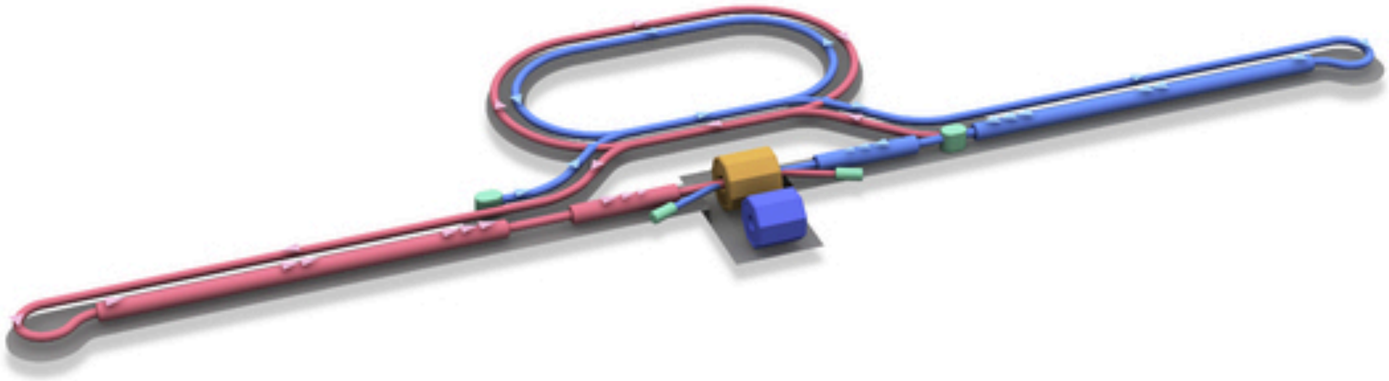
Higgs Physics at the ILC

EPS 2023

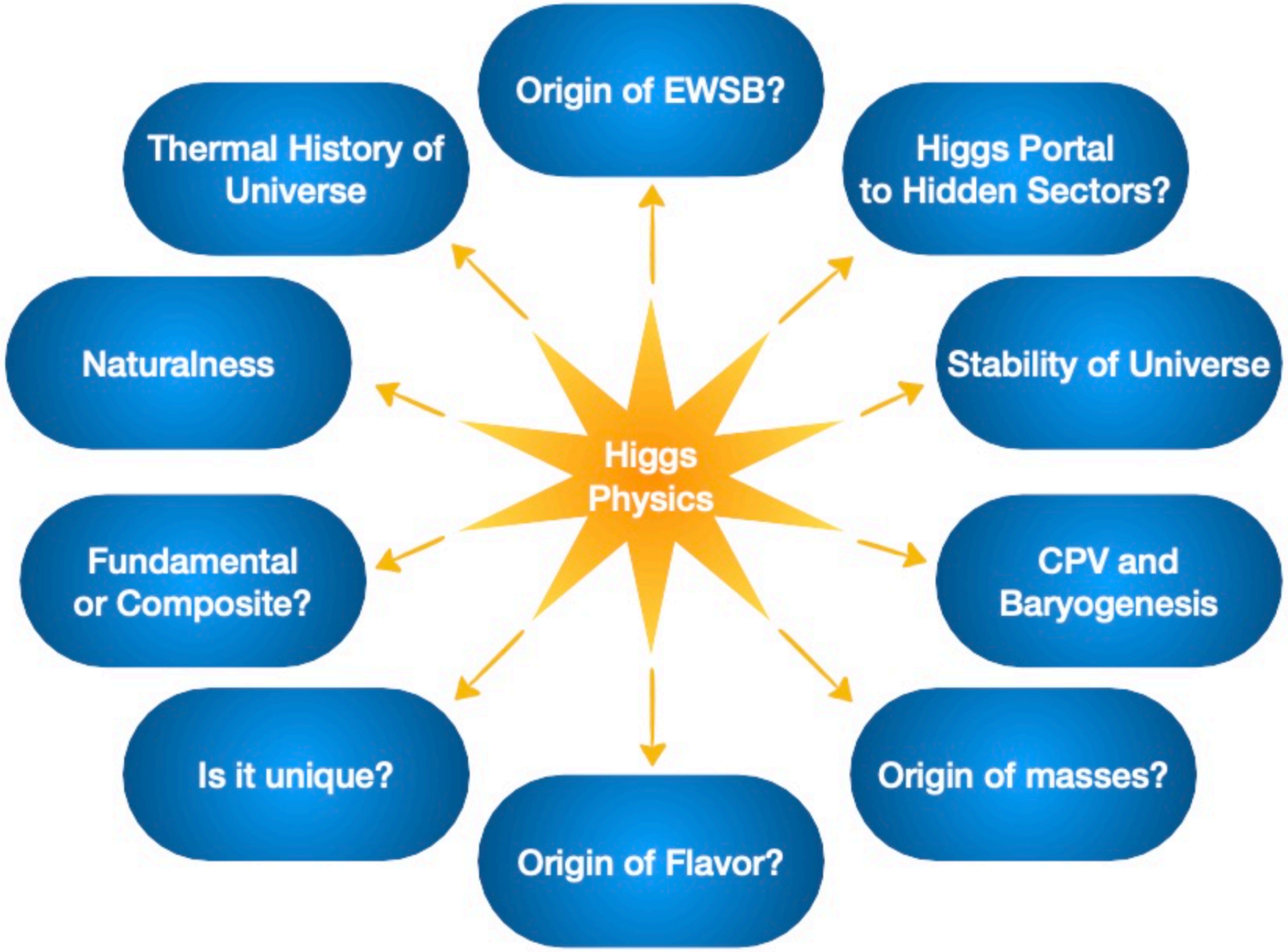
Carsten Hensel, CBPF, 24/08/2023
(on behalf of the ILC IDT WG3)

Outline

Higgs ILC Higgs Measurements Summary



Why Do We Care About Higgs Physics?



- least understood part of the Standard Model
- portal to questions of cosmological relevance

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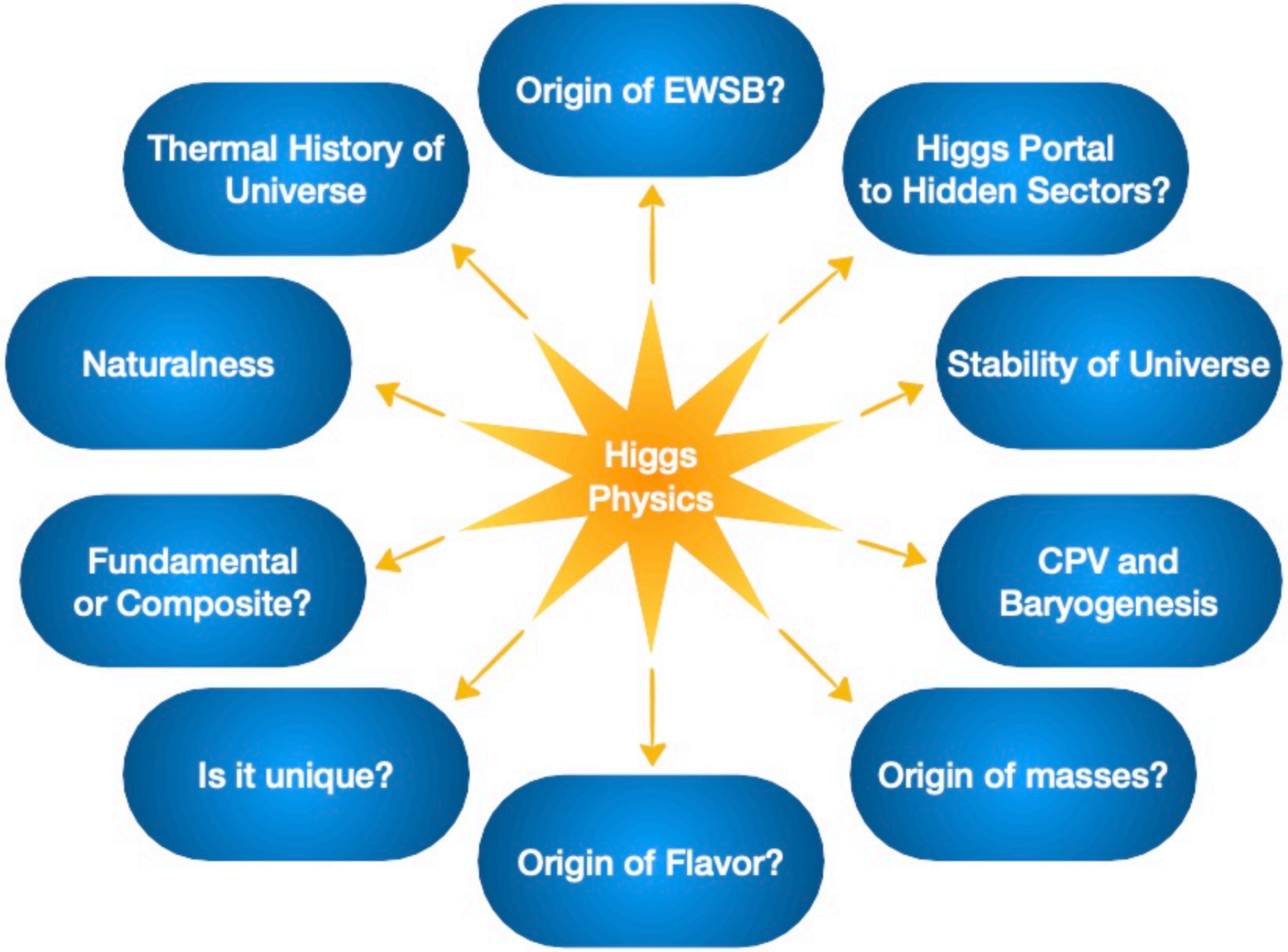
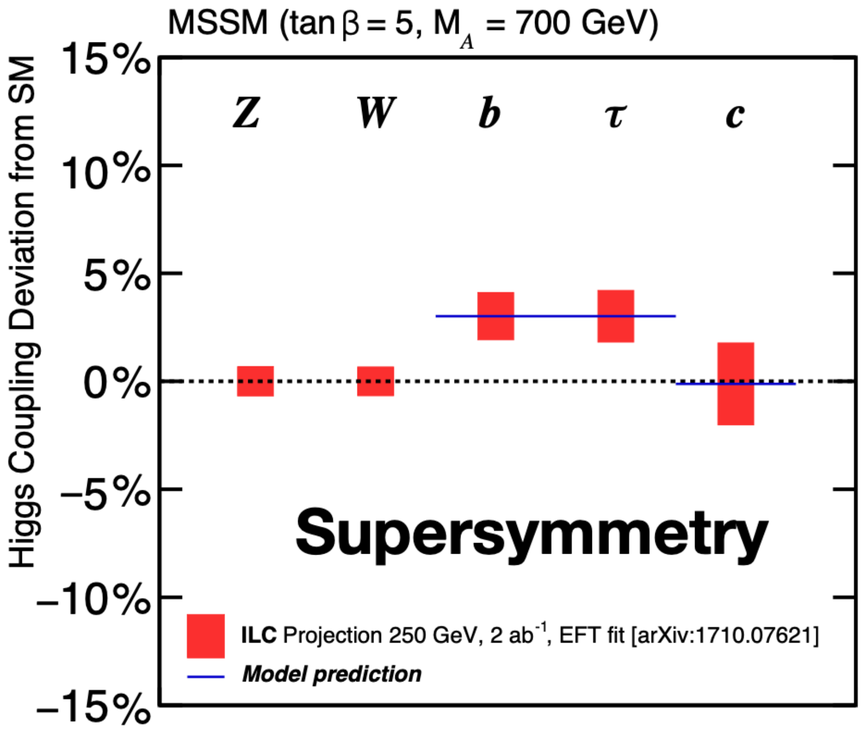
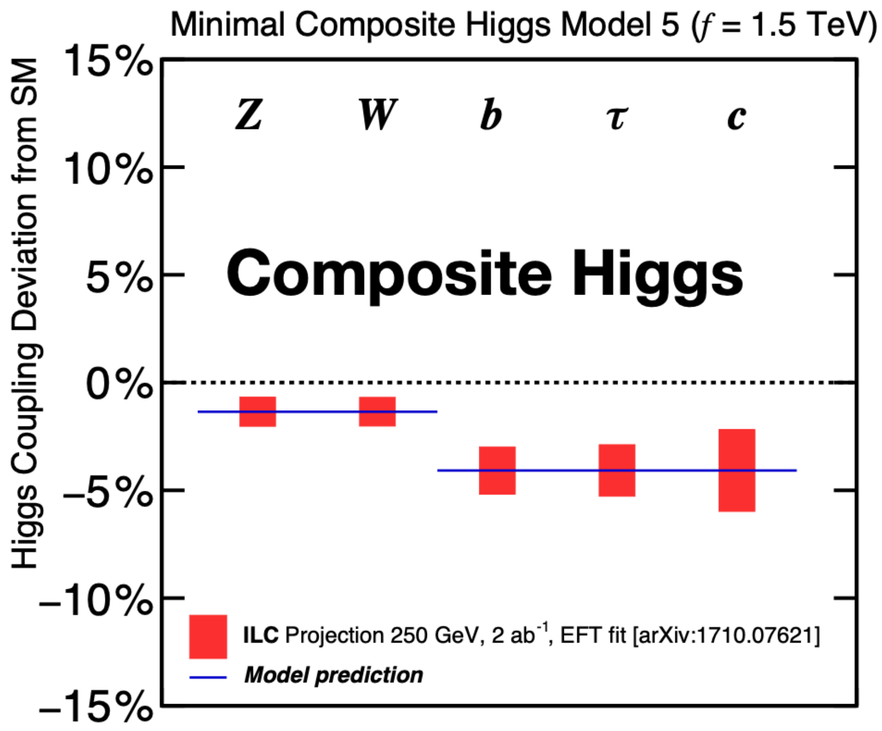


- least understood part of the Standard Model
- portal to questions of cosmological relevance
- (side note: outreach homework)

Example: Precision Higgs Couplings





[ILC TDR, arXiv: 1306.6352]

Can not only discover BSM physics,
but also identify the nature of the BSM
by precisely measuring the deviation pattern.

