ALCW2015

Highlights

from Physics

2015/05/15

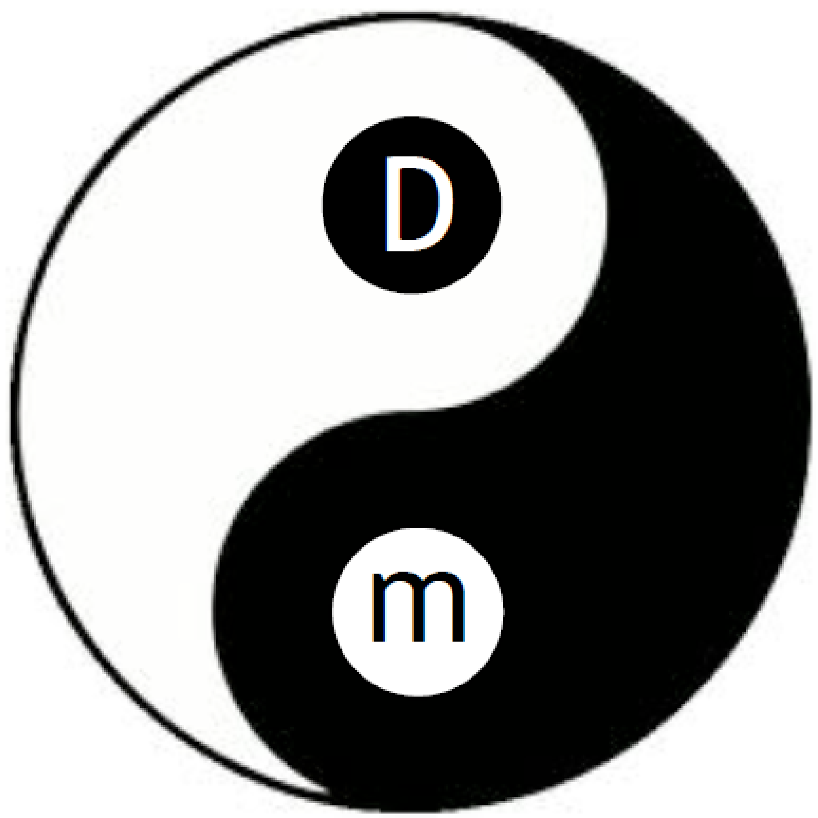
Keisuke Fujii

Higgs Physics

T.Barklow

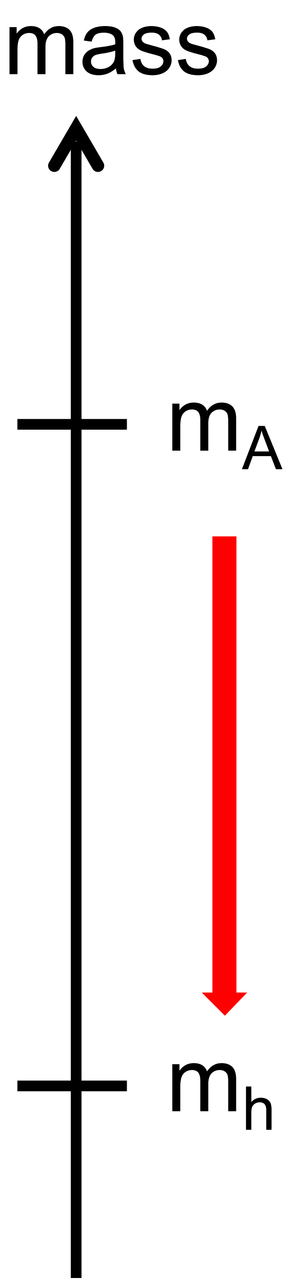
Michael Peskin often references a talk by Lev Okun that he heard at the 1981 Lepton-Photon Conference in Bonn, Germany. Okun declared in his summary talk that the #1 problem in particle physics was to search for and study the Higgs boson. Okun emphasized the dichotomy between our detailed knowledge of particle interactions based on gauge symmetry and our ignorance of mass:

Gauge principle	/	Vacuum structure *
Maxwell's equations Quantum numbers Parity violation W, Z boson Asymptotic freedom		W, Z mass Quark masses and mixings CP violation L, B violation Dark energy
Standard Model is all-powerful	Dark matter ?	Standard Model is impotent



* From Michael Peskin's talk at HPNP 2015 Toyama Japan

Deviation in Higgs Couplings



The size of the deviation depends on the scale of new physics.

Decoupling Theorem: Λ↑ → SM

<u>Example 1:</u> MSSM (tanβ=5, radiative corrections ≈ 1)

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

heavy Higgs mass

<u>Example 2:</u> Minimal Composite Higgs Model

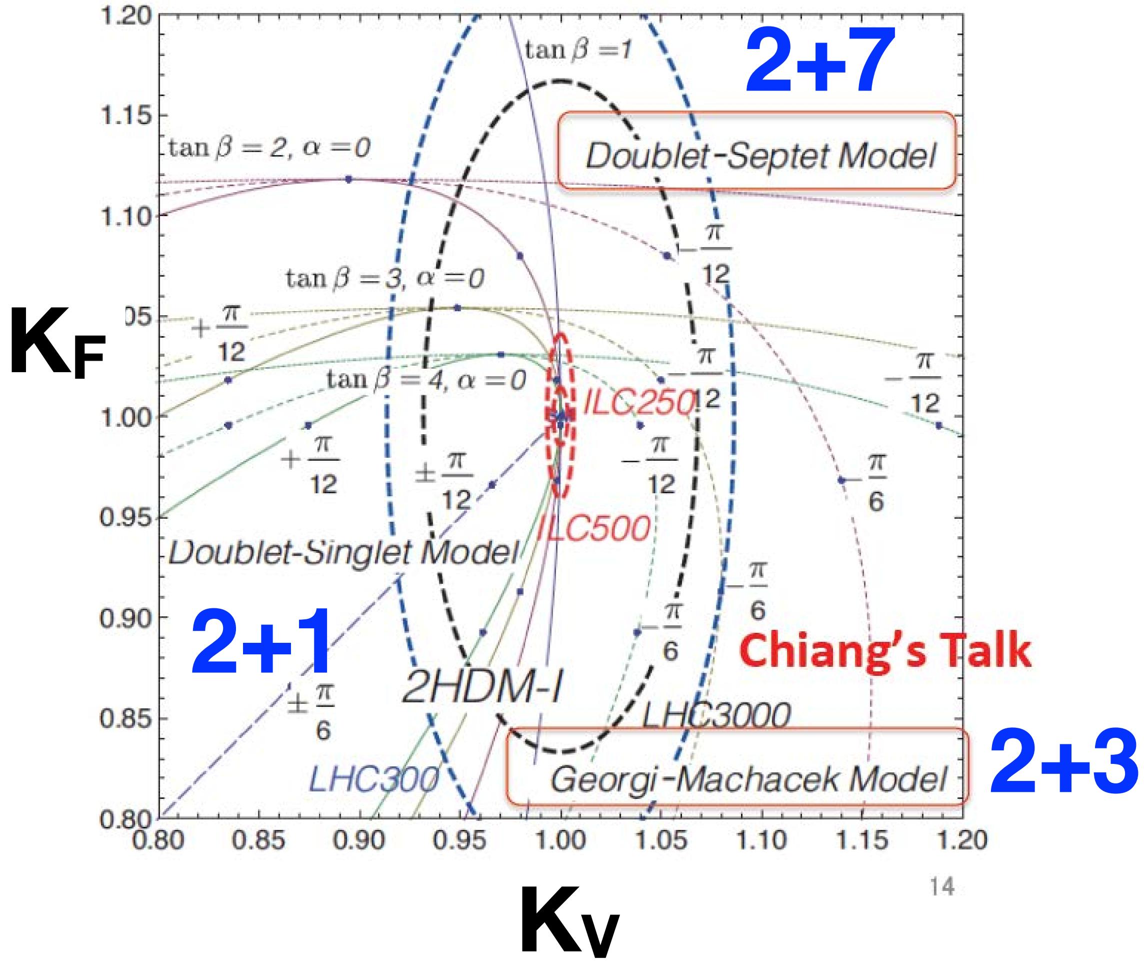
$$\frac{g_{hVV}}{g_{h_{SM}VV}} \simeq 1 - 8.3\% \left(\frac{1\ \mathrm{TeV}}{f}\right)^2$$

composite scale

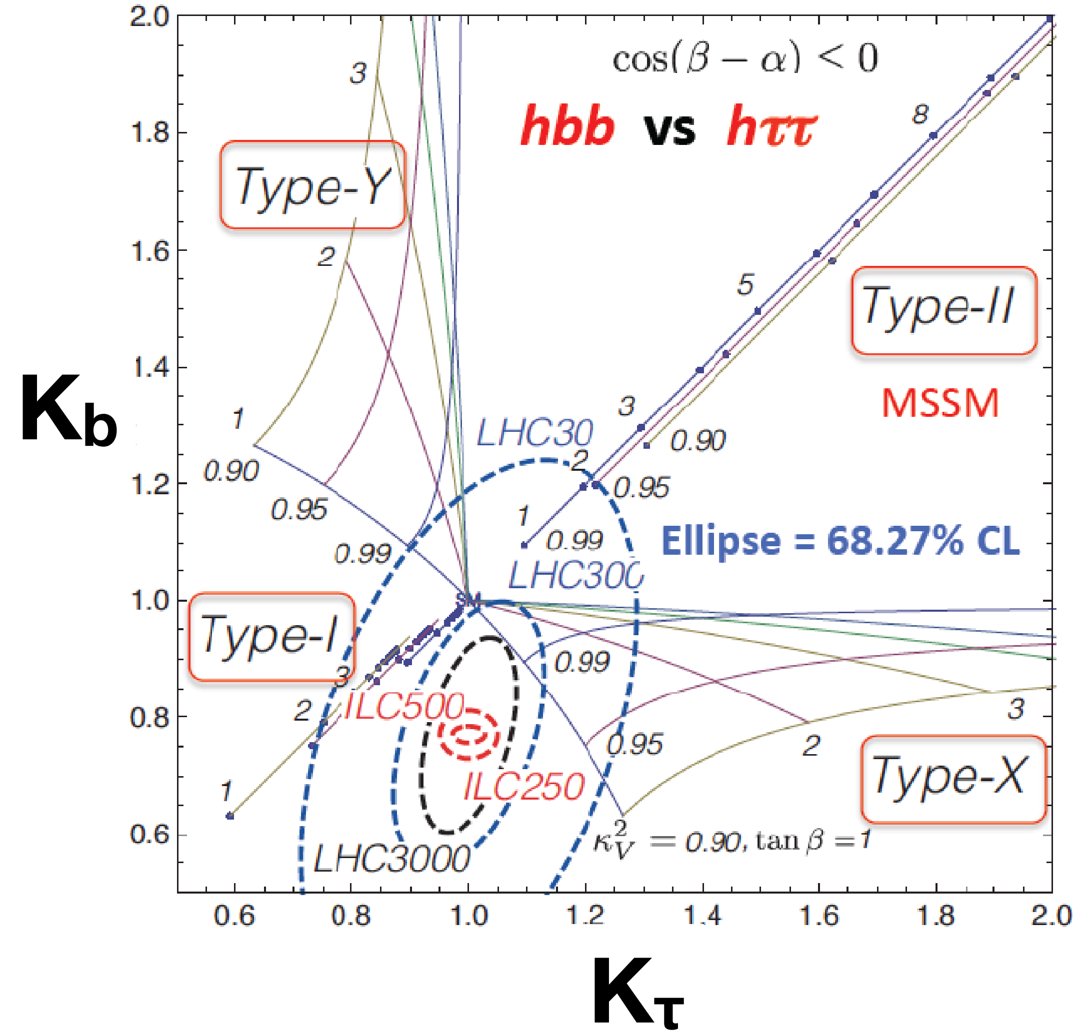
New physics at 1 TeV gives only ***a few percent*** deviation.
We ***need a %-level precision*** to see such a deviation → ***ILC***

