

Introduction to MadGraph5_aMC@NLO

SMEFT event generation exercise

Jack Araz, Ilaria Brivio, **Ken Mimasu**
King's College London

2021 EFT School on Collider Phenomenology

13th of April 2021

Simulating data

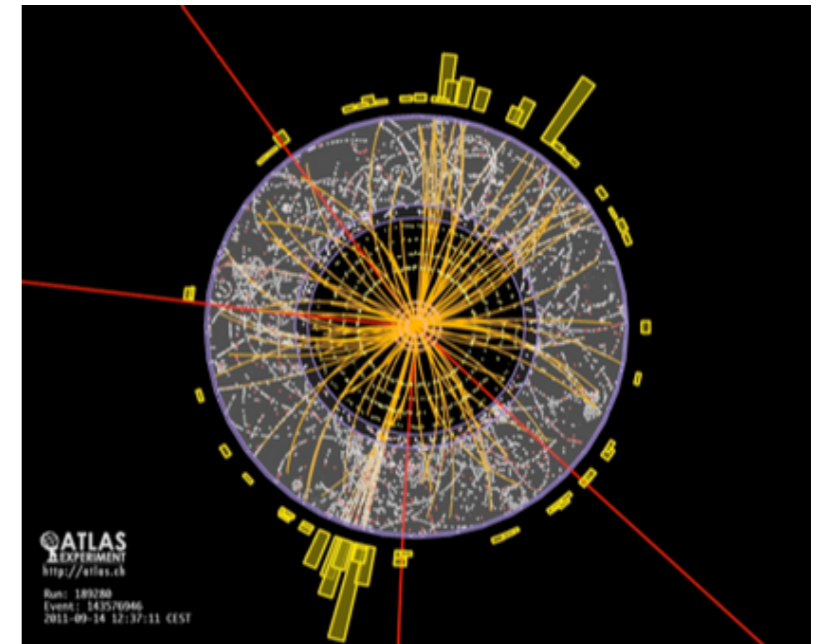
Theory



Monte Carlo Simulation



Data



Simulations provide crucial bridge between theory & data

- Testing collider measurements against SM predictions
- Searching for new physics phenomena
- Quantify theoretical uncertainties

Lagrangian \Rightarrow LHC events: $\pi^\pm, \mu^\pm, e^\pm, \gamma \Rightarrow$ detector hits

