

David Marzocca

M.Gonzalez-Alonso, A. Greljo, G. Isidori, D.M.

Eur. Phys. J. C 75 (2015) 3, 128 arXiv: [1412.6038](http://arxiv.org/abs/1412.6038) and arXiv: [1504.04018](http://arxiv.org/abs/1412.6038)

 $J^\mu_{f'}$ f′

h

 q_2

 q_1

Introduction \blacksquare samples of the ATLAS and CMS experiments at the CERN LHC in the *H* ! *gg* and

7.8 Constraints on BRBS in a scenario with free constraints on BRBS CL:
195% CL:

"kappa" formalism After the Higgs discovery at the LHC, already at Run 1 we entered the era of Higgs precision. After the Higgs discovery at the LHC the reconstructed invariant mass peaks in the two channels and for the two experi-

 $m_H = 125.09 \pm 0.21$ (stat.) \pm 0.11 (syst.) GeV

A. ATLAS-CONF-2015-007 nuisance parameters; from top to bottom: *k*^V (W and Z bosons), *k*^b (bottom quarks), *kt* (tau

 $\overline{K_{V}$ < 1 $K_{on} = K_{off}$ $\overline{BR_{i,\mu.} = 0}$

ATLAS Preliminary
√s=7TeV,4.5-4.7 fb^{−1} √s=8TeV,20.3 fb[−]

68% CL: 95% CL:

√s = 7 TeV,4.5 − 4.7 fb[−]¹ √s = 8 TeV,20.3 fb[−]¹

Run 2 (and beyond): High Precision Higgs era $\frac{1}{2}$ $\n *Q* (and hence d). Using *Q* is a real part.$ \mathcal{N} Run 2 (and beyond): High Precision Higgs era.

Introduction \blacksquare

Run 2 (and beyond): High Precision Higgs era $\frac{1}{2}$ \mathcal{N} Run 2 (and beyond): High Precision Higgs era.

Realistic Observables

Raw data, Fiducial cross sections, etc…

 $2 = -\frac{1}{6}F_{\mu\nu}F^{\mu\nu}$ $+i\bar{\psi}\not\psi\psi + k.c.$ $+ \bar{\psi}_i y_{ij} \psi_i^* + L.c.$ $+$ b_pp¹ \vee (ϕ)

Lagrangian parameters

Couplings, running masses, Wilson coefficients etc …

Realistic Observables

Raw data, Fiducial cross sections, etc…

 $2 = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$ $+i\overline{\psi}\psi\psi + k.c.$ $+ \bar{\psi}_i y_{ij} \psi_i + L.c.$ $+$ b₂ ϕ ² - $V(\phi)$

Realistic Observables

Raw data, Fiducial cross sections, etc…

Pseudo **Observables** Experimental data Pseudo Observables Lagrangian parameters masses, with the set of the set o
Eq. () and () is a set of the s **ODSe**

Pole masses, decay widths, kappas, form factors, etc..

renormalization scale, Lagrangian parameters

Couplings, running masses, Wilson coefficients etc …

PO encode experimental information in idealized observables, of easy theoretical interpretation. This approach is old: developed at LEP to describe the Z properties.

[Bardin, Grunewald, Passarino '99]

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PO encode experimental information in idealized observables, of easy theoretical interpretation. This approach is old: developed at LEP to describe the Z properties.

[Bardin, Grunewald, Passarino '99]

PO can then be matched, by theorists, to any explicit scenario — SM EFT, SUSY, Composite Higgs, etc.. — at the desired order in perturbation theory.

LEP-1 Strategy: on-shell Z decays in the SM. Once we include the best of the two-loop terms then imaginary burg als Sandegy: On-Shell Z decays and Zafazo with Ni being the total number of total number of the total number of \sim able two-loop effects. These are enhanced by factors \mathbf{r} and sometimes also \mathbf{r} **EXECTE:** LEP-1 Strategy: on-shell Z decays

At Run-1, measurements of Higgs properties were reported in the *κ*-framework: What was done in run 1? Kappa framework in run 1? Kappa framework in run 1? Kappa framework in run 1? Kappa fr
What was done in run 1? Kappa framework in run 1? Kappa framework in run 1? Kappa framework in 1980 framework Narrow width approximation (& on-shell Higgs):

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

Virtues: Clean SM limit $(k\rightarrow 1)$, well-def. exp & th, quite general.

