# Sherpa Tutorial @

CMS Topical Workshop on Off-shell Higgs Boson Production at the LPC

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# Disclaimer

- I’m also “LEARNING” during the preparation of this talk, e.g., checking the manual
- CREDITS: Thanks to Frank Siegert, Enrico Bothmann and Jie Xiao for help and a lot of materials appearing in this talk

# Sherpa Tutorial

- Brief introduction to Sherpa
  - Sherpa framework
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  - Input card
- How to run sherpa within CMS environment
  - The workflow for sherpack
  - ggH (H→$\gamma\gamma$)
  - gg→4l
  - Gg→4l (Higgs only)
  - ttH
  - ...

# Sherpa framework

- Sherpa is a complete standalone generator framework (written in C++):
  - **Matrix-Element generator (ME)**:
    - AMEGIC++ ( Sherpa's original matrix-element generator)
    - COMIX (multi-leg tree-level matrix element generator, is a useful supplement to AMEGIC++ in the high multiplicity regime)
  - **Parton Shower (PS):**
    - CSSHOWER++ (Sherpa's default parton shower)
    - DIRE (Sherpa's alternative parton shower)
  - **Multiple Interaction (MPI):** AMISIC++
  - **Hadronization:** AHADIC++
  - **Hadron and tau-lepton decay:** HADRONS++
  - **QED radiation to hadron and tau-lepton decays:** PHOTONS++

Finally, SHERPA is the steering module that initializes, controls and evaluates the different phases during the entire process of event generation

