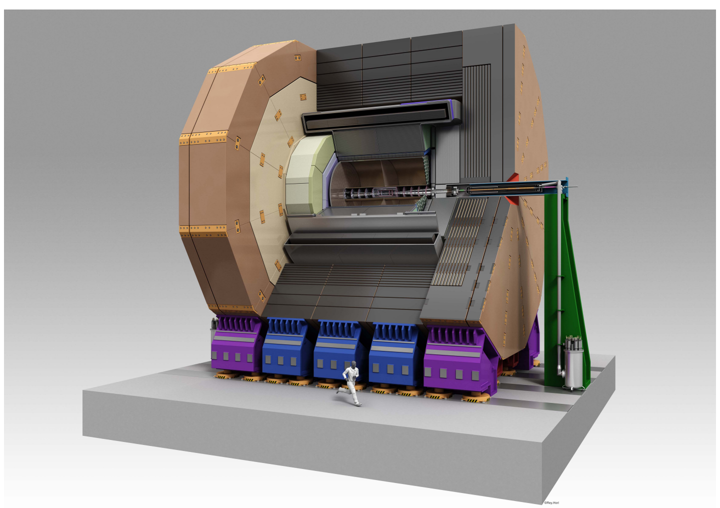
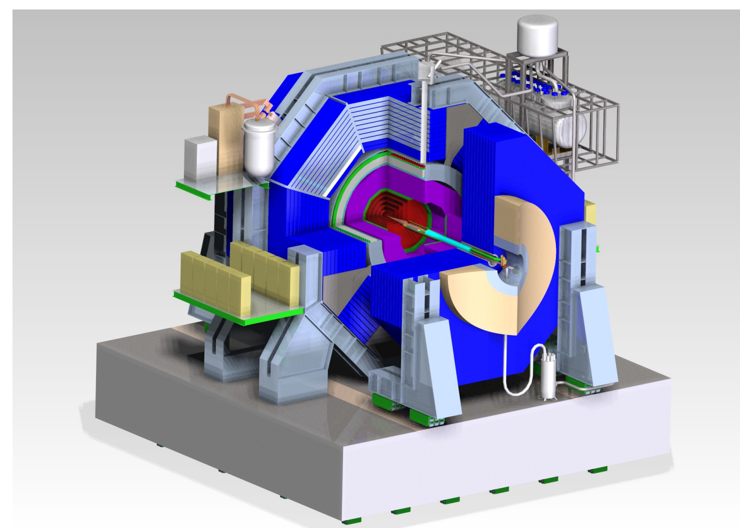
The Higgs Physics Programme at the International Linear Collider

Felix Sefkow

LINEAR COLLIDER COLLABORATION

on behalf of the ILD and SiD detector concept groups



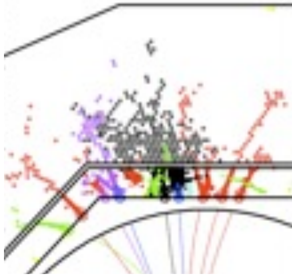


PANIC 2014, Hamburg, 28.8.2014

Menu

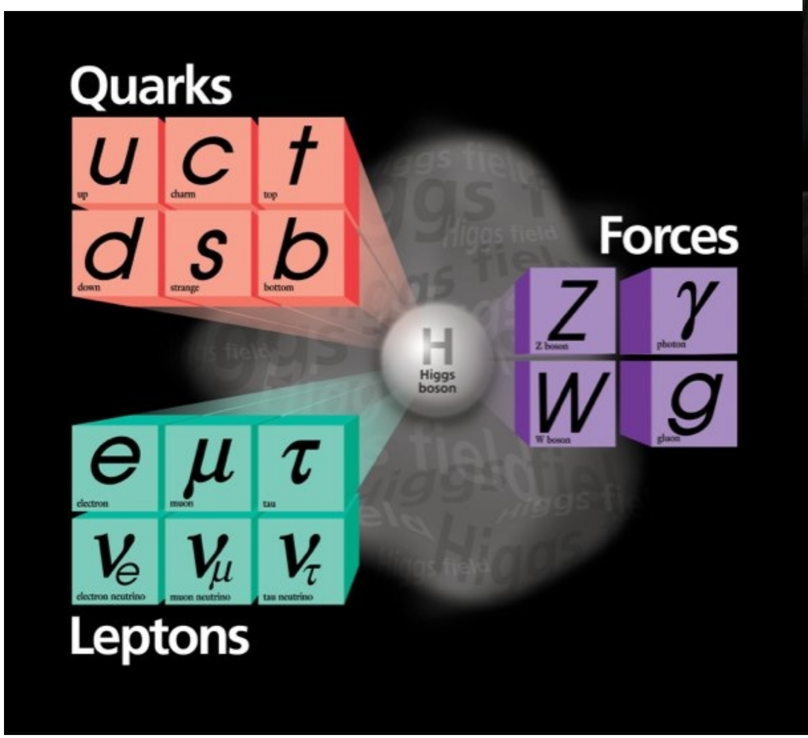
- The case for Higgs physics in e+e- collisions
- Measurements of Higgs parameters at the ILC
- Projected precision

Most results from:
ILC TDR, Vol. 4, arXiv:1306.6329
ILC Higgs White Paper, arXiv: 1310.0763

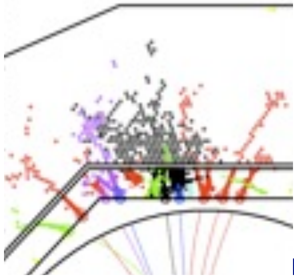


Higgs discovery

2013 Nobel prize in physics

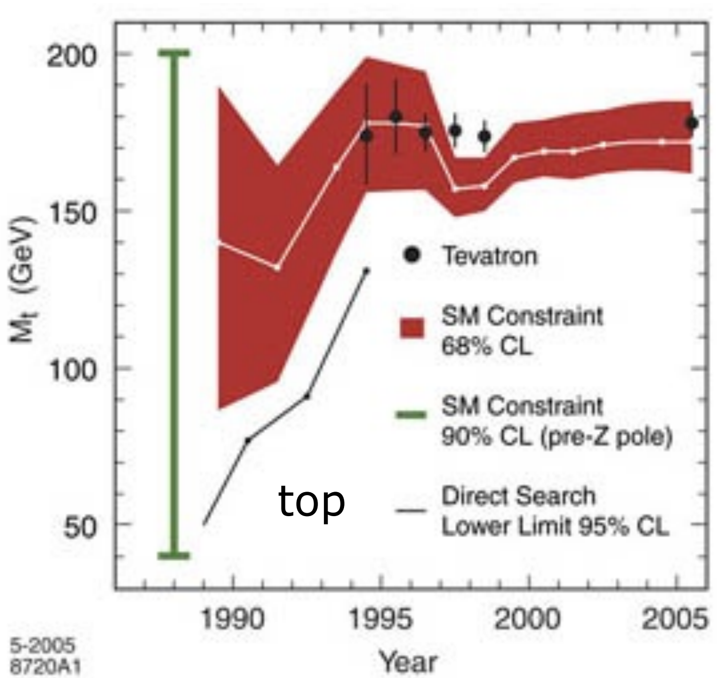


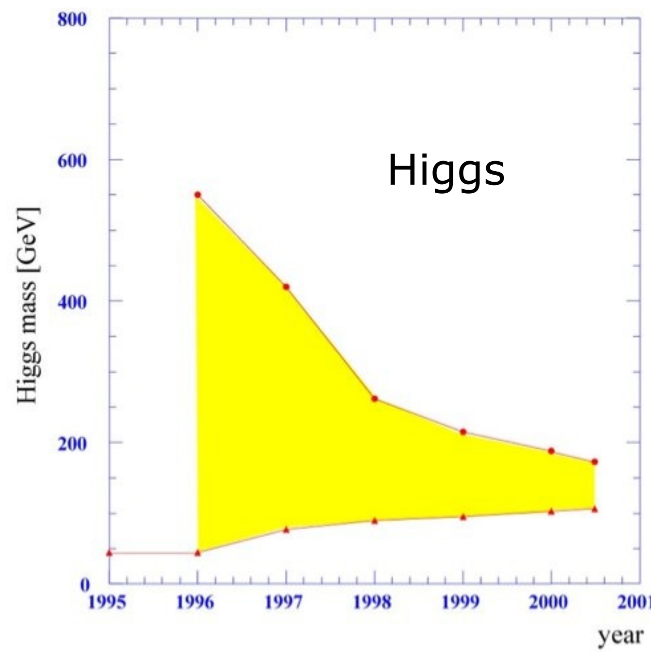
- A turning point:
- after 50 years the last building block falls into place
- and opens the door to something completely new



