

Collider phenomenology and LHC recasting studies with MADANALYSIS 5

Fuks Benjamin

LPTHE - CNRS - UPMC

**Dartmouth-TRIUMF-University of Washington
High-Energy Physics/Cosmology Tools Bootcamp**

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Outline

- I.** Monte Carlo simulations and new physics
- 2.** Overview of MADANALYSIS 5 and basic concepts
- 3.** Analyzing events with MADANALYSIS 5
- 4.** Reconstructing hadron-level events / detector simulation
- 5.** The expert mode and LHC recasting
- 6.** Summary

New physics at the LHC

◆ The quest for physics beyond the Standard Model has started!

- ♣ How to get hints of new physics?
 - ★ Confront data to the Standard Model expectation in search channels
 - ★ Observe unexplained deviations at a good confidence level
- ♣ Ingredient 1: predictions for the Standard Model background
- ♣ Ingredient 2: predictions for the new physics signals

◆ More on the new physics nature

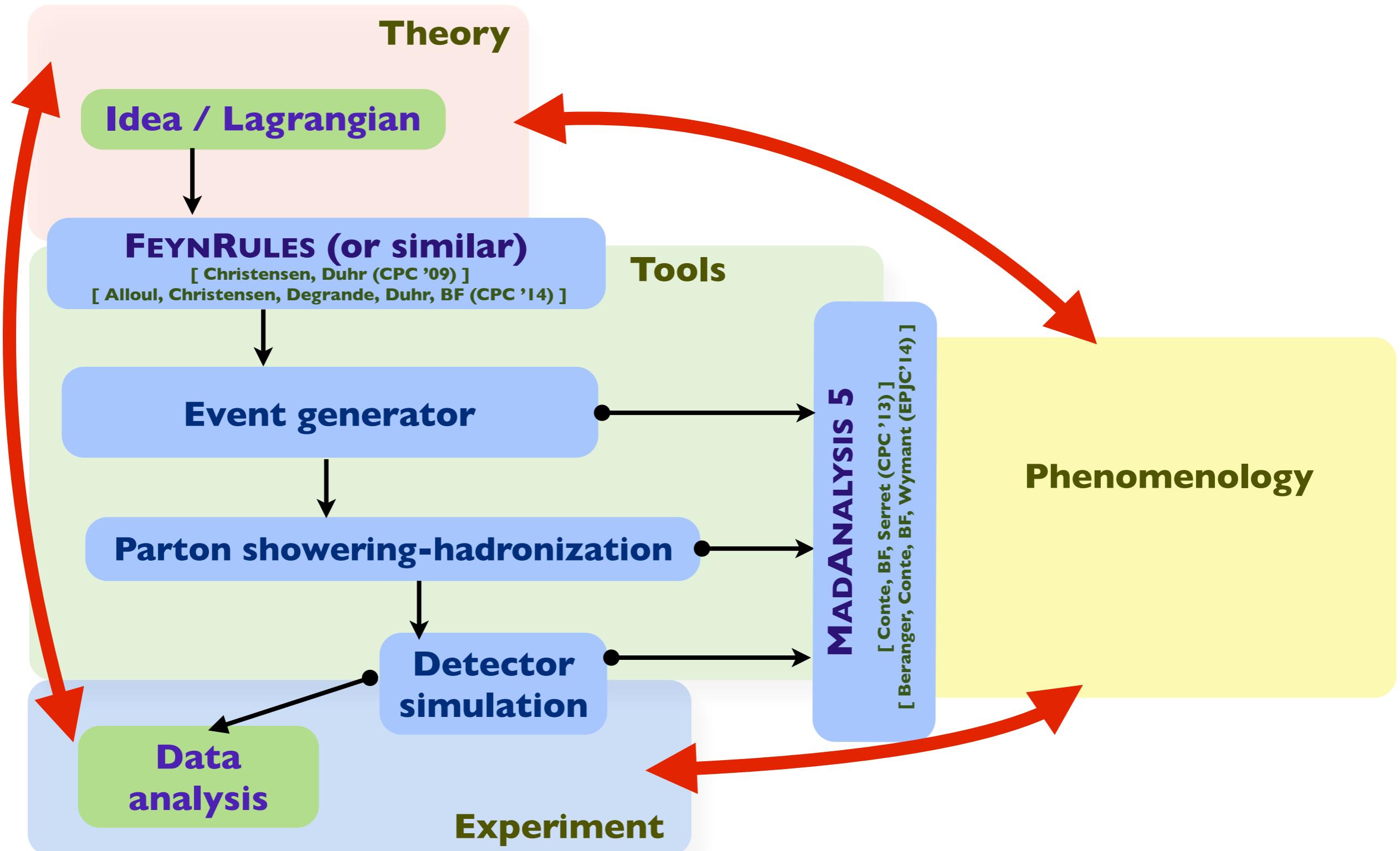
- ♣ Fitting deviations by new physics signals
 - ★ Designing new analyses to probe new ideas
 - ★ Reinterpretation of data in possibly different theoretical frameworks

Predictions; signal and background analysis

Confronting models to data

A framework for LHC analyses: a modern way

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



MADANALYSIS 5 and MG5_AMC are interfaced

[BF, Hirschi ('16)]

- ◆ Event analysis and recasting is now automated within MG5_aMC
- ❖ All the lecture and tutorial exercises can be done within MG5

The following switches determine which programs are run:

```
/-----\  
| 1. Choose the shower/hadronization program:  
| 2. Choose the detector simulation program:  
| 3. Run an analysis package on the events generated:  
| 4. Decay particles with the MadSpin module:  
| 5. Add weights to events for different model hypothesis:  
|  
shower = OFF  
detector = OFF  
analysis = MADANALYSIS_5  
madspin = OFF  
reweight = Not available (requires NumPy)  
/-----\
```

- ◆ Parton-level, hadron-level et reco-level: everything is possible within MG5_aMC

```
# Uncomment the line below to skip this analysis altogether  
# @MG5aMC skip_analysis  
  
@MG5aMC stdout_lvl=INFO  
  
@MG5aMC inputs = *.lhe  
@MG5aMC analysis_name = analysis1  
  
# Multiparticle definition  
define vl = 12 14 16  
define vl~ = -16 -14 -12  
define invisible = ve ve~ vm vm~ vt vt~ vl vl~  
  
# Histogram drawer (options: matplotlib or root)  
set main.graphic_render = root  
  
# Global event variables  
plot THT 40 0 500 [logY]  
plot MET 40 0 500 [logY]  
plot SQRTS 40 0 500 [logY]
```

```
Do you want to edit a card (press enter to bypass editing)?  
1 / param      : param_card.dat  
2 / run        : run_card.dat  
3 / pythia8    : pythia8_card.dat  
4 / madanalysis5_parton : madanalysis5_parton_card.dat  
5 / madanalysis5_hadron : madanalysis5_hadron_card.dat
```

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MADANALYSIS 5 in a nutshell

[Conte, BF, Serret (CPC '13); Conte, Dumont, BF, Wymant (EPJC '14)]

◆ 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**
- ❖ **Interfaced** to other HEP packages (detector simulation, jet clustering, ...)

◆ Normal pythonic mode

- ❖ Intuitive commands typed in a **PYTHON** interface
- ❖ Analysis performed **behind the scenes** (a C++ black box)
- ❖ Human readable output: **HTML** and **LATEX**

◆ Expert mode

- ❖ **C++ programming** within the **SAMPLEANALYZER** framework (the MA5 core)

The (normal) user-friendly mode

[Conte, BF, Serret (CPC '13); Conte, Dumont, BF, Wymant (EPJC '14)]

User inputs

Script and/or commands

Event samples

Back-end

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)]

