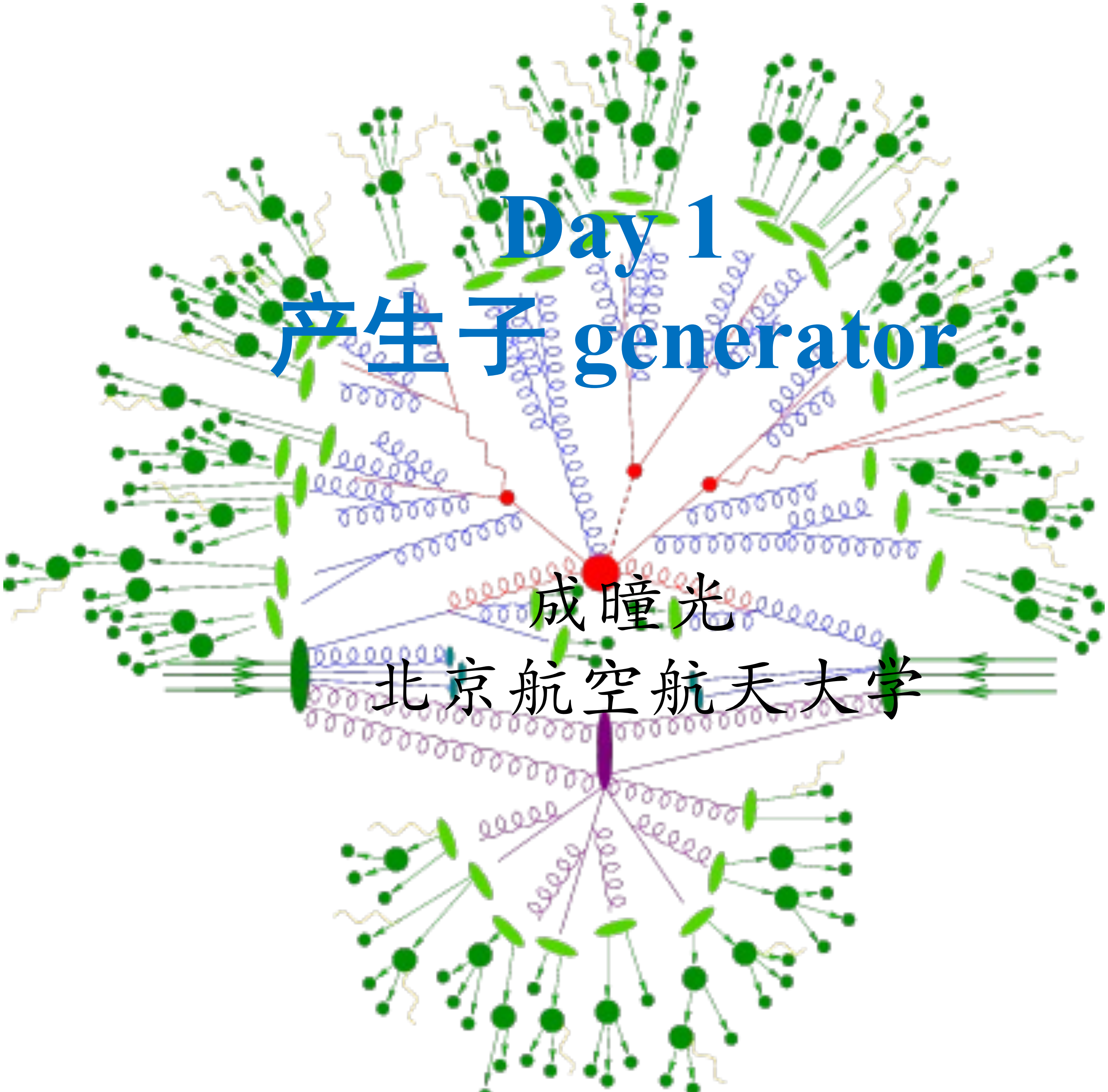
Day 1
产生子 generator



成瞳光

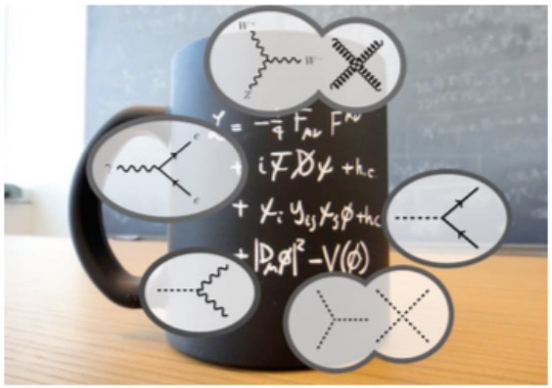
北京航空航天大学

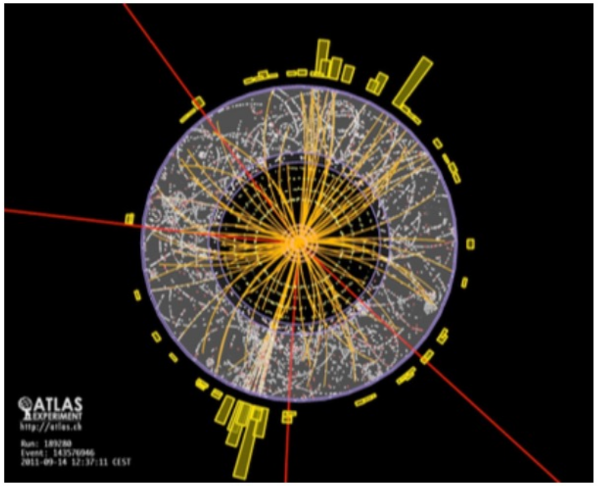
Reference

- Generator (第一届中国CMS冬令营)
  https://indico.ihep.ac.cn/event/15418/timetable/?view=standard#10-generator-basics-hands-on
  https://indico.ihep.ac.cn/event/15418/timetable/?view=standard#14-generatorsimulation-hands-o
- Tutorials on EFT tools
  (The 2021 EFT School on Collider Phenomenology)
  https://indico.ihep.ac.cn/event/13633/timetable/?view=standard_inline_minutes#16-tutorials-on-eft-tools
- iSTEP 2019
  https://indico.ihep.ac.cn/event/9898/timetable/?view=standard#7-phd

