

Search of resonant s-channel Higgs production at FCC-ee

FCC-ee physics workshop

Geneva, 19-20th June 2014

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Resonant s-channel $e^+e^- \rightarrow H$ production

- Resonant Higgs production considered so far only for muon collider:

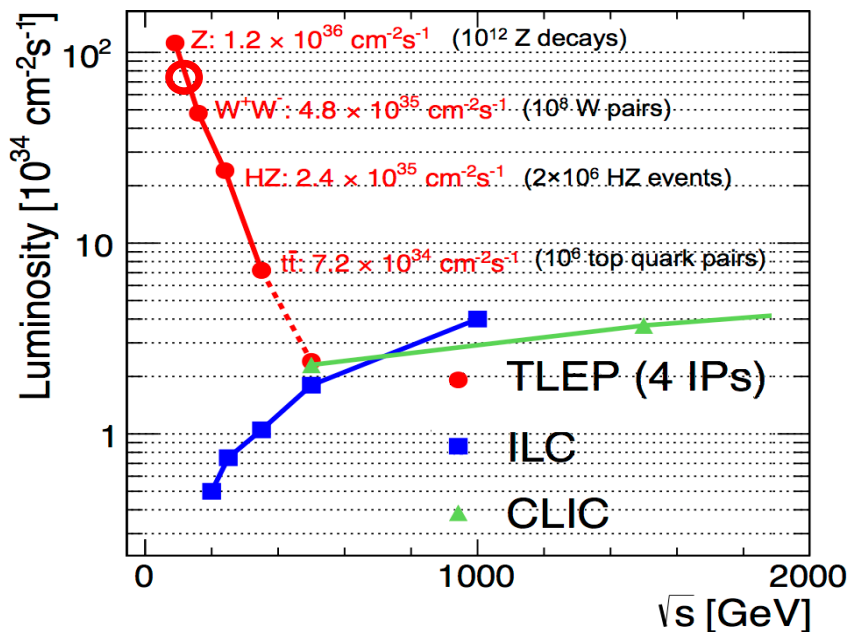
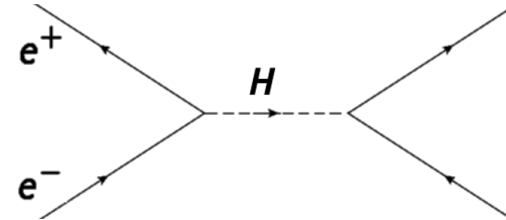
$\sigma(\mu\mu \rightarrow H) \sim 70$ pb. **Tiny $g_{H\mu\mu}$ Yukawa coupling** \Rightarrow Tiny $\sigma(ee \rightarrow H)$

$$\frac{g_{H\mu\mu}}{g_{Hee}} \propto \frac{m_\mu^2}{m_e^2} = 4.28 \times 10^4$$

$BR(H \rightarrow e^+e^-) \sim 5.3 \cdot 10^{-9}$ (**decay unobservable**)

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

- Huge luminosities** available at FCC-ee:



In theory, with $L_{\text{int}} \sim 6 \text{ ab}^{-1}$ (4 expts./year)

FCC-ee running at H pole mass

would produce $O(10.000)$ H bosons.

With reduced beam energy spread & with reduced backgrounds:

