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)

Approval presentation

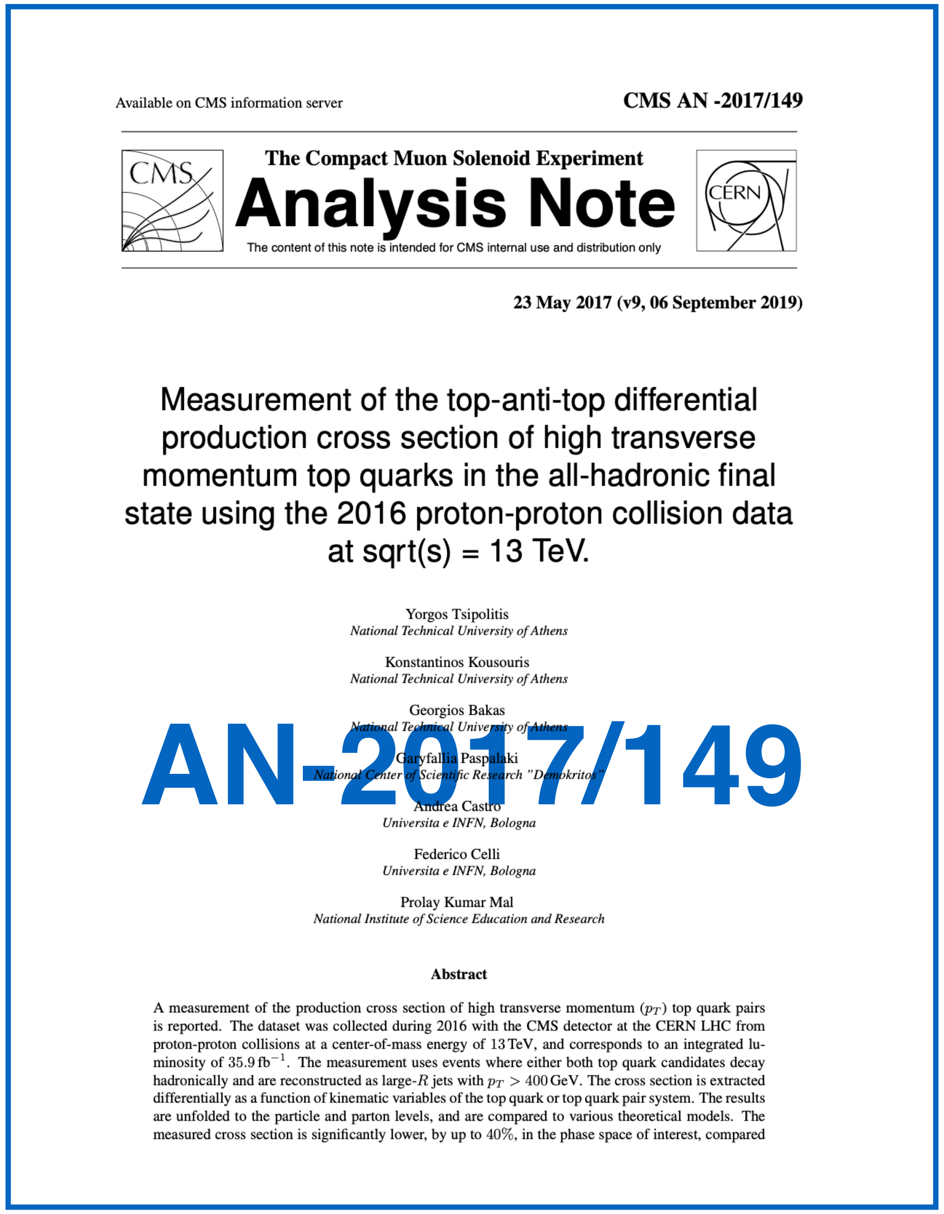
10 December 2019

(l+jets team)

S. Dittmer, L. Skinnari, J. Thom

(hadronic team)

G. Bakas, K. Kousouris, G. Paspalaki, G. Tsipolitis,



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CMS AN -2017/149

The Compact Muon Solenoid Experiment

Analysis Note

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23 May 2017 (v9, 06 September 2019)

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

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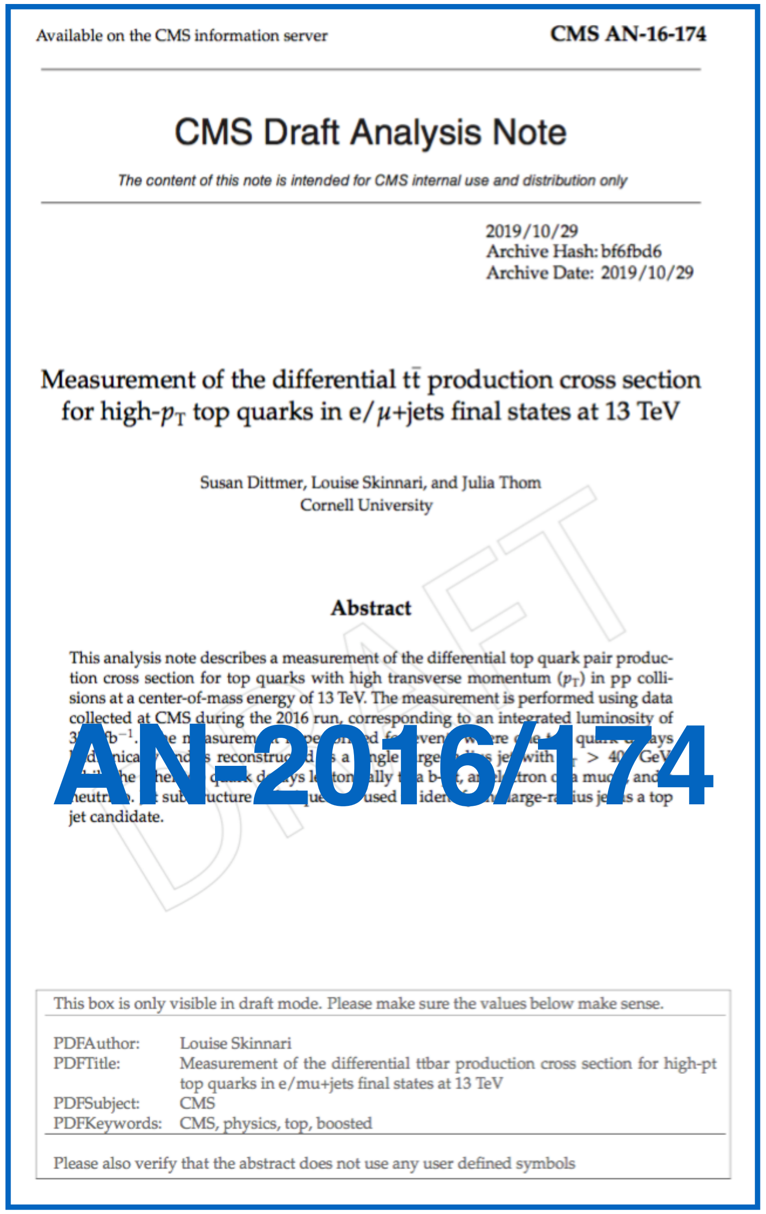
Abstract

A measurement 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 $p_T > 400$ GeV. The cross section is extracted differentially as a function of kinematic variables of the top quark or top quark pair system. The results are unfolded to the particle and parton levels, and are compared to various theoretical models. The measured cross section is significantly lower, by up to 40%, in the phase space of interest, compared



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CMS AN-16-174

CMS Draft Analysis Note

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2019/10/29
Archive Hash: bf6fbd6
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Measurement of the differential $t\bar{t}$ production cross section for high-p_T top quarks in e/μ+jets final states at 13 TeV

Susan Dittmer, Louise Skinnari, and Julia Thom
Cornell University

Abstract

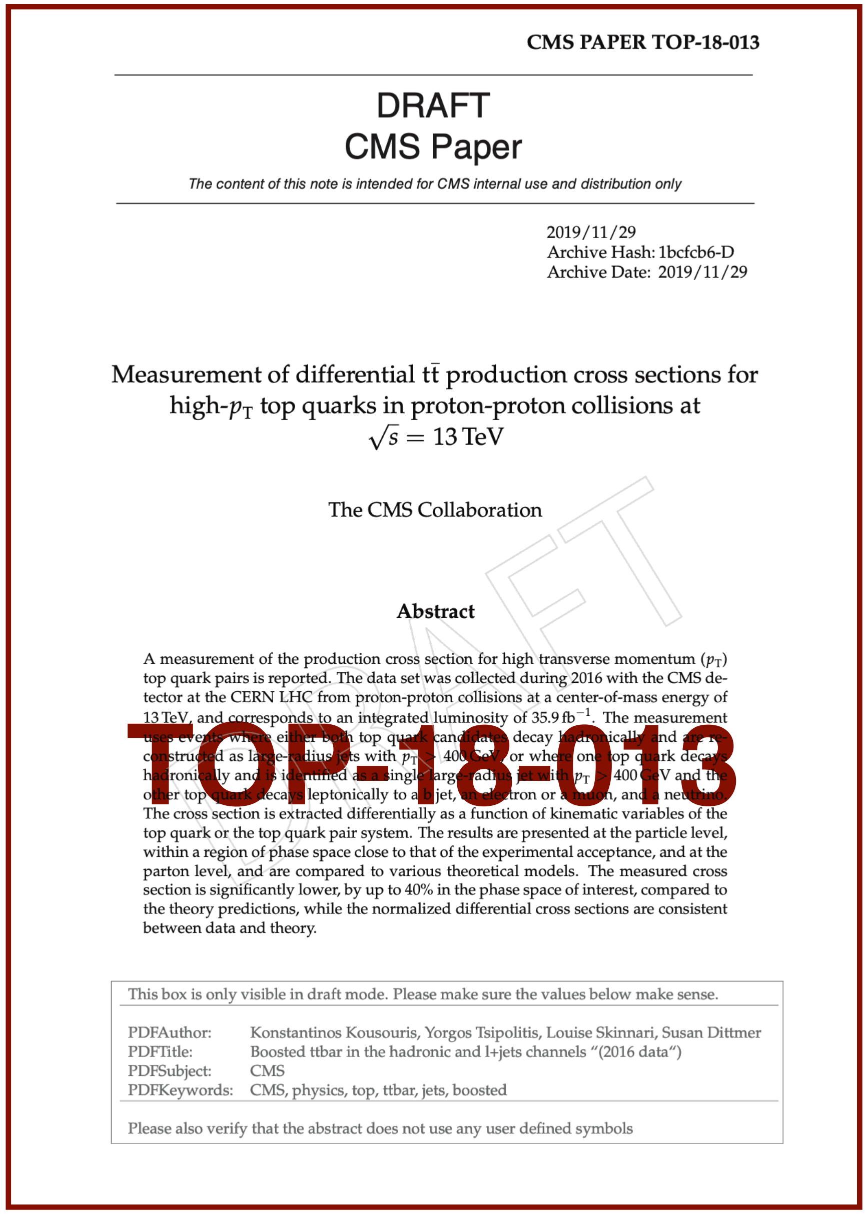
This analysis note describes a measurement of the differential top quark pair production cross section for top quarks with high transverse momentum (p_T) in pp collisions at a center-of-mass energy of 13 TeV. The measurement is performed using data collected at CMS during the 2016 run, corresponding to an integrated luminosity of ...

jet candidate.

This box is only visible in draft mode. Please make sure the values below make sense.

PDFAuthor:	Louise Skinnari
PDFTitle:	Measurement of the differential ttbar production cross section for high-pt top quarks in e/mu+jets final states at 13 TeV
PDFSubject:	CMS
PDFKeywords:	CMS, physics, top, boosted

Please also verify that the abstract does not use any user defined symbols



CMS PAPER TOP-18-013

DRAFT
CMS Paper

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2019/11/29
Archive Hash: 1bcfcb6-D
Archive Date: 2019/11/29

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

The CMS Collaboration

Abstract

A measurement of the production cross section for high transverse momentum (p_T) top quark pairs is reported. The data set 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 ... The cross section is extracted differentially as a function of kinematic variables of the top quark or the top quark pair system. The results are presented at the particle level, within a region of phase space close to that of the experimental acceptance, and at the parton level, and are 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.

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PDFAuthor:	Konstantinos Kousouris, Yorgos Tsipolitis, Louise Skinnari, Susan Dittmer
PDFTitle:	Boosted ttbar in the hadronic and l+jets channels "(2016 data")
PDFSubject:	CMS
PDFKeywords:	CMS, physics, top, ttbar, jets, boosted

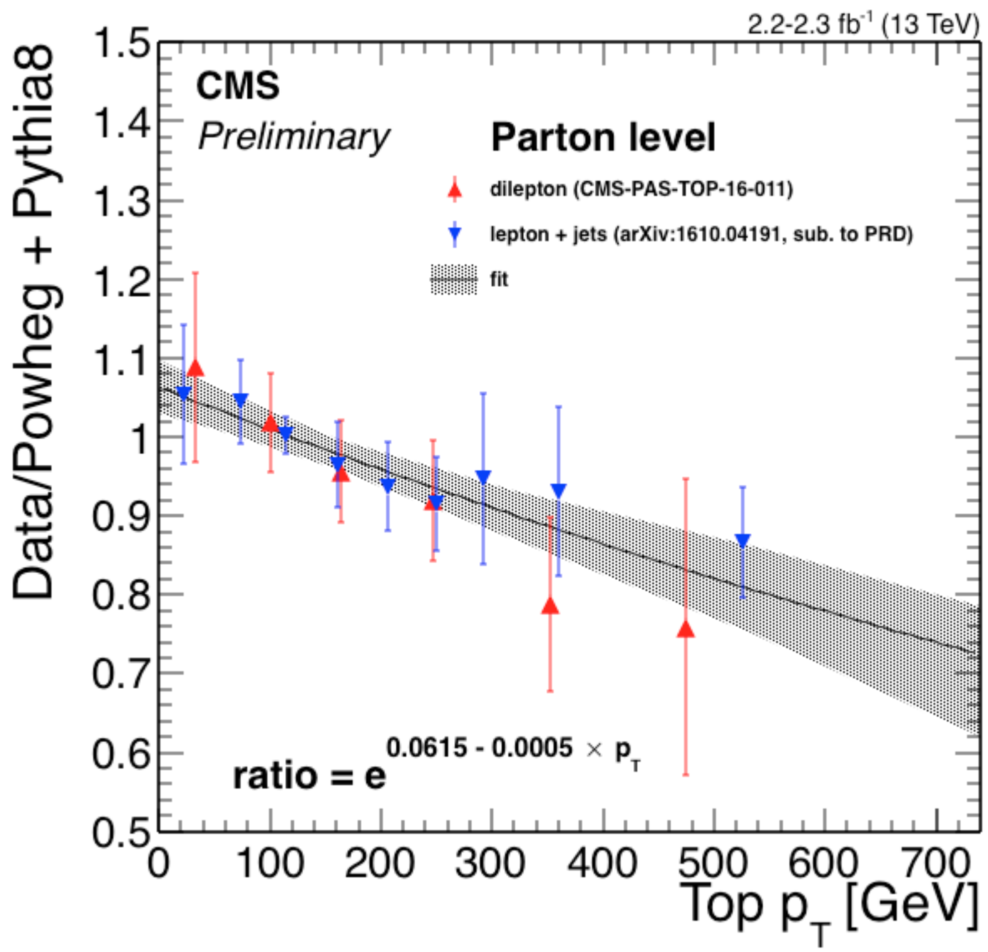
Please also verify that the abstract does not use any user defined symbols

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

ARC: **M. Mulders (chair)**, J. Hogan, A. Garcia-Bellido, G. Kasieczka

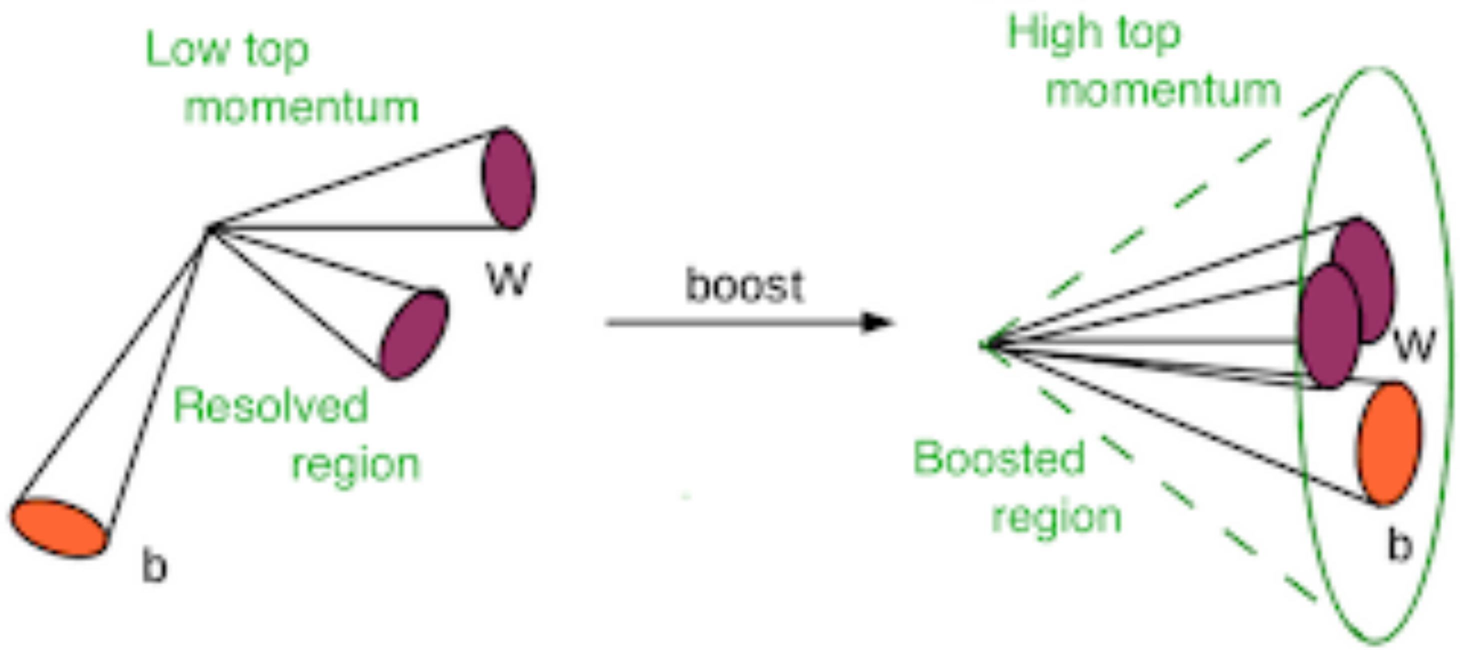
We are grateful to the Conveners and the ARC for their valuable help & constructive comments during the review process.

Motivation



- ✦ explore the kinematic region beyond the reach of the resolved analyses (p_T > 400 GeV)
  - ➡ sensitive to new physics
  - ➡ crucial test for perturbative QCD
- ✦ two distinct final states
  - ➡ l+jets (boosted hadronically decaying top quark & resolved leptonically decaying top)
  - ➡ hadonic (both boosted tops decaying hadronically)

boosted top decaying hadronically reconstructed as large-radius jet



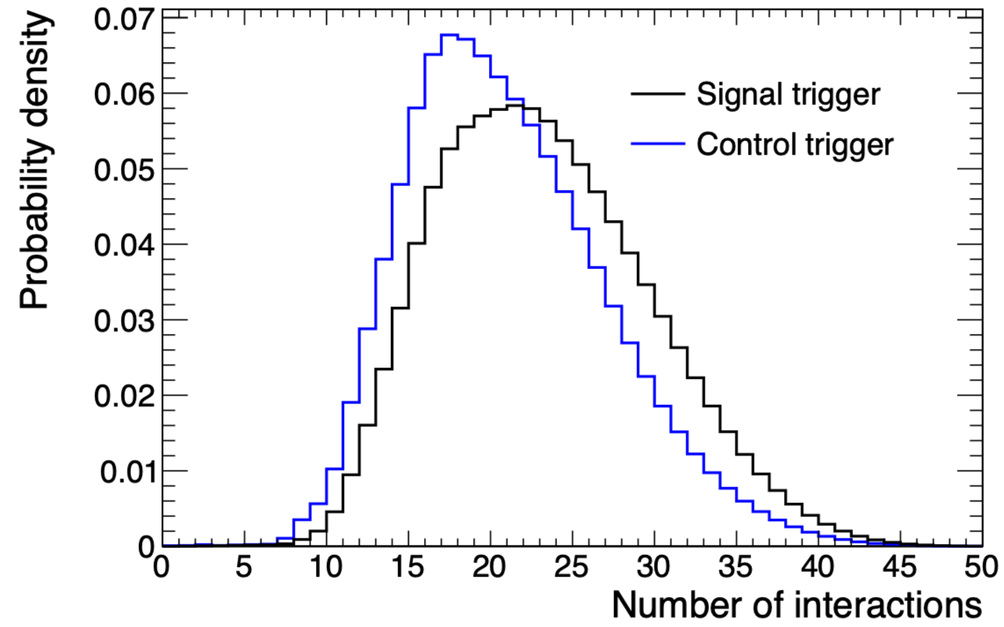
$p_T \sim 2M_t/R \sim 400$ GeV

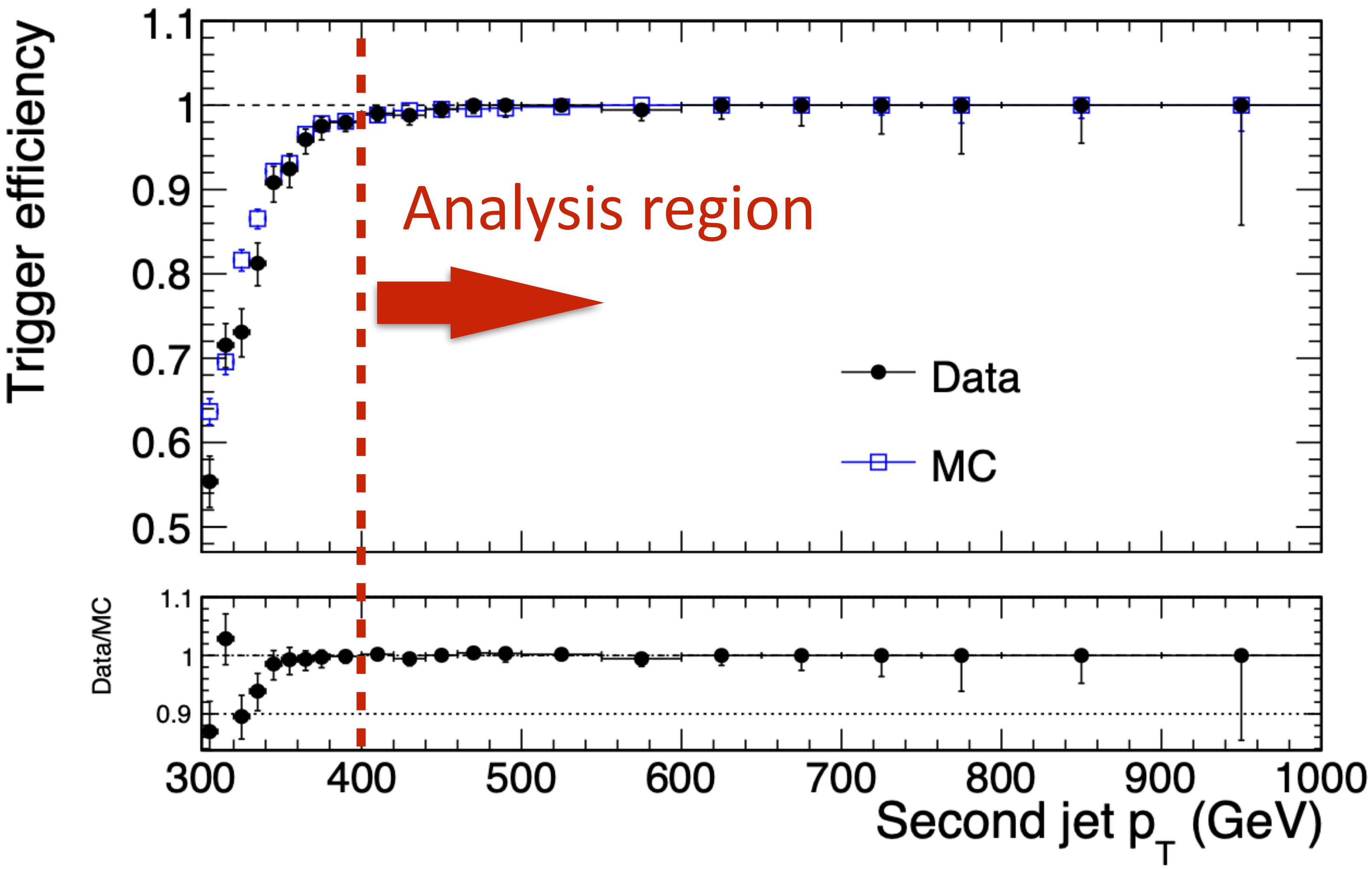
Analysis overview (hadronic)

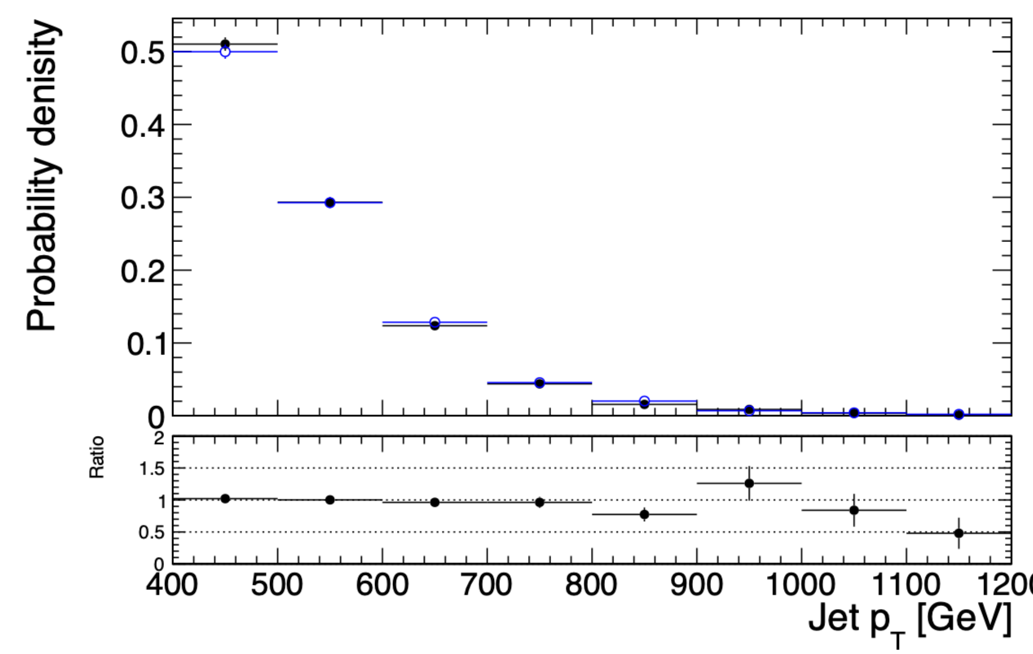
- **2016 dataset**
  - very well understood (calibrations, scale factors, etc)
  - working on the legacy measurement with full Run II dataset but it will take ~1 year to reach same level of maturity
- **Trigger:** two AK8 jets @ HLT and b tagging
- **Selection**
  - two AK8 jets with p_T > 400 GeV
  - “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
  - seven observables:leading & subleading top p_T & $|y|$, ttbar system mass, p_T & rapidity
  - 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)



