Standard Model
Higgs Physics

Results compiled from: ILC RDR, CLIC CDR, ILD LoI, SiD LoI, talks and papers representing the state-of-the-art understanding

Higgs Input to European Strategy

- ★ The Higgs physics case is a compelling argument for a LC
- ★ In the strategy document, not much space for detail – need to focus on essential points

Three main aspects:

- ★ Present compelling case for LC Higgs physics
  - High level results
- ★ Clarify arguments for different energy
  - Clear comparison of physics reach
- ★ Make physics case for need for high precision Higgs measurements
  - what does a LC bring over the LHC

Possible Structure

Divide into five main parts:

- ★ Introduction
  - Emphasis on precision, model independence
- ★ Higgs couplings from Higgs-strahlung
  - precision BRs + model independence
- ★ Higgs couplings at higher centre-of-mass energies
  - self-coupling, top Yukawa coupling
- ★ Higgs properties
  - mass, spin, CP properties
- ★ Impact of high precision measurements
  - either in Higgs section or BSM

★ **Here provide a brief introduction to what can be measured at the proposed LC centre-of-mass**

- **main purpose is to prompt discussion/input**

❶ Introduction

★ **Luminosity assumptions**

- Instantaneous luminosities from ILC TDR parameters and CLIC CDR
- Integrated luminosities from rough luminosity scaling + values used in main studies
- Quoted precisions scaled to these integrated values

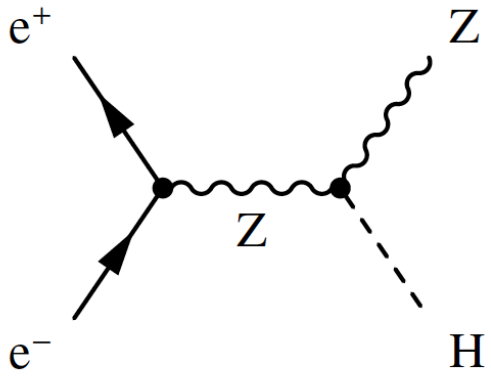
Energy/GeV	250	350	500	1000	1500	3000
Lumi [$x10^{34}$ $cm^{-2}s^{-1}$]	0.75	1.0	1.8	3.6	2.3	5.9
Int Lumi [fb]	250	350	500	1000	1500	2000

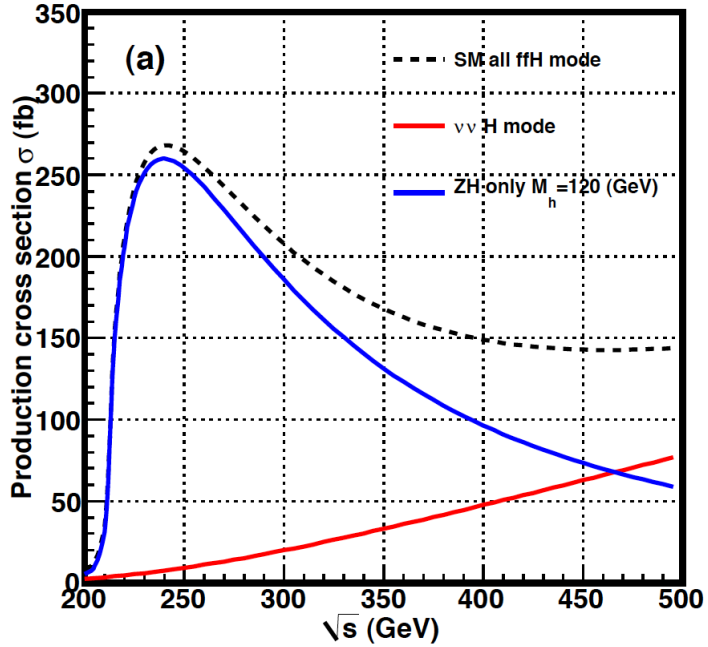
★ **Focus will be on "LHC" Higgs mass**

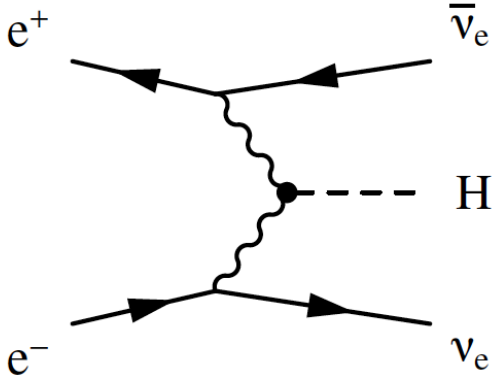
- (for now assume) Higgs mass of ~125 GeV
  - although most studies quoted for 120 GeV

