

MAD Analysis 5

STATUS AND DEVELOPMENT (v1.6)

Guillaume CHALONS
On behalf of the MA5 team

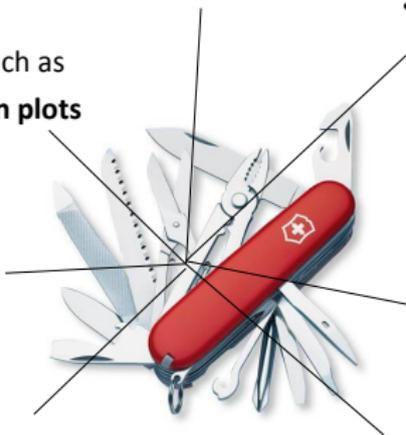
LPSC Grenoble

(Re)interpreting the results of new physics searches at the LHC

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

MadAnalysis 5: a multi-purpose tool

- **Histogramming and selection** in the normal mode
- **Producing special plots** such as **ME/PS merging validation plots**
- **Applying a jet-clustering algorithm** to your hadronic events
- **Applying a fast-simulation detector (Delphes)** to your hadronic events
- **Writing the events** in another data format.
- **Designing a sophisticated analysis** in the **expert mode**
- **Recasting an existed analysis and computing a limit** to a BSM signal



Two ways of using MadAnalysis

Normal mode
= user-friendly



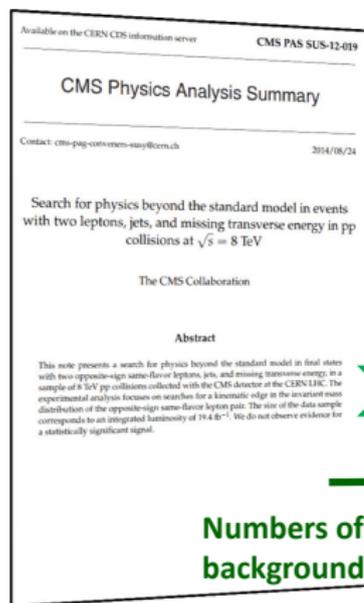
- Based on a Python console
- Analysis definition is based on a intuitive meta-language
- Plots & chart-flow automatically done
- Transparent interface to known HEP programs

Expert mode
= developer-friendly



- Writing your analysis in C++ language
- Facilitated development due to general services, physics library, program interfaces
- Analysis results are dumped into SAF files

MadAnalysis recasting way



Signal events
(STDHEP or HEPMC format)

Analysis Specific Tunes : New

**DELPHES /
DELPHESMA5TUNE**



**Recast selection
(Expert Mode)**



**Physics
Analysis
Database**

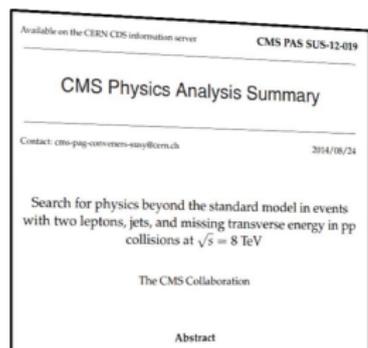


**Numbers of data and
background events**

**Limit
computation**

Eur.Phys.J. C74
(2014) 3103

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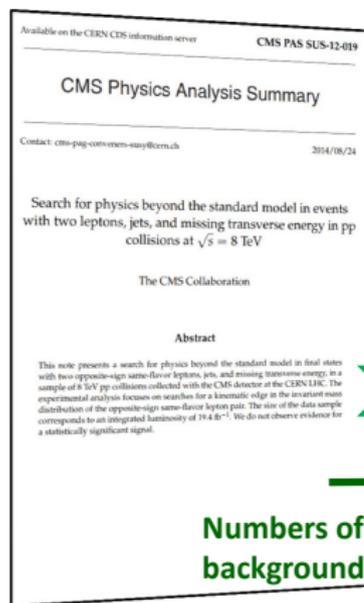


