Electron Yukawa from s-channel $e^+e^- \to$ Higgs at FCC-ee

Higgs 2021

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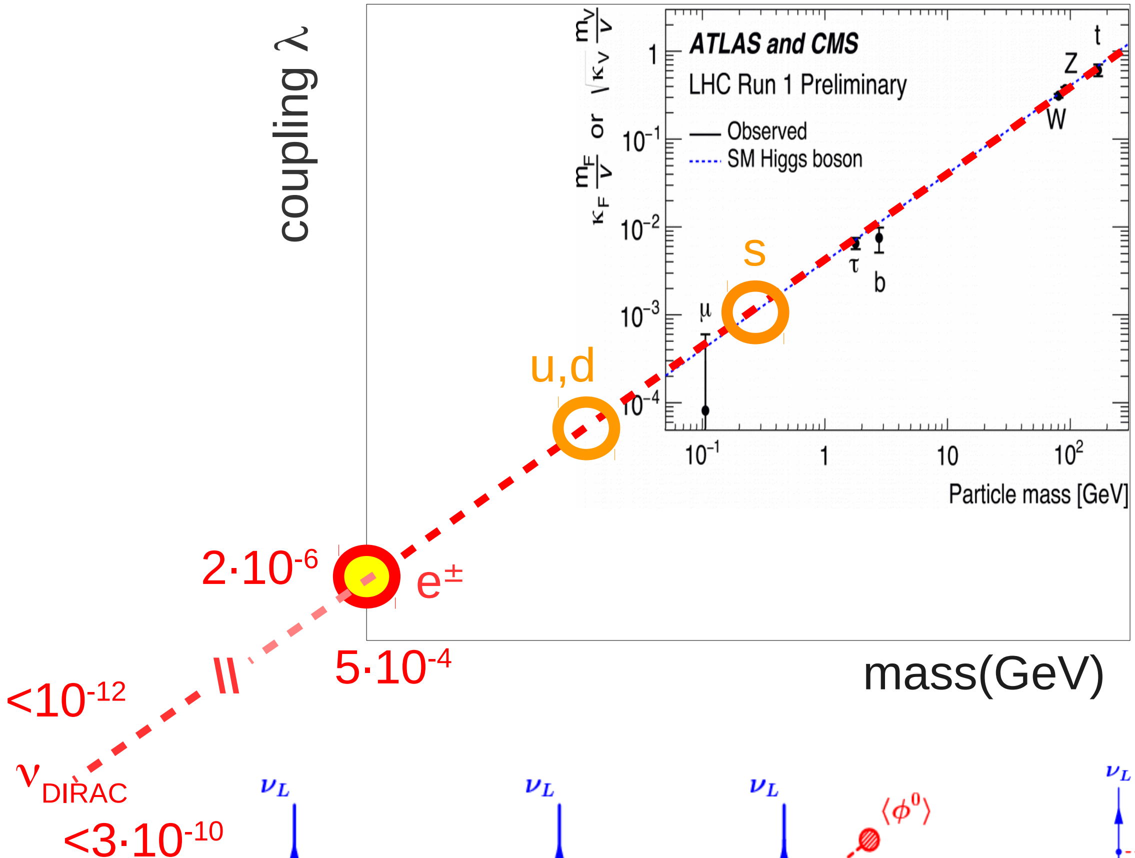
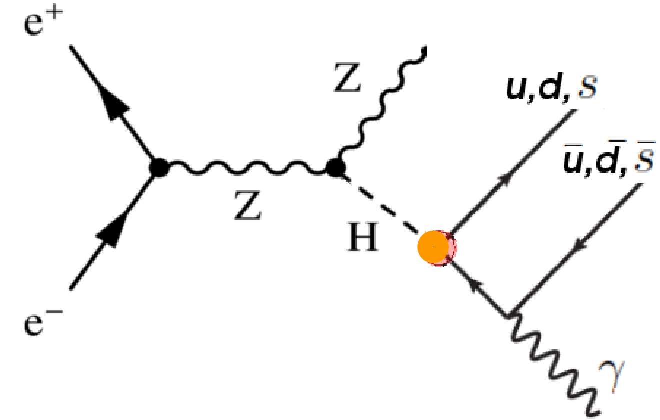
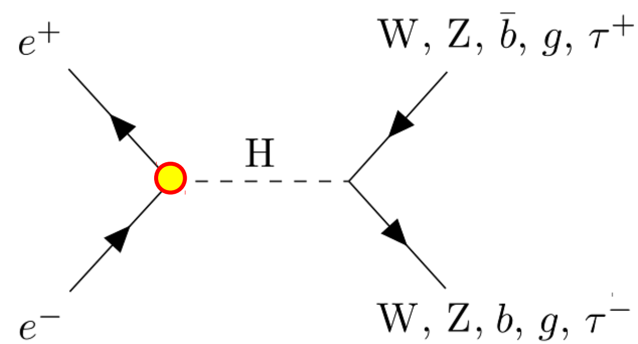
[Details in: arXiv:2107.02686]

