Triple Gauge Couplings at TESLA

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- TGC's at 500 GeV
- TGC's at 800 GeV
- Polarised Electrons/Positrons

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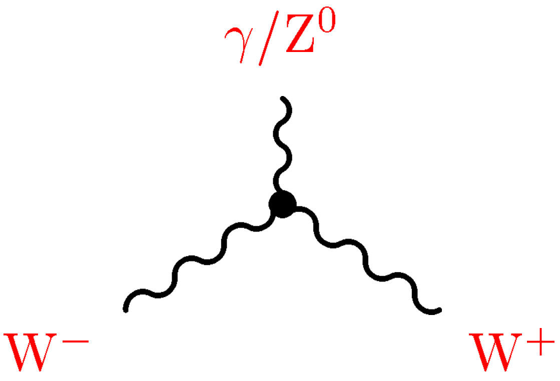
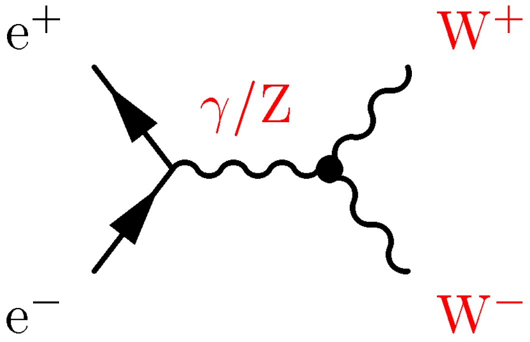
Motivation



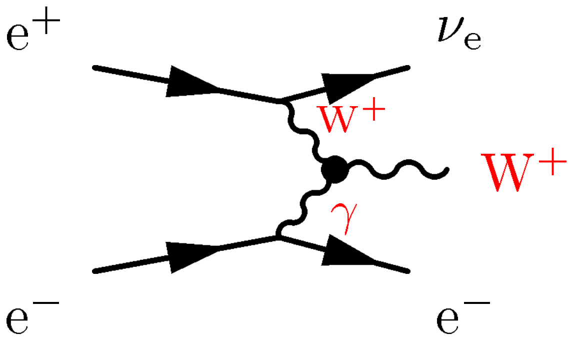
- check Standard Model (couplings are fixed by gauge structure)
- searching for new physics from SUSY, extra bosons, extra fermion, ... (loop effects)

Processes with Triple Gauge Couplings

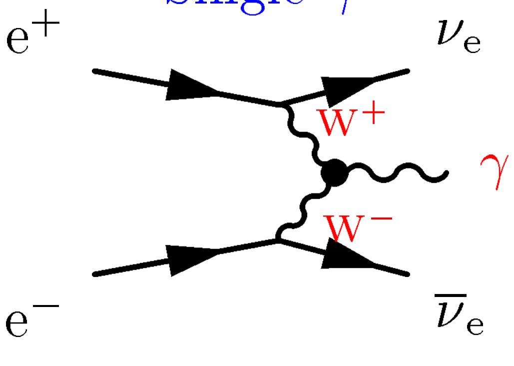
W-pair



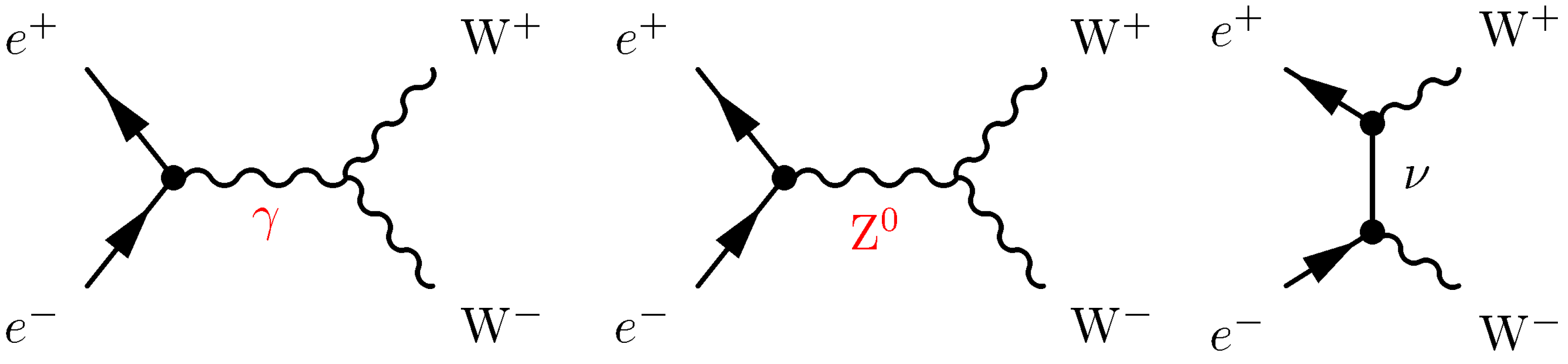
Single W



Single γ



Theory



W-pair production (CC03 diagramms)

$$\frac{\mathcal{L}^{WWV}}{g_{WWV}} =$$

$$i g_1^V V^\mu \left(W^-_{\mu\nu} W^{+\nu} - W^+_{\mu\nu} W^{-\nu} \right) + i \kappa_V W^-_\mu W^+_\nu V^{\mu\nu} + i \frac{\lambda_V}{M_{\mathrm{W}}^2} V^{\mu\nu} W^{+\rho}_\mu W^-_{\rho\nu}$$

$$+ g_5^V \varepsilon^{\mu\nu\rho\sigma} \left[(\partial^\rho W^-_\mu) W^+_\nu - W^-_\mu (\partial^\rho W^+_\nu) \right] V_\sigma$$

$$- g_4^V W^-_\mu W^+_\nu (\partial^\mu V^\nu + \partial^\nu V^\mu) + i \left[\frac{\tilde{\kappa}_V}{2} W^-_\mu W^+_\nu \varepsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} + \frac{\tilde{\lambda}_V}{2 M_{\mathrm{W}}^2} W^-_{\rho\mu} W^{+\mu}{}_\nu \varepsilon^{\nu\rho\alpha\beta} V_{\alpha\beta} \right]$$