PYTHON
interface

Libraries
ROOT / MATPLOTLIB

Reports - output

HTML

LATEX

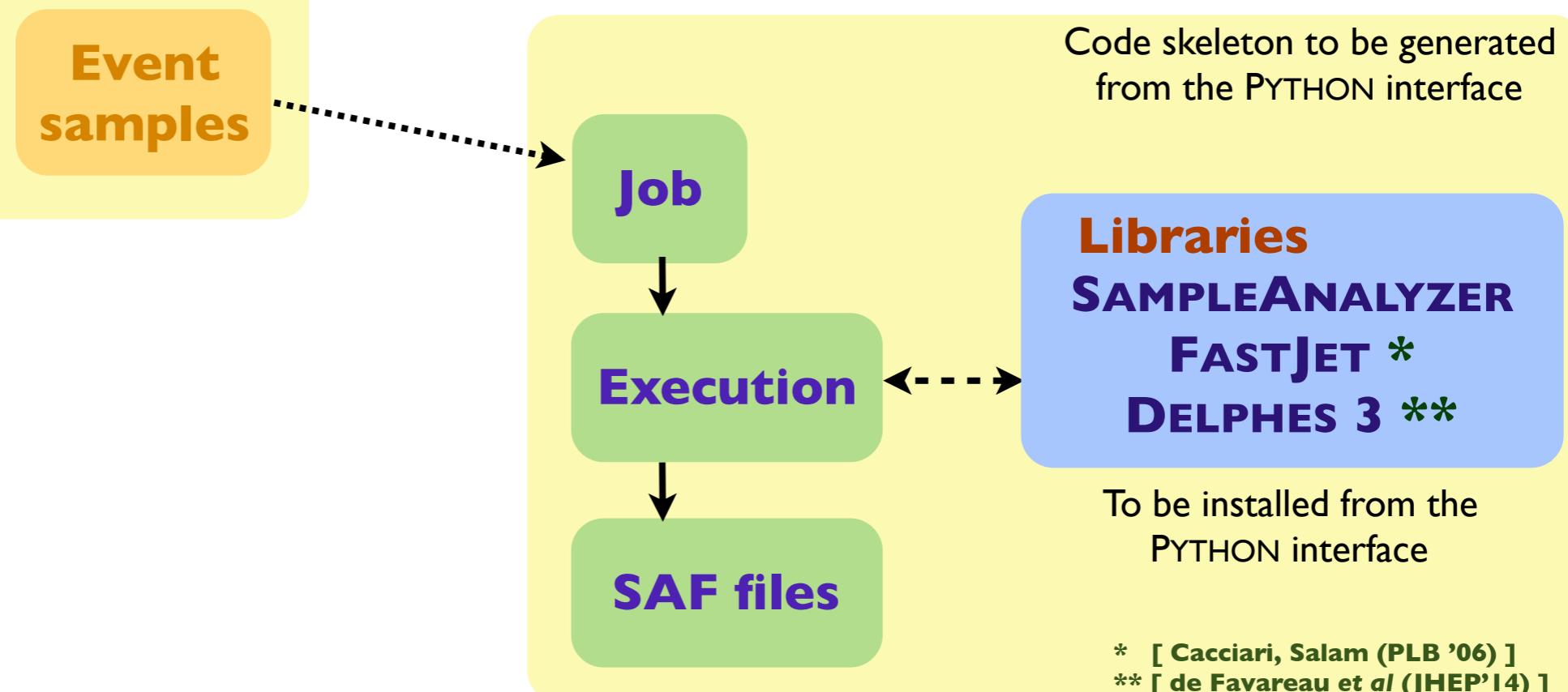
User requirements

- ❖ Implementing an analysis in a pythonic way
- ❖ Providing events

The expert (developer-friendly) mode

[Conte, BF, Serret (CPC '13); Conte, Dumont, BF, Wymant (EPJC '14)]

User inputs



User requirements

- ❖ Implementing a C++ analysis: a skeleton can be automatically generated
- ❖ Providing events
- ❖ Treatment of the output by the user

Getting started in half a second

◆ Installing the program

- ❖ Use version v1.6 beta
- ❖ Unpacking the tar-ball: `tar xf ma5_xxx.tgz`
- ❖ Start the code: `./bin/ma5`

```
[fuks@Benjamins-MacBook-Pro-6 ~/Desktop/tmp/madanalysis5$] ./bin/ma5
MA5:
MA5: ****
MA5: *
MA5: *      W E L C O M E   t o   M A D A N A L Y S I S   5
MA5: *
MA5: *      _____
MA5: *      /' \ \ \ \ - \ \ \ \ \
MA5: *      \ \ \ \ \ \ \ \ \ \ \ \ \
MA5: *      \ \ \ \ \ \ \ \ \ \ \ \ \
MA5: *      \ \ \ \ \ \ \ \ \ \ \ \ \
MA5: *      \ \ \ \ \ \ \ \ \ \ \ \ \
MA5: *      \ \ \ \ \ \ \ \ \ \ \ \ \
MA5: *
MA5: *      MA5 release : 1.6.18          2017/03/05
MA5: *
MA5: *      Comput. Phys. Commun. 184 (2013) 222-256
MA5: *          Eur. Phys. J. C74 (2014) 3103
MA5: *
MA5: *      The MadAnalysis Development Team - Please visit us at
MA5: *          https://launchpad.net/madanalysis5
MA5: *
MA5: *          Type 'help' for in-line help.
MA5: *
MA5: ****
```

Getting started: dependencies

◆ Requirements (checked on start-up)

- ❖ PYTHON 2.6 or more recent (but not 3.X)
- ❖ The GCC compiler
- ❖ gmake

The requirements

◆ Optional add-ons

- ❖ ZLIB (compressed event files)
(needed for the course ➤ see later)
- ❖ FASTJET 3.2.X or more recent
(needed for the course ➤ see later)
- ❖ ROOT 6.X (or 5.27 or more recent)
(needed for the course ➤ see later)
- ❖ DELPHES 3 (detector simulation)
(needed for the course ➤ see later)
- ❖ DELPHES 3-MA5Tune (deprecated)
- ❖ LATEX, PDFLATEX, DviPDF (reports)
- ❖ The NUMPY library (recasting)

```
MA5: Platform: Darwin 16.4.0 [MAC/OSX mode]
MA5: Reading user settings ...
MA5: Checking mandatory packages:
MA5:   - Python [OK]
MA5:   - GNU GCC g++ [OK]
MA5:   - GNU Make [OK]
MA5: Checking optional packages devoted to data processing:
MA5:   - Zlib [OK]
MA5:   - FastJet [DISABLED]
MA5:   - Root [OK]
MA5:   - Delphes [DISABLED]
MA5:   - Delphes-MA5tune [DISABLED]
MA5: Checking optional packages devoted to histogramming:
MA5:   - Root [OK]
MA5:   - Matplotlib [OK]
MA5:   - pdflatex [OK]
MA5:   - latex [OK]
MA5: Package used for graphical rendering: Root
```

The options

Getting started: compiling the MA5 core

- ◆ If the MA5 core is not up-to-date: compilation
- ❖ In case of errors, check the log files

```
MA5: Checking the MadAnalysis 5 core library:  
MA5: => First use of MadAnalysis (or the library is missing).  
MA5:  
MA5: ****=  
MA5:          Building SampleAnalyzer libraries  
MA5: ****=  
MA5: How many cores for the compiling? default = max = 8  
MA5: => Number of cores used for the compilation = 8  
MA5: Writing the setup files ...  
MA5: Writing all the Makefiles ...  
MA5: ****=  
MA5: Component 1/13 - test program: SampleAnalyzer configuration  
MA5:   - Cleaning the project before building the test program ...  
MA5:   - Compiling the source files ...  
MA5:   - Linking the test program ...  
MA5:   - Checking that the test program is properly built ...  
MA5:   - Cleaning the project after building the test program ...  
MA5:   - Running the test program ...  
MA5:   - Checking the program output...  
MA5: => Status: [OK]  
MA5: ****=
```

⋮

Getting started: invisible and hadronic stuff

- ◆ Creation of useful containers
- ❖ Important for hadronic and MET-related observables

```
MA5: ****
MA5: Component 13/13 - test program: SampleAnalyzer core
MA5:   - Cleaning the project before building the test program ...
MA5:   - Compiling the source files ...
MA5:   - Linking the test program ...
MA5:   - Checking that the test program is properly built ...
MA5:   - Cleaning the project after building the test program ...
MA5:   - Running the test program ...
MA5:   - Checking the program output...
MA5: => Status: [OK]
MA5: ****
MA5:
MA5: ****
MA5: Particle labels exported from madanalysis/input/particles_name_default.txt
MA5: => 87 particles successfully exported.
MA5: Multiparticle labels exported from madanalysis/input/multiparticles_default.txt
MA5: => Creation of the label 'invisible' (-> missing energy).
MA5: => Creation of the label 'hadronic' (-> jet energy).
MA5: => 8 multiparticles successfully exported.
```

Getting started: installing external libraries

◆ Installing the missing libraries: FASTJET

- ❖ Automated installation
- ❖ Type ‘*install fastjet*’ in the interpreter

```
[ma5>install fastjet
MA5:
MA5: ****
MA5:          Installing fastjet
MA5: ****
MA5: Detecting a previous installation ...
MA5: => not found. OK
MA5: How many cores would you like to use for the compilation ? default = max = 8
```

- FastJet

[DISABLED]

- ❖ Restart MADANALYSIS 5

◆ Works for many of the optional packages:

- ❖ Tab completion works, for the list

```
[ma5>install
delphes      fastjet      matplotlib    PAD        root       zlib
delphesMA5tune  gnuplot    numpy          PADForMA5tune  samples

MA5: Checking optional packages devoted to data processing:
MA5:   - Zlib           [OK]
MA5:   - FastJet        [OK]
MA5:   - Root           [OK]
MA5:   - Delphes         [OK]
MA5:   - Delphes-MA5tune [DISABLED]
```

Basic concepts of the normal mode (I)

Looking for help...

