

Beyond the Standard Model phenomenology with MADANALYSIS 5

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2nd Taipei School on FEYNRULES-MADGRAPH for LHC physics

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Outline

- 1. Introduction & setup for this lecture**
2. Overview of MADANALYSIS 5 and basic concepts
3. Analyzing events with MADANALYSIS 5
4. Summary

Monte Carlo tools and discoveries at the LHC

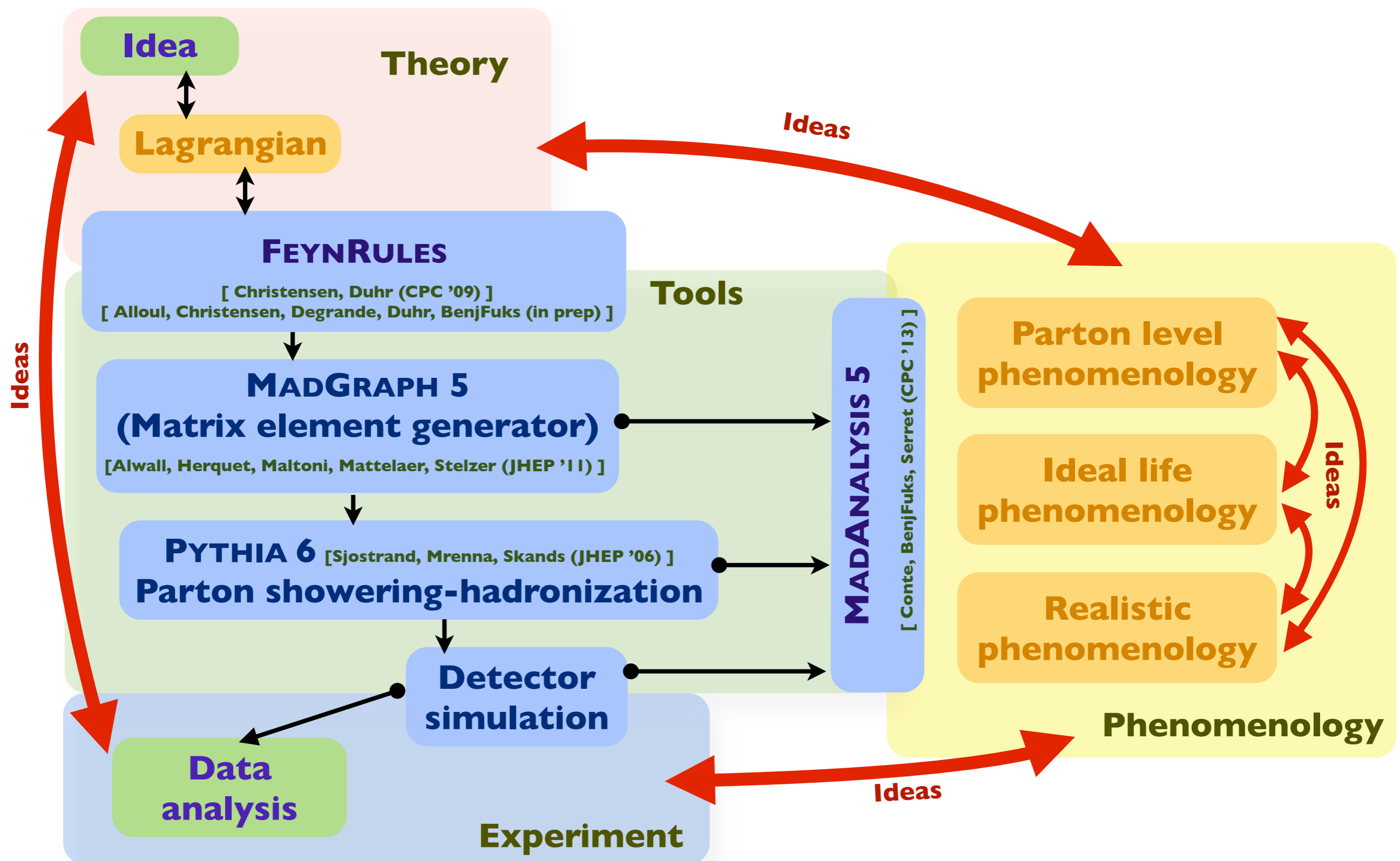
- ◆ Establishing an excess over the Standard Model backgrounds:
 - ❖ **Difficult**
 - ❖ Rely on **Monte Carlo event generators** (backgrounds, signals)
 - ❖ Possible use of **data-driven methods** (backgrounds)
- ◆ Confirmation of the excess:
 - ❖ **Model building** activities
 - ❖ **Implementation** of new models in the Monte Carlo tools
- ◆ Clarification of the new physics:
 - ❖ **Measurement** of the model parameters
 - ❖ Use of **precision** predictions (possibly with Monte Carlo generators)
 - ❖ **Sophistication** of the analyses \Leftrightarrow new physics / detector knowledge

▣▣▣➔ Monte Carlo tools play a key role!

▣▣▣➔ **How to easily analyze their output?**

A framework for LHC analyses: a modern way

[Christensen, de Aquino, Degrande, Duhr, BenjFuks, Herquet, Maltoni, Schumann (EPJC '11)]



The framework for this lecture

1. Implementation of the new physics model in FEYNRULES and generation of the UFO files

2. Event generation with MADGRAPH 5

❖ **Signal:** dilepton plus jets plus missing energy

$$pp \rightarrow U\bar{U} \rightarrow (u\Phi_1)(\bar{u}\Phi_2) \rightarrow (u\Phi_1)(\bar{u}e^+E^-) \rightarrow (u\Phi_1)(\bar{u}e^+e^-\Phi_1)$$

❖ **Backgrounds:** **precision in normalization:** (N)NLO inclusive results for the total rates

3. Parton showering and hadronization with PYTHIA 6

❖ **Precision in the shapes:** MLM-merging technique [Mangano, Moretti, Piccinini, Treccani (JHEP '07)]

4. No detector simulation here

✓ Steps 1 - 4 are not covered in this lecture (see other talks)

5. Event analysis with MADANALYSIS 5

❖ **Reconstructed-level** analyses (gathering the tons of hadrons after PYTHIA into jets)

The event samples analyzed in this lecture

◆ Setup for this tutorial

- ❖ LHC collider at a center-of-mass energy of 8 TeV, 20 fb⁻¹
- ❖ No lepton cut (pseudorapidity, transverse momentum, etc.)
- ❖ Jet cuts: $p_T > 20$ GeV, $\Delta R_{jj} > 0.4$, no pseudorapidity cut

◆ Standard Model background for a dilepton + missing energy + jets signature

- ❖ top-antitop + jets: two leptonic decays, $t\bar{t} \rightarrow (b\ell^+\nu_\ell)(\bar{b}\ell'^-\bar{\nu}_{\ell'})$
- ❖ WW + jets: two leptonic decays, $W^+W^- \rightarrow (\ell^+\nu_\ell)(\ell'^-\bar{\nu}_{\ell'})$
- ❖ single top (tW) + jets: two leptonic decays, $tW \rightarrow (b\ell^+\nu_\ell)(\ell'^-\bar{\nu}_{\ell'})$
- ❖ ZZ + jets: one leptonic and one invisible decay, $ZZ \rightarrow (\nu_\ell\bar{\nu}_\ell)(\ell'^+\ell'^-)$
- ❖ More: instrumental effects such as lepton mis-reconstruction, etc.
⇒ not considered here.

◆ Cross section for the Standard Model background

- ❖ NNLO: top-antitop pairs (≈ 27 pb)
- ❖ NLO + leading NNLO contributions: single top (≈ 2.5 pb)
- ❖ NLO: diboson (≈ 5.8 pb for WW and ≈ 0.3 pb for ZZ)

◆ Multiparton matrix element merging: up to two jets

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MADANALYSIS 5 in a nutshell

◆ What is MADANALYSIS 5?

- ❖ A framework for **phenomenological analyses**
- ❖ **Multiple input format**: STDHEP, HEPMC, LHE, LHCO, ROOT
- ❖ **Any level of sophistication**: partonic, hadronic, detector, reconstructed
- ❖ **User friendly and fast**
- ❖ **Flexible**

⇒ Professional analyses in an easy way
⇒ No limit on the analysis complexity

◆ Two modules

- ❖ A **PYTHON** command line interface (interactive and soon independent of ROOT)
- ❖ A **C++/ROOT** core module, SAMPLEANALYZER

