Beyond the Standard Model phenomenology with MADANALYSIS 5

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Outline

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

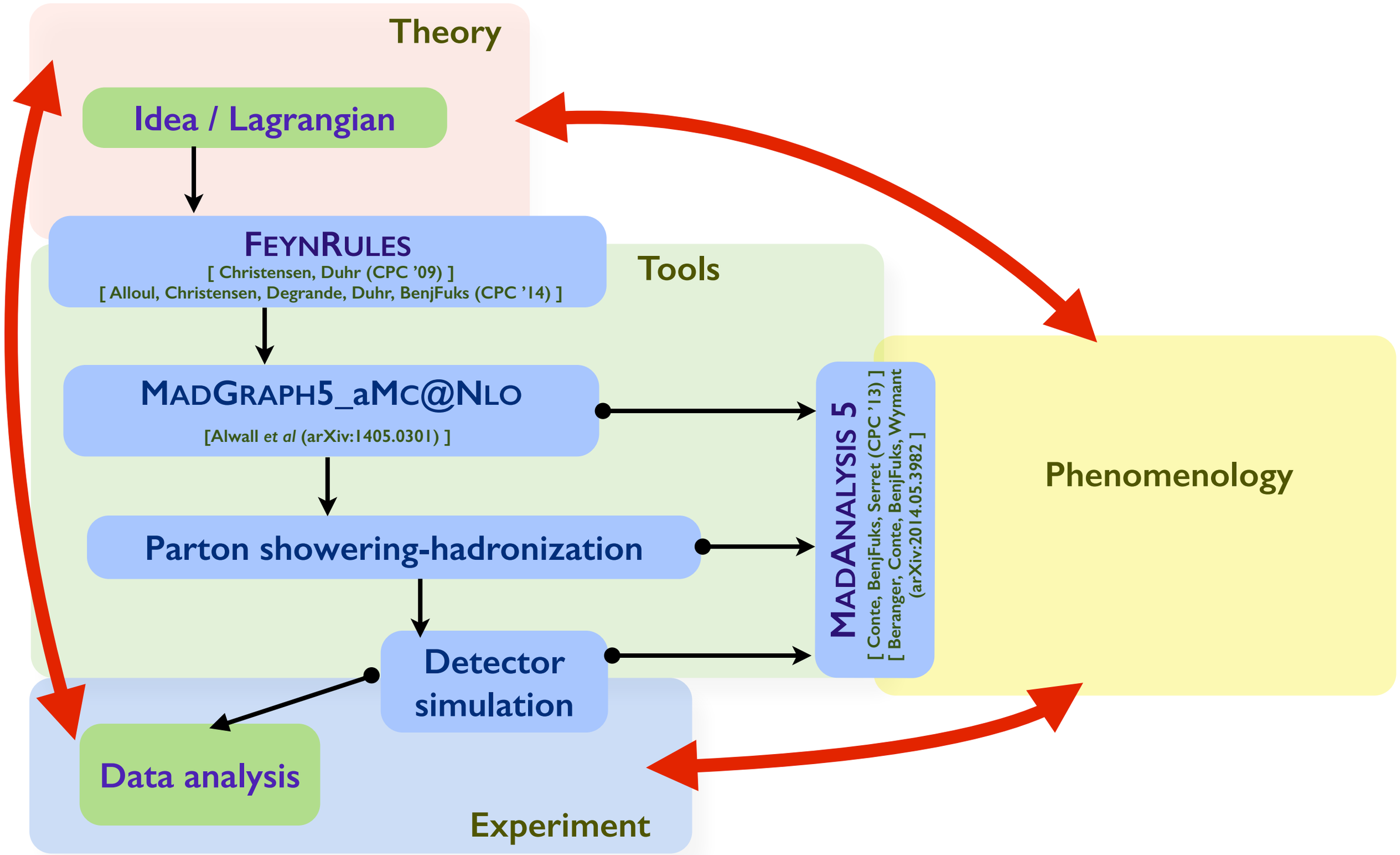
✦ Clarification of the new physics:
- ✤ Measurement of the model parameters
- ✤ Use of precision predictions (possibly with Monte Carlo generators)
- ✤ Sophistication of the analyses ⇔ new physics / detector knowledge

➠ 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

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

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

Cross sections 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

Outline

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

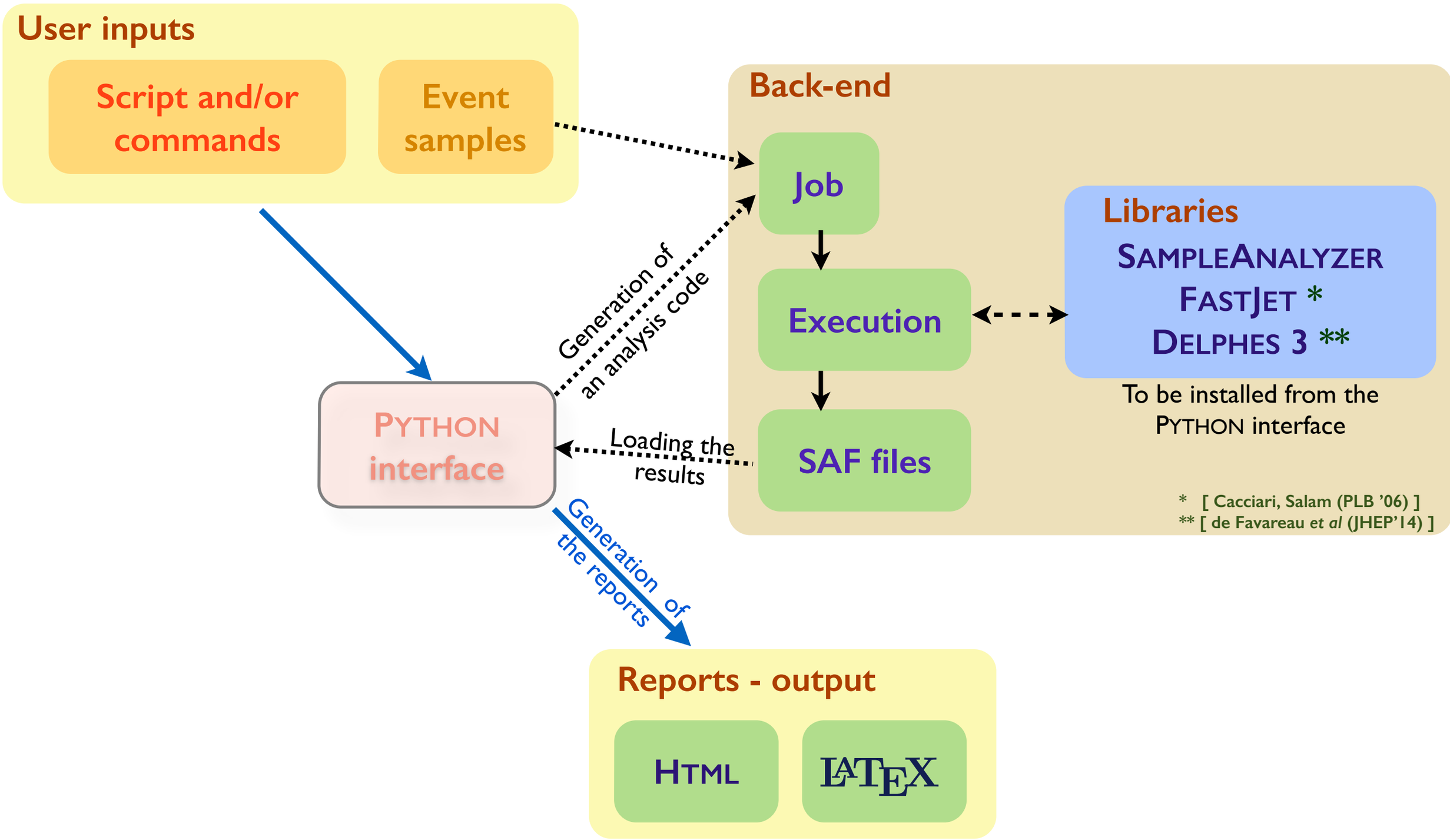
- Intuitive commands typed in the PYTHON interface
- Analysis performed behind the scenes (black box)
- Human readable output: HTML and LaTeX

