Physics impact of polarized beams

LCWS2007

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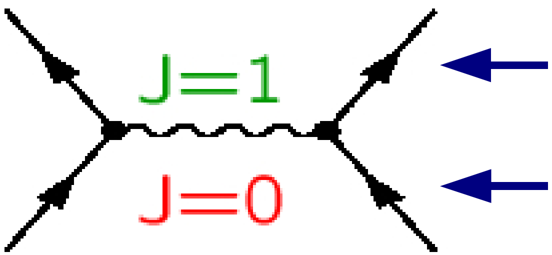
- **Introduction**
  - general remarks
- **Some physics examples and updates**
  - Higgs, sfermions, CP-violation, GigaZ
- **Some news in general**
- **Conclusion**

General remarks No. I

- **Physics goals at the ILC**
  - discovery of new particles complementary to LHC
  - unraveling the structure of the New Physics (NP)
  - discovery via high precision measurements
  - *have to be seen on basis of possible LHC results*
- **Beam polarization (e- and e+) important**
  - for analyzing coupling structure and enhancing precision
  - confirmed by all working groups -> parameter documents
  - all examples listed in the POWER report (hep-ph/0507011)
- **Baseline ILC design suffice for P(e+)~30%**
  - already some physics gain with 30% possible from the start!

No. II: Structure of interactions

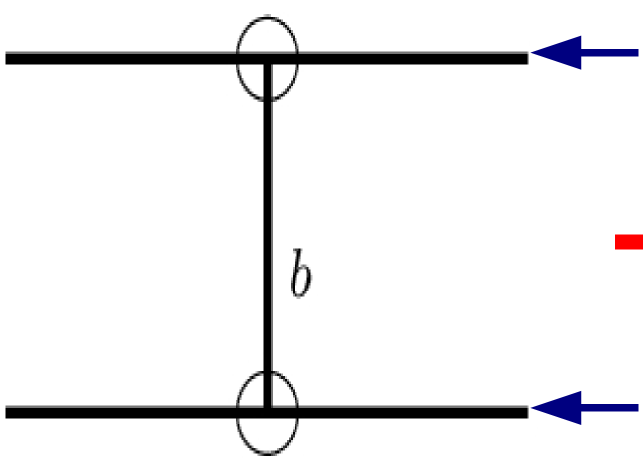
- Def.: left-handed = P(e±)<0 'L' right-handed= P(e±)>0 'R'
- Which configurations are possible in annihilation channels?



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

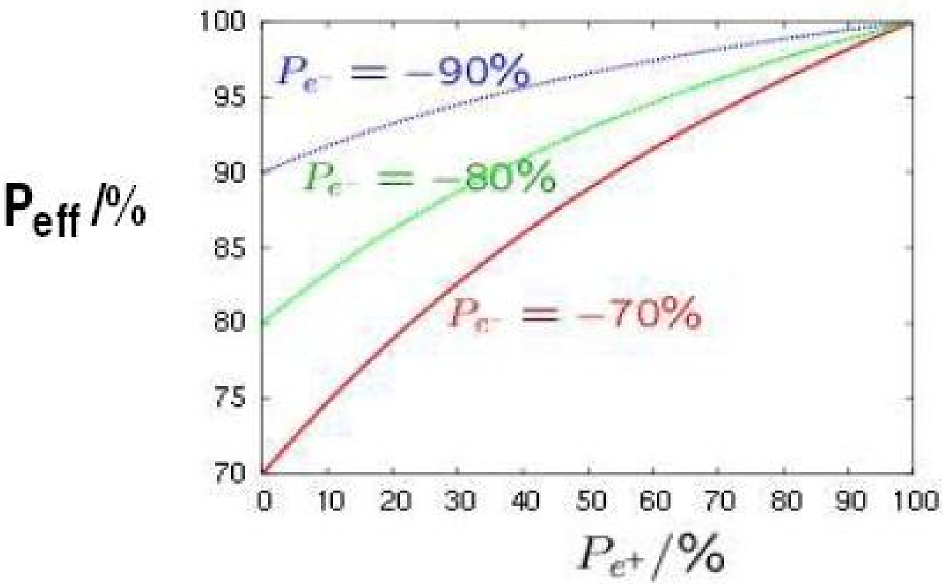
with helicity of e+ !

