GRAHAM CHAPMAN JOHN CLEESE TERRY GILLIAM
ERIC IDLE TERRY JONES MICHAEL PALIN
MONTY PYTHON'S
AND NOW FOR SOMETHING COMPLETELY DIFFERENT
THE BEST OF MONTY PYTHON'S FLYING CIRCUS


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ERIC IDLE TERRY JONES MICHAEL PALIN
PYTHON'S
AND NOW FOR SOMETHING
FORTRAN's
DIFFERENT
THE BEST OF PYTHON'S FLYING CIRCUS
C's & C++'s

# Intro to automated HEP calculations

Martin White, Csaba Balázs

# outline

- the physics of the toy model example
- FeynRules (time/interest allowing)
- Madgraph: matrix element calculation
  event generation at parton level
- PYTHIA: parton shower and hadronization
  event generation at hadron level
- what goes on inside a Monte Carlo
- Delphes
- ROOT

# from model to plots

(over)simplified view

Lagrangian

…

lot of coding

happens

…

event distributions

# from model to plots

(over)simplified view

Lagrangian

Feynman rules

partonic events

hadronic events

detector events

event distributions

# from model to plots

## (over)simplified view

Lagrangian

← FeynRules

Feynman rules

← MadGraph

partonic events

← PYTHIA

hadronic events

← Delphes

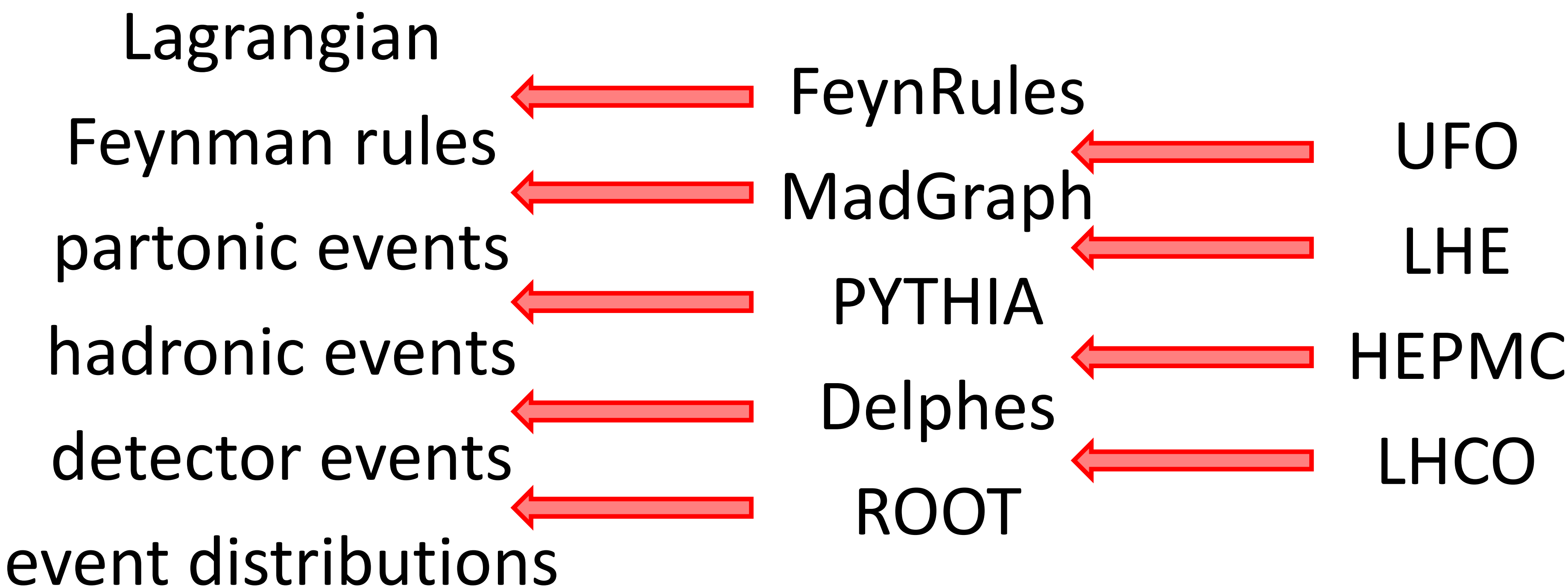
detector events

← ROOT

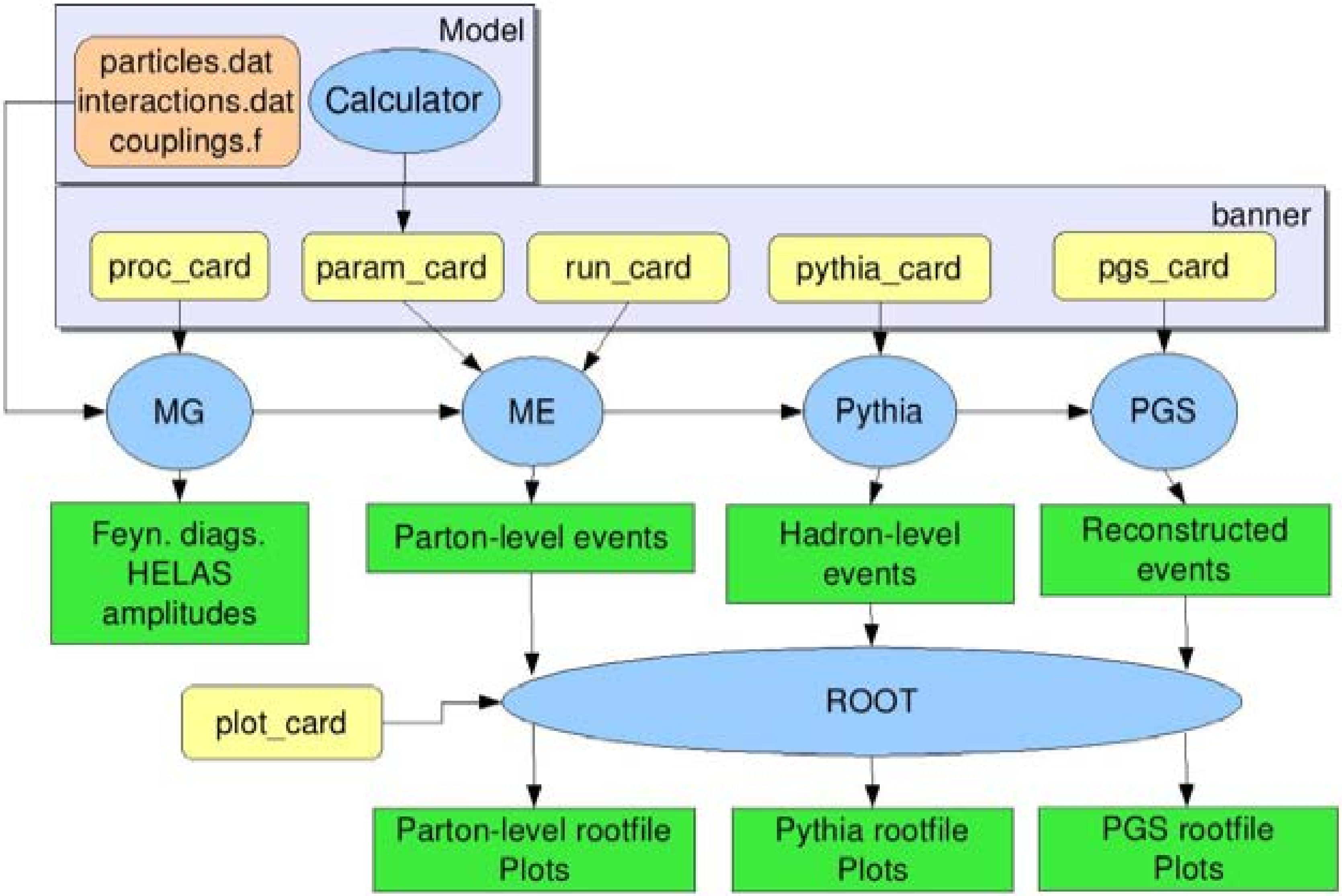
event distributions

# from model to plots

## (over)simplified view



# from model to plots
## simplified view



“And then there's this column called `six'...

