Pseudoobservables

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higgstools

What **Pseudoobservables (POs)** do is just collapsing (and/or transforming) some “primordial quantities” (say number of observed events in some pre-defined set-up) into some “secondary quantities” which we fill closer to the theoretical description of the phenomena.

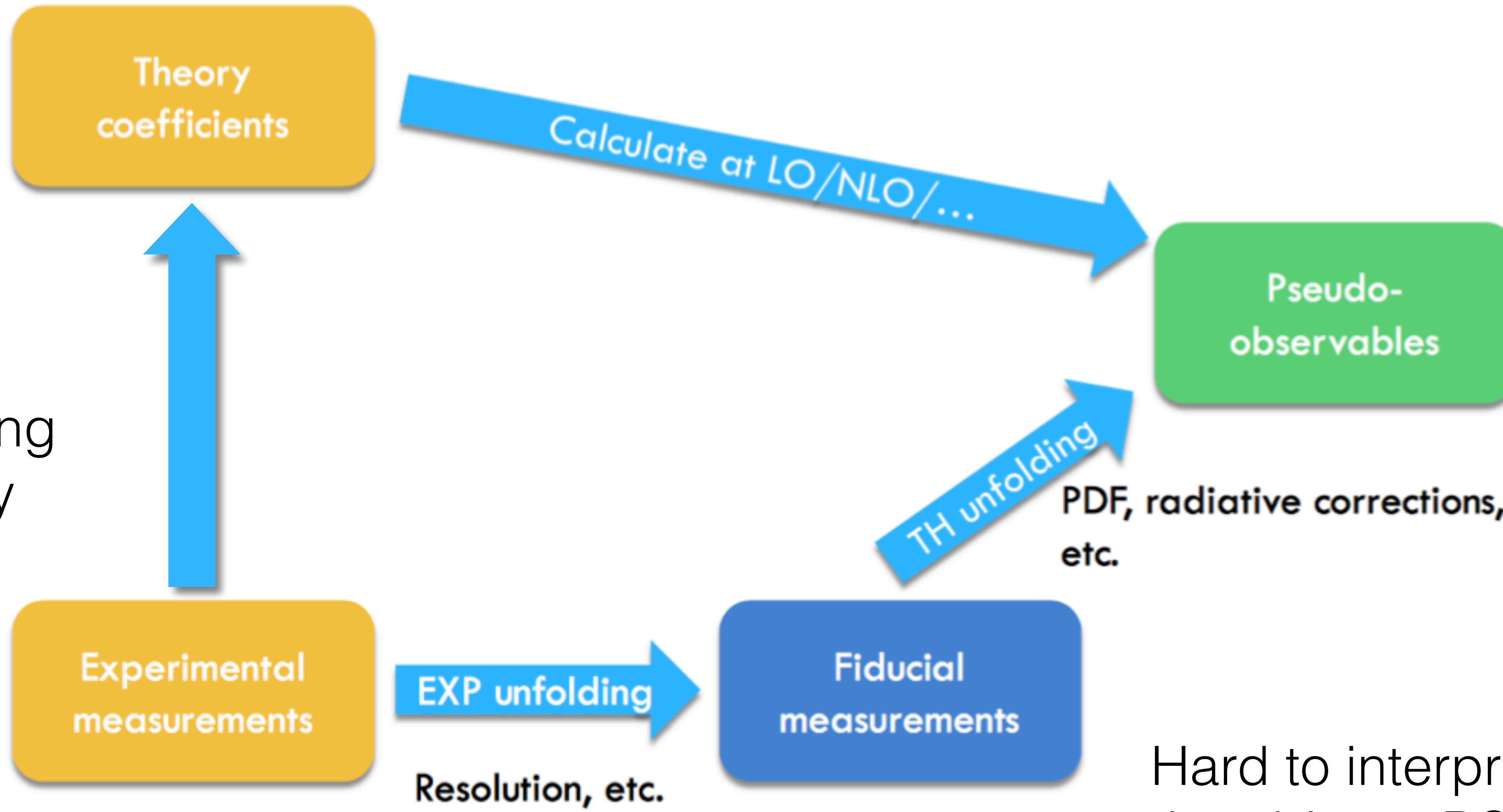
Giampiero Passarino at POs: from LEP to LHC 2015

Pseudoobservables should be the quantities which are experimentally accessible, well-defined from the point of QFT, and are able to capture the relevant New Physics without theoretical bias.

POs should be independent from the level of precision (LO, NLO, …), and their definition should be done after deconvoluting the soft SM radiation (QED and QCD), which is assumed not to depend on NP.

Many theoretical assumptions

Would require redoing analysis with every theory update



Hard to interpret directly in arbitrary BSM theory

Cannot be directly compared/combined between experiments

Pseudoobservables at LEP

In the LEP I data were taken at centre-of-mass energy within 3GeV from the Z mass

In the LEP II c.o.m. energy increased in order to produce W pairs, to reach up to 209 GeV

This enabled the measurements of Z and W properties to unprecedented precision.

Many measurements, including the angular distributions, allowed to define realistic observables (ROs) such as the cross-sections and asymmetries.

The experiments had different kinematic cuts and selection criteria.

But the ultimate goal was to have universal results.

