Gain of beam polarization for the staged approach

G. Moortgat-Pick
(Uni Hamburg/DESY)

- **Technical status**
- **Polarization basics**
- **Physics applications for the staged approach**
- **Conclusions**

LINEAR COLLIDER COLLABORATION

Polarization: Technical facts

- **P(e+) (always yield ≥1.5 imposed):** **P(e-) ~ 80-90%**

√s=240 GeV: 120 GeV e- drive beam

- Undulator with 231 m (K=0.92, λ=11.5 mm), collimator r=3.5 mm
- P(e+)~ 40%

√s=350GeV: 175 GeV e- drive beam

- Collimator with r=1.2 mm, P(e+)~ 56%

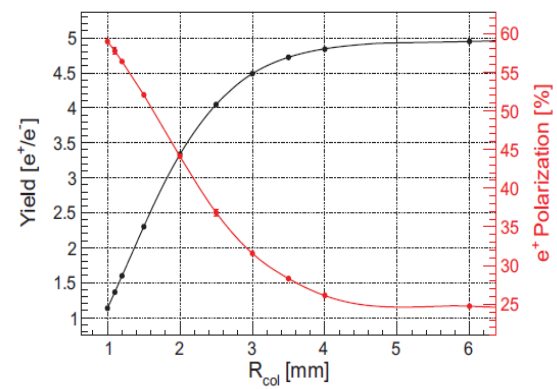
√s=500GeV: 250 GeV e- drive beam

- Undulator with 144 m, collimator r=0.7mm
- P(e+)~59%

√s=1 TeV: 500 GeV e- drive beam

- λ_u = 4:3 cm, 176 m length, collimator r=0.9mm, K=2.5
- P(e+)~54%

Eb=175 GeV



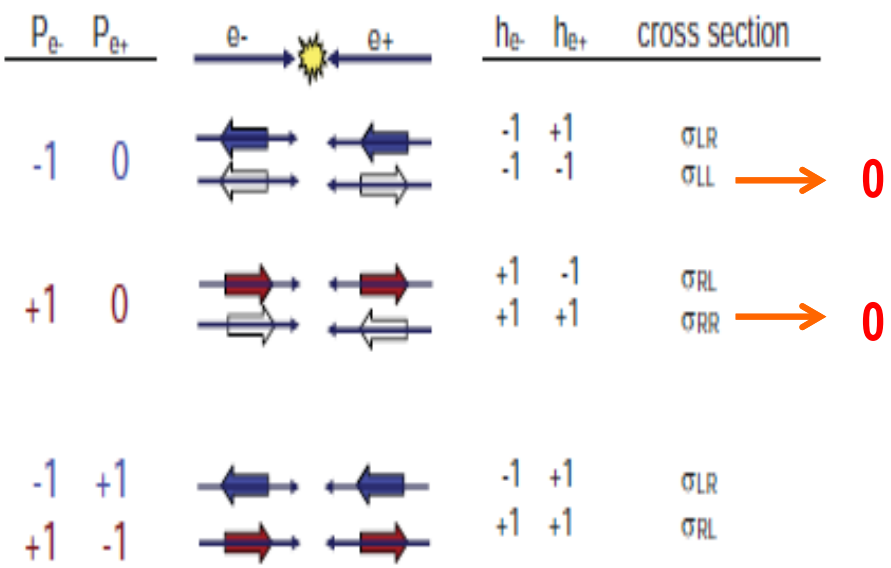
A. Ushakov, LC note

The LC physics offer

- **Staged approach:**
  - $\sqrt{s}$=240 GeV, `Higgs frontier‘
  - $\sqrt{s}$=350 GeV, `Top frontier‘
  - $\sqrt{s}$=500 GeV, `Design energy frontier‘
  - ($\sqrt{s}$=91 GeV, `Precision frontier‘)
  - $\sqrt{s}$=1000 GeV, `Energy upgrade‘

Technical facts II

- **Measurent of polarization:**
  - Compton polarimetry (up- and down-stream): $\delta P/P=0.25\%$
  - Via WW-process (lumi-weighted!): $\delta P/P(e-)\sim0.1\%$,
    $\delta P/P(e+)\sim0.2\text{-}0.3\%$
- **Helicity reversal required:**
  - Fast reversal to benefit from higher $L_{eff}=(1-P_{e-}P_{e+})L$
  - Spin rotator before DR



- **For many processes (V, A interactions) one can write:**

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

- **Effective polarization**

  → P_{eff}:=(P_{e-} -P_{e+})/(1-$P_{e-}P_{e+}$)==(#LR-#RL)/(#LR+#RL)

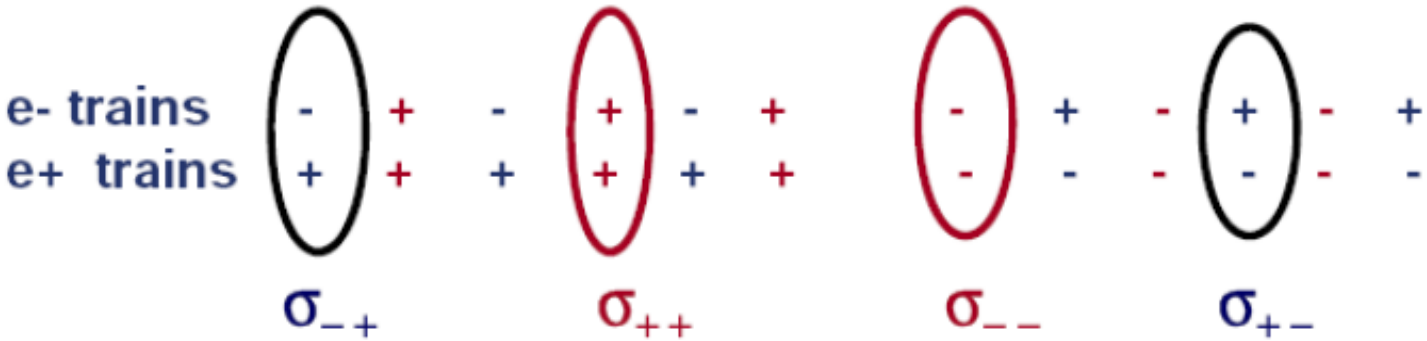
- **Fraction of colliding particles**

  → L_{eff}/ L=1/2 (1-P_{e-} P_{e+})=(#LR+#RL)/(#all)

	RL	LR	RR	LL	P_{eff}	$\mathcal{L}_{eff}/\mathcal{L}$
$P(e^-) = 0$, $P(e^+) = 0$	0.25	0.25	0.25	0.25	0.	0.5
$P(e^-) = -1$, $P(e^+) = 0$	0	0.5	0	0.5	-1	0.5
$P(e^-) = -0.8$, $P(e^+) = 0$	0.05	0.45	0.05	0.45	-0.8	0.5
$P(e^-) = -0.8$, $P(e^+) = +0.6$	0.02	0.72	0.08	0.18	-0.95	0.74

Impact of helicity flipping

- Gain in 'effective luminosity' only with P_{e-} and P_{e+}
  - ~similar flip frequency for e- and e+ needed, otherwise this gain is lost:



