BSM phenomenology with FeynRules

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+MC collaborators

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Outline

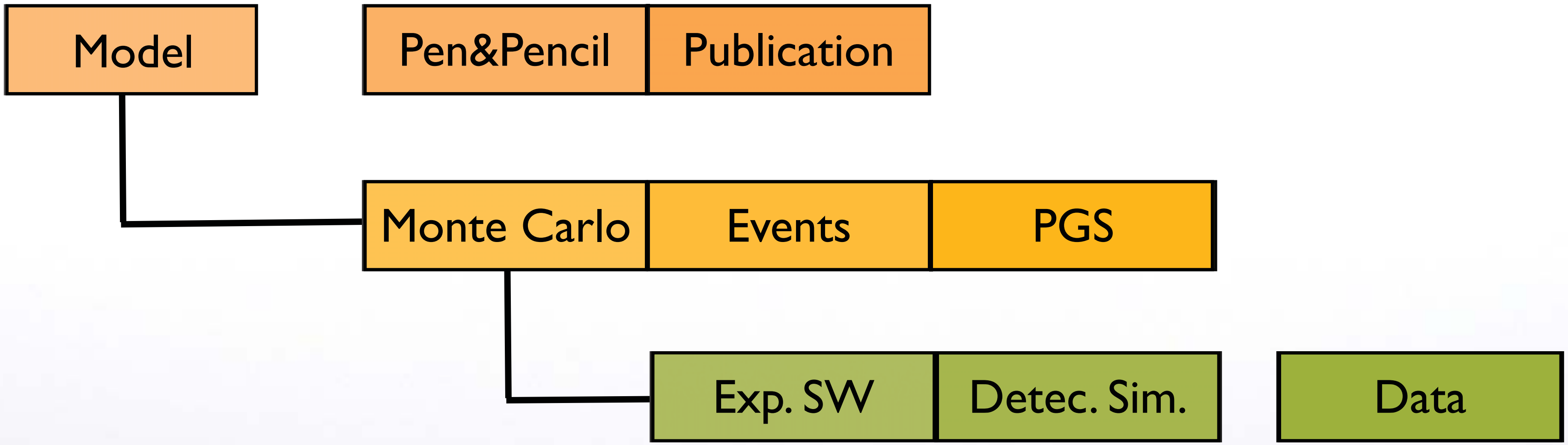
- A RoadMap to BSM @ the LHC
- FeynRules
- A simple example

A Roadmap for BSM @ the LHC

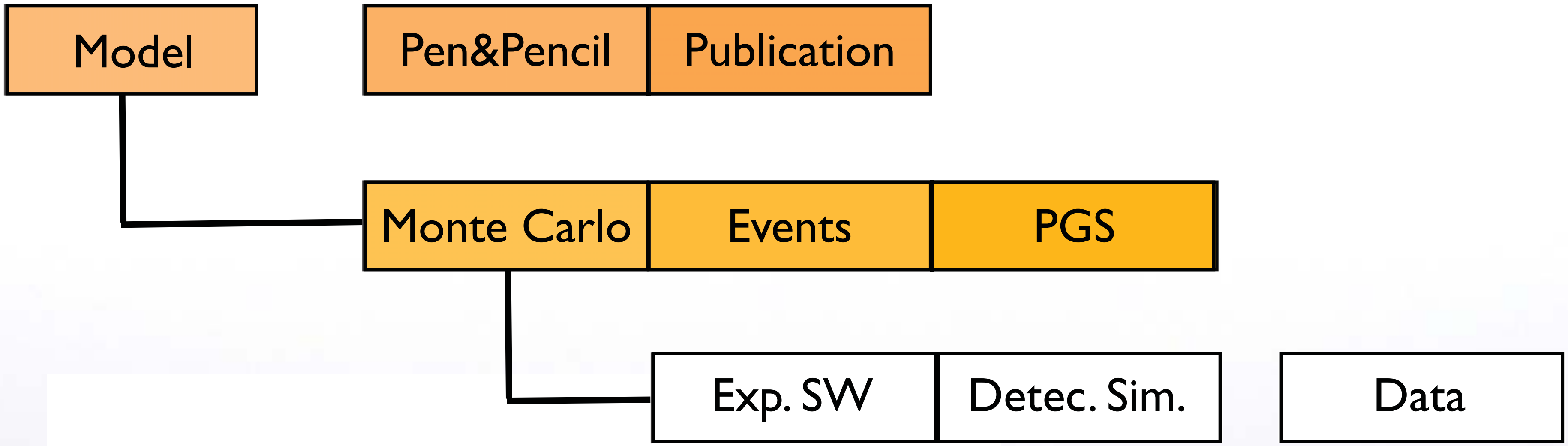
Model	Pen&Paper	Publication		„Pure Th.”
	Monte Carlo	Events	PGS	„Prof. Pheno.”
„Exp. vs. Data”	Exp. SW	Detec. Sim.	Data	

