Focus topic: Higgs self-coupling

— what ILD can contribute?

Junping Tian (U. Tokyo)

ILD Meeting 2024, Jan. 15-17, 2024 @ CERN

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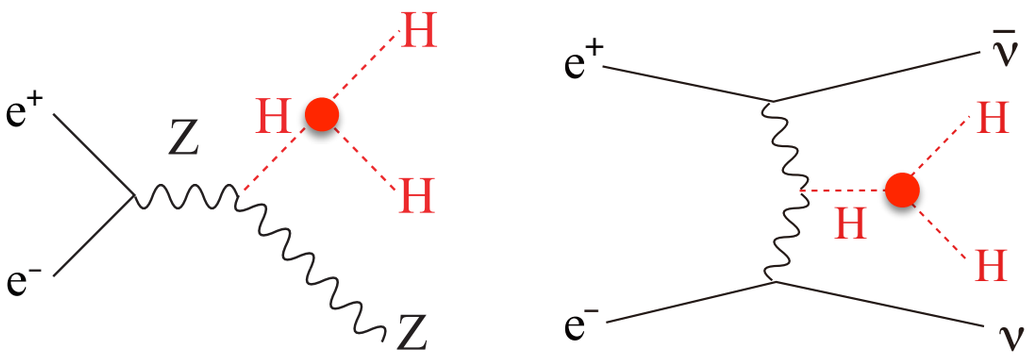
expert team

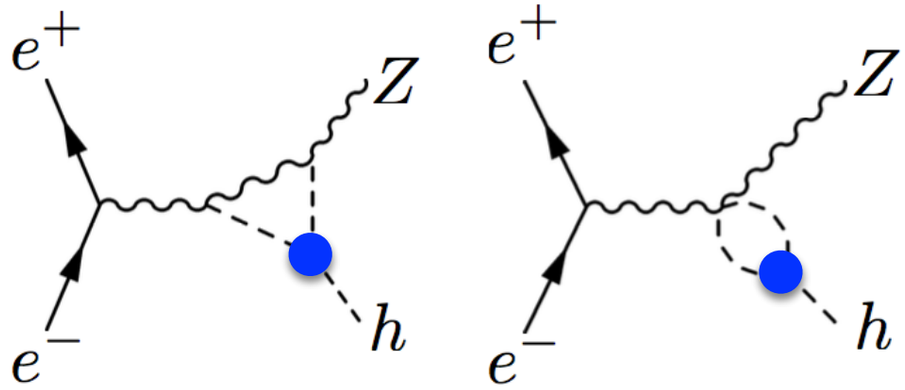
Gauthier Durieux (CERN)	Theory
Ricardo Goncalo (Coimbra)	ALTAS / FCC-ee
Sven Heynemeyer (IFT CSIC)	WG1-GLOB / Theory
Michael Peskin (SLAC)	Theory
Philipp Roloff (CERN)	CLIC
Roberto Salerno (LLR/Ecole Polytechnique)	CMS / FCC-ee
Junping Tian (U.Tokyo)	WG1-GLOB / ILC
Jenny List (ex-officio)	

λ_{HHH}: Starting point - ESU 2020

[Physics Briefing Book]

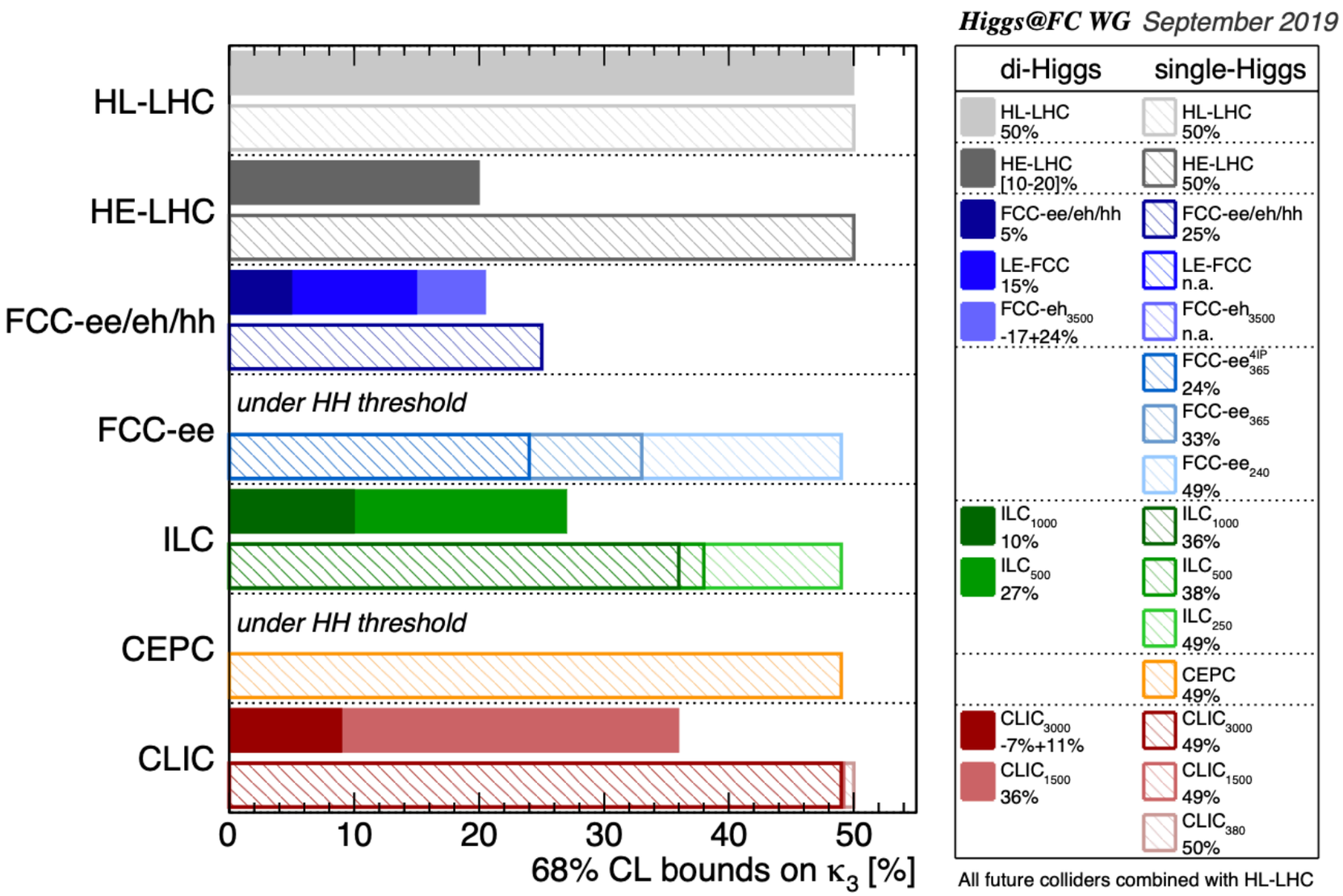


σ_{HH} ~ O(0.1) fb

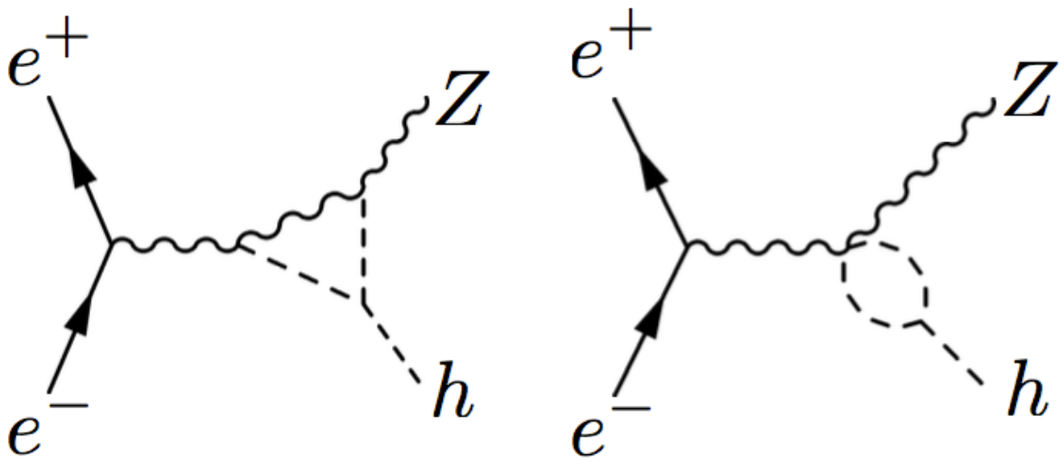


$\delta\sigma_{ZH}$ ~ O(1%)