- ❖ In-line help (in the interpreter)
 - ★ Listing all possible commands

- ❖ Auto-completion using the tab key

```
ma5>
define          help
define_region   history
display         import
display_datasets install
display_multiparticles open
display_particles plot
display_regions quit
EOF             reject
exit_           remove
reset
restart
resubmit
select
set
shell
submit
swap
```

Datasets

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

```
[ma5>import ttbar* as ttbar
MA5:    -> Storing the file 'ttbar.hep.gz' in the dataset 'ttbar'.
MA5:    -> Storing the file 'ttbar2.hep.gz' in the dataset 'ttbar'.
[ma5>import Wjets.hep.gz as W
MA5:    -> Storing the file 'Wjets.hep.gz' in the dataset 'W'.
[ma5>import VV.hep as diboson
MA5:    -> 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  normalizeZone  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 ]

```

Basic concepts of the normal mode (4)

Selection cuts - the commands *reject/select*

- ❖ Events can be selected/rejected
- ❖ Particle candidates to consider

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

All ingredients are there

Basic concepts of the normal mode (5)

Executing the analysis - the command `submit`

- ❖ Creates a C++ code
- ❖ Compilation / execution
- ❖ Histogramming / cuts
- ❖ Reports generation

```

ma5>submit
MA5: Creating folder 'ANALYSIS_3'...
MA5: Copying 'SampleAnalyzer' source files...
MA5: Inserting your selection into 'SampleAnalyzer'...
MA5: Writing the list of datasets...
MA5: Writing the command line history...
MA5: Creating Makefiles...
MA5: Compiling 'SampleAnalyzer',...
MA5: Linking 'SampleAnalyzer',...
MA5: Running 'SampleAnalyzer' over dataset 'defaultset',...
MA5: ****
* SampleAnalyzer for MadAnalysis 5 - Welcome.
* Initializing all components
- version: 1.6.18 (2017/03/05)
- general: everything is default.
- extracting the list of event samples...
- analyzer 'MadAnalysis5job'
* Running over files ...
* 1/1 /Users/fuks/Work/tools/madanalysis/bzr/v1.6beta/samples/jack_unw.lhe
  => file size: 312.12 ko
  => sample format: LHE file produced by MadGraph5.
  => progress: [=====]
  => total number of events: 100 ( analyzed: 100 ; skipped: 0 )
* Finalizing all components ...
* Total number of processed events: 100.
* Goodbye.
MA5: ****
MA5: Checking SampleAnalyzer output...
MA5: Extracting data from the output files...
MA5: Preparing data for the reports ...
MA5: Generating all plots ...
MA5: Generating the HMTL report ...
MA5:   -> To open this HTML report, please type 'open'.
MA5: Generating the PDF report ...
MA5:   -> To open this PDF report, please type 'open ANALYSIS_3/PDF'.
MA5: Generating the DVI report ...
MA5: Well done! Elapsed time = 6 seconds

```

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Toy event samples

◆ Setup

- ❖ LHC collider at a center-of-mass energy of 13 TeV, 2.3 fb⁻¹
- ❖ No lepton cut (pseudorapidity, transverse momentum, etc.)
- ❖ Jet cuts: p_T > 20 GeV, ΔR_{jj} > 0.4, no pseudorapidity cut

◆ Toy samples: parton-level (no shower/hadronization)

- ❖ Top-antitop: two leptonic decays $t\bar{t} \rightarrow (b\ell^+\nu_\ell)(\bar{b}\ell'^-\bar{\nu}_{\ell'})$
- ❖ WW: two leptonic decays $W^+W^- \rightarrow (\ell^+\nu_\ell)(\ell'^-\bar{\nu}_{\ell'})$
- ❖ ZZ = signal: one leptonic and one invisible decay $ZZ \rightarrow (\nu_\ell\bar{\nu}_\ell)(\ell'^+\ell'^-)$

◆ NLO cross sections (beware: LO generation, NLO normalization)

- ❖ Top-antitop pairs ≈ 33 pb
- ❖ WW ≈ 4.2 pb
- ❖ ZZ ≈ 0.3 pb

Importing and defining the samples

♦ Importing the LHE samples, setting their properties

- ❖ We define the **type** (signal or background) of each dataset
- ❖ We assign **cross section numbers** and the **luminosity** ➤ correct normalization

```

ma5>import zz.lhe.gz as zz
    -> Storing the file 'zz.lhe.gz' in the dataset 'zz'.
ma5>import ww.lhe.gz as ww
    -> Storing the file 'ww.lhe.gz' in the dataset 'ww'.
ma5>import ttbar.lhe.gz as ttbar
    -> Storing the file 'ttbar.lhe.gz' in the dataset 'ttbar'.
ma5>set ttbar.xsection = 33
ma5>set ww.xsection = 4.2
ma5>set zz.xsection = 0.3
ma5>set ttbar.type=background
ma5>set ww.type=background
ma5>set zz.type=signal
ma5>set main.lumi = 2.3

```

Importing
the samples

Cross sections
[in pb]

Signal and
background
definitions

Luminosity [in fb⁻¹]

Getting closer to a detector (at parton-level)

- ◆ We have not simulated any detector response
- ❖ Include reasonable selections getting us closer to a real experiment

- ❖ Soft objects are not detected
 - ★ Removal of any 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 of any 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 (isolation)

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

Global event properties

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

- ❖ Missing and visible energy (MET, TET)
- ❖ Missing and visible hadronic energy (MHT, THT)
- ❖ The (unphysical) partonic center-of-mass energy (SQRTS)
- ❖ The α_T variable (ALPHAT)
- ❖ The particle content (NPID, NAPID, N)

