Determining the Origin of Higgs Couplings at the LHC

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– Higgs Production in Weak Boson Fusion

– Determination of Parity Properties

– Contributions by Higher Dimensional Couplings

– Outlook

together with D. Rainwater, D. Zeppenfeld

Higgs Bosons in Weak Boson Fusion

Weak Boson Fusion competitive Higgs search channel at the LHC

− smaller cross section as compared to gluon fusion, $\sigma \sim 3 \cdots 5s$ pb

+ distinctive signature with tagging jets

+ not only $S/\sqrt{B} > 5$ but also $S/B > 1$

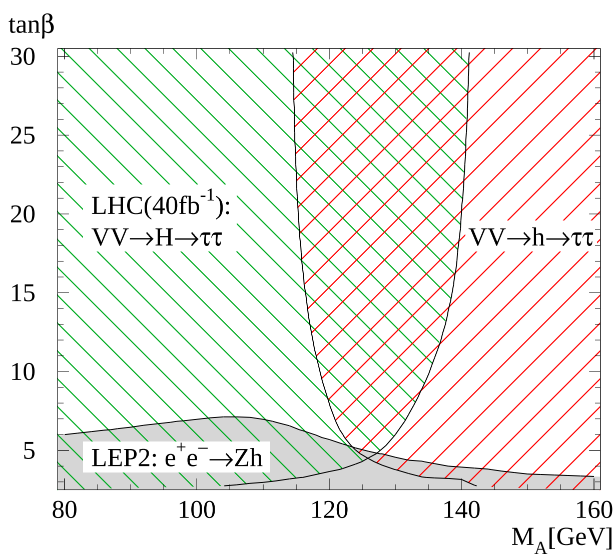
+ multitude of possible observables [e.g. Eboli & Zeppenfeld]

+ measurement of couplings [Zeppenfeld, Kinnunen, Nikitenko, Richter-Was]

M_H	$H \to \tau\tau_{e\mu}$	σ_{Gauss}	$H \to \tau\tau_{\ell j}$	σ_{Gauss}	$H \to \gamma\gamma$	σ_{Gauss}	$H \to W^* W^*$	σ_{Gauss}
110 GeV	0.58 fb	5.6	0.40 fb	5.7	0.37 fb	4.4	0.51 fb	$\sim$ 4.4
120 GeV	0.50 fb	6.8	0.34 fb	7.4	0.56 fb	5.2	1.62 fb	$\sim$ 12
140 GeV	0.23 fb	4.3	0.17 fb	4.7	0.48 fb	5.0	6.13 fb	$\sim$ 40

Moreover:

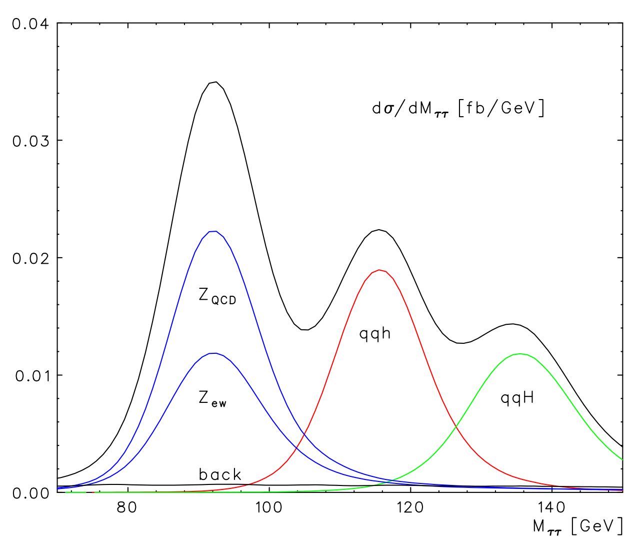
$H \to \tau\tau$ stable in MSSM



[T.P, Rainwater, Zeppenfeld, PRD61 (2000)]

Even better:

Higgs mass reconstruction



[T.P, Rainwater, Zeppenfeld, PLB454 (1999)]

Higher Dimensional Operators

Higher Dimensional Couplings WWH, ZZH

$$\mathcal{L}_5 = \frac{1}{\Lambda_\mathrm{e}} W^{\mu\nu} W_{\mu\nu}\, \Phi + \frac{1}{\Lambda_\mathrm{o}} \widetilde{W}^{\mu\nu} W_{\mu\nu}\, \Phi$$

