Triple Gauge Couplings in W-pair production @ TESLA

5/3/99
Sitges

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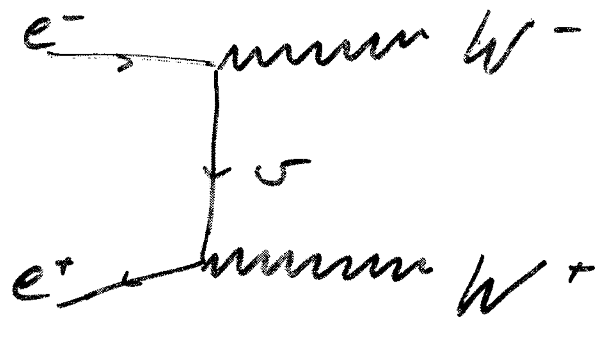
W-pair production



expect 500 fb^{-1} @ 500 GeV

↳ $4 \cdot 10^6$ WW events

WW → qqlν only ⟶ $2 \cdot 10^6$ events
(best reconstruction of the events)

basic "event selection"

force to 2 jets
1 lepton + missing p, E
→ reconstruction using $E = \sqrt{s}$
$\vec{p} = 0$

GC parameters

ost general Lorentz-invariant Lagrangian for $WWZ/WW\gamma$ $(V = Z, \gamma)$

$$= (-i)\, g_{WWV} \Big(g_1^V V^\mu \left(W^-_{\mu\nu} W^{+\nu} - W^+_{\mu\nu} W^{-\nu} \right) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} V^{\mu\nu} W^{+\rho}_\nu W^-_{\rho\mu} \Big) \qquad CP$$

$$+ g_{WWV}\, g_5^V \epsilon_{\mu\nu\rho\sigma} \left((\partial^\rho W^{-\mu}) W^{+\nu} - W^{-\mu} (\partial^\rho W^{+\nu}) \right) V^\sigma \qquad \not{C},\ CP$$

$$+ g_{WWV}\, g_4^V W^-_\mu W^+_\nu \left(\partial^\mu V^\nu + \partial^\nu V^\mu \right) \qquad \not{C},\ \not{CP}$$

$$+ i\, g_{WWV} \left(\tilde{\kappa}_V W^-_\mu W^+_\nu \epsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} + \frac{\tilde{\lambda}_V}{2 m_W^2} W^-_{\rho\mu} W^{+\mu}_\nu \epsilon^{\nu\rho\alpha\beta} V_{\alpha\beta} \right) \qquad \not{P},\ \not{CP}$$

oupling parameters are related to

charge	$q_W = e g_1^\gamma$	CP
magnetic dipole moment	$\mu_W = \frac{e}{2m_W}(g_1^\gamma + \kappa_\gamma + \lambda_\gamma)$	CP
electric quadrupole moment	$Q_W^e = -\frac{e}{m_W^2}(\kappa_\gamma - \lambda_\gamma)$	CP
electric dipole moment	$d_W = \frac{e}{2m_W}(\tilde{\kappa}_\gamma + \tilde{\lambda}_\gamma)$	$\not{CP}$
magnetic quadrupole moment	$Q_W^m = -\frac{e}{m_W^2}(\tilde{\kappa}_\gamma - \tilde{\lambda}_\gamma)$	$\not{CP}$

Experimentally

- Use information from 5 angles

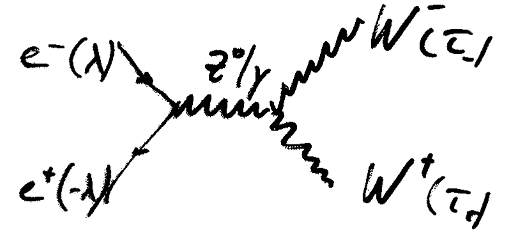
$\cos\Theta_{W^-}$ — W^- production angle

$\cos\Theta^*_\ell$, ϕ^*_ℓ — leptonic decay angles

$\cos\Theta^*_h$, ϕ^*_h — hadronic decay angles

→ information on polarisation of W

- Use reweighting fit to $\cos\Theta_W$ and spin density matrix elements to include experimental effects spin density matrix elements:

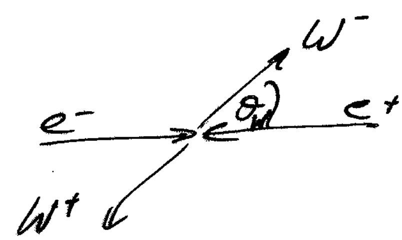


$$\rho_{\tau_-\tau_-'\tau_+\tau_+'} = \frac{\sum_\lambda F^{(\lambda)}_{\tau_-\tau_+} \left(F^{(\lambda)}_{\tau_-'\tau_+'}\right)^*}{\sum_{\lambda,\tau_+,\tau_-} \left|F^{(\lambda)}_{\tau_-\tau_+}\right|^2}$$

