# A complete pheno toolchain

## From $\mathcal{L}$ to exclusion limits

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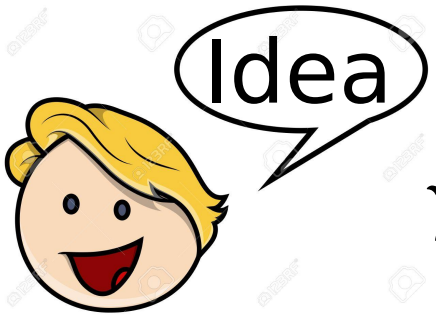
# From idea to results




$$\mathcal{L} = -\frac{1}{4} G^{a\mu\nu} G^{a}_{\mu,\nu} + \dots$$

$$\mathcal{W} = \mu \hat{H}_u \hat{H}_d + \dots$$

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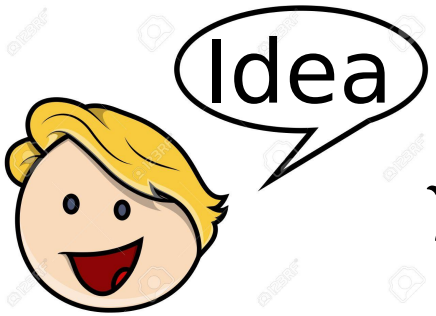


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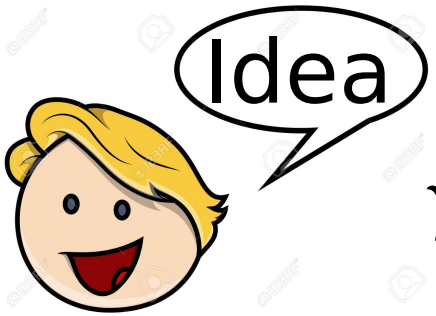


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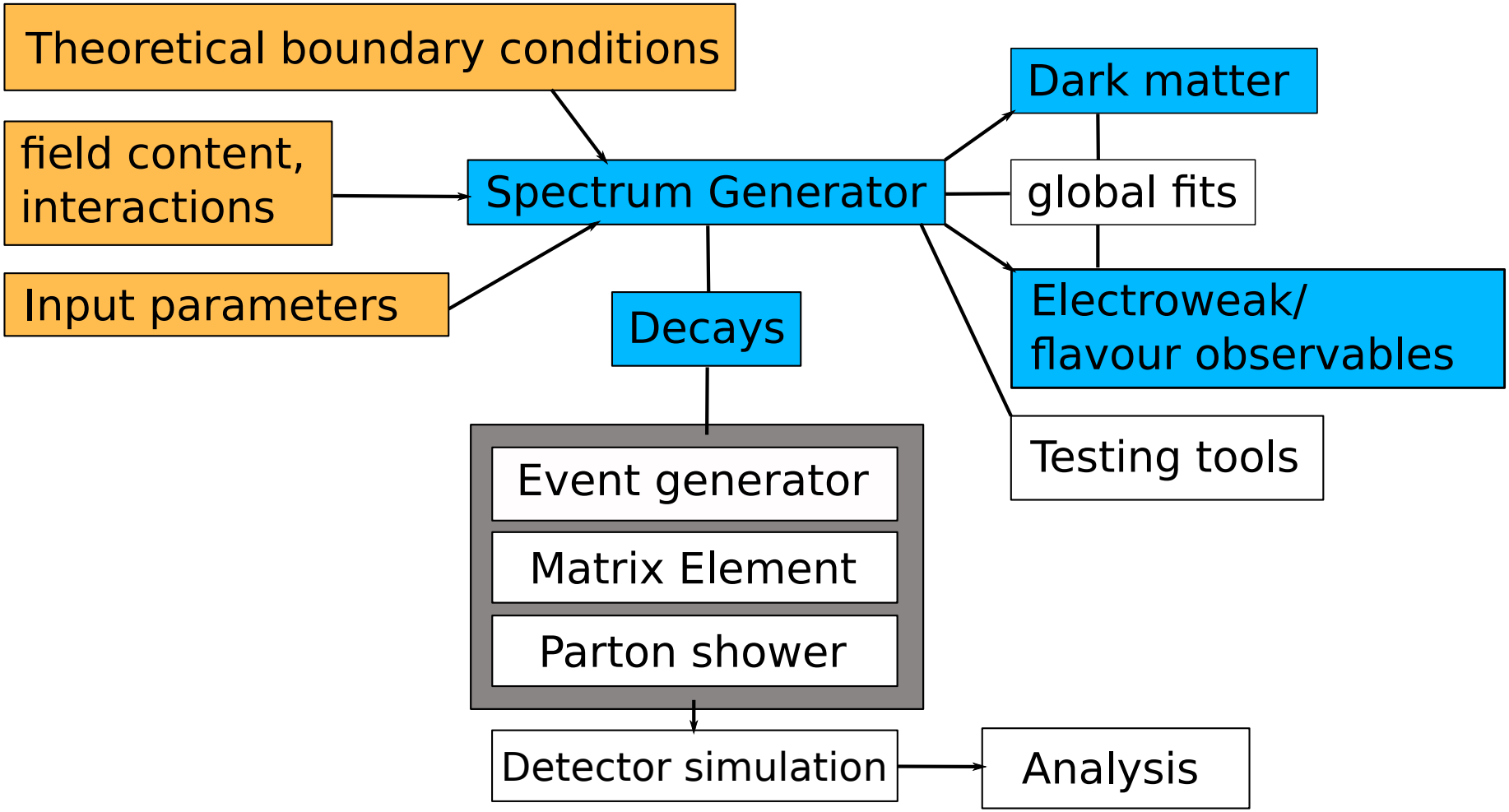


