

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



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Exp. SW

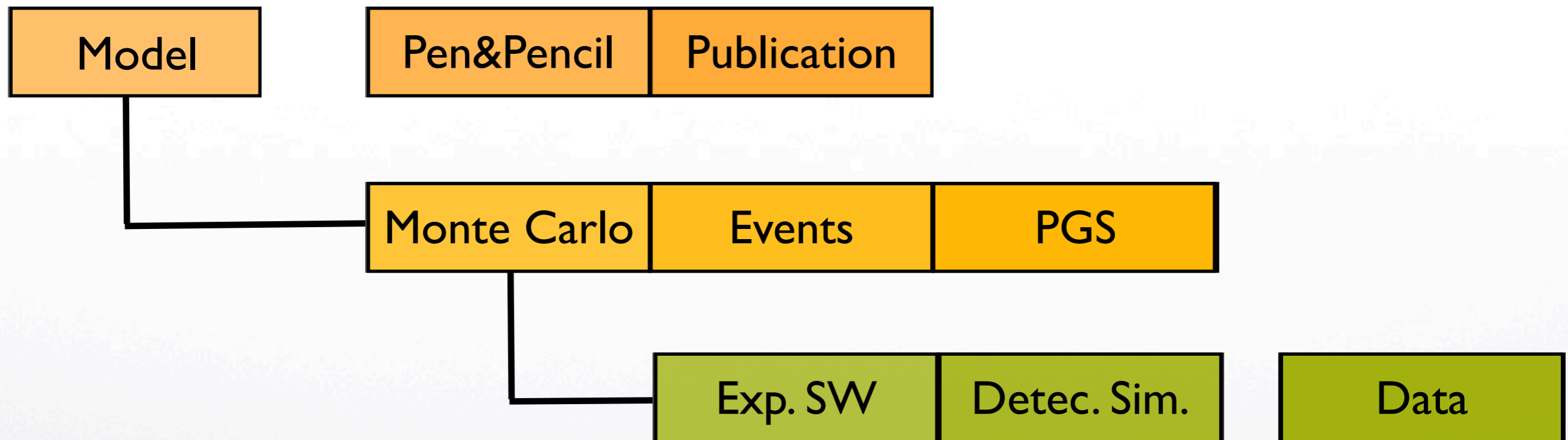
Detec. Sim.

Data

How do we get from one end to the other?

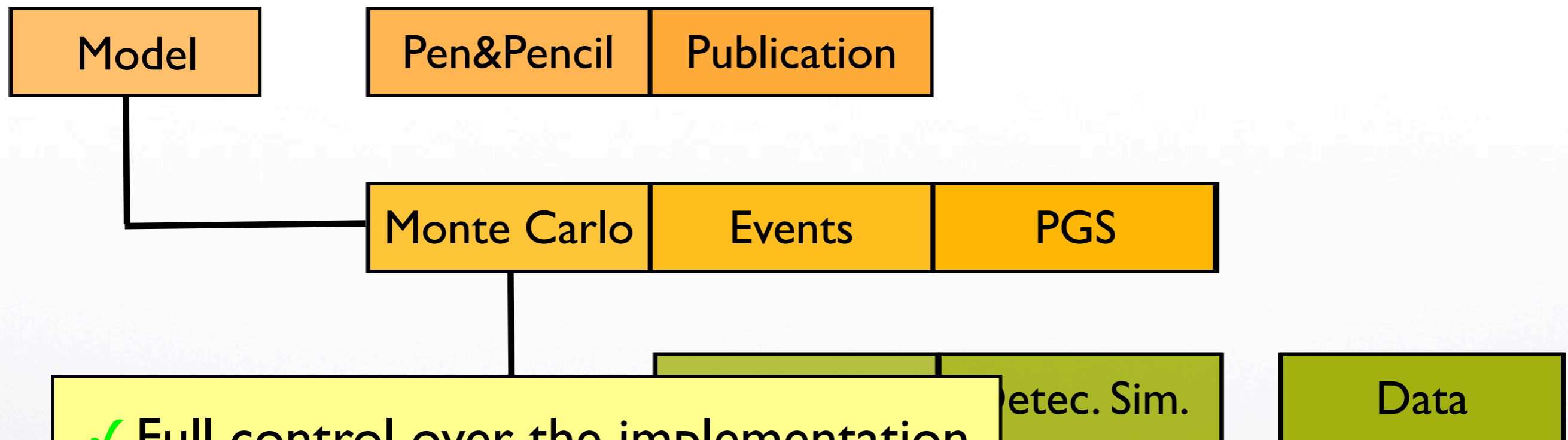


Solution I: Write your own MC!





