Learning from Higgs decays at NLO in SMEFT

Clara Del Pio

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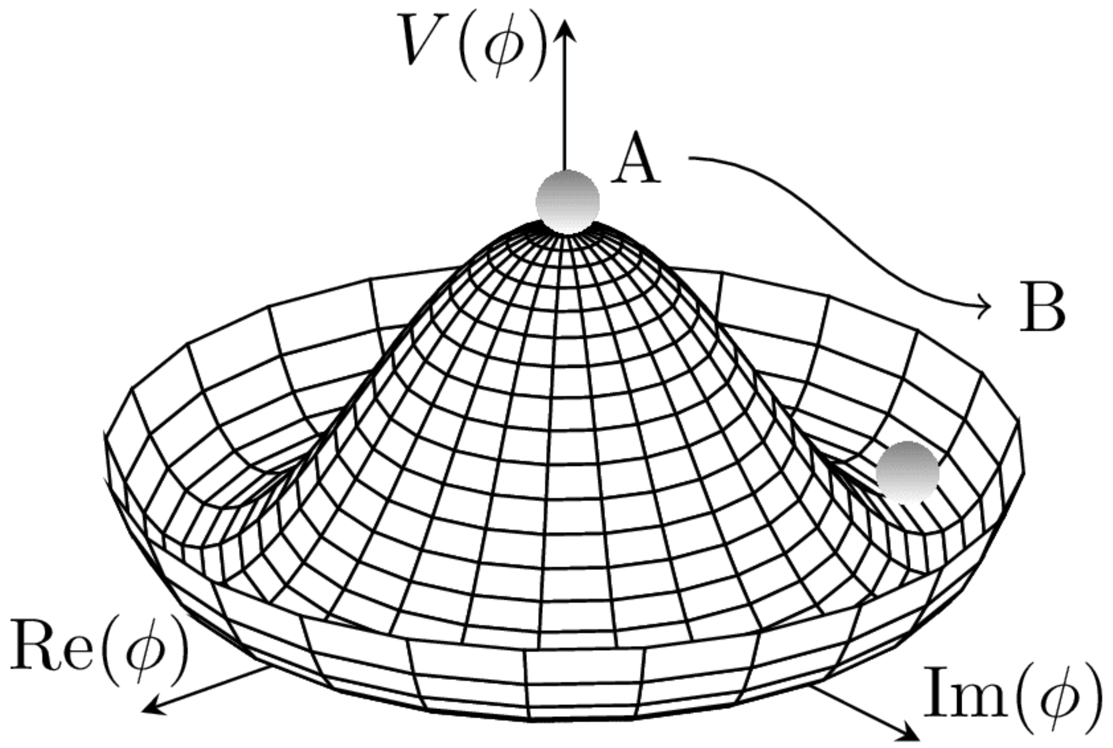
Brookhaven
National Laboratory

The Higgs sector

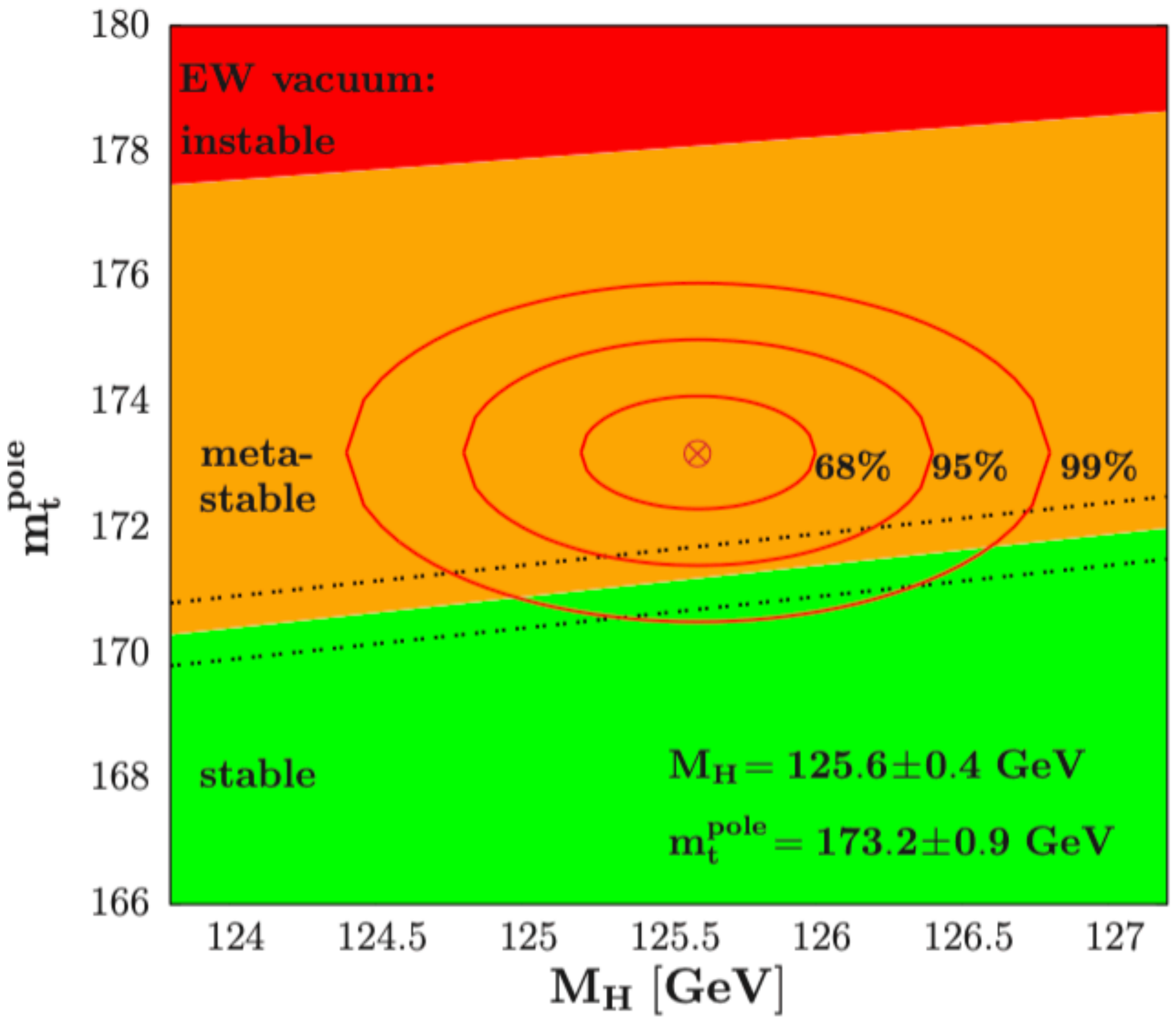
$$V(\phi) = m^2\phi^2 + \lambda\phi^4 \quad \rightarrow \quad V(H) = \frac{1}{2}m_H^2 H^2 + \underline{\lambda_3} H^3 + \underline{\lambda_4} H^4$$