[1] B. C. Allanach (2008)

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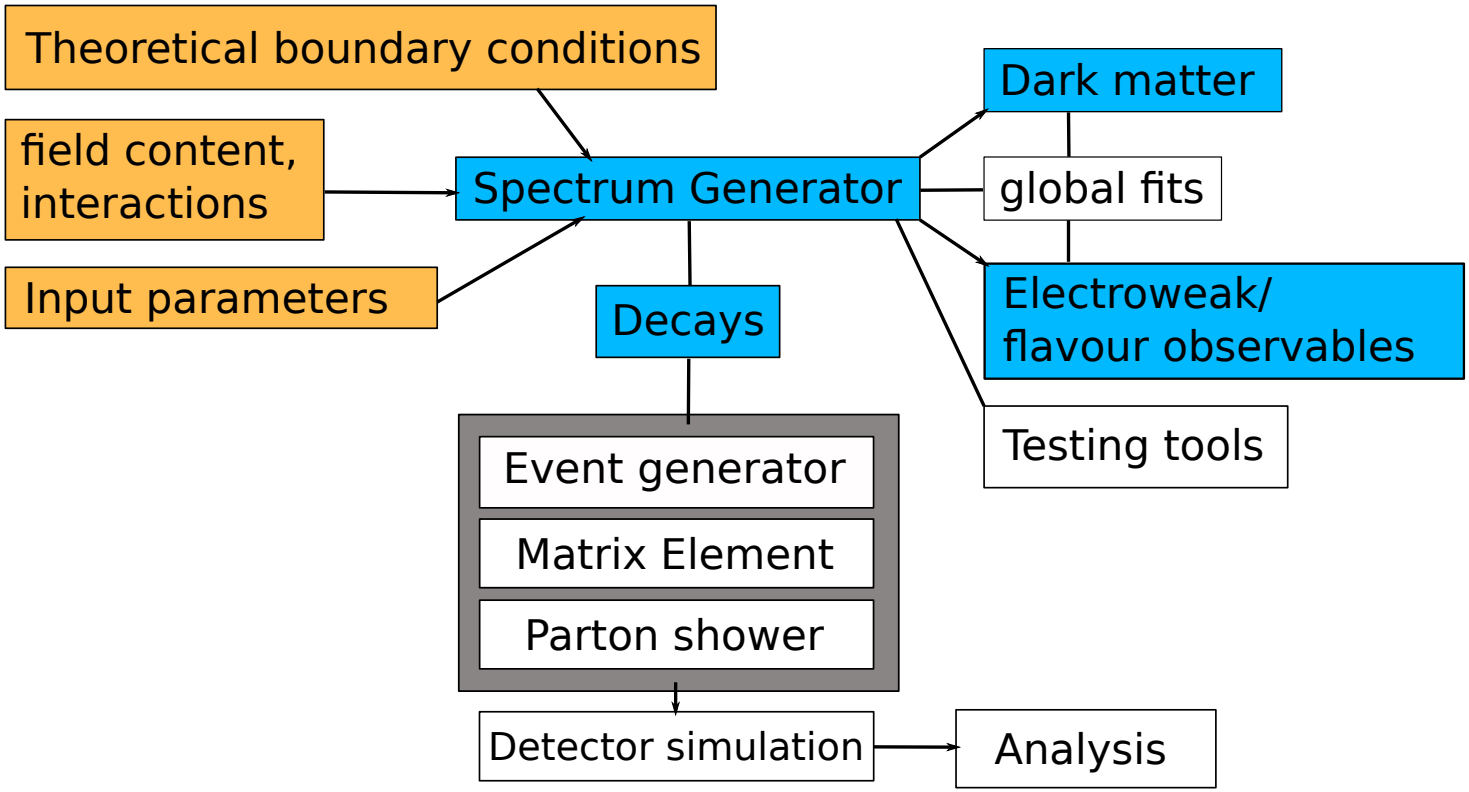