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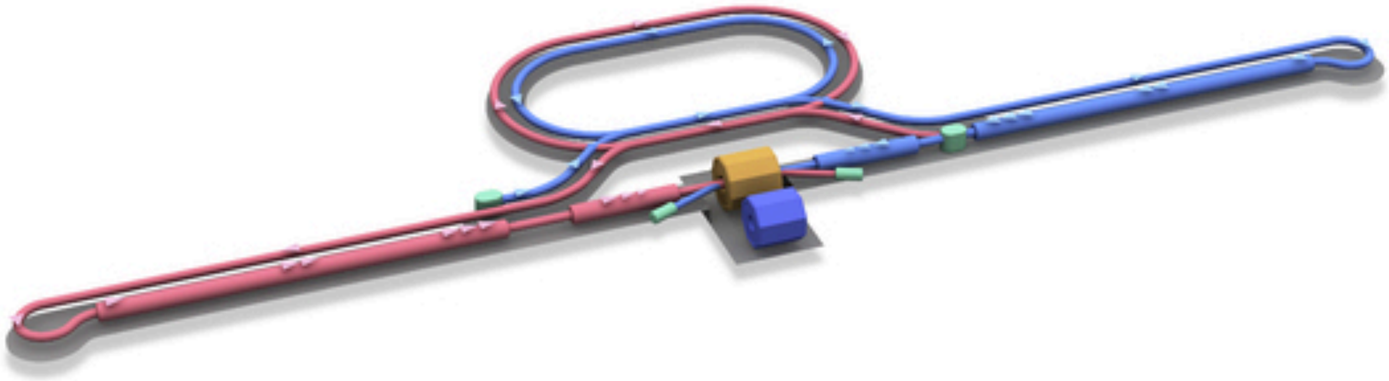
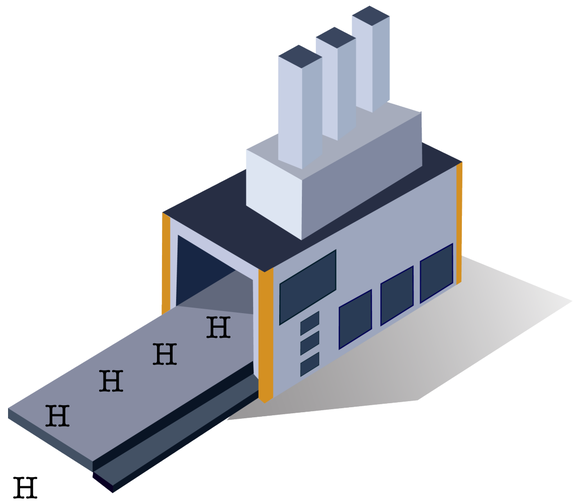


Higgs Factories

common: Higgs factory
with O(10^6) Higgs events

differ in energy reach, luminosity, polarisation, project readiness



	center-of-mass energy	beam polarisation	integrated luminosity	R&D phase
ILC	0.1-1.0 TeV	e^- 80% e^+ 30%	2 ab^{-1} @250 GeV	TDR 2013
CEPC	90-240 GeV	e^- 0% e^+ 0%	20 ab^{-1} @240 GeV	TDR 2022
FCC-ee	90-350 GeV	e^- 0% e^+ 0%	5 ab^{-1} @240 GeV	CDR 2018
CLIC	0.35-3 TeV	e^- 80% e^+ 0%	2.5 ab^{-1} @1.5 TeV	CDR 2012

(not listed: C^3, Muon Collider, μTristen)

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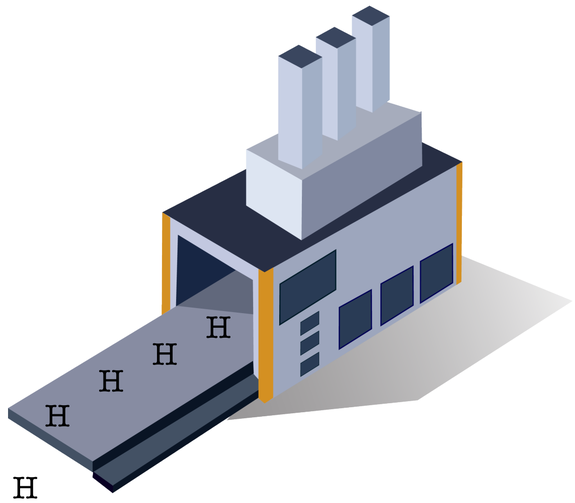

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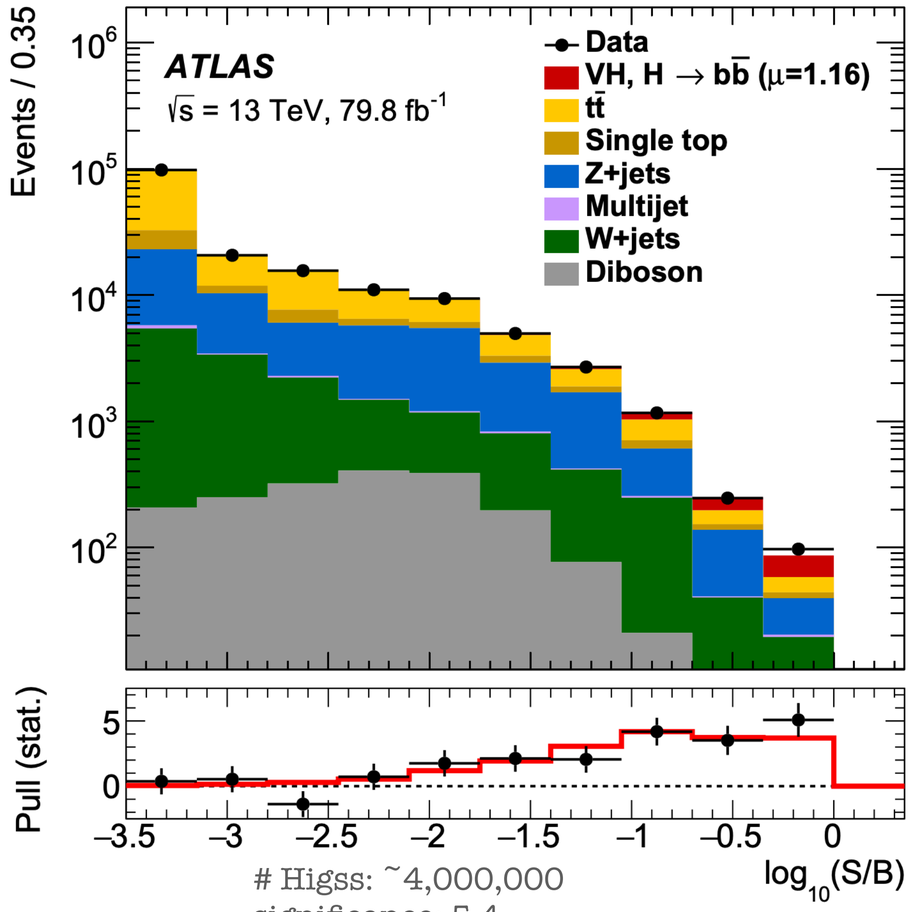
What about the LHC?

(not listed: C^3, Muon Collider, μTristen)

Statistics is not Everything

(H -> bb discovery)

LHC: super higgs factory (O(10^8))



Higgs: ~4,000,000
significance: 5.4

[1808.08238]

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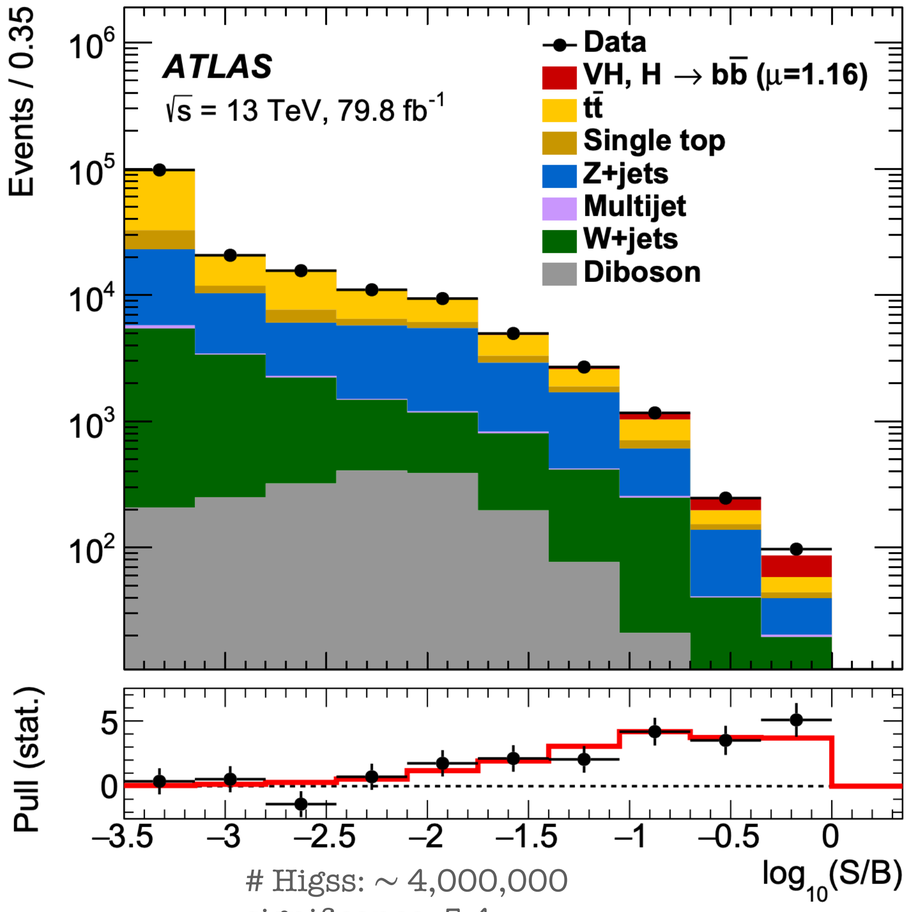

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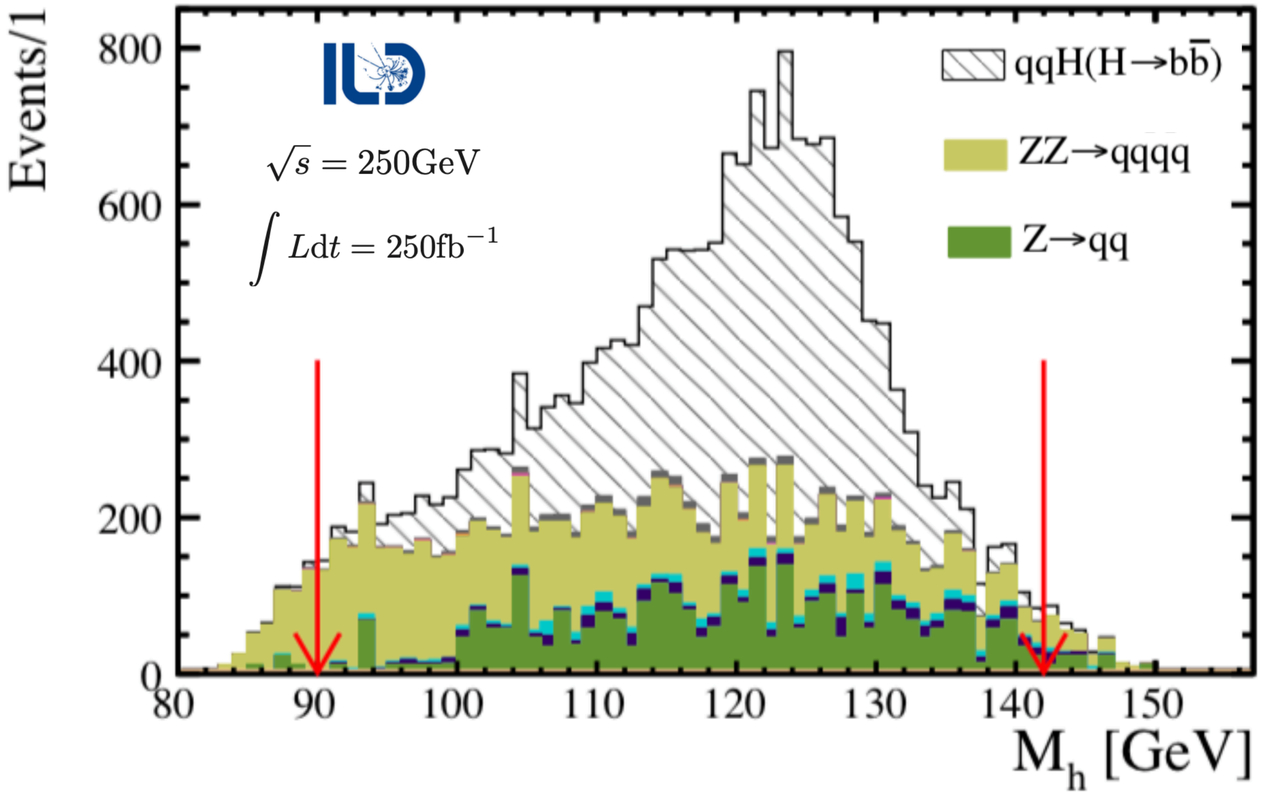
[1808.08238]

