From new physics simulations to the recasting of LHC results

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LPTHE Paris / UPMC Paris VI

9th MCNet School @ Spa, Belgium

30 August - 4 September, 2015

Outline

1. When new physics meets Monte Carlo simulations
2. New physics simulations with Monte Carlo event generators
3. Interpretation of LHC results and recasting the experimental searches
4. Conclusions - summary

Standard Model simulations at the LHC: the status

✦ The need for better simulation tools has spurred a very intense activity

- ✤ Automated matrix element generation (MADGRAPH5, SHERPA, WHIZARD, *etc.*)
- ✤ Higher-order computations (MC@NLO, POWHEG)
- ✤ Parton showering and hadronization (PYTHIA, HERWIG, SHERPA)
- ✤ Matrix element - parton showering matching
- ✤ Merging techniques (MLM, CKKW, FxFx, UNLOPS)

✦ Standard Model simulations

- ✤ All processes relevant for LHC physics can be simulated with a very good precision
- ✤ This precision will even improve within the next few years (electroweak corrections, *etc.*)

Standard Model simulations are under good control
What about new physics?

New physics simulations at the LHC: the challenge

✦ The challenges with respect to new physics simulations are of a different nature

- ✤ Theoretically, we are still in the dark
  - ★ No sign of new physics
  - ★ All measurements are Standard-Model-like
- ✤ There is not any leading new physics candidate theory
  - ★ Plethora of models to implement in the tools

✦ New physics is a standard in many tools today

- ✤ Prospective phenomenological studies
- ✤ Experimental searches (signal generation)
- ✤ Recasting of current results

Topics of this lecture

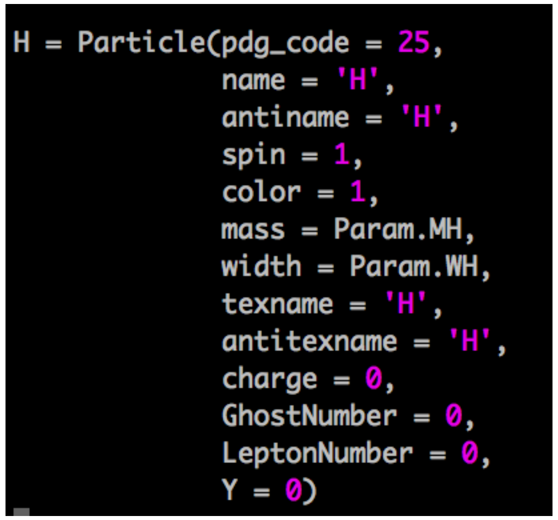
Outline

New physics implementations in Monte Carlo tools (I)

✦ How to implement a new physics model in a Monte Carlo program?

- ✤ Model definition: particles, parameters & vertices (≡ Lagrangian)
- ✤ To be translated in a programming language, following some conventions, *etc.*
- ✤ Tedious, time-consuming, error prone (and no-brainer)
- ✤ Iterations for all considered tools and models (high level of redundancy)
- ✤ Beware of the restrictions of each tool (Lorentz structures, color structures)
- ✤ Validation is tricky

$$\mathcal{L} = \frac{\bar{c}_H}{2v^2}\partial^\mu\left[\Phi^\dagger\Phi\right]\partial_\mu\left[\Phi^\dagger\Phi\right] \longrightarrow$$



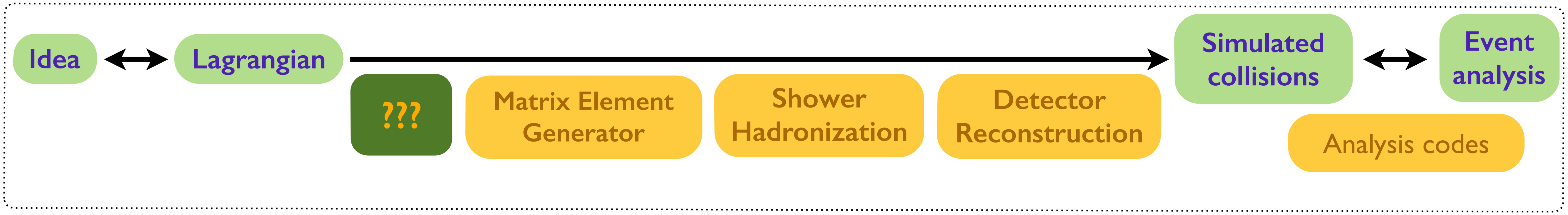
```
H = Particle(pdg_code = 25,
             name = 'H',
             antiname = 'H',
             spin = 1,
             color = 1,
             mass = Param.MH,
             width = Param.WH,
             texname = 'H',
             antitexname = 'H',
             charge = 0,
             GhostNumber = 0,
             LeptonNumber = 0,
             Y = 0)
```

+ …

New physics implementations in Monte Carlo tools (2)

✦ A comprehensive approach to Monte Carlo simulations

[Christensen, de Aquino, Degrande, Duhr, BF, Herquet, Maltoni & Schumann (EPJC'11)]



✦ How to streamline the chain from the model Lagrangian to analyzed simulated collisions

- ✤ Connect the physics (Lagrangians) to simulated LHC collisions: need for an efficient framework
  - ★ … where any new physics model can be implemented
  - ★ … where any new physics model can be tested against data
  - ★ … easy to validate, to maintain
  - ★ … easily integrable in the above chain

Automating new physics simulations

✦ Starting point: the model Lagrangians (with all the physics information)

- ✤ Is absent in the Monte Carlo tools
- ✤ Allows for a unique model definition
- ✤ New model ≡ changes in the Lagrangian (no need for hacking any code)

✦ First steps in this direction: the LANHEP package [Semenov (NIMA'97; CPC'98; CPC'09)]

- ✤ Based on the C language
- ✤ Restricted to CALCHEP/COMPHEP, FEYNARTS; also generates UFO libraries

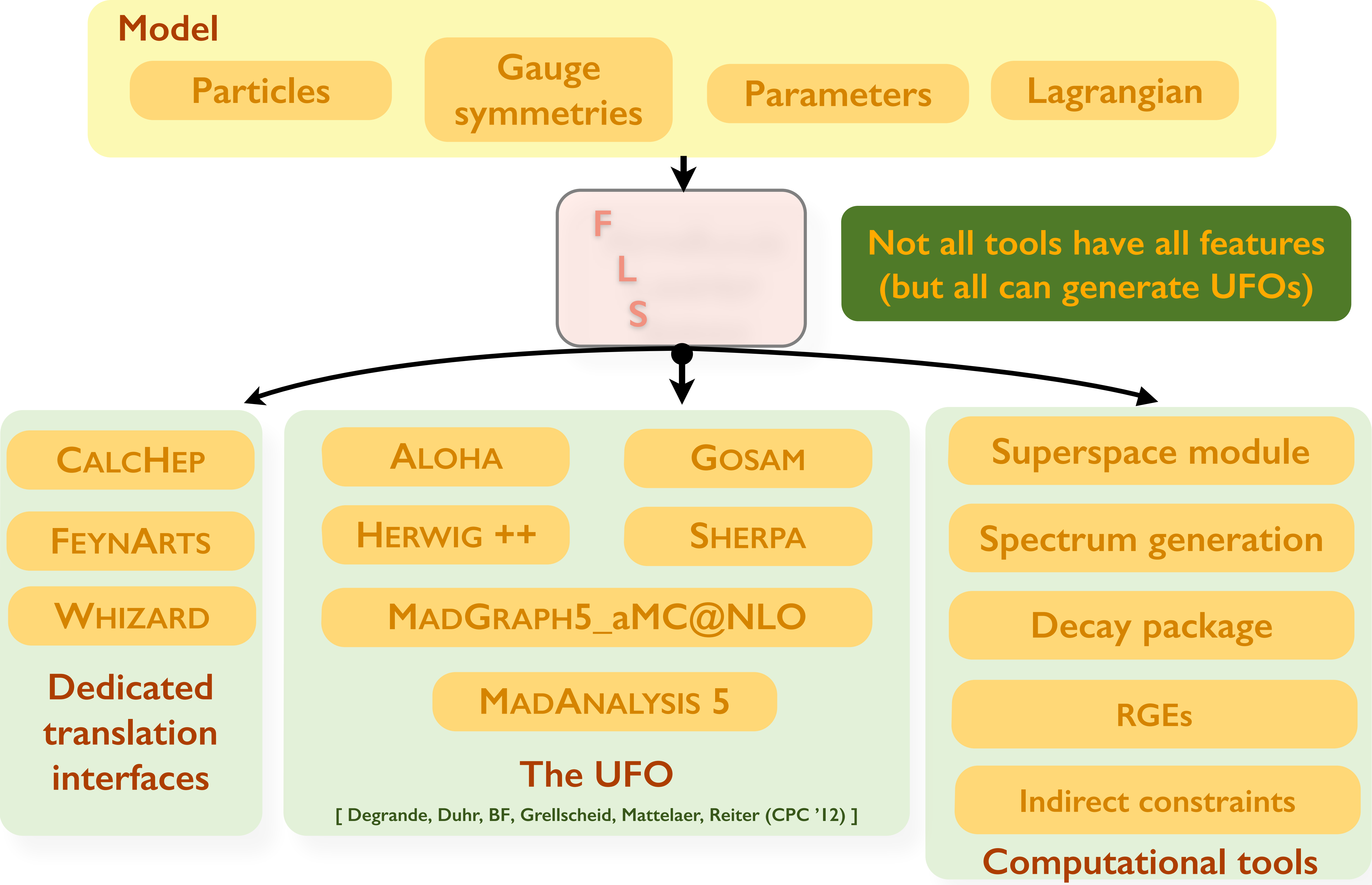
✦ The FEYNRULES package [Christensen & Duhr (CPC '09); Alloul, Christensen, Degrande, Duhr & BF (CPC'14)]

- ✤ Based on MATHEMATICA
- ✤ Initially interfaced to CALCHEP, FEYNARTS, MADGRAPH, SHERPA, WHIZARD
- ✤ The UFO (Universal FEYNRULES Output) format is now a standard
- ✤ Contains many model-builder modules

✦ The SARAH package [Staub (CPC'13; CPC'14)]

- ✤ Based on MATHEMATICA
- ✤ Interfaced to CALCHEP, FEYNARTS, MADGRAPH, WHIZARD; and to the UFO
- ✤ Contains many model-builder modules

Automating new physics simulations: the status



Model

Particles

Gauge symmetries

Parameters

Lagrangian

F

L

S

Not all tools have all features (but all can generate UFOs)

CalcHep

FeynArts

Whizard

Dedicated translation interfaces

Aloha

GoSam

Herwig ++

Sherpa

MadGraph5_aMC@NLO

MadAnalysis 5

The UFO

[Degrande, Duhr, BF, Grellscheid, Mattelaer, Reiter (CPC '12)]

Superspace module

Spectrum generation

Decay package

RGEs

Indirect constraints

Computational tools

Why is the UFO now a standard?

- Color structures: not supported in full generality by Monte Carlo generators
  - The treatment of the color information is hard-coded
  - The interfaces to a specific tool discard all non-supported vertices
  - Representations usually handled: 1, 3, 8 (limited in CALCHEP), sometimes 6

- Lorentz structures and spins not supported in full generality by Monte Carlo programs
  - The treatment of the Lorentz structures of the different vertices is hard-coded
  - The possible spins for the particles are restricted
  - The interfaces discard all non-supported vertices
  - Spin representations usually handled: 0, 1/2, 1; sometimes 3/2, 2
  - Lorentz structures usually handled: MSSM-like; sometimes any

Each interface dedicated to a given tool is specific

- ★ Removal of vertices not compliant with the tool
- ★ Translation to a specific format and programming language

⇒ not efficient

⇒ better: one translation and the tools parse it

The Universal FEYNRULES Output (UFO) in a nutshell

[Degrande, Duhr, BF, Grellscheid, Mattelaer, Reiter (CPC '12)]

✦ Definition of the UFO

- ✤ UFO ≡ Universal FEYNRULES output
  - ★ Universal as not tied to any specific Monte Carlo program
- ✤ Allows the models to contain generic color and Lorentz structures
  - ★ It is up to the different tools to discard all vertices they cannot handle
- ✤ Consists of a PYTHON module to be linked to any code
- ✤ This module contains all the model information
- ✤ Can be employed for next-to-leading order calculations

✦ The UFO is used by several programs

ALOHA

GOSAM

HERWIG ++

MADANALYSIS 5

MADGRAPH5_aMC@NLO

SHERPA

WHIZARD (soon)

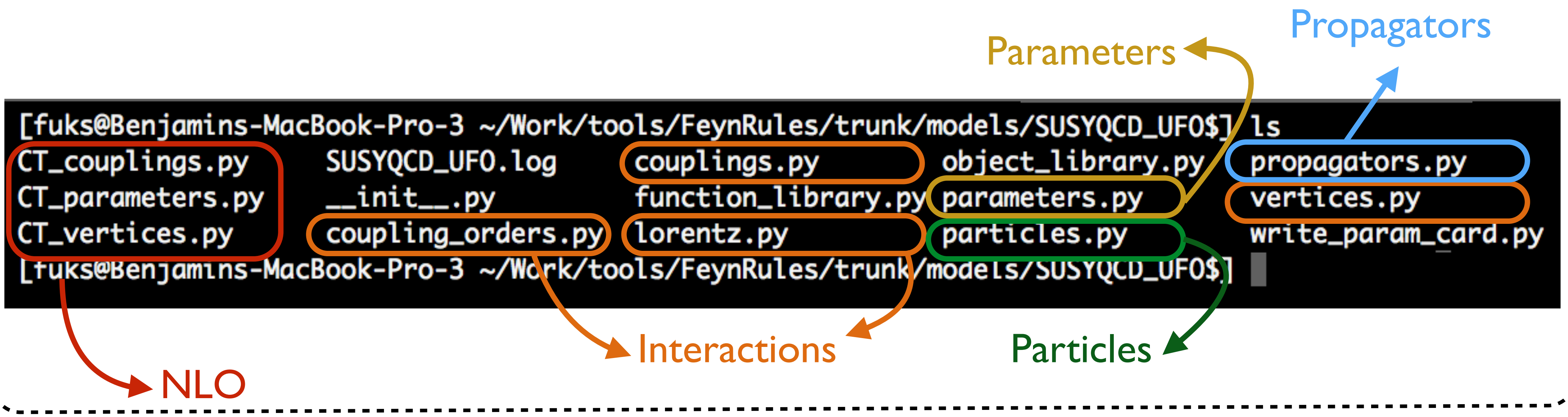
UFOs in details

✦ The UFO is a set of PYTHON files

- ✤ Particle information (particles.py)
- ✤ Interaction information (vertices.py, couplings.py, lorentz.py, couplings_orders.py)
- ✤ Parameter information (parameters.py)
- ✤ Propagator information (propagators.py)
- ✤ Tools (function_library.py, object_library.py, write_param_card.py, decays.py)
- ✤ NLO counterterms (CT_couplings.py, CT_parameters.py, CT_vertices.py)

✦ Example: a UFO for supersymmetric QCD

- ✤ All UFOs have a similar structure
- ✤ CT_xxx.py files optional: no official standards for NLO (yet)



```
[fuks@Benjamins-MacBook-Pro-3 ~/Work/tools/FeynRules/trunk/models/SUSYQCD_UFO$] ls
CT_couplings.py     SUSYQCD_UFO.log     couplings.py        object_library.py   propagators.py
CT_parameters.py    __init__.py         function_library.py parameters.py       vertices.py
CT_vertices.py      coupling_orders.py  lorentz.py          particles.py        write_param_card.py
[fuks@Benjamins-MacBook-Pro-3 ~/Work/tools/FeynRules/trunk/models/SUSYQCD_UFO$] 
```

Particles in UFOs

- Particles are stored in the particles.py file
  - Instances of the particle class
  - Attributes define the particle spin and color representation, mass, width, PDG code, *etc.*)
  - Antiparticles are automatically derived from the knowledge of the corresponding particle

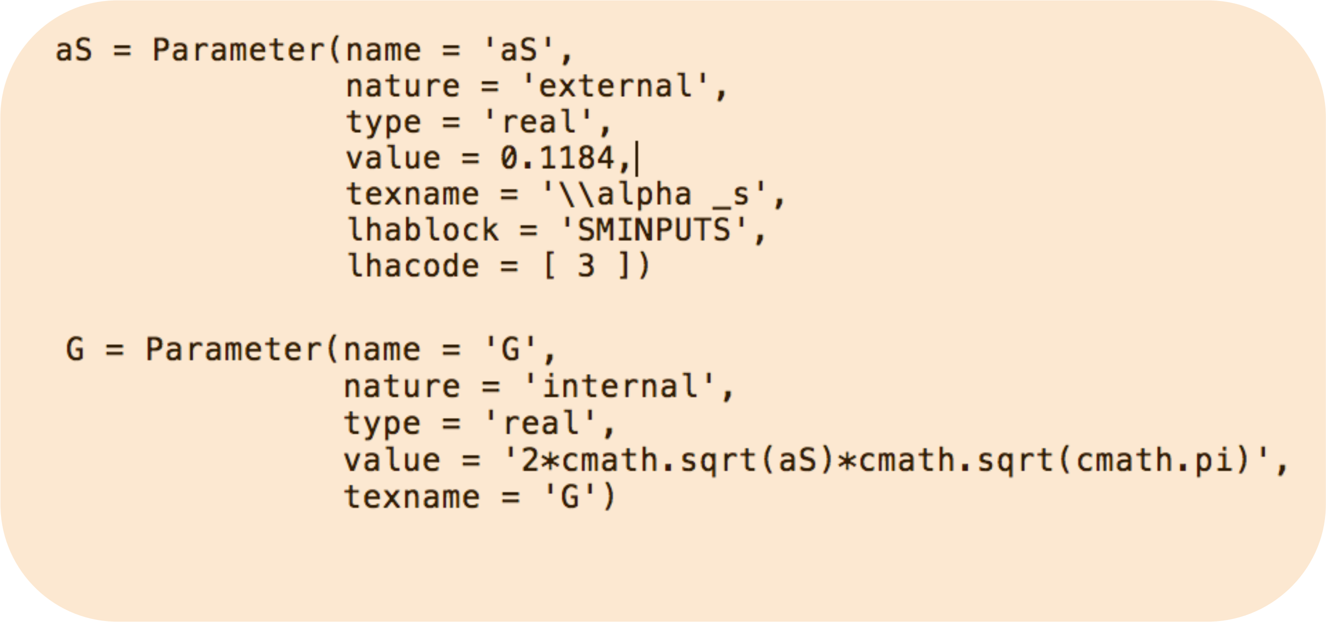
```
G = Particle(pdg_code = 21,
             name = 'G',
             antiname = 'G',
             spin = 3,
             color = 8,
             mass = Param.ZERO,
             width = Param.ZERO,
             texname = 'G',
             antitexname = 'G',
             charge = 0)

go = Particle(pdg_code = 1000021,
              name = 'go',
              antiname = 'go',
              spin = 2,
              color = 8,
              mass = Param.Mgo,
              width = Param.Wgo,
              texname = 'go',
              antitexname = 'go',
              charge = 0)
```

```
sq1 = Particle(pdg_code = 1000006,
               name = 'sq1',
               antiname = 'sq1~',
               spin = 1,
               color = 3,
               mass = Param.Msq1,
               width = Param.Wsq1,
               texname = 'sq1',
               antitexname = 'sq1~',
               charge = 0)

sq1__tilde__ = sq1.anti()

sq2 = Particle(pdg_code = 2000006,
               name = 'sq2',
               antiname = 'sq2~',
               spin = 1,
               color = 3,
               mass = Param.Msq2,
               width = Param.Wsq2,
               texname = 'sq2',
               antitexname = 'sq2~',
               charge = 0)

sq2__tilde__ = sq2.anti()
```

