Running Scenarios for a Linear Collider Facility at CERN

J.List

FutureColliders@DESY Meeting

Dec 13, 2024

A bit of History

ILC Parameters Joint Working Group

- group of accelerator and particle physics experts
- charged to develop running scenarios for the ILC
- integrated luminosities kept fixed ever since!

	integrated luminosity with $\mathrm{sgn}(P(e^-),P(e^+)) =$			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]
250 GeV	1350	450	100	100
350 GeV	135	45	10	10
500 GeV	1600	1600	400	400

	integrated luminosity with $\mathrm{sgn}(P(e^-),P(e^+)) =$			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]
1 TeV	3200	3200	800	800
90 GeV	40	40	10	10
160 GeV	340	110	25	25

ILC-NOTE-2015-068
DESY 15-102
IHEP-AC-2015-002
KEK Preprint 2015-17
SLAC-PUB-16309
June 25, 2015

ILC Operating Scenarios

ILC Parameters Joint Working Group

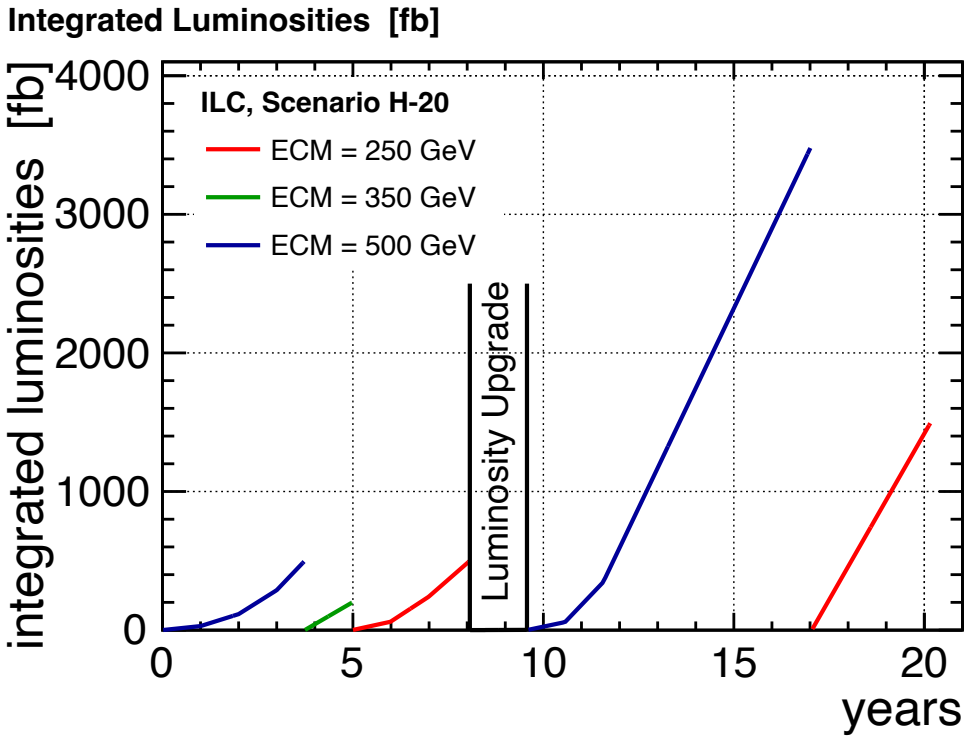
T. Barklow, J. Brau, K. Fujii, J. Gao, J. List, N. Walker, K. Yokoya

Abstract

The ILC Technical Design Report documents the design for the construction of a linear collider which can be operated at energies up to 500 GeV. This report summarizes the outcome of a study of possible running scenarios, including a realistic estimate of the real time accumulation of integrated luminosity based on ramp-up and upgrade processes. The evolution of the physics outcomes is emphasized, including running initially at 500 GeV, then at 350 GeV and 250 GeV. The running scenarios have been chosen to optimize the Higgs precision measurements and top physics while searching for evidence for signals beyond the standard model, including dark matter. In addition to the certain precision physics on the Higgs and top that is the main focus of this study, there are scientific motivations that indicate the possibility for discoveries of new particles in the upcoming operations of the LHC or the early operation of the ILC. Follow-up studies of such discoveries could alter the plan for the centre-of-mass collision energy of the ILC and expand the scientific impact of the ILC physics program. It is envisioned that a decision on a possible energy upgrade would be taken near the end of the twenty year period considered in this report.

Time-development in 2015

ILC started still at 500 GeV, but initial luminosity had already been halved ("low power" option)

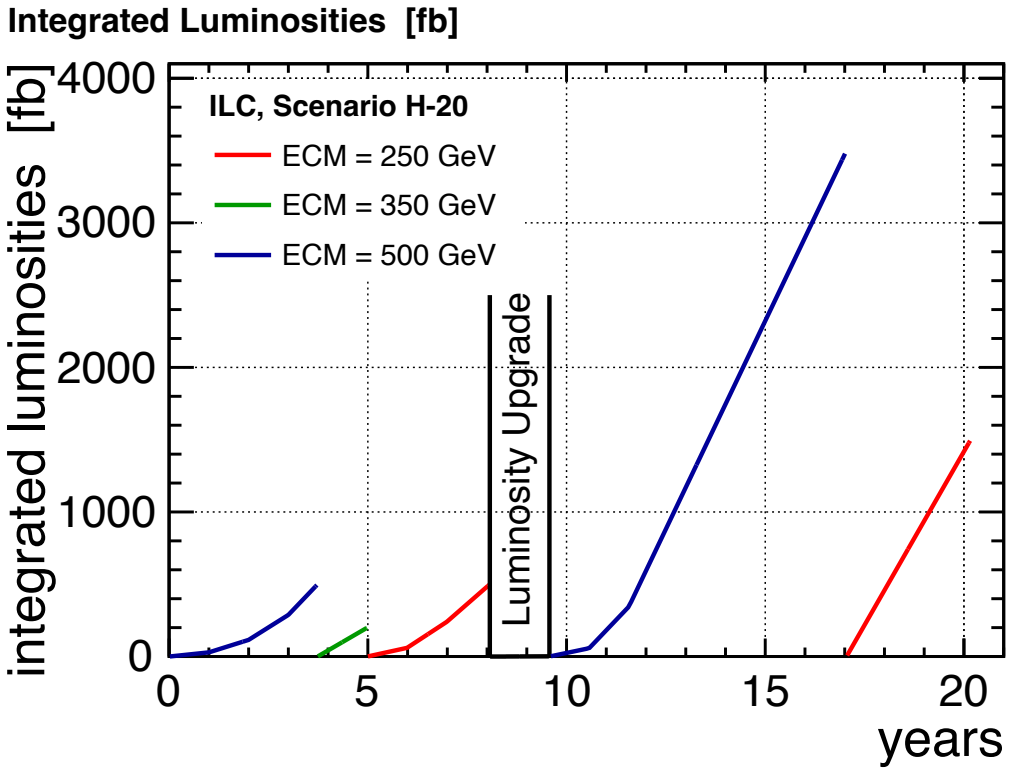


- **operation 1.6E7 s / year** (more than std CERN assumption)
- **start at 500 GeV**
  - initial peak lumi = 1.8E34 / s / cm2 (= 1315 bunches / train)
  - luminosity upgrade 3.6E34 / s / cm2 (= 2625 bunches / train)
- at lower energies
  - linac is operated at lower gradient
  - **use spare RF & cryogenic power to increase train repetition rate to 10 (7) Hz at 250 (350) GeV**
- **assume slow ramp-up to peak luminosity**
  - 0.1, 0.3, 0.6, 1.0 in years 1-4
  - 0.25, 0.75, 1.0 after first change to 10 Hz
  - 0.1, 0.5, 1.0 after lumi upgrade

Staged machine 2017

Start at 250 GeV: half the linac length, and also reduced RF & Cryo power

- **no 10 Hz operation possible in initial configuration**
- initial peak lumi 1.35E34 /s /cm2



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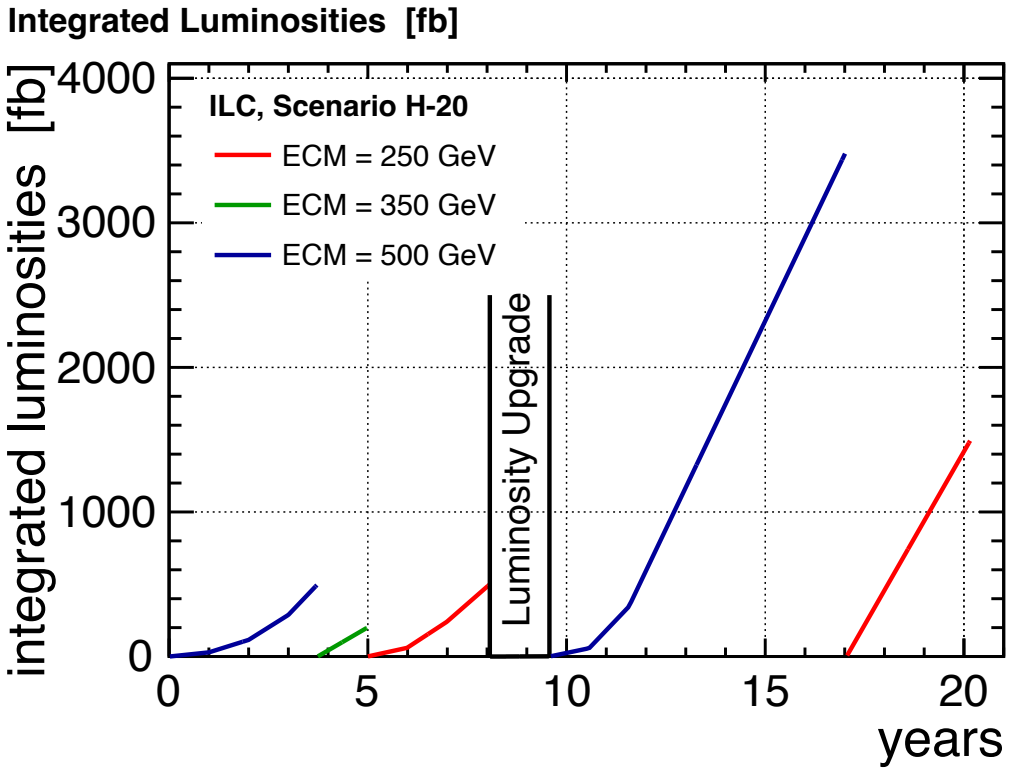
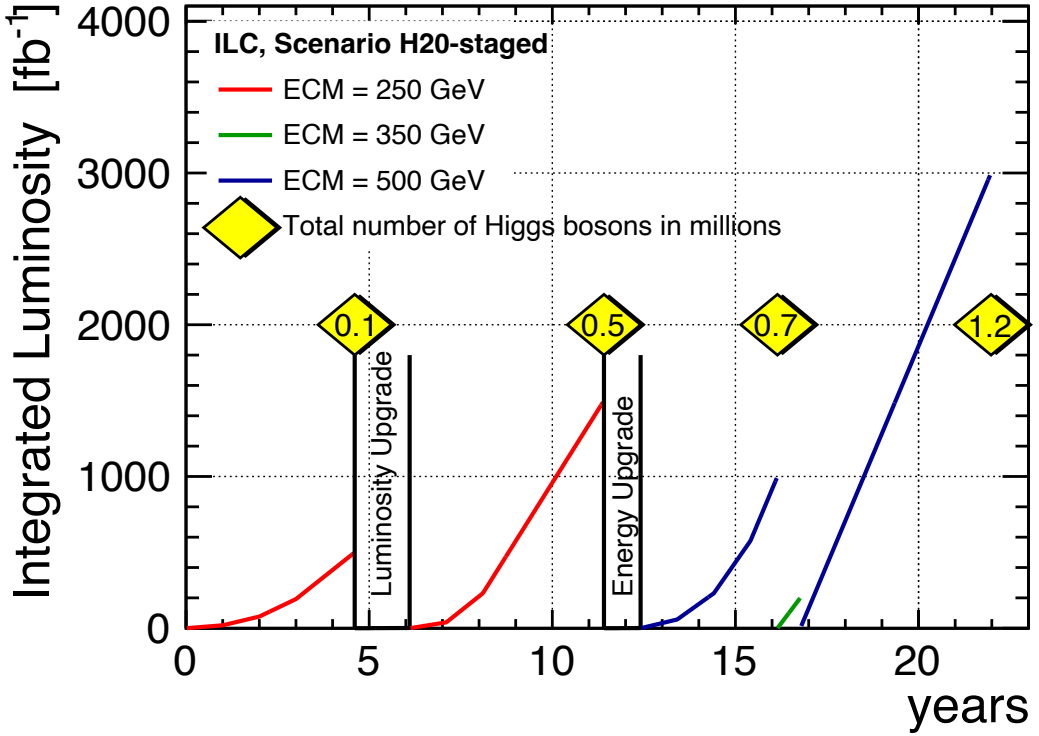
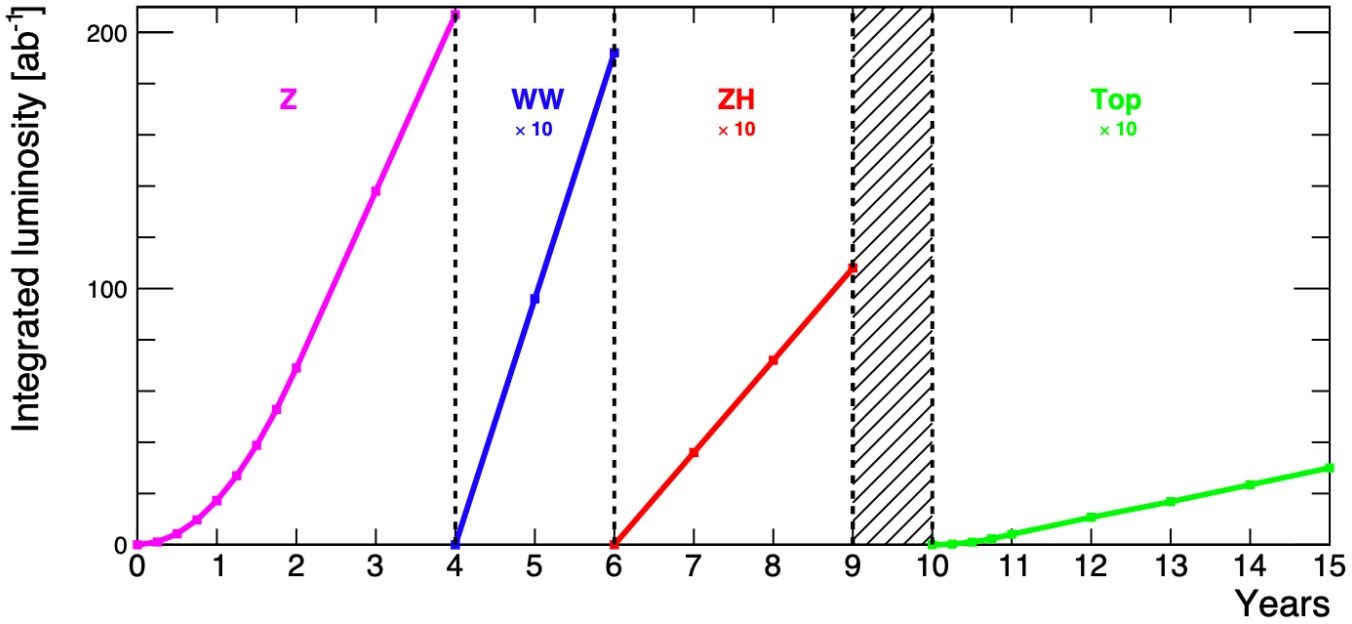