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Need to extend the *κ*-framework retaining all its good properties:

Higgs pseudo-observables

LHC and on-shell Higgs decays: extending the κ-framework

LHC and on-shell Higgs decays: extending the *κ***-framework** ехtending the к-framework *w x +he k-fram*

$$
\mathcal{A}(h \to f\bar{f}) = -\frac{i}{\sqrt{2}} \left[(y_S^f + iy_P^f) \bar{f}_L f_R + (y_S^f - iy_P^f) \bar{f}_R f_L \right] \quad \xrightarrow{\text{I} \quad f} \quad |y_S^f|^2 + |y_P^f|^2
$$

$$
\mathcal{A}[h \to \gamma(q,\epsilon)\gamma(q',\epsilon')] = i \frac{2}{v_F} \epsilon'_{\mu} \epsilon_{\nu} [\epsilon_{\gamma\gamma}(g^{\mu\nu}q \cdot q' - q^{\mu}q'^{\nu}) + \epsilon_{\gamma\gamma}^{CP} \epsilon^{\mu\nu\rho\sigma} q_{\rho} q'_{\sigma}] \underbrace{\frac{\Gamma_{\gamma\gamma}}{\sqrt{\epsilon_{\gamma\gamma}}} [\epsilon_{\gamma\gamma}]^2 + |\epsilon_{\gamma\gamma}^{CP}|^2}
$$

$$
\kappa_{\gamma\gamma}\equiv\frac{\epsilon_{\gamma\gamma}}{\epsilon_{\gamma\gamma}^{\rm SM-1L}}
$$

LHC and on-shell Higgs decays: extending the κ-framework photons (*h* !). The *h* ! 4*f* amplitudes are particularly interesting since they allow us LHC and on-shell Higgs decays: extending the **k-framework** ding the **K-frame** SM-1L *z Ing the K-Tramework*

Four-body decays $h \rightarrow 4f$

The kinematics is much richer: *The kinematics is much i*
kinematical distributions. $h \rightarrow 4f$ $h \rightarrow 4f$ $h \rightarrow 4f$ *g* μ *M E*

C

The process is **completely described by this Green function** of ON-SHELL states: *|*✏*|* ² ⁺ *[|]*✏ *|* \overline{a}

$$
\langle 0|\mathcal{T}\left\{J_f^{\mu}(x), J_{f'}^{\nu}(y), h(0)\right\}|0\rangle, \qquad J_f^{\mu}(x) = \bar{f}(x)\gamma^{\mu}f(x)
$$

^f (20)

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 \int_{f} in body decays \sum_{f} The purpose of our approach is to characterise, as precisely as possible, the three point h *Jf Jf'* ²) ⁺)
- - - - *ge Z PZ*(*q*² \sum_{I} 1) $\frac{df}{dx}$

The kinematics is much richer: *The kinematics is much i*
kinematical distributions. $h \rightarrow 4f$ $h \rightarrow 4f$ $h \rightarrow 4f$ *g inematical distributions.*

C

*q*2

*m*²

 $\mathcal{L} = \frac{1}{2} \sum_{i=1}^{n} \frac{1}{i!} \sum_{j=1}^{n} \frac{1}{j!} \sum_{j=1}^{$

*q*2 1*q*2 j.

The process is **completely described by this Green function** of ON-SHELL states: *|*✏*|* ² ⁺ *[|]*✏ *|* \overline{a} *PZ*(*q*² 1)*PZ*(*q*² ²) ⁺ *Z*✏ 2*PZ*(*q*² 1*PZ*(*q*² 2) 1*q*2 2 ⇥ *^q*¹ *· ^q*² *^g*↵ *^q*²

*q*2

2)

<u>e</u>

$$
\langle 0|\mathcal{T}\left\{J_f^{\mu}(x), J_{f'}^{\nu}(y), h(0)\right\}|0\rangle, \qquad J_f^{\mu}(x) = \bar{f}(x)\gamma^{\mu}f(x)
$$

1*PZ*(*q*²

*q*2

 Q_{in} where α are on-shell the state are on-shell. This correlation is probed by the experiments of Only 3 tensor structures allowed by Lorentz symmetry:

2*PZ*(*q*²

*q*2

Four-body decays

−body decays
Carrier b → 4f

 \mathbf{f}

Z

*q*2

Z

 $h \rightarrow 4f$

1)*PZ*(*q*²

1)*PZ*(*q*²

PZ(*q*²

PZ(*q*²

Example:
$$
h \rightarrow e^{+}e^{-}\mu^{+}\mu^{+}
$$

\n
$$
\mathcal{A} = i\frac{2m_{Z}^{2}}{v_{F}} (\bar{e}\gamma_{\alpha}e)(\bar{\mu}\gamma_{\beta}\mu) \times
$$
\n
$$
\begin{bmatrix}\nF_{1}^{e\mu}(q_{1}^{2}, q_{2}^{2})g^{\alpha\beta} + F_{3}^{e\mu}(q_{1}^{2}, q_{2}^{2})\frac{q_{1} \cdot q_{2} g^{\alpha\beta} - q_{2}^{\alpha} q_{1}^{\beta}}{m_{Z}^{2}} + F_{4}^{e\mu}(q_{1}^{2}, q_{2}^{2})\frac{\varepsilon^{\alpha\beta\rho\sigma} q_{2\rho} q_{1\sigma}}{m_{Z}^{2}}\n\end{bmatrix}
$$

^f (20)

The Higgs PO are defined from the residues on the physical poles.

9

The Higgs PO are defined from the residues on the physical poles.

hZµZ^µ hVµ⌫*V ^µ*⌫ *h*"*µ*⌫⇢*Vµ*⌫*V*⇢ *hZ^µ* ¯*fµf* (3)

$$
\begin{array}{c}\n9\n\end{array}
$$

 $\epsilon_{Z\gamma}^{\rm SM-1L}$

The Higgs PO are defined from the residues on the physical poles.

hZµZ^µ hVµ⌫*V ^µ*⌫ *h*"*µ*⌫⇢*Vµ*⌫*V*⇢ *hZ^µ* ¯*fµf* (3)

Radiative Corrections *V* = *Z, (18) Z, (1*

[M. Bordone, A. Greljo, G. Isidori, D. M., A. Pattori, work in progress] (19)

The most important radiative corrections are given by soft QED radiation effects since they M distort the spectrum. *WW ,* ✏*WW ,* ✏ *WW ,* off QED radiation effects since they and a matrix of the spectrum.
Nectrum Z *The most*

d by simple and universal $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ radiator functions: $\begin{bmatrix} 1 & 0.93 \\ 0.90 & -1 \end{bmatrix}$ Effect described by simple and universal *f* $\frac{1}{2}$ *f \frac{1}{2* $\frac{1}{4}$ *j* $\frac{1}{4}$ *j*^{*n*}</sub>

 $d\Gamma_{NLO}$ $dm_{01}dm_{02}dx_1dx_2$ = $d\Gamma_{LO}$ *dm*01*dm*⁰² $\frac{1}{2}$ *dm*01*dm*⁰² $\int_{02} dx_1 dx_2$ $dm_{01} dm_{02}$ $\int_{02}^{x_1} dx_2$

 \sim 15% effect! blue bands for *µ*+*µ* and *e*+*e* invariant mass spectra, re-Other NLO corrections are small.

$$
x = \frac{m^2}{m_0^2}
$$

Parameter counting and symmetry assumptions *CP* ting and symmetry assumptions *^Z , }* is necessary to describe *h* ! and

Symmetries impose relations among these observables. $\frac{1}{2}$ these observables to $\frac{1}{2}$ parameters to $\frac{1}{2}$ parameters to $\frac{1}{2}$ in the following subsections in the following subsections in the following subsections in the following subsections in the following w introduce symmetry arguments which allow to reduce the number of free parameters w free parameters w

Parameter counting and symmetry assumptions ✏*Ze^L ,* ✏*Ze^R ,* ✏*Zµ^L ,* ✏*Zµ^R* ting and symmetry assumptions *^Z , }* is necessary to describe *h* ! and Parameter counting and ownmatry coous *[From talk by A. Greljo at Portoroz'2015]*

Symmetries impose relations among these observables. we introduce symmetry arguments which allow to reduce the number of $\mathbf 1$

Flavor universality
\n
$$
\epsilon_{Ze_L} = \epsilon_{Z\mu_L} ,
$$
\n
$$
\epsilon_{Ze_R} = \epsilon_{Z\mu_R} ,
$$
\n
$$
\epsilon_{Z\nu_e} = \epsilon_{Z\nu_\mu} ,
$$
\n
$$
\epsilon_{We_L} = \epsilon_{W\mu_L} .
$$