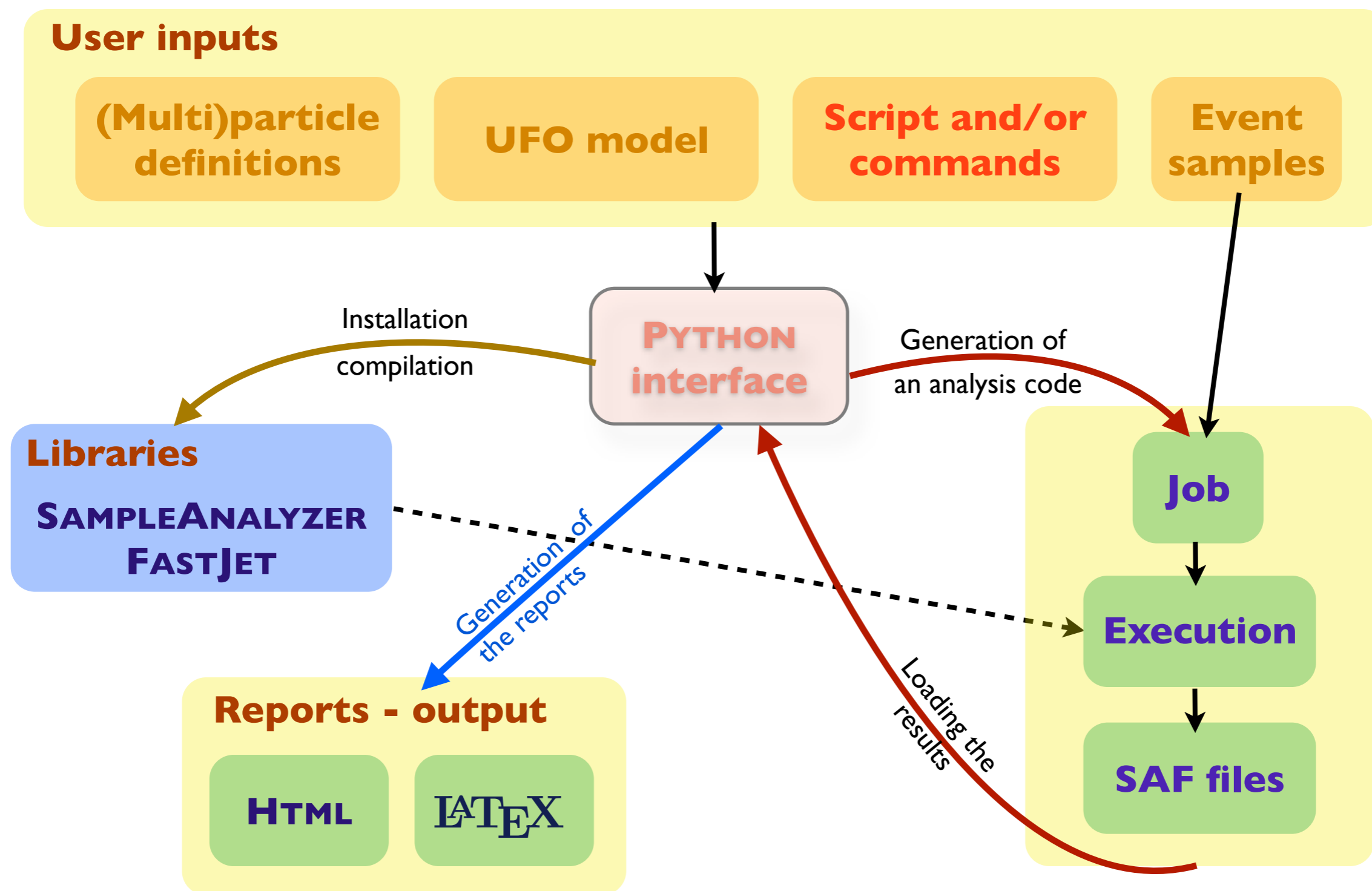
◆ Normal mode

- ❖ Intuitive commands typed in the **PYTHON** interface
- ❖ Analysis performed **behind the scenes** (black box)
- ❖ **Human readable output**: HTML and $\text{L}^{\text{A}}\text{T}_{\text{E}}\text{X}$

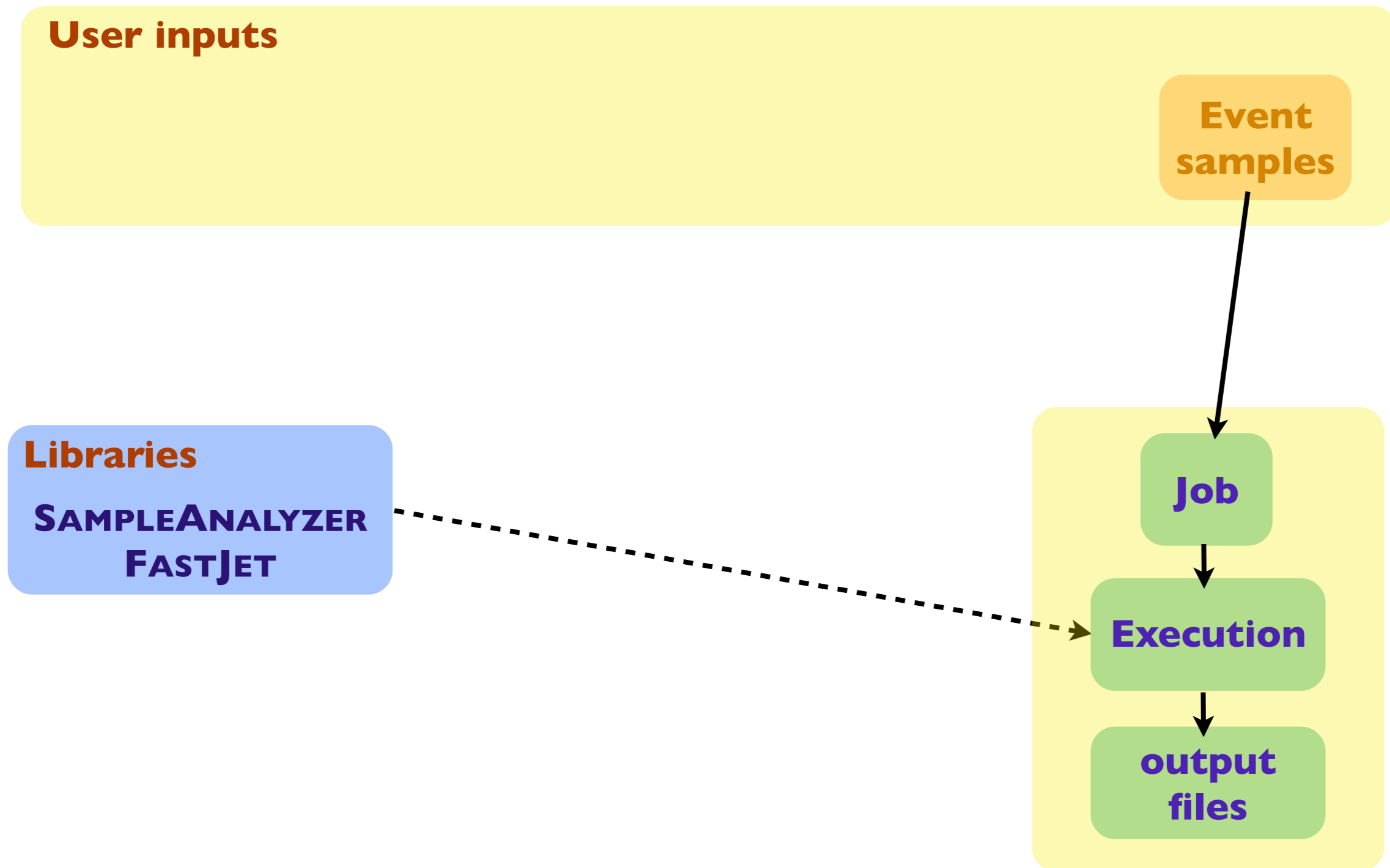
◆ Expert mode (not covered in this lecture)

- ❖ **C++/ROOT programming** within the SAMPLEANALYZER framework

MADANALYSIS 5: normal running mode



MADANALYSIS 5: expert running mode



Getting started...

◆ Installing the program

- ❖ Download: <https://launchpad.net/madanalysis5>
- ❖ Unpacking the tar-ball: `tar xvf MadAnalysis5_v1.1.8_patch1.tar.gz`
- ❖ This is it: `./bin/ma5`

◆ Requirements (checked when MADANALYSIS 5 is started)

- ❖ **PYTHON** 2.6 or more recent (but not the 3.X series)
- ❖ The **GNU GCC compiler** 4.3.0 or more recent
- ❖ **ROOT** 5.27 or more recent
 - With the PYTHON libraries (`./configure --enable-python`)
- ❖ The **NUMPY PYTHON** library

◆ Optional addons

- ❖ **ZLIB** headers and libraries (reading compressed event files)
- ❖ **LATEX, PDFLATEX, DVI2PDF** (compiling \LaTeX reports)
- ❖ **FASTJET** 3.3.0 or more recent (necessary for this lecture, to reconstruct jets)
- ❖ **DELPHES** 3 or more recent (compatibility with the DELPHES output format)
- ❖ In the future: **PYTHIA-8, HERWIG-6, HERWIG++**

Getting started: the welcome screen

```
[LeMouth@Benjamins-MacBook-Pro ~/Work/tools/madanalysis/bzr/madanalysis5$] ./bin/ma5
*****
*                                                                 *
*      W E L C O M E  t o  M A D A N A L Y S I S  5               *
*                                                                 *
*      _____  _____                                     *
*     /' \  /' \  /' \  /' \  /' \  /' \  /' \  /' \  /' \  /' \  *
*    /'  \ /'  \ /'  \ /'  \ /'  \ /'  \ /'  \ /'  \ /'  \ /'  \ *
*   /'    \ /'    \ /'    \ /'    \ /'    \ /'    \ /'    \ /'    \ *
*  /'      \ /'      \ /'      \ /'      \ /'      \ /'      \ /'      \ *
* /'        \ /'        \ /'        \ /'        \ /'        \ /'        \ *
* \          / \          / \          / \          / \          / \          / *
*  \        /  \        /  \        /  \        /  \        /  \        /  \ *
*   \      /   \      /   \      /   \      /   \      /   \      /   \ *
*    \    /     \    /     \    /     \    /     \    /     \    /     \ *
*     \  /       \  /       \  /       \  /       \  /       \  /       \ *
*      \ /        \ /        \ /        \ /        \ /        \ /        \ *
*                                                                 *
*  MA5 release : 1.1.8                2013/08/06                 *
*                                                                 *
*      Comput. Phys. Commun. 184 (2013) 222-256                 *
*                                                                 *
*  The MadAnalysis Development Team - Please visit us at        *
*    https://launchpad.net/madanalysis5                          *
*                                                                 *
*      Type 'help' for in-line help.                             *
*                                                                 *
*****
```

Getting started: checking the user system

The requirements

Checking mandatory packages:

```
- python [OK]
- python library: numpy [OK]
- g++ [OK]
- Root [OK]
- PyRoot libraries [OK]
```

Checking optional packages:

```
- gfortran [OK]
- zlib library [OK]
- delphes library [DISABLED]
- FastJet [OK]
- pdflatex [OK]
- latex [OK]
- dviPDF [OK]
- MCatNLO-utilities [DISABLED]
```

** WARNING: Library called 'delphes' not found. Delphes ROOT format will be disabled.

** WARNING: To enable this format, please type 'install delphes'.

** WARNING: MCatNLO-utilities not found. Showering aMCatNLO events deactivated.

** WARNING: To install the utilities, please type 'install MCatNLO-utilities'.

Automated installation
sometimes available

The optional packages

Getting started: SAMPLEANALYZER (the core)

[if necessary]

Installation of SAMPLEANALYZER

Checking the MadAnalysis library:

```
=> First use of MadAnalysis (or the library is missing).
Creating a 'Makefile'...
Compiling the MadAnalysis library...
  => How many cores for the compiling? default = max = 8
  Answer:
  Number of cores used for the compilation = 8
Linking the MadAnalysis library...
Checking the MadAnalysis library...
```

MadGraph 5 NOT found:

```
=> Particle labels from input/particles_name_default.txt
=> 86 particles successfully exported.
=> Multiparticle labels from madanalysis/input/multiparticles_default.txt
=> Creation of the label 'invisible' (-> missing energy).
=> Creation of the label 'hadronic' (-> jet energy).
=> 8 multiparticles successfully exported.
```

Looking for MADGRAPH 5, creating default particle labels, etc. (see next slides)

Important for variables such as H_T , MET, etc.