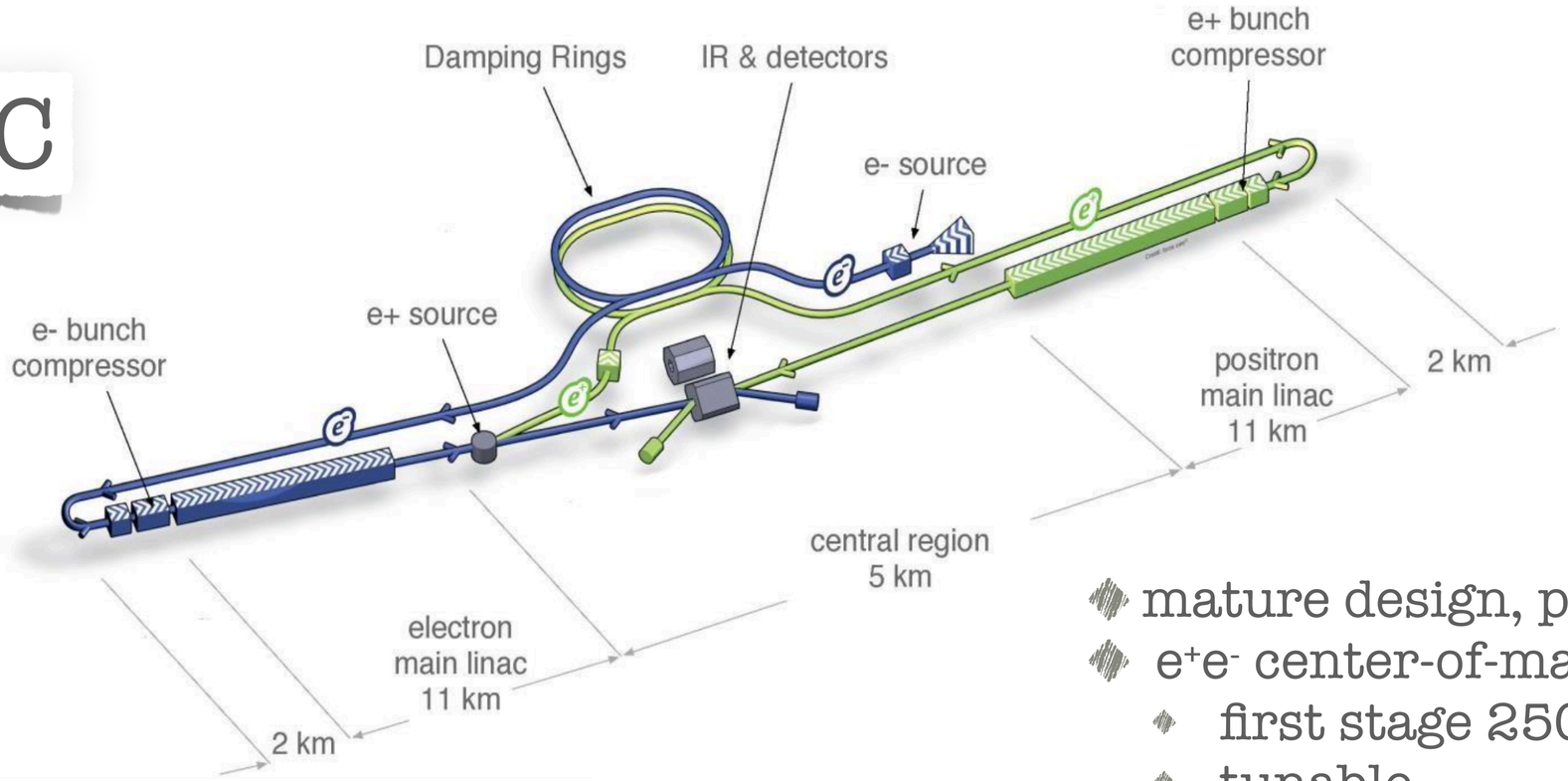
e⁺e⁻: higgs factory (O(10^6))

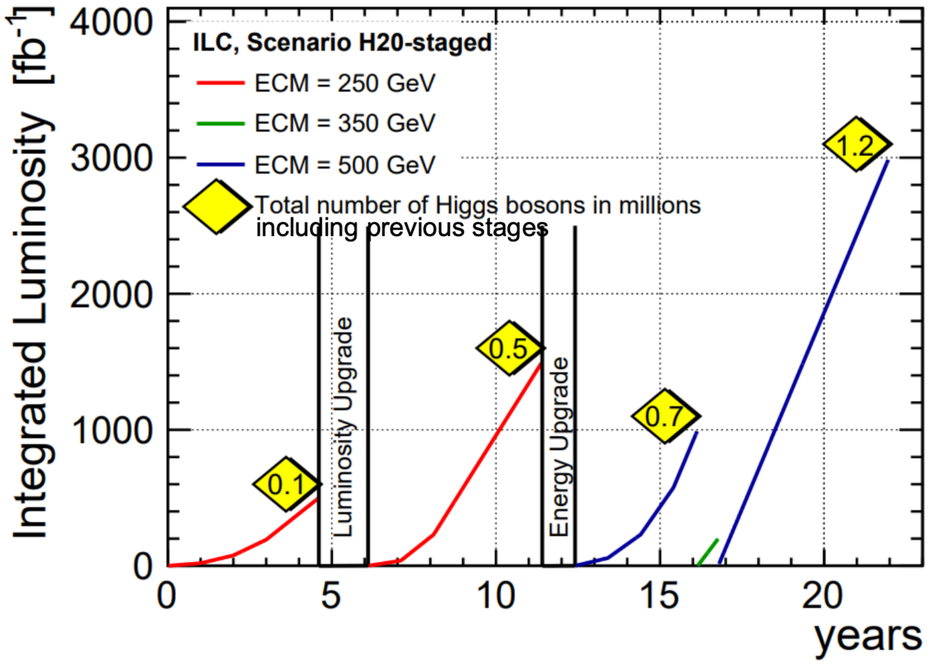


Higgs: ~ 10,000
significance: 5.2

[Ogawa, PhD thesis (Sokendai 2018)]

The ILC

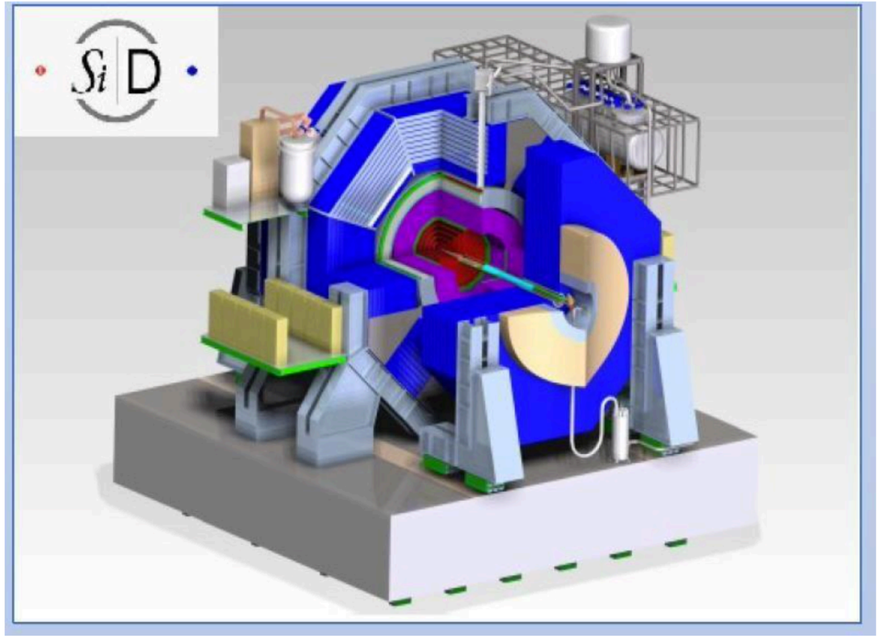




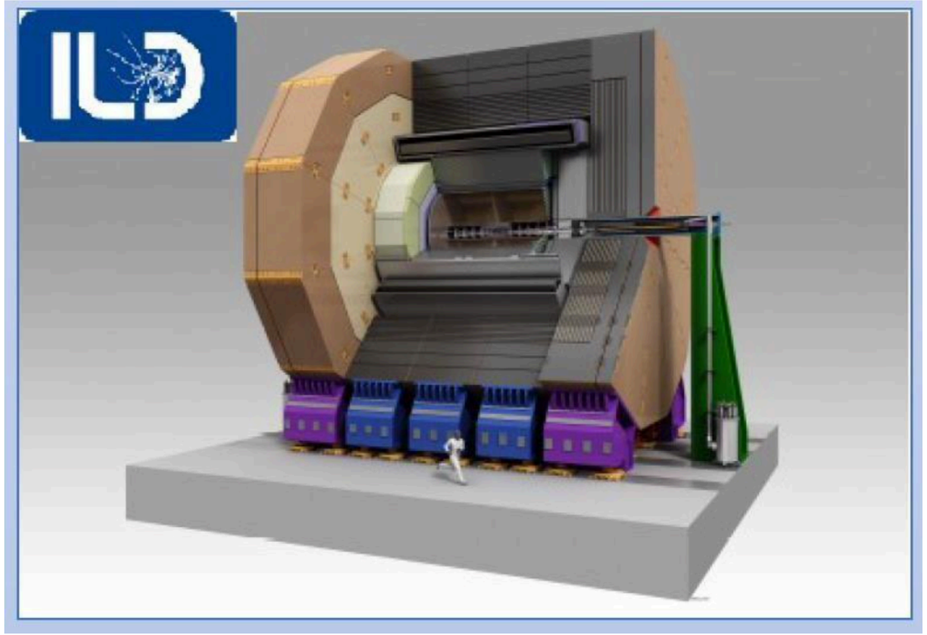
- mature design, proven technologies
- e^+e^- center-of-mass-energy
  - first stage 250 GeV
  - tunable
  - upgrades 500 GeV, 1 TeV
  - Z pole, tt threshold
- luminosity at 250 GeV
  - 1.35×10^{34} cm^{-2}s^{-1}
  - upgrade $2.7 - 5.4 \times 10^{34}$ cm^{-2}s^{-1}
- beam polarisation
  - $P(e^-) = \pm 80\%$
  - $P(e^+) = \pm 30\%$ (60% @ 500 GeV)
- total length: 30 km

Detectors at the ILC

- 2 validated detector concepts: SiD and ILD
- physics driven requirements
- decades of extensive detector R&D
- (push-pull configuration)

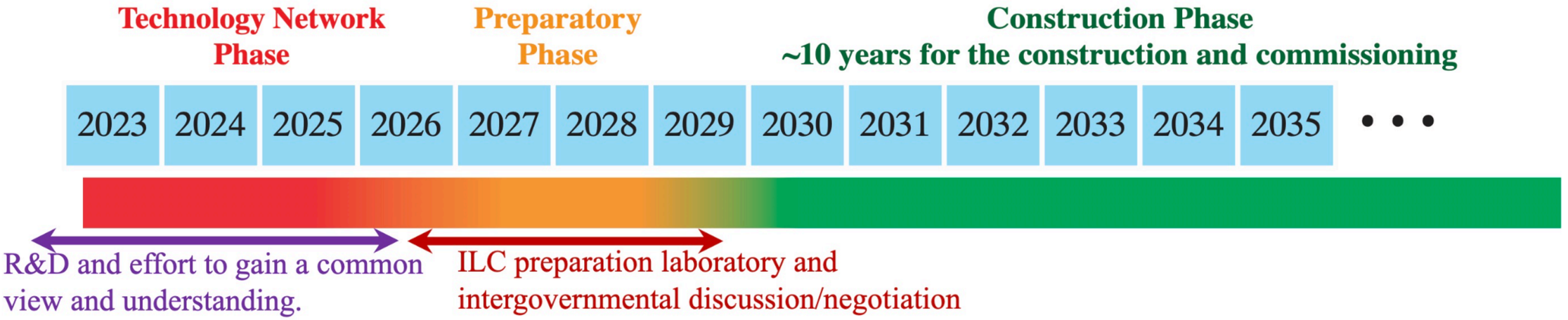


- 5T field
- more compact (than ILD)
- all Si tracking



- 3.5T field
- optimized for $\sqrt{s} = 90\,\mathrm{GeV} \ldots 1\,\mathrm{TeV}$
- Si/gaseous tracking