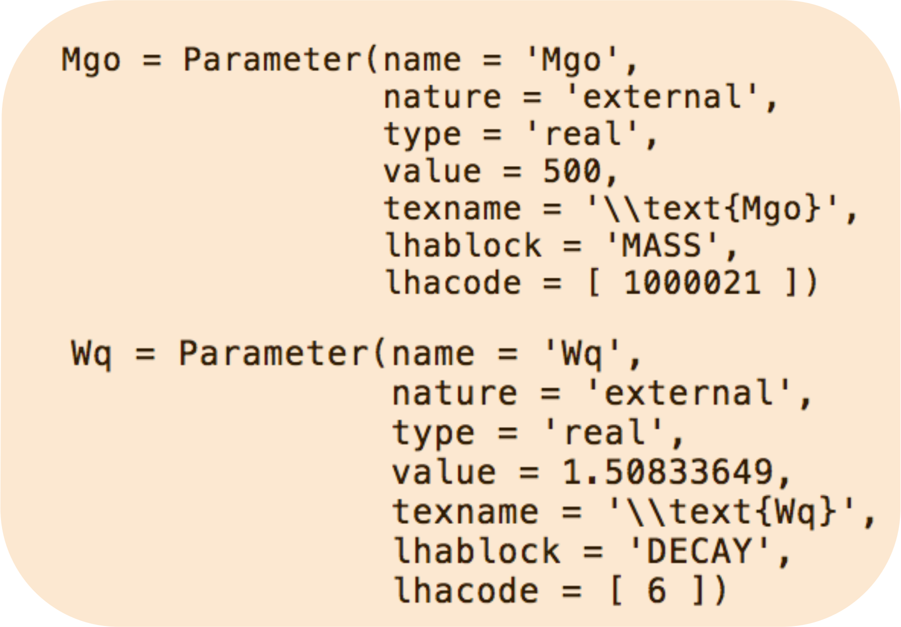
```
q = Particle(pdg_code = 6,
             name = 'q',
             antiname = 'q~',
             spin = 2,
             color = 3,
             mass = Param.Mq,
             width = Param.Wq,
             texname = 'q',
             antitexname = 'q~',
             charge = 0)

q__tilde__ = q.anti()
```

Parameters in UFOs

- Parameters are stored in the parameters.py file
  - Instances of the parameter class
  - External parameters are organized following a LesHouches-like structure (blocks and counters)
  - PYTHON-compliant formula for the internal parameters



```
aS = Parameter(name = 'aS',
               nature = 'external',
               type = 'real',
               value = 0.1184,
               texname = '\\alpha _s',
               lhablock = 'SMINPUTS',
               lhacode = [ 3 ])

 G = Parameter(name = 'G',
               nature = 'internal',
               type = 'real',
               value = '2*cmath.sqrt(aS)*cmath.sqrt(cmath.pi)',
               texname = 'G')
```



```
Mgo = Parameter(name = 'Mgo',
                nature = 'external',
                type = 'real',
                value = 500,
                texname = '\\text{Mgo}',
                lhablock = 'MASS',
                lhacode = [ 1000021 ])

 Wq = Parameter(name = 'Wq',
                nature = 'external',
                type = 'real',
                value = 1.50833649,
                texname = '\\text{Wq}',
                lhablock = 'DECAY',
                lhacode = [ 6 ])
```

Interactions: the UFO strategy

✦ Vertices are decomposed in a spin x color basis, coupling strengths being coordinates

✤ Example: the quartic gluon vertex can be written as

$$\begin{aligned} & i g_s^2\, f^{a_1 a_2 b} f^{b a_3 a_4}\, (\eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4}) \\ & \quad + i g_s^2\, f^{a_1 a_3 b} f^{b a_2 a_4}\, (\eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4}) \\ & \quad + i g_s^2\, f^{a_1 a_4 b} f^{b a_2 a_3}\, (\eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4}) \end{aligned} \Rightarrow \begin{aligned} & \left(f^{a_1 a_2 b} f^{b a_3 a_4},\ f^{a_1 a_3 b} f^{b a_2 a_4},\ f^{a_1 a_4 b} f^{b a_2 a_3}\right) \\ & \times \begin{pmatrix} i g_s^2 & 0 & 0 \\ 0 & i g_s^2 & 0 \\ 0 & 0 & i g_s^2 \end{pmatrix} \begin{pmatrix} \eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4} \\ \eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4} \\ \eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4} \end{pmatrix} \end{aligned}$$

✤ Each element of this decomposition is stored separately in the vertex.py file

★ vertices.py: defines all model decompositions

★ lorentz ≡ the spin basis (stored in lorentz.py; reused across vertices for economical reasons)

★ color ≡ the color basis (directly defined in the file)

★ couplings ≡ the coordinates (stored in couplings.py; reused across vertices for economical reasons)

```
V_2 = Vertex(name = 'V_2',
             particles = [ P.G, P.G, P.G, P.G ],
             color = [ 'f(-1,1,2)*f(3,4,-1)', 'f(-1,1,3)*f(2,4,-1)', 'f(-1,1,4)*f(2,3,-1)' ],
             lorentz = [ L.VVVV1, L.VVVV2, L.VVVV3 ],
             couplings = {(1,1):C.GC_4,(0,0):C.GC_4,(2,2):C.GC_4})
```

★ lorentz.py

```
VVVV1 = Lorentz(name = 'VVVV1',
                spins = [ 3, 3, 3, 3 ],
                structure = 'Metric(1,4)*Metric(2,3) - Metric(1,3)*Metric(2,4)')
```

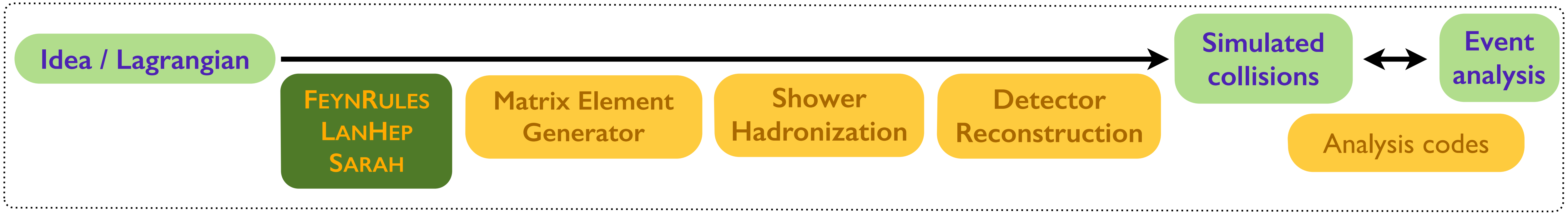
★ couplings.py

```
GC_4 = Coupling(name = 'GC_4',
                value = 'complex(0,1)*G**2',
                order = {'QCD':2})
```

Coupling orders: information that may be used for selecting diagrams

New physics simulations: other challenges

✦ A comprehensive approach to Monte Carlo simulations



✦ Implementation of any new physics theory in Monte Carlo tools is now straightforward

✦ Other challenge 1: cascade-decays

- ✤ Beyond the Standard Model theories involve lots of new particles
- ✤ These particles can decay into each other
- ✤ Large multiplicity final states

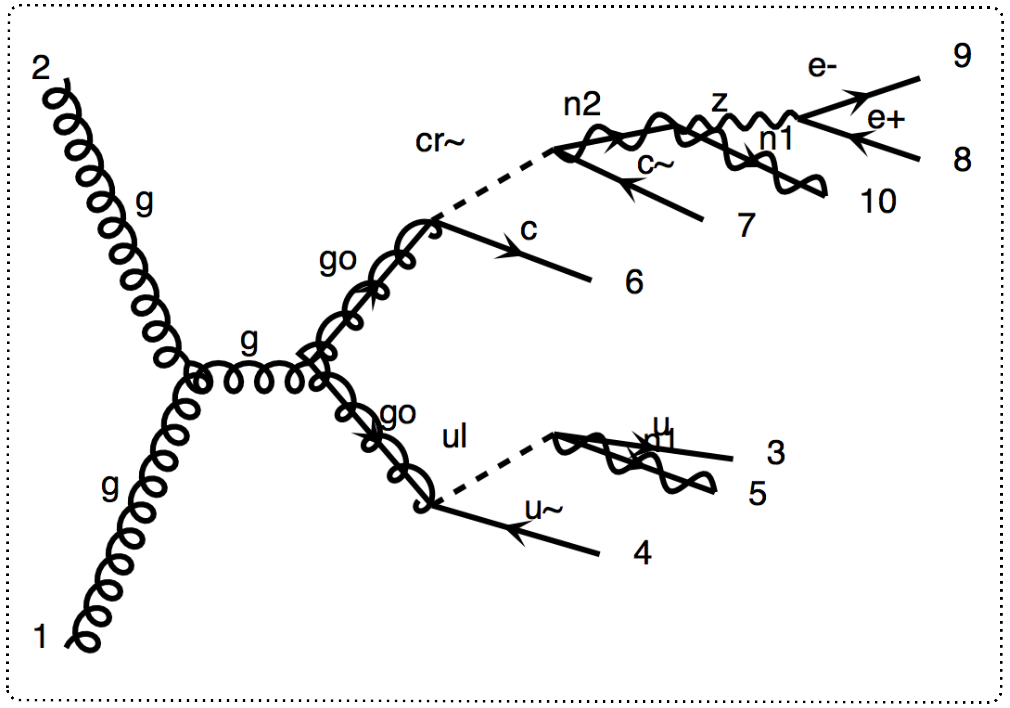
✦ Other challenge 2: QCD radiation simulation

- ✤ Merging matrix elements with different final state jet multiplicity (including parton showering)
- ✤ More accurate description of jet-related observables

New physics simulations: cascade decays (I)

✦ Concrete models

- ✤ Many new states to be supplemented to the Standard Model
- ✤ Usually pair-produced
- ✤ Further cascade-decaying into each other
- ✤ The lightest new state can be stable (and a dark matter candidate)



Is the simulation of 2 to N processes (with N large) a problem?

✦ The issue is the computing time

- ✤ Matrix element generation is possible
- ✤ Computationally challenging
- ✤ Practically useless: only diagrams with intermediate resonances usually dominate

New physics simulations: cascade decays (2)

- Production and decay processes are factorized
  - Propagators can be seen as sums of products of external wave functions

    Example: $$\mathcal{M} \sim j_1^\mu \left[g_{\mu\nu} - \frac{p_\mu p_\nu}{p^2} \right] j_2^\nu = \sum_\lambda \underbrace{j_1^\mu \varepsilon_\mu^*(\lambda)}_{\mathcal{M}_{\rm prod}(\lambda)} \underbrace{\varepsilon_\nu(\lambda) j_2^\nu}_{\mathcal{M}_{\rm dec}(\lambda)}$$
  - Case 1: loss of spin correlations
    - ★ Helicity sums performed independently at the production and decay levels
    - ★ Example:

      $$\sum_\lambda \underbrace{j_1^\mu \varepsilon_\mu^*(\lambda)}_{\mathcal{M}_{\rm prod}(\lambda)} \sum_{\lambda'} \underbrace{\varepsilon_\nu(\lambda') j_2^\nu}_{\mathcal{M}_{\rm dec}(\lambda')}$$

      PYTHIA 6
      [Sjostrand, Mrenna, Skands (JHEP '06)]
  - Case 2: including spin correlations
    - ★ Helicity sums performed after accounting for production and decays
    - ★ Example:

      $$\sum_\lambda \underbrace{j_1^\mu \varepsilon_\mu^*(\lambda)}_{\mathcal{M}_{\rm prod}(\lambda)} \underbrace{\varepsilon_\nu(\lambda) j_2^\nu}_{\mathcal{M}_{\rm dec}(\lambda)}$$

      HERWIG
      [Richardson (JHEP '01)]

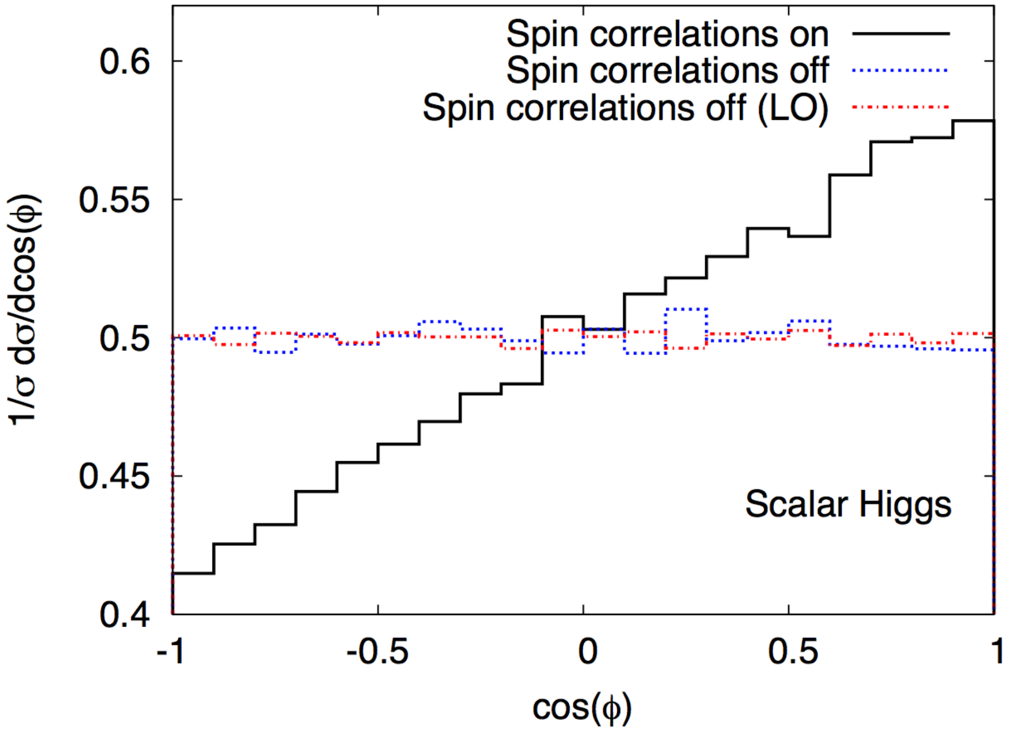
      MADSPIN
      [Artoisenet, Frederix, Mattelaer, Rietkerk (JHEP '13)]

      PYTHIA 8
      [Sjostrand, Mrenna, Skands (CPC '08)]

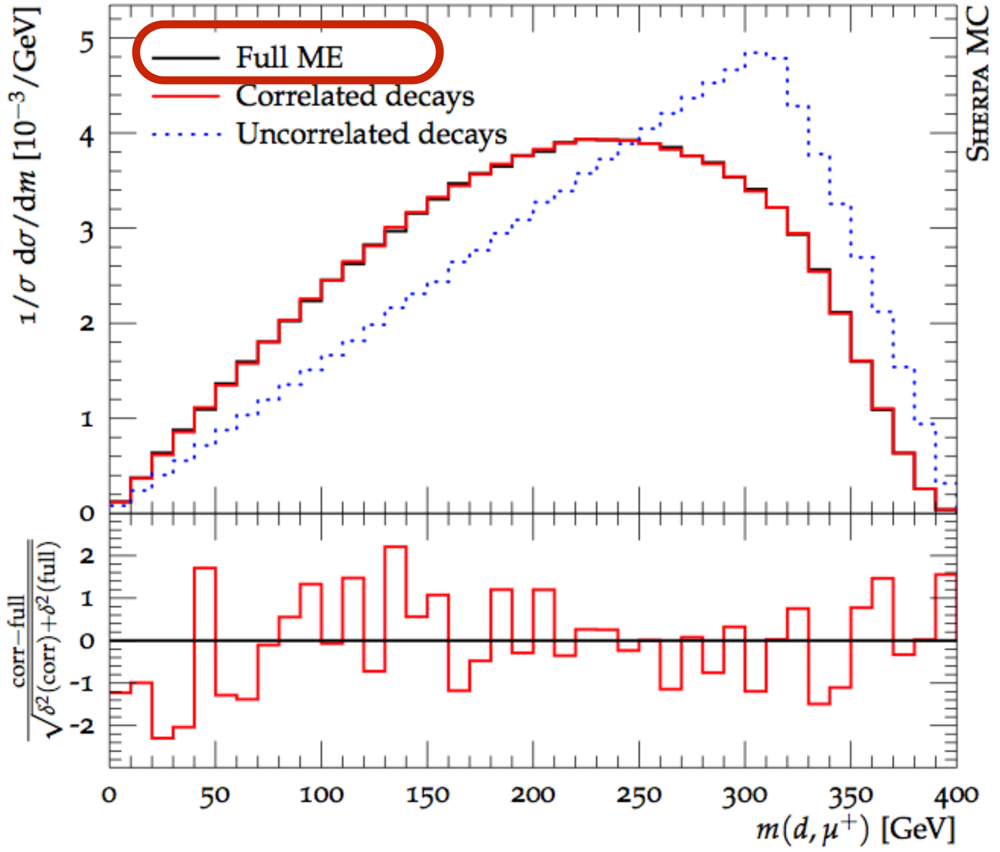
      SHERPA
      [Höche, Kuttimalai, Schumann, Siegert (EPJC '15)]
  - Off-shell effects are lost (as a result of the factorization)
    - ★ Resonance mass smearing: partial recovery [Frixione, Laenen, Motylinksi, Webber (JHEP '07)]

New physics simulations: cascade decays (3)

✦ Is a correct decay handling important: yes!