Theory

Other ρ=1 possibilities



2HDM



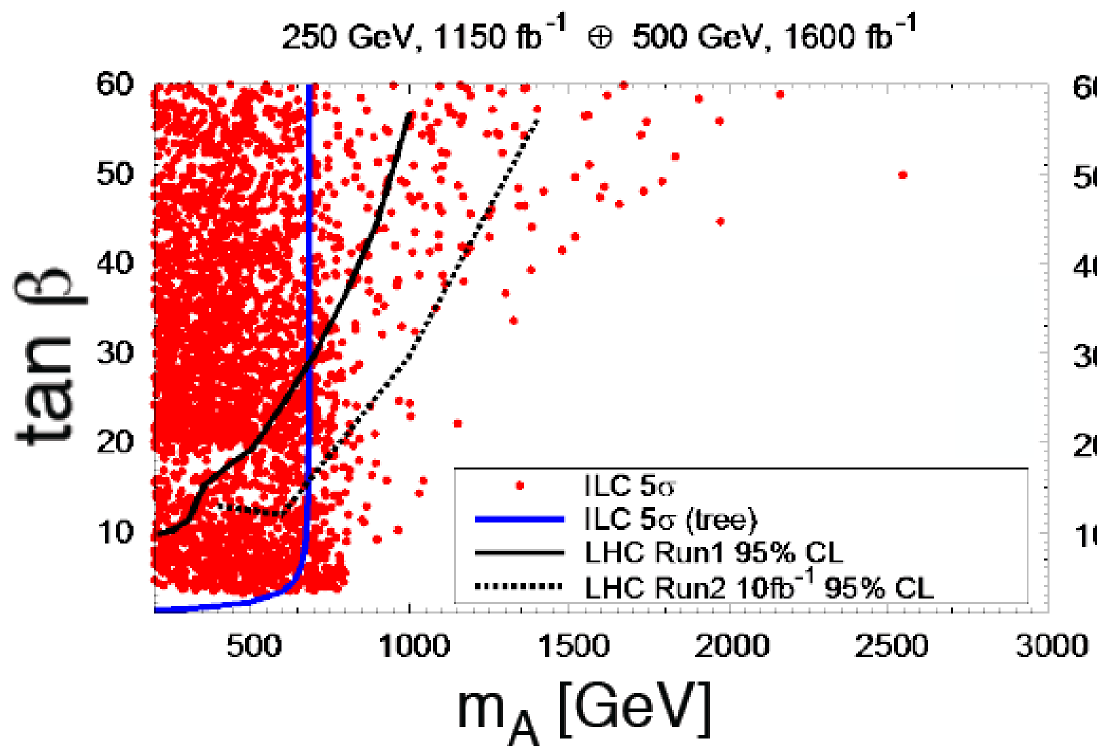
Fingerprinting!

Deviation in *hff*

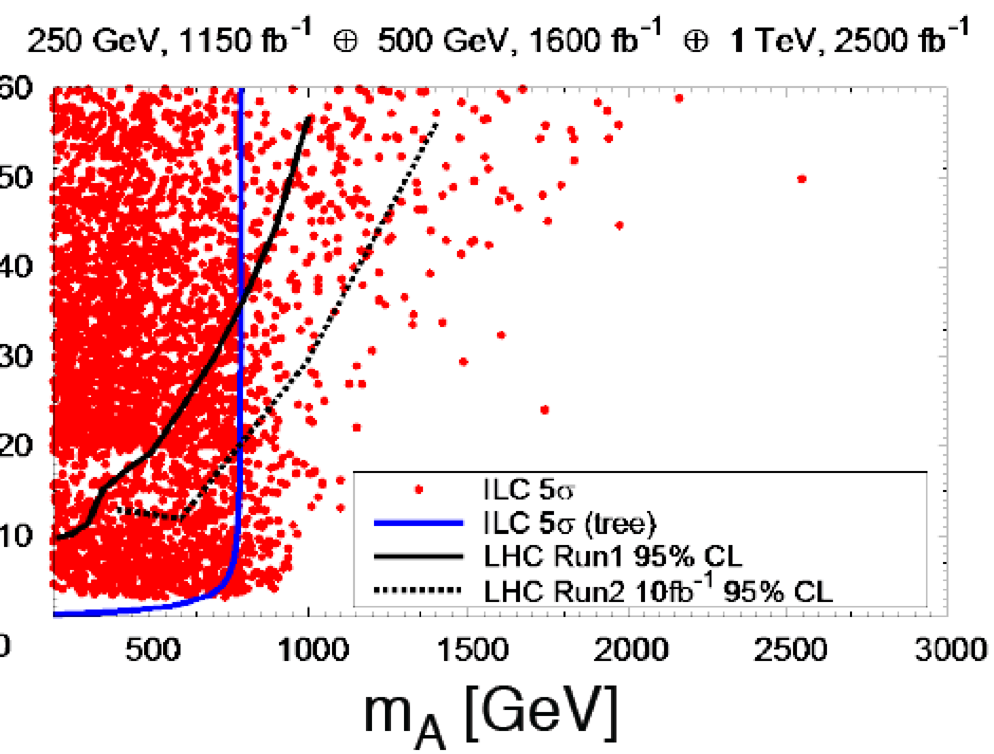
Model	$\Delta\kappa_u$	$\Delta\kappa_d$	$\Delta\kappa_\tau$	If $\Delta\kappa_V$ =1 %	
Singlet, Exotics	$\Delta\kappa_u = -(1/2)x^2$	$\Delta\kappa_d = -(1/2)x^2$	$\Delta\kappa_\tau = -(1/2)x^2$	O(1) %	**Singlet mixing**
Type I 2HDM	$\Delta\kappa_u = +\cot\beta\, x$	$\Delta\kappa_d = +\cot\beta\, x$	$\Delta\kappa_\tau = +\cot\beta\, x$	O(10) %	**2HDM**
MSSM (Type II 2HDM)	$\Delta\kappa_u = +\cot\beta\, x$	$\Delta\kappa_d = -\tan\beta\, x$	$\Delta\kappa_\tau = -\tan\beta\, x$	O(10) %	
Type X (Lepton Specific) 2HDM	$\Delta\kappa_u = +\cot\beta\, x$	$\Delta\kappa_d = +\cot\beta\, x$	$\Delta\kappa_\tau = -\tan\beta\, x$	O(10) %	
MCHM4	$\Delta\kappa_u = -(1/2)x^2$	$\Delta\kappa_d = -(1/2)x^2$	$\Delta\kappa_\tau = -(1/2)x^2$	O(1) %	**Minimal Composite**
MCHM5	$\Delta\kappa_u = -(3/2)x^2$	$\Delta\kappa_d = -(3/2)x^2$	$\Delta\kappa_\tau = -(3/2)x^2$	O(1) %	

Heavy MSSM Higgs Mass Reach (Luminosity Upgrades)

- ILC 500 LumiUp:



- ILC 1000 LumiUp:



[ILC Higgs White Paper; ATLAS (2014); Morinaga, JPS 70th Annual Meeting (2015)]

- The indirect reach through the Higgs coupling measurements can be higher than the LHC direct observation limits
- The indirect reach of the MSSM heavy Higgs boson mass can be significantly extended, compared to the tree-level results

