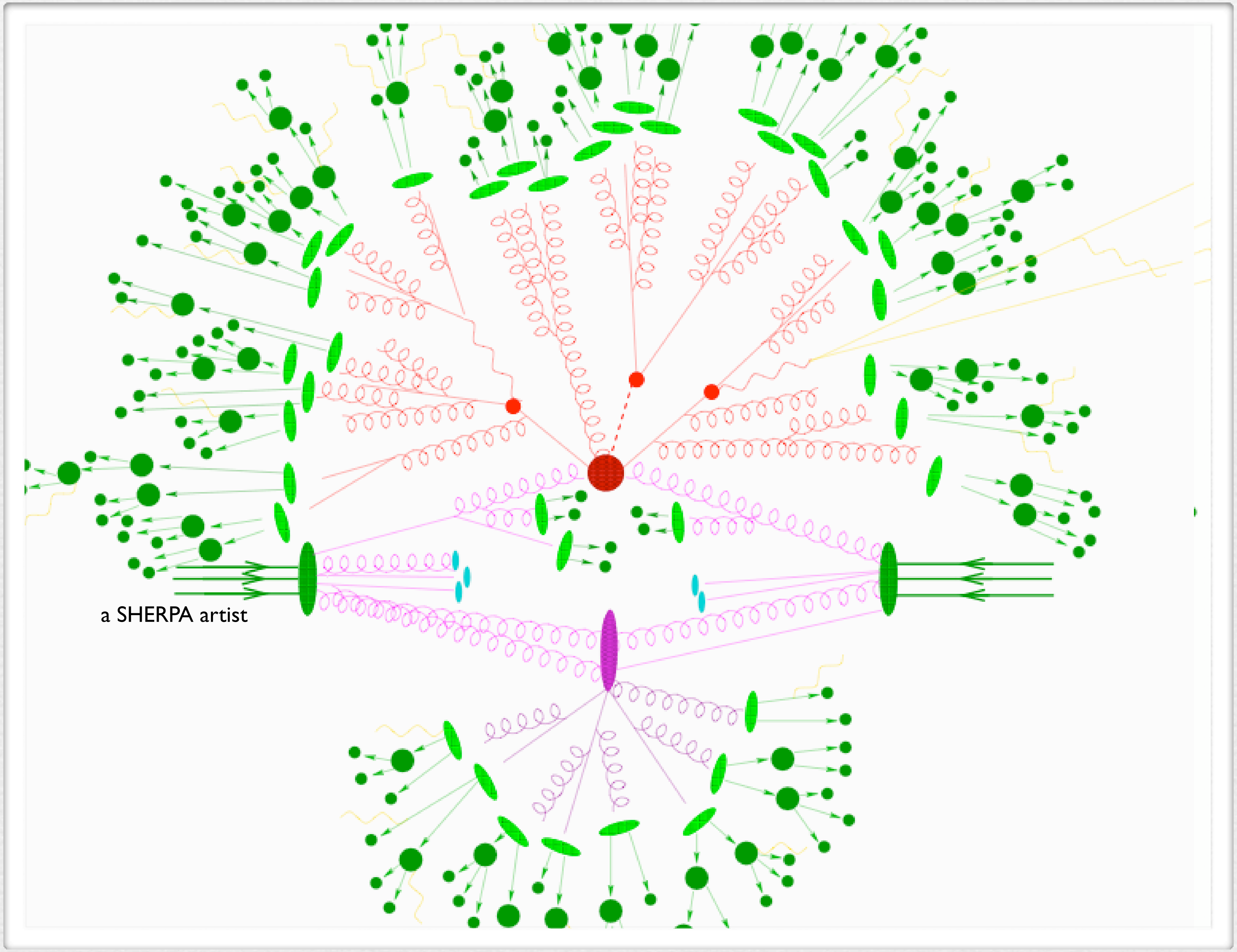
A look into the BSM hunter's toolbox

Claude Duhr

Characterization of new physics at the LHC

CERN, July 4th 2010

Simulating HE collisions



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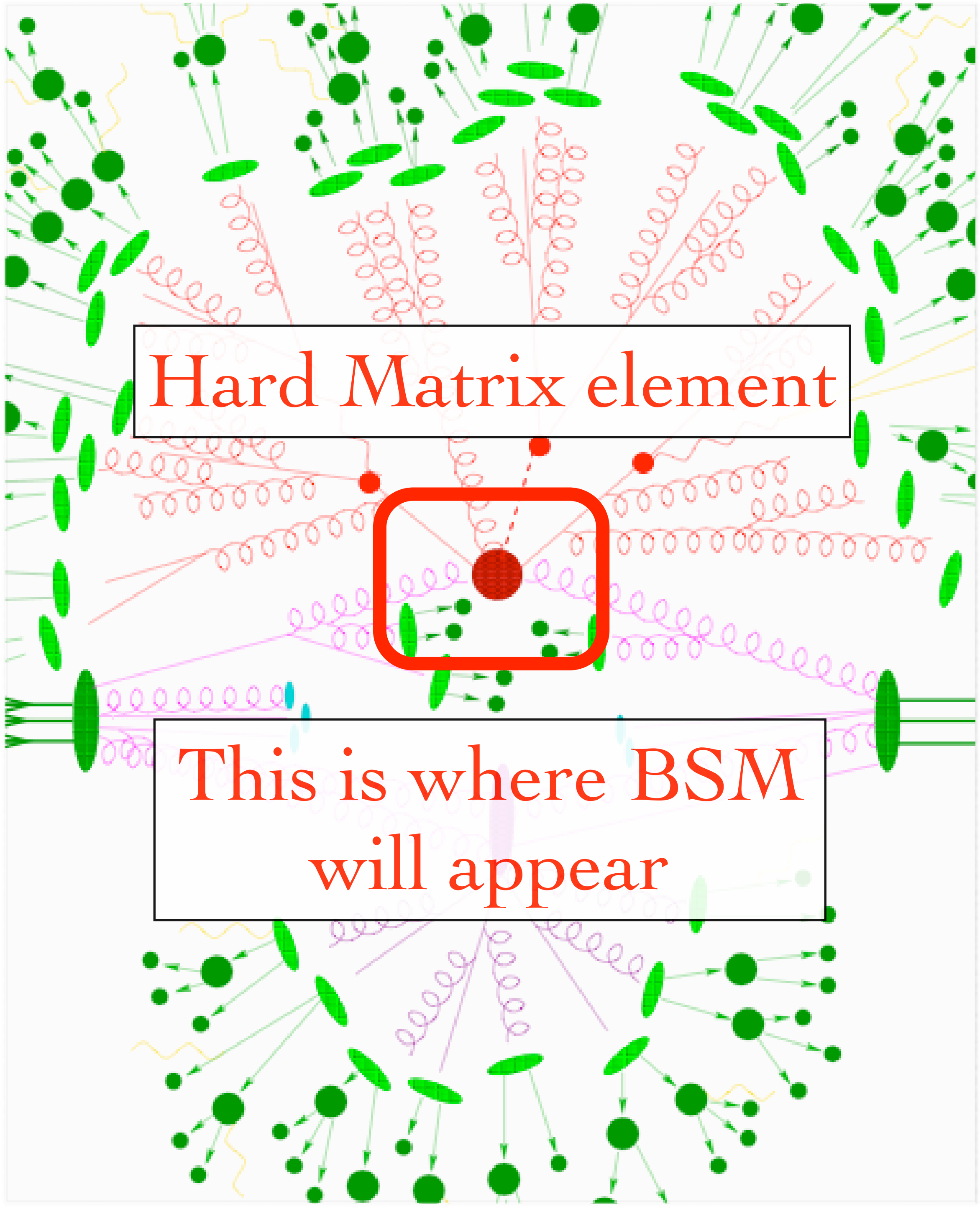


- Searching for new physics requires the modeling of hard interaction.
- Various tools have been developed on the theory side to perform this task.
- Knowing when/how to use a given tool is a valuable asset.

The zoo of HEP tools

The aim of this talk is ...

- ... to provide an overview of the different tools, their features and limitations.
- ... to show how the same tool can be used in different contexts.
- ... to trigger discussions and interaction between theorists and experimentalists, in order to further sharpen the tools.

Generating BSM matrix elements

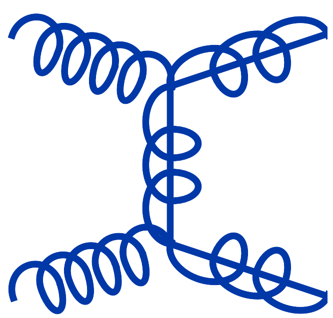
- Main approaches:
  - ➡ Compute hard ME 'by hand', and put it into the Monte Carlo program (cf. Pythia 6 and Fortran Herwig).
  - ➡ Use simplified (flat) ME (cf. OSET approach).
  - ➡ Use multi-purpose ME generators.
- Philosophy behind multi-purpose ME generators: Given a collection of particles, parameters and vertices, construct the matrix element and perform the phase space integration for the hard process.
- Advantage: All the information (spin, interference) is kept!

N.B.: This approach can be used both for model dependent **and** independent searches (cf. second part of the talk).

