THEORY ISSUES IN $e^+e^- \to H$ MEASUREMENTS

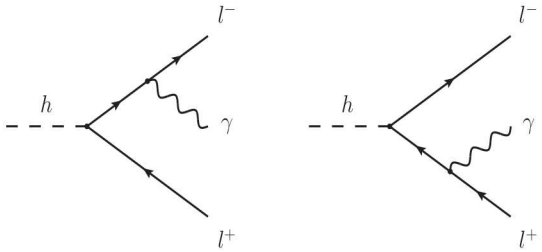
Michael Spira (PSI)

I Dalitz Decays

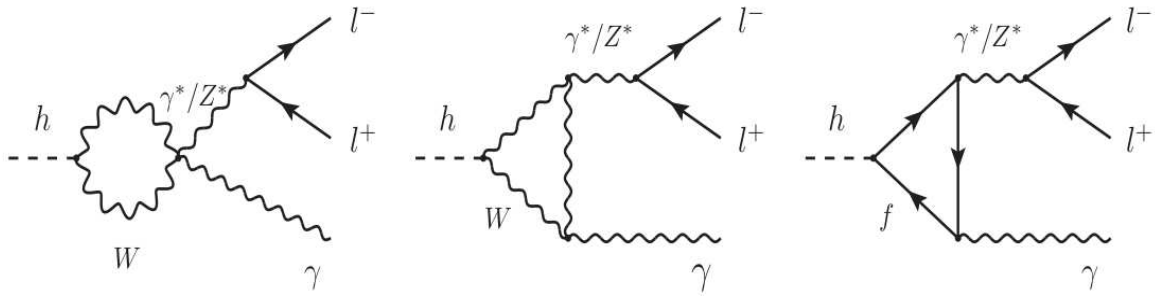
II Higgs production

III Conclusions

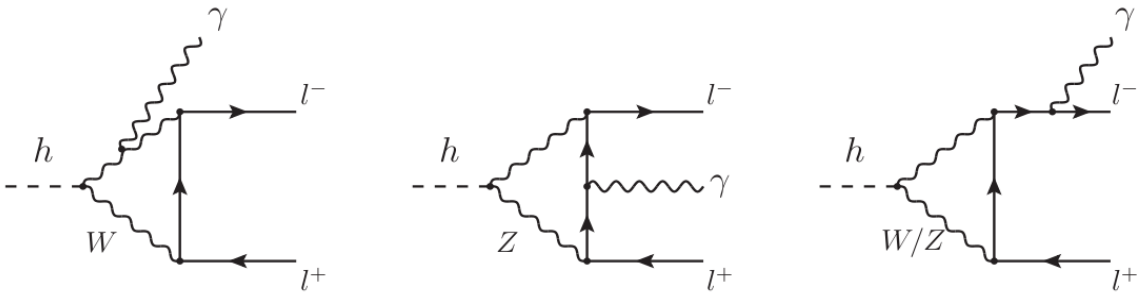
I HIGGS DALITZ DECAYS



tree



off-shell



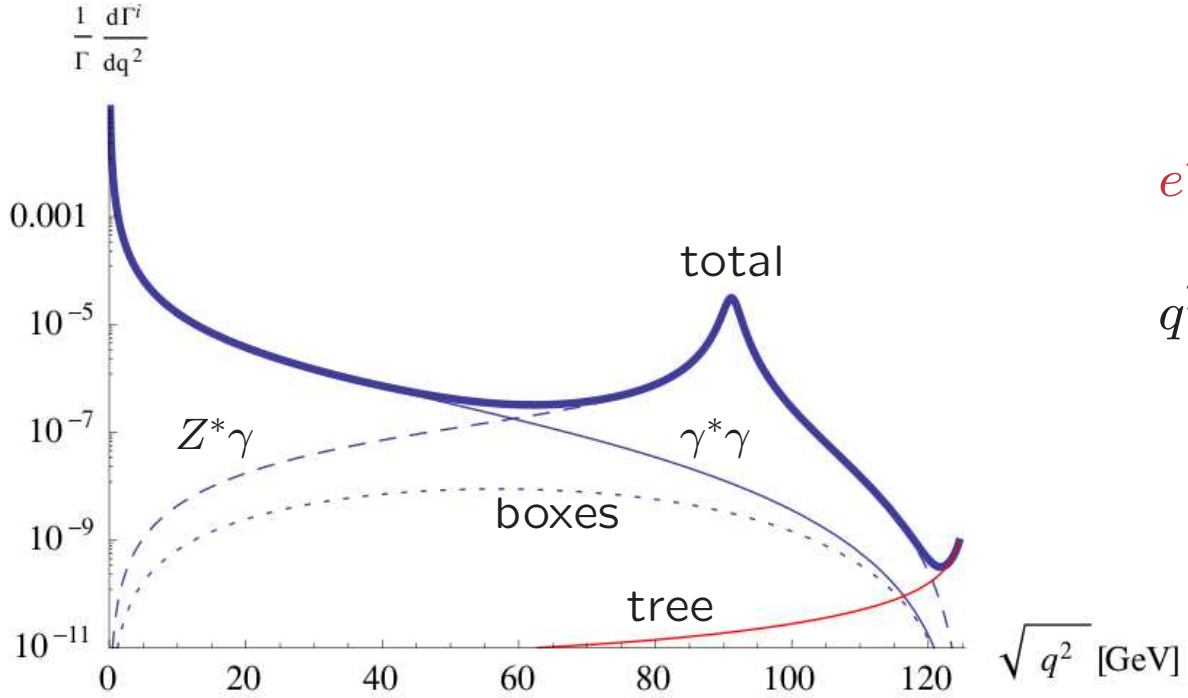
boxes

Abbasabadi, Bowser–Chao, Dicus, Repko
Sun, Chang, Gao
Passarino
Kachanovich, Nierste, Nišandžić