1. Theory
2. Spectrum Generation
3. Observables
4. Collider Simulation
5. Analysis

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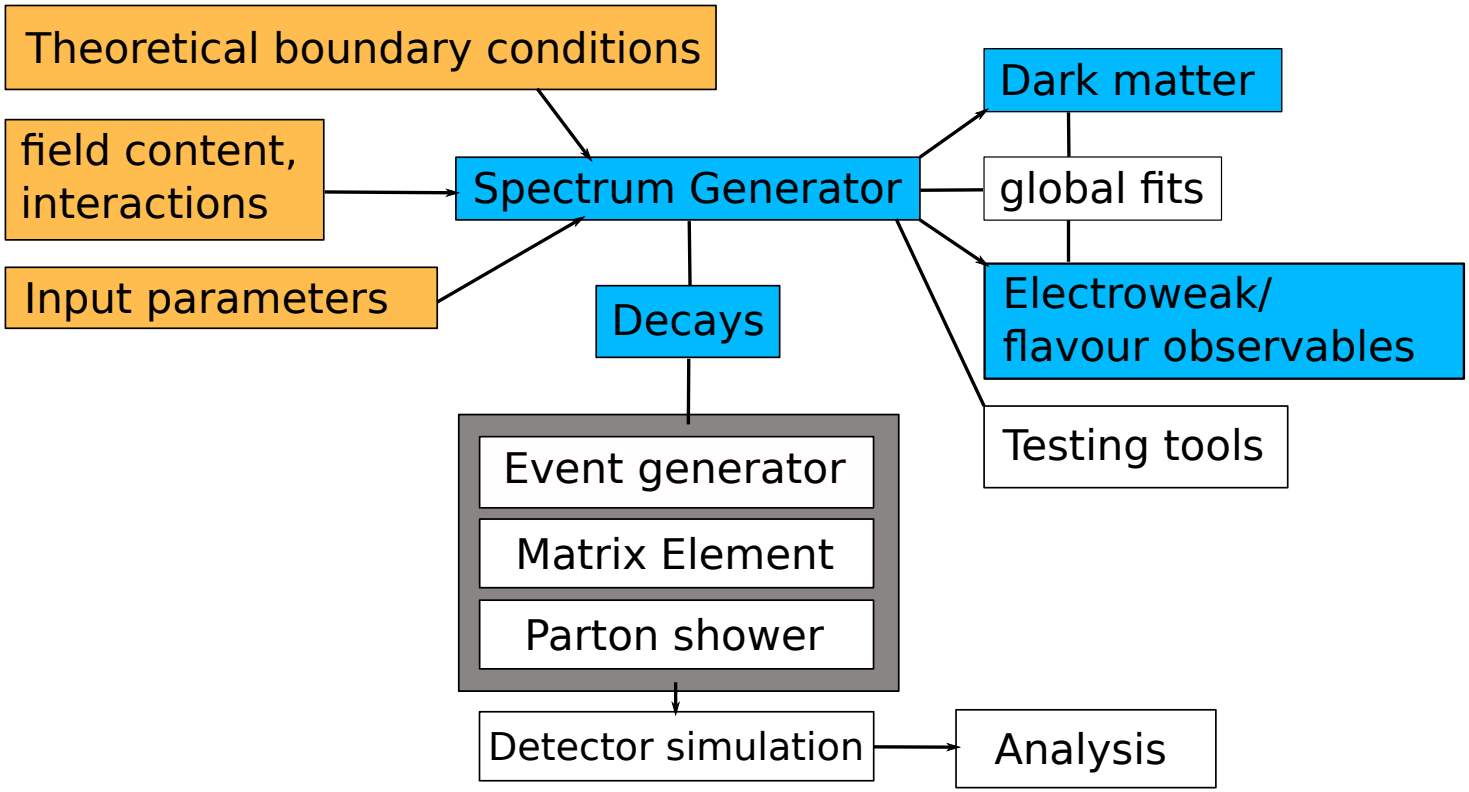


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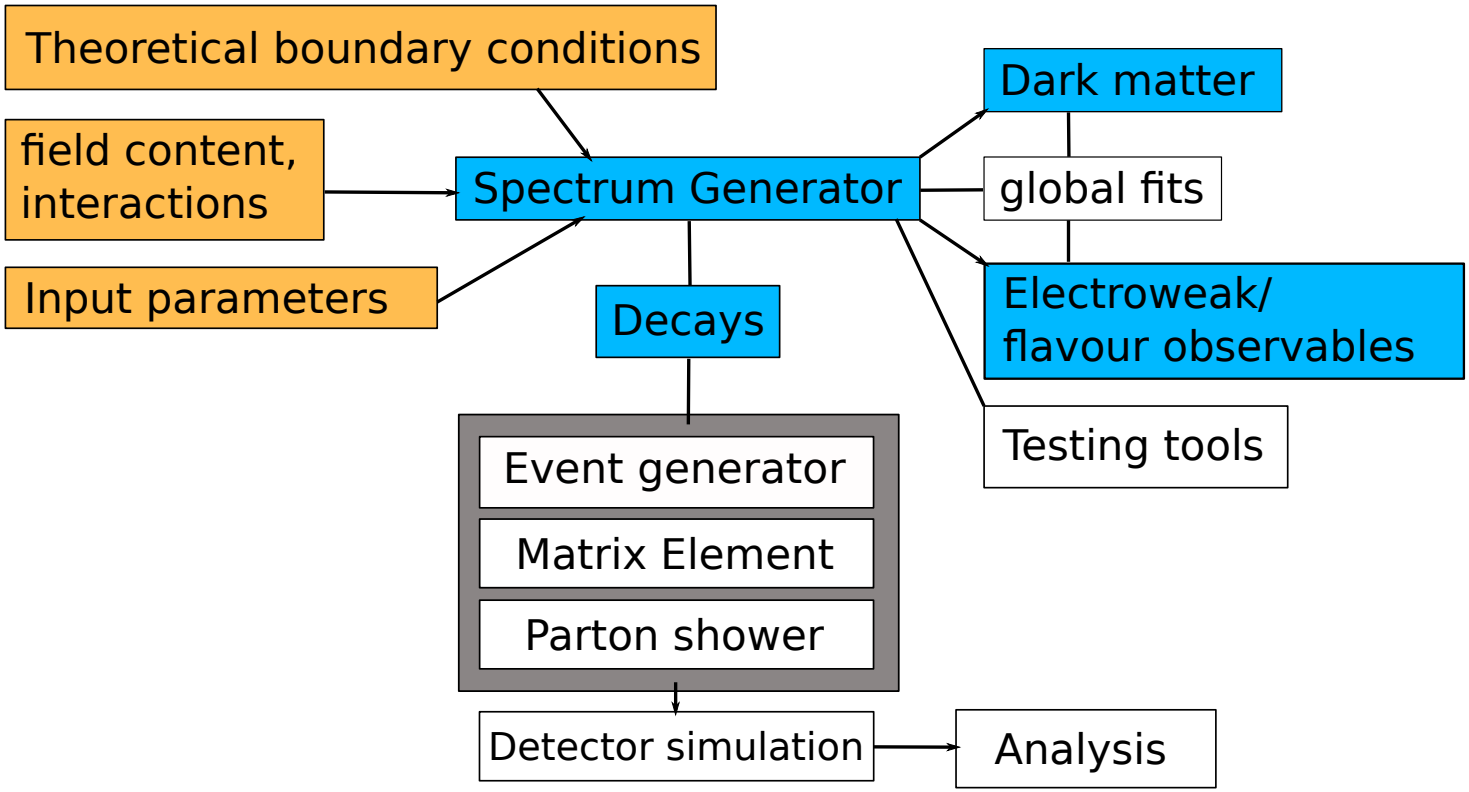


