ILD Higgs / EW: status & plans

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former co-convener: Graham Wilson (U. Kansas)

Higgs/EW subgroup webpage

recently finished / ongoing / starting Higgs/EW analyses

- ILC Physics Potential
  - BR(H—>μμ), Shin-ichi Kawada, arXiv:2009.04340
  - BR(H—>ZZ*), Evgeny Antonov, ILD note under review
  - Combined fit to Higgs BRs, Jonas Kunath, arXiv:2105.05718
  - Exotic decays (H—>ϕϕ—>4b), Yu Kato, starting
  - γ-associated Higgs production, Yumi Aoki, arXiv:2105.06665
  - WW-fusion production, G. Garillot & N. Chadeau, starting
  - Higgs CP, Tatjana Agatonovic-Jovin, arXiv:2105.06530
  - τ reconstruction, Keita Yumino, LCWS2021
  - Z LineShape / W mass, Graham Wilson, Snowmass LoI
  - A_{LR} using radiative return, Takahiro Mizuno, Snowmass LoI
  - Role of beam polarization in sys. err, Jakob Beyer, LCWS2021

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- ILD detector optimisation
  - A lot of benchmark analyses done for IDR
  - Jet energy scale calibration, Takahiro Mizuno, LCWS2021
  - $\sqrt{s}$ calibration, Graham Wilson, Snowmass LoI

no time to cover details of all analyses

highlight a few in an integrated picture including missing elements

any biased selection applies only to me

where do we start

-80% e^-, +30% e^+ polarization: [arXiv:1708.08921]

	250 GeV		350 GeV		500 GeV	
	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$
σ [50–53]	2.0		1.8		4.2	
$h \to invis.$ [54, 55]	0.86		1.4		3.4	
$h \to b\bar{b}$ [56–59]	1.3	8.1	1.5	1.8	2.5	0.93
$h \to c\bar{c}$ [56, 57]	8.3		11	19	18	8.8
$h \to gg$ [56, 57]	7.0		8.4	7.7	15	5.8
$h \to WW$ [59–61]	4.6		5.6 *	5.7 *	7.7	3.4
$h \to \tau\tau$ [63]	3.2		4.0 *	16 *	6.1	9.8
$h \to ZZ$ [2]	18		25 *	20 *	35 *	12 *
$h \to \gamma\gamma$ [64]	34 *		39 *	45 *	47	27
$h \to \mu\mu$ [65, 66]	72 *		87 *	160 *	120 *	100 *
a [27]	7.6		2.7 *		4.0	
b	2.7		0.69 *		0.70	
$\rho(a, b)$	-99.17		-95.6 *		-84.8	
$\Delta\Phi_{CP}$	4.3°					

inputs to ILC physics case, decades of simulation studies (mostly from ILD)

need to tighten many loose ends… (* are extrapolations)

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BR(H—>ZZ*)

[E. Antonov, A. Drutskoy]

- studied 4 signal channels: ZZ*—>qqll; primary Z—>qq/νν
- proposed a more sensitive observable for Higgs mass
- based on new ILD MC-2020 samples

