Electron Yukawa from s-channel Higgs production at FCC-ee(125 GeV)

EF01 Working Group Meeting

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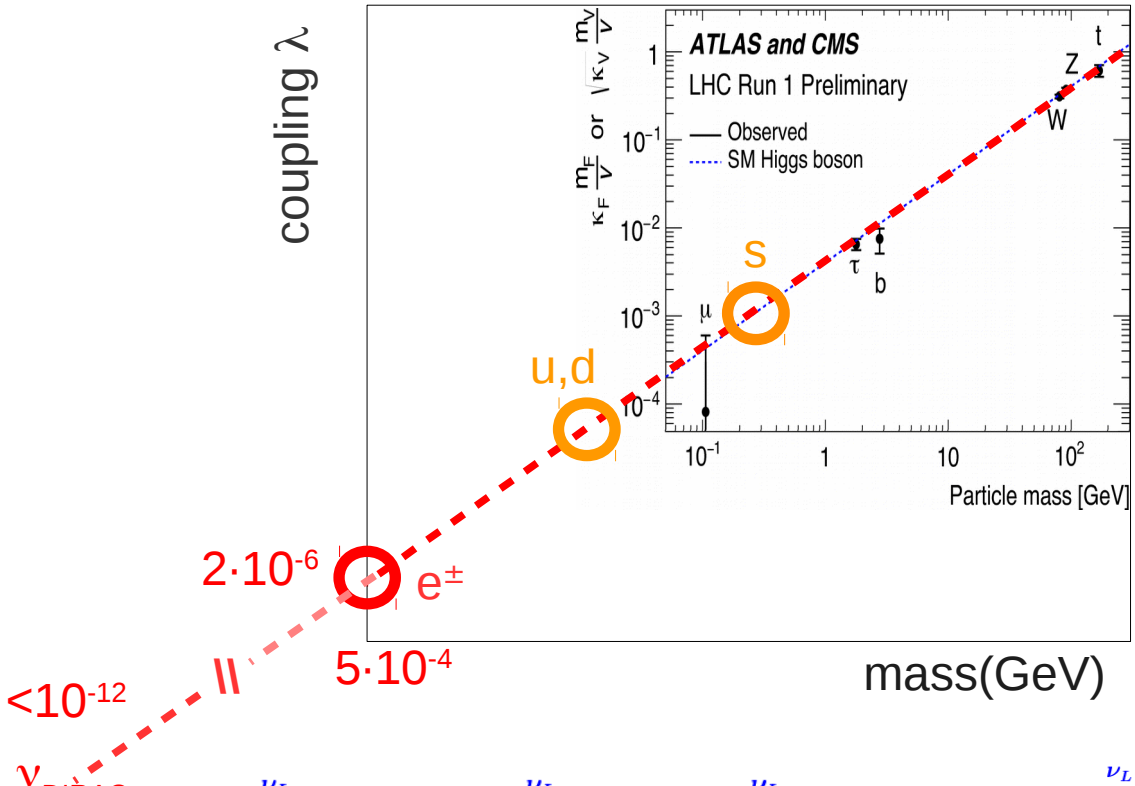
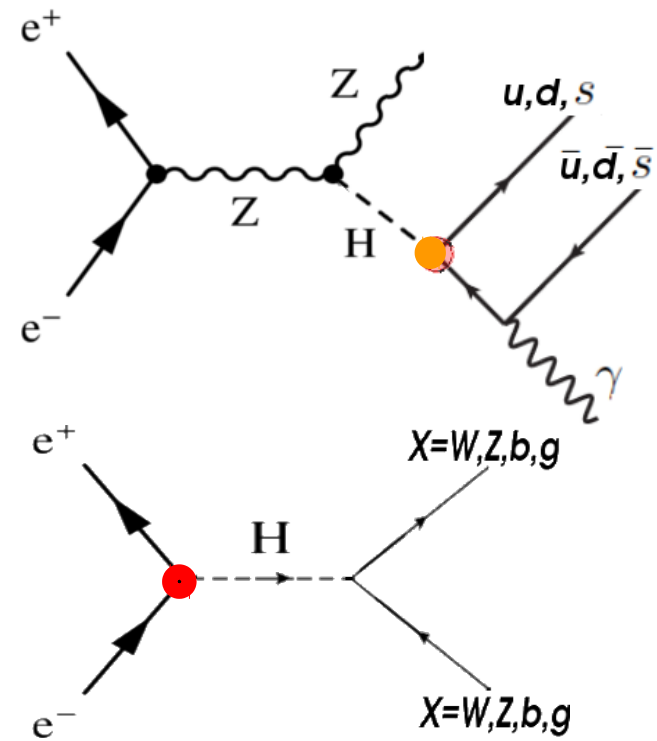
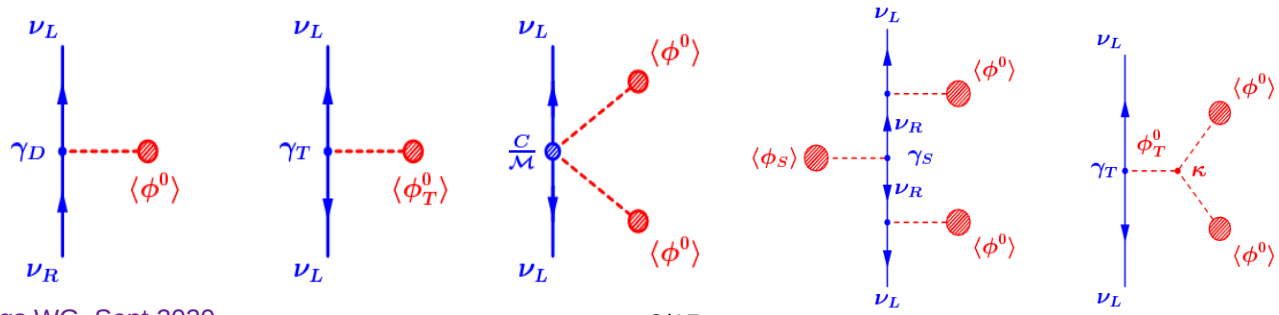
Generation of lightest fermion masses?

- 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?



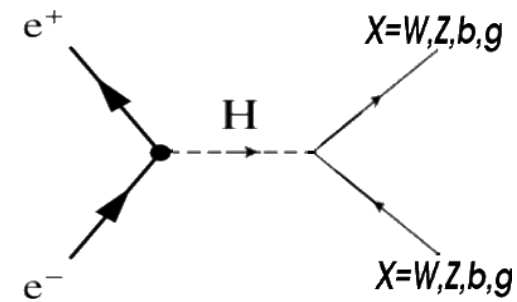




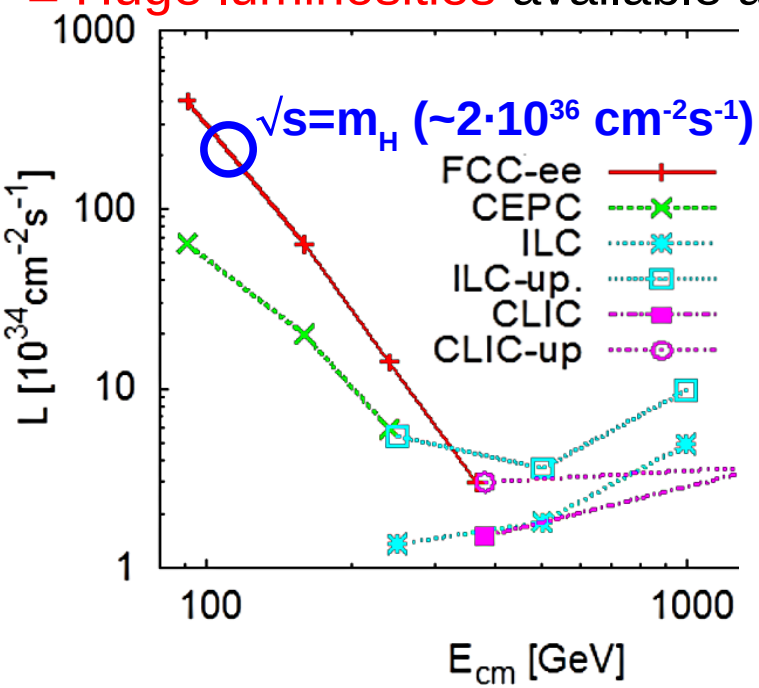
e Yukawa via s-channel $e^+e^- \to H$ production

- Higgs decay to e^+e^- is unobservable: BR($H \to e^+e^-$) $\propto m_e^2 \approx 5 \cdot 10^{-9}$
- 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 $\sigma(ee \to H)$:

$$\sigma(e^+ e^- \to H) = \frac{4\pi\Gamma_H^2 Br(H \to e^+e^-)}{(\hat{s} - M_H^2)^2 + \Gamma_H^2 M_H^2} = 1.64 \text{ fb } (m_H = 125 \text{ GeV}, \Gamma_H = 4.2 \text{ MeV})$$



- Huge luminosities available at FCC-ee:



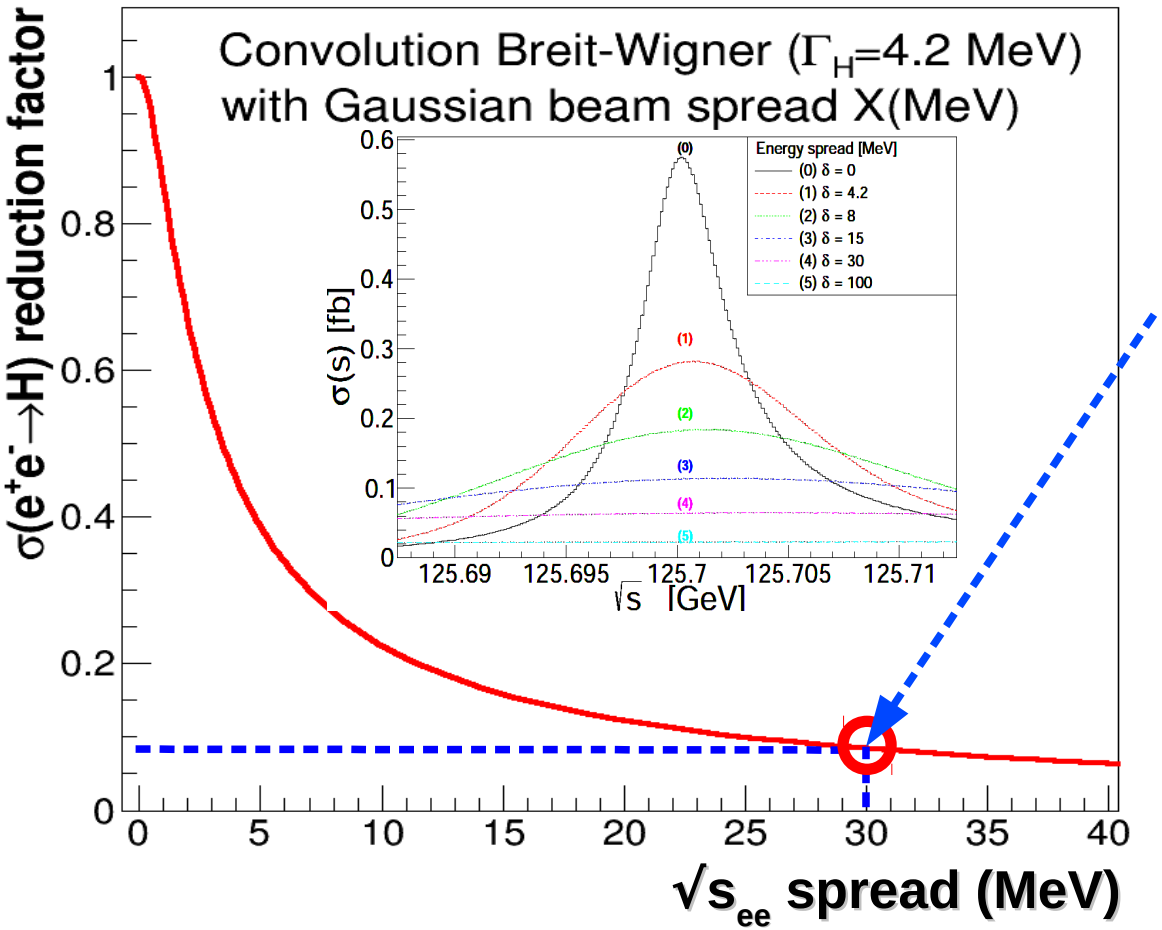
In theory, FCC-ee running at H pole-mass $L_{int} \approx 20$ ab^{-1}/yr would produce O(30.000) H's

IFF we can control: (i) beam-energy spread, (ii) ISR, and (iii) huge backgrounds, then:

→ Electron Yukawa coupling measurable.
→ Higgs width measurable (threshold scan)?
→ Separation of possible nearly-degen. H's?

"Actual" s-channel $e^+e^- \to H$ cross section

- $\sigma(e^+e^- \to H)$ = 1.64 fb for Breit-Wigner with natural Γ_H = 4.2 MeV width. But Higgs production greatly suppressed off resonant peak.
- Convolution of Gaussian energy spread of each $e^\pm$ beam with Higgs Breit-Wigner results on a (Voigtian) effective cross-section decrease:



For $\sqrt{s}_{spread} \approx$ 30 MeV:
Reduction factor: $\times$1/12

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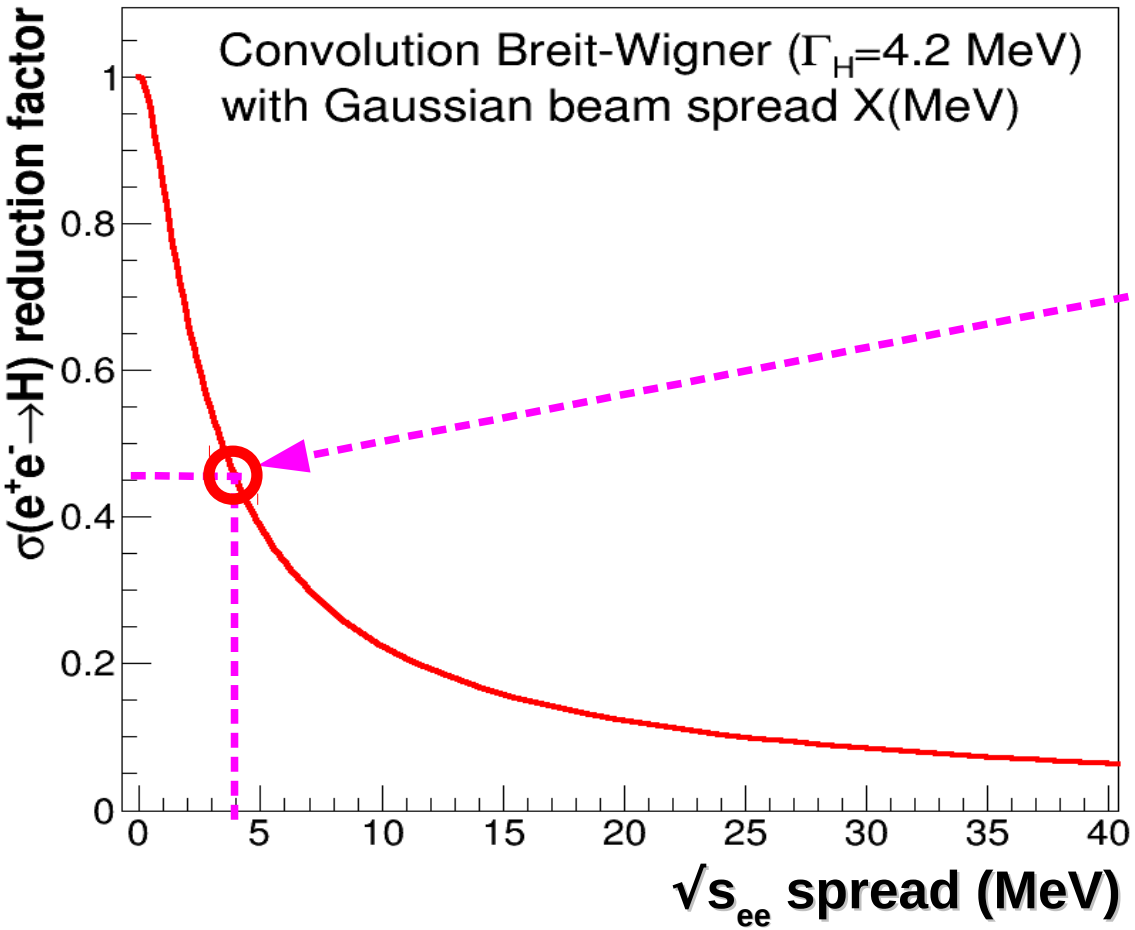


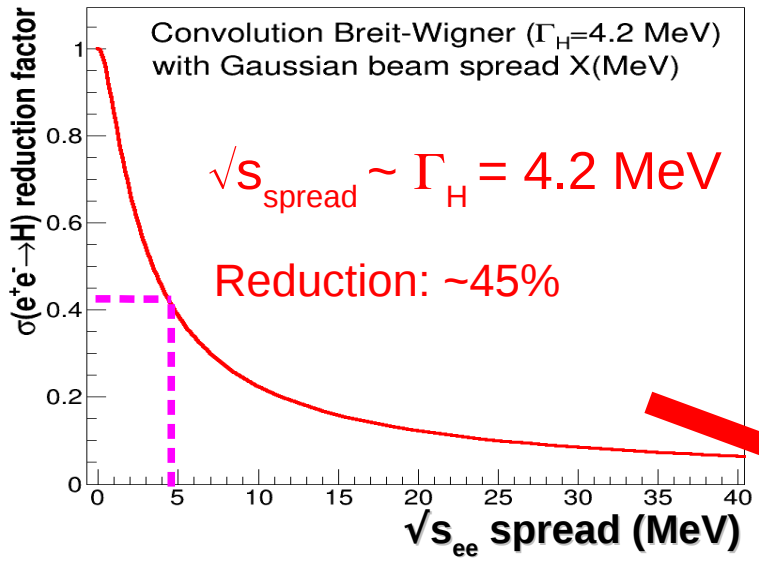
$\sqrt{s_{spread}} = \Gamma_H$ = 4.2 MeV

~45% x-section reduction

Reachable with beams monochromatization?
What luminosity loss price?

[F.Zimmermann, A.Valdivia:
JACoW-IPAC2017-WEPIK015
JACoW-IPAC2019-MOPMP035
See F. Zimmemann's slides]

