Polarized e^- and e^+ at the ILC

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Top+Higgs WG

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

2. The physics case for polarized e^- and e^+ beams – top
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Physics at the e^+e^- Linear Collider

* **Discovery of New Physics (NP)**
  - $\rightarrow$ Large potential for direct searches
  - $\rightarrow$ Impressive potential also for indirect searches!
* **Unraveling the structure of NP**
  - $\rightarrow$ precise determination of underlying dynamics and parameters
  - $\rightarrow$ model distinction through model-independent searches
* **High precision measurements**
  - $\rightarrow$ tests of the SM with unprecedented precision
  - $\rightarrow$ 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, ∼ 80 authors, ∼ 35 institutes

→ **incl. 90 pages physics, 20 pages machine, 20 pages polarimetry**

→ **hep-ph/0507011, will be submitted to Phyics Reports**

→ **http://www.ippp.dur.ac.uk/˜gudrid/power/**

→ **executive summary, 12 pages, same webpage**

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

→ **focus on use of P_{e^+} compared to P_{e^-} only**

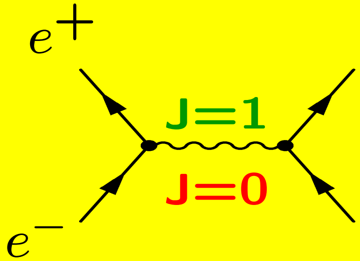
- **Machine overview about polarized e^+ source**
  and polarization measurements

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:



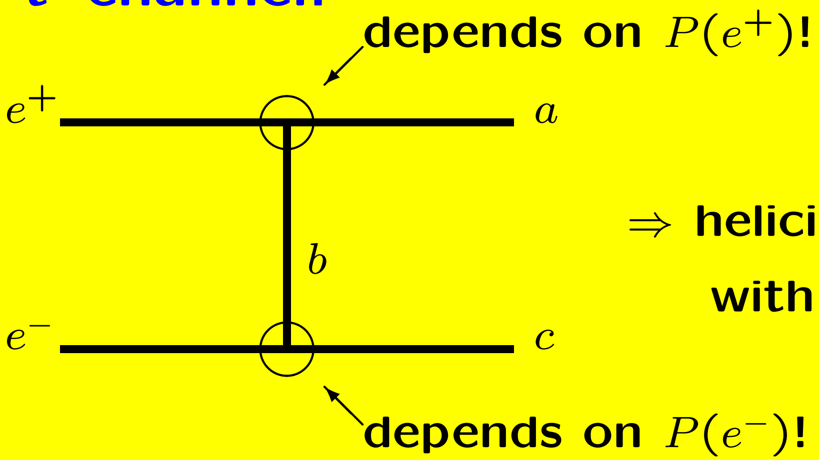
$\leftarrow$ **contributions only from RL,LR: SM and NP (γ, Z)**

$\leftarrow$ **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:

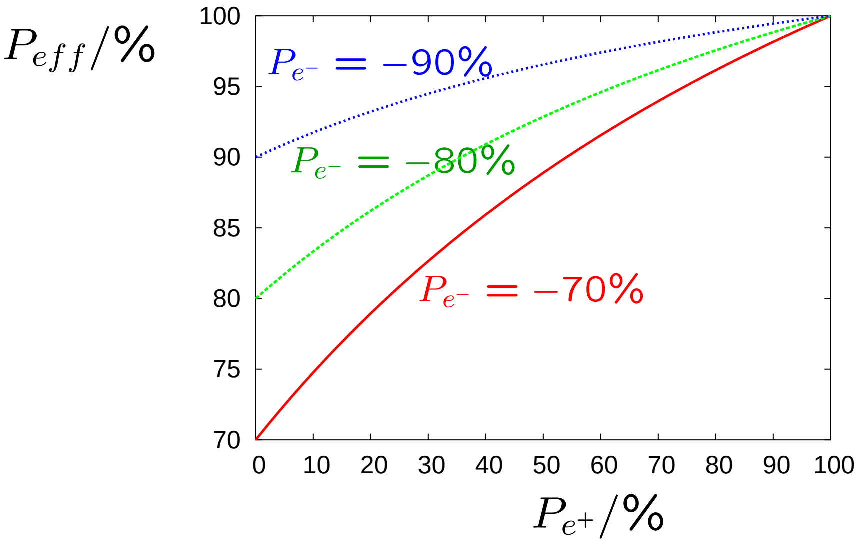


$\Rightarrow$ **helicity of e^- not coupled with helicity of e^+!**

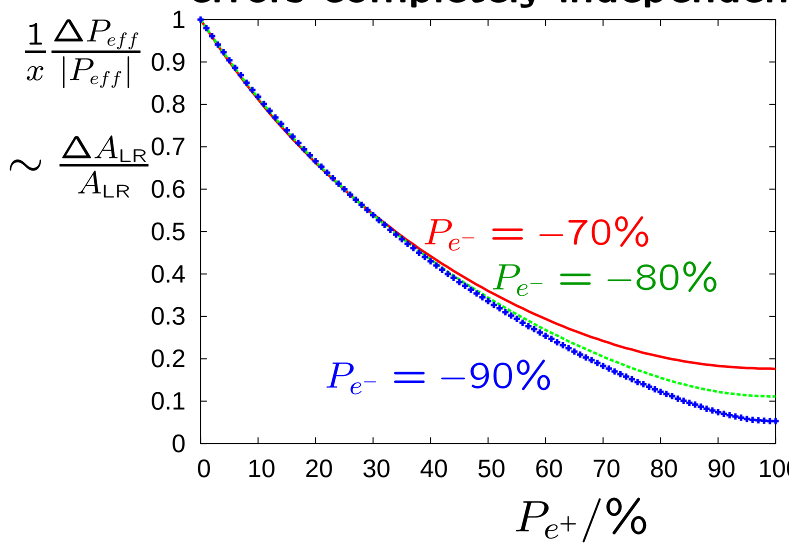
Some well-known statistical examples

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

- **Enhancement of** $P_{eff} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^-}P_{e^+}}$ **and measurement of** A_{LR}



errors completely independent



- **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!

Determination of the electroweak top properties

Process: $e^+e^- \to t\bar{t}$ (test of coupling $t \to \gamma$, Z)

$$\Gamma^{\mu}_{t\bar{t}\gamma,Z} = ie\{\gamma^{\mu}[F^{\gamma,Z}_{1V} + F^{\gamma,Z}_{1A}\gamma^5] + \frac{(p_t - p_{\bar{t}})^{\mu}}{2m_t}[F^{\gamma,Z}_{2V} + F^{\gamma,Z}_{2A}\gamma^5]\}$$

- **Studies at threshold:**

$v_t = (1 - \frac{8}{3}\sin^2\theta_W)$ **via** A_{LR}

$\Rightarrow \Delta A_{LR}/A_{LR} \sim \Delta P_{eff}/P_{eff}$

$\Rightarrow$ (80%,0)→(80%,60%): factor 3!

- **Studies at $\sqrt{s} = 500$ GeV:**

only for P_{e^-} so far!!!

estimated:

$\Rightarrow$ (80%,0)→(80%,60%): ~factor 3

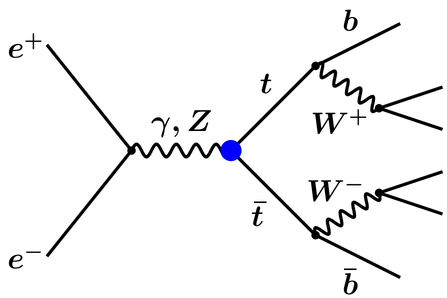
Form factor	SM value	$\sqrt{s} = 500\,\text{GeV}$		$\sqrt{s} = 800\,\text{GeV}$	
		$p = 0$	$p = -0.8$	$p = 0$	$p = -0.8$
F^Z_{1V}	1		0.019		
F^Z_{1A}	1		0.016		
$F^{\gamma,Z}_{2V} = (g-2)^{\gamma,Z}{}_t$	0	0.015	0.011	0.011	0.008
$\mathrm{Re}\,F^{\gamma}_{2A}$	0	0.035	0.007	0.015	0.004
$\mathrm{Re}\,d^{\gamma}_t$ [10^{-19} e cm]	0	20	4	8	2
$\mathrm{Re}\,F^{Z}_{2A}$	0	0.012	0.008	0.008	0.007
$\mathrm{Re}\,d^{Z}_t$ [10^{-19} e cm]	0	7	5	5	4
$\mathrm{Im}\,F^{\gamma}_{2A}$	0	0.010	0.008	0.006	0.005
$\mathrm{Im}\,F^{Z}_{2A}$	0	0.055	0.010	0.037	0.007
F^W_{1R}	0	0.030	0.012		
$\mathrm{Im}F^W_{2R}$	0	0.025	0.010		

