



# Beyond the Standard Model phenomenology with MADANALYSIS 5

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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. The expert mode of MADANALYSIS 5
5. 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:

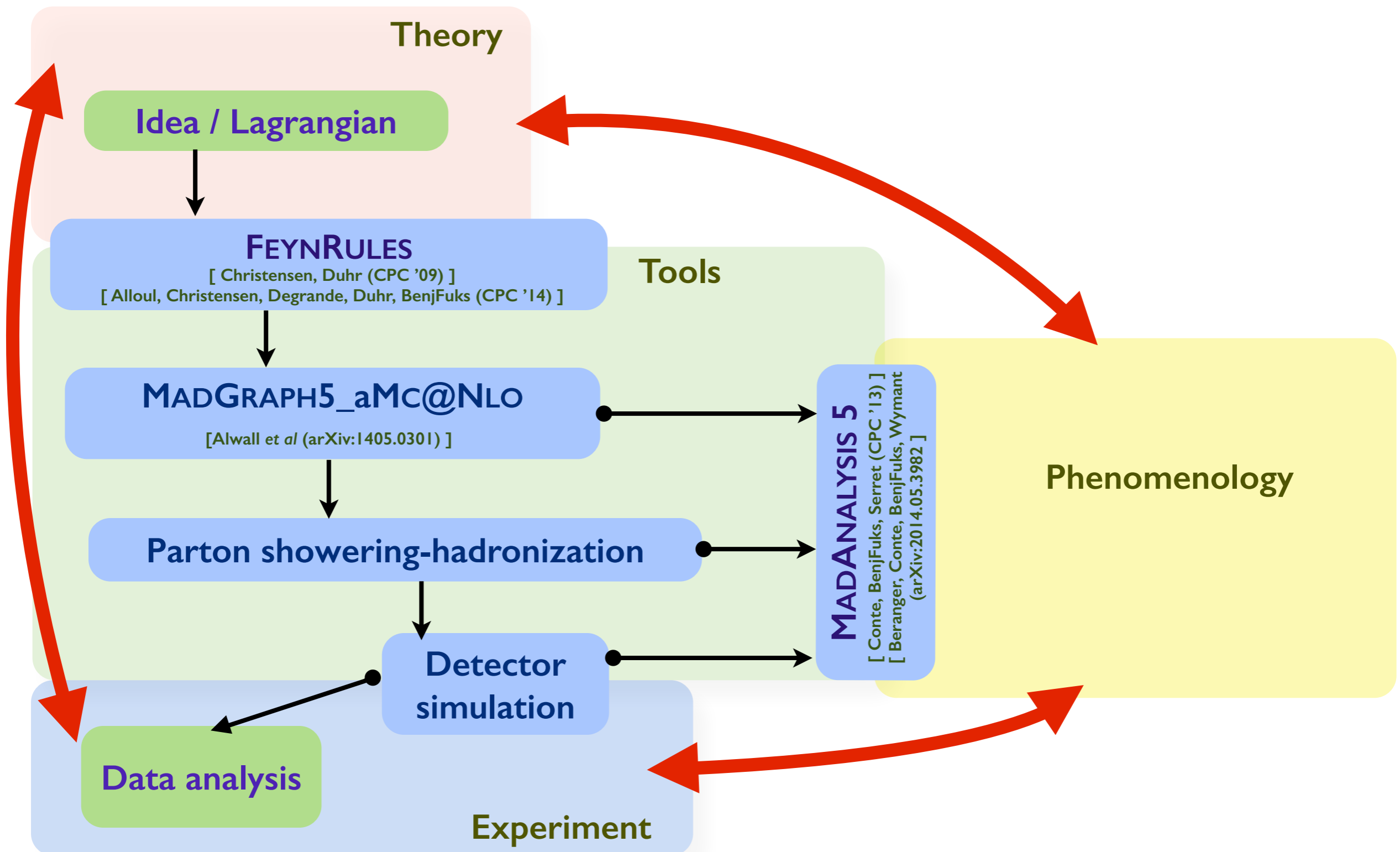
- ❖ **Measurement** of the model parameters
- ❖ Use of **precision** predictions (possibly with Monte Carlo generators)
- ❖ **Sophistication** of the analyses  $\Leftrightarrow$  new physics / detector knowledge

➡ 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) ]



# BSM phenomenology made easy: the framework

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 [Mangano, Moretti, Piccinini, Treccani (JHEP '07) ]

❖ **Precision in the shapes:** MLM-merging technique

4. Detector simulation with DELPHES 3 [ de Favareau et al (JHEP'14) ]

❖ Getting closer to the experiment

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<sup>-1</sup>
- ❖ 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.  $\Rightarrow$  not considered here

## ◆ Cross sections for the Standard Model background

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

## ◆ Multiparton matrix element merging: up to two jets

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# MADANALYSIS 5 in a nutshell

[ Conte, BenjFuks, Serret (CPC '13); Conte, BenjFuks (J.Phys.Conf.Ser '14); Conte, Dumont, BenjFuks, Wymant (1405.3982) ]

## ◆ What is MADANALYSIS 5?

- ❖ A framework for **phenomenological analyses**
- ❖ **Any level of sophistication**: partonic, hadronic, detector, reconstructed
- ❖ **Several input format**: STDHEP, HEPMC, LHE, LHCO, ROOT (from DELPHES)
- ❖ **User-friendly, flexible and fast**
- ❖ **Interfaces** to several HEP packages to process events (fast detector simulation, jet clustering, etc.)

## ◆ Two modules

- ❖ A **PYTHON** command line interface (interactive; including inline help)
- ❖ 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  $\text{L}^{\text{T}}\text{E}^{\text{X}}$

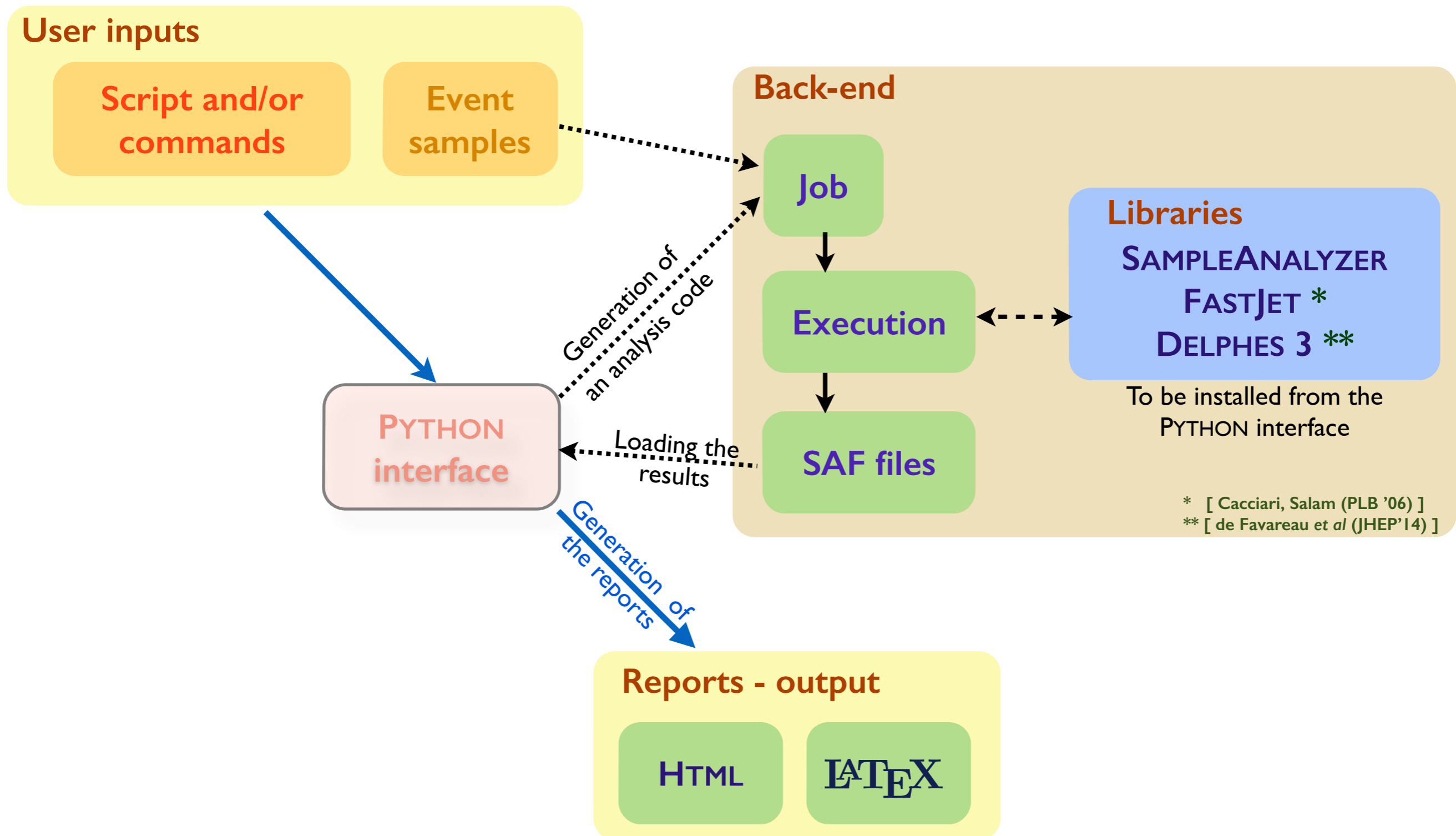
## ◆ Expert mode: recently extended for recasting existing LHC analyses

- ❖ **C++/ROOT programming** within the SAMPLEANALYZER framework
- ❖ Support for **multiple sub-analyses**, an efficient way for handling cuts and histograms, etc.



