Study of the Higgs couplings to leptons and Higgs CP measurement at the ILC

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on behalf of ILD concept group

Windows on the Universe @ Quy Nhon, Vietnam
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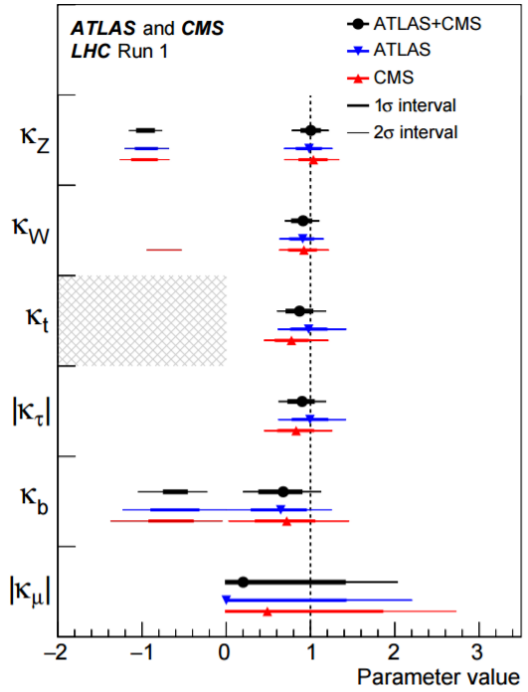
Introduction

Discovery of Higgs boson at the LHC 

But, still many open questions: 

- SM Higgs? BSM Higgs?
- dark matter, dark energy
- BSM (SUSY, composite...)
- ...



JHEP **08** (2016) 045

Precise measurement of Higgs boson

would be a key to answer the questions

- mass-coupling relation
- any deviation shows the existence of BSM
- typically small deviation

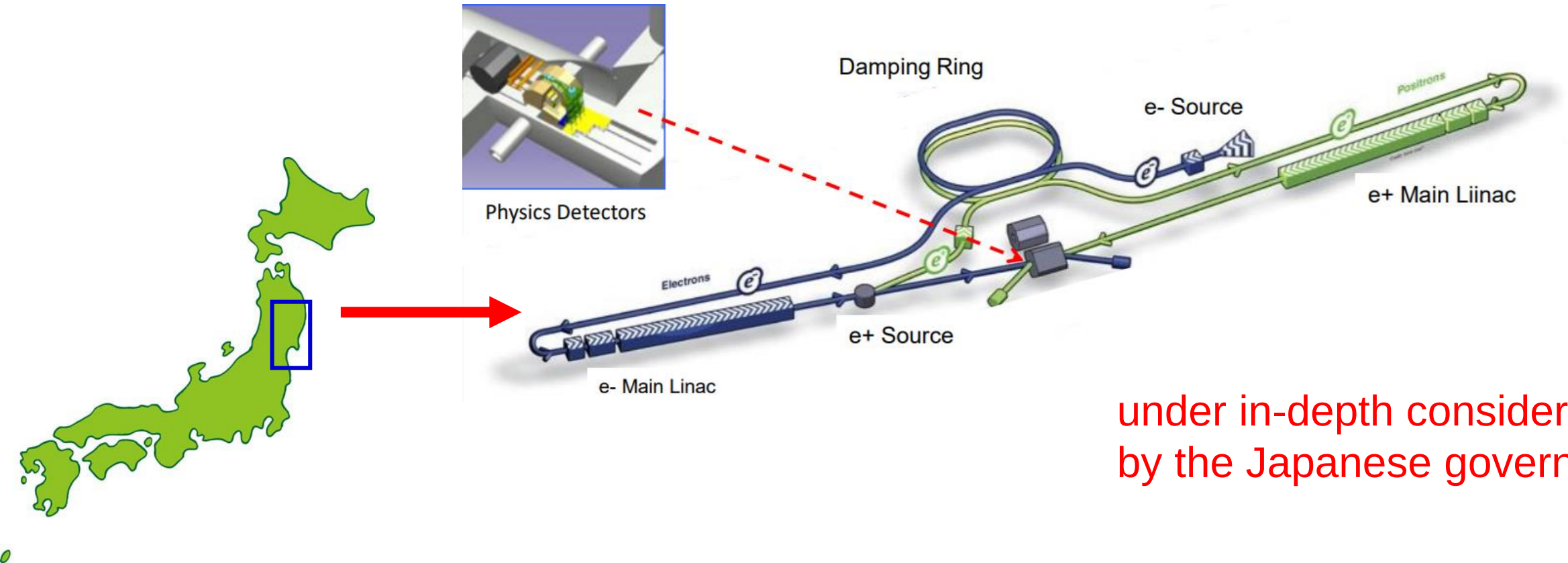
One example: Supersymmetry

$$\frac{g_{hbb}}{g_{h_{\mathrm{SM}}bb}} = \frac{g_{h\tau\tau}}{g_{h_{\mathrm{SM}}\tau\tau}} \simeq 1 + 1.7\% \left(\frac{1\ \mathrm{TeV}}{m_A}\right)^2$$

arXiv:1306.6352

The International Linear Collider (ILC)

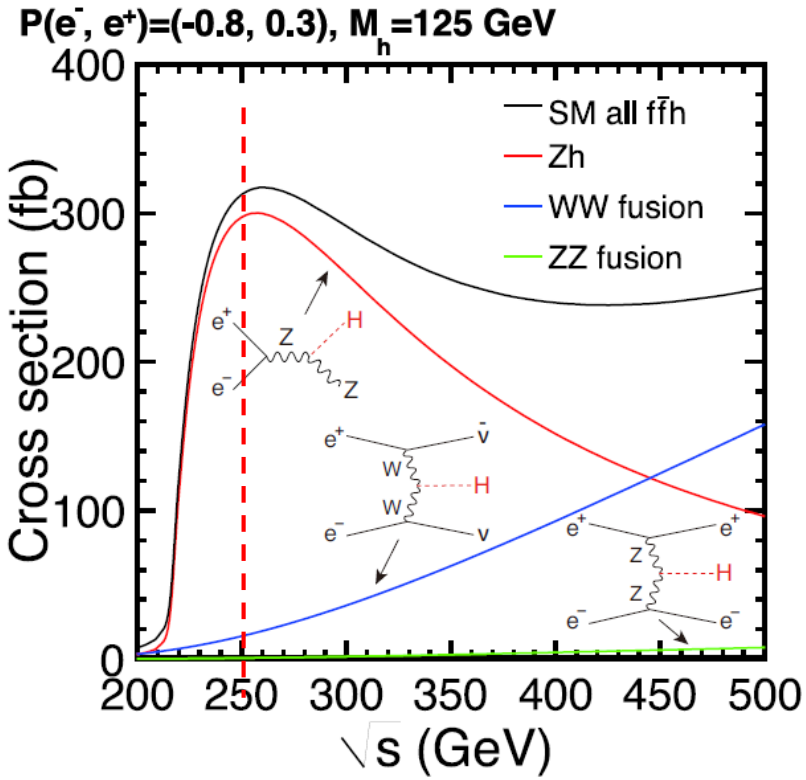
- e^+e^- collider, E_{CM} = 250 GeV (upgradable to 500 GeV, 1 TeV)
- polarized beam (e^-: ±80%, e^+: ±30%)
- clean environment, known initial state