ILC Project Status



under discussion (not government approved)

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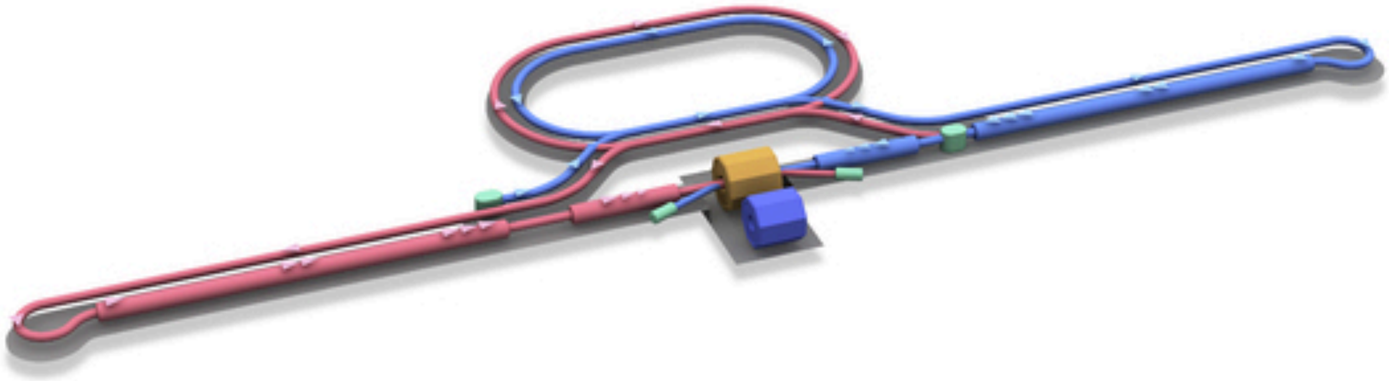


ILC Higgs Factory Roadmap

250 GeV

mass, spin, CP nature, absolute measurement of HZZ, BRs Higgs → qq, ll, VV

350 GeV

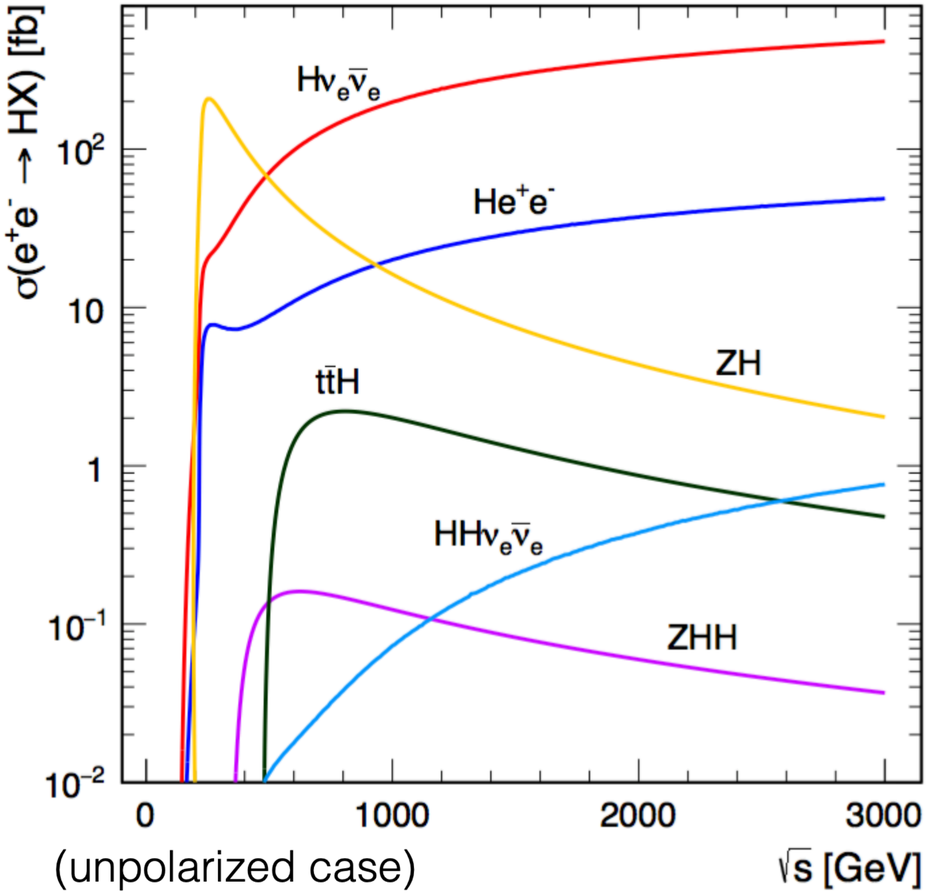
top threshold: mass, width, anomalous couplings,
more stats on Higgs BRs,...

500 GeV

HWW couplings -> total width -> absolute couplings
Higgs self-coupling, top Yukawa coupling

1 TeV

as motivated by physics



ILC Higgs Factory Roadmap

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see presentations in this session

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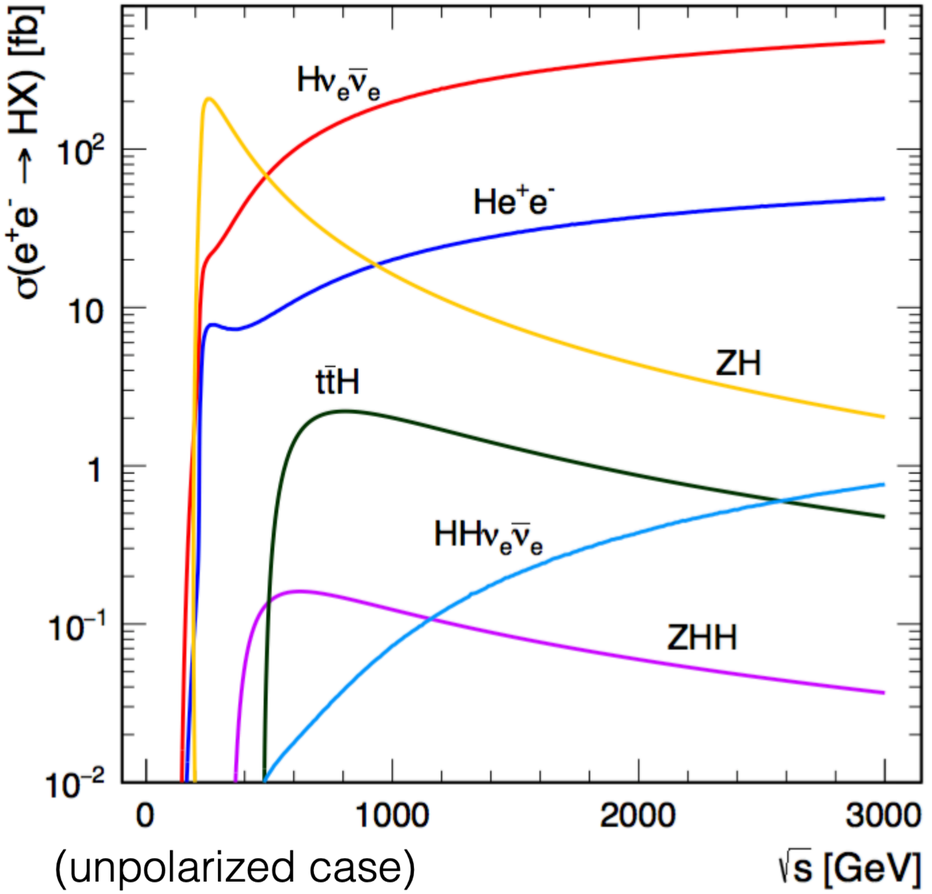

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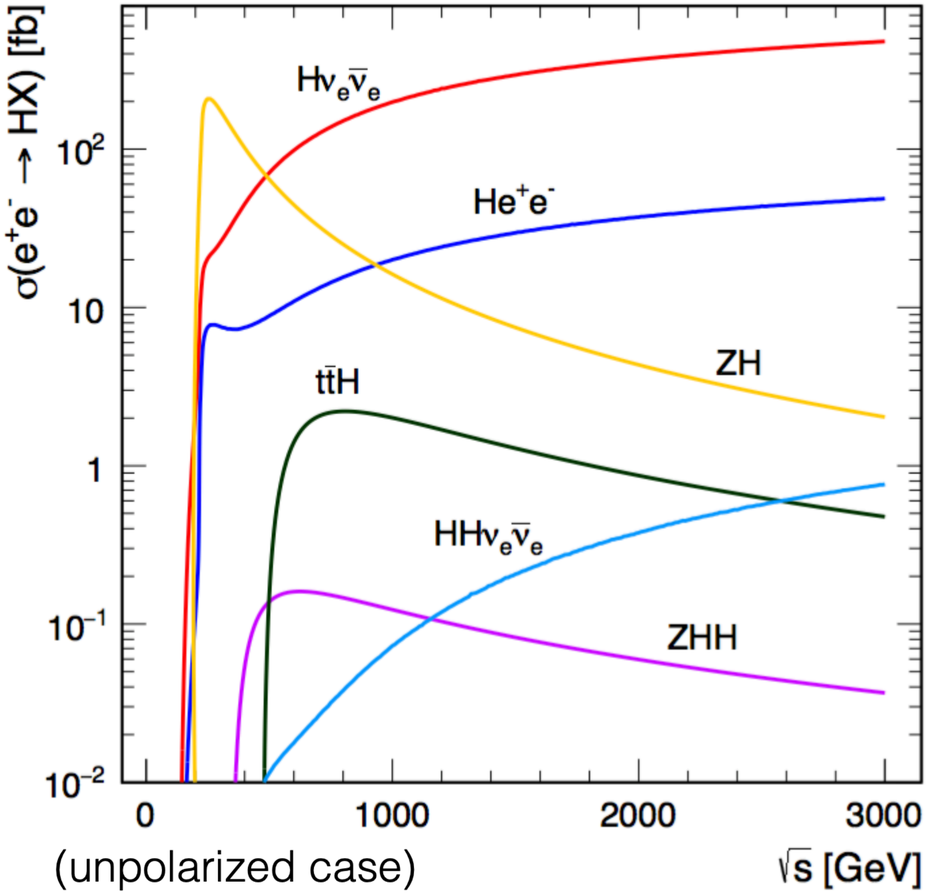
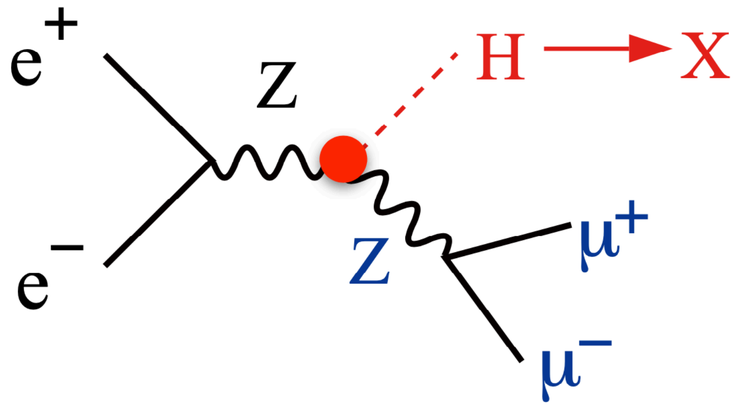