$$\Delta M = M(jj\ell\ell) - M(jj) + M(Z_{nom})$$

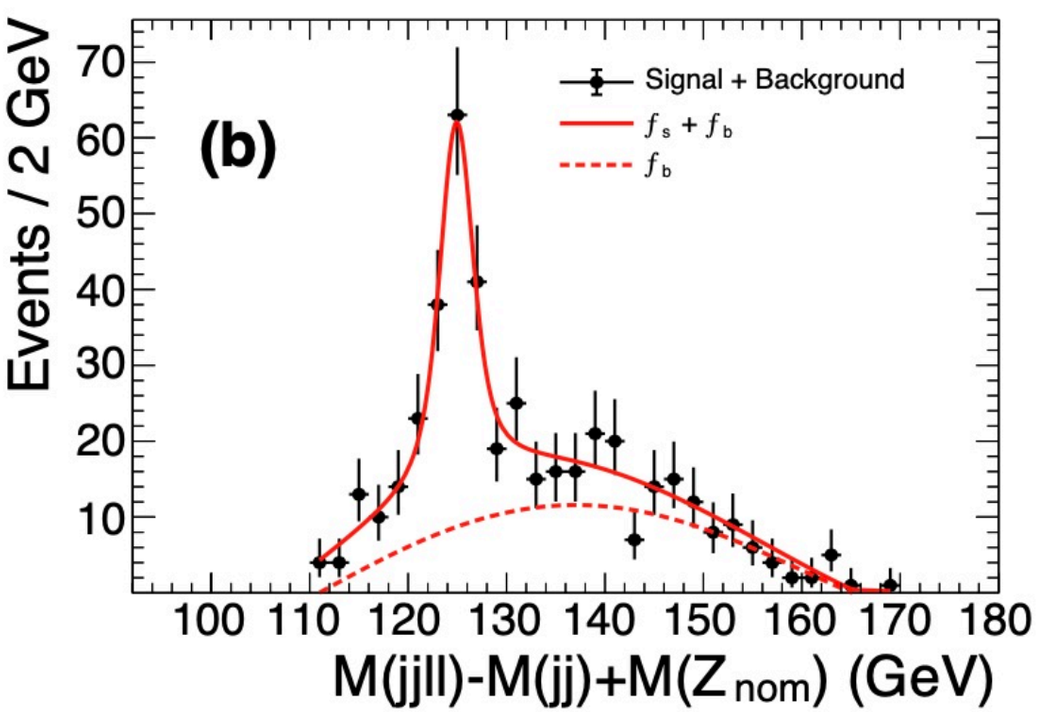


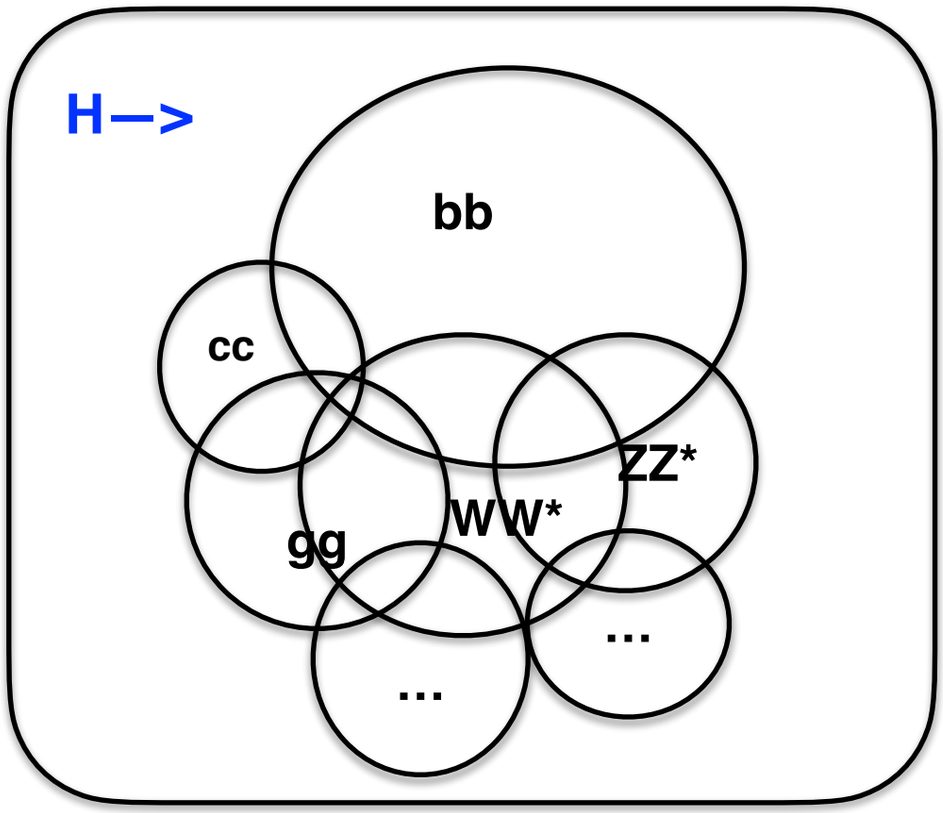
TABLE IV: Number of signal events and uncertainties obtained from fits for each channel.

