High Energy Theory

Junta de Andalucía

Universidad de Granada

LHC EFT Working Group activities

Javier Fuentes-Martín
University of Granada

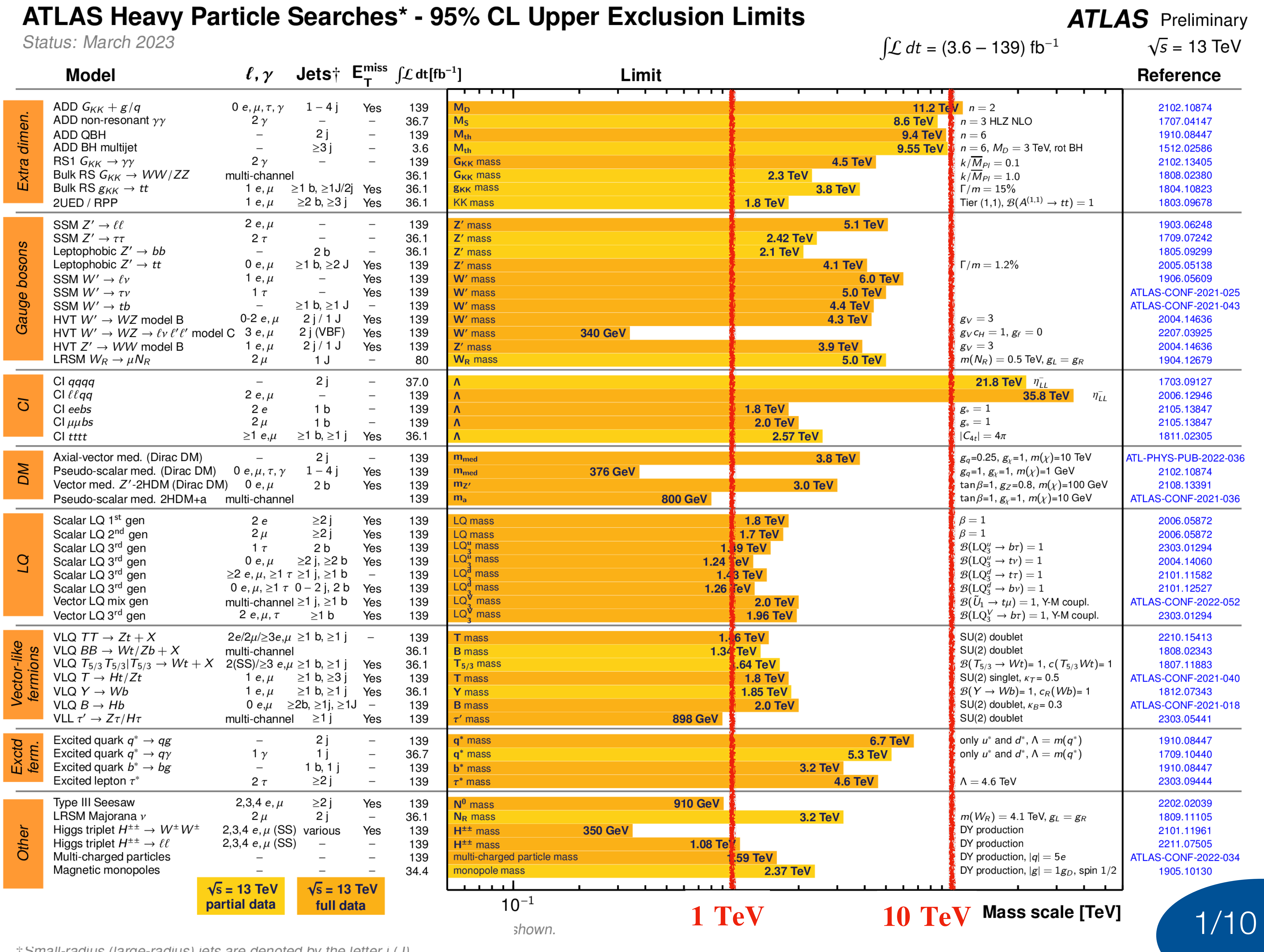
8th Red LHC Workshop, Madrid, 28-30 May 2024

What is experiment telling us?

No **direct evidence for NP** despite the many reasons for it [**presence of a mass gap?**]

↓

Indirect new physics searches?



Why Effective Field Theories (EFTs)?

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 (Renormalization Group (RG) resummation of large logs)

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

The LHC Effective Field Theory Working Group

The LHC EFT WG gathers members of the LHC experiments and the theory community to provide a framework for the interpretation of LHC data in the context of EFTs

- **Recommendations for the use of EFT by the experiments**
  (theory setup, Monte Carlo simulations, tools for EFT analyses…)

- **Forum for theoretical discussions of EFT issues**
  (theoretical constraints, higher-order corrections, BSM interpretations…)

- **Discussions on common uncertainties and combination procedures used by the experiments**
  (recommendations, developments, combinations that require coordination with other WGs…)

More info at https://lpcc.web.cern.ch/lhc-eft-wg

LHC EFT WG Conveners

The steering group of the LHC EFT WG consists of 10 experimental and 7 theory conveners:

ATLAS:

- Sarah Heim (Higgs WG contact)
- Jacob Kempster (Top WG contact)
- Karolos Potamianos (EW WG contact)
- Sandra Kortner

CMS:

- Matteo Presilla (EW WG contact)
- Robert Schoefbeck (Top WG contact)
- Nick Smith (Higgs WG contact)
- Nicholas Wardle

LHCb:

- Greg Ciezarek
- Christoph Langenbruch

Theory:

- Ilaria Brivio
- Anke Biekoetter (Higgs WG contact)
- Shankha Banerjee (EW WG contact)
- Javier Fuentes
- Ken Mimasu (Top WG contact)
- Dave Sutherland
- Peter Stangl

You can reach us at: lhc-eftwg-admin@cern.ch

LHC EFT WG Main Areas

The activities of the group are divided into 6 areas:

Theory ↕ **Experiment**

- **Area 5:** Benchmark scenarios from UV Models
- **Area 1:** EFT Formalism

Model definitions

- **Area 2:** Predictions and Tools

Model predictions

- **Area 4:** Fits and Related Systematics

Global fits

- **Area 3:** Experimental Measurements and Observables
- **Area 6:** Flavour

Measurements & observables

LHC EFT WG Activities

- Area-specific and general open meetings [https://indico.cern.ch/category/12671/]

December 2024

01 Dec - 04 Dec 8th General Meeting of the LHC EFT Working Group

Save the date. Next general meeting!

May 2024

13 May LHC EFT WG meeting

April 2024

23 Apr - 24 Apr 7th General Meeting of the LHC EFT Working Group

March 2024

18 Mar LHC EFT WG meeting: Field Redefinitions

February 2024

19 Feb LHC EFT WG meeting: tops in SMEFT

LHC EFT WG Activities

- LHC EFT WG documents [Follow this link]

  - Electroweak input parameters [Area 1]

  - Truncation, validity, uncertainties [Area 1]