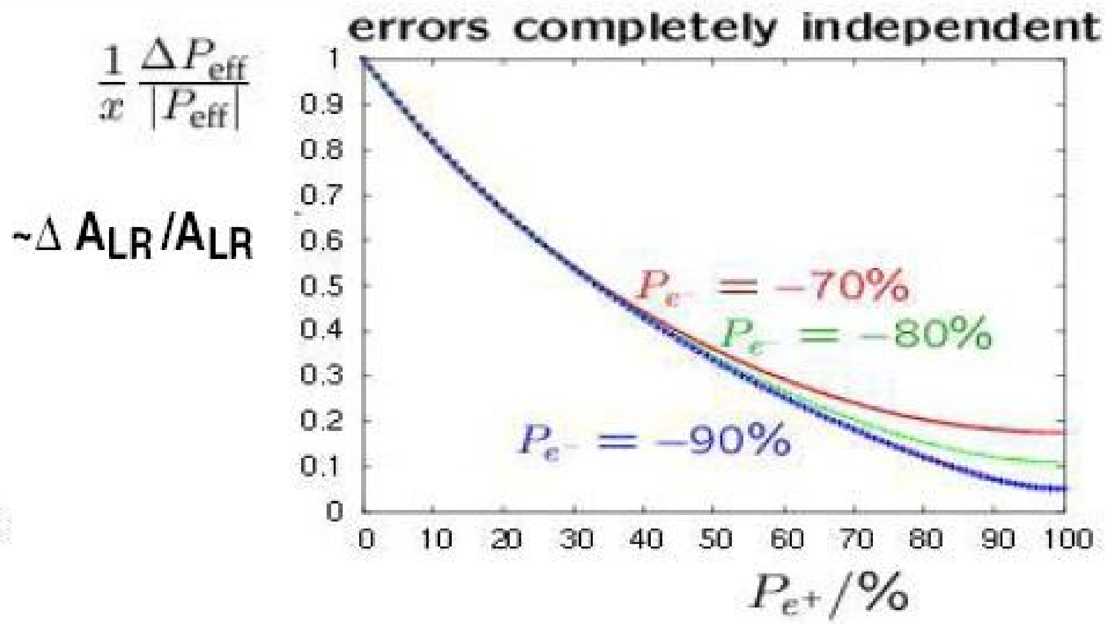
depends on P(e-) !

No. III: Peff and ALR

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

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





- (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

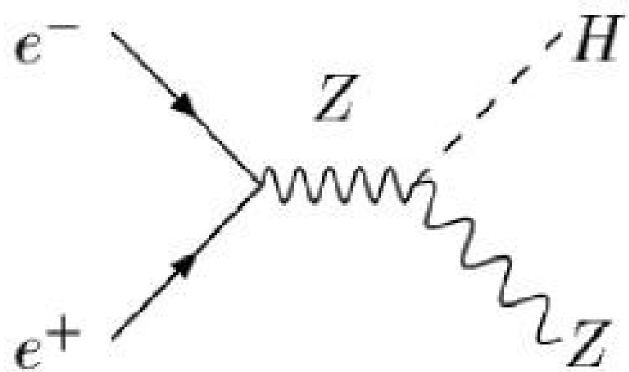
→ NO gain with only polarized e⁻ ! (error prop.: $\frac{\Delta P_{eff}}{P_{eff}} = \frac{1 - |P_{e^+}||P_{e^-}|}{1 + |P_{e^+}||P_{e^-}|}\, x$)

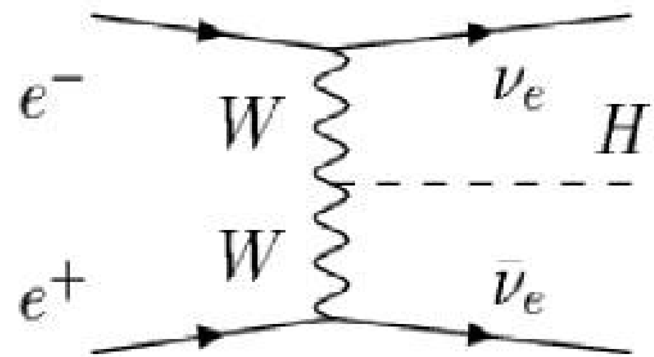
Determination of Higgs properties

- 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

Physics with a light (SM-like) higgs

- 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%)