# MADANALYSIS 5: normal running mode

[ Conte, BenjFuks, Serret (CPC '13); Conte, BenjFuks (J.Phys.Conf.Ser '14); Conte, Dumont, BenjFuks, Wymant (arXiv:1405.3982) ]



# MADANALYSIS 5: expert running mode

[ Conte, BenjFuks, Serret (CPC '13); Conte, BenjFuks (J.Phys.Conf.Ser '14); Conte, Dumont, BenjFuks, Wymant (arXiv:1405.3982) ]

## User inputs

Event  
samples

Job

Execution

SAF files

Code skeleton to be generated  
from the PYTHON interface

## Libraries

SAMPLEANALYZER  
FASTJET \*  
DELPHES 3 \*\*

To be installed from the  
PYTHON interface

\* [ Cacciari, Salam (PLB '06) ]

\*\* [ de Favareau et al (JHEP'14) ]

# Getting started...

## ◆ Installing the program

- ❖ Download: <https://launchpad.net/madanalysis5>
- ❖ Unpacking the tar-ball: `tar xvf MadAnalysis5_v1.1.1|beta2.tgz`
- ❖ 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
- ❖ gmake

## ◆ Optional addons

- ❖ ZLIB headers and libraries (reading compressed event files)
- ❖ LATEX, PDFLATEX, DVIPDF (compiling L<sup>A</sup>T<sub>E</sub>X reports)
- ❖ FASTJET 3.0.3 or more recent (necessary for this lecture, to reconstruct jets)
- ❖ DELPHES 3 (compatibility with the DELPHES output format)
- ❖ DELPHES 3-MA5Tune (compatibility with the DELPHES output format)
- ❖ In the future: PYTHIA-8, HERWIG-6, HERWIG++

# Getting started: the welcome screen

```
[fuks@Benjamins-MacBook-Pro ~/Work/tools/madanalysis/bzr/v1.1.11beta$] ./bin/ma5

*****
*                                                                 *
*  W E L C O M E  t o  M A D A N A L Y S I S  5                    *
*                                                                 *
*          _____          _____                          *
*         / \  / \  / \  / \  / \  / \  / \  / \  / \  / \  / \  *
*        ^   ^   ^   ^   ^   ^   ^   ^   ^   ^   ^   ^   ^   ^   *
*       / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \  *
*      / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \  *
*     / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \  *
*    / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \  *
*   / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \  *
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* / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \ / \  *
*                                                                 *
* MA5 release : 1.1.11.11                                     2014/06/13 *
*                                                                 *
*   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

```
Platform: Darwin 13.1.0 [MAC/OSX mode]
Reading user settings ...
Checking mandatory packages:
- python [OK]
- python library: numpy [OK]
- g++ [OK]
- GNU Make [OK]
- Root [OK]
- PyRoot libraries [OK]
Checking optional packages:
- pdflatex [OK]
- latex [OK]
- dviPDF [OK]
- zlib [OK]
- FastJet [OK]
- Delphes [DISABLED]
** WARNING: Header file called '/modules/ParticlePropagator.h' not found.
** WARNING: Delphes ROOT format will be disabled.
** WARNING: To enable this format, please type 'install delphes'.
- Delphes-MA5tune [OK]
```

The requirements

Automated installation sometimes available

The optional packages

# Getting started: SAMPLEANALYZER (the core)

```

Checking the MadAnalysis library:
=> First use of MadAnalysis (or the library is missing).

*****
                Building SampleAnalyzer libraries
*****
How many cores for the compiling? default = max = 8
Answer:
=> Number of cores used for the compilation = 8
Writing the setup files ...
Writing all the Makefiles ...
*****
Component 1/10 - library: SampleAnalyzer commons
- Cleaning the project before building the library ...
- Compiling the source files ...
- Linking the library ...
- Checking that the library is properly built ...
- Cleaning the project after building the library ...
=> Status: [OK]
:
Component 10/10 - test program: SampleAnalyzer core
- Cleaning the project before building the test program ...
- Compiling the source files ...
- Linking the test program ...
- Checking that the test program is properly built ...
- Cleaning the project after building the test program ...
- Running the test program ...
- Checking the program output...
=> Status: [OK]
*****

```

Compilation of SAMPLEANALYZER  
and all the dependencies  
[ if necessary ]

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

```

*****
MadGraph 5 NOT found:
=> Particle labels from input/particles_name_default.txt
=> 87 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.
ma5>

```

Important for variables  
such as  $H_T$ , MET, etc.



# Basic concepts of the normal mode (I)

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

## Looking for help...

```
ma5>help
```

```
Documented commands (type help <topic>):
```

```
EOF          display_multiparticles  history  plot    reset    set
define       display_particles      import   quit    restart  shell
display      exit                   install  reject  resubmit submit
display_datasets  help                   open     remove  select   swap
```

- ❖ Event file format automatically detected
- ❖ Events files associated with a label
- ❖ Supported file formats:  
LHE, STDHEP, HEPMC, LHCO,  
ROOT (from DELPHES 3)
- ❖ Several samples can be grouped  
(e.g., to increase statistics)
- ❖ Wildcards can be employed

## Datasets

```
ma5>import ttbar* as ttbar
```

```
-> Storing the file 'ttbar.hep.gz' in the dataset 'ttbar'.
```

```
-> Storing the file 'ttbar2.hep.gz' in the dataset 'ttbar'.
```

```
ma5>import Wjets.hep.gz as W
```

```
-> Storing the file 'Wjets.hep.gz' in the dataset 'W'.
```

```
ma5>import V.hep as diboson
```

```
-> Storing the file 'V.hep' in the dataset 'diboson'.
```

# Basic concepts of the normal mode (2)

## Particles and multiparticles

- ❖ **Particles** and **multiparticles** are defined via their PDG code (*labels*)
- ❖ (multi)particle labels make our life easier
- ❖ Default:
  - ★ **Standard Model** labels: as in MADGRAPH
  - ★ **MSSM** labels: as in MADGRAPH
  - ★ **invisible**: computation of observables related to the missing energy
  - ★ **hadronic**: computation of observables related to the hadronic activity
- ❖ Can be imported from a UFO model

```
ma5>define TheMuon = 13
ma5>define TheAntiMuon = -13
ma5>define AllMuons = TheMuon TheAntiMuon
ma5>display l+
  The multiparticle 'l+' is defined by the PDG-ids -15 -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 100022 100039.
ma5>remove TheMuon
ma5>display TheMuon
** ERROR: no object called 'TheMuon' found.
```



# Basic concepts of the normal mode (3)

## Histograms - the command *plot*

- ❖ *plot*: creation of an histogram
- ❖ **Global observables**  
related to the full event (MET,  $H_T$ , etc.)
- ❖ **Properties** of a particle type ( $p_T$ , E, etc.)
- ❖ Particle **ordering** can be used
- ❖ Particles can be **combined**
- ❖ **Virtual particles** can be studied
- ❖ Log scales can be **employed**
- ❖ Ways to **normalize** an histogram

```

ma5>plot MET [
]           ETAordering  initialstate  logY         POrdering  PZordering
allstate   ETordering   interstate   normalize2one PXordering  stack
Eordering  finalstate   logX        Pordering   PYordering  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 ]

```

## Selection cuts - the commands *reject/select*

- ❖ Events can be **selected/rejected**
- ❖ Particles can be **selected/rejected** from an analysis

```

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

```

# Basic concepts of the normal mode (4)

## Executing the analysis - the command *submit*

- ❖ First: create a **C++ code** with the analysis
- ❖ Second: compile and execute the code
- ❖ 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 'defaultset'...
*****
* SampleAnalyzer for MadAnalysis 5 - Welcome.
* Initializing all components
  - version: 1.1.11.11 (2014/06/13)
  - general: everything is default.
  - extracting the list of event samples...
  - analyzer 'MadAnalysis5job'
* Running over files ...
* 1/1 /Users/fuks/Work/tools/madanalysis/bzr/v1.1.11beta/samples/jjj.lhe.gz
  => file size: 1.41 Mo
  => sample format: LHE file produced by MadGraph5.
  => progress: [=====]
  => total number of events: 10000 ( analyzed: 10000 ; skipped: 0 )
* Finalizing all components ...
* Total number of processed events: 10000.
* Goodbye.
*****
Checking SampleAnalyzer output...
Extracting data from the output files...
Preparing data for the reports ...
Generating the HTML report ...
  -> To open this HTML report, please type 'open'.
Generating the PDF report ...
  -> To open this PDF report, please type 'open ANALYSIS_0/PDF'.
Generating the DVI report ...
  -> Converting the DVI report to a PDF report.
  -> To open this PDF report, please type 'open ANALYSIS_0/DVI'.
Well done! Elapsed time = 8 seconds

```

# Basic concepts of the normal mode (5)

## Interfaces to other HEP tools

- ❖ MADANALYSIS 5 has been interfaced to **FASTJET** and **DELPHES 3**

```
ma5>install  
delphes      delphesMA5tune fastjet      samples      zlib
```

- ❖ Starts from events at the hadron level and produces LHE/LHCO files (FASTJET) or ROOT files (DELPHES) from **MADANALYSIS 5**

- ❖ DELPHES is modular ➤ MADANALYSIS 5 includes some extra modules (Delphes-MA5Tune)

- ★ extra information on **lepton isolation**
- ★ **track** information
- ★ exported to the output file and in the analysis code
- ★ smaller output ROOT files (DELPHES)
- ★ This version of DELPHES can be used from MADANALYSIS 5

[ Les Houches 2013 proceedings (I405.1617) ]

# Basic concepts of the normal mode (6)

## Jet clustering and basic detector effects

- ❖ Running of **FASTJET** via the **MADANALYSIS 5** interpreter (in the reco mode)
- ❖ B-tagging efficiencies/mistagging rates, tau-tagging efficiencies/mistagging rates, etc., can be included
- ❖ The reconstructed events can be **redirected to a file**
  - ★ The output file can be used for post-proceesing
- ❖ Can also be used for checking the **merging procedure**
  - ★ Differential jet rate distributions

```
ma5>set main.fastsim.package =
delphes          delphesMA5tune fastjet          none
ma5>set main.fastsim.package = fastjet
ma5>set main.fastsim.algorithm =
antikt          cambridge cdfjetclu cdfmidpoint genkt          gridjet          kt          none          siscone
ma5>set main.fastsim.algorithm = antikt
ma5>set main.fastsim.
main.fastsim.algorithm          main.fastsim.bjet_id.misid_cjet          main.fastsim.ptmin
main.fastsim.bjet_id.eta         main.fastsim.bjet_id.misid_ljet          main.fastsim.radius
main.fastsim.bjet_id.exclusive          main.fastsim.exclusive_id          main.fastsim.tau_id.eta
main.fastsim.bjet_id.matching_dr          main.fastsim.package          main.fastsim.tau_id.misid_ljet
ma5>set main.fastsim.bjet_id.eta         = 0.60
ma5>set main.fastsim.bjet_id.misid_cjet = 0.10
ma5>set main.fastsim.bjet_id.misid_ljet = 0.01
ma5>set main.outputfile = blabla.lhe
ma5>
```

# Basic concepts of the normal mode (7)

## Fast simulation of the detector with DELPHES 3

- ❖ Running of DELPHES via the MADANALYSIS 5 interpreter (in the reco mode)
- ❖ Choice of ATLAS or CMS; pile-up can be included
- ❖ The ROOT output file is stored

```
ma5>set main.fastsim.package = delphesMA5tune
ma5>set main.fastsim.
main.fastsim.detector main.fastsim.output main.fastsim.package main.fastsim.pileup
ma5>set main.fastsim.detector =
atlas cms
ma5>set main.fastsim.detector = cms
ma5>
```

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# Recall: event samples

## ◆ Setup for this tutorial

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- ❖ 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.  $\Rightarrow$  not considered here