$\Rightarrow$ True simulation still needed!

Limits for CP-violating top dipole couplings

Process: $e^+e^- \to t\bar{t}$, $t \to \ell^+\nu_\ell b$

Test of anomalous $t\bar{t}\gamma$, $t\bar{t}Z$ couplings via ℓ energy and angular distributions:



useful observable: forward-backward asymmetry

$$\mathcal{A}^f_{\mathrm{CP}}(P_{e^-}, P_{e^+}) = \frac{\int_{\theta_0}^{\pi/2} d\cos\theta_f \frac{d\sigma^-}{d\cos\theta_f} - \int_{\pi/2}^{\pi-\theta_0} d\cos\theta_f \frac{d\sigma^+}{d\cos\theta}}{\int_{\theta_0}^{\pi/2} d\cos\theta_f \frac{d\sigma^-}{d\cos\theta_f} + \int_{\pi/2}^{\pi-\theta_0} d\cos\theta_f \frac{d\sigma^+}{d\cos\theta}}$$

$A^f_{CP} \sim$ **CP-violating coupling**

(however, if $P_{e^-} \neq P_{e^+}$: no initial CP-eigenstate)

- **study:** $\sqrt{s} = 500$ **GeV,** $\mathcal{L} = 500$ **fb^{-1}, eff**$= 60\%$ **for** b, ℓ, **CP-coupling**$\sim 10^{-2}$

$\Rightarrow$ **measurable at 5.1-σ (b), 2.4-σ (ℓ); with** $(80\%, 80\%)$: **16-σ (b), 3.5-σ (ℓ)!**

- **Further (azimuthal) asymmetries (t reconstruction): gain only** $\sim 30\%$

$\Rightarrow$ **same polarization of both beams: gain factor** ~ 3

Limits for flavour-changing neutral top-couplings

Processes: top pair production or singe top production

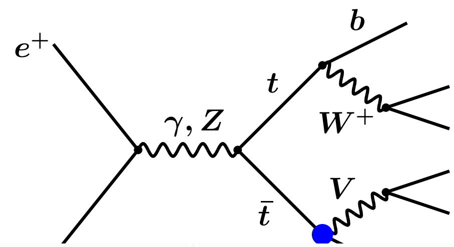
- Single top:
  → more sensitive
- top pairs+decays:
  → better for
  disentangling
- Results:

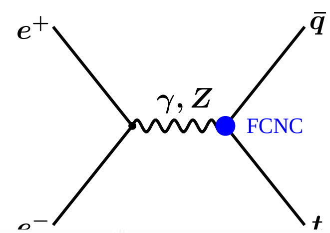
vector couplings:

(80%,0)→(80%,45%): ∼ 1.

tensor couplings:

(80%,0)→(80%,45%): ∼ 1.





