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Matchmakereft

An automated tool for EFTs

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High Energy Theory

Universidad de Granada

What is experiment telling us?

- We know (believe) there has to be new physics BSM.

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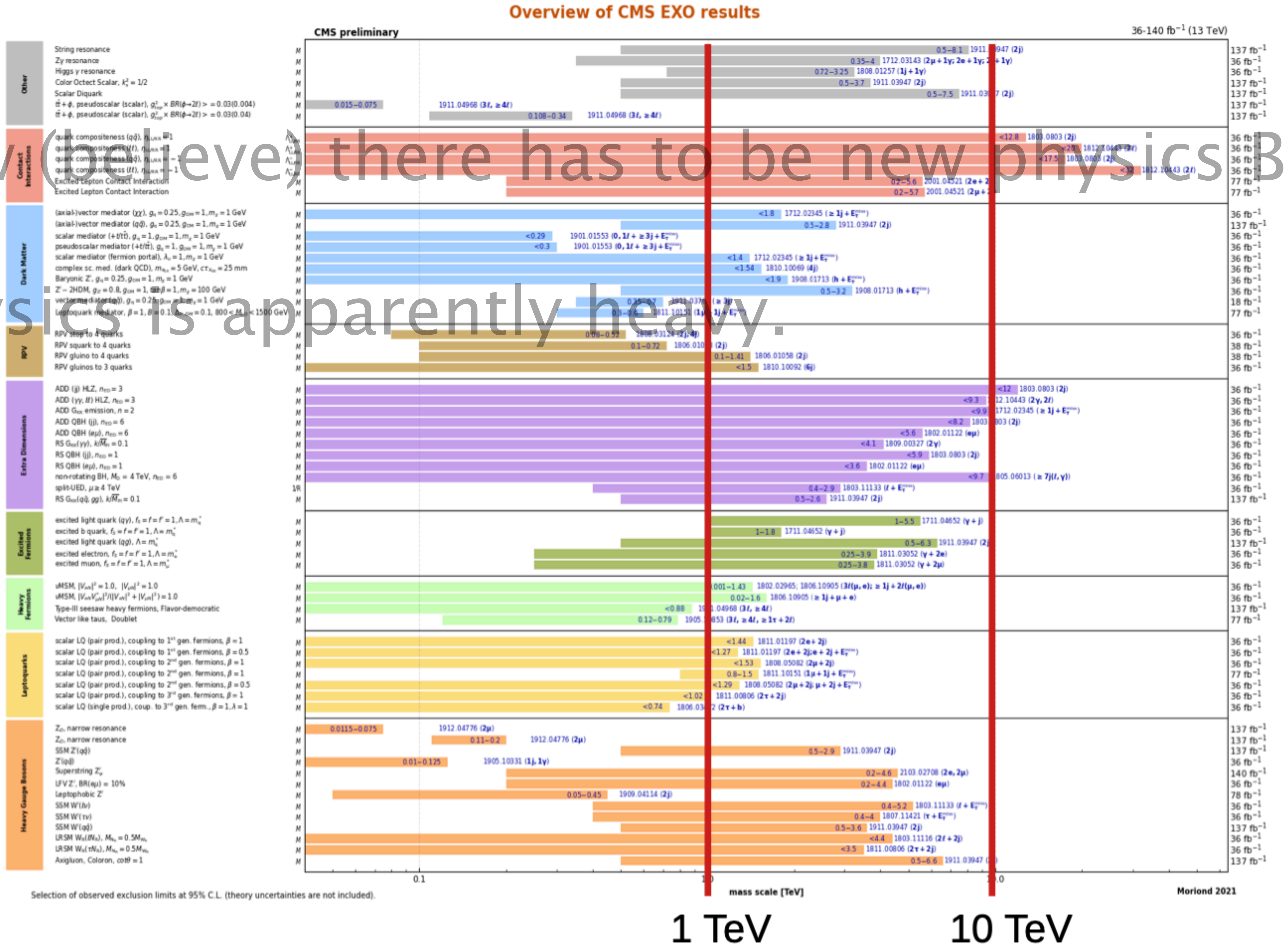