Generating BSM matrix elements

- Commonly used ME generators:
  - ➡ CalcHep / CompHep
  - ➡ Herwig++ (2-to-2)
  - ➡ MadGraph / MadEvent
  - ➡ Sherpa
  - ➡ Whizard / Omega
- Generate events for the hard process, e.g.,

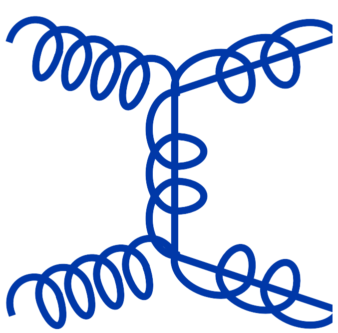
  p p > go go



- The events can be passed on to Monte Carlo codes via LHE files (where applicable).

Decay chains

- In many BSM models, particles decay via long decay chains.
- Final state multiplicity in general too high for ME generator.



- But we do not need all the diagrams, but only those that have a given set of s-channel resonances.
- In the narrow-width approximation, intermediate particles can be treated as ‘almost on shell’.

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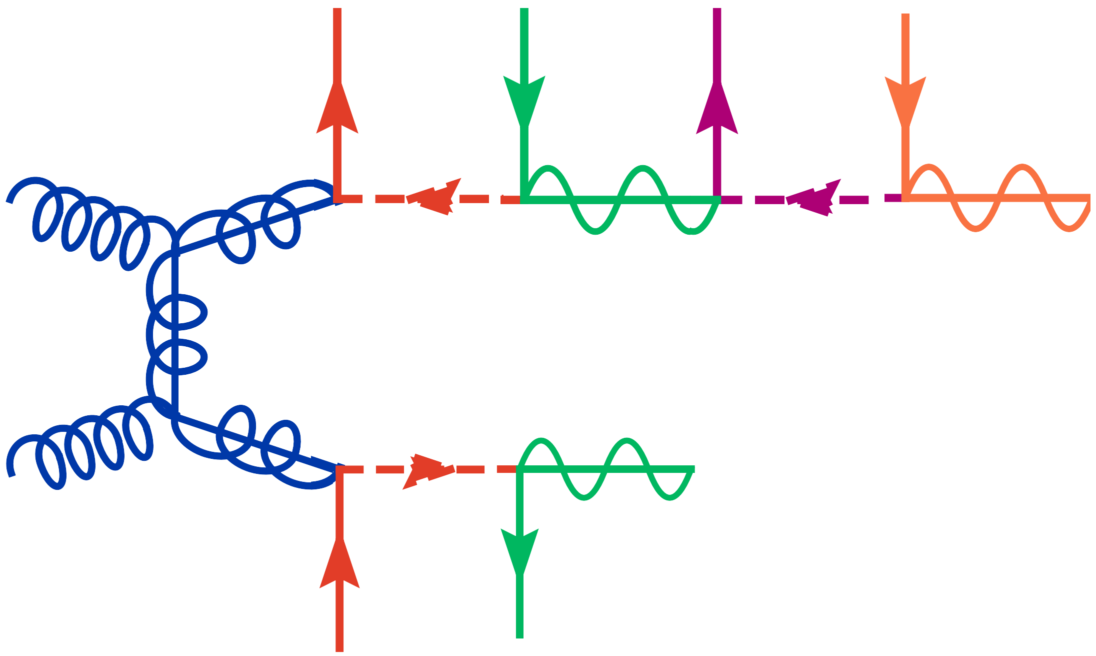