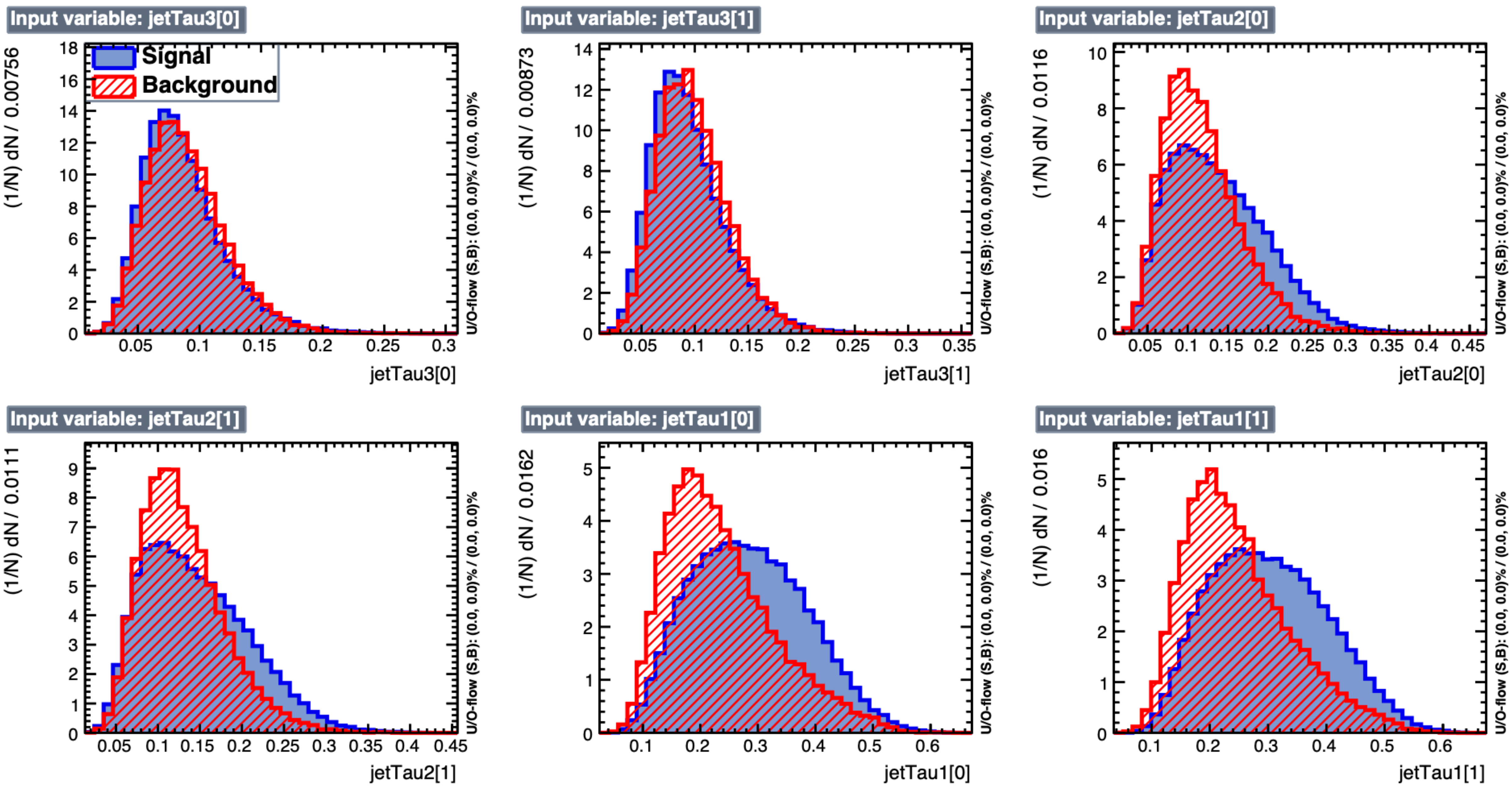




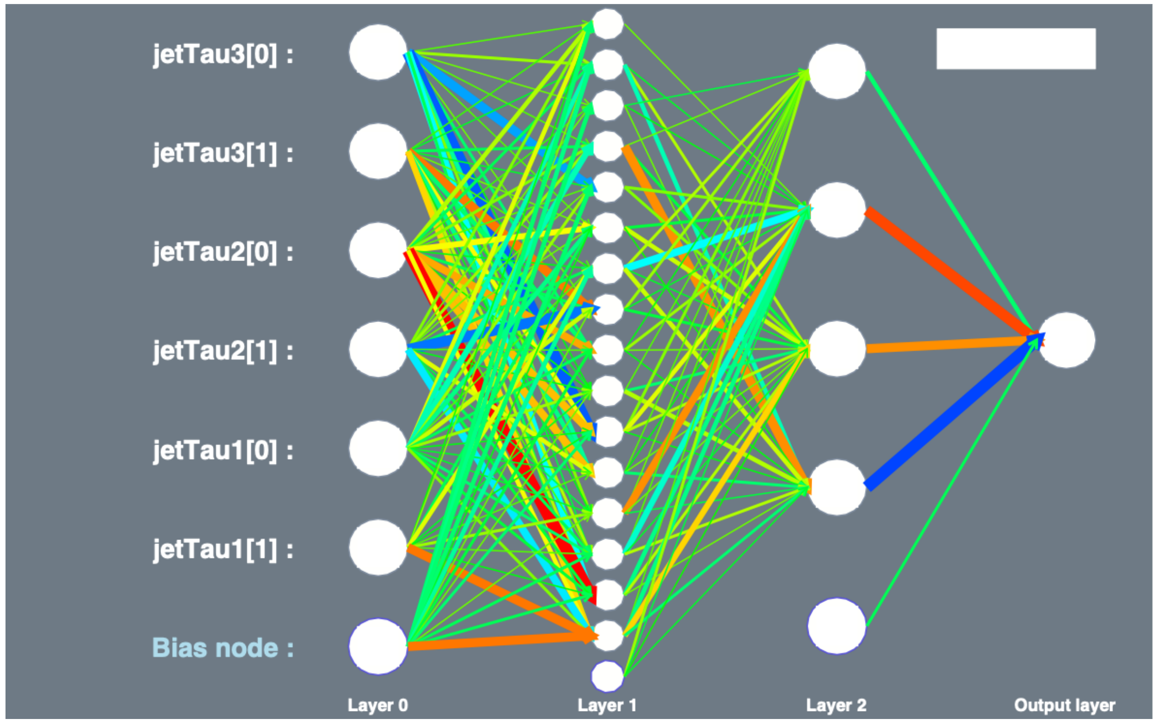
Multivariate discriminant (variables)

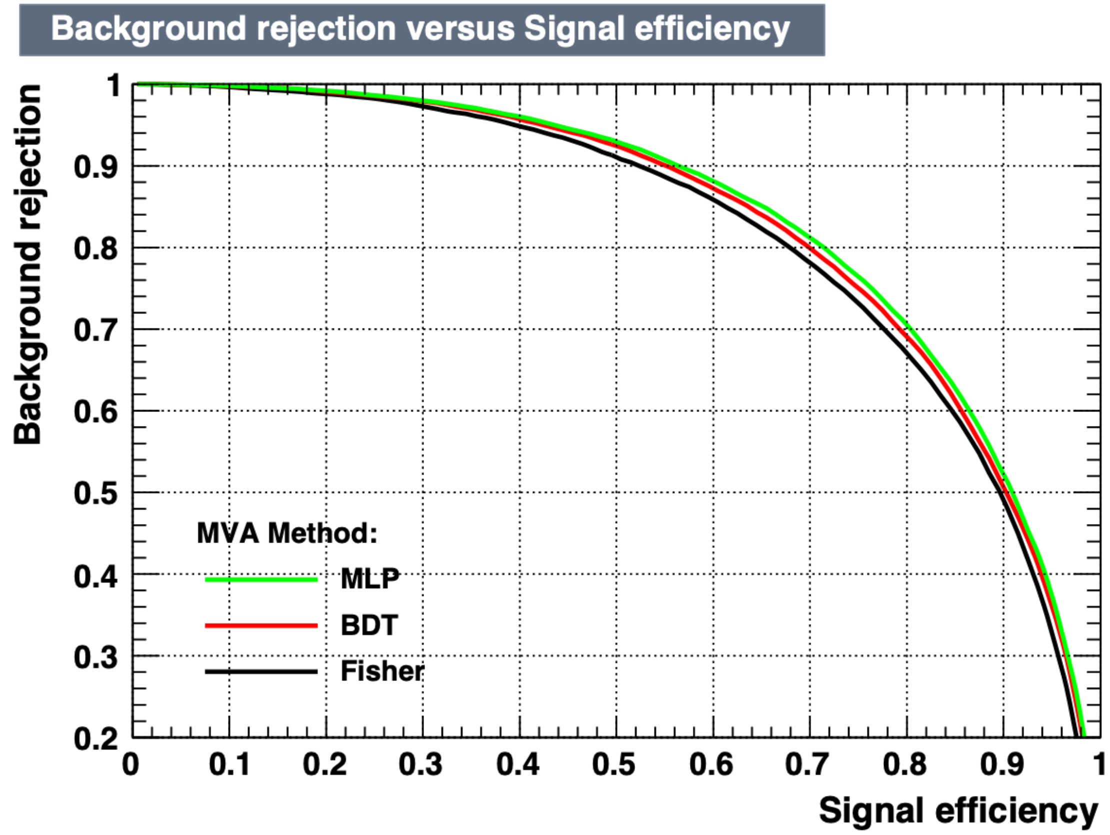
“ttbar tagger”

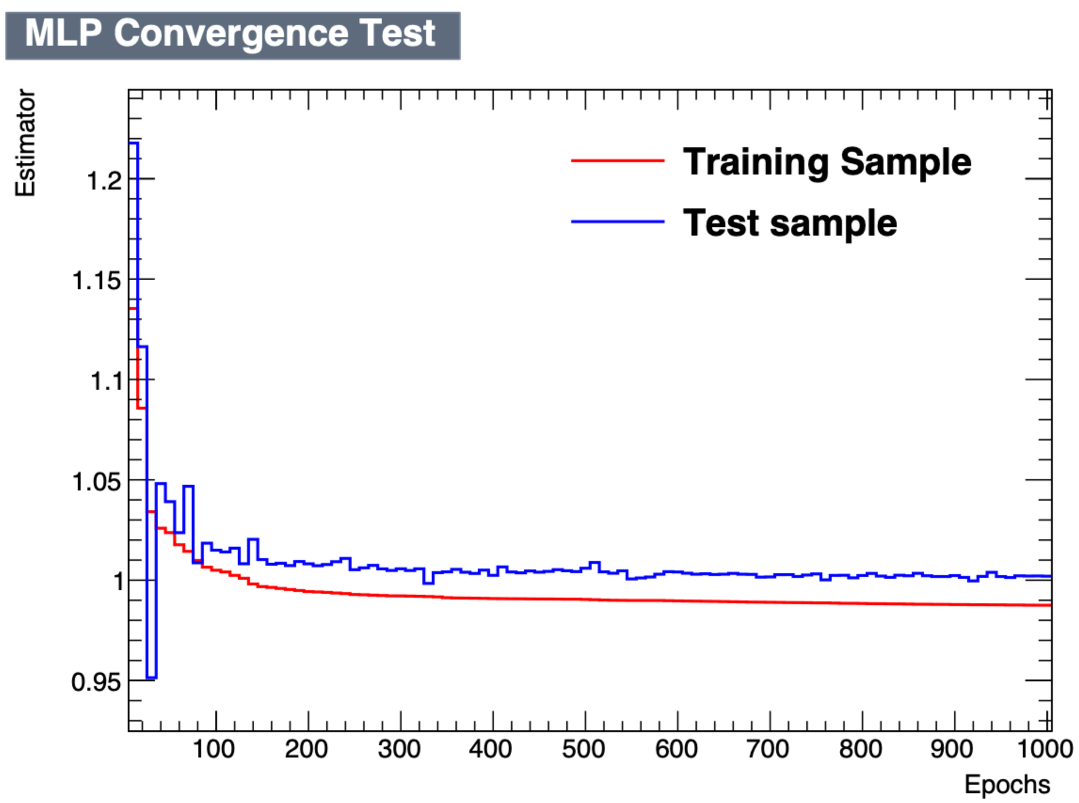
N-subjettiness $\tau_{1,2,3}$ for both jets

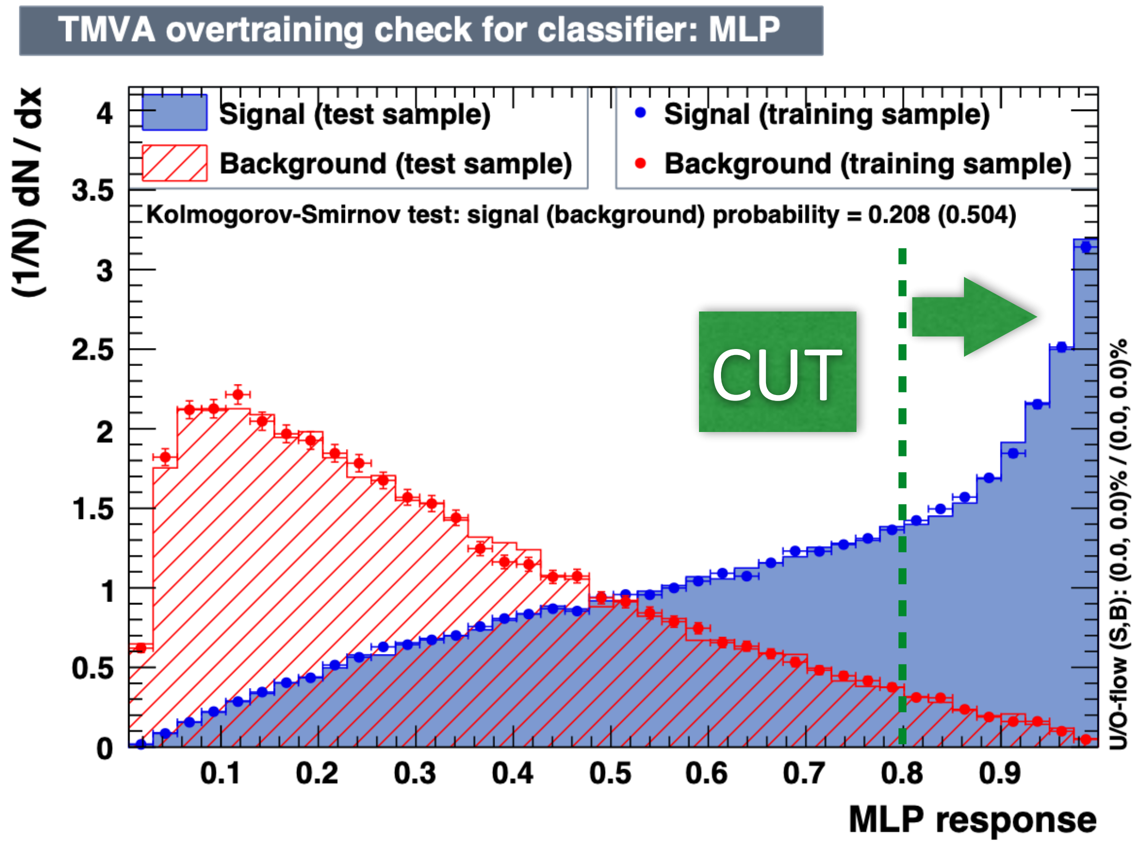


Multivariate discriminant (training)









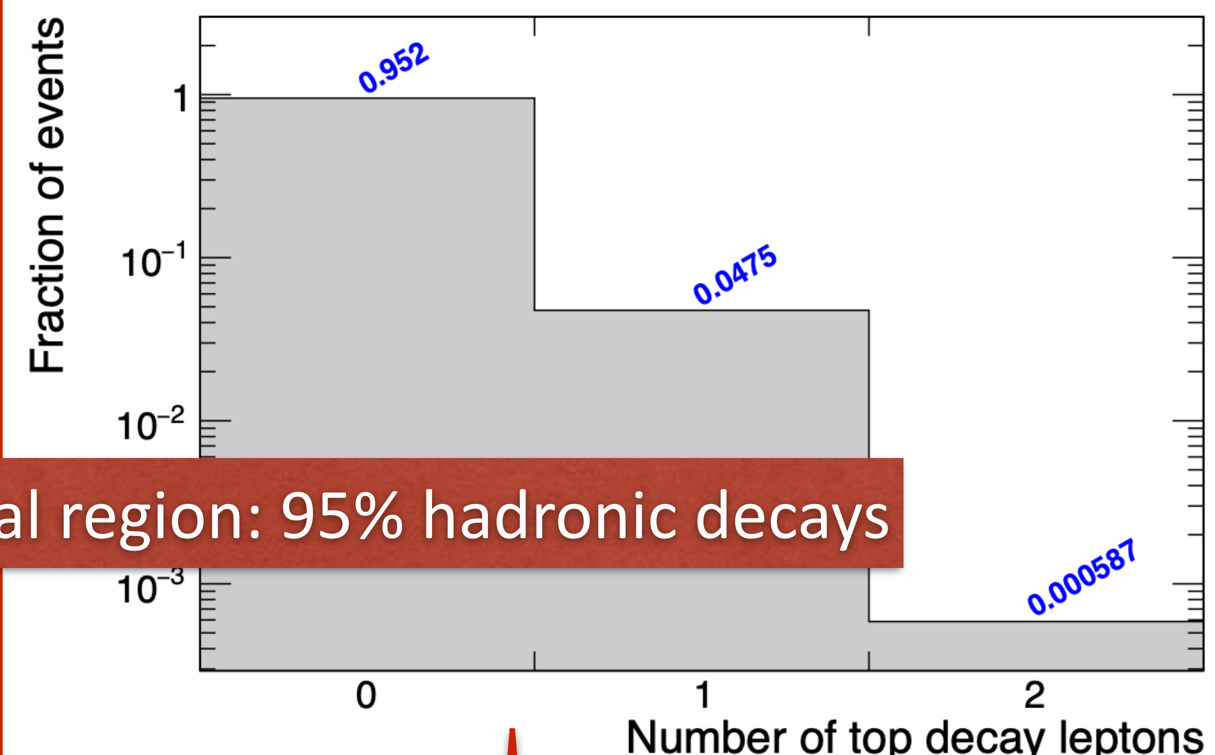
Selection

Table 1: Baseline selection requirements (hadronic channel).

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

jets: AK8 PF+CHS

NN CUT (0.8)
compromise between enough tt events and signal purity

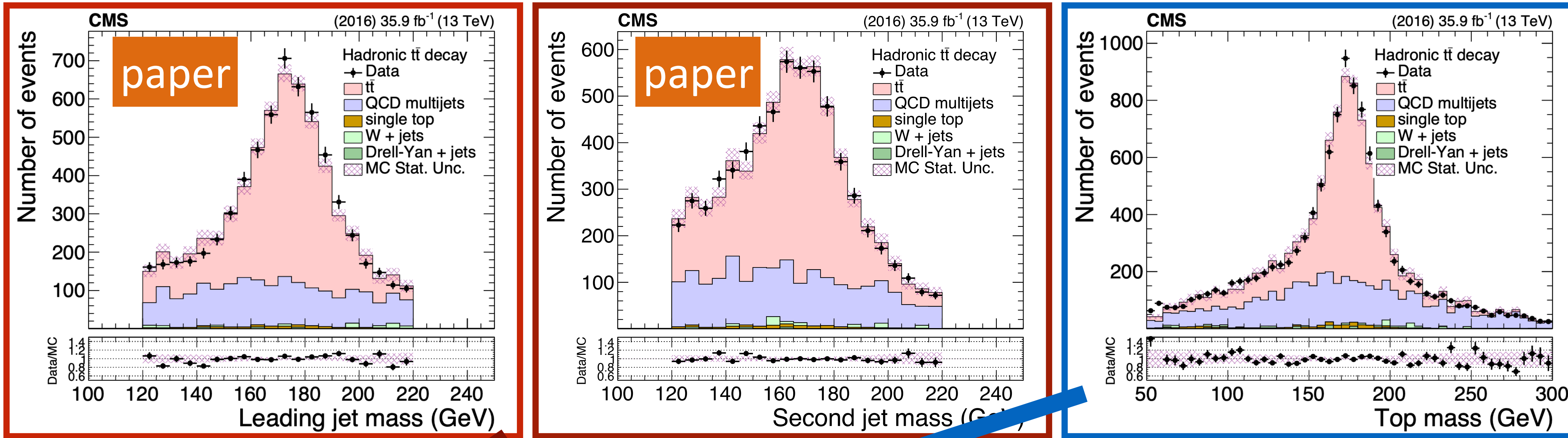


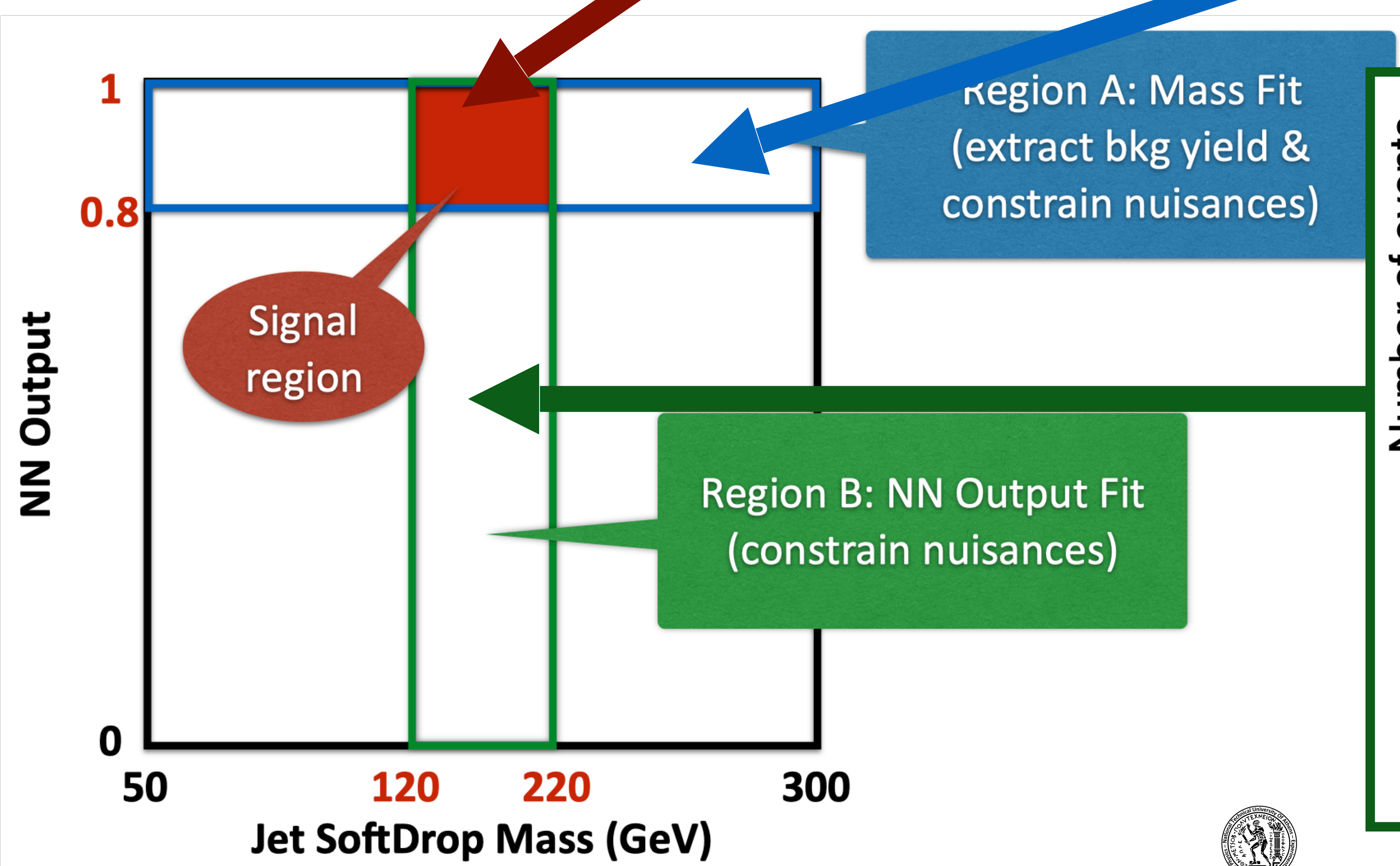
signal region: 95% hadronic decays

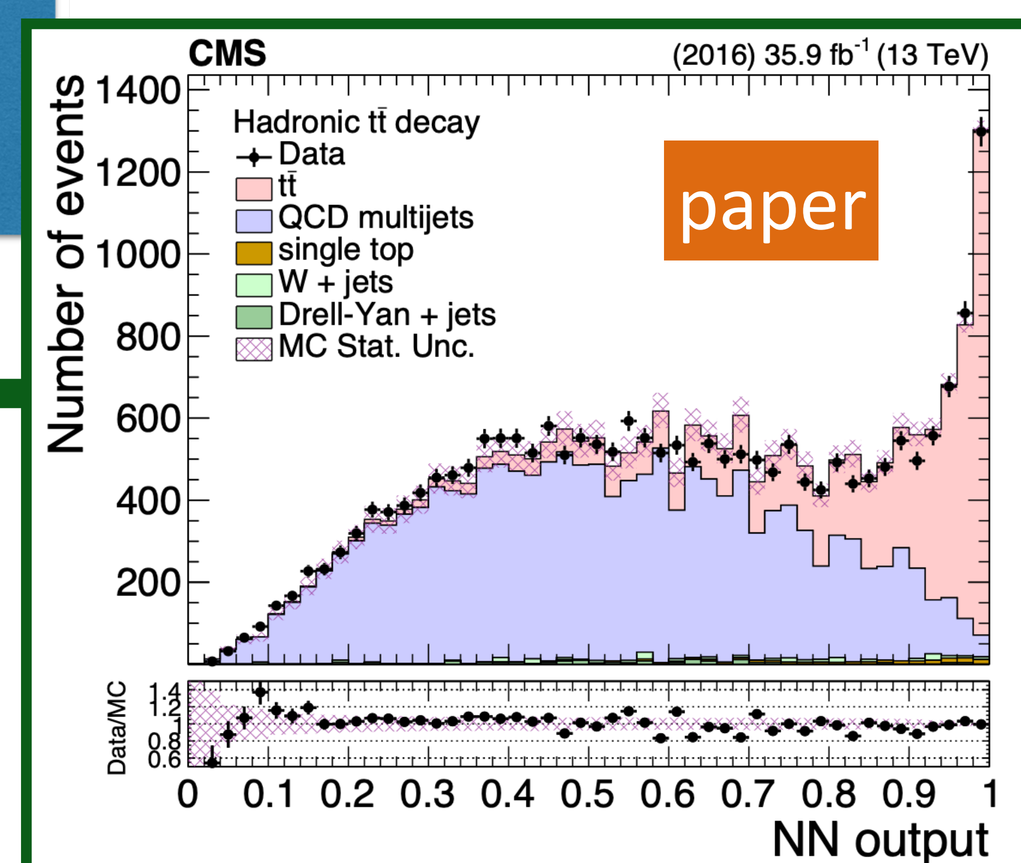
Table 2: Selection requirements per analysis region (hadronic channel).