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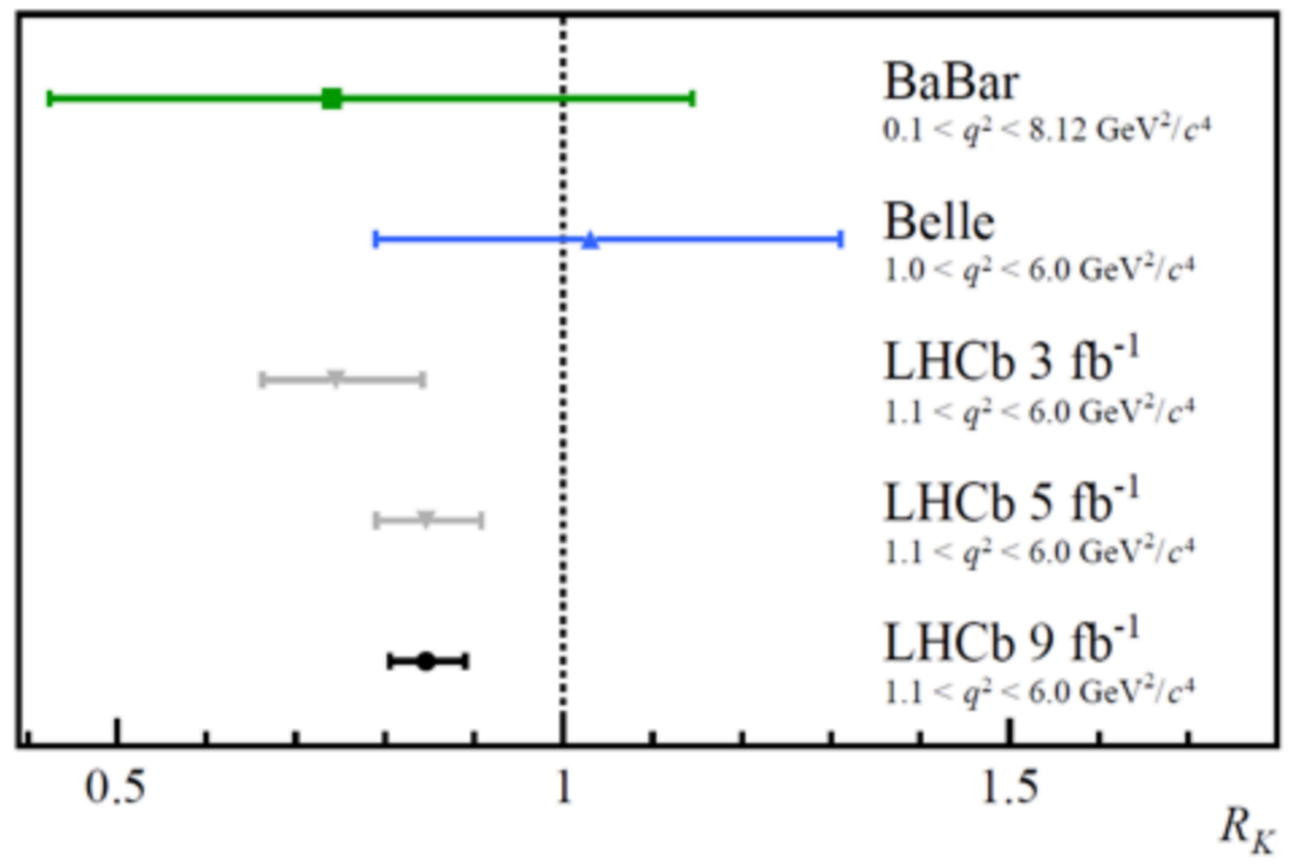
