luminosity & energy evolution for the staged ILC

on behalf of ILC Parameters Joint Working Group

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& C.Grojean, M.Peskin, et al, LCC Physics WG

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outline

- introduction
- new scenarios (start from 250 GeV)
- new developments for staging (luminosity, physics)
- evolution of Higgs coupling precisions
- evolution of discovery potential
- what is lost, what is not

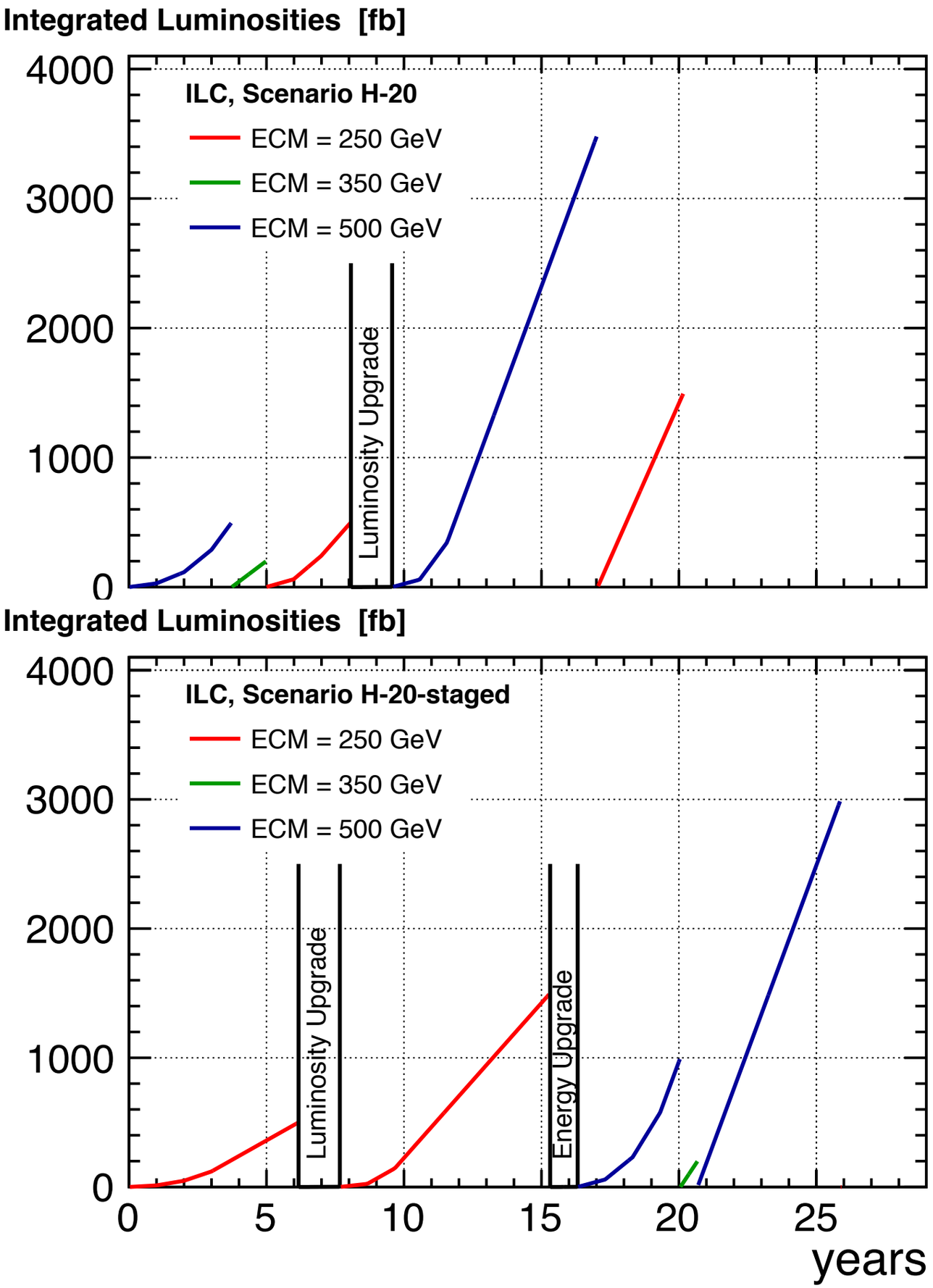
(former document, “ILC Operating Scenarios”, arXiv: 1506.07830)

introduction

- learned from LCWS16:
  - ★ “science first” with ILC
  - ★ cost reduction is important

- reduce initial $\sqrt{s}$=500 to 250 GeV would be most effective in cost reduction
- no NP discovered yet at LHC Run 2 —> weight of a “Higgs factory” gets higher
- that’s why ILC Parameters WG is investigating new staging scenarios which start from 250 GeV

scenario:
example



ILC500
H20

ILC250
H20 staged

top physics starts
after > 16y
in total ~ 6y longer

new development: higher luminosity at 250 GeV

talk by K.Yokoya

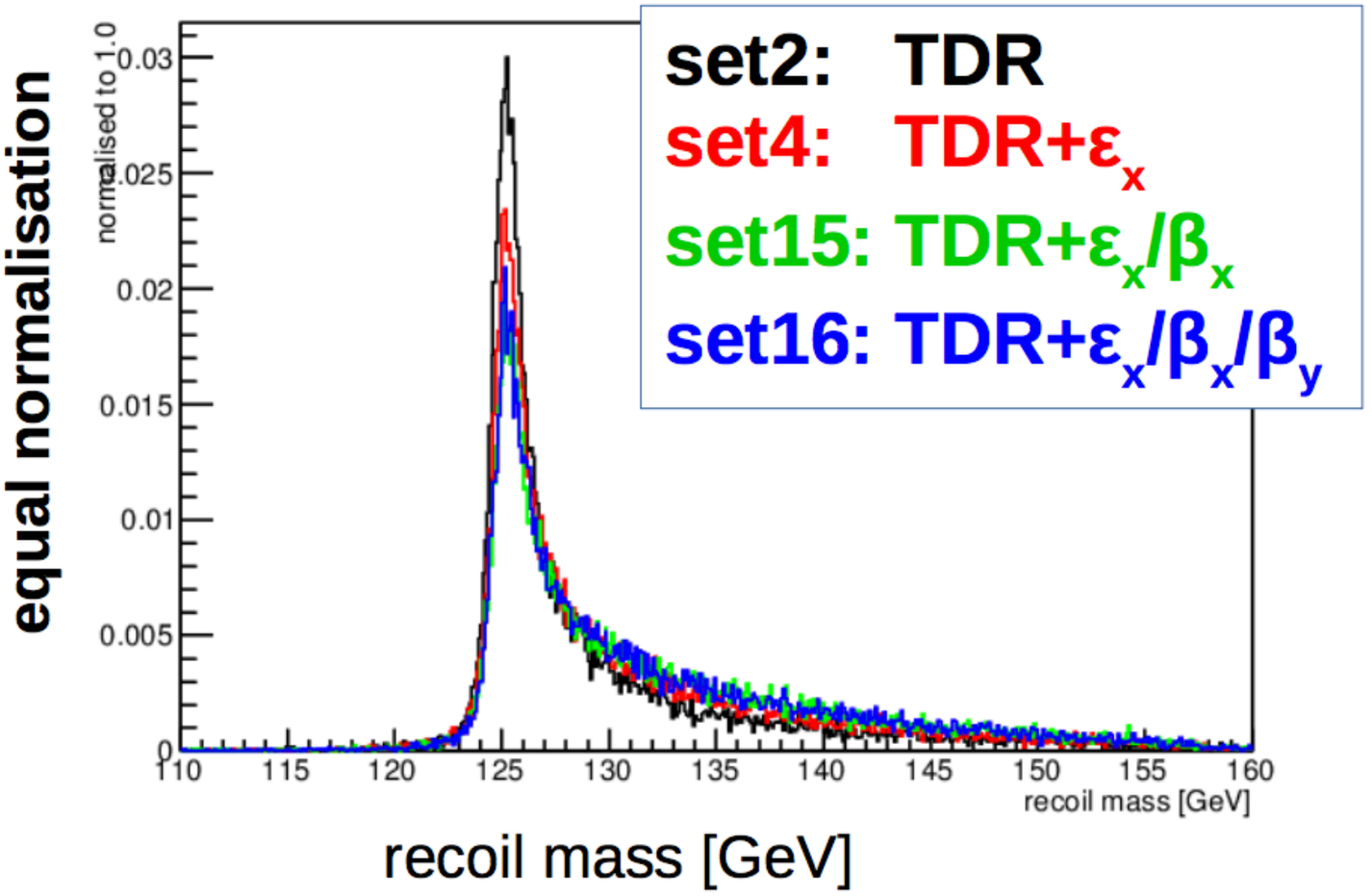
$$\mathcal{L} \approx C\frac{P_B}{E}\sqrt{\frac{\delta_{BS}}{\epsilon_{y,n}}}\min\left(1, \sqrt{\sigma_z/\beta_y}\right)$$

$$\delta_{BS} = \left\langle -\frac{\Delta E}{E} \right\rangle \approx 0.836\frac{N^2 r_e^3 \gamma}{\sigma_z \sigma_x^2}, \qquad \sigma_x = \sqrt{\frac{\epsilon_{x,n}\beta_x^*}{\gamma}}$$

- luminosity can be increased by higher δ_{BS} (beamstrahlung energy loss, which is 1% at TDR)
- higher δ_{BS} can be achieved by smaller $\varepsilon_{x,n}$ or β_x^*
- set of new beam parameters with smaller $\varepsilon_{x,n}$ is being tried —> x1.6 higher luminosity is promising
- if works —> can further try smaller β_x^*

new development: impact of higher beamstrahlung

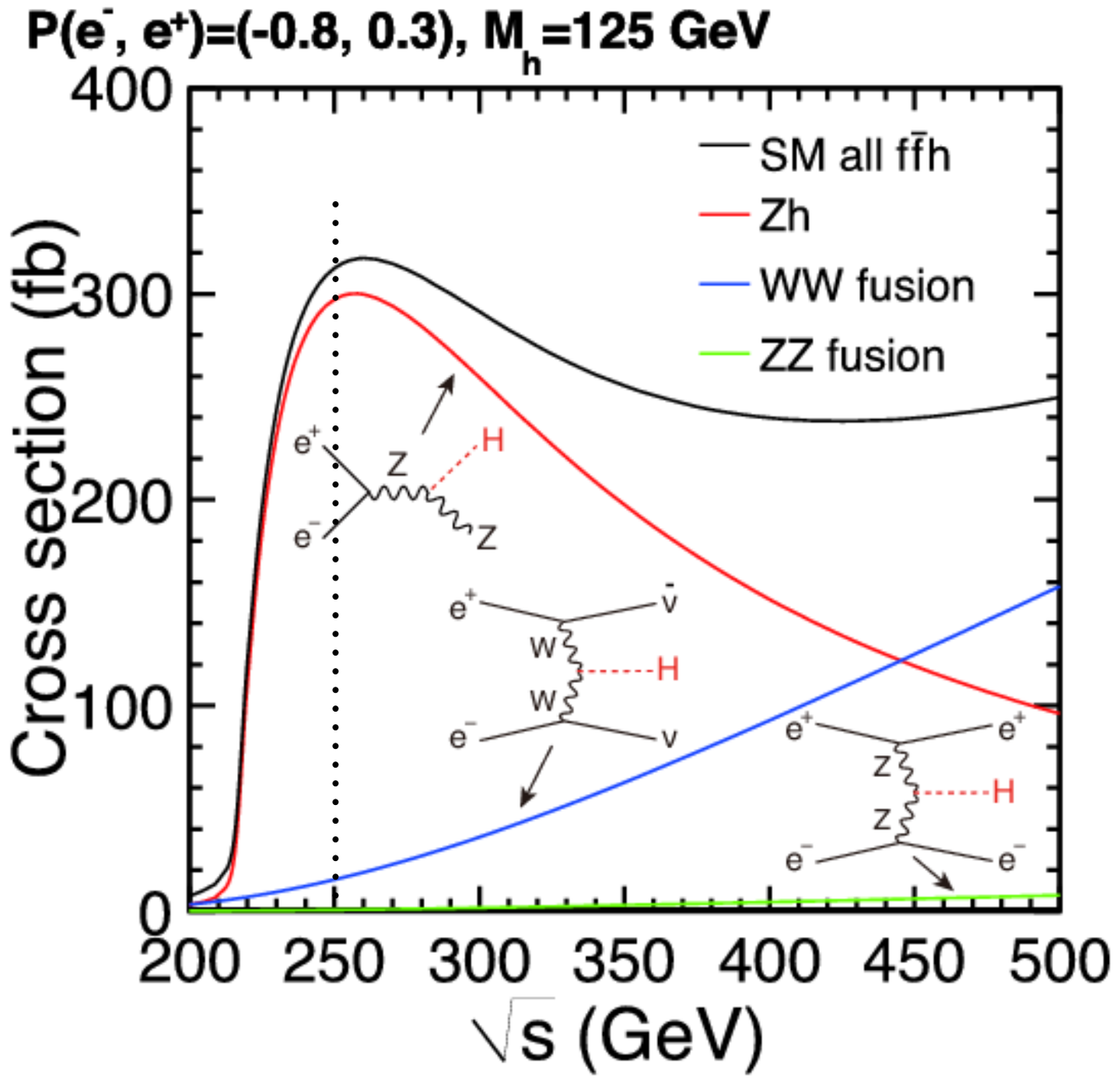
talk by D.Jeans



- at 250 GeV, even the most sensitive one, recoil mass, is not much affected, recoil mass shape is more dominated by ISR
- there is complementary method to measure Higgs mass, using h —>bb, without using z-momentum balance (J.Tian @ LCWS16)
- simulation inputs used in later slides are based on TDR beam

can we still do great physics at 250 GeV? $\Gamma_H = \frac{\Gamma_{HWW}}{\mathrm{Br}(H \to WW^*)} \propto \frac{g^2_{HWW}}{\mathrm{Br}(H \to WW^*)}$

- WW-fusion is smaller by x10 than 500 GeV



new development: EFT analysis

talks by M.Peskin & M.Perelstein

- hWW/hZZ ratio can be determined to <0.1%: feature of a general SU(2) x U(1) gauge theory

$$\Gamma(h \to ZZ^*) = (SM) \cdot (1 + 2\eta_Z - (0.50)\zeta_Z) \ ,$$

$$\Gamma(h \to WW^*) = (SM) \cdot (1 + 2\eta_W - (0.78)\zeta_W)$$

SM-like hVV

$$\eta_W = -\frac{1}{2}c_H$$
$$\eta_Z = -\frac{1}{2}c_H - c_T$$

custodial symmetry

$c_i \sim O(10^{-4}\text{-}10^{-3})$

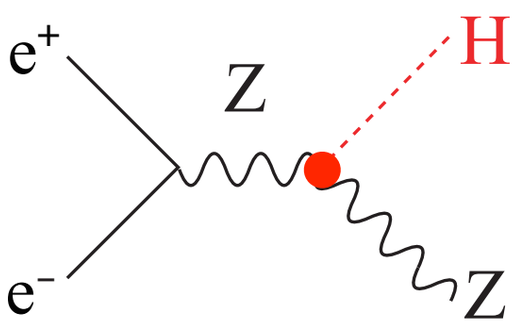
anomalous hVV

$$\zeta_W = (8c_{WW})$$
$$\zeta_Z = c_w^2(8c_{WW}) + 2s_w^2(8c_{WB}) + (s_w^4/c_w^2)(8c_{BB})$$

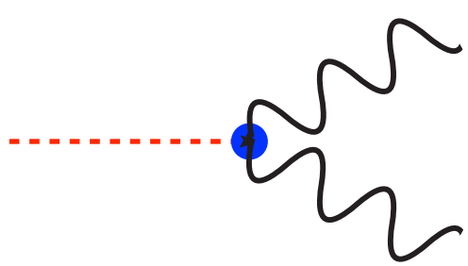
new development: EFT analysis

talks by M.Peskin
& M.Perelstein

- σ(e+e- ->Zh) ∝ κ²(hZZ) ∝Γ(h->ZZ*) not any more: EFT is more general than kappa-framework



$$\delta\mathcal{L} = (1+\eta_Z)\frac{2m_Z^2}{v}hZ_\mu Z^\mu + \zeta_Z\frac{h}{2v}Z_{\mu\nu}Z^{\mu\nu}$$



$$\sigma(e^+e^- \to Zh) = (SM)\cdot (1 + 2\eta_Z + (5.5)\zeta_Z)$$

$$\neq$$

$$\Gamma(h \to ZZ^*) = (SM)\cdot (1 + 2\eta_Z - (0.50)\zeta_Z)$$

(a combined Higgs+EWPO+TGC fit in EFT analysis)

“The leptonic future of the Higgs”, Durieux, et al, 1704.02333

“Improved Formalism for Precision Higgs Coupling Fits”, Barklow, et al, in preparation

new development: EFT analysis

(example of improvement) H20: $\int Ldt = 2\ ab^{-1}$ @ 250 GeV

coupling $\Delta g/g$	kappa-fit	EFT-fit
HZZ	0.38%	0.63%
HWW	1.9%	0.63%
Hbb	2.0%	0.89%
Γ_H	4.2%	2.1%

