DsixTools

The SMEFT Toolkit

Avelino Vicente
IFIC – CSIC / U. Valencia

In collaboration with **A. Celis**, **J. Fuentes-Martín** and **J. Virto**

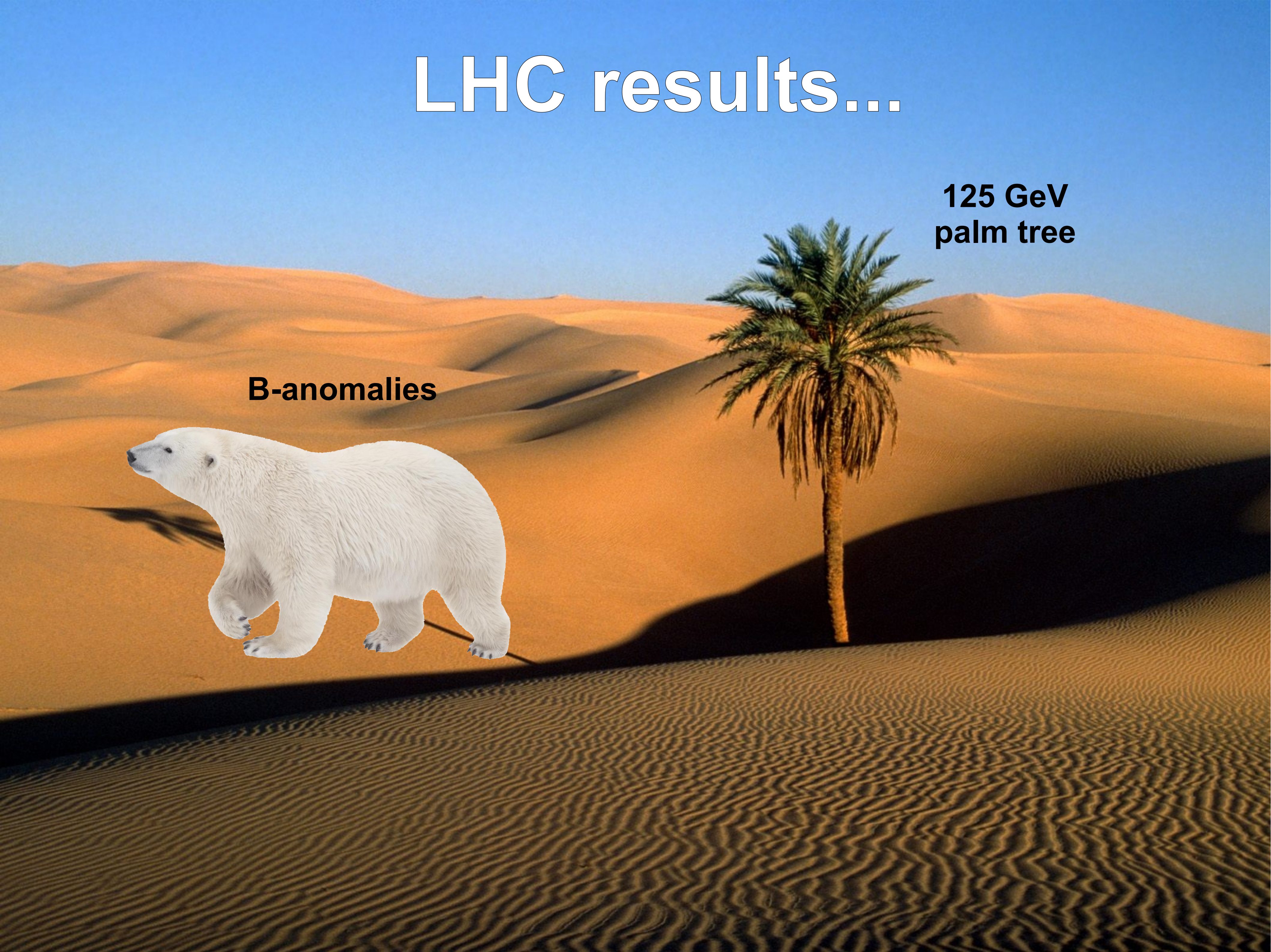
Manual: arXiv:1704.04504
Website: https://dsixtools.github.io/

