Measurement of differential production cross section for high-p_T top quarks in proton-proton collisions at 13 TeV

(l+jets & hadronic ttbar decay channels)

Pre-approval presentation

26 March 2019

(hadronic team)

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Documentation

Available on CMS information server

CMS AN -2017/149

The Compact Muon Solenoid Experiment

Analysis Note

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23 May 2017 (v5, 18 March 2019)

Measurement of the top-anti-top differential production cross section in the all-hadronic final state using the 2016 proton-proton collision data at sqrt(s) = 13 TeV.

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Abstract

A measurement is presented of the top-anti-top quark production cross section, in the boosted region of the hadronic decay, differentially, as a function of various kinematic variables. The data correspond to an integrated luminosity of 35.9 fb^{-1} from proton-proton collisions at 13 TeV center-of-mass energy and were collected by the CMS detector during the 2016 LHC run. The results are presented in the fiducial region and unfolded to the particle and parton levels.

CMS PAPER TOP-18-013

DRAFT

CMS Paper

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Archive Id: 492069P
Archive Date: 2019/03/18
Archive Tag: trunk

Measurement of differential $t\bar{t}$ production cross sections for high-p_T top quarks in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$

The CMS Collaboration

Abstract

A measurement of the production cross section of high transverse momentum (p_T) top quark pairs is reported. The dataset was collected during 2016 with the CMS detector at the CERN LHC from proton-proton collisions at a center-of-mass energy of 13 TeV, and corresponds to an integrated luminosity of 35.9 fb^{-1}. The measurement uses events where either both top quark candidates decay hadronically and are reconstructed as large-R jets with $p_T > 400\,\text{GeV}$, or where one top quark decays hadronically and is identified as a single large-R jet with $p_T > 400\,\text{GeV}$ and the other top quark decays leptonically to a b jet, an electron or a muon, and a neutrino. The cross section is extracted differentially as a function of kinematic variables of the top quark or top quark pair system, and the results are presented at the fiducial detector level and unfolded to the particle and parton levels, compared to various theoretical models. The measured cross section is significantly lower, by up to 40%, in the phase space of interest, compared to the theory predictions, while the normalized differential cross sections are consistent between data and theory.

AN-2017/149

TOP-18-013

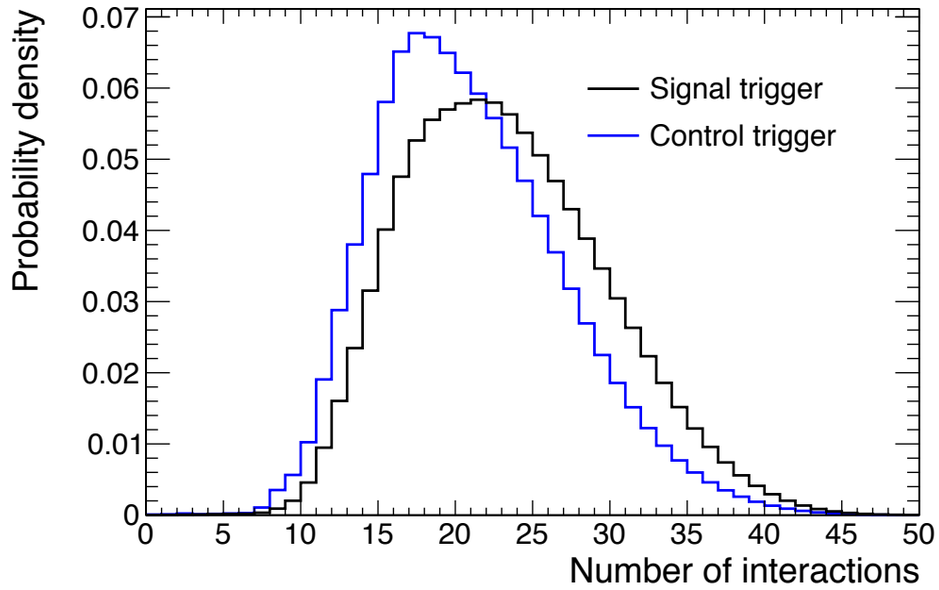
https://twiki.cern.ch/twiki/bin/viewauth/CMS/TOP18013

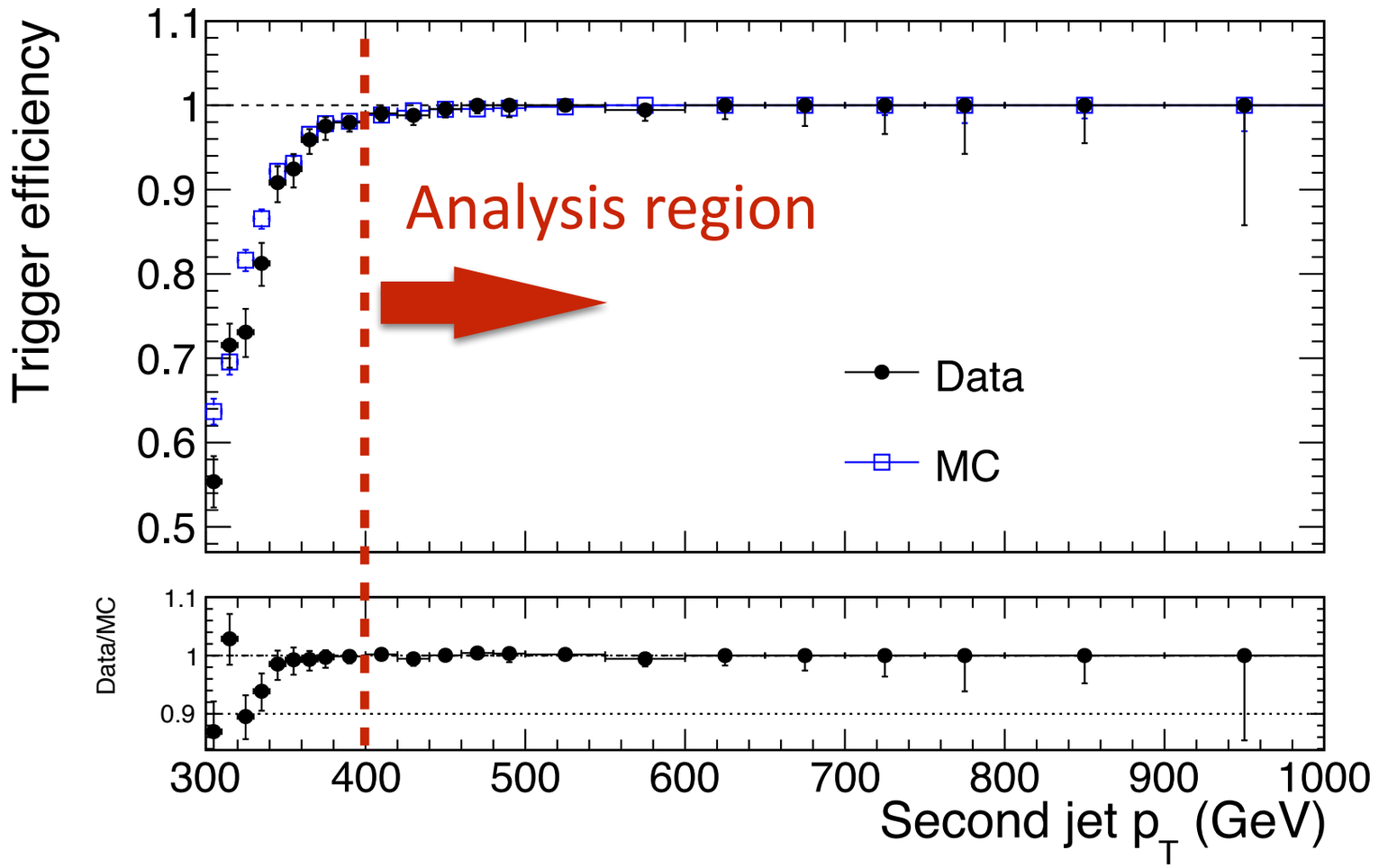
Analysis overview

- **2016 dataset**
  - very well understood (calibrations, scale factors, etc)
  - working on the legacy measurement with full Run II dataset but it will take ~1 year to reach same level of maturity
- **Trigger:** two AK8 jets @ HLT and b tagging
- **Selection**
  - two AK8 jets with $p_T > 400$ GeV
  - "ttbar event tagging" MVA using jet substructure variables as inputs
  - categories based on subjet b tagging
    - 0-btag: control
    - 2-btag: signal
  - Backgrounds
    - QCD dominant: taken from data
    - others (ST, W/Z+jets): negligible
- **Deliverables**
  - differential cross sections
  - five observables: top p_T & η, ttbar system mass, p_T & rapidity
  - fiducial, unfolded to parton level, unfolded to particle level

Trigger

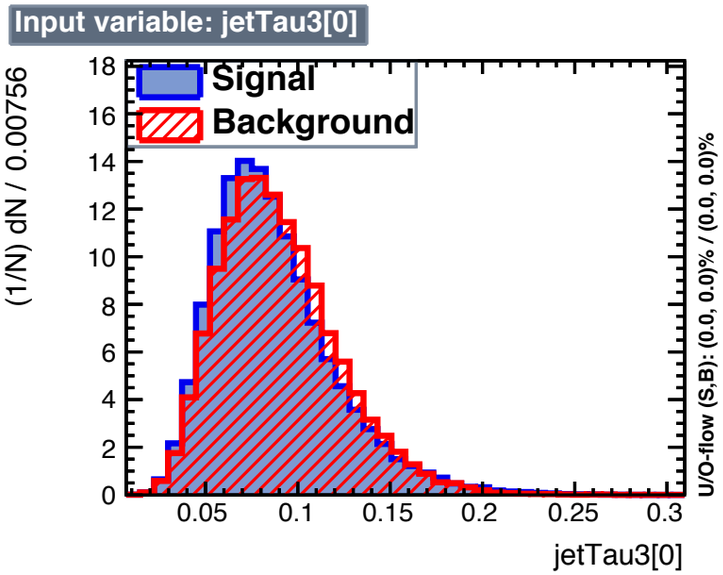
- **Signal path:** HLT_AK8DiPFJet280_200_TrimMass30_BTagCSV_p20
  - unprescaled: 35.9 fb^{-1} luminosity
  - efficiency measured wrt orthogonal muon trigger
- **Control path:** HLT_AK8DiPFJet280_200_TrimMass30
  - same kinematics, no HLT b tagging
  - prescaled: 1.67 fb^{-1} luminosity
  - somewhat lower pileup profile (analysis not sensitive to pileup)

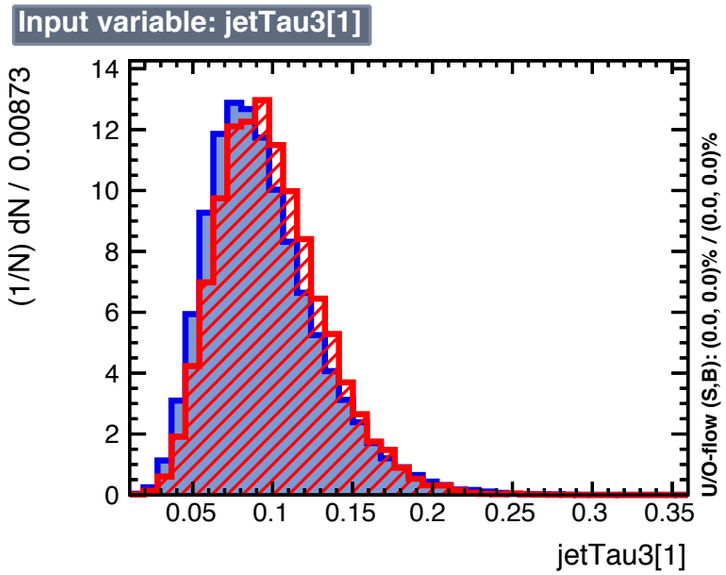


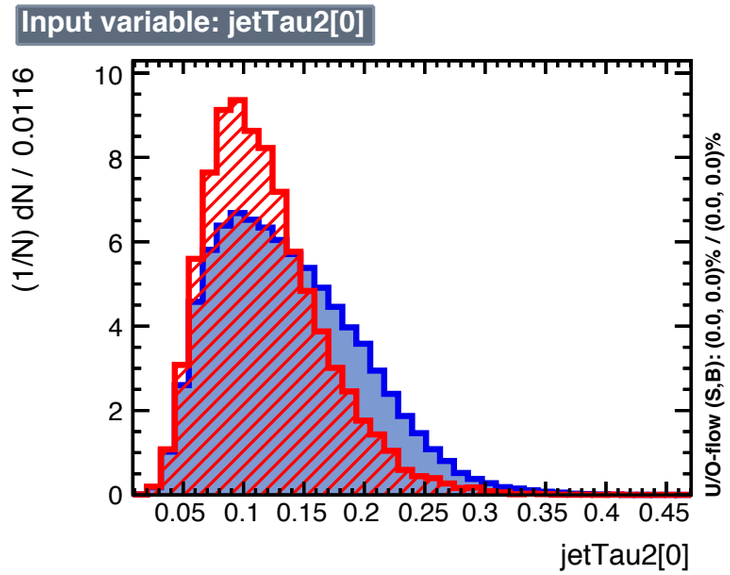


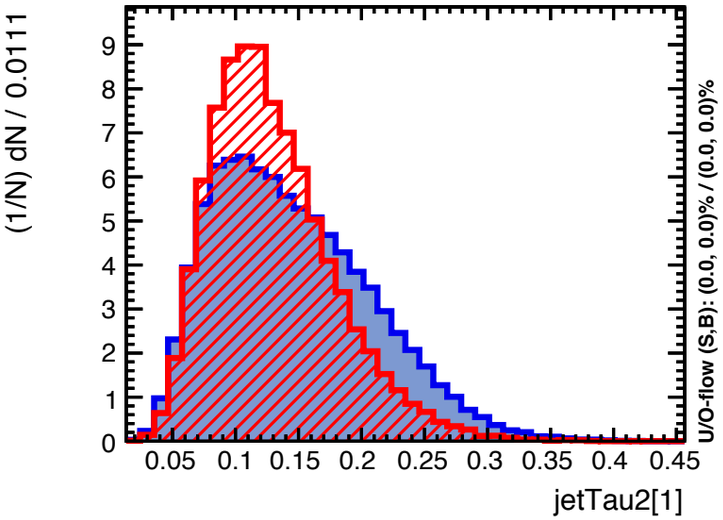
Multivariate discriminant (variables)

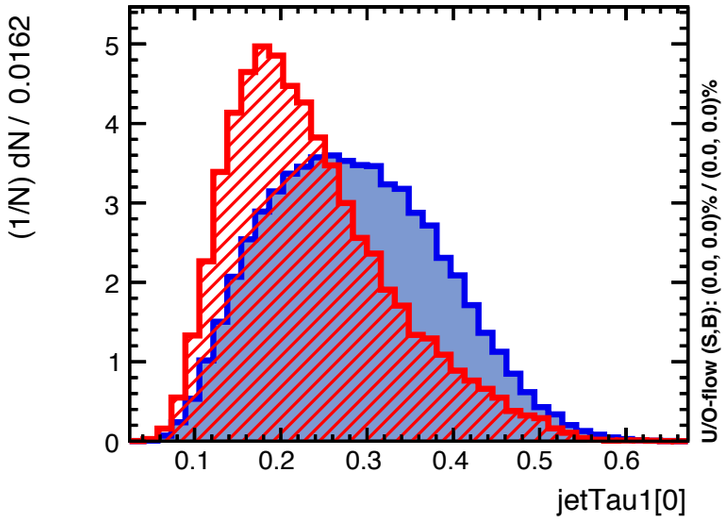
“ttbar tagger”
N-subjettiness $\tau_{1,2,3}$ for both jets

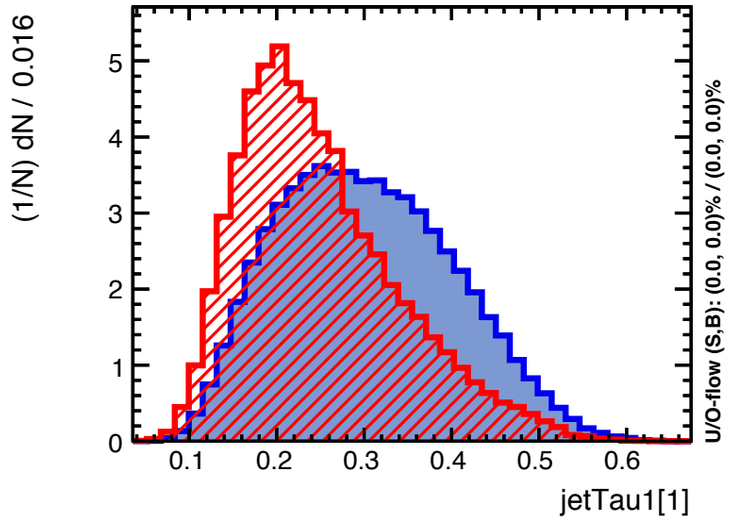




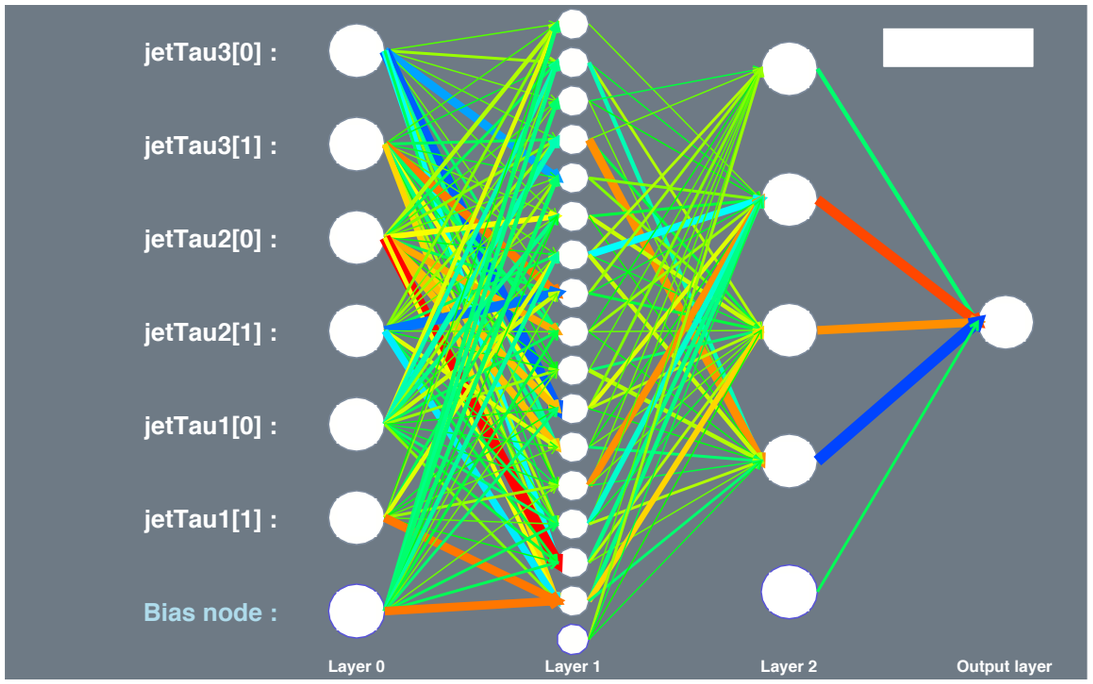




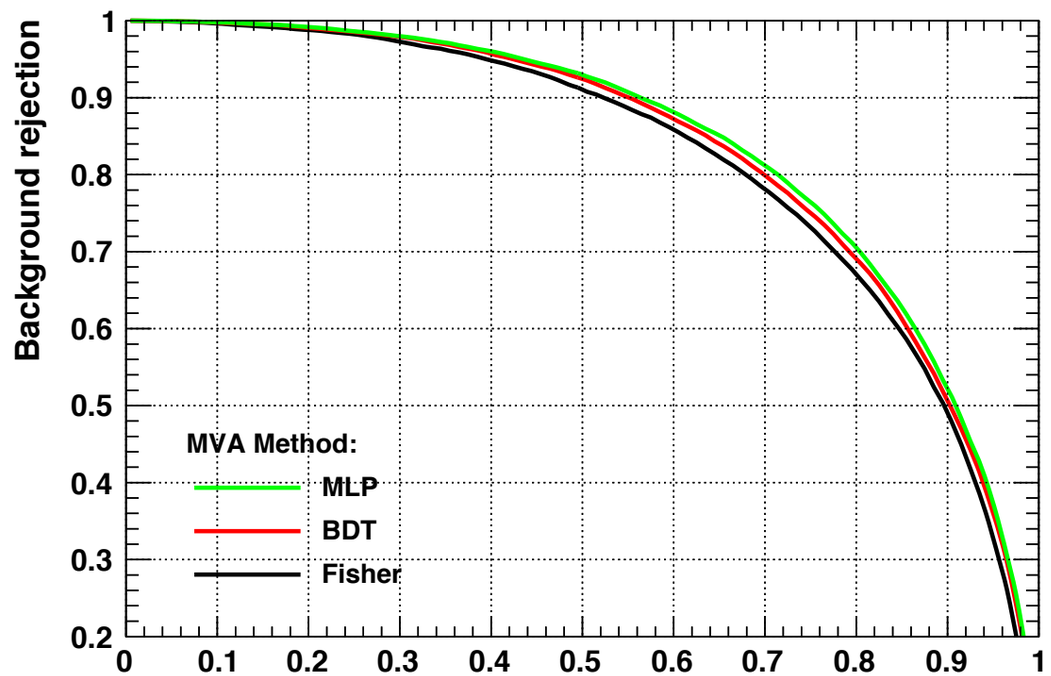




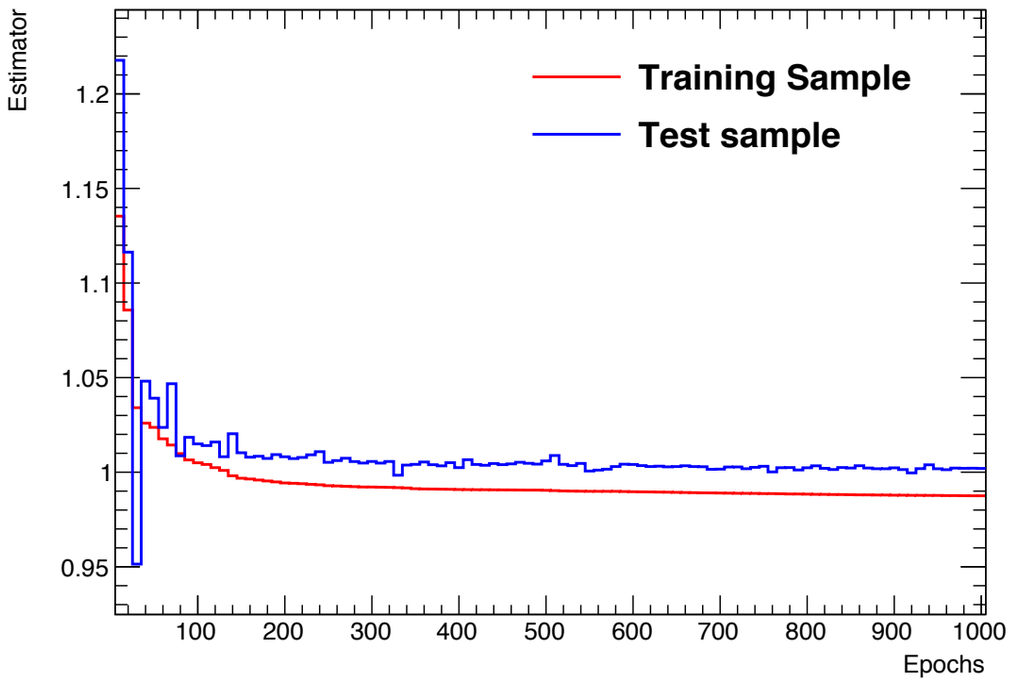
Multivariate discriminant (training)



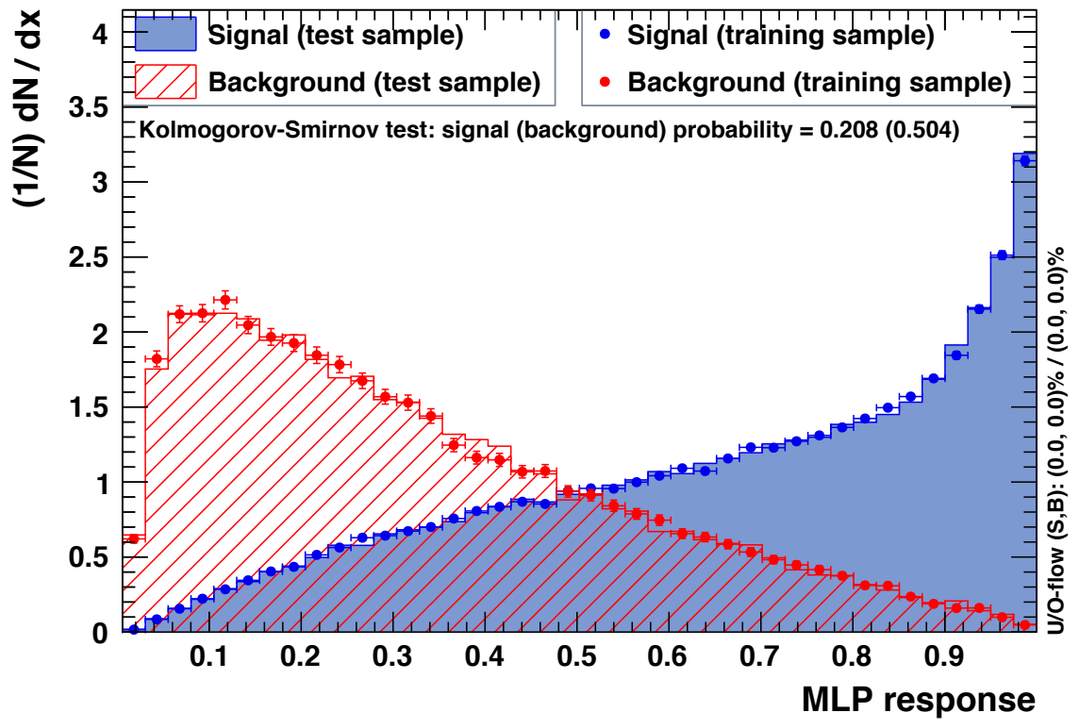
Background rejection versus Signal efficiency



MLP Convergence Test



TMVA overtraining check for classifier: MLP



Selection

Table 1: Baseline selection requirements (hadronic channel).