under in-depth consideration
by the Japanese government

ILC250 Physics Program

2 ab^{-1}: half-million Higgs (ZH) in ~11 years



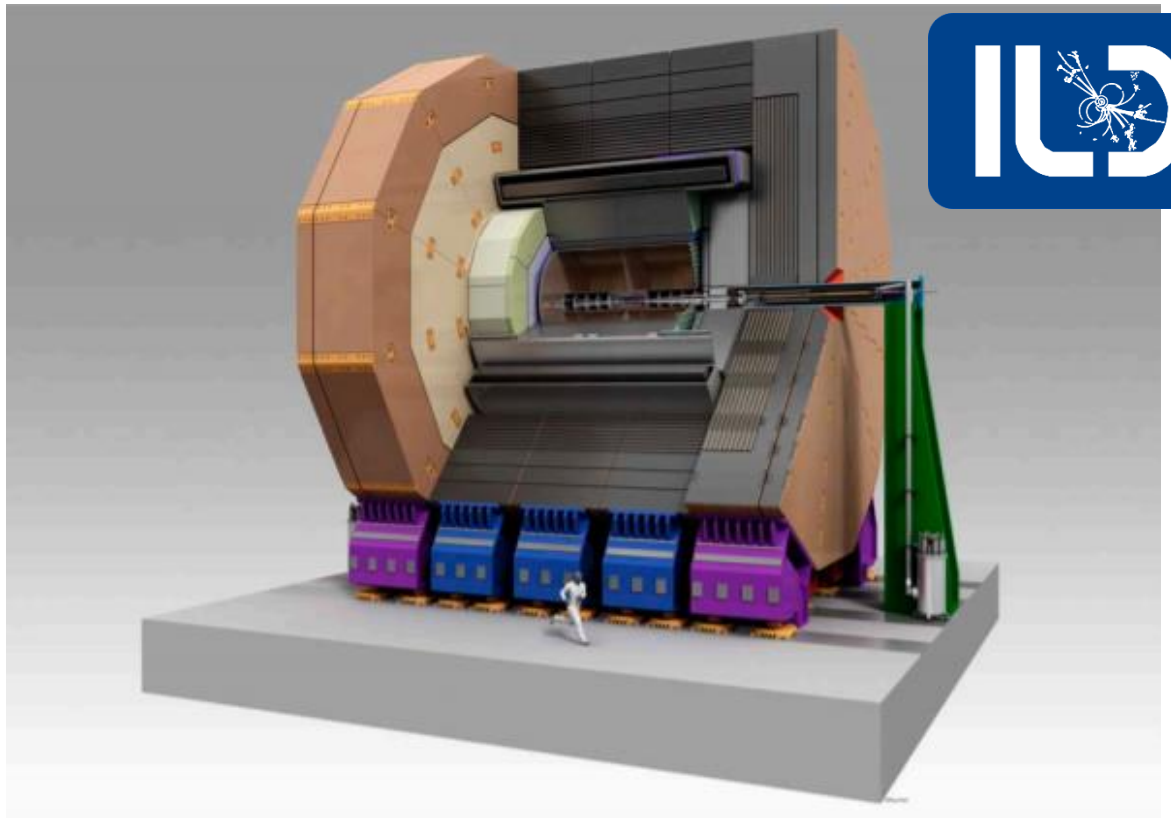
Electroweak symmetry breaking

- comprehensive and precise study of Higgs sector
  [T. Barklow et al., PRD **97** 053003 (2018)]
- electroweak process [talked by R. Yonamine (Tue.)]
  LEP2 + beam polarization/higher energy/
  better detectors/ x1000 more data

---> indirect search for BSM

Direct searches for BSM

ILD (International Large Detector)



high precision detector for
particle flow reconstruction

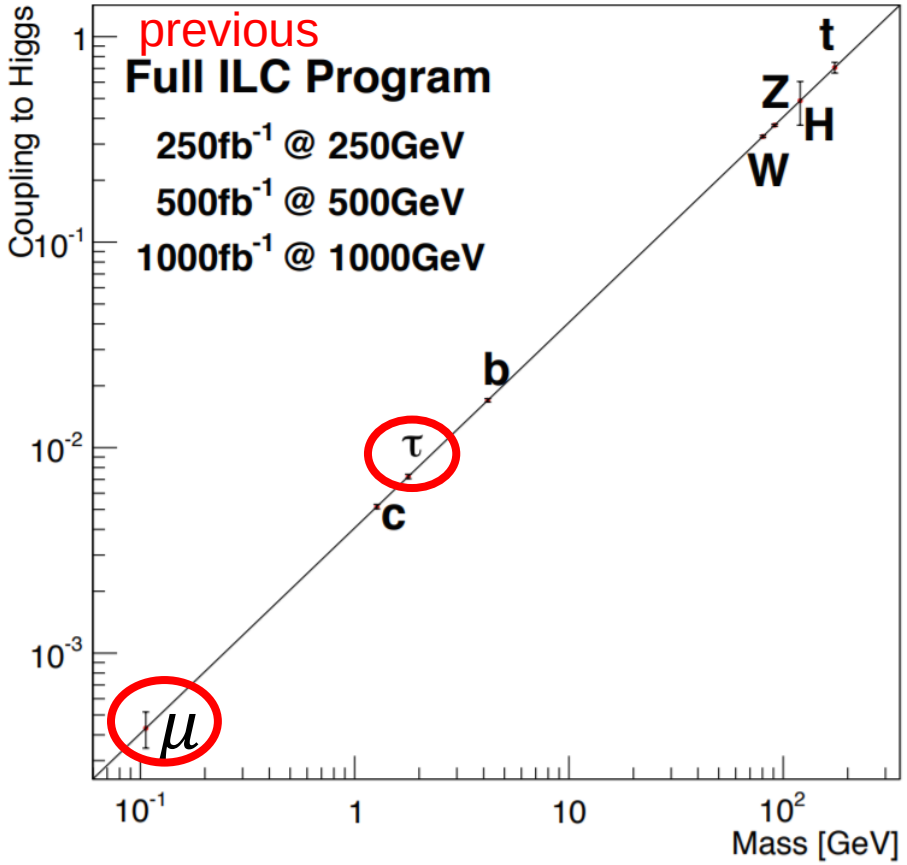
Tracker: Vertex, TPC
Calorimeter: ECAL, HCAL
3.5T magnetic field
Yoke for muon, Forward system

Requirements:

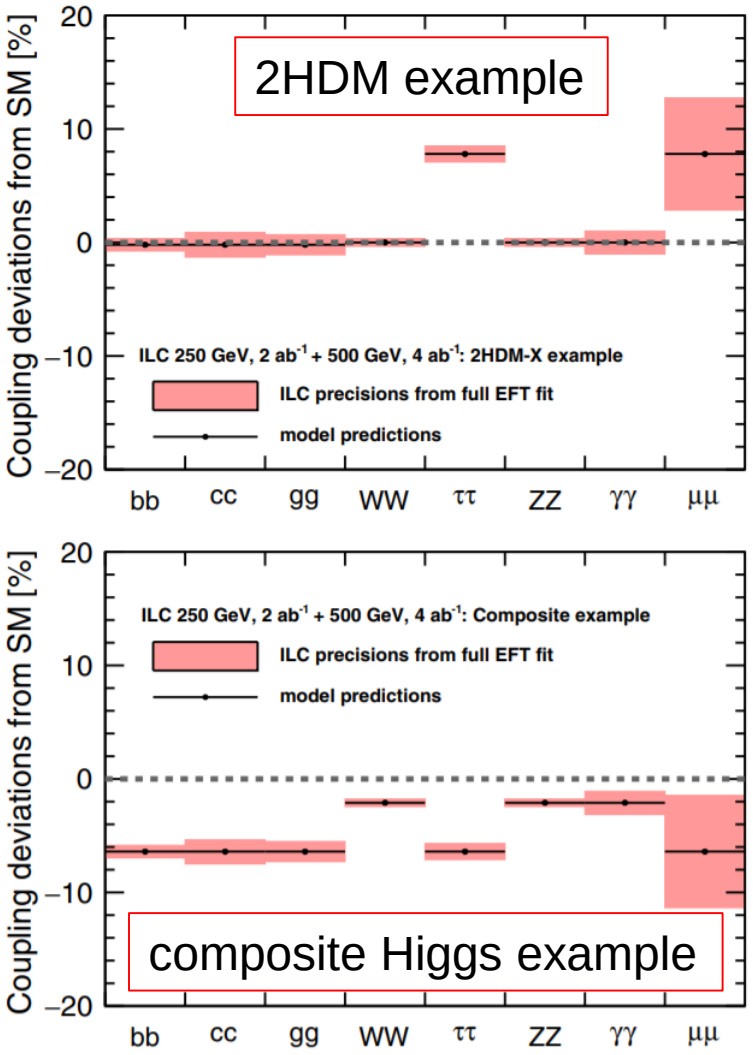
- Impact parameter resolution
  $\sigma_{r\phi} < 5 \oplus \frac{10}{p\sin^{3/2}\theta}\ \mu$m
- Momentum resolution
  σ_{1/p_T} < 2*10^{-5} GeV^{-1}
- Energy resolution
  σ_E/E = 3 - 4%

arXiv:1310.0763
T. Barklow et al., PRD **97** 053003 (2018)

Higgs Couplings To Leptons



testing Yukawa couplings
leptons: small uncertainty of its mass
---> suitable tool for precise measurement



different BSM scenario
---> different pattern of deviation from SM

SK et al., EPJC (2015) 75:617
SK's PhD thesis (2016), http://ir.lib.hiroshima-u.ac.jp/en/00040208

Higgs To Taus

full simulation with ILD, all backgrounds considered, realistic reconstruction

$e^+e^- \to HZ \to \tau^+\tau^-(q\bar{q}/e^+e^-/\mu^+\mu^-)$

isolated tau jets

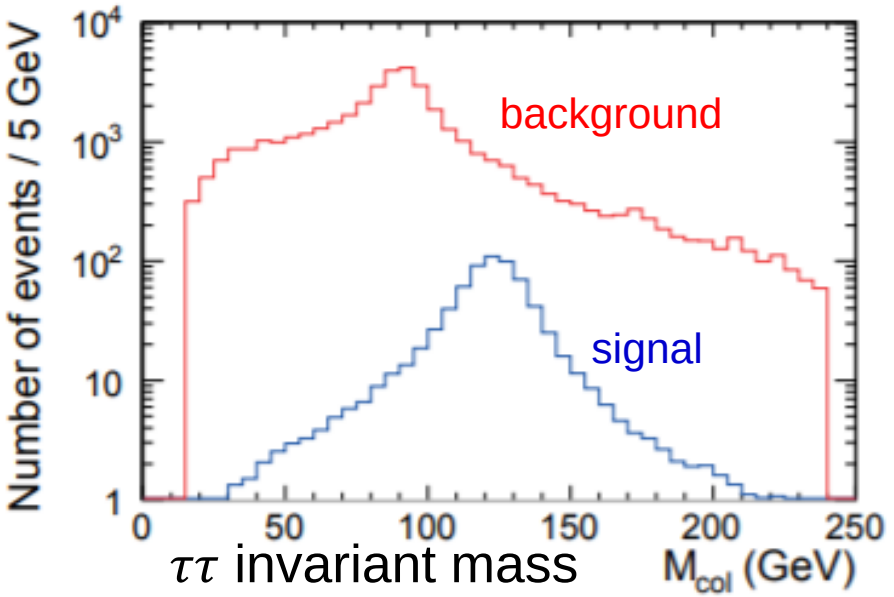
1 or 3 charged particles
jet charge = ± 1
invariant mass < 2 GeV

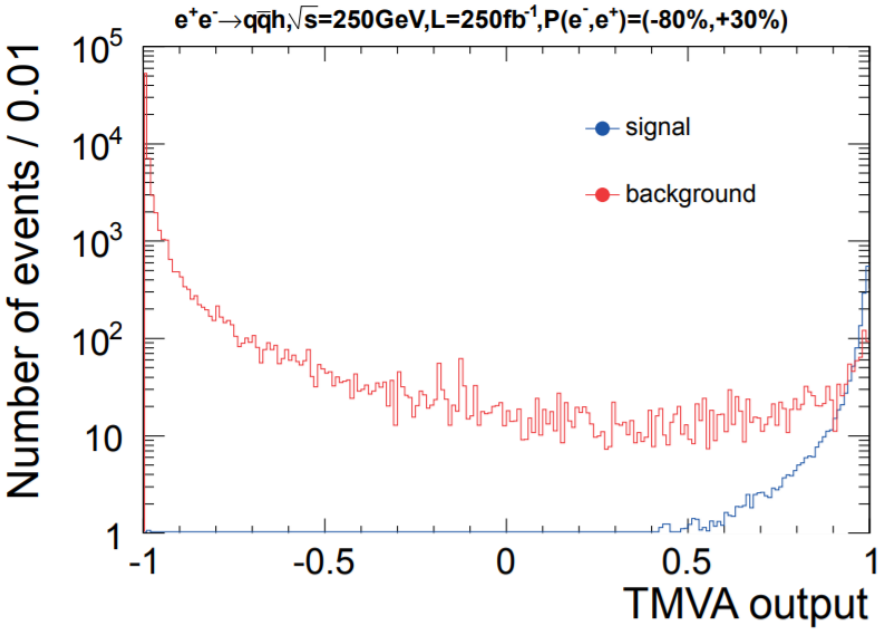
collinear approximation

to estimate ν momenta from tau decay

various precuts applied
TMVA(BDT) for final discrimination

expected precision at the ILC
$\sigma \times \mathrm{BR}(H \to \tau^+\tau^-)$:
1.2% (ILC250 / 2 ab^{-1})
1.0% (+ ILC500 / 4 ab^{-1})





Higgs To Muons

Challenging: tiny branching ratio $\mathrm{BR}(H \to \mu^+\mu^-) \sim 2.2 \times 10^{-4}$
Key detector performance: momentum resolution
$e^+e^- \to HZ \to \mu^+\mu^-(q\bar{q}/\nu\bar{\nu})$

