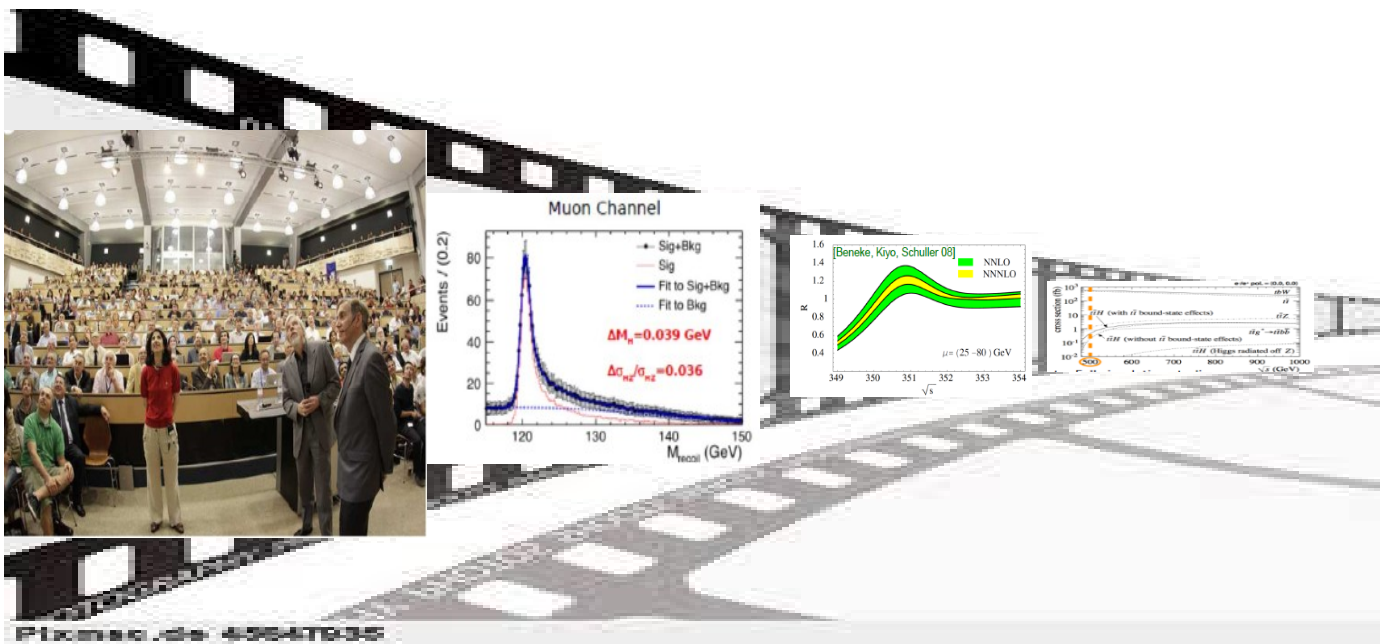
Positron polarization in the staged approach

G. Moortgat-Pick

(Uni Hamburg/DESY)



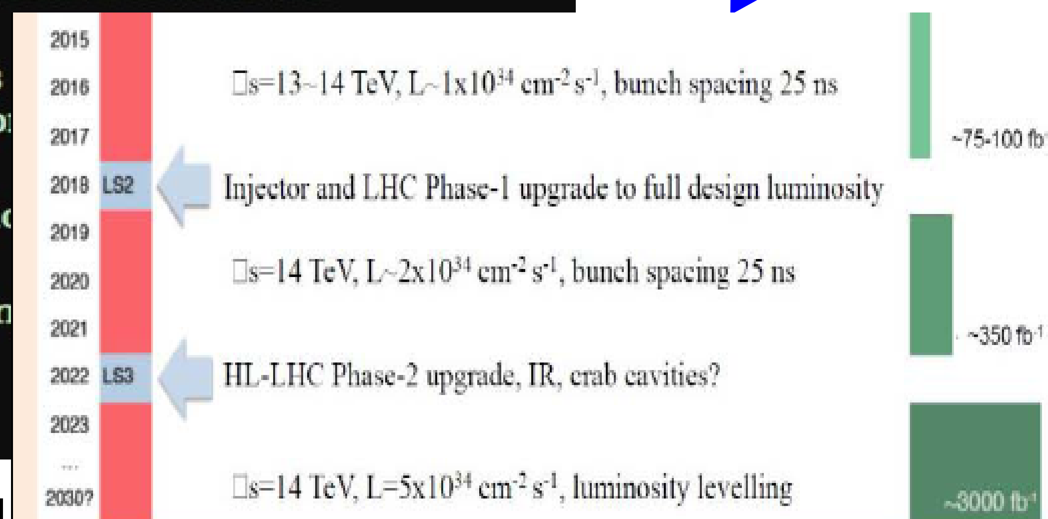
LINEAR COLLIDER COLLABORATION

Very encouraging politics!

