Polarized positrons for Higgs and SUSY

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- **Introduction**
- **SB2009**
- **Summary polarized beams in Higgs physics**
- **Summary polarized beams in SUSY 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 $\sin^2\theta=0.23098\pm0.00026$ on basis of $L\sim10^{30}\,cm^{-2}s^{-1}$**
- **Compare with results from unpolarized beams at LEP:**
  - **$\sin^2\theta=0.23221\pm0.00029$ but with $L\sim10^{31}cm^{-2}s^{-1}$**

➡ **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:

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

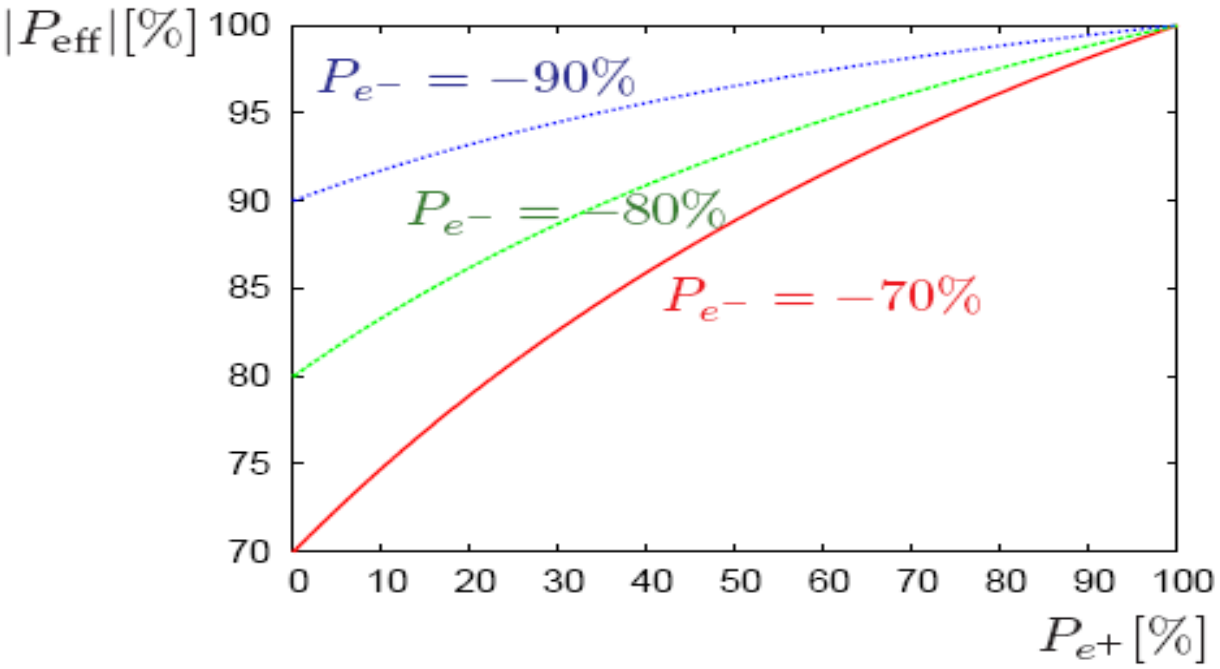
σ_{RR}, σ_{LL}, σ_{RL}, σ_{LR} are contributions with fully polarized L, R beams.

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?

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

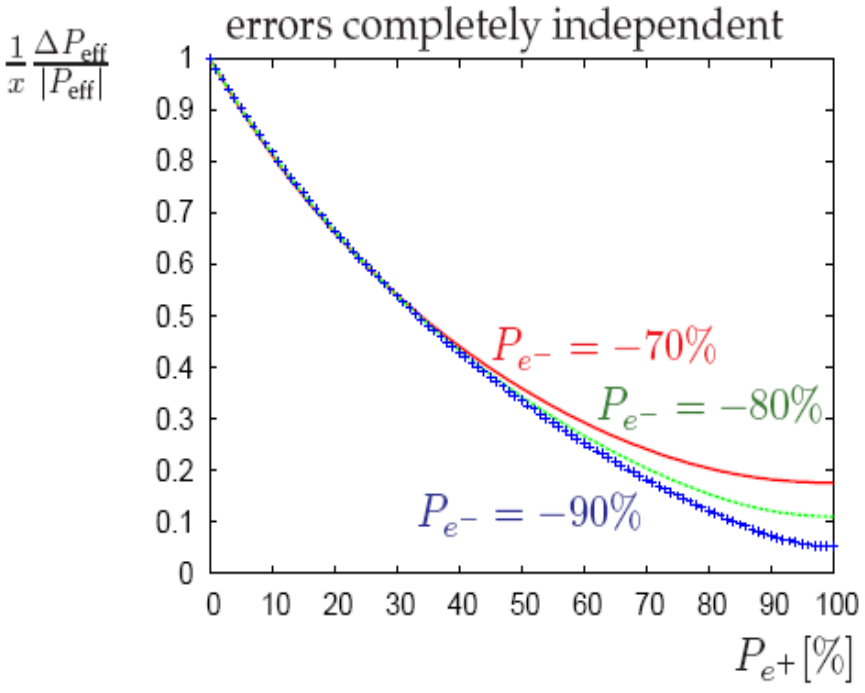
That means: $$\left|\frac{\Delta A_{\rm LR}}{A_{\rm LR}}\right| \sim \left|\frac{\Delta P_{\rm eff}}{P_{\rm eff}}\right|$$

