Polarized positrons at low energies: Physics goal and source requirements

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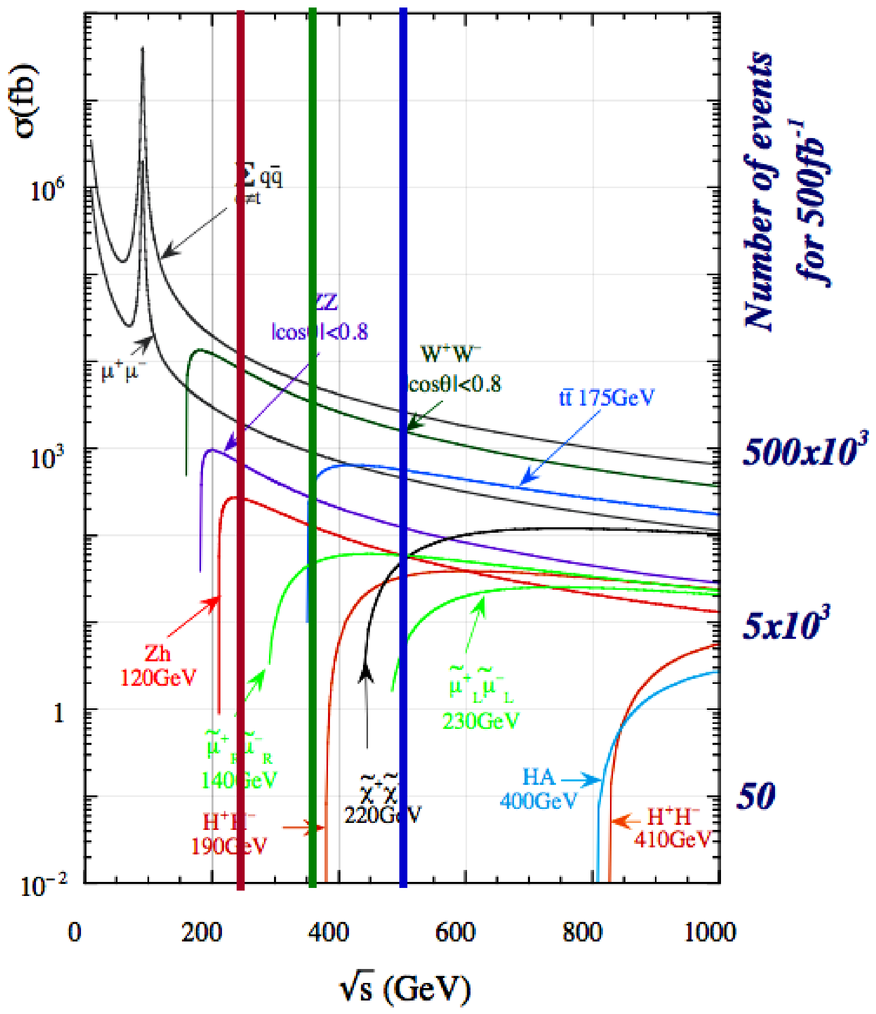
Outline:
- ILC
  - as Higgs factory
  - At the top-quark threshold
  - at E ≥ 500 GeV
- GigaZ
- Spin flipper
- Summary

Many thanks to all contributors to studies on (e+) polarization!

Physics goal of future colliders

- **Precision** measurements
  - **Higgs measurements**
  - **ee → tt**
  - **Fermion pair production,**
  - **ee → WW**

- Searches and measurements
  - **SUSY**
  - **new gauge bosons,**
  - **extra dim,**
  - **Dark matter**
  - …



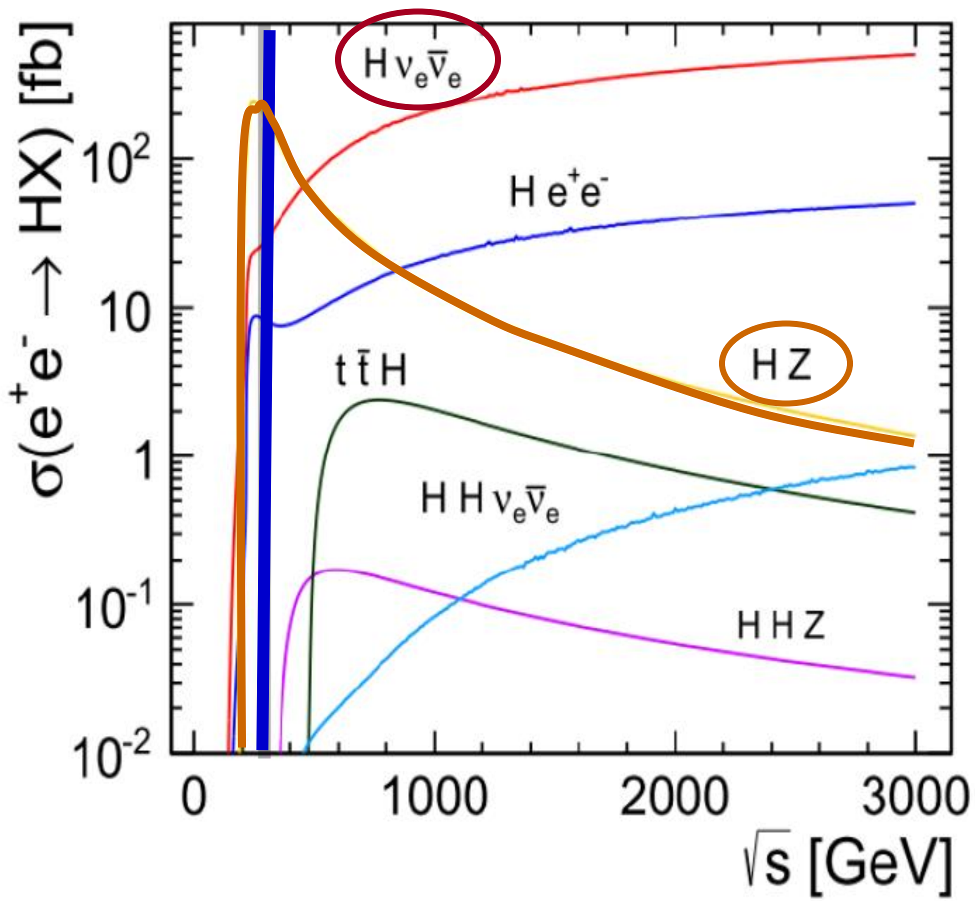
- More details see talk of M. Peskin, ILC TDR, CLIC CDR, …
- Physics with pol e+ see: Moortgat-Pick et al. Phys.Rept. 460 (2008) 131