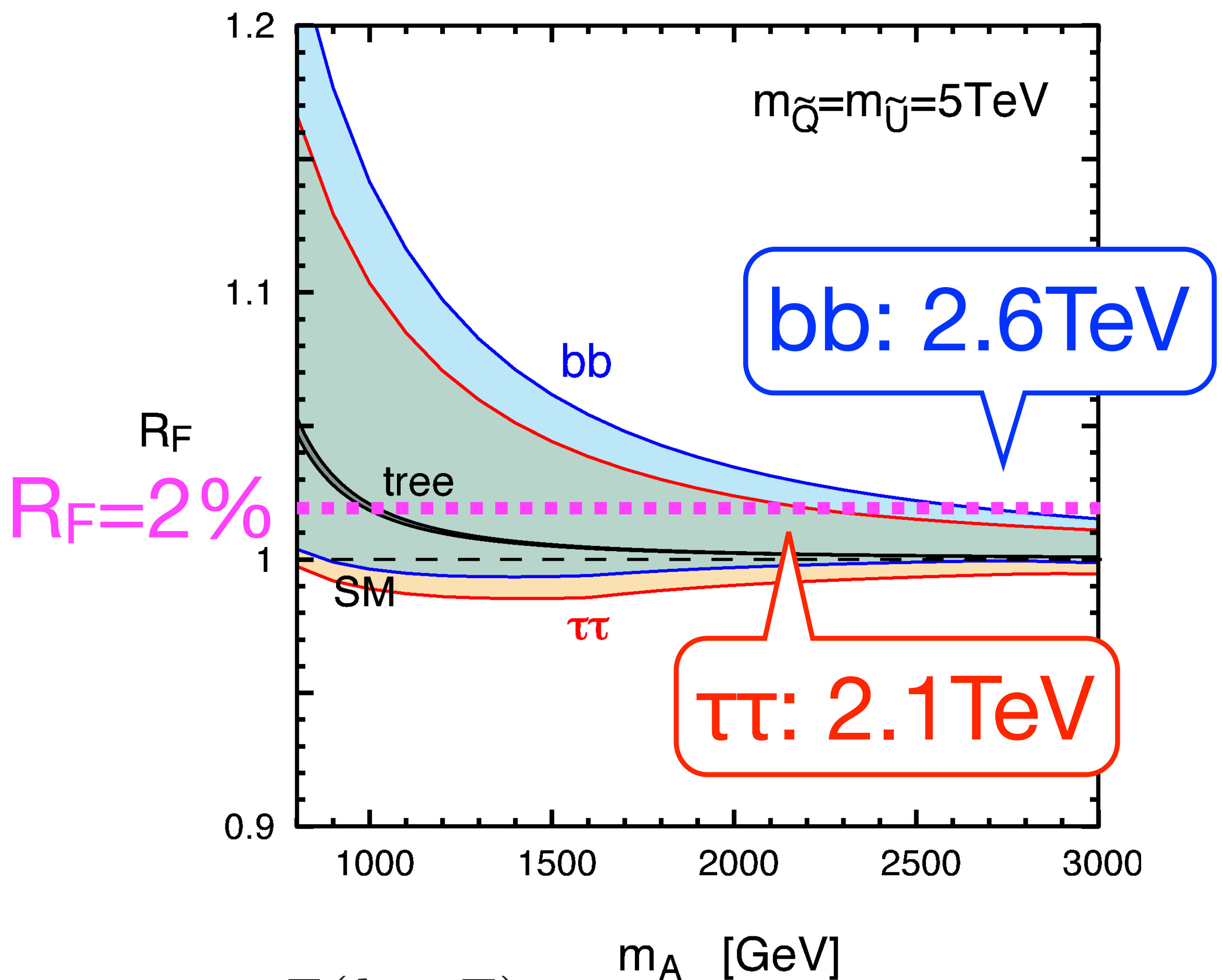
April 20, 2015 Mitsuru KAKIZAKI 11

Loop level analyses started and it helps!

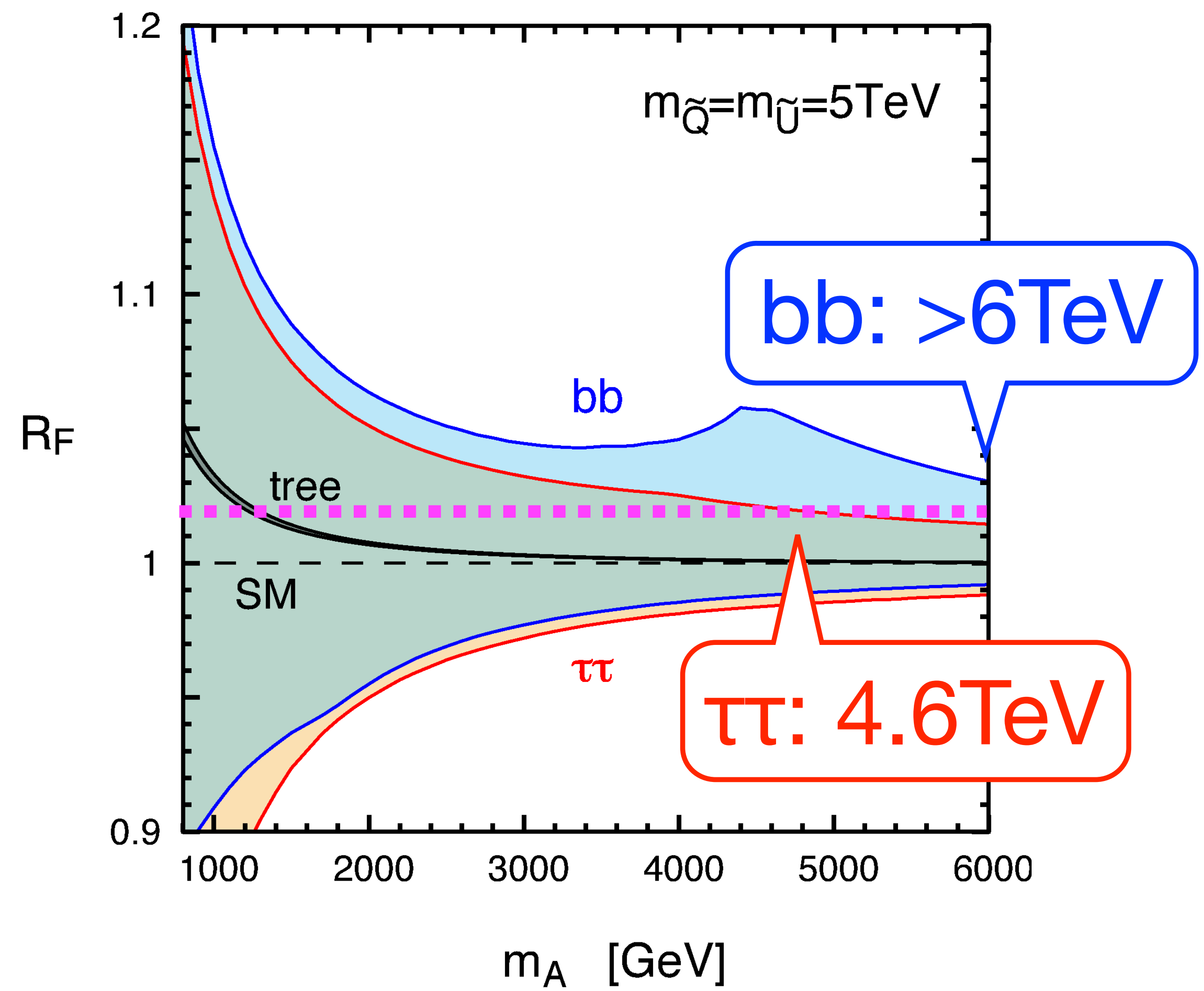
How large can deviation be?

lepton colliders have a chance to probe multi TeV scale

small A_t solutions



all A_t solutions



$$R_F = \frac{\Gamma(h \to F)}{\Gamma(h \to F)_{(\mathrm{SM})}}$$

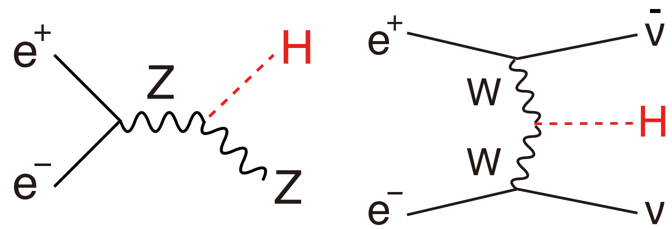
Sensitivity might reach a few TeV!

Experiment

Key Point

At LHC all the measurements are σ×BR measurements.

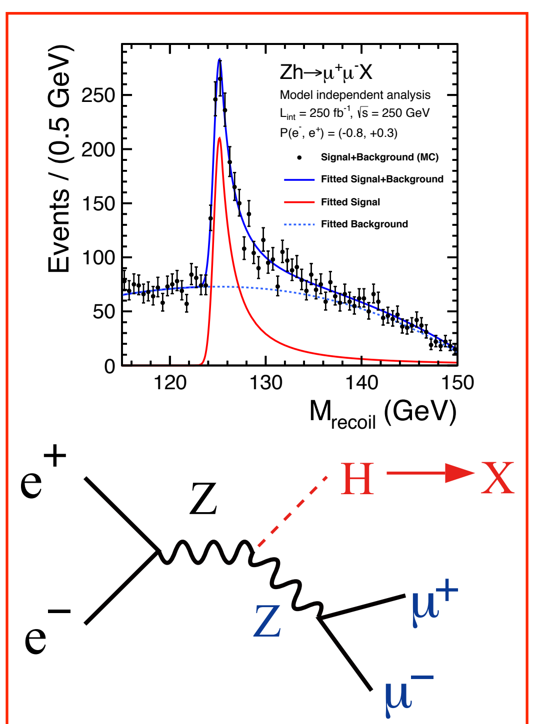
At ILC all but the σ measurement using recoil mass technique is σ×BR measurements.



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

σ×BR → **BR** → **g coupling**

The Key

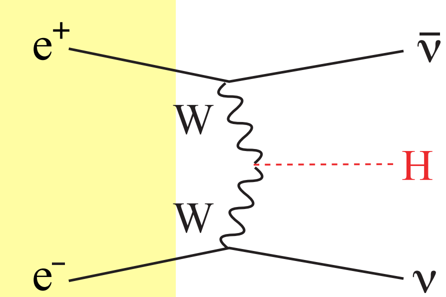


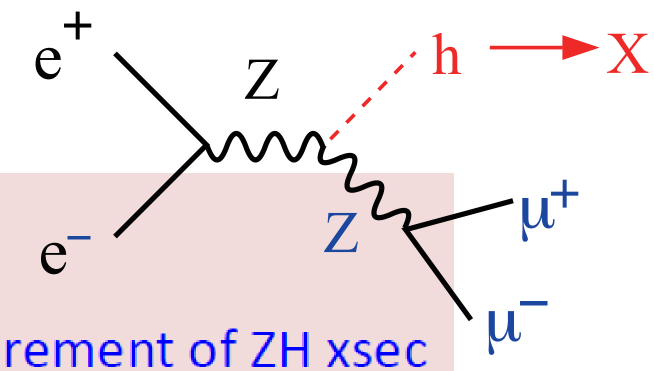
σ
from recoil mass

Z→qq is also usable.