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

Analysis regions







Signal extraction

fiducial yield

Data

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

Bkg shape (taken from CR in data)

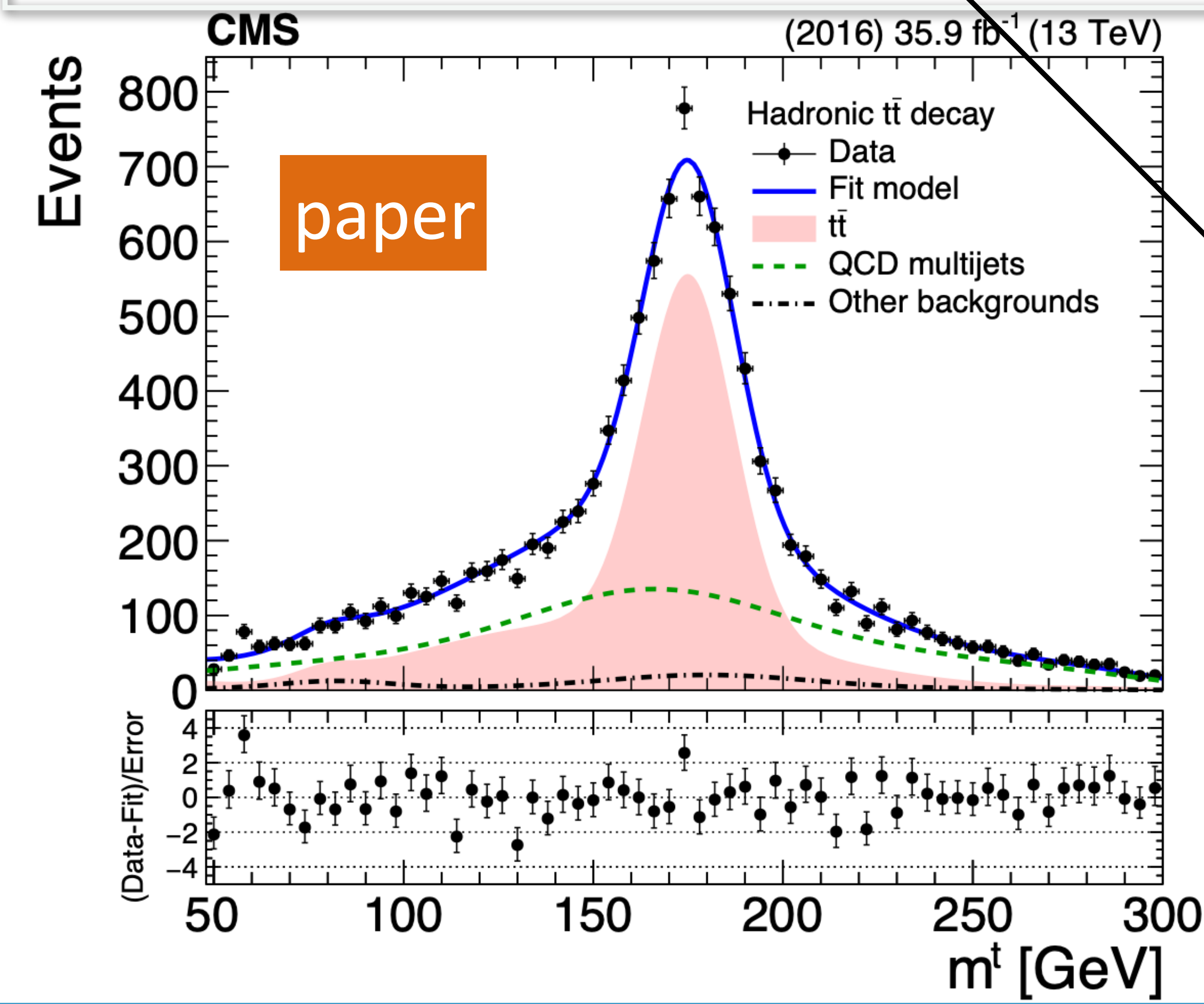
$$S_{\mathrm{fid}}\left(x_{\mathrm{reco}}\right)=D\left(x_{\mathrm{reco}}\right)-C_{\mathrm{bkg}}^{\mathrm{yield}}\cdot N_{\mathrm{bkg}}^{\mathrm{fit}}\cdot C_{\mathrm{bkg}}^{\mathrm{shape}}\left(x_{\mathrm{reco}}\right)\cdot B\left(x_{\mathrm{reco}}\right)$$

Bkg yield (fit in region SR_A)

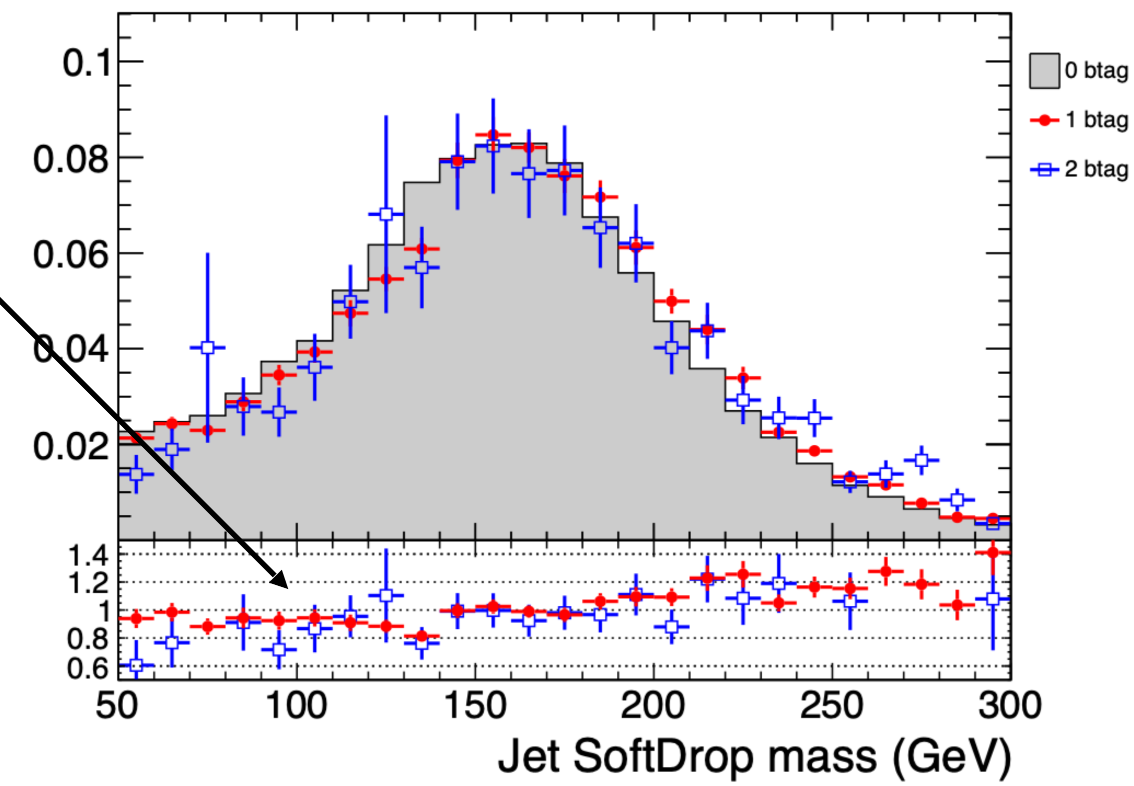
Bkg shape correction (taken from MC)

Fit in SR$_A$

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



MC QCD closure



paper

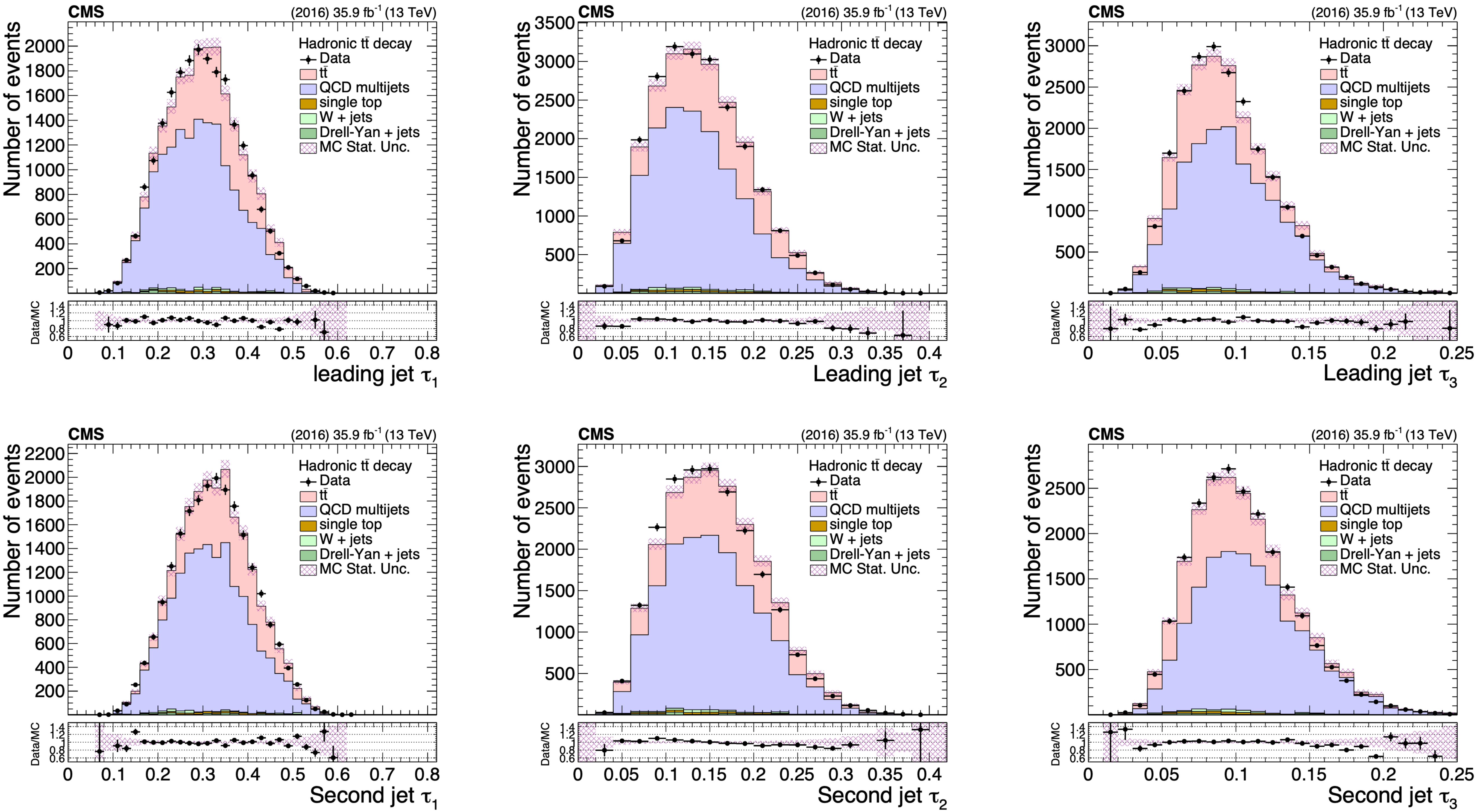
Process	SR$_A$ (pre-fit)	SR$_A$ (post-fit)	SR (pre-fit)	SR (corrected)
ttbar	9853	6238	6685	4245
QCD	5346	4539	2248	1876
single top	215	215	83	83
VJets	185	185	71	71
Data	11145		6274	

Parameter	Value
$k_{\rm res}$	0.960 ± 0.026
$k_{\rm scale}$	1.002 ± 0.002
$k_{\rm slope}$	$(5.7 \pm 1.4) \times 10^{-3}$
$N_{\rm bkg}$	400 ± 255
$N_{\rm QCD}$	4539 ± 247
$N_{t\bar{t}}$	6238 ± 181

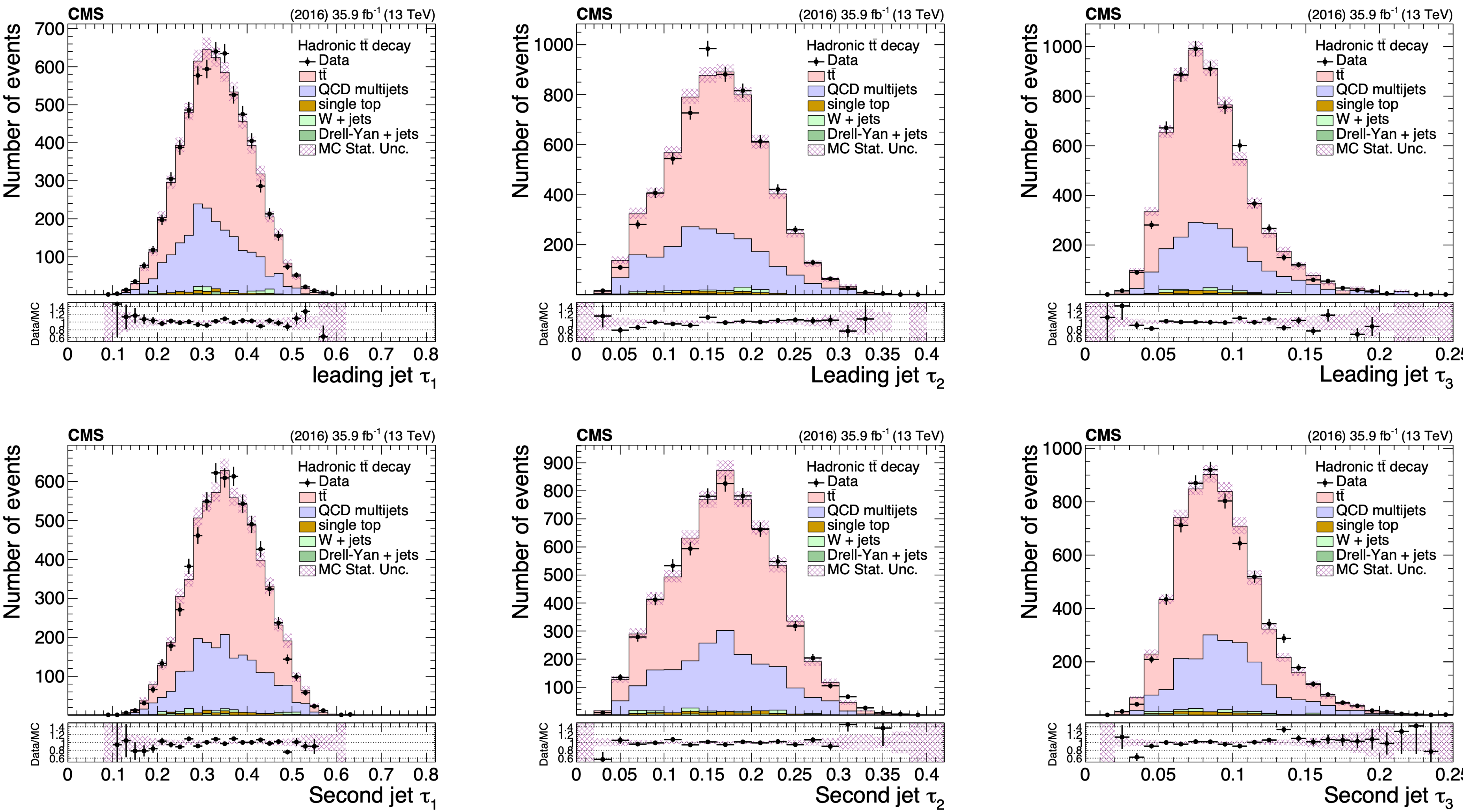
Process	Yield
$t\bar{t}$	4244 ± 127
Multijet	1876 ± 102
W+jets	58 ± 29
Z+jets	12 ± 6
Single t	83 ± 41
Total	6273 ± 171
Data	6274

$r_{tt} = 0.63$

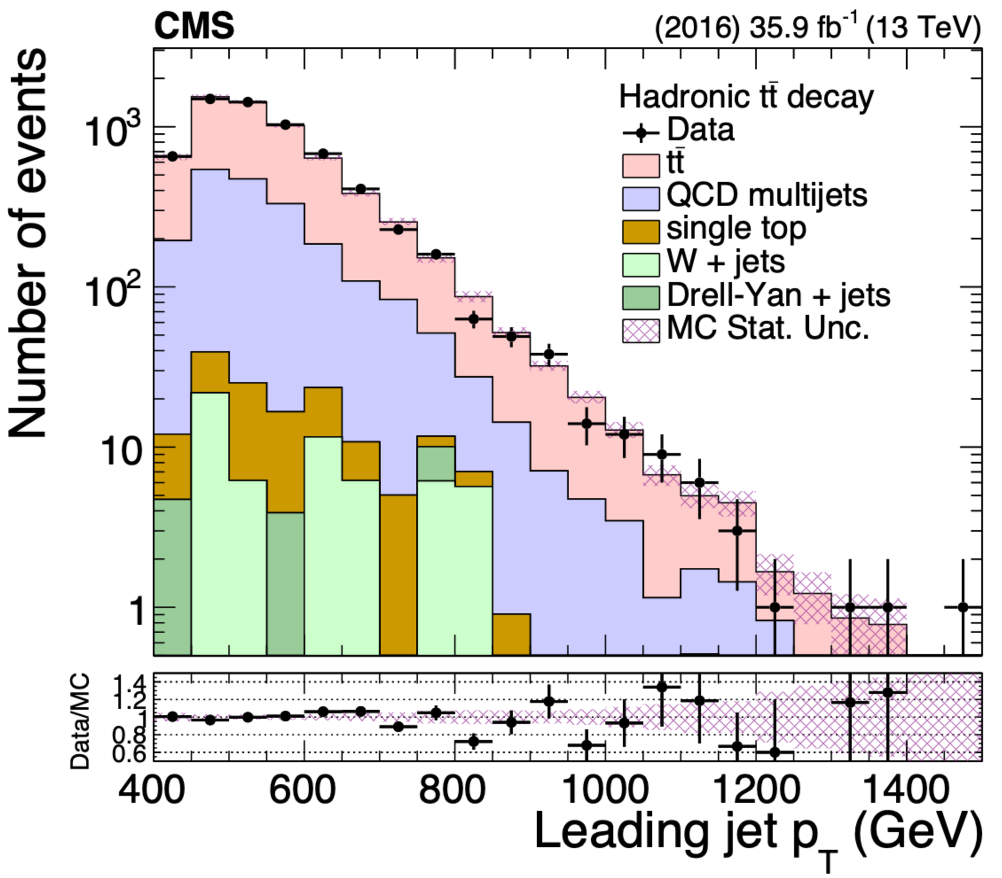
Substructure properties (before NN cut)

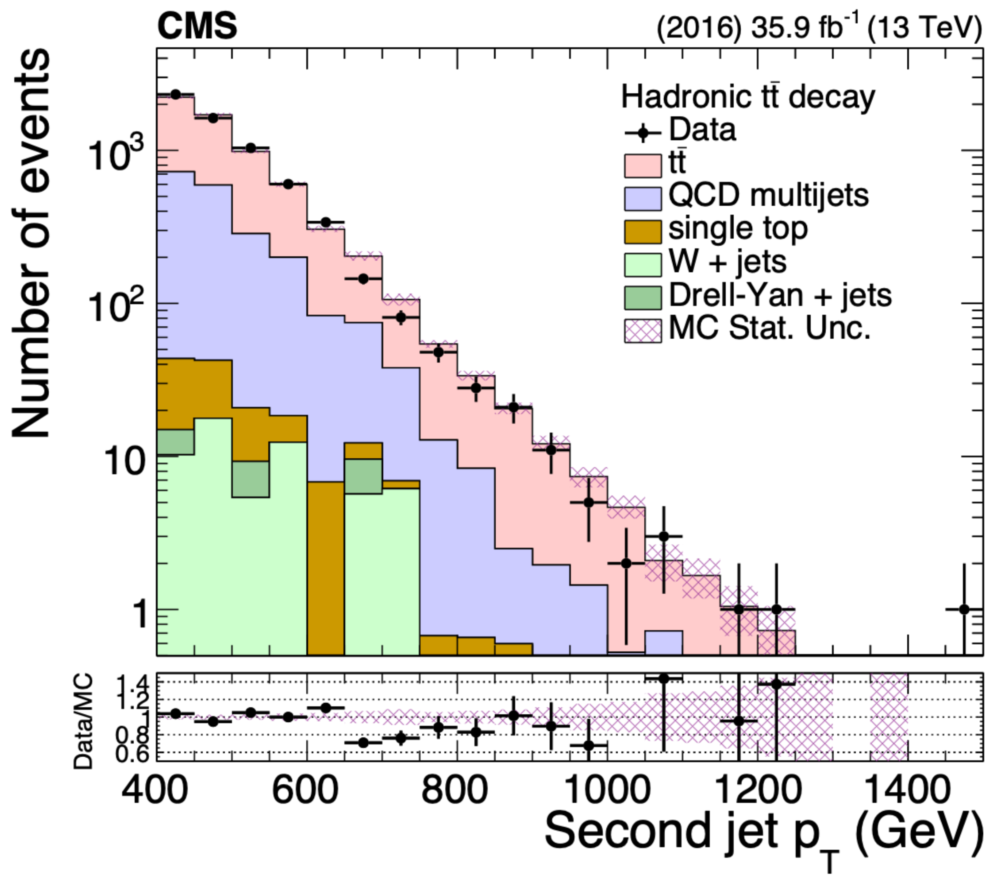


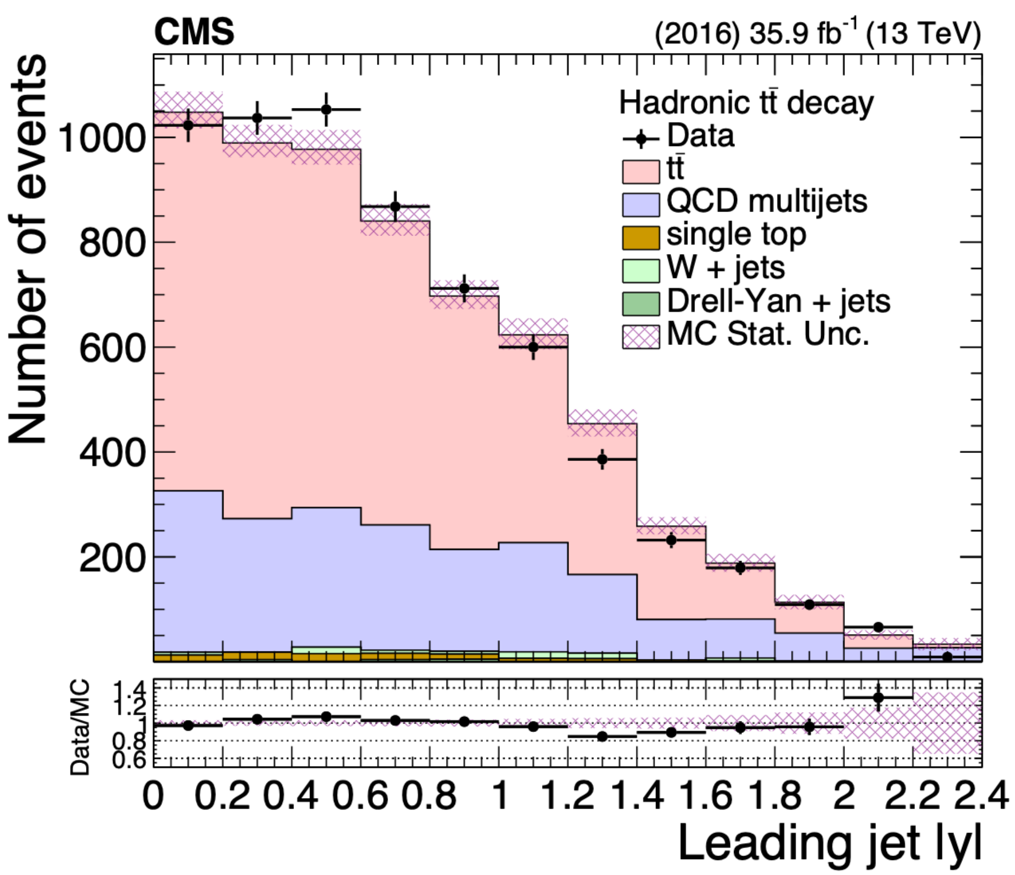
Substructure properties (after NN cut)

