Physics update for polarized beams

- Running scenarios for the ILC
- Physics examples
- Conclusions

LINEAR COLLIDER COLLABORATION

Impact of positron polarization

- **Current physics case for e+e-:**
  - Higgs precision physics
  - Top precision physics
  - Light SUSY/DM searches
  - BSM detection in general, complementary to LHC

  save physics! (Higgs precision physics, Top precision physics)

  well motivated (Light SUSY/DM searches, BSM detection)

- **Four categories for 'gain in polarization':**

  Today only top and Higgs:
  - Enhancement of signal, changing background ``higher lumi"
  - Reducing polarization uncertainty … ``higher acc"
  - Provides more observables …..``unique"
  - Since polarization=chirality: extracts new characteristics of interactions ….. ``unique"

- **In the following:**
  - Only very few physics examples

    (*more in Eur.Phys.J. C75 (2015) 'LCReview', Phys. Rept. 460 (2008) 'Power'*)

Concentrate on top and Higgs physics

- Higgs couplings in general (Yukawa, trilinear etc.)
  - ➢ Deviations from SM expected to be small
- Top couplings (form factors, etc.)
  - ➢ Top and Higgs intimately coupled!
- What has been promised by the (I)LC community ?
  - ➢ Luminosity running scenarios, *Barklow ea. 1506.07830 'Parameter Group'*
  - ➢ Precision promises, *Fujii ea. 1506.05992 'Physics Panel'*
- Status top and Higgs physics at LHC
  - ➢ HL-LHC expectations relevant
- What do we lose if no polarisation, or if only P_{e-} available?
  - ➢ How much longer runs needed to compensate lumi if no P_{e+}?
  - ➢ How much loss in precision if no P_{e+} ?

Polarization basics for category 1+2

- **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)

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

$\sqrt{s}$	$P(e^-)$	$P(e^+)$	$P_{\rm eff}$	$\mathcal{L}_{\rm eff}/L$	$\frac{1}{x}\Delta P_{\rm eff}/P_{\rm eff}$
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

higher accuracy!

higher rates!

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

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

Running scenarios

- Running time based on 20 years physics data, lumi upgrade included after 8 (10) years
- Dedicated lumi fraction on √s=250, 350 and 500 GeV 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': in total 6200 fb^{-1} (2032, >2040 HL-ILC, until 2052)
    - Physics results improve/complement LHC, HL-LHC results!
- Prospects LHC: 300 fb-1 in 2023

  HL-LHC: 3000 fb-1 in 2037 (start HL-LHC: 2027)

Assumed helicity configurations

- **Different scenarios for polarization configurations**

T. Barklow ea, 1506.07830

	fraction with $\mathrm{sgn}(P(e^-), P(e^+)) =$			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[%]	[%]	[%]	[%]
250 GeV	67.5	22.5	5	5
350 GeV	67.5	22.5	5	5
500 GeV	40	40	10	10

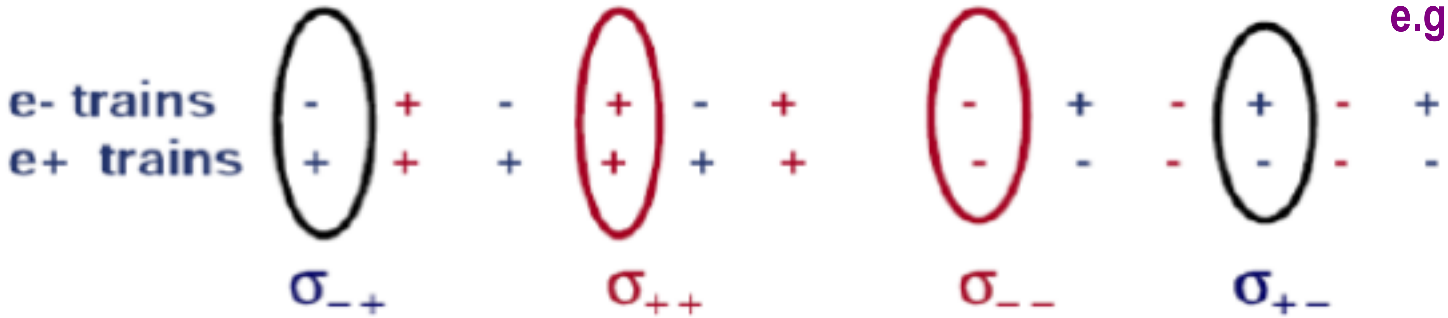
- **At √s= 250 and 350 GeV: mainly SM expected**
  - **Only 10% running time in (-,-) and (+,+) to control systematics**
- **At √s=500 GeV: more like-sign data taking motivated**
- **sensitivity to new physics and interactions**
- **Assumptions: P(e-)=80%, P(e+)=30%**
- **-> P_{eff}=89%, L_{eff}/L=1.2, $\Delta P_{eff}/P_{eff}$=0.5**