Observable	Requirement
N_{jets}	> 1
N_{leptons}	$= 0$
$p_{\text{T}}^{1,2}$	$> 400\,\text{GeV}$
$m_{SD}^{1,2}$	50–300 GeV

jets: AK8 PF+CHS

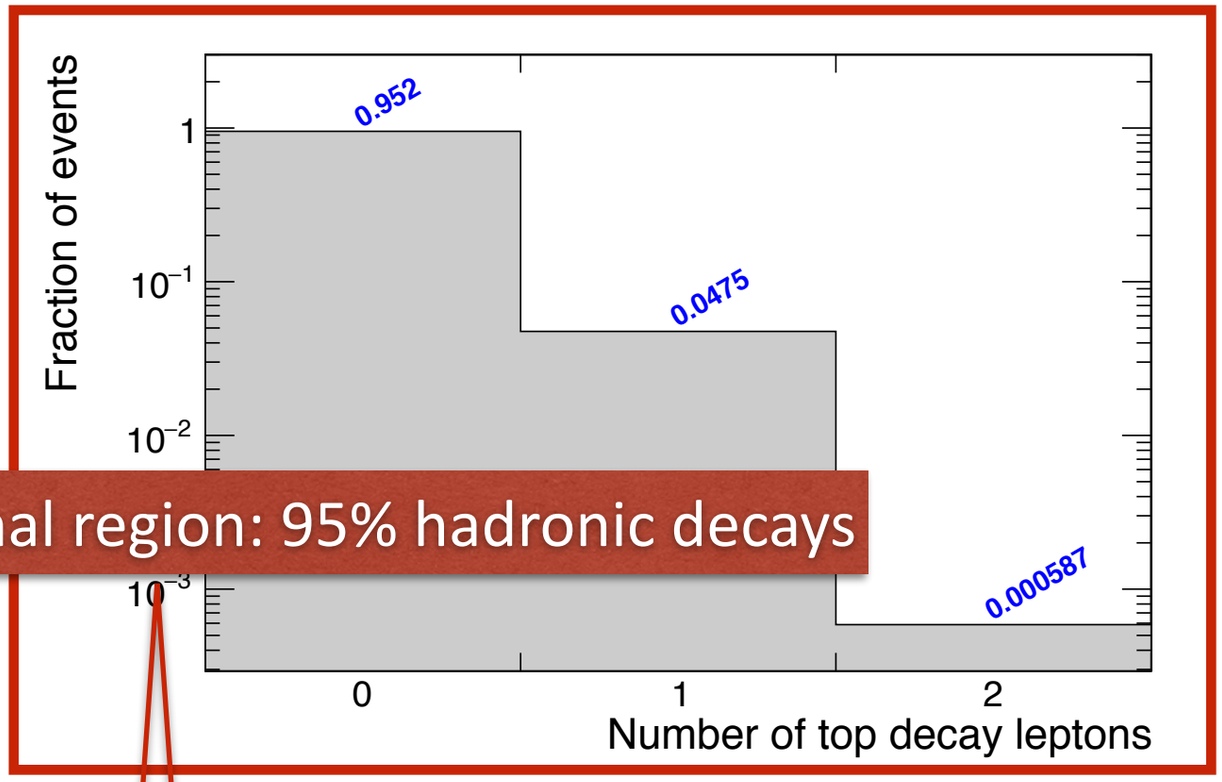


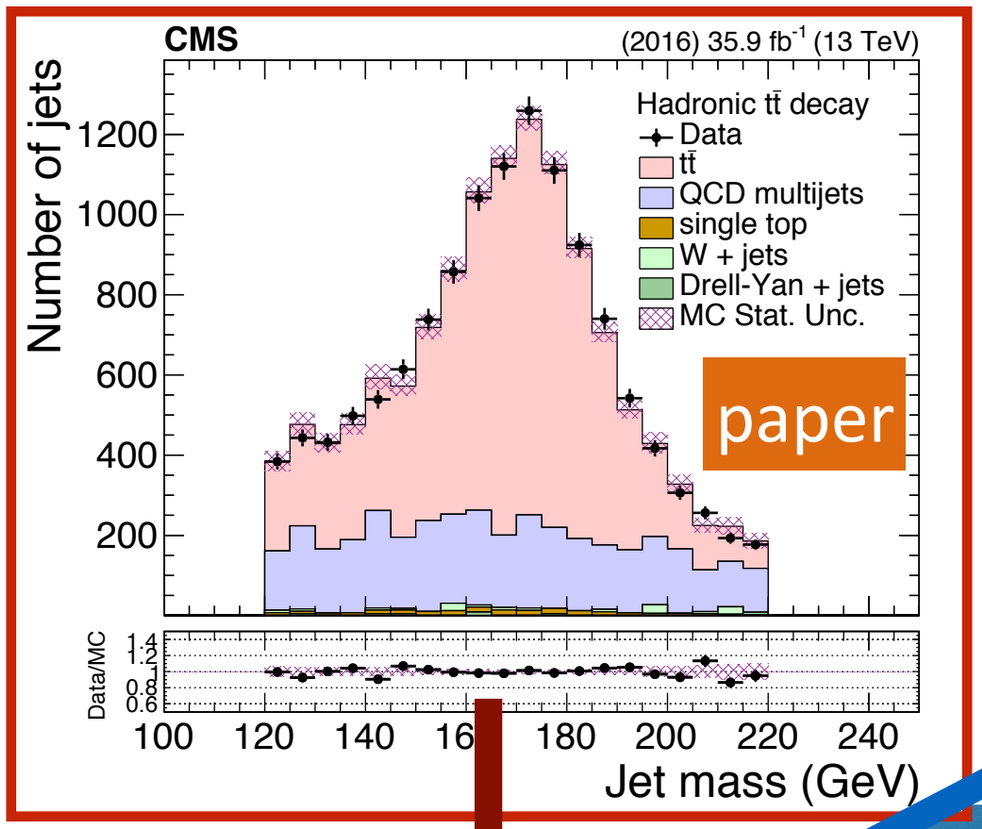
Table 2: Selection requirements per analysis region (hadronic channel).

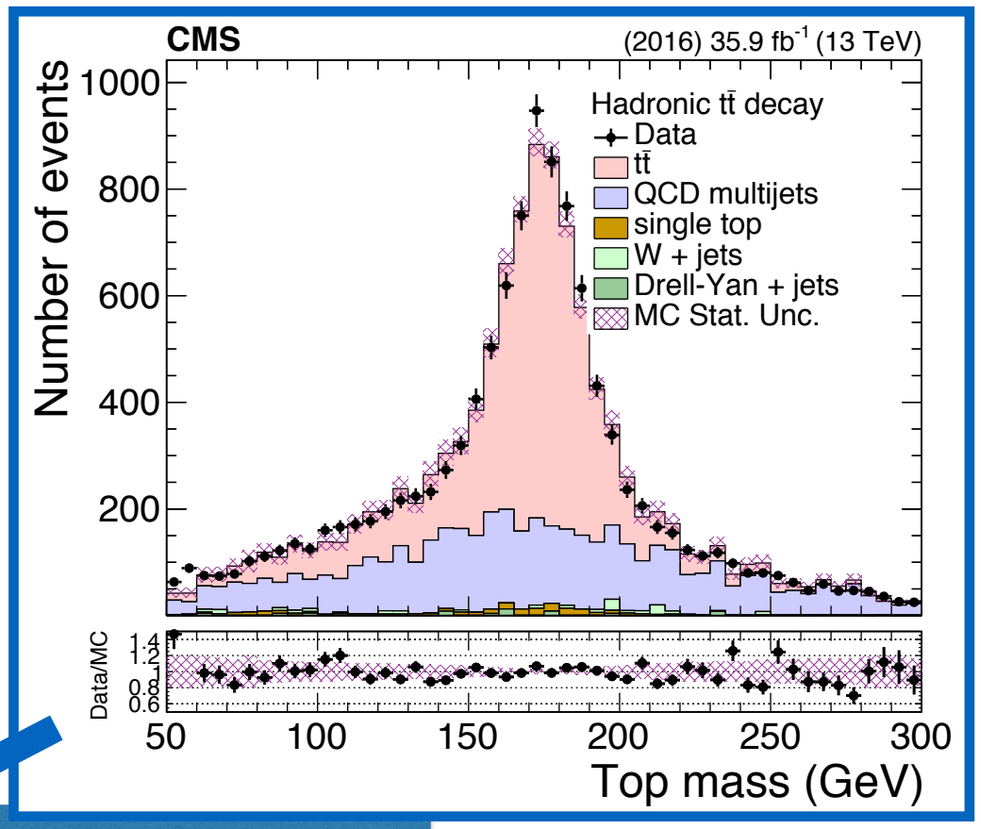
Region	Trigger	Offline Requirements
SR	signal	Base + $NN > 0.8$ + subjet b tag + $m_{SD}^{1,2} \in (120, 220)\,\text{GeV}$
SR_A	signal	Base + $NN > 0.8$ + subjet b tag
SR_B	signal	Base + subjet b tag + $m_{SD}^{1,2} \in (120, 220)\,\text{GeV}$
CR	control	Base + $NN > 0.8$ + no subjet b tag + $m_{SD}^{1,2} \in (120, 220)\,\text{GeV}$
CR_A	control	Base + $NN > 0.8$ + no subjet b tag

expected yields

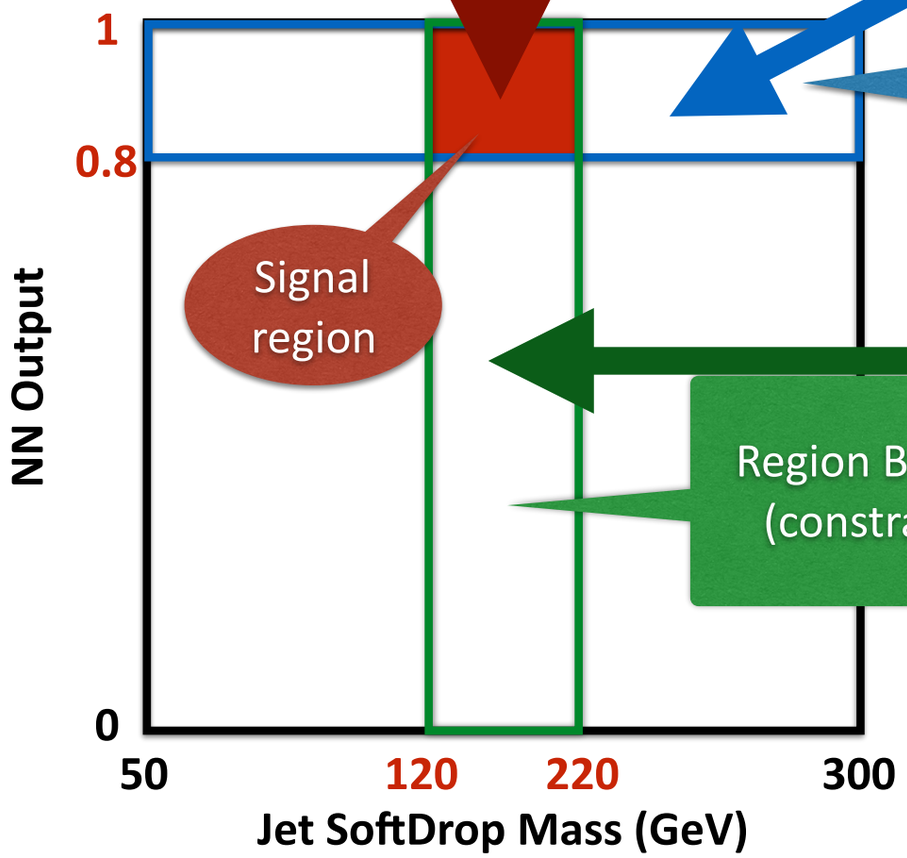
Process	Yield
$\bar{\text{t}}\text{t}$	3978
QCD	2171
W+jets	51
Z+jets	12
Single Top	83
Data	6295

Analysis regions

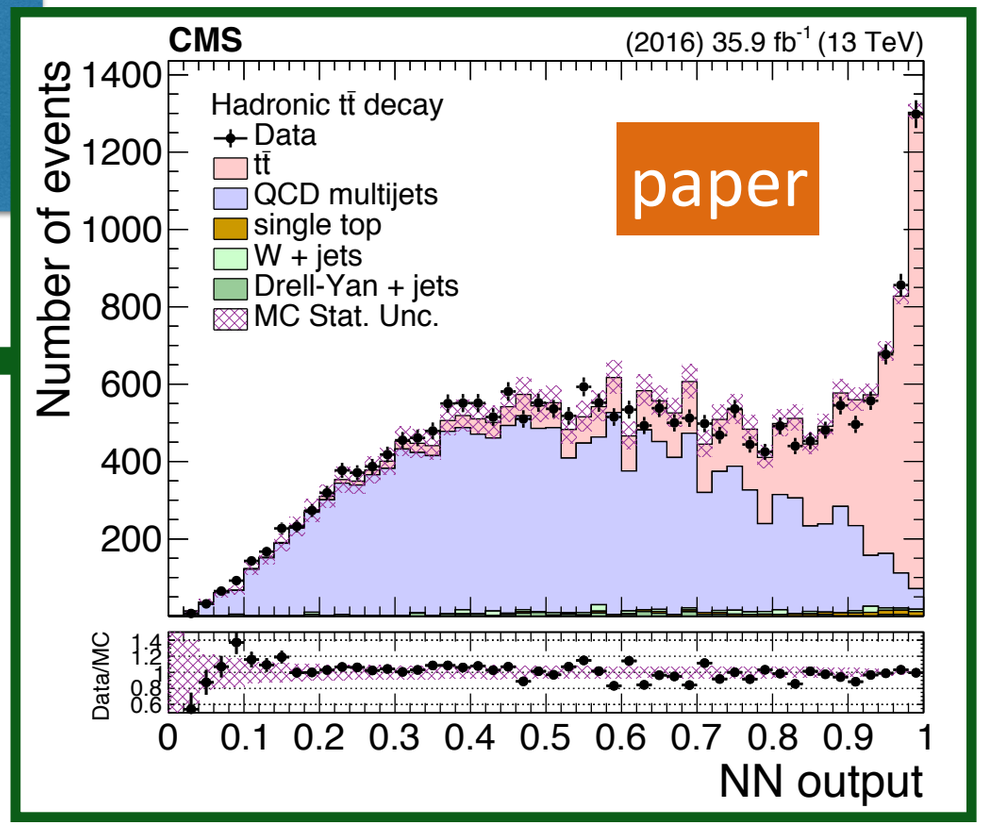




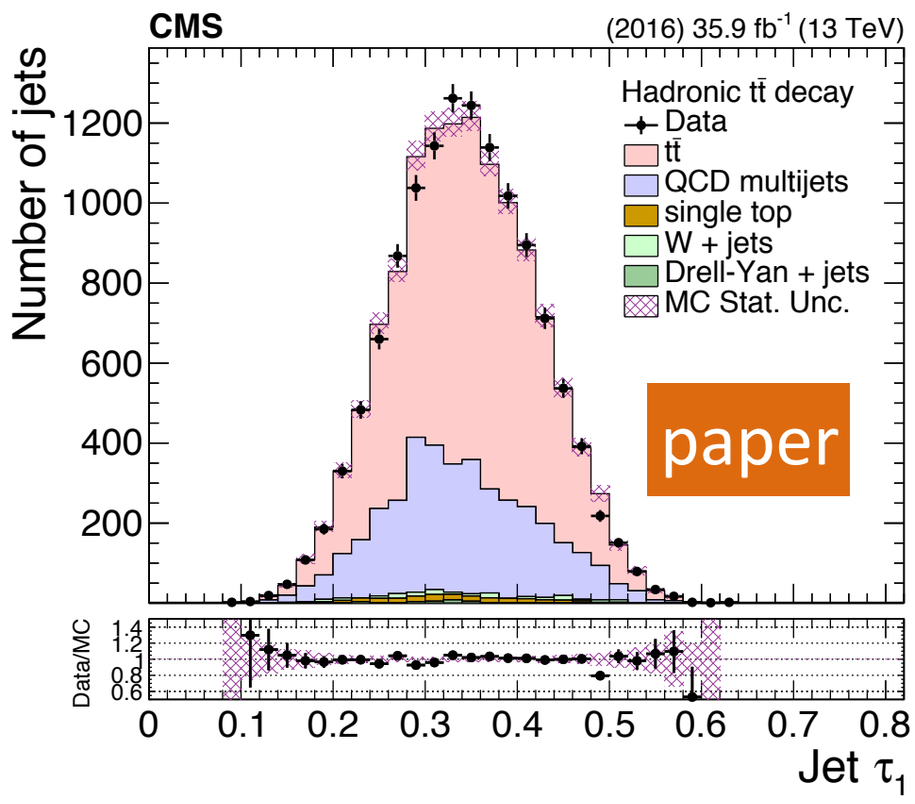
Region A: Mass Fit (extract bkg yield & constrain nuisances)

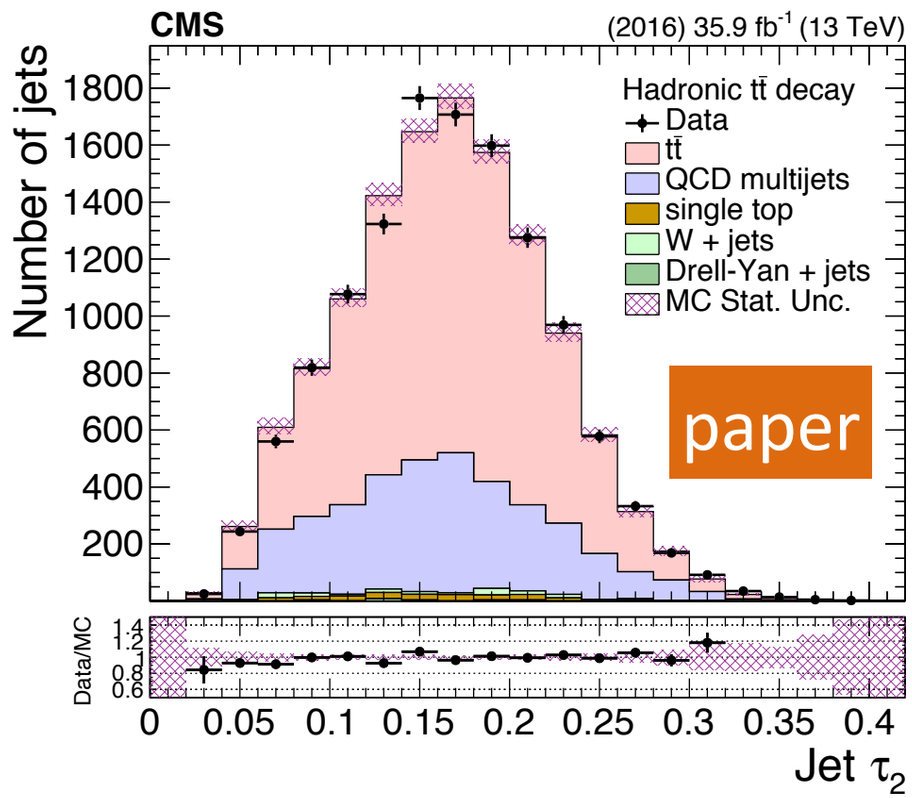


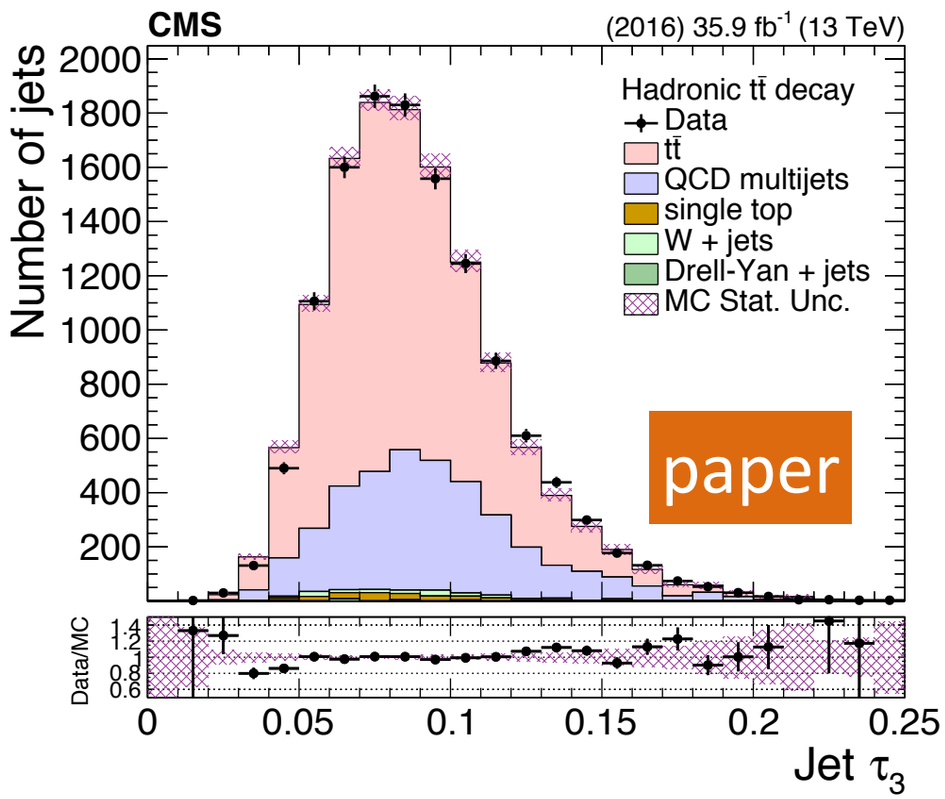
Region B: NN Output Fit (constrain nuisances)