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

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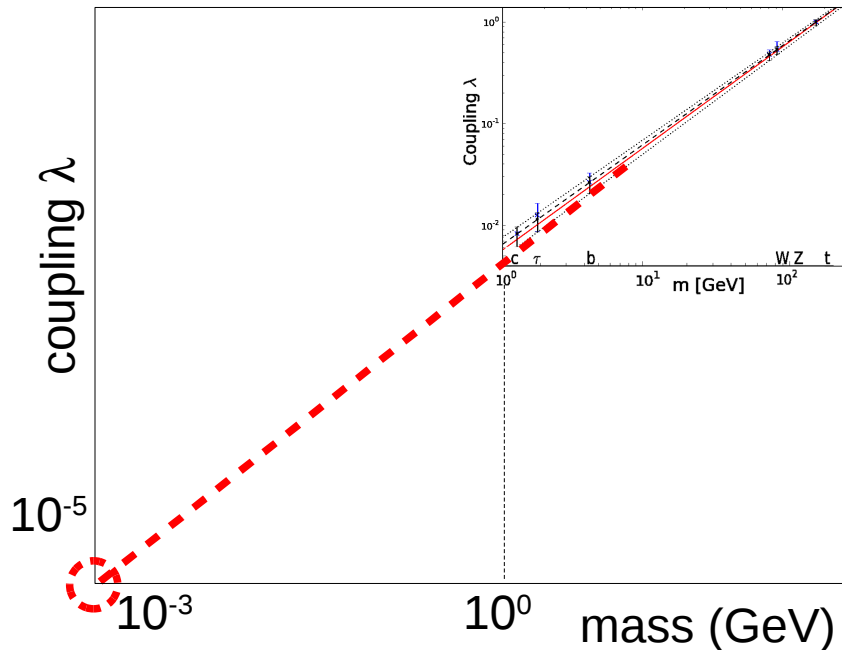
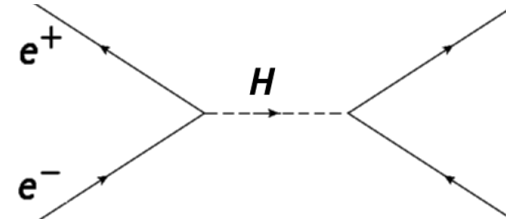
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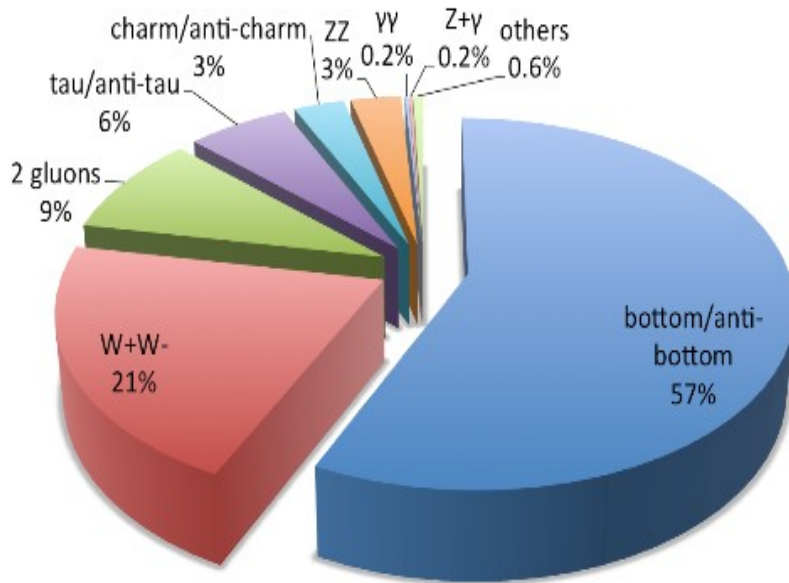
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Visible Higgs decays at FCC-ee(H/2)

Decays of a 125 GeV Standard-Model Higgs boson



- **2-jet** final-states (bb,cc,gg) swamped^(*) by $e^+e^- \rightarrow Z^*, \gamma^* \rightarrow q\bar{q}$, $\sigma \sim O(100 \text{ pb})$
- **4-jet** final-states (WW*,ZZ*) swamped^(*) by $e^+e^- \rightarrow Z^*, \gamma^* \rightarrow q\bar{q}(gg)$, $\sigma \sim O(1 \text{ pb})$
 $e^+e^- \rightarrow WW^*, ZZ^*$, $\sigma \sim O(20 \text{ fb})$
- **τ - τ** decays swamped^(*) by $e^+e^- \rightarrow Z^*, \gamma^* \rightarrow \tau\text{-}\tau$, $\sigma \sim O(10 \text{ pb})$
- **Rare** decays, ZZ(ll), $\gamma\gamma$, Z γ ,... ~ 0 counts

() Some cases to be studied in more detail, to be added in combined decays analyses*

- Cleanest channels: **WW*(2j,lv)**, **WW*(2l2v)** with $\sigma = 78 \text{ ab}$, 37 ab .
dominant **continuum** background $e^+e^- \rightarrow WW^*$ with $\sigma \sim O(5 \text{ fb})$
- In pure leptonic final-state **WW*(2l2v)** we can exploit **different lepton angular correlations from spin-0 decays** into $W^-(l_L \nu_L)W^+(l_R \nu_L)$ and continuum to reduce the latter (more difficult for 2j+lnu: requires jet-charge ...)