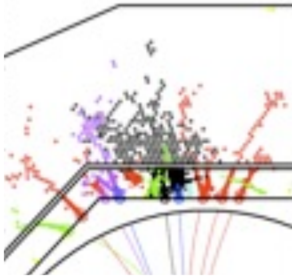
Anticipated discoveries

- The history of particle physics is full of predicted discoveries:
  - Positron, neutrino, pion, quarks, gluons, W, Z bosons, charm, bottom, top - and now Higgs
- Precision directs the way forward





From precision tests of electroweak quantum corrections



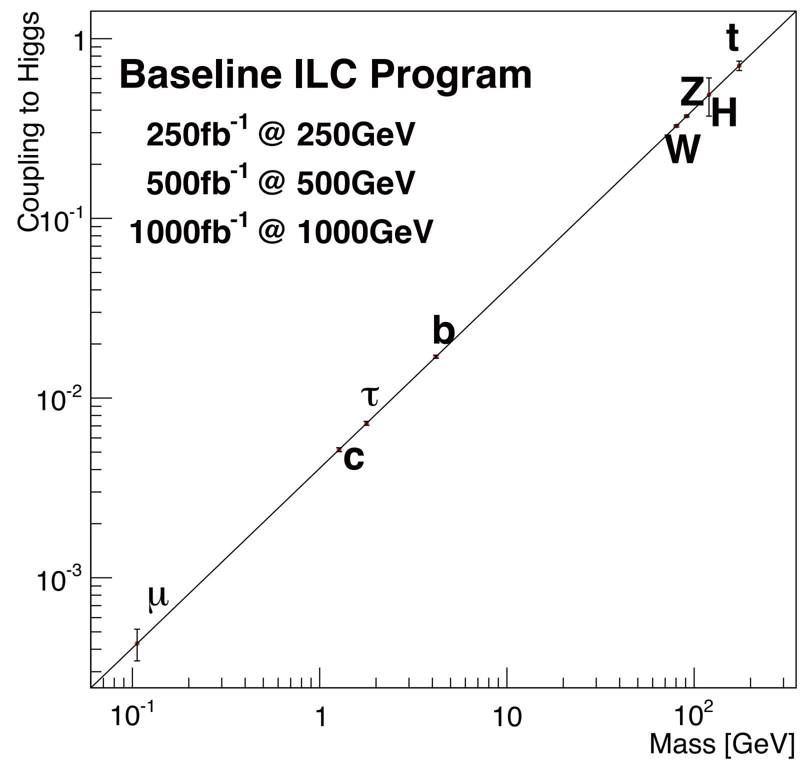
Higgs physics drives the field

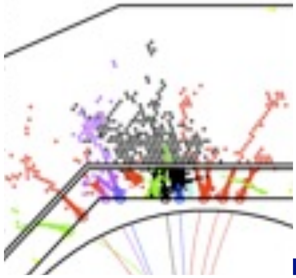
"Driver" = a compelling line of inquiry that shows great promise for major progress over the next 10-20 years. Each has the potential to be transformative. Expect surprises.

- Use the Higgs as a new tool for discovery.

S.Ritz, Report on P5

- The main question today:
- establish the Higgs profile
  - mass, spin, parity
  - above all: couplings
- Is the Higgs(125) *the* Higgs and does it fulfil its role in the Standard Model?
- Or does it hold the key to New Physics?



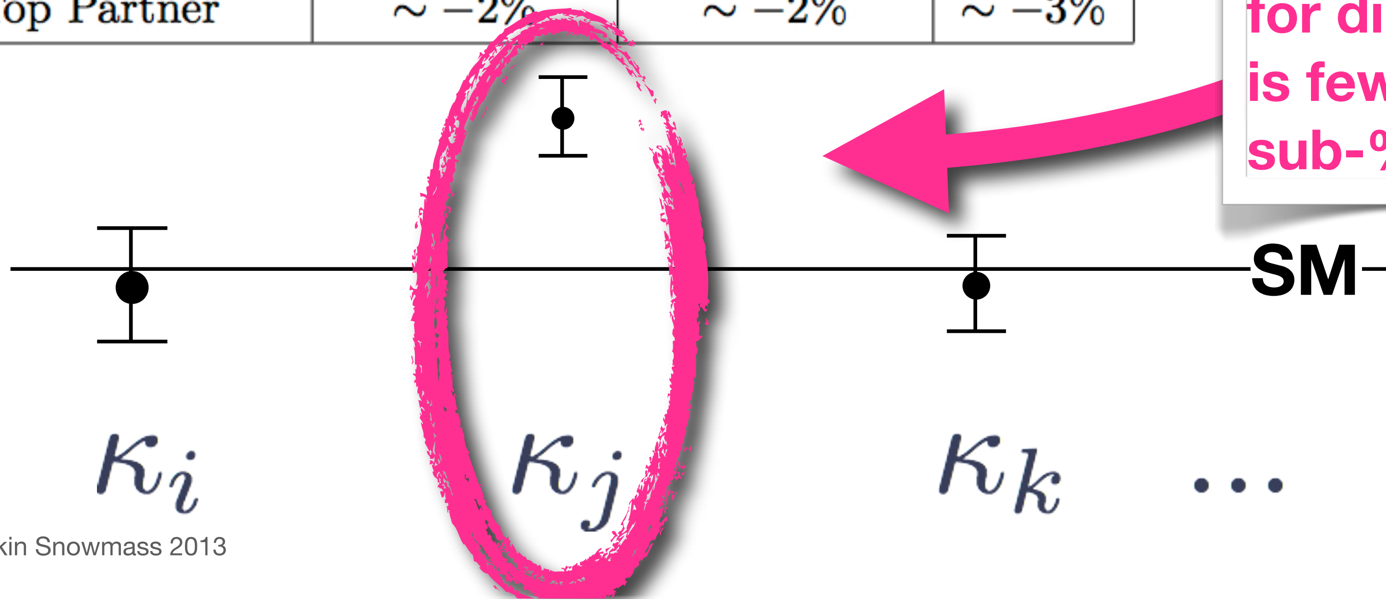


Precision for discovery

	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim -3\%$

Physics behind EW symmetry breaking: Models with new particles at the TeV scale, consistent w/ exp. constraints, lead to deviations in Higgs copings

