Simulation study of W + DM signature for identification of new physics

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  - Production angle
  - Mass determination
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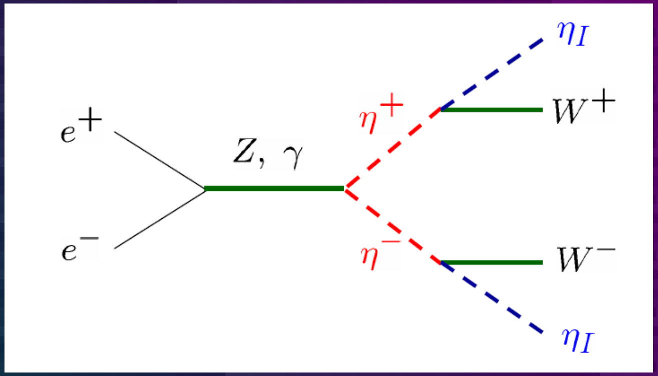
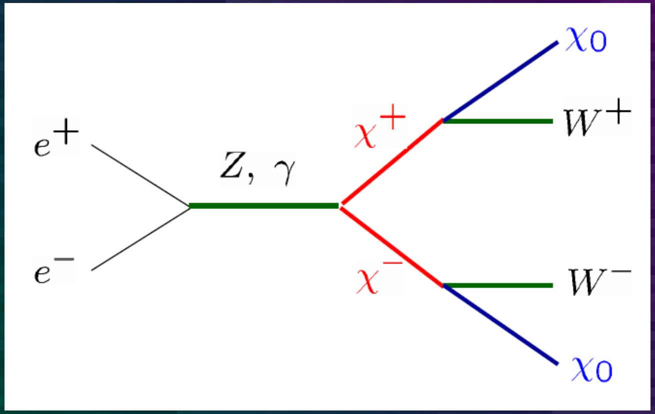
Introduction

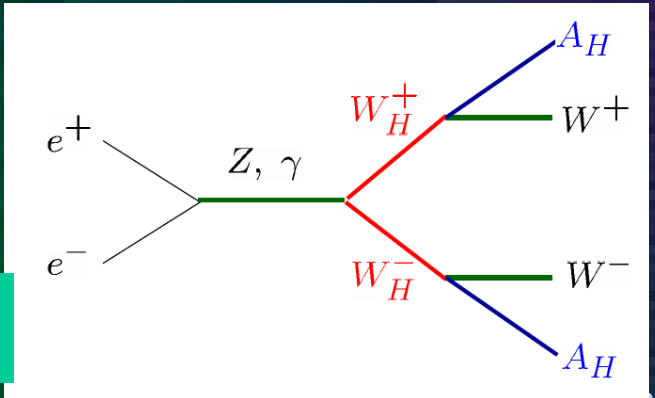
- One of the most important purpose of ILC is the precise measurement of ‘new particles’
  - if found at LHC…
- Models with a WIMP are especially attractive
  - ex1. SUSY: WIMP=neutralino
  - ex2. Little Higgs with T-parity: WIMP=A_H
- Examining spins of new particles can separate those models
- Asano-san’s talk for theoretical aspects

Three models

1. Inert Higgs model
   - WIMP: η_I (scalar)
   - Visible: $\eta^{\pm}$ (scalar)
2. SUSY model
   - WIMP: χ_0 (fermion)
   - Visible: $\chi^{\pm}$ (fermion)
3. LHT model
   - WIMP: A_H (vector)
   - Visible: $W_H^{\pm}$ (vector)







All: 2Ws + 2WIMPs final state

Strategy

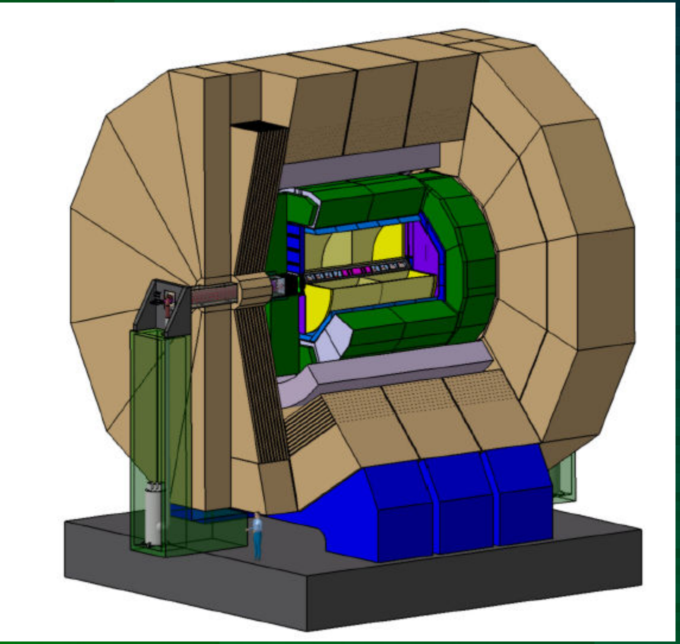
- Two parameters of ILC
  - $\sqrt{s}$ = 500 GeV, 500 fb^{-1}: full simulation
  - $\sqrt{s}$ = 1 TeV, 500 fb^{-1}: fast simulation
- No initial polarization (both)
- Three models with the same masses

  500 GeV: $m_{visible}$ = 231.57 GeV, m_{WIMP}=44.03 GeV

  1 TeV: $m_{visible}$ = 368 GeV, m_{WIMP} = 81.9 GeV
- Do not use difference of cross section
- Obtain their spin information by reconstructing production angle.

500 GeV analysis

ILD detector & analysis framework



ILD detector (ILD00)

- Vertex: Si pixel (3x2 layers)
- Silicon Tracker: 4 layers
- TPC(main tracker)
- ECAL (0.5x0.5 cm tile, Si/W)
- HCAL (3x3 cm tile, Sci/Fe)
- Solenoid (3.5Tesla)
- Muon detector

Event generation (signal, SM background)

↓ Stdhep event files

Full-MC simulation (GEANT4)

- Mass production on grid

↓ Hit, MC information(LCIO file)

Event reconstruction

- Tracking
- Particle Flow
- Flavor tagging etc.

