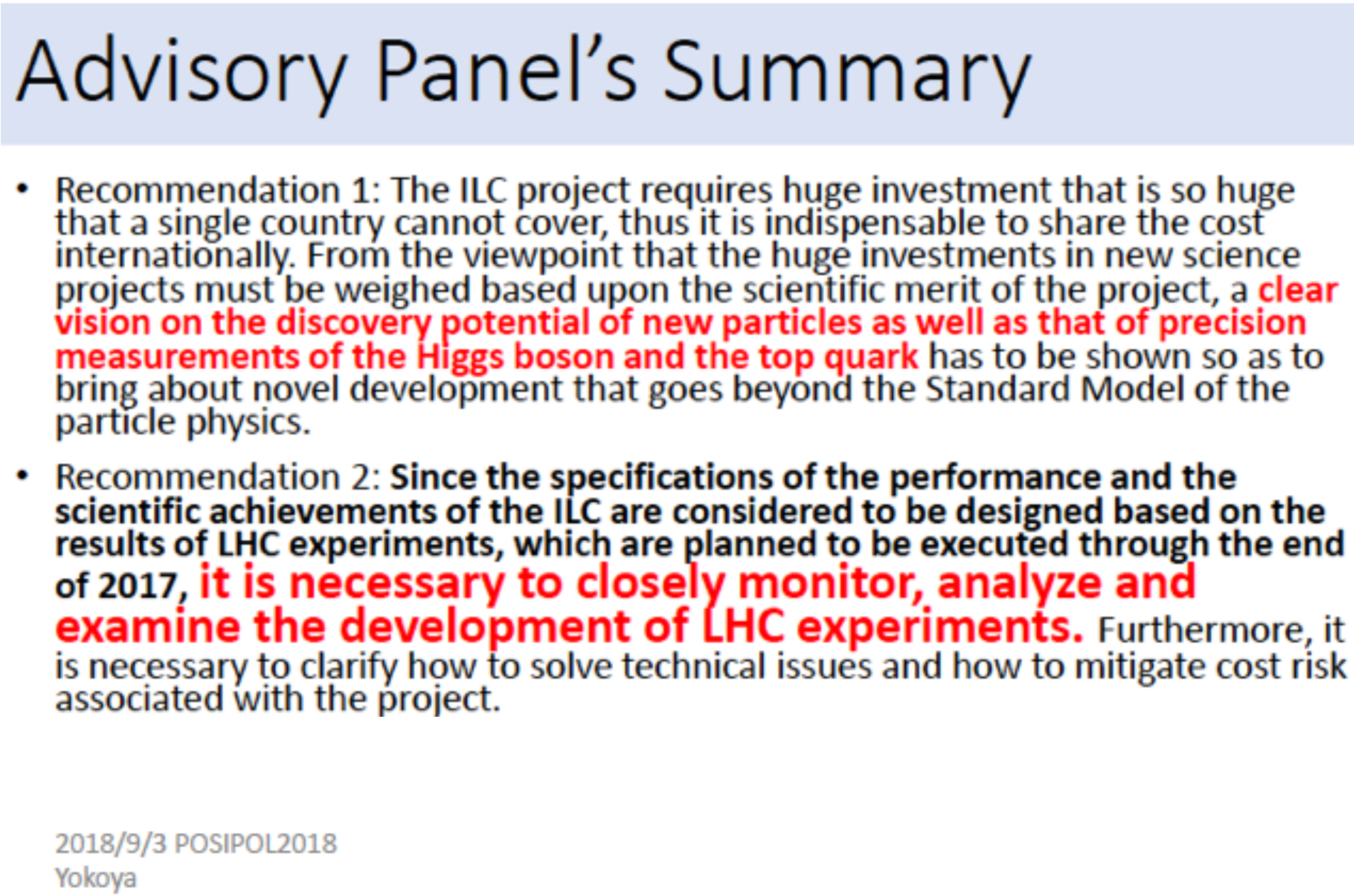
Need for simultaneous e^- and e^+ polarization

- **Recommendations**
- **Polarization basics**
- **Physics cases at $\sqrt{s}$=250 GeV**
- **Role of positron polarization**
- **Conclusions**

LINEAR COLLIDER COLLABORATION

What are the requirements?



