Polarized e^- and e^+ at the ILC

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SUSY WG

Snowmass, 22/08/2005

1. **Introduction**
   - $\rightarrow$ general remarks
   - $\rightarrow$ polarization report

2. **The physics case for polarized e^- and e^+ beams – here: SUSY**
   - $\rightarrow$ sfermions $\tilde{e}_{L,R}$, $\tilde{\mu}_{L,R}$, $\tilde{t}_1$
   - $\rightarrow$ gauginos $\tilde{\chi}_i^0$
     CP-phases: use of transversely polarized beams
   - $\rightarrow$ R-parity violating SUSY
   - $\rightarrow$ Higgs
   - $\rightarrow$ SUSY constraints from GigaZ

3. **Few examples from 'beyond SM'**

4. **Concluding remarks**

Physics at the e^+e^- Linear Collider

* Discovery of New Physics (NP)
  $\longrightarrow$ Large potential for direct searches
  $\longrightarrow$ Impressive potential also for indirect searches!
* Unraveling the structure of NP
  $\longrightarrow$ precise determination of underlying dynamics and parameters
  $\longrightarrow$ model distinction through model-independent searches
* High precision measurements
  $\longrightarrow$ tests of the SM with unprecedented precision
  $\longrightarrow$ even smallest hints of NP could be observed

$\Rightarrow$ Beam polarization = decisive tool for direct and indirect searches!

'State of the art':

Polarized e^- beam at SLAC: SLC $\sim 75\%$
E158 $\sim 90\%$
at Nagoya, KEK: $\sim 90\%$

new results show that $P(e^-) \sim 90\%$ can be expected at ILC!

$\Rightarrow$ won't such high $P(e^-)$ suffice?

Polarization report - 'The role of polarized poitrons and electrons in revealing fundamental interactions at the Linear Collider'

(working group POWER ≡ POlarization at Work in Energetic Reactions)

- **The 'physics case' for having both beams polarized:**
  150 pages, $\sim$ 80 authors, $\sim$ 35 institutes

$\longrightarrow$ **incl. 90 pages physics, 20 pages machine, 20 pages polarimetry**

$\longrightarrow$ **hep-ph/0507011, will be submitted to Phyics Reports**

$\longrightarrow$ **http://www.ippp.dur.ac.uk/˜gudrid/power/**

$\longrightarrow$ **executive summary, 12 pages, same webpage**

- **News from physics with polarized beams in Susy, SM, other NP!**

$\longrightarrow$ **focus on use of P_{e^+} compared to P_{e^-} only**

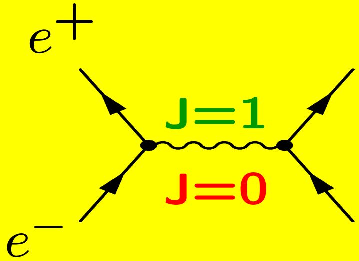
- **Machine overview about polarized e^+ source**
  and polarization measurements

General remarks about the coupling structure

Def.: **left-handed** $\equiv P(e^{\pm}) < 0$ **right-handed** $\equiv P(e^{\pm}) > 0$

Which configurations are possible in principle?

s–channel:



$\leftarrow$ **contributions only from RL,LR: SM and NP (γ, Z)**

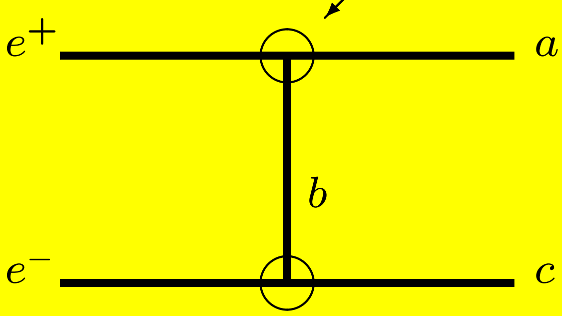
$\leftarrow$ **contributions only from LL,RR: NP!**

$\Rightarrow$ **In principle: $P(e^-)$ fixes also helicity of e^+!**

Which configurations are possible in the crossed channels?

t–channel:

depends on $P(e^+)$!



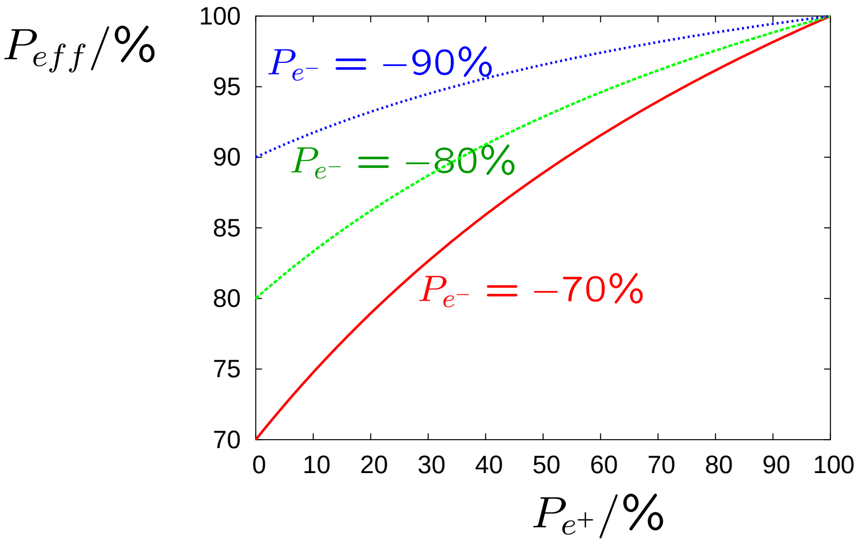
depends on $P(e^-)$!