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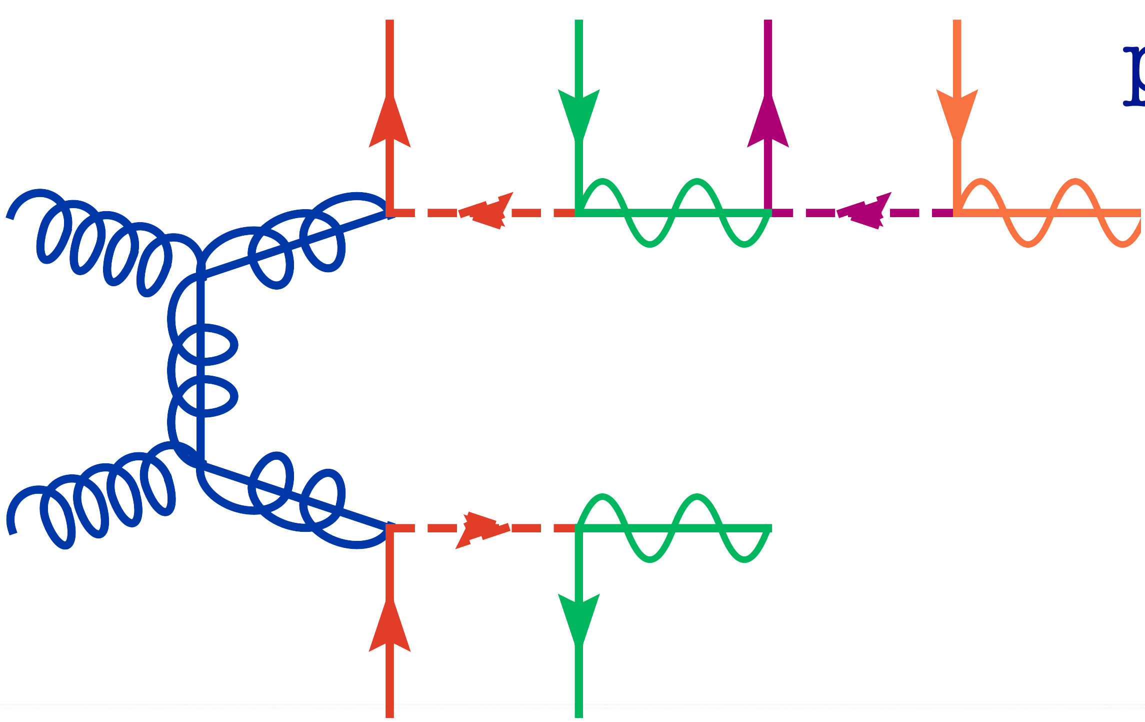
Decay chains

- Solution 1: Produce particles on shell, decay them later (e.g., in Pythia).
  - ✓ Allows to go to arbitrary high multiplicity.
  - ◉ Looses information on spin correlations, off-shell effects,...
- Solution 2: Produce particles on shell, decay them later using dedicated tools using narrow width approximation (e.g. Bridge).
  - ✓ Allows to go to arbitrary high multiplicity.
  - ✓ (Most of the) spin correlations are kept.
  - ◉ Looses information on off-shell effects.

Decay chains

- Solution 3: Use ME generators to generate the relevant resonant diagrams.