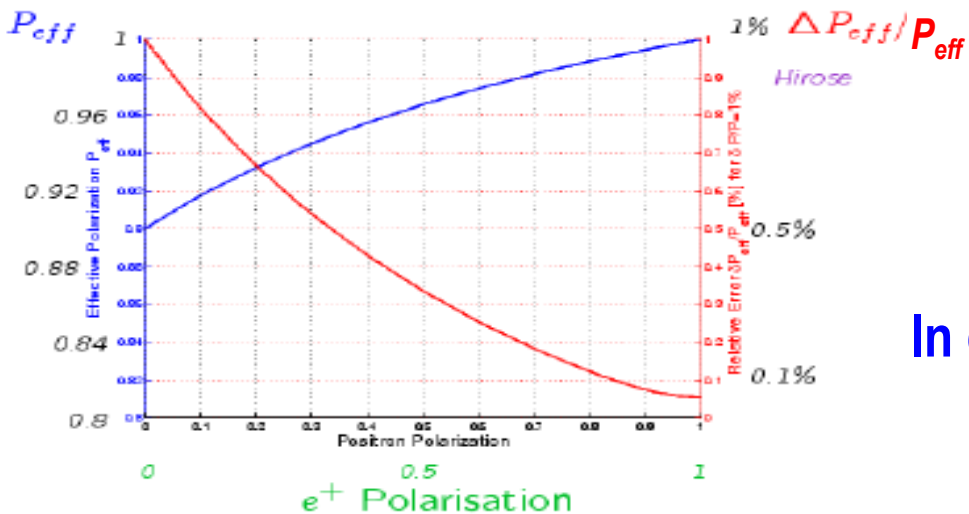
  - 50% spent to 'inefficient' helicity pairing σ_{++} and σ_{--}
  - gain due to xs enhancement for J=1 processes with e^+ were lost!
- Gain in ΔPeff remains but flipping polarity needed to understand
  - systematics and correlations P_{e-} x P_{e+}

Quantitative P(e+) effects

- **If only (axial)vector couplings involved (SM):**
  - $\sigma_{pol} = \sigma_{unpol} (L_{eff} / L) (1 - P_{eff} A_{LR})$

S. Riemann, LC note

$$\mathcal{P}_{\rm eff} = \frac{-\mathcal{P}_{e^-} + \mathcal{P}_{e^-}}{1 - \mathcal{P}_{e^-}\mathcal{P}_{e^+}} > P_e$$



If #events large:
$\delta P_{eff}/P_{eff} \sim \delta A_{LR}/A_{LR}$

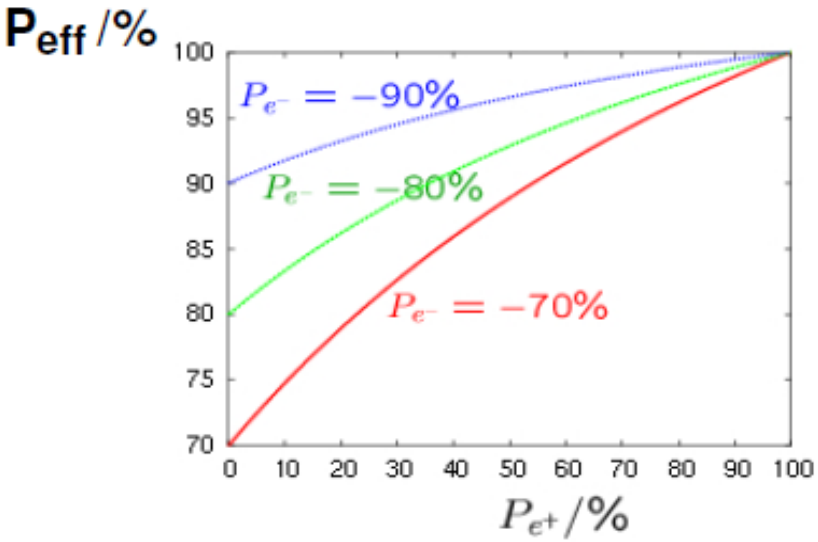
In general:

$$\delta A_{\rm LR} = \sqrt{\frac{1 - \mathcal{P}_{\rm eff}^2 A_{\rm LR}}{\mathcal{P}_{\rm eff} N} + A_{\rm LR}^2 \left(\frac{\delta \mathcal{P}_{\rm eff}}{\mathcal{P}_{\rm eff}}\right)^2}$$

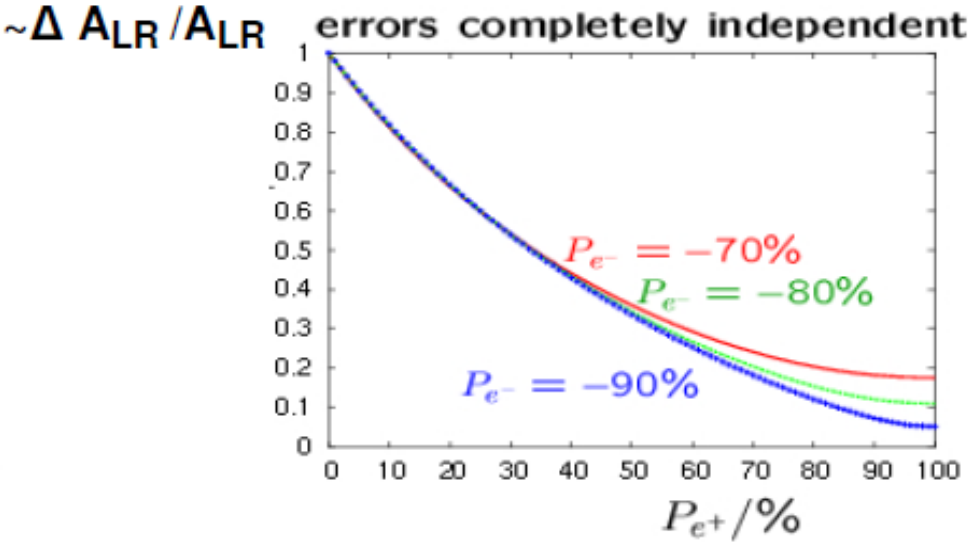
- **Enhancement of L_{eff}** ⟵ **More interactions!**
- **Reduction of δP_{eff}** ⟵ **Higher accuracy**
- **Better S/B, S/√B**

Impact of P(e+)

- **Statistics**



- **And gain in precision**



- (80%,60): P_{eff} = 95% — $\Delta A_{LR}/A_{LR}$ = 0.3 — gain: factor~3
  (90%,60%): P_{eff} =97% — $\Delta A_{LR}/A_{LR}$ = 0.27 — factor>3
  (90%, 30%): P_{eff} =94 % — $\Delta A_{LR}/A_{LR}$ =0.5 — factor~2
- **NO gain with only pol. e- (even if '100% ') !**

P_{eff} and L_{eff} for the staged approach

- **With the listed parameters:**

$\sqrt{s}$	$P(e^-)$	$P(e^+)$	$P_{\rm eff}$	$\mathcal{L}_{\rm eff}/L$	$\frac{1}{x}\Delta P_{\rm eff}/P_{\rm eff}$
total range	$\mp 80\%$	0%	$\mp 80\%$	1	1
250 GeV	$\mp 80\%$	$\pm 40\%$	$\mp 91\%$	1.3	0.43
$\geq$350 GeV	$\mp 80\%$	$\pm 55\%$	$\mp 94\%$	1.4	0.30
total range	$\mp 90\%$	0%	$\mp 90\%$	1	1
250 GeV	$\mp 90\%$	$\pm 40\%$	$\mp 96\%$	1.4	0.43
$\geq$350 GeV	$\mp 90\%$	$\pm 55\%$	$\mp 97\%$	1.5	0.29

← **No gain!**

← **No gain!**

Gain in polarization! (Almost 100%)

Gain in number of interactions!