Introduction

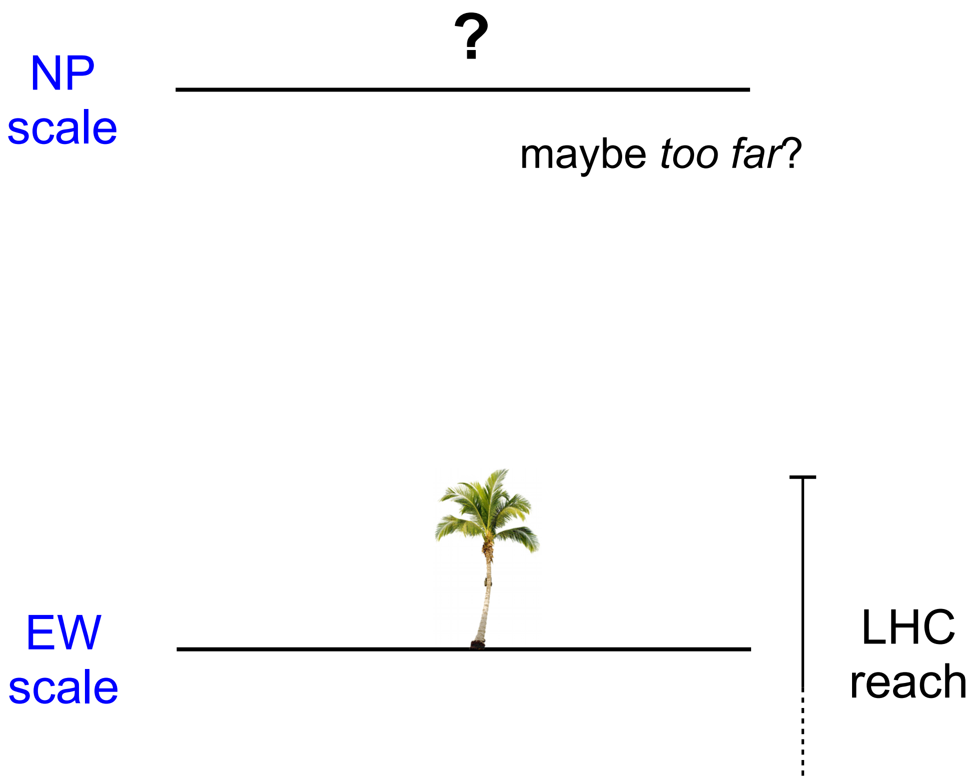
Before the LHC started operating we all hoped for great discoveries...


Microscopic
black holes
Extra dimensions
Supersymmetry
Compositeness
LHC expectations


LHC results...
125 GeV
palm tree


LHC results...
125 GeV
palm tree
B-anomalies

A message from Nature?



⇒ Effective Field Theory approach

SMEFT

See talks by
Jordy de Vries,
Adam Falkowski (?)
and Andrzej Buras

The SMEFT

$$\mathcal{L} = \mathcal{L}_{\text{SM}}^{(4)} + \frac{1}{\Lambda} \sum_k C_k^{(5)} Q_k^{(5)} + \frac{1}{\Lambda^2} \sum_k C_k^{(6)} Q_k^{(6)} + \mathcal{O}\left(\frac{1}{\Lambda^3}\right)$$

Gauge invariant operators

Focus on dimension-6 operators

Warsaw basis

[Grzadkowski et al, 2010]

2499 real parameters (3045 with B-violation)

Full 1-loop RGEs computed

[Alonso, Chang, Jenkins, Manohar,
Shotwell, Trott, 2013-2014]

The SMEFT

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Non-trivial coupled system

Computers are known to be good at complex games...