# Sherpa framework

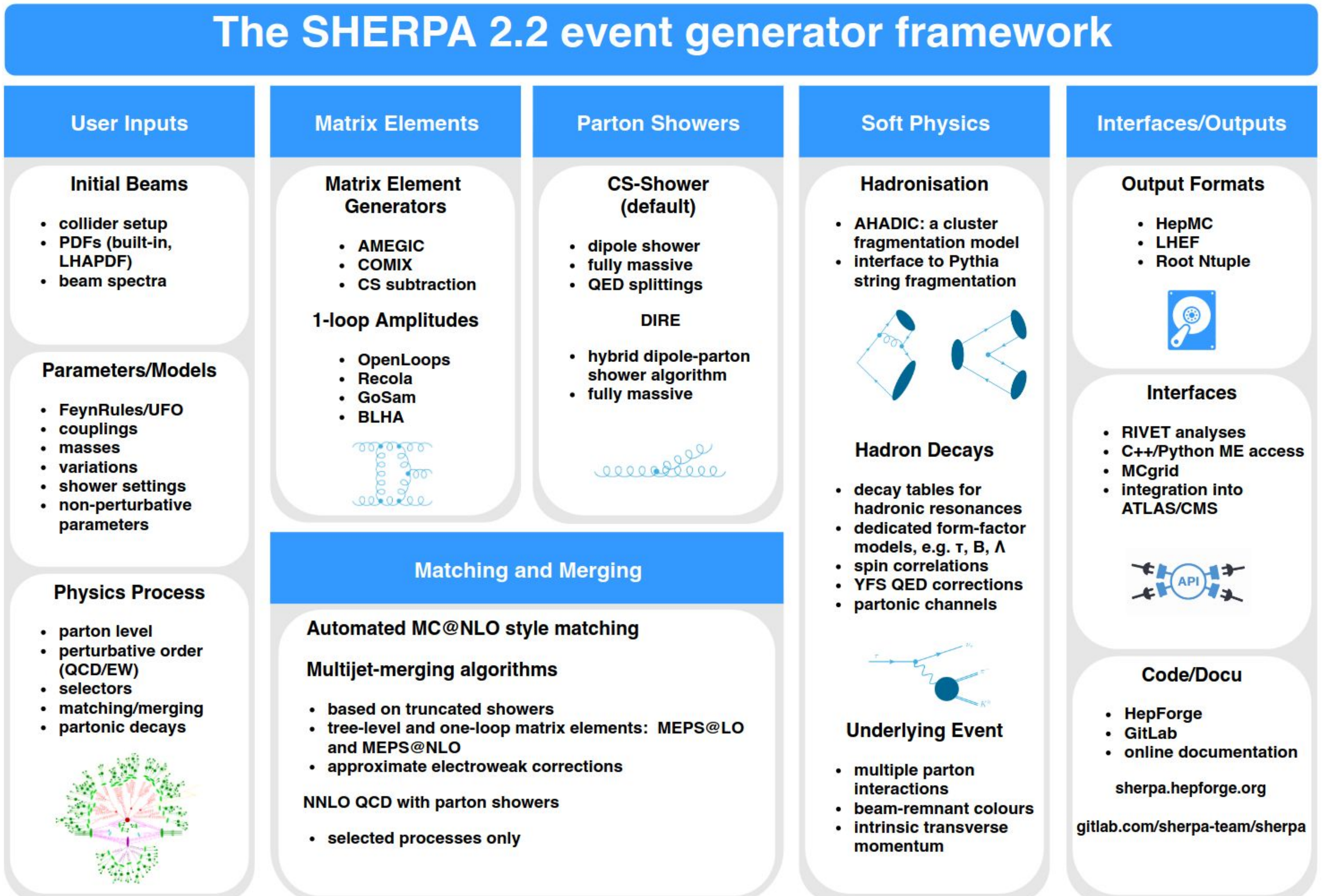


**Figure 1:** Overview of the SHERPA 2.2 event generator framework.

[arXiv: 1905.09127](https://arxiv.org/abs/1905.09127)

# Highlights

- Automated matching/merging
- Multileg production: Z+Jets, 0,1,2j @NLO + 3,4,5j @LO
- Approximate EW corrections for V+Jet
- HL-LHC readiness: significant Sherpa+Lhapdf performance improvements [arXiv:2209.00843]
    - ~x40 speed-up for Z+jet/ttbar
- HPC readiness [arXiv: 2309.13154]
- GPU [arXiv:2311.06198]
- Sherpa version3:
    - alpha version documentation
    - Fully general & automated fixed-order NLO EW [arXiv:1712.07975]
    - DY NNLO, polarized XS for massive vector boson… [arXiv:1405.3607, 2310.14803]
    - rewritten+retuned soft QCD [arXiv:2203.11385]
    - full NLL Alaric shower [arXiv:2208.06057]
    - Improved workflow for using GPU

# Input card

A Sherpa setup is steered by various parameters, associated with the different components of event generation. Generally following blocks are used:

```
(run){
  % general setting
  EVENTS 100K; ERROR 0.99;

  % scales, tags for scale variations
  FSF:=1.; RSF:=1.; QSF:=1.;
  SCALES STRICT_METS{FSF*MU_F2}{RSF*MU_R2}{QSF*MU_Q2};
  SCALE_VARIATIONS 0.25,0.25 0.25,1. 1.,0.25 1.,1. 1.,4. 4.,1. 4.,4.;
  ASSOCIATED_CONTRIBUTIONS_VARIATIONS EW EW|LO1;

  % tags for process setup
  NJET:=4; LJET:=2,3,4; QCUT:=20.;

  % me generator settings
  ME_SIGNAL_GENERATOR Comix Amegic LOOPGEN;
  EVENT_GENERATION_MODE PartiallyUnweighted;
  OL_PARAMETERS ew_renorm_scheme 1;
  LOOPGEN:=OpenLoops;
  PP_RS_SCALE VAR{0.25*H_Tp2};


 % exclude tau from lepton container
  MASSIVE[15] 1;

  % collider setup
  BEAM_1 2212; BEAM_ENERGY_1 = 6500.;
  BEAM_2 2212; BEAM_ENERGY_2 = 6500.;

  PDF_LIBRARY LHAPDFSherpa;
  PDF_SET NNPDF30_nnlo_as_0118;
  PDF_VARIATIONS NNPDF30_nnlo_as_0118[all];
}(run)
```

```
(processes){
  Process 93 93 -> 11 -11 93{NJET};
  Order (*,2); CKKW sqr(QCUT/E_CMS);
  NLO_QCD_Mode MC@NLO {LJET};
  ME_Generator Amegic {LJET};
  RS_ME_Generator Comix {LJET};
  Loop_Generator LOOPGEN {LJET};
  Associated_Contributions EW|LO1 {LJET};
  #Enhance_Observable VAR{PPerp(p[2]+p[3])}|0.|1000. {3,4,5,6};
  Enhance_Observable VAR{log10(PPerp(p[2]+p[3]))}|1.|3. {3,4,5,6};
  Integration_Error 0.02 {2};
  Integration_Error 0.02 {3};
  Integration_Error 0.02 {4};
  Integration_Error 0.05 {5};
  Integration_Error 0.05 {6};
  End process;
}(processes)

(selector){
  Mass 11 -11 50. E_CMS;
}(selector)
```