Why generators

Theory | **Monte Carlo Simulation** | **Data**

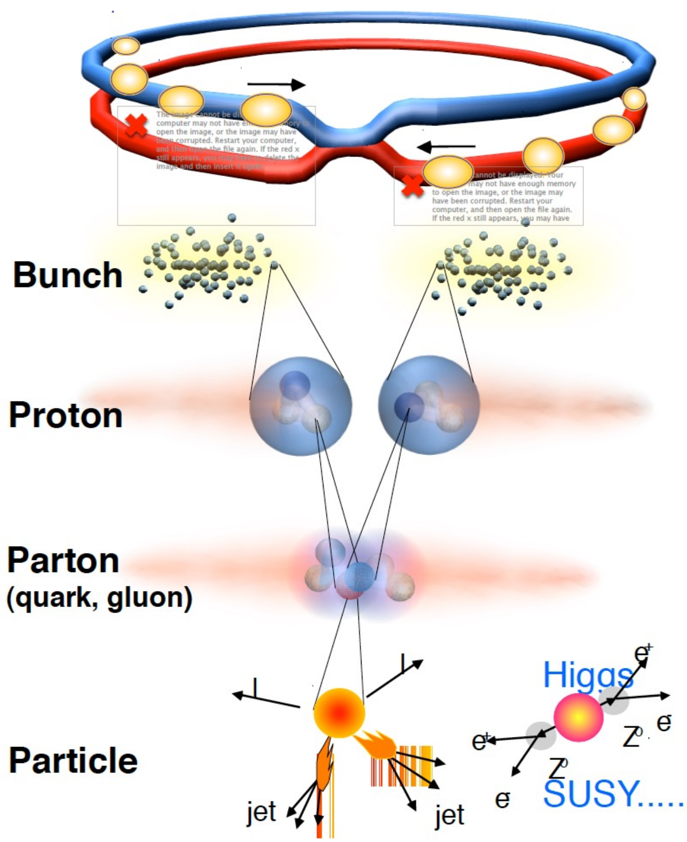


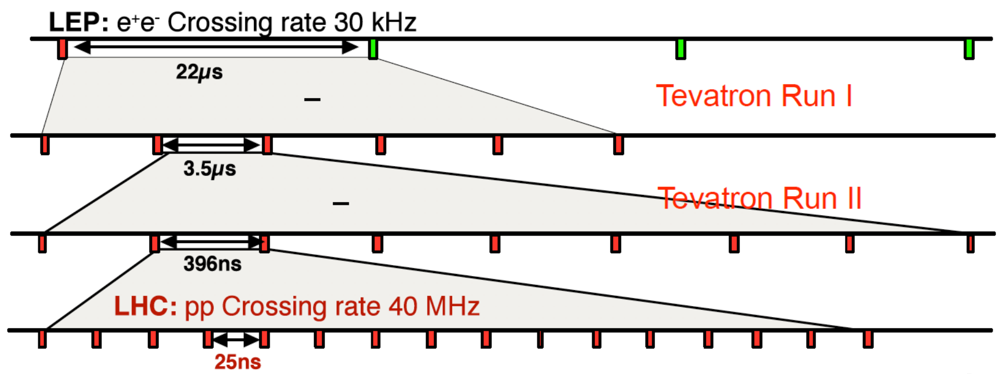


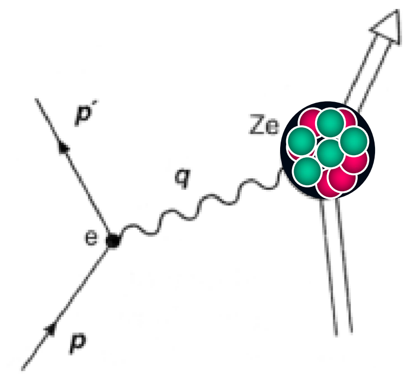
Bridge between theory and data :
generate events based on Monte Carlo (MC) method

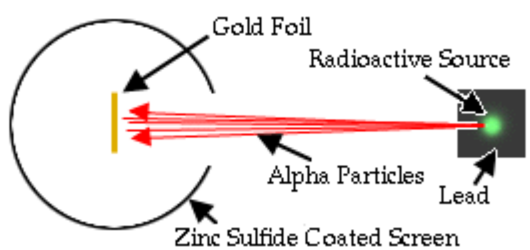
- ❑ study behavior of new physics processes (undiscovered in data)
- ❑ data/MC simulation comparison on (well)-known processes : performance checking/detector calibration/background estimation
- ❑ experiment/analysis design, feasibility and performance prediction