- **Flipping frequency: randomized on bunch train time-scales, average flipping frequency adjusted to w.r.t. the desired fraction**

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!

L. Malysheva '13

  - See TDR, Sect. 3.1 and CR08 (approved)

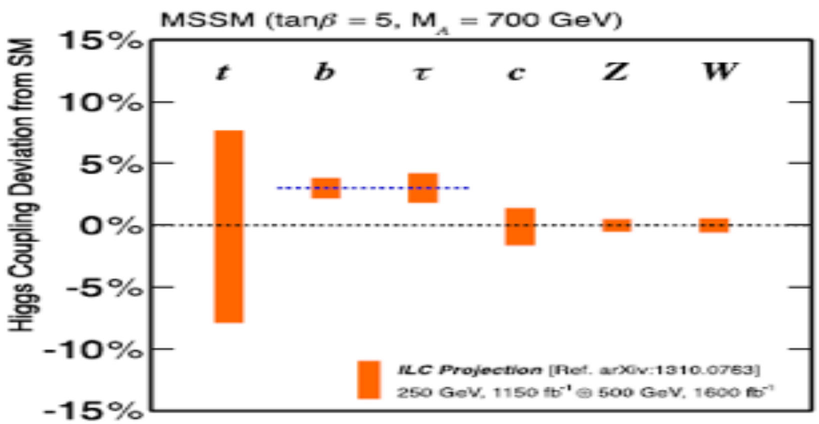
Contact also B. List for details

Status Higgs

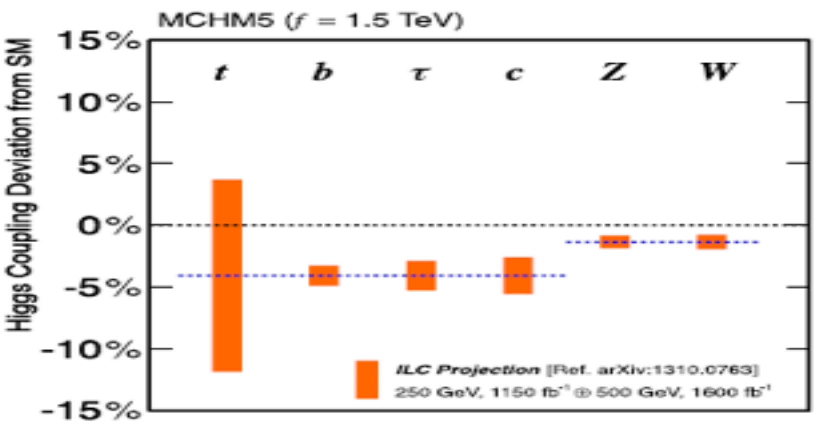
- **Higgs within achievable accuracy at LHC: SM-like**
  - Could be the only SM Higgs (what's about DM? gauge unification?)
  - Could be a SUSY Higgs (one has to be close to a SM-like one)
  - Could be a composite state

S. Komamiya, LP15

Supersymmetry (MSSM)



Composite Higgs (MCHM5)

