



ugr

Universidad
de Granada

LHC EFT Working Group activities

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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?**]



Indirect new physics searches?

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2023

ATLAS Preliminary
 $\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$
 $\sqrt{s} = 13 \text{ TeV}$

Model	ℓ, γ	Jets [†]	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference		
Extra dimen.	ADD $G_{KK} + g/q$	$0 e, \mu, \tau, \gamma$	1-4 j	Yes	139	M_D 11.2 TeV $n=2$	2102.10874	
	ADD non-resonant $\gamma\gamma$	2γ	-	-	36.7	M_S 8.6 TeV $n=3$ HLZ NLO	1707.04147	
	ADD QBH	-	2 j	-	139	M_{th} 9.4 TeV $n=6$	1910.08447	
	ADD BH multijet	-	$\geq 3 j$	-	3.6	M_{th} 9.55 TeV $n=6, M_D = 3 \text{ TeV}$, rot BH	1512.02586	
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	139	G_{KK} mass 4.5 TeV $k/\overline{M}_{Pl} = 0.1$	2102.13405	
	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	-	-	36.1	G_{KK} mass 2.3 TeV $k/\overline{M}_{Pl} = 1.0$	1808.02380	
	Bulk RS $g_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2j$	Yes	36.1	g_{KK} mass 3.8 TeV $\Gamma/m = 15\%$	1804.10823	
2UED / RPP	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	36.1	KK mass 1.8 TeV Tier (1,1), $\mathcal{B}(A^{(1,1)} \rightarrow tt) = 1$	1803.09678		
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	139	Z' mass 5.1 TeV	1903.06248	
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	36.1	Z' mass 2.42 TeV	1709.07242	
	Leptophobic $Z' \rightarrow bb$	-	2 b	-	36.1	Z' mass 2.1 TeV	1805.09299	
	Leptophobic $Z' \rightarrow tt$	$0 e, \mu$	$\geq 1 b, \geq 2 J$	Yes	139	Z' mass 4.1 TeV $\Gamma/m = 1.2\%$	2005.05138	
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	139	W' mass 6.0 TeV	1906.05609	
	SSM $W' \rightarrow \tau\nu$	1τ	-	Yes	139	W' mass 5.0 TeV	ATLAS-CONF-2021-025	
	SSM $W' \rightarrow tb$	-	$\geq 1 b, \geq 1 J$	-	139	W' mass 4.4 TeV	ATLAS-CONF-2021-043	
	HVT $W' \rightarrow WZ$ model B	$0-2 e, \mu$	$2 j / 1 J$	Yes	139	W' mass 4.3 TeV $g_V = 3$	2004.14636	
	HVT $W' \rightarrow WZ \rightarrow \ell\nu \ell' \ell'$ model C	$3 e, \mu$	$2 j$ (VBF)	Yes	139	W' mass 340 GeV $g_V c_H = 1, g_f = 0$	2207.03925	
	HVT $Z' \rightarrow WW$ model B	$1 e, \mu$	$2 j / 1 J$	Yes	139	Z' mass 3.9 TeV $g_V = 3$	2004.14636	
LRSM $W_R \rightarrow \mu N_R$	2μ	1 J	-	80	W_R mass 5.0 TeV $m(N_R) = 0.5 \text{ TeV}, g_L = g_R$	1904.12679		
CI	CI $qqqq$	-	2 j	-	37.0	Λ 21.8 TeV η_{LL}	1703.09127	
	CI $\ell\ell qq$	$2 e, \mu$	-	-	139	Λ 35.8 TeV η_{LL}	2006.12946	
	CI $eebs$	$2 e$	1 b	-	139	Λ 1.8 TeV $g_* = 1$	2105.13847	
	CI $\mu\mu bs$	2μ	1 b	-	139	Λ 2.0 TeV $g_* = 1$	2105.13847	
	CI $tttt$	$\geq 1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	Λ 2.57 TeV $ C_{4t} = 4\pi$	1811.02305	
DM	Axial-vector med. (Dirac DM)	-	2 j	-	139	m_{med} 3.8 TeV	ATL-PHYS-PUB-2022-036	
	Pseudo-scalar med. (Dirac DM)	$0 e, \mu, \tau, \gamma$	1-4 j	Yes	139	m_{med} 376 GeV	2102.10874	
	Vector med. Z' -2HDM (Dirac DM)	$0 e, \mu$	2 b	Yes	139	$m_{Z'}$ 3.0 TeV $g_q=0.25, g_\chi=1, m(\chi)=10 \text{ TeV}$	2108.13391	
	Pseudo-scalar med. 2HDM+a	multi-channel	-	-	139	m_a 800 GeV $g_q=1, g_\chi=1, m(\chi)=1 \text{ GeV}$ $\tan\beta=1, g_Z=0.8, m(\chi)=100 \text{ GeV}$ $\tan\beta=1, g_\chi=1, m(\chi)=10 \text{ GeV}$	ATLAS-CONF-2021-036	
LQ	Scalar LQ 1 st gen	$2 e$	$\geq 2 j$	Yes	139	LQ mass 1.8 TeV $\beta = 1$	2006.05872	
	Scalar LQ 2 nd gen	2μ	$\geq 2 j$	Yes	139	LQ mass 1.7 TeV $\beta = 1$	2006.05872	
	Scalar LQ 3 rd gen	1τ	2 b	Yes	139	LQ_3^u mass 1.99 TeV $\mathcal{B}(LQ_3^u \rightarrow br) = 1$	2303.01294	
	Scalar LQ 3 rd gen	$0 e, \mu$	$\geq 2 j, \geq 2 b$	Yes	139	LQ_3^d mass 1.24 TeV $\mathcal{B}(LQ_3^d \rightarrow tv) = 1$	2004.14060	
	Scalar LQ 3 rd gen	$\geq 2 e, \mu, \geq 1 \tau$	$\geq 1 j, \geq 1 b$	-	139	LQ_3^d mass 1.43 TeV $\mathcal{B}(LQ_3^d \rightarrow tr) = 1$	2101.11582	
	Scalar LQ 3 rd gen	$0 e, \mu, \geq 1 \tau$	0-2 j, 2 b	Yes	139	LQ_3^d mass 1.26 TeV $\mathcal{B}(LQ_3^d \rightarrow b\nu) = 1$	2101.12527	
	Vector LQ mix gen	multi-channel	$\geq 1 j, \geq 1 b$	Yes	139	LQ_3^V mass 2.0 TeV $\mathcal{B}(\tilde{U}_1 \rightarrow t\mu) = 1, \text{Y-M coupl.}$	ATLAS-CONF-2022-052	
Vector LQ 3 rd gen	$2 e, \mu, \tau$	$\geq 1 b$	Yes	139	LQ_3^V mass 1.96 TeV $\mathcal{B}(LQ_3^V \rightarrow br) = 1, \text{Y-M coupl.}$	2303.01294		
Vector-like fermions	VLQ $TT \rightarrow Zt + X$	$2e/2\mu \geq 3e, \mu$	$\geq 1 b, \geq 1 j$	-	139	T mass 1.6 TeV	SU(2) doublet	2210.15413
	VLQ $BB \rightarrow Wt/Zb + X$	multi-channel	-	-	36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3} T_{5/3} T_{5/3} \rightarrow Wt + X$	$2(SS) \geq 3 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	$T_{5/3}$ mass 1.64 TeV $\mathcal{B}(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3} Wt) = 1$	1807.11883	
	VLQ $T \rightarrow Ht/Zt$	$1 e, \mu$	$\geq 1 b, \geq 3 j$	Yes	139	T mass 1.8 TeV	SU(2) singlet, $\kappa_T = 0.5$	ATLAS-CONF-2021-040
	VLQ $Y \rightarrow Wb$	$1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	Y mass 1.85 TeV $\mathcal{B}(Y \rightarrow Wb) = 1, c_R(Wb) = 1$	1812.07343	
	VLQ $B \rightarrow Hb$	$0 e, \mu$	$\geq 2b, \geq 1j, \geq 1J$	-	139	B mass 2.0 TeV	SU(2) doublet, $\kappa_B = 0.3$	ATLAS-CONF-2021-018
	VLL $\tau' \rightarrow Z\tau/H\tau$	multi-channel	$\geq 1 j$	Yes	139	τ' mass 898 GeV	SU(2) doublet	2303.05441
Exctd ferm.	Excited quark $q^* \rightarrow qg$	-	2 j	-	139	q^* mass 6.7 TeV	only u^* and d^* , $\Lambda = m(q^*)$	1910.08447
	Excited quark $q^* \rightarrow q\gamma$	1γ	1 j	-	36.7	q^* mass 5.3 TeV	only u^* and d^* , $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \rightarrow bg$	-	1 b, 1 j	-	139	b^* mass 3.2 TeV		1910.08447
	Excited lepton τ^*	2τ	$\geq 2 j$	-	139	τ^* mass 4.6 TeV	$\Lambda = 4.6 \text{ TeV}$	2303.09444
Other	Type III Seesaw	$2,3,4 e, \mu$	$\geq 2 j$	Yes	139	N^0 mass 910 GeV		2202.02039
	LRSM Majorana ν	2μ	2 j	-	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1 \text{ TeV}, g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \rightarrow W^\pm W^\pm$	$2,3,4 e, \mu$ (SS)	various	Yes	139	$H^{\pm\pm}$ mass 350 GeV	DY production	2101.11961
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2,3,4 e, \mu$ (SS)	-	-	139	$H^{\pm\pm}$ mass 1.08 TeV	DY production	2211.07505
	Multi-charged particles	-	-	-	139	multi-charged particle mass 1.59 TeV	DY production, $ q = 5e$	ATLAS-CONF-2022-034
	Magnetic monopoles	-	-	-	34.4	monopole mass 2.37 TeV	DY production, $ g = 1g_D, \text{spin } 1/2$	1905.10130