(disclaimer: EFT's have their own limitations, but they give the most model-independent interpretation we are aware of today)

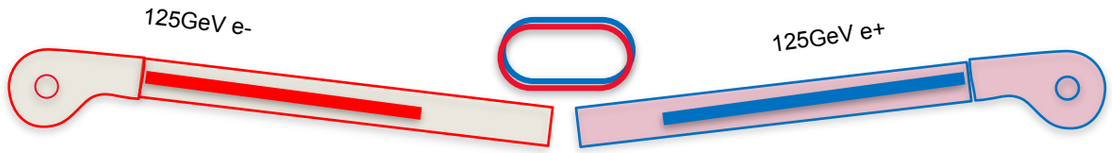
new scenarios: assumptions

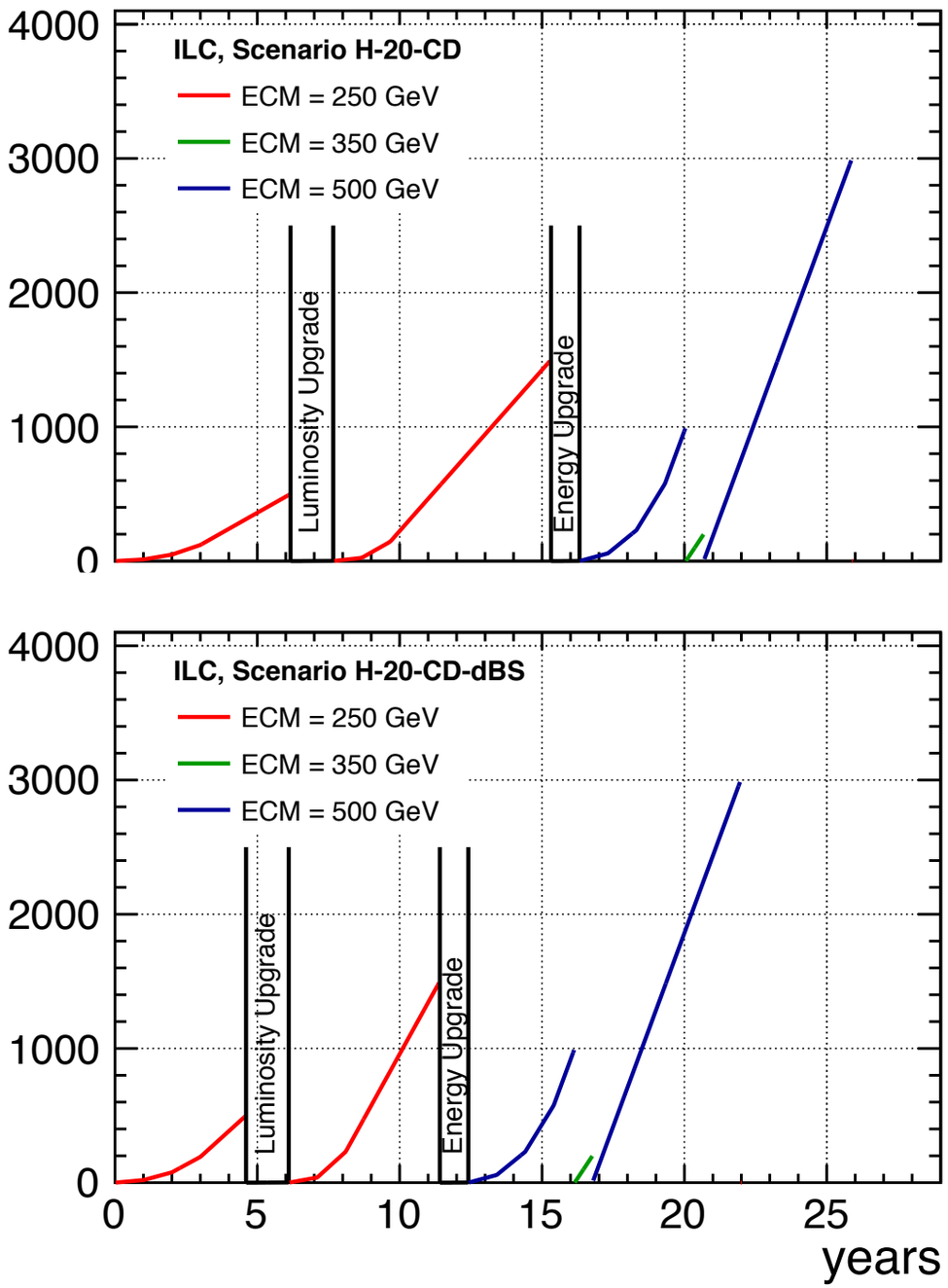
- all start with $\sqrt{s}$ = 250 GeV
- corresponding to different options of machine staged design: C,D,E,F (talks by B.List, S.Michizono)
- with or without x1.6 higher luminosity assumed (only for 250 GeV running, beamstrahlung would be too high for other $\sqrt{s}$)
- total ∫Ldt, share of left- and right-handed running for each $\sqrt{s}$ are as same as H20
- luminosity ramp up after year-0 is as same as H20

new scenarios: H-20-CD (-δ_{BS})

Option C:

(same scenario for option D)





lumi upgrade after ∫Ldt ~ 500 fb^{-1} (double bunches)

energy upgrade after ∫Ldt ~ 2 ab^{-1} at 250 GeV in ~15 (11)y

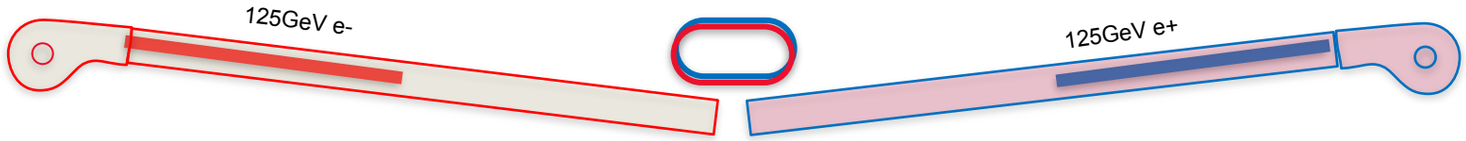
ILC500 starts with x2 bunches directly

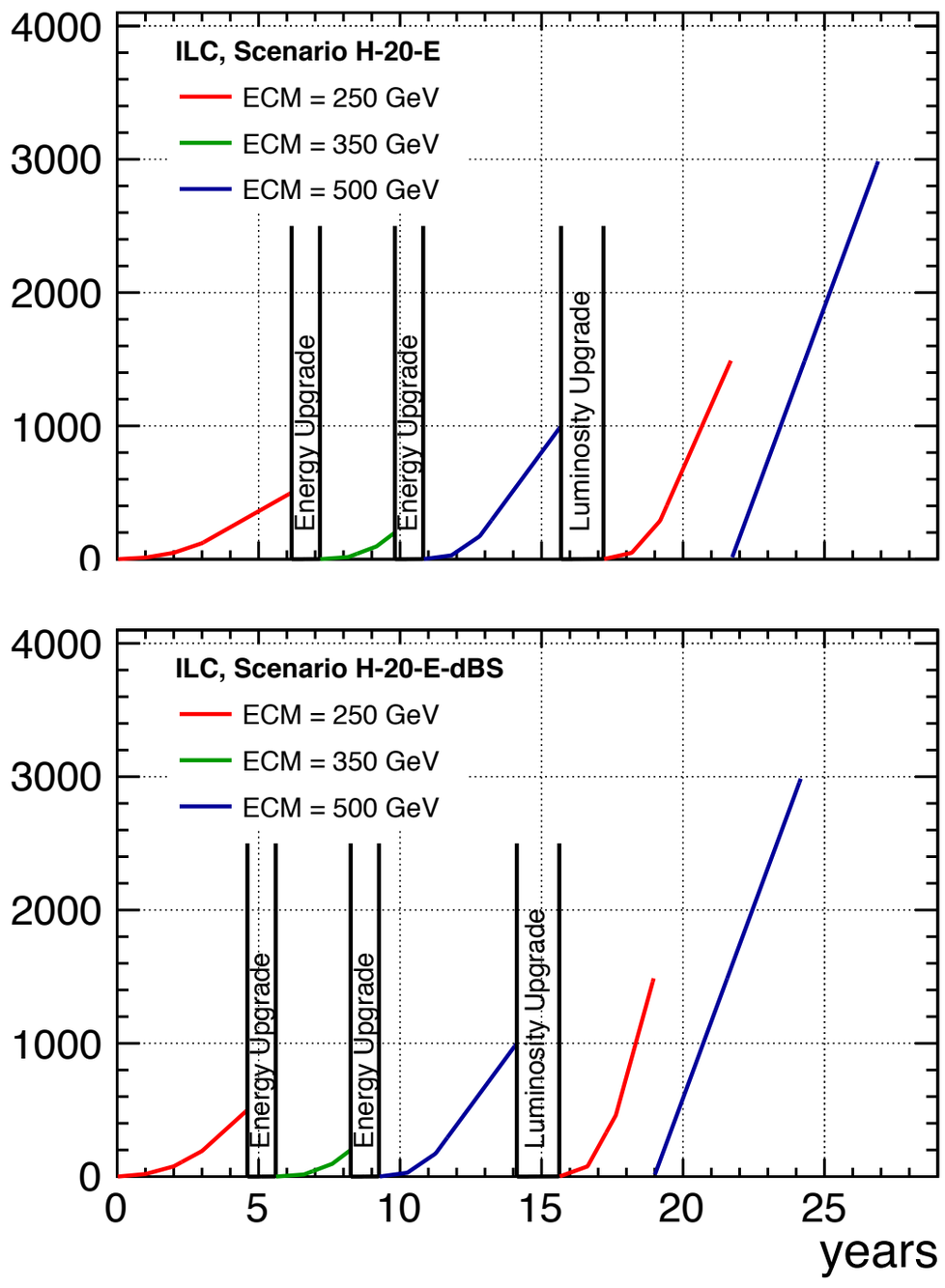
save ~4y with δ_{BS}

new scenarios: H-20-E (-δ_{BS})

Option E:

350GeV Option E':





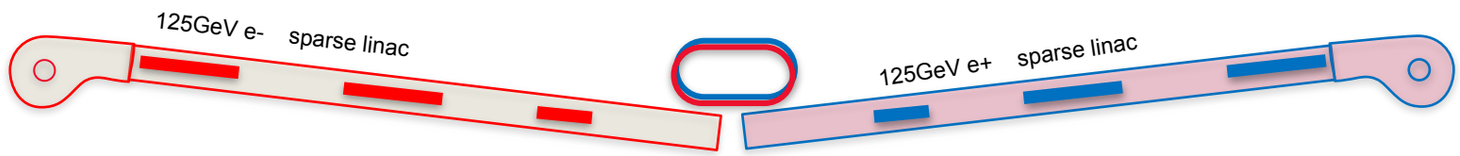
energy upgrade first
->350 GeV after ~6 (4.5)y
->500 GeV after ~10 (8)y

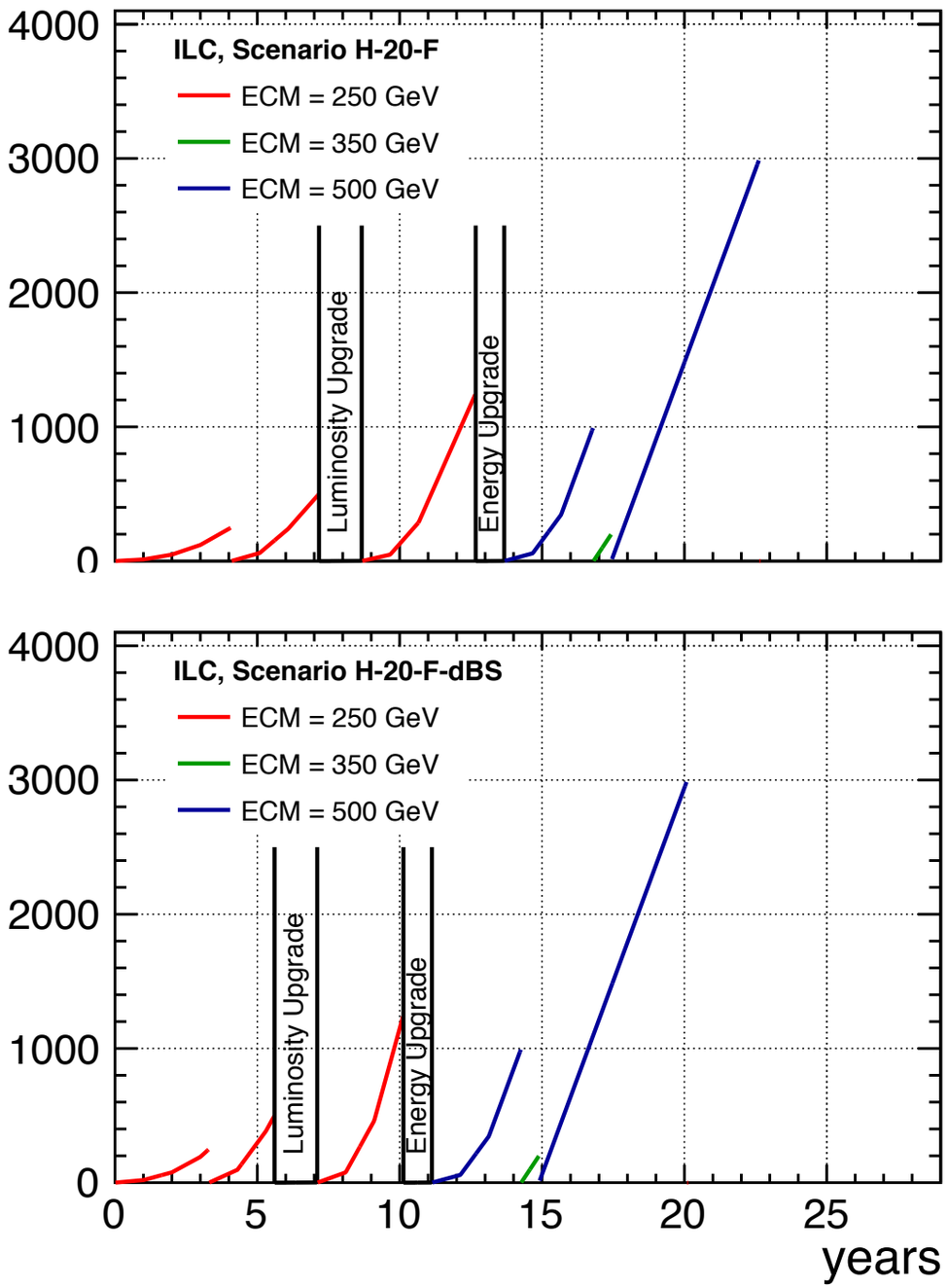
lumi upgrade after ~16 (14)y

new scenarios: H-20-F ($-\delta_{BS}$)

Option F:

350GeV Option F':