1

Parameter counting and symmetry assumptions *CP* ting and symmetry assumptions *^Z , }* is necessary to describe *h* ! and Parameter counting and ownmatry coous Parameter counting and symmetry as

Parameter counting and symmetry assumptions *CP* ✏*Ze^L ,* ✏*Ze^R ,* ✏*Zµ^L ,* ✏*Zµ^R* ting and symmetry assumptions *^Z , }* is necessary to describe *h* ! and Parameter counting and ownmatry coous *[From talk by A. Greljo at Portoroz'2015]* Parameter counting and symmetry as

Since the last contract complex in the filled in the relations which are five relations which allow the relations which allow the relations which are five relations which are five relations which are five relations which a Accidentally true also in the linear EFT.

Linear-EFT can be ruled out using only Higgs data! **Mar-CFT can be ruled out using only Hi** Linear-EFT can be ruled out using only Hig **CITIEGIL ET LIGHT DE LUIEU OUT USITIY OF ITS FITTINGS OF ITS** Linear-EFT can be ruled out using only Higgs data!

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Higgs PO and linear EFT

Higgs PO and linear EFT

Constraints on the PO in the linear EFT

$$
\epsilon_{Zf} = \frac{2m_Z}{v} \left(\delta \chi_f^f - (c_\theta^2 T_f^3 + s_\theta^2 Y_f) \mathbf{1}_3 \delta g_{1,z} + t_\theta^2 Y_f \mathbf{1}_3 \delta \kappa_\gamma \right)
$$

From the LEP-II bounds on anomalous triple-gauge couplings:

Predictions for h → 4ℓ **in the linear EFT**

From these bounds we can extract precise predictions for Higgs data, such as total decay rates or di-lepton invariant mass spectra:

(a) (b) the other hand, the other pseudo-observables, e *ZZ,Z*g*,*gg , mod-Small deviations allowed in the shape.

 τ_{base} Ω and he studied also from **Example 5 and Find and Find and Find and Equator include the example of the example of** angular distributions. These PO can be studied also from

100

100

Predictions for h → 4ℓ **in the linear EFT**

From these bounds we can extract precise predictions for Higgs data, such as total decay rates or di-lepton invariant mass spectra:

the other hand, the other pseudo-observables, e *ZZ,Z*g*,*gg , mod-Small deviations allowed in the shape. **Example 22 decay obtain be studied also from a** angular distributions. These PO can be studied also from

Conclusions

Pseudo-observables

Clear connection to measurable distributions.

Directly related to physical properties of the amplitude.

Easy to match to any EFT in any basis.

Symmetries impose relations among Higgs PO, which can be tested by Higgs data only.

Assuming a underlying linear EFT we obtained relations among Higgs and non-Higgs processes. Given LEP constraints we derived detailed predictions for $h \rightarrow 4\ell$ processes.

Testing these predictions from data would provide an important test for the linear EFT.

PO can be implemented both for Matrix Element Methods, and Montecarlo (MG5).

Thank you!

Kinematical distributions

Backup

The matrix element squared is directly obtained analytically from the amplitude.

Kinematical distributions where *q*¹ = *p*¹ + *p*2, *q*² = *p*³ + *p*4, *f* = *eL, eR*, *f*⁰ *<i>p***/2</sub>** *p/₂**p/***₂</sub> ***p/₂ p/₂**p/***₂</sub>** *p/***₂** where *q*¹ = *p*¹ + *p*2, *q*² = *p*³ + *p*4, *f* = *eL, eR*, *f*⁰ = *µL, µ^R* and *P^f* and *P^f*⁰ 2, and an an an annual distribution in an angle distribution in a q2 and q