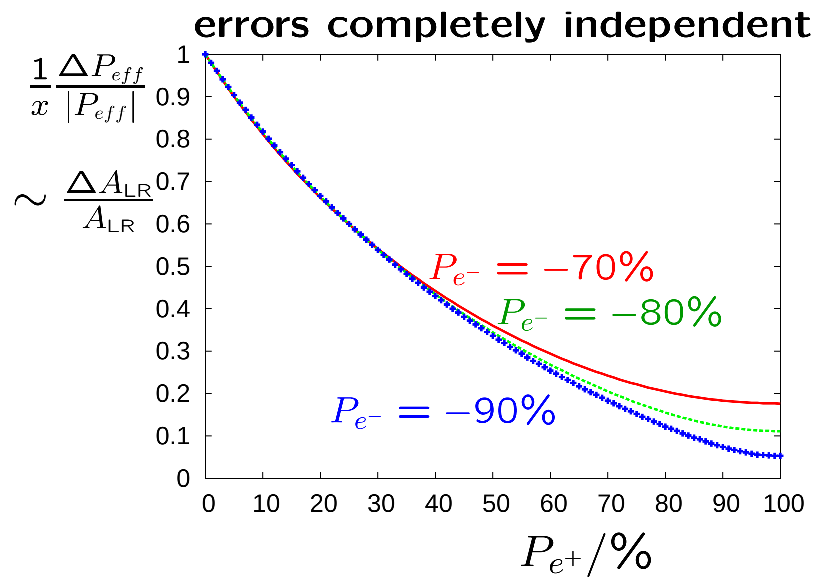
$\Rightarrow$ **helicity of e^- not coupled with helicity of e^+!**

Some well-known statistical examples

At the very end: gain in P_{eff}, A_{LR} and background suppression

- **Enhancement of effective polarization and measuement of A_{LR}**





- **Background suppression:**

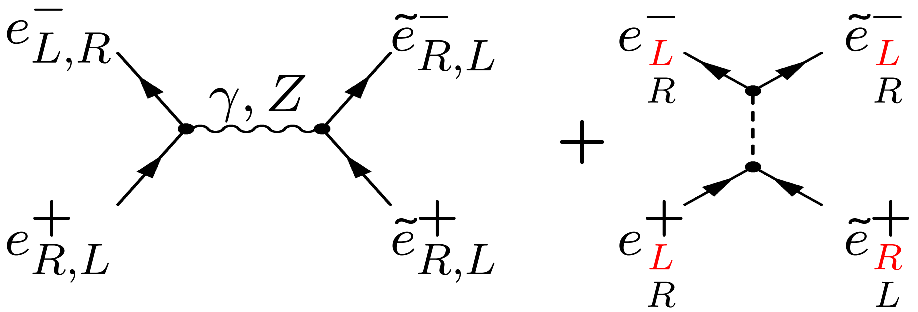
Gain with P_{e^+}	**P_{e^+} in addition to P_{e^-}**	
Signal 'S'	$\times 2$	$\times 2$
Background 'B'	$\times 0.5$	$\times 2$
S/B	$\times 4$	**Unchanged**
$S/\sqrt{B}$	$\times 2\sqrt{2}$	$\times\sqrt{2}$

$\Rightarrow$ **Both e^- and e^+ beams should be polarized!**

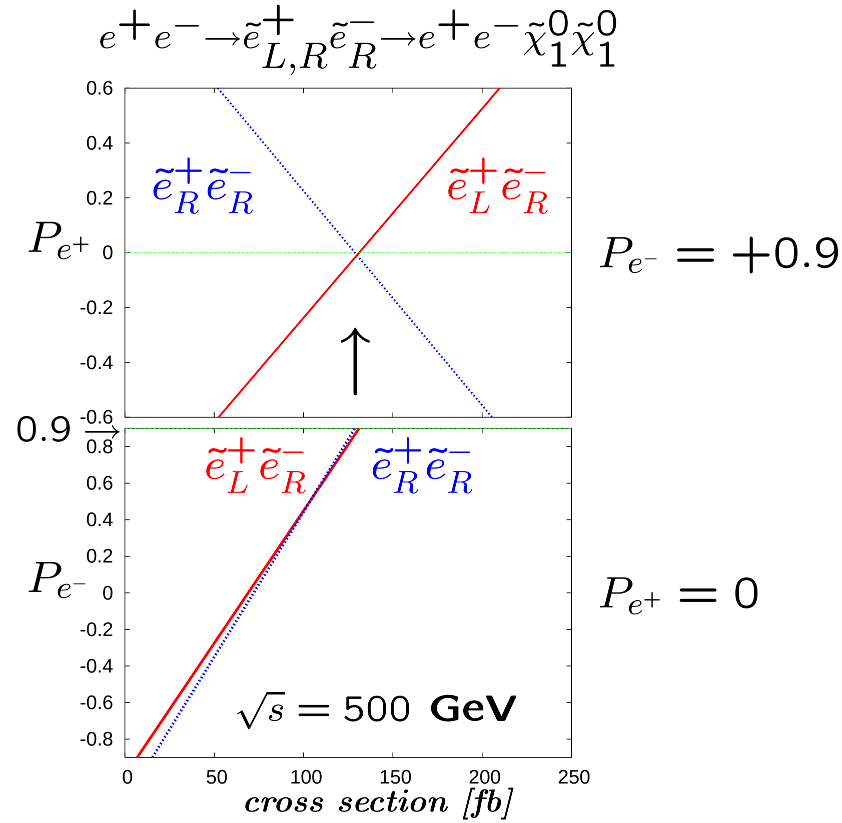
Selectron sector

Test of Susy quantum numbers:

Association of chiral electrons to scalar partners $e^-_{L,R} \leftrightarrow \tilde{e}^-_{L,R}$ and $e^+_{L,R} \leftrightarrow \tilde{e}^+_{R,L}$



1. separation of scattering versus annihilation channel
2. test of 'chirality': only $\tilde{e}^-_R \tilde{e}^+_L$ may survive at $P_{e^-} > 0$ and $P_{e^+} > 0$!



$\Rightarrow$ Even high P_{e^-} not sufficient, but P_{e^+} needed!