How do we get from one end to the other?

Solution 1: Write your own MC!

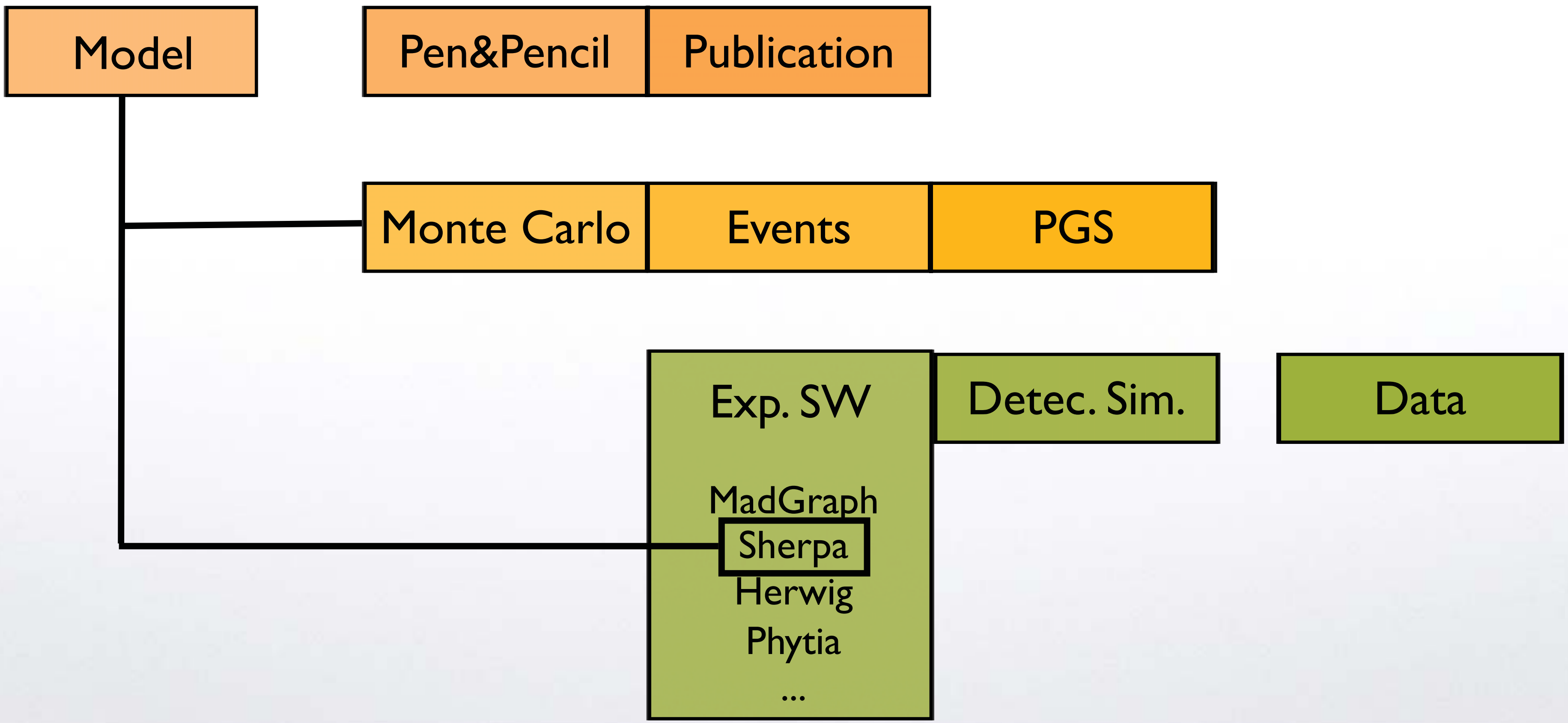


Solution 1: Write your own MC!

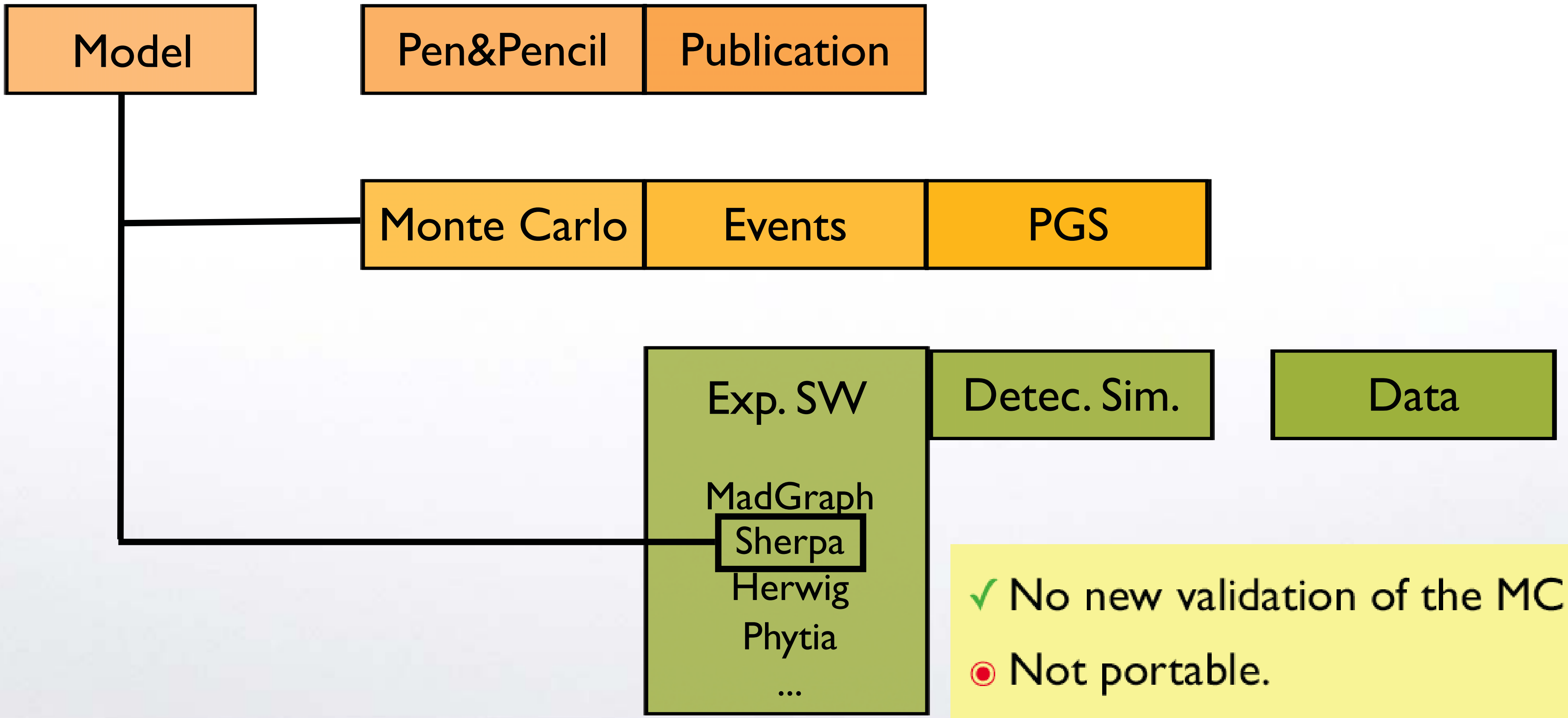


- ✓ Full control over the implementation (conventions, etc.)
- ◉ Not portable.
- ◉ Each new MC must be validated to be used inside the experimental framework.