10Hz mode after ~4 (3)y

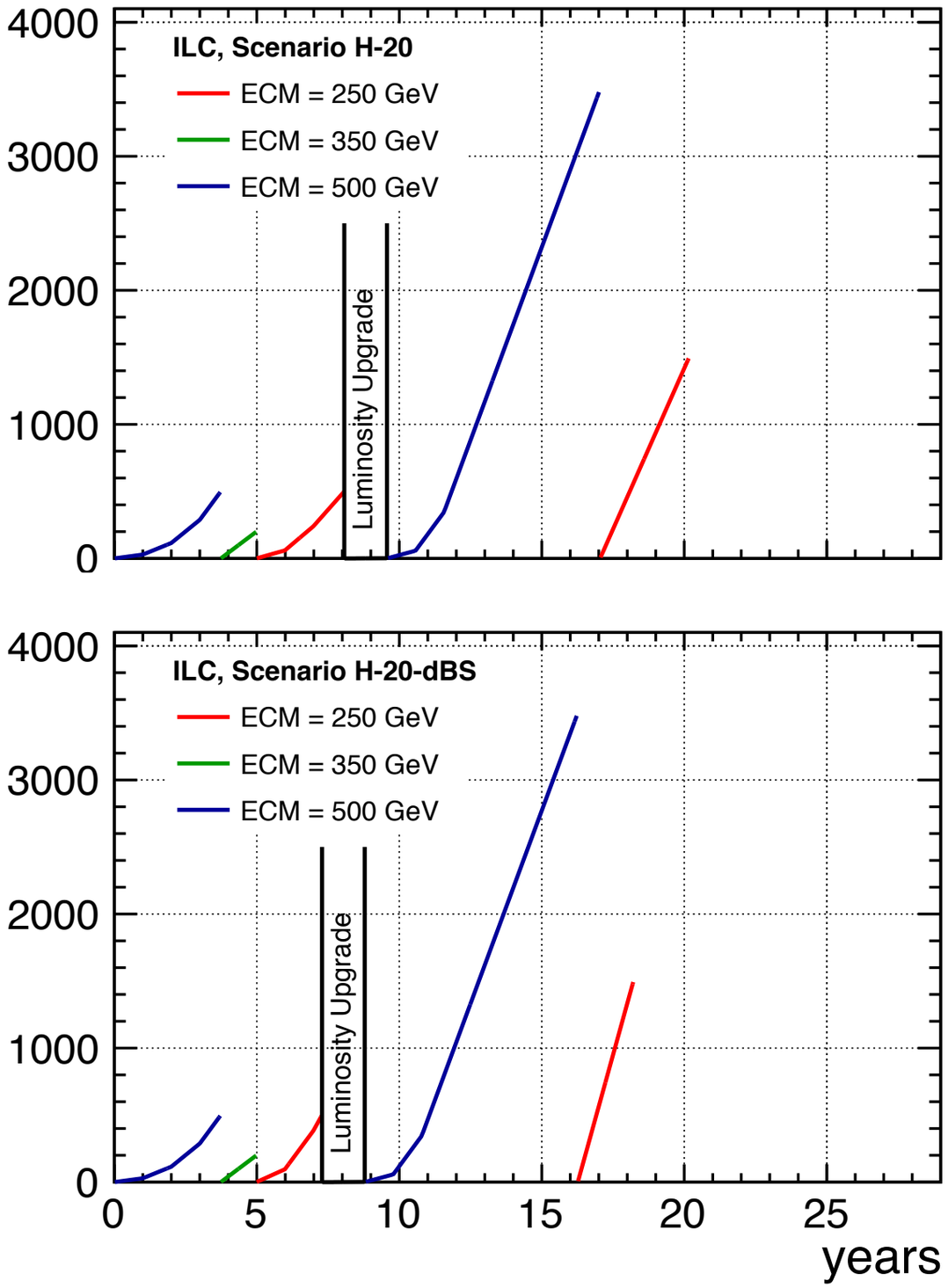
lumi upgrade after ~7 (6)y

energy upgrade after ~13 (10)y

quickest to reach full H20

most flexible choice: can do option C/D/E in F

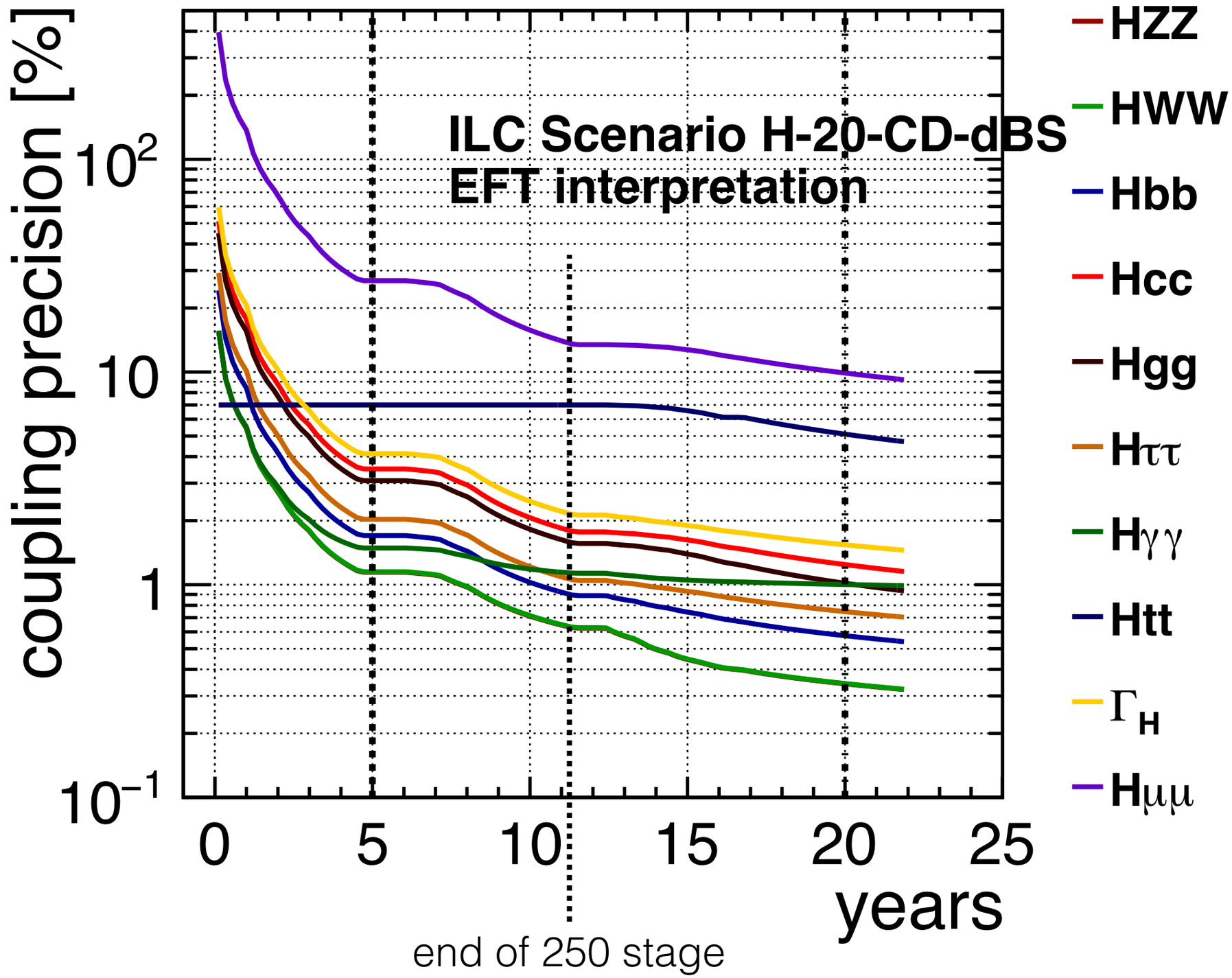
previous scenarios: H-20 ($-\delta_{BS}$)



2y shorter with δ_{BS}

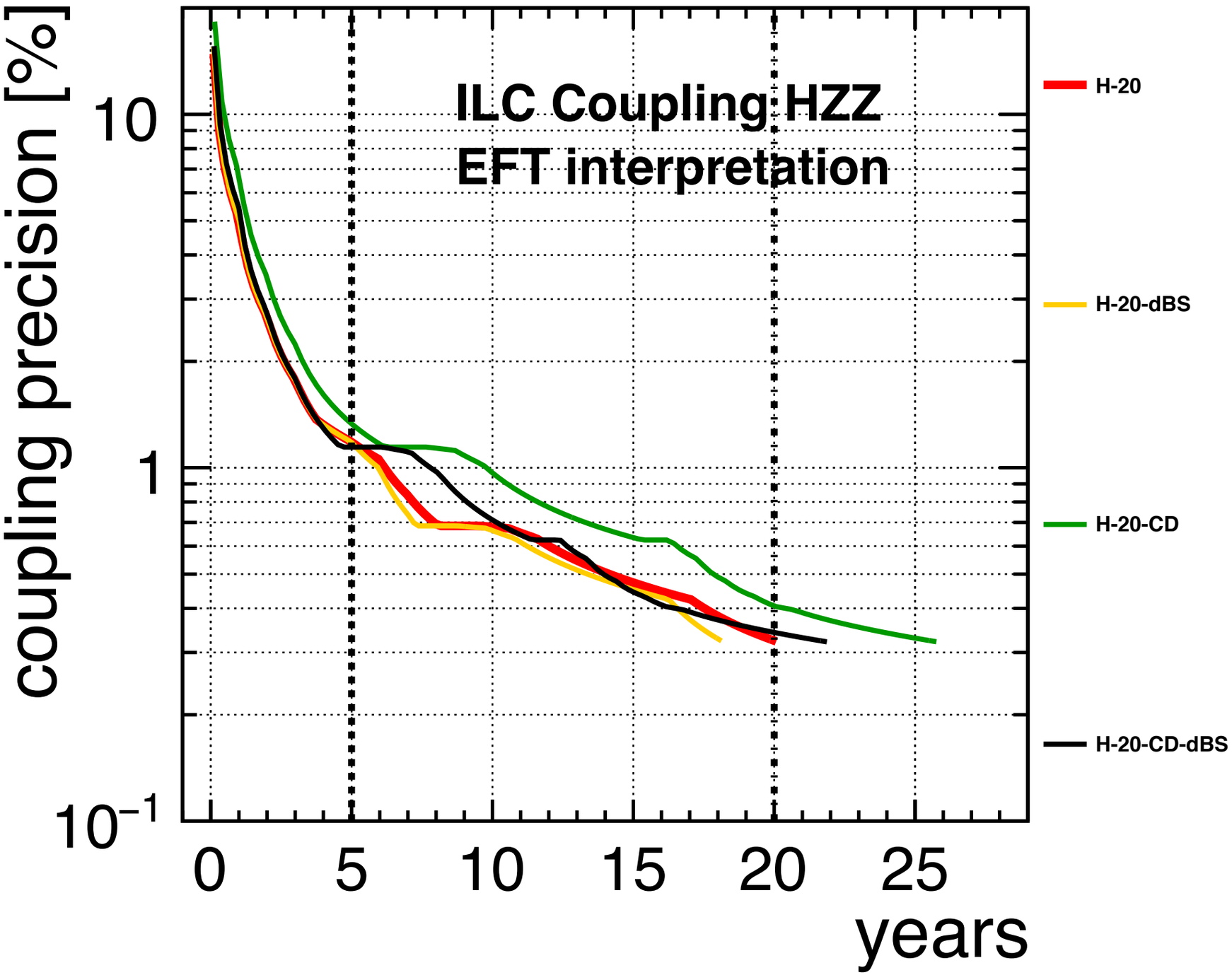
evolution of coupling precisions

(example for option C(D) with δ_{BS}, see backup more for other options)

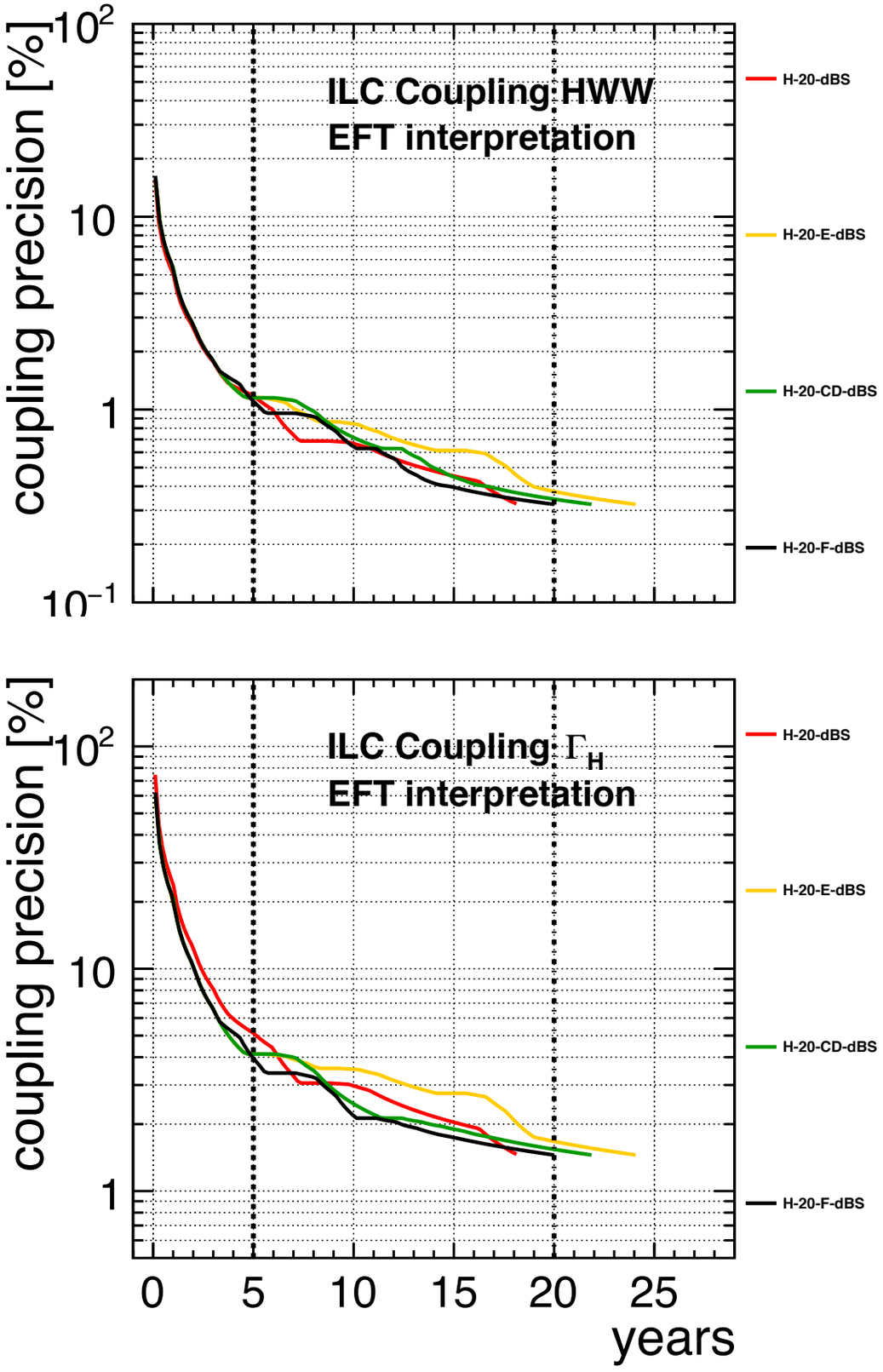


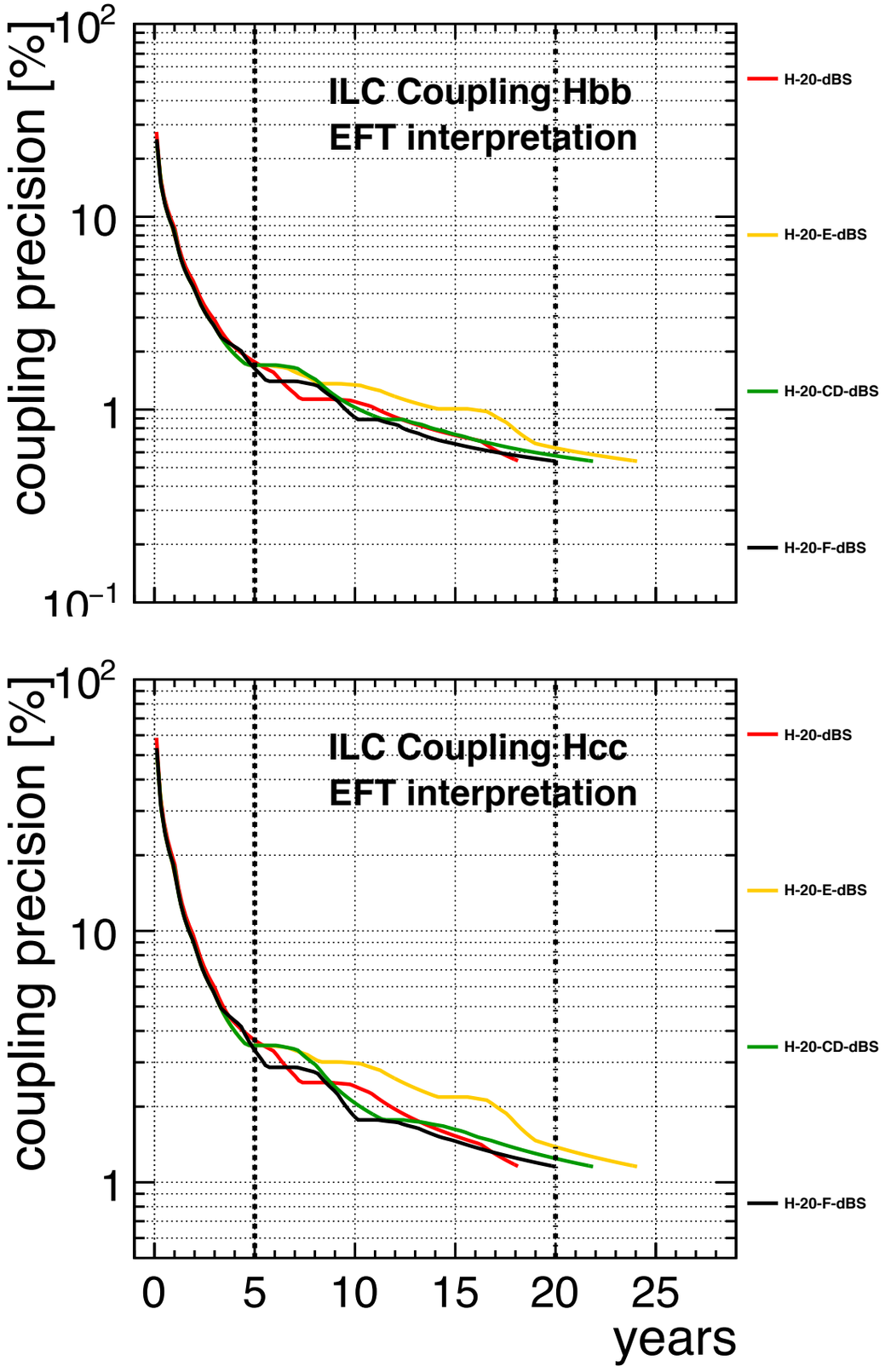
evolution of coupling precisions: hZZ

(difference between with and without δ_{BS})