E_{cm} = 240 GeV

ILC as Higgs Factory

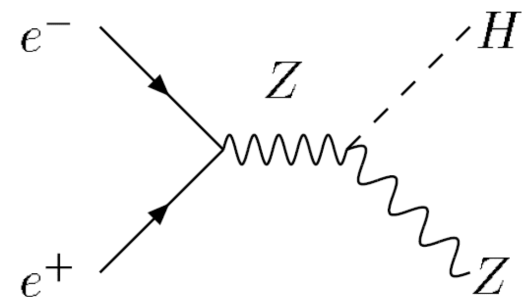
E_{cm} = 240 GeV:

m_H = 126 GeV

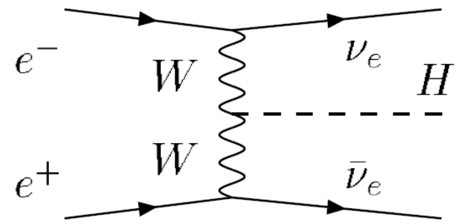


Higgs Strahlung

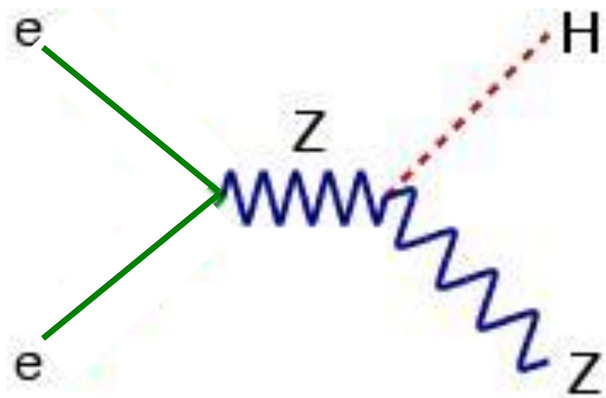
(dominating)



WW Fusion



Higgs Mass and Higgs Coupling to the Z

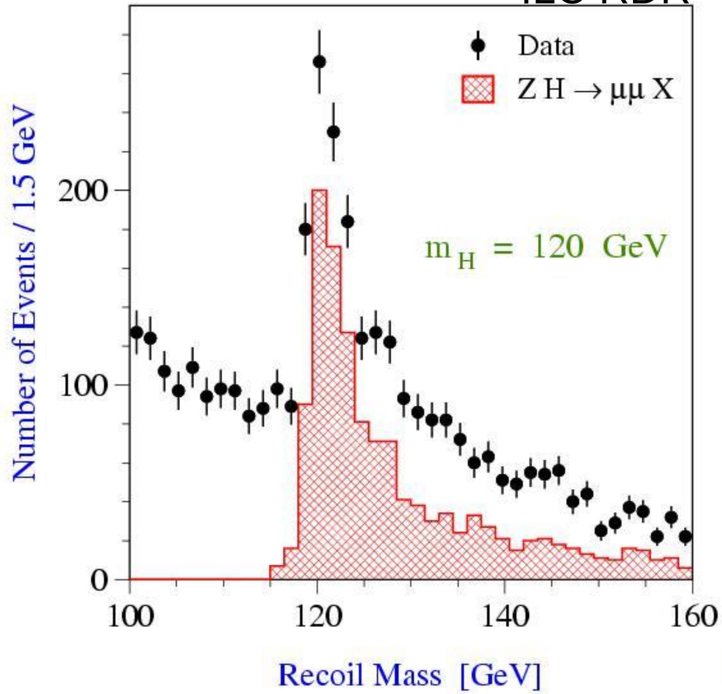


Select events:

e+e- → ZH and Z → μμ,ee

Fit to the spectrum of recoil mass of both leptons ➔ Higgs mass and coupling

ILC RDR



Peak position ⬄ Higgs mass

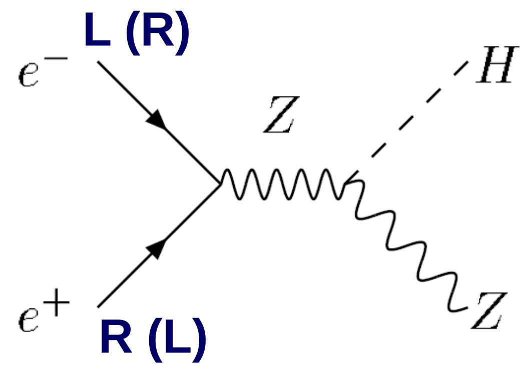
Δm < 100 MeV

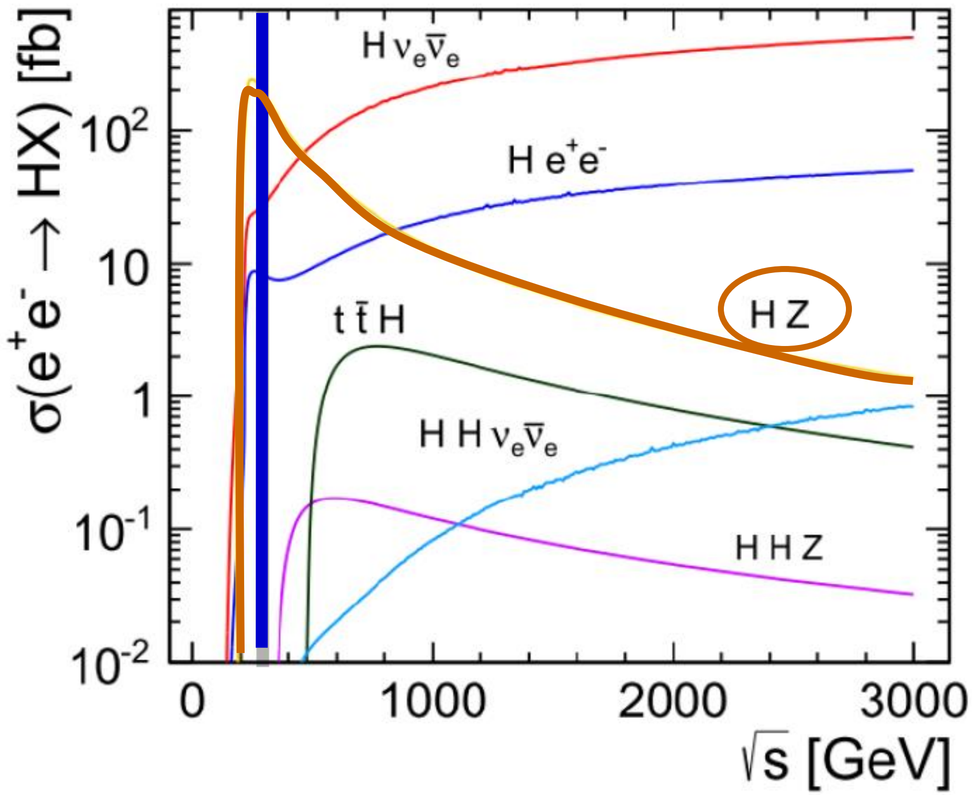
Peak hight ⬄ $\sigma_{ZH} \sim g_{ZH}^2$

Model independent measurement!!