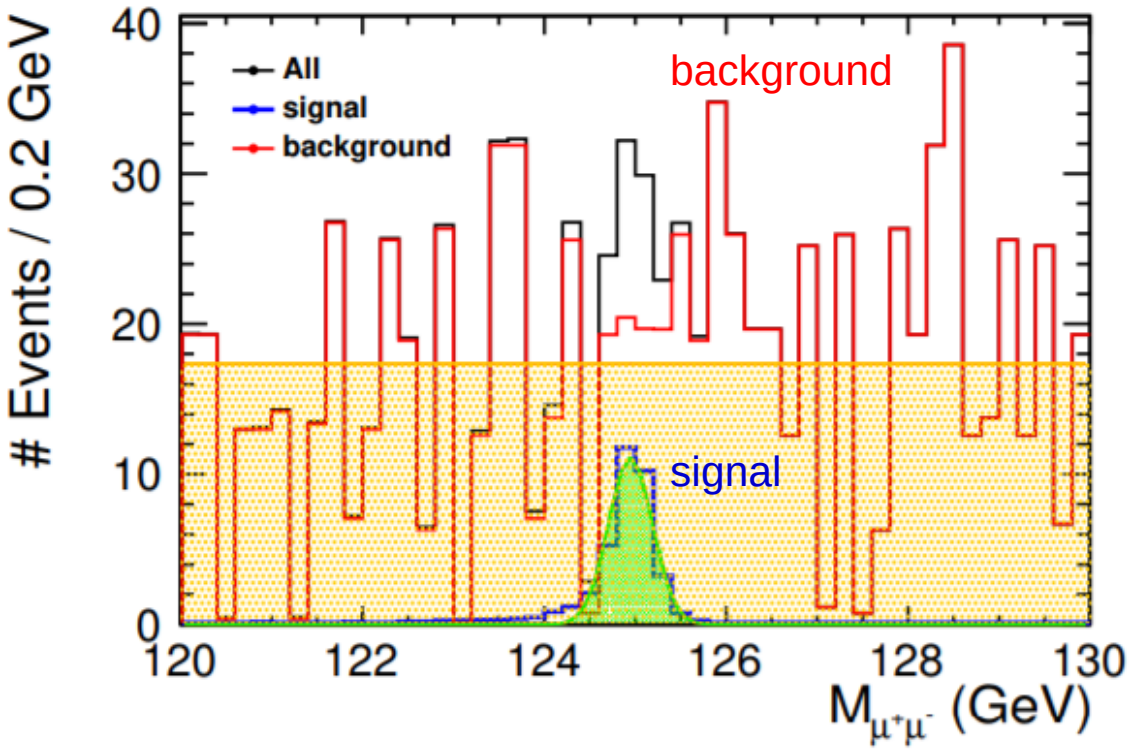
full simulation with ILD, all backgrounds considered, realistic reconstruction

muon selection

pair of prompt, isolated, opposite charged, and well-measured is selected as $H \to \mu^+\mu^-$ candidate

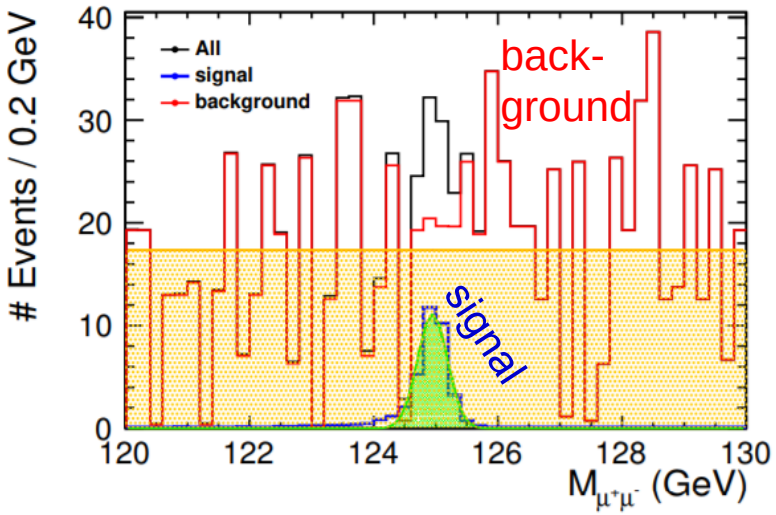
various precuts applied
TMVA(BDT) for final discrimination
pseudo-experiment (next page)

$e^+e^- \to \mu^+\mu^- q\bar{q}$, E_{CM} = 250 GeV, 0.9 ab^{-1}, $e_L^- e_R^+$



※artificial fluctuation is seen due to insufficient MC statistics

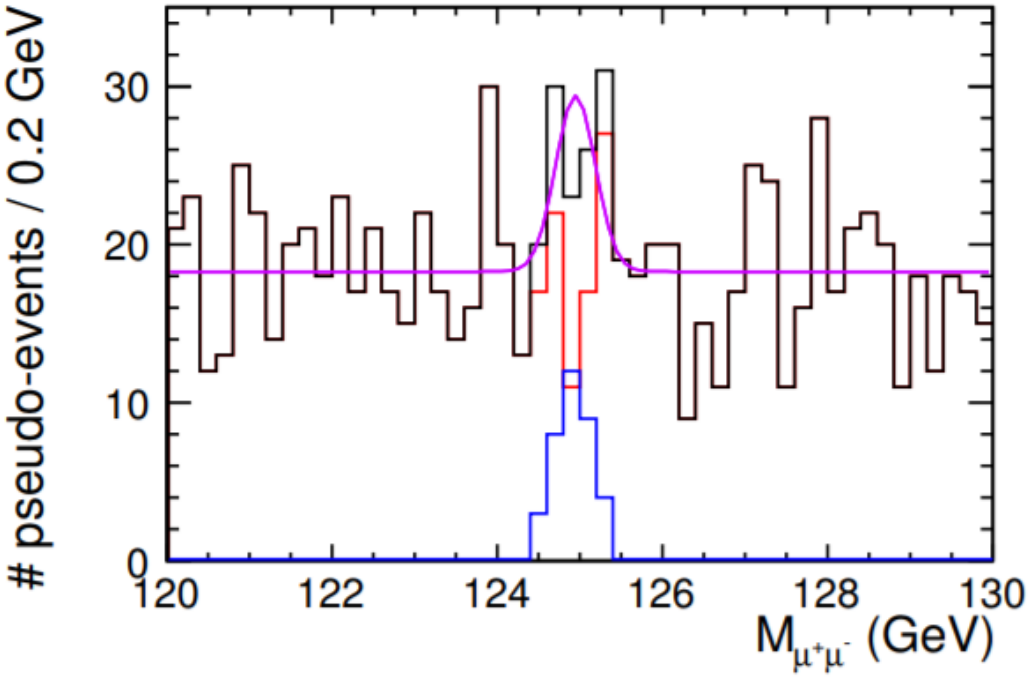
Higgs To Muons



fit full simulation results with
Gaussian(signal) and
constant(background)

fit results ---> pseudo-experiment
repeat many times

$e^+e^- \to \mu^+\mu^- q\bar{q}$, E_{CM} = 250 GeV, 0.9 ab^{-1}, $e_L^- e_R^+$,
one pseudo-experiment