Basic concepts (I)

Looking for help...

- ❖ In-line help from the command-line interface
- ❖ Auto-completion using the tab key

```
ma5>help
import tt1.hep as ttbar
import tt2.hep as ttbar
import Wj1.hep as Wjets
=====
EOFrt Wj2.hep as Wjets
display_multiparticles  history  plot  reset  shell
define                  display_particles  import  quit  resubmit  submit
display                  exit  install  reject  select  swap
display_datasets  help  open  remove  set
ma5>
```

Datasets

- ❖ Events samples are defined through a label.
- ❖ Supported file formats: LHE, STDHEP, HEPMC, LHCO, ROOT
- ❖ Several samples can be grouped (e.g., to increase statistics)
- ❖ Wildcards can be used

```
ma5>import ttbar* as top-antitop
-> Storing the file 'ttbar.hep.gz' in the dataset 'top-antitop'.
-> Storing the file 'ttbar2.hep.gz' in the dataset 'top-antitop'.
ma5>import Wjets.lhe.gz as Wboson
-> Storing the file 'Wjets.lhe.gz' in the dataset 'Wboson'.
ma5>import VV.hep as diboson
-> Storing the file 'VV.hep' in the dataset 'diboson'.
```

Basic concepts (2)

Particles and multiparticles

- ❖ **Particles** are defined through their PDG code.
- ❖ One can associate **labels** with particles (makes our lives easier)
- ❖ One can define **multiparticles**
- ❖ Default: SM + MSSM (as in MADGRAPH 5) + invisible + hadronic
- ❖ Can be defined from a UFO model

```
ma5>define TheMuon = 13
ma5>define TheAntiMuon = -13
ma5>define AllMuon = TheMuon TheAntiMuon
ma5>display l+
  The multiparticle 'l+' is defined by the PDG-ids -13 -11.
ma5>display e+
  The particle 'e+' is defined by the PDG-id -11.
ma5>display invisible
  The multiparticle 'invisible' is defined by the PDG-ids -16 -14 -12 12 14 16 1000022.
ma5>remove TheMuon
ma5>display TheMuon
** ERROR: no object called 'TheMuon' found.
```


Basic concepts (3)

Histograms - the command *plot*

- ❖ Typing *plot* implies the creation of an histogram (check the *display* command once created)
- ❖ **Global observables**: related to the full event (MET, H_T , etc.)
- ❖ **Properties** of a particle species (the p_T of the jets, etc.)
- ❖ Particle **ordering** can be used
- ❖ Particles can be **combined**
- ❖ Log scales can be **employed**
- ❖ Different ways to **normalize** the histogram
- ❖ **Virtual particle properties** can be studied

```

ma5>plot MET [
ETAordering      PTordering      PZordering      allstate      interstate      normalize2one
ETordering       PXordering      Pordering       finalstate    logX            stack
Eordering        PYordering      ]              initialstate   logY            superimpose
ma5>plot MET [ logY ]
ma5>plot N(mu)
ma5>plot PT( mu[1] )
ma5>plot ETA(t) [ interstate ]
ma5>plot M(t t~)
ma5>plot dPHI( mu[1] mu[2] ) [logX logY]

```

Basic concepts (3)

Selection cuts - the commands *reject/select*

- ❖ Events can be **selected/rejected** whether a condition is **satisfied** or not
- ❖ Particles can be **selected/rejected** from the analysis whether a condition is **satisfied** or not

```
ma5>reject MHT < 200
ma5>select N(j) > 3
ma5>reject (j) PT < 20
ma5>reject (j) DELTAR(mu) < 0.4
```

Executing the analysis - the command *submit*

- ❖ Create a **C++ code** with the analysis
- ❖ Create all the **histograms**
- ❖ Apply all the **cuts**
- ❖ Generate the **reports**

```
ma5>submit
Creating folder 'ANALYSIS_0'...
Copying 'SampleAnalyzer' source files...
Inserting your selection into 'SampleAnalyzer'...
Writing the list of datasets...
Writing the command line history...
Creating Makefiles...
Compiling 'SampleAnalyzer'...
Linking 'SampleAnalyzer'...
Running 'SampleAnalyzer' over dataset 'top-antitop'...
*****
* SampleAnalyzer for MadAnalysis 5 - Welcome.
* Initializing all components
❖ - version: 1.1.8 (2013/08/06)
- general: everything is default.
❖ - extracting the list of event samples...
- analyzer 'MadAnalysis5job'
```

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Recall: event samples

◆ Setup for this tutorial

- ❖ LHC collider at a center-of-mass energy of 8 TeV, 20 fb⁻¹

◆ New physics signal

- ❖ $pp \rightarrow U\bar{U} \rightarrow (u\Phi_1)(\bar{u}\Phi_2) \rightarrow (u\Phi_1)(\bar{u}e^+E^-) \rightarrow (u\Phi_1)(\bar{u}e^+e^-\Phi_1)$
- ❖ Two lepton + jets + missing energy

◆ Standard Model background for a dilepton + missing energy + jets signature

- ❖ **top-antitop + jets**: two leptonic decays, $t\bar{t} \rightarrow (b\ell^+\nu_\ell)(\bar{b}\ell'^-\bar{\nu}_{\ell'})$
- ❖ **WW + jets**: two leptonic decays, $W^+W^- \rightarrow (\ell^+\nu_\ell)(\ell'^-\bar{\nu}_{\ell'})$
- ❖ **single top (tW) + jets**: two leptonic decays, $tW \rightarrow (b\ell^+\nu_\ell)(\ell'^-\bar{\nu}_{\ell'})$
- ❖ **ZZ + jets**: one leptonic and one invisible decay, $ZZ \rightarrow (\nu_\ell\bar{\nu}_\ell)(\ell'^+\ell'^-)$

◆ Cross section for the Standard Model background

- ❖ **NNLO**: top-antitop pairs (≈ 27 pb)
- ❖ **NLO + leading NNLO contributions**: single top (≈ 2.5 pb)
- ❖ **NLO**: diboson (≈ 5.8 pb for WW and ≈ 0.3 pb for ZZ)
- ❖ **LO**: signal (MadGraph result: ≈ 0.02 pb)

Jet clustering (I)

- ◆ The output of PYTHIA is non-practical for an analysis
 - ❖ It contains **tons of hadrons**
 - ❖ We employ **jets** rather than each individual hadron
 - ❖ Jets have to be **reconstructed**
 - ❖ The event file is **non-readable** with human eyes (STDHEP)
 - ❖ The event file size is **very large**
- ◆ Jet reconstruction with FASTJET
 - ❖ Large selection of jet algorithms (k_T , anti- k_T , etc.)
 - ❖ **FASTJET can be used within MADANALYSIS 5**
 - ❖ If FASTJET is installed on the system, ready-to-be-used by MADANALYSIS 5; otherwise:

```
ma5>install fastjet
```

- ◆ Jet reconstruction with MADANALYSIS 5 and FASTJET
 - ❖ The output can be saved to a **LHE** or a **LHCO** file (set *main.outputfile* = ...)
 - ❖ Human-readable, smaller file size
 - ❖ **Can be reemployed later**
 - ❖ The total rate is set to zero (not present in the STDHEP file); set manually later

Jet clustering (2)

- ◆ Jet reconstruction with MADANALYSIS 5 (and FASTJET) for the five considered samples
 - ♣ The four background (top-antitop, WW, single top and ZZ) and the signal samples
 - ♣ MADANALYSIS 5 must be run in the **reconstructed mode**: `./bin/ma5 -R`

```

ma5>set main.clustering.algorithm =
antikt      cambridge      cdfjetclu      cdfmidpoint  genkt      gridjet      kt
ma5>set main.clustering.algorithm = antikt
ma5>set main.clustering.algorithm =
main.clustering.algorithm kt      main.clustering.bjet_id.misid_cjet      main.clustering.radius
main.clustering.bjet_id.eta      main.clustering.bjet_id.misid_ljet      main.clustering.tau_id.eta
main.clustering.bjet_id.exclusive      main.clustering.exclusive_id      main.clustering.tau_id.misid_ljet
main.clustering.bjet_id.matching_dr      main.clustering.ptmin
ma5>set main.clustering.radius = 0.5
ma5>set main.clustering.bjet_id.eta = .6
ma5>set main.clustering.bjet_id.misid_cjet = .1
ma5>set main.clustering.bjet_id.misid_ljet = .01
ma5>import ttbar.hep.gz 1
-> Storing the file 'ttbar.hep.gz' in the dataset 'defaultset'.
ma5>submit

```

Many clustering algorithms available

Many options (clustering parameters, b-tagging, tau-tagging, etc.)

Checking the merging procedure (I)