Simulating an event

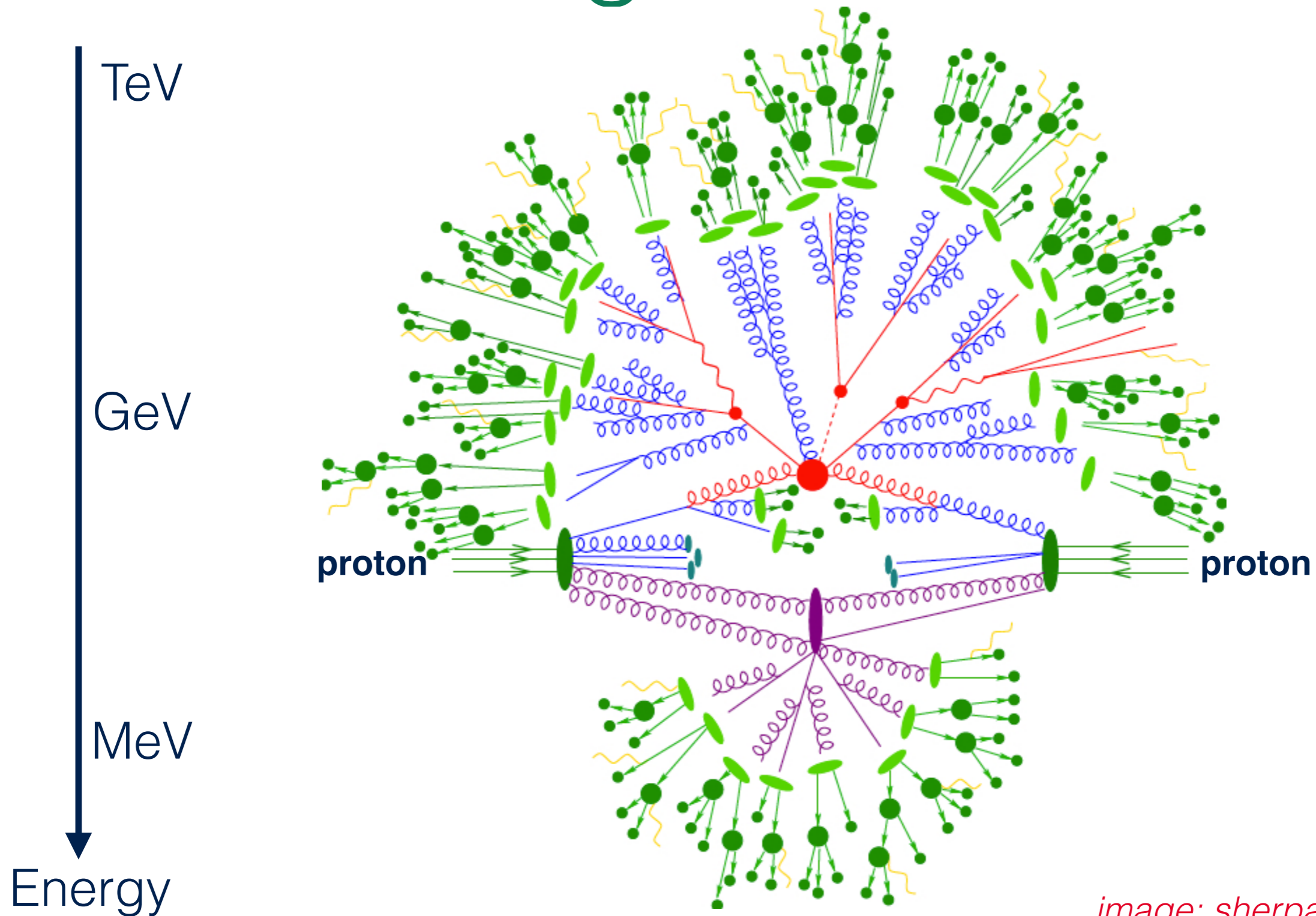
