T Odd Gauge Bosons @ $\gamma\gamma$ collider

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Hierarchy Problem Revisited

Two Important issues in Electro-Weak breaking Sector

1) We want Higgs to be light

Scale of New Physics must be low

2) We want to avoid Electro Weak Precision constraints

Scale of New Physics must be high

Goal: What Stabilizes EW Scale ????

Introduce New Physics in such a way that both issues are resolved.

Susy, Technicolor, Ex Dim, LHM

Little Higgs Models:

Concept of Collective Symmetry breaking

Higgs is a pseudo-Goldstone Boson kept light by approximate global symmetries (old idea, new features)
George, Kaplan early 80's

Global symmetries are broken explicitly in a unique way by 2 sets of interactions with each preserving a subset of symmetry
Arkani-Hamed, Cohen, Georgi hep-ph/0105239

Together couplings break all symmetries protecting the Higgs mass from one loop quadratic divergences. These divergences are cancelled by new particles at TeV scale with the same spins as the corresponding SM particles

Generic Spectrum of Little Higgs

- Based on Non-Linear σ Model describing

  SU(5)/ SO(5 global symmetry breaking

  Symmetry breaking originates from VEV of symmetric Tensor

  (convenient basis characterized by direction Σ_0)

$$\Sigma_0 = \begin{pmatrix} & & & 1 & \\ & & & & 1 \\ & & 1 & & \\ 1 & & & & \\ & 1 & & & \end{pmatrix}.$$

- Goldstone fluctuations are given by Pion fields $\Pi^a X^a$ where X are the generators of the broken symmetry

- Non Linear Σ field is then given a $\Sigma(x) = e^{i\Pi/f}\Sigma_0 e^{i\Pi^T/f} = e^{2i\Pi/f}\Sigma_0.$ $\Pi = \begin{pmatrix} 0 & \frac{H}{\sqrt{2}} & \Phi \\ \frac{H^\dagger}{\sqrt{2}} & 0 & \frac{H^T}{\sqrt{2}} \\ \Phi^\dagger & \frac{H^*}{\sqrt{2}} & 0 \end{pmatrix}$

  f is the value of VEV that accomplishes the breaking.

- $[SU(2)xU(1)]_1x[SU(2)xU(1)]_2$ subgroups are gauged whose generators are

$$Q_1^a = \begin{pmatrix} \sigma^a/2 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad Y_1 = \mathrm{diag}(3,3,-2,-2,-2)/10$$

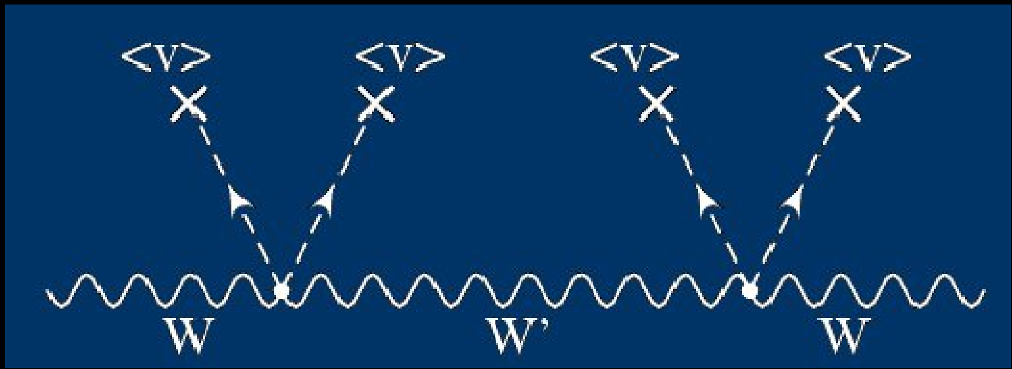
$$Q_2^a = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\sigma^{a*}/2 \end{pmatrix}, \quad Y_2 = \mathrm{diag}(2,2,2,-3,-3)/10\,,$$

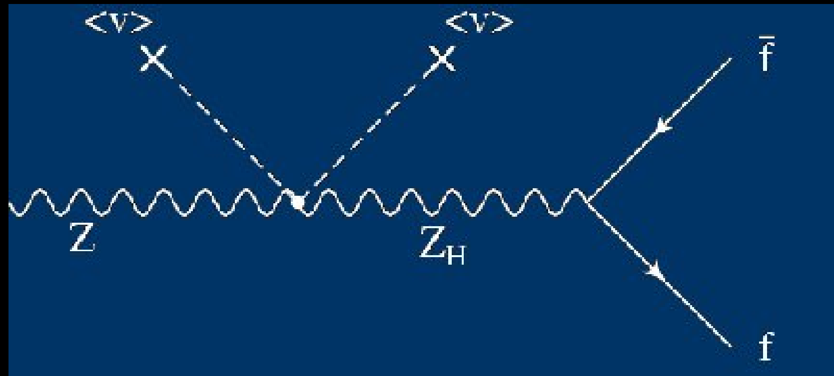
Vacuum breaks $[SU(2)xU(1)]^2$ gauge symmetry down to 2 diagonal subgroups

1) gauge bosons with masses of order f
2) mass less (SM gauge bosons)

Why Little Higgs Models did not work

Original models have stringent bounds f ~ 4 TeV   Csaki, Hubisz, Kribs, Meade, Ternin