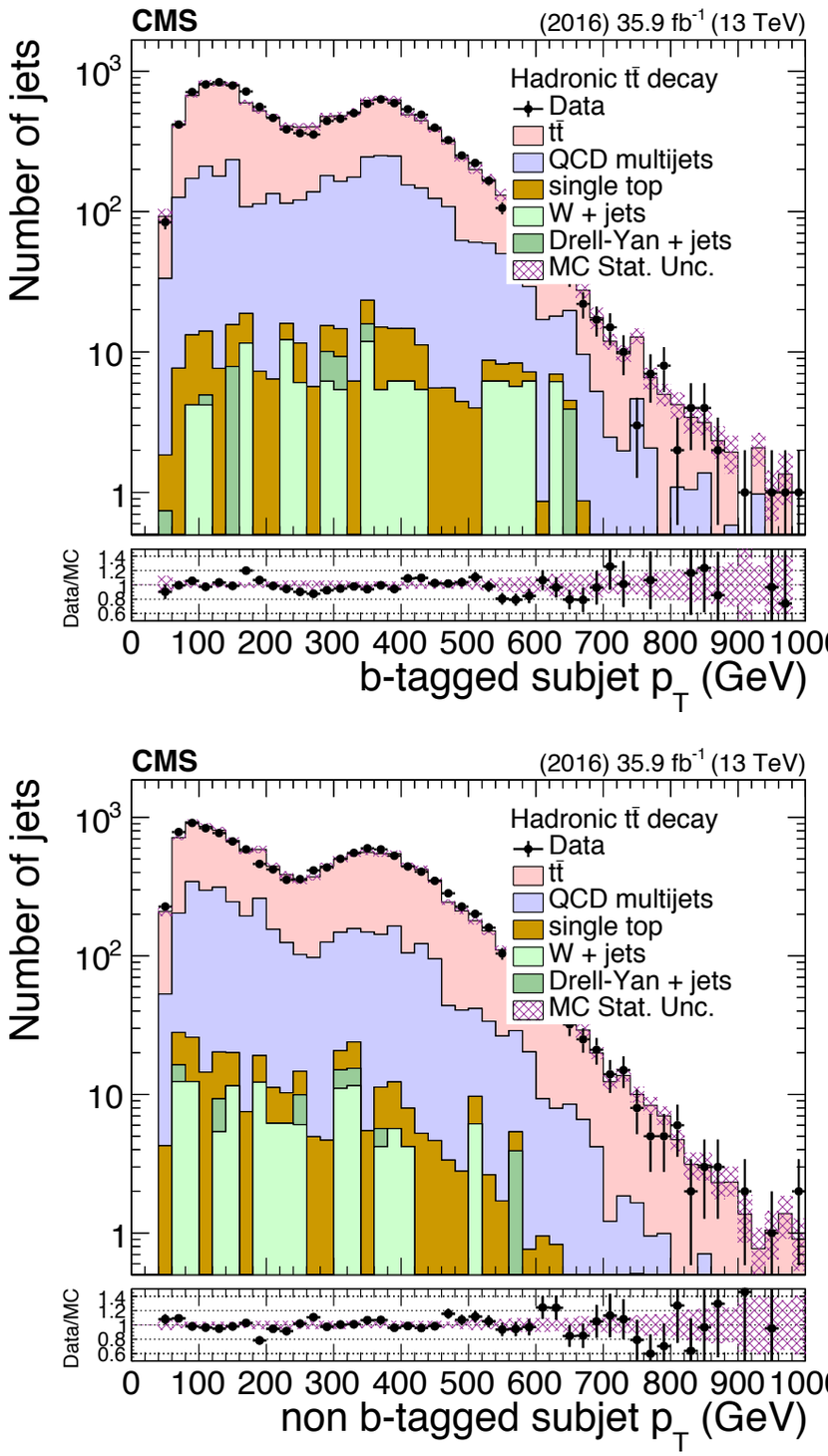
Data vs MC: substructure properties

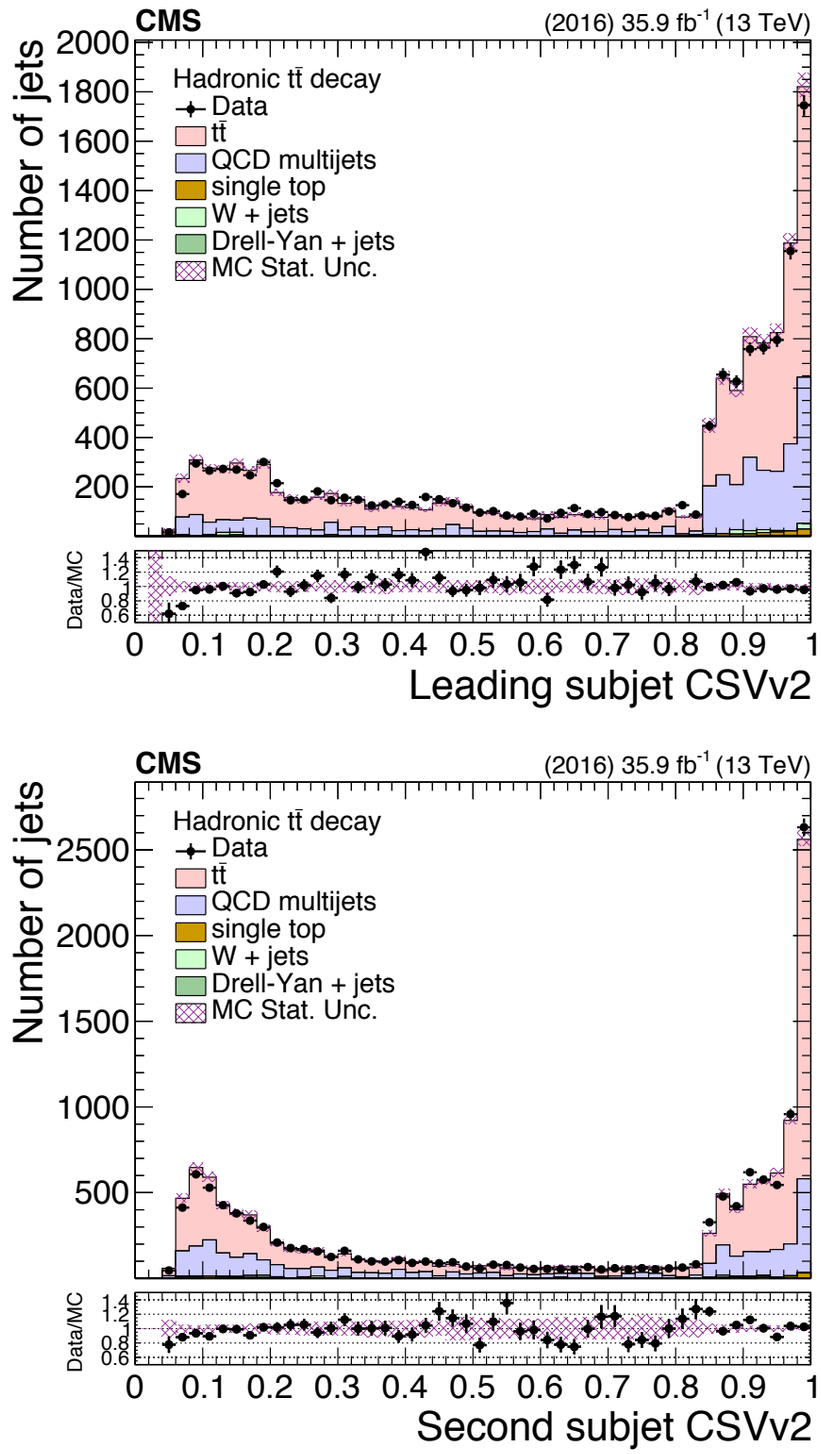


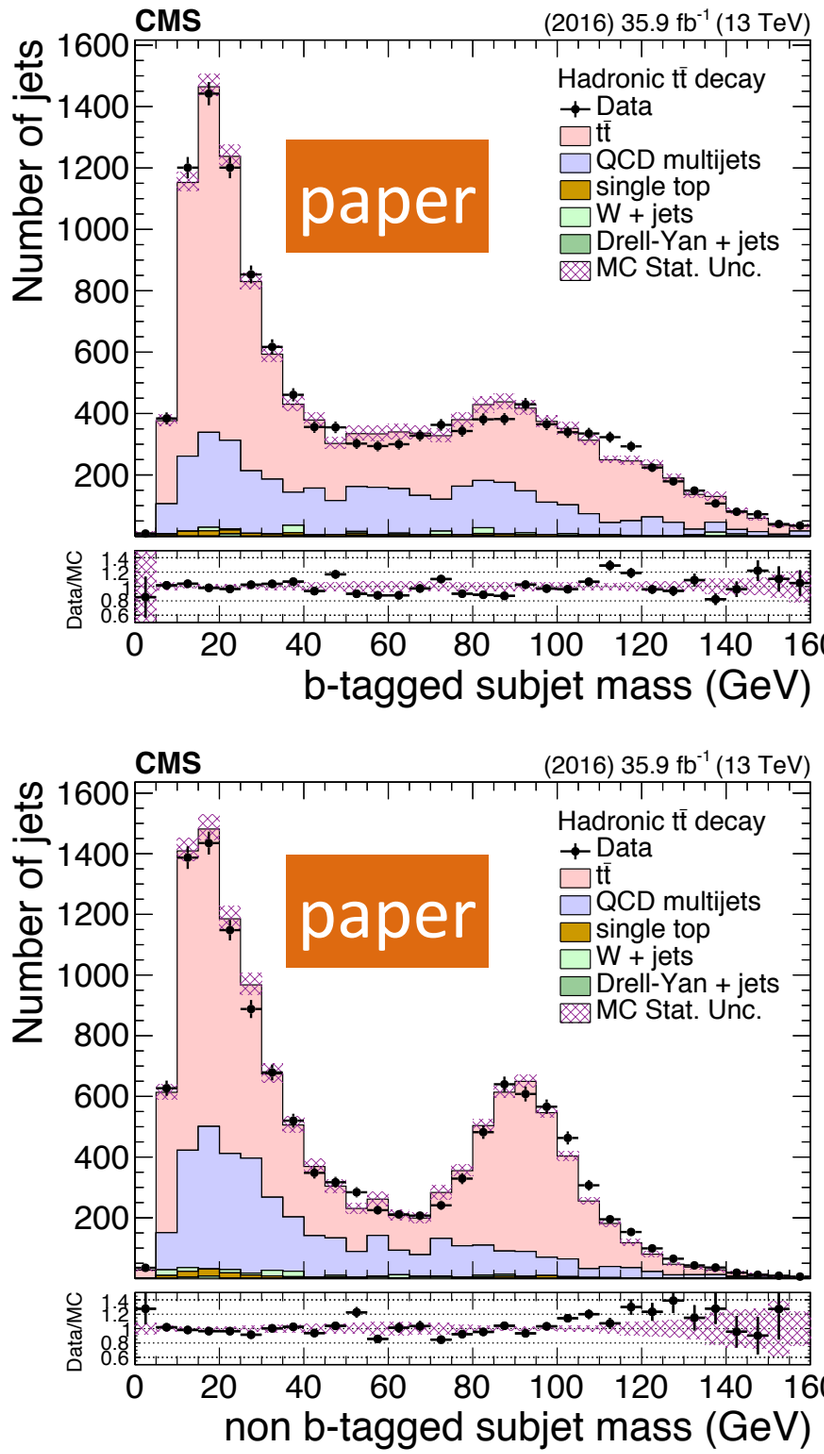




Data vs MC: subjet properties







Signal extraction

fiducial yield

Data

Transfer factor from SR_A to SR (taken from CR_A/CR in data)

Bkg shape (taken from CR in data)

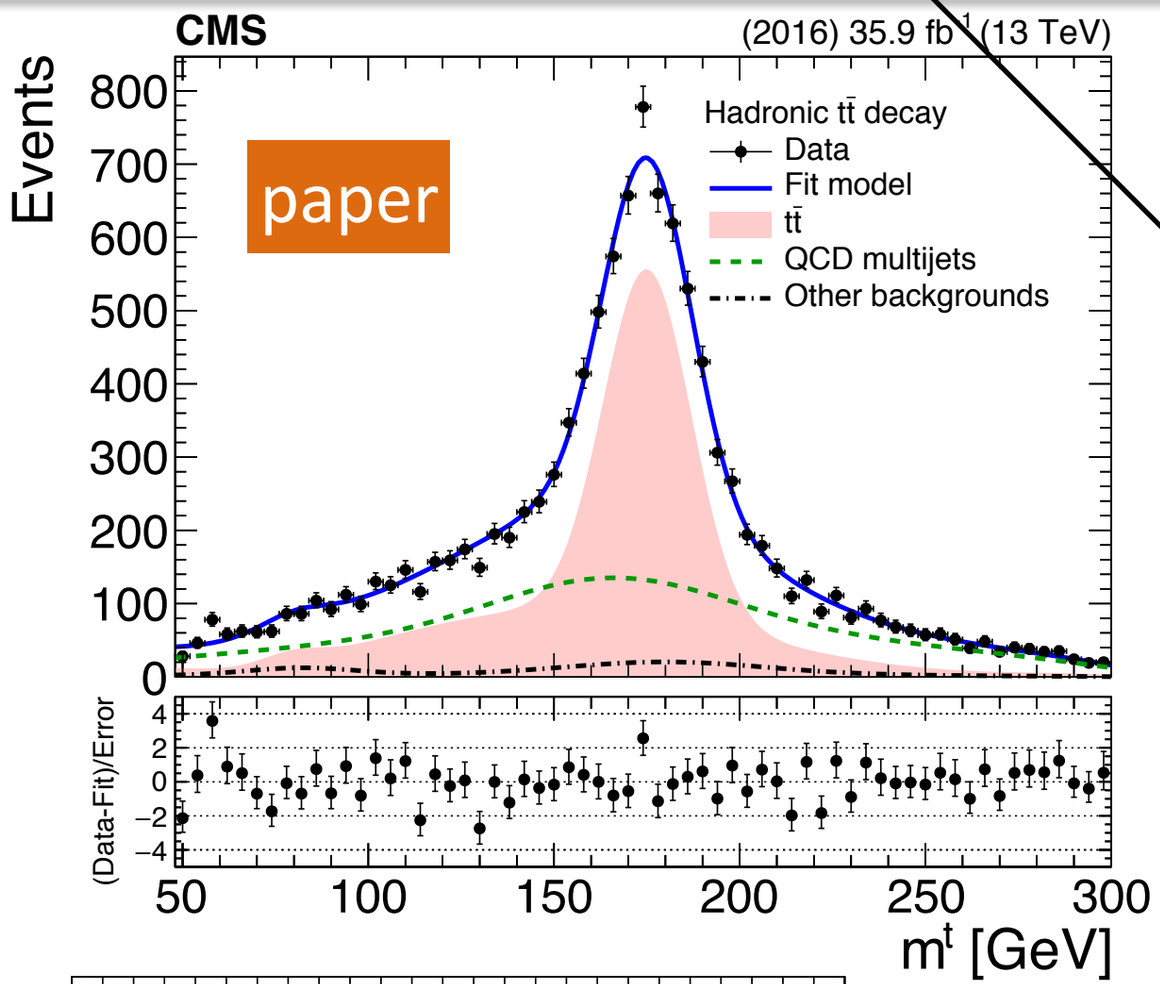
$$S_{\mathrm{fid}}\left(x_{\mathrm{reco}}\right)=D\left(x_{\mathrm{reco}}\right)-C_{\mathrm{bkg}}^{\mathrm{yield}}\cdot N_{\mathrm{bkg}}^{\mathrm{fit}}\cdot C_{\mathrm{bkg}}^{\mathrm{shape}}\left(x_{\mathrm{reco}}\right)\cdot B\left(x_{\mathrm{reco}}\right)$$

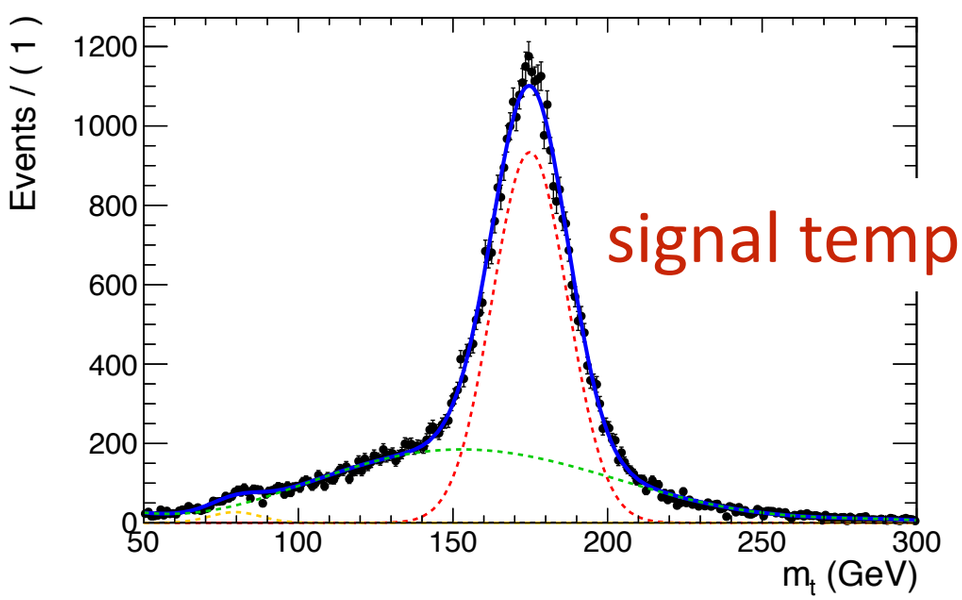
Bkg yield (fit in region SR_A)

Bkg shape correction (taken from MC)

Fit in SR_A

$$D(m^t) = N_{t\bar{t}} T(m^t; k_{scale}, k_{res}) + N_{qcd}(1 + k_{slope} m^t) Q(m^t) + N_{bkg} B(m^t)$$





MC QCD closure

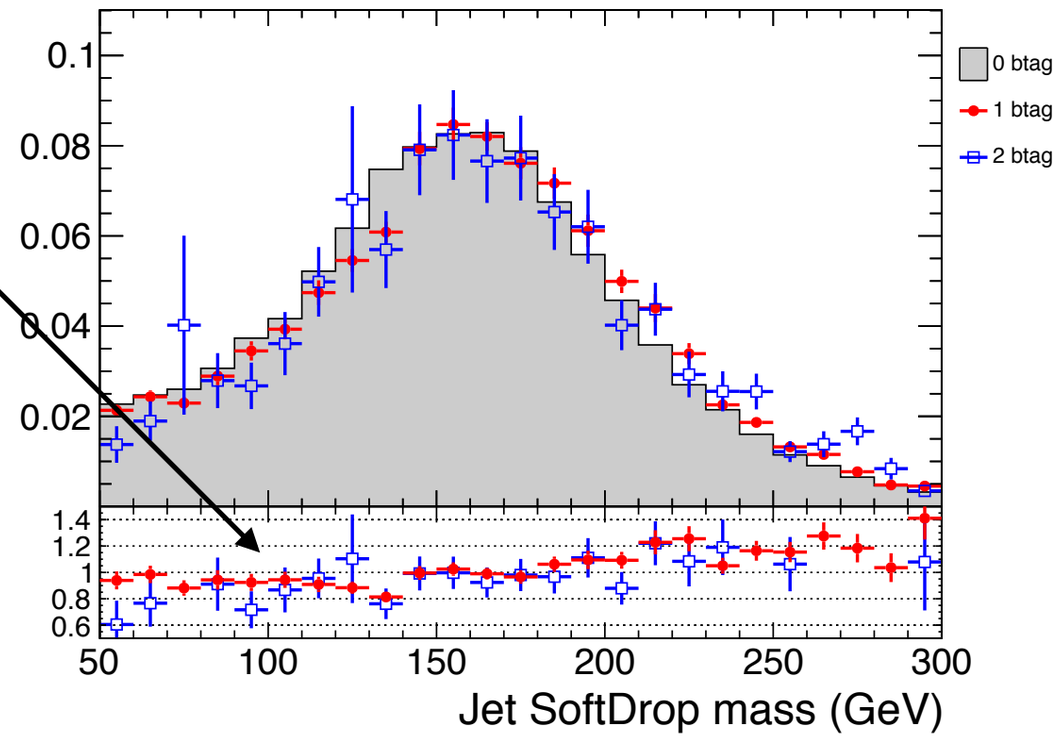
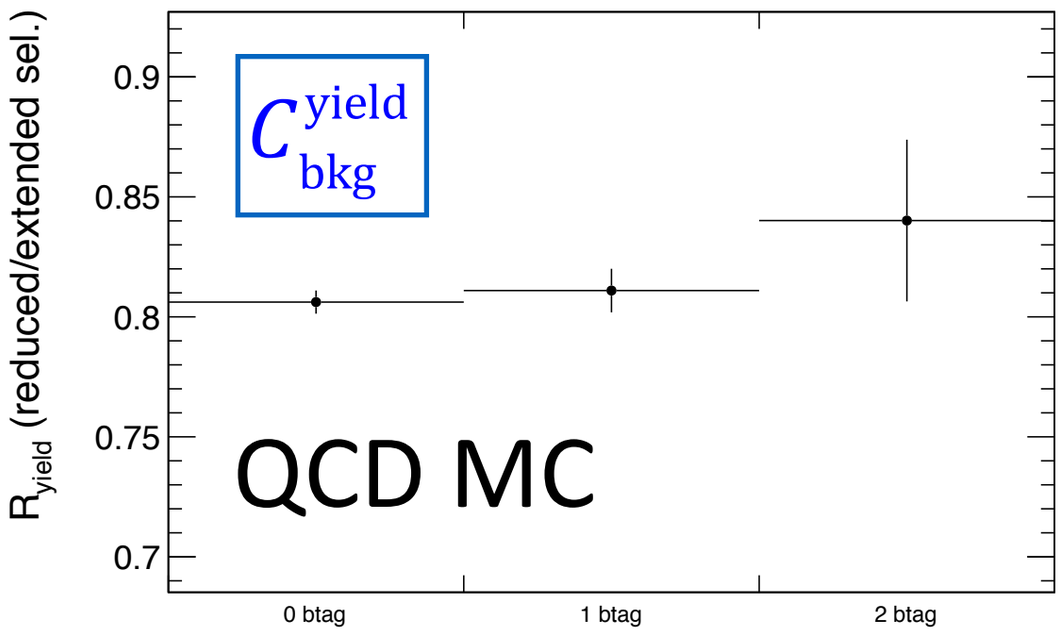


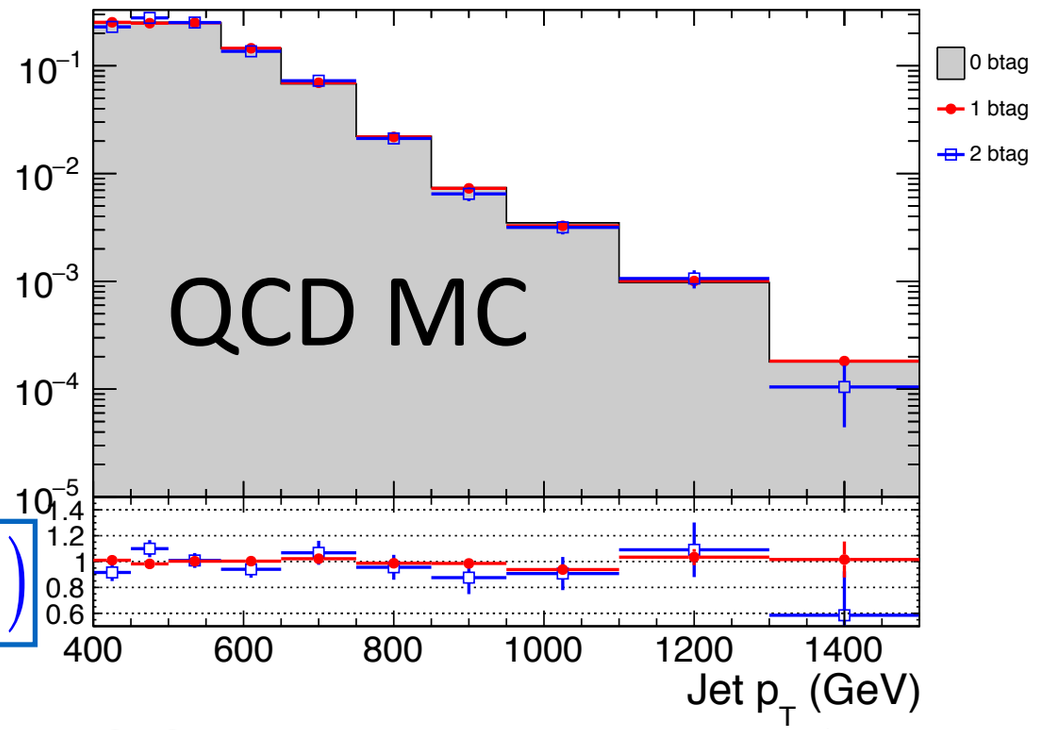
Table 8: Results of the fit in SR_A.

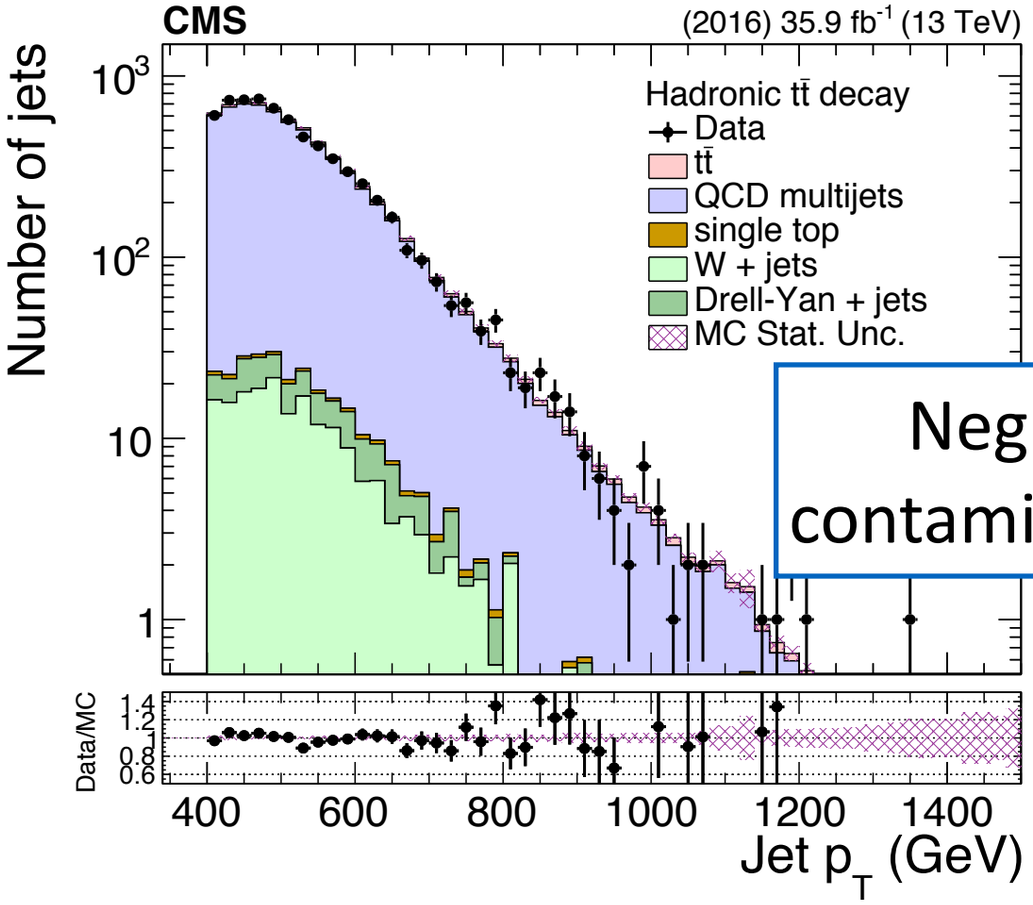
Parameter	Value	Error
k_{res}	0.960	0.026
k_{scale}	1.002	0.002
k_{slope}	5.7e-03	1.4e-03
N_{bkg}	400	255
N_{qcd}	4539	247
$N_{t\bar{t}}$	6238	181

Validation of the background method

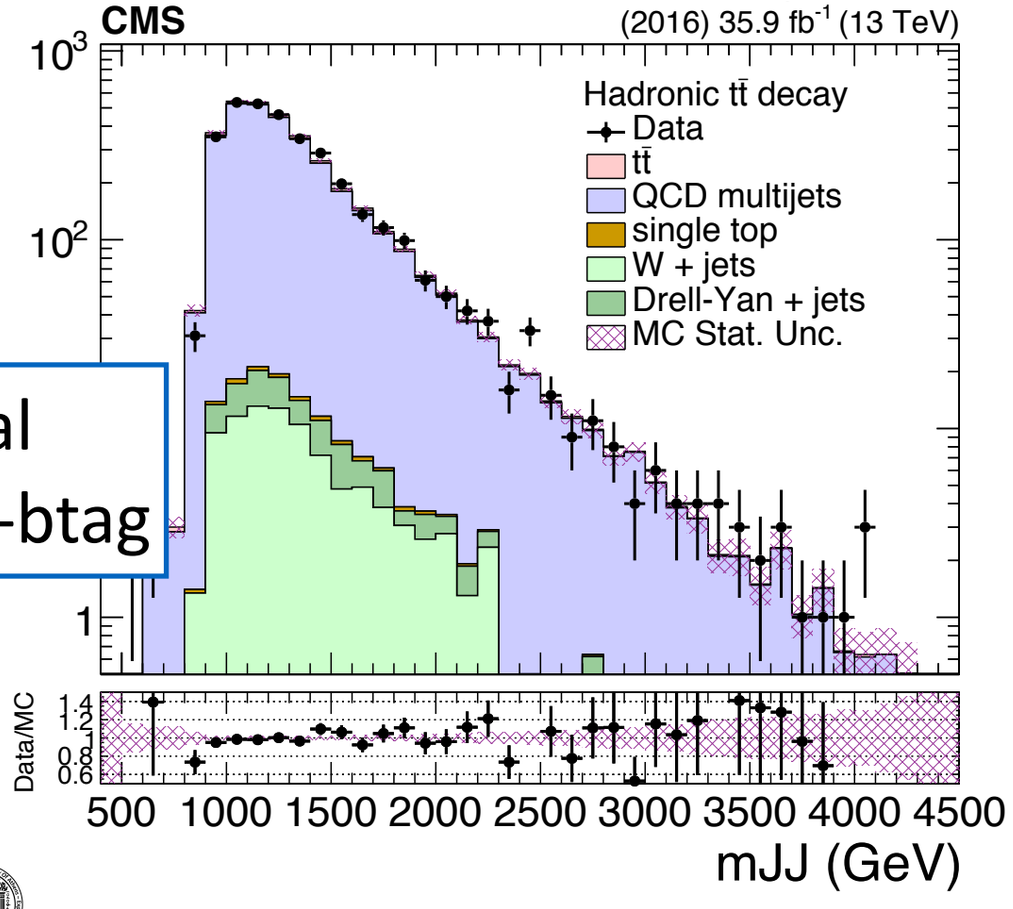


$C_{bkg}^{shape}(x_{reco})$





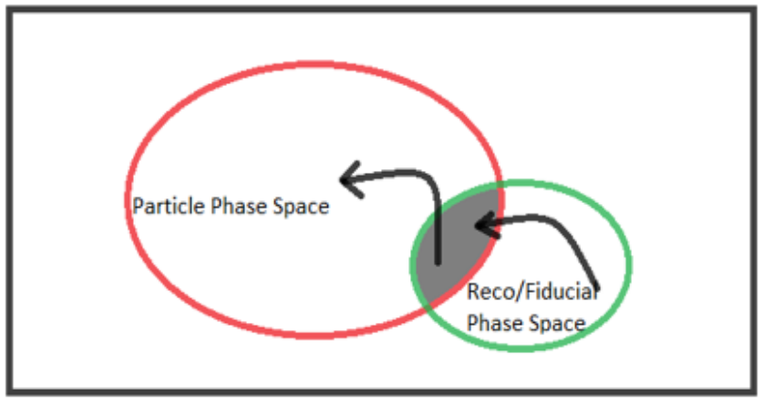
Negligible signal contamination in 0-btag