# Input card

A Sherpa setup is steered by various parameters, associated with the different components of event generation. Generally following blocks are used:

- processes: physical process is defined here, generator choice, matching parameter, integration precision...
  - Process 93 93 -> 11 -11 93{NJET} ➔ DY process with max jet multiplicity NJET
  - Order (*,2); CKKW sqr(QCUT/E_CMS); ➔ coupling order (The first number always refers to QCD, the second to electroweak. The third and following numbers are model specific.) and matching parameter
  - NLO_QCD_Mode MC@NLO {LJET}; ➔ This setting specifies whether and in which mode an QCD NLO calculation should be performed
  - Enhance_Observable VAR{log10(PPerp(p[2]+p[3]))}|1.|3. {3,4,5,6}; ➔ importance sampling
  - Integration_Error 0.02 {XX}; ➔ Integration precision at each jet multiplicity

# Input card

A Sherpa setup is steered by various parameters, associated with the different components of event generation. Generally following blocks are used:

- run: parameters describe general run information...
  - Events → This parameter specifies the number of events to be generated.
  - SCALES STRICT_METS{FSF*MU_F2}{RSF*MU_R2}{QSF*MU_Q2}; → This parameter specifies how to compute the renormalization and factorization scale and potential additional scales
  - SCALE_VARIATIONS 0.25,0.25 0.25,1. 1.,0.25 1.,1. 1.,4. 4.,1. 4.,4.; → alternative event weights for different scale and PDF choices on-the-fly
  - NJET:=4; LJET:=2,3,4; QCUT:=20.; → Predefined parameter to be used in block “processes”
  - ME_SIGNAL_GENERATOR Comix Amegic LOOPGEN; → The list of matrix element generators to be employed during the run
  - EVENT_GENERATION_MODE PartiallyUnweighted; → parameter specifies the event generation mode
  - MASSIVE[15] 1; → Specifies whether the finite mass of particle with PDG id <id> is to be considered in matrix-element calculations or not. (exclude tau from lepton container)
  - BEAM_1 2212; BEAM_ENERGY_1 = 6500.; → collider type
  - PDF_SET NNPDF30_nnlo_as_0118; → pdf choice
  - PDF_VARIATIONS NNPDF30_nnlo_as_0118[all]; → pdf variation weight to be used

# Input card

A Sherpa setup is steered by various parameters, associated with the different components of event generation. Generally following blocks are used:

- selector: The setup of cuts at the matrix element level
  - One particle selectors: PT, Energy, Rapidity ...
  - Two particle selectors: Mass, DeltaEta, DeltaR ...
    - Mass 11 -11 50. E_CMS; ➔ Invariant mass of two leptons
  - NLO selectors: Phase-space cuts that are applied on next-to-leading order calculations must be defined in a infrared safe way
    - PTNLO <flavour code> <min value> <max value> ➔ One particle selector
    - PT2NLO <flavour1 code> <flavour2 code> <min value> <max value> ➔ two particle selector
    - IsolationCut 22 <dR> <exponent> <epsilon> ➔ Cuts on photons
  - ...

# The workflow for sherpack

Like other generators, all the setup needed to produce a gridpack is stored https://github.com/cms-sw/genproductions, all the hands-on will be done in lxplus (I'm using lxplus8), in your work area,

- cd YOUR/WORKING/PATH
- git clone --depth 1 https://github.com/cms-sw/genproductions
- cd genproductions/bin/Sherpa
- curl -O https://raw.githubusercontent.com/Offshell-Workshop-LPC/Sherpa-tutorial/main/Run.dat_DYee
- ./sherpack_generation.sh DYee Run.dat_DYee

```
Process 93 93 -> 11 -11 93{NJET};
Order (*,2);
NJET:=0;
NLO_QCD_Mode MC@NLO {LJET};
Loop_Generator LOOPGEN {LJET};
```