## ◆ Cross sections for the Standard Model background

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

## ◆ Multiparton matrix element merging: up to two jets

# Jet clustering (I)

## ◆ The output of PYTHIA 6 is non-practical for an analysis

- ❖ It contains **tons of hadrons**
- ❖ We prefer to employ **jets** rather than individual hadrons
- ❖ 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;
  - ◆ If not, the user can install it by typing

```
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 (cf. the structure of STDHEP files)
  - to be 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.fastsim.algorithm =
antikt      cambridge  cdfjetclu  cdfmidpoint  genkt      gridjet    kt         none        siscone
ma5>set main.fastsim.algorithm = antikt
ma5>set main.fastsim.
main.fastsim.algorithm      main.fastsim.bjet_id.misid_cjet  main.fastsim.ptmin
main.fastsim.bjet_id.eta     main.fastsim.bjet_id.misid_ljet  main.fastsim.radius
main.fastsim.bjet_id.exclusive  main.fastsim.exclusive_id      main.fastsim.tau_id.eta
main.fastsim.bjet_id.matching_dr  main.fastsim.package           main.fastsim.tau_id.misid_ljet
ma5>set main.fastsim.radius = 0.5
ma5>set main.fastsim.bjet_id.eta = 0.60
ma5>set main.fastsim.bjet_id.misid_cjet = 0.10
ma5>set main.fastsim.bjet_id.misid_ljet = 0.01
ma5>import ttbar
ttbar.hep.gz
ma5>import ttbar.hep.gz
-> 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.)

## ◆ Les Houches event files are created (and further used)

# Checking the merging procedure (I)

## ◆ Example with a Z+jets sample

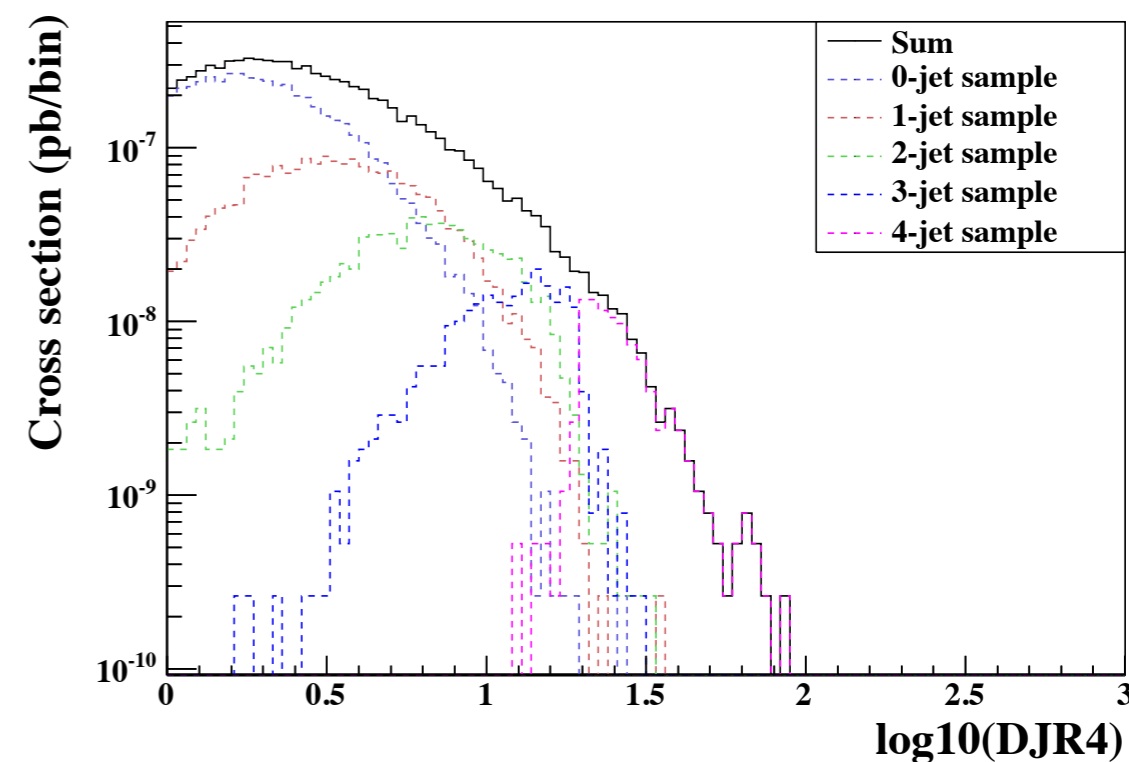
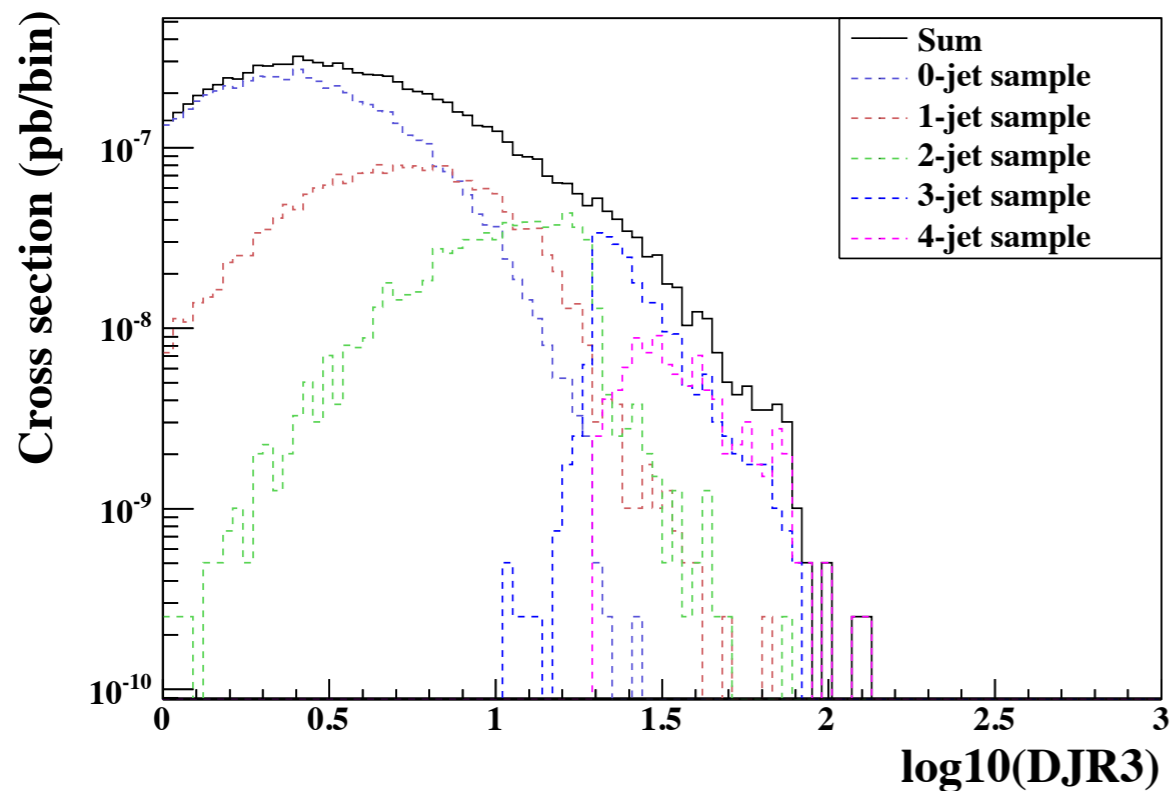
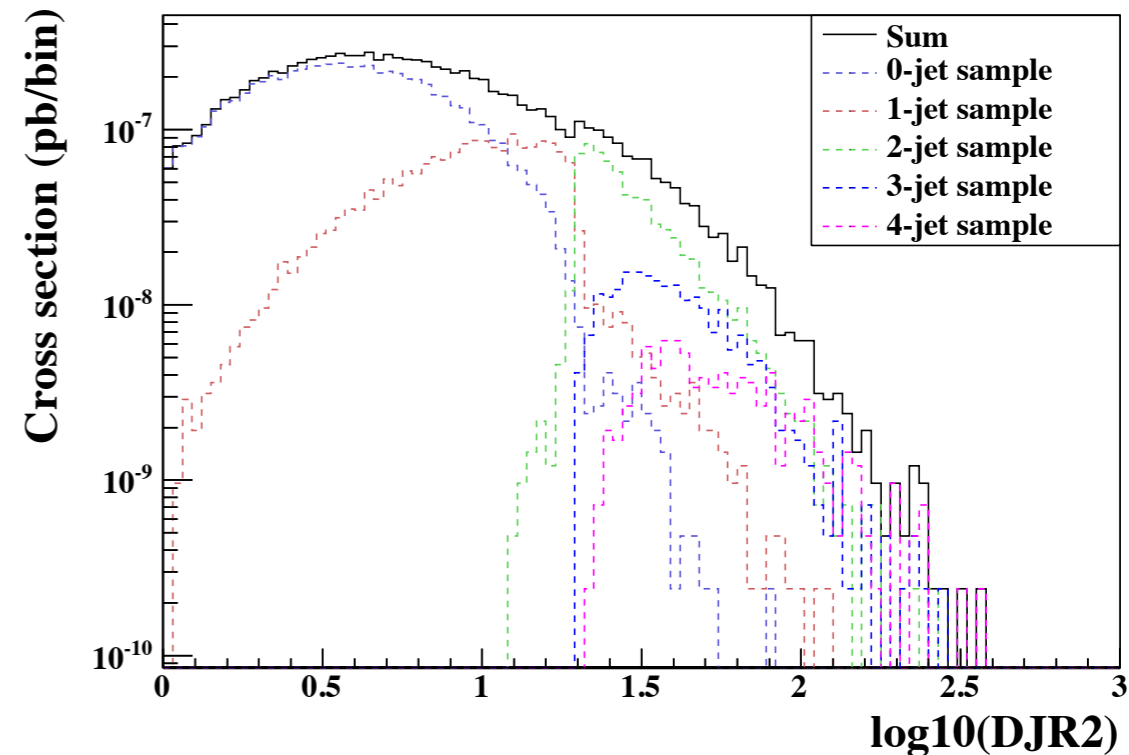
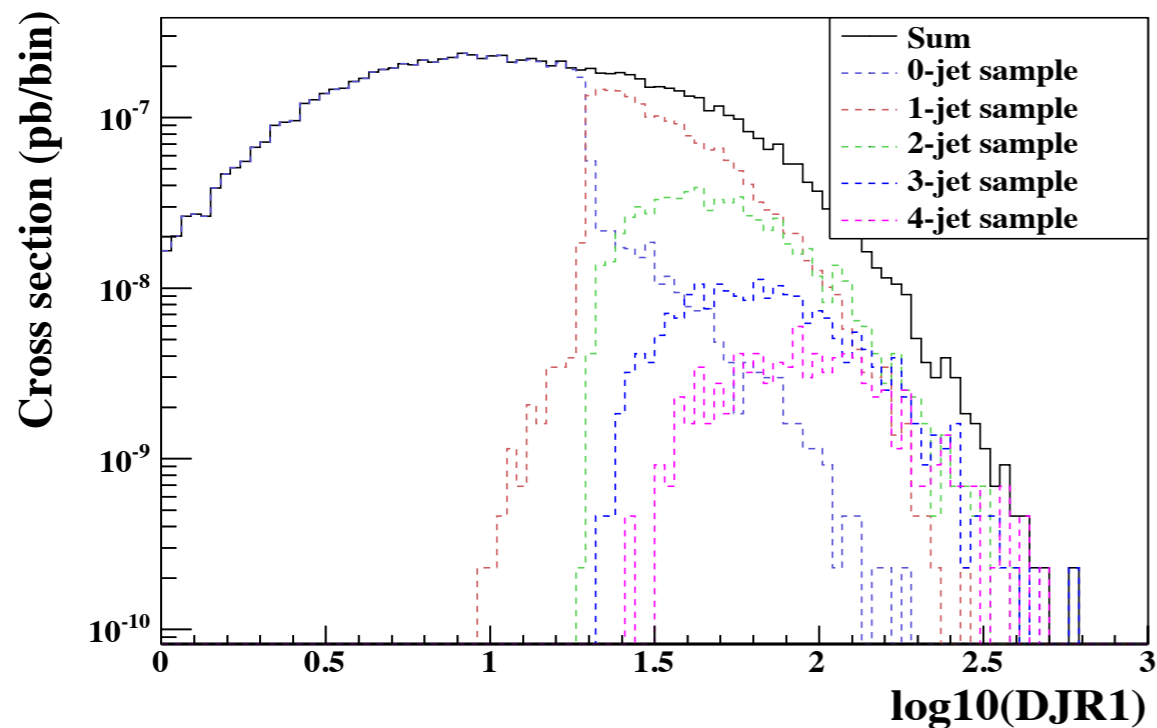
- ❖ Parton-level: Z+ 0,1,2,3,4 jets
- ❖ Parton-showering is then applied
- ❖ MLM merging: removal of the double counting consistently
- ❖ Check of that procedure: the differential jet rate (DJR) distributions
  - The scale for which one event goes from a N to a N+1 jet configuration
  - Extremely sensible 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.  
main.merging.check main.merging.njets  
ma5>set main.merging.check= true  
ma5>set main.merging.njets = 4  
ma5>import zjets.hep.gz  
    -> Storing the file 'zjets.hep.gz' in the dataset 'defaultset'.  
ma5>submit
```