$e^+e^- \rightarrow H(WW^*) \rightarrow 2l2\nu$ (preliminary)

- **PYTHIA8** for signal & backgrounds at $\sqrt{s} = m_H = 125$ GeV.

Final state: **2 leptons $e, \mu, \tau(e), \tau(\mu)$ + Miss.En.** within $|\eta| < 5$ (acceptance)

This retains 60% of the $\sigma(WW^*(2l2\nu)) = 37$ ab.

- Leptons cuts:
 - $p_T(l) > 15$ GeV/c \rightarrow Kills qqbar
 - Isolation ($\Sigma E < 0.5$ GeV, $\Delta R < 2.5$) \rightarrow Kills τ - τ
 - $m_{l_1 l_2} < 81$ GeV \rightarrow Reduces ZZ^*
 - $\cos(\theta_{l_1 l_2}) > 0$ \rightarrow Reduces WW^* continuum
- Neutrino(s) cuts: $ME > 20$ GeV \rightarrow Kills qqbar

- Signal & backgrounds after cuts:

$H(WW^*)$: $\sigma = 22$ ab \Rightarrow $\sigma(\text{after cuts}) \sim 10$ ab

qqbar: $\sigma \sim 8$ pb \Rightarrow $\sigma(\text{after cuts}) \sim 5$ ab

τ - τ : $\sigma \sim 1.2$ pb \Rightarrow $\sigma(\text{after cuts}) \sim 1$ ab

