

# Workshop on the physics of HL-LHC, and perspectives at HE-LHC

## Working Group 2 - Higgs and EWSB -

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# HL and HE

$$3/\text{ab @ 14TeV: } \left\{ \begin{array}{l} \approx 10^8 \text{ gg} \rightarrow h \\ \approx 10^7 \text{ VBF} \rightarrow h \\ > 10^6 \text{ VH} \rightarrow h \end{array} \right.$$

The typical targets of today's LHC program will be known very well by the HL LHC

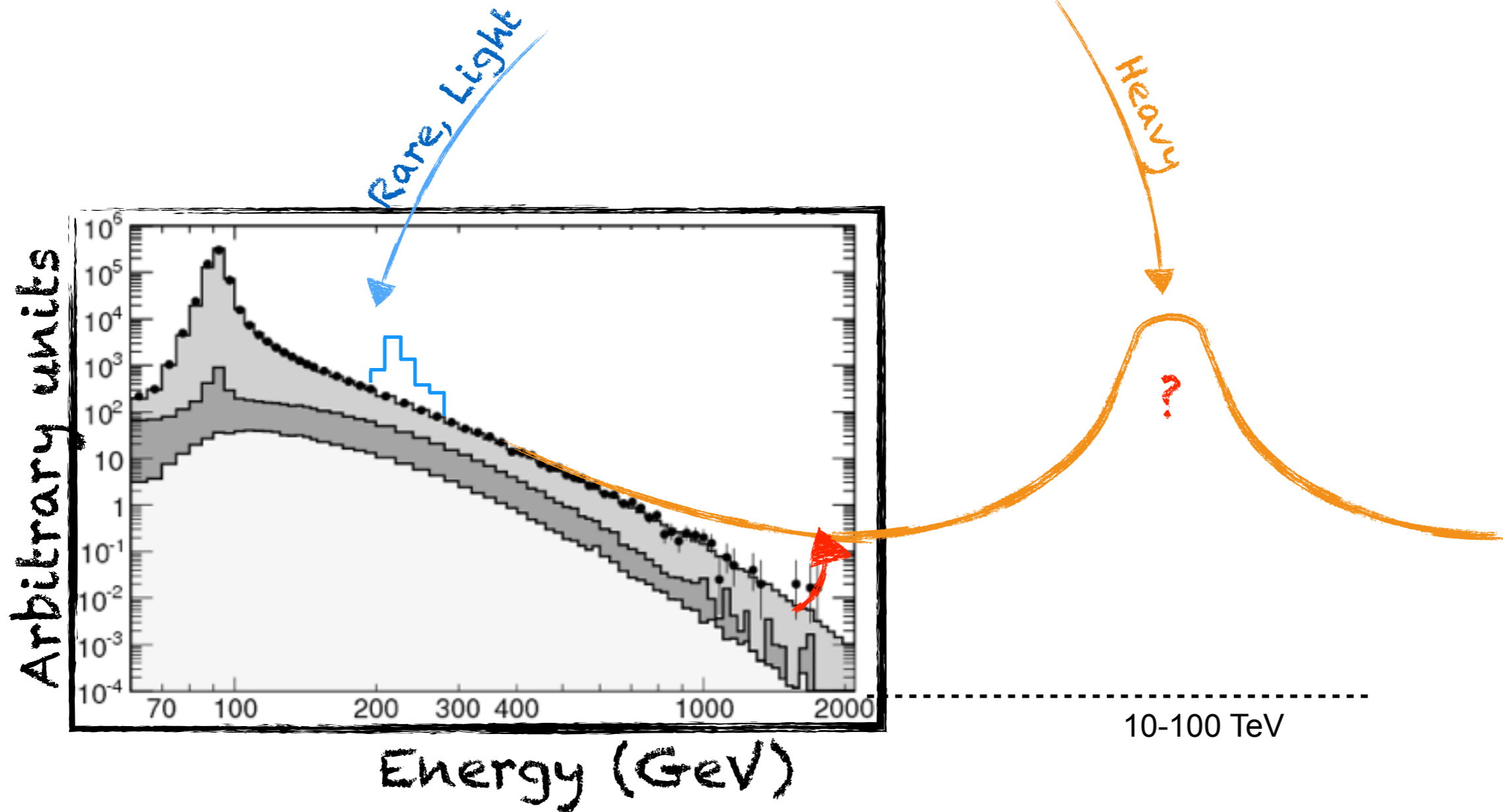
see Cepeda, Testa talk

Further goals of the workshop:

- ▶ identify measurements and scenarios that can be qualitatively better accessed at HL/HE
- ▶ identify the necessary tools and challenges to make the best of HL/HE

# Outline

## BSM Resonances



2

Rare Higgs Processes &  
New resonances

1

Differential Measurements  
(high- $p_T$ , angular variables)