I have no idea what that is.”

Maxim Perelstein

# model

## field content

$\phi_1$ $\phi_2$ $\Phi_1$ $\Phi_2$ U E

`phi1 phi2 PH1 PH2 U E.`

- $\phi_1$, $\phi_2$ interaction eigenstates
- $\Phi_1$, $\Phi_2$, U, E mass eigenstates

$$\begin{pmatrix}\phi_1\\ \phi_2\end{pmatrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix}\begin{pmatrix}\Phi_1\\ \Phi_2\end{pmatrix}$$

# model

## FeynRules input

model file: `Cairns.fr`

contains:

- field definitions
- Lagrangian
- parameter specifications

FeynRules source: http://feynrules.irmp.ucl.ac.be/downloads/feynrules-current.tar.gz

installation: http://feynrules.irmp.ucl.ac.be/attachment/wiki/WikiStart/Installation_FR.pdf

# model

## field definitions

```
M$ClassesDescription = {
     S[10] == {
     ClassName -> phi1,
     SelfConjugate -> True,
     Indices -> {},
     Unphysical -> True,
     Definitions-> {phi1 -> Cos[th] PH1 -
                    Sin[th] PH2}
     },
     ...
}
```

# model

## field definitions

```
M$ClassesDescription = {
     ...
     F[10] == {
     ClassName -> U,
     SelfConjugate -> False,
     Indices -> {Index[Colour]},
     QuantumNumbers -> {Y -> 2/3, Q -> 2/3},
     Mass -> {mU, 500},
     Width -> {Wuv,1}
     },
}
```

# model

## scalar sector

$$L_S = L_{S\,kinetic} + L_{S\,mass}$$

$$L_{S\,kinetic} = \frac{1}{2}\partial_\mu \phi_1 \partial^\mu \phi_1 + \frac{1}{2}\partial_\mu \phi_2 \partial^\mu \phi_2$$

$$L_{S\,mass} = -\frac{1}{2}\, m_1^2 \phi_1^2 - \frac{1}{2}\, m_2^2 \phi_2^2 - m_{12}^2 \phi_1 \phi_2$$

# model

## scalar sector

$$L_S = L_{S\,kinetic} + L_{S\,mass}$$

```
LS = LkS + LmS
```

$$L_{S\,kinetic} = \frac{1}{2}\partial_\mu \phi_1 \partial^\mu \phi_1 + \frac{1}{2}\partial_\mu \phi_2 \partial^\mu \phi_2$$

```
LkS = 1/2 del[phi1,mu] del[phi1,mu] + …
```

$$L_{S\,mass} = -\frac{1}{2}\, m_1^2 \phi_1^2 - \frac{1}{2}\, m_2^2 \phi_2^2 - m_{12}^2 \phi_1 \phi_2$$

```
LmS = - 1/2 m1^2 phi1^2 … - m12^2 phi1 phi2
```

# model

## fermion sector

$$L_F = L_{F\ kinetic} + L_{F\ mass}$$

$$L_{F\ kinetic} = i\bar{U}\gamma_\mu\partial^\mu U + i\bar{E}\gamma_\mu\partial^\mu E$$

$$L_{F\ mass} = -m_U\bar{U}U - m_E\bar{E}E$$

# model

## fermion sector

$$L_F = L_{F\,kinetic} + L_{F\,mass}$$

```
LF = LkF + LmF
```

$$L_{F\,kinetic} = i\bar{U}\gamma_\mu\partial^\mu U + i\bar{E}\gamma_\mu\partial^\mu E$$

```
LkF = I Ubar.Ga[mu].DC[U,mu] + …
```

