Tools for LHC physics

The long road towards NLO

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Rencontres de Physique des Particules
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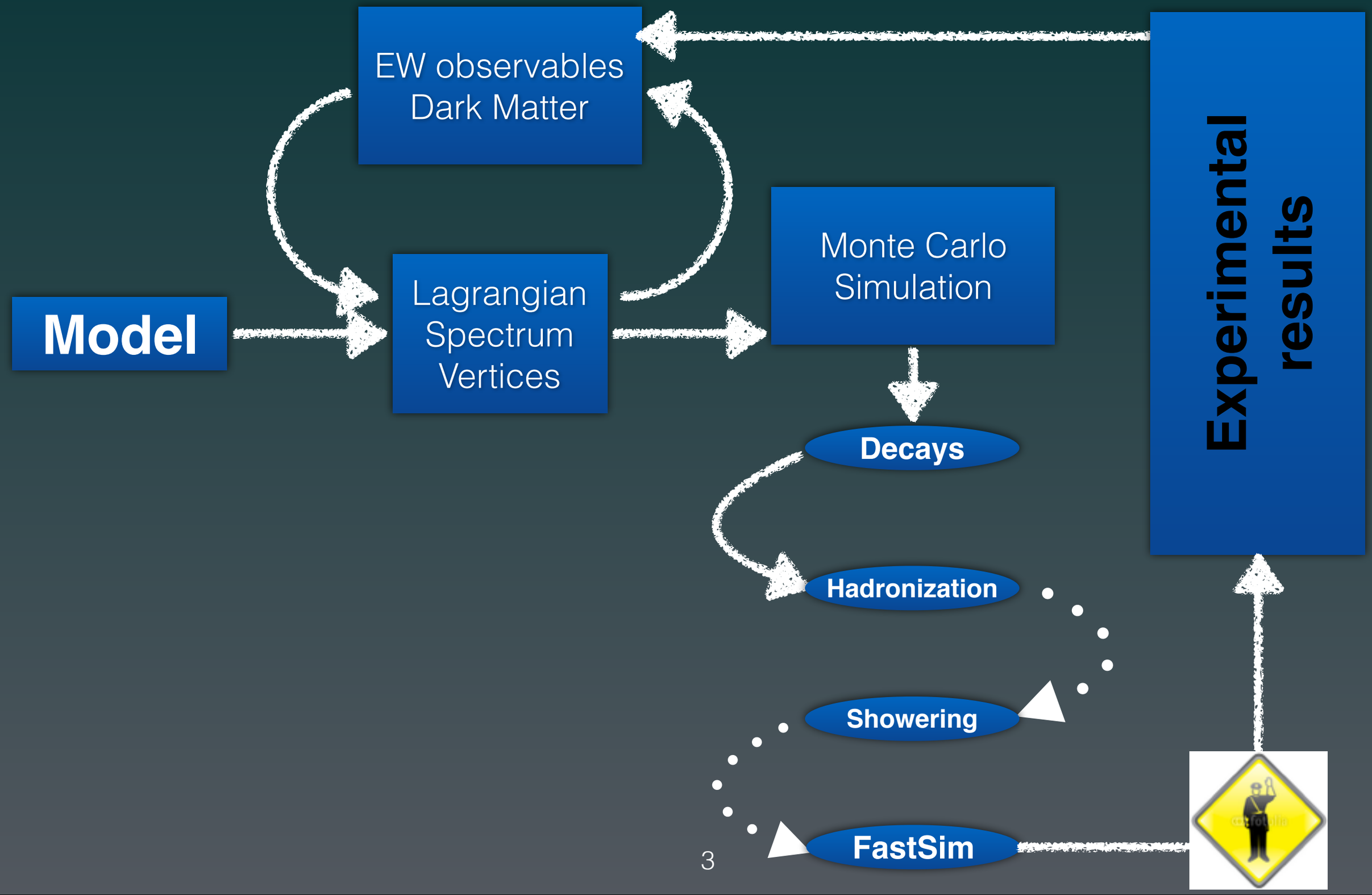
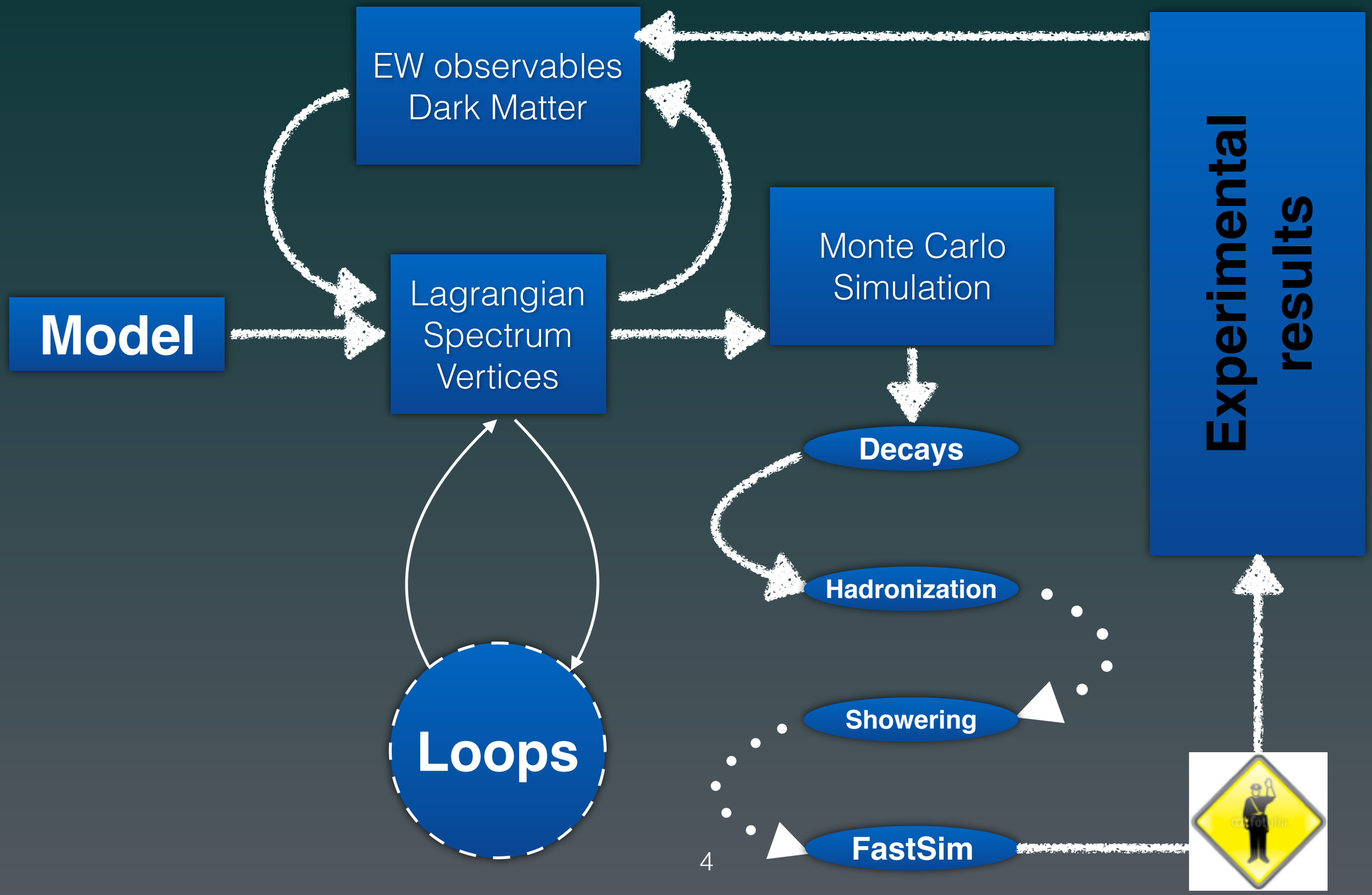
The need for automation

