Why and how much $P(e^{+})$ do we need?

POSIPOL 2007

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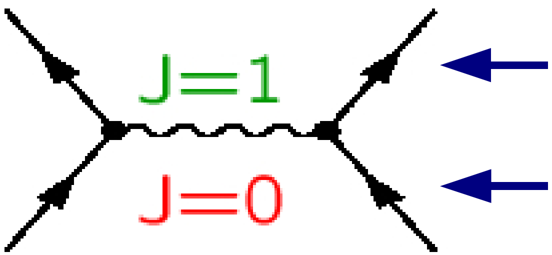
- **Few physics examples**
  - in which cases are Peff and ALR good quantities?
  - why is the ILC needed for top and Higgs?
  - how to test properties of new particles, e.g. SUSY?
  - how to measure effects of CP-violation?
  - why do we need GigaZ?
- **Conclusion**

Goals of physics at the LC

- Discovery of new particles complementary to LHC
  - all particles up to kinematical limit
- Unraveling the structure of the New Physics (NP)
  - precise determination of underlying dynamics and parameters
  - model distinction through model-independent searches
- Discovery via high precision measurements
  - test of the Standard Model (SM) with unprecedented precision
  - even smallest hints of NP could be observed
- Beam polarization (e- and e+) important
  - important for analyzing the coupling structure
  - important for enhancing the precision

Structure of interactions

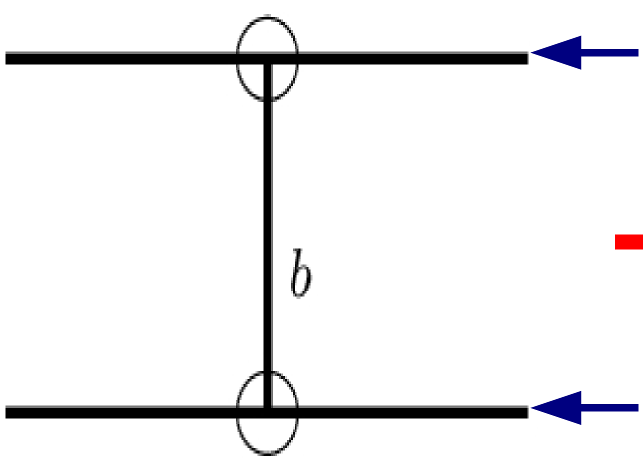
- Def.: left-handed = P(e±)<0 'L' right-handed= P(e±)>0 'R'
- Which configurations are possible in annihilation channels?



LR, RL: SM and(?) NP (γ, Z)

LL, RR: NP !

- Which configurations are possible in scattering channels?



depends on P(e+)!

helicity of e- not coupled

with helicity of e+ !

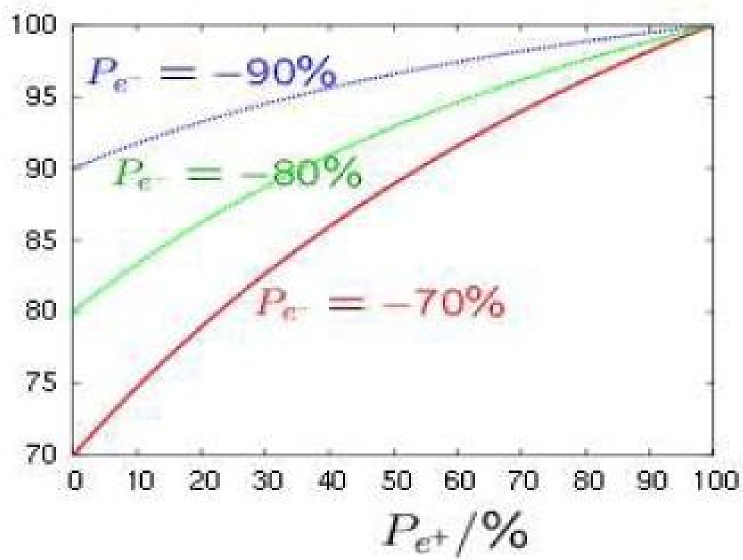
depends on P(e-) !

Peff and ALR

- For many processes (V, A interactions) the cross section is given by:

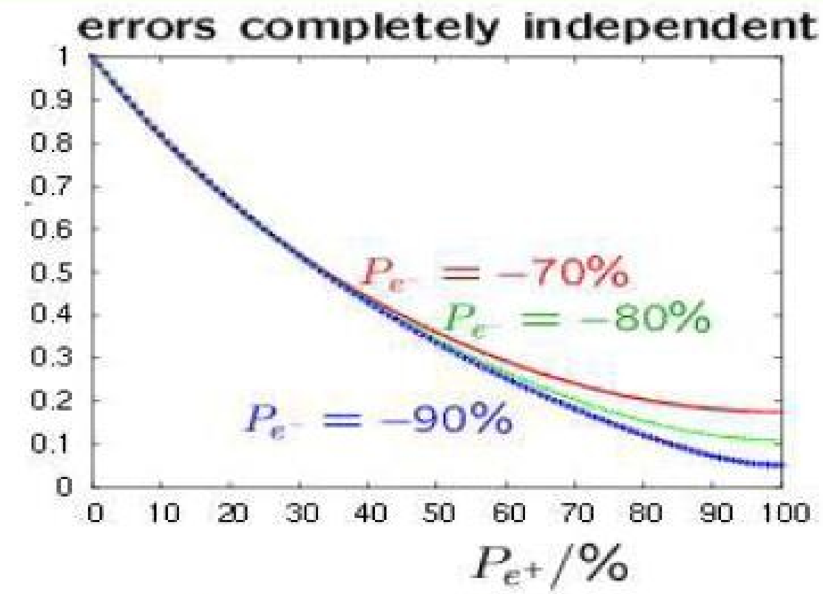
$$\sigma(P_{e-}\,P_{e+}) = (1- P_{e-}\,P_{e+})\,\sigma_0\,[1- P_{eff}\,A_{LR}] \quad \text{with} \quad P_{eff} = (P_{e-} - P_{e+}) / (1 - P_{e-}\,P_{e+})$$