◆ General setup for drawing histograms

- ❖ Superimposing curves on a single histogram (set *main.stackning_method* = ...)

```
ma5>set main.stackning_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

- ❖ Submitting and executing: *submit*
- ❖ Getting to the results: *open* (open the HTML report)

ma5>submit; open

Results: sample information

◆ Top-antitop sample information

ttbar

- Sample consisting of: **background** events.
- Generated events: **10000** events.
- * Cross section imposed by the user: **33.0 pb**.
- Normalization to the luminosity: **75900 +/- 0** events.
- **Ratio (event weight): 7.6 - warning: please generate more events (weight larger than 1)!**

Path to the event file	Nr. of events	Cross section (pb)	Negative wghts (%)
ttbar.lhe.gz	10000	33.0	0.0

❖ Signal/background nature

❖ Number of events, cross section, normalization, **event weight**

❖ Negative weight information

◆ Example 2: signal sample information

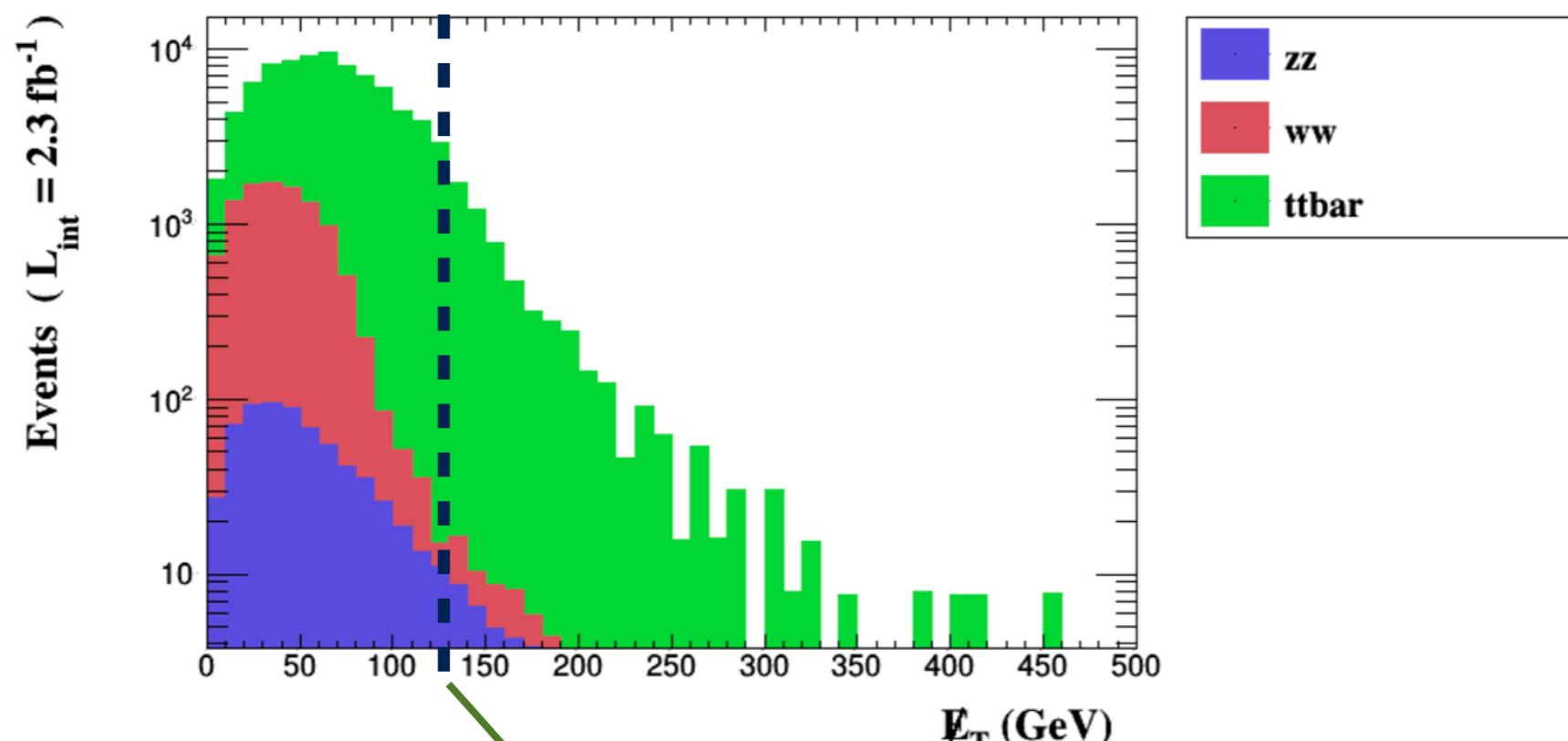
zz

- Sample consisting of: **signal** events.
- Generated events: **10000** events.
- * Cross section imposed by the user: **0.3 pb**.
- Normalization to the luminosity: **690 +/- 0** events.
- **Ratio (event weight): 0.069 .**

Path to the event file	Nr. of events	Cross section (pb)	Negative wghts (%)
zz.lhe.gz	10000	0.3	0.0

Results: histograms

◆ Missing energy distribution



◆ This suggest a selection cut: $\text{MET} < 125 \text{ GeV}$

◆ MADANALYSIS 5 also returns statistics information for each histogram

Dataset	Integral	Entries / events	Mean	RMS	%Underflow	%Overflow
zz	690	1.0	57.9969	47.37	0.0	0.05
ww	9660	1.0	39.7918	21.81	0.0	0.0
$tt\bar{b}$	75899	1.0	73.7078	39.9	0.0	0.0

Cut implementation

◆ Implementing the missing energy cut `ma5>select MET < 125`

Cut 6

Cut: select MET < 125.0

Dataset	Events kept: K	Rejected events: R	Efficiency: K / (K + R)	Cumul. efficiency: K / Initial
zz	640.80 +/- 6.76	49.20 +/- 6.76	0.9287 +/- 0.0098	0.9287 +/- 0.0098
ww	9633.9 +/- 5.1	26.1 +/- 5.1	0.997300 +/- 0.000528	0.997300 +/- 0.000528
ttbar	68826.1 +/- 80.1	7073.9 +/- 80.1	0.90680 +/- 0.00106	0.90680 +/- 0.00106

How to choose a cut?

- ★ Large signal efficiency
- ★ Small background efficiencies

◆ S vs B evolution - the formula can be changed (set `main.fom.formula = ...`)

Cut-flow chart

- How to compare signal (S) and background (B): `S/sqrt(S+B)`.

Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	690	85559	2.35
Cut 1	690	85559	2.35
Cut 2	690	85559	2.35
Cut 3	690	85559	2.35
Cut 4	690	85559	2.35
Cut 5	690	85559	2.35
Cut 6	640.80 +/- 6.76	78460.1 +/- 80.3	2.278 +/- 0.024

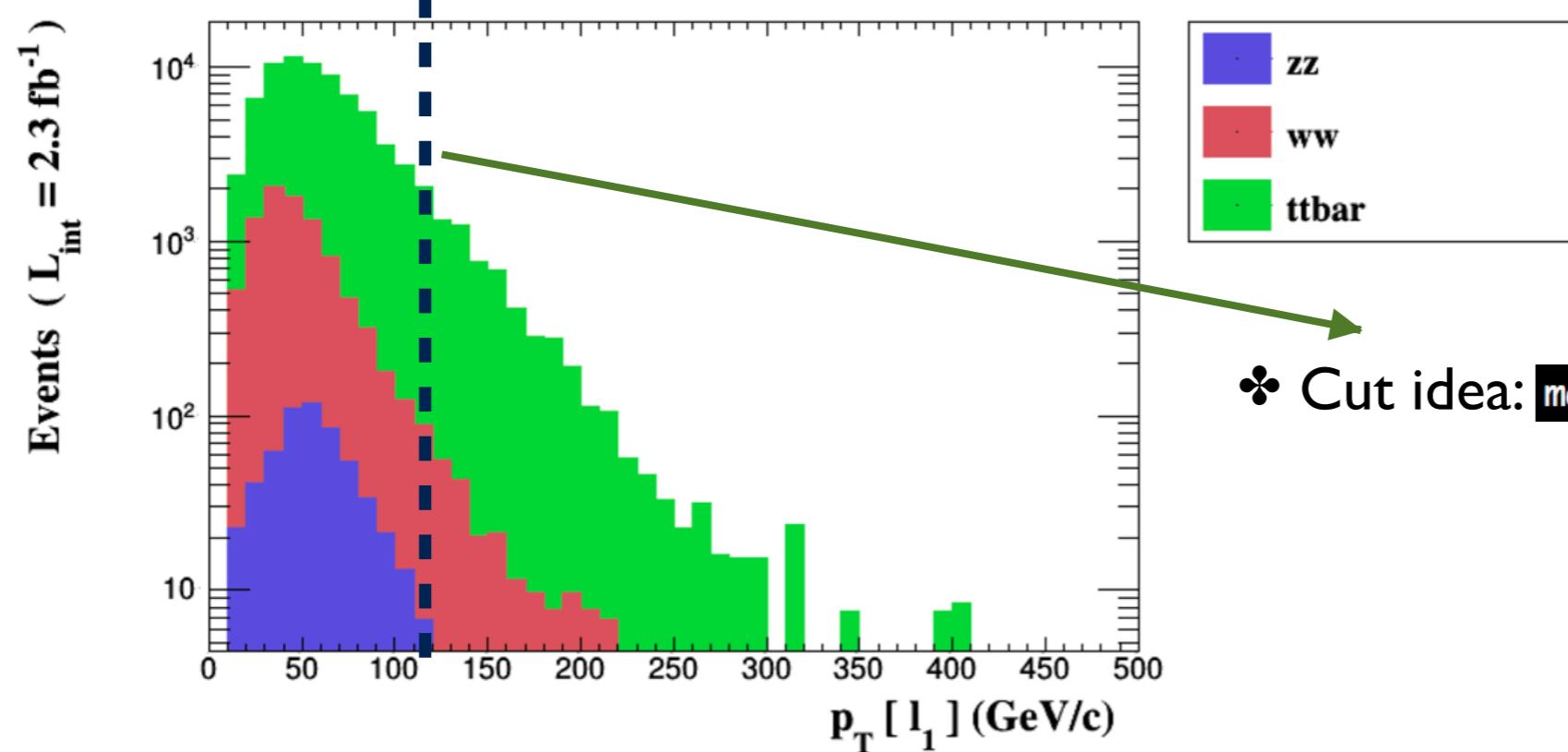
❖ The first cuts are due to the object definitions (no modification of the event count)

Investigating particle properties

- ◆ 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 a specific particle
 - ❖ Several ordering variables are available (PT, E, PX , etc.)

```
MG 2012 School of Higgs Phenomenology 02.10.2012
ma5>plot PT(l[1]) 50 0 500 [logY]
ma5>plot MT(j[1]) 50 0 500 [logY]
```

◆ Transverse momentum of the leading lepton



Particle properties: special features

◆ Combining particles

- ❖ Replace the single argument by several particles
- ❖ Four-momenta are summed before computing the observable
- ❖ **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 MET

```
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]
```

Novelty: signal regions can be implemented

- ◆ Several signal regions can be defined
- ❖ Cuts and histograms can be assigned to given regions

```
ma5>define_region SR1 SR2 CR1
ma5>select MET > 150 {SR1 CR1}
ma5>plot MET {SR1 SR2}
MA5-WARNING: Histogram found to be attached to distinguishable regions -> multiple declaration:
MA5-WARNING: * Plot: MET { SR2 }
MA5-WARNING: * Plot: MET { SR1 }
```

- ◆ Cutflows for each region

Region: "SR1"			
Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	0.021076 +/- 0.000542		
SEL: MET > 150.0	0.000146 +/- 0.012041		

Region: "SR2"			
Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	0.021076 +/- 0.000542		

Region: "CR1"			
Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	0.021076 +/- 0.000542		
SEL: MET > 150.0	0.000146 +/- 0.012041		

Outline

- I. Monte Carlo simulations and new physics
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3. Analyzing events with MADANALYSIS 5
- 4. Reconstructing hadron-level events / detector simulation**
5. The expert mode and LHC recasting
6. Summary

Reconstructing showered/hadronized events

- ◆ The output of a parton shower code 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, HEPMC)
 - ❖ 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, can be locally installed: `ma5>install fastjet`

Basic concepts for jet clustering

Jet clustering and basic detector effects

- ❖ Running of **FASTJET** via the **MADANALYSIS 5** interpreter (in the *reco* mode)
- ❖ b/tau-tagging efficiencies/mistag rates can be included
- ❖ The reconstructed events can be **redirected to a file**
 - ★ The output file can be used for post-processing
- ❖ 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>

```

Jet clustering in practice

◆ Jet reconstruction with MADANALYSIS 5 (and FASTJET)

- ❖ MADANALYSIS 5 must be run in the **reconstructed mode**: `./bin/ma5 -R`

```

ma5>set main.fastsim.package =
delphes      delphesMA5tune fastjet      none
ma5>set main.fastsim.package = fastjet
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.algorithm =
antikt      cambridge    cdfjetclu  cdfmidpoint genkt      gridjet      kt      none      siscone
ma5>set main.fastsim.algorithm = antikt
ma5>set main.fastsim.radius = 0.4

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

```

Many clustering
algorithms available
(with their options)