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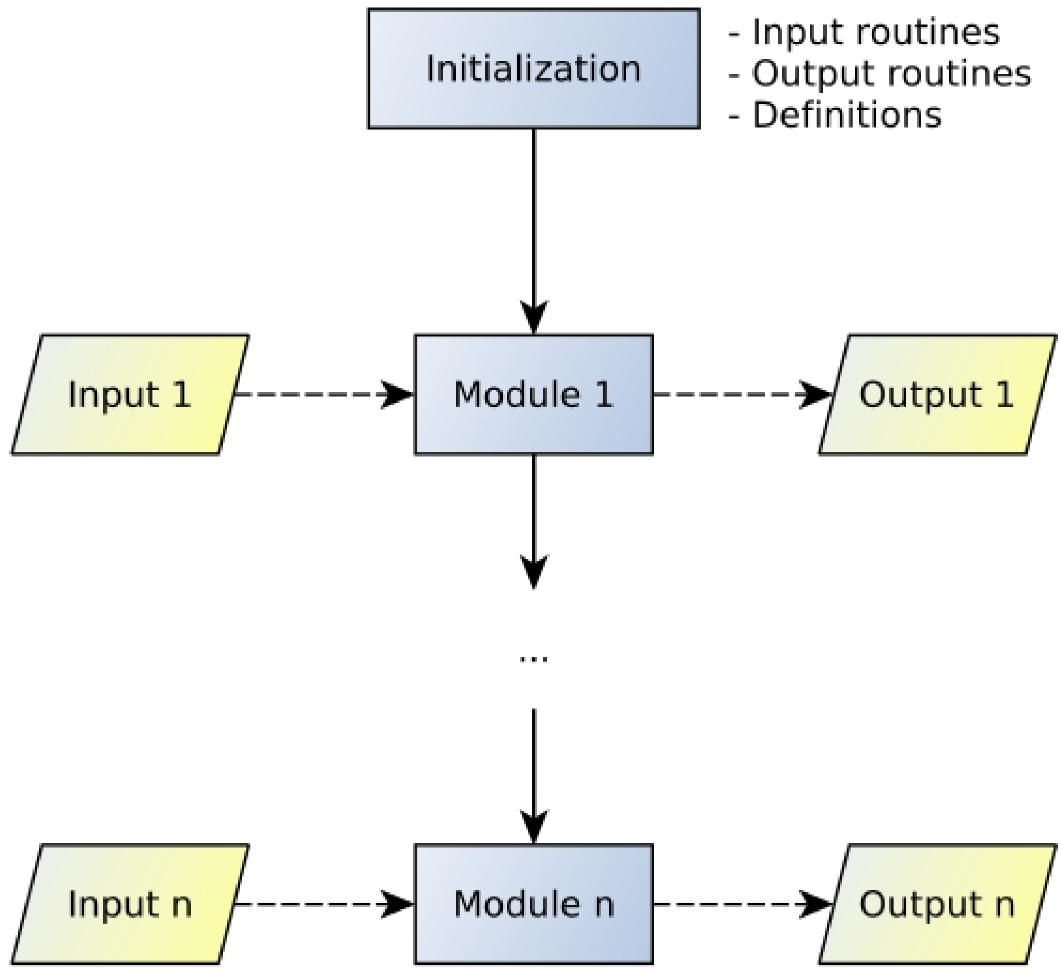
DsixTools

