Measurements of $t\bar{t}$+jets

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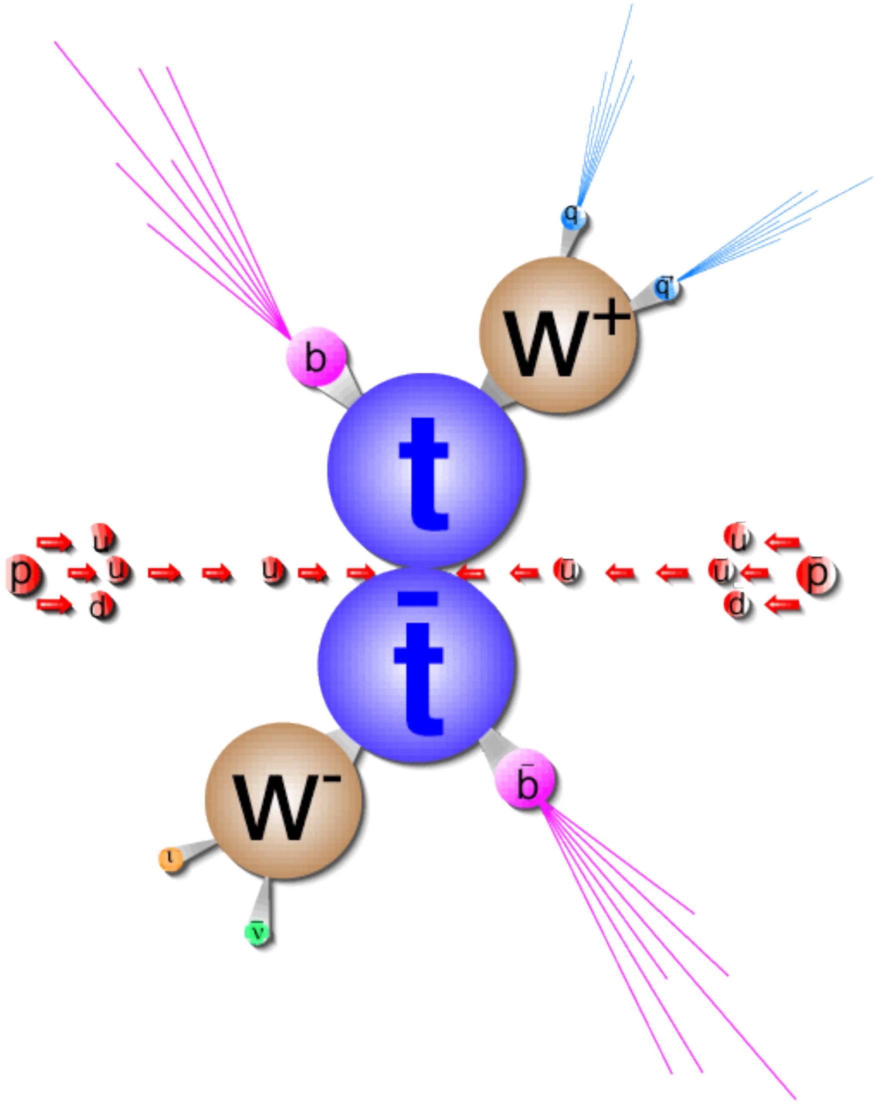
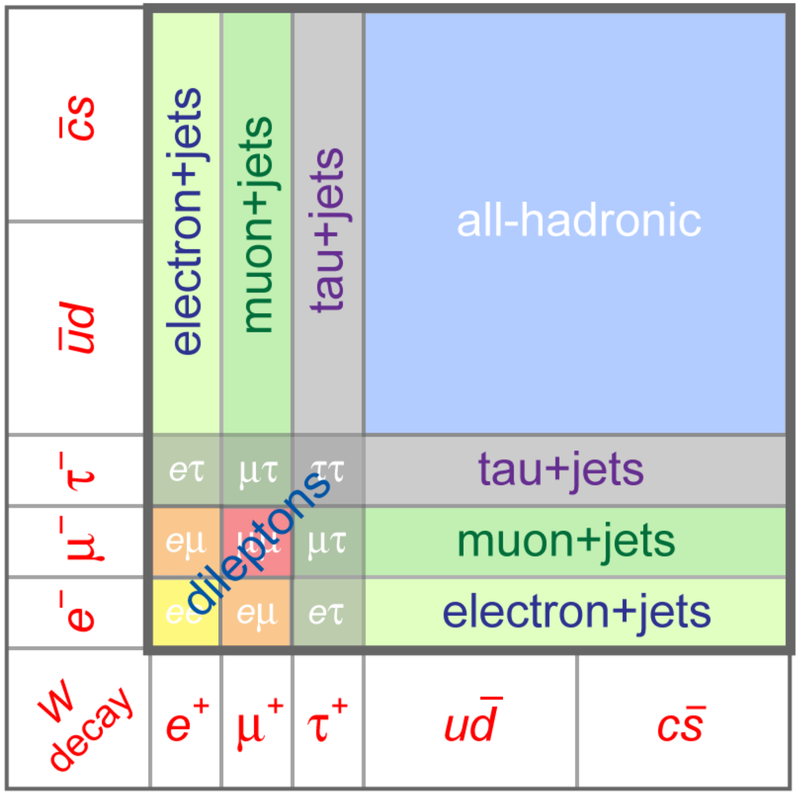
on behalf of the ATLAS and CMS Collaborations

