Anomalous couplings in $\gamma\gamma \rightarrow$ *WW* at LHC and ILC

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LC09
Perugia, 23. 9. 2009

Outline

1. Effective Lagrangian approach
2. Observables for anomalous couplings in $\gamma\gamma \to WW$
3. Sensitivities at the LHC
4. Sensitivities at the ILC
5. Comparison

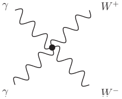
in collaboration with

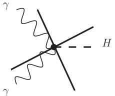
M. Manitias, O. Nachtmann, F. Nagel, M. Pospischil, A. Utermann

The Effective Lagrangian approach

Standard Model:

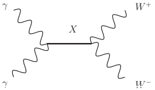
- Standard Model (SM) γ, W, Z couplings fixed by: gauge invariance & renormalisability
- deviations $\Rightarrow$ signal for new physics (NP)

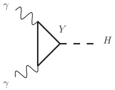




Specific NP model:

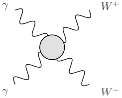
- new particles X, Y lead to new contributions

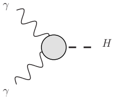


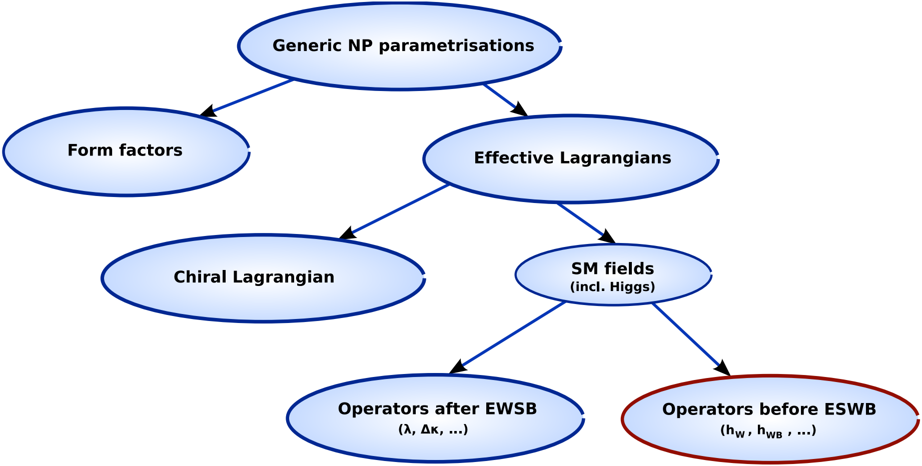


Generic NP parametrisation:

- assume $\Lambda_{NP} \gg v \approx 246$ GeV
- general effective anomalous couplings at $E \ll \Lambda_{NP}$ (beyond S, T, U)
- discovery of deviations, exclusion of models $\Rightarrow$ *multi-purpose interface*: experiment $\leftrightarrow$ theory






Generic NP parametrisations
Form factors
Effective Lagrangians
Chiral Lagrangian
SM fields
(incl. Higgs)
Operators after EWSB
(λ, Δκ, ...)
Operators before ESWB
(h_W, h_{WB}, ...)

Form factors

- parametrise effective vertices by complex momentum dep. couplings
- very general, many parameters
- process specific

example 1: form factors in DIS

- eff. $pp\gamma$ vertex

$$\Gamma^\mu = \gamma^\mu F_1(x, Q^2) - i\sigma^{\mu\nu} q_\nu \frac{1}{2m_p^2} F_2(x, Q^2)$$

example 2: form factors in $e^+e^- \to W^+W^-$

- require only Lorentz inv. $\Rightarrow$ eff. WWV ($V = \gamma, Z$) vertex:

$$\Gamma_V^{\alpha\beta\mu} = f_1^V (q-\bar{q})^\mu g^{\alpha\beta} - \frac{f_2^V}{m_W^2}(q-\bar{q})^\mu P^\alpha P^\beta + f_3^V (P^\alpha g^{\mu\beta} - P^\beta g^{\mu\alpha})$$
$$+ i f_4^V (P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha}) + i f_5^V \epsilon^{\mu\alpha\beta\rho}(q-\bar{q})_\rho - f_6^V \epsilon^{\mu\alpha^\beta\rho} P_\rho$$
$$- \frac{f_7^V}{m_W^2}(q-\bar{q})^\mu \epsilon^{\alpha\beta\rho\sigma} P_\rho (q-\bar{q})_\sigma$$

total: 28 real couplings *[Hagiwara, Peccei, Zeppenfeld, Hikasa (1987)]*

- simultan. measurement involved *[Diehl, Nachtmann, Nagel (2002)]*

EW Chiral Lagrangian

- start without Higgs, consider E/Λ expansion for $\Lambda = 4\pi v$
- replace Higgs field by matrix valued field containing only Goldstone modes $w^{\pm}$, z

$$\Sigma(x) = \exp\left(-\frac{i}{v}\mathbf{w}(x)\tau\right) = \exp\left(-\frac{i}{v}(\sqrt{2}w^{+}\tau^{+} + \sqrt{2}w^{-}\tau^{-} + z\tau^{3}/2)\right) \quad (1)$$