P_{eff} /%



$\frac{1}{x}\frac{\Delta P_{eff}}{|P_{eff}|}$

$\sim\Delta A_{LR}/A_{LR}$



- (80%,60): P_{eff} = 95% (90%,60%): P_{eff} =97% (90%, 30%): P_{eff} =94 %
- $\Delta A_{LR}/A_{LR} = 0.3$ $\Delta A_{LR}/A_{LR} = 0.27$ $\Delta A_{LR}/A_{LR} = 0.5$

gain: factor~3 factor>3 factor~2

→ NO gain with only polarized e$^-$! (error prop.: $\frac{\Delta P_{eff}}{P_{eff}} = \frac{1-|P_{e^+}||P_{e^-}|}{1+|P_{e^+}||P_{e^-}|}\,x$)

Top quark physics at ILC(500 GeV)

- Current average: $m_{top} = 172.5 \pm 2.3$ GeV
- Expectations at the LHC:
  - $\Delta m_{top} \sim 1$ GeV
  - Yukawa couplings ~ 20 % (with slight model assumptions)
- Expectations at the ILC:
  - Mass via threshold scans: $m_{top} \sim 100$ MeV (dominated by theory)
  - Yukawa couplings via $t\bar{t}H$: difficult due to small rates, but < 20%
  - Unique access to electroweak couplings
- Why are top properties so important?
  - heaviest detected elementary particle up to now
  - opens unique window to physics beyond the SM

Unique access: electroweak couplings

- Process: $e^+ e^- \to t\bar{t}$ (test of couplings $t \to \gamma, Z$)

$$\Gamma^{\mu}_{t\bar{t}\gamma,Z} = ie\{\gamma^{\mu}[F_{1V}^{\gamma,Z} + F_{1A}^{\gamma,Z}\gamma^5] + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}[F_{2V}^{\gamma,Z} + F_{2A}^{\gamma,Z}\gamma^5]\}$$

- **Studies at threshold:**

$v_t = (1 - \frac{8}{3}\sin^2\theta_W)$ **via** A_{LR}

$\Rightarrow \Delta A_{LR}/A_{LR} \sim \Delta P_{eff}/P_{eff}$

→ up to per mille level

- Can be even improved via use of polarized beams:

$\Rightarrow$ (80%,0)→(80%,60%): factor 3!

Form factor	SM value	$\sqrt{s} = 500$GeV		$\sqrt{s} = 800$GeV	
		$p = 0$	$p = -0.8$	$p = 0$	$p = -0.8$
F_{1V}^{Z}	1		0.019		
F_{1A}^{Z}	1		0.016		
$F_{2V}^{\gamma,Z} = (g-2)^{\gamma,Z}{}_t$	0	0.015	0.011	0.011	0.008
$Re\,F_{2A}^{\gamma}$	0	0.035	0.007	0.015	0.004
$Re\,d_t^{\gamma}$ $[10^{-19}$ e cm]	0	20	4	8	2
$Re\,F_{2A}^{Z}$	0	0.012	0.008	0.008	0.007
$Re\,d_t^{Z}$ $[10^{-19}$ e cm]	0	7	5	5	4
$Im\,F_{2A}^{\gamma}$	0	0.010	0.008	0.006	0.005
$Im\,F_{2A}^{Z}$	0	0.055	0.010	0.037	0.007
F_{1R}^{W}	0	0.030	0.012		
$Im\,F_{2R}^{W}$	0	0.025	0.010		

→ ILC provides unique potential for determining the properties of the top!

Top couplings

- Process: e+ e- → t $\bar{t}$ (test of couplings t → γ, Z unique for the ILC)
  - Studies at threshold: since Δ ALR / ALR ~ Δ Peff / Peff

⇒ (80%,0)→(80%,60%): factor 3!

and with only

→ (80%,0) → (80%,30%): factor 2

- Studies at $\sqrt{s} = 500$ GeV:

only for P_{e^-} so far!!!

estimated:

⇒ (80%,0)→(80%,60%): factor 3!

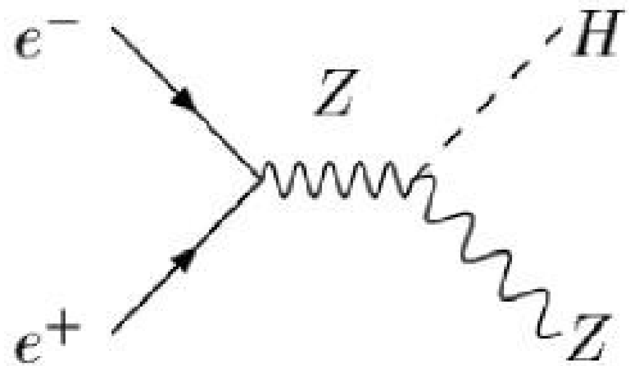
  - since again left-right asymmetry decisive: with (80%,30%) a factor 2 expected

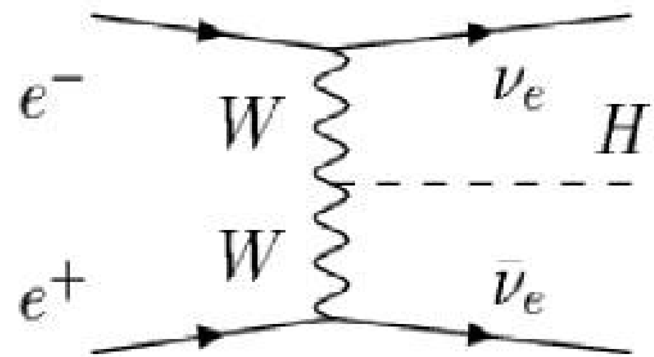
Determination of Higgs properties

- Expectations at the LHC:
  - Higgs mass: up to Δm_H =100-200 MeV
  - Higgs couplings: 15%-40% (with some model assumptions)
  - Higgs spin: challenging
- Expectations at the ILC:
  - at top threshold ($\sqrt{s}$=350 GeV) and at $\sqrt{s}$=500 GeV up to Δm_H=50 MeV !
  - absolute couplings: 1-5 %
  - Establishing of ew sym. breaking: triple Higgs couplings at 500 GeV up to 22%
  - Higgs spin: clear access via threshold scan
  - non-Standard Higgs properties: CP-properties
  - disentangling of light SUSY Higgs and SM Higgs via precision measurements of couplings

