Higgs-Hunting 2012,
18-20 July, Orsay-Paris

ILC and HL-LHC potentials

(focus on the Higgs sector !)

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Outline

- "Higgs" discovery → deep impact on Physics Case for future accelerator planning !
  - why a 126-GeV resonance is particularly interesting
  - new set up for studies on future-collider potential

- High-Luminosity LHC (HL-LHC) project and potential
- Linear Collider (LC) projects and potential: ILC (+CLIC)

Other options of interest for H physics not considered here :

- ring-based e+e- collider (see next talk): LEP3, superTristan, DLEP
  → partial overlap with following LC discussion
- LHeC [add a linac (or e^-ring) to LHC → e^-p coll.s], HE-LHC (pp,33 TeV)
- $\gamma\gamma$ colliders, $\mu\mu$ colliders

A few references

- A. De Roeck, et al,"From the LHC to Future Colliders", Eur. Phys. J. C 66, 525 (2010)
- Gianotti, Mangano, Virdee et al.,"Physics potential and experimental challenges of the LHC luminosity upgrade", Eur. Phys. J. C 39, 293–333 (2005)
- ATLAS Collaboration, TDR, arXiv:0901.0512
- CMS Collaboration, Physics TDR, CERN/LHCC/2006-021, June 2006

+ reports prepared by Linear Collider Community (>20 years work):

- TESLA Technical Design Report, TESLA Report 2001-23
- ILC Reference Design Report "Physics at the ILC", arXiv:0709.1893
- ILD Letter of Intent, arXiv:1006.3396
- SiD Letter of Intent, arXiv:0911.0006
- CLIC Conceptual Design Report "Physics and Detectors at CLIC", arXiv:1202.5940
- Input from LC community to European Strategy Process, in preparation

(many hundreds of people involved from many dozens of Institutions worldwide !)

my apologies to all whose results I am showing without explicitly quoting their contribution !

Physics Case for future colliders

- we are standing at a "turning-point" in the assessment of future (post-LHC) collider projects (under scrutiny from late 80's!) :

  ➜ narrow resonance at m~126 GeV (compatible with SM Higgs) just discovered at LHC !

- ➜ a collider planned today should better cover (also) its physics as thoroughly as possible !

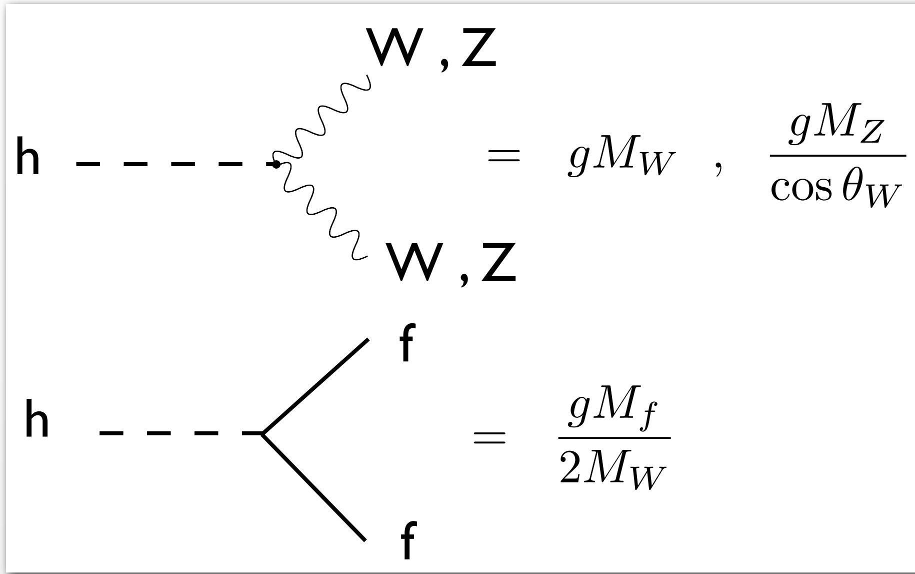
> *- is it really a Higgs boson ?*
> *- is it fundamental (➜ Susy ?) or composite ?*
> *- how many doublets ? singlets? charged H's ?*

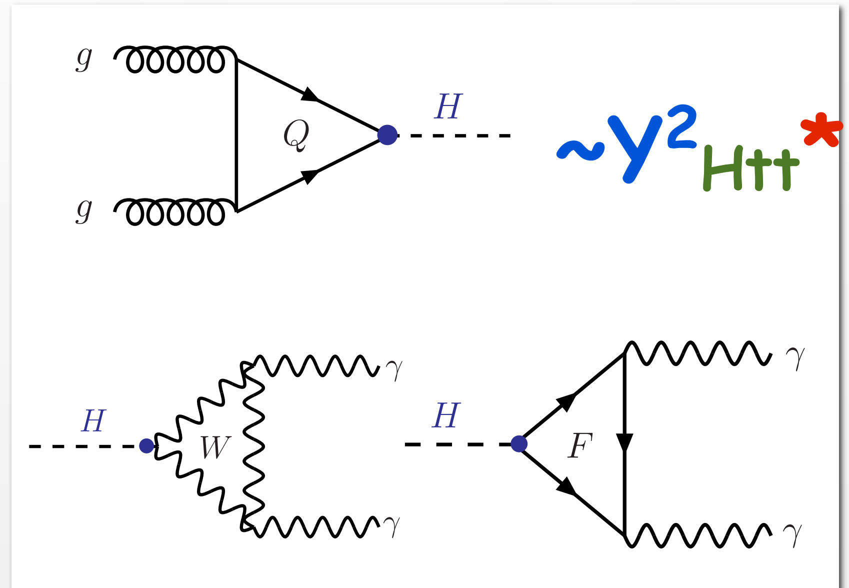
- LHC will make a lot of progress in this direction in a few years...

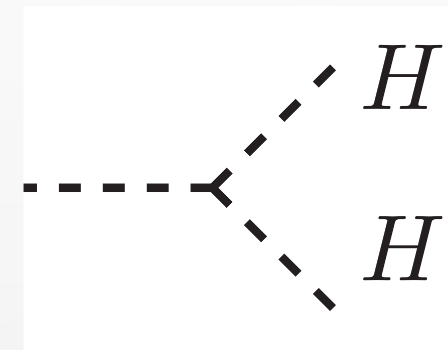
  Should we look further ?

is the LHC signal really a SM Higgs ?