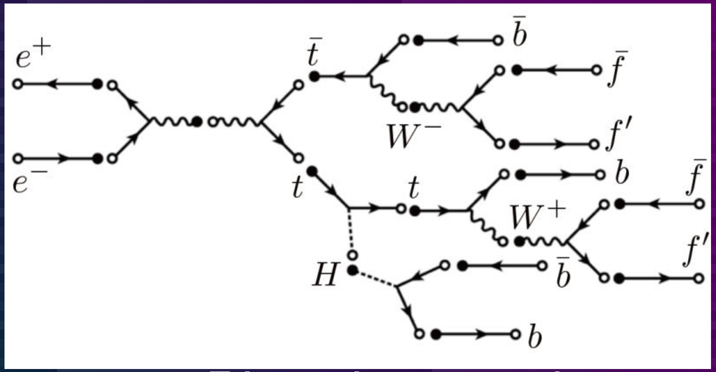
↓ Info. of reco. particles(ROOT tree)

Analysis code

- Event weighting
- Separation cuts
- Analysis (mass, angle…)

Event generation

- Signal: JSF/physsim (Framework of ILC-Japan)
  - Structure
    - HELAS for helicity amp. calculation
    - BASES for numerical integration
    - SPRING for event generation
      - Pythia for quark fragmentation
  - ISR/Beamstrahlung included
  - ~0.1 M events for each process generated

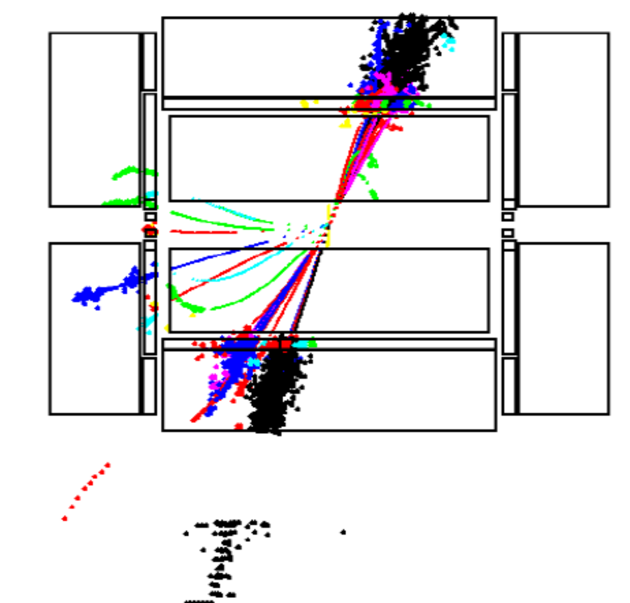


Physsim sample for tth process

- Background: SLAC (ILC standard sample)
  - whizard/pythia for all SM processes
  - ~14 M events in total (80-200 fb^{-1} for 2/4/6 fermion events, 0.1-1 fb^{-1} for eγ/γγ events)

Simulation & Reconstruction

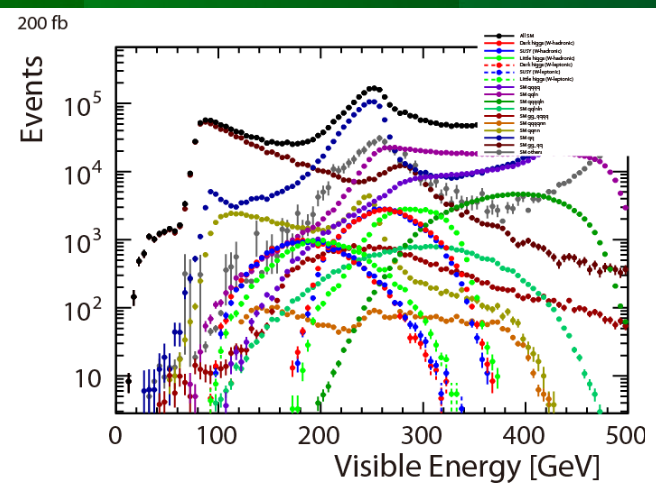
- MC simulation: Mokka (GEANT4 based)
  - Including some gaps and structures
  - 1-10 minutes/event (in a modern CPU)
    - Standard model sample(14M events) is shared in ILD group. Production took several months with thousands of cores.
    - Signal(0.3M events) is produced by CPUs of KEK.
- Reconstruction: MarlinReco/PandoraPFA
  - Modular framework (MarlinReco)
    - Tracking (helix fit)
    - PandoraPFA (particle flow)
    - LCFIVertex (neural-net based flavor ID)
    - Analysis processor (kinematic fit, ROOT tree filling)

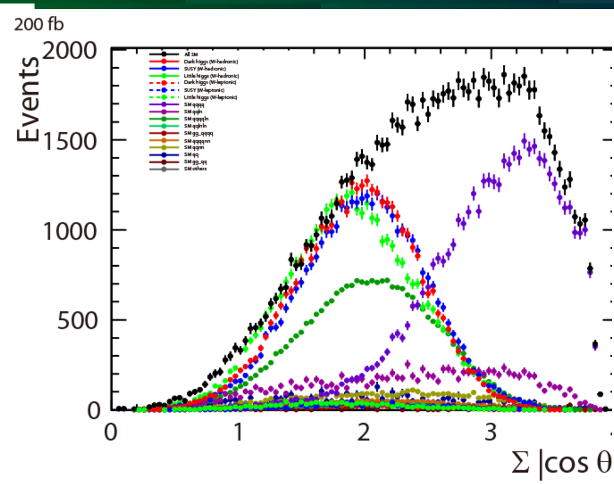


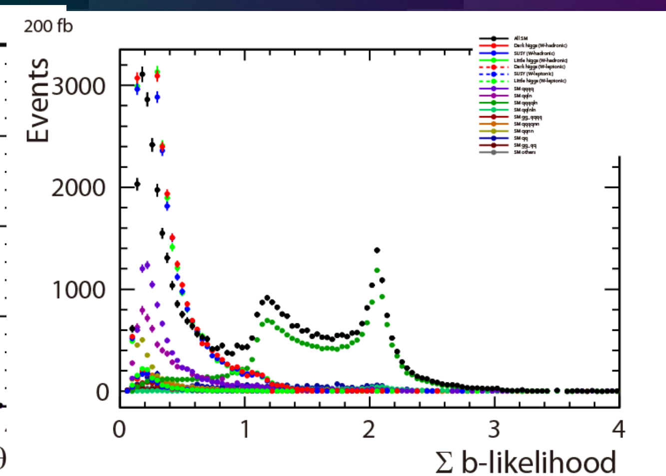
Selection cuts

BG suppression cuts — “qqqq (non-b) + missing”