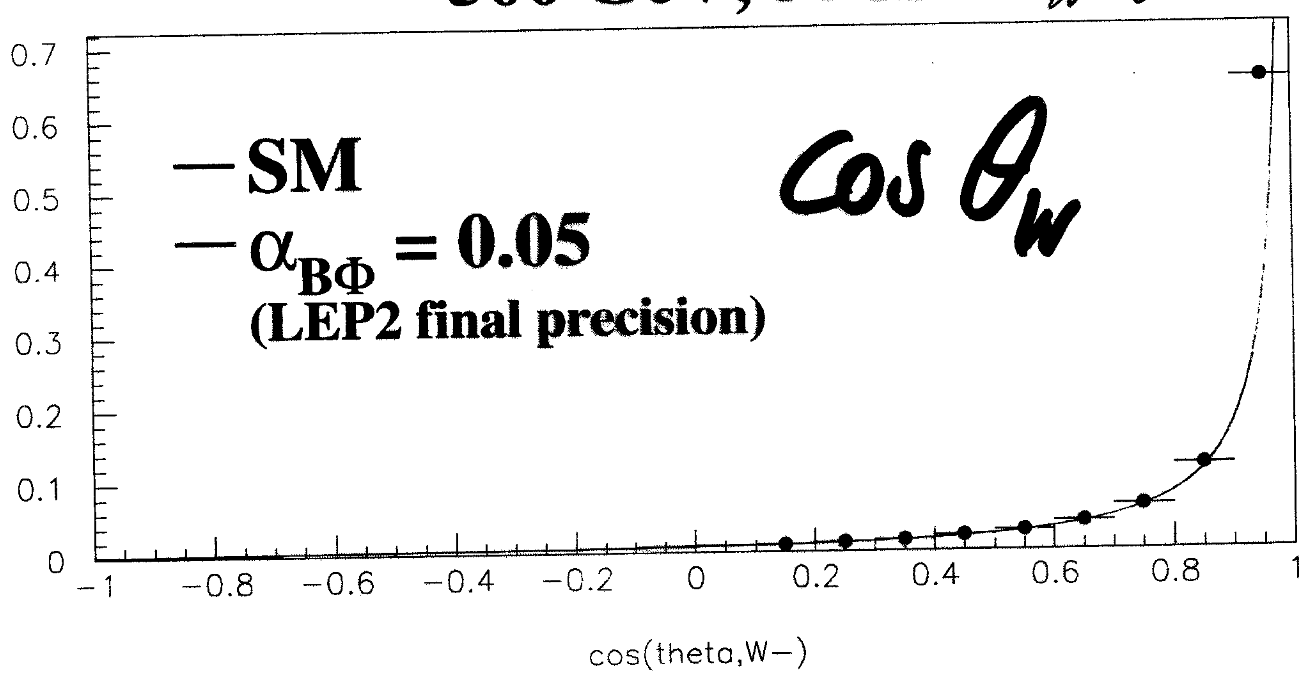
with F: helicity amplitude

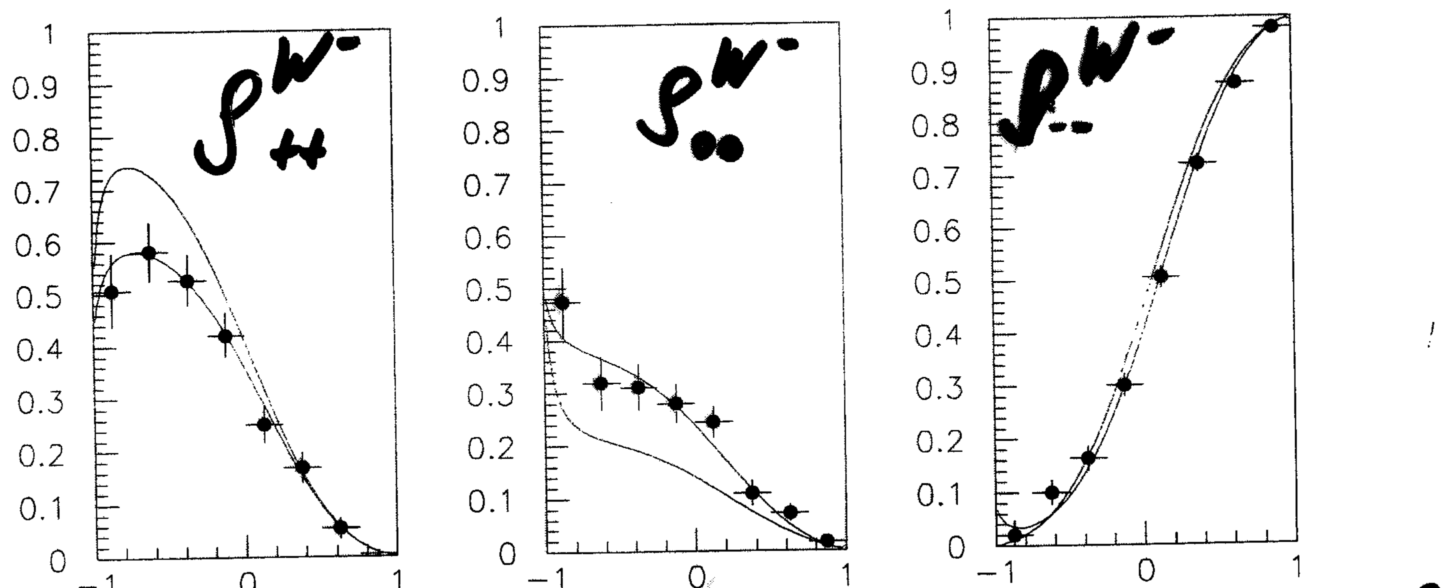
single W spin density matrix elements:

$$\rho^{W^-}_{\tau\tau'} = \sum_{\tau_+} \rho_{\tau_-\tau_-'\tau_+\tau_+}$$



500 GeV, 30 fb^{-1}

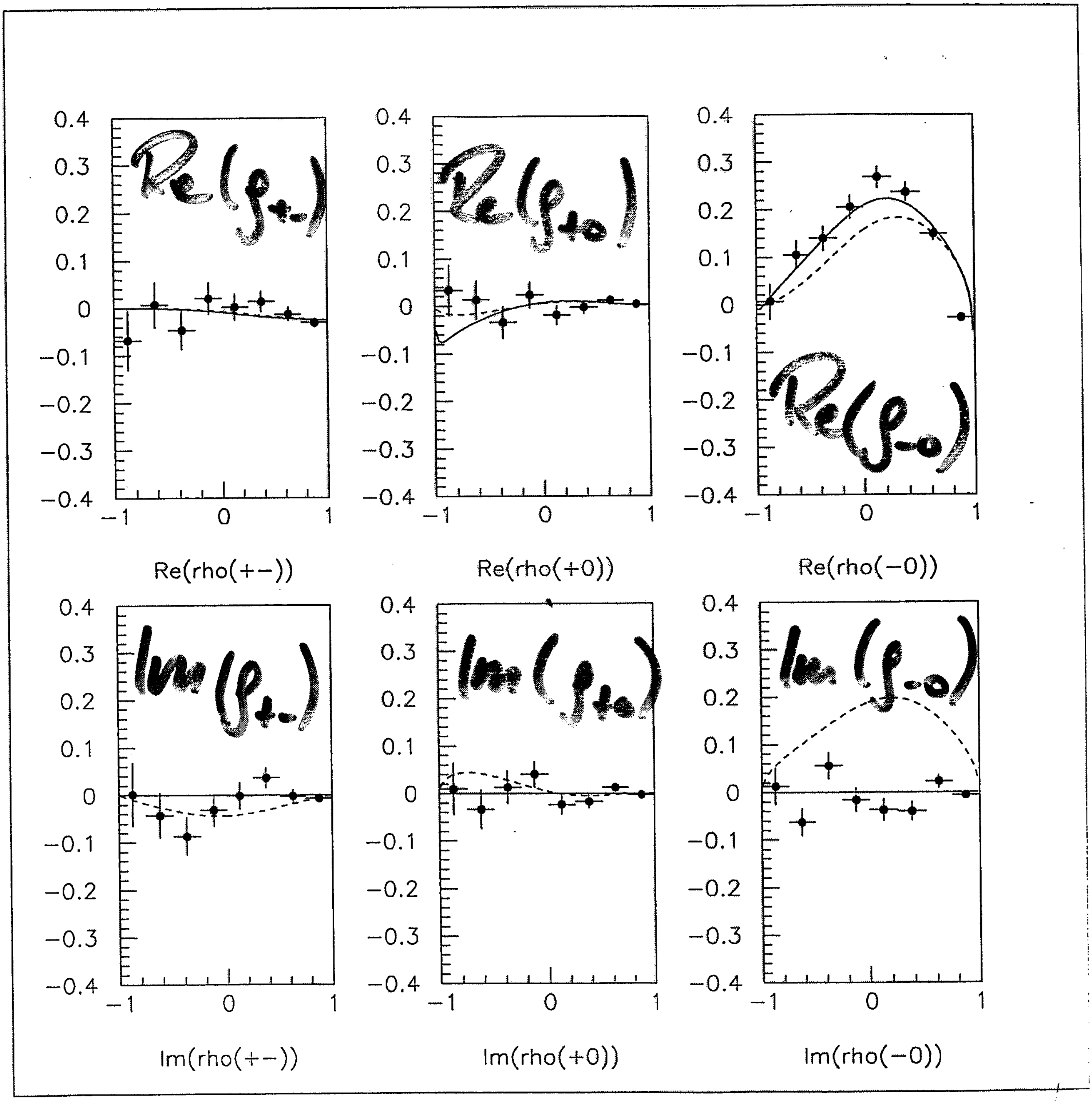




+ MC 30 fb^{-1} : SM (c.f. TESLA: 500 fb^{-1})

— — SM

---- $\lambda_{BW} = 0.6$



another ☺ for Spindensity matrix method

Simple & Modelindep. CP test

CPT: $F^{\lambda}_{\tau_-\tau_+} = \left(F^{\lambda}_{-\tau_+-\tau_-}\right)^* \rightarrow \rho^{W^-}_{\tau\tau'} = \left(\rho^{W^+}_{-\tau'-\tau}\right)^*$

CP: $F^{\lambda}_{\tau_-\tau_+} = F^{\lambda}_{-\tau_+-\tau_-} \rightarrow \rho^{W^-}_{\tau\tau'} = \rho^{W^+}_{-\tau'-\tau}$