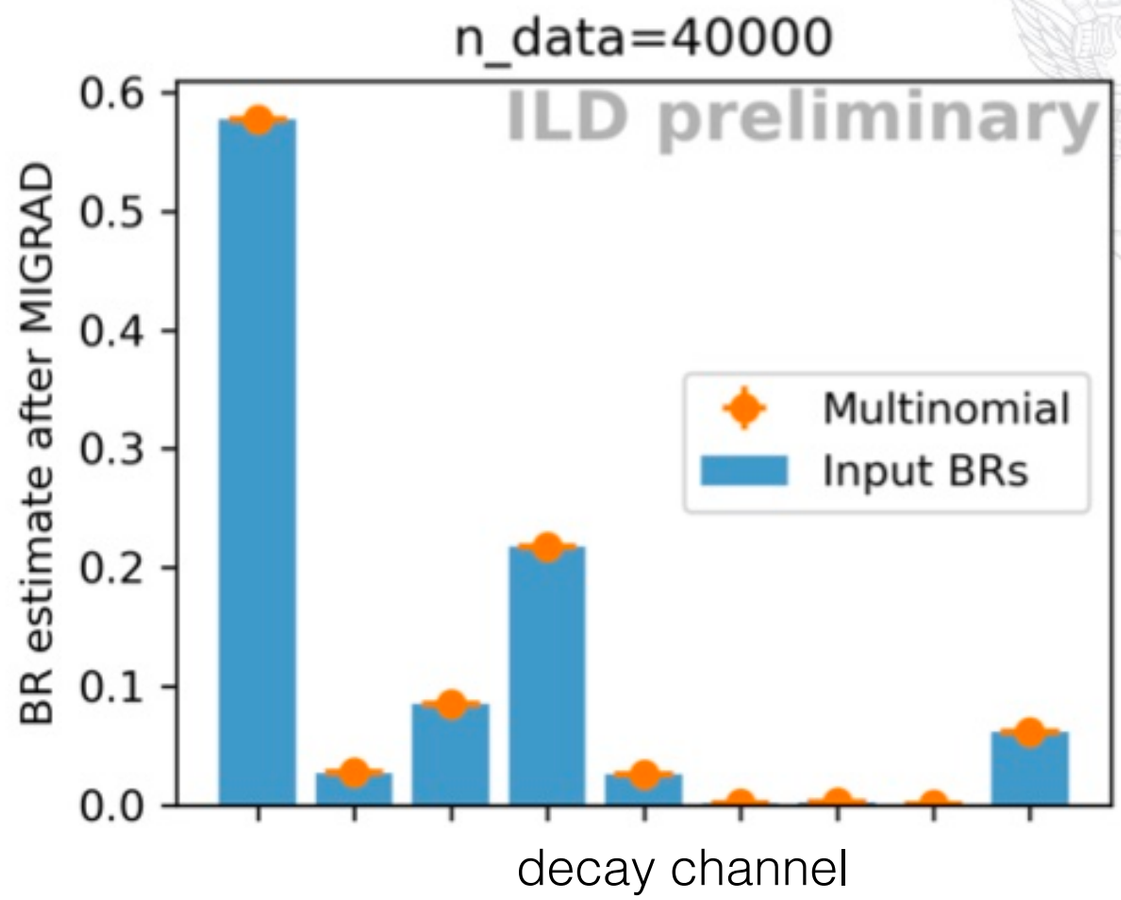
	$Z_1(jj)$, $Z(jj)$, $Z^*(\ell\ell)$	$Z_1(jj)$, $Z(\ell\ell)$, $Z^*(jj)$	$Z_1(\nu\bar{\nu})$, $Z(jj)$, $Z^*(\ell\ell)$	$Z_1(\nu\bar{\nu})$, $Z(\ell\ell)$, $Z^\star(jj)$	Sum
	2 ab^{-1} eLpR				
Number of events	251±27	301±17	71±11	90±10	-
Uncertainty	10.8%	5.6%	15.5%	11.1%	4.4%
	0.9 ab^{-1} eLpR + 0.9 ab^{-1} eRpL				
Number of events	174±21	216±15	50±8	70±8	-
Uncertainty	12.1%	6.9%	16.0%	11.4%	5.1%

- improved previous expectation (6.4%) by ~30%

A combined fit to all BRs

[J. Kunath, J. Brient, et al]





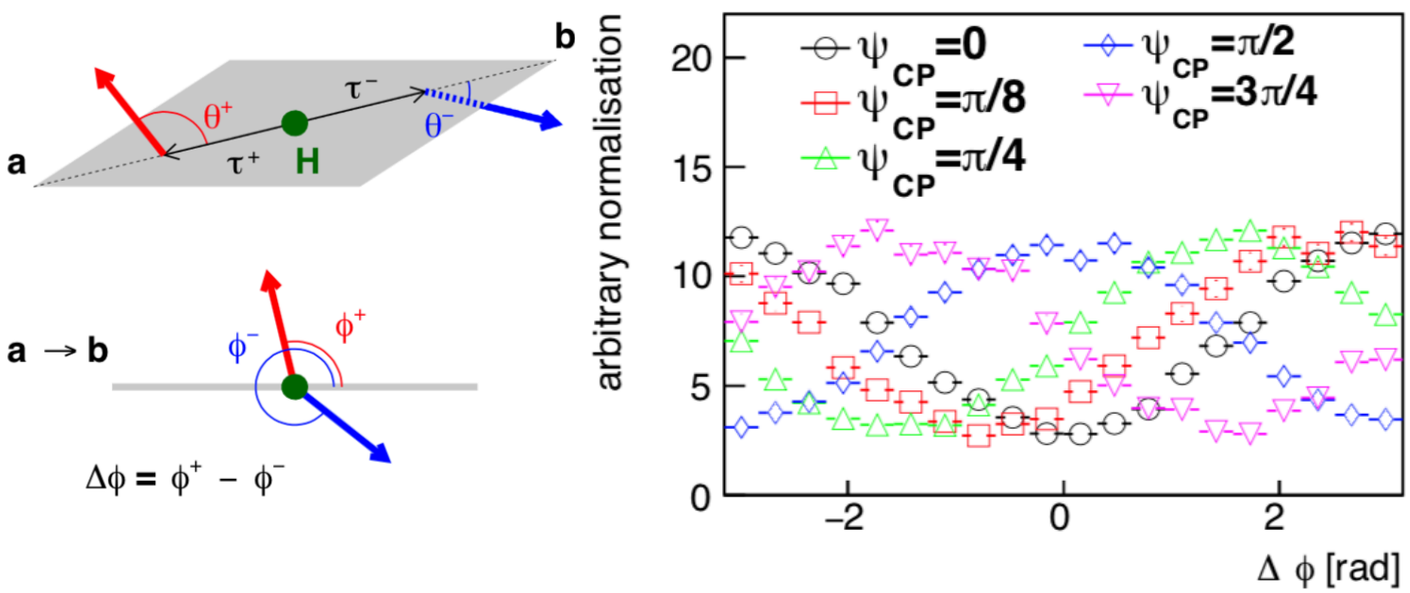
- selected signal events for a particular decay mode inevitably contain contributions from other modes
- assumed to be perfectly known in past studies
- a new idea based on τ BR method @ ALEPH
- statistical & model indep. advantages, full simulation ongoing

