LCWS08 at Chicago
2008/11/18

Simulation study of $e^+e^- \rightarrow W_H^+W_H^-$

- Introduction
- Observable to be measured
- Analysis framework
- Event selection
- Results

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with

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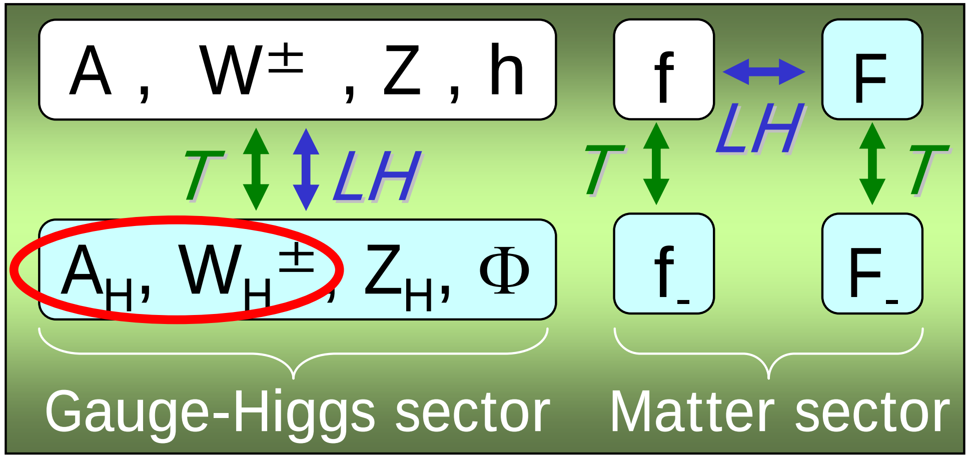
Introduction

Littlest Higgs model with T-parity

<Particle contents>



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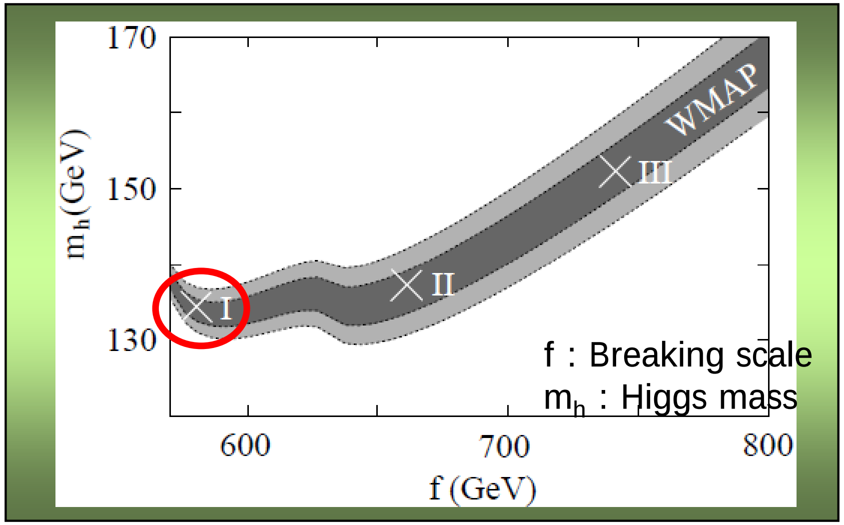


<Mass>

	Point I	Point II	Point III
f	580 (GeV)	660 (GeV)	740 (GeV)
m_h	134 (GeV)	137 (GeV)	152 (GeV)
$\Omega_{\rm DM}h^2$	0.106	0.104	0.106
m_{A_H}	81.9 (GeV)	95.9 (GeV)	110 (GeV)
m_{W_H}	368 (GeV)	421 (GeV)	474 (GeV)
m_{Z_H}	369 (GeV)	422 (MeV)	474 (MeV)
m_Φ	440 (GeV)	513 (GeV)	640 (GeV)
$m_{e_H}(\kappa_{l_1} = 0.5)$	410 (GeV)	467 (GeV)	523 (GeV)
$m_{e_H}(\kappa_{l_1} = 1.0)$	820 (GeV)	933 (GeV)	1050 (GeV)

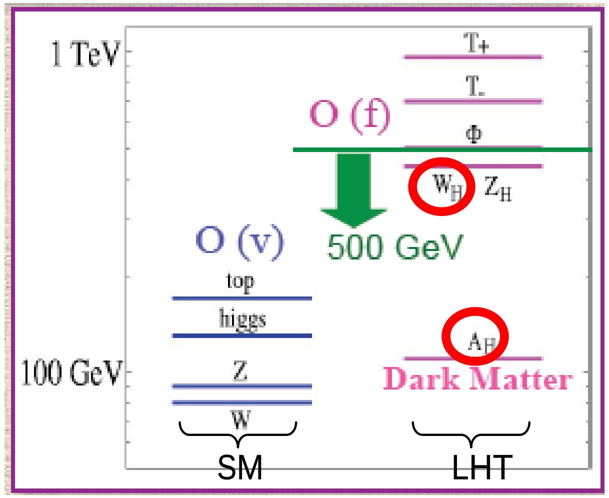
A_H and $W_H^{\pm}$ can be searched by ILC (1TeV).