DY to electron-positron process, 0j @NLO

# Simple DY

You will see many information printed out, the parameters of EW section, the particle ID, particle container, as well as the weights (scale, pdf)

```
Standard_Model::FixEWParameters(EW_SCHEME=1){
  288:1./aqed->Default()=128.802
  289:csin2thetaW=(0.222928,-0.00110708)
  290:cvev=(243.034,-3.75493)
}
One_Running_AlphaS::One_Running_AlphaS() {
  Setting \alpha_s according to PDF
  perturbative order 2
  \alpha_s(M_Z) = 0.118
}
```

```
 List of Particle Data
  IDName      kfc  MASS[<kfc>]   WIDTH[<kfc>]
IVE[<kfc>]  YUKAWA[<kfc>]
       d       1         0.01              0
         1              0
       u       2        0.005              0
         1              0
       s       3          0.2              0
         1              0
       c       4         1.42              0
```

```
List of Particle Containers
   IDName     kfc     Constituents
        l      90     {e-,e+,mu-,mu+}
        v      91     {ve,veb,vmu,vmub,vtau,vtaub}
        j      93     {d,db,u,ub,s,sb,c,cb,b,bb,G}
        Q      94     {d,db,u,ub,s,sb,c,cb,b,bb}
        r      99     {d,db,u,ub,s,sb,c,cb,b,bb,G}
```

```
Variations::InitialiseParametersVector(){
  Number of variations: 114
  Named variations:
  MUR0.5_MUF0.5_PDF261000
  MUR0.5_MUF1_PDF261000
  MUR1_MUF0.5_PDF261000
  MUR1_MUF1_PDF261000
  MUR1_MUF2_PDF261000
  MUR2_MUF1_PDF261000
```

# Simple DY

```
Process_Group::CalculateTotalXSec(): Calculate xs for '2_2__j__j__j__j__MPI' (A
misic)
Starting the calculation at 21:39:59. Lean back and enjoy ... .
3.99538e+10 pb +- ( 2.44306e+09 pb = 6.11471 % ) 5000 ( 7482 -> 66.8 % )
full optimization:  ( 0s elapsed / 52s left ) [21:40:00]
3.97496e+10 pb +- ( 1.71146e+09 pb = 4.30559 % ) 10000 ( 12591 -> 97.8 % )
full optimization:  ( 1s elapsed / 51s left ) [21:40:01]
3.90644e+10 pb +- ( 1.30884e+09 pb = 3.35048 % ) 15000 ( 17597 -> 99.8 % )
full optimization:  ( 2s elapsed / 50s left ) [21:40:01]
3.90628e+10 pb +- ( 1.0817e+09 pb = 2.76914 % ) 20000 ( 22597 -> 100 % )
```

MPI part

# Simple DY

```
Process_Group::CalculateTotalXSec(): Calculate xs for '2_2__j__j__e-__e+__QCD(BVI)' (Amegic)
Starting the calculation at 21:42:33. Lean back and enjoy ... .
#########################################################################
#                                                                       #
#                         You are using OneLOop                         #
#                                                                       #
# for the evaluation of 1-loop scalar 1-, 2-, 3- and 4-point functions #
#                                                                       #
# author: Andreas van Hameren <hamerenREMOVETHIS@ifj.edu.pl>            #
#   date: 2018-06-13                                                    #
#                                                                       #
# Please cite                                                           #
#    A. van Hameren,                                                    #
#      Comput.Phys.Commun. 182 (2011) 2427-2438, arXiv:1007.4716        #
#    A. van Hameren, C.G. Papadopoulos and R. Pittau,                   #
#      JHEP 0909:106,2009, arXiv:0903.4665                              #
# in publications with results obtained with the help of this program. #
#                                                                       #
#########################################################################
1838.46 pb +- ( 57.7728 pb = 3.14246 % ) 5000 ( 7828 -> 63.8 % )
full optimization:  ( 3s elapsed / 3m 40s left ) [21:42:37]
1836.29 pb +- ( 36.5361 pb = 1.98967 % ) 10000 ( 12967 -> 97.2 % )
full optimization:  ( 6s elapsed / 3m 36s left ) [21:42:40]
1851.24 pb +- ( 26.8835 pb = 1.45219 % ) 15000 ( 17973 -> 99.8 % )
full optimization:  ( 10s elapsed / 3m 32s left ) [21:42:44]
1859.4 pb +- ( 21.3492 pb = 1.14818 % ) 20000 ( 22973 -> 100 % )
```