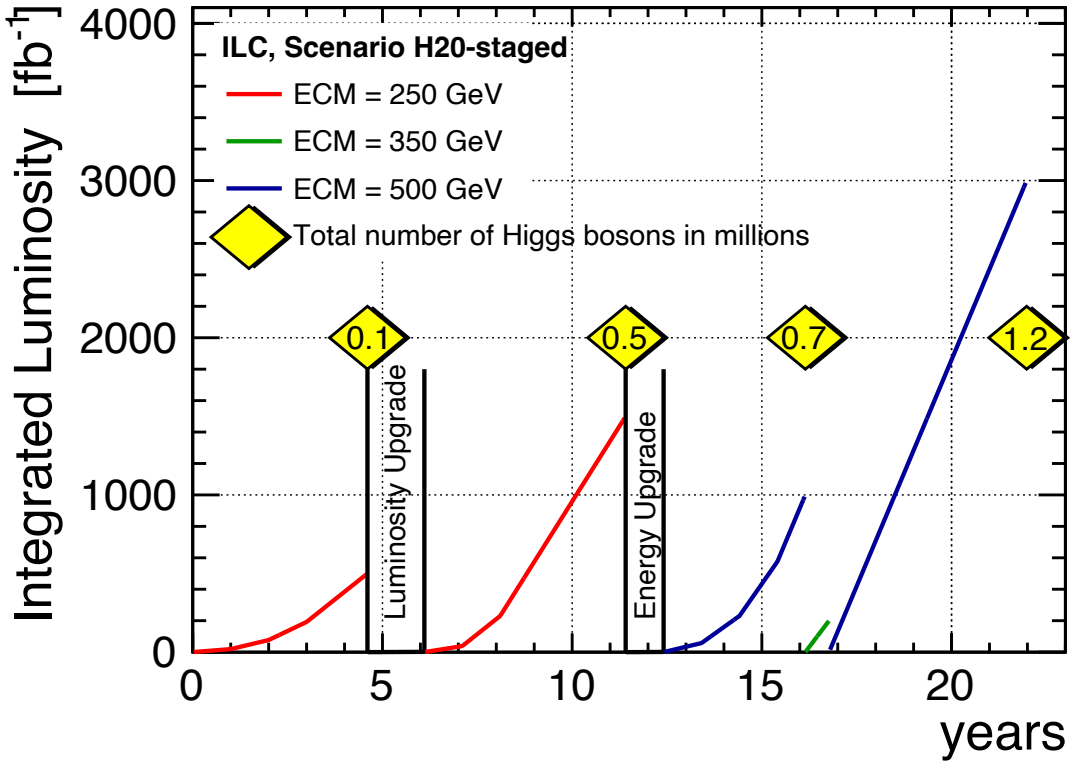
Running Scenarios

Luminosity, Power Consumption and all that

- typical criticism: “low luminosity of LCs requires much more time to do the Higgs program”
  - indeed, in std ILC250 run plan, **ZH run takes ~11 years, vs 3 years** in FCCee plan
  - **however: ILC250 starts with minimal power => let’s take a look!**



note: no lumi ramp-up assumed apart from Z pole



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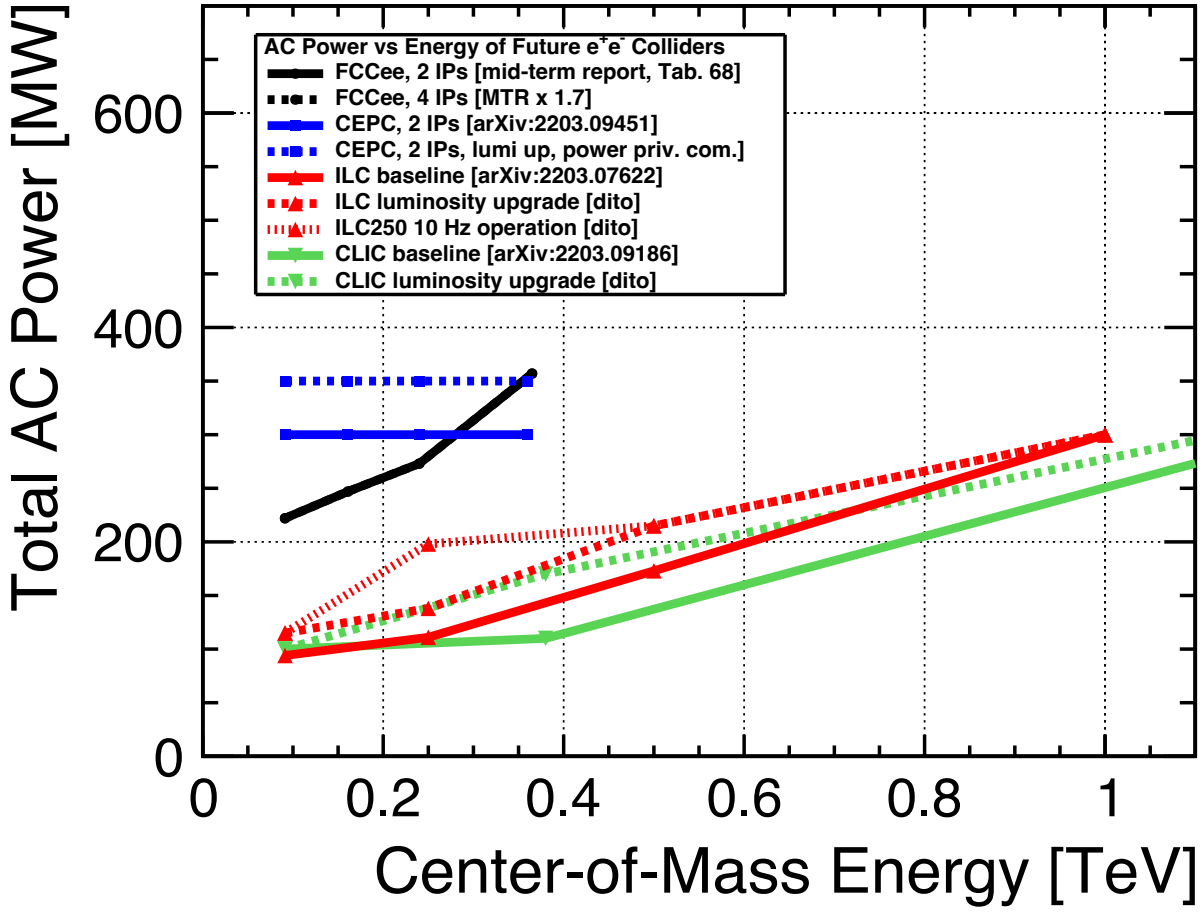