- We have come a long way since Schoonschip (Veltman 1964)
- More computer power => More complex calculations
- Since early 90's several tools developed

Tools in High Energy Physics



Tools in High Energy Physics



Model building

Model

Interactions | Field content | Symmetries | Lagrangian

FeynRules

- Mathematica package
- Not tied to SUSY
- Any Gauge group
- Vertices extraction
- Spectrum generation
- 1 -> 2 decays
- Several interfaces
- UFO interface

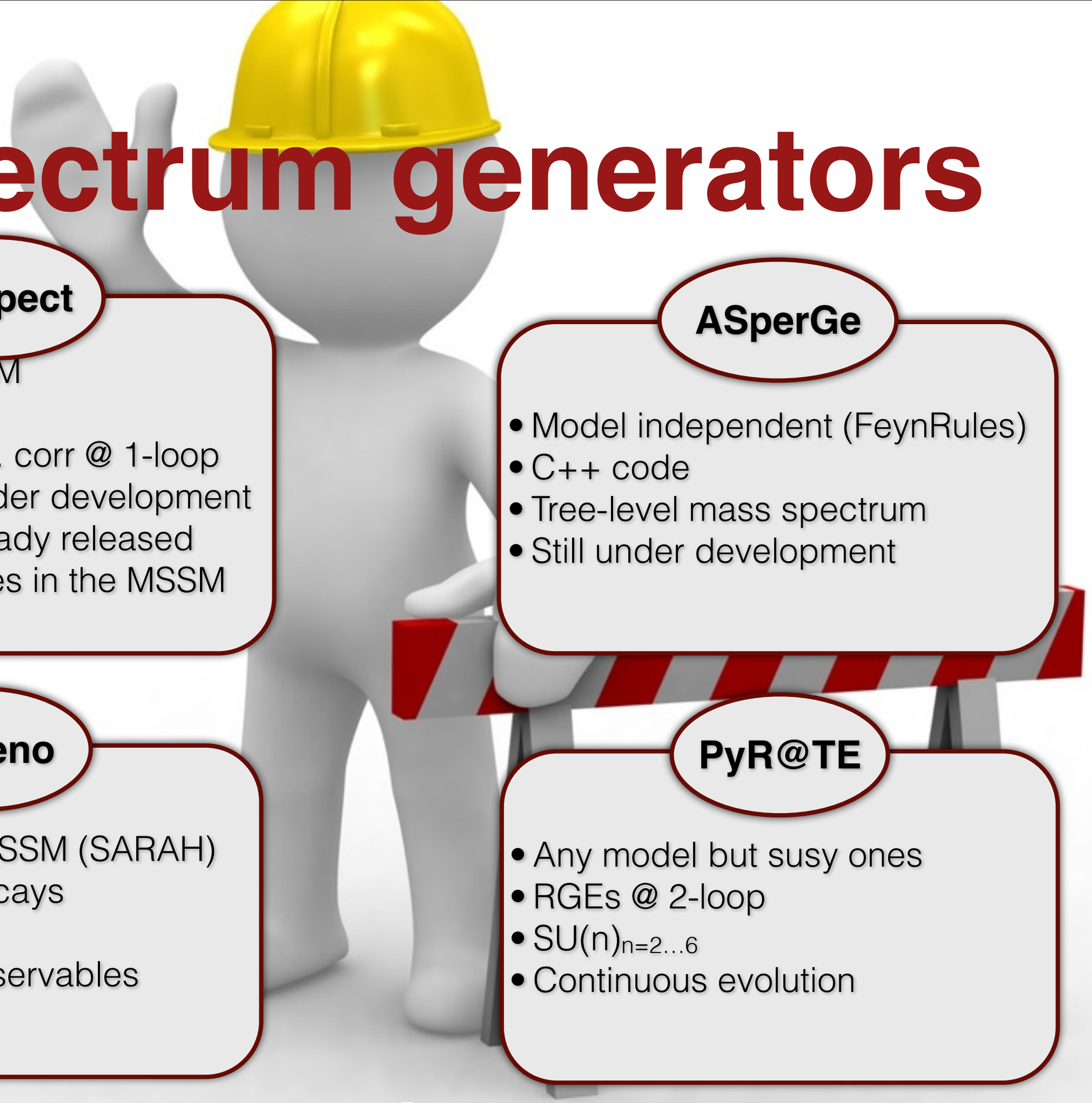
Sarah

- Mathematica package
- Specific to SUSY
- Any gauge group
- Vertices extraction
- Interface with SPheno
- Useful SUSY Toolbox
- UFO Output