$$\frac{\Gamma(h \to \gamma e^+ e^-)}{\Gamma(h \to \gamma\gamma)} = 5.7\%$$

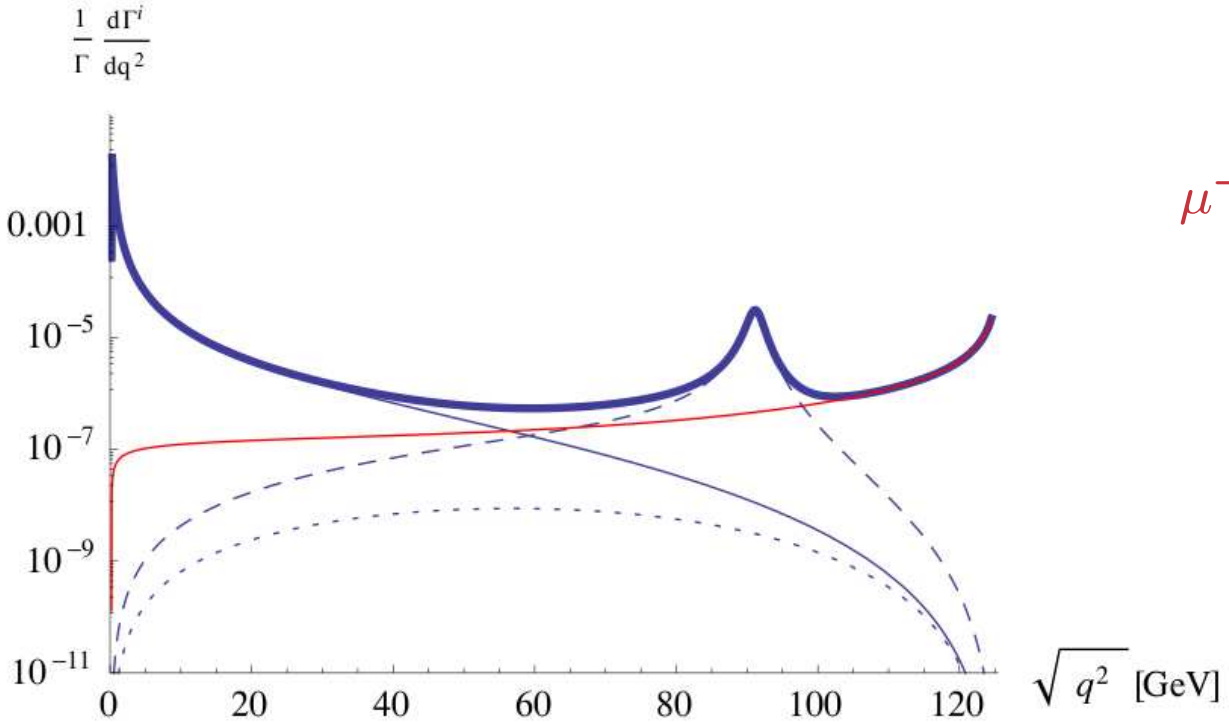
$$\frac{\Gamma(h \to \gamma \mu^+ \mu^-)}{\Gamma(h \to \gamma\gamma)} = 5.8\% \qquad (E_\gamma > 1 \text{ GeV})$$

$$\frac{\Gamma(h \to \gamma \tau^+ \tau^-)}{\Gamma(h \to \gamma\gamma)} = 3.04$$



$e^+e^-\gamma$

$q^2 = M^2_{\ell^+\ell^-}$



Sun, Chang, Gao

$\mu^+\mu^-\gamma$

Higgs Boson Decays: Theoretical Status

Michael Spira (PSI, Villigen). May 13, 2019. 12 pp.