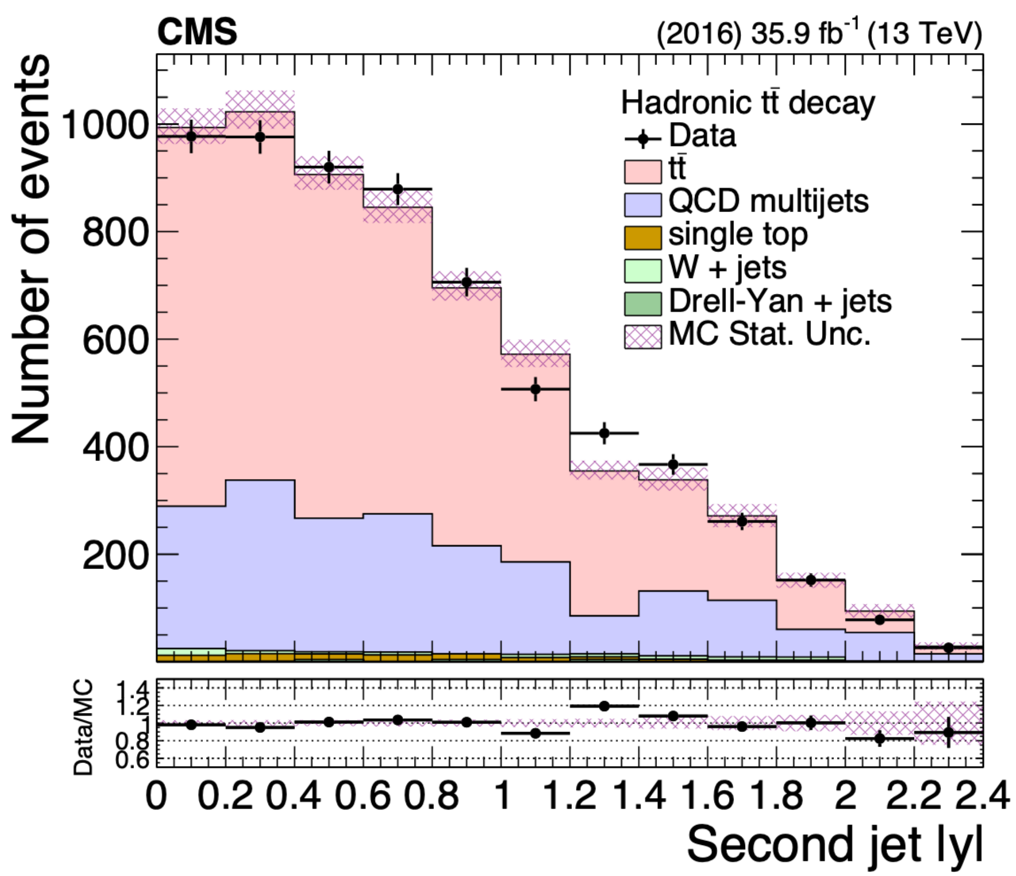


Top kinematic variables

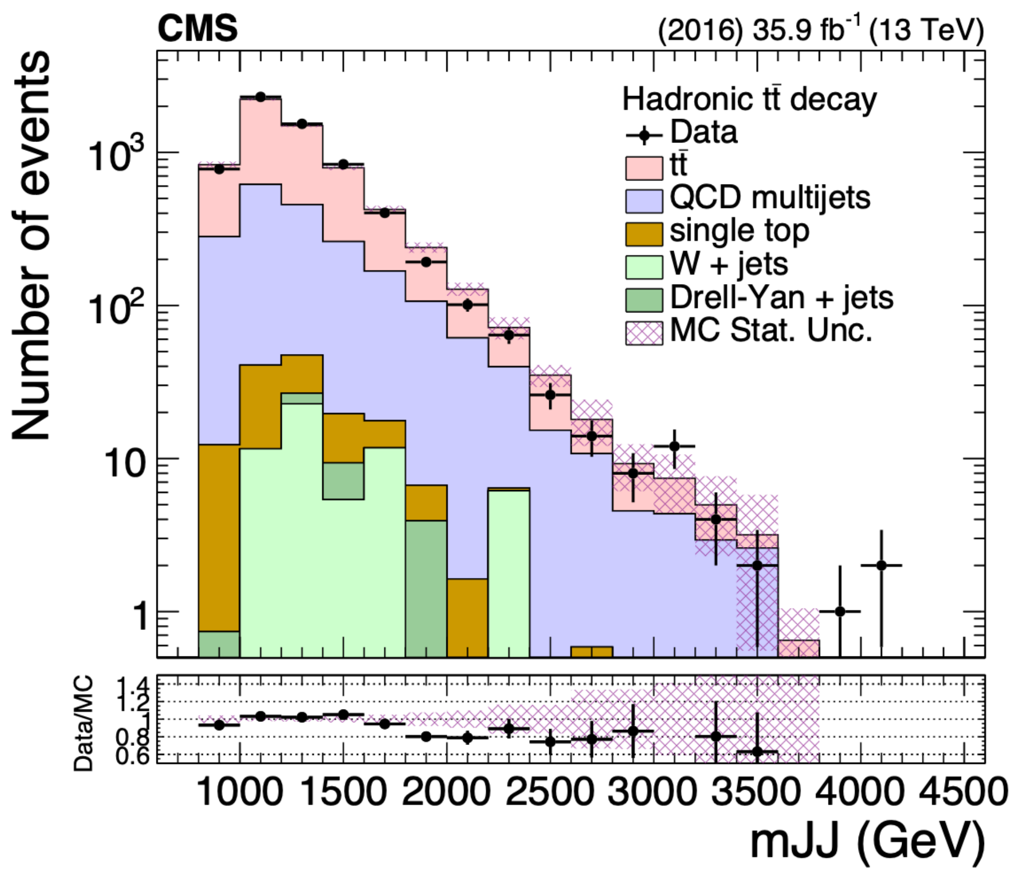


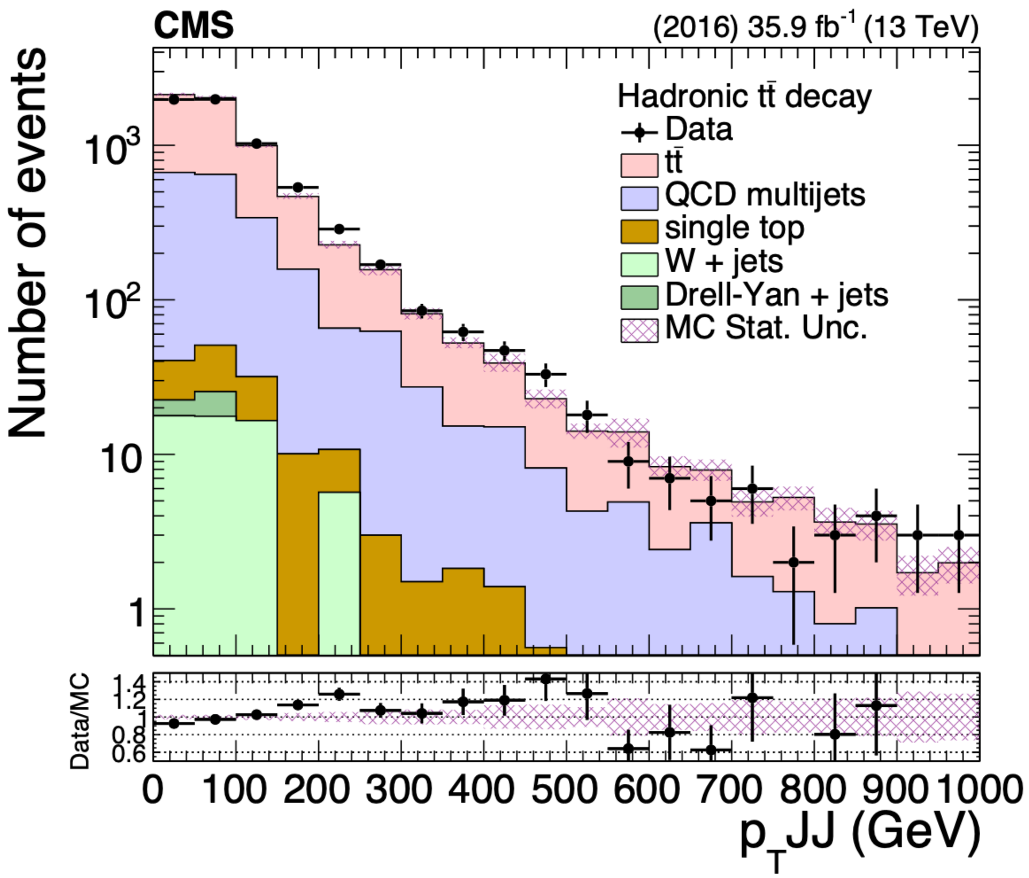


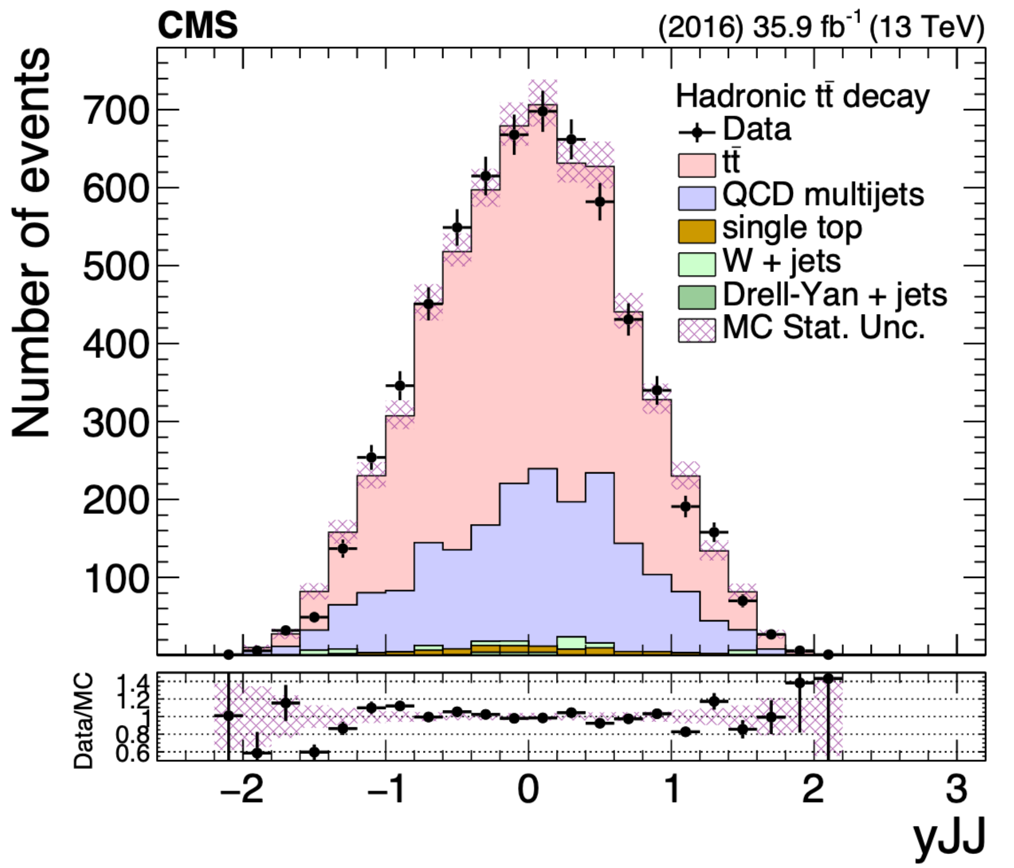




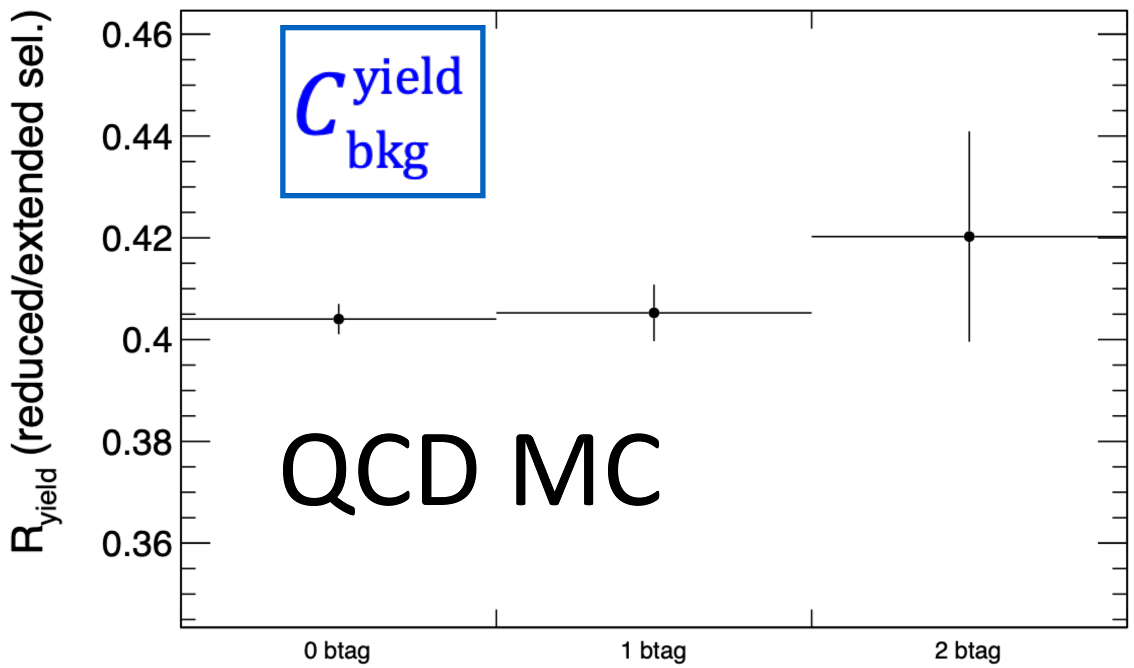
Top kinematic variables



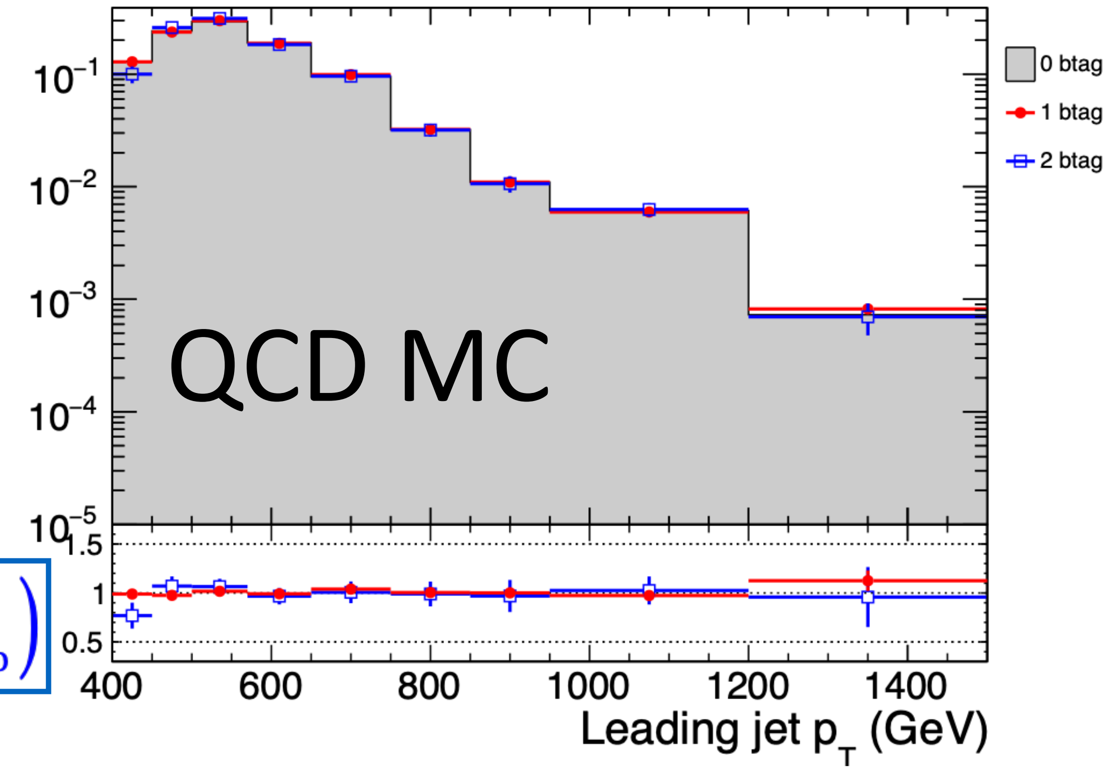


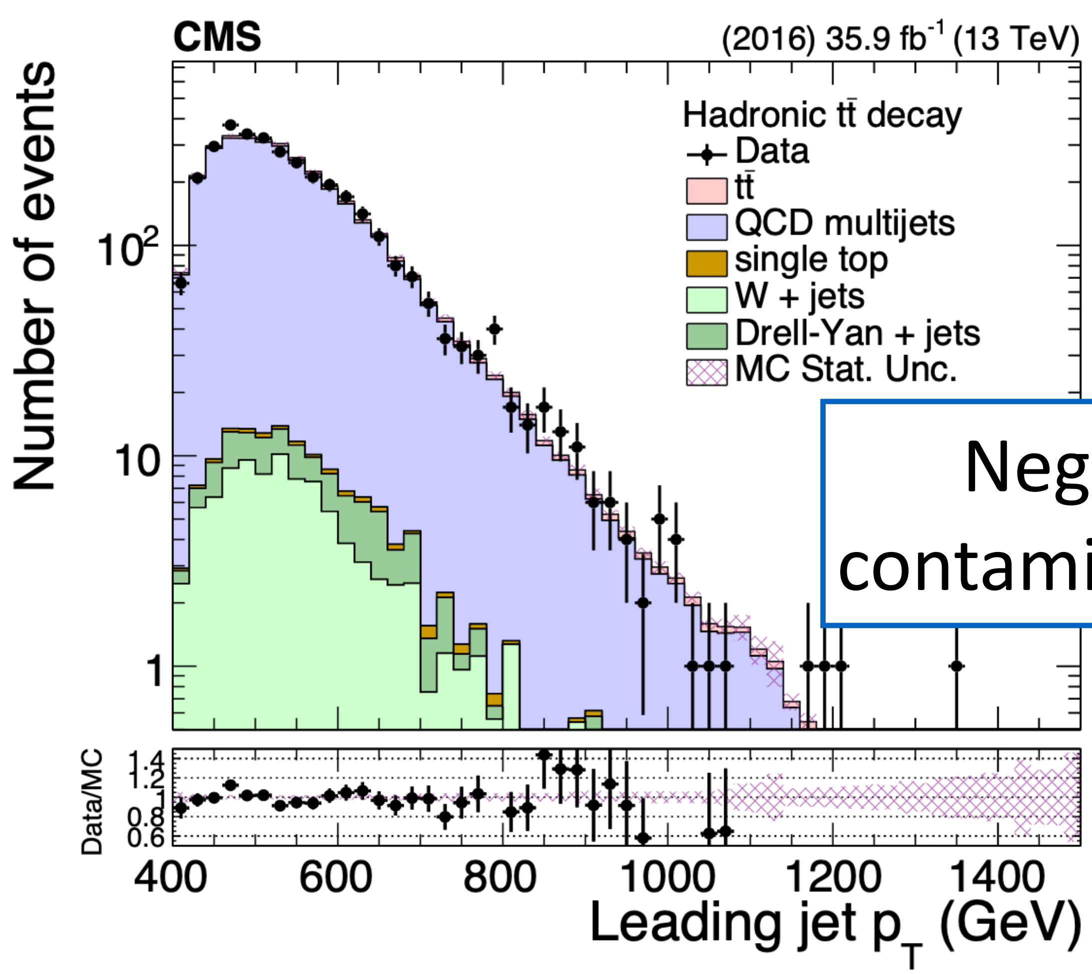


Validation of the background method

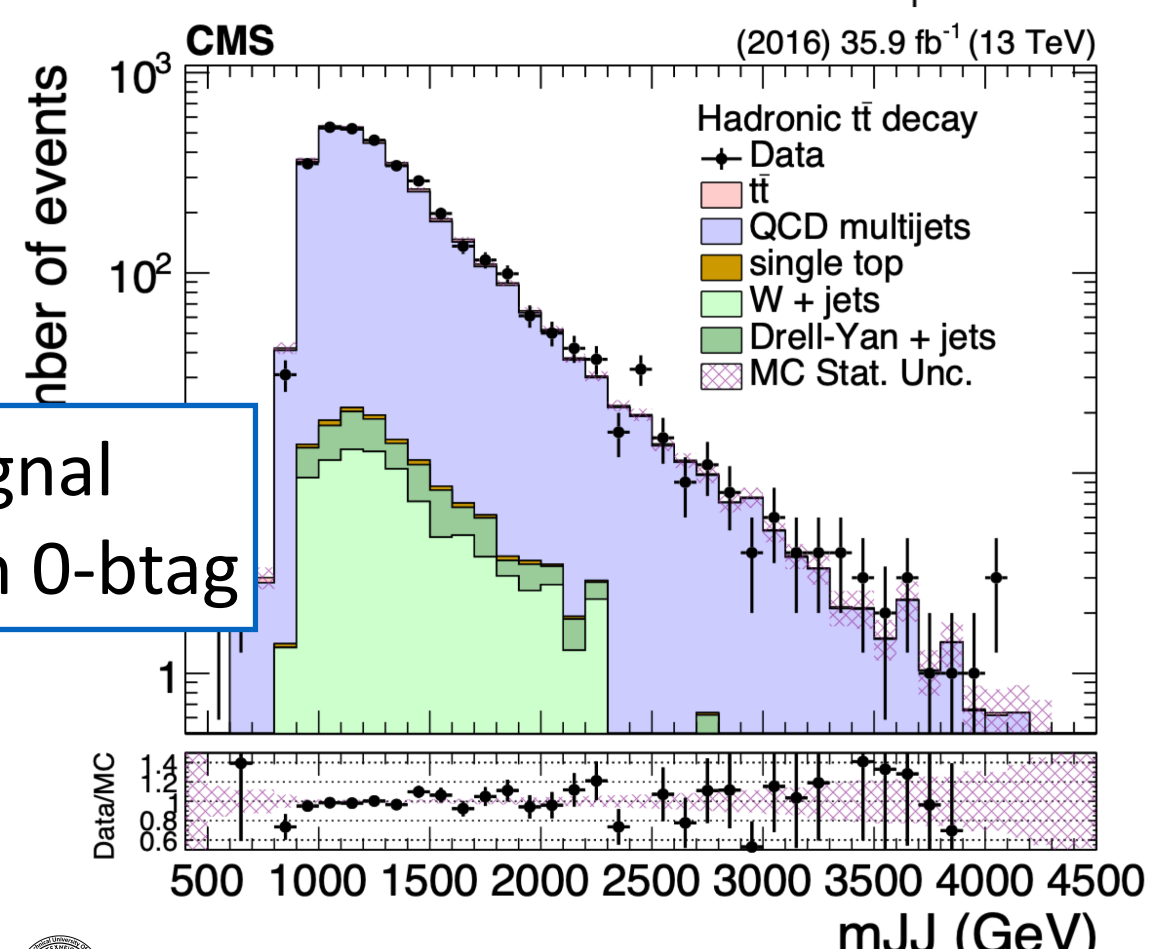


$C_{\text{bkg}}^{\text{shape}}\left(x_{\text{reco}}\right)$



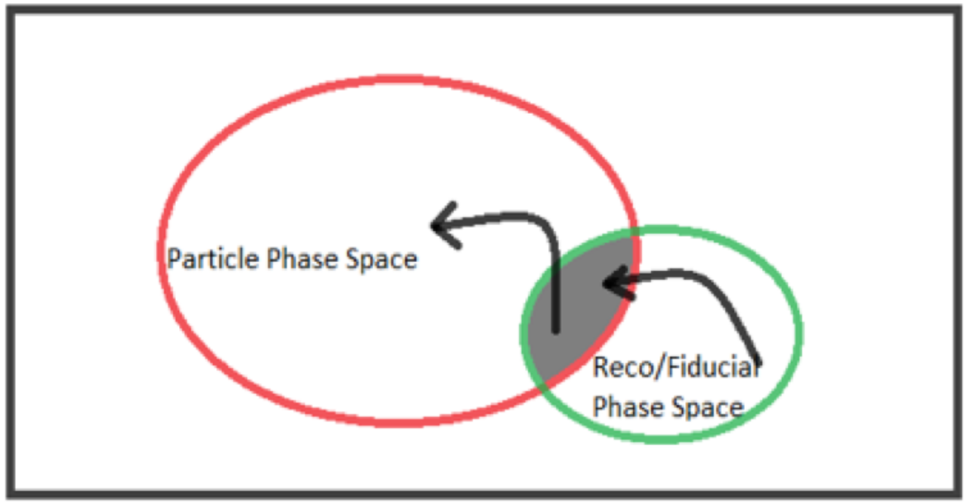


Negligible signal contamination in 0-btag



Parton

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



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}	$> 800\,\mathrm{GeV}$

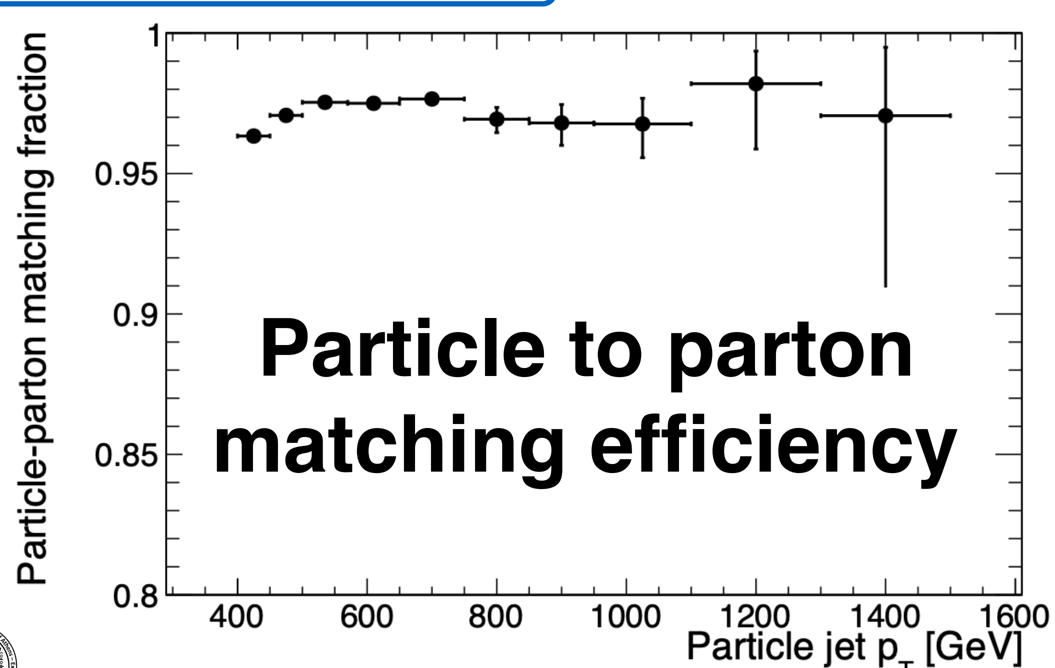
$$\frac{d\sigma_i^{\mathrm{unf}}}{dx} = \frac{1}{\mathcal{L}\cdot\Delta x_i}\cdot\frac{1}{f_{2,i}}\cdot\sum_j\left(R_{ij}^{-1}\cdot f_{1,j}\cdot S_j\right)$$