"Low" vs "High Energy"

- **Higgs production**
  - Below 450 GeV dominated by Higgs-strahlung
  - Above 450 GeV dominated by WW fusion
  - Provides a natural division of the discussion of the physics





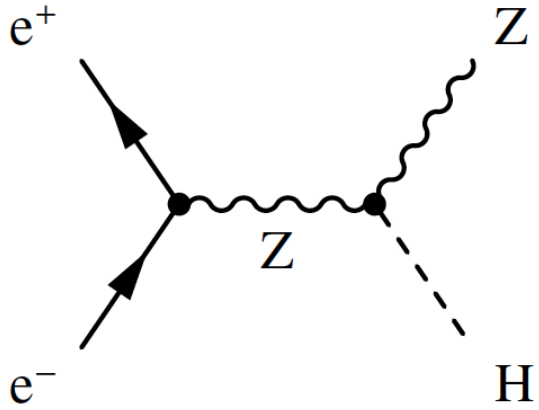


❷ Higgs-strahlung

★ **Higgs-strahlung**

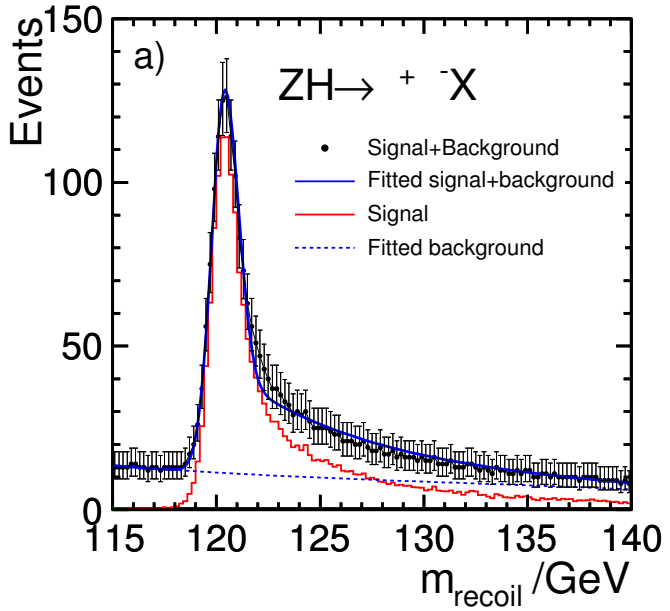
- **Dominates at low energies**
- **In terms of numbers of events –**
  being close to threshold is good
- **But this is not a strong effect since L increases with $\sqrt{s}$**

Energy/GeV	250	350
Cross section [fb]	250	130
Int Lumi [fb^{-1}]	250	350
N(ZH) Events	62500	45500



Recoil Mass Method

- **Recoil mass method**
  - **Measure Higgs production cross section independent of Higgs decay**
  - **Sensitive to invisible Higgs decay modes**
  - **Absolute measurement of HZ coupling**

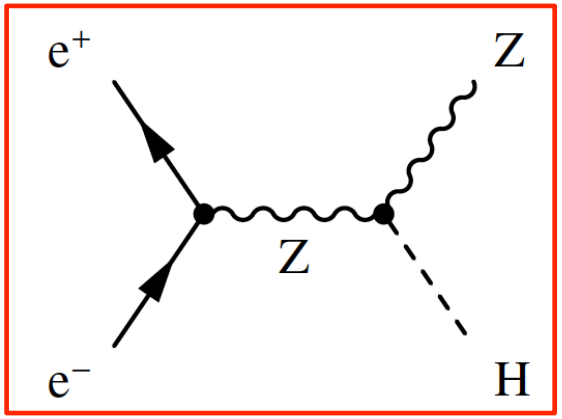


Energy/GeV	250	350
$\Delta(\sigma)/\sigma$	3.0 %	3.7 %
→ $\Delta(g_{HZZ})/g_{HZZ}$	1.5 %	1.8 %

