Dark Matter

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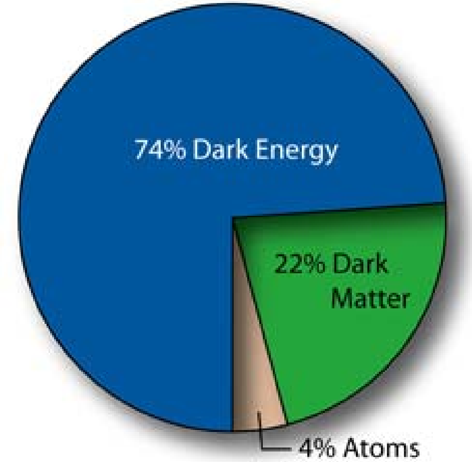
Dark Matter

http://map.gsfc.nasa.gov/



DM abundance is establish by WMAP.

The nature is
- ☐ Neutral
- ☐ Massive
- ☐ Stable

One of the most plausible candidate: **WIMP**

(Weakly Interacting Massive Particles)

WIMPs are also able to account for the large scale structure of the presence universe.

WMAP results show that WIMP DM mass m_χ around 100 GeV.

$$\Omega_\chi h^2 \sim \left(\frac{m_\chi}{1\ \mathrm{TeV}}\right)^2 \sim 0.1$$

⇨ It is also plausible that DM appears in TeV new physics model which are motivated as the solution of the hierarchy problem (which should be solved at ~ TeV).

Dark Matter Candidates

WIMP	spin	model
□ η_I	**0**	**Inert Doublet**
□ χ^0	**½**	**SUSY**
□ A_H	**1**	**Littlest Higgs**

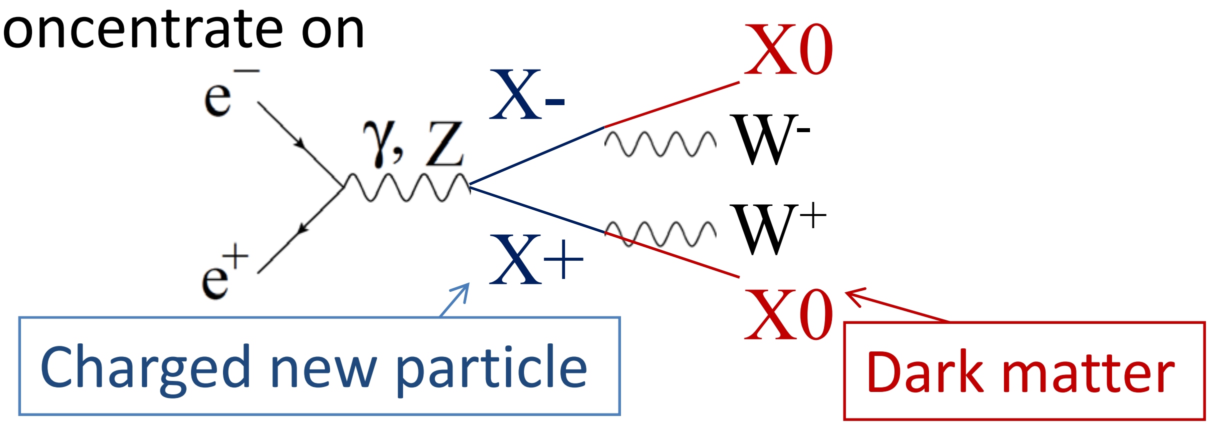
others

- □ Axion
- □ Gravitino (SUSY)
- □ …

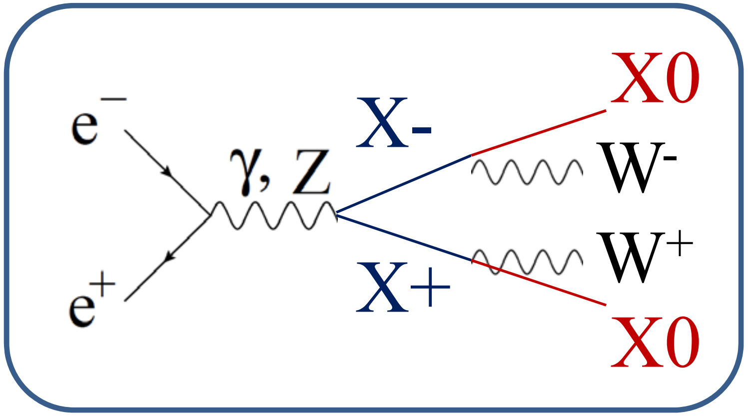
The spin of DM candidate comes in a variety of types.