= *µL, µ^R* and *P^f* and *P^f*⁰ *f f*⁰ (*q*1*, q*2)*,* (39) *Backup*

The matrix element squared is directly obtained analytically from the amplitude. \sum s AA^* matrix element spins, and summer the final lepton spins, after the final lepton spins, after the final lepton spins, after integrating over the angular variables, after integrating over the angular variables, and spins, af $\begin{matrix} \end{matrix}$ $\sum A A^*$ ient squared is directly obtained analytically from the amplitude. $\frac{80}{20}$ atrix aloment squared is directly obtained analytically from the amplitude corrective profitem oquators to allocally obtained after jacany from the amplitude. $\sum_{\mu} A_{\mu} A^*$ = ⇧4*^l AA*⇤ corresponding chirality projection operators. After integrating over the angular variables, and angular variables, ~ 0.0 ^{ou} The matrix element squared is directly obtained where \mathcal{A} is the final state four body phase space factor. T -conserving part of the double distribution can then be decomposed distri *dq*² 1*dq*² 2 s where $\frac{1}{\sqrt{2}}$ $\sum_{\mu} A_{\mu}$ 1*dq*² *,* (41) Figure 1: Normalized di↵erential *^h* ! *^e*⁺*eµ*⁺*µ* decay distribution in *^m*¹² ⌘ ^p*q*² SM. Tree level predictions and full *O*(↵) electroweak corrections with Prophecy4F Monte

*p*₂, *p*₂ This can be used for Matrix Element Method experimental analysis, or to derive differential distributions: corresponding chirality projection of the angular variables, and the angular variables, \sim we do the double distribution and analytic distribution in \mathcal{L} ¹ and *q*² where *induin* computed four and the factor. The CP-conserving part of the double distribution can then be decomposed Element Method ex where the final state four body phase space for the factor of the factor of the space space space σ . *d dq*² 1*dq*² or to derive differential distributio d for *dq*² 1*dq*² V atri[.] *dq*² 1*dq*² $\|$ I *dq*² 1*dq*² ent method exp where ⁹ *^q*² 1*q*2 I distributions: This can be used for Ma is obtained after integrating the analytic formula (Eq. 42) over *q*² ² for *ZZ* = 1 and ✏*^X* = 0.

¹)(1 ²

2

(1 ²

corresponding chirality projection operators. After integrating over the angular variables, $d\Gamma^{11}$ $d\Gamma^{13}$ $d\Gamma^{33}$ $\frac{1}{2}$ 2, $d\Gamma$ $dq_1^2 dq_2^2$ $= \Pi_{4l}$ Z $d\Omega$ \sum s $A\mathcal{A}^* = \frac{d\mathbf{a}^2}{d\mathbf{a}^2 d\mathbf{a}^2} + \frac{d\mathbf{a}^2}{d\mathbf{a}^2 d\mathbf{a}^2} + \frac{d\mathbf{a}^2}{d\mathbf{a}^2 d\mathbf{a}^2}$ *d dq*² 1*dq*² 2 = $d\Gamma^{11}$ $dq_1^2 dq_2^2$ $+$ $d\Gamma^{13}$ $dq_1^2 dq_2^2$ $+$ $d\Gamma^{33}$ $dq_1^2 dq_2^2$ *,* (41) Example for CP conserving terms The forecase $\sqrt{1-\frac{1}{2}}$ $\overline{a_2^2}$ *dq*² 1*dq*² \int ^{*d*2} *dq*² 1*dq*² $\overline{}$ $\mathcal{A}\mathcal{A}$ *dq*² 1*dq*² $\overline{a^2_1d^2_2}$ *dq*² 1*dq*² $\mu_1 \mu_2 \quad \mu_1 \mu_2$ \overline{CD} conserving torms \sim $\int d\Gamma$ $\int d\Gamma$ 3+21² 2(² ¹ + ² ²)+3² 1² $\overline{}$ f *Ff f*⁰ 1 Ì 2 $=$ $\mu \rightarrow e^+e^- \mu^+\mu^-$ ◆² 128⇡² **1** $\frac{dq_1dq_2}{s}$ <u>p</u> <u>(بالاستفاد)</u> ¹)(1 ² 2) *f,f*0 \overline{d} $h \times e^2$ $\rightarrow e^+e^-\mu^+\mu^-$ ✓2*m^Z* $\overline{18}$ $\int d\overline{q_1^2}$ $q_{\tilde{2}}$ $= \Pi_{4l}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{2}{2}$ *f,f*0 $\mathcal{A} \mathcal{A}^* =$ <u>i</u> *,* $h \to e^+e^-\mu^+\mu^-$

2)

2

*f,f*0

2

(43)