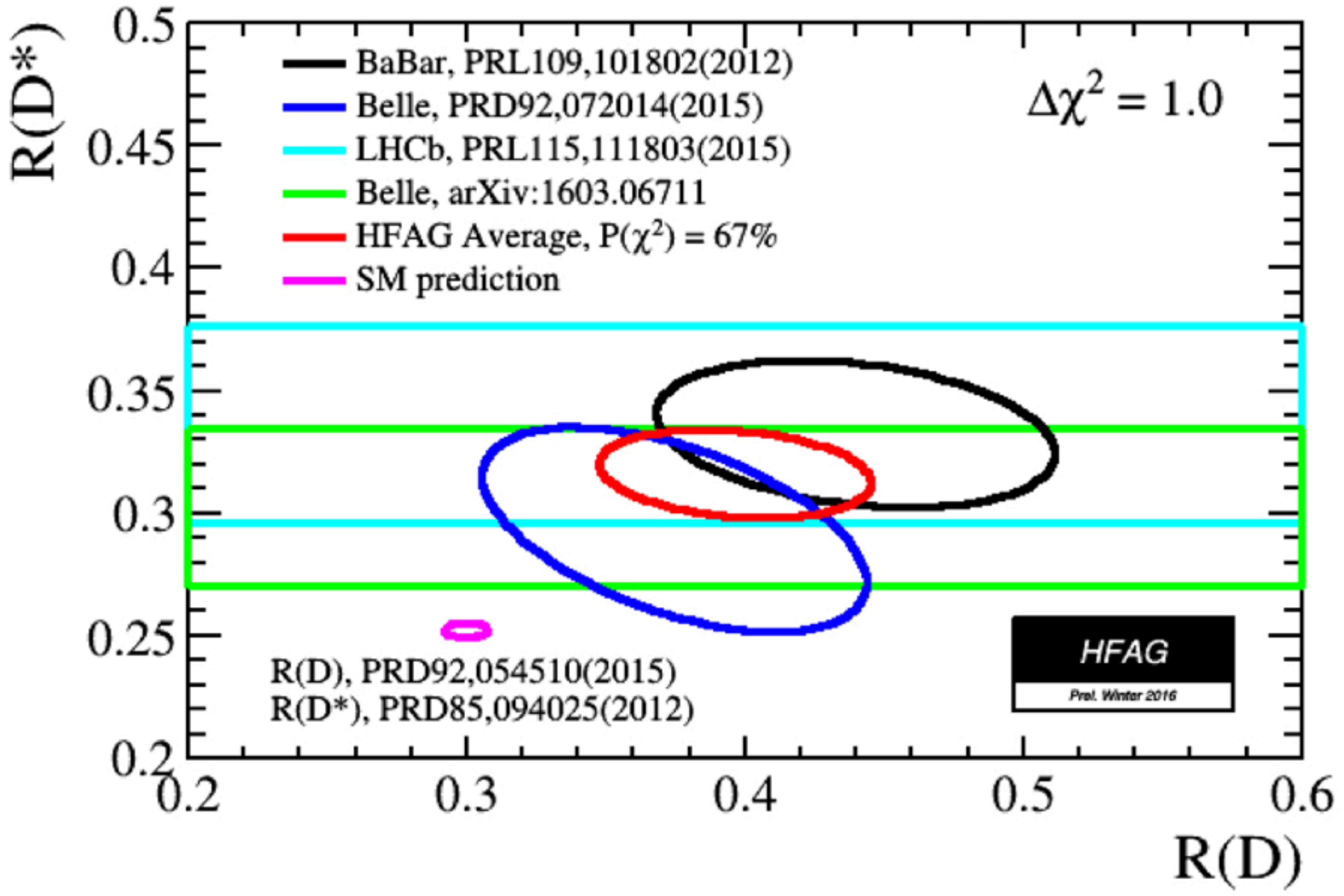
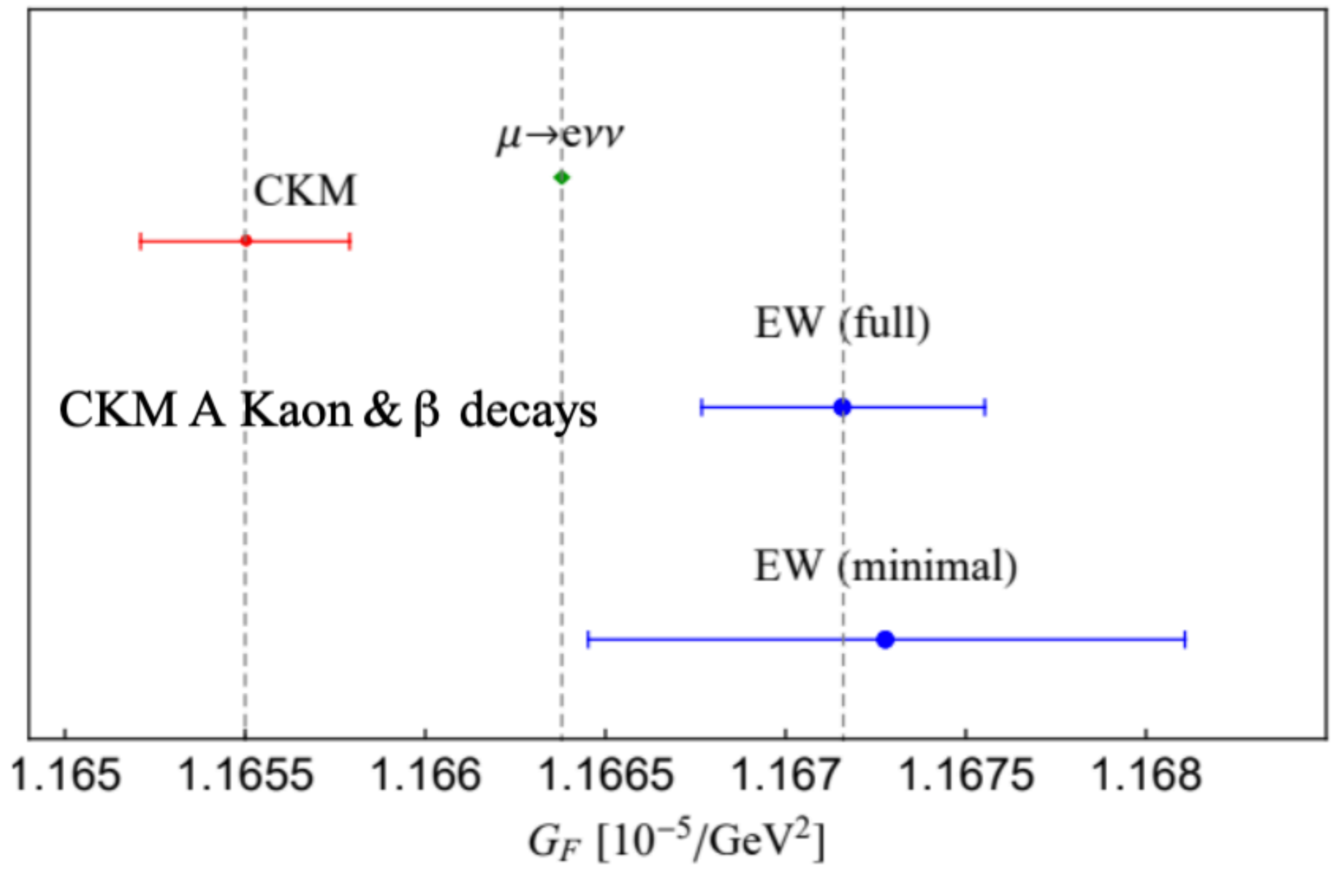