Properties of the Couplings

14 couplings in total (7 WWγ, 7 WWZ)

$\Rightarrow$ std. couplings: (C, P, CP conserving)

$g_1^\gamma,\ g_1^Z,\ \kappa_\gamma,\ \kappa_Z,\ \lambda_\gamma,\ \lambda_Z$ 6

el. mag. gauge invariance:

$g_1^Z,\ \kappa_\gamma,\ \kappa_Z,\ \lambda_\gamma,\ \lambda_Z$ 5

$SU(2) \times U(1)_Y$ gauge invariance:

$g_1^Z,\ \kappa_\gamma,\ \lambda_\gamma$ 3

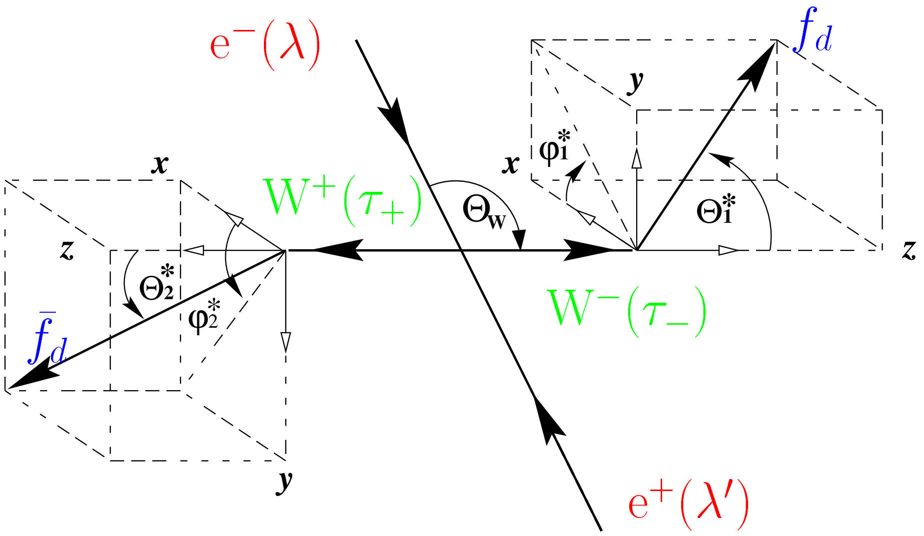
$\Rightarrow$ non std. couplings:

	g_4^V	g_5^V	$\tilde{\kappa}_V$	$\tilde{\lambda}_V$
C	$-$	$-$	$\surd$	$\surd$
P	$\surd$	$-$	$-$	$-$
CP	$-$	$\surd$	$-$	$-$

- only WWZ-couplings 4
- limits for WWγ-couplings from other processes

WW Event

Definition of angles:



Good Channel:

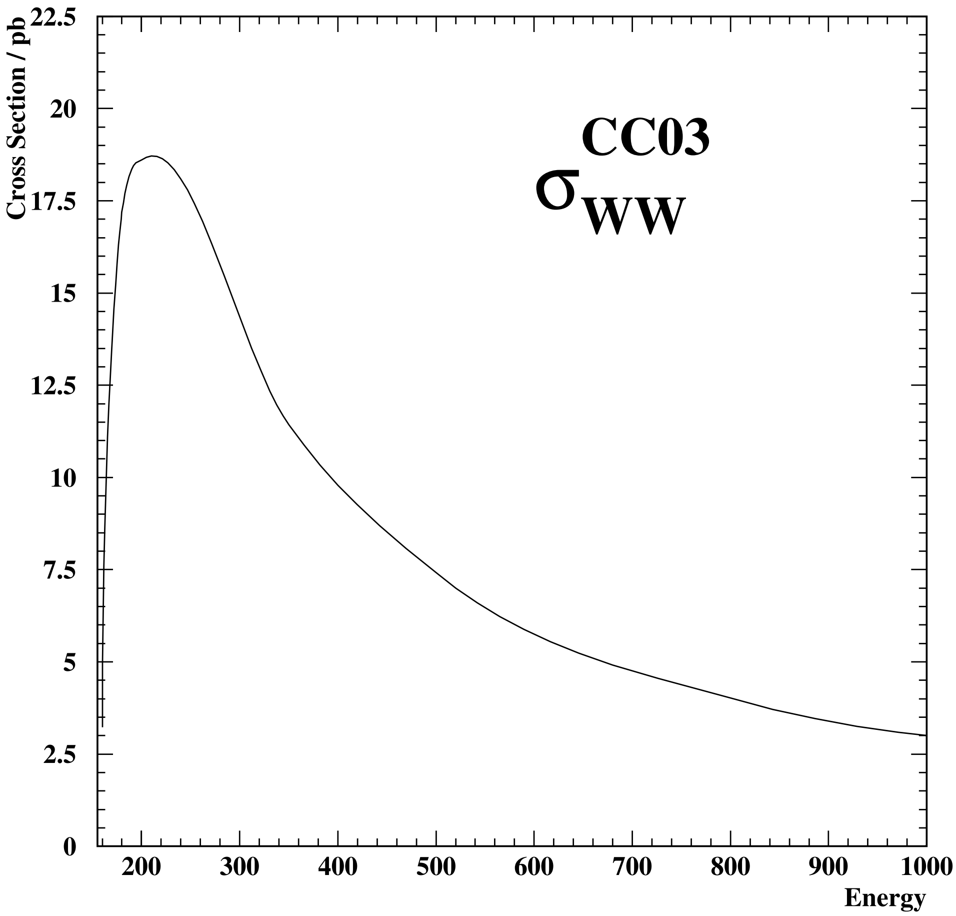
- $q\overline{q}l\bar{\nu}_l$ events (BR = 0.434, best reconstruction)

Observables:

- $\cos\theta_W$
- decay angles $\cos\theta_l^*, \phi_l^*$, $\cos\theta_j^*, \phi_j^*$

$\Rightarrow$ spin density matrix
(using projection operators)