Higgs physics

- Light Higgs, e.g. mH=130 GeV: HZ and H νν similar rates at 500 GeV





- P(e-), P(e+) needed for:
  - separation
  - background suppression
- σ(H Z) / σ (H νν):

(+80%,0) → (+80%,-60%)

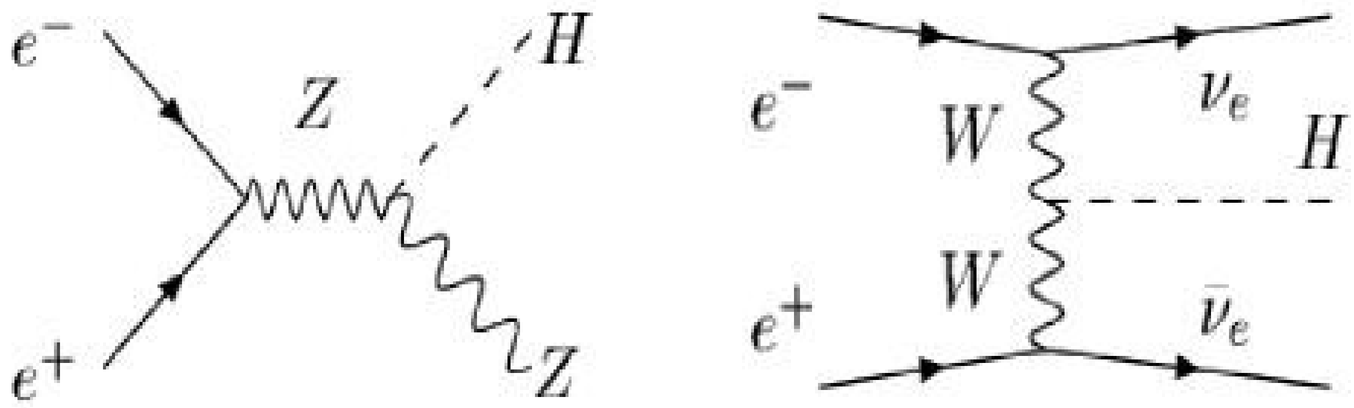
→ improves by factor 4!

Configuration (P_{e^-}, P_{e^+})	Scaling factors $e^+e^- \to H\nu\bar{\nu}$	$e^+e^- \to HZ$
$(+80\%, 0)$	0.20	0.87
$(-80\%, 0)$	1.80	1.13
$(+80\%, -60\%)$	0.08	1.26
$(-80\%, +60\%)$	2.88	1.70
(+80%, -30%)	**0.14**	**1.06**
(-80%, +30%)	**2.34**	**1.42**

- (+80%,0) → (+80%, -30%): ratio HZ / $H\nu\bar{\nu}$ → gain ~ factor 2

Higgs couplings

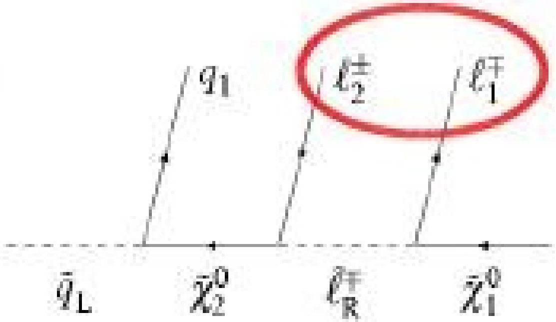
- Couplings determination: high rates and lumi needed



- measurement of couplings in Higgs-strahlungs process at $\sqrt{s}$=350 GeV
- beam polarization (80%,0) ⟶ (80%, 60%): improvement by about 30%
- triple Higgs couplings: e.g. in HHZ at $\sqrt{s}$=500 up to 22% (unpolarized beams)
- estimate: further gain of 30%-50% precision if both beams polarized

Supersymmetry

- Whats needed for establishing SUSY?
  - Spin verification: via analysis of angular distributions
  - Couplings measurement: Yukawa couplings = gauge couplings
  - Precise mass measurements
  - Unraveling the SUSY breaking mechanism and test unification
  - 'model- independent' determination of the parameters (105 already in the MSSM!)
- Expectations at the LHC:
  - Coloured SUSY partners: discovery reach $m_{\tilde{q},\tilde{g}} < 2\text{-}2.5$ TeV
  - Non-coloured partners: a) via Drell-Yan $m_\chi < 250$ GeV
    b) via cascade decay chains