Gain in precision by more then a factor 3! (large N)

- **Just by switching on P(e+)!**

Impact of positron polarization

- **Four classes:**
  - **Enhancement of specific cross sections ``higher lumi“**
  - **Changes weight between signal and background … ``higher lumi”, but can achieved evtl. by clever cuts**
  - **Provides more observables …..``unique”**
  - **Since polarization=chirality: extracts new characteristics of interactions ….. ``unique”**
- **In the following:**
  - **Relevance for different stages**

Staged approach

250 GeV

- $\sqrt{s}$=250 GeV, `Higgs frontier': HZ production
  - Determination of couplings to c, b,g

$\Delta(\sigma^*BR)/(\sigma^*BR)$	250 GeV/250 fb^{-1} P = (-0.8,+0,3)	350 GeV/250 fb^{-1} P = (-0.8,+0,3)	
H→bb	1.0%	1.0%	>factor 10 better than HL-LHC
H→cc	6.9%	6.2%	LC unique
H→gg	8.5%	7.3%	LC unique

[H.Ono, A: Miyamoto] EPJC (2013) 73

➢ *This stage is crucial for model-independence via recoil method!*

- Scaling factor about $\sigma_{pol}/\sigma_{unpol} \sim (1-0.151\, P_{eff}) * L_{eff}/L$
  - With P_{e+}=0%: $\sigma_{pol}/\sigma_{unpol} \sim 1.13$
  - With P_{e+} =40%: $\sigma_{pol}/\sigma_{unpol} \sim 1.55$ (about 37% increase comp. to 0%)

Higgs +top sector

350 GeV

- $\sqrt{s}$=350 GeV: Higgs couplings and width:
  - In Higgsstrahlung: $\sigma_{pol}/\sigma_{unpol} \sim (1-0.151\, P_{eff}) * L_{eff}/L$

    With P_{e+}=0%: $\sigma_{pol}/\sigma_{unpol} \sim 1.13$
    With P_{e+} =55%: $\sigma_{pol}/\sigma_{unpol} \sim 1.71$ (about 50% increase comp. 0%)

  - In WW-Fusion: $\sigma_{pol}/\sigma_{unpol} \sim (1-P_{eff}) * L_{eff}/L$

    With P_{e+}=0%: $\sigma_{pol}/\sigma_{unpol} \sim 1.90$
    With P_{e+} =55%: $\sigma_{pol}/\sigma_{unpol} \sim 2.95$ (about 55% increase comp. 0%)

- Important: Higgs width

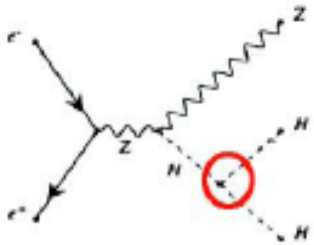
  (needed for BR's, model-ind. Coupl.)

250 GeV	11.0 %
350 GeV	3.6 % ← with (80%,30%)
500 GeV	3.2 %

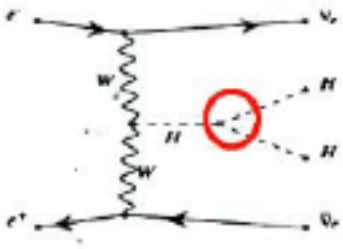
[Dürig; Meyer,KD]

Trilinear Higgs couplings

- **Very important for establishing Higgs mechanism!**
  - **LHC estimates:**
    - **about $\Delta\lambda_{HHH}$~32% at HL-LHC (14 TeV, 3000fb^{-1})**
  - **At LC: Very challenging (small rates , lots of dilution+backg.)**



$d\lambda/\lambda = 1.8\ d\sigma/\sigma$



$d\lambda/\lambda = 0.85\ d\sigma/\sigma$

500 GeV 2 ab^{-1} P=(-0,8,0,3)

	$\Delta\lambda/\lambda$
ILC 500/2ab^{-1}	44%
ILC 1000/2ab^{-1}	18%

[J.Tian LC-REP-2013-003]

state-of-the-art today

  - **Further improvement with P_{e+} =55% instead of P_{e+} =30%:**
    - **Same scaling factors as given before**
    - **In total: about 50% enhancement comp. to P_{e+}=0% !**

Top sector

500 GeV

- $\sqrt{s}$=500 GeV: top electroweak and top-Yukawa couplings:
  - Yukawa couplings: g_{ttH}

	500 GeV/ 1 ab^{-1}	1000 GeV/ 2 ab^{-1}
$\Delta g_{ttH}/g_{ttH}$	10%	4.6%

- $\sqrt{s}$=1000 GeV: $\Delta g_{ttH} / g_{ttH}$<4%

R. Yonamine, T. Tanabe, K. Fujii

E_{CM} = 500 GeV, L= 1 ab^{-1}, Pol= (-0.8,+ 0.3)

'Measure' for importance of beam polarization:

- If only P_{e-}=80%: improvement of Δg_{ttH}~19% comp. with P_{e-}=0
- With P_{eff}=89%: improvement of Δg_{ttH}~42% (with 80%/30%)
- With P_{eff}=97%: improvement of Δg_{ttH}~47% (with 90%,55%)

Top electroweak coupling $\sqrt{s}$=500 GeV

- $\sqrt{s}$=500 GeV: chiral structure of top couplings
  - Cross section ~maximal at this energy
  - Top's have sufficient velocity
  - A_{FB} well developed
- Use different observables
  - Cross section
  - A_{FB}
  - helicity angle

Coupling	SM value	LHC [1] $\mathcal{L} = 300$ fb^{-1}	e^+e^- [6] $\mathcal{L} = 300$ fb^{-1} $\mathcal{P}, \mathcal{P}' = -0.8, 0$	e^+e^- [ILC DBD] $\mathcal{L} = 500$ fb^{-1} $\mathcal{P}, \mathcal{P}' = \pm 0.8, \mp 0.3$
$\Delta\tilde{F}^{\gamma}_{1V}$	0.66	$^{+0.043}_{-0.041}$	$^{-}_{-}$	$^{+0.002}_{-0.002}$
$\Delta\tilde{F}^{Z}_{1V}$	0.23	$^{+0.240}_{-0.620}$	$^{+0.004}_{-0.004}$	$^{+0.003}_{-0.003}$
$\Delta\tilde{F}^{Z}_{1A}$	-0.59	$^{+0.052}_{-0.060}$	$^{+0.009}_{-0.013}$	$^{+0.005}_{-0.005}$
$\Delta\tilde{F}^{\gamma}_{2V}$	0.015	$^{+0.038}_{-0.035}$	$^{+0.004}_{-0.004}$	$^{+0.003}_{-0.003}$
$\Delta\tilde{F}^{Z}_{2V}$	0.018	$^{+0.270}_{-0.190}$	$^{+0.004}_{-0.004}$	$^{+0.006}_{-0.006}$

- Couplings measurable at %-level thanks to
  - the different observables
  - runs with different beam polarization configurations P(e-), P(e+)

⟶ Powerful test of the chiral structure!

