UCLouvain
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MadGraph5_aMC@NLO

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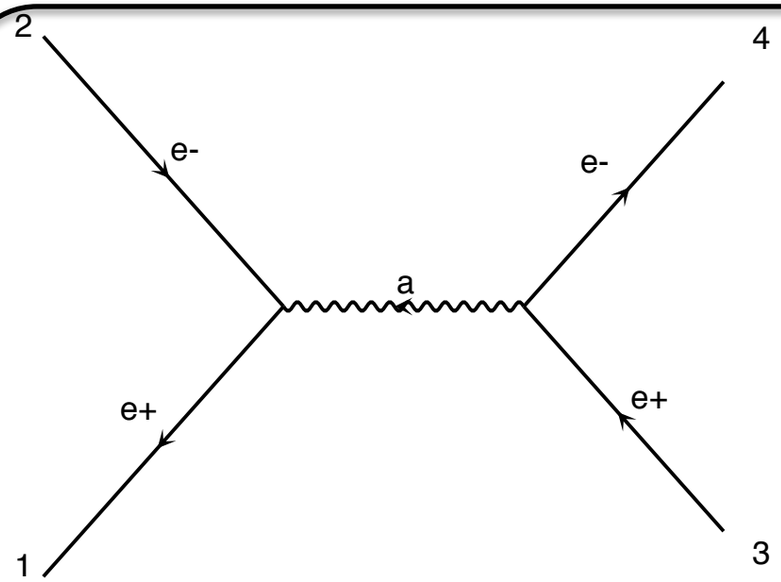
Core business:

How to evaluate a matrix-element

Helicity Amplitude

Idea

- Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|^2$
  - ➡Loop on Helicity and average the results



$$\mathcal{M} = ((\bar{u}e\gamma^{\mu}v)\frac{g_{\mu\nu}}{q^2})(\bar{v}e\gamma^{\nu}u))$$

Helicity Amplitude

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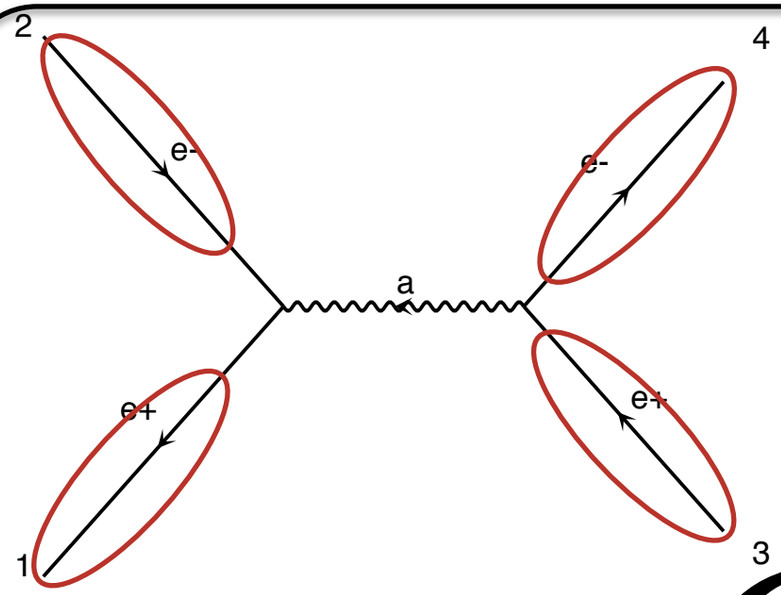


$$\mathcal{M} = ((\bar{u}e\gamma^{\mu}v)\frac{g_{\mu\nu}}{q^2})(\bar{v}e\gamma^{\nu}u))$$