Solution II: Use an already existing MC

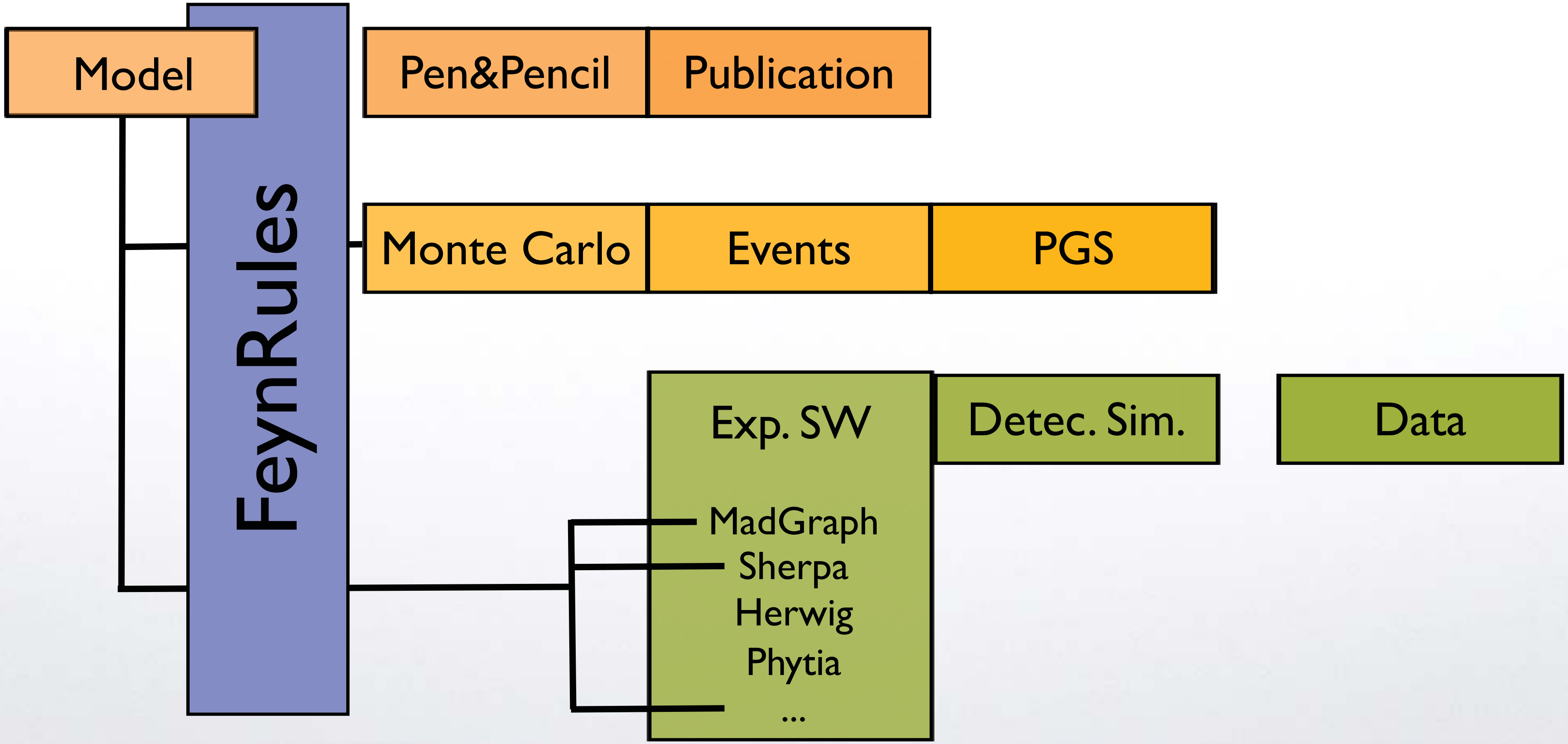


Solution II: Use an already existing MC