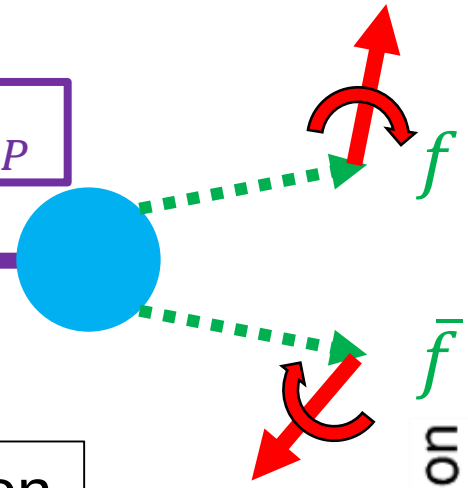


expected precision at the ILC
$\sigma \times \mathrm{BR}(H \to \mu^+\mu^-)$: preliminary
21% (ILC250 / 2 ab^{-1})
15% (+ ILC500 / 4 ab^{-1})

Higgs CP Measurement with $H \to \tau^+\tau^-$

$$h_{125} = h^{CP\text{odd}} \cos\psi_{CP} + A^{CP\text{even}} \sin\psi_{CP}$$

$$g\bar{f}(\cos\psi_{CP} + i\gamma^5 \sin\psi_{CP}) f h_{125}$$



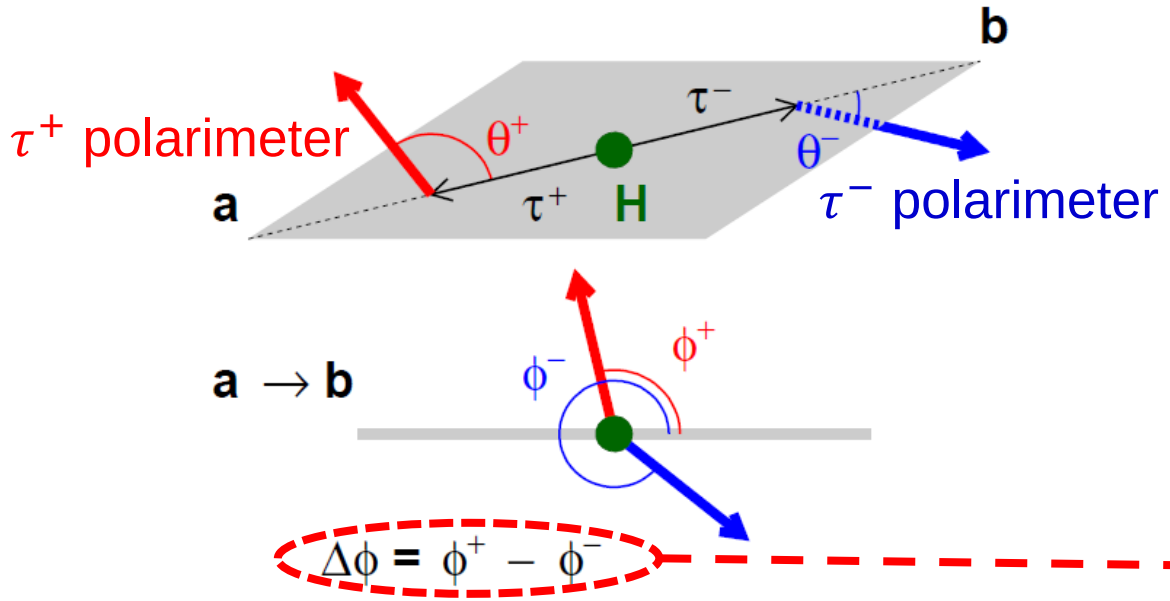
h is a spin 0 state

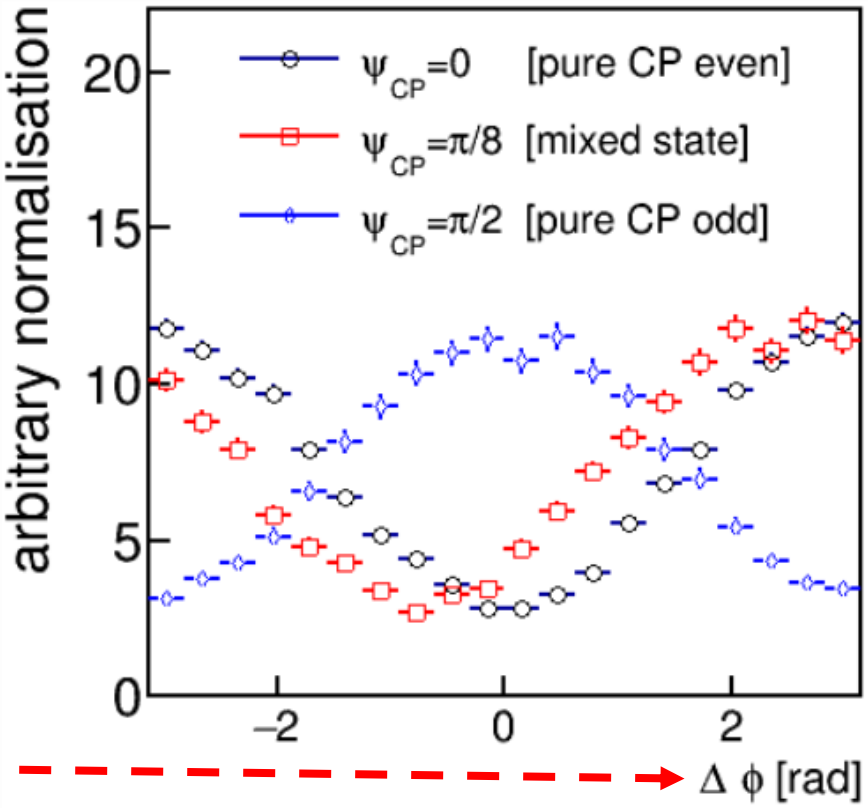
$|f\bar{f}> = |\uparrow\downarrow> + e^{2i\psi_{CP}}|\downarrow\uparrow>$

ψ_{CP} = 0 CP even (SM)

= $\pi/2$ CP odd

"**polarimeter**": estimator of spin direction from τ decay products





Full τ Reconstruction

In $e^+e^- \to ZH, H \to \tau^+\tau^-$ events:

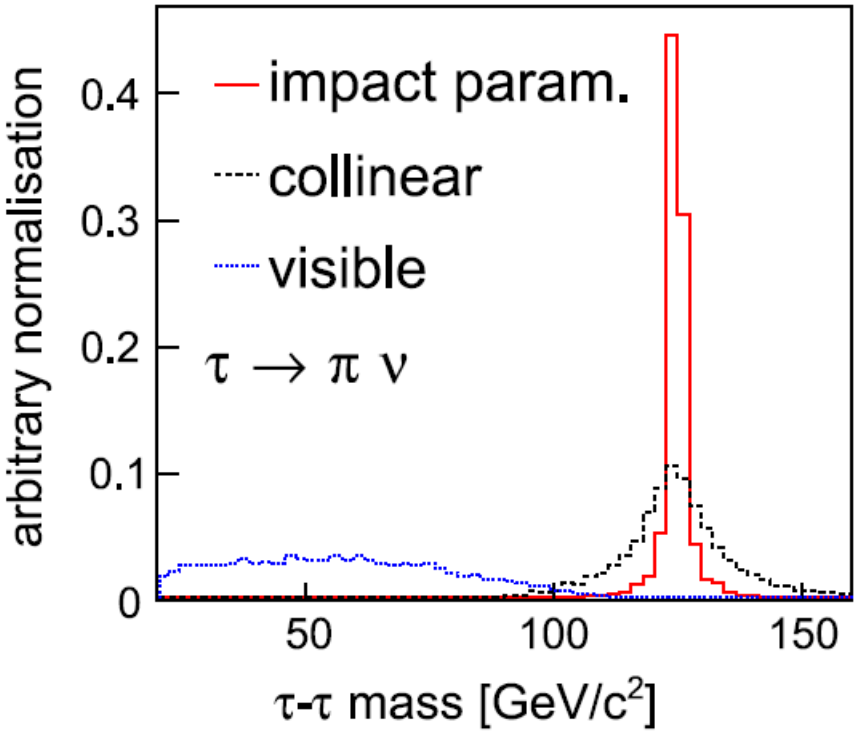
- visible Z decay products
  ---> τ production vertex
  ---> p_T of τ-pair system
- excellent vertex detector
  ---> trajectory of τ decay products
  ---> plane of τ momentum