Numbers for given helicity and momenta

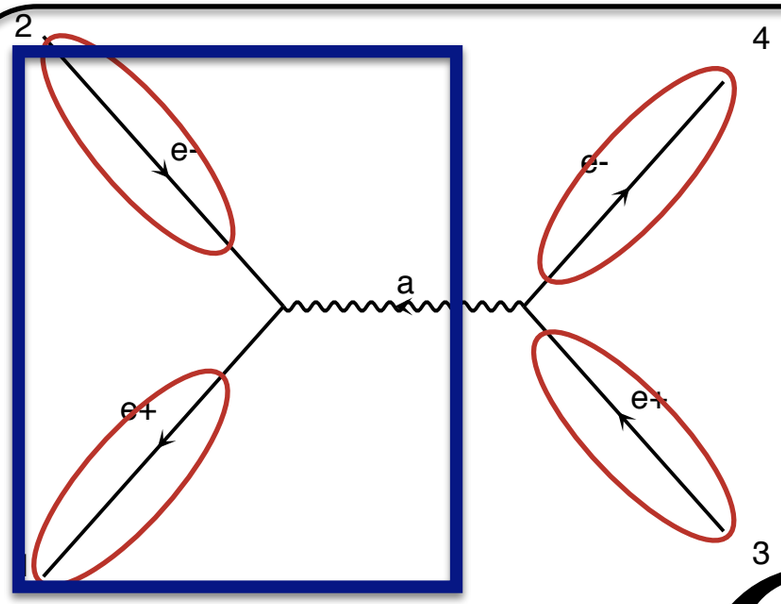
Lines present in the code.

$$\bar{v}_1 = fct(\vec{p}_1, m_1)$$
$$u_2 = fct(\vec{p}_2, m_2)$$
$$v_3 = fct(\vec{p}_3, m_3)$$
$$\bar{u}_4 = fct(\vec{p}_4, m_4)$$

Helicity Amplitude

Idea

- Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|^2$
  - ➡Loop on Helicity and average the results



$$\mathcal{M} = ((\bar{u}e\gamma^{\mu}v)\frac{g_{\mu\nu}}{q^2})(\bar{v}e\gamma^{\nu}u))$$

Numbers for given helicity and momenta

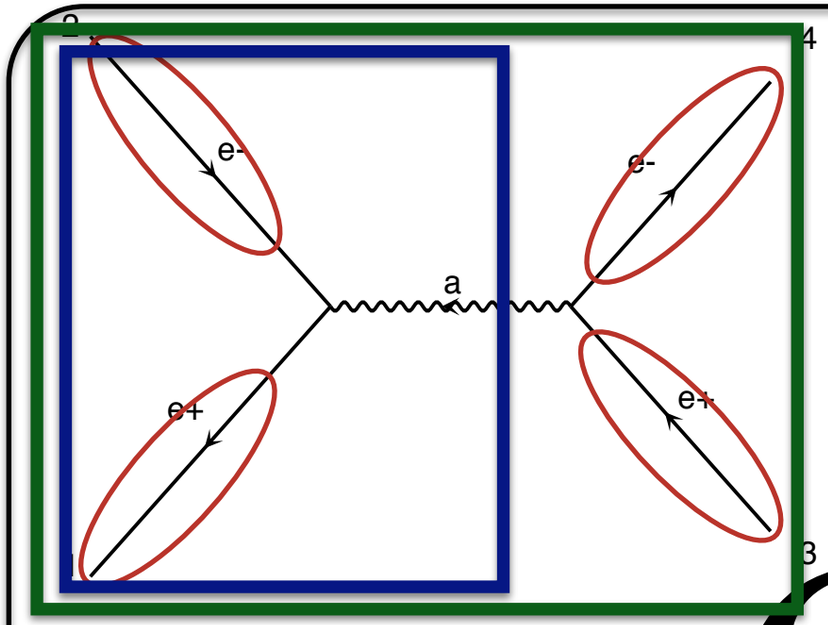
Calculate propagator wavefunctions

Lines present in the code.

$$\left\{\begin{aligned}
\bar{v}_1 &= fct(\vec{p}_1, m_1) \\
u_2 &= fct(\vec{p}_2, m_2) \\
v_3 &= fct(\vec{p}_3, m_3) \\
\bar{u}_4 &= fct(\vec{p}_4, m_4) \\
W_a &= fct(\bar{v}_1, u_2, m_a, \Gamma_a)
\end{aligned}\right.$$

Helicity Amplitude

Idea
- Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|^2$
  - ➡Loop on Helicity and average the results



$$\mathscr{M} = ((\bar{u}e\gamma^{\mu}v)\frac{g_{\mu\nu}}{q^2})(\bar{v}e\gamma^{\nu}u))$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

Finally evaluate amplitude (c-number)

Lines present in the code.