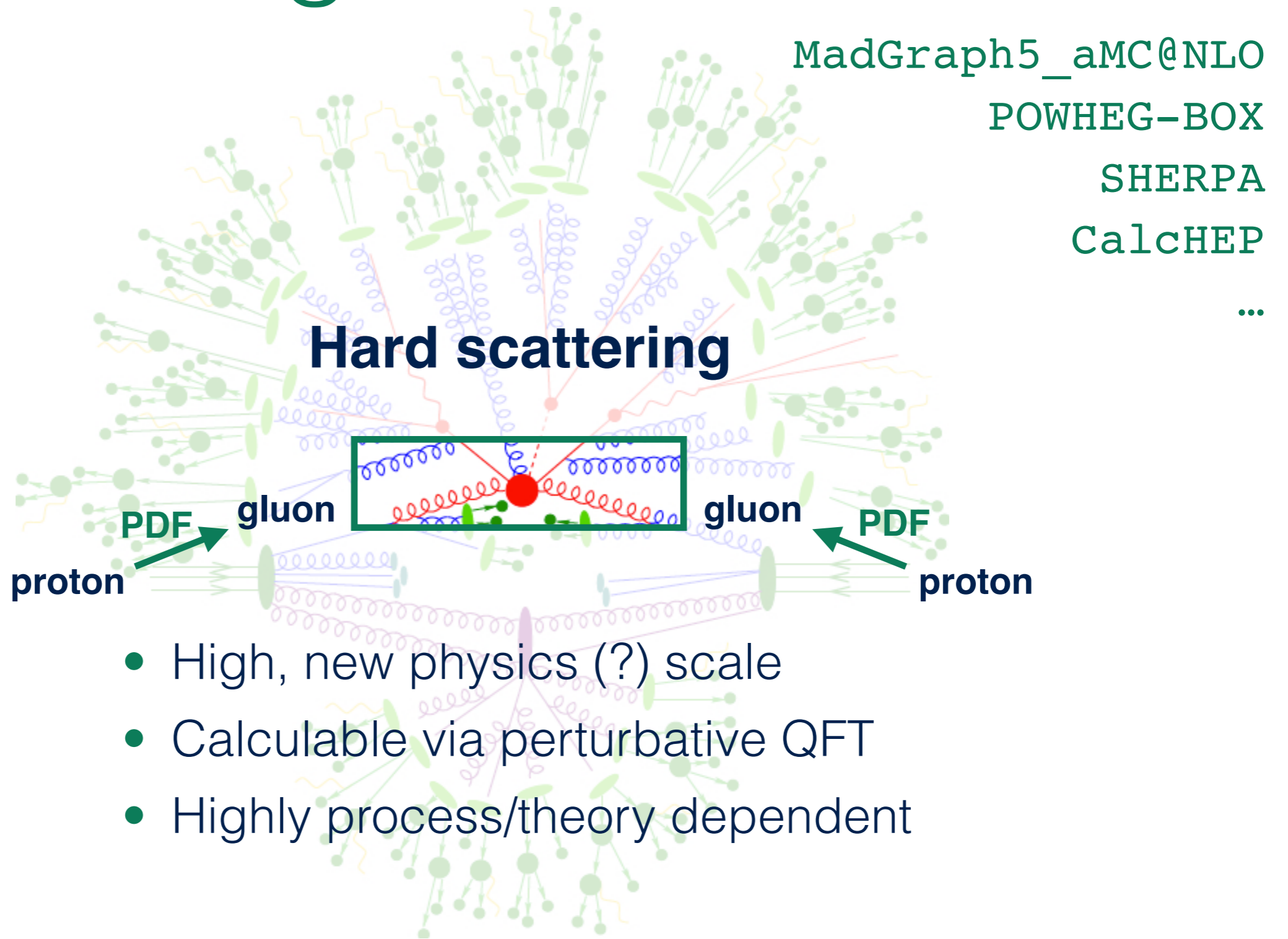
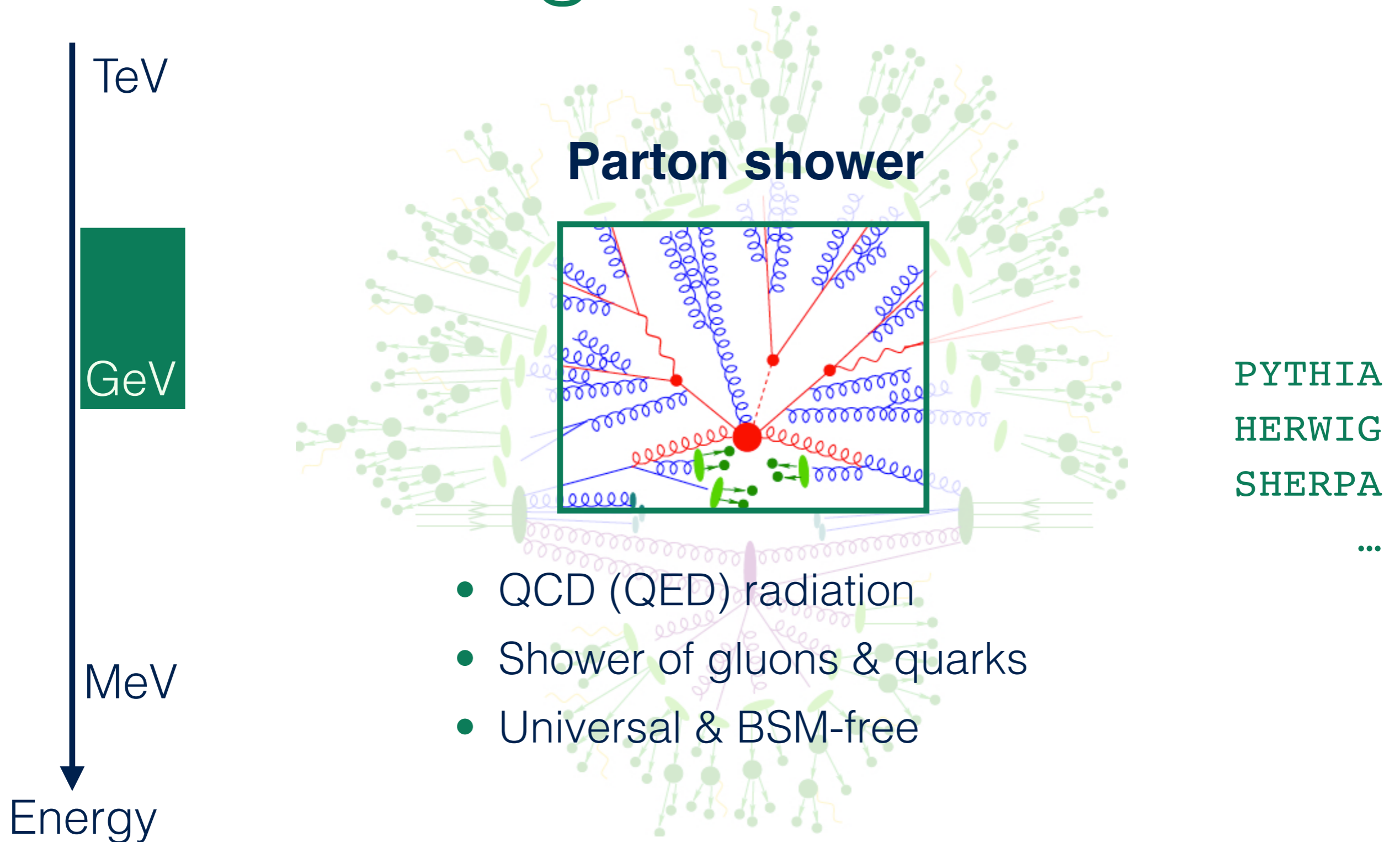