$$L_{F\,mass} = -m_U\bar{U}U - m_E\bar{E}E$$

```
LmF = -mU Ubar.U + …
```

# model

## interactions

$$L_Y = \lambda_1 \phi_1 \bar{U} P_R u + \lambda_2 \phi_2 \bar{U} P_R u + \lambda'_1 \phi_1 \bar{E} P_R e + \lambda'_2 \phi_2 \bar{E} P_R e$$

$$L = L_S + L_F + L_Y$$

more details:

http://feynrules.irmp.ucl.ac.be/attachment/wiki/WikiStart/Tutorial_FR.pdf

# model

## interactions

$$L_Y =$$
$$\lambda_1 \phi_1 \bar{U} P_R u + \lambda_2 \phi_2 \bar{U} P_R u + \lambda_1' \phi_1 \bar{E} P_R e + \lambda_2' \phi_2 \bar{E} P_R e$$

```
LY = lam1 phi1 Ubar.ProjP.U + …
```

$$L = L_S + L_F + L_Y$$

```
L = LS + LF + LY
```

## more details:

http://feynrules.irmp.ucl.ac.be/attachment/wiki/WikiStart/Tutorial_FR.pdf

# … what goes on inside a Monte Carlo generator

# … what goes on inside a Monte Carlo generator

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10480 | 15011 | 01536 | 02011 | 81647 | 91646 | 69179 | 14194 | 62590 |
| 22368 | 46573 | 25595 | 85393 | 30995 | 89198 | 27982 | 53402 | 93965 |
| 24130 | 48360 | 22527 | 97265 | 76393 | 64809 | 15179 | 24830 | 49340 |
| 42167 | 93093 | 06243 | 61680 | 07856 | 16376 | 39440 | 53537 | 71341 |
| 37570 | 39975 | 81837 | 16656 | 06121 | 91782 | 60468 | 81305 | 49684 |
| 77921 | 06907 | 11008 | 42751 | 27756 | 53498 | 18602 | 70659 | 90655 |
| 99562 | 72905 | 56420 | 69994 | 98872 | 31016 | 71194 | 18738 | 44013 |
| 96301 | 91977 | 05463 | 07972 | 18876 | 20922 | 94595 | 56869 | 69014 |
| 89579 | 14342 | 63661 | 10281 | 17453 | 18103 | 57740 | 84378 | 25331 |
| 85475 | 36857 | 53342 | 53988 | 53060 | 59533 | 38867 | 62300 | 08158 |
| 28918 | 69578 | 88231 | 33276 | 70997 | 79936 | 56865 | 05859 | 90106 |
| 63553 | 40961 | 48235 | 03427 | 49626 | 69445 | 18663 | 72695 | 52180 |
| 09429 | 93969 | 52636 | 92737 | 88974 | 33488 | 36320 | 17617 | 30015 |
| 10365 | 61129 | 87529 | 85689 | 48237 | 52267 | 67689 | 93394 | 01511 |
| 07119 | 97336 | 71048 | 08178 | 77233 | 13916 | 47564 | 81056 | 97735 |
| 51085 | 12765 | 51821 | 51259 | 77452 | 16308 | 60756 | 92144 | 49442 |
| 02368 | 21382 | 52404 | 60268 | 89368 | 19885 | 55322 | 44819 | 01188 |
| 01011 | 54092 | 33362 | 94904 | 31273 | 04146 | 18594 | 29852 | 71585 |
| 52162 | 53916 | 46369 | 58586 | 23216 | 14513 | 83149 | 98736 | 23495 |