Physics
Analysis
Database



# Analysis name	PAID type	Switch	Delphes card	
atlas_susy_2013_04	v1.1	off	delphes_card_atlas_sus_2013_04.tcl	# ATLAS - multijet + met
atlas_sus_13_05	v1.1	on	delphes_card_atlas_sus_2013_05.tcl	# ATLAS - stop/sbottom - 0 lepton + 2 bjets + met
atlas_susy_2013_11	v1.1	off	delphes_card_atlas_sus_2013_11.tcl	# ATLAS - ewkinos - 2 leptons + met
atlas_susy_2013_21	v1.1	off	delphes_card_atlas_sus_2013_05.tcl	# ATLAS - monojet
atlas_susy_2014_10	v1.1	off	delphes_card_atlas_sus_2014_10.tcl	# ATLAS - squark-gluino - 2 leptons + jets + met
atlas_1405_7875	v1.1	off	delphes_card_atlas_sus_2013_11.tcl	# ATLAS - squark-gluino - 0 leptons + 2-6 jets + met
atlas_higg_2013_03	v1.1	off	delphes_card_atlas_sus_2013_11.tcl	# ATLAS - ZH to invisible + 2 leptons
cms_sus_13_012	v1.1	off	delphes_card_cms_standard.tcl	# CMS - squark-gluino - MET/MHT
cms_sus_13_016	v1.1	off	delphes_card_cms_standard.tcl	# CMS - gluinos - 2 leptons + bjets + met
cms_sus_14_001_TopTag	v1.1	on	delphes_card_cms_sus14004.tcl	# CMS - stop - the top tagging channel
cms_sus_14_001_monojet	v1.1	off	delphes_card_cms_standard.tcl	# CMS - stop - the monojet channel
cms_sus_13_011	v1.1	on	delphes_card_cms_standard.tcl	# CMS - stop - 1 lepton + bjets + met
ATLAS_EXOT_2014_06	v1.2	off	delphes_card_atlas_sus_2013_05_pad.tcl	# ATLAS - monophoton
cms_exo_12_047	v1.2	off	delphes_card_cms_b2g_12_012.tcl	# CMS - monophoton
cms_exo_12_048	v1.2	off	delphes_card_cms_b2g_12_012.tcl	# CMS - monojet
cms_b2g_14_004	v1.2	off	delphes_card_cms_b2g_14_004.tcl	# CMS - Dark matter production with a ttbar pair
cms_b2g_12_022	v1.2	off	delphes_card_cms_b2g_14_004.tcl	# CMS - Monotop search
CMS_B2G_12_012	v1.2	off	delphes_card_cms_b2g_12_012.tcl	# CMS - TS/3 partners in the SSDL channel

MadAnalysis recasting way



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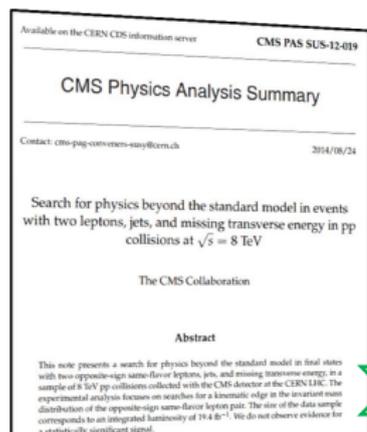
**Limit
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**Physics
Analysis
Database**



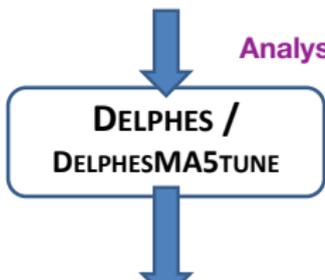
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Illustrative output (beware of low statistics for the example)

analysis name	signal region	sig95(exp)	sig95(obs)		efficiency	stat. unc
cms_sus_13_011	Stop->T+neutralino, LowDeltaM, MET>200	0.3301365	0.2651069		0.0070623	0.0083740
cms_sus_13_011	Stop->T+neutralino, LowDeltaM, MET>250	-1	-1		0.0000000	0.0000000
cms_sus_13_011	Stop->T+neutralino, LowDeltaM, MET>300	-1	-1		0.0000000	0.0000000
cms_sus_13_011	Stop->T+neutralino, HighDeltaM, MET>150	-1	-1		0.0000000	0.0000000
cms_sus_13_011	Stop->T+neutralino, HighDeltaM, MET>200	-1	-1		0.0000000	0.0000000
cms_sus_13_011	Stop->T+neutralino, HighDeltaM, MET>250	-1	-1		0.0000000	0.0000000
cms_sus_13_011	Stop->T+neutralino, HighDeltaM, MET>300	-1	-1		0.0000000	0.0000000
cms_sus_13_011	Stop->b+chargino, LowDeltaM, MET>100	2.9531986	2.7750373		0.0070623	0.0083740
cms_sus_13_011	Stop->b+chargino, LowDeltaM, MET>150	1.1270604	0.8966912		0.0070623	0.0083740
cms_sus_13_011	Stop->b+chargino, LowDeltaM, MET>200	0.4476290	0.3246151		0.0070623	0.0083740
cms_sus_13_011	Stop->b+chargino, LowDeltaM, MET>250	-1	-1		0.0000000	0.0000000