- test H couplings to vector bosons (EWSB), fermions and selfcouplings







$\sim \lambda v$

$m_H \sim 126$ GeV

$\Gamma_H = 4.2$ MeV

$\lambda = (m_H/v)^2/2 = 0.131$

$H \to WW^*$ 23%*

$H \to ZZ^*$ 2.9%*

$H \to bb$ 56%*

$H \to cc$ 2.8%

$H \to \tau\tau$ 6.2%*

$H \to \mu\mu$ 0.21‰

$H \to gg$ 8.5%*

$H \to \gamma\gamma$ 2.3‰*

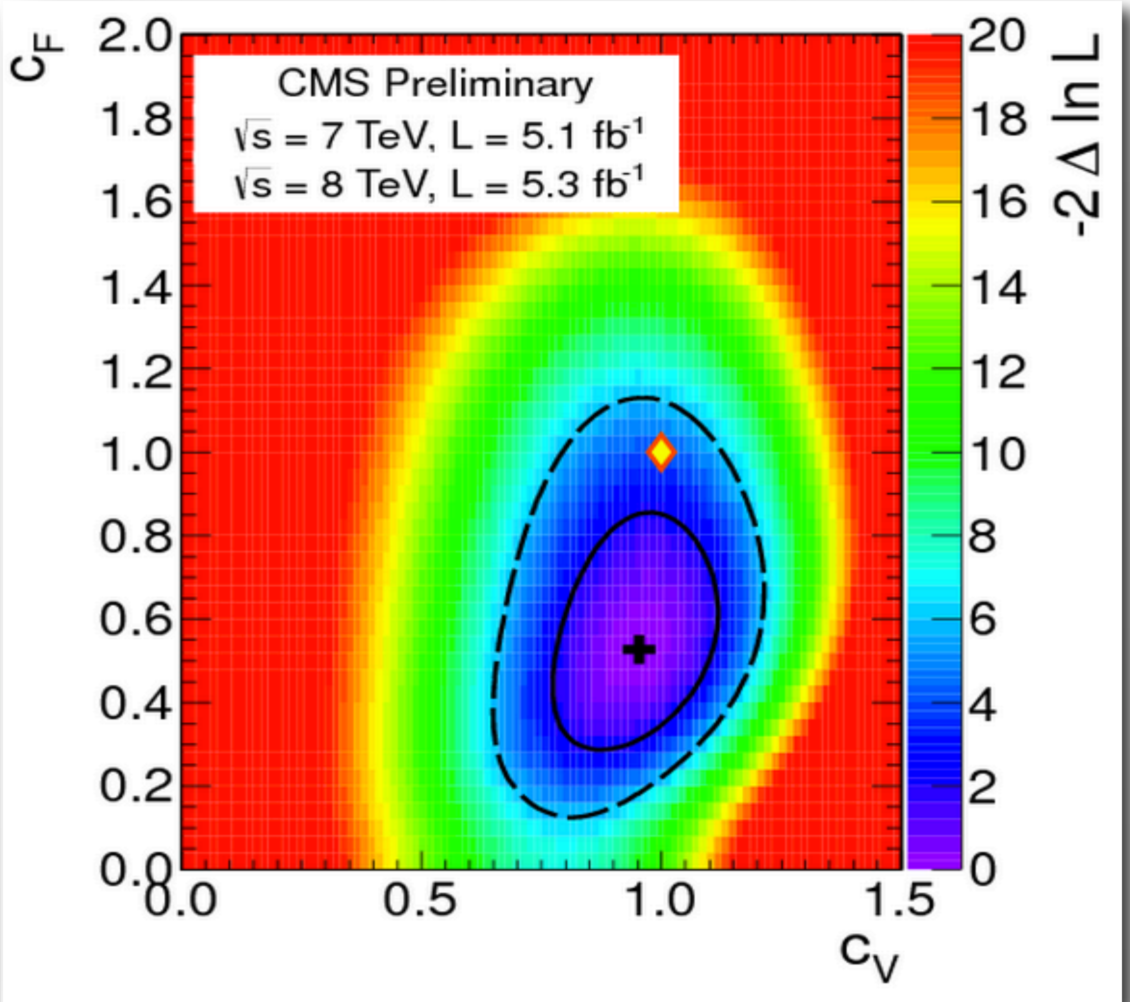
$H \to \gamma Z$ 1.6 ‰*

new set of reference SM parameters

many couplings accessible at LHC (*) !

Direct g_{HXX} determination : what we know today !

$C_F = g_{Hff} / g_{SM}$
$C_V = g_{HVV} / g_{SM}$
universal modifiers of fermion and vector H couplings



agrees with SM Higgs within 95% CL (best fit at **C_V~1 , C_F~ 0.5**)

- starting point of new exciting chapter of experimental measurements (regardless of possible further new-state discoveries at the LHC !)

note: one-loop decays ($H\to\gamma\gamma$) and production ($gg\to H$) are very sensitive to new heavy degrees of freedom that do not decouple !

- new generation of Precision Tests opens up today with excellent sensitivity to BSM effects (→ cf. EWPT's at LEP)
- ability to reach accuracies on g_{HXX}'s as large as possible crucial !

High Luminosity (HL) LHC upgrade

- after 2021, increase lumi by factor ~5 ($10^{34} \rightarrow 5.10^{35}$ $cm^{-2}s^{-1}$) then run for ~ 10 years collecting ~3000 fb^{-1}/exp
  - anything benefitting from statistics improves (e.g. coupl.s accuracy)!
  - rare processes
  - larger phase space for heavy states by (20-40)%
  - Higgs sector more accurately
  - increased precision in g_{HXX}, Higgs pairs (g_{HHH} ???)
  - $H \rightarrow \gamma Z \rightarrow \gamma \ell\ell$ (~10 σ in SM), $H \rightarrow \mu\mu$ (~7 σ in SM)
- final (updated) detector performance not yet well known !!!
  → hard to estimate now final reach ; in particular, major detector upgrade needed for Higgs physics (pile-up,b-tagging...); studies in Atlas/CMS in view of European Strategy Update in progress...

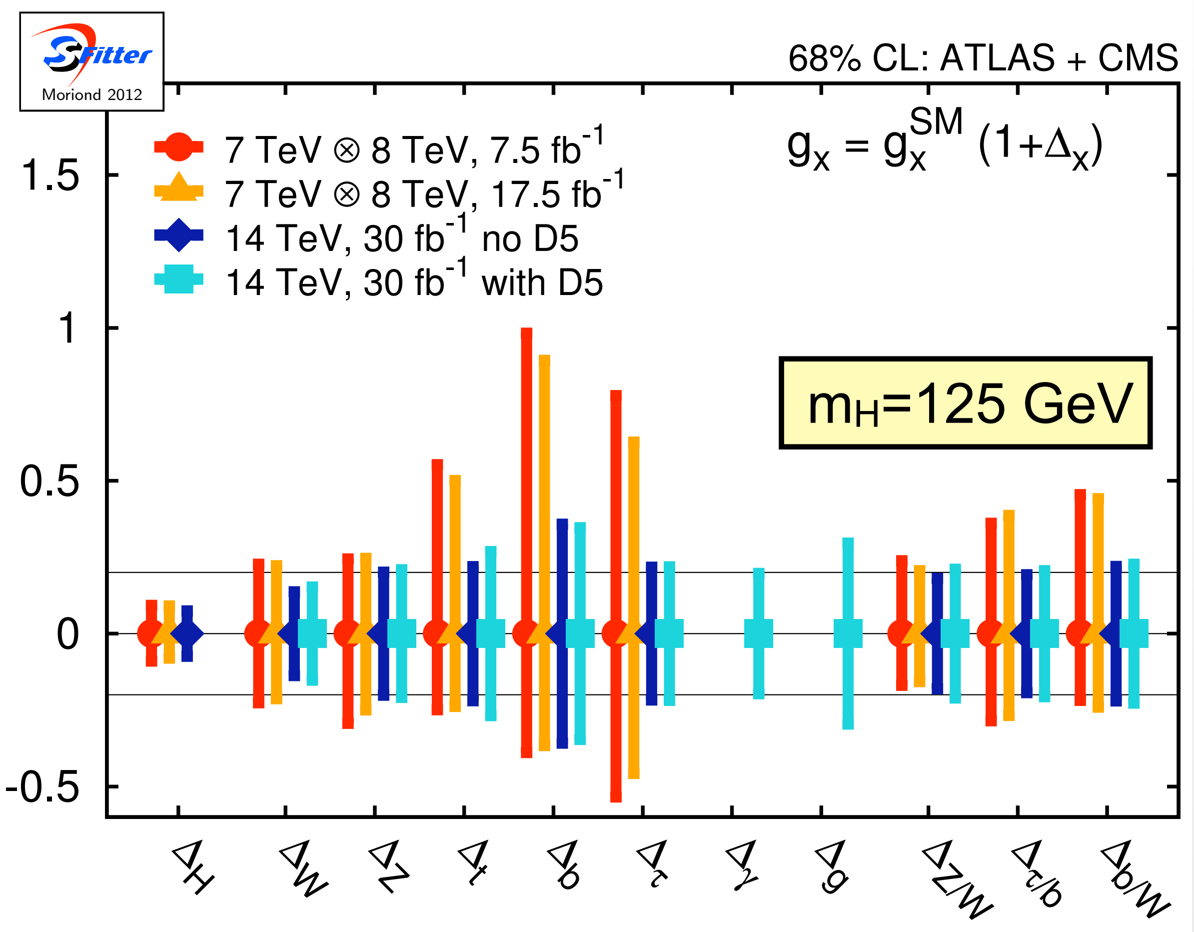
g_{HXX} analysis model dependent at pp colliders !

$$B\sigma(p\bar{p} \to h \to X_{\rm SM}) \equiv \sigma(p\bar{p} \to h)\frac{\Gamma(h \to X_{\rm SM})}{\Gamma_{\rm total}}$$

- event rates depend on 3 quantities !
- only ratios of rates (➜ ratios of Br_x's or Γ_x's) are model independent !
- at HL LHC : $\Delta\frac{\Gamma_W}{\Gamma_{Z,t}}, \sim 10\,\%$ $\Delta\frac{\Gamma_W}{\Gamma_b}, \sim 25\,\%$ $\Delta\frac{\Gamma_W}{\Gamma_\tau}, \sim 30\,\%$ hep-ph/0204087
- a common rescaling of all couplings can be accommodated by an extra invisible (=non-detected) contribution to Γ_{total}
- can get tighter constraints by simplified assumptions :

  e.g. assume universal rescaling factor for all g_{HXX} (could reflect mixing in a Higgs portal or strongly int. nature of a composite Higgs) ➜