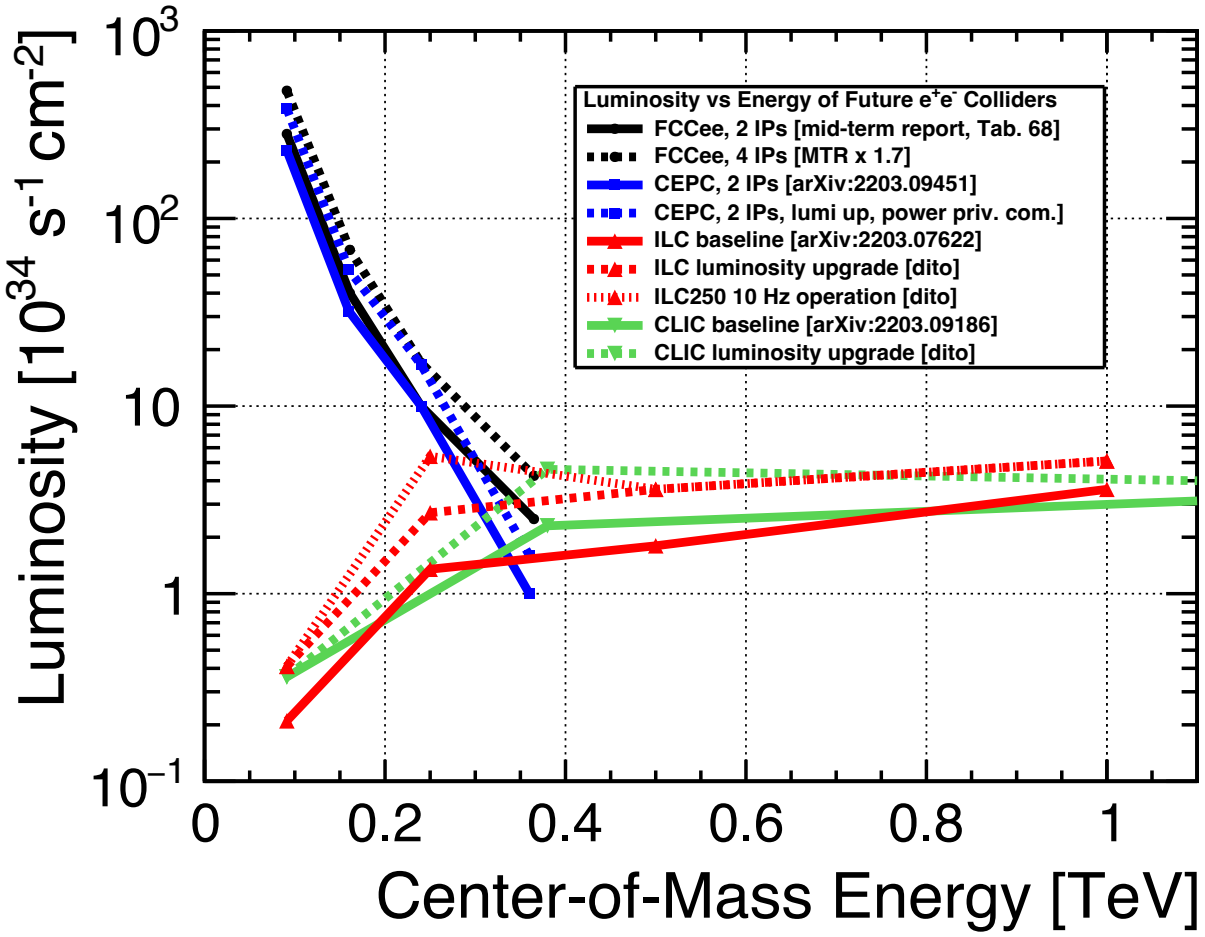

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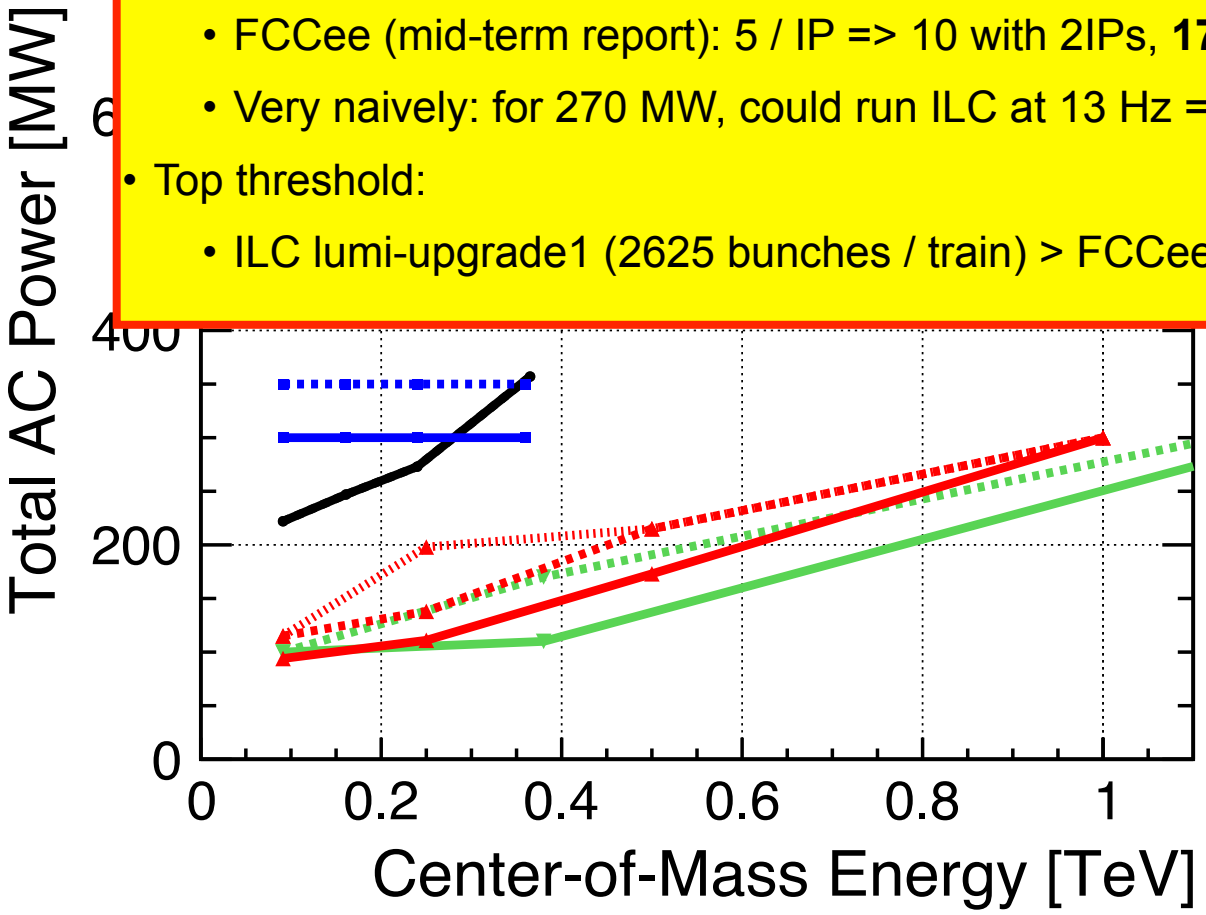
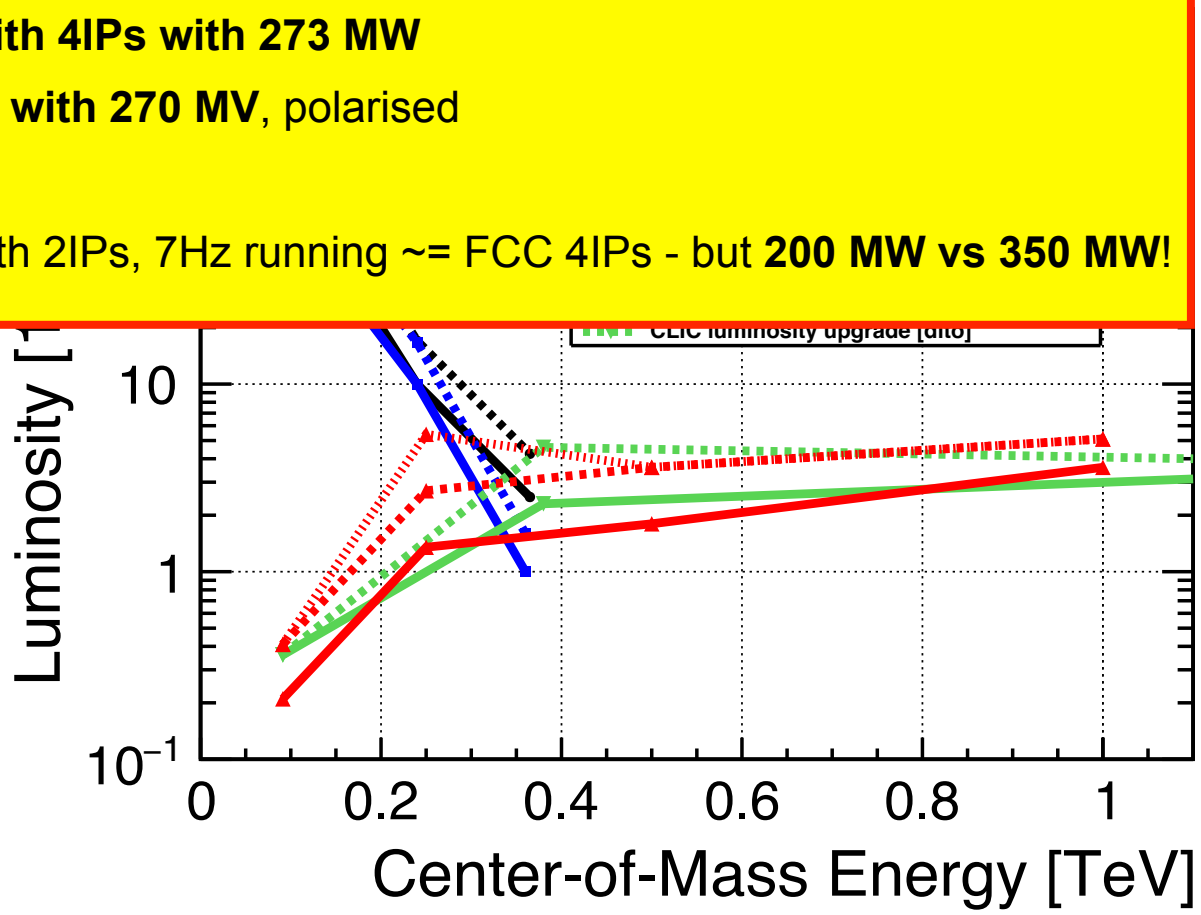
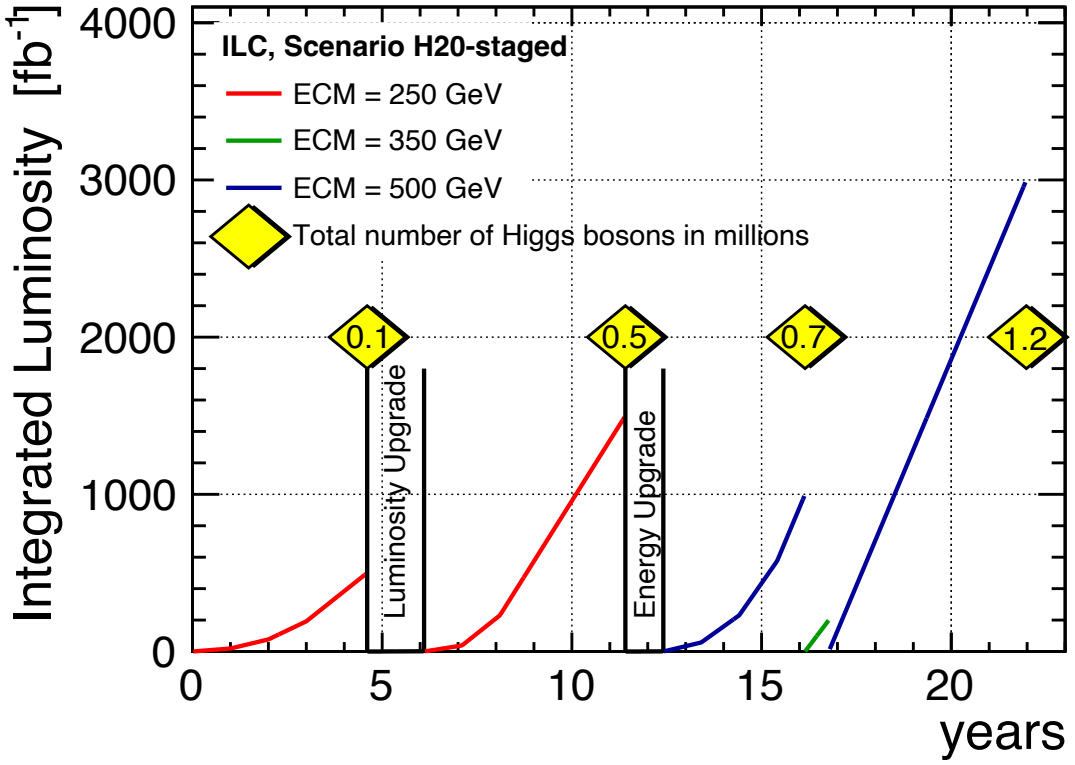
- Single-Higgs program at 240/250 GeV:
  - Linear Collider luminosity restricted by *self-assigned* power limit (all lumis in x10^34 s^-1 cm^-2)
    - 250 GeV ILC baseline lumi **1.35 => 2.7 => 5.4 with 200MW**
    - **less luminosity for *same* Higgs coupling precision due to polarised beams (2ab-1 pol ~= 5 ab-1 unpol)**
  - FCCee (mid-term report): 5 / IP => 10 with 2IPs, **17 with 4IPs with 273 MW**
  - Very naively: for 270 MW, could run ILC at 13 Hz => **7 with 270 MV**, polarised
- Top threshold:
  - ILC lumi-upgrade1 (2625 bunches / train) > FCCee with 2IPs, 7Hz running ~= FCC 4IPs - but **200 MW vs 350 MW**!