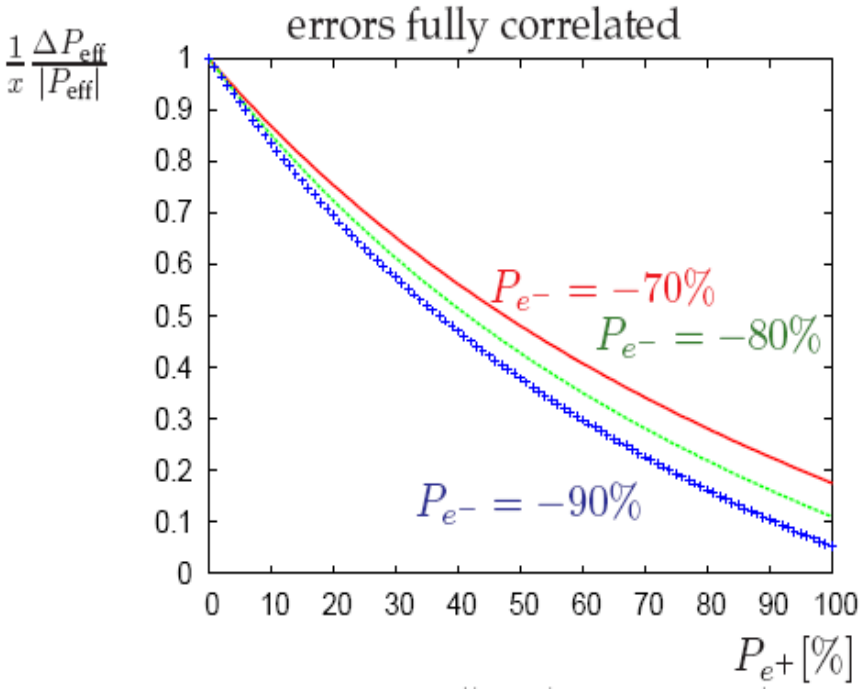
- With pure error propagation (and errors uncorrelated), one obtains:

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

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 %**

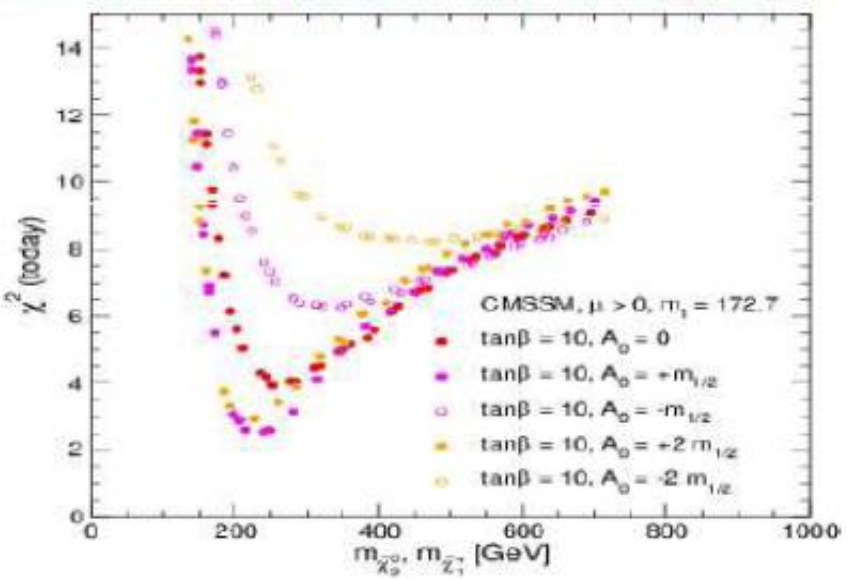
  $\Delta A_{LR}/A_{LR}$ = 0.3 **$\Delta A_{LR}/A_{LR}$ = 0.27** **$\Delta A_{LR}/A_{LR}$ =0.5**

- **(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

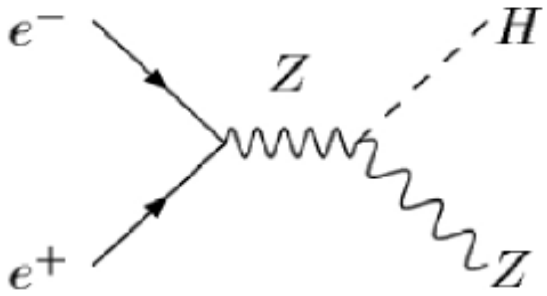
- **Supersymmetry-like signals**
  - **New physics model with high predictive power**
  - **'light' SUSY consis-tent with precision fits**

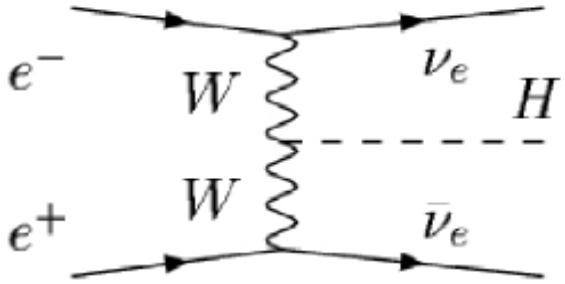


- **Extra gauge bosons and/or large extra dimensions**
  - **High precision in indirect searches allow model distinction and couplings determination**

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 $e^+e^- \to H\nu\bar{\nu}$	$e^+e^- \to HZ$
$(+80\%, 0)$	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?

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

    (-80%,+60%): $\sigma(ttH)^{Pol}/\sigma(ttH)$~2.1 ⟶ g_{ttH}^{Pol}/g_{ttH}~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!!!**

Open 'pol' questions in Higgs ?