- two approaches: di-Higgs & single-Higgs
- based on global SMEFT fits
- HL-LHC di-Higgs contribution was always combined



(ii) questions related to single-Higgs process



[McCullough, '13]

$$\delta_\sigma^{240} = 100\,(2\delta_Z + 0.014\delta_h)\,\%$$

- if only δh is deviated —> δh ~ 28% [ILC as example]
- if both δz and δh deviated —> δh ~ 90%
- δσ could receive contributions from many other sources

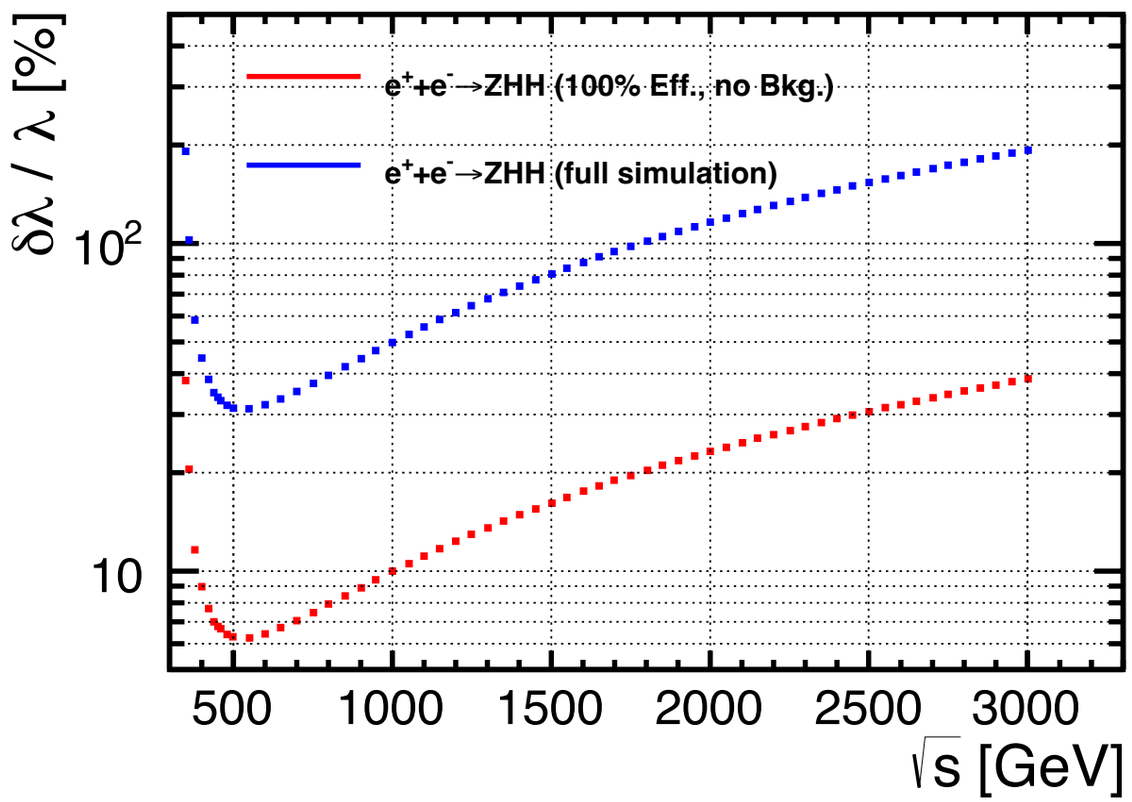
  —> **δh ~ 500%** at 250GeV only; [Gu, et al, arXiv:1711.03978]

  —> **δh ~ 50%** + 350/500GeV [Peskin, Yong, JT, paper in preparation]

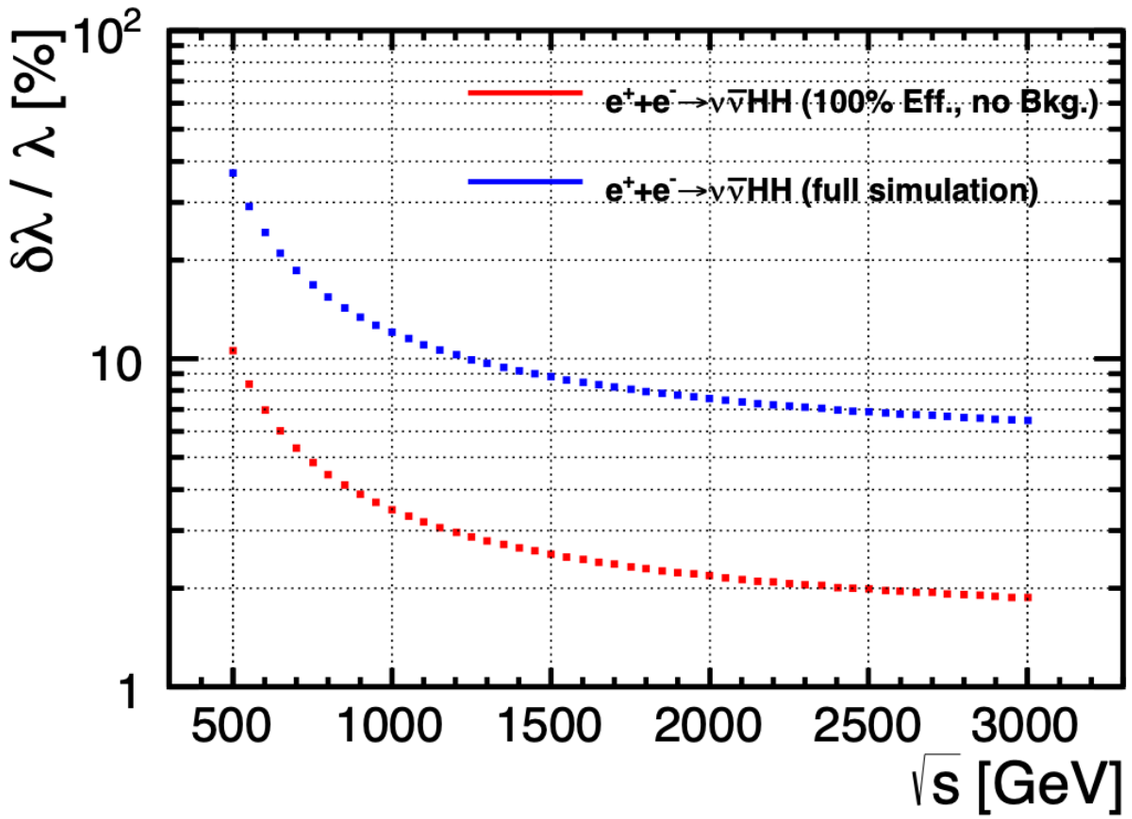
- **can we lift the degeneracies by new observables, e.g. ZHang?**
- **what if we include other NLO effects as well, e.g. top?**
- **key: a SM consistency test or a well defined measurement?**

(iii) di-Higgs: can we improve $\Delta\lambda_{HHH}$ by a factor of 5?