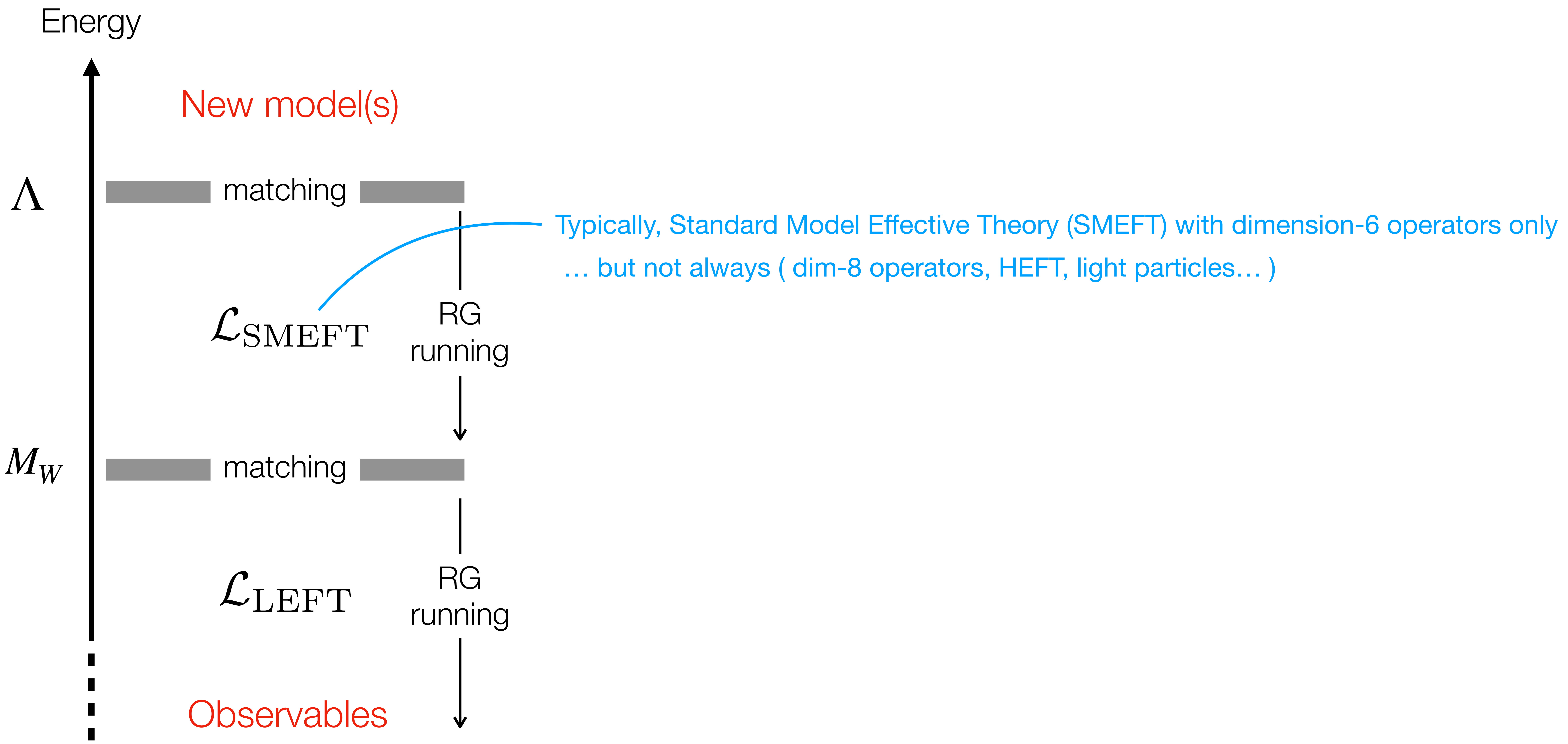
  - Experimental Measurements and Observables [Area 3]

  - Precision matching of microscopic physics to the SMEFT [Area 5]

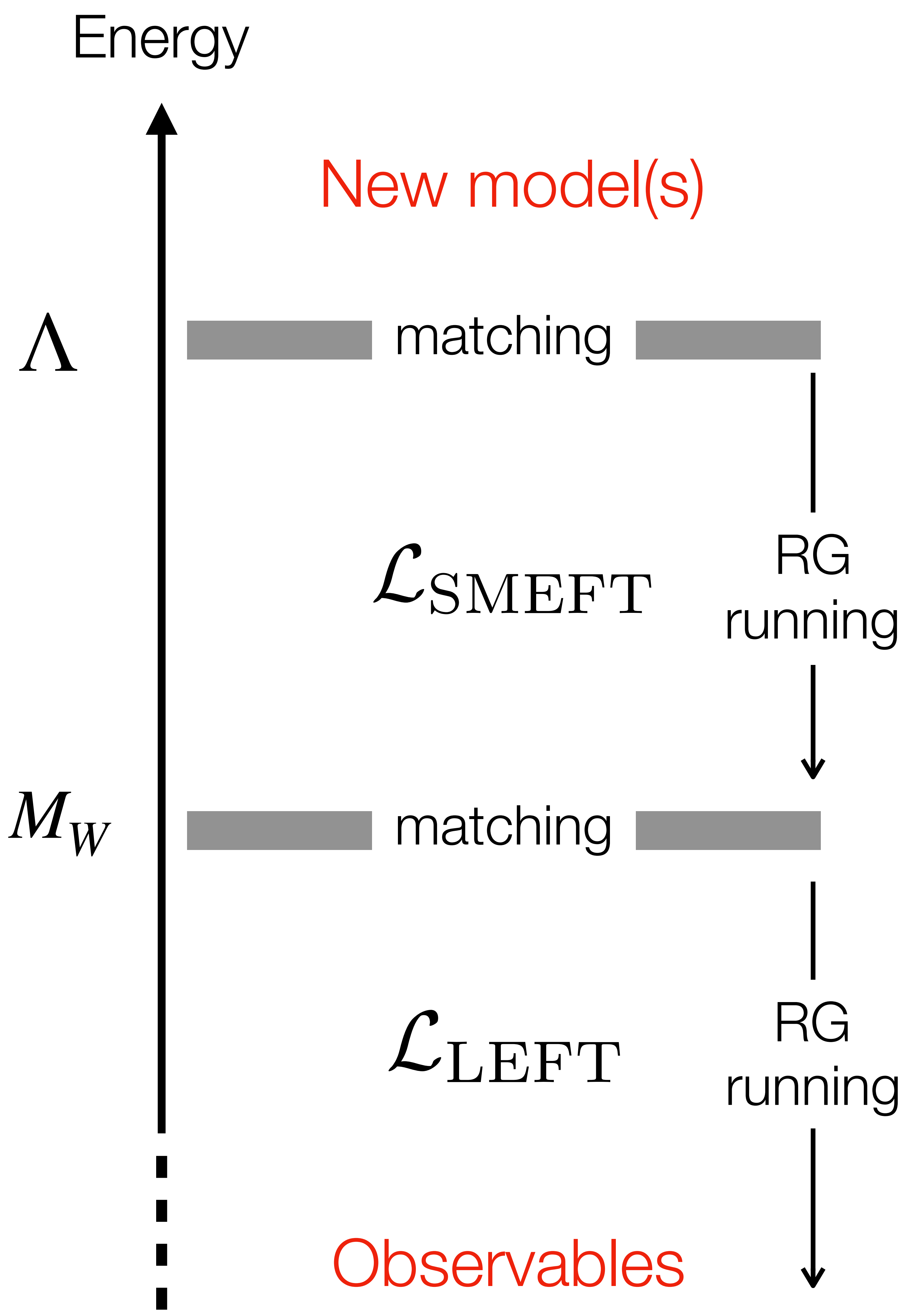
  - SMEFT predictions, event reweighting, and simulation (draft) [Area 2]

- Other early-stage activities (e.g. internal discussions on the creation of a model matching database)