Benchmark for discovery is few % to sub-%



Brock/Peskin Snowmass 2013

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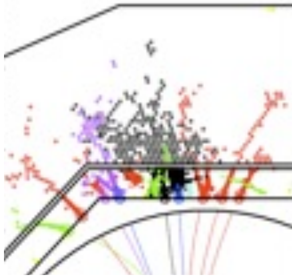
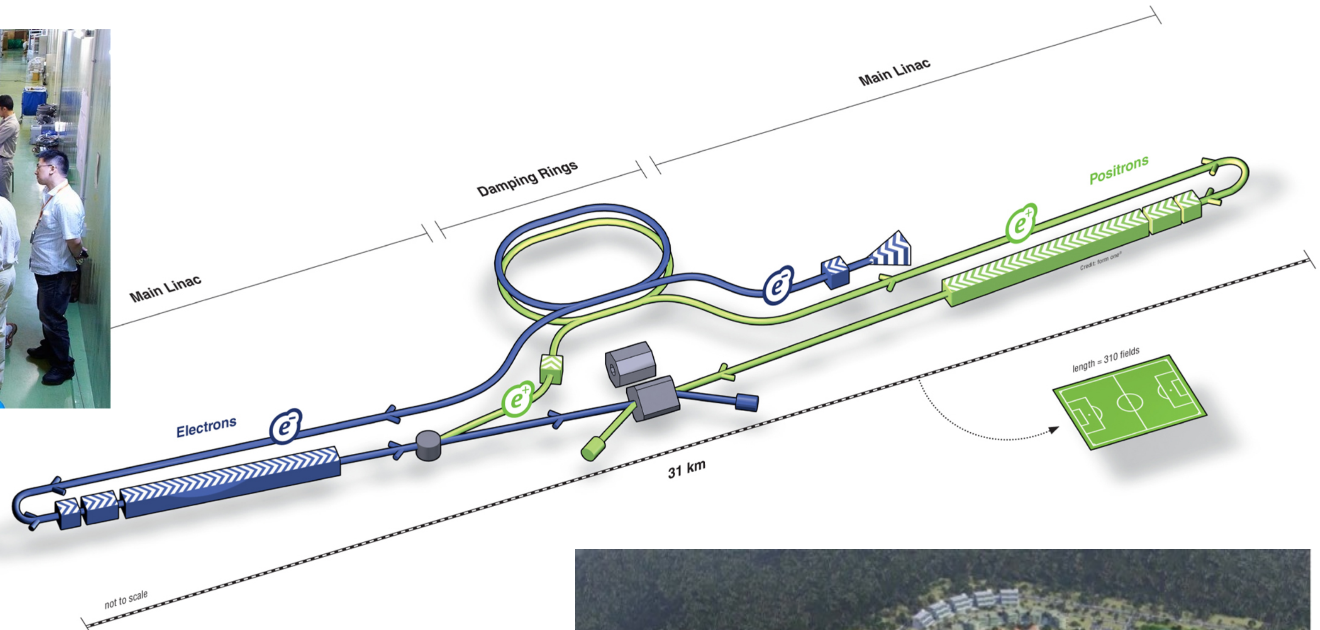
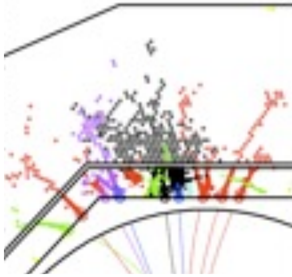


International Linear Collider

See the prototype
on Friday afternoon



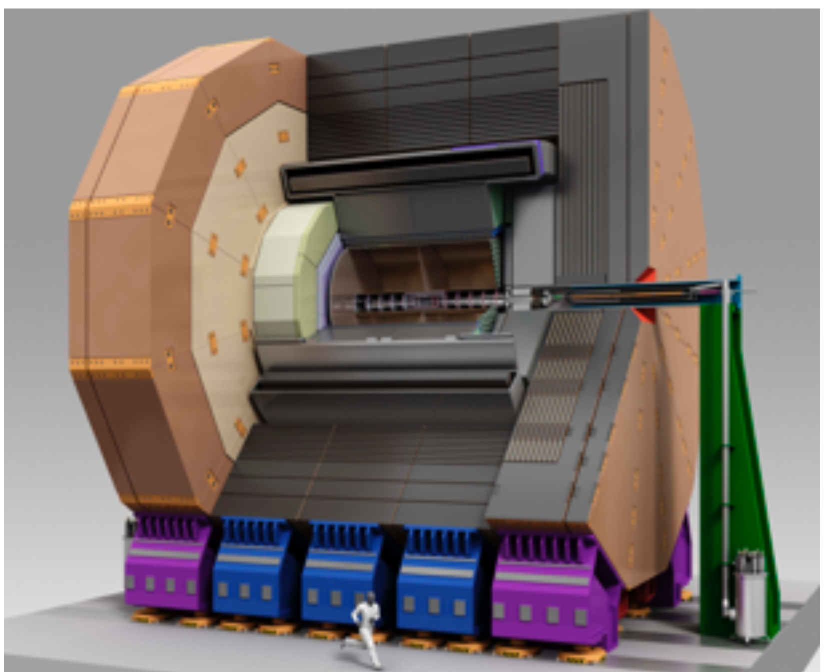
- E_{CM} = 250 - 500 GeV
  - upgradable to 1 TeV
- Luminosity ~ 250 fb^{-1}/y
- Beam polarisation -0.8, +0.3
- TDR 2012
- Proposed site: Kitakami, Japan

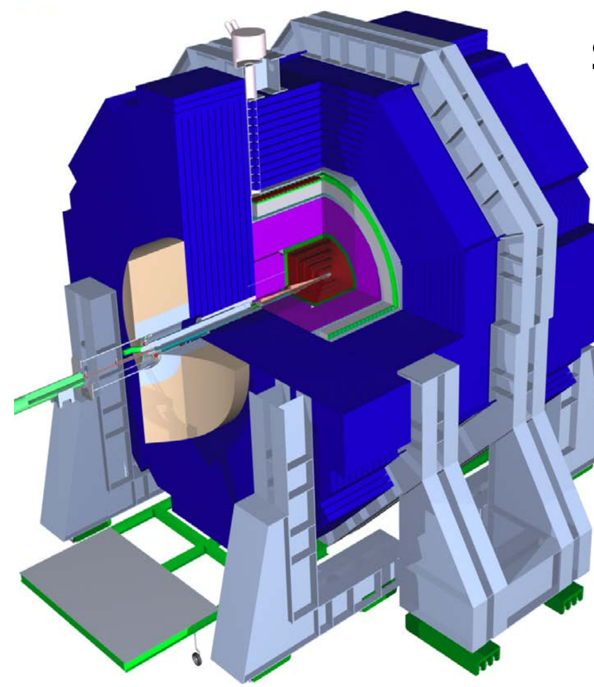


ILC detector concepts

- Optimised for precision
- Highly granular calorimeters for particle flow
- Ultra-thin and precise trackers
- Beauty and charm (!) vertex tagging
- Detailed simulation including beam background