◆ Example with a Z plus jets sample

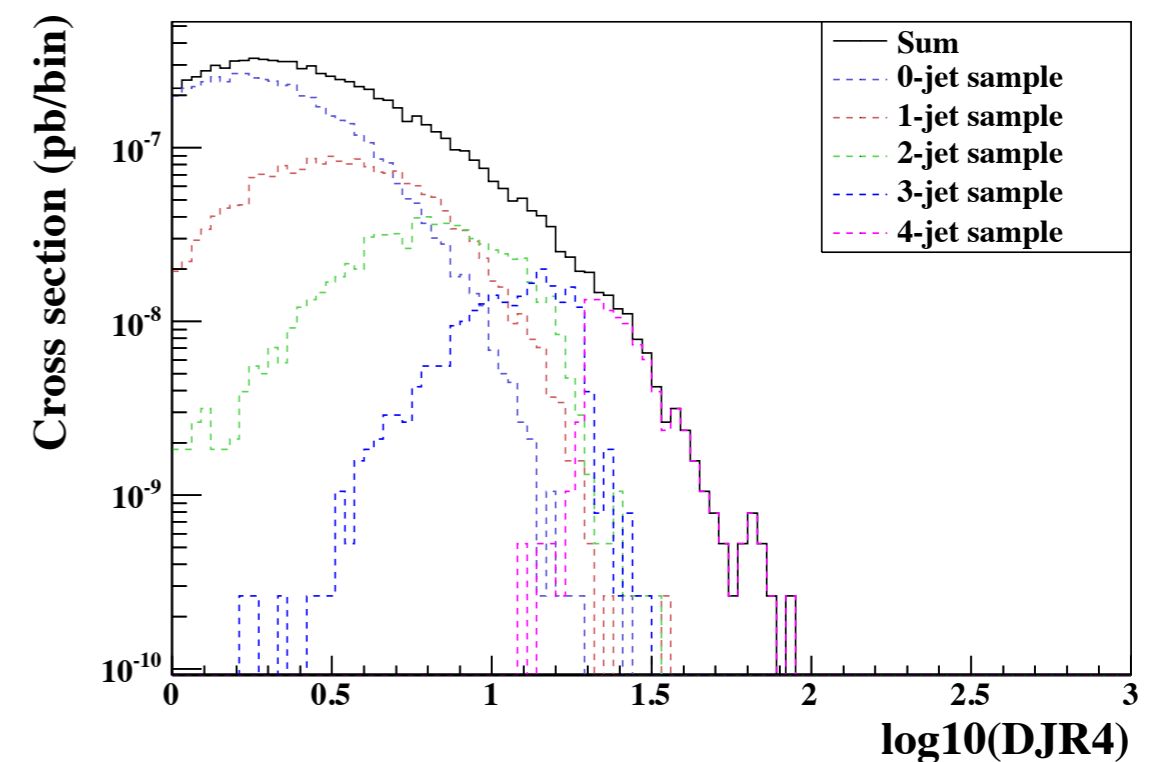
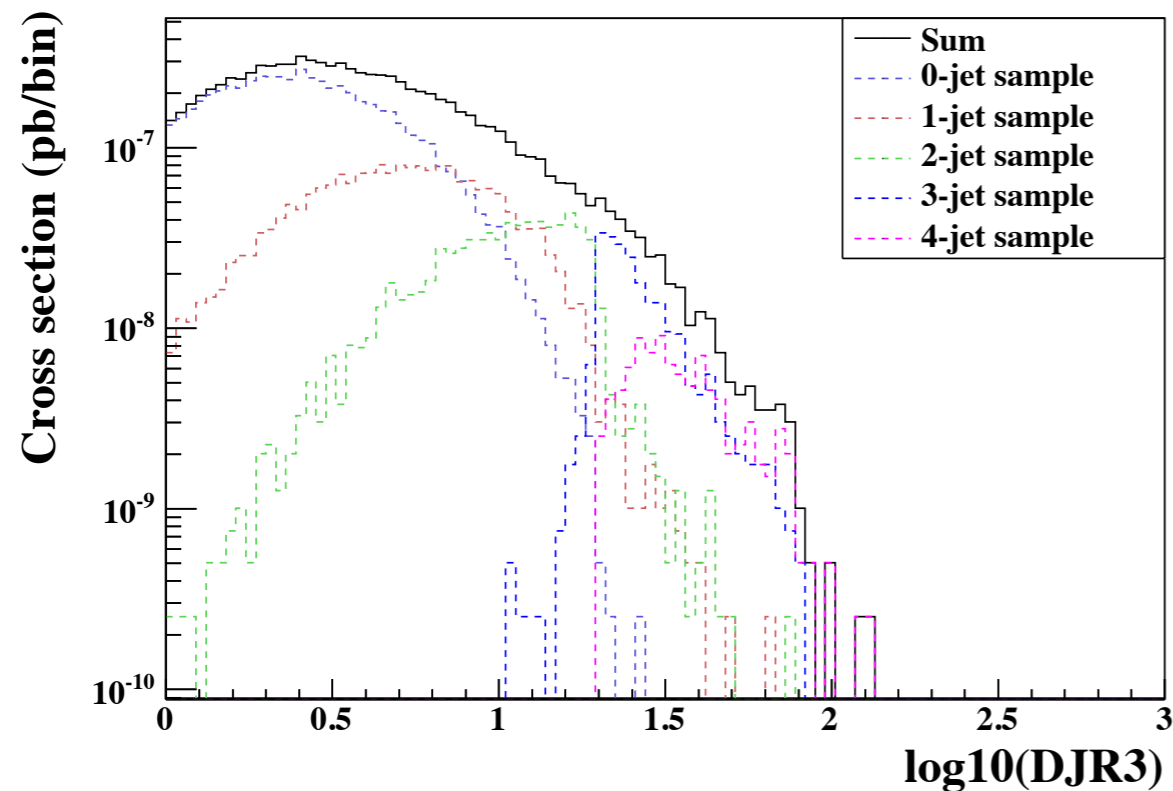
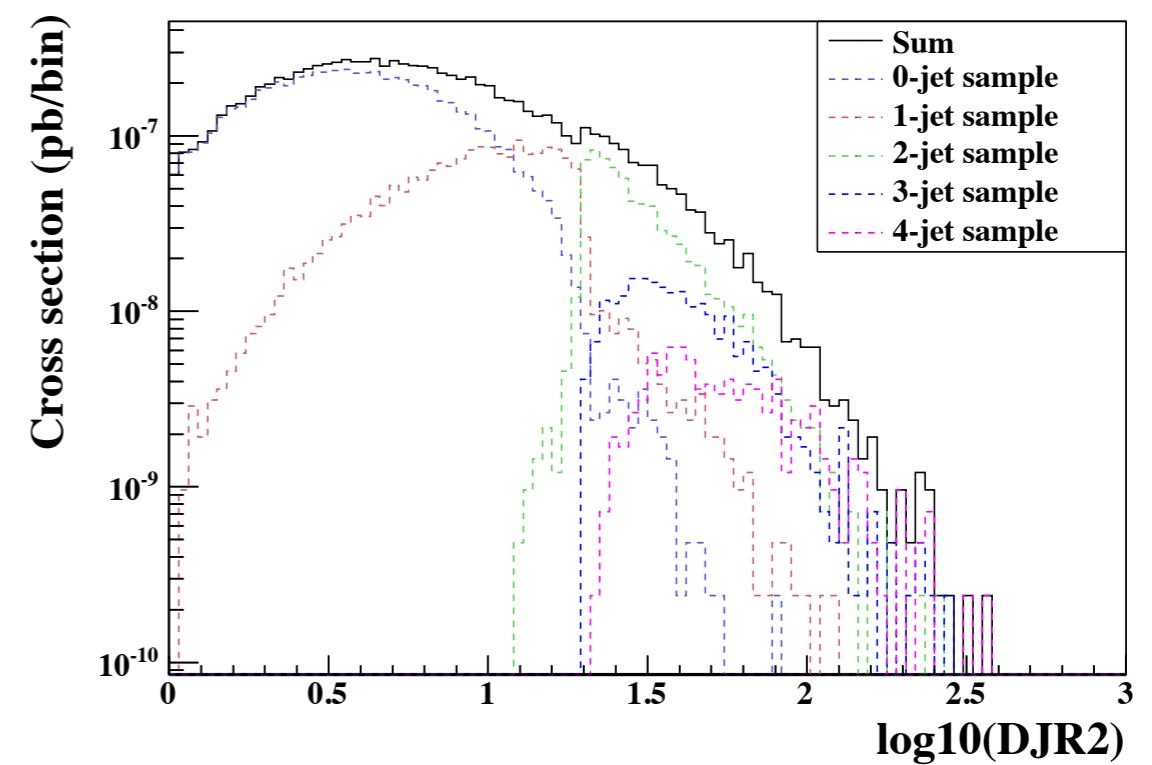
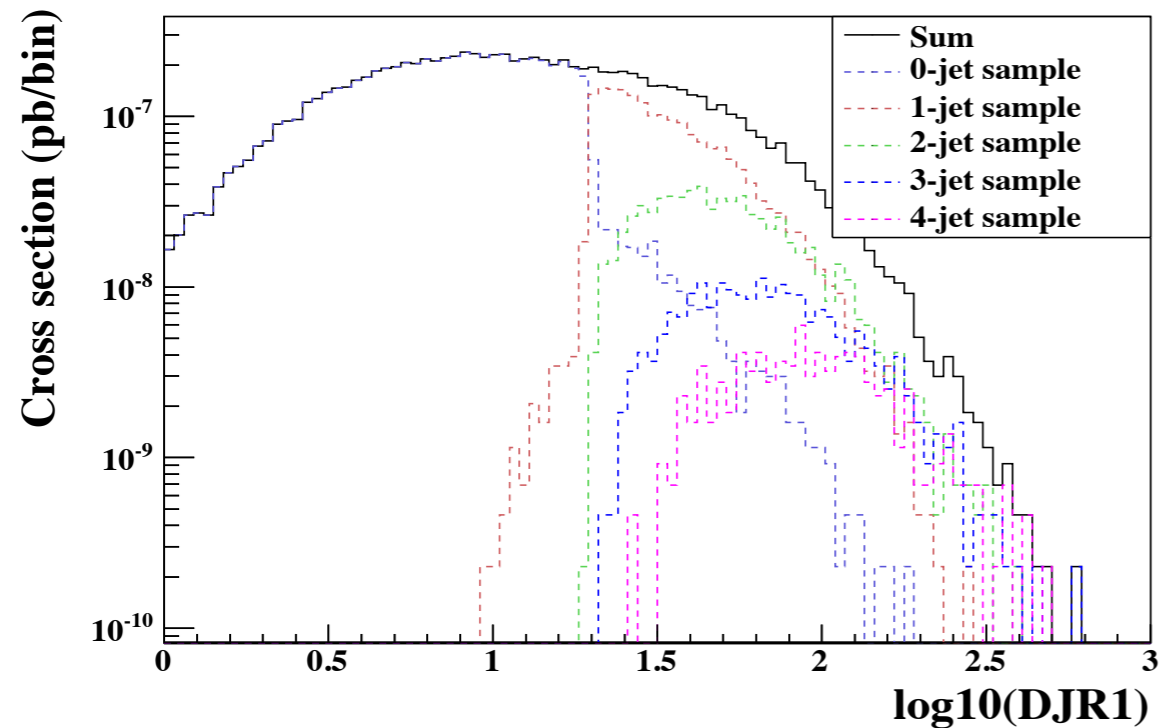
- ❖ Parton-level: Z+ 0,1,2,3,4 jets
- ❖ Parton-showering is then applied
- ❖ MLM merging: removal of the double counting consistently
- ❖ Check of that procedure: the differential jet rate (DJR) distributions
 - the scale for which one event goes from a N to a N+1 jet configuration
 - Extremely sensible to the merging procedure
 - Gives strong check of the choices for the parameters of the merging technique

◆ With MADANALYSIS 5

- ❖ MADANALYSIS 5 must be run in hadron mode: `./bin/ma5 -H`
- ❖ The maximum value for N can be entered (default: 4)

```
ma5>set main.merging.check = true ❖ Check of that procedure: th
ma5>set main.merging.njets = 4 ➤ the scale for which on
ma5>import zjets.hep.gz ➤ Extremely sensible to
  -> Storing the file 'zjets.hep.gz' in the dataset 'defaultset'.
ma5>submit ➤ Gives strong check of
```

Checking the merging procedure (2)



Importing and defining the samples

- ◆ Importing the reconstructed LHE samples, setting their properties
 - ♣ We define the **type** (signal or background) of each dataset
 - ♣ We assign the **cross section** associated with each dataset (necessary for a correct normalization)

```
ma5>import samples/signal.lhe as signal
-> Storing the file 'signal.lhe' in the dataset 'signal'.
ma5>import samples/t_tw.lhe.gz as singletop
-> Storing the file 't_tw.lhe.gz' in the dataset 'singletop'.
ma5>import samples/ttb2.lhe.gz as ttbar
-> Storing the file 'ttb2.lhe.gz' in the dataset 'ttbar'.
ma5>import samples/ww2l2v.lhe.gz as ww
-> Storing the file 'ww2l2v.lhe.gz' in the dataset 'ww'.
ma5>import samples/zz2l2v.lhe.gz as zz
-> Storing the file 'zz2l2v.lhe.gz' in the dataset 'zz'.
```

```
ma5>set ttbar.xsection = 27
ma5>set ww.xsection = 5.8
ma5>set zz.xsection = 0.3
ma5>set singletop.xsection = 2.5
ma5>set signal.xsection = 0.021
```

```
ma5>set ww.type = background
ma5>set zz.type = background
ma5>set singletop.type = background
ma5>set ttbar.type = background
```

Importing the samples

Cross sections in pb

Signal and background definitions

Getting closer to the detector...

