Polarization issues at a Z-factory and impact of SB2009

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- **Introduction**
- **SB2009**
- **Summary polarized beams in Higgs physics**
- **Summary polarized beams in SUSY/ED physics**
- **Summary and open questions/ideas**

Introduction

- Physics case for polarized e^- and e^+
  - Comprehensive overview, hep-ph/0507011, Phys.Rept., 460 (2008)
  - See also executive summary on:

  www.ippp.dur.ac.uk/LCsources/
- Polarized beams required to
  - Analyze the structure of all kinds of interactions
  - Improve statistics: enhance rates, suppress background processes
  - Get systematic uncertainties under control
- Discoveries via deviations from SM predictions in precision measurements!
  - Important in particular at $\sqrt{s} \leq 500$ GeV !

Why are polarized beams required?

- **Please remember:**
  - **excellent e- polarization ~78% at SLC:**
  - **led to best measurement of $\sin^2\theta = 0.23098 \pm 0.00026$**

    on basis of $L \sim 10^{30}$ $cm^{-2}s^{-1}$
- **Compare with results from unpolarized beams at LEP:**
  - **$\sin^2\theta = 0.23221 \pm 0.00029$ but with $L \sim 10^{31} cm^{-2}s^{-1}$**

➡ **polarization can even compensate order of magitude in luminosity for specific observables !**

But what are the precision requirements?

Reminder: requirements for precision frontier'

ICFA Parameter Group for a future LC:

- 'Scope Document no.1' (2003) and 'no.2' (2006): baseline
  - 'full luminosity of 2 x $10^{34}cm^{-2}s^{-1}$'
  - 'beam energy stability and precision below tenth of percent level.'
  - 'Machine interface must allow measurements of beam energy and diff. lumi spectrum with similar accuracy.'
  - 'electron beams with polarisation of at least 80% within whole energy range.'
- Options:
  - 'e^+ polarisation ~50% in whole energy range wo sign. loss of lumi...., Reversal of helicity ... between bunch crossings.'
  - GigaZ: e^+ polarisation+frequent flips essential; energy stability+calibration accuracy below tenth of percent level.'

SB2009

- **Comparison:**
  - RDR baseline: P(e+)~30% up to 45% (w/o collimator)
  - P(e+)=22% at $\sqrt{s}$=500 GeV
    P(e+)=31% at $\sqrt{s}$=200 GeV

  Is such a low degree appropriate for physics goals?

- **Concentrate on few examples**
  - For new SB2009 outline
  - Weight it w.r.t. LHC expectations

Physics: pol.cross sections in general

Polarized cross sections can be subdivided in:

$$\sigma_{P_{e^-}P_{e^+}} = \frac{1}{4}\{(1+P_{e^-})(1+P_{e^+})\sigma_{\rm RR} + (1-P_{e^-})(1-P_{e^+})\sigma_{\rm LL} + (1+P_{e^-})(1-P_{e^+})\sigma_{\rm RL} + (1-P_{e^-})(1+P_{e^+})\sigma_{\rm LR}\},$$

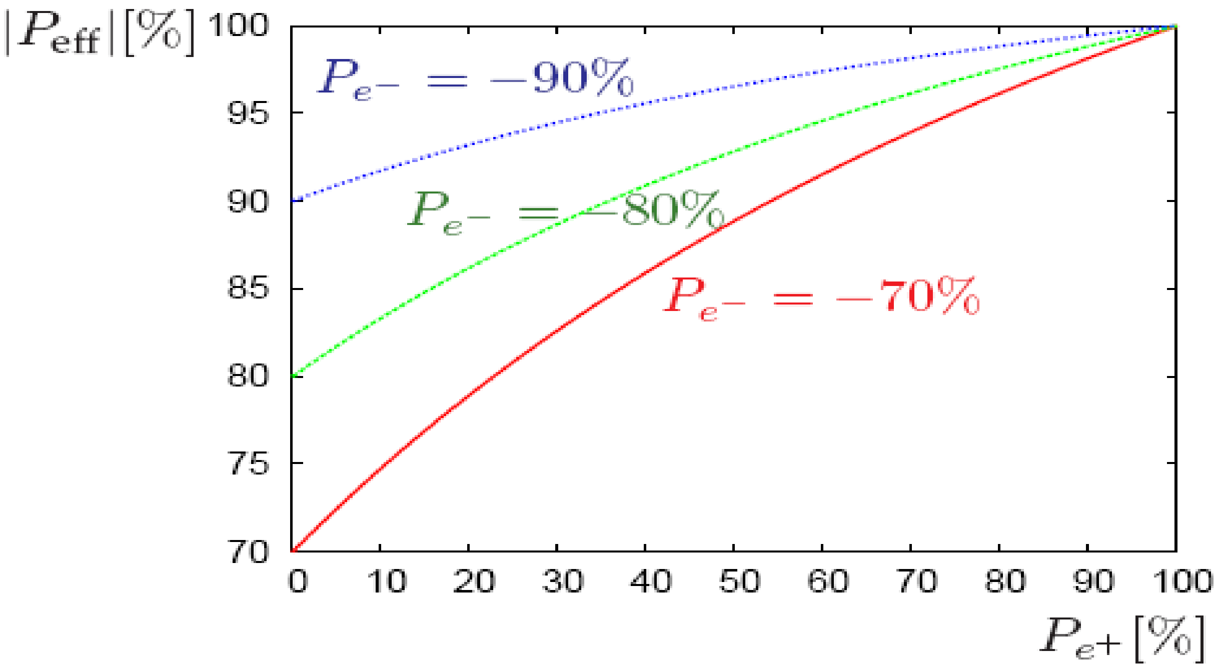
σ_{RR}, σ_{LL}, σ_{RL}, σ_{LR} are contributions with fully polarized L, R beams.

In case of a vector particle only (LR) and (RL) configurations contribute:

$$\begin{aligned}
\sigma_{P_{e^-}P_{e^+}} &= \frac{1+P_{e^-}}{2}\frac{1-P_{e^+}}{2}\sigma_{\rm RL} + \frac{1-P_{e^-}}{2}\frac{1+P_{e^+}}{2}\sigma_{\rm LR} \\
&= (1-P_{e^-}P_{e^+})\,\frac{\sigma_{\rm RL}+\sigma_{\rm LR}}{4}\left[1 - \frac{P_{e^-}-P_{e^+}}{1-P_{e^+}P_{e^-}}\,\frac{\sigma_{\rm LR}-\sigma_{\rm RL}}{\sigma_{\rm LR}+\sigma_{\rm RL}}\right] \\
&= (1-P_{e^+}P_{e^-})\;\sigma_0\;[1 - P_{\rm eff}\,A_{\rm LR}],
\end{aligned}$$

Effective polarization

Effective polarization: $$P_{\text{eff}} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^+}P_{e^-}}$$



- **(80%,60%): P_{eff}=95%, (90%,60%): P_{eff}=97%, (90%,30%): P_{eff}=94%**
- **(80%,22%): P_{eff}= 87%, (90%,22%): P_{eff}= 93%**