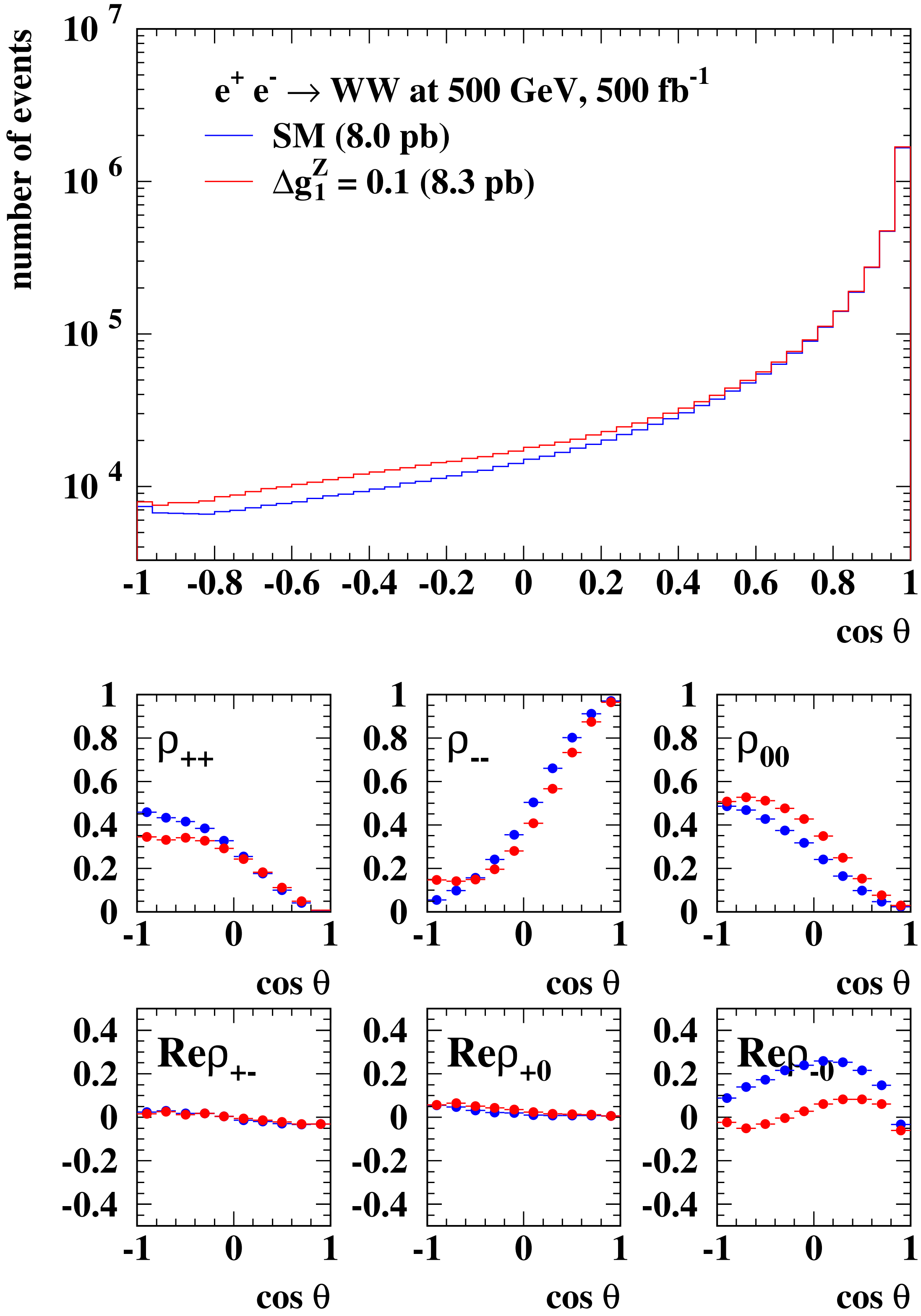
WW Cross Section



Data Sets

350 GeV	$\approx$ 11.5 pb		
500 GeV	$\approx$ 7.5 pb	500 fb^{-1}	3.75 Mevents
800 GeV	$\approx$ 4.0 pb	1000 fb^{-1}	4 Mevents
1000 GeV	$\approx$ 3.0 pb		

Observables at 500 GeV



Fit

Generator: Wopper 1.5

- W-pair generator CC03/CC11
- including ISR
- including Beamstrahlung (CIRCE)

Detector Simulation: Simdet

- no update on detector effects
- old studie from S. Petzold and C. Burgard
- detector effects are small

	$\Delta\kappa_\gamma$
generator level	3.52×10^{-4}
measured level	3.54×10^{-4}
kinematic fit	3.55×10^{-4}

Fitting procedure:

- χ^2 fit with MC reweighting
- using $\cos\theta$, spin density matrix and cross section
- includes detector effects (no yet done)
- good for 1d, 2d, 3d, ... fits

Results

1 σ errors (10^{-4}) for 1d fits

statistical error only!

	500 GeV 500 fb^{-1}	800 GeV 1000 fb^{-1}
Δg_1^Z	7.3	4.5
$\Delta\kappa_\gamma$	5.7	3.1
λ_γ	6.1	2.9
Δg_1^Z	38.1	39.0
$\Delta\kappa_\gamma$	4.8	2.6
λ_γ	12.1	5.2
$\Delta\kappa_Z$	8.7	4.9
λ_Z	11.5	5.1
g_5^Z	28	29
g_4^Z	86	42
$\tilde{\kappa}_Z$	65	23
$\tilde{\lambda}_Z$	11	5