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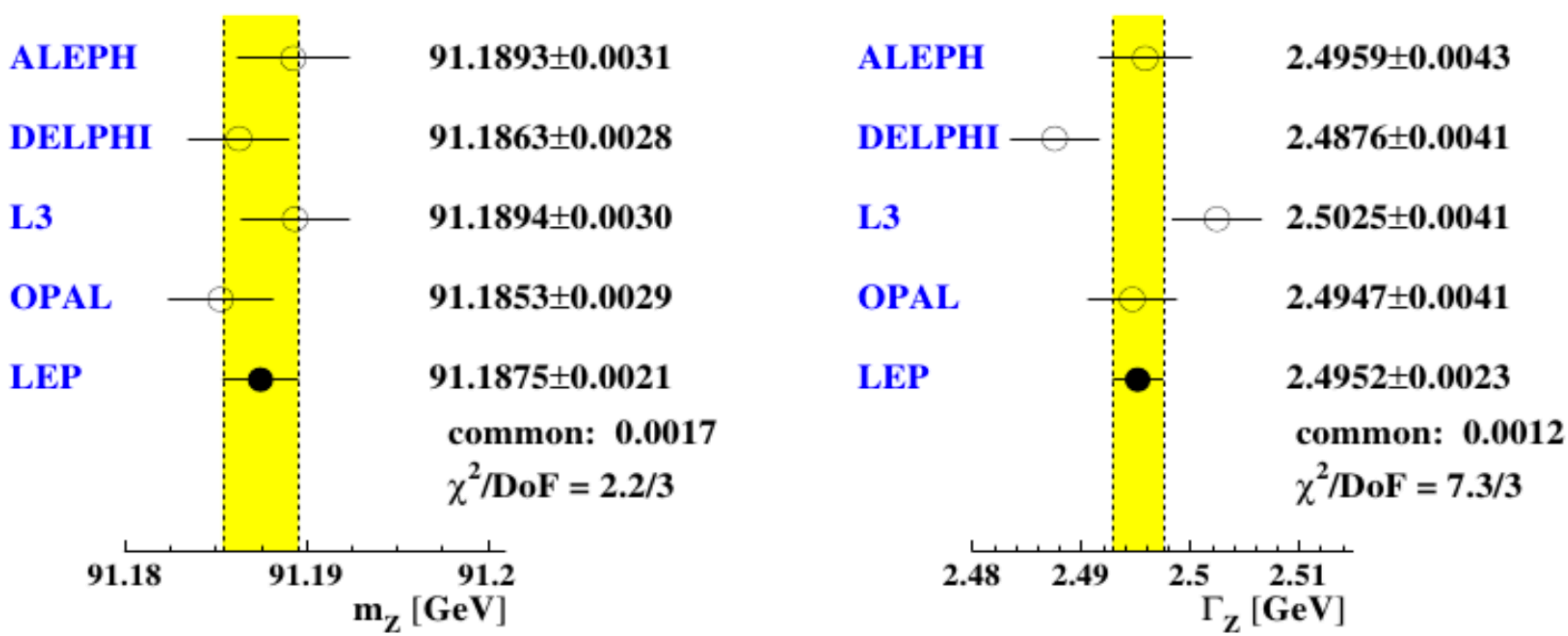
The direct fit into Z effective couplings complicated (due top the nontrivial c.o.m energy dependence)

Pseudoobservables were introduced to enable the comparison/combination of measurements between experiments.

They are known now as electroweak precision data (EWPD), and are often strong bound on the BSM models.



The general form of the Z decay matrix element:

$$\mathcal{M}^{Z}_{f\bar{f}} = \bar{u}_f \not{\epsilon}_Z \left(\mathcal{G}^f_V + \mathcal{G}^f_A \gamma_5\right) v_f$$

Two parametrisations

$$\mathcal{M}^{Z}_{f\bar{f}} = i \left(4\sqrt{2} G_F M^2_Z \rho^f_Z\right)^{1/2} \bar{u}_f \not{\epsilon}_Z \left(I^{(3)}_f \gamma_+ - 2 Q_f \kappa^f_Z s^2\right) v_f$$

To get access to the underlying hard process we need to separate from the soft EW corrections (initial and final state) and soft QCD (quark final state).

It was done by de-convoluting these processes (of course this require knowledge of them, good to compare different calculations):

$$\sigma(s) = \int_0^{1-x_{cut}} \mathrm{dx}\ \mathrm{H(x,s)}\ \sigma_0((1-\mathrm{x})\mathrm{s})$$

Radiator

In this way we are left with the Z-resonance being a modified Breit-Wigner resonance

$$\sigma_{\bar{f}f}(s) = \sigma_0^{\bar{f}f} \frac{s^2\Gamma_Z^2}{(s - M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2}$$

$$\sigma_0^f = \frac{12\,\pi}{M_z^2}\frac{\Gamma_e\Gamma_f}{\Gamma_z^2}$$

Partial widths were calculated including all the loops known, and total and partial Z widths include QED and QCD radiation in final state.

Also set of POs connected to decay widths were defined:

$$\Gamma_h = \Gamma_u + \Gamma_d + \Gamma_c + \Gamma_s + \Gamma_b, \quad \Gamma_{\mathrm{inv}} = \Gamma_z - \Gamma_e - \Gamma_\mu - \Gamma_\tau - \Gamma_h,$$

$$R_l = \frac{\Gamma_h}{\Gamma_e}, \qquad R_{b,c} = \frac{\Gamma_{b,c}}{\Gamma_h}, \qquad \sigma_h = 12\pi\frac{\Gamma_e\Gamma_h}{M_z^2\Gamma_z^2}.$$

Another object of interest is the angular distribution defined as:

$$\frac{d\sigma_f}{d\Omega} = \frac{\alpha^2}{4\,s} c_f \beta_f \left[\left(1 + c^2\right) F_1\left(s\right) + 4\,\mu_f^2 \,\left(1 - c^2\right) F_2\left(s\right) + 2\,\beta_f\, c F_3\left(s\right) \right]$$

With formfactors defined as:

$$F_1\left(s\right) = Q_e^2 Q_f^2 + 2\,Q_e Q_f g_V^e g_V^f \;\mathrm{Re}\,\chi\left(s\right) + \left[\left(g_V^e\right)^2 + \left(g_A^e\right)^2\right] \left[\left(g_V^f\right)^2 + \left(g_A^f\right)^2 - 4\,\mu_f^2\right] \left|\chi\left(s\right)\right|^2,$$

$$F_2\left(s\right) = Q_e^2 Q_f^2 + 2\,Q_e Q_f g_V^e g_V^f \;\mathrm{Re}\,\chi\left(s\right) + \left[\left(g_V^e\right)^2 + \left(g_A^e\right)^2\right] \left(g_V^f\right)^2 \left|\chi\left(s\right)\right|^2,$$

$$F_3\left(s\right) = 2\,Q_e Q_f g_A^e g_A^f \mathrm{Re}\,\chi\left(s\right) + 4\,g_V^e g_V^f g_A^e g_A^f \left|\chi\left(s\right)\right|^2.$$

or as:

$$F_1 = \frac{3}{4}\,\frac{s}{\pi\alpha^2}\,\left(\sigma_{VV} + \beta_f^2\,\sigma_{AA}\right), \quad F_2 = \frac{3}{4}\,\frac{s}{\pi\alpha^2}\,\sigma_{VV}, \quad \beta_f F_3 = \frac{3}{4}\,\frac{s}{\pi\alpha^2}\,\sigma_{VA}.$$

With this parametrisation the asymmetries can be defined:

$$A^f_{\mathrm{FB}}(s) = \frac{3}{4}\frac{\sigma_{VA}}{\sigma_T} = \frac{3}{4}\,\frac{\beta_f F_3(s)}{F_1(s) + 2\,\mu_f^2\, F_2(s)}$$

$$\mathcal{A}_f = \frac{2\,\mathrm{Re}\left[\mathcal{G}^f_V\ \left(\mathcal{G}^f_A\right)^*\right]}{\left|\mathcal{G}^f_V\right|^2 + \left|\mathcal{G}^f_A\right|^2}$$

$$A^f_{\mathrm{FB}} = \frac{3}{4}\mathcal{A}^e\mathcal{A}^f, \quad A^e_{\mathrm{LR}} = \mathcal{A}^e, \quad P^f = -\mathcal{A}^f, \quad P_{\mathrm{FB}}(\tau) = -\frac{3}{4}\mathcal{A}^e.$$

And so called effective sines:

$$4\,|Q_f|\sin^2\theta^f_{\mathrm{eff}} = 1 - \frac{\mathrm{Re}\ \mathcal{G}^f_V}{\mathrm{Re}\ \mathcal{G}^f_A} = 1 - \frac{g^f_V}{g^f_A}$$

The differential cross sections measured by the four experiments were parametrised in terms of POs in the way to minimise experimental error.