2

For example the 11 term is simply: The Chainpie, the Theorie distribution can the distribution can then be decomposed of the dis For example, the 11 term is simply: For example, the 11 term is ⁼ *^p* $2 + 4$ 2¹⁰(2⇡)⁷*m^h* ⁹ (*q*² 1*q*2 2) For example, the 11 term is simply:

AA⇤

vF

✓2*m*²

 $\ddot{\ddot{\mathbf{}}}$

 $\ddot{\bullet}$

*f,f*0

✓2*m*²

where *q*¹ = *p*¹ + *p*2, *q*² = *p*³ + *p*4, *f* = *eL, eR*, *f*⁰ = *µL, µ^R* and *P^f* and *P^f*⁰

corresponding chirality projection operators. After integrating over the angular variables, \mathcal{F}

tr(*p/*¹

where

$$
\frac{d\Gamma^{11}}{dq_1^2 dq_2^2} = \frac{\lambda_p}{2^{10}(2\pi)^7 m_h} \left(\frac{2m_Z^2}{v_F}\right)^2 \frac{128\pi^2}{9} q_1^2 q_2^2 \frac{3 + 2\beta_1 \beta_2 - 2(\beta_1^2 + \beta_2^2) + 3\beta_1^2 \beta_2^2}{(1 - \beta_1^2)(1 - \beta_2^2)} \sum_{f,f'} \left| F_1^{ff'} \right|^2
$$

$$
\lambda_p = \sqrt{1 + \left(\frac{q_1^2 - q_2^2}{m_h^2}\right)^2 - 2\frac{q_1^2 + q_2^2}{m_h^2}} \quad \beta_{1(2)} = \sqrt{1 - \frac{4q_{1(2)}^2 m_h^2}{(q_{1(2)}^2 - q_{2(1)}^2 + m_h^2)^2}}
$$

*p*₂, *p*₂ This can be used for Matrix Element Method experimental analysis, or to derive differential distributions: α r to derive differential distributions. After integrating over the angular variables, α we do the double differential distributions. where *induin* computed four and state four body phase space $\frac{1}{2}$. The CP-conserving part of the double distribution can then be decomposed *dq*² 1*dq*² 22 22 23 24 25 26 27 28 29 20 21 22 23 24 d for *dq*² 1*dq*² V *dq*² 1*dq*² $\|$ *dq*² 1*dq*² ent method exp or to derive differer ⁹ *^q*² 1*q*2 to derive differential distributions: with Prophecy¹ electroweak corrections with Prophecy4F Monte Pr is obtained after integrating the analytic formula (Eq. 42) over *q*² is can be used for Matrix Element Method experimental analysis, \vert

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corresponding chirality projection operators. After integrating over the angular variables, $d\Gamma^{11}$ $d\Gamma^{13}$ $d\Gamma^{33}$ $\frac{1}{2}$ ¹ and *q*² 2, $d\Gamma$ $dq_1^2 dq_2^2$ $= \Pi_{4l}$ Z $d\Omega$ \sum s $A\mathcal{A}^* = \frac{d\mathbf{a}^2}{d\mathbf{a}^2 d\mathbf{a}^2} + \frac{d\mathbf{a}^2}{d\mathbf{a}^2 d\mathbf{a}^2} + \frac{d\mathbf{a}^2}{d\mathbf{a}^2 d\mathbf{a}^2}$ *d dq*² 1*dq*² 2 = $d\Gamma^{11}$ $dq_1^2 dq_2^2$ $+$ $d\Gamma^{13}$ $dq_1^2 dq_2^2$ $+$ $d\Gamma^{33}$ $dq_1^2 dq_2^2$ *,* (41) Example for CP conserving terms The forecase $\sqrt{1-\frac{1}{2}}$ $\overline{a_2^2}$ *dq*² 1*dq*² \int ^{*d*2} *dq*² 1*dq*² $\overline{}$ $\mathcal{A}\mathcal{A}$ *dq*² 1*dq*² $\overline{a^2_1d^2_2}$ *dq*² 1*dq*² $\mu_1 \mu_2 \quad \mu_1 \mu_2$ \overline{CD} conserving torms \sim $\int d\Gamma$ $\int d\Gamma$ 3+21² 2(² ¹ + ² ²)+3² 1² $\overline{}$ f *Ff f*⁰ 1 Ì 2 $=$ $\mu \rightarrow e^+e^- \mu^+\mu^-$ ◆² 128⇡² ³ (*q*² J ^s <u>p</u> <u>(بالاستفاد)</u> ¹)(1 ² 2) *f,f*0 \overline{d} $h \times e^2$ $\rightarrow e^+e^-\mu^+\mu^-$ ✓2*m^Z* $\overline{18}$ $\int d\overline{q_1^2}$ $q_{\tilde{2}}$ $= \Pi_{4l}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{2}{2}$ *f,f*0 $\mathcal{A} \mathcal{A}^* =$ <u>i</u> *,* $h \to e^+e^-\mu^+\mu^-$ Carlo generator [13] are shown with blue and red dots, respectively. The solid black line pie for
inserving terms $d\Gamma$ of Γ and $d\Gamma^{11}$ and $d\Gamma^{33}$ denotes $d\Gamma^{33}$ of the custodial symmetry relations in Eqs. (33), (33), (33), (33), (34) and (36). (33), (34) and (36). (34) and (36). (36). (34) and (36). (34) and (36). (34) and (36). (34) and (36). (34). (34). (34). (34). (34). (34). (