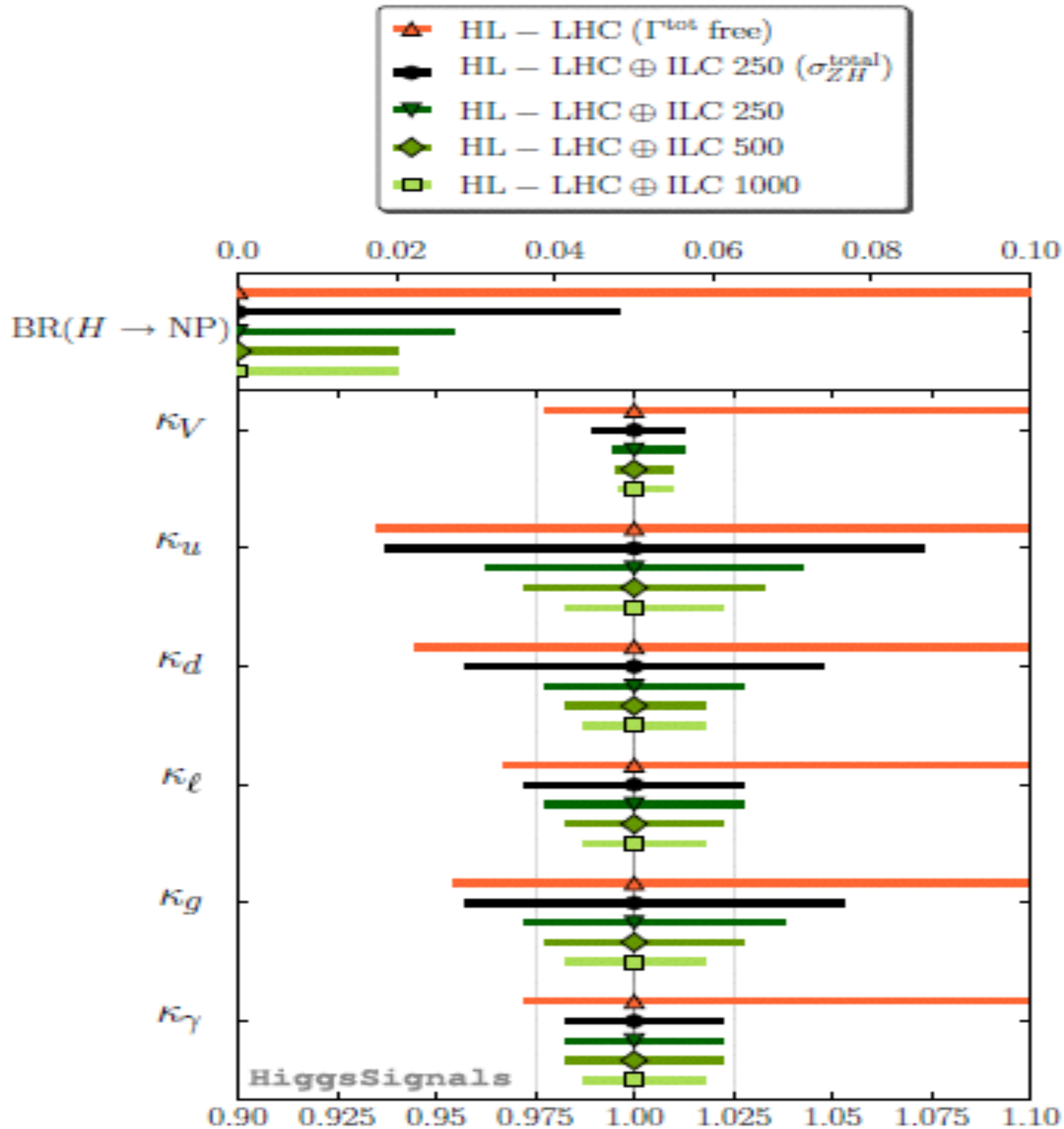


ILC 250+500 LumiUp

What did we promise?