	unpolarized beams	$\|P_{e^-}\| = 80\%$	$(\|P_{e^-}\|, \|P_{e^+}\|) = (80\%, 45\%)$
	$\sqrt{s} = 500$ GeV		
$BR(t \to Zq)(\gamma_\mu)$	6.1×10^{-4}	3.9×10^{-4}	2.2×10^{-4}
$BR(t \to Zq)(\sigma_{\mu\nu})$	4.8×10^{-5}	3.1×10^{-5}	1.7×10^{-5}
$BR(t \to \gamma q)$	3.0×10^{-5}	1.7×10^{-5}	9.3×10^{-6}
	$\sqrt{s} = 800$ GeV		
$BR(t \to Zq)(\gamma_\mu)$	5.9×10^{-4}	4.3×10^{-4}	2.3×10^{-4}
$BR(t \to Zq)(\sigma_{\mu\nu})$	1.7×10^{-5}	1.3×10^{-5}	7.0×10^{-6}
$BR(t \to \gamma q)$	1.0×10^{-5}	6.7×10^{-6}	3.6×10^{-6}

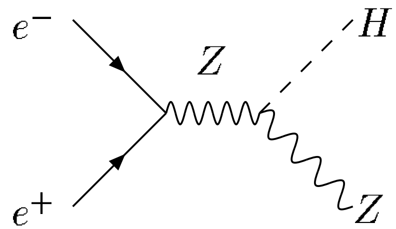
⇒ **With** $(80\%, 45\%)$ **ILC$_{500}$ extends LHC (w.r.t. γ_μ)**

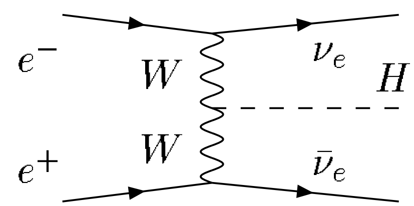
⇒ **Comparison with simulations of LHC needs to be updated!**

Beam polarization for SM Higgs searches

Light Higgs, $m_H = 130$ GeV:

$\rightarrow HZ$ **and** $H\nu\bar{\nu}$ **similar rates**





P_{e^-}, P_{e^+} **needed for:**

a) separation

b) background supp.

$\Rightarrow \sigma(HZ)/\sigma(H\nu\nu)$:

improves by factor 4

(+80%,0)$\rightarrow$ (+80%, −60%)

Configuration (P_{e^-}, P_{e^+})	Scaling factors $e^+e^- \rightarrow H\nu\bar{\nu}$	Scaling factors $e^+e^- \rightarrow HZ$
(+80%, 0)	0.20	0.87
(−80%, 0)	1.80	1.13
(+80%, −60%)	0.08	1.26
(−80%, +60%)	2.88	1.70

$\Rightarrow P_{e^-}$ **and** P_{e^+} **very helpful for a light SM Higgs!**

Determination of general Higgs couplings

Process: $e^+e^- \to HZ \to Hf\bar{f}$

general effective HZV vertex can be parametrized:

$$\mathcal{L} = (1 + a_Z)\frac{g_Z m_Z}{2} H Z_\mu Z^\mu + \frac{g_Z}{m_Z}[b_V H Z_{\mu\nu} V^{\mu\nu} + c_V(\partial_\mu H Z_\nu - \partial_\nu H Z_\mu) V^{\mu\nu} + \tilde{b}_V H Z_{\mu\nu} \tilde{V}^{\mu\nu}]$$

$\to$ 5 CP-even, 2 CP-odd

	$\epsilon_\tau = 0 = \epsilon_b$			$\epsilon_\tau = 50\%$, $\epsilon_b = 60\%$
(P_{e^-}, P_{e^+})	$(0,0)$	$(80\%, 0)$	$(80\%, 60\%)$	$(80\%, 60\%)$
$\mathrm{Re}(b_Z)$	5.5	2.8	2.3	2.2
$\mathrm{Re}(c_Z)$	6.5	1.4	1.1	1.1
$\mathrm{Re}(b_\gamma)$	123.2	5.2	3.6	3.4
$\mathrm{Re}(c_\gamma)$	54.2	1.1	0.8	0.7
$\mathrm{Re}(\tilde{b}_Z)$	10.4	9.5	7.8	5.2
$\mathrm{Re}(\tilde{b}_\gamma)$	61.8	14.5	10.1	6.3
$\mathrm{Im}(b_Z - c_Z)$	105.5	7.0	4.9	4.6
$\mathrm{Im}(b_\gamma - c_\gamma)$	20.6	7.0	5.7	5.4
$\mathrm{Im}(\tilde{b}_Z)$	52.1	3.2	2.2	2.2
$\mathrm{Im}(\tilde{b}_\gamma)$	10.1	3.2	2.6	2.6