2)

2

*f,f*0

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(43)

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For example the 11 term is simply: The Chainpie, the Theorie distribution can the distribution can then be decomposed of the dis *d*¹¹ For example, the 11 term is simply: For example, the 11 term is ⁼ *^p* $2 + 4$ 2¹⁰(2⇡)⁷*m^h* ⁹ (*q*² 1*q*2 2) For example, the 11 term is simply:

where

$$
\frac{d\Gamma^{11}}{dq_1^2 dq_2^2} = \frac{\lambda_p}{2^{10}(2\pi)^7 m_h} \left(\frac{2m_Z^2}{v_F}\right)^2 \frac{128\pi^2}{9} q_1^2 q_2^2 \frac{3 + 2\beta_1 \beta_2 - 2(\beta_1^2 + \beta_2^2) + 3\beta_1^2 \beta_2^2}{(1 - \beta_1^2)(1 - \beta_2^2)} \sum_{f,f'} \left| F_1^{ff'} \right|^2
$$
\n
$$
\lambda_p = \sqrt{1 + \left(\frac{q_1^2 - q_2^2}{m_h^2}\right)^2 - 2\frac{q_1^2 + q_2^2}{m_h^2}} \quad \beta_{1(2)} = \sqrt{1 - \frac{4q_{1(2)}^2 m_h^2}{(q_{1(2)}^2 - q_{2(1)}^2 + m_h^2)^2}}
$$

times **F**r $\overline{ }$ is we can get the total rate dependence on the PO α in this we can get the total rate denendence on the PO: **From this we can get the total rate dependence on From this we can get the total rate dependence on the** polynomial *in <i>X* and *you are total rate dependence on an* and Fro From this we can get the total rate dependence on the PO:

2

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 θ $\alpha + 0$ $-\mu$ ⁻ $2\delta\kappa_5$ \overline{z} (2) 2¹⁰(2⇡)⁷*m^h* \overline{z} $5\epsilon_2$ + 2 $+2.9\epsilon_{Z\mu_L}$. $+0.5\epsilon_{ZZ} - 0.9\epsilon_{Z\gamma} + 0.01\epsilon_{\gamma\gamma}$ $\frac{1}{2}$ $\frac{c}{\Gamma^S}$ $\frac{e}{2}$ t^+ $+2\delta\kappa_{ZZ}-2.5\epsilon_{Ze_R}+2$ ⁹ (*q*² 1*q*2 2) $-2.5\epsilon_{Z\mu_R} + 2.9\epsilon_{Z\mu_L} + 0.5\epsilon_{ZZ} - 0.9\epsilon_{Z\gamma}$ *Ff f*⁰ $\overline{1}$ ϵ *,* Γ $r_{\rm e} + e^- \mu^+ \mu^-$ in a second pace. If the pace parameters parameters parameters are not the approximate t_{TSM} to the amplitude terms in the amplitudes corresponding to t_{Ze_R} to t_{Ze_R} to t_{Ze_R} $\Gamma_{e^+e^-}$ the interference terms of NP with the SM amplitude are expected to be smaller the SM amplitude to be expected to be a smaller to be a smaller to be expected to be a smaller to be a smaller to be a smaller to b $\frac{r}{T_S}$ in a large fraction of the phase pace. If the approximate pace. If the approximate $\frac{1}{T_S}$ is $\frac{1}{T_S}$ is $\frac{1}{T_S}$ in an $\frac{1}{T_S}$ is $\frac{1}{T_S}$ in an $\frac{1}{T_S}$ is $\frac{1}{T_S}$ in an $\frac{1}{T_S}$ is $\frac{1}{$ $\frac{1}{e^+e^-\mu^+\mu^-}$ $I = \frac{1}{\sqrt{2}}$ and $I = \frac{1}{\sqrt{2}}$ $\Gamma_{e^+e^-\mu^+\mu^-}$ $\Gamma_{e^+e^-\mu^+\mu^-}^{SM}$ $= 1+2\delta\kappa_{ZZ} -2.5\epsilon_{Ze_R} +2.9\epsilon_{Ze_L} -2.5\epsilon_{Z\mu_R} +2.9\epsilon_{Z\mu_L} +0.5\epsilon_{ZZ} -0.9\epsilon_{Z\gamma} +0.01\epsilon_{\gamma\gamma}$