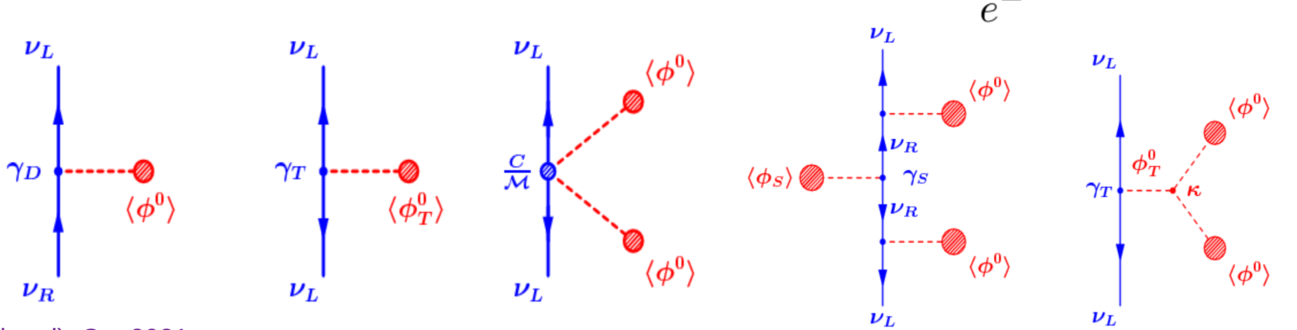
Generation of lightest fermion masses?

- LHC can only measure 3rd (plus a few 2nd) generation Yukawas.
- Can we prove mass generation for stable (u,d,e,ν) matter in the Universe?









e Yukawa via s-channel $e^+e^- \to H$ production

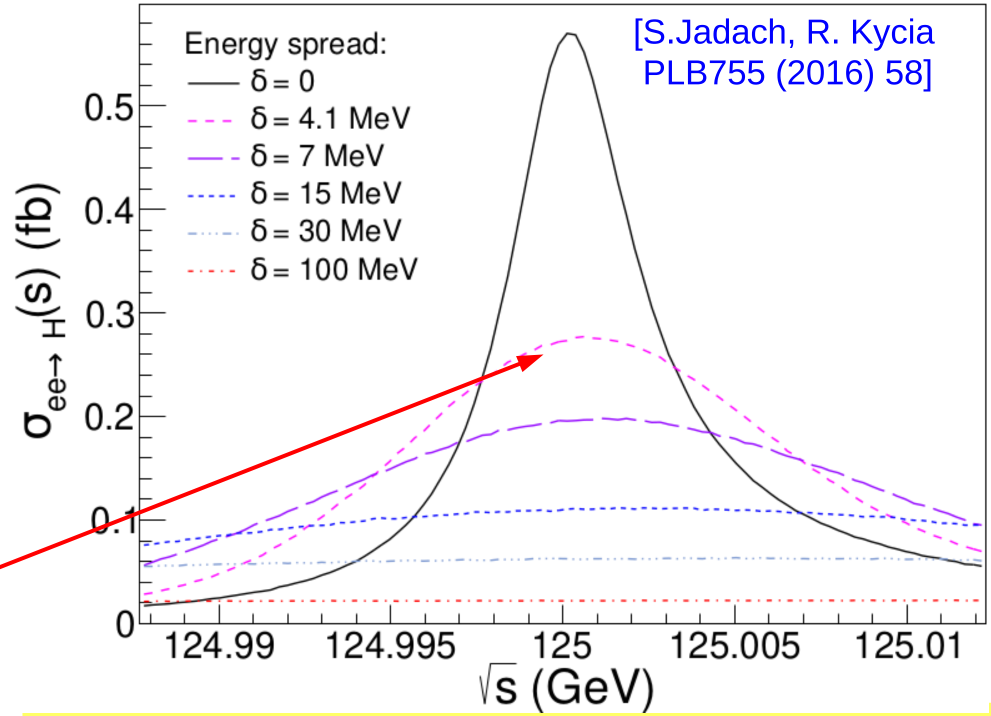
- Higgs decay to e^+e^- is unobservable: BR($H \to e^+e^-$) $\propto m_e^2 = 5.2 \cdot 10^{-9}$
- Resonant Higgs production considered so far only for muon collider: $\sigma(\mu\mu \to H) \approx 70$ pb. Tiny κ_e Yukawa coupling $\Rightarrow$ Tiny $\sigma(ee \to H)$:

$$\sigma(e^+e^- \to H) = \frac{4\pi\Gamma_H^2 Br(H \to e^+e^-)}{(\hat{s} - M_H^2)^2 + \Gamma_H^2 M_H^2} = 1.64 \text{ fb } (m_H = 125 \text{ GeV}, \Gamma_H = 4.1 \text{ MeV})$$

- Actual resonant cross section suppressed by ISR & beam-energy spread:

~40% reduction due to ISR QED radiation from $e^\pm$ beams

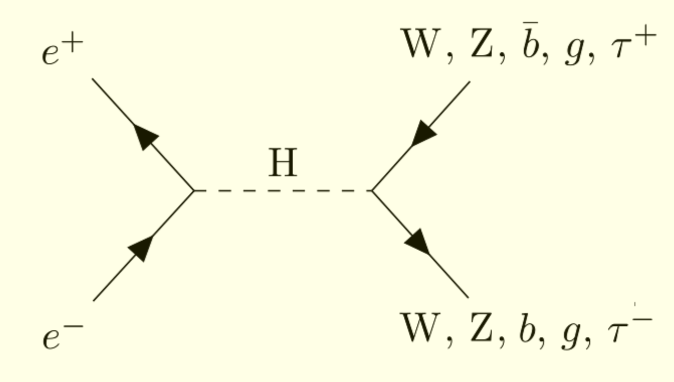
~40% reduction assuming monochromatization ref. point: $\sqrt{s}_{spread} = \Gamma_H = 4.1$ MeV



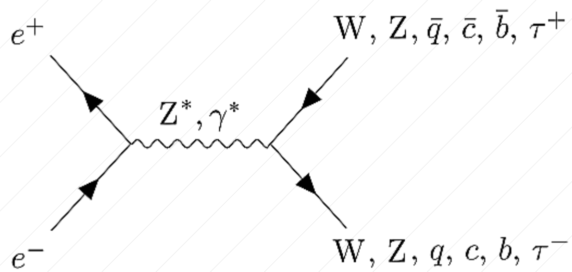
$\sigma_{spread+ISR}(e^+e^- \to H) = 0.17 \times \sigma(e^+e^- \to H) = 280$ ab

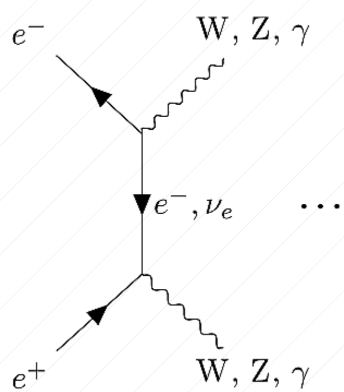
Higgs signal & backgrounds at FCC-ee(125 GeV)

- Very-rare counting experiment over 10+ decay channels:



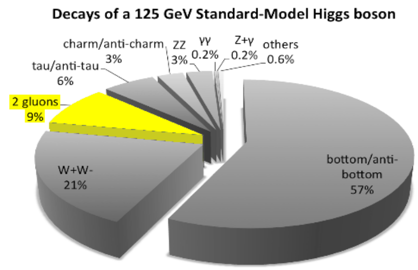
Higgs decay channel	BR	$\sigma\times$ BR (ISR$\otimes$spread incl.)
$H\to b\bar{b}$	58.2%	164 ab
$H\to gg$	8.2%	23 ab
$H\to\tau\tau$	6.3%×60%×60%	6.5 ab
$H\to c\bar{c}$	2.9%	8 ab
$H\to WW\to \ell\nu\, 2j$	21.4%×67.6%×32.4%×2	26 ab
$H\to WW\to 2\ell\, 2\nu$	21.4%×32.4%×32.4%	6.3 ab
$H\to WW\to 4j$	21.4%×67.6%×67.6%	28 ab
$H\to ZZ\to 2j\, 2\nu$	2.6%×70.%×20.%×2	2 ab
$H\to ZZ\to 2\ell\, 2j$	2.6%×70.%×10.%×2	1 ab
$H\to ZZ\to 2\ell\, 2\nu$	2.6%×20.%×10.%×2	0.3 ab
$H\to\gamma\gamma$	0.23%	0.65 ab