LanHEP

- Written in C
- Not tied to Susy
- Lagrangian written in compact form
- CompHEP interface
- FeynArts interface
- 1 Loop CT for FeynArts and FormCalc

Spectrum generators



SuSpect

- Specific to MSSM
- RGEs @ 2-loop
- Higgs mass rad. corr @ 1-loop
- C++ version under development
  - α-version already released
  - Some examples in the MSSM

ASperGe

- Model independent (FeynRules)
- C++ code
- Tree-level mass spectrum
- Still under development

SPheno

- Not specific to MSSM (SARAH)
- 2 and 3 body decays
- b -> s$\gamma\gamma$
- Several other observables

PyR@TE

- Any model but susy ones
- RGEs @ 2-loop
- $SU(n)_{n=2\ldots6}$
- Continuous evolution

Dark Matter & EW observables

SuperIso

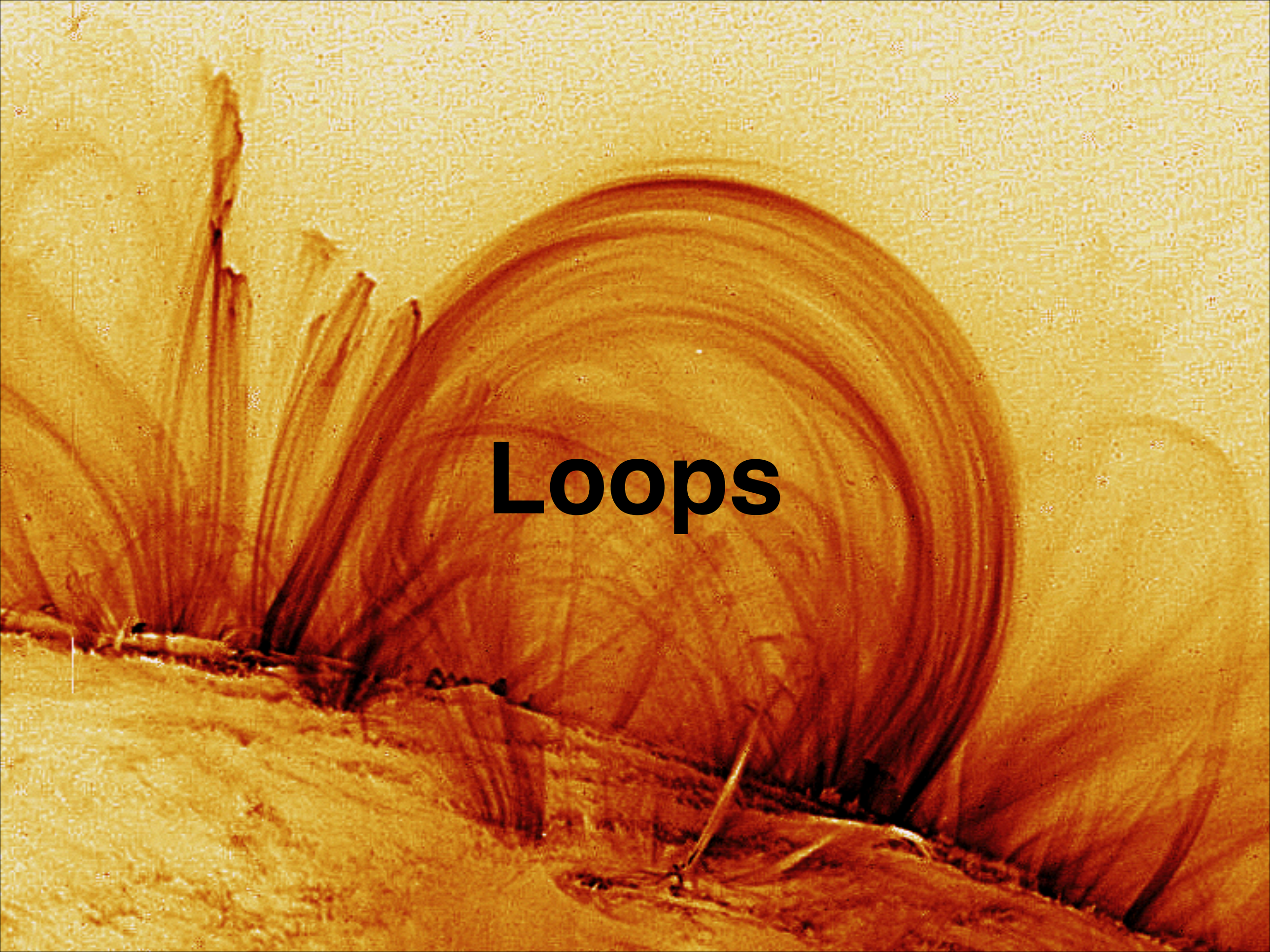
- C-program
- Flavor physics + DM observables
- Interfaced to spectrum calculators
- SM, 2HDM, MSSM, NMSSM, BMSSM
- Being interfaced with FR