evolution of couplings (-δ_{BS}): hWW, hbb, hcc, Γ_H



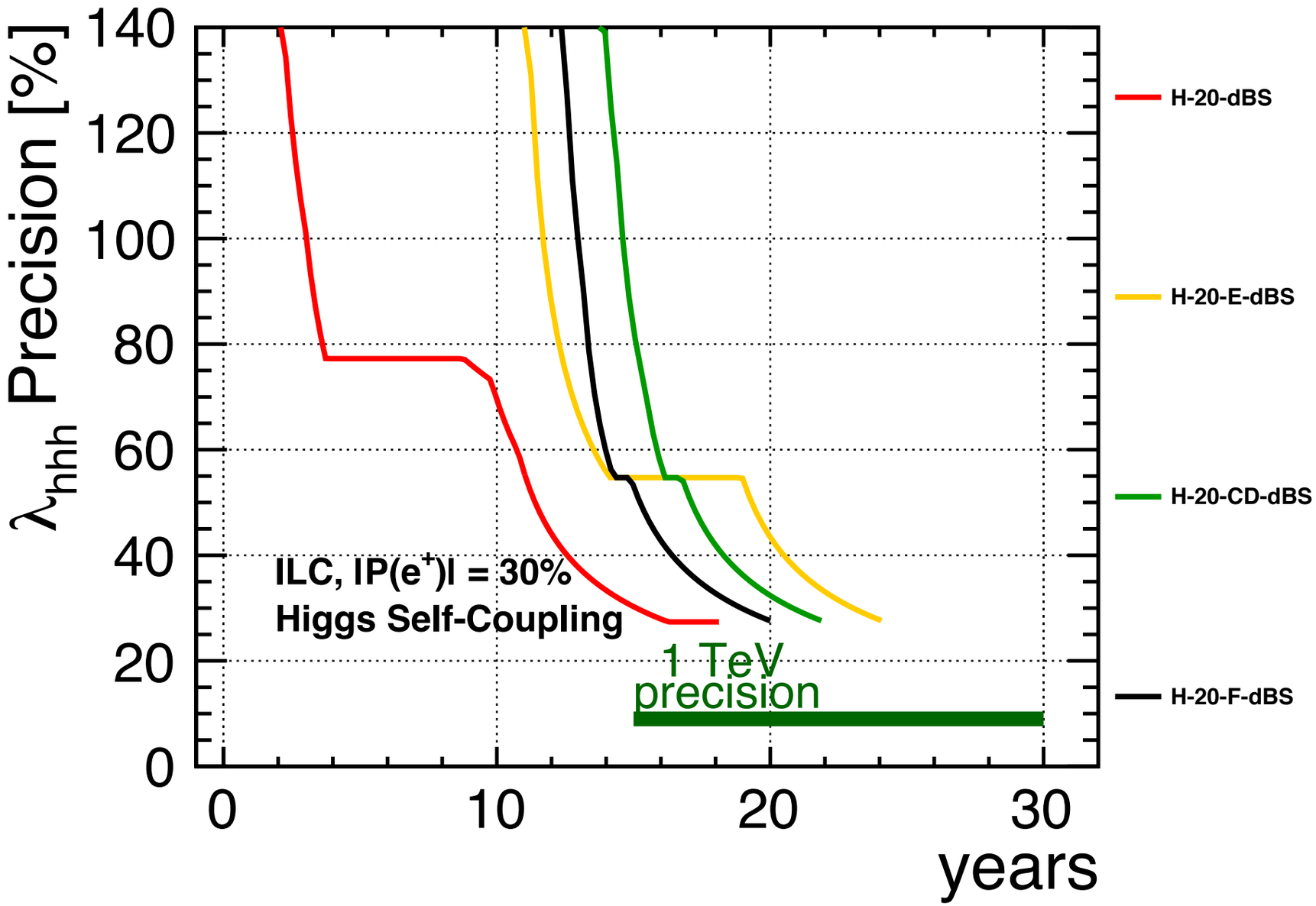


evolution of coupling precisions

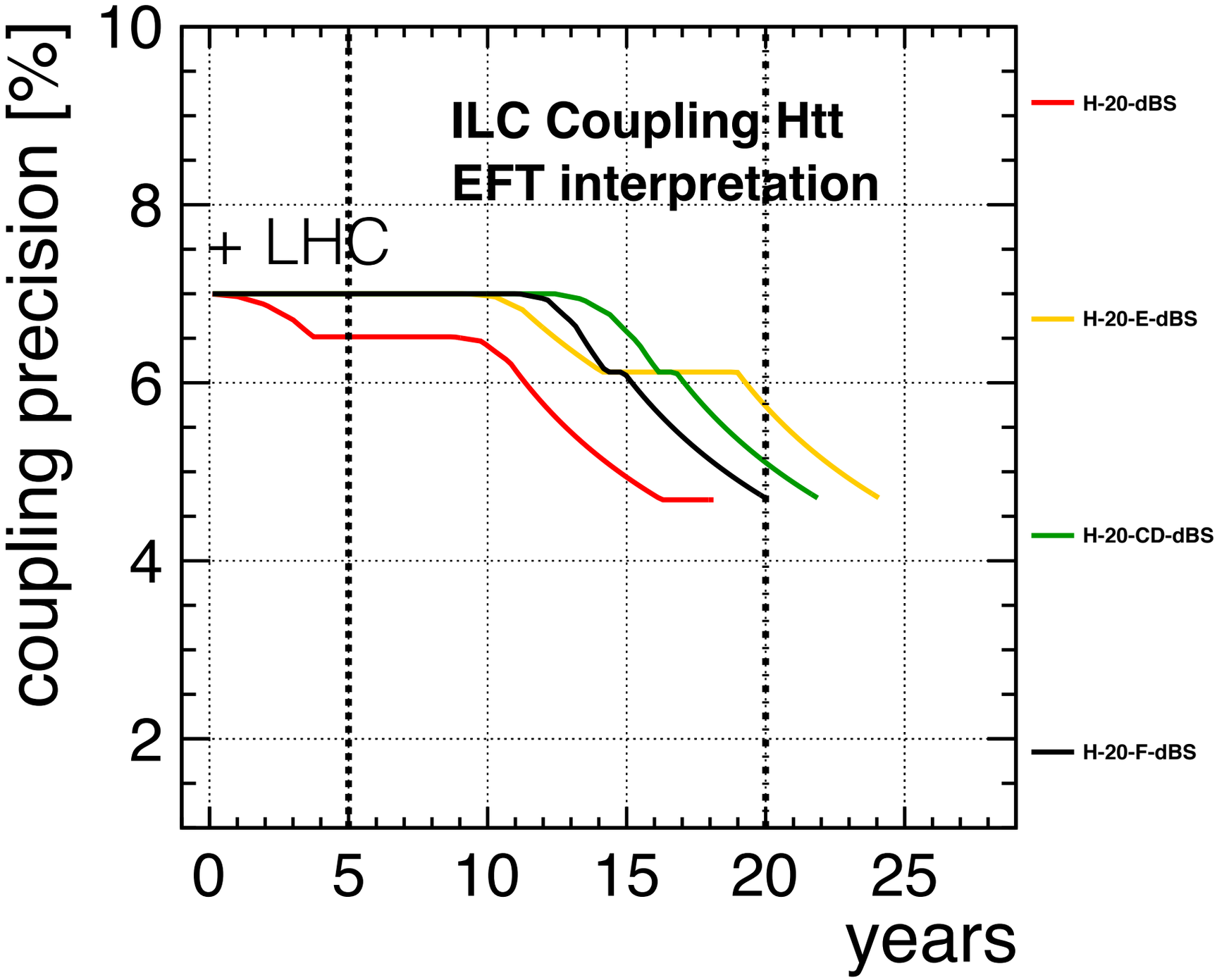
- for couplings which can be accessed by ZH, difference is not large among all scenarios, at least in the first 10 years

- how about other couplings, new particles?

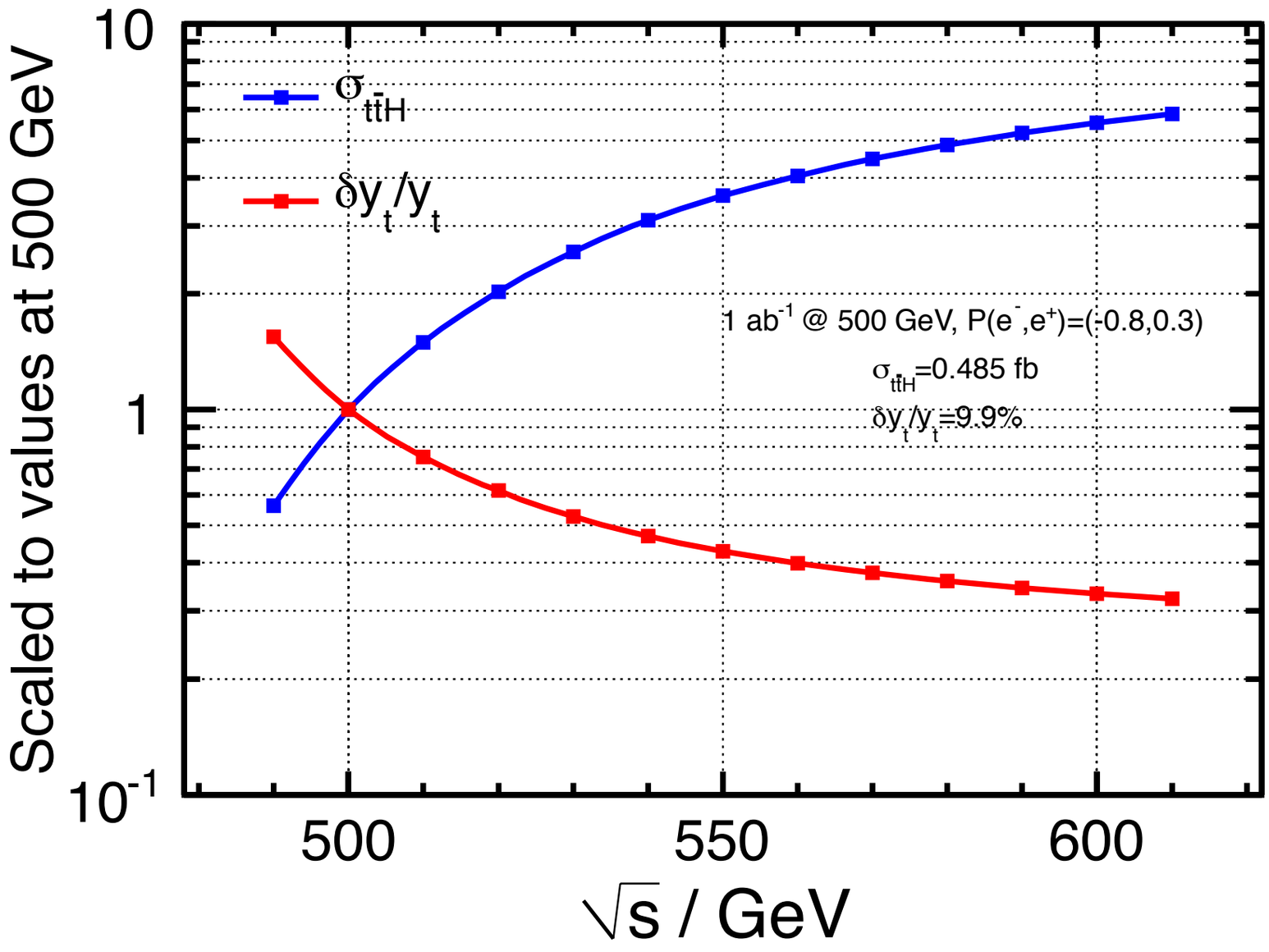
evolution of coupling precisions (-δ_{BS}): λ_{hhh}