Possible Timeline

- July 2013
  - Non-political evaluation of 2 Japanese candidate sites complete, followed by down-selecting to one
- End 2013
  - Japanese government announces its intent to bid
- 2013~2015
  - Inter-governmental negotiations
  - Completion of R&Ds, preparatio
- ~2015
  - Inputs from LHC@14TeV, decisi
- 2015~16
  - Construction begins (incl. biddin
- 2026~27
  - Commissioning

LHC timeline



Preface

- Strong physics case with m_H~126 GeV
- However:
  - LHC run (lumi, pile-up) was perfectly well, better analysis results than expected (in that time)
  - Very encouraging (and optimistic) estimates for $\sqrt{s}$=14 TeV
- We have to compete with that … in the physics landscape of 2025!!!
  - Very engaging activities in Japan, but the LC is not yet approved !
  - We need the best and optimized performance as possible: have to offer ‘new’ tools to improve the quality of analyses
  - The ‘LC’ just as little add-on to LHC will never ‘fly’ !

Status LHC results -- in short

- Discovery of a SM-like Higgs around m_H~126 GeV
  - Is an absolute revolution!
  - Completely new type
  - Not clear whether a SM-Higgs

`The properties of the Higgs boson, to be discovered at the LHC, must be thoroughly investigated in a good condition at the ILC'
(K. Kawagoe, Feb 12)

- Limits in SUSY coloured sector (approx.):
  - m_g,m_q>1 TeV
  - 3rd generation: much weaker
- Limits on Z', W': ~2 TeV
- And more limits on ED, exotics, 4th generation etc.

Physics left for a Linear Collider? Which energy steps?

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‘
- **`New’ features, impact on ‘quality’ (and quantity):**
  - Flexible energy (threshold scans)
  - Polarized e- and e+ beams

What has changed since Polarisationreport?

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 $t\bar{t}$	Azimuthal CP-odd asymmetries give access to S- and T-currents up to 10 TeV	$P_{e^-}^T P_{e^+}^T$ required	$\leftarrow P_{e+}$ 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 $\tilde{h}_+ = \mathrm{Im}(g_1^R + \kappa^R)/\sqrt{2}$	$P_{e^-}^T P_{e^+}^T$ required	} $\leftarrow P_{e+}$ required
CPV in γZ	Anomalous TGC $\gamma\gamma Z$, γZZ	$P_{e^-}^T P_{e^+}^T$ required	}
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	factor 4 with RL	
	Suppression of $B = W^+e^-\nu$	factor 1.7	
SUSY:			
$\tilde{e}^+\tilde{e}^-$	Test of quantum numbers L, R and measurement of $e^\pm$ Yukawa couplings	P_{e^+} required	$\leftarrow P_{e+}$ required
$\tilde{\mu}\tilde{\mu}$	Enhancement of S/B, $B = WW$ $\Rightarrow m_{\tilde{\mu}_{L,R}}$ 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	$\leftarrow P_{e+}$ 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	$\leftarrow P_{e+}$ 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	$\leftarrow P_{e+}$ 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	} $\leftarrow P_{e+}$ required
CPV in $Z \to b\bar{b}$	Enhancement of sensitivity	factor 3	}