Cranking up ILC power

Full number of bunches per train from day-one “lumi upgrade” on previous page



Higgs run down to 6-7 years

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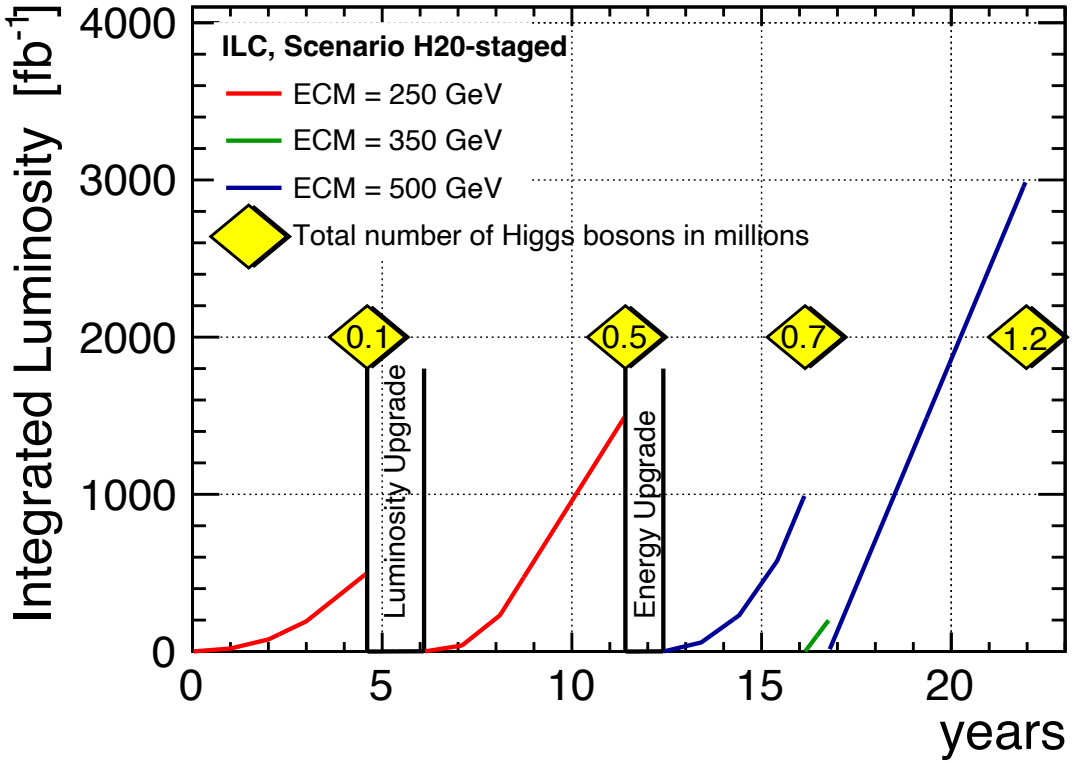

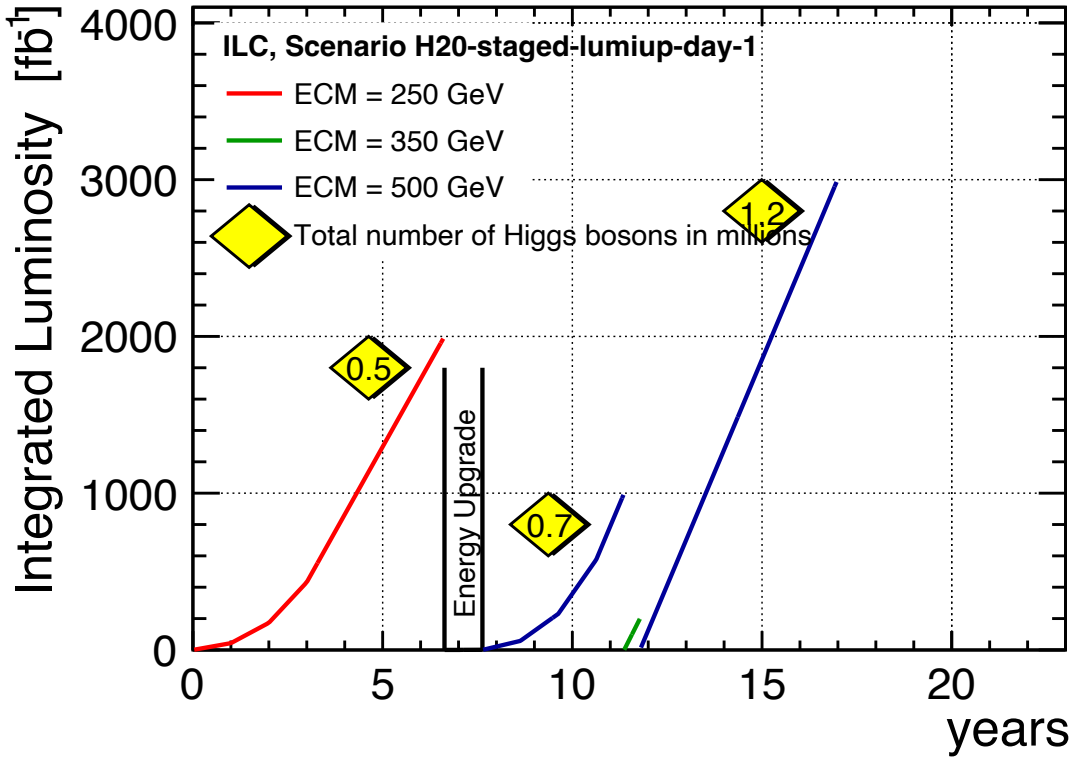

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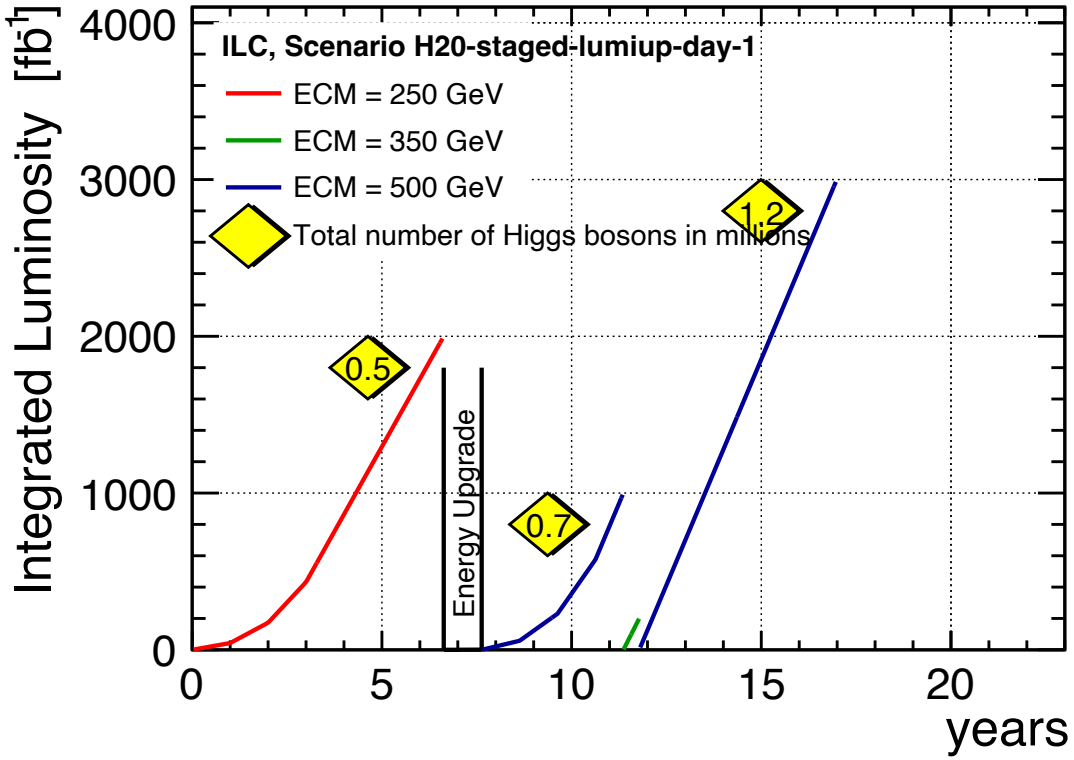
Being honest: adjusting to CERN operation year = 1.2x10^7s

Old ILC assumption used to be 1.6x10^7 s / year



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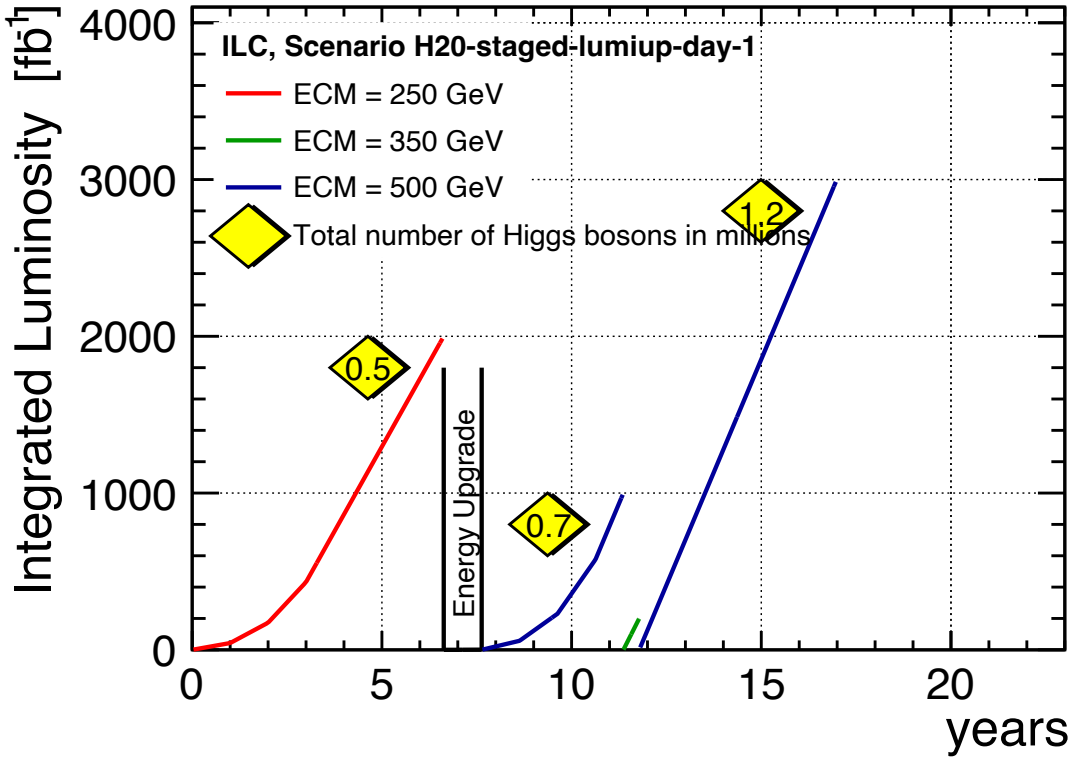