  - ✓ Work with the full resonant Feynman diagrams: Full Information on spin correlations, off-shell effects, etc. is kept.
  - ◉ Length of the decay chain can be limited (depends on the tool).



```
p p > go go,
    (go > sb~ b,
         sb~ > x2 b~,
              x2 > se+ e-
                   se+ > x1 e+),
    (go > sb b~
         sb > x1 b)
```

[MG5 syntax]

Built-in models

	CalcHep	Herwig++	MadGraph	Sherpa	Whizard
SM					
cMSSM					
MSSM					
NMSSM					
2HDM					
UED					
Technicolor					
Little Higgs					

[Snapshot of the model survey made at the FeynRules 2010 workshop]
[Only publicly available models are taken into account]

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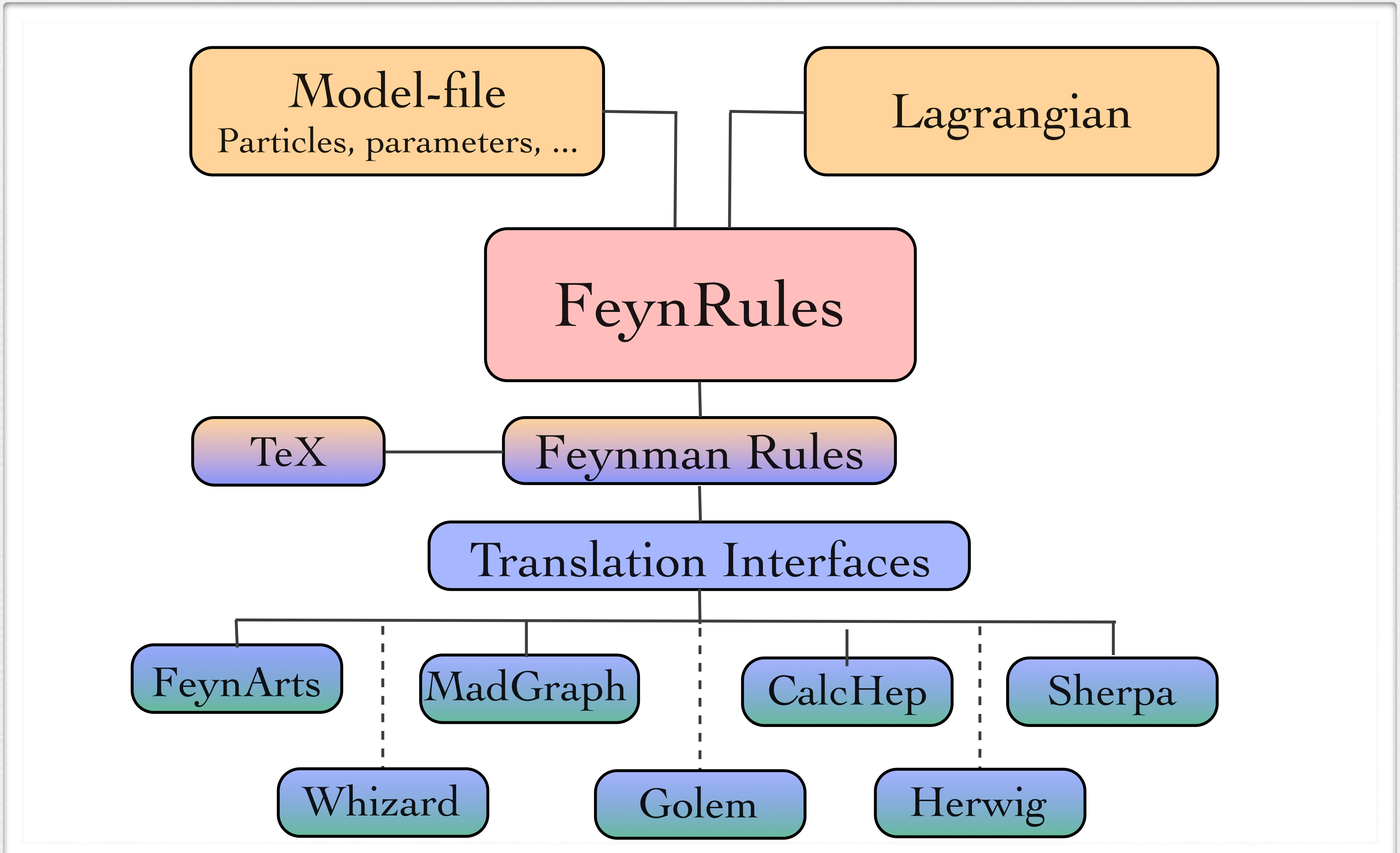
Implementing a new model