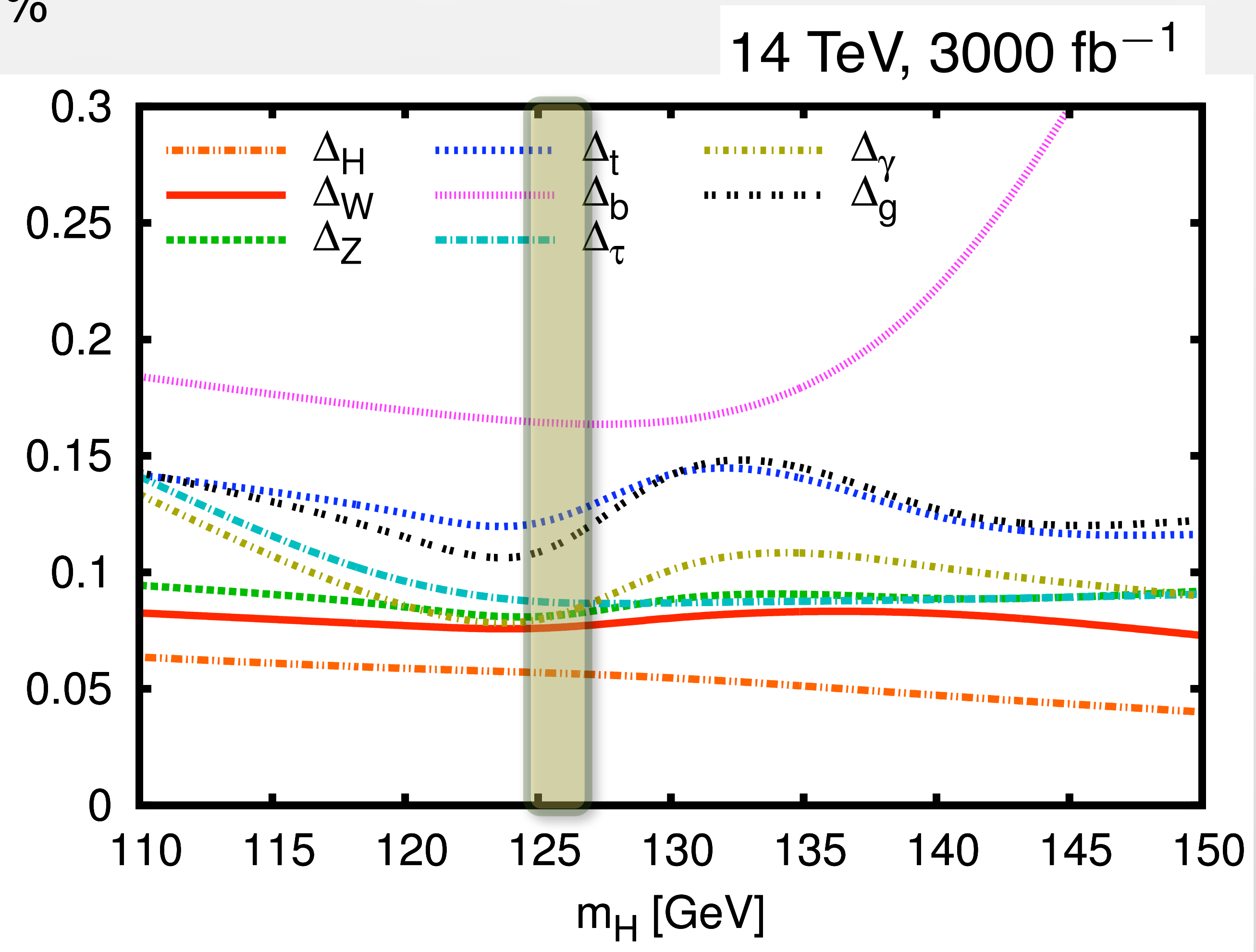
SFitter assessment for HL LHC potential



} ± 20%

map data onto weak-scale effective theory with general g_{HXX} :

$$g_x = (1 + \Delta_x)\ g_x^{\rm SM}$$



arXiv:1205.2699

1σ LHC sensitivity at 3 ab^{-1}:

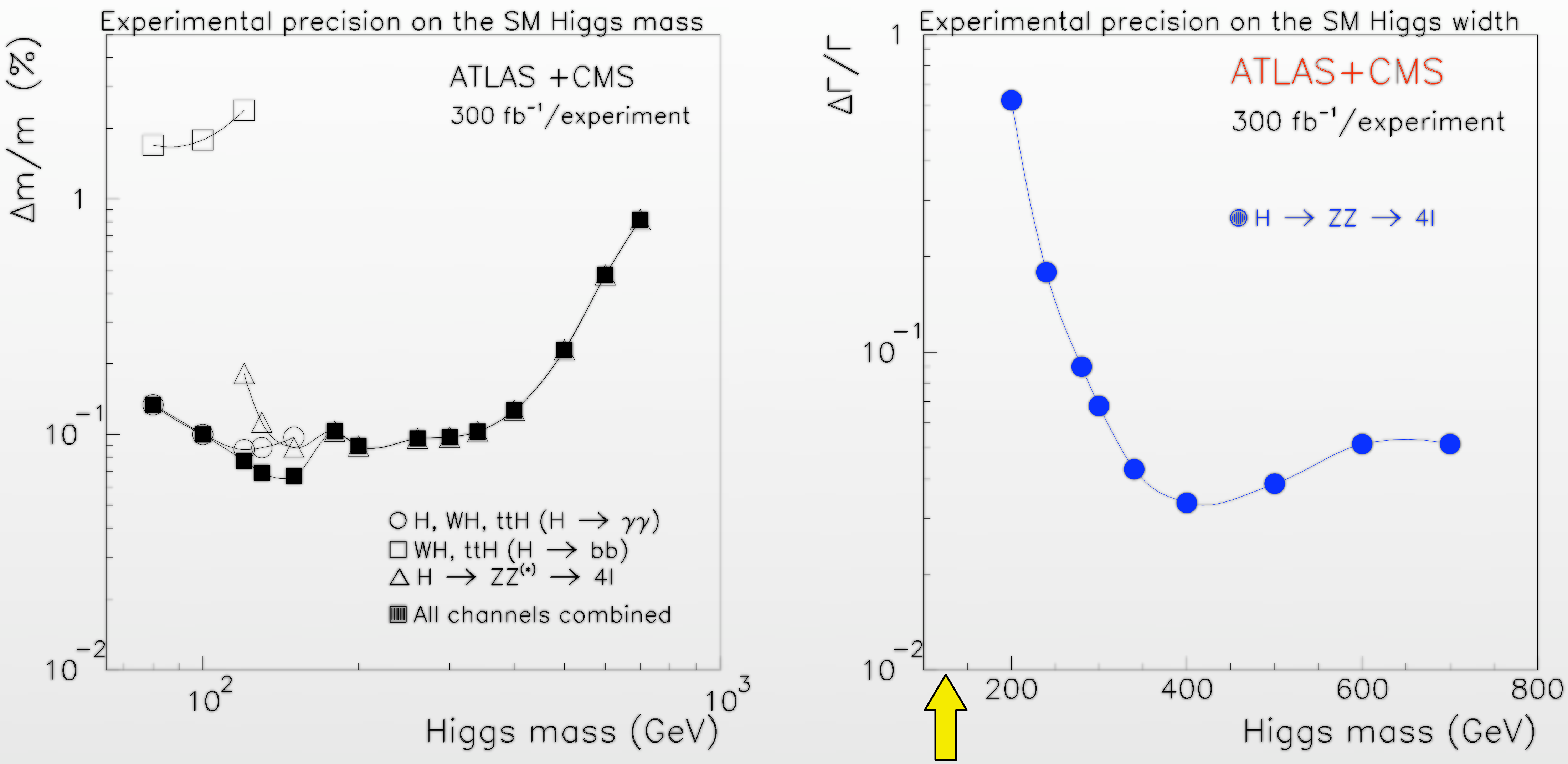
8% on g_V and g_γ

9% on g_τ

13% on g_{top}

17% on g_b

Δm_H and $\Delta \Gamma_H$, Spin and CP (LHC, 300 fb^{-1})



$\Delta m_H/m_H \sim 1‰$

Γ_H not accessible at 126 GeV !