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

Code skeleton to be generated from the PYTHON interface

Job

Execution

SAF files

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_v1.1.11beta2.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 LaTeX 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  to  M A D A N A L Y S I S  5        *
*                                                          *
*                                                          *
*                                                          *
*                                                          *
*                                                          *
*                                                          *
*                                                          *
*                                                          *
*   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]
    ************************************************************

 ************************************************************
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>
```

Compilation of SAMPLEANALYZER and all the dependencies [if necessary]

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

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

Basic concepts of the normal mode (1)

Looking for help...

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

```
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
```

Datasets

- 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

```
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 VV.hep as diboson
   -> Storing the file 'VV.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 1000022 1000039.
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          PTordering    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 HMTL 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 (1405.1617)]

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.efficiency  main.fastsim.bjet_id.misid_ljet  main.fastsim.radius
main.fastsim.bjet_id.exclusive   main.fastsim.exclusive_id        main.fastsim.tau_id.efficiency
main.fastsim.bjet_id.matching_dr main.fastsim.package             main.fastsim.tau_id.misid_ljet
ma5>set main.fastsim.bjet_id.efficiency = 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>
```

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

Recall: event samples

✦ 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, ΔR_{jj} > 0.4, no pseudorapidity cut

✦ Standard Model background for a dilepton + missing energy + jets signature
- ✤ top-antitop + jets: two leptonic decays, $t\bar{t} \to (b\ell^+\nu_\ell)(\bar{b}\ell'^-\bar{\nu}_{\ell'})$
- ✤ WW + jets: two leptonic decays, $W^+W^- \to (\ell^+\nu_\ell)(\ell'^-\bar{\nu}_{\ell'})$
- ✤ single top (tW) + jets: two leptonic decays, $tW \to (b\ell^+\nu_\ell)(\ell'^-\bar{\nu}_{\ell'})$
- ✤ ZZ + jets: one leptonic and one invisible decay, $ZZ \to (\nu_\ell\bar{\nu}_\ell)(\ell'^+\ell'^-)$
- ✤ More: instrumental effects such as lepton mis-reconstruction, *etc.* ⇒ not considered here

✦ Cross sections 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

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.efficiency main.fastsim.bjet_id.misid_ljet  main.fastsim.radius
main.fastsim.bjet_id.exclusive  main.fastsim.exclusive_id        main.fastsim.tau_id.efficiency
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.efficiency = 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)

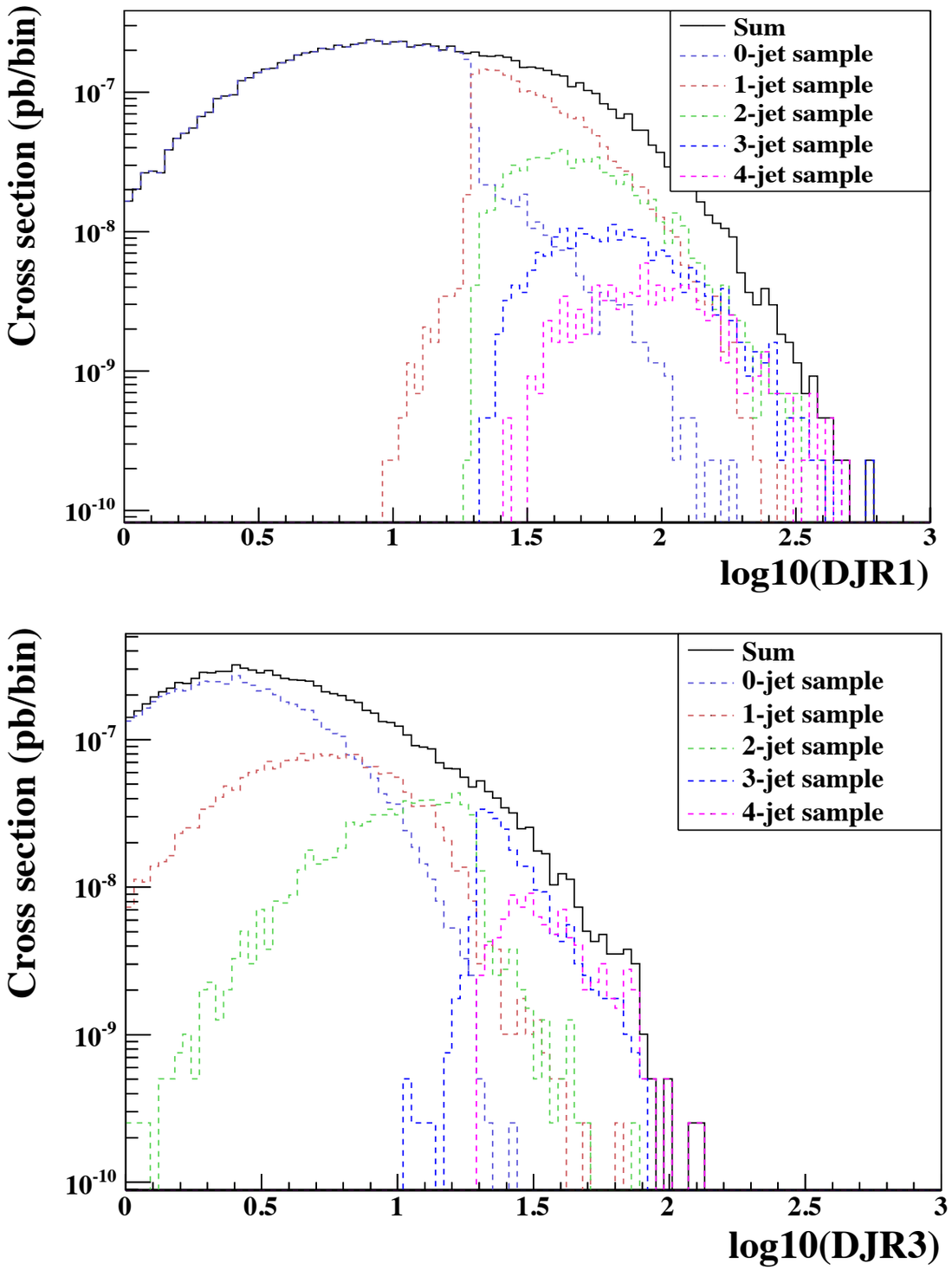
Checking the merging procedure (1)

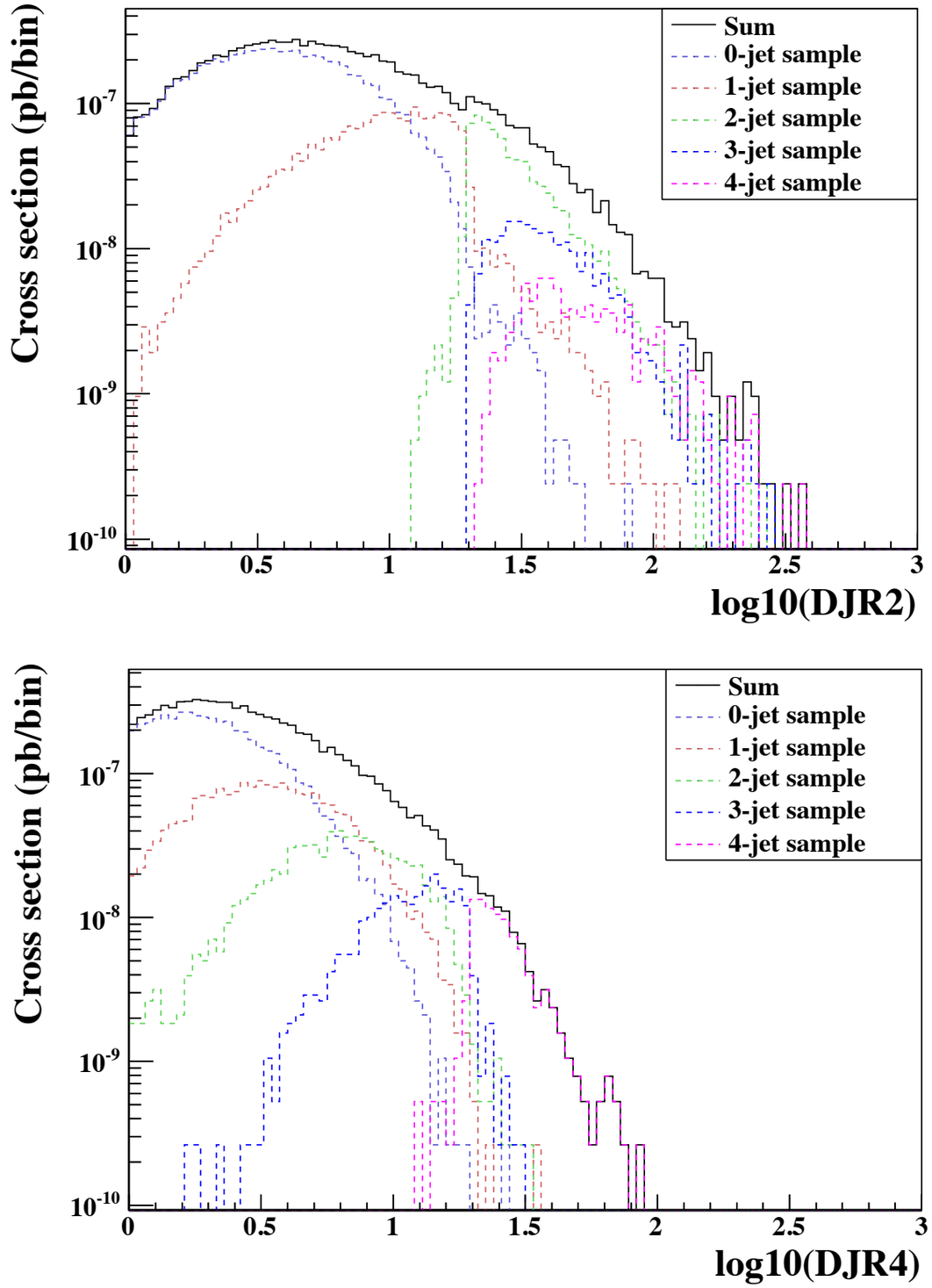
✦ Example with a Z+jets sample
- ✤ Parton-level: Z+ 0,1,2,3,4 jets
- ✤ Parton-showering is then applied
- ✤ MLM merging: removal of the double counting consistently
- ✤ Check of that procedure: the differential jet rate (DJR) distributions
  - ➢ The scale for which one event goes from a N to a N+1 jet 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
```

✤ Objet 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 (1)

✦ 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*)

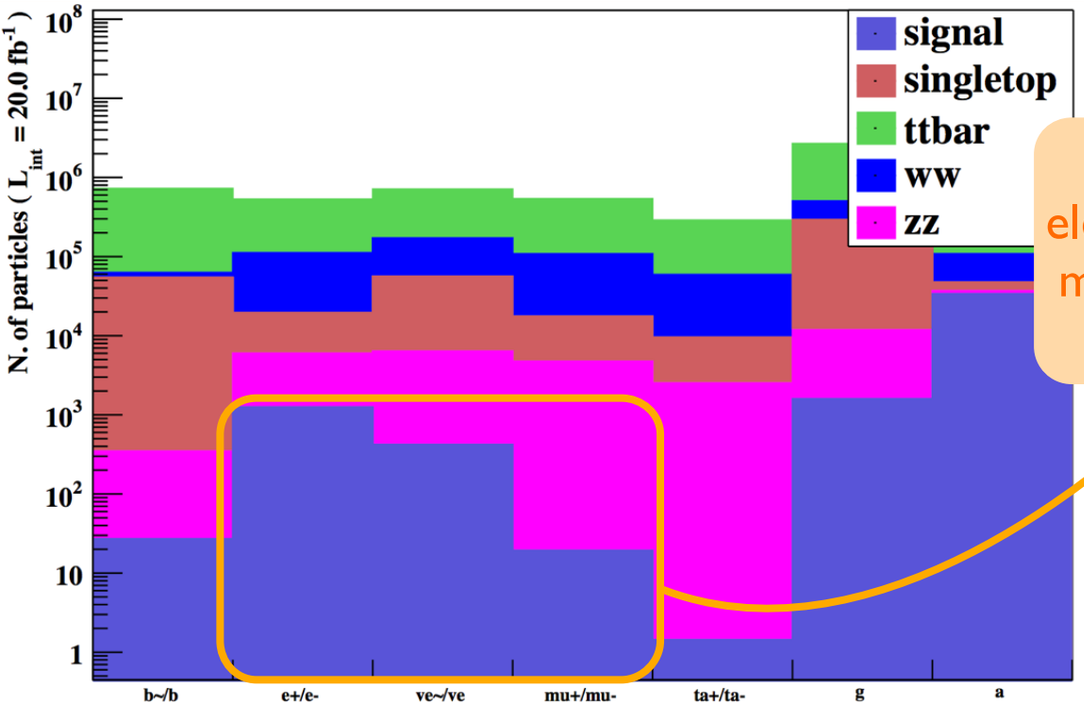
✦ General setup for drawing histograms
- ✤ The luminosity in fb^{-1} (*set main.lumi = ...*)
- ✤ How to superimpose the curves on a single histogram (*set main.stacking_method = ...*)

```
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]
```

