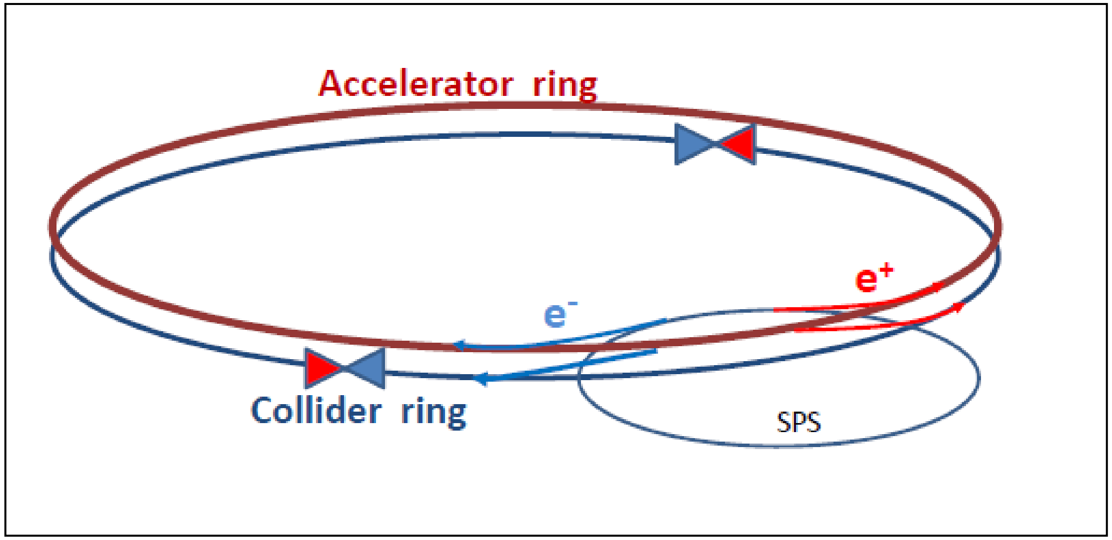
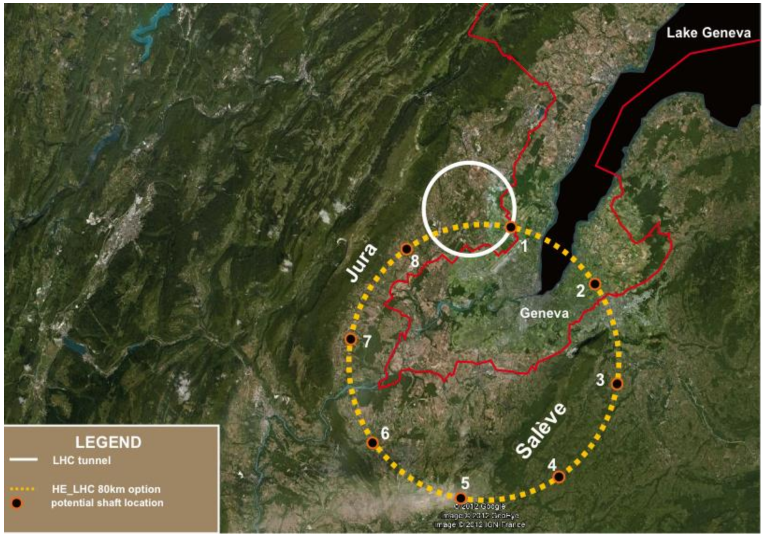
Precision Measurements : Higgs and Top

- **TLEP : A first step in a long-term vision for particle physics**
  - In the context of a global project





  - See Design Study Proposal at
    - http://tlep.web.cern.ch/

      → And sign-up the web form to express your interest !

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Introduction : Mis-conceptions about TLEP

- **A compendium of mis-conceptions about TLEP**
  - TLEP is more expensive than the ILC
  - TLEP parameters are stretched by many-order-of-magnitude extrapolations
  - TLEP will come later than ILC
  - TLEP is superfluous once ILC is approved and starts construction
  - TLEP will delay VHE-LHC
  - TLEP required electrical power is unacceptable
  - TLEP physics case is the same as that of ILC (at low energy)
  - TLEP can only do Higgs couplings / TLEP does not cover the physics case
    - We need a machine upgradeable beyond 350 GeV to make discoveries beyond LHC
  - TLEP precision is an overkill
    - Higgs couplings do not need to be measured so precisely

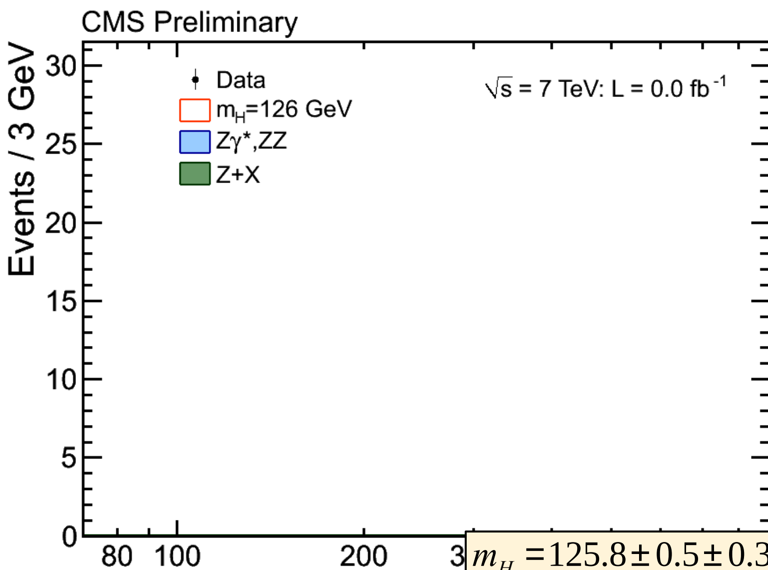
This talk

- **All are wrong**
  - With the upgrade path to a 100 TeV machine (unique to TLEP)
    - TLEP is the first step in a long-term vision for particle physics
      - ➔ And might be the only way to secure high-energy physics in Europe

Main Motivation for TLEP

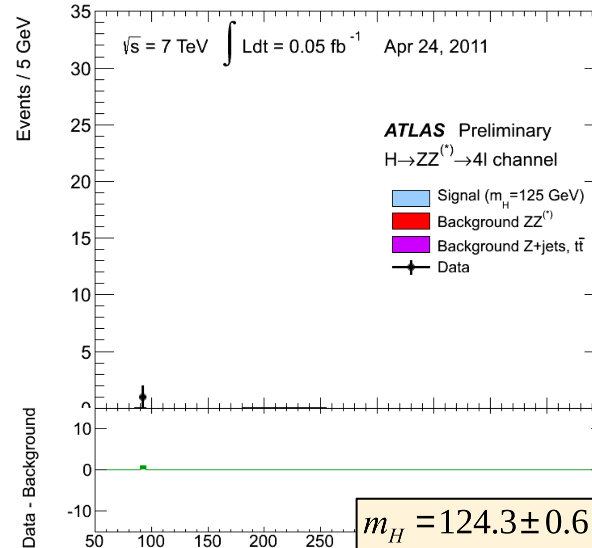
- **A new boson with mass ~ 126 GeV, and with SMS properties**
  - Example : H(126) → ZZ → 4 leptons in CMS and ATLAS

[1,2,3]



$m_H = 125.8 \pm 0.5 \pm 0.3$ GeV

$m = 0.91^{+0.30}_{-0.24}$



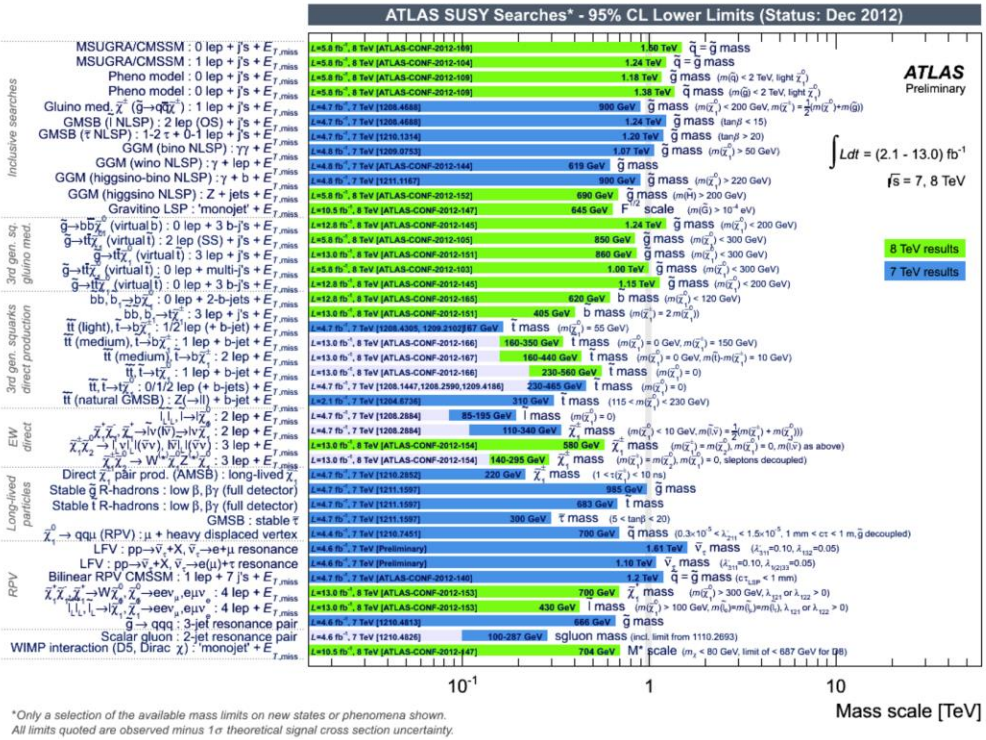
$m_H = 124.3 \pm 0.6 \pm 0.4$ GeV

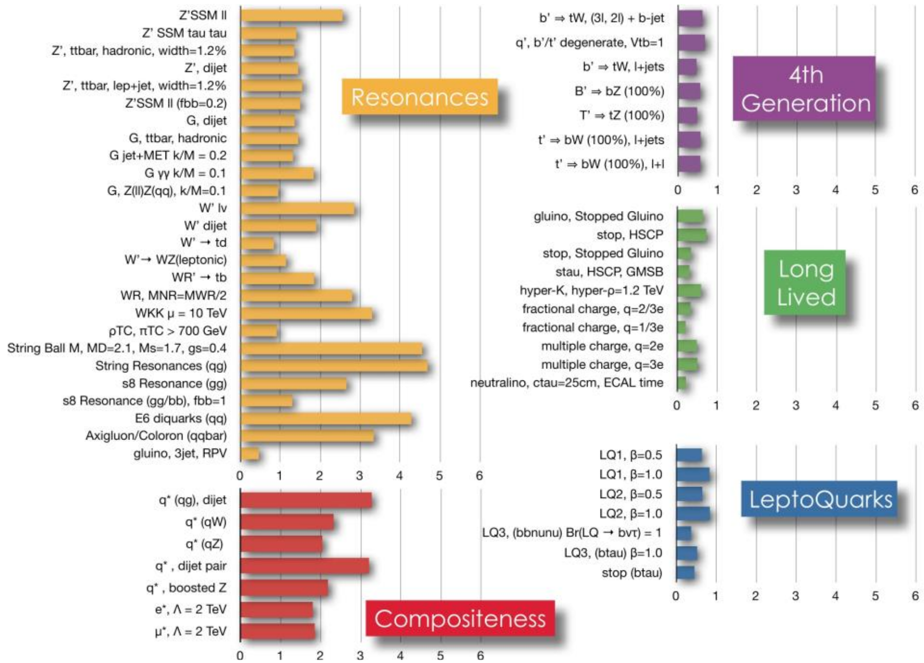
$m = 1.5 \pm 0.4$ (at 125.5 GeV)

- H(126) couples to the Z boson (important for e^+e^- colliders)
- All couplings compatible with those of the Standard Model Scalar
- Scalar hypothesis favoured over pseudo-scalar or spin-2 particle
- m_H known to ~ 400 MeV
- A factor 100 luminosity will bring the statistical uncertainty on μ to a couple %.