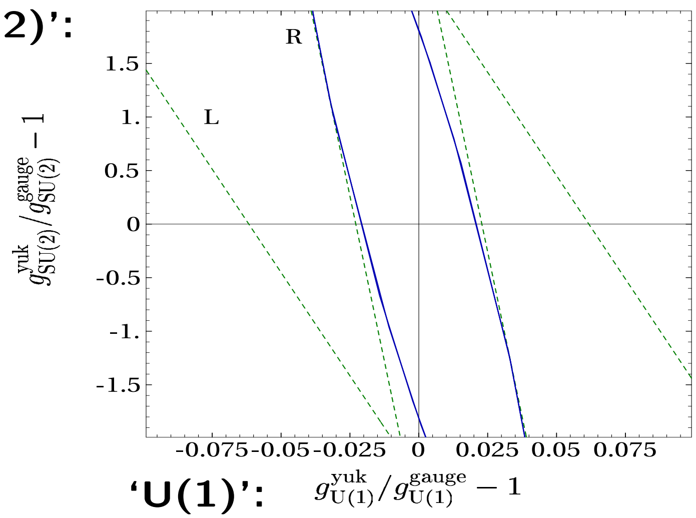
Selectron sector

Supersymmetry: Test of Yukawa couplings

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

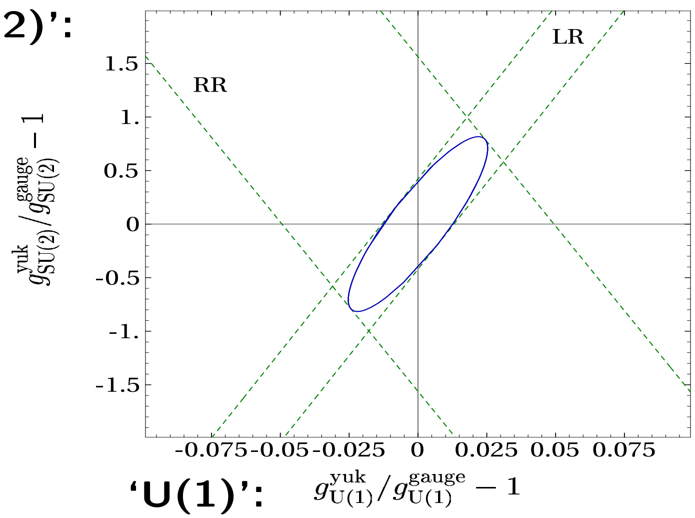
1. **separation of the pairs $\tilde{e}_R^-\tilde{e}_R^+$ and $\tilde{e}_R^-\tilde{e}_L^+$**
2. **'variation' of Yukawa couplings accepted within experimental uncertainty**

'SU(2)':



'U(1)':

'SU(2)':



'U(1)':

Freitas

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

$\Rightarrow$ **SU(2), U(1) Yukawa coupling 'not' measurable** — $\Rightarrow$ $\triangle$ **SU(2)**$\sim 80\%$, $\triangle$ **U(1)** $\sim 2.5\%$

$\Rightarrow$ Even high P_{e^-} not sufficient but P_{e^+} needed!

Selectron sector

Supersymmetry: Test of Yukawa couplings

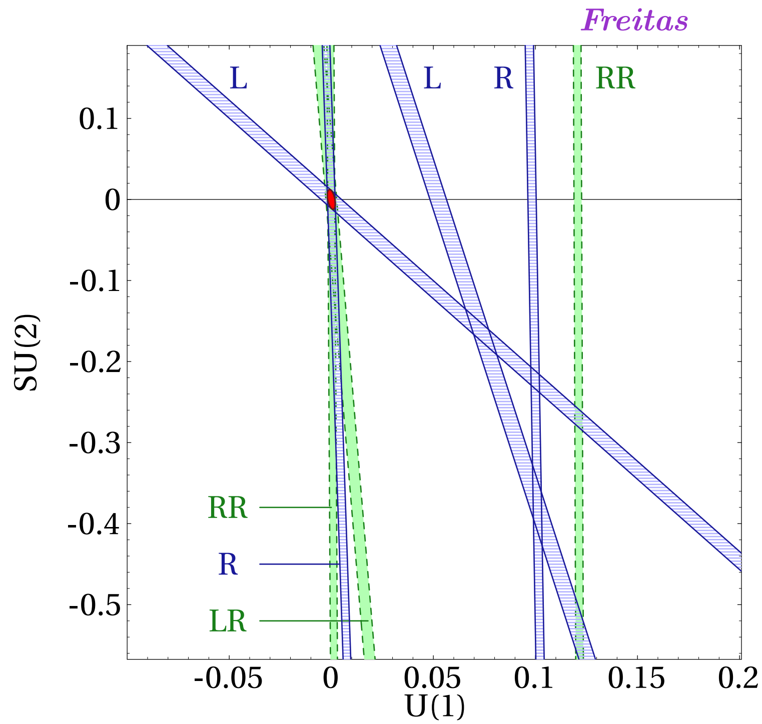
Determination of U(1), SU(2) Yukawa couplings of e^+:

further scenario with $m_{\tilde{e}_R} \ll m_{\tilde{e}_L}$, however no GUT relation between M_1 and M_2:

with $P_{e^-} = +90\%$ (R) and $P_{e^-} = -90\%$ (L)
$\Rightarrow$ four-fold ambiguity!

Adding: $(P_{e^-}, P_{e^+}) = (-60\%, +90\%)$ (LR)
and $(P_{e^-}, P_{e^+}) = (+60\%, +90\%)$ (RR)

$\Rightarrow$ unique determination with
$\Delta(U(1)) \sim 0.2\%$ and $\Delta(SU(2)) \sim 1.2\%$



$\Rightarrow$ Even high P_{e^-} not sufficient but P_{e^+} needed!

Smuon mass measurement

SUSY mass measurement in the continuum

- To optimize threshold scans $\rightarrow$ continuum measurements important!