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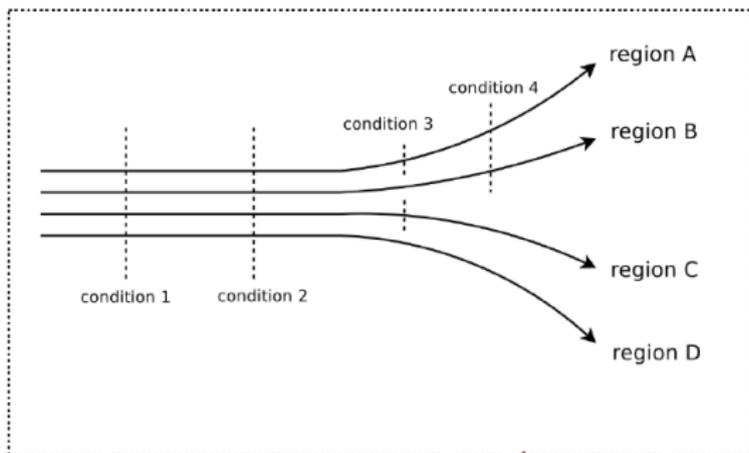
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- ☞ Public Analysis Database **extended with 13 TeV analyses**

Signal regions

- Already implemented in the **expert mode**
very useful for recasting ATLAS/CMS analyses



- Implemented now in the **normal mode**



- Defining a signal region:

```
ma5> define_region S1  
ma5> define_region S2
```

- Applying a cut selection in a given signal region

```
ma5> select N(b)=1 {S1}  
ma5> select N(b)=2 {S2}  
ma5> select N(j)>0 {S1 S2}  
ma5> select N(mu)>0
```

- Display all defined signal regions and the corresponding selection cuts:

```
ma5> display_regions  
MA5:  ***** List of defined regions *****  
MA5:  > Region 1: S1  
MA5:  ** Cut - 1: select N ( b ) = 1.0  
MA5:  ** Cut - 2: select N ( j ) > 0.0  
MA5:  ** Cut - 3: select N ( mu+ ) > 0.0  
MA5:  > Region 2: S2  
MA5:  ** Cut - 1: select N ( b ) = 2.0  
MA5:  ** Cut - 2: select N ( j ) > 0.0  
MA5:  ** Cut - 3: select N ( mu+ ) > 0.0  
MA5:  *****
```

Summary

Cut-flow charts

- How to compare signal (S) and background (B): $S/\sqrt{S+B}$.
- Object definition selections are indicated in cyan.
- Reject and select are indicated by 'REJ' and 'SEL' respectively

Region: "S1"			
Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	109999 +/- 789		
SEL: N (b) = 1.0	100795 +/- 729		
SEL: N (j) > 0.0	100795 +/- 729		
SEL: N (mu) > 0.0	34660 +/- 292		

Region: "S2"			
Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	109999 +/- 789		
SEL: N (b) = 2.0	0.0 +/- 0.0		
SEL: N (j) > 0.0	0.0 +/- 0.0		
SEL: N (mu) > 0.0	0.0 +/- 0.0		

Collaboration work between MadGraph and MadAnalysis authors



- **Installing MadAnalysis 5 from MG_aMC@NLO console**

```
MG_aMC@NLO> install zlib
MG_aMC@NLO> install MadAnalysis
```

→ strongly advised

- **Defining the physics process and launching the generation**

The following switches determine which programs are run:

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

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



MadAnalysis5 interface

Generation of a default analysis card
tuned for the final state produced
(*here a dilepton pair production*)

```
# 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

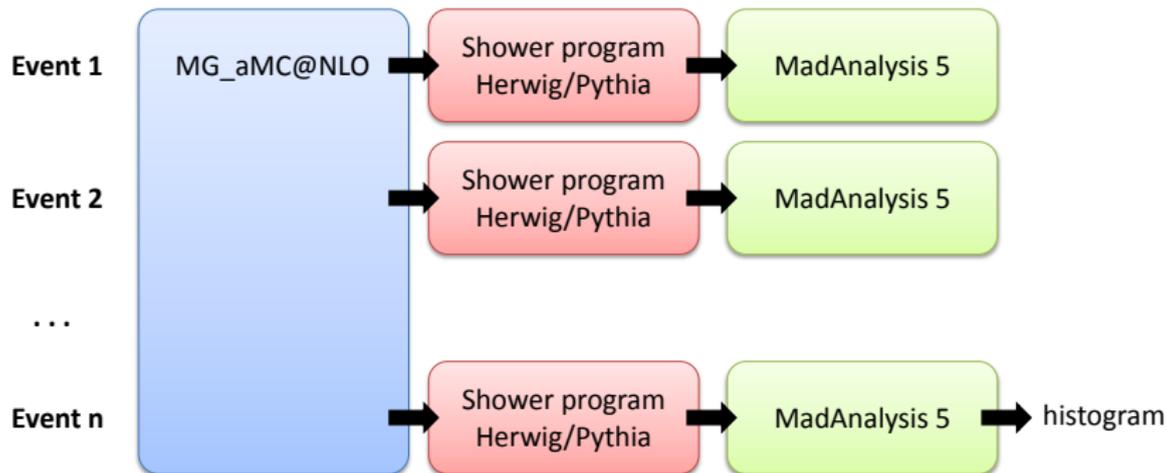
# Global event variables
plot THT 40 0 500 [logY]
plot MET 40 0 500 [logY]
plot SQRTS 40 0 500 [logY]
# PT and ETA distributions of all particles
plot PT(e-[1]) 40 0 500 [logY]
plot ETA(e-[1]) 40 -10 10 [logY]
plot PT(e+[1]) 40 0 500 [logY]
plot ETA(e+[1]) 40 -10 10 [logY]
# Invariant-mass distributions
plot M(e-[1] e+[1]) 40 0 500 [logY ]
# Angular distance distributions
plot DELTAR(e-[1],e+[1]) 40 0 10 [logY ]
```

The FIFO mode

Goal: avoiding from storing super-heavy HEP or HEPMC data file

Beta version currently. Only available at LO QCD & for Pythia8

→ Just modify the file `pythia8_card.dat`



- 📖 A database with MadAnalysis5 implementations of LHC analyses
- B. Dumont et. al, EPJC 75 (2015) 56
- <https://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase>

ATLAS analyses, 13 TeV

Analysis	Short Description	Implemented by	Code	Validation note	Version
📖 ATLAS-SUSY-2015-06	Multijet + missing transverse momentum	S. Banerjee, B. Fuks, B. Zaldivar	📖 Inspire	📖 PDF	v1.3/Delphes3
📖 ATLAS-EXOT-2015-03	Monojet (3.2 fb-1)	D. Sengupta	📖 Inspire	📖 PDF	v1.3/Delphes3
📖 ATLAS-EXOT-2016-25	Mono-Higgs (36.1 fb-1)	S. Jeon, Y. Kang, G. Lee, C. Yu	To appear	📖 PDF	v1.6/Delphes3
📖 ATLAS-EXOT-2016-27	Monojet (36.1 fb-1)	D. Sengupta	To appear	To appear	v1.6/Delphes3
📖 ATLAS-EXOT-2016-32	Monophoton (36.1 fb-1)	S. Baek, T.H. Jung	📖 Inspire	📖 PDF	v1.6/Delphes3
📖 ATLAS-CONF-2016-086	b-pair + missing transverse momentum	B. Fuks & M. Zumbihl	📖 Inspire	📖 PDF	v1.6/Delphes3

- 📖 Delphes card for ATLAS-CONF-2016-086
- 📖 Delphes card for ATLAS-EXOT-2015-03 and ATLAS-SUSY-2015-06
- 📖 Delphes card for ATLAS-EXOT-2016-25
- 📖 Delphes card for ATLAS-EXOT-2016-27
- 📖 Delphes card for ATLAS-EXOT-2016-32