Irreducible background	σ	S/B
$e^+e^-\to b\bar{b}$	19 pb	$\mathcal{O}(10^{-5})$
$e^+e^-\to q\bar{q}$ (w/ $\varepsilon_{q\text{-}g,mistag}$~1%)	61 pb	$\mathcal{O}(10^{-3})$
$e^+e^-\to\tau\tau$	10 pb	$\mathcal{O}(10^{-6})$
$e^+e^-\to c\bar{c}$	22 pb	$\mathcal{O}(10^{-7})$
$e^+e^-\to WW^*\to\ell\nu\, 2j$	23 fb	$\mathcal{O}(10^{-3})$
$e^+e^-\to WW^*\to 2\ell\, 2\nu$	5.6 fb	$\mathcal{O}(10^{-3})$
$e^+e^-\to WW^*\to 4j$	24 fb	$\mathcal{O}(10^{-3})$
$e^+e^-\to ZZ^*\to 2j\, 2\nu$	273 ab	$\mathcal{O}(10^{-2})$
$e^+e^-\to ZZ^*\to 2\ell\, 2j$	136 ab	$\mathcal{O}(10^{-2})$
$e^+e^-\to ZZ^*\to 2\ell\, 2\nu$	39 ab	$\mathcal{O}(10^{-2})$
$e^+e^-\to\gamma\gamma$	79 pb	$\mathcal{O}(10^{-8})$

Most significant channel: $e^+e^- \to H(gg) \to jj$

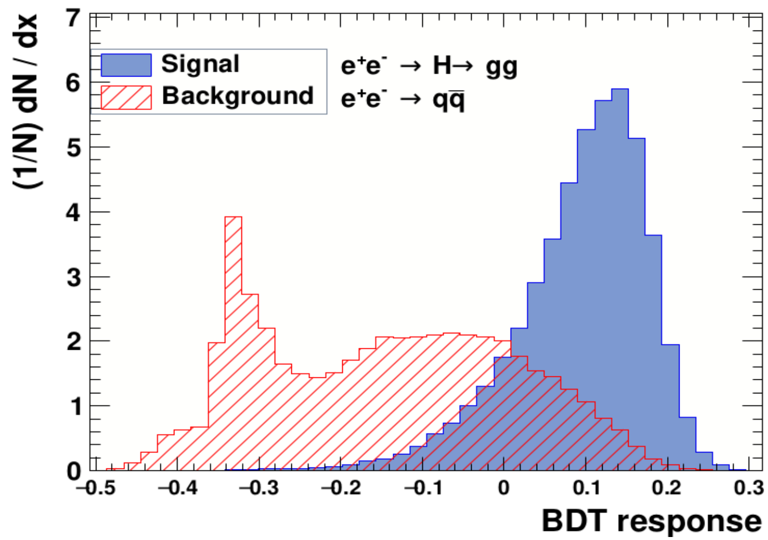


- Final state definition (retains 50% of σ(gg) = 24 ab):

  2 gluon-tagged jets (with 70% effic. each)
  Light-q mistagging rate: ~1%
  Challenging, but not impossible:
  Dedicated QCD studies needed
  (reco&PID of ALL hadrons in jets).

- BDT MVA result (removing jet vars. potentially already used in g-uds discrimination):

  Signal reduction ~50%
  Backgd. reduction: x17



- Signal & backgrounds cross sections cut flow:

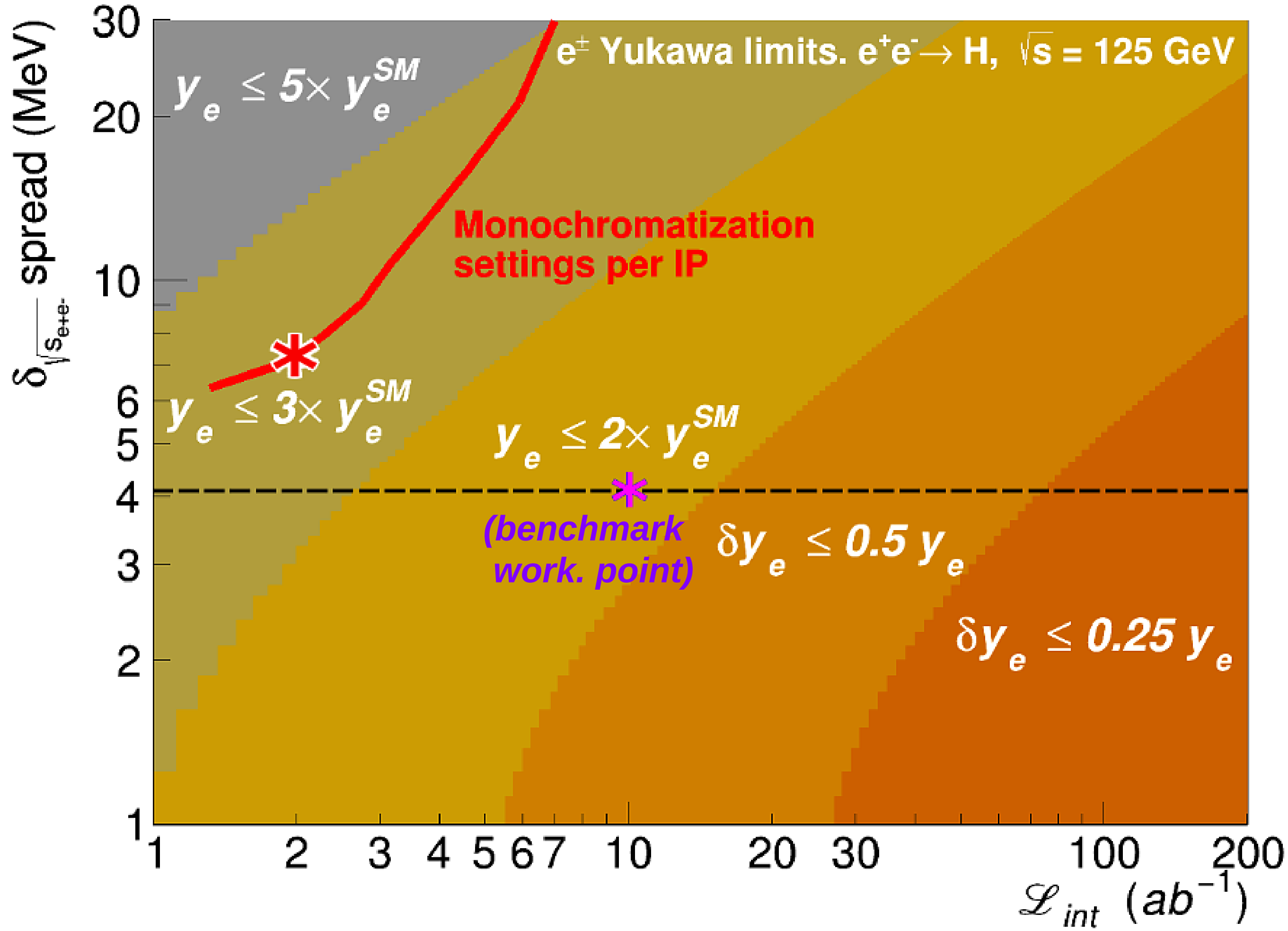
Process	Events	Passes	+ cuts	+ MVA	raw σ	Tagrate	Pass+Tag	+ Cut	Final σ
Hgg	100000	85315	80350	45440	25 ± 0 ab	$70\%^2$	10 ab	9.7 ab	5.5 ± 0.0 ab
bb	199981	140057	12532	1331	81 ± 0 pb	$0.0\%^2$	0 pb	0 pb	0 ± 0 pb
cc	200000	174120	28282	1984	73 ± 0 pb	$0.0\%^2$	0 pb	0 pb	0 ± 0 pb
qq	200000	186171	36888	2015	237 ± 0 pb	$1.0\%^2$	22 fb	4.4 fb	239 ± 5 ab
ZZ	99999	75095	49798	14261	224 ± 0 fb	$0.0\%^2$	0 pb	0 pb	0 ± 0 pb
tautau	20000	0	0	0	26 ± 0 pb	$0.0\%^2$	0 pb	0 pb	0 ± 0 pb
WW	20000	16959	12783	5413	21 ± 0 fb	$0.0\%^2$	0 pb	0 pb	0 ± 0 pb

Total bckg: 244 ab, $S/\sqrt{S+B} = 1.0973$, training data 1.1843, from MVA 1.1101

For $\mathscr{L}_{int}$=10 ab^{-1}
$S/\sqrt{B} = 55/\sqrt{2500} \approx 1.1$
Significance ≈ 1.1