→ CP-Test: $\boxed{\mathrm{Im}\left(\rho^{W^-}_{\substack{+-\\+0\\-0}}\right) - \mathrm{Im}\left(\rho^{W^+}_{\substack{-+\\-0\\+0}}\right) \overset{?}{=} 0}$

test precense of loop-effects with

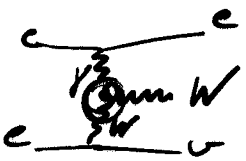
$$\mathrm{Im}\left(\rho^{W^-}_{\tau\tau'}\right) + \mathrm{Im}\left(\rho^{W^+}_{\tau'-\tau}\right) \overset{?}{=} 0$$

sensitivity of this simple test similar to full analysis
because CP-parameters enter linearly in Imaginary p.
" " quadratically in Real parts
" " " in X-sec

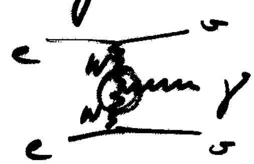
How to disentangle WWZ / WWγ

1.) alternative reactions

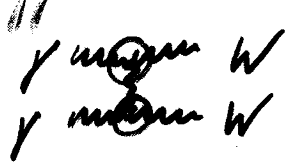
single W

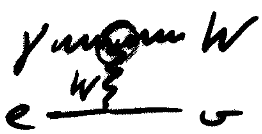


single γ



2.) γγ or eγ - collisions

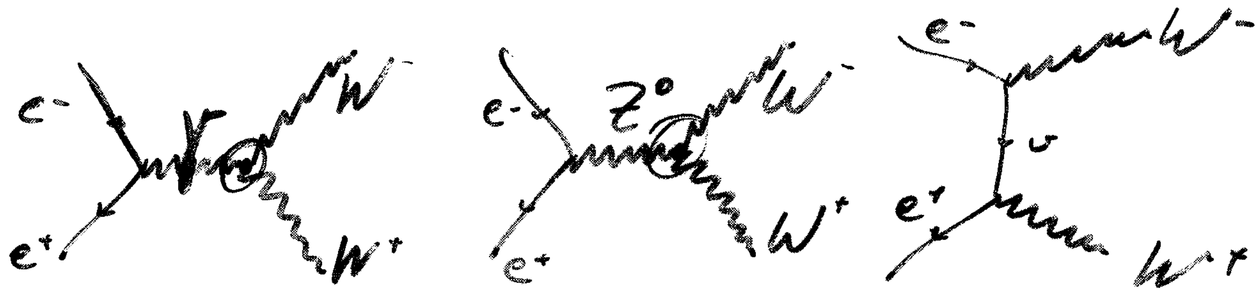




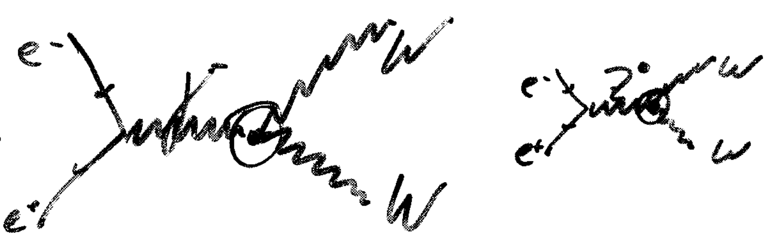
$q_\gamma^2 \approx 0$

3.) polarised beams in e^+e^-

e_L^- :



e_R^- :