Born + Virtual

# Simple DY

```
Process_Group::CalculateTotalXSec(): Calculate xs for '2_3__j__j__e-__e+__j__QCD(RS)' (Comix)
Starting the calculation at 21:46:07. Lean back and enjoy ... .
189.756 pb +- ( 7.73534 pb = 4.07646 % ) 5000 ( 7835 -> 63.8 % )
full optimization:  ( 4s elapsed / 4m 31s left ) [21:46:11]
185.839 pb +- ( 5.15317 pb = 2.77293 % ) 10000 ( 12973 -> 97.3 % )
full optimization:  ( 8s elapsed / 4m 27s left ) [21:46:15]
184.605 pb +- ( 3.93693 pb = 2.13262 % ) 15000 ( 17984 -> 99.7 % )
full optimization:  ( 12s elapsed / 4m 23s left ) [21:46:20]
184.667 pb +- ( 3.22922 pb = 1.74867 % ) 20000 ( 22984 -> 100 % )
full optimization:  ( 16s elapsed / 4m 19s left ) [21:46:24]
184.919 pb +- ( 2.75957 pb = 1.49232 % ) 25000 ( 27984 -> 100 % )
full optimization:  ( 21s elapsed / 4m 14s left ) [21:46:29]
184.689 pb +- ( 2.41782 pb = 1.30913 % ) 30000 ( 32984 -> 100 % )
full optimization:  ( 25s elapsed / 4m 10s left ) [21:46:33]
185.402 pb +- ( 1.93209 pb = 1.04211 % ) 40000 ( 42984 -> 100 % )
full optimization:  ( 33s elapsed / 4m 1s left ) [21:46:42]
185.644 pb +- ( 1.61869 pb = 0.871932 % ) 50000 ( 52984 -> 100 % )
full optimization:  ( 42s elapsed / 3m 51s left ) [21:46:50]
185.922 pb +- ( 1.40051 pb = 0.753278 % ) 60000 ( 62984 -> 100 % )
full optimization:  ( 50s elapsed / 3m 42s left ) [21:46:59]
186.341 pb +- ( 1.23935 pb = 0.665097 % ) 70000 ( 72984 -> 100 % )
full optimization:  ( 58s elapsed / 3m 34s left ) [21:47:07]
185.95 pb +- ( 1.11478 pb = 0.599505 % ) 80000 ( 82984 -> 100 % )
full optimization:  ( 1m 6s elapsed / 3m 25s left ) [21:47:16]
186.162 pb +- ( 1.01568 pb = 0.545588 % ) 90000 ( 92984 -> 100 % )
full optimization:  ( 1m 15s elapsed / 3m 17s left ) [21:47:24]
```

Real emission

# Simple DY gridpack

```
---------------------------------------------------------
  Event 101 ( 1 s total ) = 2.9088e+07 evts/day
In Event_Handler::Finish : Summarizing the run may take some time.
+------------------------------------------------------+
|                                                      |
|  Total XS is 1920.18 pb +- ( 187.992 pb = 9.79 % )  |
|                                                      |
+------------------------------------------------------+
Return_Value::PrintStatistics(): Statistics {
  Generated events: 101
  Retried events {
    From "Hadronization:Ahadic": 1 (113) -> 0.8 %
    From "Jet_Evolution:CSS": 3 (346) -> 0.8 %
  }
  Retried phases {
    From "Hadron_Decay_Handler::RejectExclusiveChannelsFromFragmentation": 1 (0) -> 1.
  }
}
------------------------------------------------------------------------
Please cite the publications listed in 'Sherpa_References.tex'.
  Extract the bibtex list by running 'get_bibtex Sherpa_References.tex'
  or email the file to 'slaclib2@slac.stanford.edu', subject 'generate'.
------------------------------------------------------------------------
Time: 10m 39s on Sun Mar 17 21:50:36 2024
```

Successful generation, 10mins for this process.

# Simple DY: event production

```
<I>  a good way to test the generated python file is to cross-check it with cmsDriver.py:
      cmsDriver.py A/B/python/sherpa_DYee_MASTER_cff.py \
       -s GEN -n 100 --no_exec --conditions auto:mc --eventcontent RAWSIM
```

```
[melu@lxplus804 Sherpa]$ ls
DYee_sherpack  DYee_workdir  README.md  Run.dat_DYee  cards  production  sherpack_generation.sh
```

```
[melu@lxplus804 Sherpa]$ ls DYee_sherpack/
Run.dat_DYee  sherpa_DYee_MASTER.md5  sherpa_DYee_MASTER.tgz  sherpa_DYee_MASTER_cff.py
```

DYee_workdir is the “CMSSW_12_4_18”

- cp DYee_sherpack/sherpa_DYee_MASTER_cff.py DYee_workdir/src/MY/PROJECT/python/
- cd DYee_workdir/src/
- cp ../../DYee_sherpack/sherpa_DYee_MASTER.tgz .
- cmsenv
- scram b
- cmsDriver.py MY/PROJECT/python/sherpa_DYee_MASTER_cff.py -s GEN -n 100 --no_exec --conditions auto:mc --eventcontent RAWSIM

