HIGGS DECAYS AND BRANE GRAVI-PHOTONS

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Outline

- Massive vector fields common feature of many locally invariant brane world models

- Couple vector to the Standard Model via intrinsic and extrinsic curvature as well as vector field strength

- Constrain vector parameters using LEP I, II accelerator data.

- Examine Higgs decays containing brane vectors.

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Presence of 4-d flexible probe brane breaks extra dimensional space-time symmetries

Focus on case of $N \geq 2$ isotropic extra co-dimensions

Associated with broken translations are Nambu-Goldstone boson fields $\phi_i(x)$, $i = 1, .., N$ whose dynamics describes motion of probe brane into the extra dimensions

Brane oscillations induces metric on the brane

Dynamics given by Nambu-Goto action

$$S_{NG} = -F_X^4 \int d^4x \sqrt{1 + \frac{1}{F_X^4} \partial_\mu \phi_i \partial^\mu \phi_i}$$

Identify F_X^4 as brane tension

Make extra dimensional translations locally invariant as part of higher dimensional general covariance

Introduce "gravi-photon" gauge field $X_i^\mu(x)$ and replace derivatives by covariant derivative

S_{NG} **contains vector mass term: Higgs mechanism**

Vector mass M_X is independent mass scale; its value is model dependent

Presence of massive vector common feature of many locally invariant brane world models

Massive vector field Proca action:

$$S_{Proca} = -\frac{1}{4}\int d^4x X_i^{\mu\nu} X_{\mu\nu i} - \frac{1}{2}M_X^2 \int d^4x X_i^\mu X_{\mu i}$$

with field strength $X_i^{\mu\nu} = \partial^\mu X_i^\nu - \partial^\nu X_i^\mu$

Invariant Couplings of XX to Standard Model

Global $O(N)$ symmetry associated with possible orientations of embedding 4-d brane in D=4+N space

X_i **is** $SU(3) \times SU(2) \times U(1)$ **singlet, but transforms as** N **under the global** $O(N)$ **(carries label** i**)**
Standard Model fields are $O(N)$ **singlets**

$O(N)$ **invariant couplings to Standard Model require even powers of** X_i **; Massive vectors are stable particles**

•**Induced metric coupling to Standard Model symmetric energy momentum tensor** $T^{\mu\nu}_{SM}$

$$S_{XXT} = \frac{M_X^2}{2F_X^4} \int d^4x X_{\mu i} X_{\nu i} T^{\mu\nu}_{SM}$$

Extrinsic curvature

$$K_i^{\mu\nu} = \frac{1}{2}(\partial^\mu X_i^\nu + \partial^\nu X_i^\mu) + \ldots$$

Measures curvature of embedded brane relative to enveloping D-dimensional geometry

- **Coupling to weak hypercharge field strength**

$$S_{XXB} = \frac{M_X^2}{2F_X^4} \int d^4x(\kappa_1 B_{\mu\nu} + \kappa_2 \tilde{B}_{\mu\nu}) X_i^{\mu\rho} K_{i\rho}^{\nu}$$

$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$ **with** $B_\mu = \cos\theta_W A_\mu - \sin\theta_W Z_\mu$

- **Coupling to scalar doublet bilinear**

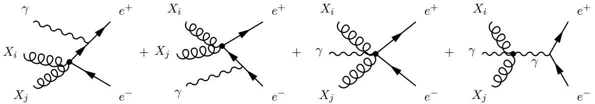
$$S_{XXH} = \frac{M_X^2}{2F_X^4} \int d^4x \left[\lambda_1 K_i^{\mu\nu} K_{i\mu\nu} + \lambda_2 X_{i\mu\nu} X_i^{\mu\nu} + \lambda_3 X_{i\mu\nu} \tilde{X}_i^{\mu\nu}\right] \phi^\dagger \phi$$