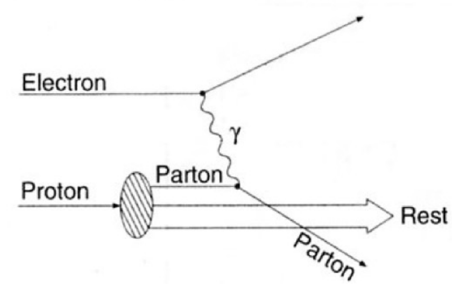
Physics from particle collisions



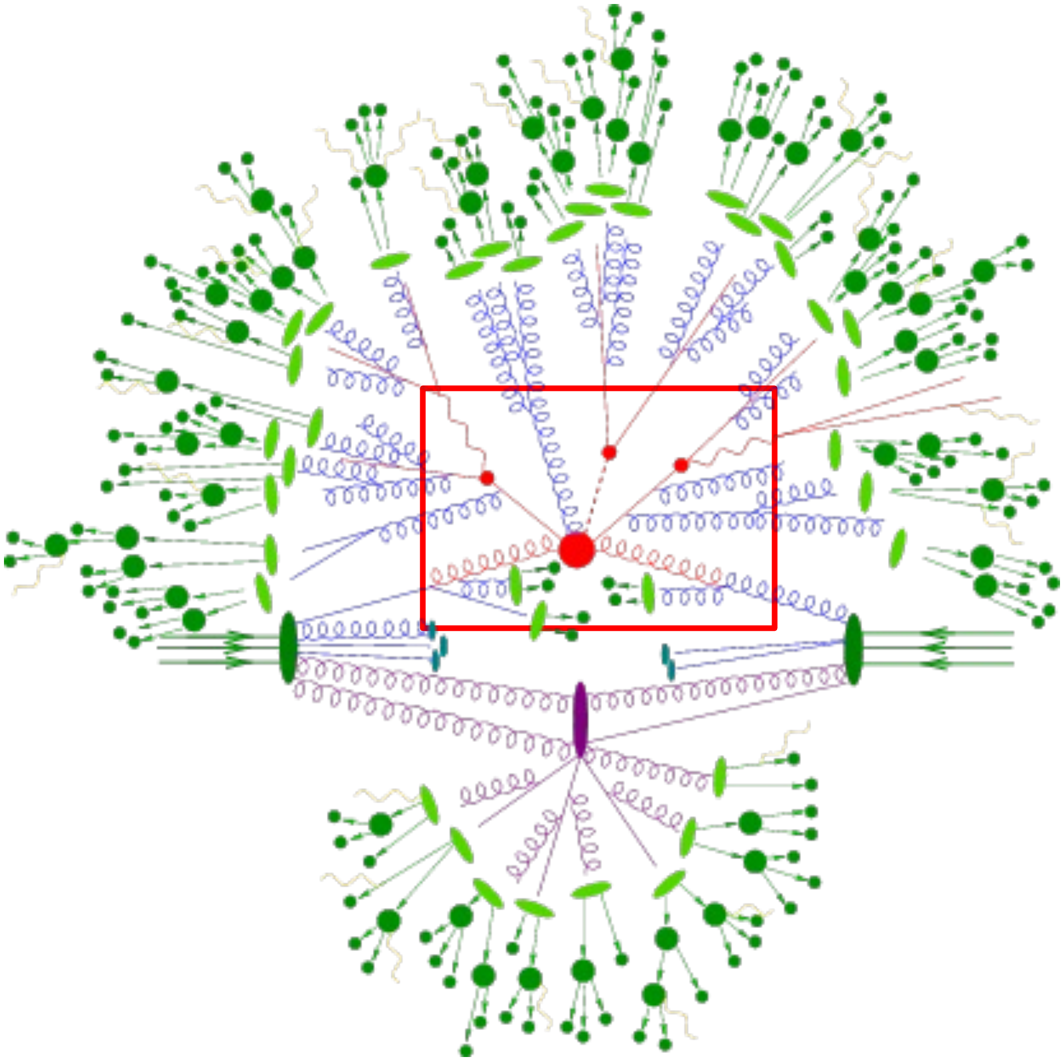






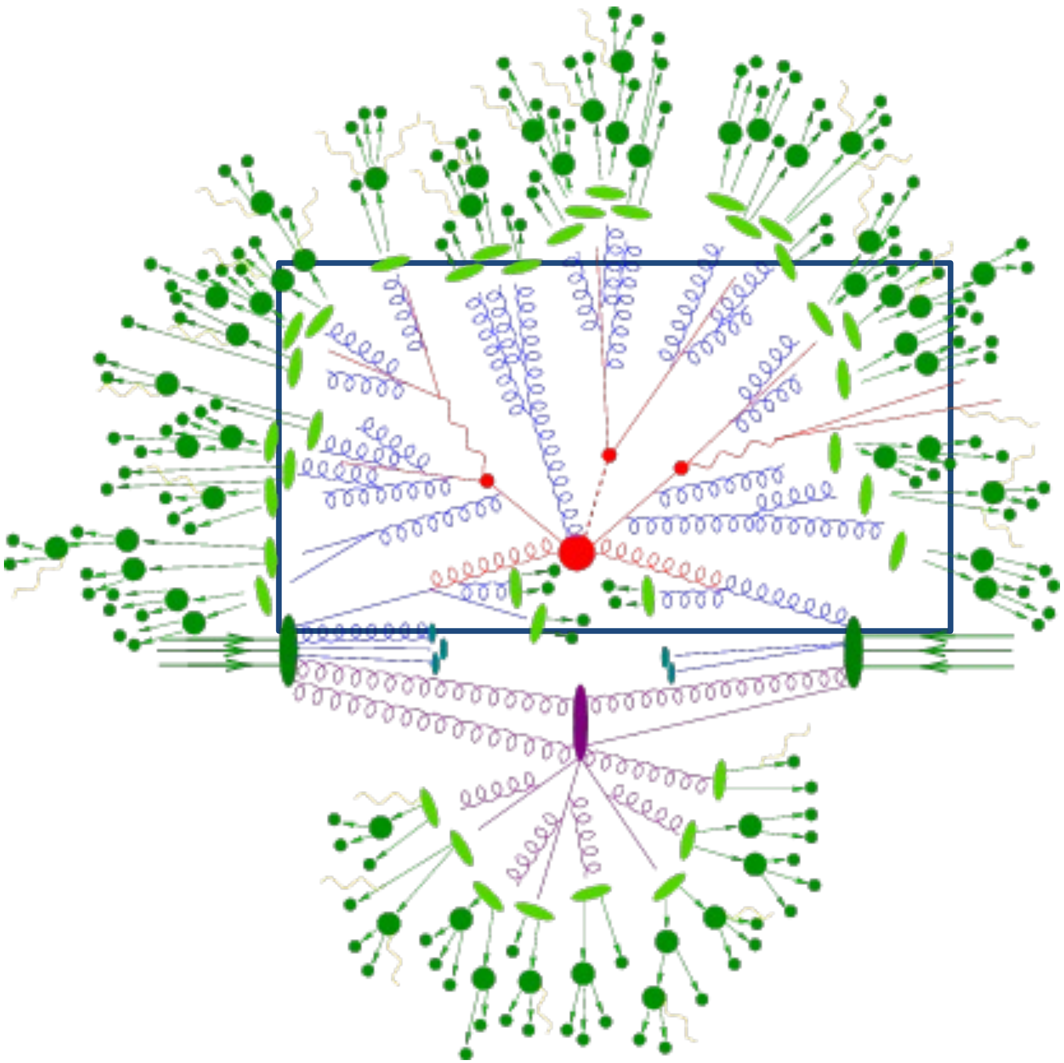


Proton-(anti)Proton collisions



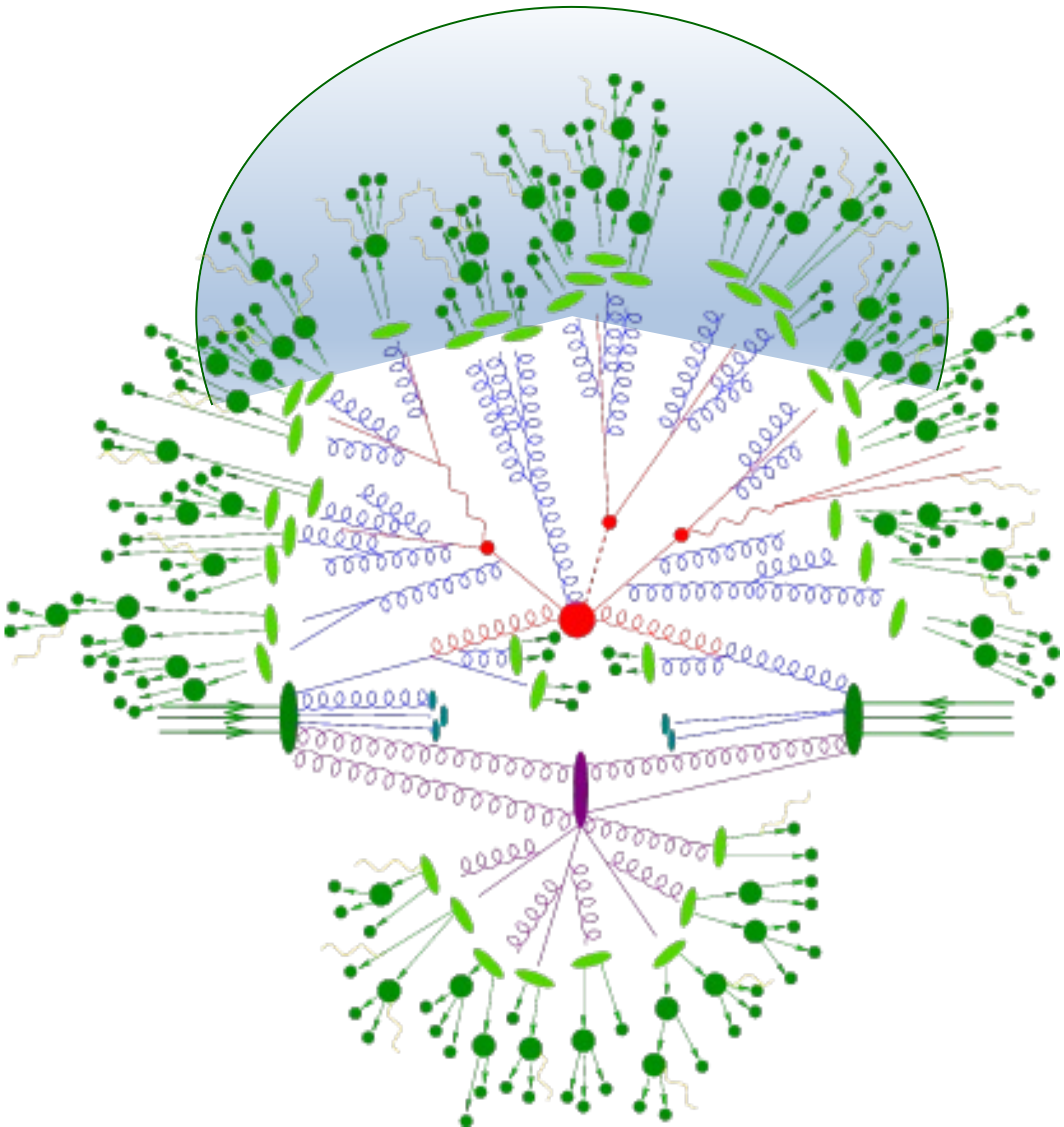
Hard scattering

Proton-(anti)Proton collisions



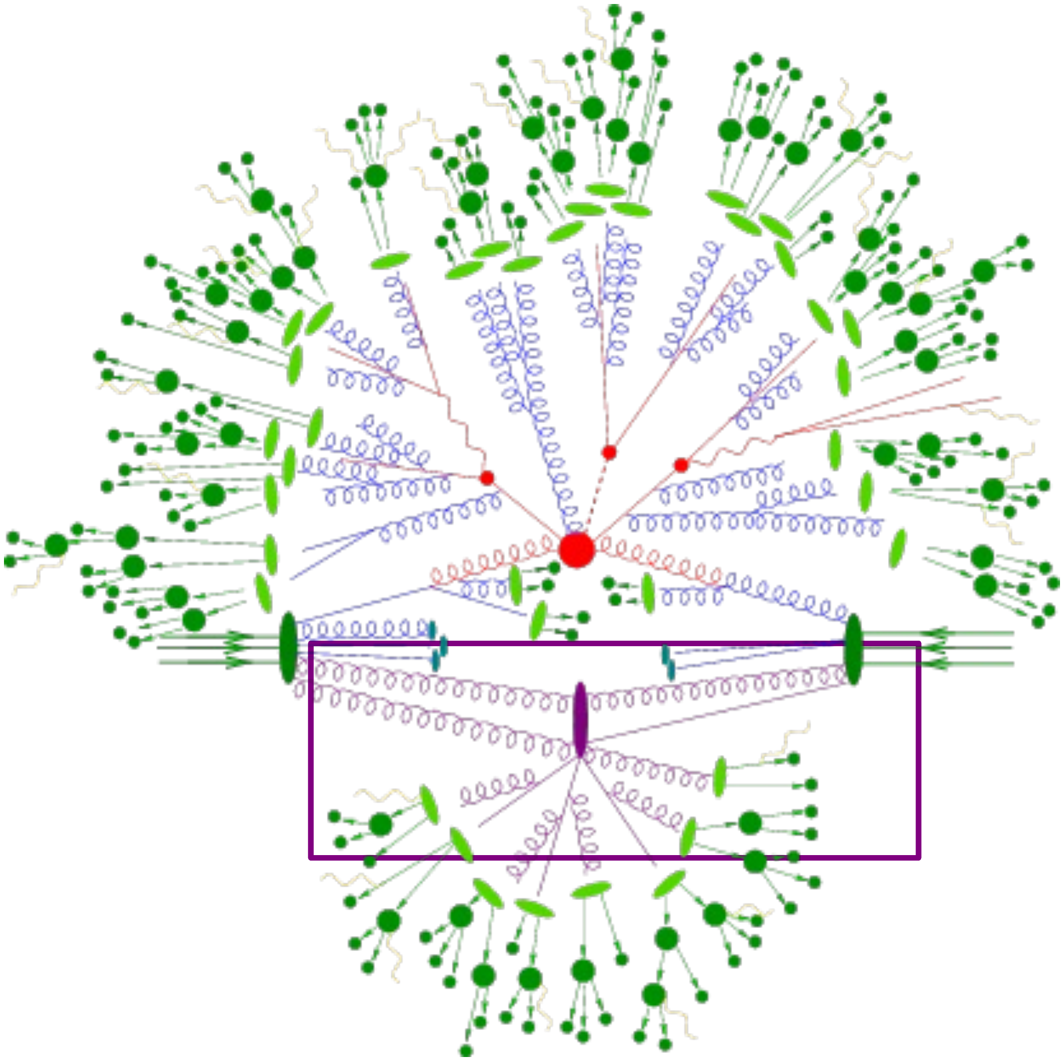
Parton shower

Proton-(anti)Proton collisions



