The Central Role of Beam Polarization at Future e+e- Linear Colliders

More details on:
- *interplay of pol&syst*

➡ *see talk Beyer/List*
- *pol and dark matter*

➡ *see talk Zarnecki*

- **Motivation**
- **Polarization basics**
- **Physics cases for polarized beams**
- **Status e+ sources at linear collider**
- **Conclusions**

LINEAR COLLIDER COLLABORATION

Required features at LHC & ILC

⇨ In order to reveal the structure of the underlying (new) physics:

- ⋆ high energy desirable to reach the scale of new physics
- ⋆ high luminosity needed to get sufficient statistics
- ⋆ high level of experimental flexibility needed
- ⋆ high precision measurements needed to get access to the quantum structure

→ *need to be prepared for the unexpected !*

⇨ Spin and polarization physics is important

→ access to quantum properties, structure of couplings, etc.

⇨ How to exploit spin effects in particle reactions?

initial particles		short-living, intermediate states		final particles
e+ e-	→	fermion1 + fermion2	→	quarks, leptons
↓		↓		↓
beam polarization		*spin correlations*		*polarization of top, τ*
LC, today only		*LHC, LC: CP e.g.*		*LC, partially LHC*

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 essential for suppression of systematics!**

see also talk J.Beyer/J. List

Literature: polarized e+e- beams at a LC

- *LCC-Physics Group: 'The role of positron polarization for the initial 250 GeV stage of ILC', arXiv: 1801.02840*
- *G. Moortgat-Pick et al. (~85 authors) : `Pol. positrons and electrons at the LC', Phys. Rept. 460 (2008), hep-ph/0507*
- *G. Wilson: `Prec. Electroweak measurements at a Future e+e- LC', ICHEP2016, R. Karl, J. List, LCWS2016, 1703.00*
- *many more (only few examples): 1206.6639, 1306.6352 (ILC TDR), 1504.01726, 1702.05377, 1908.11299,2001.03011,*
- *G. Moortgat-Pick, H. Steiner, `Physics opportunities with pol. e- and e+ beams at TESLA, Eur.Phys.J direct 3 (2001*
- *T. Hirose, T. Omori, T. Okugi, J. Urakawa, Pol. e+ source for the LC, JLC, Nucl. Instr. Meth. A455 (2000) 15-24*

Polarization basis

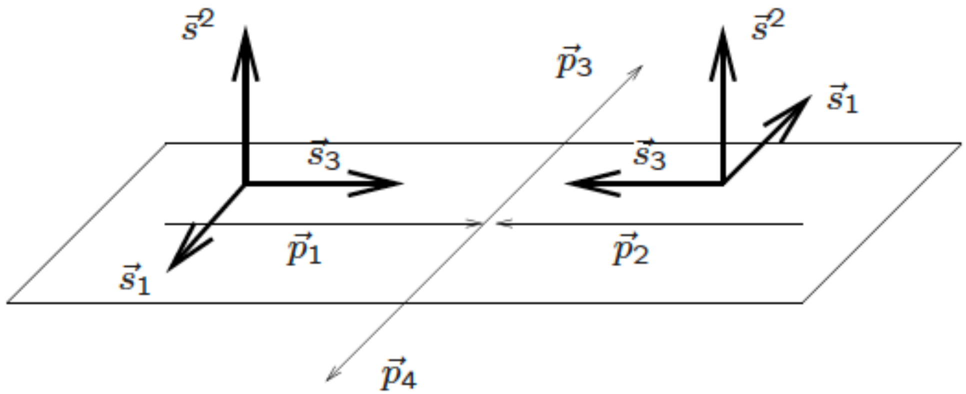
- Formalism: Use e.g. helicity spinors $u(p,\lambda)$, $v(p,\lambda)$ $\rightarrow$ density matrix
- Definition: Basis of Spinvektors s^a, $a = 1, 2, 3$ with $(s^a p) = 0$:

  build 'right-hand-system' in the CMS of $e^-(p_1)e^+(p_2) \rightarrow X(p_3)Y(p_4)$

  longitudinal Spinvektors: $s^{3\mu}(p_{1,2}) := \frac{1}{m_{1,2}}(|\vec{p_{1,2}}|, E\hat{p}_{1,2})$

  transverse Spinvektors: $s^{2\mu}(p_1) := (0, \vec{p}_1 \times \vec{p}_3)$, $\quad s^{2\mu}(p_2) = s^{2\mu}(p_1)$

  $s^{1\mu}(p_1) := (0, \vec{p}_1 \times \vec{s}^2(p_1))$, $s^{1\mu}(p_2) = -s^{1\mu}(p_1)$



- Definition: 'left-handed' and 'right-handed' $\equiv$ with respect to $\hat{p}$

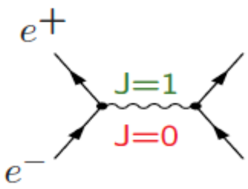
  If Spinvektor $\vec{s}^3 = \begin{pmatrix} \text{parallel } \vec{p} \\ \text{antiparallel } \vec{p} \end{pmatrix} \equiv \begin{pmatrix} \text{'right-handed': } P>0 \\ \text{'left-handed': } P<0 \end{pmatrix}$

- ***Polarization*** **= ensemble of particles with definite helicity λ = -½ left- or +½ right-handed :**

$$\boxed{\mathcal{P} = \frac{\#N_R - \#N_L}{\#N_R + \#N_L}}$$

General remarks : coupling structure

s–channel:

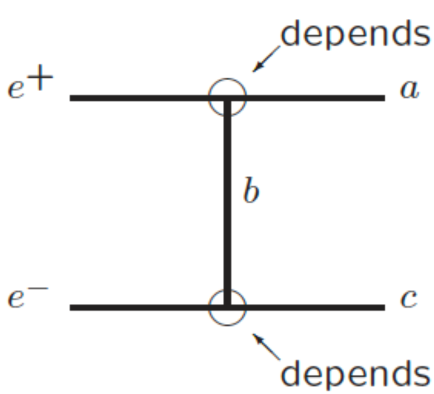


← only from RL,LR: SM (γ, Z)

← only from LL,RR: NP!