image: sherpa.hepforge.org

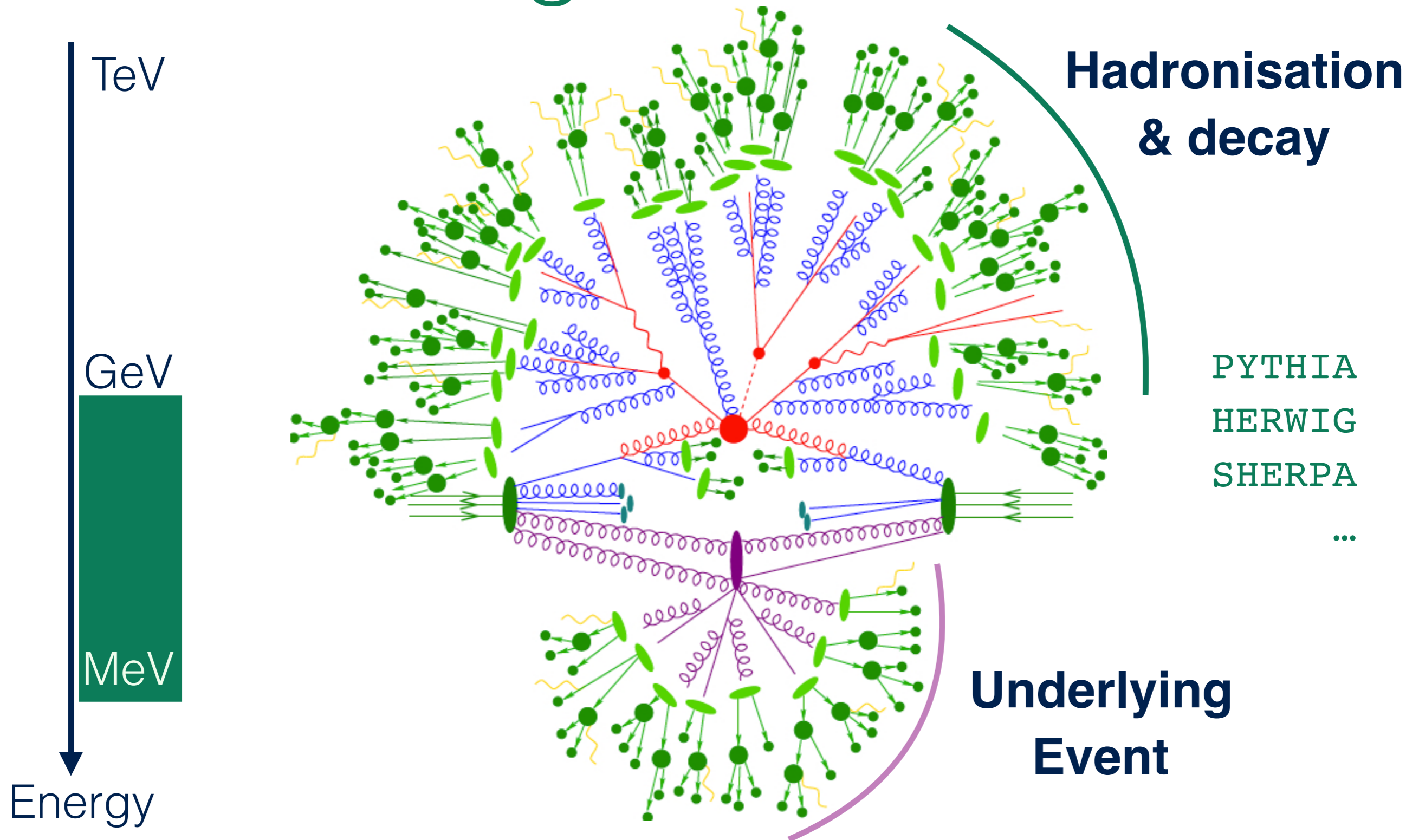
Simulating an event



Simulating an event



Simulating an event



Simulating an event

MadAnalysis5

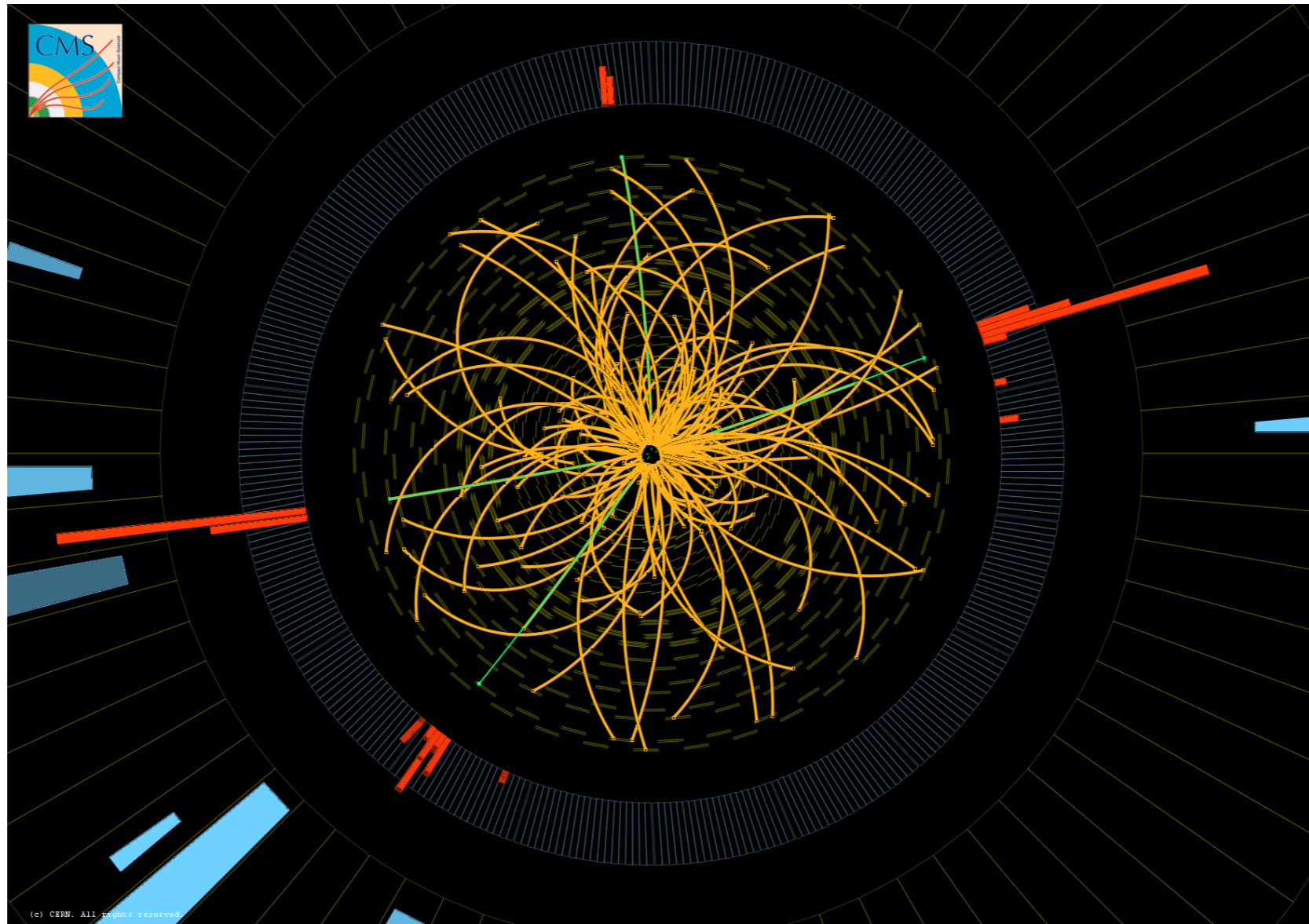
Delphes

GEANT

ROOT

...

TeV
GeV
MeV
Energy



Detector simulation & Analysis

Factorisation

MadGraph5_aMC@NLO

PYTHIA8

1) Hard scattering \Rightarrow Parton shower \Rightarrow Hadronisation

2) Hard scattering rate:

$$\sigma_{pp \rightarrow X} = \sum_{ab} \int dx_1 dx_2 d\Pi_X f_{a/p}(x_1, \mu_F) f_{b/p}(x_2, \mu_F) \hat{\sigma}_{ab \rightarrow X}(\hat{s}, \mu_F, \mu_R)$$

*phase space
Integral*

*parton distribution
functions*

*partonic
cross section*

*complex for many
body final states*

*non-perturbative
fitted from data
CTEQ, NNPDF, MSTW,...*

*Matrix element
 $|\mathcal{M}_{ab \rightarrow X}|^2$
LO, NLO, NNLO*

MG5 :

**Monte Carlo
numerical
integration**

**PDF libraries
e.g. LHAPDF
or internal**

**Helicity amplitudes,
Loop integral libraries**

MadGraph5_aMC@NLO

<https://launchpad.net/mg5amcnlo>

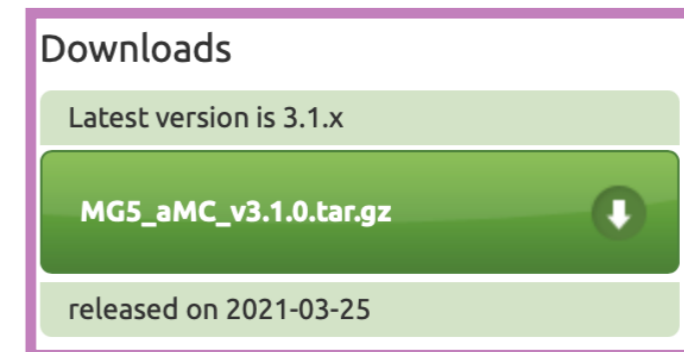
[Alwall et al.; JHEP 07 (2014), 079]

General-purpose Monte Carlo event generation software

- Calculate cross sections for collider processes: LO, NLO QCD (EW)
- Generate simulated event samples
- Interface with parton shower, detector simulation, analysis software
- `python` interface driving `Fortran` routines for helicity amplitudes & integration

Installation (already done for docker)

- a) Download & untar from launchpad site ⇒
- `tar -zxvf MG5_aMC_vX.Y.Z.tar.gz`
- b) Checkout latest stable version using bazaar (requires installing `bzr` first)