- measure Spin and CP properties through final state distributions
  [CMS,Atlas already exploiting Higgs Spin for bckgr rejection (MELA)]
- mixing of different CP states could be difficult !

e^+e^- Linear Collider (LC) Projects

$L \sim$ a few $10^{34} cm^{-2}s^{-1}$

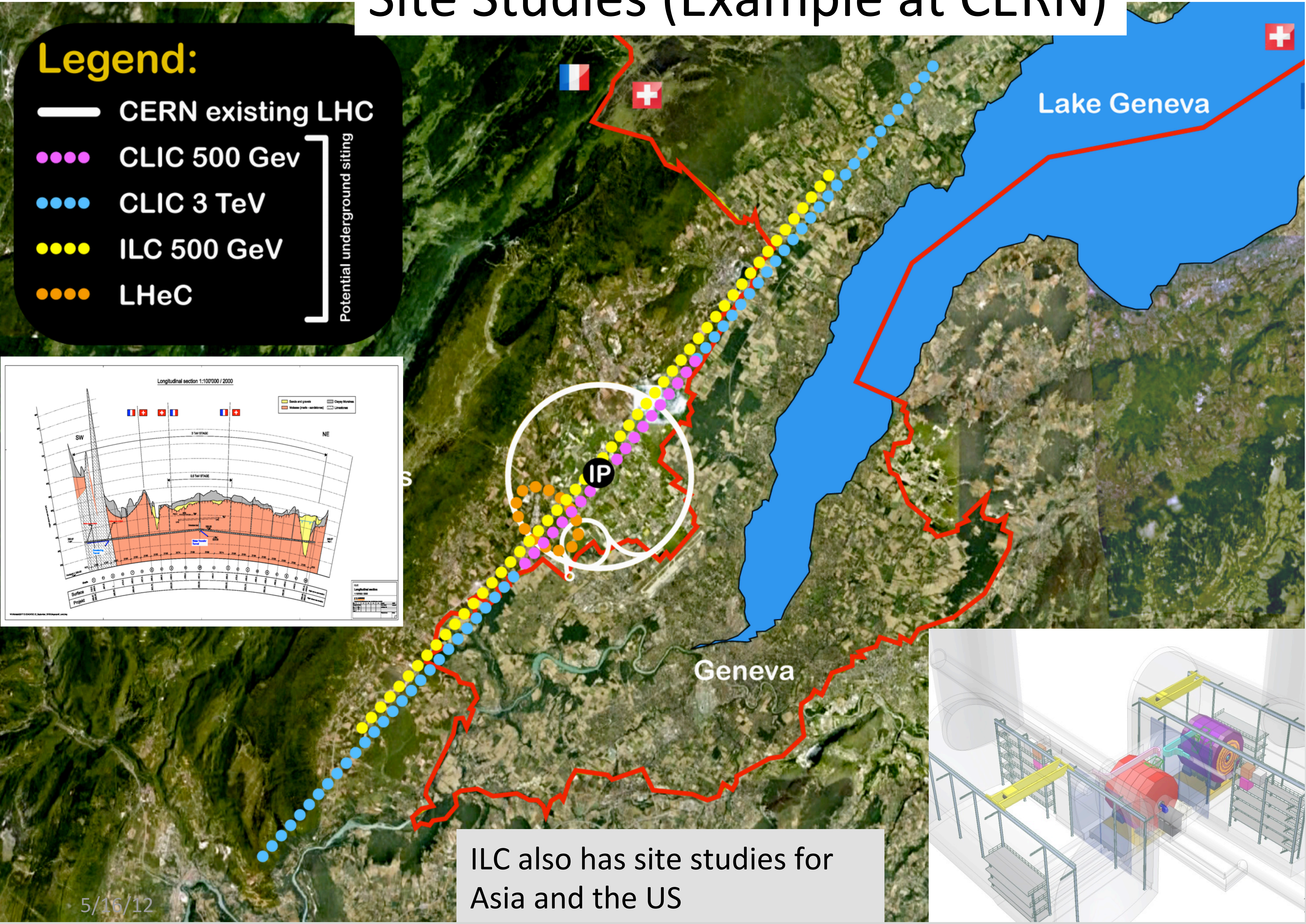
- **ILC (International Linear Collider)**
  - superconducting RF Cavities ➜ accelerat. gradient 31.5 MV/m (proven)
  - aimed at E_{cm} = 500 GeV ➜ 31 Km; possible extension to 1 TeV
  - RDR in 2007; TDR and Detailed Baseline Designs released in 2013; led by Global Design Effort since 2005

E_{cm} tunable, beam polarization...
a lot of flexibility !

- **CLIC (Compact Linear Collider)**
  - normal conducting accelerating structure : two-beam scheme (Drive Beam supplies RF power) ➜ gradient 100 MV/m (in development)
  - from Higgs/top threshold up to 3 TeV (upgradable in steps) Staged Construction ;
    E_{cm} = 0.5 TeV ➜ 14 Km, 1.4 TeV ➜ 25 Km, 3 TeV ➜ 48 Km
  - strong accelerator R&D program at CERN (CTF3)
  - currently at CDR stage (Physics and Detectors, http://arxiv.org/abs/1202.5940)

New (unified) Linear Collider (LC) organization structure is currently being set up, encompassing both ILC and CLIC. Will cover both LC accelerator studies and LC physics and detector studies, starting from 2013 !
(prepare the way for a single linear collider proposal...)

Site Studies (Example at CERN)



ILC also has site studies for Asia and the US

ILC site proposal by Japan

main campus of "ILC science city"

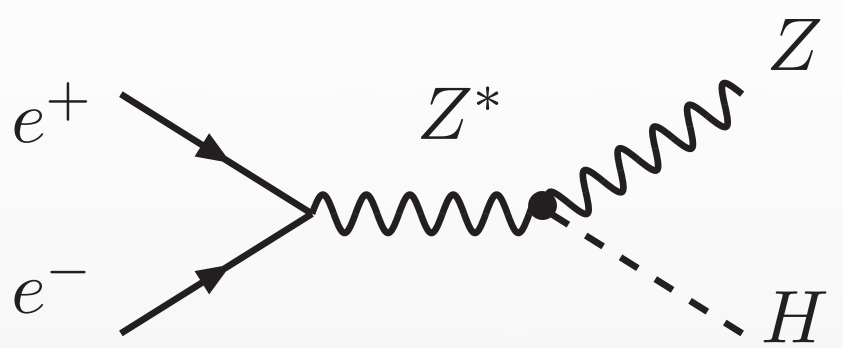
"The future vision of Tohoku with the ILC as a core facility" report presented at the Tohoku Advanced Science and Technology Study Group meeting on 10 July 2012 (Japan)

LC potential complementary to LHC / HL LHC

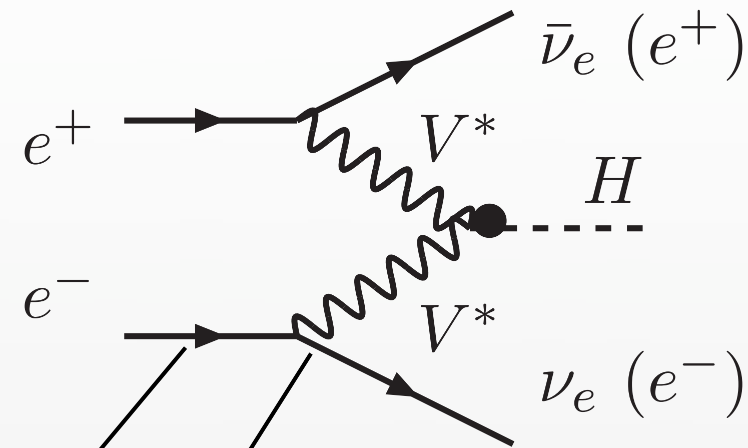
- clean experimental conditions !
- precision Higgs physics (SM and BSM) :
  σ's, absolute BR's, g_{HXX} (model independent !), g_{HHH} (!),
  mass, total width, quantum numbers
- precision top physics (mass,width,asymmetries)
- access to weakly interacting BSM states,
  like sleptons and ew-gauginos
- could detect what is "invisible" at LHC
  (untriggered operation → could find unexpected signals that do not pass LHC trigger...)
- experimental sensitivities well understood;
  2 detector concepts: ILD and SiD (→ CLIC-variants for higher E and bkgds)
- full simulation/reconstruction done extensively (pile-up of bkgds)

most measurements at the % level !