Γ_H
total width

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





Summary

Higgs recoil study using **e+e- → ZH → μ+μ-H**
@ ECM =350 GeV (and 250 GeV)

- studied impact of ECM and polarization on model – independent measurement of ZH xsec
- contributes to deciding ILC run scenario and detector design optimization

< Preliminary results >

350 GeV: **(-0.8, +0.3)** **Δσ / σ = 4.1 %**
(+0.8, -0.3) **Δσ / σ = 4.5 %**

250 GeV: **(-0.8, +0.3)** **Δσ / σ = 3.5 %**
(+0.8, -0.3) **Δσ / σ = 3.6 %**

- **ECM= 250 GeV has better Δσ/σ by 17%** w.r.t. ECM=350 GeV
- **(+0.8, -0.3) has 10% worse Δσ/ σ** better S/B , but lower statistics
- Higgs mass precision is worse at ECM=350 GeV by a factor of 3

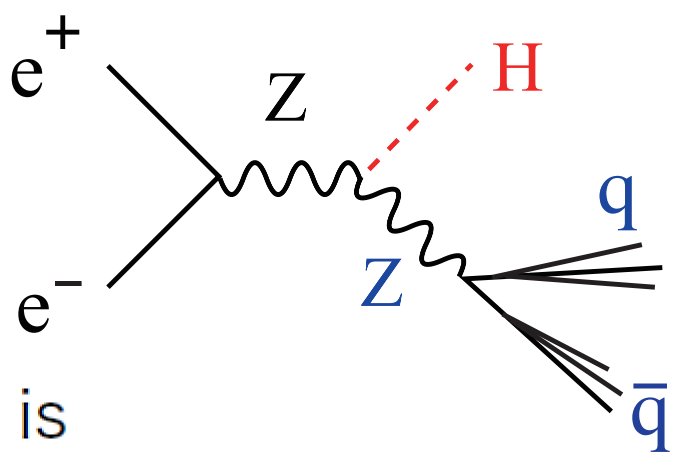
- **xsec precision improved significantly (by ~ 17 %) from AWLC 2014** (350 GeV, (-0.8, + 0.3)
- **signal bias is minimized i.e. prevent Higgs decay mode dependence**

Plans

- **analysis for ECM = 500 GeV is ongoing**
- **implement similar methods to Zee channel**
  so we can get a more reliable comparison of ECM = 250 GeV vs 350 GeV
- **study systematic errors on Higgs mass measurement**

ALCW15

New! 350GeV analysis + improved cuts



Summary and Prospects

summary

- Using categorization, the difference of cut efficiency is suppressed at most ~ 7 %.
- Stat. precision is about ~ 2.5 % which is almost the same as leptonic channel (ILC Higgs White paper's results)
- In worst case, the stat. precision is less than 4.0 % (σ_{ZH})

	significance	stat. precision
250 GeV (-0.8,+0.3) 250fb^{-1}	**38.0 σ**	**2.6%**
250 GeV (+0.8,-0.3) 250fb^{-1}	**41.8 σ**	**2.4%**
350 GeV (-0.8,+0.3) 333fb^{-1}	**30.1 σ**	**3.3%**
350 GeV (+0.8,-0.3) 333fb^{-1}	**31.1 σ**	**3.2%**

prospects

- cut optimization for 350 GeV (flavor tagging, cut variables…)
- Investigate the systematic uncertainty in both E_{CM}.

Decay mode-dependence being reduced!

Summary

preliminary

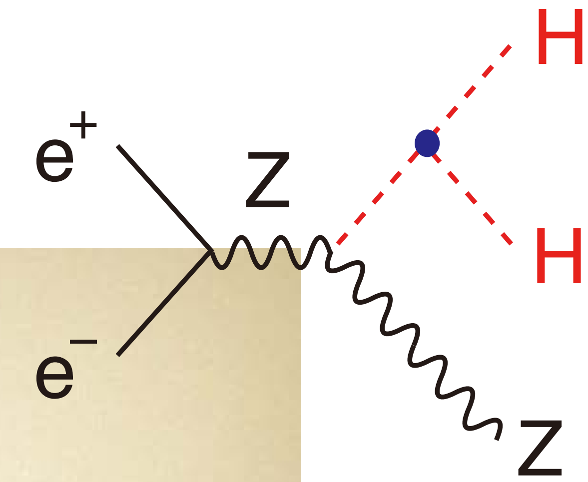
We evaluated the measurement accuracy of BR($h \to \tau^+\tau^-$) with using ILD full detector simulation at 250 GeV and 500 GeV.

$\frac{\Delta(\sigma \times \mathrm{BR})}{(\sigma \times \mathrm{BR})}$	$q\bar{q}h$	e^+e^-h	$\mu^+\mu^-h$	$\nu\bar{\nu}h$	Combined
250 GeV, 250 fb^{-1}	3.4%	14.4%	11.3%	32.4%	3.2%
500 GeV, 500 fb^{-1}	4.6%	25.2%	17.8%	6.9%	3.7%

(250 GeV, 250 fb^{-1})
+ (500 GeV, 500 fb^{-1}): **2.4%** (Combined)

now summarizing into a paper and PhD thesis...

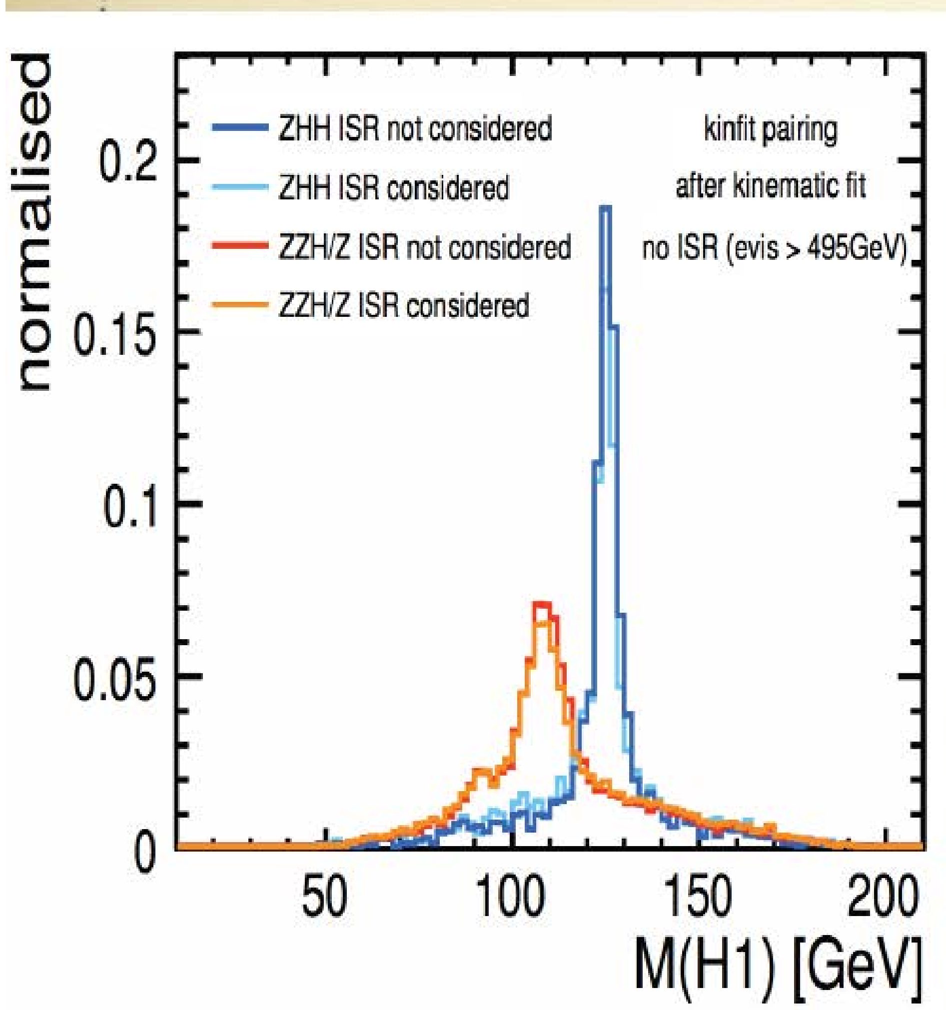
Update to mh=125GeV almost completed!



ILC 500 GeV & 1 TeV

update of Higgs self-coupling analysis

(see two talks by M. Kurata and C. Duerig)



new: analyses of all modes now are updated with M_H=125 GeV (confirmed previous extrapolation).

new: lots of efforts have been put on kinematic fitting, looks very promising. 20% improvement seen in HH—>bbbb mode.
5-10% seen in HH—>bbWW* mode.

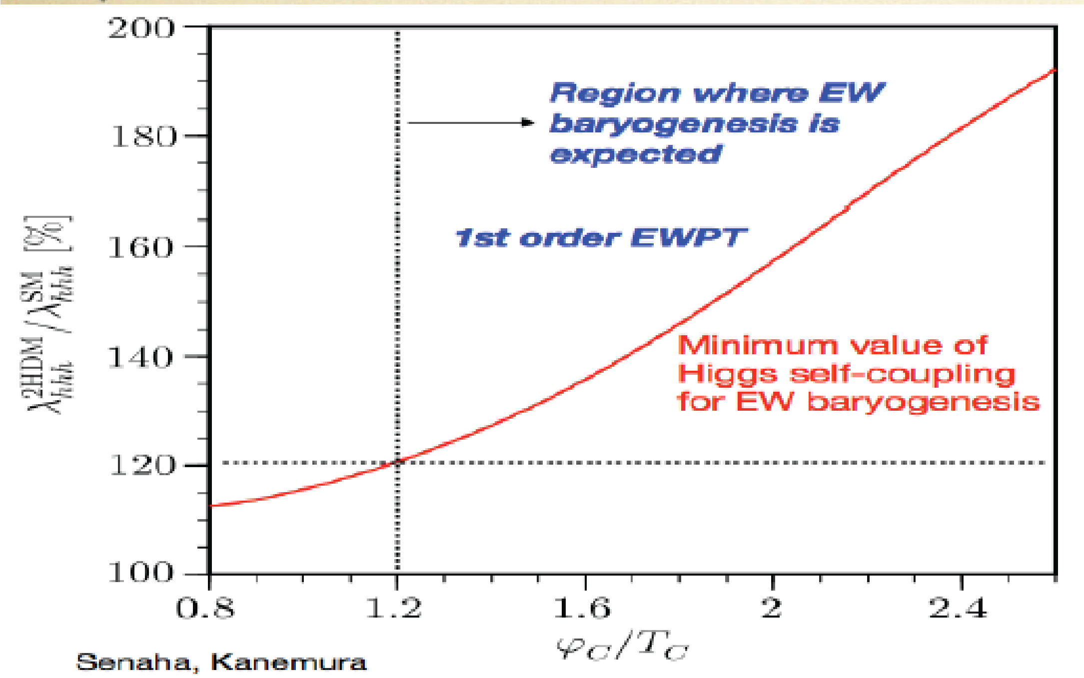
tool of matrix element method has been implemented, to be applied for analysis.