The EFT approach



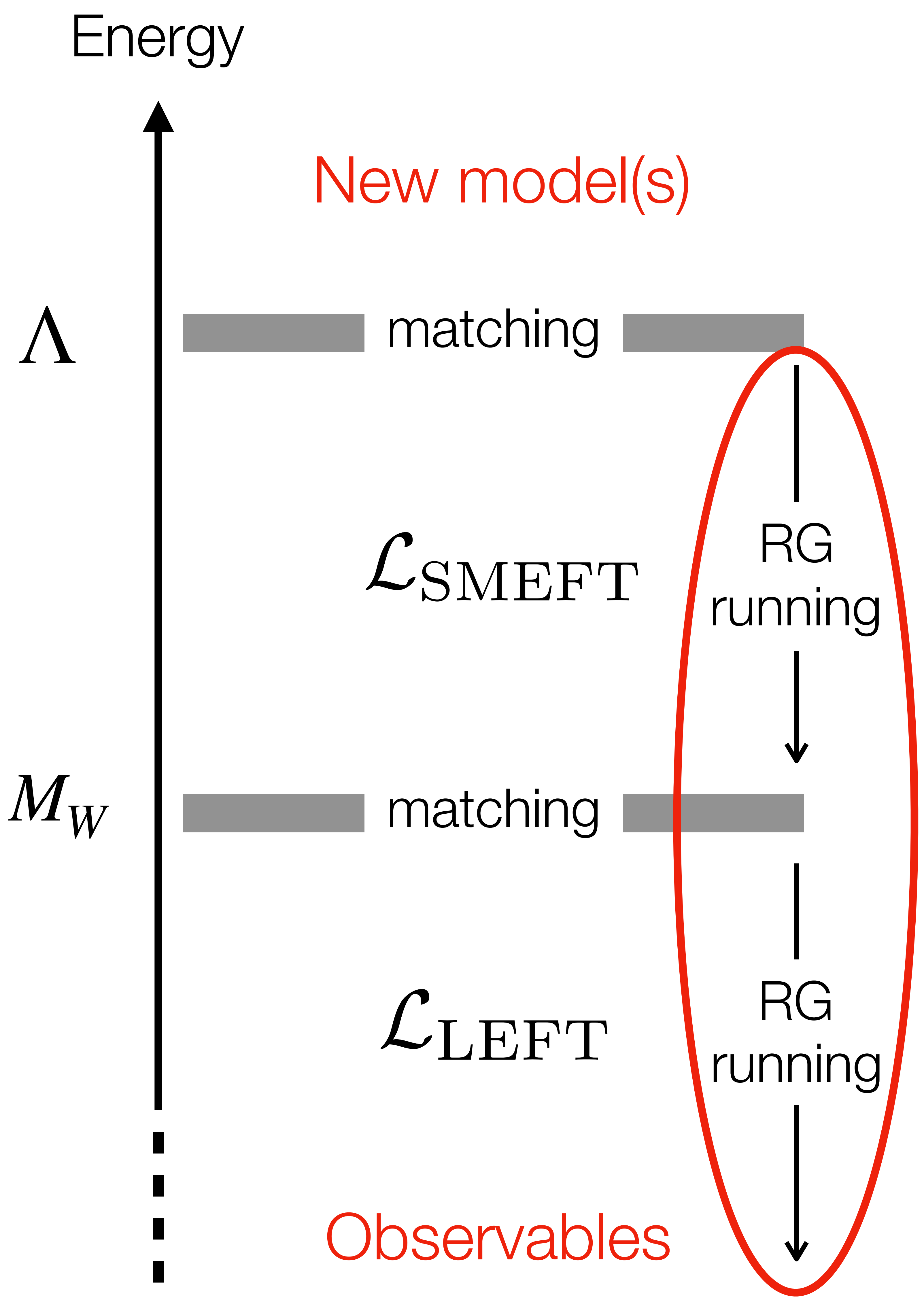
The rise of automation



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:

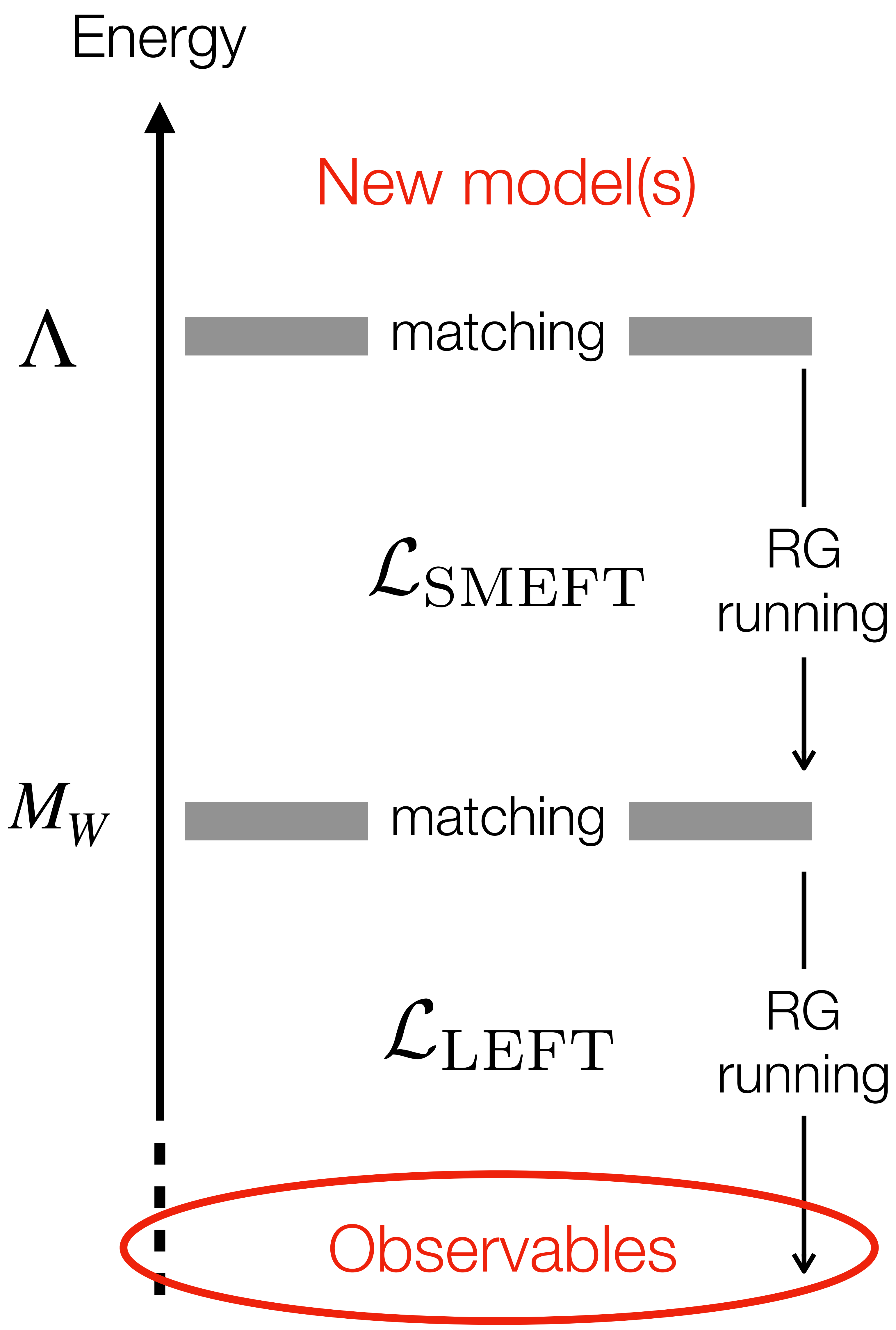
SMEFT running: Jenkins et al. '13, '14; Alonso et al. '14