$$\lambda_3^{SM} = \lambda v \qquad \lambda_4^{SM} = \lambda/4$$



EW Symmetry Breaking mechanism

Near-criticality of m_H
and stability of the minimum of the potential



Alekhin et al., Phys.Lett.B 716 (2012) 214-219

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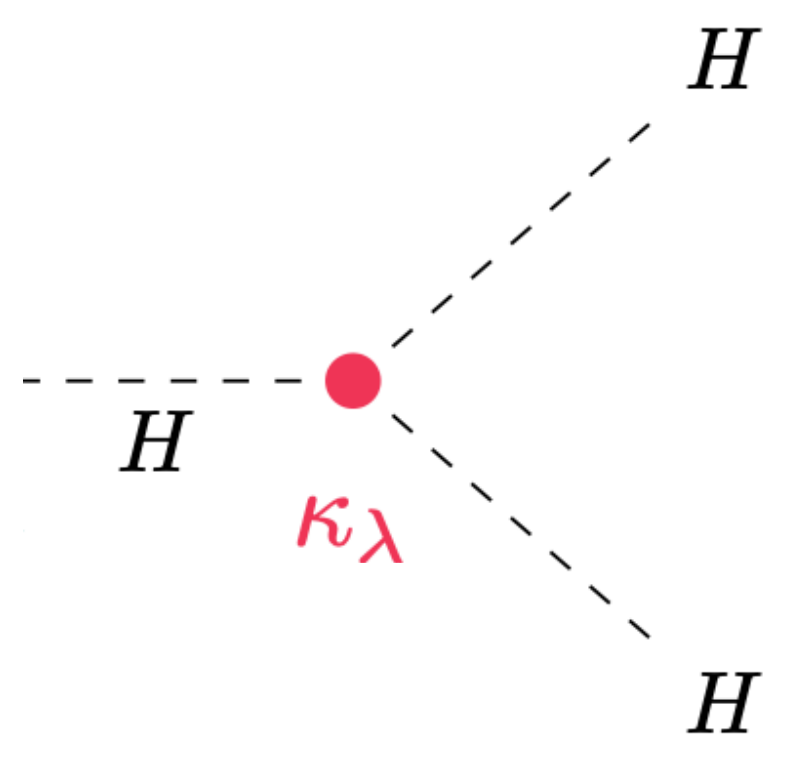
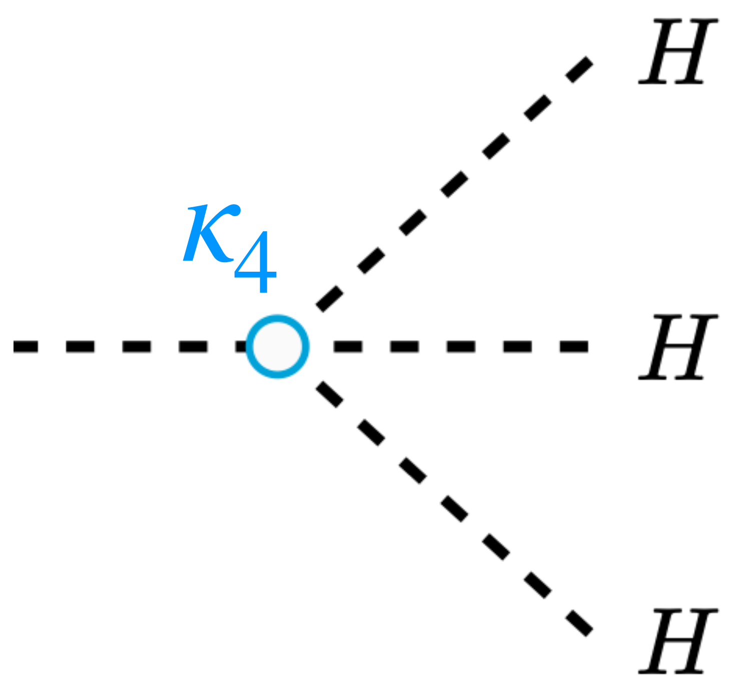
κ framework $\kappa_P = \dfrac{\lambda_P}{\lambda_P^{\mathrm{SM}}}$



$\kappa_\lambda \in [-1.2, 7.2]$
95 % CL



$\kappa_4 \sim \mathcal{O}(10^2)$

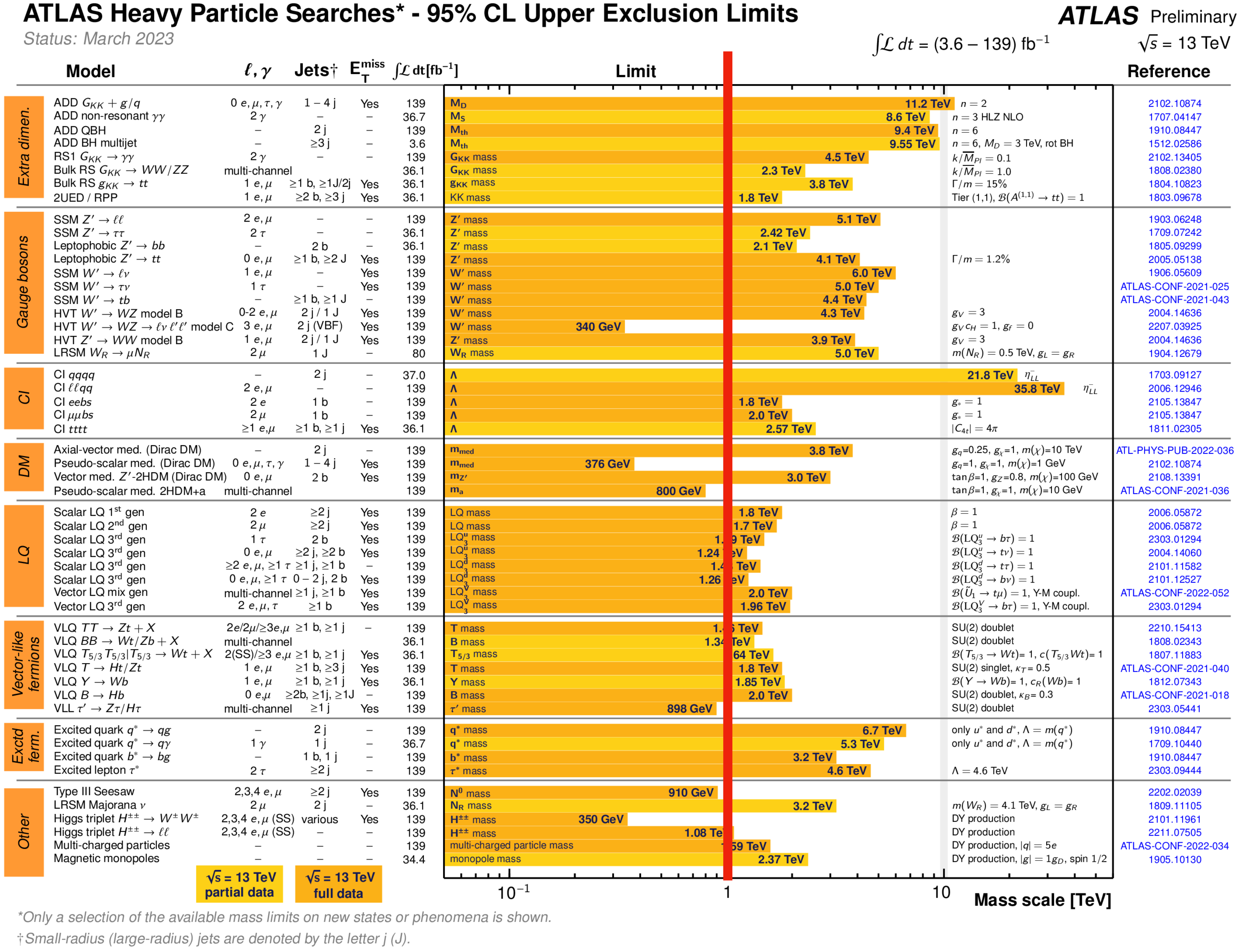
ATLAS, Phys. Rev. Lett. 133 (2024) 101801