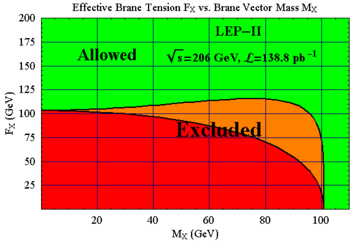
Unitary gauge: $\phi^\dagger\phi = vH + \frac{1}{2}H^2$ **with** H **Higgs scalar**

- **LEP limits**

$e^+e^- \rightarrow \gamma XX$ **appears as** γ **plus missing energy**
Expt limit: $\sigma(e^+e^- \rightarrow \gamma \not{E}) < .45\ pb$ **leads to restriction of allowed** M_X, F_X **values**

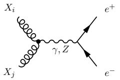
- **Induced metric coupling (to $T^{\mu\nu}_{SM}$) only**



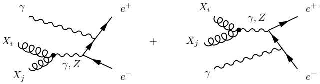


• Coupling to $B^{\mu\nu}$ only

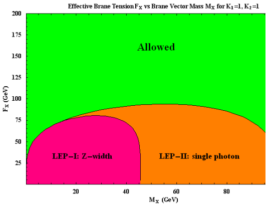
Allowed invisible Z decay width: $\Gamma_{Z \to XX} \leq 2\ MeV$



and limits from $e^+e^- \to \gamma XX$



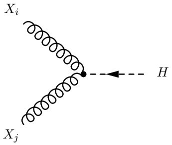
Transverse vector modes required



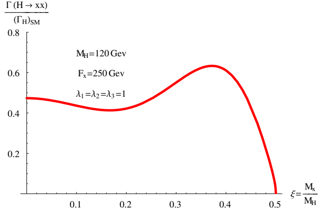
No interference in $e^+e^- \to \gamma XX$ cross section between graphs containing from S_{XXT} and S_{XXB} couplings

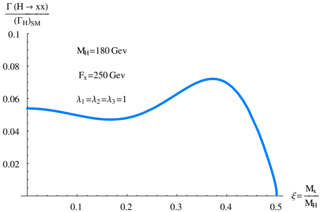
Higgs decays containing X vectors

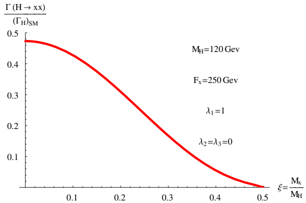
- $H \to XX$: **Appears as invisible Higgs decay**



$$\frac{\Gamma(H \to XX)}{(\Gamma_H)_{SM}} = \frac{1}{(\Gamma_H)_{SM}} \frac{N \sin^2\theta_W}{32\pi^2\alpha} \frac{M_H^7 M_W^2}{F_X^8} \sqrt{1-4\xi^2} \Big[(\frac{\lambda_1}{4} + \lambda_2)^2 (\frac{1}{4} - \xi^2 + 3\xi^4) + (\frac{\lambda_1^2}{16} - \lambda_2^2) \frac{1}{2} (1-2\xi^2)^2 (1-4\xi^2) + \frac{1}{4} (\frac{\lambda_1}{4} - \lambda_2)^2 (1-4\xi^2)^2 + 8\lambda_3^2 \xi^4 (1-4\xi^2) \Big] \quad ; \quad \xi \equiv \frac{M_X}{M_H}$$

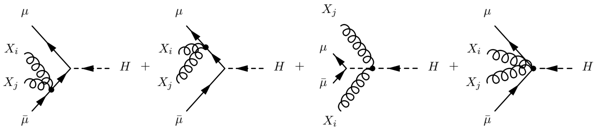

Γ (H → xx)
(Γ_H)_SM
0.8
0.6
0.4
0.2
M_H=120 Gev
F_x=250 Gev
λ_1=λ_2=λ_3=1
0.1
0.2
0.3
0.4
0.5
ξ = M_x / M_H