How to distinguish the dark matter nature in different new physics models?

⇨ We concentrate on



In order to measure mass & spin of new particles at ILC.

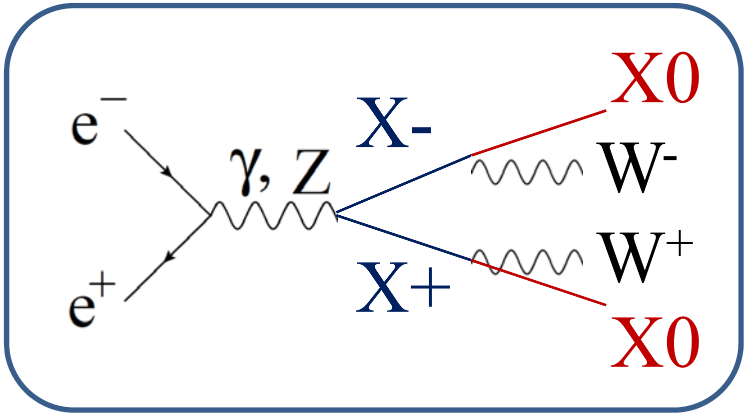


For example,

- **SUSY**

  X0: Neutralino spin ½

  X+: Chargino spin ½



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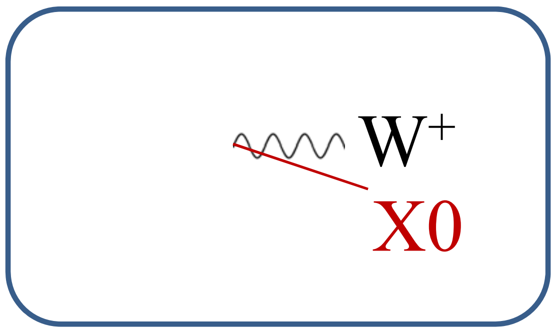
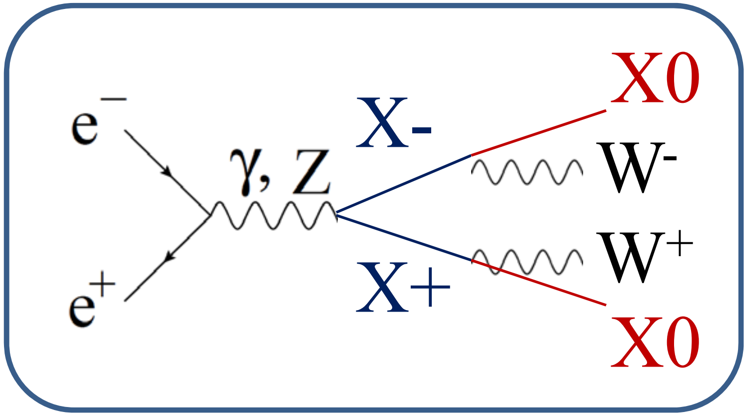
Since WIMP DM is interact SM particle weakly, the DM will interact W+- gauge boson. To conserve the charge and Z2-symmetry, the interaction also includes Charged New Particles.





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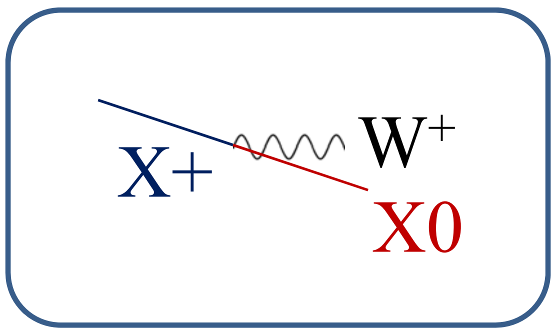