Results of the study

at $\sqrt{s} = 500$ GeV and

with $\mathcal{L} = 300$ fb^{-1}:

(using opt. observables)

$\Rightarrow$ sensitivity improved

by 30% and

limits up to 10^{-4} reachable

with $(80\%, 0) \to (80\%, 60\%)$

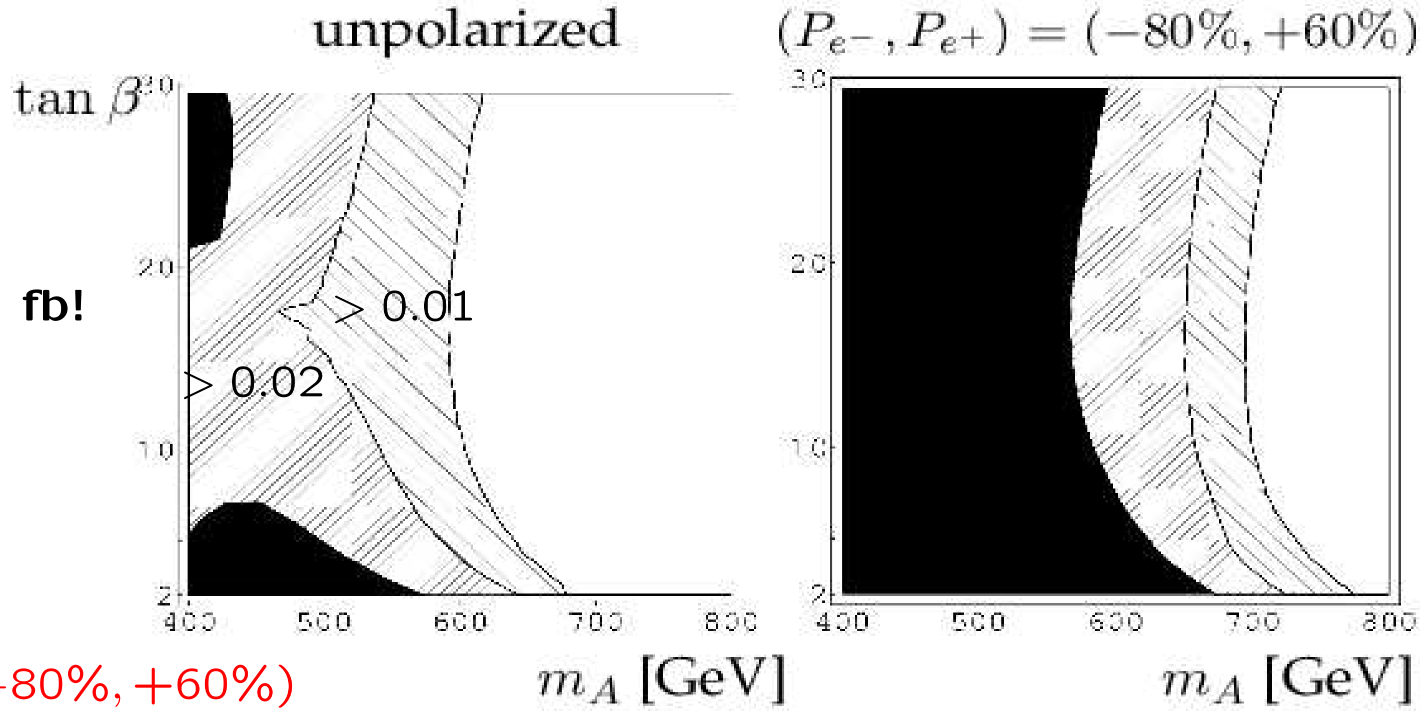
$\Rightarrow$ P_{e^-} and P_{e^+} very helpful for determining the general couplings

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!)