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

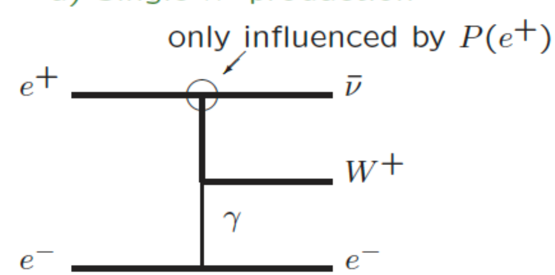
t–channel:



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

Two examples:

a) Single W production



b) Bhabha scattering

$\Rightarrow$ γ, Z exchange in s–channel: selects LR, RL

$\Rightarrow$ γ, Z exchange in t–channel: LL,RR possible!

unpolarised	4.50 pb
$P_{e^-} = -80\%$	4.63 pb
$P_{e^-} = -80\%$, $P_{e^+} = -60\%$	4.69 pb
$P_{e^-} = -80\%$, $P_{e^+} = +60\%$	4.58 pb

Physics: pol.cross sections in general

Longitudinally pol. beams

Polarized cross sections can be subdivided in:

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

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

If (axial)vector-like (i.e. γ,Z): only (LR) and (RL) configurations contribute:

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

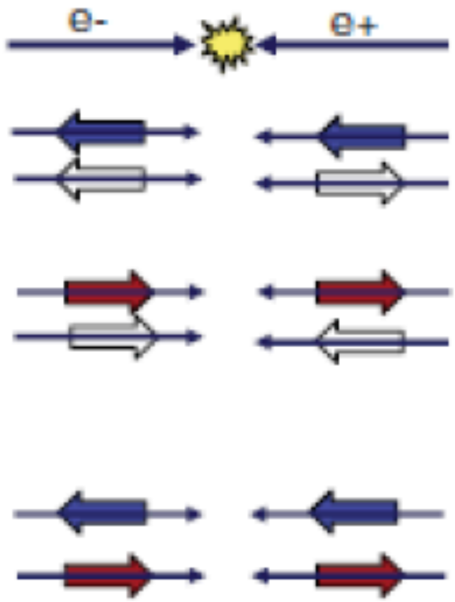
Statistical arguments

- Effective polarization

$$P_{eff} := (P_{e^-} - P_{e^+})/(1 - P_{e^-}P_{e^+})$$
$$= (\#LR - \#RL)/(\#LR + \#RL)$$

- Fraction of colliding particles

$$\mathcal{L}_{eff}/\mathcal{L} := \tfrac{1}{2}(1 - P_{e^-}P_{e^+}) = (\#LR + \#RL)/(\#all)$$



P_{e-}	P_{e+}	h_{e-}	h_{e+}	cross section
-1	0	-1	+1	σ_{LR}
		-1	-1	σ_{LL} ⟶ 0
+1	0	+1	-1	σ_{RL}
		+1	+1	σ_{RR} ⟶ 0
-1	+1	-1	+1	σ_{LR}
+1	-1	+1	+1	σ_{RL}

½ of events do not react !

⇒ Enhancing of $\mathcal{L}_{eff}$ with $P(e^-)$ and $P(e^+)$!

Statistical arguments

- Effective polarization

$$P_{eff} := (P_{e^-} - P_{e^+})/(1 - P_{e^-}P_{e^+})$$
$$= (\#LR - \#RL)/(\#LR + \#RL)$$

- Fraction of colliding particles
$\mathcal{L}_{eff}/\mathcal{L} := \frac{1}{2}(1 - P_{e^-}P_{e^+}) = (\#LR + \#RL)/(\#all)$

Colliding particles:

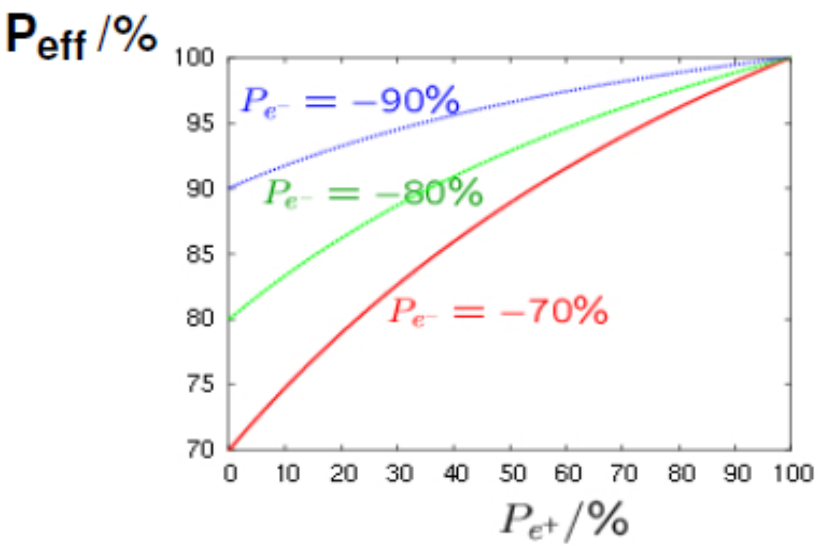
	RL	LR	RR	LL	P_{eff}	$\mathcal{L}_{eff}/\mathcal{L}$
$P(e^-) = 0$, $P(e^+) = 0$	0.25	0.25	0.25	0.25	0.	0.5
$P(e^-) = -1$, $P(e^+) = 0$	0	0.5	0	0.5	-1	0.5
$P(e^-) = -0.8$, $P(e^+) = 0$	0.05	0.45	0.05	0.45	-0.8	0.5
$P(e^-) = -0.8$, $P(e^+) = +0.6$	0.02	0.72	0.08	0.18	-0.95	0.74

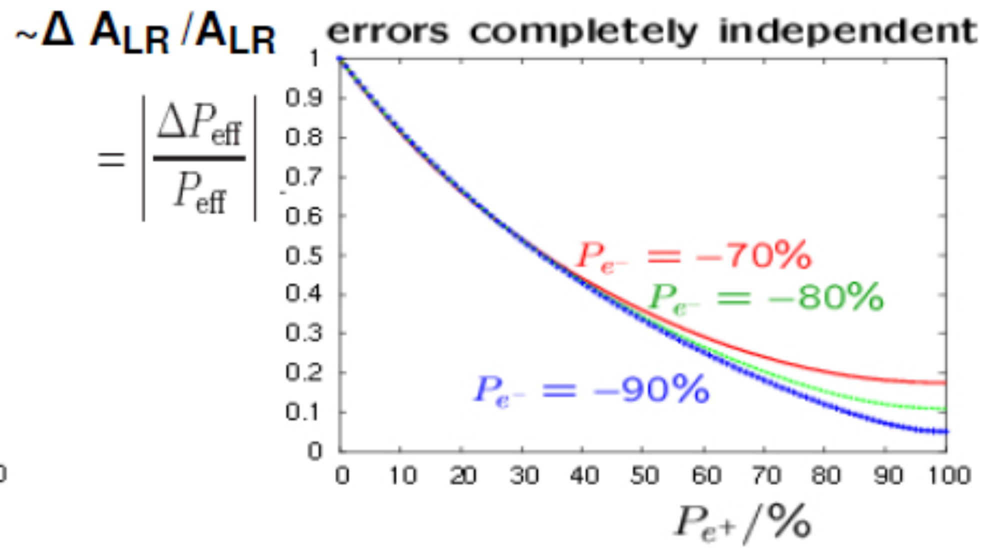
$\Rightarrow$ Enhancing of $\mathcal{L}_{eff}$ with $P(e^-)$ and $P(e^+)$!