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**
  - **key role for reduction of systematics originating from polarization measurement**

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

Gain in masurement of polarization

- Important issue: measuring amount of polarization
  - limiting systematic uncertainty for high statistics measurements
- Compton polarimeters: up- and downstream
  - envisaged uncertainties of ΔP/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

e- & e+ polarization at LC … for now

Documents

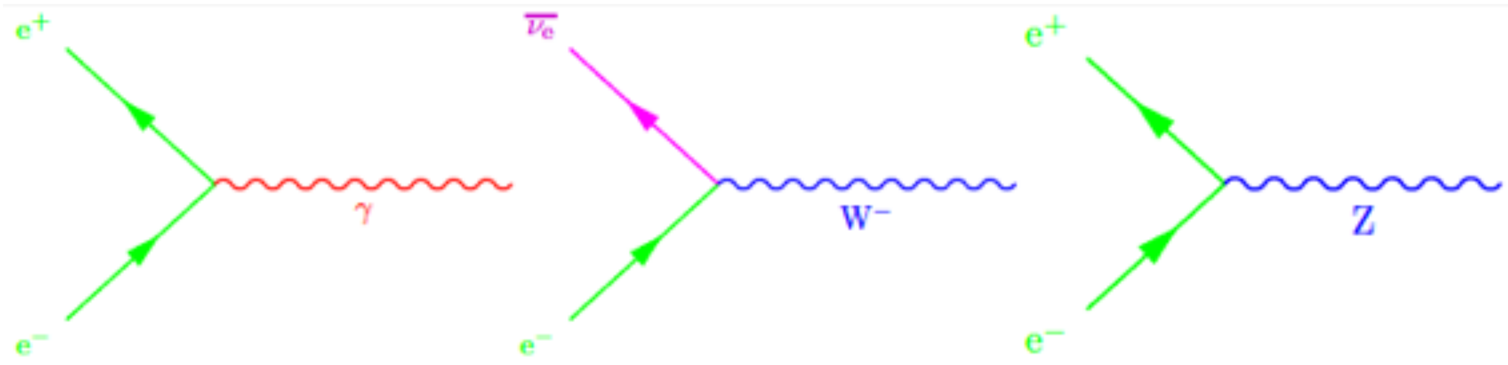
1. Comprehensive 2008 paper. Polarized positrons and electrons at the linear collider. G. Moortgat-Pick et al, Phys. Rept. 460 (2008) 131-243. 83 authors. 338 references.
2. Recent white paper commissioned by LCC. K. Fujii et al, The role of positron polarization for the initial 250 GeV stage of the ILC, arXiv: 1801.02840.

based on:

- T.Hirose, T. Omori, T.Okugi,.J. Urakawa, .Pol.e+ source for the LC, JLC Nucl.Instrum.Meth. A455 (2000) 15-24
- G. Moortgat-Pick,H. Steiner,
  `Physics opportunities with polarized e- and e+ beams at TESLA,''
  Eur.\ Phys.\ J.\ direct {\bf 3} (2001) no.1, 6

see also talk G. Wilson at LCWS17!

SM Vertices



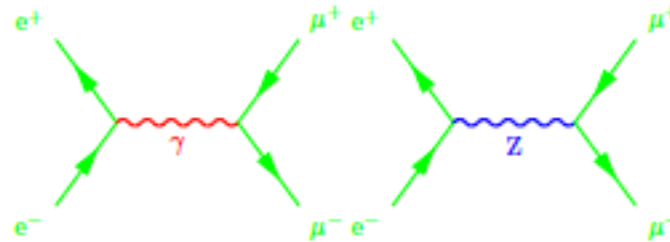
QED: parity conserved, A=0

Charged currents: A=1
Parity violating
only left-handed e^- couple

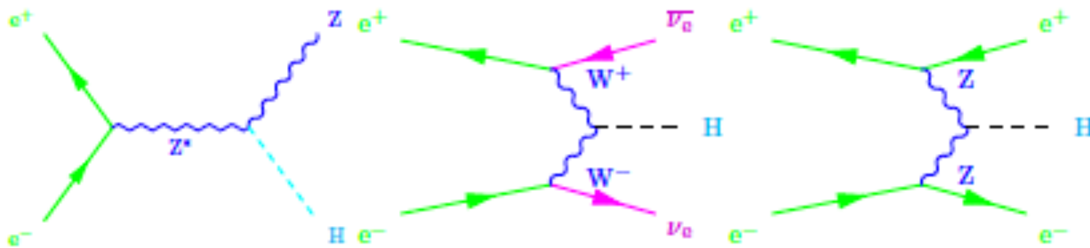
Neutral currents: A=0.15
Parity violating
left-handed e^-, right-handed e^+