# Differential Measurements

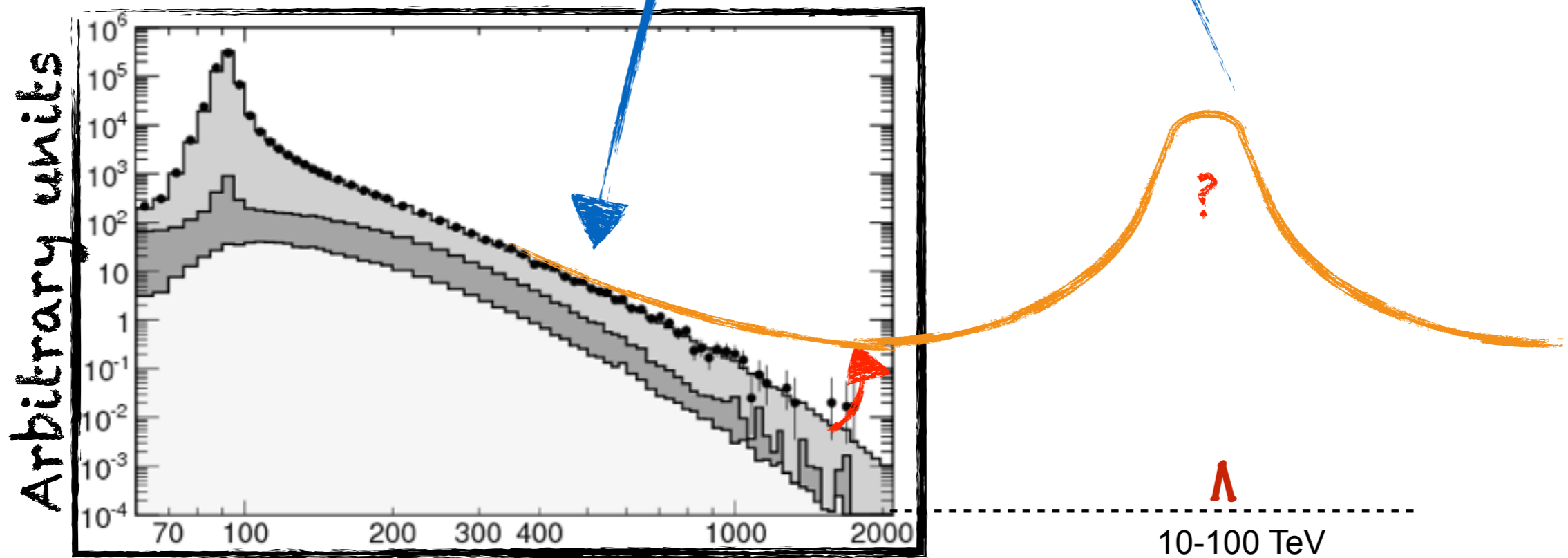
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# EFT

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_i \frac{\mathcal{O}_i}{\Lambda^2} + \dots$$