Introduction

<Property>

	mass	spin
W_H	368.2(GeV)	1
A_H	81.85(GeV)	1

<Mass spectrum>



<Mode>

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

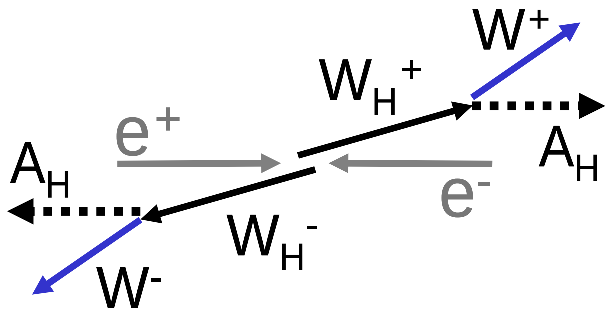
($W_H^\pm \rightarrow A_H W^\pm$ with 100% ratio)

- Large cross section
- Dark matter (A_H) appears

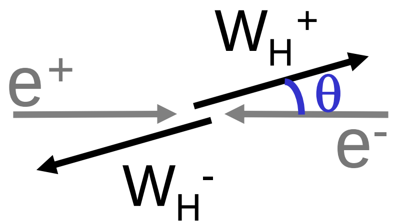
$e^+e^- \rightarrow W_H^+W_H^-$ is the best one to investigate the property of the dark matter predicted in the model.

Observable to be measured

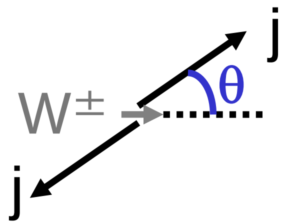
1) Energy edges of $W^{\pm}$
→lead to masses of $W_H^{\pm}$ and A_H bosons



2) Production angle of $W_H^{\pm}$
→lead to spin of $W_H^{\pm}$ boson



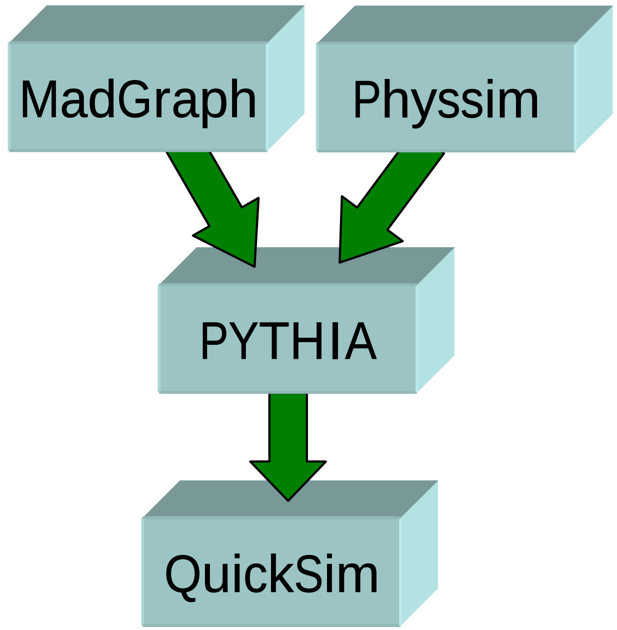
3) Angular distribution of reconstructed jets from associated $W^{\pm}$ boson decays
→lead to helicity of $W^{\pm}$ boson



Analysis framework

<Event generation>

MadGraph : for LHT process
Physsim : for Standard Model process
- helicity amplitude calculation
- gauge boson polarization effect
- phase space integration and generation of parton 4-momenta



<Hadronization>

PYTHIA
- parton showering and hadronization

<Detector simulation>

JSFQuickSimulator
- create vertex-detector hits
- smear charged-track parameters in central tracker
- simulate calorimeter signals as from individual segments

Analysis framework

<Simulation setup>

- Center-of-mass energy : 1TeV
- Integrated luminosity : 500 fb^{-1}
- Beam polarization : no
- Crossing angle of beams : no
- Beamstrahlung : ignored
- Initial-state radiation : ignored

