LHC Higgs X-section working Group 2 kickoff meeting

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Organization of the WG2

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG2

Conveners: Mingshui Chen (CMS), Chris Hays (ATLAS)
David Marzocca (th), Francesco Riva (th)

Fid.XS/STXS subgroup. *Conveners:* Nicolas Berger (ATLAS),
Pedrag Milanovic (CMS)
Frank Tackman (th),

Activities

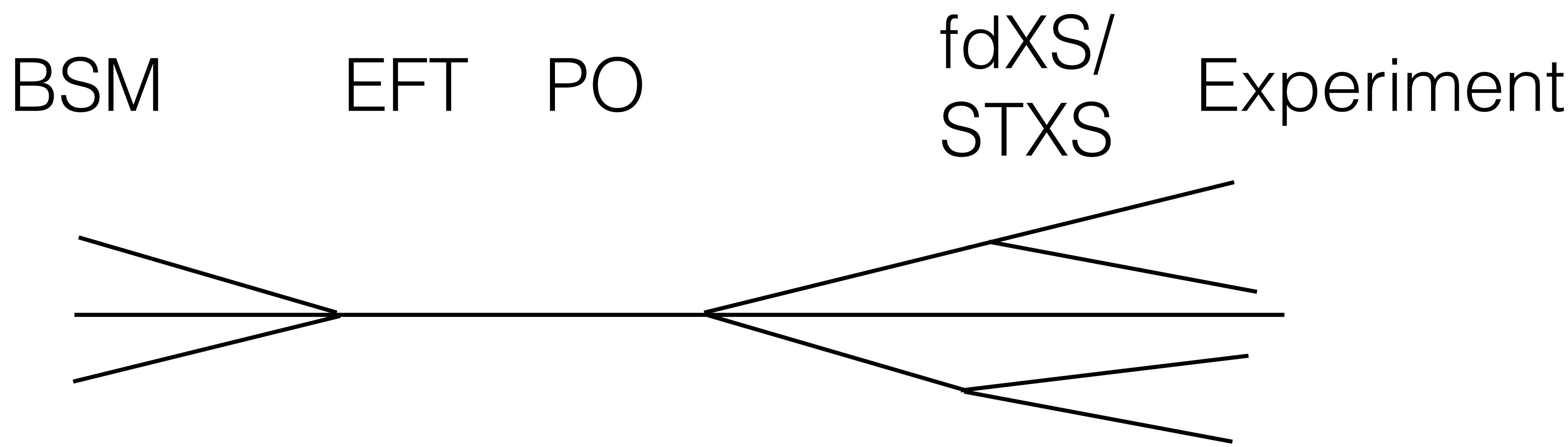
- Fid.XS, diff.XS
- STXS
- PO
- EFT

Outcomes Notes and reports on specific topics/tools.

Goals

- Foster theory-experiment discussions/collaborations
- Development of explicit tools and strategies for Higgs analysis (e.g. STXS, EFT validity,…)
- Cultivate and take advantage from the complementarity between different approaches to Higgs physics
- Work towards a Global Fit for Higgs and Electroweak physics

Approaches to Higgs physics



Target: keep relevant experiment info (for now and future) / maximize sensitivity to BSM

Approaches to Higgs physics - EFT -

- Dictionary to translate well-defined BSM hypotheses into *Lagrangian* deformations of SM couplings (main hypothesis E<<M)

- Redundancy -> different bases

$$\mathcal{O}_H = \tfrac{1}{2}(\partial^\mu |H|^2)^2,\quad \mathcal{O}_T = \tfrac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2,\quad \mathcal{O}_6 = \lambda |H|^6$$

$$\mathcal{O}_W = \tfrac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu},\quad \mathcal{O}_B = \tfrac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}$$

$$\mathcal{O}_{BB} = g'^2 |H|^2 B_{\mu\nu}B^{\mu\nu},\quad \mathcal{O}_{GG} = g_s^2 |H|^2 G^A_{\mu\nu}G^{A\mu\nu},\quad \mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$$

$$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu},\quad \mathcal{O}_{3W} = \tfrac{1}{3!} g \epsilon_{abc} W^{a\nu}_\mu W^b_{\nu\rho} W^{c\rho\mu}$$