Why EFTs?

- EFTs allow us to split the problem in two *independent* steps:
- **Bottom-up**: agnostic parametrization of experimental data in terms of WC.
    - The only input is the EFT.
    - Observables are computed just once!
- **Top-down**: re-introduce dependence with models through matching.

The problem with EFTs

UV Theory

$M_1, \ldots, M_n, m$

MATCHING $\mu = M_1$

RGE ↓

$[\ldots]$

RGE ↓

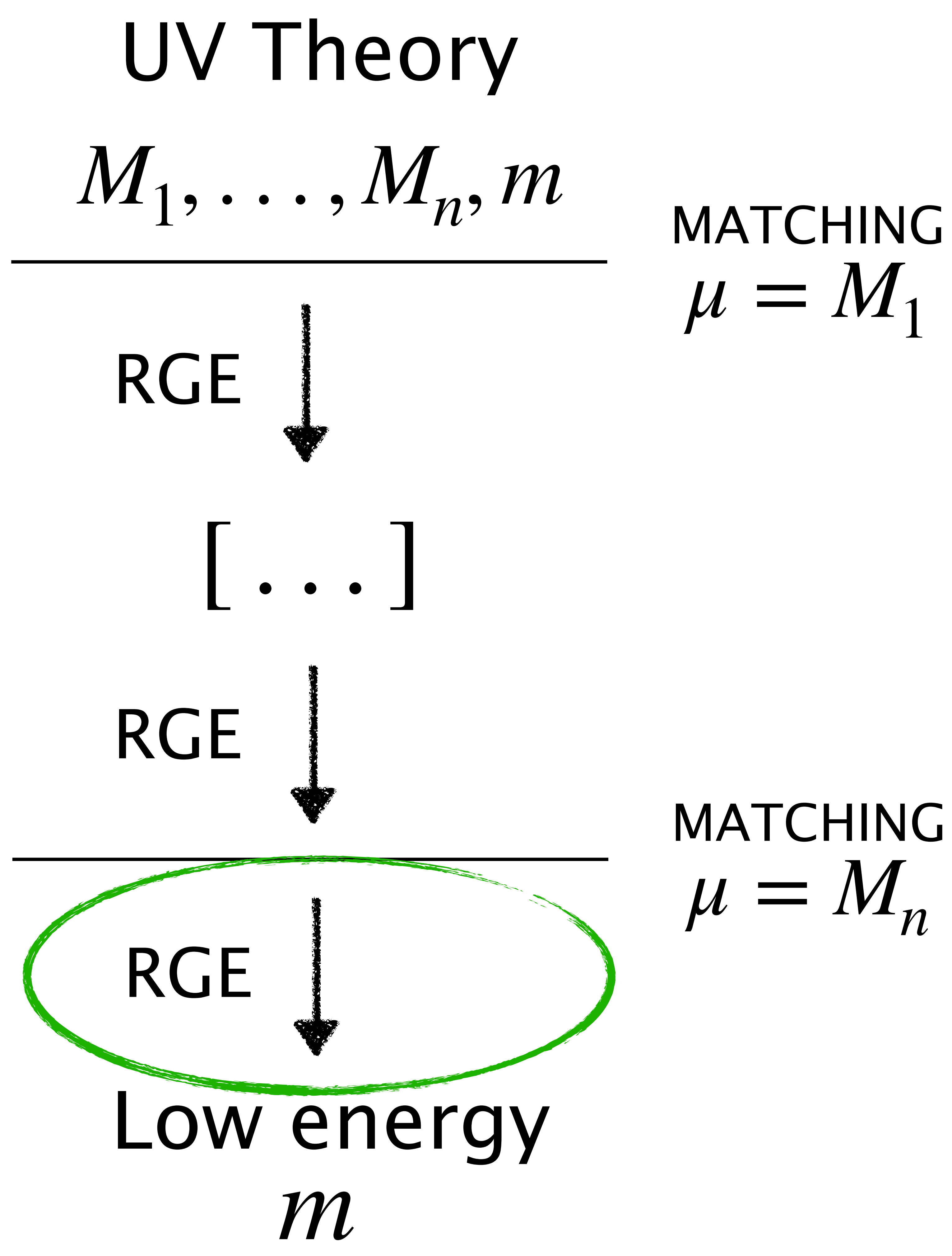
MATCHING $\mu = M_n$

RGE ↓

Low energy

m

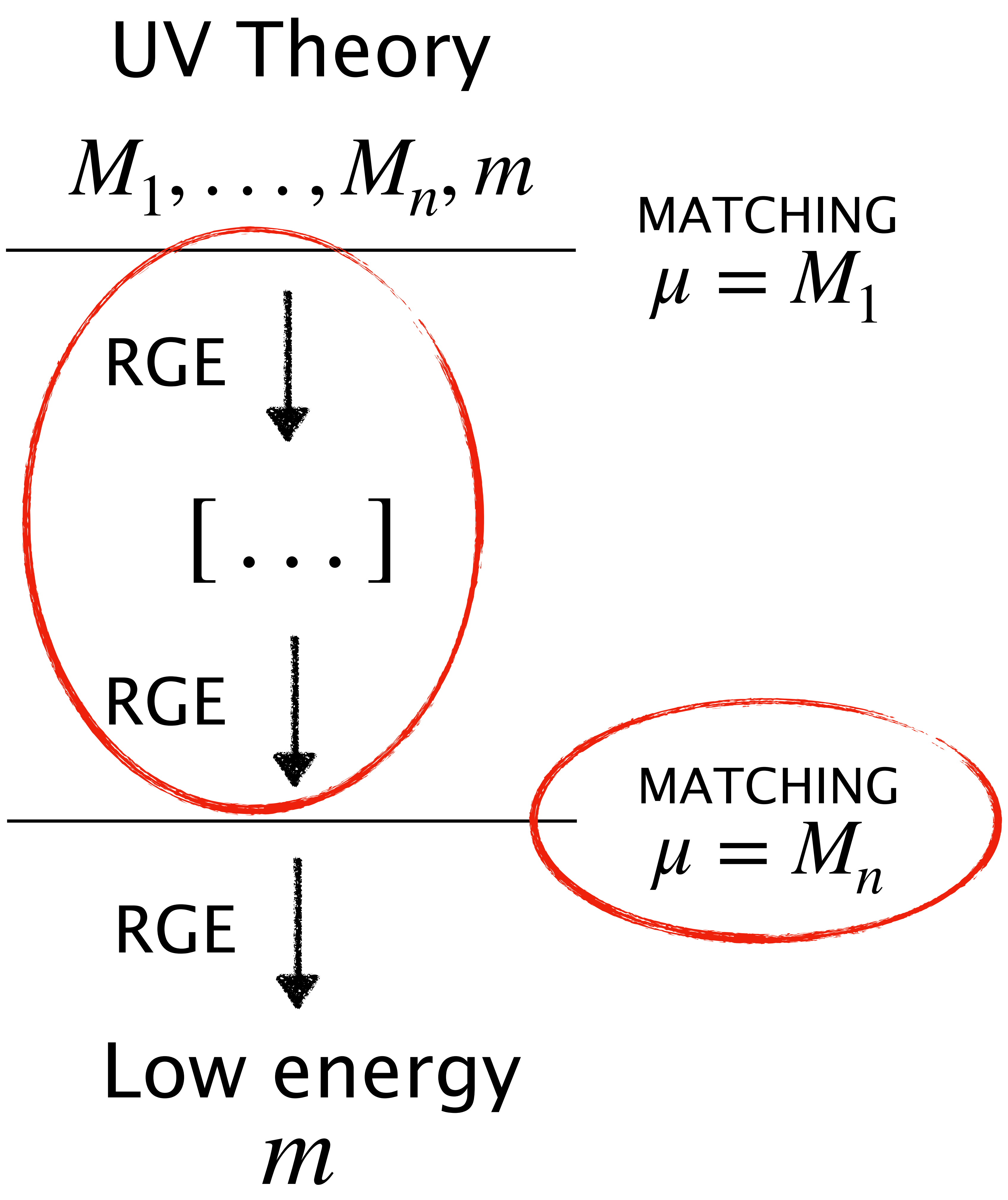
The problem with EFTs



- One-loop running known for LEFT,SMEFT
- This process is automated.

The problem with EFTs

- Tree-level matching known and classified.
- One-loop matching highly non-trivial.
- Infinite models can contribute.



Matchmakereft: Automated matching

`Matchmakereft`: automated tree-level and one-loop matching

Adrián Carmona[a,b], Achilleas Lazopoulos[b], Pablo Olgoso[a] and José Santiago[a]

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`Matchmakereft`: automated tree-level and one-loop matching

Adrián Carmona[a,b], Achilleas Lazopoulos[b], Pablo Olgoso[a] and José Santiago[a]