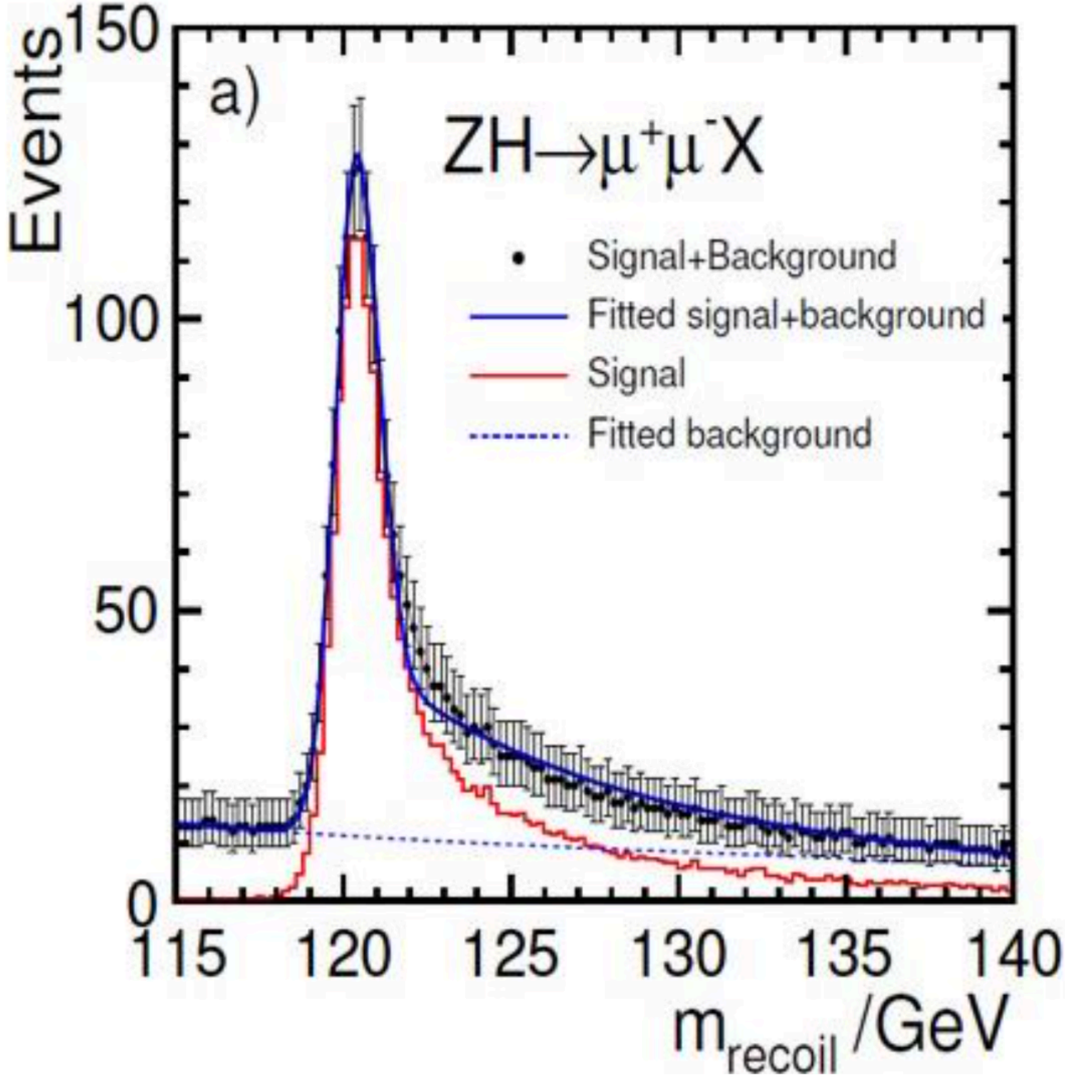
Higgs Mass Measurement



$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

recoil mass
independent of Higgs decays

250 fb^{-1} @ 250 GeV
$\Delta\sigma_H/\sigma_H = 2.5\,\%$
$\Delta m_H = 30\,\mathrm{MeV}$



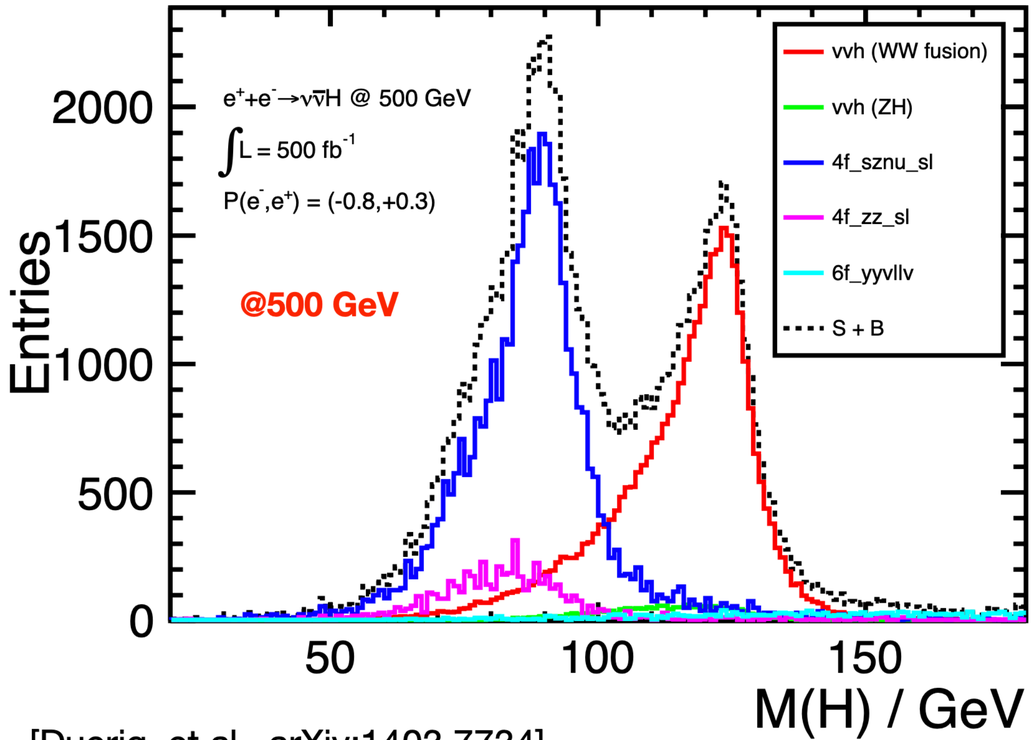
[Fuji]

Determining the Higgs Width (model independent)

- to extract couplings from BRs we need the total width
- to measure total width we need at least one partial width and corresponding BR

$$\Gamma_H = \frac{\Gamma_{HZZ}}{\mathrm{BR}(H \to ZZ^\star)} \propto \frac{g^2_{HZZ}}{\mathrm{BR}(H \to ZZ^\star)}$$

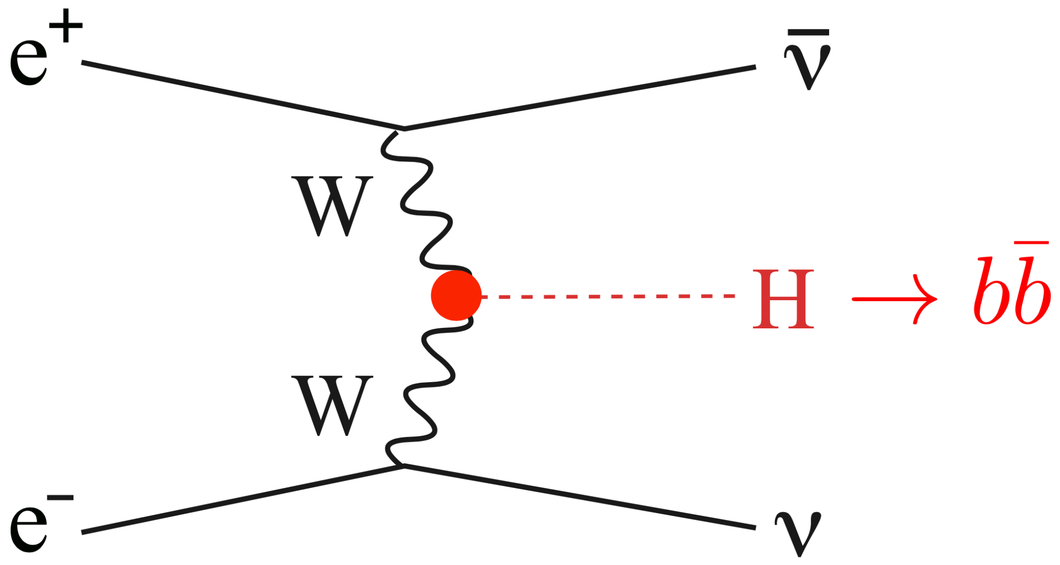
but branching ratio small



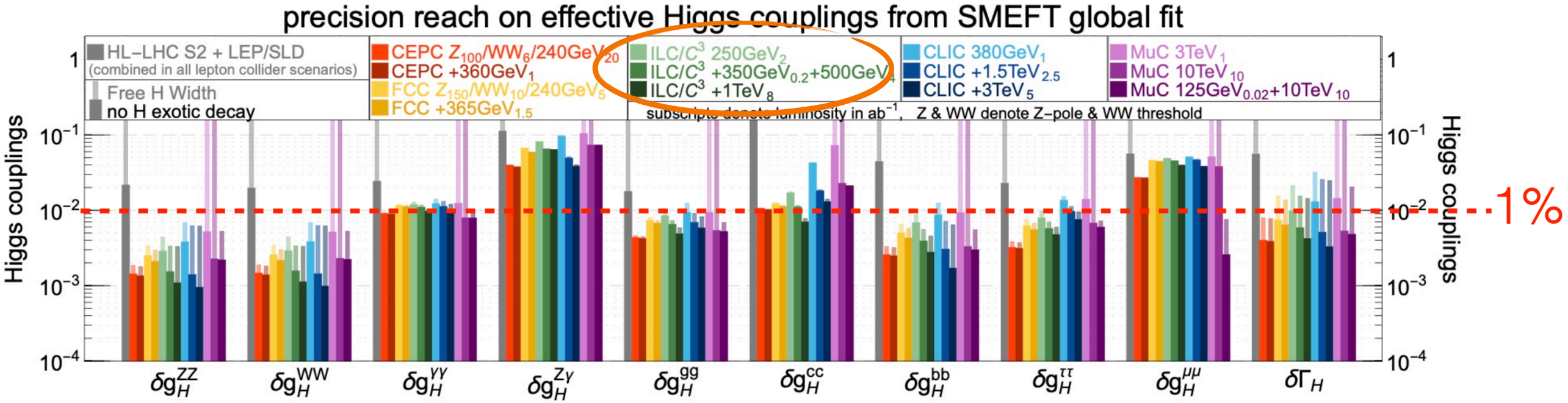
[Duerig, et al., arXiv:1403.7734]

better option: $H \to WW^\star$

$$\Gamma_H = \frac{\Gamma_{HWW}}{\mathrm{BR}(H \to WW^\star)} \propto \frac{g^2_{HWW}}{\mathrm{BR}(H \to WW^\star)}$$



Higgs Couplings

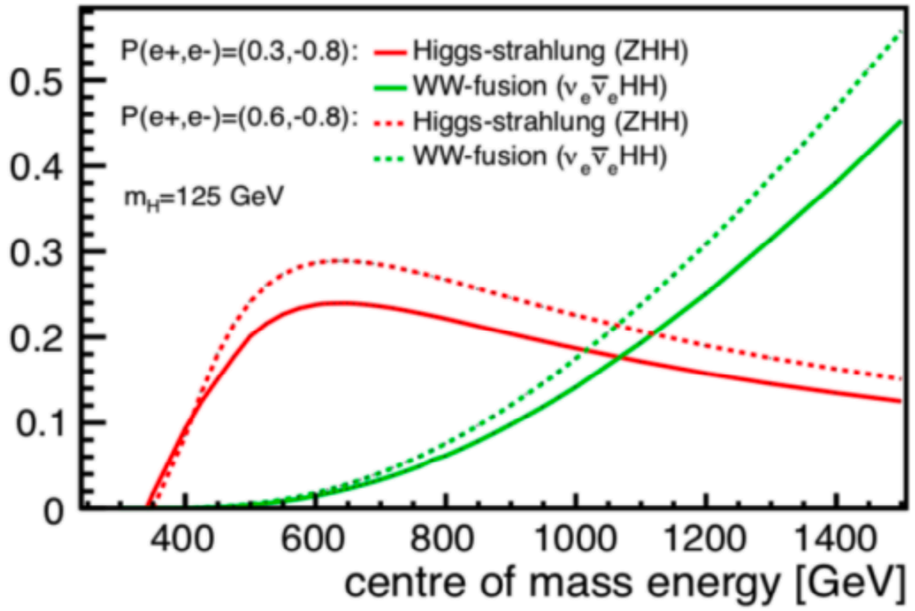


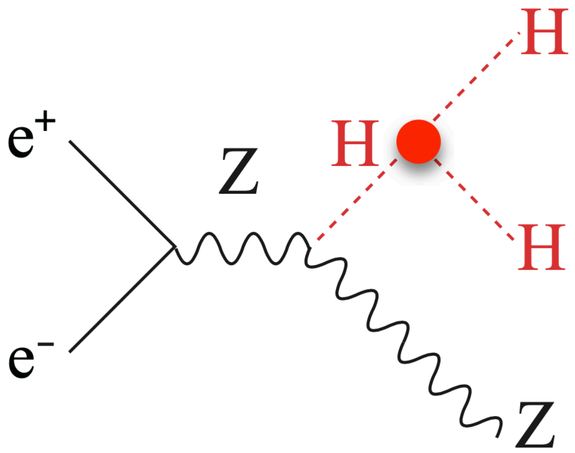
[Snowmass White Paper on Global SMEFT Fits, arXiv:2206.08326]

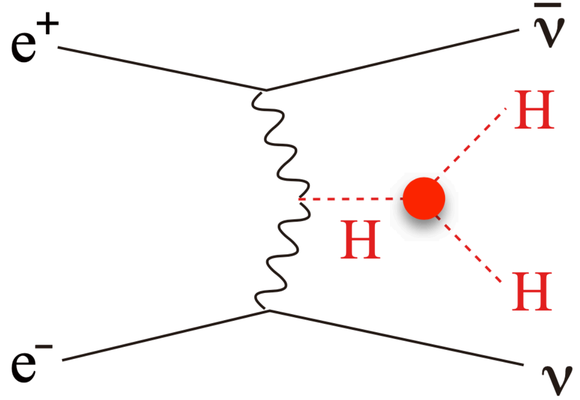
- ultimate precision achieved in global fit (model-independent in ZH, κ-framework, EFT)
- 1% or better reachable by ILC (as well as other Higgs factories)