$\sqrt{s} = 13 \text{ TeV}$ partial data $\sqrt{s} = 13 \text{ TeV}$ full data

10⁻¹ shown. 1 TeV 10 TeV Mass scale [TeV]

[†] Small-radius (large-radius) jets are denoted by the letter j (J)

Why Effective Field Theories (EFTs)?

EFTs are essential to interpret experimental observations

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

UV physics

■ Bottom → Up

EFTs offer a **model comprehensive** (“model independent”) approach to study deviations from 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://lpsc.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

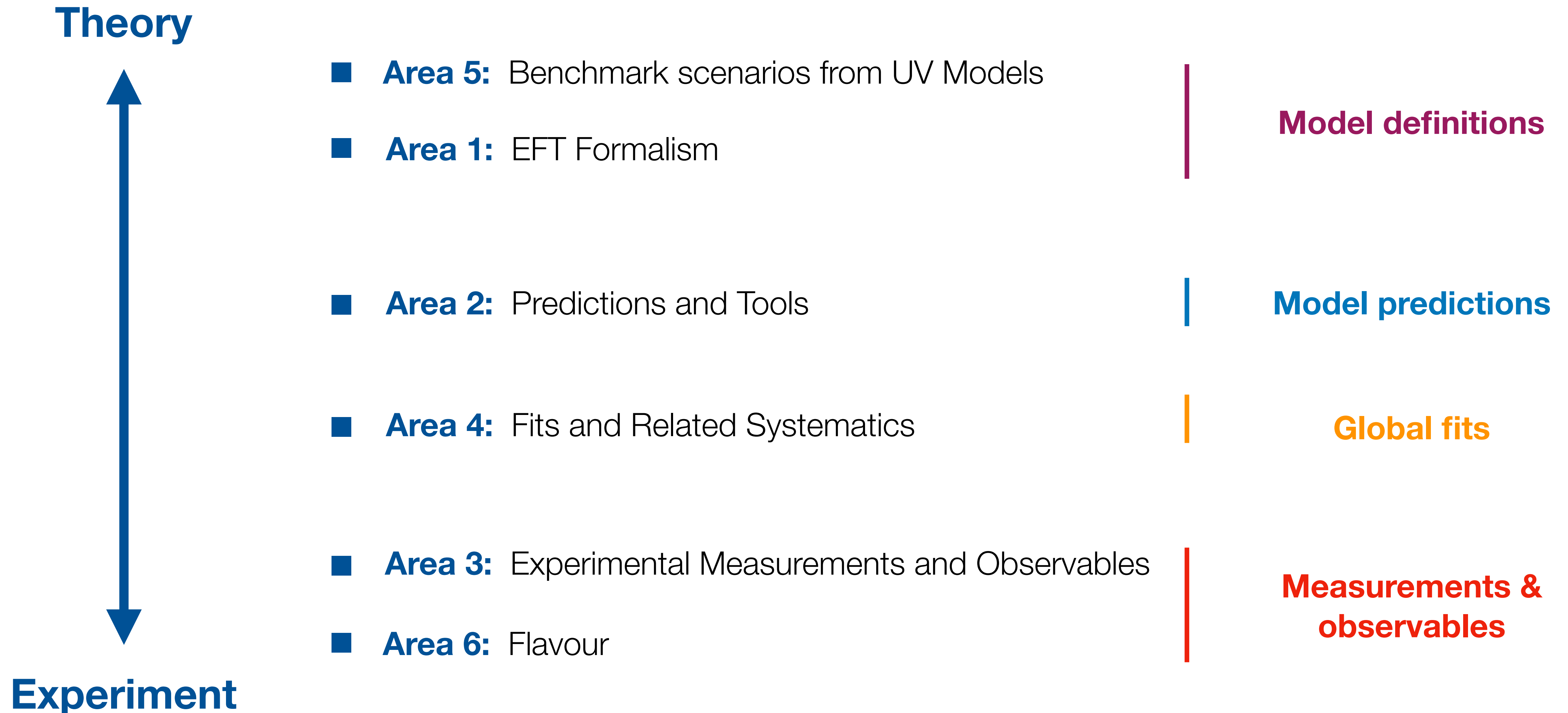
Theory:

- 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:



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

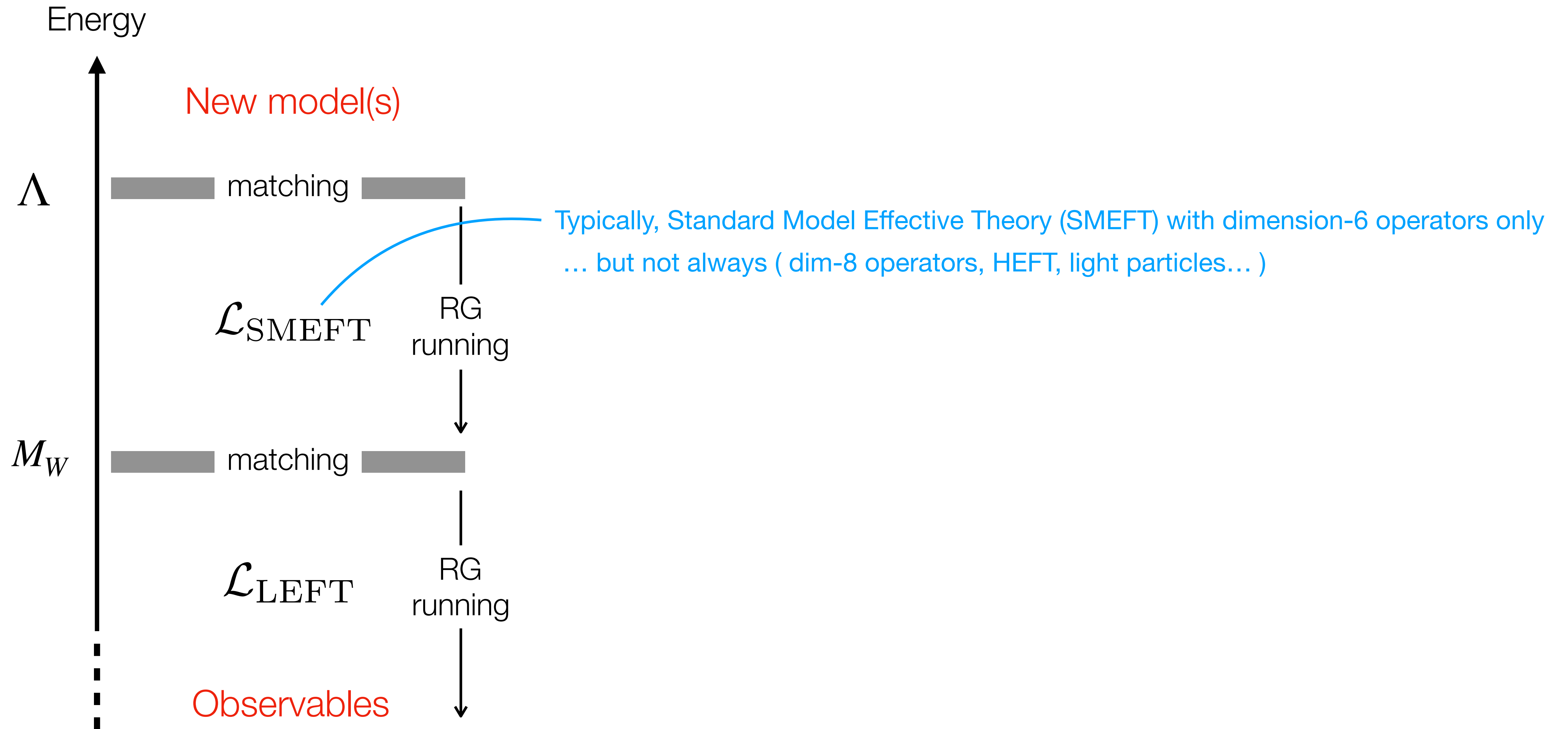


19 Feb **LHC EFT WG meeting: tops in SMEFT**

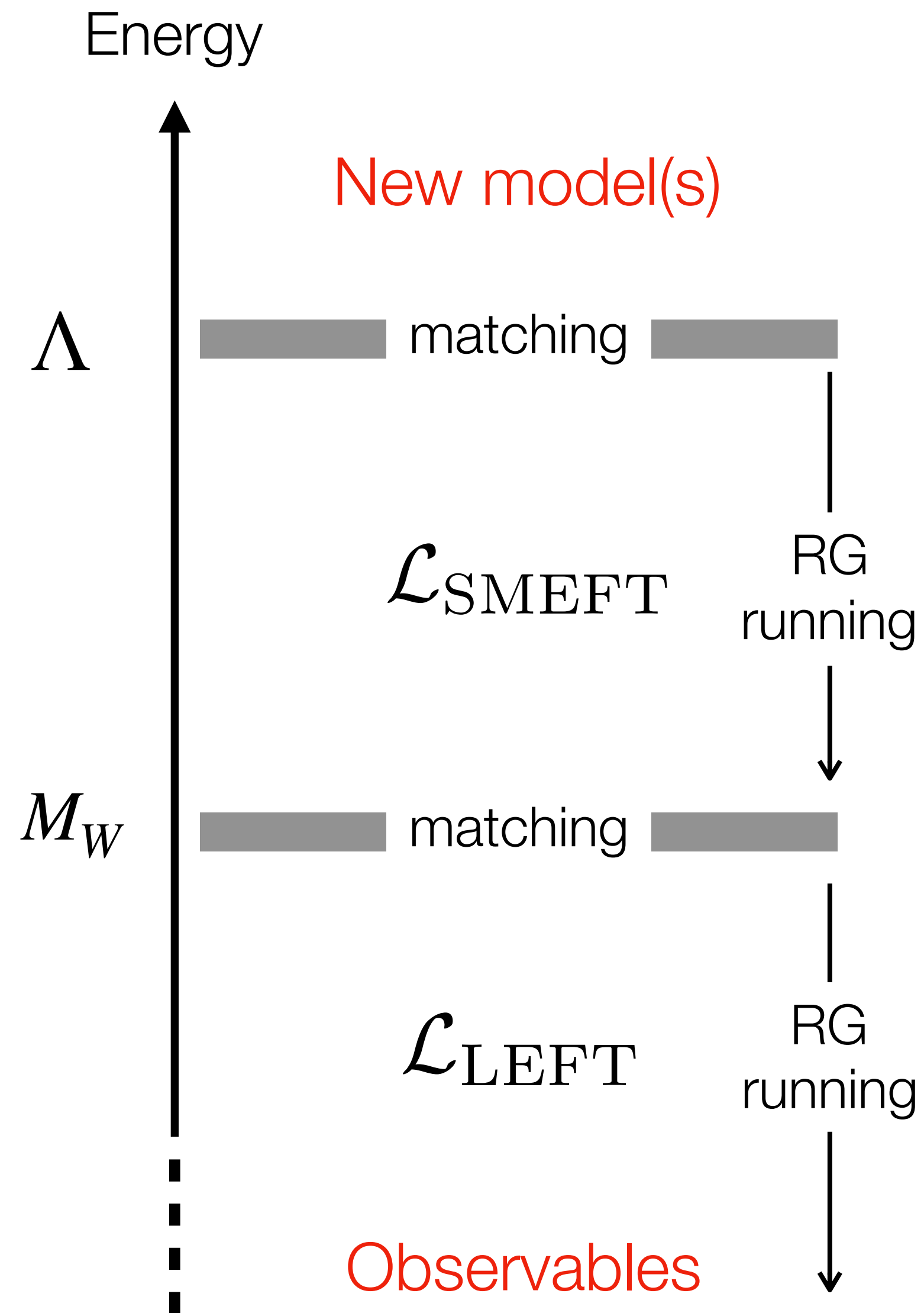
LHC EFT WG Activities

- 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



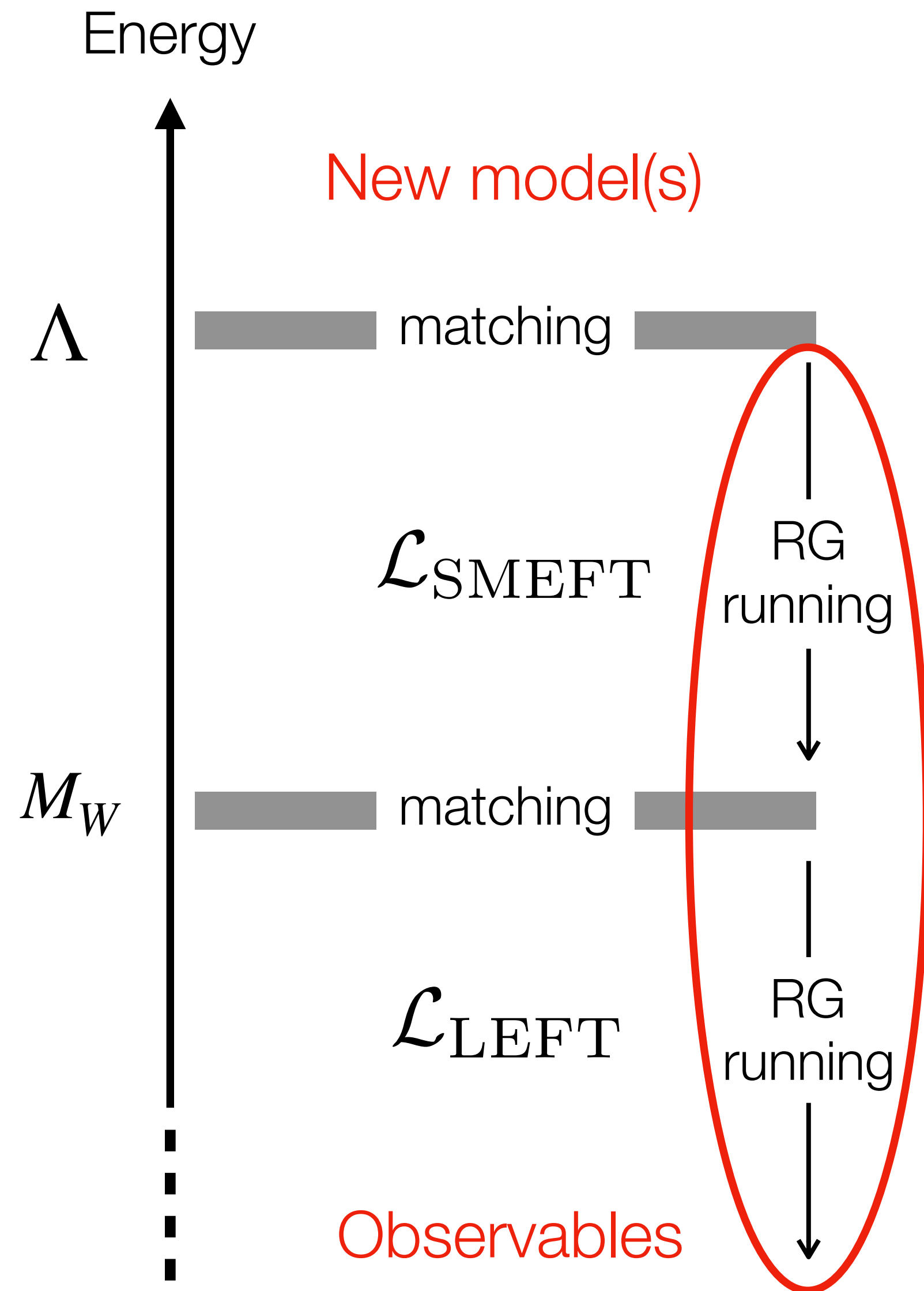