Parton & Particle levels

Parton

Observable	Requirement
$p_{\mathrm{T}}^{t,\bar{t}}$	$> 400\,\mathrm{GeV}$
$\lvert\eta^{t,\bar{t}}\rvert$	< 2.4
$m_{\mathrm{t\bar{t}}}$	$> 800\,\mathrm{GeV}$



Particle

top candidates: AK8 genjets

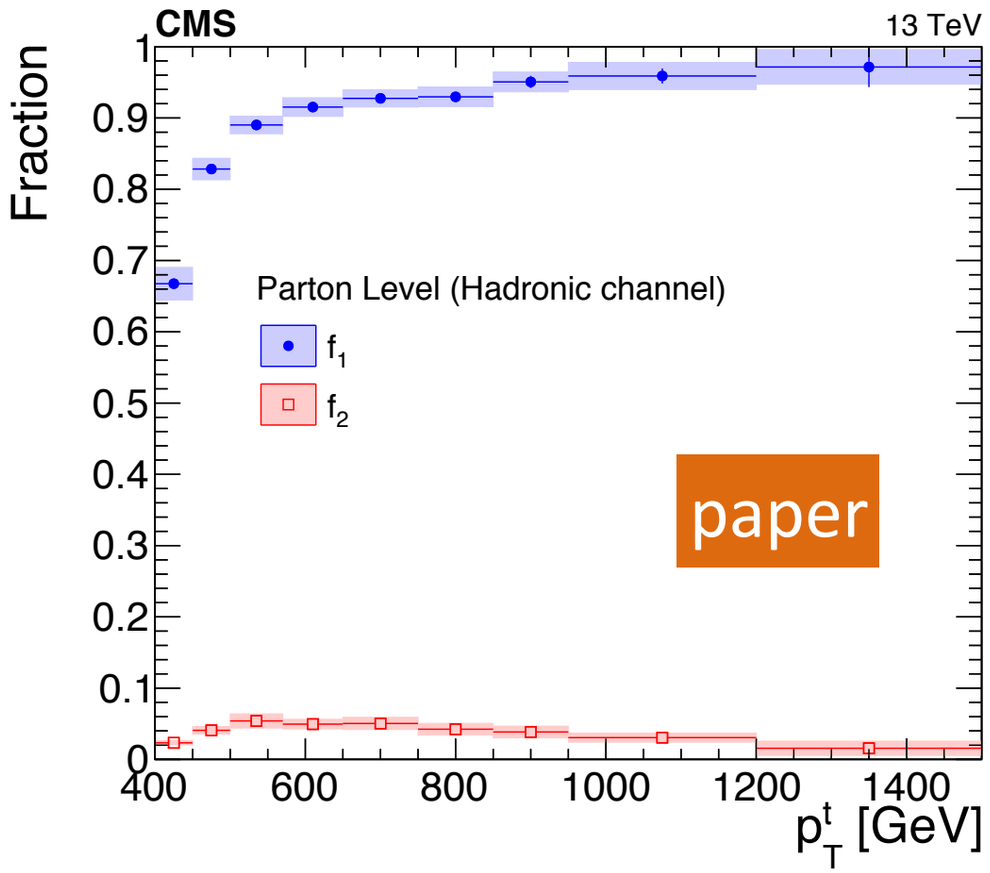
Observable	Requirement
N_{jets}	> 1
$p_{\mathrm{T}}^{\mathrm{jet1,2}}$	$> 400\,\mathrm{GeV}$
$\lvert\eta^{\mathrm{jet1,2}}\rvert$	< 2.4
$m_{SD}^{\mathrm{jet1,2}}$	$(120, 220)\,\mathrm{GeV}$
m_{jj}	$> 800\,\mathrm{GeV}$

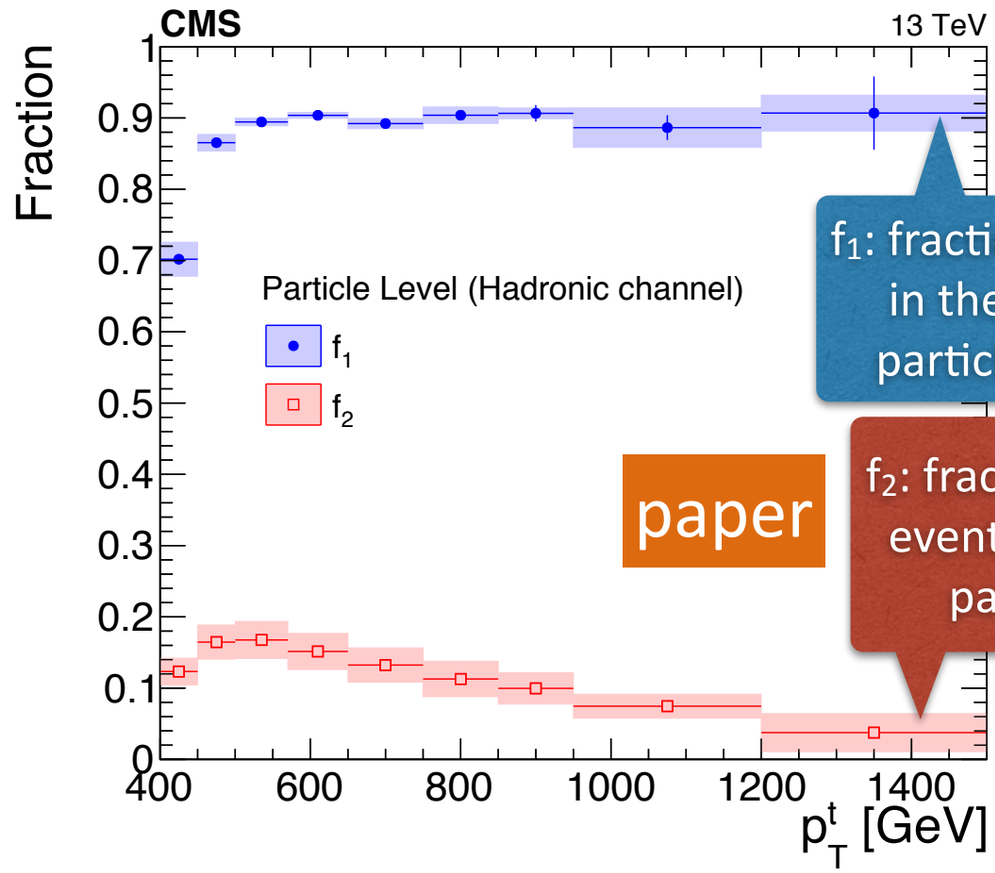
$$\frac{d\sigma_i^{\mathrm{unf}}}{dx} = \frac{1}{\mathcal{L}\cdot\Delta x_i}\cdot\frac{1}{f_{2,i}}\cdot\sum_j\left(R_{ij}^{-1}\cdot f_{1,j}\cdot S_j\right)$$

- $f_{2,i}$: efficiency of the reco +true selection
- R_{ij}^{-1}: migration matrix
- $f_{1,j}$: reco efficiency of the reco+true selection

Unfolding: simple response matrix inversion w/o regularisation

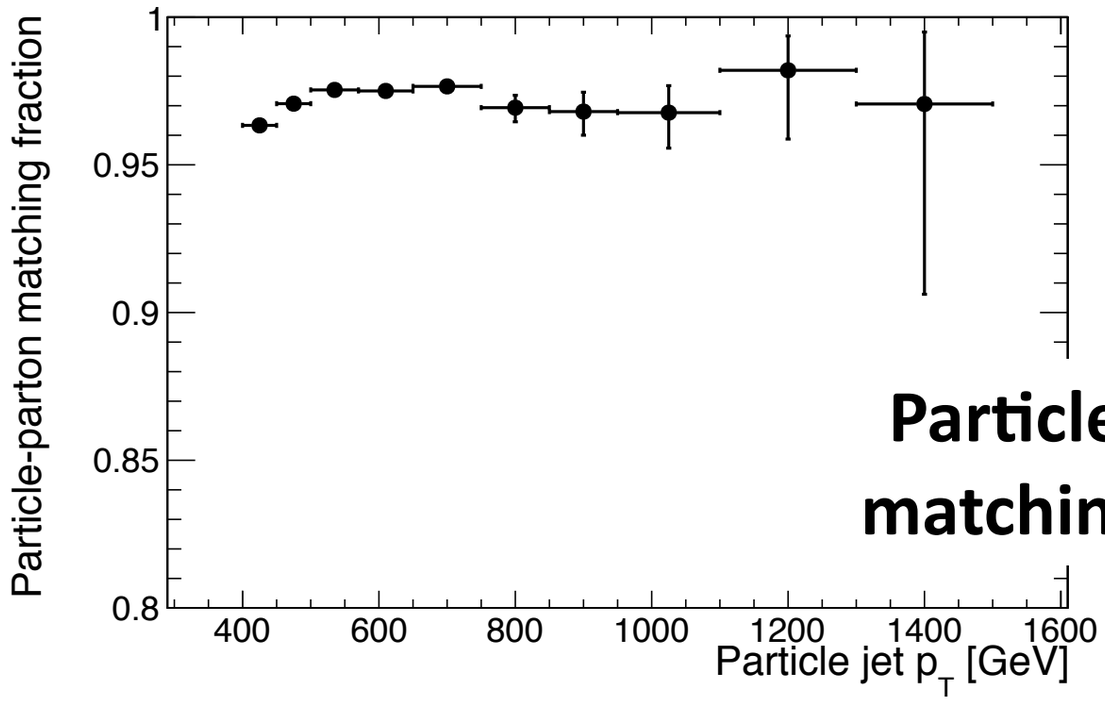
Efficiency of particle & parton level

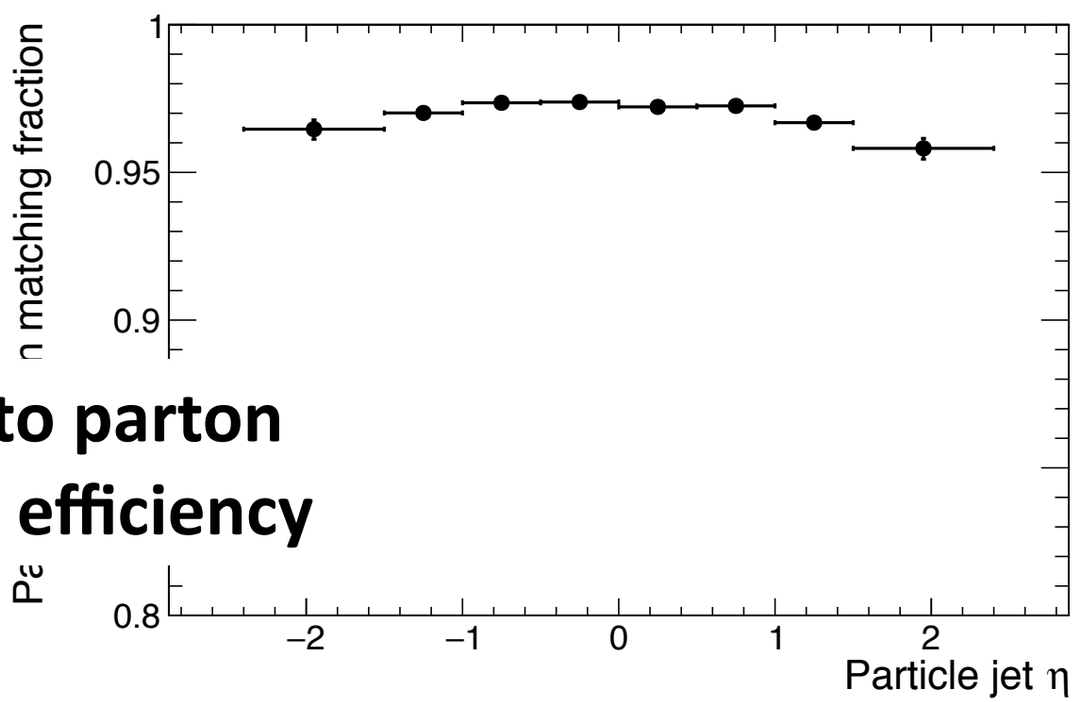




f_1: fraction of reco events in the reco+parton/ particle phase space

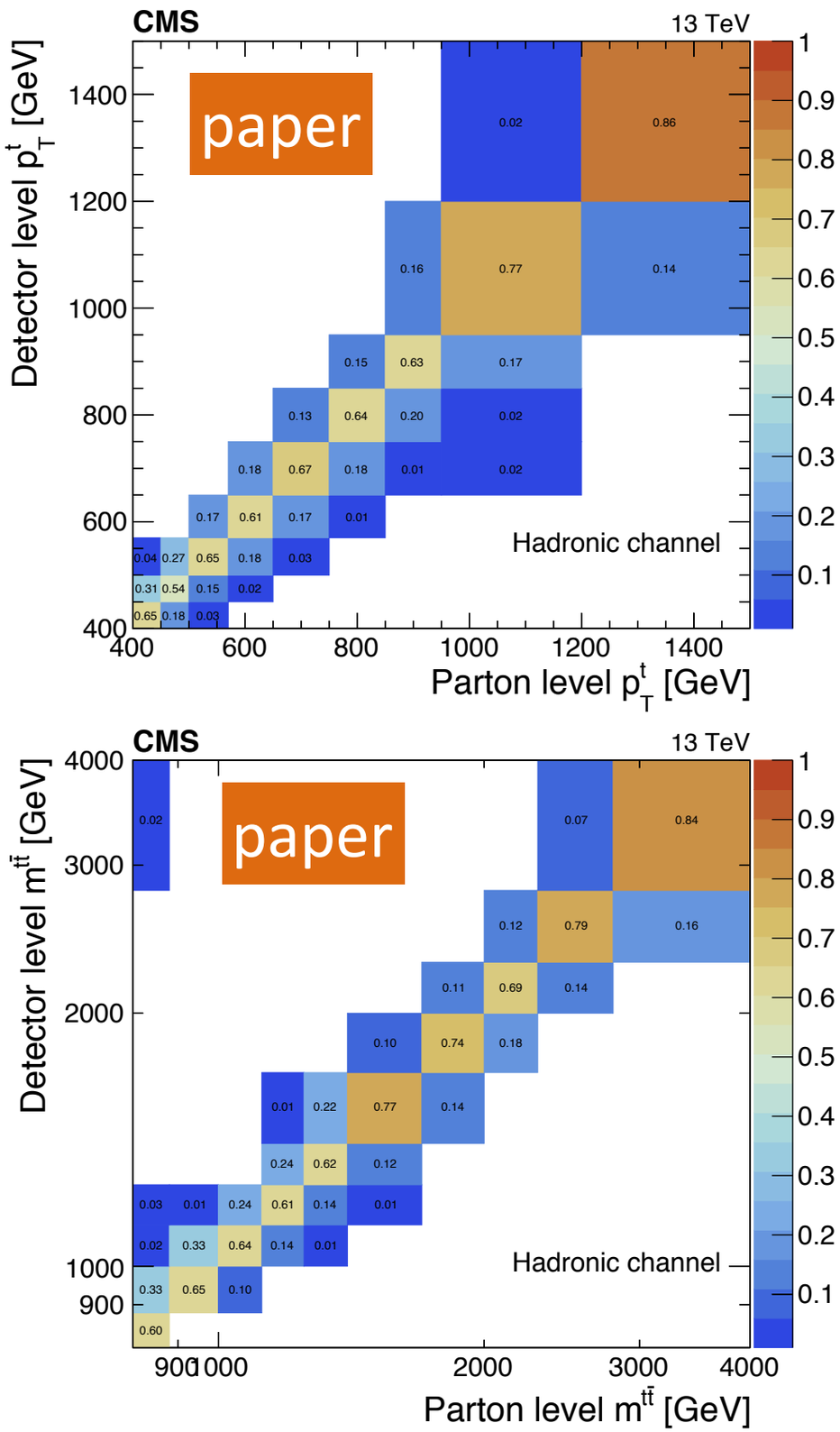
f_2: fraction of parton/particle events in the reco+parton/ particle phase space