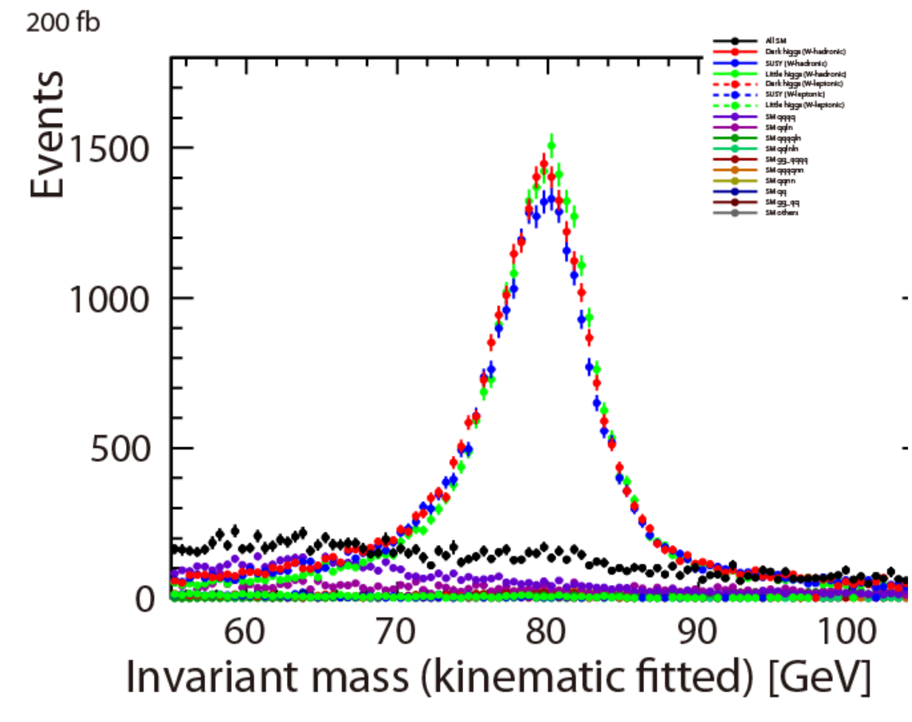
- 4-jet clustering (Durham)
- # Track >= 20
- $160 < E_{vis} < 400$ GeV
- each $E_{jet} > 5$GeV
- $|\cos\theta|_{jet} < 0.99$
- unlike 3jet ($y_{th,3} > 0.001$)
- each jet has >= 2tracks
- no > 25 GeV leptons
- $|\cos\theta|_{miss} < 0.9$
- sum $|\cos\theta| < 2.6$
- sum b-quark prob. < 1
- kinematic fit converged
- $65 < m_W < 95$ GeV