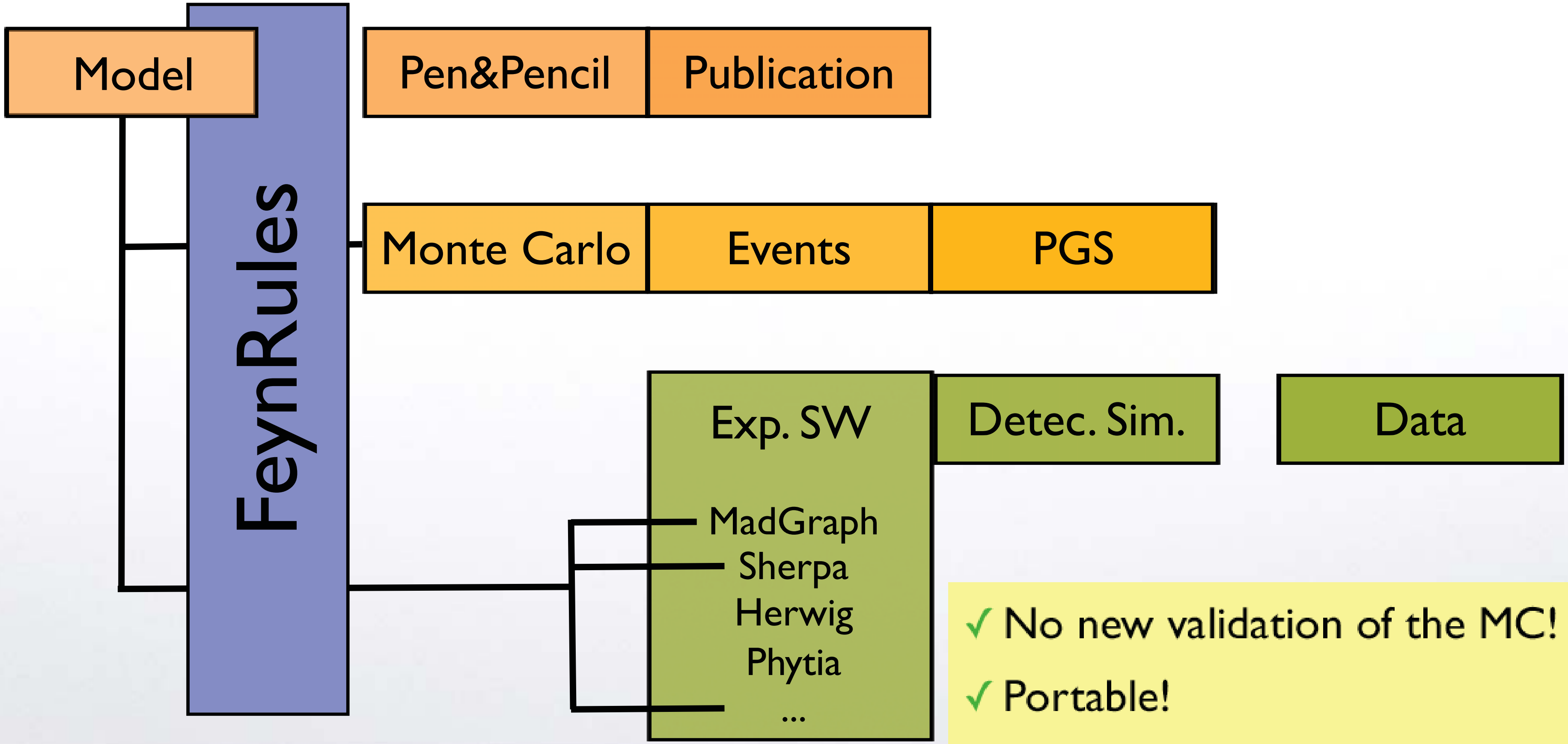


- ✓ No new validation of the MC!
- Not portable.
- Conventions and programming language imposed by the MC.