Relation between P_{eff} and A_{LR}

- **How are P_{eff} and A_{LR} related?**

$$A_{\rm LR} = \frac{1}{P_{\rm eff}} A_{LR}^{\rm obs} = \frac{1}{P_{\rm eff}} \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}},$$

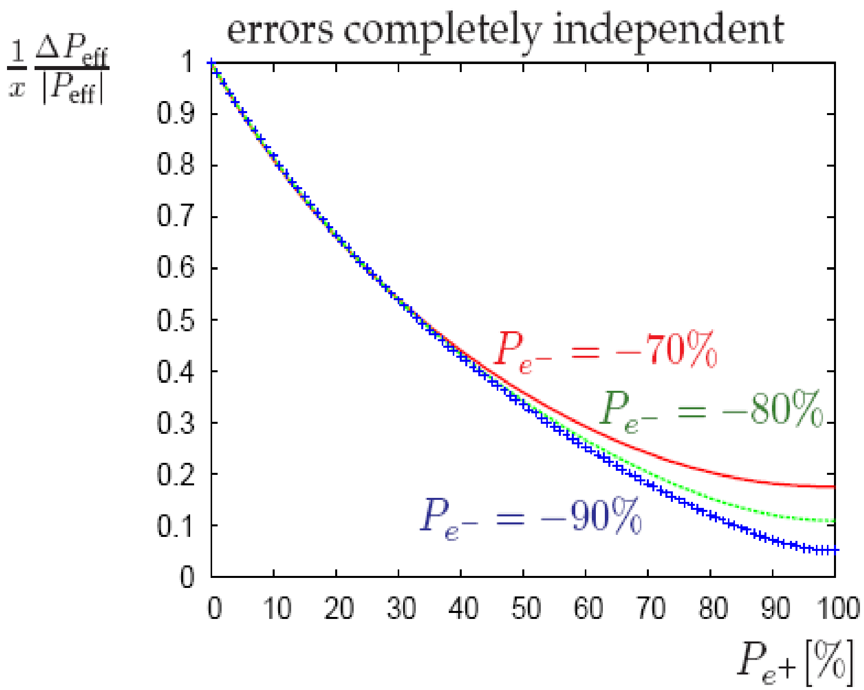
That means: $$\left|\frac{\Delta A_{\rm LR}}{A_{\rm LR}}\right| \sim \left|\frac{\Delta P_{\rm eff}}{P_{\rm eff}}\right|$$

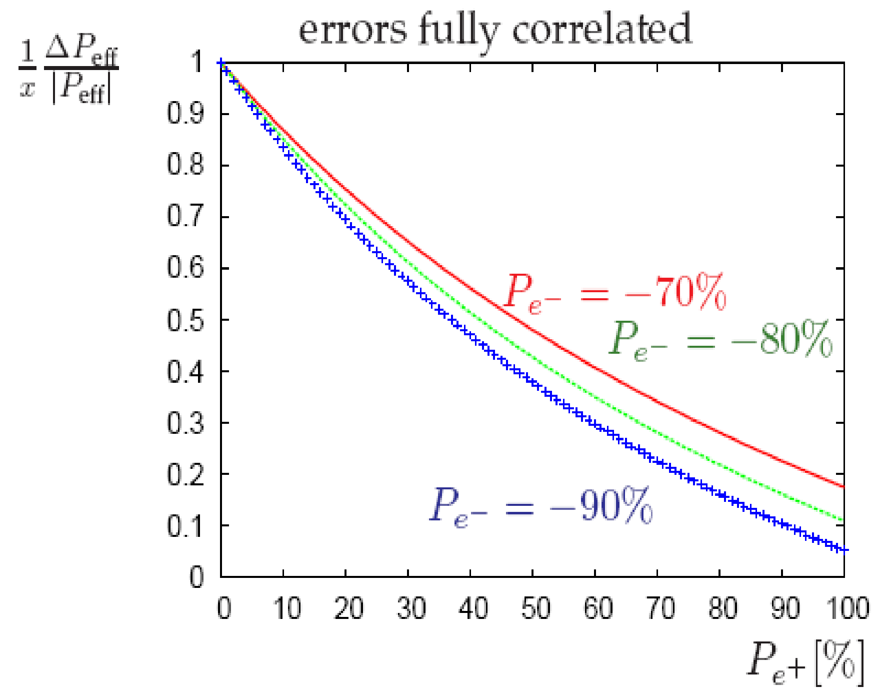
- **With pure error propagation (and errors uncorrelated), one obtains:**

$$\frac{\Delta P_{\rm eff}}{P_{\rm eff}} = \frac{x}{(|P_{e^+}| + |P_{e^-}|)\,(1 + |P_{e^+}||P_{e^-}|)} \sqrt{(1 - |P_{e^-}|^2)^2 P_{e^+}^2 + (1 - |P_{e^+}|^2)^2 P_{e^-}^2}$$

With $x \equiv \Delta P_{e^-}/P_{e^-} = \Delta P_{e^+}/P_{e^+}$

Gain in accuracy due to P(e+)





- (80%,60): P_{eff} = 95% (90%,60%): P_{eff} =97% (90%, 30%): P_{eff} =94 %

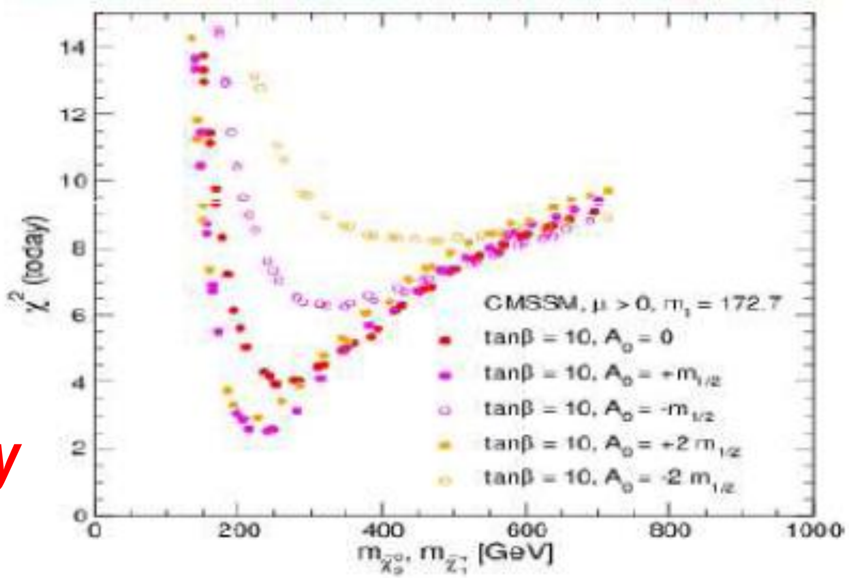
  $\Delta A_{LR}/A_{LR}$ = 0.3 $\Delta A_{LR}/A_{LR}$ = 0.27 $\Delta A_{LR}/A_{LR}$ =0.5

- **(80%,22%): $\Delta A_{LR}/A_{LR}$= 0.64** **(90%,22%): $\Delta A_{LR}/A_{LR}$= 0.64**

→ **NO gain with only polarized e⁻ !**

Something 'new' detected at early LHC

- **Supersymmetry-like signals**
  - **New physics model with high predictive power**
  - **'light' SUSY consistent with precision fits**

