Universität Zürich[UZH]

Higgs Pseudo-Observables and Radiative Corrections

based on
1412.6038
1504.04018
1507.02555

Marzia Bordone

PSI, 27/08/2015

Pseudo-Observables

WHY?

⇒ need to encode experimental results in terms of a set of idealized observables theoretically well defined

FEATURES

⇒ can be matched with lagrangian parameters of any theory (SUSY, EFT….)

⇒ defined from kinematical properties of on-shell processes

First example of POs

One first set of POs for the Higgs properties is encoded in the κ-framework

Hyp: narrow width + on-shell Higgs

$$\sigma(ii \to h + X) \times BR(h \to ff) = \sigma_{ii} \frac{\Gamma_{ff}}{\Gamma_h} = \frac{\kappa_{ii}^2 \ \kappa_{ff}^2}{\kappa_h^2} \sigma_{SM} \times BR_{SM}$$

First example of POs

$\Rightarrow$ well defined SM limits for $\kappa_i \to 1$

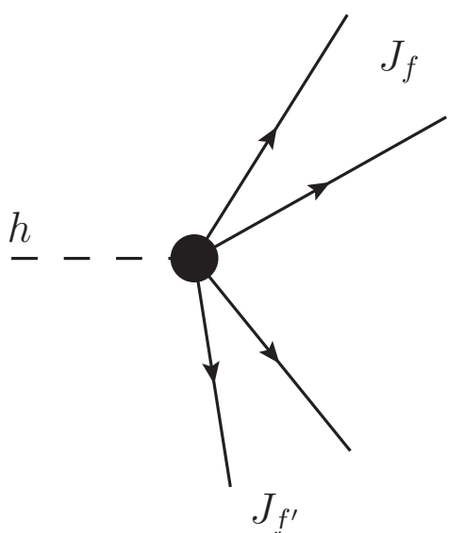
$\Rightarrow$ limited to total rates

(not suitable for multi body decays)

$\Rightarrow$ cannot describe possible deviation in differential distribution (such as CP violation)

need to extend this formalism to include all these effects

Higgs to 4-fermion decays



Hyp1: neglect helicity-violating interactions

+

Gauge and Lorentz invariance

$$\mathcal{A} = i\frac{2m_Z^2}{v_F}(\bar{e}\gamma_\alpha e)(\bar{\mu}\gamma_\beta \mu)\times$$

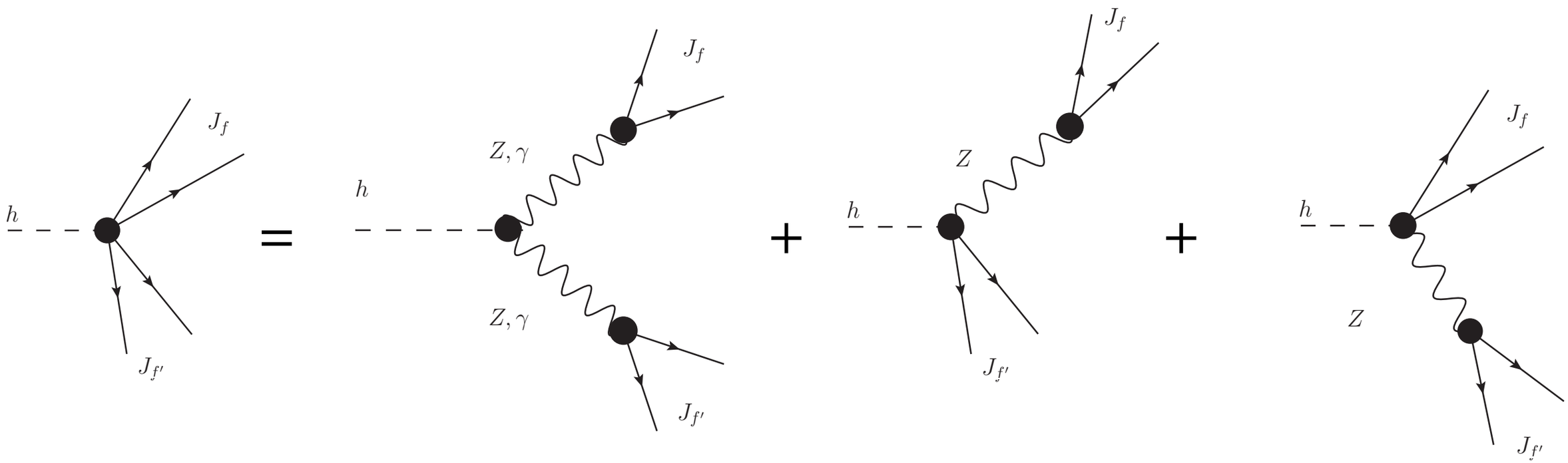
$$[F_1(q_1^2,q_2^2)g^{\alpha\beta} + F_3(q_1^2,q_2^2)\frac{q_1\cdot q_2 g^{\alpha\beta} - q_2^\alpha q_1^\beta}{m_Z^2} + F_4(q_1^2,q_2^2)\frac{\epsilon^{\alpha\beta\rho\sigma}q_{2\rho}q_{1\sigma}}{m_Z^2}]$$