"We need a machine upgradeable beyond 350 GeV" (1)

- **No sign of new physics below a scale of several 100's GeV** [4]
  - Supersymmetry (ATLAS) — Exotics (CMS)



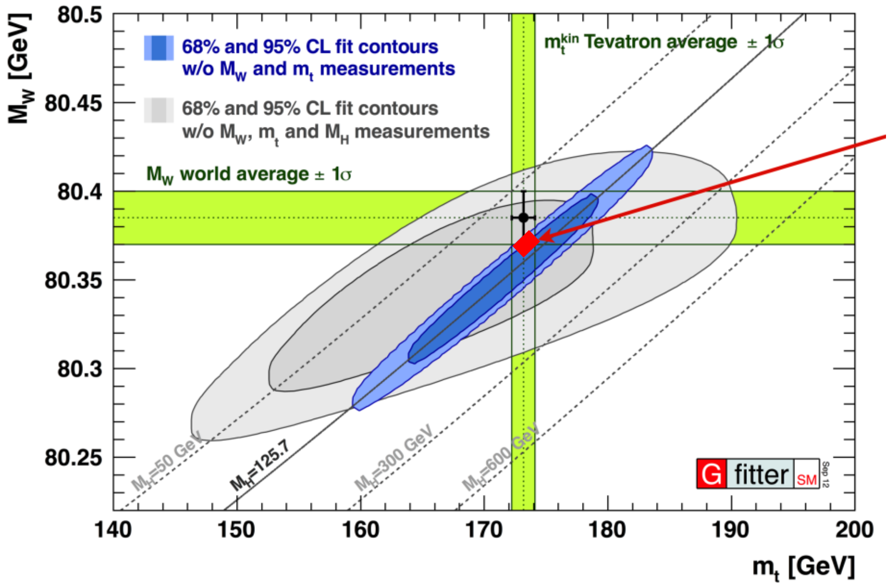


- Data at higher $\sqrt{s}$ will extend the mass reach to ~500 GeV for SUSY
  - Will know more after the next LHC run at 14 TeV (2015-2017)
    - ➔ Air is getting very thin for e^+e^- colliders with $\sqrt{s}$ = 500 GeV (and even 1 TeV)

"TLEP Precision is an overkill"

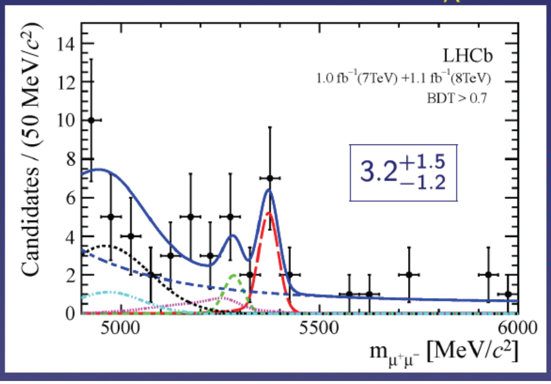
- **If no new physics is found, what next ?**
  - Once m_H is known, the standard model has nowhere to go !

[5,6]



SM: $BR(B_s \to \mu^+\mu^-) = (3.54 \pm 0.30) \times 10^{-9}$

MSSM: $BR(B_s \to \mu^+\mu^-) \propto \frac{m_b^2 m_t^2}{M_A^4} \tan^6\beta$



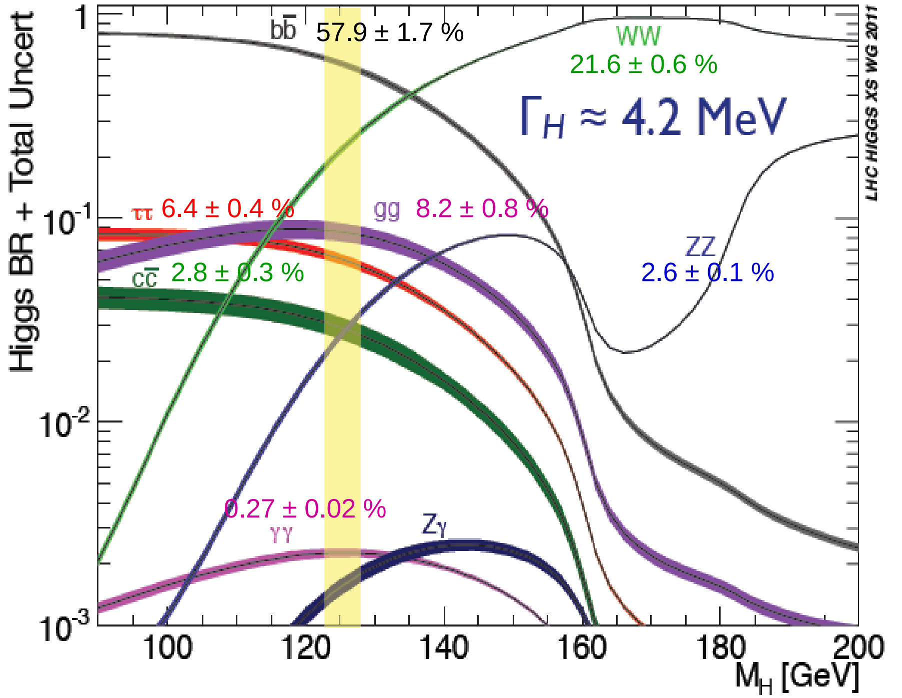
- Very strong incentive to revisit and improve all precision measurements
  - ➔ Z pole, WW threshold → **Programme unique to TLEP, see Alain's talk**
  - ➔ Higgs couplings
  - ➔ Top quark properties
    } This presentation
  - ➔ Rare decays ($B_s \to \mu\mu$, etc.) → **Also at the Z pole, unique to TLEP**
- … and find indirect effects of new physics at larger scales

"Higgs couplings do not need to be measured so precisely" (1)

❑ Precision needed for Higgs measurements ?

[7,8]

- Does H(126)
  - Couple to fermions ?
  - Account for fermion masses ?
  - Fully account for EWSB ?
  - Has SM coupling to gauge bosons ?
  - Decay to new, visible, particles ?
  - Decay to invisible particles ?
  - Have the "proper" mass and width ?
  - Show any sign of new physics ?



- What is the precision needed to answer all these questions in a useful manner ?
  - Simple answer : predict and measure as precisely as possible
    - ➔ Not very informative, especially for the last question

"Higgs couplings do not need to be measured so precisely" (2)

- **Example : Precision for Higgs couplings**
  - Maximal deviations with respect to SM couplings, as a function of new physics scale
    - SUSY $\frac{g_{hbb}}{g_{h_{\rm SM}bb}} = \frac{g_{h\tau\tau}}{g_{h_{\rm SM}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \rm TeV}{m_A}\right)^2$, for tanβ = 5
    - Composite Higgs $\frac{g_{hff}}{g_{h_{\rm SM}ff}} \simeq \frac{g_{hVV}}{g_{h_{\rm SM}VV}} \simeq 1 - 3\% \left(\frac{1\ \rm TeV}{f}\right)^2$
    - Top partners $\frac{g_{hgg}}{g_{h_{\rm SM}gg}} \simeq 1 + 2.9\% \left(\frac{1\ \rm TeV}{m_T}\right)^2, \quad \frac{g_{h\gamma\gamma}}{g_{h_{\rm SM}\gamma\gamma}} \simeq 1 - 0.8\% \left(\frac{1\ \rm TeV}{m_T}\right)^2$
    - Other models may give up to 5% deviations with respect to the Standard Model
  - Maximal deviations for the new physics scale still allowed by LHC results

	ΔhVV	$\Delta h\bar{t}t$	$\Delta h\bar{b}b$
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	$10\%^a$, $100\%^b$

- **Strongly influences the strategy for Higgs factory projects**
  - Need at least a per-cent accuracy on couplings for a 5σ "observation"
    - And sub-percent precision if new physics is at the (multi-)TeV scale [9,10]

Precision at existing colliders : (HL-)LHC (1)

Executive summary

Approved LHC, 300 fb^{-1} at 14 TeV :

- Higgs mass at 100 MeV
- Disentangle Spin 0 vs Spin 2 and main CP component in $\gamma\gamma$/ZZ*
- Coupling precision / Experiment
  - ZZ, WW, 5-6%
  - bb, $\tau\tau$ 10-15%
  - tt, $\mu\mu$ 3-2 σ effect
  - $\gamma\gamma$, gg 5-11%

HL-LHC, 3000 fb^{-1} at 14 TeV:

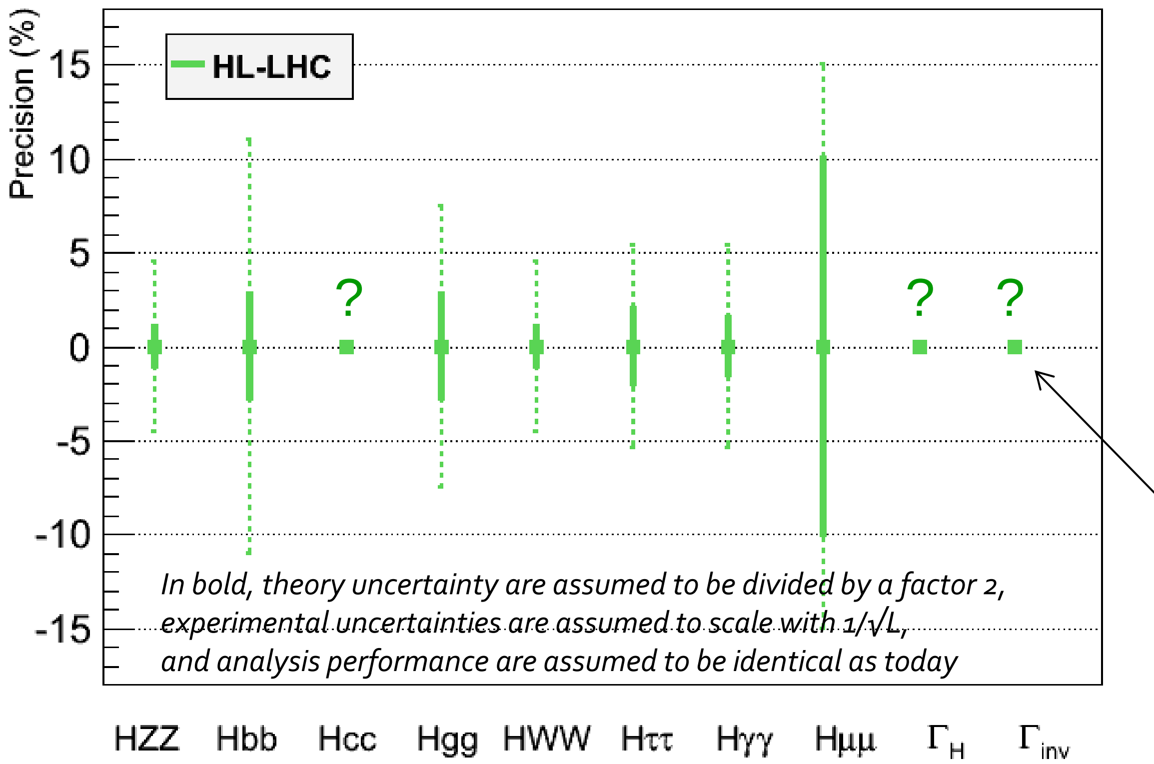
- Higgs mass at 50 MeV
- More precise studies of Higgs CP sector
- Coupling precision / Experiment
  - ZZ, ZW, 1-5%
  - bb, $\tau\tau$, tt, $\mu\mu$ 3-10%
  - $\gamma\gamma$ and gg 2-7%
  - HH >3 σ (2 Expts)

Assuming sizeable reduction of theory errors

[11,12]

Precision at existing colliders : HL-LHC (2)

- Graphic representation of HL-LHC projected performance



Assumptions :