- `bzr checkout --lightweight lp:mg5macnlo`
- `bin/mg5_aMC` ⇒ `install pythia8, madanalysis5, lhapdf6,...`

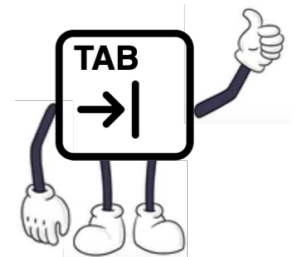


mg5_aMC basics

Executing `mg5_aMC` will open an interactive session

Top tips:

- `Tab completion` (start typing then press tab) to view suggestions/possibilities
- `help` (very useful!)
- `help COMMAND` (e.g. `generate`, `display`, `set`)
- `tutorial`
- Google is your friend: many users worldwide with similar problems ;)
- You can communicate with developers on Launchpad (questions, bugs...)



MadGraph5_aMC@NLO

Overview Code Bugs Blueprints Translations **Answers**

Questions for MadGraph5_aMC@NLO

by relevancy

Get Involved

[Report a bug](#) →

[Ask a question](#) →

a) check if a similar question & answer exist

b) report issue

Main usage

Generate process \Rightarrow output \Rightarrow launch

Process: specify initial & final state particles

```
[MG5_aMC> display particles
Current model contains 17 particles:
w+/w- ve/ve~ vm/vm~ vt/vt~ u/u~ c/c~ t/t~ d/d~ s/s~ b/b~ e-/e+ mu-/mu+ ta-/ta+
a z g h
```

```
[MG5_aMC> display multiparticles
Multiparticle labels:
p = g u c d s u~ c~ d~ s~
j = g u c d s u~ c~ d~ s~
l+ = e+ mu+
l- = e- mu-
vl = ve vm vt
vl~ = ve~ vm~ vt~
all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+ mu+ t b t~ b~ z w+ h w- ta- ta+
```

```
MG5_aMC> generate p p > t t~
MG5_aMC> output MyExample
MG5_aMC> quit()
> cd MyExample
> ls
```



```
Cards
Events
HTML
MGMEVersion.txt
README
README.systematics
Source
SubProcesses
TemplateVersion.txt
bin
index.html
lib
madevent.tar.gz
```