Micromegas

- Several DM observables
- Needs CalcHEP
- Under continuous evolution

MadDM

- Fortran wrapped in Python
- Only relic density
- Inherits from MadGraph 5


Loops

Loop reductions and integration

- Several tools/techniques available…
- … but one common denominator:
  - Reduction of tensor integrals to scalar ones
  - Numerically evaluate them
- Advanced Calculational and Analysis Techniques conference

Loop reductions and integration

- LoopTools
- BlackHat
- LiteRed
- Rocket
- OLEC
- BasisDet
- FeynCalc
- CutTools
- PJFry
- Fire4
- OpenLoops
- Contractions
- Golem95

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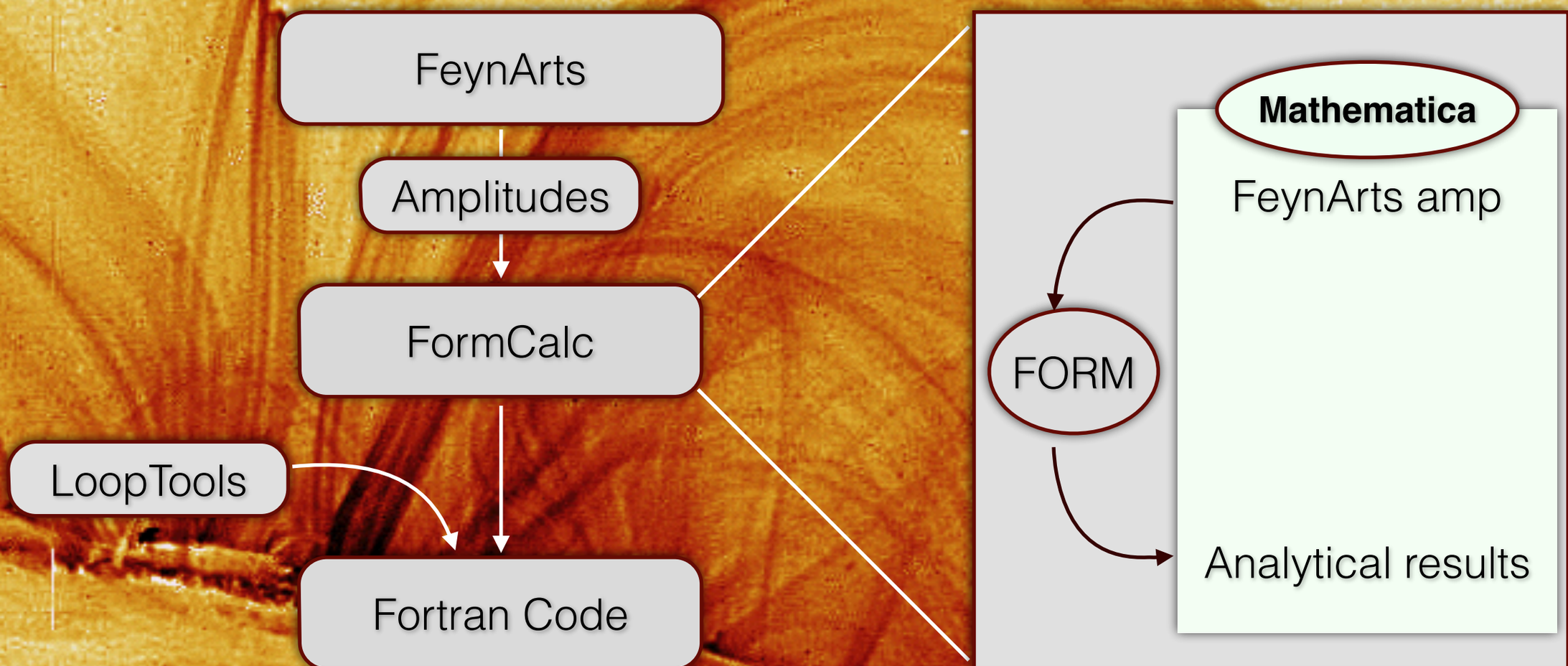
The FeynArts/FormCalc/ LoopTools suite