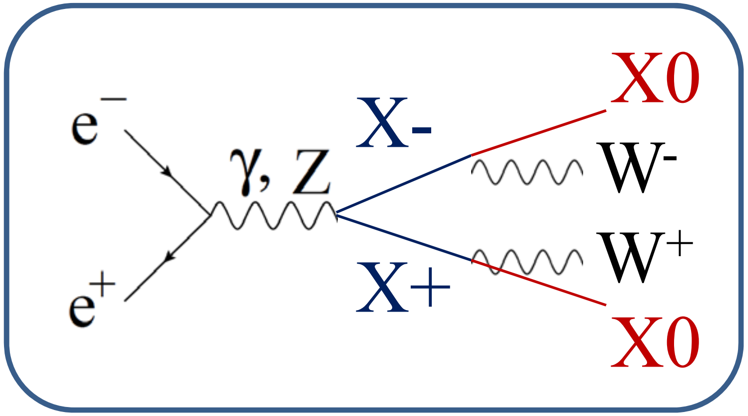

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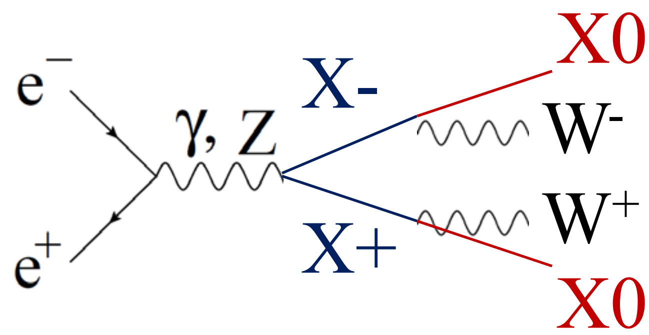
⟹ Other WIMP scenario will also have this mode.

	X_1^0	$X^{\pm}$	Model example
spin	0	0	Inert Higgs
	0	1	Unknown
	1/2	1/2	SUSY
	1	0	Unknown
	1	1	Little Higgs w/T-parity

From this mode,

we will measure



masses

⇨ mass relation between X^0 & X^{+-} will confirm the model.

Angular distribution of charged new particles $X^{\pm}$

⇨ X^{+-} spin

Angular distribution of jets from $W^{\pm}$ polarization

⇨ The decay vertex structure

We will study this mode for three models in order to distinguish the dark matter nature.

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SUSY Model

- SUSY transforms bosons into fermions and vice versa.
- Cancelation of the Quadratic div. to Higgs mass term is guaranteed by the supersymmetry.

Littlest Higgs Model

N. Arkani-Hamed, A. G. Cohen, H. Georgi ('01)

- Higgs boson is regarded as a pseudo Nambu-Goldstone boson
- The quadratic div. vanish at one-loop level due to the collective symmetry breaking.

Inert Doublet Model

R. Barbieri, L. J. Hall, V. S. Rychkov ('06)

- 2 Higgs doublet model in which 1 doublet has Z2-odd parity.
- Higgs mass ~ 500GeV while avoiding EWPM constraints.

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SM particles + R-odd SM partner (spin is different)

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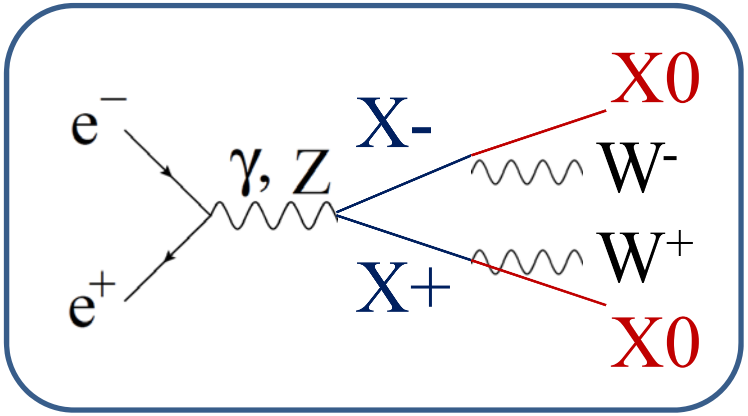
SM particles + Z2-odd Higgs doublet