ZHH



ννHH



[Duerig, PhD Theis, 2016]

a lot of room for improvement by advanced analysis technique:
flavor tagging, jet-clustering, kinematic fitting, matrix element method, machine learning, etc

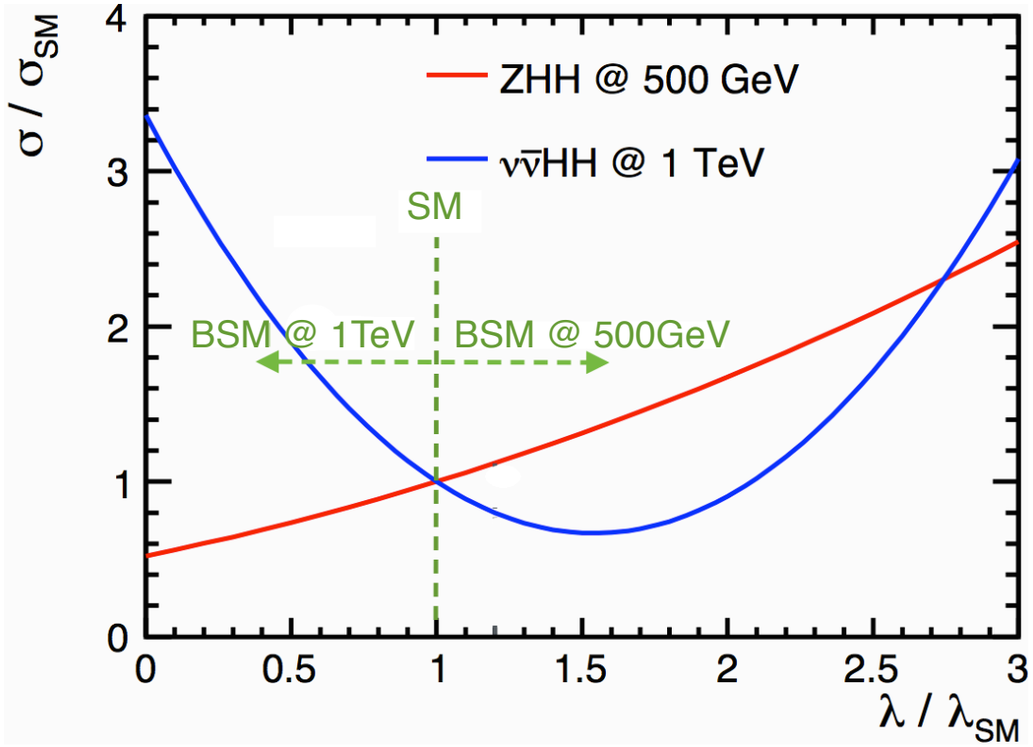
[talk by T.Suehara]

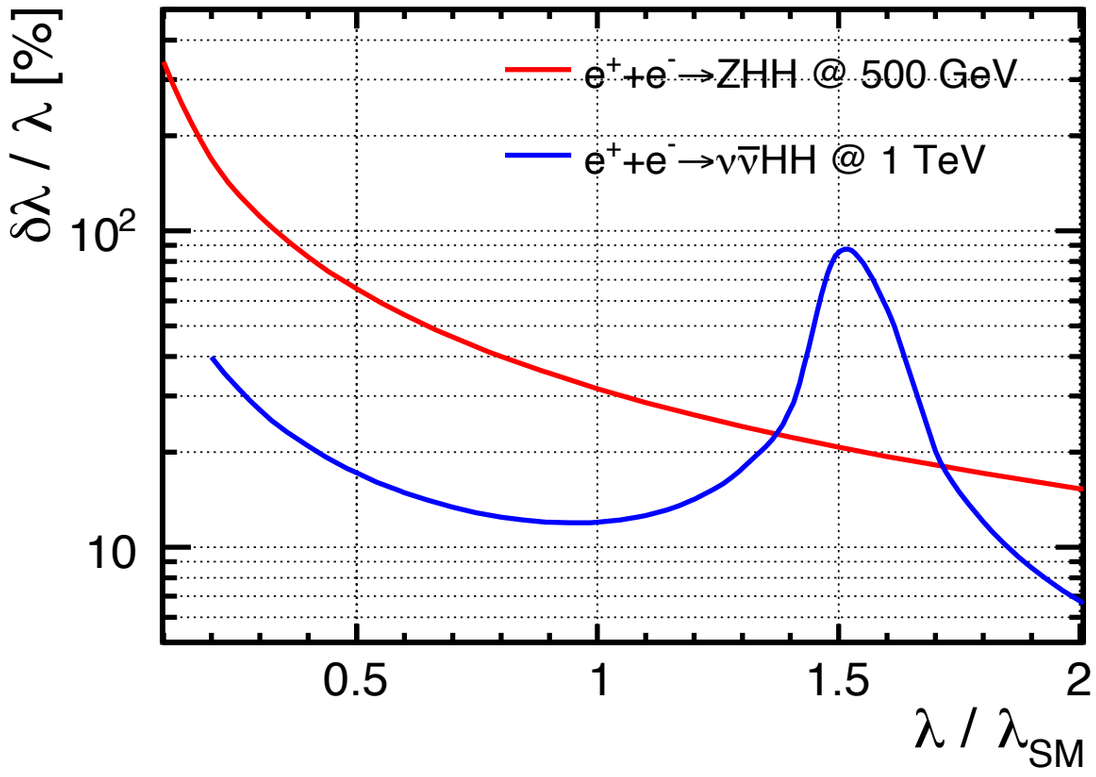
[talk by B.Bliewert]

(i) beyond SMEFT: large $\delta\lambda_{hhh}$; light scalars

(examples)

- profound effect on di-Higgs processes
- complementarity between ZHH & vvHH (& LHC): different interference
- if $\lambda_{HHH} / \lambda_{SM} = 2$, λ_{HHH} be *discovered* (~13%) using ZHH at 500 GeV e+e-