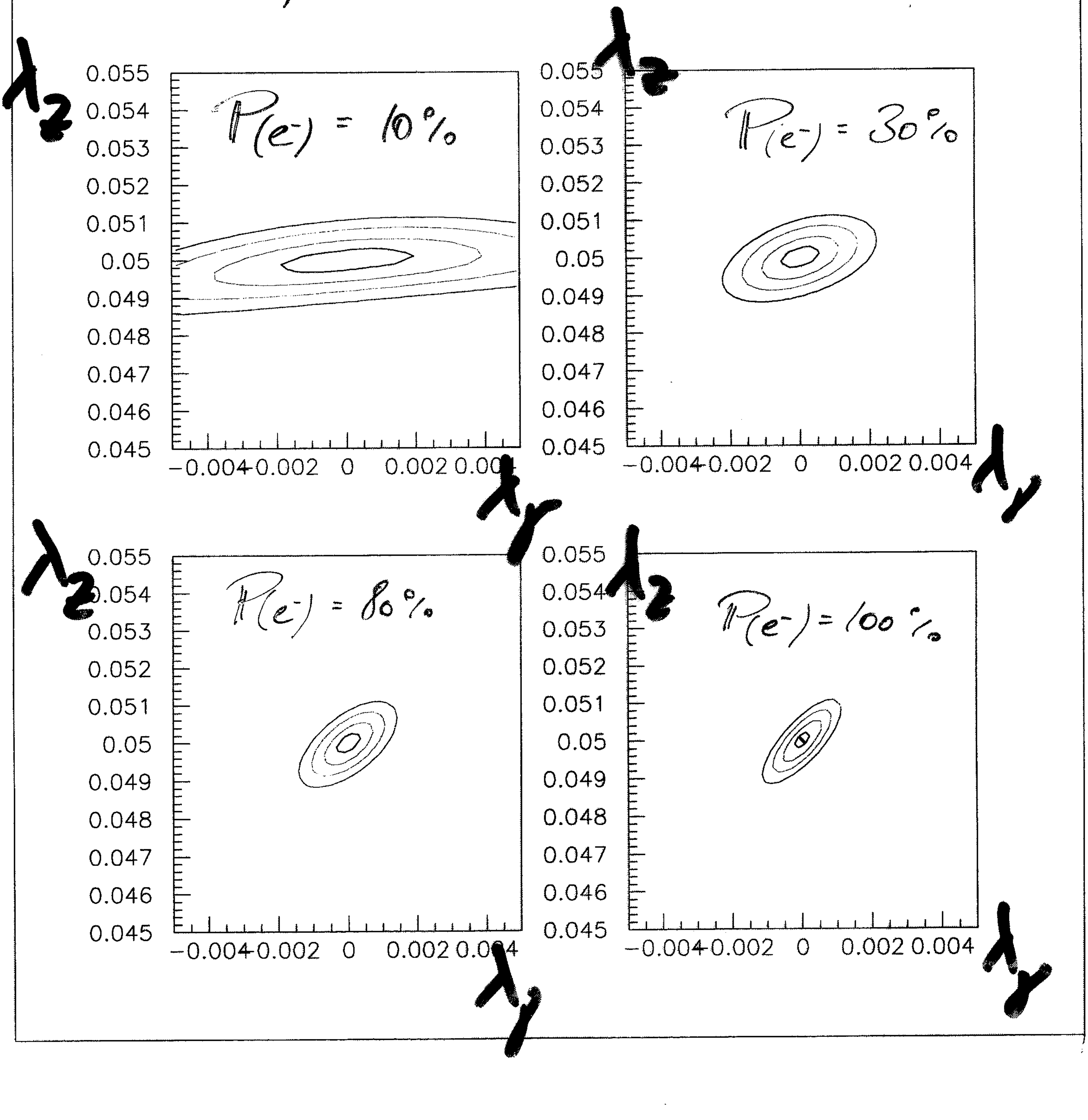


$q_\gamma^2 \approx \sqrt{s}$

Polarised beams

$\mathcal{L} = 500\ fb^{-1}$ @ 500 GeV : anomalous coupling: $\lambda_Z = 0.05$, $\lambda_\gamma = 0$

50% with e^-_L, 50% e^-_R



Results for $\not{C}\not{P}$-parameters

500 fb^{-1} @ 500 GeV

$\tilde{\kappa}_Z$	$2 \cdot 10^{-2}$
$\tilde{\kappa}_\gamma$	$2 \cdot 10^{-2}$
$\tilde{\lambda}_Z$	$1 \cdot 10^{-2}$
$\hat{\lambda}_\gamma$	$0.6 \cdot 10^{-2}$
$\tilde{\alpha}_{BW}$	$0.9 \cdot 10^{-2}$
$\hat{\alpha}_W$	$0.3 \cdot 10^{-2}$

where $\hat{\alpha}_{BW} = \hat{\kappa}_\gamma$, $\hat{\kappa}_Z = -\tan^2\theta_W \,\tilde{\kappa}_\gamma$
$\hat{\alpha}_W = \hat{\lambda}_\gamma$, $\hat{\lambda}_Z = \hat{\lambda}_\gamma$

1σ - errors for 1-parameter fits

Systematic effects

- any show-stoppers ?

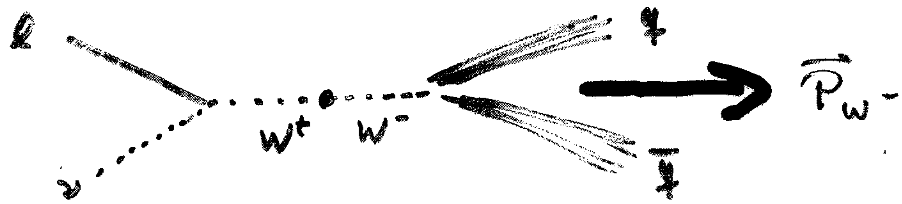
- detector effects
  (resolution, error on resolution)
- ISR / beam Strahlung
- beam energy uncertainty
- generators
- backgrounds

statistical errors compared to LEP2 :

⊗ higher sensitivity by γ_W to γ_W^2
(2.5 – 6)

⊗ 1000 fold luminosity ⇒ factor 30

Detector Effects



- large W boost

 - excellent $\cos\theta_W$ resolution

 - worse decay angle resolutions

 (+) better detector c.f. LEP

→ only small effects from detector

e.g. error on λ^γ

generator level	detector level
$7.1 \cdot 10^{-4}$	$7.2 \cdot 10^{-4}$

- **Understanding of Resolution**

<u>test</u>: change "data" resolution by <u>1%</u>, leave reweighting MC unchanged