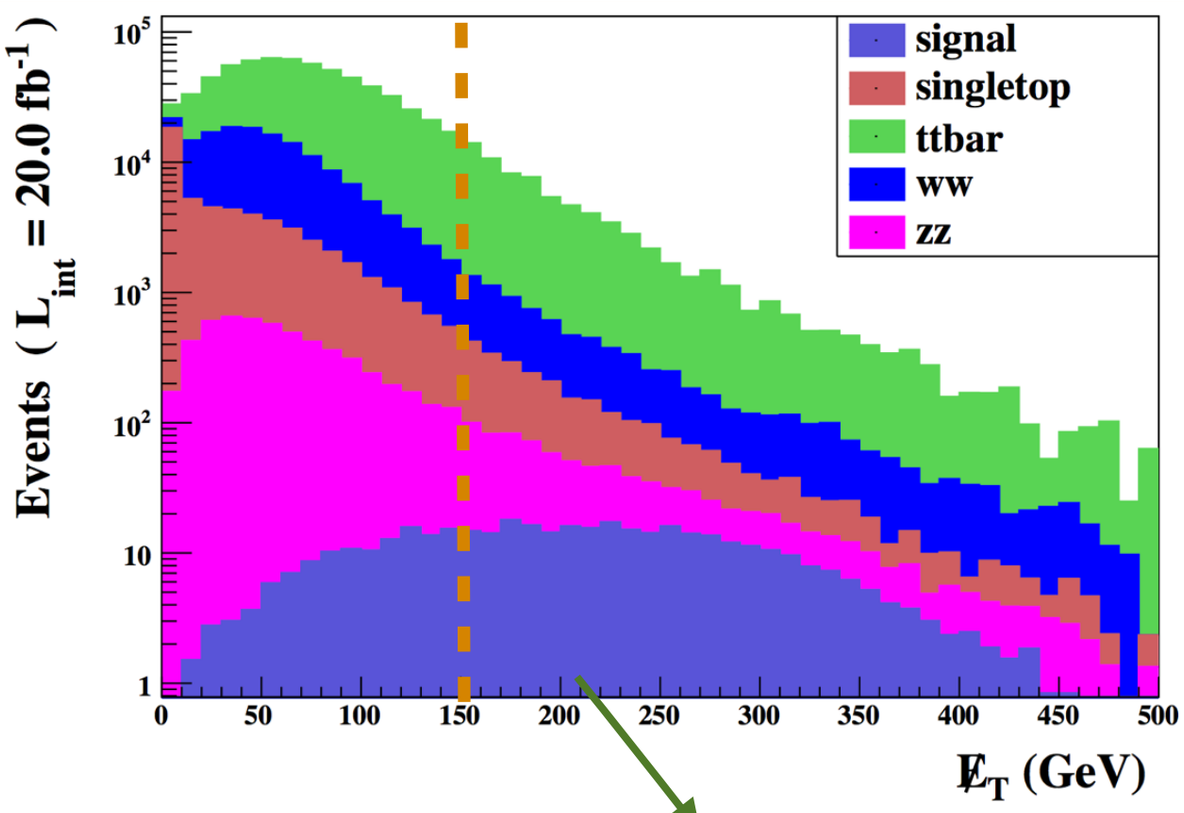
✦ Executing the analysis and browsing the results
- ✤ The command *submit* (the progress can be followed on the screen)
- ✤ The command *open* (open a webpage with the report containing all results)

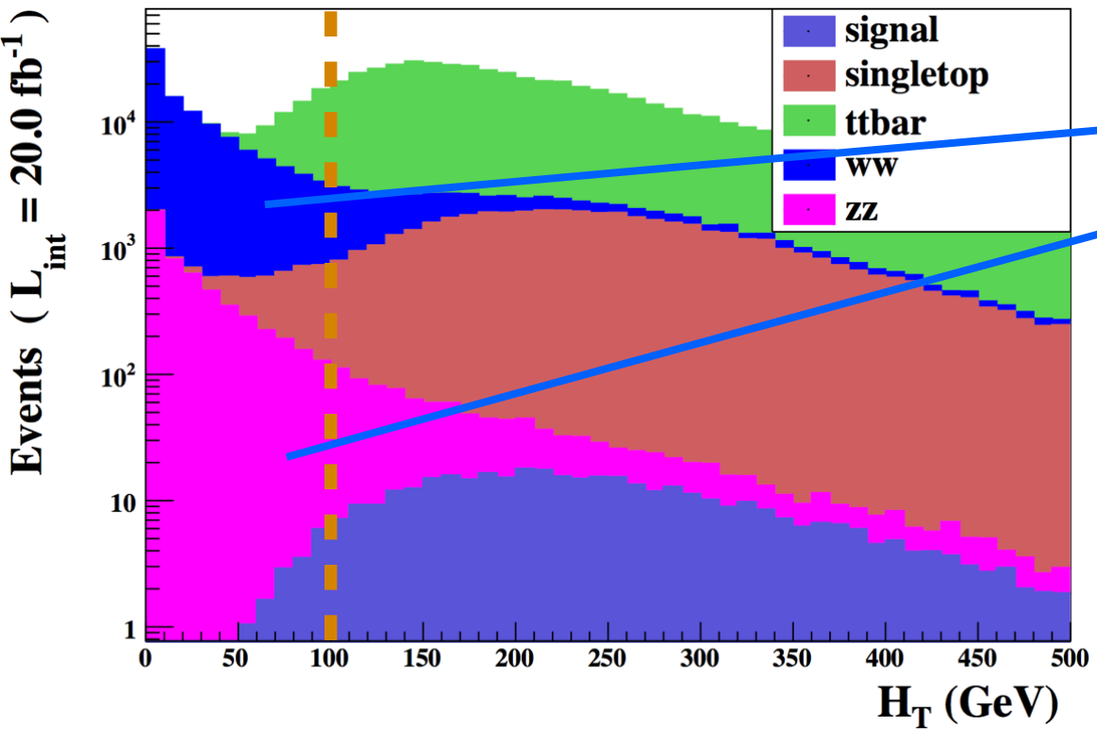
```
ma5>submit; open
```

Investigating some global event properties (2)