"Actual" s-channel $e^+e^- \to H$ cross section

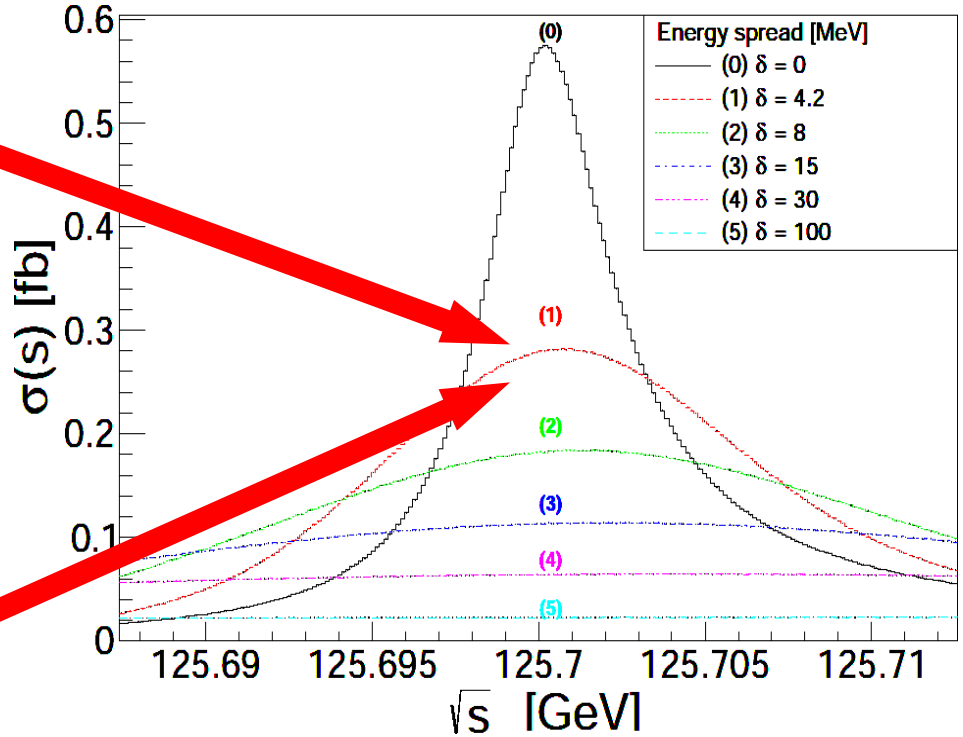


Note: Higgs pole known to within ±5MeV

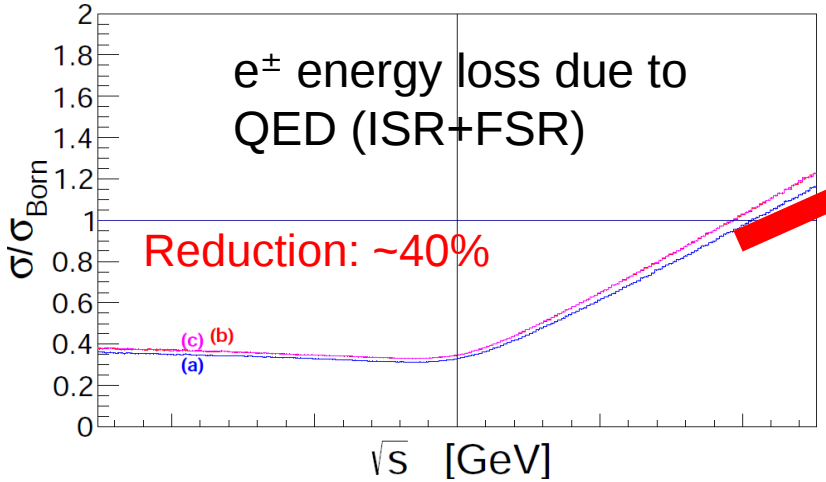
Monochrom. goal: $\sqrt{s}_{spread} \approx \Gamma_H = 4.2$ MeV

- Full convolution of both effects:

[S.Jadach, R. Kycia, PLB755 (2016) 58]



- Extra ~40% reduction due to QED radiation:

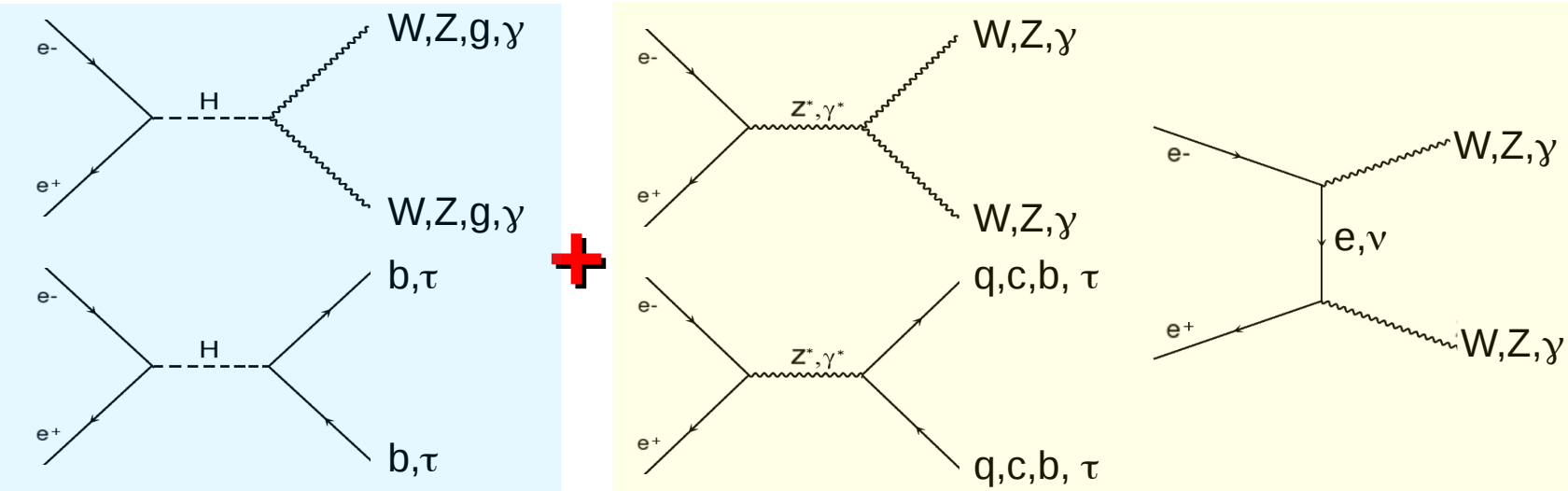


$\sigma_{spread+ISR}(e^+e^- \to H) = 0.17 \times \sigma(e^+e^- \to H) = 290$ ab

Signal & backgrounds simulation

- PYTHIA8 e^+e^- at $\sqrt{s} = m_H = 125$ GeV to generate 10 final-states for Higgs signal plus backgrounds ($e^+e^- \to WW^*, ZZ^*, \gamma\gamma$, gg, $\tau\tau$, bbar, ccbar, qqbar):

SIGNAL **BACKGROUNDS (s-channel Z/γ, all t-channels)**

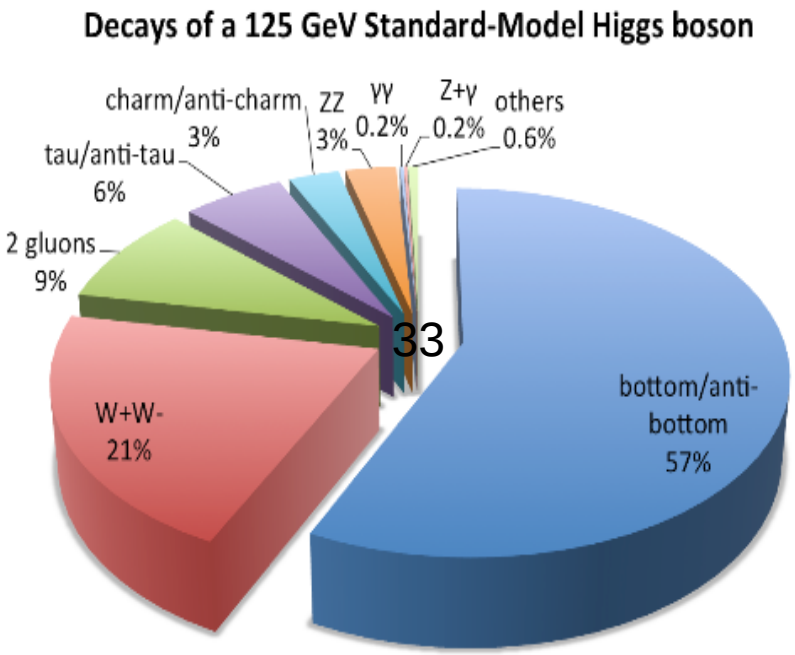


(other SM loop-induced $e^+e^- \to H$ found negligible)

- HDECAY: Higgs boson decay branching ratios
- YFSWW/ZZ/MG5 calculators to cross-check PYTHIA8 x-sections
- FastJet package: Exclusive e^+e^- (N_j=2,4) jet algorithm
- Event-shape variables: [Webber 2007]
- ISR switched-on in PY8, $\sqrt{s}_{spread}$ via scaling to match $\sigma(e^+e^- \to H)$=290 ab

Higgs measurement at FCC-ee(125 GeV)

- Very-rare counting experiment over 10 decay channels:



- *Other 2-jet final-state ($c\bar{c}$) swamped by $e^+e^- \to Z^*, \gamma^* \to cc$ (20 pb)*
- *Other 4-jet final-state (ZZ^*) swamped by $e^+e^- \to Z^*, \gamma^* \to q\bar{q}$ (100 pb), $e^+e^- \to WW^*, ZZ^*$ (20 fb)*
- *Rarer decays (4ℓ) have ~0 counts.*

1) $b\bar{b}$ (2 b-jets): σ = 156 ab

Dominant bckgd ($ee \to b\bar{b}$): σ=20 pb (S/B~10^{-5})

2) WW* (4j): σ = 28 ab

Dominant bckgd ($ee \to 4j$): σ=16 fb (S/B~10^{-3})

3) WW* (2jlν): σ = 27 ab

Dom. bckgd ($ee \to WW^*$): σ=20 fb (S/B~10^{-3})

4) WW* (2l2ν): σ = 6.7 ab

Dom. bckgd ($ee \to WW^*$): σ=5 fb (S/B~10^{-3})

5) gg (2 jets): σ = 24 ab

Dom. bckgd (ee→"gg"): σ=0.9 pb (S/B~10^{-4})

6) ττ (2 τ-jets): σ = 7.5 ab

Dom. bckgd ($ee \to \tau\tau$): σ=10 pb (S/B~10^{-7})

7) ZZ* (2j2ν): σ = 2.3 ab

Dom. bckgd ($ee \to ZZ^*$): σ=213 ab (S/B~10^{-2})

8) ZZ* (2l2j): σ = 1.14 ab

Dominant bckgd ($ee \to ZZ^*$):σ=114 ab (S/B~10^{-2})

9) ZZ* (2l2ν): σ = 0.34 ab

Dominant bckgd ($ee \to \tau\tau$):σ=10 pb (S/B~10^{-8})

10) γγ (2 isolated γ): σ = 0.65 ab

Dominant bckgd ($ee \to \gamma\gamma$): σ=36 pb (S/B~10^{-8})

Event selection variables & efficiencies

- Single & pair kinematical variables for jets, leptons :

  $p_{T,i}$, η_i, ϕ_i, $mass_i$, $charge_i$, ΔR_{isol} (Isolation: $\Sigma E<1$ GeV, $\Delta R<0.25$)

  $p_{T,max}$, $p_{T,min}$, η_{max}, η_{min}, ϕ_{max}, ϕ_{min} (All objects reconstructed within $|\eta|<5$ acceptance)

  m_{inv}, $\cos(\theta_{ij})$, $\Delta\eta_i$, $\Delta\phi_i$, H_T

- Global event variables:

  E_{tot}, missing energy vector (ME, m_{ME})

  Sphericity, aplanarity, thrust min, thrust max,...

- Jet(s)/tau reconstruction performances:

  b-jet tagging effic. = 70%
  charm-jet mistag rate = 5%
  light-q mistag rate = 1.5%

  c-jet tagging effic. = 80%
  b-jet mistag rate = 18%
  light-q mistag rate = 2%
  e-γ mistag rate = 0.3%

  g-tagging effic. = 60%
  light-q mistag rate = 5%
  τ-tagging rate = 80%
  τ-mistag rate = 0.75%

– Kinematics cuts applied to reducible backgrounds.