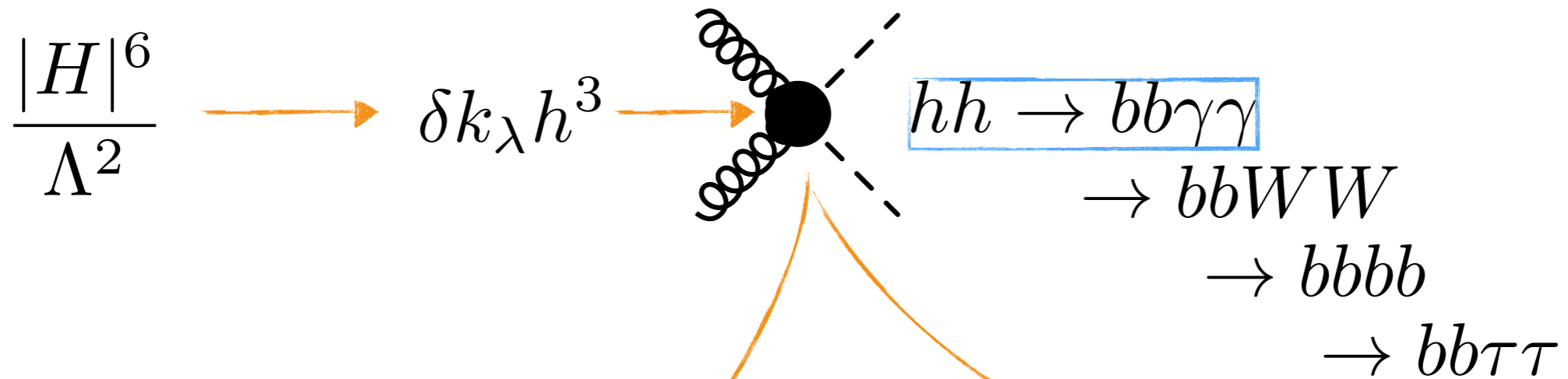
SM  
Precision  
measurements

BSM  
Explicit  
Models

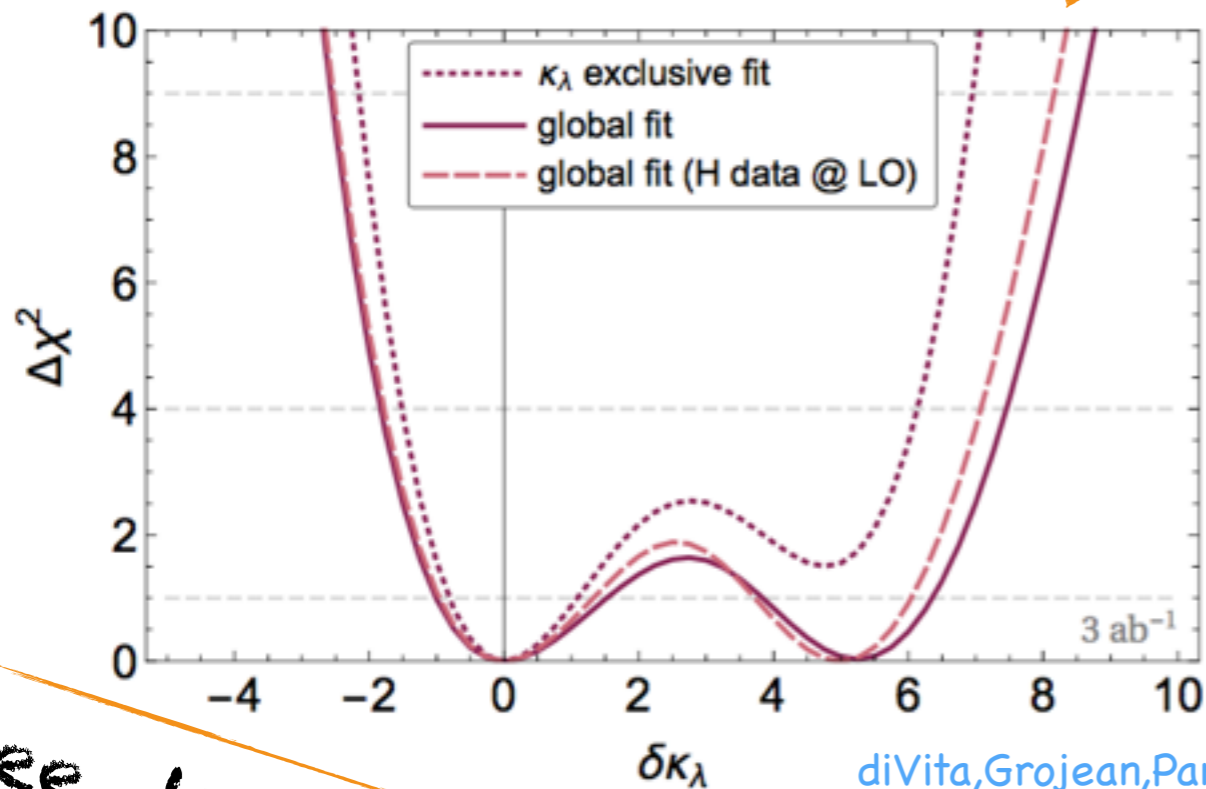


Universal language to compare explicit BSM searches  
and SM precision tests

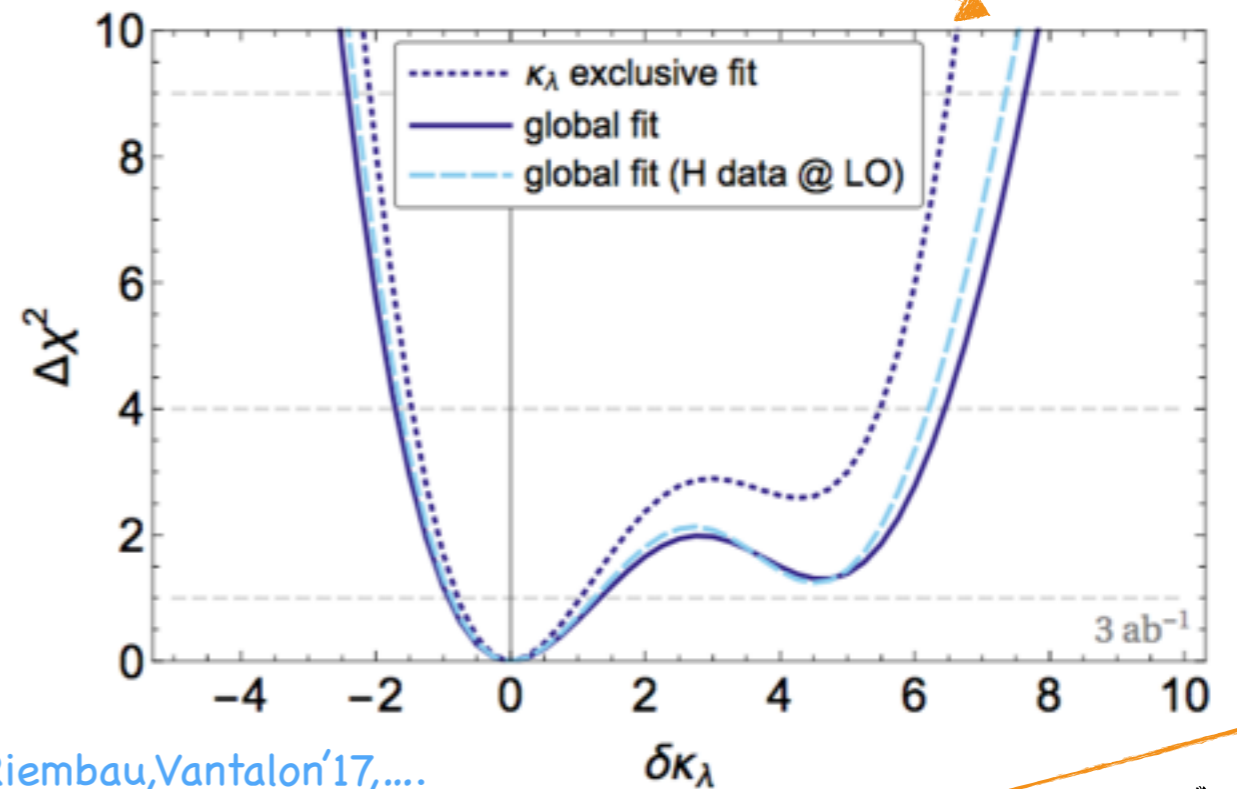