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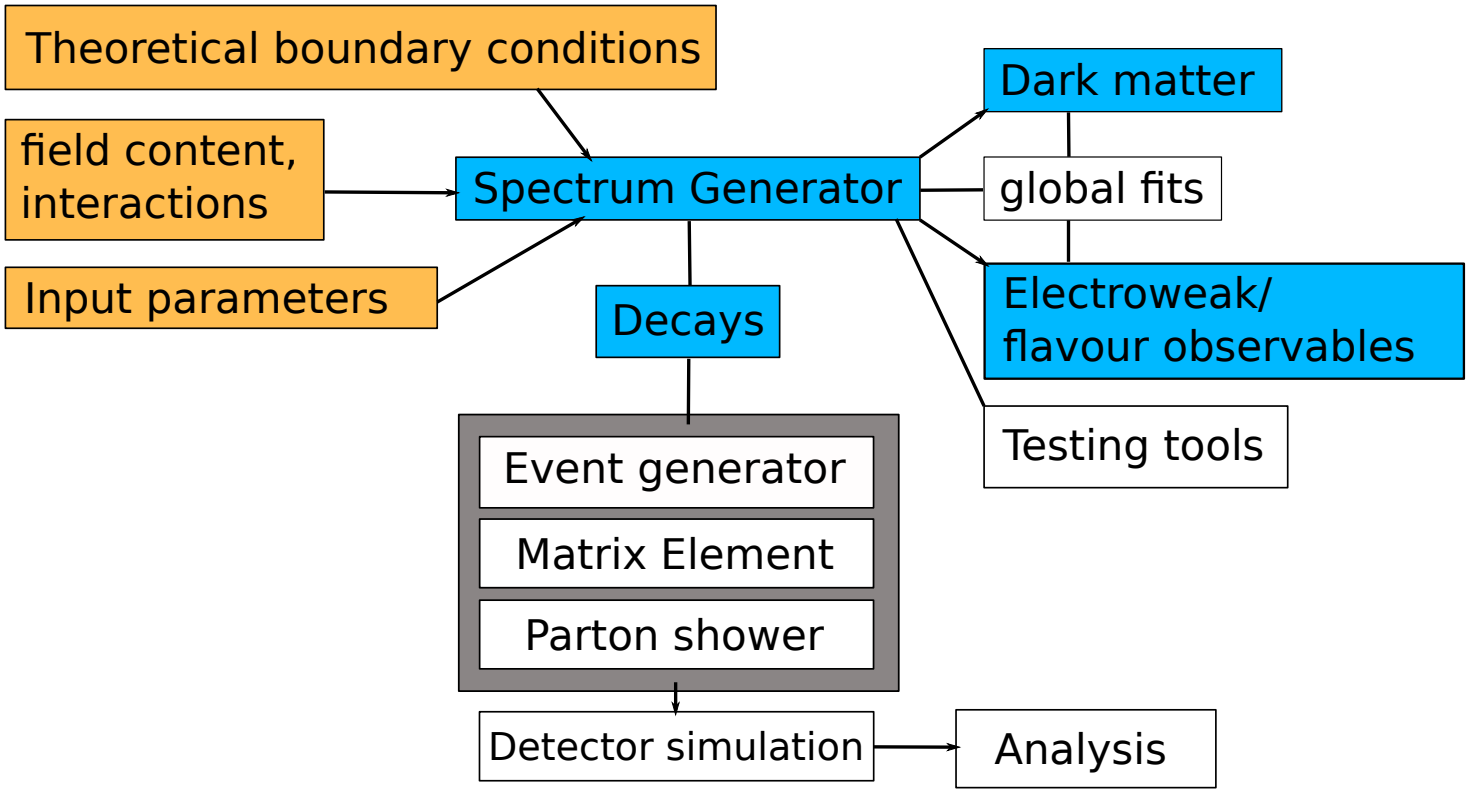