Solution III: Use FeynRules

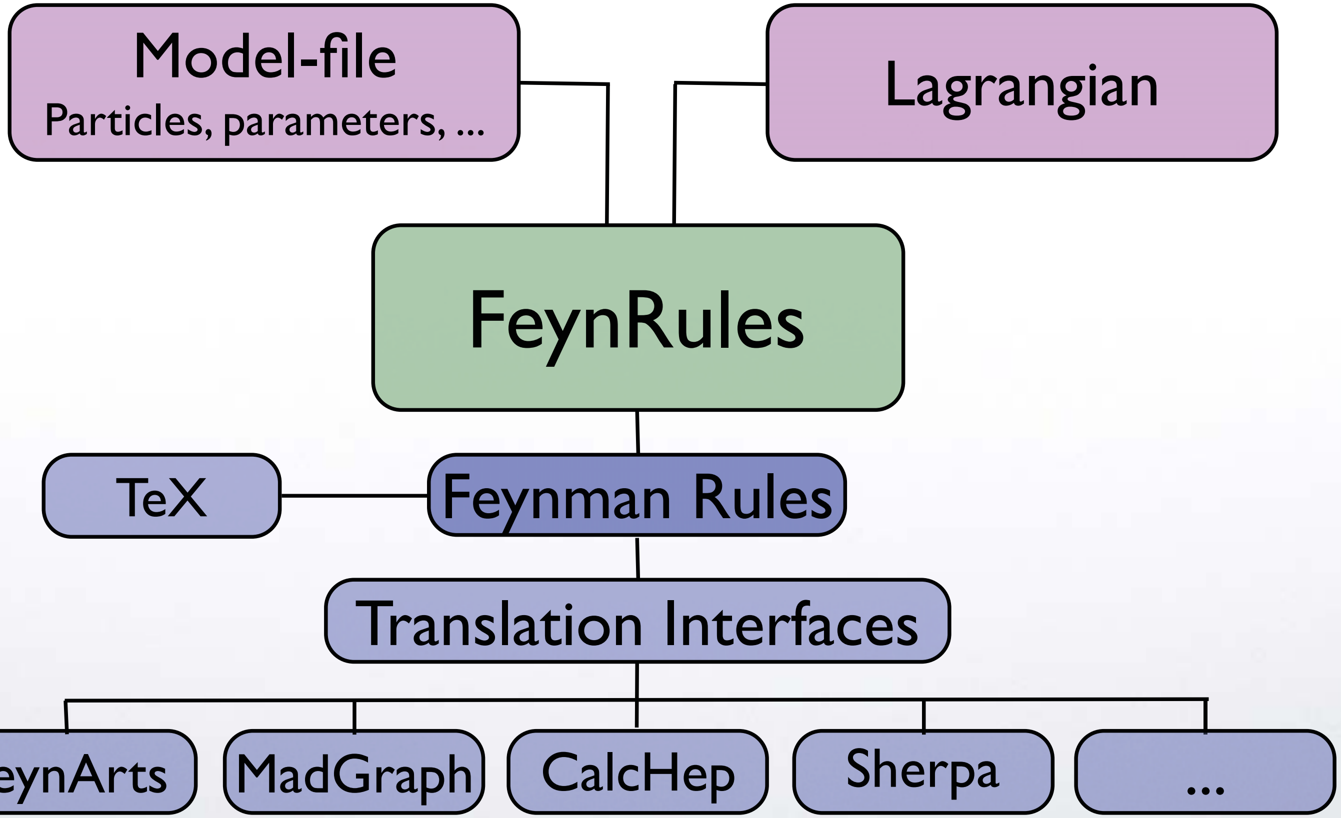


Solution III: Use FeynRules



- ✓ No new validation of the MC!
- ✓ Portable!
- ✓ Lagrangian directly entered into Mathematica!