- LO Lagrangian:

$$\mathscr{L}_0^{\Sigma} = \frac{v^2}{4}\,\mathrm{tr}\left[(D_\mu\Sigma)^\dagger(D^\mu\Sigma)\right] + \ldots \quad (2)$$

with $D_\mu\Sigma = \partial_\mu\Sigma + ig\mathbf{W}_\mu\Sigma - ig'\Sigma B\tau^3/2$

- NLO Lagrangian: add new resonances + rad. corr. from LO

$$\mathscr{L}^{\Sigma} = \mathscr{L}_0^{\Sigma} + \sum_{i=1}^{19}\mathscr{L}_i^{\Sigma} \quad (3)$$

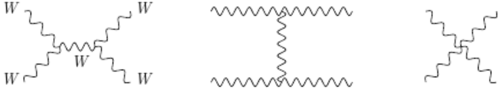
with (see e.g. *Longhitano (1981), Appelquist, Wu (1993), Kilian, Reuter*)

$$\mathscr{L}_1^{\Sigma} = \alpha_1 gg'\,\mathrm{tr}\left[W_{\mu\nu}B^{\mu\nu}\right] \qquad (S = -16\pi\alpha_1), \quad (4)$$

$$\mathscr{L}_4^{\Sigma} = \alpha_4\left(\mathrm{tr}[(D_\mu\Sigma)\Sigma^\dagger(D^\mu\Sigma)\Sigma^\dagger]\right)^2 \qquad (\text{QGC etc.}), \ldots \quad (5)$$

EW Chiral Lagrangian
Unitarity

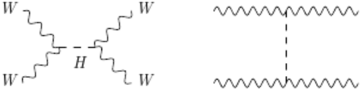
- SM without Higgs: unitarity problem in $W_L W_L \to W_L W_L$



high-energy amplitude $\propto \sqrt{s}^2 \Rightarrow$ unitarity violated above $\sqrt{s} \geq 1$ TeV

- relevant at LHC

- for SM: cured by Higgs exchanges



- for chiral Lagrangian: unitarity constraints by hand
  - employ form factors

Effective Lagrangian after EWSB

- start from SM Lagrangian *after EWSB* (standard SM fields incl. Higgs)
- add higher dim. operators which are
  - Lorentz-invariant
  - $U(1)_{em}$ invariant
- *Hagiwara, Peccei, Zeppenfeld and Hikasa (1987)*:

$$\frac{\mathscr{L}_{VWW}^{\text{HPZH}}}{ig_{VWW}} = g_1^V (W_{\mu\nu}^+ W^{-\mu} - W_{\mu\nu}^- W^{+\mu}) V^\nu \tag{6}$$
$$+ \kappa_V W_\mu^+ W_\nu^- V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W_{\lambda\mu}^+ W^{-\mu}{}_\nu V^{\nu\lambda}$$
$$+ ig_4^V W_\mu^+ W_\nu^- (\partial^\mu V^\nu + \partial^\nu V^\mu)$$
$$- ig_5^V \varepsilon^{\mu\nu\rho\sigma} \left(W_\mu^+ (\partial_\rho W_\nu^-) - W_\nu^- (\partial_\rho W_\mu^+)\right) V_\sigma$$
$$+ \tilde{\kappa}_V W_\mu^+ W_\nu^- \tilde{V}^{\mu\nu} + \frac{\tilde{\lambda}_V}{m_W^2} W_{\lambda\mu}^+ W^{-\mu}{}_\nu \tilde{V}^{\nu\lambda}$$

  with $V = \gamma$ or Z, $g_{\gamma WW} = -e$, $g_{ZWW} = -e \cot\theta_\text{w}$ and real couplings
- moderate number of couplings
- indep. couplings $\Rightarrow$ unitarity problems at larger E
  - employ form factors
  - employ approx. gauge relations $\Rightarrow$ close to eff. Lagr. *before EWSB* at low E (next slide)

Effective Lagrangian before EWSB

- start from SM Lagrangian (incl. Higgs doublet φ)
- add all higher dim. operators which are
  - Lorentz-invariant
  - $SU(3) \times SU(2) \times U(1)$ invariant