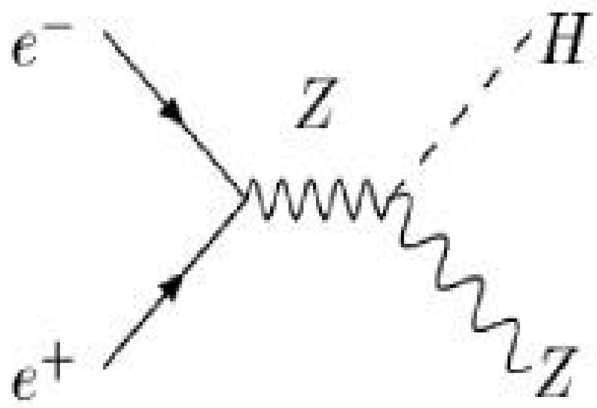
  → **improves by factor 4!**

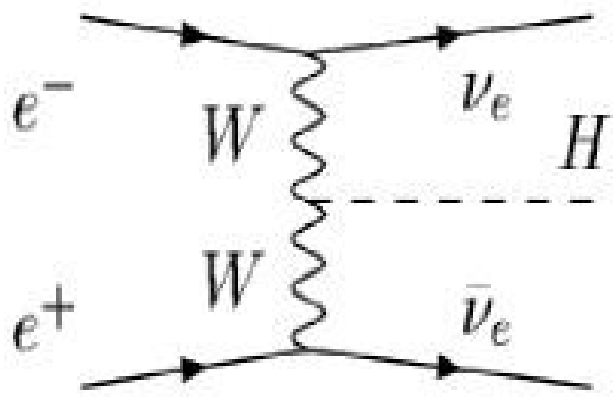
Configuration (P_{e^-}, P_{e^+})	Scaling factors $e^+e^- \to H\nu\bar{\nu}$	$e^+e^- \to HZ$
$(+80\%, 0)$	0.20	0.87
$(-80\%, 0)$	1.80	1.13
$(+80\%, -60\%)$	0.08	1.26
$(-80\%, +60\%)$	2.88	1.70
(+80%, -30%)	0.14	1.06
(-80%, +30%)	2.34	1.42

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

Higgs couplings

- Couplings determination: high rates and lumi needed





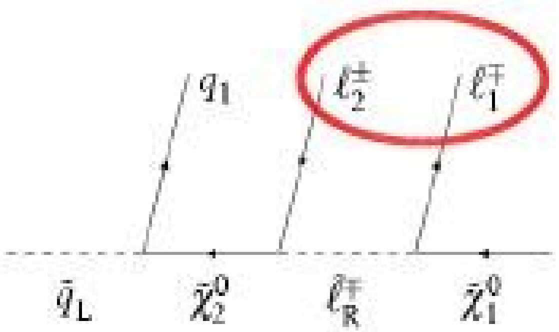
- measurement of couplings in Higgs-strahlungs process at $\sqrt{s}$=350 GeV
- beam polarization (80%,0) ⟶ (80%, 60%): improvement by about 30%
- triple Higgs couplings: e.g. in HHZ at $\sqrt{s}$=500 up to 22% (unpolarized beams)
- estimate: further gain of 30%-50% precision if both beams polarized

Top-Higgs Yukawa couplings

- **Expectations at the LHC:**
  - Yukawa couplings up to ~20% (with some model assumptions)
- **Expectations at the ILC:**
  - process t t H: difficult due to small rates (but threshold effects!)
  - accuracy about 24% for mH=120 GeV (unpolarized beams)
  - improvement factor 2.5 when (80%, 0%) -> (80%,60%)
  - due to gain in ALR accuracy
- **Precise measurement important**
  - in general
  - also for distinction between SM and SM-like Higgs ...

Further SUSY particles

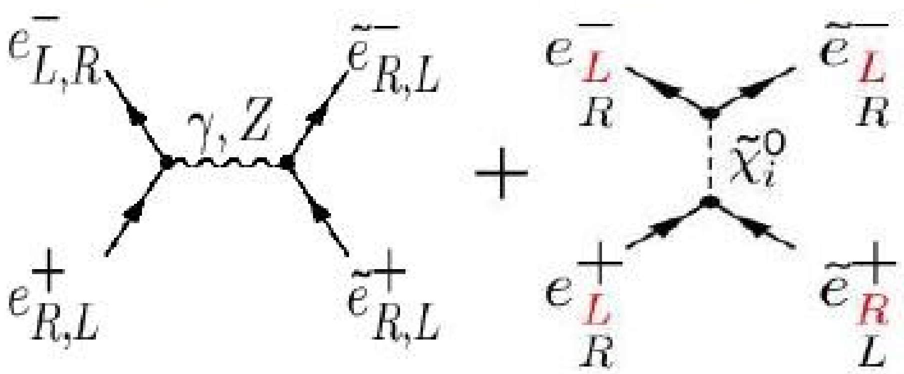
- Whats needed for establishing SUSY?
  - Spin verification: via analysis of angular distributions
  - Couplings measurement: Yukawa couplings = gauge couplings
  - Precise mass measurements
  - Unraveling the SUSY breaking mechanism and test unification
  - 'model- independent' determination of the 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 !