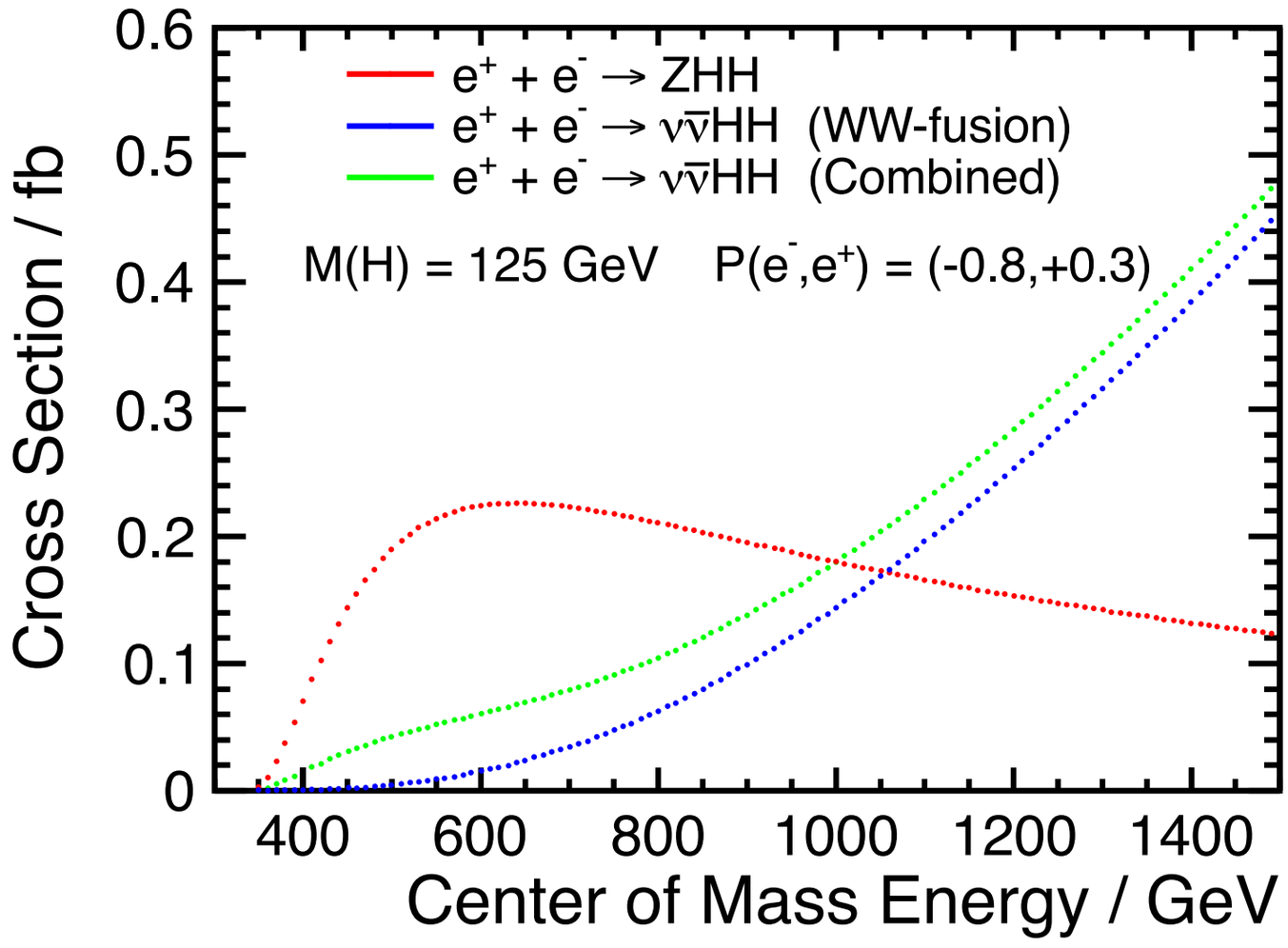
λ_{HHH}: How ILD can contribute?

(some random midnights thoughts…)

- **Analysis of e+e- —> ZH with a scan of $\sqrt{s} \sim 250$ GeV**
  - effect from λ sensitive to $\sqrt{s} \sim 250$: multiple σ_{ZH} help lift degeneracy
  - anomalous HZZ couplings also highly correlated to SM coupling ~ 250, multiple $d\sigma$ help
  - also an opportunity to find out the optimal initial $\sqrt{s}$ of ILC

- **Analysis of e+e- —> ZHH with $\lambda_{HHH}/\lambda_{SM}=2$**
  - demonstrate the (discovery) potential by full sim.
  - $\sqrt{s}$ can be chosen at ~550 GeV, in light of other benefit of y_t
  - incorporate all available improved analysis algorithms

backup

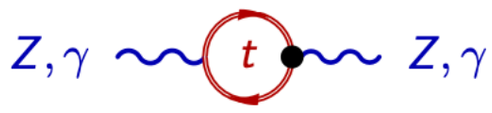

$e^+ + e^- \rightarrow ZHH$
$e^+ + e^- \rightarrow \nu\bar{\nu}HH$ (WW-fusion)
$e^+ + e^- \rightarrow \nu\bar{\nu}HH$ (Combined)
M(H) = 125 GeV P(e^-,e^+) = (-0.8,+0.3)
Cross Section / fb
0
0.1
0.2
0.3
0.4
0.5
0.6
400
600
800
1000
1200
1400
Center of Mass Energy / GeV

(ii) NLO @ single-Higgs: from top-quark

[talk by G. Durieux at ECFA mini-work HTE 2023]

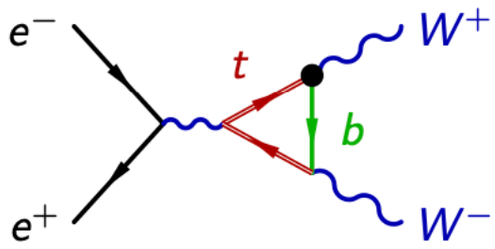
EWPO

[Zhang, Greiner, Willenbrock '12]



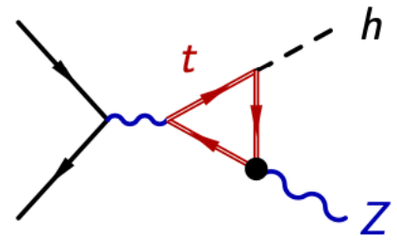
Diboson

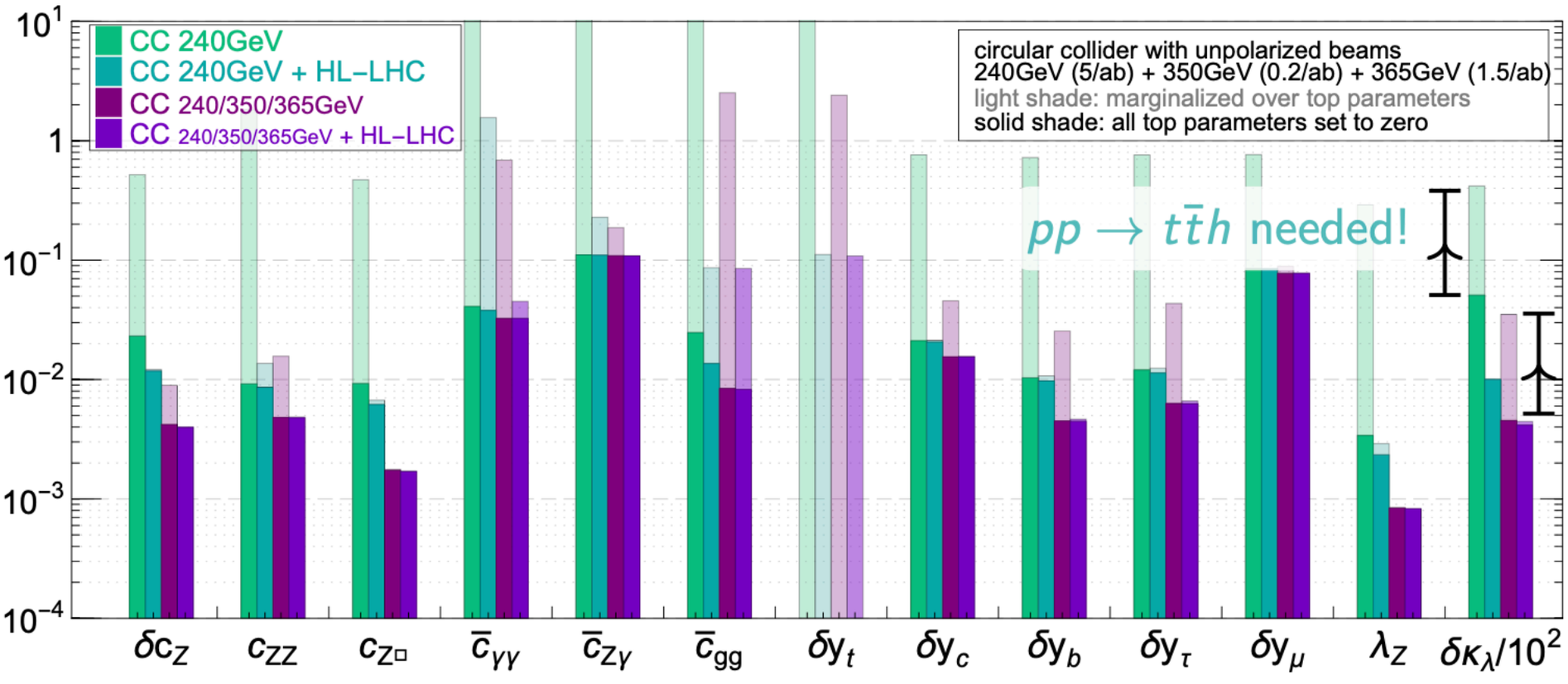
[GD, Gu, Vrionidou, Zhang '18]



