Towards a first combination: correlations and first attempts

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Workshop on top quark mass measurements

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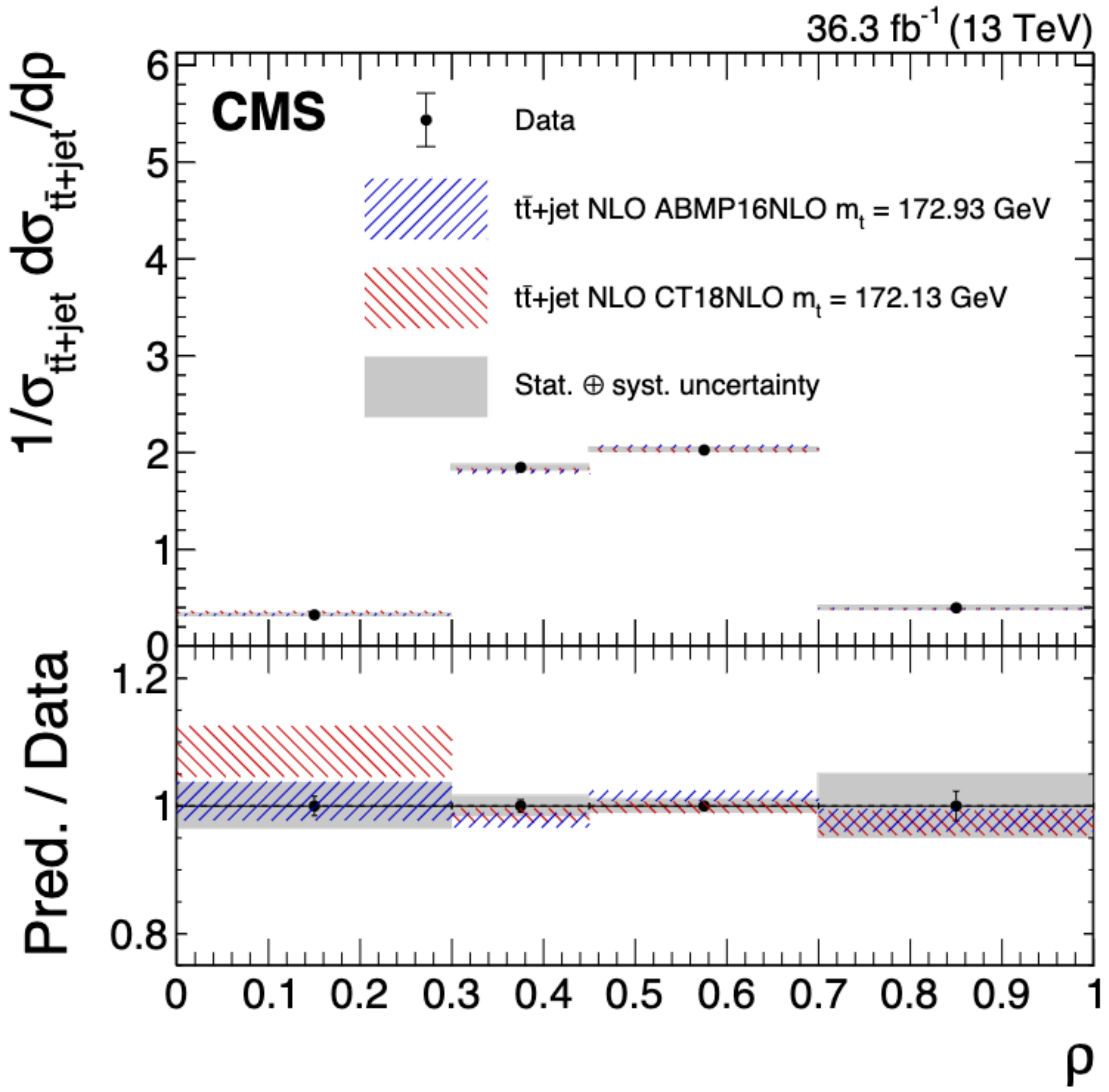
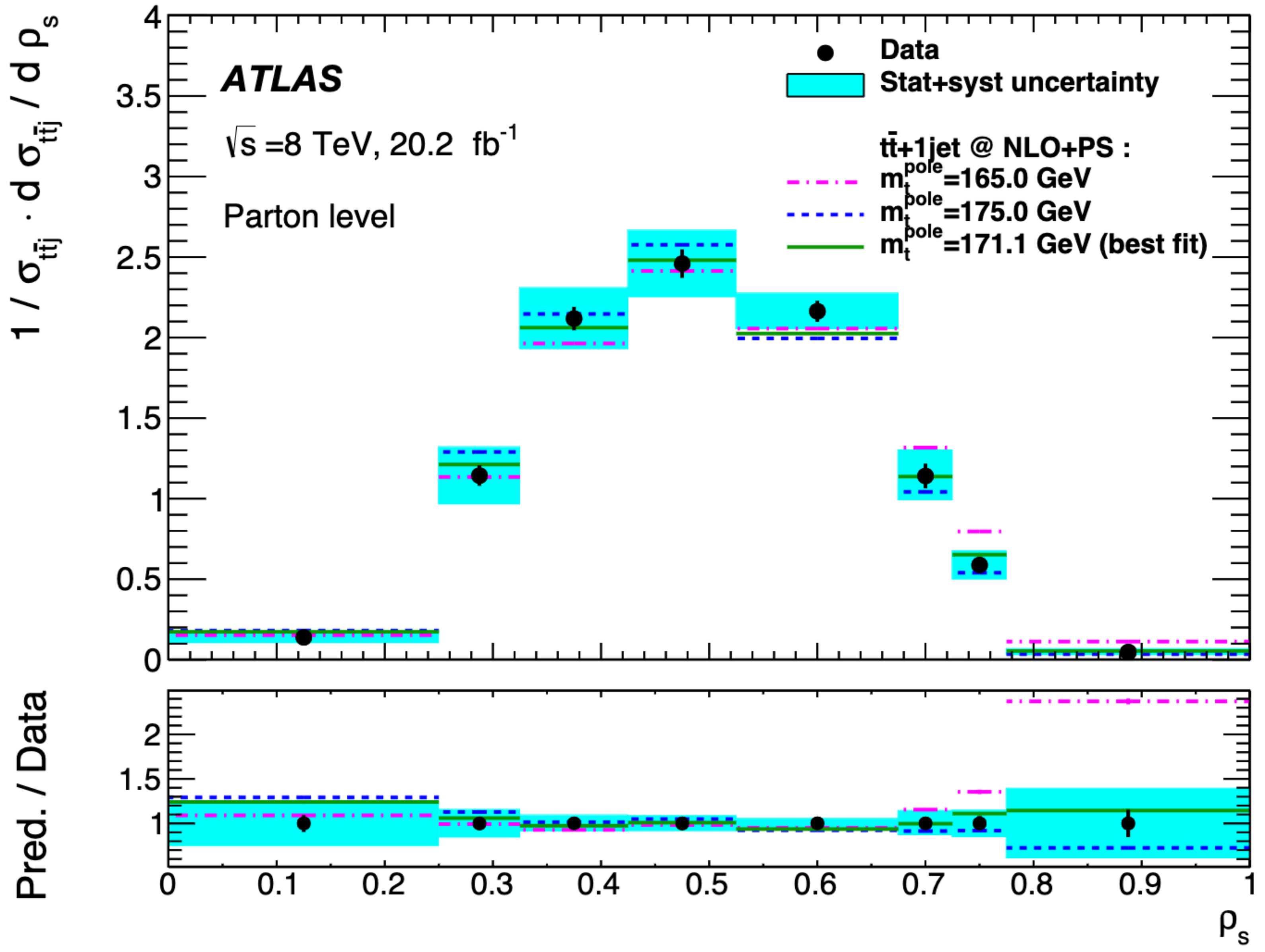
Introduction