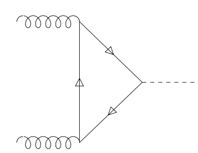
linked to dimension 6 operators

$$\mathcal{L}_6 = \frac{1}{2\Lambda_{\mathrm{e},6}^2} \left(\Phi^\dagger \Phi\right)\; W^{\mu\nu} W_{\mu\nu} + \frac{1}{2\Lambda_{\mathrm{o},6}^2} \left(\Phi^\dagger \Phi\right)\; \widetilde{W}^{\mu\nu} W_{\mu\nu} \qquad \Rightarrow \qquad \frac{1}{\Lambda_5} = \frac{v}{\Lambda_6^2}$$

lead to WWH couplings

$$\Gamma_\mathrm{e}^{\mu\nu} = \frac{2i}{\Lambda_\mathrm{e}} \left[q_1^\nu q_2^\mu - (q_1 q_2) g^{\mu\nu}\right] \qquad\qquad \Gamma_\mathrm{o}^{\mu\nu} = \frac{2i}{\Lambda_\mathrm{o}} \epsilon^{\mu\nu q_1 q_2}$$

Loop induced couplings in low energy limit of MSSM



$$\mathcal{M}^{\mu\nu}(gg \to H) \propto y_t\; \frac{2}{3m_t}\; \Gamma_\mathrm{e}^{\mu\nu} \qquad \text{for} \qquad p_g^2 = 0$$

$$\mathcal{M}^{\mu\nu}(gg \to A) \propto y_t\; \frac{i}{m_t}\; \Gamma_\mathrm{o}^{\mu\nu}$$

dimensional analysis for weak loops, however:

$$\mathcal{M}^{\mu\nu}(WW \to H) \sim y_t\; \frac{\alpha}{16\pi^2}\; \frac{1}{\max(m_t, m_H)}\; \Gamma_\mathrm{e}^{\mu\nu} \;\sim\; y_t\; \frac{1}{2 \cdot 10^5}\; \frac{1}{m_t}\; \Gamma_\mathrm{e}^{\mu\nu}$$

Higgs type scalar found in WBF $\Longrightarrow$ Parity Properties?

– Decay distributions $(H \to f\bar{f}, VV)$ [e.g. Dell'Aquila & Nelson]

– Linear Collider observables

[e.g. Krämer, Kühn, Stong, Zerwas; Hagiwara, Ishihara, Kamoshita, Kniehl; Han & Jiang]

– WBF Angular Correlations

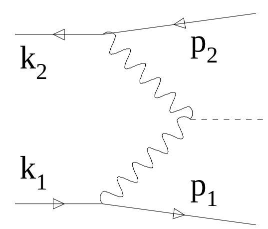
Parity Properties of Higgs Resonance

Scenario I

One Higgs scalar responsible for WBF $\tau\tau$ signal

$m_H = 120$ GeV $\to \sigma_{\rm SM} = 0.5$ fb after cuts and efficiencies, S/B=2.7
$\sigma_5 = \sigma_{\rm SM}$ requires $\Lambda_e \sim \Lambda_o \sim 500$ GeV
variable $\sigma_5/\sigma_{\rm SM}$ scales with $1/\Lambda^2$