Higgs

[Vrionidou, Zhang, '18]
[see also Boselli et al '18]





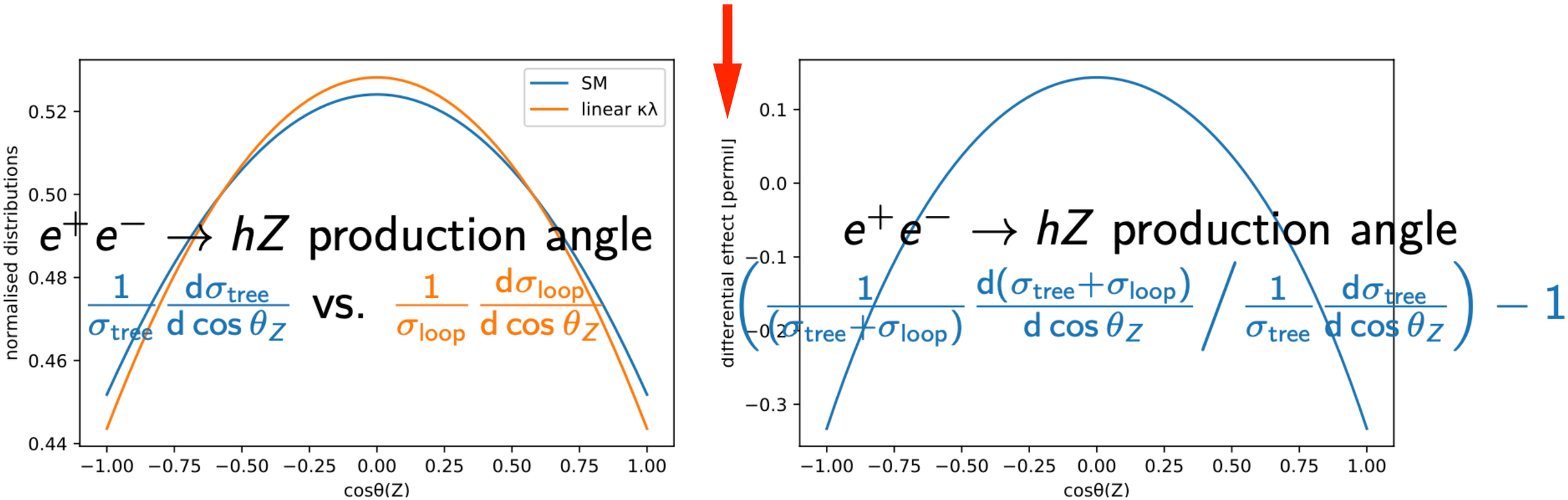
Top-quark uncertainties can impede Higgs precision!

[Durieux, Gu, Vyronidou, Zhang, '18]

[Jung, Lee, Perello, JT, Vos, '20]

(ii) single-Higgs: lift degeneracies

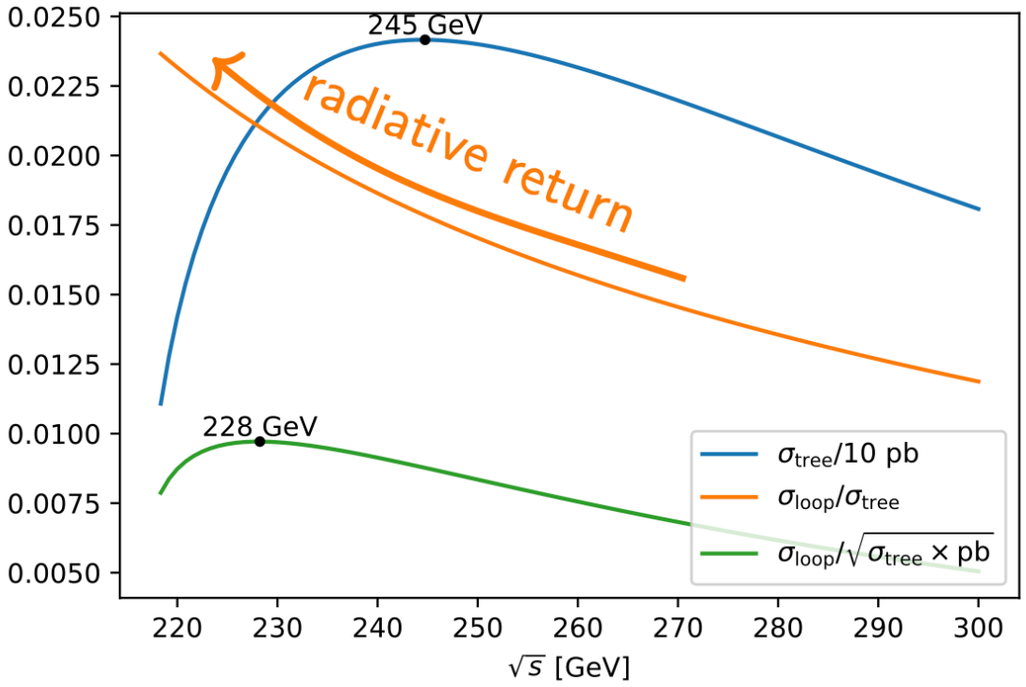
- **can differential cross sections help?**

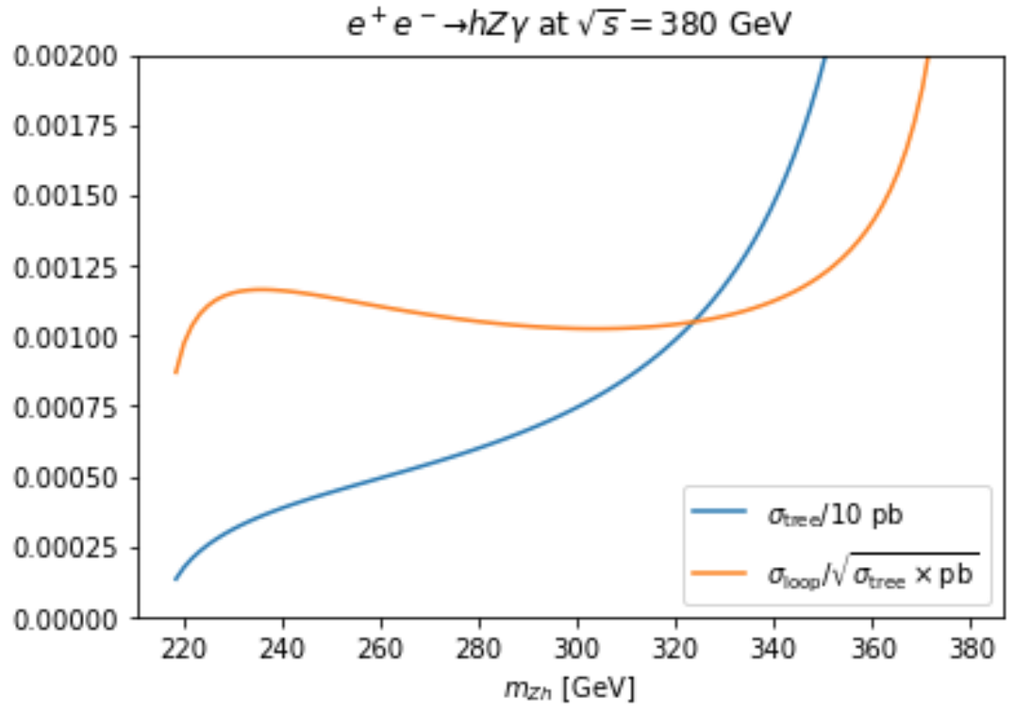


[Durieux, et al, preliminary]