SM Processes

2 Fermion: LR, RL

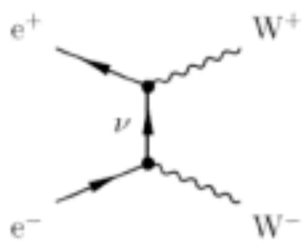


Higgs: LR, RL

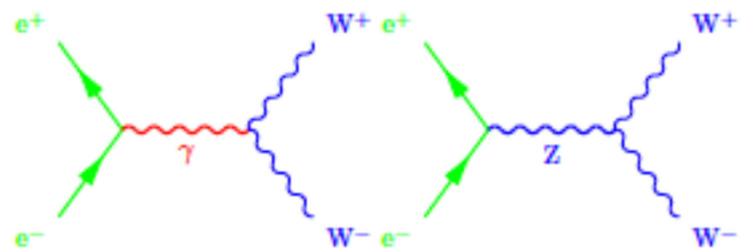


W-production:

only LR:

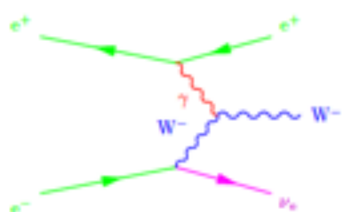


LR, RL:



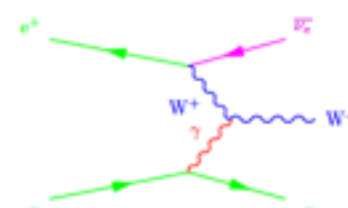
Single W$^-$:

only LR and LL!:



Single W$^+$:

only RL and RR!:



Polarization basics

- **Longitudinal polarization:** $\mathcal{P} = \frac{N_R - N_L}{N_R + N_L}$
- **Cross section:**

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

- **Unpolarized cross section:**

$$\sigma_0 = \frac{1}{4}\{\sigma_{\mathrm{RR}} + \sigma_{\mathrm{LL}} + \sigma_{\mathrm{RL}} + \sigma_{\mathrm{LR}}\}$$

- **Left-right asymmetry:** $A_{\mathrm{LR}} = \frac{(\sigma_{\mathrm{LR}} - \sigma_{\mathrm{RL}})}{(\sigma_{\mathrm{LR}} + \sigma_{\mathrm{RL}})}$
- **Effective polarization and luminosity:**

$$\mathcal{P}_{\mathrm{eff}} = \frac{\mathcal{P}_{e^-} - \mathcal{P}_{e^+}}{1 - \mathcal{P}_{e^-}\mathcal{P}_{e^+}} \qquad \mathcal{L}_{\mathrm{eff}} = \frac{1}{2}(1 - \mathcal{P}_{e^-}\mathcal{P}_{e^+})\mathcal{L}$$

Why is helicity flipping required?

- **With both beams polarized we gain in**
  - Higher effective polarization (higher effect of polarization)

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

  - Higher effective luminosity (higher fraction of collisions)

$$L_{eff}/L = 1 - P_{e-} P_{e+}$$

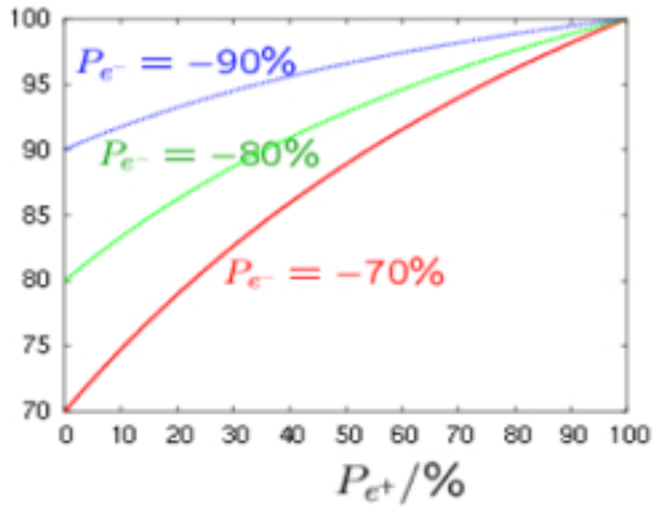
$\sqrt{s}$	$P(e^-)$	$P(e^+)$	P_{eff}	$\mathcal{L}_{eff}/L$	$\frac{1}{x}\Delta P_{eff}/P_{eff}$
total range	$\mp 80\%$	0%	$\mp 80\%$	1	1
250 GeV	$\mp 80\%$	$\pm 40\%$	$\mp 91\%$	1.3	0.43
$\geq$350 GeV	$\mp 80\%$	$\pm 55\%$	$\mp 94\%$	1.4	0.30