1. No new decay
2. Γ_H fixed in the fit (or fixed BR(cc))

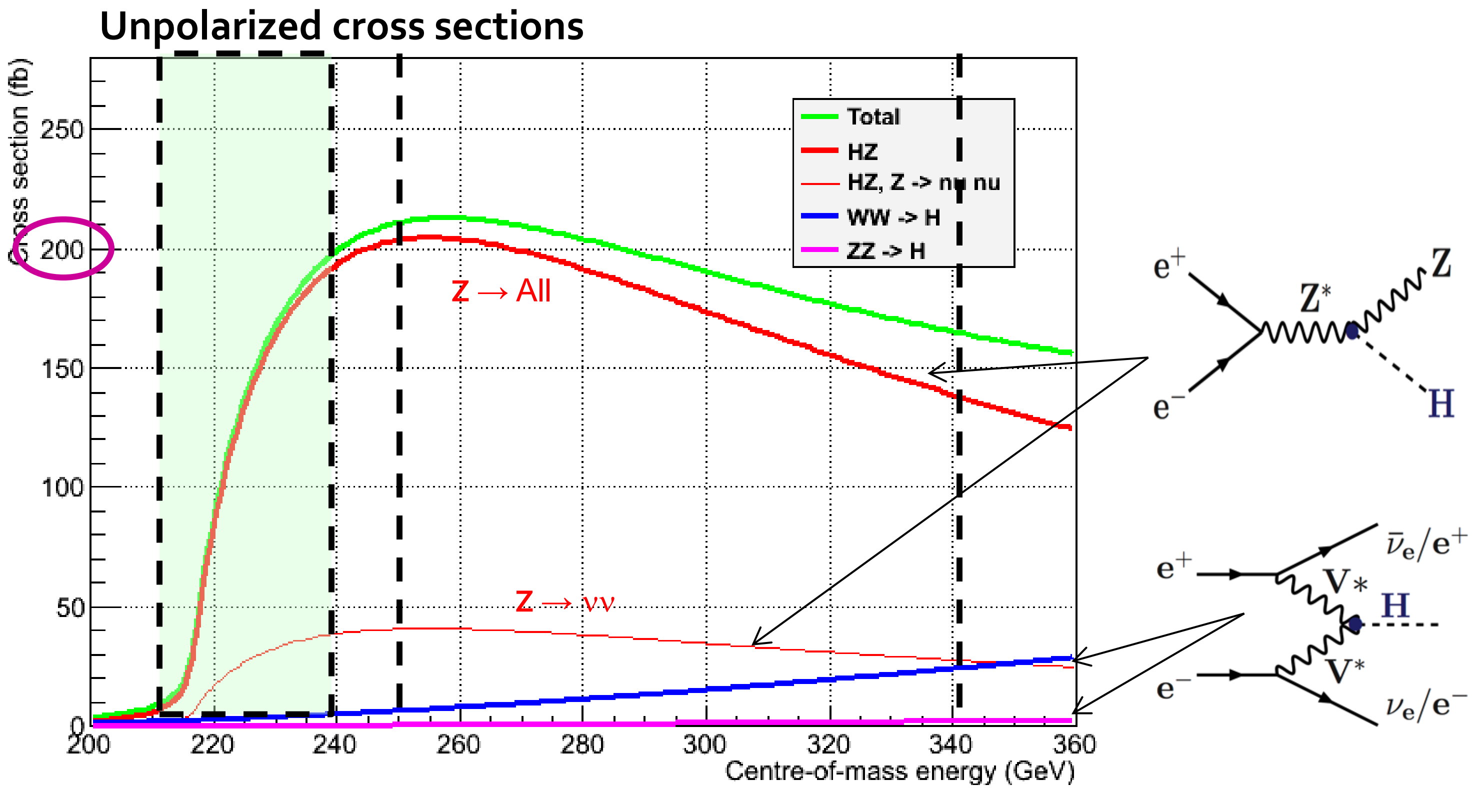
- Much better than originally expected before LHC started
  - Will need vigorous upgrade of CMS and ATLAS detectors
    - ➔ Per-cent to sub-percent precision will require new collider(s)

[11]

"TLEP Physics is the same as ILC Physics" (1)

- **Physics case not driven by the fact that the collider is linear or circular**
  - Scan of the HZ threshold : √s = 210-240 GeV — Spin
  - Maximum of the HZ cross section : √s = 240-250 GeV — Mass, BRs, Width, Decays
  - Just below the tt threshold : √s ~ 340-350 GeV — Width, CP

Need 100's fb^{-1}

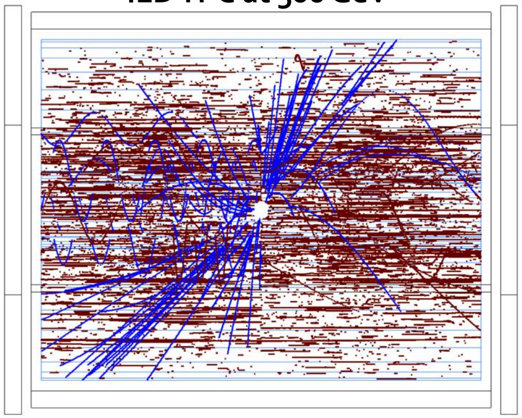


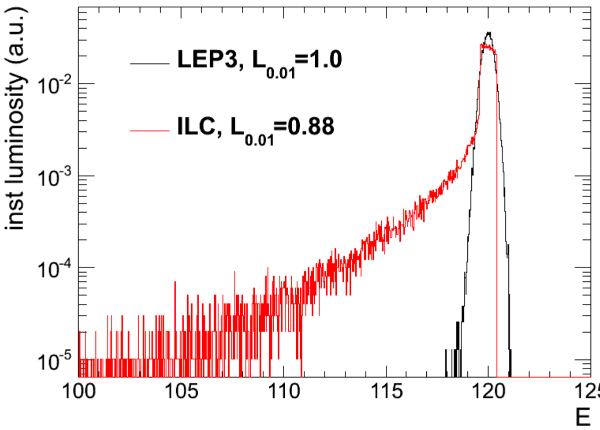
[7]

"TLEP Physics is the same as ILC Physics" (2)

- **A few specificities, though :**
  - e^- (e^+) beam polarization is easy at the source (possible) for a linear collider.
    - Not critical for Higgs studies.
  - No beam disruption from Beamstrahlung for a circular collider (σ_y ~ 300 nm vs. 5 nm @ ILC)
    - No EM backgrounds in the detector (photons, e+e- pairs);
    - No beam energy smearing – energy spectrum perfectly known (lumi measurement)
    - Negligible pile-up from $\gamma\gamma$ interactions

ILD TPC at 500 GeV





➔ No drastic requirements for the detector and the background simulation

  - Possibility of operating several IP's simultaneously in circular collider
    - vs. only one IP in linear collider

[13,14]

"TLEP Physics is the same as ILC Physics" (3)

No Hubner factor included !

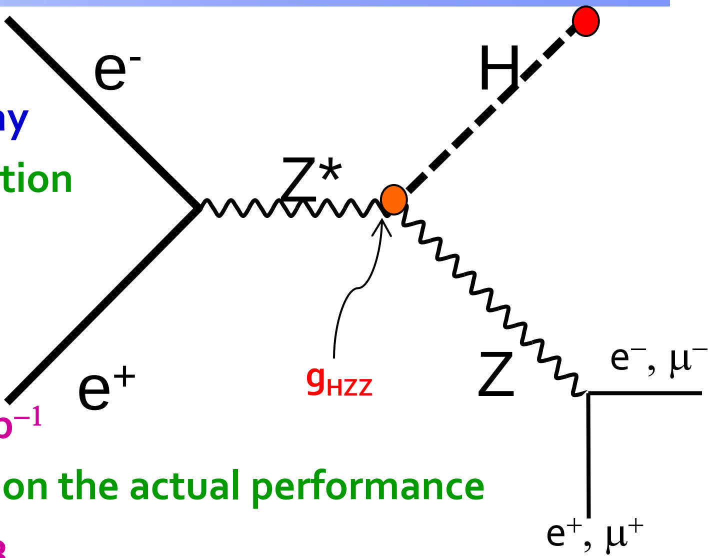
- Number of Higgs bosons produced at $\sqrt{s}$ = 240-250 GeV

	ILC-250	LEP3-240	TLEP-240
Lumi / IP / 5 years	250 fb^{-1}	500 fb^{-1}	2.5 ab^{-1}
# IP	1	2 - 4	2 - 4
Lumi / 5 years	250 fb^{-1}	1 - 2 ab^{-1}	5 - 10 ab^{-1}
Beam Polarization	80%, 30%	–	–
$L_{0.01}$ (beamstrahlung)	86%	100%	100%
Number of Higgs	70,000	400,000	2,000,000
Upgradeable to	ILC 1TeV CLIC 3 TeV	HE-LHC 33 TeV	VHE-LHC 100 TeV

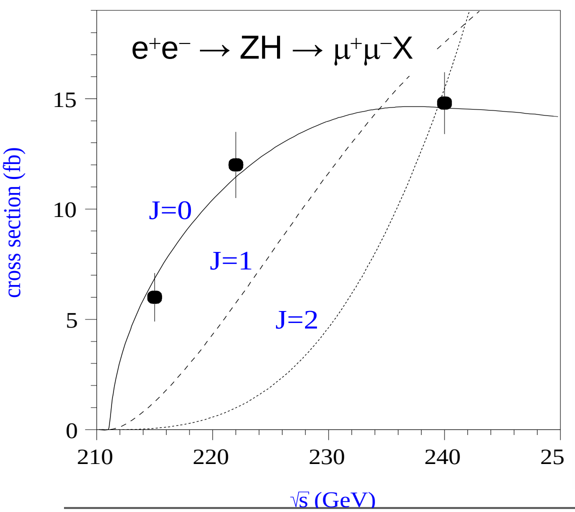
- LEP3 : 4-8 times more luminosity and 3-6 times more Higgs bosons than ILC
- TLEP : 20-40 times more luminosity and 15-30 times more Higgs bosons than ILC
  - In a given amount of time, Higgs coupling precisions scale like
    - ➔ 2.5% for ILC : 1.3% for LEP3 : 0.4% for TLEP
    - ➔ One year of TLEP = five years of LEP3 = 15-30 years of ILC (at 240 GeV)

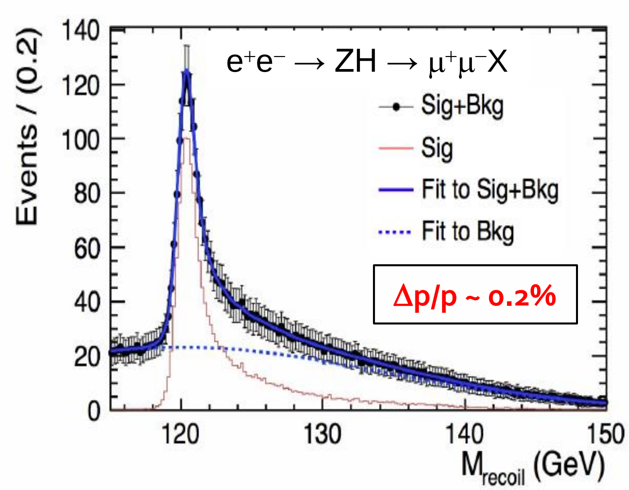
Higgs measurements at $\sqrt{s}$ ~ 240 GeV (1)

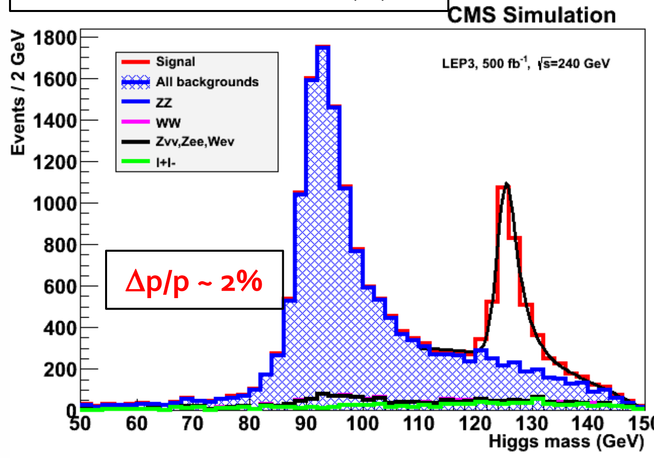
- With $e^+e^- \to ZH \to e^+e^-X$ and $\mu^+\mu^-X$ events
  - Measure HZ cross section in a model independent way
    - Find m_H peak from the leptons and E,p conservation
    - Determine spin with three-point threshold scan
      - ➔ 10 fb^{-1} / point suffice
    - Determine σ_{HZ} and g_{HZZ} coupling at 240 GeV
      - ➔ 3% (1.5%) precision on σ_{HZ} (g_{HZZ})with 250 fb^{-1}
    - Good tracker needed, but details mildly depend on the actual performance
      - ➔ Plots below with ILD@ILC and CMS@LEP3