- Based on discussion at workshop in Valencia <u>last year</u>:
  - Combination of ATLAS 8 TeV + CMS 13 TeV measurements
    - As exercise and a proof-of-principle study
  - Possible issues:
    - Different binning in ρ (4 vs. 8 bins)
    - Different CME (8 vs 13 TeV)
    - Different object definition (add. Jet p_T: 50 vs. 30 GeV)
    - Different theoretical prediction (fixed vs. dyn. scale)
    - Combination at mass level is unfeasible
  - Make a combined extraction using the same predictions for 8 and 13 TeV
    - Needs a combined cross section





Combining the differential cross section?

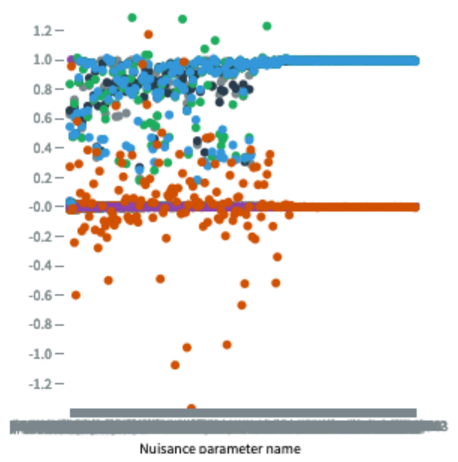
- Same problems here: binning, ρ definition, CME, …
- But, we can correlate the uncertainties and get two "combined" distributions
  - Means introducing 4+8 POIs in the combination
  - Needs ideally a full uncertainty breakdown
- CMS cross section based on likelihood unfolding:
  - Has nuisance parameters with correlations (constraints/pulls)
  - Provides the full covariance matrix, pulls, constraints, impacts, correlations, prefit and post fit on HEPData (link)
  - Only for the absolute cross section
- ATLAS result based on bin-by-bin unfolding:
  - Auxiliary material only provides total normalised cov. matrix
  - No HEPData entry…

Showing 50 of 234 values

Show All 234 values

Nuisance parameter name	fit_obs_central	fit_obs_up	fit_obs_down	fit_exp_central	fit_exp_up	fit_exp_d
JESFlavorPureGluon	0.272689	0.545318	0.834019	0.0	0.654728	0.628291
rateTT0Jet	0.955	0.027	0.027	1.0	0.03	0.029
ELE_ID	-0.010569	0.486365	0.475508	0.0	0.484463	0.477583
PSSCALE_WEIGHT_4	-0.243075	0.611843	0.70161	0.0	0.674193	0.728531
MASS	-0.6	0.5	0.6	0.0	0.5	0.6
TOP_PT	0.580362	0.638779	1.012356	0.0	0.633722	0.994527
TRIG_EMU2016	0.292021	0.878101	0.84795	0.0	0.849682	0.852957
lumi2016	0.093503	0.991703	0.991818	0.0	0.991985	0.99199
JetPileupIDMistag	-0.16402	0.549315	0.469429	0.0	0.566893	0.534907
PSSCALE_WEIGHT_5	0.02686	0.641926	0.934649	0.0	0.600224	0.814537

Visualize



Sum errors ☑ Log Scale (Y) ☐

Deselect variables or hide different error bars by clicking on them.

Variables

fit_obs_central

fit_obs_up

fit_obs_down

fit_exp_central

ρ_s range	0.000 - 0.250	0.250 - 0.325	0.325 - 0.425	0.425 - 0.525	0.525 - 0.675	0.675 - 0.725	0.725 - 0.775	0.775 - 1.000
0.000 – 0.250	331.4	−187.6	95.9	30.8	−62.5	−3.7	−10.6	−5.4
0.250 – 0.325	−187.6	1278.6	−569.8	242.9	−66.9	−62.5	39.5	34.8
0.325 – 0.425	95.9	−569.8	2966.9	−1080.7	101.0	177.7	−3.4	−26.2
0.425 – 0.525	30.8	242.9	−1080.7	4737.8	−1082.2	−210.4	63.5	81.9
0.525 – 0.675	−62.5	−66.9	101.0	−1082.2	4286.1	−301.3	−248.7	−98.0
0.675 – 0.725	−3.7	−62.5	177.7	−210.4	−301.3	940.1	95.9	−75.8
0.725 – 0.775	−10.6	39.5	−3.4	63.5	−248.7	95.9	192.9	45.3
0.775 – 1.000	−5.4	34.8	−26.2	81.9	−98.0	−75.8	45.3	123.0

Combining the differential cross section?