The rise of automation



Main motivation

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

The rise of automation



JFM et al. '17 & '21



wilson

Aebischer et al. '18

“Hard-coded” one-loop results based on:

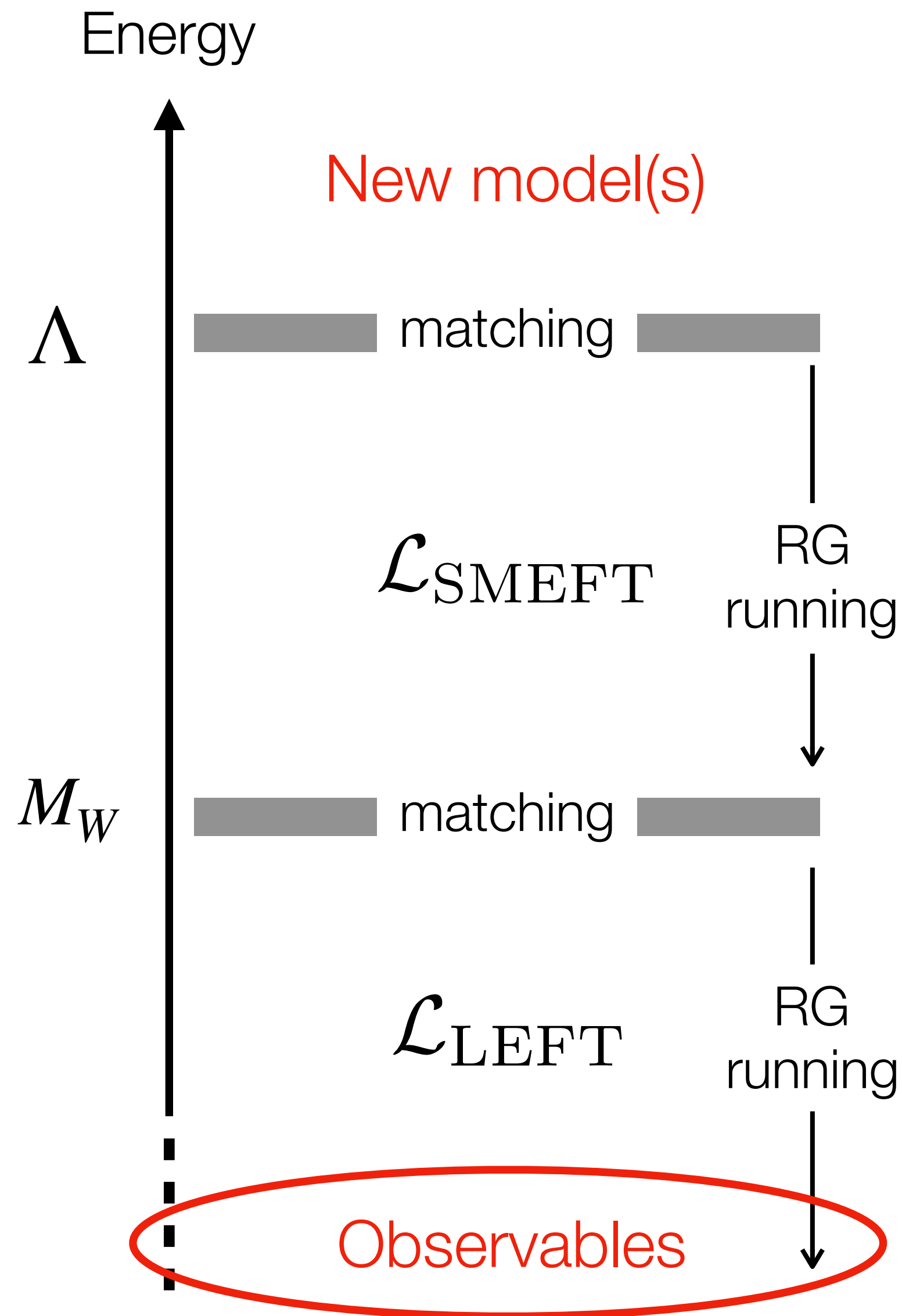
[SMEFT running](#): Jenkins et al. '13, '14;
Alonso et al. '14