| 07056 | 97628 | 33787 | 09998 | 42698 | 06691 | 76988 | 13602 | 51851 |
| 48663 | 91245 | 85828 | 14346 | 09172 | 30168 | 90229 | 04734 | 59193 |
| 54164 | 58492 | 22421 | 74103 | 47070 | 25306 | 76468 | 26384 | 58151 |
| 32639 | 32363 | 05597 | 24200 | 13363 | 38005 | 94342 | 28728 | 35806 |
| 29334 | 27001 | 87637 | 87308 | 58731 | 00256 | 45834 | 15398 | 46557 |
| 02488 | 33062 | 28834 | 07351 | 19731 | 92420 | 60952 | 61280 | 50001 |
| 81525 | 72295 | 04839 | 96423 | 24878 | 82651 | 66566 | 14778 | 76797 |
| 29676 | 20591 | 68086 | 26432 | 46901 | 20849 | 89768 | 81536 | 86645 |
| 00742 | 57392 | 39064 | 66432 | 84673 | 40027 | 32832 | 61362 | 98947 |
| 05366 | 04213 | 25669 | 26422 | 44407 | 44048 | 37937 | 63904 | 45766 |
| 91921 | 26418 | 64117 | 94305 | 26766 | 25940 | 39972 | 22209 | 71500 |
| 00582 | 04711 | 87917 | 77341 | 42206 | 35126 | 74087 | 99547 | 81817 |
| 00725 | 69884 | 62797 | 56170 | 86324 | 88072 | 76222 | 36086 | 84637 |
| 69011 | 65795 | 95876 | 55293 | 18988 | 27354 | 26575 | 08625 | 40801 |
| 25976 | 57948 | 29888 | 88604 | 67917 | 48708 | 18912 | 82271 | 65424 |
| 09763 | 83473 | 73577 | 12908 | 30883 | 18317 | 28290 | 35797 | 05998 |
| 91567 | 42595 | 27958 | 30134 | 04024 | 86385 | 29880 | 99730 | 55536 |
| 17955 | 56349 | 90999 | 49127 | 20044 | 59931 | 06115 | 20542 | 18059 |
| 46503 | 18584 | 18845 | 49618 | 02304 | 51038 | 20655 | 58727 | 28168 |
| 92157 | 89634 | 94824 | 78171 | 84610 | 82834 | 09922 | 25417 | 44137 |
| 14577 | 62765 | 35605 | 81263 | 39667 | 47358 | 56873 | 56307 | 61607 |
| 98427 | 07523 | 33362 | 64270 | 01638 | 92477 | 66969 | 98420 | 04880 |
| 34914 | 63976 | 88720 | 82765 | 34476 | 17032 | 87589 | 40836 | 32427 |
| 70060 | 28277 | 39475 | 46473 | 23219 | 53416 | 94970 | 25832 | 69975 |
| 53976 | 54914 | 06990 | 67245 | 68350 | 82948 | 11398 | 42878 | 80287 |
| 76072 | 29515 | 40980 | 07391 | 58745 | 25774 | 22987 | 80059 | 39911 |
| 90725 | 52210 | 83974 | 29992 | 65831 | 38857 | 50490 | 83765 | 55657 |
| 64364 | 67412 | 33339 | 31926 | 14883 | 24413 | 59744 | 92351 | 97473 |
| 08962 | 00358 | 31662 | 25388 | 61642 | 34072 | 81249 | 35648 | 56891 |
| 95012 | 68379 | 93526 | 70765 | 10592 | 04542 | 76463 | 54328 | 02349 |
| 15664 | 10493 | 20492 | 38391 | 91132 | 21999 | 59516 | 81652 | 27195 |