CMS, Phys.Lett.B 861 (2025) 139210

ATLAS, Phys. Rev. D 111 (2025) 032006

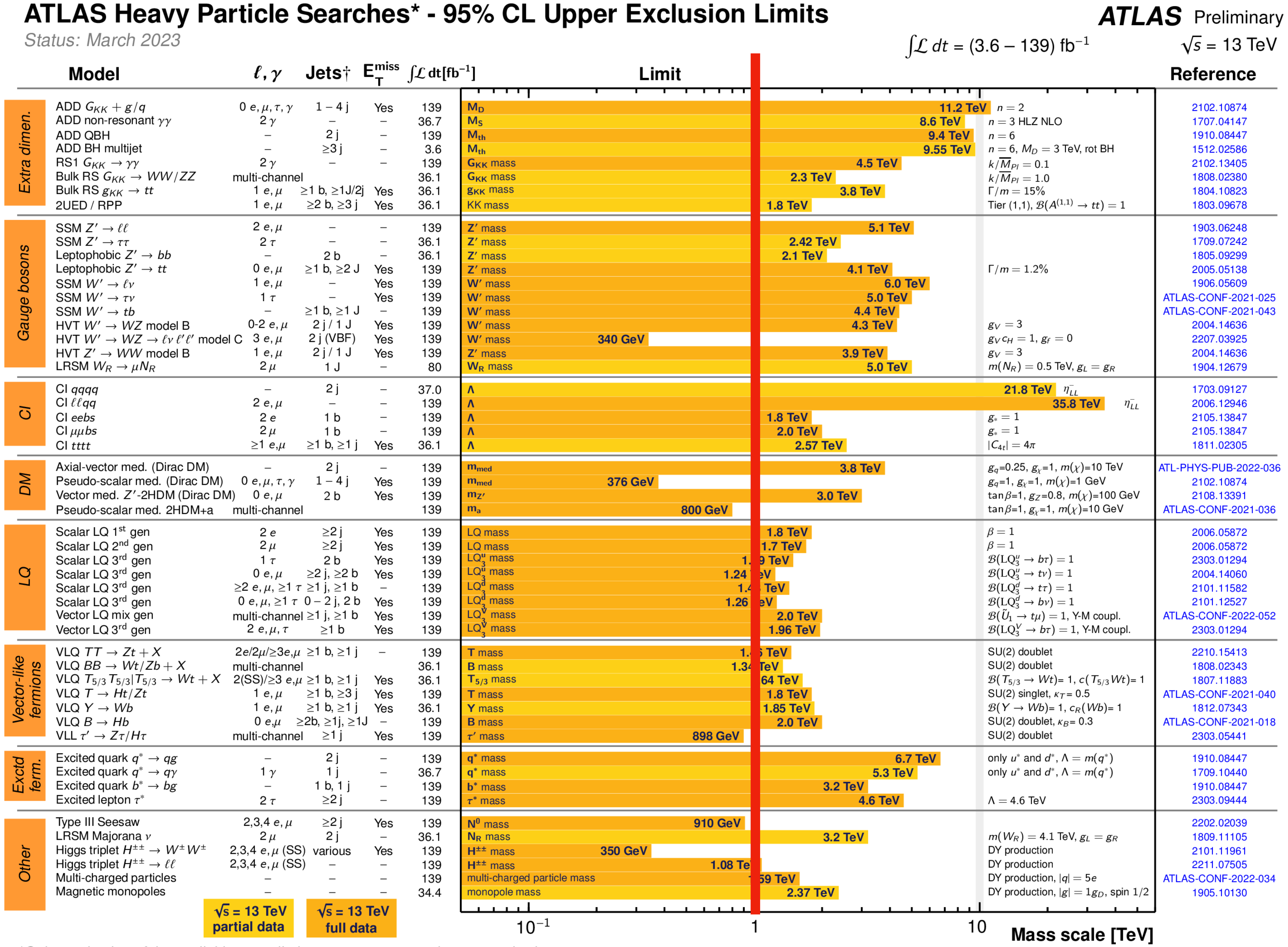
Alekhin et al., Phys.Lett.B 716 (2012) 214-219