# Simple DY: event production

```
[melu@lxplus804 src]$ ls
GeneratorInterface  MY  sherpa_DYee_MASTER_cff_py_GEN.py
```

- cmsRun sherpa_DYee_MASTER_cff_py_GEN.py

```
Begin processing the 100th record. Run 1, Event 100, LumiSection 1 on stream 0 at 17-Mar-2024 22:41:33.306 CET
  Event 100 ( 2 s total ) = 3.82301e+06 evts/day
In Event_Handler::Finish : Summarizing the run may take some time.
+-----------------------------------------------------+
|                                                     |
|  Total XS is 2282.69 pb +- ( 217.237 pb = 9.51 % )  |
|                                                     |
+-----------------------------------------------------+
  Event 100 ( 2 s total ) = 3.82301e+06 evts/day
In Event_Handler::Finish : Summarizing the run may take some time.
+-----------------------------------------------------+
|                                                     |
|  Total XS is 2282.69 pb +- ( 217.237 pb = 9.51 % )  |
|                                                     |
+-----------------------------------------------------+



------------------------------------
GenXsecAnalyzer:
------------------------------------
Before Filter: total cross section = 2.283e+03 +- 2.172e+02 pb
Filter efficiency (taking into account weights)= (1.66865e+06) / (1.66865e+06) = 1.000e+00 +- 0.000e+00
Filter efficiency (event-level)= (100) / (100) = 1.000e+00 +- 0.000e+00    [TO BE USED IN MCM]

After filter: final cross section = 2.283e+03 +- 2.172e+02 pb
After filter: final fraction of events with negative weights = 1.000e-02 +- 9.950e-05
After filter: final equivalent lumi for 1M events (1/fb) = 4.207e-01 +- 3.924e-02
```

# Simple DY: event production

```
[melu@lxplus804 src]$ ls
 GeneratorInterface                                  Result                  sherpa_DYee_MASTER.tgz
'MIG_P+P+_13000_LHA[NNPDF30_nnlo_as_0118]_2.db'    Result.db               sherpa_DYee_MASTER_cff_py_GEN.py
 MPI_Cross_Sections.dat                              Run.dat                 sherpa_DYee_MASTER_cff_py_GEN.root
 MY                                                  Sherpa_References.tex
 Process                                             sherpa_DYee_MASTER.tar
```

- curl -O https://raw.githubusercontent.com/Offshell-Workshop-LPC/Sherpa-tutorial/main/info.py

```
[melu@lxplus804 src]$ python3 info.py
#event: 100
Evt  0
pt: 0.0 pdgid: 2212 Status: 4
pt: 0.0 pdgid: 2212 Status: 11
pt: 0.0 pdgid: 2212 Status: 4
pt: 0.0 pdgid: 2212 Status: 11
pt: 1.7457729578018188 pdgid: 21 Status: 11
pt: 0.9126977920532227 pdgid: 3 Status: 11
pt: 2.02317214012146 pdgid: 21 Status: 11
pt: 0.3245411515235901 pdgid: 2203 Status: 11
pt: 0.2244596630334854 pdgid: 1 Status: 11
pt: 0.08571519702672958 pdgid: -3 Status: 11
pt: 2.16273832321167 pdgid: 2 Status: 11
pt: 3.98333740234375 pdgid: 2 Status: 11
pt: 1.414599762680054 pdgid: 21 Status: 11
pt: 1.3599739074707031 pdgid: 2103 Status: 11
pt: 0.6708537340164185 pdgid: -2 Status: 11
```

Particle list in the event after parton shower/hadronization.

You can generate more events and try get the kinematics.

# ggH (H➔$\gamma\gamma$)

Higgs process can be found in https://sherpa.hepforge.org/doc/SHERPA-MC-2.2.15.html#HJets.

```
(processes){
  Process 93 93 -> 22 22;
  NLO_QCD_Mode Fixed_Order;
  NLO_QCD_Part BVIRS;
  Order (*,2); Enable_MHV 12;
  Loop_Generator LGEN;
  Integrator PS2;
  RS_Integrator PS3;
  End process;
}(processes)

(selector){
  HiggsFinder 40 30 2.5 100 150;
  IsolationCut 22 0.4 2 0.025;
}(selector)
```