Polarization:Technical facts I

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

$\sqrt{s}$=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%

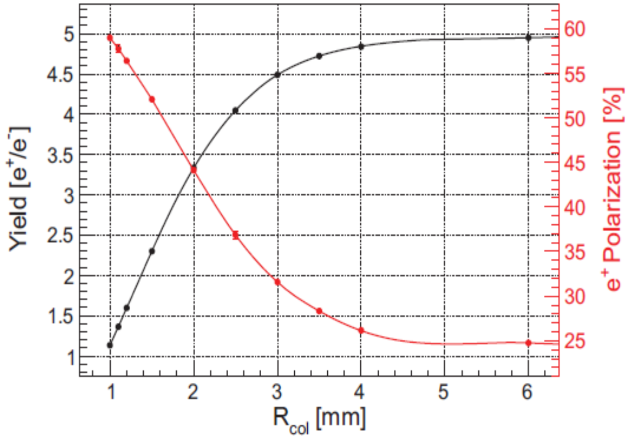
$\sqrt{s}$=350GeV: 175 GeV e- drive beam

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

$\sqrt{s}$=500GeV: 250 GeV e- drive beam

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

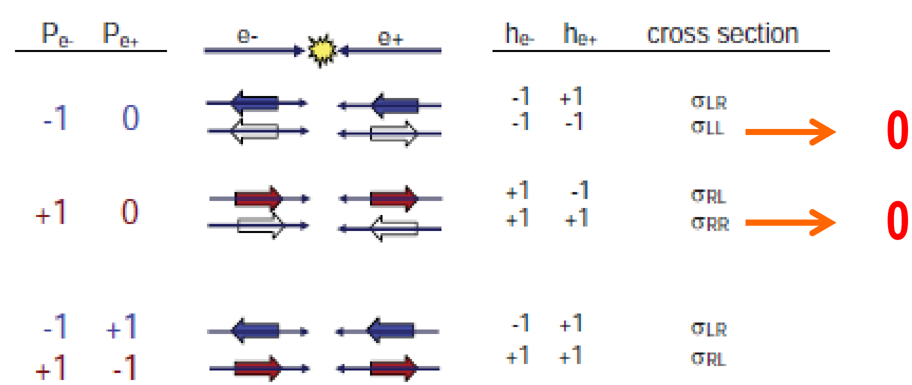
Eb=175 GeV



A. Ushakov, LC note

Technical facts II

- P(e+) (always yield ≥1.5 imposed):
  √s=1 TeV: 500 GeV e- drive beam
  – Undulator with 176 m (K=2.5), collimator r=0.9mm
  – P(e+)~54%
- Measurent of polarization:
  – Compton polarimetry (up- and down-stream): δP/P=0.25%
  – Via WW-process (lumi-weighted!): δP/P(e-)~0.1%,
    δP/P(e+)~0.2-0.3%
- Helicity reversal required:
  – Fast reversal to benefit from higher $L_{eff}=(1-P_{e-}P_{e+})L$
  – Spin rotator before DR

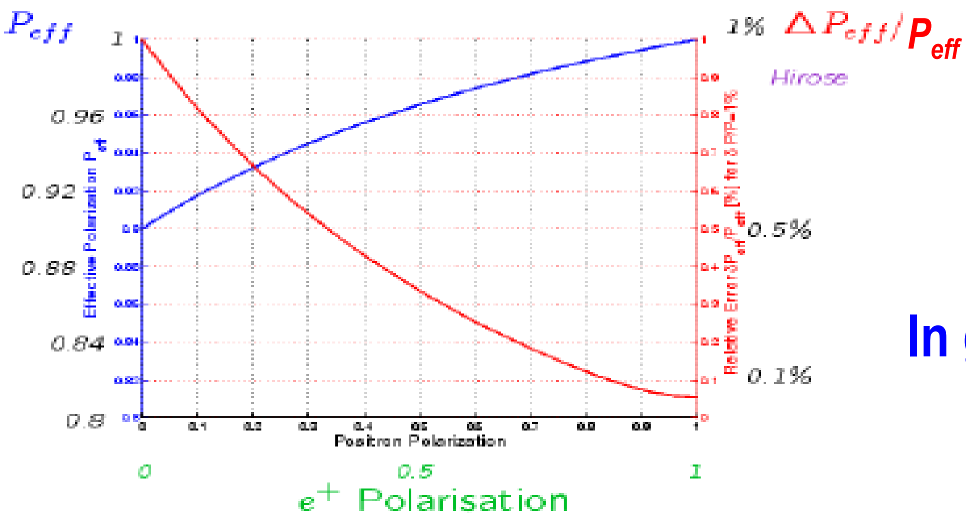


Quantitative P(e+) effects

- 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

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	← No gain!
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	← No gain!
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	

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+)!