Other models which evade EW bounds exists but have complicated gauge/symmetry structures

✓Just as R parity cures Proton decay problem in SUSY, T parity is the discrete parity needs to be introduced to solve tree level EW issues in Little Higgs Models

✓Can also provide dark matter candidate

Assigning T Parity

Assign all non-SM particles odd and all SM particles even T parity

Σ_0 VEV separates the gauged generators into   Under T Parity

unbroken generators $\{ Q_1^a + Q_2^a, Y_1 + Y_2\}$: $T^a \rightarrow T^a$

and   broken generators $\{Q_1^a - Q_2^a, Y_1 - Y_2\}$: $X^a \rightarrow - X^a$

Gauge fields : $A_1 \leftrightarrow A_2$

Scalar fields : $\Pi \rightarrow - \Omega\Pi\Omega$ where Ω= diag(1,1,-1,1,1)

Non Linear Σ field : $\Sigma \rightarrow \Sigma_0\, \Omega\, \Sigma^\dagger \Omega\, \Sigma_0$

Kinetic terms of the Non Linear σ Model field Σ

$$\frac{f^2}{8} \mathrm{Tr} D_\mu \Sigma (D^\mu \Sigma)^\dagger,$$

where

$$D_\mu \Sigma = \partial_\mu \Sigma - i \sum \left[g_j W_j^a (Q_j^a \Sigma + \Sigma Q_j^{aT}) + g'_j B_j (Y_j \Sigma + \Sigma Y_j) \right]$$

T-Parity inv. Demands

$g_1 = g_2 = 2^{1/2}$ g and $g_1' = g_2' = 2^{1/2}$ g'

Phenomenology of T Parity Little Higgs Cheng, Low

$$SU(5) \xrightarrow{f} SO(5)$$

Global Symmetry

$$(SU(2) \times U(1))^2 \xrightarrow{f} (SU(2) \times U(1))_V$$

Gauge Symmetry

New particles:

$W_H^{\pm}, Z_H$	$m \sim gf$	T odd
A_H	$m \sim \frac{g'}{\sqrt{5}} f$	T odd
Φ	$m \sim \frac{m_H}{v} f$	T odd
t'_+	$m \sim \sqrt{\lambda_1^2 + \lambda_2^2} f$	T even
t'_-	$m \sim \lambda_2 f$	T odd

Interesting properties haven't been studied in detail yet

Additional T-odd partners of ALL SM fermions!
Not due to collective symmetry breaking

Phenomenology of T Parity Little Higgs Cheng, Low

Contribution to EW observable are Loop suppressed. f ~0.5 TeV ⇒ No Fine Tuning

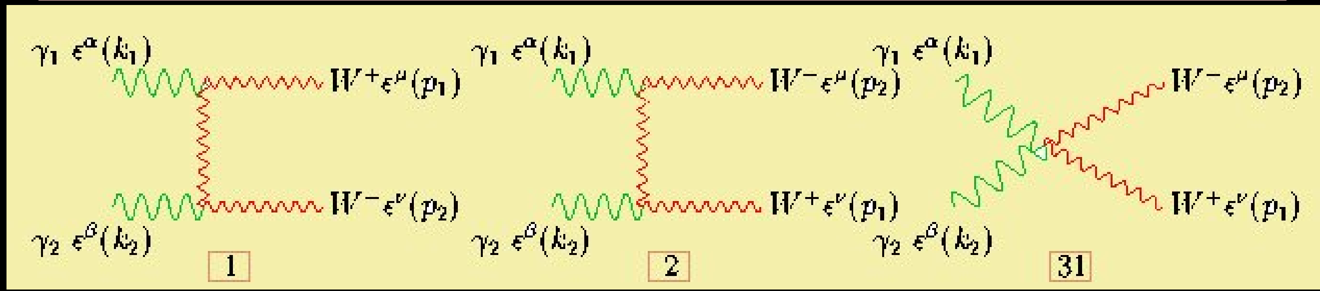
Lightest T Odd A_H Particle (LTP) is stable .
A good Dark Matter Candidate.

T Odd particles can be pair produced which can cascade down to LTP
Collider Signals: Jets/Leptons + Missing E

W_H Production @ $\gamma\,\gamma$ collider

Feynman Diagrams : Resonance production of W_H Pairs

$$\gamma\gamma \rightarrow (W_H^+\, W_H^-) \rightarrow (A_H\, W^+)\;\; (A_H\, W^-)$$