- Davide managed to recover old files from old hard disks:
  - All uncertainties and their impact on the normalised cross section
  - No information about the absolute one…
  - → We have to combine CMS absolute + ATLAS normalised

- Andrej produced consistent 8 + 13 TeV predictions
  - PDF4LHC, NNPDF31, CT18, MHSTW, ABMP PDFs + uncertainties/mass variations

- We cannot use BLUE, but can try Convino (Eur. Phys. J. C (2017) 77: 792)
  - Aims to recover the full likelihood
  - Can be fed with externalised uncertainties (ATLAS) or nuisance parameters (CMS)
  - Offers also automated correlation scans

A method and tool for combining differential or inclusive measurements obtained with simultaneously constrained uncertainties

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August 2, 2018

Setting things up

- For CMS, straightforward:
  - Load HEPData entry
  - Read in all nuisances + POIs with their constraint & correlation
  - Read in externalised extrapolation uncertainties (for all modeling NPs)
  - Write in confine config file (232 nuisances)

```

[correlation matrix]

CMS_modelling_ttbar_bfrag (0.7250135)   1.0
CMS_modelling_ttbar_bfragPythiaDefault (1.024237)   -0.193875   1.0
CMS_modelling_ttbar_bfragPeterson (0.6336765)   -7.4e-05   0.000802   1.0
CMS_modelling_ttbar_bsemilep (0.9242395)   0.018051   0.024073   0.001167   1.0
CMS_eff_b_heavy_jes (0.850888)   0.09555   0.101324   -0.002341   0.021702   1.0
CMS_eff_b_light_corr (0.857371)   -0.101167   -0.111678   0.001681   0.027412   -0.107059   1.0
```

- We can validate the CMS only "combination":
  - Only write CMS inputs
  - Combine the single result, i.e., let Convino build the likelihood
  - Run a mass extraction on the "combined" result
    - (More in Matteo's talk)
  - Spoiler: Good closure, configuration works

NB: Only issue are the extrapolation uncertainties, as they are combined on HEPData (i.e. the total covariance). Breakdown and correlation found to have no impact.

Setting things up

- For ATLAS, it's a bit more complicated:
  - Information for all 8 bins, although they are normalised…
  - Information needs to be converted into the Hessian
  - In total 122 uncertainties
  - Took some turn-arounds and attempts
    - Testing also removal of one bin
    - Also here, closure on extracted mass

```
[not fitted]
            ATLAS_eff_b_heavy_0 ATLAS_eff_b_heavy_1 ATLAS_eff_b_heavy_2 ATLAS_eff_b_heavy_3 A
        ATLAS_8TeV_2012_lj_norm_rho_0p0_0p25 3.817555325278207e-06 0.0006477653143377159 -0.00
        ATLAS_8TeV_2012_lj_norm_rho_0p25_0p325 -2.2020042074734477e-05 0.004478452515645536 -0
        ATLAS_8TeV_2012_lj_norm_rho_0p325_0p425 0.0004864239347182167 0.00714938560903131 -0.0
        ATLAS_8TeV_2012_lj_norm_rho_0p425_0p525 0.0006381599932943271 0.0031021534418115464 -0
        ATLAS_8TeV_2012_lj_norm_rho_0p525_0p675 -0.00045404306666592105 -0.0030612333560344203
        ATLAS_8TeV_2012_lj_norm_rho_0p675_0p725 -0.0005114583414261896 -0.005747087558732558 0
        ATLAS_8TeV_2012_lj_norm_rho_0p725_0p775 -0.0007093541345618208 -0.004269607109111639 0
        ATLAS_8TeV_2012_lj_norm_rho_0p775_1p0 2.8932311061774087e-05 -0.0005246052725346005 -3
[end not fitted]
```

