Functional approach for EFTs

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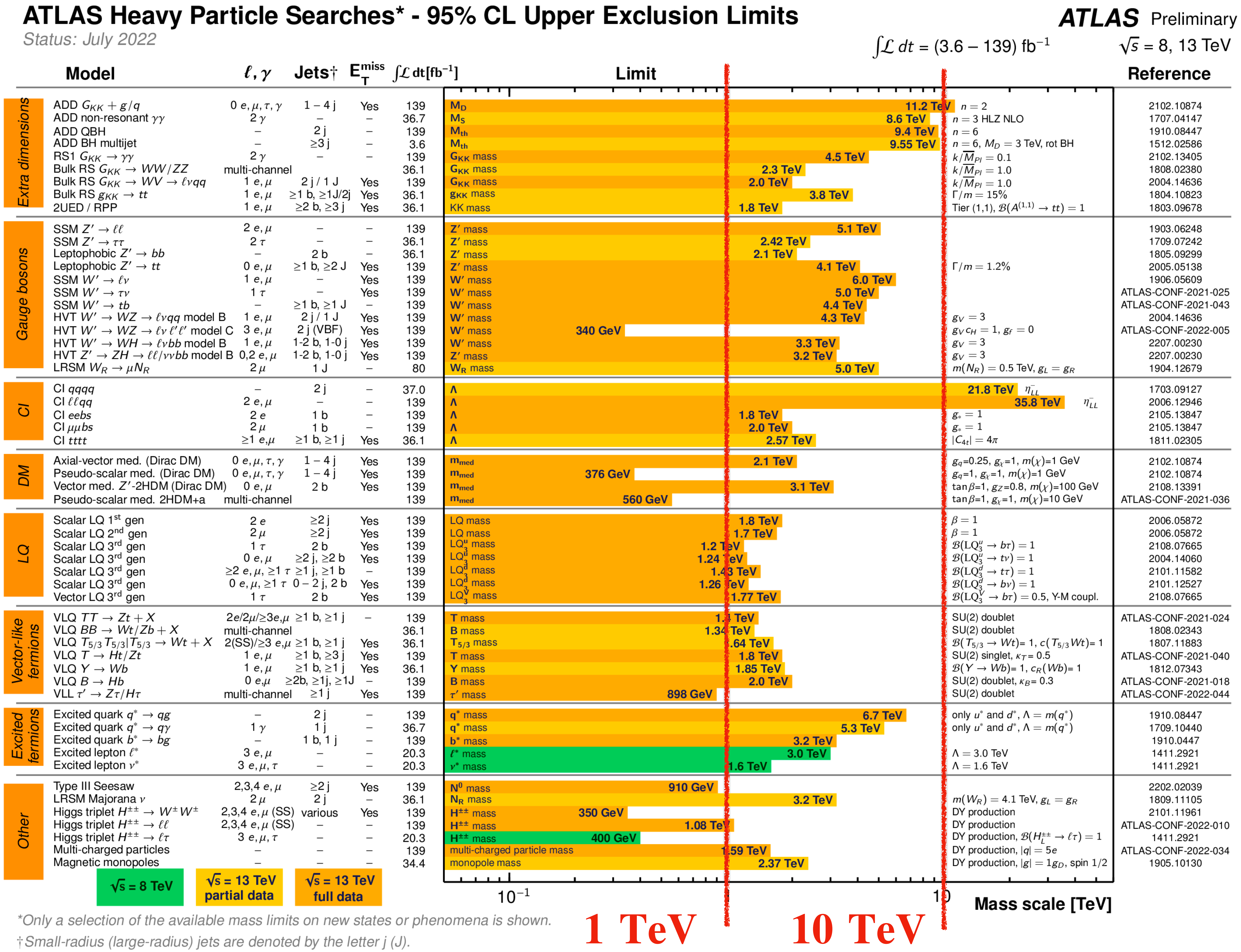
What is experiment telling us?



No **direct evidence** for NP despite the many reasons for it

[**presence of a mass gap?**]

The Effective Field Theory approach

EFTs are essential to interpret experimental observations

UV physics

$$\mathscr{L}_{\text{EFT}}(\eta_L) = \mathscr{L}_{d=4}(\eta_L) + \sum_{\ell=0}^{\infty} \sum_{n=5}^{\infty} \sum_{k} \frac{C_{n,k}^{(\ell)}}{(16\pi^2)^{\ell}\, \Lambda^{n-4}} O_{n,k}(\eta_L)$$

- Bottom → Up

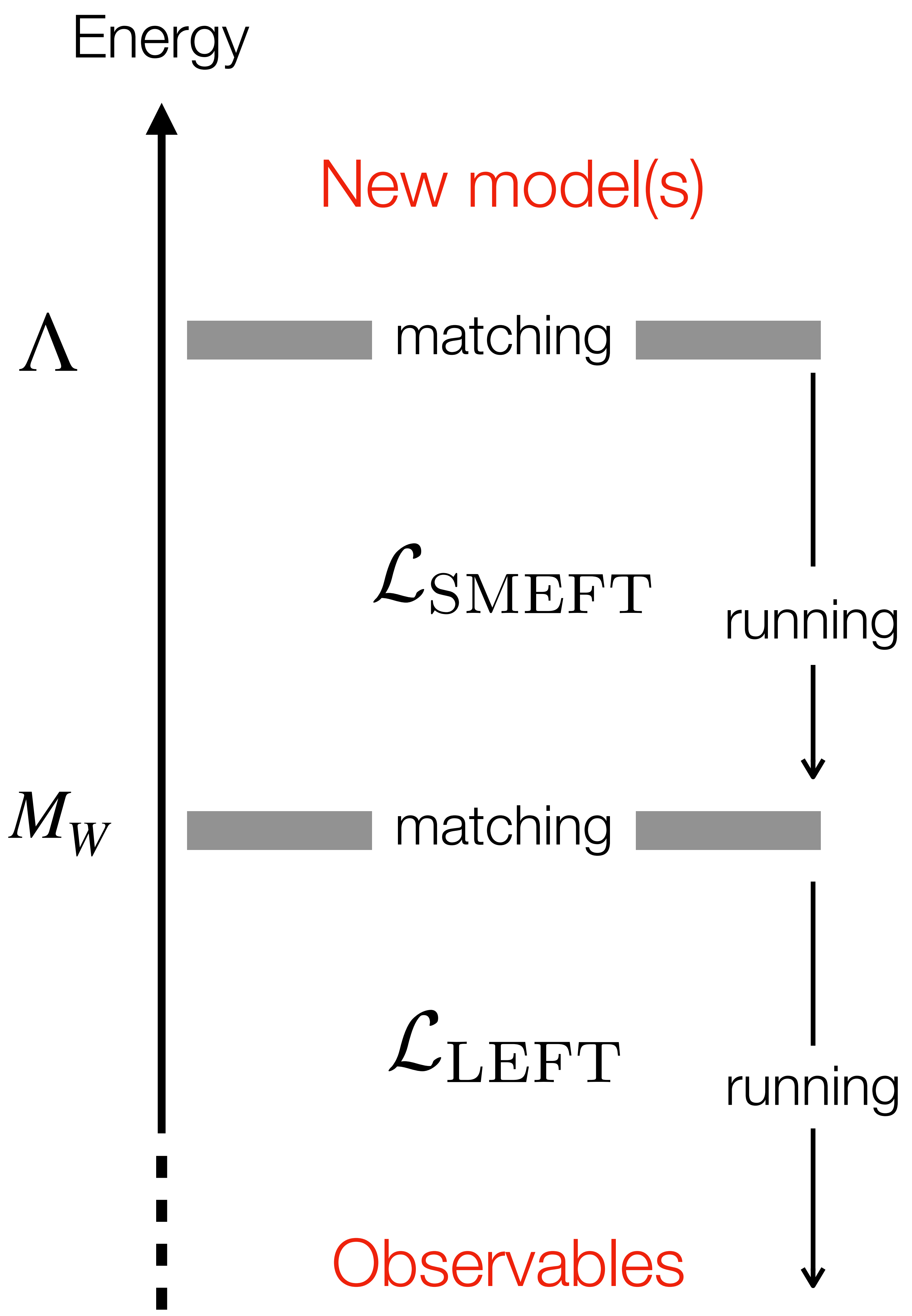
  EFTs offer a model comprehensive ("model independent") approach to study deviations form the SM, organized in a double expansion in E/Λ and loop orders.

- Top → Down

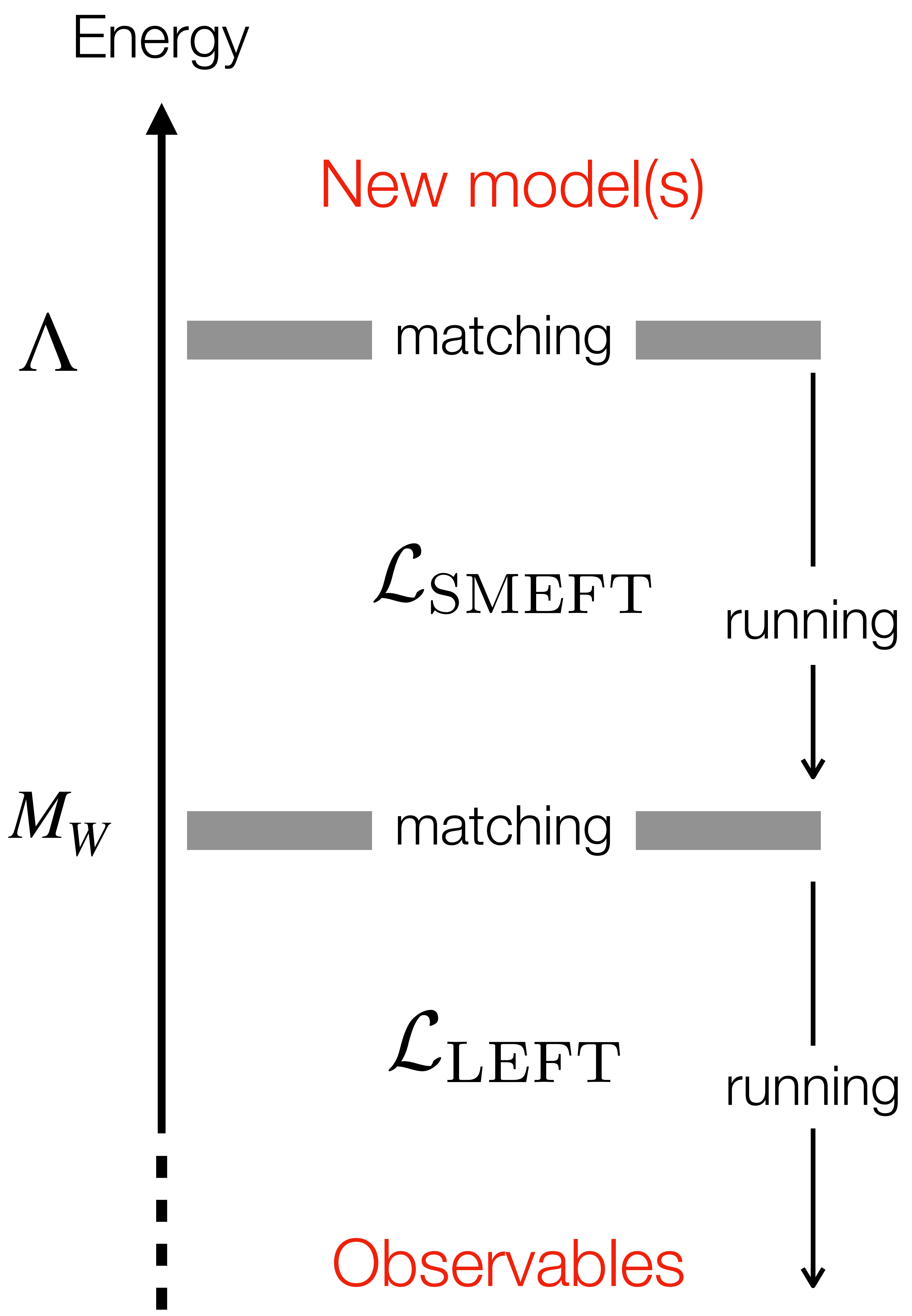
  (B)SM computations of experimental observables are multi-scale problems:
  Precision requires using EFTs (RG resummation of large logs)