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10480 | 15011 | 01536 | 02011 | 81647 | 91646 | 69179 | 14194 | 62590 |
| 22368 | 46573 | 25595 | 85393 | 30995 | 89198 | 27982 | 53402 | 93965 |
| 24130 | 48360 | 22527 | 97265 | 76393 | 64809 | 15179 | 24830 | 49340 |
| 42167 | 93093 | 06243 | 61680 | 07856 | 16376 | 39440 | 53537 | 71341 |
| 37570 | 39975 | 81837 | 16656 | 06121 | 91782 | 60468 | 81305 | 49684 |
| 77921 | 06907 | 11008 | 42751 | 27756 | 53498 | 18602 | 70659 | 90655 |
| 99562 | 72905 | 56420 | 69994 | 98872 | 31016 | 71194 | 18738 | 44013 |
| 96301 | 91977 | 05463 | 07972 | 18876 | 20922 | 94595 | 56869 | 69014 |
| 89579 | 14342 | 63661 | 10281 | 17453 | 18103 | 57740 | 84378 | 25331 |
| 85475 | 36857 | 53342 | 53988 | 53060 | 59533 | 38867 | 62300 | 08158 |
| 28918 | 69578 | 88231 | 33276 | 70997 | 79936 | 56865 | 05859 | 90106 |
| 63553 | 40961 | 48235 | 03427 | 49626 | 69445 | 18663 | 72695 | 52180 |
| 09429 | 93969 | 52636 | 92737 | 88974 | 33488 | 36320 | 17617 | 30015 |
| 10365 | 61129 | 87529 | 85689 | 48237 | 52267 | 67689 | 93394 | 01511 |
| 07119 | 97336 | 71048 | 08178 | 77233 | 13916 | 47564 | 81056 | 97735 |
| 51085 | 12765 | 51821 | 51259 | 77452 | 16308 | 60756 | 92144 | 49442 |
| 02368 | 21382 | 52404 | 60268 | 89368 | 19885 | 55322 | 44819 | 01188 |
| 01011 | 54092 | 33362 | 94904 | 31273 | 04146 | 18594 | 29852 | 71585 |
| 52162 | 53916 | 46369 | 58586 | 23216 | 14513 | 83149 | 98736 | 23495 |
| 07056 | 97628 | 33787 | 09998 | 42698 | 06691 | 76988 | 13602 | 51851 |
| 48663 | 91245 | 85828 | 14346 | 09172 | 30168 | 90229 | 04734 | 59193 |
| 54164 | 58492 | 22421 | 74103 | 47070 | 25306 | 76468 | 26384 | 58151 |
| 32639 | 32363 | 05597 | 24200 | 13363 | 38005 | 94342 | 28728 | 35806 |
| 29334 | 27001 | 87637 | 87308 | 58731 | 00256 | 45834 | 15398 | 46557 |
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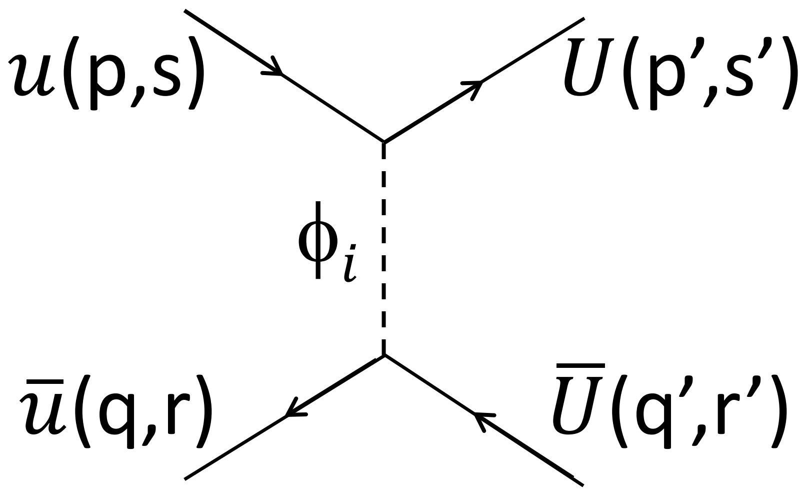