- ◆ We have not simulated any detector response
 - ❖ Include reasonable selections getting us close to the experiment
 - ❖ Soft objects are not detected
 - Remove from each event any soft jet, lepton, etc.
 - ❖ Objects lying outside the detector are not detected
 - Remove from each event any jet, lepton, etc, whose pseudorapidity is too large.
 - ❖ Remove object overlaps
 - Any electron too close to a jet is removed
 - Any jet too close to a charged lepton is the removed
(we are interested in isolated leptons)

```

ma5>define l = l+ l-
ma5>define e = e+ e-
ma5>select (l) -2.5 < ETA < 2.5
ma5>select (j) -2.5 < ETA < 2.5
ma5>select (j) PT > 20
ma5>select (l) PT > 10
ma5>reject (j) DELTAR(e) < 0.1
ma5>reject (l) DELTAR(j) < 0.4
  
```

New multiparticle labels
(more compact commands later)

Outside the
detector

Soft objects
(units: GeV)

Object overlaps

Investigating some global event properties (I)

◆ Some observables are related to the full event (called global)

- ❖ **Missing and visible energy** (MET , TET)
- ❖ **Missing and visible hadronic energy** (MHT , THT)
- ❖ The **partonic center-of-mass energy** ($SQRTS$)
- ❖ The α_T **variable** ($ALPHAT$): depends on the missing energy, H_T and jet configuration
- ❖ The **particle content** of the event ($NPID$, $NAPID$, N)

◆ General setup for the histograms

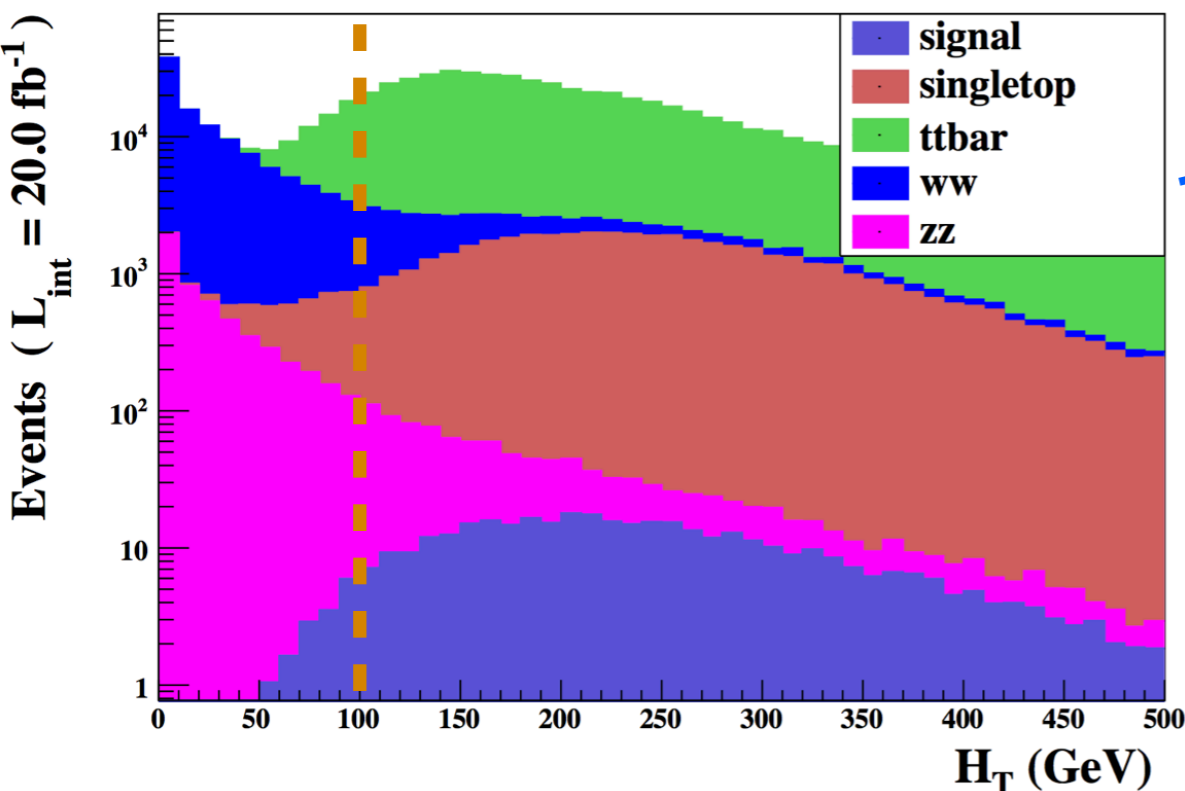
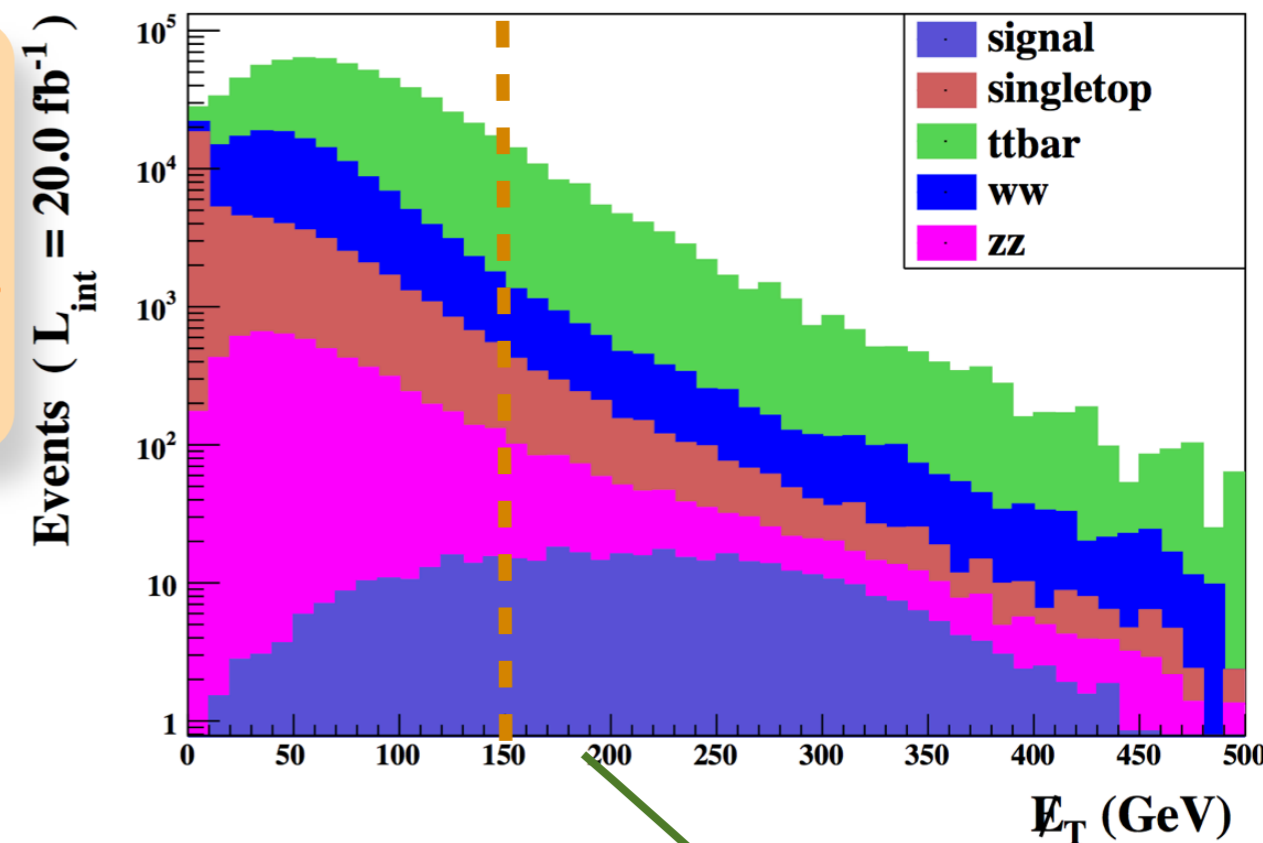
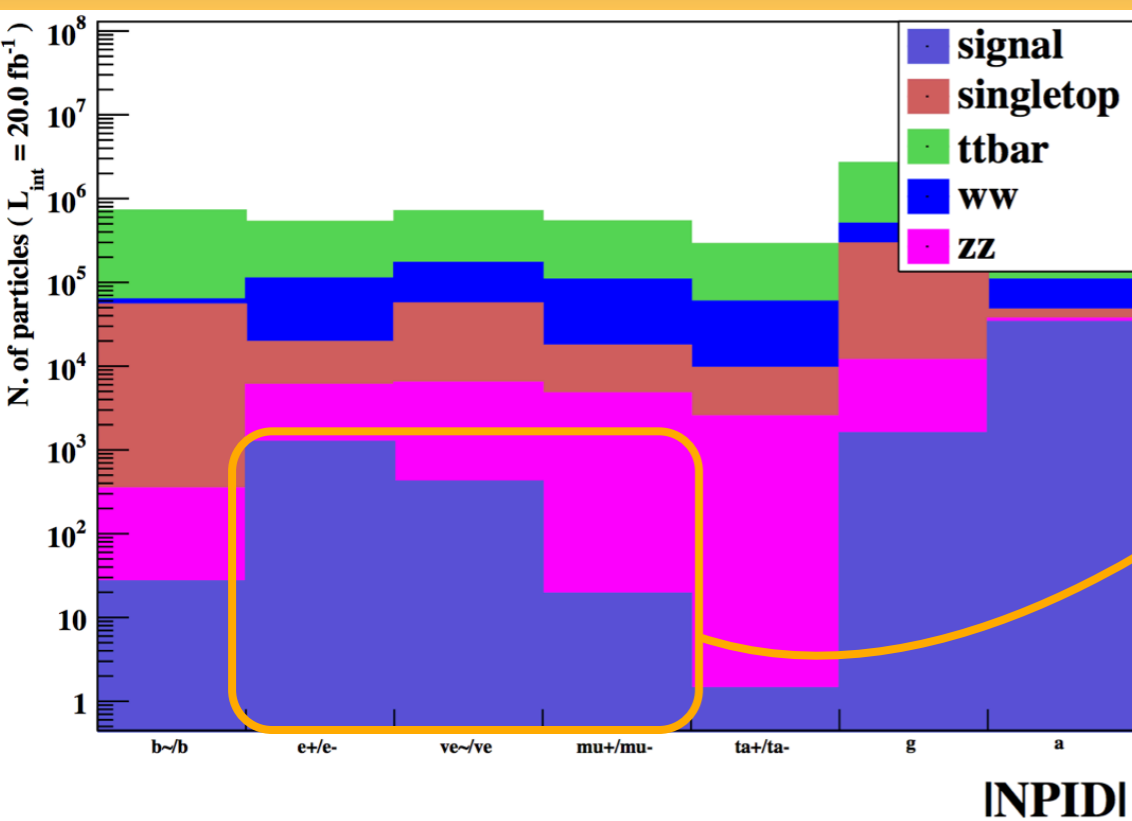
- ❖ The **luminosity** in fb^{-1} (set `main.lumi = ...`)
- ❖ How to **superimpose** the curves on a single histogram (set `main.stacking_method = ...`)

```
ma5>set main.stacking_method = stack
ma5>set main.lumi = 20
ma5>plot NAPID [logY]
ma5>plot MET 50 0 500 [logY]
ma5>plot THT 50 0 500 [logY]
```