PO in EW Higgs Production The public of our approximation of the characterise, as precisely as precisely as precisely as pointing to the three pointing and the three pointing $BackUD$ for the Higgs bound of the Higgs boson and two fermion currents, $\frac{1}{2}$

Backup

$\langle 0|\mathcal{T}\left\{J_{f}^{\mu}(x),J_{f^{\prime}}^{\nu}(y),h(0)\right\}\rangle$ $|0\rangle$

By crossing symmetry, the same correlation function by crossing symmetry, the same correlation function
(in a different kinematical region and with different fermionic currents) enters also in EW Higgs production. where all the states are on-shell. This correlation-function-function-function-function-function-function-functionwith a different milentation region and with amorem formority carrottle).
Anters also in EW Higgs production from data will allow us both to determine the e \sim

In this case since the possible high momentum transfer at the LHC could cause issues with the validity of the EFT expansion. Not an issue with form factors.

Charged current decays Backup leptonic channels, which are more interesting from the experimental point of view.

The same approach can be extended to charged current decays *www.decard* The same approach can be extended to charged current decay \blacksquare \overline{a} san ρ _proach can be ϵ *PZ*(*q*² 1)*PZ*(*q*² *<u>xtended</u> to* **10 charged cu**
p *Z q*2 1*PZ*(*q*² $\overline{\mathbf{r}}$ it deca *e*2*QeQ^µ*

 $h \rightarrow e^+e^-\nu\bar{\nu}$ of c.c. and n.c.: $h\to \mu^+\mu^-\nu\bar\nu$ *WW* (real) + ✏*W e^L ,*✏*W µ^L* (complex) *.* (29) Figure μ **of c.c. and n.c.:** $h \to \mu^+ \mu^- \nu \bar{\nu}$ *,*✏*CP ^Z , }* is necessary to describe *h* ! and ρ **b** $h \to \bar{\nu}_e e \bar{\mu} \nu_\mu$ interference of c.c. and n.c.:

$$
\begin{split} \mathcal{A} = & i \frac{2 m_W^2}{v_F} (\bar{e}_L \gamma_\alpha \nu_e) (\bar{\nu}_\mu \gamma_\beta \mu_L) \times \\ & \Big[\left(\kappa_{WW} \frac{(g_W^e)^* g_W^\mu}{P_W(q_1^2) P_W(q_2^2)} + \frac{(\epsilon_{W e_L})^*}{m_W^2} \frac{g_W^\mu}{P_W(q_2^2)} + \frac{\epsilon_{W \mu_L}}{m_Z^2} \frac{(g_W^e)^*}{P_W(q_1^2)} \right) g^{\alpha \beta} + \\ & + \epsilon_{WW} \frac{(g_W^e)^* g_W^\mu}{P_W(q_1^2) P_W(q_2^2)} \times \frac{q_1 \cdot q_2 \ g^{\alpha \beta} - q_2^{\alpha} q_1^{\beta}}{m_W^2} + \epsilon_{WW}^{\text{CP}} \frac{(g_W^e)^* g_W^\mu}{P_W(q_1^2) P_W(q_2^2)} \frac{\varepsilon^{\alpha \beta \rho \sigma} q_2^{\rho} q_1 \sigma}{m_W^2} \Big] \end{split}
$$