FeynRules



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

A simple example

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_X$$

$$\mathcal{L}_X = \frac{1}{2}\partial_\mu X \partial^\mu X + \frac{1}{2} m_X^2 X^2 + \lambda_X X^2 \Phi^\dagger \Phi$$

- Two step implementation:
  - Step I: Define your new particles and parameters.
  - Step II: Write your lagrangian.

A simple example

- Step 1: Define your particles and parameters:

```
lX == {
      Value -> 0.5,
      InteractionOrder -> {QED, 2}}

S[4] == {
      ClassName -> X,
      SelfConjugate -> True,
      Mass -> {MX, 40},
      Width -> {WX, 0}}
```

$$\mathcal{L}_X = \frac{1}{2}\partial_\mu X \partial^\mu X + \frac{1}{2} m_X^2 X^2 + \lambda_X X^2 \Phi^\dagger \Phi$$

A simple example

- Step II: Write your Lagrangian:

```
LX = 1/2 del[X, mu] del[X, mu]
  + 1/2 MX^2 X^2
  + lX X^2 HC[Phi].Phi;
```

$$\mathcal{L}_X = \frac{1}{2}\partial_\mu X \partial^\mu X$$

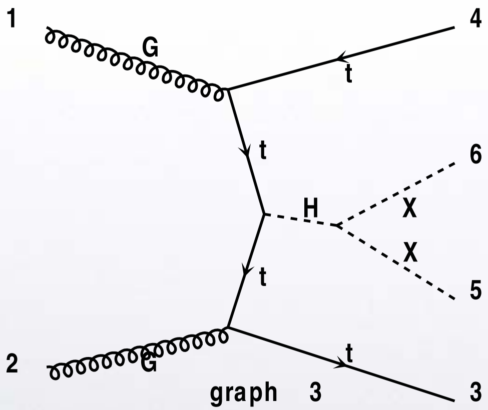
$$+\frac{1}{2}m_X^2 X^2$$

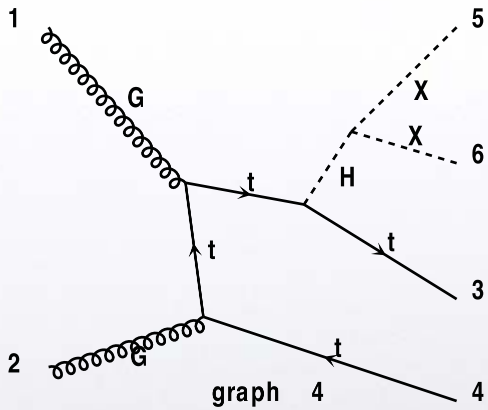
$$+\lambda_X X^2 \Phi^\dagger \Phi$$

A simple example

- Step III: Do Phenomenology!

```
WriteMGOutput[LSM, LX]
```





Validation

- SM (N.D. Christensen, CD)
  - ✓ FeynArts
  - ✓ CalcHep/CompHep (31 2-to-2 processes)
  - ✓ MadGraph/MadEvent (31 2-to-2 processes)

Process	CalcHEP Stock	CalcHEP Feynman	CalcHEP Unitary	CompHEP Feynman	MadGraph Stock	MadGraph
gg->gg	116 490.	116 490.	116 490.	116 490.	116 520.	116 460.
$u\bar{u}$->gg	199.95	199.95	199.95	199.94	200.24	200.07
$t\bar{t}$->gg	64.595	64.595	64.595	64.592	64.619	64.577
$e^+e^-\to\mu^+\mu^-$	0.37195	0.37195	0.37195	0.37194	0.372	0.37142
$e^+e^-\to e^+e^-$	734.15	734.15	734.15	734.16	733.65	735.09
$e^+e^-\to\nu_e\bar{\nu}_e$	49.145	49.145	49.145	49.145	49.135	49.086
$t\bar{t}$->$u\bar{u}$	16.018	16.018	16.018	16.018	16.002	16.016
$u\bar{u}$->$s\bar{s}$	9.6103	9.6102	9.6103	9.6097	9.6257	9.6205
$u\bar{d}$->$c\bar{s}$	0.23864	0.23864	0.23864	0.23864	0.23867	0.23859
$u\bar{s}$->$c\bar{d}$	0.018947	0.018947	0.018947	0.018947	0.018954	0.018916
$t\bar{t}$->W^+W^-	17.265	17.265	17.265	17.265	17.256	17.272
$t\bar{t}$->ZZ	1.2686	1.2686	1.2686	1.2686	1.2679	1.2705