form factors

Higgs to 4-fermion decays

Hyp2: neglecting short distance mode corresponding to local operators with d>6

⇒ we can expand the form factors around physical poles



Higgs to 4-fermion decays

Hyp2: neglecting short distance mode corresponding to local operators with d>6

⇒ we can expand the form factors around physical poles

$$F_1(q_1^2,q_2^2) = \kappa_{ZZ}\frac{g_Z^e g_Z^\mu}{P_Z(q_1^2)P_Z(q_2^2)} + \frac{\epsilon_{Ze}}{m_Z^2}\frac{g_Z^\mu}{P_Z(q_1^2)} + \frac{\epsilon_{Z\mu}}{m_Z^2}\frac{g_Z^e}{P_Z(q_2^2)} + \Delta_1^{\rm SM}(q_1^2,q_2^2)$$

$$F_3(q_1^2,q_2^2) = \epsilon_{ZZ}\frac{g_Z^e g_Z^\mu}{P_Z(q_1^2)P_Z(q_2^2)} + \kappa_{Z\gamma}\epsilon_{Z\gamma}^{\text{SM-1L}}\left(\frac{eQ_\mu g_Z^e}{q_2^2 P_Z(q_1^2)} + \frac{eQ_e g_Z^\mu}{q_1^2 P_Z(q_2^2)}\right) + \kappa_{\gamma\gamma}\epsilon_{\gamma\gamma}^{\text{SM-1L}}\frac{e^2 Q_\mu Q_e}{q_1^2 q_2^2} + \Delta_3^{\rm SM}(q_1^2,q_2^2)$$

$$F_4(q_1^2,q_2^2) = \epsilon_{ZZ}^{\rm CP}\frac{g_Z^e g_Z^\mu}{P_Z(q_1^2)P_Z(q_2^2)} + \epsilon_{Z\gamma}^{\rm CP}\left(\frac{eQ_\mu g_Z^e}{q_2^2 P_Z(q_1^2)} + \frac{eQ_e g_Z^\mu}{q_1^2 P_Z(q_2^2)}\right) + \epsilon_{\gamma\gamma}^{\rm CP}\frac{e^2 Q_\mu Q_e}{q_1^2 q_2^2}$$

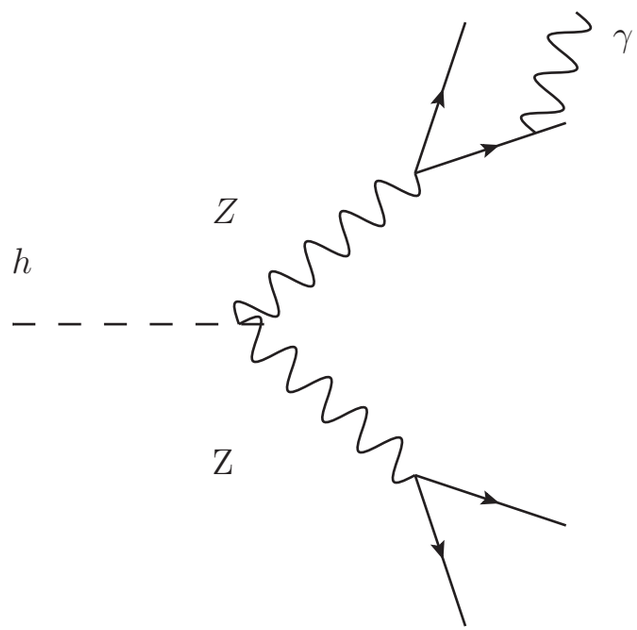
$$P_Z(q^2) = q^2 - m_Z^2 + i m_Z \Gamma_Z$$