- Fixed-order QCD (a pure QCD process, no Matching is needed)
- NLO_QCD_part: In case of fixed-order NLO calculations this switch specifies which pieces of a QCD NLO calculation are computed
  - B: born, V: virtual, I: subtraction term, RS: real emission
- Include the interference between continuum gg->$\gamma\gamma$ and ggH➔$\gamma\gamma$
- "Enable_MHV 12" ➔ hard coded module for Higgs interference calculation
- HiggsFinder: valid for diphoton process, here require the two leading photons with pt>40/30 GeV, |eta| < 2.5, and with invariant mass ~ [100, 150] GeV ➔ change this to require the off-shell Higgs
- Isolation cut, refer to Frixione isolation cone

# ggH (H→$\gamma\gamma$)

Higgs process can be found in https://sherpa.hepforge.org/doc/SHERPA-MC-2.2.15.html#HJets.

```
(run){
  % scales, tags for scale variations
  EVENTS 1M; LGEN:=Higgs;
  EVENT_GENERATION_MODE W;
  AMEGIC_ALLOW_MAPPING 0;
  ME_SIGNAL_GENERATOR Amegic LGEN;
  SCALES VAR{Abs2(p[2]+p[3])};

  % tags for process setup
  YUKAWA[4] 1.42; YUKAWA[5] 4.8;
  YUKAWA[15] 1.777;
  EW_SCHEME 3;

  % collider setup
  BEAM_1 2212; BEAM_ENERGY_1 = 6500.;
  BEAM_2 2212; BEAM_ENERGY_2 = 6500.;

  PDF_LIBRARY LHAPDFSherpa;
  PDF_SET NNPDF30_nnlo_as_0118;
  PDF_VARIATIONS NNPDF30_nnlo_as_0118[all];

  % HIGGS_INTERFERENCE_MODE 1;
}(run)
```

- Setup of pdf, EW parameters, collision energy …

```
2_2__j__j__P__P__QCD(BVI) : 0.0478947 pb +- ( 0.000223334 pb = 0.466303 % )  ex
p. eff: 3.23193 %
2_3__j__j__P__P__j__QCD(RS) : -0.00248694 pb +- ( 0.000133576 pb = 5.37108 % )
 exp. eff: 0.00616454 %
|
|  Total XS is 0.0439673 pb +- ( 0.00699675 pb = 15.91 % )  |
|
```

# gg→4l with Higgs contribution

```
(run){
  % general settings
  EVENTS 1M;

  % scales, tags for scale variations
  FSF:=1.; RSF:=1.; QSF:=1.;
  SCALES STRICT_METS{FSF*MU_F2}{RSF*MU_R2}{QSF*MU_Q2};
  CORE_SCALE VAR{Abs2(p[2]+p[3]+p[4]+p[5])/4.0};
  EXCLUSIVE_CLUSTER_MODE 1;

  % tags for process setup
  NJET:=1; QCUT:=20;

  % me generator settings
  ME_SIGNAL_GENERATOR Amegic LOOPGEN;
  EVENT_GENERATION_MODE Weighted;
  LOOPGEN:=OpenLoops;
  AMEGIC_ALLOW_MAPPING 0;
  % the following phase space libraries have to be generated with the
  % corresponding qq->llll setup (RUNDATA=Run.tree.dat) first;
  % they will appear in Process/Amegic/lib/libProc_fsrchannels*.so
  SHERPA_LDADD Proc_fsrchannels4 Proc_fsrchannels5;

  % collider setup
  BEAM_1 2212; BEAM_ENERGY_1 6500.;
  BEAM_2 2212; BEAM_ENERGY_2 6500.;
}(run)
```

```
(processes){
  Process 93 93 -> 90 90 90 90 93{1};
  CKKW sqr(QCUT/E_CMS);
  Order (2,4) {4};
  Order (3,4) {5};
  Integrator fsrchannels4 {4};
  Integrator fsrchannels5 {5};
  Enable_MHV 10; # initialises external process
  Loop_Generator LOOPGEN;
  Integration_Error 0.02 {5};
  End process;
}(processes)

(selector){
  Mass 11 -11 10.0 E_CMS;
  Mass 13 -13 10.0 E_CMS;
  Mass 15 -15 10.0 E_CMS;
}(selector)
```

hard coded module for Higgs interference calculation

Just put the card here, not able to run yet, the external libs should be included during compiling sherpa, which seems not the case in CMSSW