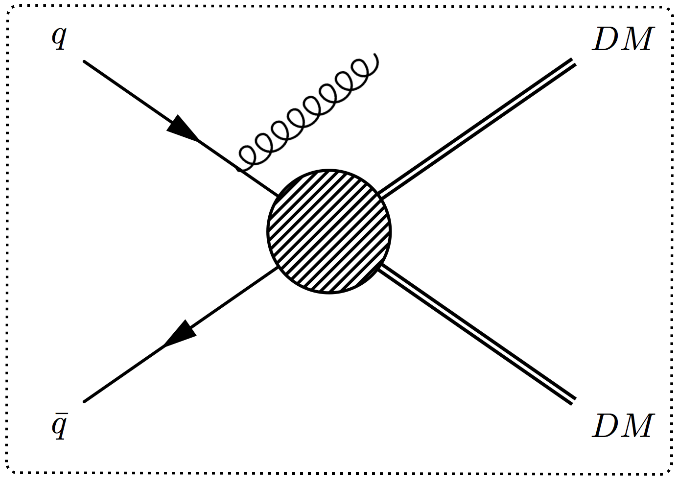
MADSPIN
$t\bar{t}H$ production @ NLOQCD
[LHC8, dileptonic $t\bar{t}$ decay]



SHERPA
squark pair production @ LO
[LHC8, $\tilde{u} \to d\,\chi_1^+\,[\to \chi_1^0\,W^+\,[\to \mu^+\,\nu_\mu]]$
$\tilde{u}^* \to \bar{u}\,\chi_2^0\,[\to e^+\,\tilde{e}_R^-\,[\to e^-\,\chi_1^0]]$]

Multipartonic matrix element merging (I)

- Initial (and final) state radiation modeling is crucial
  - Monojet-based dark matter searches
  - Compressed spectra searches
  - *etc.*
- Radiation can be predicted in different ways



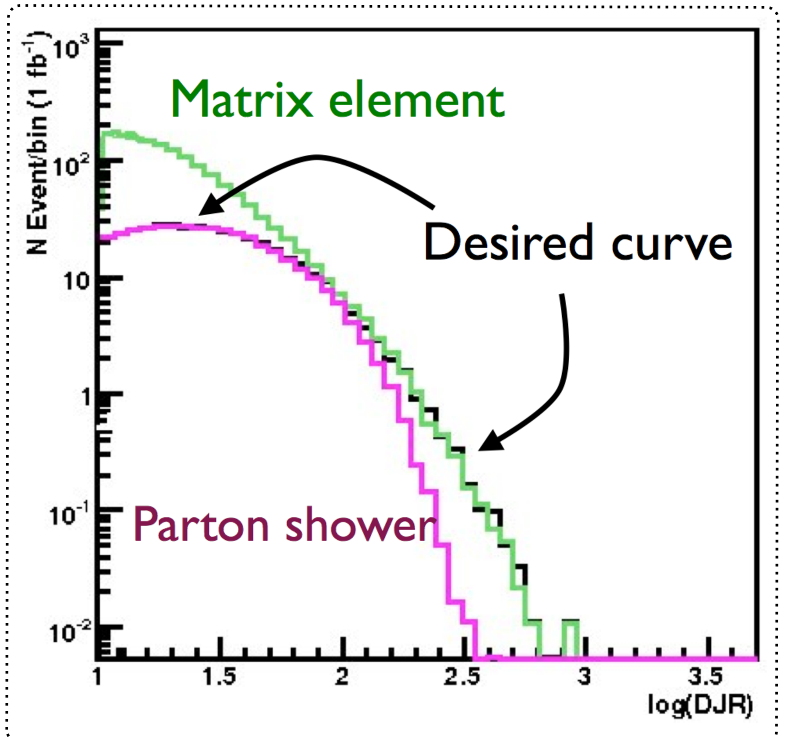
- Matrix-element-based predictions
  - This relies on the fixed-order theory
  - Technical limit on the number of final state particles
  - Valid for hard and well-separated partons
  - Correct handling of the color and spin information and of the quantum interferences

- Parton-shower-based predictions
  - This resums of large soft-collinear logarithms
  - Technically easy and no limit on the final-state multiplicity
  - Valid for soft and/or collinear partons
  - Approximate handling of the color and spin information, of the quantum interferences

Multipartonic matrix element merging (2)

✦ Matrix-element-based and parton-shower based predictions are complementary

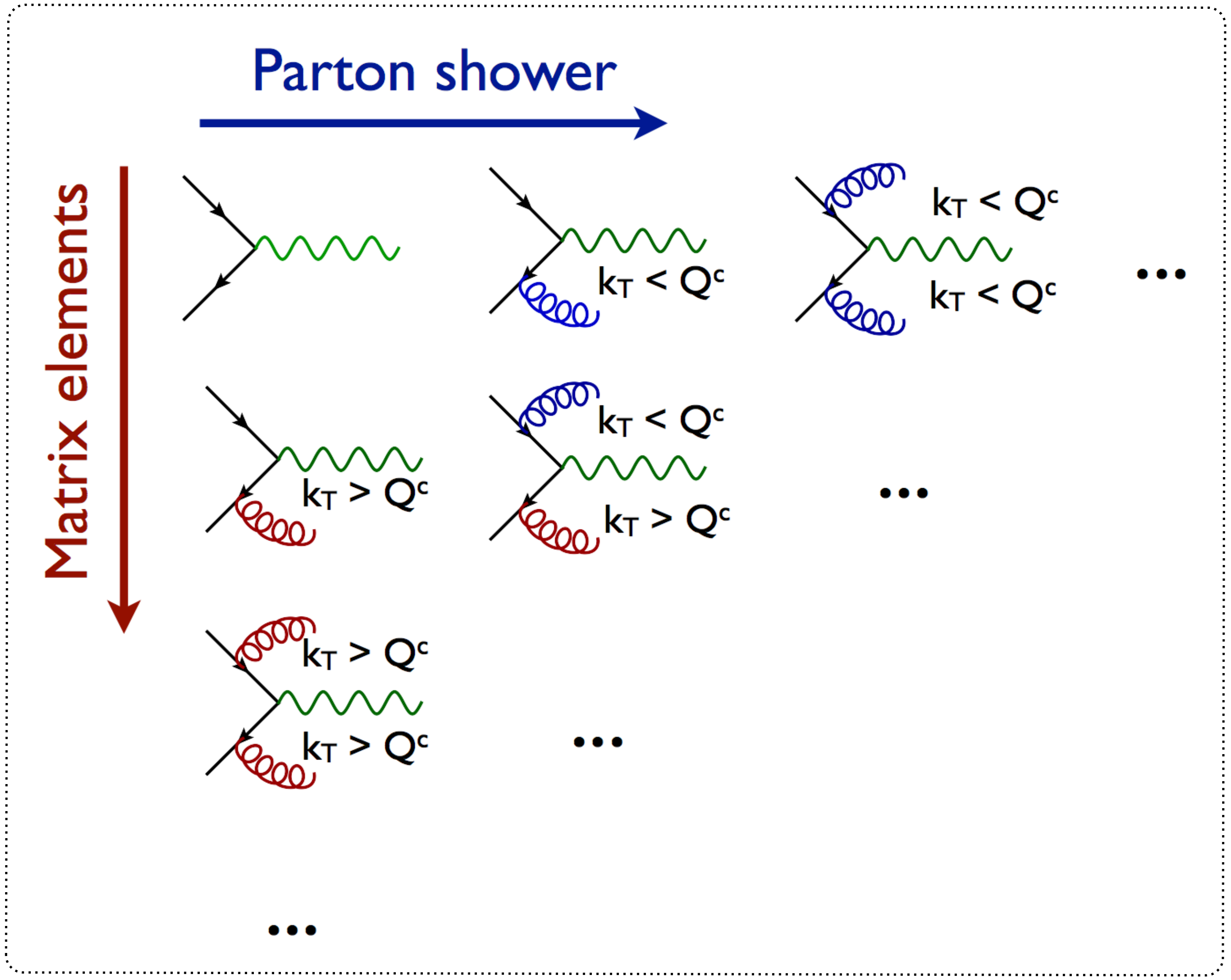
- ✤ Both can be combined
- ✤ Matrix elements containing 0, 1, 2, … *N* extra partons
- ✤ Parton showering included for each of the *N* samples
- ✤ Merging prescription (or scheme):
  - ★ Matrix elements: hard radiation
  - ★ Parton showers: soft and collinear radiation



MADGRAPH 5; $t\bar{t}$ production @ LHC
[second jet radiation]

Multipartonic matrix element merging (3)

✦ The double-counting of specific radiation must be prevented



- Matrix elements:
  - ⇒ only hard radiation
- Parton showers:
  - ⇒ only soft-collinear
- Cut in phase space (Q^c)
- Check of the procedure
  - ★ Matrix elements mimic parton showers near Q^c
  - ★ Verification with Q^c independent observables

Main merging techniques used for new physics

✦ The MLM merging technique [Mangano, Moretti, Piccinini & Traccani (JHEP '07); Alwall, de Visscher & Maltoni (JHEP'09)]

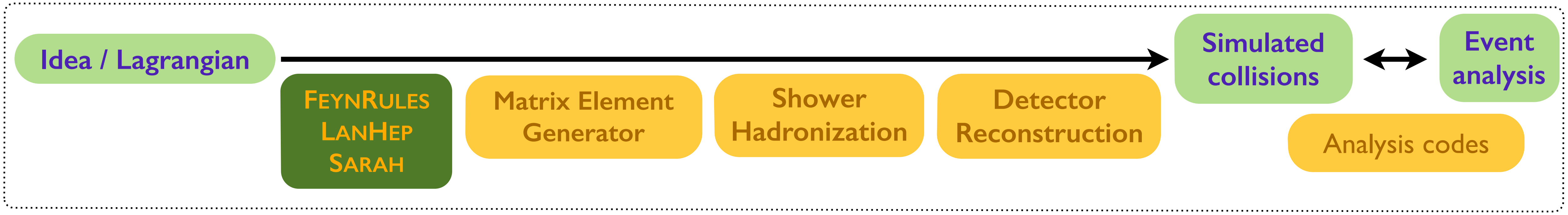
- ✤ Define a jet measure for parton-level jets (after showering): $k_T^2 = \min(p_{Ti}^2, p_{Tj}^2) R_{ij}$ or $k_T = p_{Ti}$
- ✤ An event is selected if each reconstructed jet matches one parton and *vice versa*
- ✤ Extra jets are allowed for the highest multiplicity topology
- ✤ NLO extension: the FxFx merging scheme [Frederix & Frixione (JHEP '12)]

✦ The CKKW(-L) merging technique [Catani, Krauss, Kuhn, Webber (JHEP'01); Lönnblad & Prestel (JHEP'12)]

- ✤ Reweighting according to the most-likely shower history (Sudakovs, α_s, parton densities)
- ✤ Emission already included at the matrix-element level are vetoed
- ✤ Improvement: unitarized merging (all-order subtractions makes the subsamples Q^c independent)
  [Lönnblad & Prestel (JHEP'13)]

New physics simulations: NLO calculations

- ✦ A comprehensive approach to Monte Carlo simulations



Idea / Lagrangian

FeynRules
LanHEP
Sarah

Matrix Element Generator

Shower Hadronization

Detector Reconstruction

Simulated collisions

Event analysis

Analysis codes

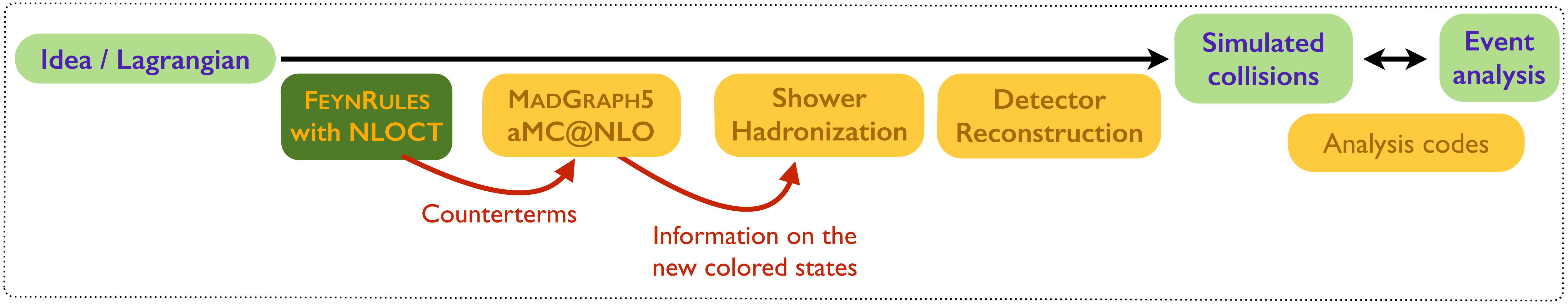
- ✦ Works very well at the leading order in QCD
  - ✤ Fully tested and validated in the context of large classes of new physics models

- ✦ Many processes are implemented within the PowHeg/MC@NLO methods
  - ✤ Handmade, non-automated implementation

What about **automated** new physics event generation at the next-to-leading order in QCD?

Automated NLO calculations with MadGraph5_aMC@NLO

✦ Works in the MadGraph5_aMC@NLO context **only**


Idea / Lagrangian

FeynRules with NLOCT

MadGraph5 aMC@NLO

Shower Hadronization

Detector Reconstruction

Simulated collisions

Event analysis

Analysis codes

Counterterms

Information on the new colored states

✦ Streamline the chain from the model Lagrangian to analyzed simulated collisions

- ✤ FeynRules is linked to the NLOCT module [Degrande ('14)]
  - ★ Calculation of UV and R_2 counterterms (necessary for loop calculations in aMC@NLO)
- ✤ The UFO format has been extended to include NLO calculation information [Degrande, Duhr, BF, Hirschi, Mattelaer & Shao (*in preparation*)]
- ✤ Matching to parton showers
  - ★ Monte Carlo counterterms associated with the new colored states are included
  - ★ Restrictions on the parton shower code to employ (Pythia 8.2, Herwig++)

A few models are now available …
and validated

[http://feynrules.irmp.ucl.ac.be/wiki/NLOModels]

Example: a stop simplified model

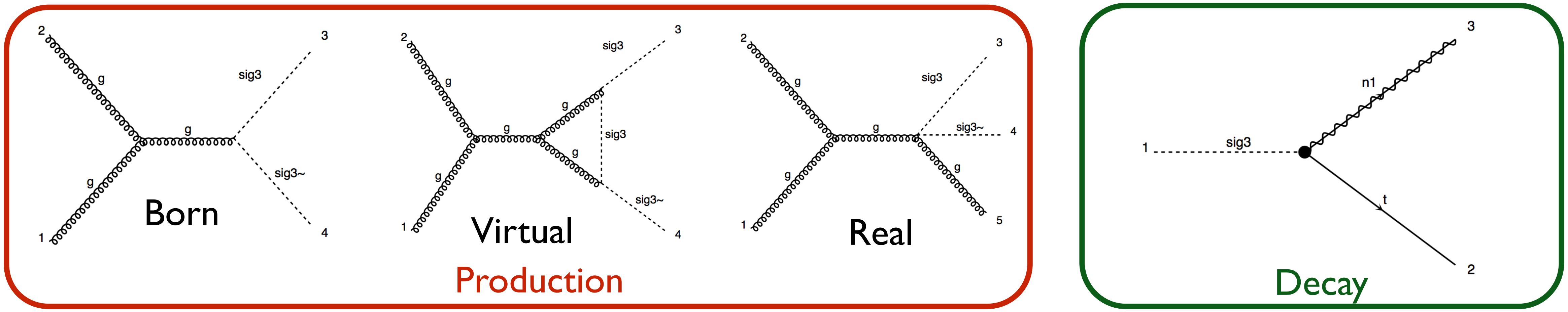
[Degrande, BF, Hirschi, Proudom & Shao (PRD'15)]

✦ The stop (σ_3) / bino (χ) model

$$\mathcal{L}_3 = \underbrace{D_\mu\sigma_3^\dagger D^\mu\sigma_3 - m_3^2\sigma_3^\dagger\sigma_3}_{\text{Production}} + \underbrace{\frac{i}{2}\bar{\chi}\not{\partial}\chi - \frac{1}{2}m_\chi\bar{\chi}\chi + \left[\sigma_3\bar{t}(\tilde{g}_L P_L + \tilde{g}_R P_R)\chi + \text{h.c.}\right]}_{\text{Decay}}$$

- ✤ One scalar field in the fundamental representation (σ_3)
- ✤ One gauge-singlet Majorana fermion (χ) coupling the stop to the top

✦ Representative Feynman diagrams (yielding a top-antitop plus missing energy signature)



Example: stop simplified model

✦ UV behavior (on-shell scheme, zero-momentum subtraction for α_s)

Analytical validation

✤ Analytical checks are important (the fully automated approach is new)

$$\delta Z_g = \delta Z_g^{(SM)} - \frac{g_s^2}{96\pi^2}\left[\frac{1}{\bar\epsilon} - \log\frac{m_3^2}{\mu_R^2}\right]$$

$$\delta Z_{\sigma_3} = 0 \quad \text{and} \quad \delta m_3^2 = -\frac{g_s^2 m_3^2}{12\pi^2}\left[\frac{3}{\bar\epsilon} + 7 - 3\log\frac{m_3^2}{\mu_R^2}\right]$$

$$\frac{\delta\alpha_s}{\alpha_s} = \frac{\alpha_s}{2\pi\bar\epsilon}\left[\frac{n_f}{3} - \frac{11}{2}\right] + \frac{\alpha_s}{6\pi}\left[\frac{1}{\bar\epsilon} - \log\frac{m_t^2}{\mu_R^2}\right] + \frac{\alpha_s}{24\pi}\left[\frac{1}{\bar\epsilon} - \log\frac{m_3^2}{\mu_R^2}\right]$$

$$R_2^{\sigma_3^\dagger\sigma_3} = \frac{ig_s^2}{72\pi^2}\delta_{c_1c_2}\left[3m_3^2 - p^2\right]$$

$$R_2^{g\sigma_3^\dagger\sigma_3} = \frac{53ig_s^3}{576\pi^2}T^{a_1}_{c_2c_3}\left(p_2 - p_3\right)^{\mu_1}$$

$$R_2^{gg\sigma_3^\dagger\sigma_3} = \frac{ig_s^4}{1152\pi^2}\eta^{\mu_1\mu_2}\left[3\delta^{a_1a_2} - 187\{T^{a_1}, T^{a_2}\}\right]_{c_3c_4}$$

✦ Total rates at 8 TeV and 13 TeV

Numerical validation

m_3 [GeV]	$\sigma^{\rm LO}$ [pb]	$\sigma^{\rm NLO}$ [pb]	$\sigma^{\rm LO}$ [pb]	$\sigma^{\rm NLO}$ [pb]
100	$3.893 \pm 0.0095 \cdot 10^2\ ^{+34.2\%}_{-23.9\%}$	$5.548 \pm 0.018 \cdot 10^2\ ^{+14.9\%}_{-13.5\%}\ ^{+1.6\%}_{-1.6\%}$	$1.066 \pm 0.0025 \cdot 10^3\ ^{+29.1\%}_{-21.4\%}$	$1.497 \pm 0.0054 \cdot 10^3\ ^{+14.1\%}_{-12.1\%}\ ^{+1.2\%}_{-1.2\%}$
250	$4.118 \pm 0.0096 \cdot 10^0\ ^{+40.4\%}_{-27.2\%}$	$5.503 \pm 0.017 \cdot 10^0\ ^{+13.1\%}_{-13.7\%}\ ^{+3.7\%}_{-3.7\%}$	$1.553 \pm 0.0037 \cdot 10^1\ ^{+35.2\%}_{-24.8\%}$	$2.156 \pm 0.0067 \cdot 10^1\ ^{+12.1\%}_{-12.3\%}\ ^{+2.4\%}_{-2.4\%}$
500	$6.594 \pm 0.016 \cdot 10^{-2}\ ^{+45.5\%}_{-29.1\%}$	$7.764 \pm 0.025 \cdot 10^{-2}\ ^{+12.1\%}_{-14.1\%}\ ^{+6.7\%}_{-6.7\%}$	$3.890 \pm 0.0093 \cdot 10^{-1}\ ^{+39.6\%}_{-26.4\%}$	$5.062 \pm 0.015 \cdot 10^{-1}\ ^{+11.2\%}_{-12.8\%}\ ^{+4.4\%}_{-4.4\%}$
750	$3.504 \pm 0.0084 \cdot 10^{-3}\ ^{+48.8\%}_{-30.5\%}$	$3.699 \pm 0.012 \cdot 10^{-3}\ ^{+12.3\%}_{-14.6\%}\ ^{+10.2\%}_{-10.2\%}$	$3.306 \pm 0.0081 \cdot 10^{-2}\ ^{+41.8\%}_{-27.5\%}$	$4.001 \pm 0.012 \cdot 10^{-2}\ ^{+10.8\%}_{-12.9\%}\ ^{+6.1\%}_{-6.1\%}$
1000	$2.875 \pm 0.0067 \cdot 10^{-4}\ ^{+51.5\%}_{-31.5\%}$	$2.775 \pm 0.0087 \cdot 10^{-4}\ ^{+13.1\%}_{-15.2\%}\ ^{+15.5\%}_{-15.5\%}$	$4.614 \pm 0.011 \cdot 10^{-3}\ ^{+43.6\%}_{-28.3\%}$	$5.219 \pm 0.016 \cdot 10^{-3}\ ^{+10.9\%}_{-13.2\%}\ ^{+7.9\%}_{-7.9\%}$