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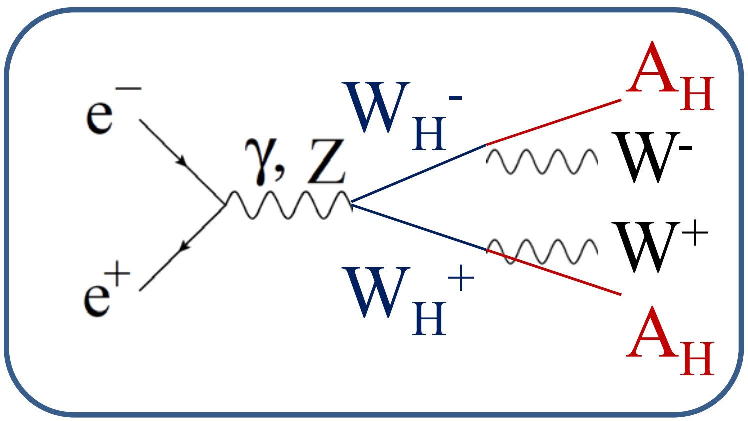
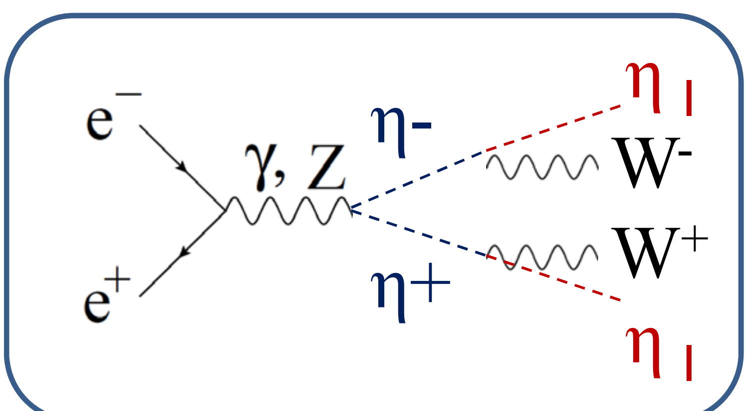
  - X+: Chargino spin ½



- **Littlest Higgs with T-parity**
  - A_H: Heavy Photon spin 1
  - W_H^+: Heavy W boson spin 1



- **Inert Doublet model**
  - η | : Neutral Inert Higgs spin
  - η^{θ}: Charged Inert Higgs spin 0

Our Plan

1. We will analysis for three models using same masses.

2. The cross section will adjust the smallest cross section in three models in order to more general WIMP study.

This is ongoing study.

We have not finished simulation study for all models.

I show only the Little Higgs case which have already finished.

Event

Little Higgs@ 1 TeV ILC

$e^+e^- \rightarrow W_H W_H \rightarrow A_H A_H WW$

Process	cross sec. [fb]
Signal	
$W_H^+ W_H^- \rightarrow A_H A_H qqqq$	120
Background	
$W^+W^- \rightarrow qqqq$	1307
$e^+e^-W^+W^- \rightarrow e^+e^-qqqq$	490
$e\nu_e WZ \rightarrow eqqqq$	24.5
$Z_H Z_H \rightarrow A_H A_H qqqq$	18.8
$\nu\bar{\nu}W^+W^- \rightarrow \nu\bar{\nu}qqqq$	7.23
$ZW^+W^- \rightarrow \nu\bar{\nu}qqqq$	5.61