  Multiple BSM models share the same EFT, so many computations are reusable ("compute once for all")

The rise of automation



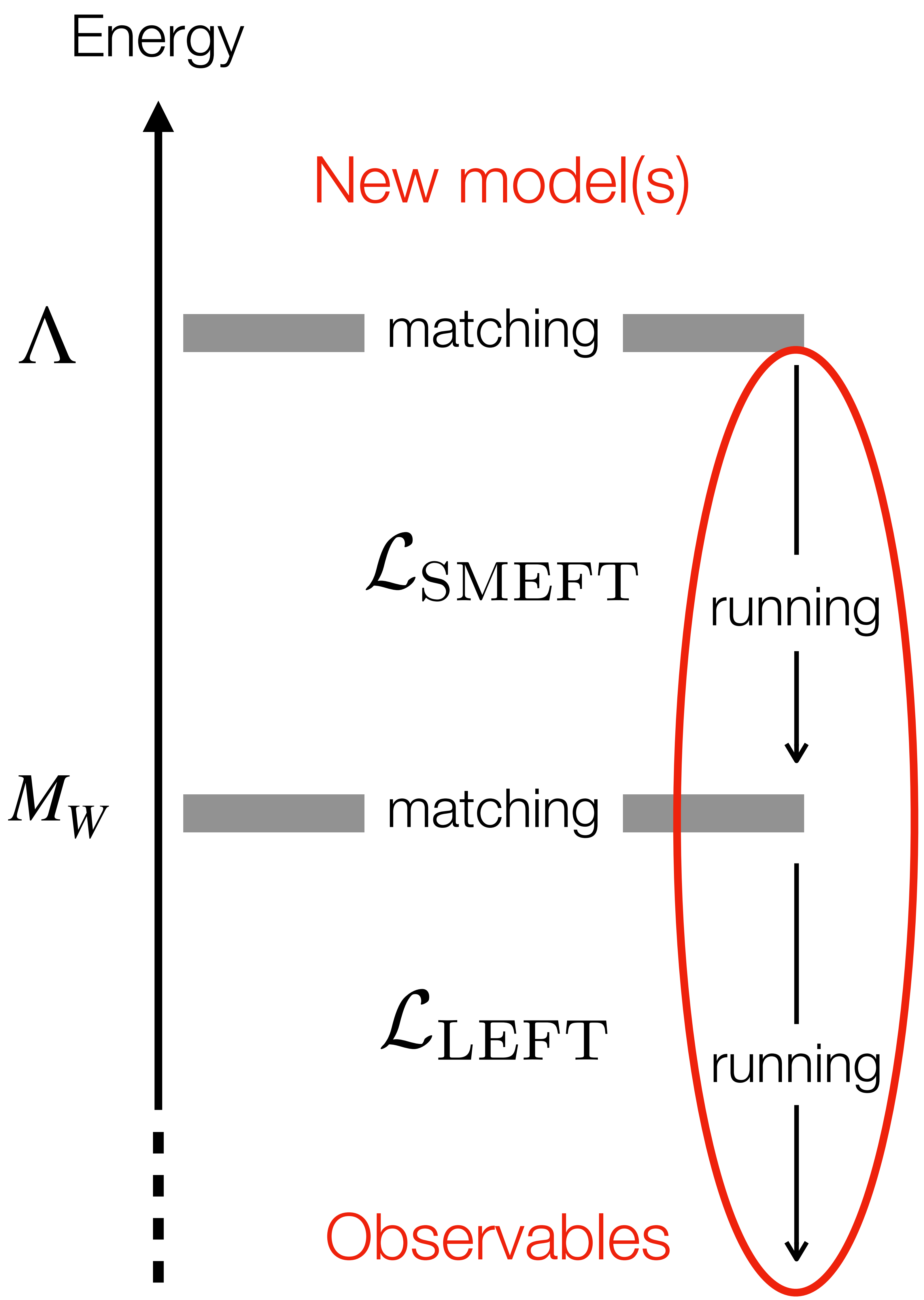
The rise of automation



Main motivation

The vast landscape of BSM models and the repetitive nature of EFT computations call for automated solutions

The rise of automation



DsixTools

JFM et al. '17 & '21

wilson

Aebischer et al. '18

"Hard-coded" one-loop results based on:

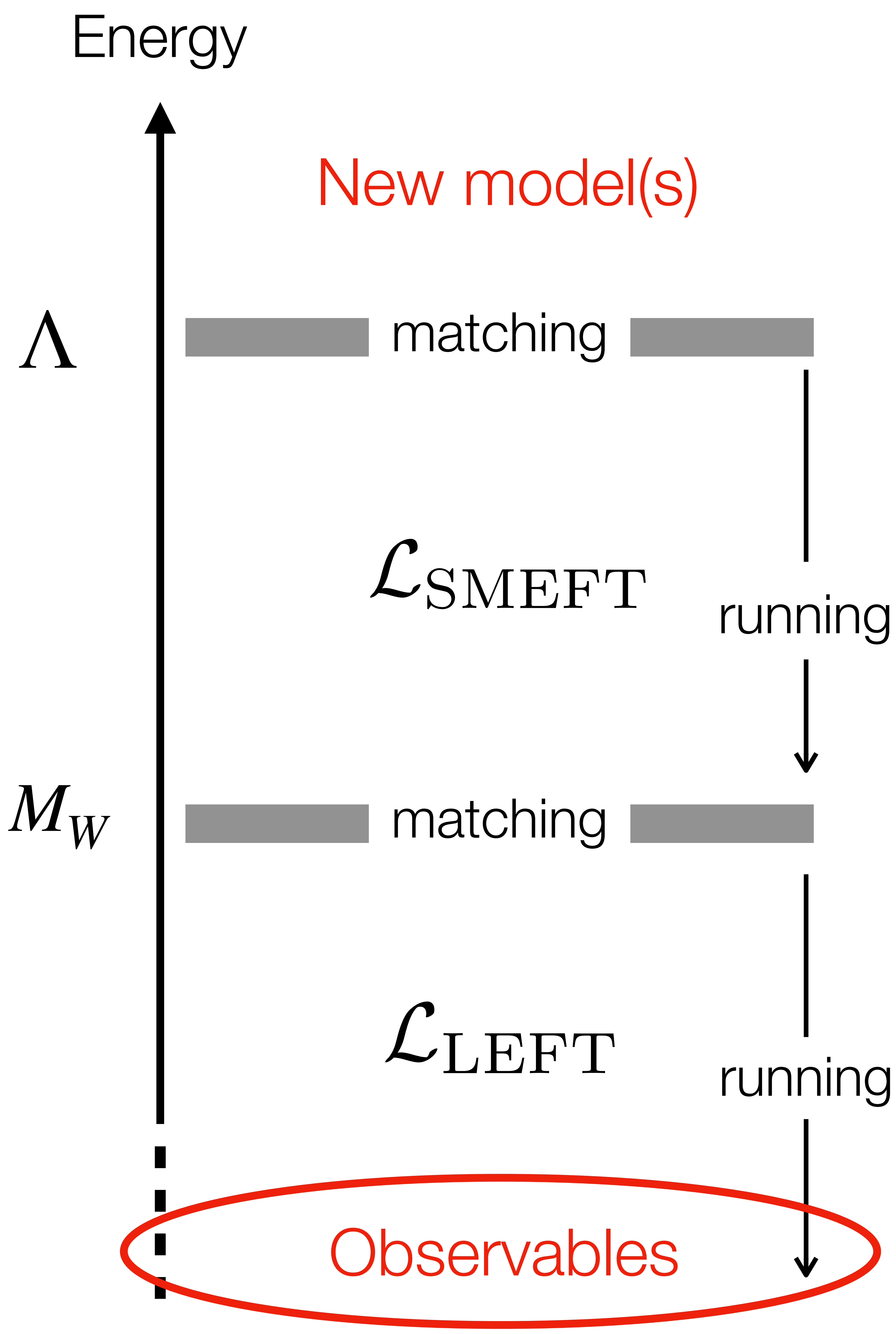
SMEFT running: Jenkins et al. '13, '14; Alonso et al. '14

LEFT basis: Jenkins et al. '18

SMEFT-LEFT matching: Dekens, Stoffer '19

LEFT running: Jenkins et al. '18

The rise of automation



SMEFT likelihood (smelli)