Higher lumi improves precision

Higgs Strahlung dominates





$e^+_R\, e^-_L \rightarrow ZH$

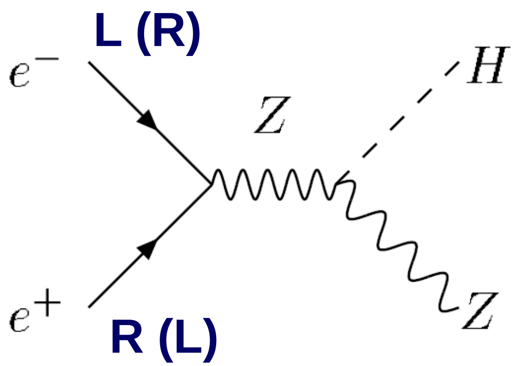
$e^+_L\, e^-_R \rightarrow ZH$

~~$e^+_L\, e^-_L \rightarrow ZH$~~

~~$e^+_R\, e^-_R \rightarrow ZH$~~

With e+ <u>and</u> e- polarization 'ineffective' processes are suppressed

Higgs Strahlung



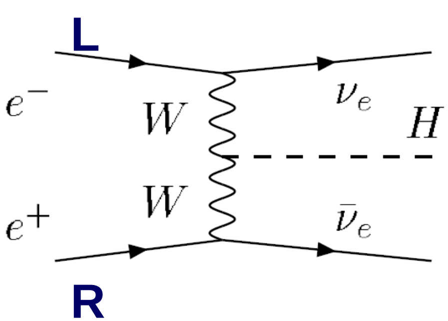
$e^+_R e^-_L \rightarrow ZH$
$e^+_L e^-_R \rightarrow ZH$
~~$e^+_L e^-_L \rightarrow ZH$~~
~~$e^+_R e^-_R \rightarrow ZH$~~
} $\sigma(ee \rightarrow ZH) = 0$

eff. luminosity

$$L_{eff} = (1 - P_{e+} P_{e-})$$

P(e-,e+) = (±80%; ∓30%) ⇔ 24% lumi gain
➔ $\Delta\sigma_{ZH}$ reduced by 11%

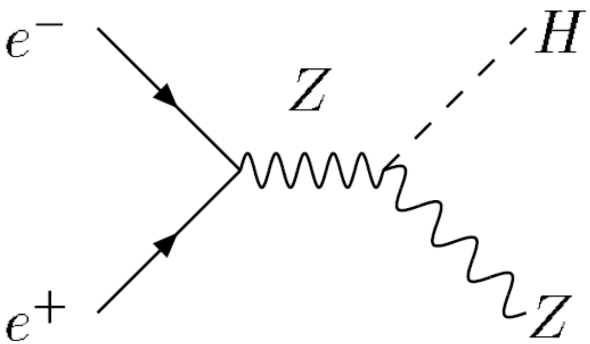
WW Fusion



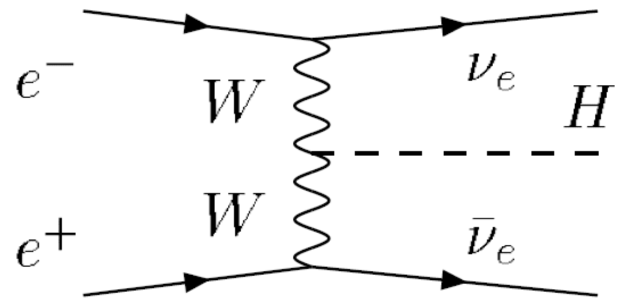
$e^+_R e^-_L \rightarrow \nu\nu H$
~~$e^+_L e^-_R \rightarrow \nu\nu H$~~
~~$e^+_L e^-_L \rightarrow \nu\nu H$~~
~~$e^+_R e^-_R \rightarrow \nu\nu H$~~
} for P(e+)=+1
$\sigma(e^+_R e^-_L \rightarrow \nu\nu H)$ enhanced by factor 2

LC as Higgs factory

Higgs Strahlung



WW Fusion



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

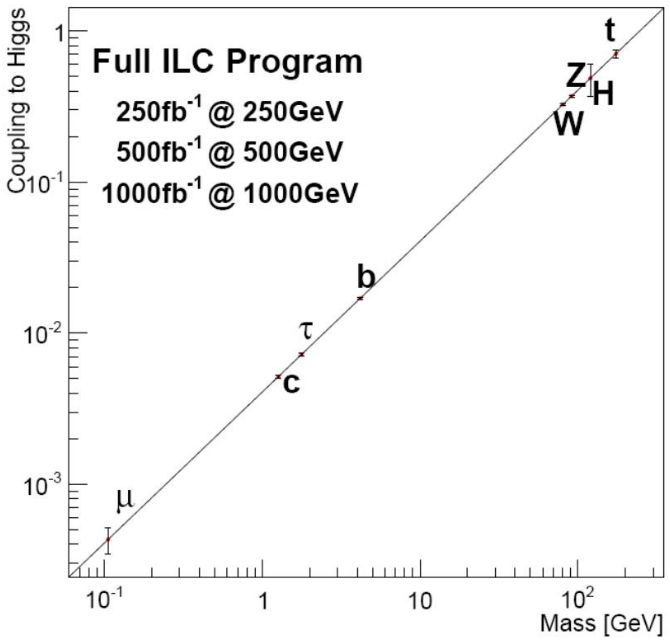
- **Enhancement of Higgs Strahlung by factor (1-Pe-Pe+)**
- **Enhancement of Higgs Production by WW Fusion**

The Higgs @ LC

To establish the Higgs mechanism implies:

- **Measurements of Higgs quantum numbers**
  - Spin and parity determined at LHC
- **Investigation of coupling - mass relations**
  - In SM, Higgs mass determines the couplings:
    linear coupling – mass relation
  - Deviations from linearity
    → non-SM Higgs Boson
- **Model-independent measurement of Higgs coupling**