(ii) single-Higgs: lift degeneracies

- **can energy scan around 240-250 help? or using radiative return from 365/380 GeV?**





[Durieux, et al, preliminary]

(ii) single-Higgs: other questions

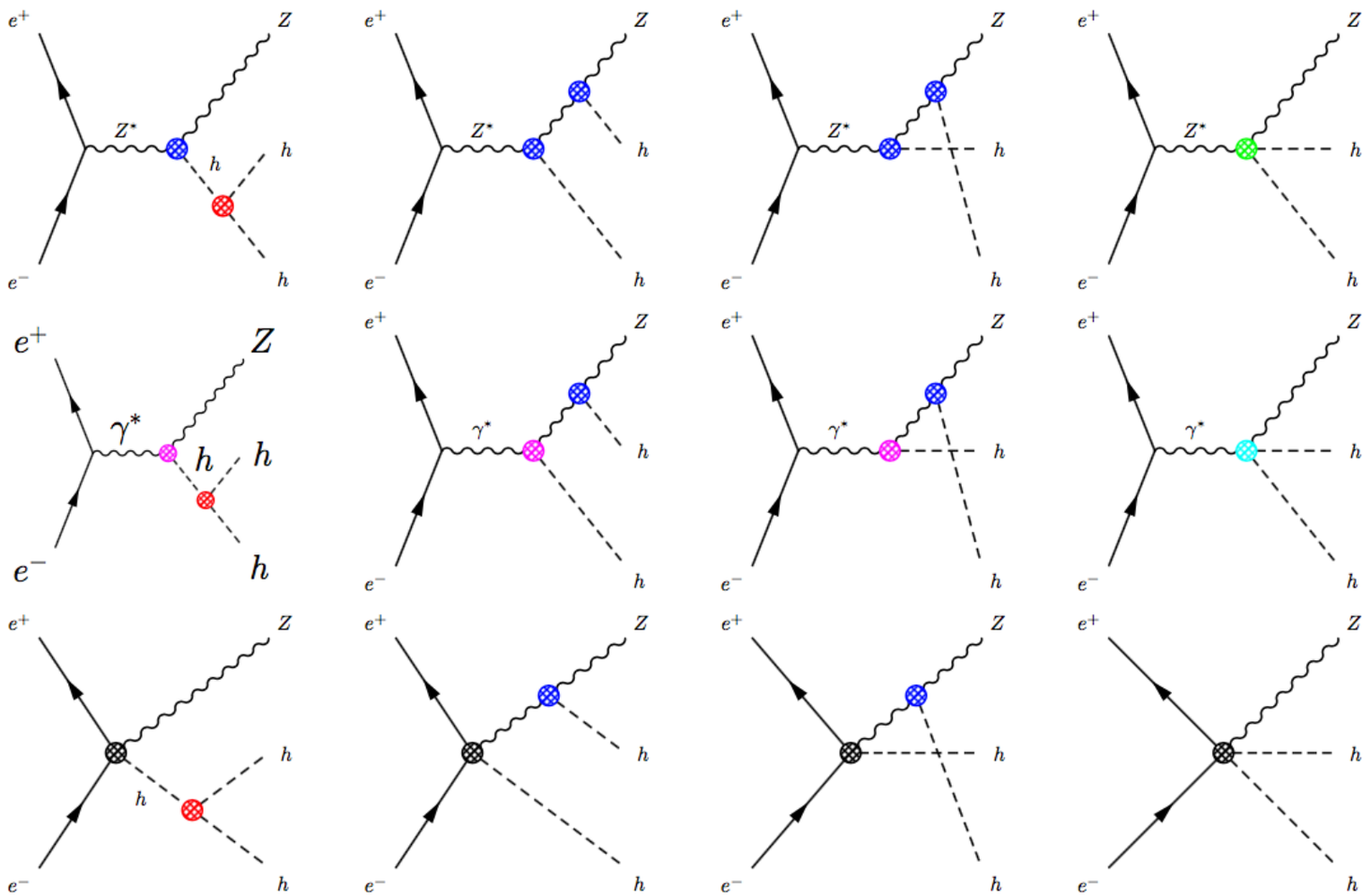
- **can we clarify the importance of each input measurement for the λ_{hhh} in the global fit?**

- **do we expect any update from experimental analyses about sing-Higgs observables?**

- **single-Higgs contribution at $\sqrt{s} \geq 500$ GeV should be combined with double-Higgs for λ_{hhh}**

- **...**

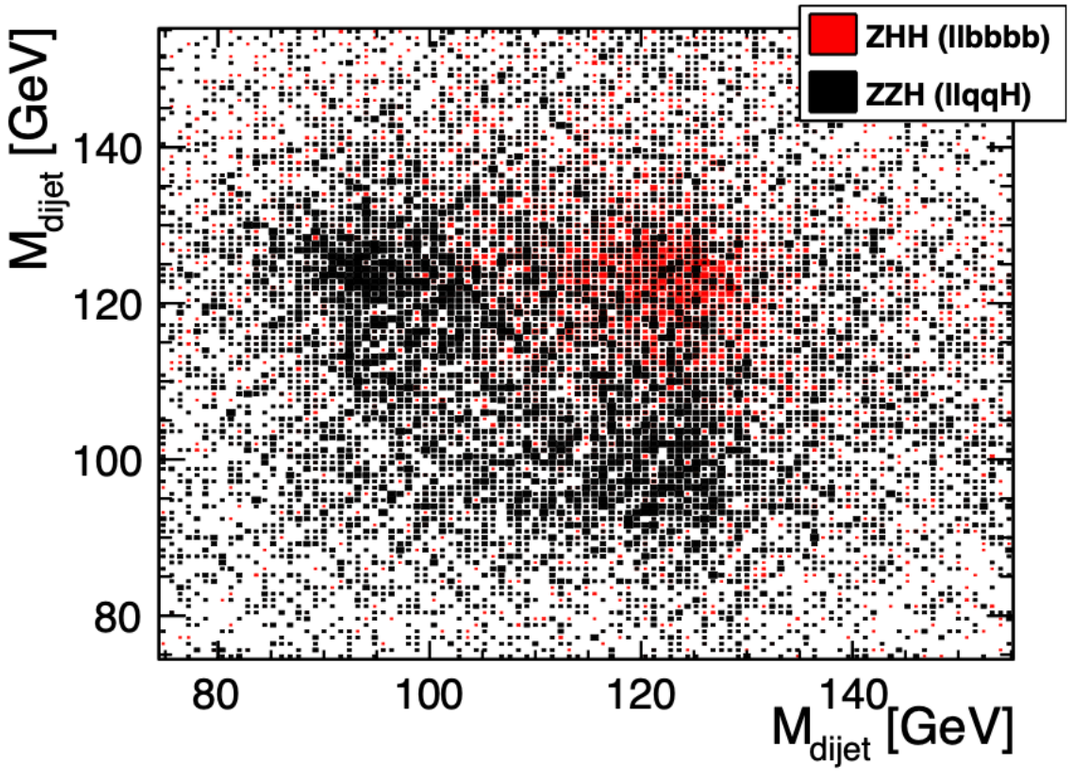
(iii) questions related to double-Higgs process



[Barklow, Fujii, Jung, Peskin, JT, '17]