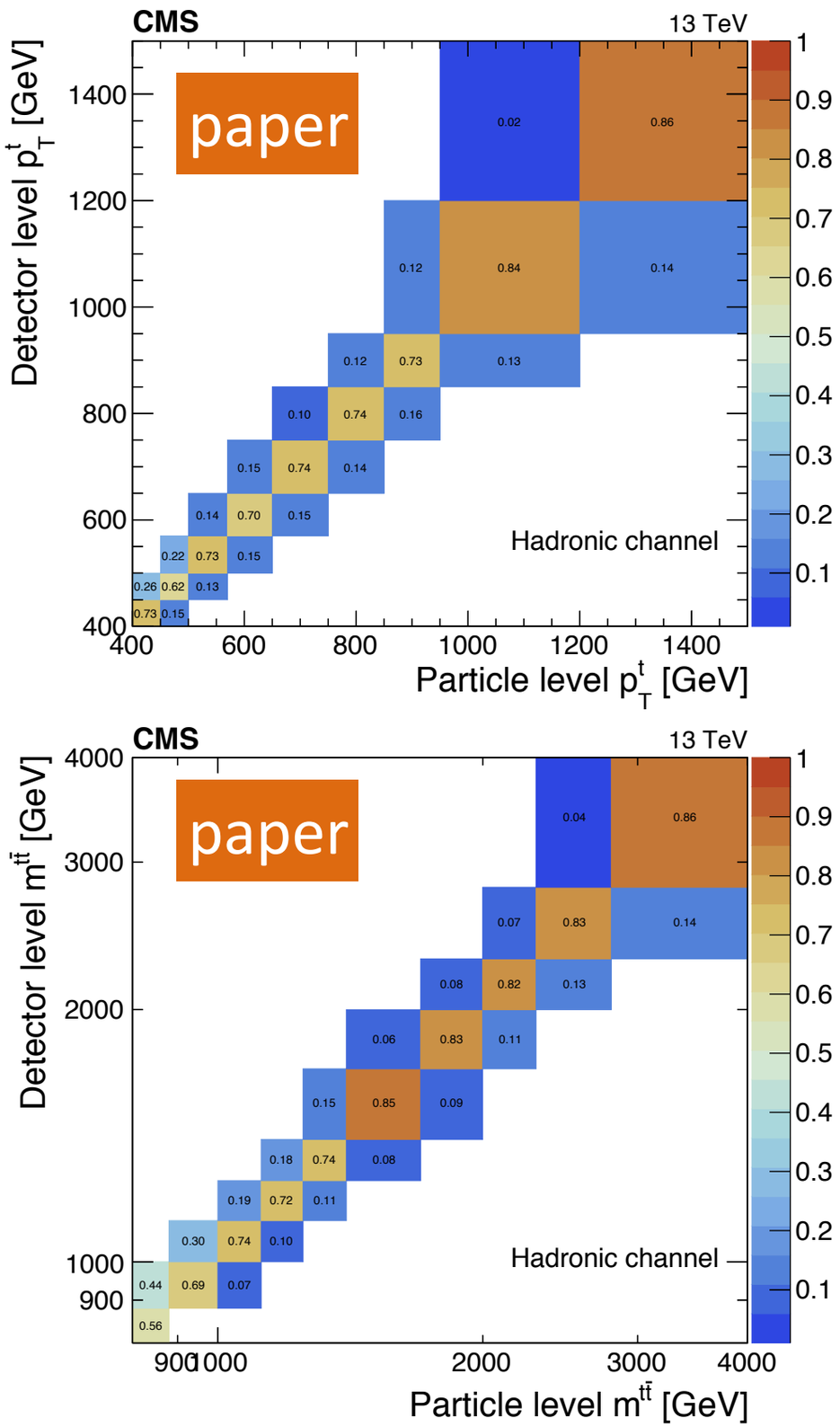




Particle to parton matching efficiency

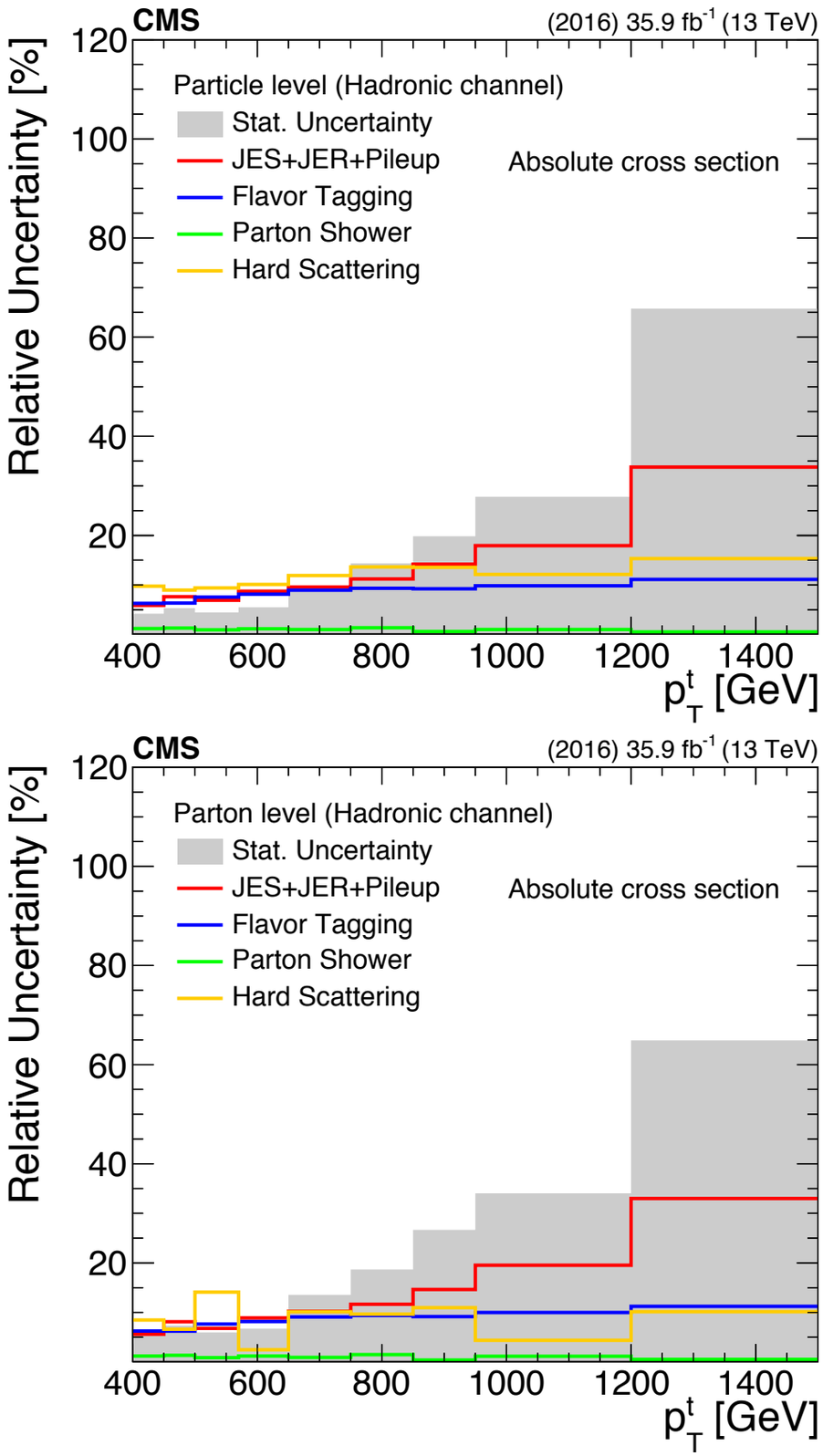
Migration matrices

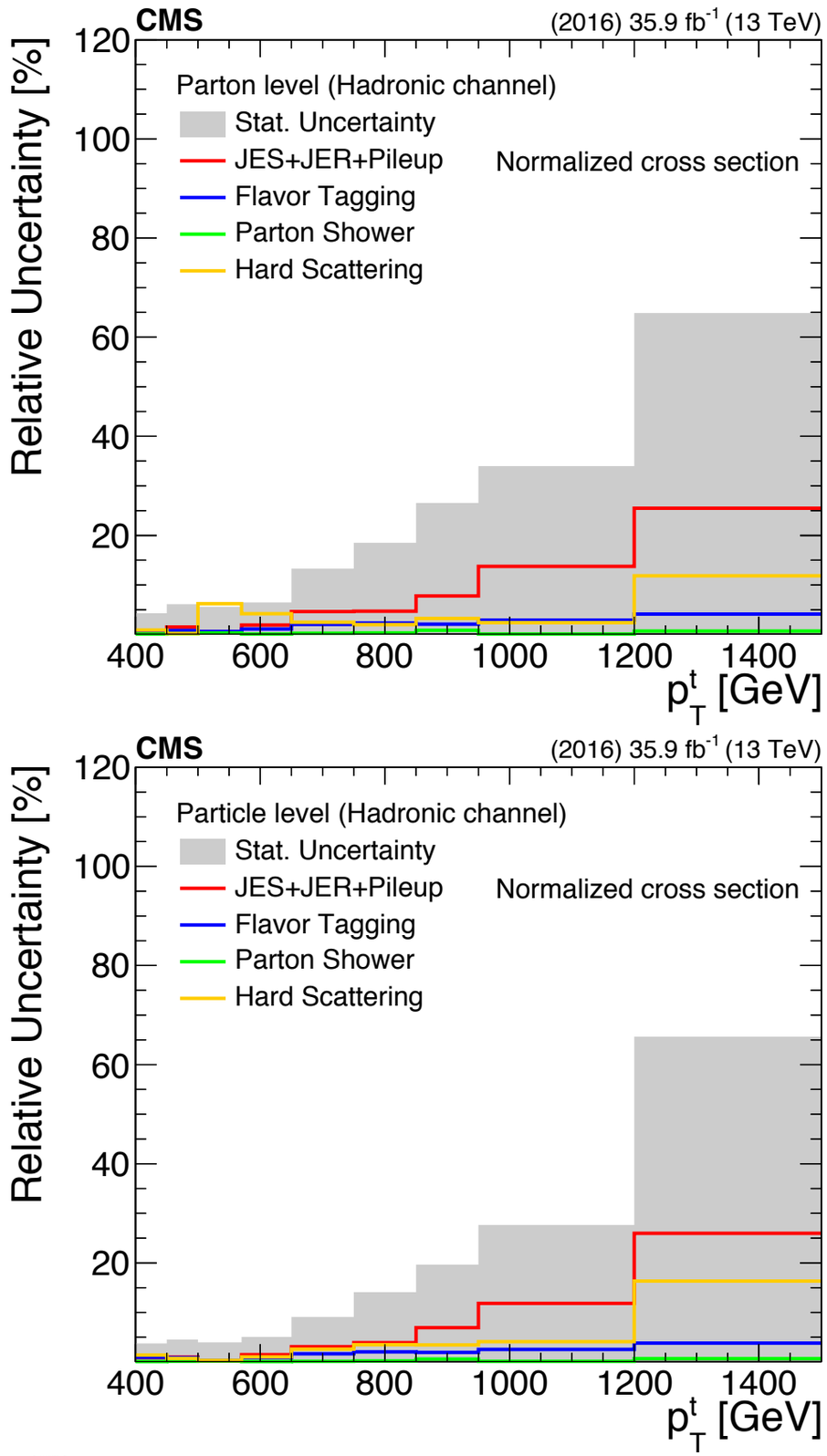




Uncertainties

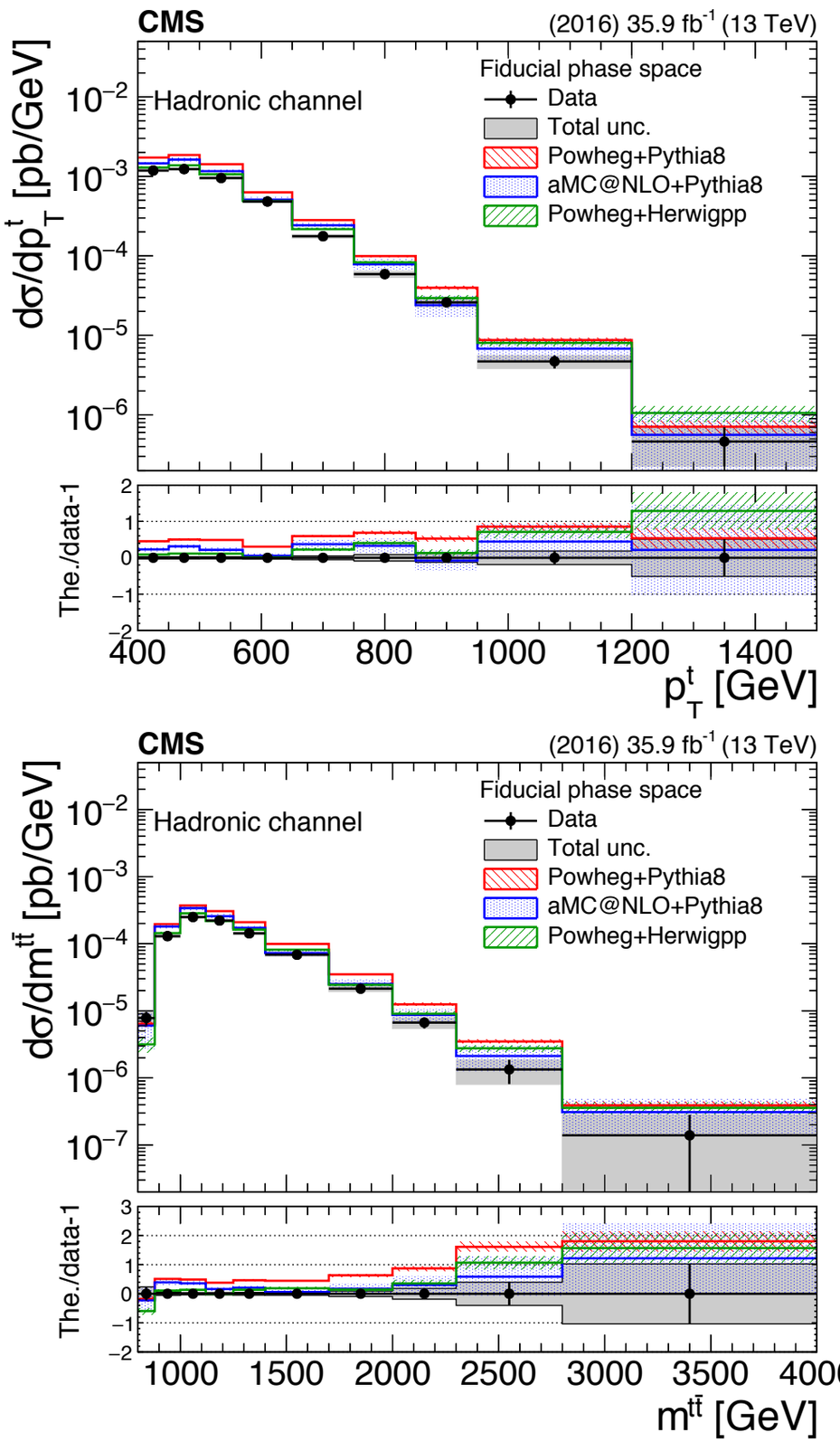
paper

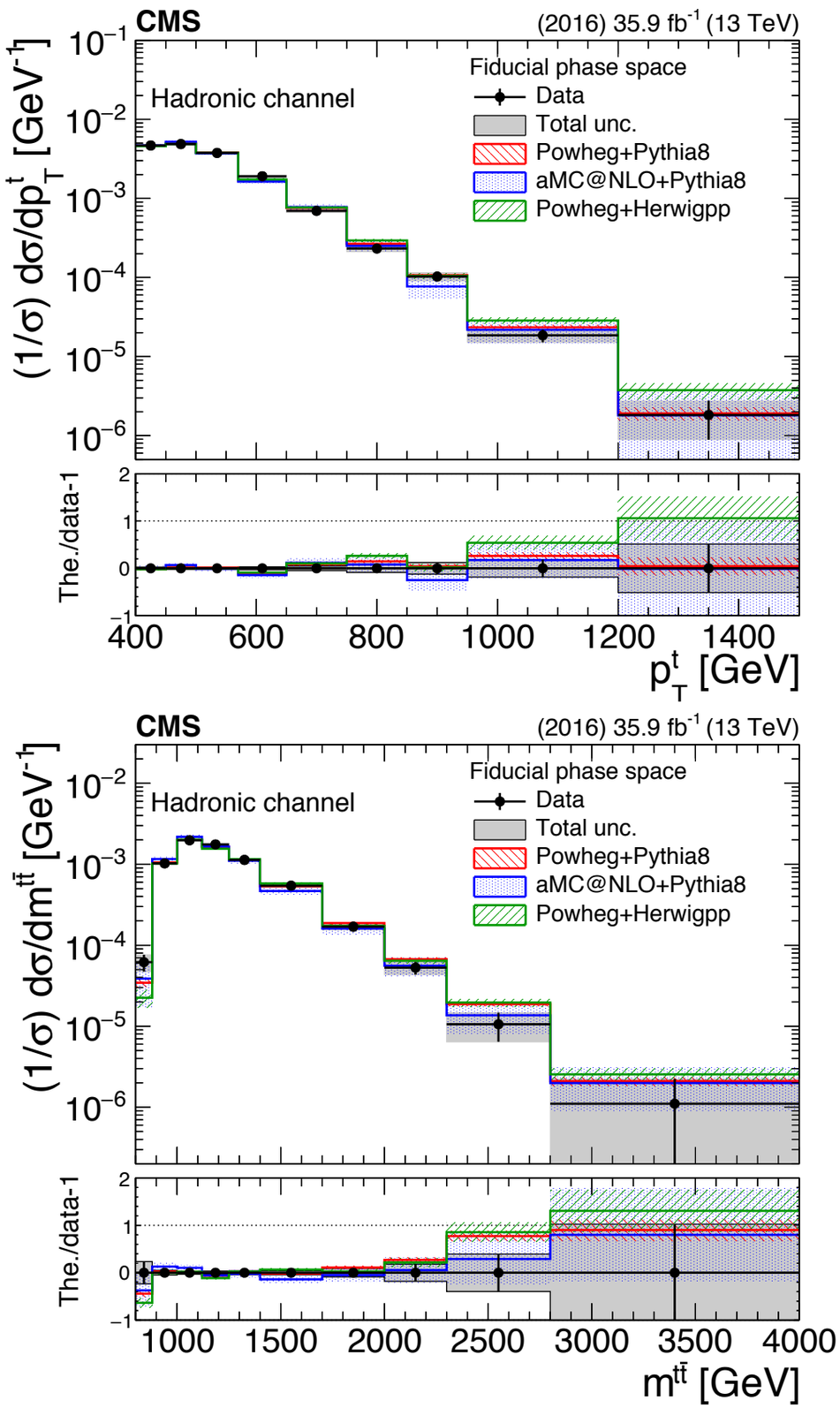




Results (fiducial, top p_T, m_{tt})

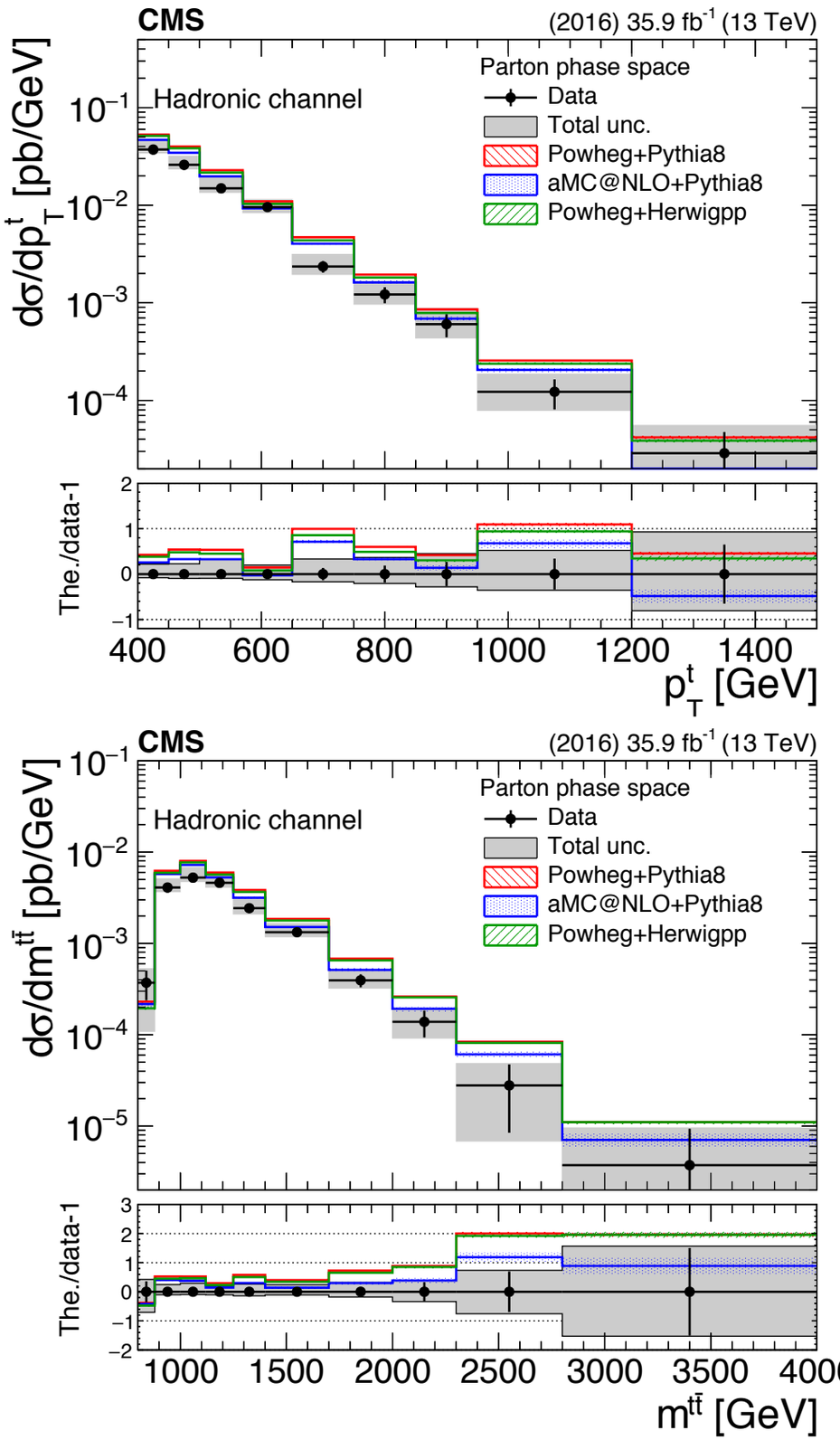
paper

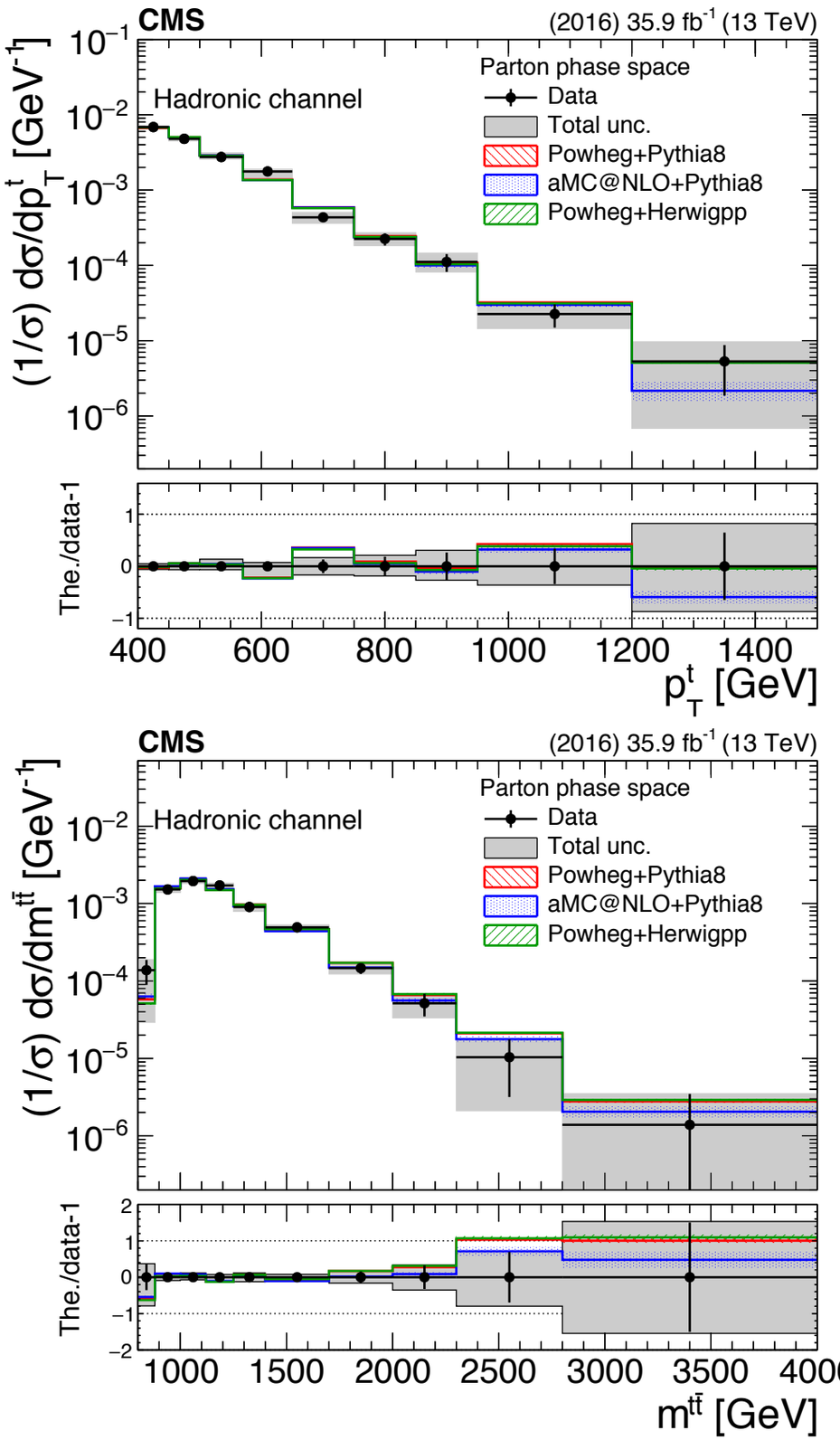




Results (parton, top p_T, m_{tt})

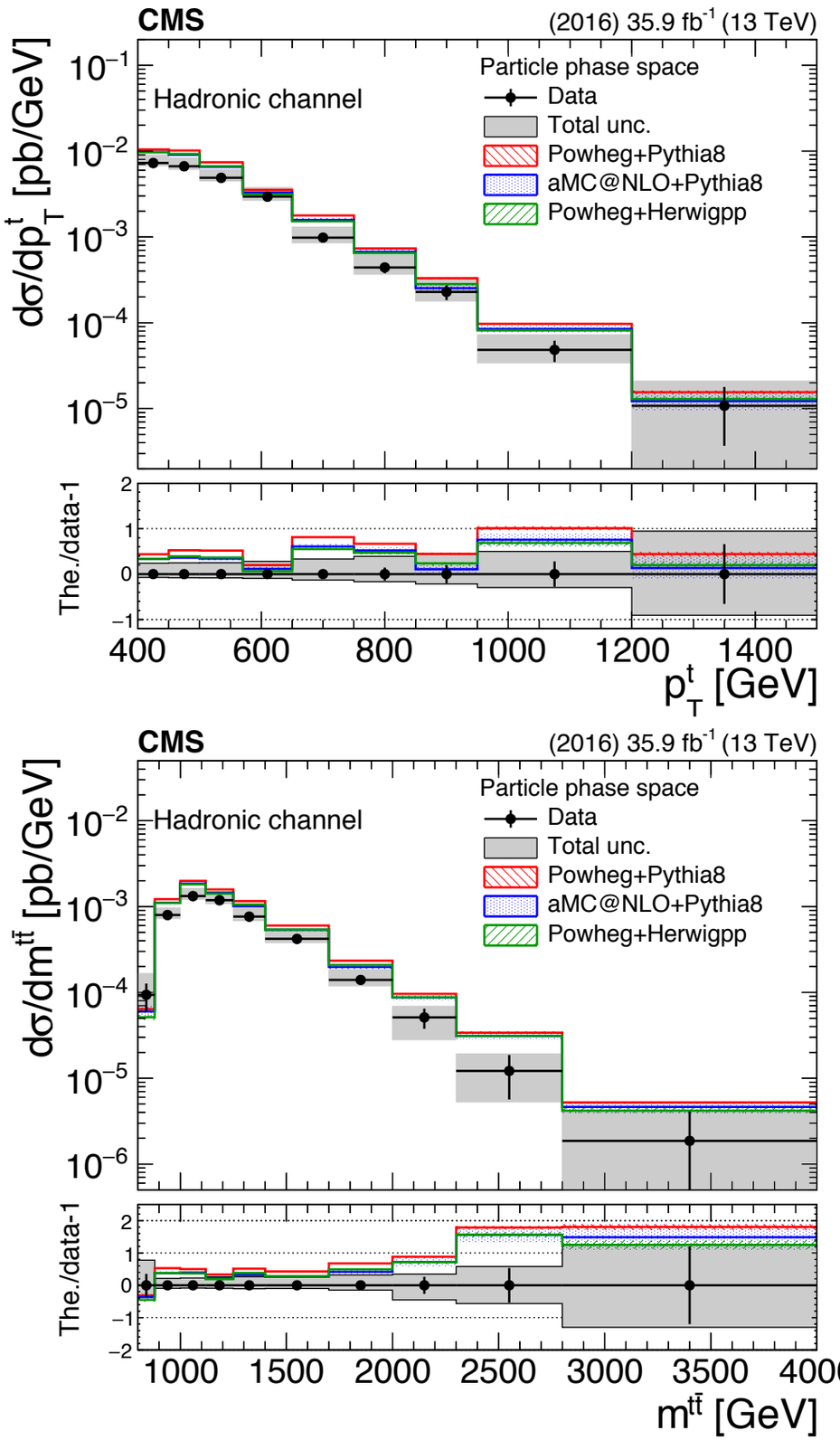
paper

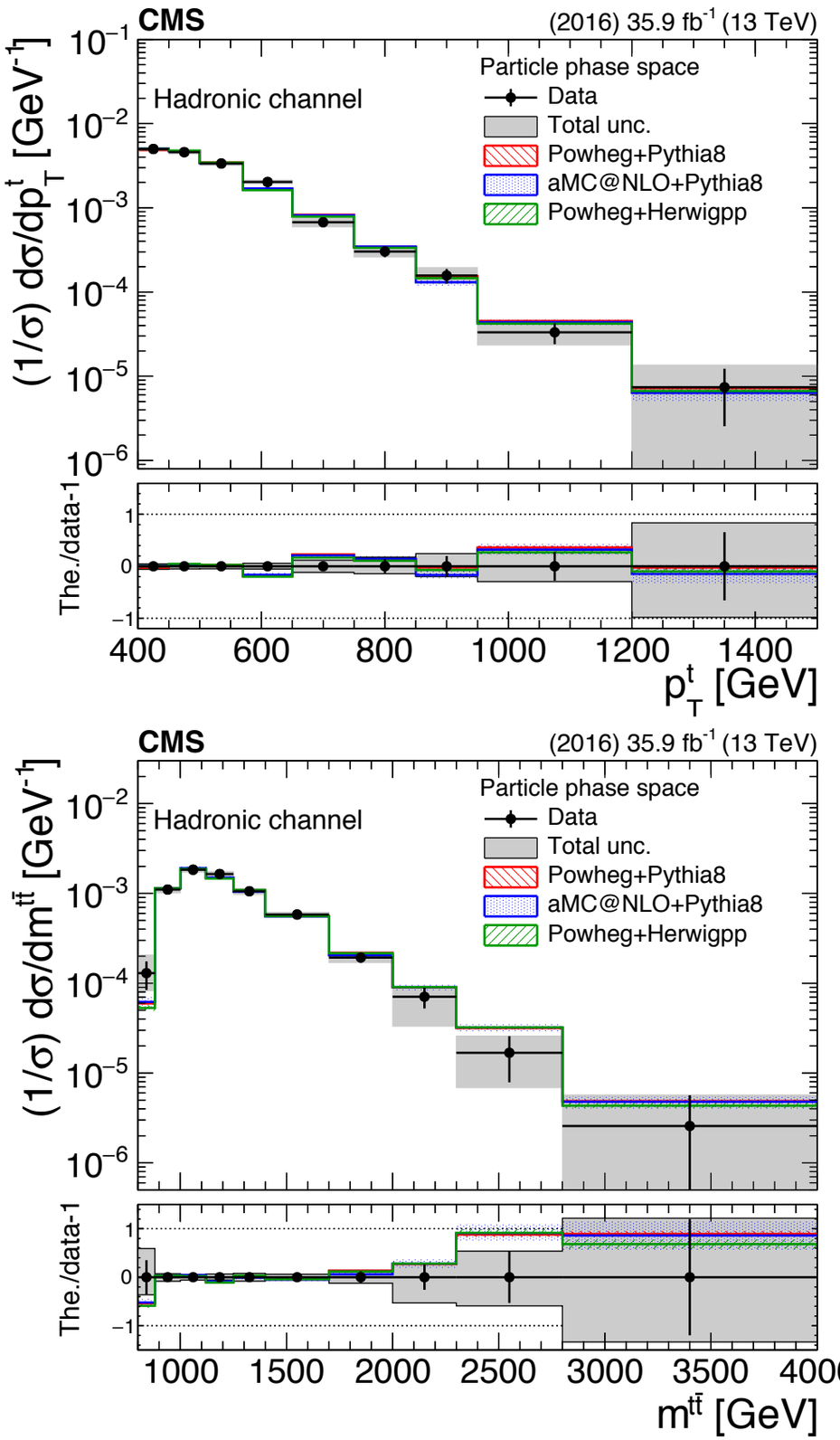




Results (particle, top p_T, m_{tt})