Example: $e^+e^- \rightarrow \tilde{\mu}^+_{L,R}\tilde{\mu}^-_{L,R}$

$\rightarrow$ only s-channel

Strong WW-background

$\rightarrow$ all edges observable

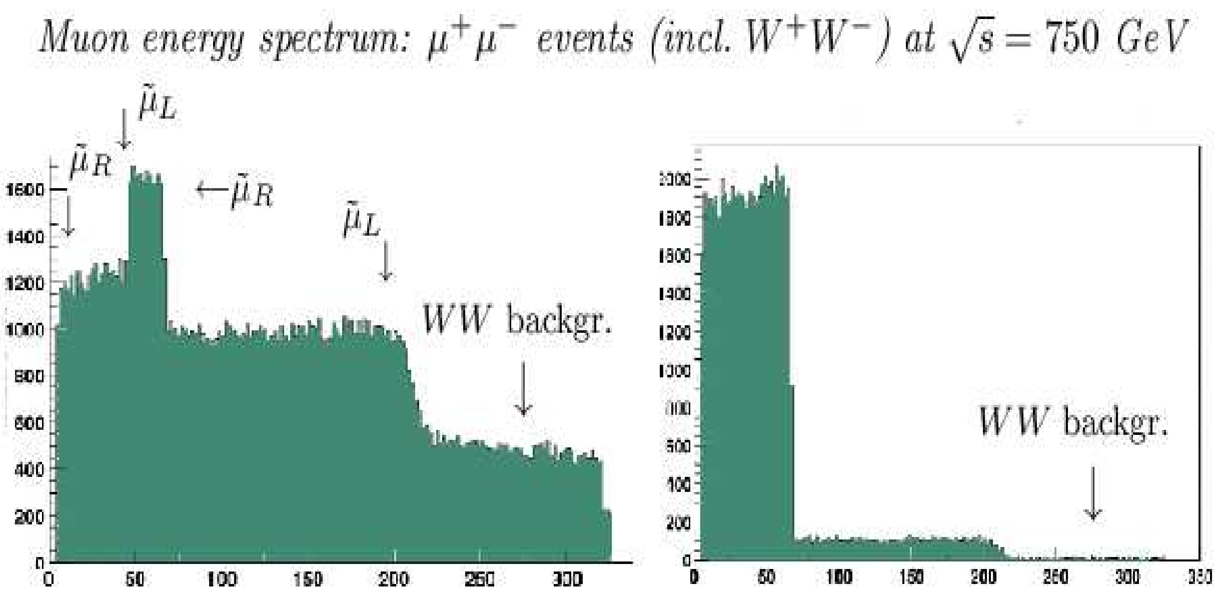
only with P_{e^-} and P_{e^+}

$\sim$65 GeV and 220 GeV

$\rightarrow$ **S/B=0.07** $(+80\%, 0)$

$\rightarrow$ **S/B=0.46** $(+80\%, -80\%)$

$\Rightarrow$ $\Delta(m_{\tilde{\mu}_{L,R}}) \sim$ few GeV



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

$\Rightarrow$ **Even high P_{e^-} not sufficient but P_{e^+} needed!**

Third family: stop sector

Determination of stop mixing angle

Process $e^+e^- \to \tilde{t}_1\tilde{t}_1$ **(only** γ, Z **exchange): determination of** $\theta_{\tilde{t}}$

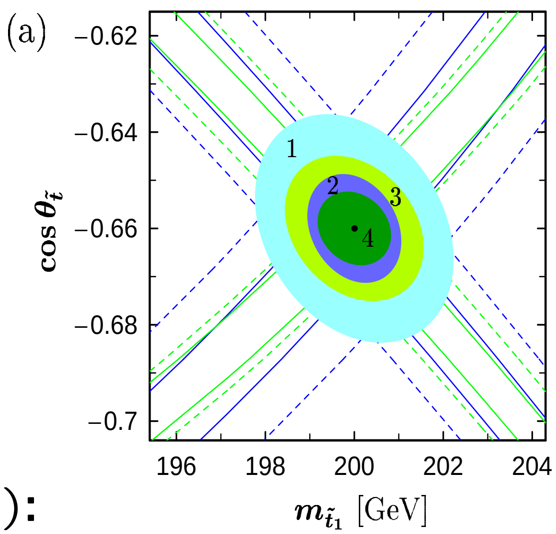
with $\sigma(\tilde{t}_1\tilde{t}_1)$ **or with** A_{LR}

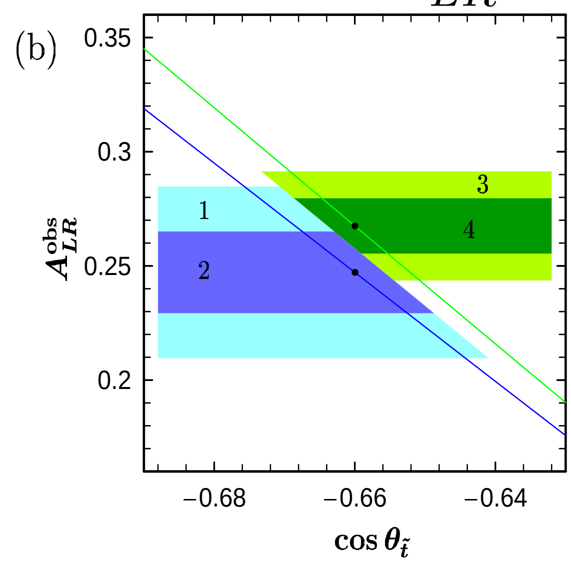
light colours '1', '3':

$\to \mathcal{L}_{\rm int} = 100$ **fb**$^{-1}$

dark colours '2', '4':

$\to \mathcal{L}_{\rm int} = 500$ **fb**$^{-1}$





$(\pm 90\%, 0) \to (\pm 90\%, \mp 60\%)$:

with $\mathcal{L}_{\rm int} = 100$ **fb**$^{-1}$	$\Delta \cos\theta_{\tilde{t}} \sim 3.6 \to 2.4\%$	$\Delta \cos\theta_{\tilde{t}} \sim 2.3 \to 1.4\%$
with $\mathcal{L}_{\rm int} = 500$ **fb**$^{-1}$	$\Delta \cos\theta_{\tilde{t}} \sim 1.8 \to 1.1\%$	$\Delta \cos\theta_{\tilde{t}} \sim 1.1 \to 0.7\%$

$\Rightarrow$ **'gain' factor about 1.6 for accuracy in** $\cos\theta_{\tilde{t}}$
and about 1.4 for $\Delta m_{\tilde{t}}$

Gaugino/higgsino sector

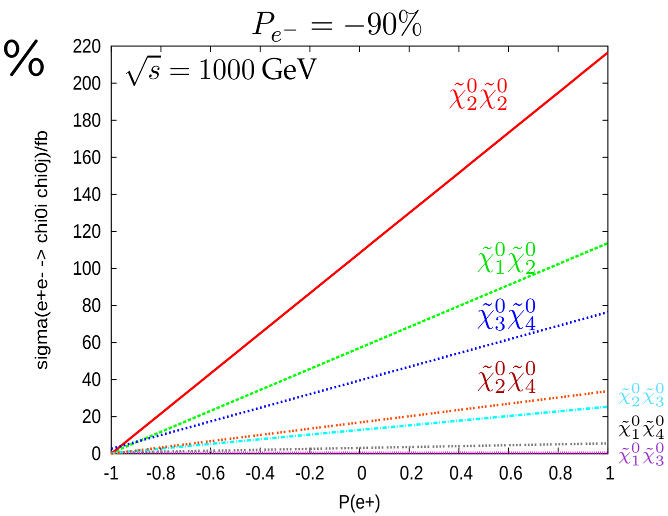
SUSY: determination of the new parameters
(already 105 new parameters in the 'minimal' model (MSSM)!)