– MVA BDT applied to (dominant) irreducible continuum.

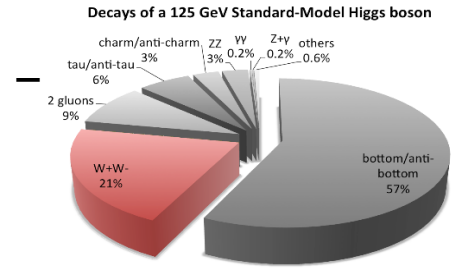
- ISR events tagged via 2 methods (depending on ν's in final state):

  (1) Cut on the ME vector. ISR photons mostly emitted along beam axis:
  Large missing energy (ME) but low transverse missing energy (MET).

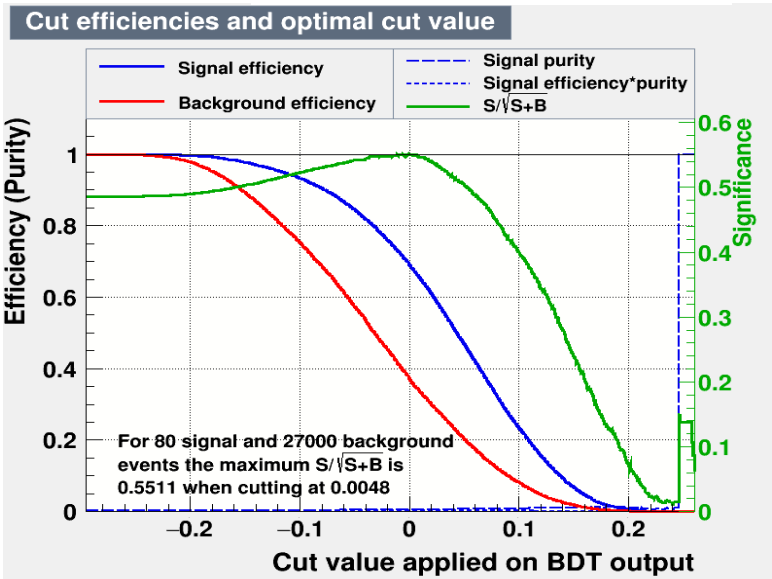
  (2) Cut on E_{tot} (computed without isolated ISR photons within $|\eta|<5$):
  Isolated photons with E>5 GeV omitted: $E_{total} > 120$ GeV

Most significant channel: $e^+e^- \to H(WW^*) \to l\nu jj$

- Final state (retains 80% of $\sigma(WW^*(l\nu jj))$ = 28 ab):
  1 isolated $e,\mu,\tau(e),\tau(\mu)$ + ME>2 GeV + 2 jets (excl.)



- Analysis cuts:
  - ✓ $E_{j1,j2} < 52,45$ GeV ← Kills $e^+e^- \to q\bar{q}$
  - ✓ $m_{w(l\nu)} > 12$ GeV/c^2 ← Kills $e^+e^- \to q\bar{q}$
  - ✓ $E_{lepton} > 10$ GeV ← Kills $e^+e^- \to q\bar{q}$
  - ✓ ME > 20 GeV ← Kills $e^+e^- \to q\bar{q}$
  - ✓ $m_{ME} < 3$ GeV/c^2 ← Kills $e^+e^- \to \tau\tau$
  - ✓ BDT MVA ← Kills $e^+e^- \to WW^*$ continuum
    (exploits opposite $W^\pm$ polarizations in H decay)



- Signal & backgrounds before/after cuts:

$q\bar{q}$:	σ = 22 pb	⇒	σ(after) = 4 ab
$\tau\ \tau$:	σ = 1 pb	⇒	σ(after) = 2.6 ab
WW*:	σ = 16.3 fb	⇒	σ(after) = 2.7 fb
H(WW*):	σ = 23 ab	⇒	σ(after) = 8 ab

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 80/\sqrt{27000} \approx 0.5$
Significance ≈ 0.5

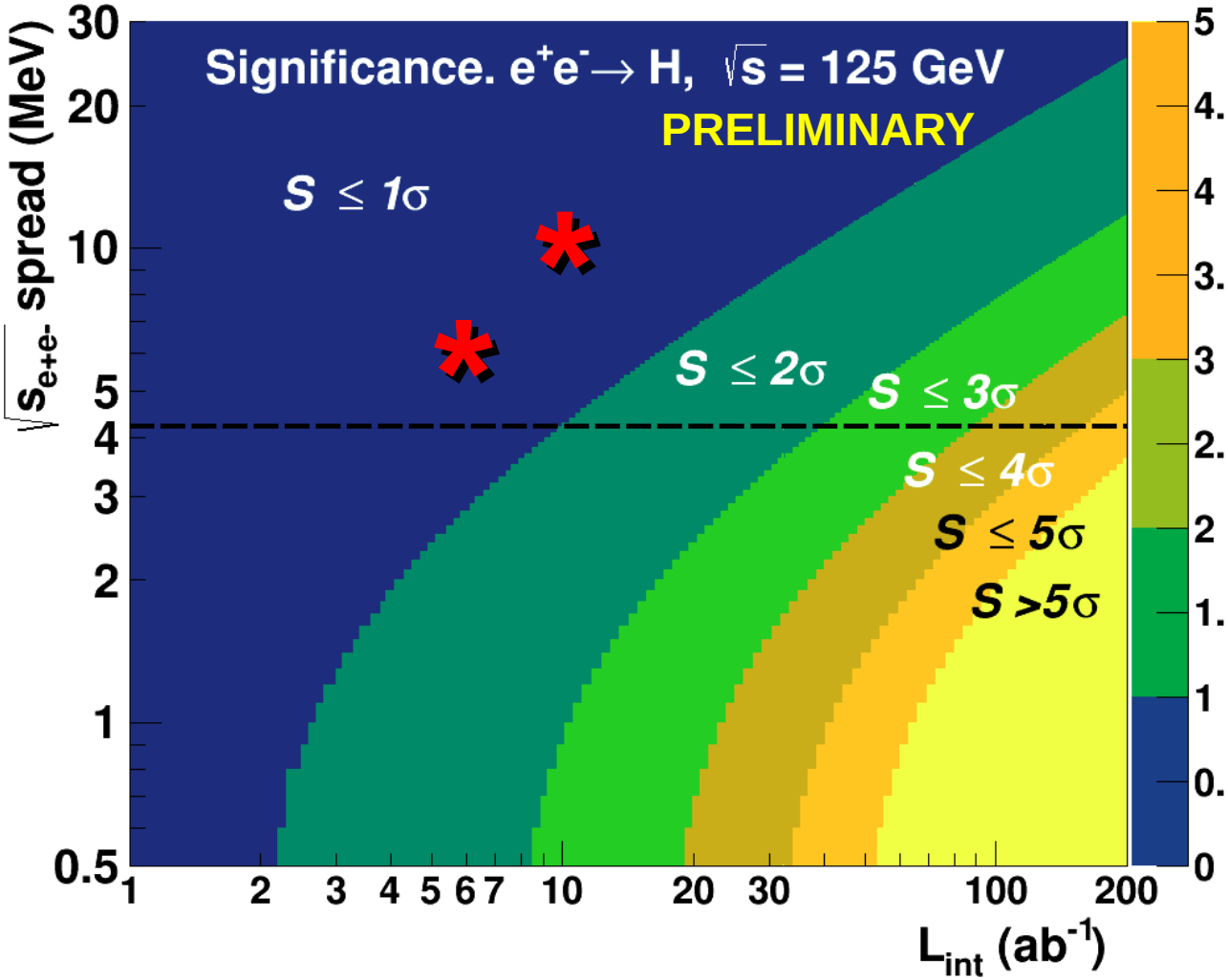
$e^+e^- \to H$ significance: Multi-channel combination

- Channels combination using RooStats-based tool for LHC Higgs analyses: Profile likelihood & hybrid significances give ~identical results, which are also very close to naive $S/\sqrt{B}$ expectation (no background uncertainty).

Channel	Significance (1 ab^{-1})	Significance (10 ab^{-1})
$WW \to l\nu 2j, 2l2\nu, 4j$	$0.15 \oplus 0.09 \oplus 0.03$	$0.50 \oplus 0.30 \oplus 0.08$
$ZZ \to 2j2\nu, 2l2j, 2l2\nu$	$0.07 \oplus 0.05 \oplus 0.01$	$0.21 \oplus 0.16 \oplus 0.03$
bb	0.03	0.10
gg	0.12	0.4
$\tau\tau$	–	0.02
$\gamma\gamma$	–	0.01
Combined	**0.3σ**	**$\sim 1\sigma$**

- For 10 ab^{-1}, and $\sqrt{s}_{spread} \approx \Gamma_H = 4.2$ MeV:
  Significance $\approx 1\sigma$ (preliminary value, optimizations ongoing)