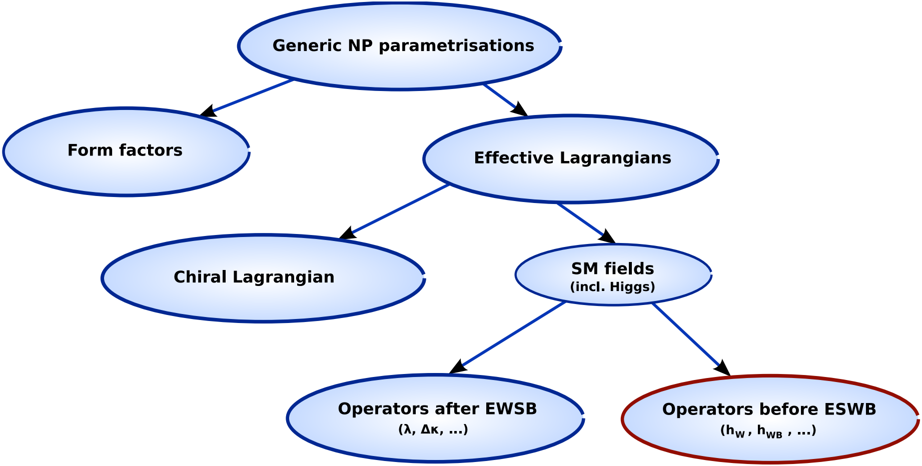
$$\Rightarrow \quad \mathscr{L}_{eff} = \mathscr{L}_0 + \underbrace{\mathscr{L}_1}_{\text{dim 5 op.}} + \underbrace{\mathscr{L}_2}_{\text{dim 6 op.}} + \dots$$

- imposing
  - equation of motion
  - lepton and baryon number conservation

$\Rightarrow$ $\mathscr{L}_1$: none, $\mathscr{L}_2$: $\propto$80 operators $\ni$ 10 pure gauge/Higgs

Buchmüller, Wyler (1986)

- robust NP decoupling for $\Lambda \gg v$
- small number of couplings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Effective Lagrangian before EWSB

Gauge and gauge-Higgs anomalous couplings

- pure gauge and gauge-Higgs part: $\mathscr{L}_2 = \frac{1}{v^2} \sum h_i O_i$

$$O_W = \epsilon_{ijk} W_\mu^{i\,\nu} W_\nu^{j\,\lambda} W_\lambda^{k\,\mu}, \qquad O_{\tilde{W}} = \epsilon_{ijk} \tilde{W}_\mu^{i\,\nu} W_\nu^{j\,\lambda} W_\lambda^{k\,\mu},$$

$$O_{\varphi W} = \frac{1}{2} \left(\varphi^\dagger \varphi\right) W_{\mu\nu}^i W^{i\,\mu\nu}, \qquad O_{\varphi \tilde{W}} = \left(\varphi^\dagger \varphi\right) \tilde{W}_{\mu\nu}^i W^{i\,\mu\nu},$$

$$O_{\varphi B} = \frac{1}{2} \left(\varphi^\dagger \varphi\right) B_{\mu\nu} B^{\mu\nu}, \qquad O_{\varphi \tilde{B}} = \left(\varphi^\dagger \varphi\right) \tilde{B}_{\mu\nu} B^{\mu\nu},$$

$$O_{WB} = \left(\varphi^\dagger \tau^i \varphi\right) W_{\mu\nu}^i B^{\mu\nu}, \qquad O_{\tilde{W}B} = \left(\varphi^\dagger \tau^i \varphi\right) \tilde{W}_{\mu\nu}^i B^{\mu\nu},$$

$$O_\varphi^{(1)} = \left(\varphi^\dagger \varphi\right) \left(\mathcal{D}_\mu \varphi\right)^\dagger \left(\mathcal{D}^\mu \varphi\right), \qquad O_\varphi^{(3)} = \left(\varphi^\dagger \mathcal{D}_\mu \varphi\right)^\dagger \left(\varphi^\dagger \mathcal{D}^\mu \varphi\right).$$

- 10 dimensionless anomalous couplings h_i, where 4 ops. CP odd

$$h_i \sim \mathcal{O}\left(v^2/\Lambda_{NP}^2\right),$$

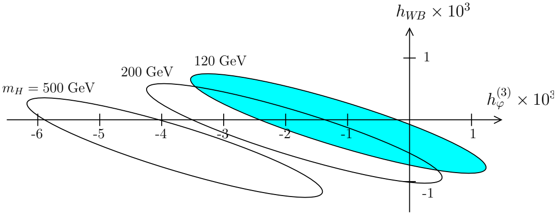
- EWSB: anomalous contrib. to kinetic and mass terms of gauge bosons
  - kinetic: $h_{\varphi W}$, $h_{\varphi B}$, h_{WB}
  - mass: $h_\varphi^{(1)}$, $h_\varphi^{(3)}$