Higgs CP properties

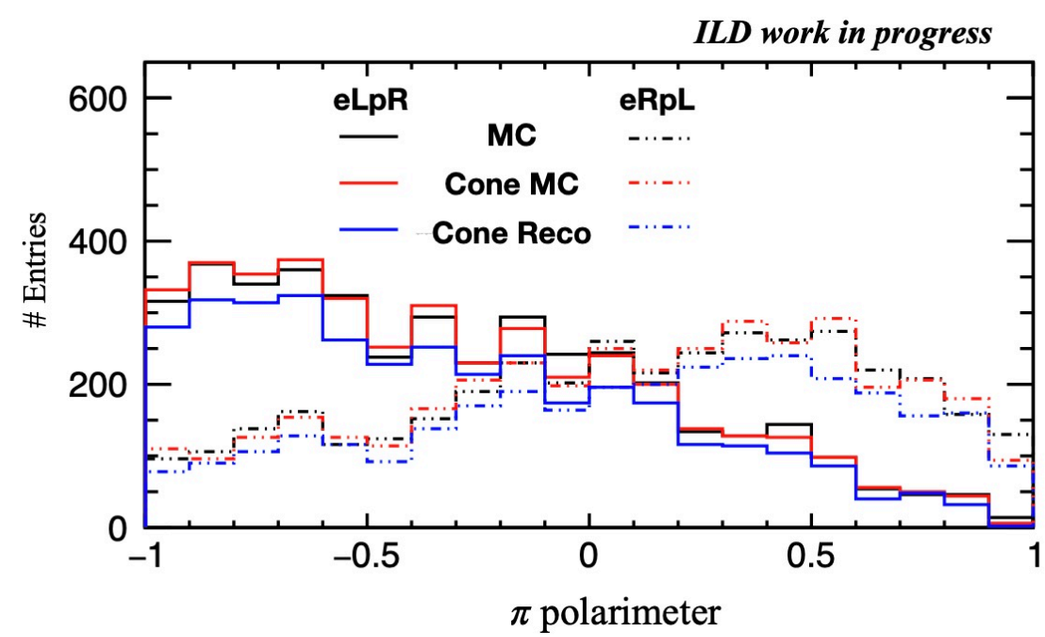
[K. Yumino, D. Jeans]

$$L_{Hff} = -\frac{m_f}{v} H \bar{f}(\cos\Phi_{CP} + i\gamma^5 \sin\Phi_{CP}) f$$

- observable in H—>ττ: transverse correlation between spins of two τ
- key algorithm: τ reconstruction with ν-momentum determined
- previous analysis $\Delta\phi_{CP}$ ~ 4.3 degree, based on a method using impact parameters to reconstruct τ decay plane —> large room suggested
- a complementary method being studied: full kinematic constraints; benefit from study of a cone method in e+e- —> ττ



[Jeans, Wilson, arXiv:1804.01241]