Realistic
b-tagging

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

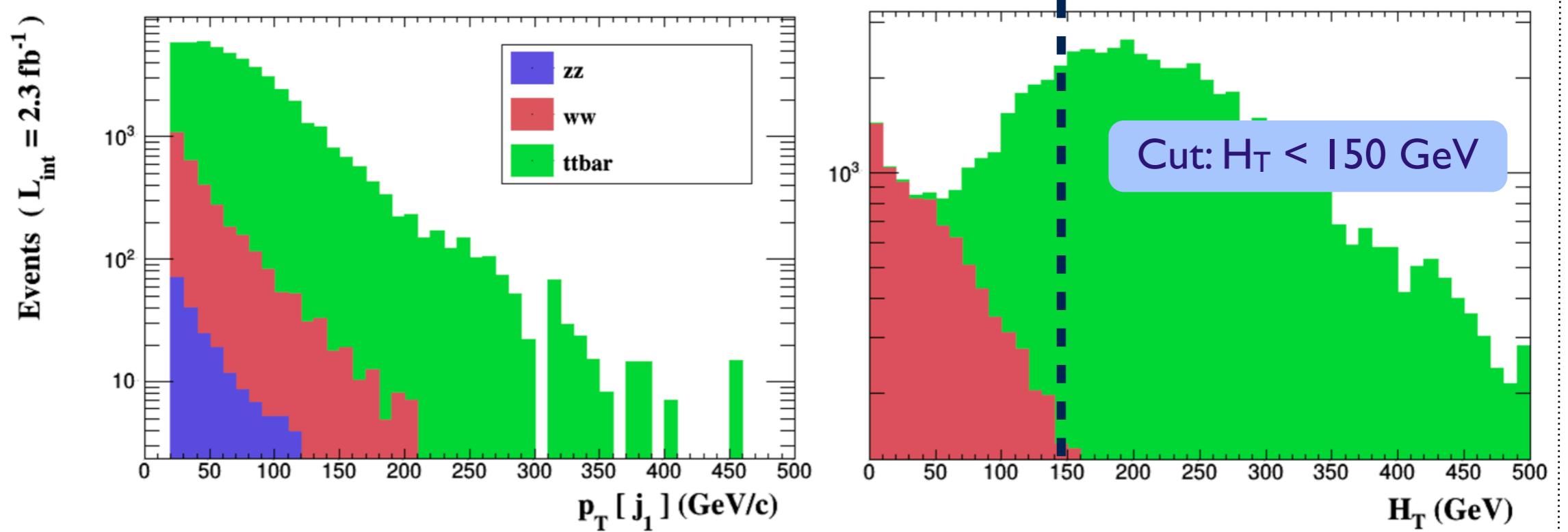
- ◆ LHE/LHCO files are created (and can be further used)

Investigating the event jet activity

- ◆ Studying the kinematical properties of the jets
 - ❖ $BETA, E, ET, ETA, GAMMA, M, MT, P, PHI, PT, PX, PY, PZ, R, THETA, Y$
- ◆ Reminder: the particles (and thus the jets) are ordered
 - ❖ Use squared brackets to select a specific particle
- ◆ Cuts: we keep the previously mentioned cuts

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

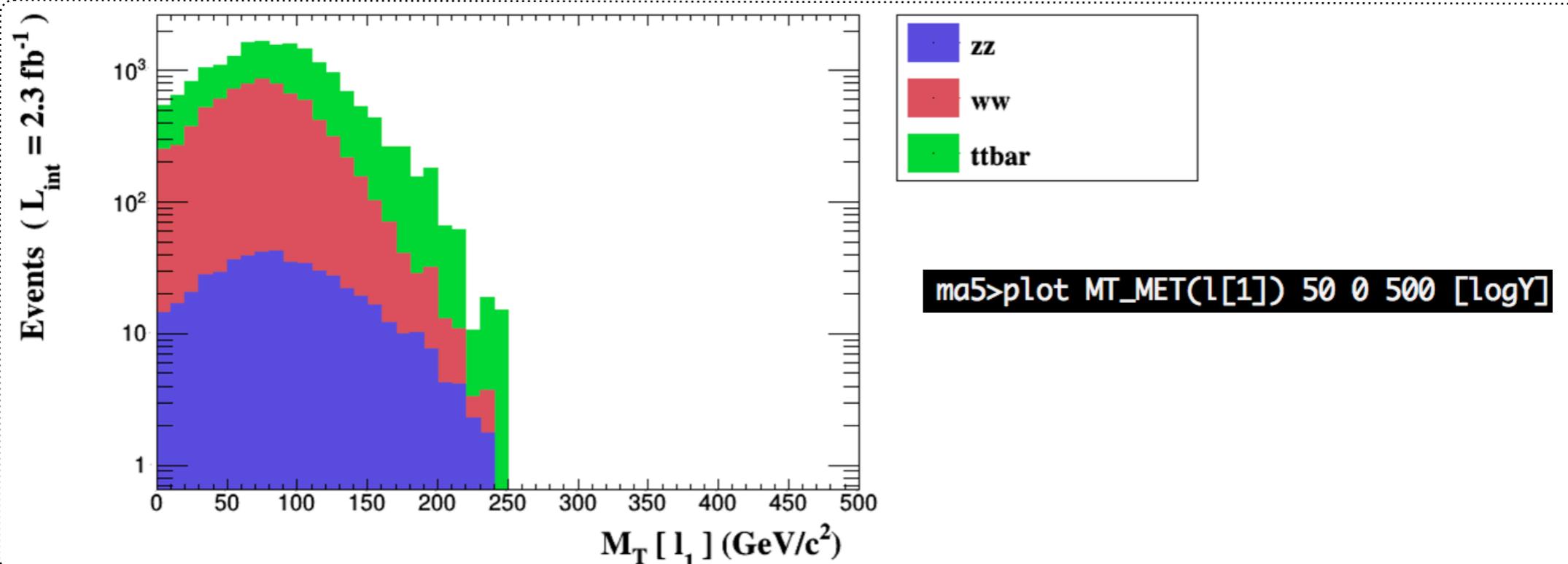
- ◆ Transverse momentum of the leading jet and total hadronic activity



- ❖ H_T distribution: the signal is hidden (cf. y-axis range)

Final results: missing momentum and cutflow

◆ Reconstructed 'W transverse mass'



◆ Cut flow chart: 4 σ is reachable!

Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	690	85559	2.35
Cut 1	690	85559	2.35
Cut 2	690	85559	2.35
Cut 3	690	85559	2.35
Cut 4	690	85559	2.35
Cut 5	690	85559	2.35
Cut 6	624.32 +/- 7.71	70481 +/- 110	2.3413 +/- 0.0288
Cut 7	611.39 +/- 8.35	65997 +/- 121	2.3689 +/- 0.0323
Cut 8	562.3 +/- 10.2	18996 +/- 102	4.0209 +/- 0.0727

Realistic detector simulation

◆ Event reconstruction with DELPHES (ROOT is mandatory)

- ❖ DELPHES 3 (possibly with MA5TUNE detector cards) is interfaced to MADANALYSIS 5
- ❖ Can be installed easily `ma5>install delphes`
- ❖ Easy to use


```
ma5>set main.fastsim.package = delphes
ma5>set main.fastsim.detector = cms-ma5tune
```
- ❖ Output: DELPHES ROOT file with all reconstructed objects (can be further used)

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 = delphes
[ma5>set main.fastsim.
main.fastsim.detector      main.fastsim.pileup      main.fastsim.skim_genparticles
main.fastsim.output         main.fastsim.rootfile  main.fastsim.skim_towers
main.fastsim.package        main.fastsim.skim_eflow  main.fastsim.skim_tracks
[ma5>set main.fastsim.detector =
atlas          atlas-ma5tune cms           cms-ma5tune
[ma5>set main.fastsim.detector = cms-ma5tune
```

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- 6.** Summary

The expert mode of MADANALYSIS 5

[Conte, BF, Serret (CPC '13); Conte, Dumont, BF, Wymant (EPJC '14)]

◆ MADANALYSIS 5 without its PYTHON interface

- ❖ More freedom in the **observables** (only some 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

Services

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

Interfaces

- ★ FASTJET
- ★ DELPHES 3
- ★ ROOT

Scripts

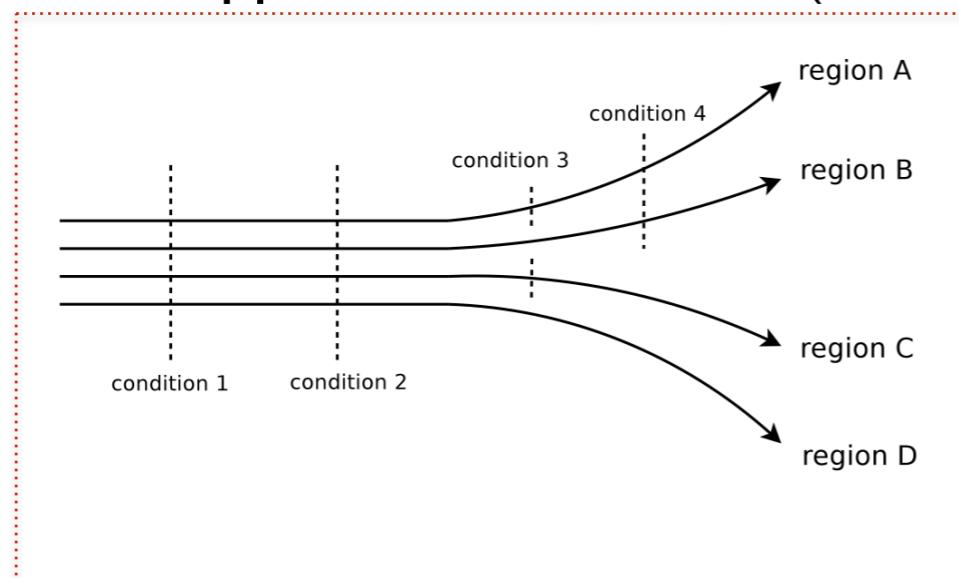
- ★ Compilation
- ★ Linking
- ★ Analysis skeleton generator

The new extension of the expert mode

[Conte, BF, Serret (CPC '13); Conte, Dumont, BF, Wymant (EPJC '14)]

- ◆ Main features (enable a recast of most cut-based LHC analyses)
 - ❖ 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

Implementing a new analysis (I)

◆ Recommendation: start from any existing recasted LHC analysis

- ❖ More information:

<http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase>

- ❖ Installation: `ma5>install PAD`

◆ A pre-existing script allows for the generation of a new analysis skeleton

- ❖ The `newAnalyzer.py` script located in PAD/Build/SampleAnalyzer
- ❖ Add an empty analysis in PAD/Build/SampleAnalyzer/User/Analyzer/
- ❖ To be modified on the basis of the other analyses in that folder

◆ Declaring regions, cuts and histograms via the *Manager* (*Initialize* method)

- ❖ Region: `Manager()->AddRegionSelection("signal");`

- ❖ Histogram: `Manager()->AddHisto("MET_selected_mu", 15, 0, 1500);`

- ❖ Cut: `Manager()->AddCut("2leptons", "SR1");`