Higgs Self-coupling

direct probe of the Higgs potential







- λ is determined from the total rate of HH events
- high energy (double Higgs) production is the most sensitive to deviation from the Higgs self-coupling
- polarization almost doubles $HH\nu\nu$ rate
- higher center of mass energies offer particular sensitivity to BSM values of λ

Higgs Self-coupling

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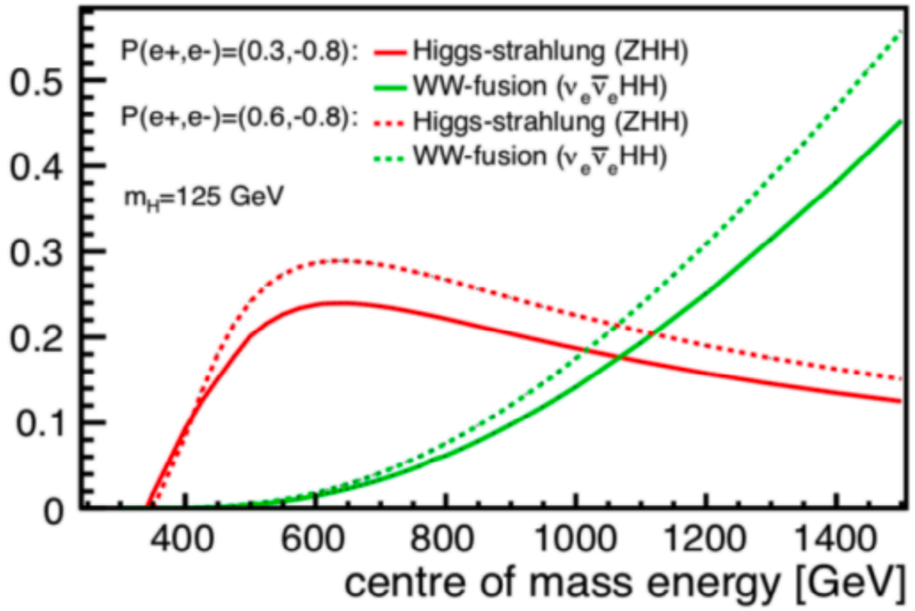

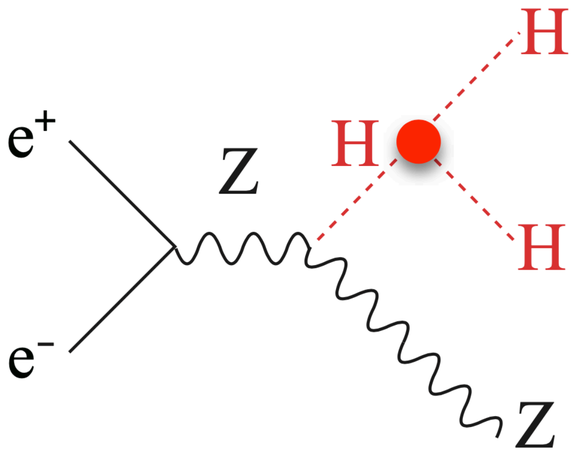

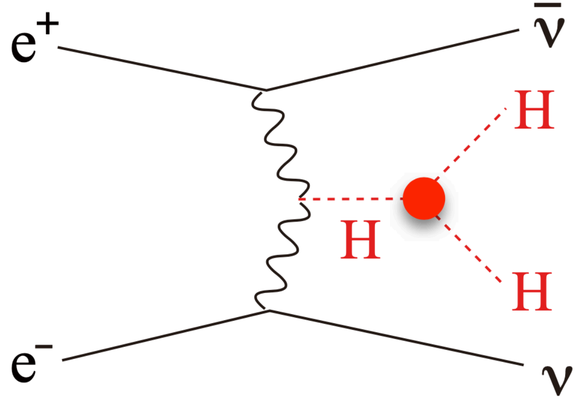

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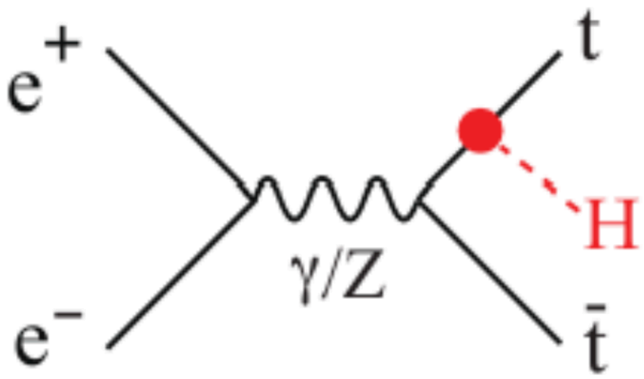
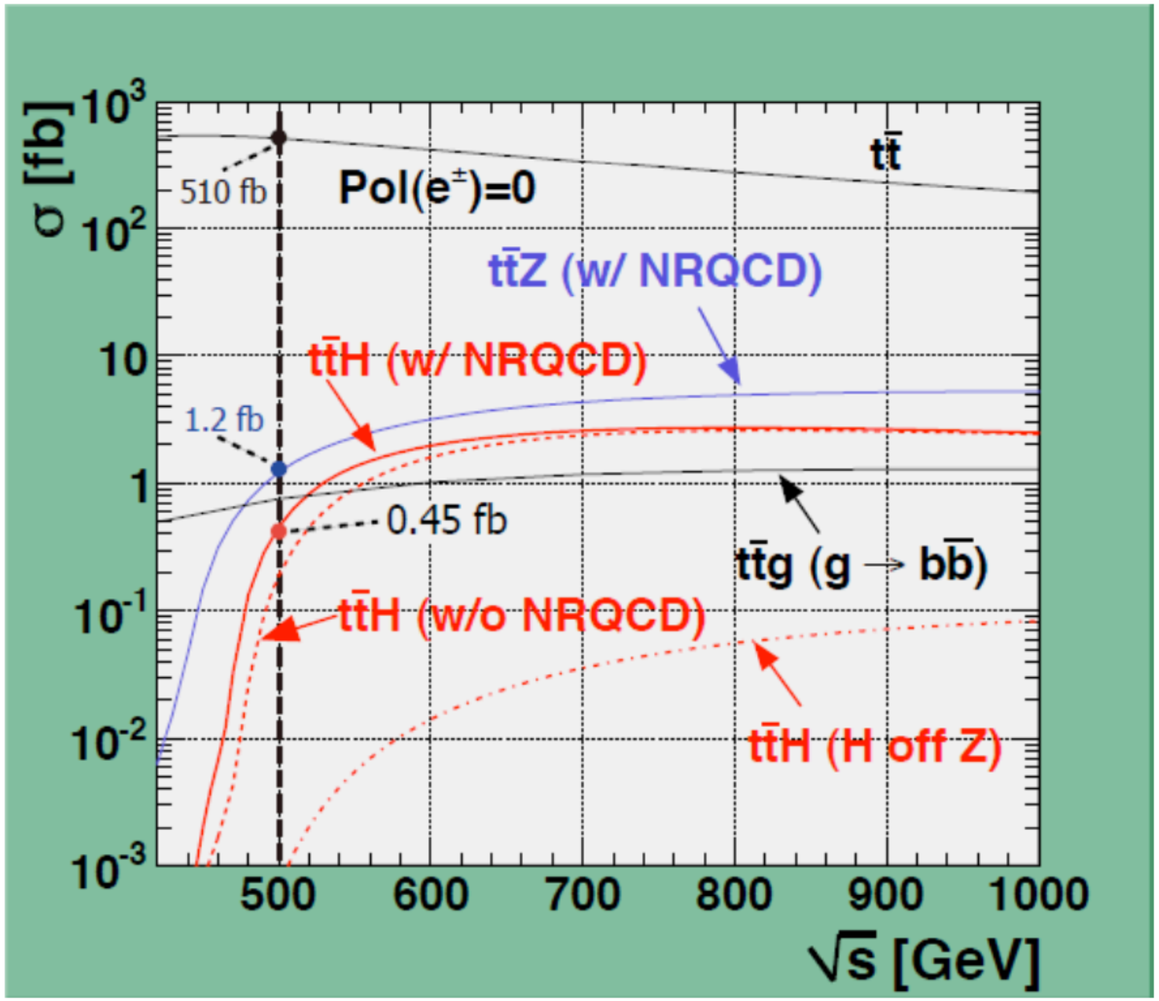
for more details see next presentation

Higgs Top-coupling

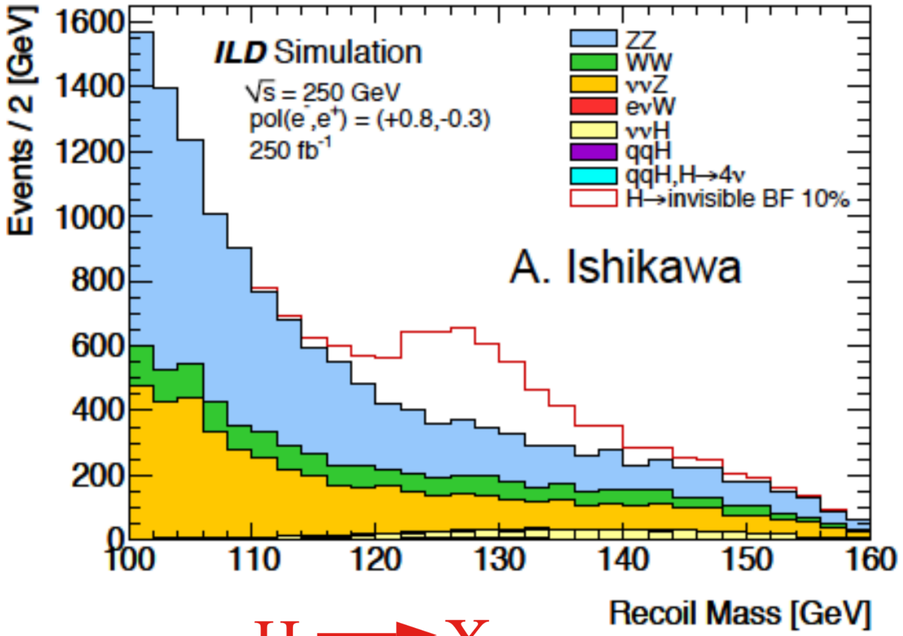




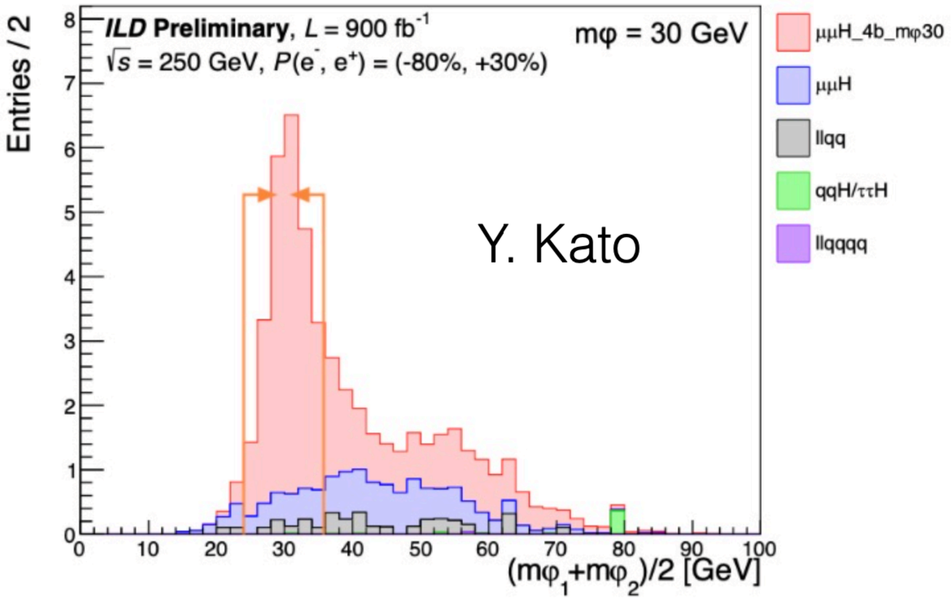
- 1 ab^{-1} @ 500 GeV
- $\Delta g_{H}^{tt}/g_{H}^{tt} = 10\,\%$