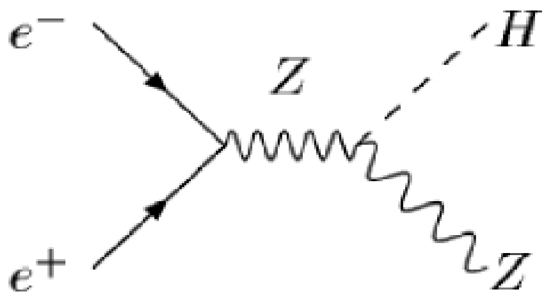


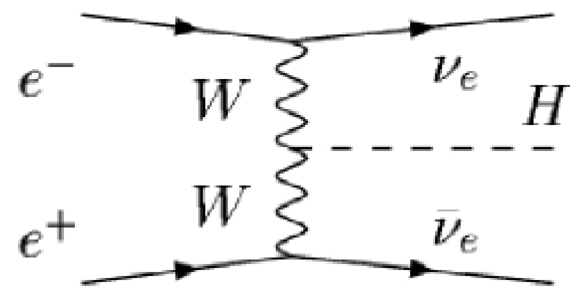
Practically all scenarios with only heavy particles violate exp. bounds (gμ-2) !!!

- **Extra gauge bosons and/or large extra dimensions**
  - **High precision in indirect searches allow model distinction and couplings determination**

Polarized e+ for Higgs searches

- 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 3.6

Improves by factor 1.7

improves by factor 1.5

Configuration (P_{e^-}, P_{e^+})	Scaling factors $e^+e^- \to H\nu\bar{\nu}$	Scaling factors $e^+e^- \to HZ$
(+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%,-22%)	0.16	1.02
(-80%,+22%)	2.20	1.33

What else in Higgs?

- $t\bar{t}H$ couplings:
  - Interplay between $(1-P_{e-}P_{e+})$ and $(1-P_{eff}\,A_{LR})$: *(A. Juste in 2005)*

    (-80%,+60%): $\sigma(ttH)^{Pol}/\sigma(ttH) \sim 2.1$ → $g_{ttH}^{Pol}/g_{ttH} \sim 45\%$

    (-80%,0%): ~1.4 → ~19%
  - 'My' Personal estimates:

    (-80%,+30%): ~1.7 → ~31%

    (-80%,+22%): ~1.6 → ~27%

- Study was done at $\sqrt{s}=500$ GeV
  - since A_{LR}~constant up to ~1TeV: factors also valid at ~800 GeV

→ more detailed studies absolutely desirable!!!

Still on the task list of Higgs studies ?

- **What's about influence of pol e+ in triple Higgs couplings?**
  - estimates exist: gain in determination of couplings either in HHZ or HHvv by about 30%-50% (?)

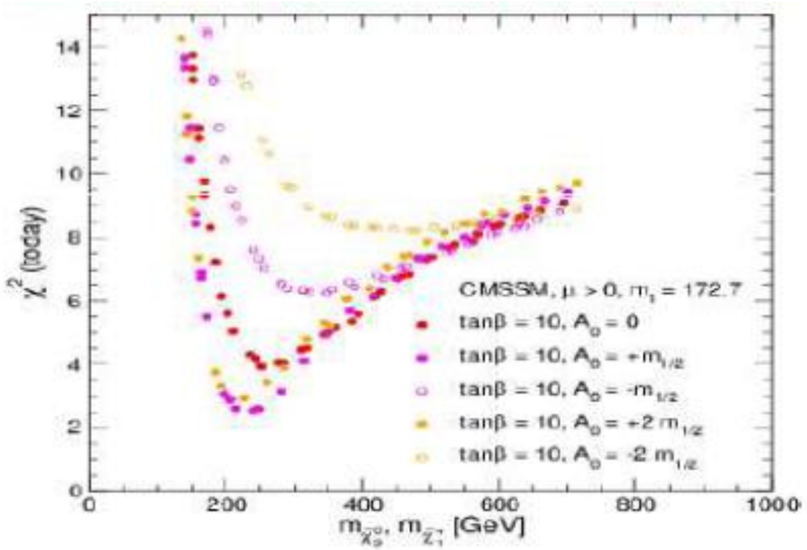
→ **Detailed simulations were highly appreciated …**

- **Distinction SM vs. SUSY light Higgs:**
  - Influence of polarization ?
  - (80%,0), (80%,60%) or might already be (80%,22%) be helpful?
- **Hbb couplings determination?**

Aside: Polarization should be always helpful even if Signal scales like Background in $S/\sqrt{B}$!

Some NP events at LHC: pol e+ useful?

- **SUSY-like signals**
  - **At least partial spectrum accessible at ILC**
  - **'light' SUSY consis-tent with precision fits**

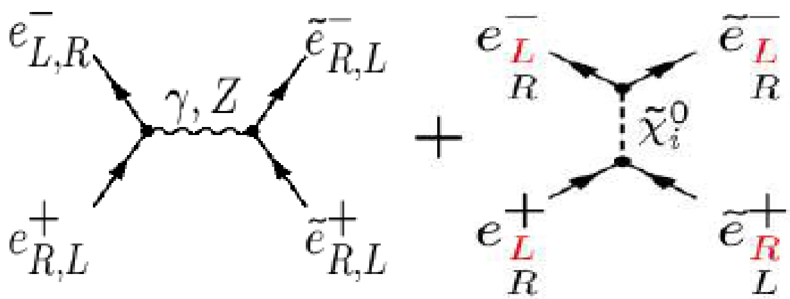


- **Extra gauge bosons and/or large extra dimensions**
  - **High precision in indirect searches allow model distinction and couplings determination**