- Large missing energy
- 4 jet in final state

Selection Cut

All events are forced to 4 jets in final state

χ_W^2 < 10 : χ^2 for $W^\pm$ reconstruction from jets

P_T^{miss} > 50 GeV/c : Missing transverse momentum

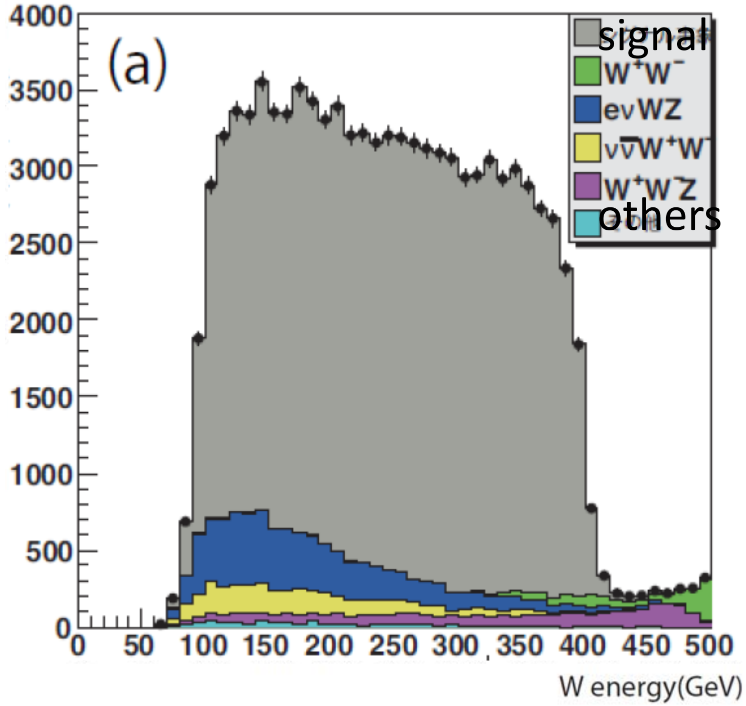
$$\chi_w^2 = \left(\frac{m_{W_1} - m_W}{\sigma_{m_W}}\right)^2 + \left(\frac{m_{W_2} - m_W}{\sigma_{m_W}}\right)^2$$

W^+W^- and $e^+e^-W^+W^-$ are effectively reduced by P_T^{miss} cut.

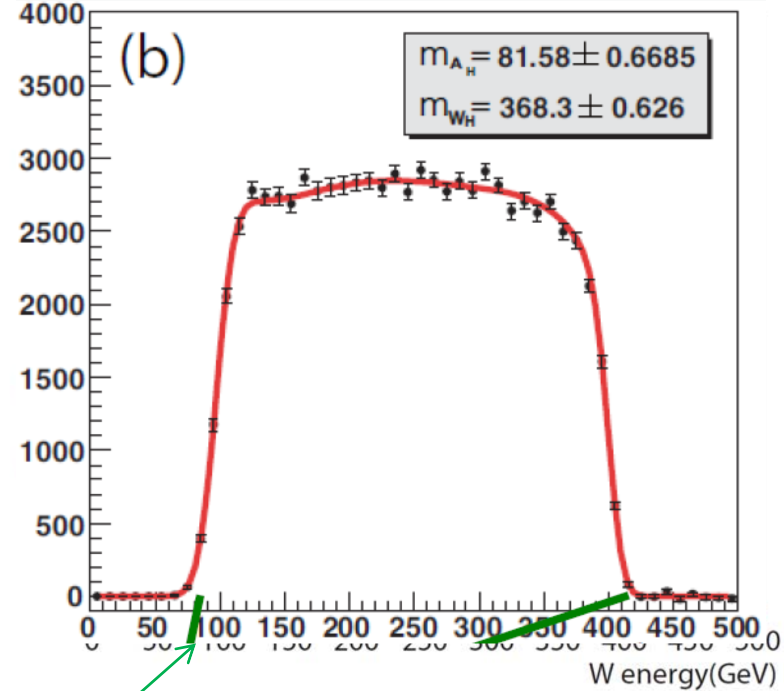
$Z_H Z_H$ is negligible after χ_W^2 cut.

$\nu\nu W^+W^-$ and W^+W^-Z remain after 2 cuts.

Little Higgs@ 1 TeV ILC



Energy distribution of reconstructed W bosons after subtracting BG



An energy distribution of W's from $W_H W_H$ after subtraction of the backgrounds, whose number of events was estimated by independent background samples. The distribution is fitted by a polynomial function convoluted with an error function.

Masses of $\mathbf{A_H}$ and $\mathbf{W_H}$ can be determined from edges of W energy distribution.

High accuracy !