SM-Limit:

$$\kappa_X \to 1$$

$$\epsilon_X \to 0$$

Radiative corrections



- soft+collinear photon ⇒ **IR div**
- IR div **factorize** for each dilepton couple

need of **two** conditions for IR div

$$(p_l + k_\gamma)^2 > m_*^2$$

$$x = \frac{m^2}{m_0^2} \Rightarrow 0 < x < x_{max}$$

Defining the radiator function

$$\omega(x, x_*) \rightarrow x_* = \frac{2m_*^2}{m_0^2}$$

$$\omega(x, x_*) \rightarrow x_{max} = 1 - x_*$$

$$\omega(x, x_*) = \omega_1(x, x_*)\theta(1 - x_* - x) + \omega_2(x, x_*)\delta(1 - x)$$

Defining the radiator function

$$\omega(x, x_*) \rightarrow x_* = \frac{2m_*^2}{m_0^2}$$

$$\omega(x, x_*) \rightarrow x_{max} = 1 - x_*$$

$$\omega(x, x_*) = \omega_1(x, x_*)\theta(1 - x_* - x) + \omega_2(x, x_*)\delta(1 - x)$$

emission of a
real photon
above IR cut-off

Defining the radiator function

$$\omega(x, x_*) \rightarrow x_* = \frac{2m_*^2}{m_0^2}$$

$$\omega(x, x_*) \rightarrow x_{max} = 1 - x_*$$

$$\omega(x, x_*) = \omega_1(x, x_*)\theta(1 - x_* - x) + \omega_2(x, x_*)\delta(1 - x)$$

virtual correction
+
soft radiation below IR cutoff

Defining the radiator function

leading order

$$(1-x) \ll 1$$
$$x_* \ll 1$$

$$\omega_1(x, x_*) = -\frac{\alpha}{\pi}\left(1 + x - \frac{2}{1-x}\right)\log\left(\frac{2(1-x) - x_*}{x_*}\right)$$

$$\omega_2(x, x_*) = 1 + \frac{\alpha}{\pi}\left[\frac{\pi^2}{3} - \frac{7}{2} - 3\log\left(\frac{x_*}{2}\right) - 2\log\left(\frac{x_*}{2}\right)^2\right]$$

ω_1 $\Rightarrow$ explicit calculation

ω_2 $\Rightarrow$ obtained imposing $\int_0^1 dx\ \omega(x, x_*) = 1$

Convolution with LO calculation

$$\frac{\mathrm{d}^4\Gamma}{\mathrm{d}m_{01}\mathrm{d}m_{02}\mathrm{d}x_1\mathrm{d}x_2} = F_0(m_{01}, m_{02})\omega(x_1, x_{1*})\omega(x_2, x_{2*})$$

non radiative spectrum

Convolution with LO calculation

$$\frac{\mathrm{d}^4\Gamma}{\mathrm{d}m_{01}\mathrm{d}m_{02}\mathrm{d}x_1\mathrm{d}x_2} = F_0(m_{01}, m_{02})\omega(x_1, x_{1*})\omega(x_2, x_{2*})$$

one radiator for
each dilepton couple

Convolution with LO calculation

$$\frac{\mathrm{d}^4\Gamma}{\mathrm{d}m_{01}\mathrm{d}m_{02}\mathrm{d}x_1\mathrm{d}x_2} = F_0(m_{01}, m_{02})\omega(x_1, x_{1*})\omega(x_2, x_{2*})$$

⇒ but we need the double differential spectrum respect to the **physical invariant mass** of the dilepton couples