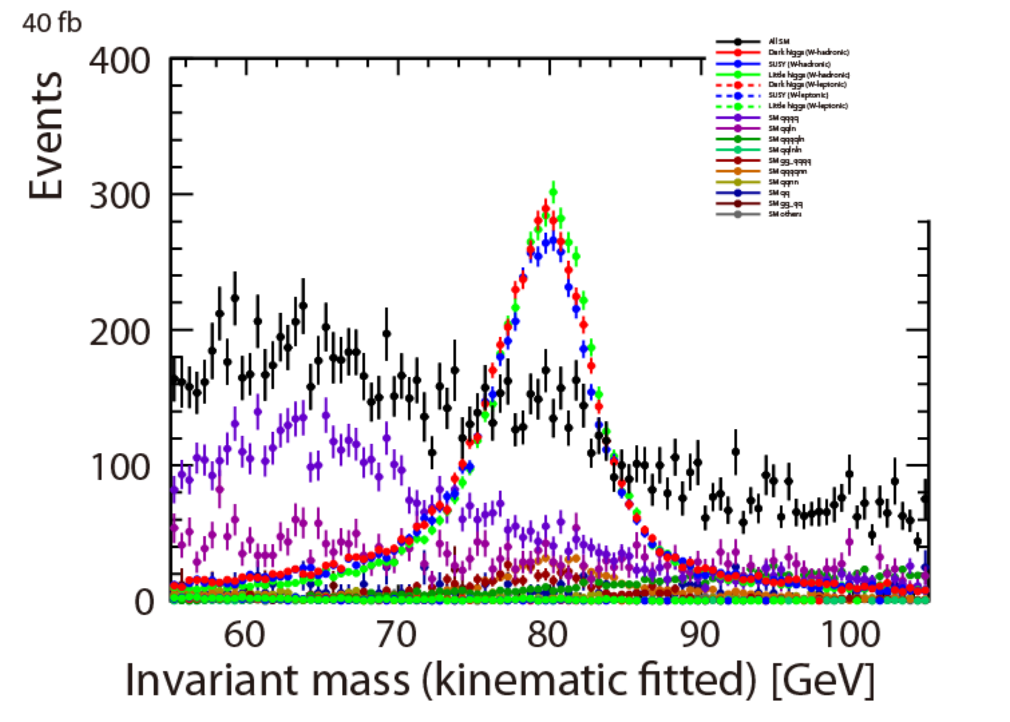






Selection efficiency

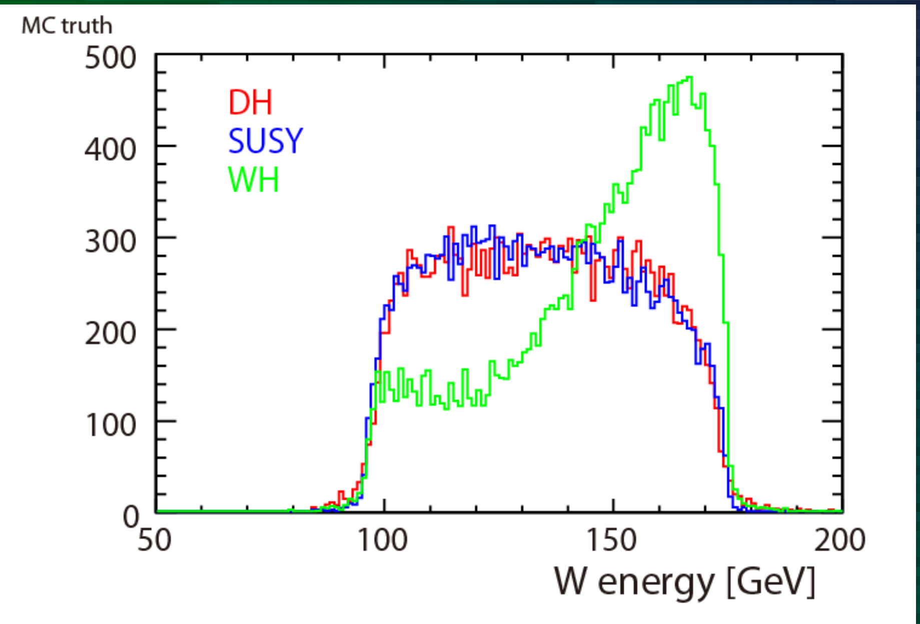




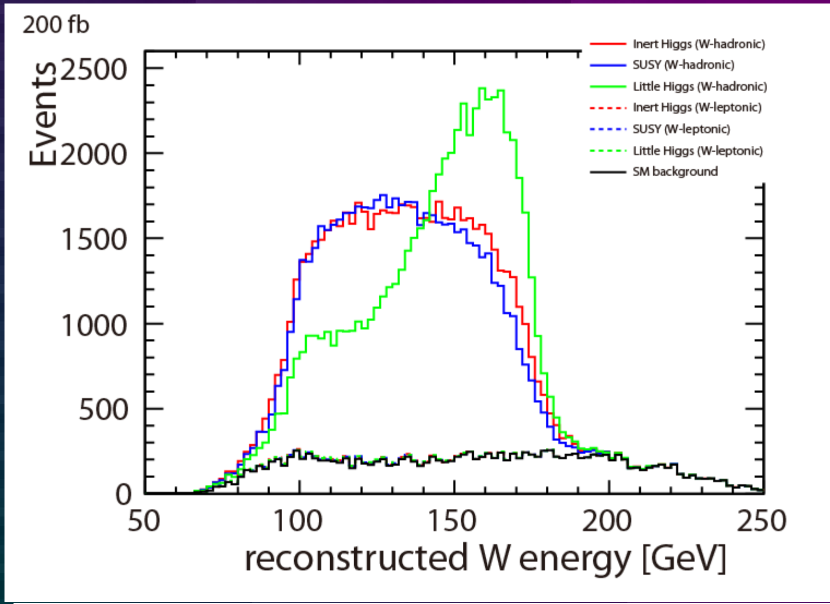
- IH eff: 59.8%, pur (200 fb): 78.6%, pur (40 fb): 42.3%
- SUSY eff: 58.3%, pur (200 fb): 77.7%, pur (40 fb): 41.0%
- LHT eff: 58.9%, pur (200 fb): 78.2%, pur (40 fb): 41.8%

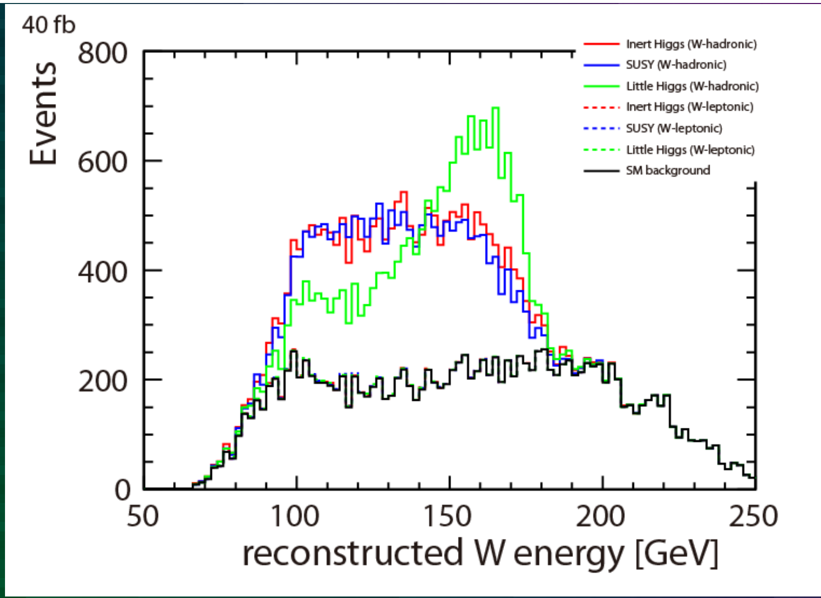
Good bg separation with ~60% signal efficiency.

W energy distribution



MC truth (signal only)



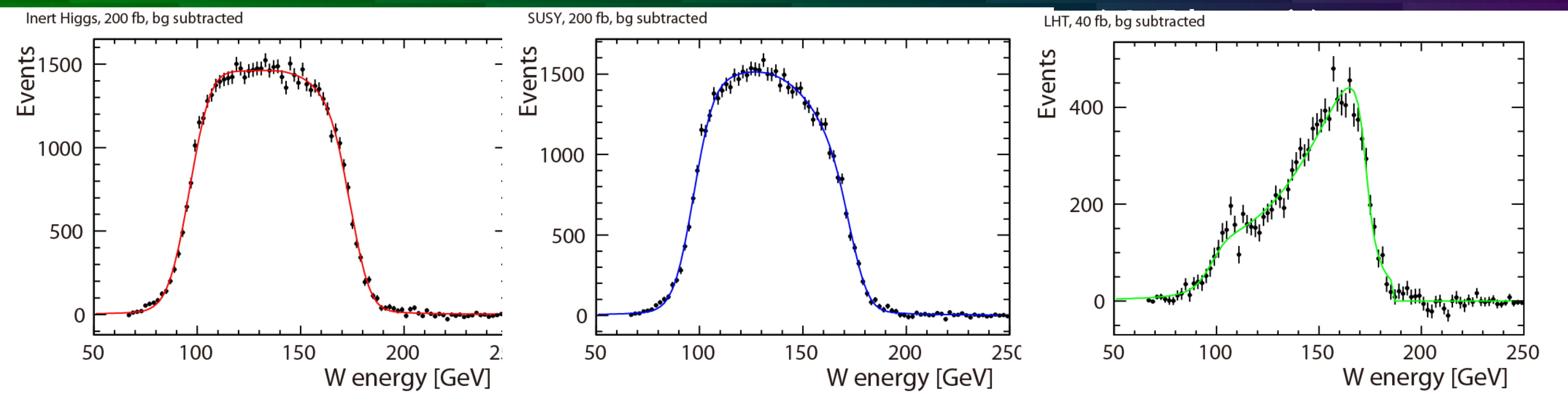


Reco (kin-fitted)

MC & reco give good agreement
LHT has different distribution
but we do not use it for the model ID.