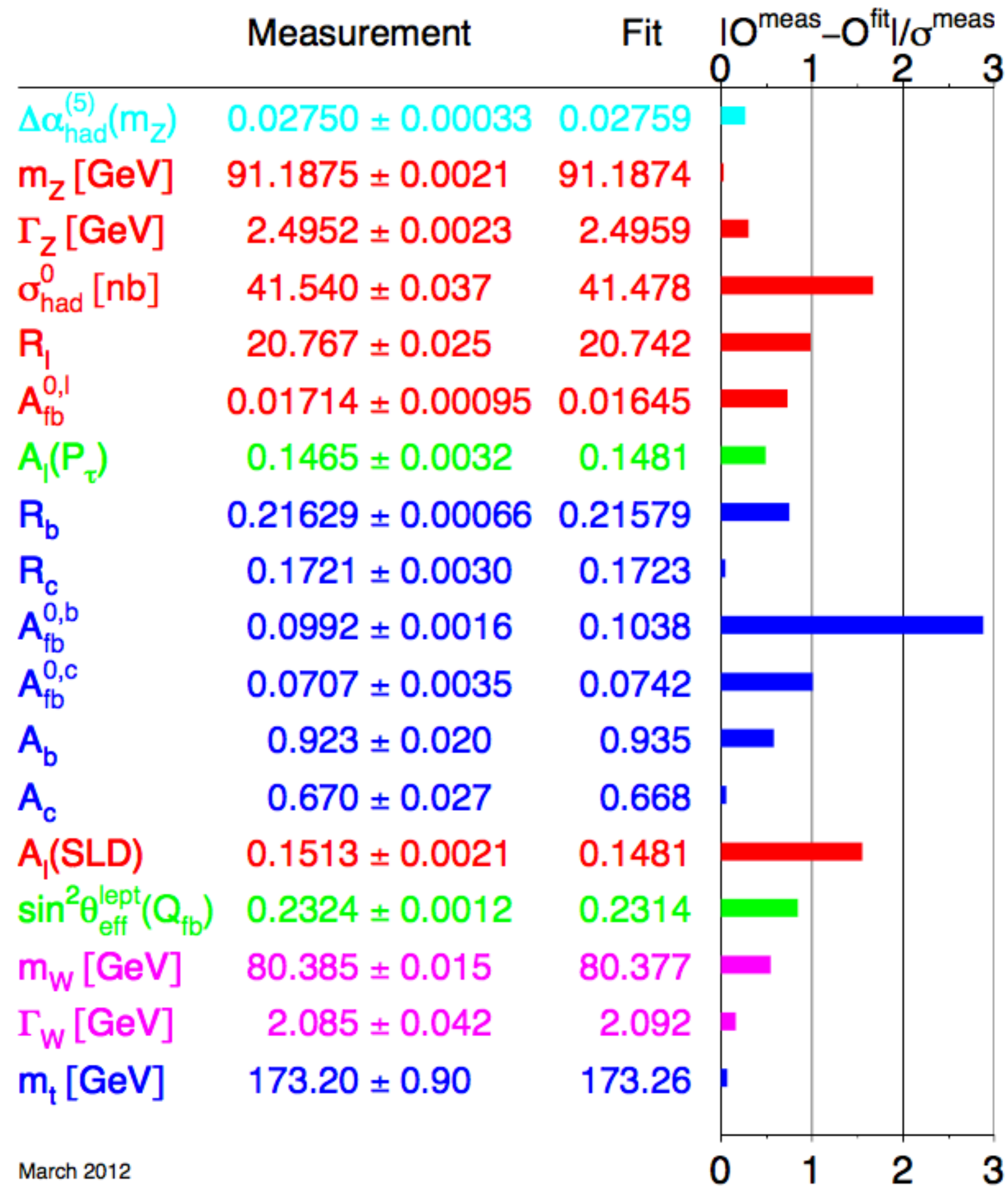
The experimental POs could be confronted against theoretical calculations including the all available at the time corrections via codes ZFITTER/TOPAZ0.

The POs are functions of SM parameters, even ones not known at the time (Higgs and top mass)

M_H (GeV)		65	300	1000
	Measurement with Total Error			
a) LEP				
Γ_z [GeV]	2.4939 ± 0.0024	2.4974	2.4934	2.4884
		2.4975	2.4935	2.4886
σ_h^0 [nb]	41.491 ± 0.058	41.471	41.474	41.479
		41.473	41.475	41.479

25 Pseudoobservables were defined and used:

- W mass
- hadronic peak cross section
- partial leptonic and hadronic width
- total width
- total hadronic width
- total invisible width
- various ratios
- asymmetries and polarisations
- effective sines



Differences then and now

Two key differences between LEP and LHC times are:

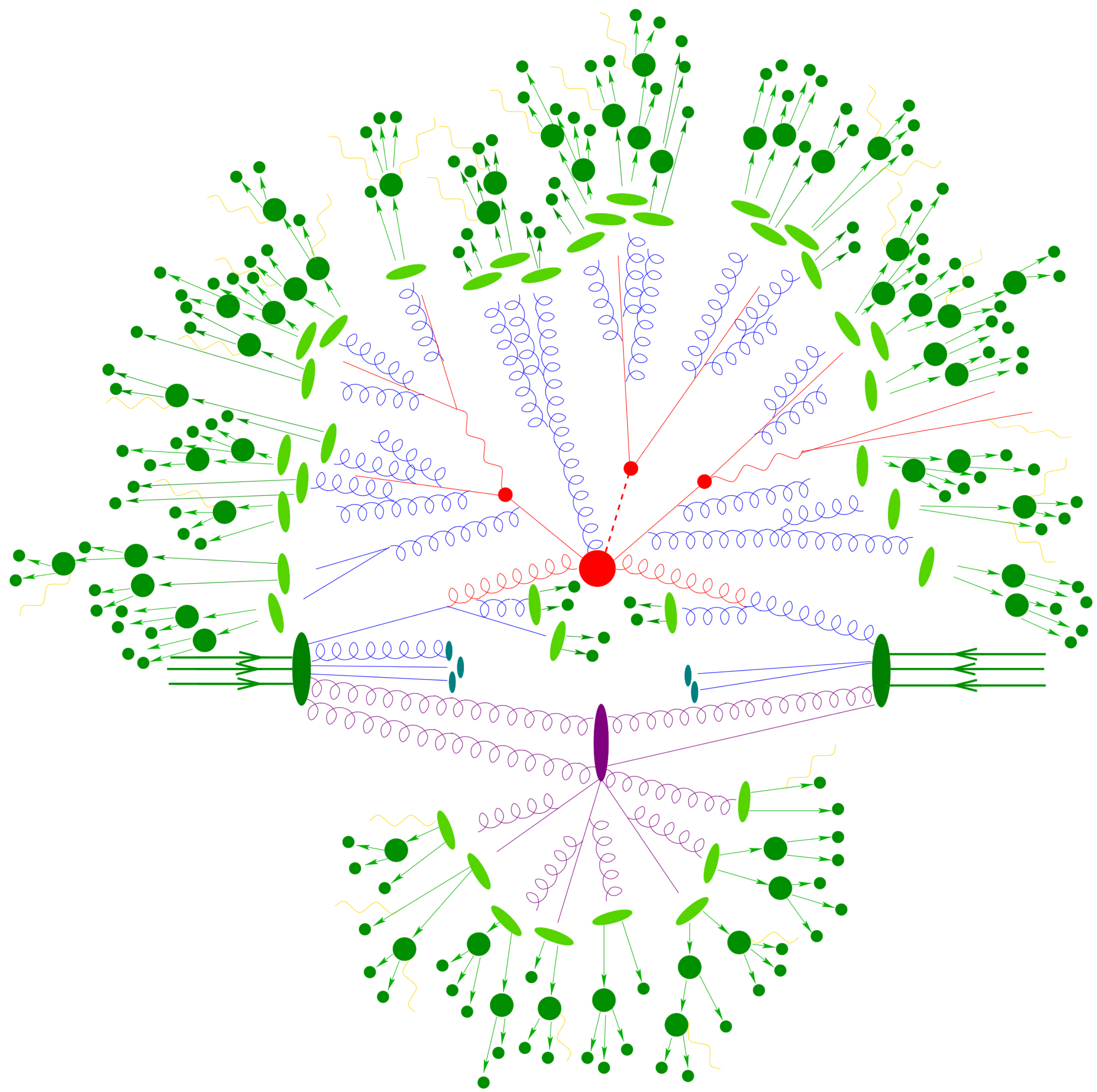
LEP was a electron-positron machine, while LHC is a proton-proton machine

20 years ago, despite strong evidence that SM is currently working model, two important parameters were missing: top quark and Higgs mass

At LEP the initial and final states were subjected to EW, and EW+QCD corrections respectively, however the collisions were much “cleaner” than LHC.

At LHC we have numerous sources of uncertainty, starting with the c.o.m. energy of the hard process on which the POs are defines.

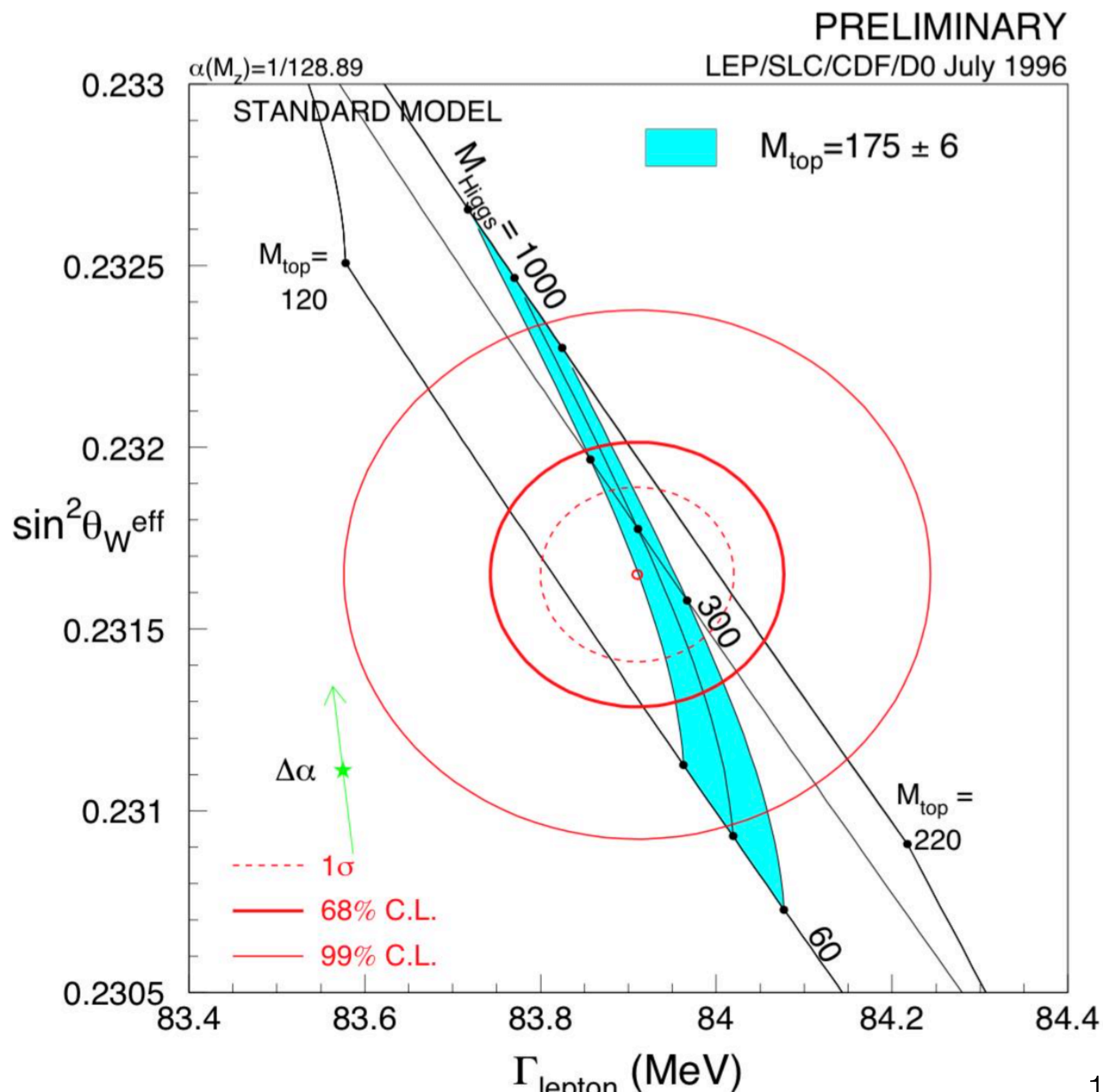
This all is caused by the sizeable QCD corrections as well as dependence on parton distribution functions, parton showers, …



LEP was not able to reach the Higgs boson mass (missed it by few GeV = 209 - (125+91)), but general theoretical assumption was that SM with not-yet-seen Higgs and top quark is valid model.