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

HighPT

Allwicher et al. '22

HEPfit

De Blas et al. '19

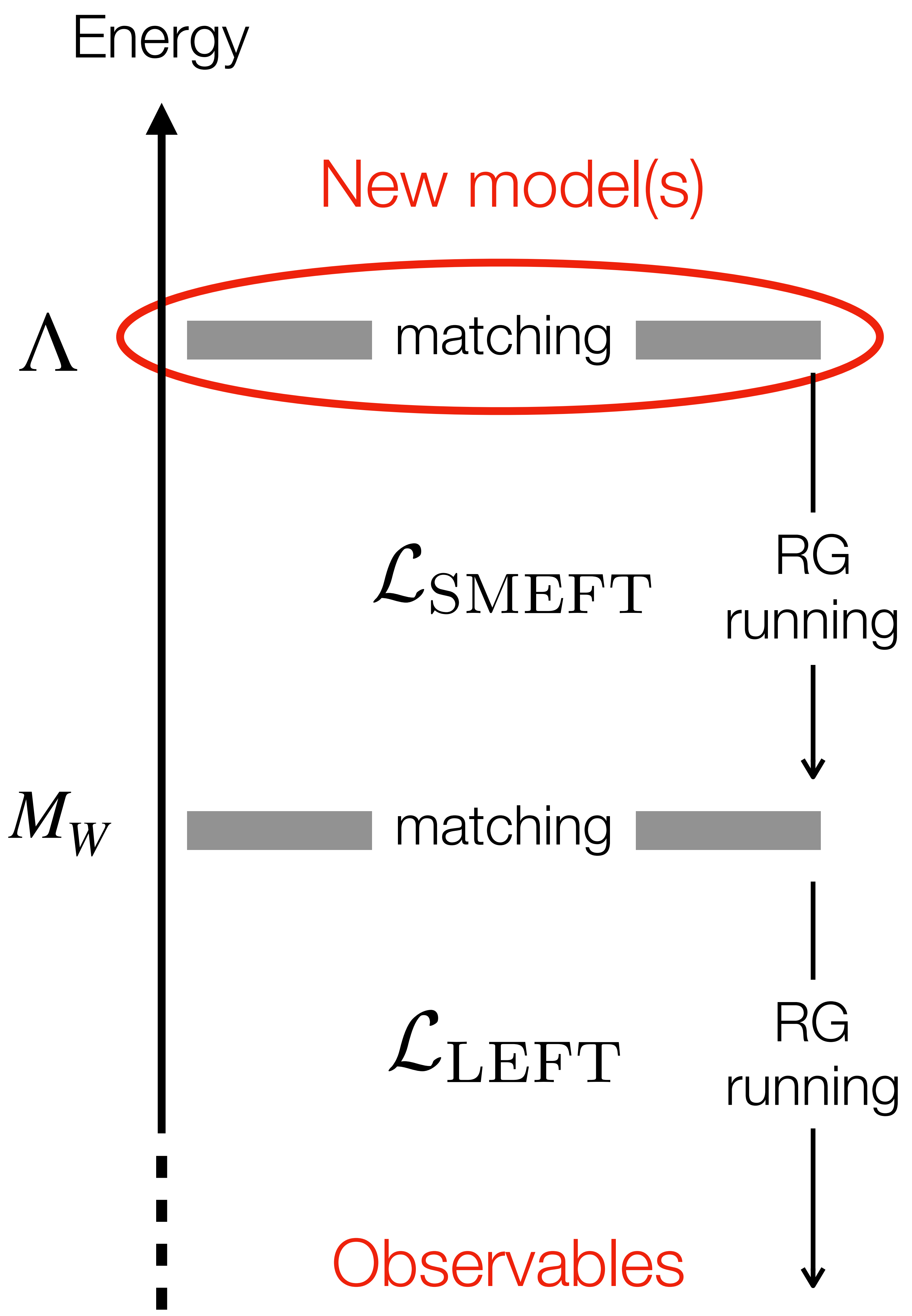
SMEFiT

Giani et al. '23

+ others

Involvement of experimental collaborations into this program is crucial

The rise of automation



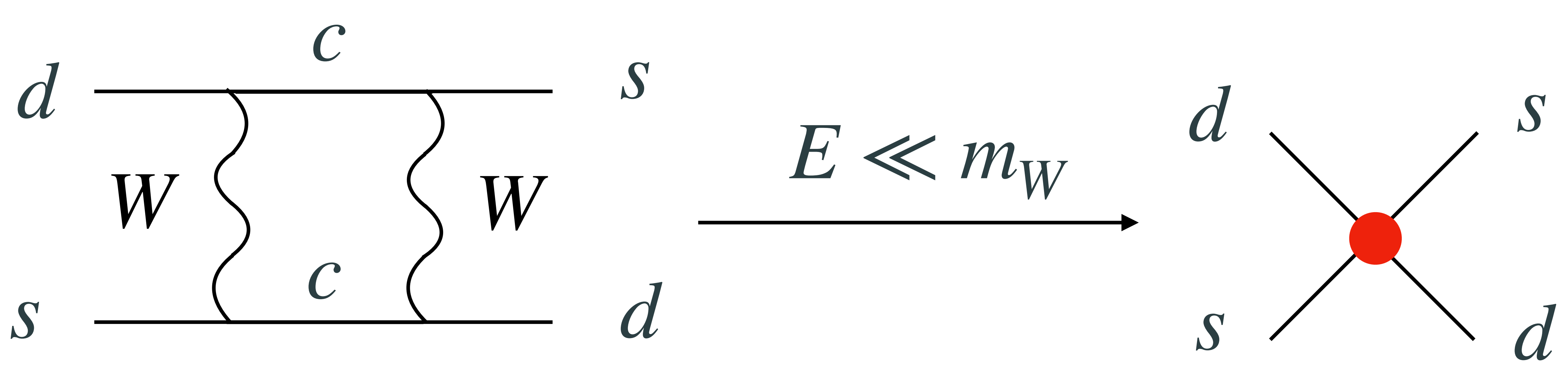
Much progress has been made:

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

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

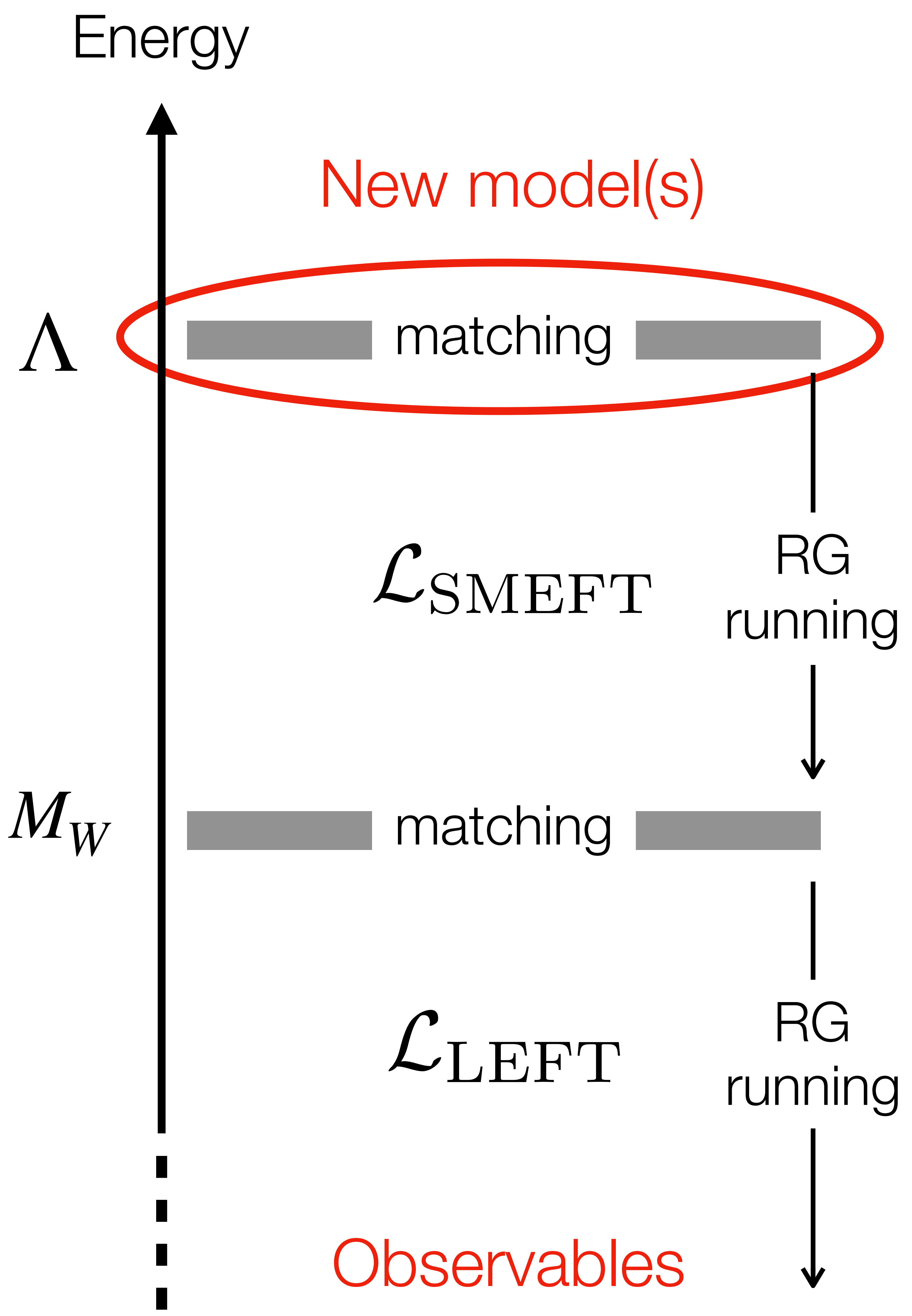
  MatchingTools: [Criado '17]

- 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. ‘21

[2112.10787]

(See backup)