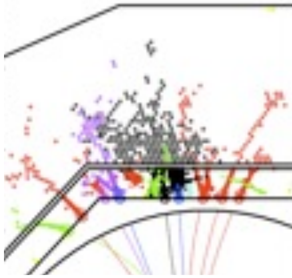
ILD





SiD

Measurements of Higgs couplings



How to measure a coupling

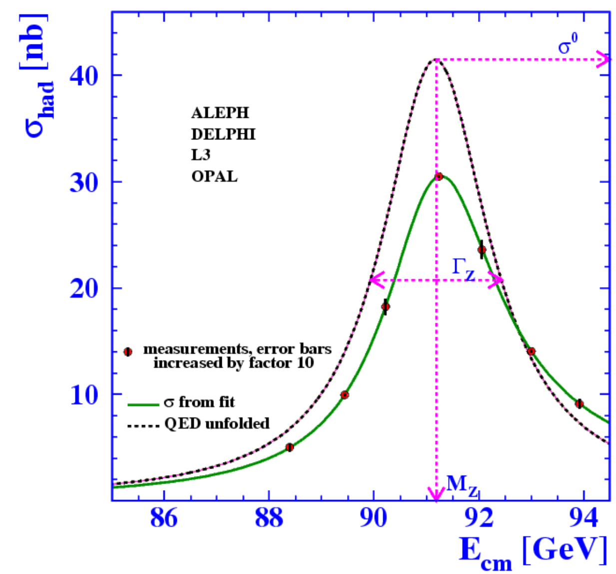
- We perform counting experiments:
- N events / integr. luminosity = cross section x branching ratio
- Branching ratio := partial width / total width

- **$\sigma \cdot BR = \sigma_i \cdot \Gamma_f \,/\, \Gamma_T \sim g_i^2\, g_f^2 \,/\, \Gamma_T$**

- Need σ and total width to convert branching ratios into couplings
  - e.g. Z line shape at LEP
- $\Gamma_T\,(\mathrm{Higgs})_{SM}$ = 4 MeV - unobservable

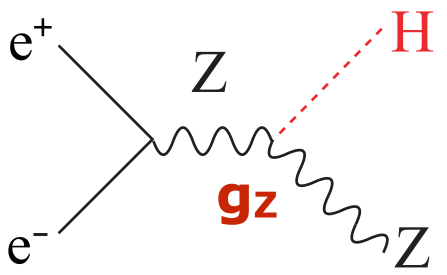
- At LHC, only poorly constraint
  - or SM value assumed

- At ILC, play the cards of e+e-…

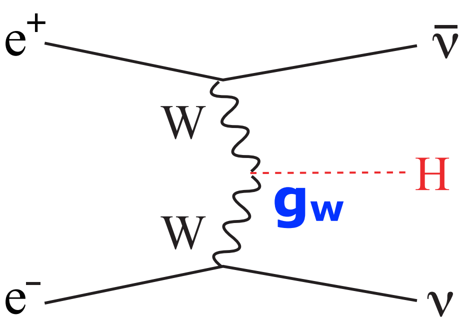


Higgs production

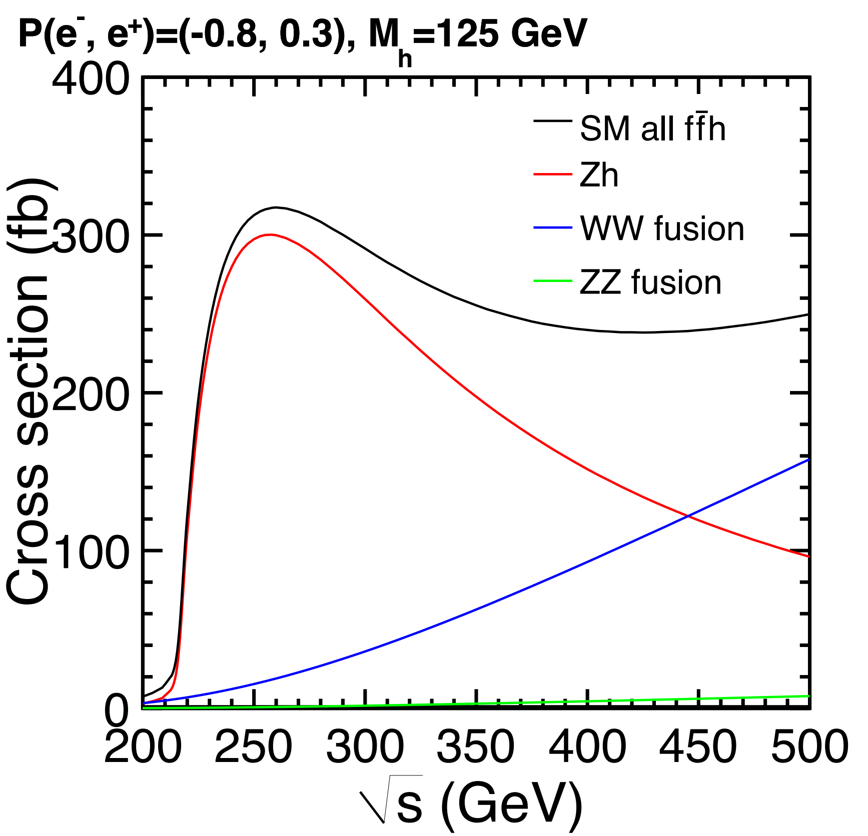
- Higgs strahlung



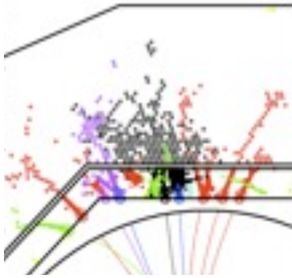
- W fusion



- Z fusion

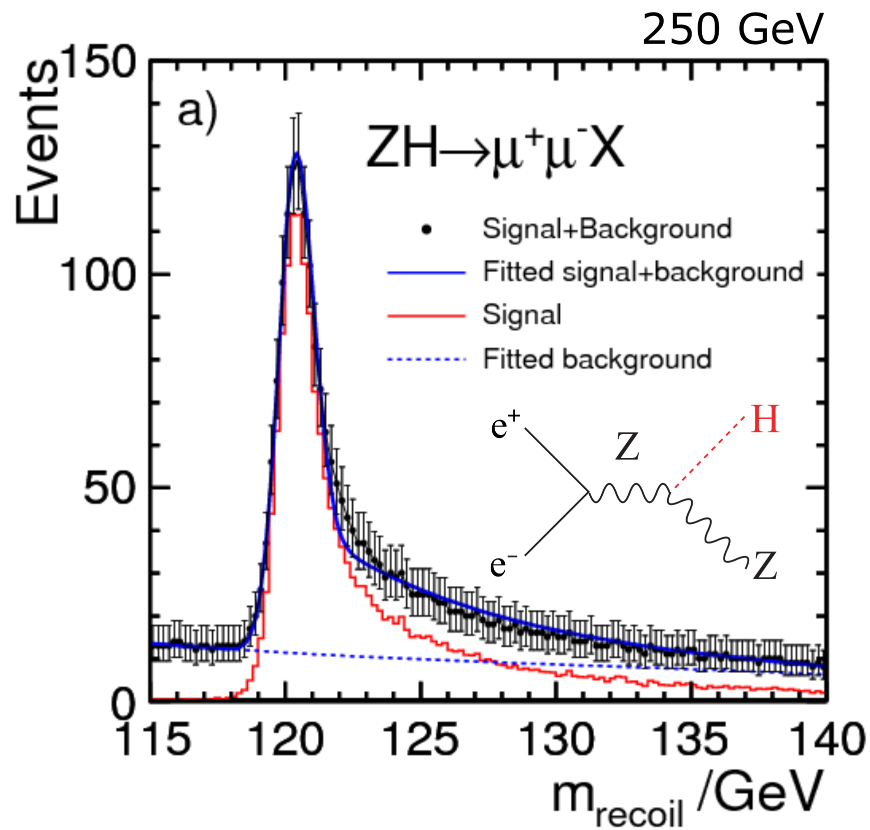


- Use polarisation to enhance cross section
- Vary beam energy to select W or Z coupling