# Higgs Self-Coupling



Inclusive



With  $m_{hh}$  diff. measurement



see diVita talk

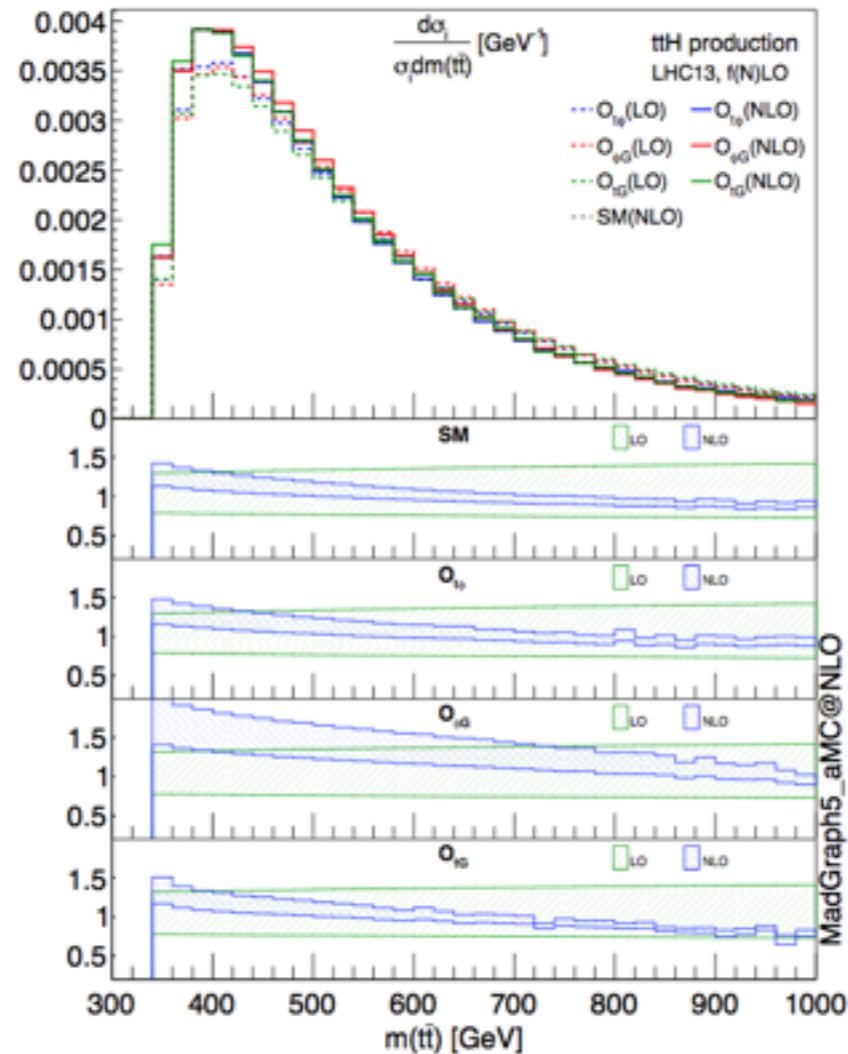
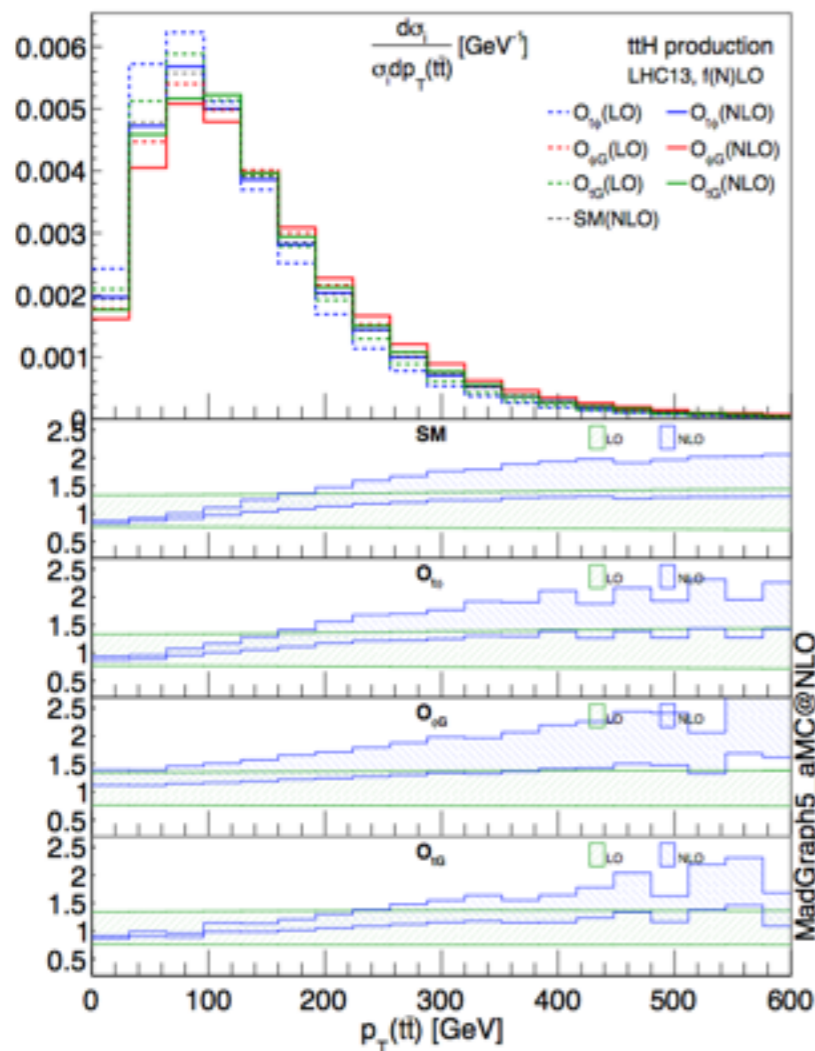
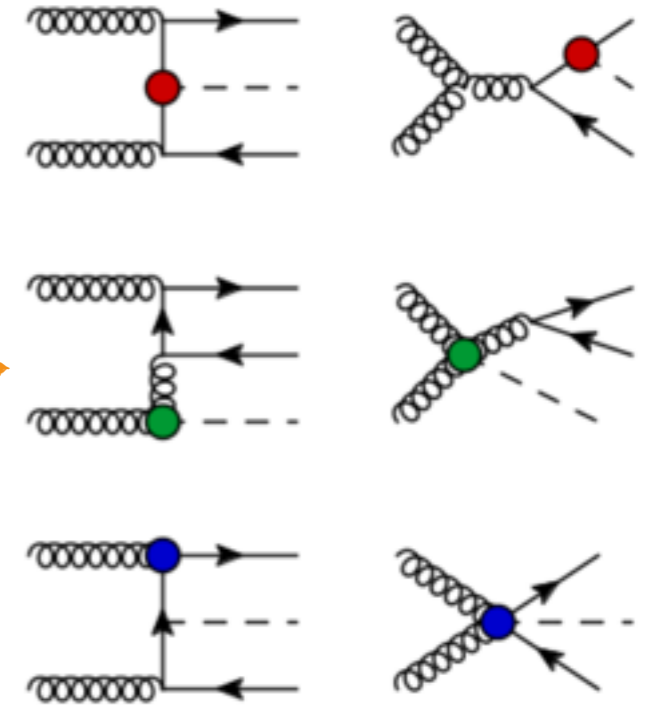
diVita, Grojean, Panico, Riemann, Vantalon'17, ...