efficiency of the reco+true selection

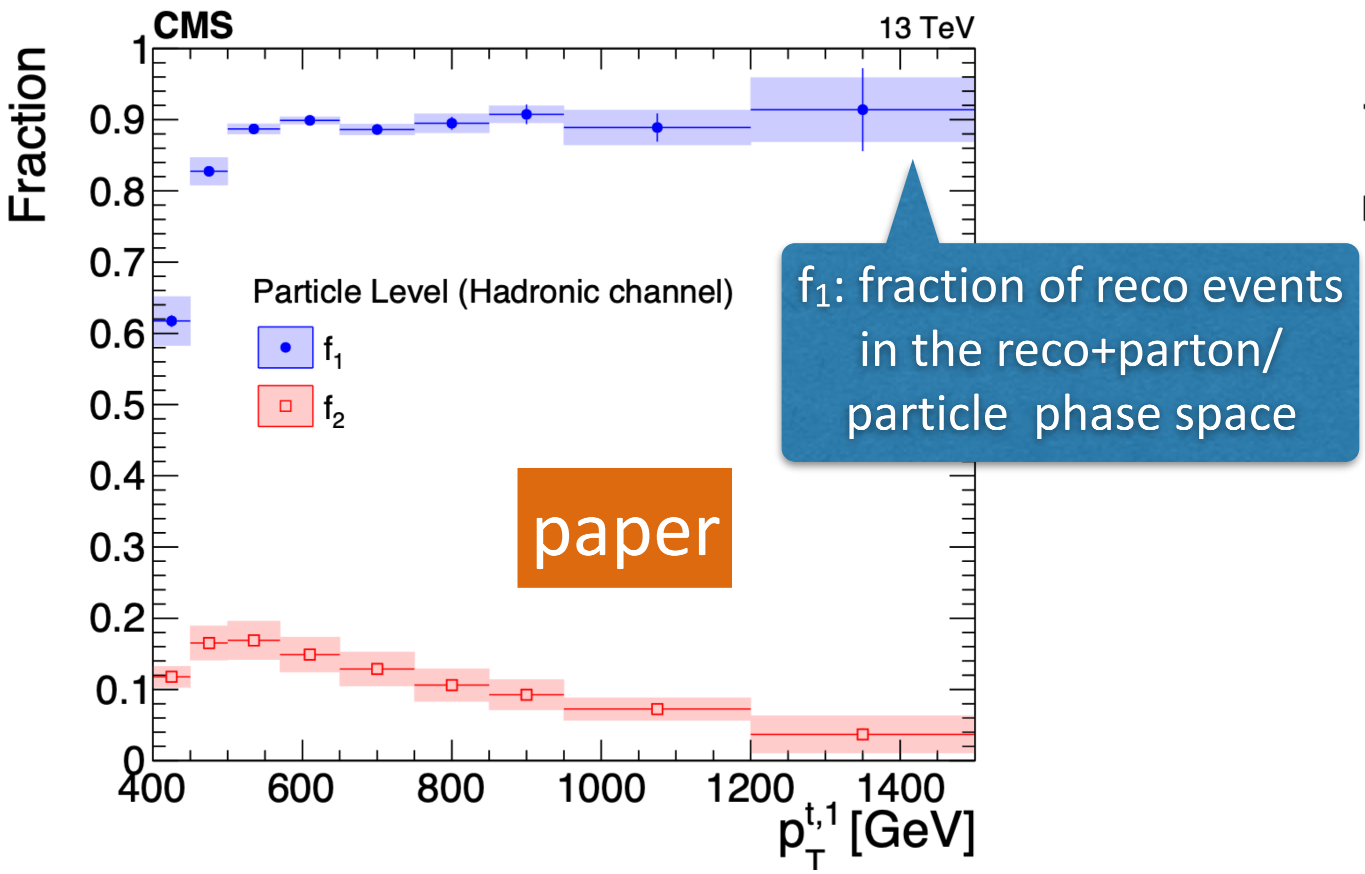
migration matrix

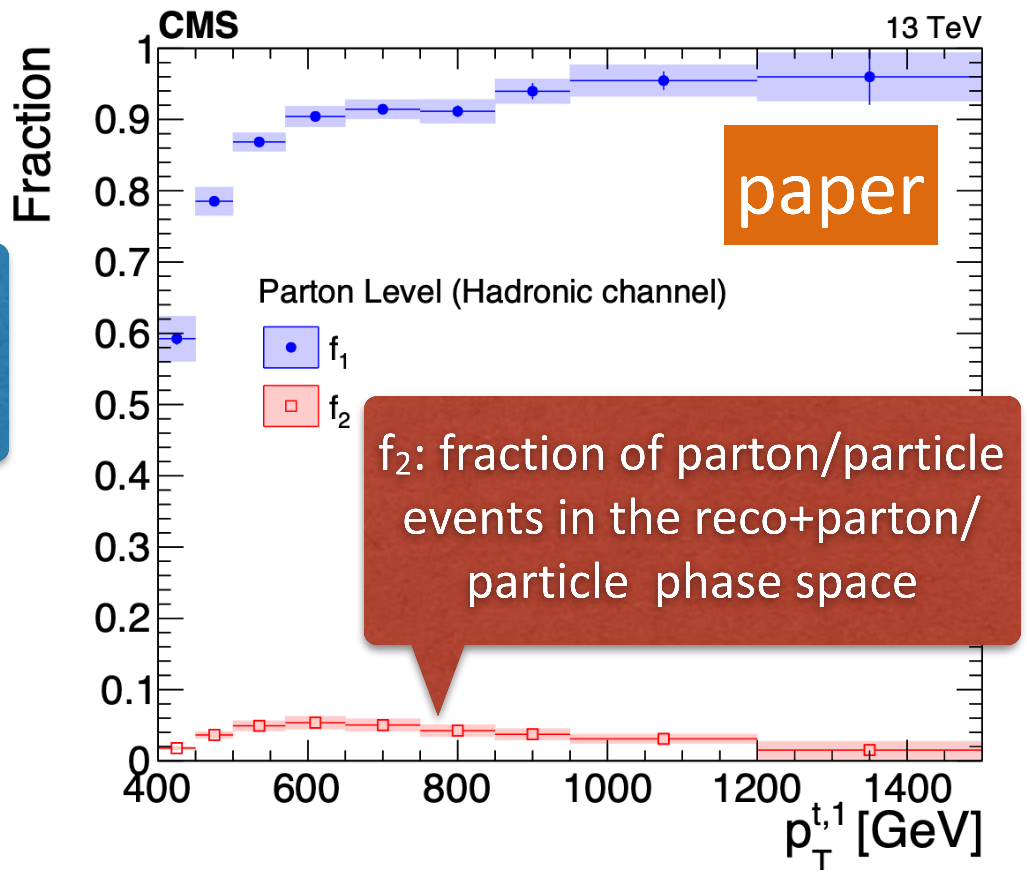
reco efficiency of the reco+true selection

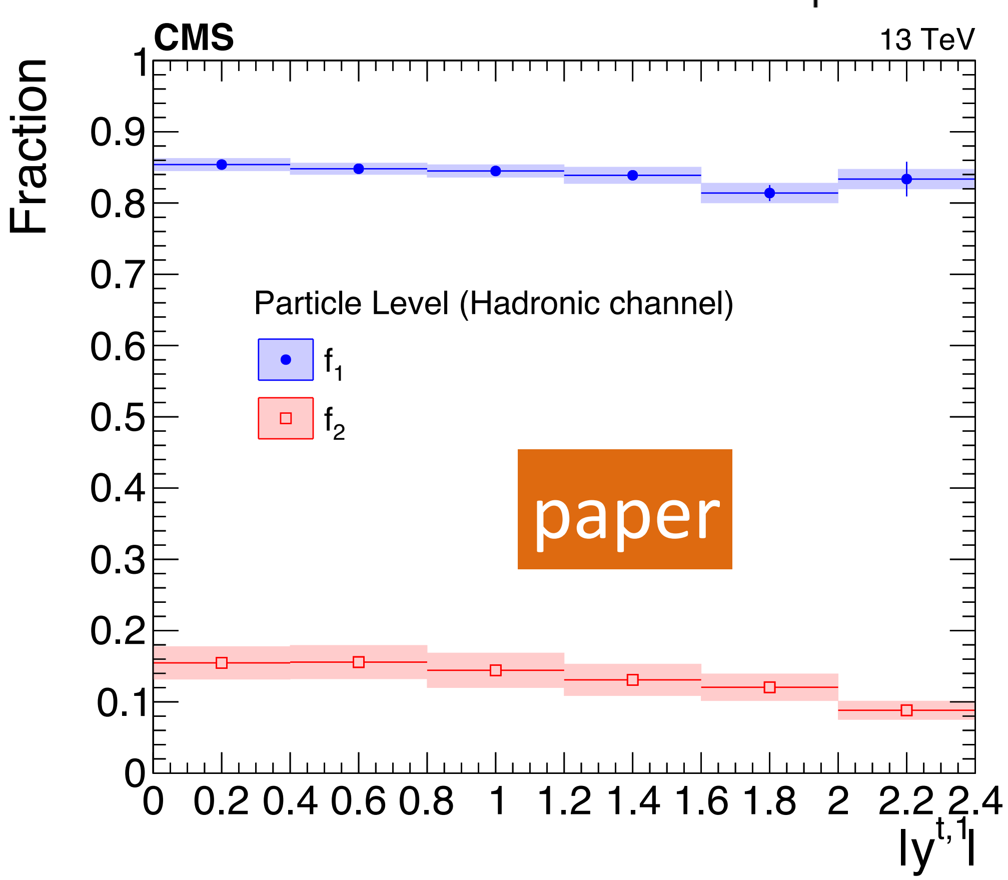
Unfolding: simple response matrix inversion w/o regularisation

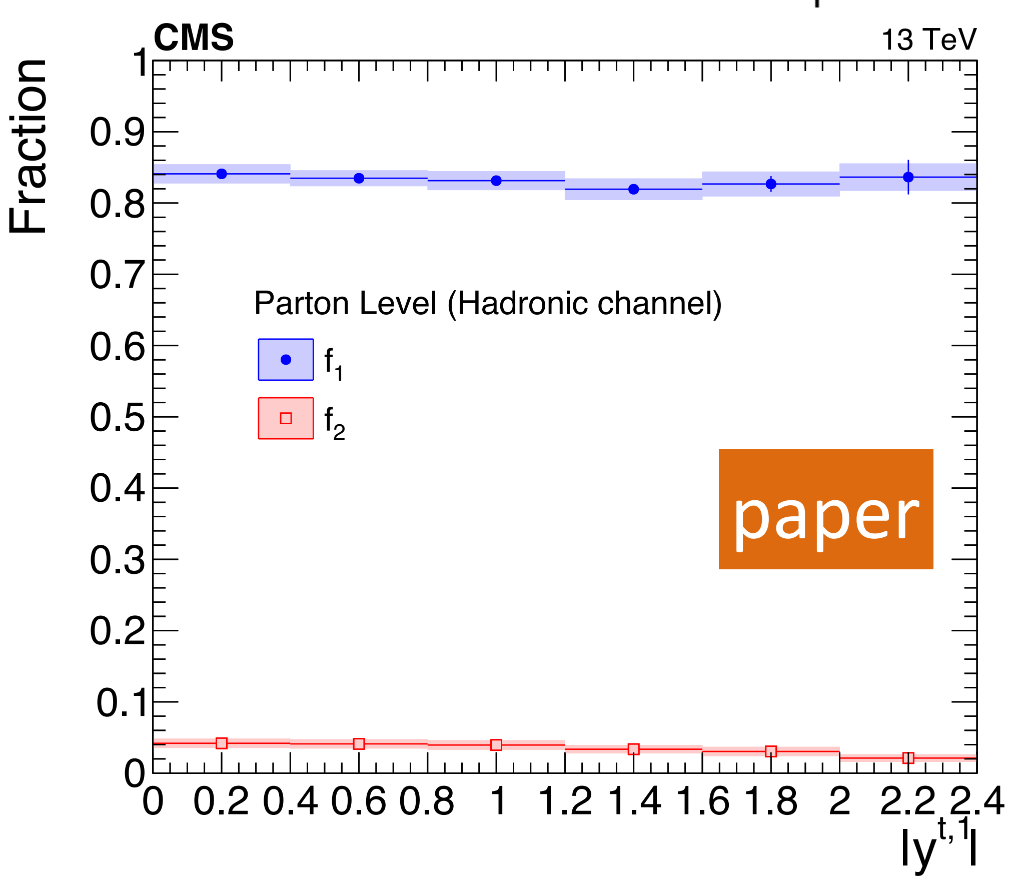


Fractions of particle & parton level definitions









Migration matrices

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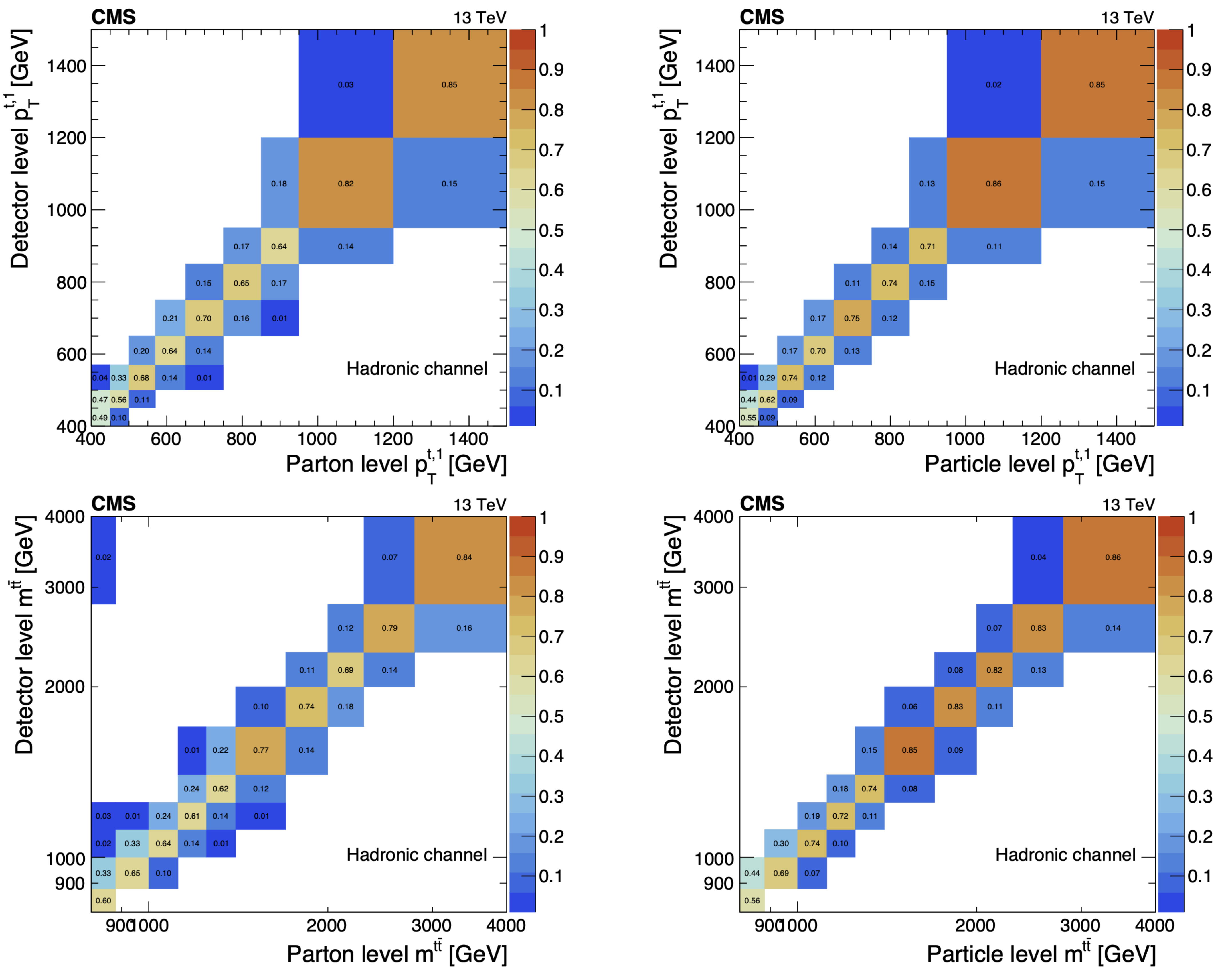


Systematic uncertainties

Two TYPES:

- Experimental: object performance between data and simulation
- Theoretical: related to the simulation itself(acceptance, efficiency, migration matrix)

Experimental

- Jet Energy Scale
- Jet Energy Resolution
- Pileup
- Subjet b-tagging efficiency
- QCD bkg prediction
- Trigger
- Luminosity

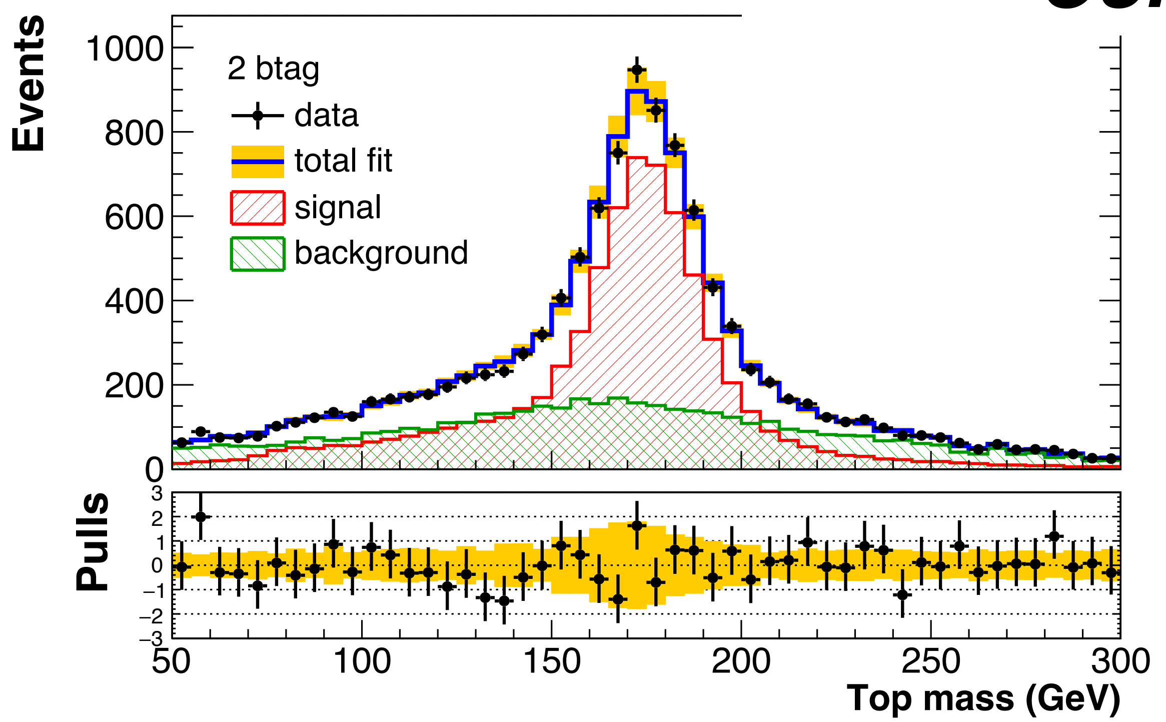
For every single source of uncertainty we extract the differential cross sections separately and then add in quadrature the difference from the nominal measurement

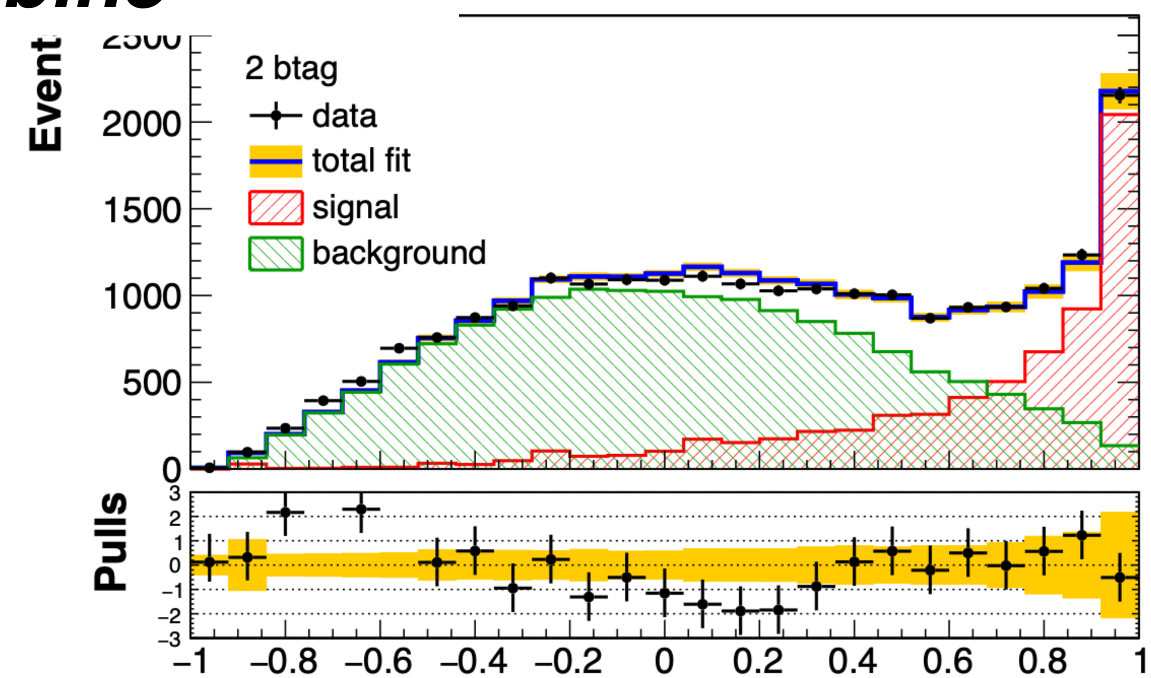
Theoretical:

- Parton Distribution Functions
- Renormalisation and factorisation scales:
- Strong coupling constant
- Final State Radiation (FSR): in situ constrained
- Initial State Radiation (ISR)
- Matrix Element-Parton showering matching
- Underlying event tune

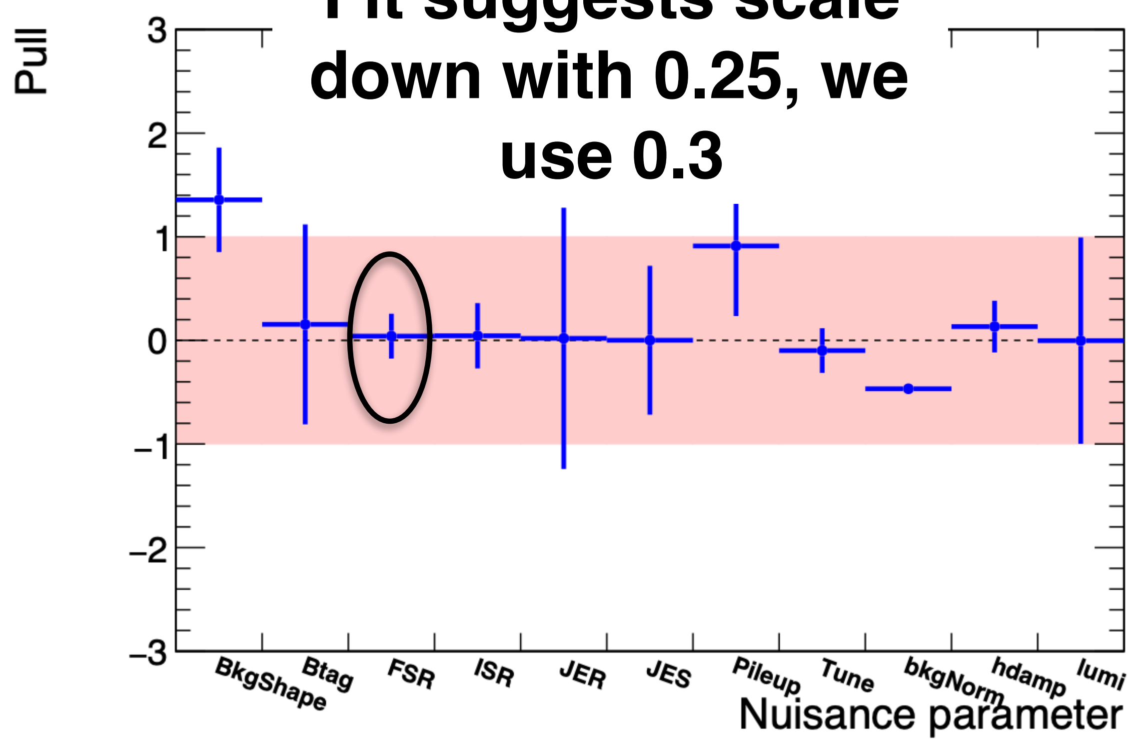
In situ constraint of the FSR uncertainty

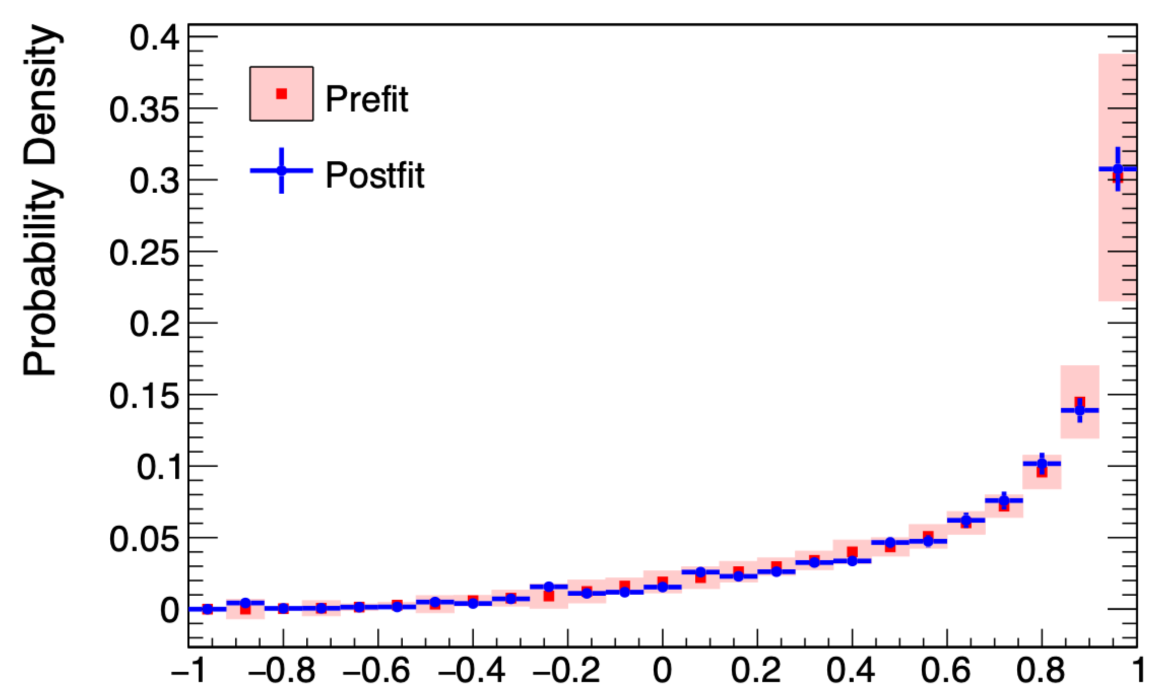
Template fits with *Combine*





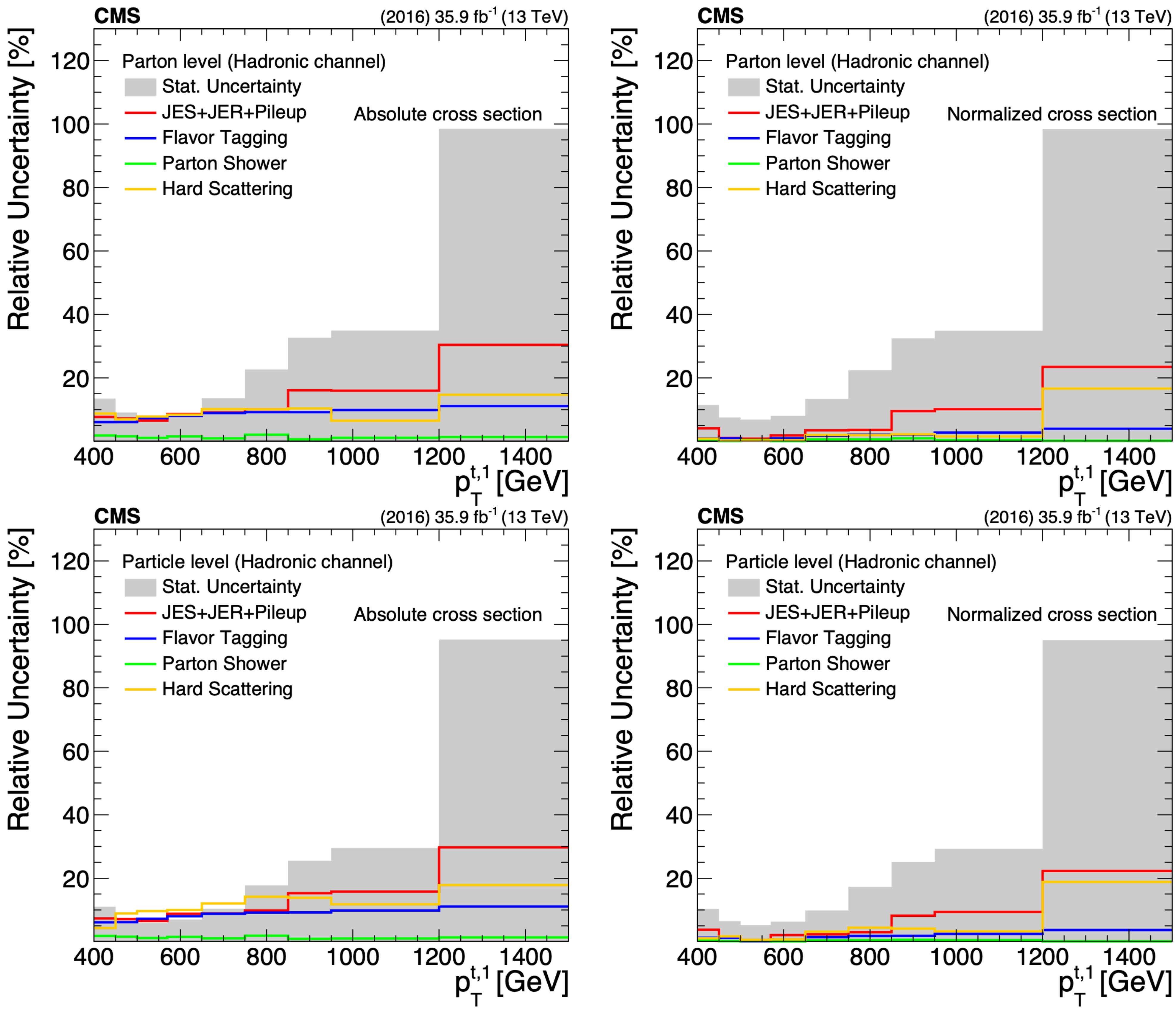
Fit suggests scale down with 0.25, we use 0.3