‘New tools’: Qualitative P(e+) effects

- **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** (see LC notes)

- **Exploitation of transversely-polarized beams** (~ P_{e-} P_{e+})

Staged approach

- $\sqrt{s}$=240 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

- Scaling factor about $\sigma_{pol}/\sigma_{unpol} \sim (1\text{-}0.151\, P_{eff}) * L_{eff}/L$
  - 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

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

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

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

    With P_{e+}=0%: $\sigma_{pol}/\sigma_{unpol}$~1.90
    With P_{e+} =55%: $\sigma_{pol}/\sigma_{unpol}$~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]

Top sector

- $\sqrt{s}$=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%

R. Yonamine, T. Tanabe, K. Fujii

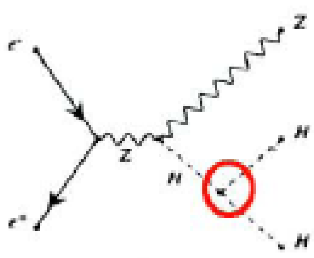
E_{CM} = 500 GeV, L= 1 ab^{-1}, Pol= (-0.8,+0.3)

'Measure' for importance of beam polarization:

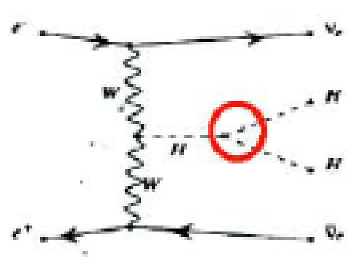
- If only P_{e-}=80%: improvement of Δg_{ttH}~19% comp. with P_{e-}=0
- With P_{eff}=89%: improvement of Δg_{ttH}~42% (with 80%/30%)
- With P_{eff}=97%: improvement of Δg_{ttH}~47% (with 90%,55%)

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% !**

What's about BSM/SUSY?

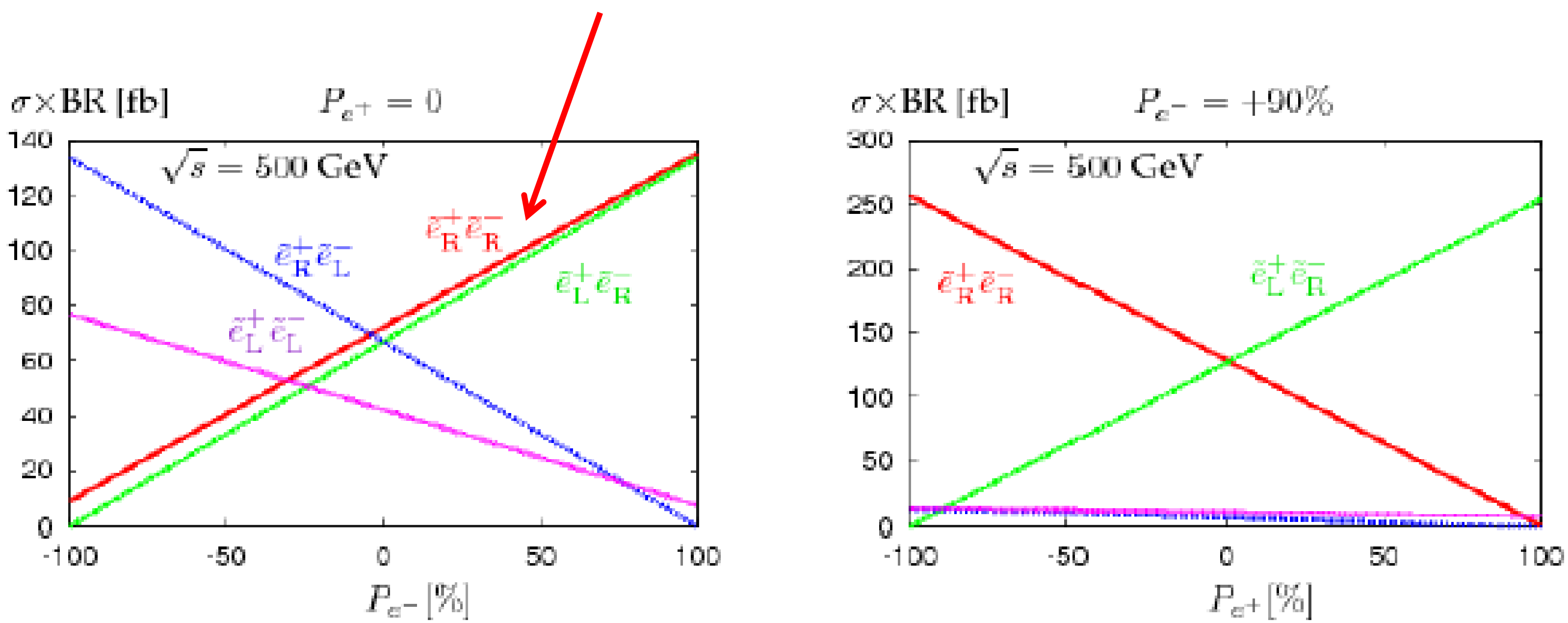
- **SUSY: still strongly motivated and beautiful, but**
  - so far, no hints of a signal at LHC, only rather high exclusion limits in the coloured sector
  - Since Higgs mass of in SUSY not free, mH=126GeV constrains the model
  - But only specific SUSY models (CMSSM,…) less favoured
- **Further hints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