see Heinrich talk

# top-higgs tth

Effects in top+Higgs particularly relevant in interesting BSM scenarios

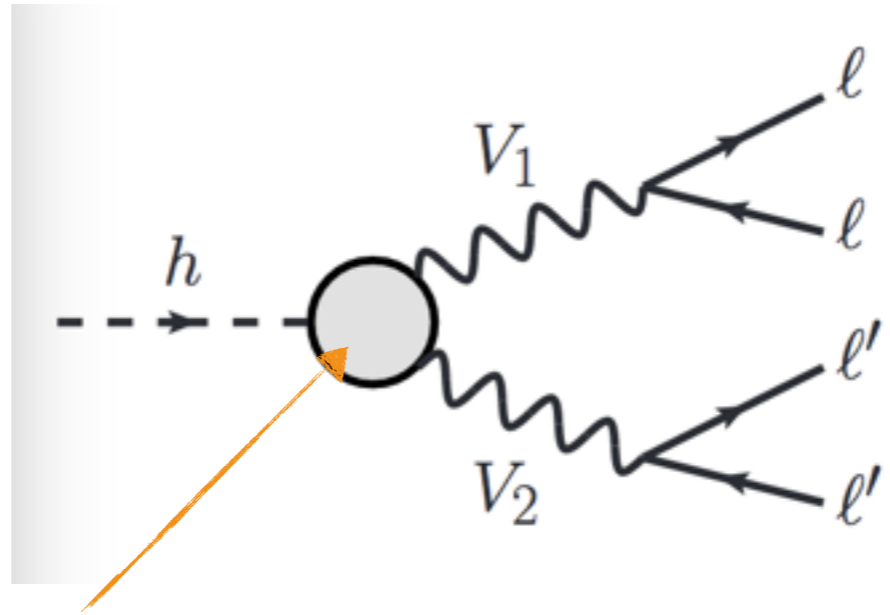
Information hidden in several differential distributions:



see Maltoni talk

# Higgs couplings

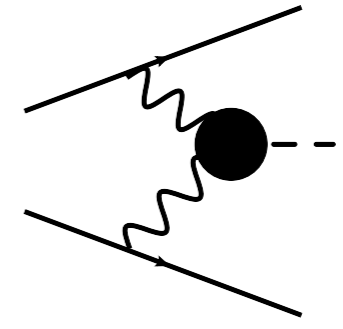
How much more can we learn from measuring Higgs couplings?



CP, Custodial, energy-dependence?

Same physics that modifies VBF, VH rates

- ▶ Important HL and HE interplay!



see Falkowski, Yu, Chen talks



# dibosons

In the SM, all scalars belong to Higgs doublet

$$\begin{pmatrix} h^+ \\ h + ih^0 \end{pmatrix} \begin{matrix} \swarrow W_L \\ \longleftarrow Z_L \end{matrix}$$

► Their interactions are related also in BSM:

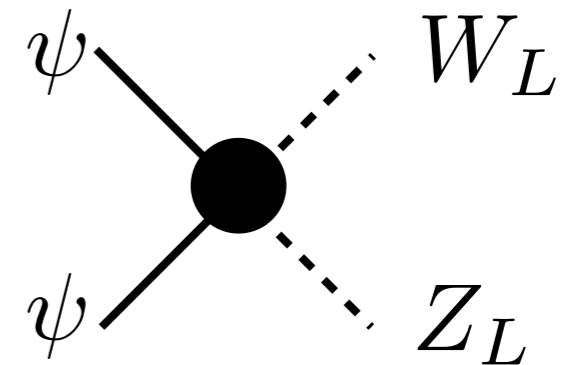
$$\frac{1}{\Lambda^2} H^\dagger D_\mu H \bar{\Psi} \gamma^\mu \Psi \longrightarrow \begin{matrix} \psi & & W_L & & \psi \\ & \diagdown & & \diagup & \\ & \bullet & & \bullet & \\ & \diagup & & \diagdown & \\ \psi & & W_L & & \psi \end{matrix} + \begin{matrix} \psi & & Z & & \\ & \diagdown & & \diagup & \\ & \bullet & & \bullet & \\ & \diagup & & \diagdown & \\ \psi & & h & & \end{matrix} + \dots$$