[9,10,11]



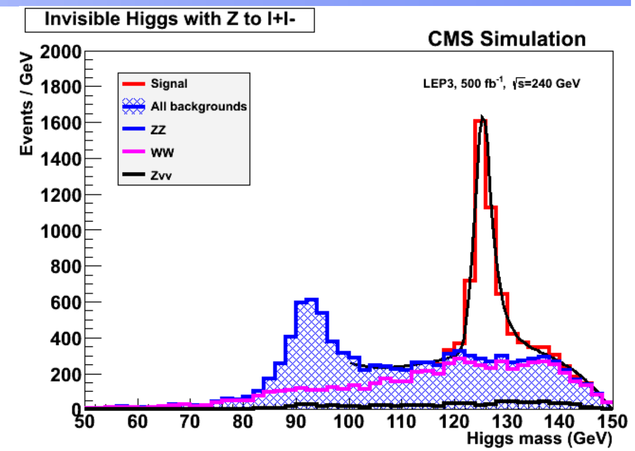




[15,16]

Higgs measurements at $\sqrt{s}$ ~ 240 GeV (2)

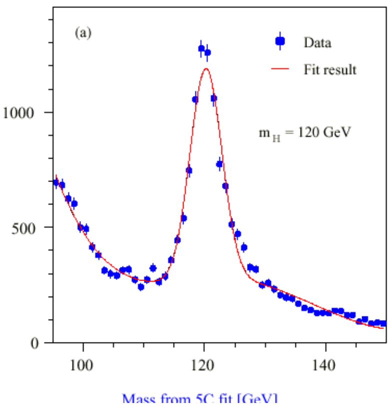
- **With ZH → e^+e^-X and $\mu^+\mu^-X$ events (cont'd)**
  - Measure invisible decay branching ratio (X = nothing)
    - Precision on BR_{INV} ~ 1% with 250 fb^{-1}
    - Or exclude BR_{INV} > ~2% at 95% C.L.



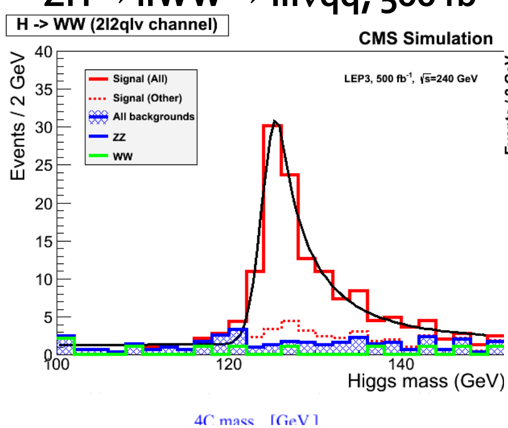
- **Measure other σ_{HZ}×BR(H→ ff, VV)**
  - With exclusive selections of Z and H decays
    - Precision of 1.5% to 8% with 250 fb^{-1} for the copious decays (bb, WW, gg, ττ, cc)
    - Need more luminosity for rare decays (γγ, Zγ, μμ)

➔ Particle flow, b and c tagging, lepton and photon capabilities needed

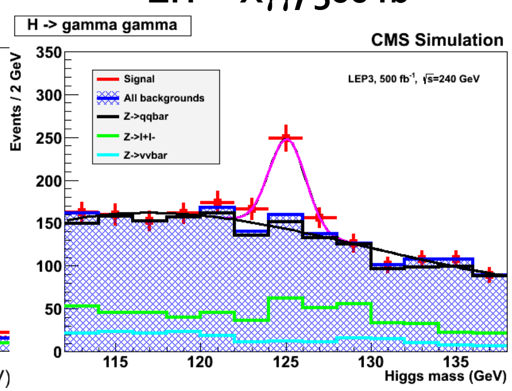
ZH→ qqbb, 250 fb^{-1}



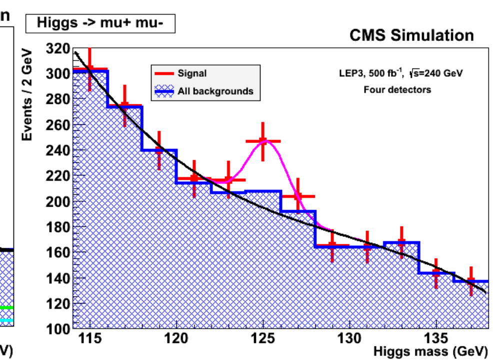
ZH→ llWW→ lllνqq, 500 fb^{-1}



ZH→ Xγγ, 500 fb^{-1}



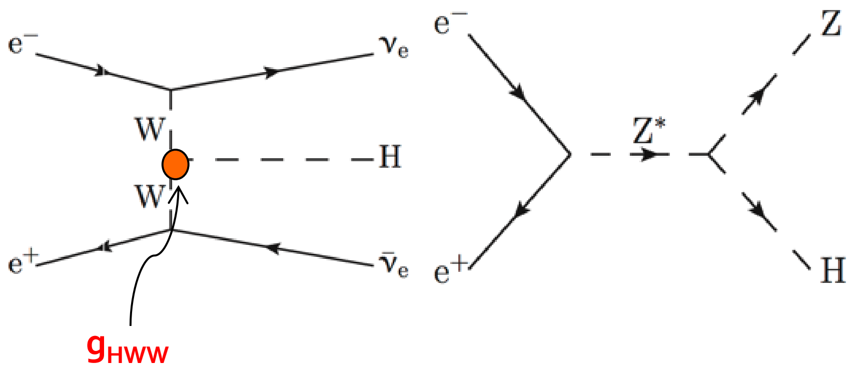
ZH→ Xμμ, 2 ab^{-1}



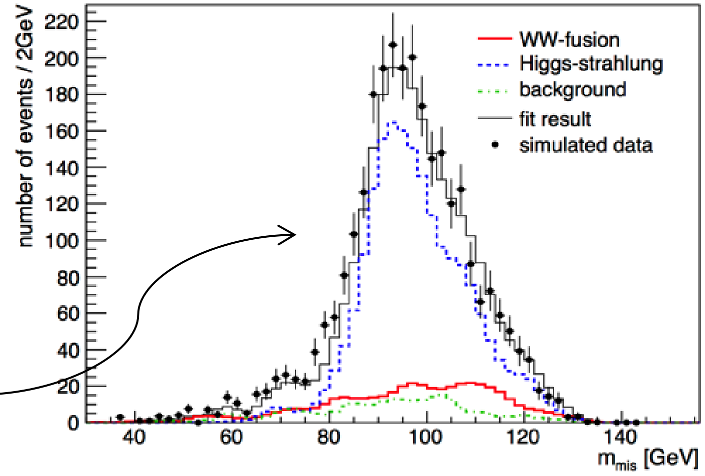
[10,15,16]

Higgs measurements at $\sqrt{s}$ ~ 240 GeV (3)

- Higgs width from the $H\nu\nu$ final state
  - From $\sigma_{WW\to H}$ and BR($H\to WW$)
    - $\sigma_{WW\to H} \sim g^2_{HWW}$
    - $BR(H\to WW) = \Gamma_{H\to WW} / \Gamma_H \sim g^2_{HWW} / \Gamma_H$
      - ➔ $\Gamma_H \sim \sigma_{WW\to H} / BR(H\to WW)$



  - Contribution to $H\nu\nu$ from HZ ~ 40 pb
    - Known from ZH → e^+e^-X and $\mu^+\mu^-X$
  - Contribution from WW fusion ~ 6 pb
    - To be measured
  - Select $\nu\nu bb$ events from ZH and WW fusion
    - Needs adequate b tagging and particle flow
  - Fit the missing mass distribution for $N_{WW\to H\to bb}$
    - σ_{HZ} x BR($H\to bb$) known to ~1.5% or better
    - $\sigma_{WW\to H} = N_{WW\to H\to bb} / BR(H\to bb)$
      - ➔ Precision on $\sigma_{WW\to H}$ ~ 14% with 250 fb^{-1}
      - ➔ $\Gamma_H \sim \sigma_{WW\to H} / BR(H\to WW)$, measured up to 15% precision with 250 fb^{-1}

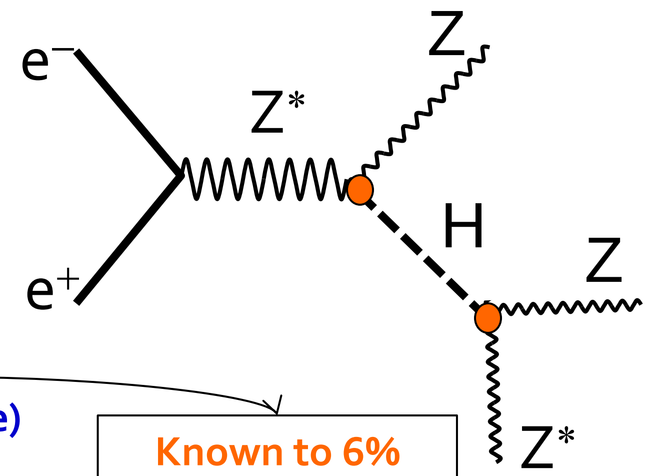


[17]

Higgs measurements at $\sqrt{s}$ ~ 240 GeV (4)

Higgs width from the ZZZ final state

- Number of ZZZ events ~ $\sigma_{HZ} \times BR(H \rightarrow ZZ)$
  - $\sigma_{HZ} \sim g^2_{HZZ}$
  - $BR(H \rightarrow ZZ) = \Gamma_{H\rightarrow ZZ}/\Gamma_H \sim g^2_{HZZ} / \Gamma_H$
    - ➔ Number of ZZZ events ~ g^4_{HZZ} / Γ_H



Known to 6% from l^+l^-X events with 250 fb-1

- Select $l^+l^- l'^+l'^-$ X events (~ background and H →WW free)
  - Number of events in 250 fb^{-1} @ 240 GeV :
    - ➔ 250 $fb^{-1} \times$ 200 fb $\times BR(H\rightarrow ZZ) \times BR(Z\rightarrow ll)^2 \times 3$
      - → About 40 events, of which ~25 selected

- Hence measure the total width Γ_H with a precision of 21%
  - Reduced to 12% in combination with WW fusion measurement
    - ➔ Could be further reduced with other Z decays
      - (Need full simulation and WW/ZZ simultaneous fit)

- Note : Precision of a few % can be reached on Γ_H if one assumes no exotic Higgs decays

"TLEP does not cover the Physics Case" (1)

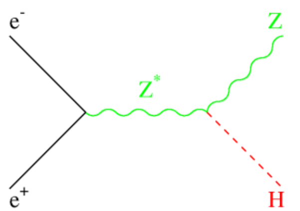
- Precision on H(125) branching fractions, width, mass, … after 5 years

	ILC	LEP3 (4)	TLEP (4)
σ_{HZ}	2.5%	1.3%	0.4%
$\sigma_{HZ} \times BR(H\to bb)$	1.0%	0.5%	0.1%
$\sigma_{HZ} \times BR(H\to cc)$	6.9%	4% (*)	1.3%
$\sigma_{HZ} \times BR(H\to gg)$	8.5%	4.5% (*)	1.4%
$\sigma_{HZ} \times BR(H\to WW^*)$	8.0%	3.0%	0.9%
$\sigma_{HZ} \times BR(H\to \tau\tau)$	5.0%	3.0%	0.9%
$\sigma_{HZ} \times BR(H\to ZZ^*)$	28%	7.1%	3.1%
$\sigma_{HZ} \times BR(H\to \gamma\gamma)$	27%	6.8%	3.0%
$\sigma_{HZ} \times BR(H\to \mu\mu)$	–	28%	13%
$\sigma_{WW\to H}$	12%	5% (*)	2.2%
Γ_H, Γ_{INV}	10% , < 1.5%	4% , < 0.7%	1.8% , < 0.3%
m_H	40 MeV	26 MeV	8 MeV