8 TeV 13 TeV

✤ NNPDF2.3; scales set to the stop mass

✤ Agrees with PROSPINO [Beenakker, Kramer, Plehn, Spira & Zerwas (NPB'98)]

✤ Scale varied by a factor of two up and down

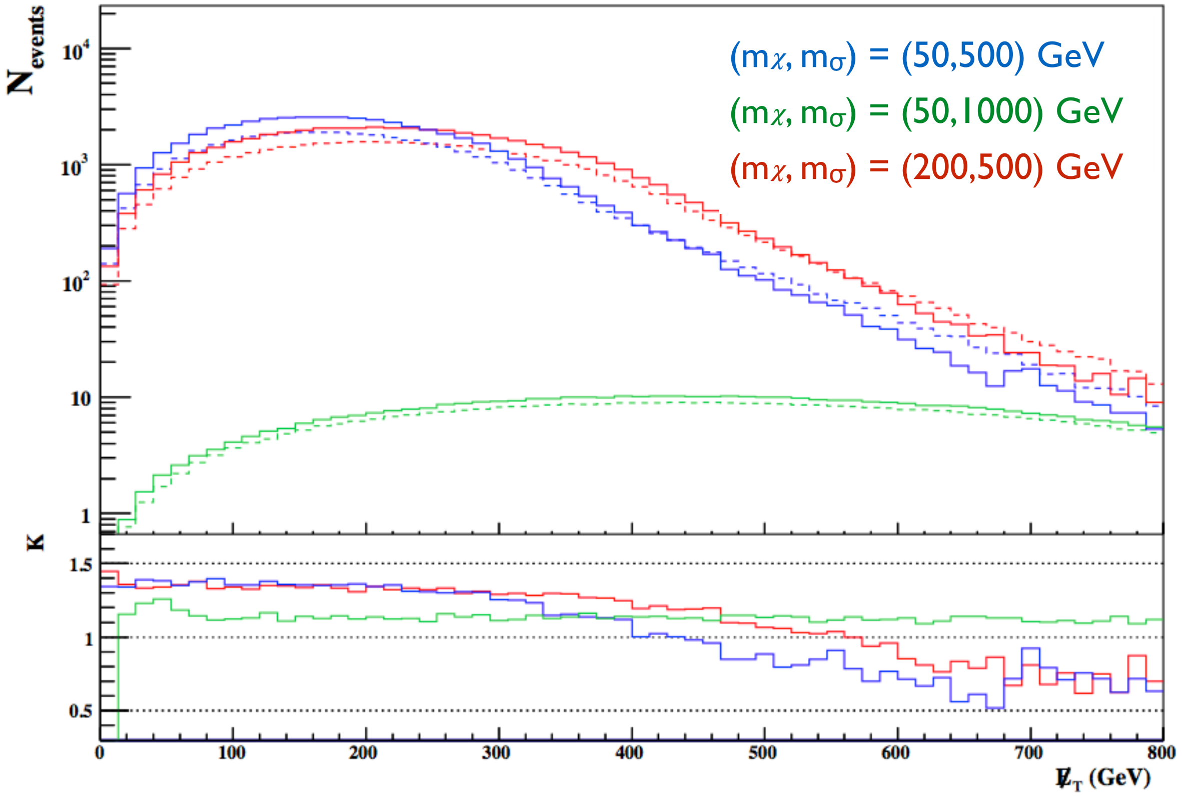
✤ PDF variations obtained with the 100 NNPDF replica provided with the central set of densities

The stop simplified model: kinematical distributions

✦ NLO matrix elements matched to parton showering: differential distributions

- ✤ Test case: 500/1000 GeV stop; 50/200 GeV bino; 13 TeV collisions
- ✤ Standard coupling strengths for a maximally mixing stop and a bino
- ✤ Shower: PYTHIA 8.2 [Sjostrand, Mrenna & Skands (CPC'08)]
- ✤ Jet reconstruction: anti-k_T & FASTJET [Cacciari, Salam & Soyez (JHEP'08, EPJC'12)]
- ✤ Analysis (single lepton case) & figures: MADANALYSIS 5 [Conte, BF, Serret (CPC'13)]

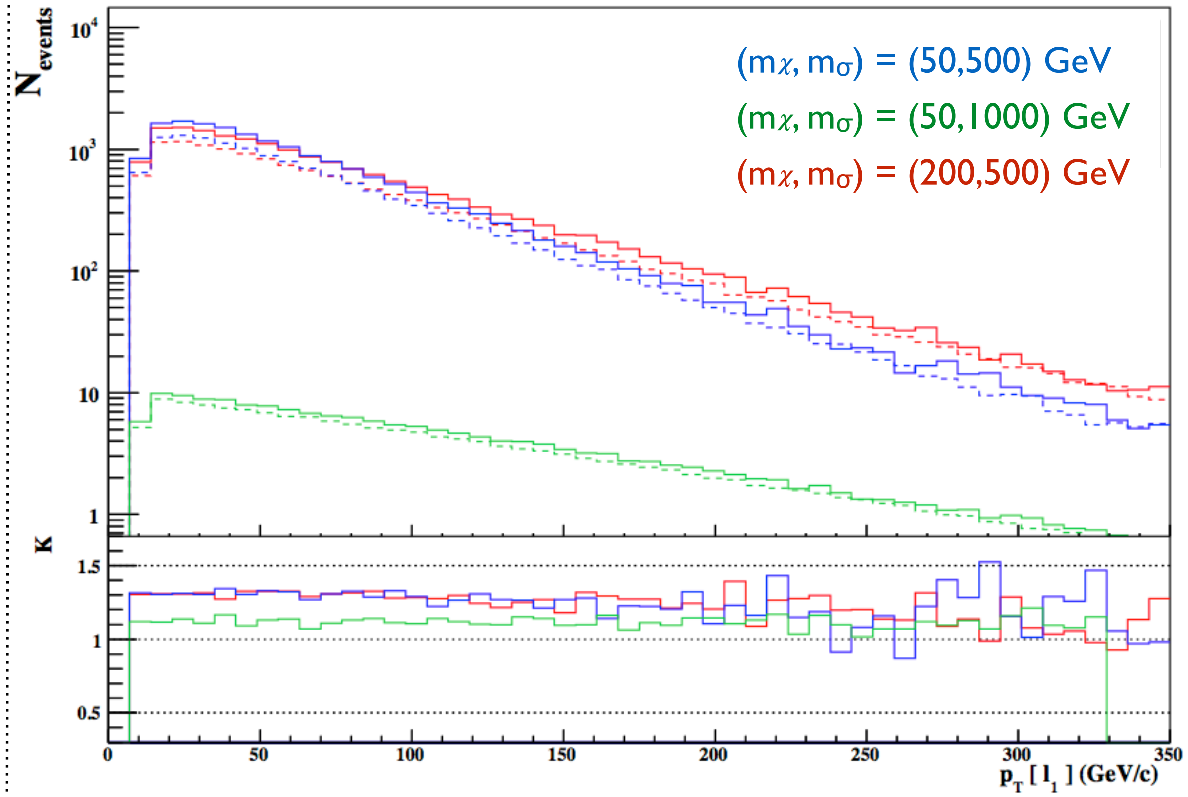
Missing transverse energy



★ Constant *K*-factors not suitable

★ The K-factor depends on the scenario

Leading lepton transverse momentum (single lepton signature)



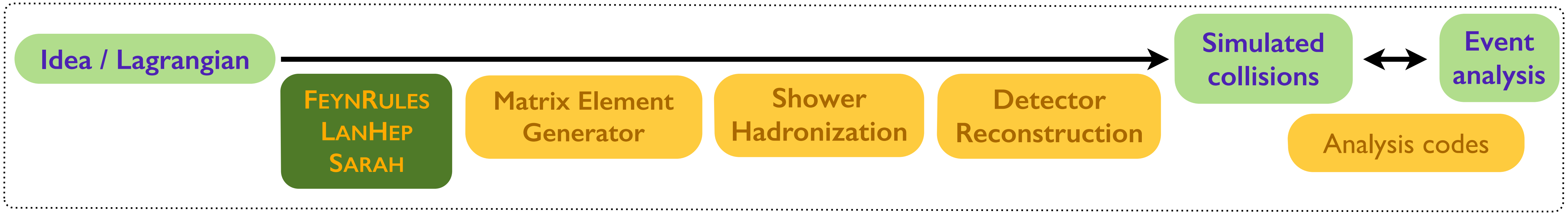
★ Constant *K*-factors okayish

★ The K-factor depends on the scenario

Outline

New physics simulations so far

- A comprehensive approach to Monte Carlo simulations



- Works very well at the leading order in QCD and can work at the next-to-leading order

Let’s reverse the chain…

Reinterpreting LHC physics analyses (1)

- ✦ Exploit the full potential of the LHC (for new physics)
  - ✤ Priority #1 of the European strategy for particle physics
  - ✤ Designing new analyses to probe new ideas — Prospectives for new physics (based on MC simulations)
  - ✤ Recasting LHC analyses to study models not experimentally considered — The LHC legacy

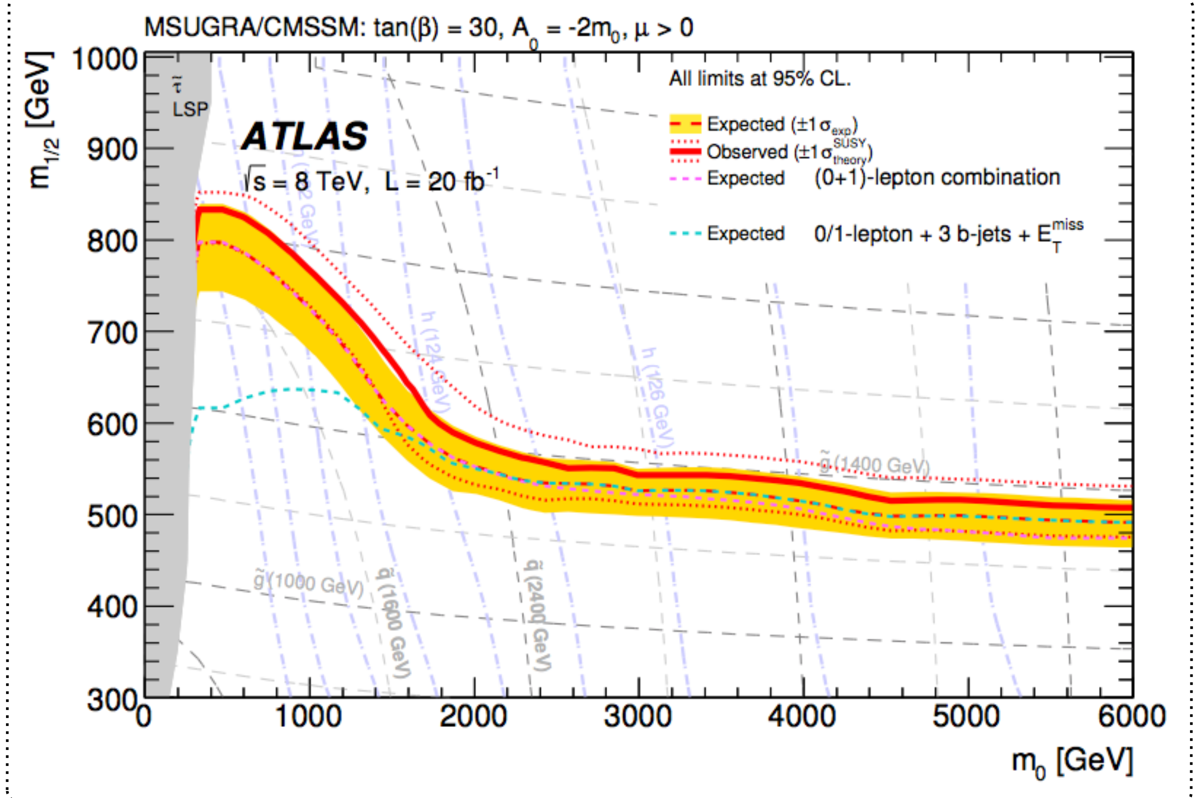
- ✦ LHC data has been collected with significant human and financial efforts
  - ✤ Important for on-going analyses (within popular theoretical contexts of today)
  - ✤ Important for future opportunities (within future scientific contexts)
- ✦ Data preservation in high-energy physics is mandatory [Kogler, South & Steder (JPCS'12)]
  - ✤ Studies are on-going and go beyond raw data (ICFA DPHEP Study Group)

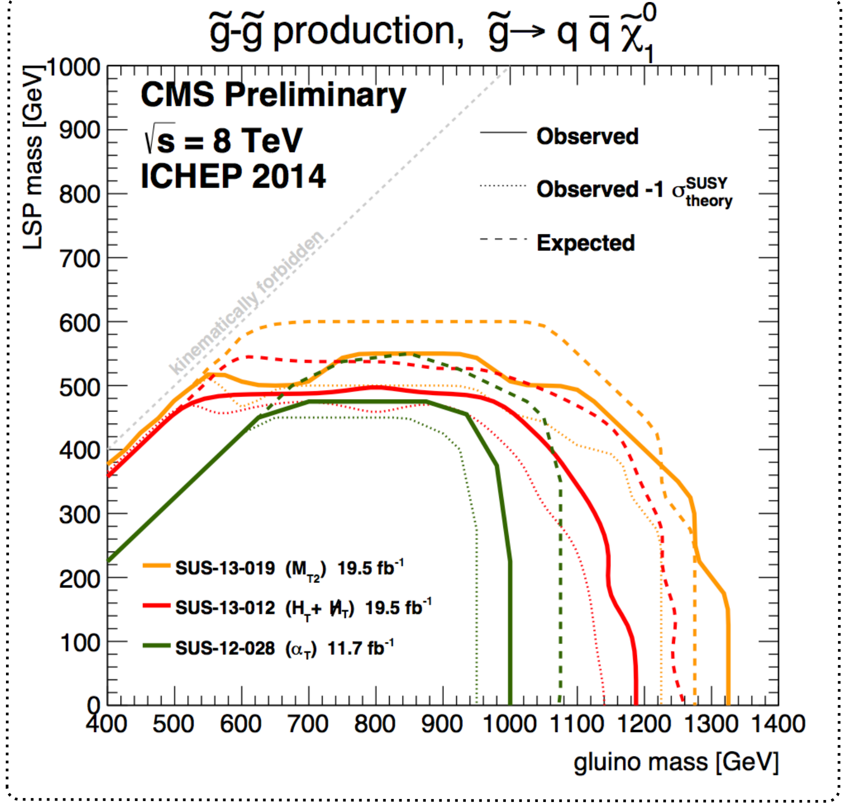
- ✦ Related tools need to be supported by the entire community [Kraml *et al.* (EPJC'12)]
  - ✤ Both theorists and experimentalists
  - ✤ Allowing for the reinterpretation of the LHC analysis results

Reinterpreting LHC physics analyses (2)

✦ The LHC has been built as a discovery machine

- ✤ There are many ATLAS and CMS searches for new physics
- ✤ Interpretation within popular frameworks and simplified models





✦ Theorists need to reinterpret the results for all kinds of models [Community-wide effort]

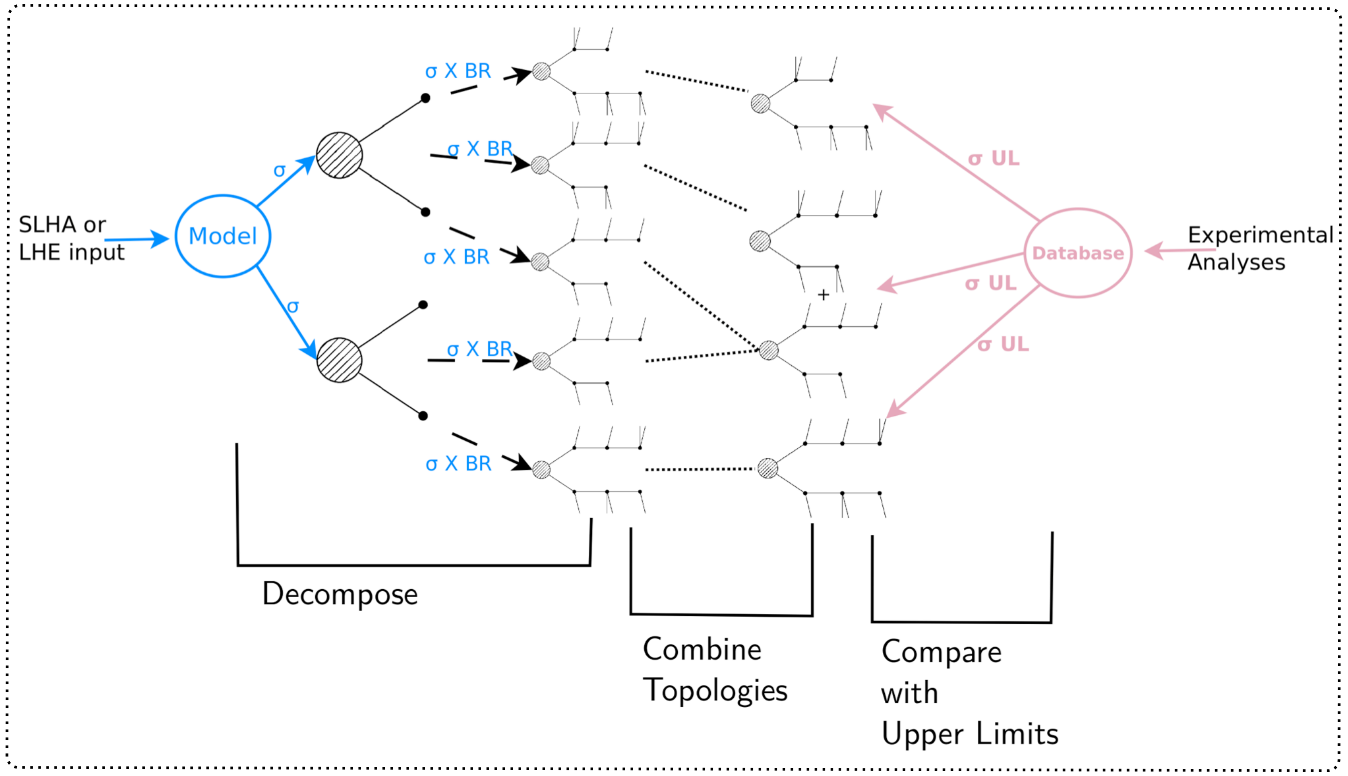
✦ The simplified model spectrum (SMS) approach is fast and powerful, but limited

- ✤ Too conservative (final state topologies, different kinematics, *etc.*)
- ✤ Considered decay patterns and assumptions rarely realized (many channels, *etc.*)
- ✤ Works however not too bad in many cases for a fair estimate of constraints

The SMS approach for LHC result reinterpretations (I)