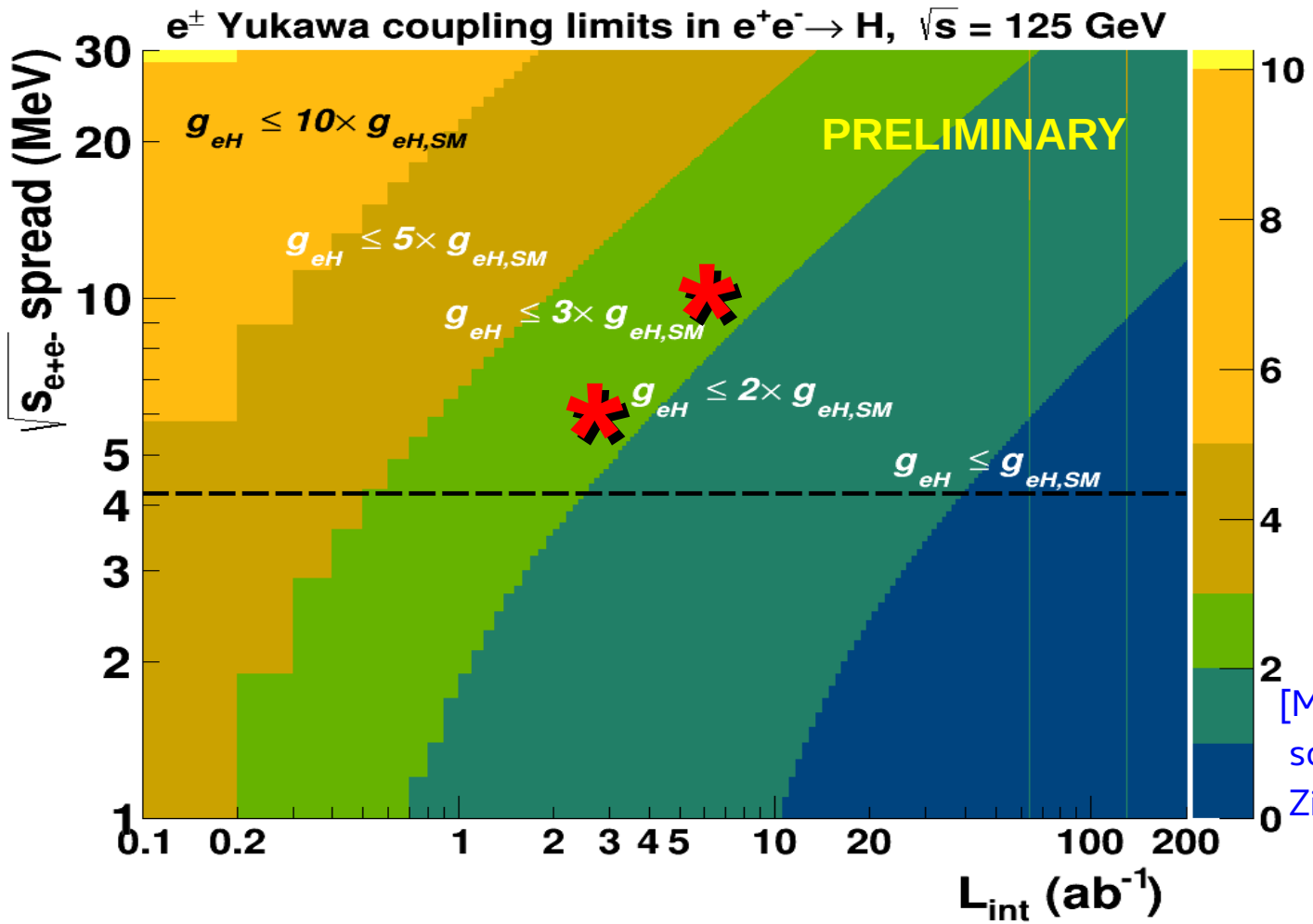
$e^+e^- \to H$ significance vs. L_{int} & $\sqrt{s}_{spread}$



[Monochromatization scenarii so far: See F. Zimmermann's slides]

- Baseline monochromatization ($\sqrt{s}_{spread}$ = 6 MeV, L_{int} = 3 ab^{-1}) : Signif. ~ 0.7σ
- Optimized monochromatization ($\sqrt{s}_{spread}$ = 10 MeV, L_{int} =7 ab^{-1}) : Signif. ~ 0.7σ

κ_e Yukawa limits vs. L_{int} & $\sqrt{s}_{spread}$

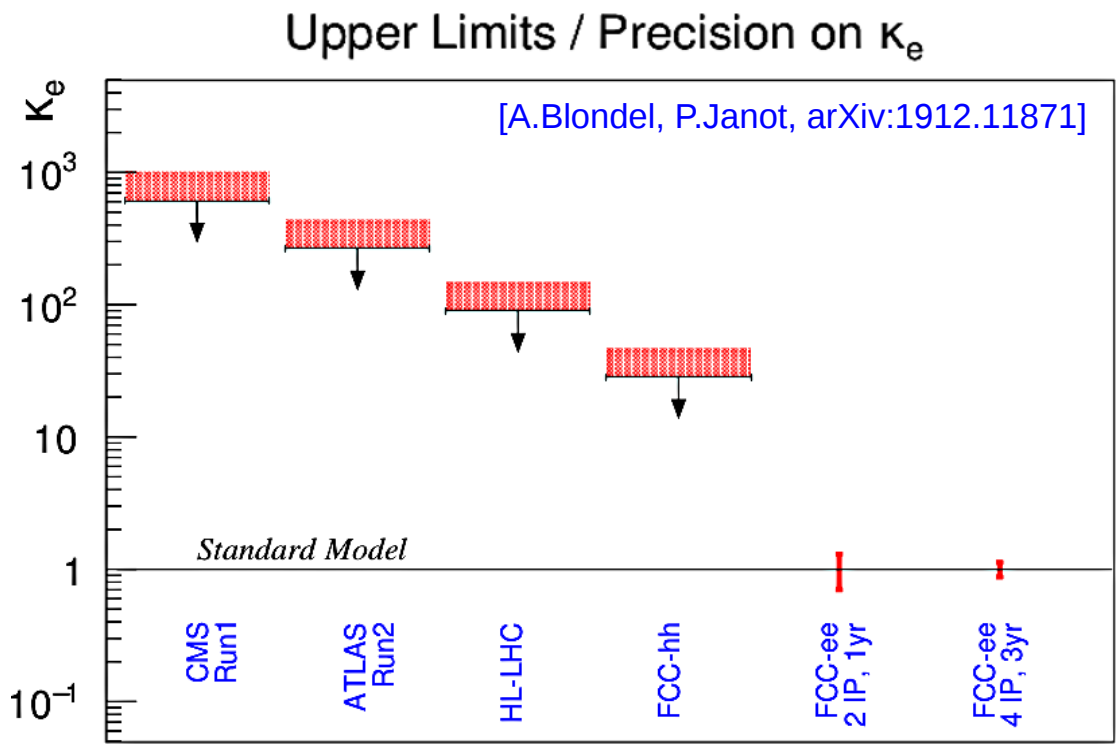


[Monochromatization scenarii so far: See F. Zimmermann's slides]

- Baseline monochrom. ($\sqrt{s}_{spread}$ = 6 MeV, 3 ab^{-1}): $\kappa_e < 3\times \kappa_{e,SM}$ (95% CL)
- Optimized monochrom. ($\sqrt{s}_{spread}$ = 10 MeV, 7 ab^{-1}): $\kappa_e < 3\times \kappa_{e,SM}$ (95% CL)

κ_e Yukawa limits at various machines

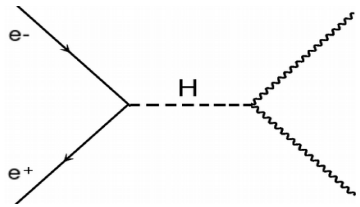
- Hadron machines can very loosely constrain κ_e via $H \to e^+e^-$ searches on top of huge DY (and $H \to \gamma\gamma$) backgrounds:



- Limits on κ_e are $\times 100$ ($\times 30$) better than at HL-LHC (FCC-hh).
- Depending on # IPs, yrs, improved monochrom.: $\kappa_e < 1 \times \kappa_{e,SM}$ (95% CL) at reach

Conclusions

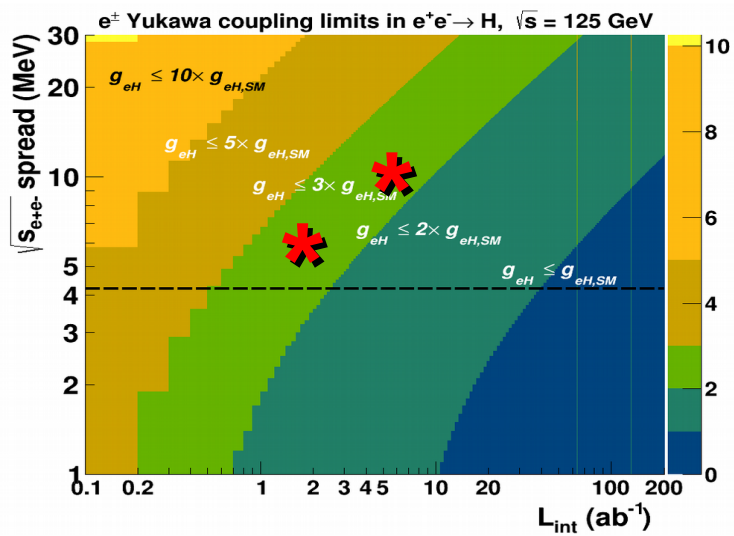
- Resonant s-channel Higgs production at FCC-ee ($\sqrt{s}$ = 125 GeV):

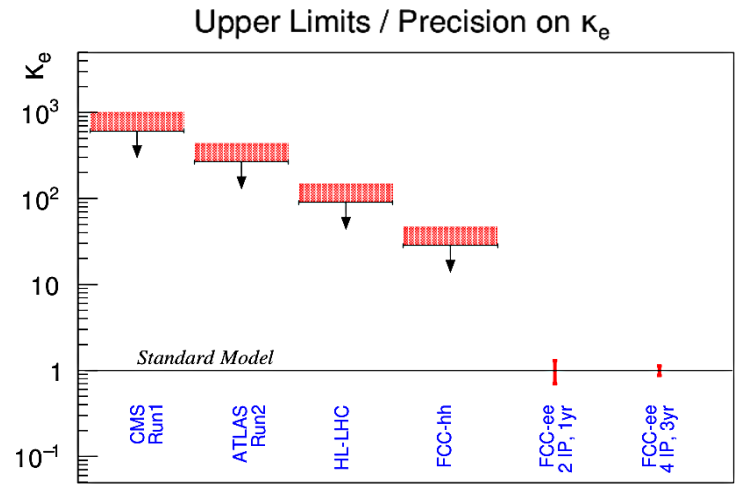


$\sigma(e^+e^-\to H)_{B\text{-}W}$ = 1.64 fb

$\sigma(e^+e^-\to H)_{spread}$ = 290 ab (ISR + $\sqrt{s}_{spread} = \Gamma_H$ = 4.2 MeV)

- Preliminary study for signal + background for 10 decay channels.