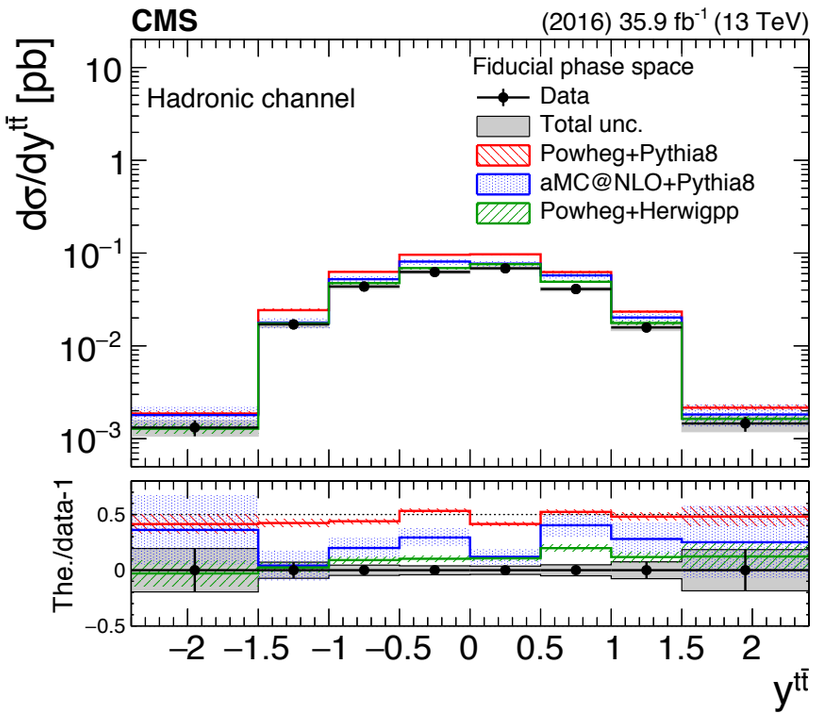
paper

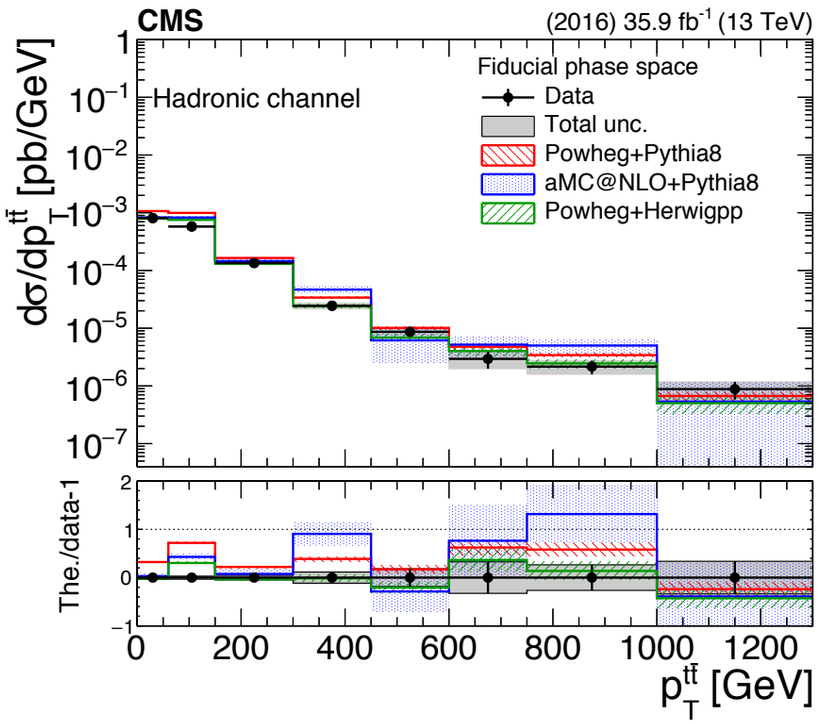


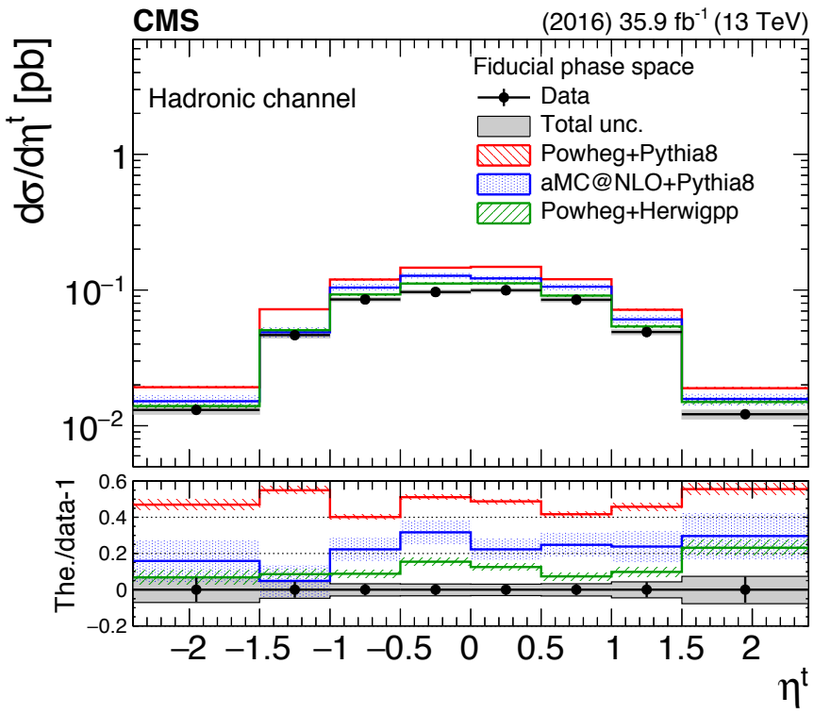


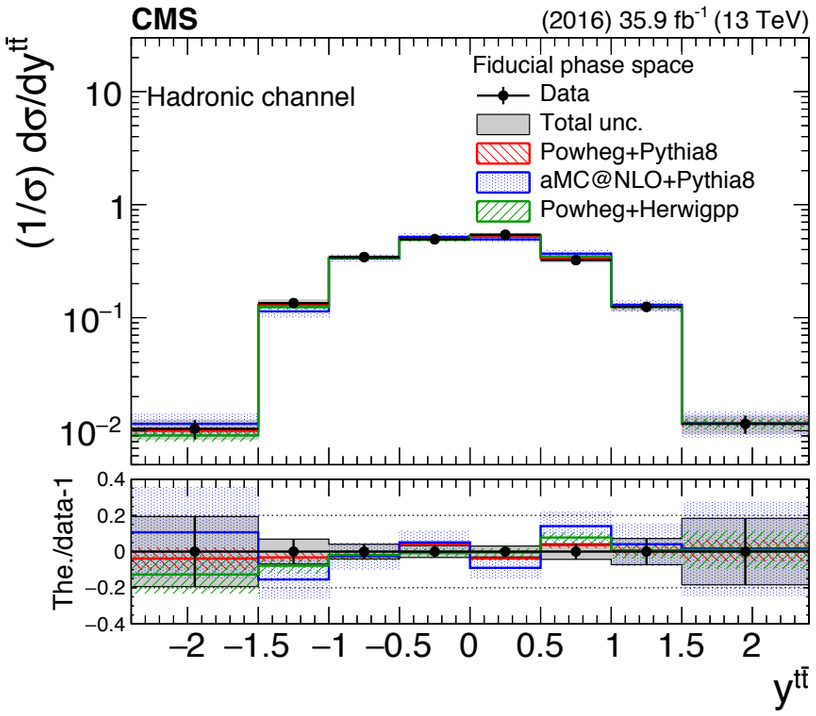
Results (fiducial, top η, y_{tt}, $p_{T,tt}$)

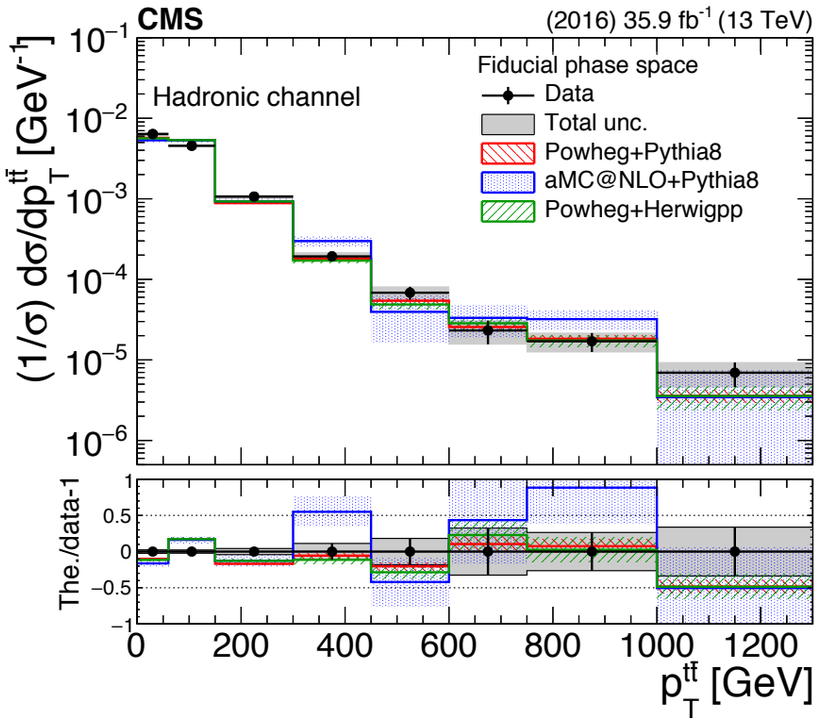
paper

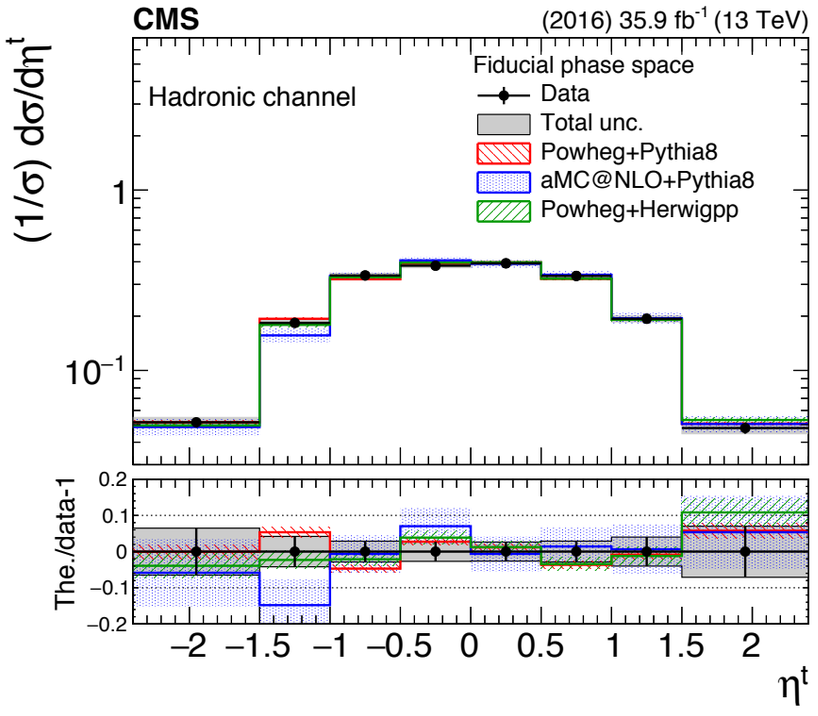






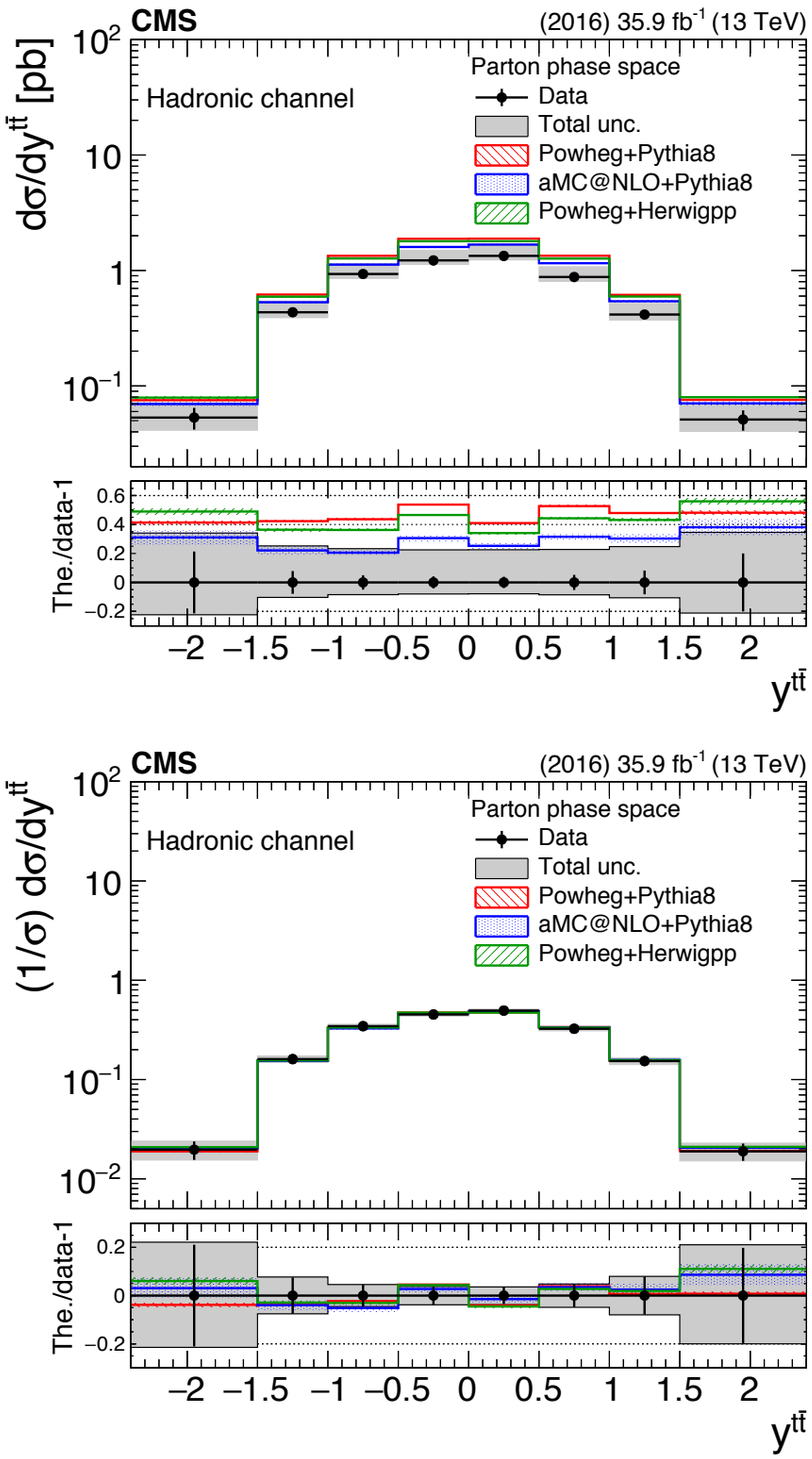


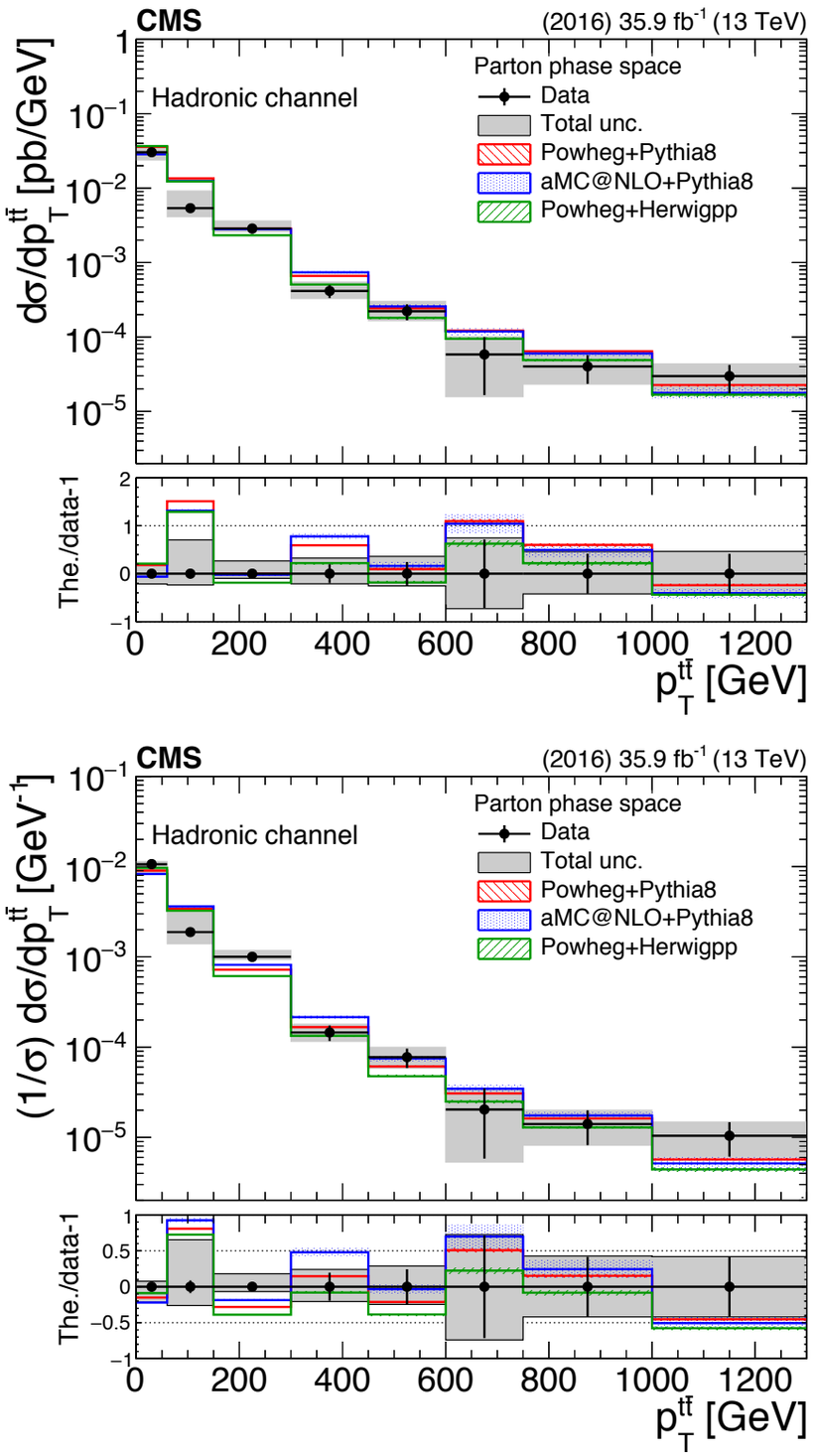


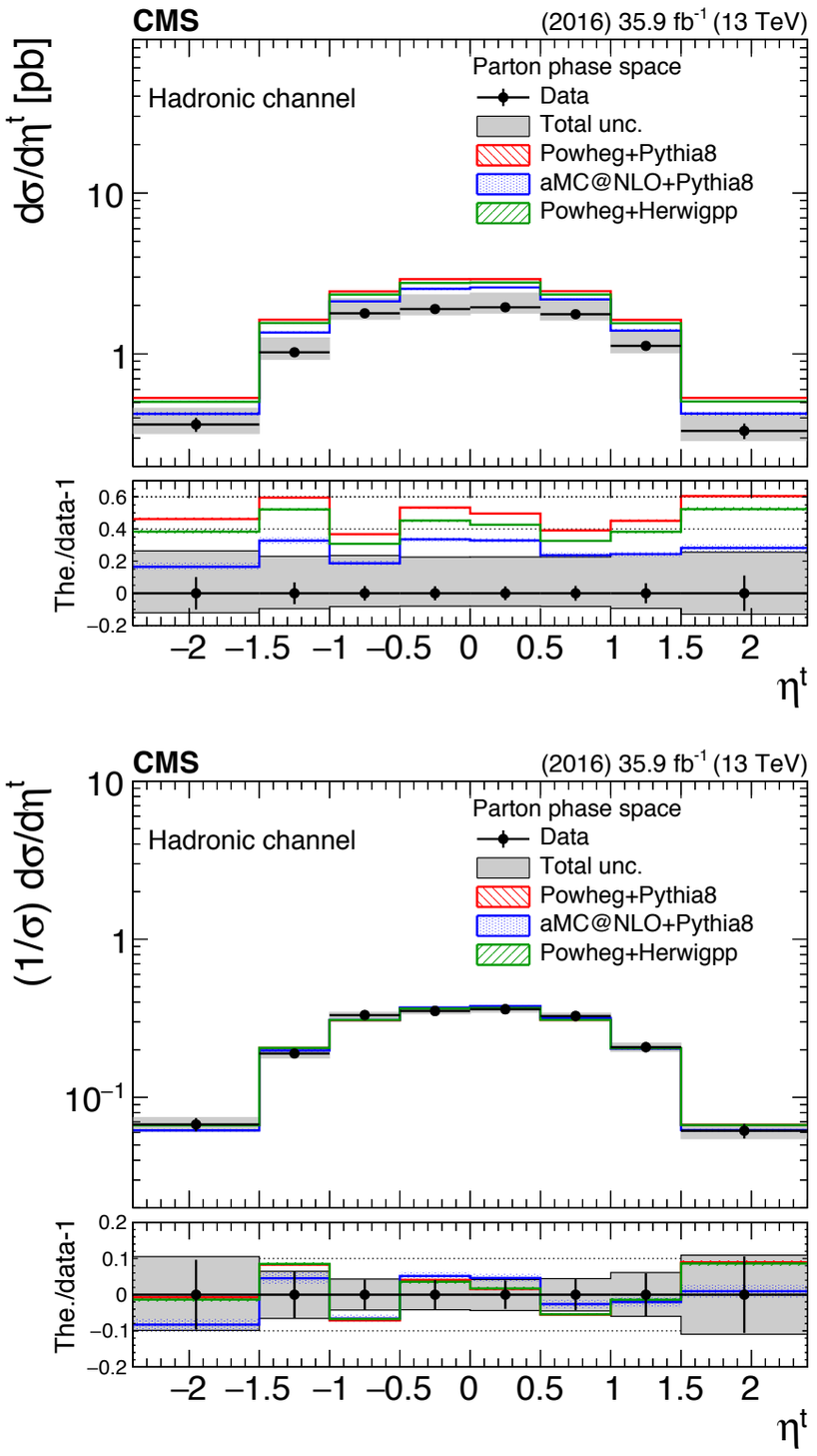


Results (parton, top η, y_{tt}, $p_{T,tt}$)

paper

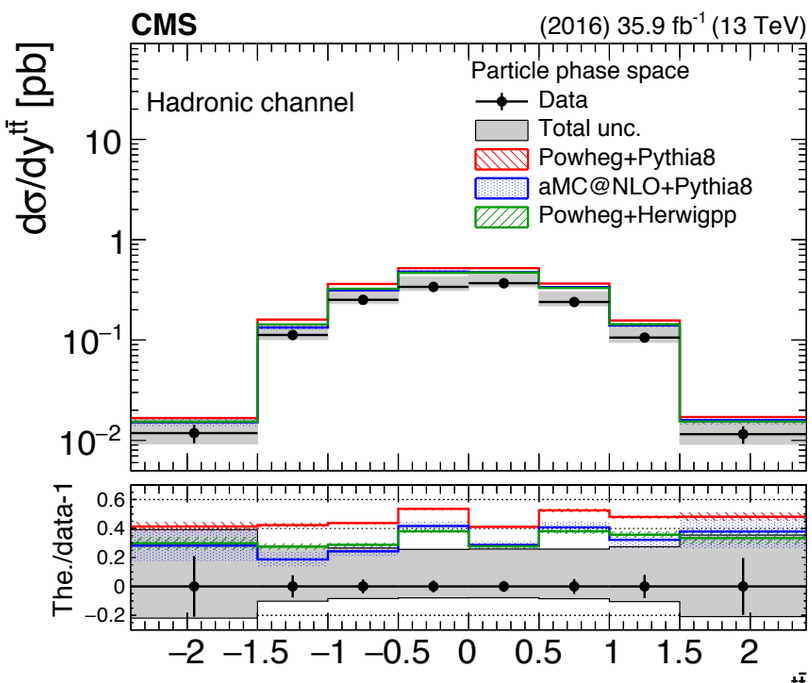


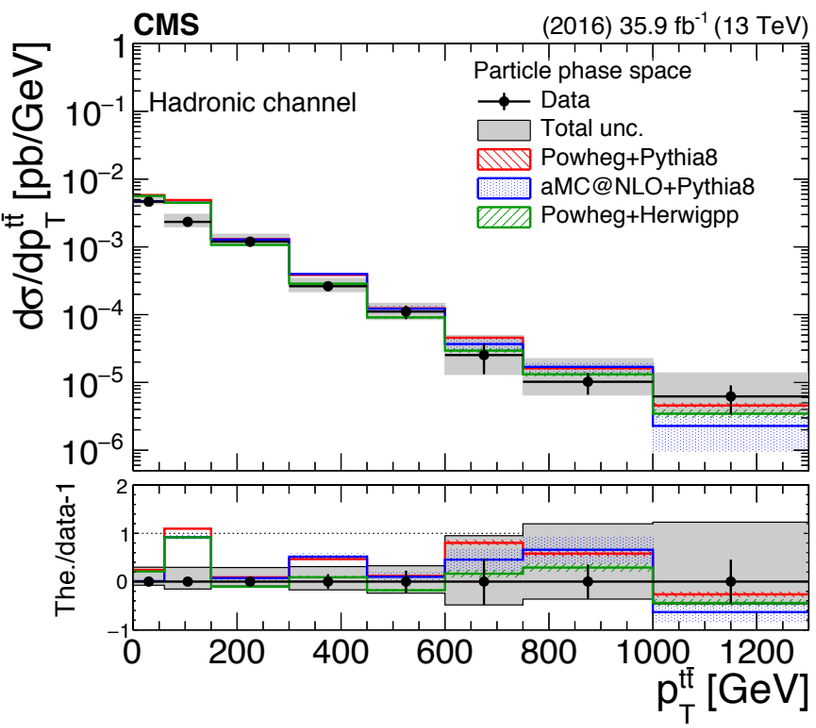


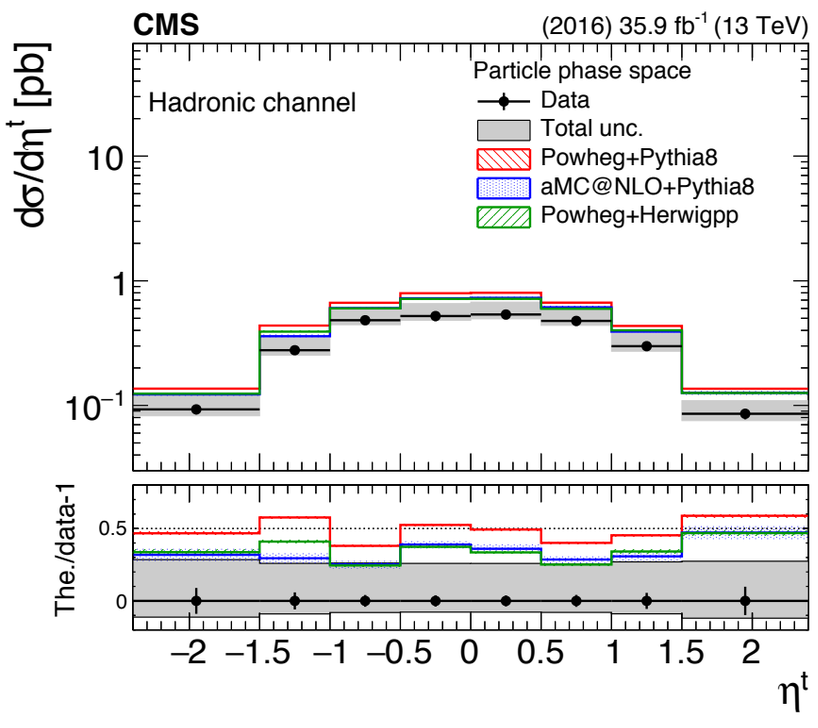


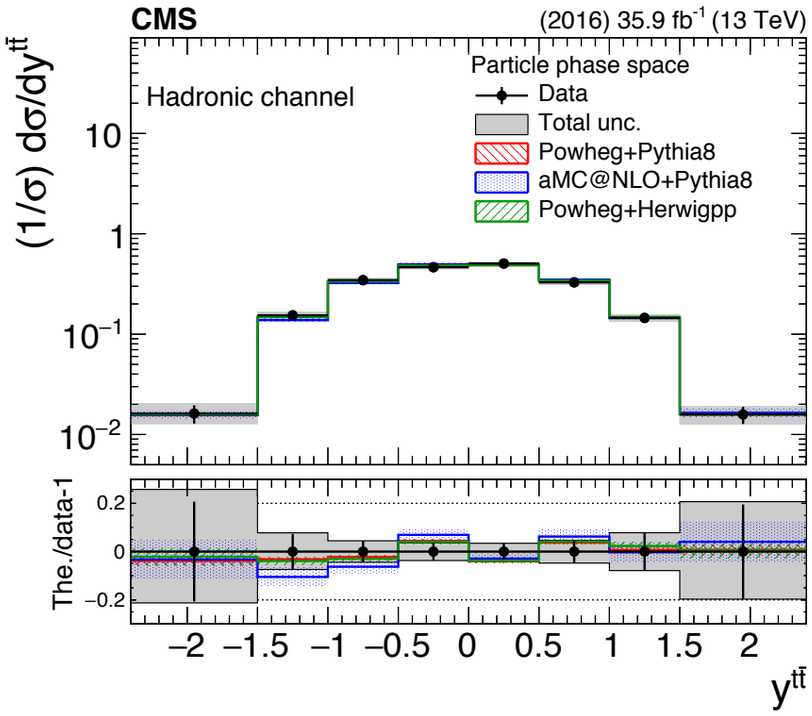
Results (particle, top η, y_{tt}, $p_{T,tt}$)