- **complicated interplay of SUSY parameters**

  $\Rightarrow$ **as many as possible observables needed!**

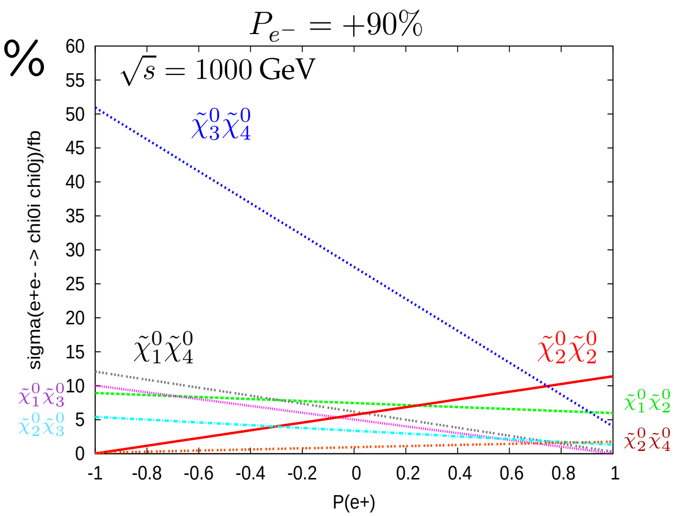
  exploit e.g. all possible cross sections of $\tilde{\chi}^0_i\tilde{\chi}^0_j$: $\sigma(e^+e^- \to \tilde{\chi}^0_i\tilde{\chi}^0_j)$**/fb**

$P_{e^-} = -90\%$



P_{e^+}

$P_{e^-} = +90\%$



P_{e^+}

- **with P_{e^+} gain in cross sections up to factor $\sim$2 wrt P_{e^-} only**

$\Rightarrow$ Both e^- and e^+ beams should be polarized!

Azimuthal asymmetries with trans. polarization CP-odd observables in neutralino production

- Cross sections: $\sigma^T \sim P^T_{e^-} P^T_{e^+} \int d\phi Re f_1 \cos(\eta - 2\phi) + Im f_2 \sin(\eta - 2\phi)$

(η gives azimuthal orientation of transverse beams w.r.t. to fixed reference frame)

$\Rightarrow$ both beams have to polarized, otherwise no contribution ($m_e \to 0$!)

- CP-odd terms are $\sim \sin(\eta - 2\phi)$

$\rightarrow$ Dirac case: in $\tilde{\chi}^+_i \tilde{\chi}^-_j$ production CP-odd terms$\sim \sin(\eta - 2\phi)$ vanish! Bartl ea '04

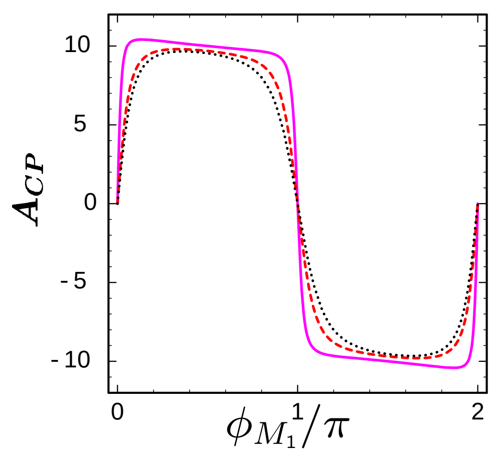
$\rightarrow$ Majorana case: in $\tilde{\chi}^0_i \tilde{\chi}^0_j$ production CP-odd terms$\sim \sin(\eta - 2\phi)$ contribute!

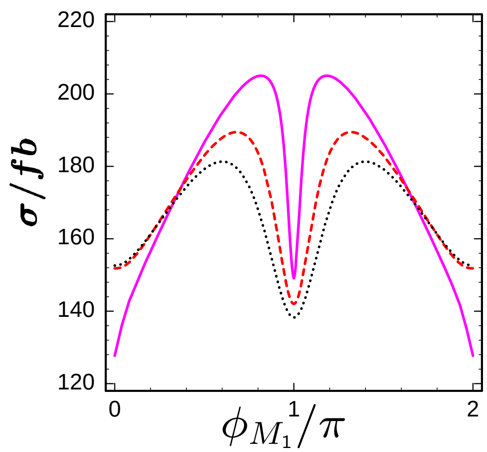
(because of t, u channel)

$e^+e^- \to \tilde{\chi}^0_1 \tilde{\chi}^0_2$:

at $\sqrt{s} = 500$ GeV

for $\tan\beta = 3, 10, 30$





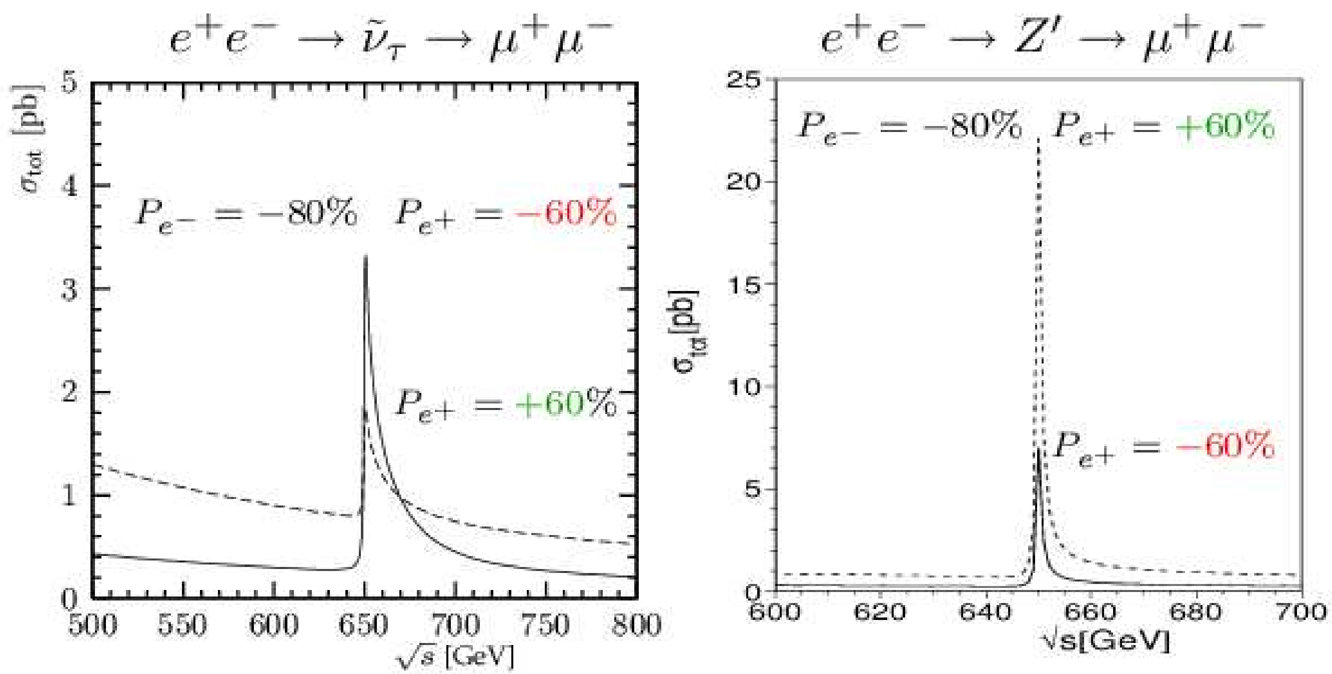
$\Rightarrow$ Rather large A_{CP} expected, even for small CP-phases!