$$\bar{v}_1 = fct(\vec{p}_1, m_1)$$
$$u_2 = fct(\vec{p}_2, m_2)$$
$$v_3 = fct(\vec{p}_3, m_3)$$
$$\bar{u}_4 = fct(\vec{p}_4, m_4)$$
$$W_a = fct(\bar{v}_1, u_2, m_a, \Gamma_a)$$
$$\mathcal{M} = fct(v_3, \bar{u}_4, W_a)$$

Comparison

	M diag	N particle	
Analytical	M^2	$(N!)^2$	
Helicity	M	$(N!)\,2^N$	
Recycling	M	$(N-1)!\,2^{(N-1)}$	
Hel Recycling	M	$(N-1)!2^{N-3}$	**NEW: 2102.00773**

Take Away

- Analytical method are slower that numerical method
- Still work in progress to speed this up

Which matrix-element ?

Model

- We do support a huge class of BSM model
  - ➡ 164 model in our database
  - ➡ We support UFO model
    - Generated by FeynRules/Sarah/ LanHEP
  - ➡ Model limitation
    - Spin supported up to spin 2
    - Color supported up to octet
      - Including sextet and epsilon
    - Lorentz invariance and CPT

Which matrix-element ?

Type of matrix-element

- Tree-Level
  - ➡ Production process up to 7 QCD parton
    - Decay can be added up to 2>16
  - ➡ Interference term, Polarised production
  - ➡ Polarised onshell decay
- One loop amplitude (NLO and loop-induced)
  - Linked to five reduction algorithm
  - reduce the need of quadruple precision

Which matrix-element ?

Computing language

- Tree-Level
  - ➡ Available in Fortran, C++ and python
  - ➡ work in progress:
    - Tensorflow
    - Cuda (kokos, oneapi,...)
- One loop amplitude
  - ➡Available in Fortran only

Cool but what I want/need is

- a cross-section
- a theoretical distribution
- a sample of events

Cool but what I want/need is

- a cross-section
- a theoretical distribution
- a sample of events

And I do not want to code my own tools for doing that

MadGraph5_aMC@NLO

Framework

- We are a framework of tools
- All feature use the matrix-element computation to do something

Oldest feature: LO (since 2002)

- Ability to compute LO cross-section and to generate un-weighted sample of events for any of those matrix-element
  - Possible convolution with collinear PDF
  - Large set of cuts available

demo

Command

```
import model MSSM_SLHA2
generate p p > go go
output
launch
```

Tutorial

Tutorial with nloaccess website this afternoon

Results

```
INFO: #*********************************************************************
#
# original cross-section: 4.759639051059447
#     scale variation: +39.7% -26.7%
#     central scheme variation: +1.72e-09% -29.9%
# PDF variation: +13.2% -13.2%
#
# dynamical scheme # 1 : 4.36894 +39.5% -26.5% # \sum ET
# dynamical scheme # 2 : 3.48877 +36.4% -25.2% # \sum\sqrt{m^2+pt^2}
# dynamical scheme # 3 : 4.75964 +39.7% -26.7% # 0.5 \sum\sqrt{m^2+pt^2}
# dynamical scheme # 4 : 3.33845 +35.9% -24.9% # \sqrt{\hat s}
#*********************************************************************
```

Results in the MSSM_SLHA2 for p p > go go

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	4.761 ± 0.0076 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation