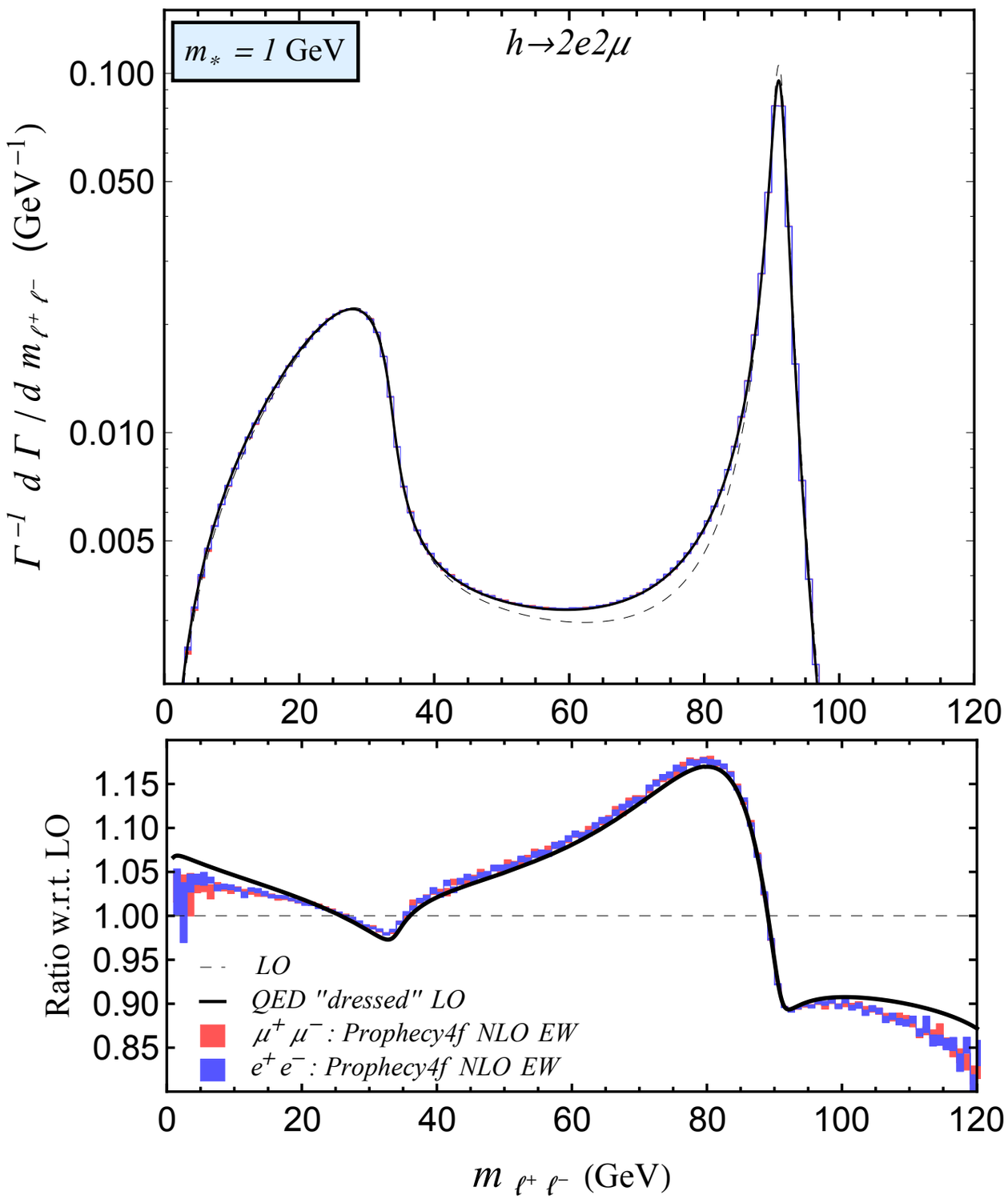
Convolution with LO calculation

$$\frac{\mathrm{d}^4\Gamma}{\mathrm{d}m_{01}\mathrm{d}m_{02}\mathrm{d}x_1\mathrm{d}x_2} = F_0(m_{01}, m_{02})\omega(x_1, x_{1*})\omega(x_2, x_{2*})$$

⇒ but we need the double differential spectrum respect to the **physical invariant mass** of the dilepton couples