Hadronization

Proton-(anti)Proton collisions



Underlying event

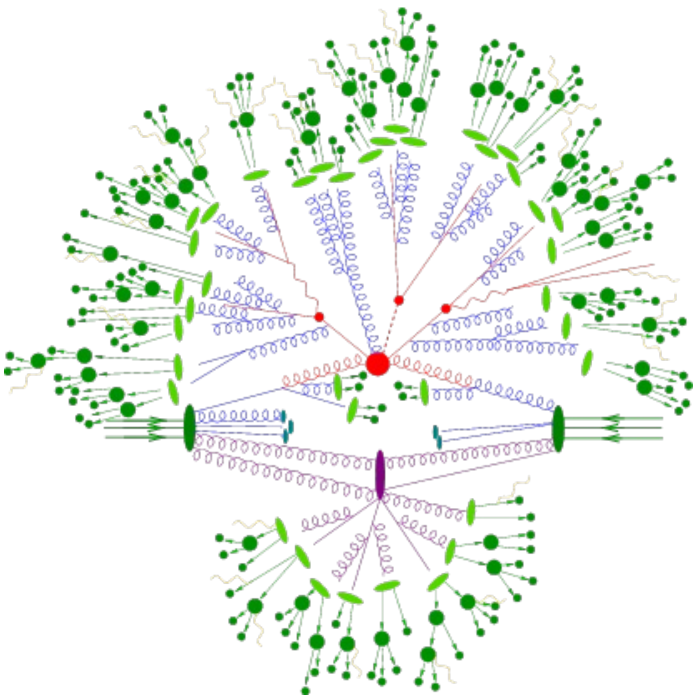
Proton-(anti)Proton collisions

MadGraph5_aMC@NLO	PYTHIA8	
Hard scattering ⇒	Parton shower ⇒	Hadronisation

$$\sigma_{pp\to X} = \sum_{ab} \int dx_1 dx_2 d\Pi_X \, f_{a/p}(x_1, \mu_F)\, f_{b/p}(x_2, \mu_F)\, \hat{\sigma}_{ab\to X}(\hat{s}, \mu_F, \mu_R)$$

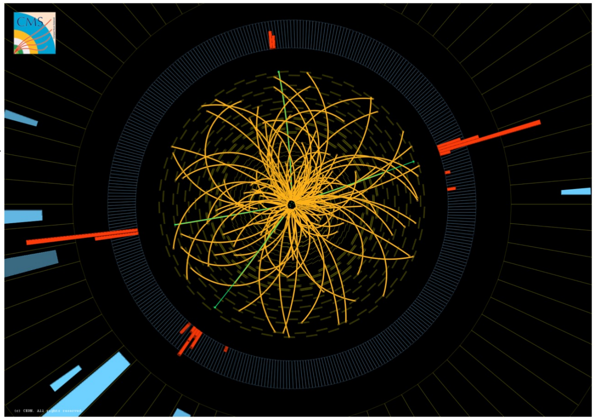
	phase space Integral	parton distribution functions	partonic cross section
	complex for many body final states	non-perturbative fitted from data CTEQ, NNPDF, MSTW,…	Matrix element $\lvert \mathcal{M}_{ab\to X}\rvert^2$ LO, NLO, NNLO
MG5:	**Monte Carlo numerical integration**	**PDF libraries e.g. LHAPDF or internal**	**Helicity amplitudes, Loop integral libraries**