- Introduction
- MC generators
- Fully leptonic channel
- Lepton + jets channel
- Summary

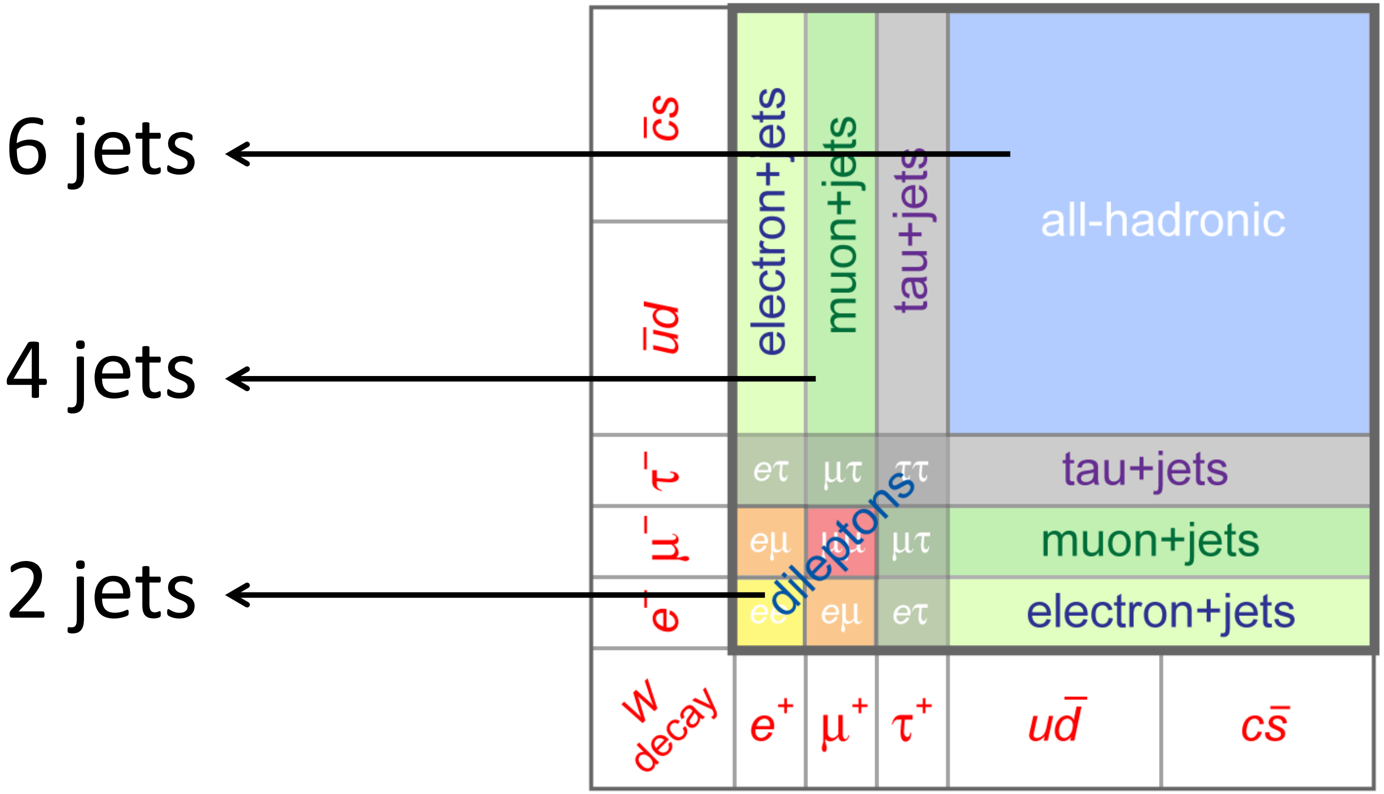
TOP 2013, Durbach, 16 September 2013

$t\bar{t}$ decays topology