```
std::string SRs[] = {"SR1", "SR2"};
```

```
Manager()->AddCut("3leptons", SRs);
```

Number of
bins, range

Weight management

◆ The *Execute* method must include an initialization of the weights

- ❖ Correct cutflow management
- ❖ Correct weights in the histograms
- ❖ Efficiency of the application of the cuts

```
double myEventWeight;  
if(Configuration().IsNoEventWeight()) myEventWeight=1.;  
else if(event.mc()->weight()!=0.) myEventWeight=event.mc()->weight();  
else  
{  
    WARNING << "Found one event with a zero weight. Skipping...\n";  
    return false;  
}  
Key command  
Manager()->InitializeForNewEvent(myEventWeight);
```

To be included in
any single analysis

Objects

◆ Object definitions

- ❖ Key C++ class: the `event.rec()`
- ★ Key collections: `electrons()`, `muons()`, `jets()`, ...
- ❖ Illustrative loose and tight electron definition

```
std::vector<const RecLeptonFormat*> SignalLeptons, LooseElectrons;
for(unsigned int ii=0; ii<event.rec()->electrons().size(); ii++)
{
    const RecLeptonFormat *MyElec = &(event.rec()->electrons()[ii]);
    double eta = fabs(MyElec->eta());
    double pt = MyElec->pt();
    double iso_var = PHYSICS->Isol->eflow->sumIsolation(MyElec,
        event.rec(), 0.4, 0., IsolationEFlow::ALL_COMPONENTS);

    if( (eta>1.44) and (eta<1.57) ) continue;
    if(eta>2.5) continue;

    if(iso_var>0.15*pt) continue;

    if (pt>20) SignalLeptons.push_back(MyElec);
    if (pt>10) LooseElectrons.push_back(MyElec);
}
```

Loop over all electrons

Acceptance

Isolation

PT cuts

Cuts and histograms

♦ Cuts must be implemented in a very specific way

- ❖ Ensures the correct treatment of the cutflows
- ❖ Ensures an efficient running of the code

```
if(!Manager()->ApplyCut(cut1_cond,"2_leptons")) return true;
```

Cut condition

Declared cut name

♦ Filling a declared histograms is straightforward

- ❖ Ensures the correct treatment of the cutflows
- ❖ Ensures an efficient running of the code

```
Manager()->FillHisto("MET",MET);
```

Histogram name

Observable value

♦ More info: existing analyses or the manual ([I405.3982](#) and [I407.3278](#))

Reinterpreting LHC physics analyses

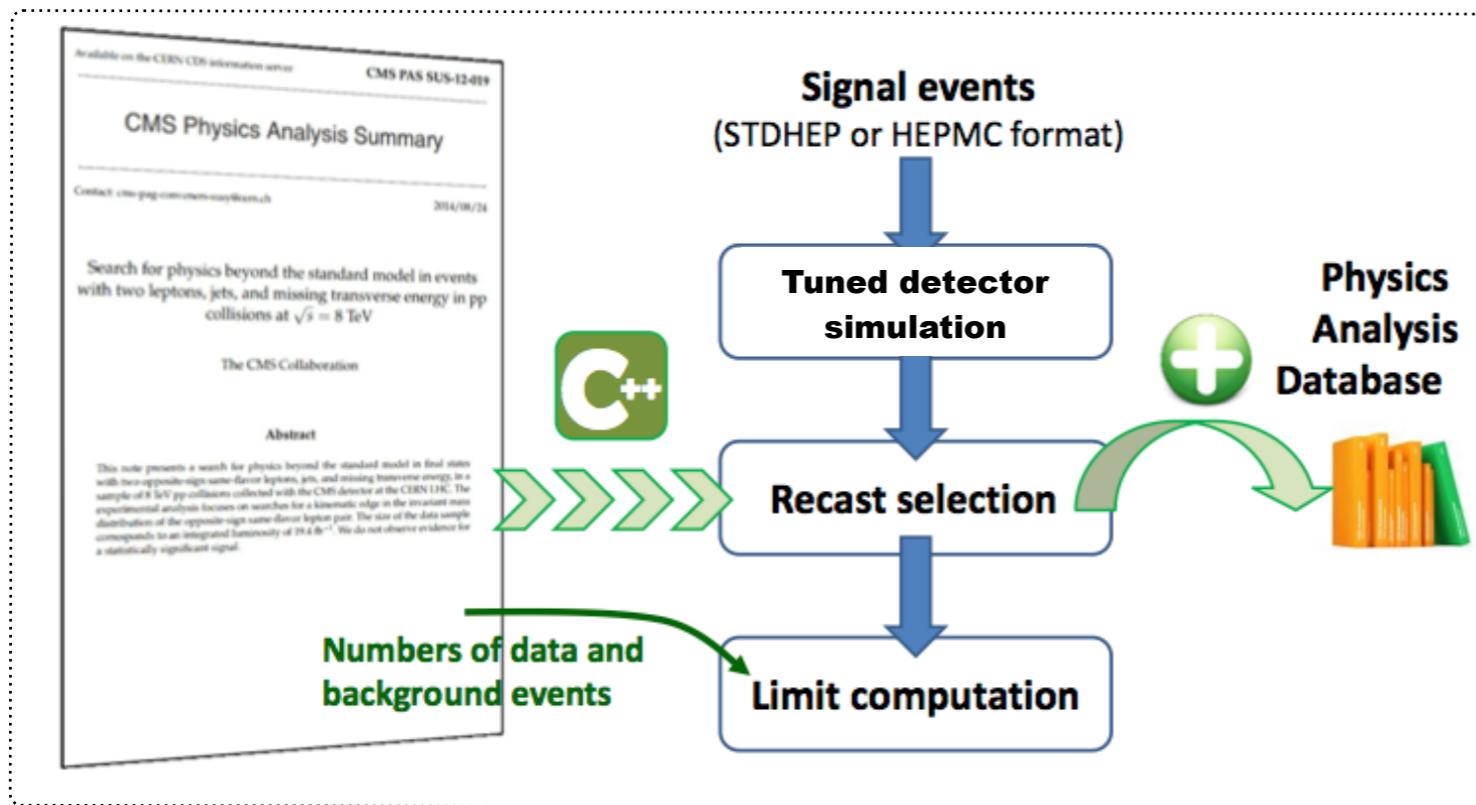
- ◆ Exploit the full potential of the LHC (for new physics)
 - ❖ Priority #1 of the European strategy for particle physics
 - ❖ Designing new analyses to probe new ideas Prospectives (based on MC simulations)
 - ❖ Recasting LHC analyses to study models not considered The LHC legacy
- ◆ LHC data has been collected with significant human and financial efforts
 - ❖ Important for on-going analyses (within popular theoretical contexts of today)
 - ❖ Important for future opportunities (within future scientific contexts)
- ◆ Data preservation in high-energy physics is mandatory [Kogler, South & Steder (JPCS'12)]
- ◆ Related tools need to be supported by the entire community [Kraml et al. (EPJC'12)]
 - ❖ Both theorists and experimentalists
 - ❖ Allowing for the reinterpretation of the LHC analysis results

Recasting in MADANALYSIS 5

[Conte, Dumont, BF, Wymant (EPJC '14); Dumont, BF, Kraml et al. (EPJC '15)]

- ◆ There are plethora of new physics realizations that deserve to be studied
 - ❖ Experimentalists cannot study all the options
 - ❖ Our choice: rely on a public detector simulator mimicking ATLAS and CMS
 - ❖ Need for a (public) framework where LHC analyses can be easily implemented

◆ The recasting strategy in MADANALYSIS 5



- ❖ 2 options for detector effects
 - ★ DELPHES/PGS-like (resolutions, efficiencies, etc.)
 - ★ RIVET-like (transfer functions)

Recasting made easy with MADANALYSIS 5 (I)

[Conte, Dumont, BF, Wymant (EPJC '14); Dumont, BF, Kraml et al. (EPJC '15)]

◆ Confronting a BSM signal to LHC analyses is straightforward

- ❖ Starting point: a showered/hadronized event file
- ❖ Installation of the detector simulators: ‘install DELPHES’
- ❖ Installation of the analysis libraries: ‘install PAD’ (more analyses with the MA5tune)

◆ In practice:

```
ma5>set main.recast = on
MA5-WARNING: DelphesMA5tune and/or the PADForMA5tune are not installed (or deactivated): the corresponding analyses will be unavailable
ma5>import samples/stops.hep.gz
MA5:    -> Storing the file 'stops.hep.gz' in the dataset 'defaultset'.
ma5>submit
MA5:   Creating folder 'ANALYSIS_0'...
MA5: Would you like to edit the recasting Card ? (Y/N)
Answer: Y
```

◆ Snippet of the recasting card (only on/off switches to be set by the user)

- ❖ O(20) 8 TeV ATLAS and CMS analyses; 2 13 TeV ATLAS analyses (+10 new analyses soon)

atlas_1605_03814	v1.2	on	delphes_card_ATLAS_1604_07773.tcl	# ATLAS - 13 TeV - multijet (2-6 jets) + met
ATLAS_1604_07773	v1.2	on	delphes_card_ATLAS_1604_07773.tcl	# ATLAS - 13 TeV - monojet
ATLAS_EXOT_2014_06	v1.2	on	delphes_card_atlas_sus_2013_05_pad.tcl	# ATLAS - 8 TeV - monophoton
cms_exo_12_047	v1.2	on	delphes_card_cms_b2g_12_012.tcl	# CMS - 8 TeV - monophoton
cms_exo_12_048	v1.2	on	delphes_card_cms_b2g_12_012.tcl	# CMS - 8 TeV - monojet
cms_b2g_14_004	v1.2	on	delphes_card_cms_b2g_14_004.tcl	# CMS - 8 TeV - Dark matter production with a ttbar pair
cms_b2g_12_022	v1.2	on	delphes_card_cms_b2g_14_004.tcl	# CMS - 8 TeV - Monotop search
CMS_B2G_12_012	v1.2	on	delphes_card_cms_b2g_12_012.tcl	# CMS - 8 TeV - T5/3 partners in the SSDL channel

Recasting made easy with MADANALYSIS 5 (2)

[Conte, Dumont, BF, Wymant (EPJC '14); Dumont, BF, Kraml et al. (EPJC '15)]

◆ Snippet of the output file (example: low statistics ➤ lots of '-1' in the example)

- ❖ CLs if a signal cross section is provided
- ❖ Cross sections excluded at the 95% CL

ATLAS_1604_07773	EM1	25.8538538	27.4980471		0.0100000	0.0099499	0.0000000	0.0099499
ATLAS_1604_07773	EM2	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	EM3	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	EM4	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	EM5	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	EM6	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	EM7	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	IM1	58.3118133	52.7020233		0.0100000	0.0099499	0.0000000	0.0099499
ATLAS_1604_07773	IM2	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	IM3	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	IM4	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	IM5	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000
ATLAS_1604_07773	IM6	-1	-1		0.0000000	0.0000000	0.0000000	0.0000000

Implementing a new analysis in MADANALYSIS 5

- ◆ Picking up an experimental publication
 - ♣ Reading
 - ♣ Understanding



Relatively easy

- ◆ Writing the analysis code in the tool internal language



Relatively easy

- ◆ Getting the information missing from the publication for a proper validation
 - ♣ Efficiencies (trigger, electrons, muons, b-tagging, JES, etc.)
 - ★ Including p_T and/or η dependence
 - ★ Accurate information
 - ♣ Detailed **cutflows** for some well-defined **benchmark** scenarios
 - ★ Exact definition of the benchmarks (spectra)
 - ★ Event generation information (cards, tunes, etc.)
 - ♣ Expected **number of events** in each region and **cross sections**
 - ♣ **Digitized histograms** (e.g., on HEPDATA)



Essential



Often difficult!

- ◆ Comparing theory tools and real life

Recasting CMS-EXO-12-048

[Conte, BF, Guo ('16)]

◆ Missing information for the validation

- ♣ Discussion with CMS to get validation benchmarks
- ♣ Cutflows and Monte Carlo information for given benchmarks

 **Discussions with CMS needed**

◆ Validation:

	Selection step	CMS	ϵ_i^{CMS}	MA5	ϵ_i^{MA5}	δ_i^{rel}
0	Nominal	84653.7		84653.7		
1	One hard jet	50817.2	0.6	53431.28	0.631	5.2%
2	At most two jets	36061	0.7096	38547.75	0.721	1.61%
3	Requirements if two jets	31878.1	0.884	34436.35	0.893	1.02%
4	Muon veto	31878.1	1	34436.35	1.000	0
5	Electron veto	31865.1	1	34436.35	1.000	0
6	Tau veto	31695.1	0.995	34397.54	0.998	0.3%
	$\cancel{E}_T > 250 \text{ GeV}$	8687.22	0.274	7563.04	0.219	20.00%
	$\cancel{E}_T > 300 \text{ GeV}$	5400.51	0.621	4477.67	0.592	4.66%
	$\cancel{E}_T > 350 \text{ GeV}$	3394.09	0.628	2813.70	0.628	0.00%
	$\cancel{E}_T > 400 \text{ GeV}$	2224.15	0.6553	1753.71	0.623	4.93%
	$\cancel{E}_T > 450 \text{ GeV}$	1456.02	0.654	1110.92	0.633	3.21%
	$\cancel{E}_T > 500 \text{ GeV}$	989.806	0.679	722.83	0.650	4.27%
	$\cancel{E}_T > 550 \text{ GeV}$	671.442	0.678	487.54	0.674	0.59%

 **Validated at the 20% level**


Issue with the low-MET modelling in DELPHES

◆ The $t\bar{t}$ +MET analysis (CMS-B2G-14-004) was validated to the 2-3% level

MADANALYSIS 5 analyses on INSPIRE

[BF, Martini ('16)]

- Implementation of LHC analyses can be uploaded on INSPIRE
- DOI are assigned: can be cited, searched for, etc.

The screenshot shows a detailed view of an INSPIRE record. At the top, there are three tabs: 'Information' (blue), 'Citations (1)' (red circle), and 'Files' (green circle). A green arrow points from the 'Files' tab to a callout box containing the text 'Files are versioned, can be downloaded'. Below the tabs, the title of the analysis is displayed: 'MadAnalysis5 implementation of the CMS search for dark matter production with top quark pairs in the single lepton channel (CMS-B2G-14-004)'. To the left of the title is a red button labeled 'DOI and citations'. To the right is the author information: 'Fuks, Benjamin; Martini, Antony'. Under the title, a 'Description' section provides a brief overview of the analysis. Below the description, instructions for using the code and links to validation summaries and CMS documentation are provided. The 'Cite as' section includes the citation details and a DOI link, which is circled in red. At the bottom of the record, a note states 'Automatic installation of all implemented analyses from MADANALYSIS 5'. The footer of the page indicates the record was added and last modified on 2016-05-09.