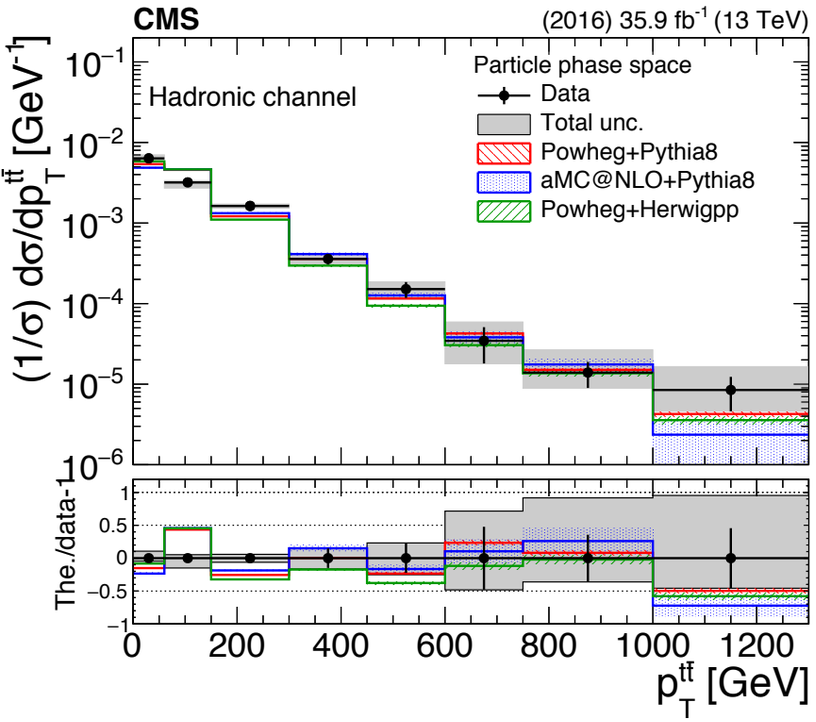
paper

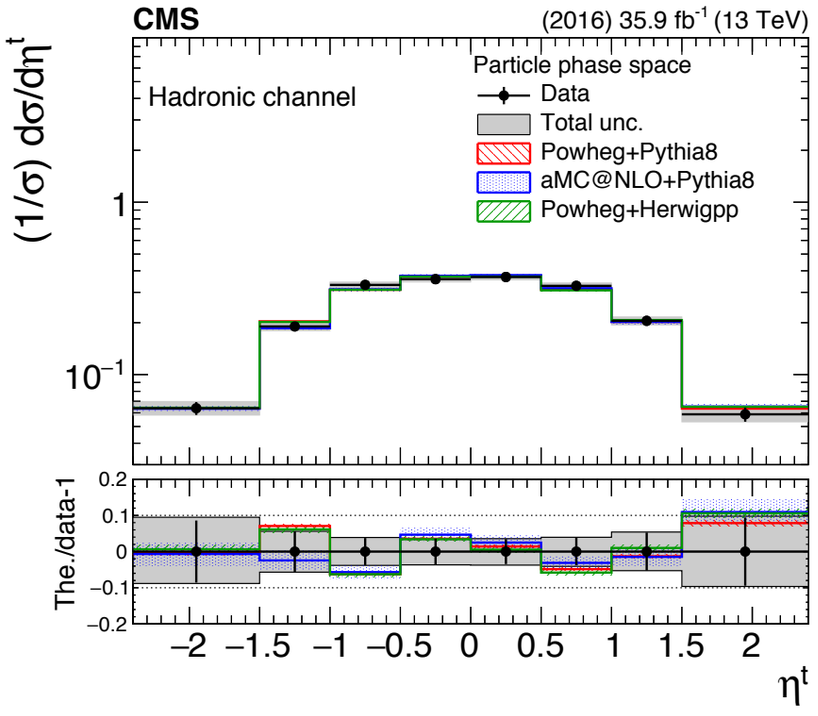










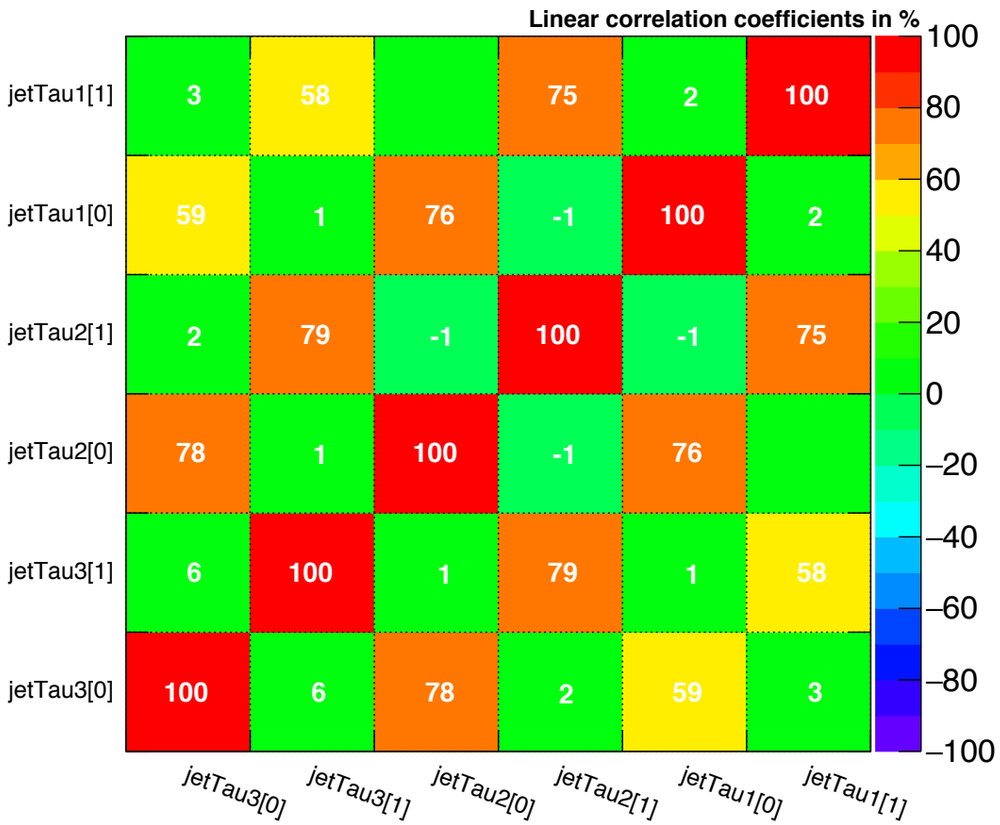


Summary

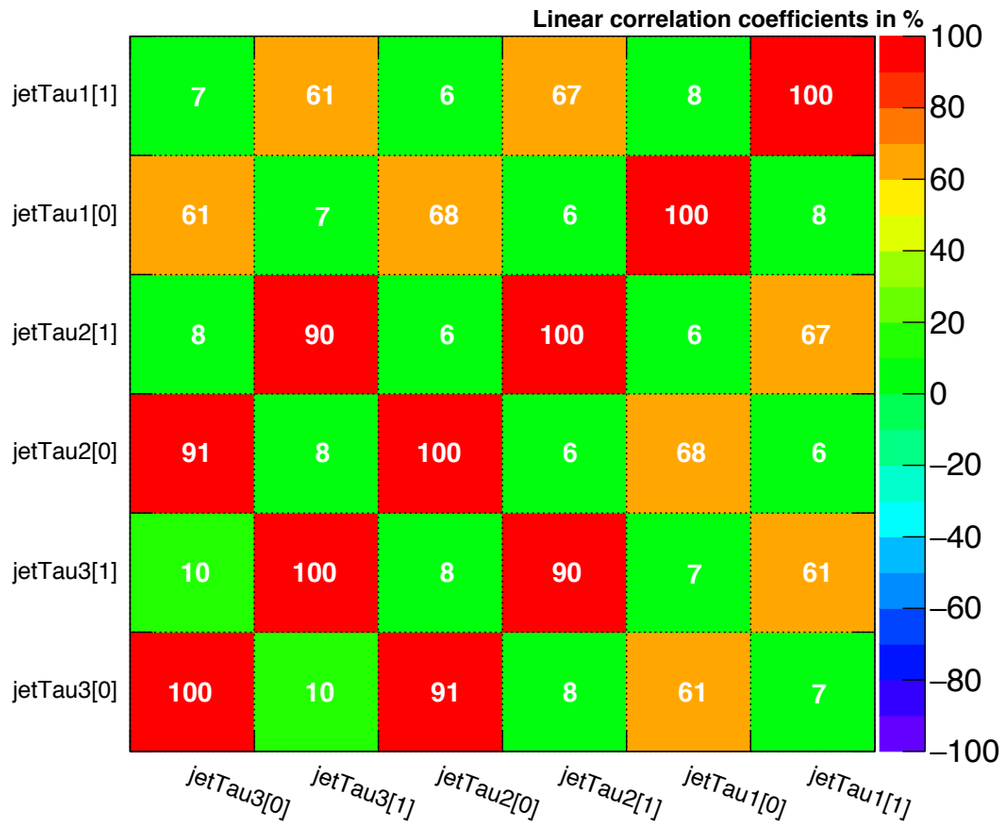
- ✦ we have performed a measurement of differential ttbar cross section with boosted top quarks in the hadronic channel
  - 2016 data, 35.9 fb^{-1}
  - highest reach so far: 1.5 TeV in top p_T and 4 TeV in m_{tt}
- ✦ five observables: inclusive top p_T & η, m_{tt}, $p_{t,TT}$, y_{TT}
  - fiducial, parton, particle level
  - absolute & normalised cross sections
- ✦ results
  - comparison with MC models: Powheg+Pythia8, Powheg+Herwig++, aMC@NLO+Pythia8
  - shapes overall compatible with theory
    - no top p_T slope *(food for thought: does it make sense to recommend top p_T reweighting in the full spectrum??)*
  - overall shift of the order of 40% in the total cross section (Powheg+Pythia8 shows the largest discrepancy)
- ✦ we seek the pre-approval of TOP-18-013

MVA training: correlation matrices

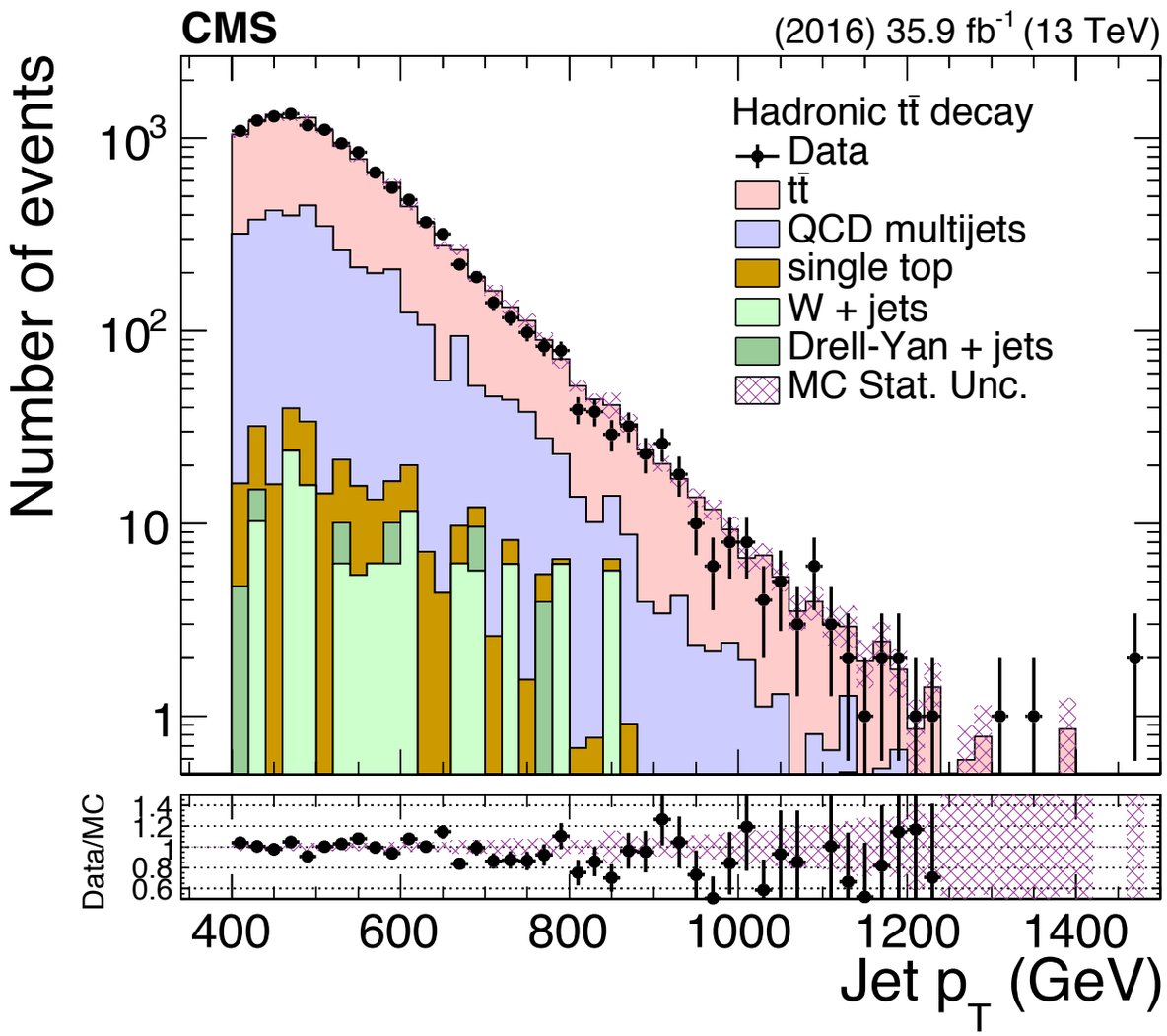
Correlation Matrix (signal)

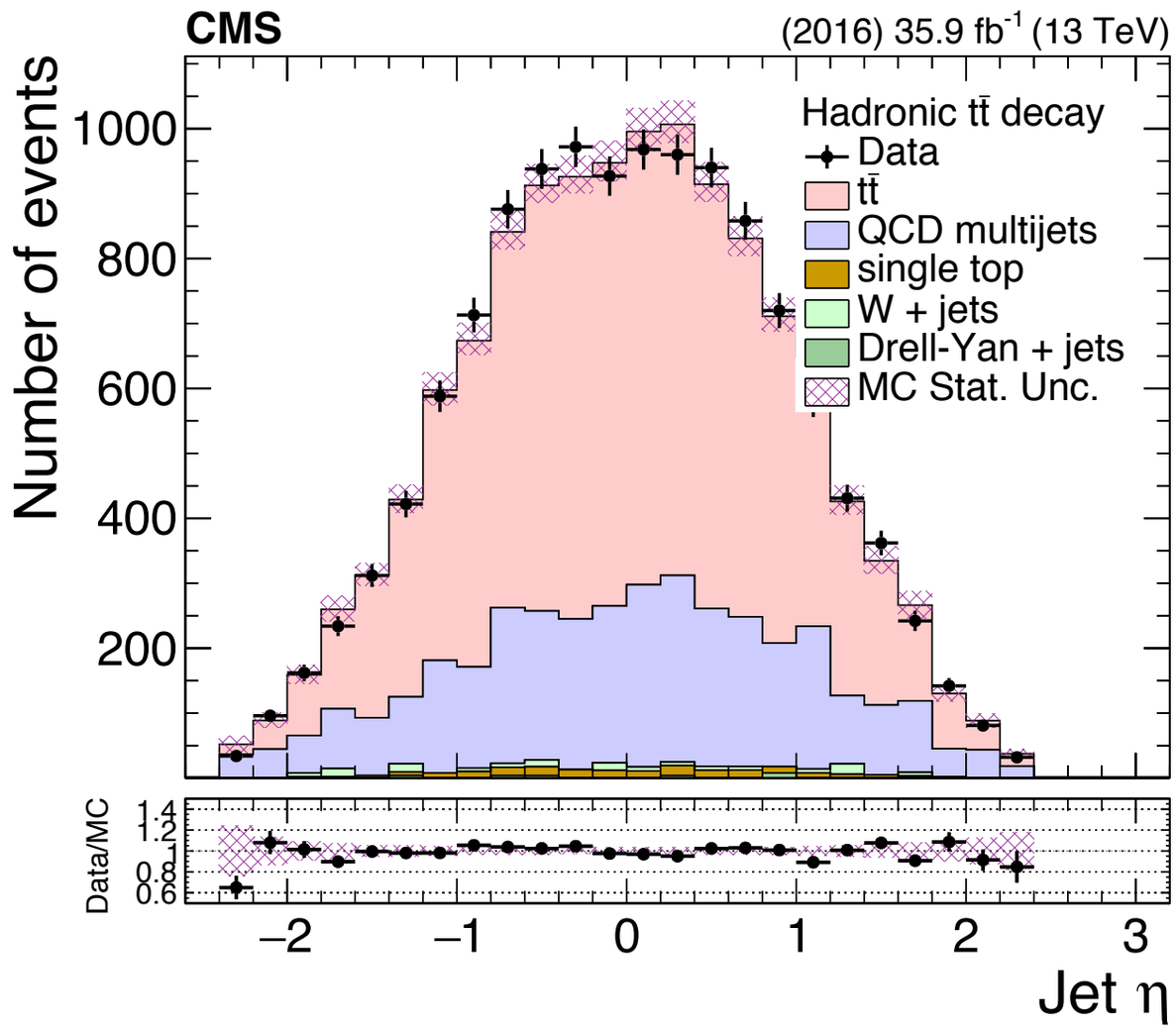


Correlation Matrix (background)