Hunting Signatures : Four Hard Jets from 2 W's and Missing Energy/p_T

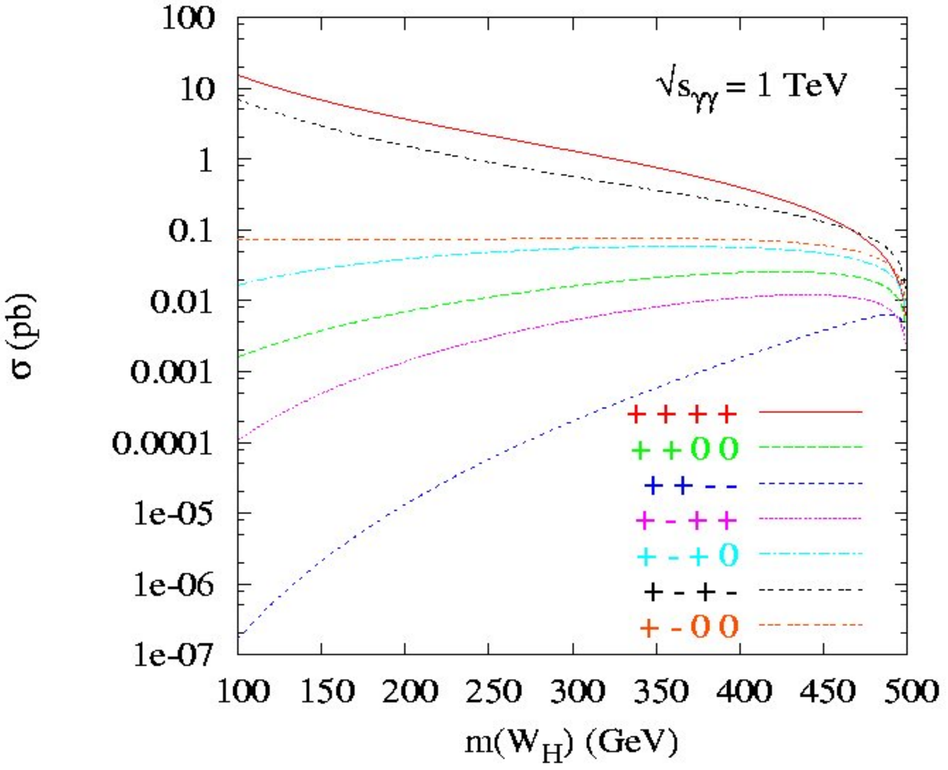
Potential Backgrounds 1) $\gamma\gamma \longrightarrow W^+\, W^- + \nu\bar{\nu}$

2) $\gamma\gamma \longrightarrow W^+\, W^-$

W_H Production with Fixed C.M. Energy

- Matrix Element Squared is computed using MADGRAPH

For Fixed C.M. Energy of Two Photons =1 TeV, for various Polarization Choices :



Spectrum of Colliding Photons

$$F_{\gamma/e}(x) = \frac{1}{D(\xi)}\left[1 - x + \frac{1}{1-x} - \frac{4x}{\xi(1-x)} + \frac{4x^2}{\xi^2(1-x)^2} - 2\lambda_e P_c\left(\frac{x}{1-x} - \frac{2x^2}{(1-x)^2\xi}\right)(2-x)\right],$$

and

$$D(\xi) = \left(1 - \frac{4}{\xi} - \frac{8}{\xi^2}\right)\ln(1+\xi) + \frac{1}{2} + \frac{8}{\xi} - \frac{1}{1(1+\xi)^2},$$

$x = \omega / E_e$ is fraction of electron energy carried by scattered photon

ω is the backscattered photon energy, E_e is the incident electron energy,

$\xi = 4E_e\omega_0 / m_e^2$, ω_0 is the laser-photon energy, $\xi = 4.8$, so $D(\xi) = 1.8$

λ_e polarizaton of electron, P_c is polarizaton of laser

$$dL_{\gamma\gamma} = 2z dz \int_{z^2/x_{max}}^{x_{max}} \frac{dx}{x} F_{\gamma/e}(x) F_{\gamma/e}(z^2/x).$$

with $z = \sqrt{\hat{s}/s}$, and $x_{max} = \omega_{max}/E_e$,

Kinematics Cuts

- 1) Minimum Energy of Jets from W decay $E_{\text{jet}} \geq 10 \text{ GeV}$
- 2) Minimum Missing P_T required $p_T \geq \mathbf{50\ GeV}$
- 3) Rapidity Cut for each jet $|\eta_{\text{jet}}| \leq 3$
- 4) Invariant Mass of any 2 of the 4 Smeared jets should satisfy $\mathbf{75\ GeV} \leq |M_{i,j}| \leq \mathbf{85\ GeV}$
- 5) Isolation cut

$$\Delta R_{i,j} = \sqrt{(\Delta\Phi_{i,j})^2 + (\Delta\eta_{i,j})^2} \geq .7$$

(Between any two jets)

Smearing

Used CERN Routine SMEAR

$$\sigma_{HAD}(E_j) = \frac{\delta E_j}{E_j} = \frac{0.5}{\sqrt{E_j/1GeV}} + 0.04$$

$1/p_T$ and ϕ are Gaussian of half-width given by $\sqrt{V_{\rm COV}(1,1)}$ and $\sqrt{V_{\rm COV}(1,1)}$. PRES, PMSPTS,PMSPHS and PMSPCS are function of the scattering angle θ.