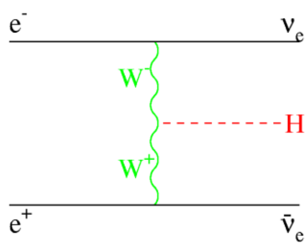
- LEP3 numbers obtained from a CMS simulation x 4, except (*) extrapolated from ILC
  - Need a refined vertex detector for gg and cc BR accurate measurements
- TLEP numbers extrapolated from LEP3 column – ILC numbers with super-duper ILC detector

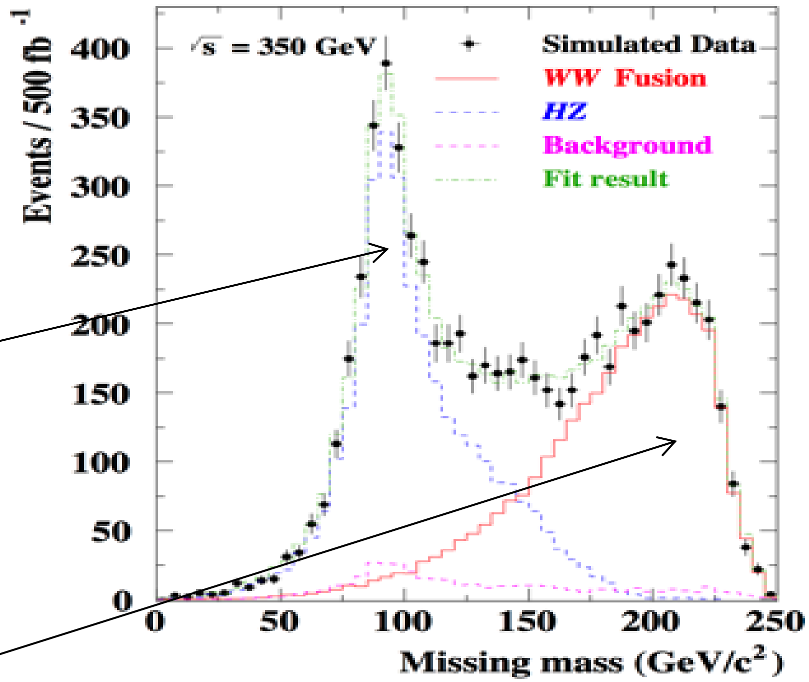
Higgs Measurements at √s ~ 350 GeV

- **Luminosity similar for ILC and TLEP**
  - At each IP : 350 fb^{-1} over 5 years
    - With possibly 4 detectors at TLEP
  - More study of the Hνν final state with H→bb
    - Contribution from HZ : ~ 25 fb



    - Contribution from WW→H : ~ 25 fb





	ILC (250+350)	TLEP (240+350)
$\sigma_{WW\to H}$	12% → 4%	2.2% → 1.5%
Γ_H	10% → 5.5%	1.8% → 1.3%

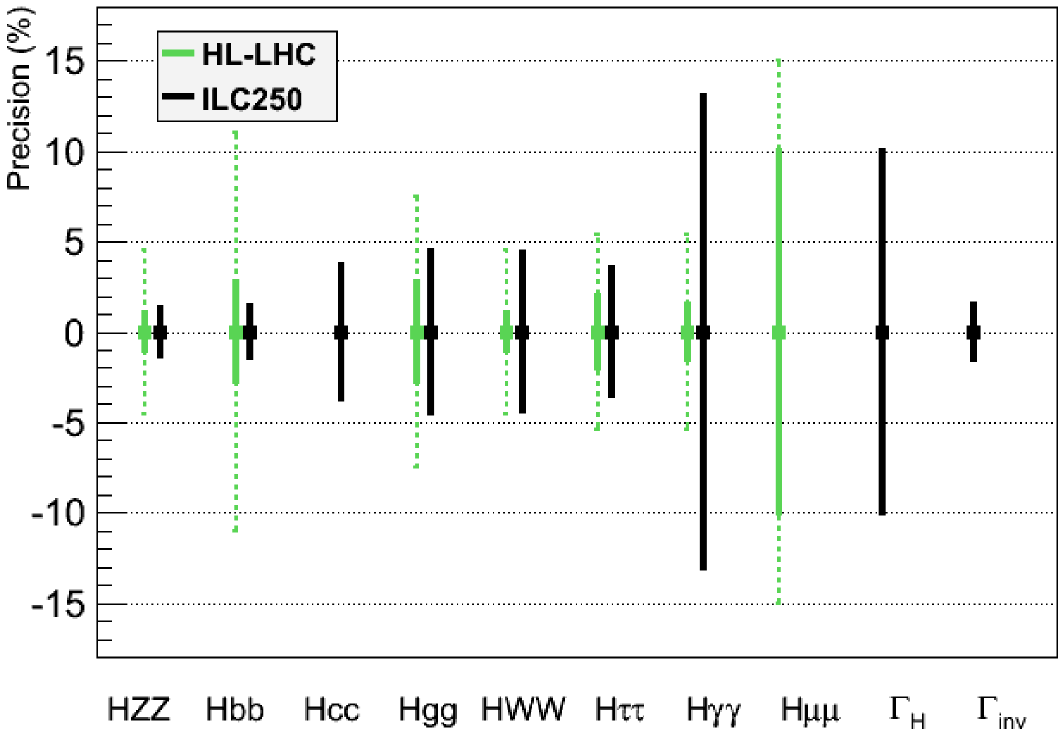
➔ Improves precision on Γ_H and HWW coupling

➔ Smaller improvement of other σ×BR measurements

"TLEP does not cover the Physics Case" (2)

- **Same assumptions as for HL-LHC for a sound comparison**
  - No exotic decay, fixed decay width

$$\sigma_{HZ} \propto g^2_{HZZ}, \text{ and } \sigma_{HZ} \times \text{BR}(H \to XX) \propto g^2_{HZZ} g^2_{HXX} / \Gamma_H$$

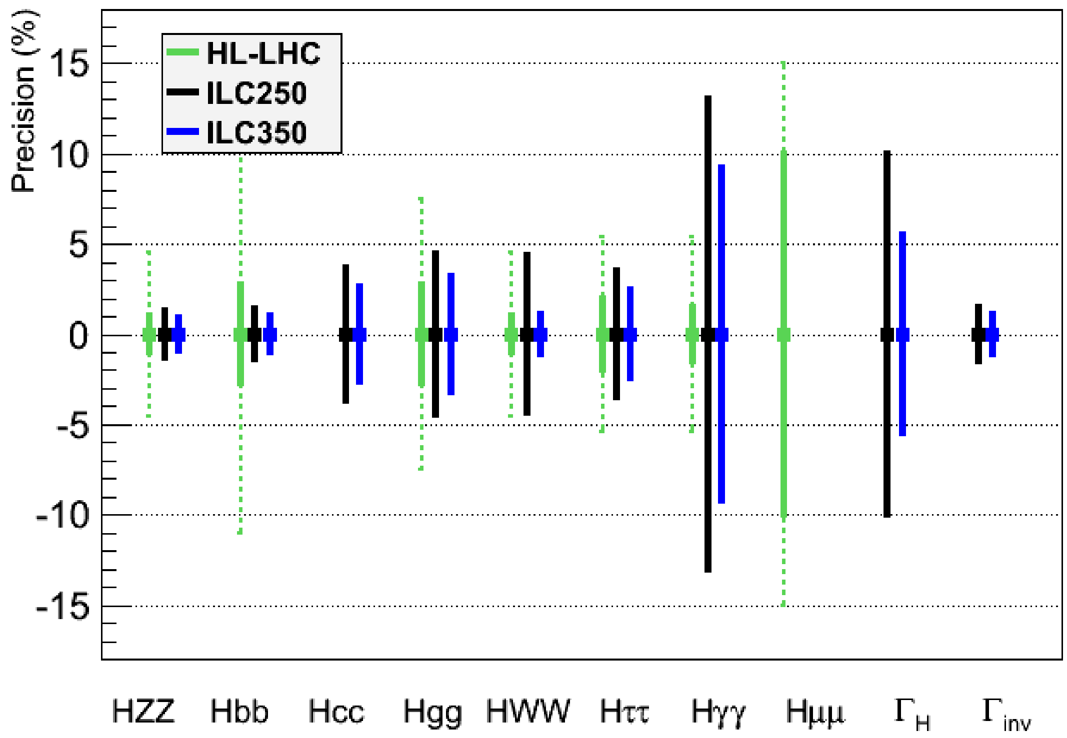


➔ ILC250 would complement LHC (esp. for Γ_H, Γ_{inv}, g_{Hcc}, g_{Hbb})

"TLEP does not cover the Physics Case" (3)

- **Same assumptions as for HL-LHC for a sound comparison**
  - **No exotic decay, fixed decay width**

$$\sigma_{HZ} \propto g^2_{HZZ}, \text{ and } \sigma_{HZ} \times \mathrm{BR}(H \to XX) \propto g^2_{HZZ} g^2_{HXX} / \Gamma_H$$

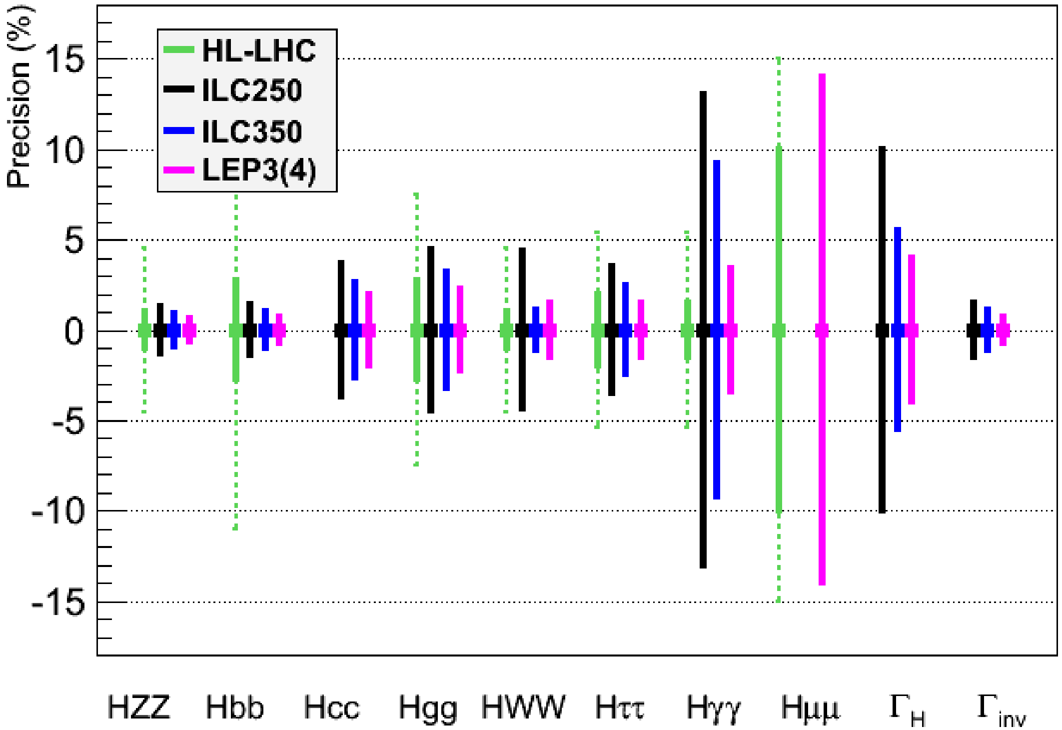


➔ **ILC250/350 would further complement LHC, but does not cover the physics case**

"TLEP does not cover the Physics Case" (4)

- **Same assumptions as for HL-LHC for a sound comparison**
  - **No exotic decay, fixed decay width**

$$\sigma_{HZ} \propto g^2_{HZZ}, \text{ and } \sigma_{HZ} \times \mathrm{BR}(H \to XX) \propto g^2_{HZZ} g^2_{HXX} / \Gamma_H$$