Beyond the Standard Model

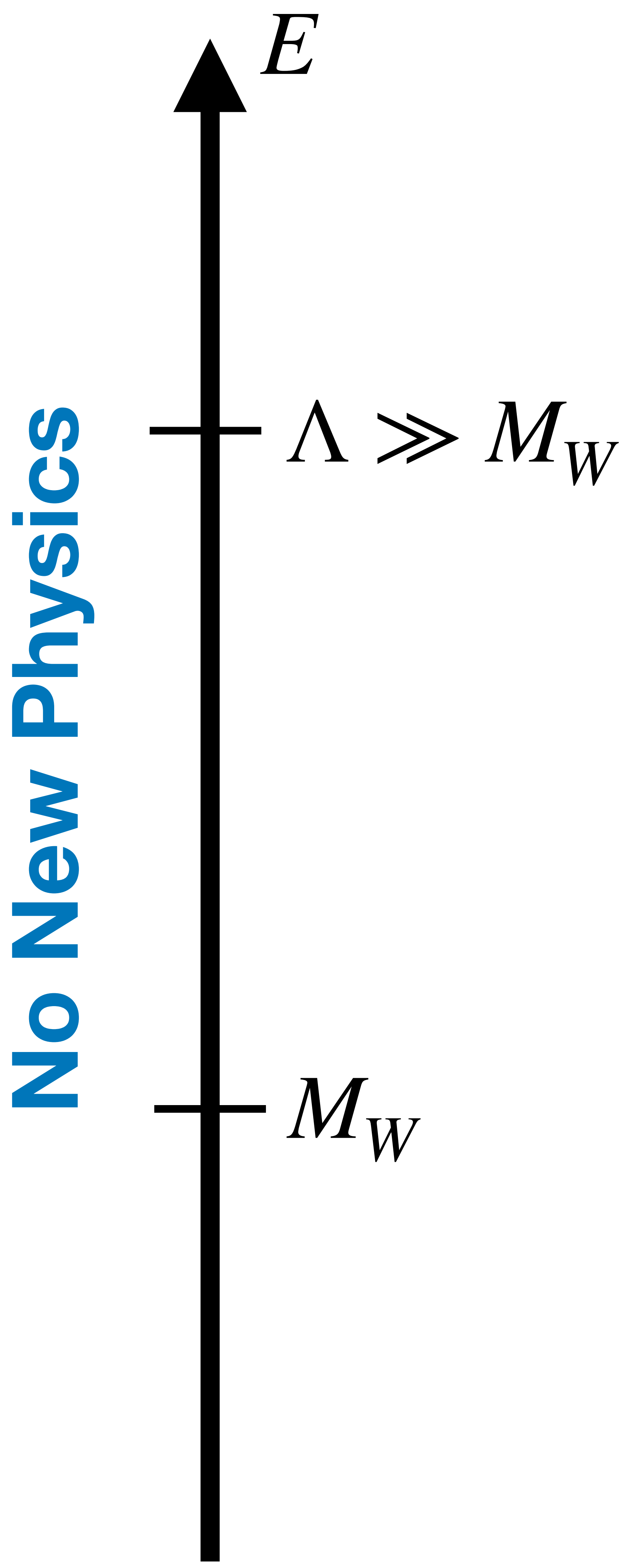


Beyond the Standard Model

Effective Field Theory approach

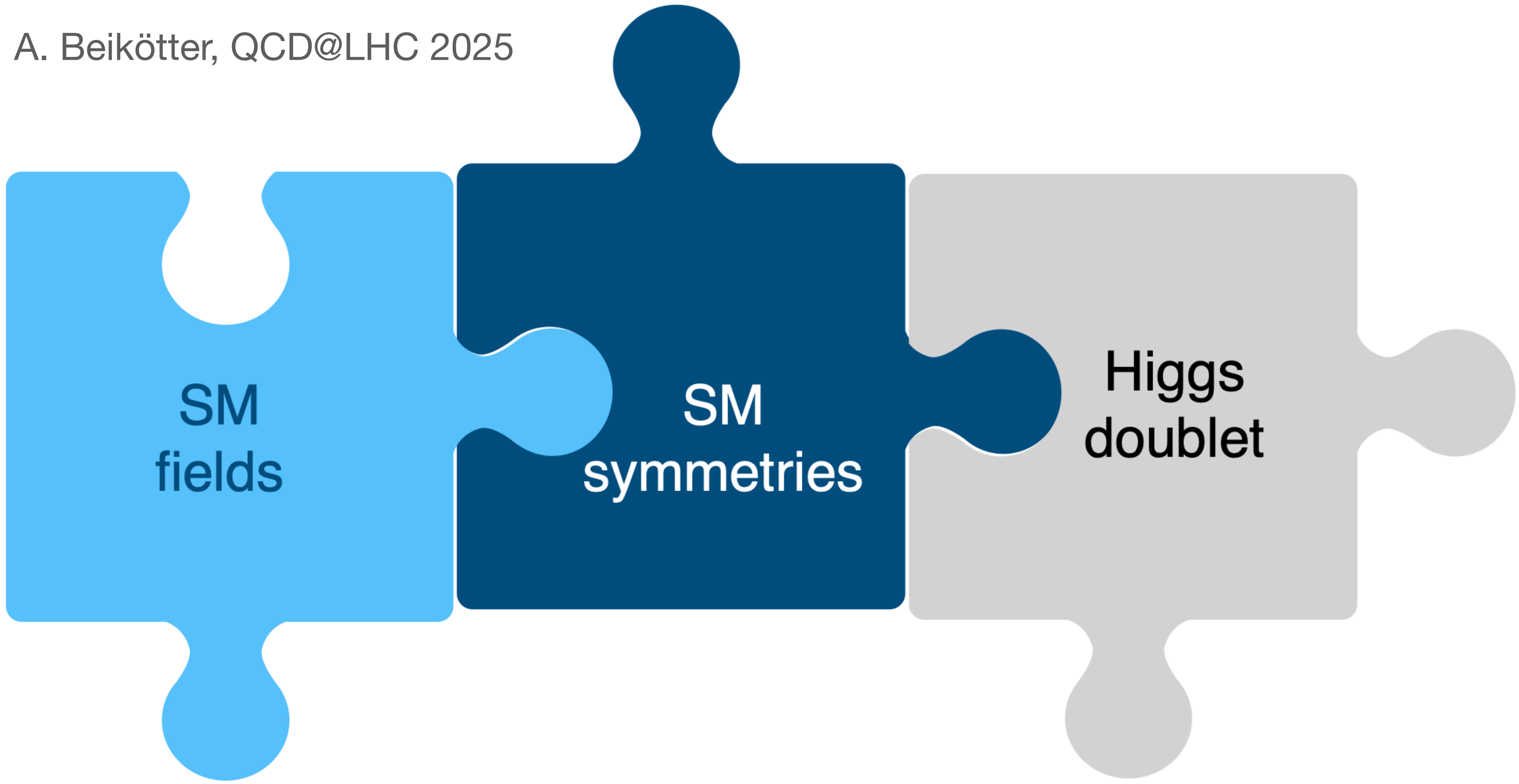


*Only a selection of the available mass limits on new states or phenomena is shown.
†Small-radius (large-radius) jets are denoted by the letter j (J).



The Standard Model Effective Theory

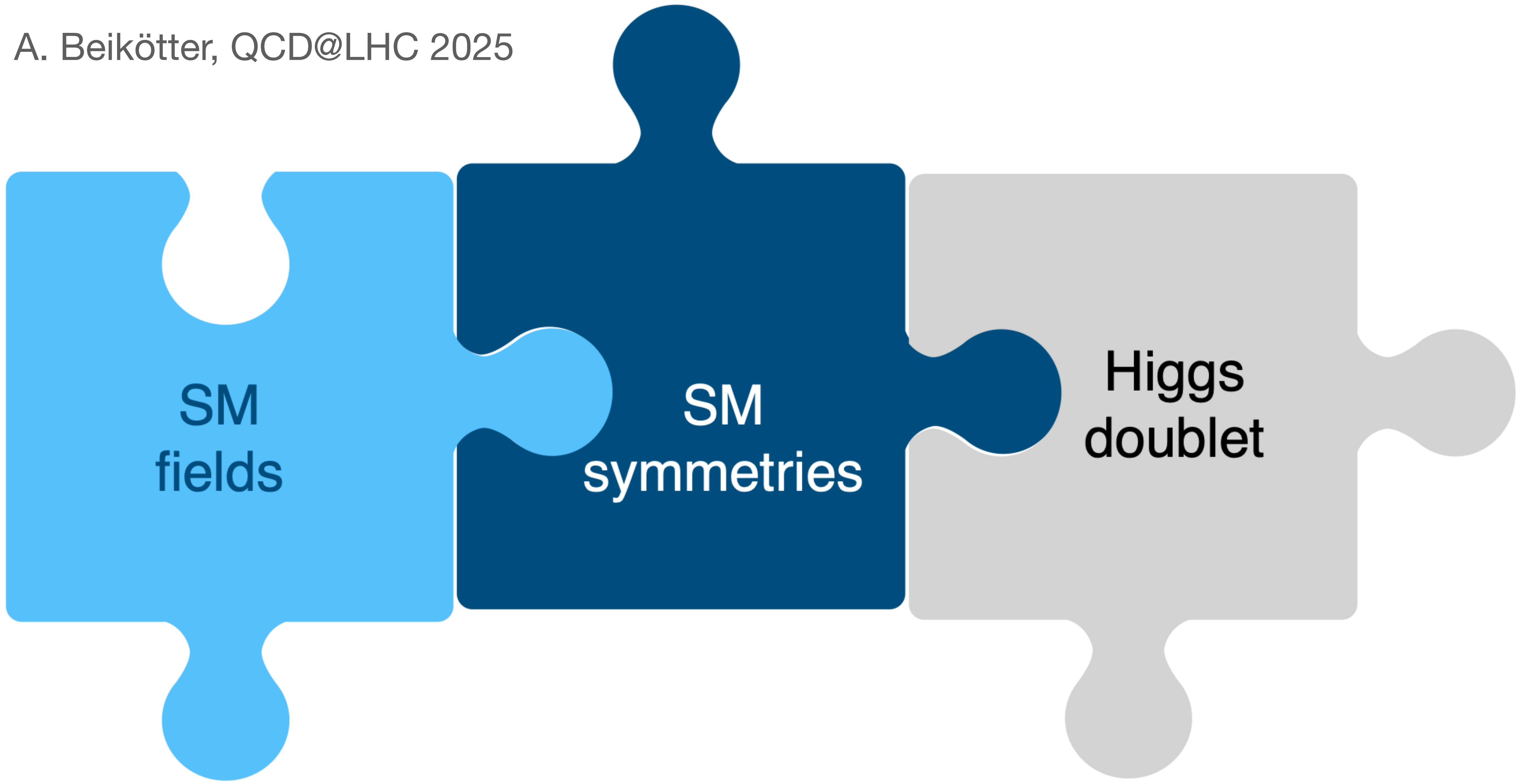
A. Beikötter, QCD@LHC 2025



$$\mathscr{L} = \mathscr{L}_{SM}^{(4)} + \frac{1}{\Lambda}\sum_i C_i^{(5)} O_i^{(5)} + \frac{1}{\Lambda^2}\sum_i C_i^{(6)} O_i^{(6)} + \mathcal{O}\left(\frac{1}{\Lambda^3}\right)$$

The Standard Model Effective Theory

A. Beikötter, QCD@LHC 2025



New physics effects contained in the matching Wilson coefficients C_i

$C_i \neq 0$ means new Physics!