Many POs were displayed showing dependence on Higgs and top quark mass.

Now, with top quark and Higgs boson being observed at TeVatron and LHC, we have completed SM. The new ZOO of new models however requires broad and general set of measurements.



Pseudoobservables at LHC

The aim of the **Higgs PO** is to

characterise the properties of **h(125)** in generic BSM (with heavy NP) encoding the experimental results in terms of a limited set of simplified/idealized observables of easy theoretical interpretation (→ minimum theory bias)

Gino Isidori at HC2016

Universität Zürich[UZH]

Higgs PO

DESCRIPTION | DOWNLOAD | CONTACTS

Higgs pseudo-observables

Higgs pseudo-observables (PO) is a general framework to parametrize smooth deviations from the Standard Model in single Higgs production and decays. They are based on a general characterization of on-shell amplitudes, via a momentum expansion around the physical poles, corresponding to the intermediate propagation of the Standard Model gauge bosons.

In order to perform collider studies of these PO via a Montecarlo event generator, we implemented the framework in a FeynRules 2 UFO model. This can be imported in the MG5_aMC@NLO or Sherpa generator.

Our intention is to use the same notation for the Higgs PO as the one which will be adopted by the LHC Higgs cross section Working Group. In particular, we will update the code in order to be consistent with the work being done within the working group.

Download links to the model files, the manual, as well as tutorial notes, can be found in the Download page.

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Physik-Institut, Universitaet Zuerich I Last update on 25-Apr-16

http://www.physik.uzh.ch/data/HiggsPO

Defined to parametrise Higgs properties

Reuse EW POs from LEP and kappas

Defined from on-shell amplitudes as the momentum expansion around the physical poles

Inspired by SMEFT dim 6 lagrangian (ie. lack of Higgs - 4 fermion couplings)

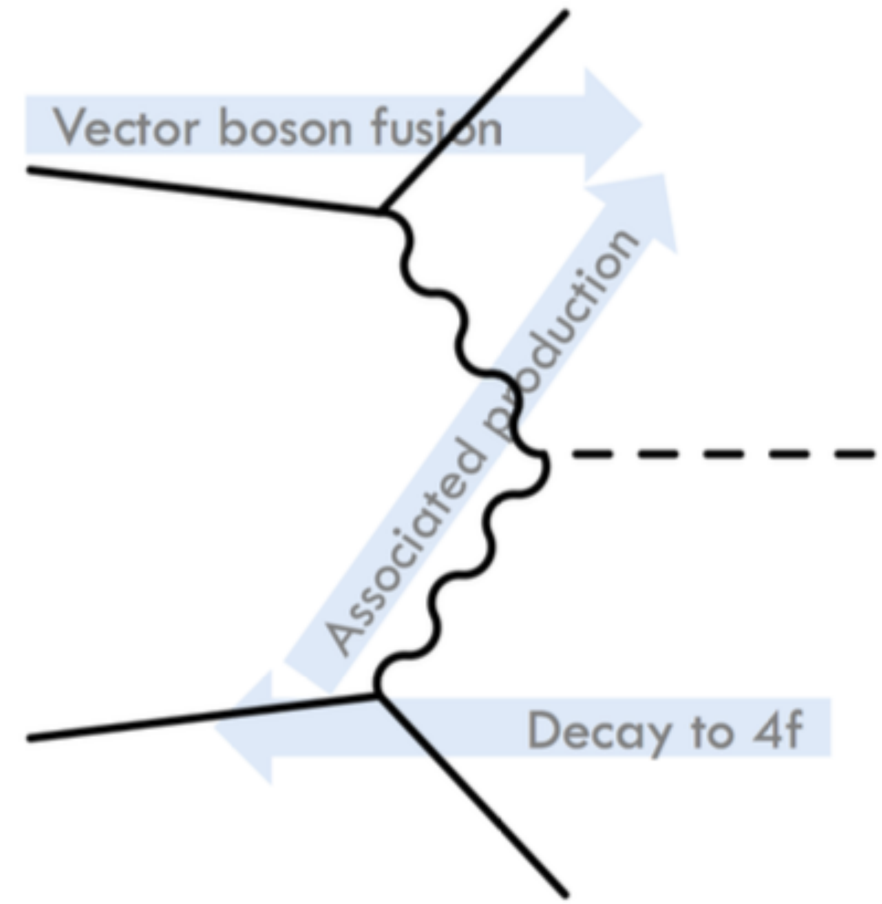
Defined both for Higgs decays and electroweak productions (VBF and Higgstralung)

Implemented into UFO format to allow to interface with generators (MadGraph, Prophecy4f, OpenLoops+Sherpa)

Studies in both decay and production include soft QED and QCD effects (eg. as parton showers, soft photon emission).

Higgs decaying to 4 fermions and electroweak production modes correspond to the same sets of pseudoobservables, since they share the tensor decomposition of amplitudes.

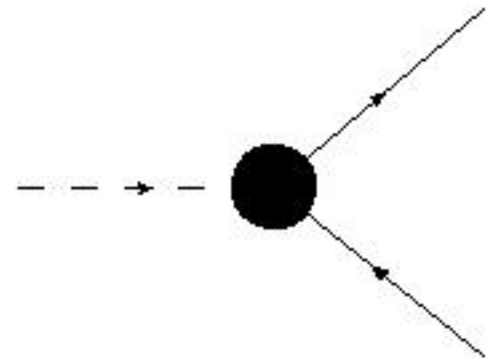
BUT! keep in mind the kinematic regime: POs defined from the on-shell amplitudes!
In case of production it may not be the case. Then measurements of formfactors would be a desirable approach.



For electroweak decay we will have 20 POs, while for production there is additional 32 POs connected with light quarks.