Mass determination

- W energy distribution gives low/high edges due to the kinematical constraint from masses of WIMP & visible new particle
- Obtain edge position by fit -> calc mass
  - Fit by convolution of 3rd polynomial and Voigt func with box integration, lower/upper limits of the box gives kinematical edges



Mass resolution (preliminary)

- Edge positions obtained by fits:

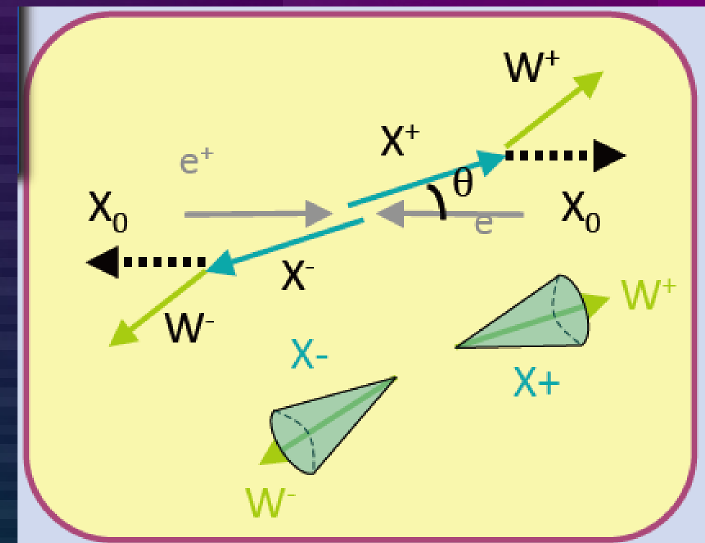
	Low edge (200 fb)	High edge (200 fb)	Low edge (40 fb)	High edge (40 fb)
IH	96.61 ± 0.55 GeV	174.60 ± 0.79 GeV	95.85 ± 1.46 GeV	174.68 ± 2.19 GeV
SUSY	97.05 ± 0.55 GeV	173.65 ± 1.08 GeV	96.96 ± 3.39 GeV	168.29 ± 4.13 GeV
LHT	98.12 ± 0.41 GeV	174.06 ± 0.29 GeV	97.42 ± 1.35 GeV	172.73 ± 0.44 GeV

- Calculate masses from above

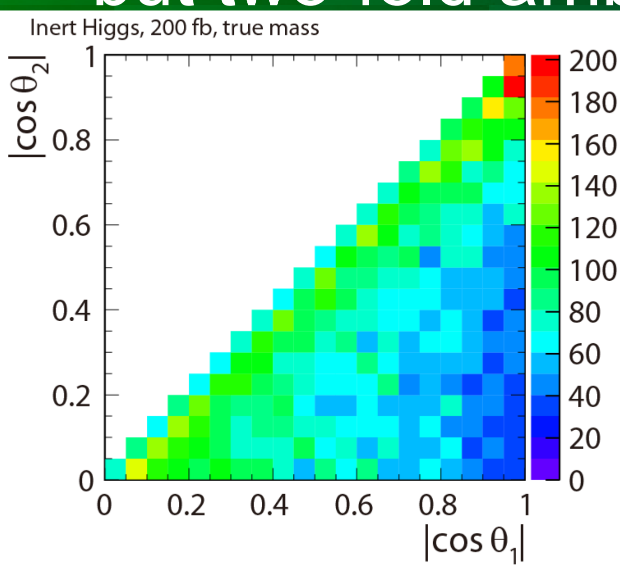
	Visible (200 fb)	WIMP (200 fb)	Visible (40 fb)	WIMP (40 fb)
IH	231.9 ± 0.50 GeV	43.57 ± 2.43 GeV	231.2 ± 1.39 GeV	45.08 ± 6.53 GeV
SUSY	232.5 ± 0.53 GeV	44.51 ± 2.94 GeV	233.7 ± 2.92 GeV	54.92 ± 11.23 GeV
LHT	233.2 ± 0.32 GeV	40.44 ± 1.46 GeV	233.0 ± 1.05 GeV	45.53 ± 3.82 GeV

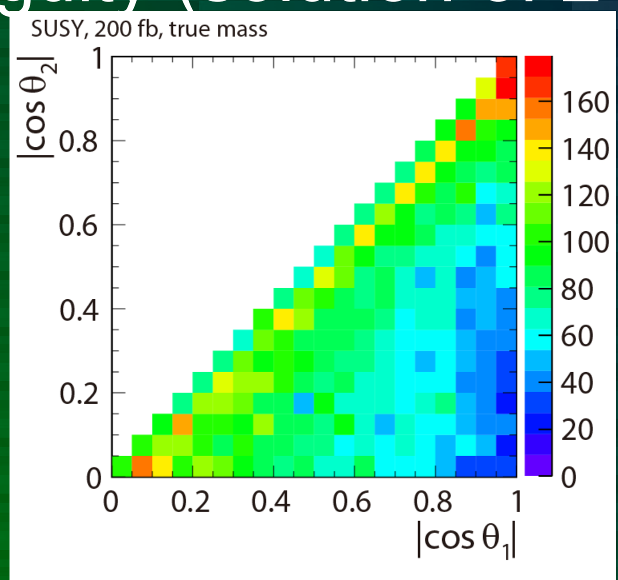
Production angle

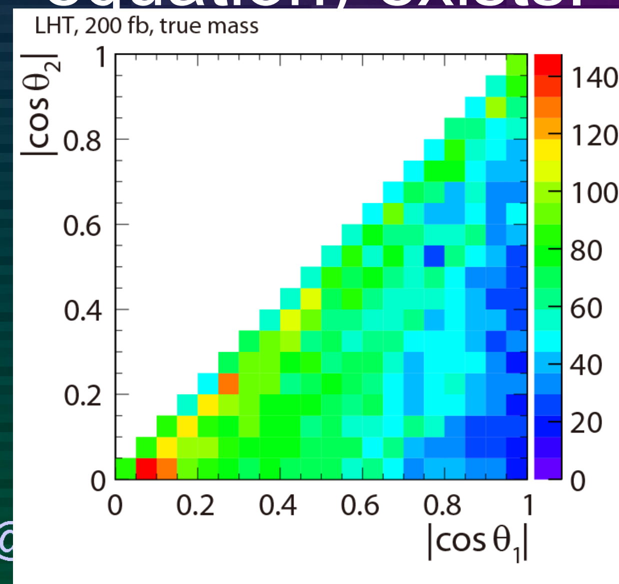
- Production angle of the visible new particle can be calculated from W directions with masses of new particles and back-to-back assumption.