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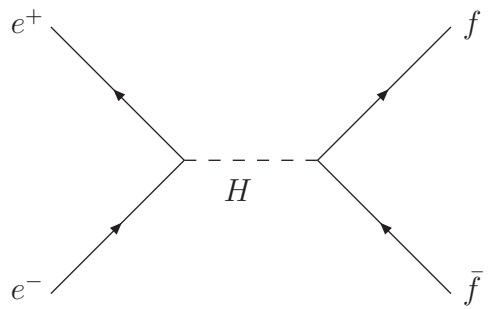
‡It should be noted that the end point in the $e^+e^-\gamma$ case is 4–5 orders of magnitude smaller than the photon and Z-exchange contributions thus making it impossible to determine the electron Yukawa coupling. The same conclusion is also valid for the reverse process $e^+e^- \to H\gamma$ so that the s-channel line-shape measurement proposed in Ref. [89] will not be sensitive to the electron Yukawa coupling but dominated by the loop-induced contribution with an additional photon.

[89] S. Jadach, R. A. Kycia, Lineshape of the Higgs boson in future lepton colliders, Phys. Lett. B755 (2016) 58–63. arXiv:1509.02406, doi:10.1016/j.physletb.2016.01.065.

II HIGGS PRODUCTION

$$e^+e^- \to H \to f\bar{f}$$

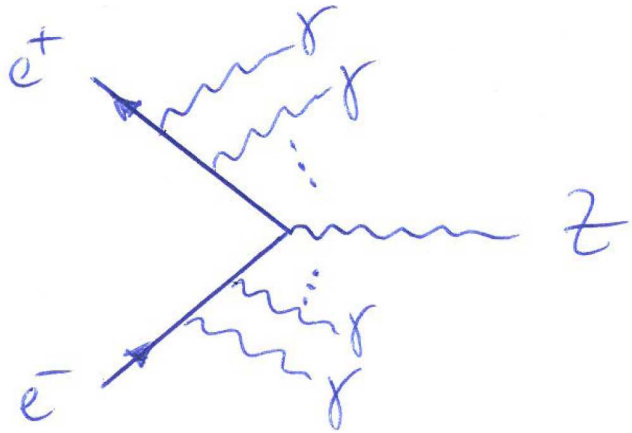


$$\sigma_0(e^+e^- \to H \to f\bar{f}) = N_{cf}\frac{m_e^2 m_f^2}{16\pi v^4}\frac{s}{(s-M_H^2)^2+M_H^2\Gamma_H^2}$$

$$\Gamma(H \to f\bar{f}) = N_{cf}\frac{m_f^2}{8\pi v^2}M_H$$

$$\Rightarrow \sigma_0(e^+e^- \to H) = \frac{m_e^2\Gamma_H}{2v^2 M_H}\frac{s}{(s-M_H^2)^2+M_H^2\Gamma_H^2}$$

initial state radiation (ISR):



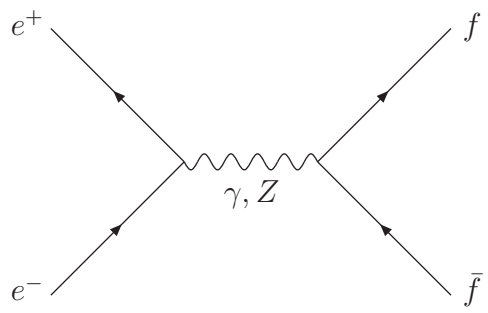
$$\sigma(e^+e^- \to H) \;=\; \int_0^1 d\nu \;\rho(\nu)\;\sigma_0[\hat{s} = (1-\nu)s]$$