  $\Rightarrow$ physical $W^\pm$, Z, γ modified wrt. SM
- Z decays sensitive to anom. couplings: $h_\varphi^{(3)}$, h_{WB} (scheme P_Z)
- approx. relations to $U(1)_{em}$ effect. Lagr.: $\lambda \propto h_W$, $\Delta\kappa \propto h_{WB}$, ...

Present limits

Nachtmann, Nagel, Pospischil

Present bounds on CP conserving couplings (P_Z)
from LEP1, LEP2, SLD, and Tevatron:



	TGCs	
	h	δh
$h_{\tilde{W}}$	0.068	0.081
$h_{\tilde{W}B}$	0.033	0.084

		s^2_{eff}, Γ_Z, σ^0_{had}, R^0_ℓ, m_W, Γ_W, TGCs						
m_H		120 GeV	200 GeV	500 GeV	$\delta h \times 10^3$			
h_W	$\times 10^3$	-62.4	-62.5	-62.8	36.3	1	-0.007	0.008
h_{WB}	$\times 10^3$	-0.06	-0.22	-0.45	0.79		1	-0.88
$h_\varphi^{(3)}$	$\times 10^3$	-1.15	-1.86	-3.79	2.39			1

Selected processes at ILC and LHC

- $e^+e^- \to Z$ (Giga Z) highly sensitive to (P_Z):

$$h_{WB}, h_{\varphi}^{(3)}$$

- $e^+e^- \to W^+W^-$ sensitive to (P_W):

$$h_W,\ h_{WB},\ h_{\varphi}^{(3)},\ h_{\tilde{W}},\ h_{\tilde{W}B}$$

  (3 CP conserving, 2 CP violating)

- $\gamma\gamma \to W^+W^-$ sensitive to (P_W):

$$h_W,\ h_{WB},\ h_{\tilde{W}},\ h_{\tilde{W}B}, (s_1^2 h_{\varphi W} + c_1^2 h_{\varphi B}),\ (s_1^2 h_{\varphi \tilde{W}} + c_1^2 h_{\varphi \tilde{B}})$$

  (3 CP conserving, 3 CP violating)

- of these, only $\gamma\gamma$ process allows direct measurement of:

$$h_{\varphi WB} := s_1^2\, h_{\varphi W} + c_1^2\, h_{\varphi B}$$
$$h_{\varphi \tilde{W}\tilde{B}} := s_1^2\, h_{\varphi \tilde{W}} + c_1^2\, h_{\varphi \tilde{B}}$$

  where $s_1^2 \equiv \frac{e^2}{4\sqrt{2} G_F m_W^2}, \quad c_1^2 \equiv 1 - s_1^2$

- all processes together: 7 out of 10 indep. couplings observable

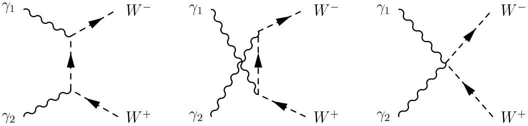
Feynman diagrams

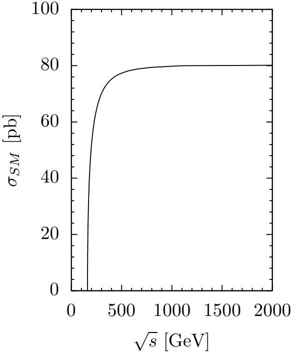
Consider

$$\gamma\gamma \to W^+W^- \to f\bar{f}\, f\bar{f}$$

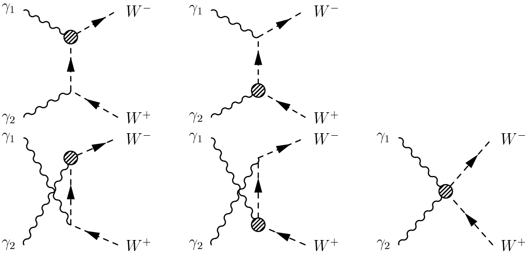
in narrow-width-approximation.