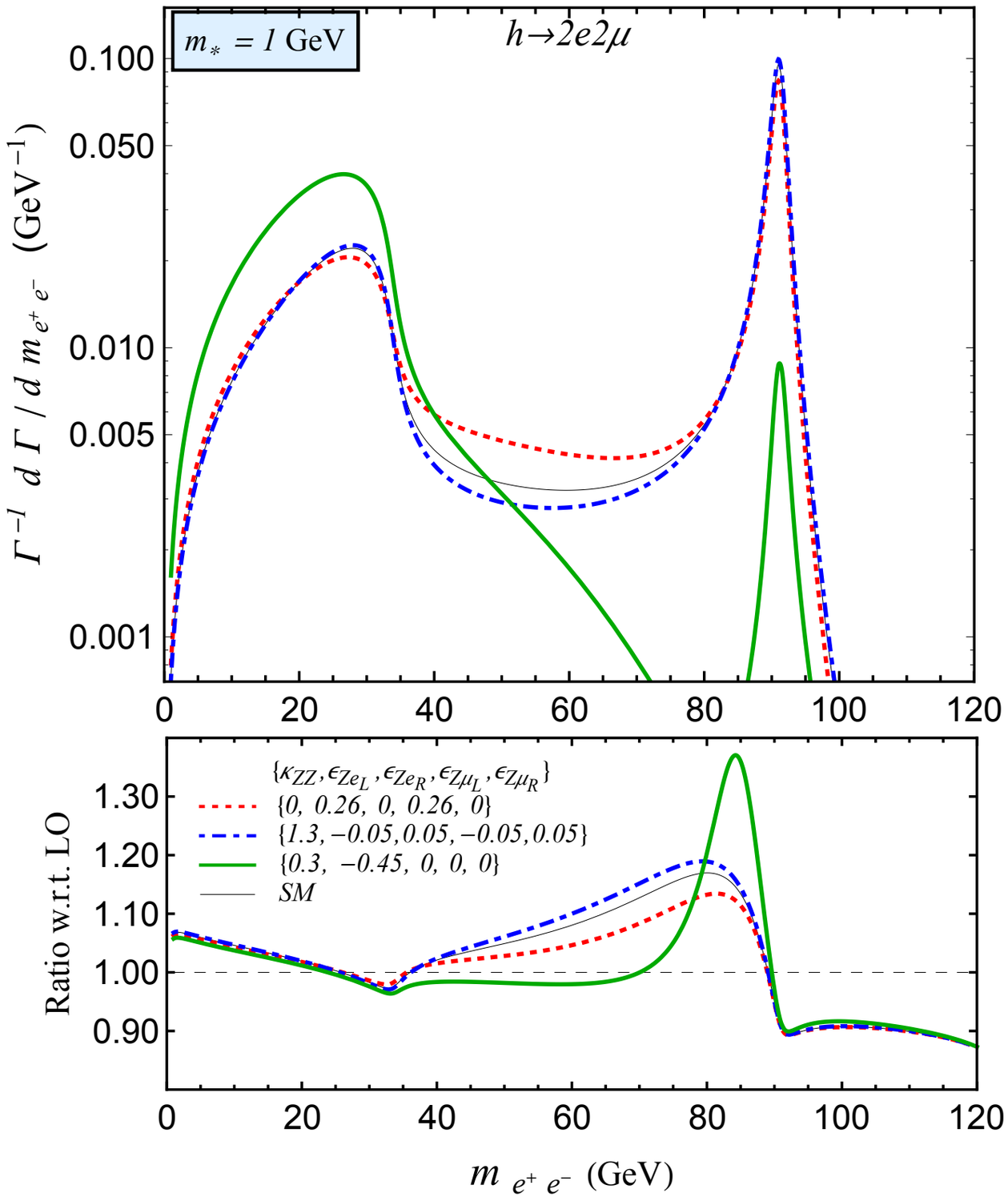
$$x_i \Leftrightarrow m_i \quad \Rightarrow \frac{\mathrm{d}^2\Gamma}{\mathrm{d}m_1\mathrm{d}m_2}$$

Results



- good agreement of the spectrum dressed with QED correction the one obtained with full NLO correction
- the effect of QED correction in some region of the phase space are sizable so they have to be included when looking for NP
- at $\mathcal{O}(\alpha/\pi)$ correction to the ϵ parameter are small

Results



1. Deviation from SM points are small.
2. Deviation from SM spectrum are sizable but still the relative impact of QED correction in SM-like.
3. Distortion from SM spectrum is sizable and the QED impact is not SM-like.

Conclusions

Presented a **general tool** to accomodate radiative corrections in the PO framework and applied to the higgs to 4 lepton decay

LO dressed with QED corrections in **agreement** with full NLO EW corrections at % level

New tool valid to describe NP at **NLO** (EW) accuracy