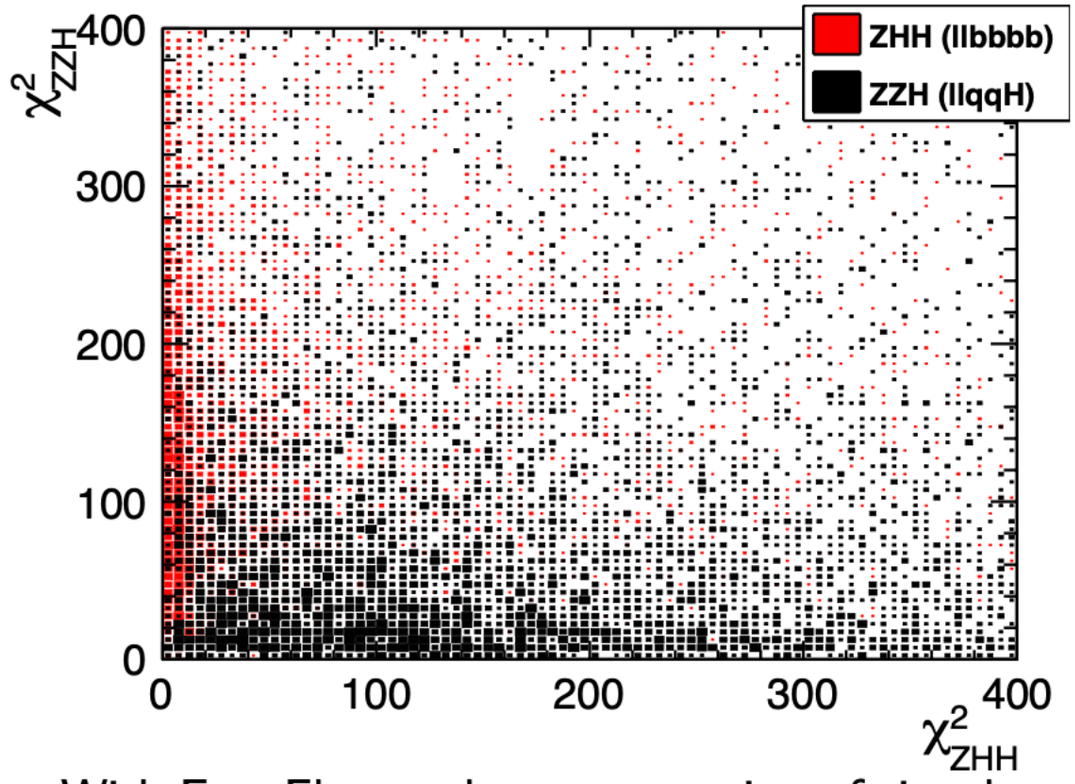
- Much less challenge from degeneracies
- Main questions are related to how we can improve experimental analyses

(iii) potential improvement by kinematic fitting?



- Pre-fitted dijet-masses show large overlap between signal (*ZHH*) and background (*ZZH*)

→



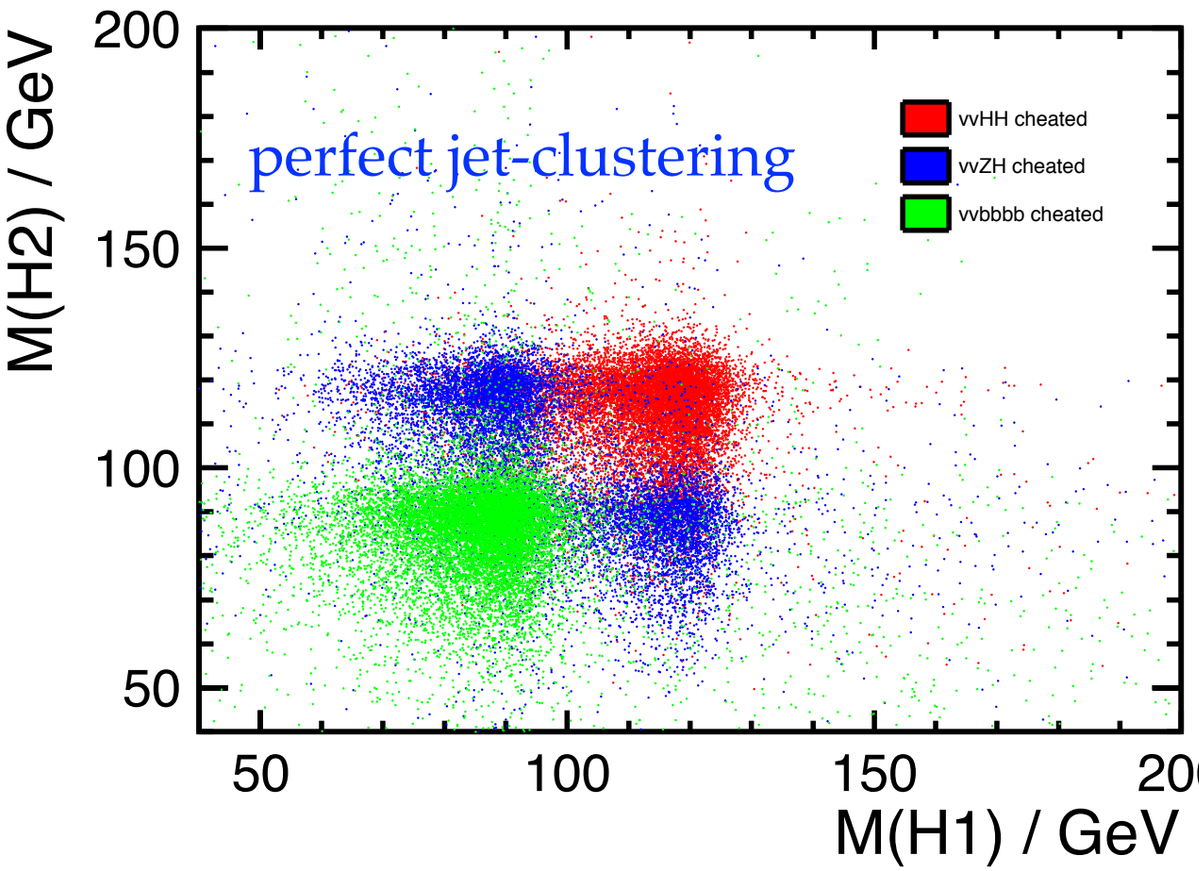
- With ErrorFlow → larger separation of signal (*ZHH*) and background (*ZZH*)

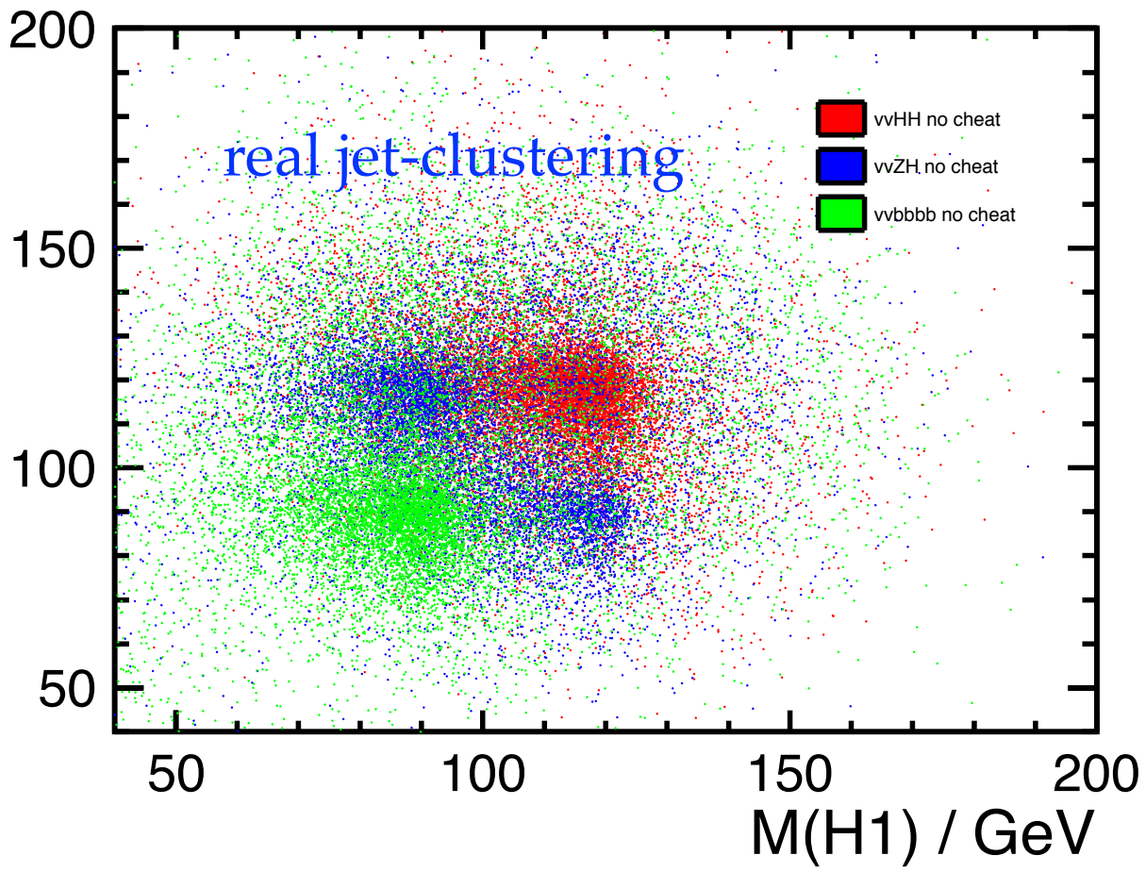
[Torndal, talk at LCWS 2023]