| 81525 | 72295 | 04839 | 96423 | 24878 | 82651 | 66566 | 14778 | 76797 |
| 29676 | 20591 | 68086 | 26432 | 46901 | 20849 | 89768 | 81536 | 86645 |
| 00742 | 57392 | 39064 | 66432 | 84673 | 40027 | 32832 | 61362 | 98947 |
| 05366 | 04213 | 25669 | 26422 | 44407 | 44048 | 37937 | 63904 | 45766 |
| 91921 | 26418 | 64117 | 94305 | 26766 | 25940 | 39972 | 22209 | 71500 |
| 00582 | 04711 | 87917 | 77341 | 42206 | 35126 | 74087 | 99547 | 81817 |
| 00725 | 69884 | 62797 | 56170 | 86324 | 88072 | 76222 | 36086 | 84637 |
| 69011 | 65795 | 95876 | 55293 | 18988 | 27354 | 26575 | 08625 | 40801 |
| 25976 | 57948 | 29888 | 88604 | 67917 | 48708 | 18912 | 82271 | 65424 |
| 09763 | 83473 | 73577 | 12908 | 30883 | 18317 | 28290 | 35797 | 05998 |
| 91567 | 42595 | 27958 | 30134 | 04024 | 86385 | 29880 | 99730 | 55536 |
| 17955 | 56349 | 90999 | 49127 | 20044 | 59931 | 06115 | 20542 | 18059 |
| 46503 | 18584 | 18845 | 49618 | 02304 | 51038 | 20655 | 58727 | 28168 |
| 92157 | 89634 | 94824 | 78171 | 84610 | 82834 | 09922 | 25417 | 44137 |
| 14577 | 62765 | 35605 | 81263 | 39667 | 47358 | 56873 | 56307 | 61607 |
| 98427 | 07523 | 33362 | 64270 | 01638 | 92477 | 66969 | 98420 | 04880 |
| 34914 | 63976 | 88720 | 82765 | 34476 | 17032 | 87589 | 40836 | 32427 |
| 70060 | 28277 | 39475 | 46473 | 23219 | 53416 | 94970 | 25832 | 69975 |
| 53976 | 54914 | 06990 | 67245 | 68350 | 82948 | 11398 | 42878 | 80287 |
| 76072 | 29515 | 40980 | 07391 | 58745 | 25774 | 22987 | 80059 | 39911 |
| 90725 | 52210 | 83974 | 29992 | 65831 | 38857 | 50490 | 83765 | 55657 |
| 64364 | 67412 | 33339 | 31926 | 14883 | 24413 | 59744 | 92351 | 97473 |
| 08962 | 00358 | 31662 | 25388 | 61642 | 34072 | 81249 | 35648 | 56891 |
| 95012 | 68379 | 93526 | 70765 | 10592 | 04542 | 76463 | 54328 | 02349 |
| 15664 | 10493 | 20492 | 38391 | 91132 | 21999 | 59516 | 81652 | 27195 |