Bechtle ea, '14

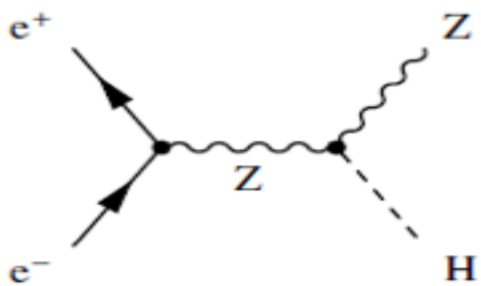
- **Precision of 1-2% achievable in Higgs couplings !!!**
- **Crucial input from ILC**
  - **total cross section σ(HZ)**
  - **Has to be measured at √s=250GeV**
  - **Input parameter for all further Higgs studies (Higgs width etrc.) !**
- **Lots of improvement if only σ(HZ) from ILC is added**



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!



	ILC500	ILC500 LumiUP
Δm_H	25 MeV	15 MeV
$\Delta g_{HZZ}/g_{HZZ}$	0.58 %	0.31 %

  - Allows access to H-> invisible/exotic
  - Allows with measurement of Γ^h_{tot} absolute measurement of BRs!

Higgs sector@250 GeV

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

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

    With P_{e+}=40%: $\sigma_{pol}/\sigma_{unpol}$~1.55 (about 37% 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/√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 ...**

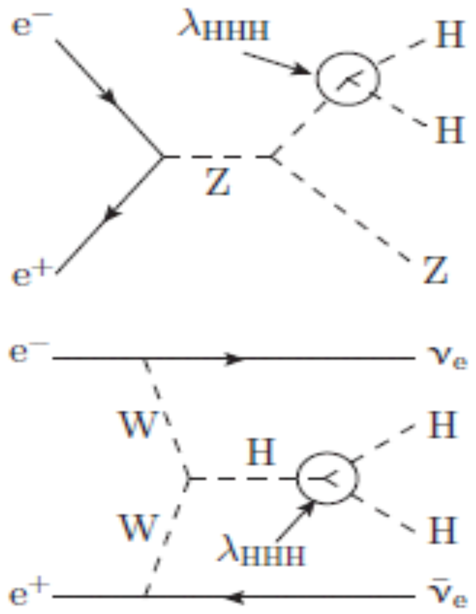
Trilinear Higgs couplings

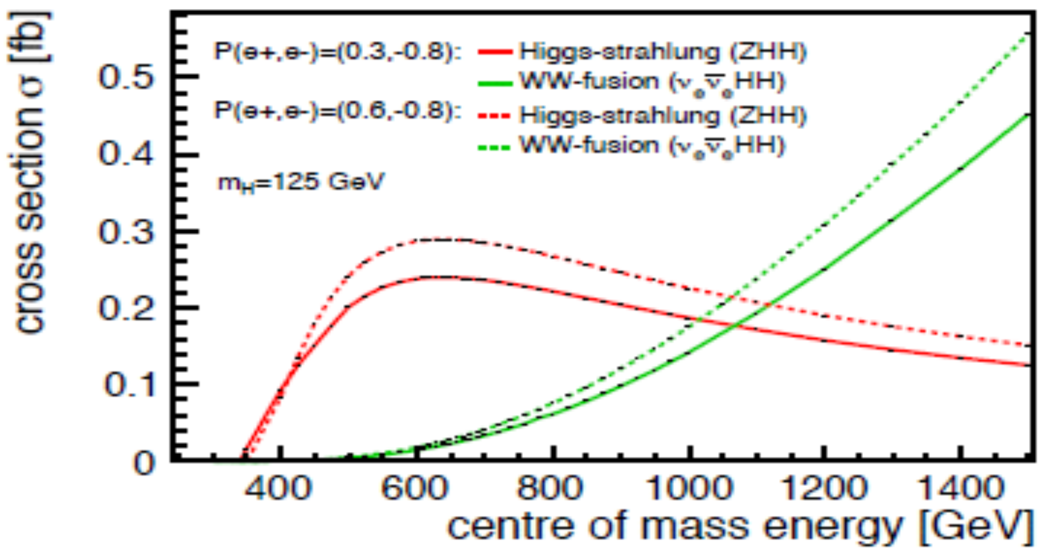
- **Very important for establishing Higgs mechanism!**
  - **LHC estimates:**
    - **about $\Delta\lambda_{HHH}$~32% at HL-LHC (14 TeV, 3000fb^{-1})**

no official LHC number provided!