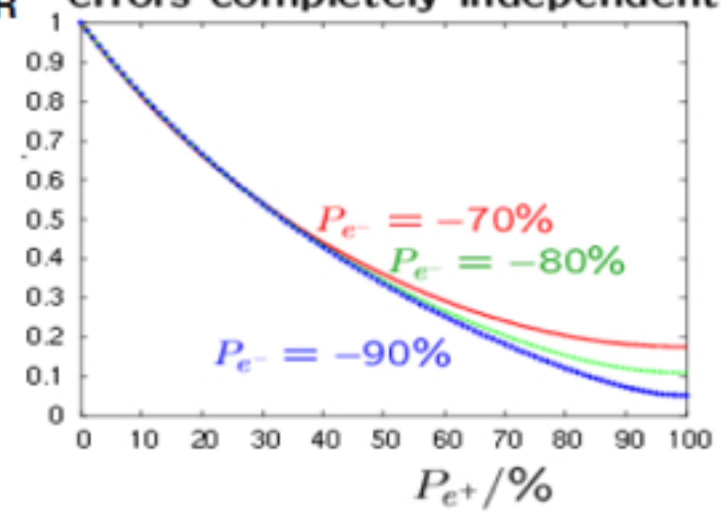
- **Applicable for V,A processes (most SM, some BSM)**

$$\sigma\,(Pe-,Pe+) = (1 - Pe-\,Pe+)\,\sigma_{unpol}\,[1 - P_{eff}\,A_{LR}]$$

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% ') !

L_{eff} and P_{eff}

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

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

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

here:

With $\mp 80\%$, $\pm 30\%$, 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):**

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

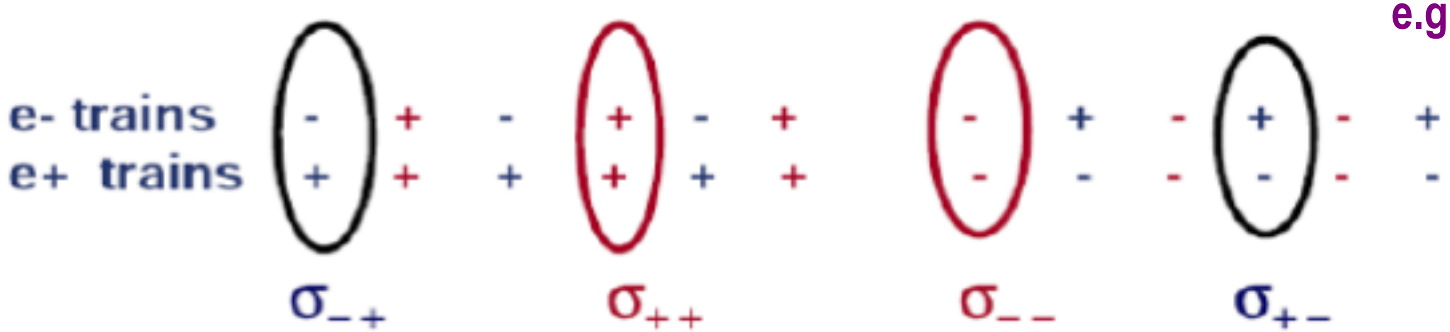
In other words: ***no P_{e+} means 30% more running time needed !***

Quite substantial in Higgs production via WW-fusion!