# … what goes on inside a Monte Carlo generator

# MadGraph

## scattering amplitude

- scattering process: $pp \to U\bar{U}$
- parton level processes: $u\bar{u} \to U\bar{U}$




$$A_{u\bar{u}\to U\bar{U}} = -\frac{\lambda_i \bar{U}^{s'}_{p'}.u^s_p \;\; \lambda_i \bar{v}^r_q.V^{r'}_{q'}}{(p-p')^2 - m_i^2} - \cdots$$

# MadGraph

partonic events

- parton level differential cross section

$$\frac{d\sigma_{u\bar{u}\to U\bar{U}}}{d\Omega} = \frac{1}{64\pi^2 s}\frac{|\vec{p}'|}{|\vec{p}|}\sum_{\phi_i, spin, color}\frac{1}{N}|A_{u\bar{u}\to U\bar{U}}|^2$$

helicity amplitudes don't interfere

- parton level total cross section

$$\sigma_{u\bar{u}\to U\bar{U}} = \int_{4\pi}\frac{d\sigma_{u\bar{u}\to U\bar{U}}}{d\Omega}d\Omega$$

- parton level events

$$N_{U\bar{U}} = \sigma_{u\bar{u}\to U\bar{U}}\,L$$

# MadGraph

## event generation

MC event generators evaluate the phase space integral numerically

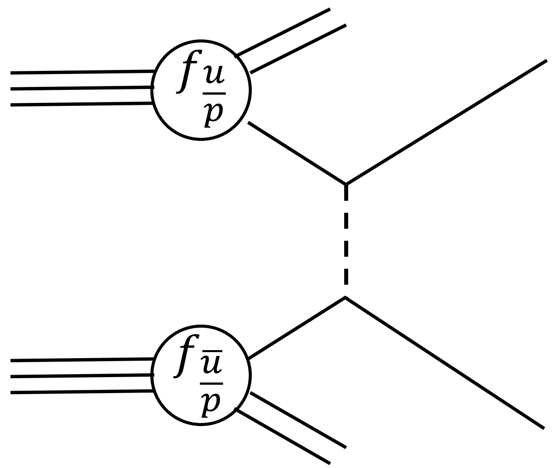
$$\sigma_{u\bar{u}\to U\bar{U}} = \int_{4\pi} \frac{d\sigma_{u\bar{u}\to U\bar{U}}}{d\Omega} d\Omega$$

They

- generate the event kinematics (4-momenta)
- calculate the differential cross section (weight)
- sample the phase-space using algorithm: random, importance sampling, Metopolis, etc.

# PYTHIA

## hadronic cross section

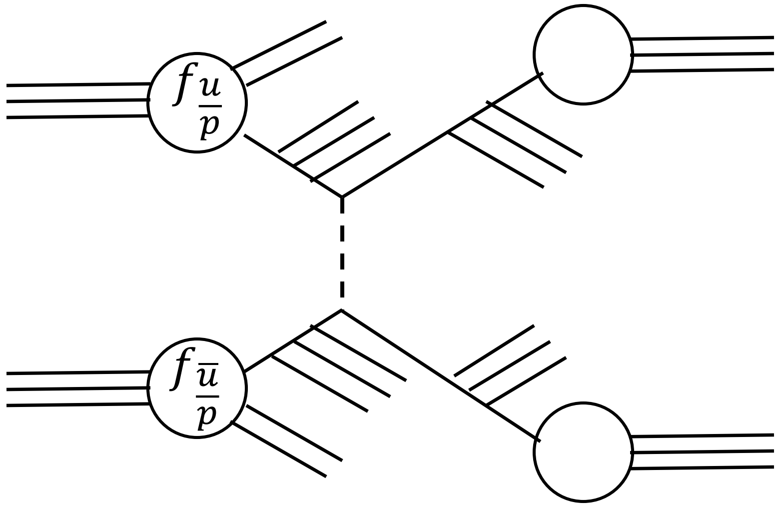



$$\frac{d\sigma_{pp\rightarrow U\bar{U}}}{d\Omega} = \int_0^1 dx_1 dx_2\, f_{\frac{u}{p}}(x_1) f_{\frac{\bar{u}}{p}}(x_2)\, \frac{d\sigma_{u\bar{u}\rightarrow U\bar{U}}(x_1, x_2)}{d\Omega}$$

- $f_{\frac{u}{p}}(x_i)$ parton distribution function
- $x_i$ longitudinal momentum fraction of u in p

# PYTHIA

## hadronic events




- initial and finals state radiation
- decays
- hadronization: jet formation, fragmentation
- hadronic cross section calculation

# Delphes

## detector events

Delphes simulates an "LHC style" detector

- in: hadronic events, out: reconstructed events

$$N = \varepsilon \, \sigma \, L$$

  - calculates effeciencies

    for tracking of charged hadrons, $e^-$, …
  - parameterizes momentum resolution
  - parametrizes (EM & hadronic) calorimeters

    fraction of energy deposited by a particle
  - isolation settings for $e^-$, $\mu^-$; jet algorithms


A FAKE MASTERPIECE.
THE PERFECT PLAN.
GAMBiT
CONNING SOON

# GAMBIT

## Global And Modular BSM Inference Tool

- Global: collider, dark matter, flavor, …
- And: cosmology, astrophysics, …
- Modular: easily switch any[1] modules
- BSM: calculate for any[2] models
- Inference: built-in credibility assessment
- Tool: observables, likelihoods, posteriors