Electron Yukawa limits in ($\sqrt{s}_{spread}$, $\mathscr{L}_{int}$) plane

- Monochromatization working points ($\sqrt{s}_{spread}$ vs. $\mathscr{L}_{int}$ per IP/year):

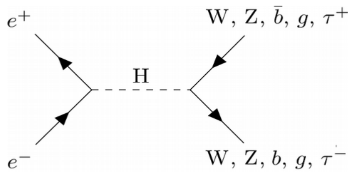


[Monochromatization studies: Valdivia-Zimmermann]

- Best limit per IP/year: $y_e < 2.5\times y_{e,SM}$ (95% CL) in ($\sqrt{s}_{spread}$=7–10 MeV, $\mathscr{L}_{int}$=2–3 ab^{-1}) region.

Conclusions

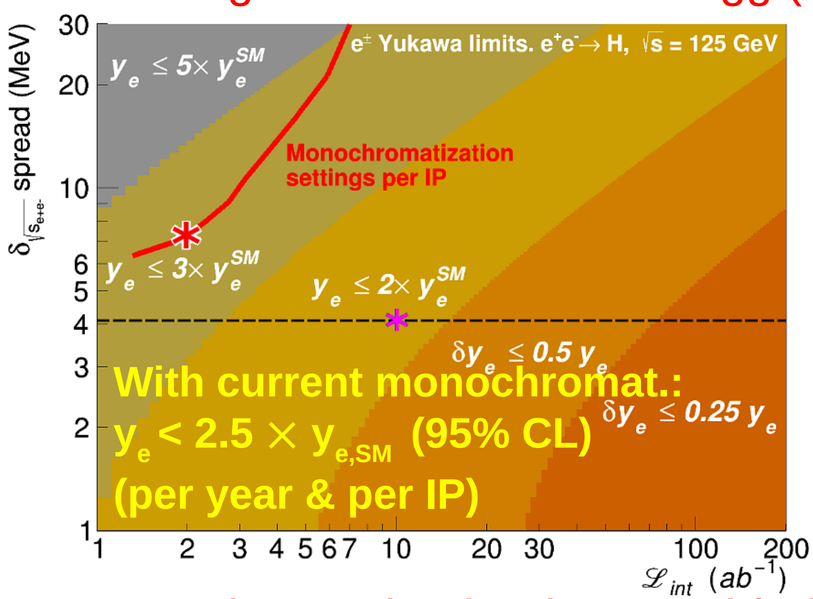
- Resonant s-channel Higgs production at FCC-ee ($\sqrt{s}$ = 125.00 GeV):



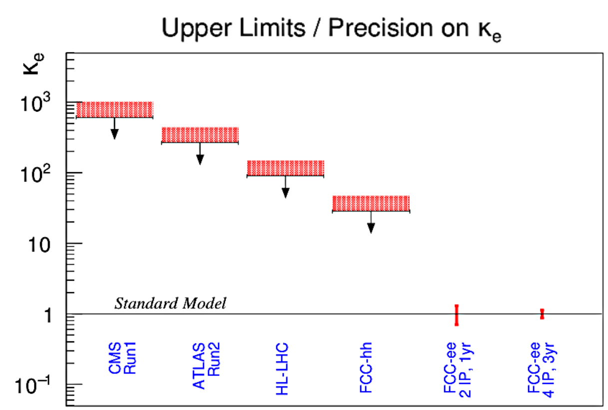
$\sigma(e^+e^-\to H)_{B\text{-}W}$ = 1.64 fb

$\sigma(e^+e^-\to H)_{spread}$ = 280 ab (ISR + $\sqrt{s}_{spread} = \Gamma_H$ = 4.1 MeV)

- Prerequisite: Higgs mass extraction δm_H = O(3 MeV) via HZ @ 240,217 GeV
- Generator-level study for signal + backgrounds for 10 decay channels:
  Most significant channels: H→gg (for light-q mistag ~1%), H→WW*→l+jets



For 10 ab^{-1} & $\sqrt{s}_{spread} = \Gamma_H$: Signif ≈ 1.3σ



- Monochromatization improvable beyond ($\sqrt{s}_{spread}$, $\mathscr{L}_{int}$)≈(7 MeV, 2 ab^{-1})?
- Fundamental unique physics accessible:
  → Electron Yukawa coupling: Limits ×100 (×30) better than HL-LHC (FCC-hh)
  → BSM scale affecting $e^\pm$ Yukawa pushed up to Λ_{BSM} > 110 TeV