- 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 …

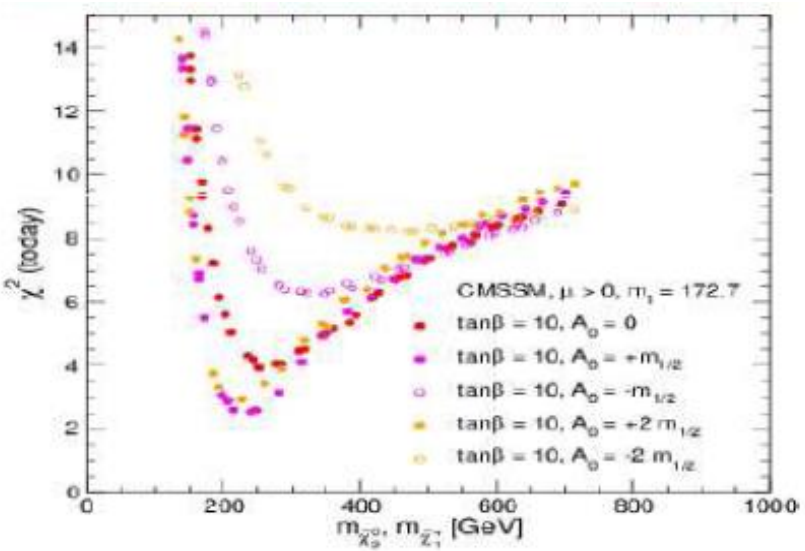
- Distinction SM vs. SUSY light Higgs:
  - Influence of polarization ?
  - (80%,0), (80%,60%) or might already be (80%,22%) be helpful?
- Hbb couplings determination?

Aside: Polarization should be always helpful even if Signal scales like Background in S/√B !

- Further ideas / proposals?

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**

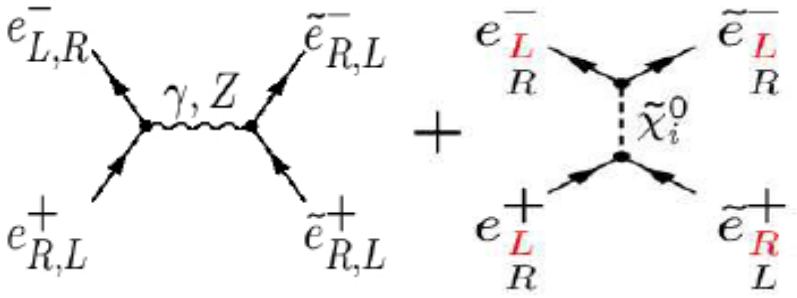


- **Extra gauge bosons and/or large extra dimensions**
  - **High precision in indirect searches allow model distinction and couplings determination**

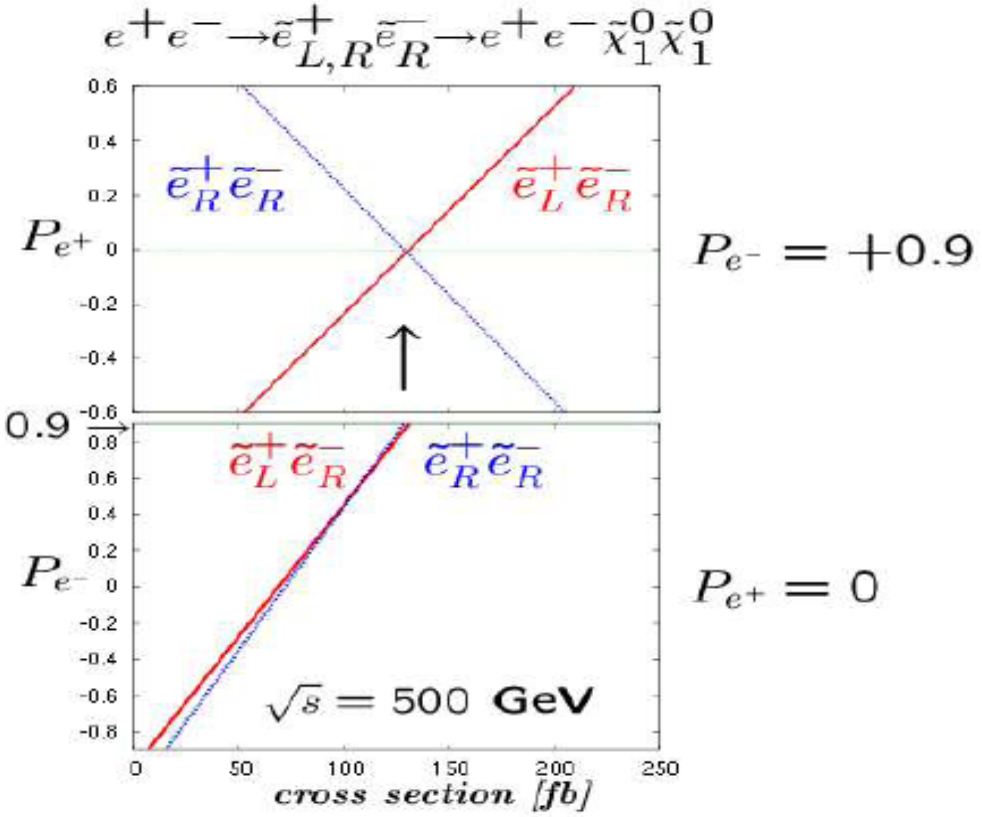
Slepton `chiral' quantum numbers

- 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

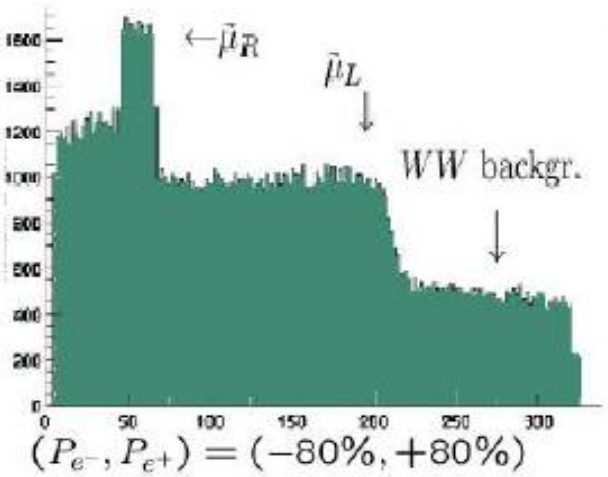
- To optimize threshold scans: precise continuum measurements important!
- Worst SM background is WW-pair production
  - e.g. $e^+e^- \to \tilde{\mu}^+_{L,R}\tilde{\mu}^-_{L,R}$