Impact of P(e+)

- **Statistics**

- **And gain in precision**





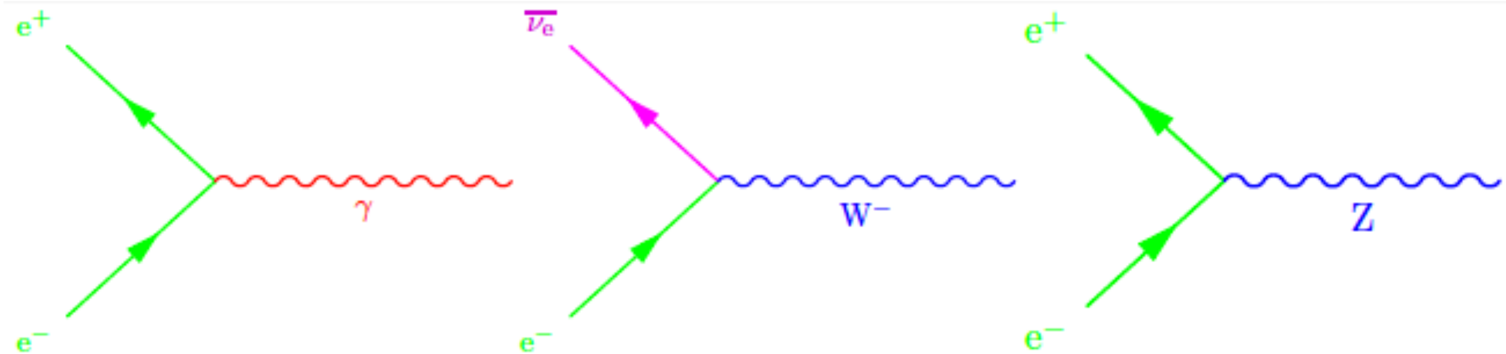
- (80%,60): P_{eff} = 95% (90%,60%): P_{eff} =97% (90%, 30%): P_{eff} =94 %

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

  gain: factor~3 factor>3 factor~2

- **NO gain with only pol. e- (even if '100% ') !**

Back to SM Vertices



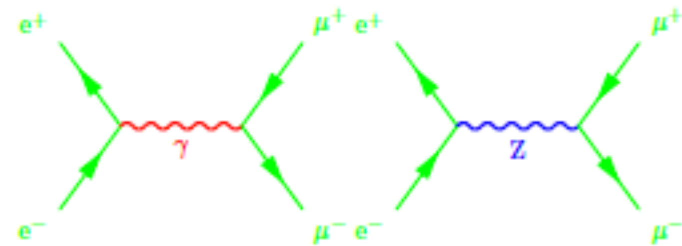
QED: parity conserved, $A_{LR}=0$

Charged currents: $A_{LR}=1$
Parity violating
only left-handed e^- couple

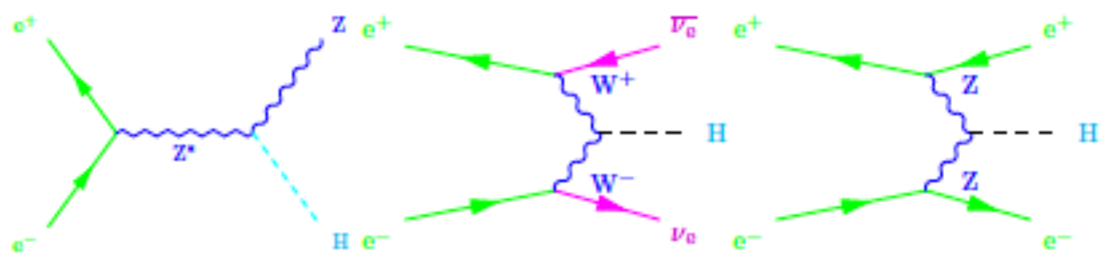
Neutral currents: $A_{LR}=0.15$
Parity violating
left-handed e^-,
right-handed e^+

SM Processes: coupling structures

2 Fermion: LR, RL

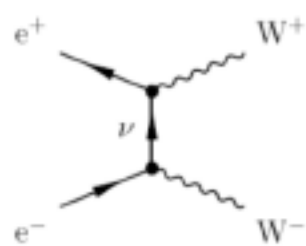


Higgs: LR, RL

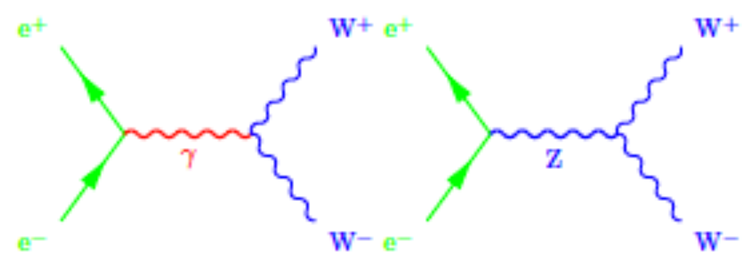


W-production:

only LR:

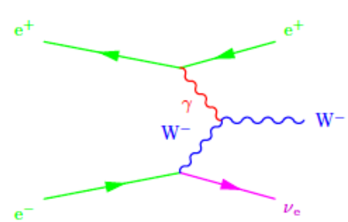


LR, RL:



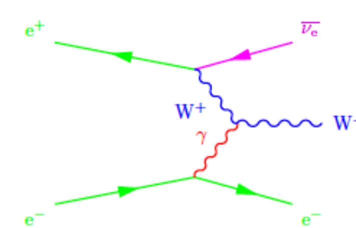
Single W-:

only LR and LL!:



Single W+:

only RL and RR!:



Statistics Suppression of WW and ZZ production

WW, ZZ production = large background for NP searches!

W^- couples only left–handed:
$\rightarrow$ WW background strongly suppressed with right polarized beams!