# 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 ➤ correct normalization

```
ma5>import signal.lhe as signal
-> Storing the file 'signal.lhe' in the dataset 'signal'.
ma5>import singletop.lhe.gz as singletop
-> Storing the file 'singletop.lhe.gz' in the dataset 'singletop'.
ma5>import ttb.lhe.gz as ttbar
-> Storing the file 'ttb.lhe.gz' in the dataset 'ttbar'.
ma5>import ww.lhe.gz as ww
-> Storing the file 'ww.lhe.gz' in the dataset 'ww'.
ma5>import zz.lhe.gz as zz
-> Storing the file 'zz.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 closer to a real experiment

- ✦ Soft objects are not detected

- ★ Removal from each event any reconstructed jet and lepton that is softer than some threshold

```
ma5>define l = l+ l-  
ma5>select (l) PT > 10  
ma5>select (j) PT > 20
```

(a new multiparticle label *l* is created)

- ✦ Objects lying outside the detector are not detected

- ★ Removal from each event any reconstructed object lying outside the detector acceptance

```
ma5>select (l) -2.5 < ETA < 2.5  
ma5>select (j) -2.5 < ETA < 2.5
```

- ✦ Object overlap removal

- ★ Any charged lepton too close to a jet is removed (we are interested in isolated leptons)

```
ma5>reject (l) DELTAR(j) < 0.4
```

# 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  **$\alpha_T$  variable** (*ALPHAT*): depends on the missing energy,  $H_T$  and jet configuration
- ❖ The **particle content** of the event (*NPID, NAPID, N*)

## ◆ General setup for drawing histograms

- ❖ The **luminosity** in  $\text{fb}^{-1}$  (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]
```

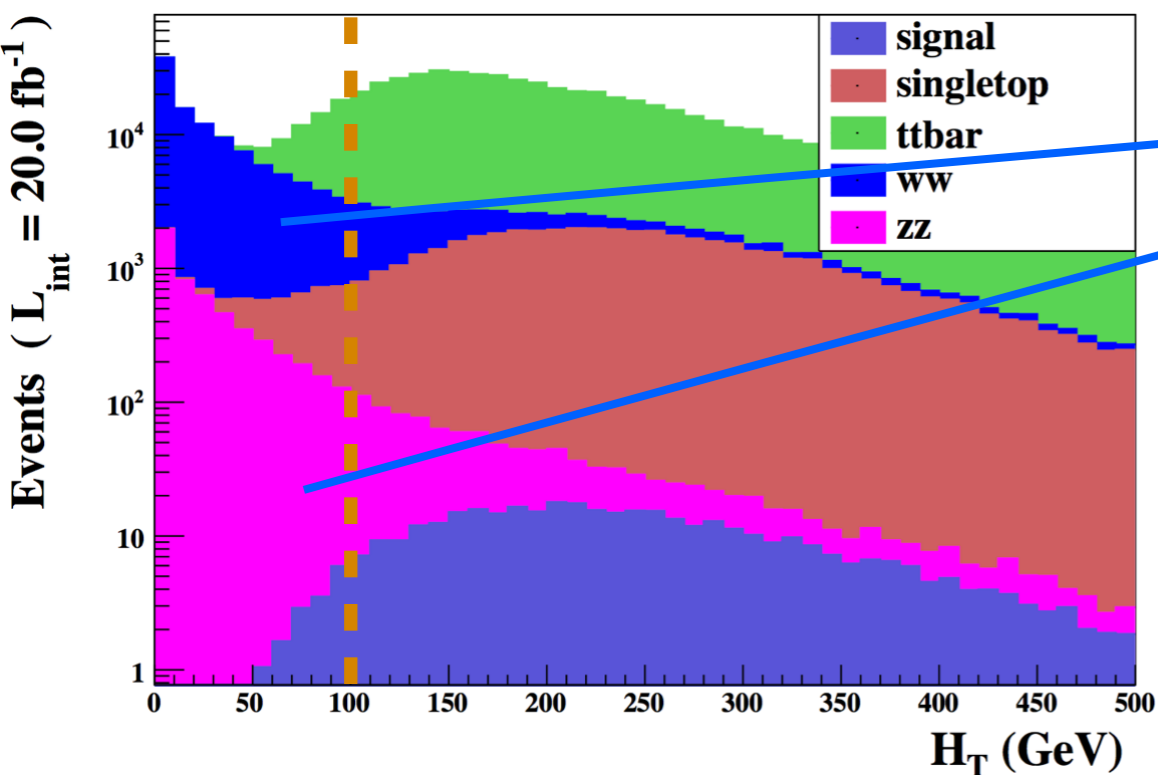
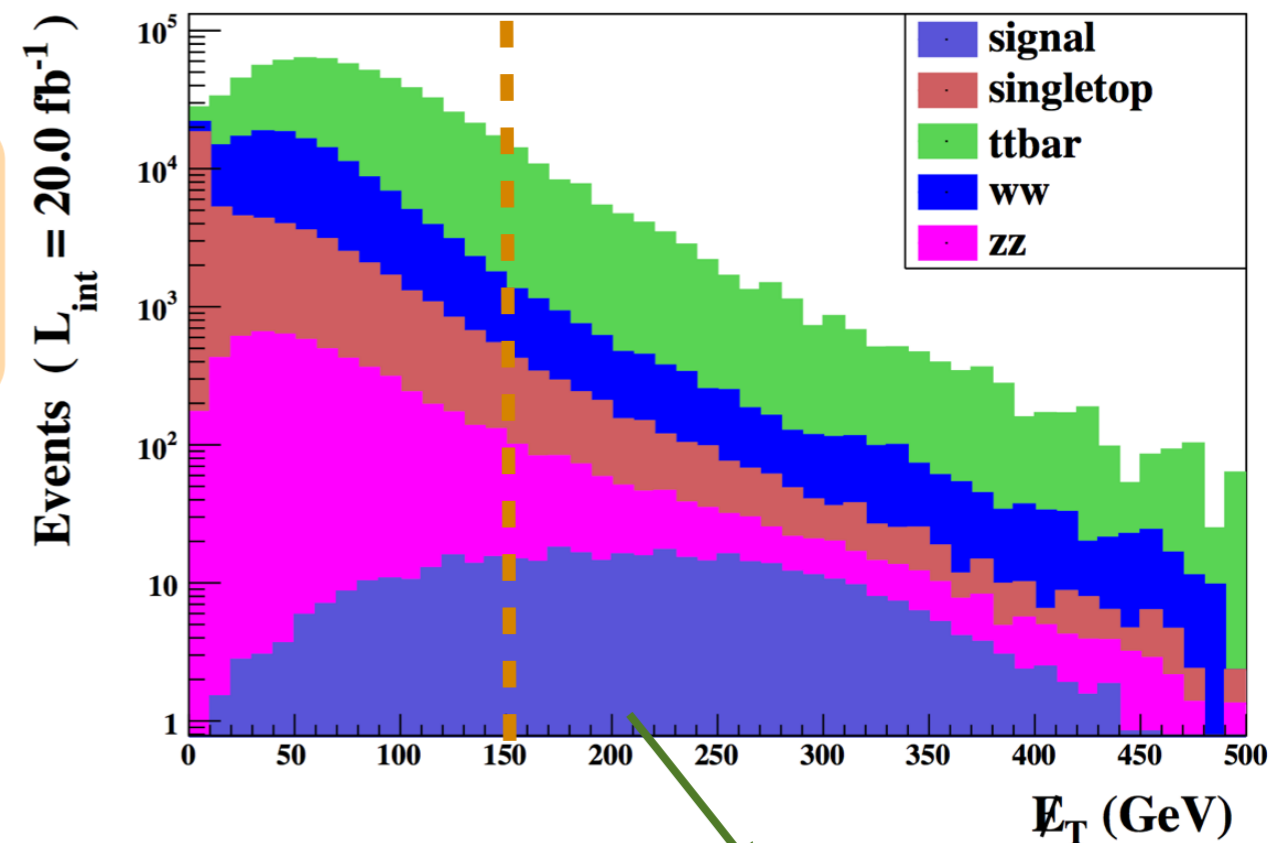
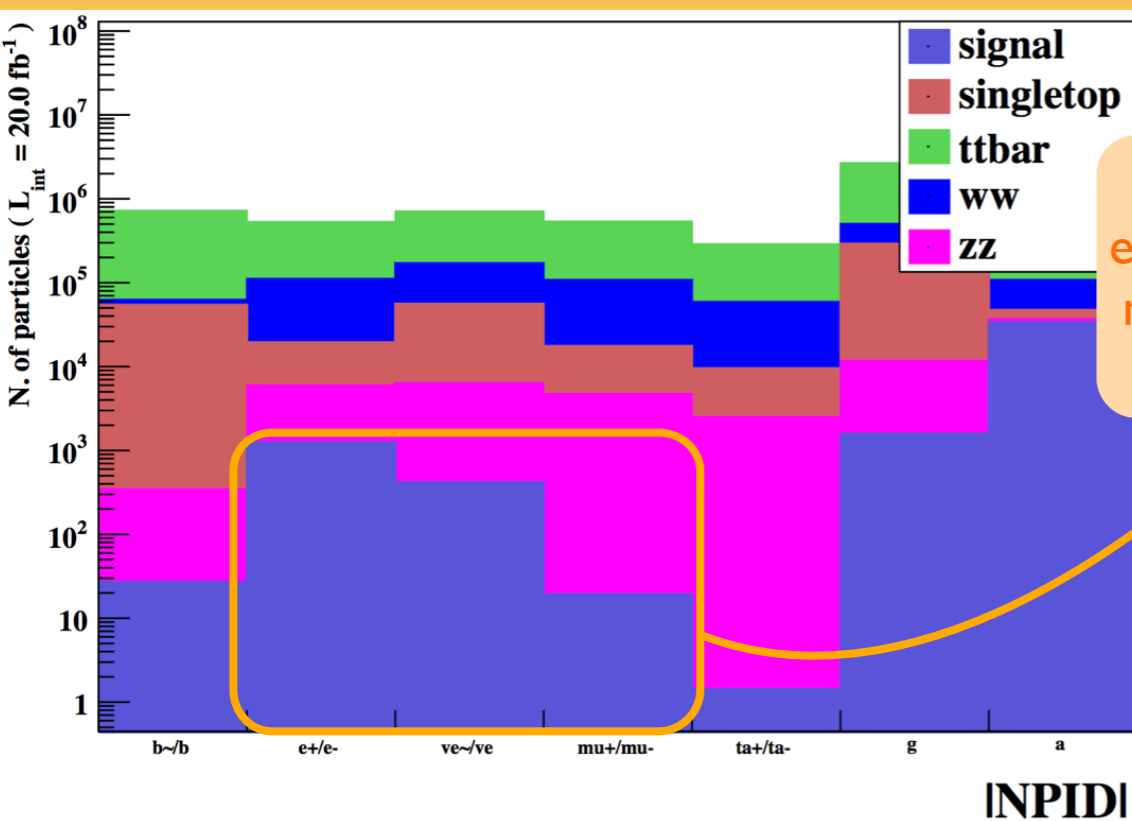
## ◆ Executing the analysis and browsing the results