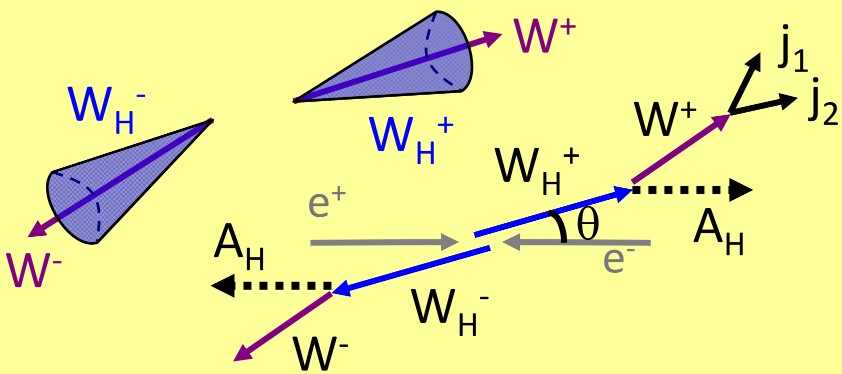
- Mass determination

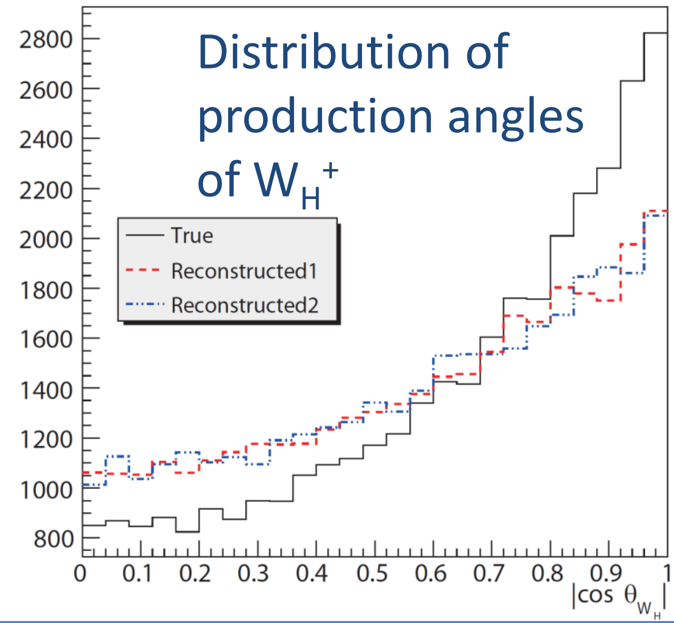
  m_{AH} = 81.58 ± 0.67 GeV, m_{WH} = 368.3 ± 0.63 GeV

  true(81.85) true(368.2)

Production angle of $W_H^{\pm}$

$W_H^{\pm}$ candidates are reconstructed as corn around $W^{\pm}$. If W_H^{+} and W_H^{-} are assumed as back-to-back, there are 2 solutions for $W_H^{\pm}$ candidates. In this mode, however, 2 solutions should be close to true $W_H^{\pm}$.

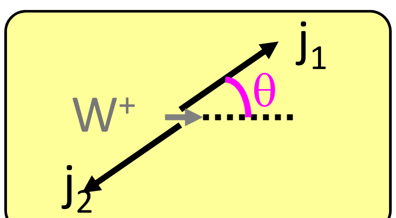




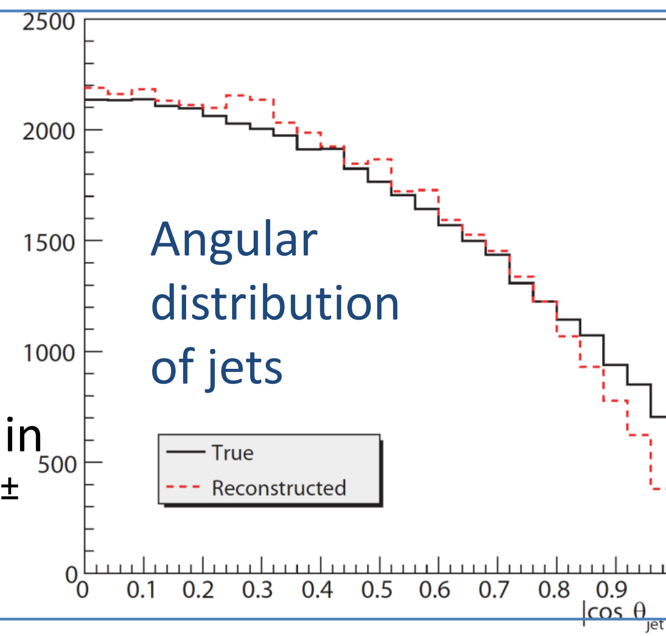
This shape shows $W_H^{\pm}$ spin as spin-1.