WBF production-side angular correlation $\Delta\phi_{jj}$



(1) CP even scalar coupling through $\Gamma_e^{\mu\nu}$

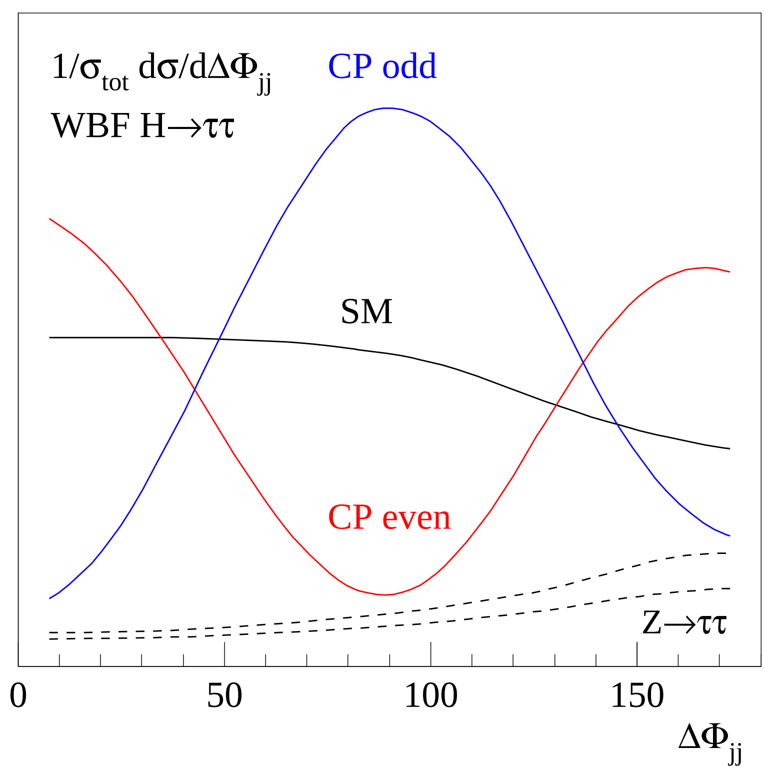
$\Rightarrow d\sigma \propto (k_1 k_2)\,(p_1 p_2)$

$\Rightarrow$ approx. zero for forward jets with $\angle(p_1 p_2) = \pi/2$

(2) CP odd scalar coupling through $\Gamma_o^{\mu\nu}$

$\Rightarrow$ four independent vectors needed

$\Rightarrow$ exact zero at $\angle(p_1 p_2) = 0, \pi$



Important background:
$pp \to H$+2 jets
$\Rightarrow$ systematical uncertainty
Oleari & Zeppenfeld, talk Friday

Interference Terms

Scenario II

Standard Model type Higgs with additional WWH coupling

(1) CP odd scalar coupling

$\Rightarrow$ observable $\Delta\phi_{\rm jj}$ symmetrizing over two jets

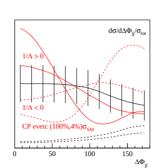
$\Rightarrow$ no interference with CP even $g^{\mu\nu}$ coupling

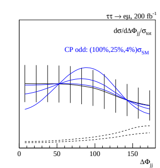
(2) CP even scalar coupling: $\mathcal{M} \sim (J_1 J_2)(p_1^T p_2^T)$

$\Rightarrow$ change in sign of interference

$\Rightarrow$ statistical error function of number of bins

$\Rightarrow$ define asymmetry





Azimuthal angle asymmetry

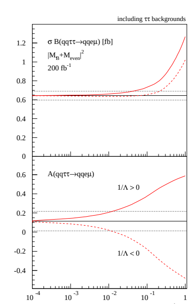
$$A_\phi = \frac{\sigma(\Delta\phi < \pi/2) - \sigma(\Delta\phi > \pi/2)}{\sigma(\Delta\phi < \pi/2) + \sigma(\Delta\phi > \pi/2)}$$

∗ Standard Model leading order $A_\phi \sim 0.1$

∗ $\text{sign}(A_\phi) = \text{sign}(\Lambda)$

∗ reach compared to counting experiment?

[e.g. Eboli, Gonzales–Garcia, Lietti, Novaes]