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

```
ma5>submit; open
```



# Investigating some global event properties (2)



VV: jets generated by parton showering, then softer

Different shapes for signal and background

This suggest selections to improve the S vs B ratio:

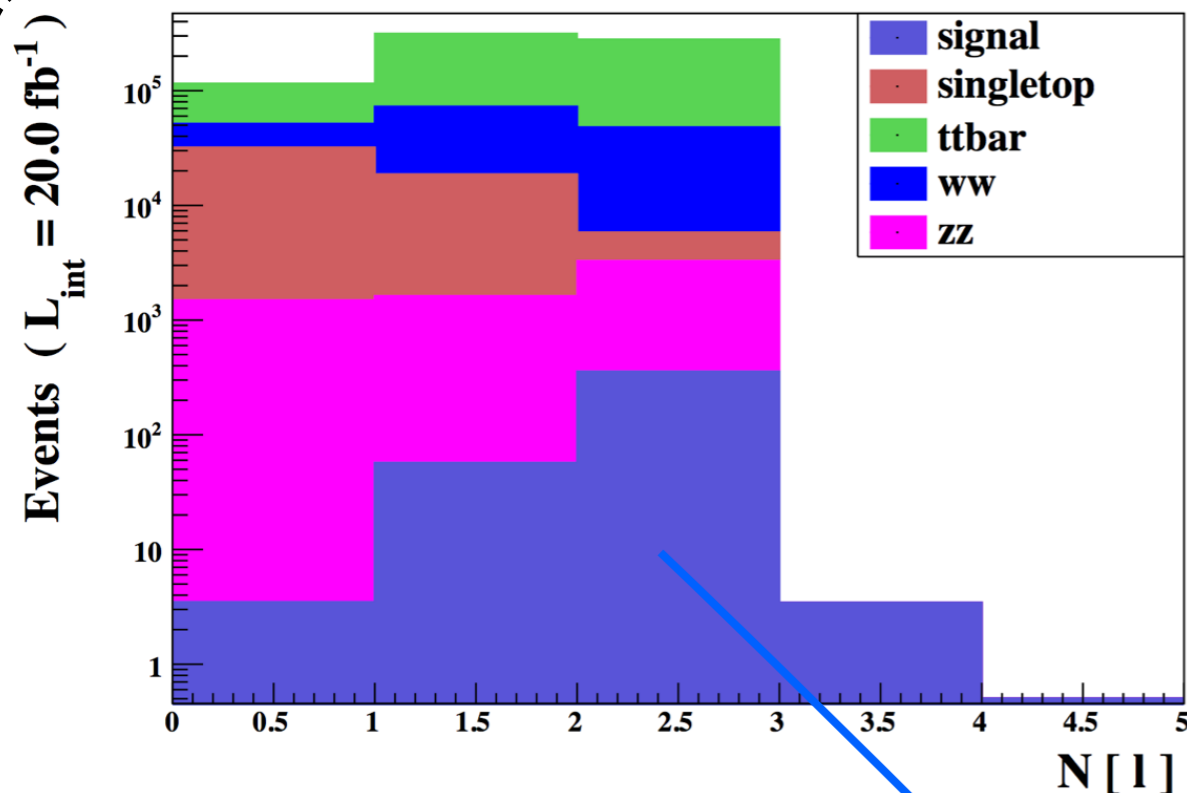
- ★ on the missing energy (e.g., 150 GeV)
- ★ on the  $H_T$  (e.g., 100 GeV)

# Investigating some global event properties (3)

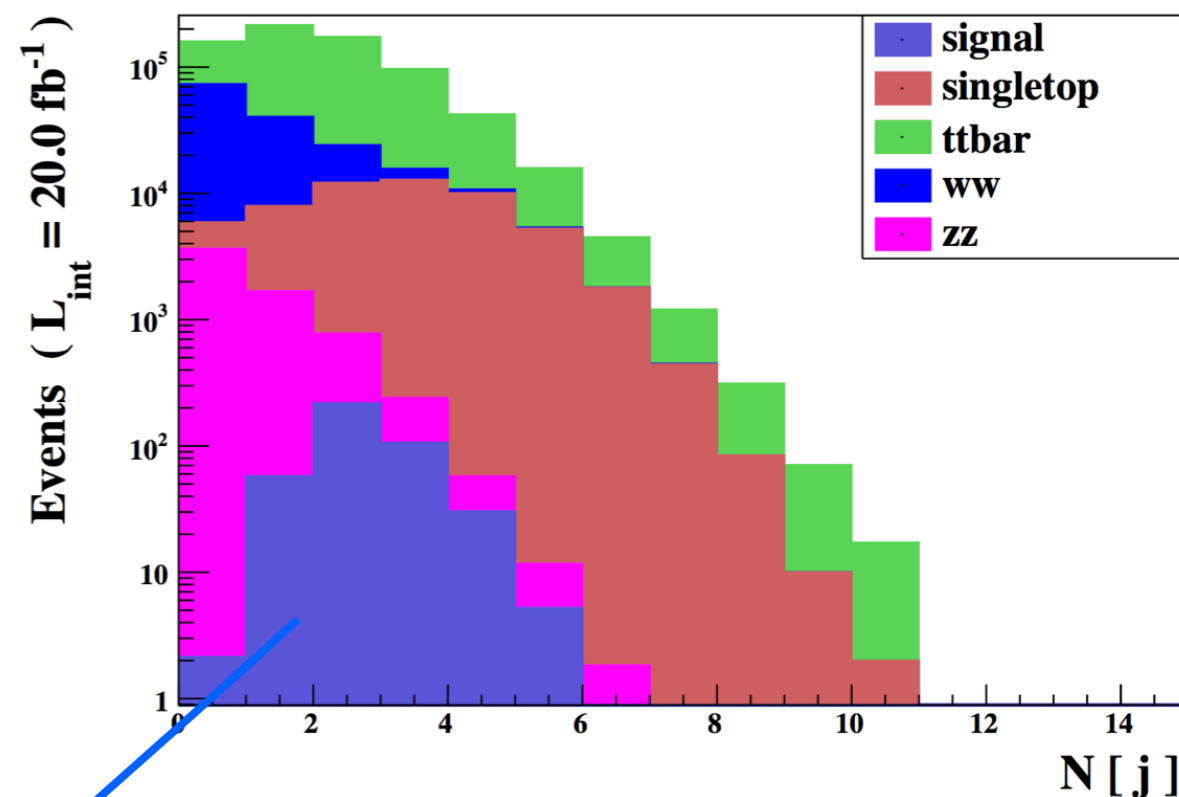
## ◆ Investigation of the number of jets and leptons

- ♣ The studied signature consists of a lepton pair, missing energy and jets
- ♣ Cutting on the number of jets/leptons 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 cuts to improve the S vs B ratio:

- ★ exactly two leptons;
- ★ two or three jets.