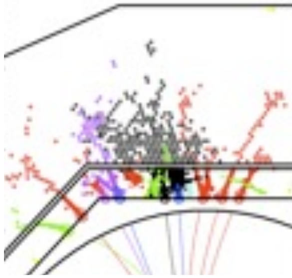
Higgs signal in Z recoil

- In e+e-, use kinematic constraints
- recoil mass against Z
  - $M^2 = E^2 - p^2$
  - beam energy: $E = \sqrt{s} - E_Z$, $p = p_Z$
  - Z mass: $E_Z^2 = M_Z^2 + p_Z^2$

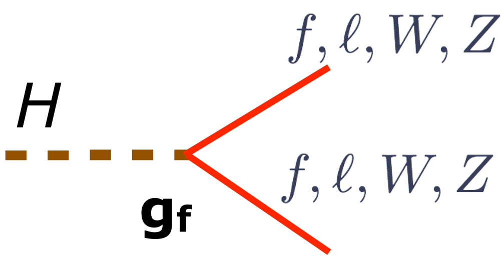


works best with muons,
also well with electrons
jets: not so easy

- No use of Higgs final state, can even be invisible
- **Model-independent** ZH cross section
- Absolute normalisation for BRs
  - sensitive to invisible decays
- **Direct extraction of g_Z**
  - *the* central measurement



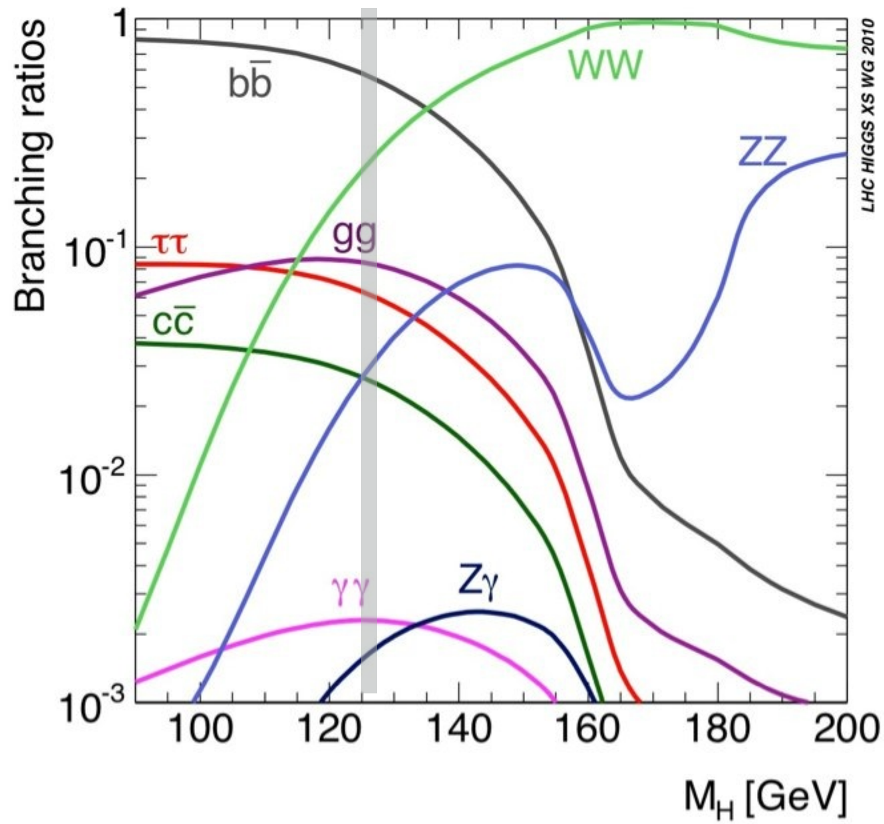
Higgs decays

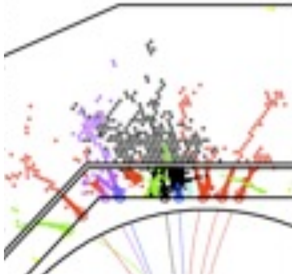


- M_H = 125 GeV
- ideal for ILC
  - but not for $H \rightarrow ZZ^*$

- BR ($H \rightarrow ZZ^*$) = $\Gamma_Z / \Gamma_T \sim g_Z^2 / \Gamma_T$
- $\Rightarrow \Gamma_T \sim g_Z^2 /$ BR ($H \rightarrow ZZ^*$)

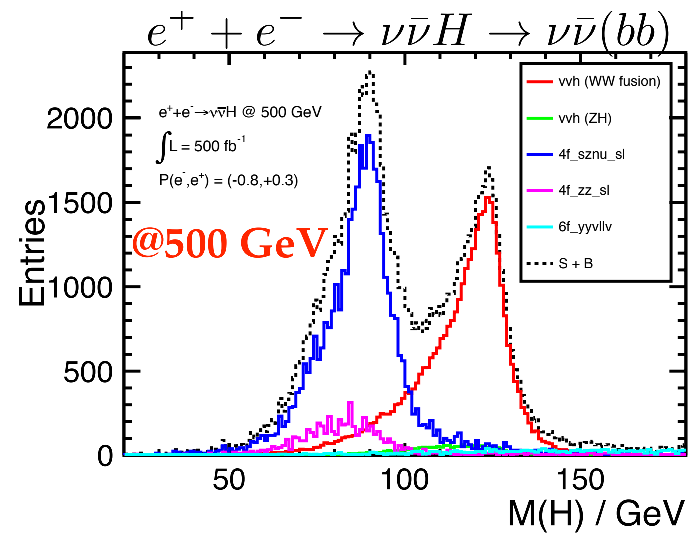
- in principle possible - but large error (20%)

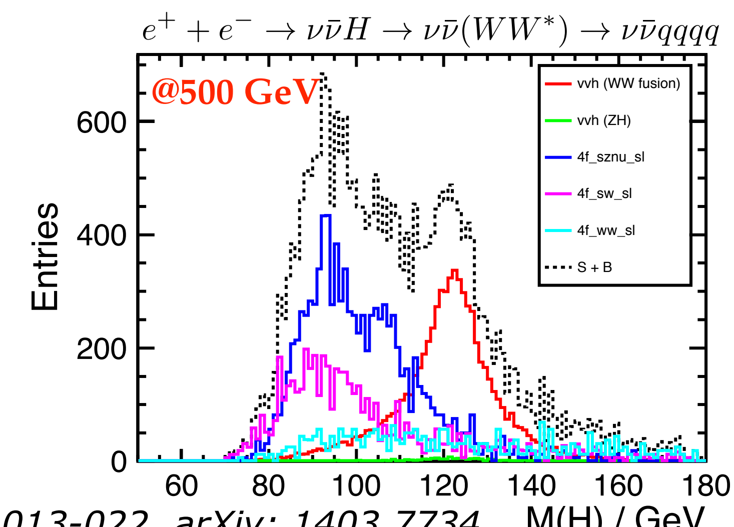




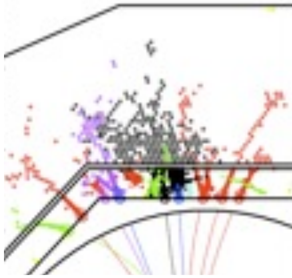
Higgs total width

- Use **W fusion cross section** and H→WW* branching ratio
- $\Gamma_T \sim g_W^2 \,/\, BR\,(H\to WW^*)$
- W fusion σ is not model independent
  - ff = bb or WW* final state
  - measure same f.s. in ZH and scale
- $g_W^2/g_Z^2 \sim \sigma_{\nu\nu H}\, B(H\to ff) \,/\, \sigma_{ZH}\ \ B(H\to ff)$
- g_Z^2 from Z recoil
- BR (H→WW*) in vvH or ZH prod
- Done! 👍
  - self-contained set for absolute couplings