Aebischer et al. '18

flavio

Straub ‘16

HEPfit

De Blas et al. ‘19

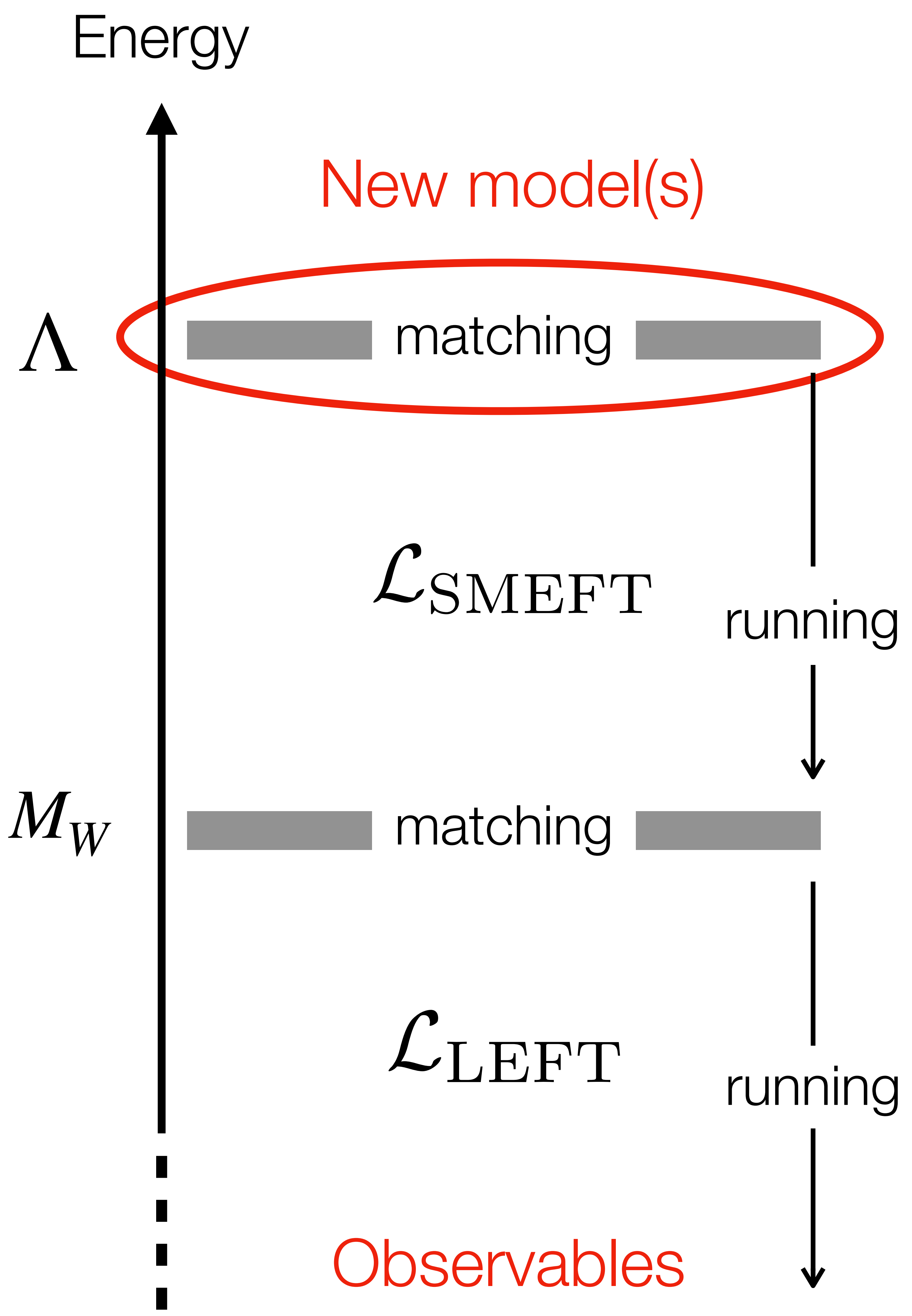
SMEFiT

Giani et al. ‘23

+ others

Involvement of experimental collaborations into this program is crucial

The rise of automation



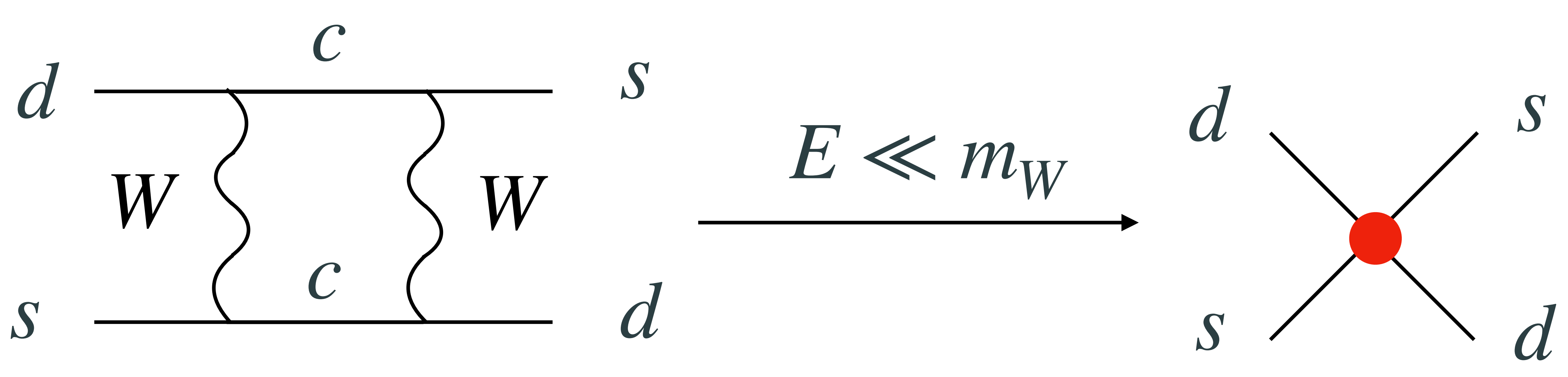
Much progress has been made:

- Tree-level matching to the SMEFT is a solved problem

  [de Blas, Criado, Pérez-Victoria, Santiago, '17]

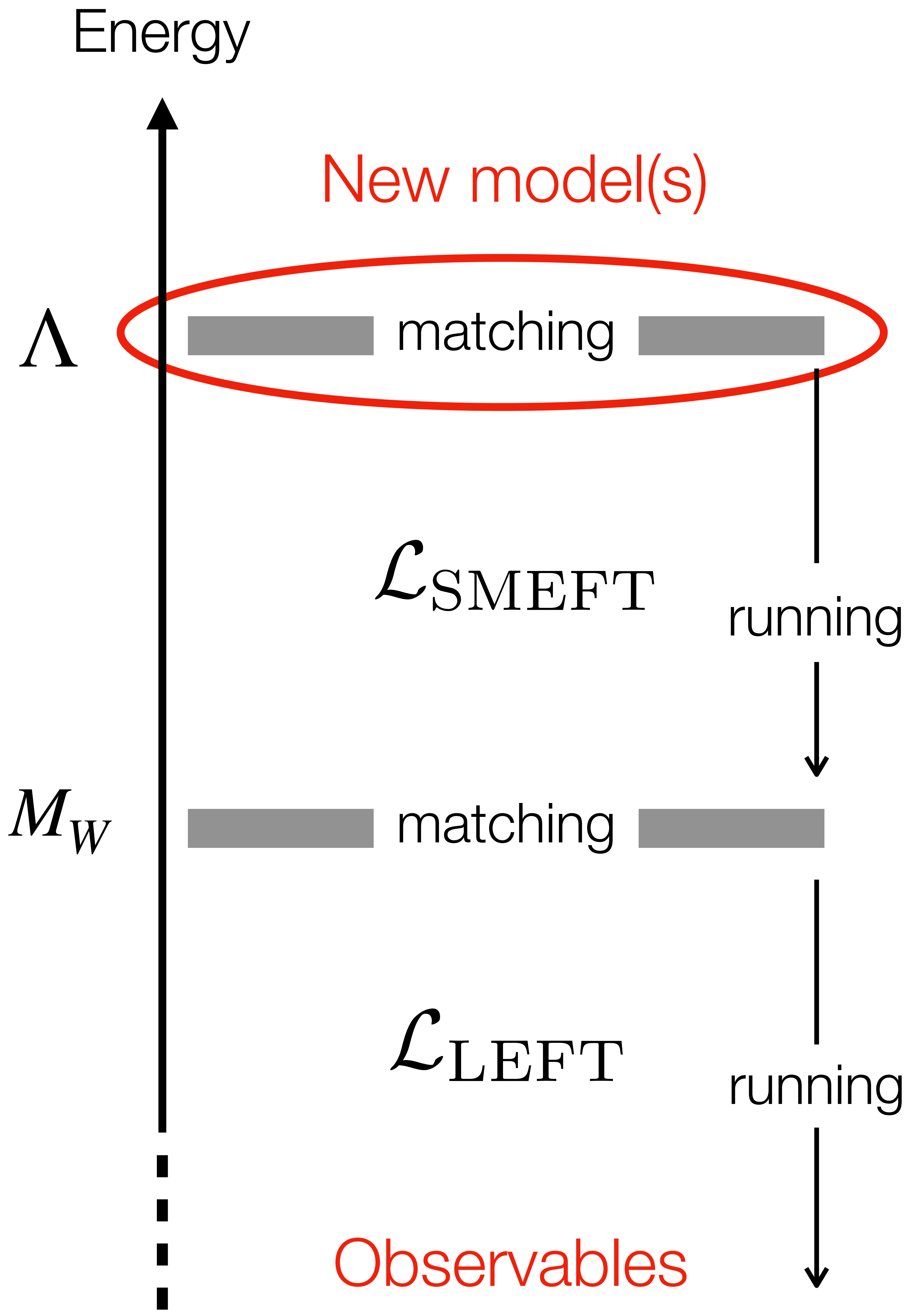
  MatchingTools: [Criado '17]

- One-loop can be the leading effect in important processes. E.g., in the SM



Similarly, in BSM models: dipoles, FCNCs, EW precision…

The rise of automation



matchmakereft
Carmona et al. '22

MATCHETE
JFM et al. '23

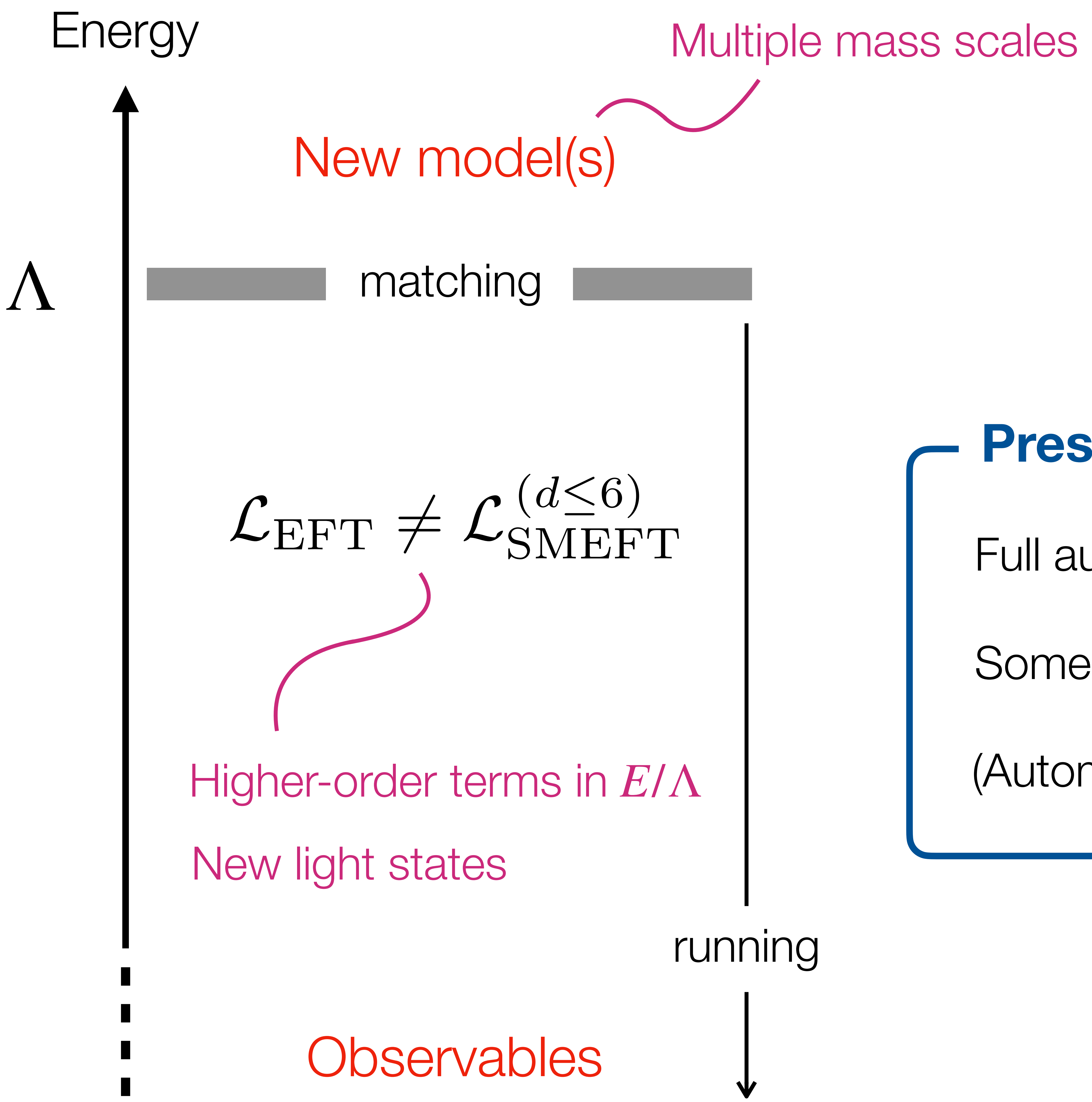
Automated one-loop matching of many models