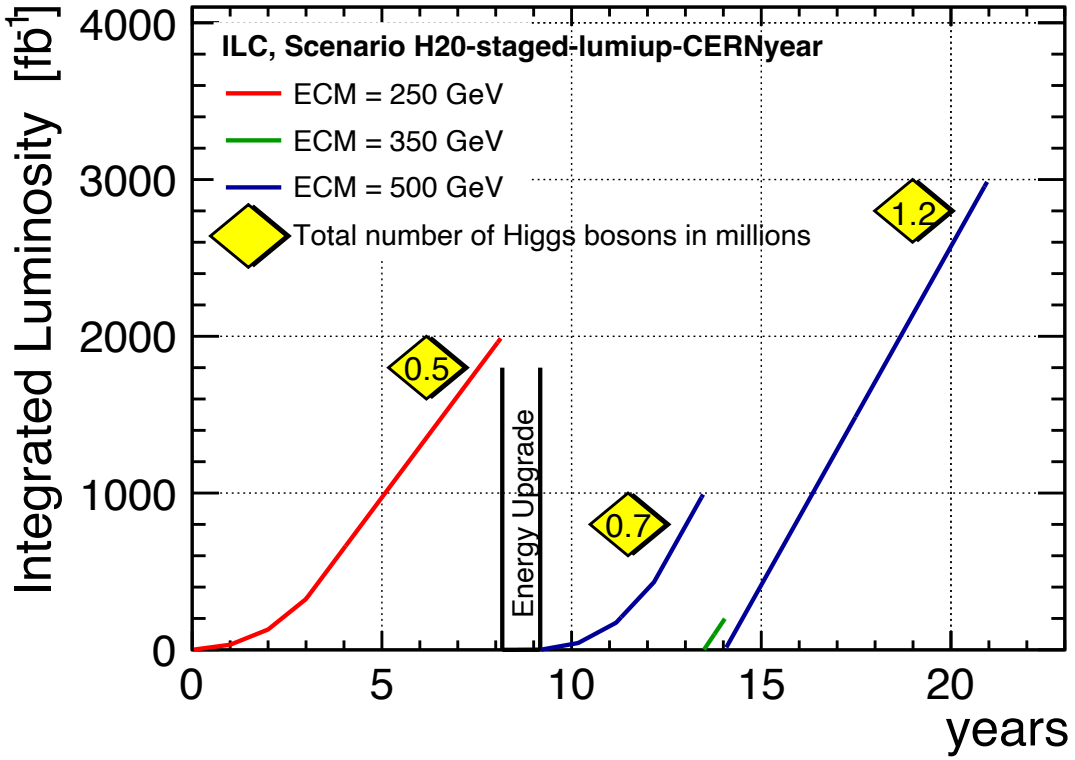

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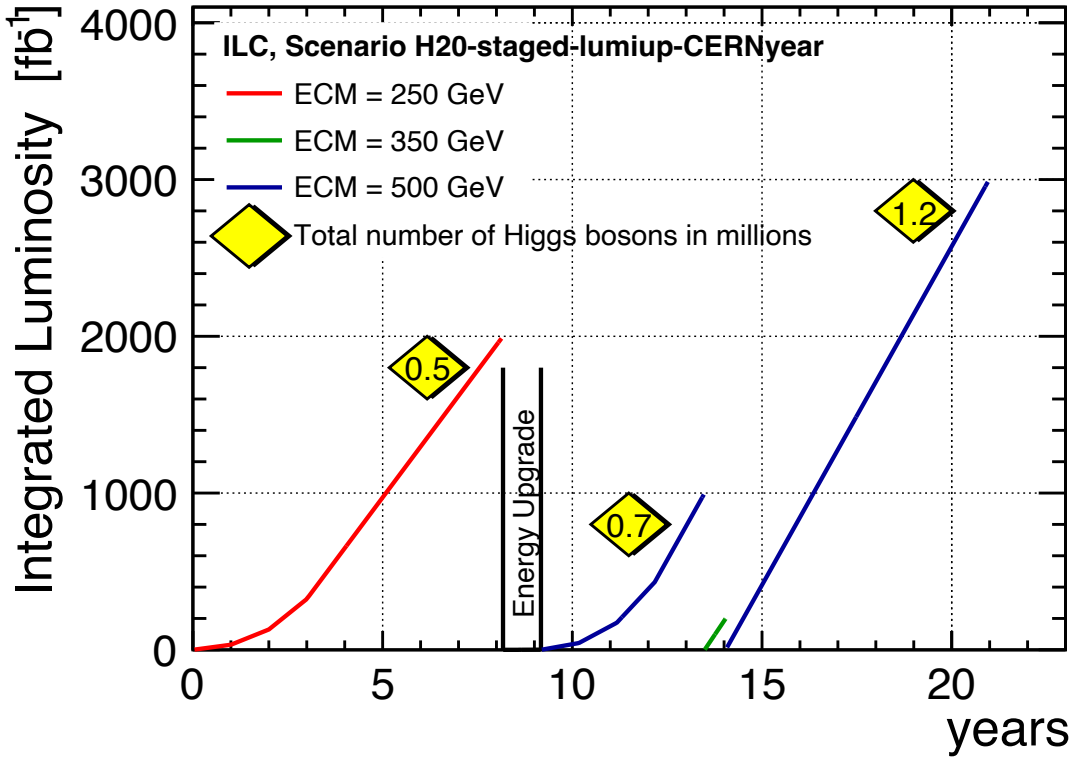
200 MW (aka 10 Hz scheme) from day 1

Remember: FCCee uses 270-350 MW



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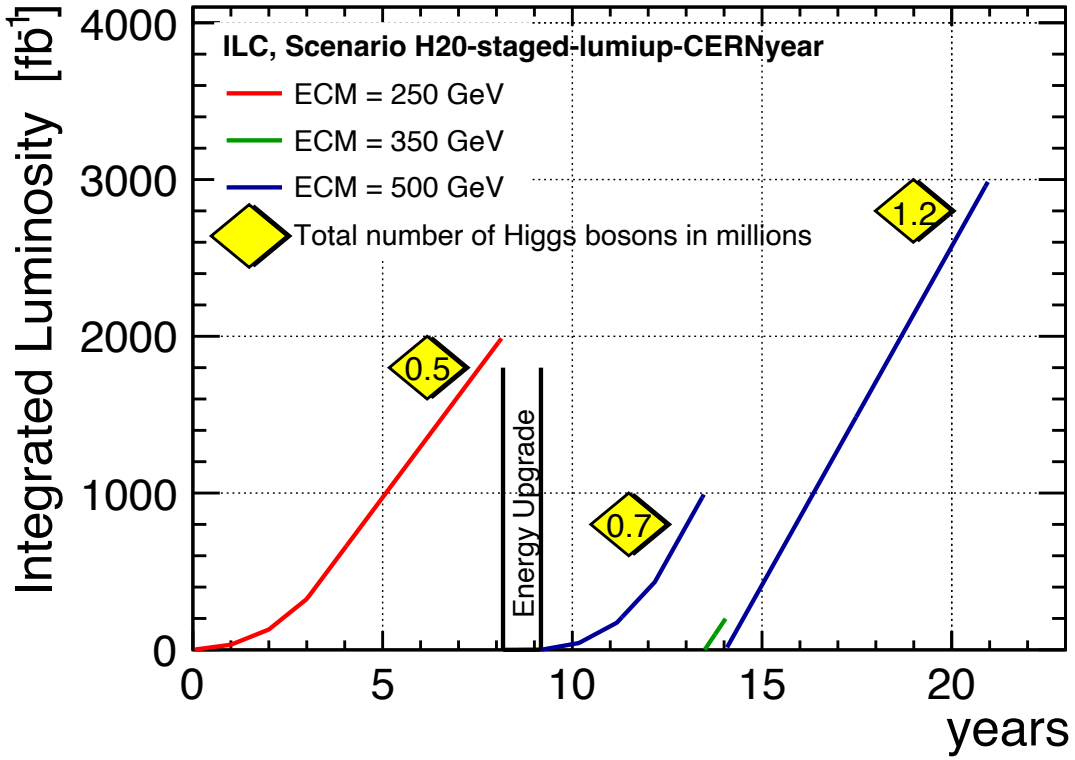
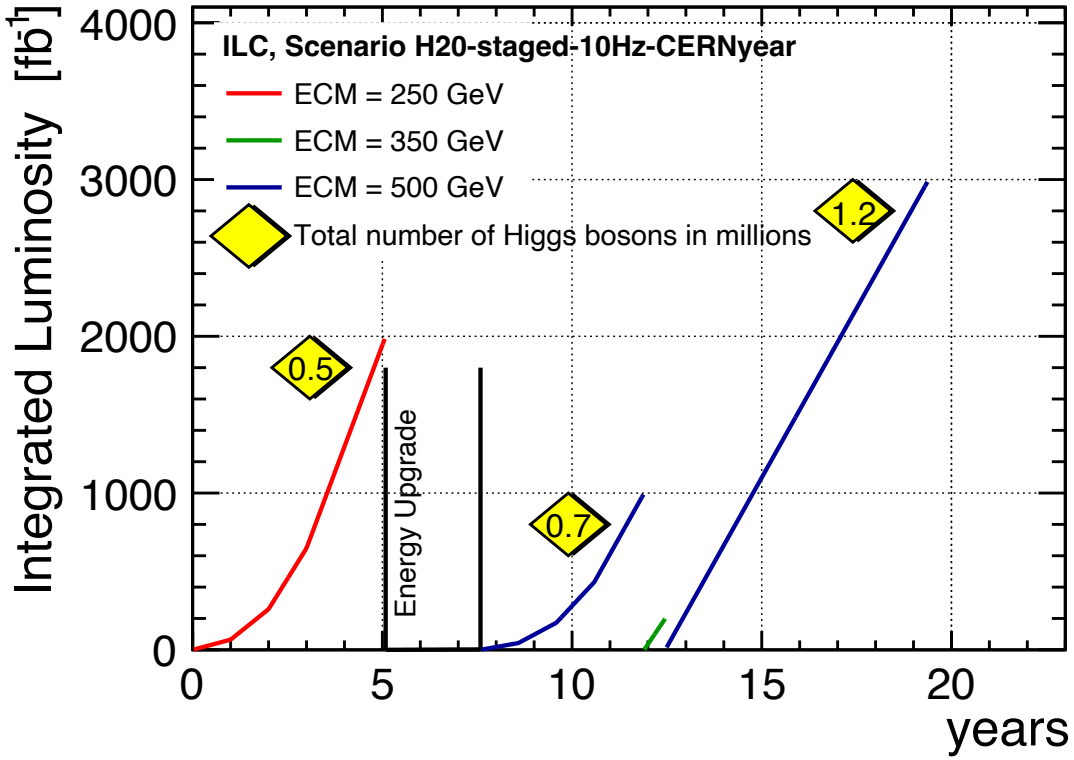
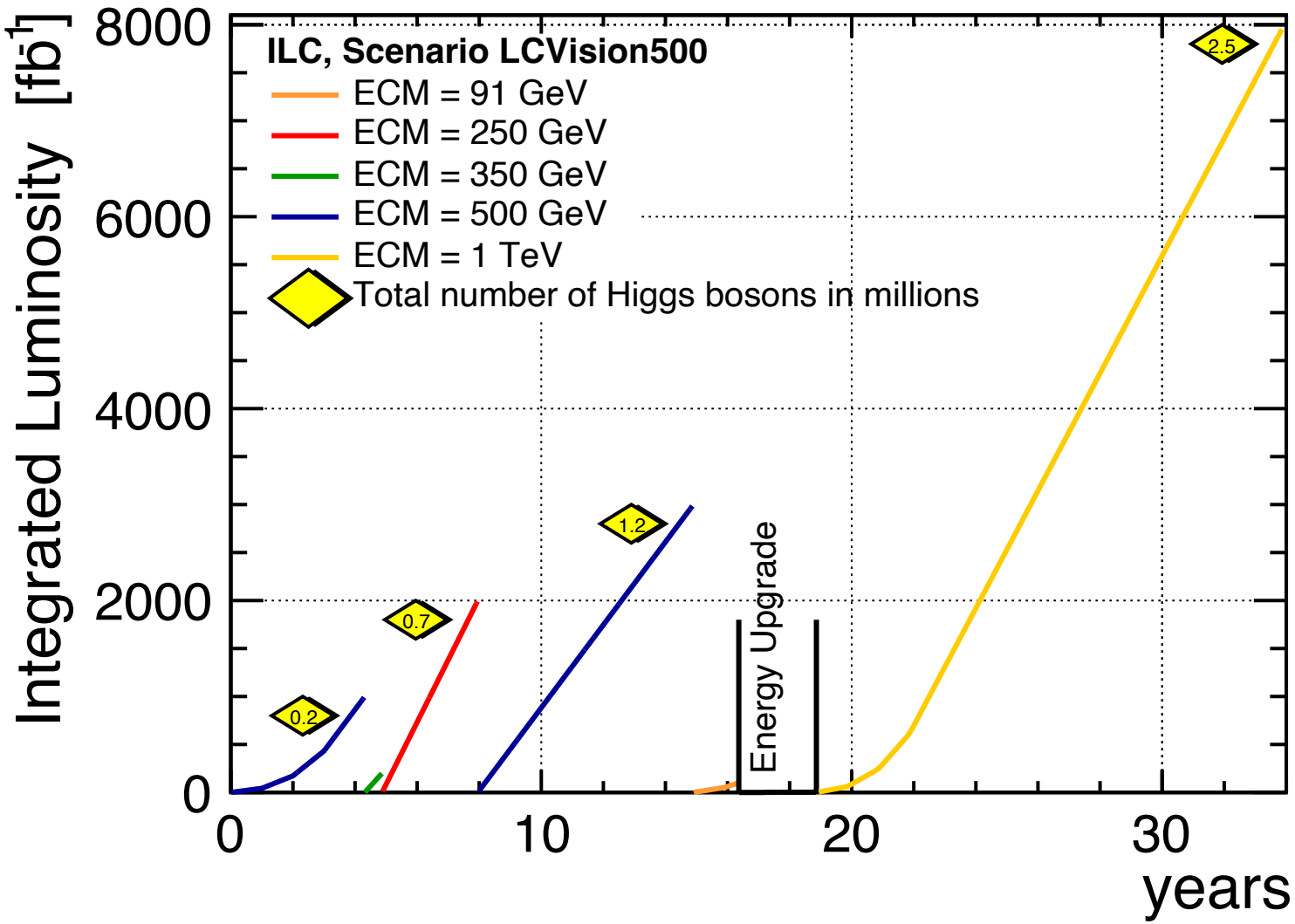