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

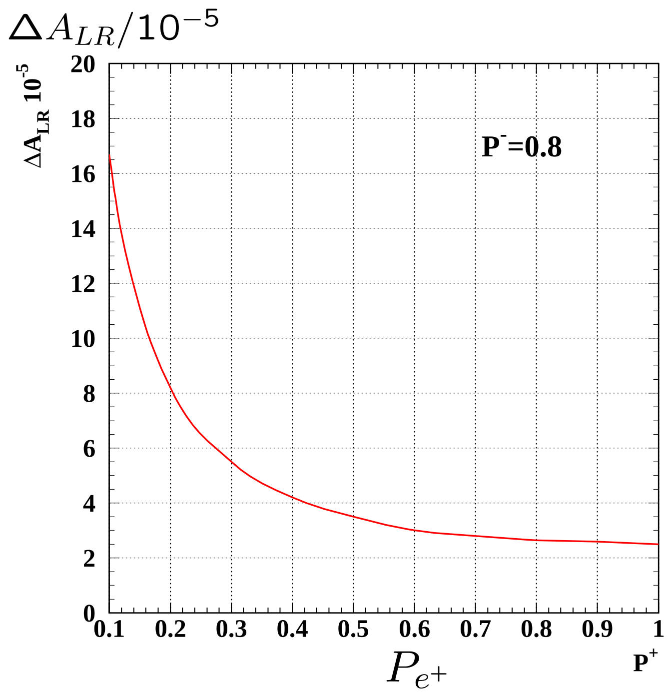
$$\stackrel{Blondel}{=} \sqrt{\frac{(\sigma^{RR}+\sigma^{RL}-\sigma^{LR}-\sigma^{LL})(-\sigma^{RR}+\sigma^{RL}-\sigma^{LR}+\sigma^{LL})}{(\sigma^{RR}+\sigma^{RL}+\sigma^{LR}+\sigma^{LL})(-\sigma^{RR}+\sigma^{RL}+\sigma^{LR}-\sigma^{LL})}}$$

- 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*)



Moenig

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

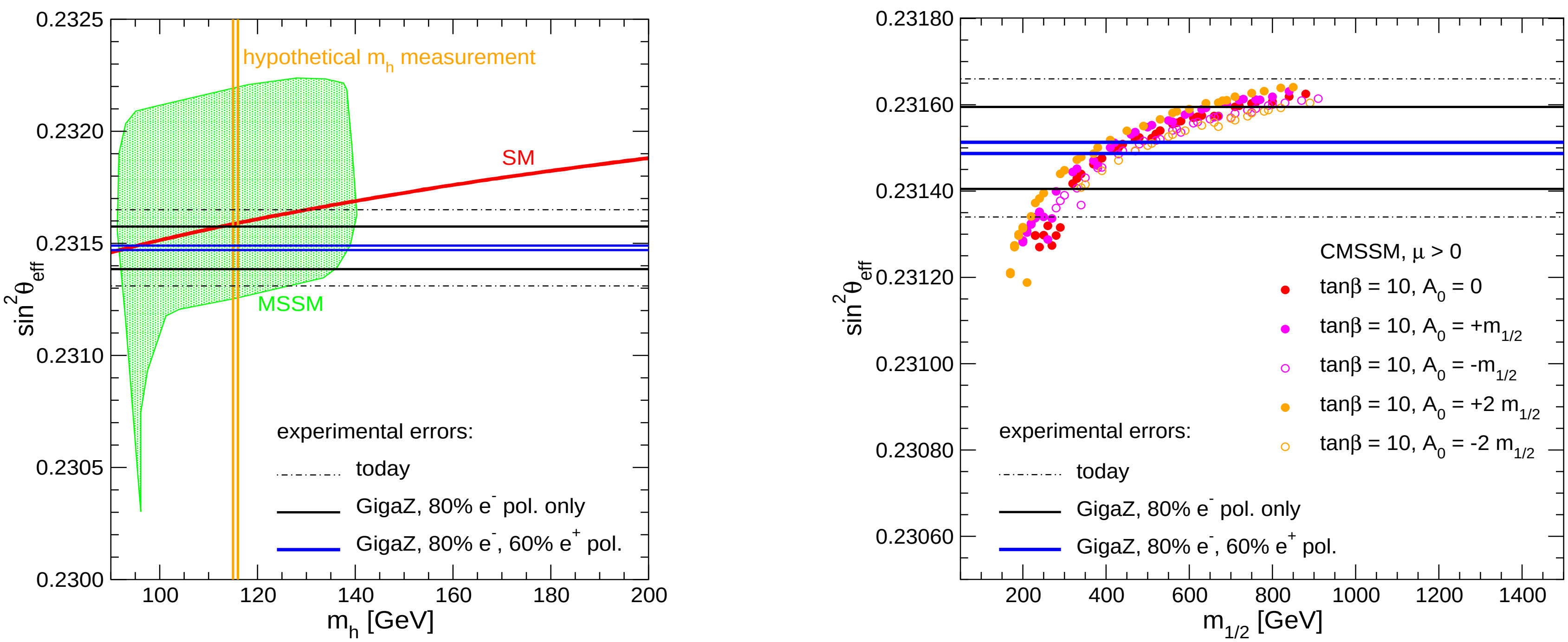
  $\Rightarrow \Delta\sin^2\theta^\ell_{\rm eff} = 1.3\times 10^{-5}$ *Moenig*