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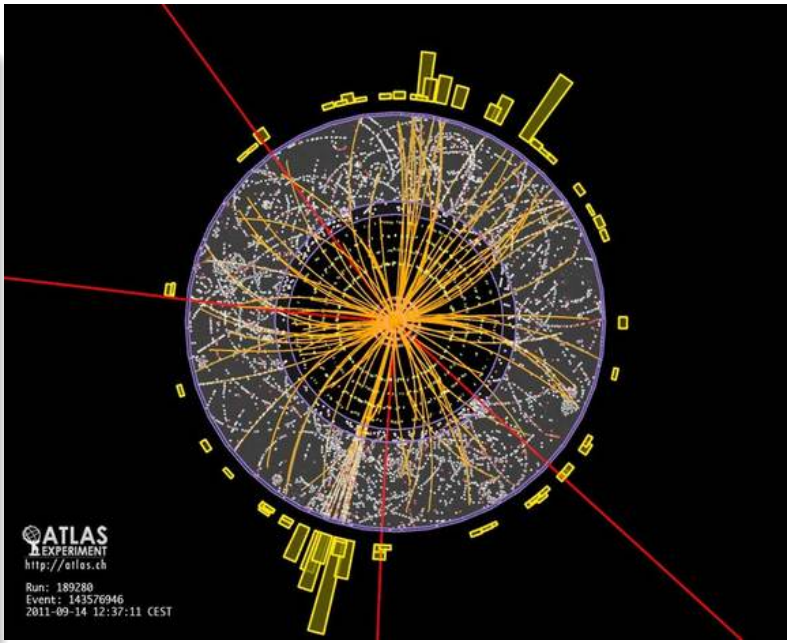
# Collider Simulators

## Well known ones

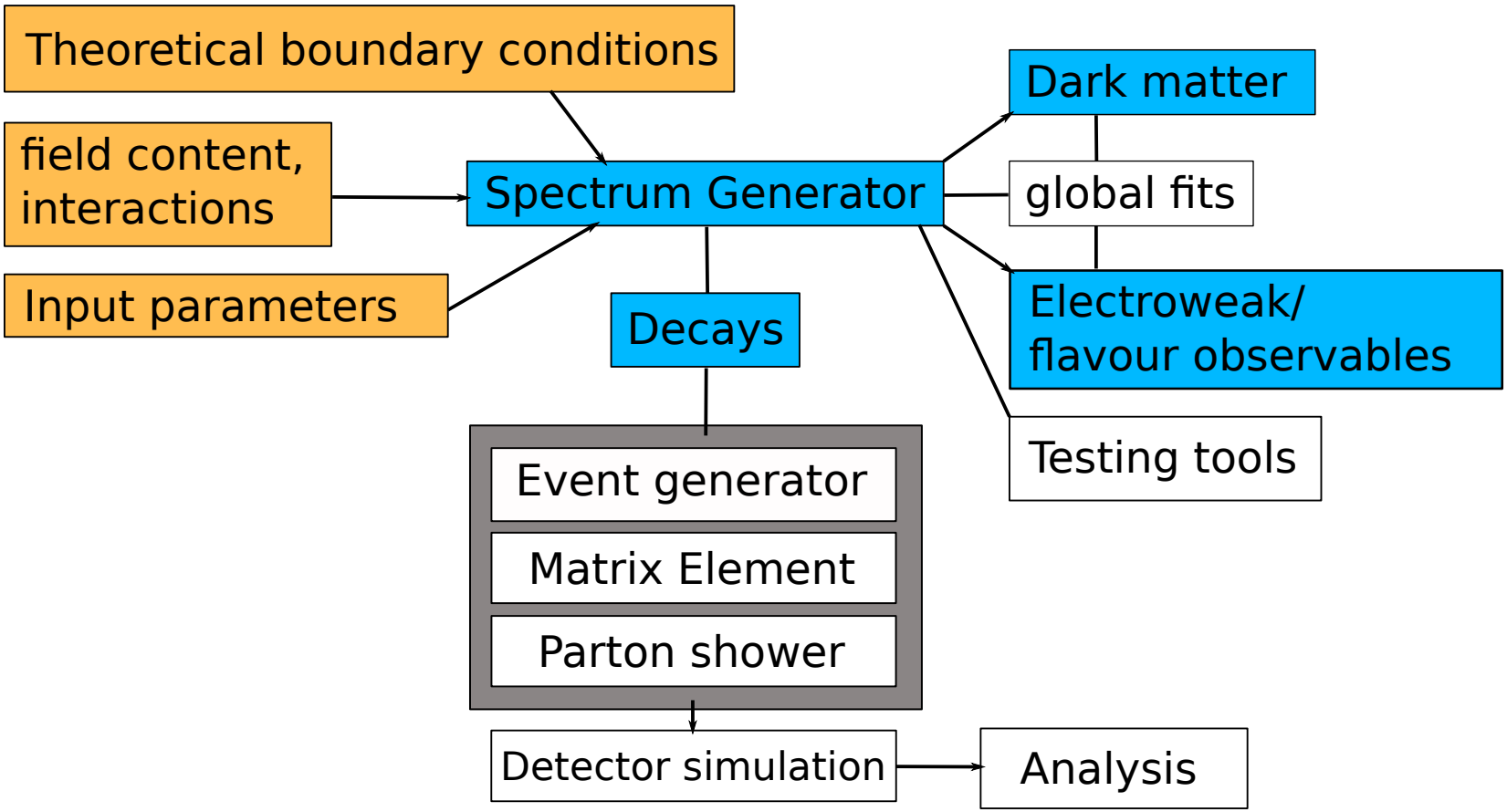
- MadGraph
- Pythia
- SHERPA
- WHIZARD
- HERWIG
- . . .




*user provides*: model files, parameter point

*also:* PDFs, collider settings, matching settings, . . .