$\uparrow$

YFS resummation kernel

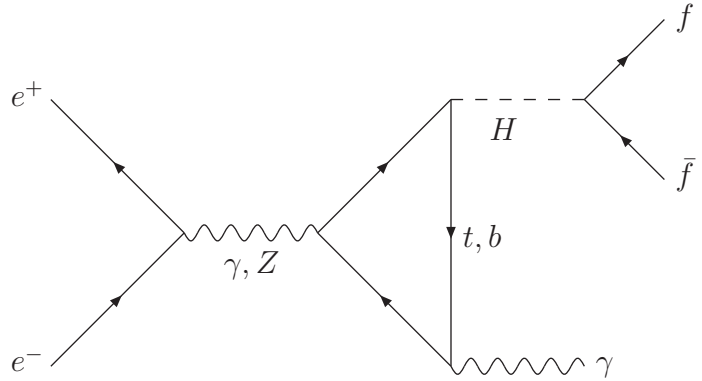
Jadach, Kycia

$e^+e^- \to f\bar{f}$



$$\sigma(e^+e^- \to f\bar{f}) \;\sim\; (10^3 \ldots 10^4) fb$$

inverse Dalitz: $e^+e^- \to H\gamma \to f\bar{f}\gamma$

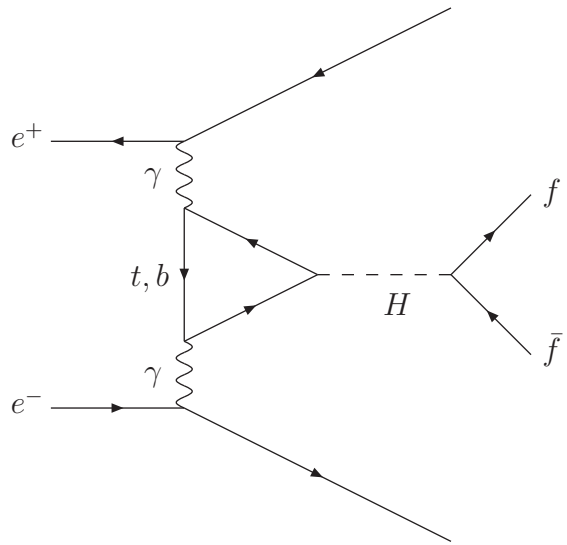


$+ \cdots$

$$\sigma(e^+e^- \to H\gamma) \;=\; \frac{2\pi\Gamma_H}{sM_H} \sum |\mathcal{M}|^2 \, \frac{p^2}{(p^2 - M_H^2)^2 + M_H^2\Gamma_H^2} \, dPS_3$$

Abbasabadi, Bowser–Chao, Dicus, Repko

photon fusion: $\gamma\gamma \to H \to f\bar{f}$



$+\cdots$

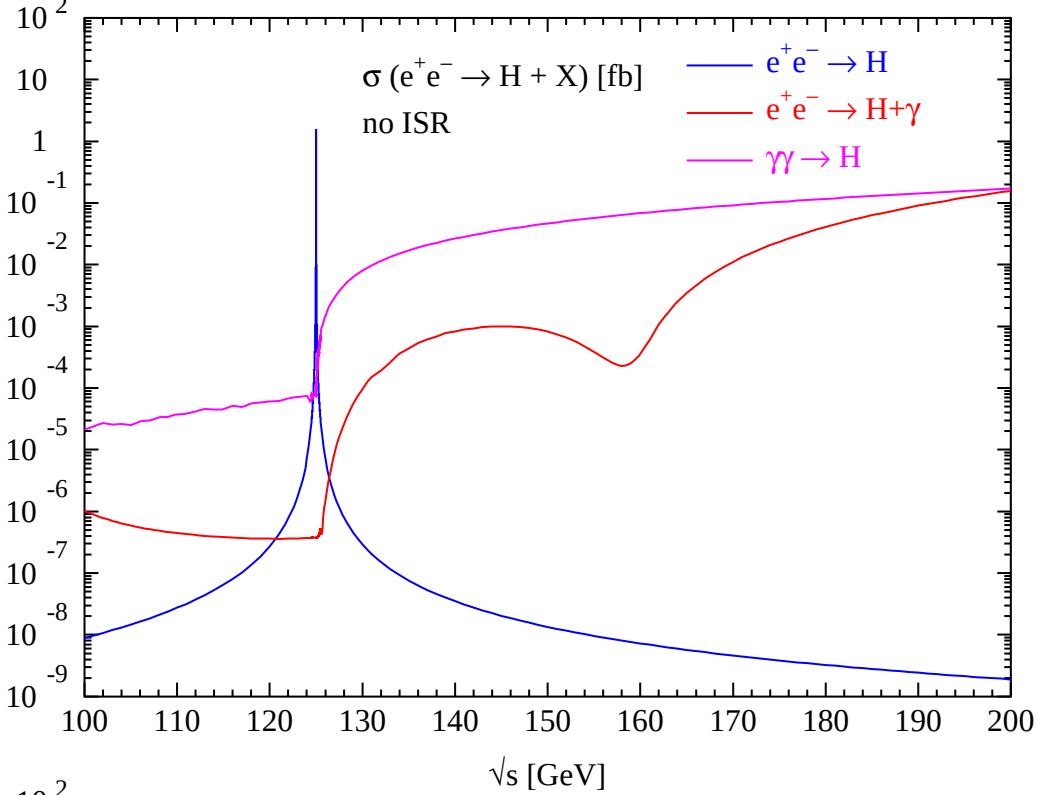
$$\sigma(e^+e^- \to He^+e^-) \approx \int_{\tau_0}^{1} d\tau \int_{\tau}^{1} \frac{dx}{x}\, f_{\gamma/e}(x)\; f_{\gamma/e}\left(\frac{\tau}{x}\right)\; \sigma_{\gamma\gamma\to H}(\hat{s} = \tau s)$$