ILC TDR

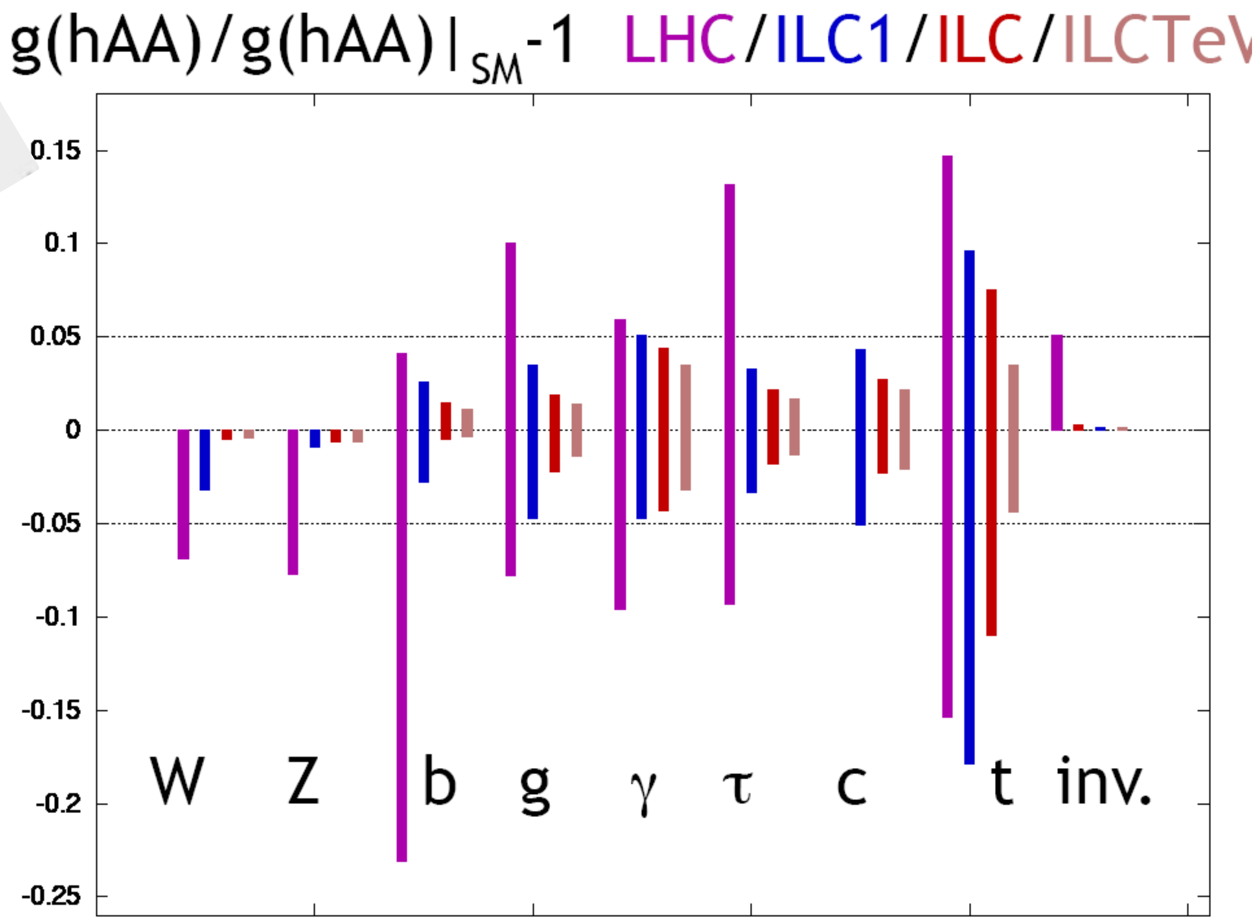


LHC alone won't be able to provide a complete and comprehensive picture of the Higgs mechanism since precision is insufficient to discriminate between different models

Sensitivity to Higgs couplings in model-independent analyses

Fitting all Higgs couplings together

LHC requires theory assumptions



ILC1: E=250GeV

ILC: up to E=500GeV (full program)

ILCTeV: E=1TeV

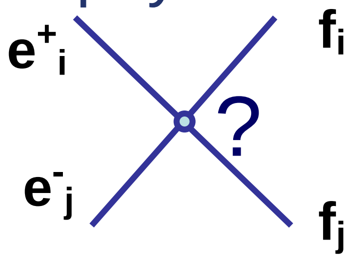
ILC TDR

ILC as Higgs Factory (E_{cm} = 240 GeV)

- 10 Hz scheme (suggested in TDR) **not** necessary
    - See B. List, LC-REP-2013-018; Harrison, Walker, Ross, arXiv:1308.3726; Ushakov, LC-REP-2013-019
  - **See Andriy's talk:**
    - 5Hz Undulator based source is possible, Pe+ = 30%
- Spinning target wheel (see Friedrich's talk):
  - **Rotation speed of ≤1000 rpm is sufficient**
- Goal of physics measurements @ 240GeV
  - **Higgs mass**
  - **Higgs cross section**
  - **Higgs coupling**
    - To be improved with measurements at higher energies
- Expected benefit for P(e+) = 30%:
  - **24% more luminosity ⇔ coupling uncertainty reduced by ~11%**
  - **Improved background separation**
- Polarization upgrade is not required as long as there is no new physics found at low energies
- At 240 GeV also other processes than Higgs production will be studied where e+ pol improves performance (ee→ff, WW)

Sensitivity to new physics (E_{cm} ≥240 GeV)

sensitivity to new physics expressed by 4 fermion contact interaction



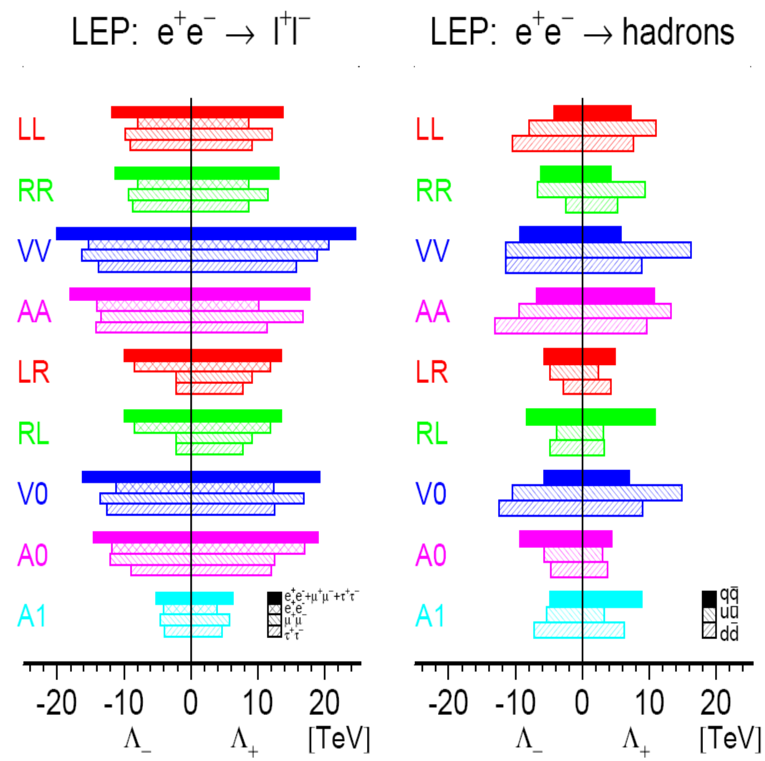
$$\sim \frac{\eta_{ij} \cdot E_{cm}^2}{\Lambda^2}$$

i,j = L,R

Scaling of sensitivity:

$\Lambda \sim (L_{int})^{1/4} \sqrt{E_{cm}}$

- **LEP (130GeV < E_{cm} ≤ 208 GeV)**
  L_{int} = 3 fb-1
- **ILC @ 240 GeV:**
  L_{int} ≈ 200 fb-1
- **sensitivity reach of Λ improves by factor 3 up to ~10-70TeV**
- **Further improvement by at least ~7% for 30% e+ pol**



e+ polarization improves substantially identification of models in case of deviations from SM

E_{cm} = 350 GeV

Top quark physics @ LC

- heaviest quark (as heavy as gold atom), pointlike
- Extremely unstable ($\tau \sim 4 \times 10^{-25}$s)
  - **Decay of top-quark before hadronization**
  - **Top-polarization gets preserved to decay (similar to τ-lepton)**
  - ➔ **The 'pure' top quark can be studied**
  - **Top mass and coupling are important for quantum effects affecting many observables**
  - **Top quark coupling as test of SM and physics beyond**

→ top quark coupling, spin, spin correlations are observable by measuring polarization and LR asymmetries with **high precision**

- **Need high degree of polarization**
- **e+ polarization highly desired** **(see i.e., Grote, Koerner, arXiv:1112.0908)**
- **Need precise measurement of polarization**