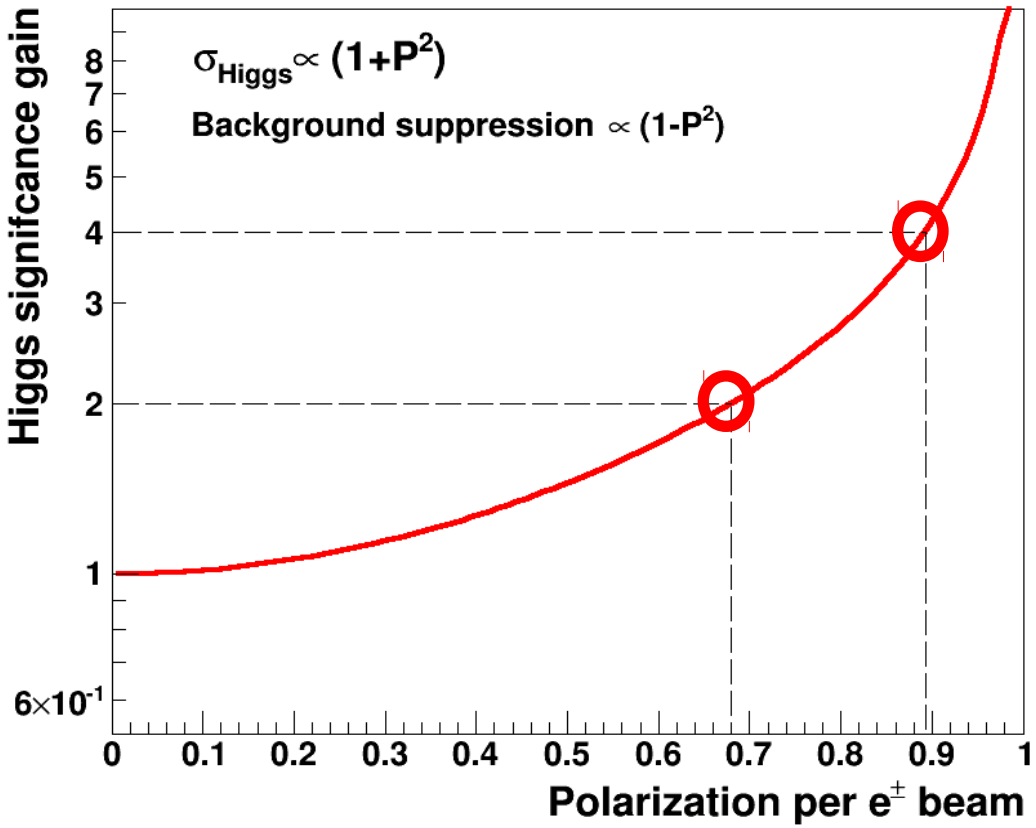
Significance ~ 1σ (ongoing improvements). Bounds on κ_e at SM level.

- Improve analysis? Study best monochromatization $\sqrt{s}_{spread}$,L_{int} working point
- Fundamental unique physics accessible:
  - → Electron Yukawa coupling: Limits ×100 (×30) better than HL-LHC (FCC-hh)
  - → Higgs width ("natural" threshold scan)? Separation of BSM nearly-degen. H's?

Backup slides

Polarized beams? Other physics at √s=125 GeV?

- Polarization of beams would enhance the signal by (1+Pol^2) and suppress background by (1-Pol^2). However, realistic longit. polarization estimates (Pol=20-30%) are clearly insufficient, higher polarizations would reduce Luminosity, unclear with monochromatization...



- Significance increase:

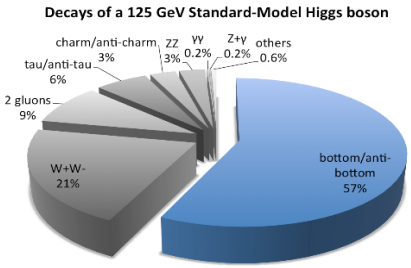
  Pol. = 68%: ×2 significance

  Pol. = 90%: ×4 significance

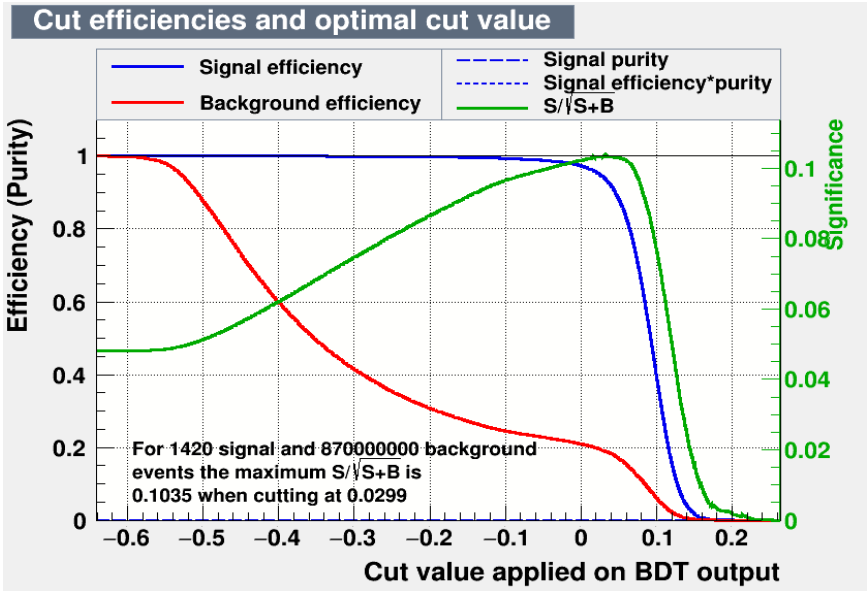
- What other physics can one do running at Higgs pole?
  – Counting of number of neutrinos, Z with ISR, QCD, flavour,...

Channel 1: $e^+e^- \to H(bb) \to 2$ b-jets

- Final state (retains 90% of σ(bb) = 156 ab):
  2 jets (exclusive) + 1 b-jet tagged + 0 τ(had)



- Analysis cuts:
  - ✓ Kinematics: None.
  - ✓ BDT MVA applied to reduce dominant $Z^*\gamma^* \to$bbar continuum



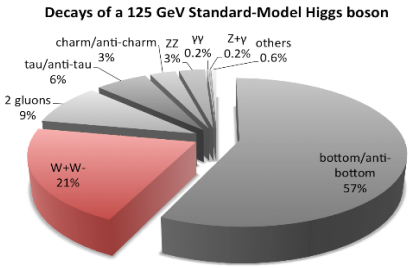
- Signal & backgds before/after MVA cuts:

H(bb): σ = 142 ab $\Rightarrow$ σ (after) = 131 ab
qqar: $\sigma \approx$ 20 pb $\Rightarrow$ σ (after) = 17 pb
τ-τ: σ = 607 ab $\Rightarrow$ σ (after) = 375 ab

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 1310/\sqrt{1.7e+8} \approx 0.1$
Significance $\approx$ 0.1

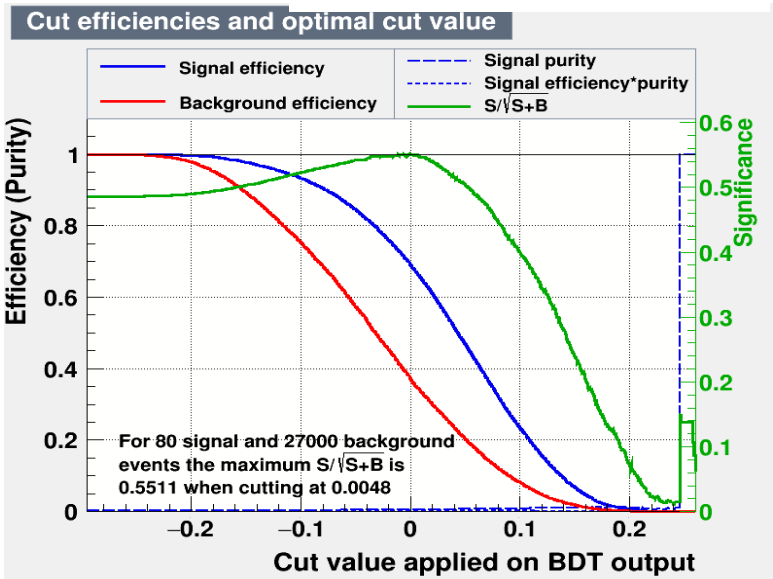
Channel 2: $e^+e^- \to H(WW^*) \to l\nu jj$

- Final state (retains 80% of $\sigma(WW^*(l\nu jj))$ = 28 ab):
  1 isolated $e,\mu,\tau(e),\tau(\mu)$ + ME>2 GeV + 2 jets (excl.)



- Analysis cuts:
  - ✓ $E_{j1,j2} < 52,45$ GeV ← Kills qqbar
  - ✓ $m_{w(l\nu)} > 12$ GeV/c^2 ← Kills qqbar
  - ✓ $E_{lepton} > 10$ GeV ← Kills qqbar
  - ✓ ME > 20 GeV ← Kills qqbar
  - ✓ $m_{ME} < 3$ GeV/c^2 ← Kills τ-τ
  - ✓ BDT MVA ← Kills WW* continuum

(exploits opposite W± polarizations in H decay)



- Signal & backgrounds before/after cuts:

H(WW*):	σ = 23 ab	⇒	σ(after) = 8 ab
WW*:	σ = 16.3 fb	⇒	σ(after) = 2.7 fb
qqbar:	σ = 22 pb	⇒	σ(after) = 4 ab
τ-τ:	σ = 1 pb	⇒	σ(after) = 2.6 ab

For L_{int}=10 ab^{-1}

$S/\sqrt{B} = 80/\sqrt{27.e3} \approx 0.5$

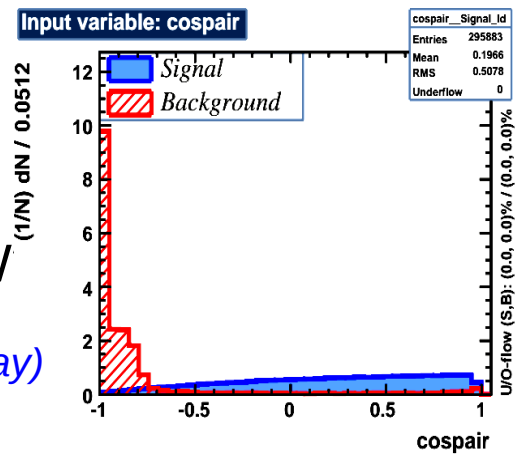
Significance ≈ 0.5

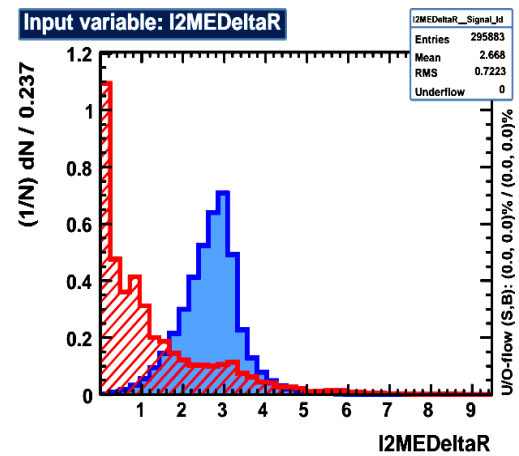
Channel 3: $e^+e^- \to H(WW^*) \to 2l2\nu$