# Spectrum Generation and observables



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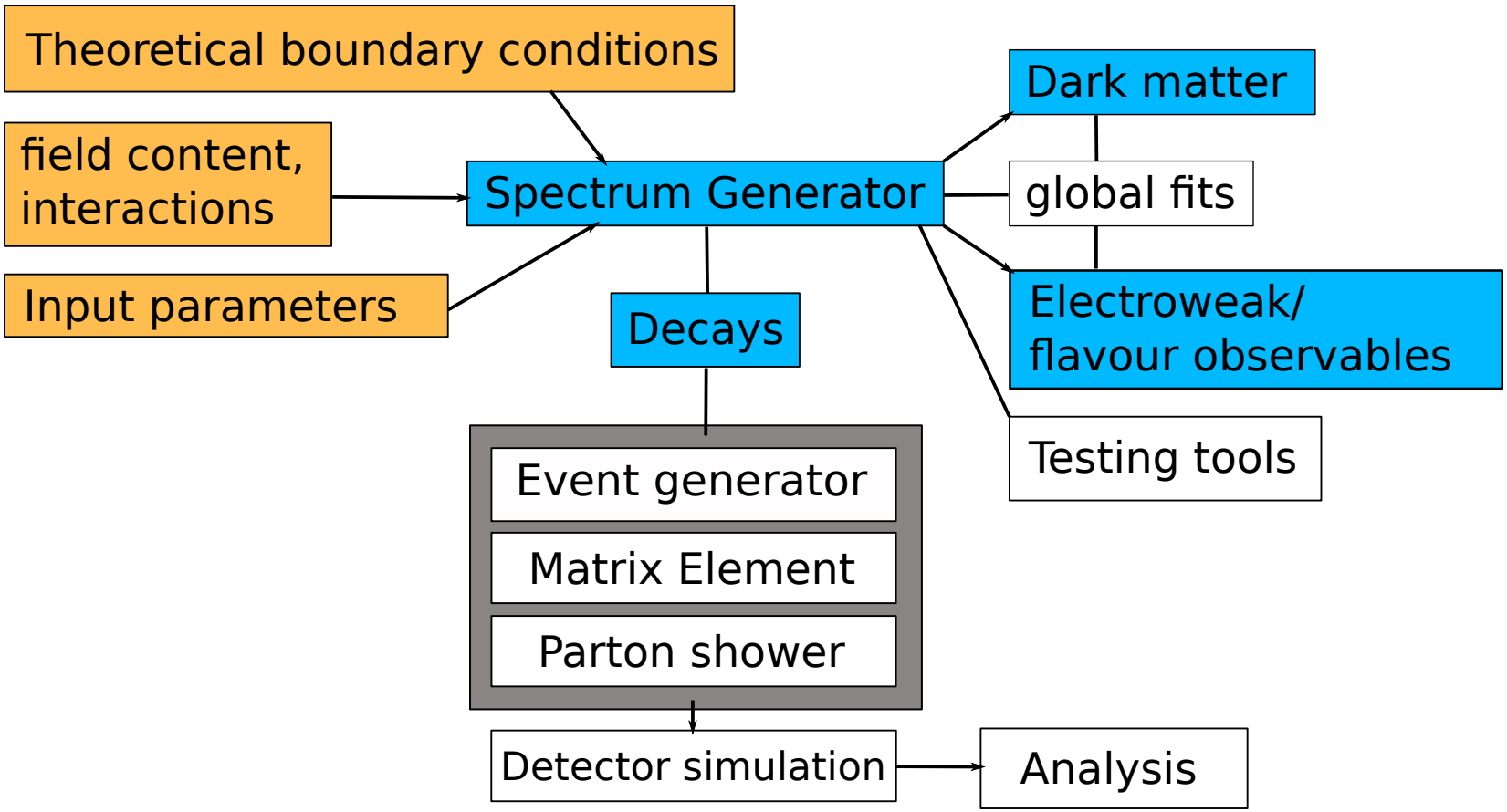


*How to interface all the data?*

# SUSY Les Houches Accord[2]

```
Block SPINFO         # Program information
     1   SPhenoSARAH      # spectrum calculator
     2   v3.3.7      # version number of SPheno
     9   4.5.8       # version number of SARAH
Block MODSEL  # Input parameters
     1  1   #  GUT scale input
     2  1   #  Boundary conditions
Block MINPAR  # Input parameters
    1    4.92000000E+02  # m0
    2    3.50588000E+02  # m12
    3    2.61665000E+00  # TanBeta
    5    8.20000000E+01  # Azero
Block EXTPAR  # Input parameters
   61    1.64700000E+00  # LambdaInput
   62   -1.03000000E-01  # KappaInput
   65   -1.91820000E+01  # vSInput
  101    7.19258000E+03  # MSInput
  102    1.96745900E+01  # a
  103    5.64504000E+00  # b
  203    5.86792612E+06  # bmsinput
Block gaugeGUT Q=  1.39407430E+16  # (GUT scale)
   1    7.02261609E-01  # g1(Q)^DRbar
   2    7.02261609E-01  # g2(Q)^DRbar
   3    7.06549228E-01  # g3(Q)^DRbar
Block SMINPUTS  # SM parameters
         1     1.27932591E+02  # alpha_em^-1(MZ)^MSbar
         2     1.16637000E-05  # G_mu [GeV^-2]
         3     1.18700000E-01  # alpha_s(MZ)^MSbar
         4     9.11887000E+01  # m_Z(pole)
         5     4.18000000E+00  # m_b(m_b), MSbar
         6     1.73500000E+02  # m_t(pole)
         7     1.77669000E+00  # m_tau(pole)
Block GAUGE Q=  1.45030944E+03  # (SUSY Scale)
   1    3.62857200E-01  # g1
   2    6.37466913E-01  # g2
   3    1.05642077E+00  # g3
```

- Lagrangian (input) parameters
- model settings
- SM input
- masses and mixings
- decay widths and BRs
- anything!