Precision Measurements with $P_{e+} > 0$

One key observable: Left-right polarization asymmetry

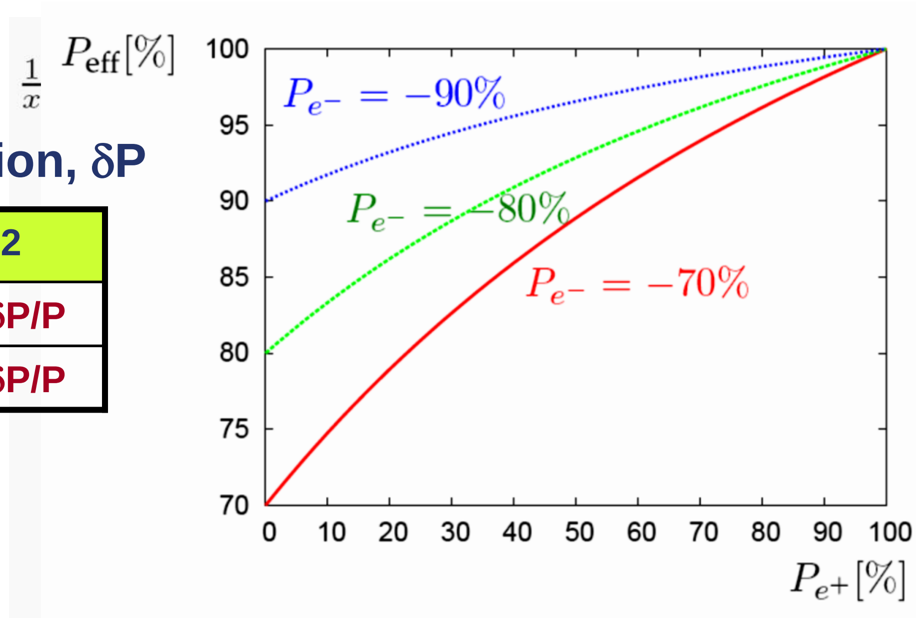
$$A_{LR} = \frac{\sigma_{LR} - \sigma_{RL}}{\sigma_{LR} + \sigma_{RL}} \cdot \frac{1 - P_{e^-} P_{e^+}}{-P_{e^-} + P_{e^+}} \cong \frac{N_{LR} - N_{RL}}{N_{LR} + N_{RL}} \cdot \frac{1}{P_{eff}}$$

$=1/P_{eff}$

for measurements with equal luminosities for (- +) and (+ -) helicity

- Effective polarization
  - P_{eff} is larger than e- polarization
  - error propagation → ΔP_{eff} is substantially smaller than the uncertainty of e- beam polarization, δP

P_{e-}	P_{e+} 0.6	0.34	0.22
0.8	0.27 δP/P	0.50 δP/P	0.64 δP/P
0.9	0.25 δP/P	0.49 δP/P	0.64 δP/P



- Higher effective luminosity

$$L_{eff} = (1 - P_{e+} P_{e-})$$

→ Smaller statistical error

Photon collimator parameters for polarization upgrade

ILC TDR

Parameter	Unit					L upgrade
Centre-of-mass energy	GeV	200-250	350	500	500	500
Drive-electron-beam energy	GeV	150	175	250	250	250
Undulator K value				0.92		
Undulator period	cm			1.15		
Positron polarisation	%	55	59	50	59	50
Collimator-iris radius	mm	2.0	1.4	1.0	0.7	1.0
Active undulator length	m	231	196	70	144	70
Photon beam power	kW	98.5	113.8	83	173	166
Power absorbed in collimator	kW	48.1	68.7	43.4	121	86.8
Power absorbed in collimator	%	48.8	60.4	52.3	70.1	52.3

60% e+ polarization at 350GeV ⇔ ~60% of photon beam power absorbed in collimator

→ high load on the collimator materials

Spinning target: <2000 rpm (see Friedrich's talk)

E_{cm} = 500 GeV

E_{cm}=500GeV (and higher)

- Full spectrum of physics processes

  Higgs production

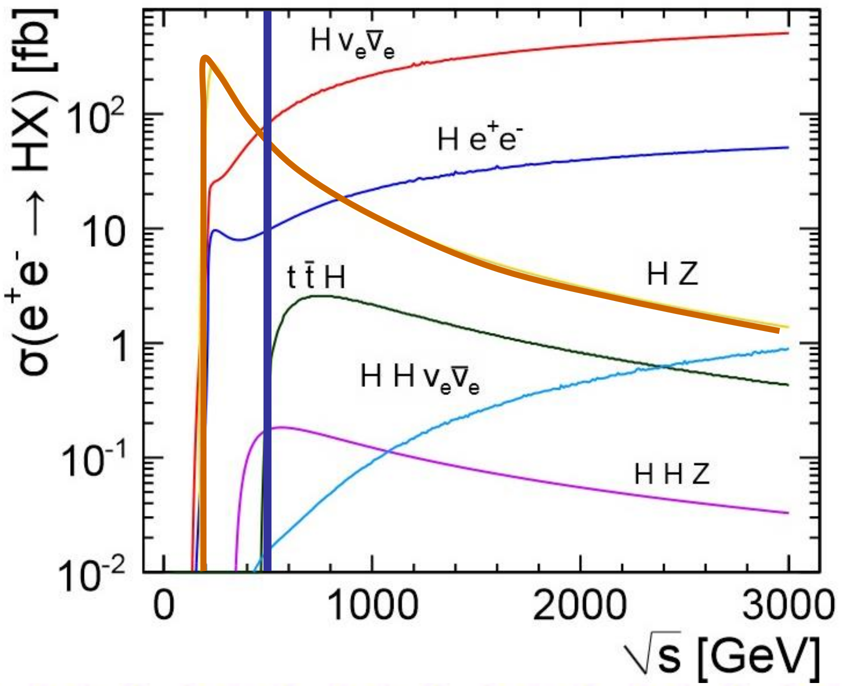
  Top-quarks

  WW production

  Fermion-pair production (indirect search for new physics)

  SUSY (if it exists)

  ….