<Detector parameter>

Detector	Performance	Coverage
VTX	$\delta_b \leq 5 \oplus 10/p\beta \sin^{3/2}\theta$ (μm)	$\lvert\cos\theta\rvert \leq 0.90$
TPC	$\delta p_t/p_t^2 \leq 5 \times 10^{-5}$ (GeV/c)$^{-1}$	$\lvert\cos\theta\rvert \leq 0.98$
ECAL	$\sigma_E/E = 12\%/\sqrt{E} \oplus 1\%$	$\lvert\cos\theta\rvert \leq 0.98$
HCAL	$\sigma_E/E = 33\%/\sqrt{E} \oplus 2\%$	$\lvert\cos\theta\rvert \leq 0.98$

Ref) GLD Detector Outline Document Ver.1.2.1

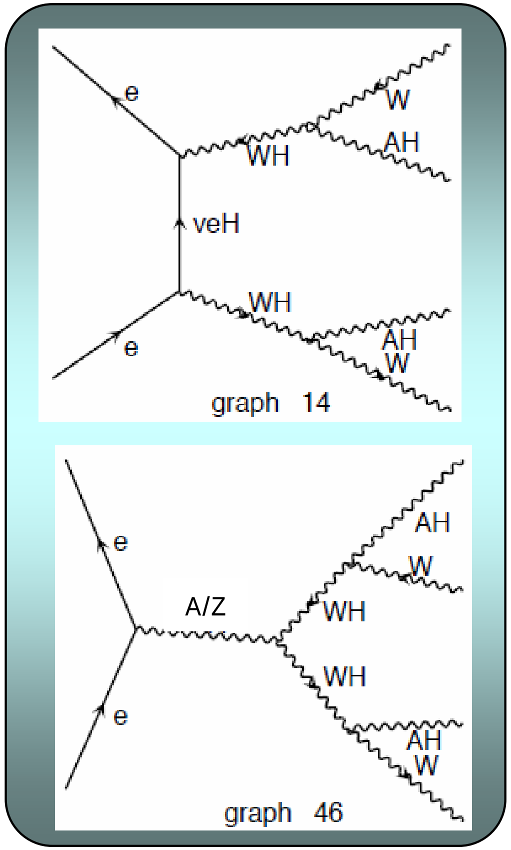
Event selection

<Signal>

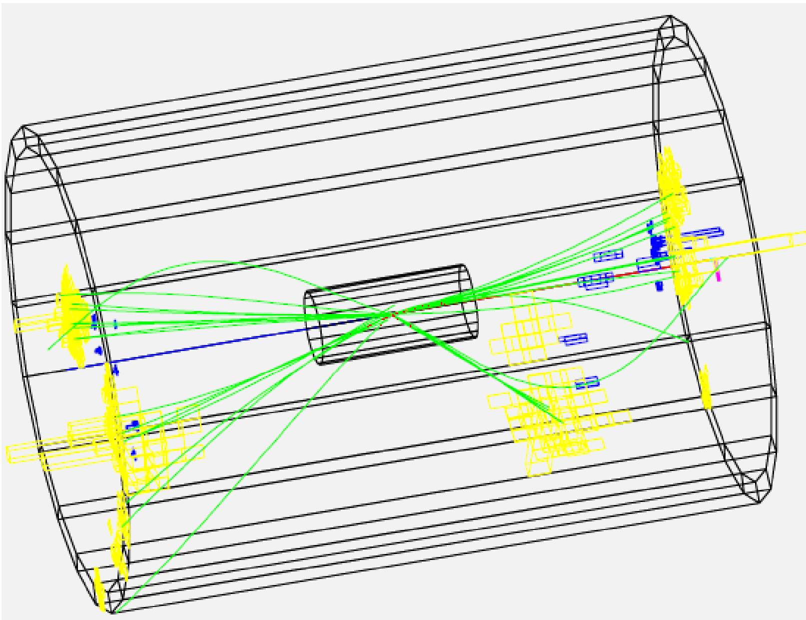
$e^+e^- \rightarrow W_H^+ W_H^-$

- $W_H^\pm$ decays to $A_H W^\pm$
- followed by $W^\pm \rightarrow$ qq-bar
  - Large missing energy
  - 4 jets in final state

<Diagram>



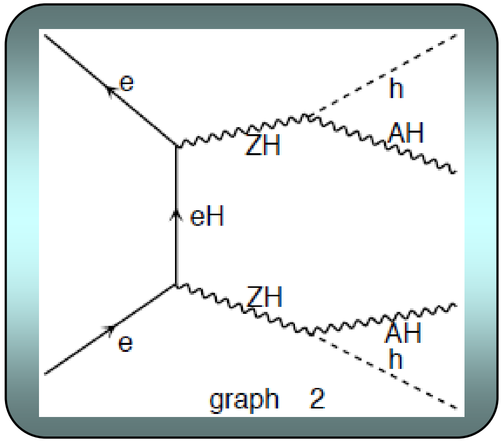
<Event display>



Event selection

<LHT background>

$e^+e^- \rightarrow Z_H Z_H$
- Z_H decays to $A_H h$
- followed by $h \rightarrow q\bar{q}$ (qq-bar)