Proton-(anti)Proton collisions



simulation : GEANT
digitization, reconstruction

Delphes



Madgraph: Hands-on

generate process ⇒ output ⇒ launch

```
MG5_aMC>tutorial
========== Tutorial ==========

        You have entered tutorial mode. This will introduce you to the main
        syntax options of MadGraph5_aMC@NLO.

        To learn more about the different options for a command, you can use
        MG5_aMC>help A_CMD
        To see a list of all commands, use
        MG5_aMC>help

        The goal of this tutorial is to learn how to generate a process and to
        produce the output for MadEvent. In this part we will learn
        a) How to generate a process
        b) How to create output for MadEvent
        c) How to run the MadEvent output

        Let's start with the first point, how to generate a process:
        MG5_aMC>generate p p > t t~
        Note that a space is mandatory between the particle names.
```

Madgraph: Hands-on

generate process ⇒ output ⇒ launch

- display particles, display multiparticles
  - define multi-particles: e.g., define lep+ = e+ mu+ ta+
- display diagrams
- add process
- output NAME_OF_OUTPUT
- exit

Madgraph: Hands-on

generate process ⇒ output ⇒ launch

- Cards
  - proc_card_mg5.dat:
    commands used to generate process folder
  - run_card.dat:
    set up run parameters
  - param_card.dat:
    model input parameters
  - pythia8_card.dat:
    parton shower settings

- bin: python executable to generate events

Madgraph: Hands-on

generate process ⇒ output ⇒ launch

- ❑ bin: python executable to generate events

- ❑ ./bin/mg5_aMC then launch NAME_OF_OUTPUT

```
/=================== Description ===================|============= values ==============|===== other options =====\
| 1. Choose the shower/hadronization program        |         shower = OFF             |     Pythia8             |
| 2. Choose the detector simulation program         |       detector = OFF             |     Delphes             |
| 3. Choose an analysis package (plot/convert)      |       analysis = ExRoot          |     OFF                 |
| 4. Decay onshell particles                        |        madspin = OFF             |     ON|onshell|full     |
| 5. Add weights to events for new hypp.            |       reweight = OFF             |     ON                  |
\=========================================================================================================================/
```

```
/--------------------------------------------------------------\
|  1. param    : param_card.dat                                 |
|  2. run      : run_card.dat                                   |
|  3. pythia8  : pythia8_card.dat                               |
|  4. delphes  : delphes_card.dat                               |
\--------------------------------------------------------------/
```

Madgraph: Hands-on

generate process ⇒ output ⇒ launch

- ❑ bin: python executable to generate events
- ❑ ./bin/mg5_aMC then launch NAME_OF_OUTPUT

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\=========================================================================================================================/
```

```
/------------------------------------------------------------\
|  1. param    : param_card.dat                               |
|  2. run      : run_card.dat                                 |
|  3. pythia8  : pythia8_card.dat                             |
|  4. delphes  : delphes_card.dat                             |
\------------------------------------------------------------/
```

Madgraph: LHE output (matrix element)

status: -1 incoming, 2 intermediate, 1 final state particle

4-vector (px, py, pz, energy) and mass