Inputs & runs (LO mode)

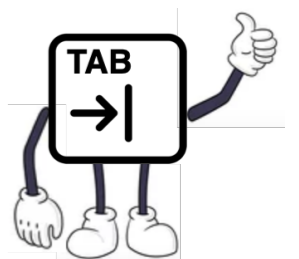
Cards directory: contains input cards to set up runs

- `proc_card_mg5.dat`: commands used to generate process folder
- `run_card.dat`: set up run parameters (CM energy, PDFs, cuts, # events, ...)
- `param_card.dat`: model input parameters (masses couplings, widths, ...)
- `pythia8_card.dat`: parton shower settings (optional)
- `madanalysis5_(parton|hadron)_card.dat`: analysis settings (optional)

From inside MyExample:

- launch setup phase
- determine additional programs to run (shower, detector sim, analysis)
 - Edit relevant cards or set parameters

```
> bin/madevent
MG5_aMC> help launch
MG5_aMC> launch MyRun
MG5_aMC> shower = OFF
MG5_aMC> analysis = OFF
MG5_aMC> set use_syst False
```



Results in MyExample/Events/MyRun

```
MyRun_tag_1_banner.txt unweighted_events.lhe.gz
```

← LHE file

Les Houches Event file

https://en.wikipedia.org/wiki/Les_Houches_Accords

```
> cd Events/MyRun
> less unweighted_events.lhe.gz
```

xml (~html) style format (<tag>...</tag>)

- <header>: metadata (proc_card, run_card, param_card)
- <init>: Sample information (beam energy, PDF set, total XS)

- <event>: Event weight (w_i), initial & final state particle 4 vectors, ... $\sigma_{\text{tot.}} \propto \sum_i w_i$

```
<init>
2212 2212 6.500000e+03 6.500000e+03 0 0 247000 247000 -4 1
5.054910e+02 2.813358e+00 5.054910e+02 1
<generator name='MadGraph5_aMC@NLO' version='2.9.3'>please cite 1405.0301 </generator>
</init>
```

```
<event>
4      1 +5.0549100e+02 1.89563600e+02 7.54677100e-03 1.15885500e-01
      21 -1      0      0 501 502 +0.0000000000e+00 +0.0000000000e+00 +7.6821084071e+01 7.6821084071e+01
      21 -1      0      0 502 503 -0.0000000000e+00 -0.0000000000e+00 -4.6779365138e+02 4.6779365138e+02
      6  1      1      2 501      0 -2.6796879100e+01 -7.2713805621e+01 -1.9343202106e+02 2.7083263657e+02
      -6  1      1      2      0 503 +2.6796879100e+01 +7.2713805621e+01 -1.9754054625e+02 2.7378209888e+02
</event>
<event>
4      1 +5.0549100e+02 1.76253000e+02 7.54677100e-03 1.17147900e-01
      21 -1      0      0 501 502 +0.0000000000e+00 +0.0000000000e+00 +2.5012000721e+02 2.5012000721e+02
      21 -1      0      0 502 503 -0.0000000000e+00 -0.0000000000e+00 -4.6779365138e+02 4.6779365138e+02
      6  1      1      2 501      0 -2.6796879100e+01 -7.2713805621e+01 -1.9343202106e+02 2.7083263657e+02
      -6  1      1      2      0 503 +2.6796879100e+01 +7.2713805621e+01 -1.9754054625e+02 2.7378209888e+02
</event>
```

w_i

PID P_x P_y P_z $E...$

Parton shower interface

<http://home.thep.lu.se/~torbjorn/Pythia.html>

Integrated

```
> bin/madevent
MG5_aMC> launch MyRun
MG5_aMC> shower=PYTHIA8
```

Standalone

```
> bin/madevent
MG5_aMC> shower MyRun
```

Use PYTHIA to decay $h \rightarrow b\bar{b}$

- `pythia8_card.dat`: add to the end of file \Rightarrow

PYTHIA8 settings

```
25:onMode = off
25:onIfMatch = 5 -5
```

Output: `hepmc` file (very large! ~ GB)

- Too much information for most pheno applications
- Can use `MadAnalysis5` to process `hepmc` \Rightarrow `lhe`
- Discard intermediate states, hadrons \Rightarrow jets (PID 21) + E_{miss}^T (PID 12)
- Bypass `hepmc` generation: `shower_card.dat` \Rightarrow `HEPMCoutput:file = fifo`
- During launch setup, set `analysis=MadAnalysis5`

Coupling orders

Used to specify desired Feynman diagrams

- SM: **QCD** (strong coupling g_S) & **QED** (weak couplings g, g', e)
- **SMEFTsim** & **SMEFTatNLO**: **NP** (new physics, Λ^2, Λ)

```
generate p p > t t~ QCD=2 QED=0
```