Expansion in $1/\Lambda$ and couplings

Theory is renormalizable order-by-order in $1/\Lambda$

Consistent and systematic approach for data interpretation!

$$\mathscr{L} = \mathscr{L}_{SM}^{(4)} + \frac{1}{\Lambda}\sum_i C_i^{(5)} O_i^{(5)} + \frac{1}{\Lambda^2}\sum_i C_i^{(6)} O_i^{(6)} + \mathscr{O}\left(\frac{1}{\Lambda^3}\right)$$

Precision in SMEFT

Why higher orders?

$$\boxed{\Delta o_n} = \boxed{o_n^{\mathrm{EXP}}} - \boxed{o_n^{\mathrm{SM}}} = \sum_i \boxed{\frac{a_{n,i}^{(6)}(\mu)\, c_i^{(6)}(\mu)}{\Lambda^2}} + \mathcal{O}\left(\frac{1}{\Lambda^3}\right)$$

Precise experimental data and SM predictions

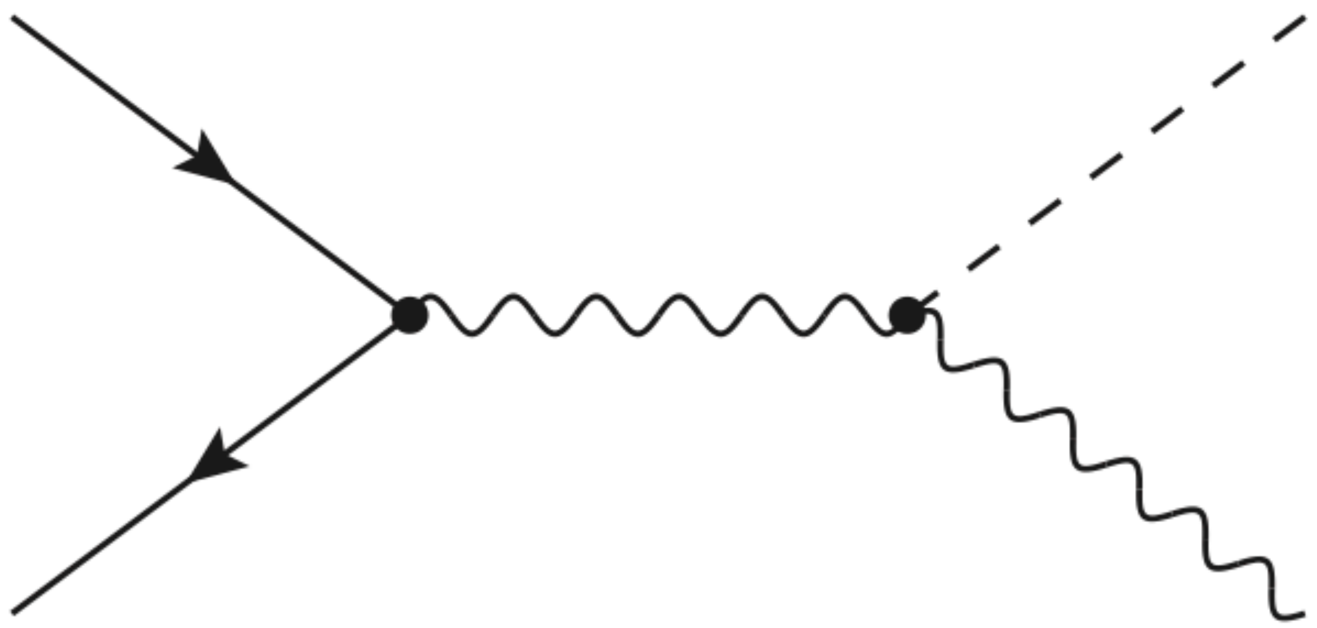
Precise SMEFT predictions
to determine Wilson coefficients

We consider the contributions given by
dim-6 operators in the Warsaw basis at NLO

Uncertainty and correlation estimation crucial for data interpretation

Higgs-strahlung production

- At LHC easier to identify some decays e.g. $H \to b\bar{b}$ in this channel
- At FCC-ee will be main production channel



- $e^+e^- \to ZH$ known up to NLO in the SM

  NNLO EW+QCD and EW partial results for polarised initial states

Fleischer, Jegerlehner, Phys.Rev.D 23 (1981) 2001-2026

Kniehl, Z.Phys.C 55 (1992) 605-618

Denner et al., Z.Phys.C 56 (1992) 261-272

Freitas et al., Phys.Rev.D 108 (2023) 5, 053006

Freitas, Song, Phys.Rev.Lett. 130 (2023) 3, 031801

Chen et al., 2209.14953 [hep-ph]

Gong et al., Phys. Rev. D 95, 093003

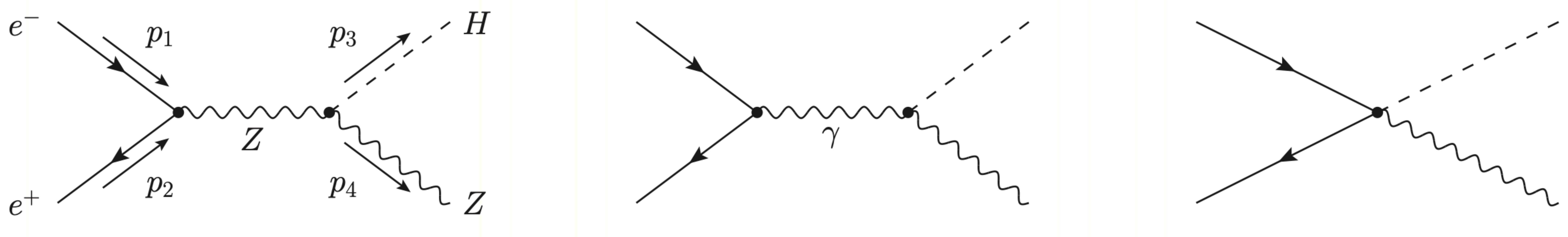
Sun et al., Phys.Rev.D 96 (2017) 5, 051301