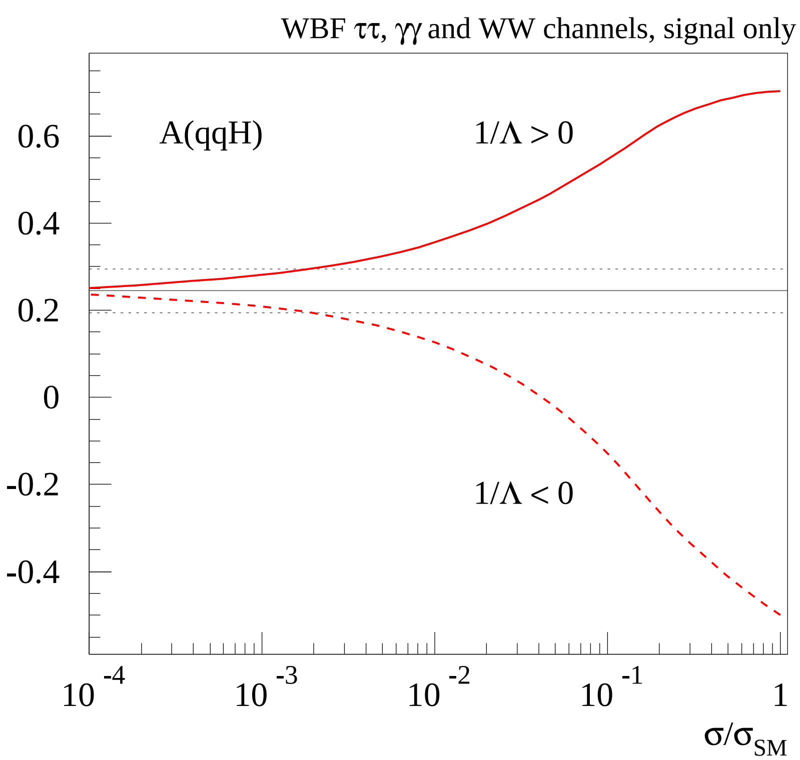
OUTLOOK

– higher dimensional couplings observable at the LHC

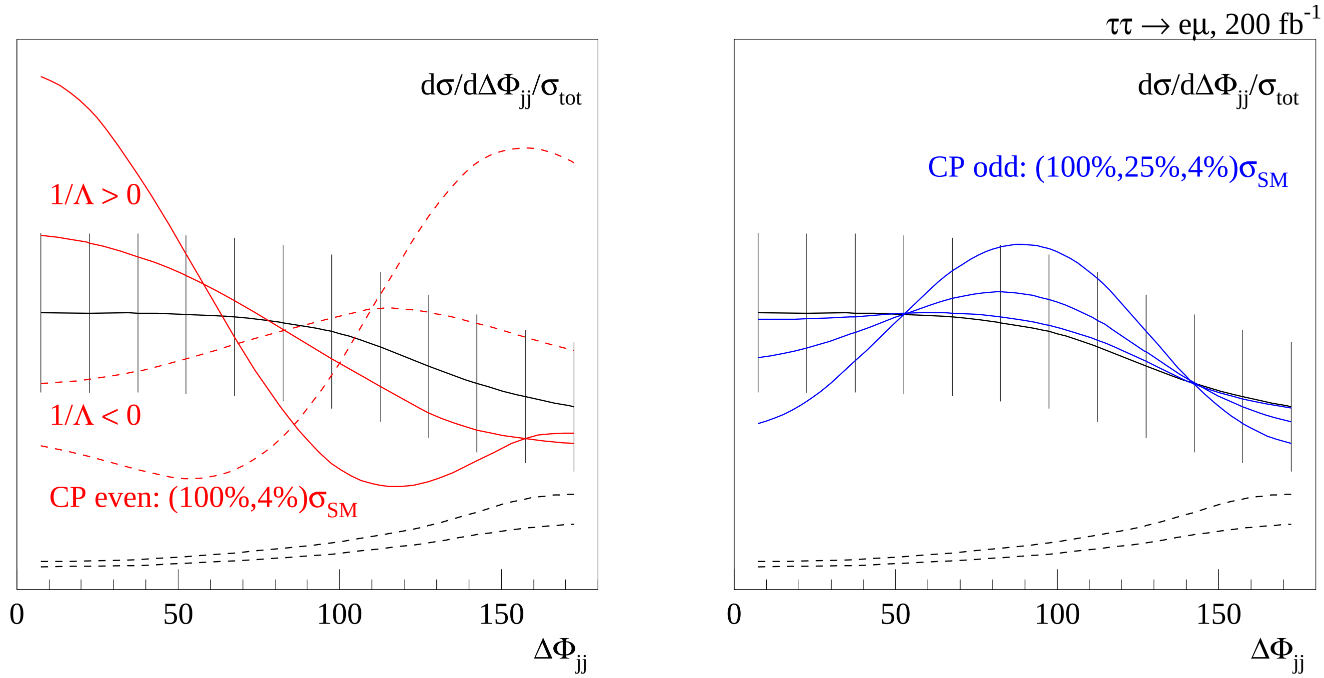
– WBF azimuthal angle distribution and asymmetry shown for $H \to \tau\tau$ channel