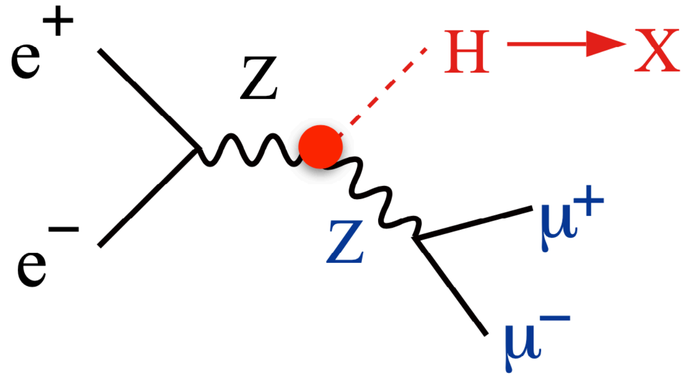
Access to Hidden Sector

H—>Invisible

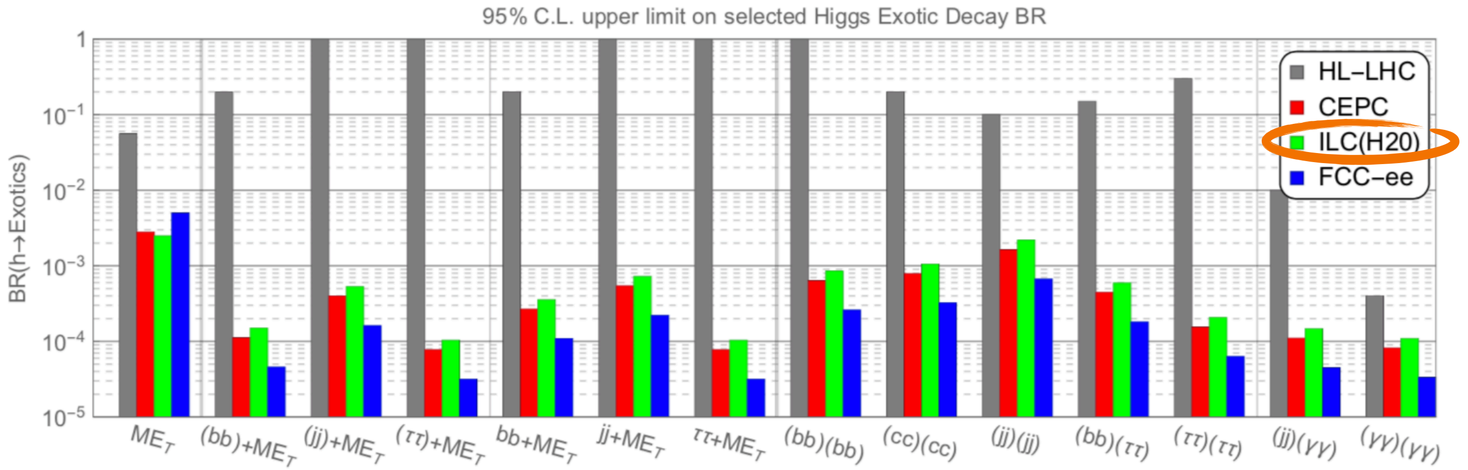


H—>ϕϕ—>4-b





a few exotic decays of BR ~ 0.1% confirmed by full simulation



[Liu, Wang, Zhang, arXiv:1612.09284]

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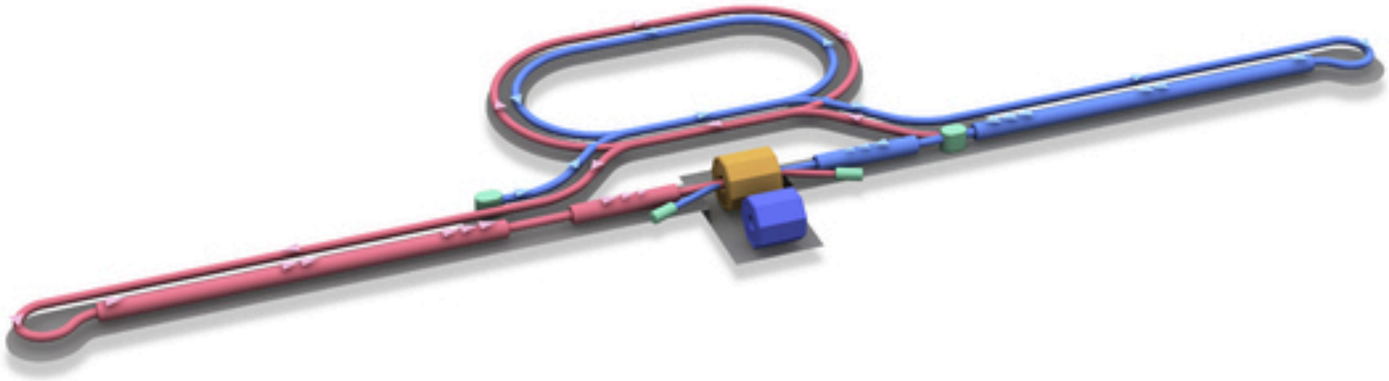
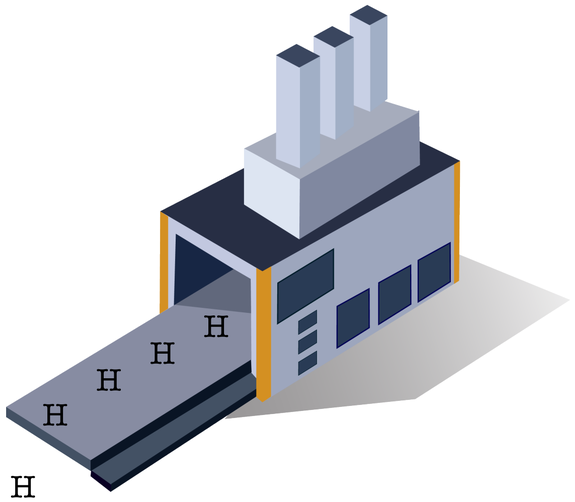


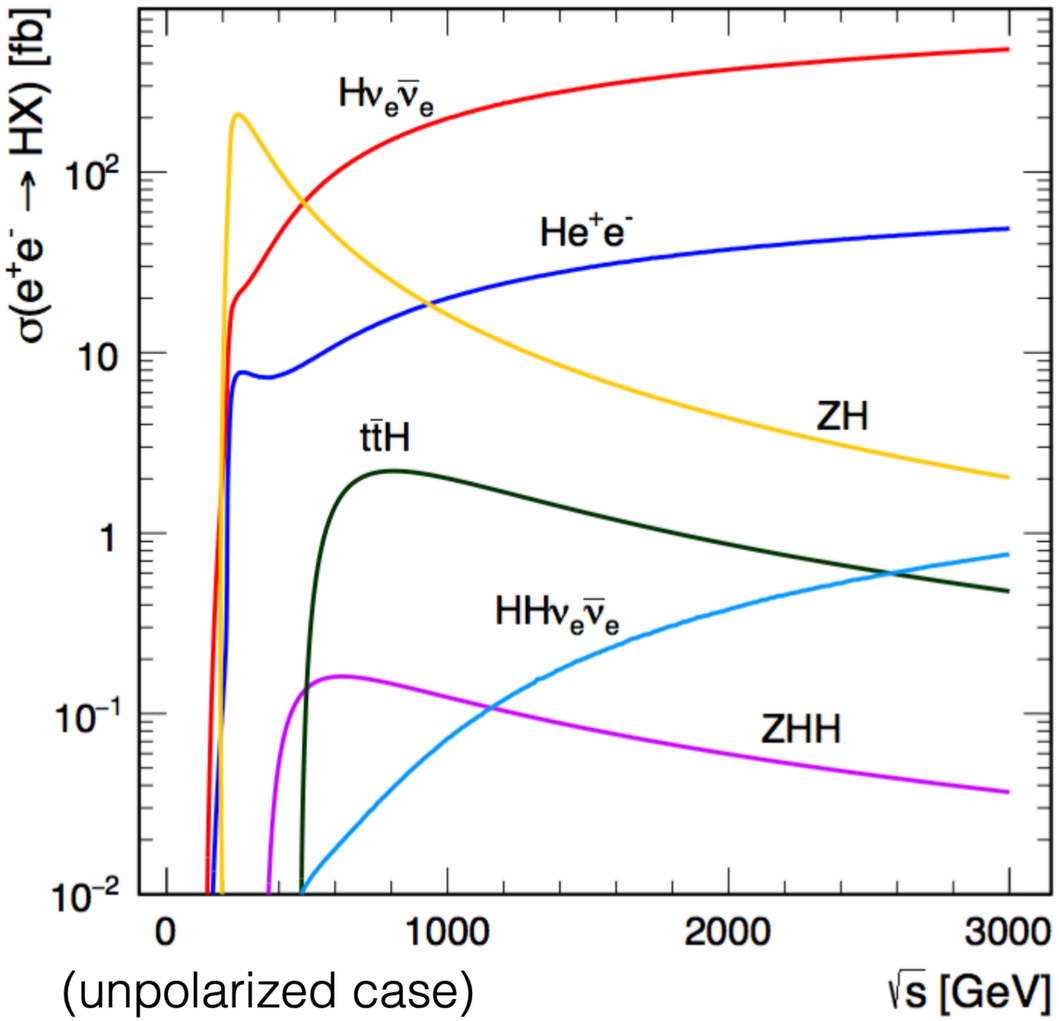
Summary

- ILC promising and mature Higgs factory proposal
- features: clean environment, flexible polarization, upgradable in energy
- rich precision Higgs physics potential

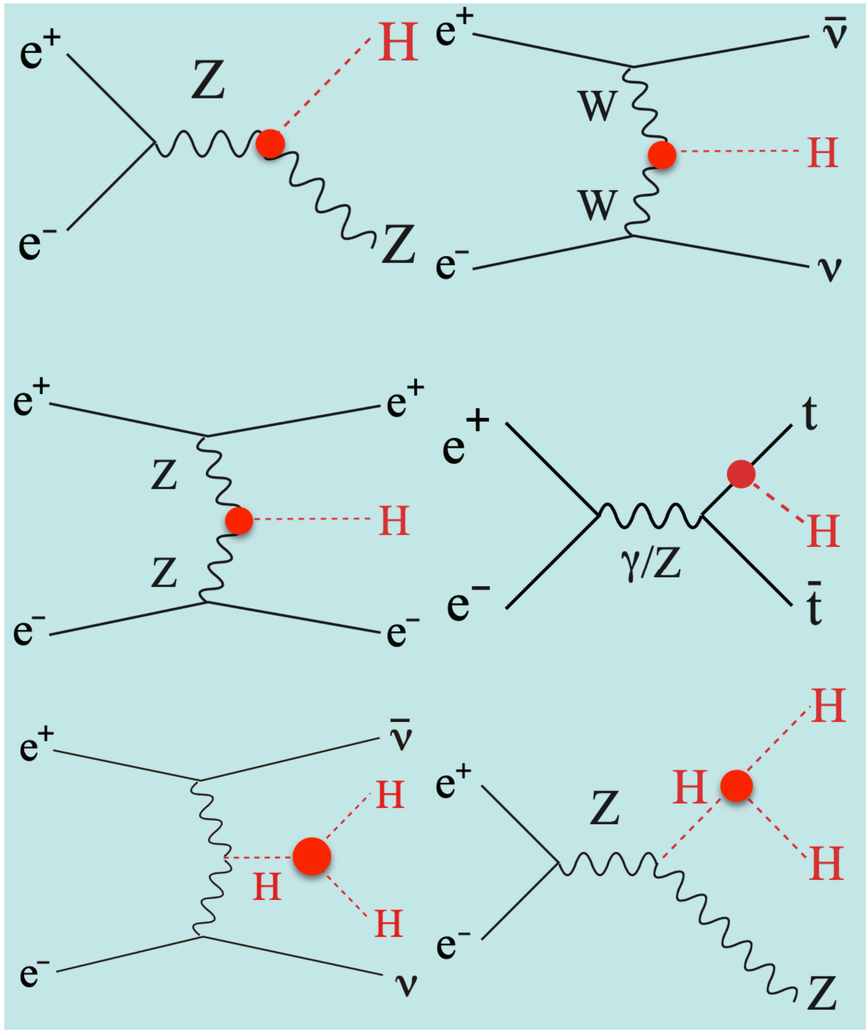


Additional Information

Higgs production @ e^+e^-



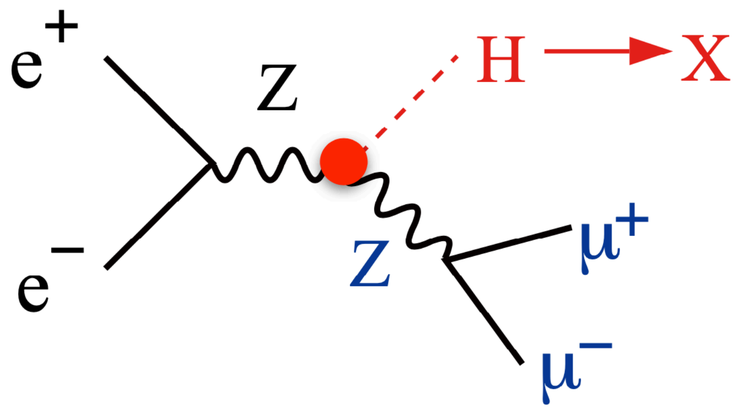
(unpolarized case)