Higgs Physics  $\longleftrightarrow$  EW Physics

# dibosons - challenges

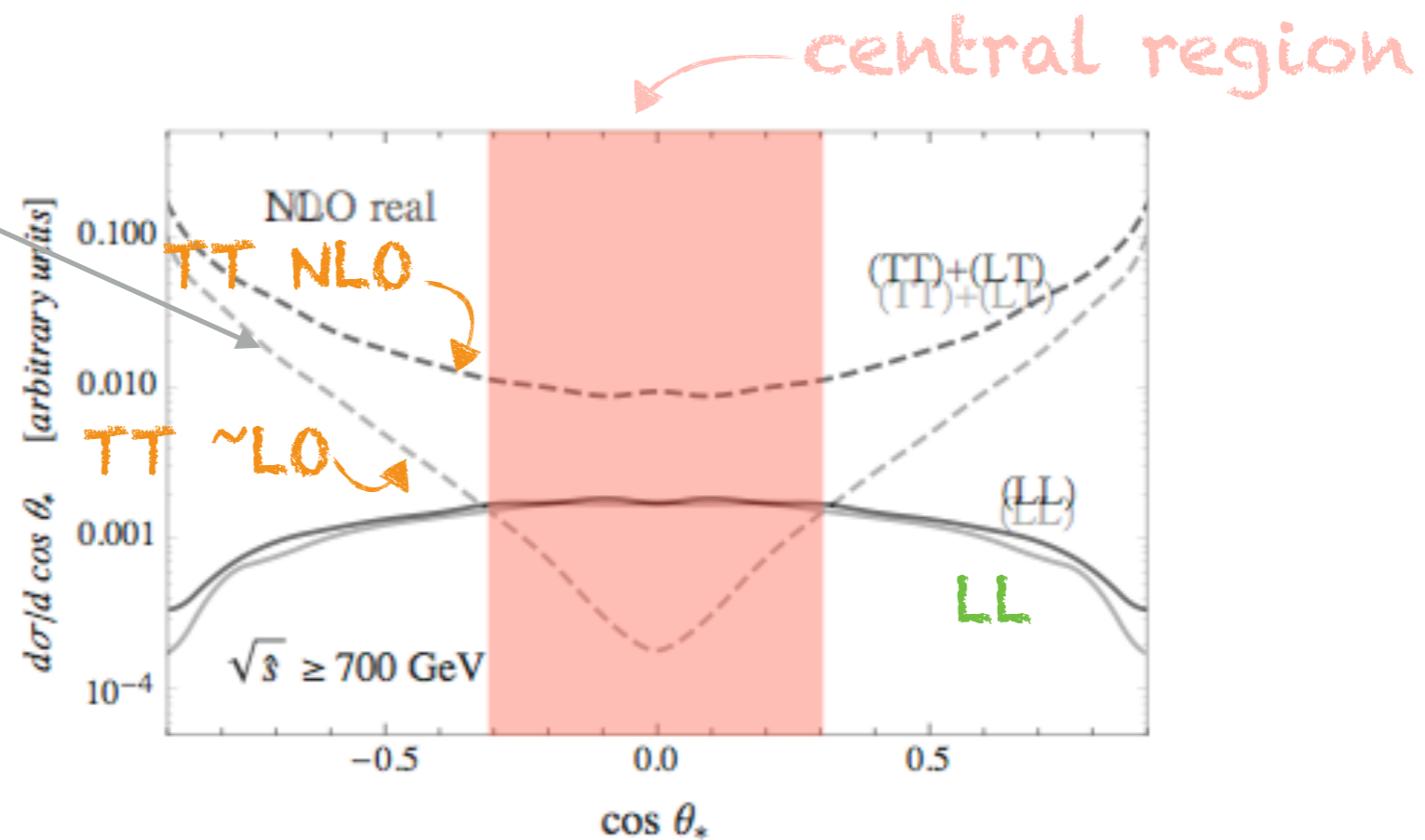
New EWSB physics in **longitudinals**

☹ WW/WZ x-sec dominated by **transverse**



▶ Longitudinals accessible in

LO kinematics  
(small  $p_{Tj}$ )



▶ Important HL and HE interplay!