6 constraints for ν

6 unknowns: two ν 3-momenta in hadronic τ decay events

"**polarimeter**": estimator of spin direction from τ decay products

ILD full simulation

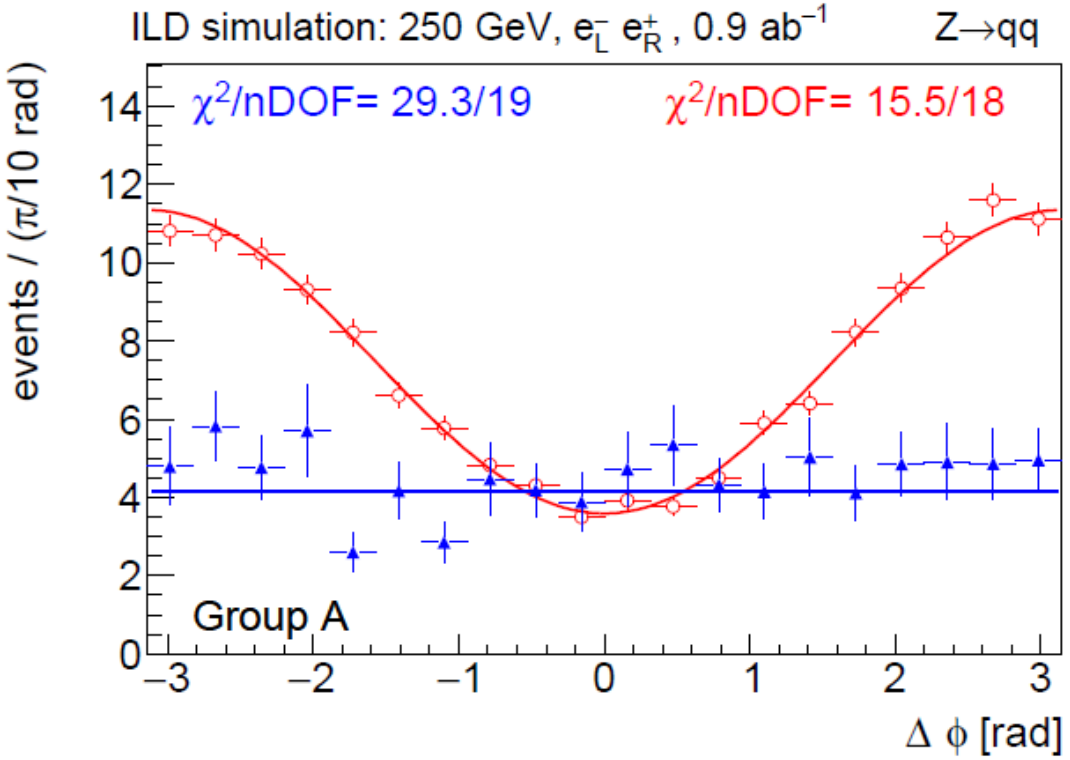


Information on τ momentum and spin relies on excellent detector performance

impact parameter, tracking, photon and jet measurement

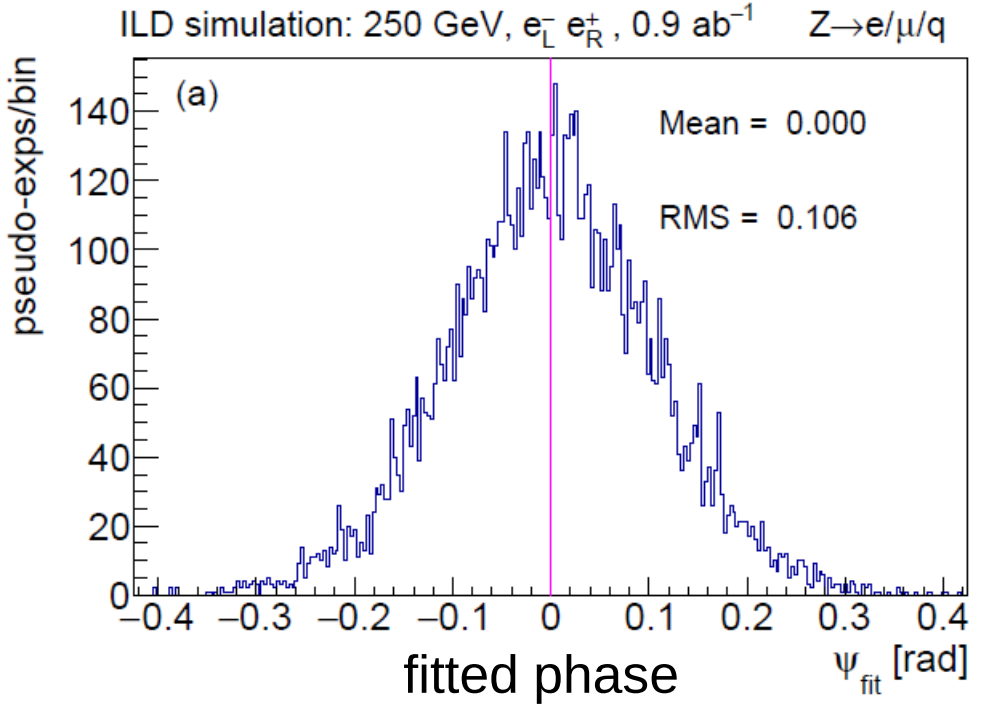
CP in $H \to \tau^+\tau^-$: Sensitivity

$e^+e^- \to HZ \to \tau^+\tau^-(q\bar{q}/e^+e^-/\mu^+\mu^-)$
$\tau^\pm \to \pi^\pm\nu$ (BR 11%),
$\tau^\pm \to \pi^\pm\pi^0\nu$ (BR 26%)



signal: phase of $\Delta\phi$ distribution sensitive to CP
background: consistent with flat distribution