Unique access to elecweak top couplings

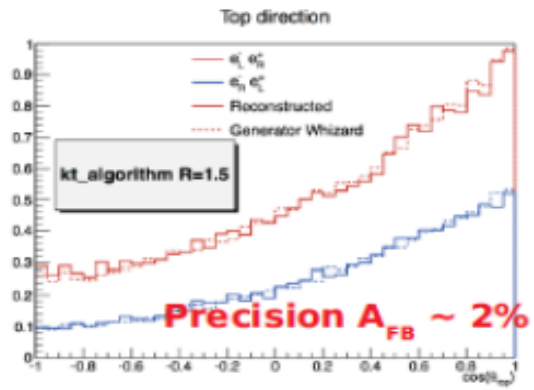
Roman Poeschl, Lyon, Mai 2013

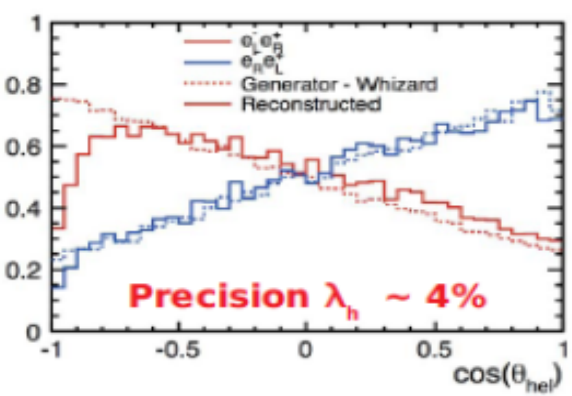
$\sqrt{s}$=500 GeV

Results of full simulation study for DBD at $\sqrt{s}$ = 500 GeV

LC-REP-2013-007

Precision: x section ~ 0.5%





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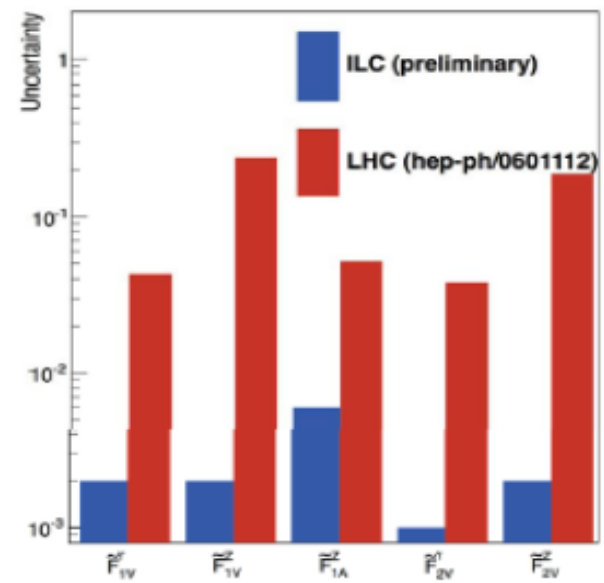
Precision of couplings



ILC might be up to two orders of magnitude more precise than LHC ($\sqrt{s}$ = 14 TeV, 300 fb^{-1})

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Effects of transverse beams $\sqrt{s}$=500 GeV

Ananthanarayan, Patra, Rindani

- **Transversely-polarized beams in e+e- -> tt**
  - **probe scalar- and tensor-like interactions**
- **Parametrization via eff. four-Fermi operators:**

$$\mathcal{L}^{\Lambda F} = \sum_{i,j=L,R} \left[S_{ij}(\bar{e}P_i e)(\bar{t}P_j t) + T_{ij}(\bar{e}\frac{\sigma_{\mu\nu}}{\sqrt{2}}P_i e)(\bar{t}\frac{\sigma^{\mu\nu}}{\sqrt{2}}P_j t) \right]$$

- **Use angular distributions with P^T_{e+} P^T_{e+}**
  - **Sensitive to azimuthal angle: specific asymmetries**
  - **Assumed 100% beams**
- **Sensitive to small S-,T-admixtures**

$\sqrt{s}$	Case	Coupling	Individual limit from asymmetries			
			$A_1(\theta_0)$	$A_2(\theta_0)$	$A_1^{FB}(\theta_0)$	$A_2^{FB}(\theta_0)$
500GeV	+−	ReS		2.3×10^{-3}TeV^{-2}		
		ReT				5.2×10^{-3}TeV^{-2}
		ImT	1.2×10^{-3}TeV^{-2}		1.0×10^{-2}TeV^{-2}	
	++	ImS	2.3×10^{-3}TeV^{-2}			
		ReT		1.2×10^{-3}TeV^{-2}		1.0×10^{-2}TeV^{-2}
		ImT			5.2×10^{-3}TeV^{-2}	

'New tools' for new physics: polarization

- **Access to chirality**

  In practically all new physics models
  - **Chirality of particles/interactions has to be identified**
  - **Since for E>>m: chirality = helicity = polarization**
- **Access to specific asymmetries** (ν, heavy leptons, …, see LC notes)

$$A_{\text{double}} = \frac{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)-\sigma(P_1,P_2)-\sigma(-P_1,-P_2)}{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)+\sigma(P_1,P_2)+\sigma(-P_1,-P_2)},$$

- **Exploitation of transversely-polarized beams** (~ P_{e-} P_{e+})
  - **Access to tensor-like interactions (Extra dimensions, etc.)**
  - **Access to CP-violating phenomena**
  - **Access to specific triple gauge couplings**

What's about BSM/SUSY?