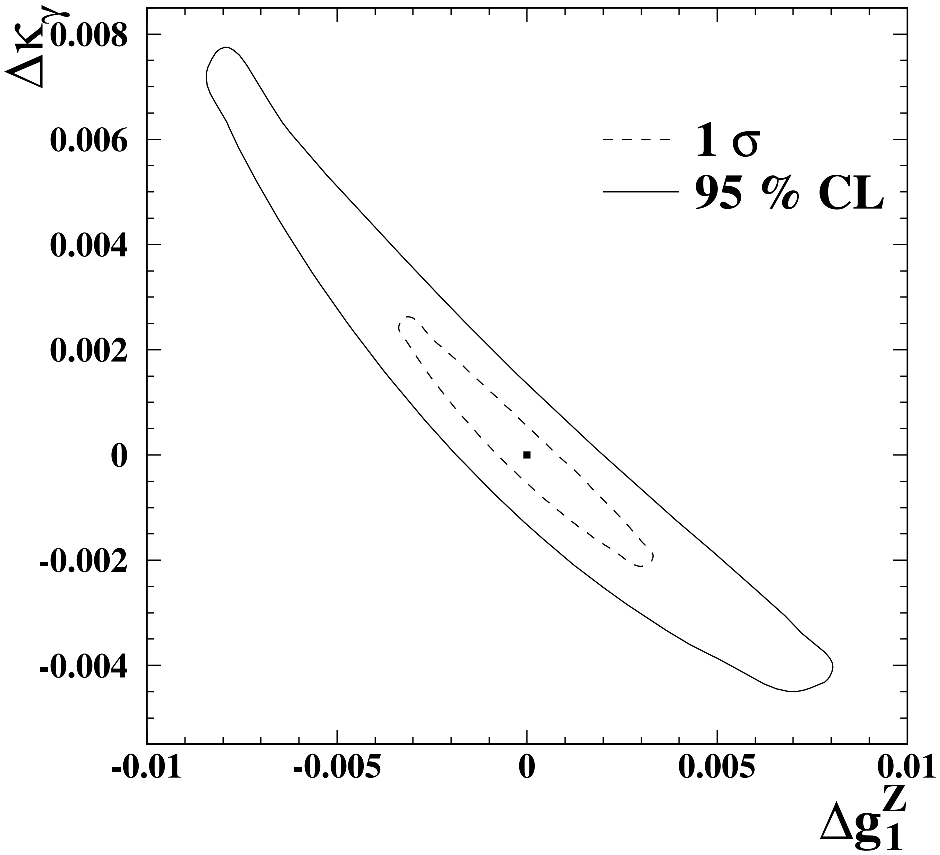
CP conserving couplings

$500\,\mathrm{GeV},\ 500\,\mathrm{fb}^{-1}$

	$1d$	$3d$	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
Δg_1^Z	7.3	34.0	1.000	-0.969	-0.253
$\Delta\kappa_\gamma$	5.7	22.9		1.000	0.173
λ_γ	6.1	6.6			1.000

$800\,\mathrm{GeV},\ 1000\,\mathrm{fb}^{-1}$

	$1d$	$3d$	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
Δg_1^Z	4.5	34.2	1.000	-0.987	-0.223
$\Delta\kappa_\gamma$	3.1	18.4		1.000	0.198
λ_γ	2.9	3.0			1.000



CP violating Couplings

	g_4^Z	g_5^Z	$\tilde{\kappa}_Z$	$\tilde{\lambda}_Z$
C	$-$	$-$	$\surd$	$\surd$
P	$\surd$	$-$	$-$	$-$
CP	$-$	$\surd$	$-$	$-$

expected errors (10^{-4}) for 1d/4d fits

$500\,\mathrm{GeV},\ 500\,\mathrm{fb}^{-1}$

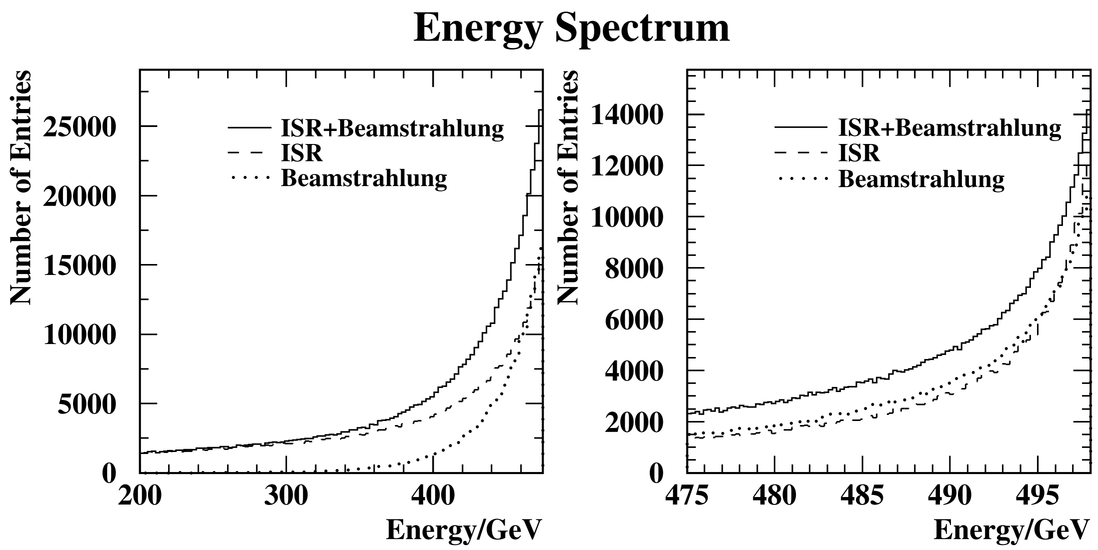
	1d	4d	g_4^Z	g_5^Z	$\tilde{\kappa}_Z$	$\tilde{\lambda}_Z$
g_4^Z	86	88	1.00	-0.03	$+0.28$	-0.05
g_5^Z	28	28		1.00	$+0.00$	$+0.01$
$\tilde{\kappa}_Z$	65	75			1.00	$+0.44$
$\tilde{\lambda}_Z$	12	13				1.00

$800\,\mathrm{GeV},\ 1000\,\mathrm{fb}^{-1}$

	1d	4d	g_4^Z	g_5^Z	$\tilde{\kappa}_Z$	$\tilde{\lambda}_Z$
g_4^Z	42	41	1.00	-0.01	$+0.14$	-0.02
g_5^Z	29	28		1.00	-0.04	$+0.02$
$\tilde{\kappa}_Z$	30	35			1.00	$+0.53$
$\tilde{\lambda}_Z$	5	6				1.00

$\Rightarrow$ Couplings with different transformation properties under C, P and CP decouple.