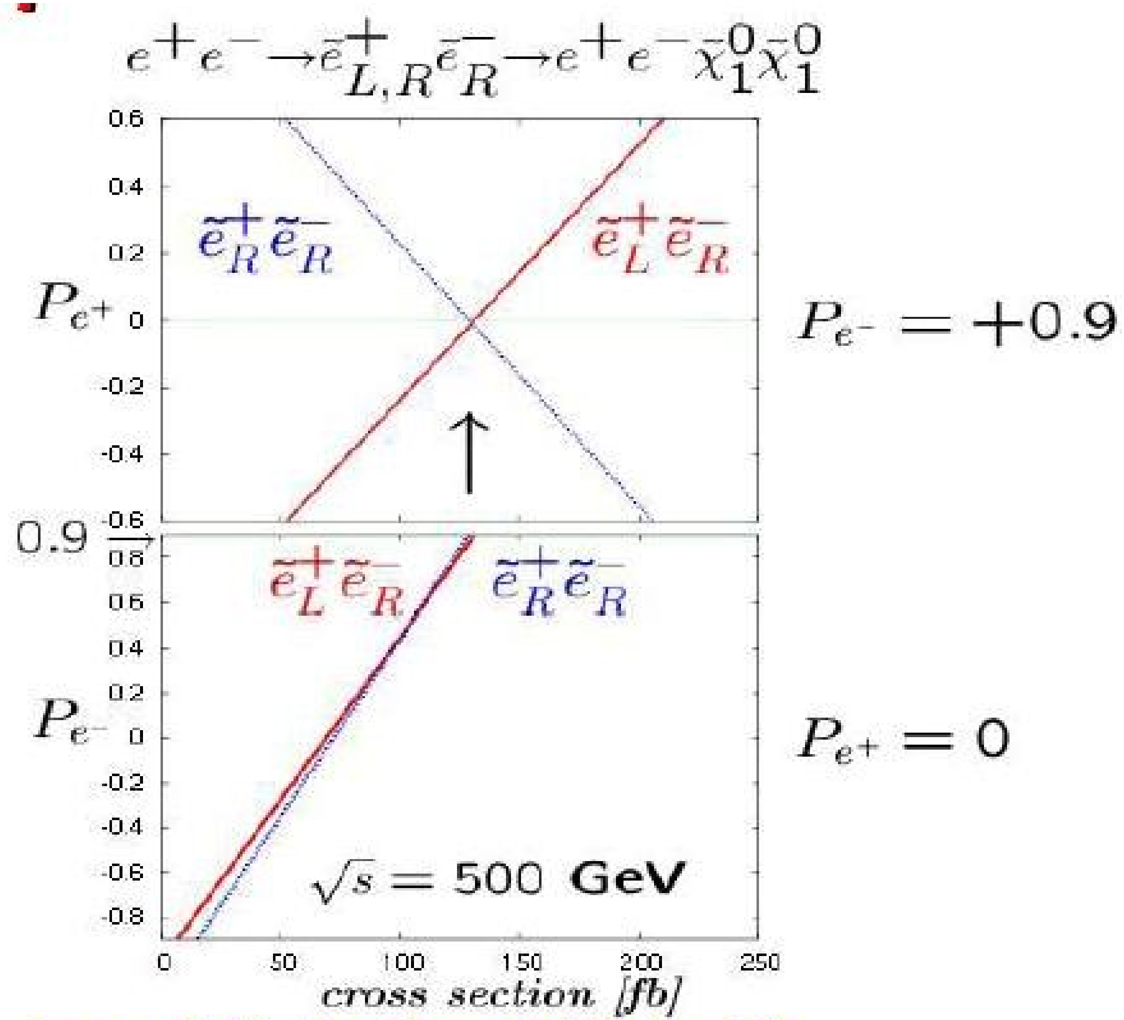


Properties of SUSY particles

- 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

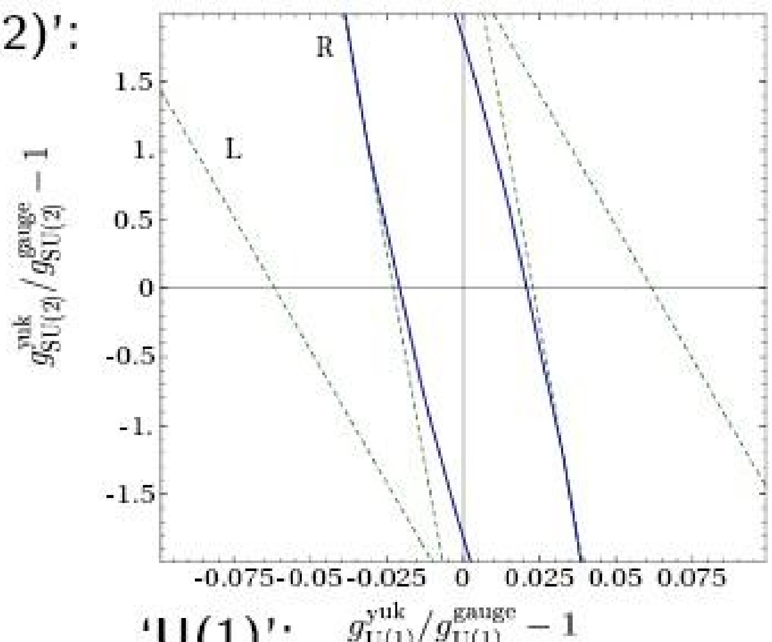
- *Even high P(e-) not sufficient, P(e+) is substantial!*