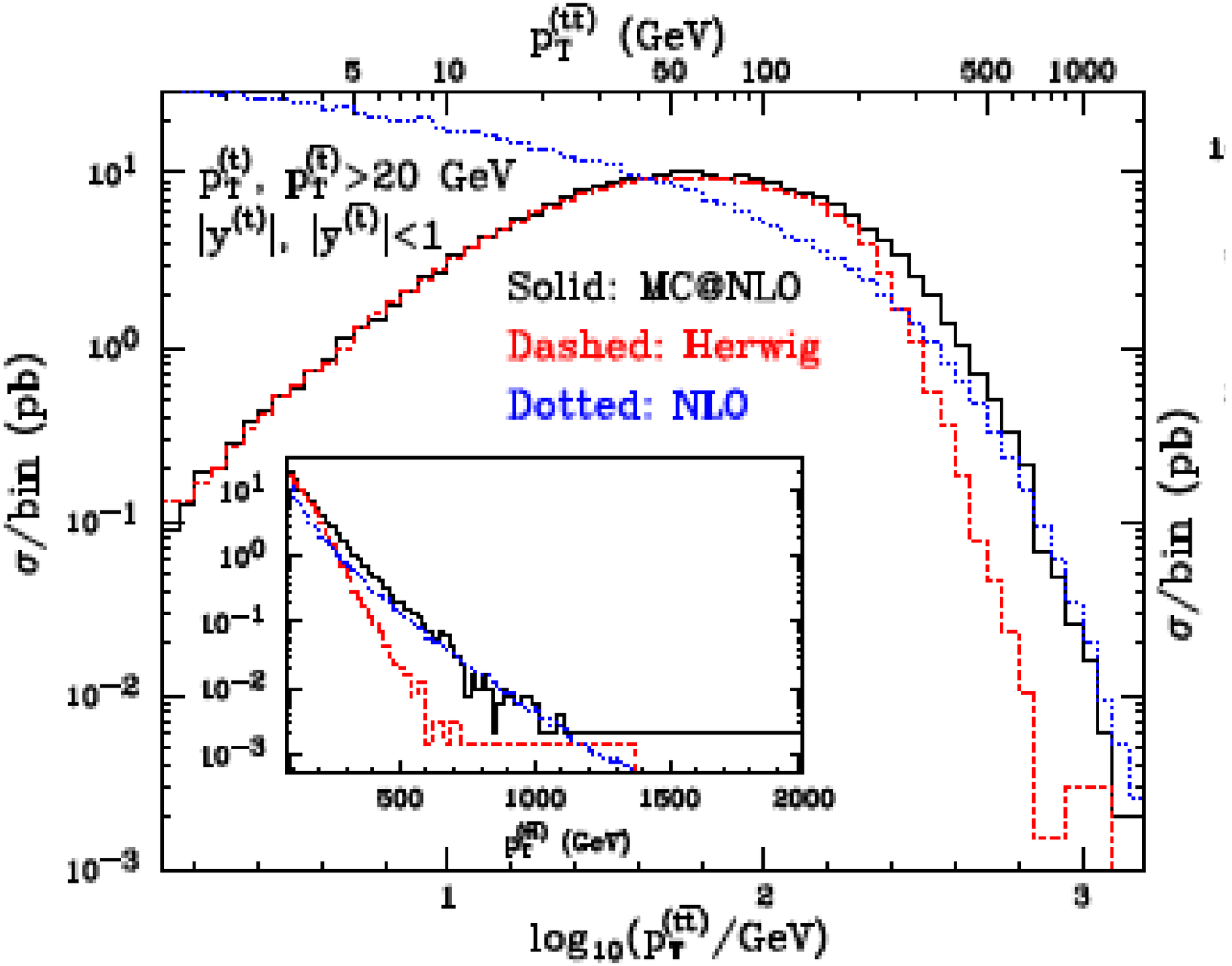
Main Page

NLO Computation

Biggest feature: NLO in QCD (since 2014)

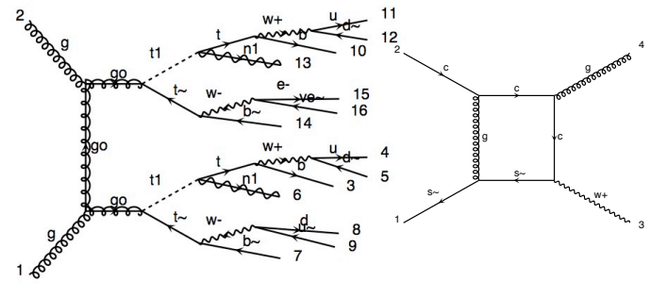
- Using the FKS subtraction scheme
- Supporting two NLO mode
  - Fixed-order NLO (pure NLO computation)
    - No event generation
    - Plot on the flight
  - NLO+PS
    - MC@NLO matching procedure
    - MC@NLO-Delta to be release soon
      - Less negative events