[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



De Blas et al. '19

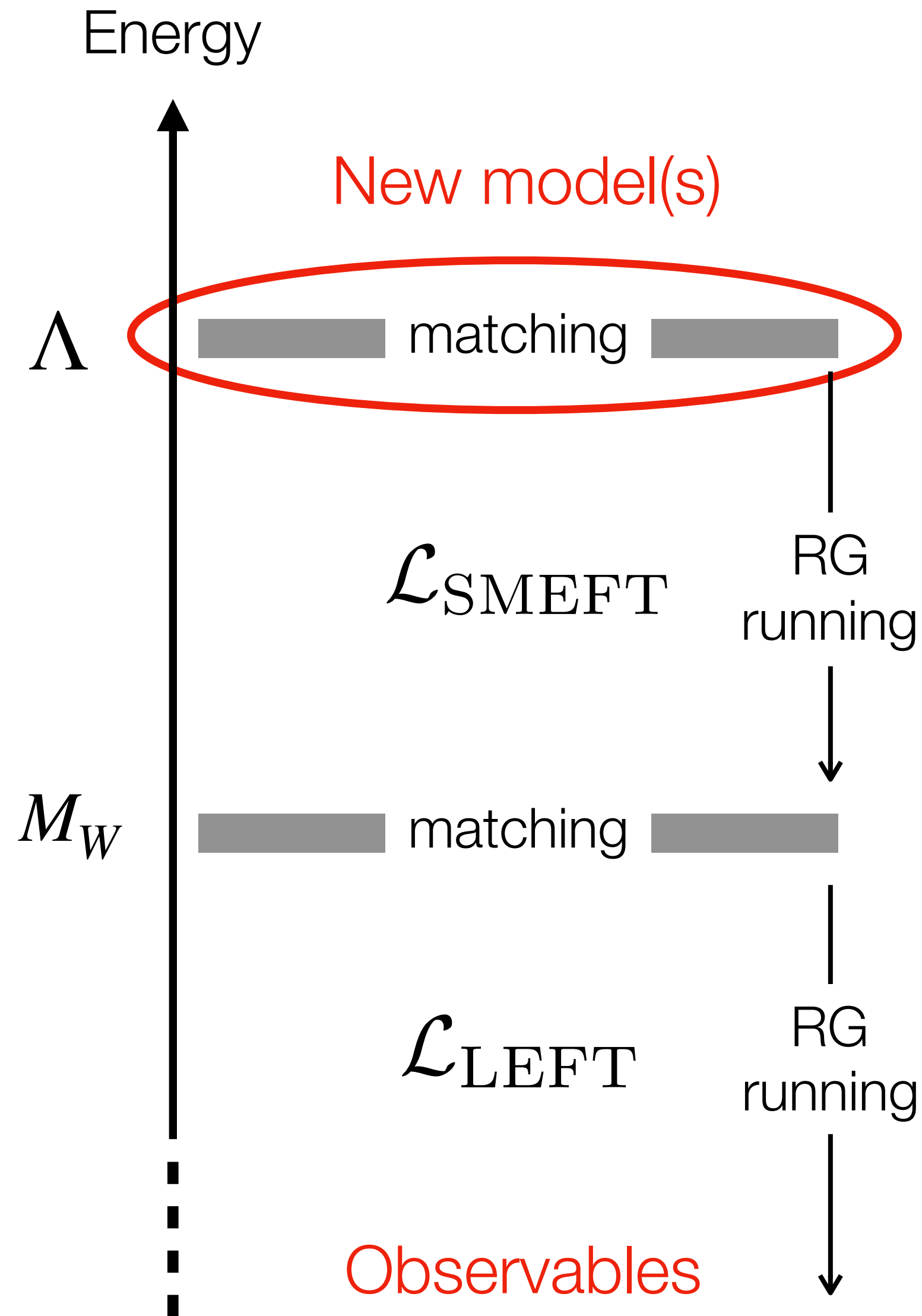
+ others



Giani et al. '23

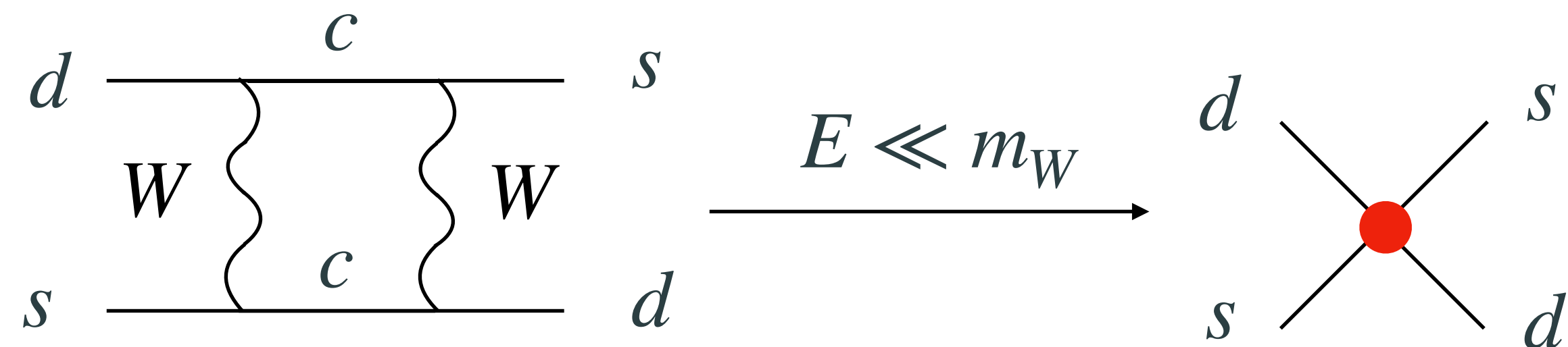
Involvement of experimental collaborations into this program is crucial

The rise of automation



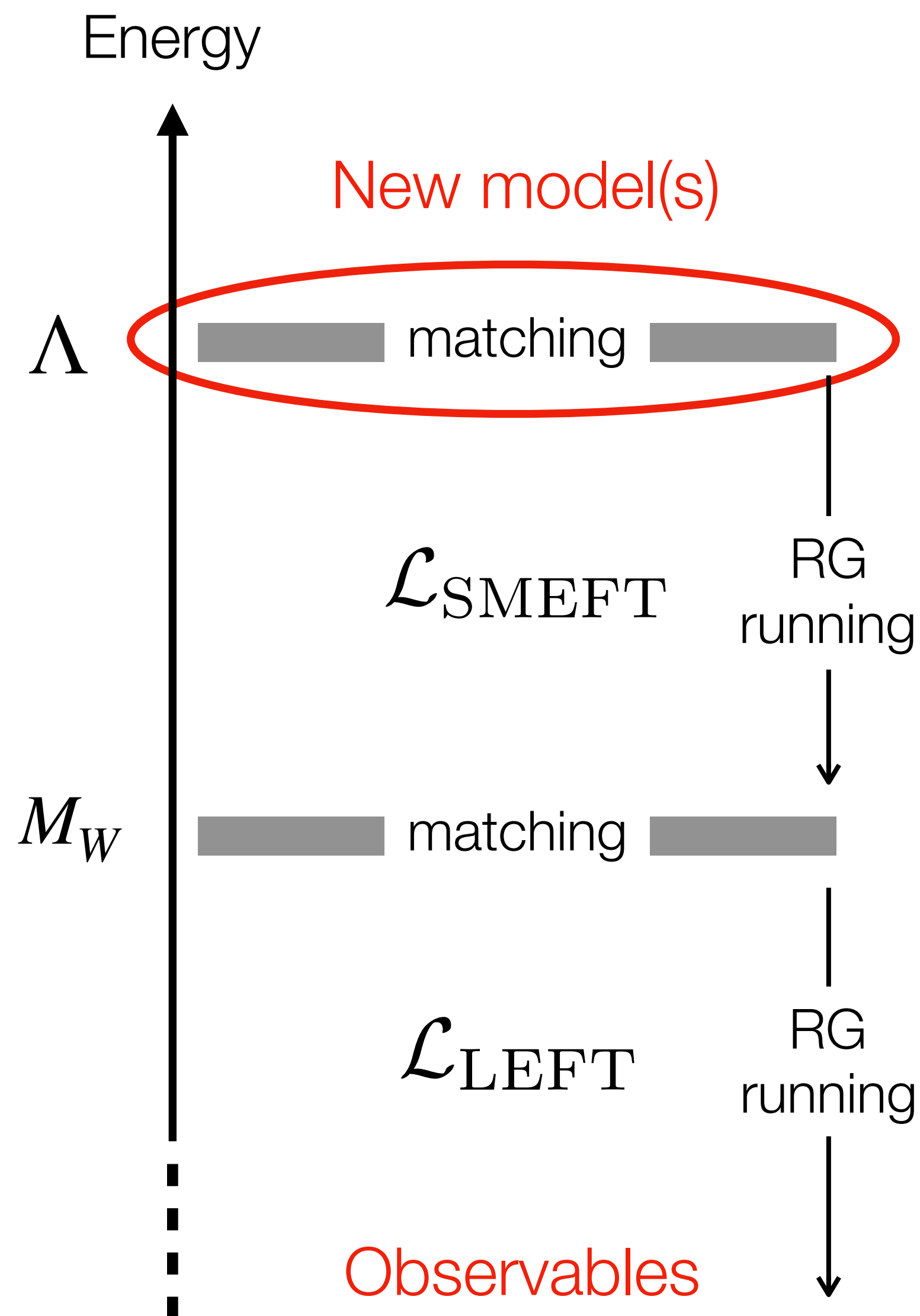
Much progress has been made:

- 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)