Transverse Momentum p_T and azimuth ϕ are smeared together, taking into their correlation.

$$\sigma^2\left(\frac{1}{p_T}\right) = V_{\rm COV}(1,1) = \mathrm{PRES}^2 + \left[\frac{\mathrm{PMSPTS}}{p_T\sqrt{\sin(\theta)}}\right]^2$$

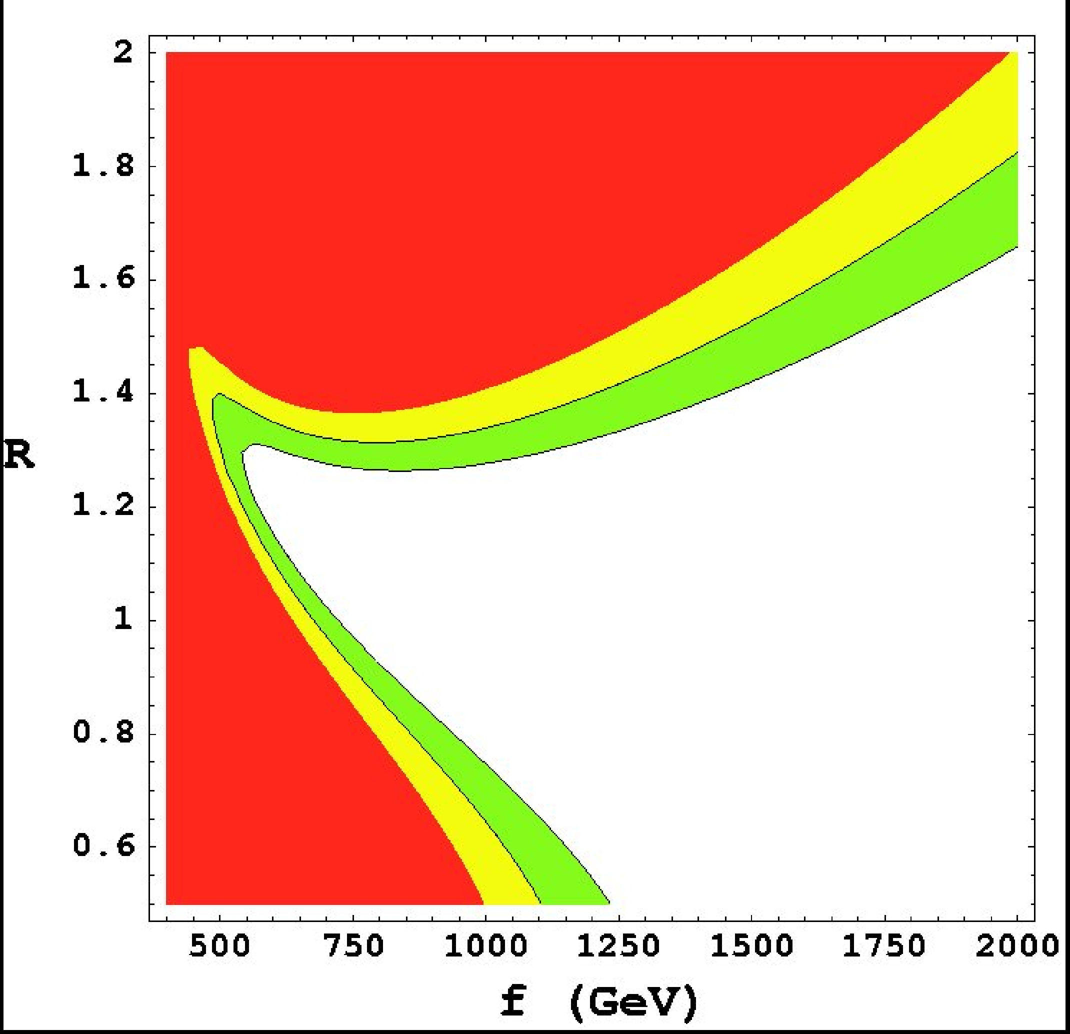
$$\sigma^2\left(\frac{1}{\phi}\right) = V_{\rm COV}(2,2) = \mathrm{PRES}^2 + \left[\frac{\mathrm{PMSPHS}}{p_T\sqrt{\sin(\theta)}}\right]^2$$

and correlation $$V_{\rm COV}(1,2) = -\left[\frac{\mathrm{PMSPCS}}{p_T\sqrt{\sin(\theta)}}\right]^2$$

The z-component is smeared as a Gaussian in $1/p_Z$ with half-width

$$\sigma\left(\frac{1}{p_Z}\right) = \left[\frac{\mathrm{PMSPTS}}{p_Z\sqrt{\sin(\theta)}}\right]^2$$