- Even though all the ME elements generators can in principle handle any renormalisable model, implementing a new model can be a very tough task!
- In general, all the vertices need to be entered one at the time.
- For complicated models, one can easily end up with 1000's of vertices!
  - ➡ extremely tedious and error-prone!
- Additional tools have been developed that allow to go directly from a Lagrangian to a model implementation:
  - ➡ FeynRules
  - ➡ LanHep

FeynRules



Model-file
Particles, parameters, ...
Lagrangian
FeynRules
TeX
Feynman Rules
Translation Interfaces
FeynArts
MadGraph
CalcHep
Sherpa
Whizard
Golem
Herwig

Implemented models

	CalcHep	Herwig	MadGraph	Sherpa	Whizard
SM	✓	✓	✓	✓	✓
cMSSM	✓	✓	✓	✓	✓
MSSM	✓			✓	✓
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NMSSM	✓	✓	✓	✓	✓
2HDM	✓	✓	✓	✓	✓
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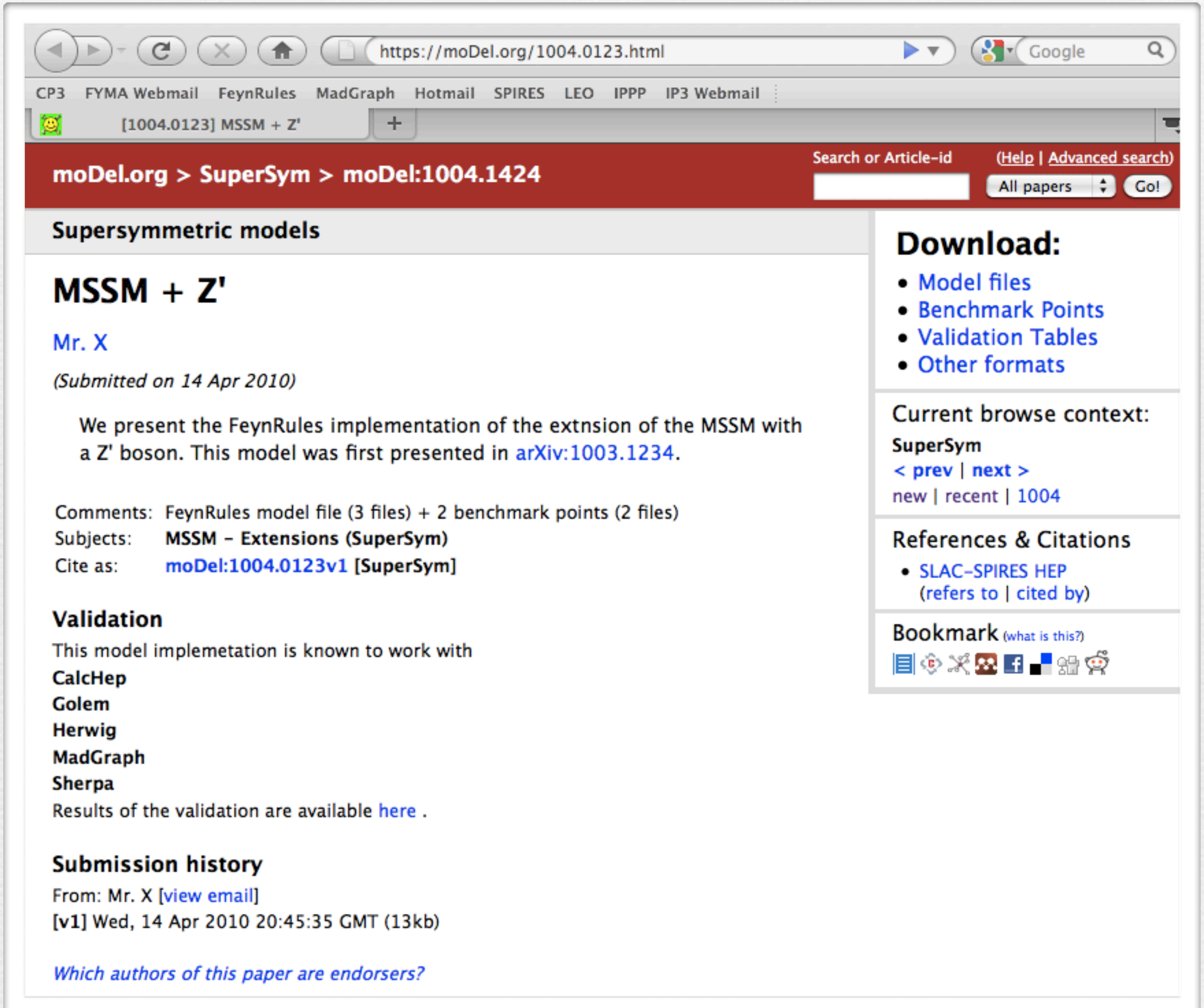
- Still many model missing/private... how to make them public..?