```
<event>
 5      1 +2.6351600e+03 9.07160600e+01 7.54677100e-03 1.30112700e-01
       -2 -1    0    0    0  501 -0.0000000000e+00 +0.0000000000e+00 +2.3607368840e+02 2.3607368840e+02 0.0000000000e+00 0.0000e+00 1.0000e+00
        2 -1    0    0  501    0 +0.0000000000e+00 -0.0000000000e+00 -8.7148676183e+00 8.7148676183e+00 0.0000000000e+00 0.0000e+00 -1.0000e+00
       23  2    1    2    0    0 +0.0000000000e+00 +0.0000000000e+00 +2.2735882078e+02 2.4478855602e+02 9.0716061259e+01 0.0000e+00 0.0000e+00
      -15  1    3    3    0    0 +1.1166069998e+01 -3.6540230108e+01 +1.7946313231e+02 1.8349398661e+02 1.7770000000e+00 0.0000e+00 1.0000e+00
       15  1    3    3    0    0 -1.1166069998e+01 +3.6540230108e+01 +4.7895688476e+01 6.1294569410e+01 1.7770000000e+00 0.0000e+00 -1.0000e+00
<mgrwt>
<rscale>  0 0.90716061E+02</rscale>
<asrwt>0</asrwt>
<pdfrwt beam="2">  1        2 0.13407490E-02 0.90716061E+02</pdfrwt>
<pdfrwt beam="1">  1       -2 0.36319024E-01 0.90716061E+02</pdfrwt>
<totfact> 0.58531905E+04</totfact>
</mgrwt>
```

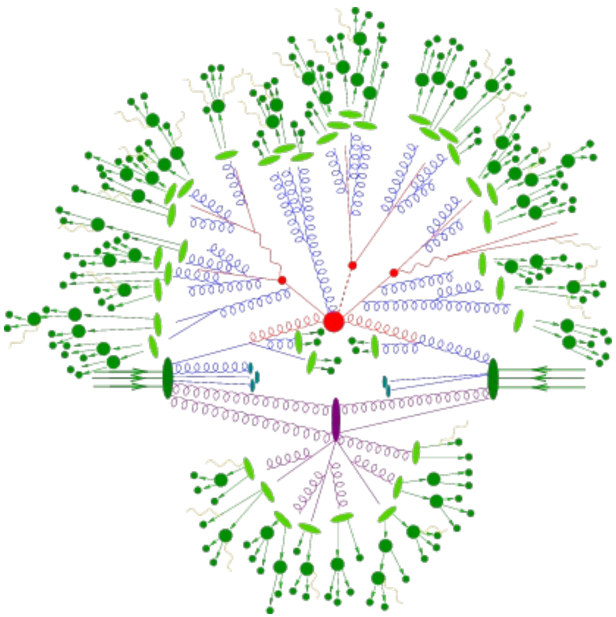
Madgraph: pythia output HEPMC

Pythia.org

Welcome to PYTHIA

PYTHIA is a program for the generation of high-energy physics collision events, i.e. for the description of collisions at high energies between electrons, protons, photons and heavy nuclei. It contains theory and models for a number of physics aspects, including hard and soft interactions, parton distributions, initial- and final-state parton showers, multiparton interactions, fragmentation and decay. It is largely based on original research, but also borrows many formulae and other knowledge from the literature. As such it is categorized as a **general purpose Monte Carlo event generator**.

Download and install PYTHIA 8.310



HEPMC data are huge!

Pythia : matrix element and parton shower

Pythia.org

Welcome to PYTHIA

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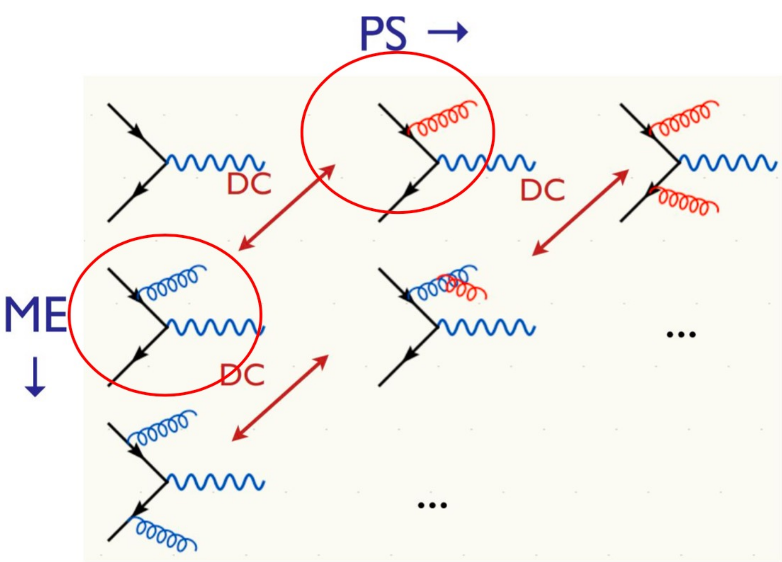
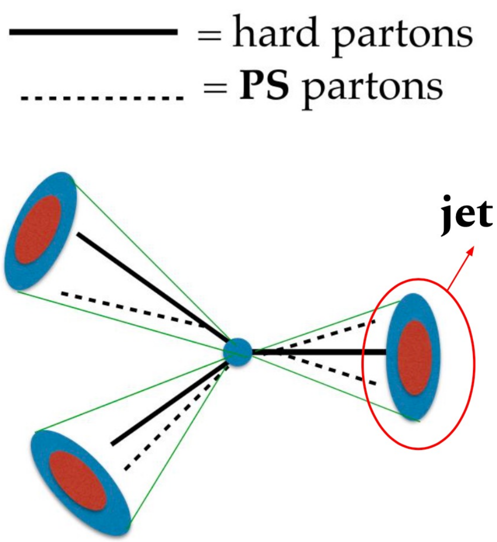
Download and install PYTHIA 8.310



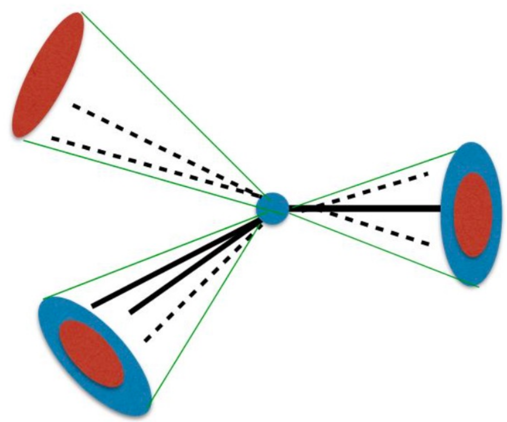
- ❑ Pythia itself is also a generator
- ❑ Pythia does the parton shower and hadronization
- ❑ Pythia provides "match" between matrix element and parton shower algorithm: MLM (LO) FxFx (NLO)

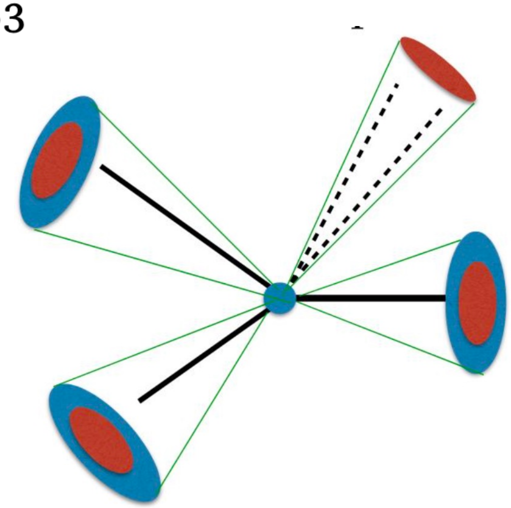
Pythia : matrix element and parton shower

https://pythia.org/latest-manual/JetMatching.html




```
generate p p > e+ e- @0
add process p p > e+ e- j @1
add process p p > e+ e- j j @2
add process p p > e+ e- j j j @3
```





Pythia : matrix element and parton shower

https://pythia.org/latest-manual/JetMatching.html