JFM et al. ‘22

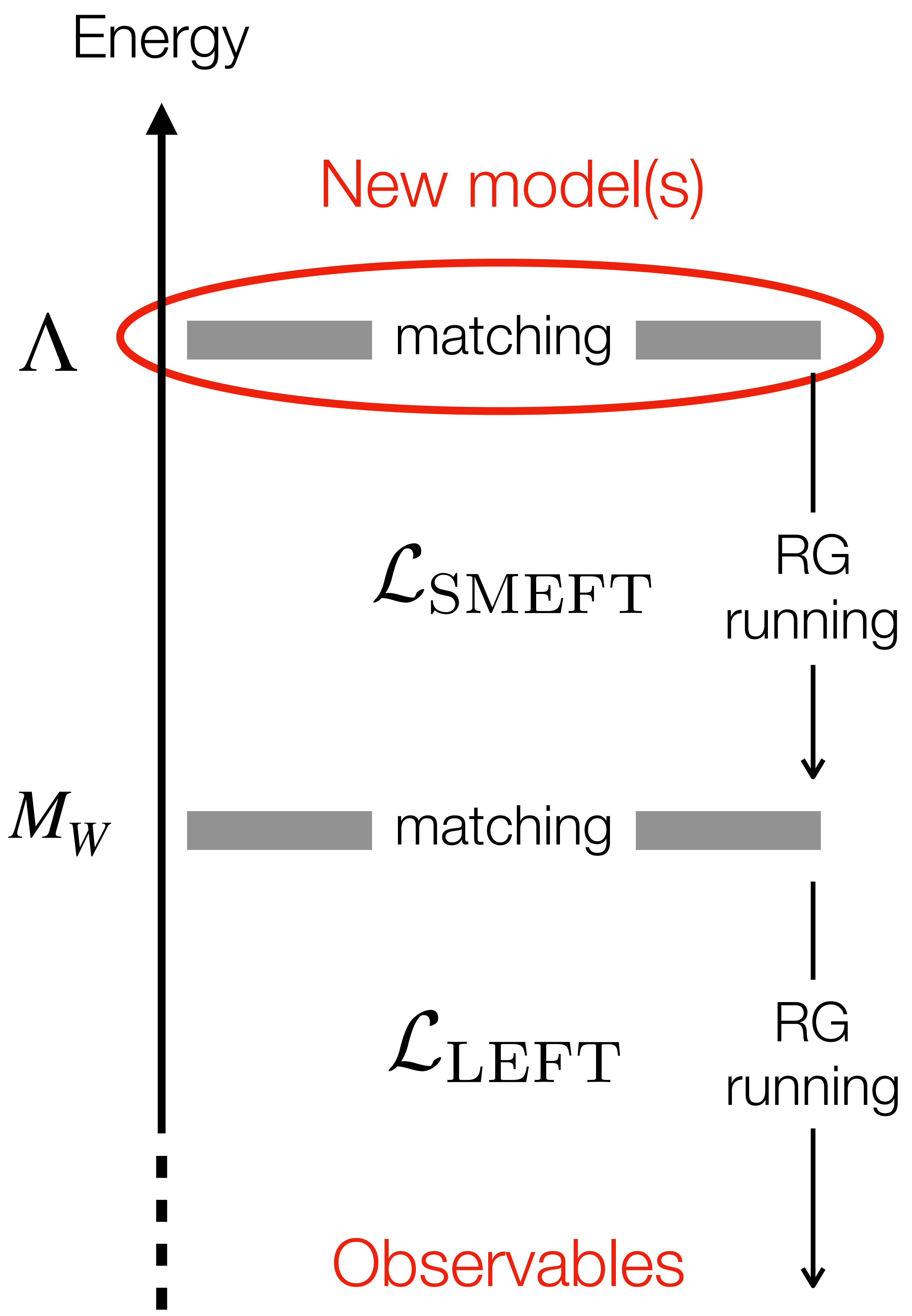
[2212.04510]

Automated one-loop matching of *many* models

(no heavy vectors for now!)

Completely different approaches: amplitude vs functional matching

The rise of automation



matchmakereft

Carmona et al. ‘21

[2112.10787]

MATCHETE

(**See backup**)

JFM et al. ‘22

[2212.04510]

Automated one-loop matching of *many* models

(no heavy vectors for now!)

Completely different approaches: amplitude vs functional matching

Current discussions in LHC EFT WG Area 5:

- A matching database could be useful for further validation and benchmarking (also as a SMEFT-UV dictionary)
  - Need to establish common conventions and data formats
- Interfaces with SMEFT phenomenology tools
  - Need to be aware of limitations of the matching results

Summary and conclusions

- Given the current experimental landscape, EFTs are taking a more prominent role in BSM searches
- The LHC EFT WG is active and welcomes participation from both theorist and experimentalist
- You can follow all recent activities at the WG Indico page or by subscribing to the general WG mailing list
- Huge progress towards complete (one-loop) automation of EFT matching
- The ultimate goal is a tool (or chain of tools) that fully automates
  - Matching
  - RG evolution

  } **Multi-step matching**
  - Connection to observables / fit to data **Interface with EFT pheno codes and experimental fits**

  streamlining future BSM analyses

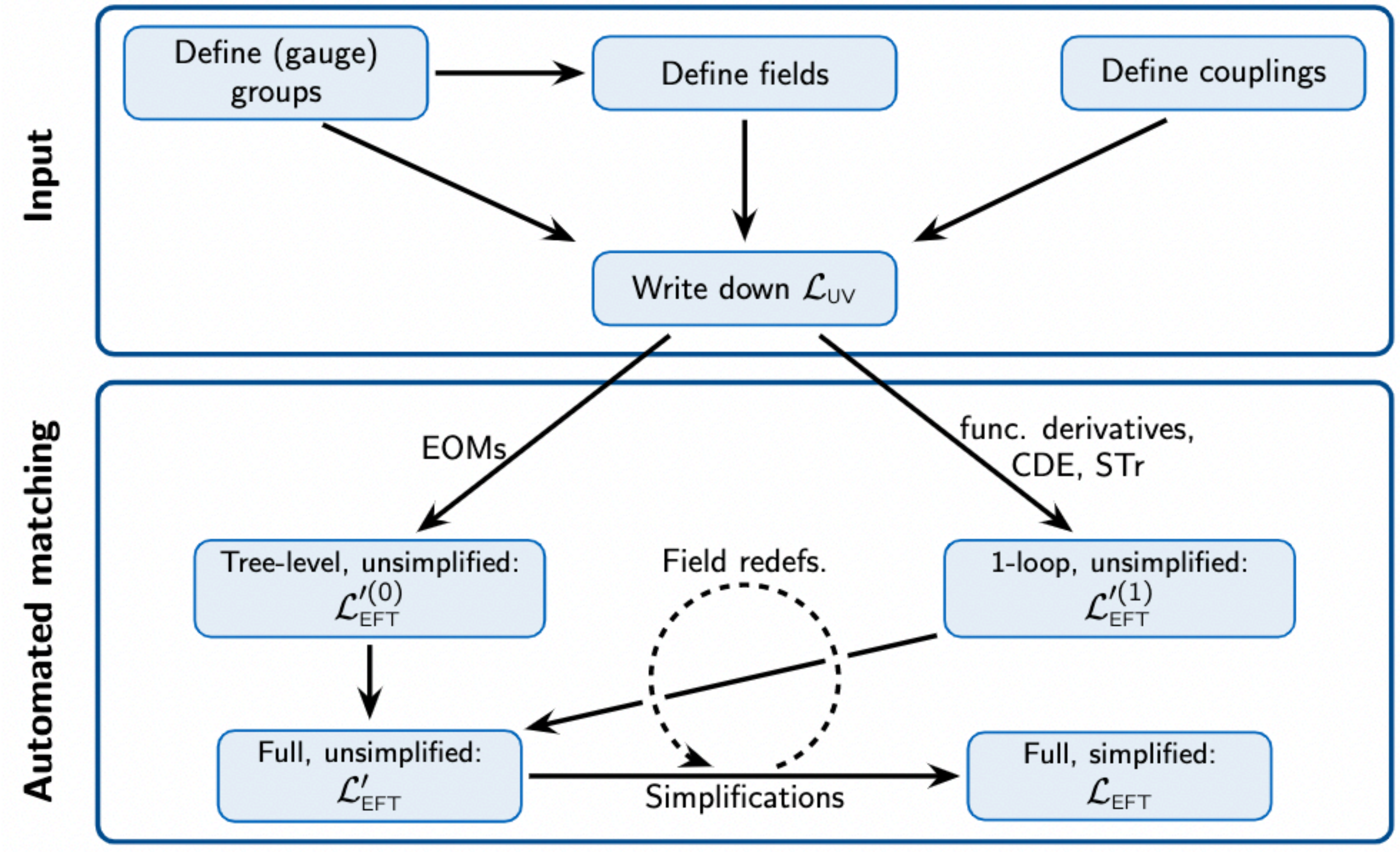
Thank you

MATCHETE

To make your way through the BSM jungle

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]

https://gitlab.com/matchete/matchete

Matchete v0.2 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)
- Fully automated simplifications to EFT basis (IBP, field redefinitions/EOMs,…)
- Computation of RGEs not yet available (Coming soon!)
- SSB and heavy vectors not yet supported