  - **At LC: Very challenging (small rates ~0.1-0.2fb, lots of dilution+backg.)**

C. Duerig, EPS'15



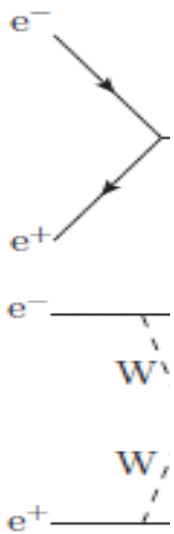


- ***In total: about 50% enhancement comp. to P_{e+}=0% !***

Trilinear Higgs couplings

- **Very important for establishing Higgs mechanism!**
  - LHC estimates:
    - al
  - **At LC**

C. Duerig, EPS'15



before luminosity upgrade precision of 77 % on Higgs self-coupling

after full ILC program precision of 27% can be achieved

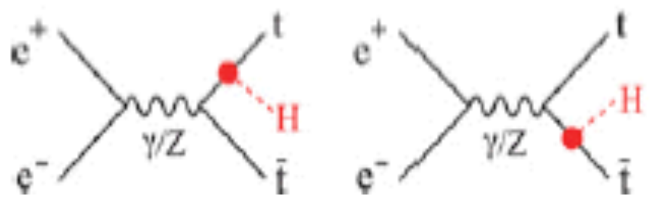
possible energy upgrade to 1 TeV could improve precision to 10% or better

- *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

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

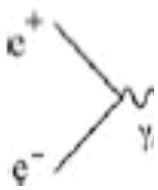
- Numbers very ambitious
- Used so far: (±80,-+30)
- Further improvement with (+-80,-+60):
  - S increases by 24% if from (80,30) to (80,60)
  - S/√B increases by 50%
- *If no P_{e+}: S decreases by about 20%*