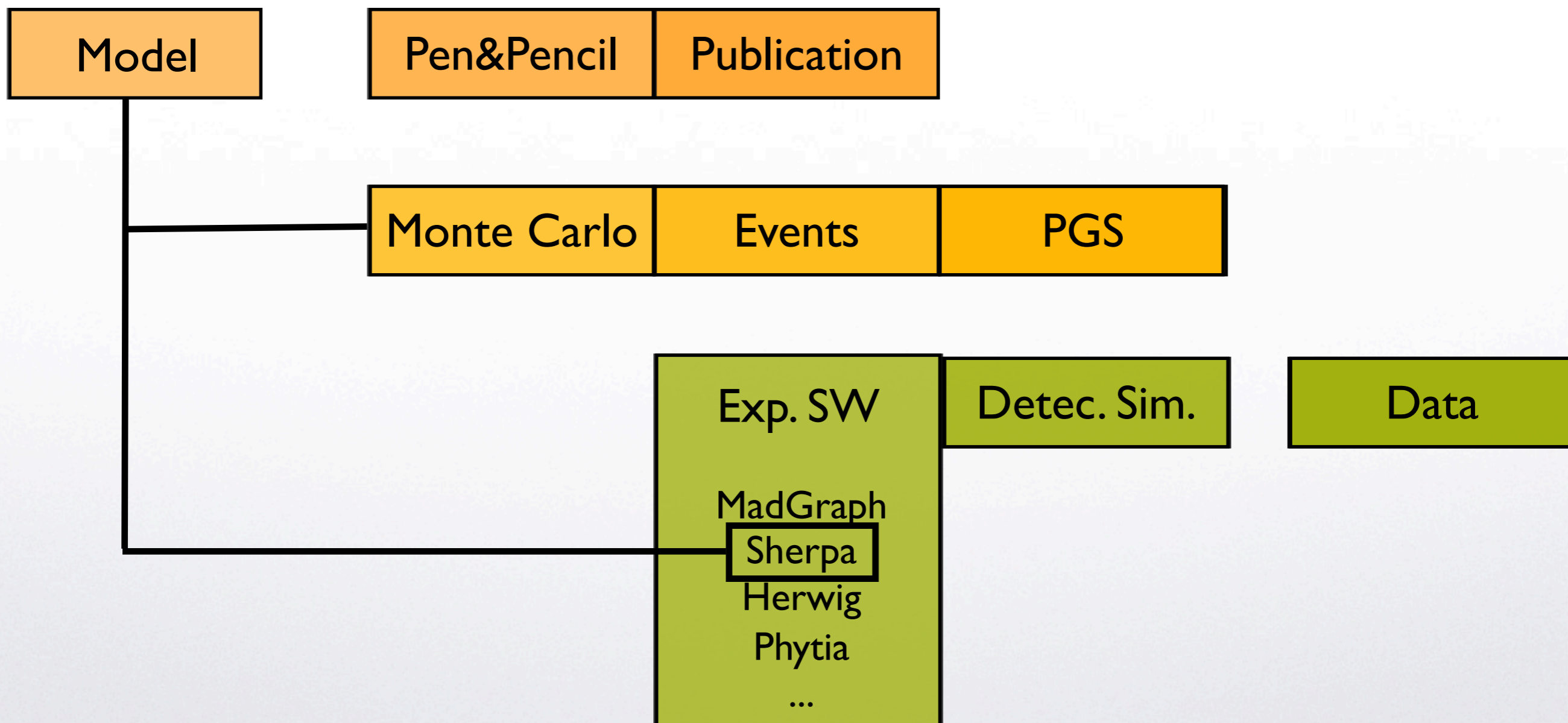
Solution 1: Write your own MC!