→ biases $\mathcal{O}$(statistical error) of 500 fb^{-1}

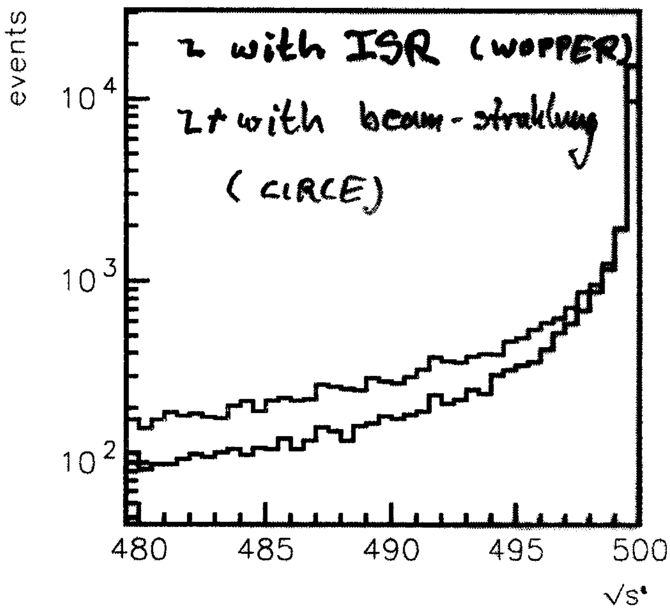
→ looks controllable

• ISR + beam-strahlung

test (very crude):

switch off ISR,
switch off beam-str.

in "data", leave reweighting MC unchanged



ISR: biases $\mathcal{O}$(100 * stat. error) for 100% change

→ need to understand to better than 1%

beam-strahlung: biases < $\mathcal{O}$(10 * stat. error) for 100 % change

→ understand to 10 %

expectations ...

estimated sensitivity from 500 fb^{-1} @ 500 GeV
from $WW \to qq\ell\nu$ ...

1-parameter fits :	$\mathcal{O}(10^{-4}) - \mathcal{O}(10^{-3})$	CP
α - models (assuming gauge invariance) :	$\mathcal{O}(10^{-4})$	CP
1-parameter fits :	$\mathcal{O}(10^{-2})$	$\not{CP}$
α - models	$\mathcal{O}(10^{-3})$	$\not{CP}$

... and expected in models

SM :		10^{-3}	CP
SUSY, THDM		10^{-3} (-10^{-4})	CP
SM:		10^{-8}	$\not{CP}$
SUSY :	WWZ	$10^{-4} - 10^{-6}$	$\not{CP}$
	WWγ	$10^{-3} - 10^{-4}$	$\not{CP}$

...sitivities units 10^{-4} (...%)	TESLA 500 GeV 500 fb^{-1} unpolarised	TESLA 500 GeV 500 fb^{-1} 80% e^-	TESLA 1 TeV 500 fb^{-1} unpolarized	TESLA 1 TeV 500 fb^{-1} 80% e^-	LHC 14 TeV 100 fb^{-1} Kuss & Nuss '98
[illegible] z	25	12	25	10	31
[illegible] γ	5	4	3	3	280
[illegible] z	8	4	6	3	260
[illegible] γ	7	6	4	3	13
[illegible]	7	3	3	3	25
[illegible]	4	3	3	2	270
[illegible]	5	5	3	3	12
[illegible]	2	2	2	2	11

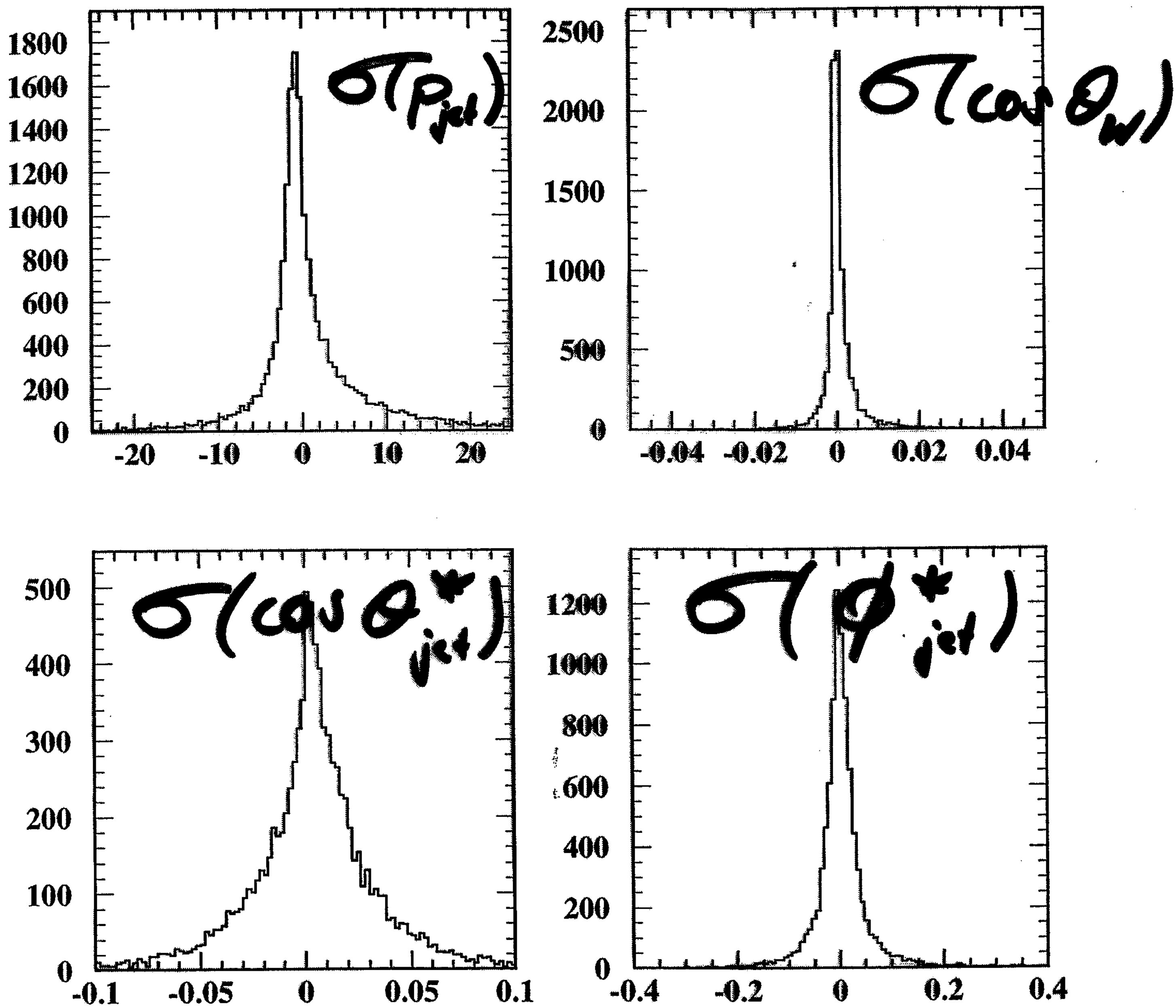
statistical errors (one year running)