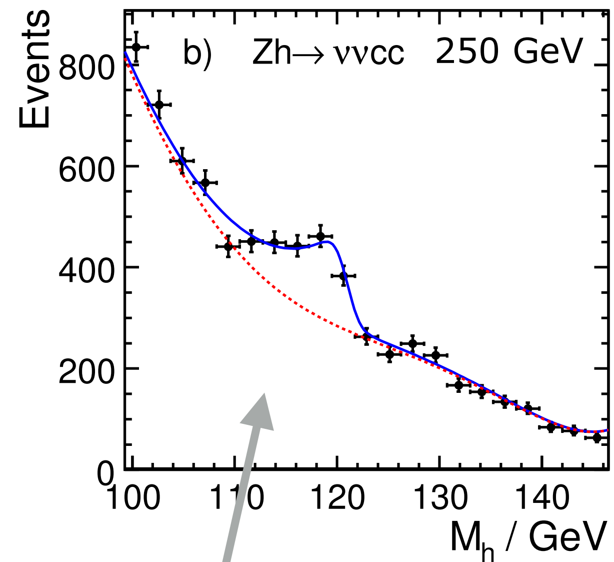


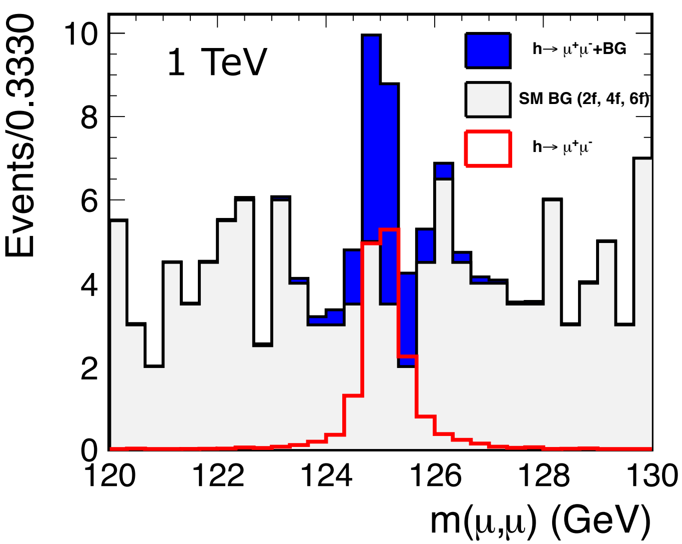
C. Duerig, J. Tian, et al. LC-REP-2013-022, arXiv: 1403.7734

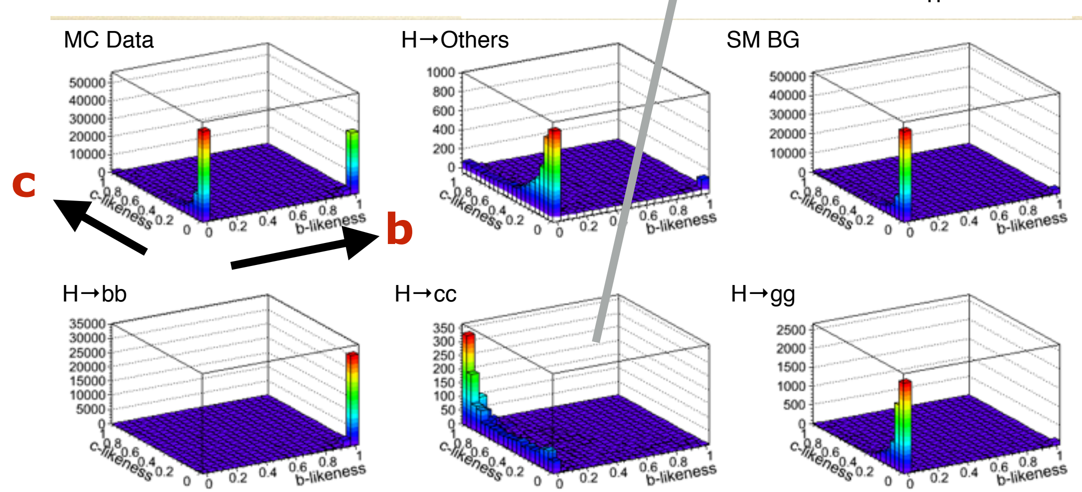


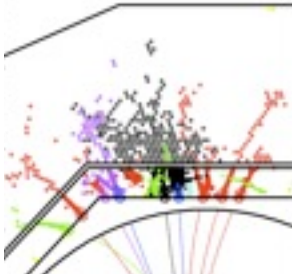
2nd generation fermion couplings

- Charm tagging at LHC: hopeless
  - constrain g_c by m_c / m_t
- At ILC: unique access to 2nd family
  - obtain bb and gg, too
- H→μμ: also possible, but few events