Choice of Parameters in LHM



Hubisz, Maede, Noble, Perelstein

Choice 1

Mass of W_H = 350 GeV

Mass of A_H = 100 GeV

Collider e^+e^- C.M. = 1 TeV

Choice 2

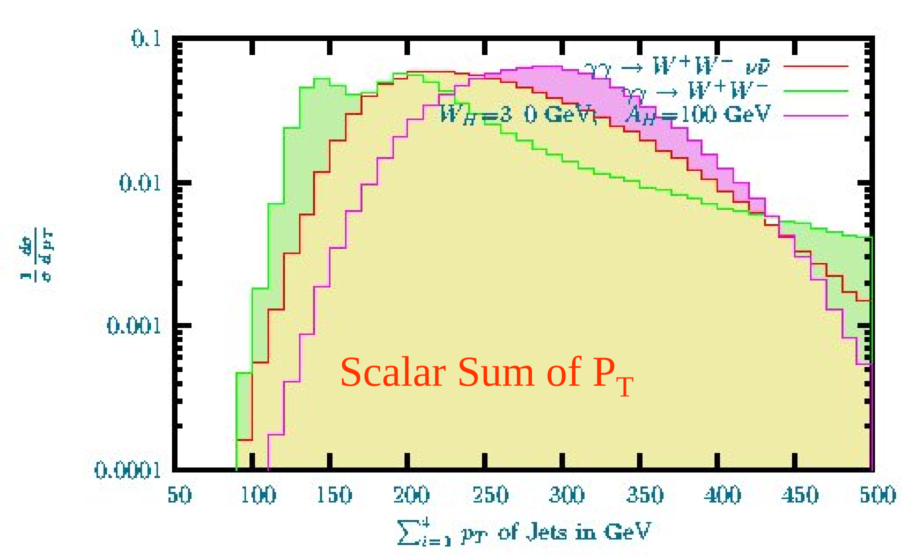
Mass of W_H = 650 GeV

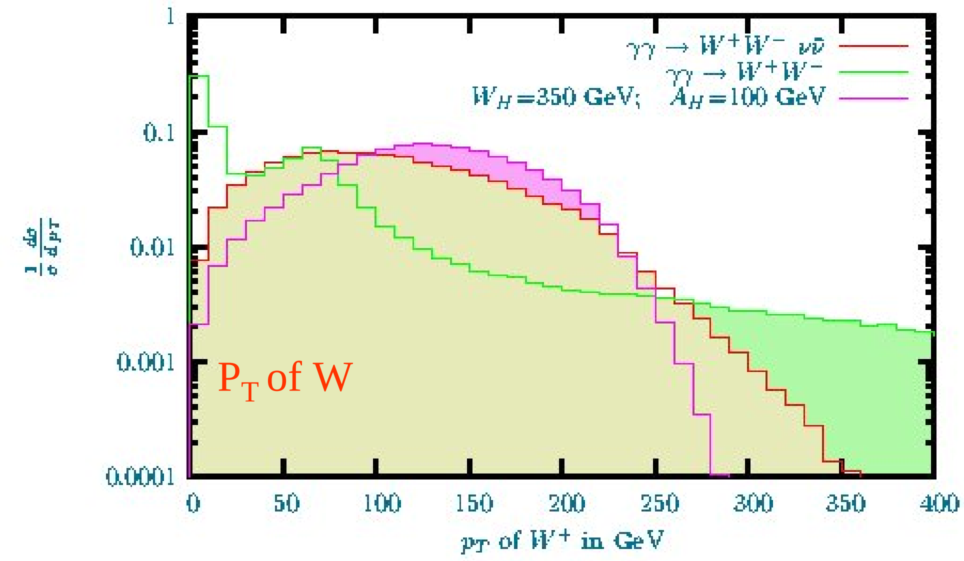
Mass of A_H = 100 GeV

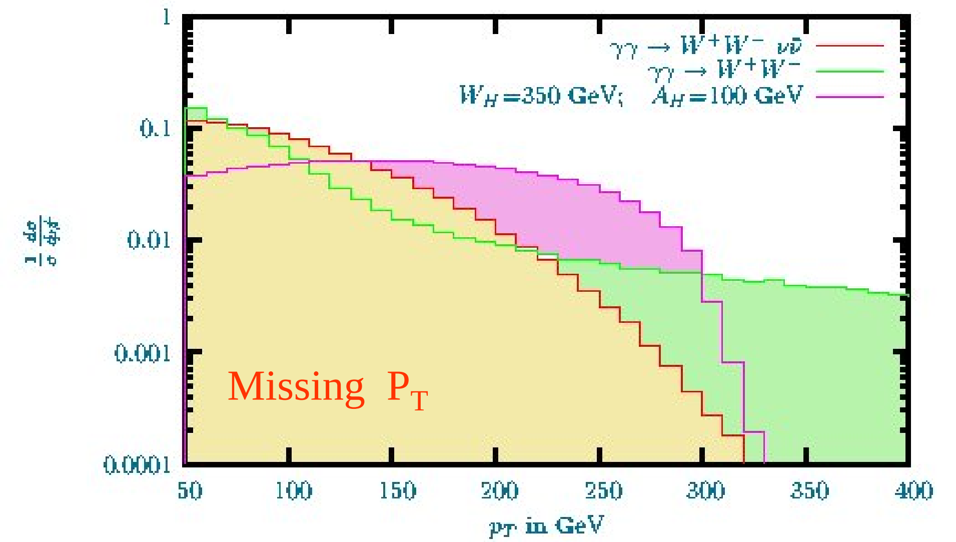
Collider e^+e^- C.M. = 2 TeV

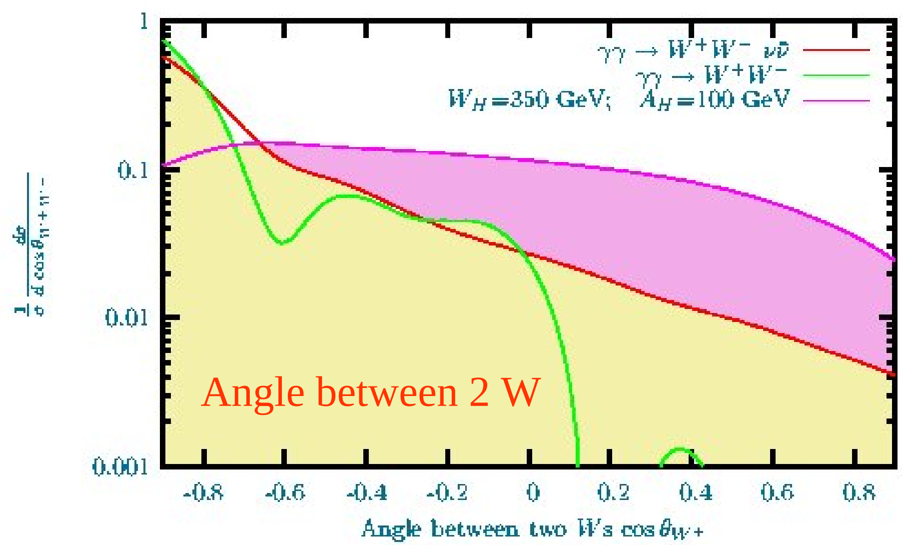
100 % decay of W_H into A_H and W