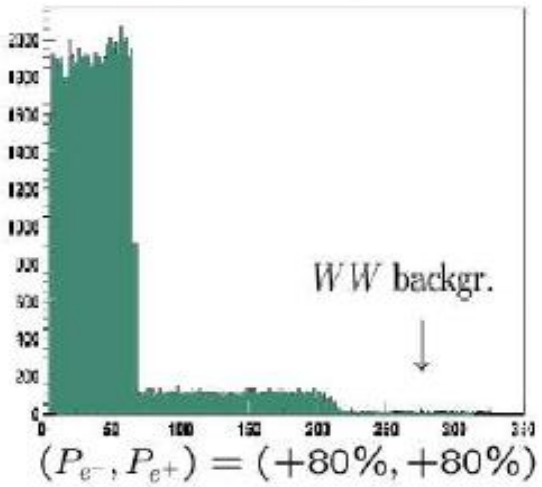
Muon energy spectrum: $\mu^+\mu^-$ events (incl. W^+W^-) at $\sqrt{s} = 750$ GeV

- 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%)

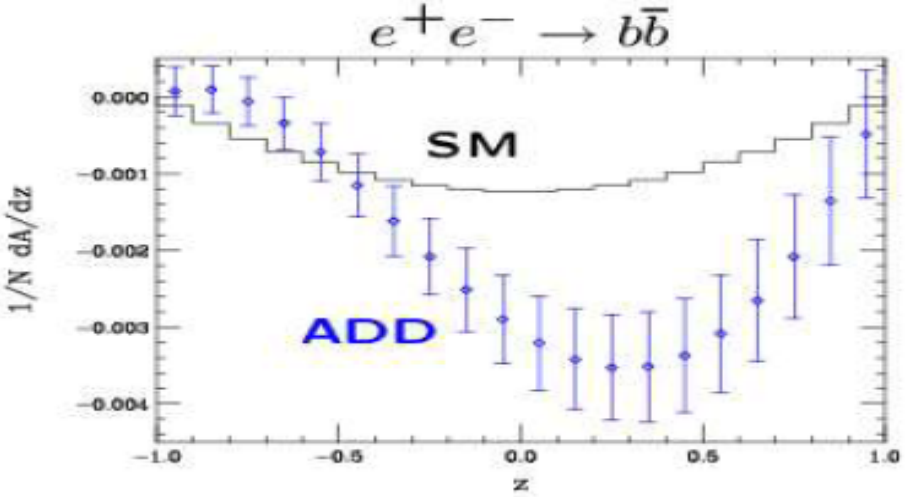




- **Background not sufficiently suppressed with (80%,22%) ….gain~1.25**

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 $P_T(e^-)$ x $P_T(e^+)$-dependence:
  - effects decrease by about a factor 2 when using (80%,30%) instead of (80%60%)

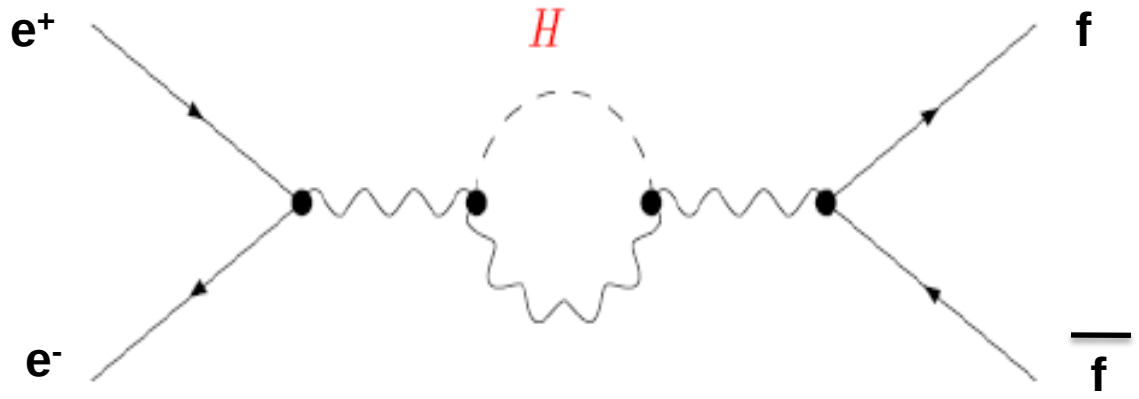
➢ by about a factor 1.8 if (80%,22%)

➢ could be compensated by (90%,22%) !