✦ The SMS-based reinterpretation framework

- ✤ All signatures of a given theory are decomposed according to those of the SMS searches
- ✤ Fiducial cross sections are calculated on the basis of public efficiency maps
- ✤ Comparisons to published upper bounds are made



✦ Basic features

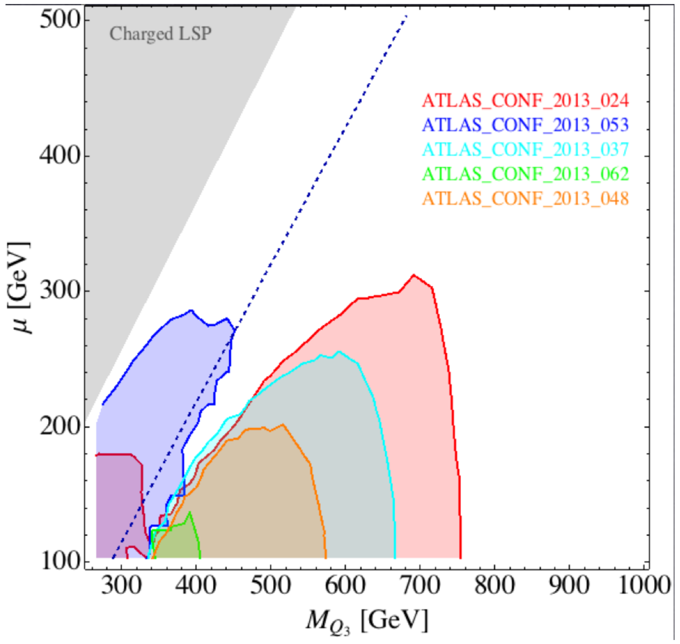
- ✤ Extremely fast
- ✤ Moderately accurate and general
  - ★Kinematical configurations often not close to the SMS ones
  - ★Multistep or asymmetric decays

The SMS approach for LHC result reinterpretations (2)

✦ Existing tools

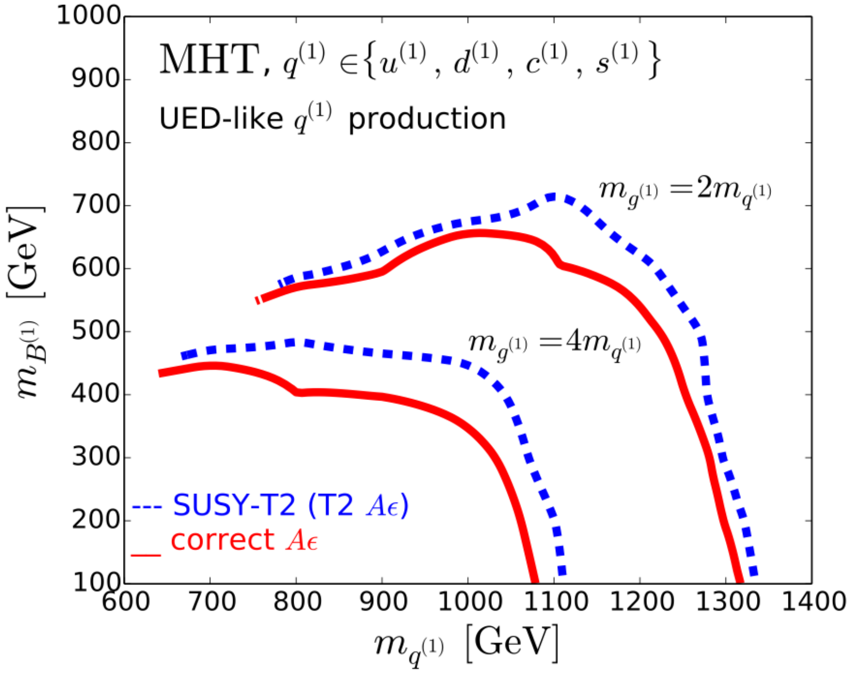
- ✤ FastLim: 11 ATLAS analyses [Papucci, Sakurai, Weiler & Zeune (EPJC'14)]
- ✤ SModelS: 13 ATLAS and 13 CMS analyses [Kraml, Kulkarni, Laa, Lessa, Magerl, Proschofsky-Spindler & Waltenberger (EPJC'14)]
- ✤ XQCat: 7 CMS analyses [Barducci, Belyaev, Buchkremer, Marrouche, Moretti, Panizzi (CPC'15)]

✦ Examples



MSSM reinterpretations with FastLim

[Edelhäuser, Krämer, Sonneveld (JHEP'15)]



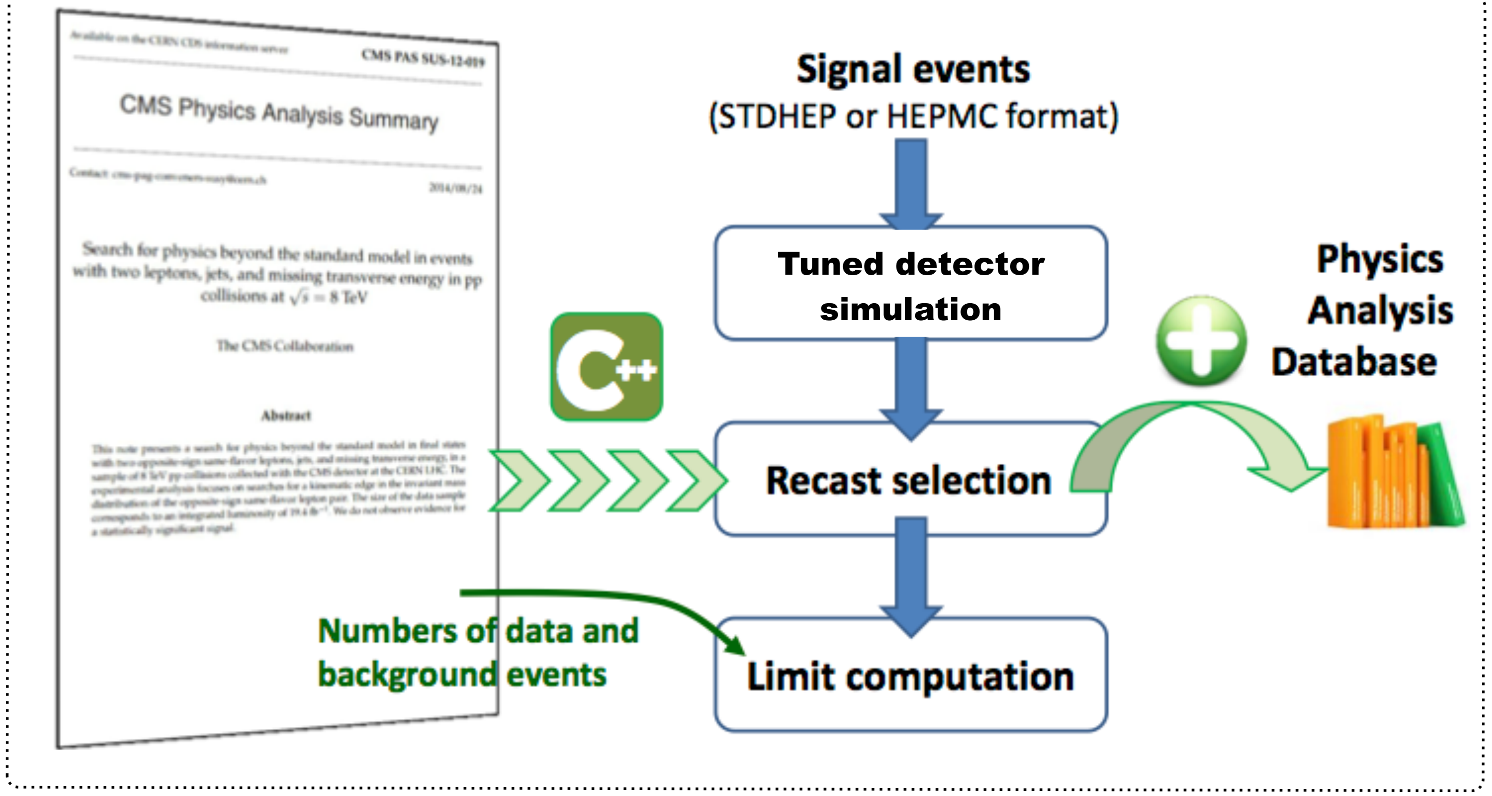
Limitations (using SModelS): SUSY *versus* UED

Beyond the SMS approach

✦ There are plethora of new physics realizations that deserve to be studied

- ✤ The simplified model approach is often not sufficient (*e.g.*, different topologies)
- ✤ Need to rely on a (public) detector simulation closely mimicking ATLAS and CMS simulations
- ✤ Need for a (public) framework where LHC analyses can be easily implemented

✦ Recasting strategy



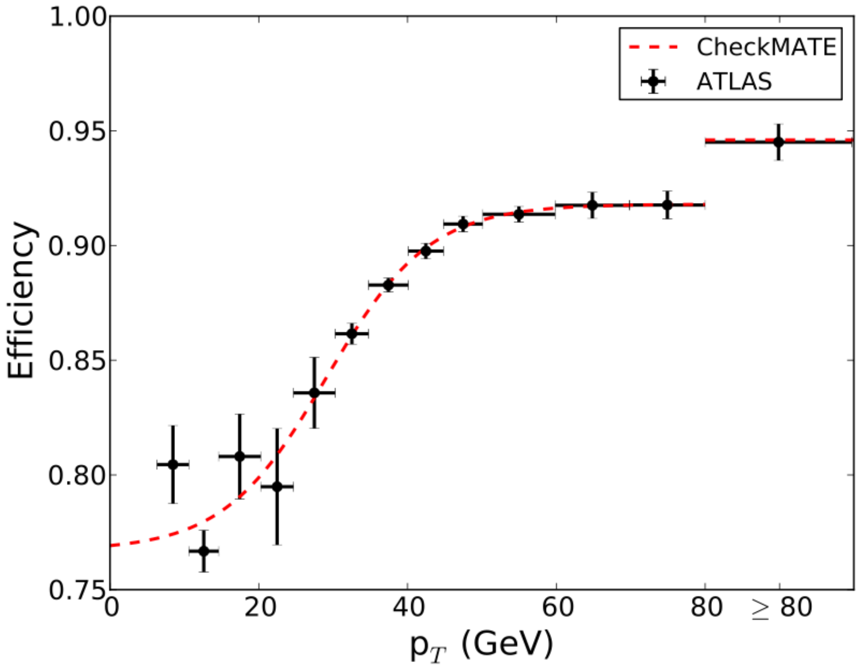
✤ 2 options for detector simulation

- ★ DELPHES/PGS-like (resolutions, efficiencies, *etc.*)
- ★ RIVET-like (transfer functions)

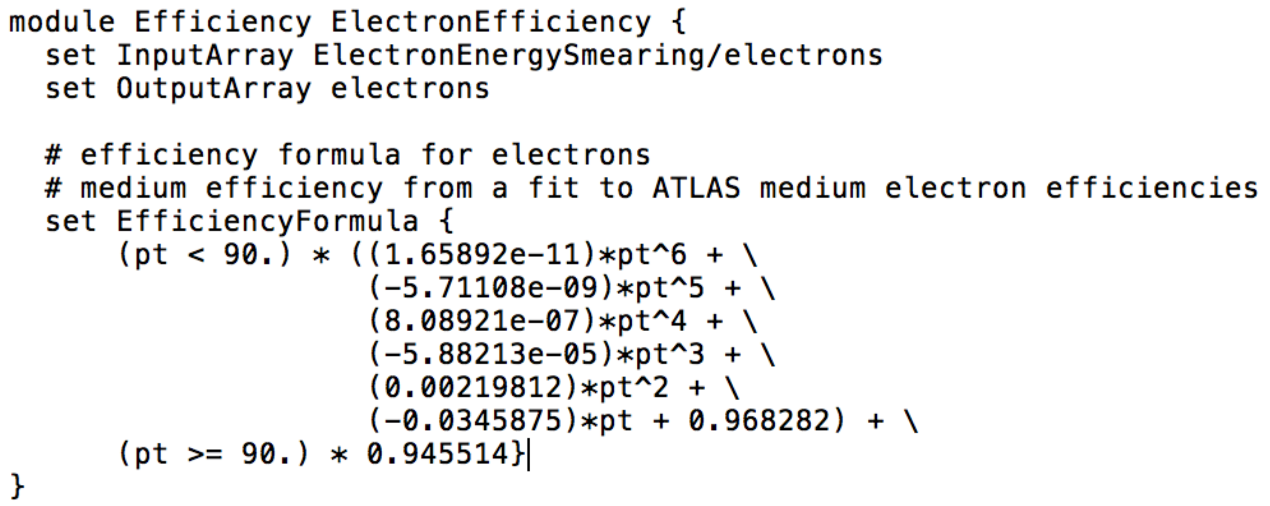
Detector modeling with DELPHES

✦ Detector simulation with DELPHES 3 [de Favereau, Delaere, Demin, Giammanco, Lemaître, Mertens & Selvaggi (JHEP'14)]

- ✤ Starts from hadron-level Monte Carlo information
- ✤ Derive calorimetric and track information; object reconstruction is then necessary
  - ★ Close to what actually happens
- ✤ DELPHES is modular ➢ extra modules and tuning can be added / included
  - ★ Extra information on lepton isolation or track information; skimming of the output files. *etc.*



Medium electron efficiency in CHECKMATE



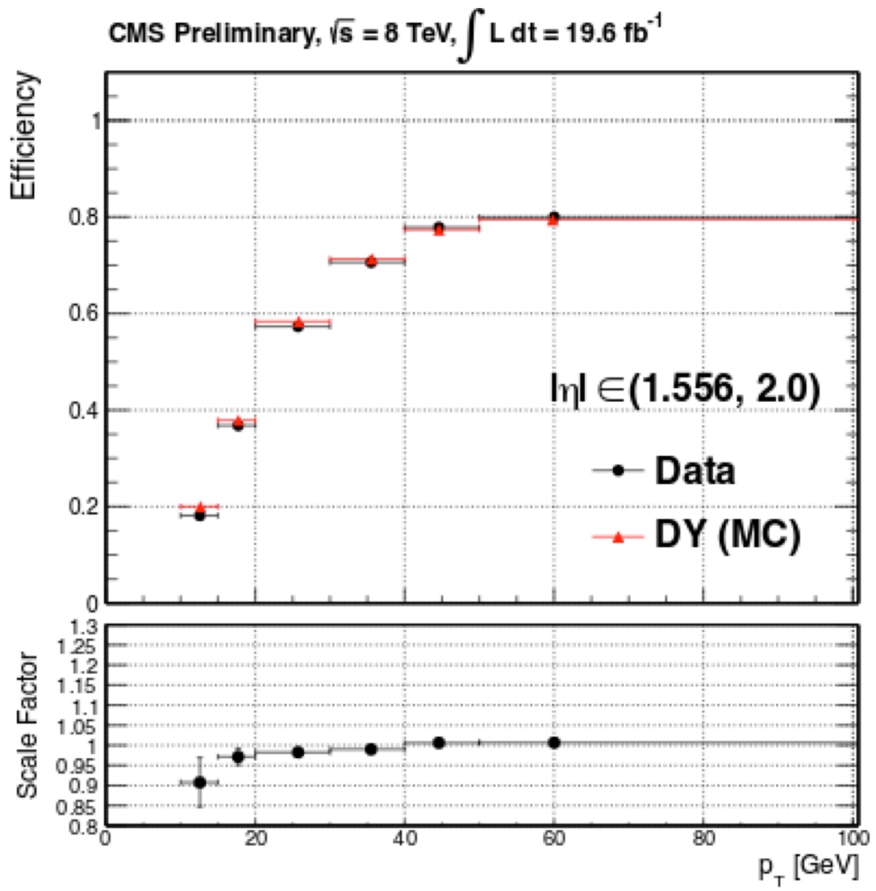
```
module Efficiency ElectronEfficiency {
  set InputArray ElectronEnergySmearing/electrons
  set OutputArray electrons

  # efficiency formula for electrons
  # medium efficiency from a fit to ATLAS medium electron efficiencies
  set EfficiencyFormula {
      (pt < 90.) * ((1.65892e-11)*pt^6 + \
                    (-5.71108e-09)*pt^5 + \
                    (8.08921e-07)*pt^4 + \
                    (-5.88213e-05)*pt^3 + \
                    (0.00219812)*pt^2 + \
                    (-0.0345875)*pt + 0.968282) + \
      (pt >= 90.) * 0.945514}
}
```

Corresponding implementation in MADANALYSIS 5

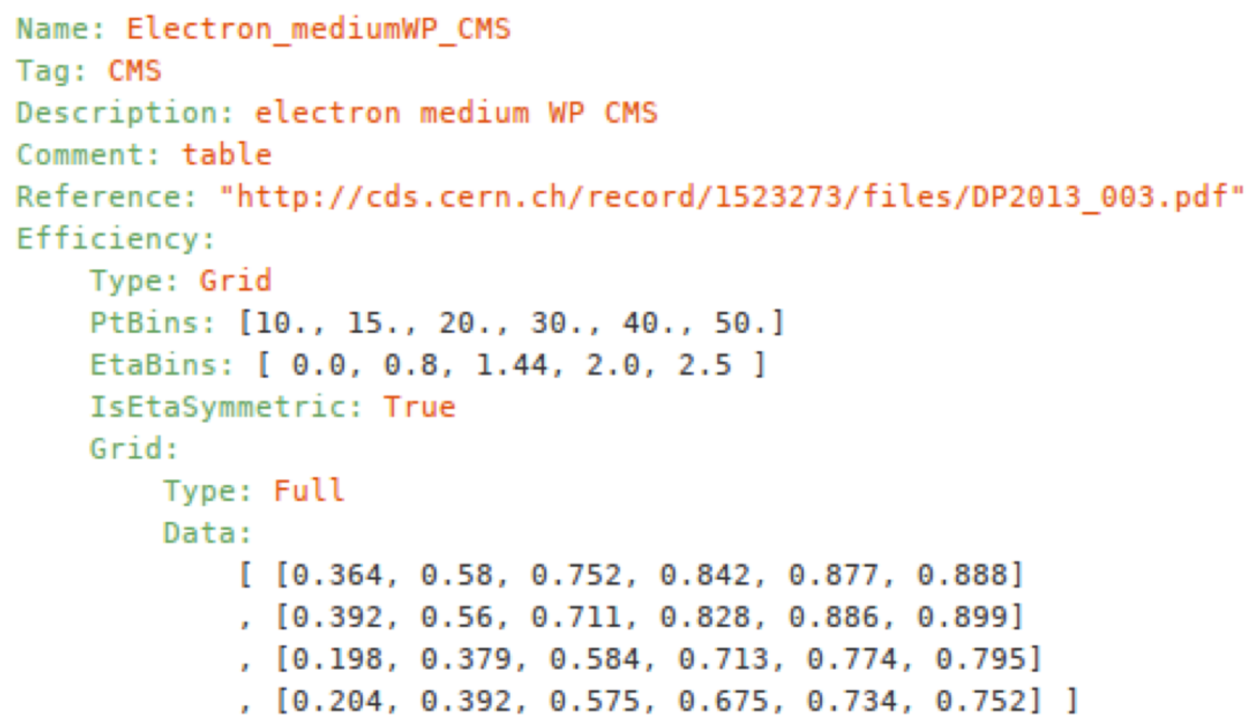
Detector modeling with RIVET

✦ Detector simulation based on RIVET [Buckley, Butterworth, Lonnblad, Grellscheid, Hoeth, Monk, Schulz & Siegert (CPC'13)]