Angular distribution of jets

<Rest frame of W^+>



Angular distribution of jets in the helicity-frame of the $W^{\pm}$ carries information on the polarization of the $W^{\pm}$.



$W^{\pm}$ helicity as longitudinal mode.

Little Higgs@ 1 TeV ILC

masses

⇨ mass relation between A_H & W_H^{+-} can be confirmed with good accuracy.

Angular distribution of charged new particles $W_H^{\pm}$

⇨ W_H is spin 1 particle!

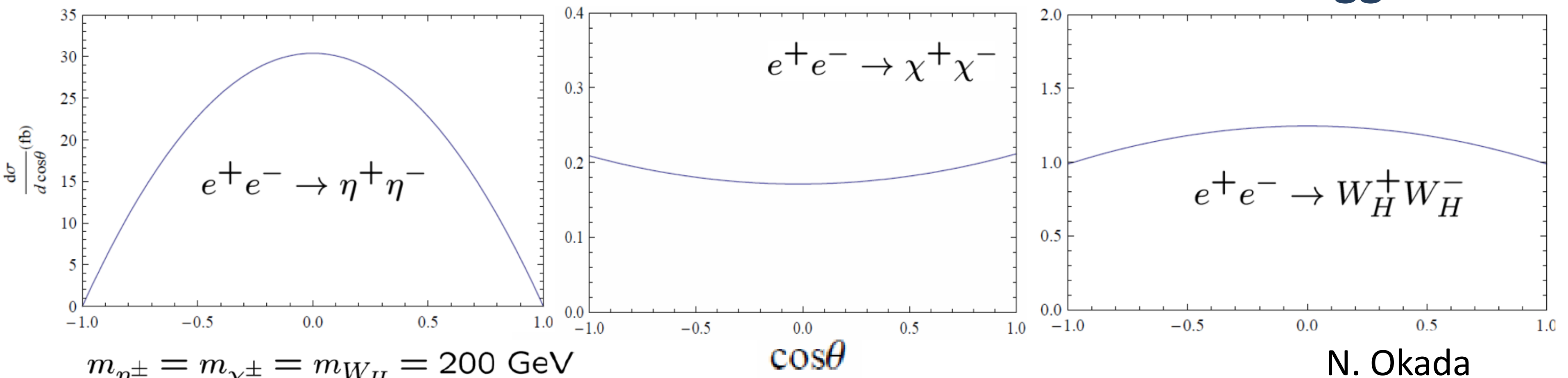
Angular distribution of jets from $W^{\pm}$ polarization

⇨ The dominance of the longitudinal mode!

⇨ The coupling arises from EWSB!

Angular distribution in three models @ $\sqrt{s} = 500$ GeV

Inert Doublet **SUSY** **Little Higgs**



$m_{\eta^\pm} = m_{\chi^\pm} = m_{W_H} = 200$ GeV

N. Okada

Since, angular distribution is different from each models, this is the powerful probe of the dark matter nature.

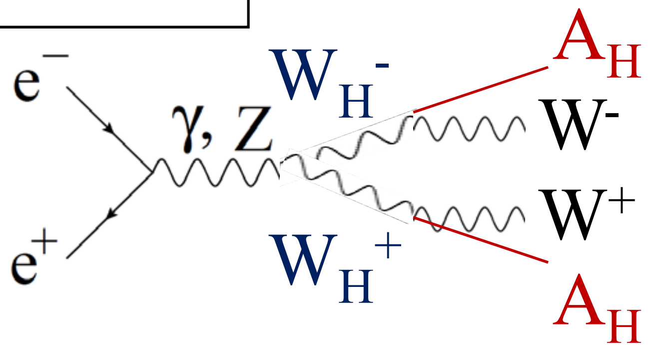
→ We need full simulation for each models in next step .

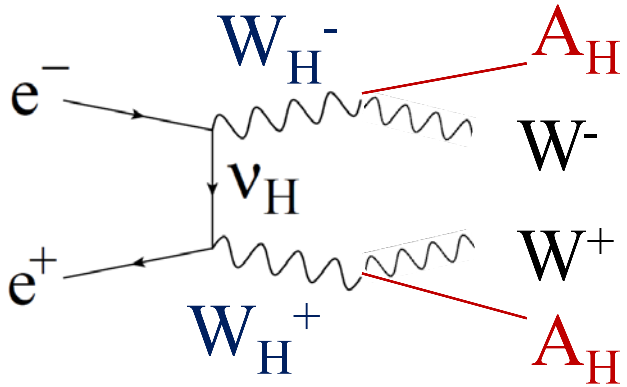
But, we now neglect the t-channel process. The case in which the t- channel process is significant, is more complicated.