*Mass measurement described later

BR Measurements

★ **Inclusive analysis of final states**
- **Production rate known through recoil analysis**
- **Provided absolute measurements of of Higgs BRs and ultimately couplings**

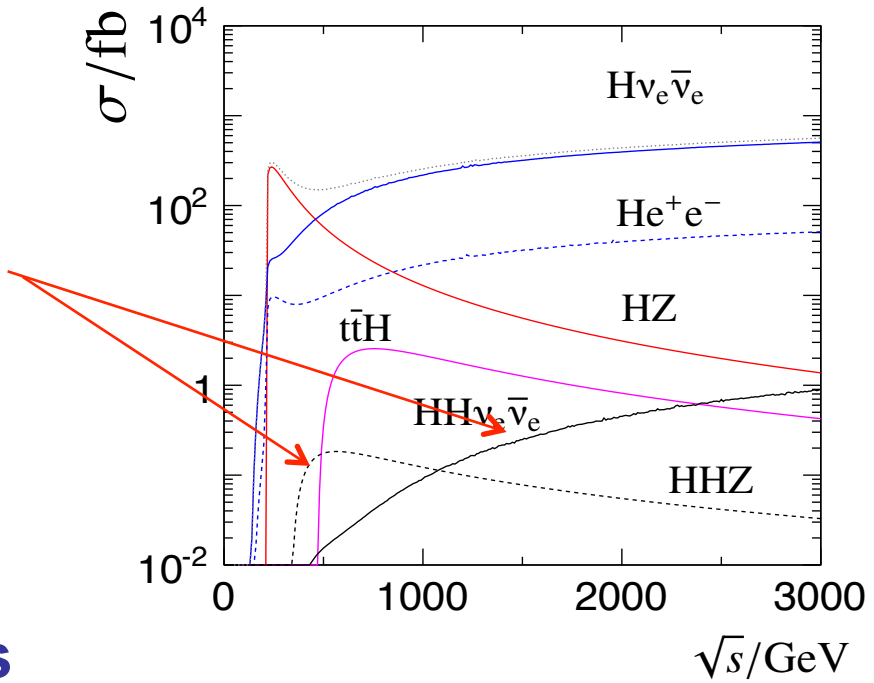


Energy/GeV	250	350
H→bb: Δ(BR)/BR	2.7 %	2.3 %
H→cc: Δ(BR)/BR	9 %	6.5 %
H→gg: Δ(BR)/BR	10 %	7 %
H→ττ: Δ(BR)/BR	~6 %	6 %
H→WW*: Δ(BR)/BR	~5 %	~4 %

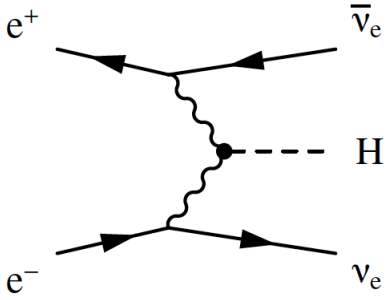
- **Increased sensitivity at 350 GeV due to improved signal/background separation**

❸ Higgs at Ecm >= 450 GeV

- ★ **At high energies**
  - **Fusion dominates**
  - **Sensitivity to self-couplings**
  - **ttH channel opens**



- ★ **Large numbers of $H\nu_e\bar{\nu}_e$ events**



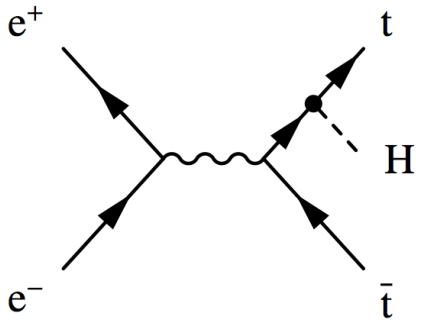
Energy/GeV	500	1000	1500	3000
Int Lumi [fb]	500	1000	1500	2000
Cross section [fb]	80	220	320	510
N(Hνν) Events	4E4	2E5	5E5	1E6