- Transfer functions (efficiencies, resolution) extracted from ATLAS and CMS information
- Starts from hadron-level Monte Carlo information and then gets reconstructed object



Medium electron efficiency in CMS



```
Name: Electron_mediumWP_CMS
Tag: CMS
Description: electron medium WP CMS
Comment: table
Reference: "http://cds.cern.ch/record/1523273/files/DP2013_003.pdf"
Efficiency:
    Type: Grid
    PtBins: [10., 15., 20., 30., 40., 50.]
    EtaBins: [ 0.0, 0.8, 1.44, 2.0, 2.5 ]
    IsEtaSymmetric: True
    Grid:
        Type: Full
        Data:
            [ [0.364, 0.58, 0.752, 0.842, 0.877, 0.888]
            , [0.392, 0.56, 0.711, 0.828, 0.886, 0.899]
            , [0.198, 0.379, 0.584, 0.713, 0.774, 0.795]
            , [0.204, 0.392, 0.575, 0.675, 0.734, 0.752] ]
```

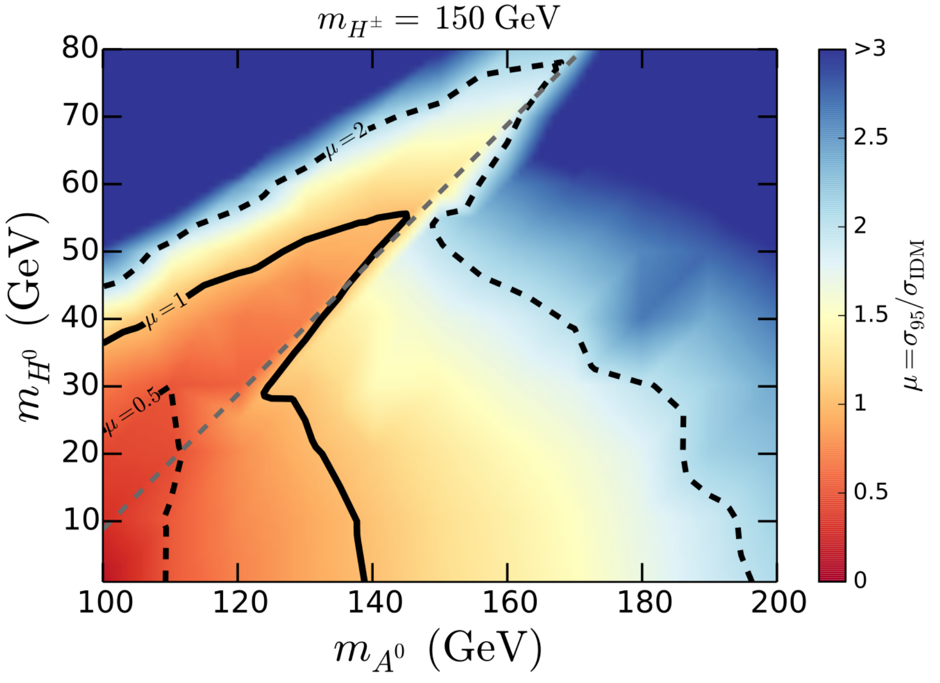
Corresponding implementation in ATOM

Current existing programs

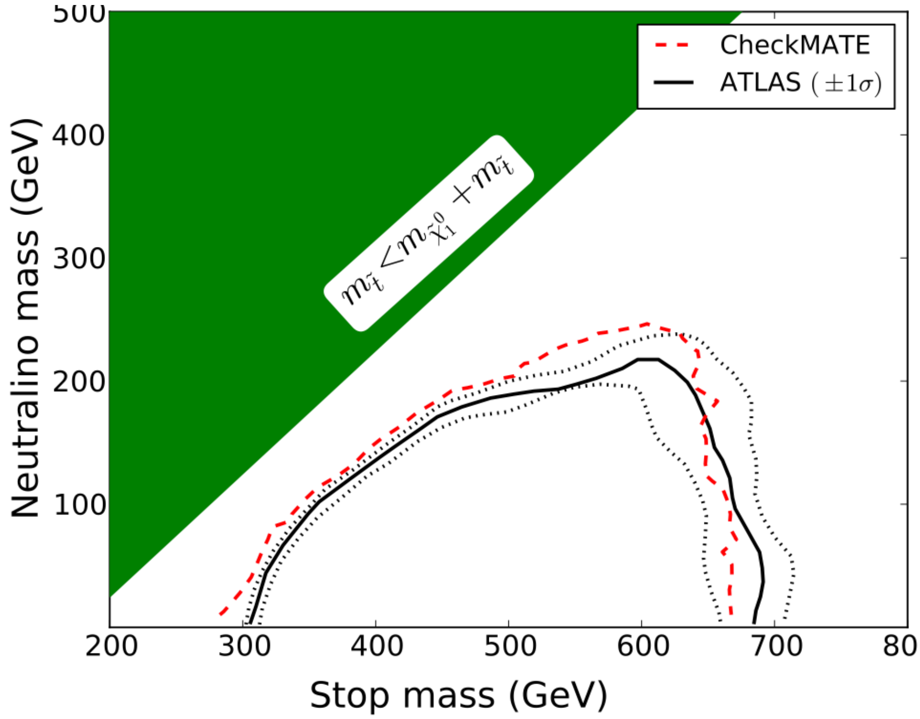
- Two public programs using DELPHES (soon cross-compatible)
  - CHECKMATE: 19 validated analyses [Drees, Dreiner, Schmeier, Tattersall & Kim (CPC'14)]
  - MADANALYSIS 5: 14 validated analyses [Conte, BF & Serret (CPC'12); Conte, Dumont, BF & Wymant (EPJC'14)] [Dumont, BF, Kraml *et al.* (EPJC'15)]
- One private program (that could be obtained on request) based on RIVET
  - ATOM: 15 validated analyses [Kim, Papucci, Sakurai & Weiler]

- Examples

[Belanger, Dumont, Goudelis, Herrmann, Kraml, Sengupta (PRD'15)]



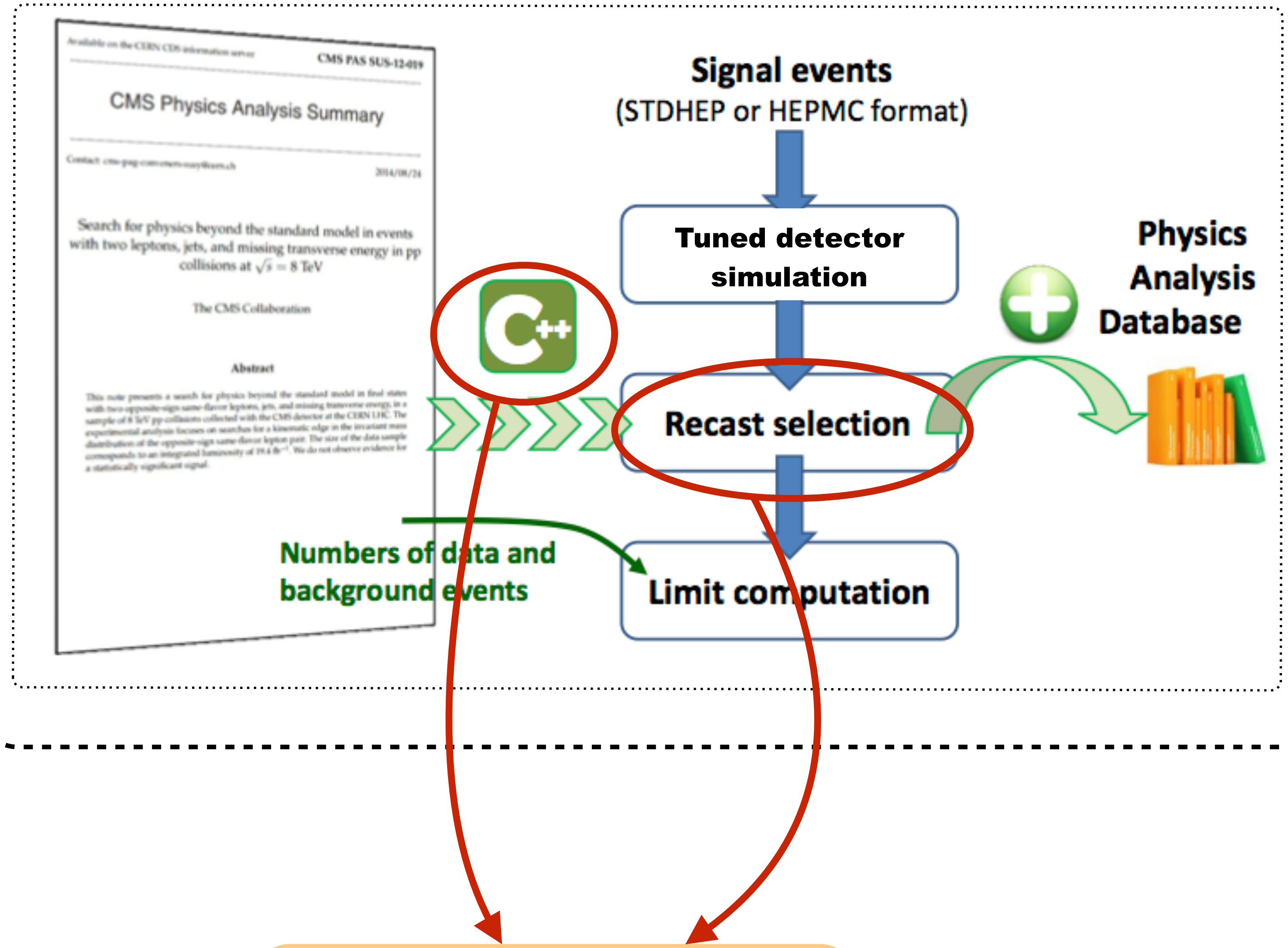
Constraining the inert Higgs doublet model with SUSY searches and MADANALYSIS 5



Confronting ATLAS to CHECKMATE

Reimplementing new physics analyses: challenges

✦ Recasting strategy



How easy is it to implement (and validate) an LHC analysis?

- ✤ 2 options for detector simulation
  - ★ DELPHES/PGS-like (resolutions, efficiencies, *etc.*)
  - ★ RIVET-like (transfer functions)

Implementing a new analysis in a recasting tool

✦ Picking up an experimental publication

- Reading
- Understanding

✅ Relatively easy

✦ Writing the analysis code in the tool internal language

✅ Relatively easy

✦ Getting the information missing from the publication for a proper validation

- Efficiencies (trigger, electrons, muons, b-tagging, JES, *etc.*)
  - ★ Including p_T and/or η dependence
  - ★ Accurate information
- Detailed cutflows for some well-defined benchmark scenarios
  - ★ Exact definition of the benchmarks (SLHA spectra)
  - ★ Event generation information (cards, tunes, LHE files if possible)
- Expected number of events in each region and cross sections
- Digitized histograms (e.g., on HEPDATA)

⚠ **Essential**

✗ **Often difficult!**

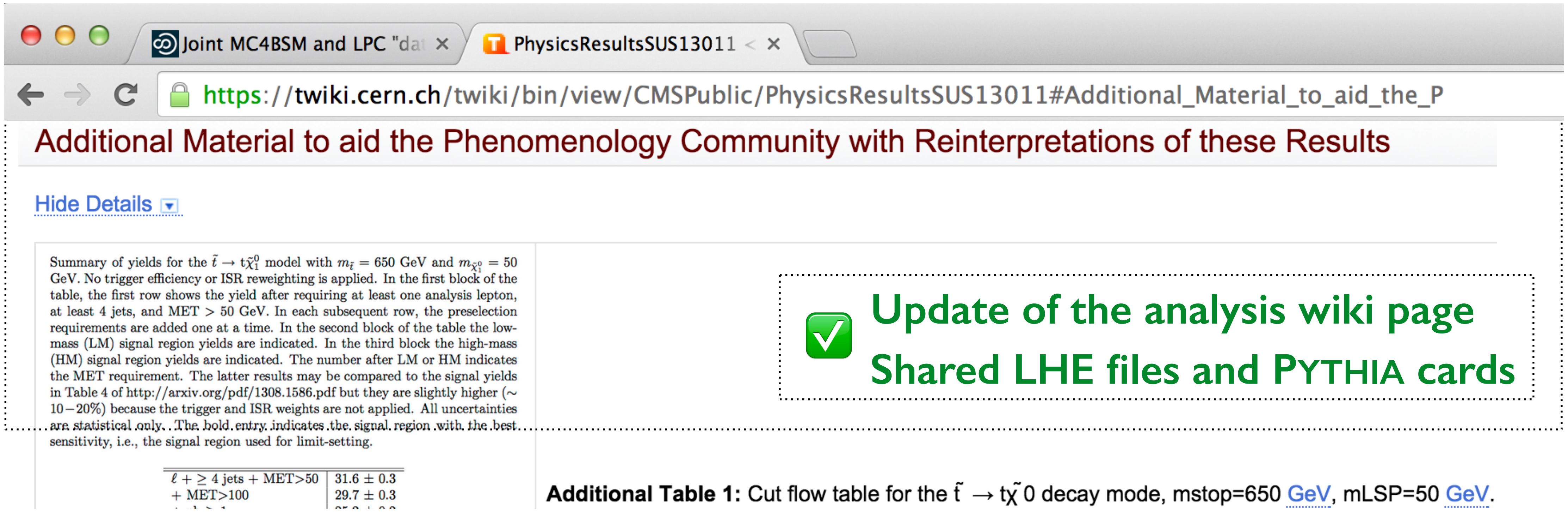
✦ Comparing tools and real life

Example 1: CMS-SUS-13-11 (stops with one lepton)

- Missing information for the validation
  - Efficiencies
  - Cutflows and Monte Carlo information for given benchmarks

✓ Discussions with CMS needed

- All missing information was provided



Additional Material to aid the Phenomenology Community with Reinterpretations of these Results

Summary of yields for the $\tilde{t} \to t\tilde{\chi}_1^0$ model with $m_{\tilde{t}} = 650$ GeV and $m_{\tilde{\chi}_1^0} = 50$ GeV. No trigger efficiency or ISR reweighting is applied. In the first block of the table, the first row shows the yield after requiring at least one analysis lepton, at least 4 jets, and MET > 50 GeV. In each subsequent row, the preselection requirements are added one at a time. In the second block of the table the low-mass (LM) signal region yields are indicated. In the third block the high-mass (HM) signal region yields are indicated. The number after LM or HM indicates the MET requirement. The latter results may be compared to the signal yields in Table 4 of http://arxiv.org/pdf/1308.1586.pdf but they are slightly higher ($\sim$ 10 – 20%) because the trigger and ISR weights are not applied. All uncertainties are statistical only. The bold entry indicates the signal region with the best sensitivity, i.e., the signal region used for limit-setting.

$\ell + \geq 4$ jets + MET>50	31.6 ± 0.3
+ MET>100	29.7 ± 0.3

Additional Table 1: Cut flow table for the t̃ → tχ̃0 decay mode, mstop=650 GeV, mLSP=50 GeV.

✓ Update of the analysis wiki page

Shared LHE files and PYTHIA cards

Example 2: ATLAS-EXO-2014-04 (monophotons)

- ✦ Missing information
  - ✤ Crack in the detector: no photons in the [1.37-1.52] η-range
  - ✤ Tight photon requirements

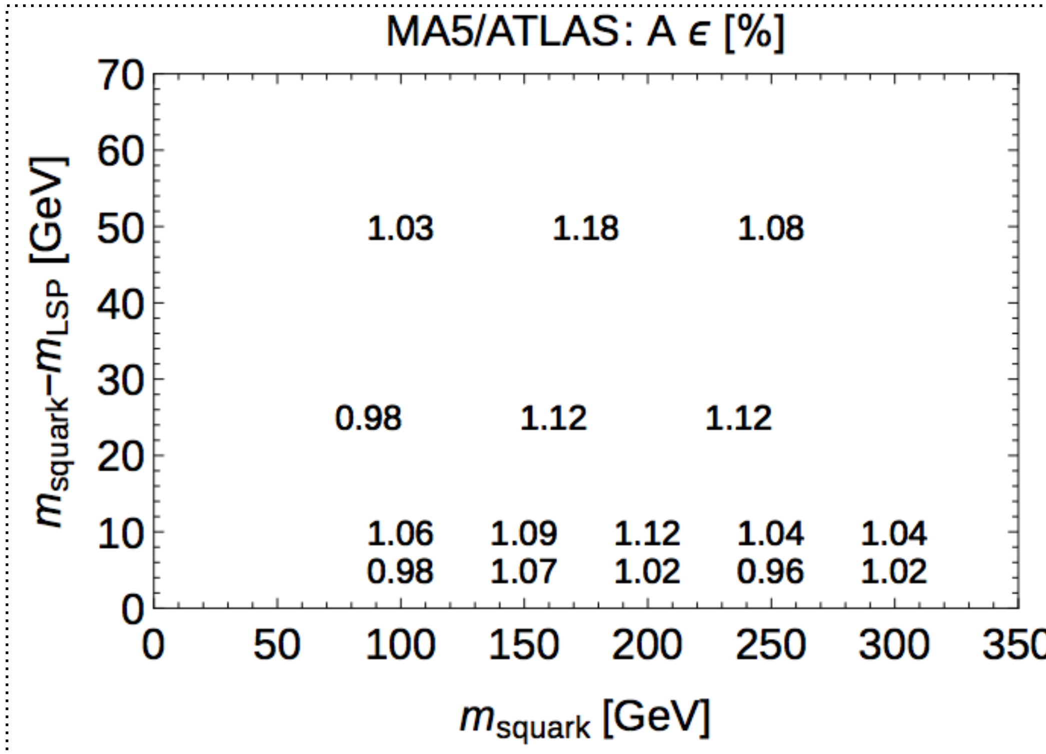
✅ Discussions with ATLAS needed

✅ In ATLAS-COM-PHYS-2014-542

- ✦ Event generation for the test benchmarks
  - ✤ Monte Carlo information (cards, tunes, *etc.*)

✅ Kindly provided by ATLAS

Very good results
(ratio of efficiencies)



[Barducci (2015)]

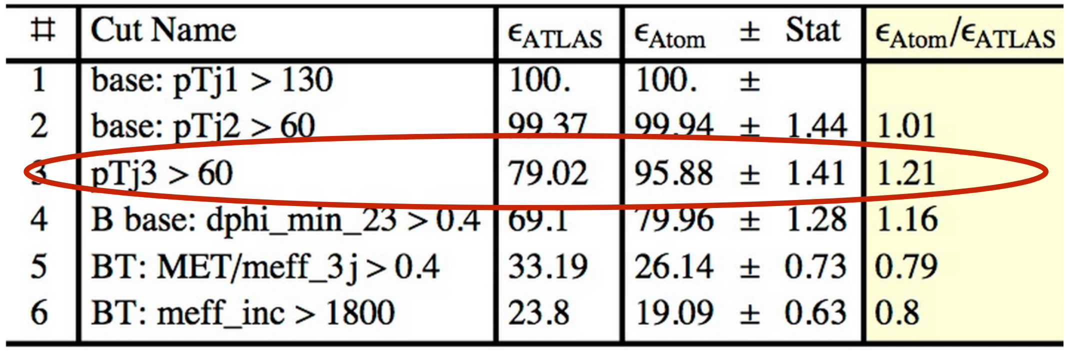
Example 3: When things are borderline… (1)