# Selection cuts

## ◆ 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 THT > 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?

- ★ Large signal efficiency
- ★ Small background efficiencies

# The signal over background ratio (I)

## ◆ Are those cuts sufficient?

- ❖ Let us investigate the evolution of the **signal over background ratio** with each cut
  - ★ We can indicate to MADANALYSIS 5 **how to calculate it** (using S and B)
- ❖ This number comes with **an error**
  - ★ We can indicate to MADANALYSIS 5 **how to calculate it** (using S, B, ES and EB)

## ◆ 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)
```

$$\frac{S}{\sqrt{S+B}}$$

$$\frac{\sqrt{(S+2B)^2(\Delta S)^2 + S^2(\Delta B)^2}}{(S+B)^{3/2}}$$

# 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

# 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 single 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)

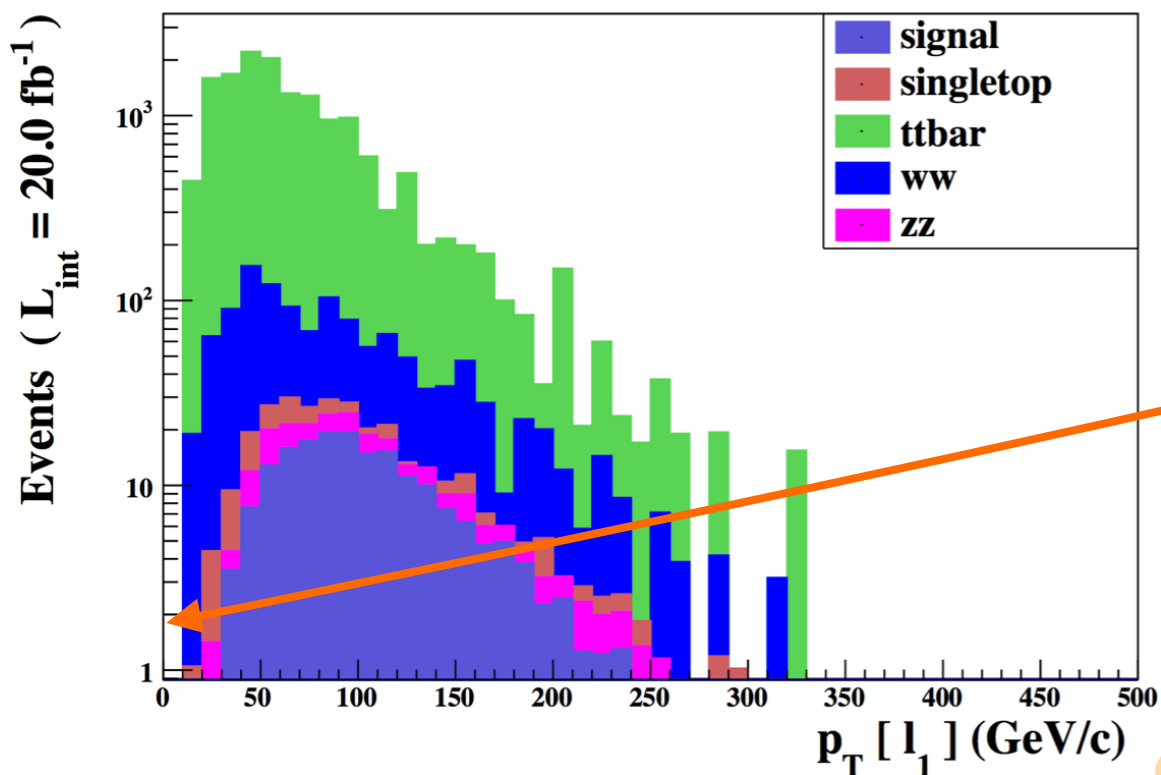
```
ma5>plot M(l[1] l[2]) 50 0 500 [logY]
ma5>plot dPHI(l[1] l[2]) 15 0 6.28 [logY]
```

## ◆ Four special functions

- ❖ *DELTAR, DPHI\_0\_PI, DPHI\_0\_2PI*: take two arguments
- ❖ *MT\_MET*: transverse mass when combining a particle with the missing momentum

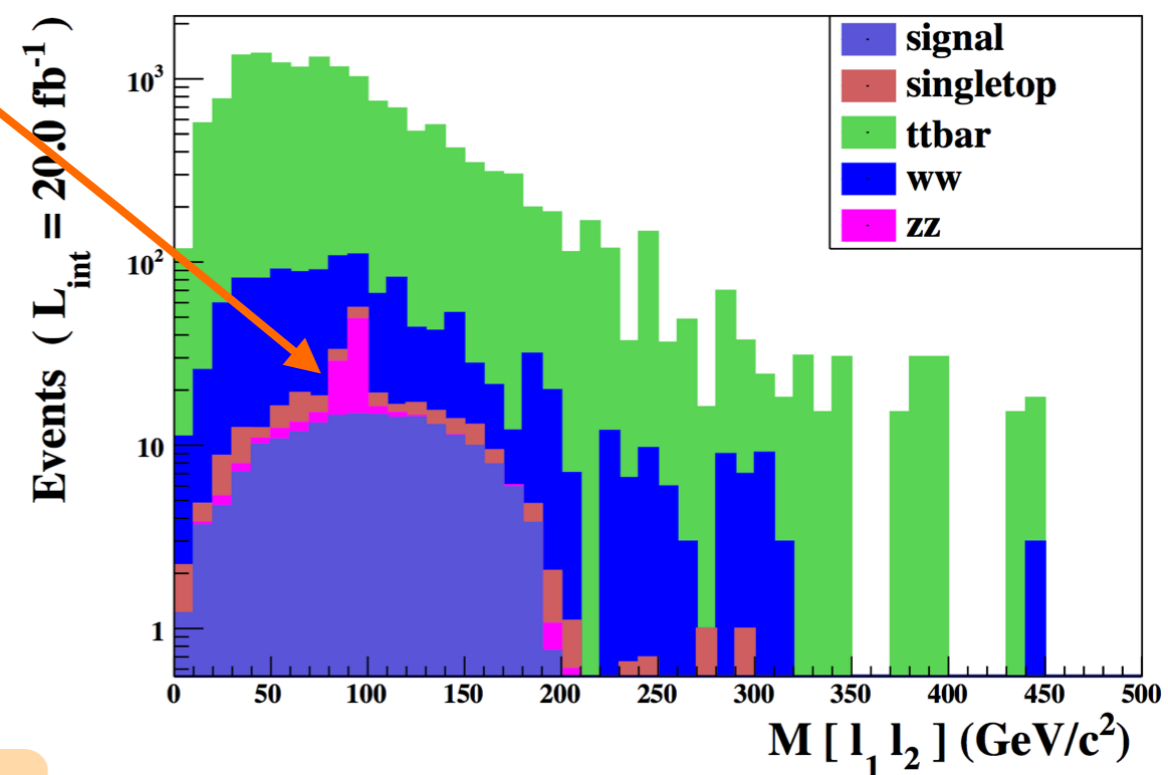
```
ma5>plot DELTAR(l[1],l[2]) 15 0 5 [logY]
ma5>plot MT_MET(l[1]) 50 0 500 [logY]
ma5>plot MT_MET(j[2]) 50 0 500 [logY]
```

# Investigating particle properties (2)

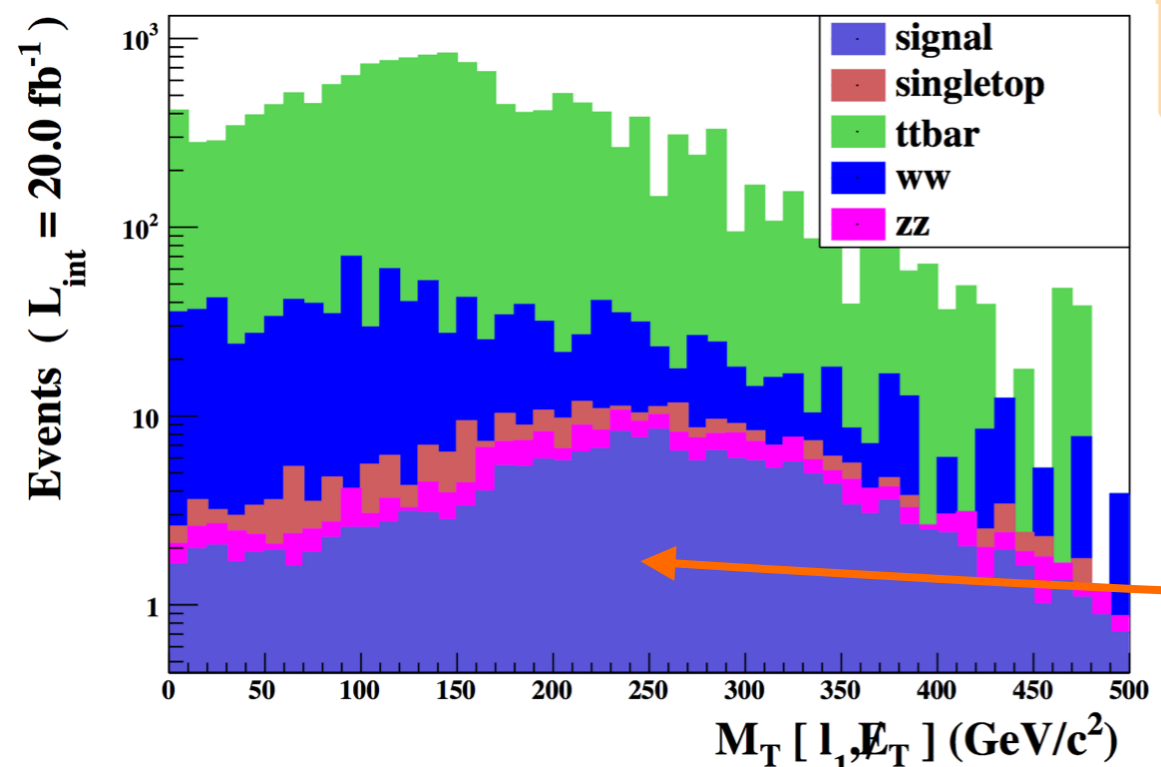


Bonus: the Z-peak

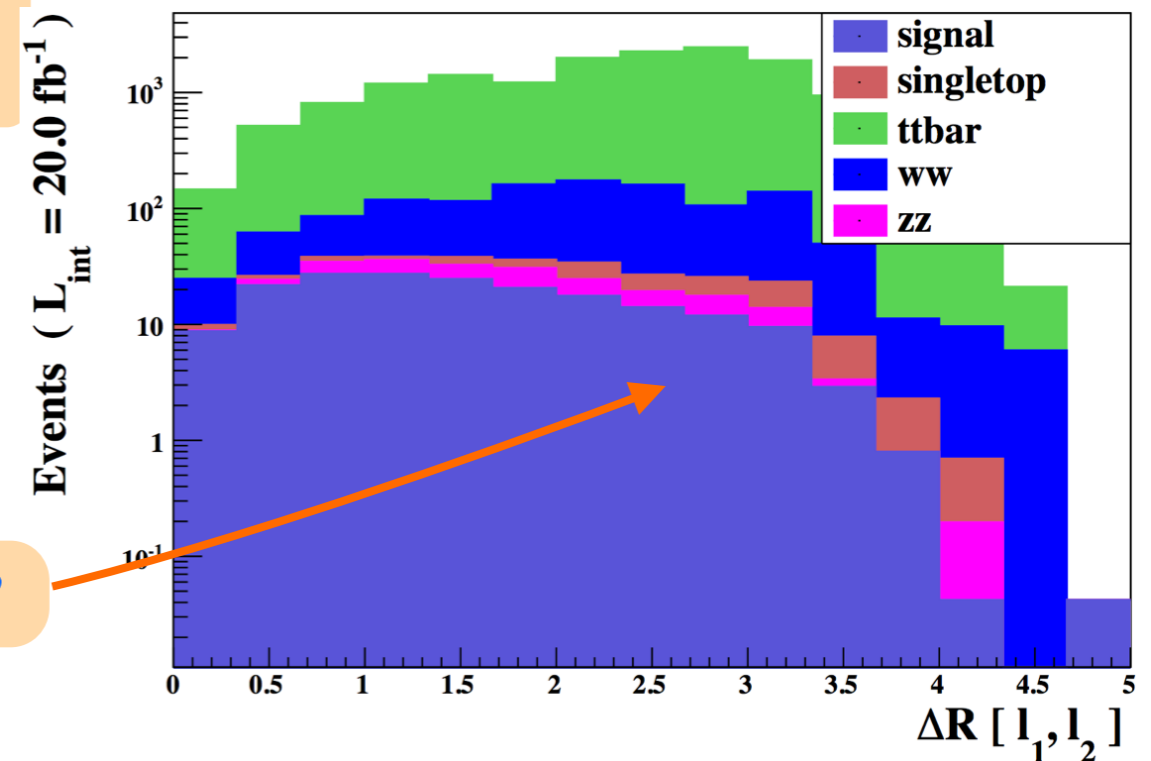
The first bin is empty



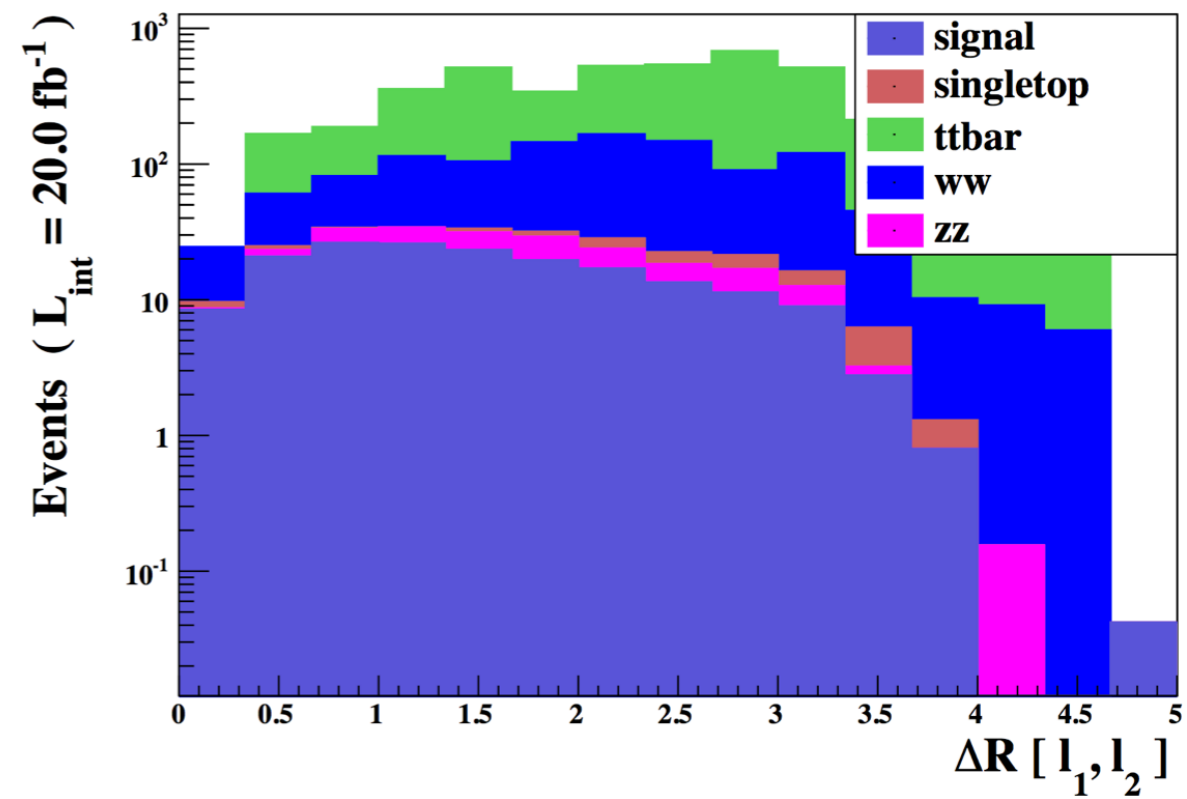
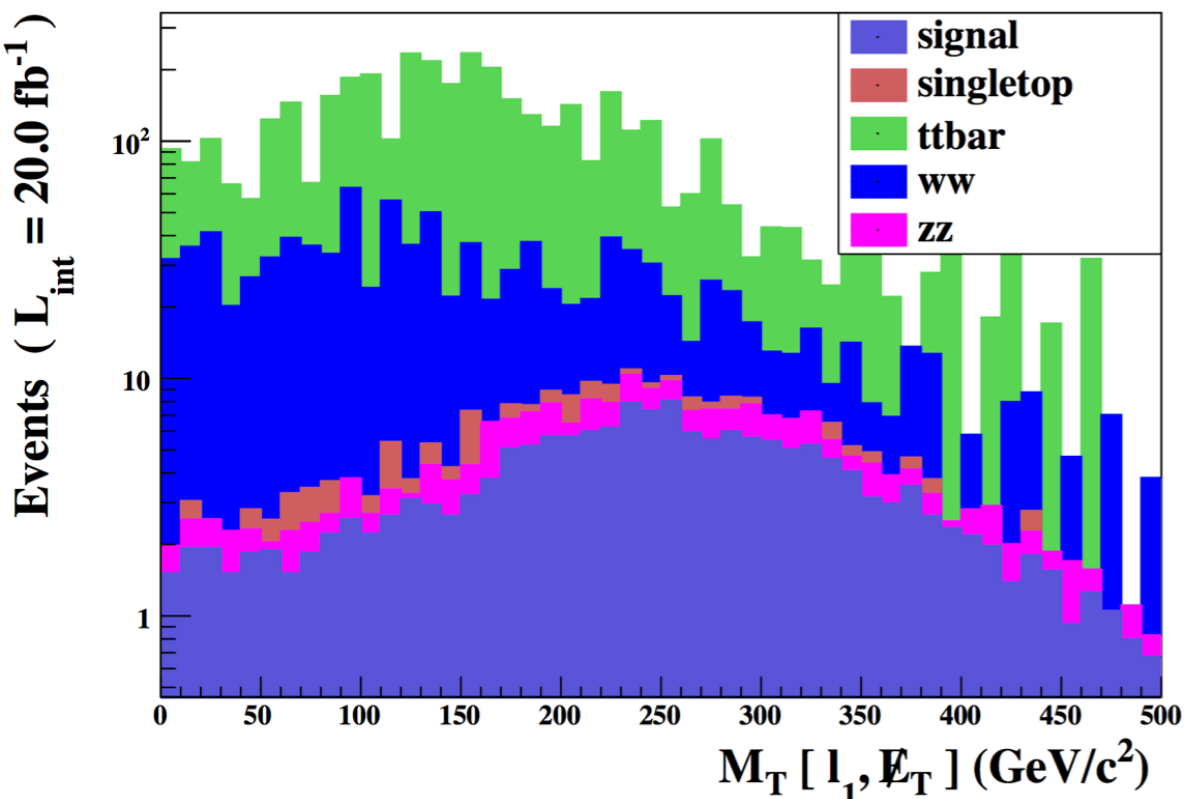
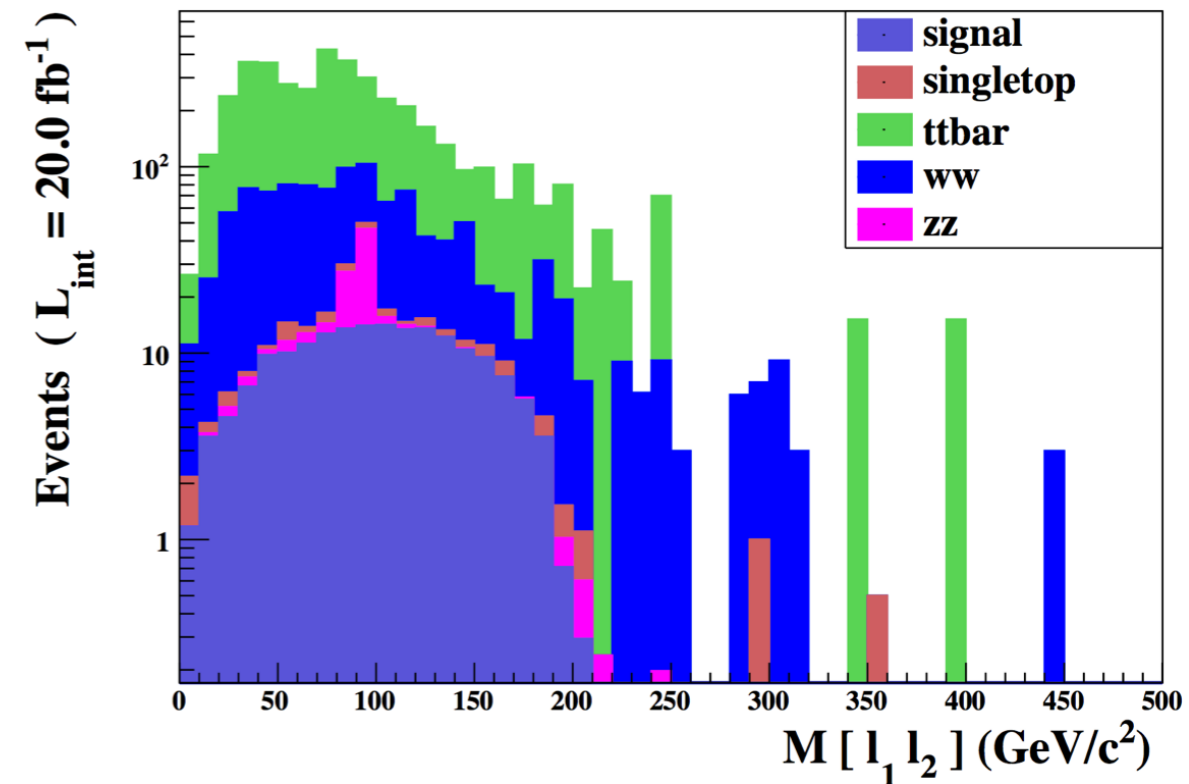
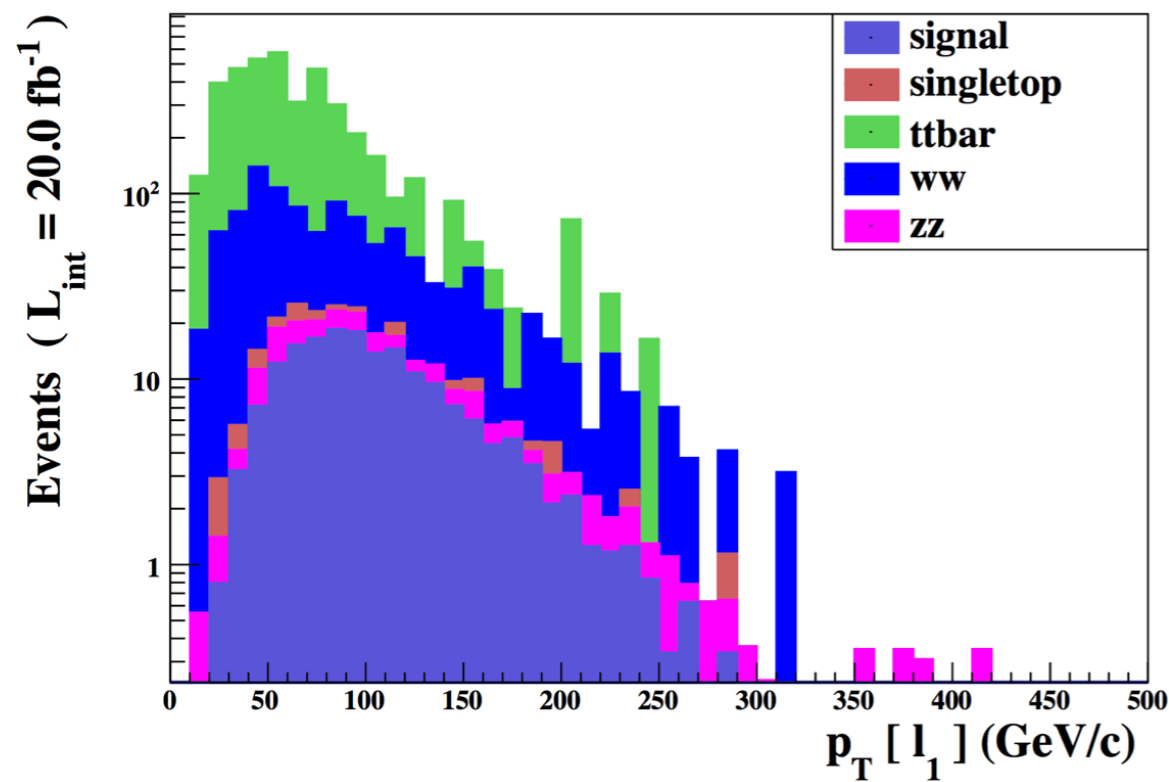
How to kill the dominant top background?