SUSY Yukawa couplings

Test of SU(2), U(1) gauge couplings $\equiv$ SUSY Yukawa couplings

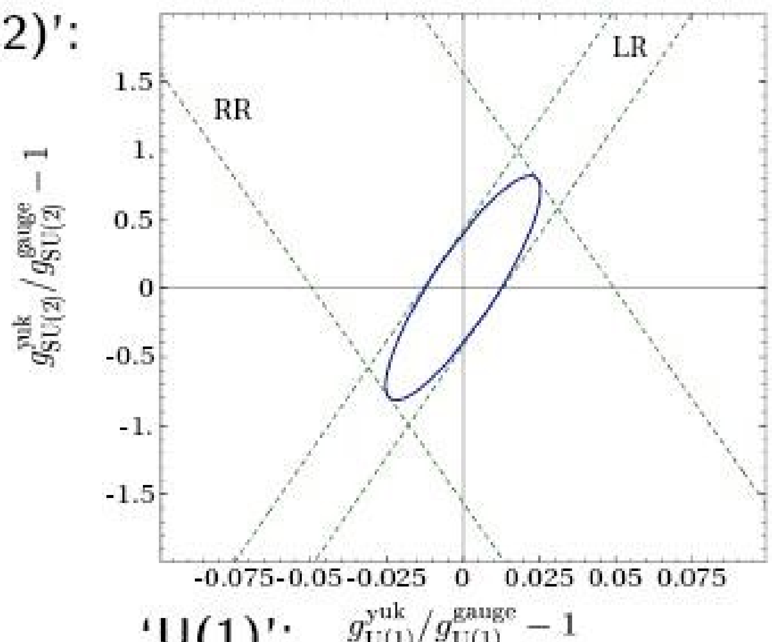
1. separation of the pairs $\tilde{e}^-_R \tilde{e}^+_R$ and $\tilde{e}^-_R \tilde{e}^+_L$
2. 'variation' of Yukawa couplings accepted within experimental uncertainty

'SU(2)':



'U(1)':

'SU(2)':



'U(1)':

e^+ Yukawa couplings: only P_{e^-} | P_{e^-} and P_{e^+}

$\Rightarrow$ SU(2), U(1) Yukawa coupling 'not' measurable | $\Rightarrow$ Δ SU(2)$\sim$ 80%, Δ U(1) $\sim$ 2.5%

CP-violation phases

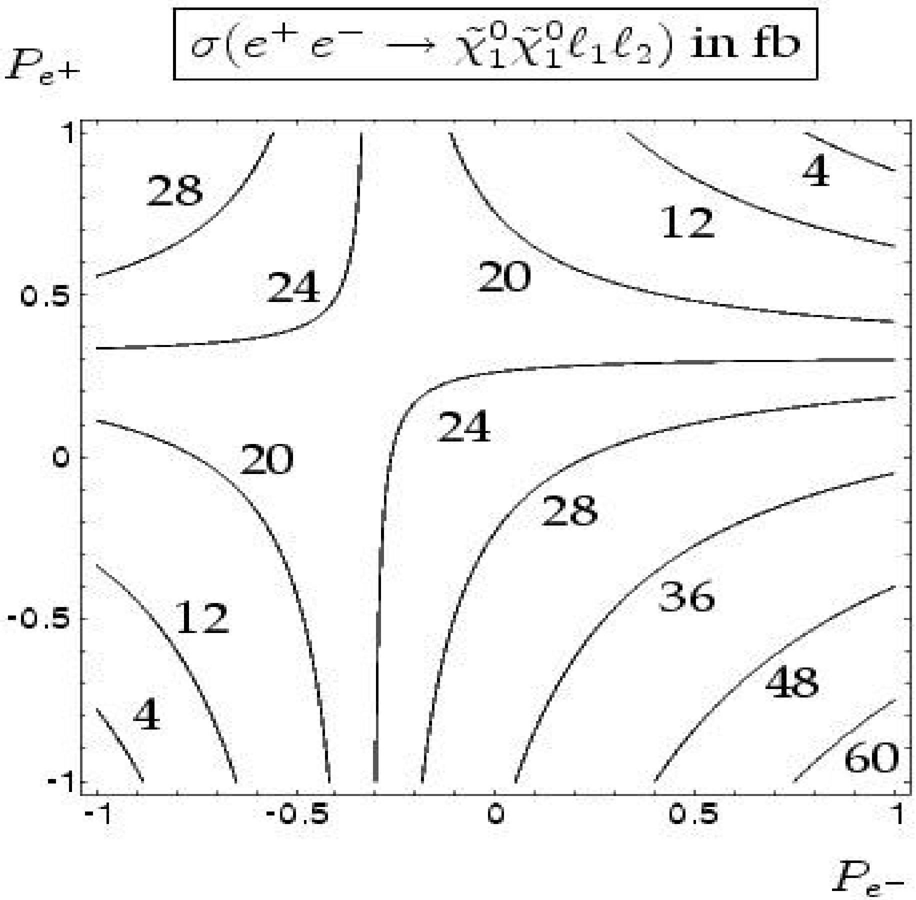
- SUSY provides new sources for CP-violation (→ explain baryon asymmetry....)
  - many phases available in SUSY, but strong experimental constraints from measurements of the e, n, Hg, Tl dipole moments
  - sensitive observables needed to detect even small phases: very sensitive are asymmetries constructed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