SOLD
Guedes et al. '23

UV-SMEFT dictionaries

"Breaking SMEFT operators"
UV-to-SMEFT mapping
Cepedello et al. '23

The rise of automation



Present limitations

Full automation only for the simplest scenarios

Some steps/approaches require prior knowledge of the target EFT

(Automated) inclusion of higher-loop orders is (so far) non-trivial

The traditional approach to matching

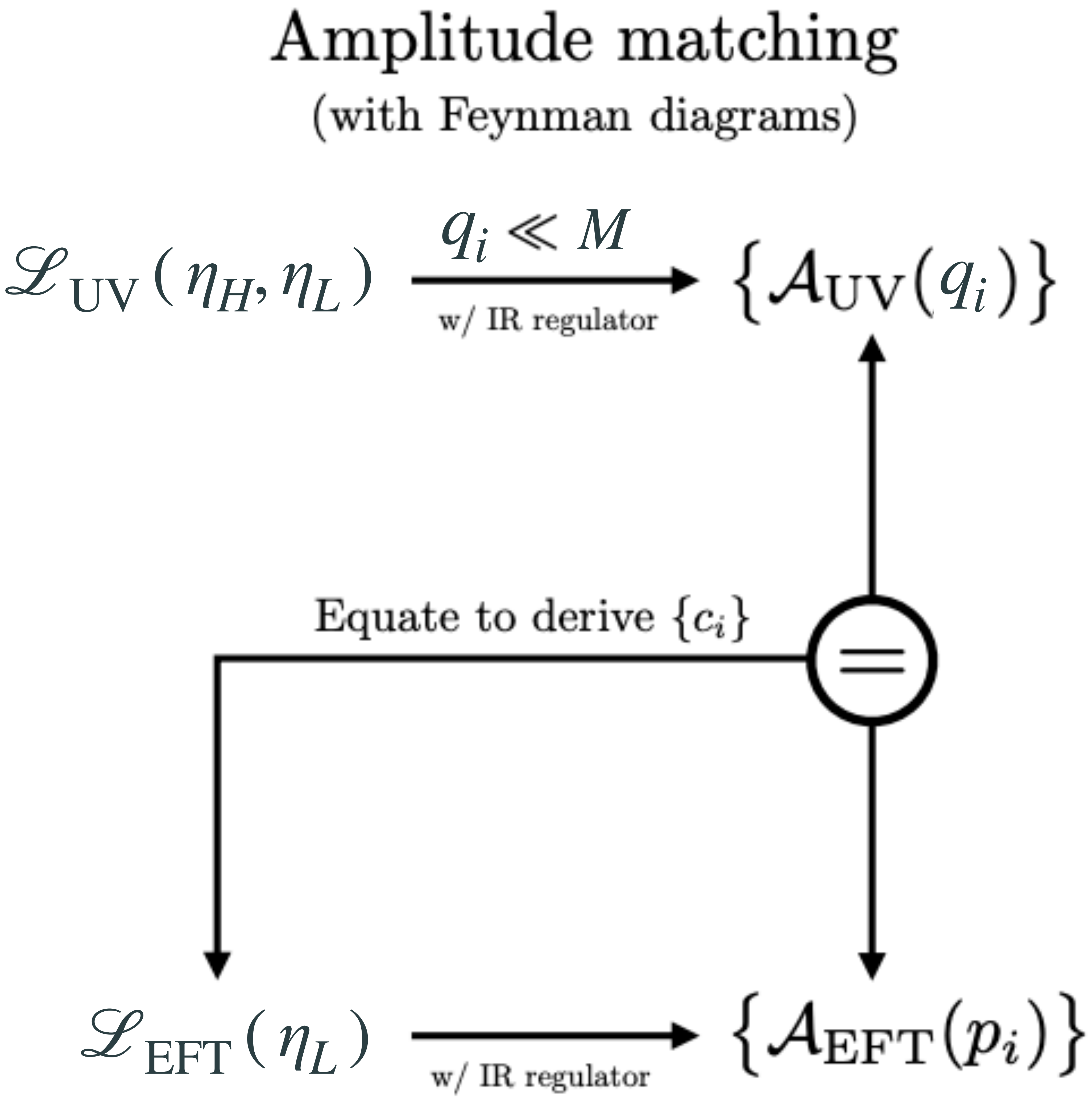


Figure from Cohen, Lu, Zhang, '21

- Well-established procedure to any loop order
- Matching usually done off-shell: Additional redundancies but need to consider 1LPI diagrams only
- Explicit breaking of gauge symmetry in intermediate steps
- Need a priori knowledge of the EFT Lagrangian in off-shell basis and with redundancies (e.g. Fierz related ops.)

SMEFT basis in Gherardi, Marzocca, Venturini, '20;
Carmona, Lazopoulos, Olgoso, Santiago, '21

Functional matching

- **Lagrangian:** $\mathscr{L}_{\mathrm{UV}}$ with fields $\eta = (\eta_H \; \eta_L)^\intercal$ and hierarchy $m_H \gg m_L$

- **Background field method:** shift all fields $\eta \to \hat{\eta} + \eta$

  $\hat{\eta}$: background fields (satisfy the quantum EOM) [Tree lines in Feynman graphs]

  $\hat{\eta}$: quantum fluctuations [Loop lines in Feynman graphs]

- **Quantum effective action:**

$$e^{i\,\Gamma_{\mathrm{UV}}[\hat{\eta}]} = \int \mathscr{D}\eta \; \exp\left(i \int \mathrm{d}^d x \; \mathscr{L}_{\mathrm{UV}}(\eta + \hat{\eta}) \right)$$

Goal: Evaluate the path integral and isolate ("integrate out the quantum configuration) and isolate the EFT contribution

Functional matching

- **Expanding the Lagrangian in η:**

$$\mathscr{L}_{\mathrm{UV}}(\hat{\eta}+\eta) = \mathscr{L}_{\mathrm{UV}}(\hat{\eta}) + \left.\frac{\delta \mathscr{L}_{\mathrm{UV}}}{\delta \eta_i}\right|_{\eta=\hat{\eta}} \eta_i + \frac{1}{2}\bar{\eta}_i \left.\frac{\delta^2 \mathscr{L}_{\mathrm{UV}}}{\delta \eta_j\, \delta \bar{\eta}_i}\right|_{\eta=\hat{\eta}} \eta_j + \mathscr{O}(\eta^3)$$

Functional matching

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- **Tree-level:** $\mathscr{L}^{(0)}_{\mathrm{EFT}} = \mathscr{L}_{\mathrm{UV}}\big(\hat{\eta}_L, \hat{\eta}_H(\hat{\eta}_L)\big)$

  — Substitute $\hat{\eta}_H$ by its EOM expanded in m_H^{-1}

$$\left.\frac{\delta \mathscr{L}_{\mathrm{UV}}}{\delta \eta_H}\right|_{\eta=\hat{\eta}} = 0$$

Functional matching

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- **Expanding the Lagrangian in η:**

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  — Substitute $\hat\eta_H$ by its EOM expanded in m_H^{-1}

$$\frac{\delta \mathscr{L}_{\mathrm{UV}}}{\delta \eta_H}\bigg|_{\eta=\hat\eta} = 0$$

- **1-loop:** $e^{i\Gamma^{(1)}_{\mathrm{UV}}[\hat\eta]} = \int \mathscr{D}\eta\ \exp\left(i\int \mathrm{d}^d x\ \bar\eta_i Q_{ij}\eta_j\right) \Longrightarrow \Gamma^{(1)}_{\mathrm{UV}}[\hat\eta] = -\,i\ln \mathrm{SDet}\, Q^{-1/2} = \frac{i}{2}\mathrm{STr}\ln Q$

Gaussian integration

Functional matching

- **Expanding the Lagrangian in η:**

$$\mathscr{L}_{\mathrm{UV}}(\hat{\eta}+\eta) = \boxed{\mathscr{L}_{\mathrm{UV}}(\hat{\eta})} + \cancelto{0}{\frac{\delta \mathscr{L}_{\mathrm{UV}}}{\delta \eta_i}\bigg|_{\eta=\hat{\eta}}} \eta_i + \frac{1}{2}\bar{\eta}_i \overset{\substack{Q_{ij}^{-1} \\ \equiv}}{\boxed{\frac{\delta^2 \mathscr{L}_{\mathrm{UV}}}{\delta \eta_j \, \delta \bar{\eta}_i}\bigg|_{\eta=\hat{\eta}}}} \eta_j + \boxed{\mathscr{O}(\eta^3)}$$

Higher-loop orders (more later)

- **Tree-level:** $\mathscr{L}^{(0)}_{\mathrm{EFT}} = \mathscr{L}_{\mathrm{UV}}\big(\hat{\eta}_L, \hat{\eta}_H(\hat{\eta}_L)\big)$

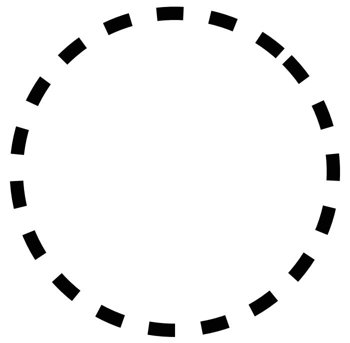
  — Substitute $\hat{\eta}_H$ by its EOM expanded in m_H^{-1}

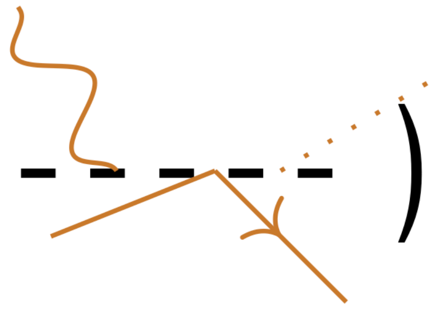
$$\frac{\delta \mathscr{L}_{\mathrm{UV}}}{\delta \eta_H}\bigg|_{\eta=\hat{\eta}} = 0$$

- **1-loop:** $e^{i\Gamma^{(1)}_{\mathrm{UV}}[\hat{\eta}]} = \int \mathscr{D}\eta \, \exp\left(i \int \mathrm{d}^d x \, \bar{\eta}_i Q_{ij} \eta_j\right) \quad \Longrightarrow \quad \Gamma^{(1)}_{\mathrm{UV}}[\hat{\eta}] = -\, i \ln \mathrm{SDet}\, Q^{-1/2} = \frac{i}{2} \mathrm{STr} \ln Q$

Gaussian integration

Evaluating supertraces

- **Supertraces:** $\Gamma^{(1)}_{\mathrm{UV}}[\hat{\eta}] = \frac{i}{2}\,\mathrm{STr}\ln Q = \pm\frac{i}{2}\int\frac{d^dk}{(2\pi)^d}\,\langle k\,|\,\mathrm{tr}\ln Q[\hat{\eta}]\,|\,k\rangle \;=\pm\frac{i}{2}\ln$ 

$Q\,[\hat{\eta}] = \Big($  $\Big)^{-1}$

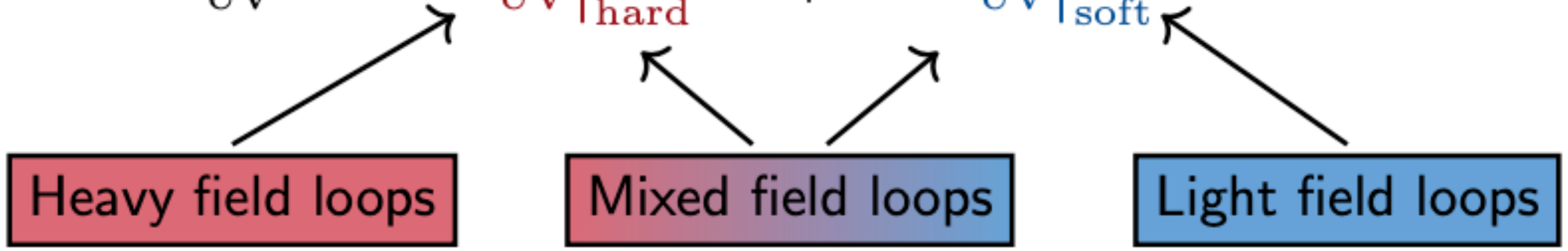
Disclaimer: (quantum) effective action $\neq$ EFT action!

The EFT Lagrangian comes from the hard part

We can separate $\Gamma^{(1)}_{\text{UV}}$ in two regions (for $q^2, m^2 \ll M^2$): hard ($p^2 \sim M^2$) & soft ($p^2 \sim m^2$)

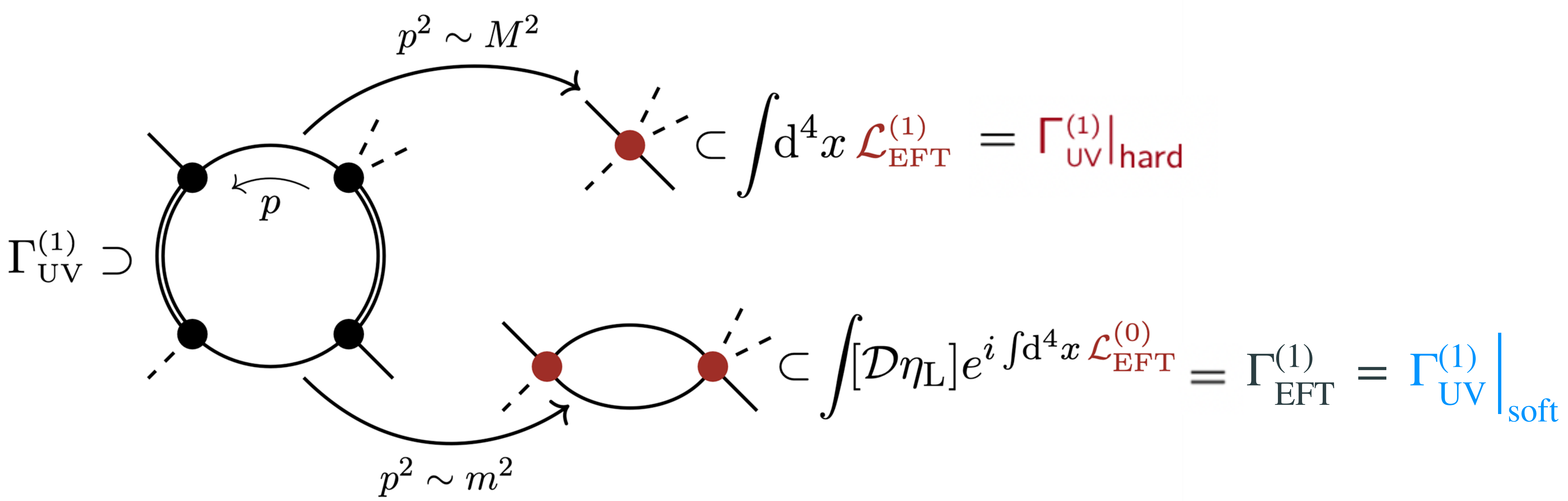
Method of regions: Beneke, Smirnov ’97, Jantzen ‘11

$$\Gamma^{(1)}_{\text{UV}} = \Gamma^{(1)}_{\text{UV}}\Big|_{\text{hard}} + \Gamma^{(1)}_{\text{UV}}\Big|_{\text{soft}}$$