Combining the results

- I'll leave the interpretation and extraction to Matteo, but:
  - We combined the results without correlations (noCorr)
  - We correlated only the jet energy scale uncertainties (JES)
  - We correlated in addition modeling uncertainties
  - And we correlated the tt+0jet normalisation (CMS) with ATLAS modeling uncertainties

- How did we decide on the correlations?
  - Work was already done: Run 1 direct top quark mass combination
  - We didn't change the important uncertainty prescription (CMS)
  - ATLAS input is Run 1 result
  - → Fully applicable for JES and modeling

Correlation assumptions: JES

- Looking at TOPLHC NOTE: link

Description	Components, CMS	Components, ATLAS	Corr. range
1a. Statistical *in situ* terms	AbsoluteStat, SinglePionHCAL, RelativeStat[FSR][EC2][HF]	[11] **Z**-jet balance `stat./meth.` terms (p_T), [13] γ-jet balance `stat./meth.` terms (p_T), [10] multi-jet balance `stat./meth.` terms (p_T), η-intercalibration statistical term (p_T,η)	0%
1b. Detector *in situ* terms	AbsoluteScale, SinglePionECAL, RelativeJER[EC1][EC2][HF], RelativePt[BB][EC1][EC2][HF]	**Z**-jet balance `det.` term, γ-jet balance `det.` term, [2] correlated **Z**/γ-jet balance `det.` terms (p_T)	0%
2. Absolute balance modeling	AbsoluteMPFBias	[7] **Z**-jet balance `model` + `mixed` terms (p_T), [4] γ-jet balance `model` + `mixed` terms (p_T), [2] correlated **Z**/γ-jet balance terms (p_T), [5] multi-jet balance `model` + `mixed` terms (p_T)	0-50%
3. Relative balance modeling	RelativeFSR	η-intercalibration modeling (p_T,η)	50-100%
4. *g*-jet fragmentation	FlavorPureGluon	Flavor response (p_T,η)	100%
5. *b*-jet fragmentation	FlavorPureBottom	*b*-jet response (p_T)	50-100%
6. Other fragmentation types	FlavorPureQuark, FlavorPureCharm	Flavor composition (p_T,η)	0%
7. Pileup	PileupDataMC, PileupPt[Ref][BB][EC1][EC2][HF]	N_{PV} offset (p_T,η,N_{PV}), $\langle\mu\rangle$ offset (p_T,η,$\langle\mu\rangle$), p_T term (p_T,η,N_{PV},$\langle\mu\rangle$), ρ topology (p_T,η)	0%
8. High-p_T	Fragmentation	High-p_T (p_T)	0%
9. Single-experiment terms	TimeEta, TimePt	Fast simulation closure (p_T,η), punch-through (p_T,η,$N_{segments}$)	0%

Table 4: The range of correlation coefficients to be used for each individual ATLAS and CMS JES uncertainty source and component grouping when combining measurements between the experiments. The variables used to parametrize each ATLAS uncertainty component are listed in parentheses. If more than one ATLAS uncertainty component matches a given classification, the corresponding number is listed at the start in square brackets. The variable named $N_{segments}$ is the number of segments in the muon system behind the jet, as described in Ref. [10].

Implement it one to one:

```
# Obvious ones from the JES mapping
ATLAS_scale_b = (0.75)  CMS_scale_j_flavorBottom
ATLAS_scale_j_flavorresponse = (0.9)  CMS_scale_j_flavorGluon
ATLAS_scale_j_EtaIntercalibrationModel = (0.75)  CMS_scale_j_relativeFSR
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix1
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix2
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix3
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Mix4
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model1
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model2
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model3
CMS_scale_j_absoluteMPFBias = (0.25)  ATLAS_scale_j_Model4
```

Correlation assumptions: modeling

- Looking at analysis note of Run 1 combination: link

- LHC Had: CMS b fragmentation and ATLAS Herwig vs Pythia

LHC HAD This term includes uncertainties associated with hadronisation. As discussed in Section 3, there are significant differences between ATLAS and CMS in the way the uncertainty is evaluated. The category is therefore treated as partially correlated (0.5).