Mathematica package

Modular structure

Each module can be used independently



DsixTools

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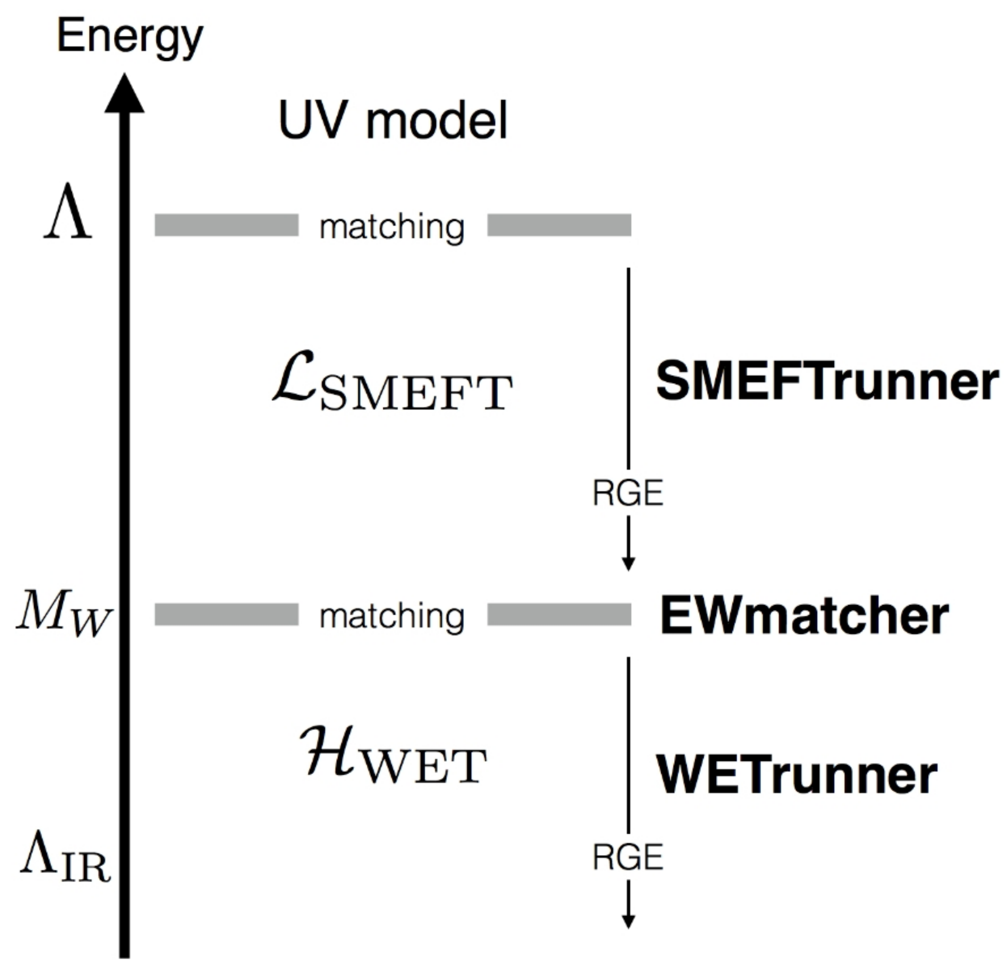
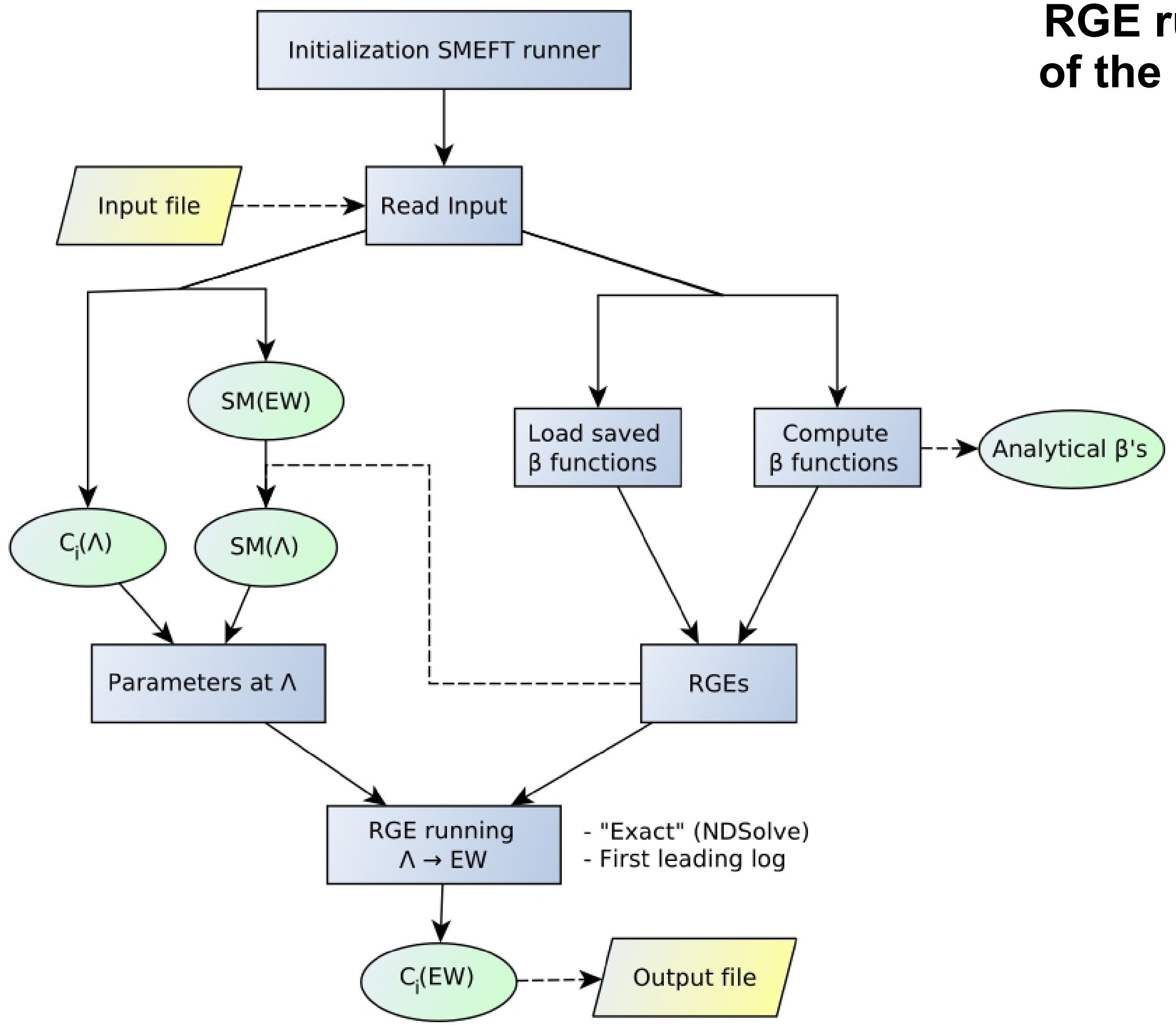