evolution of coupling precisions ($-\delta_{BS}$): htt

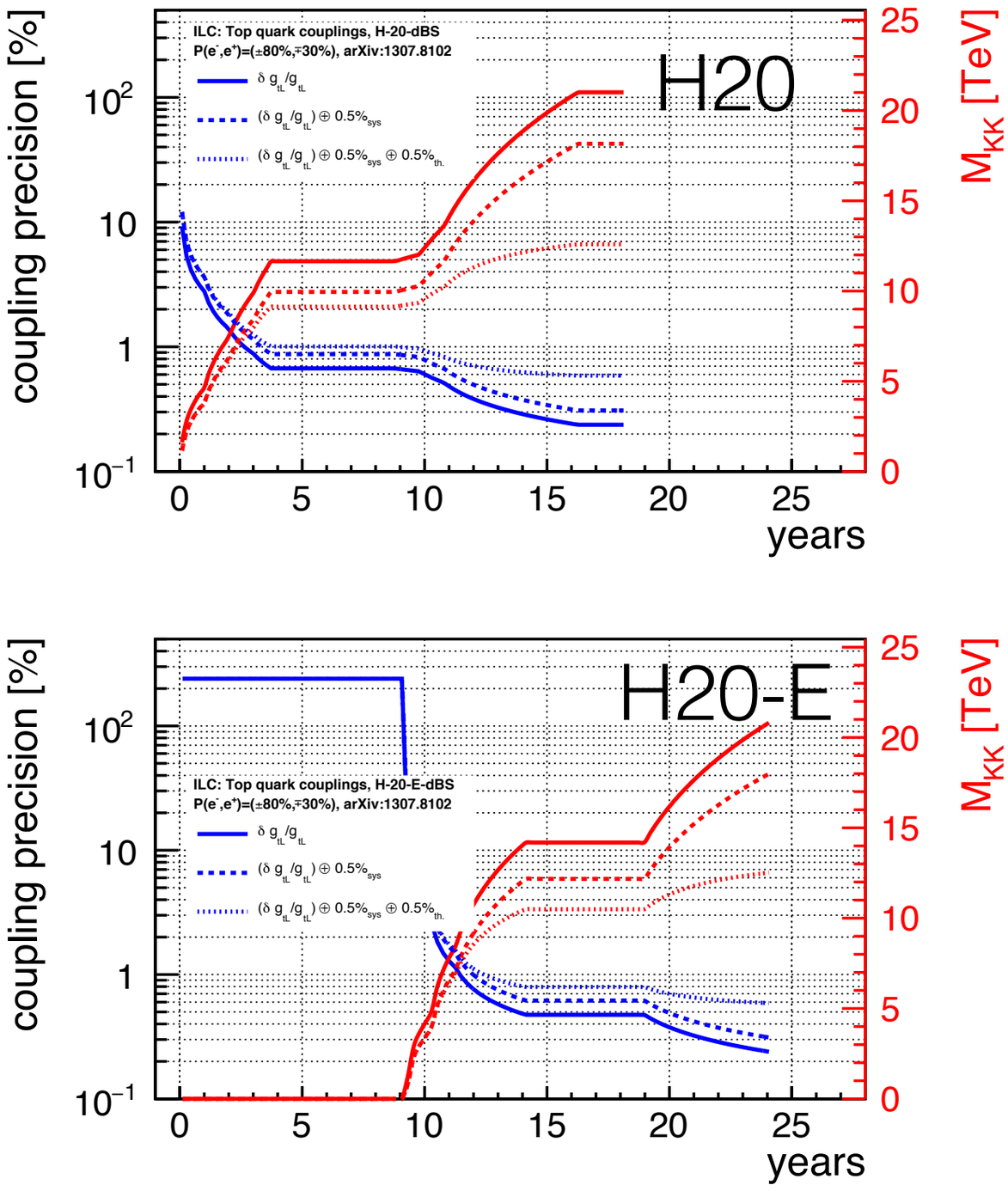


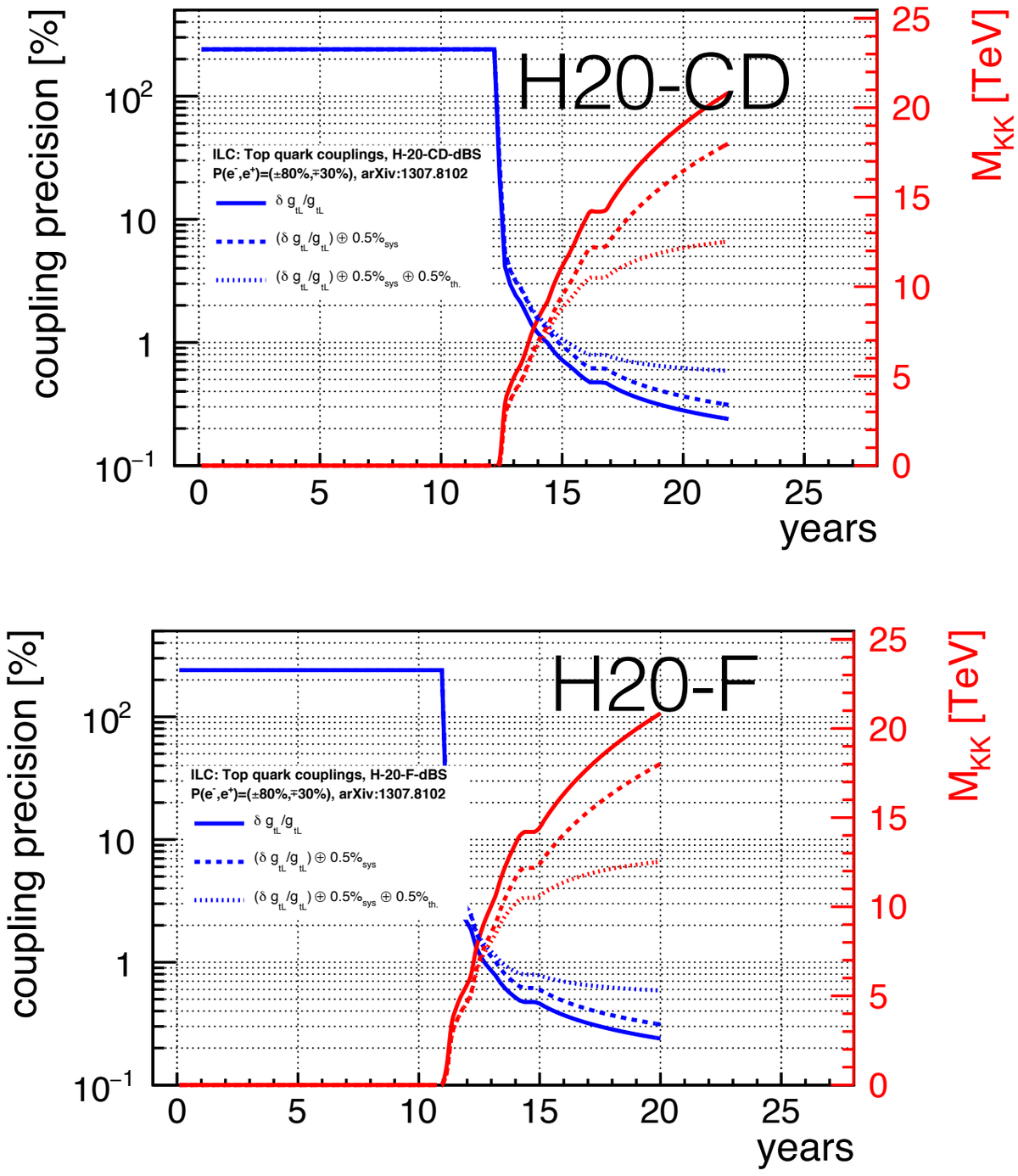
opportunity for top-Yukawa coupling



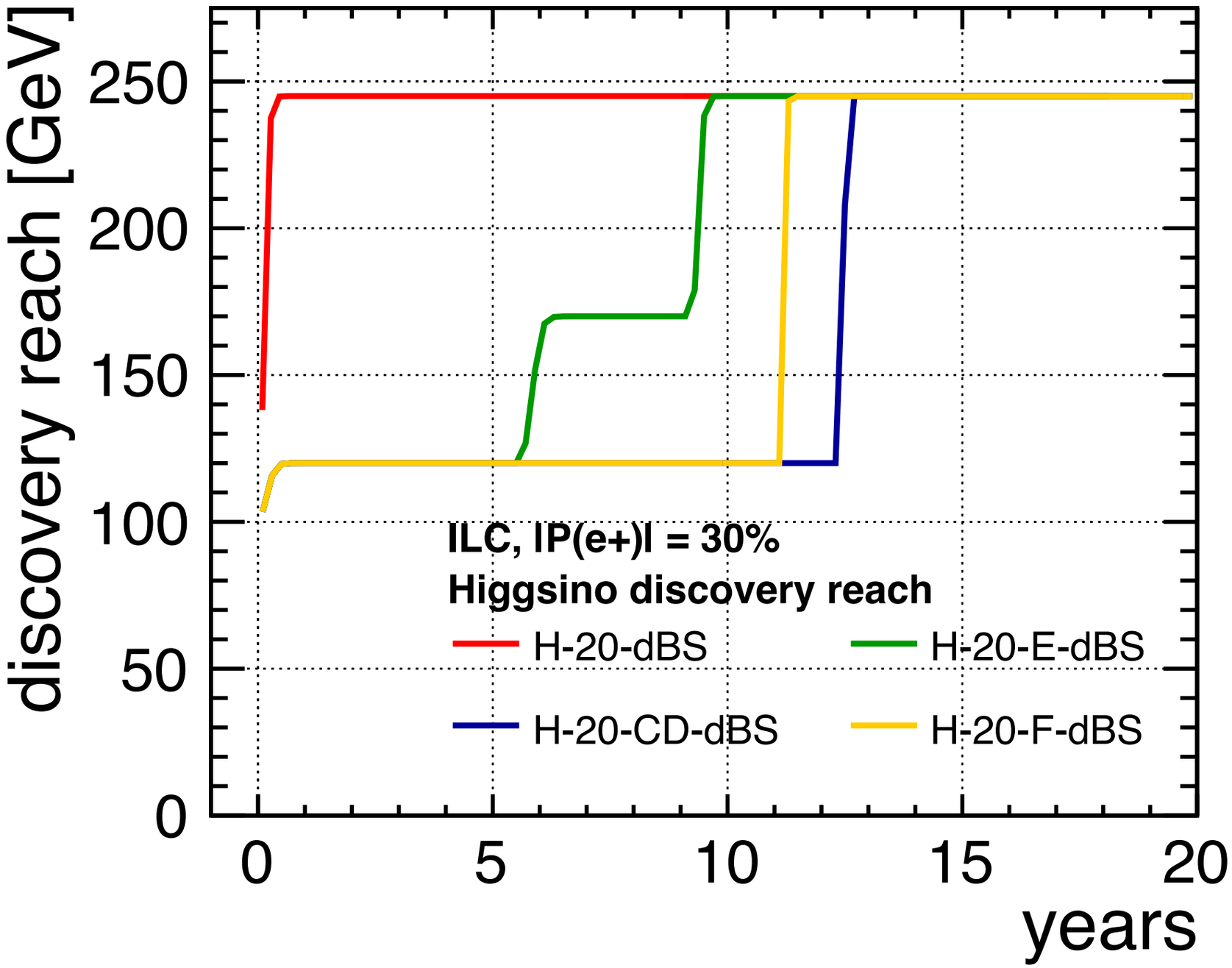
after 250 stage, taking advantage of possible technology improvement, we may afford 550-600 GeV, dreaming for ~2% htt precision

top EW couplings (-δ_{BS})

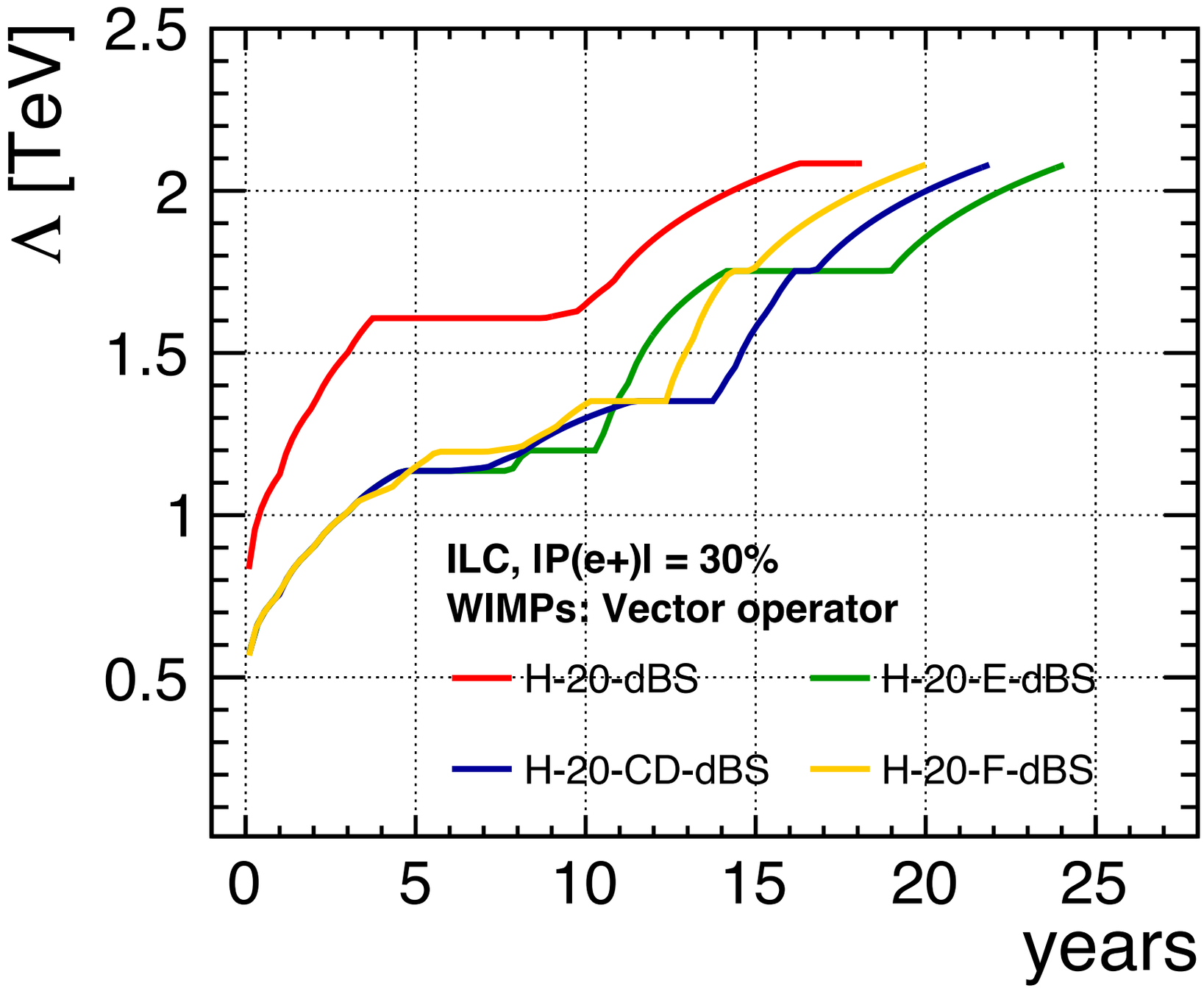




direct search (-δ_{BS}): Higgsino



direct search (-δ_{BS}): WIMPs



evolution of coupling precisions

- for Higgs self-coupling, top coupling, new particle search, clearly new scenarios are worse than H-20
- nevertheless, same precisions will be reached in the end by additional 4, 6, 2 years for option C/D, E, F

- what about the indirect discovery potential by Higgs precision couplings?

new development: model discrimination by EFT

talk by M.Peskin

$$(\chi^2)_{AB} = (g_A^T - g_B^T)\ [VCV^T]^{-1}\ (g_A - g_B)$$

g_A, g_B: vector of couplings in Model A, B

Vij: linear dependence of coupling gi on EFT coefficient cj

C: covariance matrix of EFT coeffs

- given the coupling deviations in two models, this χ2 gives the most appropriate separation power, taking into account all correlations

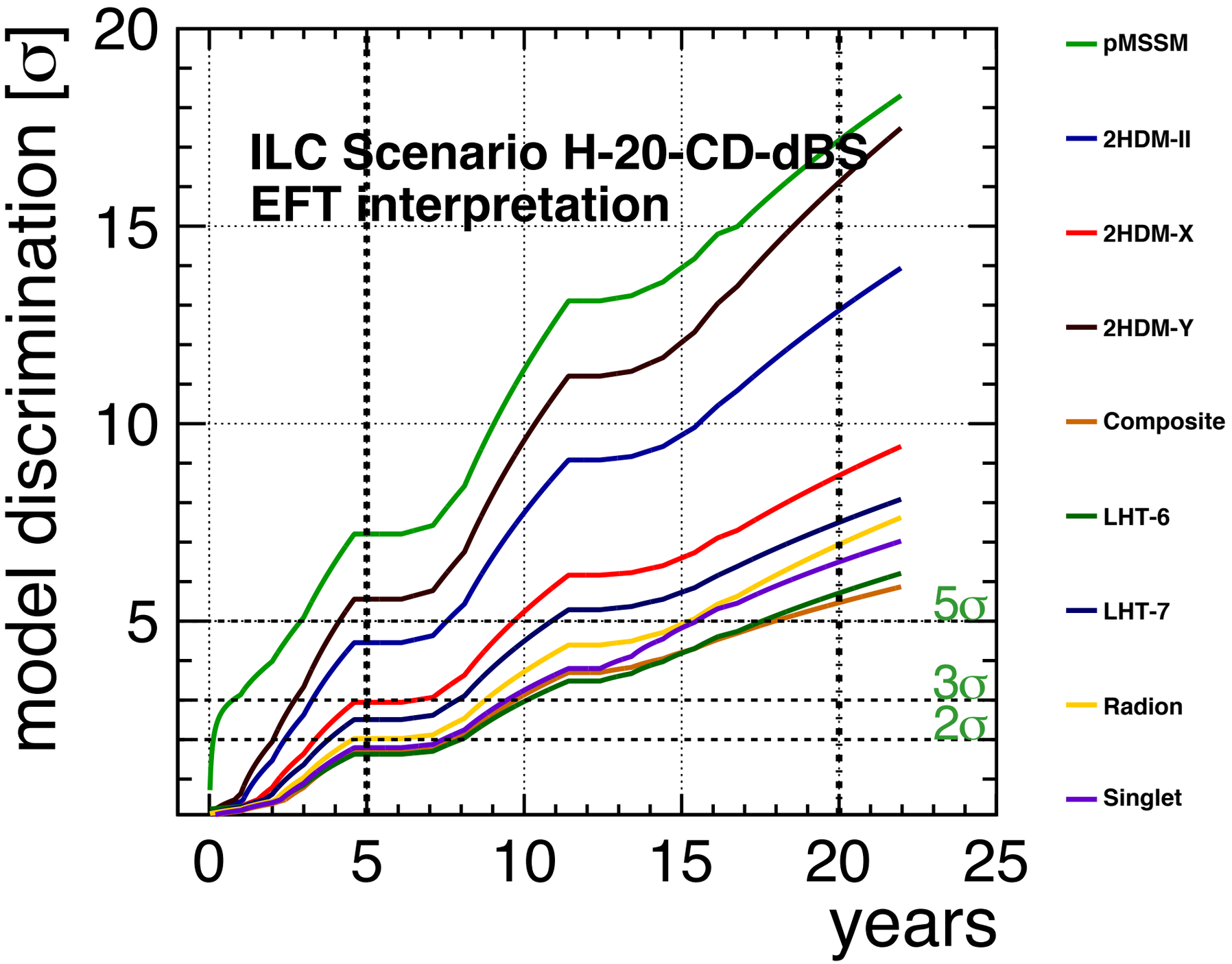
new development: model discrimination by EFT

talk by M.Peskin

	Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$\mu\mu$
1	MSSM [34]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.5	+0.1	+0.3
2	Type II 2HD [36]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1	+9.8
3	Type X 2HD [36]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0	+7.8
4	Type Y 2HD [36]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1	-0.2
5	Composite Higgs [38]	-6.4	-6.4	-6.4	-2.1	-6.4	-2.1	-2.1	-6.4
6	Little Higgs w. T-parity [39]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5	0.0
7	Little Higgs w. T-parity [40]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0	-7.8
8	Higgs-Radion [41]	-1.5	- 1.5	10.	-1.5	-1.5	-1.5	-1.0	-1.5
9	Higgs Singlet [42]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

Table 4: Deviations from the Standard Model predictions for the Higgs boson couplings, in %, for the set of new physics models described in the text. As in Table 1, the effective couplings $g(hWW)$ and $g(hZZ)$ are defined as proportional to the square roots of the corresponding partial widths.