FeynArts

- ✦Generates Feynman diags
- ✦Generates counter terms
- ✦Effective theories

FormCalc

- ✦Index contraction
- ✦Fermion traces evaluation
- ✦Tensor integrals reduction

LoopTools

Numerical integration of scalar and tensor integrals for 1-loop processes

The Golem/Samurai tandem

Golem 95

- Tensor reduction method
- Up to 6 external legs
- Focus on virtual corrections
- Arbitrary rank
- Integral libraries
  - OneLoop & Golem95C

+

SAMURAI

- OPP method
- Any number of external legs
- Integral libraries
  - OneLoop & QCDLoop & Golem95C

= **GoSam**

GoSam

- ✦ Virtual part in NLO calculation
  - ✦ Code generation via FORM
    - ✦ Effective vertices
- ✦ Choice of best method @ Runtime
  - ✦ **QCD**, EW, BSM
    - ✦ UFO interface

Some recent results in NLO calculations

BlackHat/Sherpa

W+4/5 (6?) jets
Z+4jets

FeynArts/FormCalc

Renormalized Complex MSSM

GoSam

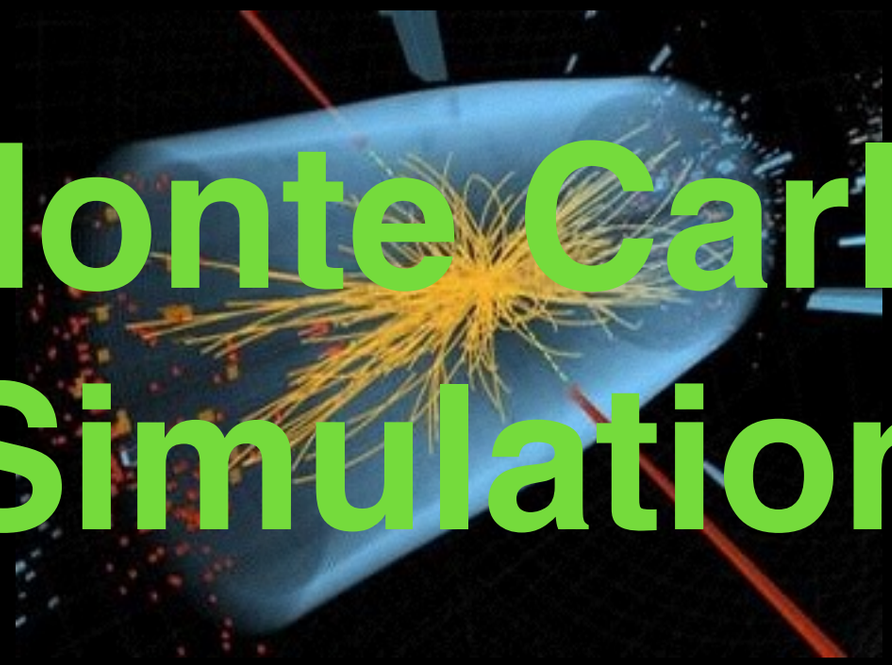
Higgs + 2/3 jets

MG5_aMC@NLO

Higgs effective Lagrangian @NLO

NJets

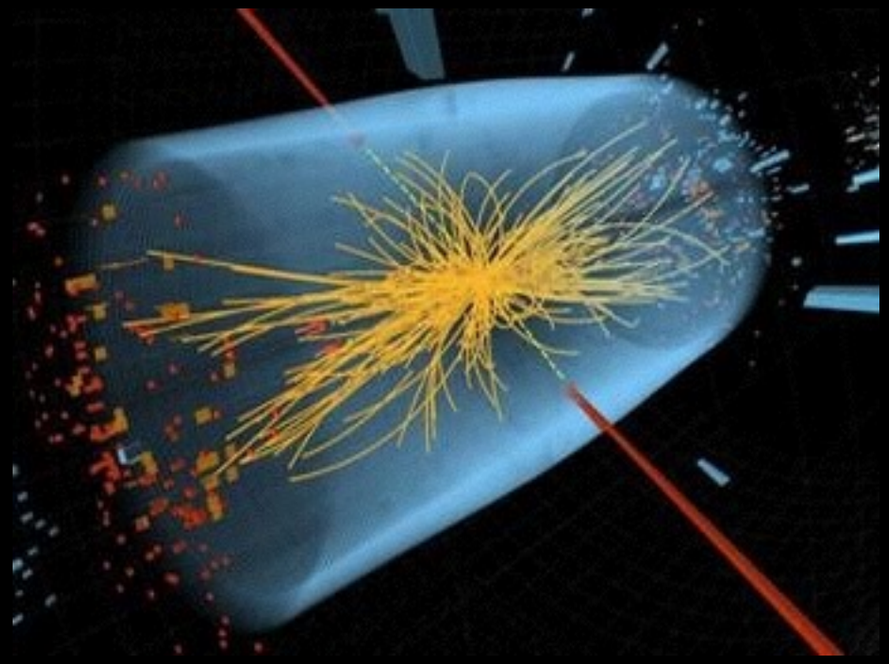
p p > 5 jets



Monte Carlo Simulation

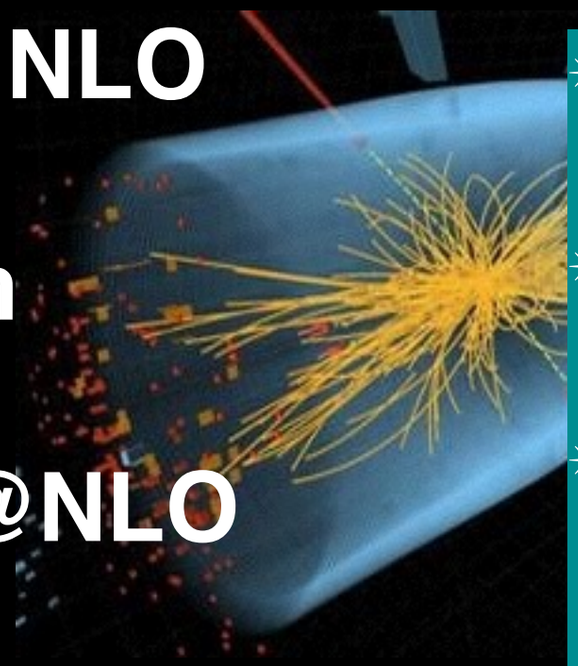
General purpose MC generators

- MadGraph
- Herwig
- Sherpa
- Grappa
- Pythia
- Whizard



General purpose MC generators @NLO

- MG5_aMC@NLO