An example

SM + Vector-like lepton

$$E \sim (\mathbf{1}, \mathbf{1})_{-1}$$

Setup

SM Lagrangian

In[3]:=
```
LSM = LoadModel["SM"];
```

Define new field

In[4]:=
```
DefineField[EE, Fermion, Charges → {U1Y[-1]}, Mass → {Heavy, ME}]
```

Define new coupling

In[5]:=
```
DefineCoupling[yE, EFTOrder → 0, Indices → {Flavor}]
```

Write interactions

In[6]:=
```
Lint = -yE[p] × Bar@l[i, p] ** PR ** EE[] × H[i] // PlusHc;
Lint // NiceForm
```

Out[7]//NiceForm=

$$-\overline{yE}^{p}\,\overline{H}_{i}\left(\overline{EE}\cdot P_{L}\cdot l^{ip}\right)-yE^{p}\,H^{i}\left(\overline{l}^{p}_{i}\cdot P_{R}\cdot EE\right)$$

Define full UV Lagrangian

In[8]:=
```
LUV = LSM + FreeLag[EE] + Lint;
LUV // NiceForm
```

Out[9]//NiceForm=

$$-\frac{1}{4}B^{\mu\nu 2}-\frac{1}{4}G^{\mu\nu A2}-\frac{1}{4}W^{\mu\nu I2}+D_{\mu}\overline{H}_{i}\,D_{\mu}H^{i}+\mu^{2}\,\overline{H}_{i}\,H^{i}+i\left(\overline{d}^{p}_{a}\cdot\gamma_{\mu}P_{R}\cdot D_{\mu}d^{ap}\right)+i\left(\overline{e}^{p}\cdot\gamma_{\mu}P_{R}\cdot D_{\mu}e^{p}\right)+$$
$$i\left(\overline{EE}\cdot\gamma_{\mu}\cdot D_{\mu}EE\right)-ME\left(\overline{EE}\cdot EE\right)+i\left(\overline{l}^{p}_{i}\cdot\gamma_{\mu}P_{L}\cdot D_{\mu}l^{ip}\right)+i\left(\overline{q}^{p}_{ai}\cdot\gamma_{\mu}P_{L}\cdot D_{\mu}q^{aip}\right)+i\left(\overline{u}^{p}_{a}\cdot\gamma_{\mu}P_{R}\cdot D_{\mu}u^{ap}\right)-$$
$$\frac{1}{2}\lambda\,\overline{H}_{i}\,\overline{H}_{j}\,H^{i}\,H^{j}-\overline{Yd}^{pr}\,\overline{H}_{i}\left(\overline{d}^{r}_{a}\cdot P_{L}\cdot q^{aip}\right)-\overline{Ye}^{pr}\,\overline{H}_{i}\left(\overline{e}^{r}\cdot P_{L}\cdot l^{ip}\right)-Ye^{pr}\,H^{i}\left(\overline{l}^{p}_{i}\cdot P_{R}\cdot e^{r}\right)-Yd^{pr}\,H^{i}\left(\overline{q}^{p}_{ai}\cdot P_{R}\cdot d^{ar}\right)-$$
$$Yu^{pr}\,\overline{H}_{i}\left(\overline{q}^{p}_{aj}\cdot P_{R}\cdot u^{ar}\right)\varepsilon^{ji}-\overline{Yu}^{pr}\,H^{j}\left(\overline{u}^{r}_{a}\cdot P_{L}\cdot q^{aip}\right)\overline{\varepsilon}_{ij}-\overline{yE}^{p}\,\overline{H}_{i}\left(\overline{EE}\cdot P_{L}\cdot l^{ip}\right)-yE^{p}\,H^{i}\left(\overline{l}^{p}_{i}\cdot P_{R}\cdot EE\right)$$

An example: SM + Vector-like lepton

Main matching routine

In[9]:=
```
LEFT = Match[LUV, LoopOrder → 1, EFTOrder → 6] /. ϵ^-1 → 0;
```

Simplification to on-shell basis

In[10]:=
```
LEFTOnShell = LEFT // EOMSimplify;
Length@%
```

» The Lagrangian contains terms of lower power than dimension 4. Defining effective couplings and assuming these terms to be dimension 4. Use 'PrintEffectiveCouplings' and 'ReplaceEffectiveCouplings' to recover explicit expressions.

» Added new CG cg1 with indices {Bar[SU2L[fund]], SU2L[adj], Bar[SU2L[fund]]}

Out[11]= 66

Select Higgs-lepton current operator

In[12]:=
```
SelectOperatorClass[LEFTOnShell, {e, Bar@e, H, Bar@H}, 1] // GreensSimplify // NiceForm
```

Out[12]//NiceForm=

$$\frac{i}{360}\,\hbar\,\frac{1}{ME^2}\left(48\,gY^4\,\delta^{pr} + 5\,\overline{yE}^s\left(3\,yE^t\,\overline{Ye}^{tr}\,Ye^{sp}\left(1 + 6\,\mathrm{Log}\left[\frac{\bar{\mu}^2}{ME^2}\right]\right) - 2\,yE^s\,gY^2\left(13 + 6\,\mathrm{Log}\left[\frac{\bar{\mu}^2}{ME^2}\right]\right)\delta^{pr}\right)\right)$$
$$\left(-D_\mu\bar{H}_i\,H^i\left(\bar{e}^r\cdot\gamma_\mu P_R\cdot e^p\right) + \bar{H}_i\,D_\mu H^i\left(\bar{e}^r\cdot\gamma_\mu P_R\cdot e^p\right)\right)$$

$$Q_{He}^{pr} = (H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p\gamma^\mu e_r)$$

What's new since December 2022?

v0.1.0 ⟶ v0.2.0

- More robust simplification routines: flavor, symmetry-vanishing operators…
- Changed evaluation of supertraces: from CDE to Wilson lines [Theory: JFM, Palavric, Sánchez, Thomsen, WIP]
- Significant performance improvements!

Version	Match [s]	EOMSimplify [s]
v0.1.0	74	281
v0.2.0	12	81

Dimension-six one-loop matching

Model: SM + S1 + S3 (LQs)

CPU: Apple M3 (single core)

- Bug fixing: matching, group theory, simplifications…

The community has been a tremendous help bringing issues to our attention!