ZH production at FCC-ee in SMEFT

Asteriadis et al., JHEP 02 (2025) 162

Asteriadis et al., Phys.Rev.Lett. 133 (2024) 23, 231801

LO contributions



$C_{\phi D}$, $C_{\phi\Box}$, — ZZH vertex

$C_{\phi e}$, → eeZ vertex

$C^1_{\phi l}$, $C^3_{\phi l}$, — 4p interactions eeZ vertex

C_{ll}, → G_F

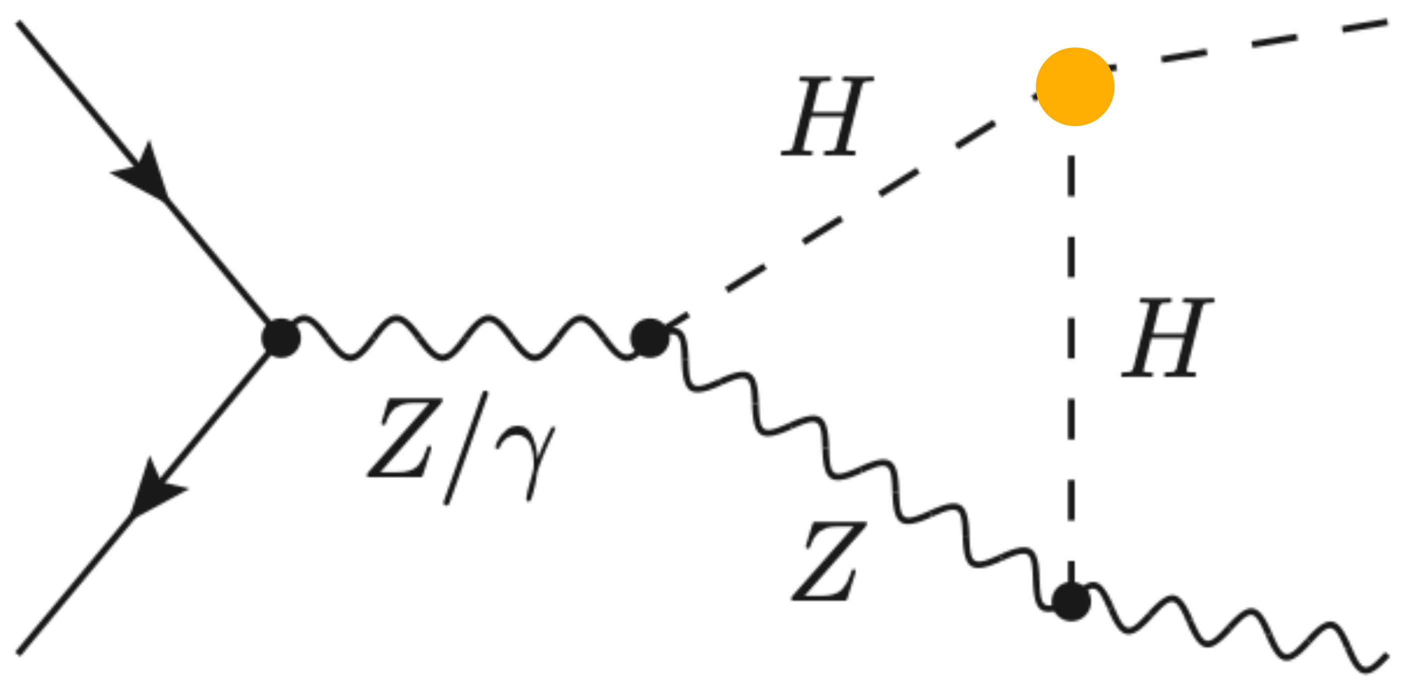
$C_{\phi WB}$, $C_{\phi W}$, $C_{\phi B}$ — ZZH and ZHγ vertices

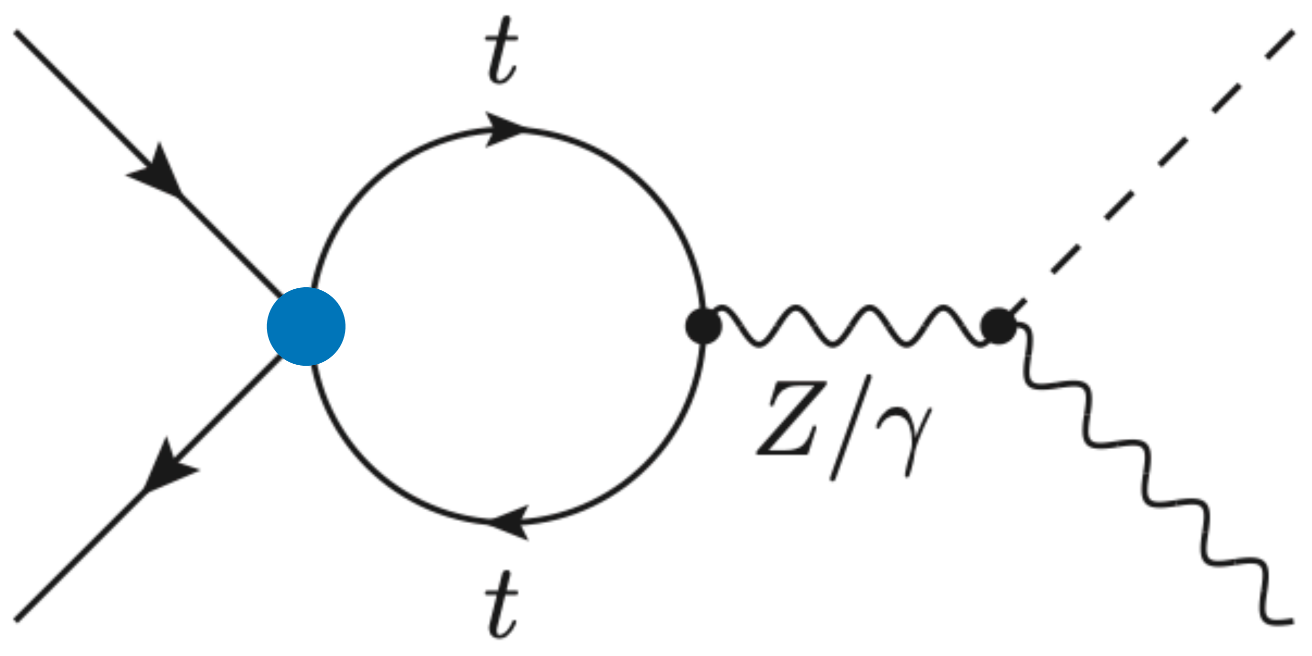
ZH production at FCC-ee in SMEFT

Asteriadis et al., JHEP 02 (2025) 162

Asteriadis et al., Phys.Rev.Lett. 133 (2024) 23, 231801

NLO contributions: example





$C_\phi \longrightarrow$ trilinear coupling

$C_{lq}^{1133} \longrightarrow$ 4f interactions

70 SMEFT operators at NLO with no flavor assumptions

Let’s decay the Higgs in SMEFT

$H \to b\bar{b}$	Gauld, Pecjak, Scott, Phys.Rev.D 94 (2016) 7, 074045	Cullen, Pecjak, Scott, JHEP 08 (2019) 173
$H \to \tau^+\tau^-$	Gauld, Pecjak, Scott, JHEP 05 (2016) 080	Cullen, Pecjak, JHEP 11 (2020) 079
$H \to \gamma\gamma$	Hartmann, Trott, Phys.Rev.Lett. 115 (2015) 19, 191801 Hartmann, Trott, JHEP 07 (2015) 151	Dawson, Giardino, Phys.Rev.D 98 (2018) 9, 095005 Dedes et al., JHEP 08 (2018) 103
$H \to Z\gamma$	Dawson, Giardino, Phys. Rev. D 97, 093003 (2018)	Dedes, Suxho, Trifyllis, JHEP 06 (2019) 115
$H \to gg$	Deutschmann et al., JHEP 12 (2017) 063	Martin, Trott, JHEP 01 (2024) 170 Corbett, Martin, Trott, JHEP 12 (2021) 147
$H \to Zf\bar{f}$	Dawson et al., Phys.Rev.D 111 (2025) 1, 015016	
$\boxed{H \to Wf\bar{f}'}$	NEW!	

Let's decay the Higgs in SMEFT

Bellafronte et al., 2508.14966 [hep-ph]

$H \to b\bar{b}$

$H \to \tau^+\tau^-$

$H \to \gamma\gamma$

$H \to Z\gamma$

$H \to gg$

$H \to Zf\bar{f}$

$H \to Wf\bar{f}'$ NEW!