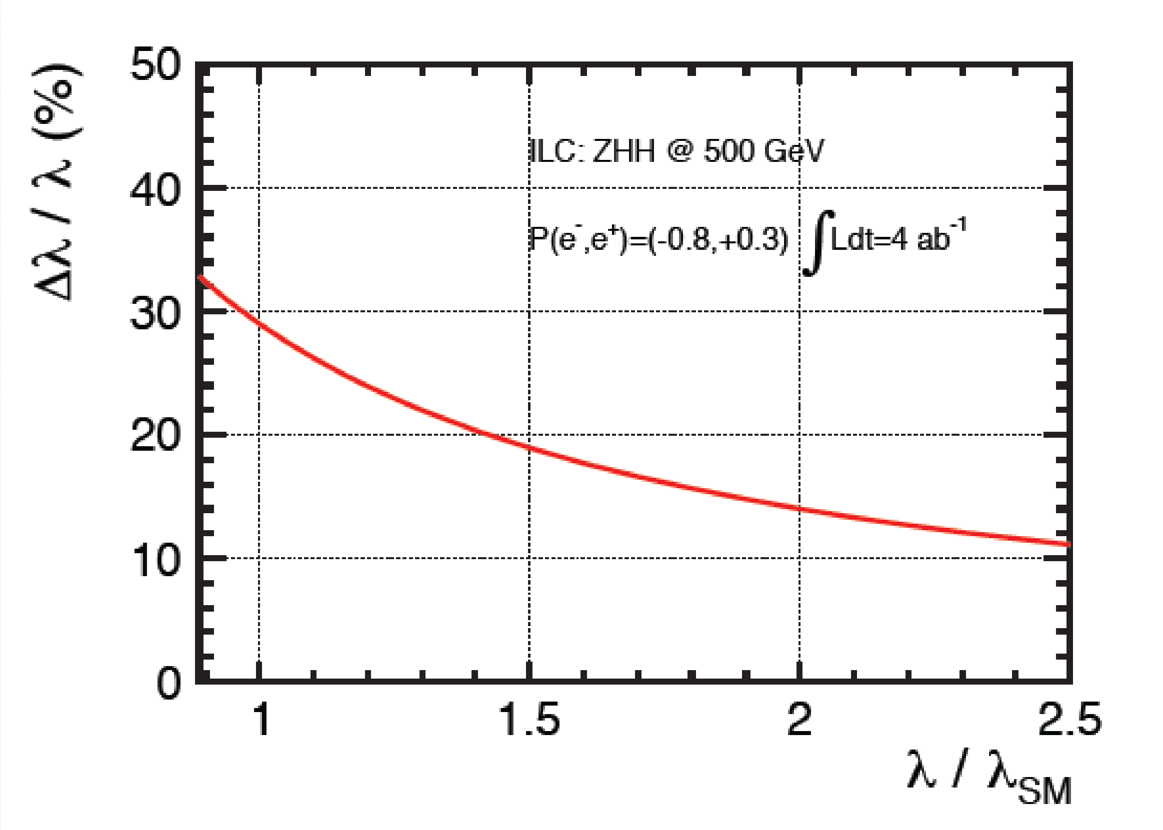
impact of overlay remains to be improved.

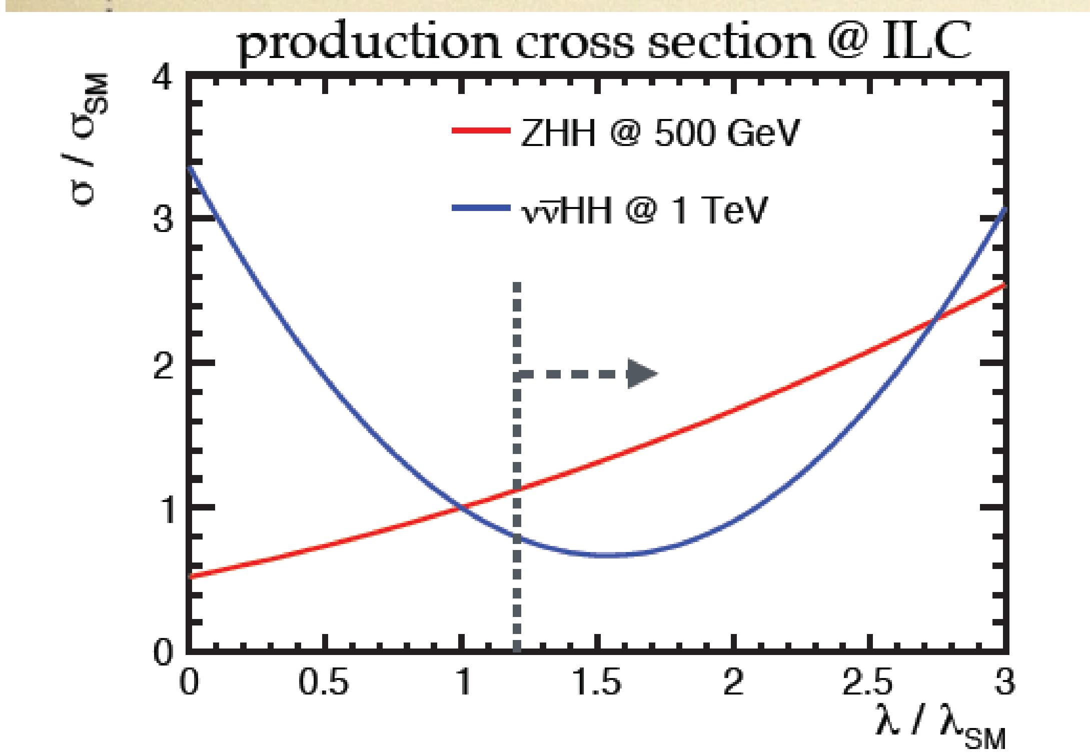
Various analysis improvements!

λ_{HHH} in Electroweak Baryongenesis

can be significantly enhanced — good for measurement using ZHH @ 500 GeV







example: if $\lambda_{HHH} = 2\lambda_{SM}$

σ_{ZHH} enhanced by 60%; λ_{HHH} and interference diagram become more dominant comparing irreducible diagram; $\Delta\lambda/\lambda$ improved by a factor of 2

λ_{HHH} will be measured to 14% —> 7σ discovery —> more than 3σ deviation from SM

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ZHH-vvHH complimentary

4-loop mass formula

A very precise measurement of the top quark mass, $\Delta m_t \sim$ 50 MeV, can be extracted from a threshold scan

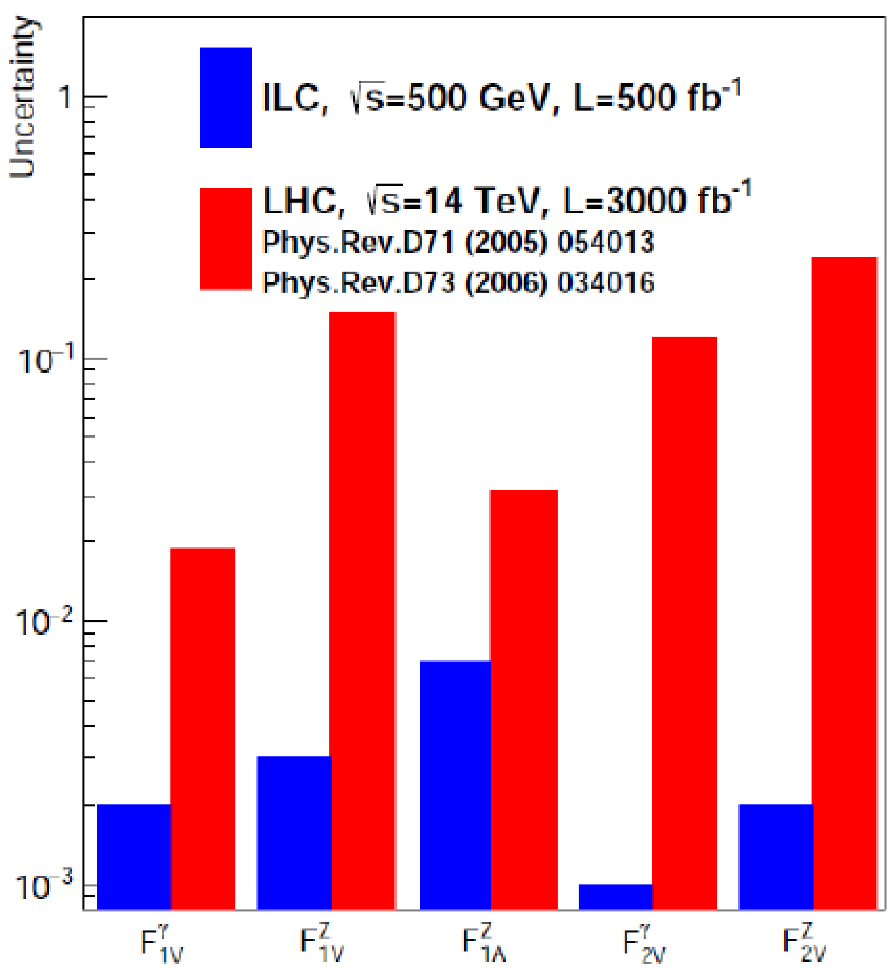
+ $\Delta \alpha s$ < 0.001 (not competitive with world average)

+ $\Delta \Gamma_t$ < 30 MeV (translate to constraint on V_{tb})

+ $\Delta y_t/y_t \sim$ 4.2% (if a precise value of α_s is inserted, otherwise 35%)

Note that one has to read several articles and contact a few people to assemble a correct and complete LC prospect

→ produce a single authorative source for this prospect…



Matrix element on di-lepton final state

Khiem, Kou, Kurihara, le Diberder, Probing new physics using top quark polarization in the e+e- → tt process at future Linear Colliders, arXiv:1503.04247 [hep-ph]

GRACE six-fermion process without narrow-width approximation
(no ISR, no single top, no hadronization, no detector)

Show feasibility of kinematic reconstruction of the di-lepton final state: $e^+e^- \to t\bar{t} \to l^+\nu l^-\bar{\nu}b\bar{b}$

Optimal analysis extracts all ten form factors – simultaneously – from angular distribution using the (LO) matrix element

$\mathcal{R}e\,\delta\tilde{F}^{\gamma}_{1V}$	$\mathcal{R}e\,\delta\tilde{F}^{Z}_{1V}$	$\mathcal{R}e\,\delta\tilde{F}^{\gamma}_{1A}$	$\mathcal{R}e\,\delta\tilde{F}^{Z}_{1A}$	$\mathcal{R}e\,\delta\tilde{F}^{\gamma}_{2V}$	$\mathcal{R}e\,\delta\tilde{F}^{Z}_{2V}$	$\mathcal{R}e\,\delta\tilde{F}^{\gamma}_{2A}$	$\mathcal{R}e\,\delta\tilde{F}^{Z}_{2A}$	$\mathcal{I}m\,\delta\tilde{F}^{\gamma}_{2A}$	$\mathcal{I}m\,\delta\tilde{F}^{Z}_{2A}$
0.0037	−0.18	−0.09	+0.14	+0.62	−0.15	0	0	0	0
	0.0063	+.14	−0.06	−0.13	+0.61	0	0	0	0
		0.0053	−0.15	−0.05	+0.09	0	0	0	0
			0.0083	+0.06	−0.04	0	0	0	0
				0.0105	−0.19	0	0	0	0
					0.0169	0	0	0	0
						0.0068	−0.15	0	0
							0.0118	0	0
								0.0069	−0.17
									0.0100

Sub-% precision. Note 0 correlation F2A with CP-conserving form factors
Lepton+jets final state, with same optimal ME extraction, yields factor two better precision

Simultaneous extraction of all form factors!