WW^* : $\sigma = 3.4$ fb \Rightarrow $\sigma(\text{after cuts}) \sim 250$ ab

ZZ^* : $\sigma = 1.8$ fb \Rightarrow $\sigma(\text{after cuts}) \sim 10?$ ab

For $L_{\text{int}} = 1$ ab $^{-1}$

$S/\sqrt{B} \sim 10/\sqrt{270} \sim 0.6$

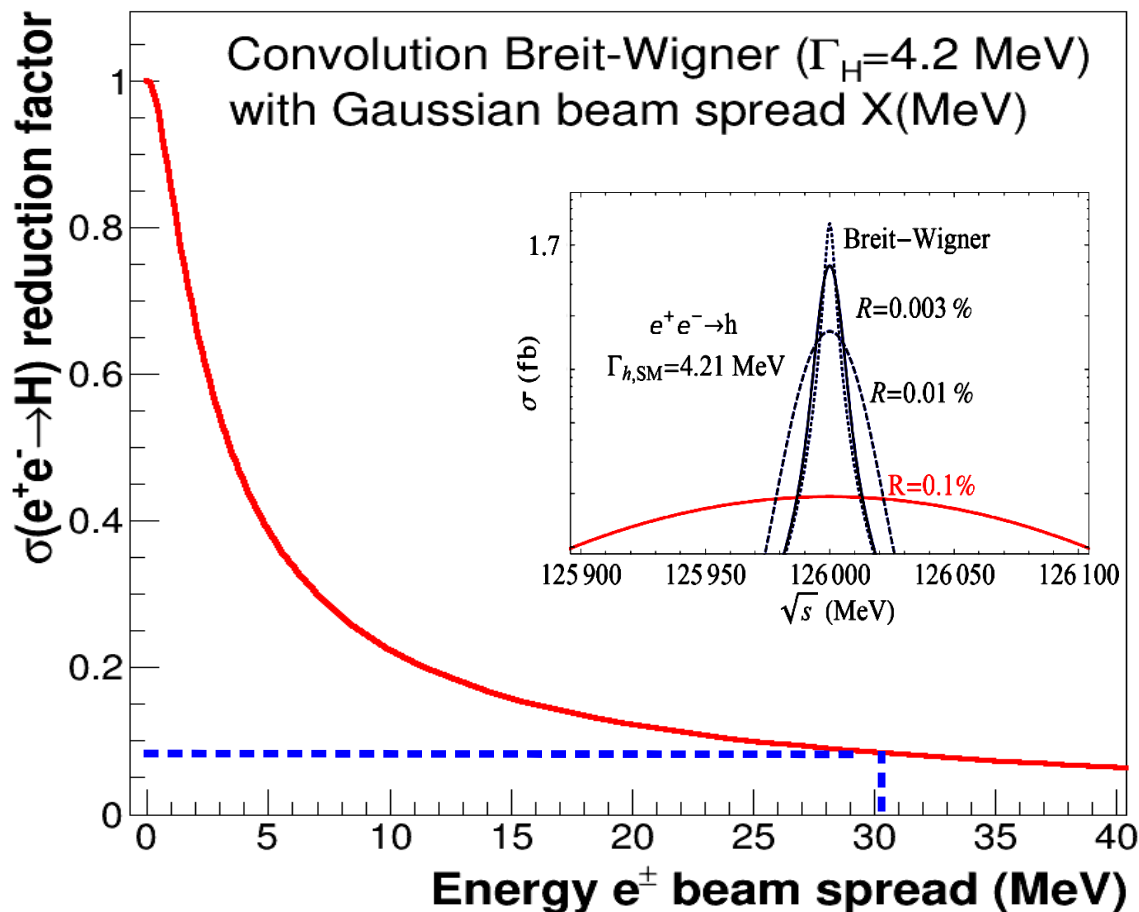
$BR(H_{ee}) < 5 \times BR_{SM}$ (3σ)

$g_{hee} < 2.2 \times g_{Hee,SM}$ (3σ)

Multi-Variate Analysis (in progress) will improve significance.

$e^+e^- \rightarrow H$ x-section: Beam energy spread

- $\sigma(e^+e^- \rightarrow H)$ considered so far is for B.-W. with natural 4.2 MeV width...
- Convolution of increasing Gaussian energy spread of each e^\pm beam with Higgs B.W. results on a (Voigtian) effective cross-section decrease:



$E_{\text{spread}} \sim \Gamma_H \sim 4.2$ MeV:
Reduction factor: 45%

Current FCC-ee nominal
($\Delta E_{\text{beam}}/E_{\text{beam}} \sim 0.05\%$):