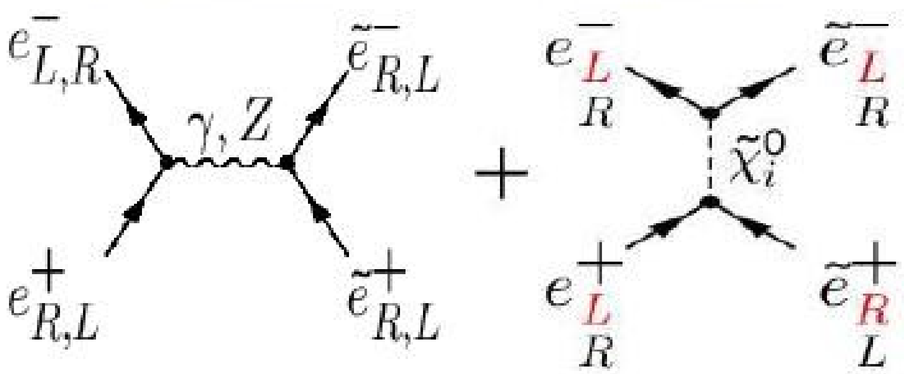


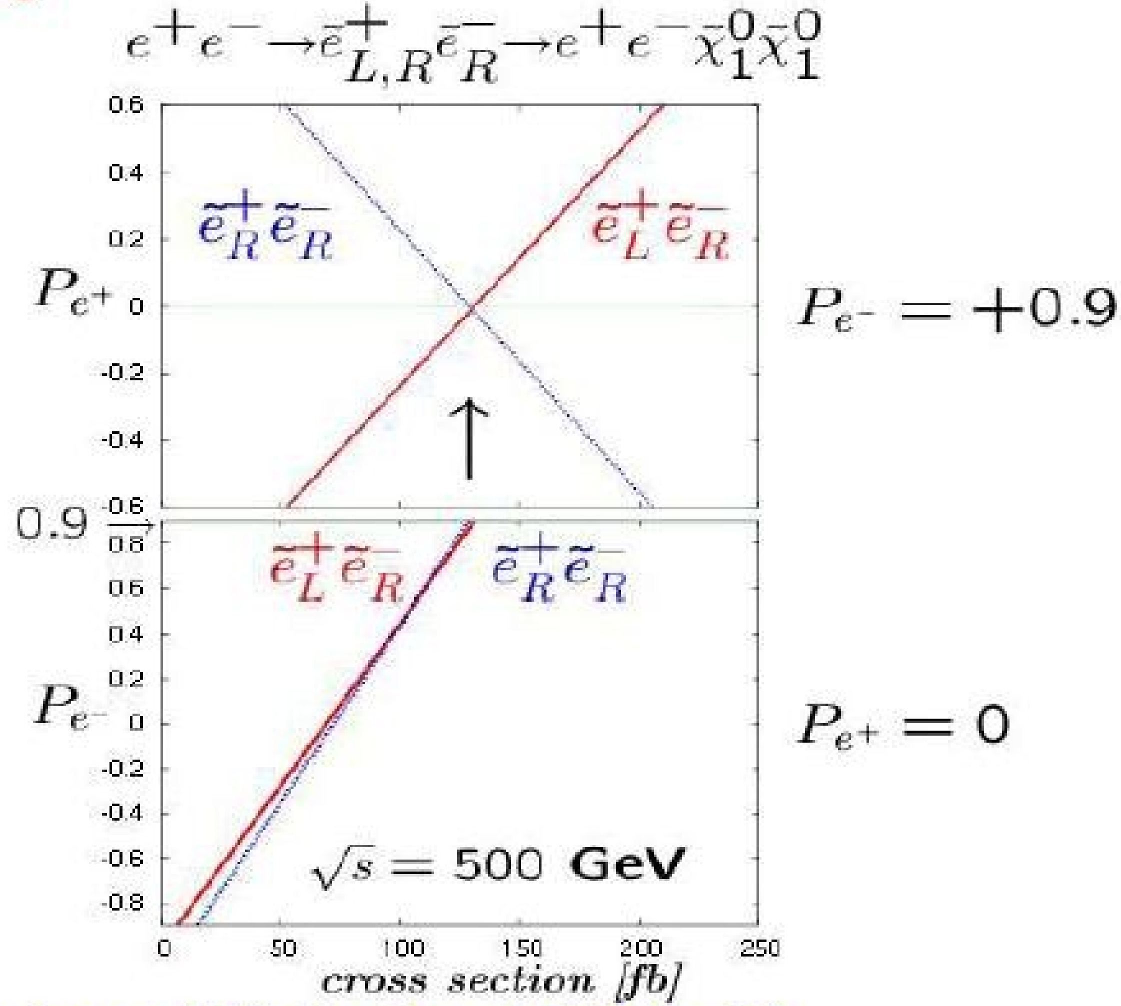
  - Parameter determinations: in specific SUSY breaking models
- Particularly promising field for LHC/ILC interplay studies !

Properties of SUSY particles

- Association of chiral electrons to scalar partners $e^-_{L,R} \leftrightarrow \tilde{e}^-_{L,R}$ and $e^+_{L,R} \leftrightarrow \tilde{e}^+_{R,L}$:

s-channel t-channel





1. separation of scattering versus annihilation channel
2. test of 'chirality': only $\tilde{e}^+_L\tilde{e}^-_R$ survives at P(e-) > 0 and P(e+) > 0 !

→ (90%,60%)~200 fb / 50 fb ~ 4 , (90%, 30%)~ 175 fb / 75 fb ~ 2.3

- *Even high P(e-) not sufficient, P(e+) is substantial!*

New sources of CP-violation

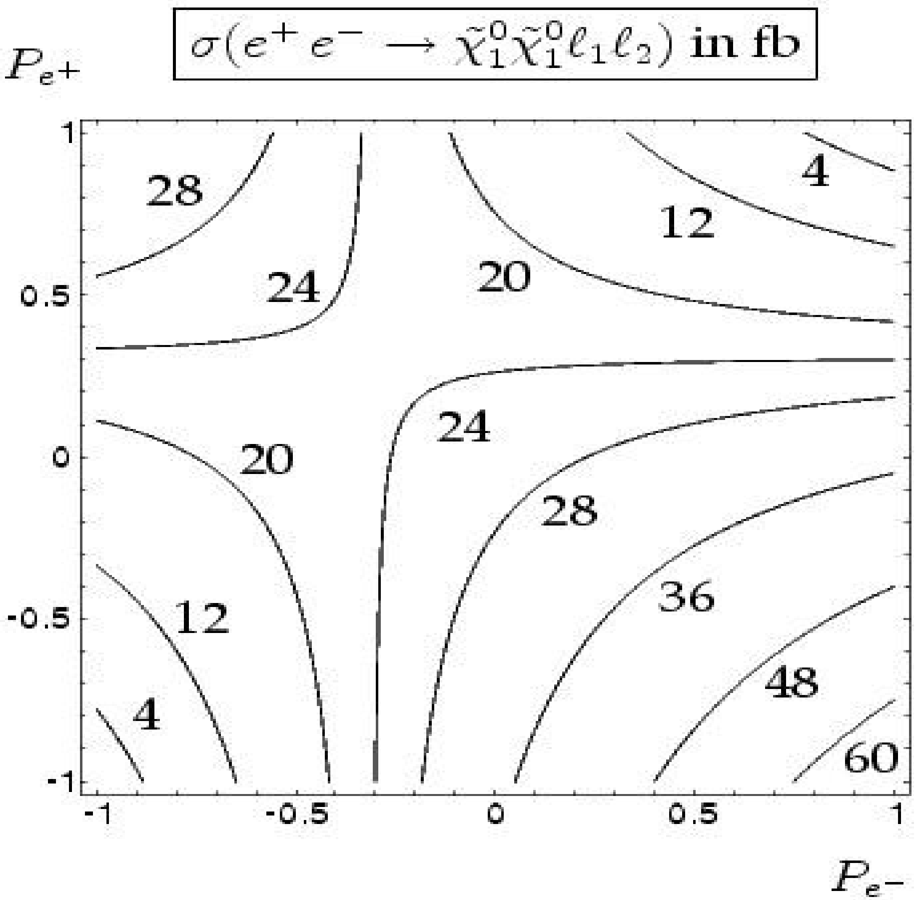
- SUSY provides new sources for CP-violation (→ explain baryon asymmetry....)
  - many phases available in SUSY, but strong experimental constraints from measurements of the e, n, Hg, Tl dipole moments
  - sensitive observables needed to detect even small phases: very sensitive are asymmetries constructed via three momenta 'triple products'