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

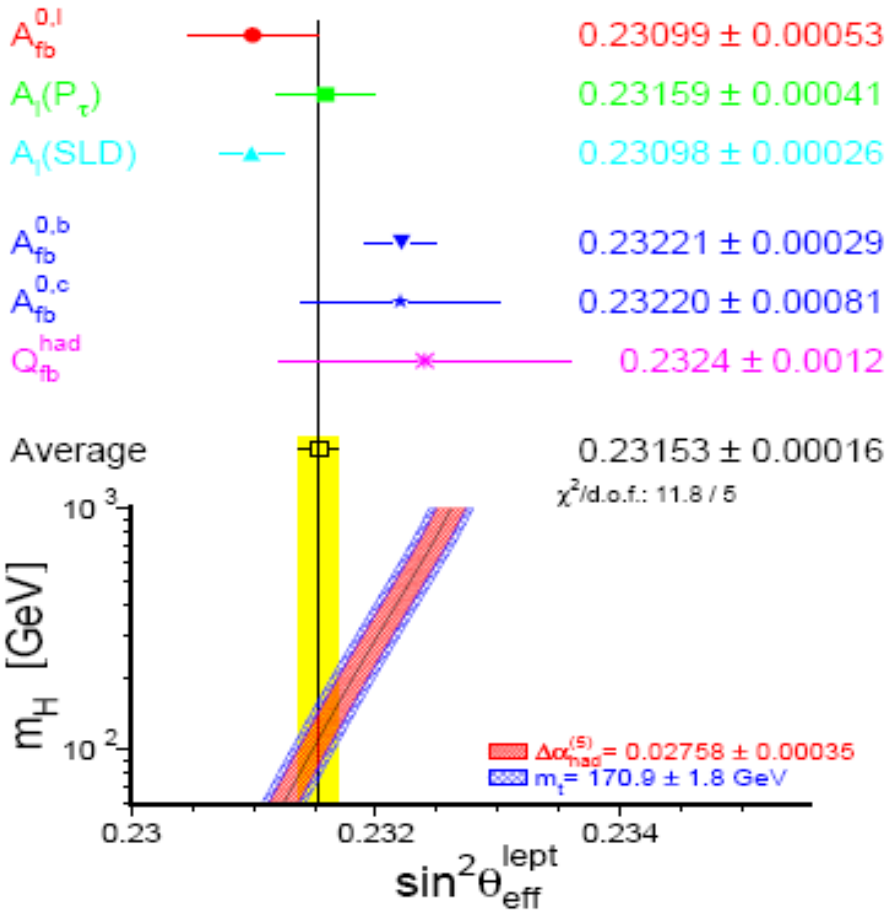
Why indirect searches at a e^+e^- Z-factory?

- **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



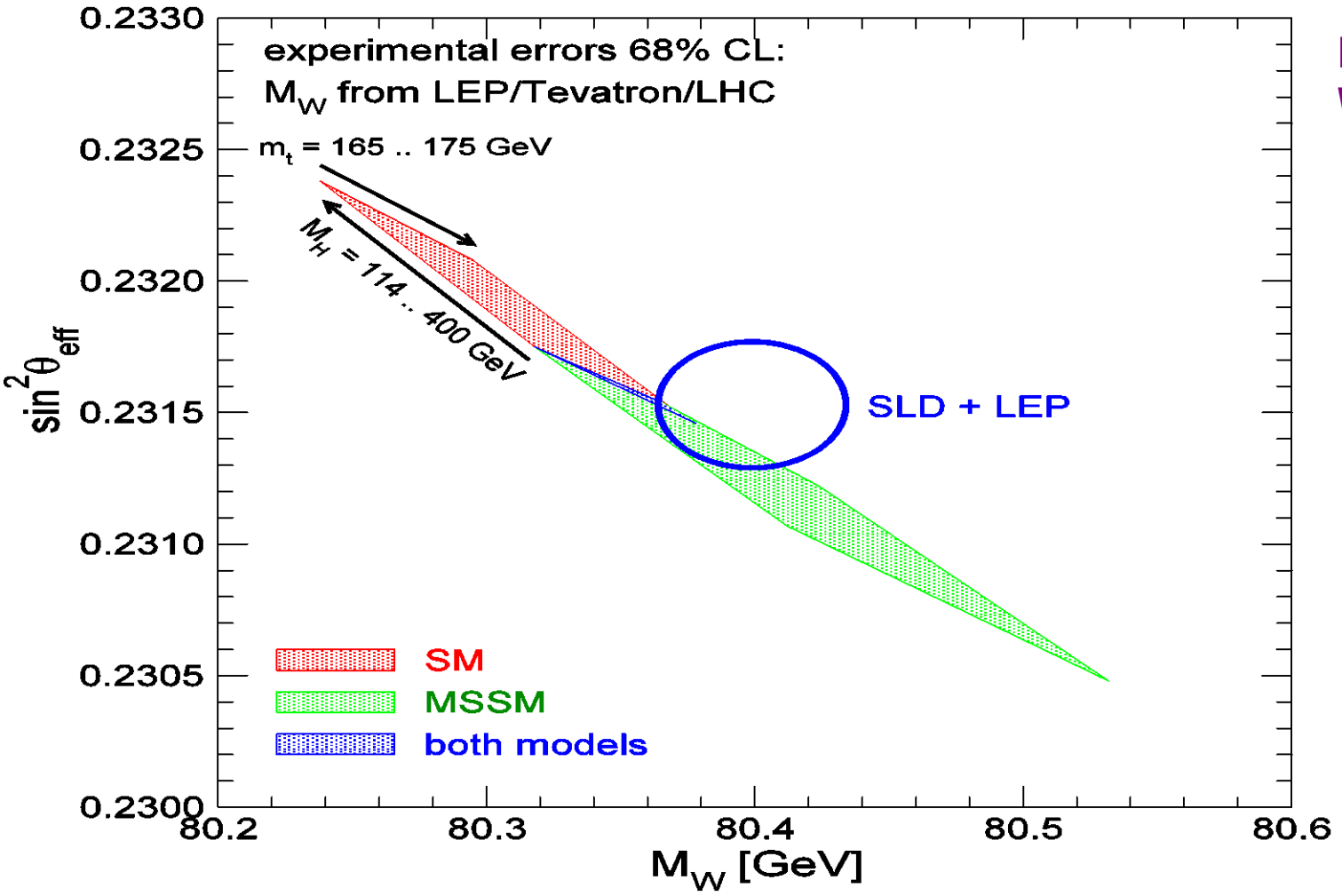
LEP:
$\sin^2\theta_{eff}(A_{FB}^b) = 0.23221 \pm 0.00029$