First Estimate of ISR & Beamstrahlung Systematics



very simple test:

- switch off ISR in "data", leave reweighting MC unchanged
- switch off Beamstrahlung in "data", leave reweighting MC unchanged

ISR:

- 500 GeV: biases of $\mathcal{O}(100 * stat.error)$
- 800 GeV: biases of $\mathcal{O}(100 * stat.error)$

$\Rightarrow$ need to understand to order of 1 %

Beamstrahlung:

- 500 GeV: biases of $\mathcal{O}(10 * stat.error)$
- 800 GeV: biases of $\mathcal{O}(10 * stat.error)$

$\Rightarrow$ need to understand to better than 10 %

Systematics
M_W & Beam Energy

- change M_W by $\pm 50\,\mathrm{MeV}$ in "data", leave reweighting MC unchanged
- change E_{beam} by $\pm 1 \times 10^{-4} E_{beam}$ in "data", leave reweighting MC unchanged
- systematic error in percent of statistical error

systematic error from M_W

	CP(3)	CP(5)	$\cancel{CP}$
500 GeV	30 %	40 %,	25 %
800 GeV	35 %	35 %,	20 %

systematic error from E_{beam}

	CP(3)	CP(5)	$\cancel{CP}$
500 GeV	20 %	20 %,	10 %
800 GeV	10 %	10 %,	10 %

$\Rightarrow$ Systematics due to M_W and E_{beam} are small!

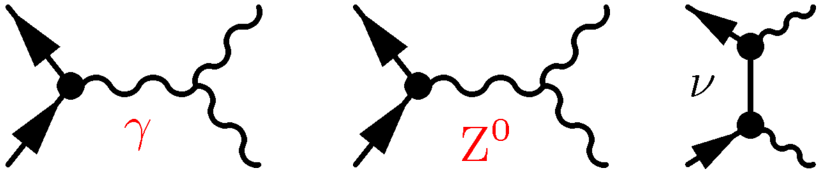
Polarisation

Polarised electrons and positrons helps

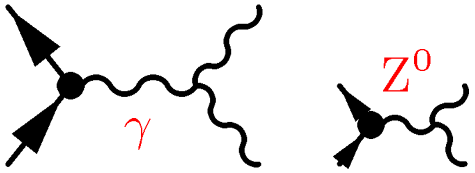
- to switch off the t-channel ν exchange
- to disentangle the WWZ- and WWγ-vertex