◆ Executing the analysis and browsing the results

- ❖ The command `submit` (the progress can be followed on the screen)
- ❖ The command `open` (open a webpage with the report containing all results)

Investigating some global event properties (2)



VV: jets generated by parton showering, then softer

Different shapes for signal and background

This suggest selection cuts to improve the signal vs background ratio (see in two slides)

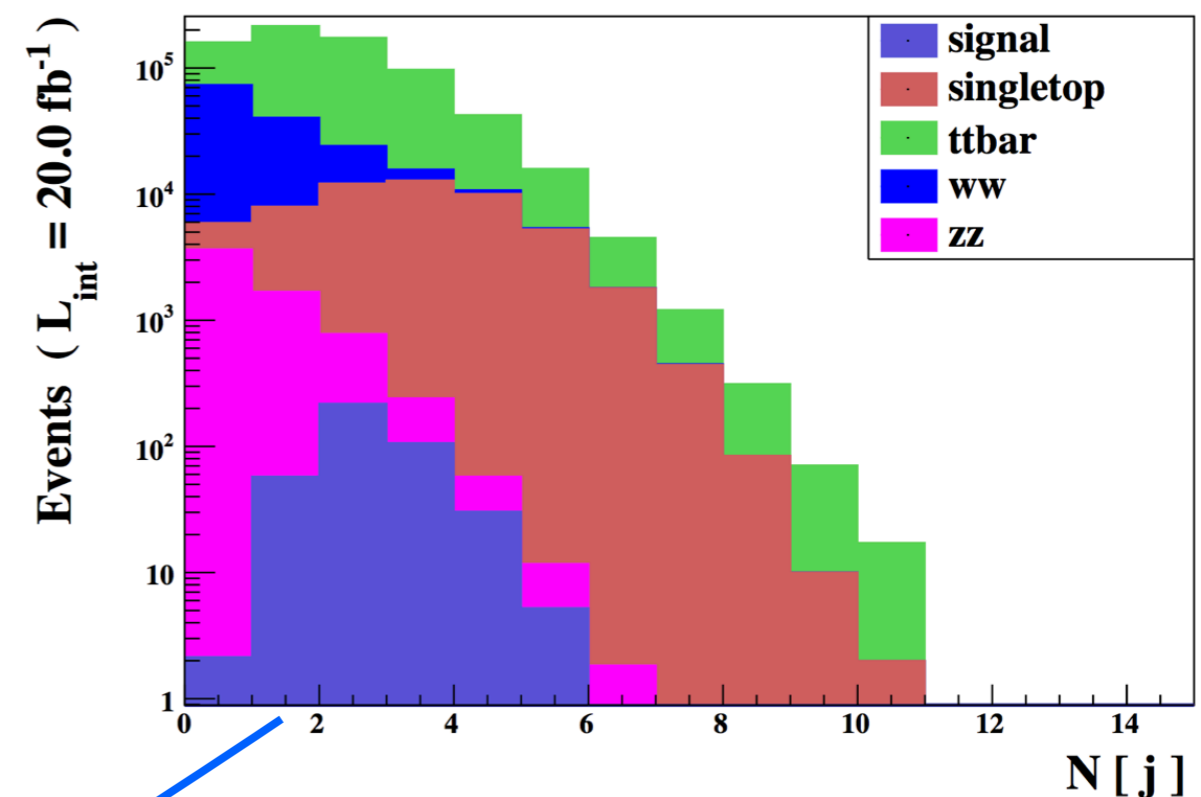
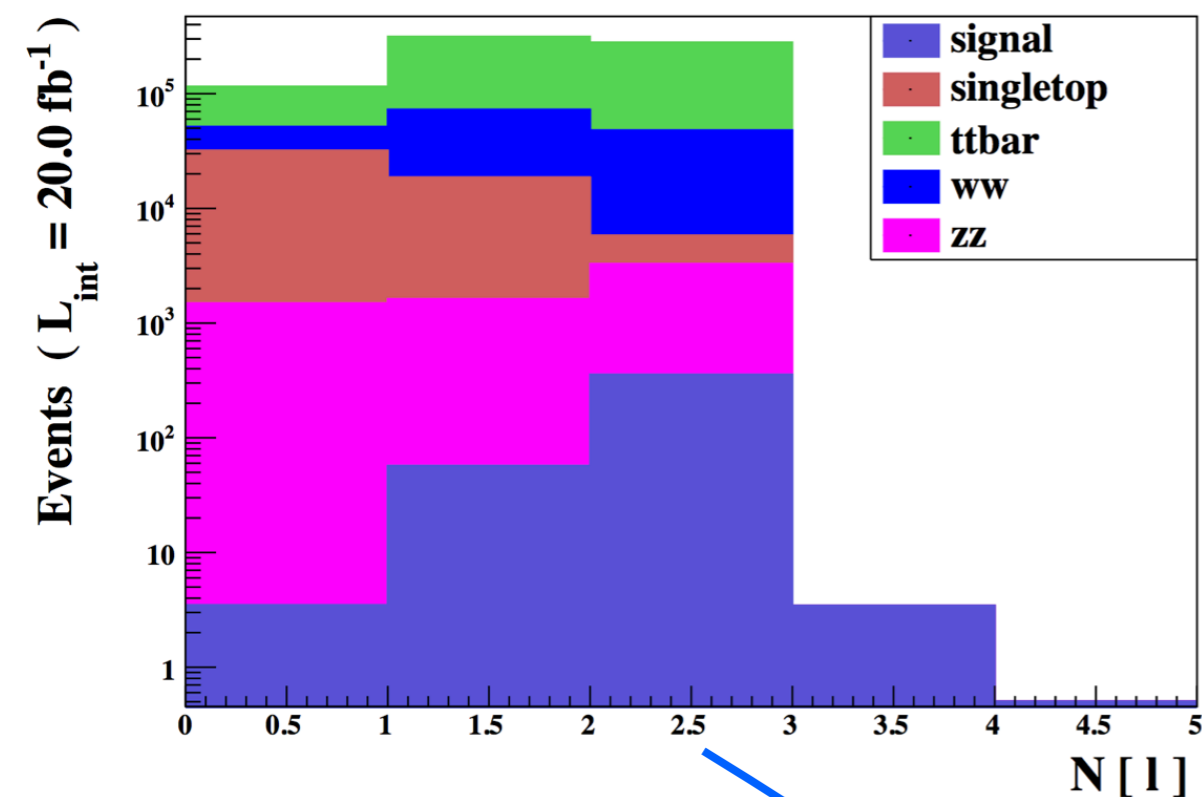
- on the missing energy (e.g., 150 GeV);
- on the H_T (e.g., 100 GeV)

Investigating some global event properties (3)

◆ Let us study the number of jets and leptons

- ♣ We have defined our backgrounds by assuming a dilepton + missing energy + jets topology
- ♣ Can we add a **selection** on the number of jets to increase the sensitivity?

```
ma5>plot N(l) 5 0 5 [logY]
ma5>plot N(j) 15 0 15 [logY]
ma5>submit
```



Most of the signal events have two leptons and two jets

This suggests selection cuts to improve the signal vs background ratio

- exactly two leptons;
- two or three jets.

Selection cuts

◆ Disclaimer: the cuts should be optimized

- ❖ This is not the scope of this lecture
- ❖ This consists of a complete physics project
- ❖ **Instead: we take rough cuts here based on the previous findings**

◆ Four selections:

- ❖ The missing energy must be greater than 150 GeV
- ❖ The H_T must be greater than 100 GeV
- ❖ We want exactly two charged leptons
- ❖ We want two or three light jets

```
ma5>reject MET < 150
ma5>select TH_T > 100
ma5>reject N(l) != 2
ma5>select 2 <= N(j) <= 3
```

◆ MADANALYSIS 5 provide the efficiencies for each sample and for each cut

Cut: reject MET < 150.0

Dataset	Events kept: K	Rejected events: R	Efficiency: K / (K + R)	Cumul. efficiency: K / Initial
signal	297.78 +/- 9.31	122.22 +/- 9.31	0.7090 +/- 0.0222	0.7090 +/- 0.0222
singletop	1801.5 +/- 41.7	48198.5 +/- 41.7	0.036030 +/- 0.000833	0.036030 +/- 0.000833
ttbar	67347 +/- 242	472652 +/- 242	0.12472 +/- 0.00045	0.12472 +/- 0.00045
ww	5804.9 +/- 74.3	110195.1 +/- 74.3	0.05004 +/- 0.00064	0.05004 +/- 0.00064
zz	598.5 +/- 23.2	5401.5 +/- 23.2	0.09974 +/- 0.00387	0.09974 +/- 0.00387

How to choose a cut?