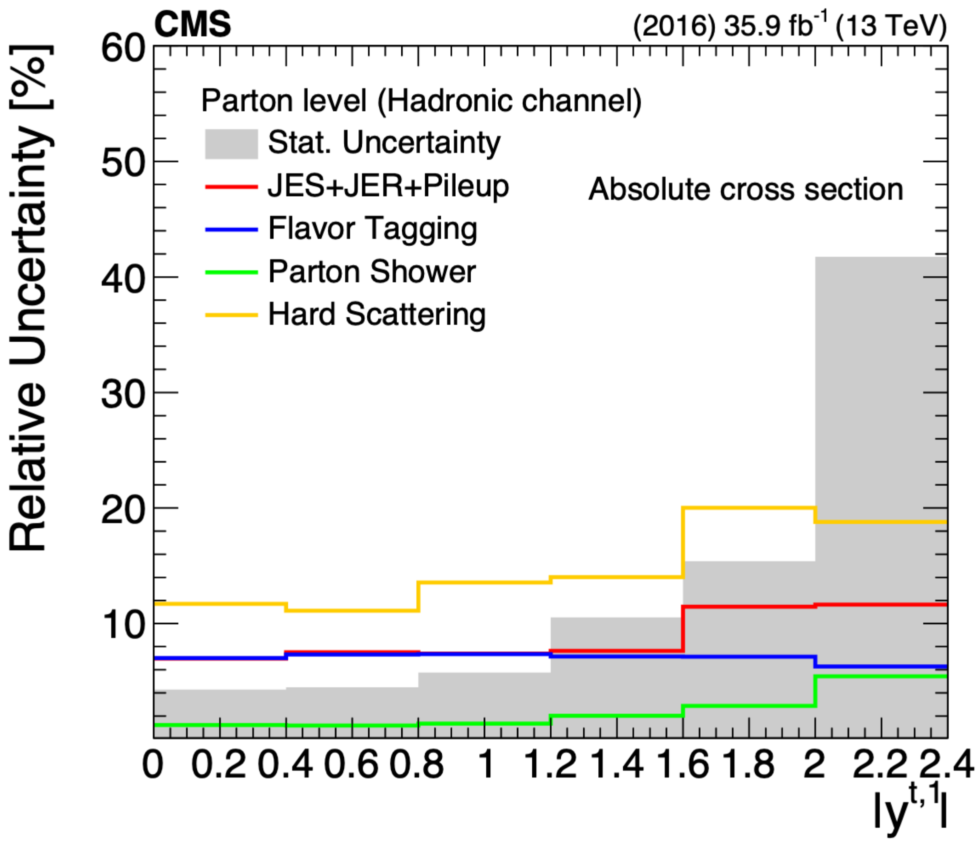
Uncertainties vs leading top p_T

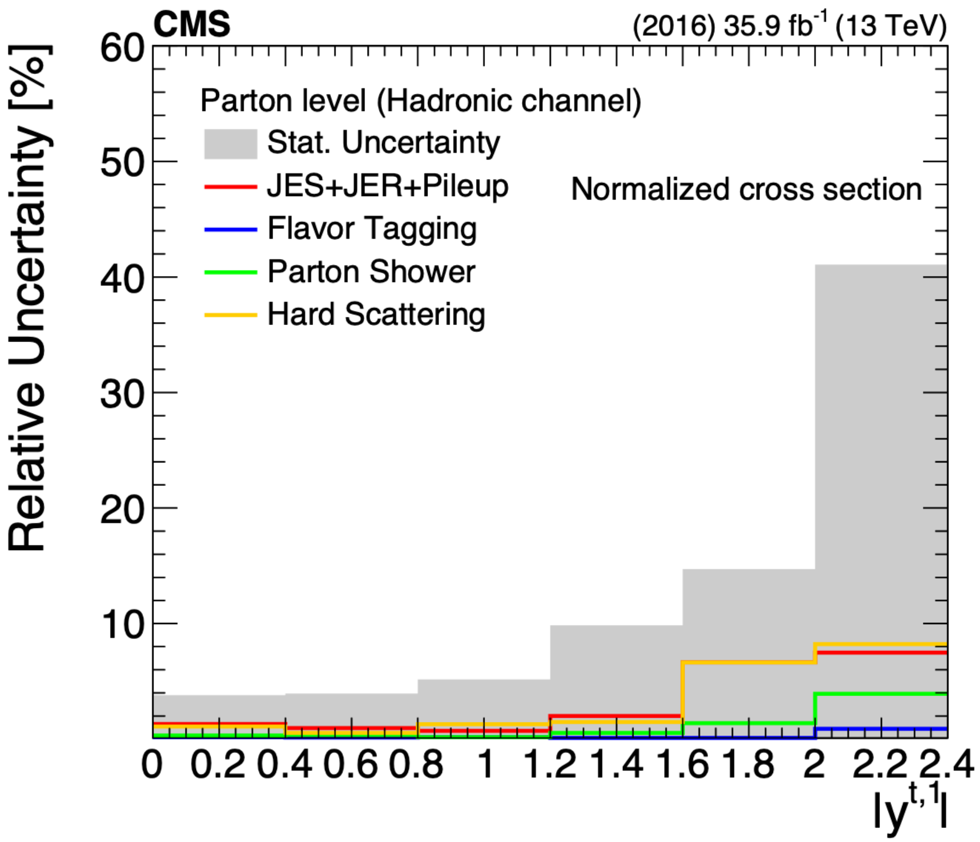
paper

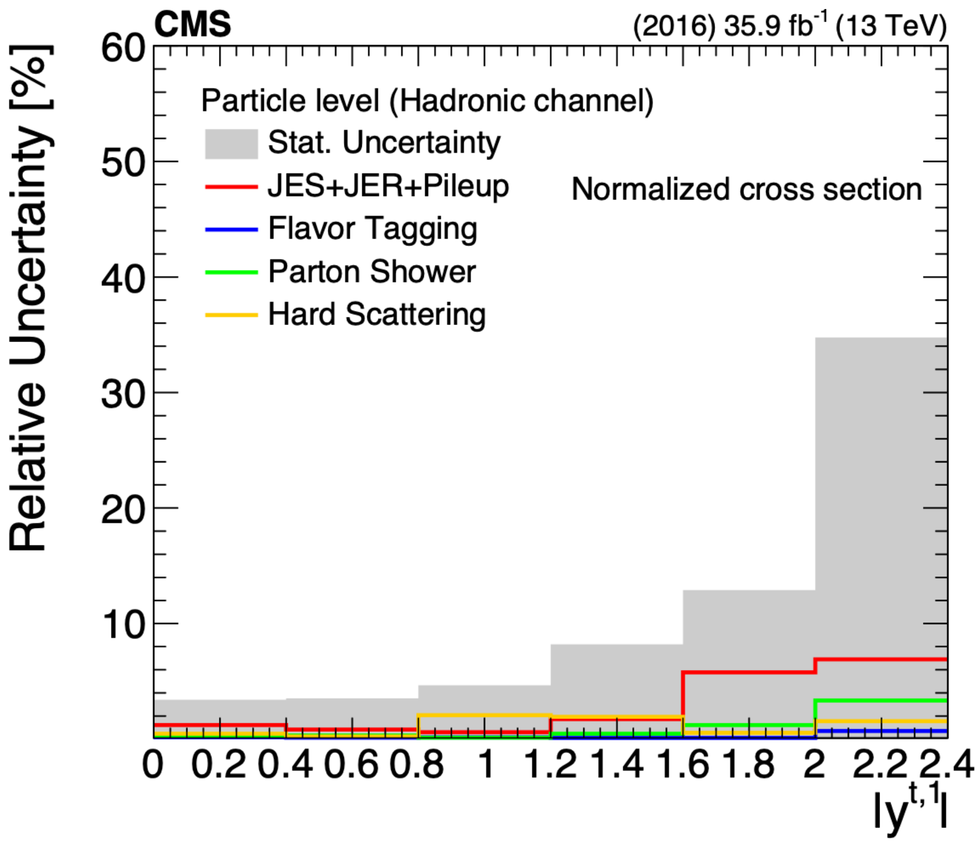


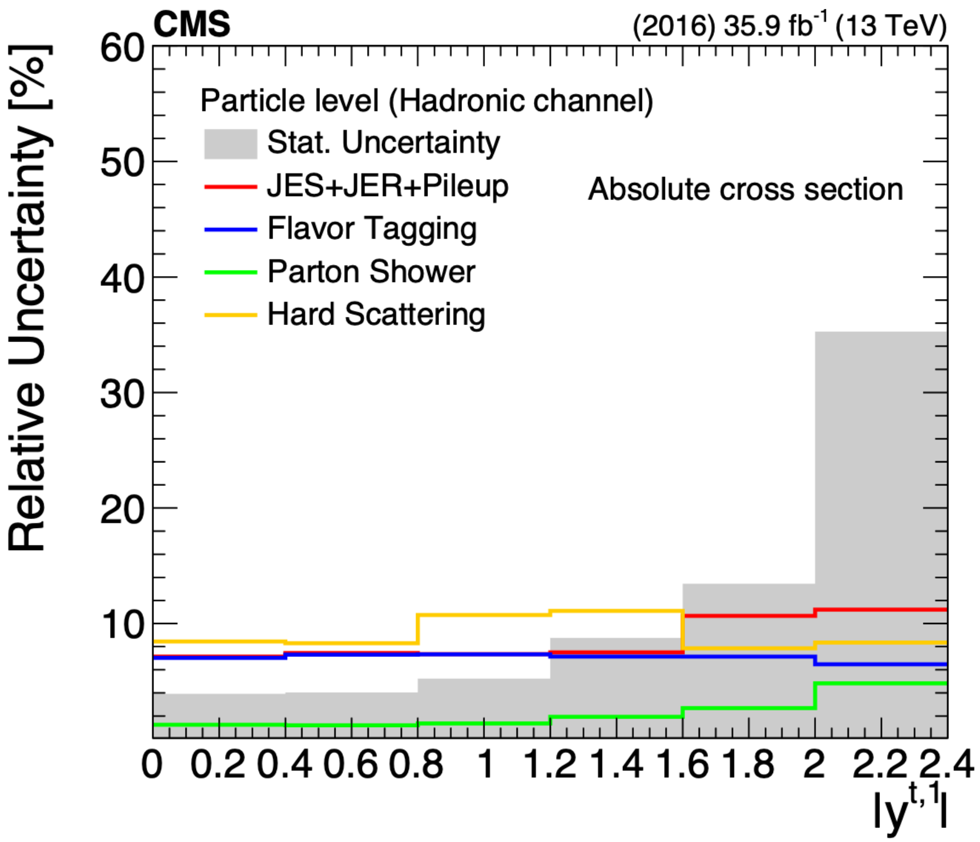
Uncertainties vs leading top |y|

paper



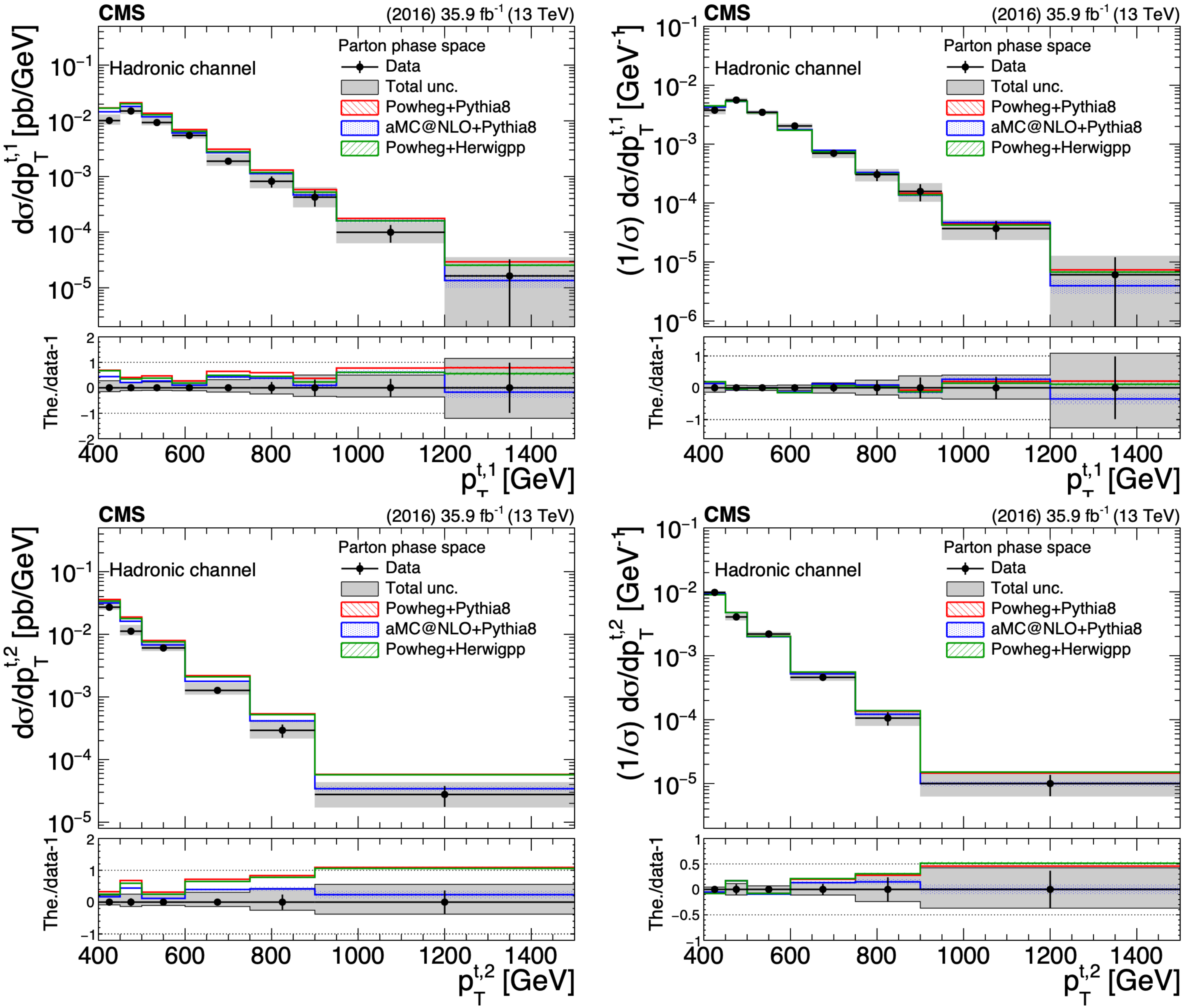






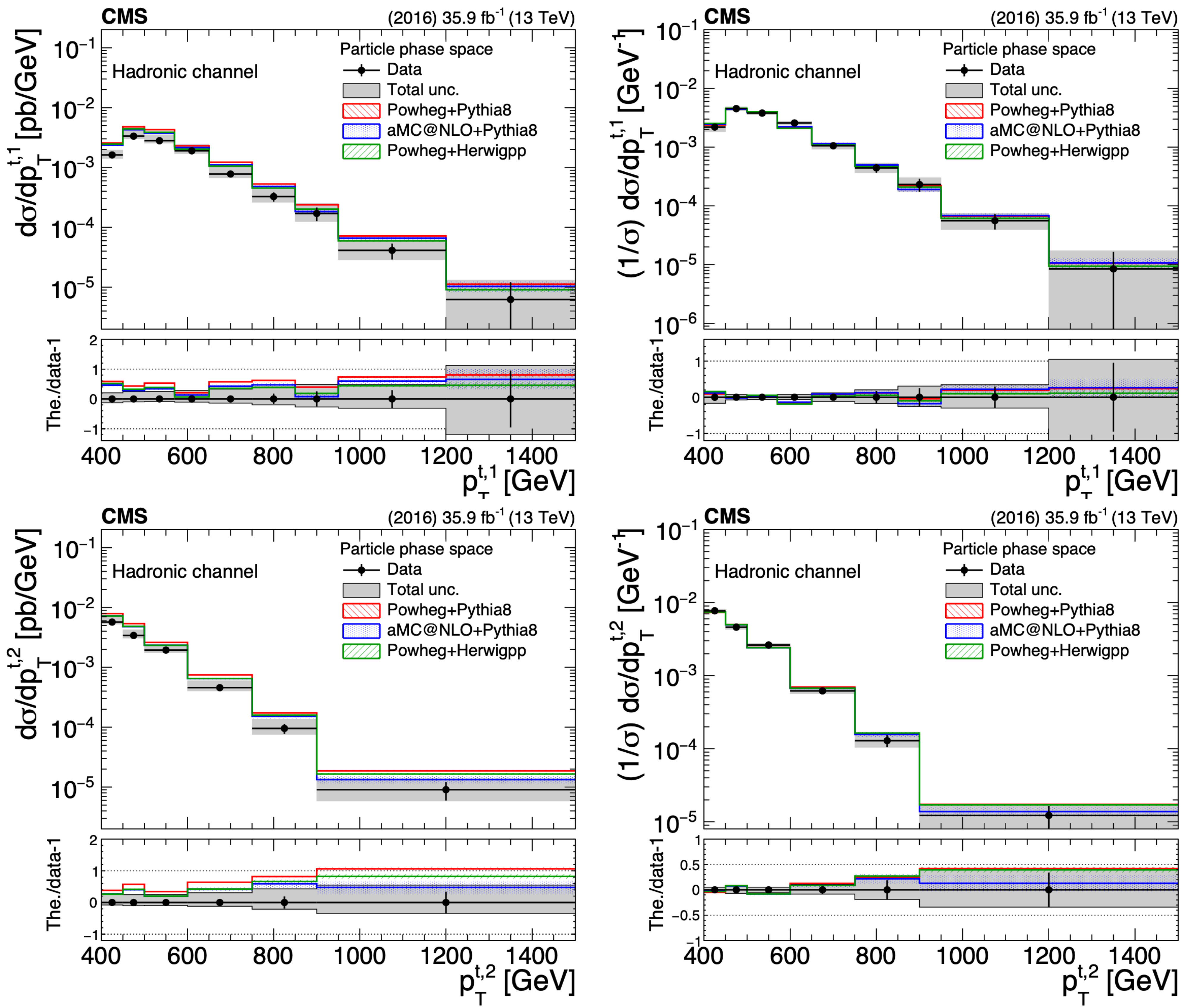
Results (parton, top p_T)

paper



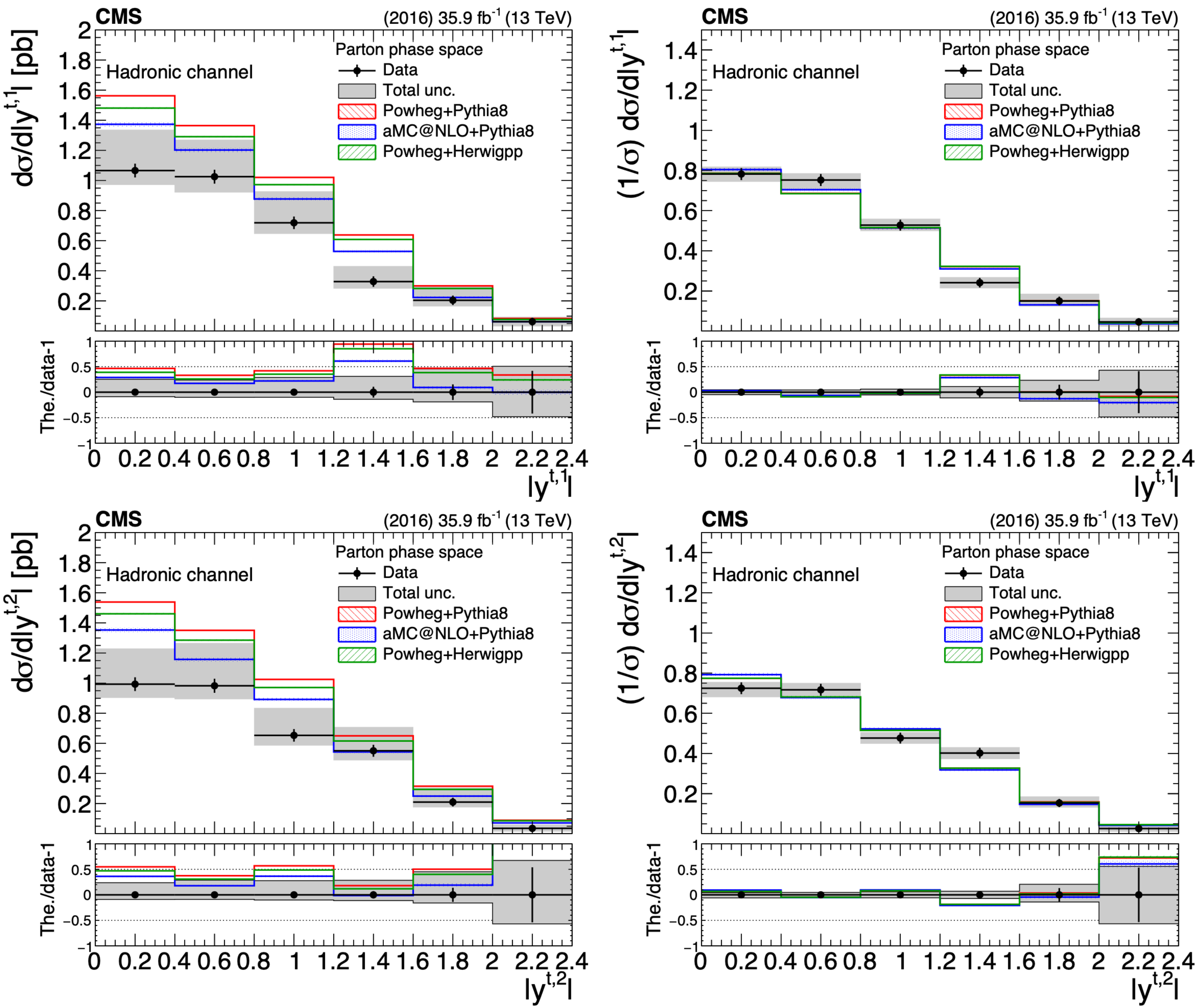
Results (particle, top p_T)

paper



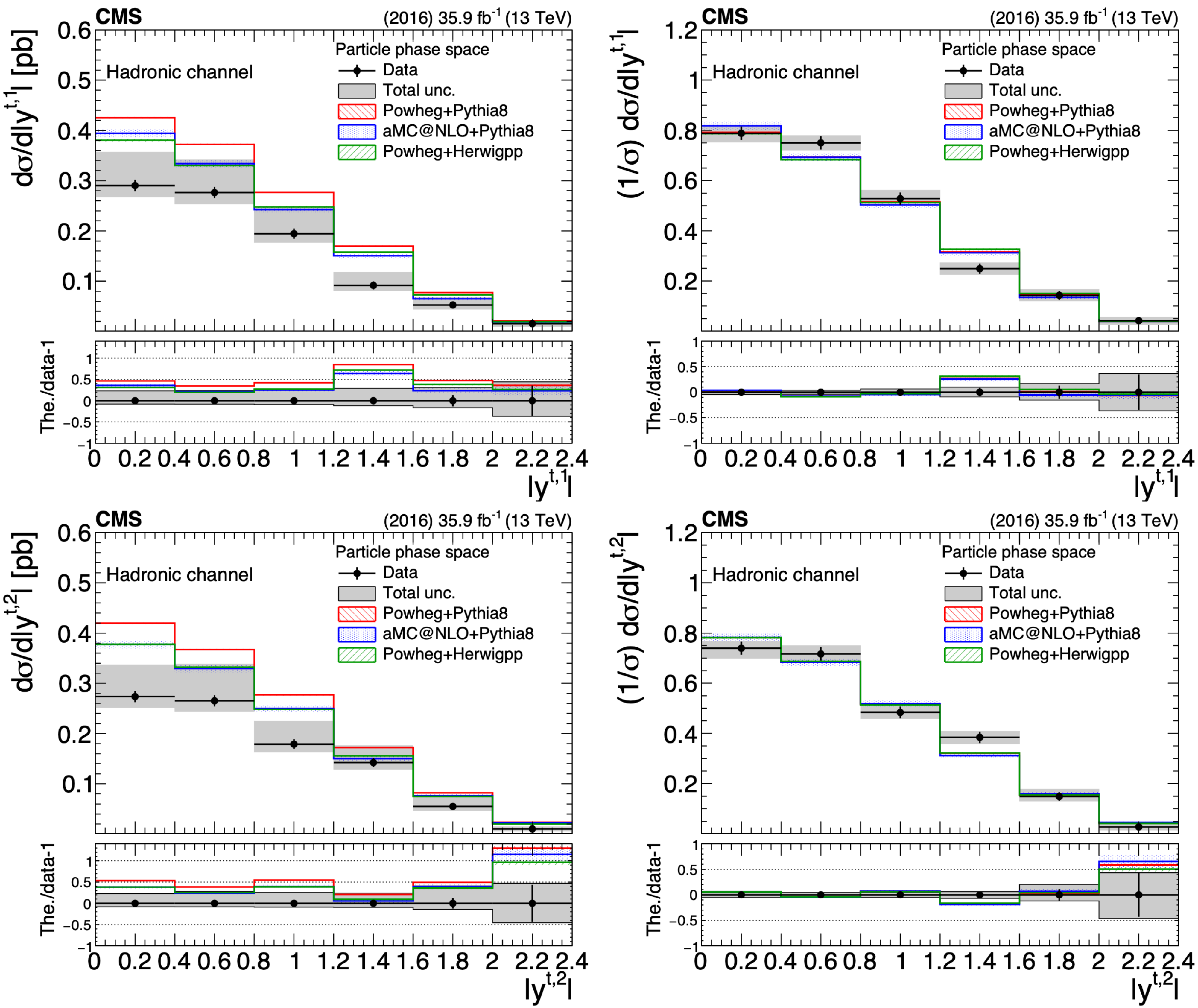
Results (parton, top |y|)