$\mathcal{O}_{y_u} = y_u \lvert H\rvert^2 \bar{Q}_L \tilde{H} u_R + \text{h.c.}$	$\mathcal{O}_{y_d} = y_d \lvert H\rvert^2 \bar{Q}_L H d_R + \text{h.c.}$	$\mathcal{O}_{y_e} = y_e \lvert H\rvert^2 \bar{L}_L H e_R + \text{h.c.}$
$\mathcal{O}^u_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma^\mu u_R)$; $\mathcal{O}^q_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L \gamma^\mu Q_L)$; $\mathcal{O}^{(3)q}_L = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L \sigma^a \gamma^\mu Q_L)$	$\mathcal{O}^d_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}^e_R = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$
$\mathcal{O}^{(3)q}_{LL} = (\bar{Q}_L \sigma^a \gamma_\mu Q_L)(\bar{L}_L \sigma^a \gamma^\mu L_L)$		$\mathcal{O}^{(3)l}_{LL} = (\bar{L}_L \sigma^a \gamma^\mu L_L)(\bar{L}_L \sigma^a \gamma_\mu L_L)$

SILH

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \tilde{\varphi})$
Q_W	$\varepsilon^{IJK} W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu\varphi)^* (\varphi^\dagger D_\mu\varphi)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\tilde{W}}$	$\varepsilon^{IJK} \tilde{W}^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi\tilde{G}}$	$\varphi^\dagger\varphi\, \tilde{G}^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\tilde{\varphi}\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi\tilde{W}}$	$\varphi^\dagger\varphi\, \tilde{W}^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \tilde{\varphi}\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tilde{\varphi}\, B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\tilde{B}}$	$\varphi^\dagger\varphi\, \tilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi\tilde{W}B}$	$\varphi^\dagger \tau^I \varphi\, \tilde{W}^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\tilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

Warsaw

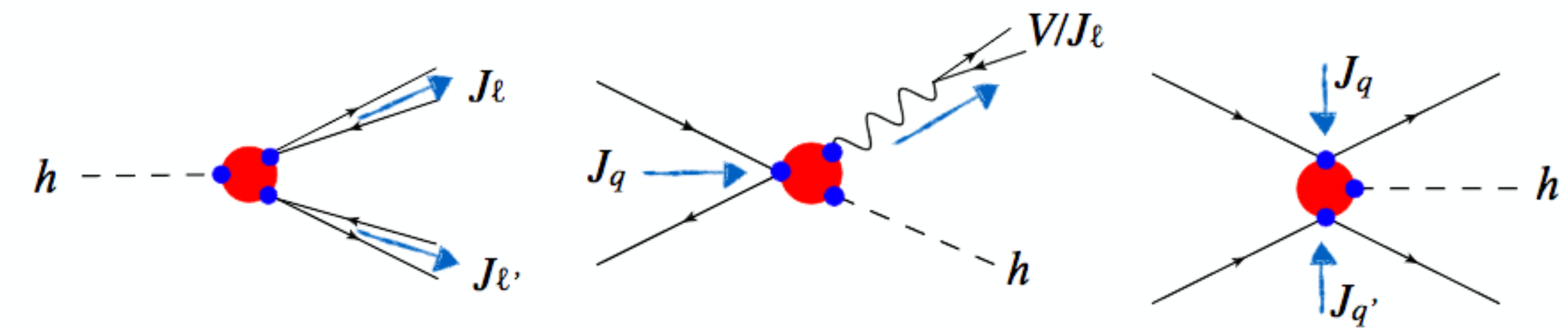
$$\begin{aligned}
\mathcal{L}_{h^2} = \;& h^2\left(1+2\delta c_z^{(2)}\right)\frac{g^2+g'^2}{4} Z_\mu Z_\mu + h^2\left(1+2\delta c_w^{(2)}\right)\frac{g^2}{2} W^+_\mu W^-_\mu \\
& - \frac{h^2}{2v^2}\sum_{f;ij}\sqrt{m_{f_i} m_{f_j}}\left[\bar{f}_{i,R}[y_f^{(2)}]_{ij} f_{j,L} + \text{h.c.}\right]. \\
& + \frac{h^2}{8v^2}\left(c_{gg}^{(2)} g_s^2 G^a_{\mu\nu}G^a_{\mu\nu} + 2c_{ww}^{(2)} g^2 W^+_{\mu\nu}W^-_{\mu\nu} + c_{zz}^{(2)}(g^2+g'^2)Z_{\mu\nu}Z_{\mu\nu} + 2c_{z\gamma}^{(2)} gg' Z_{\mu\nu} \right. \\
& + \frac{h^2}{8v^2}\left(\tilde{c}_{gg}^{(2)} g_s^2 G^a_{\mu\nu}\tilde{G}^a_{\mu\nu} + 2\tilde{c}_{ww}^{(2)} g^2 W^+_{\mu\nu}\tilde{W}^-_{\mu\nu} + \tilde{c}_{zz}^{(2)}(g^2+g'^2)Z_{\mu\nu}\tilde{Z}_{\mu\nu} + 2\tilde{c}_{z\gamma}^{(2)} gg' Z_{\mu\nu} \right. \\
& - \frac{h^2}{2v^2}\left(g^2 c_{w\Box}^{(2)}(W^+_\mu \partial_\nu W^-_{\nu\mu} + W^-_\mu \partial_\nu W^+_{\nu\mu}) + g^2 c_{z\Box}^{(2)} Z_\mu \partial_\nu Z_{\nu\mu} + gg' c_{\gamma\Box}^{(2)} Z_\mu \partial_\nu A_{\nu\mu}\right)
\end{aligned}$$