$$\sigma_{\gamma\gamma\to H} = \frac{\Gamma_H}{4\hat{s}M_H} \sum |\mathcal{M}|^2 \frac{\hat{s}}{(\hat{s} - M_H^2)^2 + M_H^2\Gamma_H^2}$$

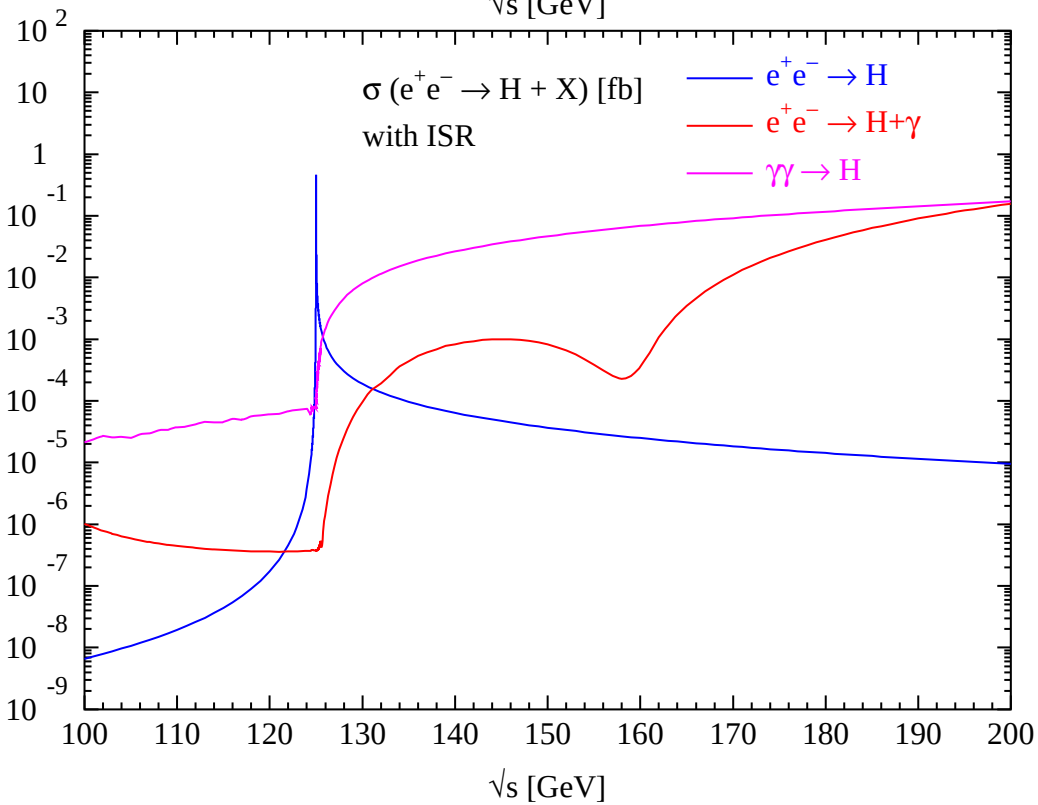
$$f_{\gamma/e}(x) = \frac{\alpha}{2\pi}\left\{\frac{1+(1-x)^2}{x} \log \frac{s(1-x)}{m_e^2 x^2} - 2\frac{1-x}{x}\right\}$$