Idea for a cut?



# Investigating particle properties (3)



# Outline

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



# Motivation for the expert mode of MADANALYSIS 5

[ Conte, Dumont, BenjFuks, Wymant (arXiv:1405.3982) ]

## ◆ MADANALYSIS 5 is used without its PYTHON interface

- ❖ More freedom in the **observables** (only some of them can be called from the PYTHON console)
- ❖ **Complicated cuts** can be implemented
- ❖ More suitable for **large numbers of events** (using several cores)

## ◆ The expert mode is developer-friendly

The analysis is a C++ class

### The SAMPLEANALYZER internal data format

- ★ Readers for LHE, STDHEP, HEPMC, LHCO and DELPHES
- ★ Many classes and methods for particle and object properties
- ★ Specific methods for histograms and cuts
- ★ etc. (see 1405.3982)

### Services

- ★ Physics observables (transverse variables, object identification, isolation)
- ★ Streamers
- ★ Exceptions
- ★ etc.

### Interfaces

- ★ FASTJET
- ★ DELPHES 3
- ★ New DELPHES modules [ LH 2013 proceedings ]

The new DELPHES modules (linked to SAMPLEANALYZER):

- ★ isolation
- ★ tracks
- ★ output files

### Scripts

- ★ Compilation
- ★ Linking
- ★ Analysis skeleton generator



# The new extension of the expert mode

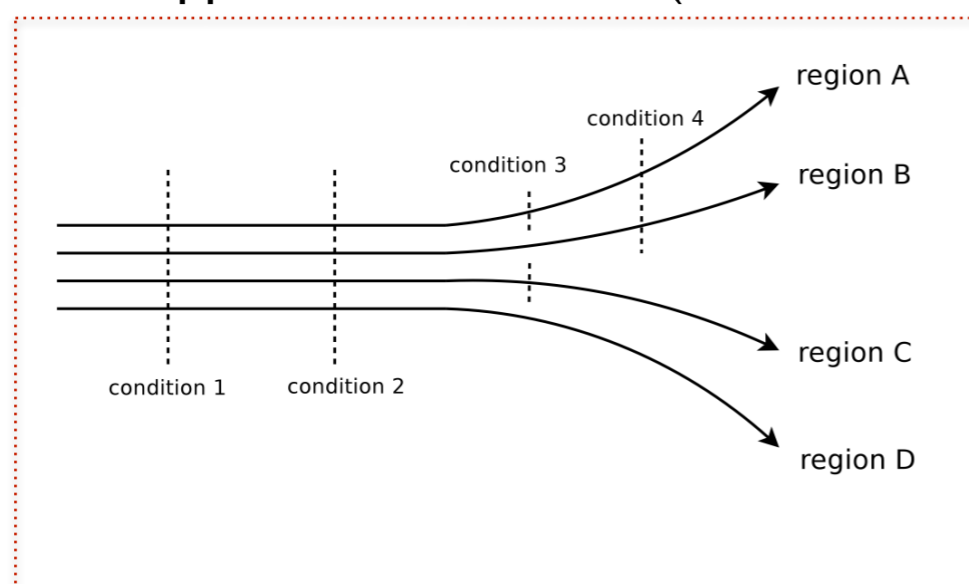
[ Conte, Dumont, BenjFuks, Wymant (1405.3982) ]

## ◆ Main features (enable a recast of most of the cut-based LHC analyses on the market)

- ❖ Support for **multiple sub-analyses** (signal and control regions)
- ❖ New ready-to-use observables ( $M_{T2}$ ,  $M_{T2W}$ , etc.)
- ❖ New optimized handling of cuts and histograms

## ◆ Handling cuts and histograms

- ❖ Naive approach **not efficient** (see cut #4 for instance)