10k pseudo-experiment



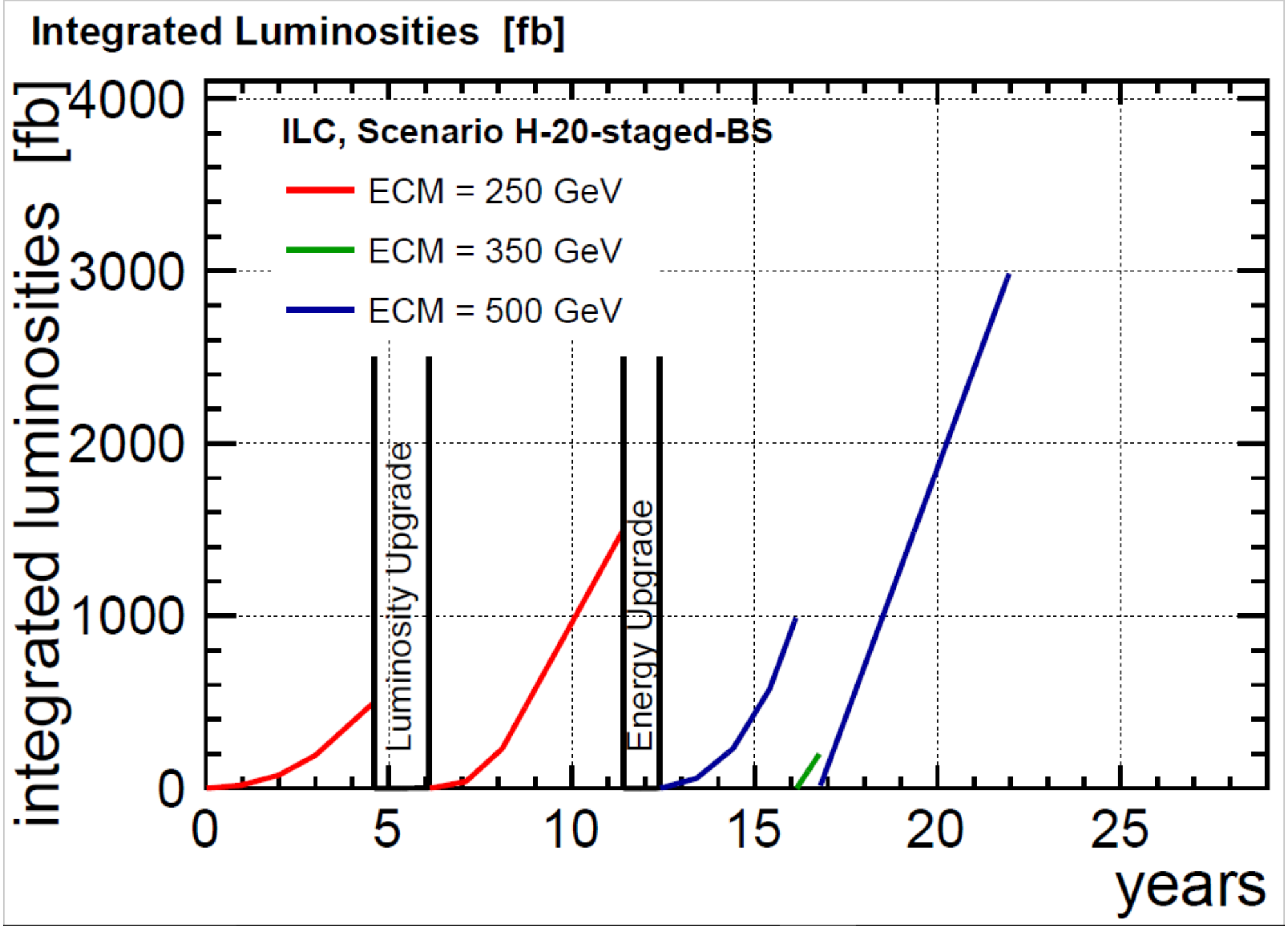
pseudo-experiment: simultaneous likelihood fit to $\Delta\phi$ distributions in all channels

expected precision at the ILC
ψ_{CP}: 75 mrad (ILC250 / 2 ab^{-1})

Summary

- Precise measurement of Higgs boson would be a key to uncover new physics
- Presented Higgs to leptonic channel and Higgs CP measurement at the ILC
- At ILC250;
  - $\sigma \times \mathrm{BR}(H \to \tau^+\tau^-)$ with a precision of 1.2% (1.0% with ILC500)
  - $\sigma \times \mathrm{BR}(H \to \mu^+\mu^-)$ with a precision of 21% (15% with ILC500)
  - CP mixing angle ψ_{CP} in $H \to \tau^+\tau^-$ with a precision of 75 mrad

BACKUP

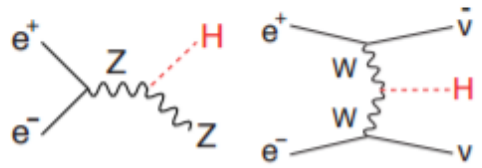

Integrated Luminosities [fb]
ILC, Scenario H-20-staged-BS
ECM = 250 GeV
ECM = 350 GeV
ECM = 500 GeV
Luminosity Upgrade
Energy Upgrade
integrated luminosities [fb]
4000
3000
2000
1000
0
0
5
10
15
20
25
years