[2] P. Skands, B.C. Allanach, H. Baer, C. Balázs, G. Bélanger, F. Boudjema, etc. (2003)

# Spectrum Generators & Observables

## General features

RGE running, Higgs potential minimisation, 1-loop mass corrections, mass matrix diagonalization

$\Rightarrow$ masses, couplings, mixing matrices

## Advanced features

decay widths and BRs, fine tuning,
low energy observables ($(g-2)_\mu$, $b \to s\gamma$, $B_s \to \mu^+\mu^-$, $\Delta M_{B^0}$),
**2-loop Higgs mass corrections**

`FeynHiggs`, `SPheno`, `SoftSUSY`, `SUSPECT`, `ISAJET`
`NMSSMtools` (NMSSM), `CPsuperH` (CPV-MSSM)

`FeynArts/FormCalc` (Feynman diagrams)

# More tools

## Observables

- flavour violation (`SuperLFV`[a], `SUSYFLAVOR`[b], `FlavorKit` (add-on to `SPheno`))
- dark matter (`micrOmegas`)[c]

---

[a] B. Murakami (2013)

[b] A. Crivellin, J. Rosiek, P. Chankowski, A. Dedes, S. Jäger, P. Tanedo (2010), +updates

[c] G. Bélanger, F. Boudjema, A. Pukhov, A. Semenov (2006), updates

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## Testing tools

- `HiggsBounds/HiggsSignals`[a]
- vacuum stability (`Vevacious`[b])

[a] P. Bechtle, O. Brein, S. Heinemeyer, O. Stal, T. Stefaniak, G. Weiglein, K. Williams (2008) +updates

[b] J.E. Camargo-Molina, B. O'Leary, W. Porod, F. Staub (2013)

# More tools

If you want to go **beyond** the MSSM/NMSSM . . .

## As general as possible: Spectrum generator-generators

- `SARAH`[a]
- `FlexibleSUSY`[b]

[a] F. Staub: (2009), (2010), (2012), (2013)

[b] P. Athron, J.Park, D. Stöckinger, A. Voigt (2015)

- Those tools rely on generic calculations
- can be used for a wide range of models

# SARAH – A model builders' tool

Enter your model:
gauge group $\mathcal{G}$,
superpotential $\mathcal{W}$ (or $\mathcal{L}_{\rm int}$), particle content & mixing,
high-scale boundary conditions

## SARAH output

- Lagrangian (analytic, Mathematica)
- RGEs (2-loop)
- model files (CalcHEP, FeynArts, WHIZARD, micrOmegas, UFO format)
- **SPheno source code (Fortran)**

F. Staub: (2009) [arXiv:0909.2863], (2010) [arXiv:1002.0840], (2012) [arXiv:1207.0906], (2013) [arXiv:1309.7223]

# Analysis

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## Analysis

- defining kinematic variables ($E_T^{\text{mis}}$, $\alpha_T$ etc.)
- applying cuts
- signal and background count
- discovery / exclusion limits

# Automated Analyses with CheckMATE

[M. Drees, H. Dreiner, D. Schmeier, J. Tattersall, J. S. Kim (2014)]

## Idea

- Heaps of analyses by CMS & ATLAS exist, signal and BG count from real LHC data
- *Is my model compatible with their findings?*

# Automated Analyses with CheckMATE

[M. Drees, H. Dreiner, D. Schmeier, J. Tattersall, J. S. Kim (2014)]

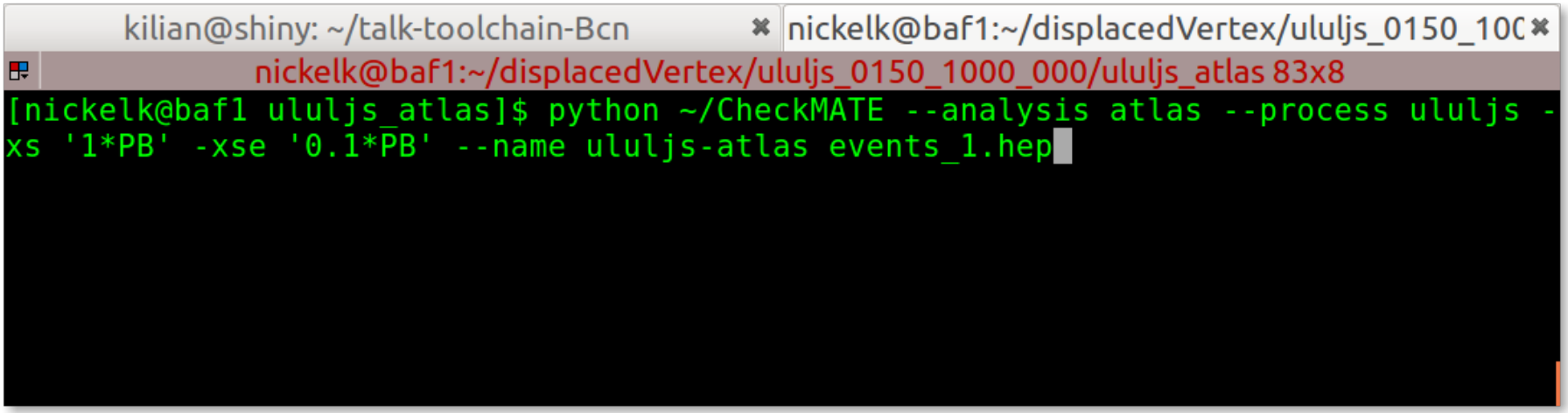
## Realisation

- Provide `hep` file for your process $p$
- Provide cross section $\sigma \pm \Delta\sigma$ of process $p$
- *($\star$ implement your own analysis)*