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

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

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

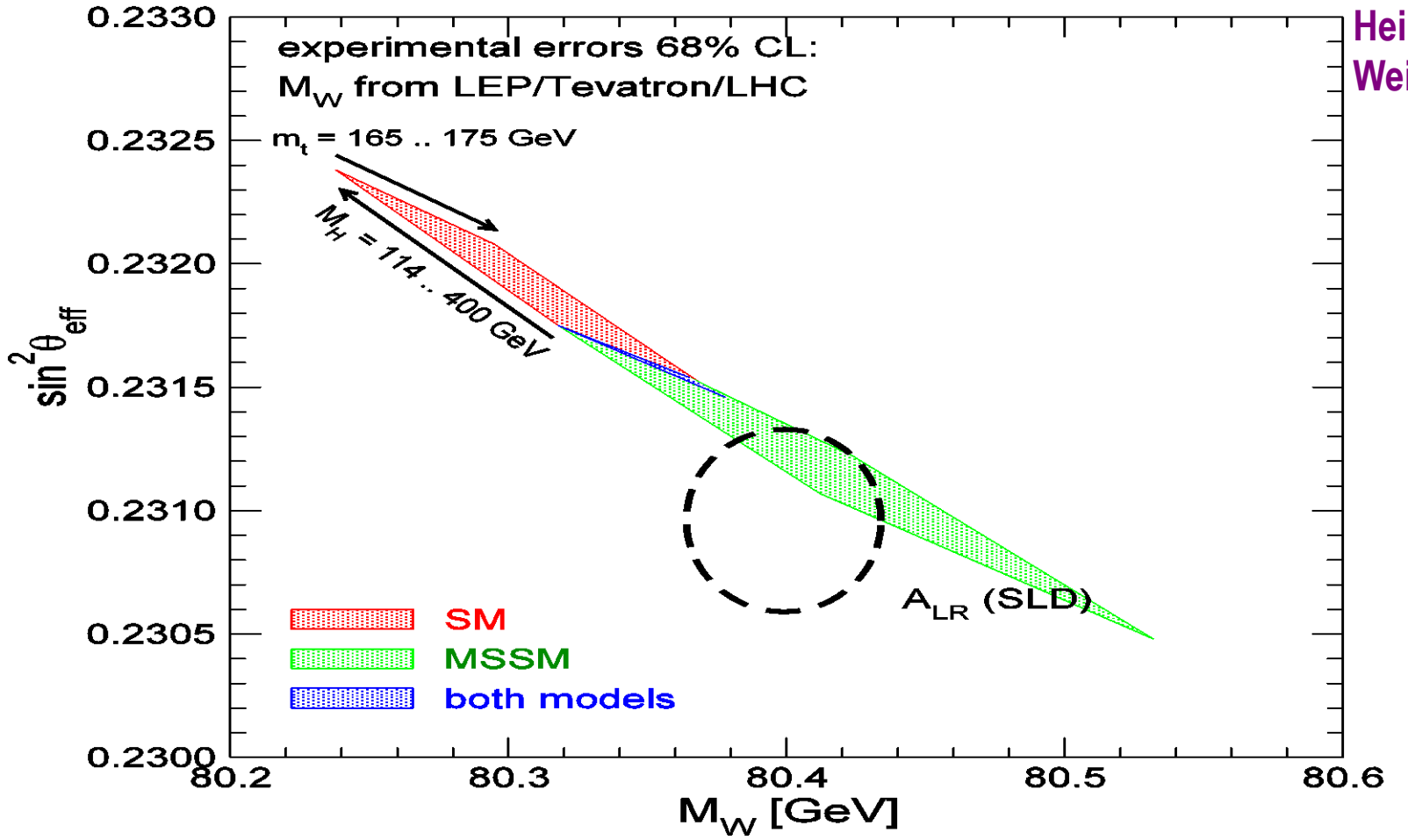
M_W vs. central value $\sin^2\theta_{eff}$