✦ Large differences are found

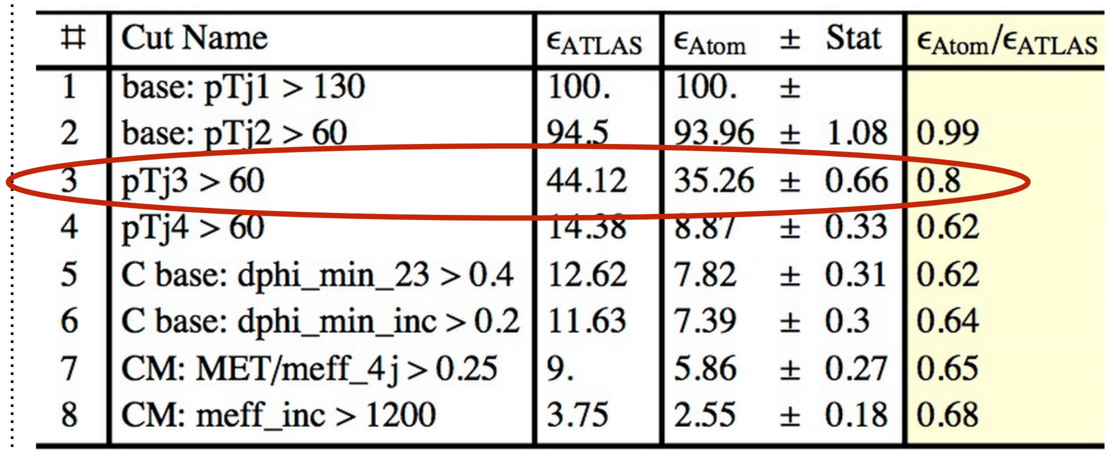
- ✤ ATLAS-CONF-2013-047 (multijet + missing energy)
  - ★ Large differences for one or two signal regions (out of 8)
  - ★ The reinterpretation cannot be totally wrong as 6 regions are fine
  - ★ Issues related to the jets (smearing, Monte Carlo details)

Monte Carlo info is desirable

Jet smearing info is desirable



#	Cut Name	ϵ_{ATLAS}	ϵ_{Atom}	±	Stat	$\epsilon_{Atom}/\epsilon_{ATLAS}$
1	base: pTj1 > 130	100.	100.	±		
2	base: pTj2 > 60	99.37	99.94	±	1.44	1.01
3	pTj3 > 60	79.02	95.88	±	1.41	1.21
4	B base: dphi_min_23 > 0.4	69.1	79.96	±	1.28	1.16
5	BT: MET/meff_3j > 0.4	33.19	26.14	±	0.73	0.79
6	BT: meff_inc > 1800	23.8	19.09	±	0.63	0.8



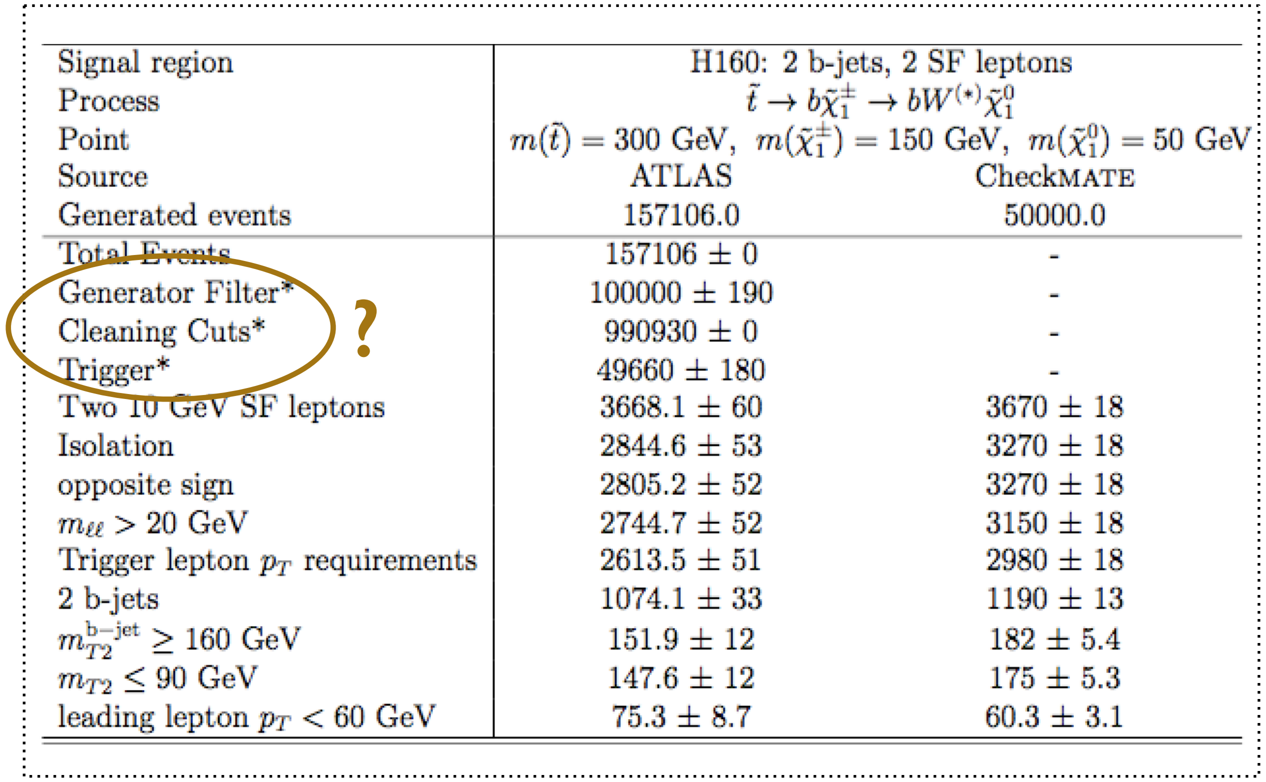
#	Cut Name	ϵ_{ATLAS}	ϵ_{Atom}	±	Stat	$\epsilon_{Atom}/\epsilon_{ATLAS}$
1	base: pTj1 > 130	100.	100.	±		
2	base: pTj2 > 60	94.5	93.96	±	1.08	0.99
3	pTj3 > 60	44.12	35.26	±	0.66	0.8
4	pTj4 > 60	14.38	8.87	±	0.33	0.62
5	C base: dphi_min_23 > 0.4	12.62	7.82	±	0.31	0.62
6	C base: dphi_min_inc > 0.2	11.63	7.39	±	0.3	0.64
7	CM: MET/meff_4j > 0.25	9.	5.86	±	0.27	0.65
8	CM: meff_inc > 1200	3.75	2.55	±	0.18	0.68

Example 4: When things are borderline… (2)

- ATLAS-EXOT-2014-04 (monophotons)
  - Effects non-reproducible with DELPHES (cleaning cuts, triggers, good vertexing)
- ATLAS-SUS-2013-09 (stops in the dilepton channel)
  - Information on effects non-reproducible with DELPHES lost (student has quit physics)

⚠ Efficiencies computed by hand
Maybe model-dependent

Very good results
(for a SUSY benchmark)



Signal region	H160: 2 b-jets, 2 SF leptons	
Process	$\tilde{t} \to b\tilde{\chi}_1^\pm \to bW^{(*)}\tilde{\chi}_1^0$	
Point	$m(\tilde{t}) = 300$ GeV, $m(\tilde{\chi}_1^\pm) = 150$ GeV, $m(\tilde{\chi}_1^0) = 50$ GeV	
Source	ATLAS	CheckMATE
Generated events	157106.0	50000.0
Total Events	157106 ± 0	-
Generator Filter*	100000 ± 190	-
Cleaning Cuts*	990930 ± 0	-
Trigger*	49660 ± 180	-
Two 10 GeV SF leptons	3668.1 ± 60	3670 ± 18
Isolation	2844.6 ± 53	3270 ± 18
opposite sign	2805.2 ± 52	3270 ± 18
$m_{\ell\ell} > 20$ GeV	2744.7 ± 52	3150 ± 18
Trigger lepton p_T requirements	2613.5 ± 51	2980 ± 18
2 b-jets	1074.1 ± 33	1190 ± 13
$m_{T2}^{\text{b-jet}} \geq 160$ GeV	151.9 ± 12	182 ± 5.4
$m_{T2} \leq 90$ GeV	147.6 ± 12	175 ± 5.3
leading lepton $p_T < 60$ GeV	75.3 ± 8.7	60.3 ± 3.1

?

Example 5: sometimes…

✦ Missing or incomplete validation information

- ✤ CMS-SUS-12-028 (α_T)
  - ★ No cutflows; no answers from CMS to requests

✕ Dead end!

- ✤ CMS-SUS-13-007 (1 lepton+b-jets+met)
  - ★ Semi-official validation material provided (that cannot be used in the public validation)
  - ★ No cutflows
  - ★ Messy definition of the benchmark points

⚠ We'll do our best…

✦ Missing or incomplete analysis information

⚠ Too vague!

- ✤ ATLAS-EXOT-2013-10 (monolepton)
  - ★ The average trigger efficiency is 80%–90% in the muon channel"
  - ★ 80% of the muons are reconstructed with most of the loss coming from…
  - ★ No precise information on signal event generation
  - ★ No signal distributions on HEPDATA

Unfortunately: many more examples!

A wishlist from theorists to experimentalists - part I

✦ Analysis description

- ✤ Clear description of the selections, including their sequence
  - ★ A tabulated form would be appreciable (possibly on the analysis wiki pages)
- ✤ Efficiencies for physics (electrons, muons, jets, taus, b-tagging, mistagging rates, *etc.*)
  - ★ Including p_T and η dependence
  - ★ Or a reference with the information
- ✤ Efficiencies for triggers, event cleaning, *etc.*
  - ★ Effects that cannot be modeled in our fast simulation
- ✤ Digitized figures
  - ★ Missing in particular the performance results (reading off log-scale histograms…)
  - ★ ROOT format, text format, *etc.*
- ✤ Special variables (e.g., the CMS razor)
  - ★ Providing snippets of code would be highly appreciated
  - ★ Some variables have different definitions in different analyses (e.g., asymmetric M_{T2})

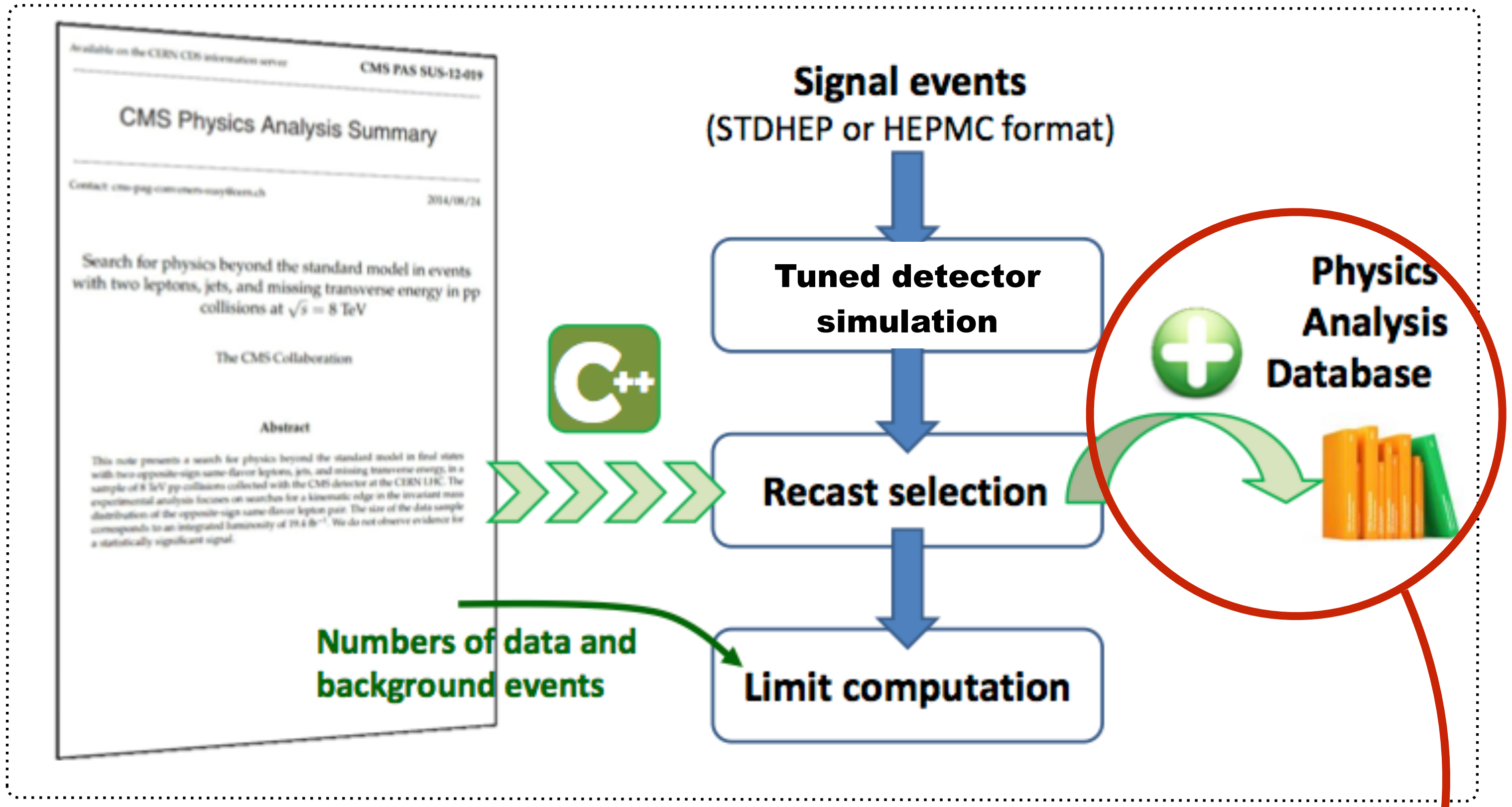
A wishlist from theorists to experimentalists - part 2

✦ Validation material ➢ quality of the reinterpretation

- ✤ Benchmark scenarios
  - ★ Spectra and decay tables (under an SLHA-form)
  - ★ Several scenarios are appreciable
  - ★ Publicly available on the wiki pages or HEPDATA
- ✤ Monte Carlo tools configuration
  - ★ Cards, tunes, merging information, *etc.*
  - ★ Better, the CMS way: LHE files with shower inputs (no new source of discrepancies)
  - ★ Publicly available on the wiki pages or HEPDATA
- ✤ Detailed cutflows for the benchmarks, with the correct selection ordering
  - ★ Including each step of the (pre)selection
  - ★ For several benchmarks
  - ★ The more steps are available, the better (even the preselection, the cleaning, *etc.*) (pin-down the differences in our machinery, in the fastsim *vs.* CMS-ATLAS simulation)
- ✤ Kinematical distributions at different steps of the selection
  - ★ Extra cross-check of our machinery

The LHC legacy (I)

✦ Recasting strategy



CMS PAS SUS-12-019

CMS Physics Analysis Summary

Search for physics beyond the standard model in events with two leptons, jets, and missing transverse energy in pp collisions at $\sqrt{s}$ = 8 TeV

The CMS Collaboration

Abstract

Signal events
(STDHEP or HEPMC format)

Tuned detector simulation

Recast selection

Limit computation

Numbers of data and background events

Physics Analysis Database

✤ 2 options for detector simulation

- ★ DELPHES/PGS-like (resolutions, efficiencies, *etc.*)
- ★ RIVET-like (transfer functions)

How to store recasted analyses?
Part of the LHC legacy

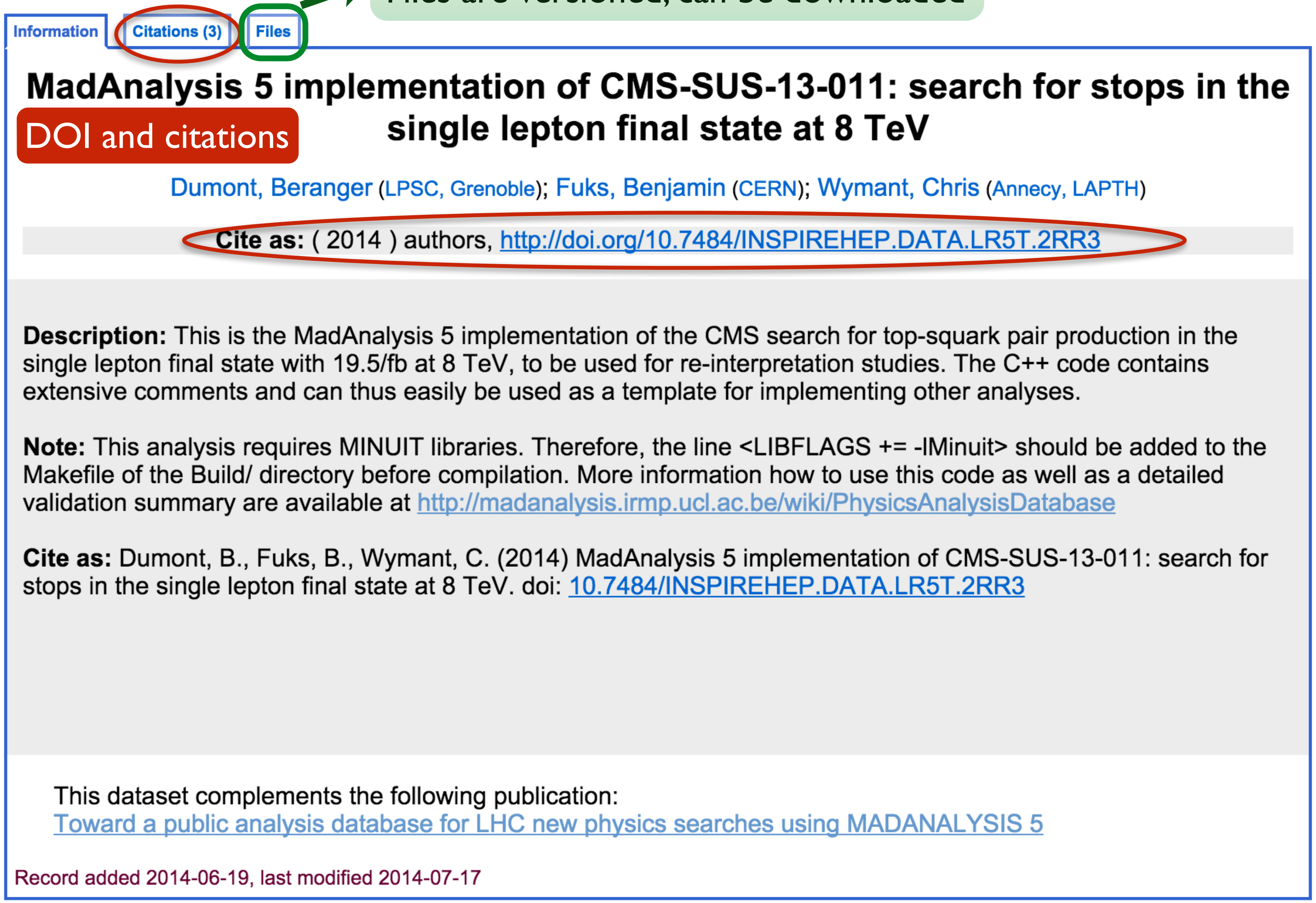
The LHC legacy: data preservation

[Dumont, BF, Kraml *et al.* (EPJC '15)]

- Implementation of LHC analyses can be uploaded on Inspire
  - DOI are assigned: can be cited, searched for, *etc*.
  - Used by MadAnalysis 5 only at the moment

Files are versioned, can be downloaded

DOI and citations



MadAnalysis 5 implementation of CMS-SUS-13-011: search for stops in the single lepton final state at 8 TeV

Dumont, Beranger (LPSC, Grenoble); Fuks, Benjamin (CERN); Wymant, Chris (Annecy, LAPTH)

Cite as: (2014) authors, http://doi.org/10.7484/INSPIREHEP.DATA.LR5T.2RR3

Description: This is the MadAnalysis 5 implementation of the CMS search for top-squark pair production in the single lepton final state with 19.5/fb at 8 TeV, to be used for re-interpretation studies. The C++ code contains extensive comments and can thus easily be used as a template for implementing other analyses.