- detector simulation with `Delphes`
- apply cutflow defined in the analyses $\rightarrow$ signal counts
- compare to measured signal count at LHC
- Allowed or excluded at 95% CL (also, gives CL)

# Automated Analyses with CheckMATE

## Input



# Automated Analyses with CheckMATE

## Input

kilian@shiny: ~/talk-toolchain-Bcn | nickelk@baf1:~/displacedVertex/ululjs_0150_10C

nickelk@baf1:~/displacedVertex/ululjs_0150_1000_000/ululjs_atlas 83x8

```
[nickelk@baf1 ululjs_atlas]$ python ~/CheckMATE --analysis atlas --process ululjs -
xs '1*PB' -xse '0.1*PB' --name ululjs-atlas events_1.hep
```

## Output

kilian@shiny: ~/talk-toolchain-Bcn | nickelk@baf1:~/displacedVertex/ululjs_0150_

nickelk@baf1:~/displacedVertex/ululjs_0150_1000_000/ululjs_atlas 78x12

```
[nickelk@baf1 ululjs_atlas]$ cat result.txt

Test: Calculation of r = signal/(95%CL limit on signal)
Warning: Error is dominated by Monte Carlo statistics!
Result: Excluded
Result for r: r_max = 119.30976
SR: atlas_conf_2013_047 - AM
[nickelk@baf1 ululjs_atlas]$
```

# Automated Analyses with CheckMATE

*It can be used to deal with the following questions*

- Is my SUSY model excluded (95% CL) by current LHC null results?

[3] A. Belyaev, S. Moretti, KN, M. C. Thomas, I. Tomalin (2015)

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  [Hunting long-lived exotic particles at LHC, arXiv:1512.02229][3]

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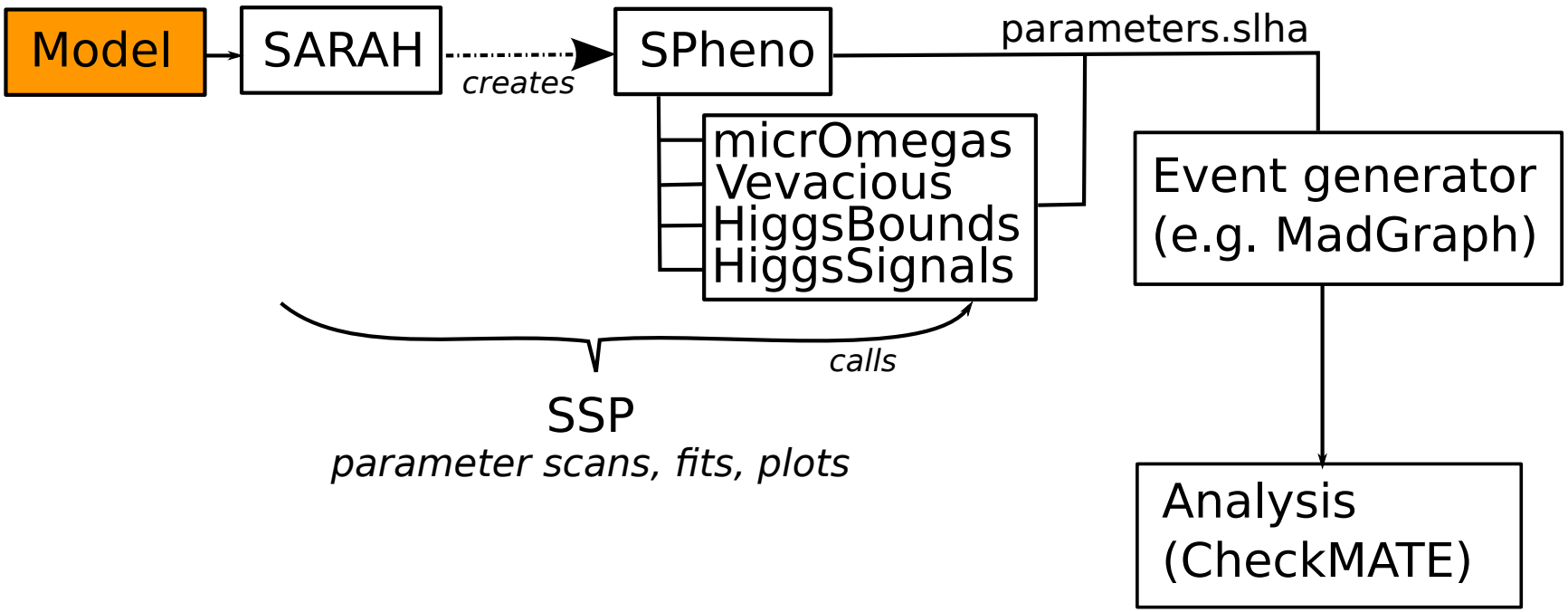
# A complete tool chain



## Thank you for your attention!

# Bon profit!