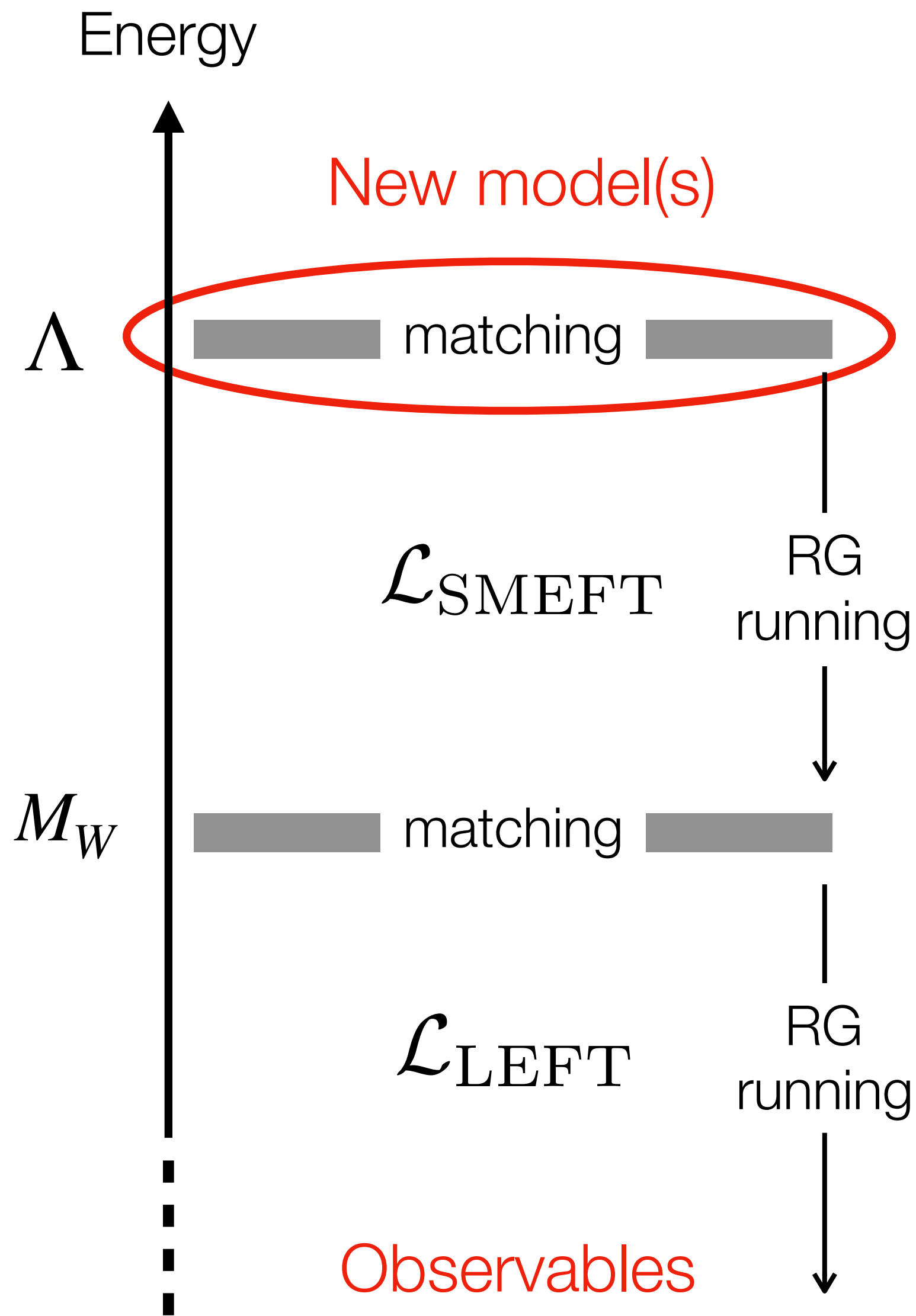
JFM et al. '22

[[2212.04510](#)]

Completely different approaches: amplitude vs functional matching

Automated one-loop matching of *many* models
(no heavy vectors for now!)

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

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
 - Connection to observables / fit to data

Multi-step matching

Interface with EFT pheno codes and experimental fits

streamlining future BSM analyses

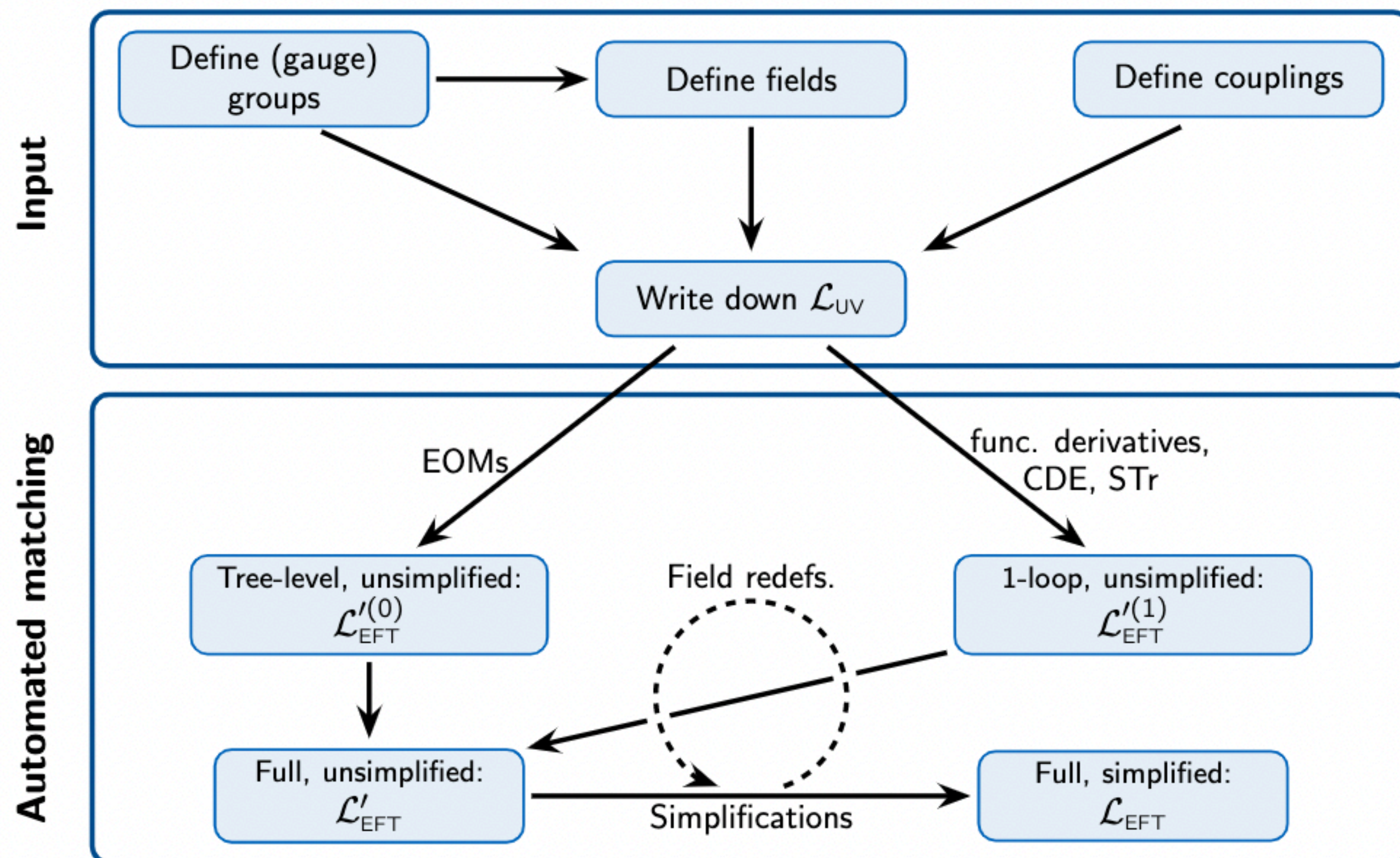
Thank you



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



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

[JFM, König, Pagès, Thomsen, Wilsch, [2212.04510](https://arxiv.org/abs/2212.04510)]