- ❖ The signal efficiency must be large
- ❖ The background efficiencies must be small

The signal over background ratio (I)

◆ Are those cuts sufficient?

♣ Let us investigate the evolution of the **signal over background ratio**

♣ We can indicate to MADANALYSIS 5 **how to calculate it**

➤ In our example:
$$\frac{S}{\sqrt{S+B}}$$

S = number of signal events;

B = number of background events

♣ This number comes with **an error**

➤ In our example:
$$\frac{\sqrt{(S+2B)^2(\Delta S)^2 + S^2(\Delta B)^2}}{(S+B)^{3/2}}$$

ΔS = error on the number of signal events;

ΔB = error on the number of background events

◆ The user can enter any formula (using S, B, ES, EB)

```
ma5>set main.SBratio = "S/sqrt(S+B)"
Checking the formula ...
Formula corresponding to the uncertainty calculation has been found and set to the variable main.SBerror:
1./pow(S+B,3./2.)*sqrt((S+2*B)**2*ES**2+S**2*EB**2)
ma5>
```

The signal over background ratio (2)

Cut-flow chart

- How to compare signal (S) and background (B): $S/\sqrt{S+B}$.
- Associated uncertainty: $1./\text{pow}(S+B,3./2.)*\text{sqrt}((S+2*B)**2*ES**2+S**2*EB**2)$.

Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	420	712000	0.498
Cut 1	4.20e+02 +/- 2.38e-07	712000	4.98e-01 +/- 5.65e-10
Cut 2	4.20e+02 +/- 2.38e-07	712000	4.98e-01 +/- 5.65e-10
Cut 3	4.20e+02 +/- 2.38e-07	712000	4.98e-01 +/- 5.65e-10
Cut 4	4.20e+02 +/- 2.38e-07	712000	4.98e-01 +/- 5.65e-10
Cut 5	4.20e+02 +/- 2.38e-07	712000	4.98e-01 +/- 5.65e-10
Cut 6	4.20e+02 +/- 2.38e-07	712000	4.98e-01 +/- 5.65e-10
Cut 7	297.78 +/- 9.31	75552 +/- 258	1.0812 +/- 0.0676
Cut 8	288.16 +/- 9.51	69996 +/- 249	1.0869 +/- 0.0717
Cut 9	240.2 +/- 10.1	32182 +/- 174	1.334 +/- 0.112
Cut 10	187.7 +/- 10.2	15172 +/- 121	1.514 +/- 0.164

Not relevant
(cuts on objects)

Our cuts improve
the sensitivity, but
not enough

We need to investigate other variables

Investigating particle properties (I)

- ◆ Many kinematical properties of a given particle can be studied
 - ❖ *BETA, E, ET, ETA, GAMMA, M, MT, P, PHI, PT, PX, PY, PZ, R, THETA, Y*
 - ❖ Each of these functions take a **single argument** (a particle)
- ◆ The particles are ordered
 - ❖ Use squared brackets to select the right one
 - ❖ Several ordering variables are available (*PT, E, PX, etc.*)

```
ma5>plot PT(l[1]) 50 0 500 [logY]
ma5>plot MT(j[1]) 50 0 500 [logY]
```

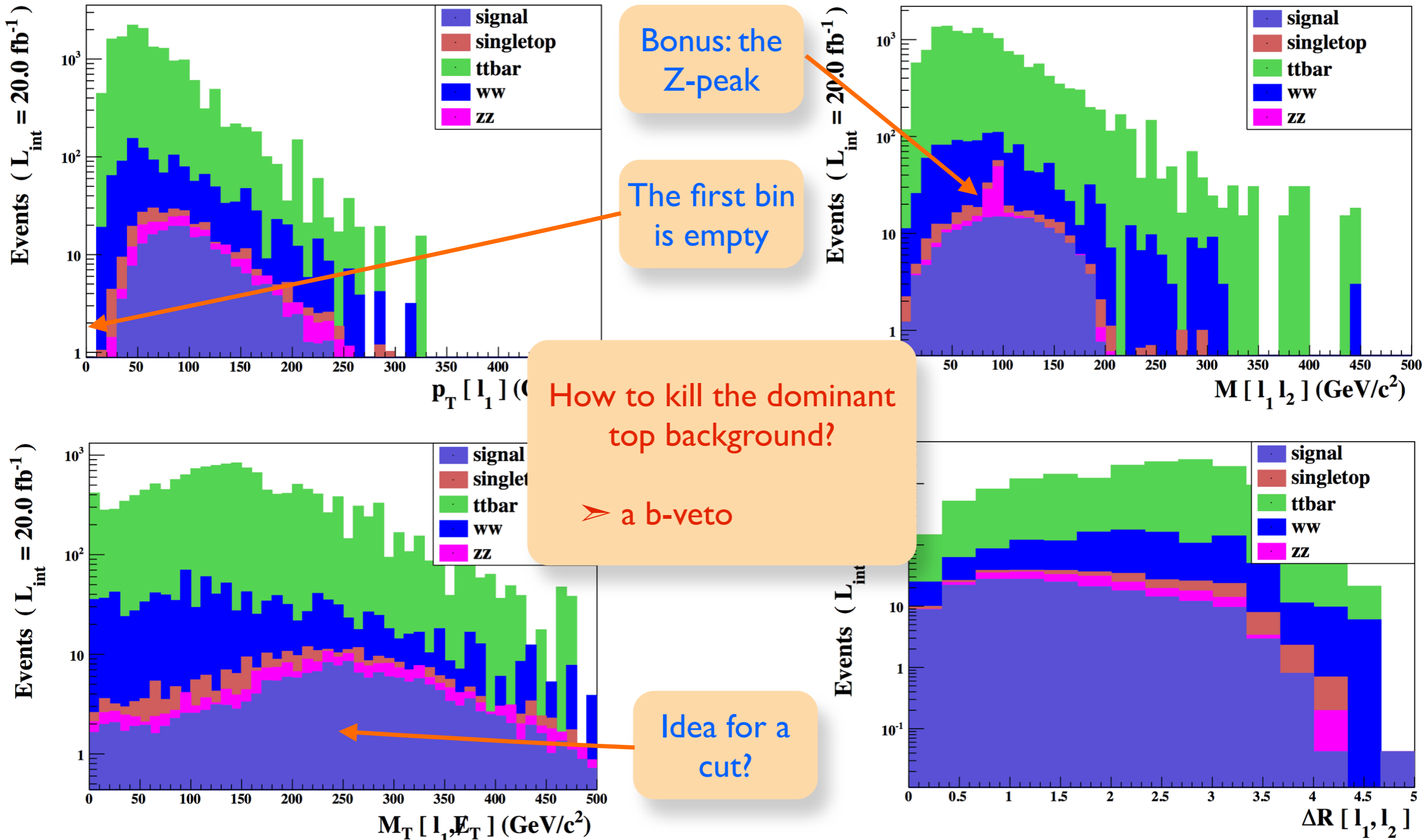
- ◆ Combining particles
 - ❖ Replace the argument by several particles
 - ❖ Their **four-momenta** are summed and the relevant observable is then computed
 - ❖ **Vectorial and scalar sums/differences as well as ratios** are available (*s, v, ds, dv, r* prefixes)

```
ma5>plot M(l[1] l[2]) 50 0 500 [logY]
ma5>plot dPHI(l[1] l[2]) 15 0 6.28 [logY]
```