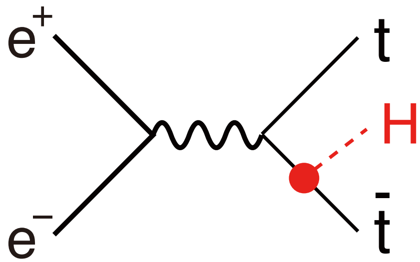


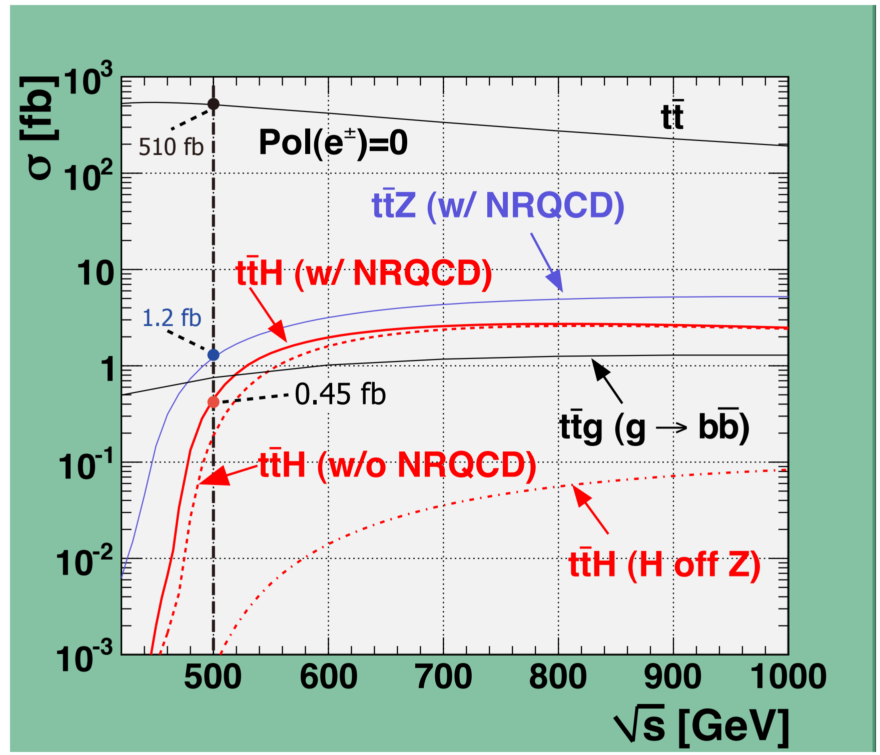


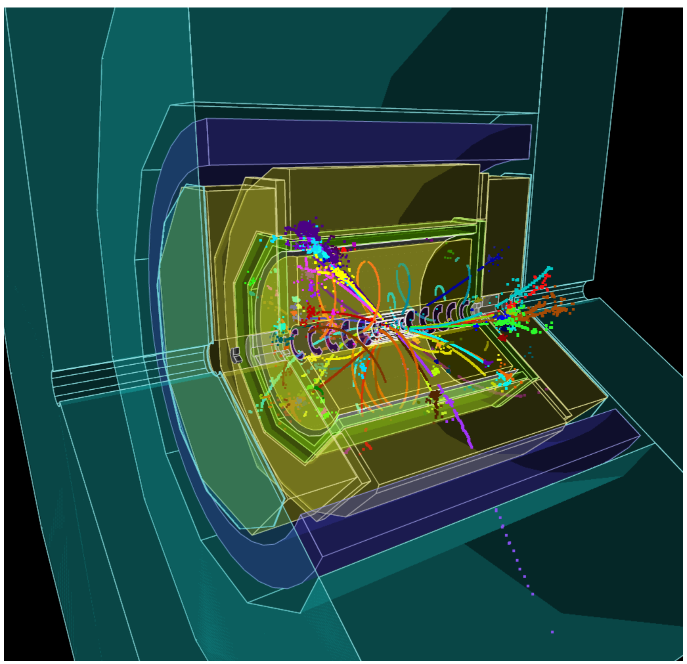




Top Yukawa coupling

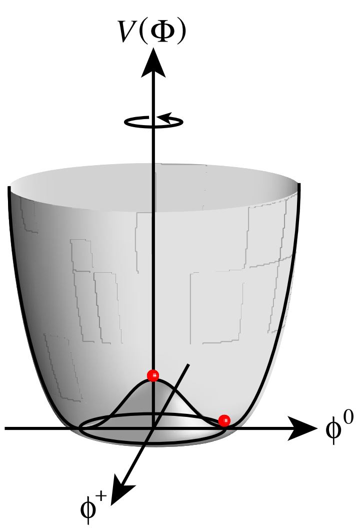


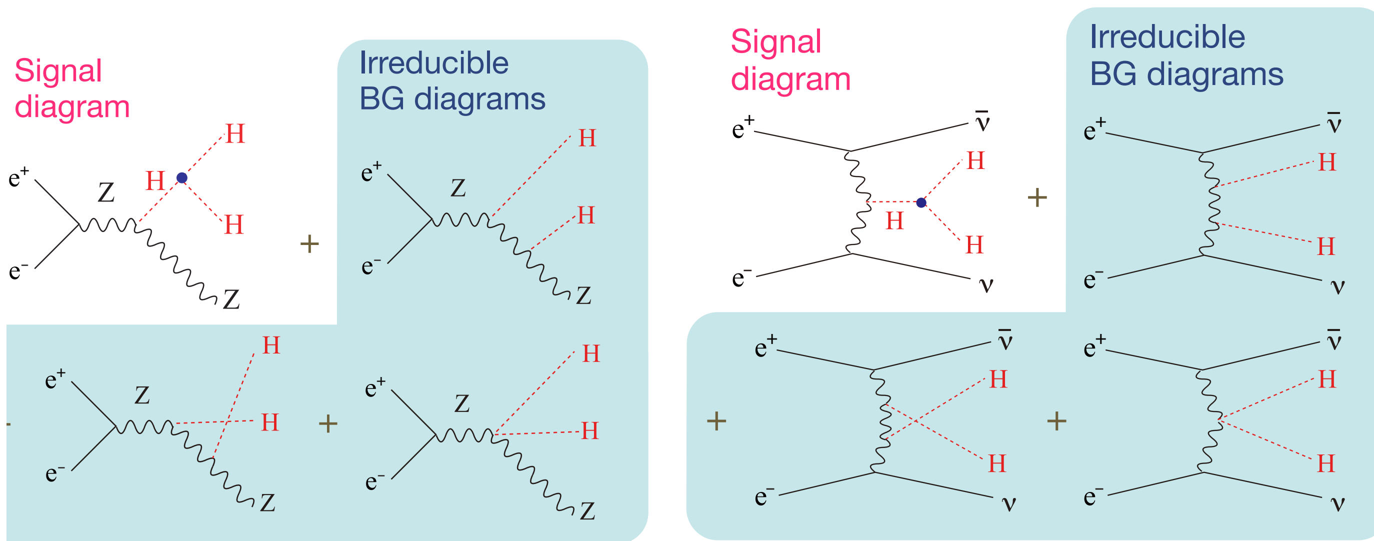




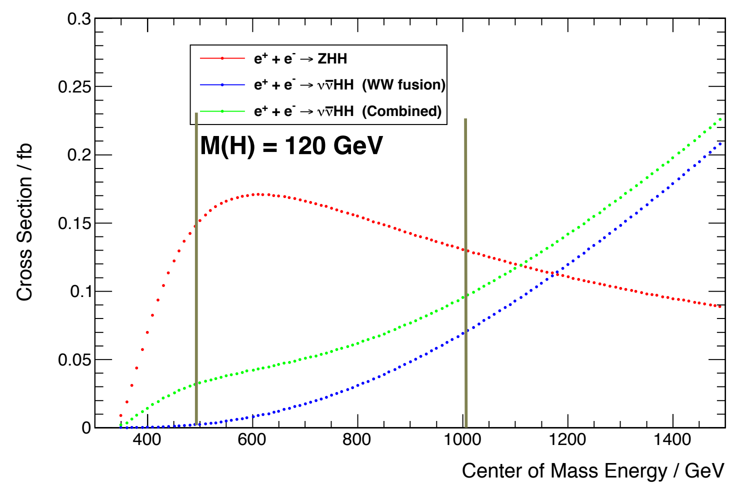
- Counting experiment, multi-jet final states
- 4% measurement of g_{ttH} possible
- sizeable QCD corrections
- a few more GeV beam energy most valuable

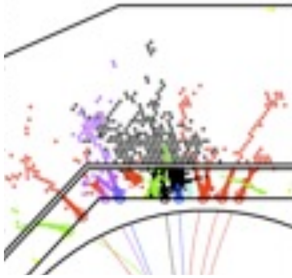
Top Yukawa and H self coupling





- difficult even at ILC
- $\delta\lambda/\lambda > 0.5\ \delta\sigma/\sigma$
- W fusion offers better sensitivity
- possible at 500 GeV, best at 1 TeV