More electrons than muons in the signal





VV: jets generated by parton showering, then softer

Different shapes for signal and background

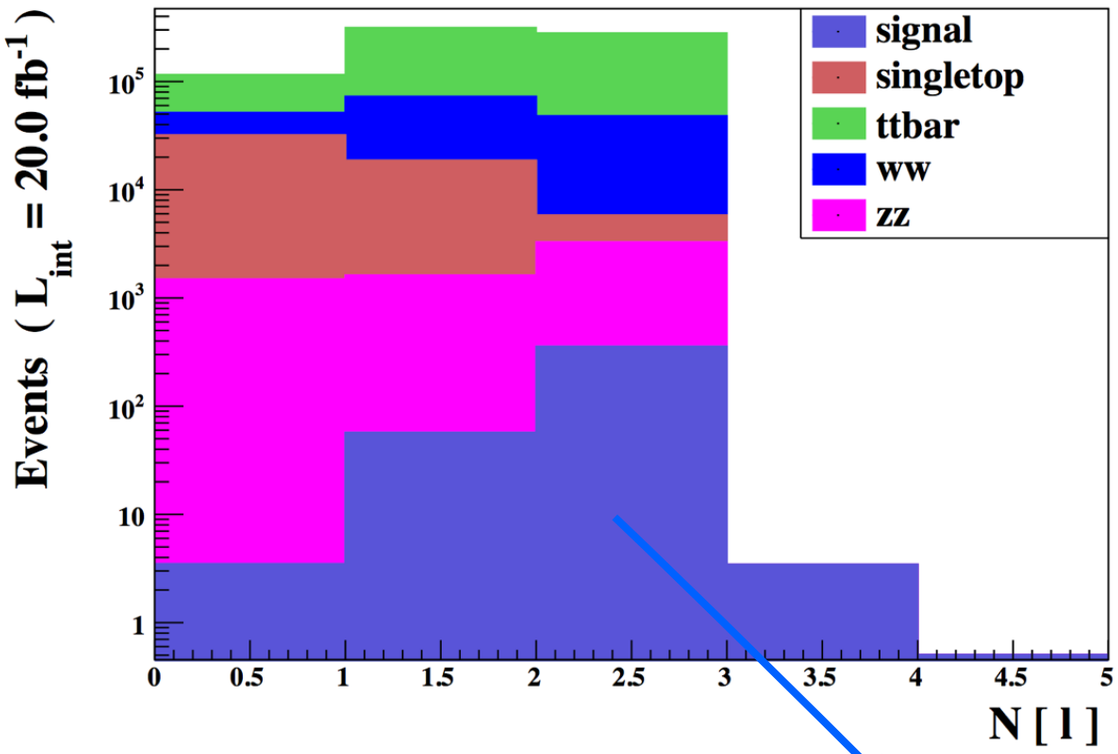
This suggest selections to improve the S *vs* B ratio:
- ★on the missing energy (*e.g.*,150 GeV)
- ★on the H_T (*e.g.*, *100* GeV)

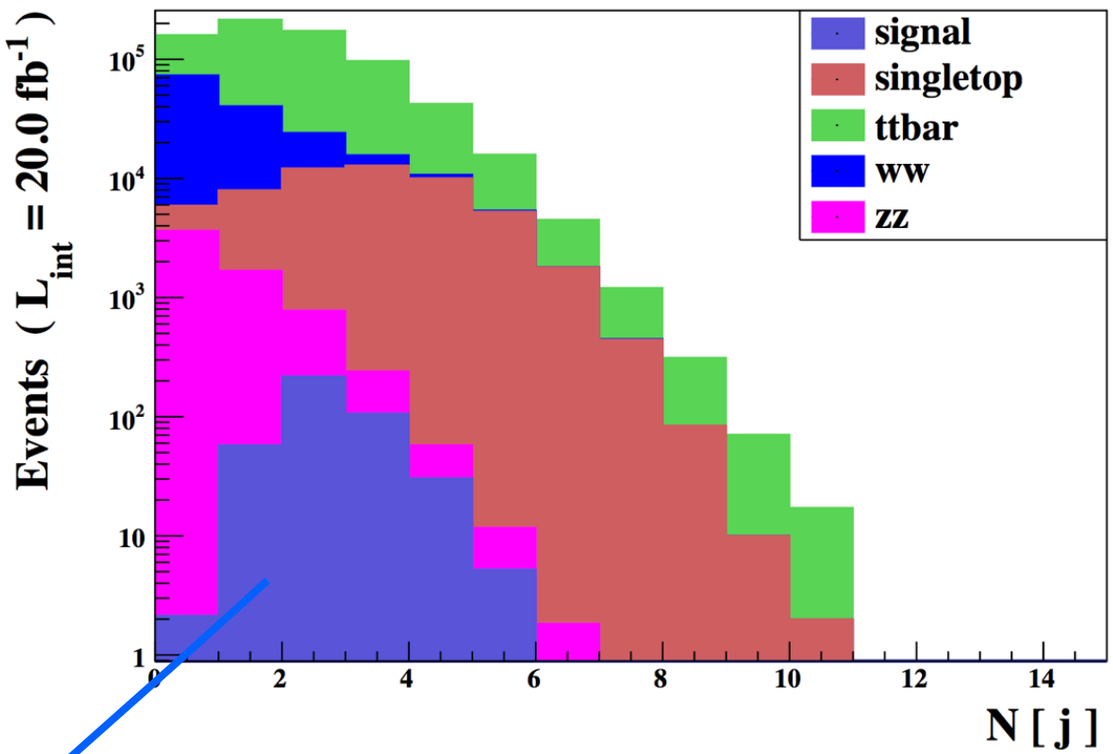
Investigating some global event properties (3)

✦ 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 (1)

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*)

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

```
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)
```

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

The signal over background ratio (2)

Cut-flow chart

- How to compare signal (S) and background (B): S/sqrt (S+B) .
- Associated uncertainty: 1./pow(S+B,3./2.)*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)