Scaling factor= $\sigma^{pol}/\sigma^{unpol}$ for WW and ZZ:

$P_{e^-} = \mp 80\%$, $P_{e^+} = \pm 60\%$	$e^+e^- \to W^+W^-$	$e^+e^- \to ZZ$
$(+0)$	0.2	0.76
(-0)	1.8	1.25
$(+-)$	0.1	1.05
$(-+)$	2.85	1.91

'No lose theorem':
scaling factors for
signals&background

	S	B	S/B	$S/\sqrt{B}$
Example 1	$\times 2$	$\times 0.5$	$\times 4$	$\times 2\sqrt{2}$
Example 2	$\times 2$	$\times 2$	Unchanged	$\times\sqrt{2}$

Main benefits of simultaneous e^+ polarization?

- **Better Statistics: Less running time/operation cost for same physics**
  - higher rates, lower background, higher analyzing power for chosen channels

- **Lower Systematics**

  see also talk J.Beyer/J. List

  - key role for reduction of systematics originating from polarization measurement

- **More Observables**
  - Four distinct data-sets: opposite-site polarization collisions plus like-sign configuration $\longrightarrow$ unique feature of ILC (including transversely but also unpolarized configurations!)

Transversely polarized beams

Transversely polarized beams

→ enables to exploit azimuthal asymmetries in fermion production !

- the process $e^+e^- \to W^+W^-$:

  ⇒ azimuthal asymmetry projects out $W_L^+W_L^-$
- the process e+e- ⟶ tt:

  ➡ probe leptoquark models

  e.g. Rindani, Poulose, et al.
- the process e+e- ⟶ ff:

  ➡ probe extra dimensions

- the construction of CP violating oservables:

  ⇒ matrix elements $|M|^2 \sim \mathcal{C}\times\Delta(\alpha)\Delta^*(\beta)\times\mathcal{S}$($\mathcal{C}$=coupl., Δ=prop., $\mathcal{S}$=momenta)

  if CP violation: contributions of $Im(\mathcal{C})\times Im(\mathcal{S})$(e.g. contributions of ϵ tensors!)

  ⇒ azimuthal dependence ('not only in scattering plane')

  ⇒ observables are e.g. asymmetries of CP-odd quantities: $\vec{p}_a(\vec{p}_b\times\vec{p}_c)$

Remember: $\vec{s}^{2\mu} := \vec{p}_1 \times \vec{p}_3$ perpendicular scattering plane, CP even

$\vec{s}^{1\mu} := \vec{p}_1 \times \vec{s}^2(p_1)$ transverse in plane, CP odd

In general: Interactions and Polarization

- **Different Interaction structures:**

  S=scalar-, P=pseudoscalar-, V=vector-, A=axial-vector-, T=tensor- like interactions

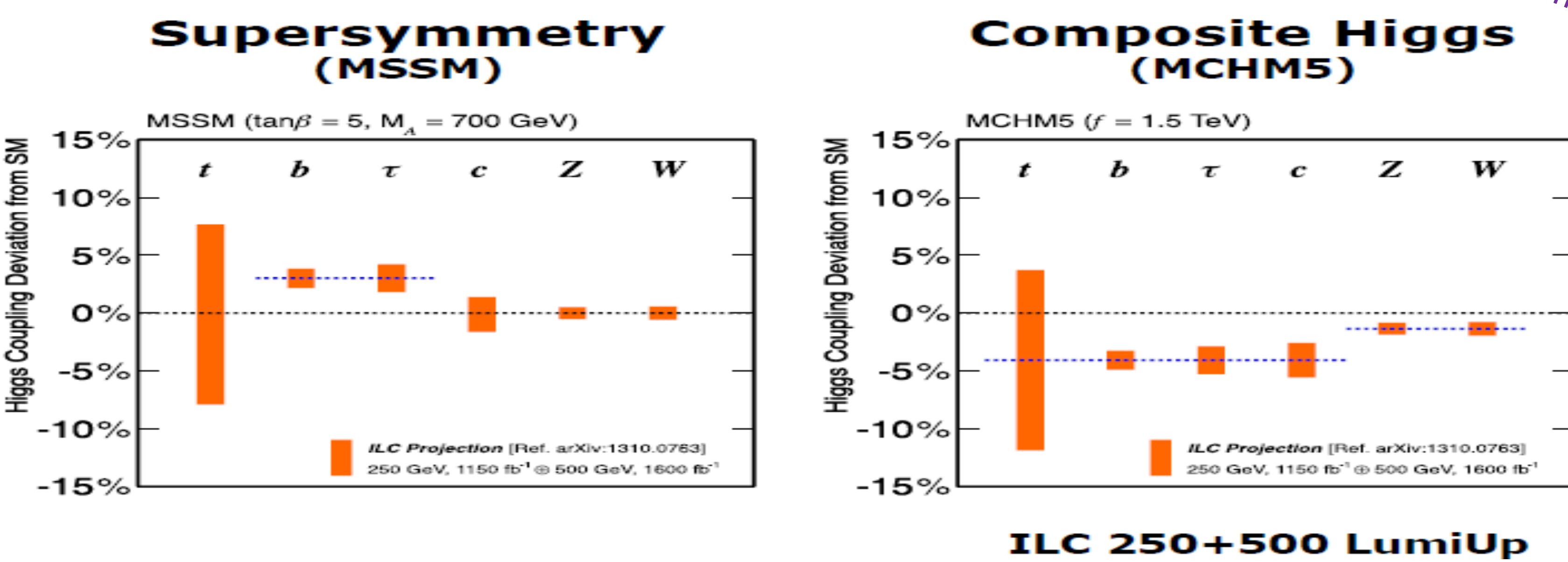
Interaction structure		Longitudinal		Transverse		Longitudinal/Transverse
Γ_k	$\bar{\Gamma}_\ell$	Bilinear	Linear	Bilinear	Linear	Interference
S	S	$\sim P_{e^-}P_{e^+}$	–	$\sim P^T_{e^-}P^T_{e^+}$	–	–
S	P	–	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	–	–
S	V,A	–	–	–	$\sim P^T_{e^\pm}$	$\sim P_{e^\pm}P^T_{e^\mp}$
S	T	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$		–
P	P	$\sim P_{e^-}P_{e^+}$	–	$\sim P^T_{e^-}P^T_{e^+}$	–	–
P	V,A	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	$\sim P^T_{e^\pm}$	$\sim P_{e^\pm}P^T_{e^\mp}$
P	T	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$		–
V,A	V,A	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	–	–
V,A	T	–	–	–	$\sim P^T_{e^\pm}$	$\sim P_{e^\pm}P^T_{e^\mp}$
T	T	$\sim P_{e^-}P_{e^+}$	$\sim P_{e^\pm}$	$\sim P^T_{e^-}P^T_{e^+}$	–	–