Production in SM:

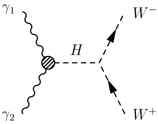




via anom. gauge couplings:



via anom. $\gamma\gamma H$ coupling:

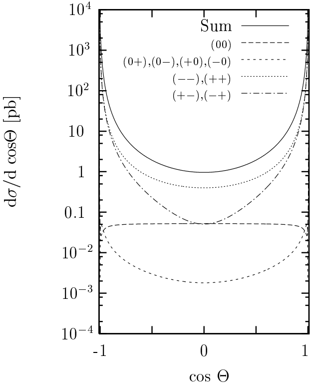


Disentanglement of anomalous contributions

- specific γ-enhancements for anom. amplitudes, *W* pol. dependent
- more information via angular distributions, e.g.:

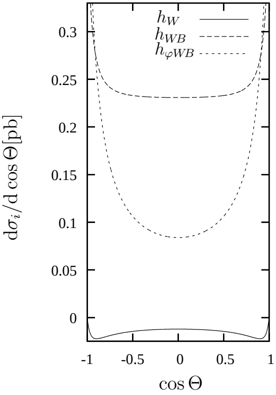
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\Theta} = \frac{\mathrm{d}\sigma_{SM}}{\mathrm{d}\cos\Theta} + \sum_i h_i \frac{\mathrm{d}\sigma_i}{\mathrm{d}\cos\Theta} + \mathcal{O}(h^2)$$

Standard Model:

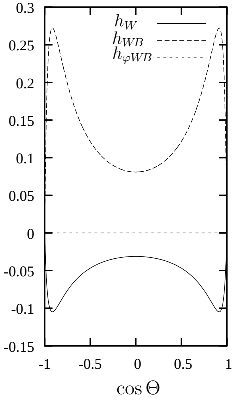


Anomalous CP even:

$(\lambda_3, \lambda_4) = (0, 0)$



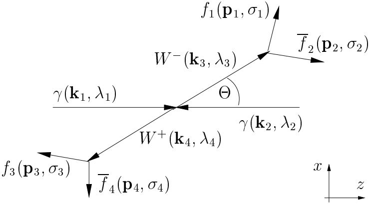
$(\lambda_3, \lambda_4) = (0, \pm), (\pm, 0)$



Optimal observables

How to measure anom. coupl. with best statistical accuracy ?

- full information: diff. cross section incl. *W* decays



- access via optimal observables *(Atwood & Soni, Davier et al., Diehl & Nachtmann)*
  - expand fully diff. cross section:

$$\frac{d\sigma}{d\phi} = S_0(\phi) + \sum_i h_i S_{1i}(\phi) + \mathcal{O}(h^2) \qquad \text{where} \quad \phi = \text{phase space variables}$$

  - statist. optimal observables for small h_i (wo/ rate info):

$$\mathcal{O}_i \equiv \frac{S_{1i}(\phi)}{S_0(\phi)}$$

- access to $\mathcal{O}(h)$ contrib. for all h_i (total cross section $\mathcal{O}(h^2)$ for CP odd)
- norm. distrib. $\Rightarrow$ lumi precision irrelevant for small h_i

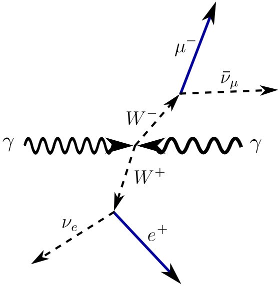
Choice of final states

- center-of-mass system not fixed in photon production
- loss of kinem. information $\Rightarrow$ treatable with opt. observ., but: lower sensitivies
- balance: signature, branching ratio, available information

type	signature	branching ratio	kinem. information
leptonic ($l = e, \mu$)	++	4/81	-
semi-leptonic ($l = e, \mu$)	+	24/81	+
hadronic	-	36/81	(++)

Leptonic final state:

- if CMS known: full reconstruction of final state
- if CMS unknown: no rec. possible



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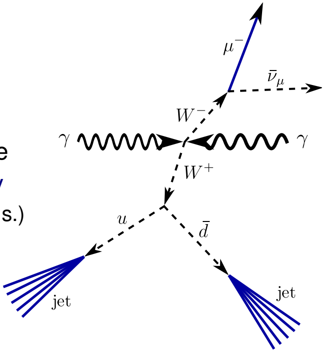
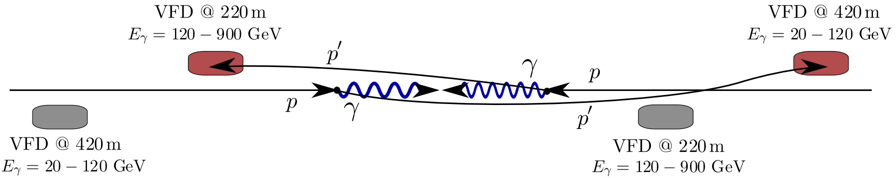
hadronic	-	36/81	(++)