Cross Sections (m_H=120 GeV)



$$\sigma \sim \frac{1}{s}$$

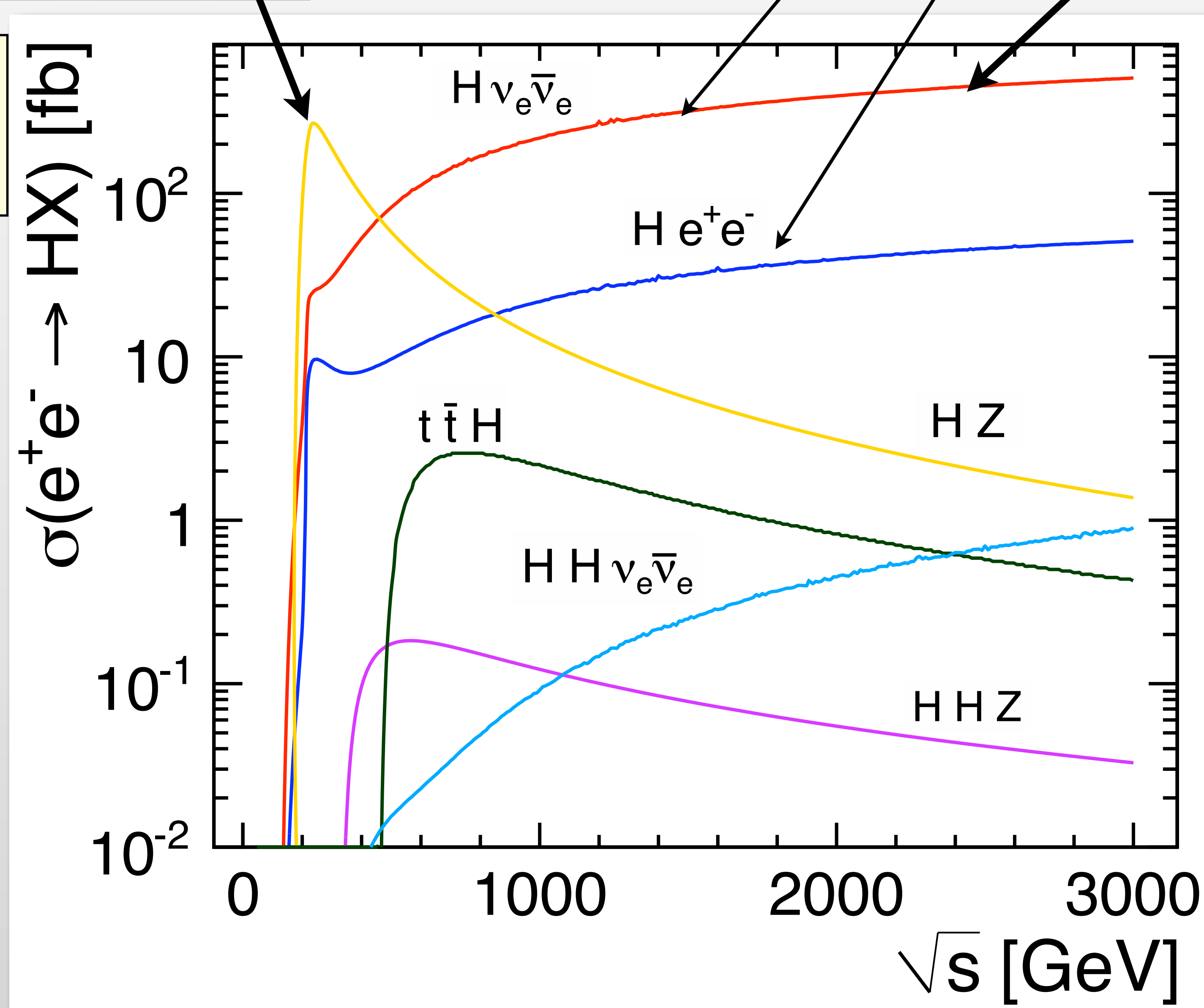


$$\sigma \sim \ln \frac{s}{m_H^2}$$

dominant from ~ threshold up to √S < 400 GeV

dominant for √S > 500 GeV

accurate reconstruction !



ZZ component easy to pin down !

$\Delta(g_{HZZ}/g_{HWW})$ < 1%

at √S > 1 TeV high statistics, access to sub-leading channels !

Expected # of Events (m_H=125 GeV)

H-strahlung vs WW-fusion ($\sqrt{S}$ ~ 250 GeV - 3 TeV)

L expected after ~5 ys

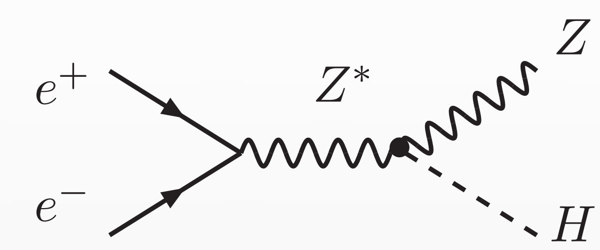
$\sqrt{S}$	250 GeV	350 GeV	500 GeV	1 TeV	1.5 TeV	3 TeV
$\sigma(e^+e^- \to ZH)$	240 fb	129 fb	57 fb	13 fb	6 fb	1 fb
$\sigma(e^+e^- \to H\nu_e\bar{\nu}_e)$	8 fb	30 fb	75 fb	210 fb	309 fb	484 fb
Int. $\mathcal{L}$	250 fb^{-1}	350 fb^{-1}	500 fb^{-1}	1000 fb^{-1}	1500 fb^{-1}	2000 fb^{-1}
# ZH events	60,000	45,500	28,500	13,000	7,500	2,000
# $H\nu_e\bar{\nu}_e$ events	2,000	10,500	37,500	210,000	460,000	970,000

expected # of events

a Linear Coll. is
a Higgs Factory !

H-strahlung allows model indep. g_{HXX} measurements

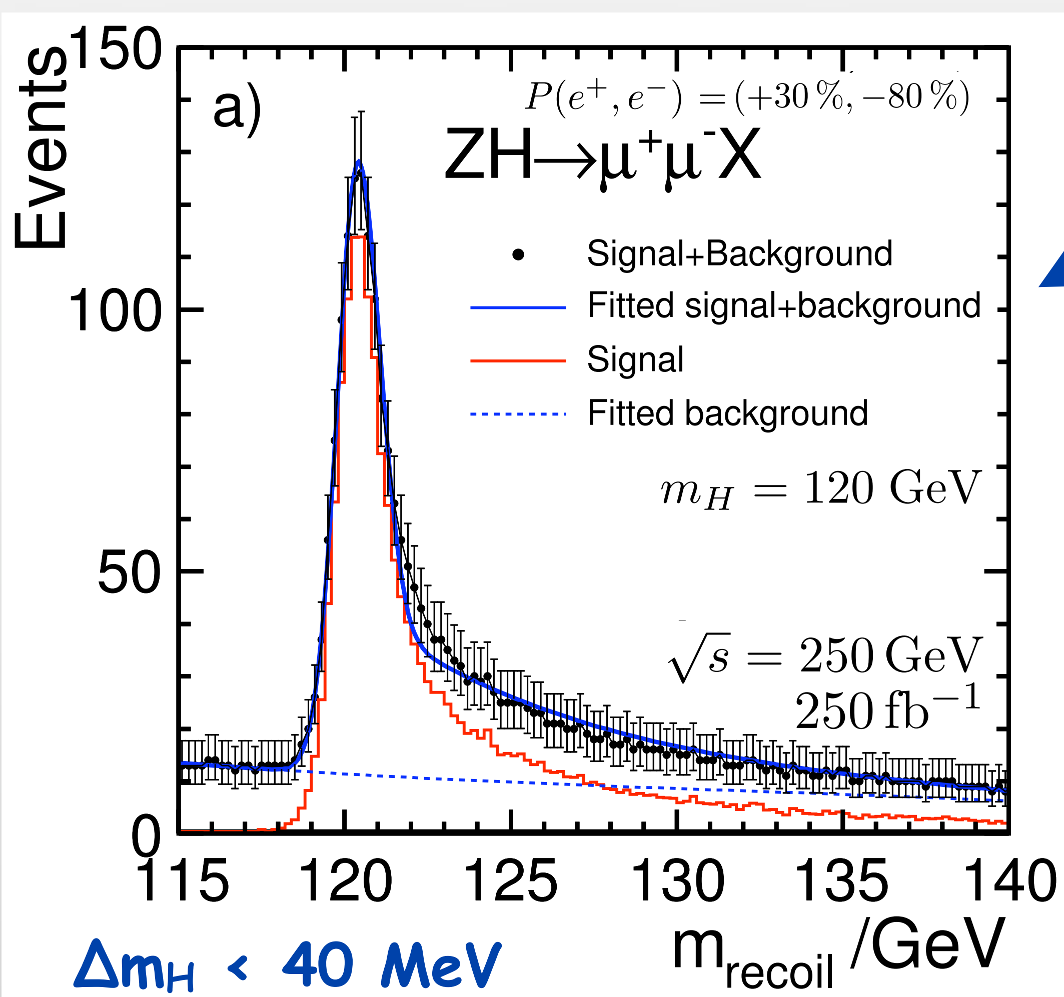
- selected by just identifying Z decay products
  → absolute σ_{tot} measurement → model indep. g_{HZZ}