Γ (H → xx)
(Γ_H)_SM
0.1
0.08
0.06
0.04
0.02
M_H=180 Gev
F_x=250 Gev
λ_1=λ_2=λ_3=1
0.1
0.2
0.3
0.4
0.5
ξ = M_x / M_H

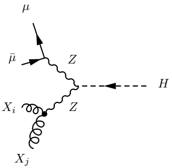

Γ (H → xx)
(Γ_H)_SM
0.5
0.4
0.3
0.2
0.1
M_H=120 Gev
F_x=250 Gev
λ_1=1
λ_2=λ_3=0
0.1
0.2
0.3
0.4
0.5
ξ = M_x / M_H

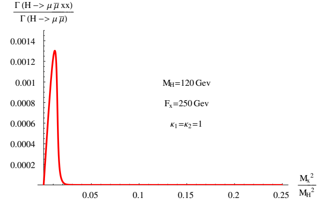
• $H \to \mu\bar{\mu}XX$

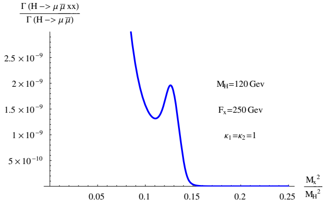
Couplings involving $(T_{\mu\nu})_{SM}$

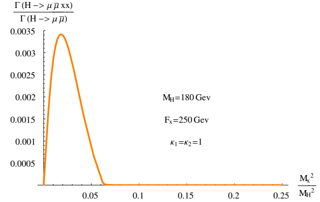


Amplitude varies as $\frac{m_\mu}{F_X^4}$.
In general, suppressed relative to graph containing extrinsic curvature coupling S_{XXB}



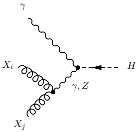

Γ (H −> μ μ̄ xx) / Γ (H −> μ μ̄)
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
M_H=120 Gev
F_x=250 Gev
κ1=κ2=1
0.05
0.1
0.15
0.2
0.25
M_x^2 / M_H^2


Γ (H −> μ μ̄ xx) / Γ (H −> μ μ̄)
2.5 × 10^−9
2 × 10^−9
1.5 × 10^−9
1 × 10^−9
5 × 10^−10
M_H=120 Gev
F_x=250 Gev
κ1=κ2=1
0.05
0.1
0.15
0.2
0.25
M_x^2 / M_H^2

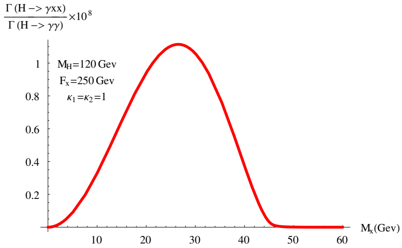

Γ (H −> μ μ̄ xx) / Γ (H −> μ μ̄)
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
M_H=180 Gev
F_x=250 Gev
κ1=κ2=1
0.05
0.1
0.15
0.2
0.25
M_x^2 / M_H^2

- $H \to \gamma XX$

Appears as photon plus missing energy



For the $H\gamma\gamma$ and $H\gamma Z$ vertices use the effective couplings $F_{\mu\nu}F^{\mu\nu}H$ and $F_{\mu\nu}Z^{\mu\nu}H$; For the γXX and ZXX vertices use S_{XXB}



Summary

• 4-d probe brane breaks extra dimensional translation invariances. Gauging broken translations leads to massive, Standard Model singlet, stable Proca vector fields

• Coupled vectors to the Standard Model using both intrinsic and extrinsic curvatures

• Limits on effective Lagrangian parameters (M_X, F_X) from LEP I, LEP II data

• Rate for $H \to XX$ (invisible Higgs decay) could prove comparable to any Standard Model Higgs decay rate for presently allowed M_X, F_X values

• $\Gamma(H \to \mu\bar{\mu}XX) \sim 10^{-3}\Gamma(H \to \mu\bar{\mu})$ for small range of M_X values which varies as function of M_H