Higgs run 5 years

Dream a little dream…

Starting at 550 GeV



without lumi ramp-up (i.e. like FCCee assumption): Higgs run < 2 years

Conclusions

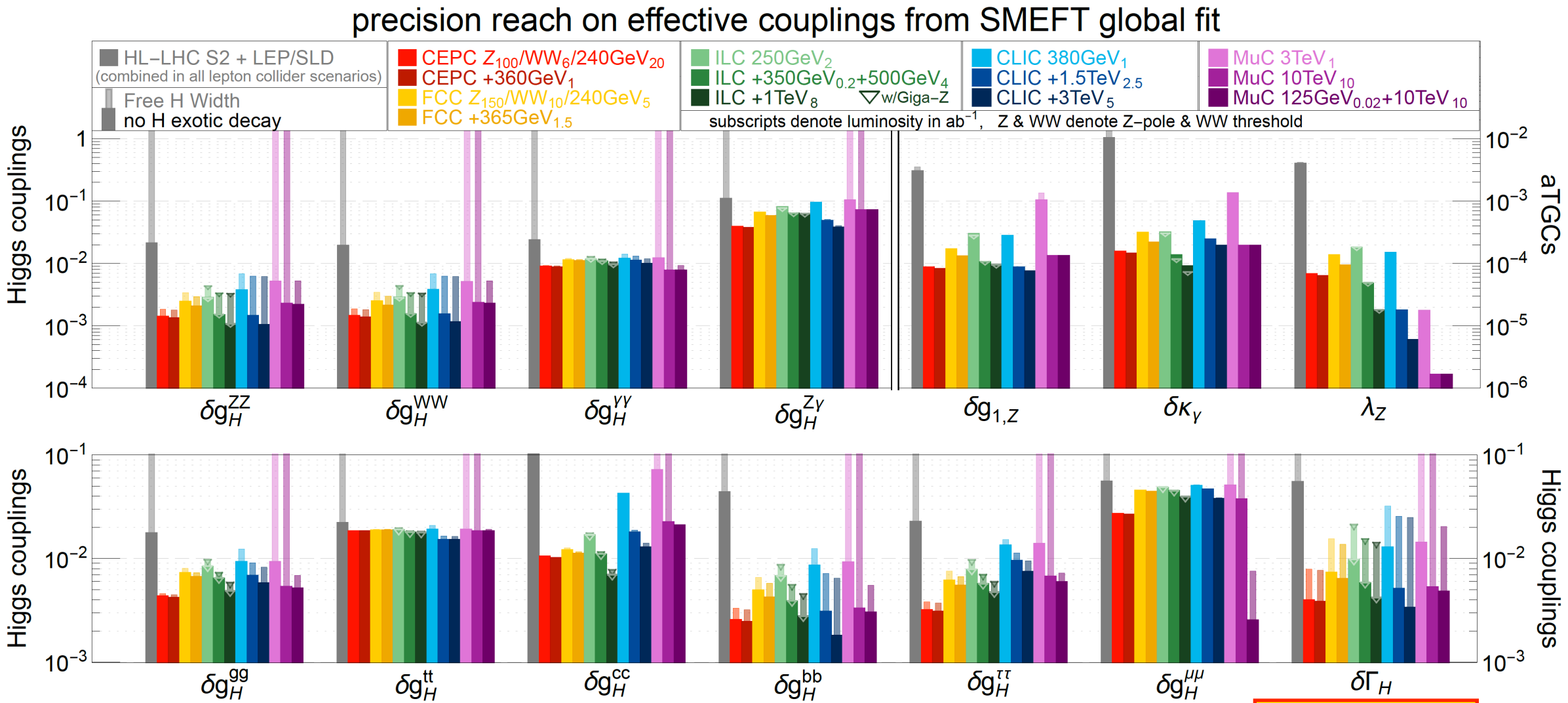
Some take-away messages

- for physics results, the combination of energy, integrated luminosity and beam polarisation counts
- for construction and operation costs, the total AC power counts
- power and instantaneous luminosity are strongly correlated
- Integrated luminosity depends on peak instantaneous luminosity and assumed operating efficiencies, learning curves etc pp
- the 11years the minimal ILC250 needs to collect the 250 GeV sample is driven by all the cost reductions applied to the orginal design
- **If we could build a 550 GeV machine right away, and the same AC power and the same operation assumptions as for FCC-ee, the same data set could be taken in < 2 years**
- **Would be awesome if we could find a way to pay for this!!! :)**

Any Questions?

Higgs Couplings: The Snowmass SMEFT fit

Rainbow-Manhattans



arXiv:2206.08326

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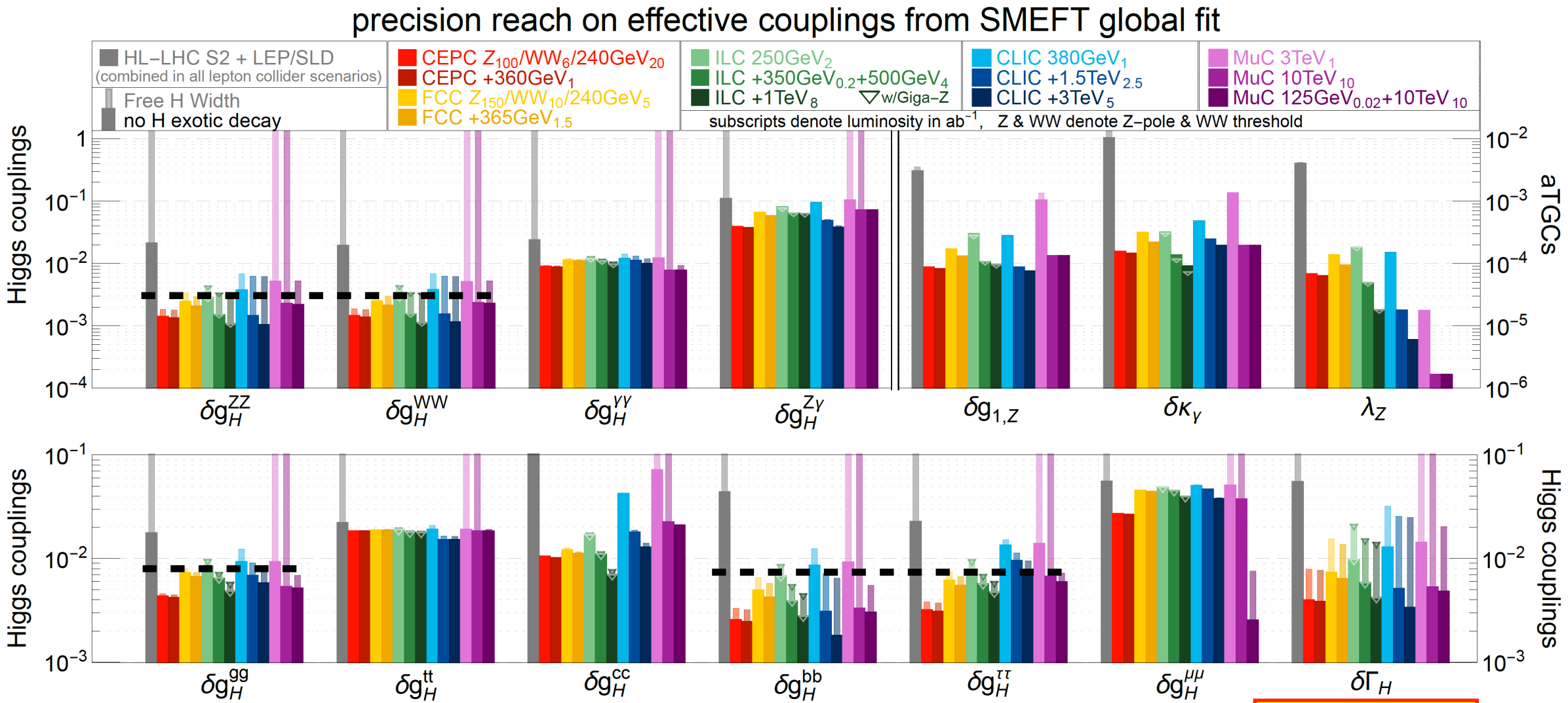

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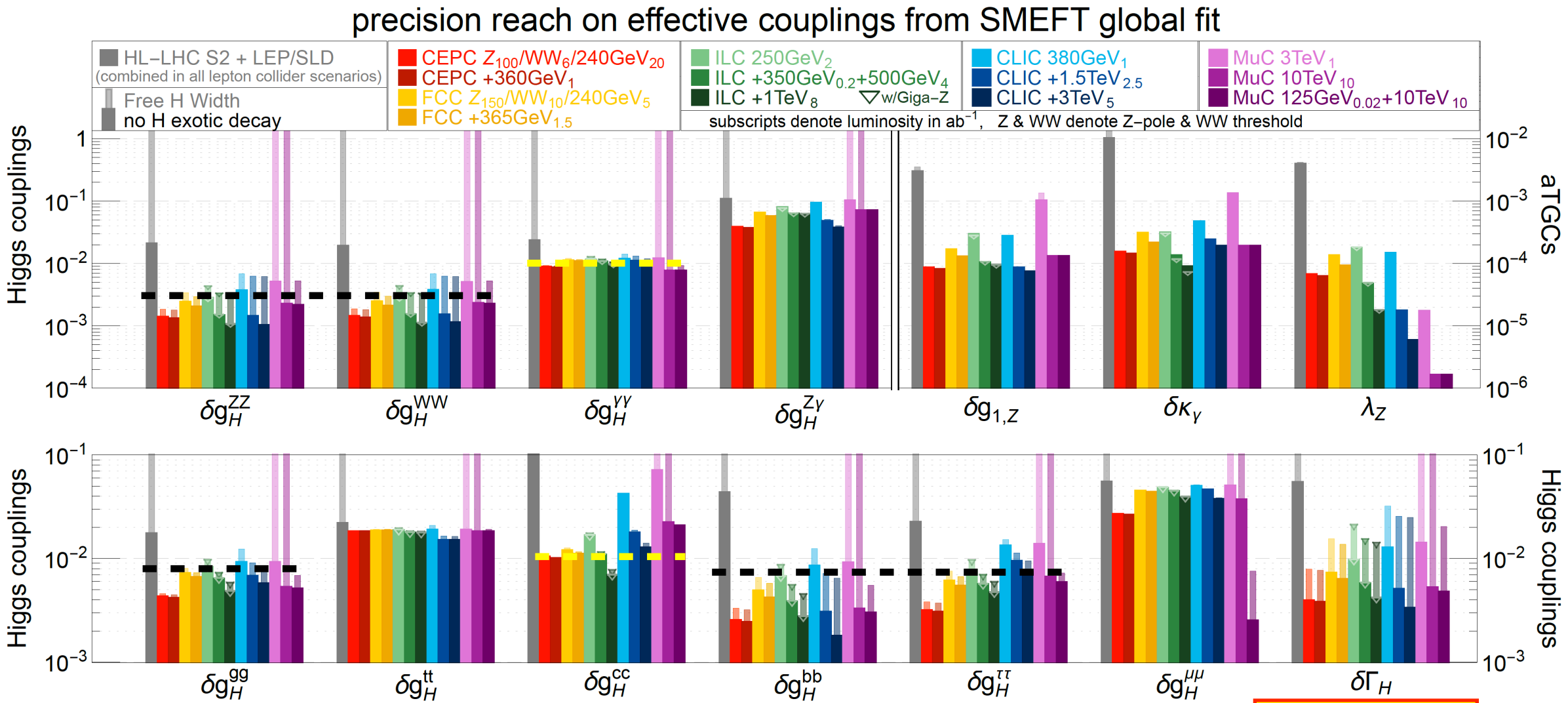