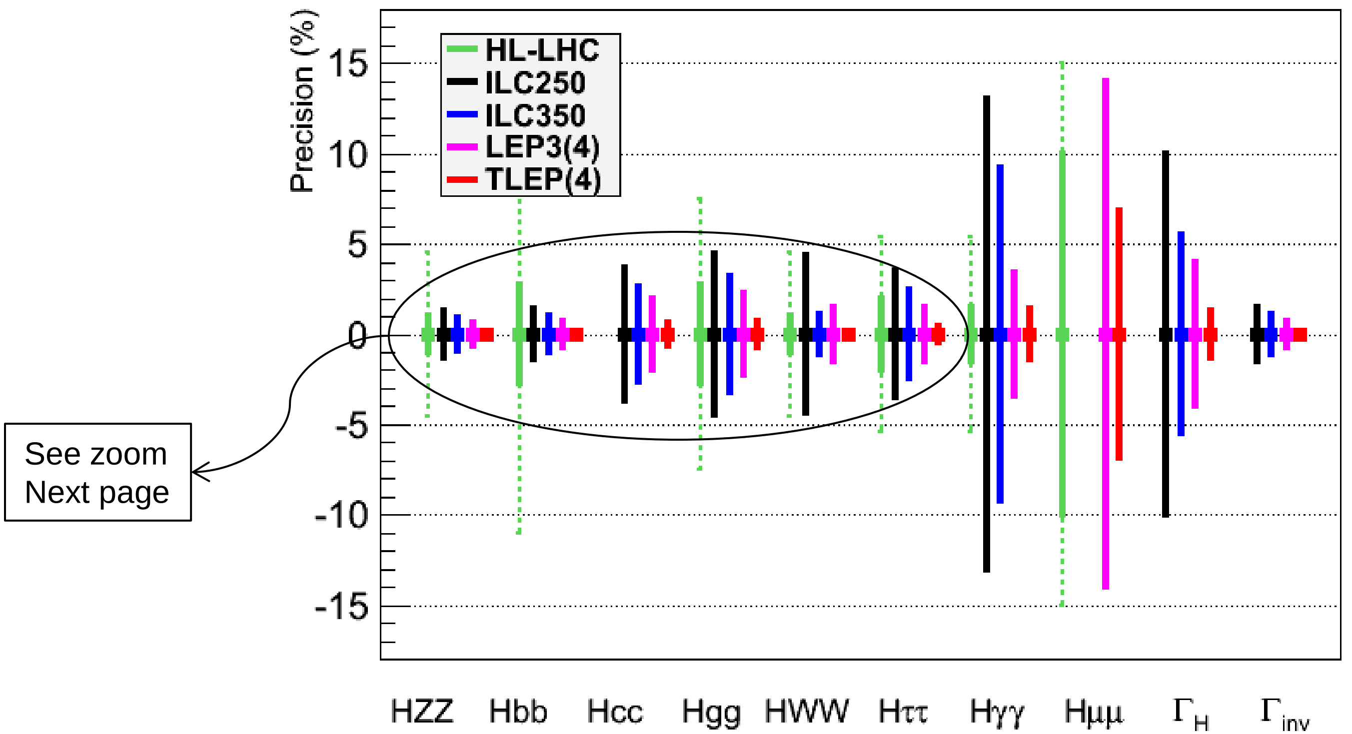


→ **LEP3 would be an advantageous back-up : larger lumi, several IPs, smaller cost**

"TLEP does not cover the Physics Case" (5)

- **Same assumptions as for HL-LHC for a sound comparison**
  - **No exotic decay, fixed decay width**

$$\sigma_{HZ} \propto g_{HZZ}^2, \text{ and } \sigma_{HZ} \times \mathrm{BR}(H \rightarrow XX) \propto g_{HZZ}^2 g_{HXX}^2 / \Gamma_H$$

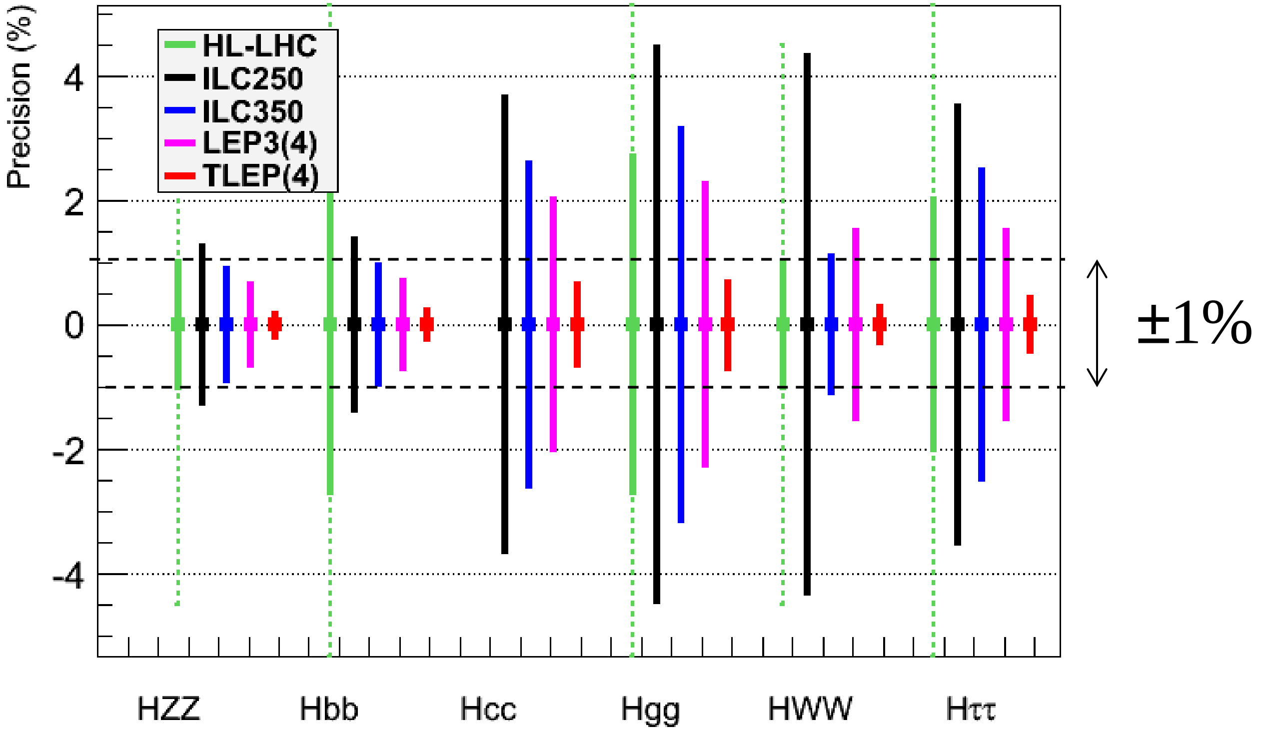


➔ **TLEP would be a superior option (see zoom next page)**

"TLEP does not cover the Physics Case" (6)

- **Same assumptions as for HL-LHC for a sound comparison**
  - **No exotic decay, fixed decay width**

$$\sigma_{HZ} \propto g^2_{HZZ}, \text{ and } \sigma_{HZ} \times \mathrm{BR}(H \to XX) \propto g^2_{HZZ} g^2_{HXX} / \Gamma_H$$

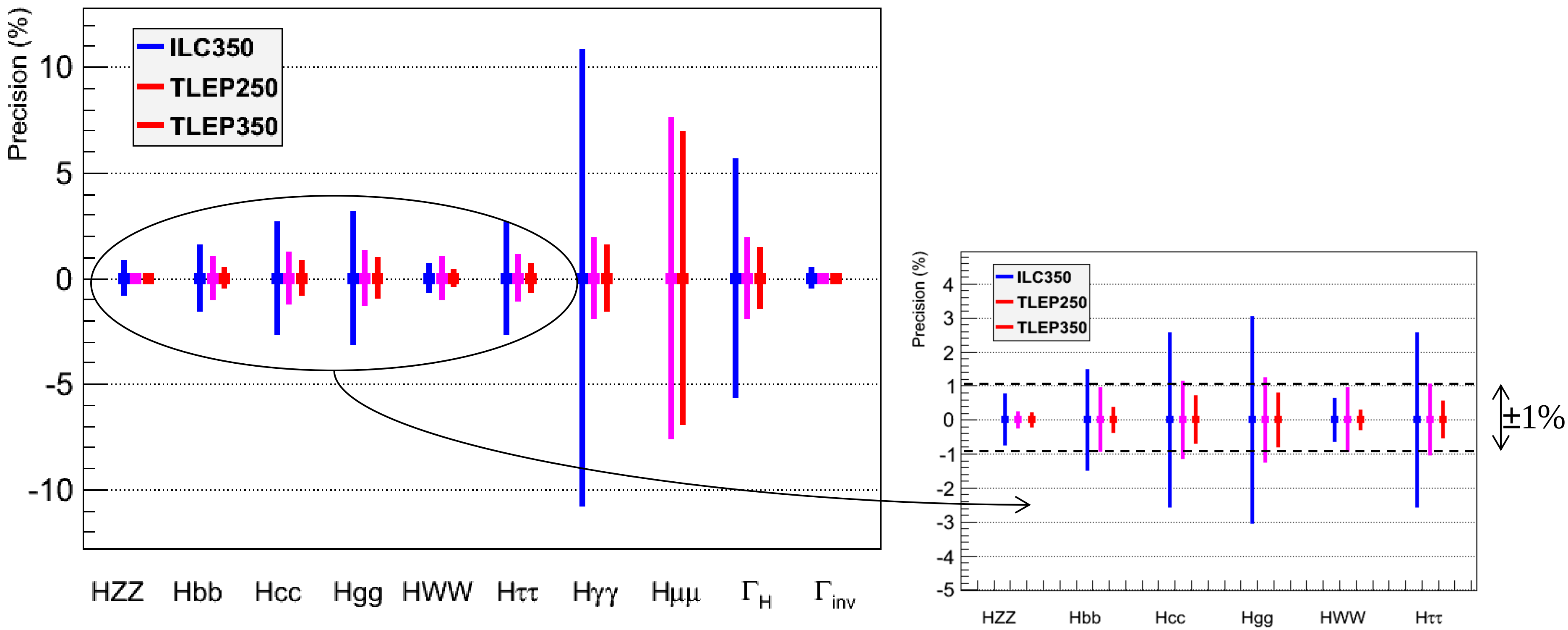


➔ **TLEP : sub-percent precision, needed for (multi)-TeV New Physics sensitivity**

“TLEP does not cover the Physics Case” (7)

- **Same conclusion when Γ_H is a free parameter in the fit**
  - **Plot shown only for ILC350 and TLEP, with an accurate width measurement**

$$\sigma_{HZ} \propto g_{HZZ}^2, \text{ and } \sigma_{HZ} \times \mathrm{BR}(H \rightarrow XX) \propto g_{HZZ}^2 g_{HXX}^2 / \Gamma_H$$



➔ **TLEP : sub-percent precision, adequate for NP sensitivity beyond 1 TeV** [19]

"TLEP does not cover the Physics Case" (8)

Table 2.1: Expected performance on the Higgs boson couplings from the LHC and e^+e^- colliders, as compiled from the Higgs Factory 2012 workshop. CLIC numbers from Ref [11-12].