CMS analyses, 13 TeV

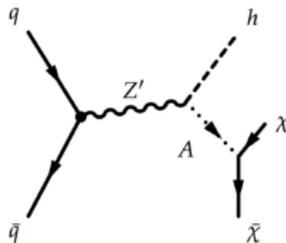
Analysis	Short Description	Implemented by	Code	Validation note	Version
📖 CMS-SUS-16-052	SUSY in the 1l + jets channel (36 fb-1)	D. Sengupta	To appear	📖 PDF	v1.6/Delphes3
📖 CMS-SUS-17-001	Stops in the OS dilepton mode (35.9 fb-1)	S.-M. Choi, S. Jeong, D.-W. Kang, J. Li et al.	📖 Inspire	📖 PDF	v1.6/Delphes3
📖 CMS-EXO-16-010	Mono-Z-boson (2.3 fb-1)	B. Fuks	📖 Inspire	To appear	v1.6/Delphes3
📖 CMS-EXO-16-012	Mono-Higgs (2.3 fb-1)	S. Ahn, J. Park, W. Zhang	📖 Inspire	📖 PDF	v1.6/Delphes3
📖 CMS-EXO-16-022	Long-lived leptons (2.6 fb-1)	J. Chang	📖 Inspire	📖 PDF	v1.6_tracks/Delphes3 [1]

- 📖 Delphes card for CMS-EXO-16-010 and CMS-SUS-17-001
- 📖 Delphes card for CMS-EXO-16-012
- 📖 Delphes card for CMS-SUS-16-041
- 📖 Delphes card for CMS-SUS-16-052

[1] This analysis requires this 📖 Delphes card, to be used with a special version of MadAnalysis 5 (📖 this version of the code)

- 📖 + Many **more analyses** implementation/validation ongoing
- 📖 For each analysis implemented, there is a **detailed validation** note

- Search for associated production of $DM+H(\rightarrow \gamma\gamma/b\bar{b})$.
- Interpreted within a $Z' - 2HDM$
- Recasted during the [workshop](#) “The first MadAnalysis 5 workshop on LHC recasting Korea”



- Only $\gamma\gamma$ analysis implemented (cut-based), lack of publicly available information to implement the $b\bar{b}$ channel.
- Signature is quite generic in scalar extensions of the SM, the recasting could enable [more reinterpretations](#).

Events are selected if

- $\gamma\gamma$ pair satisfies given $m_{\gamma\gamma}$ and p_T
- Selection on $p_T(\gamma_i)/m_{\gamma\gamma}$, $p_{T,\gamma\gamma}$, E_T^{miss} and $|\Delta\phi(\gamma\gamma, \mathbf{p}_T^{\text{miss}})|$

Variable	Barrel Selection	Endcap Selection
H/E		<0.1
Iso_{ch} [GeV]	< 3.32	< 1.97
Iso_{Neu} [GeV]	$< 1.92 + 0.14p_T + 0.000019(p_T)^2$	$< 11.86 + 0.0139p_T + 0.000025(p_T)^2$
Iso_{γ} [GeV]	$< 0.81 + 0.0053p_T$	$< 0.83 + 0.0034p_T$

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- ▶ $p_T(\gamma_1) > 30$ GeV & $p_T(\gamma_2) > 18$ GeV
- ▶ $m_{\gamma\gamma} > 95$ GeV
- ▶ $p_T\gamma_1/m_{\gamma\gamma}$ & $p_T\gamma_2/m_{\gamma\gamma} > 0.25$
- ▶ $p_T\gamma\gamma > 90$ GeV & $E_T^{\text{miss}} > 105$ GeV
- ▶ $|\Delta\phi(\gamma\gamma, \mathbf{p}_T^{\text{miss}})| > 2.1$ & $\min(|\Delta\phi(j, \mathbf{p}_T^{\text{miss}})|) > 0.5$
- ▶ Final SR defined as $120 < m_{\gamma\gamma} < 130$ GeV