```
generator = cms.EDFilter("Pythia8HadronizerFilter",
    maxEventsToPrint = cms.untracked.int32(1),
    pythiaPylistVerbosity = cms.untracked.int32(1),
    filterEfficiency = cms.untracked.double(1.0),
    pythiaHepMCVerbosity = cms.untracked.bool(False),
    comEnergy = cms.double(13000.),
    PythiaParameters = cms.PSet(
        pythia8CommonSettingsBlock,
        pythia8CP5SettingsBlock,
        pythia8PSweightsSettingsBlock,
        processParameters = cms.vstring(
            'JetMatching:setMad = off',
            'JetMatching:scheme = 1',
            'JetMatching:merge = on',
            'JetMatching:jetAlgorithm = 2',
            'JetMatching:etaJetMax = 5.',
            'JetMatching:coneRadius = 1.',
            'JetMatching:slowJetPower = 1',
            'JetMatching:qCut = 19.', #this is the actual merging scale
            'JetMatching:nQmatch = 5', #4 corresponds to 4-flavour scheme (no matching of b-quarks), 5 for 5-
flavour scheme
            'JetMatching:nJetMax = 4', #number of partons in born matrix element for highest multiplicity
            'JetMatching:doShowerKt = off', #off for MLM matching, turn on for shower-kT matching
            'TimeShower:mMaxGamma = 4.0',
        ),
        parameterSets = cms.vstring('pythia8CommonSettings',
                                    'pythia8CP5Settings',
                                    'pythia8PSweightsSettings',
                                    'processParameters',
                                    )
    )
)
```

Pythia configuration used in CMS MC event generation

Madgraph: model

- ❑ Default model is sm (standard model)
- ❑ Can import other models
  - ❑ can include new particles, new interactions
- ❑ Universal FeynRules Output (UFO) model (just a python module)

MG5_aMC> import model SMEFTsim_topU3l_MwScheme_UFO

- ❑ Automatically downloaded from FeynRules database
  https://feynrules.irmp.ucl.ac.be
- ❑ Feynrules：input Mathematica formula to output UFO model

Madgraph: model

```
QCD = CouplingOrder(name = 'QCD',
                    hierarchy = 1,
                    expansion_order = -1,
                    perturbative_expansion = 1)

QED = CouplingOrder(name = 'QED',
                    hierarchy = 2,
                    expansion_order = -1,
                    perturbative_expansion =0)
```

coupling order.py
e.g.,
generate p p > lep+ lep- QCD=0 QED=2

```
py3_model.pkl                   restrict_no_masses.dat
restrict_c_mass.dat             restrict_no_tau_mass.dat
restrict_ckm.dat                restrict_no_widths.dat
restrict_default.dat            restrict_parallel_test.dat
restrict_lepton_masses.dat      restrict_test.dat
restrict_no_b_mass.dat          restrict_zeromass_ckm.dat
```

restrict_XYZ.dat: restriction card
parameters fixed or =0 to simplify model
e.g., import model loop_sm-no_b_mass

Hands-on: additional slide

- ❑ Madgraph can generate NLO events
  generate p p > lep+ lep- QCD=0 QED=2 [QCD]

- ❑ Can exclude a particle from a process
  e.g.,
  1. p p > e+ e- (all contributions)
  2. p p > z, z > e+ e- (z is on-shell)
  3. p p > z > e+ e- (z is on-shell or off-shell)
  4. p p > e+ e- $z (forbids s-channel z to be on-shell)
  5. p p > e+ e- /z (forbids any z)

<u>**Excercises:**</u>

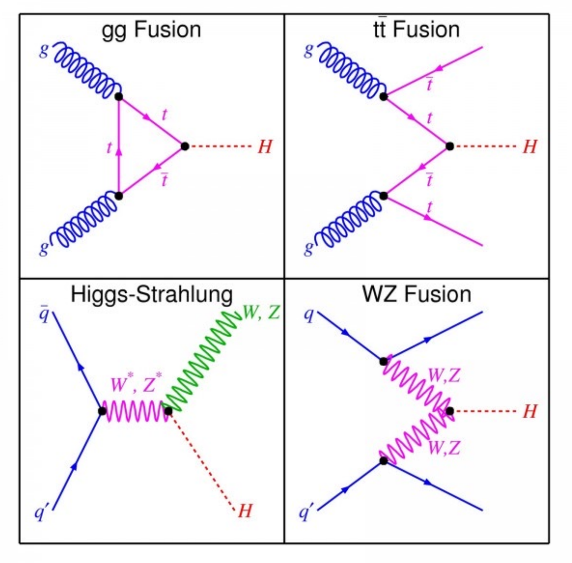
1. <u>**Compare Feynman diagram between LO and NLO DY**</u>
2. <u>**Compare 1-5 diagrams DY processes**</u>

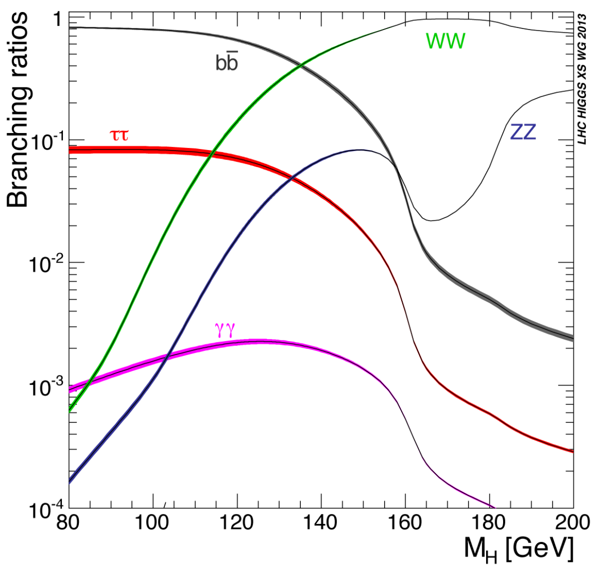
Hands-on: homework

Consider standard model Higgs with mass at 125GeV

- ❑ Calculate Higgs production cross sections in pp collision at different collision energy (7TeV 8TeV 14TeV etc..)

- ❑ Calculate Higgs decay width and branch ratio





Hands-on: homework

Results from Higgs cross section working group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

Figures : link

Tables : cross section link
decay width / branching ratio link

Hint :

- Does model standard model have gluon gluon Higgs vertex?
  If not, you may consider using model heft
- Can 125GeV Higgs decay to two Z or two W bosons in Madgraph?
  (Z mass is about 91GeV, W mass is about 80GeV)
  Anything you can do about it to get the branch ratio of HZZ/HWW decay?

Links might useful

Madgraph syntax

https://www.niu.edu/spmartin/madgraph/madsyntax.html

Problem of install MG on mac

https://blog.csdn.net/Veronica_gogo/article/details/125373332

Problem of install Delphese on mac
https://cp3.irmp.ucl.ac.be/projects/delphes/ticket/1579