Implemented in
fixed-order Monte Carlo code

total widths and branching ratios
at NLO in SMEFT

NEWiSH

NLO

Electro**W**eak

in the

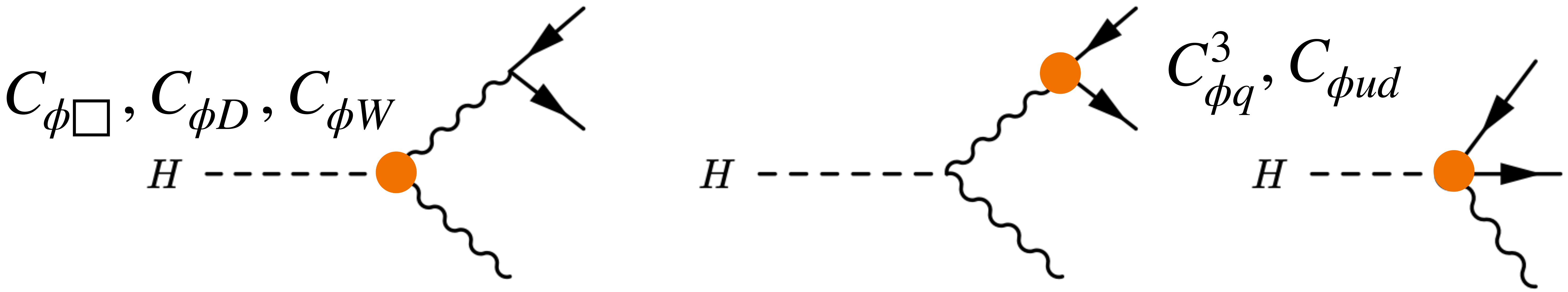
SMEFT for

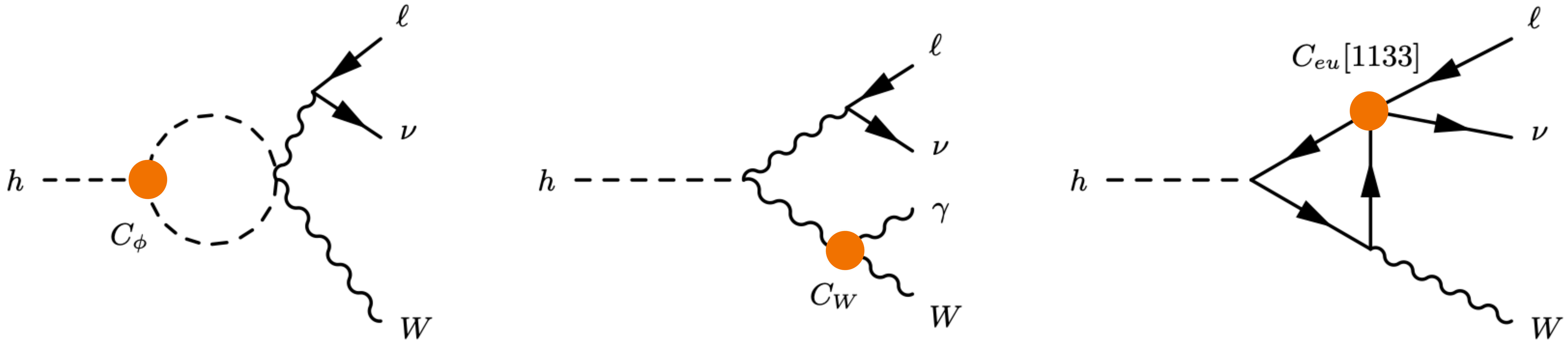
Higgs widths

$H \to Wf\bar{f}'$ at NLO EW in SMEFT

Bellafronte et al., 2508.14966 [hep-ph]

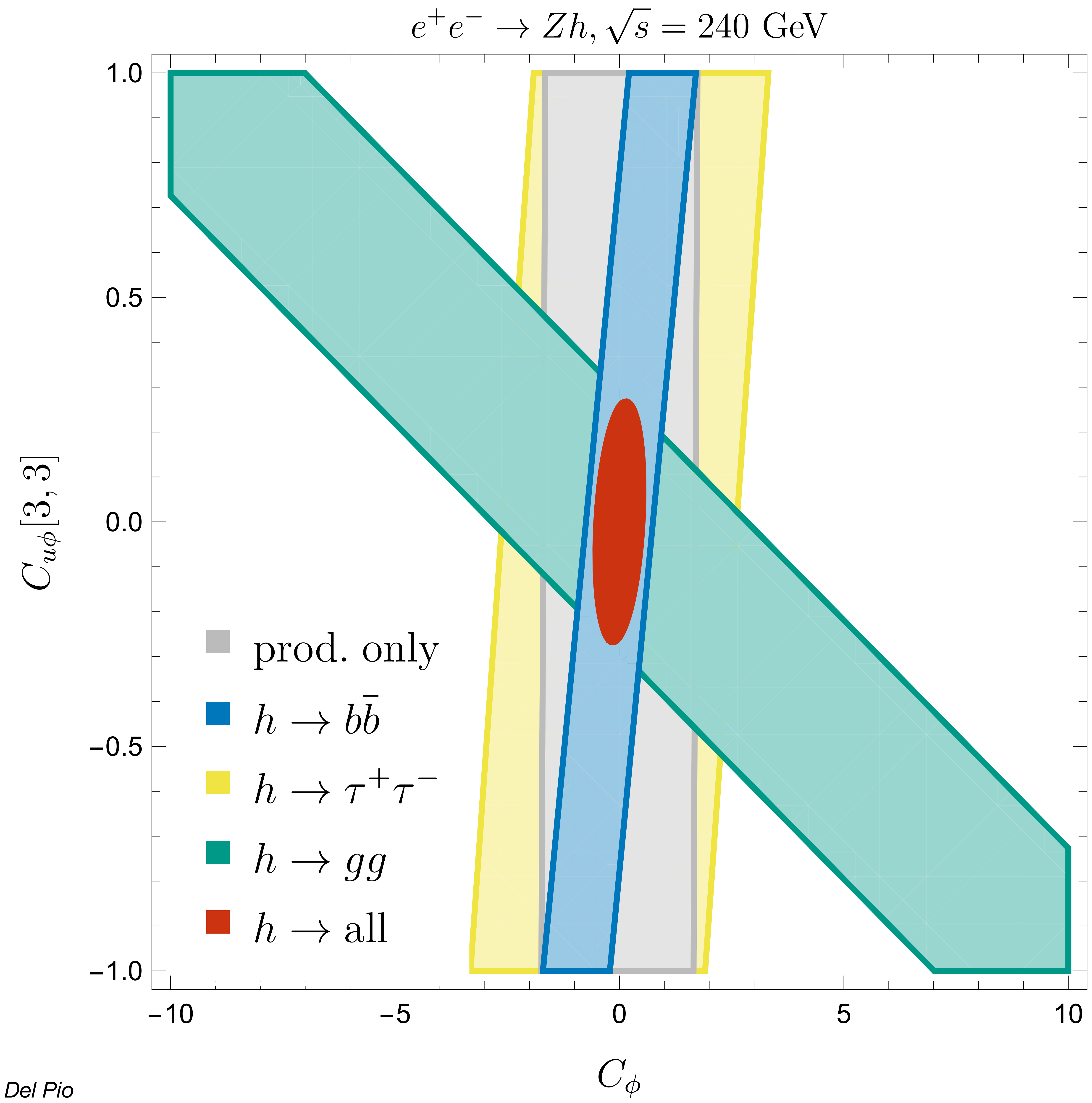
at LO $C_{\phi D}$, $C_{\phi\Box}$, $C^3_{\phi l}/C^3_{\phi q}$, C_{ll}, $C_{\phi W}$, $C_{\phi ud}$





Adding the decays

Bellafronte et al., 2508.14966 [hep-ph]