paper



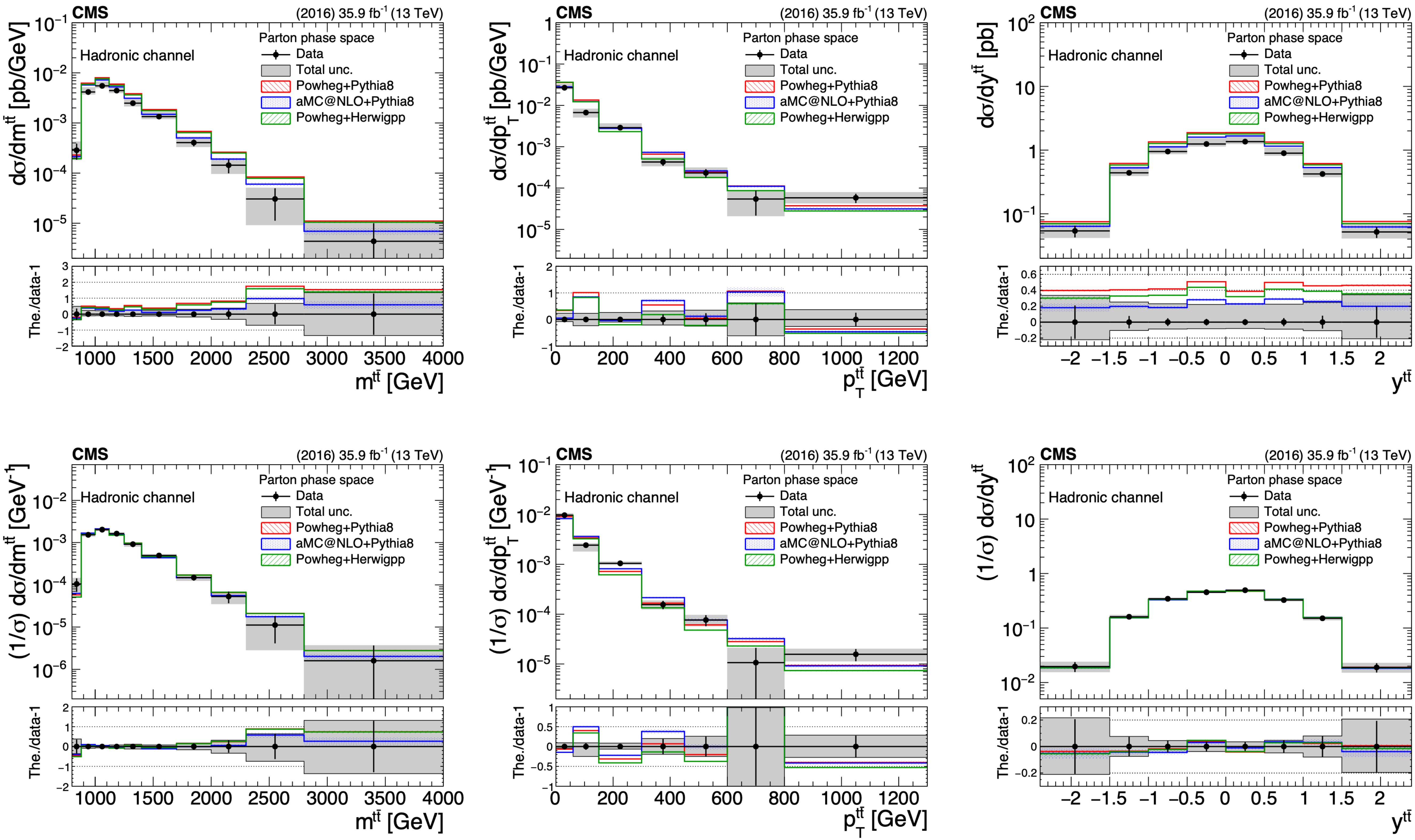
Results (particle, top |y|)

paper



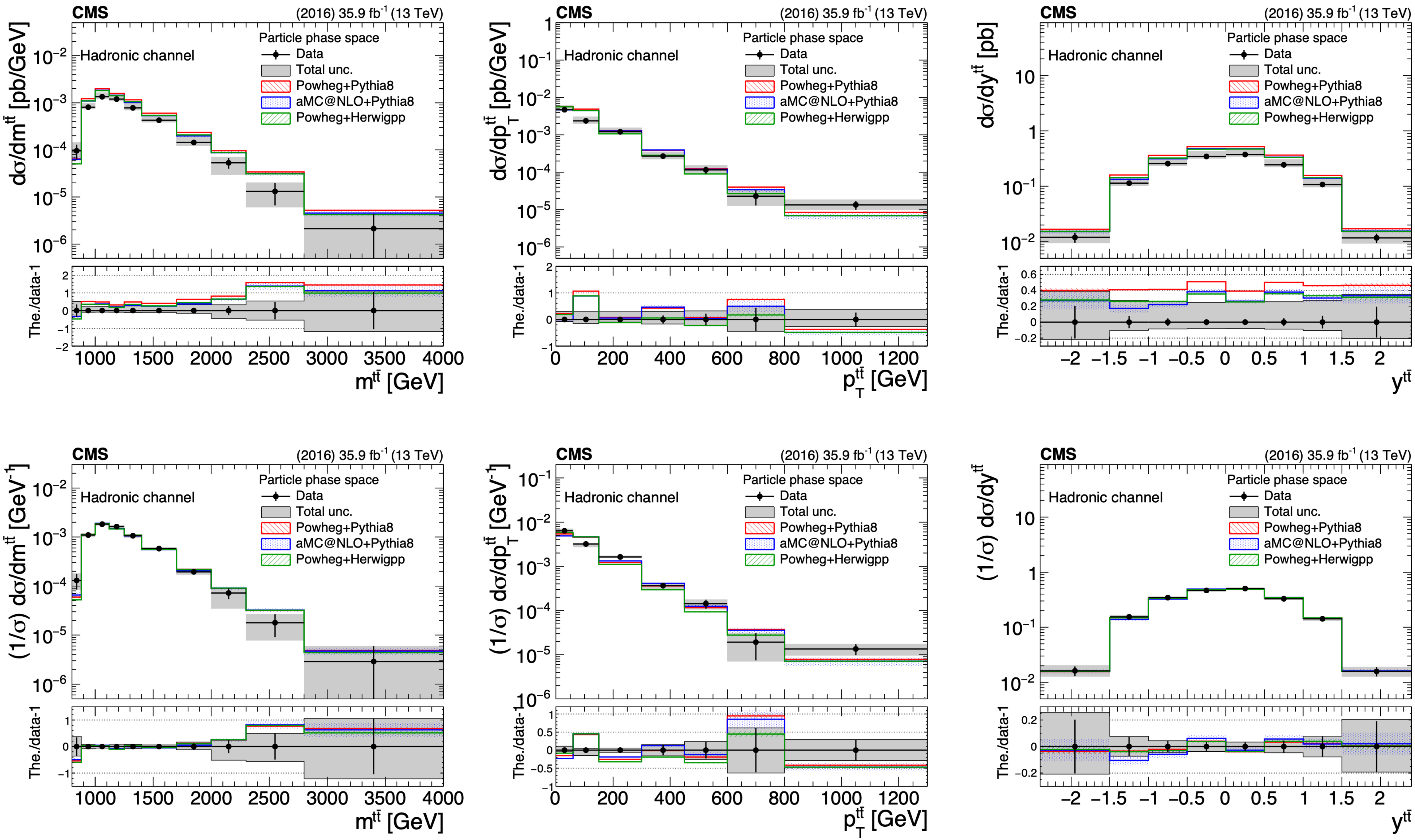
Results (parton, m_{tt}, y_{tt}, $p_{T,tt}$)

paper



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

paper

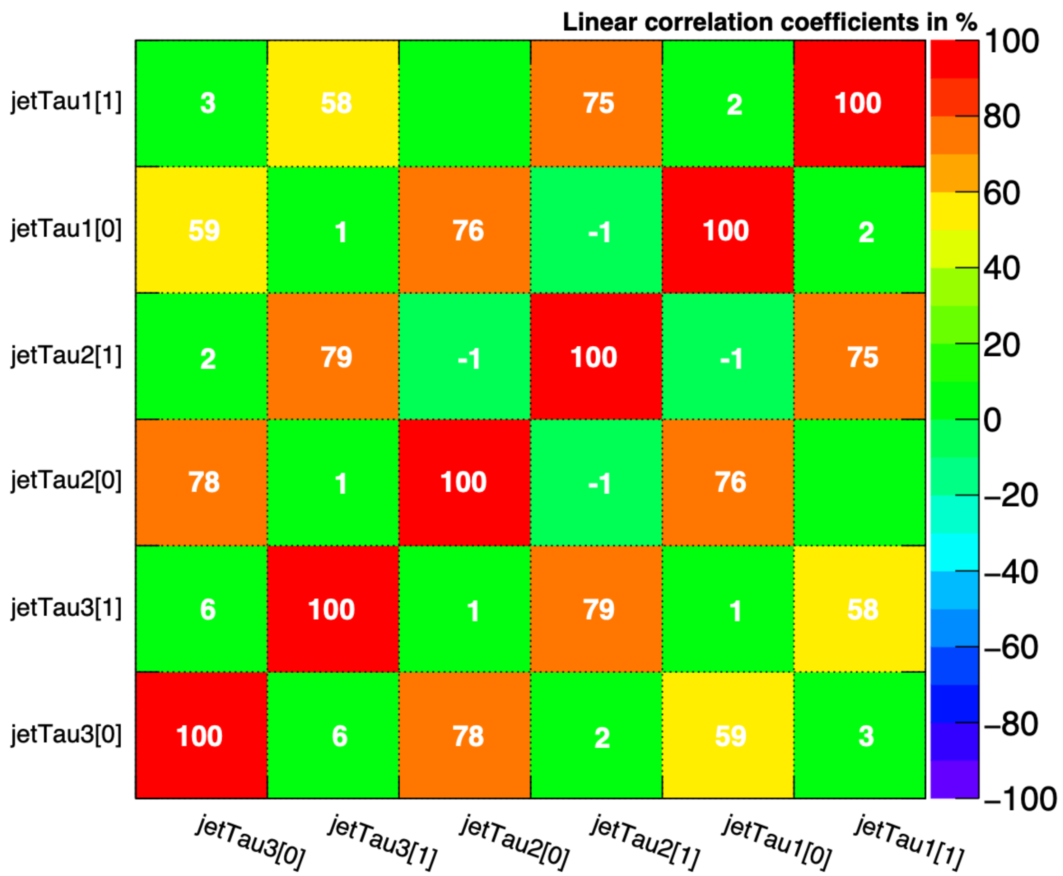


Summary

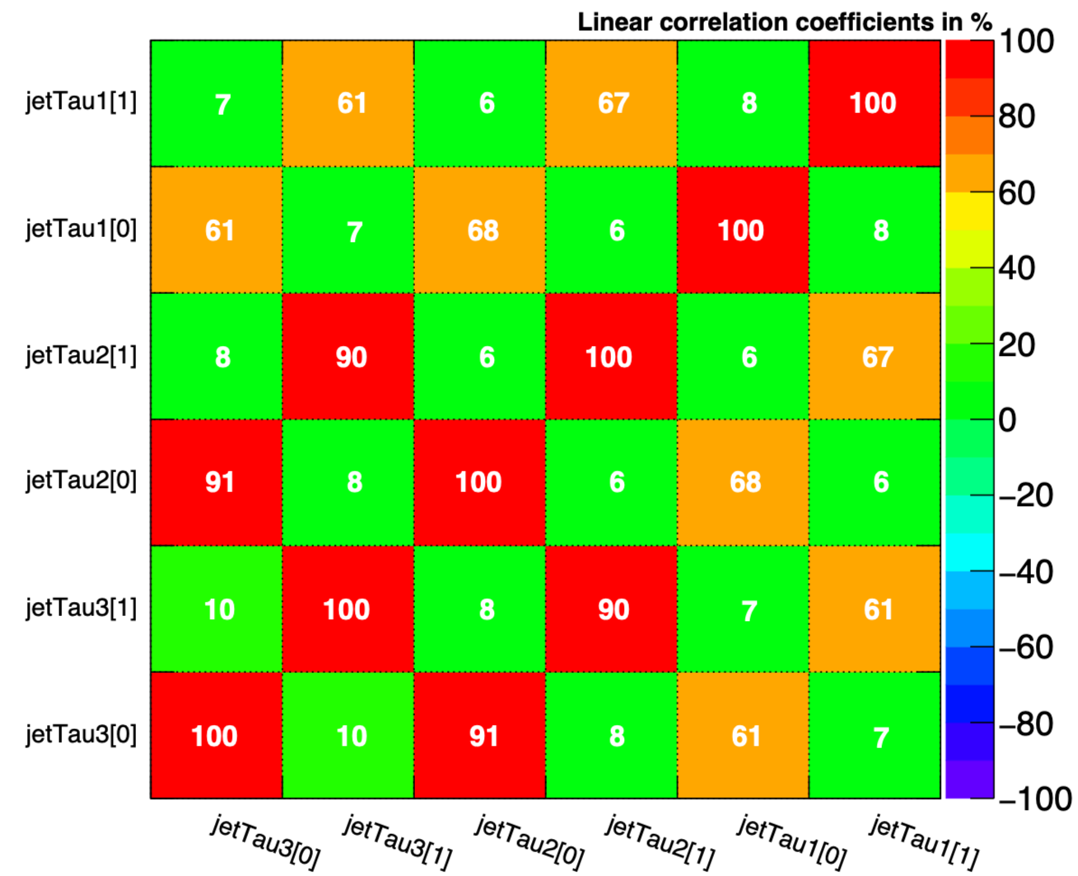
- we have performed a measurement of differential ttbar cross section with boosted top quarks in the hadronic channel
  - 2016 data, 35.9 fb^{-1}
  - highest reach so far: 1.5 TeV in top p_T and 4 TeV in m_{tt}
- seven observables: leading & subleading top p_T & $|y|$, m_{tt}, $p_{t,TT}$, y_{TT}
  - parton & particle level
  - absolute & normalised cross sections
- results
  - comparison with MC models: Powheg+Pythia8, Powheg+Herwig++, aMC@NLO+Pythia8
    - awaiting for NNLO calculations
  - shapes overall compatible with theory
    - no top p_T slope
  - overall shift of the order of 40% in the total cross section (Powheg+Pythia8 shows the largest discrepancy)
- we seek the approval of TOP-18-013

MVA training: correlation matrices

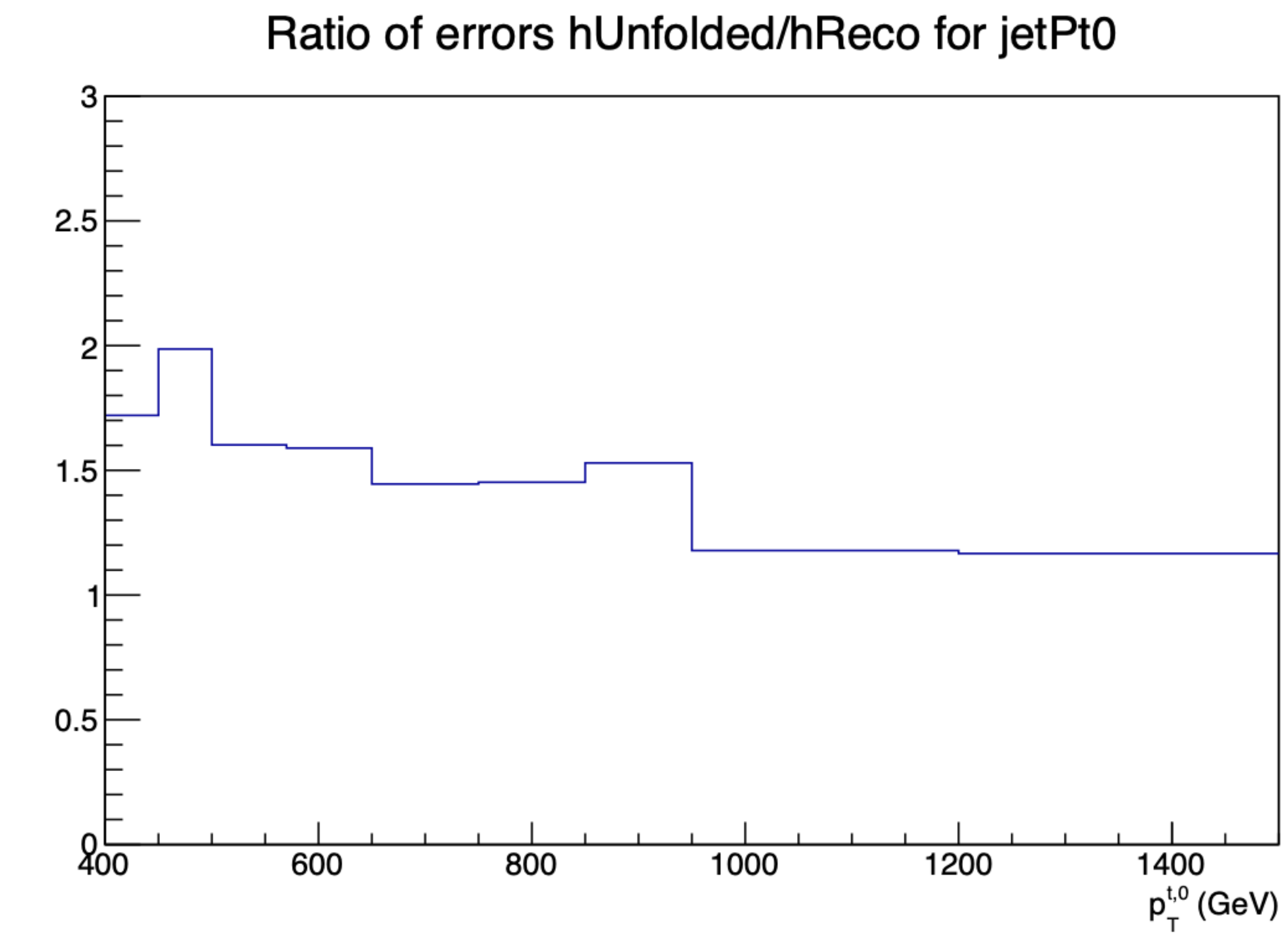
Correlation Matrix (signal)

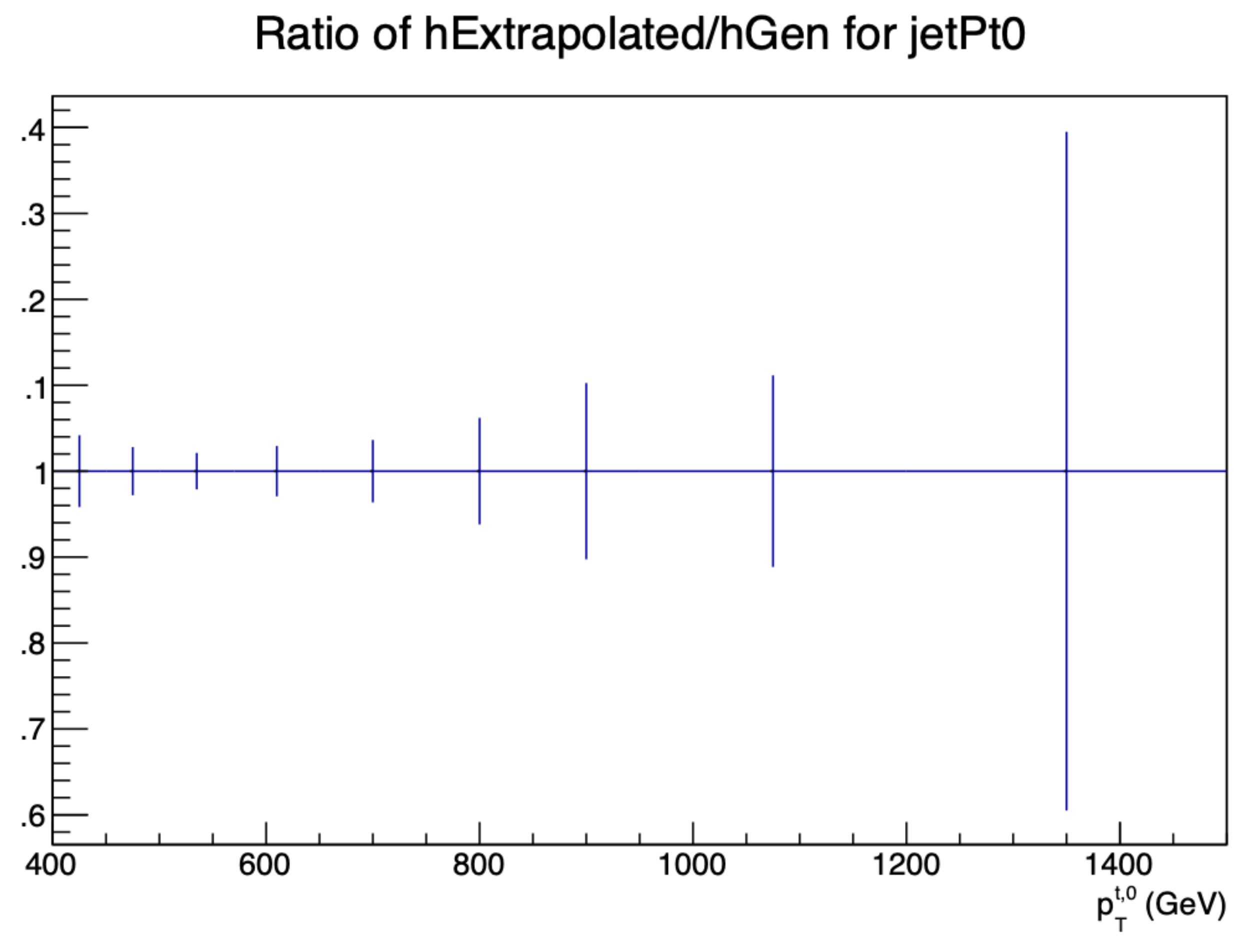


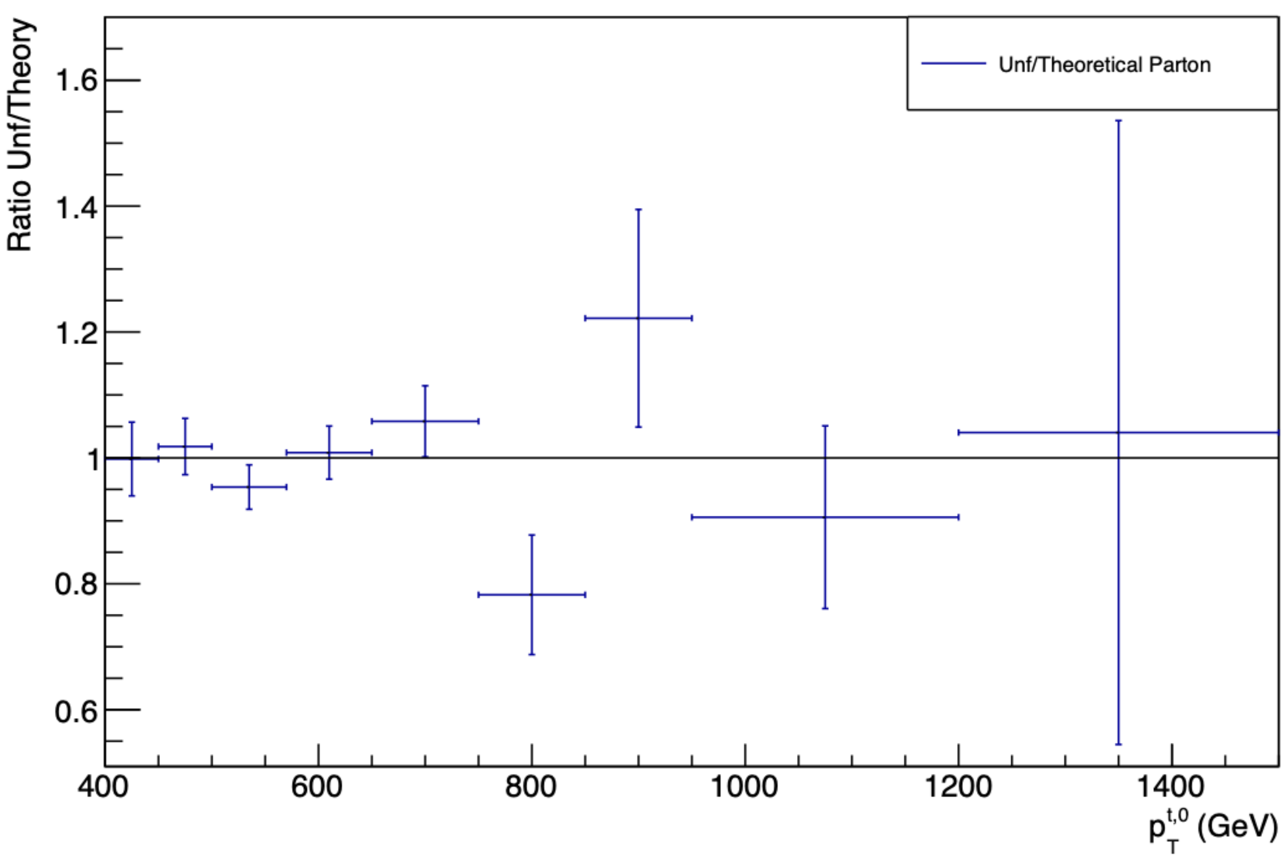
Correlation Matrix (background)



