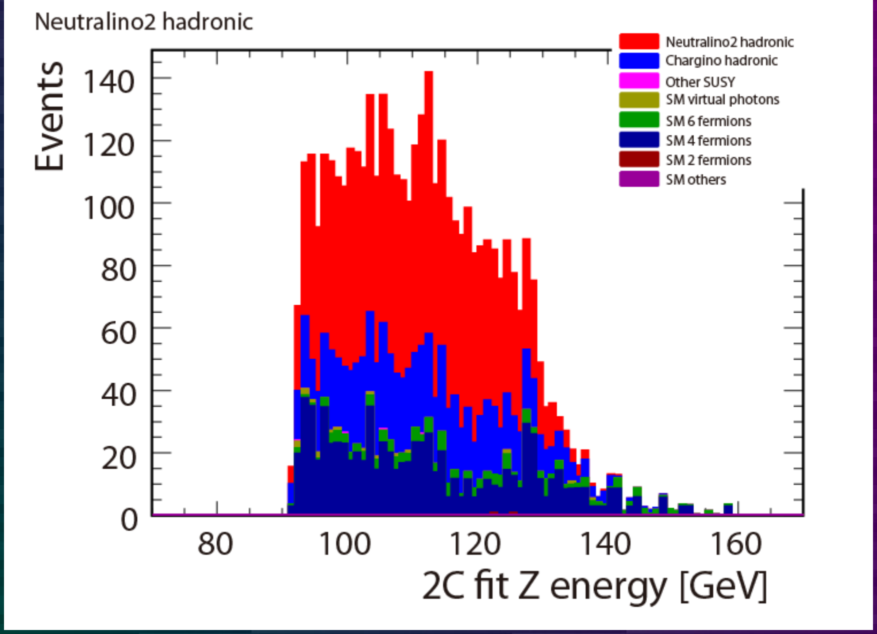


Neutralino selection (no SM)

Selection	Signal efficiency	Signal purity	SUSY bg	SM bg
Chargino	35.9%	83.4%	5.4%	11.2%
Neutralino2	20.4%	53.8%	22.3%	23.8%

Edge fit procedures





Procedure

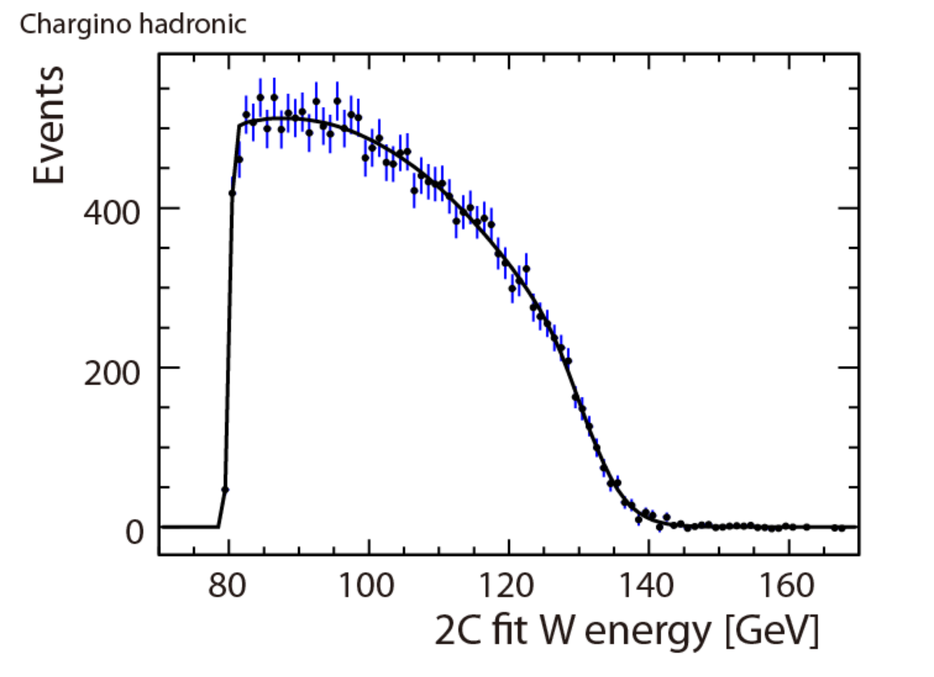
1. 2C Kinematic fit (fit di-jet masses to m_W/m_Z)
   Pair selection by fit probability, selection by χ^2 (prev. slide)
2. Subtract SM background with statistical fluctuation included
3. Fit 100 times with following function to obtain edge position.