Chirality proof of sleptons

- **Test of chirality of new particles via beam polarization**

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.



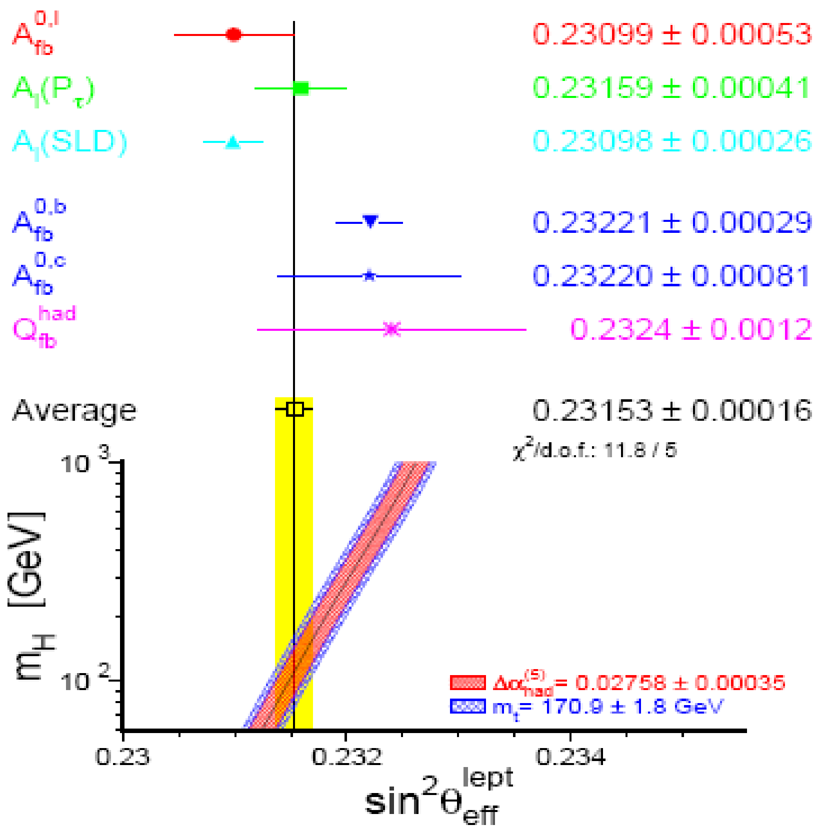
P_{e+} required!

What if nothing else than H is found ?

- 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
- 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:

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

SLC:

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

World average:

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

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

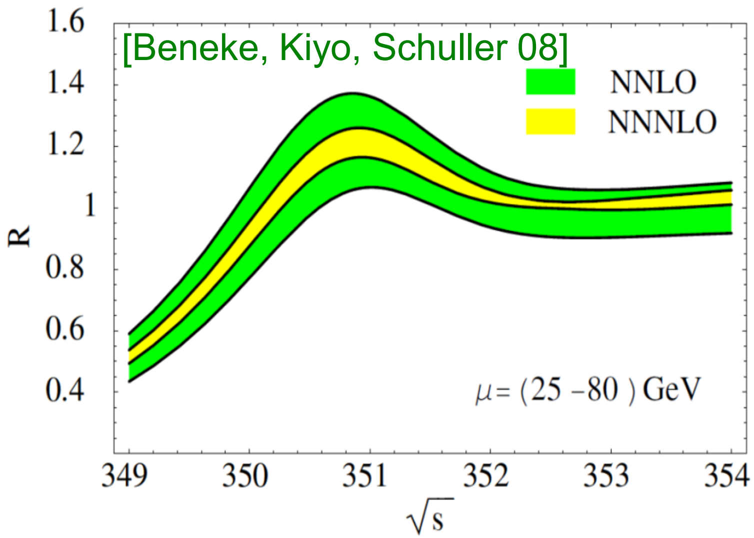
- **Uncertainties from input parameters: Δm_Z, $\Delta\alpha_{had}$, m_{top} ,…**

Heinemeyer, Kraml, Porod, Weiglein

Higgs story has just started …

√s=91 GeV

- **But such a precision requires Δm_{top}=0.1 GeV**



Important shift due to non-logarithmic NNNLO terms

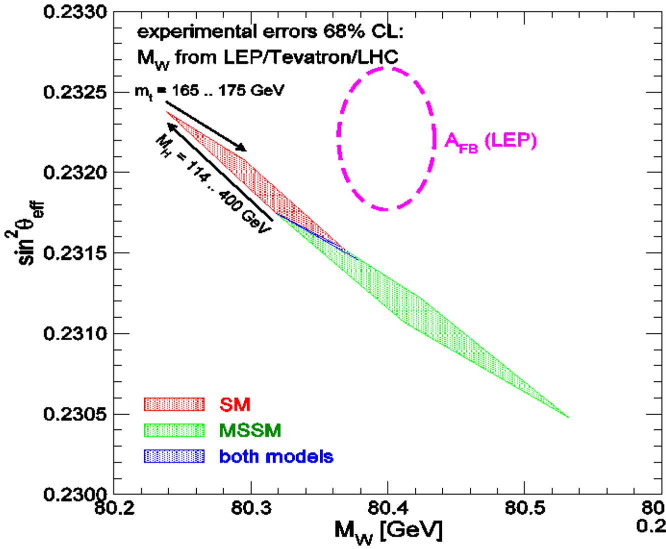
√s=350 GeV

- **LC: Peak position remains stable: m_t=100 MeV expected accuracy confirmed!**
- **However: dedicated threshold scan required!**

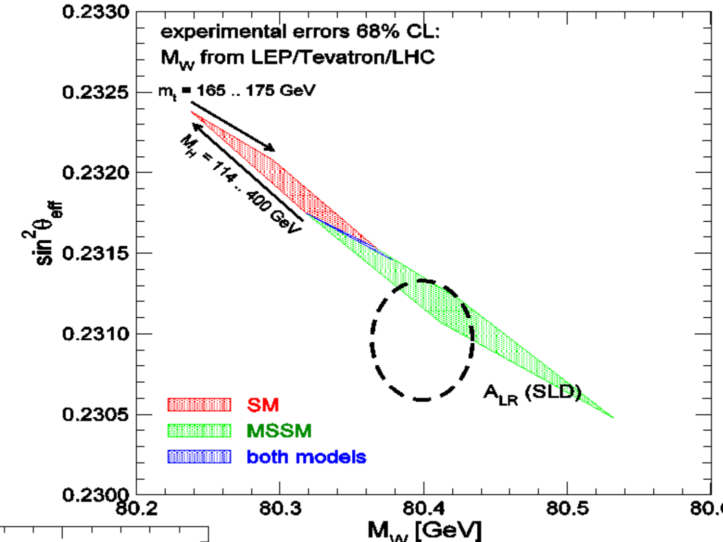
To close the story… GigaZ $\sqrt{s}=91$ GeV