Semi-leptonic final state:

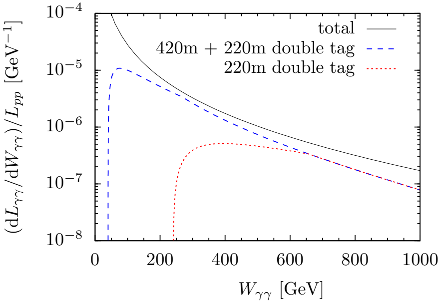
- if CMS known: full reconstruction of final state
- if CMS unknown: up to 4-fold discr. ambiguity
  - 2-fold ambiguity for neutrino energy (part of p.s.)
  - 2-fold ambiguity for jets if no q flavour ID



Elastic photon production at the LHC



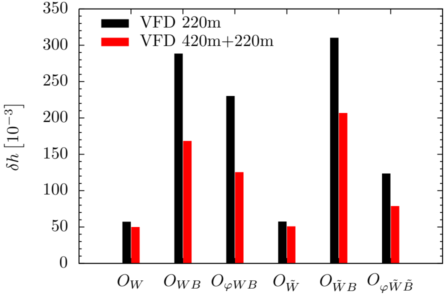
- almost real photons
  by elastic radiation off p
- tagging by very forward dectectors (VFD):
  120 GeV $\leq E_\gamma \leq$ 900 GeV (@220m)
  20 GeV $\leq E_\gamma \leq$ 900 GeV (@220m+420m)
- $\gamma\gamma$ CMS known via double tag
- $\mathrm{d}\sigma_{pp} \approx \mathrm{d}\sigma_{\gamma\gamma}\, \mathrm{d}N_1\, \mathrm{d}N_2$ (EPA)

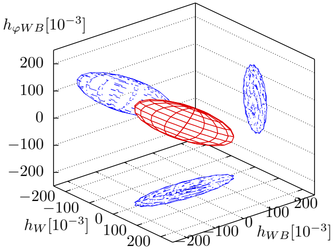


Results: Sensitivities at the LHC

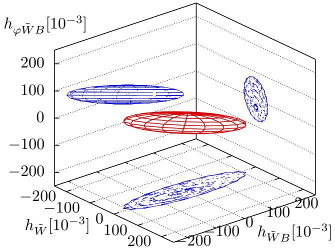
preliminary

- leptonic channels
- $\int L_{pp} = 30\ \text{fb}^{-1}$
- both charged leptons: $|\eta| \leq 2.5$, $p_T \geq 10$ GeV
- $m_{Higgs} = 120$ GeV
- CP even-odd corr. vanish





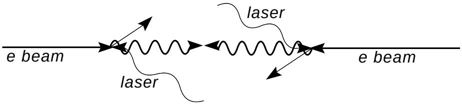
CP even (VFD 420m+220m)



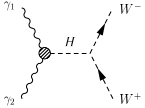
CP odd (VFD 420m+220m)

Photon collider at the ILC

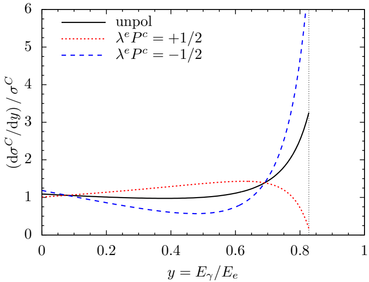
Photons via Compton backscattering of laser on *e* beam



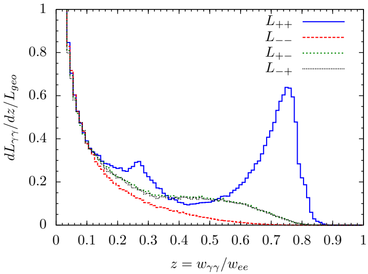
- high lumi for hard photons
- higher energies through polarisation
- $\gamma\gamma$ CMS statistically distrib.
- beyond LO: multiple scatt., nonlin., ...
- here: energy / polarisation distrib.
  helps to disentangle contrib.
  e.g. $|J_z| = 2$ "switches off" Higgs prod.



norm. single γ spectrum (LO):



norm. $\gamma\gamma$ luminosity spectrum (sim.):