Extended SUSY model: R-parity violation

R-parity violation: single $\tilde{\nu}$ production in s-channel

- **Process $e^+e^- \to \tilde{\nu}_\tau \to \mu^+\mu^-$ (only s-channel γ, Z, $\tilde{\nu}_\tau$ exchange)**

  $\Rightarrow$ **'spin 0-$\tilde{\nu}$' $\to$ favours LL configuration, but e.g. Z' in SSM favours LR!**



- **direct test of spin in resonance production**

$\Rightarrow$ Both e^- and e^+ beams should be polarized!

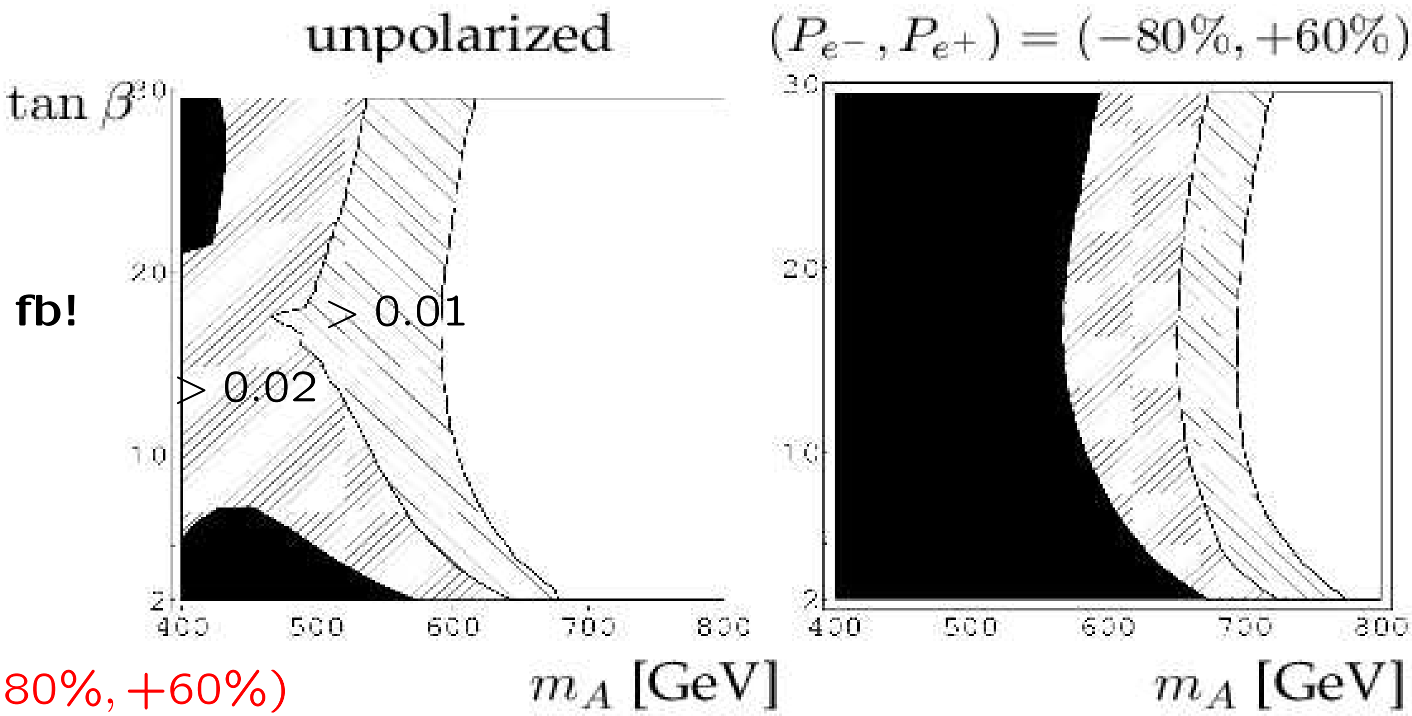
SUSY Higgs production

Heavy Higgs production in decoupling regime:

- **Process: single Higgs in $e^+e^- \to \nu\bar{\nu}H$ for $m_A \gg m_Z$**

  (rare process, since coupling (H,gauge bosons) suppressed!)

black: $\sigma > 0.05$ **fb!**



'gain':

$(-80\%, 0) \to (-80\%, +60\%)$

$\Rightarrow$ **factor 1.6**

$\Rightarrow$ **Both e^- and e^+ beams should be polarized for such rare processes!**

Last-but-not-least: SM physics tests at GigaZ

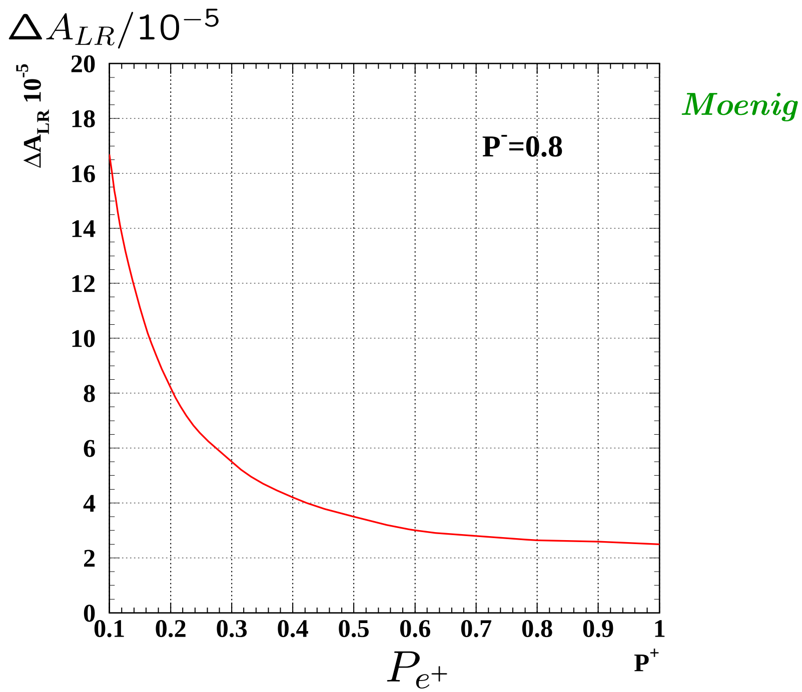
Measurement of $\sin^2\theta^\ell_{\rm eff}$ in $e^+e^- \to Z \to f\bar{f}$:

- **'usually' $\Delta P/P \sim 0.5\%$ sufficient**

  (maybe $\Delta P/P \sim 0.25\%$ reachable!)