$t\bar{t}$ decays multiplicity (LO)



$t\bar{t}$ decays multiplicity

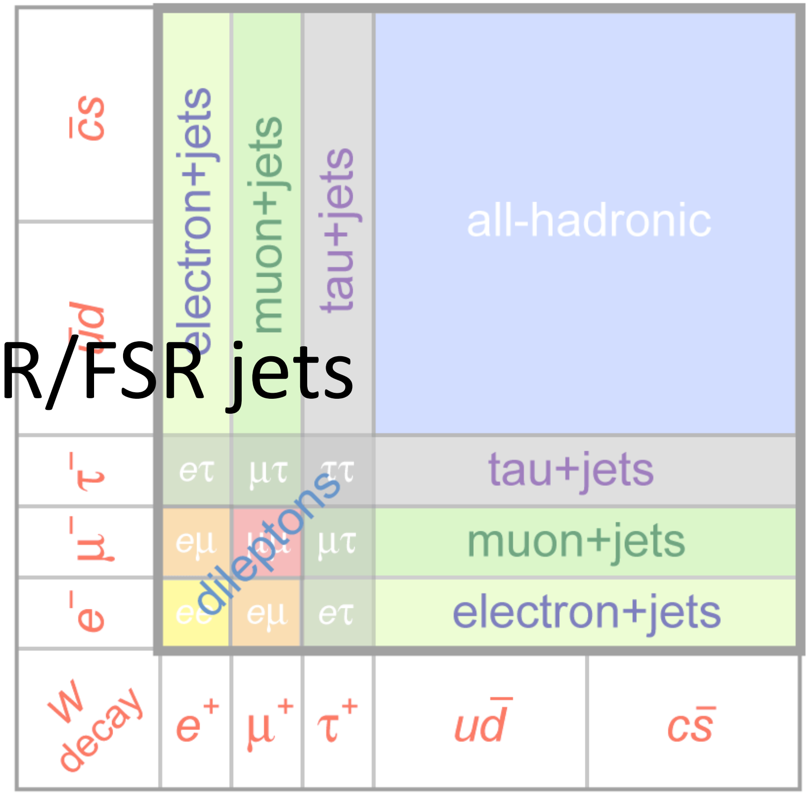
About half of the $t\bar{t}$ production @ LHC energies have extra jets