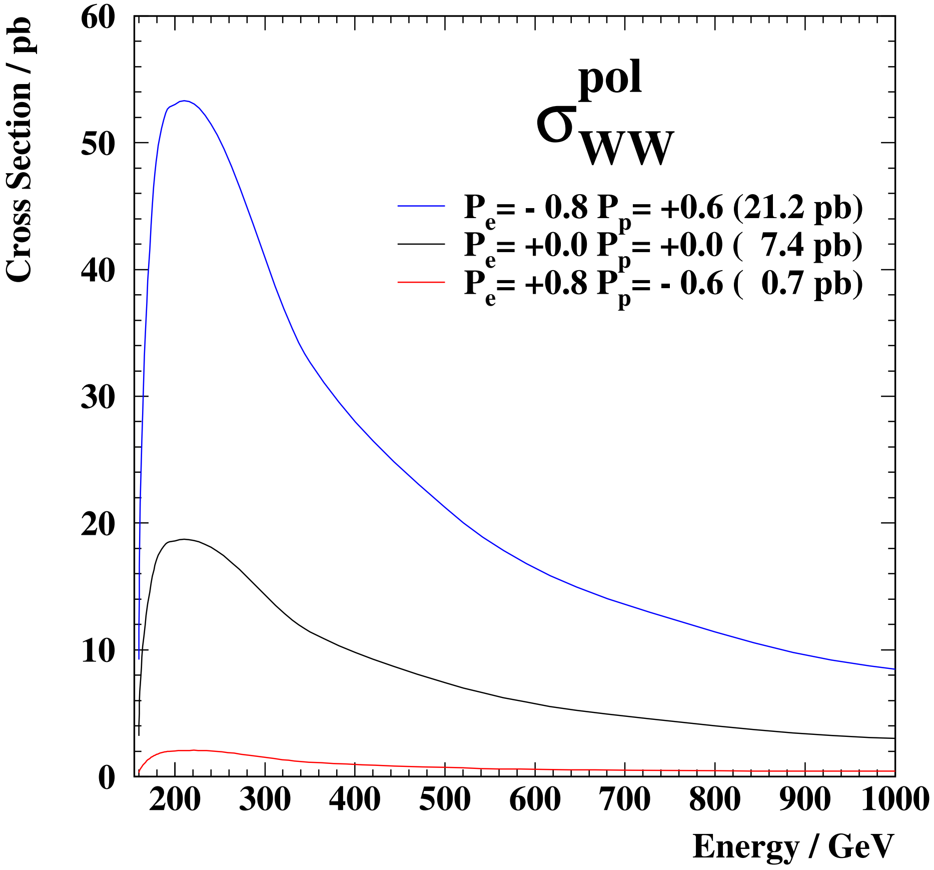
Idea

LR



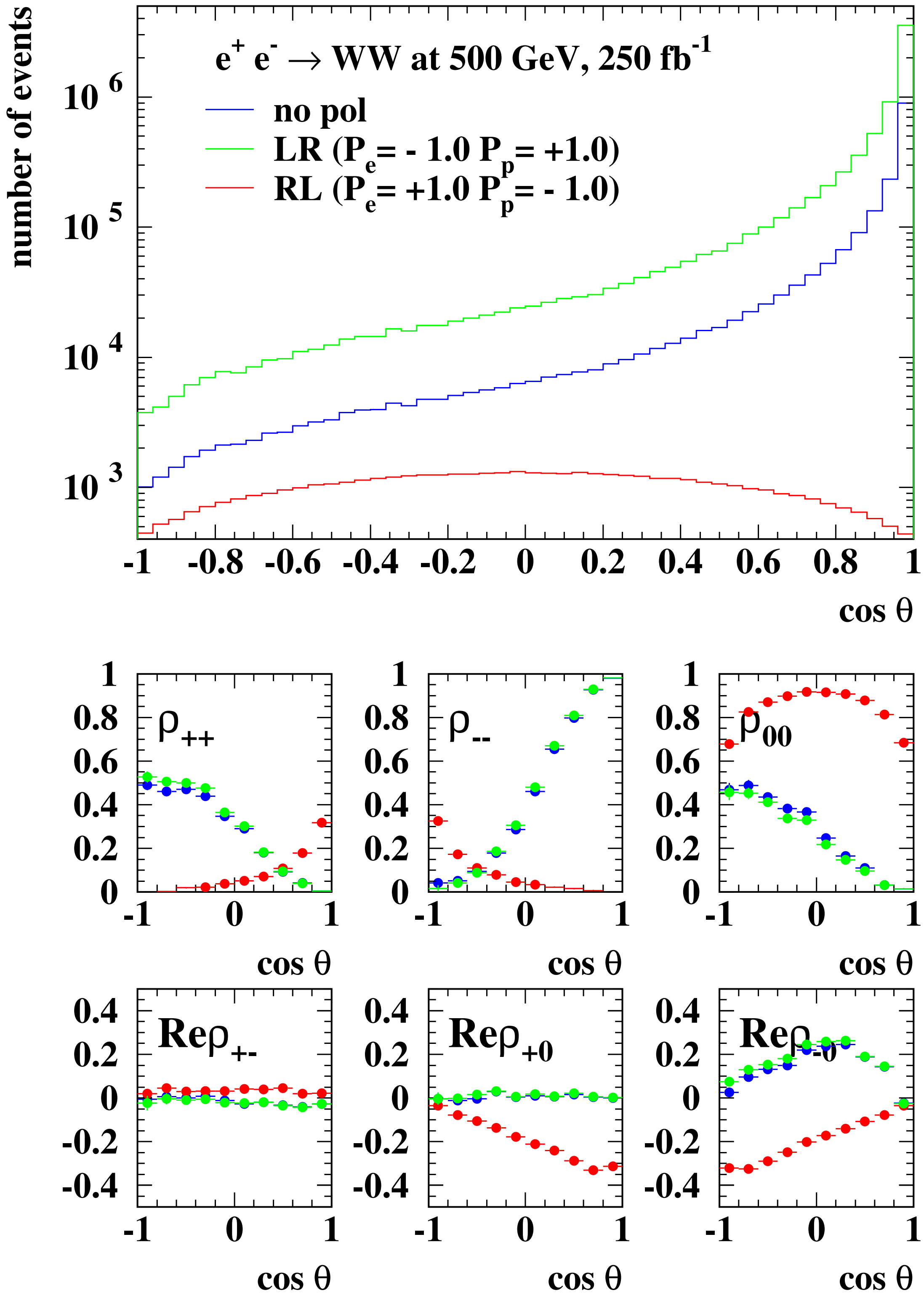
RL





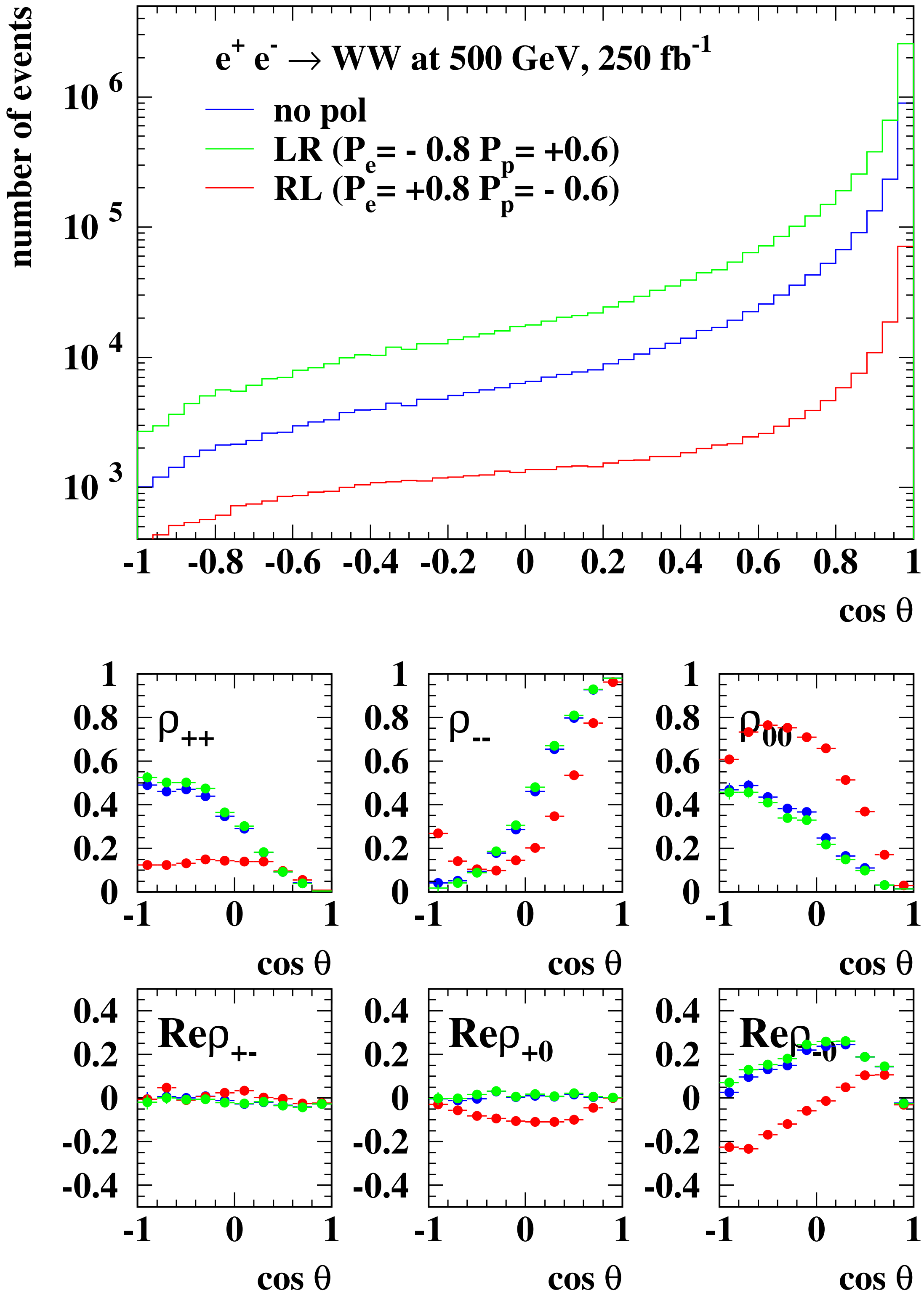
Observables for Ideal Polarisation

Standard Modell



Observables for Real Polarisation

Standard Modell



Results

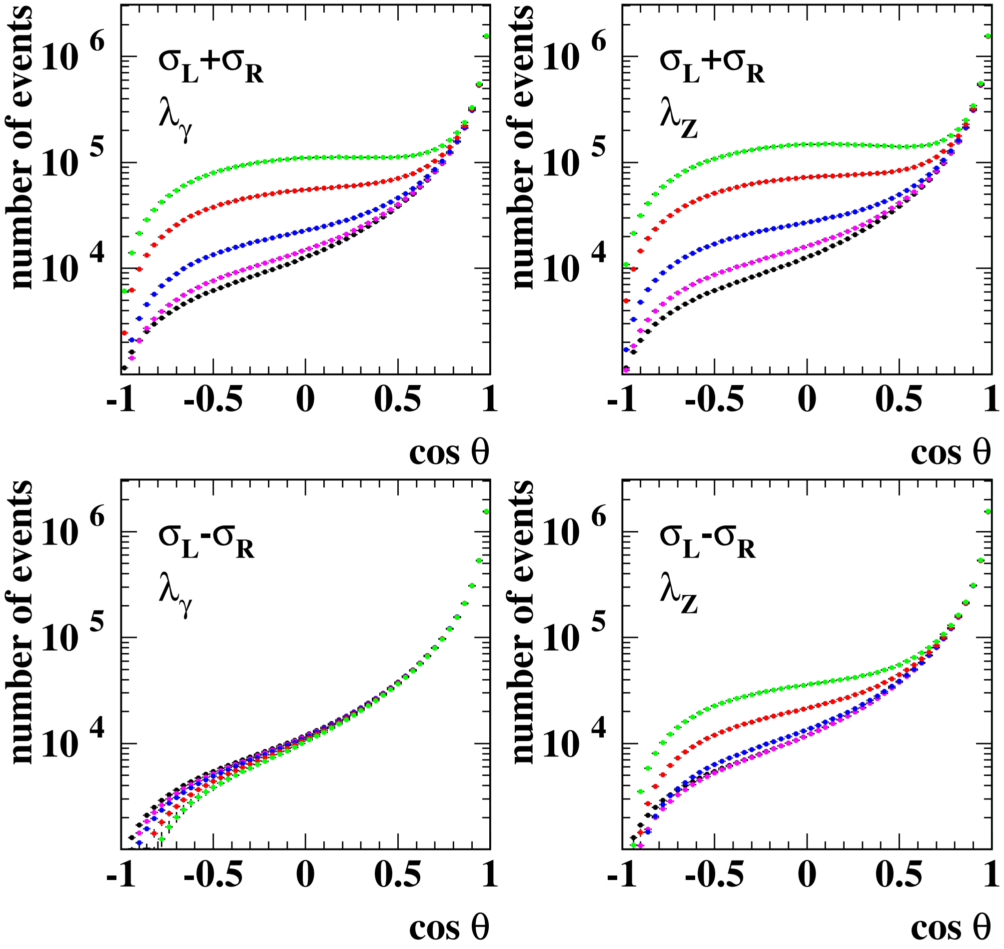
- **1 σ errors (10^{-4}) for 1d fits**
- **Energy**: 500 GeV
- **Polarisation**: LR ($P_{e^-} = -0.8, P_{e^+} = +0.6$)
  RL ($P_{e^-} = +0.8, P_{e^+} = -0.6$)

	no pol. 500 fb^{-1}	RL 250 fb^{-1}	LR 250 fb^{-1}	RL+LR 250 + 250 fb^{-1}
Δg_1^Z	7.3	4.0	3.7	2.8
$\Delta\kappa_\gamma$	5.7	3.4	7.9	3.1
λ_γ	6.1	32.6	4.4	4.3
Δg_1^Z	38.1	20.3	21.0	15.5
$\Delta\kappa_\gamma$	4.8	4.3	5.2	3.3
λ_γ	12.1	11.4	9.6	5.9
$\Delta\kappa_Z$	8.7	4.7	4.4	3.2
λ_Z	11.5	14.1	7.9	6.7