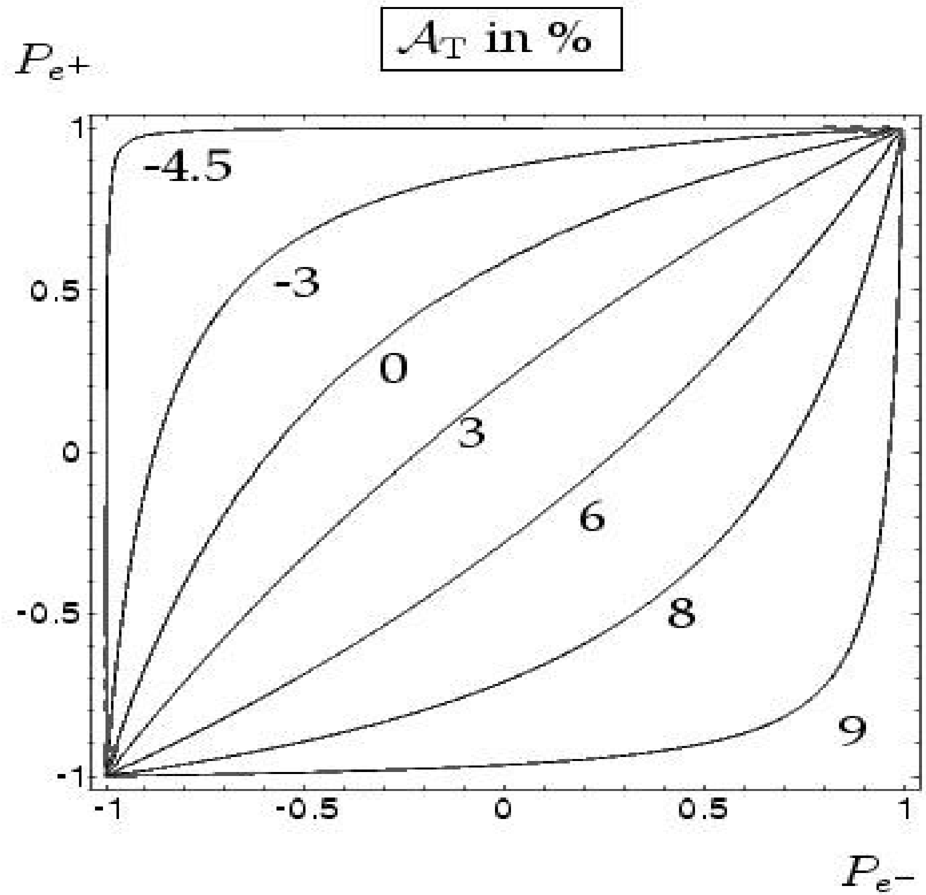
- **Asymmetry detectable if delta asy < asy**

$$\Delta\mathcal{A}_{\rm T} = \mathcal{N}_\sigma \frac{\sqrt{1-\mathcal{A}_{\rm T}^2}}{\sqrt{\sigma\mathcal{L}}}$$

  - **Nsigma=# of standard deviations**

Measurability of phases: example





- **E.g. asy with 3% (unpolarized beams) not measurable with 500 fb**
- **with Pe-=90% (and Pe+=60%): for 5 sigma 115 fb (60 fb) needed**

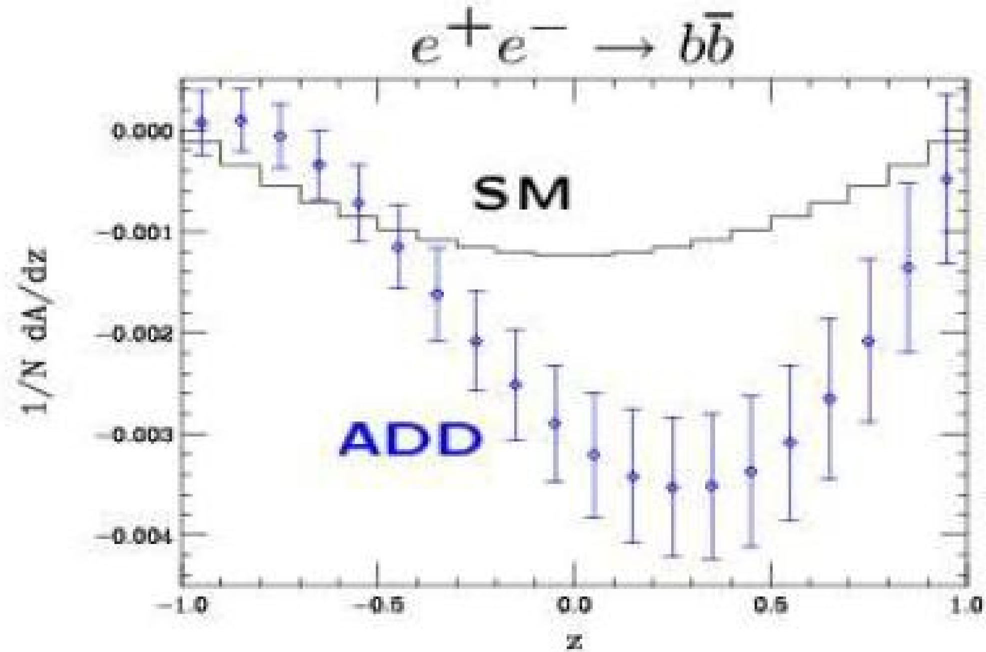
Transversely pol. beams

- Transversely polarized beams (only effects detectable of P(e⁻) and P(e⁺) !)