– possible for all WBF channels

– at some point dominated by systematics in background for LHC



σ_5/σ_{SM}	Λ_5	Λ_6
1	0.5 TeV	0.3 TeV
10^{-1}	1.6 TeV	0.6 TeV
10^{-2}	5.0 TeV	1.1 TeV
10^{-3}	16.4 TeV	2.0 TeV



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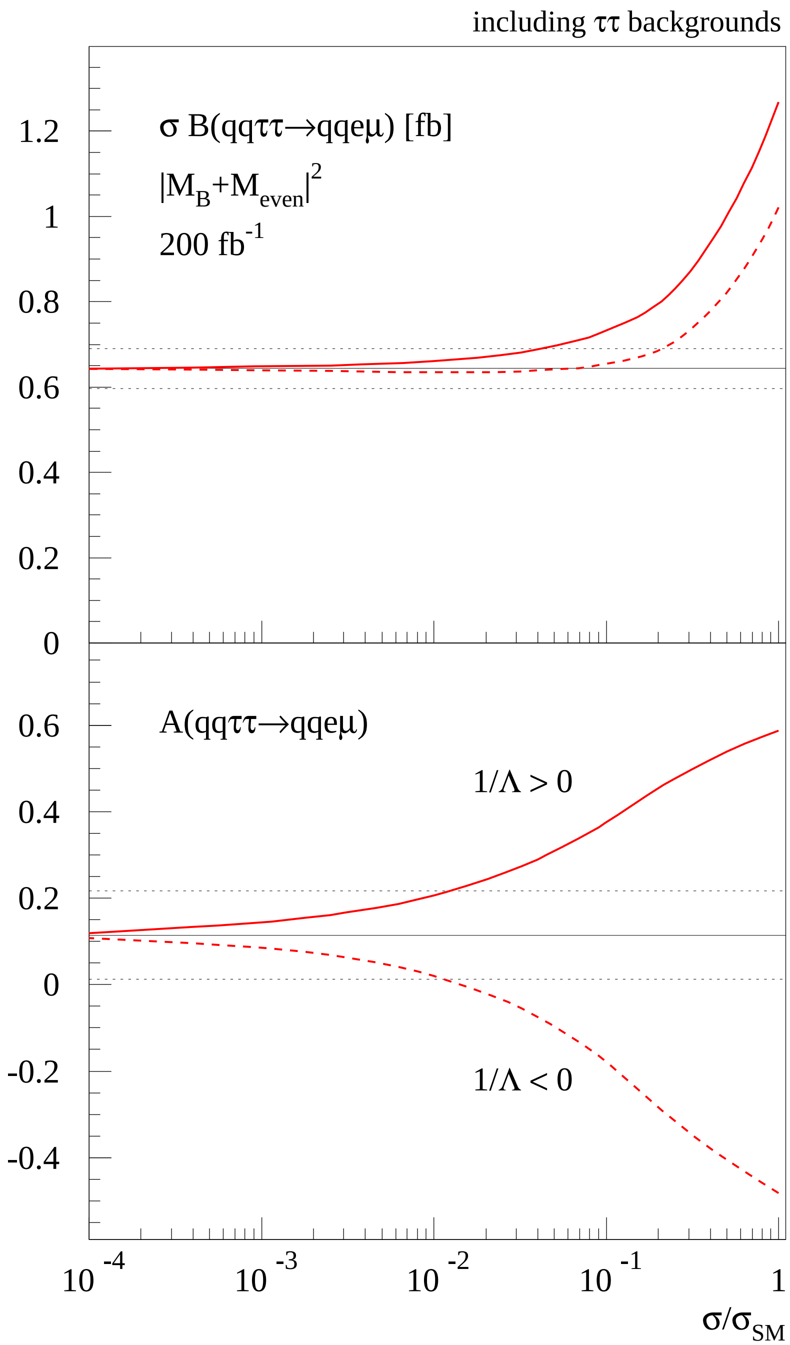

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