Distribution Plots : W_H = 350 GeV and A_H = 100 GeV

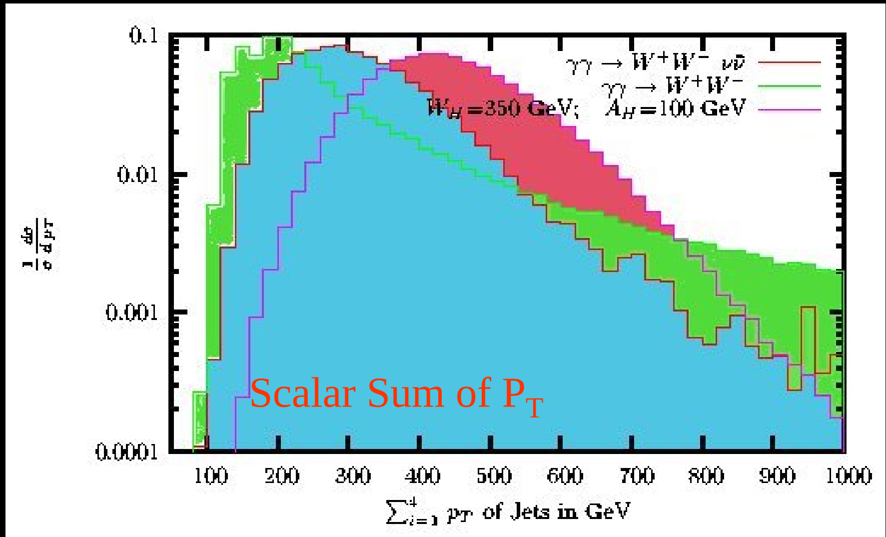


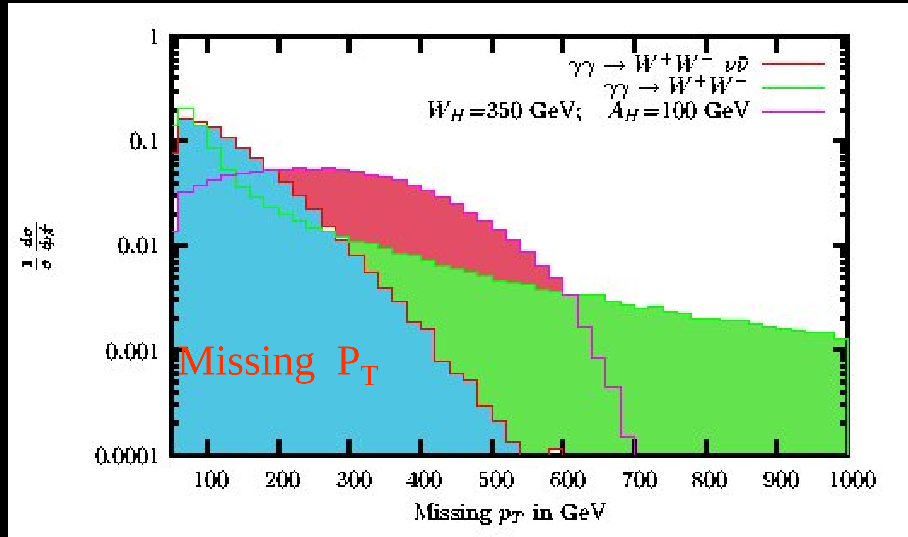


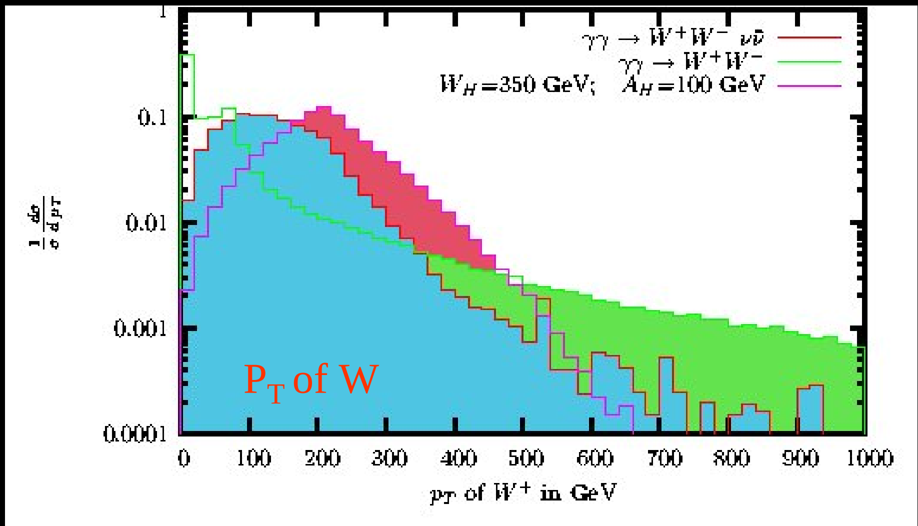


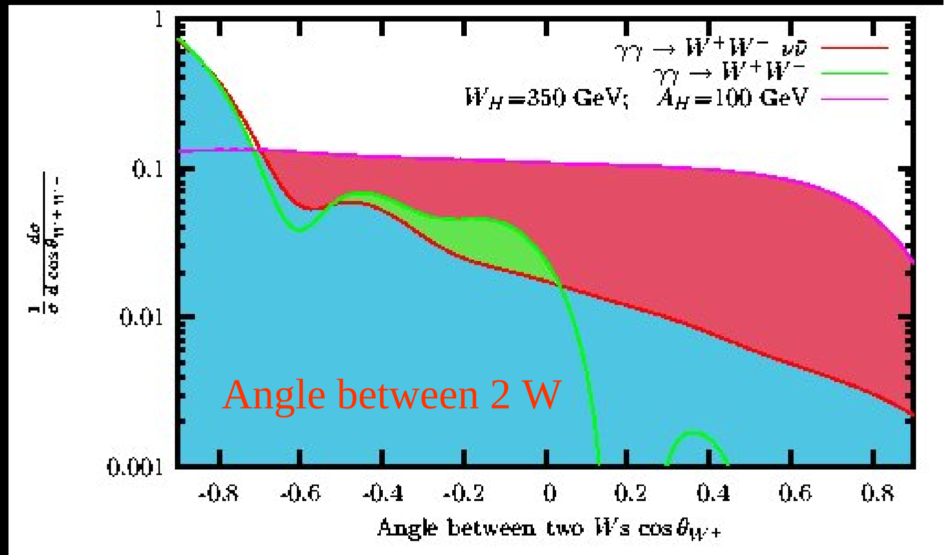


Distribution Plots : W_H = 650 GeV and A_H = 100 GeV

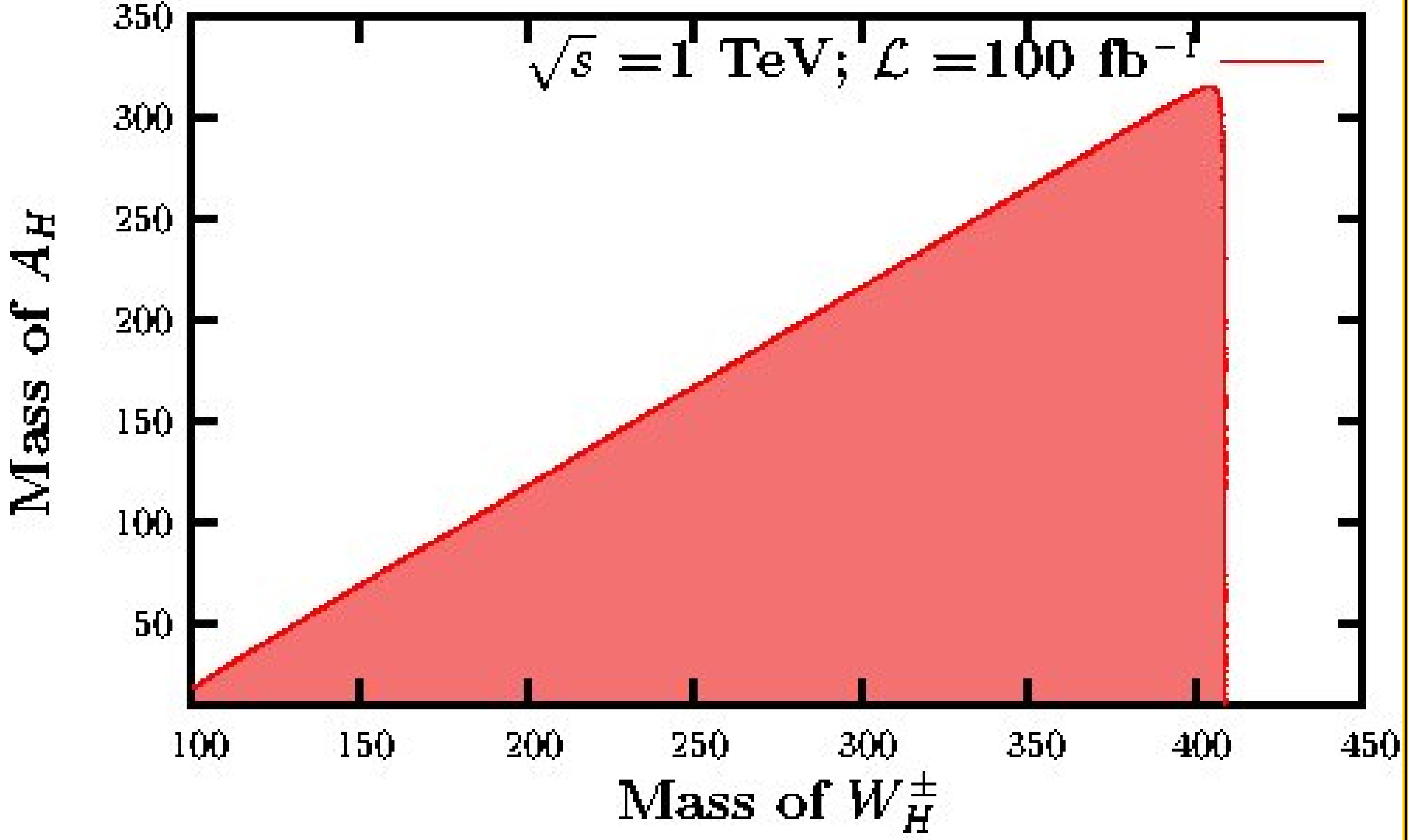








95 % C.L. Contours in W_H and A_H Plane



95 % C. L. Contour in $W_H^{\pm}$ and A_H plane

Summary