The modules

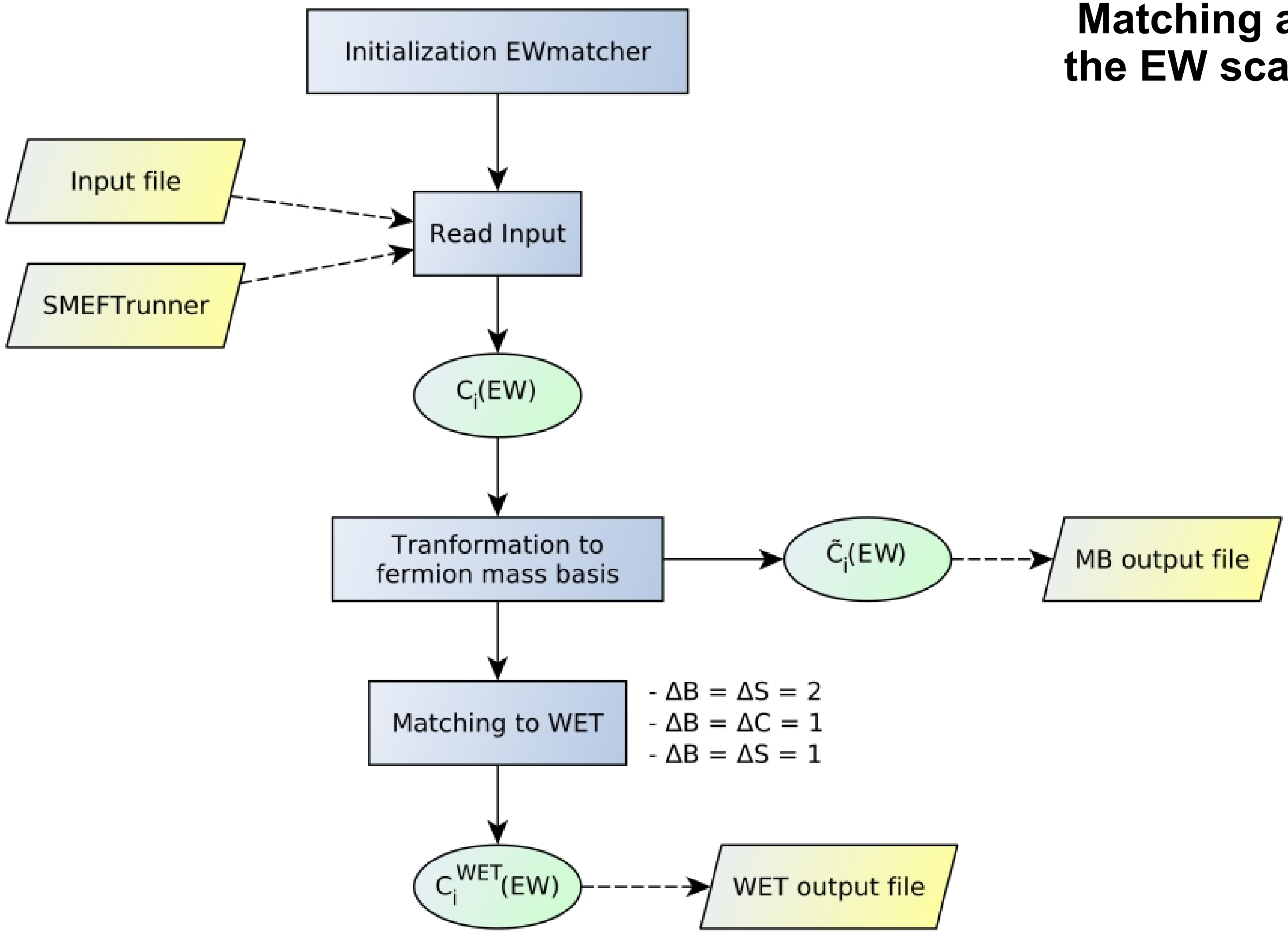
SMEFTrunner

RGE running of the SMEFT



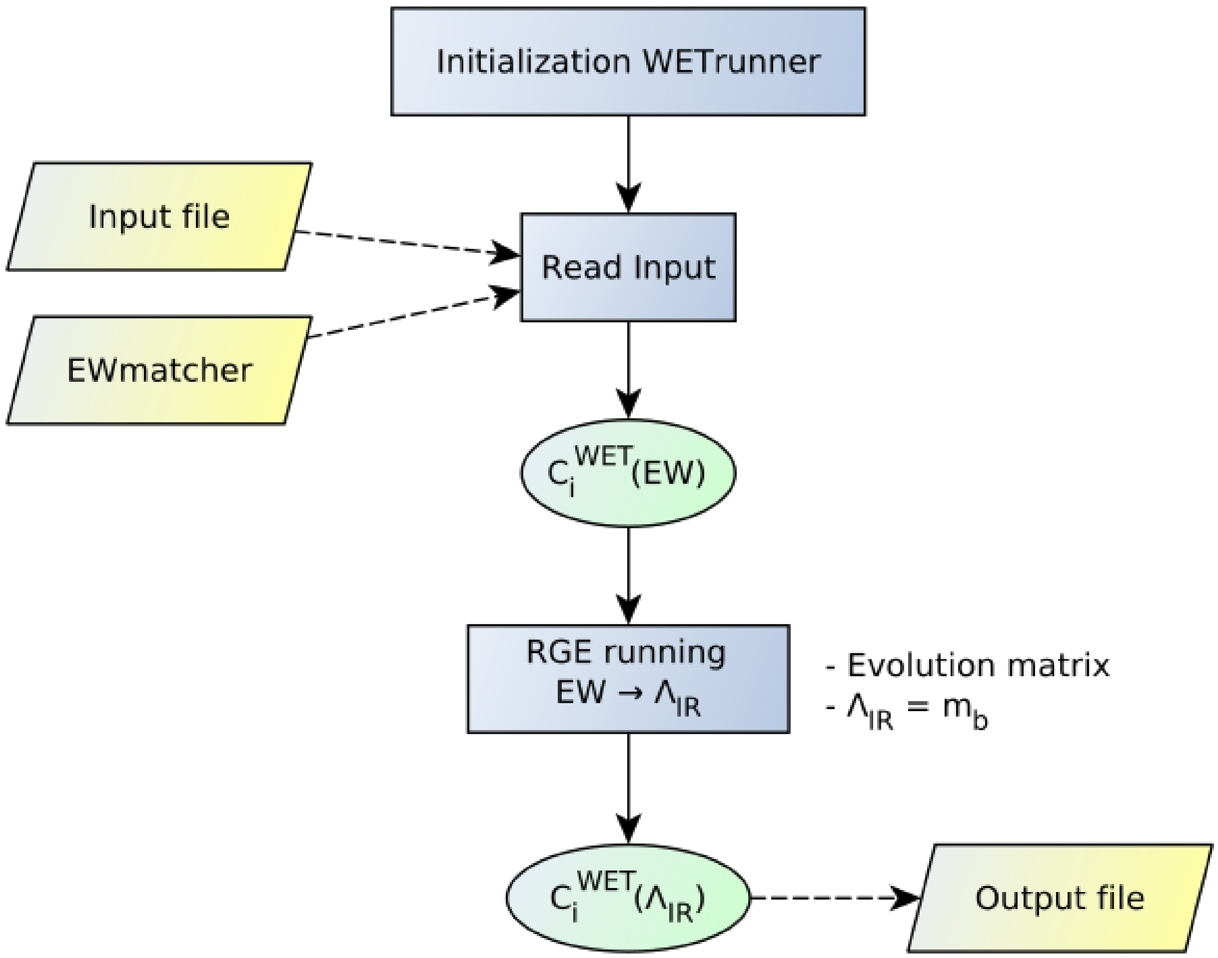
EWmatcher

Matching at the EW scale



WETrunner

RGE running of the WET



Examples and applications

Chuck Norris fact of the day

Chuck Norris lost his virginity before his dad

A DsixTools Program

This notebook loads DsixTools and shows how to use the SMEFTrunner module.

```
SetDirectory[NotebookDirectory[]];
```

Start DsixTools

```
Needs["DsixTools`"]
```

Read input files

```
ReadInputFiles["Options.dat", "WCsInput.dat", "SMInput.dat"];
```

Load SMEFTrunner module

```
LoadModule["SMEFTrunner"]
```

Use SMEFTrunner module

```
LoadBetaFunctions;
```

```
RunRGEsSMEFT;
```

SMEFT WCs input file

```
Block WC4
6 1.0          # phiBtilde
Block IMWCDPHI
1 1 0.1        # dphi(1,1)
1 2 0.2        # dphi(1,2)
1 3 0.3        # dphi(1,3)
2 1 0.1        # dphi(2,1)
2 2 0.2        # dphi(2,2)
2 3 0.3        # dphi(2,3)
3 1 0.4        # dphi(3,1)
3 2 0.5        # dphi(3,2)
3 3 0.6        # dphi(3,3)
Block WCDD
2 3 2 3 1.0    # dd(2,3,2,3)
Block WCPHIQ3
1 3 1.0        # phiq3(1,3)
```