- dependence on polarization provides information on kind of interaction

Expected deviation in Higgs measurements

- **Higgs couplings achievable at LHC:**
  - Could be the only SM Higgs (what's about DM? gauge unification?)
  - Could be a SUSY Higgs (one has to be close to a SM-like one)
  - Could be a composite state

S. Komamiya,



- *Determination of Higgs couplings in 1% level essential for ILC250!*

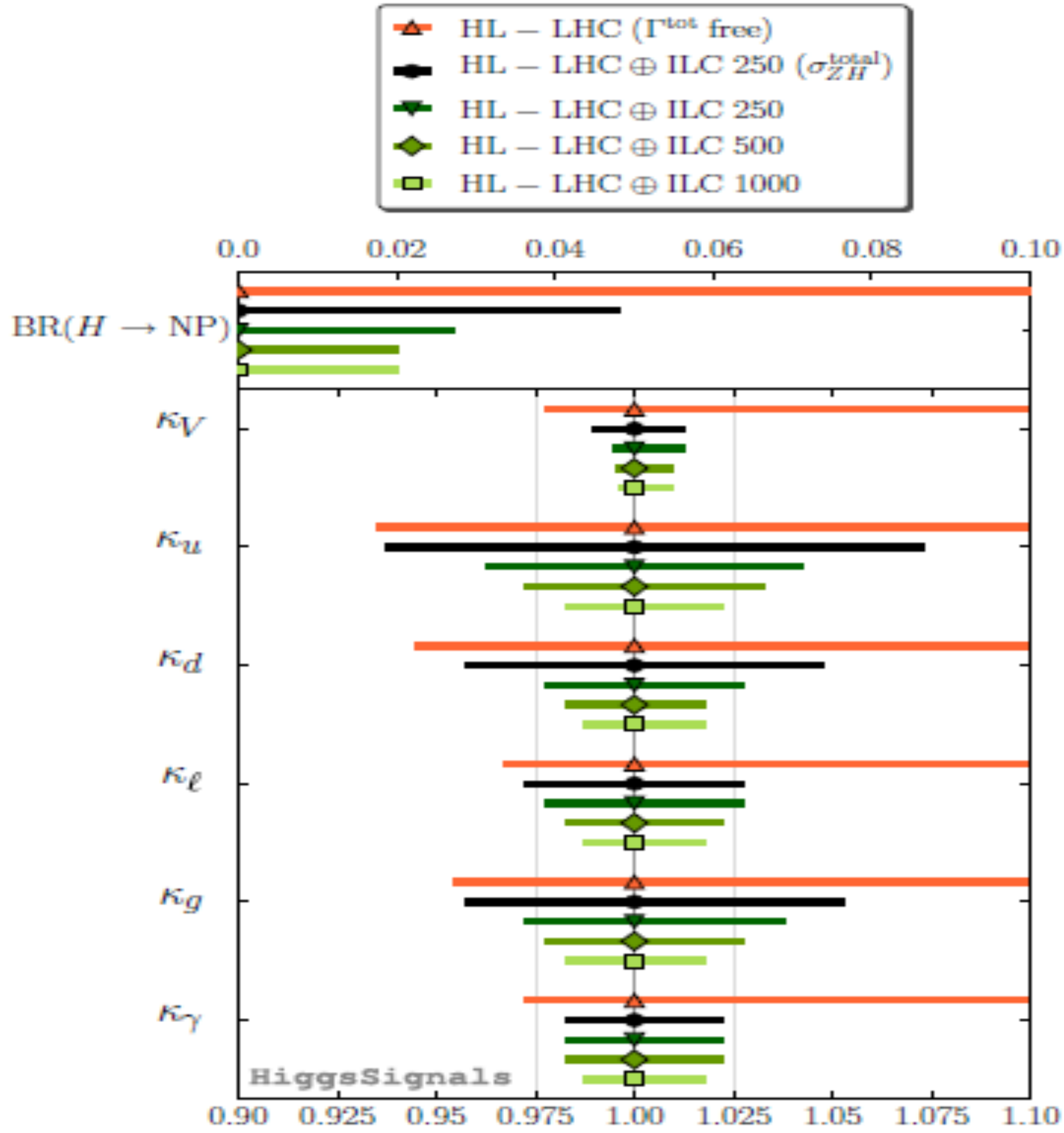
What did we promise for e+e- colliders?

Bechtle et al.

- **Precision of 1-2% achievable in Higgs couplings !!!**

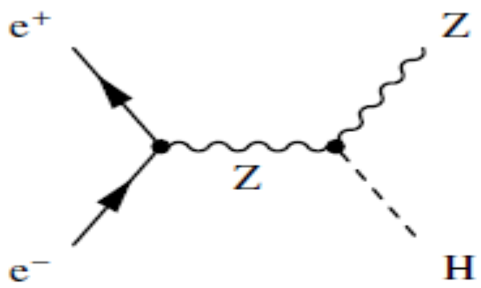
- **Crucial input from ILC**
  - **total cross section σ(HZ)**
  - **Has to be measured at √s=250GeV**
  - **Input parameter for all further Higgs studies (Higgs width etrc.) !**

- **Lots of improvement if only σ(HZ) from ILC is added**



Process: Higgs Strahlung

$\sqrt{s}$=250 GeV



- $\sqrt{s}$=250 GeV: dominant process
- Why crucial?
  - allows model-independent access!
  - Absolute measurement of Higgs cross section $\sigma(HZ)$ and g_{HZZ}:
    crucial input for all further Higgs measurement!
  - Allows access to H-> invisible/exotic
  - Allows with measurement of Γ^h_{tot} absolute measurement of BRs!
  - If no P(e+): 20% longer running time!…..*~few years and less precision!*

Higgs Sector @250 GeV

- **What if no polarization / no P_{e+} available?**
  - Higgsstrahlung dominant $\sigma_{pol}/\sigma_{unpol} \sim (1-0.151\, P_{eff}) * L_{eff}/L$