<https://gitlab.com/matchete/matchete>

An example

SM + Vector-like lepton

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

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] x Bar@l[i, p] ** PR ** EE[] x H[i] // PlusHc;
Lint // NiceForm
```

Out[7]//NiceForm=

$$-\bar{y}E^p \bar{H}_i (\bar{E}E \cdot P_L \cdot l^{ip}) - yE^p H^i (\bar{l}_i^p \cdot P_R \cdot EE)$$

Define full UV Lagrangian

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

Out[9]//NiceForm=

$$\begin{aligned} & -\frac{1}{4} B^{\mu\nu 2} - \frac{1}{4} G^{\mu\nu A 2} - \frac{1}{4} W^{\mu\nu I 2} + D_\mu \bar{H}_i D_\mu H^i + \mu^2 \bar{H}_i H^i + i (\bar{d}_a^p \cdot \gamma_\mu P_R \cdot D_\mu d^{ap}) + i (\bar{e}^p \cdot \gamma_\mu P_R \cdot D_\mu e^p) + \\ & i (\bar{E}E \cdot \gamma_\mu \cdot D_\mu EE) - ME (\bar{E}E \cdot EE) + i (\bar{l}_i^p \cdot \gamma_\mu P_L \cdot D_\mu l^{ip}) + i (\bar{q}_{ai}^p \cdot \gamma_\mu P_L \cdot D_\mu q^{aip}) + i (\bar{u}_a^p \cdot \gamma_\mu P_R \cdot D_\mu u^{ap}) - \\ & \frac{1}{2} \lambda \bar{H}_i \bar{H}_j H^i H^j - \bar{Y}d^{pr} \bar{H}_i (\bar{d}_a^r \cdot P_L \cdot q^{aip}) - \bar{Y}e^{pr} \bar{H}_i (\bar{e}^r \cdot P_L \cdot l^{ip}) - Y_e^{pr} H^i (\bar{l}_i^p \cdot P_R \cdot e^r) - Y_d^{pr} H^i (\bar{q}_{ai}^p \cdot P_R \cdot d^{ar}) - \\ & Y_u^{pr} \bar{H}_i (\bar{q}_{aj}^p \cdot P_R \cdot u^{ar}) \varepsilon^{ji} - \bar{Y}u^{pr} H^j (\bar{u}_a^r \cdot P_L \cdot q^{aip}) \bar{\varepsilon}_{ij} - \bar{y}E^p \bar{H}_i (\bar{E}E \cdot P_L \cdot l^{ip}) - yE^p H^i (\bar{l}_i^p \cdot P_R \cdot EE) \end{aligned}$$

An example: SM + Vector-like lepton

Main matching routine

```
In[9]:= LEFT = Match[LUV, LoopOrder → 1, EFTOrder → 6] /.  $\epsilon^{-1} \rightarrow 0$ ;
```

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=

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

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

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
- Significant performance improvements!

[Theory: JFM, Palavric, Sánchez, Thomsen, WIP]

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=

$$-\frac{1}{4} B^{\mu\nu 2} - \frac{1}{4} G^{\mu\nu A 2} - \frac{1}{4} W^{\mu\nu I 2} + D_\mu H_i D_\mu H^i + \mu^2 H_i H^i + i (\bar{d}_a^p \cdot \gamma_\mu P_R \cdot D_\mu d^{ap}) + i (\bar{e}^p \cdot \gamma_\mu P_R \cdot D_\mu e^p) + i (\bar{l}_i^p \cdot \gamma_\mu P_L \cdot D_\mu l^{ip}) + i (\bar{q}_{ai}^p \cdot \gamma_\mu P_L \cdot D_\mu q^{aip}) + i (\bar{u}_a^p \cdot \gamma_\mu P_R \cdot D_\mu u^{ap}) - \frac{1}{2} \lambda H_i H_j H^i H^j - \bar{Y}d^{pr} H_i (\bar{d}_a^r \cdot P_L \cdot q^{aip}) - \bar{Y}e^{pr} H_i (\bar{e}^r \cdot P_L \cdot l^{ip}) - Yd^{pr} H^i (\bar{l}_i^p \cdot P_R \cdot e^r) - Yd^{pr} H^i (\bar{q}_{ai}^p \cdot P_R \cdot d^{ar}) - Yu^{pr} H_i (\bar{q}_{aj}^p \cdot P_R \cdot u^{ar}) \varepsilon^{ji} - \bar{Y}u^{pr} H^j (\bar{u}_a^r \cdot P_L \cdot q^{aip}) \bar{\varepsilon}_{ij}$$

UVDivergentAction[LSM, EFTOrder → 4] // NiceForm

eForm=

$$\frac{1}{\epsilon} \left(-\frac{41}{24} \hbar gY^2 B^{\mu\nu 2} + \frac{5}{2} \hbar gs^2 G^{\mu\nu A 2} + \frac{31}{24} \hbar gL^2 W^{\mu\nu I 2} + \frac{1}{8} \hbar \mu^2 (15 gL^2 + 5 gY^2 - 24 \bar{Y}d^{pr} Yd^{pr} - 8 \bar{Y}e^{pr} Ye^{pr} - 24 \bar{Y}u^{pr} Yu^{pr} - 24 \lambda) H_i H^i + \hbar \left(\frac{9}{16} gL^4 - \frac{1}{16} gY^4 - 3 \bar{Y}d^{pr} \bar{Y}d^{st} Yd^{pt} Yd^{sr} - \bar{Y}e^{pr} \bar{Y}e^{st} Ye^{pt} Ye^{sr} - 3 \bar{Y}u^{pr} \bar{Y}u^{st} Yu^{pt} Yu^{sr} - \frac{5}{8} \lambda gY^2 + 3 \bar{Y}d^{pr} Yd^{pr} \lambda + \bar{Y}e^{pr} Ye^{pr} \lambda + 3 \bar{Y}u^{pr} Yu^{pr} \lambda + 3 \lambda^2 - \frac{1}{8} gL^2 (gY^2 + 15 \lambda) \right) H_i H_j H^i H^j + \hbar \left(\frac{3}{4} (\bar{Y}d^{ps} \bar{Y}d^{tr} Yd^{ts} - \bar{Y}d^{sr} \bar{Y}u^{pt} Yu^{st}) + \frac{1}{144} \bar{Y}d^{pr} (-27 gL^2 + 192 gs^2 - 17 gY^2 + 216 \bar{Y}d^{st} Yd^{st} + 72 \bar{Y}e^{st} Ye^{st} + 216 \bar{Y}u^{st} Yu^{st}) \right) H_i (\bar{d}_a^r \cdot P_L \cdot q^{aip}) + \frac{1}{16} \hbar (12 \bar{Y}e^{ps} \bar{Y}e^{tr} Ye^{ts} + \bar{Y}e^{pr} (-3 gL^2 + 7 gY^2 + 24 \bar{Y}d^{st} Yd^{st} + 8 \bar{Y}e^{st} Ye^{st} + 24 \bar{Y}u^{st} Yu^{st})) 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 \bar{Y}d^{st} Yd^{st} Ye^{rp} - 12 \bar{Y}e^{st} Ye^{rt} Ye^{sp} - 8 \bar{Y}e^{st} Ye^{rp} Ye^{st} - 24 Ye^{rp} \bar{Y}u^{st} Yu^{st}) H^i (\bar{l}_i^r \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 \bar{Y}d^{st} Yd^{rt} Yd^{sp} + 216 \bar{Y}d^{st} Yd^{rp} Yd^{st} + 72 Yd^{rp} \bar{Y}e^{st} Ye^{st} - 108 Yd^{sp} \bar{Y}u^{st} Yu^{rt} + 216 Yd^{rp} \bar{Y}u^{st} Yu^{st}) H^i (\bar{q}_{ai}^r \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 \bar{Y}d^{st} Yd^{st} Yu^{rp} + 72 \bar{Y}e^{st} Ye^{st} Yu^{rp} - 108 \bar{Y}d^{st} Yd^{rt} Yu^{sp} + 108 \bar{Y}u^{st} Yu^{rt} Yu^{sp} + 216 \bar{Y}u^{st} Yu^{rp} Yu^{st}) H_i (\bar{q}_{aj}^r \cdot P_R \cdot u^{ap}) \varepsilon^{ji} + \hbar \left(\frac{1}{144} \bar{Y}u^{pr} (-27 gL^2 + 192 gs^2 + 7 gY^2 + 216 \bar{Y}d^{st} Yd^{st} + 72 \bar{Y}e^{st} Ye^{st} + 216 \bar{Y}u^{st} Yu^{st}) + \frac{3}{4} \bar{Y}u^{tr} (-\bar{Y}d^{ps} Yd^{ts} + \bar{Y}u^{ps} Yu^{ts}) \right) H^j (\bar{u}_a^r \cdot P_L \cdot q^{aip}) \bar{\varepsilon}_{ij} \right)$$

*Ghost loops are not yet included

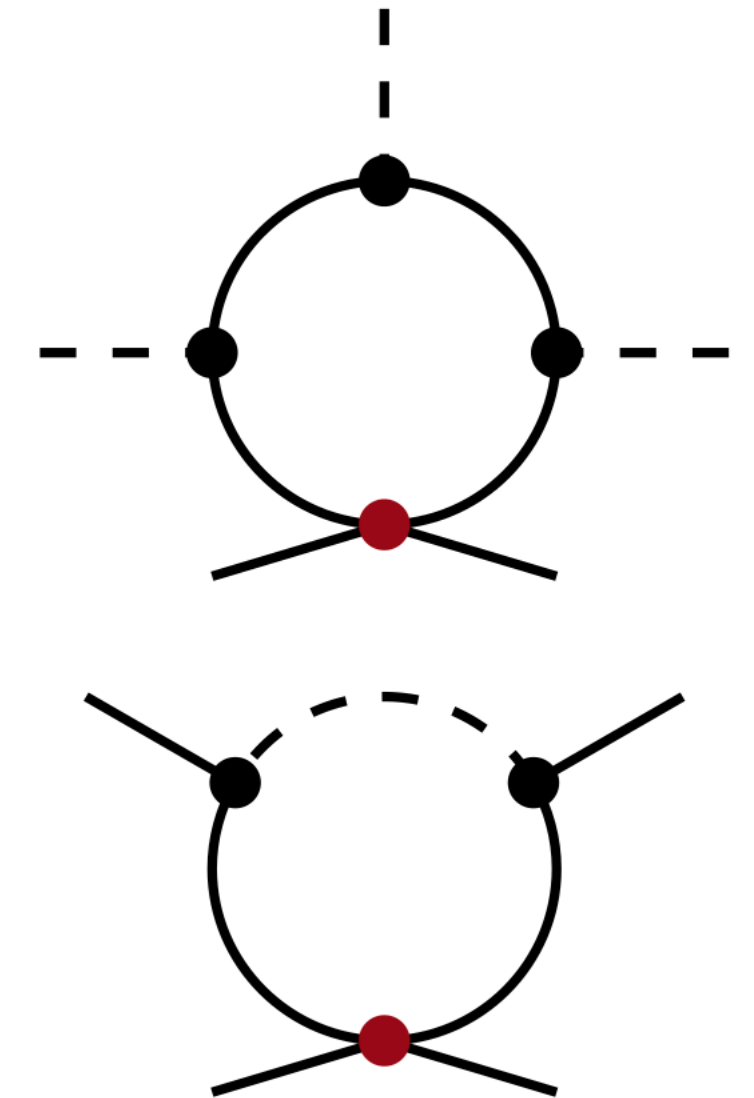
Work in progress: Fierz (and other) identities and evanescent contributions

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

Application to the SMEFT: JFM, König, Pagès, Thomsen, Wilsch, [2211.09144](#)

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

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



- Initial step: automatic identification of evanescent operators!

*Sample diagrams

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

OutForm=

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