comment by E. Bagnaschi

Preliminary

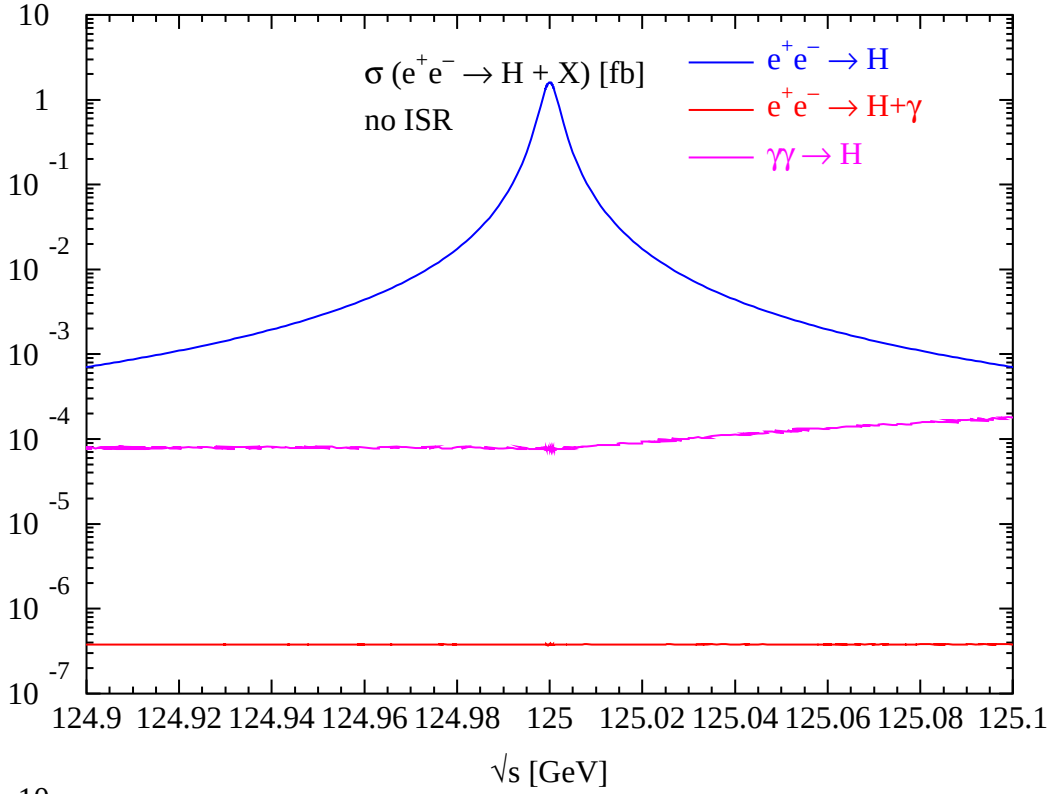


signal: no ISR

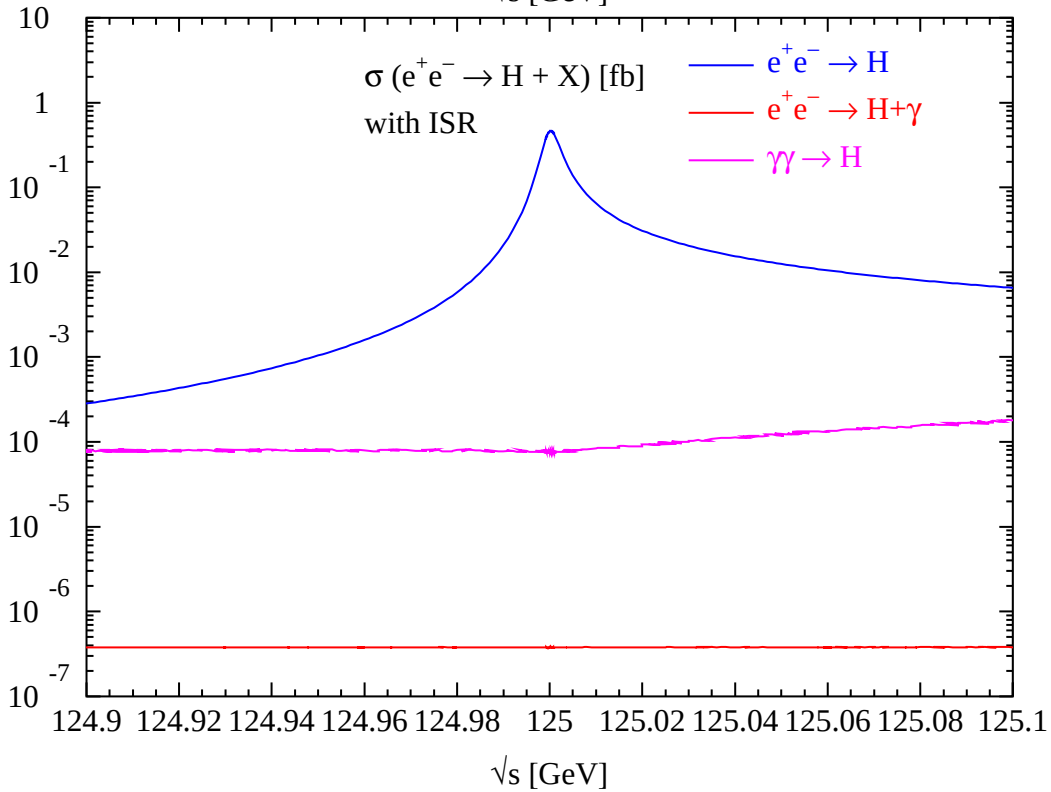


signal: with ISR

Preliminary



signal: no ISR



signal: with ISR

III *CONCLUSIONS*

- peak in $e^+e^- \to H$ large and narrow

- concurring process $e^+e^- \to H\gamma$ [t, W-loop induced] small

- concurring process $e^+e^- \to He^+e^-$ [t, W-loop induced $\gamma\gamma$ fusion] small

- huge background from non-Higgs processes $\to$ very large lumninosities required

- experimental energy spread limiting factor

BACKUP SLIDES