6 jets

4 jets

2 jets

$\left.\right\}$ + ISR/FSR jets

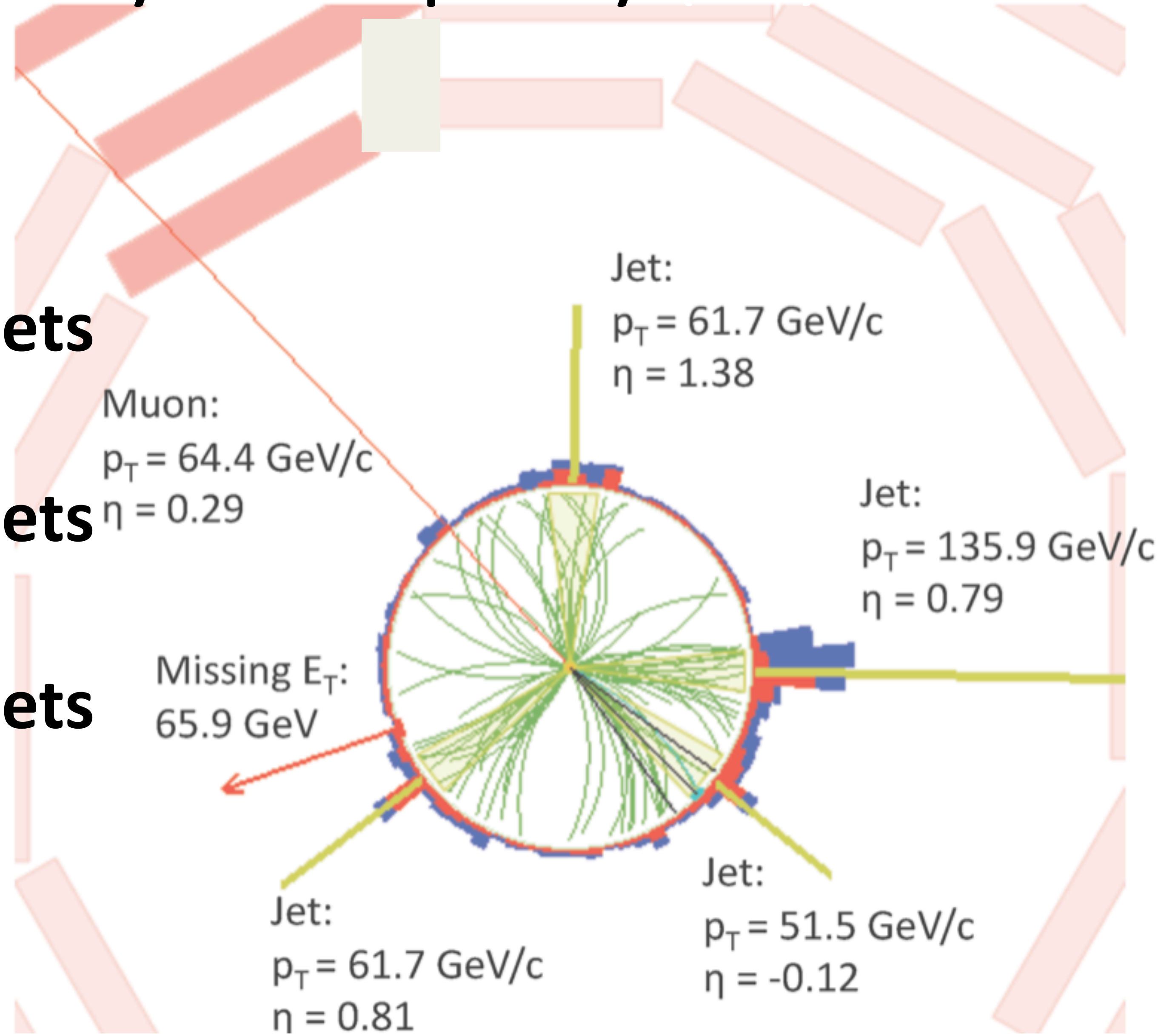


$t\bar{t}$ decays multiplicity

≥ 6 jets

≥ 4 jets

≥ 2 jets



$t\bar{t}$ decays multiplicity

≥ 6 jets

- Constraint of ISR/FSR @ m_{top} scale
- Test of perturbative QCD @ LHC energies