Measurements

★ **At 500 GeV and above, can measure top-Yukawa coupling**

- **Full simulation studies ongoing**

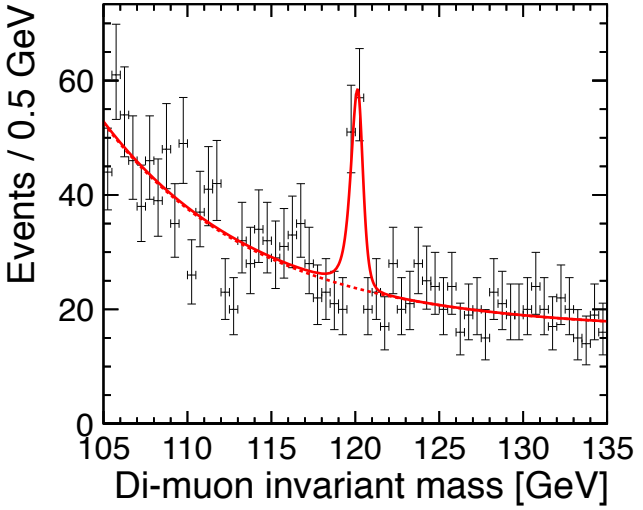
Energy/GeV	500
$\Delta(g_{Htt})/g_{Htt}$	~10 %?
$\Delta(g_{HWW})/g_{HWW}$	1.2 %



★ **At 3 TeV large numbers of $H\nu_e\bar{\nu}_e$ events**

- **Precise BR measurements**
- **Rare decays**

Energy/GeV	3000
H→bb: Δ(BR)/BR	2 %
H→cc: Δ(BR)/BR	3 %
H→μμ: Δ(BR)/BR	15 %

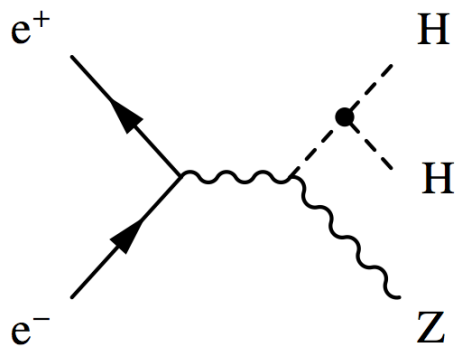


Self-Couplings

★ **At 500 GeV and above can measure self-couplings from ZHH**

- **Full simulation study in progress**

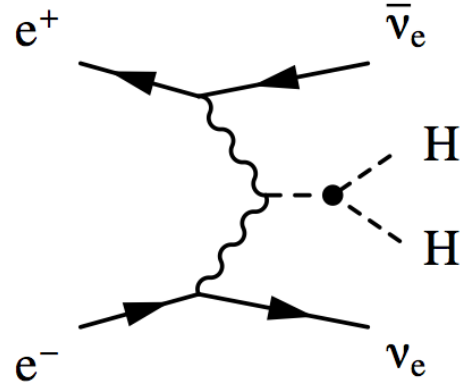
Energy/GeV	500
$\Delta\lambda/\lambda$	<50 %