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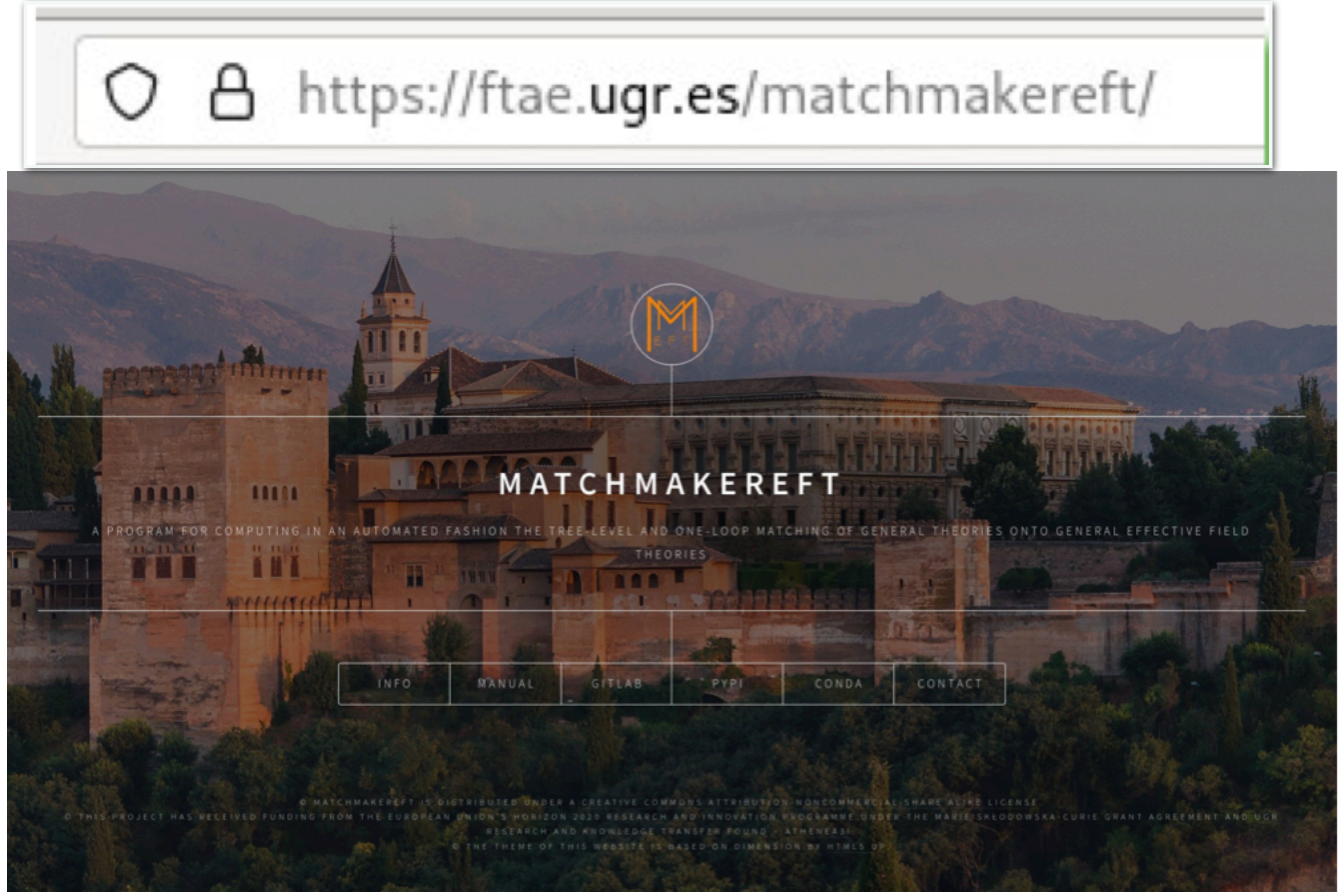
Abstract

We introduce `matchmakereft`, a fully automated tool to compute the tree-level and one-loop matching of arbitrary models onto arbitrary effective theories. `Matchmakereft` performs an off-shell matching, using diagrammatic methods and the BFM when gauge theories are involved. The large redundancy inherent to the off-shell matching together with explicit gauge invariance offers a significant number of non-trivial checks of the results provided. These results are given in the physical basis but several intermediate results, including the matching in the Green basis before and after canonical normalization, are given for flexibility and the possibility of further cross-checks. As a non-trivial example we provide the complete matching in the Warsaw basis up to one loop of an extension of the Standard Model with a charge −1 vector-like lepton singlet. `Matchmakereft` has been built with generality, flexibility and efficiency in mind. These ingredients allow `matchmakereft` to have many applications beyond the matching between models and effective theories. Some of these applications include the one-loop renormalization of arbitrary theories (including the calculation of the one-loop renormalization group equations for arbitrary theories); the translation between different Green bases for a fixed effective theory or the check of (off-shell) linear independence of the operators in an effective theory. All these applications are performed in a fully automated way by `matchmakereft`.



Matchmakereft: Automated matching

- Matchmakereft is a fully automated tool to perform tree-level and one-loop matching between arbitrary models and arbitrary EFTs.

  [Carmona, Lazopoulos, PO, Santiago '21]

- Matching is performed off-shell, diagrammatically and using BFM.

- Flexible, reliable, fast and powerful:

  - Less than 1 minute to compute the one-loop matching of the scalar singlet extension of the SM (which was correctly computed only after some iterations in the literature).