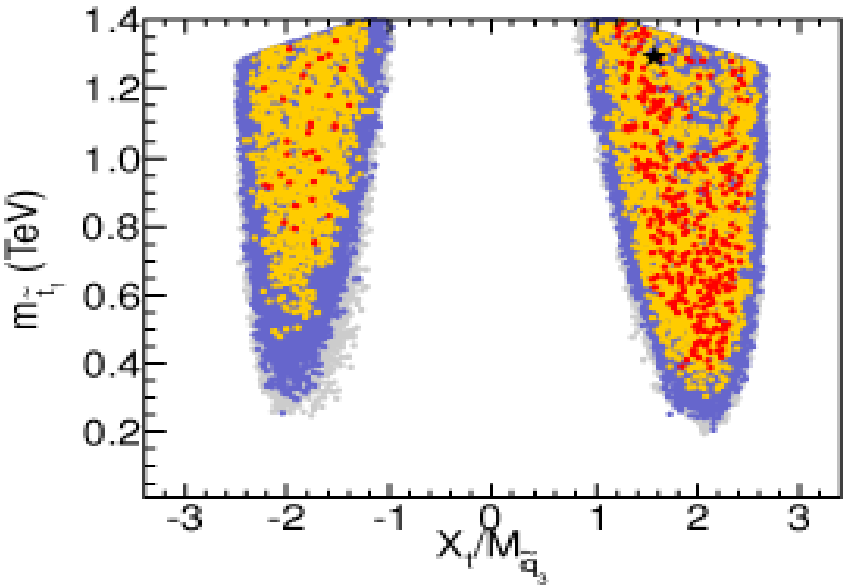
- **SUSY: still strongly motivated and beautiful, but**
  - **so far, no hints of a signal at LHC, only rather high exclusion limits in the coloured sector**
  - **Since Higgs mass of in SUSY not free, mH=126GeV constrains the model**
  - **But only specific SUSY models (CMSSM,…) less favoured**
- **Further hints from theory?**
  - **From low energy precision experiments and theory**

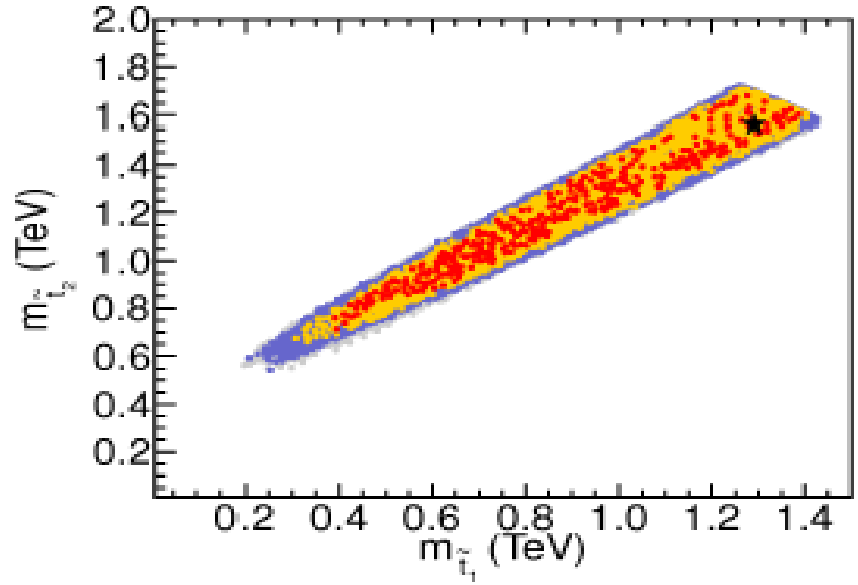
- ***some SUSY particles very light and probably not the simplest model …. Open playground for the LC!***

Impact of stop mixing on light Higgs

- **MSSM fit, preferred values for stop masses**

Bechtle, Heinemeyer,Stal,Stefaniak,Weiglein,Zeune





- **Rather large $X_t = A_t - \mu \cot \beta$**

➢ **Large stop mixing required**

Best fit prefers heavy stops beyond 1 TeV

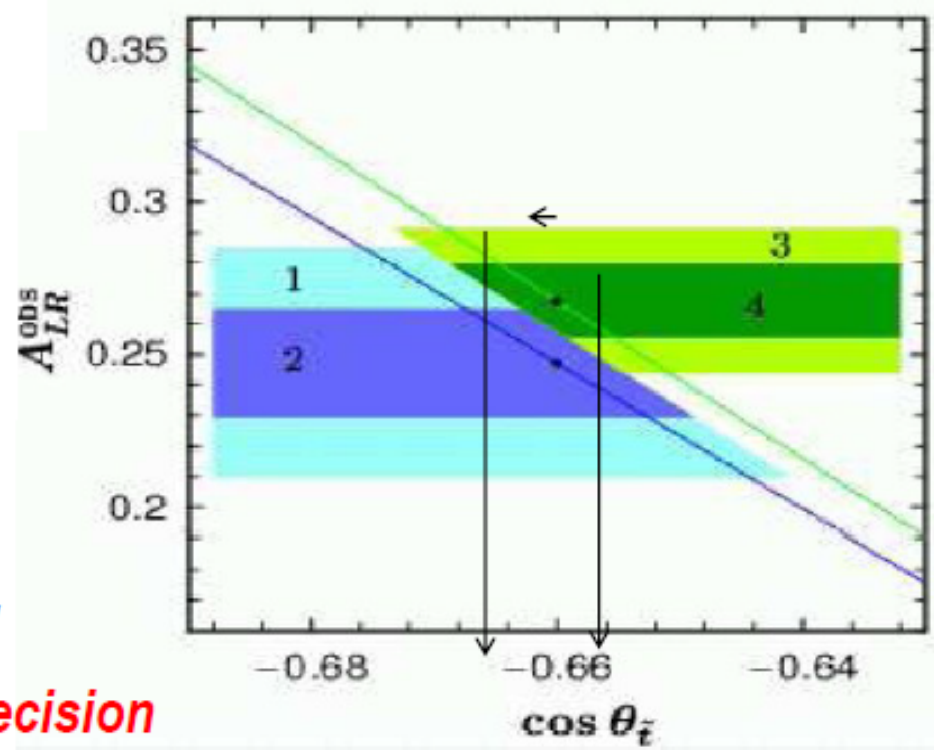
But good fit also for light stops down to ≈300 GeV

Relevance of stop mixing angle: Higgs mass

- **With polarized beams: A_{LR} applicable**

Eberl, Kraml,'05

$\mathcal{L}_{\rm int}$	P_{e^-}	P_{e^+}	$\Delta m_{\tilde{t}_1}$	$\Delta\cos\theta_{\tilde{t}}$
100 fb^{-1}	∓ 0.9	0	1.1%	2.3%
500 fb^{-1}	∓ 0.9	0	0.5%	1.1%
100 fb^{-1}	∓ 0.9	± 0.6	0.8%	1.4%
500 fb^{-1}	∓ 0.9	± 0.6	0.4%	0.7%



- **Mixing angle $\Delta\cos\theta_t$<1%**
  - **If $\Delta X_t \pm 1\%$: $\Delta m_h = \pm 0.2$GeV**