# gg→4l, Higgs only

Sherpa interface with openloops, we can add corresponding openloops libs to get the desired process, i.e., gg→4l with Higgs only contribution

| | | |
|---|---|---|
| pplll2_onlyh | gg → llll | Approximation 'onlyh'; Loop-induced production of four leptons (all combinations of leptons and neutrinos) in gluon fusion: only diagrams which contain a Higgs Yukawa coupling |
| ppllllj | pp → llllj | Production of four leptons (all combinations of leptons and neutrinos) and a jet. |
| ppllllj2 | pp → llllj | Squared one-loop matrix elements for four lepton production (all combinations of leptons and neutrinos); gluon fusion (+qq splitting), i.e. gggllll and gqqllll where the four-lepton system is directly coupled to the quark loop. |
| ppllllj2_onlyh | gg → llllj | Approximation 'onlyh'; Loop-induced production of four leptons (all combinations of leptons and neutrinos) in gluon fusion (+qq splitting), i.e. gggllll and gqqllll: only diagrams which contain a Higgs Yukawa coupling |

# gg→4l, Higgs only

```
(run){
  % general settings
  EVENTS 1M;

  % scales, tags for scale variations
  FSF:=1.; RSF:=1.; QSF:=1.;
  SCALES STRICT_METS{FSF*MU_F2}{RSF*MU_R2}{QSF*MU_Q2};
  CORE_SCALE VAR{Abs2(p[2]+p[3]+p[4]+p[5])/4.0};
  EXCLUSIVE_CLUSTER_MODE 1;

  % tags for process setup
  NJET:=1; QCUT:=20;

  % me generator settings
  ME_SIGNAL_GENERATOR Amegic LOOPGEN;
  EVENT_GENERATION_MODE Weighted;
  LOOPGEN:=OpenLoops;
  AMEGIC_ALLOW_MAPPING 0;
  % the following phase space libraries have to be generated with the
  % corresponding qq->llll setup (RUNDATA=Run.tree.dat) first;
  % they will appear in Process/Amegic/lib/libProc_fsrchannels*.so
  SHERPA_LDADD Proc_fsrchannels4 Proc_fsrchannels5;
  OL_PARAMETERS preset 2 allowed_libs pplllll2_onlyh,ppllllj2_onlyh;
```

```
  % collider setup
  BEAM_1 2212; BEAM_ENERGY_1 6500.;
  BEAM_2 2212; BEAM_ENERGY_2 6500.;
}(run)


(processes){
  Process 93 93 -> 90 90 90 90 93{1};
  CKKW sqr(QCUT/E_CMS);
  Order (2,4) {4};
  Order (3,4) {5};
  Integrator fsrchannels4 {4};
  Integrator fsrchannels5 {5};
  Enable_MHV 10; # initialises external process
  Loop_Generator LOOPGEN;
  Integration_Error 0.02 {5};
  End process;
}(processes)

(selector){
  Mass 11 -11 10.0 E_CMS;
  Mass 13 -13 10.0 E_CMS;
  Mass 15 -15 10.0 E_CMS;
}(selector)
```

# ttH

```
(run){
  # generator parameters
  EVENTS 0; LGEN:=TTH;
  ME_SIGNAL_GENERATOR Amegic LGEN;
  HARD_DECAYS On;
  % particle properties (ME widths need to be zero if external)
  WIDTH[6] 0; WIDTH[6] 0;
  STABLE[25] 0; WIDTH[25] 0.;

  % settings for hard decays
  HDH_STATUS[25,22,22] 2;

  # physics parameters
  SCALES VAR{sqr(175+125/2)};
  PDF_LIBRARY LHAPDFSherpa;
  PDF_SET MSTW2008nlo90cl;
  USE_PDF_ALPHAS 1;

  # collider parameters
  BEAM_1 2212; BEAM_ENERGY_1 6500;
  BEAM_2 2212; BEAM_ENERGY_2 6500;
}(run);

(processes){
  Process 93 93 -> 25 6 -6;
  NLO_QCD_Mode MC@NLO;
  Loop_Generator LGEN;
  Order (*,1);
  End process;
}(processes);
```

Process 93 93 -> 25 6 -6;
➡ Higgs is produced on-shell

STABLE[25] 0; WIDTH[25] 0.;
➡ set Higgs to unstable

HARD_DECAYS On;
HDH_STATUS[25,22,22] 2;
➡ force Higgs decays to diphoton

# Summary

- Sherpa is a very powerful and automated generator, especially in the high multiplicity production
- Sherpa is integrated into CMSSW and ready for use
- For some specific processes, further development is needed in CMS side, i.e., including the necessary libs
- CMS doesn't use sherpa that much, a lot of space for contributions, for sure with the help of the sherpa authors

Thanks!