Note: This analysis requires MINUIT libraries. Therefore, the line <LIBFLAGS += -lMinuit> should be added to the Makefile of the Build/ directory before compilation. More information how to use this code as well as a detailed validation summary are available at http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase

Cite as: Dumont, B., Fuks, B., Wymant, C. (2014) MadAnalysis 5 implementation of CMS-SUS-13-011: search for stops in the single lepton final state at 8 TeV. doi: 10.7484/INSPIREHEP.DATA.LR5T.2RR3

This dataset complements the following publication:
Toward a public analysis database for LHC new physics searches using MADANALYSIS 5

Record added 2014-06-19, last modified 2014-07-17

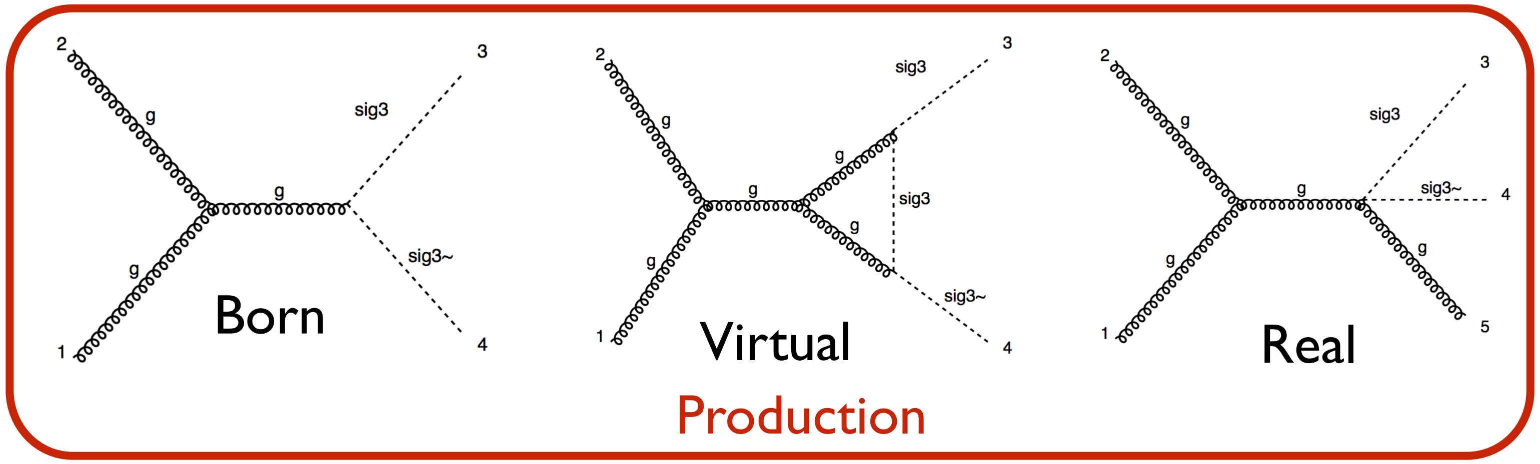
The stop simplified model: the recasting episode

✦ The stop (σ_3) / bino (χ) model

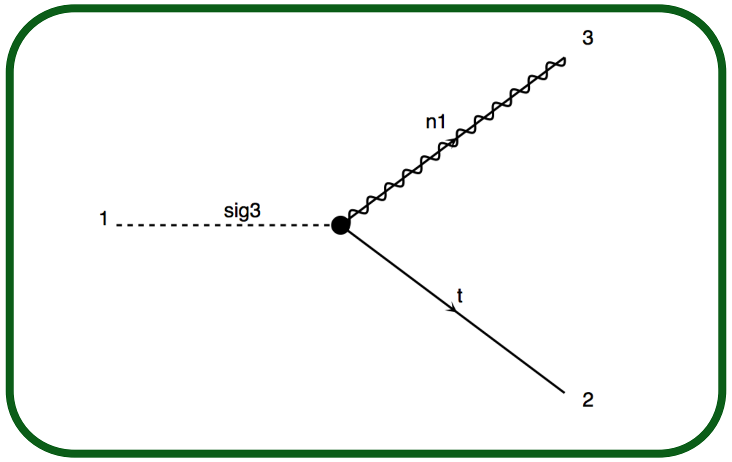
$$\mathcal{L}_3 = \underbrace{D_\mu \sigma_3^\dagger D^\mu \sigma_3 - m_3^2 \sigma_3^\dagger \sigma_3}_{\text{Production}} + \underbrace{\frac{i}{2}\bar{\chi}\not{\partial}\chi - \frac{1}{2} m_\chi \bar{\chi}\chi + \left[\sigma_3 \bar{t}(\tilde{g}_L P_L + \tilde{g}_R P_R)\chi + \text{h.c.}\right]}_{\text{Decay}}$$

- ✤ One scalar field in the fundamental representation (σ_3)
- ✤ One gauge-singlet Majorana fermion (χ) coupling the stop to the top

✦ Representative Feynman diagrams (yielding a top-antitop plus missing energy signature)



Production



Recasting of the CMS analysis

The CMS-SUS-13-011 analysis: recasting and simulations

✦ The CMS study relies on leading order simulation and MLM merging

- ✤ Simulated signal: p p → $\tilde{t}\,\tilde{t}^*$ + 0,1,2 jets at the leading order
- ✤ Parton showering: PYTHIA 6 with the Z2 tune [Field (APPB '11)]

✦ Analysis

- ✤ Selection of top-antitop plus missing energy final states yielding a single lepton signature
- ✤ One single lepton and 4 jets (mainly issued from the stop-antistop system decay)
- ✤ Large missing energy
- ✤ At least one *b*-jet
- ✤ Top reconstruction quality
- ✤ Transverse variable constraints

✦ Observation

- ✤ The selection does not really depend on the extra jets
  - ★ The main hadronic activity comes from the decay products
- ✤ The limit should be agnostic of the merging

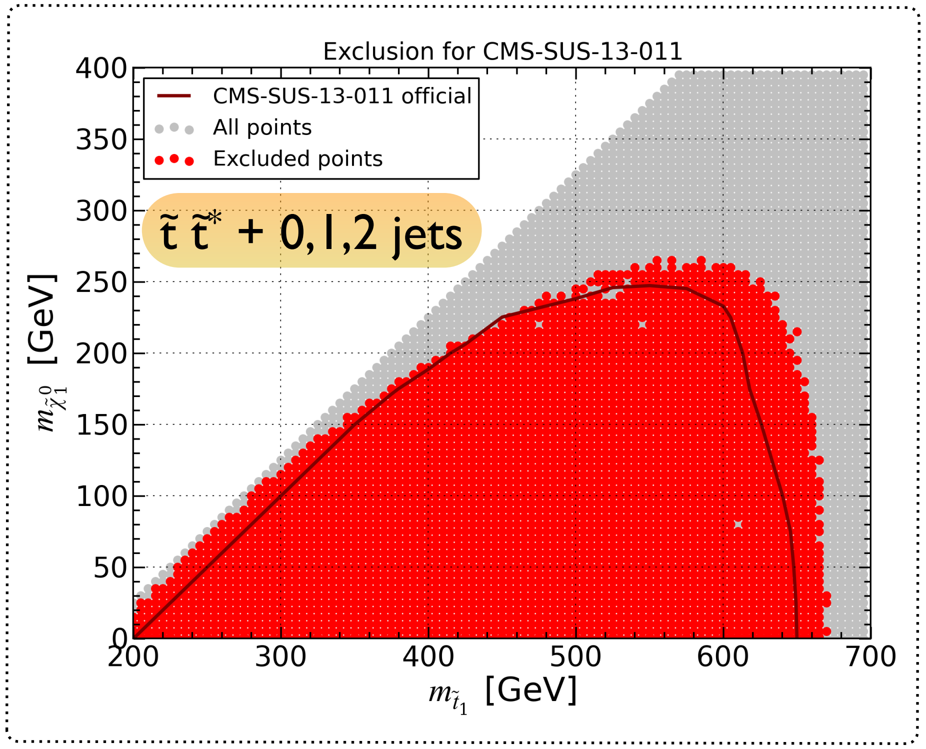
The CMS-SUS-13-011 analysis: multijet merging

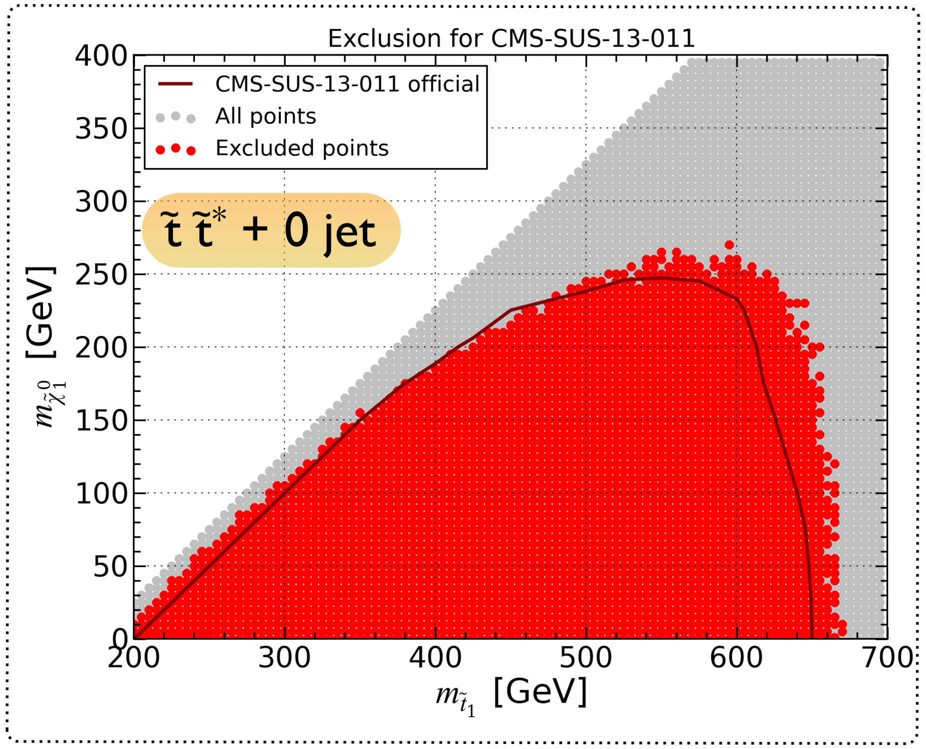
- ✦ Relies on leading order simulation and MLM merging
  - ✤ Simulated signal: p p → $\tilde{t}\,\tilde{t}^*$ + 0,1,2 jets at the leading order; PYTHIA 6 with the Z2 tune
- ✦ Observation
  - ✤ The selection does not really depend on the extra jets
  - ✤ The limit should be agnostic of the merging

- ✦ Verification with MADANALYSIS 5

[Ambrogi, Conte, BF, Kulkarni & Molter (in preparation)]

  - ✤ Good agreement of the exclusion at the 20 GeV level
  - ✤ The limit does not depend on the merging





The CMS-SUS-13-011 analysis: modern tools effects

✦ Moving towards more modern tools

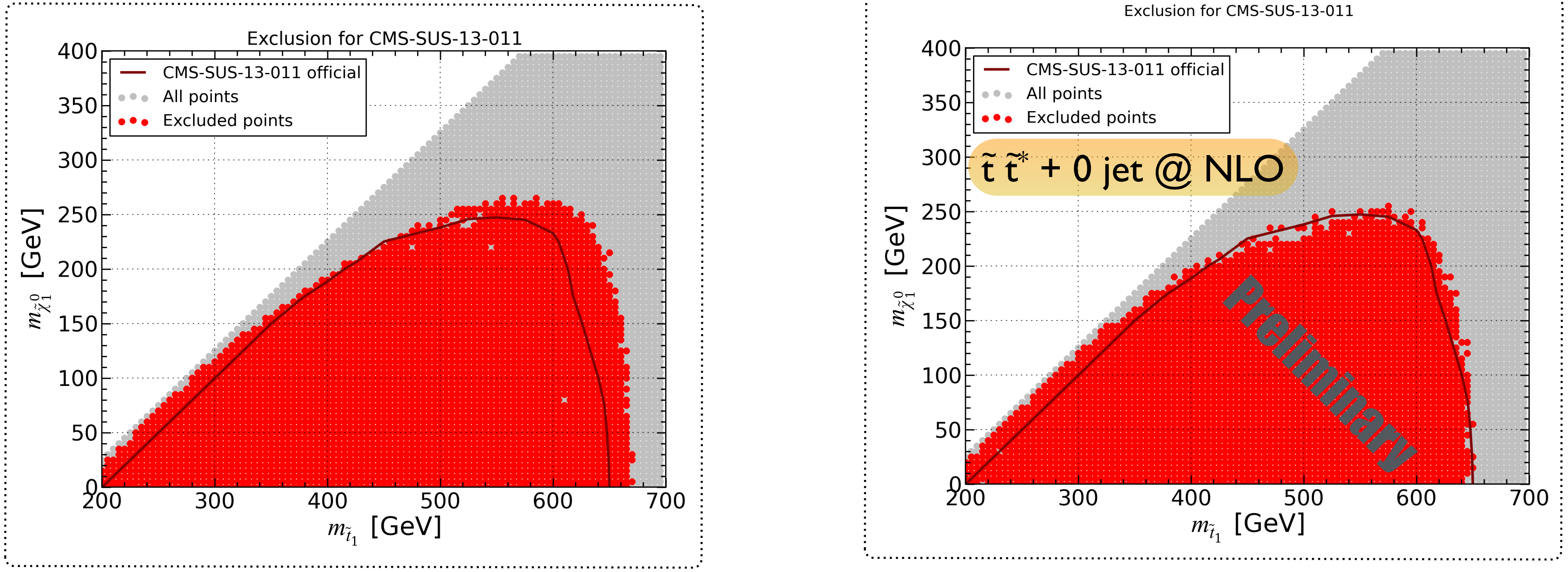
- ✤ Simulated signal: p p → $\tilde{t}\,\tilde{t}^*$ + 0 jet at the next-to-leading order in QCD
- ✤ Parton-showering, hadronization, underlying event: PYTHIA 8 with the MONASH tune

[Skands, Carrazza & Rojo (EPJC '14)]

✦ How are the limits changing (with MADANALYSIS 5)?

[Ambrogi, Conte, BF, Kulkarni & Molter (in preparation)]

- ✤ Limits stable at the 20-40 GeV level
- ✤ Origins of the differences: to be understood (a PYTHIA effect?)



The CMS-SUS-13-011 analysis: merging and NLO

✦ Adding FxFx NLO merging

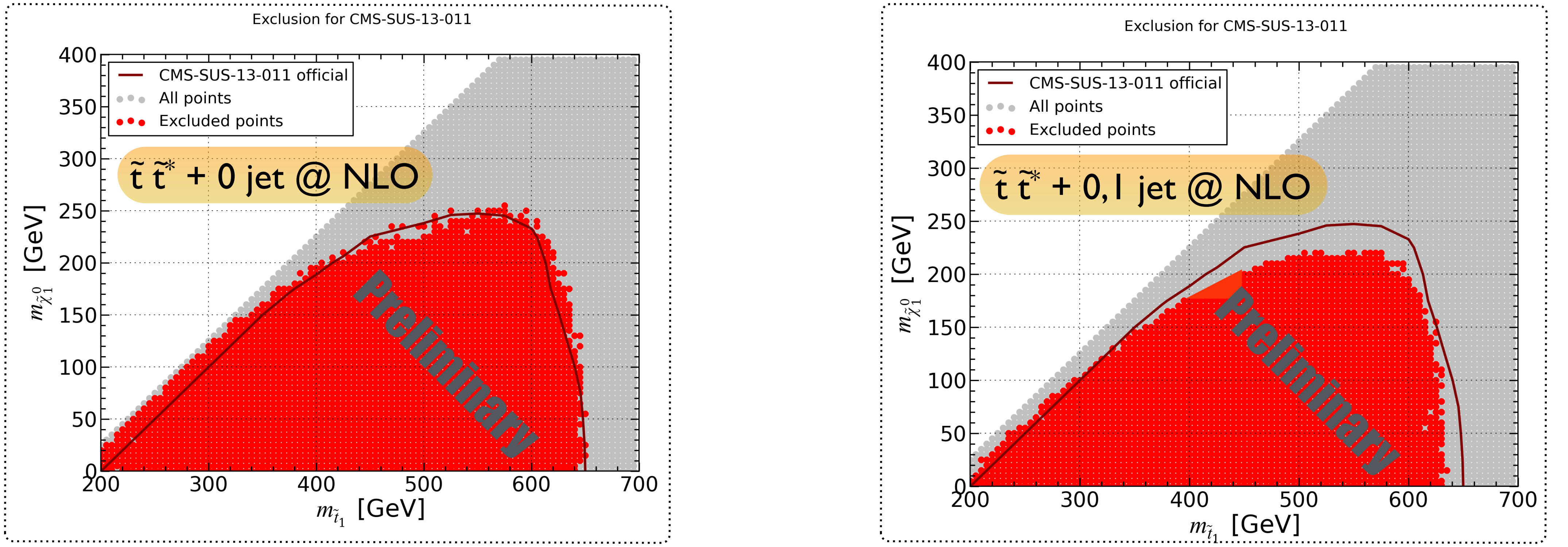
- ✤ Simulated signal: $p\ p \to \tilde{t}\ \tilde{t}^*$ + 0,1 jets at the next-to-leading order in QCD
- ✤ Parton-showering, hadronization, underlying event: PYTHIA 8 with the MONASH tune

[Skands, Carrazza & Rojo (EPJC '14)]

✦ How are the limits changing (with MADANALYSIS 5)

[Ambrogi, Conte, BF, Kulkarni & Molter (in preparation)]

- ✤ Slightly weaker constraints: to be understood… (role of the virtuals?)



Outline

1. When new physics meets Monte Carlo simulations

2. New physics simulations with Monte Carlo event generators

3. Interpretation of LHC results and recasting the experimental searches

4. **Conclusions - summary**

Summary

✦ Lots of effort have been invested in new physics simulations during the last decade

- ✤ Streamlining the link between models and events
- ✤ Multipartonic matrix element merging
- ✤ Cascade decays
- ✤ Next-to-leading order corrections
- ✤ Techniques are (and will be) used for signal simulations both by theorists and experimentalists

✦ The LHC legacy

- ✤ It is crucial to be able to reinterpret the LHC results in any theoretical context
- ✤ This is a very active field of the last few years: several tools are now ready to be used
- ✤ **Reproducibility** is the ability of an entire experiment to be reproduced, possibly by an independent (pheno) study