Validation

- 3-Site Model (N.D. Christensen)
  - ✓ CalcHep/CompHep (205 2-to-2 processes)
  - ✓ MadGraph/MadEvent (on-going)

$W^+W^-{}' \to \gamma\gamma$	2.4585×10^{-34}	–	7.7583×10^{-32}	–
$W^+{}'W^-{}' \to \gamma\gamma$	0.72004	–	0.72051	–
$W^+W^- \to \gamma Z$	165.11	–	165.21	–
$W^+W^- \to \gamma Z'$	6.4746	–	6.4788	–
$W^+W^-{}' \to \gamma Z$	7.7444	–	7.7495	–
$W^+W^-{}' \to \gamma Z'$	38.348	–	38.373	–
$W^+{}'W^-{}' \to \gamma Z$	0.82867	–	0.82921	–
$W^+{}'W^-{}' \to \gamma Z'$	54.991	–	55.027	–
$W^+W^- \to ZZ$	367.67	–	367.91	–
$W^+W^- \to ZZ'$	27.18	–	27.197	–
$W^+W^-{}' \to ZZ$	18.94	–	18.952	–
$W^+W^- \to Z'Z'$	13.334	–	13.343	–
$W^+W^-{}' \to ZZ'$	729.11	–	729.59	–
$W^+{}'W^-{}' \to ZZ$	30.952	–	30.972	–
$W^+{}'W^-{}' \to ZZ'$	29.914	–	29.934	–

Validation

- Generic MSSM (105 free parameters, B. Fuks)
  - ✓ FeynArts
  - ✓ MadGraph/MadEvent (320 1-to-2 processes
    456 2-to-2 processes)

d,d~>sd4,sd4~	5.7209×10^{-1}	5.7239×10^{-1}	OK: 0.0524118%
d,d~>sd6,sd6~	1.112×10^{-1}	1.1102×10^{-1}	OK: 0.162133%
d,d~>sd3,sd3~	1.1535×10^{-1}	1.1534×10^{-1}	OK: 0.00867002%
d,d~>sd1,sd1~	1.2567×10^{-1}	1.2567×10^{-1}	OK: 0.%
d,d~>sd2,sd2~	1.1572×10^{-1}	1.157×10^{-1}	OK: 0.0172861%
d,d~>sd1,sd2~	2.8765×10^{-4}	2.8788×10^{-4}	OK: 0.0798944%
d,d~>n1,n1	8.7534×10^{-5}	8.7552×10^{-5}	OK: 0.0205592%
d,d~>n1,n2	3.5249×10^{-4}	3.5292×10^{-4}	OK: 0.121841%
d,d~>n1,n3	1.6881×10^{-4}	1.6929×10^{-4}	OK: 0.283537%
d,d~>n1,n4	1.3771×10^{-4}	1.3788×10^{-4}	OK: 0.123296%

Conclusion

- FeynRules is a new Mathematica package which derives Feynman rules from a Lagrangian.
- The package contains a set of translation interfaces allowing an automatic implementation of BSM models into various Feynman diagram generators:
  - CalcHep/CompHep
  - FeynArts/FormCalc
  - MadGraph/MadEvent
  - Sherpa
  - ...
- The package can be downloaded from:

  http://feynrules.phys.ucl.ac.be

Validation

- More models are being implemented and validated!
  - Non linear sigma model (C. Degrande)
  - Large extra dimensions (CD)
  - Minimal UED (P. Aquino & T. Figy)
  - Little Higgs model with T-parity (T. Figy)
  - Quantum gravity (C. Reuschle)