Further reduction of number of POs due to the symmetry assumptions

Higgs decaying to two fermions



Eg in the tau in bottom quark final states

Two POs: CP even and CP odd

$$\mathcal{A}(h \to f\bar{f}) = -\frac{i}{\sqrt{2}}(y_S^f \bar{f} f + i y_P^f \bar{f}\gamma_5 f)$$

$$\kappa_f = \frac{y_S^f}{y_{S,SM}^f}; \quad \delta_f^{CP} = \frac{y_P^f}{y_{S,SM}^f}$$

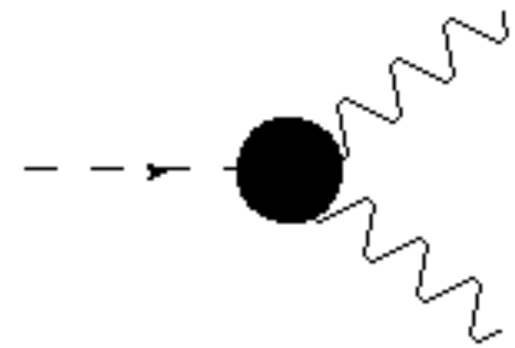
As in Kappa framework

Can be determined by measuring the polarisation of final state fermions: most probably not accessible at LHC

$$\Gamma(h \to f\bar{f}) = [{\kappa_f}^2 + {\delta_f^{CP}}^2]\Gamma_{SM}(h \to f\bar{f})$$

Effects conspire in the measurement of decay widths

Higgs decaying to two photons



For massless VB we have 2 tensor structures:

$$\mathcal{A}\left[h \to \gamma(q,\epsilon)\gamma(q',\epsilon')\right] \;=\; i\frac{2}{v_F}\epsilon'_\mu\epsilon_\nu\left[F_3^{\gamma\gamma}(g^{\mu\nu}\; q{\cdot}q' - q^\mu q'^\nu) + F_4^{\gamma\gamma}\varepsilon^{\mu\nu\rho\sigma}q_\rho q'_\sigma\right]$$

$$F_3^{\gamma\gamma} = \epsilon_{\gamma\gamma}$$

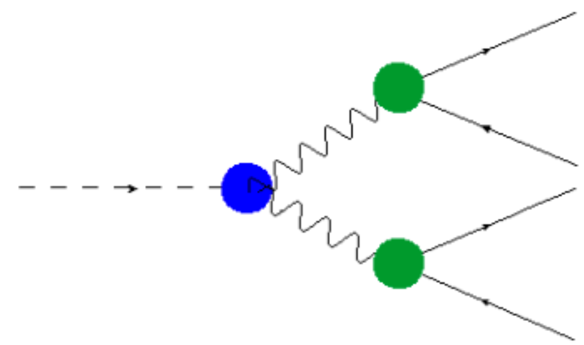
$$F_4^{\gamma\gamma} = \epsilon_{\gamma\gamma}^{\mathrm{CP}}$$

They are simply CP even and odd

Again effects conspire in the total decay width, and the need of measurement of photon polarisation makes it hardly accessible at LHC (at least in direct measurement)

Higgs decaying to four fermions (muons-electrons case)

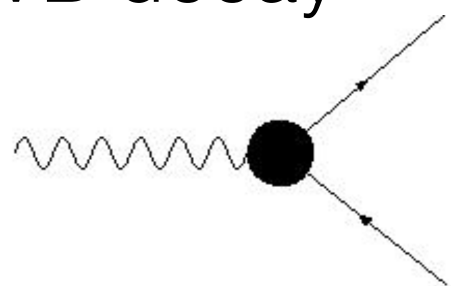
Just one combination of intermediate vector bosons: ZZ



"2-step" decay

Note, direct H-4f coupling would be dim 7

We start with POs for VB decay



$$\mathcal{A}(Z \to f\bar{f}) = \sum_{f=f_L,f_R} \epsilon_\mu g_Z^{ff'} \bar{f}'\gamma^\mu f$$

Use LEP values!

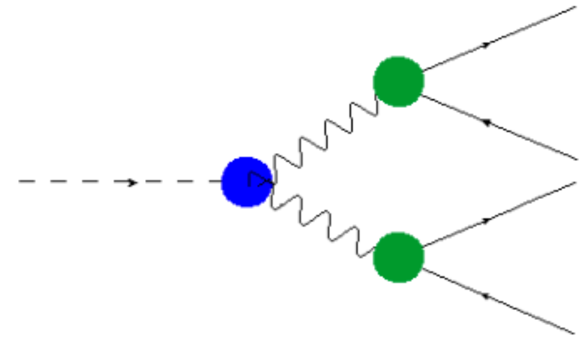
General amplitude form:

$$\mathcal{A}(h \to \mu^+(p_1)\mu^-(p_2)e^+(p_3)e^-(p_4)) = i\frac{2m_Z^2}{v} \sum_{\mu=\mu_L,\mu_R} \sum_{e=e_L,e_R} (\bar{\mu}\gamma_\mu \mu)(\bar{e}\gamma_\nu e)\mathcal{T}_{nc}^{\mu\nu}(q_1,q_2)$$

For massive VB we have 3 tensor structures:

$$\mathcal{T}_{nc}^{\mu\nu}(q_1,q_2) = g^{\mu\nu}F_L^{\mu e}(q_1,q_2) + \frac{g^{\mu\nu}q_1\cdot q_2 + q_1^\nu q_2^\mu}{m_Z^2} + F_T^{\mu e}(q_1,q_2) + \frac{\epsilon^{\mu\nu\rho\sigma}q_{1,\sigma}q_{2,\rho}}{m_Z^2}F_{CP}^{\mu e}(q_1,q_2)$$

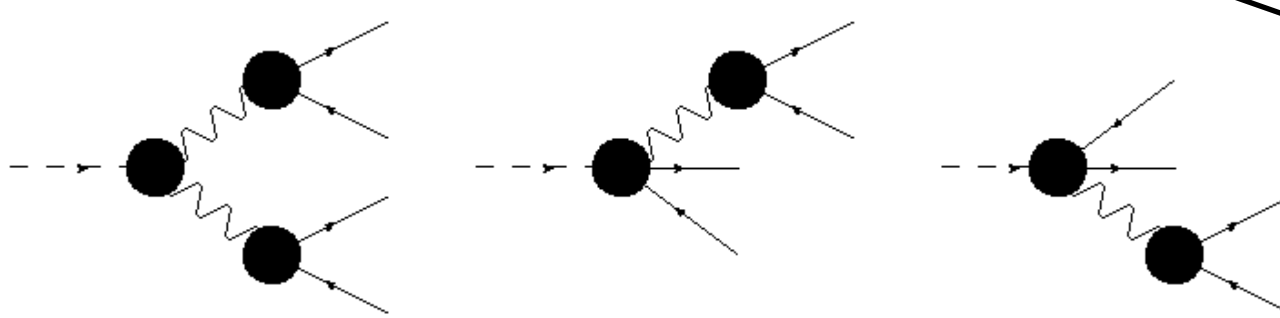
Higgs decaying to four fermions (muons-electrons case)



$$\mathcal{T}_{nc}^{\mu\nu}(q_1, q_2) = g^{\mu\nu} F_L^{\mu e}(q_1, q_2) + \frac{g^{\mu\nu} q_1 \cdot q_2 + q_1^{\nu} q_2^{\mu}}{m_Z^2} + F_T^{\mu e}(q_1, q_2) + \frac{\epsilon^{\mu\nu\rho\sigma} q_{1,\sigma} q_{2,\rho}}{m_Z^2} F_{CP}^{\mu e}(q_1, q_2)$$