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

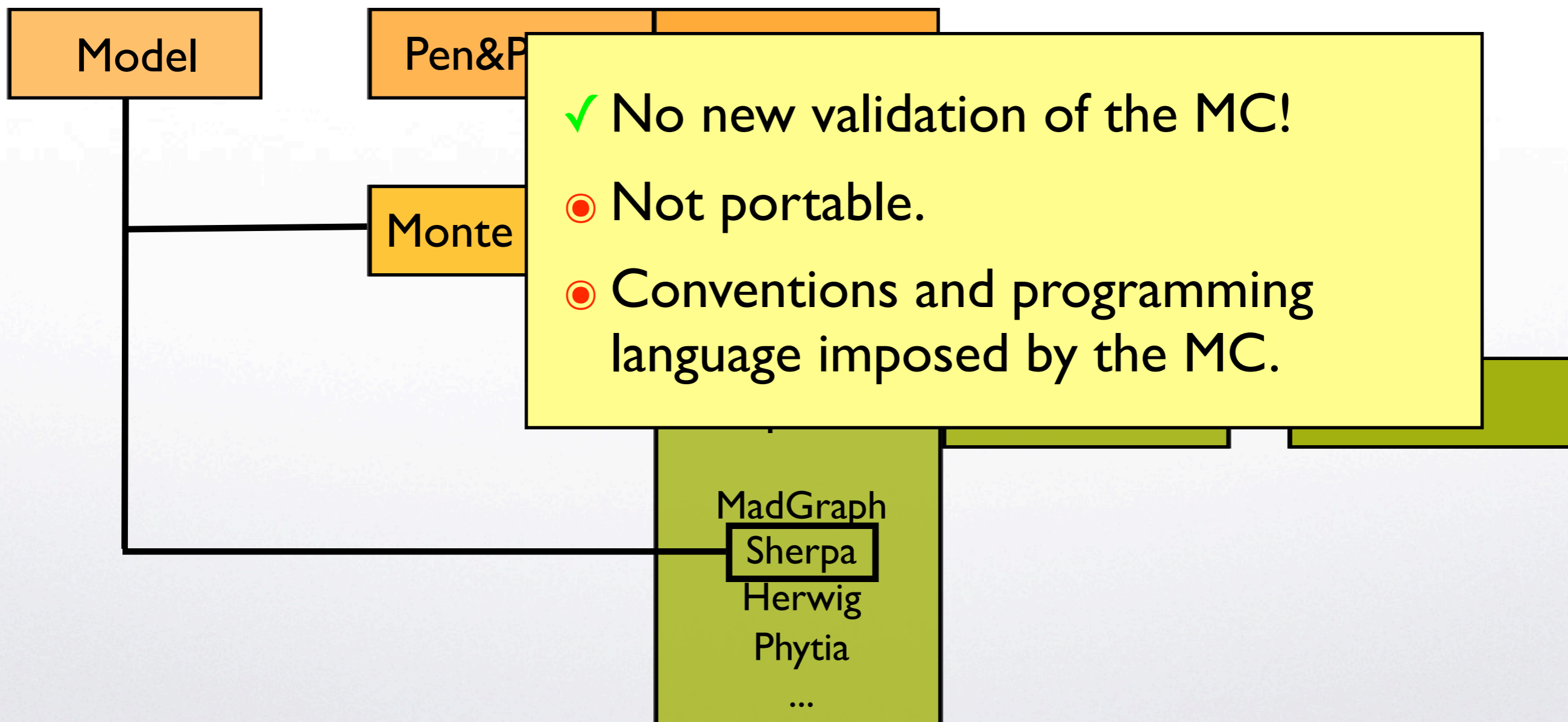


Solution II: Use an already existing MC



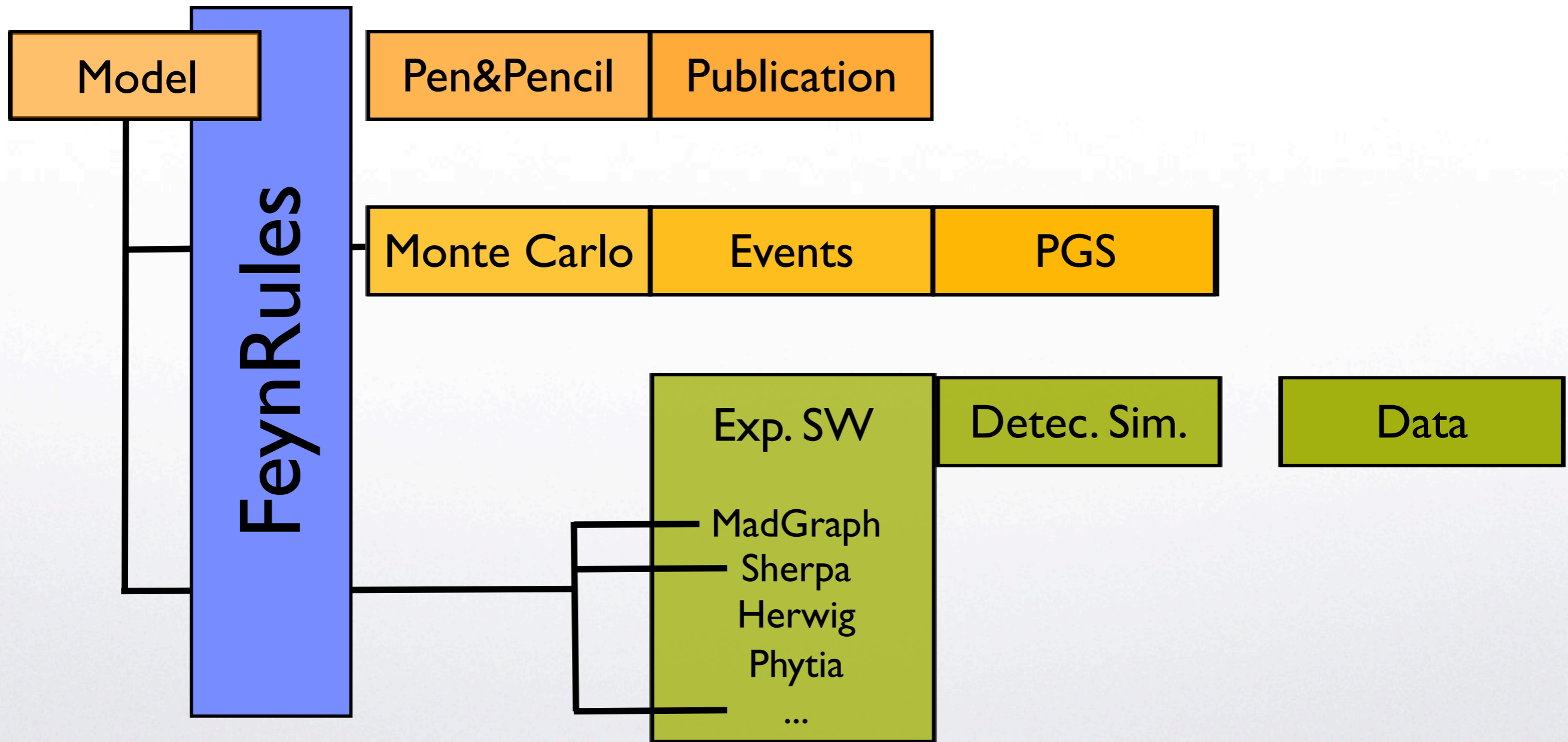