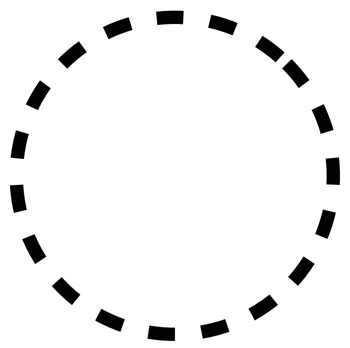


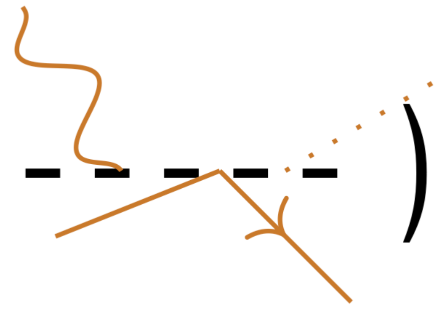
If only the <u>hard part of the loop</u> is considered we get the EFT Lagrangian *directly*

JFM, Portolés, Ruiz-Femenía, '16

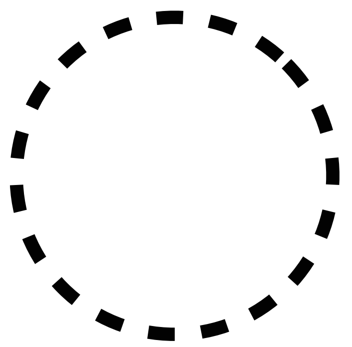


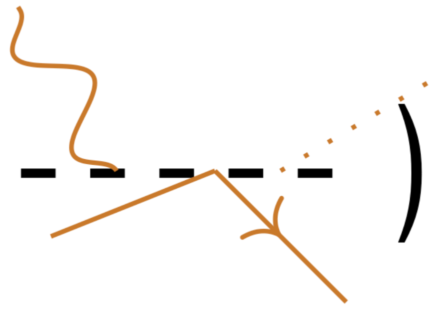
Evaluating supertraces

- **Supertraces:** $\int d^dx\, \mathscr{L}_{\mathrm{EFT}} = \Gamma^{(1)}_{\mathrm{UV}}\Big|_{\mathrm{hard}} = \frac{i}{2}\,\mathrm{STr}\ln Q\Big|_{\mathrm{hard}} = \pm\frac{i}{2}\ln$  $\Big|_{\mathrm{hard}}$

$Q\,[\hat{\eta}] = \Big($  $\Big)^{-1}$

Evaluating supertraces

- **Supertraces:** $\int d^dx\,\mathscr{L}_{\mathrm{EFT}} = \Gamma^{(1)}_{\mathrm{UV}}\Big|_{\mathrm{hard}} = \frac{i}{2}\,\mathrm{STr}\ln Q\Big|_{\mathrm{hard}} = \pm\frac{i}{2}\ln$  $\Big|_{\mathrm{hard}}$

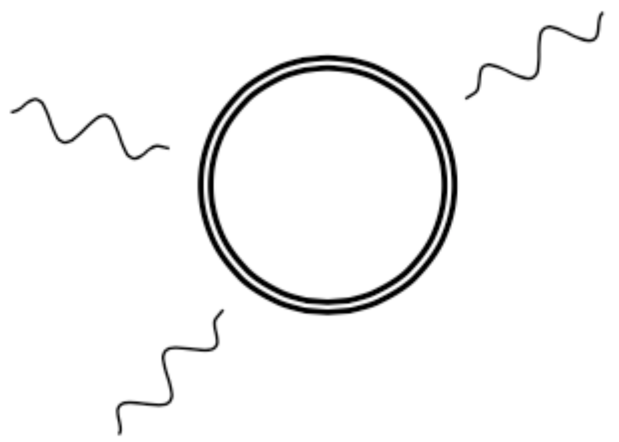
$Q\,[\hat{\eta}] = \Big($  $\Big)^{-1}$

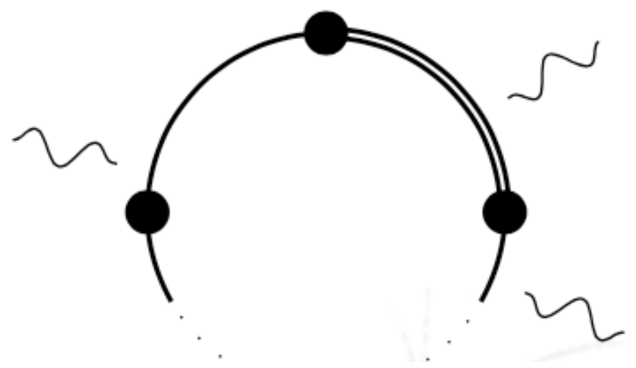
- **Fluctuation operator:** $Q_{ij} \equiv \frac{\delta^2\mathscr{L}_{\mathrm{UV}}}{\delta\eta_j\,\delta\bar{\eta}_i}\Big|_{\eta=\hat{\eta}} = \underbrace{\delta_{ij}\Delta_i^{-1}}_{\text{propagators}} - \overbrace{X_{ij}}^{\text{interaction terms}} = \Delta_i^{-1}(\delta_{ij} - \Delta_i X_{ij})$

$$\boxed{\Delta_i^{-1} = \begin{cases} -(D^2+M_i^2) \\ i\gamma^\mu D_\mu - M_i \\ g^{\mu\nu}(D^2+M_i^2) \end{cases}}$$

Expanding the logarithm and taking ΔX at most $\mathcal{O}(m_H^{-1})$

$$\int d^dx\,\mathscr{L}_{\mathrm{EFT}} = \Gamma^{(1)}_{\mathrm{UV}}\Big|_{\mathrm{hard}} = \frac{i}{2}\,\mathrm{STr}\,\ln\,\Delta^{-1}\Big|_{\mathrm{hard}} - \frac{i}{2}\sum_{n=1}^{\infty}\mathrm{STr}\left[(\Delta X)^n\right]\Big|_{\mathrm{hard}}$$





Covariant evaluation:

Chan '86; Cheyette '88; Gaillard '86

Going beyond one loop

$$C_{ijk}[\hat{\eta}] \equiv \left. \frac{\delta^3 \mathscr{L}_{\mathrm{UV}}}{\delta\eta_i\, \delta\eta_j\, \delta\eta_k} \right|_{\eta=\hat{\eta}}$$

$$\Gamma_{\mathrm{UV}}[\hat{\eta}] = S_{\mathrm{UV}}[\hat{\eta}] - i \ln \int \mathscr{D}\eta \exp\left[i\left(\frac{\eta^2}{2} Q[\hat{\eta}] + \frac{\eta^3}{3!} C[\hat{\eta}] + \frac{\eta^4}{4!} D[\hat{\eta}] + \ldots \right)\right]$$

$$D_{ijkl}[\hat{\eta}] \equiv \left. \frac{\delta^4 \mathscr{L}_{\mathrm{UV}}}{\delta\eta_i\, \delta\eta_j\, \delta\eta_k\, \delta\eta_l} \right|_{\eta=\hat{\eta}}$$

$$= S_{\mathrm{UV}}[\hat{\eta}] - i \ln \int \mathscr{D}\eta e^{\frac{i}{2}\left(Q[\hat{\eta}] + Q[\hat{\eta}]^{(1)}\right)\eta^2} \left[1 + \frac{i}{24}\eta^4 D[\hat{\eta}] - \frac{1}{72}\eta^6 C^2[\hat{\eta}] + \mathcal{O}(\hbar^3) \right]$$

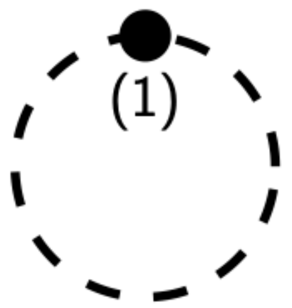
Going beyond one loop

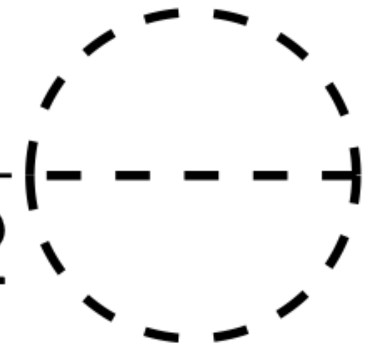
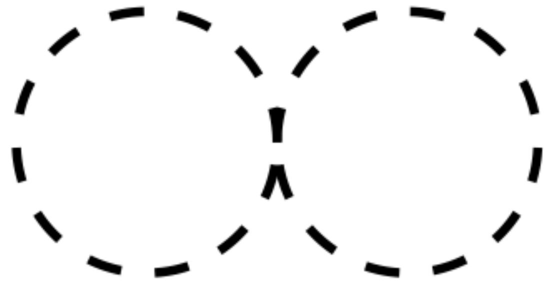
$$\Gamma_{\mathrm{UV}}[\hat{\eta}] = S_{\mathrm{UV}}[\hat{\eta}] - i \ln \int \mathscr{D}\eta \exp \left[i \left(\frac{\eta^2}{2} Q[\hat{\eta}] + \frac{\eta^3}{3!} C[\hat{\eta}] + \frac{\eta^4}{4!} D[\hat{\eta}] + \ldots \right) \right]$$

$$C_{ijk}[\hat{\eta}] \equiv \left. \frac{\delta^3 \mathscr{L}_{\mathrm{UV}}}{\delta\eta_i \, \delta\eta_j \, \delta\eta_k} \right|_{\eta=\hat{\eta}}$$

$$D_{ijkl}[\hat{\eta}] \equiv \left. \frac{\delta^4 \mathscr{L}_{\mathrm{UV}}}{\delta\eta_i \, \delta\eta_j \, \delta\eta_k \, \delta\eta_l} \right|_{\eta=\hat{\eta}}$$

$$= S_{\mathrm{UV}}[\hat{\eta}] + \frac{1}{2} \mathrm{STr} \ln Q + \frac{i\hbar^2}{2} Q^{-1}_{ij} Q^{(1)}_{ij} - \frac{\hbar^2}{8} Q^{-1}_{ij} \, D_{ijkl} \, Q^{-1}_{kl} + \frac{\hbar^2}{12} C_{ijk} \, Q^{-1}_{il} Q^{-1}_{jm} Q^{-1}_{kn} \, C_{lmn} + \mathcal{O}(\hbar^3)$$

$= S_{\mathrm{UV}}[\hat{\eta}] + \frac{i}{2} \log$  $+ \frac{i}{2}$ 

$+ \frac{1}{12}$  $- \frac{1}{8}$  $+ \mathcal{O}(\hbar^3)$

General EFT matching formula

The EFT action is given by

$$S_{\rm EFT}[\phi] = \Gamma_{\rm UV}[\hat{\Phi}, \phi]\Big|_{\rm hard} \qquad\qquad \frac{\delta \Gamma_{\rm UV}\big|_{\rm hard}}{\delta \Phi}[\hat{\Phi}, \phi] = 0$$