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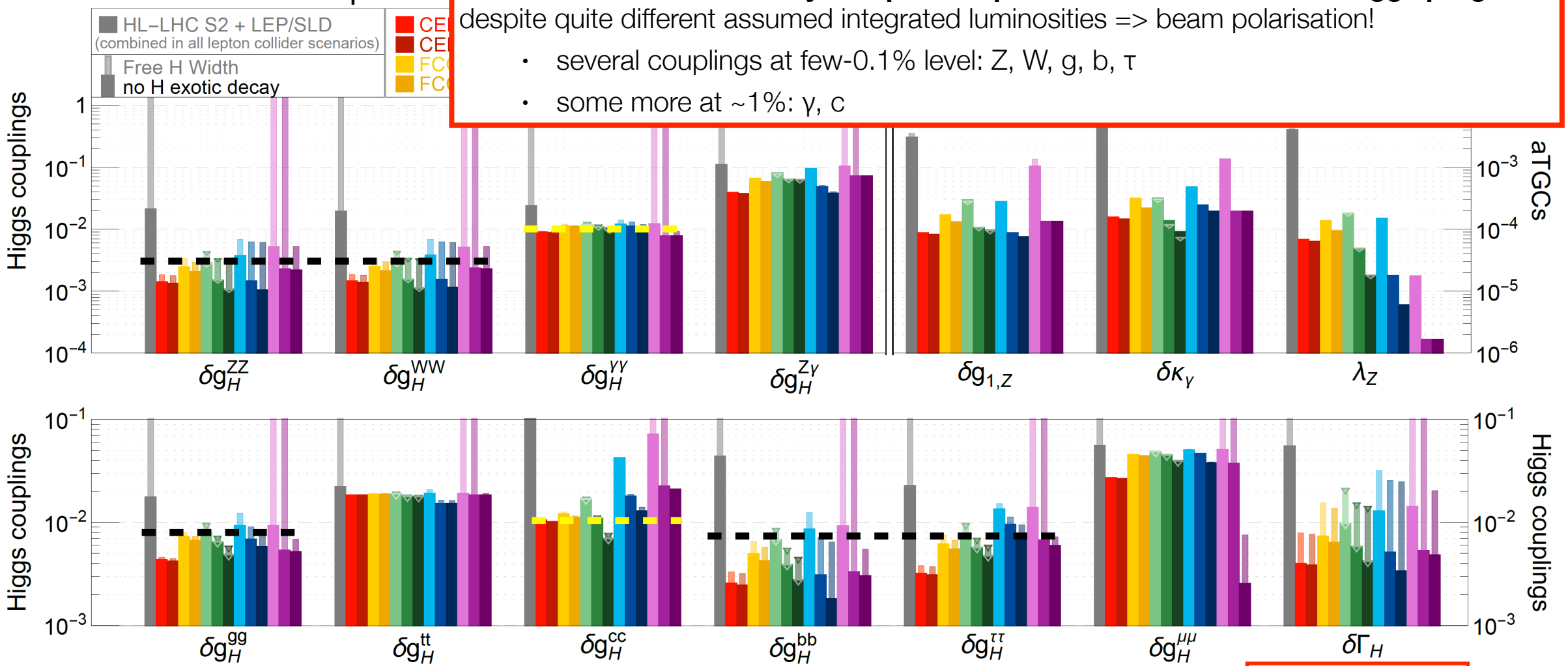
all e+e- colliders show very comparable performance for standard Higgs program
despite quite different assumed integrated luminosities => beam polarisation!

- several couplings at few-0.1% level: Z, W, g, b, τ
- some more at ~1%: γ, c



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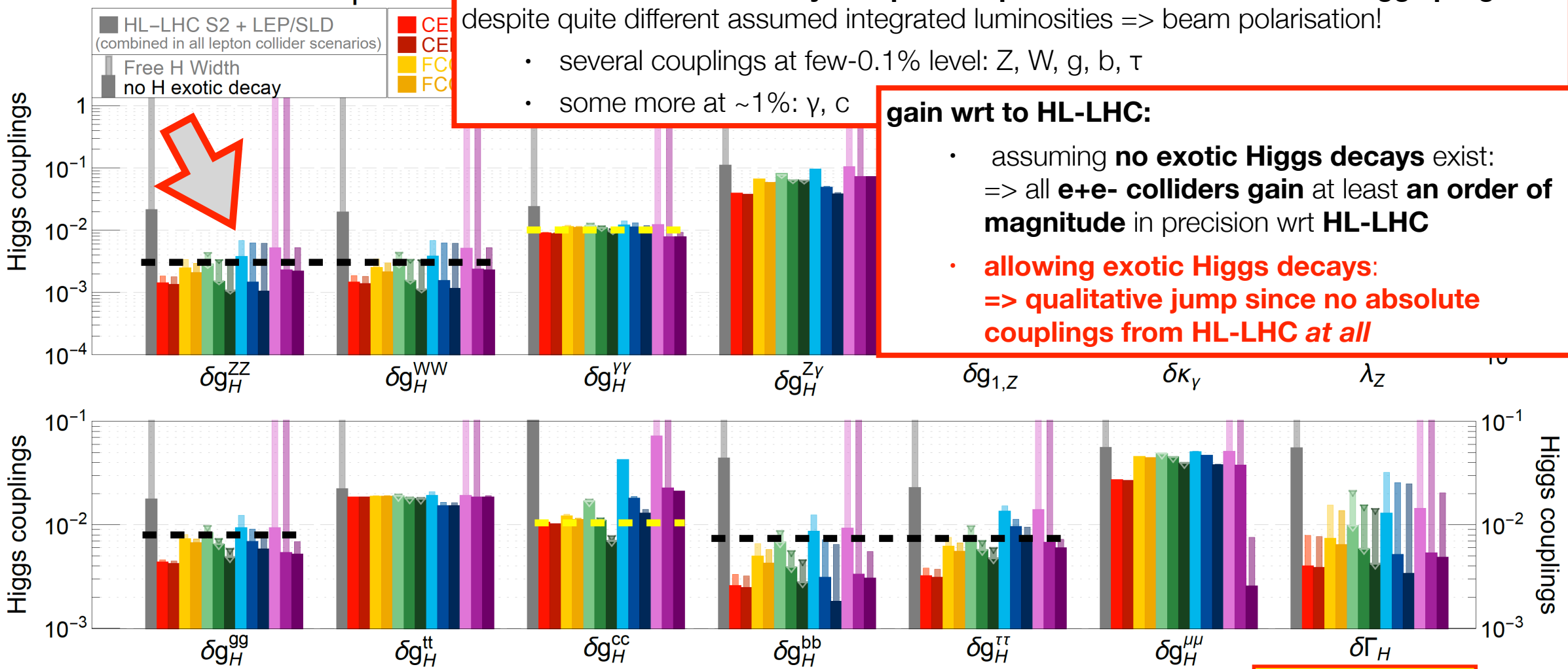

gain wrt to HL-LHC:

- assuming **no exotic Higgs decays** exist:
  => all **e+e- colliders gain** at least **an order of magnitude** in precision wrt **HL-LHC**
- **allowing exotic Higgs decays:**
  => qualitative jump since no absolute couplings from HL-LHC *at all*

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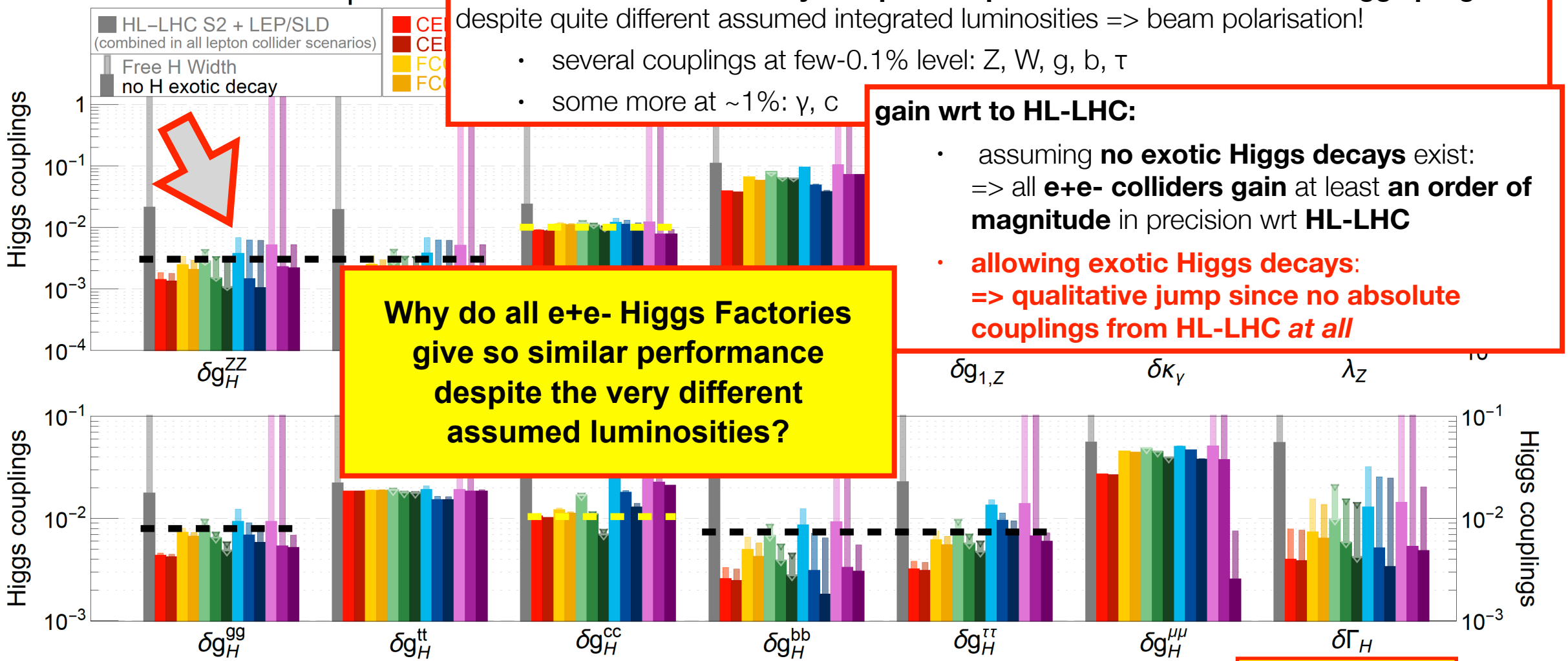

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Why do all e+e- Higgs Factories give so similar performance despite the very different assumed luminosities?

arXiv:2206.08326

Interlude: Chirality in Particle Physics

Just a quick reminder…

- Gauge group of weak x electromagnetic interaction: $SU(2)_L$ x U(1)

- L: left-handed, spin anti-|| momentum*
  R: right-handed, spin || momentum*
- **left-handed particles are fundamentally different from right-handed ones:**
  - only left-handed fermions (e^-) and right-handed anti-fermions (e^+) take part in the charged weak interaction, i.e. couple to the W bosons
  - there are (in the SM) no right-handed neutrinos
  - right-handed quarks and charged leptons are singlets under $SU(2)_L$
  - also couplings to the Z boson are different for left- and right-handed fermions

$$P = \frac{N_R - N_L}{N_R + N_L}$$

- **checking whether the differences between L and R are as predicted in the SM is a very sensitive test for new phenomena!**

* for massive particles, there is of course a difference between chirality and helicity, no time for this today, ask at the end in case of doubt!

Physics benefits of polarised beams

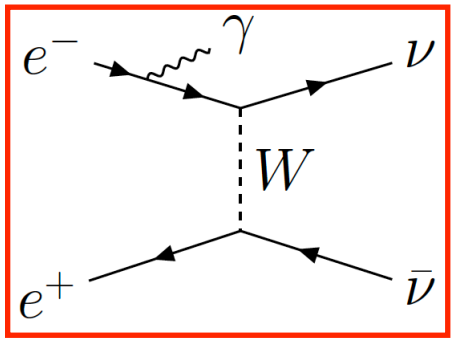
Much more than statistics!