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

Heinemeyer, Hollik, Weber, Weiglein



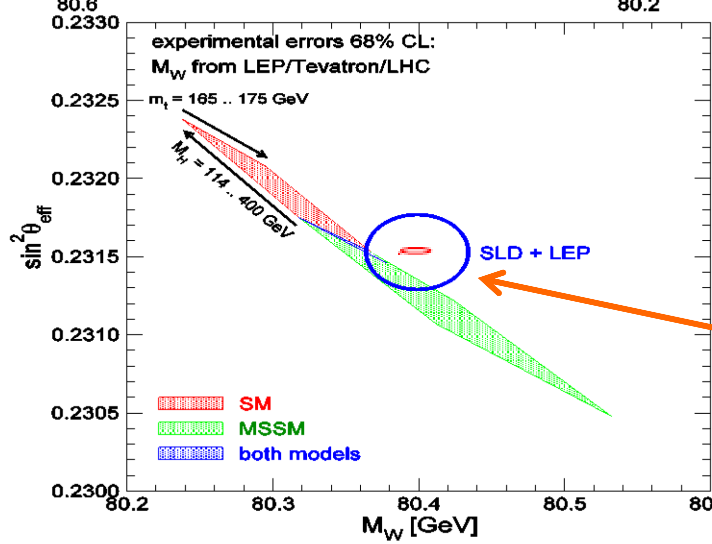
← LEP value disfavours both, SM+MSSM



↑ SLD value disfavours SM

World average → happy with both!

Central value has large impact !!!

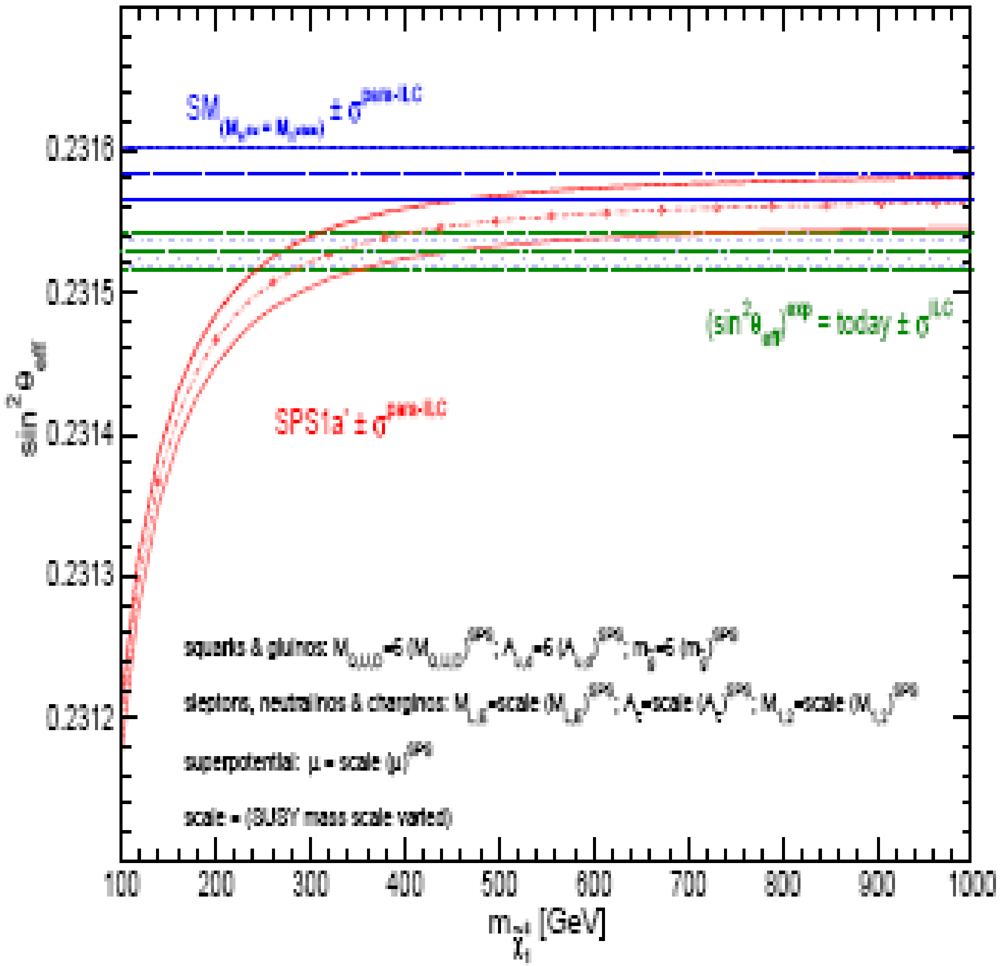


GigaZ precision!

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

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

Heinemeyer, Hollik, Weber, Weiglein



- **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!**

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: play a safety !!!