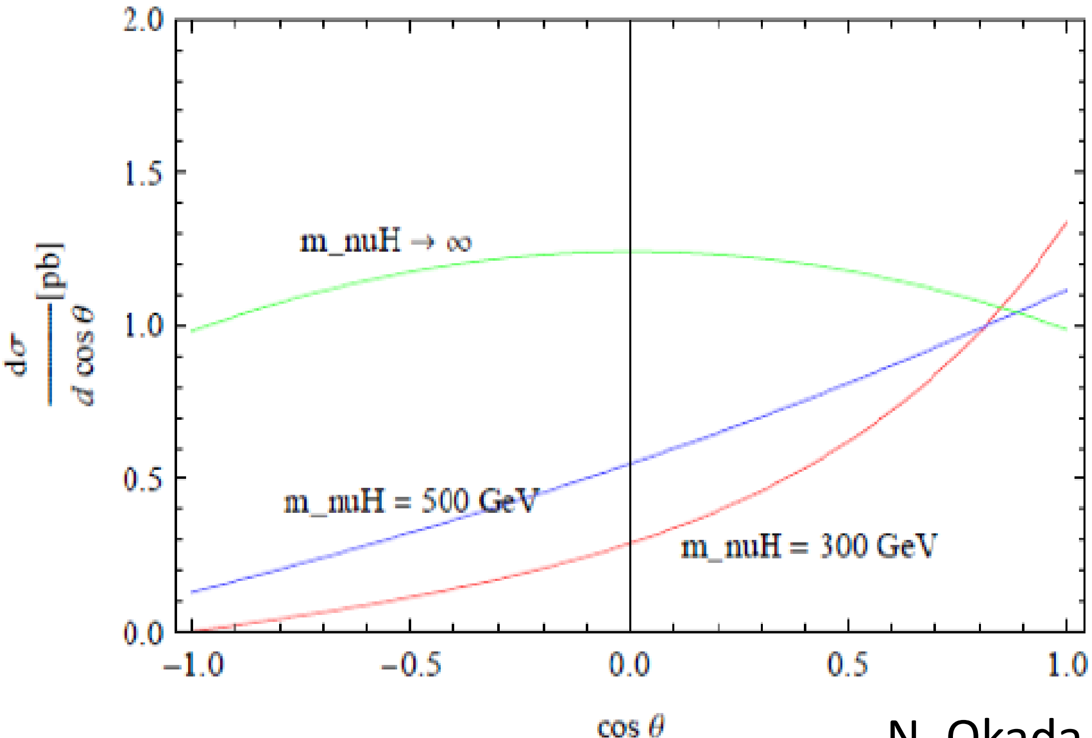
Advanced study

In these three models, there are also t-channel process.

Ex. LHT







N. Okada

When vH is very heavy, t-channel is neglidgible, there will be no asymmetry. If the t-channel process is significant, the cross section shows big FB asymmetry.

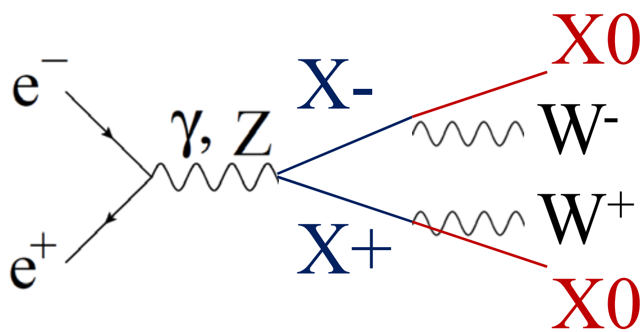
-> W charge ID is important.

Summary

- Dark matter candidates which suggested by models of TeV new physics come in a variety of types.
- For new physics models, we are studying

  How accurately ILC can determine the dark matter properties

  using



Generic WIMP Study!