    With P_{e+}=0%: $\sigma_{pol}/\sigma_{unpol} \sim 1.13$

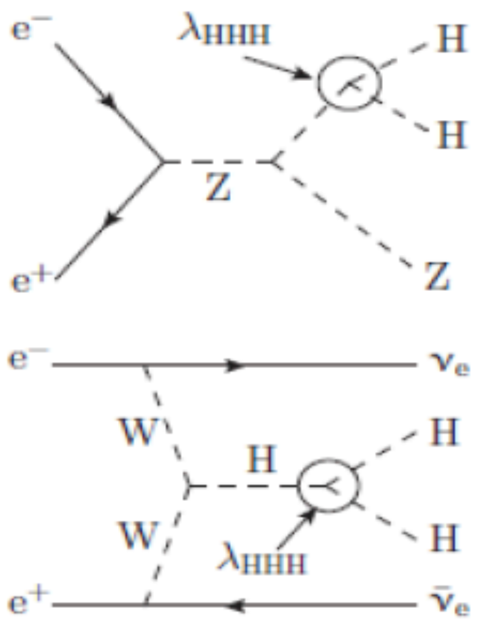
    With P_{e+} = 30% $\sigma_{pol}/\sigma_{unpol} \sim 1.51$ (about 33% increase comp. to 0%)
  - Background: mainly ZZ (if leptonic), WW (if hadronic)

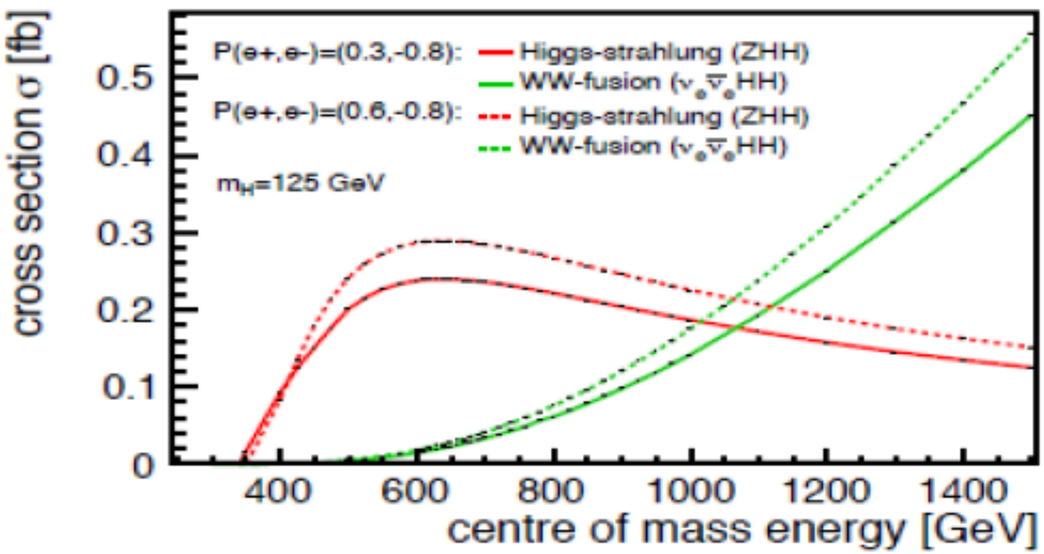
– S/B:	1.14 (+,0)	4.35 (+,0)
	1.20 (+,-)	12.6 (+,-)
– $S/\sqrt{B}$:	0.99 (+,0)	1.95 (+,0)
	1.22 (+,-)	3.98 (+,-)
➢ *Loss if no P_{e+} :*	~20%	~ factor 2

- **Physics Panel used both beams polarized! P_{e+} is important …**

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 ~0.2fb, lots of dilution+backg.)





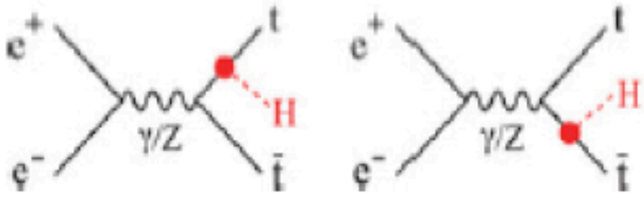
see also talk J.Beyer/J. List

- At cms=1TeV $\Delta\lambda_{HHH}$~10% achievable
- ***In total: about 50% enhancement comp. to P_{e+}=0% !***

Top Yukawa Coupling

- **top-Yukawa coupling crucial:**
  - since strongest coupling to Higgs sector
  - g_{ttH} offers new surprises, needs model-independent measurement

see, e.g. C. Duerig, EPS'15



$\Delta g_{Htt}/g_{Htt}$	ILC500	ILC500 LumiUP
500 GeV	18 %	6.3 %
550 GeV	$\sim$ 9 %	$\sim$ 3 %

increasing $\sqrt{s}$ by 10%, precision improves by factor two for same integrated luminosity

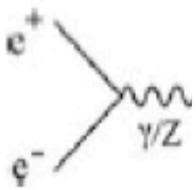
- Numbers very ambitous
- Used so far: (±80,-+30)
- Further improvement with (+-80,-+60):

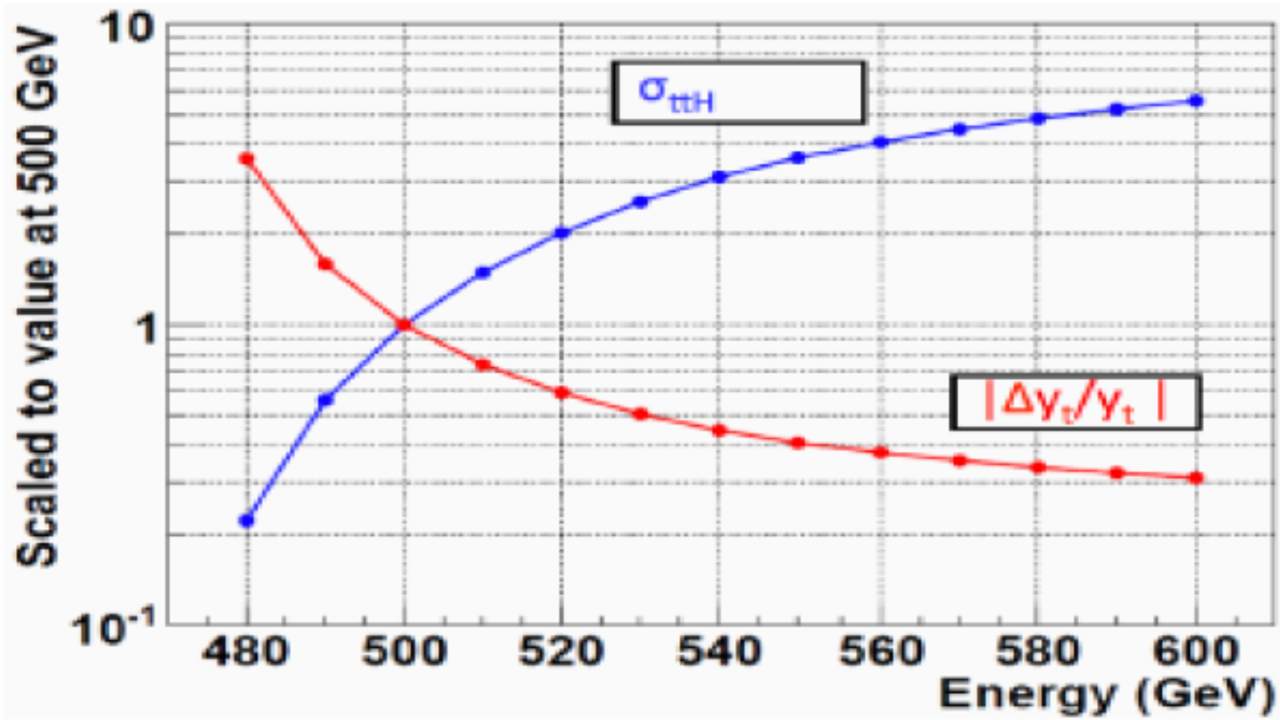
  S increases by 24% if from (80,30) to (80,60)