<Standard Model background>

(Large cross section)

$e^+e^- \rightarrow W^+W^-$

$e^+e^- \rightarrow e^+e^-W^+W^-$

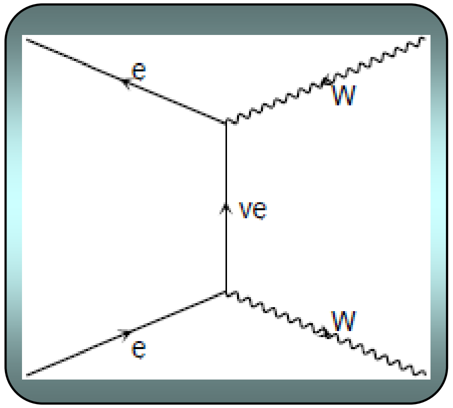
(Small cross section)

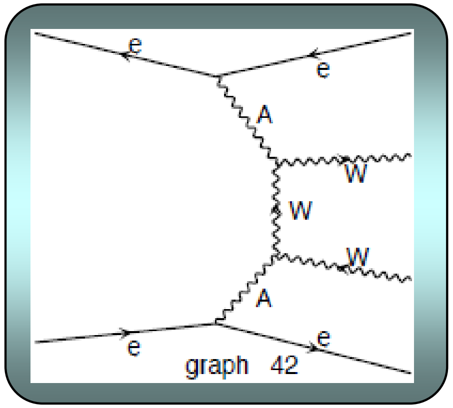
$e^+e^- \rightarrow \nu\nu W^+W^-$

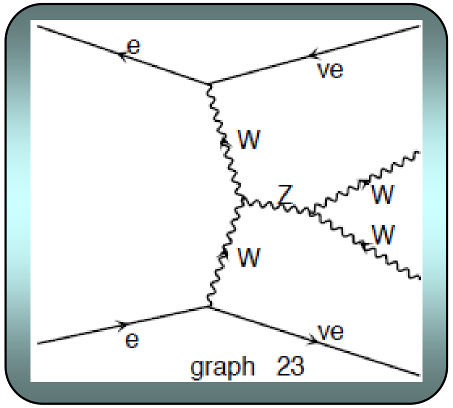
$e^+e^- \rightarrow W^+W^-Z$

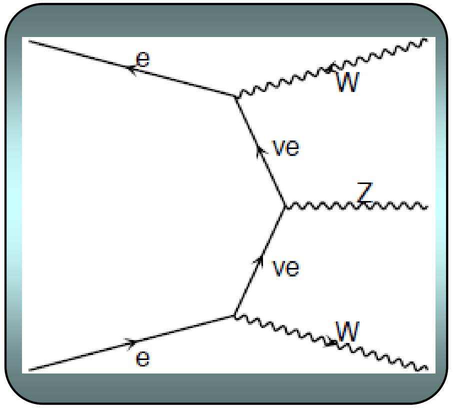
- followed by $W^\pm \rightarrow q\bar{q}$ (qq-bar)

  $Z \rightarrow \nu\bar{\nu}$ ($\nu\nu$-bar)









Event selection

<Selection cut>

All events are forced to 4 jets in final state
χ_W^2 : χ^2 for $W^\pm$ reconstruction from jets
P_T^{miss} : Missing transverse momentum

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

<Cut statistics and breakdown of efficiency>

Selection cut	$W_H^+W_H^-$	W^+W^-	$e^+e^-W^+W^-$	Z_HZ_H	$\nu\bar{\nu}W^+W^-$	W^+W^-Z
σ (fb)	122	1306	490	19	7.2	5.6
No cut	60,500(1.00)	653,000(1.00)	245,000(1.00)	9,500(1.00)	3,600(1.00)	2,800(1.00)
$\chi_W^2 \leq 10$	51,400(0.85)	238,000(0.37)	144,000(0.59)	431(0.05)	2,820(0.78)	1,970(0.70)
$P_T^{miss} \geq 50$ GeV/c	57,000(0.95)	51,200(0.07)	8,700(0.04)	8,780(0.92)	2,980(0.83)	2,500(0.89)
Total	48,300(0.80)	8,680(0.01)	2,550(0.01)	395(0.04)	2,350(0.65)	1,800(0.64)

#event (efficiency)

W^+W^- and $e^+e^-W^+W^-$ are effectively reduced by P_T^{miss} cut.
Z_HZ_H is negligible after χ_W^2 cut.
$\nu\nu W^+W^-$ and W^+W^-Z remain after 2 cuts.