- MG5/GoSam
- Herwig/MC@NLO
- Herwig/POWHEG
- Sherpa/BlackHat



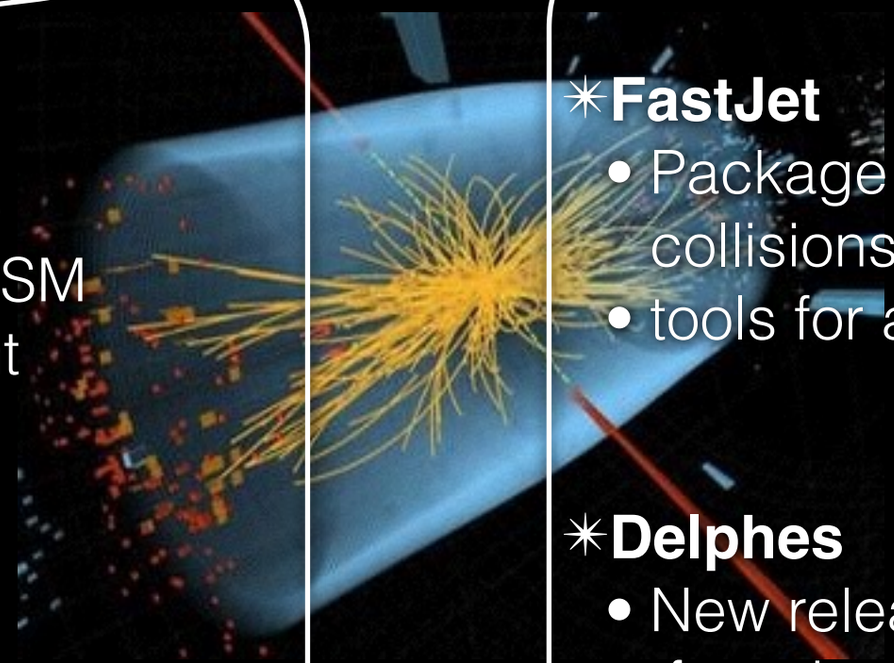
- Model independent @LO
- UFO interface
- QCD @ NLO fully automated
- Hadronization and decays
- Spin correlations

Decays, hadronization, QCD effects …

Hadronization/Parton Showering

✳**Pythia 8**
- Several models available
- Works for both SM and BSM
- Input from par tonic event generators

✳**Tauola**
- Handles tau decays
- Best suited for « simple » models
- Interfaced with MG5



Jet Clustering/FastSim/Detector

✳**FastJet**
- Package for jet finding in pp and e+e- collisions
- tools for advanced jet manipulation

✳**Delphes**
- New release version 3 in 2013
- fast simulation of a generic collider experiment
- Several improvements

Analysis Tools

Anlysis tools

MadAnalysis5

- ✳C++ core wrapped in Python
- ✳Easy to use and intuitive
- ✳Compatible with parton/hadron/detector level events
- ✳Interfaced to FastJET and Delphes
- ✳Expert Mode

Rivet

- ✳C++ program
- ✳Huge list of ‘ready-to-apply’ analyses ->LEP, Tevatron, LHC, Hera, Rhic
- ✳Expert mode
- ✳On the fly analysis

CheckMATE

- ✳Feeded by event files
- ✳Determines whether excluded or not @95% C.L.
- ✳Calculates confidence limits
- ✳Provides detailed information about signal region of interest

Conclusion

Even more tools

- RooStats
- HiggsBounds
- TMVA
- SecDec
- RooFit
- RooStats
- NJets
- Omega
- Bridge++
- Fewz
- Hathor
- MCFM
- DCM
- Helac
- HiggsSignals
- Contractions

Still a long road

- LO is under good control
- Need for more precision
  - Development of NLO techniques
  - Multi-leg xsections for EFT
- Limited by computing power

MG5_aMC@NLO

- Matching of any NLO QCD computation with parton showers following the MC@NLO approach
- MadFks: Born + real emissions + IR singularities
- MadLoop: 1 Loop amplitude using the OPP integrand reduction method

Sherpa/BlackHat

- BlackHat: Virtual matrix elements + real-emission matrix elements
- Sherpa: Born + substractions terms + integration over phase space

MC@NLO vs POWHEG

- Parton shower simulation implements approximate NLO (LL approximation)
- Problem: How to merge parton shower and exact NLO calculation and avoid over counting

MC@NLO

- Calculate exact NLO
- Calculate the MC subtraction term

Parton shower algortihm dependent

- Substract both results

Negative weight events

POWHEG

- Hardest emission generated first
- Correct the first emission @ NLO
- Generate other emissions with p_T veto

Requires modifications of parton shower codes