Conclusions

- TGC measurement @ TESLA:
  Systematics are controllable!
- statistical power needed to reach interesting regions and distinguish models
  → high Lumi version
- polarised beams very helpful to
  → disentangle WWZ / WWγ couplings
  → reach higher precision (mainly Z-couplings)
- running at different energies desirable (with high Lumi each!)
  → distinguish SM ↔ SUSY
  → q^2-dependence of form factors
  → distinguish possible second minima (in fit) from 'true' one

detector resolution

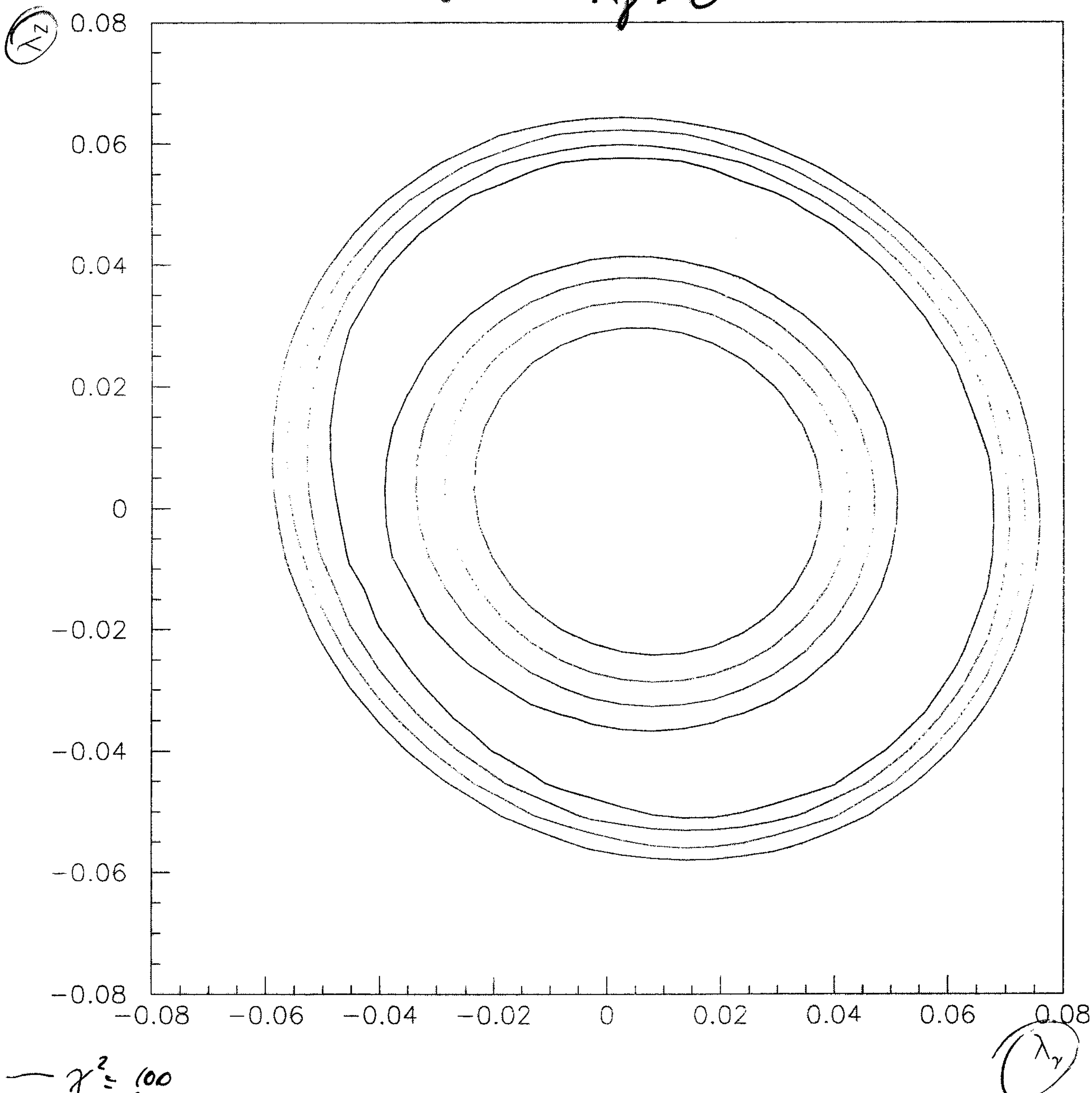
(TESLA reference detector)