Result

1) Energy edge of $W^{\pm}$
- Fit method
- Result of fit

2) Production angle of $W_H^{\pm}$
- Reconstruction of $W_H^{\pm}$ from $W^{\pm}$
- $\cos\theta$ distribution

3) Angular distribution of reconstructed jets from associated $W^{\pm}$ boson decays
- Boost jets to $W^{\pm}$ rest frame
- $|\cos\theta|$ distribution

1) Energy edges of $W^{\pm}$

<Fit function>

$$F_{error}(E_W, par[]) = \frac{1}{4} par[0]\left(1 + Erf\left(\frac{E_W - E_{min}}{par[1]}\right)\right)\left(1 - Erf\left(\frac{E_W - E_{max}}{par[2]}\right)\right)$$

$$F_{poly}(E_W, par[]) = 1 + par[3]E_W + par[4]E_W^{\ 2} + par[5]E_W^{\ 3} + par[6]E_W^{\ 4}$$

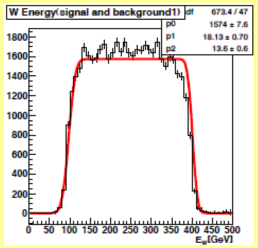
$$[E_{min}, E_{max} : edge] \quad \left[Erf(x) \equiv \int_0^x \frac{2}{\sqrt{\pi}} \exp(-t^2)dt\right]$$

<Fit step>

1) Cheat E_{min},E_{max}

$F_{fit1} = F_{error}(par[1,2])$

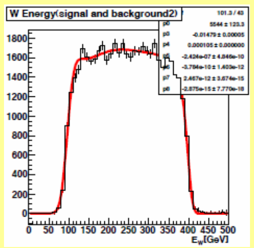
→ Get resolution(par[1,2])



2) Cheat E_{min},E_{max} & Fix par[1,2]

$F_{fit2} = F_{error}\ x\ F_{poly}(par[3\sim9])$

→ Get shape(par[3~9])

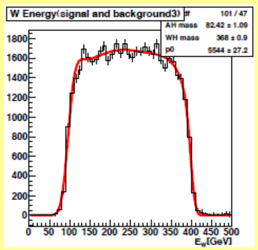


3) Fix par[1~9]

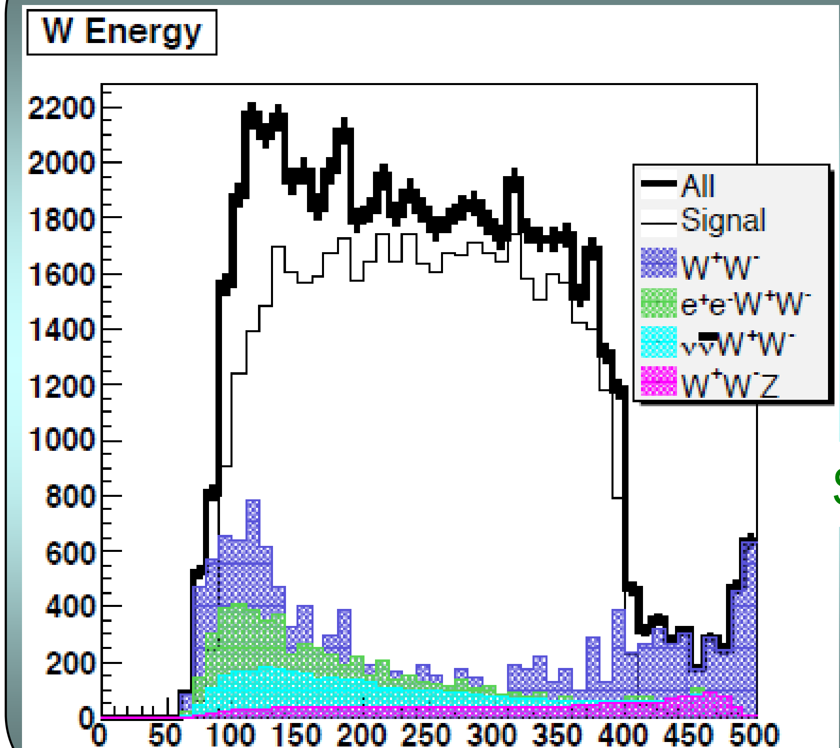
$F_{fit3} = F_{error}(E_{min,max})\ x\ F_{poly}(E_{min,max})$

→ Get edge(E_{min},E_{max})