YFS resummation: ($\gamma_E = 0.57721566490153286060651209$)

$$\rho(\nu) = e^{\delta_{YFS}}\ F(\gamma)\ \gamma\ \nu^{\gamma-1}\ [d_s + \Delta_H(\nu)]$$

$$\gamma = 2\frac{\alpha}{\pi}\left(\log\frac{s}{m_e^2} - 1\right)$$

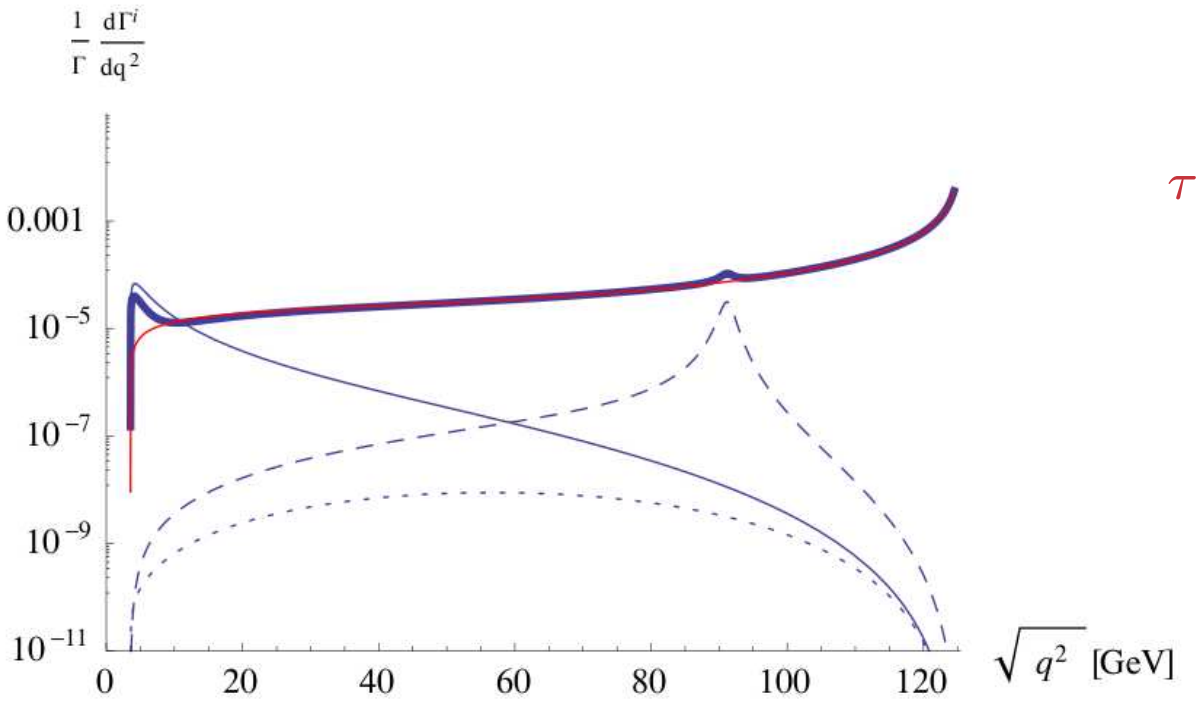
$$\delta_{YFS} = \frac{\gamma}{4} + \frac{\alpha}{\pi}\left(-\frac{1}{2} + \frac{\pi^2}{3}\right)$$

$$F(\gamma) = \frac{\exp(-\gamma_E\ \gamma)}{\Gamma(1+\gamma)}$$

$$d_s = 1 + \frac{\gamma}{2} + \frac{\gamma^2}{8}$$

$$\Delta_H(\nu) = -\frac{\nu}{2} + \gamma\left[-\frac{\nu}{2} - \frac{1+3(1-\nu)^2}{8}\log(1-\nu)\right]$$