```
count the event in region D
if (condition 3)
{
  count the event in region C
  if (condition 4)
  {
    count the event in region A
  }
}
if (condition 4)
{
  count the event in region B
}
```

- ❖ A **more efficient** algorithm has been implemented
  - ★ Each cut condition is only evaluated once
  - ★ It is applied to all surviving regions **simultaneously**
- ❖ Similar treatment for histograms

# Example (proof of concept): CMS-SUS-13-011

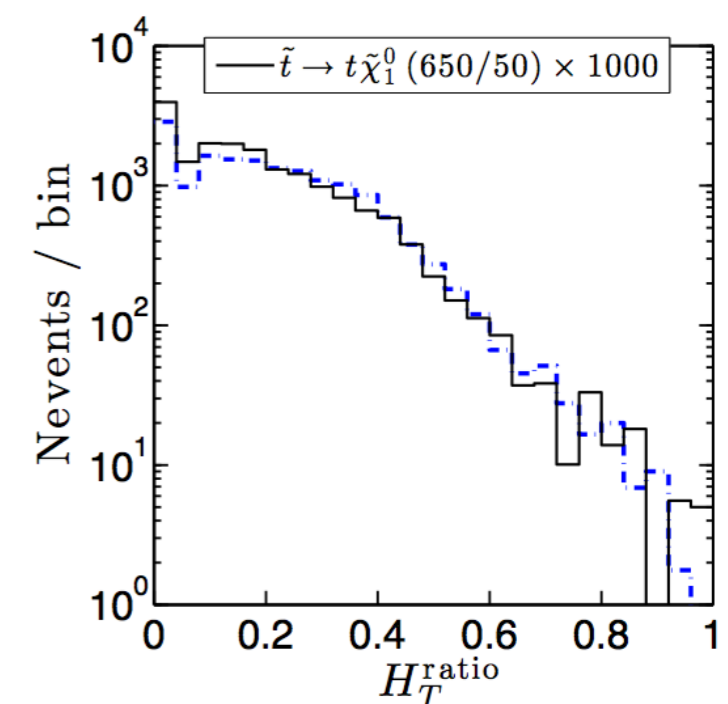
## ◆ CMS search for stops in the single lepton channel

- ♣ SUSY benchmark: stop of 650 GeV and neutralino of 50 GeV
- ♣ Normalization: NLO+NLL total cross sections (14 fb here)
- ♣ Simulation chain:

SLHA  $\triangleright$  FEYNRULES  $\triangleright$  UFO  $\triangleright$  MADGRAPH 5  $\triangleright$  PYTHIA 6  $\triangleright$  DELPHES-MA5TUNE  $\triangleright$  MADANALYSIS 5

## ◆ Cross check with publicly available material from CMS

Cut	MADANALYSIS 5	CMS
At least one lepton, four jets and 100 GeV of missing transverse energy	31.4	29.7
At least one $b$ -tagged jet	27.1	25.2
No extra loosely-isolated lepton or track	22.5	21.0
No hadronic tau	22.0	20.6
Angular separation between the missing momentum and the two hardest jets	18.9	17.8
Hadronic top quark reconstruction	12.7	11.9
The transverse mass $M_T$ (defined in the text) is larger than 120 GeV	10.4	9.6
At least 300 GeV of missing transverse energy and $M_{T2}^W > 200$ GeV	5.1	4.2



CMS results (for this analysis) can be reproduced with a pretty good accuracy: at the 20%-30% level

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# Summary

## ◆ The quest for new physics at the LHC has started

- ❖ Relies on **MC event generators** (such as MADGRAPH5\_aMC@NLO) for backgrounds and signals
- ❖ **Satellite tools** have been intensively developed (FEYNRULES, MADANALYSIS 5, ...)

## ◆ MADANALYSIS 5 in a nutshell

- ❖ A **unique** framework for collider phenomenology (parton, hadron, detector and reconstructed levels)
- ❖ **User-friendly** by means of its PYTHON interface (normal mode)
- ❖ **Flexible** thanks to its C++ kernel (expert mode)
- ❖ **Interfaced** to several other HEP packages

## ◆ MADANALYSIS 5 and LHC analyses

- ❖ The expert mode has been extended to facilitate the implementation of LHC analyses
- ❖ **Proof of concept**: CMS-SUS-13-011 (**good agreement** has been found)
- ❖ More analyses are coming...

## ◆ Website: <http://launchpad.net/madanalysis5>