Unfolding tests

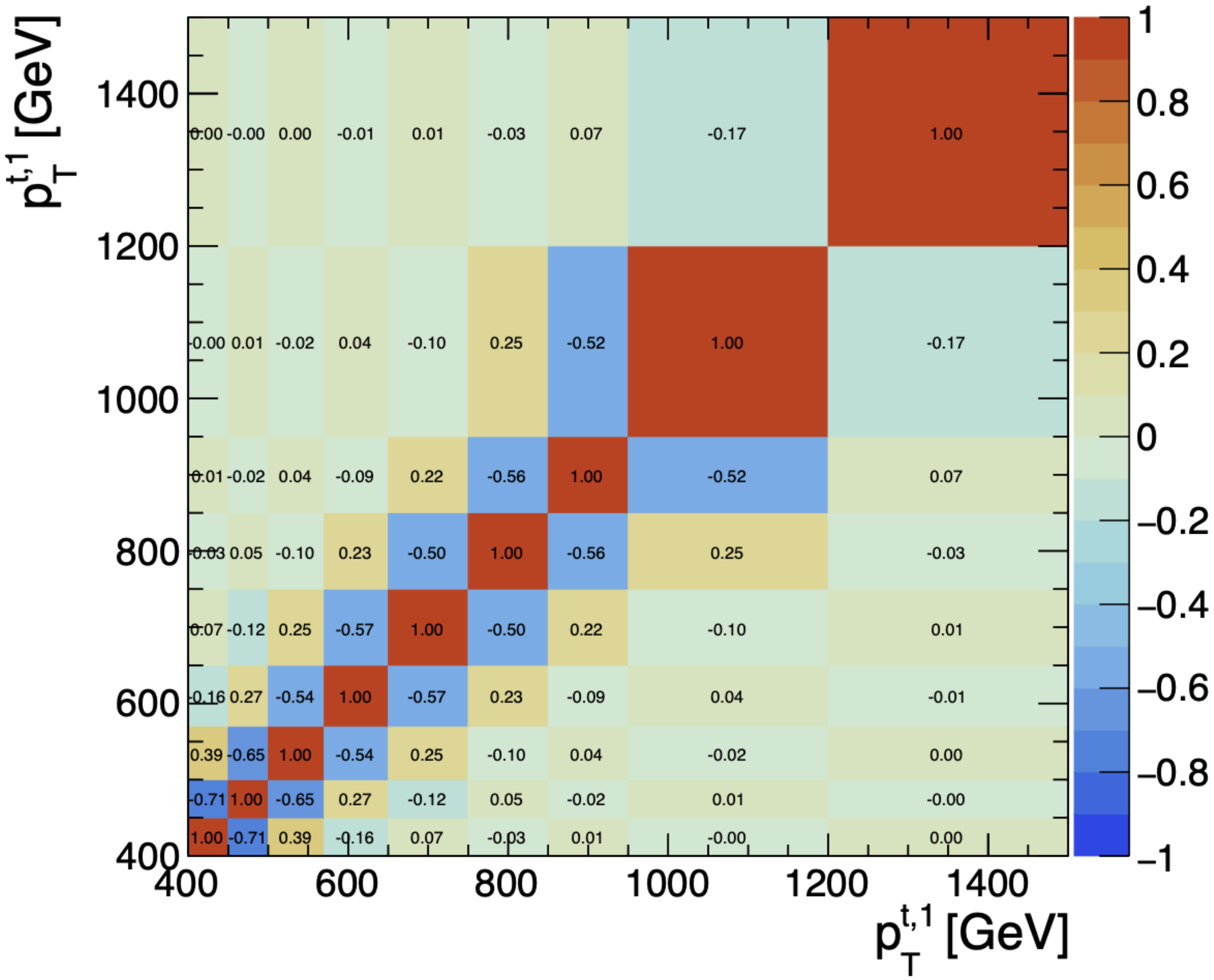




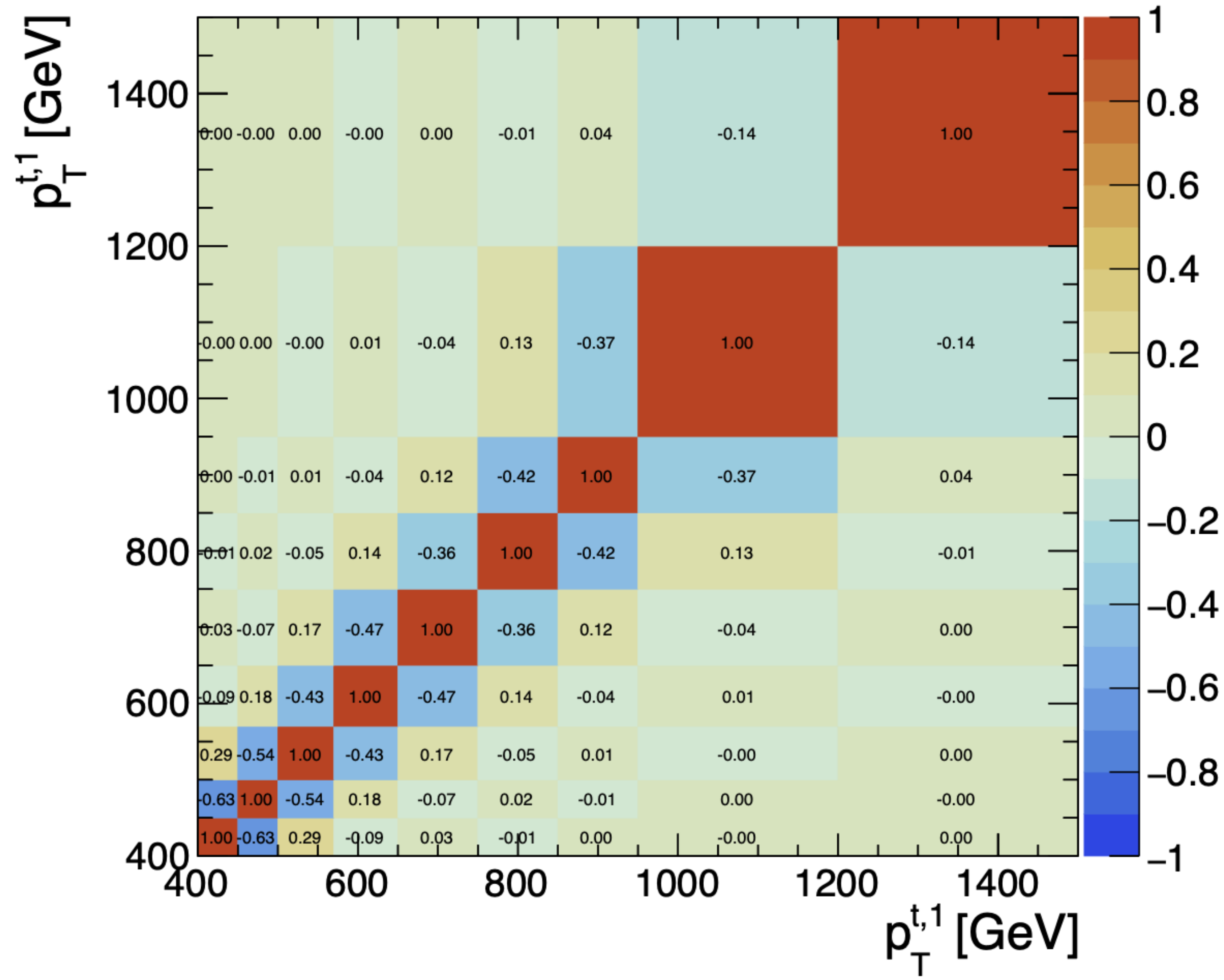


Post-unfolding correlations

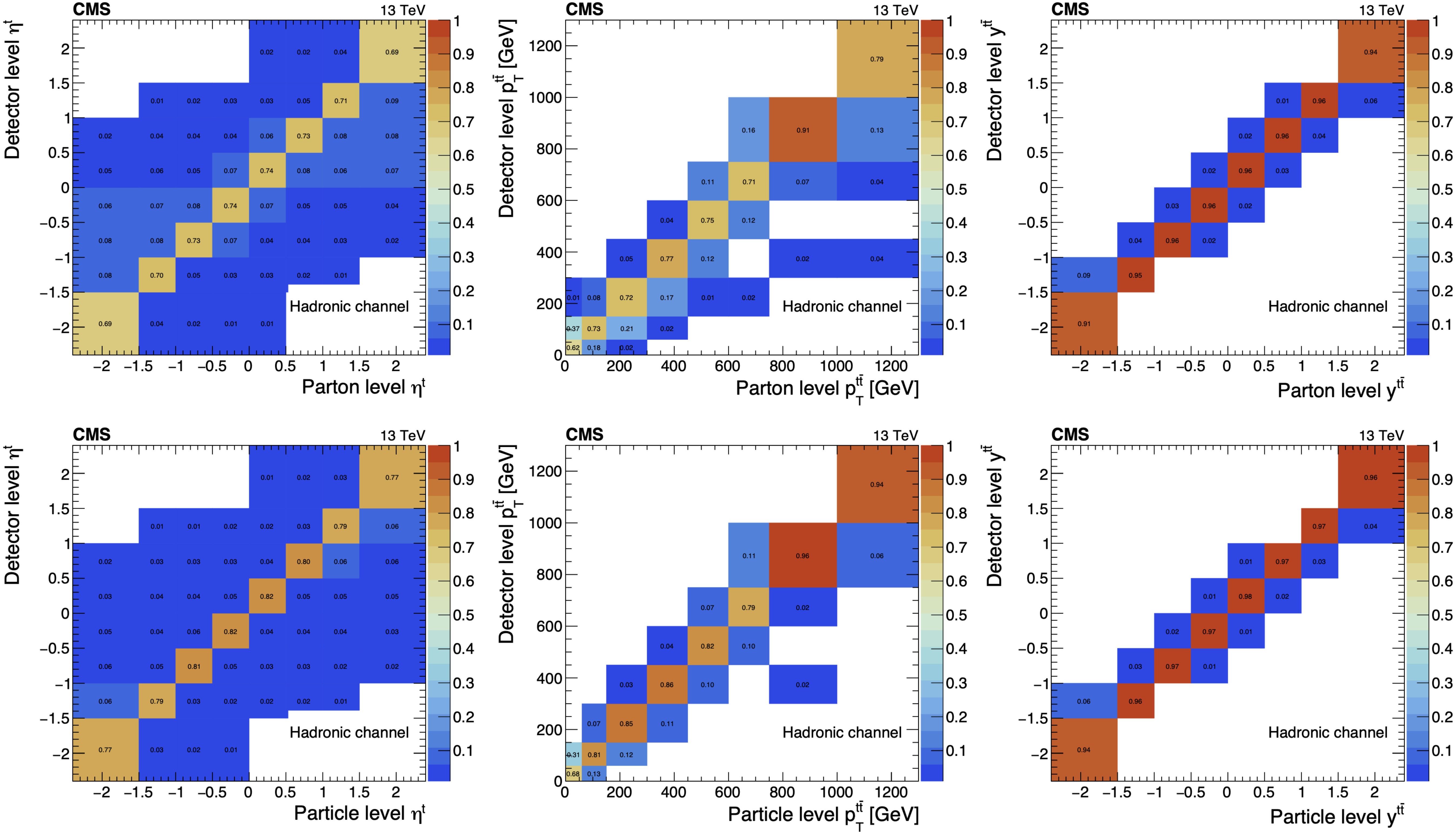
Parton



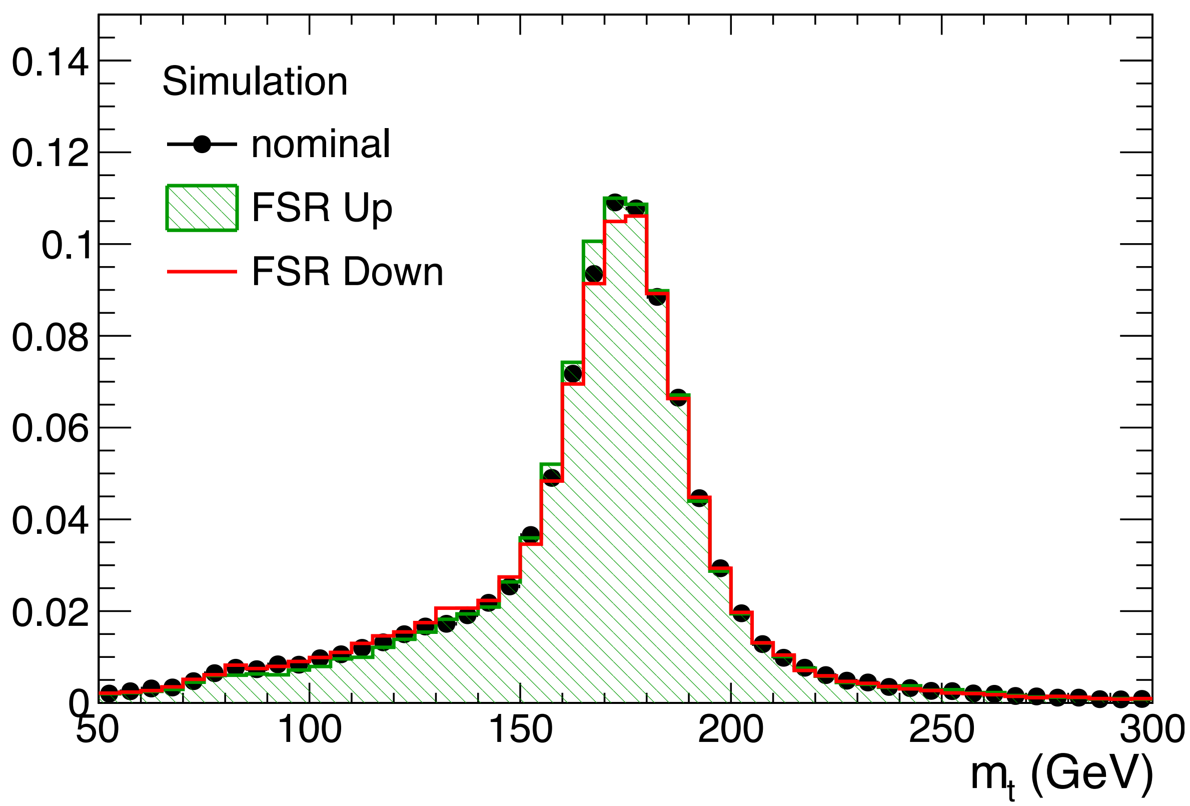
Particle

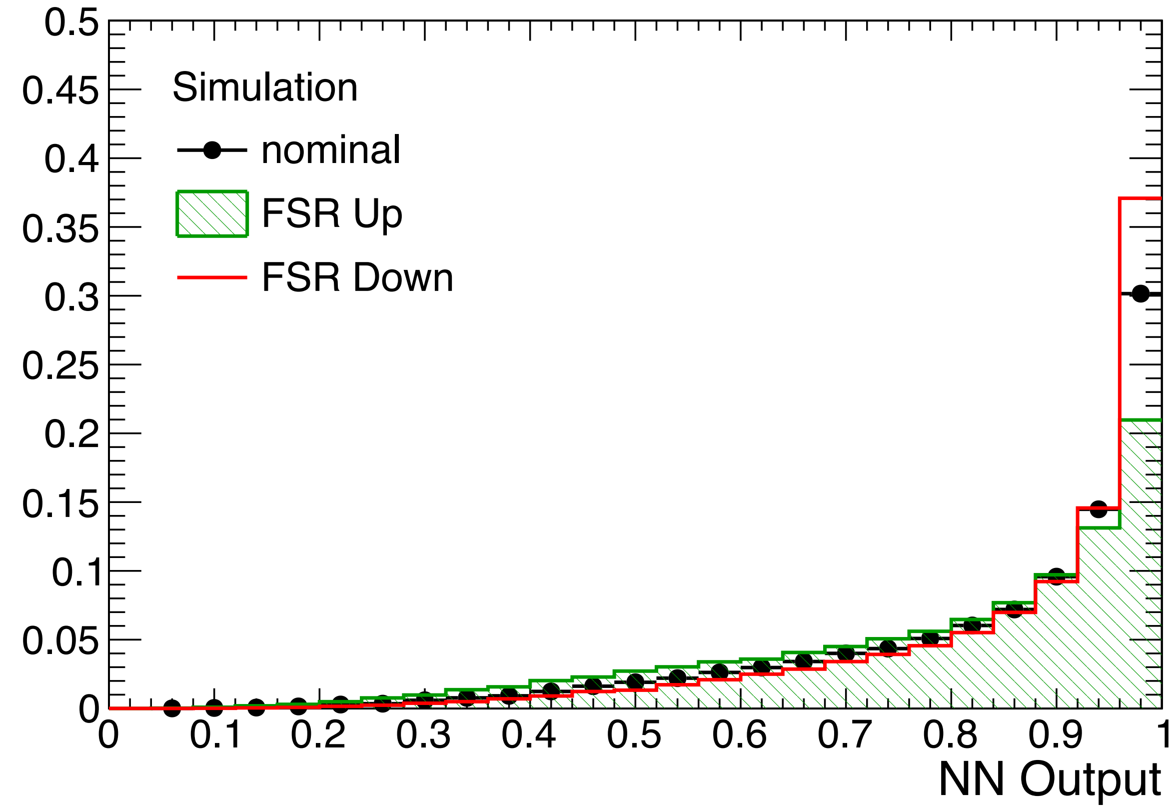


Migration matrices

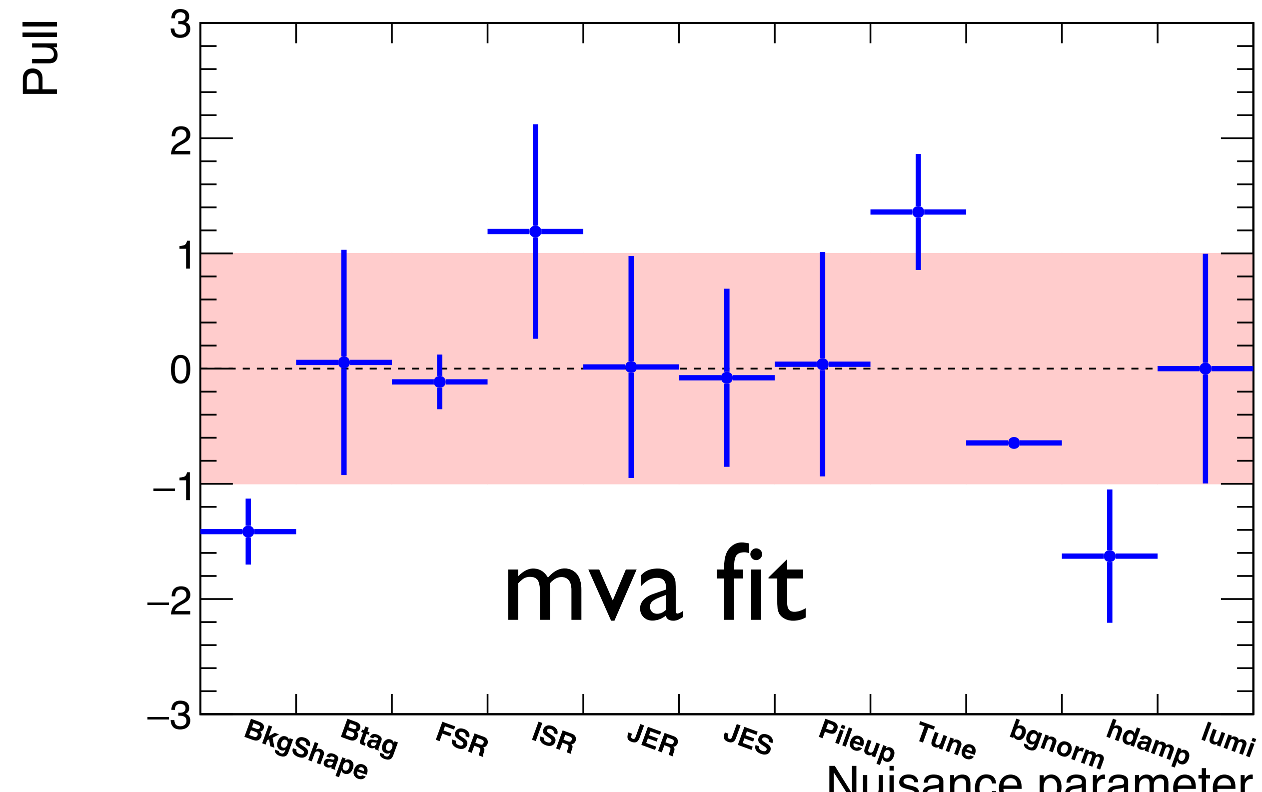


Default FSR variations

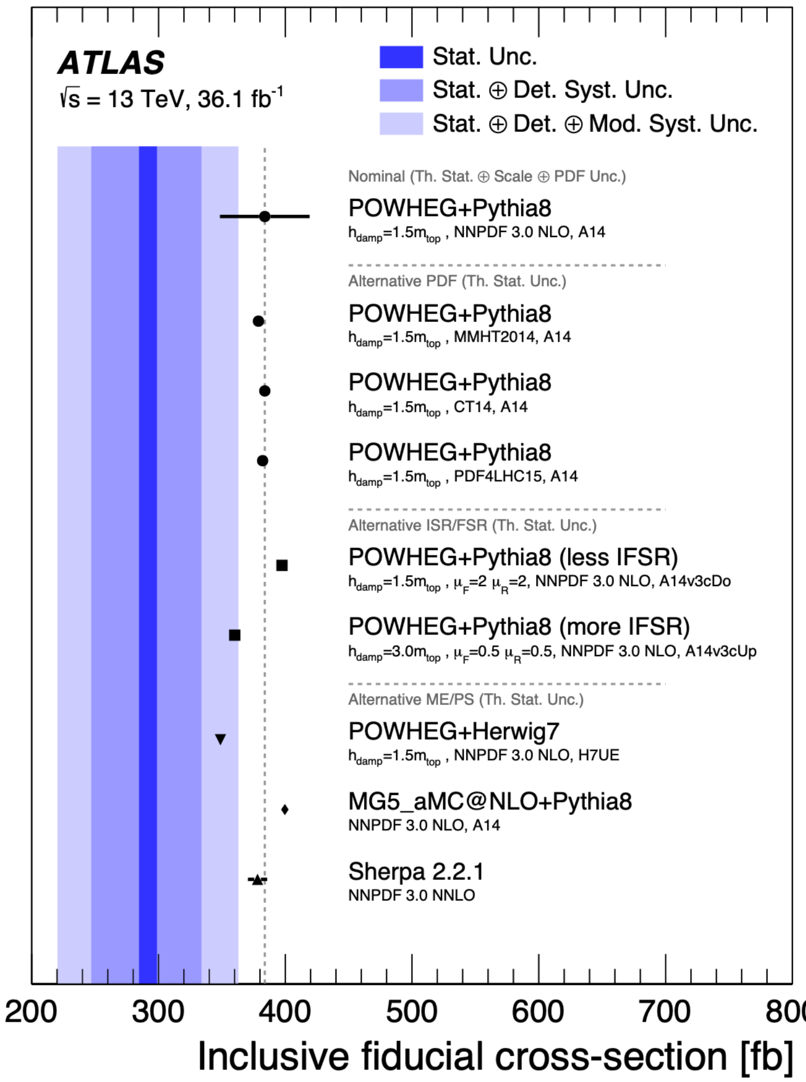


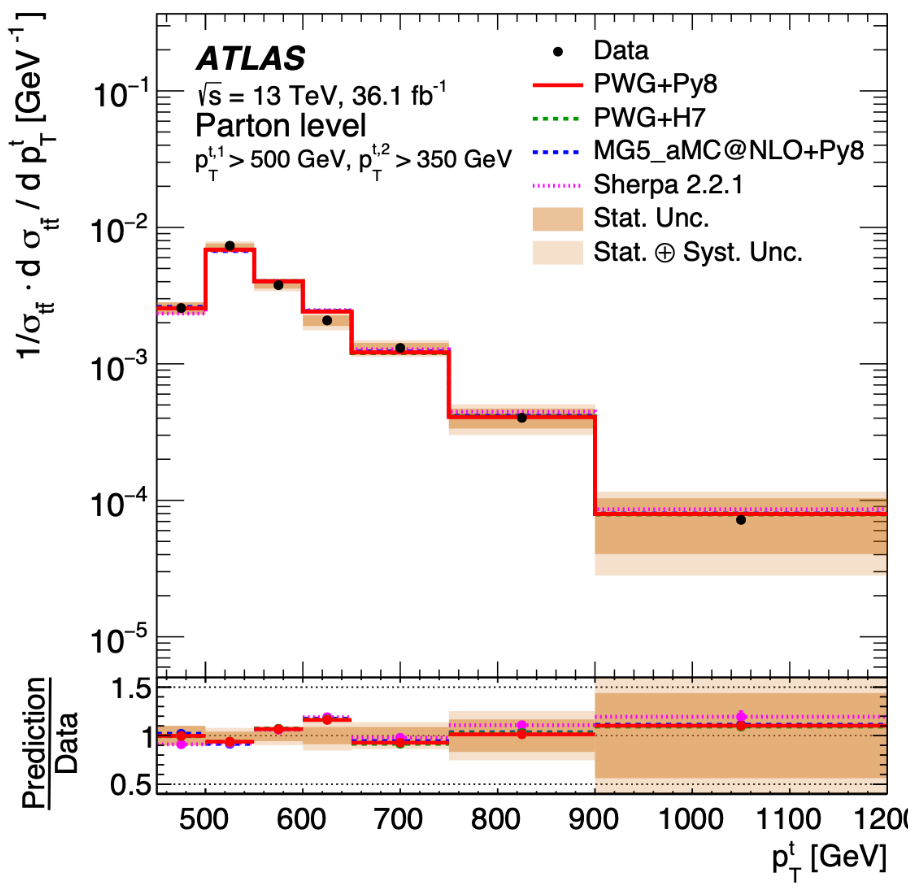


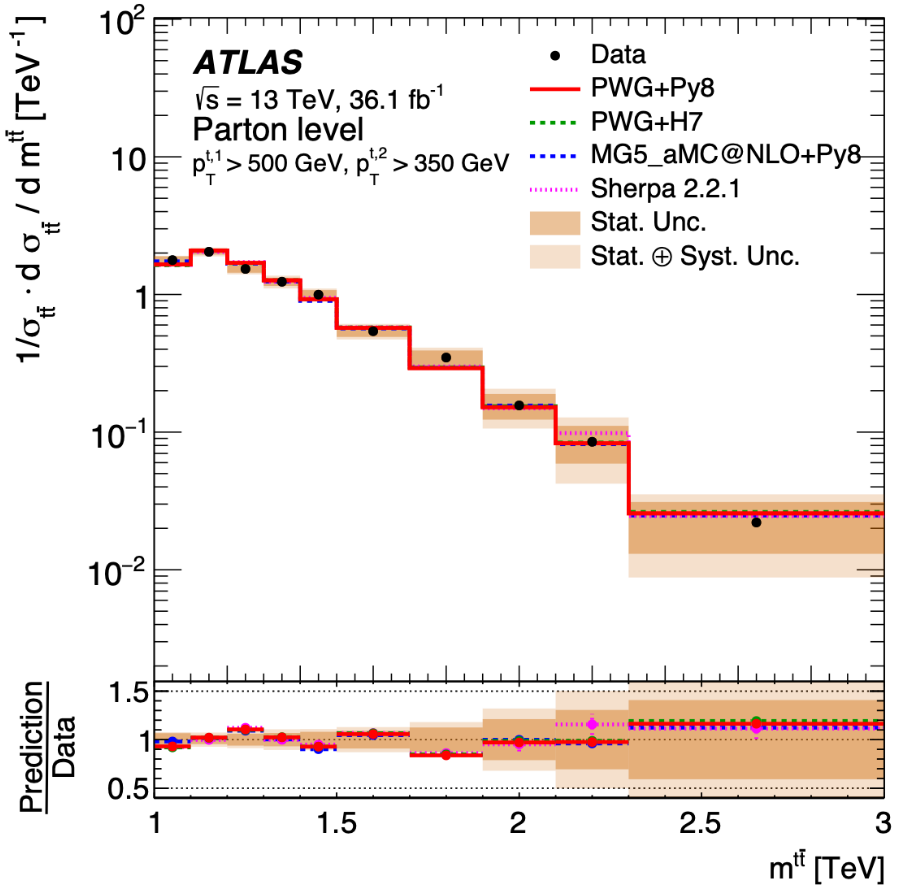
Extreme FSR variations are not justified by data



ATLAS results







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