Towards a database of models...



Overview of features

	Final states	Decay chains	Spins	Lorentz	Color
CalcHep	~6	no limit/no cor.	0,1/2,1,2	< 5 particles	1,3,8
CompHep	~6		0,1/2,1,2	< 5 particles	1,3,8
Herwig	2		0,1/2,1,2	no restric.*	1,3,8
MG4	8	8	0,1/2,1,2	limited	1,3,8
MG5beta	no limit**	no limit**	no limit**	no restric.**	1,3,8**
Sherpa	8	8	0,1/2,1,2	limited	1,3,8
Whizard	~8	no known limit	0,1/2,1, 3/2, 2	limited****	1,3,8****

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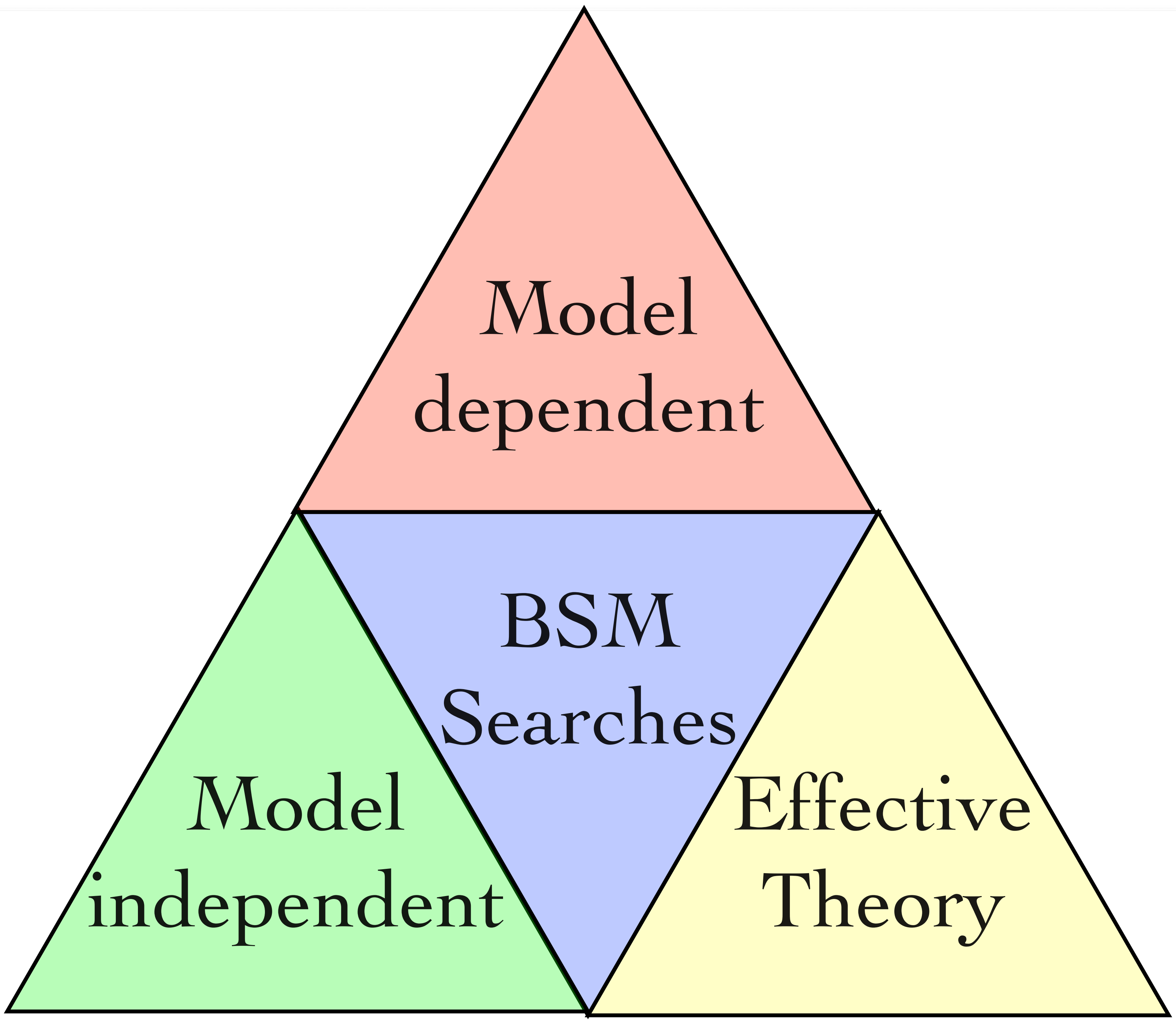
* Lorentz structures will be provided by FeynRules output in the future.