  S/√B increases by 50%
- *If no P_{e+}: S decreases by about 20%*

Top Yukawa Coupling

- top-Yukawa coupling crucial:
  - sinc
  - g_{ttH} ... surement
    ...rig, EPS'15





LumiUP

%

%

nproves by
minosity

  - Num
  - Usec
  - Furth... imp...
    S increas...
    S/√B incr...
  - *If no P_{e+}: S*

$\sqrt{s} = 550$ GeV better precision on $g_{Ht\bar{t}}$

- by factor 4 enhanced cross section
- main backgrounds decrease

Further Physics Examples

Case	Effects	Gain
SM:		
top threshold	Improvement of coupling measurement	factor 3
$t\bar{q}$	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	$P^T_{e^-} P^T_{e^+}$ 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 $\tilde{h}_+ = \mathrm{Im}(g_1^R + \kappa^R)/\sqrt{2}$	$P^T_{e^-} P^T_{e^+}$ required
CPV in γZ	Anomalous TGC $\gamma\gamma Z$, $\gamma Z Z$	$P^T_{e^-} P^T_{e^+}$ required
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	factor 4 with RL
	Suppression of $B = W^+\ell^-\nu$	factor 1.7
SUSY:		
$\tilde{e}^+\tilde{e}^-$	Test of quantum numbers L, R and measurement of $e^\pm$ Yukawa couplings	P_{e^+} required
$\tilde{\mu}\tilde{\mu}$	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 $\tilde{\chi}^0_i\tilde{\chi}^0_j$	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	

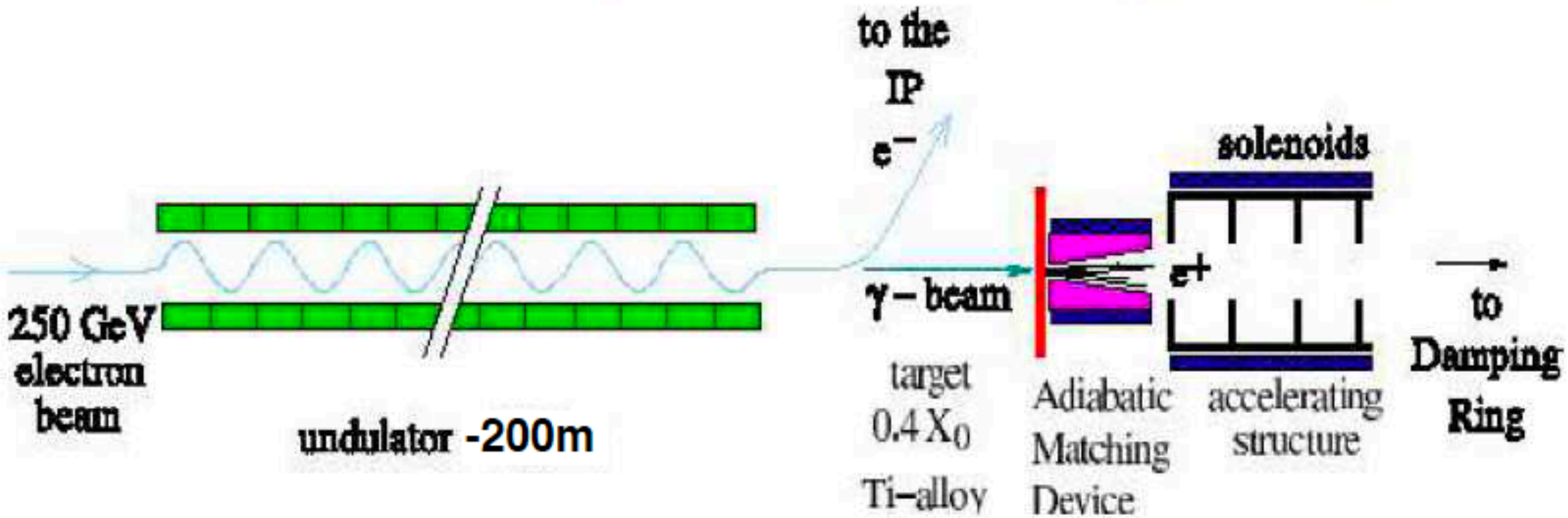
Further Physics Examples

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	$P^T_{e^-} P^T_{e^+}$ 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
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
CPV in $Z \to b\bar{b}$	Enhancement of sensitivity	factor 3

- **Many new physics examples**
- **Beam polarization always provides 'physics gain'**
- **Crucial sensitivity to coupling structures**
- **Still further new studies ongoing……..**

Short overview: e^+ sources at ILC

- Conventional source: e- scattering in target ⟶ pair production ⟶ e+
- Undulator-based scheme: polarized e+ via circularly polarized photons



- deviation of e- beam via helical magnetic field in undulator
- radiated circularly polarized photons onto thin target, pair production
- e+ yield and polarization depends on beam energy and undulator length

Short overview: e^+ sources at ILC

	SLC	ILC (RDR)	CLIC
e+/bunch	3.5×10^{10}	2×10^{10}	0.64×10^{10}
Bunches/ pulse	1	2685	312
Pulse rep rate	120	5	50
e+/s	0.042×10^{14}	2.6×10^{14}	1×10^{14}

➢ in general: demanding challenges for the e+ source!