FNLO versus NLO+PS



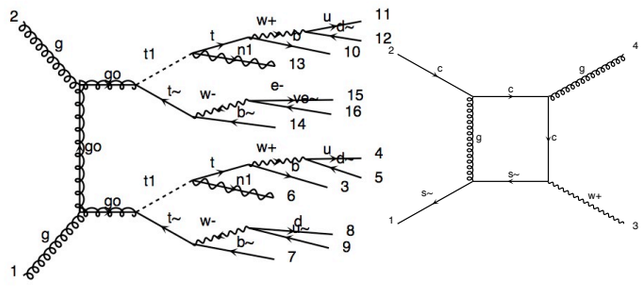
Type of generation

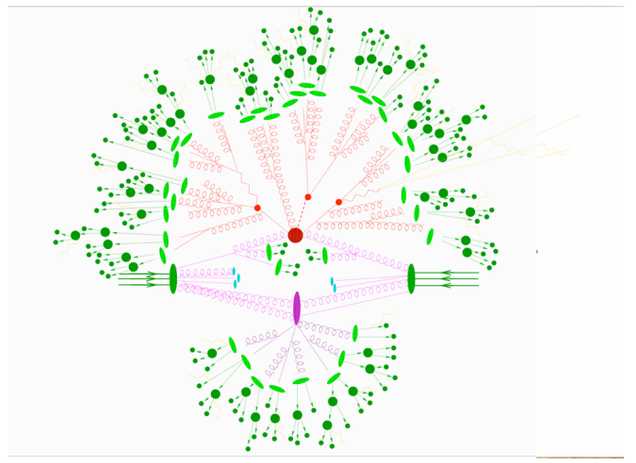
	Tree (B)SM	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	Loop Induced (B)SM
Fix Order	✓	✓	✓	✓	✓



Type of generation

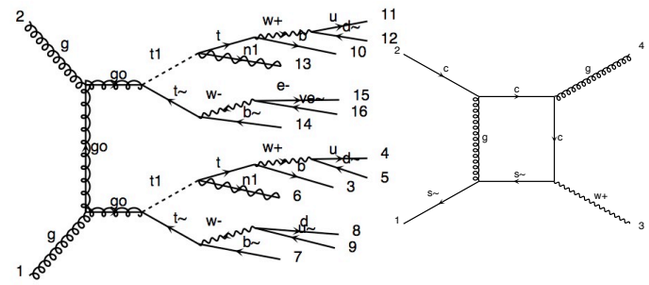
	Tree (B)SM	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	Loop Induced (B)SM
Fix Order	✓	✓	✓	✓	✓
+Parton Shower	✓	✓	✓	✗	✓

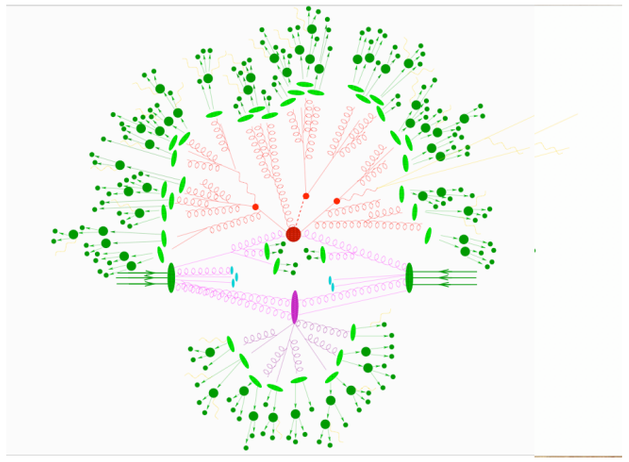




Type of generation

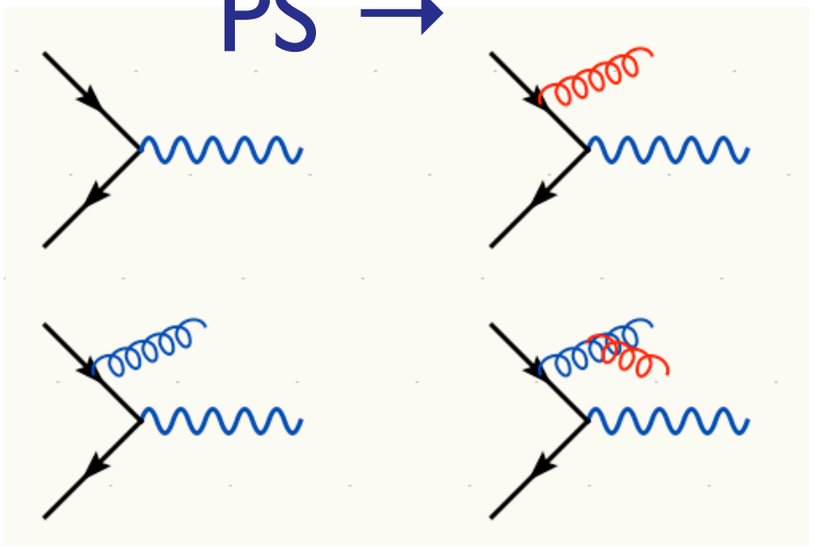
	Tree (B)SM	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	Loop Induced (B)SM
Fix Order	✓	✓	✓	✓	✓
+Parton Shower	✓	✓	✓	✗	✓
Merged Sample	✓	✓	?	✗	✓