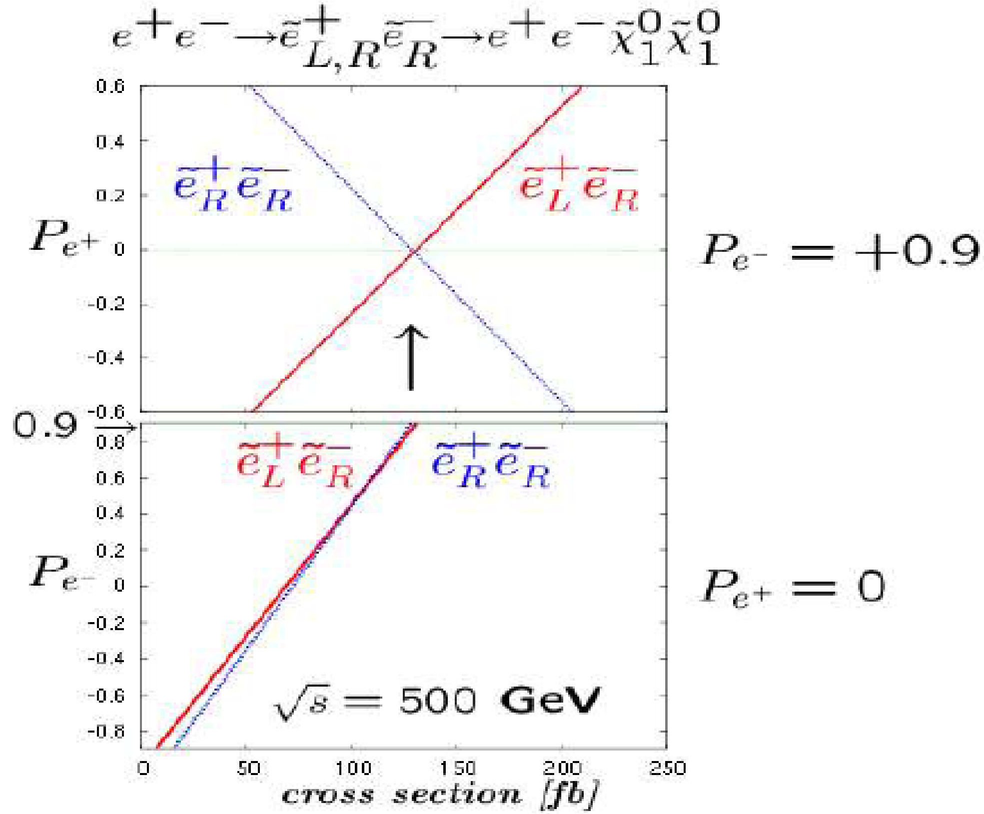
Slepton `chiral' quantum numbers

- 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 $\tilde{e}^+_L \tilde{e}^-_R$ may survive at P(e-) > 0 and P(e+) > 0 !



(90%, 60%):200 fb/50 fb factor ~4, (90%,30%):175 fb/75 fb factor~2.3, (90%,22%): ~1.6

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

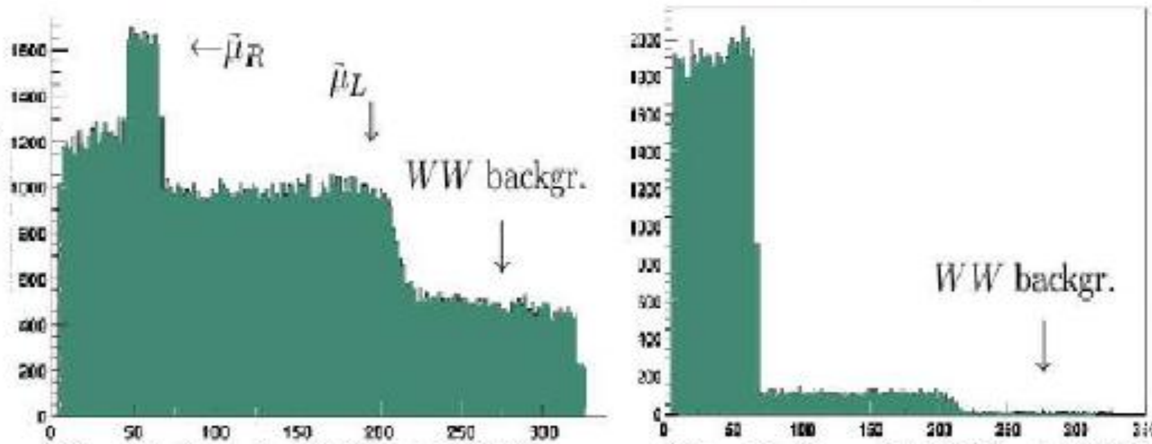
Reminder: background suppression

- To optimize threshold scans: precise continuum measurements important!
- Worst SM background is WW-pair production
  - e.g. $e^+e^- \to \tilde{\mu}^+_{L,R}\tilde{\mu}^-_{L,R}$

Muon energy spectrum: $\mu^+\mu^-$ events (incl. W^+W^-) at $\sqrt{s} = 750$ GeV

- Strong WW-backgr.:
  - all edges observable only with P(e-) and P(e+)
  - at 65 GeV and 220 GeV

S / B = 0.07 (+80%,0)
S / B= 0.46 (+80%,-80%)

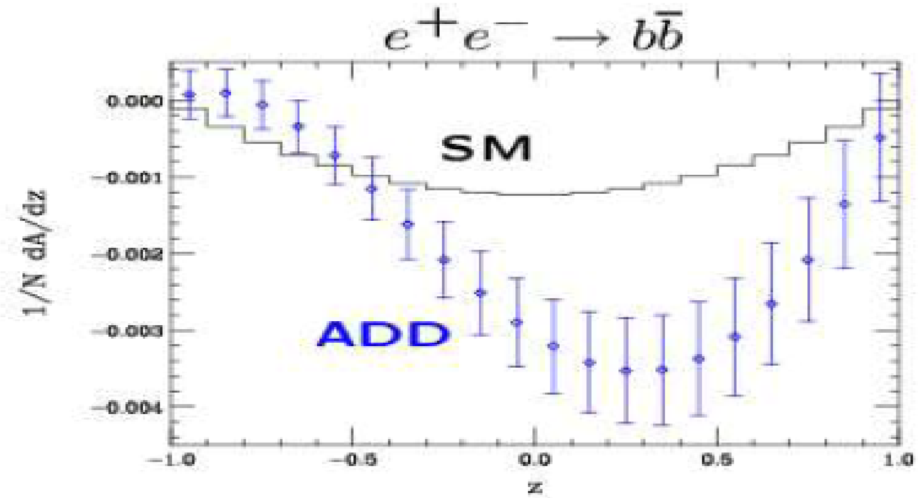


$(P_{e^-}, P_{e^+}) = (-80\%, +80\%)$ $(P_{e^-}, P_{e^+}) = (+80\%, +80\%)$

- **Background not sufficiently suppressed with (80%,22%) ….gain~1.25**

Indirect searches: extra dimensions

- 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%)

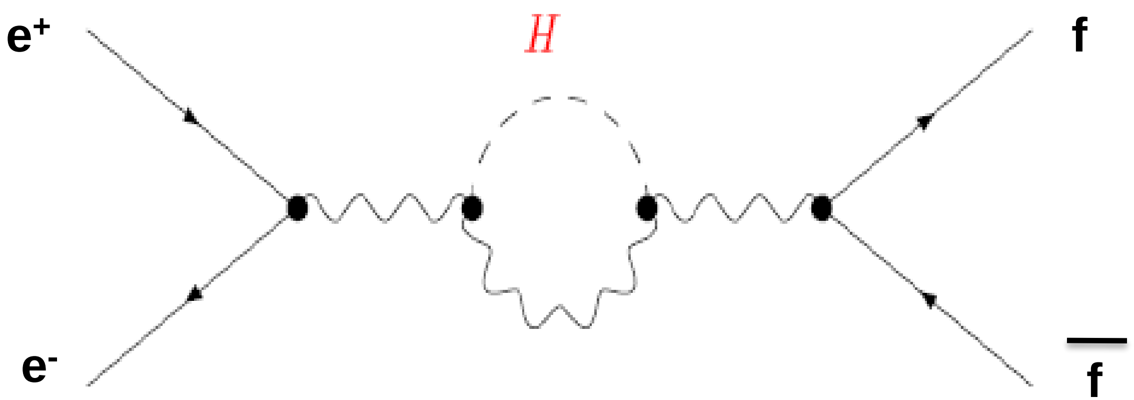
➢ by about a factor 1.8 if (80%,22%)

➢ could be compensated by (90%,22%) !