- Final state (retains 60% of $\sigma(WW^*(2l2\nu))$ = 7 ab):
  2 isolated $e,\mu,\tau(e),\tau(\mu)$ + ME > 2 GeV
  + 0 non-isolated leptons or ch.had.
- Analysis cuts (Preselection kills qqbar entirely):
  - ✓ $\cos(\theta_{l1l2})>-0.6$ ← Kills τ-τ
  - ✓ $\Delta R(l_2,ME) > 1.5$ ← Kills τ-τ
  - ✓ $E_{l1,l2} > 3$ GeV ← Kills τ-τ
  - ✓ ME > 20 GeV ← Kills τ-τ
  - ✓ BDT MVA ← Kills WW

(exploits opp. $W^\pm$ polarizations in H decay)

(indicative distributions only: normalized to 1)





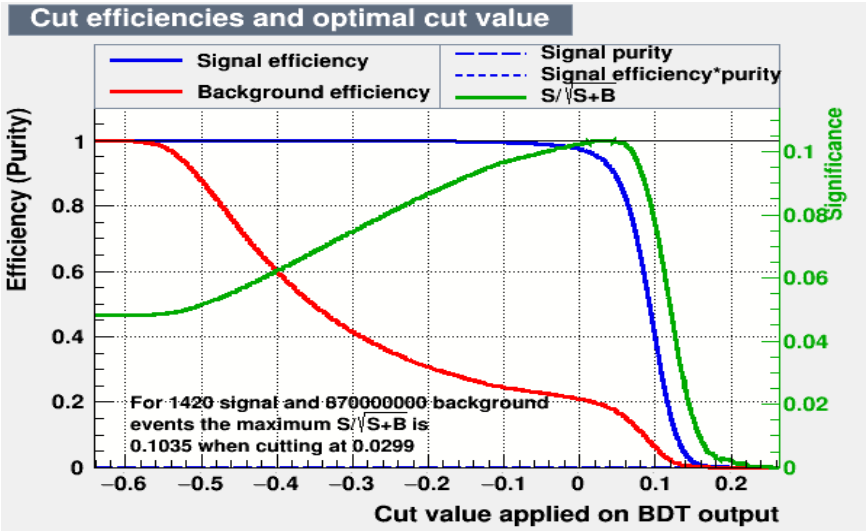
- Signal & backgds before/after cuts:
  H(WW*): σ = 4 ab ⇒ σ(after) = 2.1 ab
  WW*: σ = 2.9 fb ⇒ σ(after) = 454 ab
  τ-τ: σ = 3.1 pb ⇒ σ(after) = 51 ab
  qqbar: σ ~ 0 pb ⇒ σ(after) = 0 ab
  ZZ*: σ = 24 ab ⇒ σ(after) = 0.4 ab

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 21/\sqrt{5000} \approx 0.3$
Significance ≈ 0.3

Channel 4: $e^+e^- \to H(WW^*) \to 4j$

- Final state (retains 9% of σ(WW*(4j)) = 29 ab):
  4 jets (excl.) + >=1 jet c-tagged jet + 0 b-jets + 0 g-jets
  Jets with $m_{j1j2} \sim m_W$ not both c-tagged + 0 τ(had)
  + 0 isolated e,μ,τ(e),τ(μ)

- Analysis cuts:
  - ✓ $-\ln(y_{j3,jet4}) > 5.$, $E_{total} > 110$ GeV
  - ✓ $\max(M_{jj}) = 60$–85 GeV/c^2
  - ✓ $|\Delta\phi_{Z\ decay\ planes}| < 1.$
  - ✓ BDT MVA



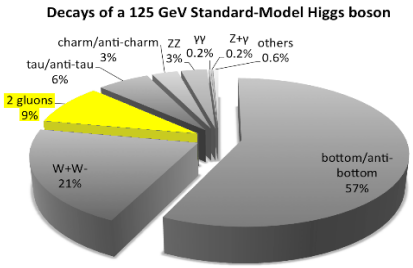
- Signal & backgrounds before/after cuts:

H(WW*):	σ = 2.75 ab	$\Rightarrow$	σ(after) = 1.4 ab
qqbar:	σ = 15.7 fb	$\Rightarrow$	σ(after) = 2 fb
WW*:	σ = 1.4 fb	$\Rightarrow$	σ(after) = 810 ab
τ-τ:	σ= 0 ab	$\Rightarrow$	σ(after) = 0 ab
ZZ*:	σ = 4 ab	$\Rightarrow$	σ(after) = 1.38 ab

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 14/\sqrt{29.e3} \approx 0.08$
Significance $\approx$ 0.08

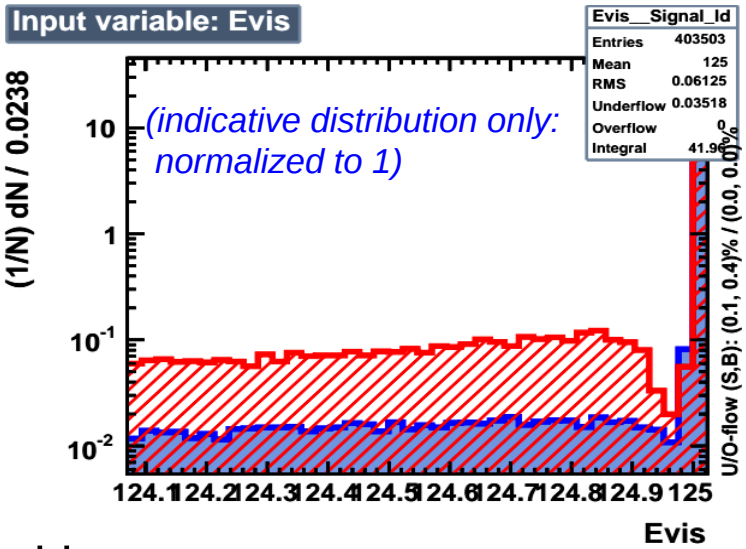
Channel 5: $e^+e^- \to H(gg) \to jj$

- Final state (retains 30% of σ(gg) = 24 ab):
  2 gluon-tagged jets
  + 0 isolated e,μ,τ(e),τ(μ) + 0 τ(had)



- Analysis cuts:

  ✓ E_{tot} > 124 GeV
  Kills part of $\tau\tau$,WW,ZZ



- Signal & backgrounds before/after kin. cuts:

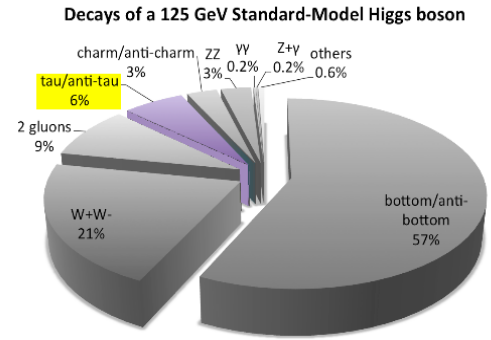
H(gg):	σ=7.34 ab	$\Rightarrow$	σ (after) = 3.91 ab
qqbar:	σ=0.86 pb	$\Rightarrow$	σ (after) = 1.1 fb
τ-τ:	σ = 607 ab	$\Rightarrow$	σ (after) = 257 ab
WW*:	σ = 44.6 ab	$\Rightarrow$	σ (after) = 26 ab
ZZ*:	σ = 0.74 ab	$\Rightarrow$	σ (after) = 0.26 ab

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 39/\sqrt{1.1e5} \approx 0.4$
Significance $\approx$ 0.4

Channel 6: $e^+e^- \to H \to \tau_{had}\tau_{had}$

- Final state (retains 65% of $\sigma(\tau\tau)$ = 7.4 ab):

  2 jets (exclusive) + 2 tau-jet tagged
  + 0 isolated final-state leptons



- Analysis cuts:

  ✓ Kinematics cuts: None

  ✓ MVA BDT applied to reduce dominant $Z^*/\gamma^* \to \tau\tau$ continuum.

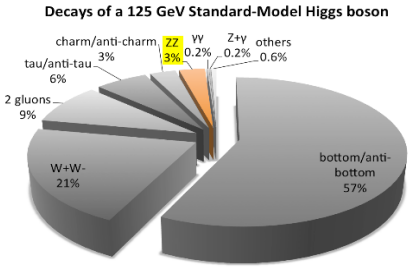
- Signal & backgds before/after MVA cuts:

H($\tau\tau$): σ = 7.4 ab $\Rightarrow$ σ (after) = 1.5 ab
qqbar: σ = 87 pb $\Rightarrow$ σ (after) = 75 ab
τ-τ: σ = 10 pb $\Rightarrow$ σ (after) = 100 fb

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 15/\sqrt{1e+6} \approx 0.02$
Significance $\approx$ 0.02

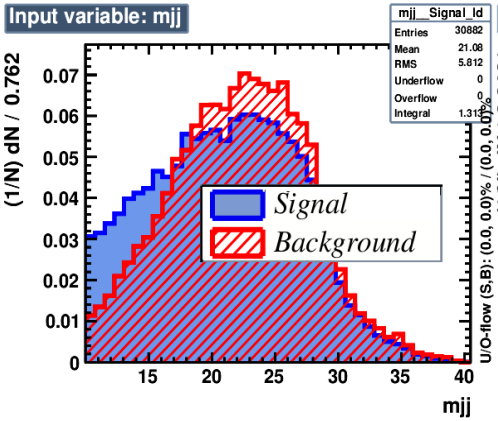
Channel 7: $e^+e^- \to H(ZZ^*) \to 2j2\nu$