Φ : Heavy

ϕ : Light

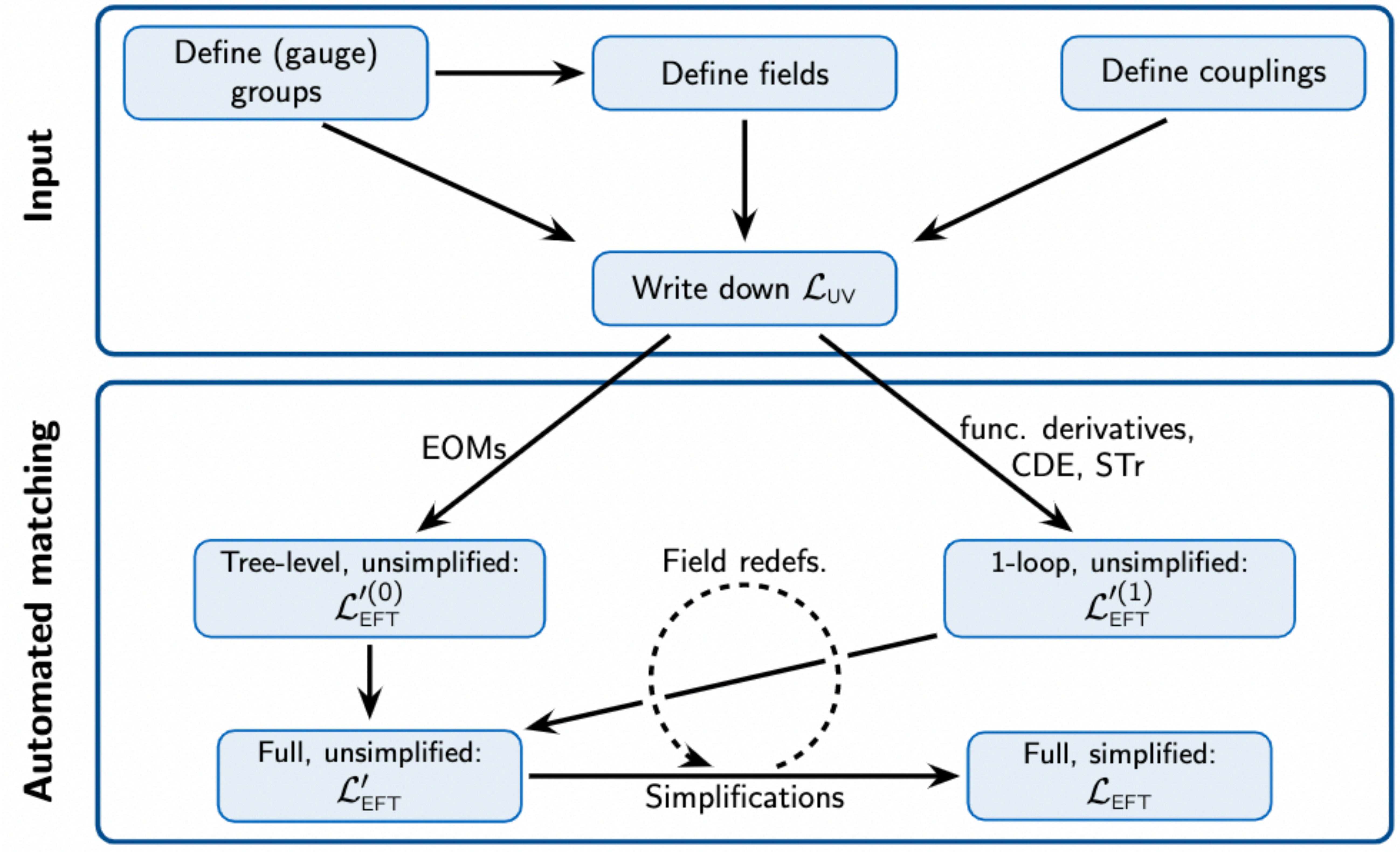
"hard" denotes the part where all loop momenta are $p \sim \Lambda$ (incl. tree-level contributions) $^{(*)}$

- Already used at one loop order [JFM, Portolés, Ruiz-Femenía, 1607.02142; Z. Zhang 1610.00710]
- Explicit proof to two-loop order [JFM, Thomsen, Palavic, w.i.p]
- The hard region is by far the easiest to compute (only vacuum diagrams at zero external momenta)
- Enables functional matching at any loop order

$^{(*)}$ Method of regions: Beneke, Smirnov, '97; Jantzen, '11

The Matchete package

MATCHETE is a Mathematica package aimed at fully automating EFT matching and RG evolution of arbitrary weakly-coupled UV theories using functional methods



[JFM, König, Pagès, Thomsen, Wilsch, 2212.04510]

Proof-of-concept version (Matchete v0.1) now publicly available:

- One-loop matching of *any* model with heavy scalars and/or fermions
- Simple and intuitive input/output
- Handles *all* group theory (any group and reps)
- Partial simplifications of the resulting EFT Lagrangian (IBP, field redefinitions,…)
- SSB and heavy vectors not yet supported
  [w.i.p with Olgoso, Santiago, Thomsen]
- Computation of the RGE not yet available

Two BSM matching examples

SM extension with a scalar SM-singlet

$$\mathscr{L}_{\mathrm{UV}} = \mathscr{L}_{\mathrm{SM}} + \frac{1}{2}(\partial_\mu S)^2 - \frac{1}{2}M^2 S^2 - \frac{\mu_S}{3!} S^3 - \frac{\lambda_S}{4!} S^4 - \frac{\lambda_{SH}}{2}(H^\dagger H) S^2 - \kappa (H^\dagger H) S \qquad \text{with } M, \kappa, \mu_S \gg v_{\mathrm{EW}}$$

Less than half a minute to compute the one-loop matching
(which was correctly determined only after several literature iterations)

[Henning, Lu, Murayama 1412.1837;
Ellis, Quevillon, You, Zhang 1706.07765;
Jiang, Craig, Li, Sutherland 1811.08878;
Haisch, Ruhdorfer, Salvioni, Venturini, Weiler 2003.05936]

SM extension with a vector-like lepton ($E \sim (\mathbf{1}, \mathbf{1})_{-1}$)

$$\mathscr{L}_{\mathrm{UV}} = \mathscr{L}_{\mathrm{SM}} + i(\bar{E}\gamma_\mu D^\mu E) - m_E \bar{E} E - \left(y_E \ell_L H E_R + \mathrm{h.c.}\right) \qquad \text{with } M_E \gg v_{\mathrm{EW}}$$

Less than a minute to compute the one-loop matching and simplify the result
(result validated against **matchmakereft**)

Reducing the EFT Lagrangian to its basis

$$\mathscr{L} = \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4 + \frac{C_1}{\Lambda^2}\phi^6 + \frac{C_2}{\Lambda^2}\phi^3\partial^2\phi + \frac{C_3}{\Lambda^2}\phi^2(\partial_\mu\phi)^2$$

Exact simplifications (linear): IBP, Dirac and group identities, commutation relations…

$$\mathscr{L} = \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4 + \frac{C_1}{\Lambda^2}\phi^6 + \frac{3C_2 - C_3}{3\Lambda^2}\phi^3\partial^2\phi$$

On-shell equivalence (non-linear): Field redefinitions (sometimes equivalent to using of EOMs)

$$\phi \to \phi + \frac{3\,C_2 - C_3}{3\,\Lambda^2}\phi^3 \qquad \left[\partial^2\phi = -\,m^2\phi - \frac{\lambda}{3!}\phi^3 + \mathcal{O}(\Lambda^{-2})\right]$$

$$\mathscr{L} \to \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m^2\phi^2 - \left(\frac{\lambda}{4!} + \frac{m^2(3C_2 - C_3)}{3\,\Lambda^2}\right)\phi^4 + \frac{18\,C_1 - \lambda\,(3C_2 - C_3)}{18\,\Lambda^2}\phi^6$$

Removal of evanescent operators: Solved for SMEFT [JFM, König, Pagès, Thomsen, Wilsch, 2211.09144]

Evanescent operators

In $d = 4$, we can use the Fierz identity $R_{\ell e} = -\frac{1}{2} Q_{\ell e}$

$$\mathscr{L}_{\mathrm{EFT}} \supset C_{\ell e}^{prst} R_{\ell e}^{prst} \qquad R_{\ell e}^{prst} = (\bar{\ell}_p e_r)(\bar{e}_s \ell_t)$$

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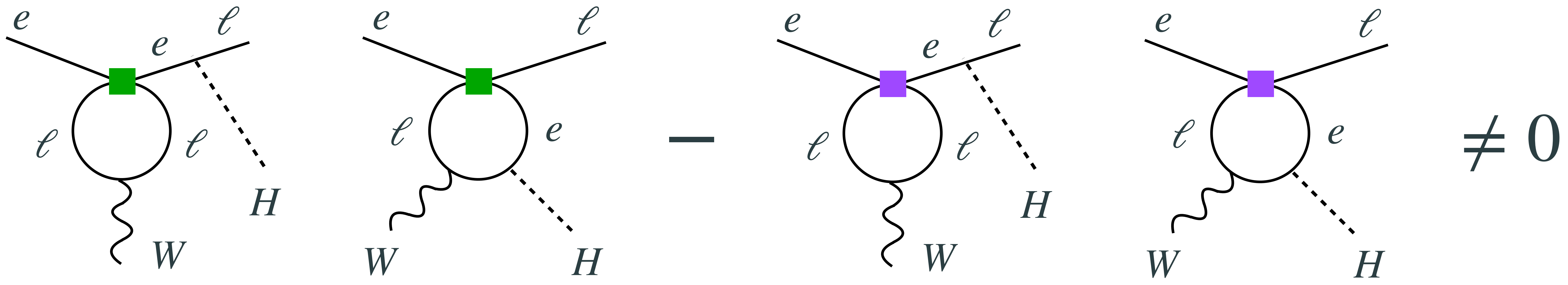
so that $\mathscr{L}_{\mathrm{EFT}} = \mathscr{L}'_{\mathrm{EFT}}$ at tree level. However,



Evanescent operators

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$$\mathscr{L}_{\mathrm{EFT}} \supset C^{prst}_{\ell e}\, R^{prst}_{\ell e} \qquad\qquad R^{prst}_{\ell e} = (\bar{\ell}_p\, e_r)(\bar{e}_s\, \ell_t)$$

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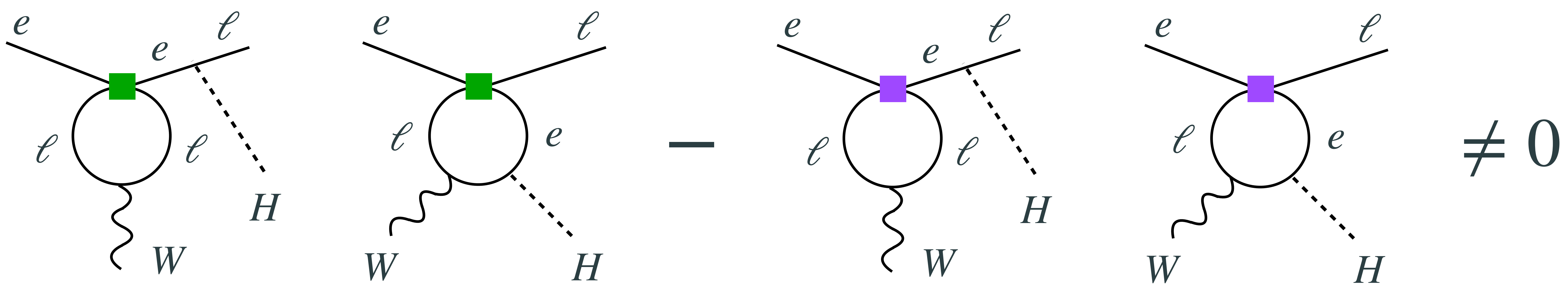


In $d = 4 - 2\epsilon$, there is an evanescent operator that also contributes to the amplitude

$$R^{prst}_{\ell e} = -\frac{1}{2}\, Q^{prst}_{\ell e} + E^{prst}_{\ell e} \qquad E^{prst}_{\ell e} \xrightarrow{\epsilon \to 0} 0 \qquad E^{prst}_{\ell e} \to -\frac{g_L\, y^{ts}_e}{128\pi^2}\, Q^{pr}_{eW} + \text{[many other contributions]}$$