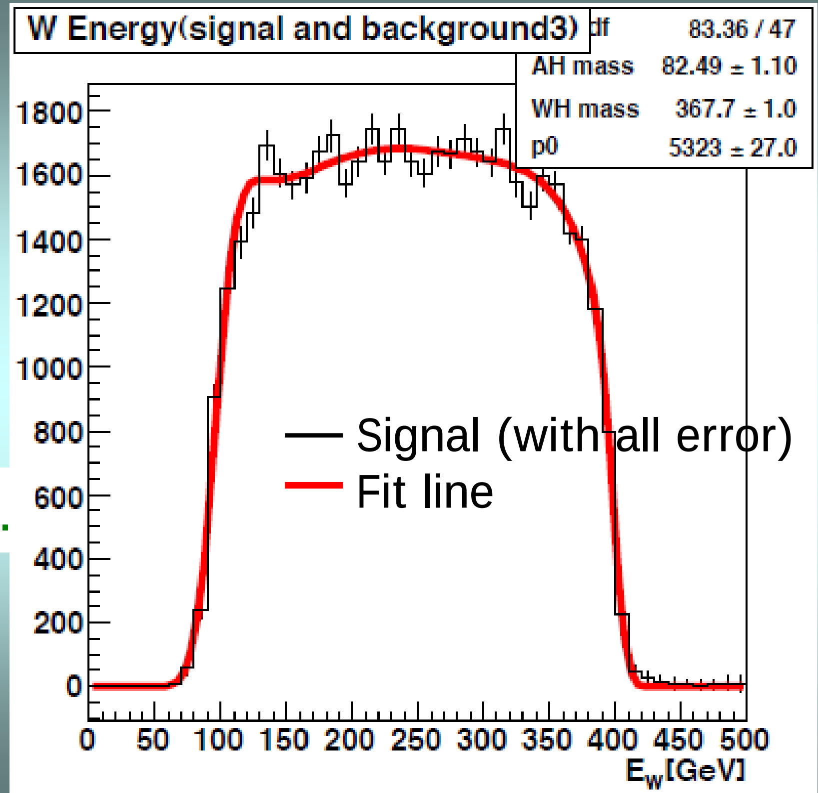
→ Calculate mass(m_{AH},m_{WH})



1) Energy edges of $W^{\pm}$



Subtract B.G.



<Result of fit>

m_{AH} = 82.49±1.10 : 0.58
m_{WH} = 367.7±1.0 : 0.50

(True)
m_{AH}=81.85
m_{WH}=368.2

$$\text{accuracy} = \frac{m_{True} - m_{Fit}}{\sigma_{Fit}}$$

Masses of A_H and $W_H^{\pm}$ are determined with high accuracy!!

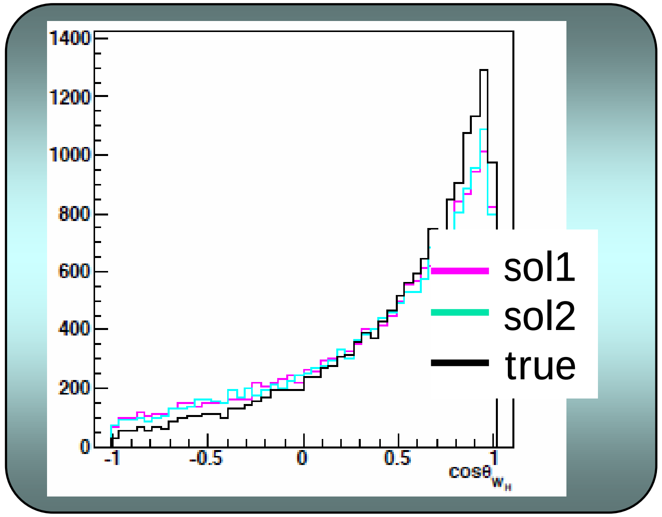
2) Production angle of $W_H^{\pm}$

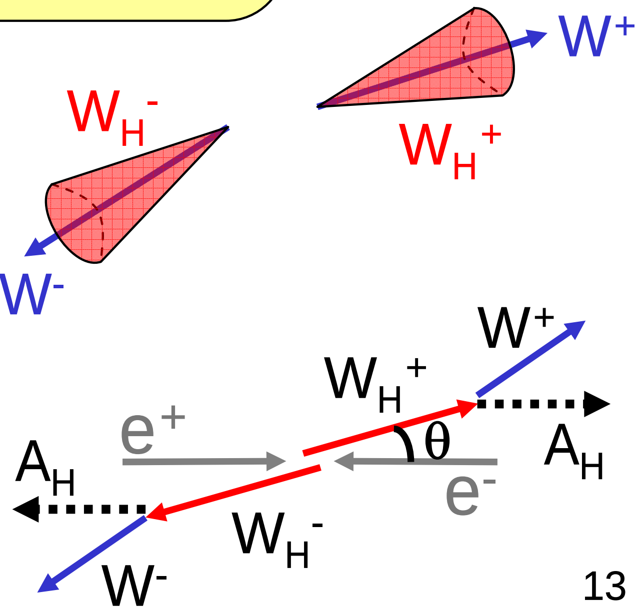
<Reconstruction of $W_H^{\pm}$ from $W^{\pm}$>

$W_H^{\pm}$ 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 $W_H^{\pm}$.