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m_{Z_p} (GeV)	Acceptance \times efficiency ($A \cdot \epsilon$)		
	CMS EXO-16-012	MA5	Error
600	0.317 ± 0.004	0.317 ± 0.001	0 %
800	0.399 ± 0.004	0.410 ± 0.001	-2.8 %
1000	0.444 ± 0.004	0.441 ± 0.001	0.6 %
1200	0.474 ± 0.004	0.343 ± 0.001	27.6 %
1400	0.492 ± 0.004	0.221 ± 0.001	55.1 %
1700	0.493 ± 0.004	0.129 ± 0.0004	73.8 %
2000	0.351 ± 0.004	0.082 ± 0.0002	76.4 %
2500	0.213 ± 0.004	0.046 ± 0.0001	78.4 %

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800	0.399 ± 0.004	0.451 ± 0.001	-13 %
1000	0.444 ± 0.004	0.494 ± 0.001	-8.2 %
1200	0.474 ± 0.004	0.513 ± 0.001	-0.6 %
1400	0.492 ± 0.004	0.515 ± 0.001	-4.7 %
1700	0.493 ± 0.004	0.494 ± 0.001	-0.2 %
2000	0.351 ± 0.004	0.355 ± 0.001	-1.1 %
2500	0.213 ± 0.004	0.208 ± 0.001	2.3 %

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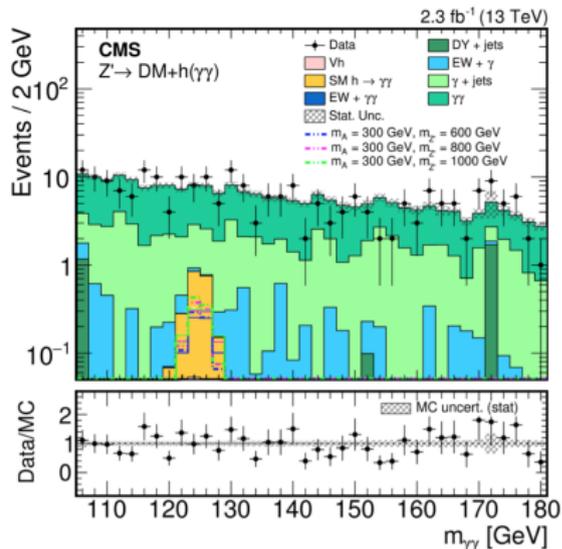
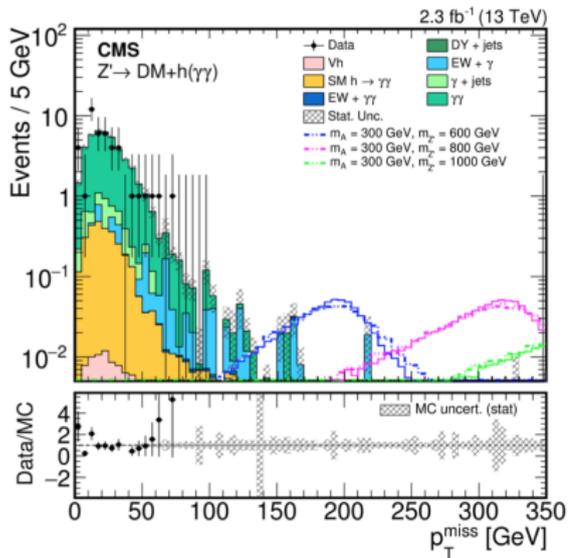
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1400	0.492 ± 0.004	0.515 ± 0.001	-4.7 %
1700	0.493 ± 0.004	0.494 ± 0.001	-0.2 %
2000	0.351 ± 0.004	0.355 ± 0.001	-1.1 %
2500	0.213 ± 0.004	0.208 ± 0.001	2.3 %