- direct access to inv. H decays, H → cc, H → gg

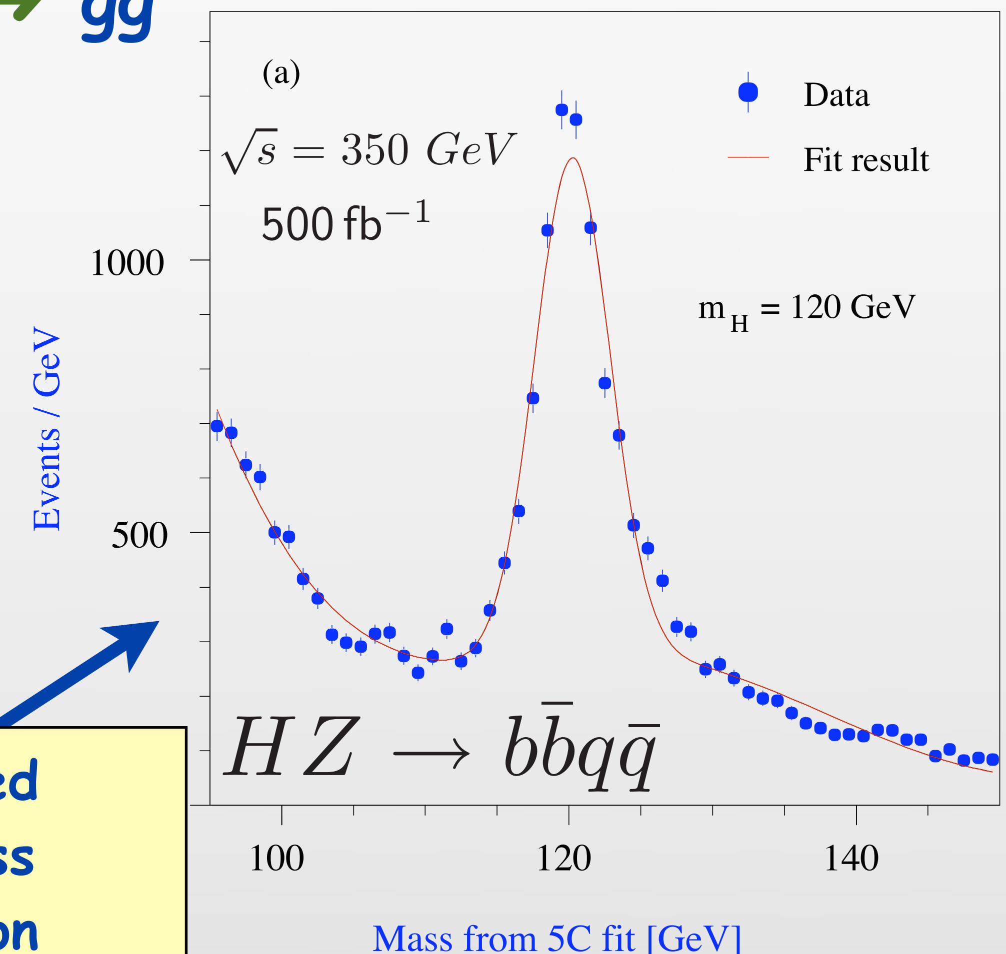
$m_H = 120$ GeV

$\sqrt{s}$	250 GeV	350 GeV
Int. $\mathcal{L}$	250 fb^{-1}	350 fb^{-1}
$\Delta(\sigma)/\sigma$	3 %	4 %
$\Delta(g_{HZZ})/g_{HZZ}$	1.5 %	2 %



Δm_H < 40 MeV

independent from H decay



constrained fit to mass distribution
→Δm_H~ 50MeV

- by identifying Higgs final states
  → absolute measurement of BR

LC precision on (~SM) BR's and g_{HXX}'s

	250 GeV	350 GeV	3 TeV
$\sigma \times Br(H \to bb)$	1.0 %	1.0 %	0.2 %
$\sigma \times Br(H \to cc)$	8 %	6 %	3 %
$\sigma \times Br(H \to \tau\tau)$	6 %*	6 %	?
$\sigma \times Br(H \to WW)$	8 %	6 %	?
$\sigma \times Br(H \to \mu\mu)$	–	–	15 %
$\sigma \times Br(H \to gg)$	9 %	7 %	?

$$m_H = 120 \text{ GeV}$$

full simulation
(* estimates ; ? ongoing studies)

from WW fusion

Δg_{HXX} includes Δg_{HZZ} from absolute σ_{ZH} measurement

	250 GeV	350 GeV	3 TeV
g_{Hbb}	1.6 %	1.4 %	2 %
g_{Hcc}	4 %	3 %	2 %
$g_{H\tau\tau}$	3 %*	3 %	?
g_{HWW}	4 %	3 %	< 2 %
$g_{H\mu\mu}$	–	–	7.5 %
g_{HWW}/g_{HZZ}	?	?	< 1 %*

$\Delta g_{HXX} < 5$ %

including ZH results at low $\sqrt{s}$

total width determination

- 2 possible procedures, both using direct measur. of $Br(H \to WW^*)$

$$\left.\begin{array}{r} \sigma(e^+e^- \to \nu\nu H) \\ g_{HZZ},\ (\frac{g_{HWW}}{g_{HZZ}} = \cos\theta_W) \end{array}\right\} \Rightarrow \quad g_{HWW} \quad \Rightarrow \quad \Gamma(H \to WW^*)$$

$$\Longrightarrow \qquad \Gamma_H = \frac{\Gamma(H \to WW^*)}{Br(H \to WW^*)}$$

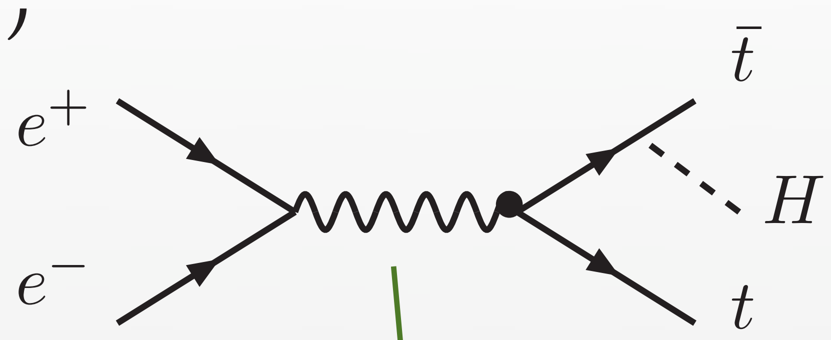
- with either approach $\Longrightarrow$

$$\Delta\Gamma_H \sim 6\,\% \quad \text{at} \quad \sqrt{s} = 500 \ \ \text{GeV}$$

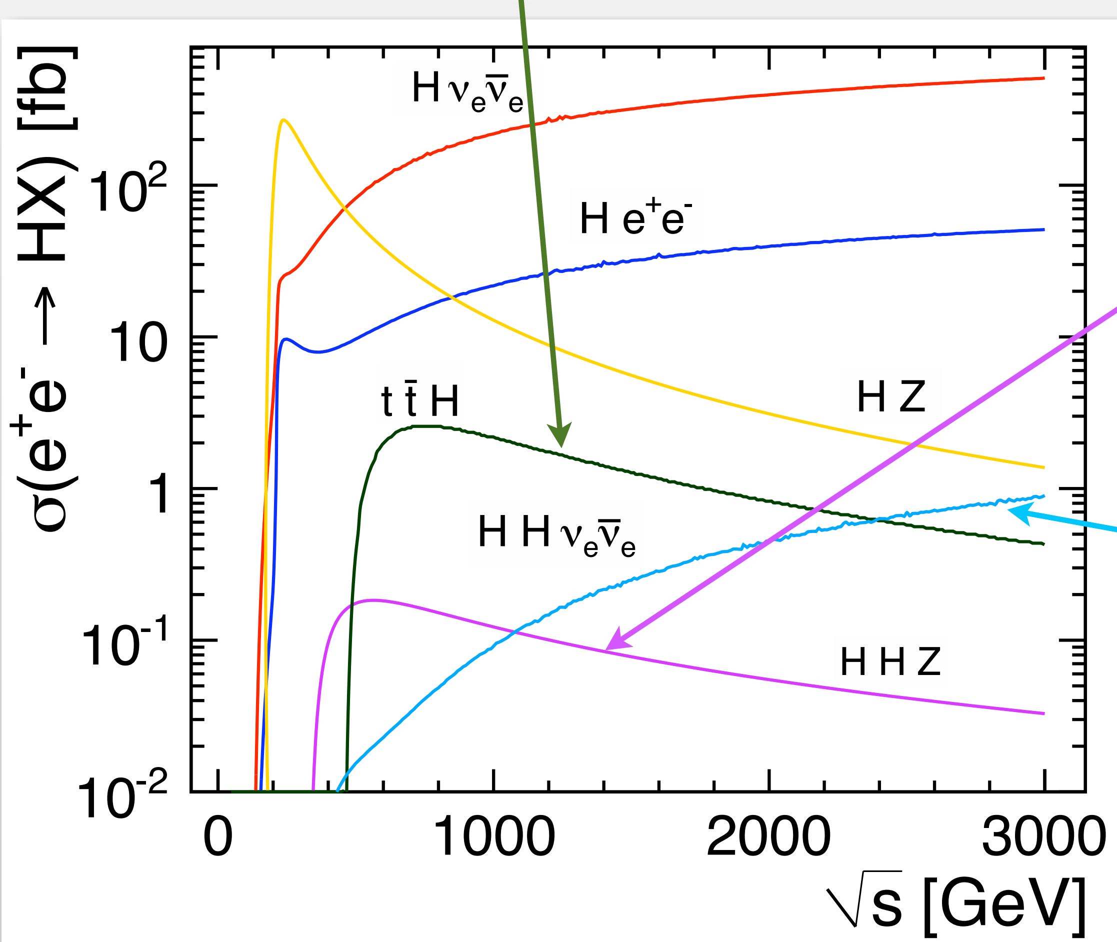
$$\Delta\Gamma_H \sim 4\,\% \quad \text{at} \quad \sqrt{s} = 1 \ \ \text{TeV}$$