see Wulzer talk

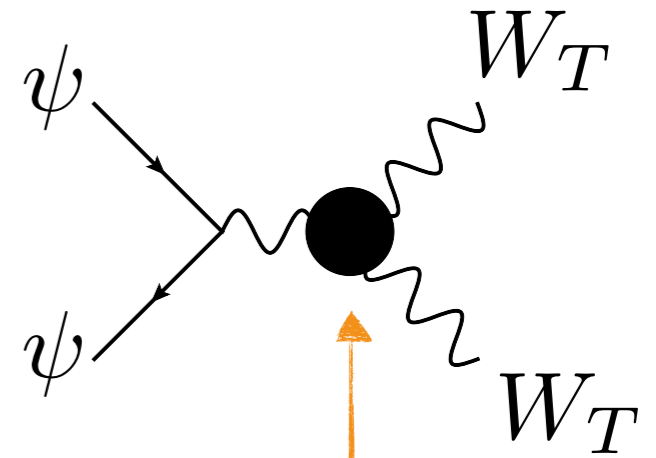
# dibosons - challenges

New EWSB physics in **transverse**

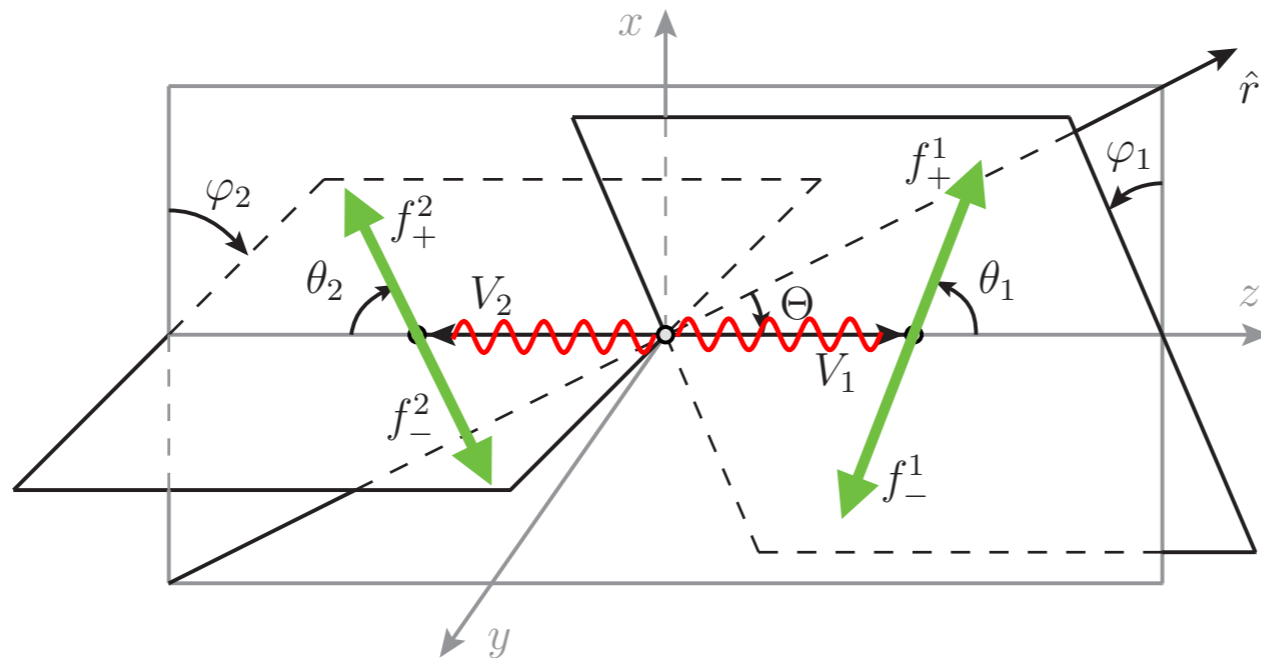
SM LO: helicity  $+-$

BSM dim-6: helicity  $++$

**No-interference!**



$$\frac{1}{\Lambda^2} W_{\mu}^{a\nu} W_{\nu\rho}^b W^{c\rho\mu}$$



► Exclusive measurement of **azimuthal distribution**  
Sensitive to **interference!**

► **NLO** kinematics **interferes**

► Important HL and HE interplay!

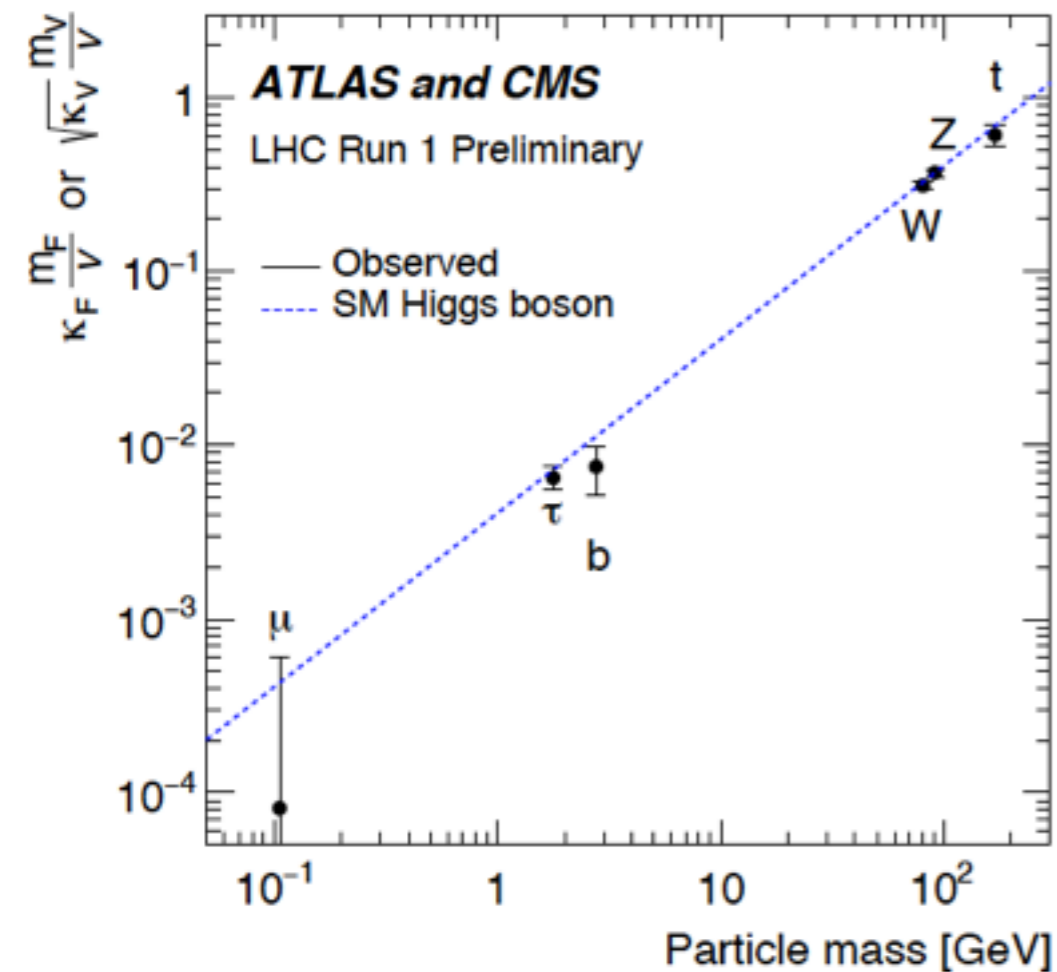
see ELIAS-MIRO talk

2

Rare Higgs processes &  
new resonances

# Higgs SM rare decays

## Learning the Higgs flavour structure



- ☑ What about the coupling to first and second generations?
- \* Precise measurement of  $h\mu\mu$  coupling
- \*  $hcc$  coupling
- ☑ Access to other decays to mesons?
- ☑ Higgs flavour violating couplings:  
 $t \rightarrow ch, h \rightarrow \tau\mu, \dots$

LHCb?