```
GreensSimplify[redOp, Basis4D -> Evanescent] // NiceForm
```

OutForm=

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

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=

$$\mu \rightarrow \sqrt{-2 \hbar \bar{y} E^P y E^P M E^2 - 2 \hbar \frac{1}{\epsilon} \bar{y} E^P y E^P M E^2 + \mu^2 - 2 \hbar \bar{y} E^P y E^P M E^2 \text{Log}\left[\frac{\mu^2}{M E^2}\right]}$$

$$\lambda \rightarrow \lambda$$

$$\text{CHBox} \rightarrow -\frac{1}{30} \hbar g Y^4 \frac{1}{M E^2} - \frac{5}{24} \hbar \bar{y} E^P y E^P g L^2 \frac{1}{M E^2} + \frac{13}{72} \hbar \bar{y} E^P y E^P g Y^2 \frac{1}{M E^2} - \frac{1}{3} \hbar \bar{y} E^P \bar{y} E^r y E^P y E^r \frac{1}{M E^2} + \frac{3}{2} \hbar \bar{y} E^P y E^r \bar{y} E^{rs} y E^{ps} \frac{1}{M E^2} - \frac{1}{4} \hbar \bar{y} E^P y E^P g L^2 \frac{1}{M E^2} \text{Log}\left[\frac{\mu^2}{M E^2}\right] + \frac{1}{12} \hbar \bar{y} E^P y E^P$$

$$\text{CHD} \rightarrow -\frac{2}{15} \hbar g Y^4 \frac{1}{M E^2} + \frac{13}{18} \hbar \bar{y} E^P y E^P g Y^2 \frac{1}{M E^2} - \frac{1}{2} \hbar \bar{y} E^P \bar{y} E^r y E^P y E^r \frac{1}{M E^2} + \frac{1}{2} \hbar \bar{y} E^P y E^r \bar{y} E^{rs} y E^{ps} \frac{1}{M E^2} + \frac{1}{3} \hbar \bar{y} E^P y E^P g Y^2 \frac{1}{M E^2} \text{Log}\left[\frac{\mu^2}{M E^2}\right] + \hbar \bar{y} E^P y E^r \bar{y} E^{rs} y E^{ps} \frac{1}{M E^2} \text{Log}\left[\frac{\mu^2}{M E^2}\right]$$

$$\text{CH} \rightarrow \frac{1}{3} \hbar \bar{y} E^P \bar{y} E^r \bar{y} E^s y E^P y E^r y E^s \frac{1}{M E^2} + 2 \hbar \bar{y} E^P \bar{y} E^r y E^P y E^s \bar{y} E^{st} y E^{rt} \frac{1}{M E^2} - 2 \hbar \bar{y} E^P y E^r \bar{y} E^{rs} \bar{y} E^{tu} y E^{pu} y E^{ts} \frac{1}{M E^2} - \frac{5}{18} \hbar \bar{y} E^P y E^P \lambda g L^2 \frac{1}{M E^2} - \hbar \bar{y} E^P \bar{y} E^r y E^P y E^r \lambda \frac{1}{M E^2} + \hbar \bar{y} E^P$$

$$\text{CHB} \rightarrow \frac{1}{8} \hbar \bar{y} E^P y E^P g Y^2 \frac{1}{M E^2}$$

$$\text{CHG} \rightarrow 0$$

$$\text{cG} \rightarrow 0$$

$$\text{CHWB} \rightarrow -\frac{1}{6} \hbar g L g Y \bar{y} E^P y E^P \frac{1}{M E^2}$$

$$\text{CHW} \rightarrow \frac{1}{24} \hbar \bar{y} E^P y E^P g L^2 \frac{1}{M E^2}$$

$$\text{cW} \rightarrow 0$$

$$\text{CHBt} \rightarrow 0$$

$$\text{CHGt} \rightarrow 0$$

$$\text{CHWtB} \rightarrow 0$$

$$\text{CHWt} \rightarrow 0$$

$$\text{cGt} \rightarrow 0$$

~~0~~ SMEFT coefficients

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