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

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



- **with $\Delta P/P = 0.5\%$ and $P_{e^-} = 80\%$ only:**

  $\Rightarrow \Delta \sin^2\theta^\ell_{\rm eff} = 9.5 \times 10^{-5}$

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

  $\Rightarrow \Delta \sin^2\theta^\ell_{\rm eff} = 5 \times 10^{-5}$ *Rowson*)

- **with Blondel scheme: $(P_{e^-}, P_{e^+}) = (80\%, 60\%)$:**

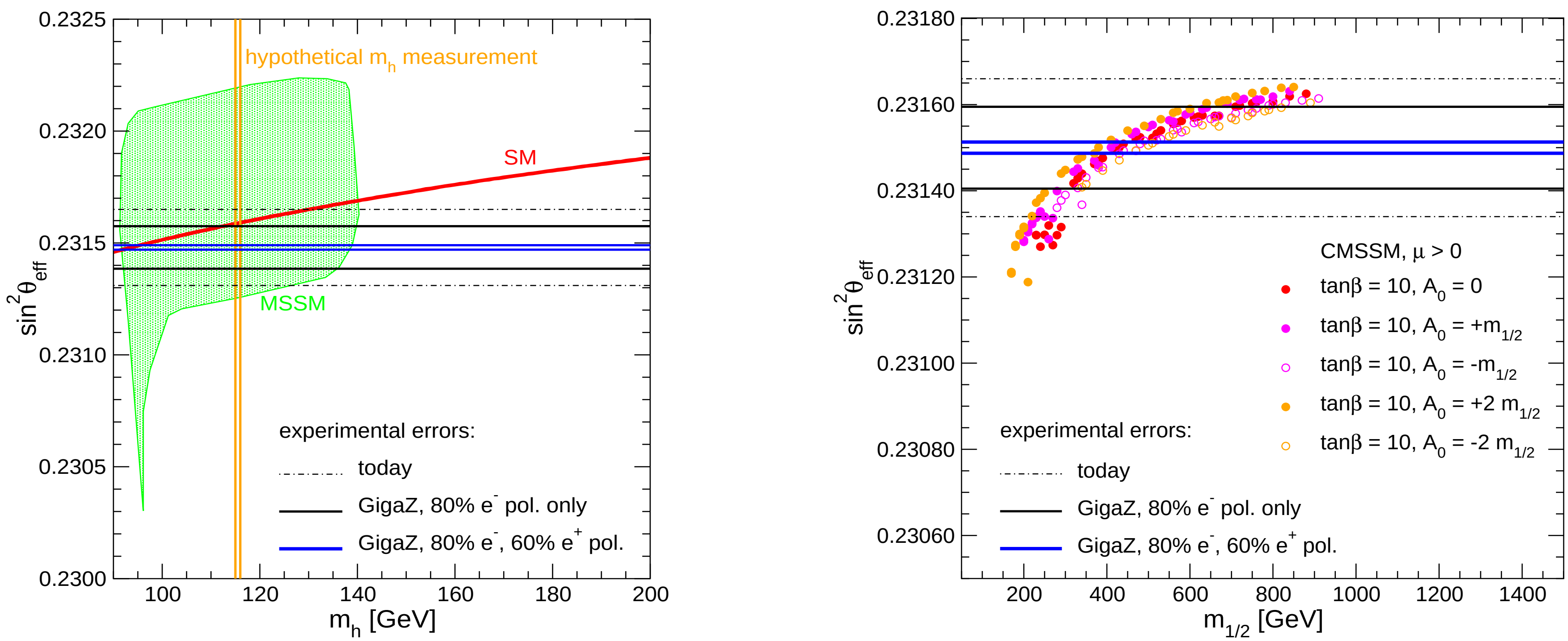
  $\Rightarrow \Delta \sin^2\theta^\ell_{\rm eff} = 1.3 \times 10^{-5}$ *Moenig*

$\Rightarrow$ Both e^- and e^+ beams polarized needed to reach desired precision!

Impact of GigaZ for SUSY searches

Gain of about one order of magnitude in $\Delta \sin^2\theta_{\rm eff}$:

⇒ **Prediction/constaints for m_h and $m_{1/2}$**



- **'gain': bounds on SM $m_H \sim$ order of magnitude, on $m_{1/2} \sim$ factor 5!**

⇒ Both e^- and e^+ beams polarized to exploit GigaZ constraints!

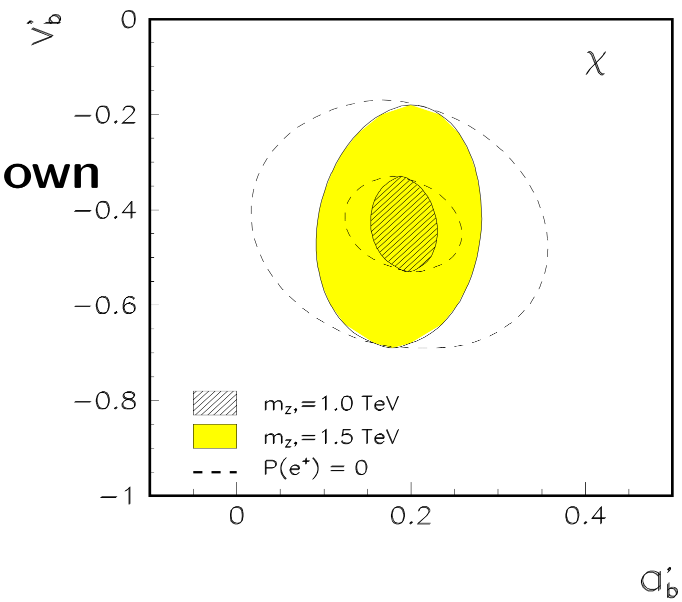
Some more 'non-SUSY' examples: indirect searches

Who guarantees that we will ever reach the new heavy scale? ...