WCsInput.dat

Simple text file

Inspired by the SLHA

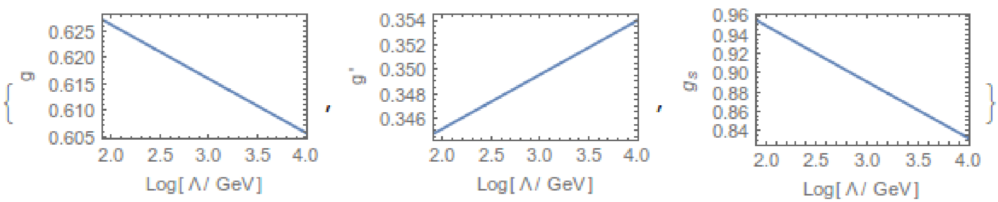
Similar format for the output file

Also possible to give input directly on the notebook

Results after SMEFTrunner

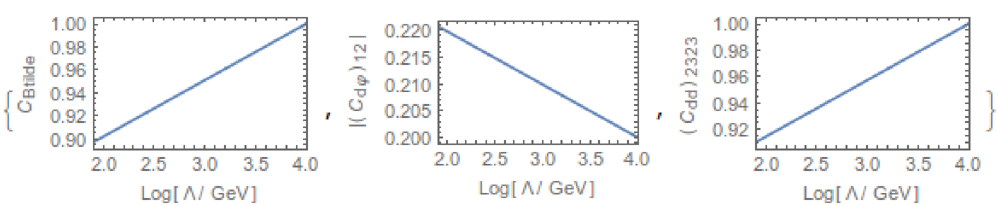
```
In[7]:= (* The results can also be plotted as a function of the energy scale *)

In[8]:= (* Gauge couplings *)
plotGauge1 = Plot[outSMEFTrunner[[1]], {t, tLOW, tHIGH}, Frame → True, Axes → False, PlotRange → {{tLOW, tHIGH}, Automatic},
   FrameLabel → {"Log[Λ/GeV]", "g", None, None}];
plotGauge2 = Plot[outSMEFTrunner[[2]], {t, tLOW, tHIGH}, Frame → True, Axes → False, PlotRange → {{tLOW, tHIGH}, Automatic},
   FrameLabel → {"Log[Λ/GeV]", "g'", None, None}];
plotGauge3 = Plot[outSMEFTrunner[[3]], {t, tLOW, tHIGH}, Frame → True, Axes → False, PlotRange → {{tLOW, tHIGH}, Automatic},
   FrameLabel → {"Log[Λ/GeV]", "gs", None, None}];
plotGauge = {plotGauge1, plotGauge2, plotGauge3}
```

Out[11]=




```
In[12]:= (* Wilson coefficients *)
plotWC1 = Plot[outSMEFTrunner[[48]], {t, tLOW, tHIGH}, Frame → True, Axes → False, PlotRange → {{tLOW, tHIGH}, Automatic},
   FrameLabel → {"Log[Λ/GeV]", "CBtilde", None, None}];
plotWC2 = Plot[Abs[outSMEFTrunner[[61]]], {t, tLOW, tHIGH}, Frame → True, Axes → False, PlotRange → {{tLOW, tHIGH}, Automatic},
   FrameLabel → {"Log[Λ/GeV]", "|(Cdφ)12|", None, None}];
plotWC3 = Plot[outSMEFTrunner[[443]], {t, tLOW, tHIGH}, Frame → True, Axes → False, PlotRange → {{tLOW, tHIGH}, Automatic},
   FrameLabel → {"Log[Λ/GeV]", "(Cdd)2323", None, None}];
plotWC = {plotWC1, plotWC2, plotWC3}
```

Out[15]=



Another simple program: analytics

A DsixTools Program

This notebook shows how to use the SMEFTrunner module to study SMEFT β functions analytically.

```
SetDirectory[NotebookDirectory[]];
```