- **Beam polarization status: at cms=250 GeV: P(e^-)~80-90%, P(e^+)~30%**

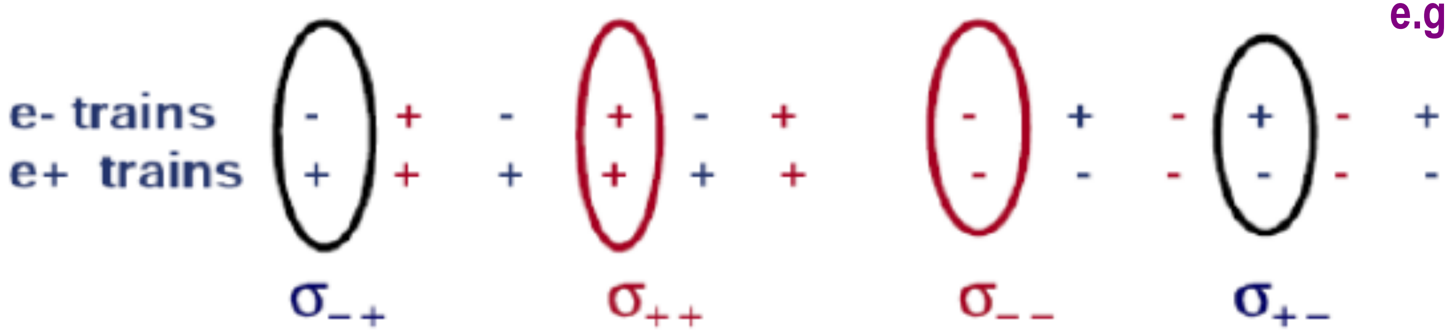
  =350, 500 GeV: P(e^-)~80-90%, P(e^+)=40% (60% with collimator)

  (with chosen undulator parameters for cms=500 GeV)

Caution: helicity flipping is required

- **Gain in effective lumi lost if no flipping available**

e.g. S. Riemann



  – 50% spent to 'inefficient' helicity pairing (most SM, BSM)
  – Similar flip frequency for both beams ~ pulse-per-pulse
- **Gain in ΔP_{eff} remains, but flipping required to understand:**
  – Systematics and correlations P_{e-} x P_{e+}
- **Spin rotator before DR and spinflipper in set-up for baseline!**
  – done!

Conclusions

- **Beam polarization e^- and e^+ gives 'added-value' to ILC**
  - Crucial 'new' analysis tools compared to LHC physics
  - Access to chirality: since $E \gg m$: chirality=helicity='polarization'
- **P_{e+} important at $\sqrt{s}$=250 GeV (Higgs!) and higher $\sqrt{s}$**
  - Saves running time
  - Essential to control systematics
  - Crucial to compete with LHC options
  - Essential to match precision promises/expectations!
  - ➢ Precision allows sensitivity to beyond SM physics! *e.g. LCC physics group,1801.02840*
- **Access to new/specific asymmetries (*e.g. also access to heavy leptons etc…..LC notes*)**
  - $$A_{\text{double}} = \frac{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)-\sigma(P_1,P_2)-\sigma(-P_1,-P_2)}{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)+\sigma(P_1,P_2)+\sigma(-P_1,-P_2)},$$
- **Exploitation of both longitudinally-&transversely-pol. beams**
  - Access to tensor-like interactions, CP-violating pheno, specific TGC,….

- Not covered today: polarization to determine properties of new particles directly, as chiral quantum numbers, CP quantities, large extra dimensions etc. as well as dark matter also at 250!more details see talk by J.Beyer/J. List and A. Zarnecki

Back to longitudinally polarized beams

- **Important issue: measuring amount of polarization**
  - limiting systematic uncertainty for high statistics measurements
- **Compton polarimeters: up- and downstream**
  - envisaged uncertainties of $\Delta P/P=0.25\%$. Essential for monitoring, but need to correct wrt IP.
- **(Differential) Cross-section based in-situ measurements**
  - need some physics assumptions
  - often under assumption of perfect helicity reversal
- **Adding positron polarization helps in several ways:**
  - Providing additional measurements, improving limiting systematics
  - Enhancing effective polarization
  - 'Allow' in-situ measurements: 'ultimate' measurements, but require running time in same-sign configurations

Polarization measurement

- **Compton polarimeters: up- and downstream**
  - envisaged uncertainties of ΔP/P=0.25% (at polarimeters!)
  - But that's is not enough for IP!
- **Use collision data to derive luminosity-weighted polarization**
  - single W, WW, ZZ, Z, etc.: combined fit

$$P^{-}_{e\pm} = -|P_{e\pm}| + \tfrac{1}{2}\delta_{e\pm} \qquad P^{+}_{e\pm} = \ |P_{e\pm}| + \tfrac{1}{2}\delta_{e\pm}$$

  - assume H-20 set-up concerning lumi *Karl, List,1703.00214*
  - helicity reversal is important
  - non-perfect helicity-reversal can be compensated
  - 0.1% accuracy in ΔP/P is achievable at IP!
  - *NOT achievable without Pe+!*

Remember: even if no Pe+ (SLC! dedicated experiment at SLACs Endstation A), the P_{e+}~0.0007 had to be derived a posteriori for physics reason!

L_{eff} and P_{eff}

- More concrete: If only LR and RL contributions: only 50 % of collisions useful

effective luminosity: $L_{\rm eff}/L = \frac{1}{2}(1 - P_{e^-} P_{e^+})$

This quantity = the effective number of collisions, can only be changed with P_{e-} and P_{e+}:

here: $\boxed{\text{With } \mp 80\%, \pm 30\%, \text{ the increase is } 24\%}$

With $\mp$80%, $\pm$60%, the increase is 48%

With $\mp$90%, $\pm$60%, the increase is 54%

In other words: *no P_{e+} means 24% more running time (!)*

and

10% loss in P_{eff} = 10% loss in analyzing power!

Quite substantial in Higgs strahlung and electroweak 2f production !

L_{eff} and P_{eff}: further example

- **Charged currents, i.e. t-channel W- or ν-exchange (A_{LR}=1):**

$$\sigma(\mathcal{P}_{e^-}, \mathcal{P}_{e^+}) = 2\sigma_0(\mathcal{L}_{\rm eff}/\mathcal{L})[1 - \mathcal{P}_{\rm eff}]$$

In other words: ***no P_{e+} means 30% more running time needed !***

Quite substantial in Higgs production via WW-fusion!