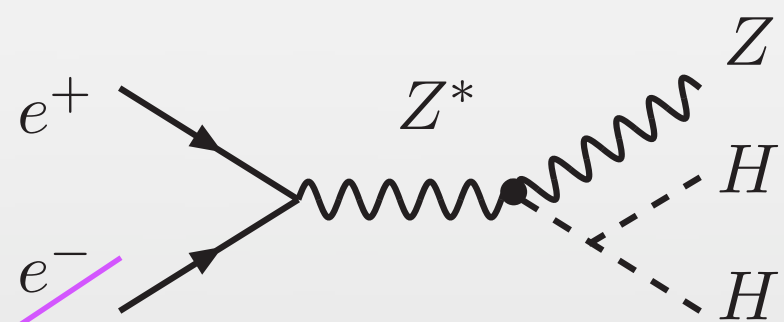
smaller-σ processes

give access to g_{Htt} and H self-coupling (→ λ → Higgs mechanism)

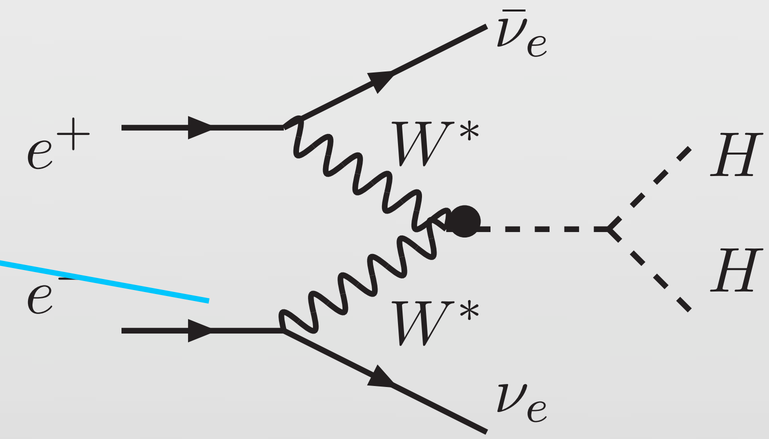


- $\Delta g_{Htt}/g_{Htt}$ ~ 10% (preliminary)





√S ~ 500 GeV



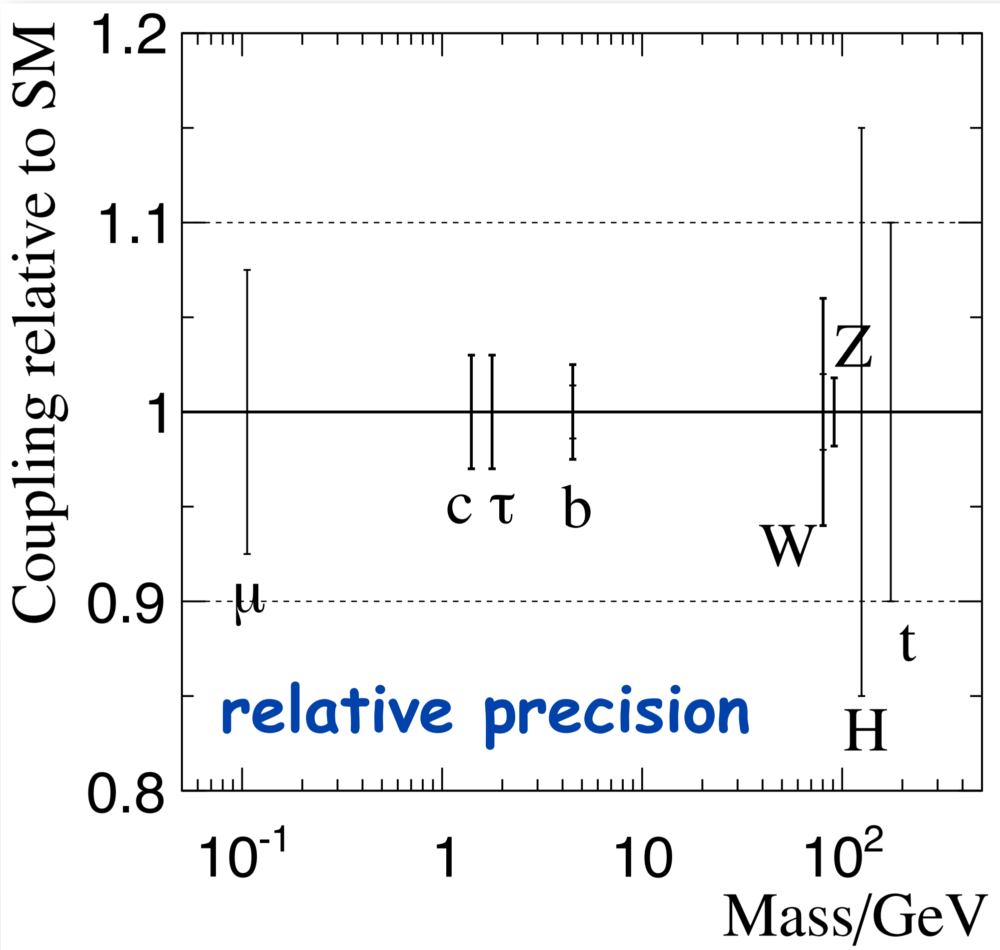
√S > 1 TeV

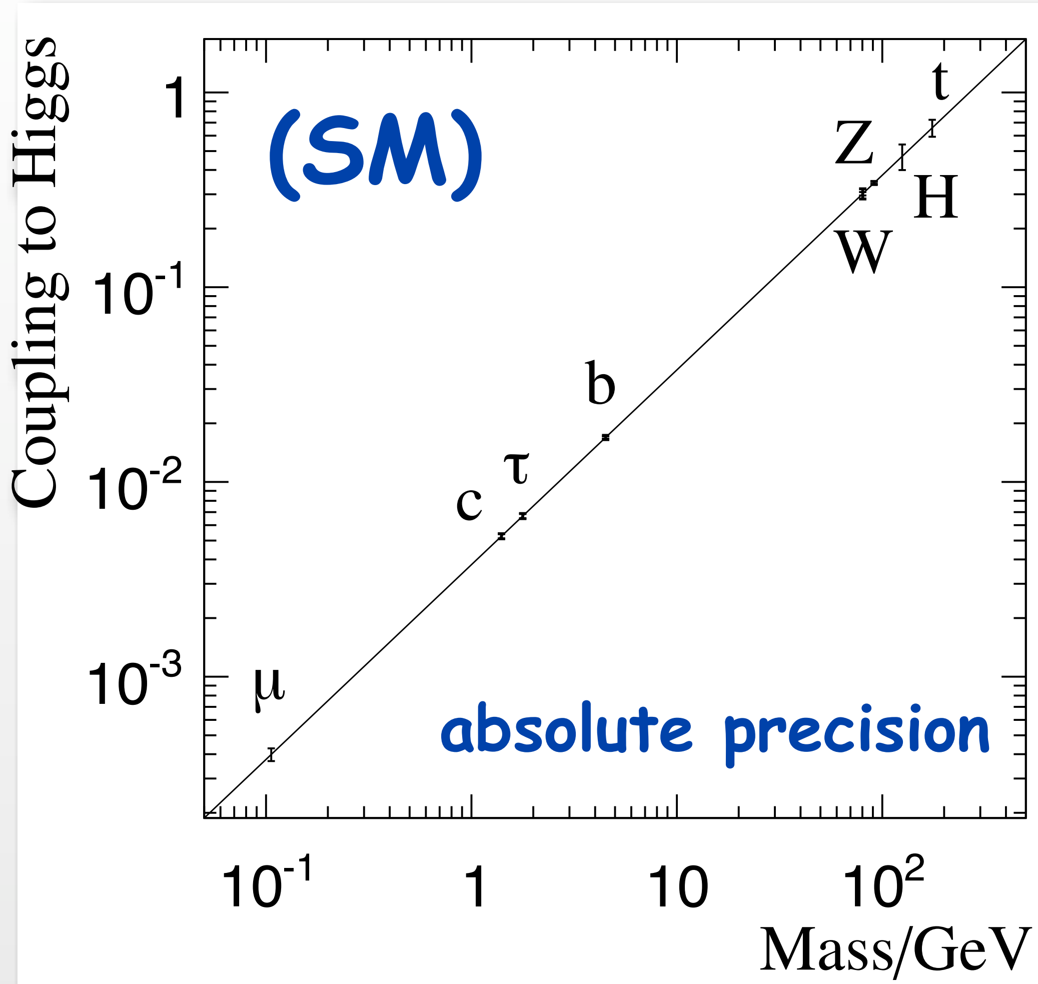
(more sensitive !)