Accelerator → Physical Quantity ↓	**LHC** 300 fb^{-1} /expt	**HL-LHC** 3000 fb^{-1} /expt	**ILC** 250 GeV 250 fb^{-1} 5 yrs	**Full ILC** 250+350+ 1000 GeV 5yrs each	**CLIC** 350 GeV (500 fb^{-1}) 500 GeV (500 fb^{-1}) 1.4 TeV (2 ab^{-1}) 5 yrs each	**LEP3, 4 IP** 240 GeV 2 ab^{-1} (*) 5 yrs	**TLEP, 4 IP** 240 GeV 10 ab^{-1} 5 yrs (*) 350 GeV 1.4 ab^{-1} 3 yrs (*)
N_H	1.7×10^7	1.7×10^8	6×10^4 ZH	10^5 ZH 1.4×10^5 Hvv		4×10^5 ZH	2×10^6 ZH
m_H (MeV)	100	50	35	35	~70	26	7
$\Delta\Gamma_H / \Gamma_H$	--	--	10%	3%	6%	4%	1.3%
$\Delta\Gamma_{inv} / \Gamma_H$	Indirect (30%?)	Indirect (10% ?)	1.5%	1.0%	--	0.35%	0.15%
$\Delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$	6.5 – 5.1%	5.4 – 1.5%	--	5%	N/A	3.4%	1.4%
$\Delta g_{Hgg} / g_{Hgg}$	11 – 5.7%	7.5 – 2.7%	4.5%	2.5%	N/A	2.2%	0.7%
$\Delta g_{Hww} / g_{Hww}$	5.7 – 2.7%	4.5 – 1.0%	4.3%	1%	1%	1.5%	0.25%
$\Delta g_{HZZ} / g_{HZZ}$	5.7 – 2.7%	4.5 – 1.0%	1.3%	1.5%	1%	0.65%	0.2%
$\Delta g_{HHH} / g_{HHH}$	--	< 30% (2 expts)	--	~30%	~20%	--	--
$\Delta g_{H\mu\mu} / g_{H\mu\mu}$	< 30%	< 10%	--	--	15%	14%	7%
$\Delta g_{H\tau\tau} / g_{H\tau\tau}$	8.5 – 5.1%	5.4 – 2.0%	3.5%	2.5%	3%	1.5%	0.4%
$\Delta g_{Hcc} / g_{Hcc}$	--	--	3.7%	2%	4%	2.0%	0.65%
$\Delta g_{Hbb} / g_{Hbb}$	15 – 6.9%	11 —2.7%	1.4%	1%	2%	0.7%	0.22%
$\Delta g_{Htt} / g_{Htt}$	14 – 8.7%	8.0 – 3.9%	--	15%	3%	--	30%

[20]

"TLEP does not cover the Physics Case" (9)

- A slide from M. Peskin at the 3rd TLEP/LEP3 Worskshop (10-Jan-2013)

The 80 km tunnel envisioned for TLEP can also host a hadron collider (TLHC). This might well be the future of particle physics in Europe.

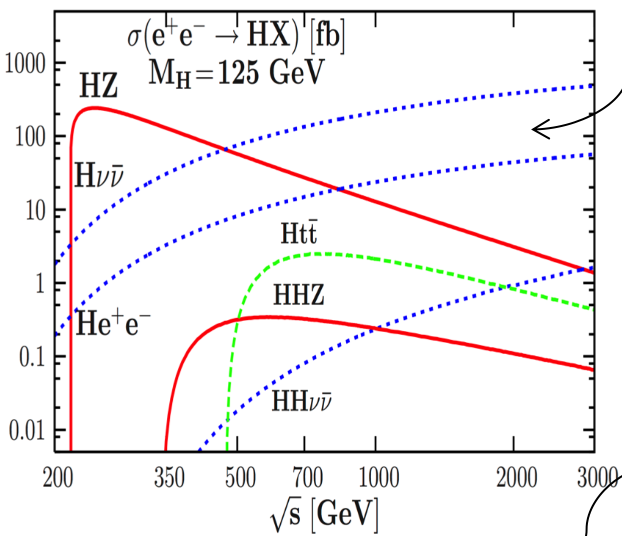
I will now discuss the estimates of Higgs measurement capabilities of these machines and the conversion of those estimates to measurement errors on the Higgs couplings.

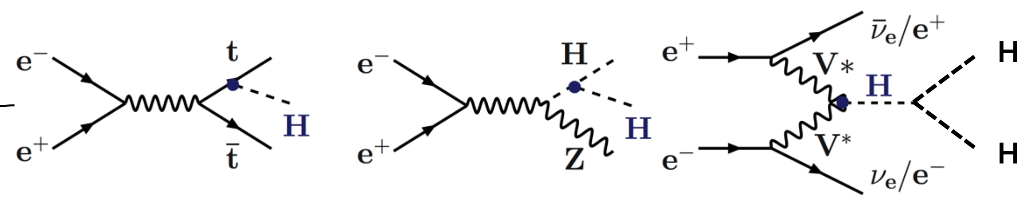
It will be obvious that - weighting all claims equally - TLEP has the best capabilities. It has the highest luminosity, can plausibly support multiple detectors, and can reach energies well above the Higgs threshold. In the following, I will omit the comparison with TLEP in the figures. The final errors would in any event be tiny on the graphs that I will show. These are given in a table at the end of the lecture.

"We need a machine upgradeable beyond 350 GeV" (2)

- **All existing proposals have access to larger √s** [25]
  - **To discover New Physics in a direct manner**
  - **To measure more difficult Higgs couplings : g_{Htt} and g_{HHH}**
    - **ILC350 can be upgraded to ILC500/ILC1TeV, or even to CLIC (3 TeV) [600 MW!]**
    - **LEP3 can be upgraded to (or preceded by) HE-LHC (33 TeV)**
    - **TLEP can be upgraded to VHE-LHC (100 TeV)**

Cross sections in e⁺e⁻ collisions



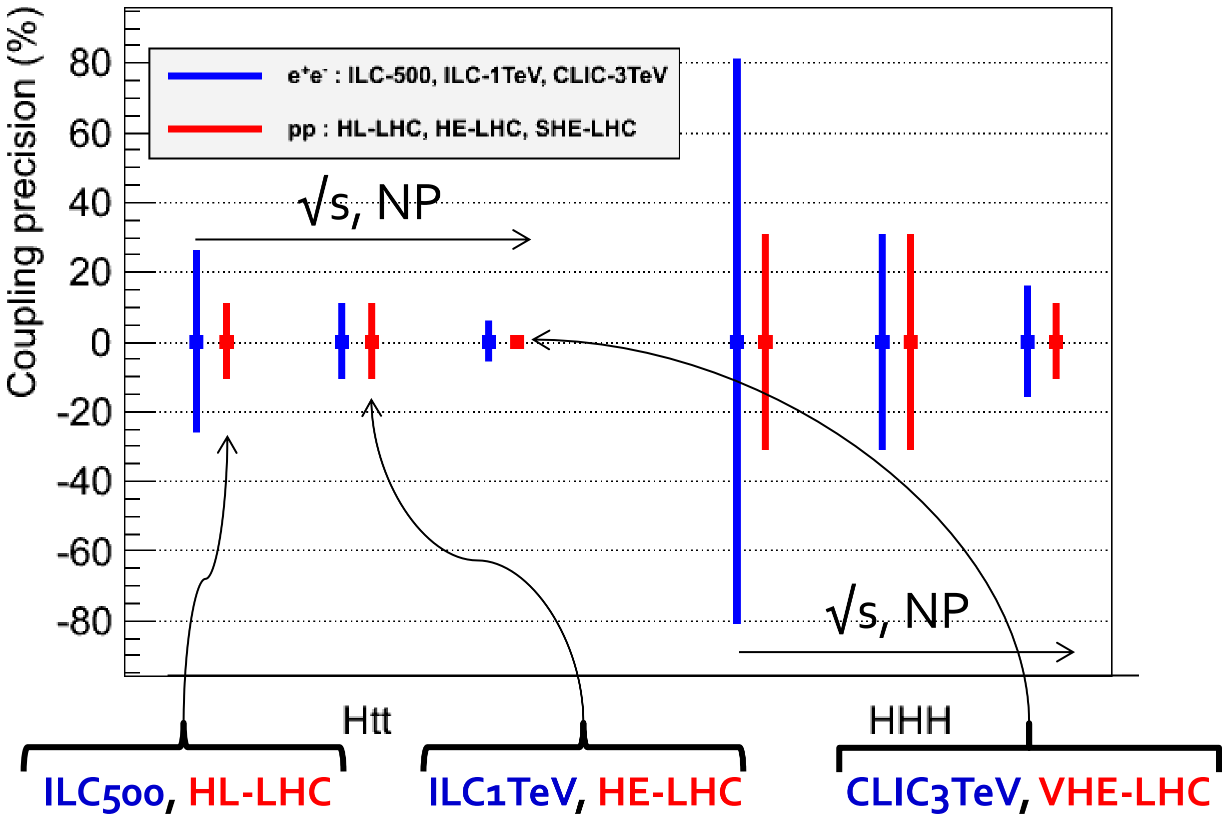


Cross sections in pp collisions

	σ(14 TeV)	R(33)	R(40)	R(60)	R(80)	R(100)
ggH	50.4 pb	3.5	4.6	7.8	11.2	14.7
VBF	4.40 pb	3.8	5.2	9.3	13.6	18.6
WH	1.63 pb	2.9	3.6	5.7	7.7	9.7
ZH	0.90 pb	3.3	4.2	6.8	9.6	12.5
ttH	0.62 pb	7.3	11	24	41	61
HH	33.8 fb	6.1	8.8	18	29	42

"We need a machine upgradeable beyond 350 GeV" (3)

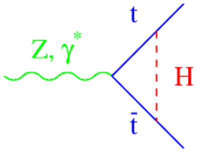
- **Summary for Htt and HHH couplings** [11,12,26,27,28]
  - Other Higgs couplings benefit only marginally from high energy

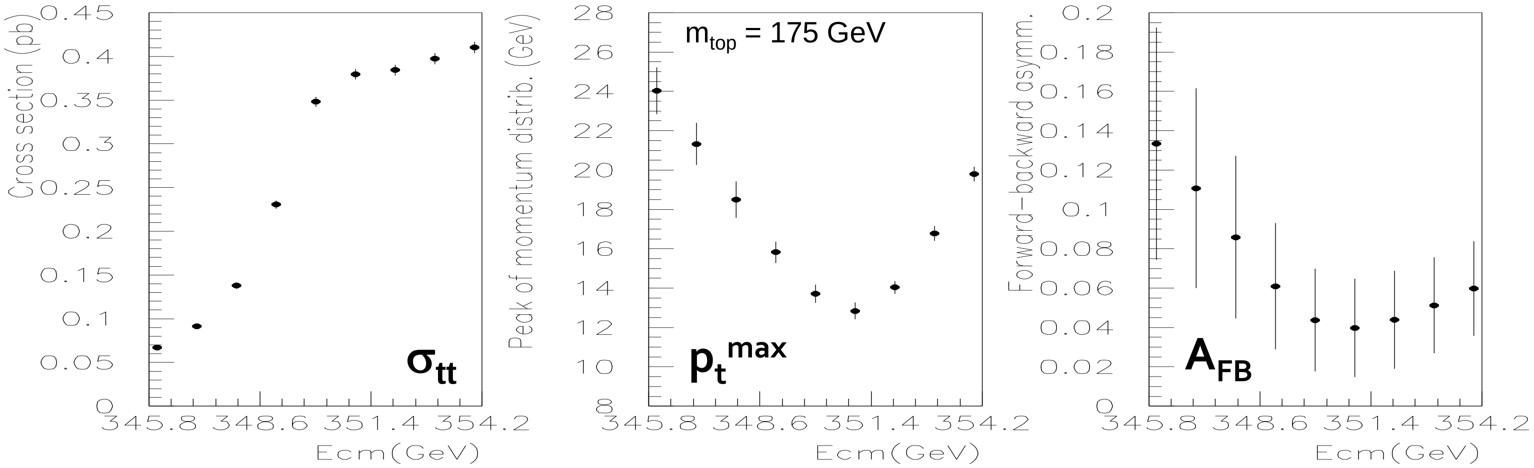


- For similar/larger new physics reach, ttH/HHH precision with pp better than e^+e^-
  - ➔ ILC500 does not cover the (new) physics case – ILC1TeV vastly insufficient

Top Measurements at √s ~ 350 GeV (1)

- **Scan of the tt threshold**
  - Observables σ_{tt}, A_{FB} and $<p_t^{max}>$ sensitive to m_{top}, Γ_{top}, and λ_{top} (ttH Yukawa coupling)
    - Experimental precision (for ILC)
      - ➔ No beamstrahlung at TLEP is a advantage