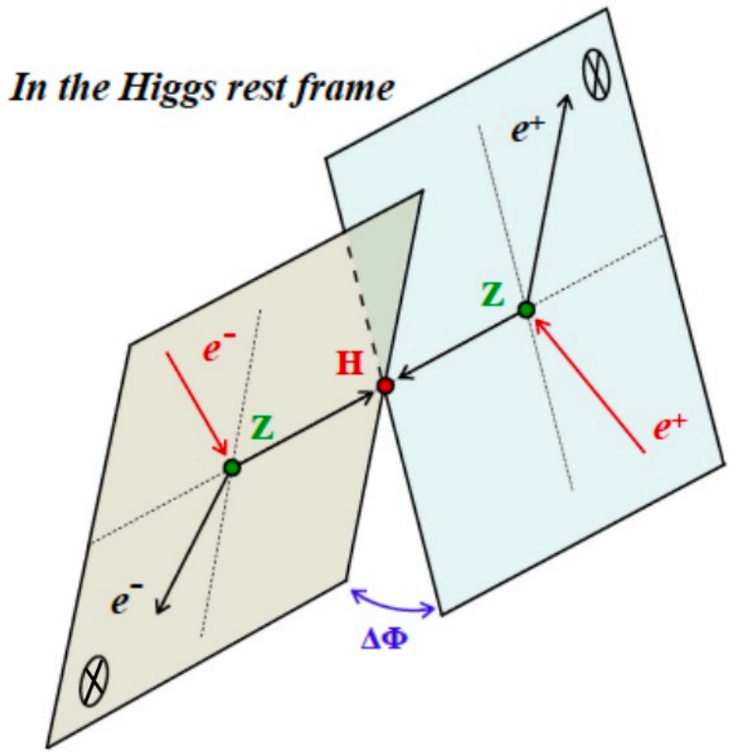


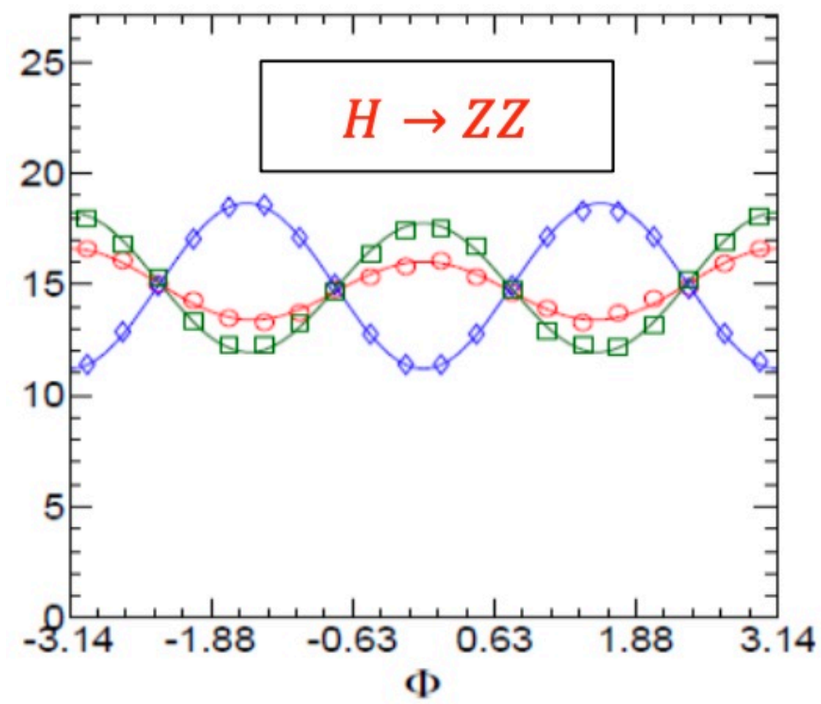
[Yumino, LCWS2021]

Higgs CP properties

[T. Jovin, I. Bozovic, et al]

$$L_{hZZ} = M_Z^2(\frac{1}{v} + \frac{a}{\Lambda})hZ_\mu Z^\mu + \frac{b}{2\Lambda}hZ_{\mu\nu}Z^{\mu\nu} + \frac{\tilde{b}}{2\Lambda}hZ_{\mu\nu}\tilde{Z}_{\mu\nu}$$





- observable in HVV: angle between two V planes
- previously studied by T.Ogawa at 250 & 500 GeV
- ongoing analysis focuses on ZZ-fusion production at 1 TeV
- signal selection algorithm is ready, background to be included

still many loose ends not picked up

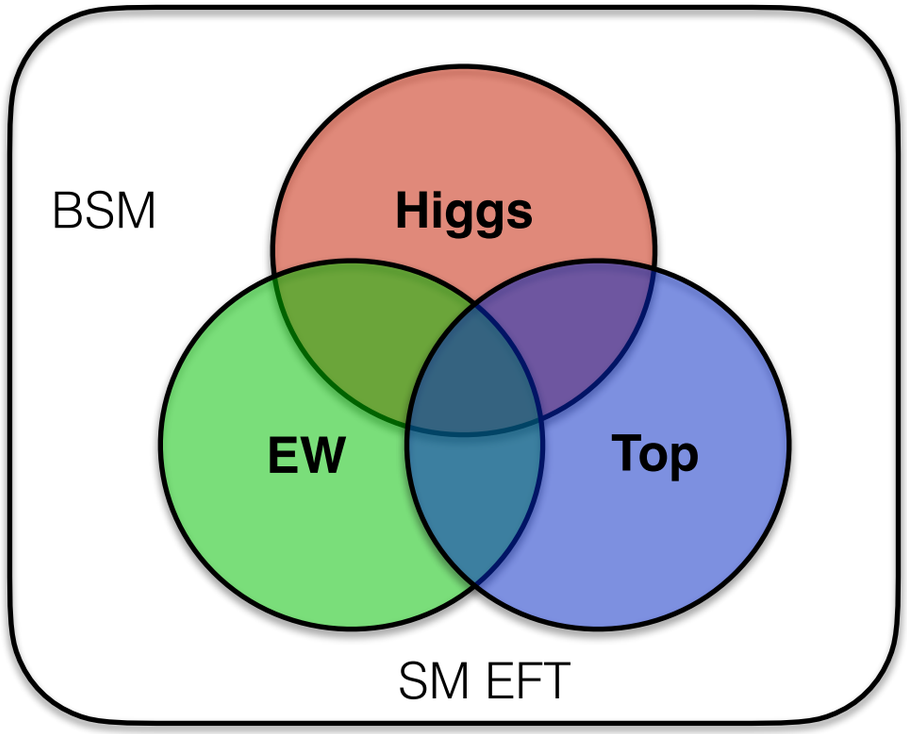
- Recoil mass in hadronic channel: model independence is still far away from our goal ~ 0.1%; challenging, already studied by >= three groups, Thomson, Miyamoto, Tomita
- Impact of new beam spectrum: need full simulation analysis to justify the benefit (if any) of increased luminosity
- Higgs mass systematic error due to beam energy: can benefit from ongoing √s calibration by G.Wilson