→ *matches long-term LHC precision*

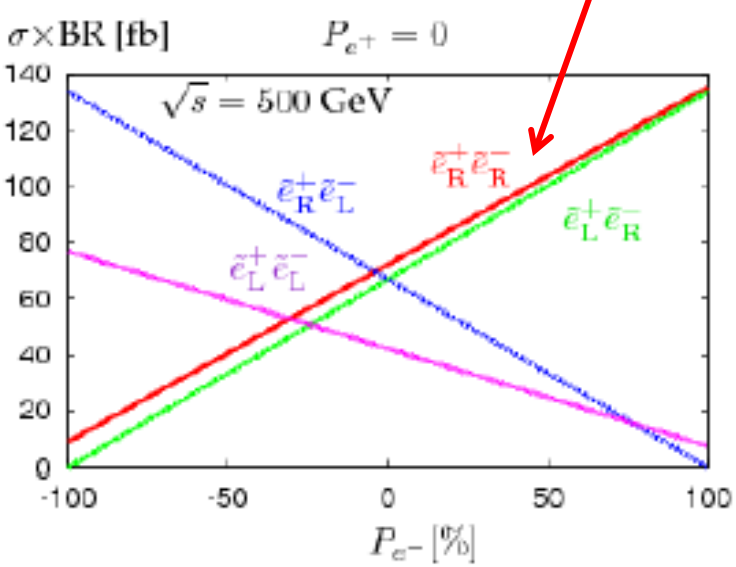
  - **If $\Delta X_t \pm 10\%$: $\Delta m_h = \pm 1.5$GeV**

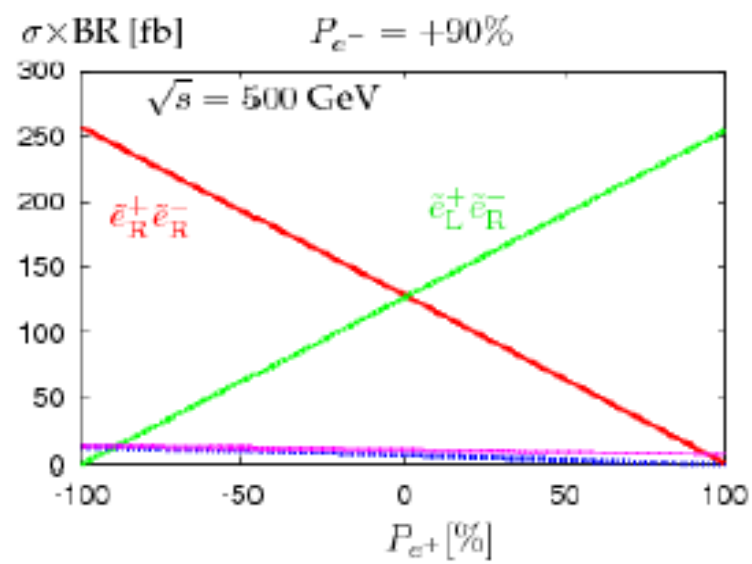
→ *Too big to check the consistency of the model!*

Chirality proof of sleptons

- **Test of chirality of new particles via beam polarization**
  - **Selectrons = SUSY partner of electrons sel_L,sel_R**

Even with $P_{e^-} \geq +90\%$, one can't disentangle the pairs $\tilde{e}_L^+\tilde{e}_R^-$ and $\tilde{e}_R^+\tilde{e}_R^-$': Ratio of the cross sections $\approx$ constant.



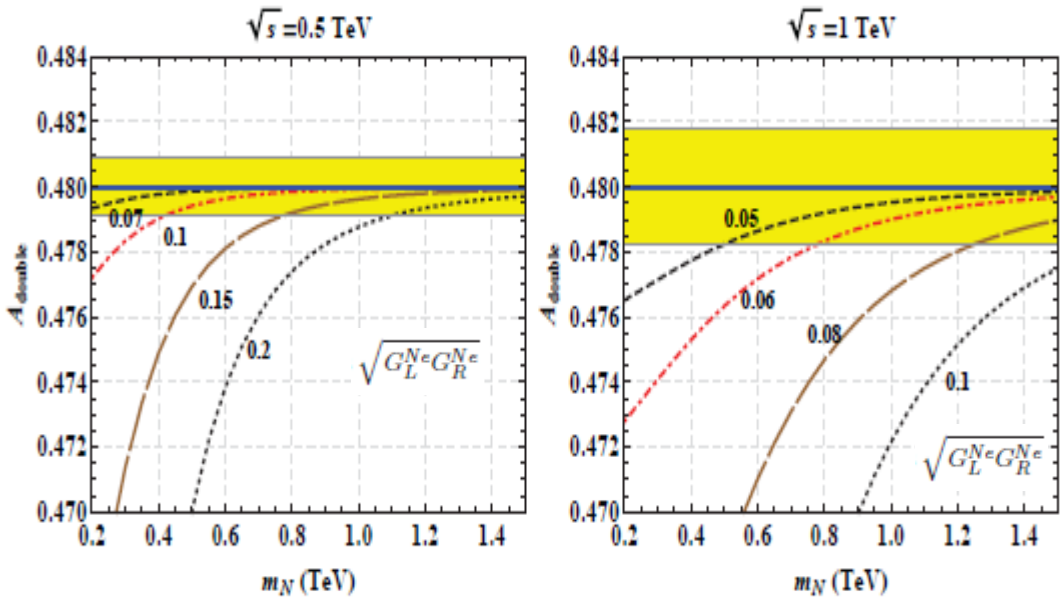


P_{e+} required!

Exotics in ew sector: heavy Leptons

- **Study: e+e- -> W+W-**
  - Very sensitive to leptonic verrtices and trilinear gauge couplings
  - New heavy neutral boson or heavy leptons can contribute
  - E.g., E6 inspired model are consistent with Z's but also new heavy leptons (SU(2))
- **Model identification = exclusion of competitive models (incl. SM)**
  - Double polarization asymmetries very useful:

$$A_{\text{double}} = P_1 P_2 \frac{(\sigma^{RL} + \sigma^{LR}) - (\sigma^{RR} + \sigma^{LL})}{(\sigma^{RL} + \sigma^{LR}) + (\sigma^{RR} + \sigma^{LL})}.$$

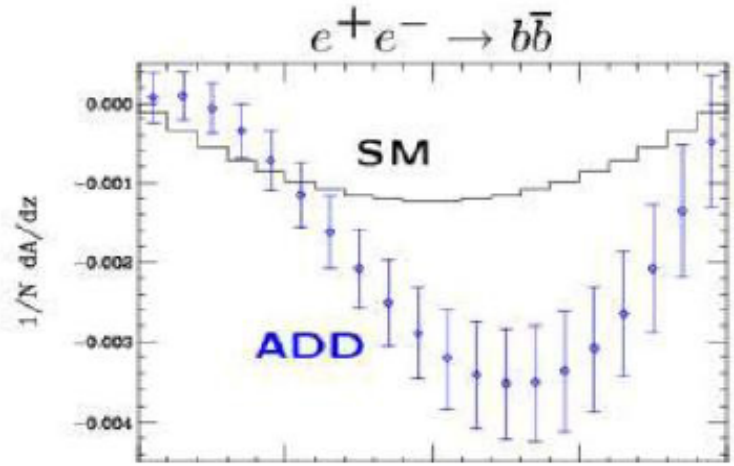


$$A_{\text{double}}^{\text{SM}} = A_{\text{double}}^{Z'} = A_{\text{double}}^{\text{AGC}}$$

Sensitive to effects from such models and model distinction already at 500 GeV!

Structure of interactions: extra dimensions

- 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^+ !