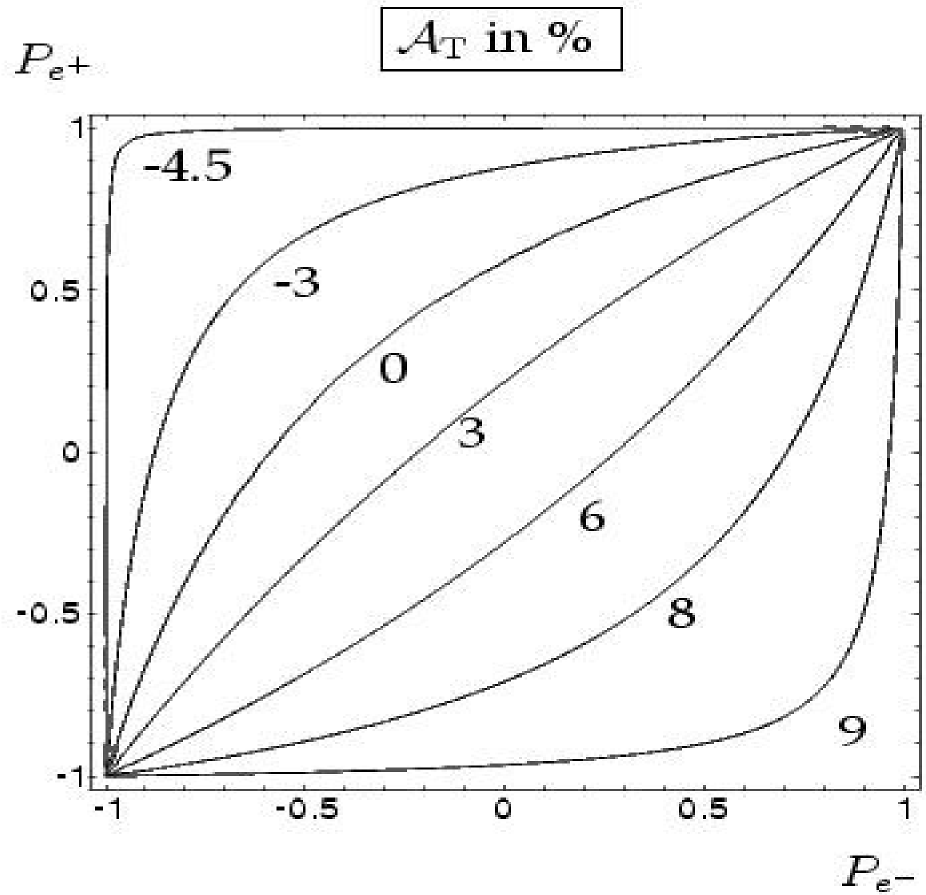
- **Asymmetry detectable if Δasy < asy**

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

  - **Nσ=# of standard deviations**

Measurability of phases: example

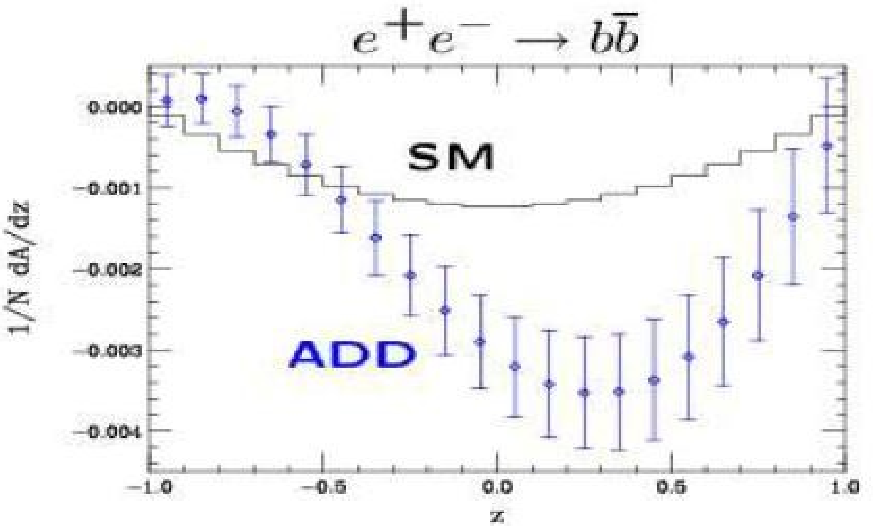




- E.g. asy with 3% (unpolarized beams) not measurable with 500 fb
- with Pe-=90% (and Pe+=60%): for 5 sigma 115 fb (60 fb) needed

Transversely polarized beams

- Remember: only effects detectable if P(e-) and P(e+)
  - ➙ enables to exploit azimuthal asymmetries
- Offers the construction of CP-odd observables in neutralino production
- Offers distinction between SM and different models of extra dimensions



- 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^+ !