Measuring the Normalization of the Higgs Couplings

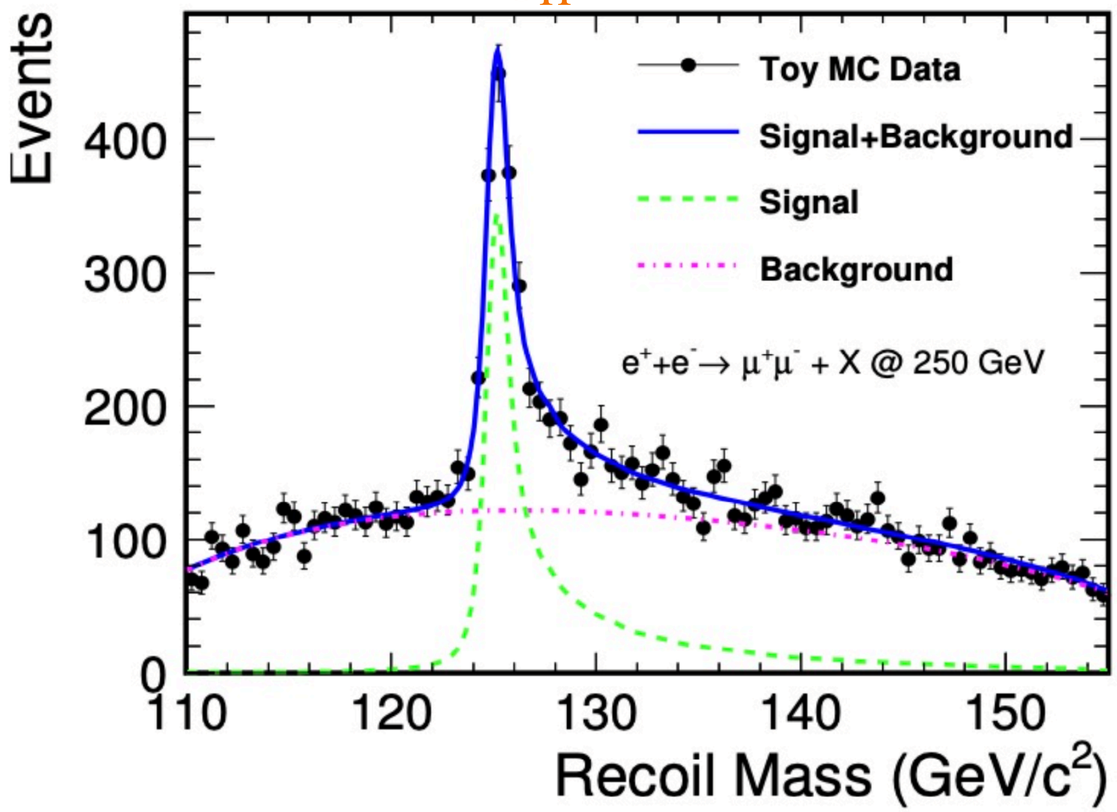
measure σ instead of $\sigma \times \mathrm{BR}$

> well defined initial state at e+e-
> tag Z only and calculate recoil mass
> decay independent Higgs tag
> absolute cross-section of $e^+e^- \to ZH$



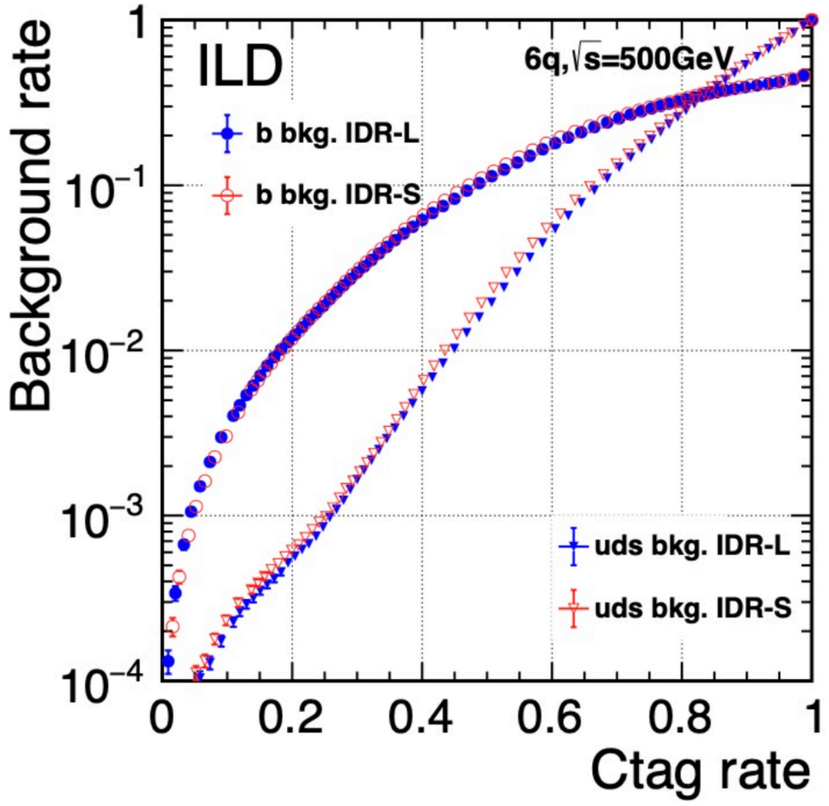
$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

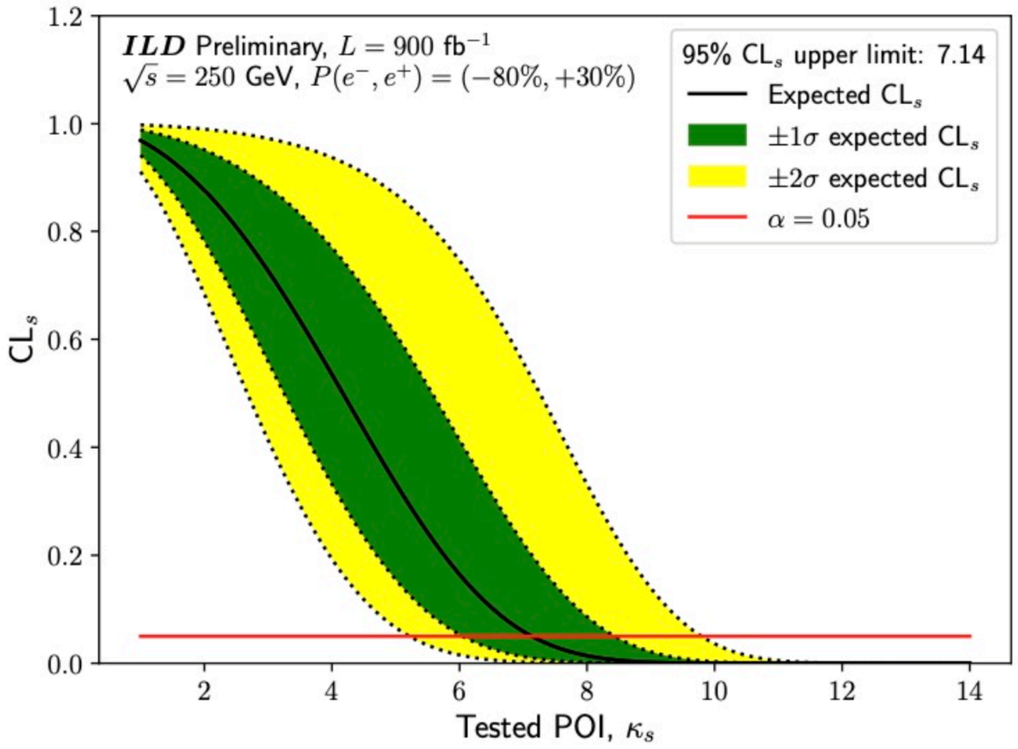
$\delta g_{\mathrm{H}}^{ZZ} \sim 0.3\,\%$



recoil technique unique at e+e- colliders

Yukawa Coupling to Second Genration Quarks

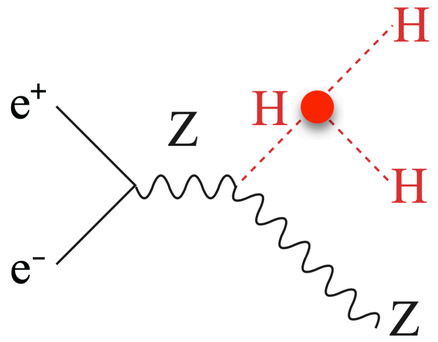


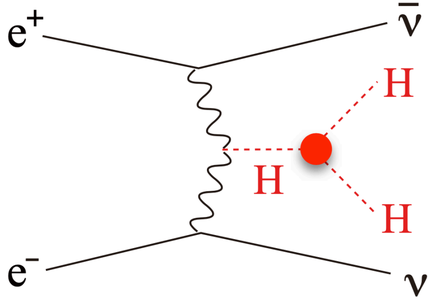


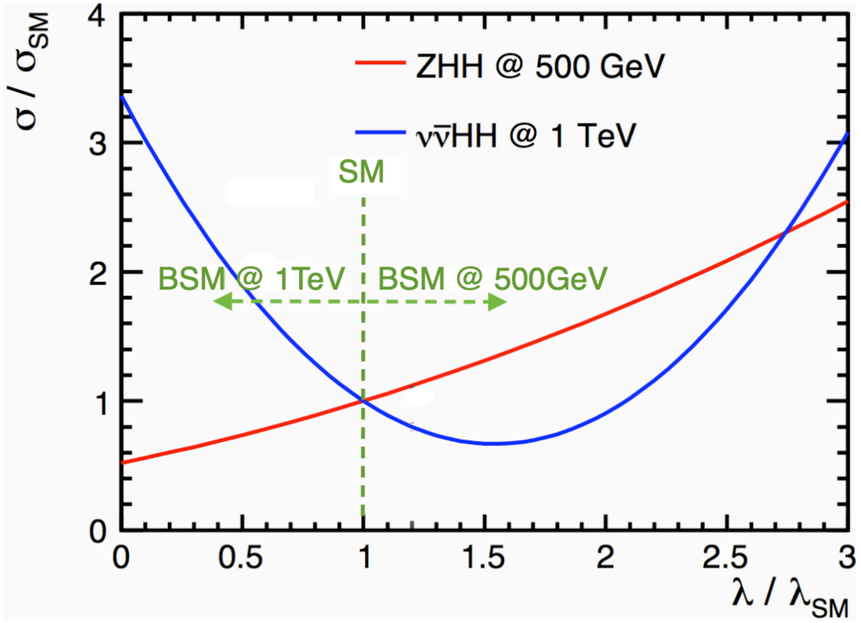
> e+e- offers low QCD backgroung
> excellent flavor tagging performance for b- and c-quarks
> s-quark tagging bing pursued

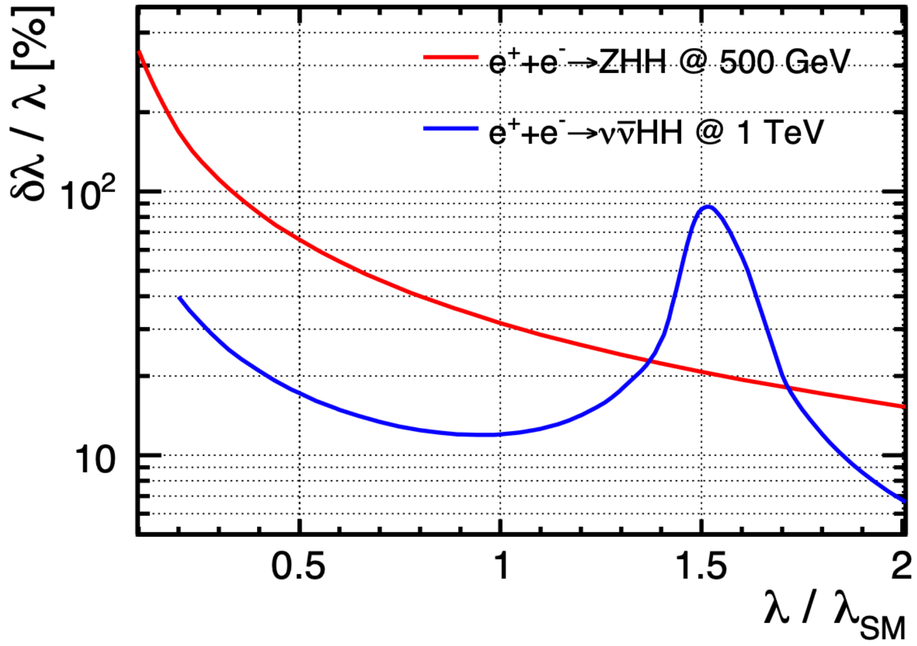
[Ono, et. al, Euro. Phys. J. C73, 2343;
F.Mueller, PhD thesis (DESY);
M.Basso, 2203.07535]

Higgs Self-coupling









> complementarity between ZHH and $\nu\nu HH$ due to different interference

> λ_{HHH}: large deviation possible in BSM

> if $\lambda_{HHH}/\lambda_{SM} = 2$, λ_{HHH} measure to 13% using ZHH at 500 GeV e+e-

Grojean, et al., PRD71, 036001;
Kanemura, et al., 1508.03245;
Kaori, Senaha, PHLTA,B747,152;
Perelstein, et al., JHEP 1407, 108

for more details see next presentation