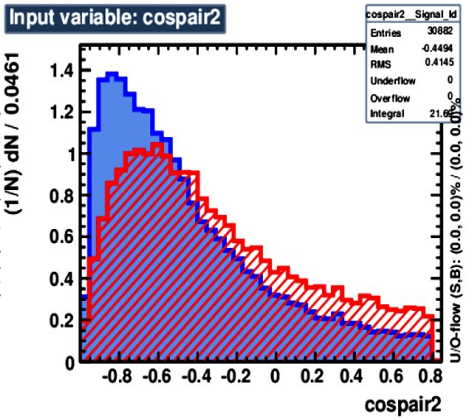
- Final state (retains 75% of σ(WW*(2j2ν)) = 2.3 ab):
  2 jets (excl.) + ME > 30 GeV
  + 0 isolated e,μ,τ(e),τ(μ) + 0 τ(had)



- Kinematic cuts:
  - ✓ $\min(|m_{ME}-m_Z|,|m_{jj}-m_Z|)<10$ GeV ← Kills qqbar,τ-τ
  - ✓ $E_{tot} > 120$ GeV ← Kills qqbar,τ-τ
  - ✓ $m_{ME} > 60$ GeV/c^2 ← Kills qqbar,τ-τ
  - ✓ $\cos(\Delta\theta_{ME,j2}) < 0.8$ ← Kills τ-τ
  - ✓ $|\eta_{jj}| < 2$ ← Kills qqbar,τ-τ
  - ✓ $E_{jj} > 14$ GeV ← Kills τ-τ

(indicative distributions only: normalized to 1)





- Signal & backgrounds before/afte
  H(ZZ*): σ = 1.75 ab ⇒ σ(after cuts) = 0.37 ab
  ZZ*: σ = 179 ab ⇒ σ(after cuts) = 25 ab
  qqbar: σ = 963 fb ⇒ σ(after cuts) = 4 ab
  τ-τ: σ = 471 ab ⇒ σ(after cuts) = 2 ab
  WW*: σ = 526 ab ⇒ σ(after cuts) = 0 ab

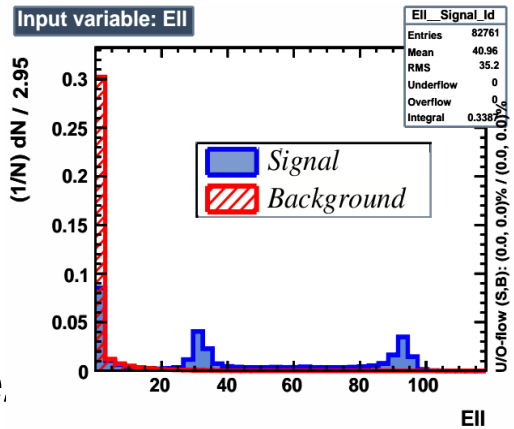
For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 3.7/\sqrt{316} \approx 0.21$
Significance ≈ 0.21

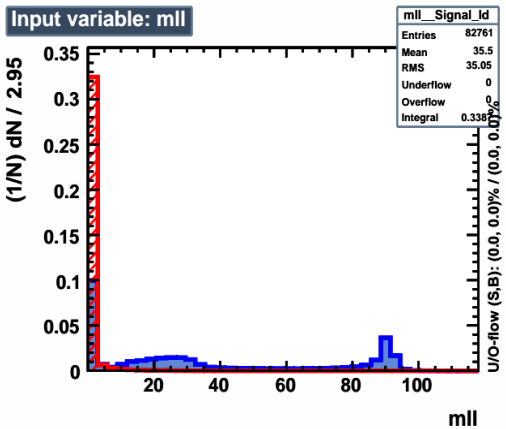
Channel 8: $e^+e^- \to H(ZZ^*) \to 2l2j$

- Final state (retains 73% of σ(WW*(2l2j)) = 1.14 ab):
  2 isolated opposite-charge leptons e,μ,τ(e),τ(μ)
  + 2 jets (exclusive)

- Kinematic cuts:
  - ✓ $\min(|M_{ll}-M_Z|,|M_{jj}-M_Z|) < 20$GeV ← Kills qqbar, τ-τ
  - ✓ ME < 10 GeV
  - ✓ $E_{lepton} > 6$ GeV ← Kills τ-τ
  - ✓ $E_{l1}+E_{l2} > 20$ GeV ← Kills qqbar
  - ✓ $M_{ll} > 20$ GeV/c^2 ← Kills qqbar
  - ✓ $M_{jj} > 10$ GeV/c^2 ← Kills qqbar
  - ← Kills τ-τ

(indicative distributions only: normalized to 1)





- Signal & backgrounds before

H(ZZ*):	σ = 0.84 ab	⇒	σ(after) = 0.27 ab
ZZ*:	σ = 87 ab	⇒	σ(after) = 23 ab
τ-τ:	$\sigma \sim$ 0.8 pb	⇒	σ(after) = 2.5 ab
WW*:	σ = 3.1 fb	⇒	σ(after) = 0.04 ab
qqbar:	σ = 17 pb	⇒	σ(after) = 4 ab

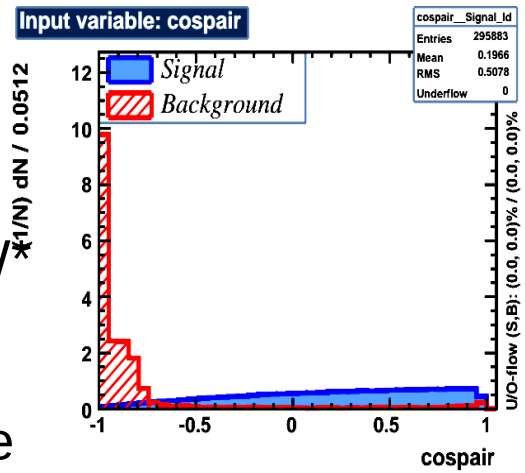
For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 2.7/\sqrt{296} \approx 0.16$
Significance $\approx$ 0.16

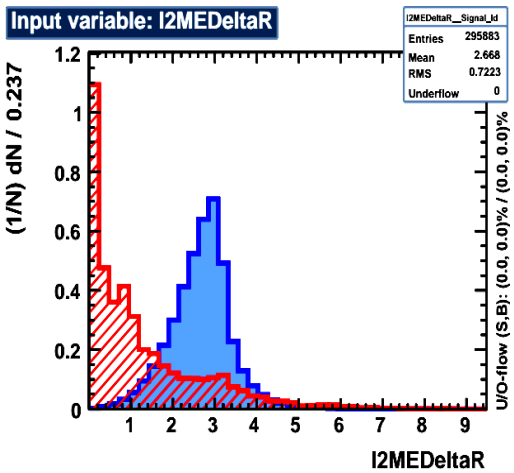
Channel 9: $e^+e^- \to H(ZZ^*) \to 2l2\nu$

- Final state (retains 60% of $\sigma(ZZ^*(2l2\nu))$ = 0.34 ab):
  2 isolated $e,\mu,\tau(e),\tau(\mu)$ + ME>2 GeV
  + 0 non-isolated leptons or ch.had.
- Analysis cuts (Preselection kills qqbar entirely):

✓ $\cos(\theta_{l1l2})>-0.6$ ← Kills τ-τ
✓ $\Delta R(l_2,ME) > 1.5$ ← Kills τ-τ
✓ $E_{l1,l2} > 3$ GeV ← Kills τ-τ
✓ ME > 20 GeV ← Kills τ-τ
✓ BDT MVA ← Kills WW*

(indicative distributions only: normalized to 1)





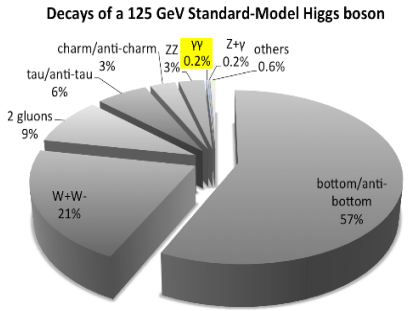
- Signal & backgds before/afte

H(ZZ*): σ = 0.2 ab $\Rightarrow \sigma$(after) = 0.04 ab
WW*: σ = 29 fb $\Rightarrow \sigma$(after) = 144 ab
τ-τ: σ = 3.1 pb $\Rightarrow \sigma$(after) = 51 ab
qqbar: $\sigma \sim 0$ pb $\Rightarrow \sigma$(after) = 0 ab
ZZ*: σ = 24 ab $\Rightarrow \sigma$(after) = 9 ab

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 0.4/\sqrt{2000} \approx 0.01$
Significance $\approx$ 0.01

Channel 10: $e^+e^- \to H \to \gamma\gamma$

- Final state (retains 95% of the $\sigma(\tau\tau)$ = 0.64 ab):
  2 isolated photons (exclusive) + nothing else



- Analysis cuts:

  ✓ E_γ > 60 GeV reduces diphoton continuum & Bhabha scatt. backgd where e^+e^- mis'id for γ with P≈0.35%.

  ✓ MVA BDT doesn't improve result

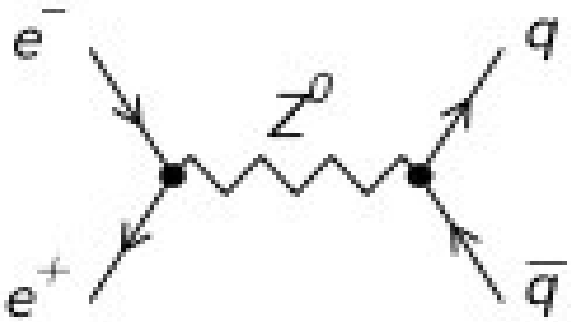
- Signal & backgds before/after cuts:

$H(\gamma\gamma)$:	σ = 0.61 ab	⇒	σ (after) = 0.3 ab
$\gamma\gamma$:	σ = 25 pb	⇒	σ (after) = 900 fb
e^+e^-:	σ = 2.3 pb	⇒	σ (after) = 59 ab

For L_{int}=10 ab^{-1}
$S/\sqrt{B} = 30/\sqrt{1.e4} \approx 0.01$
Significance ≈ 0.01

$e^+e^- \to H(WW^*) \to 4j$

- The qqbar background σ ~O(100 pb) produces mainly 2-jet events, which can be killed by cutting on event shape variables (sphericity & aplanarity), but ~6 pb remains from quarks that radiate gluons to produce 4-jet events.



- Tagging b-jets (which are produced ~20% of the time in the qqbar background and ~5% of the time in the signal) and removing events with any b-tagged jets provides marginal improvement in separation, but the qqbar background still dominates and washes out the signal almost entirely
- Attempts to reconstruct W mass to apply cuts met with little success (low discriminating power). Try hemisphere separation ...