Decay mode	$\varepsilon^{\text{vis.}}_{\mathscr{L}>0.65}$	$\varepsilon^{\text{invis.}}_{\mathscr{L}>0.60}$	$\varepsilon^{\text{vis.}}+\varepsilon^{\text{invis.}}$
$H \to$ invis.	<0.1 %	23.5 %	23.5 %
$H \to q\bar{q}/gg$	22.6 %	<0.1 %	22.6 %
$H \to WW^*$	22.1 %	0.1 %	22.2 %
$H \to ZZ^*$	20.6 %	1.1 %	21.7 %
$H \to \tau^+\tau^-$	25.3 %	0.2 %	25.5 %
$H \to \gamma\gamma$	25.7 %	<0.1 %	25.7 %
$H \to Z\gamma$	18.6 %	0.3 %	18.9 %
$H \to WW^* \to q\bar{q}q\bar{q}$	20.8 %	<0.1 %	20.8 %
$H \to WW^* \to q\bar{q}\ell\nu$	23.3 %	<0.1 %	23.3 %
$H \to WW^* \to q\bar{q}\tau\nu$	23.1 %	<0.1 %	23.1 %
$H \to WW^* \to \ell\nu\ell\nu$	26.5 %	0.1 %	26.5 %
$H \to WW^* \to \ell\nu\tau\nu$	21.1 %	0.5 %	21.6 %
$H \to WW^* \to \tau\nu\tau\nu$	16.3 %	2.3 %	18.7 %

[Thomson, arXiv:1509.02853]

- BR(H—>bb/cc/gg): need revisit at 250 GeV (previous back to 2012), lots of new dev. of flavor tagging
- a large category of exotic decay analysis
- Higgs self-coupling revisit