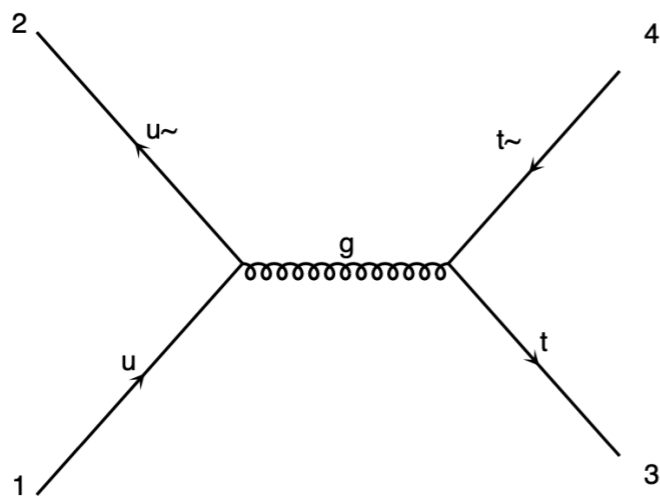


diagram 1 QCD=2, QED=0

```
generate p p > t t~ QCD=0 QED=2
```

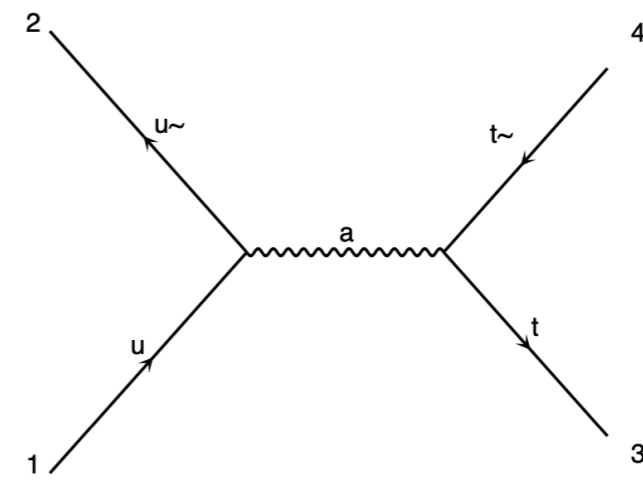


diagram 1 QCD=0, QED=2

```
MG5_aMC> display diagrams
```

```
MG5_aMC> cd SubProcesses/P...
```

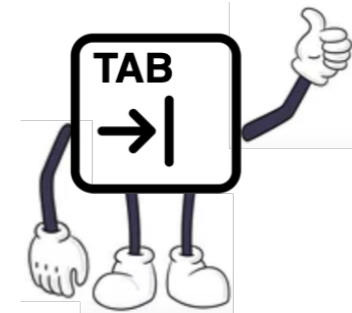
Open file viewer (doesn't work in docker!)

After output: [access matrix.ps](#)

Models

MG5 loads the SM by default

- Other sm versions (`sm_loop`, `sm-no_bmass`,...)



BSM models can be imported (SMEFT, MSSM, 2HDM,...)

- New particles, coupling orders
- Universal FeynRules Output (UFO) model (just a python module!)

[Degrande et al.; Comp.Phys.Comm. 183 (2012) 1201]

```
MG5_aMC> import model SMEFTsim_topU31_MwScheme_UFO
MG5_aMC> import model SMEFTatNLO
MG5_aMC> convert model ... (python3 compatibility thing)
```

Automatically downloaded from FeynRules database <https://feynrules.irmp.ucl.ac.be>

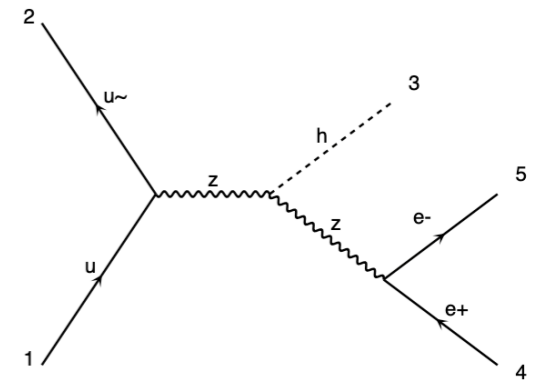
Restriction cards inside model folder: `restrict_XYZ.dat`

- `param_card` with e.g. parameters fixed or =0 to simplify model



```
MG5_aMC> import model SMEFTatNLO-XYZ
```


EFT Exercise



Higgs production in association with a leptonic Z boson

- Parton-level generation
- Interface with Parton shower (PYTHIA8) \Rightarrow hadron-level
- MadAnalysis5 \Rightarrow implement cuts, signal regions & plot distributions
- MadAnalysis5 \Rightarrow fast detector simulation

```
MG5_aMC> generate p p > h e+ e- QED=3 QCD=0
MG5_aMC> output MyZH
```

Check diagrams



<https://indico.ihep.ac.cn/event/13633/page/1>

- Docker users: mount a shared folder (`--mount`) & generate processes there
- Alternative: on shell Z production & decay in Narrow Width Approximation

```
MG5_aMC> generate p p > h z QED=2 QCD=0, z > e+ e-
MG5_aMC> output MyZH2
```