$$F_L^{\mu e}(q_1, q2) = \kappa_{ZZ} \frac{g_Z^{\mu} g_Z^{e}}{P_Z(q_1^2) P_Z(q_2^2)} + \frac{\epsilon_{Z\mu}}{m_Z^2} \frac{g_Z^{e}}{P_Z(q_2^2)} + \frac{\epsilon_{Ze}}{m_Z^2} \frac{g_Z^{\mu}}{P_Z(q_1^2)} + \Delta_L^{SM}(q_1^2, q_2^2)$$

momentum expansion around the physical pole



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

$$F_T^{\mu e}(q_1, q2) = \epsilon_{ZZ} \frac{g_Z^{\mu} g_Z^{e}}{P_Z(q_1^2) P_Z(q_2^2)} + \epsilon_{Z\gamma} \left(\frac{e Q_{\mu} g_Z^{e}}{q_1^2 P_Z(q_2^2)} + \frac{e Q_e g_Z^{\mu}}{q_2^1 P_Z(q_1^2)} \right) + \epsilon_{\gamma\gamma} \frac{e^2 Q_{\mu} Q_e}{q_1^2 q_2^2} + \Delta_T^{SM}(q_1^2, q_2^2)$$

$$F_{CP}^{\mu e}(q_1, q2) = \epsilon_{ZZ}^{CP} \frac{g_Z^{\mu} g_Z^{e}}{P_Z(q_1^2) P_Z(q_2^2)} + \epsilon_{Z\gamma}^{CP} \left(\frac{e Q_{\mu} g_Z^{e}}{q_1^2 P_Z(q_2^2)} + \frac{e Q_e g_Z^{\mu}}{q_2^1 P_Z(q_1^2)} \right) + \epsilon_{\gamma\gamma}^{CP} \frac{e^2 Q_{\mu} Q_e}{q_1^2 q_2^2}$$

Higgs decaying to four fermions

The definition is analogous in the case of decaying via WW bosons pair, e.g. electron, muon and neutrinos in the final state. Just replace Z couplings, mass and propagator with the W one, and omit Z-photon terms

$$G_L^{\ell\ell'}(q_1^2,q_2^2) = \kappa_{WW}\frac{(g_W^\ell)^* g_W^{\ell'}}{P_W(q_1^2)P_W(q_2^2)} + \frac{(\epsilon_{W\ell})^*}{m_W^2}\frac{g_W^{\ell'}}{P_W(q_2^2)} + \frac{\epsilon_{W\ell'}}{m_W^2}\frac{(g_W^\ell)^*}{P_W(q_1^2)}\,,$$

$$G_T^{\ell\ell'}(q_1^2,q_2^2) = \epsilon_{WW}\frac{(g_W^\ell)^* g_W^{\ell'}}{P_W(q_1^2)P_W(q_2^2)}\,,$$

$$G_{CP}^{\ell\ell'}(q_1^2,q_2^2) = \epsilon_{WW}^{\mathrm{CP}}\frac{(g_W^\ell)^* g_W^{\ell'}}{P_W(q_1^2)P_W(q_2^2)}\,,$$

The situation may be more complicated in some final states in which contributes both the neutral and charged currents. Then we need to take both cases into account:

$$\begin{aligned}\mathcal{A}(h\to\mu^+\mu^-\nu_\mu\bar\nu_\mu) &= \mathcal{A}_{nc}(h\to(Z\to\mu^+\mu^-)(Z\to\nu_\mu\bar\nu_\mu))\\ &\quad+\mathcal{A}_{cc}(h\to(W^+\to\mu^+\nu_\mu)(W^-\to\mu^-\bar\nu_\mu))\end{aligned}$$

Effective coupling POs vs Physical POs

PO	Physical PO		Relation to the eff. coupl.
$\kappa_f,\ \lambda_f^{\rm CP}$	$\Gamma(h\to f\bar f)$	$=$	$\Gamma(h\to f\bar f)^{\rm (SM)}[(\kappa_f)^2+(\lambda_f^{\rm CP})^2]$
$\kappa_{\gamma\gamma},\ \lambda_{\gamma\gamma}^{\rm CP}$	$\Gamma(h\to\gamma\gamma)$	$=$	$\Gamma(h\to\gamma\gamma)^{\rm (SM)}[(\kappa_{\gamma\gamma})^2+(\lambda_{\gamma\gamma}^{\rm CP})^2]$
$\kappa_{Z\gamma},\ \lambda_{Z\gamma}^{\rm CP}$	$\Gamma(h\to Z\gamma)$	$=$	$\Gamma(h\to Z\gamma)^{\rm (SM)}[(\kappa_{Z\gamma})^2+(\lambda_{Z\gamma}^{\rm CP})^2]$
κ_{ZZ}	$\Gamma(h\to Z_LZ_L)$	$=$	$(0.209\ {\rm MeV})\times\lvert\kappa_{ZZ}\rvert^2$
ϵ_{ZZ}	$\Gamma(h\to Z_TZ_T)$	$=$	$(1.9\times10^{-2}\ {\rm MeV})\times\lvert\epsilon_{ZZ}\rvert^2$
$\epsilon_{ZZ}^{\rm CP}$	$\Gamma^{\rm CPV}(h\to Z_TZ_T)$	$=$	$(8.0\times10^{-3}\ {\rm MeV})\times\lvert\epsilon_{ZZ}^{\rm CP}\rvert^2$
ϵ_{Zf}	$\Gamma(h\to Zf\bar f)$	$=$	$(3.7\times10^{-2}\ {\rm MeV})\times N_c^f\ \lvert\epsilon_{Zf}\rvert^2$
κ_{WW}	$\Gamma(h\to W_LW_L)$	$=$	$(0.84\ {\rm MeV})\times\lvert\kappa_{WW}\rvert^2$
ϵ_{WW}	$\Gamma(h\to W_TW_T)$	$=$	$(0.16\ {\rm MeV})\times\lvert\epsilon_{WW}\rvert^2$
$\epsilon_{WW}^{\rm CP}$	$\Gamma^{\rm CPV}(h\to W_TW_T)$	$=$	$(6.8\times10^{-2}\ {\rm MeV})\times\lvert\epsilon_{WW}^{\rm CP}\rvert^2$
ϵ_{Wf}	$\Gamma(h\to Wf\bar f')$	$=$	$(0.14\ {\rm MeV})\times N_c^f\ \lvert\epsilon_{Wf}\rvert^2$

Effective coupling POs vs EFTs

One can ask why not fit measurements directly into EFTs, however even this by definition model independent framework is subjected to some choices: linear or non-linear realisation of EWSB, LO or NLO, which basis?