Sensitivity to Higgs couplings in model-independent analyses

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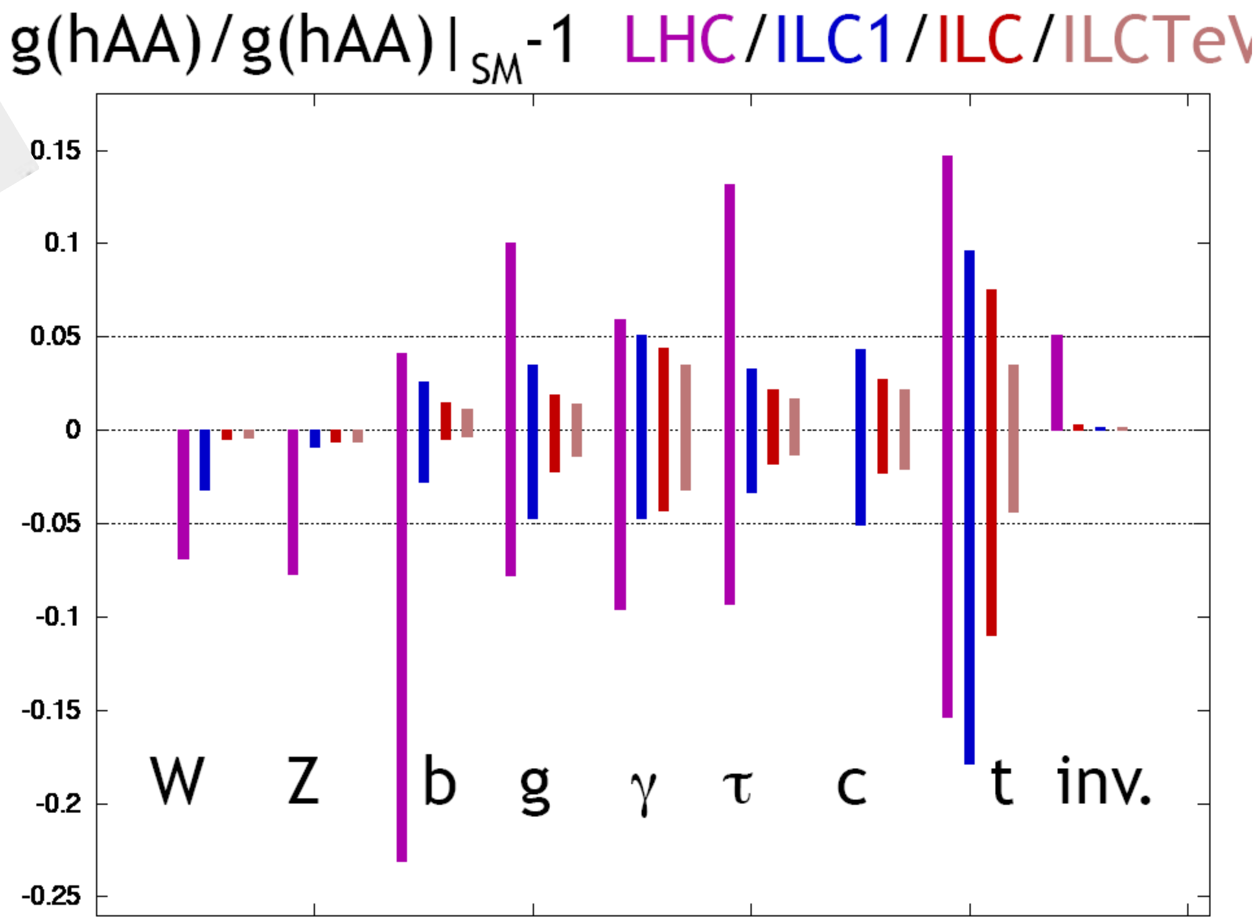
LHC requires theory assumptions



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ILC TDR

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- Full spectrum of physics processes

  Higgs production

  Top-quarks

  WW production

  Fermion-pair production (indirect search for new physics)

  SUSY (if it exists)

  ….

- Best flexibility with polarized e+ and polarized e- beam
  - **Physics with transversely polarized beams; only possible if both beams are polarized**

Which degree of e+ polarization is required?

- **As much as 'possible'**

Photon collimator parameters for polarization upgrade

ILC TDR

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60% e+ polarization at 500GeV ⬄ collimator absorbs ~70% of photon beam power

→ 50% e+ polarization should be 'sufficient'

Spinning wheel: <2000rpm (see Friedrich's talk)

GigaZ

- Running again at the Z resonance (LEP, SLC)
- High statistics: 10^9 Z decays/few months
- **With polarized e+ and e- beams** the left-right asymmetry A_{LR} and the effective polarization P_{eff} can be determined simultaneously with highest precision

➔ relative precision of less than $5x10^{-5}$ can be achieved for the **effective weak mixing angle, $\sin^2\theta_W^{eff}$**, 10x better than LEP/SLD

➔ Together with other LC precision measurements at higher energies (i.e. top-quark mass) theoretical predictions can be tested and physics models beyond the Standard Model distinguished

Blondel scheme

- Can perform 4 **independent** measurements (s-channel)

$$\sigma_{\pm\pm} = \tfrac{1}{4}\sigma_u\left[1 + P_{e^+}P_{e-} + A_{LR}\left(\pm P_{e^+} \pm P_{e-}\right)\right]$$

=0 (SM) if both beams 100% polarized

$$\sigma_{\mp\pm} = \tfrac{1}{4}\sigma_u\left[1 - P_{e^+}P_{e-} + A_{LR}\left(\mp P_{e^+} \pm P_{e-}\right)\right]$$

- determination of P_{e+} and P_{e-}, σ_u and A_{LR} simultaneously ($A_{LR}\neq 0$); for $P_e(+) = P_e(-)$:

$$P_{e^\pm} = \left[\frac{(\sigma_{+-} + \sigma_{-+} - \sigma_{++} - \sigma_{--})}{(\sigma_{+-} + \sigma_{-+} + \sigma_{++} + \sigma_{--})} \cdot \frac{(\mp\sigma_{+-} \pm \sigma_{-+} - \sigma_{++} + \sigma_{--})}{(\mp\sigma_{+-} \pm \sigma_{-+} + \sigma_{++} - \sigma_{--})}\right]^{1/2}$$

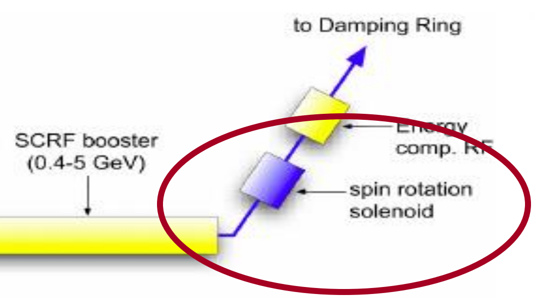
→ need polarimeters at IP for measuring polarization differences between + and – helicity states

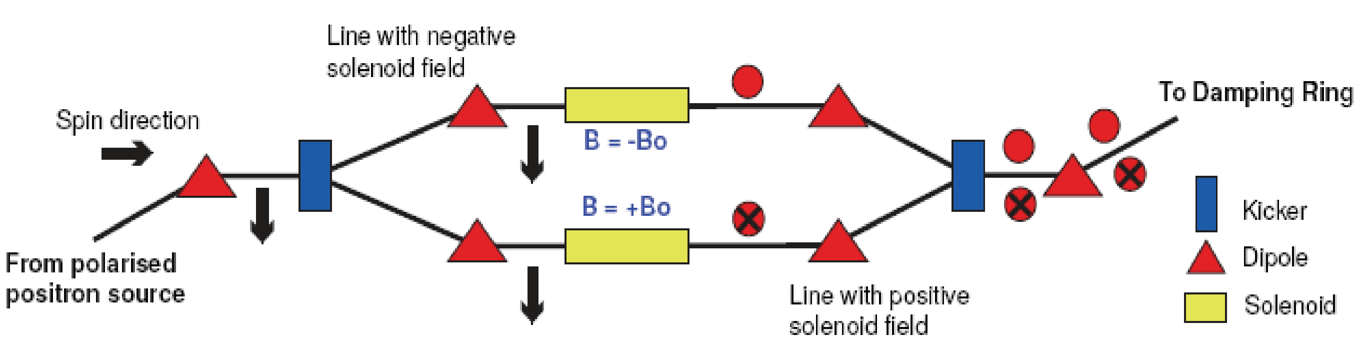
→ Have to understand correlation between $P_e(+) = P_e(-)$