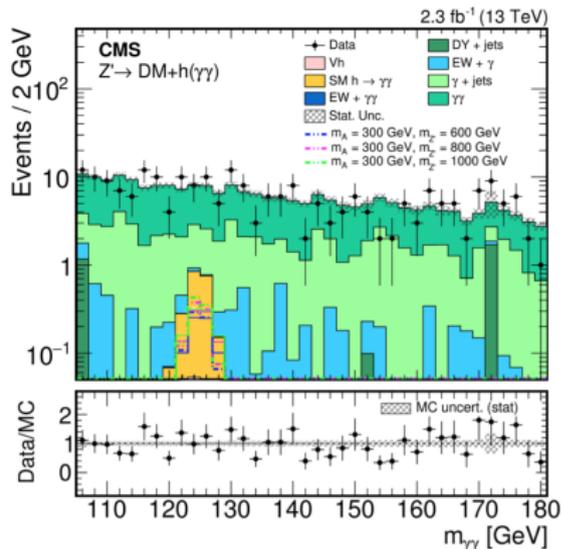
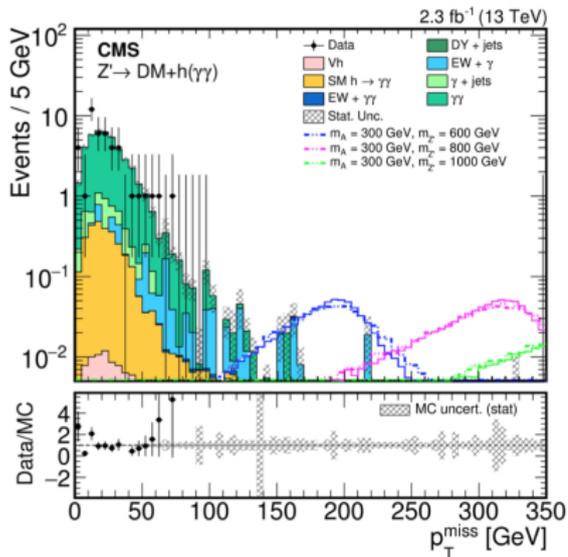
- ☞ Without a detailed cutflow **difficult to track** the source of the discrepancy
- ☞ Fortunately team had close contact within CMS, **problem solved** by setting, at the reconstructed level, the photon isolation cone at $\Delta R = 0.3$
- ☞ Excellent agreement !

- ▶ Unfortunately **no cutflow available**, but an acceptance \times efficiency table instead

m_{Z_p} (GeV)	Acceptance \times efficiency ($A \cdot \epsilon$)		
	CMS EXO-16-012	MA5	Difference
600	0.317 ± 0.004	0.355 ± 0.001	-11 %
800	0.399 ± 0.004	0.451 ± 0.001	-13 %
1000	0.444 ± 0.004	0.494 ± 0.001	-8.2 %
1200	0.474 ± 0.004	0.513 ± 0.001	-0.6 %
1400	0.492 ± 0.004	0.515 ± 0.001	-4.7 %
1700	0.493 ± 0.004	0.494 ± 0.001	-0.2 %
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- ☞ Fortunately team had close contact within CMS, **problem solved** by setting, at the reconstructed level, the photon isolation cone at $\Delta R = 0.3$
- ☞ Excellent agreement !
- ☞ Still for reinterpretation studies a more detailed cutflow **is desirable**, in particular *viz* preselection





Very Good Agreement ⇒ Analysis validated

- ☞ To be fair this wishlist **has decreased** in size over the years
- ☞ Great efforts from exp. collaboration to make **more and more material available** (see Talks of ATLAS and CMS on Monday)
- ☞ Especially regarding the SUSY analyses, if **EXO analyses could reach the same level of details**(SLHA files, cutflows, etc...) there would be even less to say

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-
- ☞ **Clear definitions of objects** (most difficult part for the recasting) ex: b-tagging algorithm, leptons efficiencies $f(p_T, \eta)$
 - ☞ **Well-defined** and **relevant** benchmarks
 - ☞ MC cards to generate the benchmarks
 - ☞ **Generalise** “additional ressources”: covariance matrices, code snippets, simplified likelihoods, aggregate SRs, BDTs
 - ☞ Make info available on HepData

NEWS

- ☞ MadAnalysis 1.6 is out
- ☞ Fully interfaced with MG_aMC@NLO
- ☞ Normal mode can handle Signal regions
- ☞ Improving the MA5 tune of Delphes to handle displaced leptons

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A RECASTING TOOL

- ☞ Recasted Analyses are stored on the Public Analysis Database (12 at 13 TeV, 18 at 8 TeV)
- ☞ All the recasted analyses can be applied on a given signal to determine if it is excluded or not
- ☞ Perform a phenomenological analysis
- ☞ If you recast your own analysis using MA5, you are welcomed to enrich the PAD by your contribution (each analysis gets a DOI)