- The angle has spin info. but two-fold ambiguity (solution of 2nd equation) exists.

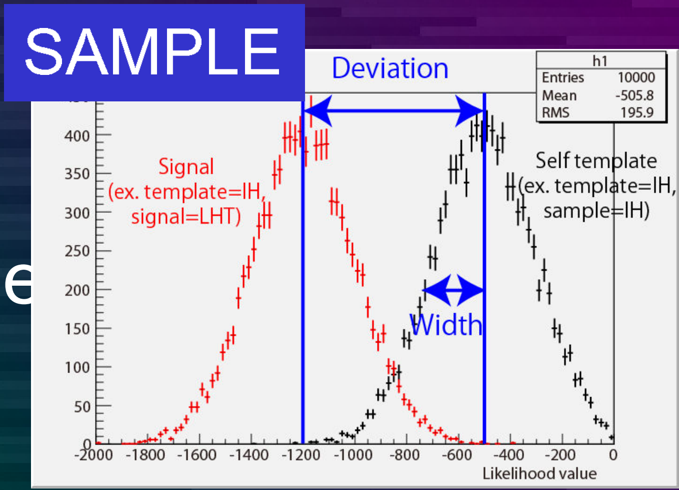






Comparing Production Angle

- Difference of the distributions can be quantified by the likelihood value to each template
  - ‘Signal’ is made by Poisson randomization of the templates
  - All distribution are normalized
    - (not to use cross section information)
- Significance is the deviation of the mean value in unit of likelihood of self template.



Significance@ 200fb	IH sample	SUSY sample	LHT sample
IH template	-	3.6	7.1
SUSY template	3.3	-	5.7
LHT template	10.9	9.8	-

preliminary

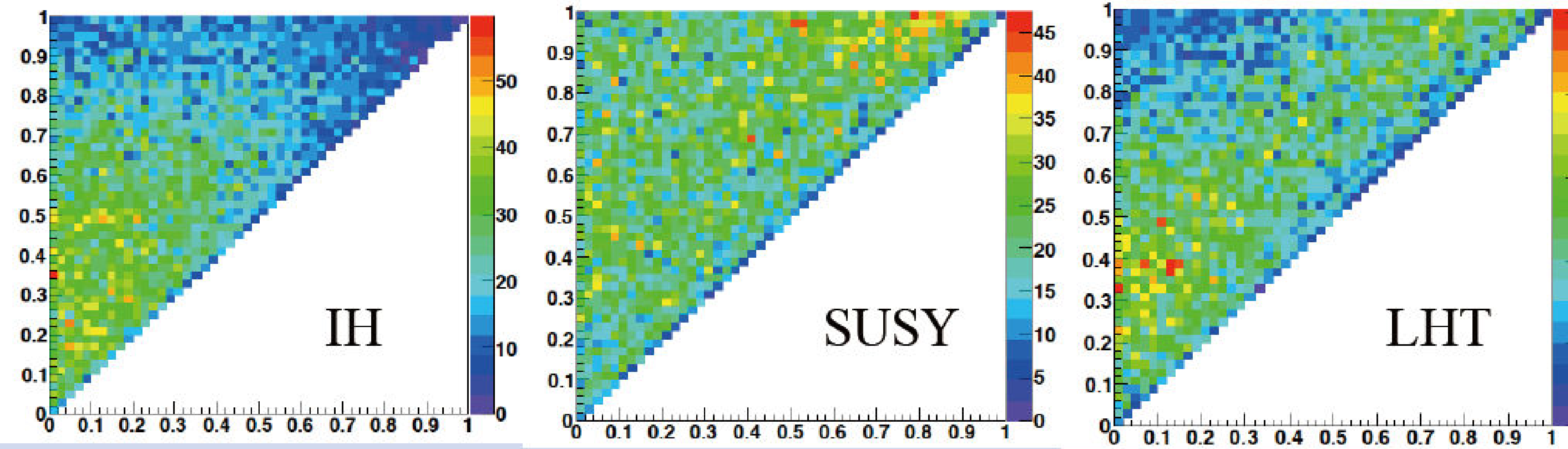
1 TeV analysis

by a fast simulation of JSF framework

Production angle plot

The distribution of $\boldsymbol{cos\,\theta_1}$ **vs** $\boldsymbol{cos\,\theta_2}$ are investigated on each model

|cosθ1| **$|\cos\theta_1|$ vs $|\cos\theta_2|$ of charged particle (σ=200fb)**



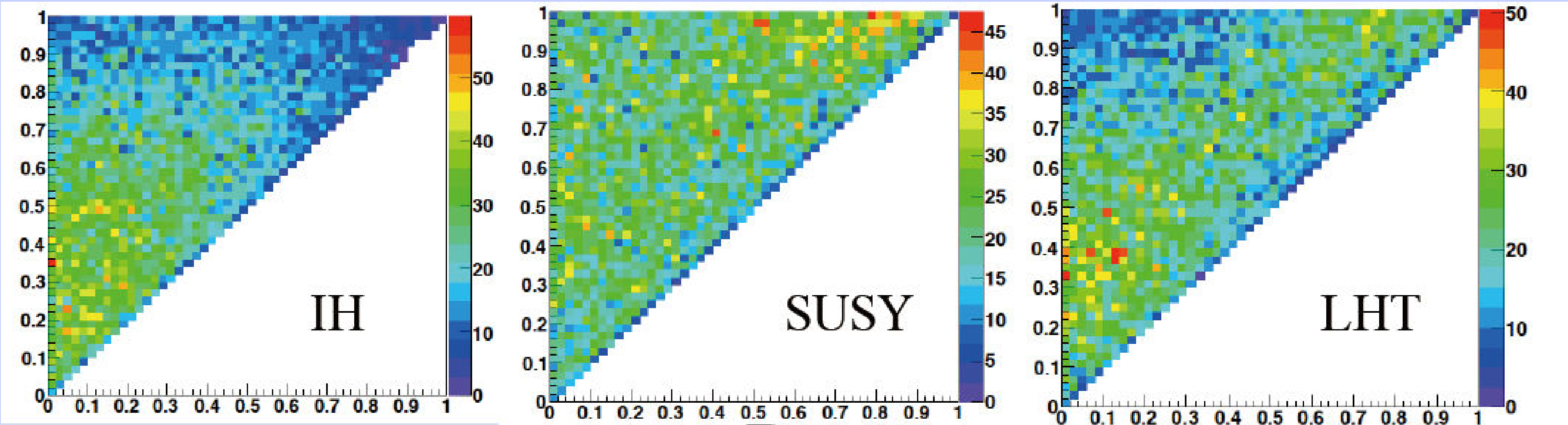
|cosθ2|

The differences about distributions can be seen.