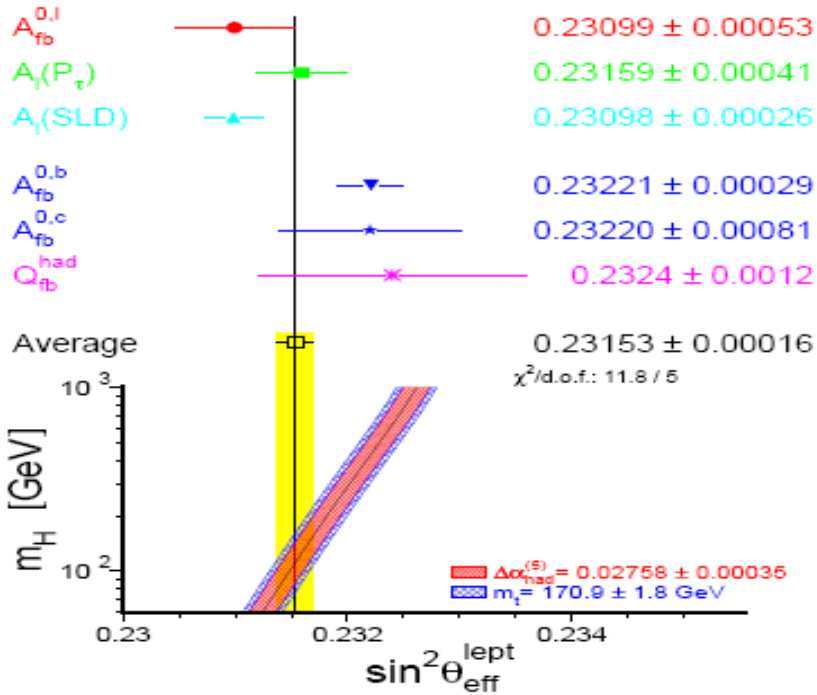
What if nothing else than H is found now?

The exciting Higgs story has just started….

- **Since m_H is free parameter in SM at tree level**
  - **Crucial relations exist, however, between m_{top}, m_W and $\sin^2\theta_{eff}$**
  - **If nothing else appears in the electroweak sector, these relations have to be urgently checked**
- **Which strategy should one aim?**
  - **exploit precision observables and check whether the measured values fit together at quantum level**
  - **m_Z ,m_W,α_{had}, $\sin^2\theta_{eff}$ und m_{top}**
- **Exploit `GigaZ' option: high lumi run at $\sqrt{s}$ = 91 GeV**
  - **Pe-=80% and Pe+=60% required !**

    (If only Pe-=90% : precision ~factor 4 less!)

Higgs story has just started … $\sqrt{s}$=91 GeV



LEP:

$\sin^2\theta_{eff}(A_{FB}^b)$= 0.23221±0.00029

SLC:

$\sin^2\theta_{eff}(A_{LR})$= 0.23098±0.00026

World average:

$\sin^2\theta_{eff}$ = 0.23153±0.00016

Goal GigaZ: $\Delta\sin\theta$=1.3 10^{-5}

- **Uncertainties from input parameters: Δm_Z, $\Delta\alpha_{had}$, m_{top} ,…**

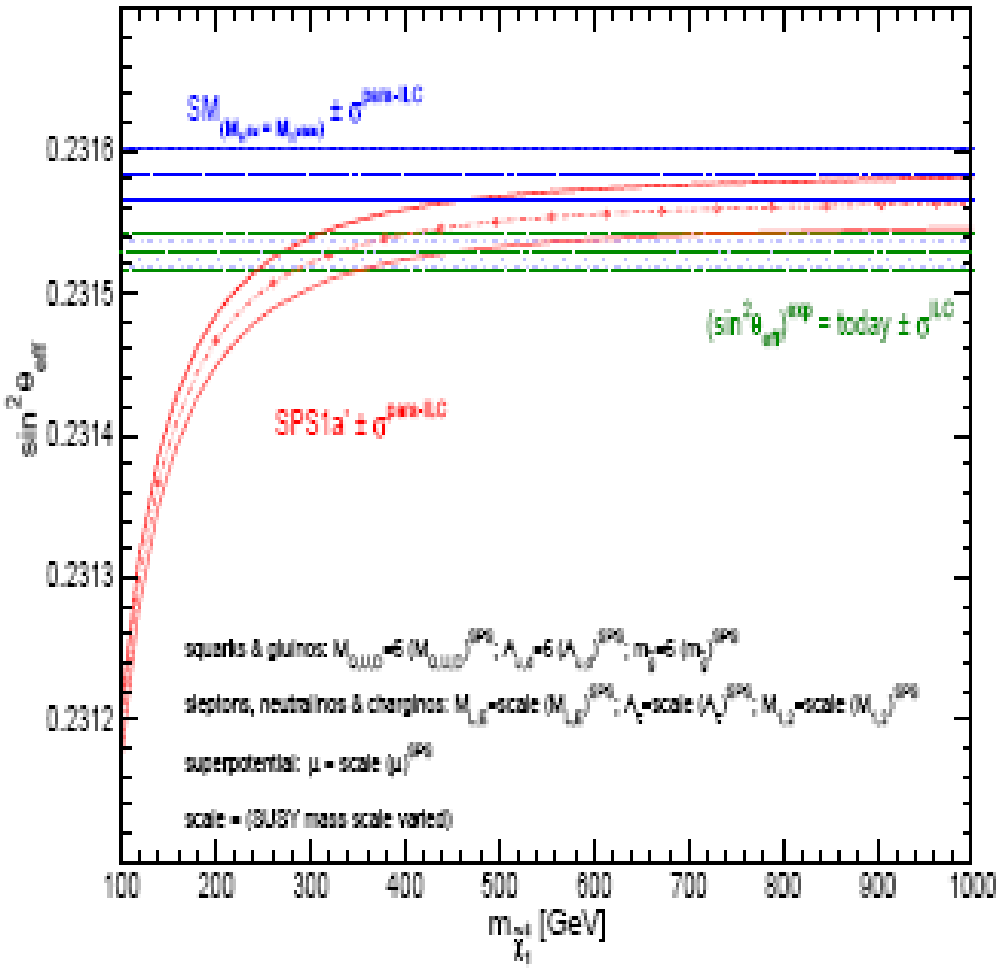
Δm_Z=2.1 MeV:	$\Delta\sin^2\theta_{eff}^{para}$~1.4x$10^{-5}$
$\Delta\alpha_{had}$~10 (5 future) x 10^{-5} :	$\Delta\sin^2\theta_{eff}^{para}$~3.6 (1.8 future)x$10^{-5}$
Δm_{top}~1 GeV (Tevatron/LHC):	$\Delta\sin^2\theta_{eff}^{para}$~3x$10^{-5}$
Δm_{top}~0.1 GeV (ILC):	$\Delta\sin^2\theta_{eff}^{para}$~0.3x$10^{-5}$

What else could we learn? $\sqrt{s}$=91 GeV

- **Assume only Higgs@LHC but no hints for SUSY:**
  - **Really SM?**
  - **Help from $\sin^2\theta_{eff}$?**