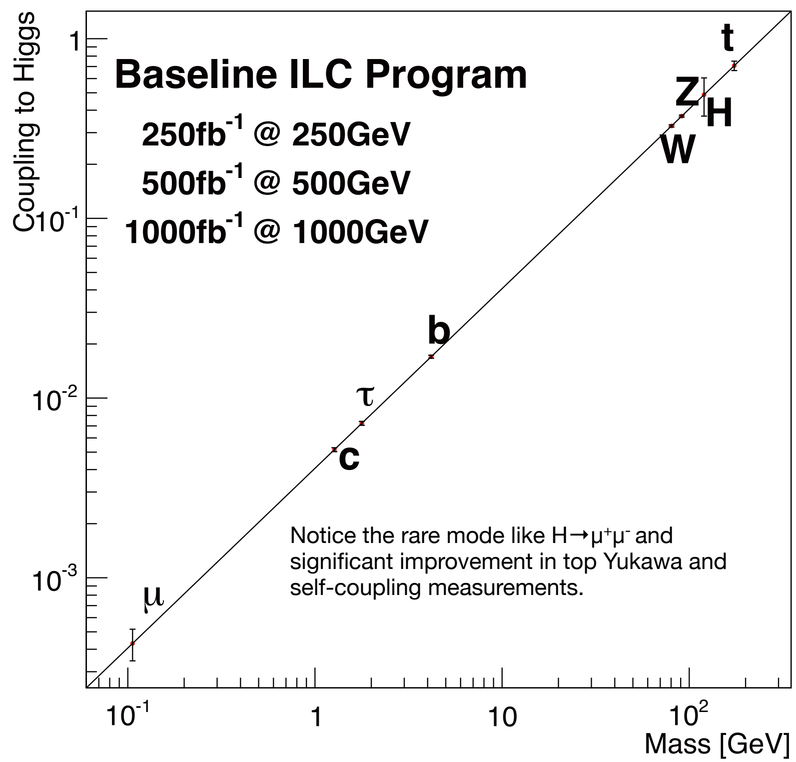
Global fits

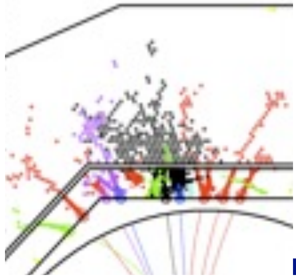
- Staged running scenario 250, 500, 1000 GeV
- 33 σ·BR measurements - 10 free parameters

$$g_{HZZ},\ g_{HWW},\ g_{Hbb},\ g_{Hcc},\ g_{Hgg},\ g_{H\tau\tau},\ g_{H\gamma\gamma},\ g_{H\mu\mu},\ g_{Htt},\ \Gamma_0$$

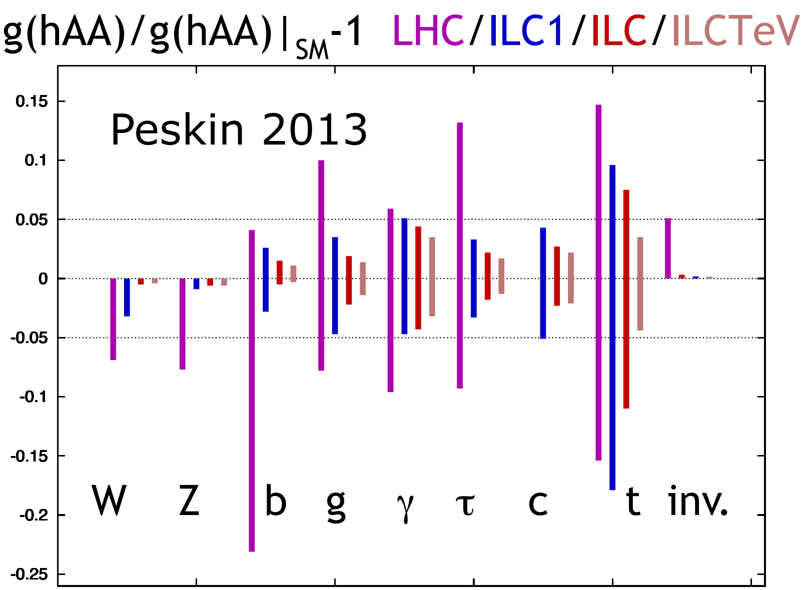
coupling	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
HZZ	1.3%	1%	1%
HWW	4.8%	1.1%	1.1%
Hbb	5.3%	1.6%	1.3%
Hcc	6.8%	2.8%	1.8%
Hgg	6.4%	2.3%	1.6%
Hττ	5.7%	2.3%	1.6%
Hγγ	18%	8.4%	4%
Hμμ	91%	91%	16%
Γ	12%	4.9%	4.5%
Htt	-	14%	3.1%
HHH	-	83%(*)	21%(*)

K.Fujii, LC School, Aug. 13, 2014

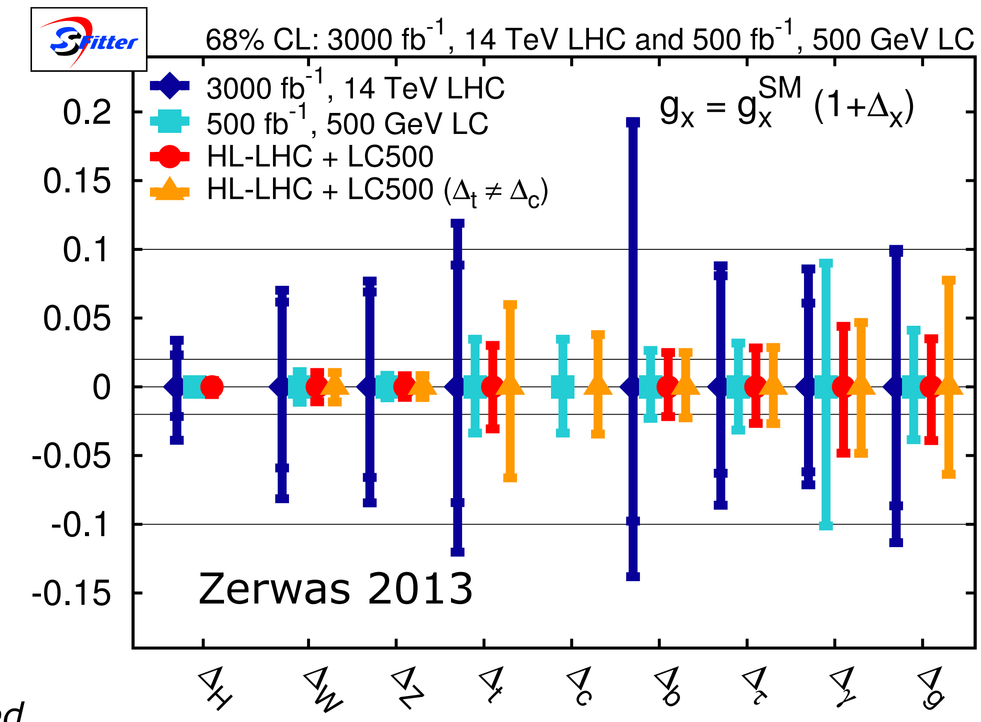




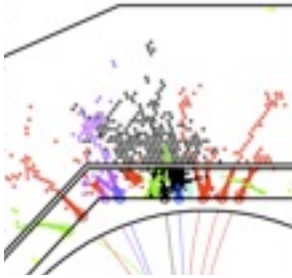
ILC and LHC



LHC 300 fb^{-1} @ 14 TeV
ILC1 250 fb^{-1} @ 250 GeV
ILC 500 fb^{-1} @ 500 GeV
ILC1T 1000 fb^{-1} @ 1 TeV *successively included*



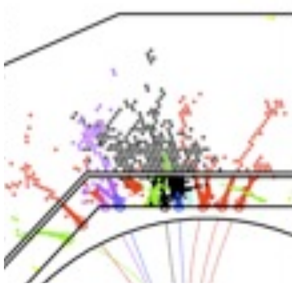
- Only the ILC can go to the percent level precision to probe new physics
- also true for ILC vs high lumi LHC



Conclusion

- The Higgs discovery opens the door to a completely new kind of matter and a completely new phenomenology
- An e+e- machine provides the clean conditions and a self-contained set of Higgs observables
- Only the ILC can reach the precision at percent level to detect deviations which can direct us to new physics
- There is so much more
  - direct discoveries, top physics, ..
  - see talks by Frank Simon and Jürgen Reuter

Back-up



Constrained fit to ILC results

- Need to be careful when comparing LC and LHC results
- Impact of constraints on precision can be large
- Example:

error in Γ_T	unconstrained	$\sum BR = 1$
ILC 500	5.0%	1.6%
ILC 500 up	2.8%	0.75%
ILC 1000	4.6%	1.2%

(from Snowmass study)