Higgs Basis/BSM Primaries

- EFT validity: ensure assumption E<<M satisfied

Approaches to Higgs physics - POs -

- Description of the physical on-shell *amplitude* via a momentum expansion around physical poles



(connected by cross symmetry)

- Applies to h→4f decays, VH, and VBF production.

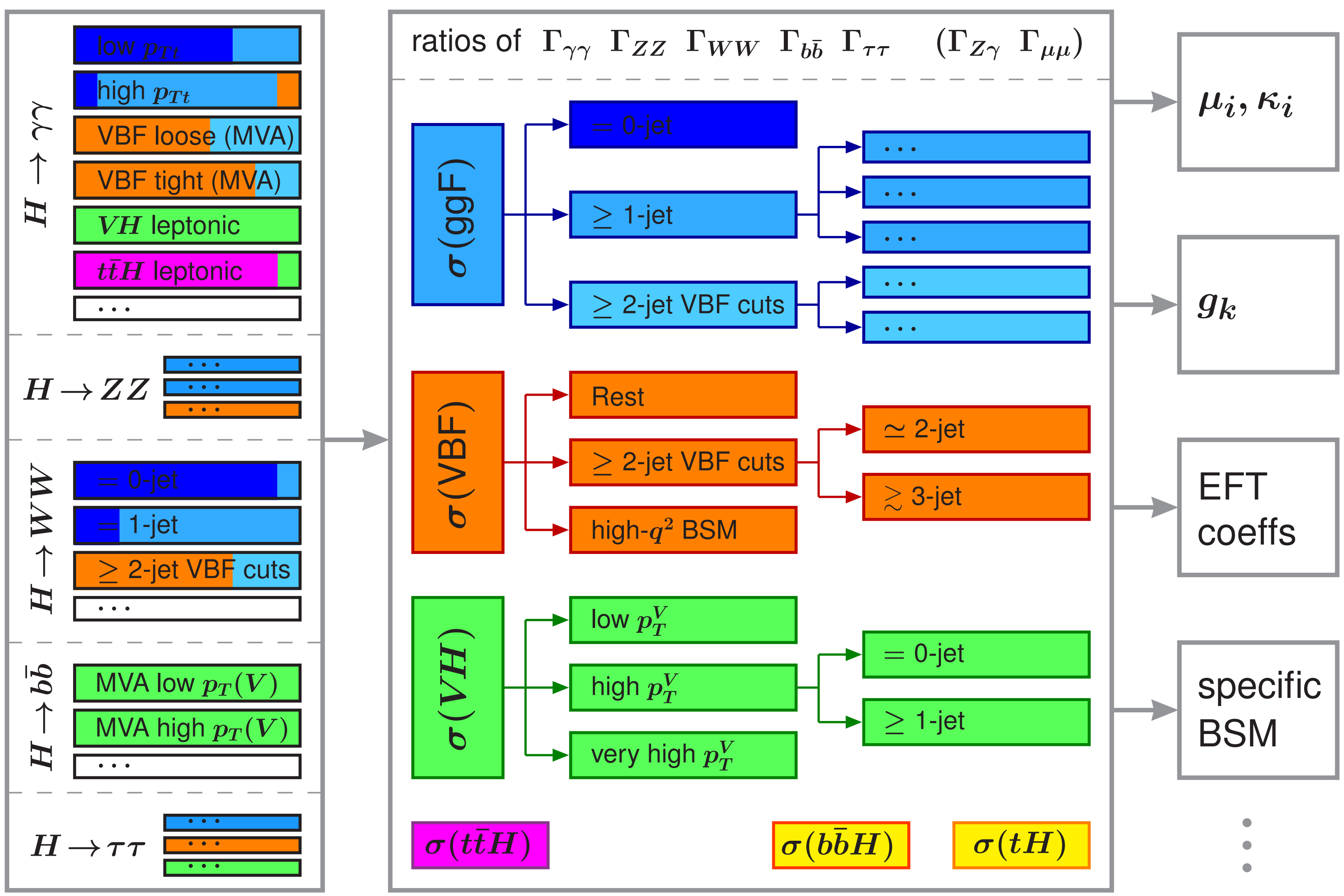
Approaches to Higgs physics
- STXSs -

Mutually exclusive bins with simple acceptance cuts - minimal extrapolation needed.

Signal regions, divided in categories with different sensitivity to production modes.

STXS, each production mode is split in bins of relevant kinematical variable.

Mapping to PO, EFT, etc..



Complementarity

- EW processes ($h \to 4f$,VH,VBF) well parametrized by POs
- QCD process (ggH,ttH,bbH,..) better captured by STXS

➡ Find balance between sensitivity and generality.

➡ Goal: extract info on EFT coefficients.

Global Fits

- H-> h, Z_L, W_L: Higgs Physics ⟷ EW Physics
- Even for generic dimension-6 EFT relations persist

➡ Extend discussions to LHC EWK WG

➡ Perform fits within experimental collaborations (e.g. aTGC+Higgs)

State of the Art

Parametrizations:

EFT ✓
PO's: VH/VBF ✓
STXS/… ✓

Tools/Practical implementations:

MonteCarlos: LO in EFT and PO ✓
EFT Validity: Cutoff procedure (CMS ZZ) ✓

Global Fits: Theory ✓

Complementarity: x

Where we are going

- Short Term -

Parametrizations: PO's/STXS in tth — See Kamenik

Tools/Practical implementations:

- POs NLO: Higgs (QCD), VH (EW) — See Greljo/Pattori
- EFT: NLO — See Mimasu
- EFT Validity: proper treatment — See Wulzer

Global Fits: Higgs + TGC at experiment level

Complementarity: Map STXS <-> EFT — See Zemaityte

Where we are going

- Long Term -

Tools/Practical implementations:

Maintain tools at state-of-the-art precision

EFT validity (energy-info)embedded at analysis level

Global Fits: Full Higgs + TGC + EW at experiment level

Complementarity: Complete map of processes/procedures

Future

- Precision tests: a growing part of the BSM search program (H-L LHC, Linear colliders, FCCee,…)

- A modified Higgs sector can potentially modify most SM processes

➡ Recommendations developed in HXSWG likely impact Collider physics for decades

➡ LHC HXSWG legacy

- Ideas developed by th+exp for both th and exp

- Long-term perspective: recommendations must endure test of time (e.g. improvement of NLO calculations, change in BSM perspective,…)