  → enables to exploit azimuthal asymmetries !

- Distinction between SM and different models of extra dimension:

  → asymmetry signals contribution from spin-2 graviton



- Since $P_T(e^-) \times P_T(e^+)$-dependence:

  → effects decrease by about a factor 2 when using (80%,30%) instead of (80%60%)

→ Transversely polarized beams very effective, need polarized e^- and e^+ !

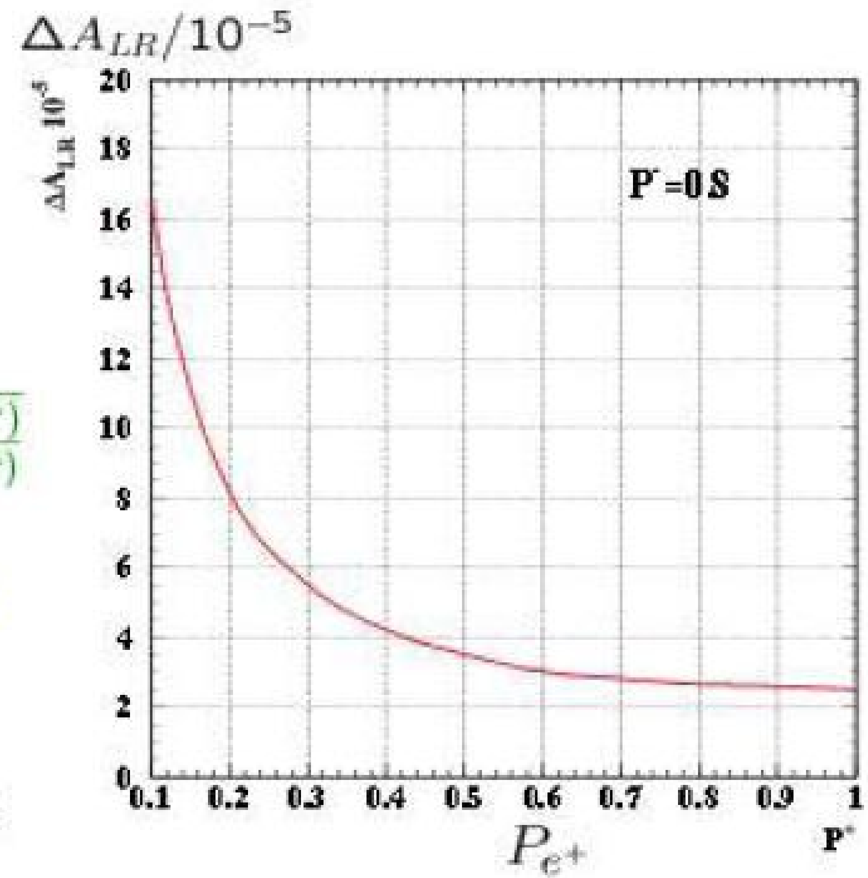
High precision at GigaZ

- Measurement of $\sin^2\theta_{eff}$ in $e^+e^- \rightarrow Z \rightarrow f\bar{f}$:

  usually $\Delta P/P \sim 0.5\%$ sufficient
  (maybe $\Delta P/P \sim 0.25\%$ reachable !)

$$A_{LR} = \frac{2(1-4\sin^2\Theta^{\ell}_{eff})}{1+(1-4\sin^2\Theta^{\ell}_{eff})^2}$$

$$\overset{Blondel}{=} \sqrt{\frac{(\sigma^{RR}+\sigma^{RL}-\sigma^{LR}-\sigma^{LL})(-\sigma^{RR}+\sigma^{RL}-\sigma^{LR}+\sigma^{LL})}{(\sigma^{RR}+\sigma^{RL}+\sigma^{LR}+\sigma^{LL})(-\sigma^{RR}+\sigma^{RL}+\sigma^{LR}-\sigma^{LL})}}$$



- with $\Delta P/P \sim 0.5\%$ and $P(e^-)=80\%$ only:

$$\Rightarrow \Delta \sin^2\theta^{\ell}_{eff} = 9.5 \times 10^{-5}$$

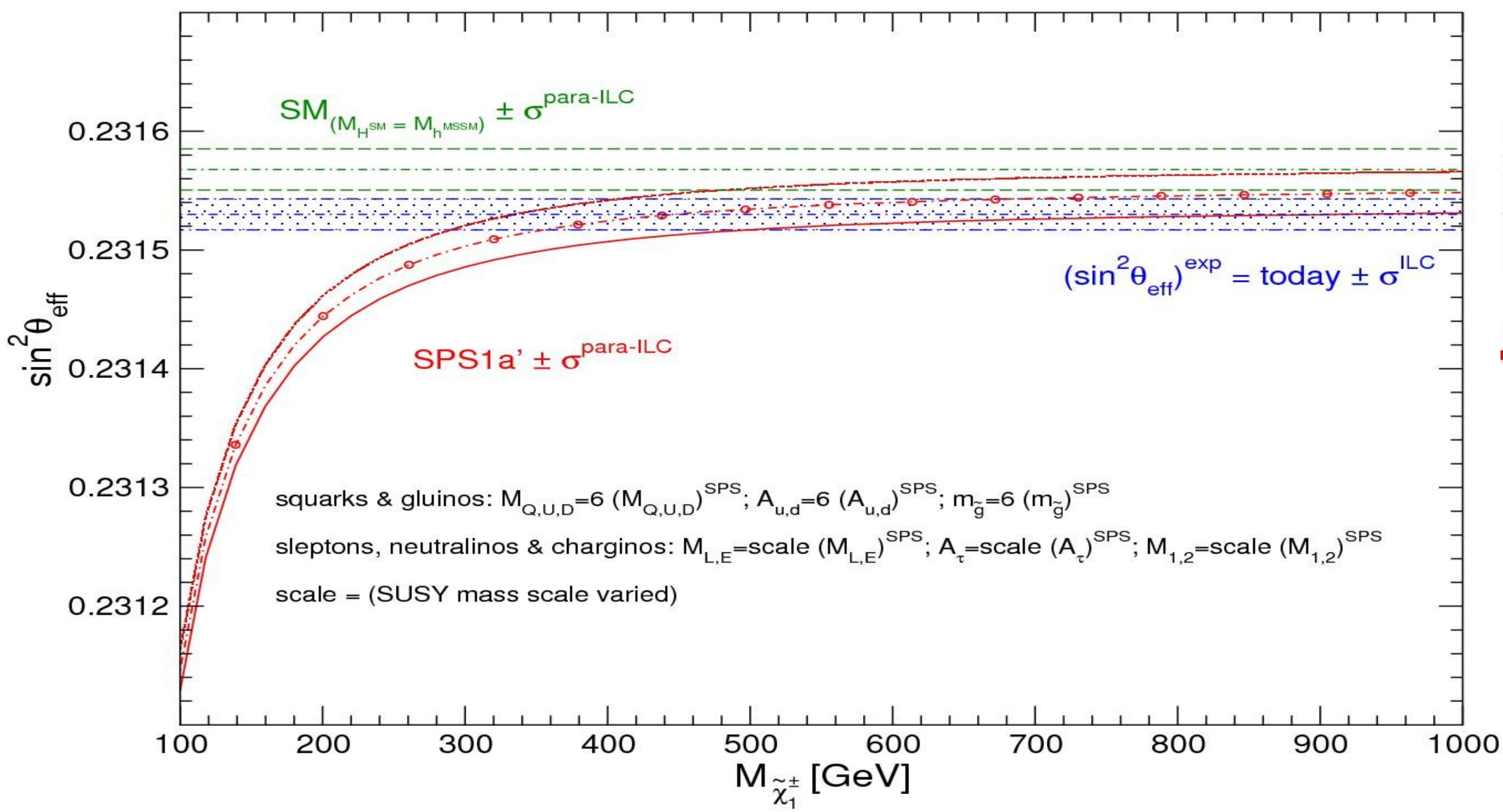
(• with $\Delta P/P = 0.25\%$ and $P_{e^-} = 90\%$:
$\Rightarrow \Delta \sin^2\theta^{\ell}_{eff} = 5 \times 10^{-5}$)

- with Blondel scheme: [$P(e^-)$, $P(e^+)$]= [80%,60%] : $\Rightarrow \Delta \sin^2\theta^{\ell}_{eff} = 1.3 \times 10^{-5}$

- [80%,30%] : about a factor 2 worse

Sensitivity to high scales at GigaZ

- Maybe quick upgrade path straight from 500 GeV to GigaZ needed?
  - study worst (?) case scenario: no SUSY hints at LHC, none at ILC500 ....
  - help from GigaZ possible? concentrate on energy upgrade? or what else?



Arne Weber, Georg Weiglein

SM-value in '~decoupling' limit
current exp. value

SUSY prediction depending on mass scale of EW SUSY particles

- no sensitivity of only P(e-) or unpolarized beams!

Summary table, I

- Comparison with (80%,0): estimated gain factor when

Case	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	Gain& Requirement most (80%, 60%)	(80%, 30%)
Standard Model:			
top threshold	Electroweak coupling measurement	factor 3	gain factor 2
$t\bar{q}$	Limits for FCN top couplings improved	factor 1.8	gain factor 1.4
CPV in $t\bar{t}$	Azimuthal CP-odd asymmetries give access to S- and T-currents up to 10 TeV	$P^T_{e^-} P^T_{e^+}$ required	P^T_{e-} P^T_{e+} required factor 1.3 worse
W^+W^-	Enhancement of $\frac{S}{B}, \frac{S}{\sqrt{B}}$	up to a factor 2	
	TGC: error reduction of $\Delta\kappa_\gamma, \Delta\lambda_\gamma, \Delta\kappa_Z, \Delta\lambda_Z$	factor 1.8	
	Specific TGC $\tilde{h}_+ = \mathrm{Im}(g_1^R + \kappa^R)/\sqrt{2}$	$P^T_{e^-} P^T_{e^+}$ required	P^T_{e-} P^T_{e+} required
CPV in γZ	Anomalous TGC $\gamma\gamma Z, \gamma ZZ$	$P^T_{e^-} P^T_{e^+}$ required	
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	factor 4	gain factor 2
	Suppression of $B = W^+\ell^-\nu$	factor 1.7	
$t\bar{t}H$	Top Yukawa coupling measurement at $\sqrt{s} = 500$ GeV	factor 2.5	gain factor 1.6

Summary table, cont.

- Estimated gain factor when only P(e+)=30%

Case	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	Gain& Requirement
Supersymmetry:		
$\tilde{e}^+\tilde{e}^-$	Test of quantum numbers L, R	P_{e^+} required
	and measurement of $e^\pm$ Yukawa couplings	
$\tilde{\mu}\tilde{\mu}$	Enhancement of S/B, $B = WW$	factor 5-7
	$\Rightarrow m_{\tilde{\mu}_{L,R}}$ in the continuum	
HA, $m_A > 500$ GeV	Access to difficult parameter space	factor 1.6
$\tilde{\chi}^+\tilde{\chi}^-$, $\tilde{\chi}^0\tilde{\chi}^0$	Enhancement of $\frac{S}{B}$, $\frac{S}{\sqrt{B}}$	factor 2–3
	Separation between SUSY models,	
	'model-independent' parameter determination	
CPV in $\tilde{\chi}_i^0\tilde{\chi}_j^0$	Direct CP-odd observables	$P_{e^-}^{\mathrm{T}} P_{e^+}^{\mathrm{T}}$ required
RPV in $\tilde{\nu}_\tau \to \ell^+\ell^-$	Enhancement of S/B, $S/\sqrt{B}$	factor 10 with LL
	Test of spin quantum number	

P_{e+} required
factor <2 worse

Summary table, cont.