- LHC Rad: ATLAS envelope of scales, hdamp, ISR/FSR
  CMS split of the same uncertainties

LHC RAD This term includes uncertainties in the amount of extra QCD radiation in $t\bar{t}$ events. As the nominal MC setups are different between ATLAS and CMS, the category is treated as partially correlated (0.5).

- Color reconnection and UE: ATLAS sum, CMS breakdown

Color reconnection and underlying event For both these categories, ATLAS and CMS rely on simulated event samples. The nominal tunes differ between the experiments and the variations, while similar as discussed in Section 3 are not identical, and hence these categories are assumed to be partially correlated between ATLAS and CMS.

Implement it similarly:

```
# Other ones taken from the Run 1 mass combination
CMS_modelling_ttbar_bfrag = (0.50) ATLAS_modelling_ttbar_ShowerHadronization
CMS_modelling_ttbar_bfragPythiaDefault = (0.50) ATLAS_modelling_ttbar_ShowerHadronization
CMS_modelling_ttbar_bfragPeterson = (0.50) ATLAS_modelling_ttbar_ShowerHadronization
CMS_modelling_ttbar_erdOn = (0.50) ATLAS_modelling_ttbar_ColorReconnection
CMS_modelling_ttbar_tuneQCD  = (0.50) ATLAS_modelling_ttbar_ColorReconnection
CMS_modelling_ttbar_tuneGluon  = (0.50) ATLAS_modelling_ttbar_ColorReconnection
CMS_modelling_ttbar_hdamp = (0.50) ATLAS_modelling_ttbar_Radiation
CMS_modelling_ttbar_isr = (0.50) ATLAS_modelling_ttbar_Radiation
CMS_modelling_ttbar_fsr = (0.50) ATLAS_modelling_ttbar_Radiation
CMS_modelling_ttbar_tune = (0.50) ATLAS_modelling_ttbar_UnderlyingEvent
```

Correlation assumptions

- Numbers taken from final table
  - Correlation scans need to be done

Uncertainty category	ρ	Scan range	$\Delta m_t/2$ [MeV]	$\Delta\sigma_{m_t}/2$ [MeV]
LHC JES 1	0	—	—	—
LHC JES 2	0	$[-0.25, +0.25]$	8	7
LHC JES 3	0.5	$[+0.25, +0.75]$	1	<1
LHC b-JES	0.85	$[+0.5, +1]$	26	5
LHC g-JES	0.85	$[+0.5, +1]$	2	<1
LHC l-JES	0	$[-0.25, +0.25]$	1	<1
CMS JES 1	—	—	—	—
JER	0	$[-0.25, +0.25]$	5	1
Leptons	0	$[-0.25, +0.25]$	2	2
b tagging	0.5	$[+0.25, +0.75]$	1	1
p_T^{miss}	0	$[-0.25, +0.25]$	<1	<1
Pileup	0.85	$[+0.5, +1]$	2	<1
Trigger	0	$[-0.25, +0.25]$	<1	<1
ME generator	0.5	$[+0.25, +0.75]$	<1	4
LHC radiation	0.5	$[+0.25, +0.75]$	7	1
LHC hadronization	0.5	$[+0.25, +0.75]$	1	<1
CMS B hadron BR	—	—	—	—
Color reconnection	0.5	$[+0.25, +0.75]$	3	1
Underlying event	0.5	$[+0.25, +0.75]$	1	<1
PDF	0.85	$[+0.5, +1]$	1	<1
Top quark p_T	—	—	—	—
Background (data)	0	$[-0.25, +0.25]$	8	2
Background (MC)	0.85	$[+0.5, +1]$	2	<1
Method	0	—	—	—
Other	0	—	—	—