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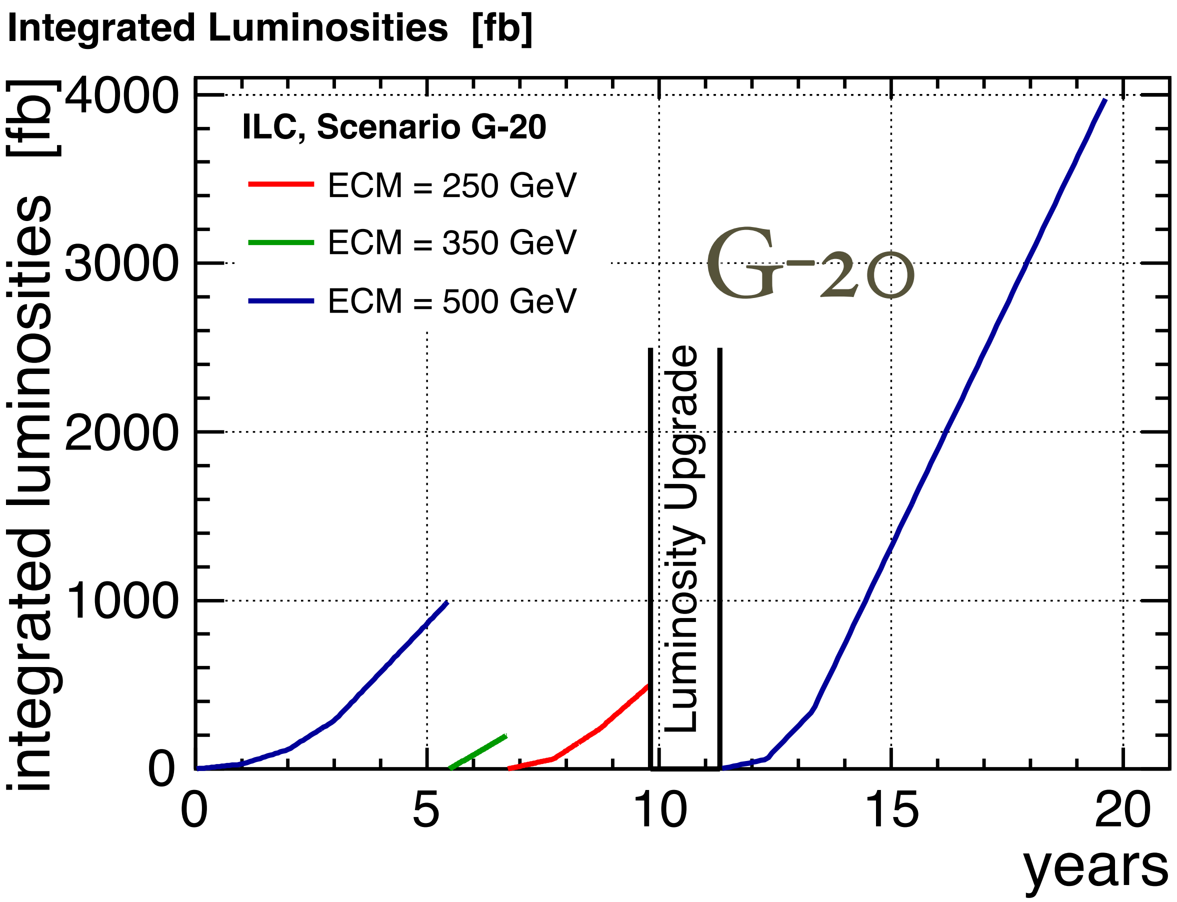
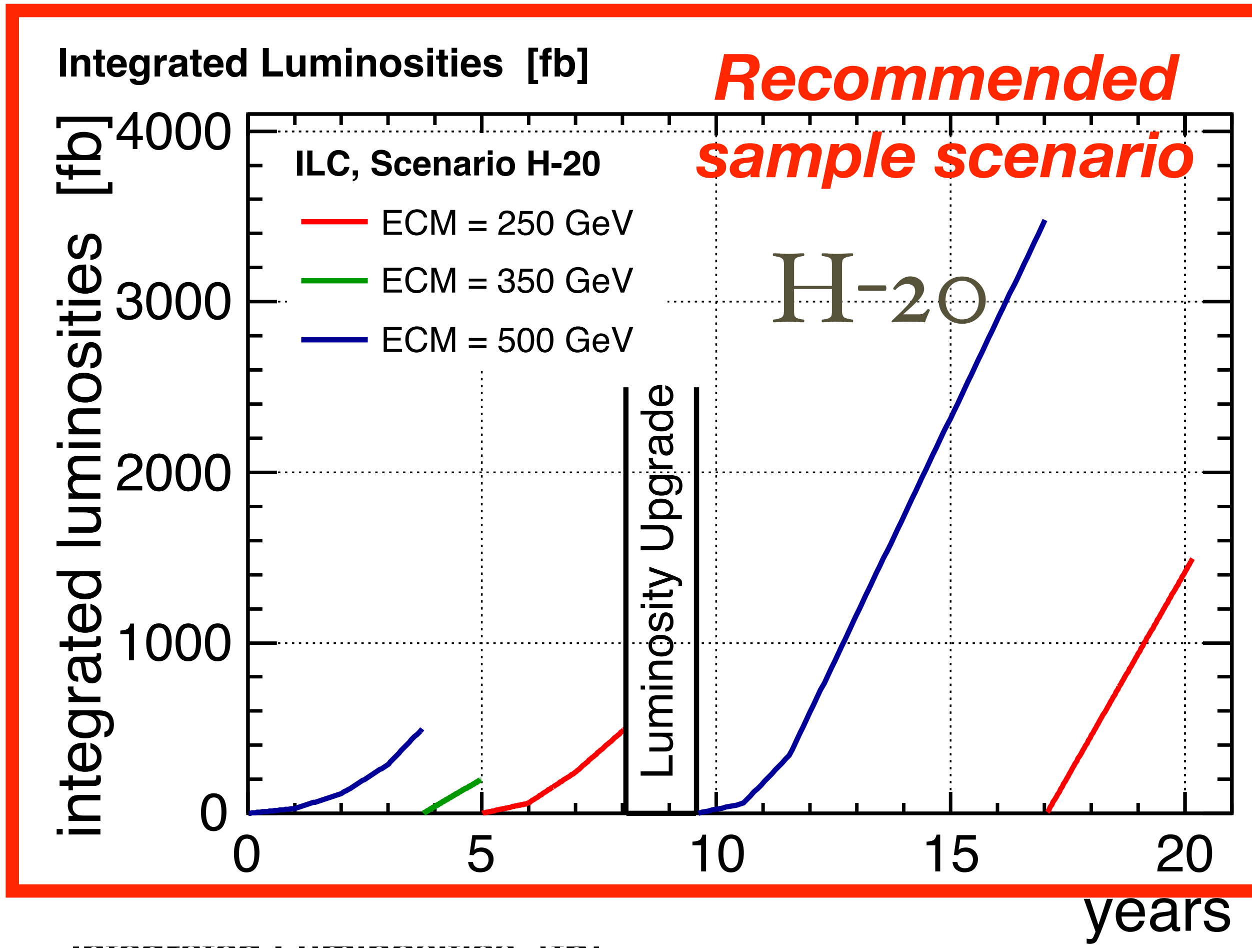
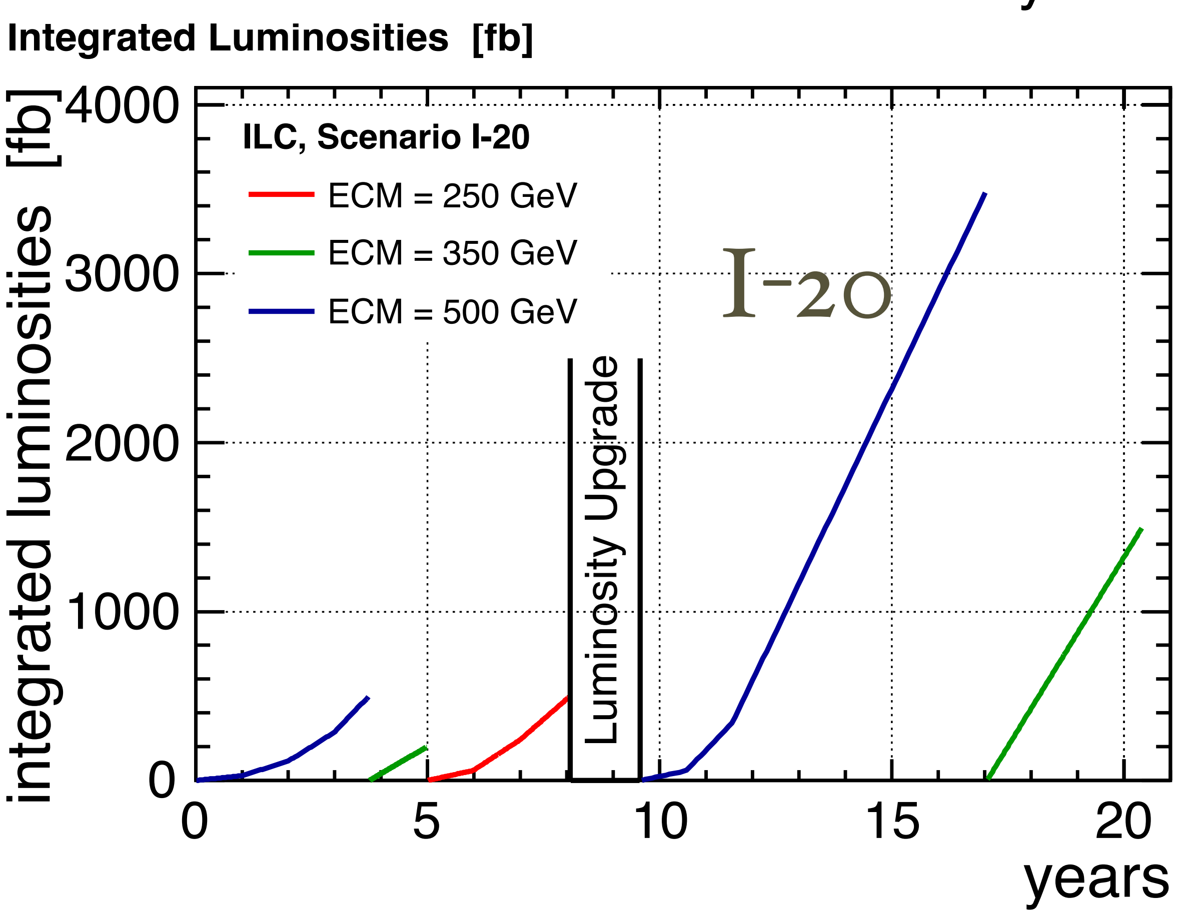
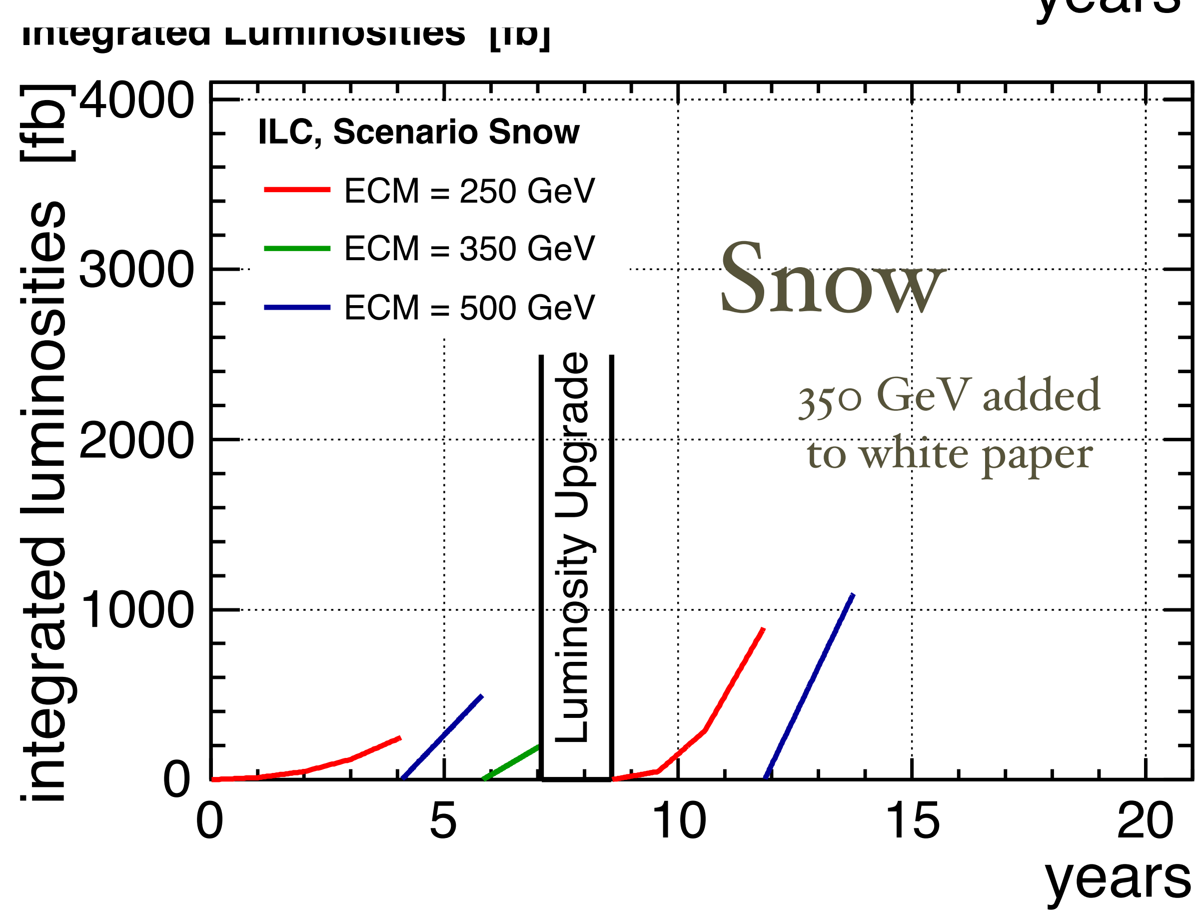
Running Scenarios