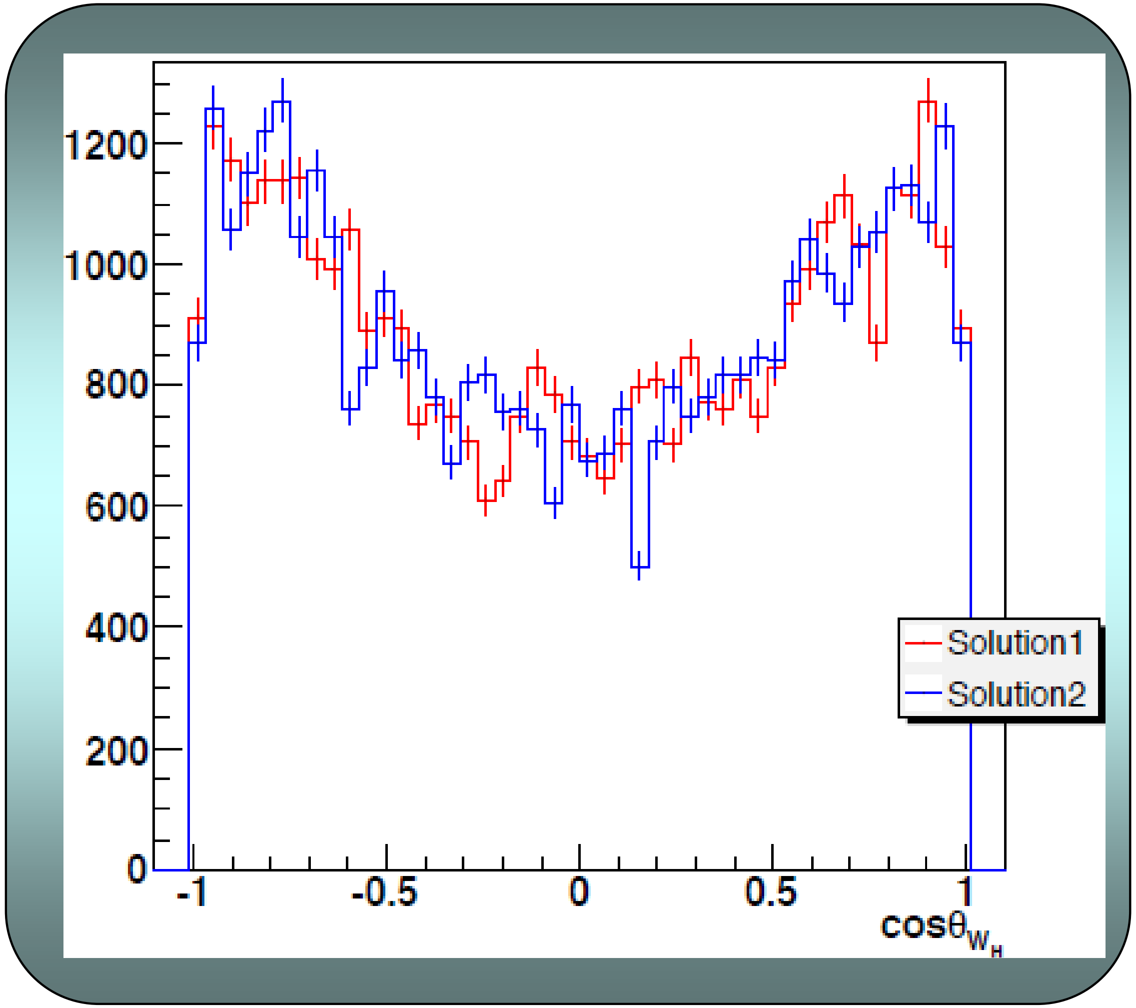
<W_H^{+} of generator information>

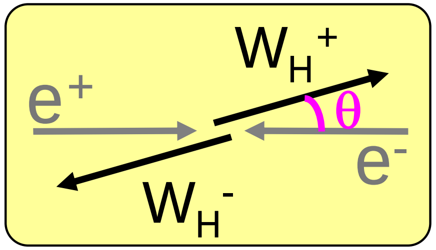




2) Production angle of $W_H^{\pm}$

<W_H^+ and W_H^- of detector simulation>

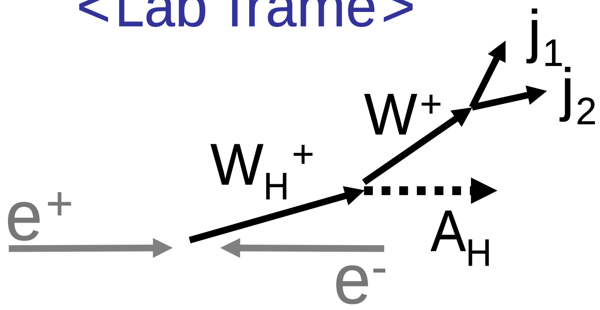




This shape shows $W_H^{\pm}$ spin as spin-1.