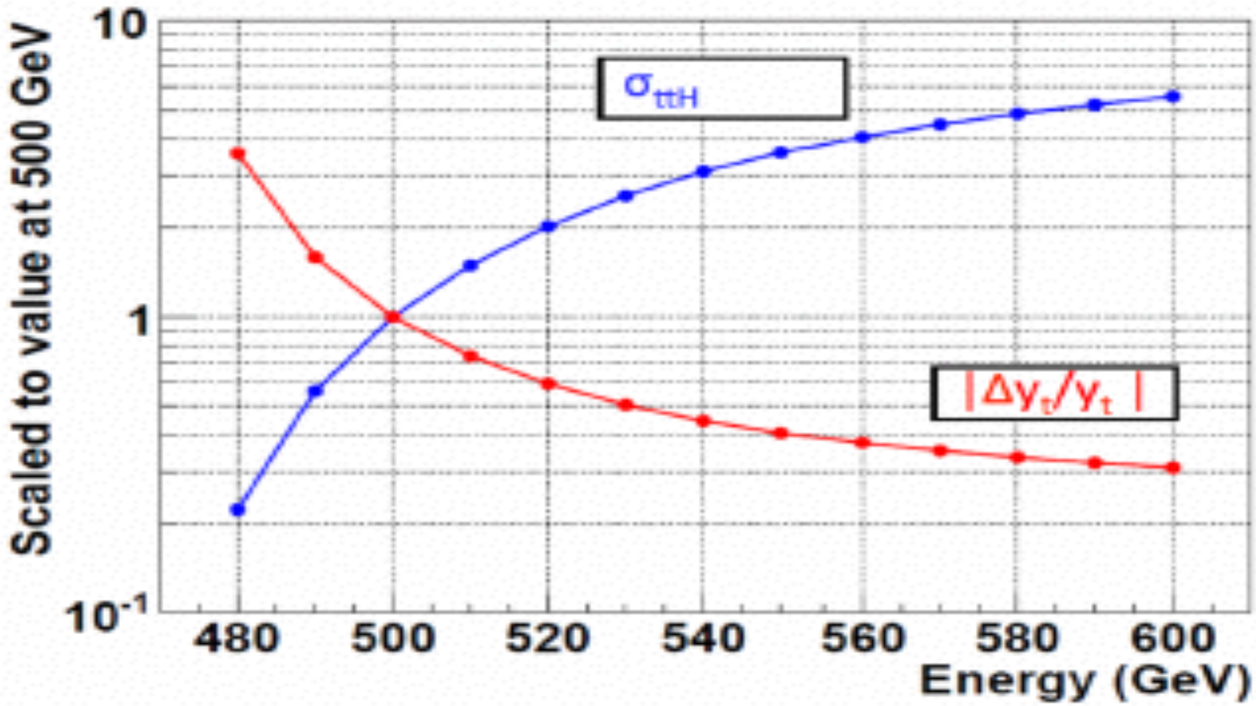
Top Yukawa coupling

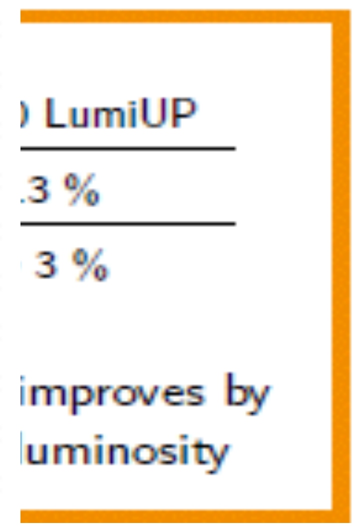
- **top-Yukawa coupling crucial:**
  - since strongest coupling to Higgs sector

Fujii ea, arXiv: 1506.05992

  - g_{ttH} … surement







  - Nu…
  - Us…
  - Fur…

    S increases by 2

    S/√B increas…

  - If no P_{e+}: S de…

$\sqrt{s} = 550$ GeV better precision on g_{Htt}

- by factor 4 enhanced cross section
- main backgrounds decrease

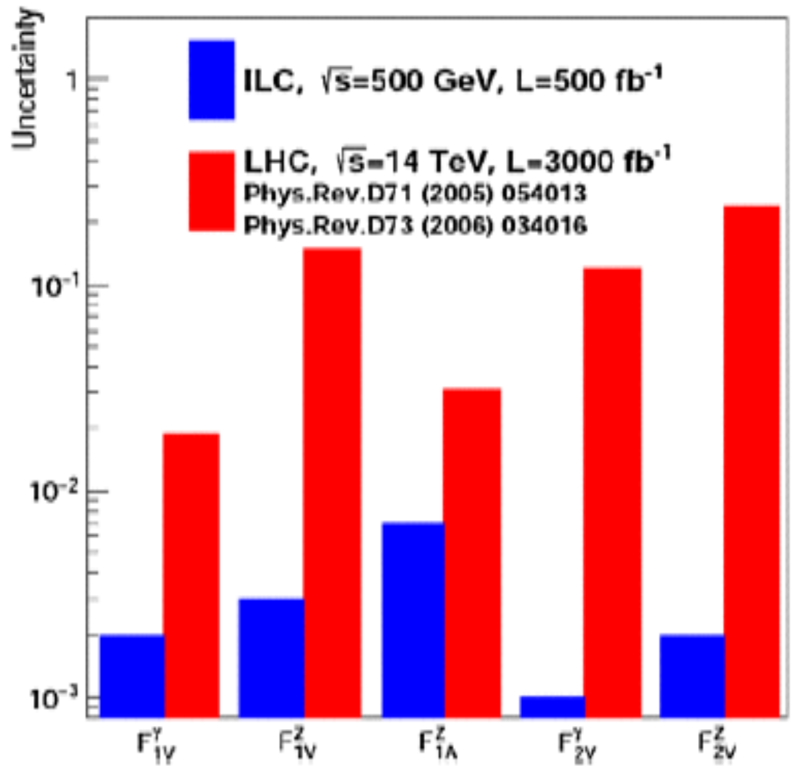
Top electroweak coupling

- Test of the chiral structure of top couplings
  - Cross section ~maximal at this energy

R. Poeschl, EPS15,
see also EPJC 75 (2015)

- Use different observables
  - Cross section, A_{FB}, helicity angle

- Couplings
  - measurable at %-level thanks to:
  - the different observables
  - runs with different (+-),(-+)
  - P_{e+} important to fit independently!