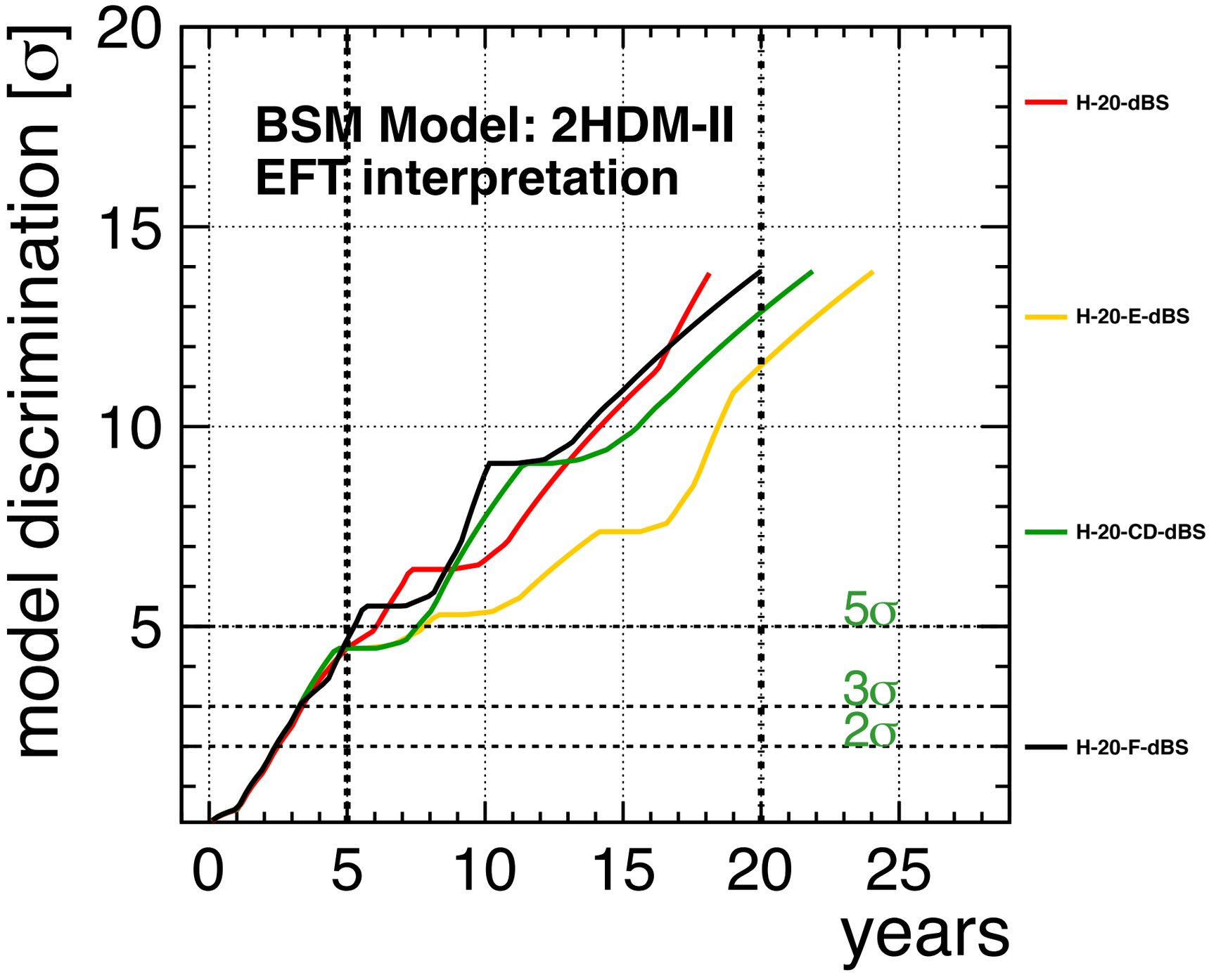
evolution of discovery potential (against SM)



after the 250 GeV stage (~11y): >3σ for all models
after ~18y): >5σ for all models

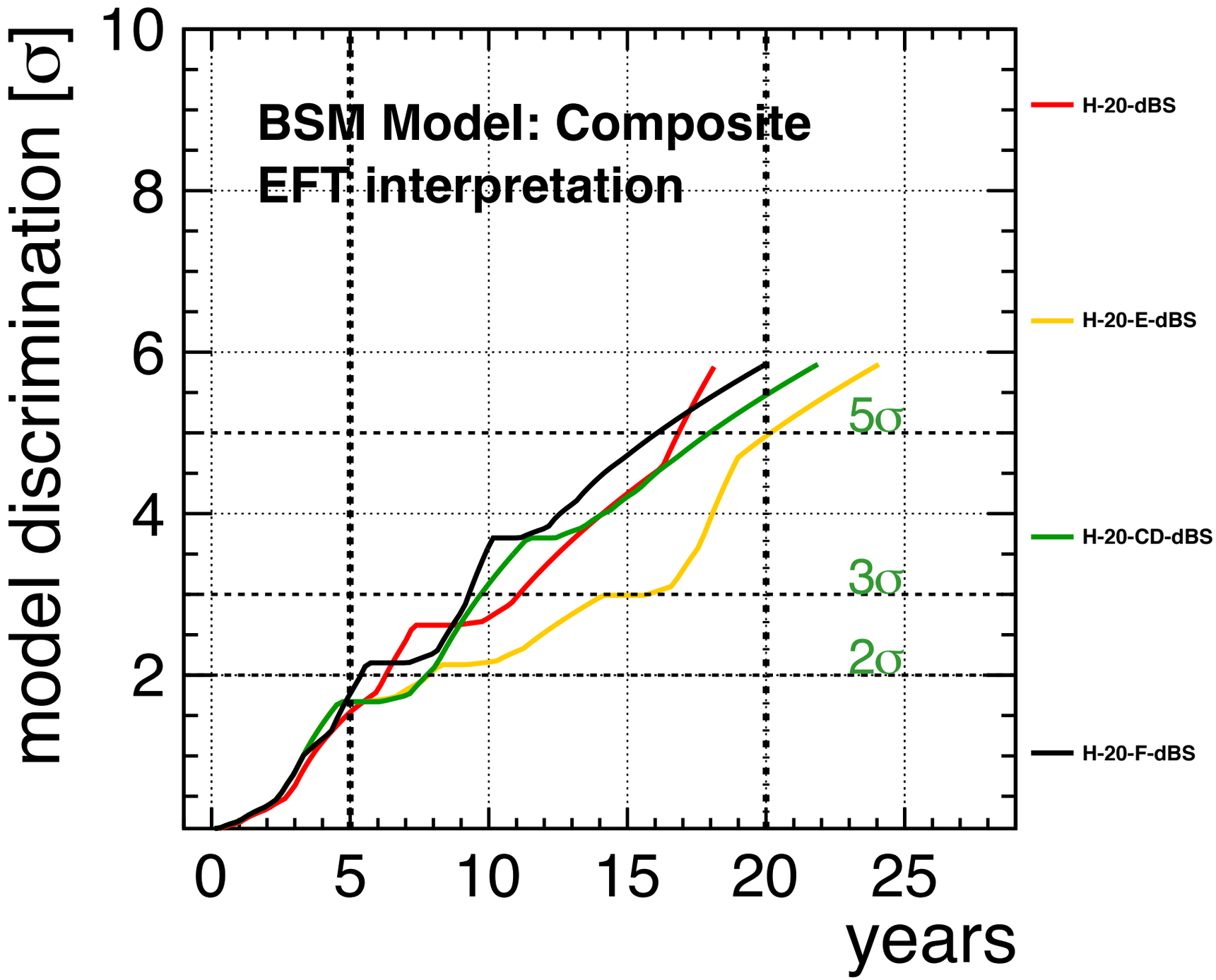
evolution of discovery potential ($-\delta_{BS}$): 2HDM-II

(m_A=600GeV; tanβ=7)

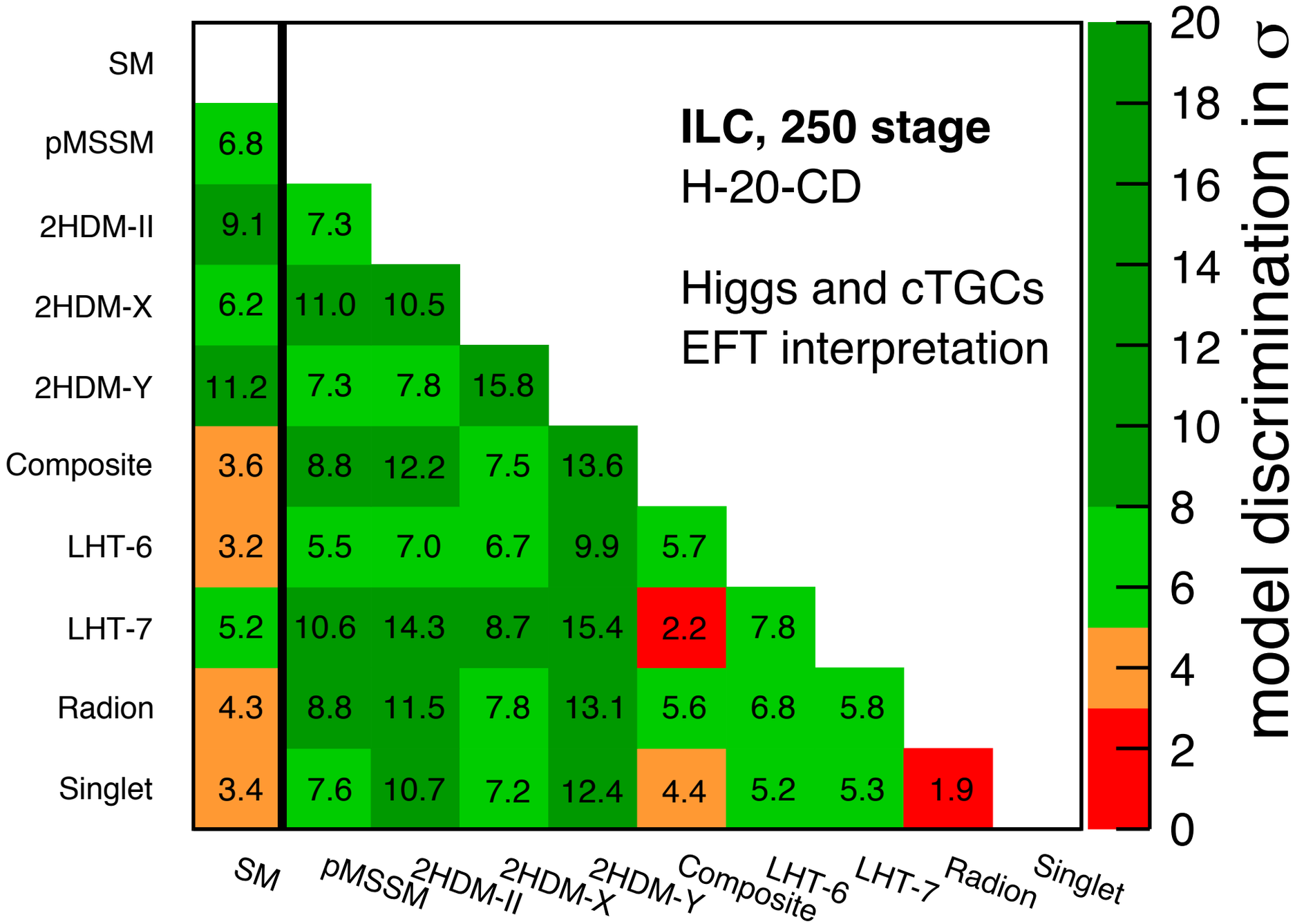


evolution of discovery potential (-δ_{BS}): Composite

(f=1.2TeV; T=1.7TeV)

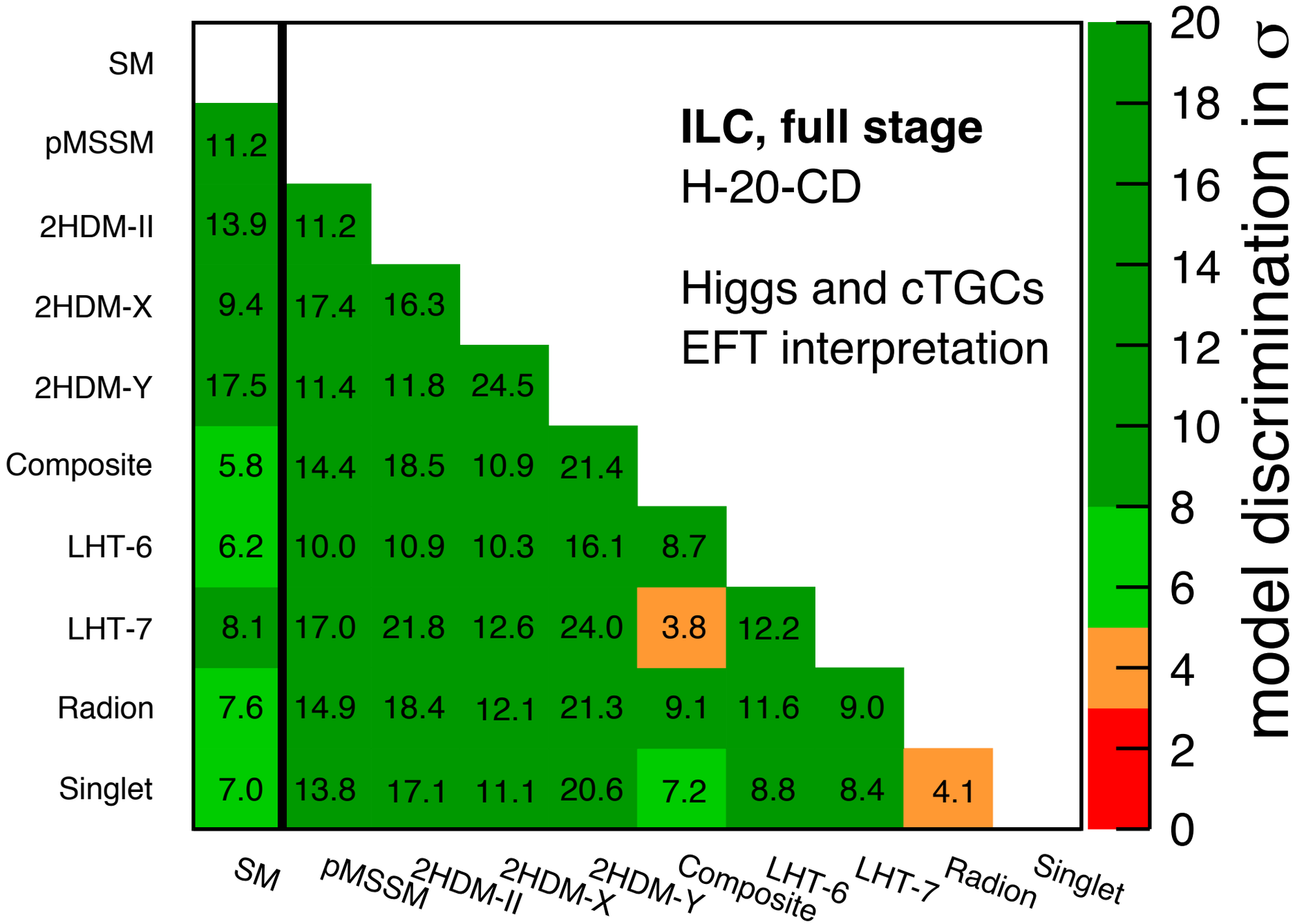


discrimination between BSM models (ILC250 stage)



once find deviation against SM —> can tell which BSM

discrimination between BSM models

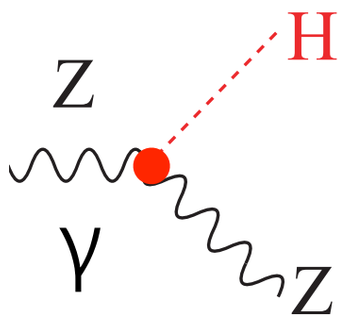


pin down the story after 250 + 500 full ILC

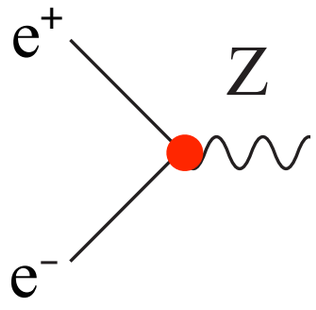
comments on beam polarizations

- not changed: important for systematics control, nature of new particle (once found), e.g. Higgsino, WIMPs
- new roles in EFT

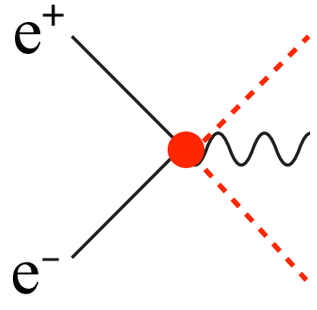
-> separate hZZ and hγZ couplings



-> improve A_{LR} in Z-e-e coupling



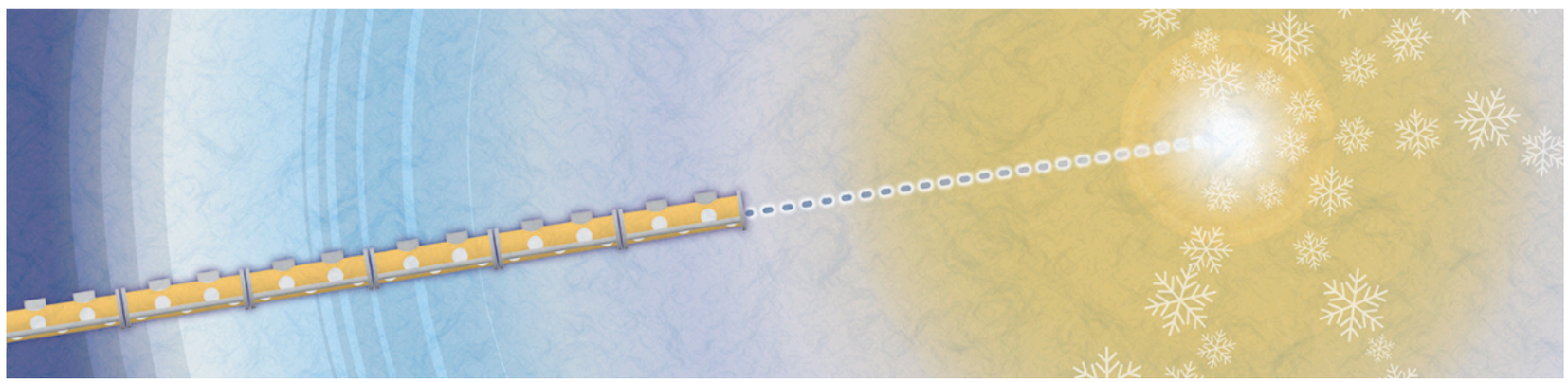
important to constrain contact interaction



summary

- a few new staging scenarios are investigated, differences are manifest in the promise of energy upgrade
- new developments on both luminosity and physics study get the physics case at 250 GeV stronger
- initial 250 GeV stage can deliver great physics in terms of Higgs coupling precisions and BSM discovery potential (see more in Maxim's talk)
- there is clear physics case beyond 250 GeV, and the greatest advantage of linear colliders is energy extendibility
- so if budget is allowed, it is highly preferable to integrate the upgrade path in the design of the initial stage