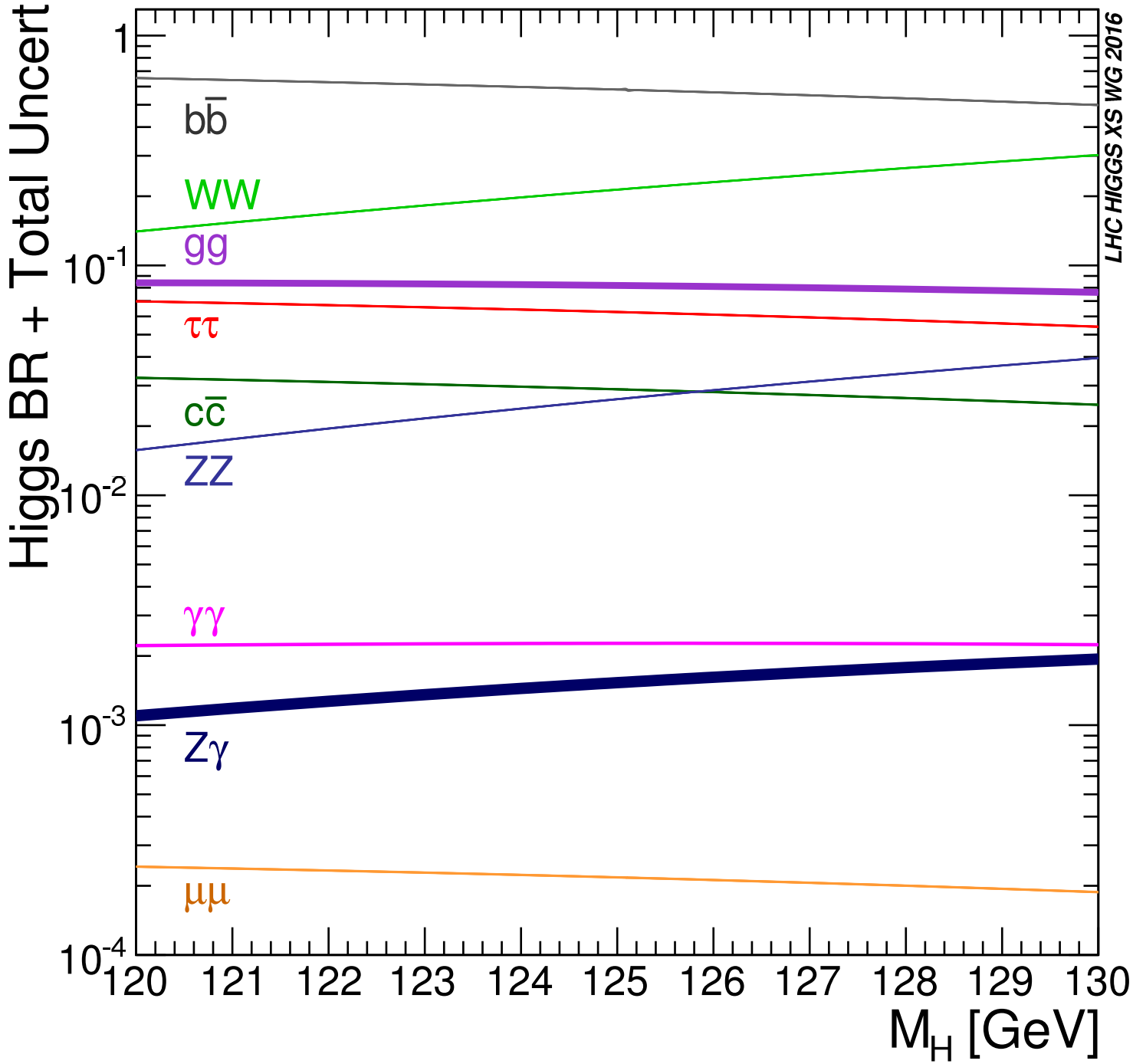
Jadach, Ward, Was



$\tau^+\tau^-\gamma$

Sun, Chang, Gao

- Dalitz decays ($H \to Z\gamma \Leftrightarrow H \to \ell^+\ell^-\gamma \Leftrightarrow H \to \ell^+\ell^-$)
  [waiting for agreement ATLAS/CMS]


Higgs BR + Total Uncert
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$b\bar{b}$
WW
gg
$\tau\tau$
$c\bar{c}$
ZZ
$\gamma\gamma$
$Z\gamma$
$\mu\mu$
120 121 122 123 124 125 126 127 128 129 130
M_H [GeV]
LHC HIGGS XS WG 2016