** Still under development / beta testing.

***Possible to extend to arbitrary color structures.

**** Sextets and decuplets and arbitrary Lorentz structures are foreseen.

Using the tools

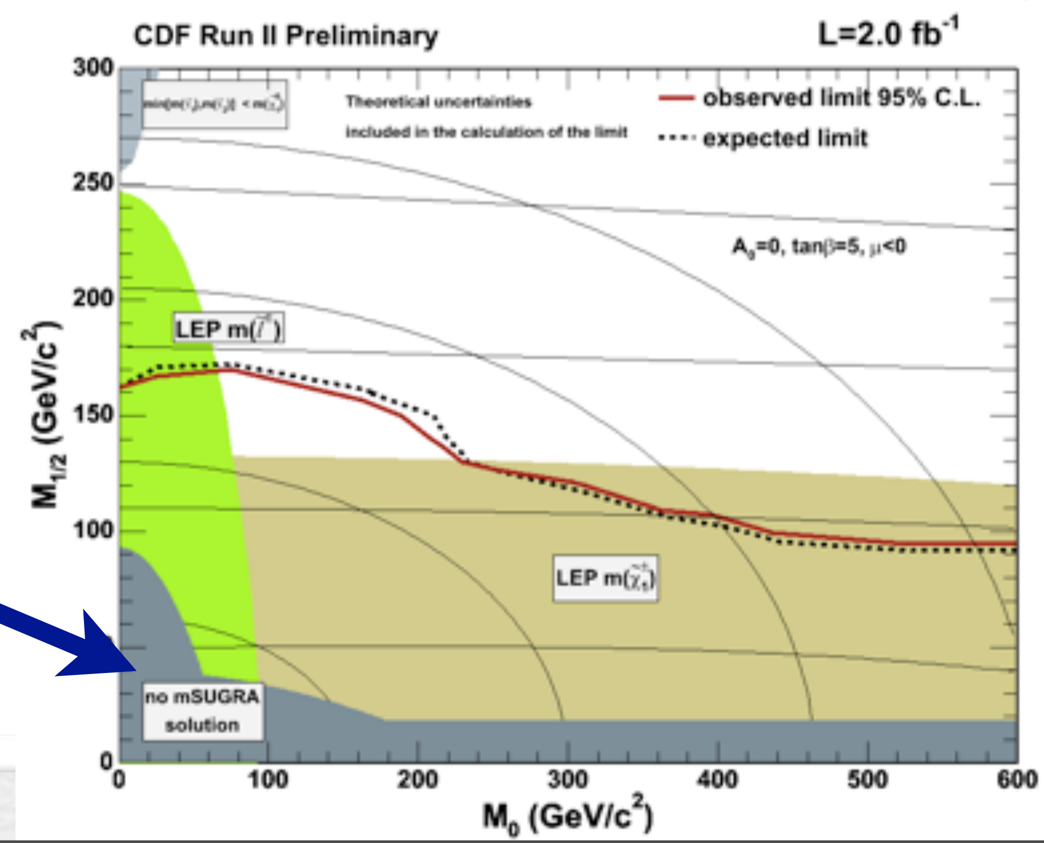


Model dependent searches

- Can directly use built-in and/or FeynRules generated models.
- Aim: Characterize excesses and/or set exclusion limits on parameter space of the model.
- Advantages:
  - ➡ Work in a fully fledged consisted model.
  - ➡ Models provide guidance for the interesting signals and / or benchmark points.
  - ➡ Allows to search for multiple signals predicted by one same model.
- But in some cases advantages can turn into disadvantages...

Model dependent searches

- Complicated models in general depend on too many free parameters:
  - ➡ Work with restricted models.
  - ➡ E.g.: MSSM : 124 free parameters.
    mSugra : 5 free parameters.
- Models may imply relations between masses and / or couplings
  - ➡ can lead to bias in the search and in the ranges of masses and couplings.



Model independent searches

- Some of these problems can be overcome by using simplified models.
- Example: Both ED and certain SUSY models predict color octet scalars.
  - ➡ can search for these new particles independently of the underlying model.
  - ➡ Simplified model:
    SM + color octect scalar + new couplings.
  - ➡ Parameters of the model:
    mass of the scalar + (cross section x branching ratio)

Model independent searches

- One way to tackle the problem is to use an OSET / Topology approach.
    - ➡ Use a parametrized / flat matrix element.
    - ➡ See talks by Arkani-Hamed and Torre.
- Alternatively, matrix element generators can also be used in this context, e.g., if spin information is required
    - ➡ Just add a few new particles and interactions to the SM.
    - ➡ Some tools, like MadGraph, have a dedicated framework that allows to do this very easily (USRMOD).

Model independent searches

- USRMOD approach in MadGraph
  - ➡ Add new particle

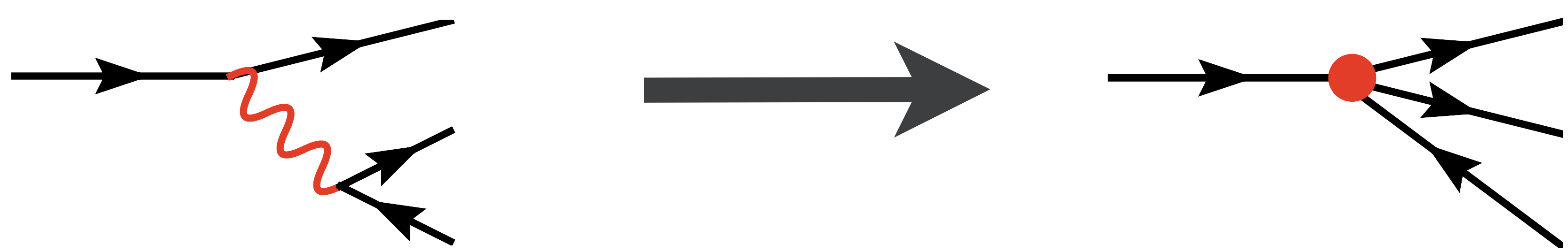
```
#MODEL EXTENSION
so      so      S    D    SMASS  SWIDTH   O   so   9000000
# END
```

  - ➡ Add new interaction

```
#  USRVertex
so  so   g    G    QCD
u   u    so   G    QCD
```

Effective theory approach

- New physics can leave traces in SM processes, even if we do not directly observe the new particles.
- Best known example : Fermi interaction



- Even though we do not observe the new particles directly, we could obtain interesting new signatures.
- Even more so, many models involving a new strong interaction are described at the weak scale by an effective theory involving higher dimensional operators.

Effective theory approach

- The simulation of higher dimensional operators was for a long time hampered by the fact that (most of) the ME generators did not support these types of vertices.

- The situation is about to change dramatically:
  - ➡ Herwig++, MadGraph 5 and Pythia 8 will receive full information on the vertices from FeynRules.
  - ➡ This will allow for the first time to simulate these kinds of interactions with these tools.

Summary

- The BSM hunter's toolbox starts to fill up!
- We slowly get to the point that we can easily generate matrix elements for all kinds of (Lagrangian-based) models.

Lagrangian → FeynRules / LanHep → ME generator → Events

- This chain can be used easily in different contexts
  - ➡ Top-down / model dependent
  - ➡ Bottom-up / model independent
  - ➡ Effective theories and higher dimensional operators.