→ **compared with template using χ^2.**

|cosθ1|

|cosθ1| vs |cosθ2| of charged particle (σ=200fb)

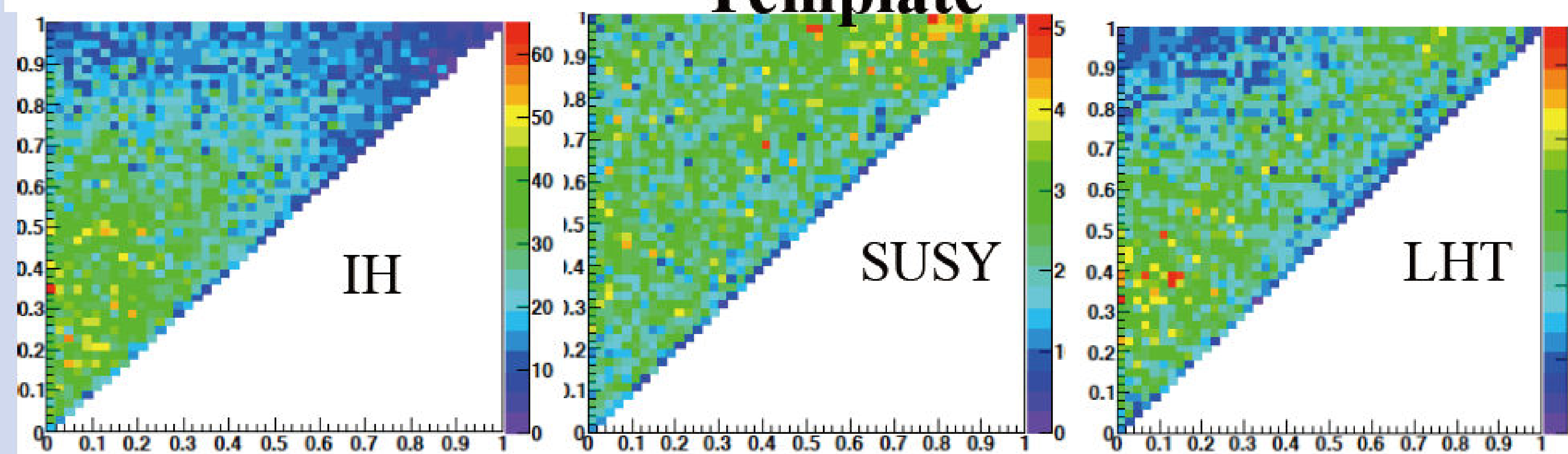


|cosθ2|

Data

Compared using χ^2

Template



χ^2/ndf

χ^2/ndf s are investigated about each models, changing the template.

$L_{\rm int}$	Physics model	IH template	SUSY template	LHT template
40 fb	IH	0.43	1.05	0.94
	SUSY	0.48	0.44	0.92
	LHT	0.94	0.79	0.43
200 fb	IH	0.48	3.65	2.97
	SUSY	4.08	0.48	2.69
	LHT	3.08	2.42	0.48