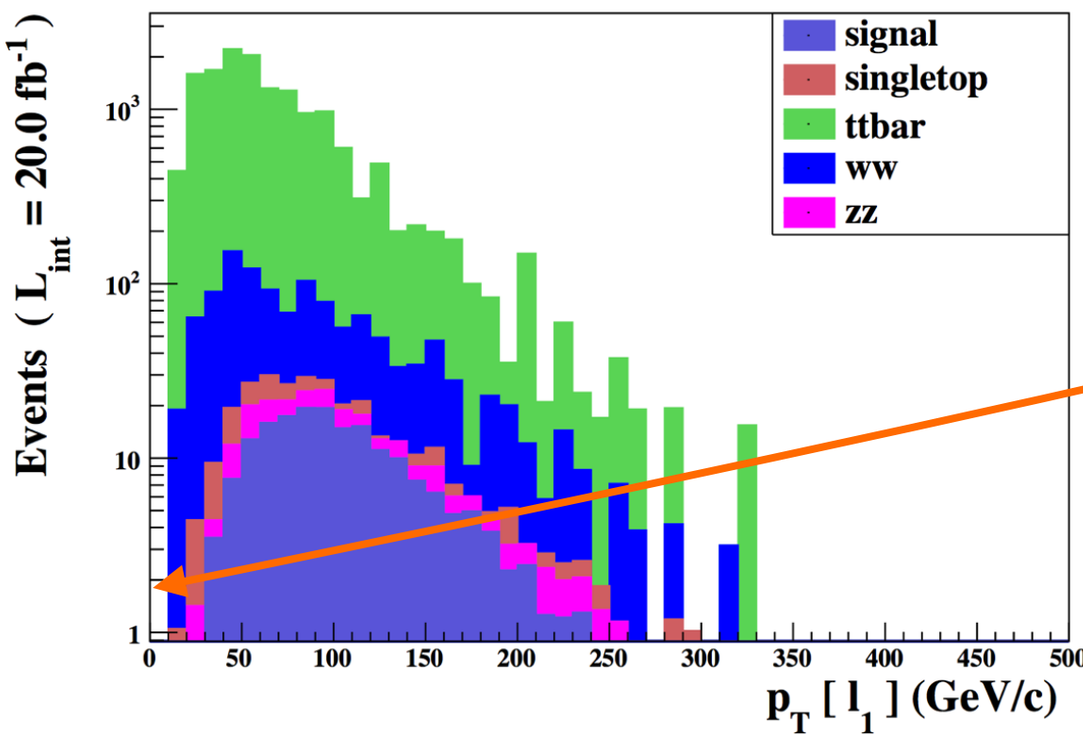
```
ma5>plot M(l[1] l[2]) 50 0 500 [logY]
ma5>plot dPHI(l[1] l[2]) 15 0 6.28 [logY]
```

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

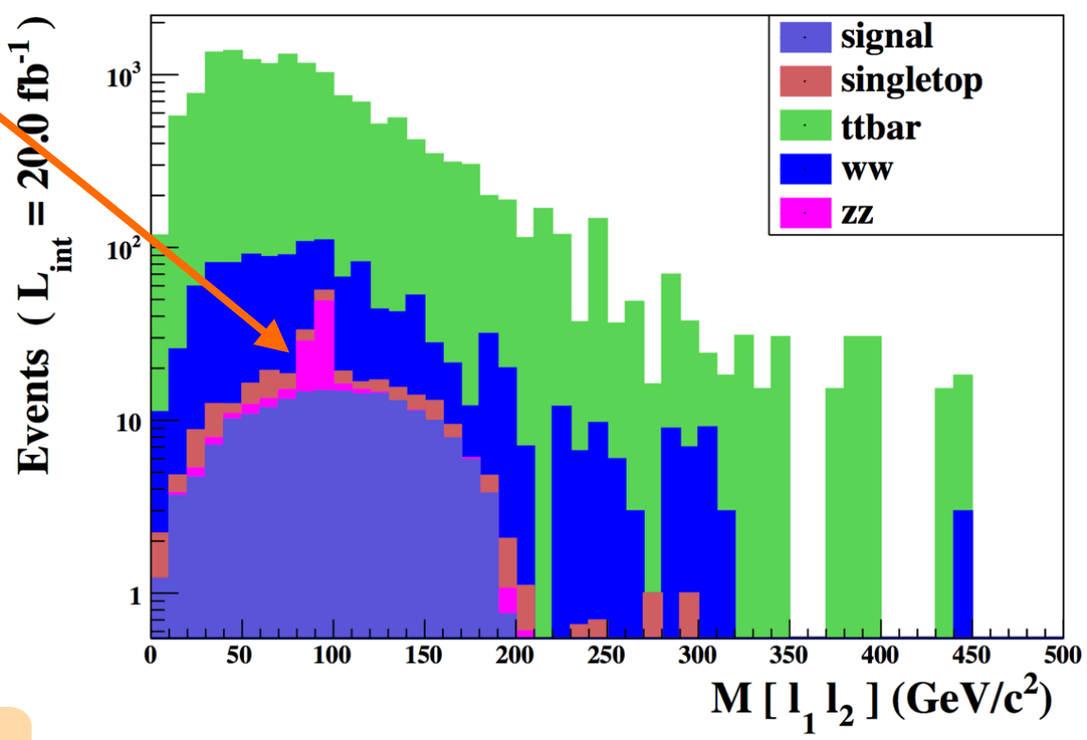
```
ma5>plot DELTAR(l[1],l[2]) 15 0 5 [logY]
ma5>plot MT_MET(l[1]) 50 0 500 [logY]
ma5>plot MT_MET(j[2]) 50 0 500 [logY]
```

Investigating particle properties (2)