Why is helicity flipping 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 has been set-up!**
  - See TDR, Sect. 3.1 and CR08 (approved)

L. Malysheva '13

Lumi scenarios

- **Running time based on 20 years physics data, lumi upgrade included after 8 (10) years……..but**

T. Barklow ea,:1506.07830

	$\int \mathscr{L} dt$ [fb^{-1}]		
$\sqrt{s}$	G-20	H-20	I-20
250 GeV	500	2000	500
350 GeV	200	200	1700
500 GeV	5000	4000	4000

- **Most popular 'H-20': but stick to √s=250 GeV….**
- **Prospects LHC: 300 fb-1 in 2023**

  HL-LHC: 3000 fb-1 in 2037 (start HL-LHC: 2027)
- **Request: 'Physics results improve/complement LHC, HL-LHC results'**

	fraction with sgn$(P(e^-), P(e^+))$ =			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[%]	[%]	[%]	[%]
250 GeV	67.5	22.5	5	5

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

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

Karl, List,1703.00214

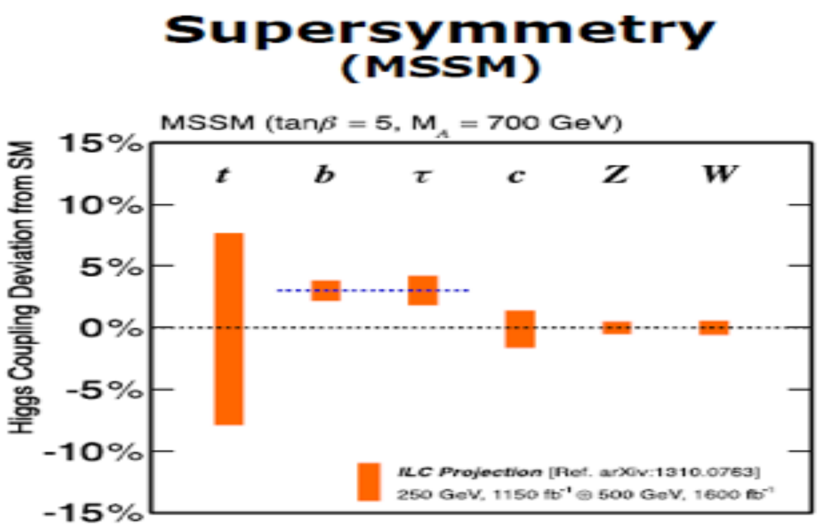
  - assume H-20 set-up concerning lumi
  - helicity reversal is important
  - non-perfect helicity-reversal can be compensated
  - 0.1% accuracy in ΔP/P is achievable at IP!
  - *NOT achievable without Pe+!*

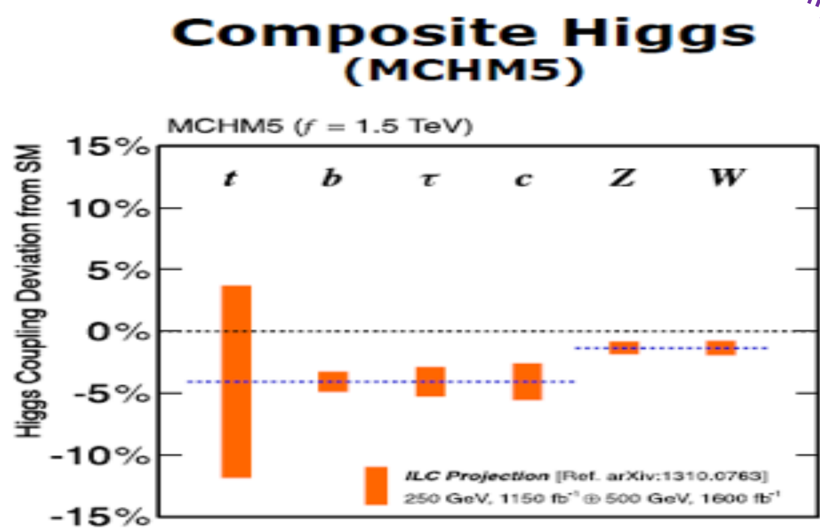
Remember: even if no Pe+ (SLC! dedicated experiment at SLACs Endstation A), the P_{e+}~0.0007 had to be derived a posteriori for physics reason!