    - Sensitivity with 300 fb^{-1} for ILC (expected to be better for TLEP)

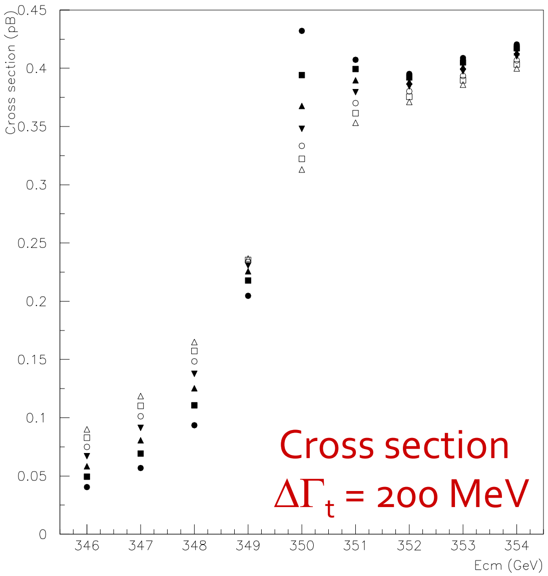
Δm_{top}	$\Delta\Gamma_{top}$	$\Delta\lambda_{top}/\lambda_{top}$
30 MeV (0.02%)	35 MeV (3%)	30%

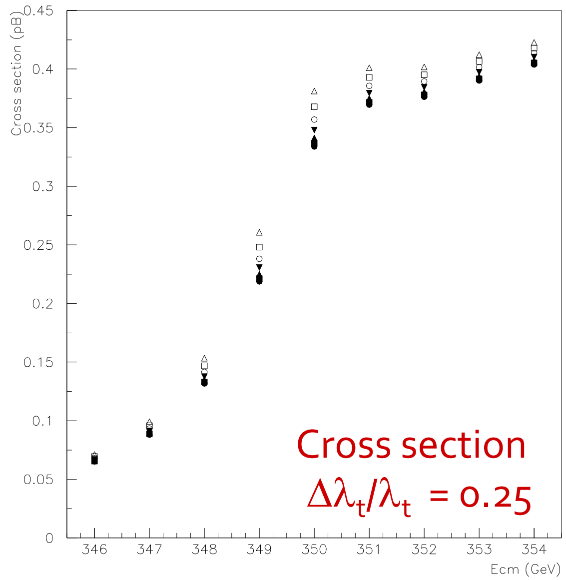
[21]

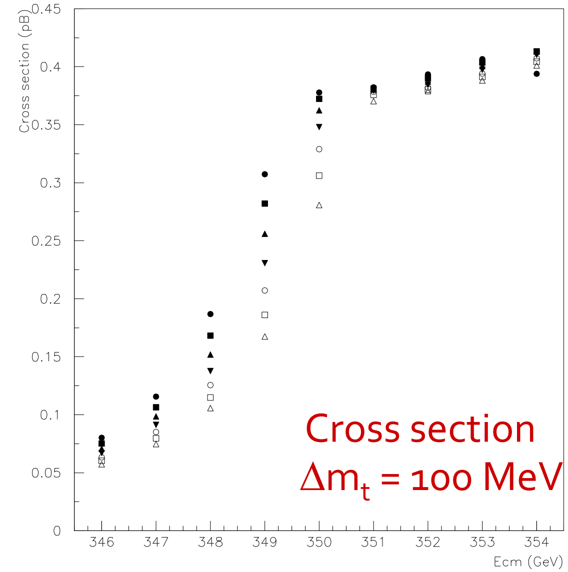
    - Studies of rare top decays

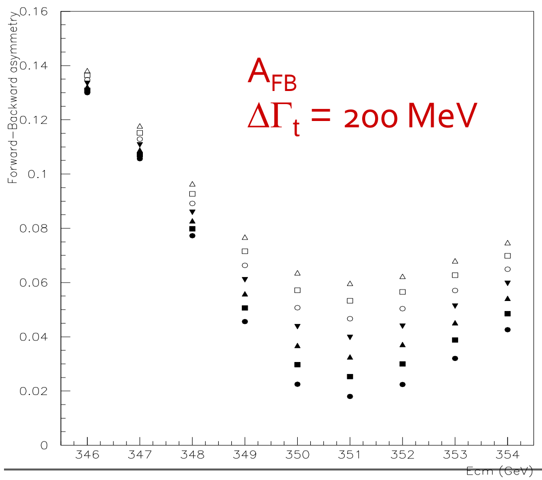
Top Measurements at √s ~ 350 GeV (2)

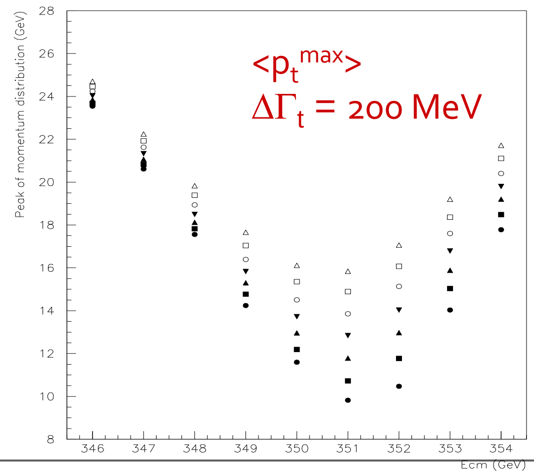
- Examples of sensitivities (for ILC-like beamstrahlung)









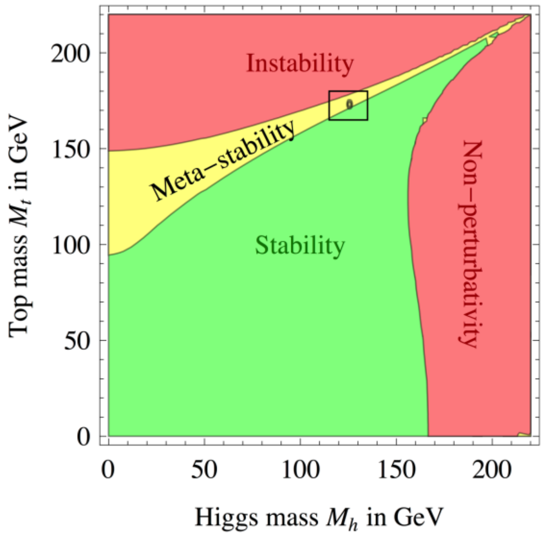


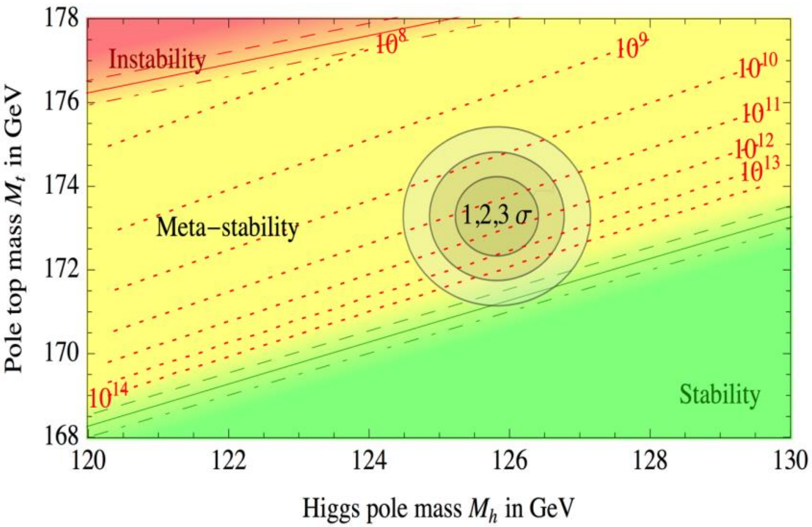
(m_{top} = 175 GeV)

[21]

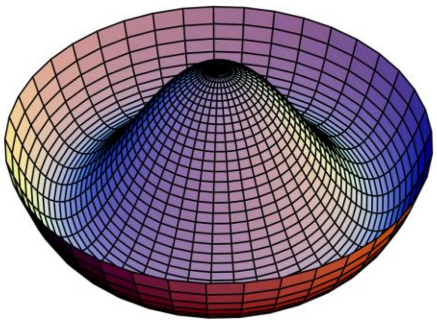
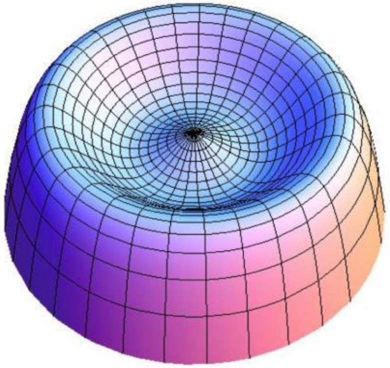
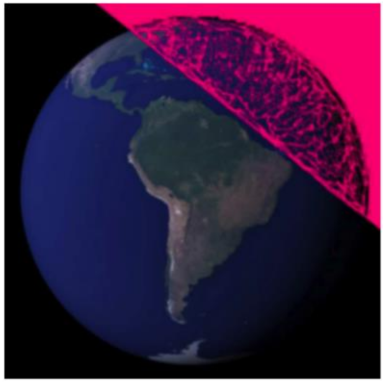
Top Measurements at √s ~ 350 GeV (3)

- **Measurement of m_{top} perhaps more important than originally thought**





Meta-stability favoured at 2σ : need to know m_{top} from e^+e^-

 →  → 

Design Study : 2013 – 2018 (1)

- Long list of things to do (not exhaustive)
  - Propose a sound detector design
    - With performance between those of CMS and a ILC detector
      - ➔ Suited for Z, W, H and top studies (with feedback from physics analyses)
    - Particle-Flow friendly
    - Able to take data at the Z pole (30 kHz of Z, 120 kHz of Bhabha)
      - ➔ Forward region, luminosity measurement, …
      - ➔ Work out the offline and online computing challenges
    - Upgradeable for VHE-LHC
  - Develop a parametric, a fast, and a full (?) simulation of this detector
    - And an event reconstruction for the fast (and full) simulations
      - ➔ Can use CMS or ATLAS for a while, but then need to move on
  - Develop a common analysis framework
  - Understand experimental environment: beam backgrounds, machine/detector interface
    - e.g., Beamstrahlung, …
    - e.g., By-passes for the accelerator ring

Design Study : 2013 – 2018 (2)

- **Long list of things to do (not exhaustive, cont'd)**
  - Repeat and improve Higgs properties measurements, develop missing ones
    - σ_{HZ}, σ_{HZ} x BR, $\sigma_{WW\to H}$, $\sigma_{WW\to H}$ x BR, invisble decays, total width, mass, …
    - Investigate ttH and HHH coupling in pp collisions at 100 TeV
    - Make a global fit towards coupling determination
  - Develop analyses for the top properties measurements
    - Cross section, AFB, momentum distribution, exclusive decays, other ?
    - Global fit towards mass, width, Yukawa coupling, α_s, …
  - Assess the precision of EW measurements at the Z pole and WW threshold
    - See Alain's talk
  - Global fit of all centre-of-mass energies outcome
  - Improve the theoretical SM predictions to match expected experimental precisions
    - Higgs branching fractions
    - Electroweak observables
    - Develop accurate Monte Carlo generators accordingly
  - Evaluate the effect of new physics, in a few benchmark models
    - Assess the overall sensitivity of TLEP

Design Study : 2013 – 2017

TLEP design study –preliminary structure for discussion

Institutional board

Steering group
web site, mailing lists, speakers board, etc..

International Advisory board

Accelerator

1. Optics, low beta, alignment and feedbacks
2. Beam beam interaction
3. Magnets and vacuum
4. RF system
5. Injector system
6. Integration w/(SHE)-LHC
7. Interaction region
8. Polarization &E-calib.
9. Elements of costing

Experiments

1. H(126) properties
2. Precision EW measurements at the Z peak and W threshold
3. Top quark physics
4. Experimental environment
5. Detector design
6. Online and offline computing

Physics

1. Theoretical implications and model building
2. Precision measurements, simulations and monte-carlos
3. Combination + complementarity with LHC and other machines ; global fits