PS →

ME ↓



Plugin mode

Definition

- Extension of the capabilities of the code

MadDM

- Code dedicated to dark matter searches
  - Relic density
  - Direct detection
  - Indirect detection

Madump

- Code for beam dump experiment
  - Determination of 2D PDF
- Associated convolution
- Used by Ship

Conclusion

- Core business the matrix-element
  - ➡ And all application that can be done with it.
    - LO/NLO cross-section
    - MC@NLO sample of events
- auto-width, matrix-element method, ...
- Extendable via plugin
- Available online -> crash test in a few moment

“demo”

Framework

- We provide a shell to indicate the computation/tools that you want to use

Model : import model_xxxx

```
MG5_aMC>import model MSSM_SLHA2
INFO: Restrict model MSSM_SLHA2 with file models/MSSM_SLHA2/restrict_default.dat .
INFO: Detect SLHA2 format. keeping restricted parameter in the param_card
INFO: Change particles name to pass to MG5 convention
Kept definitions of multiparticles p / j / l+ / l- / vl / vl~ unchanged
Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+
r sr b2 ul~ cl~ t1~ ur~ cr~ t2~ dl~ sl~ b1~ dr~ sr~ b2~ t b t~ b~ z w+ h01 h2 h3 h+
 ta2- w- h- sve~ svm~ svt~ el+ mul+ ta1+ er+ mur+ ta2+ n1 n2 n3 n4 x1+ x2+ ta- x1-
MG5_aMC>
```

Matrix-element: generate A B > C D E

```
MG5_aMC>generate p p > go go
INFO: Checking for minimal orders which gives processes.
```

```
5 processes with 23 diagrams generated in 0.199 s
Total: 5 processes with 23 diagrams
MG5_aMC>
```

“demo”

Framework

- We provide a shell to indicate the computation/tools that you want to use

Model : import model_xxxx

```
MG5_aMC>import model MSSM_SLHA2
INFO: Restrict model MSSM_SLHA2 with file models/MSSM_SLHA2/restrict_default.dat .
INFO: Detect SLHA2 format. keeping restricted parameter in the param_card
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Kept definitions of multiparticles p / j / l+ / l- / vl / vl~ unchanged
Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+
r sr b2 ul~ cl~ t1~ ur~ cr~ t2~ dl~ sl~ b1~ dr~ sr~ b2~ t b t~ b~ z w+ h01 h2 h3 h+
 ta2- w- h- sve~ svm~ svt~ el+ mul+ ta1+ er+ mur+ ta2+ n1 n2 n3 n4 x1+ x2+ ta- x1-
MG5_aMC>
```

Matrix-element: generate A B > C D E

```
MG5_aMC>generate p p > go go
INFO: Checking for minimal orders which gives processes.
```

```
5 processes with 23 diagrams generated in 0.199 s
Total: 5 processes with 23 diagrams
MG5_aMC>
```

“demo 2”

Choice of tools: output TOOLS PATH

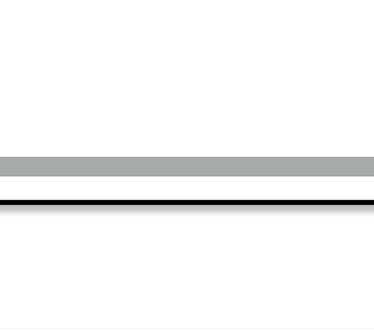
```
MG5_aMC>output
INFO: initialize a new directory: PROC_MSSM_SLHA2_0
INFO: remove old information in PROC_MSSM_SLHA2_0
```

```
Output to directory /Users/omattelaer/Documents/workspace/2.9.4/PROC_MSSM_SLHA2_0 done.
Type "launch" to generate events from this process, or see
/Users/omattelaer/Documents/workspace/2.9.4/PROC_MSSM_SLHA2_0/README
Run "open index.html" to see more information about this process.
```