Status Higgs

- **Higgs within achievable accuracy at LHC: SM-like**
  - 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, LP15





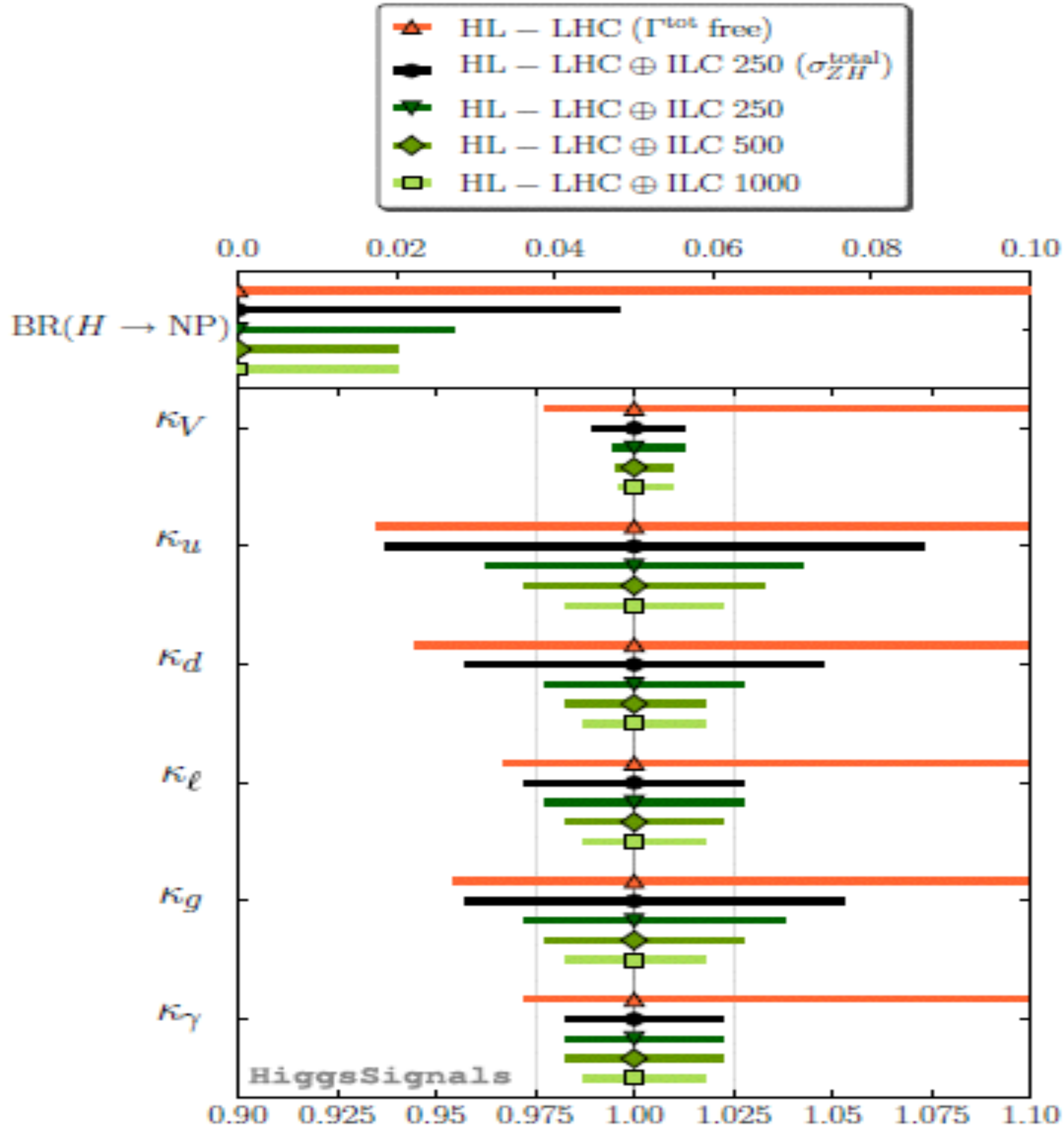
ILC 250+500 LumiUp

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

What did we promise?

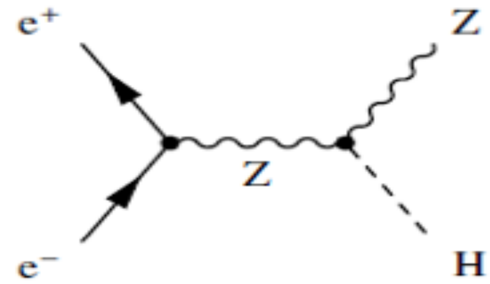
Bechtle ea, '14

- **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 σ(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!*

Conclusions

- Beam polarization e^- and e^+ gives 'added-value' to ILC
  - Crucial 'new' analysis tools compared to LHC numbers
- Strong precision promises……
  - Require both beams polarized from the beginning
  - Well thought scenarios for different configurations/flipping
- 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!

LCC physics group,1801.02840

- 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!