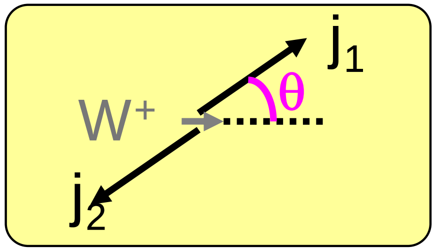
3) Angular distribution of jets

<Lab frame>

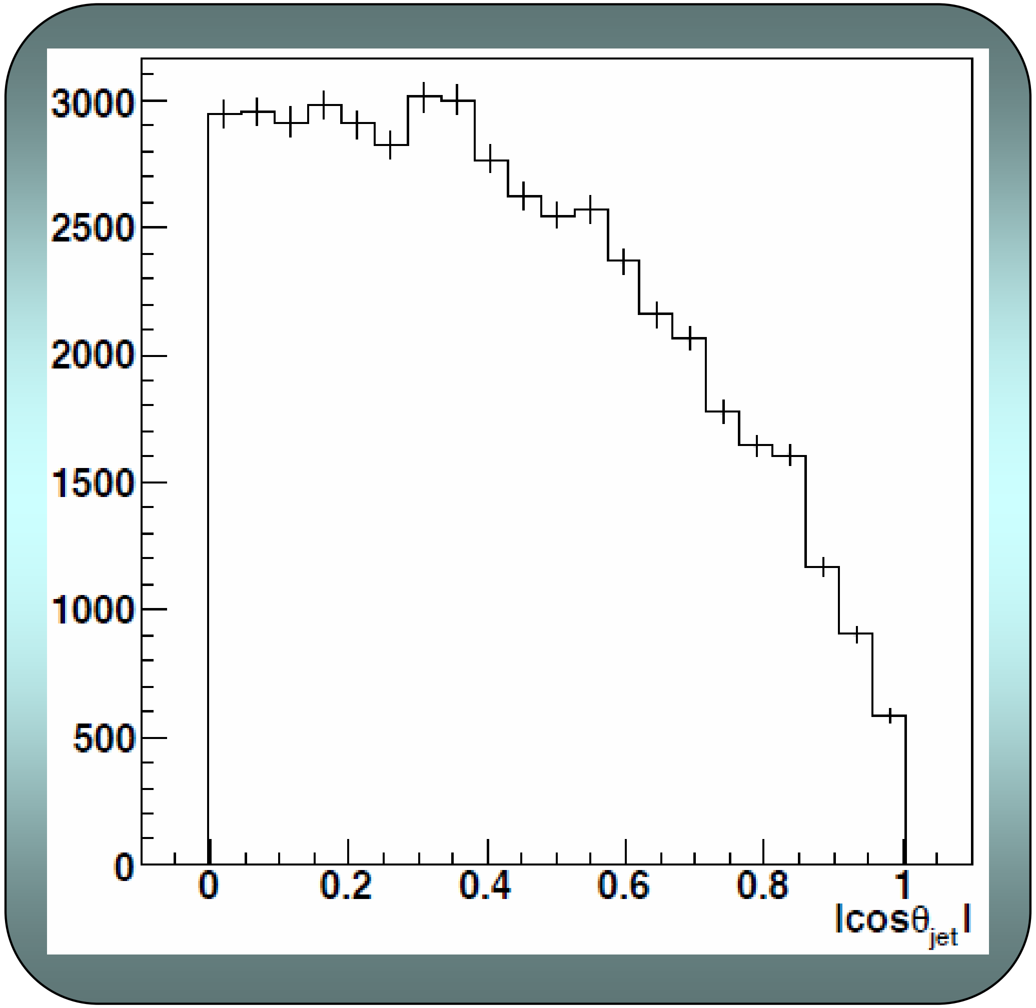


Boost

<Rest frame of W+>



<Angular distribution of jets>



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

Conclusion

- $e^+e^- \rightarrow W_H^+ W_H^-$ is the best mode to investigate the LHT model.

- Background candidates are W^+W^-, $e^+e^-W^+W^-$, $Z_H Z_H$, $\nu\nu W^+W^-$ and W^+W^-Z.

- Selection cuts, $\chi_W^2 < 10$ and $P_T^{miss} > 50$(GeV), reduce effectively backgrounds.

1) Masses of A_H and $W_H^{\pm}$ are determined with high accuracy: 0.58 and 0.40.
2) Spin of $W_H^{\pm}$ can be determined as spin-1.
3) Helicity of $W^{\pm}$ can be determined as longitudinal mode.