Correlation assumptions

Mass scheme	m_t^{pole} [GeV]	$m_t(m_t)$ [GeV]
Value	**171.1**	**162.9**
Statistical uncertainty	**0.4**	**0.5**
Simulation uncertainties		
Shower and hadronisation	0.4	0.3
Colour reconnection	0.4	0.4
Underlying event	0.3	0.2
Signal Monte Carlo generator	0.2	0.2
Proton PDF	0.2	0.2
Initial- and final-state radiation	0.2	0.2
Monte Carlo statistics	0.2	0.2
Background	<0.1	<0.1
Detector response uncertainties		
Jet energy scale (including *b*-jets)	0.4	0.4
Jet energy resolution	0.2	0.2
Missing transverse momentum	0.1	0.1
b-tagging efficiency and mistag	0.1	0.1
Jet reconstruction efficiency	<0.1	<0.1
Lepton	<0.1	<0.1
Method uncertainties		
Unfolding modelling	0.2	0.2
Fit parameterisation	0.2	0.2
Total experimental systematic	**0.9**	**1.0**
Scale variations	(+0.6, −0.2)	(+2.1, −1.2)
Theory PDF⊕α_s	0.2	0.4
Total theory uncertainty	**(+0.7, −0.3)**	**(+2.1, −1.2)**
Total uncertainty	**(+1.2, −1.1)**	**(+2.3, −1.6)**

Uncertainty Source	$\Delta\sigma^1_{t\bar{t}+jet}$ [%]	$\Delta\sigma^2_{t\bar{t}+jet}$ [%]	$\Delta\sigma^3_{t\bar{t}+jet}$ [%]	$\Delta\sigma^4_{t\bar{t}+jet}$ [%]
Experimental				
Muon identification	1.8	1.5	1.5	1.4
Muon energy scale and resolution	0.7	0.2	0.3	0.5
Electron identification	2.0	1.7	1.7	2.1
Electron energy scale and resolution	0.9	1.0	0.9	1.5
Jet energy scale	2.6	2.0	2.2	3.6
Jet energy resolution	0.6	0.5	0.5	0.4
Jet identification	1.1	0.8	0.8	1.3
p_T^{miss}	0.2	0.3	0.4	0.8
b jet identification	1.0	0.7	0.6	1.2
Trigger efficiency	1.8	1.2	1.1	1.8
Total	4.0	3.1	3.1	4.7
Background normalization				
$t\bar{t}$+0 jet	2.2	2.0	1.7	0.7
Z+jets	2.4	1.9	1.7	2.6
Single top quark	0.9	0.8	0.7	0.1
Total	3.1	2.5	2.4	2.7
Modeling				
Z+jets ME scale	0.7	0.4	0.2	0.3
Single top quark ME/FSR/ISR scales	1.2	0.6	0.4	0.1
$t\bar{t}$ PDF	0.1	0.1	0.1	0.6
$t\bar{t}$ ME scale	1.0	0.5	0.6	0.4
$t\bar{t}$ ISR scale	1.2	0.8	0.6	1.6
$t\bar{t}$ FSR scale	1.3	0.8	0.6	1.7
$t\bar{t}$ top quark p_T	2.0	1.3	0.1	1.2
b fragmentation	0.9	0.7	0.8	0.8
Color reconnection	0.5	0.6	0.2	0.7
$t\bar{t}$ matching scale	0.6	0.5	0.6	≤0.1
Underlying-event tune	0.2	0.5	0.2	0.5
Total	3.2	1.9	1.8	3.1
Integrated luminosity	1.2	1.4	1.3	1.2
m_t^{MC}	1.7	1.0	0.4	2.3
Finite size of simulated samples	2.0	1.4	1.3	2.2
Total systematic	5.0	3.4	3.2	5.6
Statistical	1.6	1.0	0.8	2.4
Total	5.2	3.6	3.3	6.1