★ **At higher energies most sensitivity from fusion process**

- **Full simulation study in progress**

Energy/GeV	1400	3000
$\Delta\lambda/\lambda$	<20 %	<25 %



★ **Crucial measurement for testing test EWSB mechanism**

❹ Higgs properties

★ **Higgs Mass**

- **Can be obtained from recoil mass or direct reconstruction**

Energy/GeV	250	350
Δ(mH) recoil	30 MeV	80 MeV
Δ(mH) direct	-	40 MeV

★ **Higgs Width**

- **e.g. for low mass Higgs can be obtained from**

$$\Gamma_H = \frac{\Gamma(H \to WW^*)}{BR(H \to WW^*)}$$

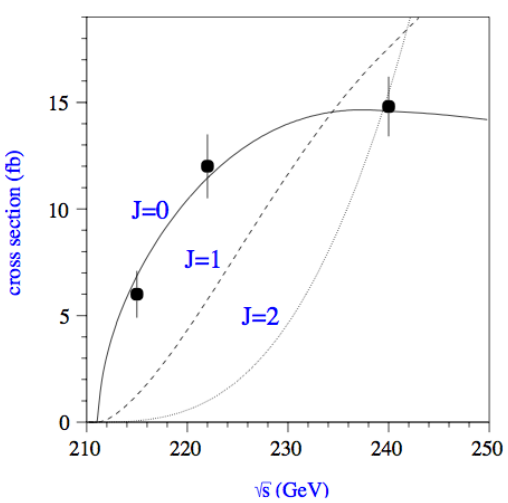
← from WW fusion cross section

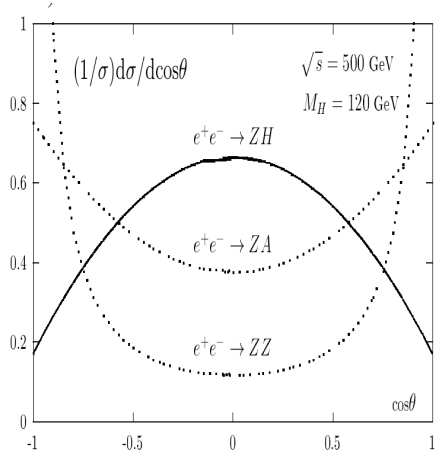
← from BR measurement

Energy/GeV	350	1 TeV
Γ_H recoil	7 %	3.5 %

Higgs properties

- **Spin**
  - From threshold and/or direct reconstruction of decay angles
  - e.g.





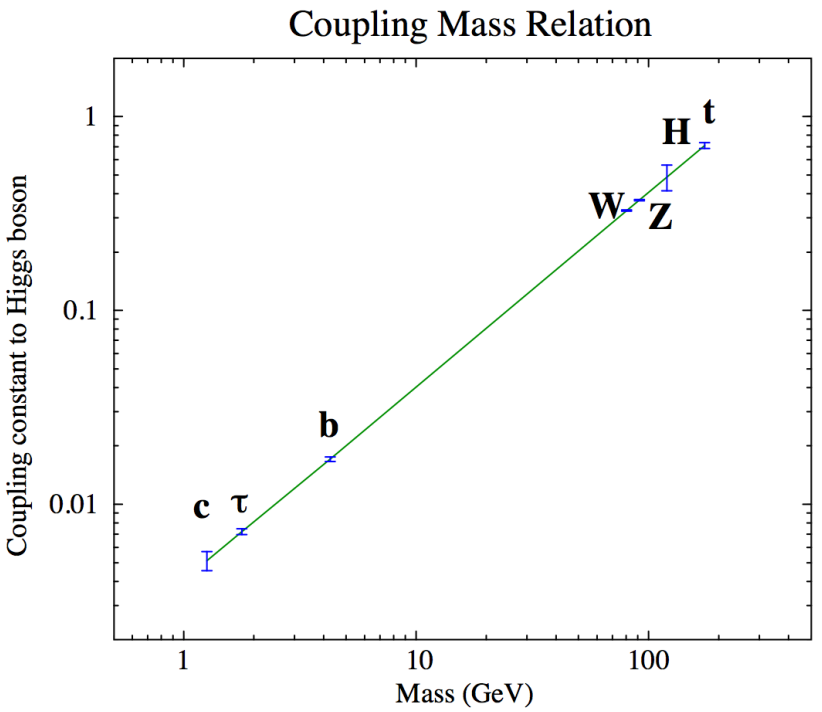
- **Quantum numbers (J^{PC})**
  - In principle Higgs can be an admixture of CP odd and even states
  - Size of possible mixing can be measured by looking at spin correlations in HZ events

❺ Challenging the SM

★ **Higgs couplings provide an essential test of Higgs sector**

- **LC can provide precise model independent measurements of almost all Higgs couplings**

	250	350	500	>1.5 TeV
g_{HWW}	?	?	1.2 %	?
g_{HZZ}	1.5 %	1.8 %		
g_{Hbb}	1.3 %	1.1 %		
g_{Hcc}	4.5 %	3.2 %		1.5 %
$g_{H\tau\tau}$	~3 %	~3 %		?
g_{Htt}	-	-	10 %	?
$g_{H\mu\mu}$	-	-		8 %
$\lambda_{(HHH)}$	-	-	<50 %	<20 %



❻ Discussion

- ★ **Possible topics for discussion**
  - best illustrations of need for precision
    - SM vs SUSY models
    - General 2HDMs
    - …
  - balance coupling and other measurements
  - how to handle different energies?
  - what other topics need to be included?
  - …