Work in progress: Counterterm evaluation and RG equations

- The functional approach can be easily adapted to extract UV divergencies
- A taste of what it will look like using **Matchete** for the SM

```
LSM // NiceForm
```

eForm=

$$\begin{aligned}&-\frac{1}{4} B^{\mu\nu 2} - \frac{1}{4} G^{\mu\nu A2} - \frac{1}{4} W^{\mu\nu I2} + D_\mu \bar{H}_i D_\mu H^i + \mu^2 \bar{H}_i H^i + i (\bar{d}^p_a \cdot \gamma_\mu P_R \cdot D_\mu d^{ap}) + i (\bar{e}^p \cdot \gamma_\mu P_R \cdot D_\mu e^p) + i (\bar{l}^p_i \cdot \gamma_\mu P_L \cdot D_\mu l^{ip}) + i (\bar{q}^p_{ai} \cdot \gamma_\mu P_L \cdot D_\mu q^{aip}) + i (\bar{u}^p_a \cdot \gamma_\mu P_R \cdot D_\mu u^{ap}) - \\ &\frac{1}{2} \lambda \bar{H}_i \bar{H}_j H^i H^j - \overline{Yd}^{pr} \bar{H}_i (\bar{d}^r_a \cdot P_L \cdot q^{aip}) - \overline{Ye}^{pr} \bar{H}_i (\bar{e}^r \cdot P_L \cdot l^{ip}) - Ye^{pr} H^i (\bar{l}^p_i \cdot P_R \cdot e^r) - Yd^{pr} H^i (\bar{q}^p_{ai} \cdot P_R \cdot d^{ar}) - Yu^{pr} \bar{H}_i (\bar{q}^p_{aj} \cdot P_R \cdot u^{ar}) \varepsilon^{ji} - \overline{Yu}^{pr} H^j (\bar{u}^r_a \cdot P_L \cdot q^{aip}) \bar{\varepsilon}_{ij}\end{aligned}$$

```
UVDivergentAction[LSM, EFTOrder → 4] // NiceForm
```

eForm=

$$\begin{aligned}&\frac{1}{\epsilon} (-\frac{41}{24} \hbar\, gY^2 B^{\mu\nu 2} + \frac{5}{2} \hbar\, gs^2 G^{\mu\nu A2} + \frac{31}{24} \hbar\, gL^2 W^{\mu\nu I2} + \frac{1}{8} \hbar \mu^2 (15 gL^2 + 5 gY^2 - 24 \overline{Yd}^{pr} Yd^{pr} - 8 \overline{Ye}^{pr} Ye^{pr} - 24 \overline{Yu}^{pr} Yu^{pr} - 24 \lambda) \bar{H}_i H^i + \\ &\hbar \Big(\frac{9}{16} gL^4 - \frac{1}{16} gY^4 - 3 \overline{Yd}^{pr} \overline{Yd}^{st} Yd^{pt} Yd^{sr} - \overline{Ye}^{pr} \overline{Ye}^{st} Ye^{pt} Ye^{sr} - 3 \overline{Yu}^{pr} \overline{Yu}^{st} Yu^{pt} Yu^{sr} - \frac{5}{8} \lambda gY^2 + 3 \overline{Yd}^{pr} Yd^{pr} \lambda + \overline{Ye}^{pr} Ye^{pr} \lambda + 3 \overline{Yu}^{pr} Yu^{pr} \lambda + 3 \lambda^2 - \frac{1}{8} gL^2 (gY^2 + 15 \lambda) \Big) \\ &\bar{H}_i \bar{H}_j H^i H^j + \hbar \Big(\frac{3}{4} (\overline{Yd}^{ps} \overline{Yd}^{tr} Yd^{ts} - \overline{Yd}^{sr} \overline{Yu}^{pt} Yu^{st}) + \frac{1}{144} \overline{Yd}^{pr} (-27 gL^2 + 192 gs^2 - 17 gY^2 + 216 \overline{Yd}^{st} Yd^{st} + 72 \overline{Ye}^{st} Ye^{st} + 216 \overline{Yu}^{st} Yu^{st}) \Big) \bar{H}_i (\bar{d}^r_a \cdot P_L \cdot q^{aip}) + \\ &\frac{1}{16} \hbar (12 \overline{Ye}^{ps} \overline{Ye}^{tr} Ye^{ts} + \overline{Ye}^{pr} (-3 gL^2 + 7 gY^2 + 24 \overline{Yd}^{st} Yd^{st} + 8 \overline{Ye}^{st} Ye^{st} + 24 \overline{Yu}^{st} Yu^{st})) \bar{H}_i (\bar{e}^r \cdot P_L \cdot l^{ip}) - \\ &\frac{1}{16} \hbar (3 Ye^{rp} gL^2 - 7 Ye^{rp} gY^2 - 24 \overline{Yd}^{st} Yd^{st} Ye^{rp} - 12 \overline{Ye}^{st} Ye^{rt} Ye^{sp} - 8 \overline{Ye}^{st} Ye^{rp} Ye^{st} - 24 Ye^{rp} \overline{Yu}^{st} Yu^{st}) H^i (\bar{l}^r_i \cdot P_R \cdot e^p) + \\ &\frac{1}{144} \hbar (-27 Yd^{rp} gL^2 + 192 Yd^{rp} gs^2 - 17 Yd^{rp} gY^2 + 108 \overline{Yd}^{st} Yd^{rt} Yd^{sp} + 216 \overline{Yd}^{st} Yd^{rp} Yd^{st} + 72 Yd^{rp} \overline{Ye}^{st} Ye^{st} - 108 Yd^{sp} \overline{Yu}^{st} Yu^{rt} + 216 Yd^{rp} \overline{Yu}^{st} Yu^{st}) H^i (\bar{q}^r_{ai} \cdot P_R \cdot d^{ap}) + \\ &\frac{1}{144} \hbar (-27 Yu^{rp} gL^2 + 192 Yu^{rp} gs^2 + 7 Yu^{rp} gY^2 + 216 \overline{Yd}^{st} Yd^{st} Yu^{rp} + 72 \overline{Ye}^{st} Ye^{st} Yu^{rp} - 108 \overline{Yd}^{st} Yd^{rt} Yu^{sp} + 108 \overline{Yu}^{st} Yu^{rt} Yu^{sp} + 216 \overline{Yu}^{st} Yu^{rp} Yu^{st}) \bar{H}_i (\bar{q}^r_{aj} \cdot P_R \cdot u^{ap}) \varepsilon^{ji} + \\ &\hbar \Big(\frac{1}{144} \overline{Yu}^{pr} (-27 gL^2 + 192 gs^2 + 7 gY^2 + 216 \overline{Yd}^{st} Yd^{st} + 72 \overline{Ye}^{st} Ye^{st} + 216 \overline{Yu}^{st} Yu^{st}) + \frac{3}{4} \overline{Yu}^{tr} (-\overline{Yd}^{ps} Yd^{ts} + \overline{Yu}^{ps} Yu^{ts}) \Big) H^j (\bar{u}^r_a \cdot P_L \cdot q^{aip}) \bar{\varepsilon}_{ij})\end{aligned}$$

*Ghost loops are not yet included

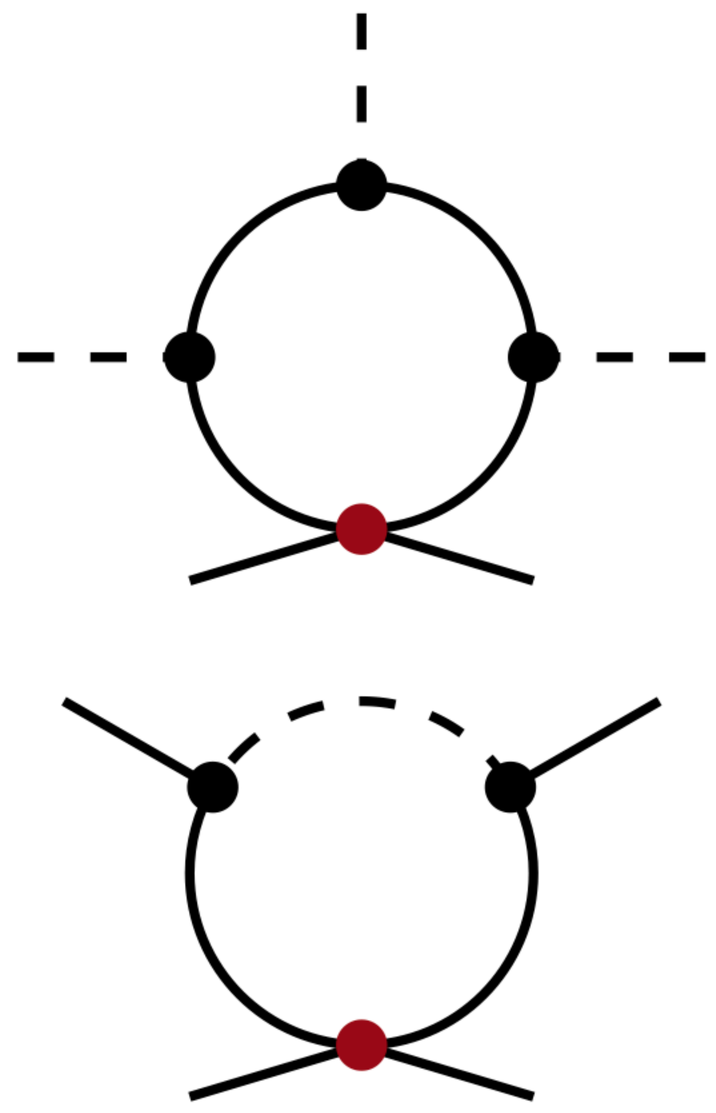
Work in progress: Fierz (and other) identities and evanescent contributions