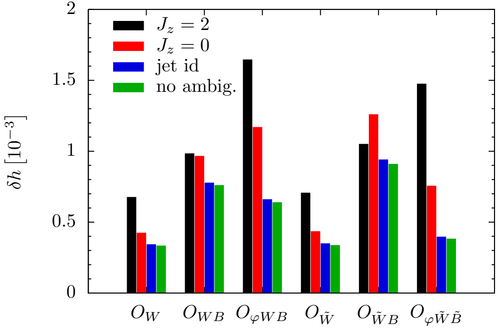
simulation by Telnov

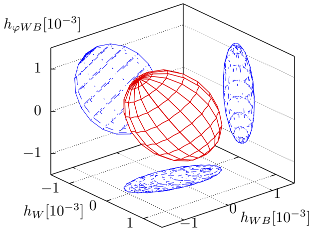
Results: Sensitivities at the ILC

semi-leptonic channels

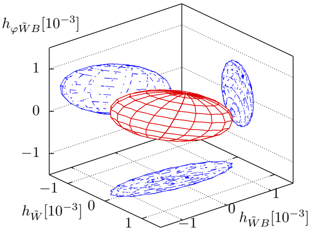
preliminary

- semi-leptonic, no jet id
  $\Rightarrow$ ambiguities (ν, jet)
- $\int L_{ee} = 500\ \text{fb}^{-1}$;
- $m_{Higgs} = 120$ GeV
- cuts on observed fermions:
  - energy ≥ 10 GeV
  - angle wrt. beam $\geq 10°$
  - angle betw. ferm. $\geq 25°$





CP even ($J_z = 0$)



CP odd ($J_z = 0$)

Comparison of sensitivities

preliminary

	present	LHC estimates	ILC estimates	
	LEP, SLD, Tevatron *(*)*	$\gamma\gamma \to WW$ elast., lept., $\int L = 30 fb^{-1}$	$ee \to WW$ *(*)* sl, $\int L = 500 fb^{-1}$	$\gamma\gamma \to WW$ sl, $J_z = 0$, $\int L = 500 fb^{-1}$
	h_i $[10^{-3}]$	δh_i $[10^{-3}]$	δh_i $[10^{-3}]$	δh_i $[10^{-3}]$

measurable CP conserving couplings:

h_W	-69 ± 39	50	0.3	0.4
h_{WB}	-0.06 ± 0.79	170	0.3	1.0
$h_{\varphi WB}$	$\times$	130	$\times$	1.2
$h_\varphi^{(3)}$	-1.15 ± 2.39	$\times$	36	$\times$

measurable CP violating couplings:

$h_{\tilde{W}}$	68 ± 81	50	0.3	0.4
$h_{\tilde{W}B}$	33 ± 84	210	2.2	1.3
$h_{\varphi\tilde{W}\tilde{B}}$	$\times$	80	$\times$	0.8

(*) Nachtmann, Nagel, Pospischil

- $h_\varphi^{(1)}, h'_{\varphi WB}, h'_{\varphi\tilde{W}\tilde{B}}$: unaccessible by above methods
- $h_{WB}, h_\varphi^{(3)}$: best measured at Giga-Z
- contrast to $U(1)_{\rm em}$ schemes: *Piotrzkowski e.a., Royon e.a. (2009)*: LHC improves LEP bounds up to factors $\mathcal{O}(10^3)$ (!)

Summary

Gauge symmetric effective Lagrangian approach:

- generic NP parametrisation
- robust effective description up to possibly large E
- 10 anomalous gauge / gauge-Higgs couplings (6 CP cons., 4 CP viol.)
- LEP, SLD & Tevatron restrict 5 of them
- substantial improvements by $ee \to WW$, Giga-Z at ILC

Normalised distributions for $\gamma\gamma \to WW$:

- access to 2 new anom. Higgs couplings (not in $ee \to WW$)
- allows important cross checks with ee data
- LHC (elastic γ production): $\delta h \approx \mathcal{O}(10^{-1})$
- ILC (photon collider mode): $\delta h \approx \mathcal{O}(10^{-3})$

Supplementary Slides

6. Optimal observables in some more detail
7. Previous work on anom. coupl. in $\gamma\gamma \longrightarrow$ *WW*
8. Energy dependencies of anomalous contributions
9. Sensitivities at the LHC for semi-leptonic channel

Optimal observables

Atwood & Soni, Davier et al., Diehl & Nachtmann

How to measure anom. coupl. with best statistical accuracy ? $\Rightarrow$ optimal observables

- expand diff. cross section:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\phi} = S_0(\phi) + \sum_i h_i S_{1i}(\phi) + \mathcal{O}(h^2) \qquad \text{where} \qquad \begin{aligned} h_i &= \text{anomalous couplings} \\ \phi &= \text{phase space variables} \end{aligned}$$