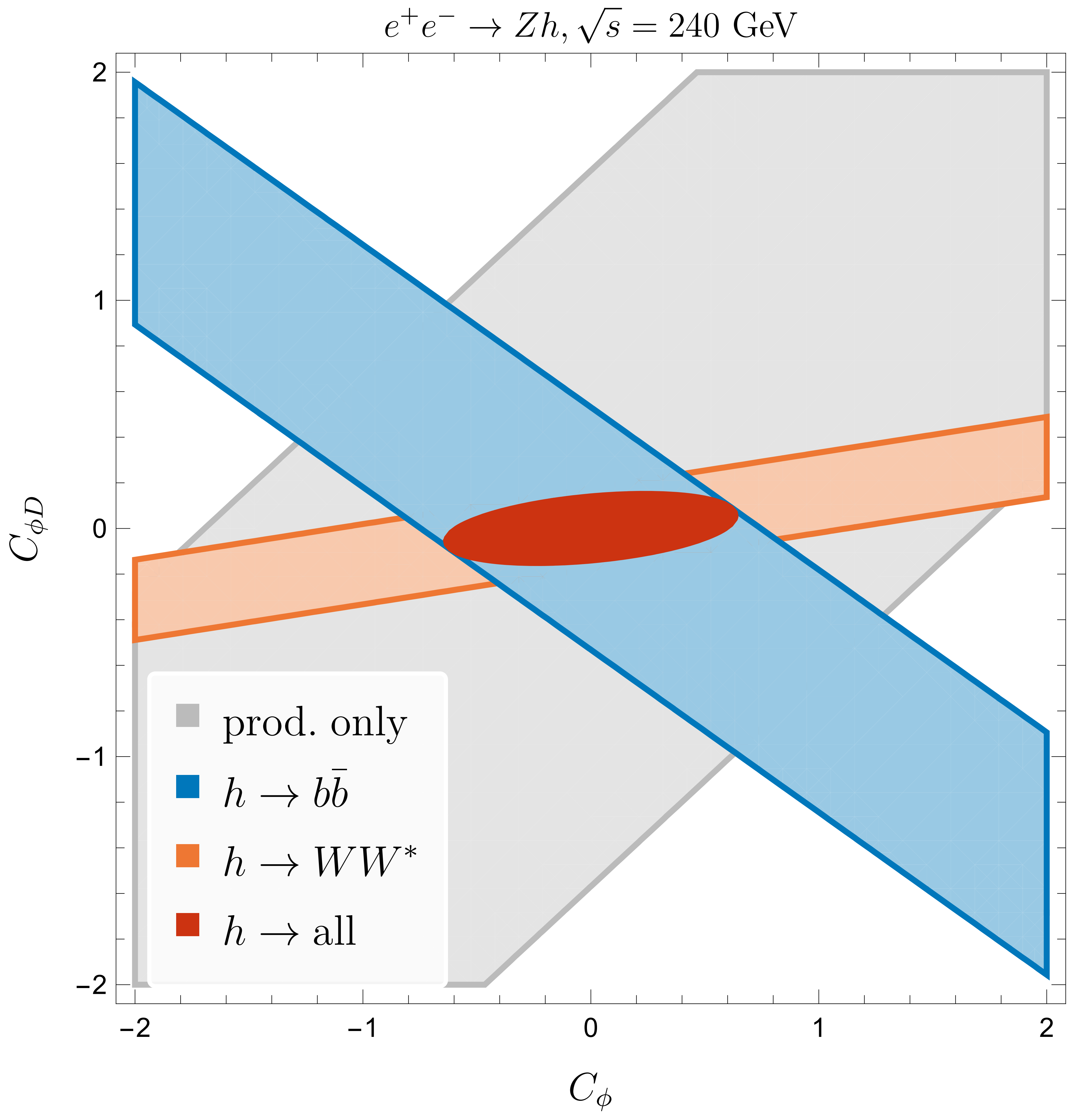
Narrow width approximation

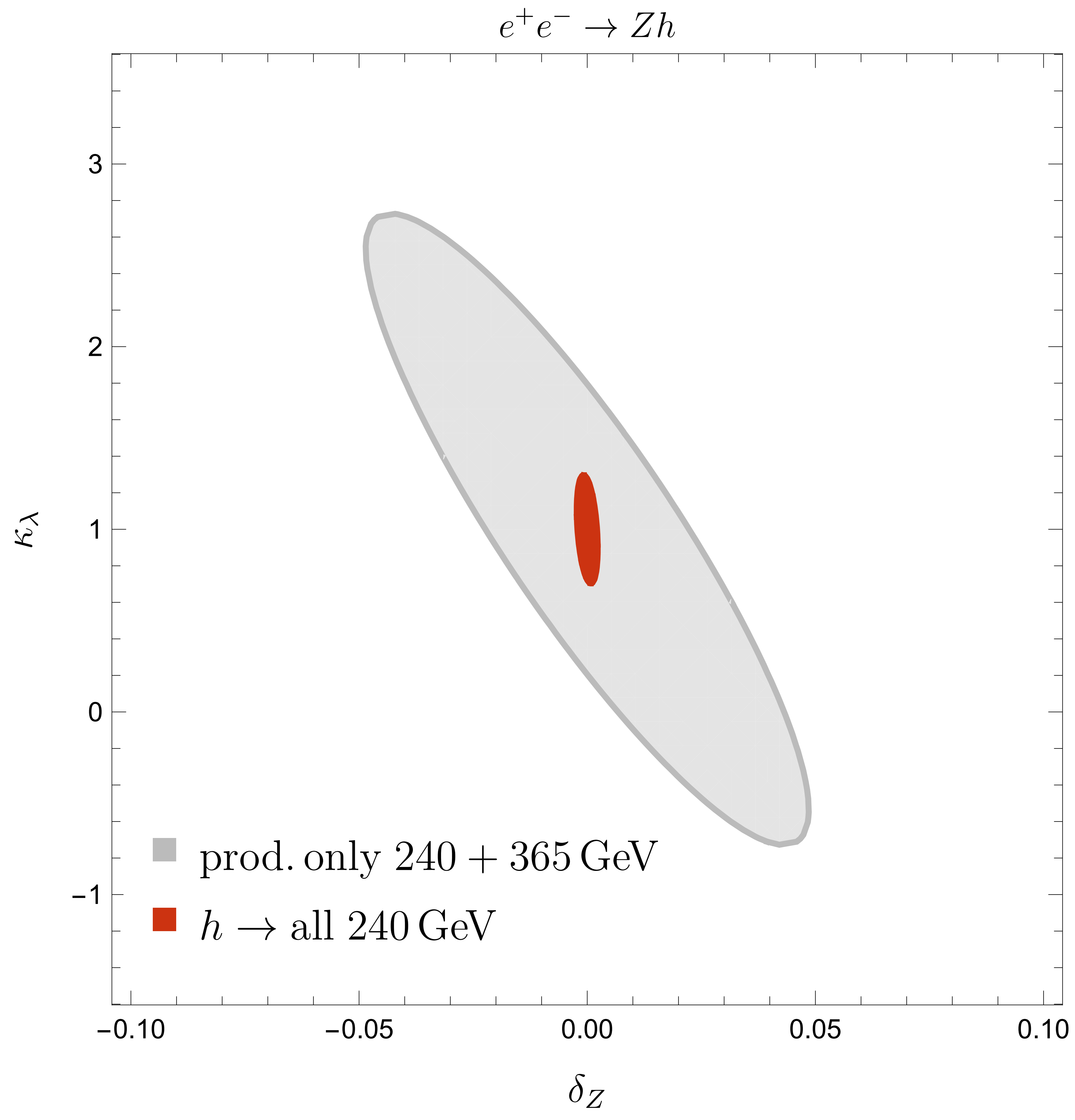
$$\sigma(e^+e^- \to HZ; H \to XZ) = \sigma(e^+e^- \to HZ)\,\mathrm{BR}(H \to XZ)$$

Adding the information of the decays provides much better constraints!

Higgs couplings

Bellafronte et al., 2508.14966 [hep-ph]





$$C_{\phi\Box} = 0 \qquad \delta_Z = \frac{1}{4}\frac{v^2}{\Lambda^2}C_{\phi D} \qquad \kappa_\lambda = 1 + \frac{v^2}{\Lambda^2}\left(\frac{3}{4}C_{\phi D} - 2\frac{v^2}{m_H^2}C_\phi\right)$$

Outlook

The Higgs sector is fundamental for understanding the SM and the physics beyond

Consistent parameterisation of New Physics effects in **Higgs production and decay** with **SMEFT at NLO**

Inclusion of the decays **improves bounds** on many coefficients at **FCC-ee**

Thank you!