Integrated Luminosities [fb]
ILC, Scenario G-20
ECM = 250 GeV
ECM = 350 GeV
ECM = 500 GeV
G-20
Luminosity Upgrade
integrated luminosities [fb]
years


Integrated Luminosities [fb]
Recommended sample scenario
ILC, Scenario H-20
ECM = 250 GeV
ECM = 350 GeV
ECM = 500 GeV
H-20
Luminosity Upgrade
integrated luminosities [fb]
years

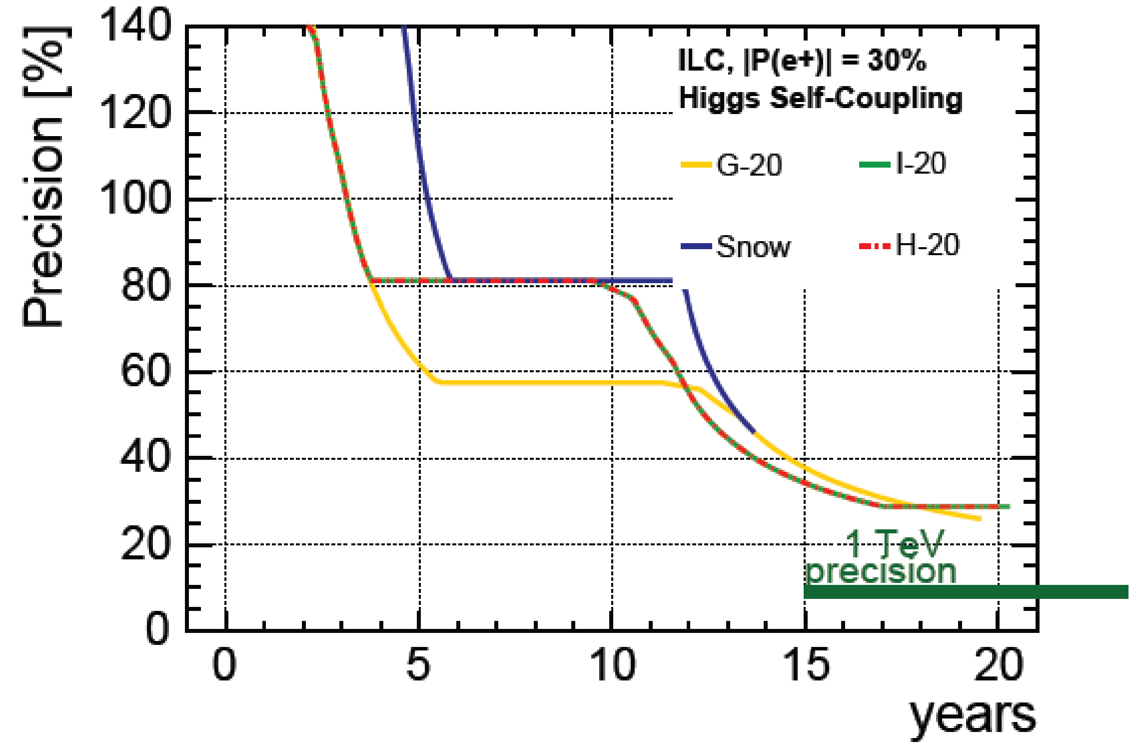

Integrated Luminosities [fb]
ILC, Scenario I-20
ECM = 250 GeV
ECM = 350 GeV
ECM = 500 GeV
I-20
Luminosity Upgrade
integrated luminosities [fb]
years

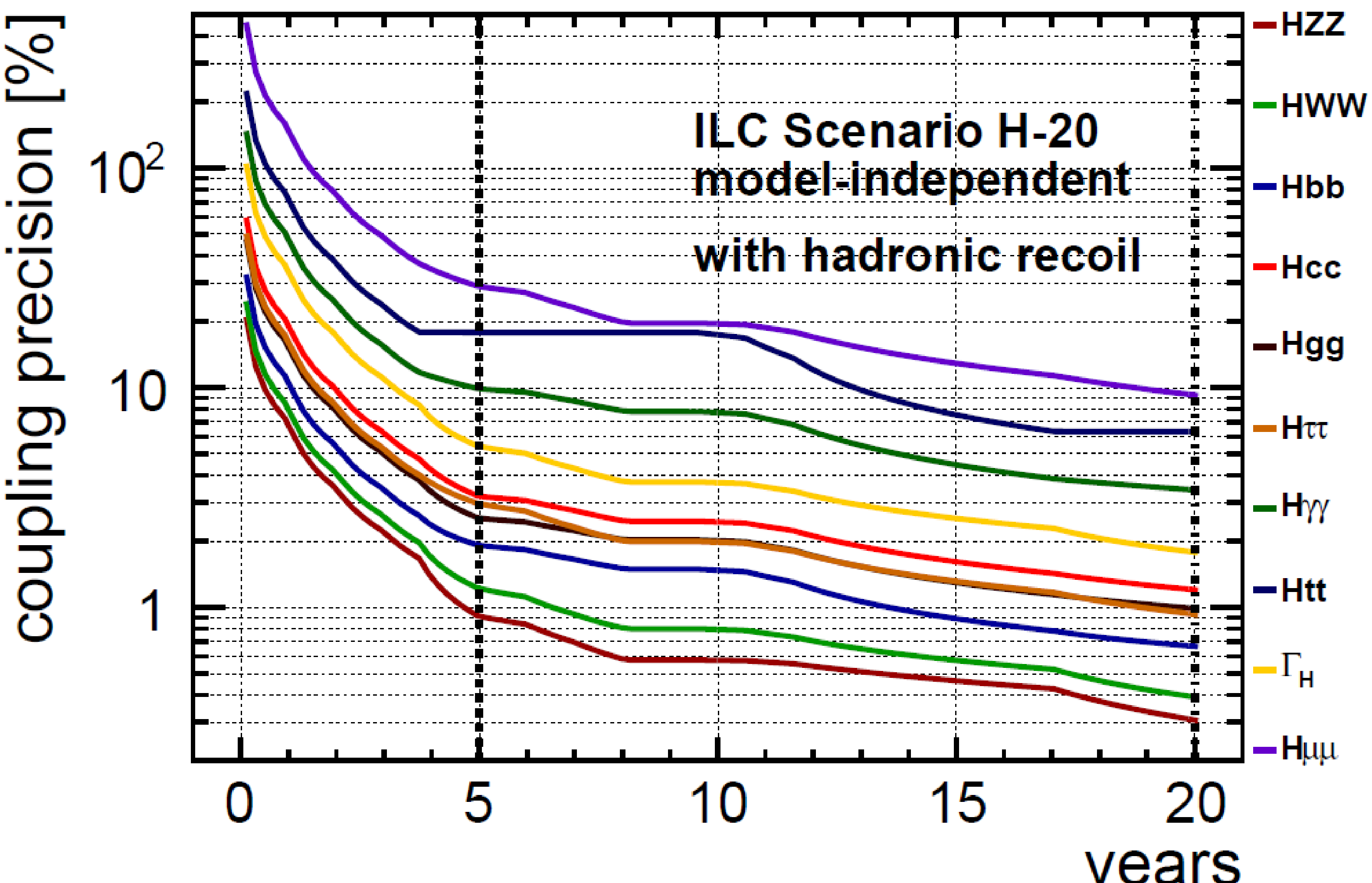

Integrated Luminosities [fb]
ILC, Scenario Snow
ECM = 250 GeV
ECM = 350 GeV
ECM = 500 GeV
Snow
350 GeV added to white paper
Luminosity Upgrade
integrated luminosities [fb]
years