Some operator identities (like Fierz) are only valid in strictly $d = 4$ dimensions

Application to the SMEFT: JFM, König, Pagès, Thomsen, Wilsch, 2211.09144

$$O_d = \underbrace{\mathcal{P}\, O_d}_{\text{phys. part}} + \underbrace{\mathcal{E}_{\mathcal{P}}\, O_d}_{\text{ev. part}}, \qquad \mathcal{E}_{\mathcal{P}} = \text{id} - \mathcal{P}$$

$$\mathcal{L}_{\text{EFT}} + \text{ev.} \longrightarrow \mathcal{L}_{\text{EFT}} + \Delta\mathcal{L}$$



*Sample diagrams

- Initial step: automatic identification of evanescent operators!

```
redOp = CRqe[p, r, s, t] (Bar@q[c, i, p] ** e[r]) (Bar@e[s] ** q[c, i, t]);
% // NiceForm
```

:eForm=

$\text{CRqe}^{prst}\, (\bar{e}^{s} \cdot P_L \cdot q^{cit})\, (\bar{q}^{p}_{ci} \cdot P_R \cdot e^{r})$

```
GreensSimplify[redOp, Basis4D → Evanescent] // NiceForm
```

:eForm=

$\text{CRqe}^{prst}\, E_1^{stpr} - \frac{1}{2}\, \text{CRqe}^{tpsr}\, (\bar{e}^{s} \cdot \gamma_\mu P_R \cdot e^{p})\, (\bar{q}^{t}_{ai} \cdot \gamma_\mu P_L \cdot q^{air})$

Work in progress: Matching to a particular SMEFT basis

Compute on-shell EFT Lagrangian from UV model

```
LEFTOnShell = Match[LUV, LoopOrder → 1, EFTOrder → 6] // EOMSimplify // AdjustWIP;
```

```
The Lagrangian contains terms of lower power than dimension 4. Defining effective couplings and assuming these
  terms to be dimension 4. Use 'PrintEffectiveCouplings' and 'ReplaceEffectiveCouplings' to recover explicit expressions.
```

Load generic SMEFT Lagrangian

```
LSMEFT = LoadModel["SMEFT"] // EOMSimplify // ShiftRenCouplings;
```

Equate the two, to solve for the SMEFT coefficients

```
MatchLagrangians[LEFTOnShell, LSMEFT] // CleanUpFlavor // TableForm // NiceForm
```

iceForm=

$$\mu \to \sqrt{-2\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{ME}^2 - 2\hbar\,\frac{1}{\epsilon}\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{ME}^2 + \mu^2 - 2\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{ME}^2\,\mathrm{Log}\left[\frac{\bar{\mu}^2}{\mathrm{ME}^2}\right]}$$

$$\lambda \to \lambda$$

$$\mathrm{cHBox} \to -\frac{1}{30}\hbar\,\mathrm{gY}^4\frac{1}{\mathrm{ME}^2} - \frac{5}{24}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{gL}^2\frac{1}{\mathrm{ME}^2} + \frac{13}{72}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{gY}^2\frac{1}{\mathrm{ME}^2} - \frac{1}{3}\hbar\,\overline{\mathrm{yE}}^{p}\,\overline{\mathrm{yE}}^{r}\,\mathrm{yE}^{p}\,\mathrm{yE}^{r}\frac{1}{\mathrm{ME}^2} + \frac{3}{2}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{r}\,\overline{\mathrm{Ye}}^{rs}\,\mathrm{Ye}^{ps}\frac{1}{\mathrm{ME}^2} - \frac{1}{4}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{gL}^2\frac{1}{\mathrm{ME}^2}\mathrm{Log}\left[\frac{\bar{\mu}^2}{\mathrm{ME}^2}\right] + \frac{1}{12}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}$$

$$\mathrm{cHD} \to -\frac{2}{15}\hbar\,\mathrm{gY}^4\frac{1}{\mathrm{ME}^2} + \frac{13}{18}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{gY}^2\frac{1}{\mathrm{ME}^2} - \frac{1}{2}\hbar\,\overline{\mathrm{yE}}^{p}\,\overline{\mathrm{yE}}^{r}\,\mathrm{yE}^{p}\,\mathrm{yE}^{r}\frac{1}{\mathrm{ME}^2} + \frac{1}{2}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{r}\,\overline{\mathrm{Ye}}^{rs}\,\mathrm{Ye}^{ps}\frac{1}{\mathrm{ME}^2} + \frac{1}{3}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{gY}^2\frac{1}{\mathrm{ME}^2}\mathrm{Log}\left[\frac{\bar{\mu}^2}{\mathrm{ME}^2}\right] + \hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{r}\,\overline{\mathrm{Ye}}^{rs}\,\mathrm{Ye}^{ps}\frac{1}{\mathrm{ME}^2}\mathrm{Log}\left[\frac{\bar{\mu}^2}{\mathrm{ME}^2}\right]$$

$$\mathrm{cH} \to \frac{1}{3}\hbar\,\overline{\mathrm{yE}}^{p}\,\overline{\mathrm{yE}}^{r}\,\overline{\mathrm{yE}}^{s}\,\mathrm{yE}^{p}\,\mathrm{yE}^{r}\,\mathrm{yE}^{s}\frac{1}{\mathrm{ME}^2} + 2\hbar\,\overline{\mathrm{yE}}^{p}\,\overline{\mathrm{yE}}^{r}\,\mathrm{yE}^{p}\,\mathrm{yE}^{s}\,\overline{\mathrm{Ye}}^{st}\,\mathrm{Ye}^{rt}\frac{1}{\mathrm{ME}^2} - 2\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{r}\,\overline{\mathrm{Ye}}^{rs}\,\overline{\mathrm{Ye}}^{tu}\,\mathrm{Ye}^{pu}\,\mathrm{Ye}^{ts}\frac{1}{\mathrm{ME}^2} - \frac{5}{18}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\lambda\,\mathrm{gL}^2\frac{1}{\mathrm{ME}^2} - \hbar\,\overline{\mathrm{yE}}^{p}\,\overline{\mathrm{yE}}^{r}\,\mathrm{yE}^{p}\,\mathrm{yE}^{r}\,\lambda\frac{1}{\mathrm{ME}^2} + \hbar\,\overline{\mathrm{yE}}$$

$$\mathrm{cHB} \to \frac{1}{8}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{gY}^2\frac{1}{\mathrm{ME}^2}$$

$$\mathrm{cHG} \to 0$$

$$\mathrm{cG} \to 0$$

$$\mathrm{cHWB} \to -\frac{1}{6}\hbar\,\mathrm{gL}\,\mathrm{gY}\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\frac{1}{\mathrm{ME}^2}$$

$$\mathrm{cHW} \to \frac{1}{24}\hbar\,\overline{\mathrm{yE}}^{p}\,\mathrm{yE}^{p}\,\mathrm{gL}^2\frac{1}{\mathrm{ME}^2}$$

$$\mathrm{cW} \to 0$$

$$\mathrm{cHBt} \to 0$$

SMEFT coefficients

$$\mathrm{cHGt} \to 0$$

$$\mathrm{cHWtB} \to 0$$

$$\mathrm{cHWt} \to 0$$

$$\mathrm{cGt} \to 0$$

The aim is to use the SMEFT Warsaw basis to interface with smelli and HighPT!

Aebischer et al., 1810.07698

Allwicher et al., 2207.10756

*Example model: SM + vector-like lepton $E \sim (\mathbf{1},\mathbf{1})_{-1}$