Information Citations (1) Files Files are versioned, can be downloaded

MadAnalysis5 implementation of the CMS search for dark matter production with top quark pairs in the single lepton channel (CMS-B2G-14-004)

DOI and citations Fuks, Benjamin; Martini, Antony

Description: This is the MadAnalysis5 implementation of the CMS search for dark matter in a channel where a pair of dark matter particles is produced in association with a top-antitop system. This search targets events featuring a single lepton originating from the top decays and a large amount of missing transverse energy.

Information how to use this code and a detailed validation summary are available at <http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase>. The CMS analysis is documented at <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G14004>.

Cite as: Fuks, B., Martiny, A. (2016). MadAnalysis5 implementation of the CMS search for dark matter production with top quark pairs in the single lepton channel (CMS-B2G-14-004). doi: [10.7484/INSPIREHEP.DATA.MIHA.JR4G](https://doi.org/10.7484/INSPIREHEP.DATA.MIHA.JR4G)

Automatic installation of all implemented analyses from MADANALYSIS 5

Record added 2016-05-09, last modified 2016-05-09

The Public Analysis Database of MADANALYSIS

[Dumont, BF, Kraml et al. (EPJC '15)]

- ◆ A database with MADANALYSIS 5 implementations of LHC analyses exists
 - ❖ <http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase>
- ◆ Snippet of the webpage

ATLAS analyses, 13 TeV					
Analysis	Short Description	Implemented by	Code	Validation note	Version
ATLAS-EXOT-2015-03	monojet + missing transverse energy	D. Sengupta	Inspire Inspire	PDF PDF	v1.3/Delphes3
ATLAS-SUSY-2015-06	jets + missing transverse momentum	S. Banerjee, B. Fuks, B. Zaldivar			v1.3/Delphes3

[Delphes card for ATLAS-EXOT-2015-03](#)

Dedicated
DELPHES cards

Code from INSPIRE

Validation information
(cutflows, distributions, etc.)

- ◆ Can be automatically installed within MADANALYSIS 5

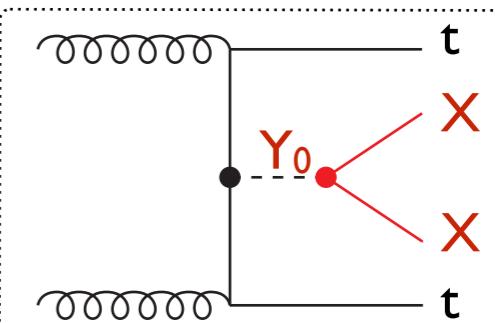
NLO effects on a CLs: top-philic dark matter

[Arina, Backovic, Conte, BF, Guo et al. (JHEP'16)]

- ◆ A simplified model for top-philic dark matter
 - ❖ A dark sector with a fermionic dark matter candidate X
 - ❖ A (scalar) mediator Y_0 linking the dark sector and the top

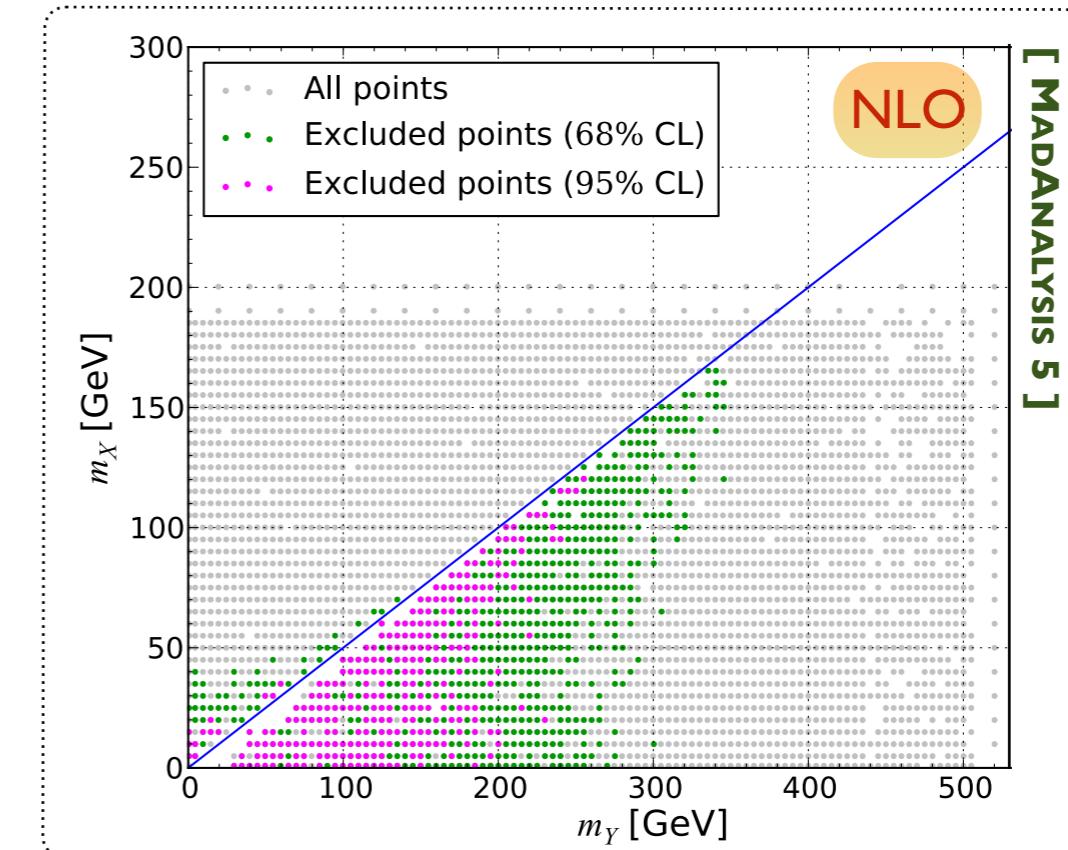
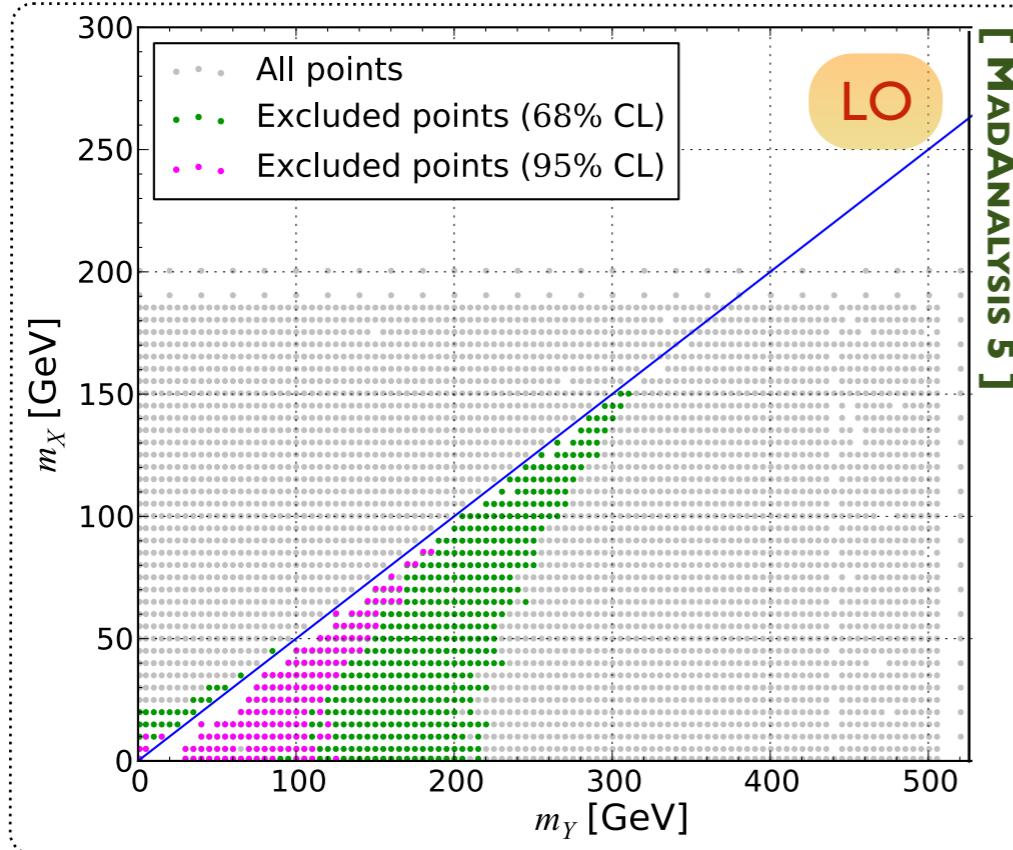
$$\mathcal{L}_{t,X}^{Y_0} = - \left(g_t \frac{y_t}{\sqrt{2}} \bar{t}t + g_X \bar{X}X \right) Y_0$$

[BF & Martini (2016)]



- ❖ Could be probed with $tt+MET$ events (CMS-B2G-14-004)

- ◆ For central scales: mild (but visible) NLO effects on the exclusions



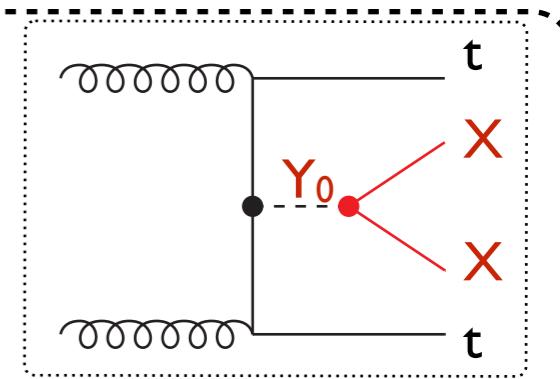
- ❖ How is the picture changing when including scale variations?

NLO effects on a CLs: top-philic dark matter

[Arina, Backovic, Conte, BF, Guo et al. (JHEP'16)]

◆ There are theoretical uncertainties on a CLs number

(m_Y, m_X)	$\sigma_{\text{LO}} [\text{pb}]$	$\text{CL}_{\text{LO}} [\%]$	$\sigma_{\text{NLO}} [\text{pb}]$	$\text{CL}_{\text{NLO}} [\%]$
I (150, 25) GeV	$0.658^{+34.9\%}_{-24.0\%}$	$98.7^{+0.8\%}_{-13.0\%}$	$0.773^{+6.1\%}_{-10.1\%}$	$95.0^{+2.7\%}_{-0.4\%}$
II (40, 30) GeV	$0.776^{+34.2\%}_{-24.1\%}$	$74.7^{+19.7\%}_{-17.7\%}$	$0.926^{+5.7\%}_{-10.4\%}$	$84.2^{+0.4\%}_{-14.4\%}$
III (240, 100) GeV	$0.187^{+37.1\%}_{-24.4\%}$	$91.6^{+6.4\%}_{-18.1\%}$	$0.216^{+6.7\%}_{-11.4\%}$	$86.5^{+8.6\%}_{-5.5\%}$



- ❖ An excluded point (95% CL) may not be excluded when accounting for errors
- ❖ The CLs number can increase / decrease at NLO
- ❖ The error band is reduced

Outline

- I.** Monte Carlo simulations and new physics
- 2.** Overview of MADANALYSIS 5 and basic concepts
- 3.** Analyzing events with MADANALYSIS 5
- 4.** Reconstructing hadron-level events / detector simulation
- 5.** The expert mode and LHC recasting
- 6. Summary**

Summary

◆ MADANALYSIS 5:

- ❖ A **framework** for collider phenomenology (parton, hadron & reco level)
- ❖ **User-friendly** by means of its PYTHON interface
- ❖ **Flexible** thanks to its C++ kernel
- ❖ **Interfaced** to several HEP packages

<http://launchpad.net/madanalysis5>

◆ Two modes of the code

- ❖ **PYTHONIC**: intuitive commands typed in a PYTHON interface
 - ★ Analyses performed behind the scenes
 - ★ Human readable reports as output
- ❖ **C++**: programming in the SAMPLEANALYZER framework (the MADANALYSIS 5 core)

◆ The LHC legacy

<http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase>

- ❖ Crucial to be able to reinterpret the LHC results in any theoretical context
- ❖ MADANALYSIS 5 has been actively developed along these lines
 - ★ User-friendly way to confront any MC-simulated BSM signal to LHC results
- ❖ **Reproducibility** is the ability of an entire experiment to be reproduced (possibly by an independent theoretical study)