- **If GigaZ precision:**
  - **i.e. Δm_{top}=0.1 GeV…**
  - **Deviations measurable**

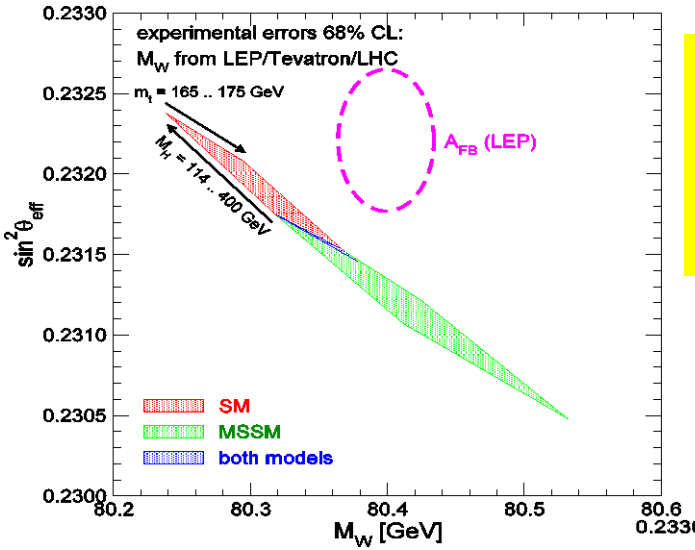
- **$\sin^2\theta_{eff}$ can be the crucial quantity to reveal effects of NP!**



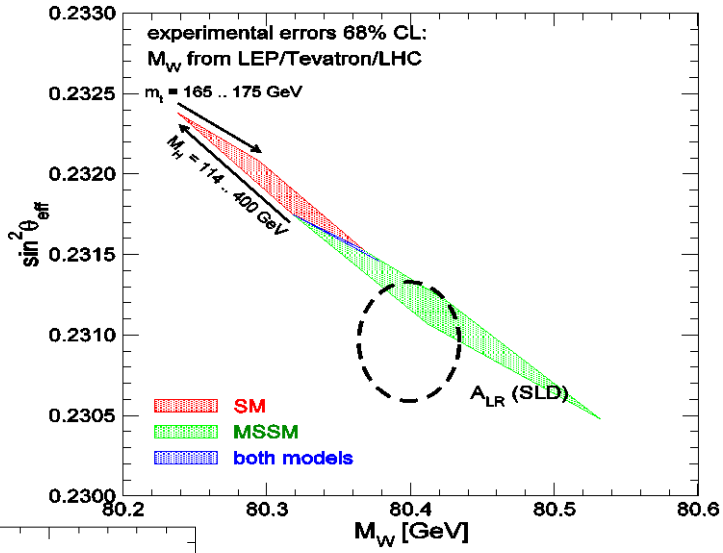
To close the story… GigaZ

$\sqrt{s}$=91 GeV

- Measure $\sin^2\theta_{eff}$ via A_{LR} with high precision: $\Delta\sin\theta = 1.3\ 10^{-5}$



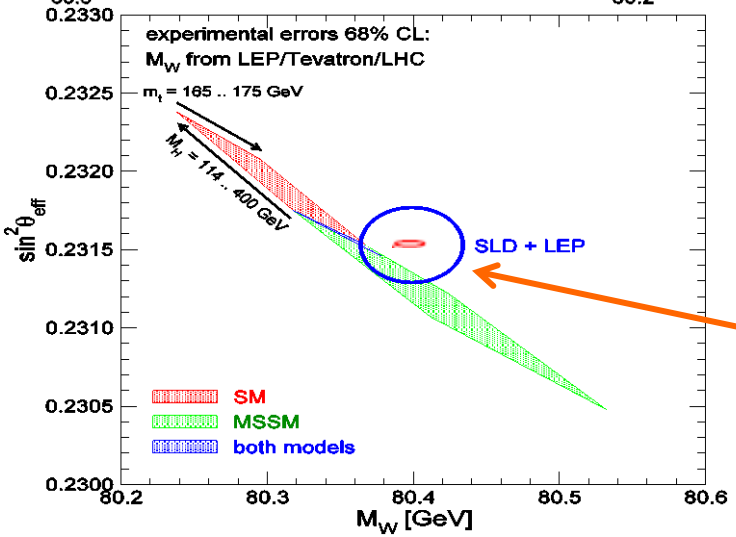
← *LEP value disfavours both, SM+MSSM*



↑ *SLD value disfavours SM*

World average → happy with both!

Central value has large impact !!!



GigaZ precision!

Conclusions

- Beam polarization gives 'added-value' to ILC
  - Provides 'new' analysis tools comp. with LHC
- Positron polarization quality and quantity
  - higher lumi
  - less uncertainty
  - Access to something 'new'
- Important from beginning (Higgs + top!)
  - Optimizes physics potential
  - Crucial to compete with LHC options!
  - And…..do not forget GigaZ option: the important safety ticket!!!

Not so much: summary table still valid!

hep-ph/0507011

Case	Effects	Gain	
SM:			
top threshold	Improvement of coupling measurement	factor 3	
tq	Limits for FCN top couplings reduced	factor 1.8	
CPV in tt	Azimuthal CP-odd asymmetries give access to S- and T-currents up to 10 TeV	$P_{e^-}^T P_{e^+}^T$ required	← P_{e+} required
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 $\tilde{b}_+ = \mathrm{Im}(g_1^R + \kappa^R)/\sqrt{2}$	$P_{e^-}^T P_{e^+}^T$ required	} ← P_{e+} required
CPV in γZ	Anomalous TGC $\gamma\gamma Z$, γZZ	$P_{e^-}^T P_{e^+}^T$ required	
HZ	Separation: $HZ \to H\bar{\nu}\nu$	factor 4 with RL	
	Suppression of $B = W^+\ell^-\nu$	factor 1.7	
SUSY:			
$\tilde{e}^+\tilde{e}^-$	Test of quantum numbers L, R and measurement of $e^\pm$ Yukawa couplings	P_{e^+} required	← P_{e+} required
$\tilde{\mu}\tilde{\mu}$	Enhancement of S/B, $B = WW$ $\Rightarrow m_{\tilde{\chi}_{L,R}}$ in the continuum	factor 5-7	
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	$P_{e^-}^T P_{e^+}^T$ required	← P_{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		
ED:			
$G\gamma$	Enhancement of S/B, $B = \gamma\nu\bar{\nu}$,	factor 3	
$e^+e^- \to f\bar{f}$	Distinction between ADD and RS modes	$P_{e^-}^T P_{e^+}^T$ required	← P_{e+} required
Z':			
$e^+e^- \to f\bar{f}$	Measurement of Z' couplings	factor 1.5	
CI:			
$e^+e^- \to q\bar{q}$	Model independent bounds	P_{e^+} required	← P_{e+} required
Precision measurements of the Standard Model at GigaZ:			
Z-pole	Improvement of $\Delta\sin^2\theta_W$	factor 5–10	
	Constraints on CMSSM space	factor 5	} ← P_{e+} required
CPV in $Z \to b\bar{b}$	Enhancement of sensitivity	factor 3	