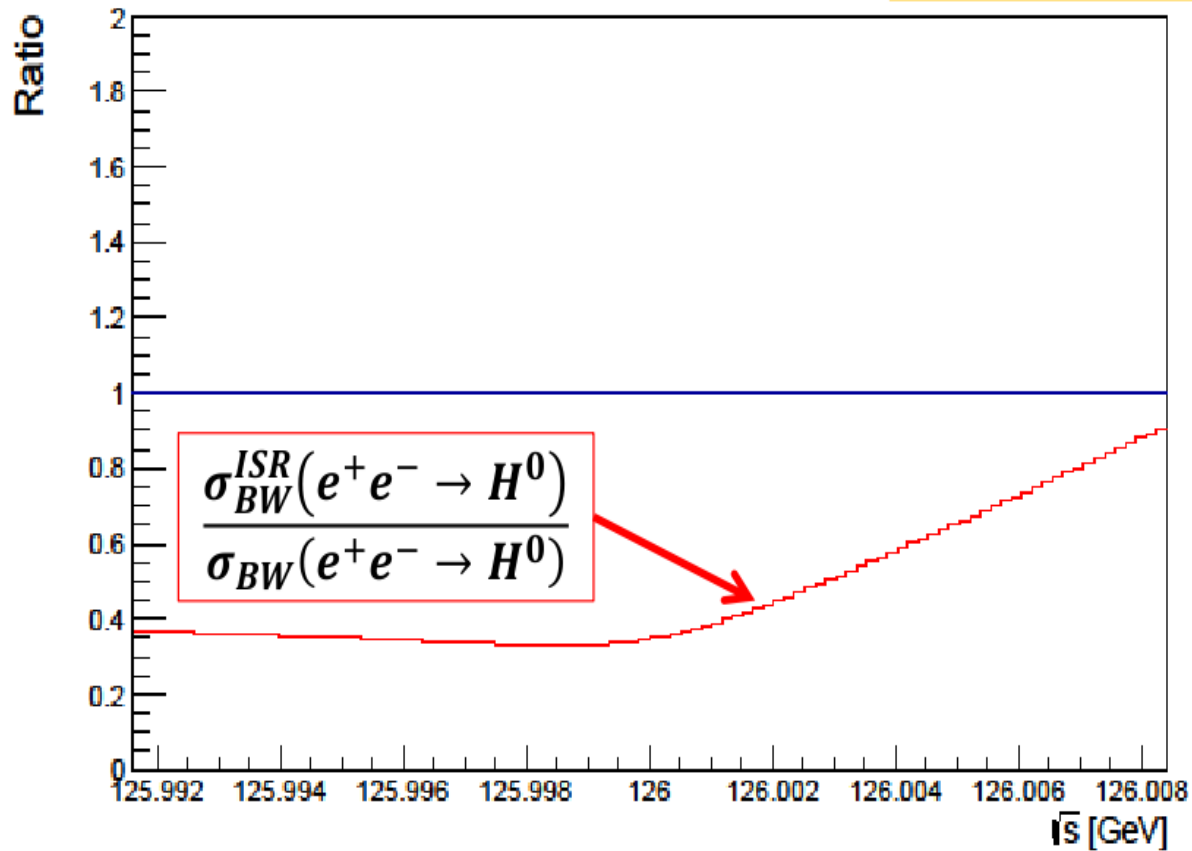
$E_{\text{spread}} \sim 30$ MeV:
Reduction factor: 8%

$e^+e^- \rightarrow H$ x-section: ISR reduction factor

- Extra ~40% reduction in $\sigma(e^+e^- \rightarrow H)$ due to initial state radiation:

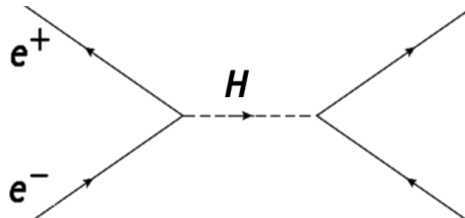
Higgs boson

Courtesy S. Jadach



Conclusions

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



$$\sigma(e^+e^- \rightarrow H)_{B-W} \sim 1.64 \text{ fb} \quad (m_H=125 \text{ GeV}, \Gamma_H=4.2 \text{ MeV})$$

(potentially visible thanks to huge FCC-ee lumi)

- Cleanest channels: $WW^*(2j,lv)$, $WW^*(2l2\nu)$ with $\sigma = 78,37$ ab

Preliminary PYTHIA8 analysis for $WW^*(2j,lv)$ for $l=e,\mu,\tau(e),\tau(\mu)$:

Dominant background: WW^* continuum (~ 250 ab, after cuts)

For $L_{\text{int}} = 1 \text{ ab}^{-1}$, $S/\sqrt{B} \sim 10/\sqrt{270} \sim 0.6$

$$\Rightarrow \text{BR}(H_{ee}) < 5 \times \text{BR}_{\text{SM}} \quad (3\sigma), \quad g_{\text{hee}} < 2.2 \times g_{\text{Hee,SM}} \quad (3\sigma)$$

(to be improved with: MVA & combination of various channels)

- Significance reduction ($\times 1/20$) due to: ISR (0.6), beam E_{spread} (~ 0.1).

Crucial to improve current $E_{\text{spread}} \sim 0.05\%$ by 1 order of magnitude

- Fundamental & unique physics accessible if measurement feasible:

→ Electron Yukawa coupling

→ Higgs width measurable (“natural” threshold scan)

→ Separation of possible **nearly-degenerate** H's

Backup slides