Solution II: Use an already existing MC



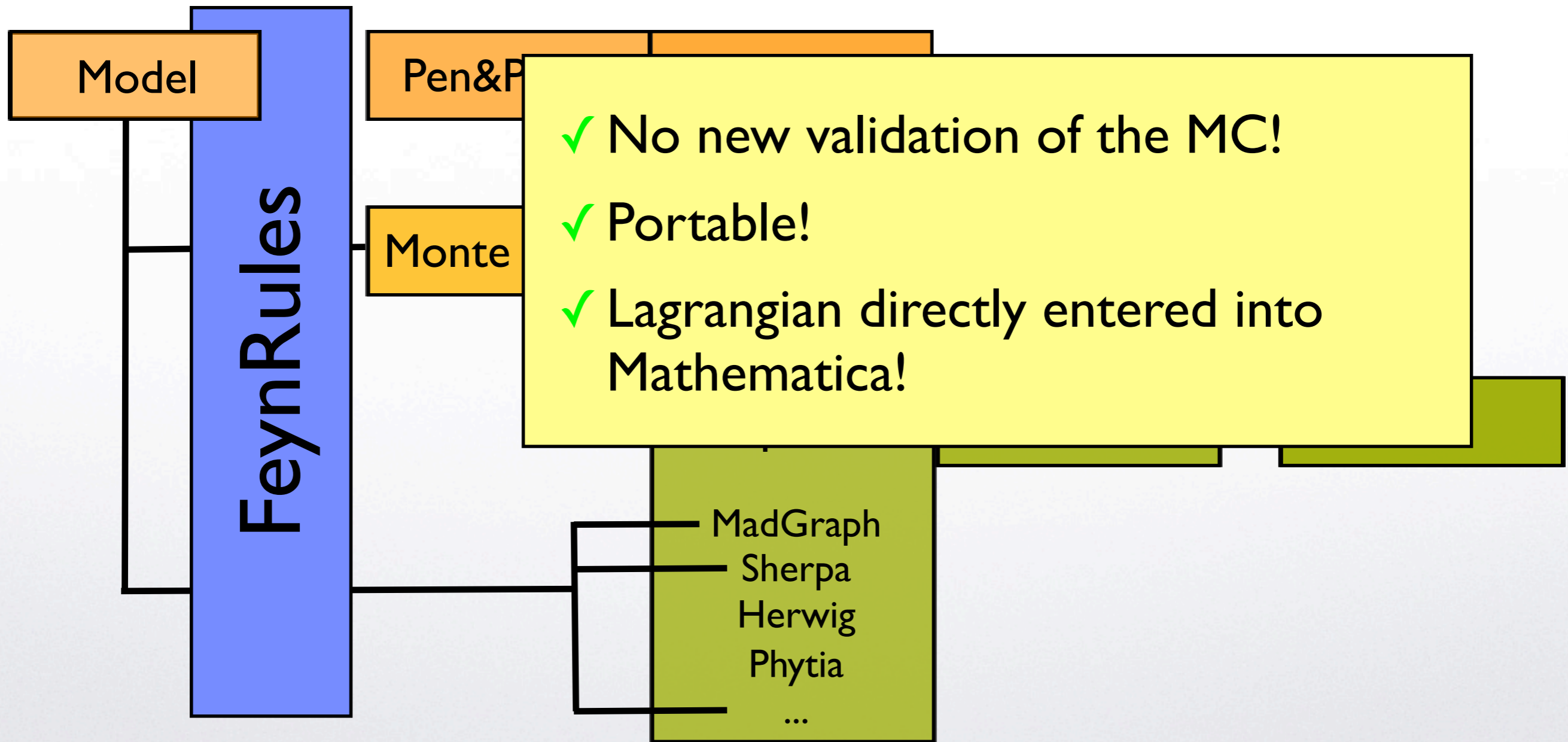


Solution III: Use FeynRules



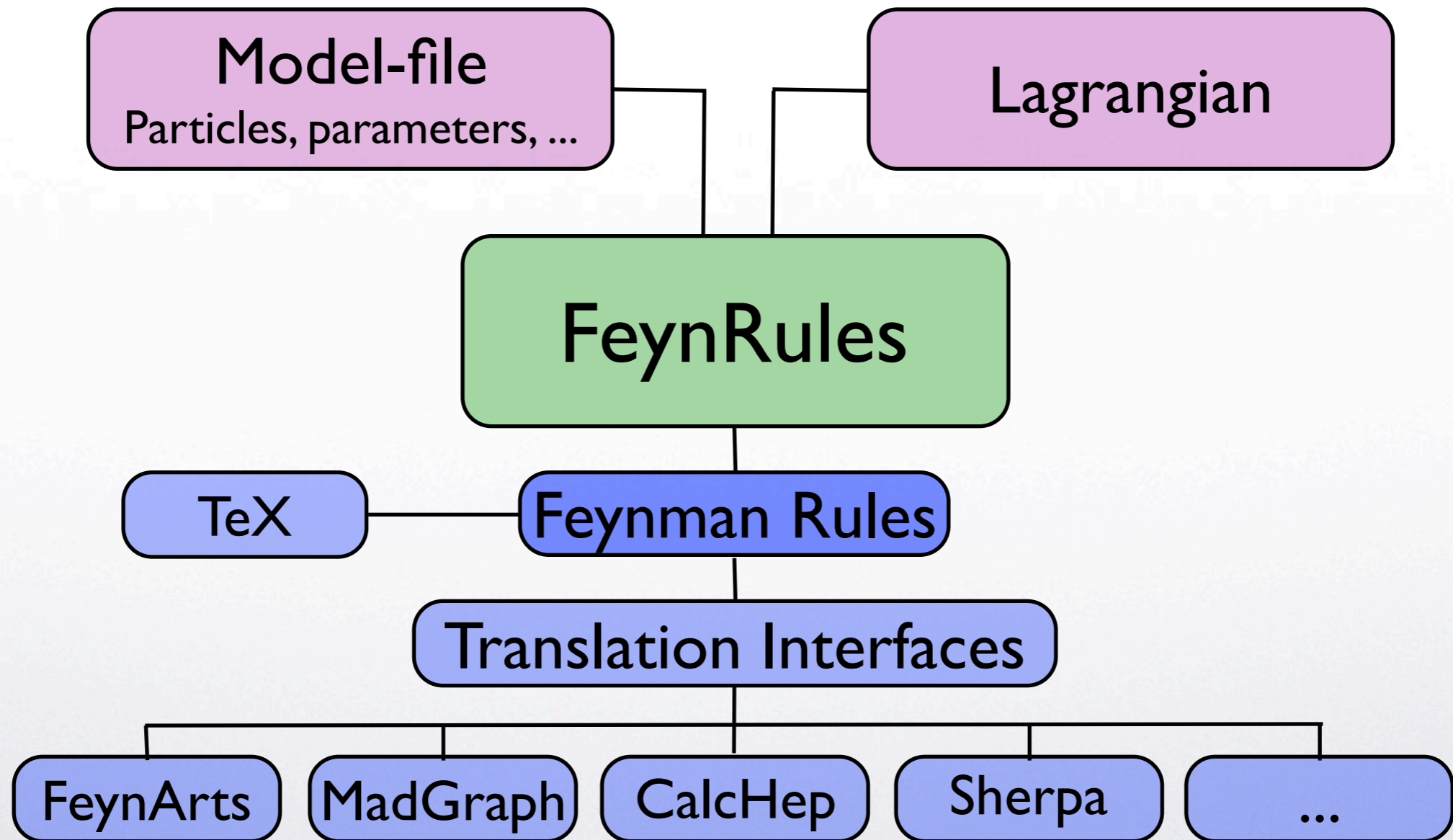


Solution III: Use FeynRules





FeynRules





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 I: Define your particles and parameters:

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

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

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



A simple example

- Step II: Write your Lagrangian:

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

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

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

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

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

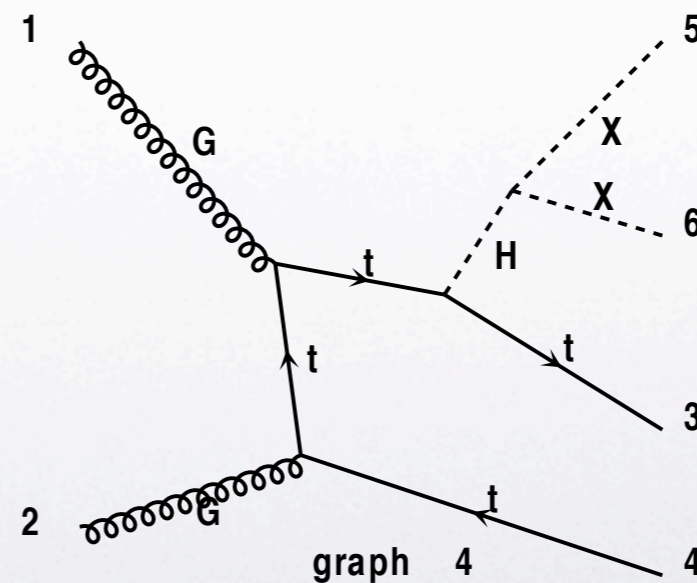
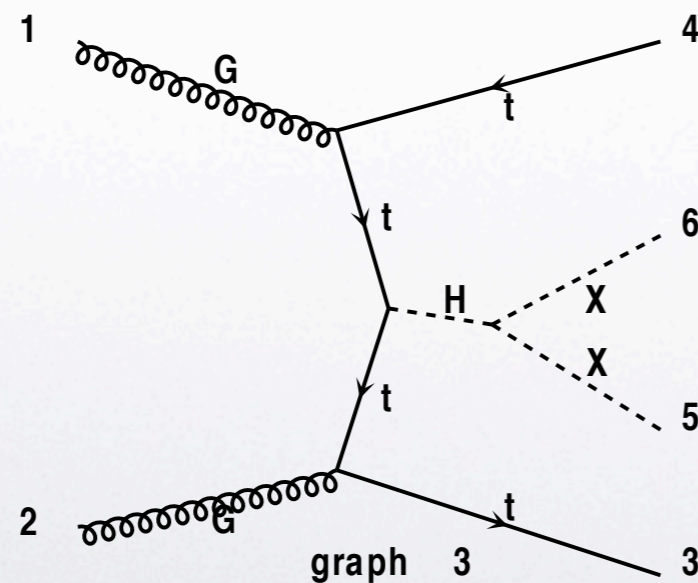
$$+ \lambda_X X^2 \Phi^\dagger \Phi$$



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)

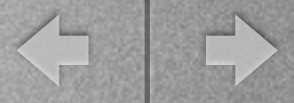
Process	CalcHEP Stock	CalcHEP Feynman	CalcHEP Unitary	CompHEP Feynman	MadGraph Stock	MadGraph
gg->gg	116 490.	116 490.	116 490.	116 490.	116 520.	116 460.
uū->gg	199.95	199.95	199.95	199.94	200.24	200.07
t \bar{t} ->gg	64.595	64.595	64.595	64.592	64.619	64.577
e ⁺ e ⁻ ->μ ⁺ μ ⁻	0.37195	0.37195	0.37195	0.37194	0.372	0.37142
e ⁺ e ⁻ ->e ⁺ e ⁻	734.15	734.15	734.15	734.16	733.65	735.09
e ⁺ e ⁻ ->ν _e $\bar{\nu}$ _e	49.145	49.145	49.145	49.145	49.135	49.086
t \bar{t} ->uū	16.018	16.018	16.018	16.018	16.002	16.016
uū->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)

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

$d, d \rightarrow sd4, sd4$	5.7209×10^{-1}	5.7239×10^{-1}	OK: 0.0524118%
$d, d \rightarrow sd6, sd6$	1.112×10^{-1}	1.1102×10^{-1}	OK: 0.162133%
$d, d \rightarrow sd3, sd3$	1.1535×10^{-1}	1.1534×10^{-1}	OK: 0.00867002%
$d, d \rightarrow sd1, sd1$	1.2567×10^{-1}	1.2567×10^{-1}	OK: 0.0%
$d, d \rightarrow sd2, sd2$	1.1572×10^{-1}	1.157×10^{-1}	OK: 0.0172861%
$d, d \rightarrow sd1, sd2$	2.8765×10^{-4}	2.8788×10^{-4}	OK: 0.0798944%
$d, d \rightarrow n1, n1$	8.7534×10^{-5}	8.7552×10^{-5}	OK: 0.0205592%
$d, d \rightarrow n1, n2$	3.5249×10^{-4}	3.5292×10^{-4}	OK: 0.121841%
$d, d \rightarrow n1, n3$	1.6881×10^{-4}	1.6929×10^{-4}	OK: 0.283537%
$d, d \rightarrow n1, n4$	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) 