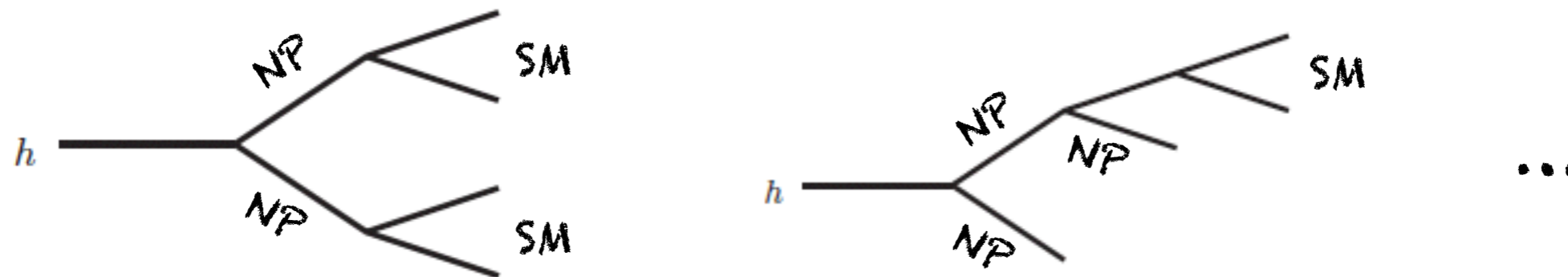
Other rare decays:  $Z$  gamma, ...

see Bishara talk

# Higgs exotic decays

see Katz,  
Robinson, Curtin  
talks

Novel searches for Higgs decays to New Physics particles?



\* A much larger statistics for rare and clean decay modes (eg.  $h \rightarrow 4l$ ,  $h \rightarrow$  displaced objects, ...)

\* Access to subleading Higgs production modes (eg.  $VH$ ,  $t\bar{t}h$ , ...) for background limited decay modes (eg.  $h \rightarrow 4b$ ,  $h \rightarrow 2b 2\tau$ )

✓ Upgrades of the detectors?

✓ New triggers?

✓ New detectors?

(Codex-b, Faser, MATHUSLA, ...)

Novel ways to set bounds on the Higgs width?

eg.  $gg \rightarrow \gamma\gamma$  and  $gg \rightarrow h \rightarrow \gamma\gamma$  (Dixon, Li, 1305.3854)

# Searches for new Higgs bosons

What models with an extended Higgs sector can we test?

New signatures coming from SUSY scenarios at low  $\tan\beta$ ...  
(eg.  $t\bar{t}H/A$ ,  $H/A \rightarrow t\bar{t}$ , ...)

Decay modes to NP particles  
(eg.  $H/A \rightarrow$  electro-weakinos)

see Shakyia talk

Interference effects with SM backgrounds

see Liebler talk

New production modes of Higgs singlet states  
(eg.  $pp \rightarrow (h_{SM})^* \rightarrow aa$ )

see McCullough talk

New flavor signatures  
(eg.  $(tc)H \rightarrow t c$ )

# Conclusions

Workshop will show new ideas / measurements for HL-HE

Many more activities for WG2:

- Synthesis of available HL work
- Develop new ideas accessible at HL (e.g. VBF,...)
- HE
- Non-Higgs measurements relevant for Higgs
- ...

We need you!

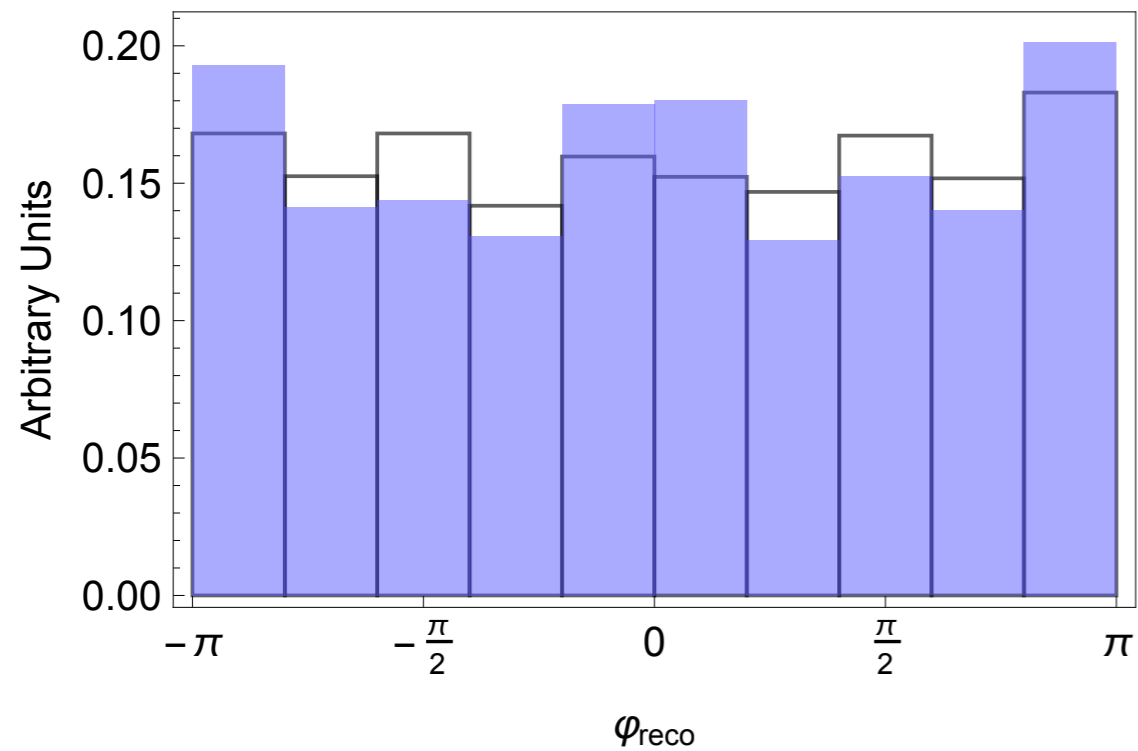
Please join us with proposals and suggestions...



# HL and HE

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Differential Measurements  
(high- $p_T$ , angular variables)



2

Rare Higgs Processes &  
New resonances