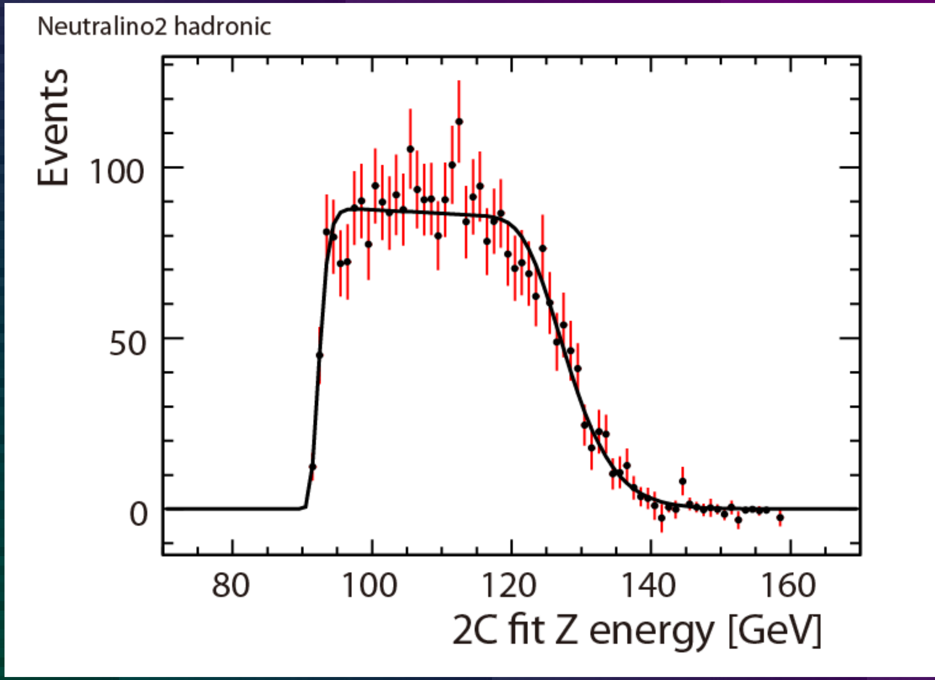
$$f(x; t_{0-1}, b_{0-2}, \sigma_{0-1}, \Gamma) = \int_{t_0}^{t_1} (b_2 t^2 + b_1 t + b_0) V(t - x, \sigma(t), \Gamma) dt \quad (7)$$

$$\sigma(t; \sigma_0, \sigma_1) = \sigma_0 + \frac{(\sigma_1 - \sigma_0)(t - 80)}{40}.$$

7-8 parameters
(for χ^0_2 b_2 is fixed to 0)

Edge fit result





Edge positions (t_0,t_1)

W lower: 80.04 ± 0.055 GeV (MC: 79.80 GeV)
W higher:131.8 ± 0.59 GeV (MC: 132.77 GeV)
Z lower: 92.68 ± 0.32 GeV (MC: 93.09 GeV)
Z higher: 127.9 ± 0.74 GeV (MC: 129.92 GeV)

Edge to mass

- Kinematics are used to interpret edge position to SUSY masses.

PROBLEM: W lower edge is just at m_W thus has no information for SUSY masses!

- We don't use W lower edge but use other three edges for the mass calculation (3 variables -> 3 masses: χ^+_1, χ^0_2 and χ^0_1)
- Statistical error of the masses is estimated by toy-MC including correlation between masses. (edge positions are independent)

Results and comments

Gaugino masses w/o correction	Gaugino masses w/ correction
$m(\chi^{\pm}_1) = 220.7 \pm 2.8$ GeV	$m(\chi^{\pm}_1) = (216.5) \pm 3.1$ GeV
$m(\chi^{0}_2) = 219.2 \pm 1.1$ GeV	$m(\chi^{0}_2) = (216.7) \pm 1.0$ GeV
$m(\chi^{0}_1) = 118.2 \pm 0.85$ GeV	$m(\chi^{0}_1) = (115.7) \pm 0.82$ GeV

- Edge position can be corrected in real experiment using MC distribution.
  - Upper left: w/o correction
  - Upper right: assumed that the edge position can be perfectly corrected and the error of the edge position is the same as it without correction.
- Point 5 is a very special scenario which cannot use W lower edge, resulting in worse mass resolution (especially for χ^{+}_1).

Summary

- ILD has sufficient power to separate chargino/neutralino events in point5 SUSY.
- < 1% ($\chi^{\pm}$) and 2-3% (χ^0_2) pair production cross section resolution is obtained.
- With 2C kinematic fit, ~ 1 GeV (χ^0_2) and ~3 GeV ($\chi^{\pm}$) mass resolution is obtained.
- Although mass fit includes some conservative assumptions, it should be a good first estimate of real analyses.
  - Of course having a room to improve analysis…

The end