Further news on trans. beams, see also T. Rizzo's talk on the web!

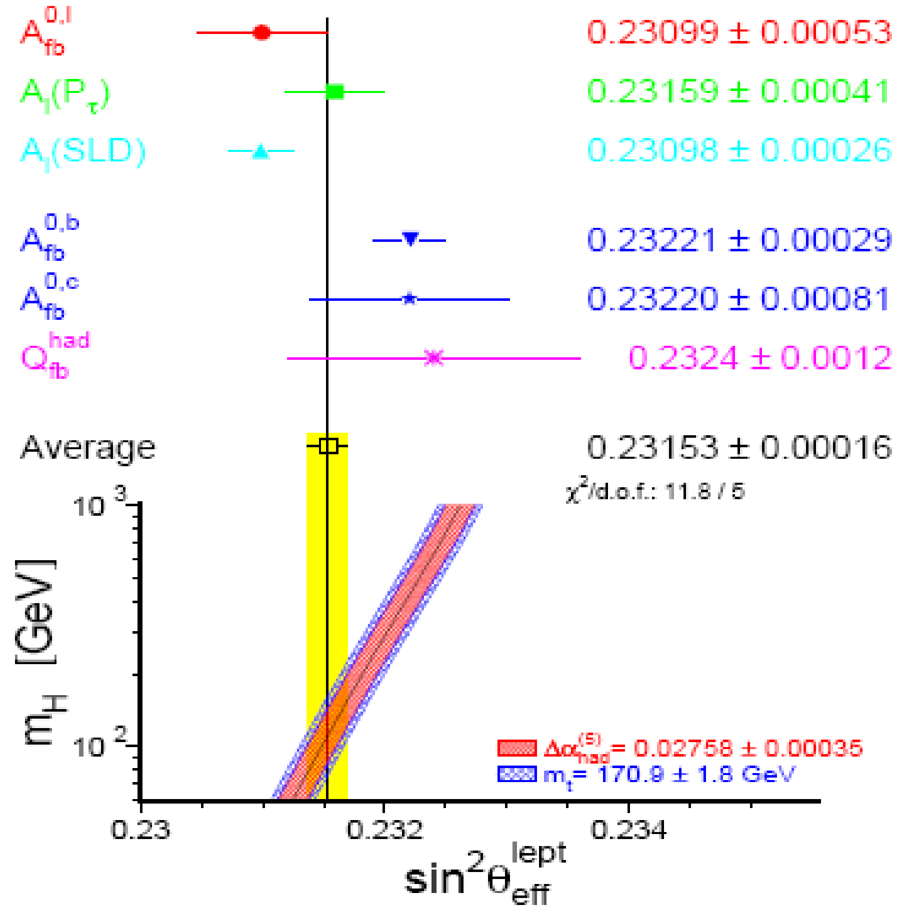
Why indirect searches at a e^+e^- Z-factory?

- Electroweak precision physics



  - Sensitivity to quantum effects of new physics
    - All states contribute, including the ones that are too heavy to be produced directly
    - Probing the underlying physics and the properties of new particles

Experimental situation



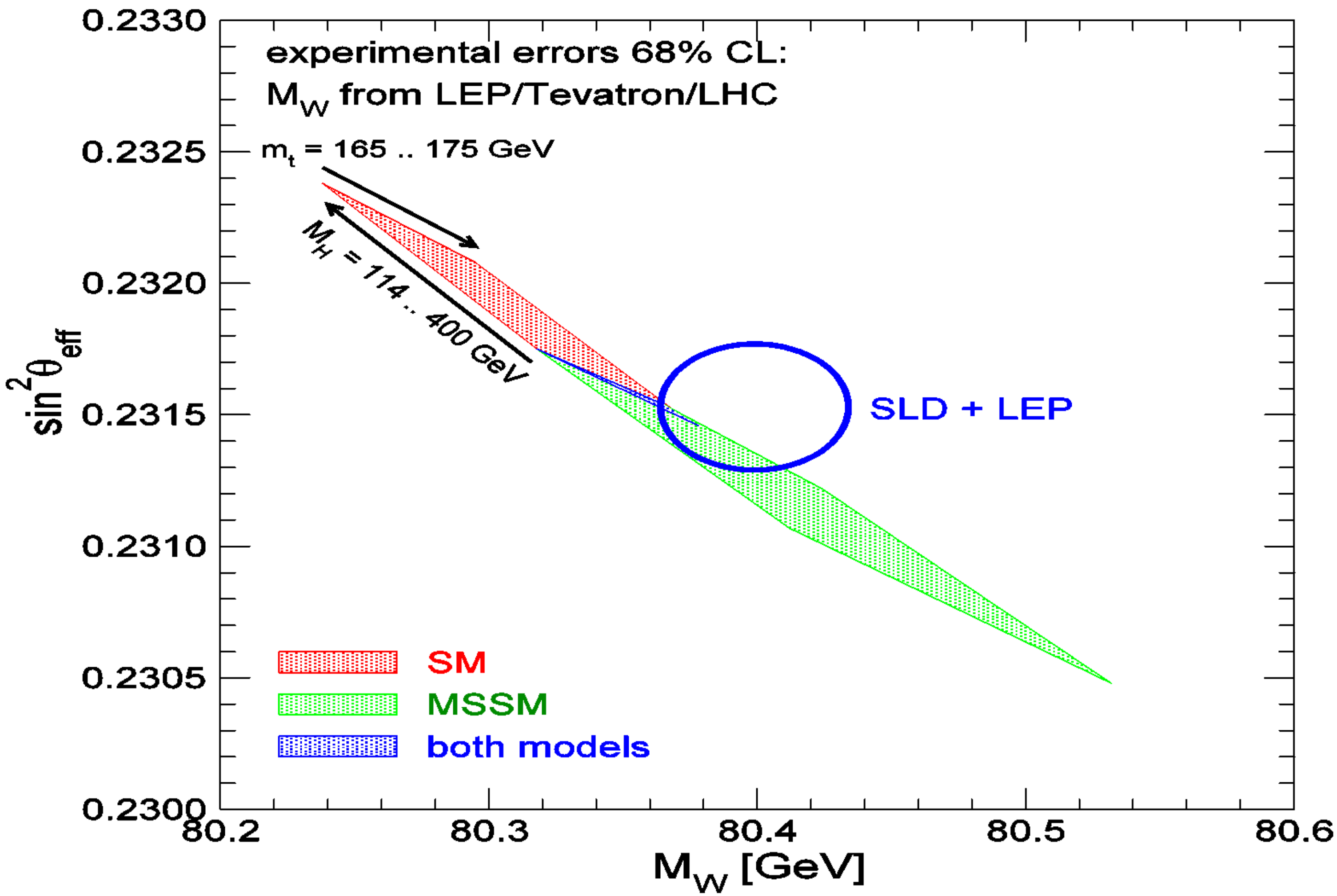
LEP:
$\sin^2\theta_{eff}(A_{FB}^{b})$= 0.23221±0.00029