HTML INFO:

MadEvent Card for p p > go go

Created: Unknown

Process: p p > go go **Model: MSSM_SLHA2**	

Links	Status
Process Information	Generation Complete
Code Download	Available
On-line Event Generation	Only available from the web
Results and Event Database	No runs available

Notes:

Last Update: Sun May 30 22:04:36 CEST 2021

“demo 3”

Running the code: launch PATH

```
MG5_aMC>launch
*************************************************************
*                                                           *
*                W E L C O M E to                           *
*          M A D G R A P H 5 _ a M C @ N L O                *
*                M A D E V E N T                            *
*                                                           *
*                    *                   *                  *
*                 *       * *       *                       *
*                   * * * * 5 * * * *                       *
*                 *       * *       *                       *
*                    *                   *                  *
*                                                           *
*         VERSION 2.9.4                 2021-05-28          *
*                                                           *
*    The MadGraph5_aMC@NLO Development Team - Find us at    *
*    https://server06.fynu.ucl.ac.be/projects/madgraph      *
*                                                           *
*               Type 'help' for in-line help.               *
*                                                           *
*************************************************************
```

“demo 4”

First Question: Do you want to do post-processing?

```
The following switches determine which programs are run:
/================ Description ================|================ values ================|=== other options ====\
| 1. Choose the shower/hadronization program   |   shower = OFF                         |   Pythia6|Pythia8    |
| 2. Choose the detector simulation program    | detector = OFF                         |   PGS|Delphes         |
| 3. Choose an analysis package (plot/convert) | analysis = MadAnalysis4                |   MadAnalysis5|OFF   |
| 4. Decay onshell particles                   |  madspin = OFF                         |   ON|onshell|full    |
| 5. Add weights to events for new hypp.       | reweight = OFF                         |   ON                 |
\=============================================================================================================/
Either type the switch number (1 to 5) to change its setting,
Set any switch explicitly (e.g. type 'shower=Pythia6' at the prompt)
Type 'help' for the list of all valid option
Type '0', 'auto', 'done' or just press enter when you are done.[60s to answer]
[timer stopped]
launch
```

- Do you want to run a parton-shower?
- A detector simulation?
- Do you want to decay particles?
- Do you want to do plots

“demo 5”

Second Question: set the parameters of your run

```
Do you want to edit a card (press enter to bypass editing)?
/------------------------------------------------------------\
|  1. param : param_card.dat                                 |
|  2. run   : run_card.dat                                   |
|  3. plot  : plot_card.dat                                  |
\------------------------------------------------------------/
 you can also
   - enter the path to a valid card or banner.
   - use the 'set' command to modify a parameter directly.
     The set option works only for param_card and run_card.
     Type 'help set' for more information on this command.
   - call an external program (ASperGE/MadWidth/...).
     Type 'help' for the list of available command
 [0, done, 1, param, 2, run, 3, plot, enter path][90s to answer]
```

- You can edit files with the parameters
  - ➡ Or many different options here.
- fix-target? Heavy-ion beam? Lepton collider? ...

“demo 6”

Results

```
INFO: #*********************************************************************
#
# original cross-section: 4.759639051059447
#     scale variation: +39.7% -26.7%
#     central scheme variation: +1.72e-09% -29.9%
# PDF variation: +13.2% -13.2%
#
# dynamical scheme # 1 : 4.36894 +39.5% -26.5% # \sum ET
# dynamical scheme # 2 : 3.48877 +36.4% -25.2% # \sum\sqrt{m^2+pt^2}
# dynamical scheme # 3 : 4.75964 +39.7% -26.7% # 0.5 \sum\sqrt{m^2+pt^2}
# dynamical scheme # 4 : 3.33845 +35.9% -24.9% # \sqrt{\hat s}
#*********************************************************************
```

Results in the MSSM_SLHA2 for p p > go go

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	4.761 ± 0.0076 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation

Tutorial

- Run p p > t t~
  - ➡ At LO
  - ➡ At NLO+PS
  - ➡ At fixed-order NLO (provide the analysis card)
  - ➡ Compute the K-factor