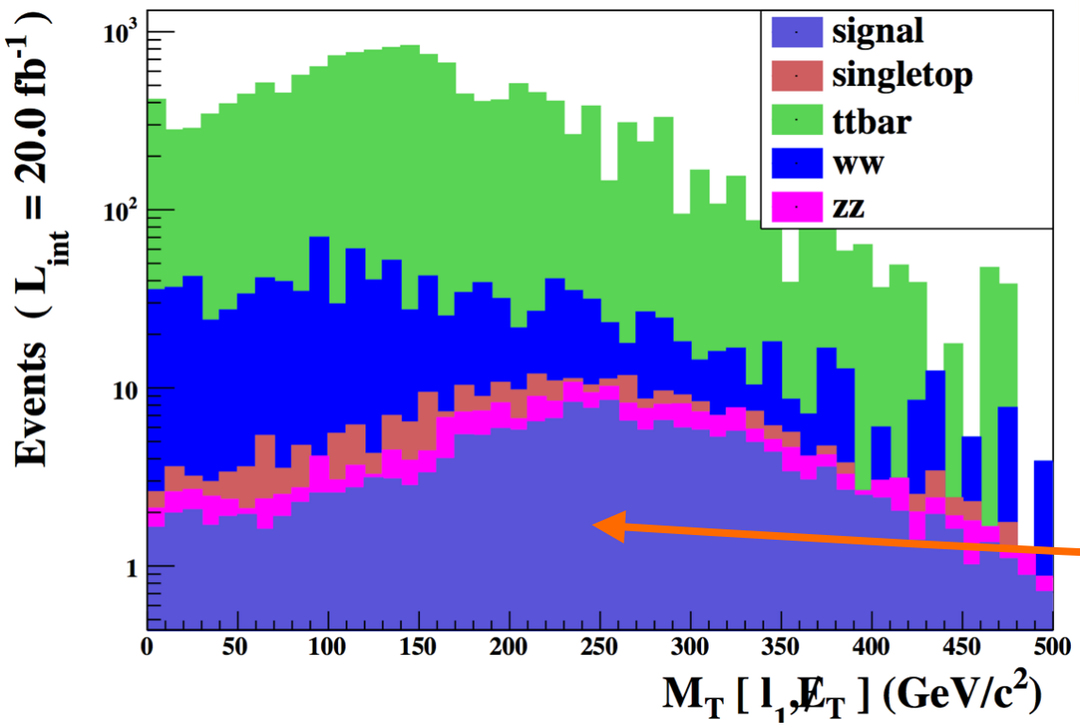


Bonus: the Z-peak

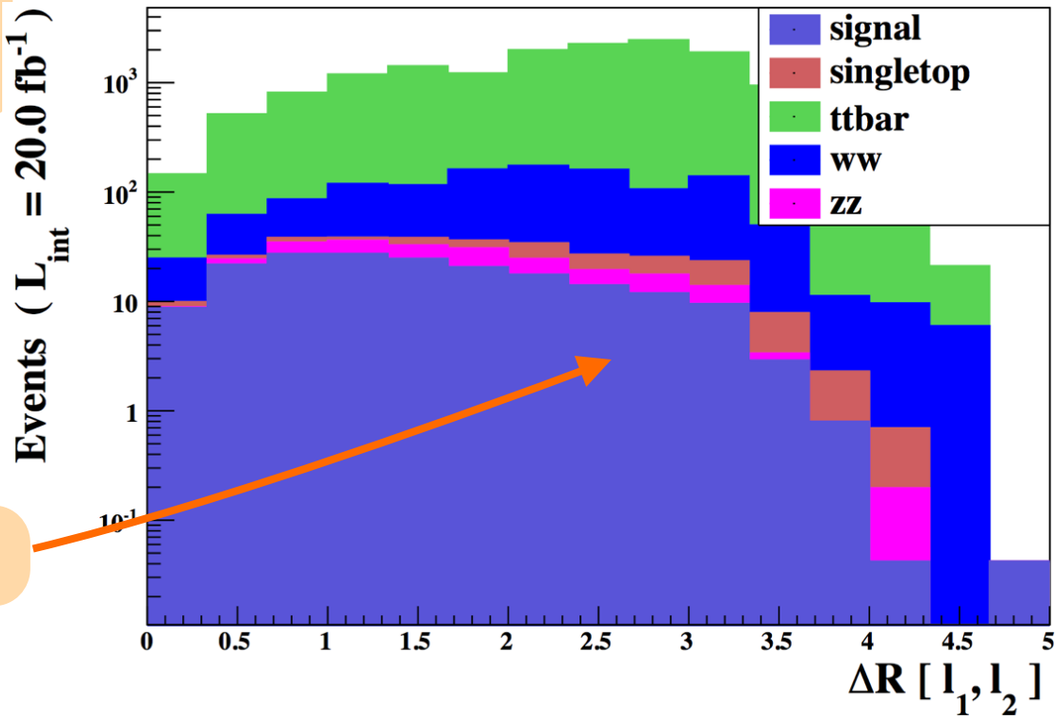
The first bin is empty



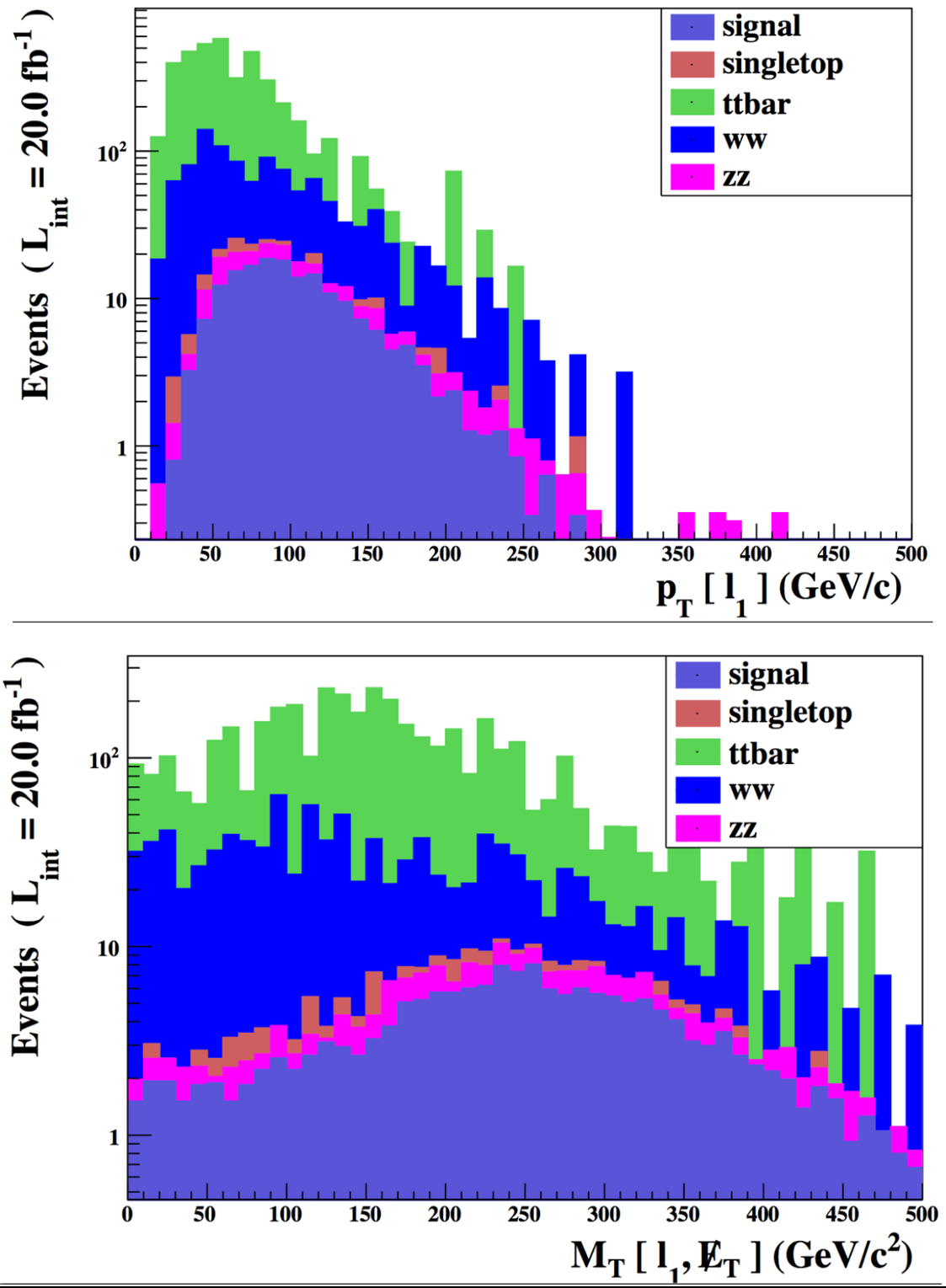
How to kill the dominant top background?