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

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

→ **Large impact of discrepancy between the two most precise measurements**

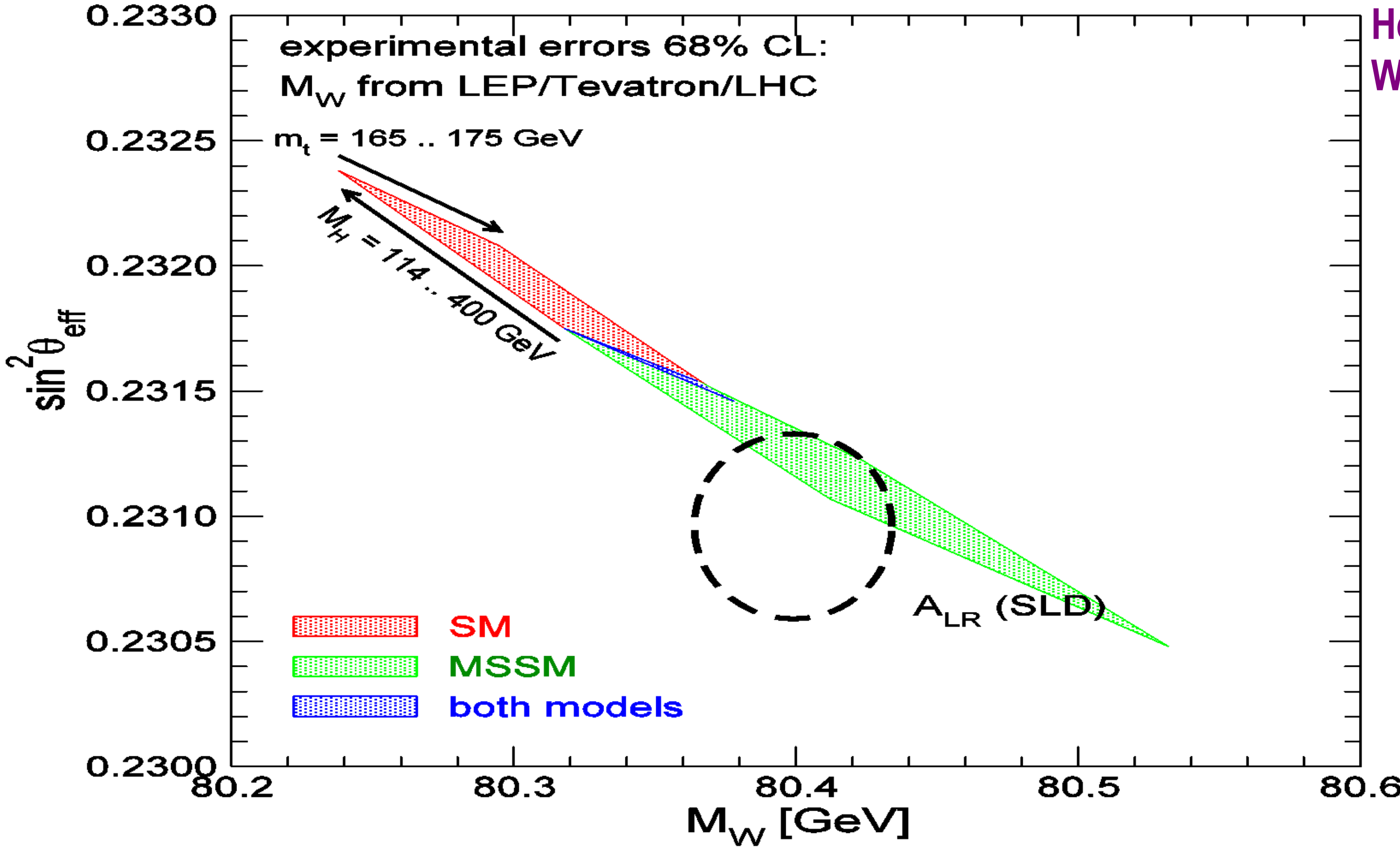
M_W vs. central value $\sin^2\theta_{eff}$



Heinemeyer, Weiglein

→ Consistent with SM and SUSY

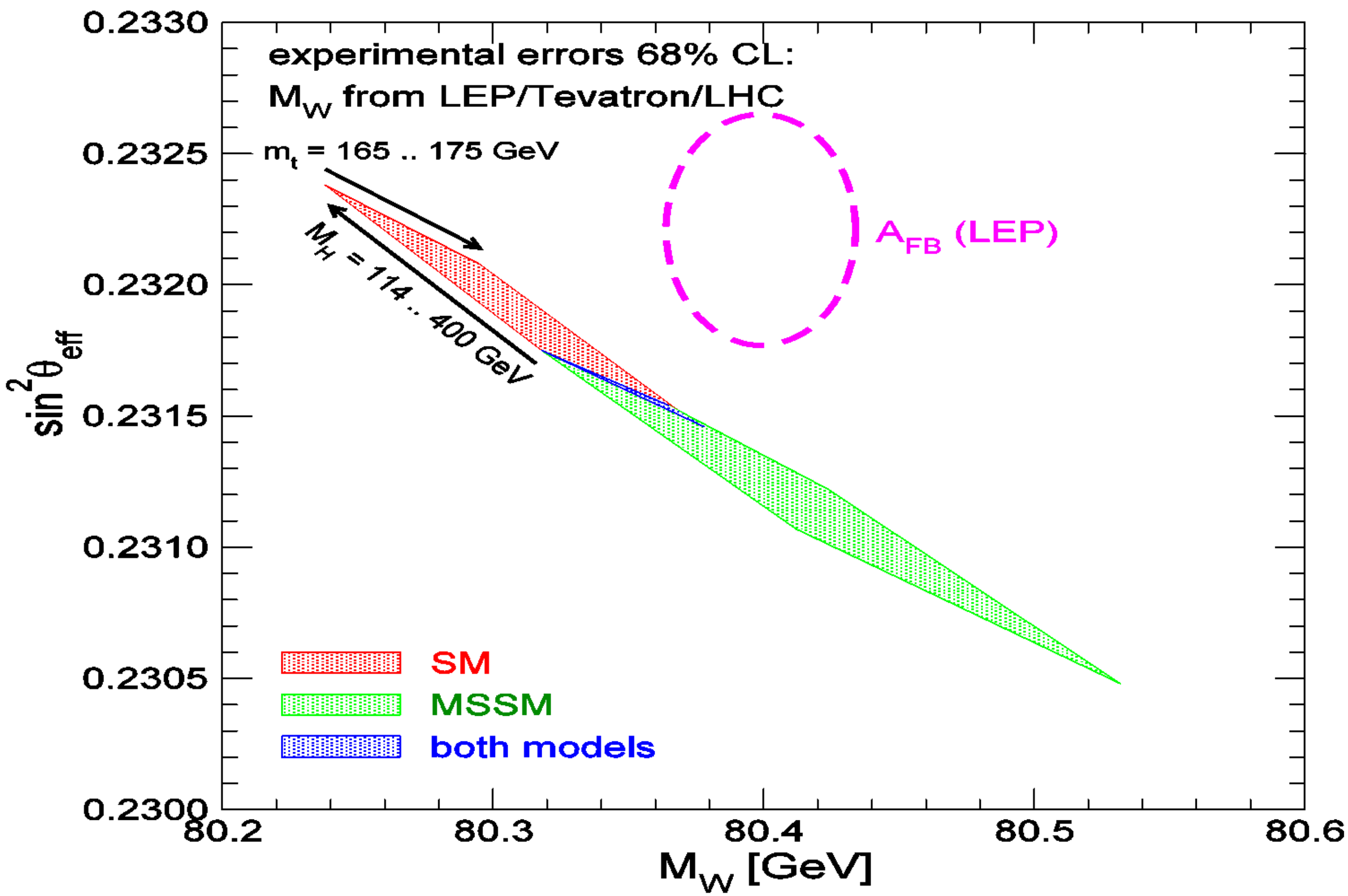
M_W vs. A_{LR}(SLD)-value $\sin^2\theta_{eff}$