❖Little Higgs theories provide a new mechanism to solve the naturalness problem. T parity theories evades EW constraints and provides a good dark Matter candidate. A natural link between TeV Physics and Cosmology

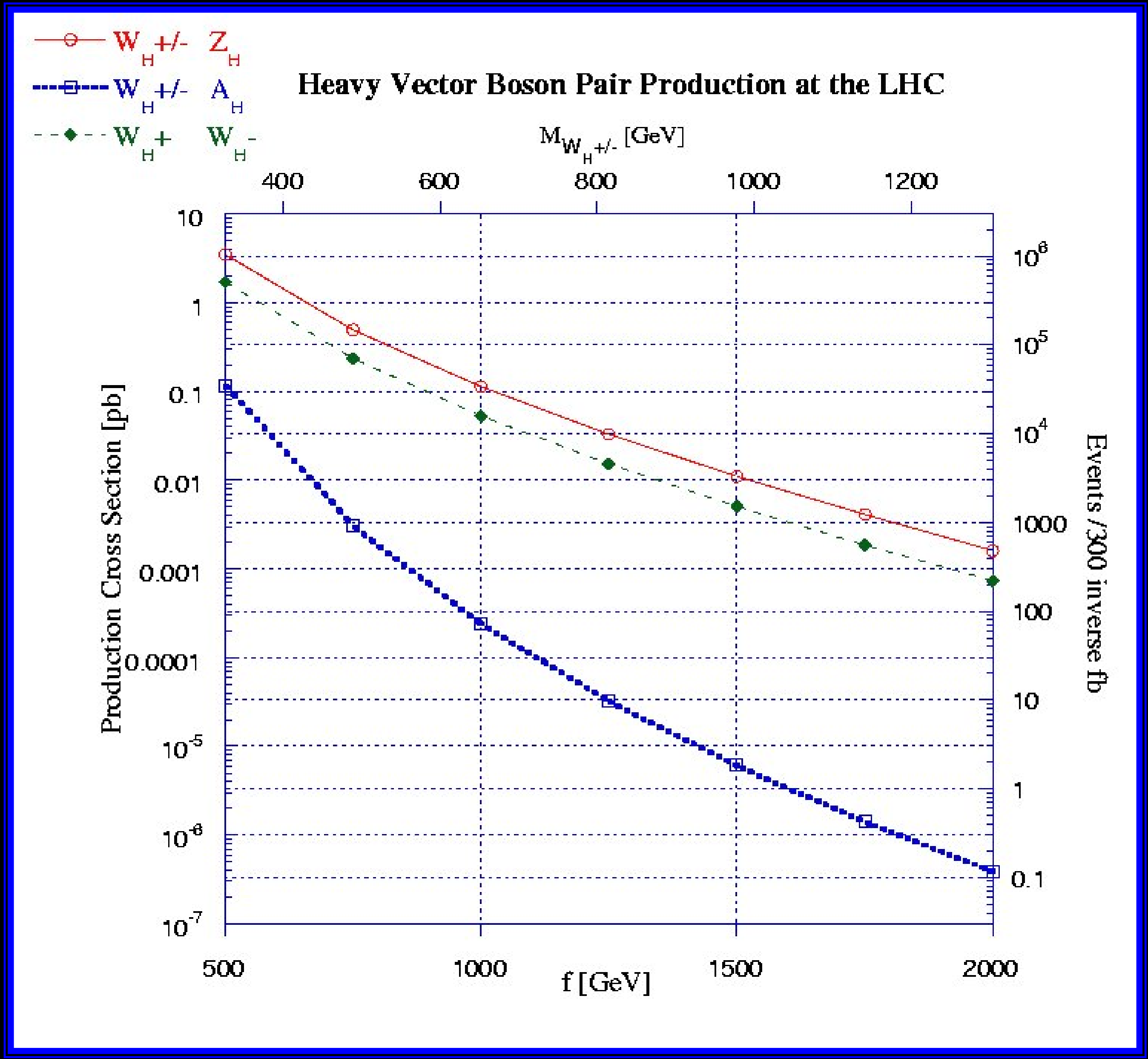
❖The masses of various new particles in LHM are model-dependent and can be very different. They are not expected to be degenerate as in UED models. This affects the relic density calculation and also the production rates.

❖The $\gamma\gamma $ collider has high sensitivity mass reach for heavy charge gauge boson production.

❖ Study for initial polarized beam and distribution of different helicities of W_H are required for the complete Analysis (Work in Progress)

❖LHC will discover new stabilizing EW particles but their origin and detailed property has to come from ILC with **$\gamma\gamma$ option**

Production Cross- Section in LHC



Thank You