General references on polarised e^+e^- physics:

- **arXiv:**
-

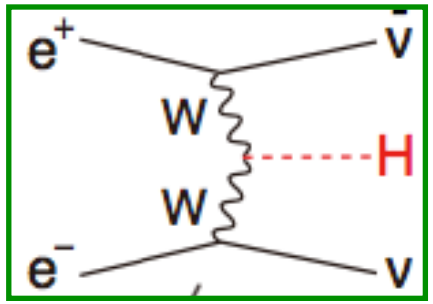
background suppression:

- $e^+e^- \rightarrow WW / \nu_e\nu_e$ strongly P-dependent since t-channel only for $e^-_L e^+_R$



signal enhancement:

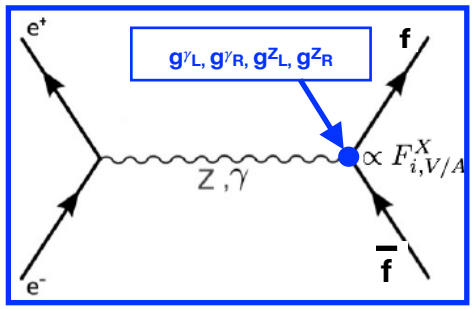
- Higgs production in WW fusion
- many BSM processes



have strong polarisation dependence => higher S/B

chiral analysis:

- SM: Z and γ differ in couplings to left- and right-handed fermions
- BSM: chiral structure unknown, needs to be determined!



redundancy & control of systematics:

- "wrong" polarisation yields "signal-free" control sample
- flipping *positron* polarisation controls nuisance effects on observables relying on *electron* polarisation
- essential: fast helicity reversal for *both* beams!

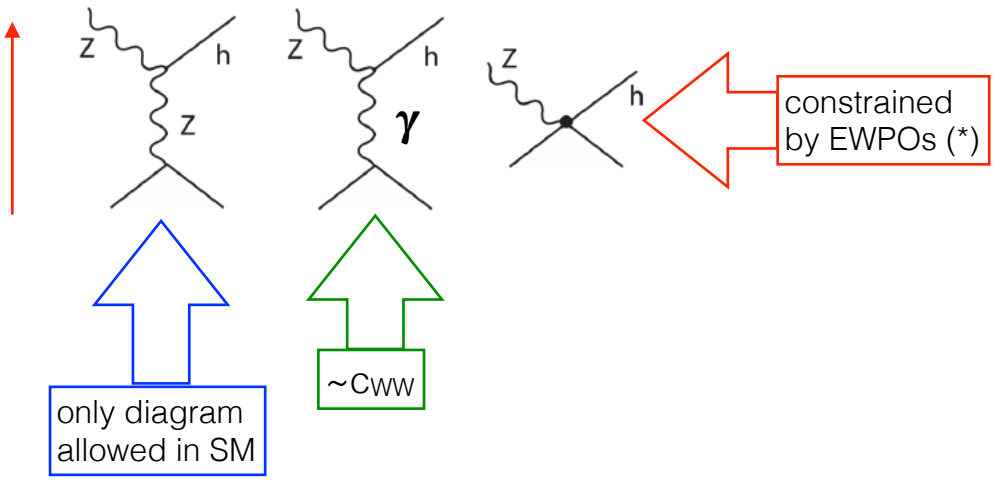
Polarisation & Higgs Couplings

A relationship only appreciated a few years ago…

- **THE key process** at a Higgs factory:

  Higgsstrahlung $e^+e^- \rightarrow Zh$

- A_{LR} of Higgsstrahlung: very important to **disentangle** different **SMEFT operators!**



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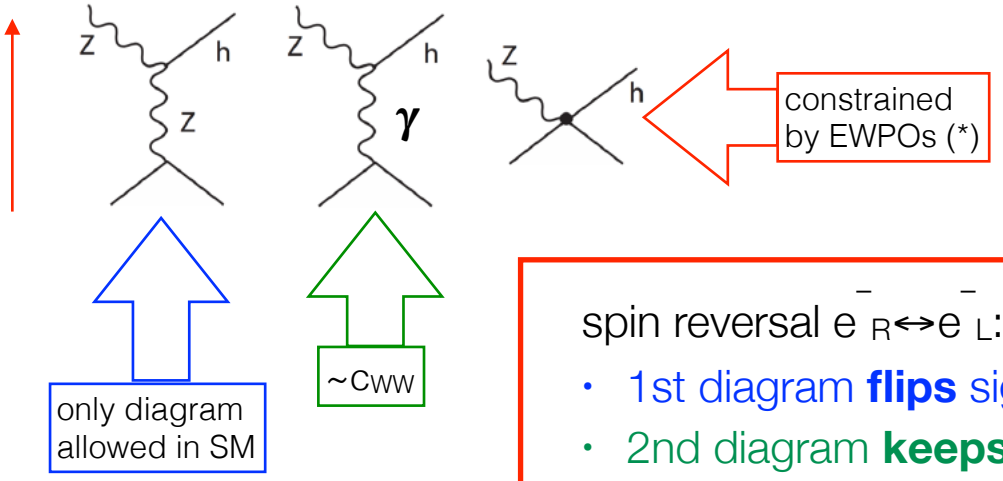

spin reversal $e^-_R \leftrightarrow e^-_L$:

- 1st diagram **flips** sign
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⇒ A_{LR} lifts degeneracy between operators!

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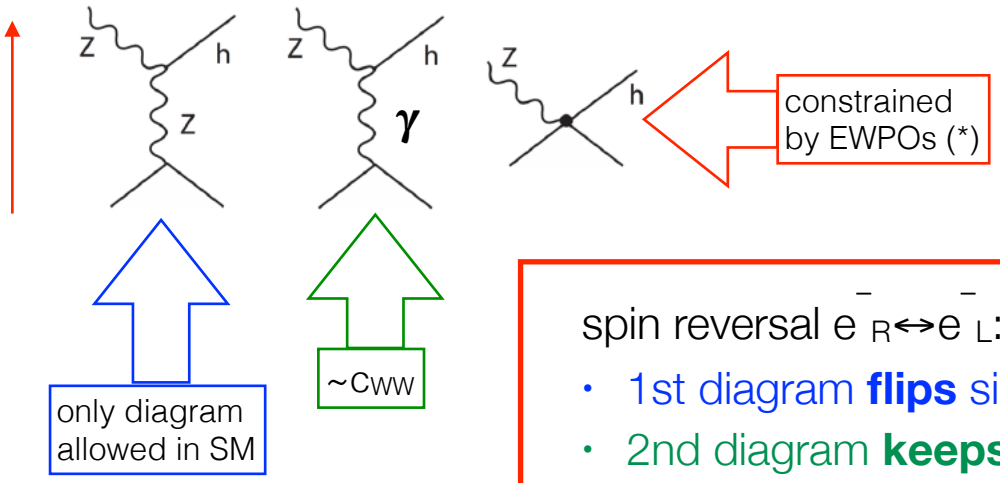

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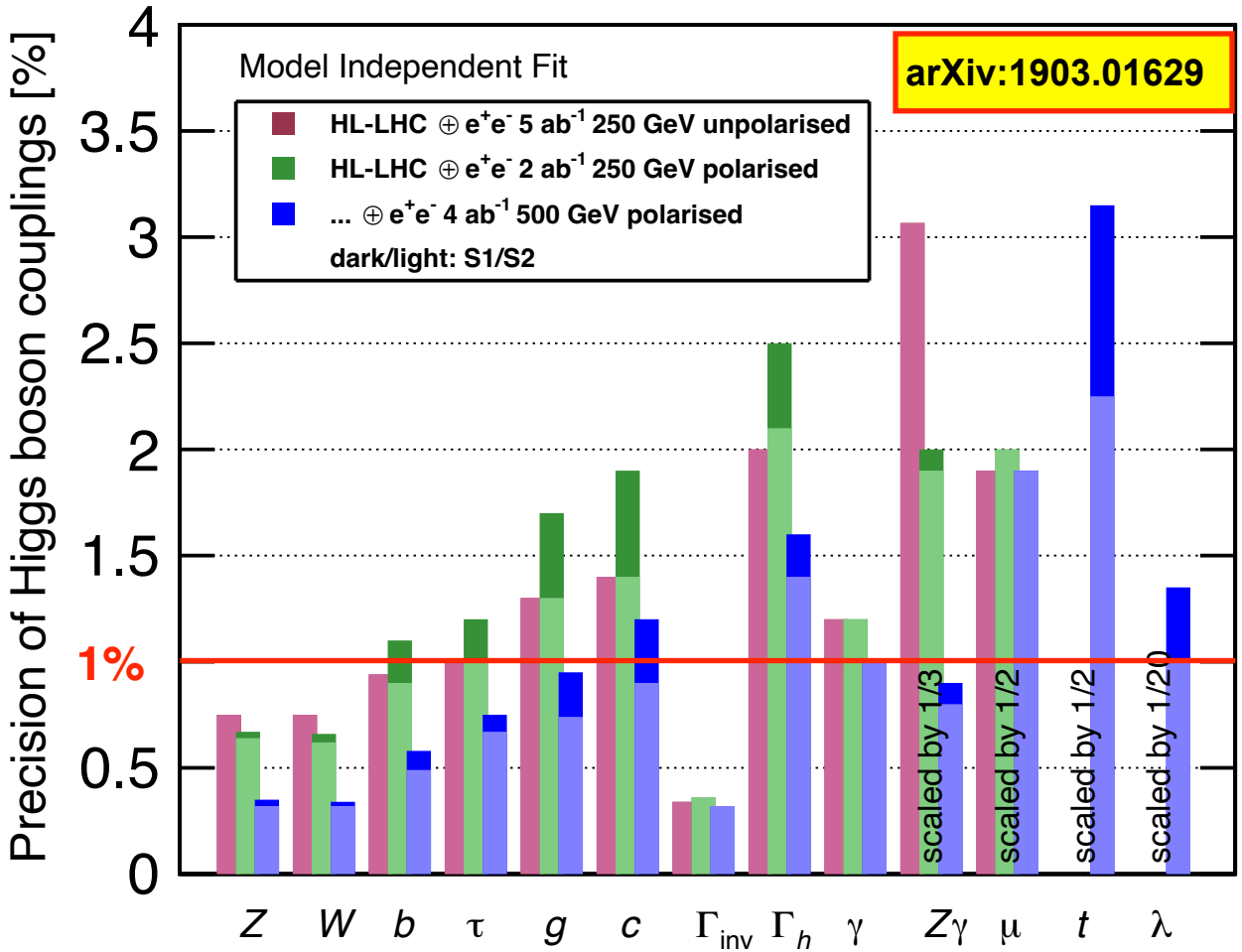

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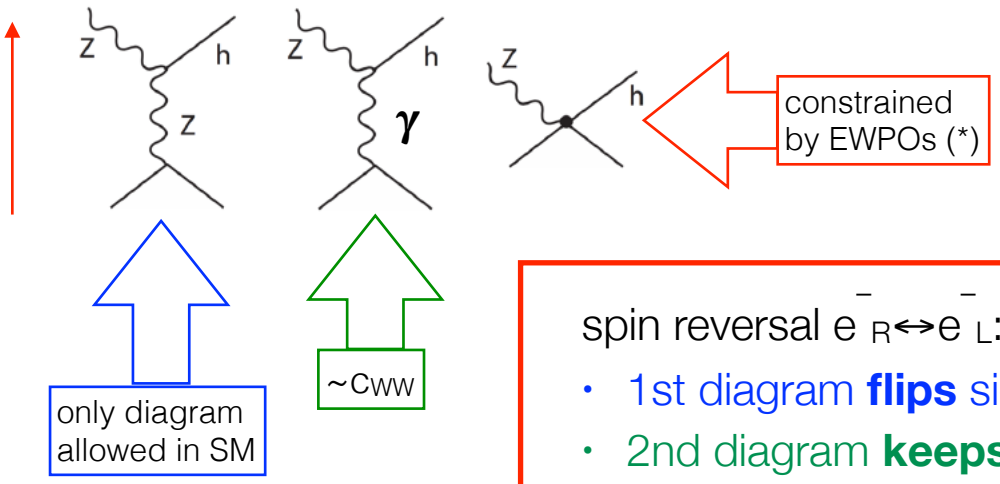

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