- statist. optimal observables for small h_i (wo/ rate info):

$$\mathcal{O}_i \equiv \frac{S_{1i}(\phi)}{S_0(\phi)}$$

- measure ϕ_k for each event $k = 1, \ldots, N$, evaluate:

$$\bar{\mathcal{O}}_i = \frac{1}{N} \sum_k \mathcal{O}_i(\phi_k)$$

and calculate $c_{ij} \equiv \left\langle \, (\mathcal{O}_i - \langle \mathcal{O}_i \rangle_0) \, (\mathcal{O}_j - \langle \mathcal{O}_j \rangle_0) \, \right\rangle_0$ with $\langle \circ \rangle_0 = \frac{\int \mathrm{d}\phi S_0(\phi) \circ}{\int \mathrm{d}\phi S_0(\phi)}$
to get estimate of couplings

$$h_i = \sum_j c_{ij}^{-1} \, (\bar{\mathcal{O}}_j - \langle \mathcal{O} \rangle_0)$$

- covariance matrix for h_i computable without data

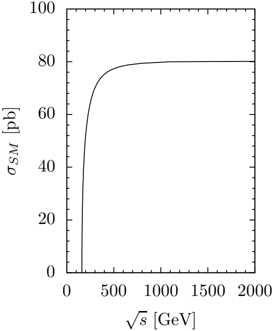
$$V(h) = \frac{1}{N} c_{ij}^{-1}$$

Previous work

- anomalous couplings in $\gamma\gamma \to WW$ at PC and LHC: e.g. (incomplete)
  Tupper, Samuel (1981),
  Choi, Schrempp (1991),
  Yehudai (1991),
  Bélanger, Boudjema (1992),
  Herrero, Ruiz-Morales (1992),
  Bélanger, Couture (1994),
  Choi, Hagiwara, Baek (1996),
  Baillargeon, Bélanger, Boudjema (1997),
  Piotrzkowski (2001),
  Božović-Jelisavčić, Mönig, Šekarić (2002),
  Éboli, Gonzalez-Garcia, Lietti (2003),
  Bredenstein, Dittmaier, Roth (2004),
  Mönig, Šekarić (2005),
  Nachtmann, Nagel, Pospischil, Utermann (2005),
  Kepka, Royon (2008),
  Englert, Jäger, Worek, Zeppenfeld (2008),
  de Favereau de Jeneret, Lemaître, Liu, Ovyn, Pierzchała, Piotrzkowski, Rouby, Schul, Vander Donckt (2009), . . .
- here:
  - gauge invariant scheme
  - simultan. measurement of all 6 gauge-Higgs couplings at LHC and ILC

Total cross section and energy dependencies

Standard Model:



High energy dependence of leading amplitudes:

$\mathcal{M}_i$	CP even				CP odd		
	SM	W	φW	WB	$\tilde{W}$	$\varphi\tilde{W}$	$\tilde{W}B$
LL	$1^{(*)}$	γ^{-2}	1	$\gamma^{2\,(\dagger)}$	γ^{-2}	1	$\gamma^{2\,(\dagger)}$
TL	γ^{-1}	γ^{-1}	0	γ	γ^{-1}	0	γ
TT	1	1	γ^{-2}	1	1	γ^{-2}	1

where $\gamma := \sqrt{s_{\gamma\gamma}}/(2m_W)$,
$(*)$: for $(\lambda_1 = -\lambda_2)$,
$(\dagger)$: for $(\lambda_1 = \lambda_2)$,

- up to γ^2 enhancements for anomalous amplitudes
- CP odd only at quadratic order

Results: Sensitivities at the LHC

preliminary

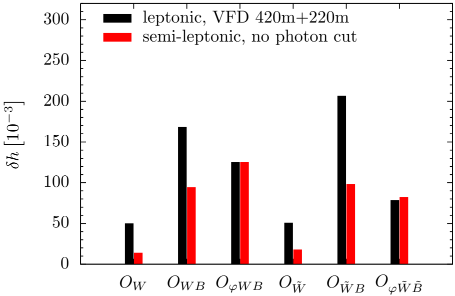
elastic spectrum, comparison of channels

- semi-leptonic measurements more difficult (background)
- but:
  - VFD tagging not crucial for reconstruction of final state
  - gain color factor 3 in event rate
- interesting (at low lumi) ?

$\int L_{pp} = 30 \text{ fb}^{-1}$;

accept. events =
73 lept. (VFD 420m+220m),
421 semi-lept. (no photon cut);

jet cuts as for $l^{\pm}$



But this means for $\int L_{pp} = 1 \text{ fb}^{-1}$:

- only 14 semi-lept. events
- sensitiv. worse by factor of 5.5 wrt. fig.