Heinemeyer, Weiglein

→ **not consistent with the SM**

M_W vs. A_{FB}(LEP)-value $\sin^2\theta_{eff}$



Heinemeyer, Weiglein

→ **neither consistent with the SM nor SUSY**

- **precise $\sin^2\theta_{eff}$-measurement has the potential to rule out both models**

$\sin^2\theta_{eff}$ at the Z-factory

- **Measure both A_{FB} and A_{LR} in same experiment !**

  → with improved precision w.r.t. LEP and SLC

  → resolve discrepancy and interpret it w.r.t. new physics@LHC

- **Which precision should one aim for?**
  - Theoretical uncertainties: $\Delta \sin 2\theta_{eff}^{ho} \sim 5 \times 10^{-5}$ (currently)
  - Uncertainties from input parameters: Δm_Z, $\Delta\alpha_{had}$, m_{top}
    - $\Delta m_Z = 2.1$ MeV: $\Delta \sin^2\theta_{eff}^{para} \sim 1.4 \times 10^{-5}$
    - $\Delta\alpha_{had} \sim 35$ (5 future) x 10^{-5} : $\Delta \sin^2\theta_{eff}^{para} \sim 12$ (1.7 future)$\times 10^{-5}$
    - $\Delta m_{top} \sim 1$ GeV (LHC): $\Delta \sin^2\theta_{eff}^{para} \sim 3 \times 10^{-5}$
    - $\Delta m_{top} \sim 0.1$ GeV (ILC): $\Delta \sin^2\theta_{eff}^{para} \sim 0.3 \times 10^{-5}$

→ ***If $\Delta \sin^2\theta_{eff} \sim 3 \times 10^{-5}$ achievable: big physics impact***

$\sin^2\theta_{eff}$ at the Z-factory

- **Measure both A_{FB} and A_{LR} in same experiment !**

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- **Which precision should one aim for?**
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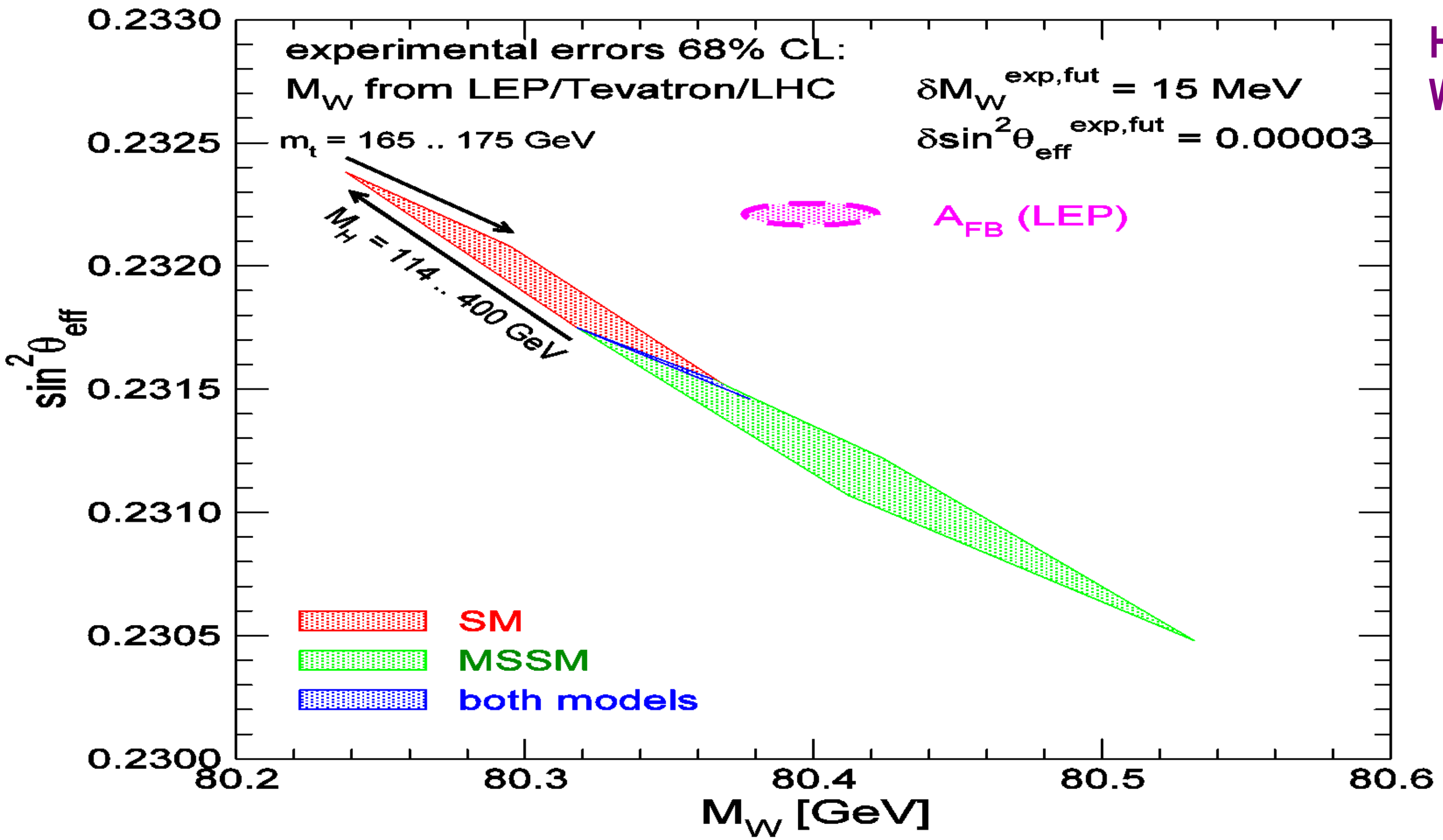
  - Uncertainties from input parameters: Δm_Z, $\Delta\alpha_{had}$, m_{top}
    - Δm_Z=2.1 MeV: $\Delta\sin^2\theta_{eff}^{para} \sim 1.4\text{x}10^{-5}$
    - yesterday Davier: $\Delta\alpha_{had} \sim 10\text{x}\ 10^{-5}$: $\Delta\sin^2\theta_{eff}^{para} \sim 3.4\text{x}10^{-5}$
    - $\Delta m_{top} \sim 1$ GeV (LHC): $\Delta\sin^2\theta_{eff}^{para} \sim 3\text{x}10^{-5}$
    - $\Delta m_{top} \sim 0.1$ GeV (ILC): $\Delta\sin^2\theta_{eff}^{para} \sim 0.3\text{x}10^{-5}$

→ ***If $\Delta\sin^2\theta_{eff} \sim 3\text{x}10^{-5}$ achievable: big physics impact***

Possible result of a Z-factory



Heinemeyer, Weiglein

→ ***would unambiguously rule out SM+MSSM !***

What's the role of polarization?