➢ Result substantially improves best LHC result!

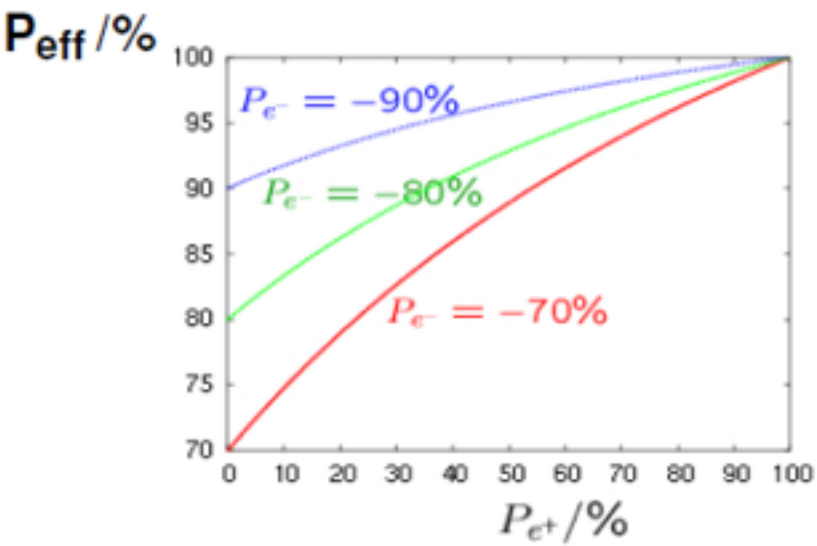
Conclusions

- **Beam polarization gives 'added-value' to ILC**
  - **Crucial 'new' analysis tools compared to LHC numbers**
- **Strong precision promises have been made……**
  - **Require both beams polarized from the beginning**
  - **Well thought scenarios for different configurations/flipping**
- **P_{e-} and P_{e+} important at $\sqrt{s}$=250 GeV (Higgs!) and beyond**
  - **Essential to match precision promises/expectations!**
- **At higher energies required as well for precision, chirality etc**
  - ➢ **Precision allows sensitivity to beyond SM!**

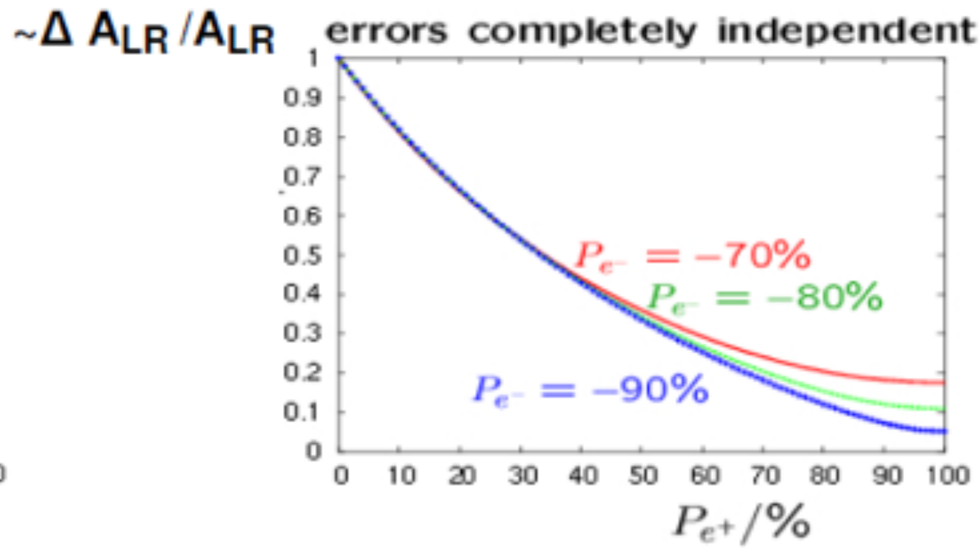
- ***Not covered today: polarization to determine properties of new particles directly, as chiral quantum numbers, CP quantities, large extra dimensions etc. as well as GigaZ, ….***
  - ***please see LCReview and POWER report for more example!s***