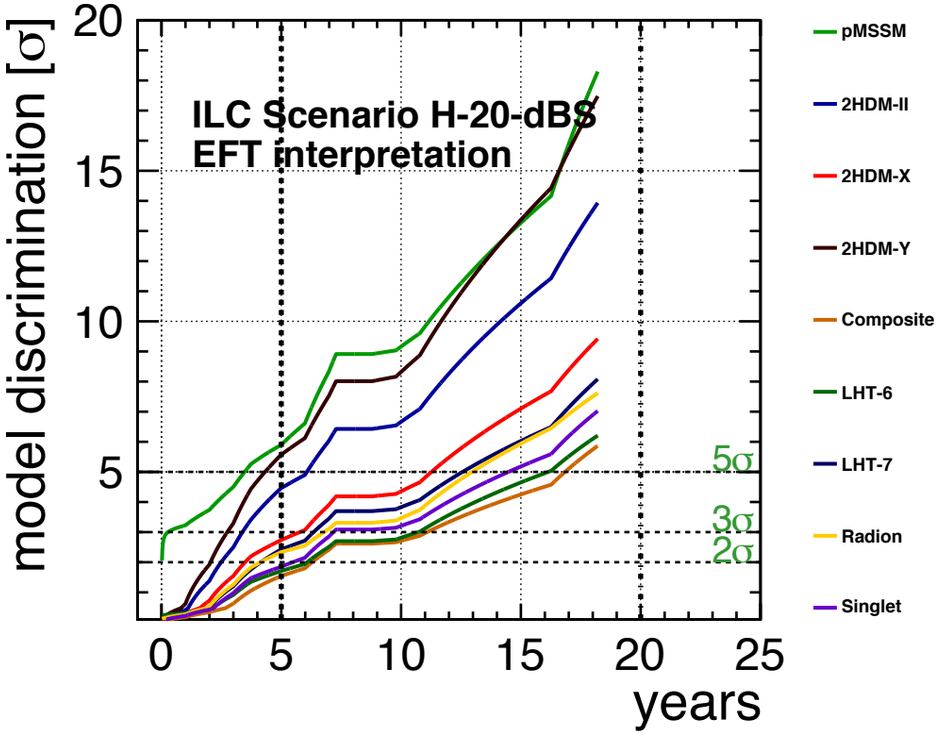
summary (personal)

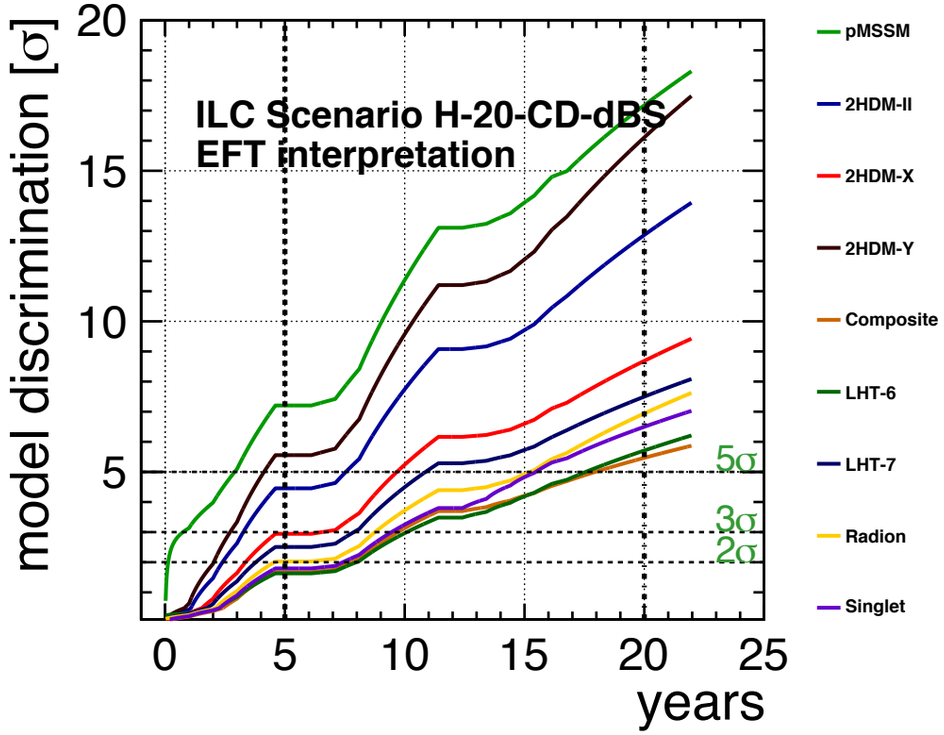


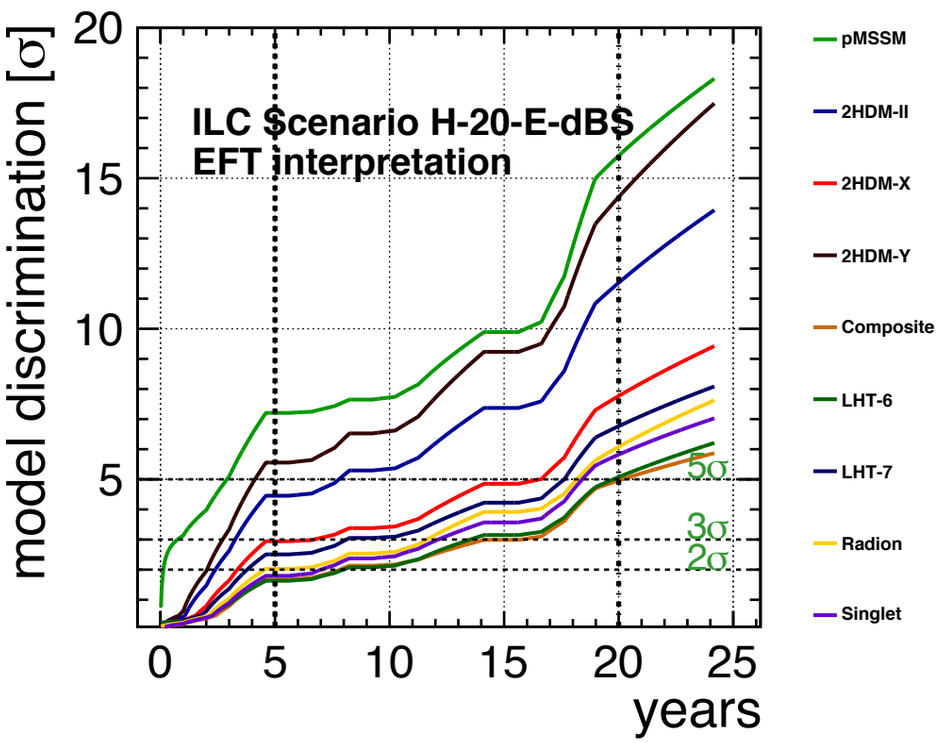
- learned from LCWS17 (by above time machine):
  - ★ “science first” with ILC250
  - ★ cost reduction is just more than enough
  - ★ physics at ILC250 is great
  - ★ go ahead, ILC250 (from LCWS18)

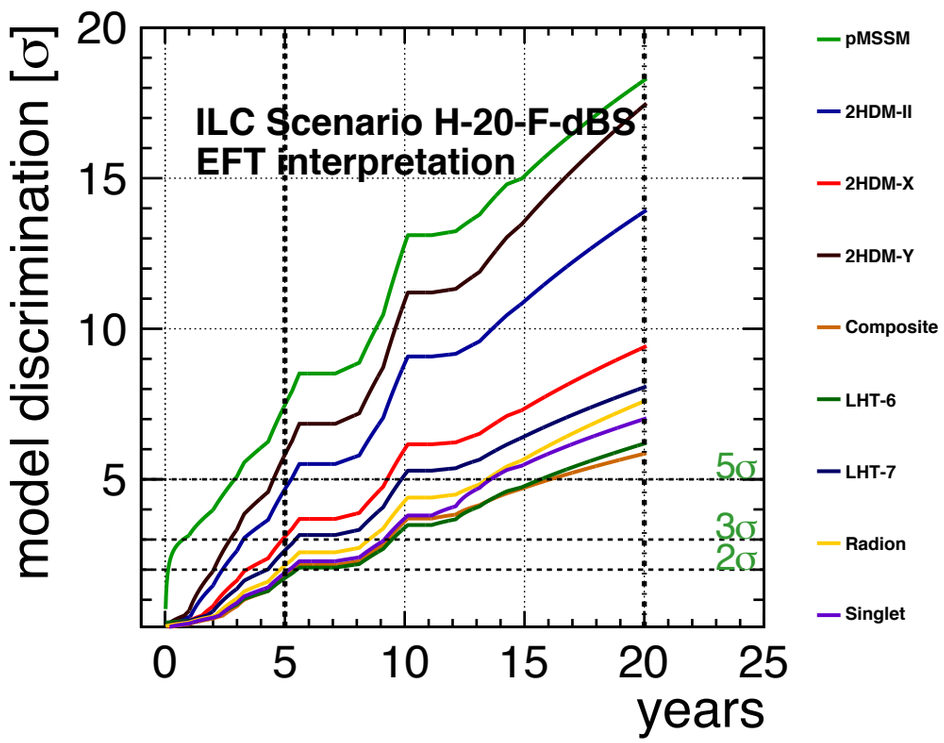
backup

evolution of discovery potential (against SM)

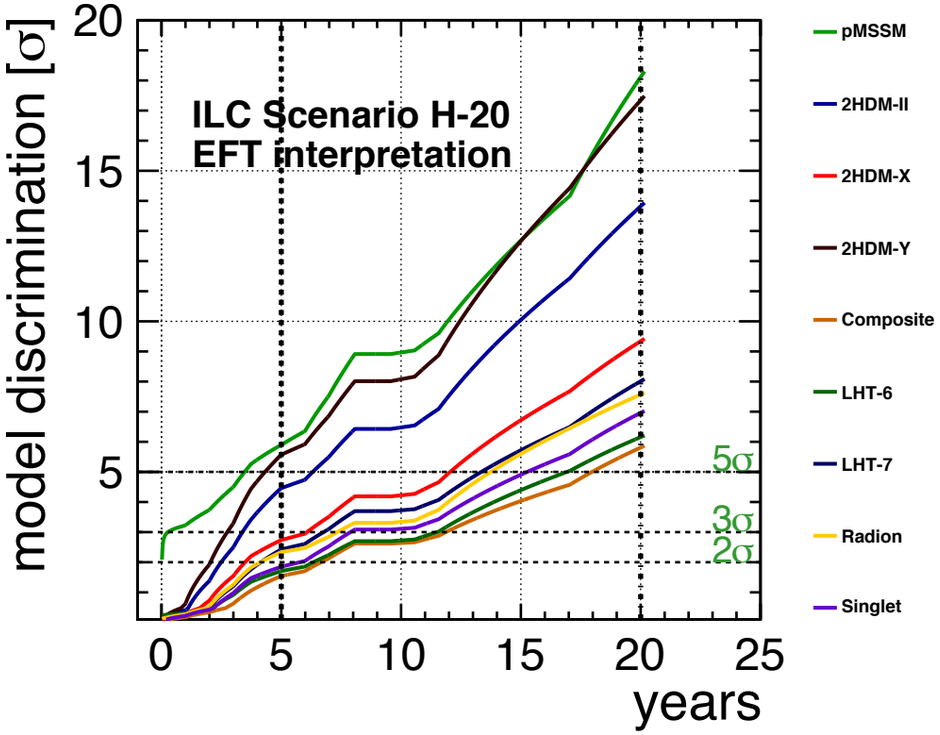


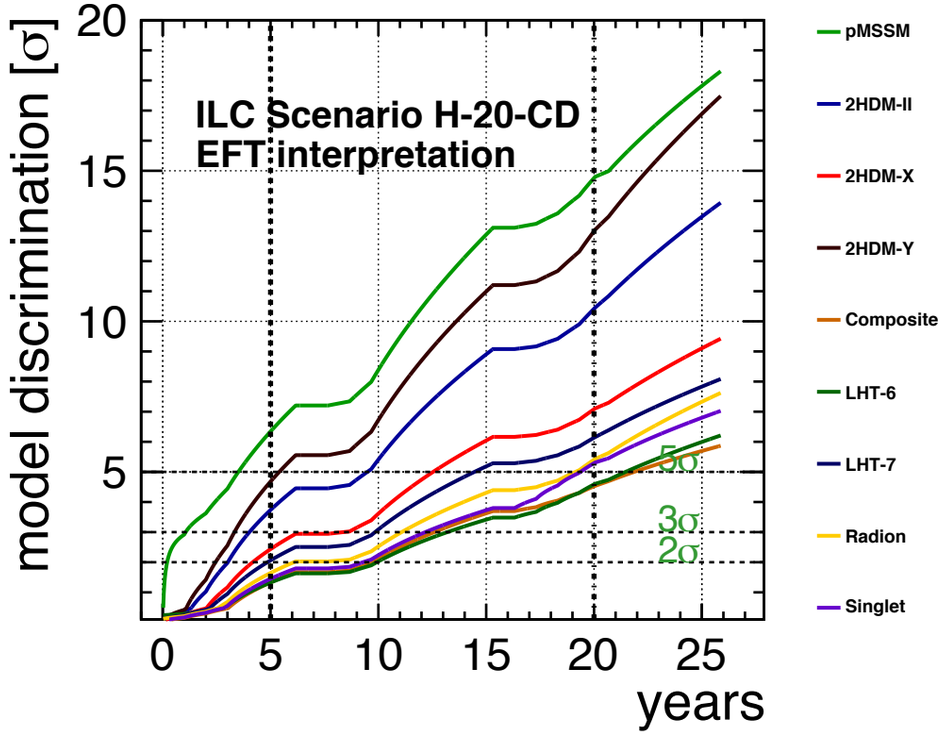


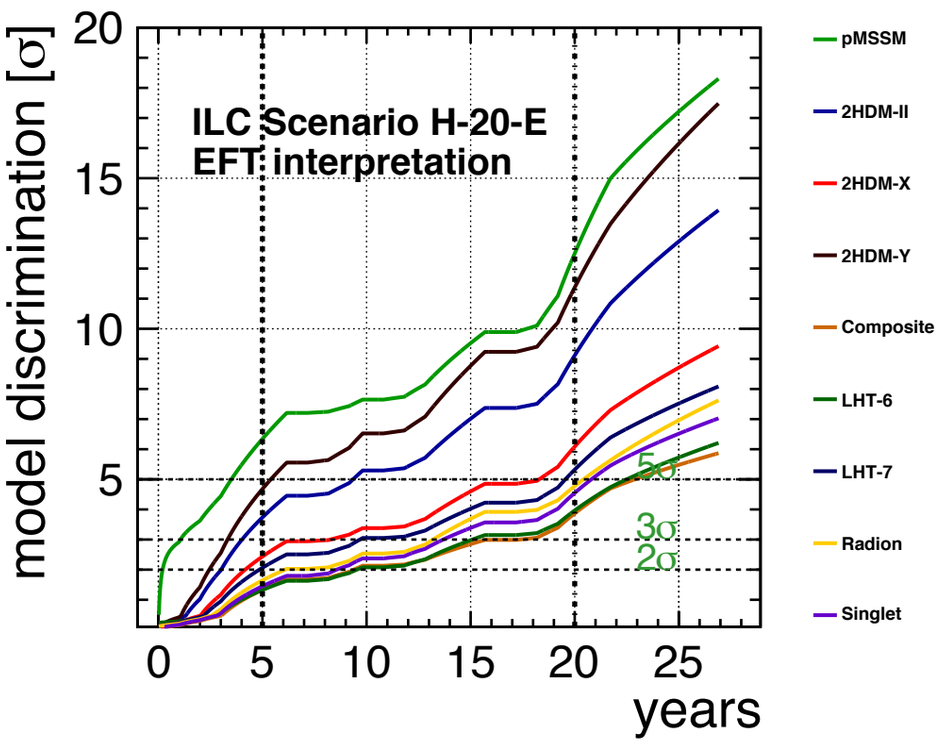


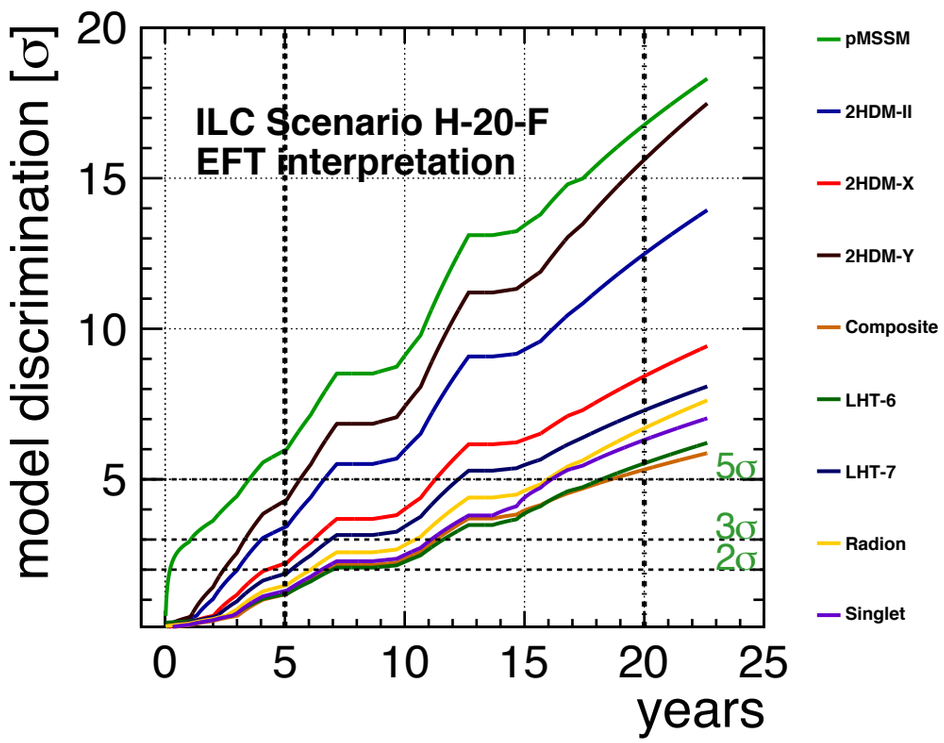


evolution of discovery potential (against SM)