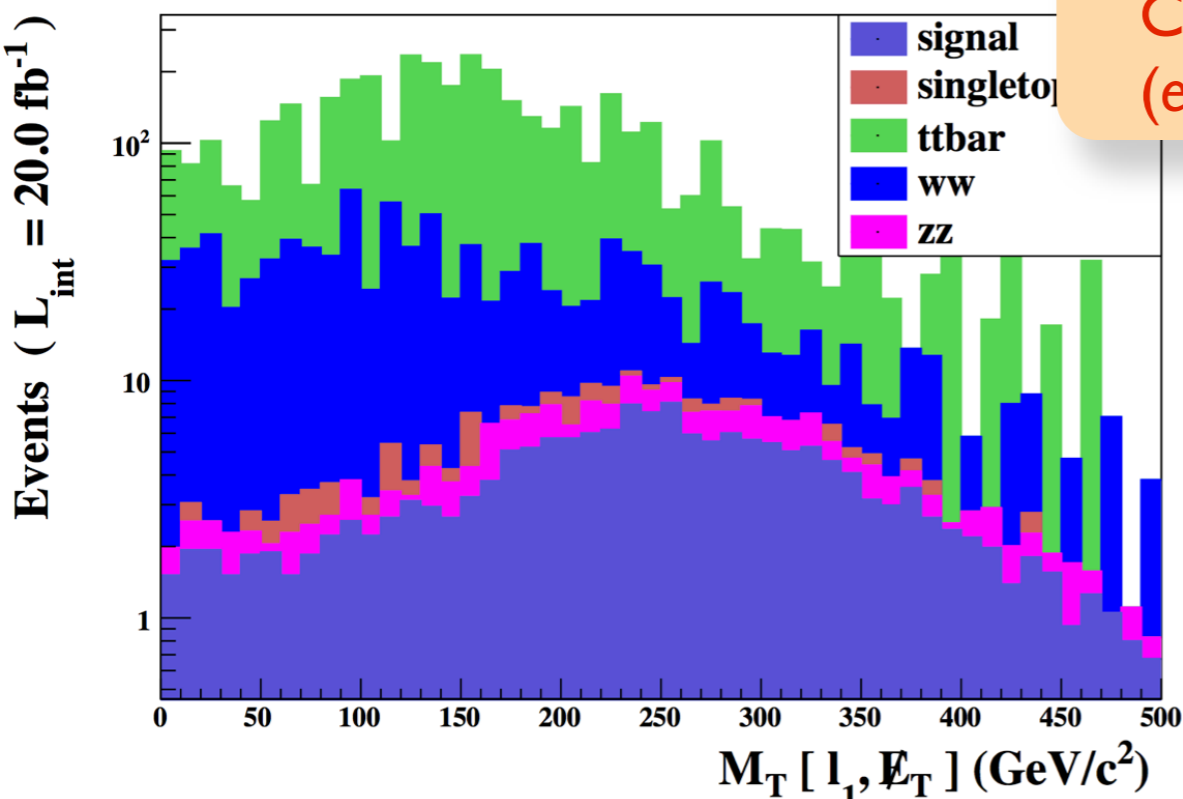
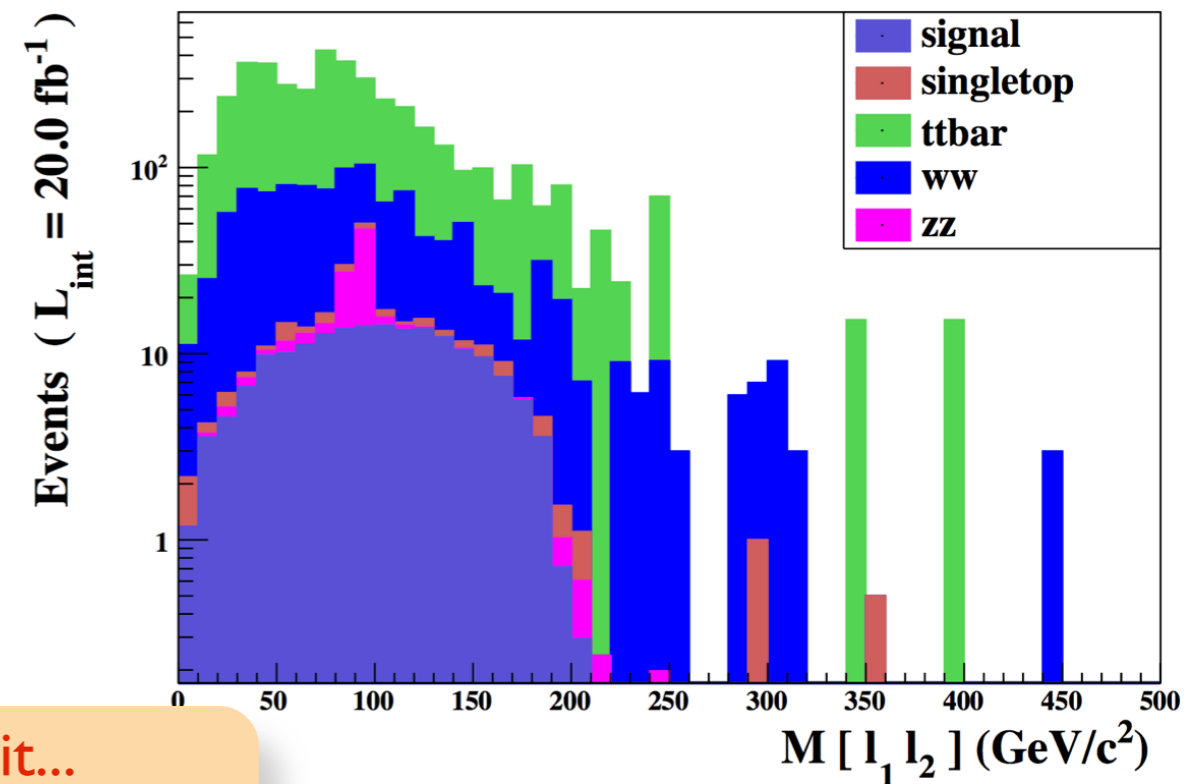
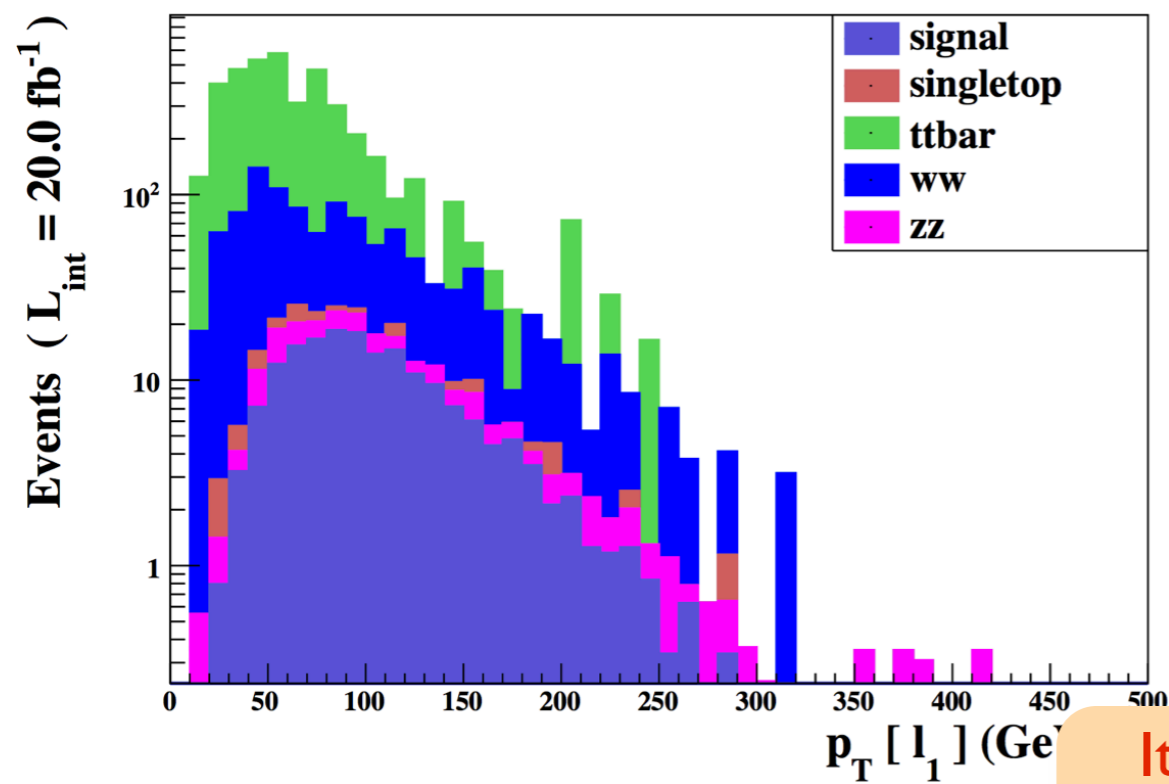
- ◆ Two special functions
 - ❖ *DELTAR*: take two arguments
 - ❖ *MT_MET*: compute the transverse mass obtained when combining one particle with the missing momentum

```
ma5>plot DELTAR(l[1],l[2]) 15 0 5 [logY]
ma5>plot MT_MET(l[1]) 50 0 500 [logY]
ma5>plot MT_MET(j[2]) 50 0 500 [logY]
```

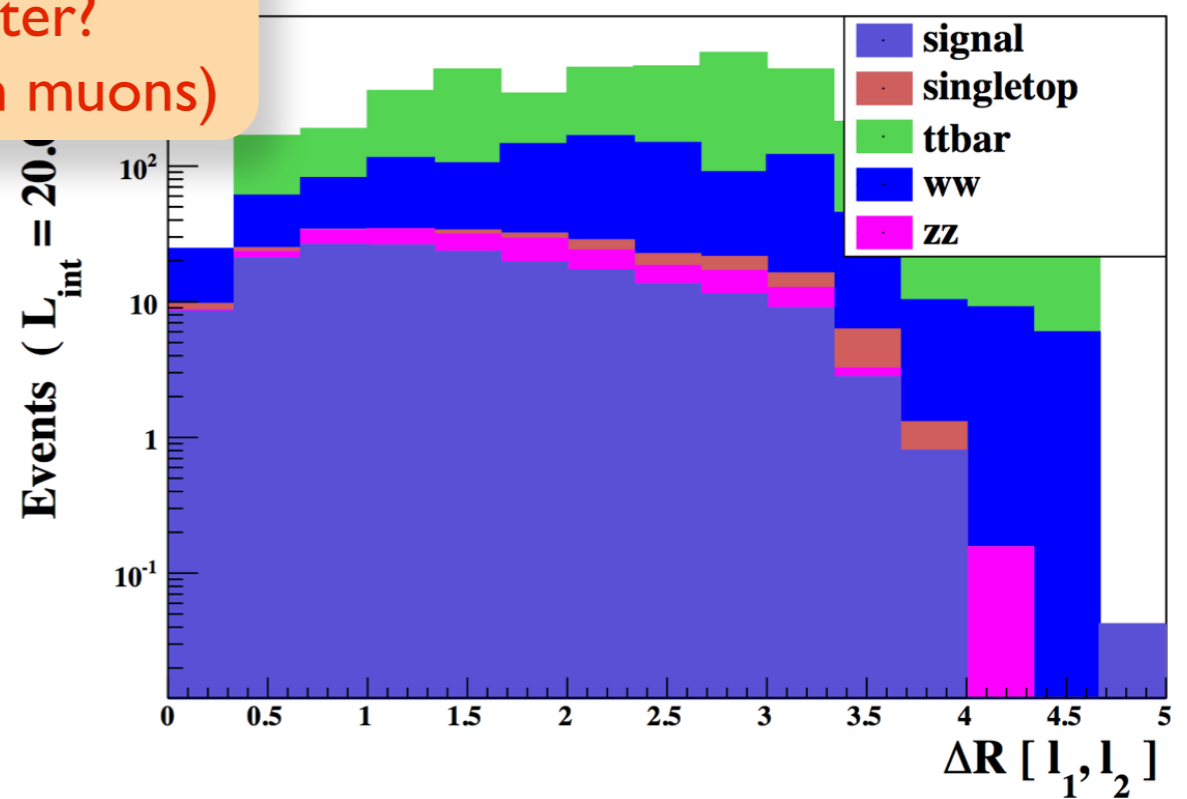
Investigating particle properties (2)



Investigating particle properties (3)



It improves a bit...
Can we do better?
(e.g., cutting on muons)



Outline

1. Introduction & setup for this lecture
2. Overview of MADANALYSIS 5 and basic concepts
3. Analyzing events with MADANALYSIS 5
4. **Summary**

Summary

- ◆ The quest for new physics at the LHC has started
 - ❖ Relies on **Monte Carlo event generators** (such as MADGRAPH 5) for background and signal modeling (and also on data for the background)
 - ❖ **Satellite tools** have been intensively developed (FEYNRULES, MADANALYSIS 5, ...)
- ◆ MADANALYSIS 5:
 - ❖ A **unique** framework for collider phenomenology (parton-, hadron-, reco-levels)
 - ❖ **User-friendly** by means of its PYTHON interface
 - ❖ **Flexible** thanks to its C++ kernel
 - ❖ **Allows to perform professional phenomenological analyses in an easy way**

Please try the code, you will love it! :)
<https://launchpad.net/madanalysis5>