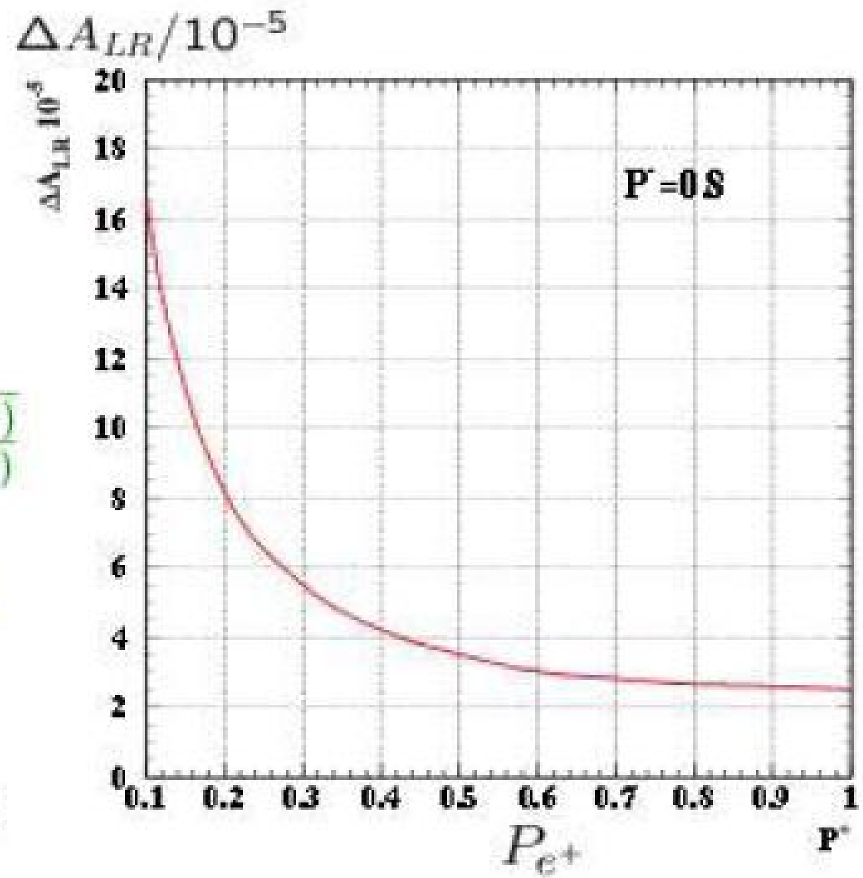
High precision at GigaZ

- 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 !)

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

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



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

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

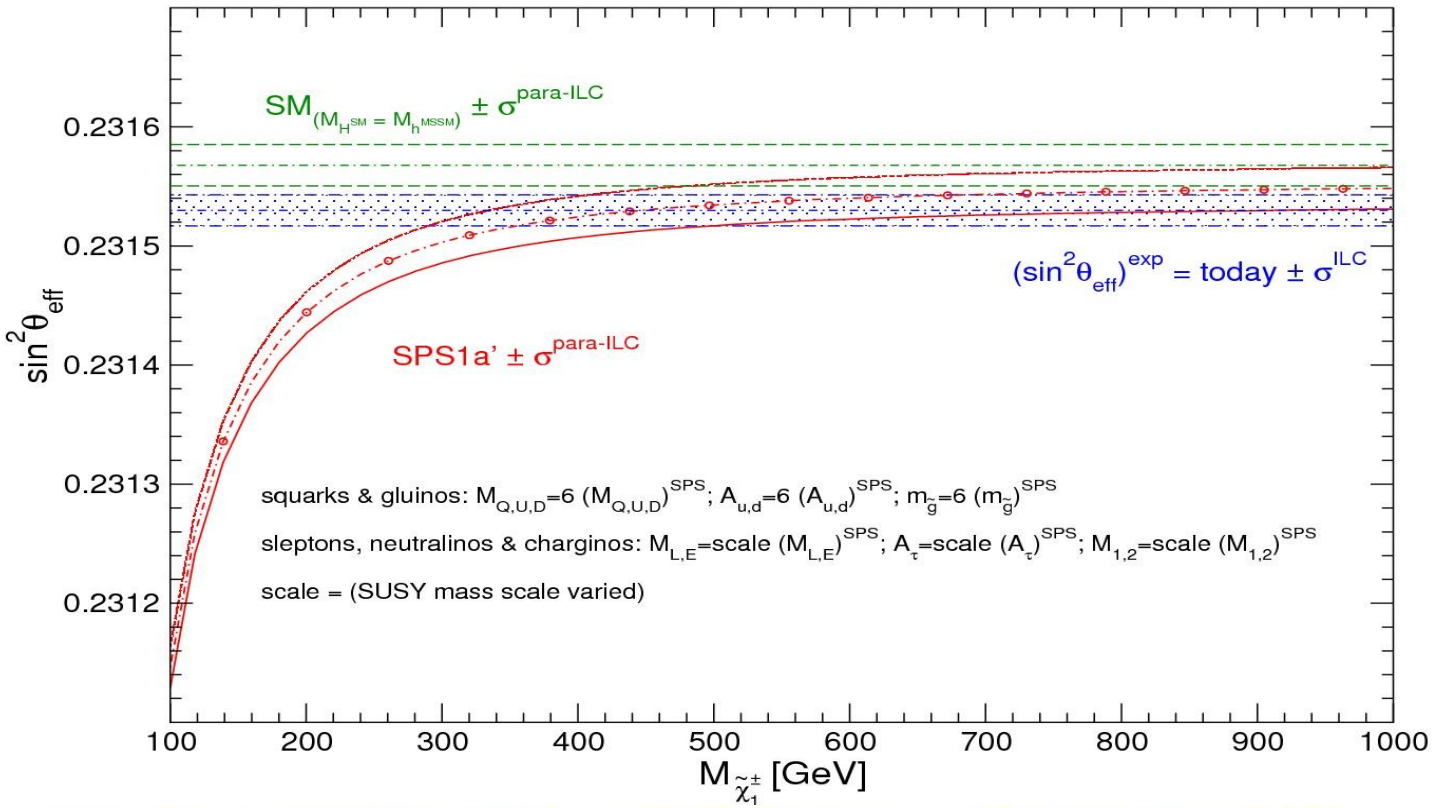
(• with $\Delta P/P = 0.25\%$ and $P_{e^-} = 90\%$:

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

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

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	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ 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 $\tilde{h}_+ = \mathrm{Im}(g_1^{\mathrm{R}} + \kappa^{\mathrm{R}})/\sqrt{2}$	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required	P^T_{e-} P^T_{e+} required
CPV in γZ	Anomalous TGC $\gamma\gamma Z$, γZZ	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ 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 $\tilde{\chi}^0_i\tilde{\chi}^0_j$	Direct CP-odd observables	$P^T_{e^-}P^T_{e^+}$ 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	$P^T_{e^-}P^T_{e^+}$ 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

Further news: positron webpages

- Idea: provide data base for 'sources' and 'non-sources' experts
  - cover all ILC sources
  - list all agreed facts and numbers
  - publications (e.g. POWER report, executive summary + 4 pages summary !)
  - provide useful links
  - all new results should be listed there as soon as possible ....please let me know!
- Pages should cover topics from source to IP
  - all possible technologies
  - target issues
  - related topics, e.g. damping rings, reliability etc.
  - list of open questions and topics
  - prototypes and current R&D status: many activities at Cornell, KEK, Orsay, UK !
- Please look at: *http://www.ippp.dur.ac.uk/~gudrid/source*

Main Menu

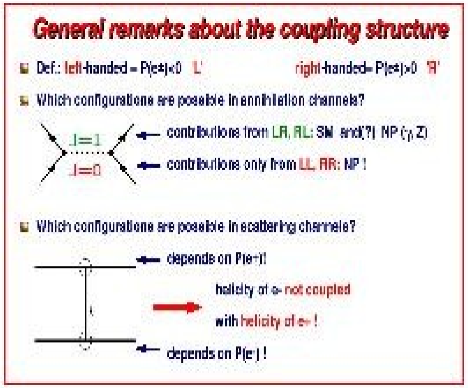
Physics case for polarized positrons at the ILC

A short version of the POWER report and its executive summary has been summarized in this quintessence, including the summary table. More details of the listed examples as well as references to the original studies are given in the POWER report.

Couplings structure:

The dominant processes in e+ e- experiments are annihilation (s-channel) and scattering (t-channel) processes. In annihilation diagrams the helicities of the incoming beams are coupled to each other by the spin of the exchanged particle(s) in the s-channel (in the Standard Model only J=1 possible).

In t-channel diagrams the helicities of the incoming beams are directly coupled to the chirality of the (new) particles produced. If both beams are polarized, it is possible to adjust independently the polarizations of both beams. This ability provides unique possibilities for probing directly the properties of the produced particles.



Statistical issues:

- **Talks, plots, papers listed**
- **Your input/files are welcome!**

Conclusions

- **P(e+) essential to reveal the new physics (CP, SUSY, ED)**
- **P(e+) essential to match required accuracy at ILC(500)**
  - **Higgs mechanism and couplings**
  - **Properties and quantum numbers of new particles**
  - **GigaZ: sensitivity to new physics in worst case scenarios *(a quick upgrade path to this option may be highly desirable!)***
- **Transversely polarized beams important ~ P(e-)P(e+)**
- **P(e+)=30% from the start: already sufficient for some cases, but higher P(e+)>=60% beneficial, of course!**
- **'Sources' webpages : your input is welcome!**
- **Still to do: more on P(e+)=30%, lumi vs. |P(e+)|, ΔP/P=0.05%...**