$\Rightarrow$ 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 $\Delta \sin^2\theta_{\rm eff}$:

$\Rightarrow$ 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!

$\Rightarrow$ Both e^- and e^+ beams polarized to exploit GigaZ constraints!

Searches for scalar leptoquarks in $t\bar{t}$ production

Process: $e^+e^- \to t\bar{t}$ SM+SU(2)$_L$ doublet of scalar LQ

If P_{e^-} and P_{e^+}: effects of transversely-polarized beams (limes $m_e \to 0$)

- **unique tool for chirality-violating couplings**

  interferences with SM cause:

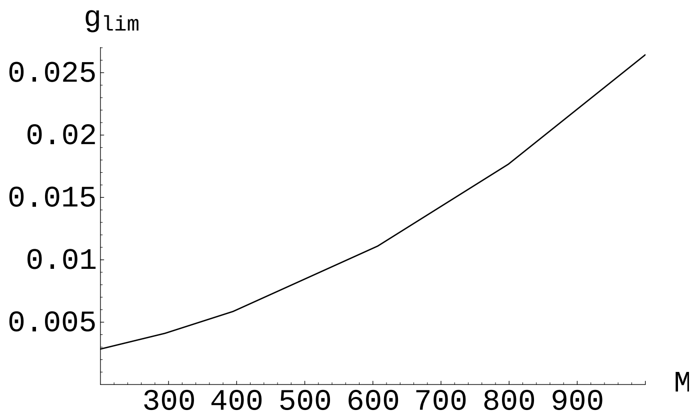
  $\to$ $\sin\theta\cos\phi$, $\sin\theta\sin\phi$

- **with long./unp. beams: no interferences**

- **Azimuthal asymmetries as:**

  $$A_1(\theta_0) = \frac{1}{r\sigma(\theta_0)} \int_{-\cos\theta_0}^{\cos\theta_0} d\cos\theta \left[\int_0^{\pi} d\phi - \int_{\pi}^{2\pi} d\phi\right] \frac{d\sigma}{d\Omega}$$

  (cut-off in forward, backward direction)



- **Limits on $Re(g_R g_L)$ four times better than those from e^- dipole limits**

$\Rightarrow$ If P_{e^-}, P_{e^+}: exploitation of tranversely-polarized beams possible

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:**
  - $\star$ **many** $\equiv (n+1)$ examples from **different** physics scenarios!

$\Rightarrow$ **Report should be seen as contemporary status report!**
still studies ongoing, new ideas+examples coming up

- **Still missing: e.g. true simulation of elecroweak top properties!**
  Maybe exploitation of beam polarization for CP-higgs?

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

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

$\Rightarrow$ **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** $\Delta P_\pm / P_\pm = 0.25\%$