- $\Delta\lambda/\lambda$ < 20% (in progress)

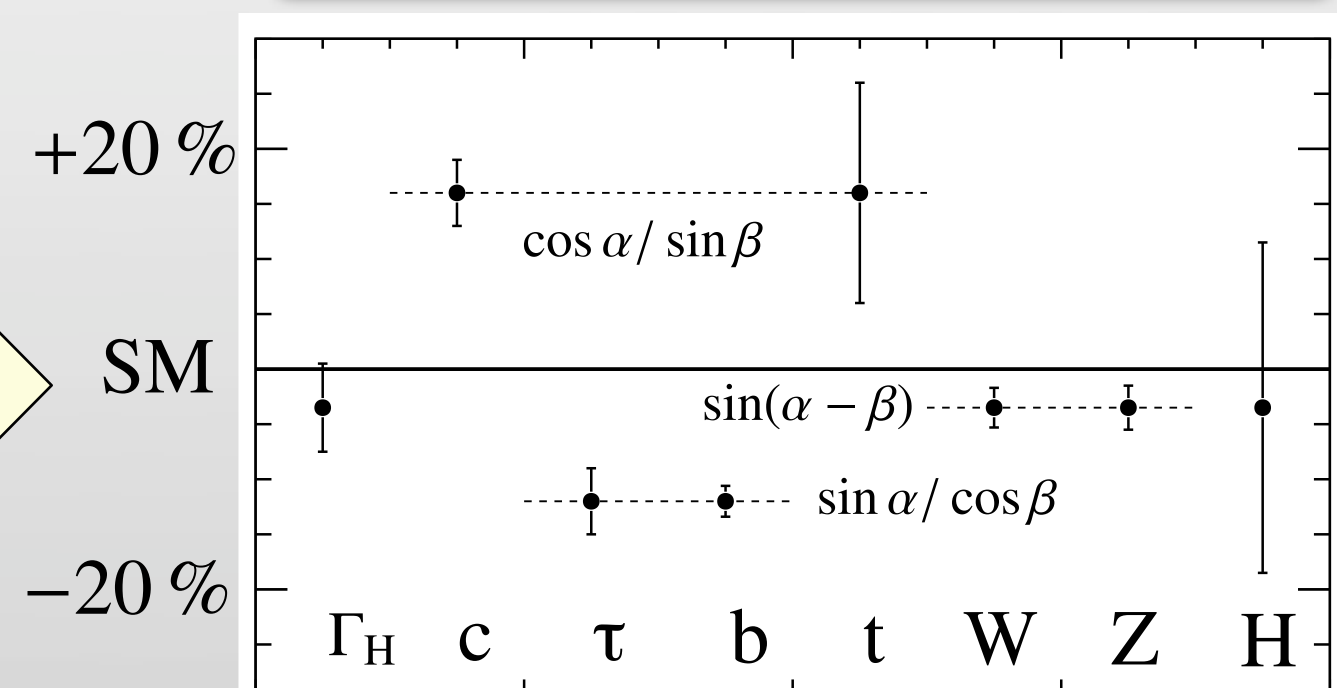
challenging ! (low σ, mostly HH → bbbb)

test (SM) g_{HXX}'s dependence on masses !

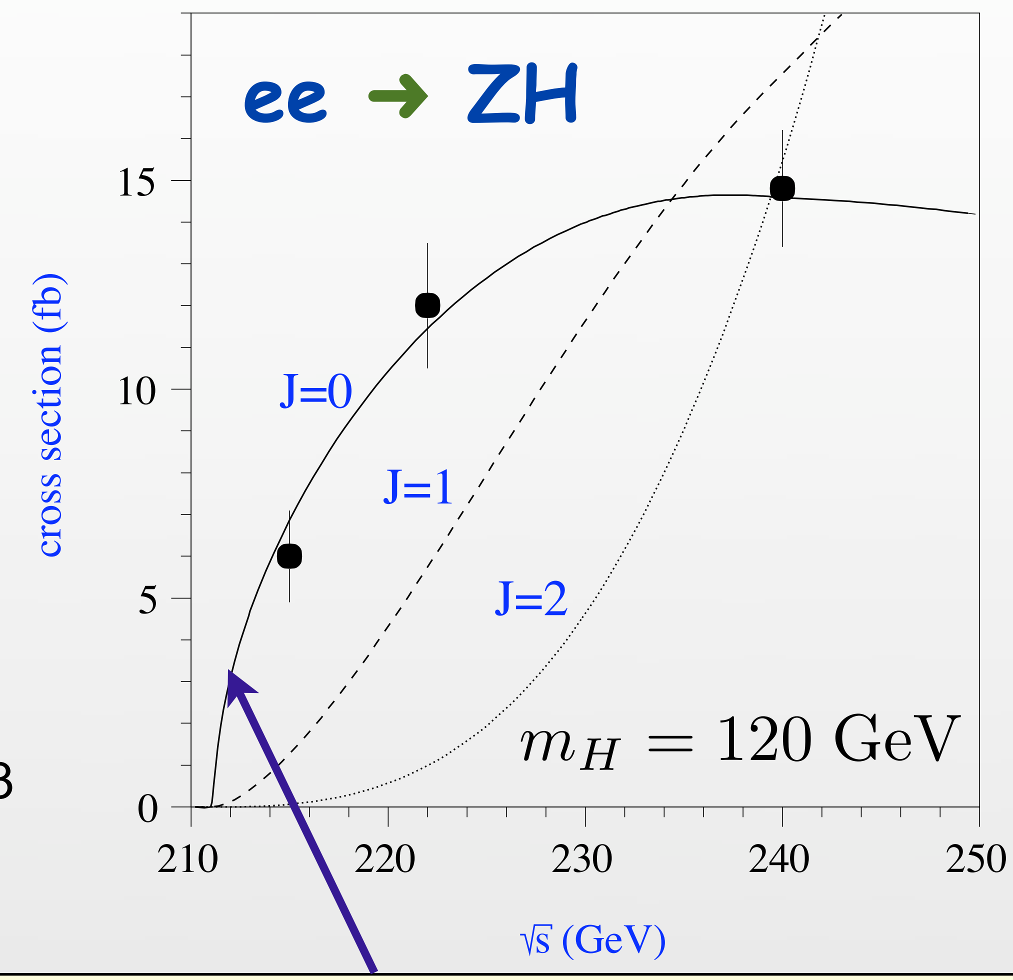




impact on coupling determination in 2HDM's



σ scan at threshold gives a lot of information !



hep-ph/0302113

(20 fb^{-1} at each scan point)

sensitive to H spin, and also to scalar CP nature

good sensitivity to both CP and CP-mixing

in threshold behavior of σ(ee → ttH) [g_{Htt} dependent]

Outlook

- new Higgs-like resonance at 126 GeV opens up the stage of particle-properties determination, and makes the Physics Case for future accelerators stronger than ever !
- HL LHC can improve g_{HXX} measurements (accurate potential assessments need to better know detector performance in HL experimental environment)
- a LC just above the ZH threshold can have a huge impact on g_{HXX} precision, larger energies can do even better also thanks to LC flexibility
- in this talk focus on (mainly SM) Higgs ➔ much greater LC potential that includes heavier Higgs's, top, and BSM physics
- stay tuned with Eur Strategy Update 2012/13 *"Strategy of Europe in a global context"*
- one final remark ! In the long standing competition between pp and ee colliders, we are today a bit late in the decision making process ...
  One glorious example :
  LEP project was approved in 1981, 2 years before W/Z discovery at CERN ppbar in 1983. In 1984, public discussion on LHC project starts ...