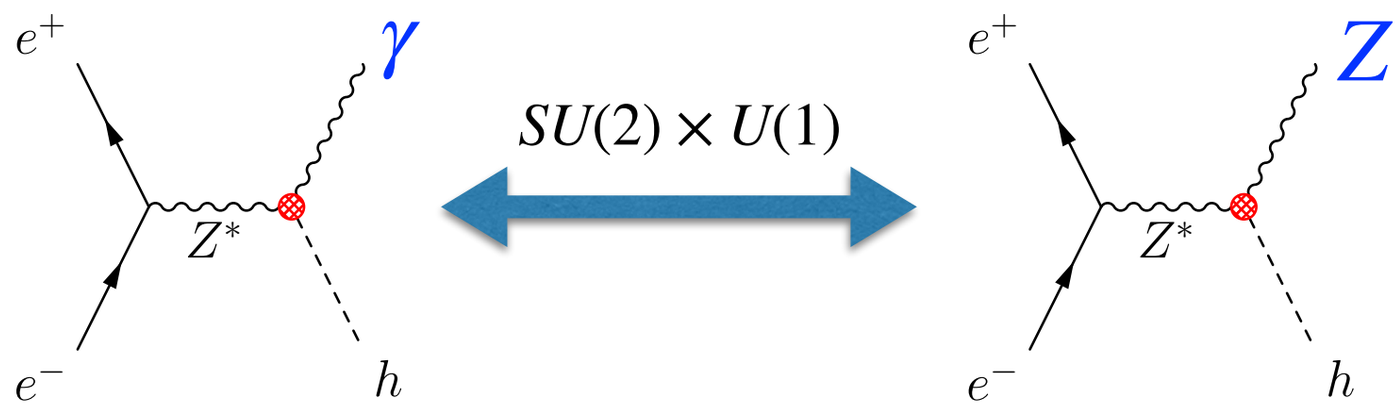
new opportunities



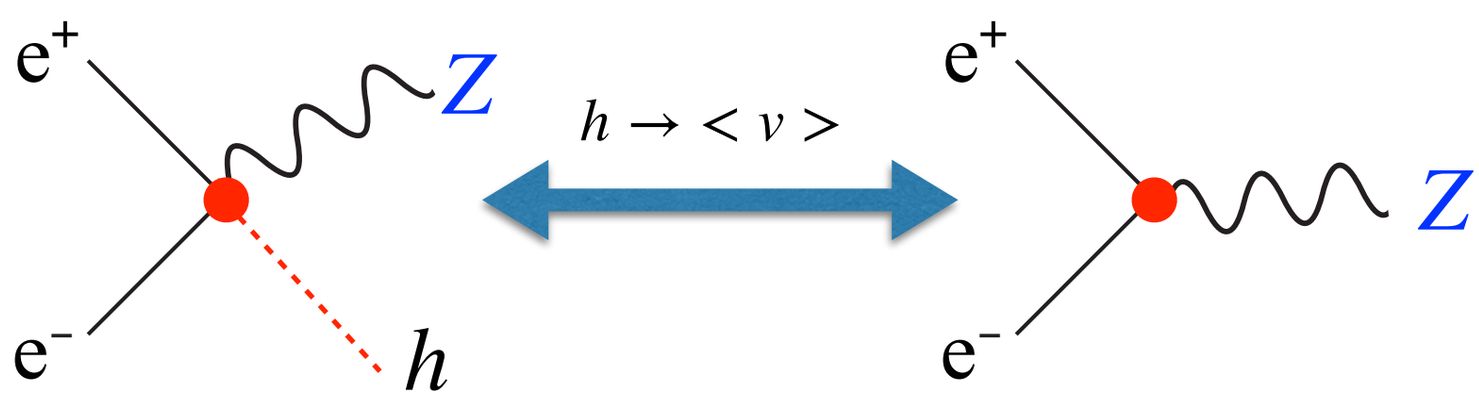
- analyses are used to be pursued alone looking for new physics effects
- but they are all related: gauge symmetries & Higgs field nature of W/Z longitudinal modes
- a new category of analyses are emerging: explore every channel one can think of, likely all are useful in a global interpretation

new opportunities

- γ-associated Higgs production [Y. Aoki et al]



- Left-right asymmetry [T. Mizuno et al]; Z LineShape [G. Wilson]



- beyond TGCs in e+e- —> WW [Snowmass SMEFT group]
- interplay with top physics / 4-fermion interaction

Role of beam polarizations

- observables with e_L or e_R are completely different: very important to continue exploring roles played by beam polarizations
- try to do our analyses not only for e_L as long as possible
- in factor σ_{ZH} by e_R is most useful in determining absolute Higgs coup.
- ongoing analysis understanding roles of beam polarization in helping control systematic errors [J. Beyer et al]

$\sqrt{s}$=250 GeV

$$\delta\sigma_L = -c_H + 7.7(8c_{WW}) + \ldots$$

$$\delta\sigma_R = -c_H + 0.6(8c_{WW}) + \ldots$$

$$\delta\sigma_0 = -c_H + 4.6(8c_{WW}) + \ldots$$

$$\frac{g^2 c_{WW}}{m_W^2}\Phi^\dagger\Phi W^a_{\mu\nu}W^{a\mu\nu}$$

summary

- Higgs/EW subgroup has been actively working on variate of analyses, contributing to both ILC Physics Potential & ILD detector optimization
- many ideas not be able to cover due to lack of person power
- welcome to join us

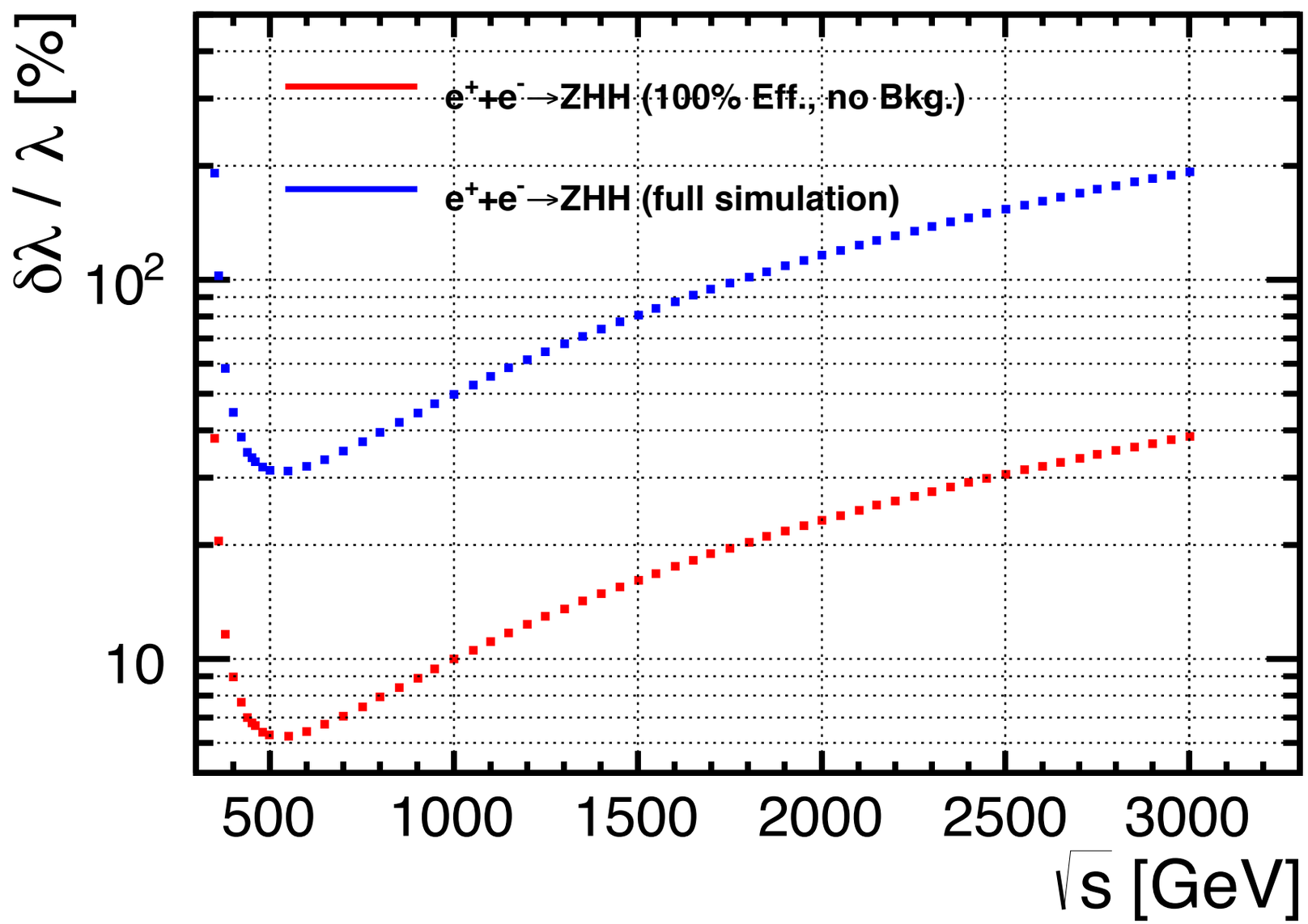
discussion points:

- what else are missing? welcome suggestions from all of you
- when would we start doing analyses with proper QCD implemented in generators? (Whizard 3 is essentially ready for that)

backup

expected precision of λ: impact from analysis & √s

ZHH



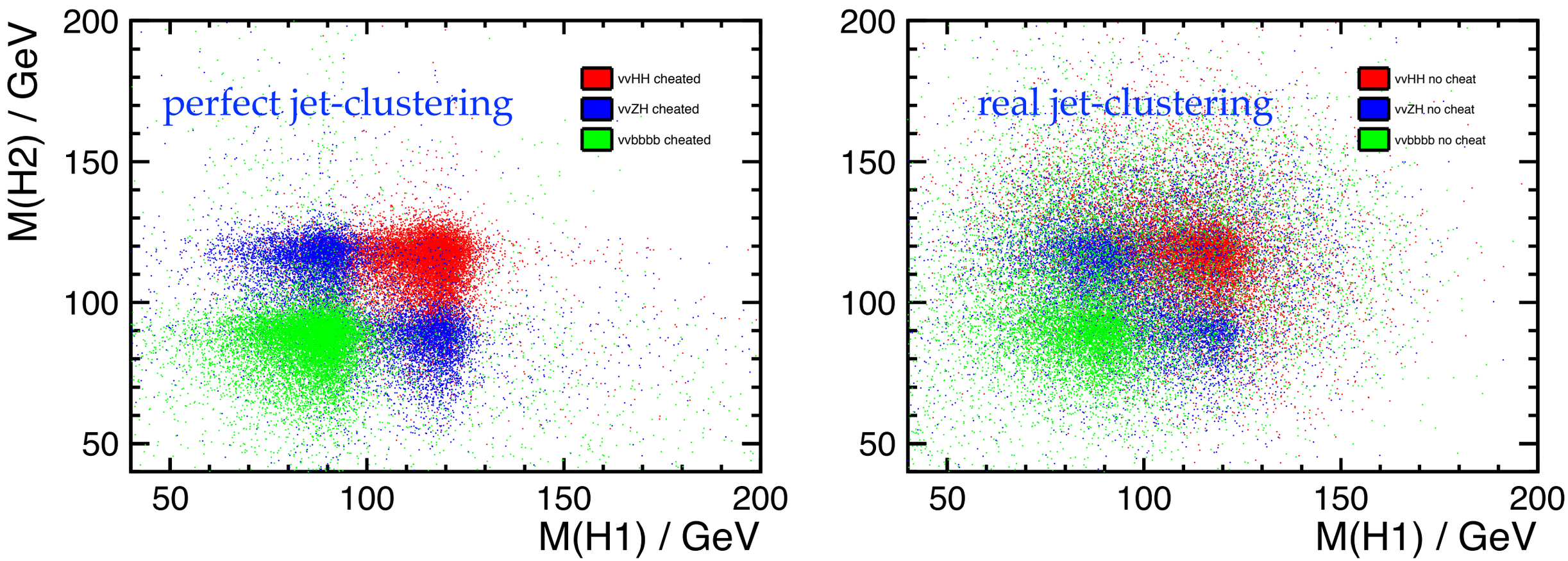
- huge gap of these two expectations —> room of improvement
- for ZHH: optimal at 500-600 GeV; significantly worse at higher √s

Di Micco et al, arXiv:1910.00012

one limiting factor: 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%!