It is possible to distinguish each models by chi2

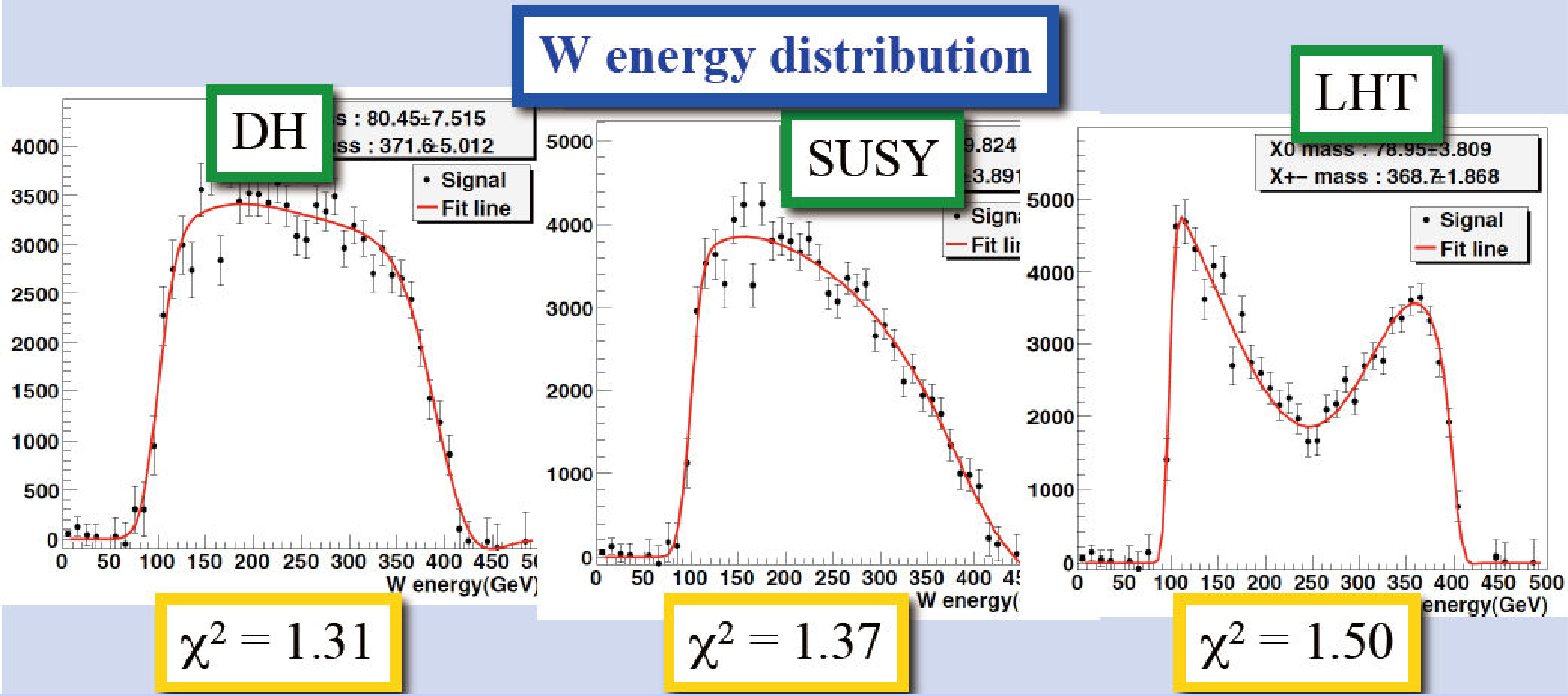
$$\chi^2 = \Delta L = -2logL - logL_0$$

$$P_{ij} = \frac{e^{-\mu}\mu^x}{x!} \qquad \mu = N_{ij}^{temp} \qquad x = N_{ij}^{data}$$

$$L = \prod_{ij} P_{ij}$$: Likelihood

W energy distribution

W energy distributions are investigated to get the masses of $X^{\pm}$, X^0.



The distribution itself may be used for Model ID ⇒ Need to study

Sensitivity of mass

The masses of $X^{\pm}$ and X^{0} are obtained by fitting W energy.

Mass of $X^{\pm}$ and X^{0}

	Physics model	$L_{\rm int} = 40$ fb	$L_{\rm int} = 200$ fb
$M_{\chi^{\pm}}$ (GeV)	IH	382.9 ± 18.8	371.6 ± 5.0
	SUSY	383.3 ± 14.8	371.4 ± 3.9
	LHT	370.9 ± 6.7	368.7 ± 1.9
$M_{\chi^{0}}$ (GeV)	IH	85.0 ± 32.3	81.5 ± 7.5
	SUSY	122.1 ± 35.0	84.8 ± 9.8
	LHT	71.4 ± 16.4	79.0 ± 3.8

The masses are determined at ~10 % level at 200 fb

Threshold scan

The cross section rising is checked through the threshold scan.

Fit function : $\alpha(s - 4m_C^2)^{1/2} + \beta(s - 4m_C^2)^{3/2}$

N	: Normalized factor
s	: Square of √s
m_C	: Mass of charged particle
α, β	: Fit parameter

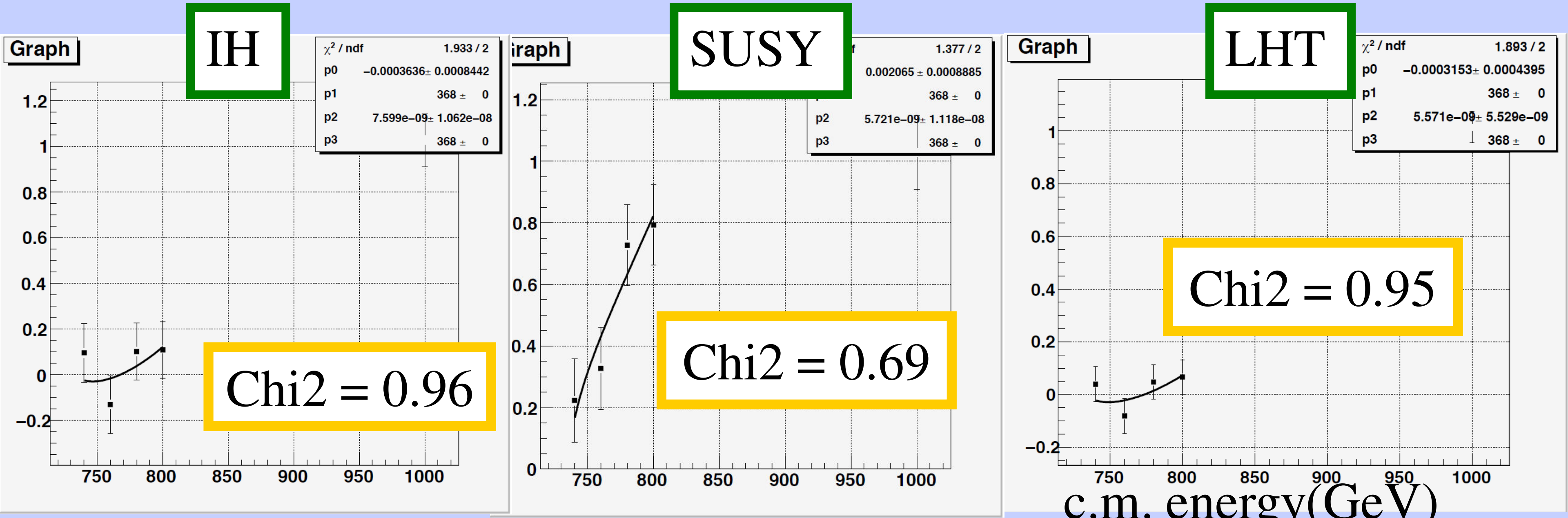
Fit region : 740 ~ 800 GeV
Luminosity per one plot : 40 fb^{-1}

The α, β are investigated by the fit results,
changing the model's cross section, 40 and 200 fb.

Threshold scan (σ=40fb)

The threshold scan are performed. (All model = 40fb)

The normalized cross section



These fits are good ⇒ Fit parameters are compared

Threshold scan fit result

The fit parameter α, β are compared with each model.

	cross section (fb)	α	β	β/α
IH	40	3.47E-05	5.78E-09	1.67E-04
	200	0.0001	5.48E-09	5.48E-05
SUSY	40	0.002075	5.67E-09	2.73E-06
	200	0.002454	3.97E-09	1.62E-06
LHT	40	-0.0003153	5.57E-09	-1.77E-05
	200	-0.0001505	4.82E-09	-3.20E-05

It is possible to identification by α at 200 fb.

Summary

- Separation of Inert Higgs/SUSY/Little Higgs with T-parity mode has been studied for both $\sqrt{s}$ = 500 GeV and 1 TeV.
- Masses of particles can be measured for less than 10% resolution with 500 fb^{-1} luminosity, 200 fb cross section.
- With production angle, three models can be separated by $\geq 3\sigma$ for 200 fb cross section.
- Threshold scan is also useful to separate models.