In this account pseudoobservables are somehow more “basic”, and definitely closer to experiments.

POs can always be translated into Wilson coefficients (here translated into BSMCharacterisation basis)

$$\kappa_{ZZ} = 1 + \delta c_z + g^2 c_{z\Box} \ ,$$

$$\kappa_{WW} = 1 + \delta c_w + g^2 c_{w\Box} \ ,$$

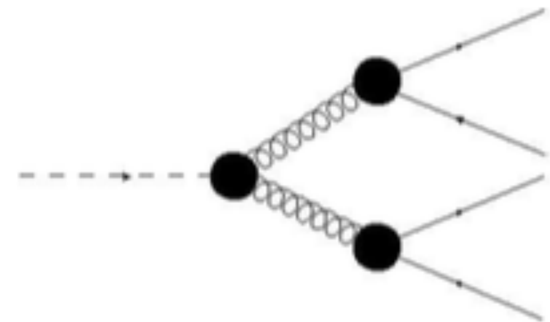
$$\epsilon_{ZZ} = -\frac{g^2 + g'^2}{2} c_{zz} \ , \qquad \epsilon_{ZZ}^{CP} = -\frac{g^2 + g'^2}{2} \widetilde{c}_{zz} \ ,$$

$$\epsilon_{Z\gamma} = -\frac{e\sqrt{g^2 + g'^2}}{2} c_{z\gamma} \ , \qquad \epsilon_{Z\gamma}^{CP} = -\frac{e\sqrt{g^2 + g'^2}}{2} \widetilde{c}_{z\gamma} \ ,$$

$$\epsilon_{\gamma\gamma} = -\frac{e^2}{2} c_{\gamma\gamma} \ , \qquad \epsilon_{\gamma\gamma}^{CP} = -\frac{e^2}{2} \widetilde{c}_{\gamma\gamma} \ ,$$

$$\epsilon_{WW} = -\frac{g^2}{2} c_{ww} \ , \qquad \epsilon_{WW}^{CP} = -\frac{g^2}{2} \widetilde{c}_{ww} \ ,$$

New Pseudoobservables: Higgs decaying into 4 quarks via gluons



Can be also useful while considering the Higgs boson production

We start with gluon-quark POs

$$\mathcal{A}(g \to q\bar{q}) = i\Sigma_q g_g^q \epsilon_\mu \bar{q} T^a \gamma^\mu q$$

$$\mathcal{A}(h \to q(p_1)\bar{q}(p_2)q'(p_3)\bar{q}'(p_4)) = i\alpha_s^2 \Sigma_{q.q'} (\bar{q}\gamma^\mu q)(\bar{q}'\gamma^\nu q')\delta_{ab}\mathcal{T}^{\mu\nu}(q_1, q_2)$$

$$\mathcal{T}^{\mu\nu}(q_1, q_2) = (g^{\mu\nu} q_1 \cdot q_2 - q_1^\nu q_2^\mu) F^g(q_1, q_2) + \epsilon^{\mu\nu\rho\sigma} q_{1,\rho} q_{2,\sigma} F^g_{CP}(q_1, q_2)$$

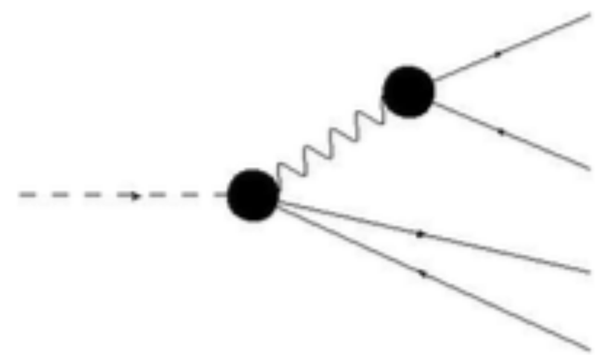
Tensor structure for the massless vector boson

$$F^g(q_1, q_2) = \kappa_{gg} \frac{g_g^q g_g^{q'}}{q_1^2 q_2^2}$$

$$F^g_{CP}(q_1, q_2) = \kappa_{gg}^{CP} \frac{g_g^q g_g^{q'}}{q_1^2 q_2^2}$$

New Pseudoobservables:
Higgs decaying via magnetic dipol operator

Vector boson-fermion POs as previously



Can be also useful while considering the Higgs boson production (ttH)

$$\mathcal{A}(h \to f(p_1)\bar{f}(p_2)f'(p_3)\bar{f}'(p_4)) = i\Sigma_{f,f'}(\bar{f}'\gamma^{\mu}f)(\bar{f}\sigma_{\mu\nu}f)\mathcal{T}^{\nu}(q)$$

$$\mathcal{T}^{\nu}(q) = q^{\nu}F^{dip}(q) + q^{\nu}\gamma_5 F^{dip}_{CP}(q)$$

Only one L. index in tensor structure

$$F^{dip}(q) = \kappa^{dip}_{Zff}\frac{g^f_Z}{P_Z(q)} + \frac{\epsilon^{dip}_{Zff}}{m^2_Z}$$

$$F^{dip}_{CP}(q) = \epsilon^{CP,dip}_{Zff}\frac{g^f_Z}{P_Z(q)}$$

P(q) depend on mediating vector boson

Prepared with use of:

* Bardin, Passarino *The standard model in the making*, 1999
* Talks presented at workshop *Pseudoobservables: from LEP to LHC, 2015*
* Grejlo, Isidori, Marzocca et al *arXiv:1412.6038, 1504.04018, 1507.02555,1512.06135*
* Talks given by Isidor, Marzocca and Grejlo
* Talks given by A. David
* LHC HXSWG Yellow Report 4: Section III.1

* Other papers cited in above and in our chapter

Conclusions

POs first introduced at LEP to allow the combinations between experiments. Defined at Z poles, deconvoluted from the SM soft radiation.

Their success at LEP suggests they might be good approach also at LHC, to bridge between fiducial observables and theoretical parameters.

The set of Higgs POs, based on momentum expansion of on-shell amplitudes around the physical poles, is defined and available to use in many generators.

Conclusions
(final!)

One approach does not exclude others!
Which is better depends on the purpose and person who is using it, they are usually compatible to each other.

Kappas should stay as part of PO/EFT framework,
POs especially in decays (the threshold region!)

Experiments should publish fiducial+STXS, since they are the most theory free, however may be hard to use and interpret.

Translate (project) into PO/EFT for better usability for Model Builders/BSMers

To interpret STXS/fiducial needed generator which allows to implement all the cuts - no matter how fancy idea is, it is useless unless it is implemented in the code