Key Point

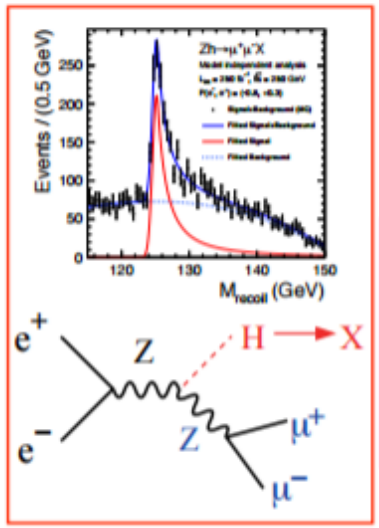
K. Fujii's talk, LCWS2014

LHC: all measurements are $\sigma \times \mathrm{BR}$

ILC: $\sigma \times \mathrm{BR}$ measurements + σ measurement



$$g^2_{HAA} \propto \Gamma(H \to AA) = \Gamma_H \cdot BR(H \to AA)$$



σ×BR

BR

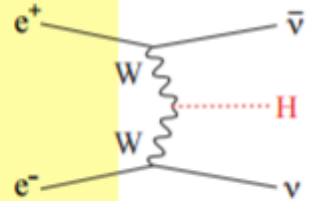
g coupling

The Key

σ from recoil mass

Γ_H total width

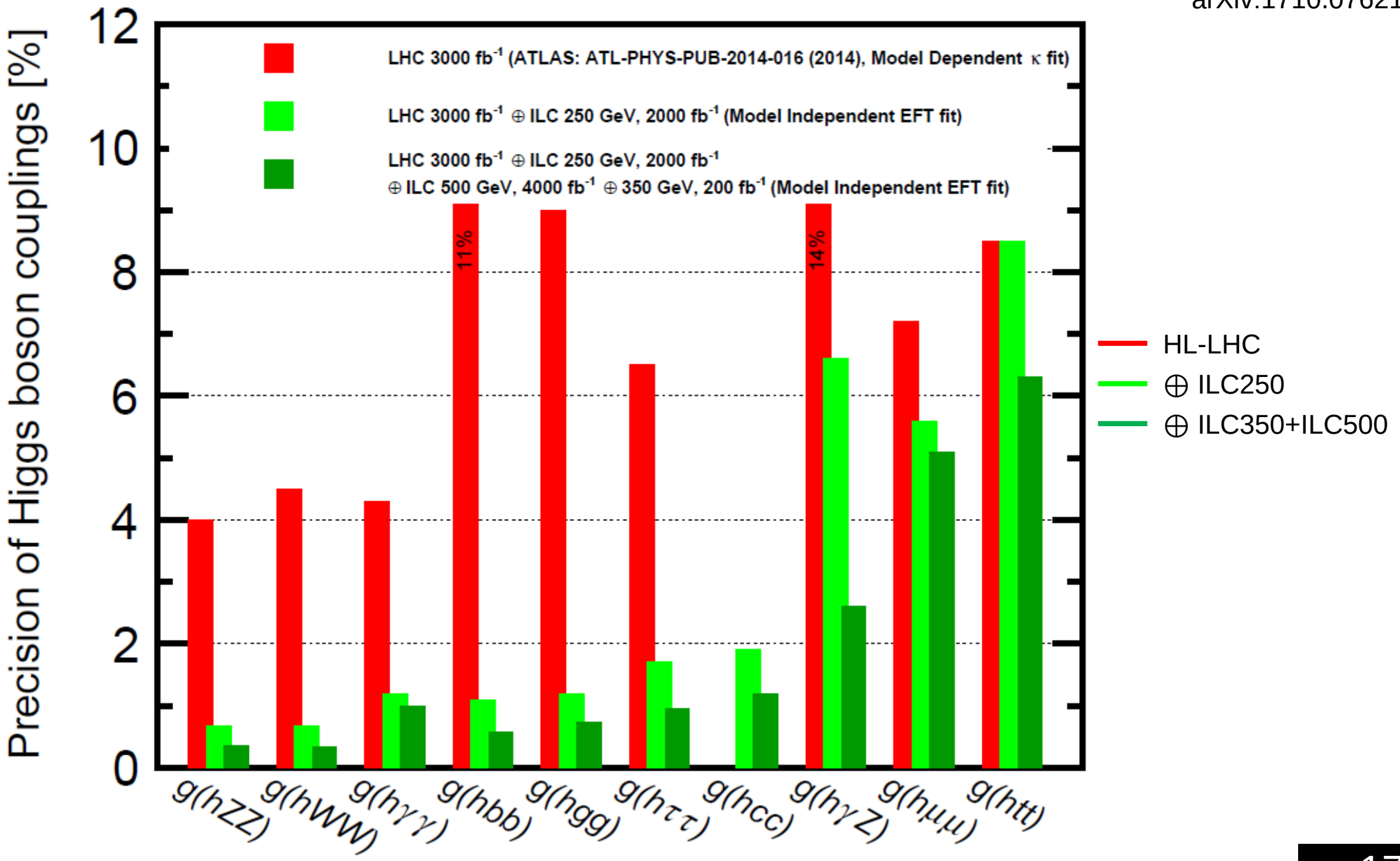
WW-fusion is crucial for precision total width measurement → Ecm > 350GeV



Z→qq is also usable.

15

arXiv:1710.07621



arXiv:1506.05992 [hep-ex]

Single Higgs Production

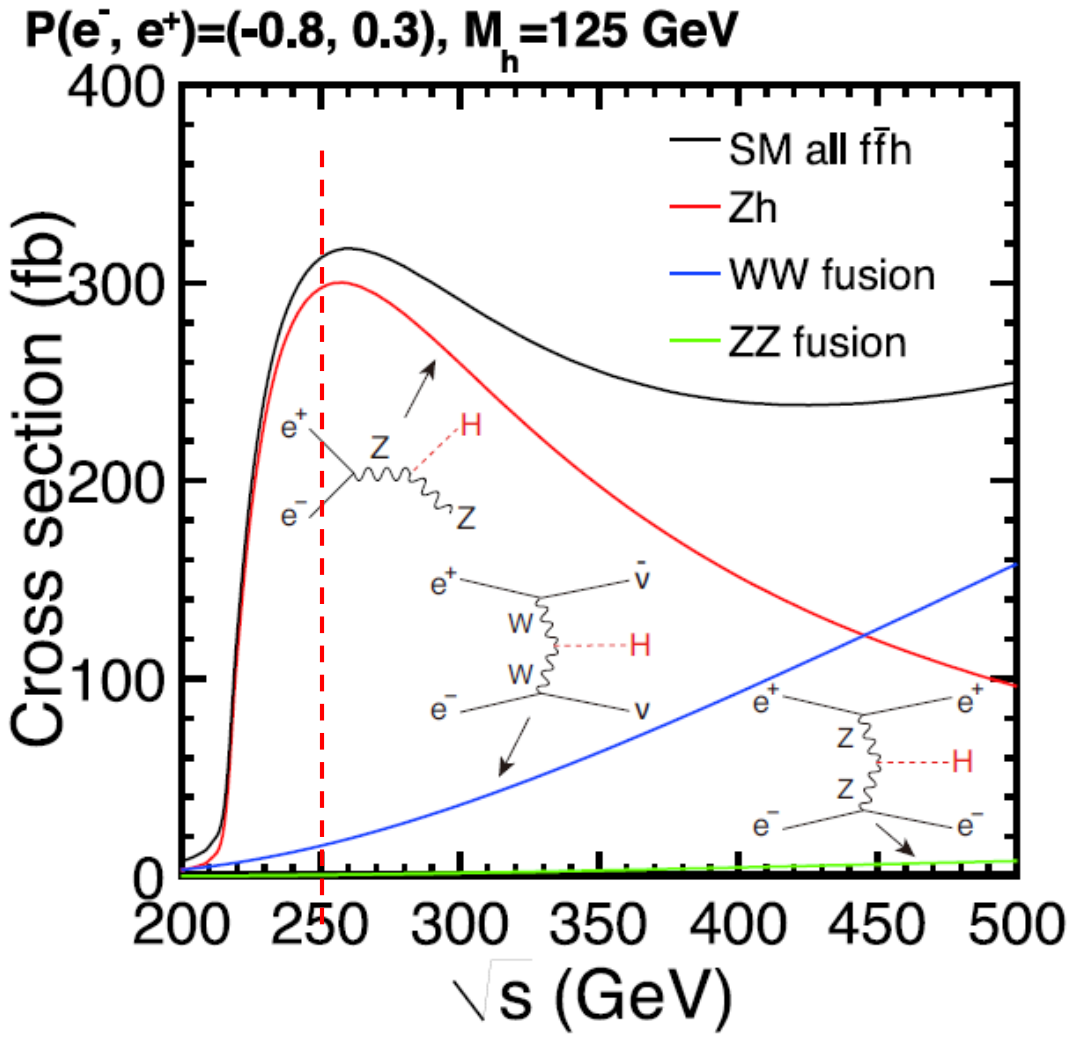
$\sqrt{s}$ = 250 GeV

Higgs-strahlung (Zh) dominant

$\sqrt{s}$ = 500 GeV

WW-fusion dominant

E_{CM}	process	beam pol.	$\int Ldt$ (fb^{-1})	# events
500	$\nu\bar{\nu}h$	L	1600	58
		R	1600	8
	$q\bar{q}h$	L	1600	25
		R	1600	16
250	$\nu\bar{\nu}h$	L	900	28
		R	900	8
	$q\bar{q}h$	L	900	41
		R	900	15



L: (e^-, e^+) = (-0.8, +0.3)

R: (e^-, e^+) = (+0.8, -0.3)