Fit TGC with unpolarised beams

@ 500 GeV (Born level), $\int \mathcal{L} = 500\ fb^{-1}$

anomalous coupling: $\lambda_Z = 0.05$, $\lambda_\gamma = 0$

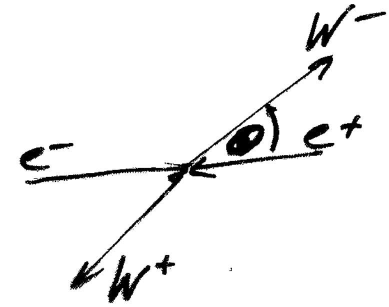


— $\chi^2 = 100$
— $\chi^2 = 400$
— $\chi^2 = 900$
— $\chi^2 = 1600$

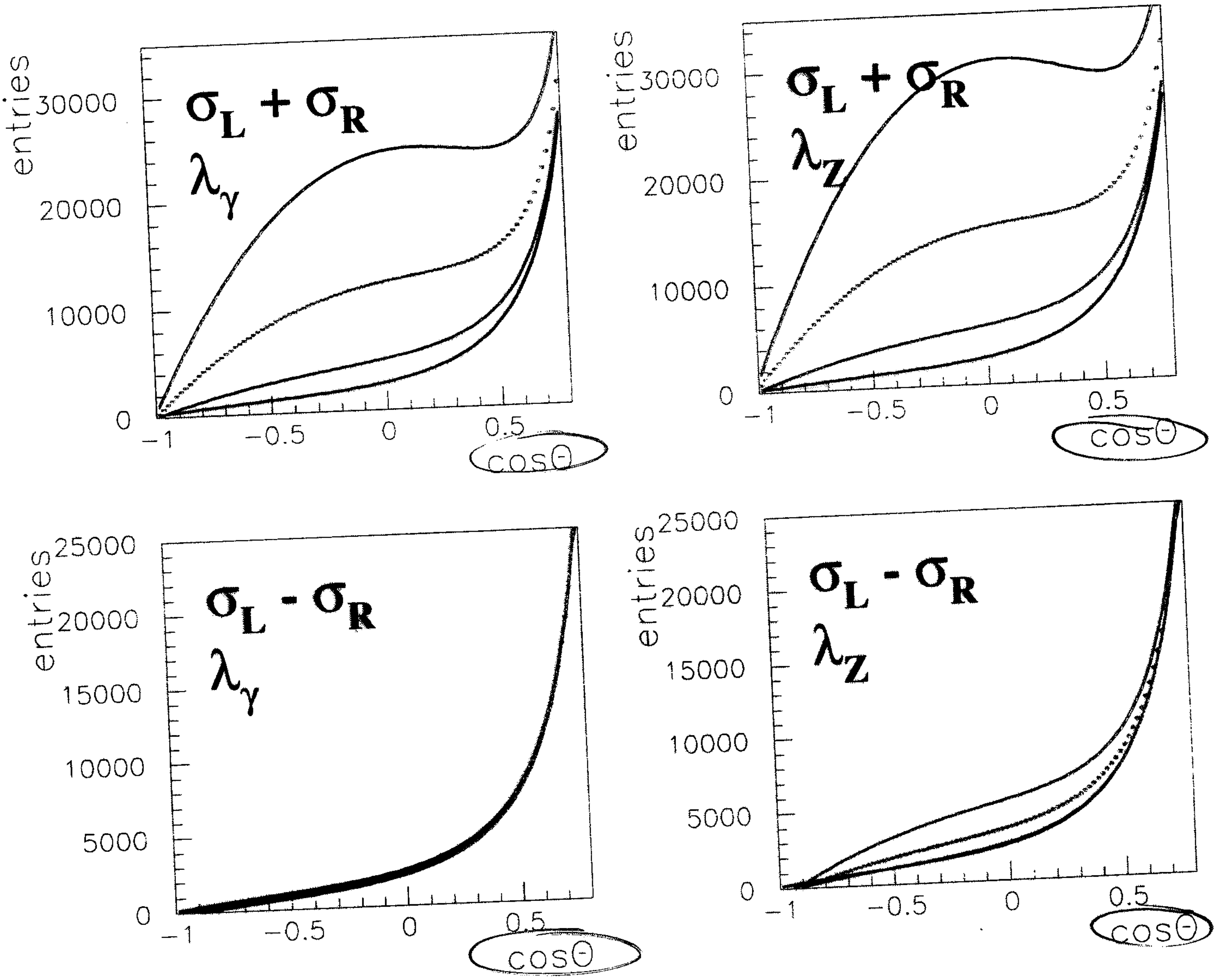
Fit to W production angle only!

⇒ cannot distinguish

... to illustrate ...



$\lambda_{\gamma/Z} = 0,\ 0.1,\ 0.2,\ 0.3$



+ statistical errors expected for 500 fb⁻¹ @ 500 Ge