- Estimated gain factor when only P(e+)=30%

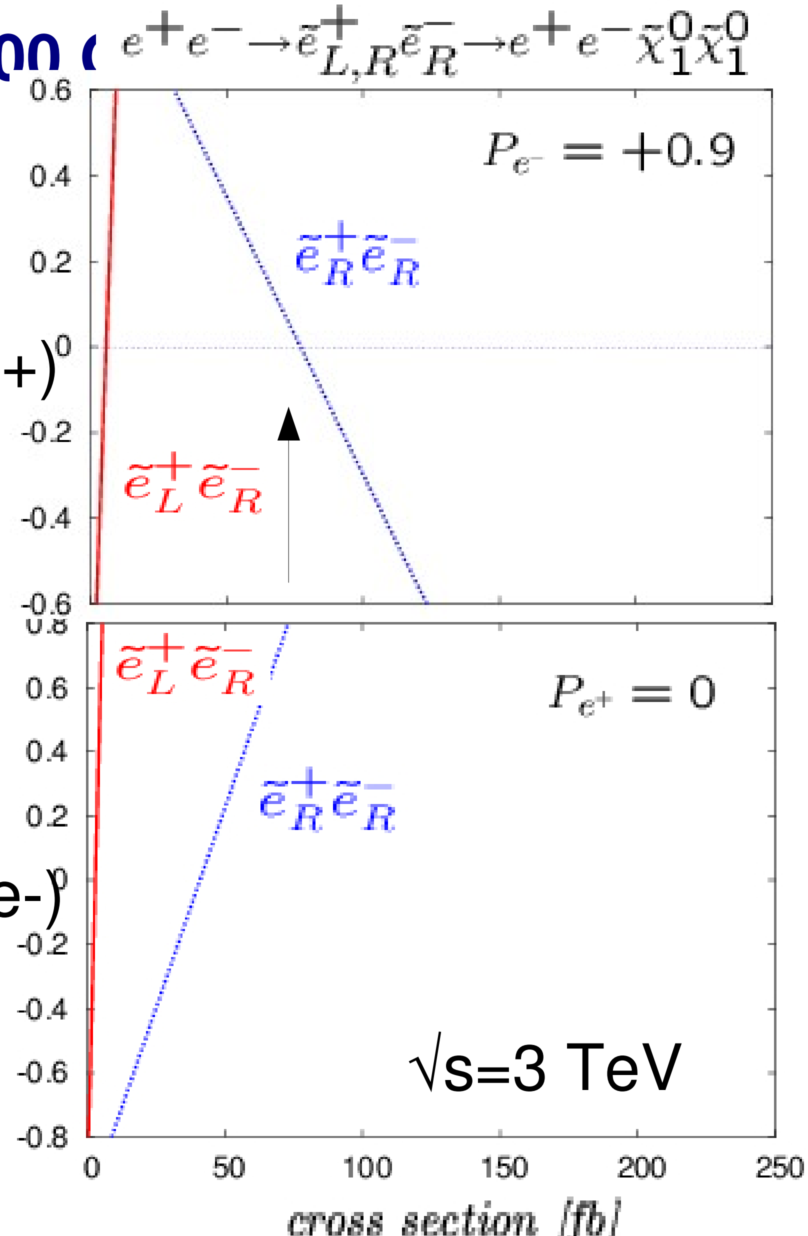
Case	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	Gain& Requirement
Extra Dimensions:		
$G\gamma$	Enhancement of S/B, $B = \gamma\nu\bar{\nu}$,	factor 3
$e^+e^- \to f\bar{f}$	Distinction between ADD and RS models	$P^{\mathrm{T}}_{e^-}P^{\mathrm{T}}_{e^+}$ required
New gauge boson Z′ :		
$e^+e^- \to f\bar{f}$	Measurement of Z' couplings	factor 1.5
Contact interactions:		
$e^+e- \to f\bar{f}$	Model independent bounds	P_{e^+} required
Precision measurements of the Standard Model at GigaZ:		
Z-pole	Improvement of $\Delta\sin^2\theta_W$	$\sim$ factor 10
	Improvement of Higgs bounds	$\sim$ factor 10
	Constraints on CMSSM parameter space	factor 5
CPV in $Z \to b\bar{b}$	Enhancement of sensitivity	factor 3

Conclusions (-> POWER report)

- **P(e+) and P(e-) together fix the initial state**
  - **analyse in detail the kind of interactions (A,V,S,V!)**
- **P(e+) essential to reveal the new physics (CP, SUSY, ED)**
  - **determination of quantum numbers of new physics**
- **P(e+) essential to match required accuracy at ILC(500)**
  - **top quark couplings and Higgs mechanism**
  - **GigaZ: sensitivity to new physics in worst case scenarios**
- **In some cases P(e+)=30% sufficient, but in most case P(e+)>=60% wanted!**
- **Transversely polarized beams ~ P(e-)P(e+)**
- **Most studies on basis delta P/P=0.5%**
  - **detailed simulations needed, whether that is really sufficient**

Selectron quantum numbers at 3 TeV

- **Same scenario, same pairs and same polarization as before**
  but change $\sqrt{s}$ = 500 (



  - **scattering channel kinematically suppressed** $\tilde{e}^+_L\tilde{e}^-_R$
  - **no separation of wanted**
  - **no test of quantum numbers**

- **Tunable energy needed, also at multi-TeV region**
  - **here: back to 500 GeV**