WWγ- versus WWZ-couplings

for illustration: $P_{e^-} = \pm 1.0$

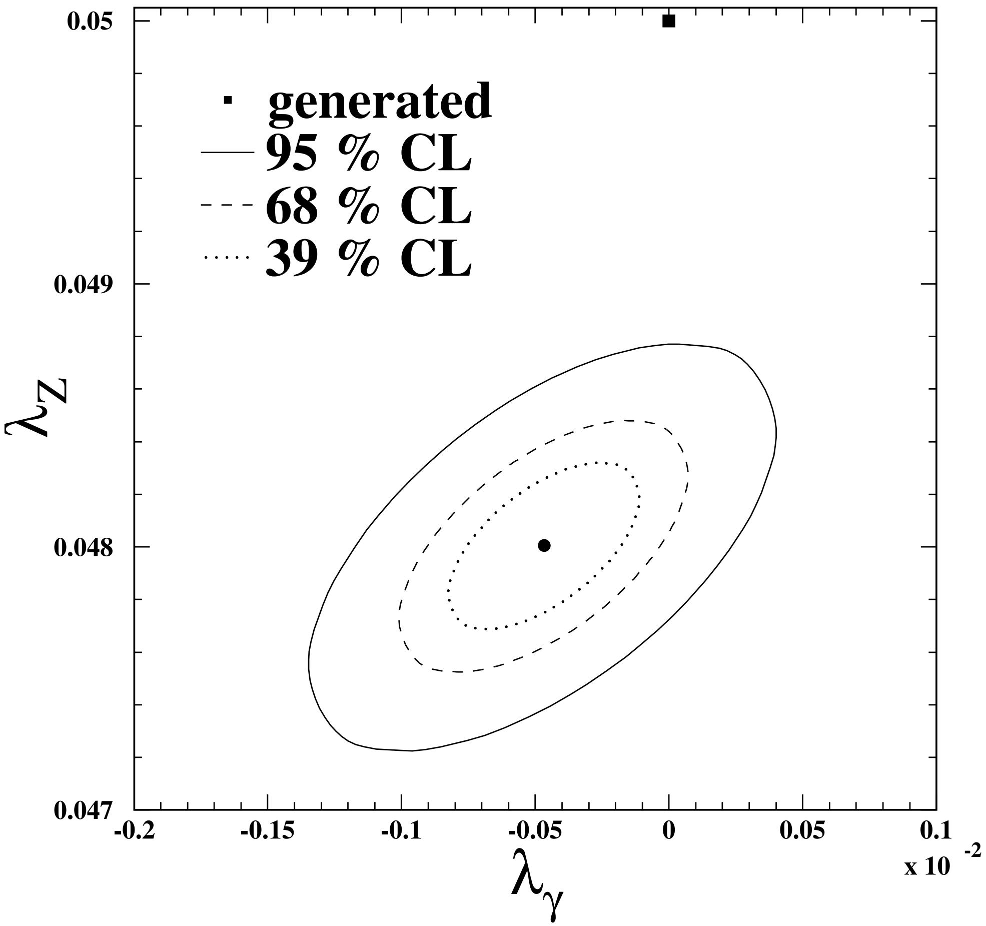
$\lambda_\gamma/\lambda_Z = 0.0,\ 0.05,\ 0.1,\ 0.2,\ 0.3$



real case

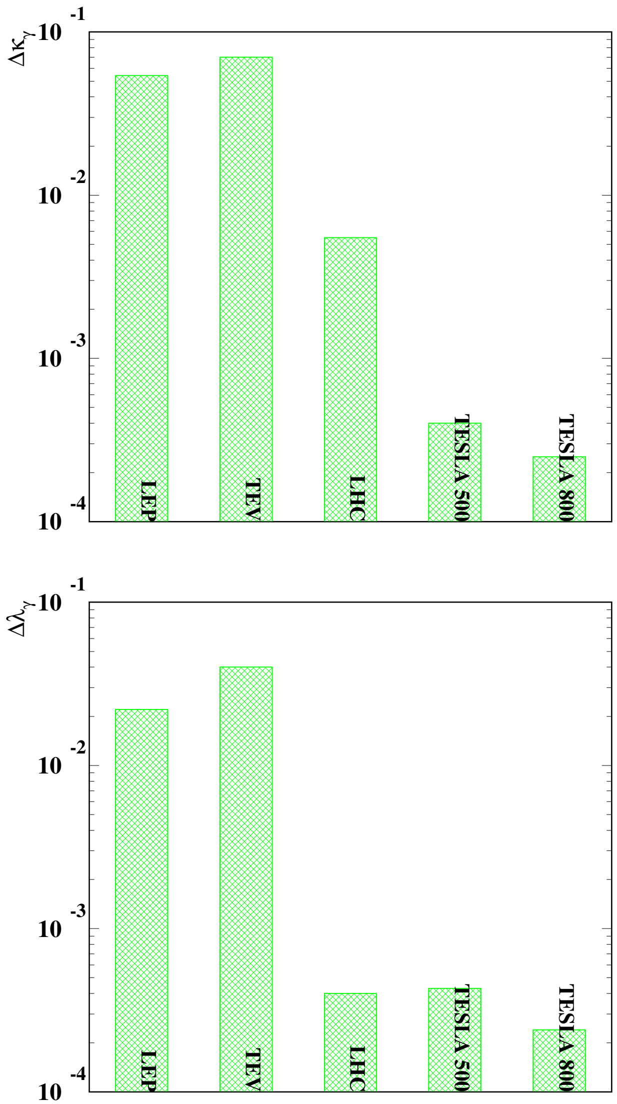
$P_{e^-} = +0.8, P_{e^+} = -0.6, 250\,\mathrm{fb}^{-1}$

$P_{e^-} = -0.8, P_{e^+} = +0.6, 250\,\mathrm{fb}^{-1}$



Comparison

- exp. error of std. couplings in order of 10^{-4}
- exp. error of CP violating couplings in order of 10^{-3}
- polarisation improves results
- polarisation will disentangle WWγ-WWZ couplings
- systematics look okay!



	LEP limits (ICHEP 2000)			TESLA 500	TESLA 800
Δg_1^Z	-0.025	+0.026	-0.026	$\pm$ 0.00073	$\pm$ 0.00045
$\Delta\kappa_\gamma$	-0.002	+0.067	-0.065	$\pm$ 0.00057	$\pm$ 0.00031
λ_γ	-0.036	+0.028	-0.027	$\pm$ 0.00061	$\pm$ 0.00029
g_5^Z	+0.05	+0.16	-0.17	$\pm$ 0.0028	$\pm$ 0.0029

Outlook

some work has still to be done:

- further studies on polarisation
- detector simulation
  (previous studies showed no problems)
- selection efficiencies
  (LEP: 80 – 90 %)
- ...