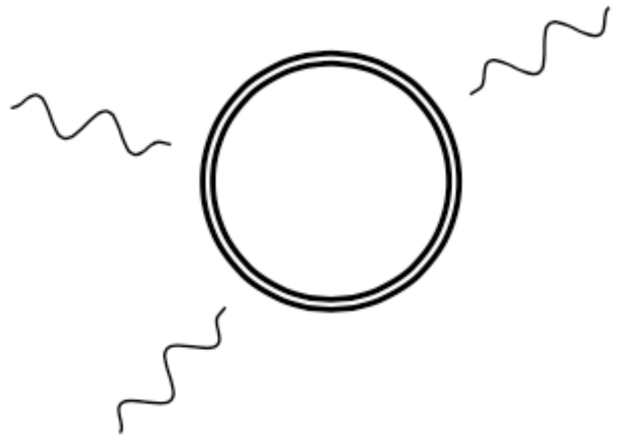
Linear simplifications

Example: Integrating out a heavy fermion in the fundamental representation of SU(3)

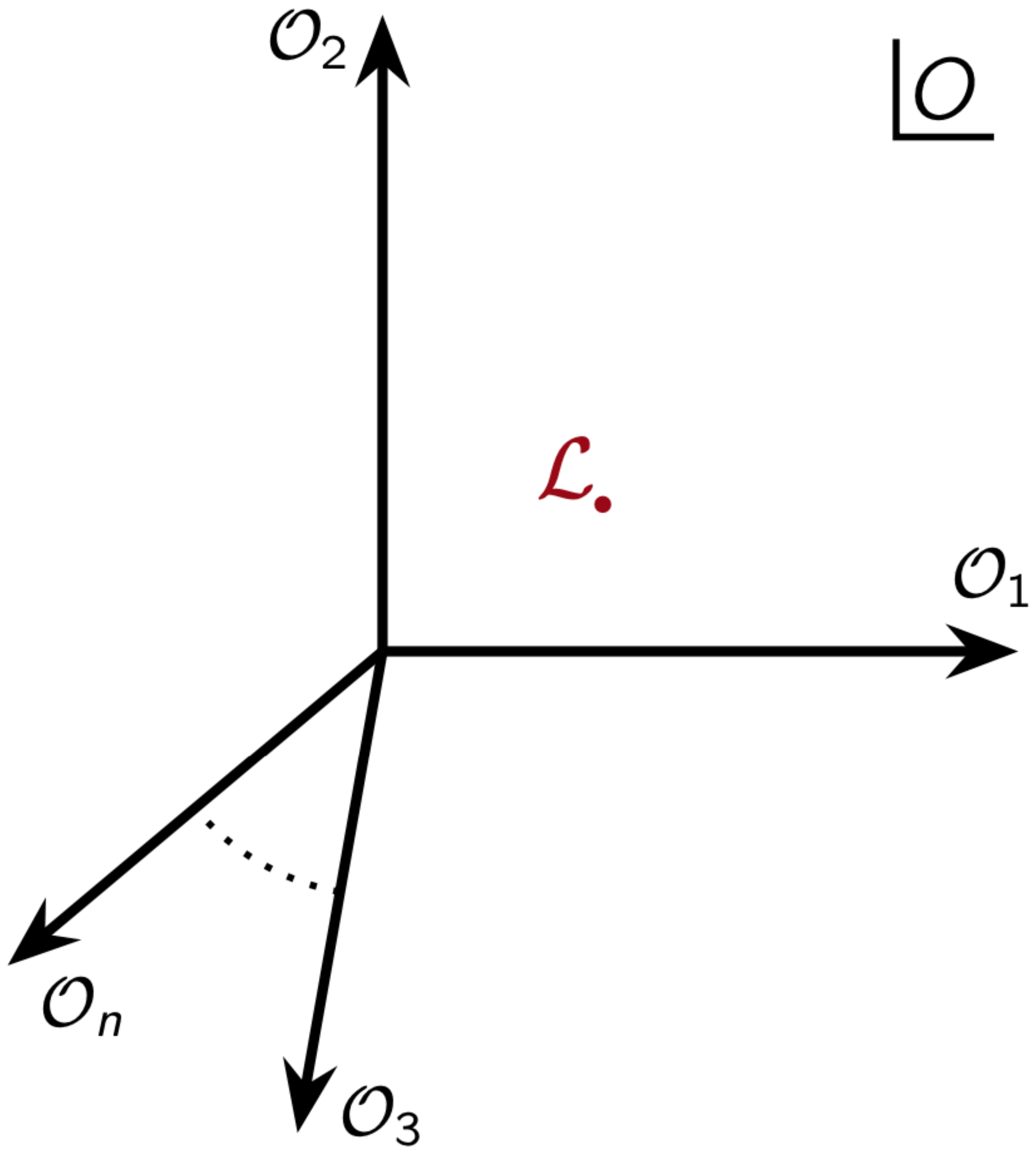
```
In[12]:= LEFT // NiceForm
Out[12]//NiceForm=
```

$$\frac{7}{540}\hbar g^2 \frac{1}{M\Psi^2}\left(D_\rho G^{\mu\nu A}\right)^2 + \frac{1}{40}\hbar g^2 \frac{1}{M\Psi^2} G^{\mu\nu A} D^2 G^{\mu\nu A} + \frac{7}{540}\hbar g^2 \frac{1}{M\Psi^2} D_\rho G^{\mu\nu A} D_\nu G^{\mu\rho A} - \frac{1}{180}\hbar g^2 \frac{1}{M\Psi^2} D_\nu G^{\mu\nu A} D_\rho G^{\mu\rho A} + \frac{1}{40}\hbar g^2 \frac{1}{M\Psi^2} G^{\mu\nu A} D_\nu D_\rho G^{\mu\rho A} + \frac{1}{40}\hbar g^2 \frac{1}{M\Psi^2} G^{\mu\nu A} D_\rho D_\nu G^{\mu\rho A} - \frac{1}{24}\hbar g^3 \frac{1}{M\Psi^2} G^{\mu\nu A} G^{\mu\rho B} G^{\nu\rho C} f^{ABC}$$

$$\mathscr{L}_{\mathrm{EFT}} = \sum_i C_i \mathscr{O}_i \in O$$



(log supertrace)



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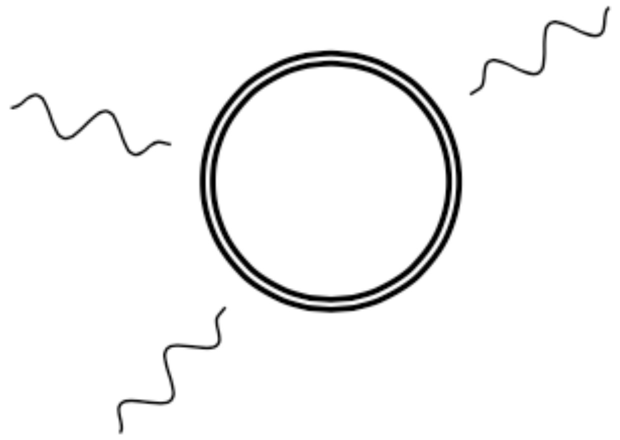
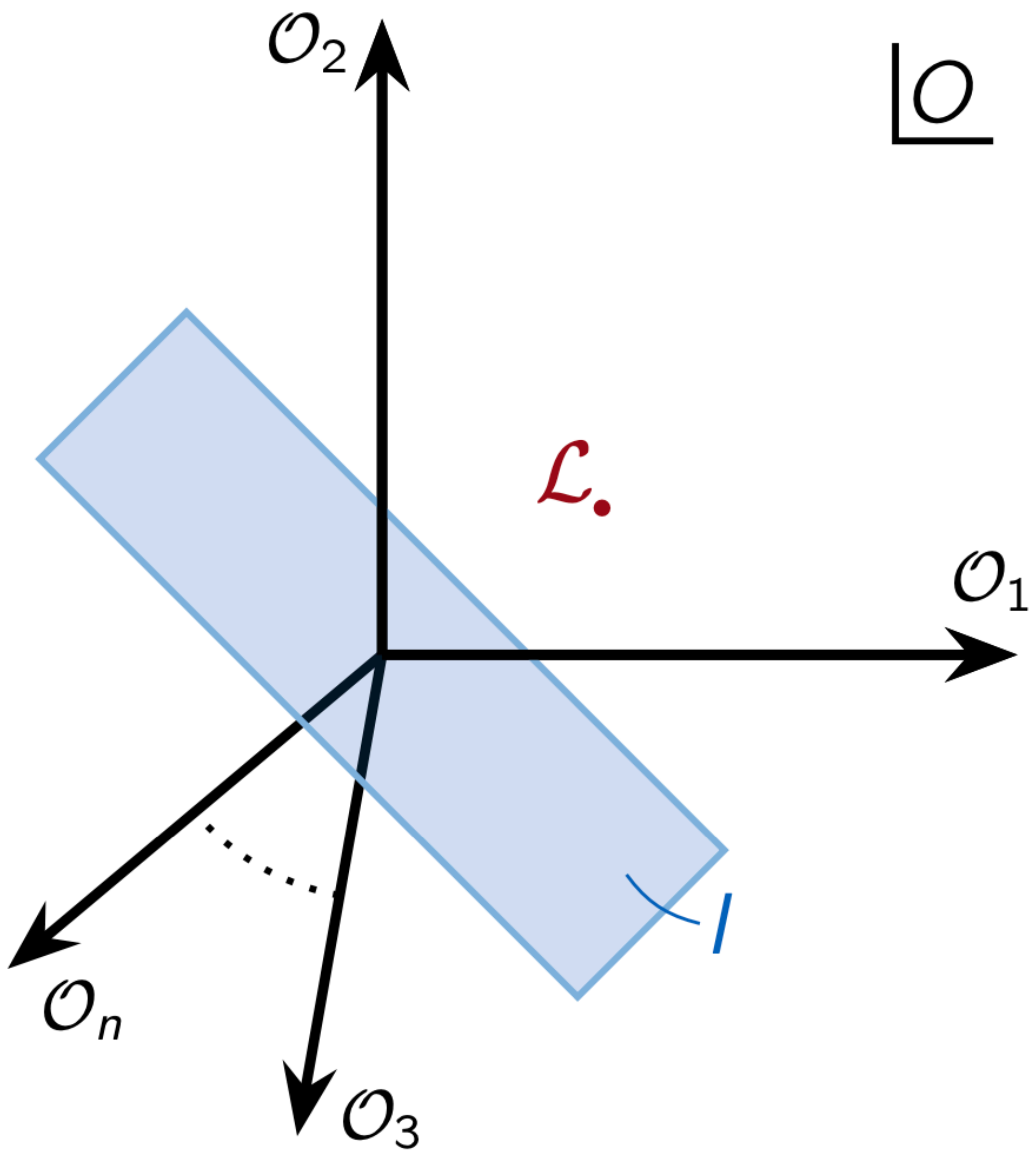


(log supertrace)



$I \subseteq O$ is the space of all operators identities, such as IBP relations, yielding e.g.

$$\mathscr{O}_1 + 2\,\mathscr{O}_3 = 0$$

interpreted as

$$\mathscr{O}_1 + 2\,\mathscr{O}_3 \in I$$

Linear simplifications

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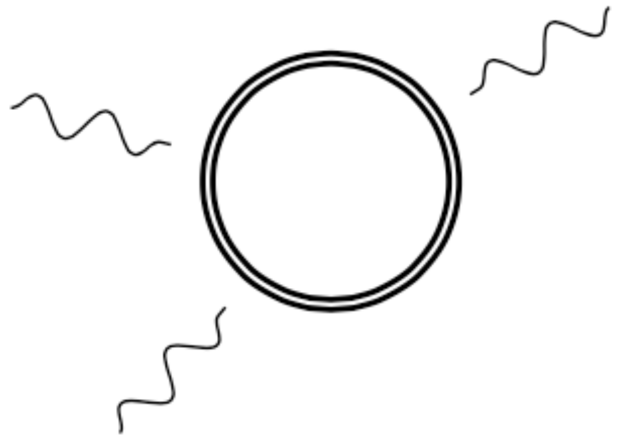


(log supertrace)