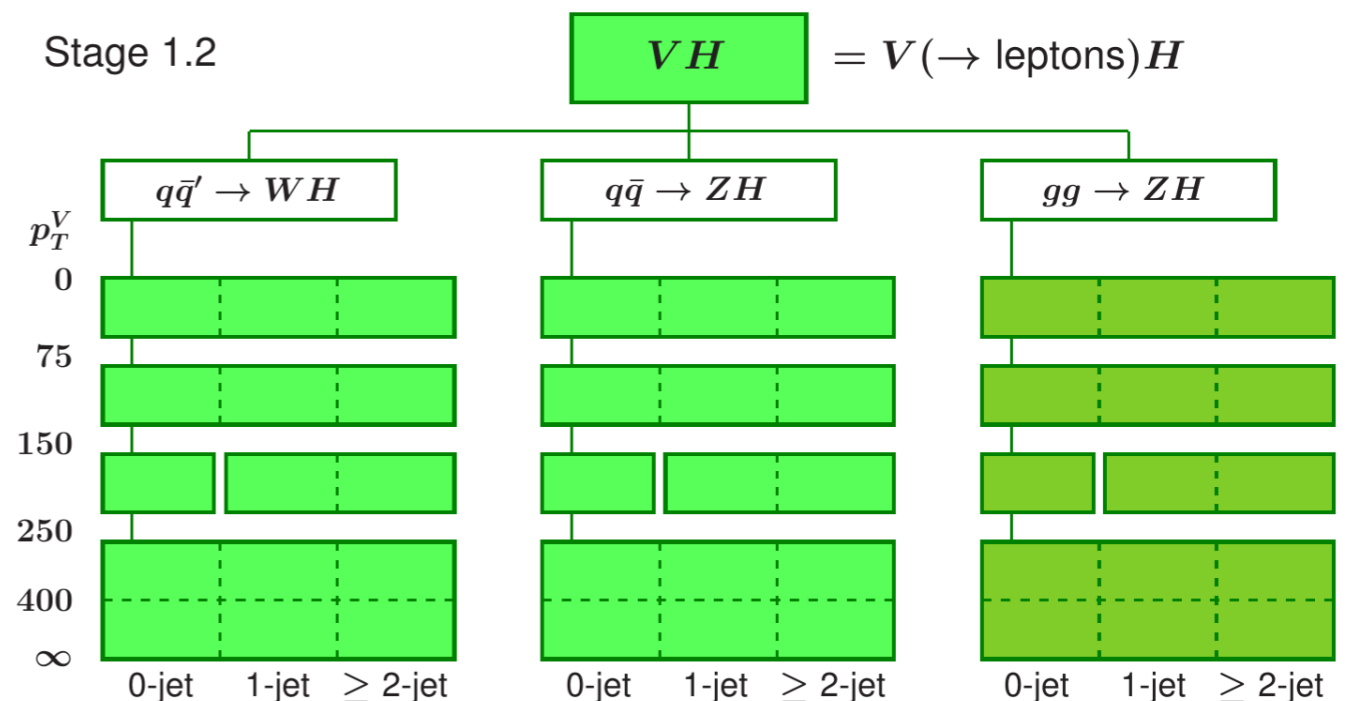
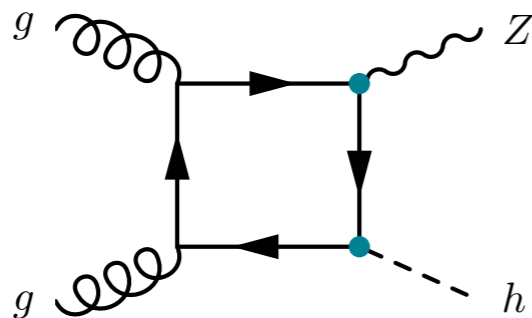
EFT Exercise: goals

Generate & analyse ZH events

- Shower & decays (**PYTHIA8**), reconstructions & analysis (**MadAnalysis5**)
- Plot some differential distributions (m_{Zh} , p_Z^T, \dots)
- Study dependence on SMEFT operators at LO with **SMEFTsim** (Ilaria's talk)
- Compute predictions for Simplified Template Cross Section bins

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGFiducialAndSTXS>

- Upgrade predictions to NLO QCD accuracy with **SMEFTatNLO**
- Bonus: loop-induced sensitivity to top couplings via $gg \rightarrow Zh$



Exercise Tips

Default text editor launched by MG5 = `vim`

- “`i`” (insert) “`ESC`” (stop insert) “`:w`” (save) “`:q`” (quit) “`:wq`” (save+quit)
- Can be modified in `mg5amcnlo/input/mg5_configuration.txt`

Options to save time & space:

```
# text_editor = None
text_editor = nano (emacs,...)
```

- `run_card.dat`: lower `nevents`, set `use_syst=False`
- Parton-level, during launch setup: `shower=OFF`, `analysis=OFF`

• `shower_card.dat`:

⇒

```
!partonlevel:mpi = off
partonlevel:mpi = off
```

- Delete `hepmc` files after converting to `lhe`

`ma5` standalone in `mg5`

```
> bin/madevent
MG5_aMC> madanalysis5_hadron MyRun
```

Convert `hepmc` ⇒ `lhe` file in `Events/MyRun`

Analysis in `Cards/madanalysis5_hadron.card.dat`

`ma5` standalone

See next lecture by Jack!