Spin Flipper

Spin flipper

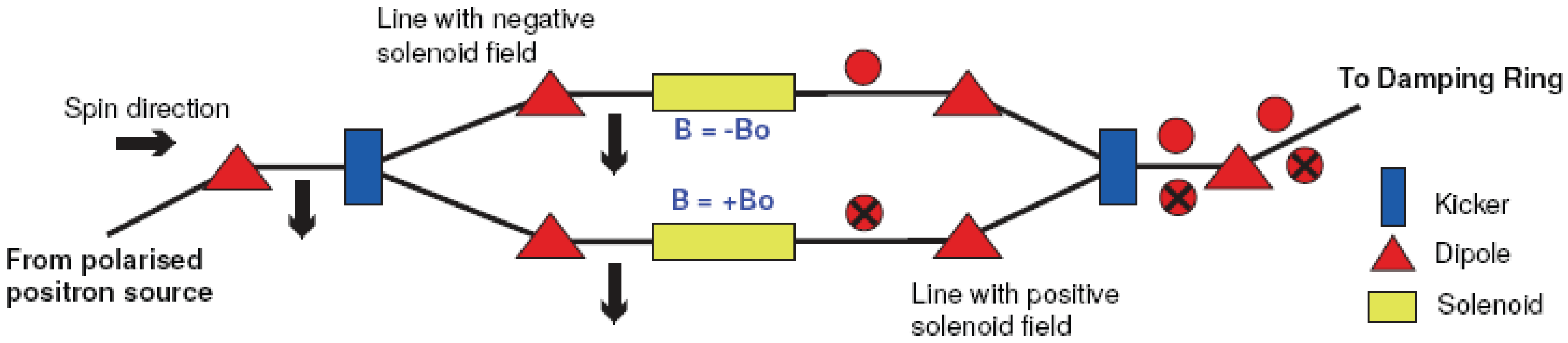
- Net polarization depends on direction of undulator windings
- Reversal of e+ helicity necessary
- It has to be synchronous with reversal of e- polarization to achieve
  - **enhanced luminosity**
  - **Cancellation of time-dependent effects ⇔ small systematic errors**
- Helicity reversal requires spin flipper
  - **near the DR where the spins have to be rotated**





Spin flipper

- beam is kicked into one of **two identical parallel transport lines** to rotate the spin
- Horizontal bends rotate the spin by 3 × 90° from the longitudinal to the transverse horizontal direction.
- In each of the two symmetric branches a 5m long solenoid with an integrated field of 26.2Tm aligns the spins parallel or anti-parallel to the B field in the damping ring.
- Both lines are merged using horizontal bends and matched to the PLTR lattice.
- The length of the splitter/flipper section section ~26m; horizontal offset of 0.54m for each branch



Summary

- Weak interaction is parity violating

  → Polarized beam(s) are mandatory for future precision physics at high energy e+e- colliders

- Positron polarization P(e+) ≥ 30% is useful for physics at **all** energies
  - **Higher effective luminosity**
  - **Enhancement of interesting processes**
  - **new physics signals can be fixed and interpreted with substantially higher precision**
  - **For ee → tt measurements P(e+) ~60% are desired**
  - **High e+ polarization allows polarization measurement using annihilation data (⇔ cross check!)**
- TDR: most physics prospects are derived assuming e+ polarization

Summary

- Source requirements
  - **E_{cm} = 240 GeV is possible without 10Hz scheme**
  - **30% can be achieved without photon collimator**
  - **60% (50%) at E_{cm}=350GeV (500GeV) with γ collimator**
  - **Target: spinning wheel to distribute heat load**
    - See Friedrich's talk: rotation speed below 2000rpm is possible
    - Improved target design ⇔ resources required
    - Alternatives considered / to be considered:
      - W doped Li target (Target + Li lens in one device) does not improve (see Andriy's talk)
      - cooling options (radiative cooling?)
  - **FC seems workable but still need to demonstrate full average power operation**
    - Run with 5Hz over extended period and full average power with cooling
  - **spin flipper**
- 300Hz scheme vs. undulator based source: Both have (dis)advantages.

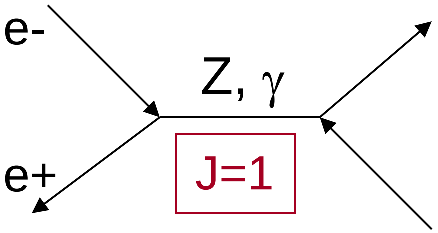
Substantially better physics potential with positron polarization

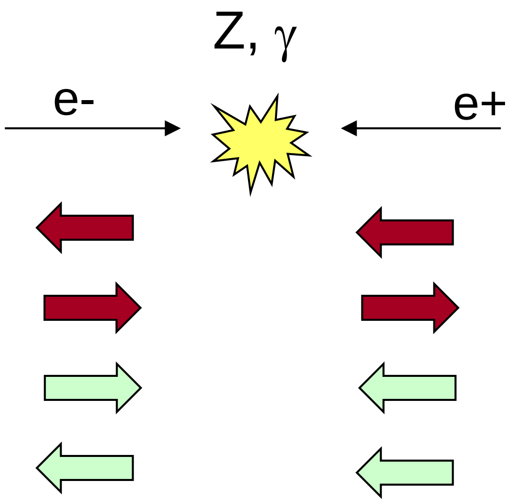
- Backup

Positron polarization in e+e- collisions

Consider unpolarized beam(s) in e+e- collisions:

- s-channel processes



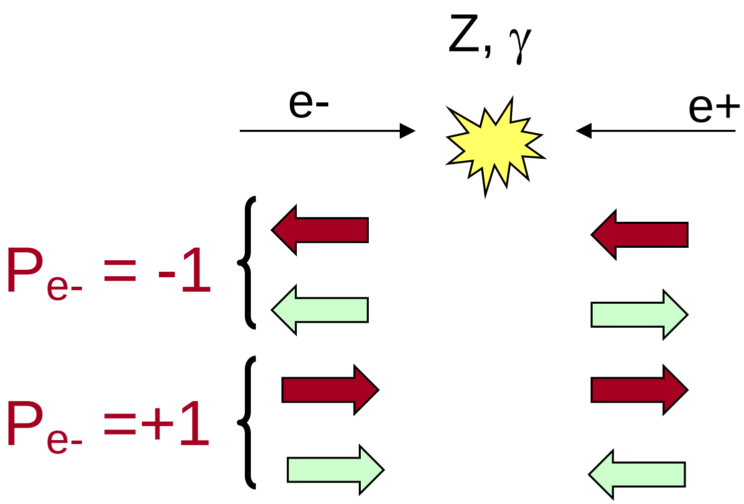


	Helicity		cross section
J=1	-	+	$\sim(g_L(e))^2$
J=1	+	-	$\sim(g_R(e))^2$
J=0	+	+	0
J=0	-	-	0

→ only half of all possible processes yield $\sigma \neq 0$

Polarized e- beam in e+e- collisions

- Collisions of 100%-polarized e- beam and unpolarized positron beam:

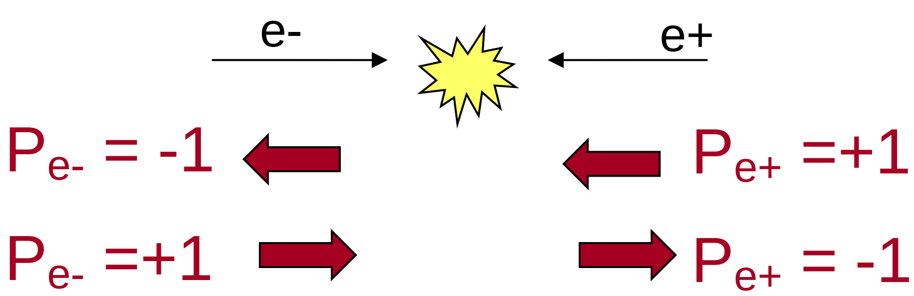


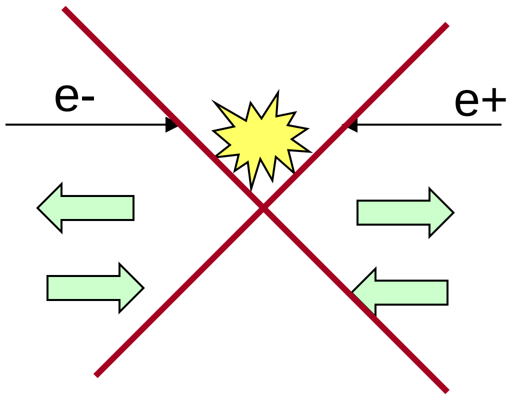
Helicity		cross section
-	+	$\sim(g_L(e))^2$
-	-	0
+	-	$\sim(g_R(e))^2$
+	+	0