Heinemeyer, Weiglein

→ Consistent with SM and SUSY

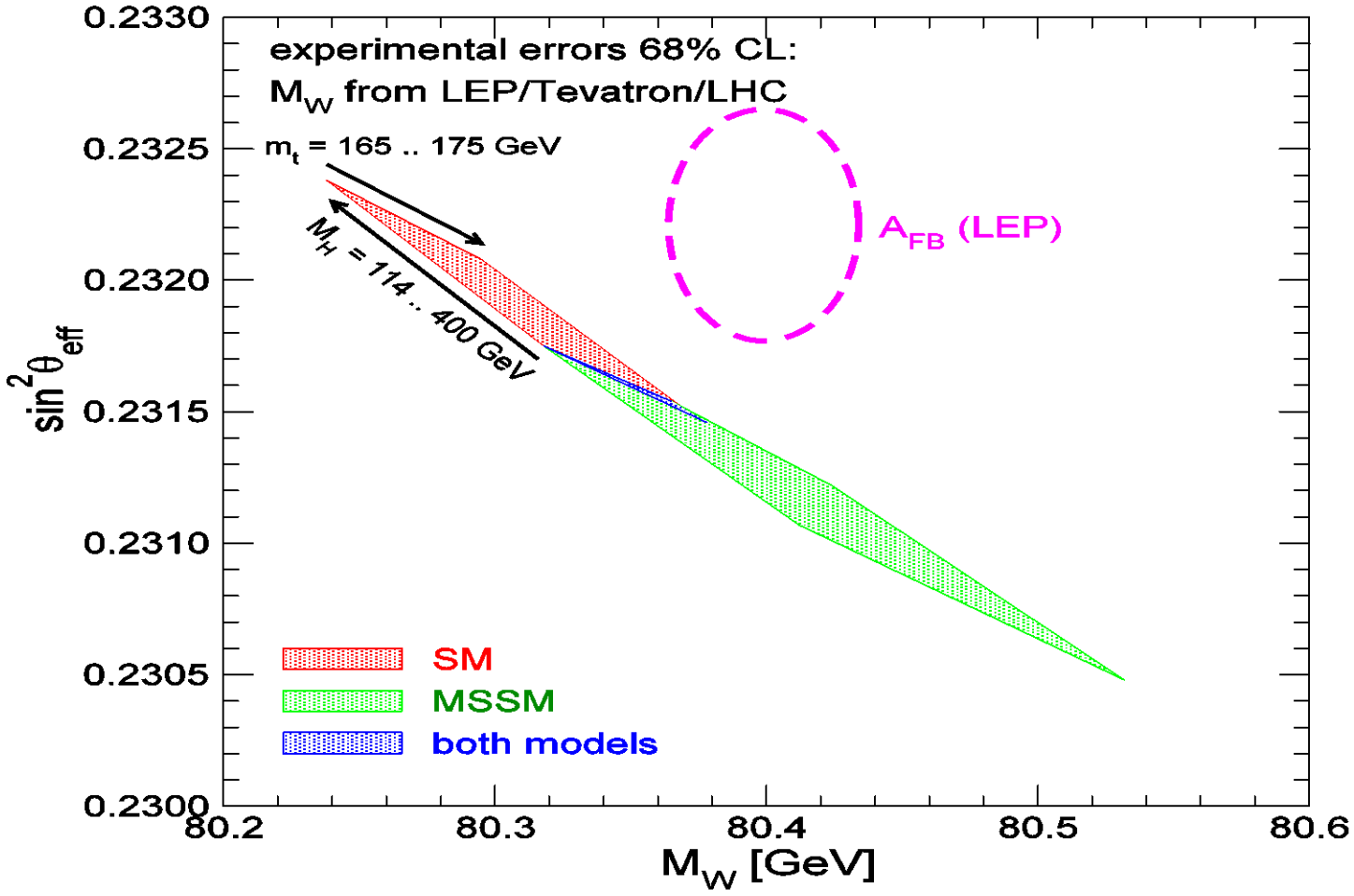
M_W vs. A_{LR}(SLD)-value $\sin^2\theta_{eff}$



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: $\Delta\sin2\theta_{eff}^{ho} \sim 5\times10^{-5}$ (currently)
  - Uncertainties from input parameters: Δm_Z, $\Delta\alpha_{had}$, m_{top}
    - Δm_Z=2.1 MeV: $\Delta\sin^2\theta_{eff}^{para} \sim 1.4\times10^{-5}$
    - $\Delta\alpha_{had} \sim 35$ (5 future) x 10^{-5} : $\Delta\sin^2\theta_{eff}^{para} \sim 12$ (1.7 future)$\times10^{-5}$
    - $\Delta m_{top} \sim 1$ GeV (LHC): $\Delta\sin^2\theta_{eff}^{para} \sim 3\times10^{-5}$
    - $\Delta m_{top} \sim 0.1$ GeV (ILC): $\Delta\sin^2\theta_{eff}^{para} \sim 0.3\times10^{-5}$

→ ***If $\Delta\sin^2\theta_{eff} \sim 3\times10^{-5}$ achievable: big physics impact***

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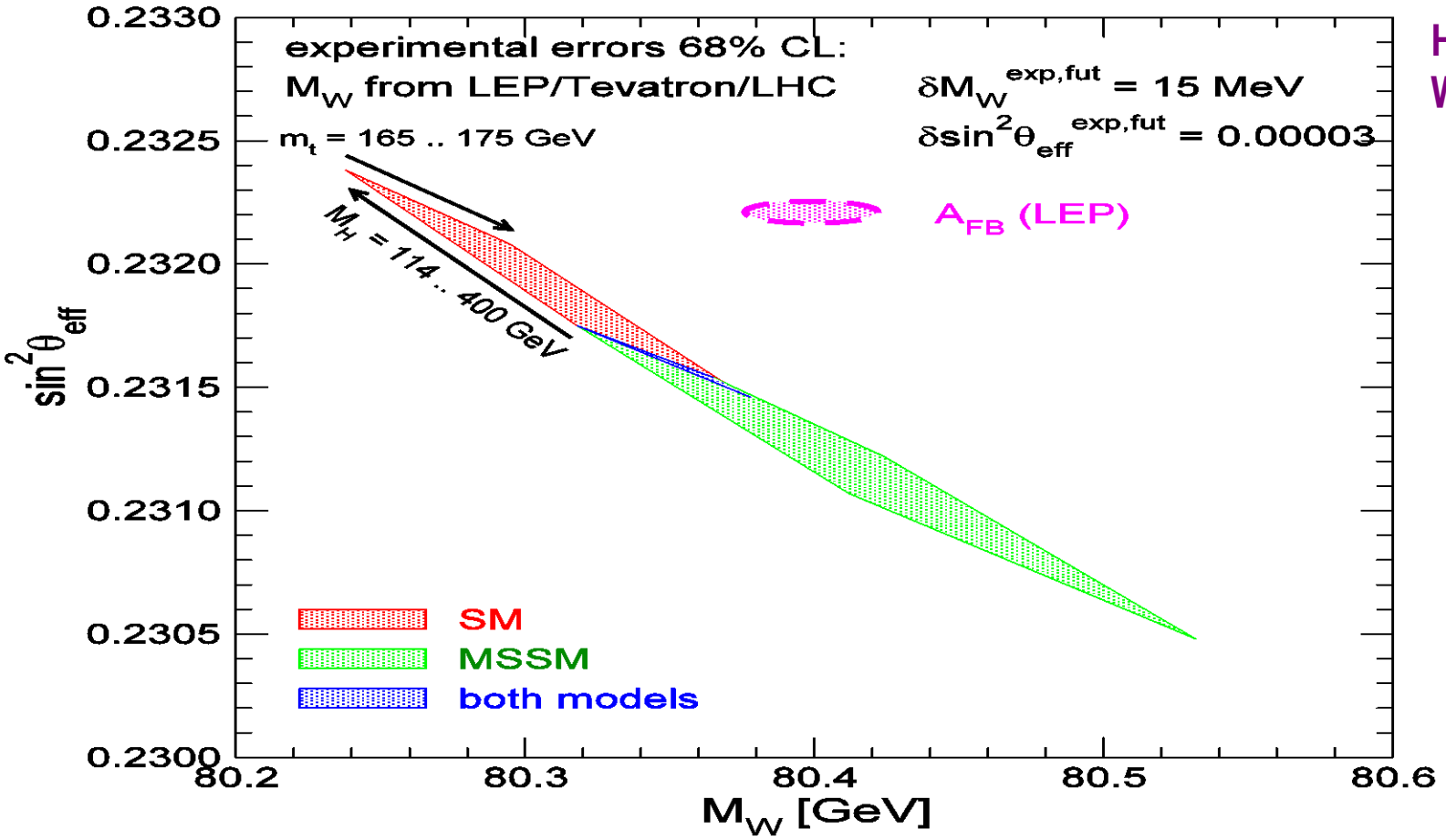
    - yesterday Davier: $\Delta\alpha_{had} \sim 10\times 10^{-5}$: $\Delta\sin^2\theta_{eff}^{para} \sim 3.4\times10^{-5}$
    - Δm_{top}~1 GeV (LHC): $\Delta\sin^2\theta_{eff}^{para} \sim 3\times10^{-5}$
    - Δm_{top}~0.1 GeV (ILC): $\Delta\sin^2\theta_{eff}^{para} \sim 0.3\times10^{-5}$