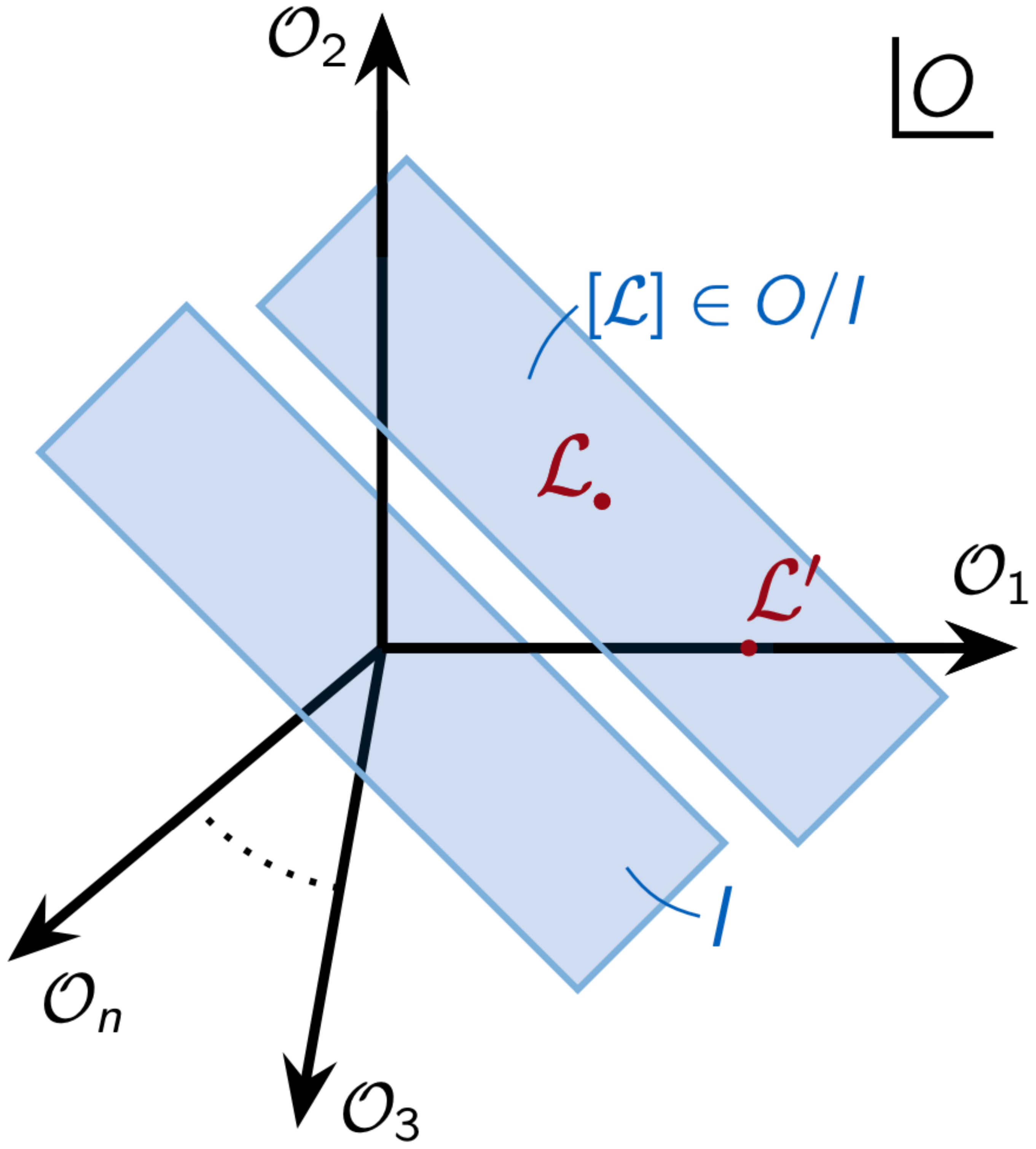
$$\mathscr{L}_{\rm EFT} = \sum_i C_i \mathcal{O}_i \in O$$

By gaussian elimination, we can *choose* a representative element for $[\mathscr{L}_{\rm EFT}] \in O/I$ to get an EFT basis

In[13]:= `LEFT // GreensSimplify // NiceForm`

Out[13]//NiceForm=

$$-\frac{1}{15}\hbar g^2 \frac{1}{M\Psi^2} D_\nu G^{\mu\nu A} D_\rho G^{\mu\rho A} - \frac{1}{180}\hbar g^3 \frac{1}{M\Psi^2} G^{\mu\nu A} G^{\mu\rho B} G^{\nu\rho C} f^{ABC}$$



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Linear simplifications with evanescent operators

Evanescent operators appear from a special type of linear simplification (valid only for $d = 4$)

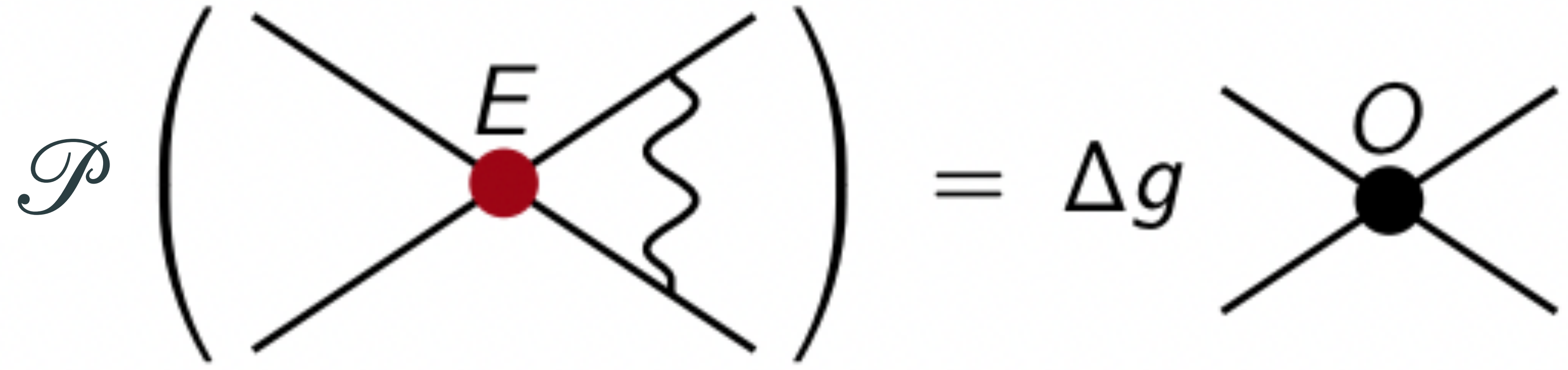
$$O_d = \underbrace{\mathscr{P}\, O_d}_{\text{Physical part}} + \underbrace{\overset{Id - \mathscr{P}}{\mathscr{E}}\, O_d}_{\text{Evanescent part}}$$

$\mathscr{P} \equiv$ Projection to the physical ($d = 4$) basis

E.g. Fierz identities

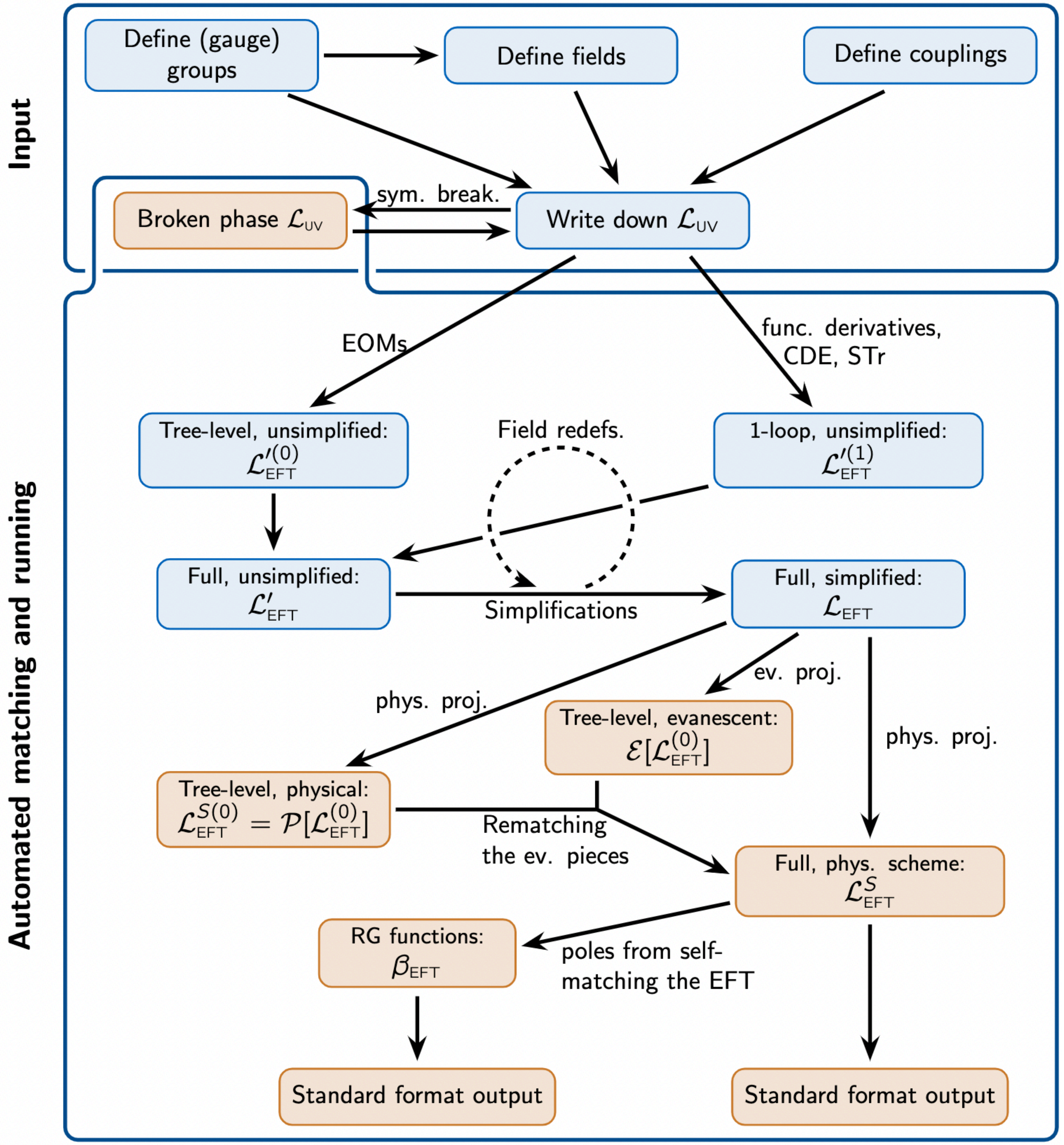
$$(\bar{\ell}_p e_r)(\bar{e}_s \ell_t) = -\frac{1}{2}(\bar{\ell}_p \gamma_\mu \ell_t)(\bar{e}_s \gamma^\mu e_r) + \overset{\text{rank}\,(d-4)}{E_{\ell e}^{prst}} \longrightarrow (\bar{\ell}_p e_r)(\bar{e}_s \ell_t) + \frac{1}{2}(\bar{\ell}_p \gamma_\mu \ell_t)(\bar{e}_s \gamma^\mu e_r) - E_{\ell e}^{prst} \in I$$

Representative elements are chosen so evanescent operators are retained. Afterwards, these are removed by shifting the coefficients of physical operators



e.g. $E_{\ell e}^{prst} \to -\dfrac{g_L\, y_e^{ts}}{128\pi^2}\, Q_{eW}^{pr} +$ [other contributions]

Future plans



MATCHETE

Proof of concept already available at:
https://gitlab.com/matchete/matchete

Expected future functionalities include:

- Handling of evanescent contributions
- Complete basis reduction and identification
- One-loop RG computations
- Heavy vectors and symmetry breaking
- Interface with other EFT tools (UFO / WCxf outputs)
- Matching and running beyond one loop
- Other γ_5 and regularization/renormalization schemes

Conclusions

- (Automated) EFT matching is crucial to BSM phenomenology
- Functional matching is ideal for automation (also useful for pen-and-paper computations!)
- Complete one-loop automation: Lagrangian in, fully simplified EFT Lagrangian out not yet available
    - Ongoing progress with MATCHETE
- The ultimate goal is a code (or chain of codes) that fully automates
    - Matching
    - RG evolution
    - Connection to observables / fit to data

  Multi-step matching (Matching, RG evolution)

  Interface with other EFT pheno codes (Connection to observables / fit to data)

  streamlining future BSM analyses

Thank you

Matching models is about to become easy!