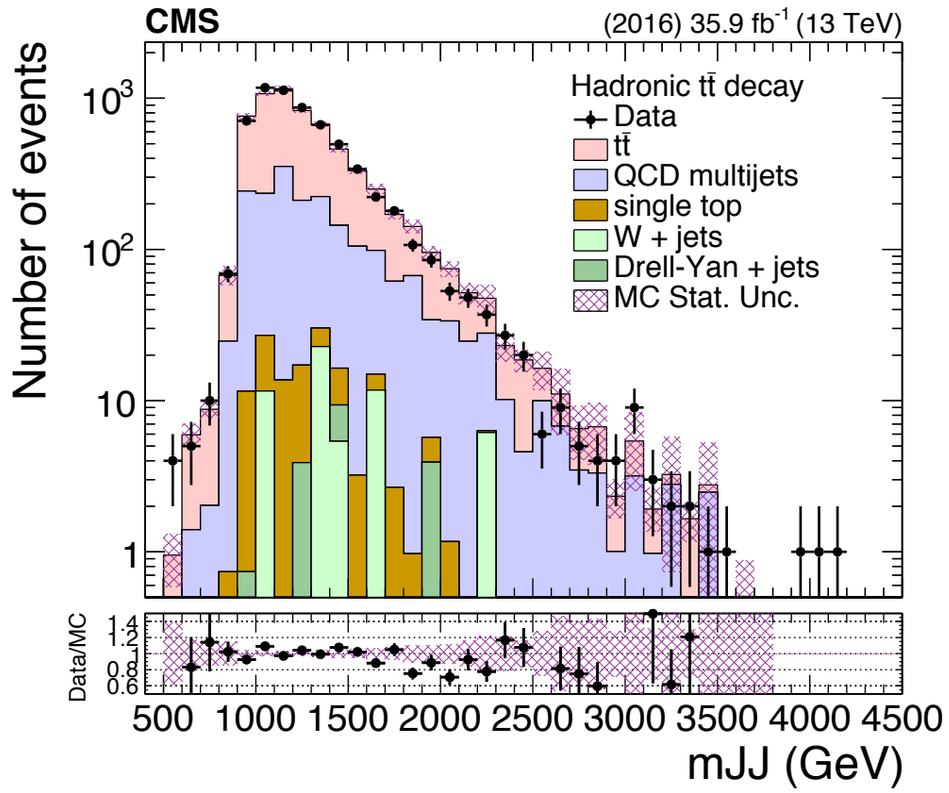


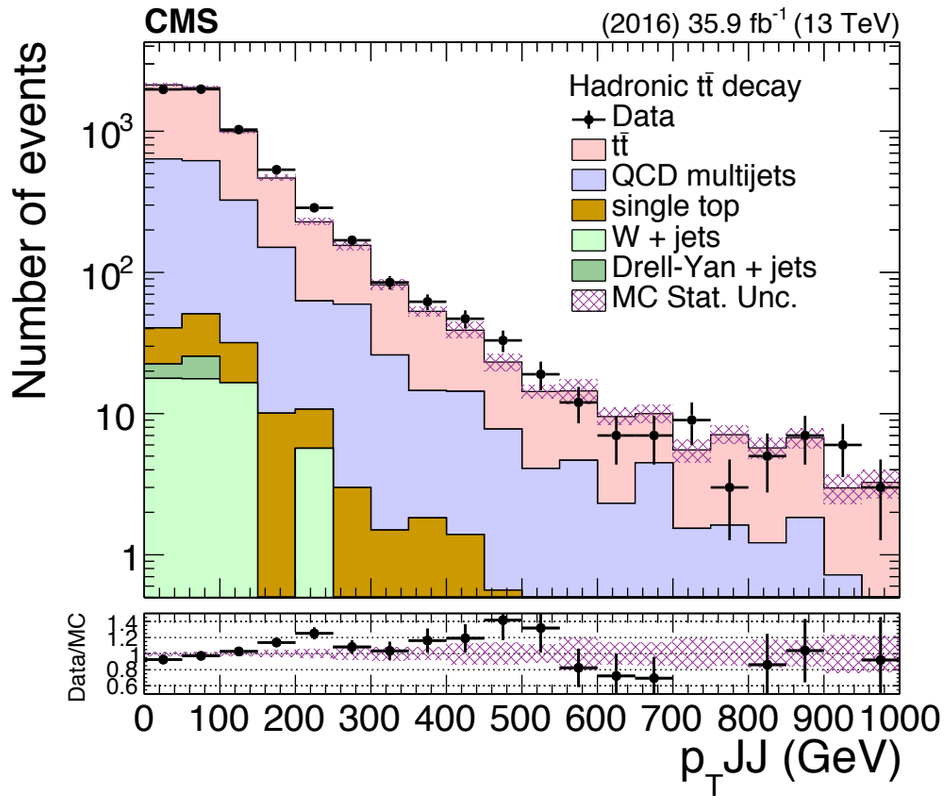
Data vs MC: top kinematics

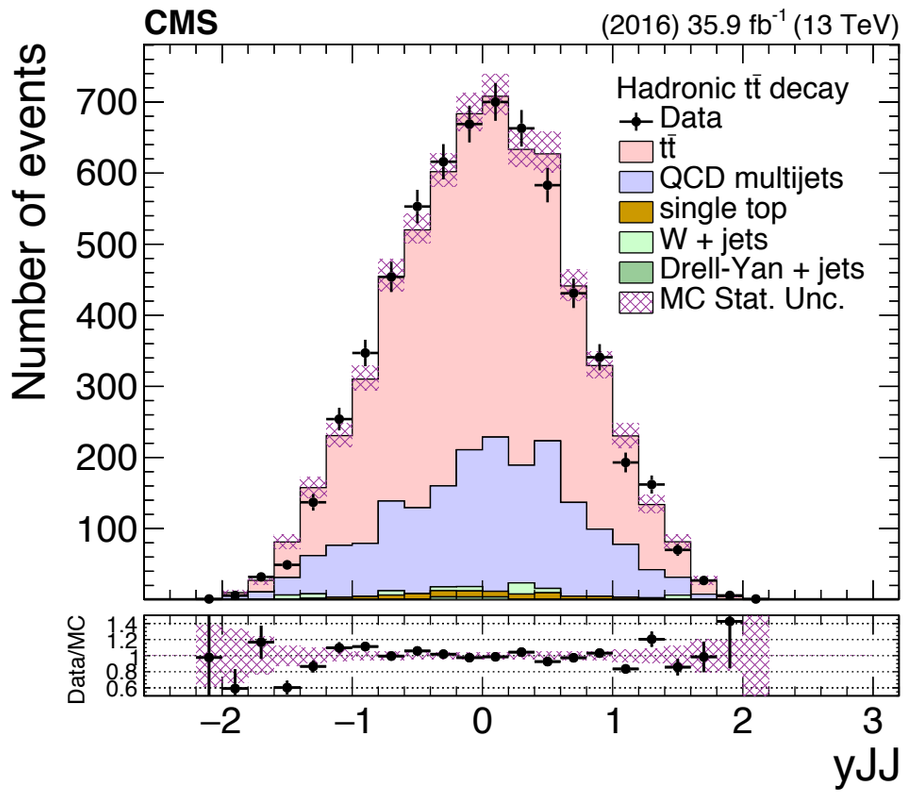




Data vs MC: ttbar kinematics

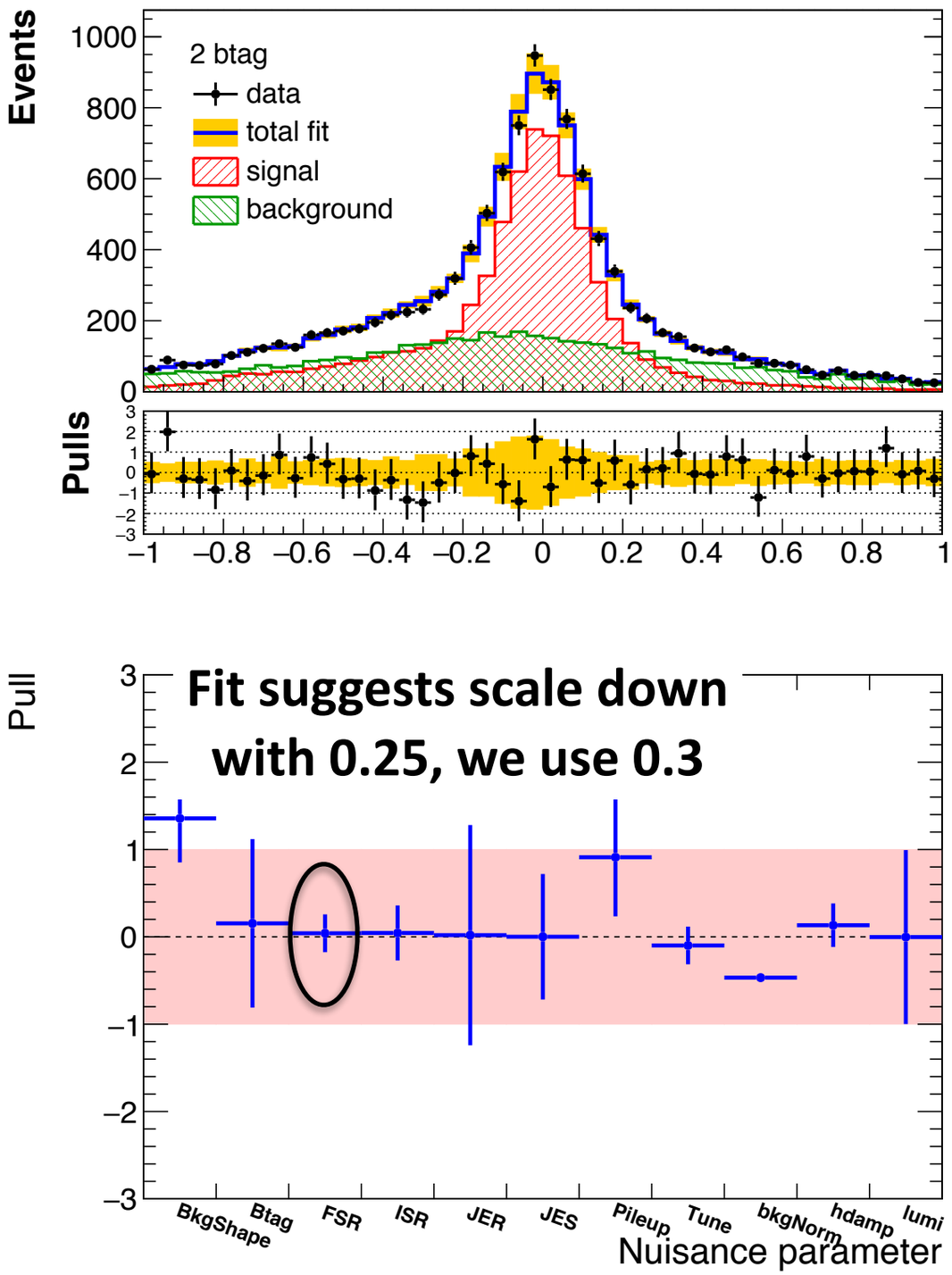


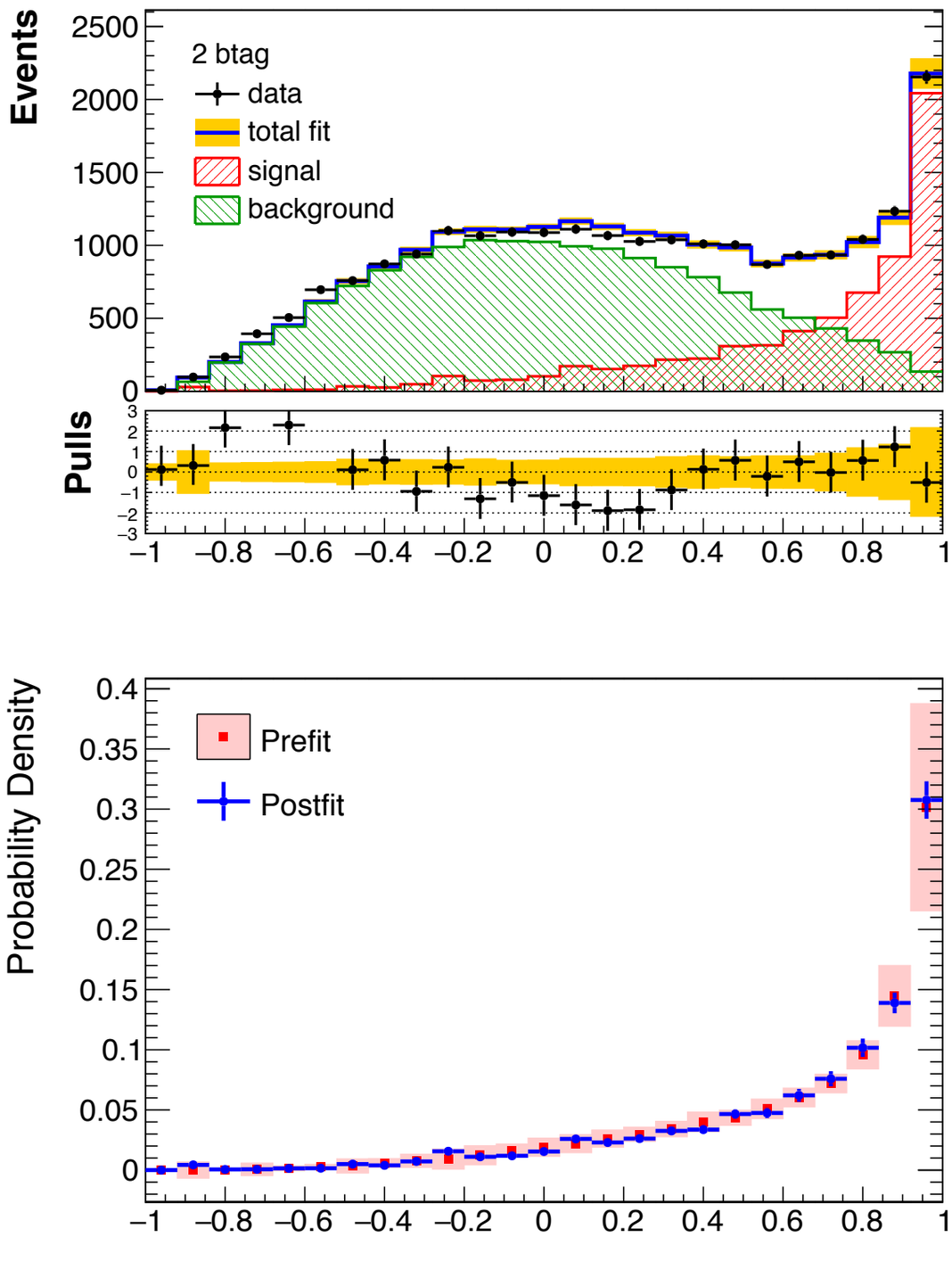




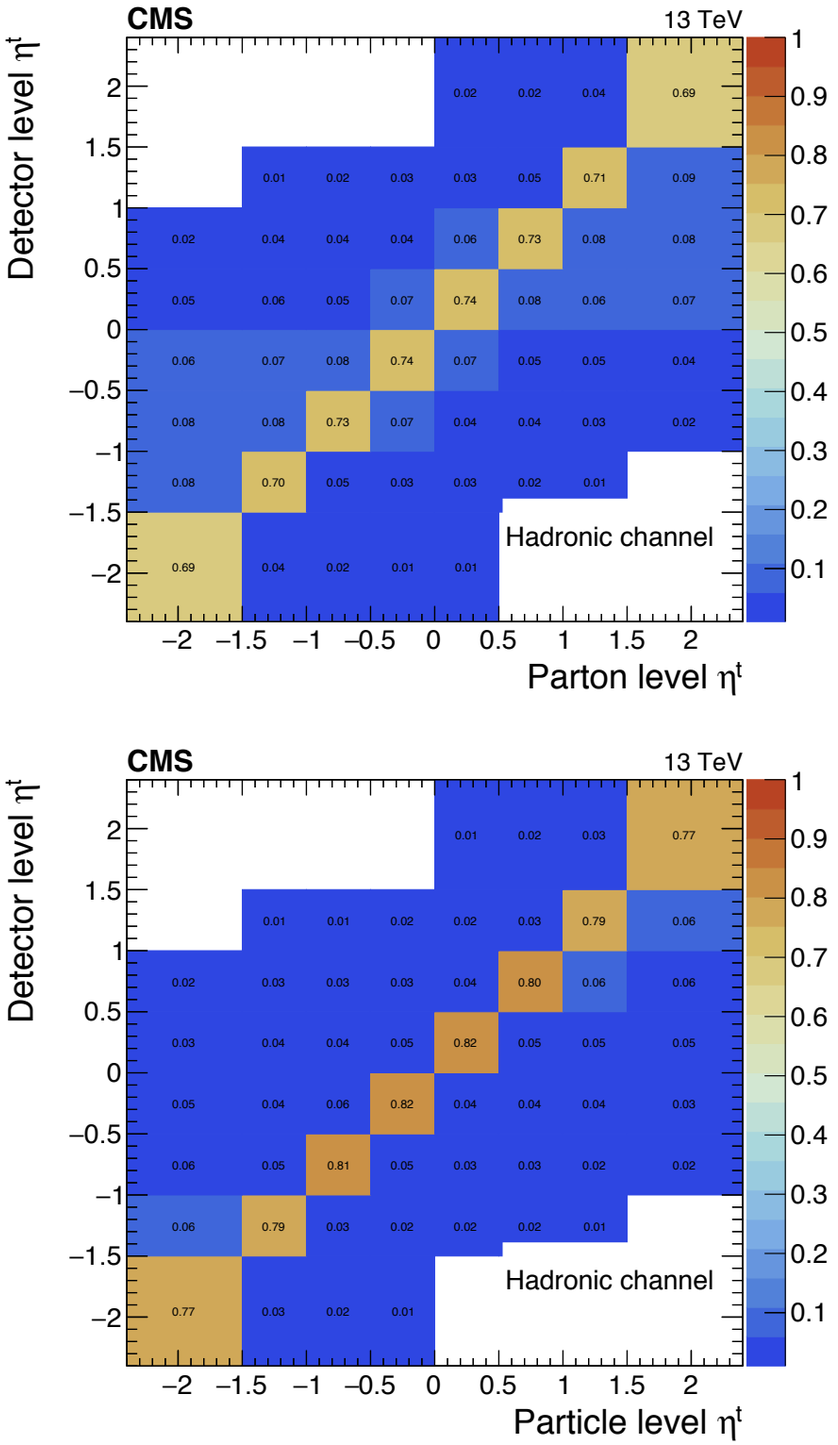
In situ constraint of the FSR uncertainty

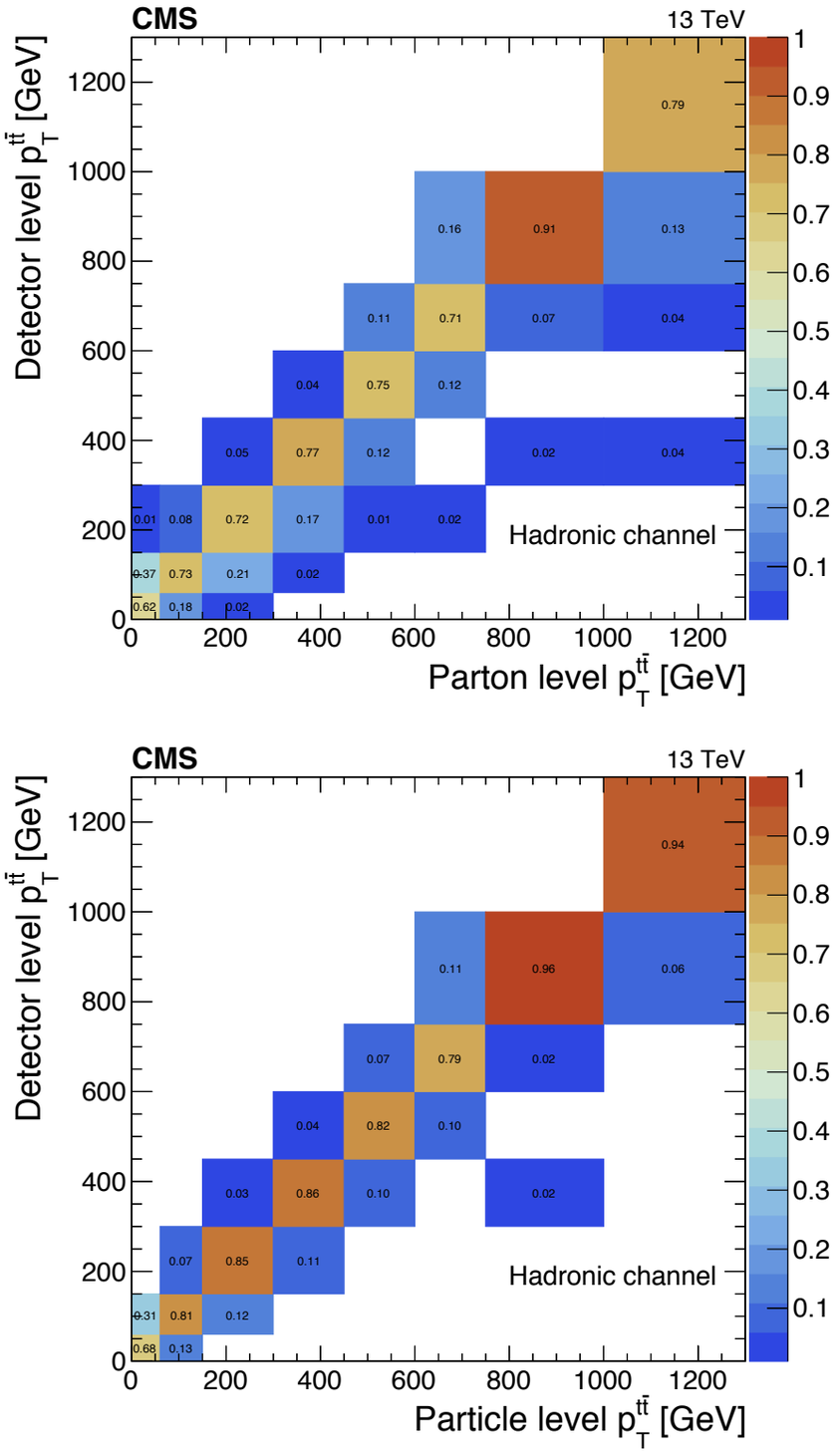
Template fits with *Combine*

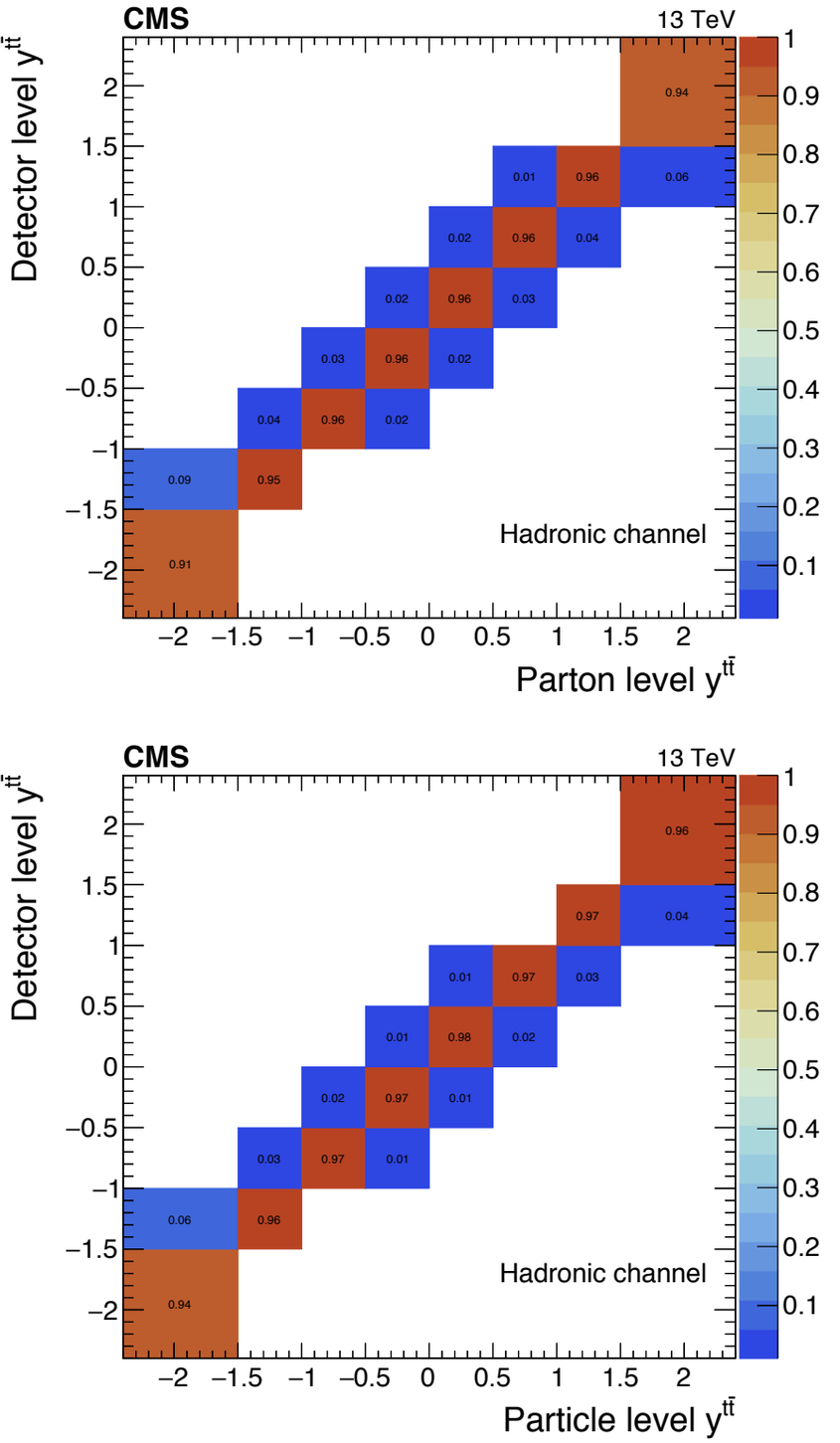




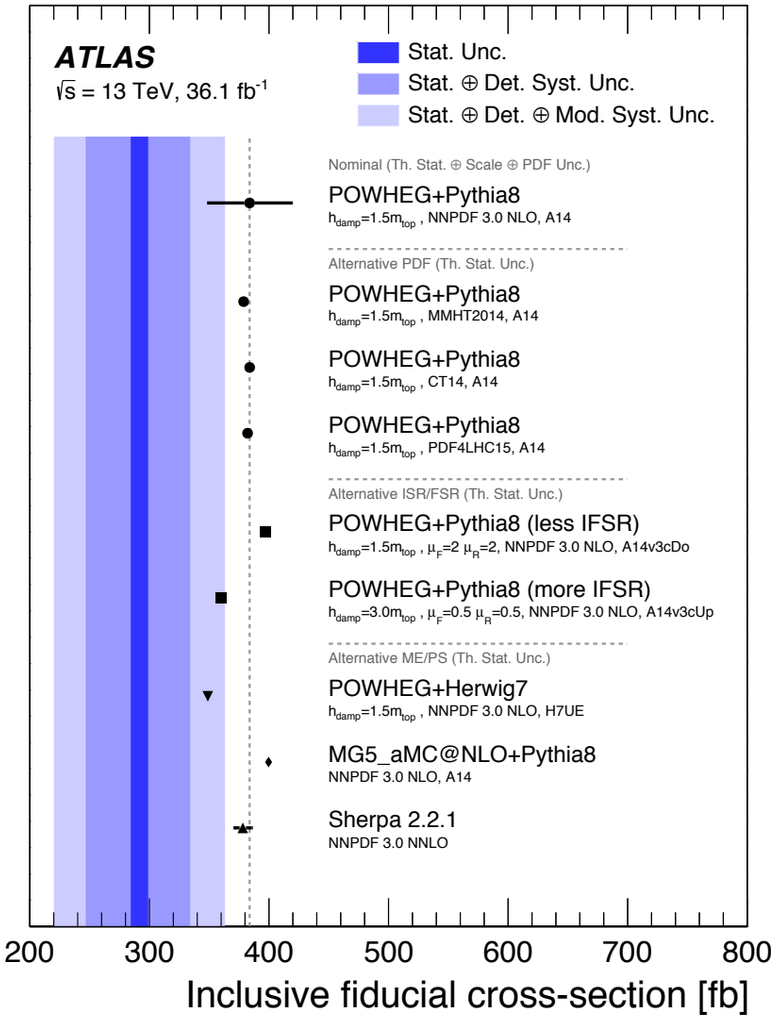
Migration matrices

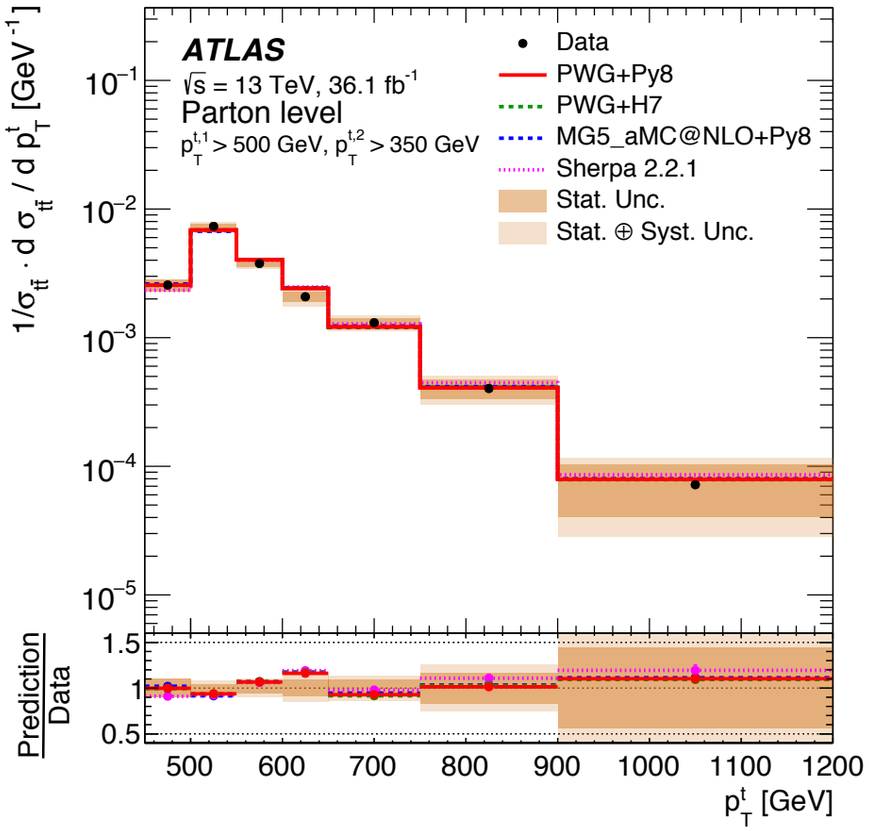


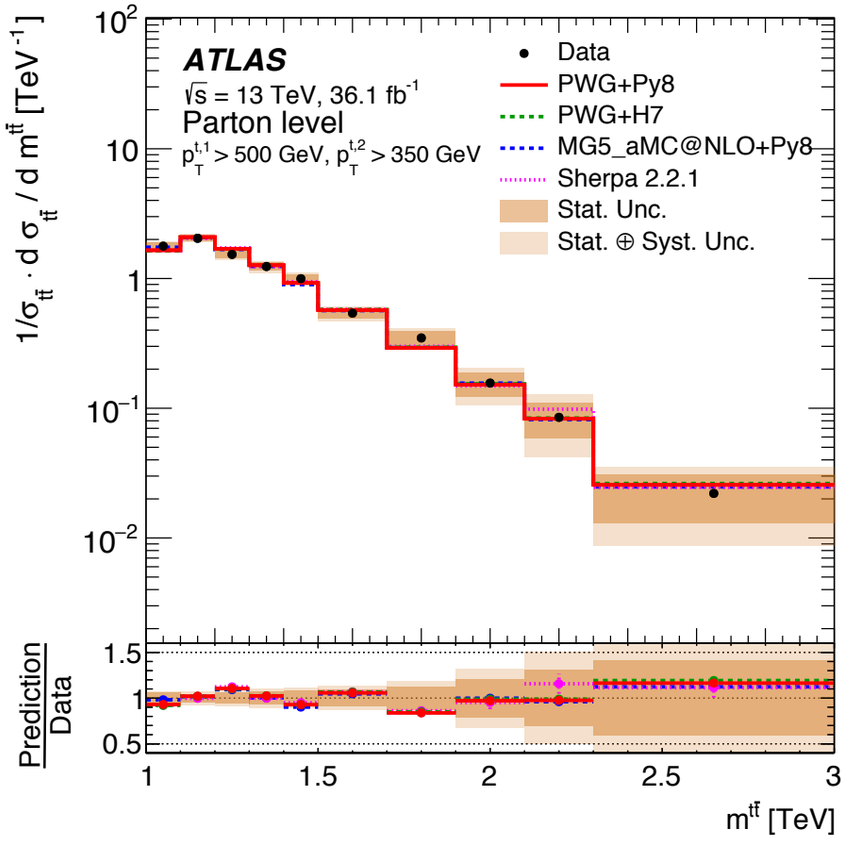




ATLAS results







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