→ ***If $\Delta\sin^2\theta_{eff} \sim 3\times10^{-5}$ 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 $\Delta\sin^2\theta_{eff}=1.6\times10^{-4}$**
- **$P(e^-)=90\%$, $\Delta P/P=0.5\text{-}1\%$ (for $e^\pm$)**

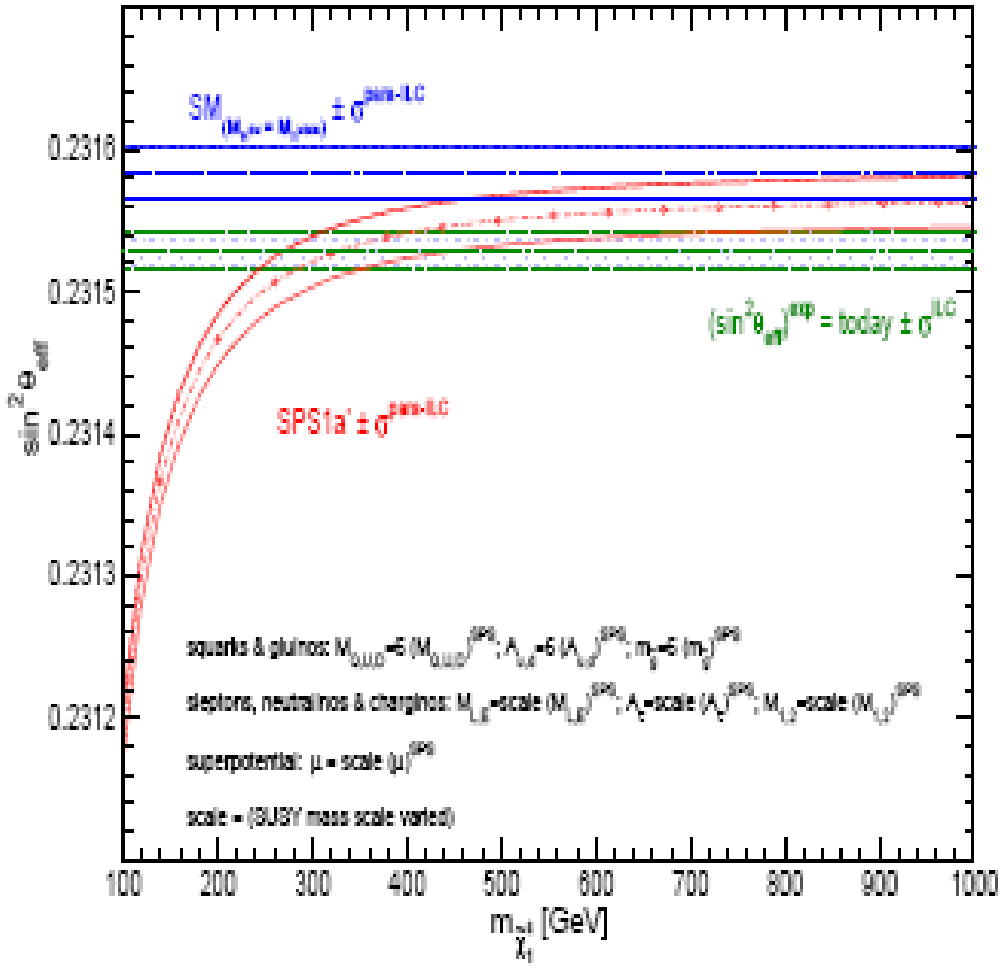
$P(e^+)$	#Z's	$\Delta\sin^2\theta_{eff}$	
0%	4.5×10^7	1.0×10^{-4}	No further progress
	9.0×10^8	9.8×10^{-5}	
22%	1.7×10^9	3.0×10^{-5}	3×10^{-5}: high sensitivity to new physics!
30%	7.7×10^8	3.0×10^{-5}	
50%	2.3×10^8	3.1×10^{-5}	
22%	9.1×10^9	1.3×10^{-5}	'GigaZ': full exploitation only if $m_{top}=0.1$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

- Polarized $e^{\pm}$ beams required for many Higgs/SUSY 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 in Higgs and SUSY missing……!?*