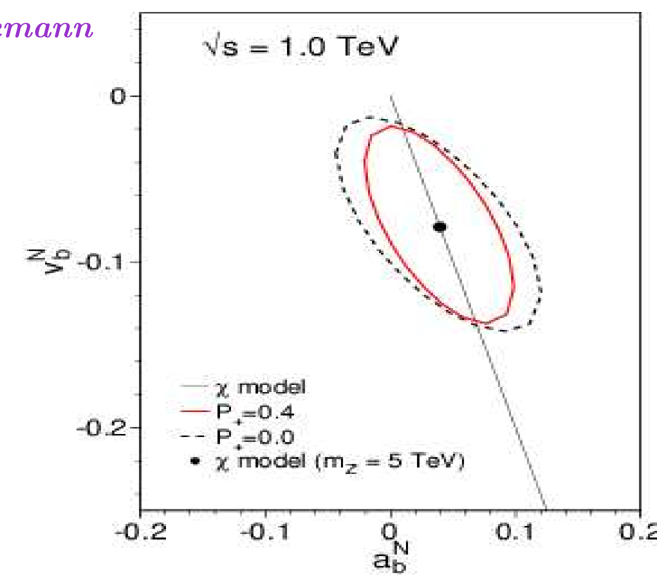
$\Rightarrow$ **indirect searches important!**

- e.g. in $e^+e^- \to f\bar{f}$ searches for Z', extra dimensions, etc.

m'_Z known



Riemann



m'_Z unknown

$\rightarrow$ determination of couplings and mass reconstruction

$\rightarrow$ gain factor with P_{e^+} $\sim$1.6 cf. P_{e^-} only (reduction of systematic error!)

- e.g. P_{e+} decisive for model-independent bounds in CI *Babich*

$\Rightarrow$ **Both e^- and e^+ beams should be polarized!**

Further gain for indirect searches

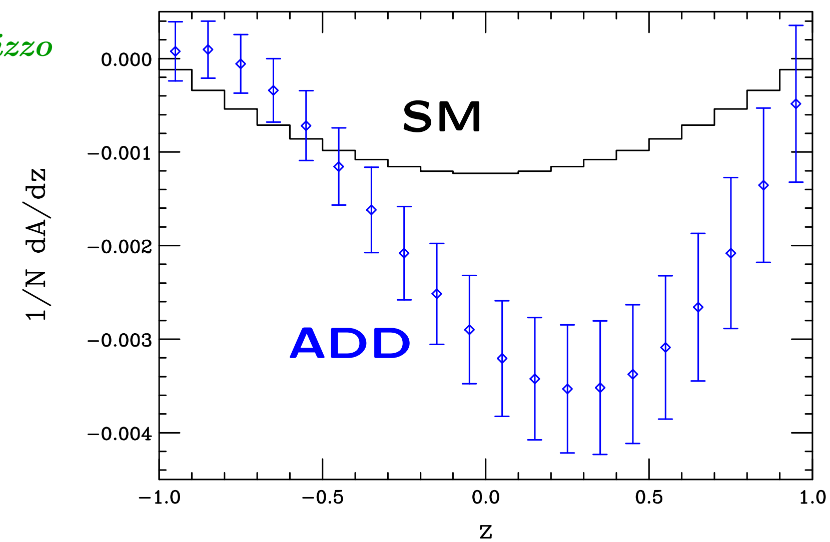
With transversely polarized beams:

$\rightarrow$ exploit azimuthal asymmetries also for indirect searches!

- distinction between SM and different models of large extra dimensions!

Rizzo

$e^+e^- \rightarrow b\bar{b}$



- access to new CP-violating kind of interactions in $t\bar{t}$, γZ, W^+W^-

  Nagel
  Rindani

  $\rightarrow$ unique access to $\Re$ parts of CP-sensitive couplings!

$\Rightarrow$ Transversely polarized beams are very effective also for indirect seaches w/wo CP-violation

$\rightarrow$ in principle both e^- and e^+ beams polarized required!

Possible interactions: pol-dependences in general

Which effects are possible? $|M|^2 \sim \bar{v}(\lambda_{e^+})\Gamma u(\lambda_{e^-})\bar{u}(\lambda'_{e^-})\Gamma^\dagger v(\lambda'_{e^+})$

Interaction structure		Longitudinal		Transverse	
Γ	$\Gamma^\dagger$	Bilinear	Linear	Bilinear	Linear
S	S	$\sim P_{e^-}P_{e^+}$	$-$	$\sim P^T_{e^-}P^T_{e^+}$	$-$
P	S	$-$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	$-$
V,A	S	$-$	$-$	$-$	$\sim P^T_{e^\pm}$
T	S	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	
P	P	$\sim P_{e^-}P_{e^+}$	$-$	$\sim P^T_{e^-}P^T_{e^+}$	$-$
V,A	P	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	$\sim P^T_{e^\pm}$
T	P	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	
V,A	V,A	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	$-$
T	V,A	$-$	$-$	$-$	$\sim P^T_{e^\pm}$
T	T	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	$-$

$P, S =$(pseudo)scalar

$A, V =$(axial)vector

$T =$tensor

$\Rightarrow$ impact of beam polarization depends on kind of interaction(s)

- with P_{e^-} and P_{e^+} much higher 'flexibility' with regard to NP candidates for direct as well as indirect searches!

The physics case for polarized e^- and e^+

- **Results of the report:**
  - ⋆ **many**$\equiv (n+1)$ examples from **different** physics scenarios!

⇒ **Report should be seen as contemporary status report!**

still studies ongoing, new ideas+examples coming up

- P_{e^+} ⇒ **only gains, independent in which direction NP points**
  - ⋆ **key additional observables for unraveling the underlying physics: kind of interaction, particle properties, parameter determination,. . .**
  - ⋆ **significant improvement for model-independent approaches in direct as well as indirect searches for NP**
  - ⋆ **Analyzing NP might be challenging → best of all tools needed!**

- P_{e^+} **crucial preparation for 'being prepared for the Unexpected'!**

⇒ **full potential of the ILC could only be realized with P_{e^-} and P_{e^+}!**

expected: $P_{e^-} = \pm 90\%$, $P_{e^+} = \pm 60\%$ **and** $\Delta P_\pm / P_\pm = 0.25\%$