[Henning, Lu, Murayama '14]

[Ellis, Quevillon, You, Zhang '17]

[Jiang, Craig, Li, Sutherland '18]

[Haisch, Ruhdorfer, Salvioni, Venturini, Weiler '20]

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- Matching is performed off-shell, diagrammatically and using BFM.

- Flexible, reliable, fast and powerful:

  - Already used in several highly non-trivial calculations.

[Chala, Guedes, Ramos, Santiago '20] (ALPs RGEs)

[Chala, Guedes, Ramos, Santiago '21] (Dim 8 SMEFT RGEs)

[Chala, Santiago,'21] (Positivity bounds dim 8)

[Chala, Díaz-Carmona, Guedes '21] (Green basis dim 8)

[Bakshi, Chala, Díaz-Carmona, Guedes '22] (Dim 8 SMEFT RGEs)

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- Matching is performed off-shell, diagrammatically and using BFM.

- Flexible, reliable, fast and powerful:

  - Several cross-checks have been performed.

Scalar Singlet [Haisch, Ruhdorfer, Salvioni, Venturini, Weiler '20]

SMEFT RGEs [Jenkins, Manohar, Trott '13]

Type I Seesaw [Zhang, Zhou '21]

Matchmakereft: Automated matching

- Matchmakereft is a fully automated tool to perform tree-level and one-loop matching between arbitrary models and arbitrary EFTs.
  [Carmona, Lazopoulos, PO, Santiago ’21]

- Matching is performed off-shell, diagrammatically and using BFM.

- Flexible, reliable, fast and powerful.

- It can also be used to:
  - Compute one-loop RGEs of arbitrary EFTs.
  - Check off-shell (in)dependence of a set of operators.
    [Chala, Díaz-Carmona, Guedes ’21] (Green basis dim 8)

Inside Matchmakereft

- FeynRules model.

Inside Matchmakereft

- FeynRules model.
    - Particle content and masses.

```
F[105] == {
  ClassName        -> HL,
  Indices          -> {Index[SU2D]},
  SelfConjugate    -> False,
  QuantumNumbers -> {Y -> -1/2},
  FullName         -> "heavy",
  Mass             -> ML,
  Width            -> 0
},

S[108] == {
  ClassName        -> HT,
  Indices          -> {},
  SelfConjugate    -> True,
  FullName         -> "heavy",
  Mass             -> MS,
  Width            -> 0
}
```

Inside Matchmakereft

- FeynRules model.
    - Particle content and masses.
    - Lagrangian.

```
yuk =
yD[ff1] HLbar[sp1,ii].LR[sp1,ff1] Phi[ii]
+ yT[ff1] HLbar[sp1,ii].LL[sp1,ii,ff1] HT;

yuk2=
YHL HLbar[sp1,ii].HL[sp1,ii] HT;

 yuk+HC[yuk]+yuk2
```

Inside Matchmakereft

- FeynRules model.

```
qLbar  dR  Phi  (-I/2)*deltaF[ll1,ll3]*deltaF[mm1,mm2]*gam[yy1,SIX,yy2]*yd[flfl1,flfl2]
HLbar  eR  Phi  (I/2)*deltaF[ll1,ll3]*gam[yy1,SIX,yy2]*yD[flfl2]
lLbar  eR  Phi  (-I/2)*deltaF[ll1,ll3]*gam[yy1,SIX,yy2]*yl[flfl1,flfl2]
HLbar  lL  HT  (I/2)*deltaF[ll1,ll2]*gam[yy1,SEVEN,yy2]*yT[flfl2]
qLbar  uR  Phibar  (-I/2)*deltaF[mm1,mm2]*eps[ll1,ll3]*gam[yy1,SIX,yy2]*yu[flfl1,flfl2]
lLbar  lL  B  (-I/4)*g1*deltaF[flfl1,flfl2]*deltaF[ll1,ll2]*gam[yy1,mumu3,SEVEN,yy2]
lLbar  lL  BQuantum  (-I/4)*g1*deltaF[flfl1,flfl2]*deltaF[ll1,ll2]*gam[yy1,mumu3,SEVEN,yy2]
lLbar  lL  Wi  (I/2)*g2*deltaF[flfl1,flfl2]*gam[yy1,mumu3,SEVEN,yy2]*Ta[nn3,ll1,ll2]
lLbar  lL  WiQuantum  (I/2)*g2*deltaF[flfl1,flfl2]*gam[yy1,mumu3,SEVEN,yy2]*Ta[nn3,ll1,ll2]
qLbar  qL  B  (I/12)*g1*deltaF[flfl1,flfl2]*deltaF[ll1,ll2]*deltaF[mm1,mm2]*gam[yy1,mumu3,SEVE
qLbar  qL  BQuantum  (I/12)*g1*deltaF[flfl1,flfl2]*deltaF[ll1,ll2]*deltaF[mm1,mm2]*gam[yy1,mum
qLbar  qL  G  (I/2)*g3*deltaF[flfl1,flfl2]*deltaF[ll1,ll2]*gam[yy1,mumu3,SEVEN,yy2]*T[aa3,mm1,
qLbar  qL  GQuantum  (I/2)*g3*deltaF[flfl1,flfl2]*deltaF[ll1,ll2]*gam[yy1,mumu3,SEVEN,yy2]*T[a
qLbar  qL  Wi  (I/2)*g2*deltaF[flfl1,flfl2]*deltaF[mm1,mm2]*gam[yy1,mumu3,SEVEN,yy2]*Ta[nn3,ll
qLbar  qL  WiQuantum  (I/2)*g2*deltaF[flfl1,flfl2]*deltaF[mm1,mm2]*gam[yy1,mumu3,SEVEN,yy2]*Ta
eRbar  eR  B  (-I/2)*g1*deltaF[flfl1,flfl2]*gam[yy1,mumu3,SIX,yy2]
```