Impact of P(e+)

- **Statistics**



- **And gain in precision**



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

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

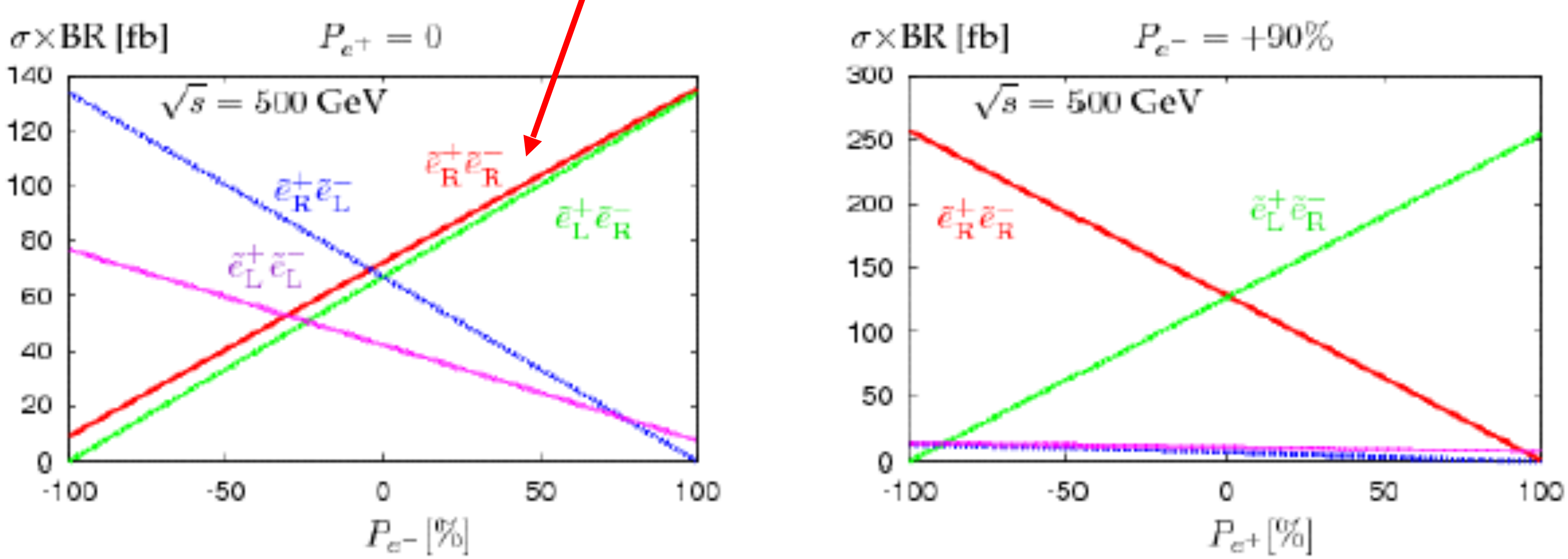
  gain: factor~3 | factor>3 | factor~2

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

Chirality proof of sleptons

- **Test of chirality of new particles via beam polarization**
  - **Selectrons = SUSY partner of electrons sel_L,sel_R**

Even with $P_{e^-} \geq +90\%$, one can't disentangle the pairs $\tilde{e}^+_L \tilde{e}^-_R$ and $\tilde{e}^+_R \tilde{e}^-_R$': Ratio of the cross sections $\approx$ constant.



P_{e+} required!