Start DsixTools

```
Needs["DsixTools`"]
```

Set CP conservation

```
CPV = 0;
```

Load SMEFTrunner module

```
LoadModule["SMEFTrunner"]
```

Compute β functions

```
GetBeta;
```

Results

```
In[6]:= (* Let us compute β1q(1) and β1q(3) assuming top dominance and no NP effects in the 1st fermion family *)

In[7]:= (* Top dominance approximation *)
        top = {GD[i_, j_] :> 0, GE[i_, j_] :> 0, GU[i_, j_] :> If[i == j == 3, Vtb yt, If[i == 2 && j == 3, Vts yt, 0]]};

In[8]:= (* No NP in 1st family *)
        WCs2F = {φL1, φL3, φQ1, φQ3};
        WCs4F = {LQ1, LQ3, LU, QE, QU1, QU8, QD1, QD8, QQ1, QQ3};
        nofirst2F = Table[Part[WCs2F, i][a_, b_] → If[AnyTrue[{a, b}, # == 1 &], 0, 1] Part[WCs2F, i][a, b], {i, 1, Length[WCs2F]}];
        nofirst4F = Table[Part[WCs4F, i][a_, b_, c_, d_] → If[AnyTrue[{a, b, c, d}, # == 1 &], 0, 1] Part[WCs4F, i][a, b, c, d],
           {i, 1, Length[WCs4F]}];
        nofirst = Join[nofirst2F, nofirst4F];

In[13]:= βlq1 = β[lq1][[2, 2, 2, 3]] /. top /. nofirst // Expand
```

Out[13]=

$$\frac{1}{2} Vtb\, Vts\, yt^2\, LQ1[2,2,2,2] - \frac{1}{3} gp^2\, LQ1[2,2,2,3] + \frac{1}{2} Vtb^2\, yt^2\, LQ1[2,2,2,3] + \frac{1}{2} Vts^2\, yt^2\, LQ1[2,2,2,3] + \frac{1}{2} Vtb\, Vts\, yt^2\, LQ1[2,2,3,3] + \frac{2}{3} gp^2\, LQ1[3,3,2,3] + 9\, g^2\, LQ3[2,2,2,3] - Vtb\, Vts\, yt^2\, LU[2,2,3,3] + \frac{2}{3} gp^2\, QD1[2,3,2,2] + \frac{2}{3} gp^2\, QD1[2,3,3,3] + \frac{2}{3} gp^2\, QE[2,3,2,2] + \frac{2}{3} gp^2\, QE[2,3,3,3] - \frac{2}{9} gp^2\, QQ1[2,2,2,3] - \frac{4}{3} gp^2\, QQ1[2,3,2,2] - \frac{14}{9} gp^2\, QQ1[2,3,3,3] - \frac{2}{3} gp^2\, QQ3[2,2,2,3] - \frac{2}{3} gp^2\, QQ3[2,3,3,3] - \frac{4}{3} gp^2\, QU1[2,3,2,2] - \frac{4}{3} gp^2\, QU1[2,3,3,3] + Vtb\, Vts\, yt^2\, \varphi L1[2,2] - \frac{1}{3} gp^2\, \varphi Q1[2,3]$$

```
In[14]:= βlq3 = β[lq3][[2, 2, 2, 3]] /. top /. nofirst // Expand
```

Out[14]=

$$3\, g^2\, LQ1[2,2,2,3] + \frac{1}{2} Vtb\, Vts\, yt^2\, LQ3[2,2,2,2] - \frac{16}{3} g^2\, LQ3[2,2,2,3] - gp^2\, LQ3[2,2,2,3] + \frac{1}{2} Vtb^2\, yt^2\, LQ3[2,2,2,3] + \frac{1}{2} Vts^2\, yt^2\, LQ3[2,2,2,3] + \frac{1}{2} Vtb\, Vts\, yt^2\, LQ3[2,2,3,3] + \frac{2}{3} g^2\, LQ3[3,3,2,3] + \frac{2}{3} g^2\, QQ1[2,2,2,3] + \frac{2}{3} g^2\, QQ1[2,3,3,3] - \frac{2}{3} g^2\, QQ3[2,2,2,3] + 4\, g^2\, QQ3[2,3,2,2] + \frac{10}{3} g^2\, QQ3[2,3,3,3] - Vtb\, Vts\, yt^2\, \varphi L3[2,2] + \frac{1}{3} g^2\, \varphi Q3[2,3]$$

Other stuff DsixTools can do for you

- Direct input on the notebook
- Easy loops with varying WCs and/or energy scales
- Output to simple SLHA inspired text files
- Transformation to fermion mass basis at the EW scale
- EW matching to many WET operators for B-physics
- QED and QCD running from the EW scale down to the b-quark mass scale

And much more to come!

Summary

Summary

A Mathematica package for the matching and RGE evolution from the new physics scale to the scale of low energy observables

Manual: arXiv:1704.04504
Website: https://dsixtools.github.io/

Easy implementation of new modules
Comments (including critical ones!), questions and suggestions are welcome!

Thank you!