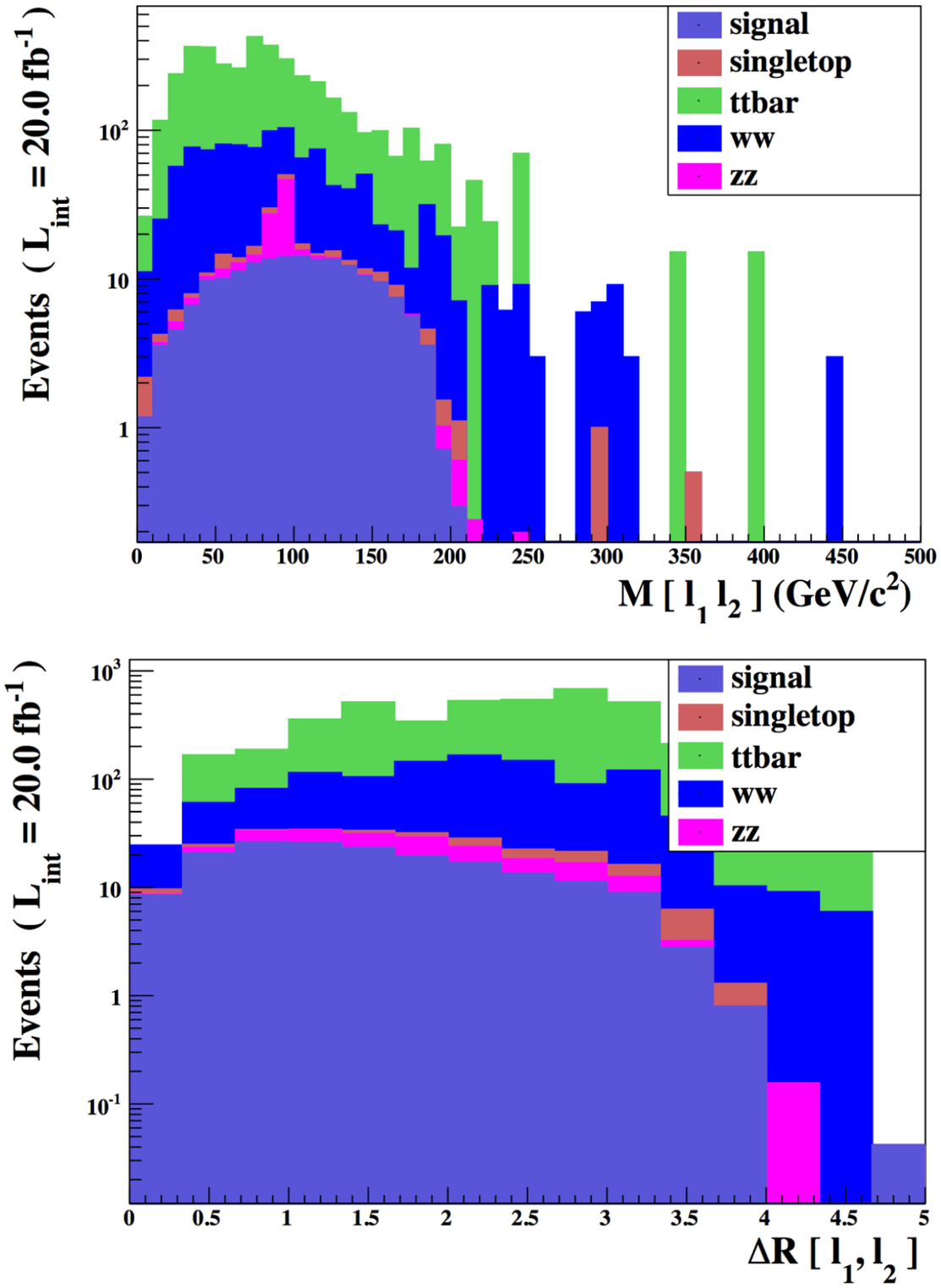


Idea for a cut?



Investigating particle properties (3)





Outline

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

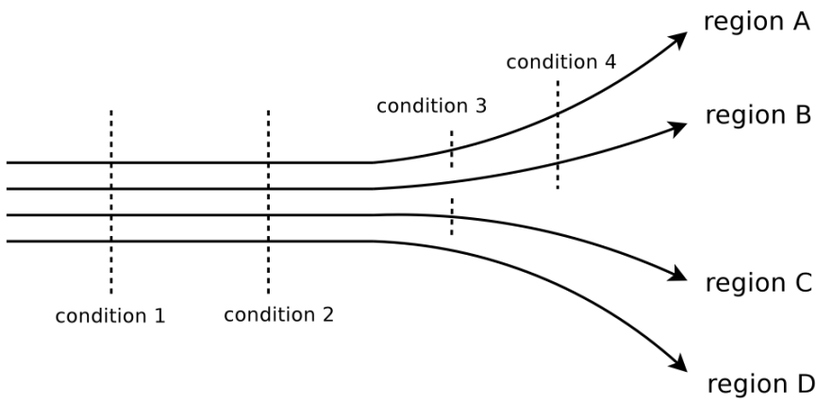
[Conte, Dumont, BenjFuks, Wymant (1405.3982)]

✦ 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

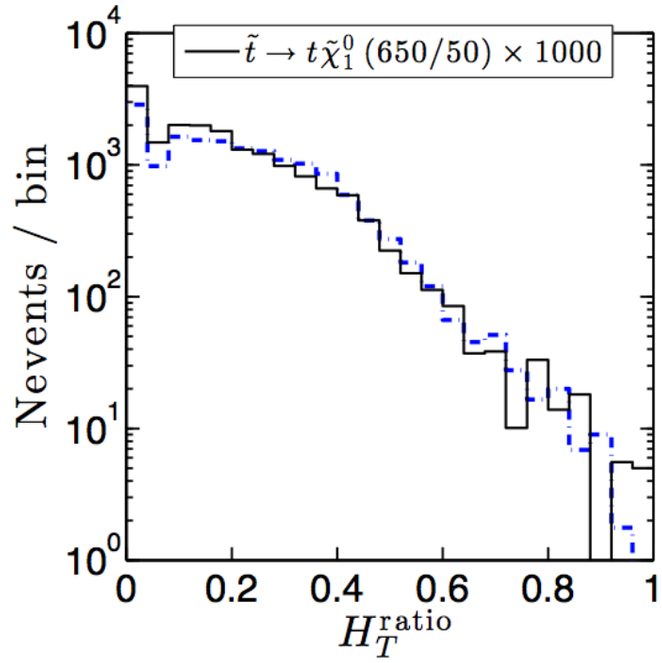
✦ CMS search for stops in the single lepton channel

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

  SLHA ➢ FEYNRULES ➢ UFO ➢ MADGRAPH 5 ➢ PYTHIA 6 ➢ DELPHES-MA5TUNE ➢ 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

Outline

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