- **Statistical uncertainty of A_{LR}**
  - If only polarized electrons (from source):

    → ΔA_{LR} depends mainly on polarimeter resolution $\Delta P/P \sim 0.5\%-1\%$
  - If both beams are polarized (e^+ from ring): apply

    Blondel scheme: $A_{LR} = f(\sigma_{LR}, \sigma_{RL}, \sigma_{LL}, \sigma_{RR})$

    → uncertainty depends on $\Delta\sigma_{LL}$, $\Delta\sigma_{LR}$, $\Delta\sigma_{RL}$, $\Delta\sigma_{RR}$ not on $\Delta P/P$!

    → Some running in LL and RR required: ~10% of time
- **Assume**
  - $P(e^-)=90\%$
  - Vary $P(e^+)= 22\%, 30\%, 50\%$

  How many Z's are needed for $\Delta \sin^2\theta_{eff}=3 \times 10^{-5}$ or even 1.3×10^{-5}?

  As comparison: lumi(GigaZ)= 10^9 Z's in ~70 days

Required polarization & years

- **Remember:** currently $\Delta \sin^2\theta_{eff}=1.6\text{x}10^{-4}$
- $P(e^-)=90\%$, $\Delta P/P=0.5\text{-}1\%$ (for $e^\pm$)

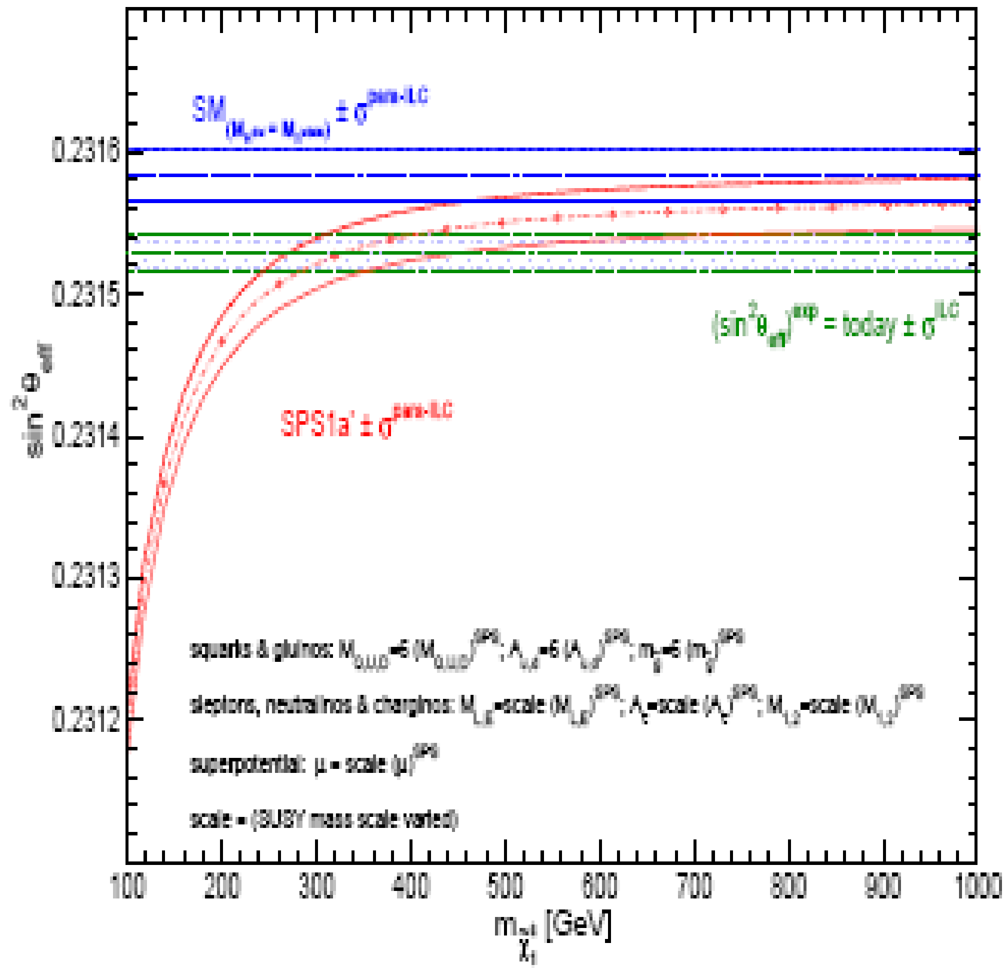
$P(e^+)$	#Z's	$\Delta \sin^2\theta_{eff}$	
0%	$4.5\text{x}10^7$	$1.0\text{x}10^{-4}$	No further progress
	$9.0\text{x}10^8$	$9.8\text{x}10^{-5}$	
22%	$1.7\text{x}10^9$	$3.0\text{x}10^{-5}$	$3\text{x}10^{-5}$: high sensitivity to new physics!
30%	$7.7\text{x}10^8$	$3.0\text{x}10^{-5}$	
50%	$2.3\text{x}10^8$	$3.1\text{x}10^{-5}$	
22%	$9.1\text{x}10^9$	$1.3\text{x}10^{-5}$	'GigaZ': full exploitation only if m_{top}=0.1 GeV
30%	$4.1\text{x}10^9$	$1.3\text{x}10^{-5}$	
50%	$1.4\text{x}10^9$	$1.3\text{x}10^{-5}$	

- **Polarization of both beams is mandatory !**

→ ***GigaZ precision does need high polarization of $e^\pm$!***

Help in challenging LHC scenarios ?

- 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 !



Summary table and gain factor

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

hep-ph/0507011

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	$P^T_{e^-} P^T_{e^+}$ required	$P^T_{e-} P^T_{e+}$ required
	access to S- and T-currents up to 10 TeV		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 and gain factor

hep-ph/0507011

- 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	$P^T_{e^-}P^T_{e^+}$ 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 and gain factor

hep-ph/0507011
P(e+)=30%

- Estimated gain factor when only

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

Summary and open studies?

- Polarized $e^{\pm}$ beams required for many LC studies
- Some effects can only be achieved with polarized e^- and e^+:
  - verification of SUSY properties, quantum numbers
  - accuracy in ΔA_{LR} (important for many studies!)
  - precision measurements on $\sin^2\theta_{eff}$ at the Z-pole
- New strawman baseline design foresees P(e+)~22%:
  - can be compensated in some cases by achieving P(e-)=90%
  - results in some studies to practically no physics gain!
- 'Cheap and easy' tools for reinstallation of at least 30% should be done (e.g. via implementation of a collimator)
  - Otherwise powerful tool for some studies lost!
- *Still studies missing……stay tuned!?*