→ still ½ of possible collisions yields $\sigma = 0$

Polarized e+ and e- beams

- Collisions of 100%-polarized e- beam and 100%-polarized e+ beam:





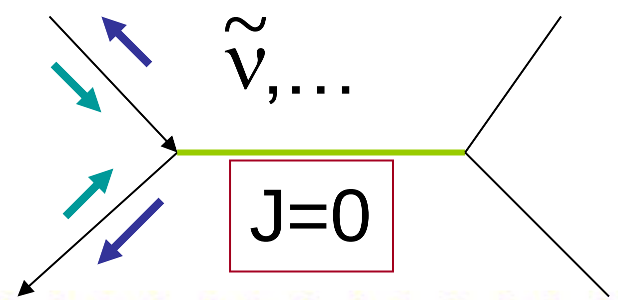
- All collisions contribute to σ_{SM}

  → effective luminosity is enhanced

- Physics beyond the Standard Model could show up if $\sigma_{\leftrightarrows\rightleftarrows}$ = 0 is expected but $\sigma_{\leftrightarrows\rightleftarrows} \neq 0$ is measured

Flexible choice of initial states,

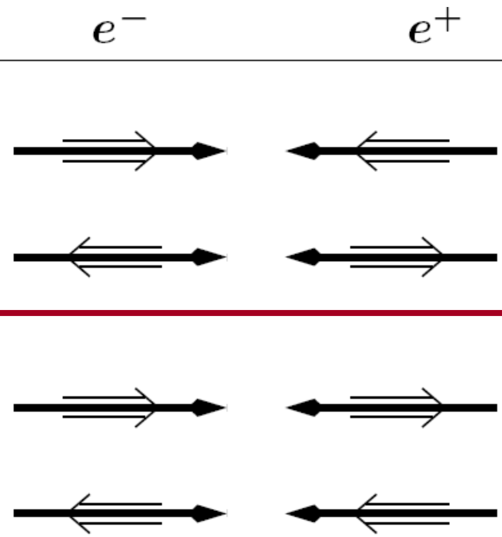
- +, + -, - -, + +, is desired



Realistic polarization

P < 100% ⇔ measured cross sections $\sigma_{\leftrightarrows\rightleftarrows}$ are not zero

Consider s-channel processes:



	Contibution to cross section	
σ_{RR}	$\frac{1+P_{e-}}{2}\cdot\frac{1+P_{e+}}{2}$	$J_z = 0$
σ_{LL}	$\frac{1-P_{e-}}{2}\cdot\frac{1-P_{e+}}{2}$	
σ_{RL}	$\frac{1+P_{e-}}{2}\cdot\frac{1-P_{e+}}{2}$	$J_z = 1$ (SM)
σ_{LR}	$\frac{1-P_{e-}}{2}\cdot\frac{1+P_{e+}}{2}$	

SM

$$\sigma_{ij}^{meas} = \sigma_0 (1 - P_{e-} P_{e+})(1 + A_{LR} P_{eff})$$

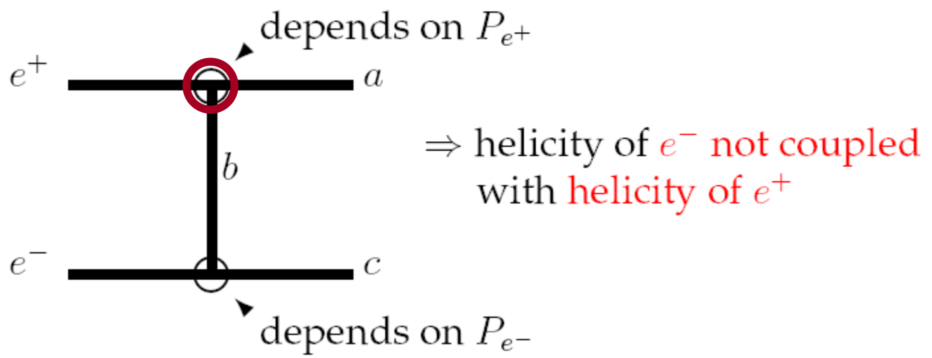
$$P_{eff} = \frac{P_{e-} - P_{e+}}{1 - P_{e-} P_{e+}}$$

σ_u = unpolarized cross section

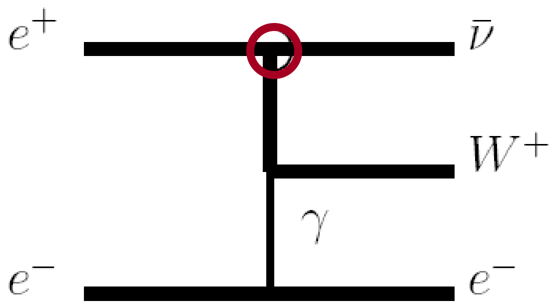
u,t – channel processes

At all ILC energies

- helicities of initial and final state are directly coupled, but independent of the helicity of the second incoming beam particle



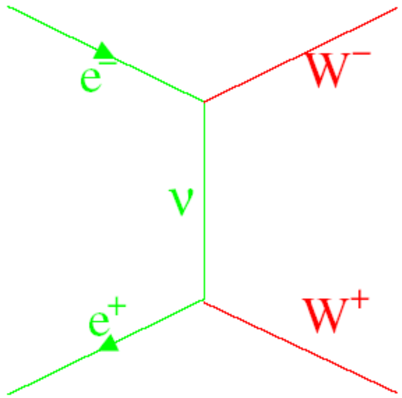
- Single W production ⇔ vertex depends only on P(e+)

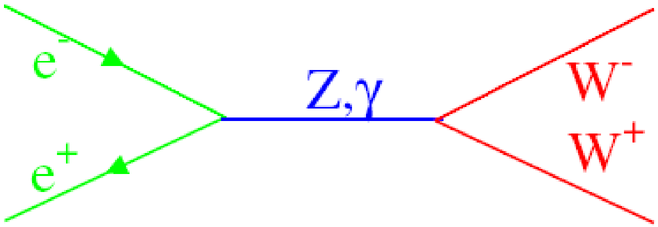


➔ enhancement / suppression of processes using P(e+)

ee→ WW (Ecm > 160 GeV)

suppression of t-channel contribution (ν exchange)





Suppression factors for t-channel contributions depending on e+ polarization

P_{e-}	P_{e+}	0	-0.6	-0.3	-0.22
0.8		0.2	0.08	0.14	0.16
0.9		0.1	0.04	0.07	0.08