Correlation assumptions

- Numbers taken from final table
  - Correlation scans need to be done

- Expectations:
  - None will really matter, besides
    - b-JES
    - tt0Jet normalization as it has a large impact for the CMS absolute measurement

Uncertainty Source	$\Delta\sigma^1_{t\bar{t}+\text{jet}}$ [%]	$\Delta\sigma^2_{t\bar{t}+\text{jet}}$ [%]	$\Delta\sigma^3_{t\bar{t}+\text{jet}}$ [%]	$\Delta\sigma^4_{t\bar{t}+\text{jet}}$ [%]
Experimental				
Muon identification	1.8	1.5	1.5	1.4
Muon energy scale and resolution	0.7	0.2	0.3	0.5
Electron identification	2.0	1.7	1.7	2.1
Electron energy scale and resolution	0.9	1.0	0.9	1.5
Jet energy scale	2.6	2.0	2.2	3.6
Jet energy resolution	0.6	0.5	0.5	0.4
Jet identification	1.1	0.8	0.8	1.3
p_T^{miss}	0.2	0.3	0.4	0.8
b jet identification	1.0	0.7	0.6	1.2
Trigger efficiency	1.8	1.2	1.1	1.8
Total	4.0	3.1	3.1	4.7
Background normalization				
$t\bar{t}$+0 jet	2.2	2.0	1.7	0.7
Z+jets	2.4	1.9	1.7	2.6
Single top quark	0.9	0.8	0.7	0.1
Total	3.1	2.5	2.4	2.7
Modeling				
Z+jets ME scale	0.7	0.4	0.2	0.3
Single top quark ME/FSR/ISR scales	1.2	0.6	0.4	0.1
$t\bar{t}$ PDF	0.1	0.1	0.1	0.6
$t\bar{t}$ ME scale	1.0	0.5	0.6	0.4
$t\bar{t}$ ISR scale	1.2	0.8	0.6	1.6
$t\bar{t}$ FSR scale	1.3	0.8	0.6	1.7
$t\bar{t}$ top quark p_T	2.0	1.3	0.1	1.2
b fragmentation	0.9	0.7	0.8	0.8
Color reconnection	0.5	0.6	0.2	0.7
$t\bar{t}$ matching scale	0.6	0.5	0.6	$\leq$0.1
Underlying-event tune	0.2	0.5	0.2	0.5
Total	3.2	1.9	1.8	3.1
Integrated luminosity	1.2	1.4	1.3	1.2
m_t^{MC}	1.7	1.0	0.4	2.3
Finite size of simulated samples	2.0	1.4	1.3	2.2
Total systematic	5.0	3.4	3.2	5.6
Statistical	1.6	1.0	0.8	2.4
Total	5.2	3.6	3.3	6.1

Looking at some impacts: no correlation

x-axis: relative impact in % (max. is 25%)

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- As expected, no cross-impacts

Looking at some impacts: JES correlation

x-axis: relative impact in % (max. is 25%)

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- JES and tt model impact the other measurement, although only JES correlated by hand

Looking at some impacts: JES+modeling correlation

x-axis: relative impact in % (max. is 25%)

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- JES and tt model impact the other measurement, although only JES correlated by hand
- b jet efficiency and MC stat pla a role, too

Looking at some impacts: JES+modeling+tt0jet correlation

CMS uncertainties, grouped

ATLAS uncertainties, grouped

- JES and tt model impact the other measurement, although only JES correlated by hand
- b jet efficiency and MC stat pla a role, too
- Explicitly correlated tt0jet makes no difference, entered already before

Conclusion and summary

- First combination attempt of 8 + 13 TeV results successful!
  - ATL:AS normalised + CMS differential
- Results look reasonable:
  - Impacts as expected based on by-hand entered correlations
  - Results seem largely uncorrelated
- Most of the correlations we can take from existing work:
  - Run 1 mass combination for JES + modeling
  - We should run some scans to test the impact of the correlation
- Technical steps implemented, we can run any combination we want
- **How does the extraction look like?**