Higgs Measurements

H-20

	first phase	lumi upgrade	total
250 GeV	500 fb⁻¹	1500 fb⁻¹	2 ab⁻¹
350 GeV	200 fb⁻¹		0.2 ab⁻¹
500 GeV	500 fb⁻¹	3500 fb⁻¹	4 ab⁻¹
time	8.1 yrs	10.6 yrs	20.2 yrs*





Self-coupling reaches <30% for SM case.
<15% if lamda=2xSM

ILC parameter WG report *Jim BRAU*

Most couplings reach <1% even with model-independent fitting

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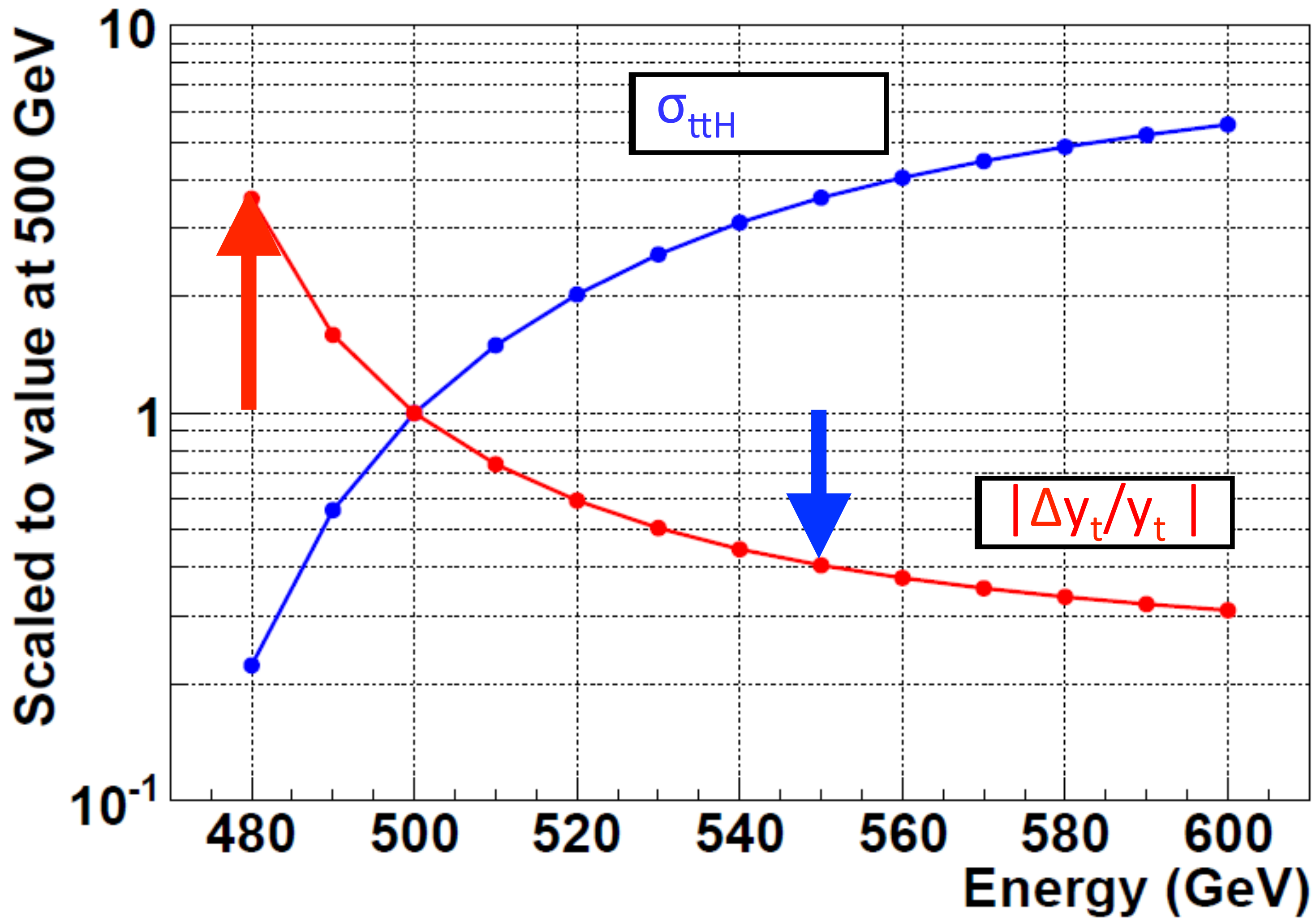
500 GeV vs. 550 GeV & ttH



550 GeV is 2.4 precision improvement over 500 GeV

- Failing to achieve 500 GeV loses reach quickly

Work in progress

Update ILC physics performance for H20
taking into account new results
(350 GeV analyses, mh update to125GeV,
various analysis improvements)

Note: ***H20 >> Snow***

Stay tuned!

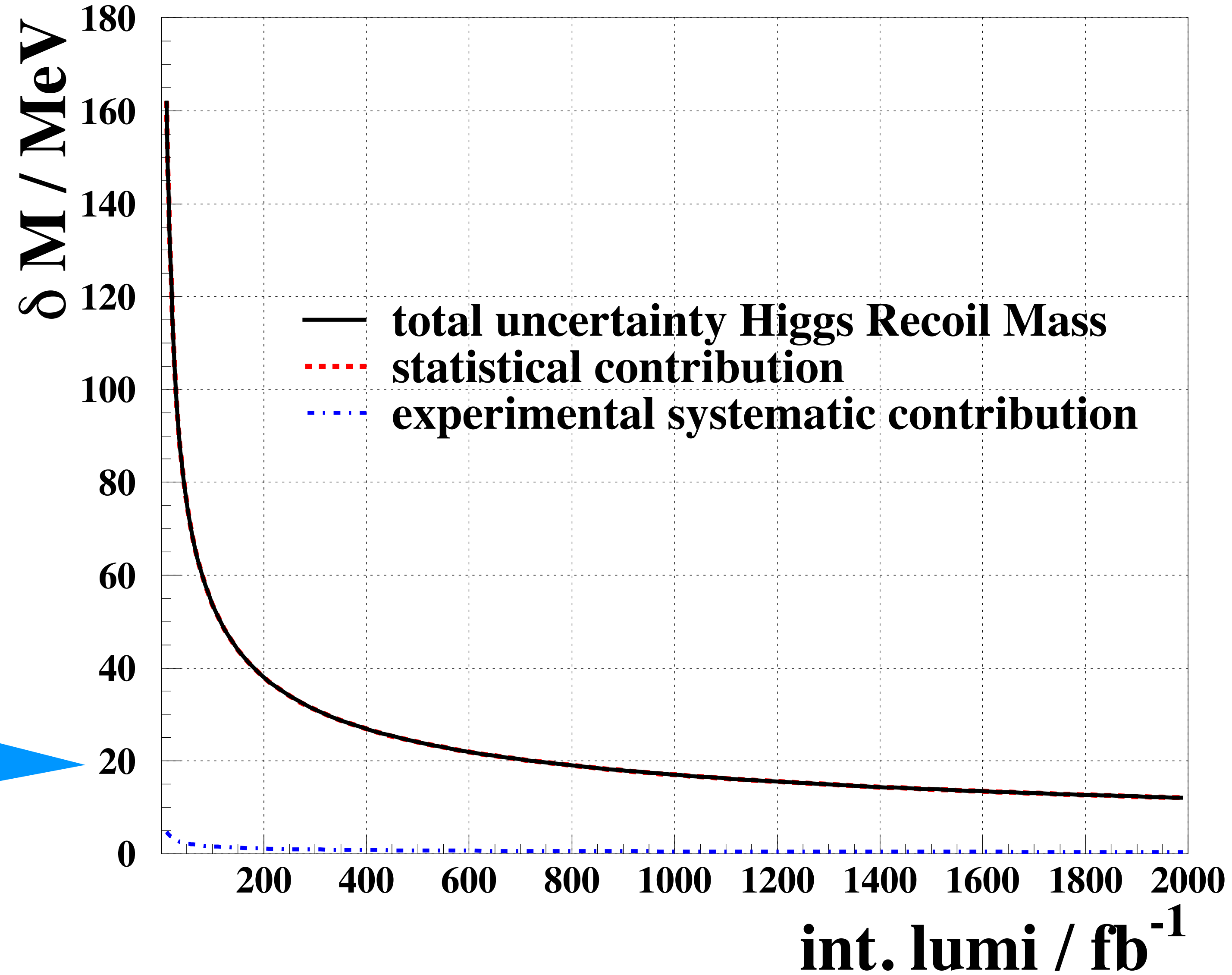
Backup

Assumptions

- Full calendar year is assumed to be 8 months at a 75% efficiency (the RDR assumption). This corresponds to Y = 1.6 x 10^7 seconds of integrated running. (significantly higher than a Snowmass year of 10^7 seconds.)
- A **ramp-up** of luminosity performance is in general assumed after:
  - (a) initial construction and after 'year 0' commissioning;
  - (b) after a downtime for a luminosity upgrade;
  - (c) a change in operational mode which may require some learning curve (e.g. going to 10-Hz collisions).
- For initial physics run *after construction and year 0 commissioning*, the RDR ramp of 10%, 30%, 60% and 100% is assumed over the first four years.
- The ramp *after the shutdowns for installation of the luminosity upgrade* is assumed slightly shorter (10%, 50%, 100%) with no year 0.
- *Going down in centre of mass energy* from 500 GeV to 350 GeV or 250 GeV is assumed to have no ramp, since there is no machine modification.
- *Going to 10-Hz operation at 50% gradient* does assume a ramp (25%, 75%, 100%), since 10-Hz affects the entire machine.
- A major 18 month shutdown is assumed for the luminosity upgrade.
- Unlike TDR: 10-Hz and 7-Hz operation assumed at 250 GeV and 350 GeV

Higgs mass

- Fundamental parameter of SM, important to know in own right
- Higgs decay partial width dependence on m_h requires 20 MeV m_h precision to achieve desired 0.2% on partial widths



- Higgs recoil from $Z \rightarrow \mu\mu$ (expect 1 MeV systematic uncertainty)
- Note - direct reconstruction at 500 GeV in $h \rightarrow bb$ and $\rightarrow WW$ shows similar level of promise