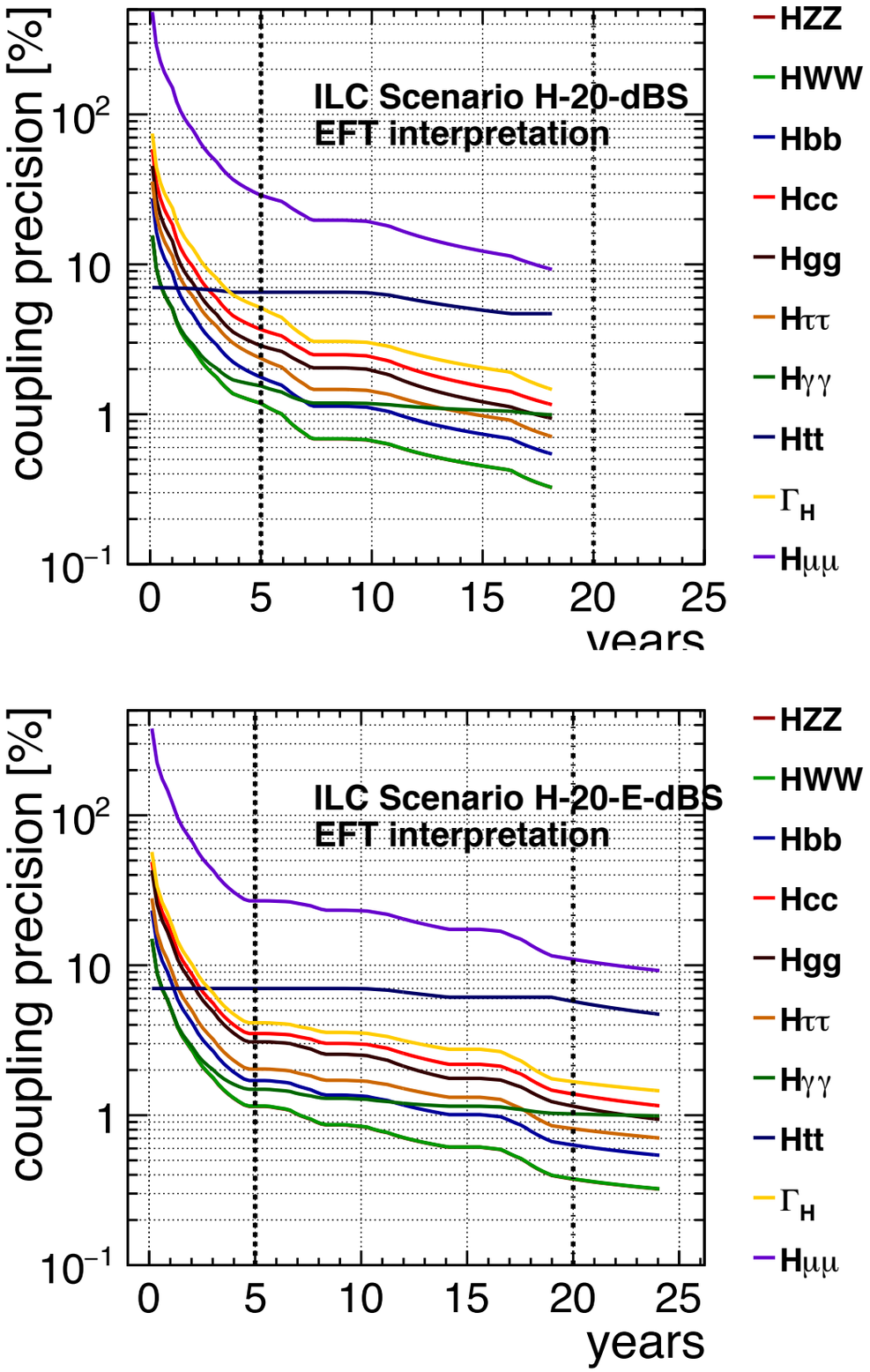


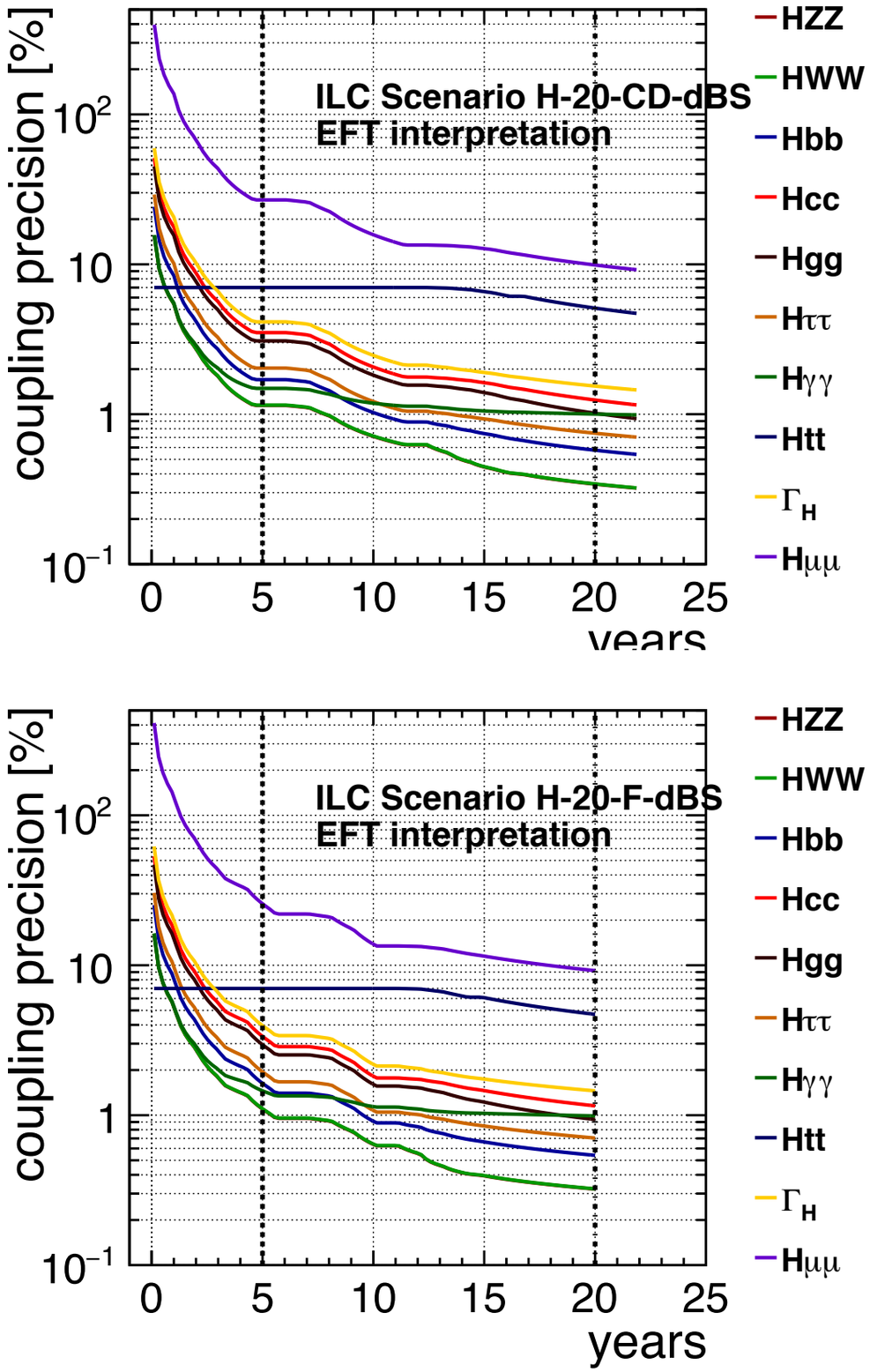
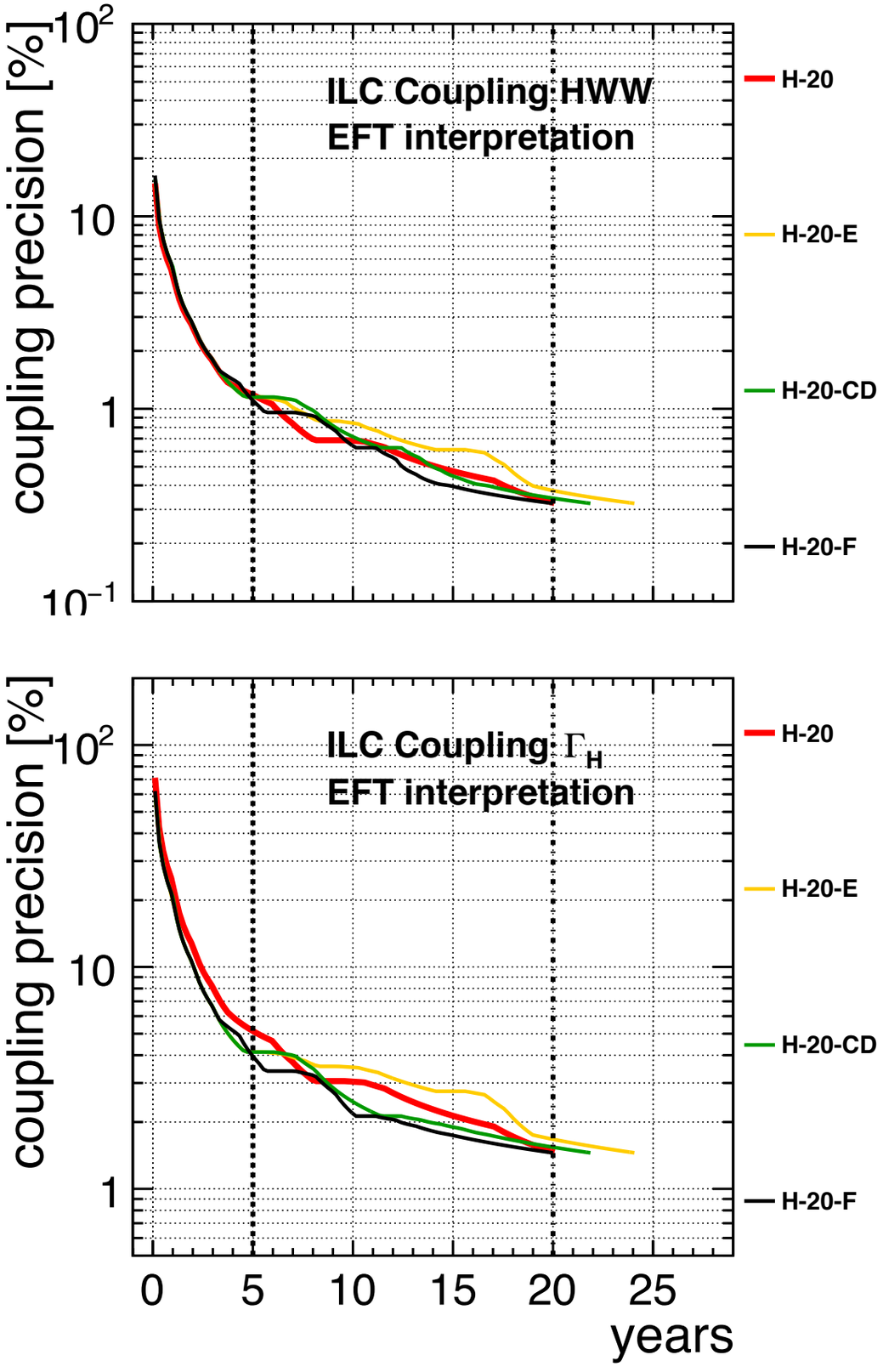
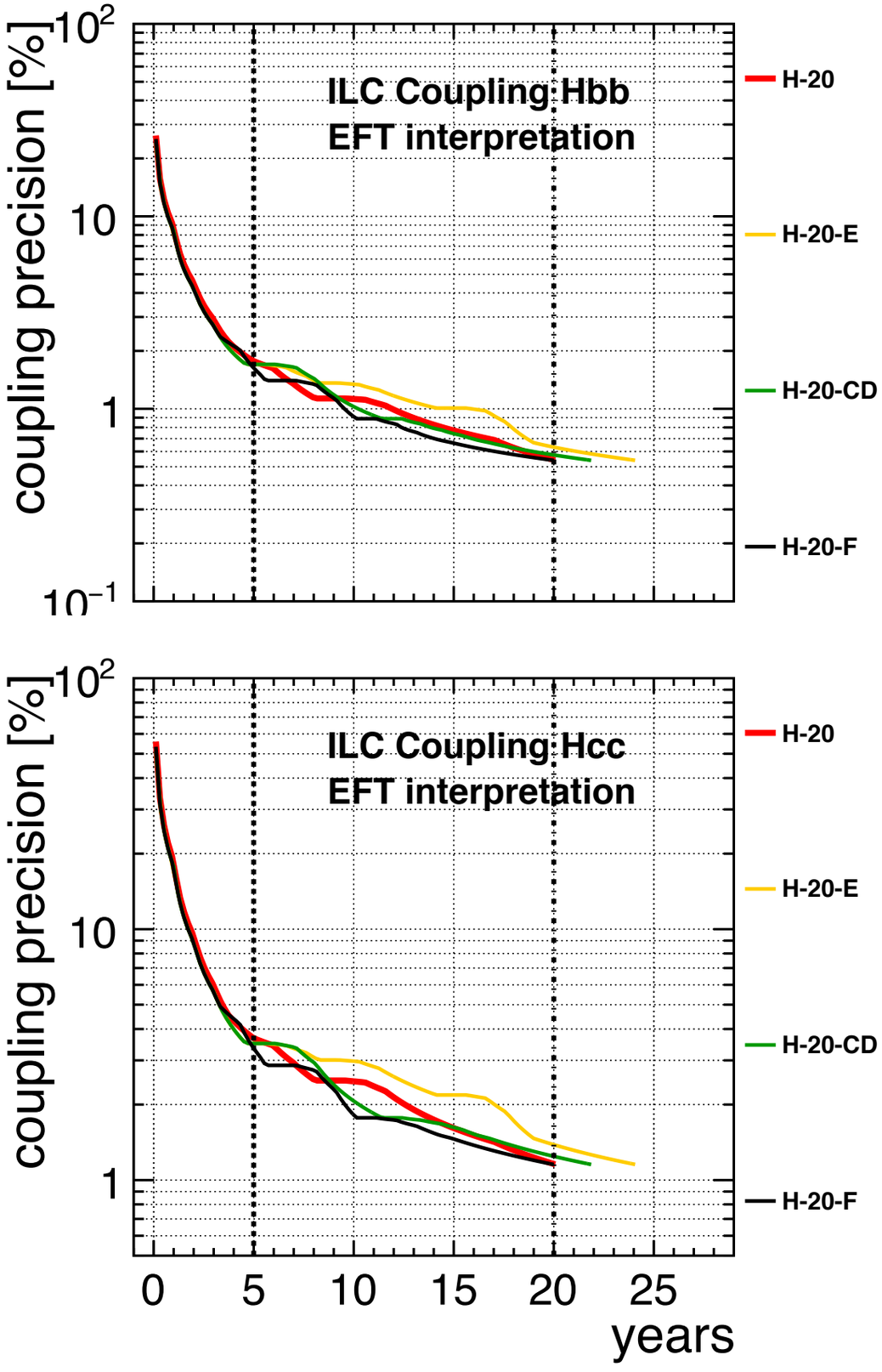






evolution of coupling precisions: H-20 (-CD/E/F)





evolution of couplings: hWW, hbb, hcc, Γ_H