Inside Matchmakereft

- FeynRules model (+ gauge file).

```
replacegaugedata = {
       fsu2 -> SparseArray[Automatic, {3, 3, 3}, 0,
       {1, {{0, 2, 4, 6}, {{2, 3}, {3, 2}, {1, 3}, {3, 1}, {1, 2}, {2, 1}}},
        {1, -1, -1, 1, 1, -1}}],
        Ta -> SparseArray[Automatic, {3, 2, 2}, 0,
       {1, {{0, 2, 4, 6}, {{1, 2}, {2, 1}, {1, 2}, {2, 1}, {1, 1}, {2, 2}}},
        {1/2, 1/2, -I/2, I/2, 1/2, -1/2}}],
        Tabar -> SparseArray[Automatic, {3, 2, 2}, 0,
       {1, {{0, 2, 4, 6}, {{1, 2}, {2, 1}, {1, 2}, {2, 1}, {1, 1}, {2, 2}}},
        {1/2, 1/2, I/2, -I/2, 1/2, -1/2}}],
     Ta4 -> SparseArray[Automatic, {3, 4, 4}, 0,
       {1, {{0, 6, 12, 16}, {{1, 2}, {2, 1}, {2, 3}, {3, 2}, {3, 4}, {4, 3},
         {1, 2}, {2, 1}, {2, 3}, {3, 2}, {3, 4}, {4, 3}, {1, 1}, {2, 2}, {3,
         3}, {4, 4}}}, {Sqrt[3]/2, Sqrt[3]/2, 1, 1, Sqrt[3]/2, Sqrt[3]/2,
         (-I/2)*Sqrt[3], (I/2)*Sqrt[3], -I, I, (-I/2)*Sqrt[3], (I/2)*Sqrt[3],
         3/2, 1/2, -1/2, -3/2}}],
```

Inside Matchmakereft

- FeynRules model.
- QGRAF.
  - Computes all possible diagrams.

```
(-1)*
 cpol(lLbar(-1,p1))*
 cpol(lL(-3,p2))*
 cpol(lL(-5,p3))*
 cpol(lLbar(-7,p4))*

 prop(HL(1,-k1),HLbar(2,-k1))*
 prop(HT(3,k1-p1),HT(4,k1-p1))*
 prop(HT(5,-k1-p2),HT(6,-k1-p2))*
 prop(HL(7,-k1+p1+p3),HLbar(8,-k1+p1+p3))*
 v3(lLbar(-1,p1),HL(1,-k1),HT(3,k1-p1))*
 v3(HLbar(2,k1),lL(-3,p2),HT(5,-k1-p2))*
 v3(HLbar(8,k1-p1-p3),lL(-5,p3),HT(4,-k1+p1))*
 v3(lLbar(-7,p4),HL(7,-k1+p1+p3),HT(6,k1+p2)),
```

Inside Matchmakereft

- FeynRules model.
- QGRAF.
- FORM.
    - Expansion by regions.
    - Gamma processing.

Inside Matchmakereft

- FeynRules model.
- QGRAF.
- FORM.
- Mathematica.
    - Solve for Wilson Coefficients.
    - Canonical Normalization.
    - Redundancies.

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$$\text{alpha03W} \to -\frac{\text{g2}^3\left(\text{MF}^2+2\,\text{ML}^2\right)\text{onelooporder}}{2880\,\text{MF}^2\,\text{ML}^2\,\pi^2}$$

Let's see how it works!

Future developments

- Today, the main bottlenecks are:
  - Model generation.
  - Reduction to physical basis (redundancies).

- Both fronts are being already tackled:
  - Interplay with Sym2Int (with R. Fonseca) to automatically generate models.
  - On-shell matching (with M. Chala) to compute the redundancies.

Conclusions

- EFTs are a very efficient way to look for new physics.
- Comparing theory vs experiment at one-loop is a highly non-trivial multi-step problem.
- Matchmakereft is an automated tool to overcome this difficulties.
- Its output can be easily combined with other tools to study the low energy phenomenology of any model.
- We encourage you to try!