(iii) improving jet-clustering algorithm?

ZHH->ννbbbb (BG: ZZH and ZZZ)

scatter plot of two Higgs masses





- the mis-clustering of particles degrades significantly the separation between signal and BG.
- it is studied that using perfect color-singlet-jet-clustering can improve $\delta\lambda/\lambda$ by 40%

(iii) double-Higgs: other questions

- **would energy slightly above 500 help the analysis? e.g. from more boosted jets**

- **since large λ_{hhh} alter significantly the event shape, can we do some simulation analysis with non-SM value of λ_{hhh}?**

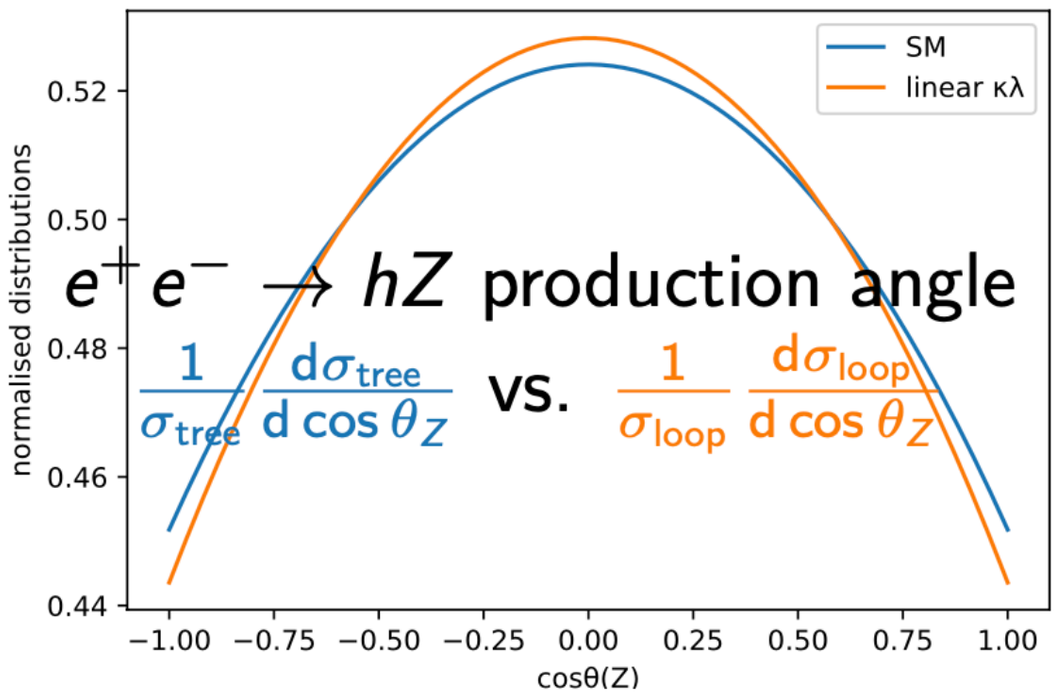
- **how significantly other algorithms such as b-tagging can be improved? e.g. by machine learning**

For Discussion Session

(some of my random thoughts)

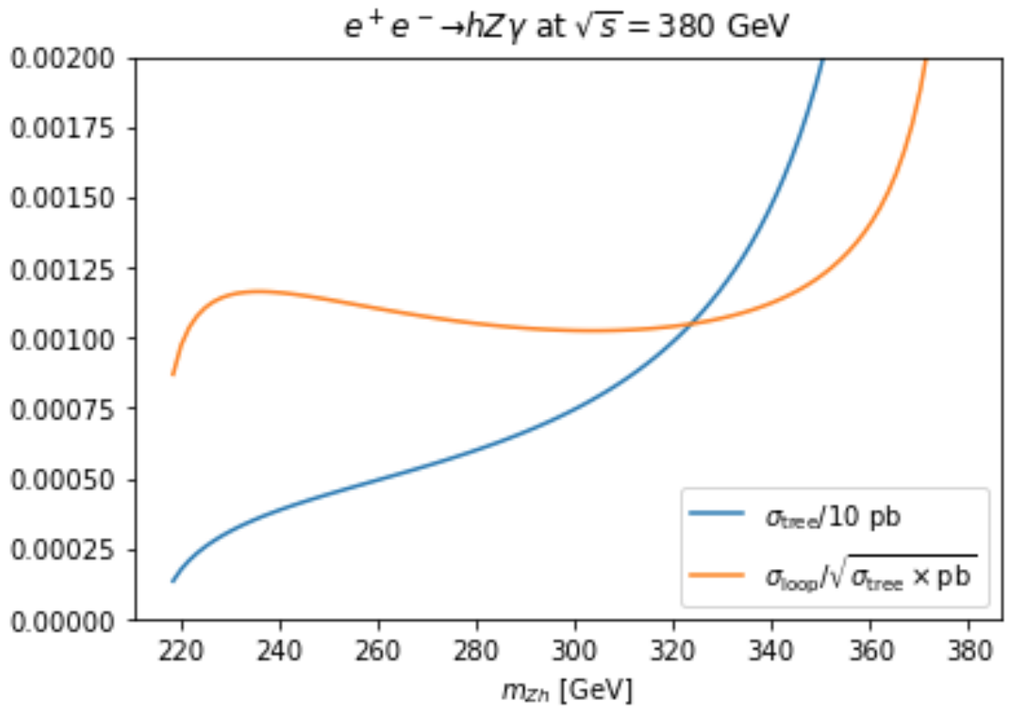
- Any comment or addition to the proposed list of questions by expert team?
- How would we get the real work started?
- As a community effort, it might be helpful to unify the strategy when different groups are working to address similar questions
- Some examples which are really ready to be picked up

example: how to incorporate angular observables consistently



- **like standard template different cross section? (complicated to exchange)**
- **optimal observables (convenient based on Snowmass global fit experience; easy to achieve consistency for different colliders)**
- **“condense” all the angular effects into few effective parameters**

example: common generators



* **ISR here is crucial to achieve the effective scan of √s**

example: common effort on new analysis techniques

- **much improved flavor tagging by machine learning: cross check and share tasks such as samples**

- **jet-clustering algorithms are not only important for HH (e.g. linear colliders), but also for hadronic ZH (all e+e-)**

clear need of new state-of-art Global SMEFT Fits

- **include as complete as possible NLO effect to address λ in single-Higgs**

- **include ZH (or / and others) angular observables in the fit to address their impact**

clear need of benchmark BSM models

- **with extra (light) Higgs bosons**
- **non-SM value of λ**