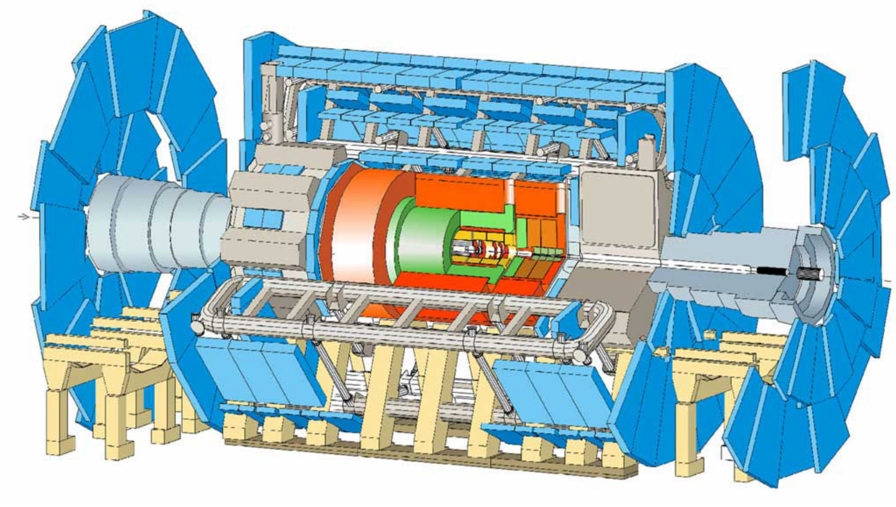
≥ 4 jets

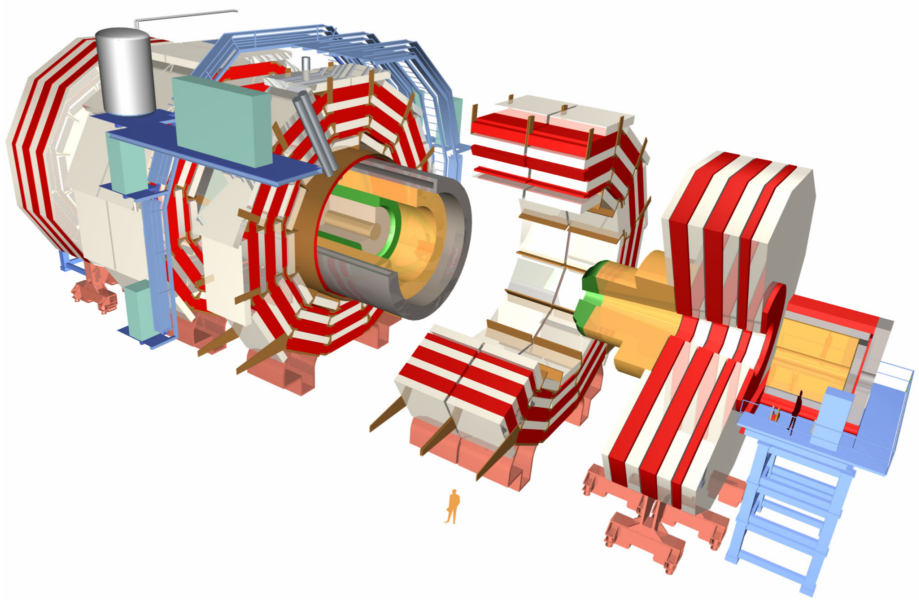
- $t\bar{t}$+jets important background to $t\bar{t}H$ and other BSM final states

≥ 2 jets

- Anomalous $t\bar{t}$+jets production could signal BSM physics

Analyses covered

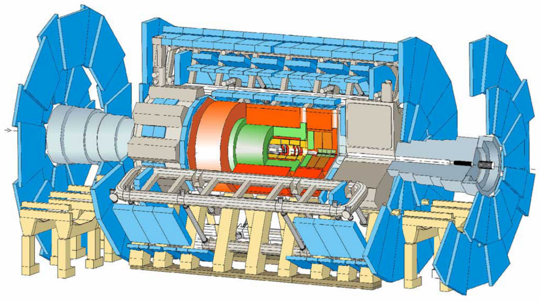




• 4.7 fb^{-1} @ 7 TeV lepton + jets channel
ATLAS-CONF-2012-155
• 2.05 fb^{-1} @ 7 TeV dilepton channel
Eur. Phys. J C (2012) 72-2043

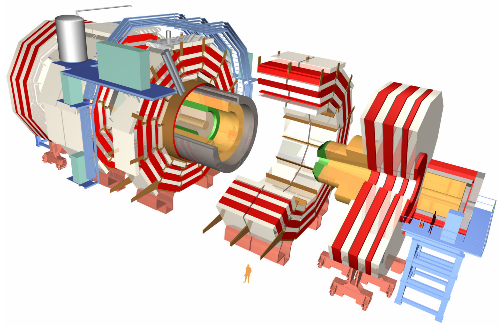
• 5.0 fb^{-1} @ 7 TeV lepton+jets channel
CMS PAS TOP-12-018
• 5.0 fb^{-1} @ 7 TeV dilepton channel
CMS PAS TOP-12-023
• 19.6 fb^{-1} @ 8 TeV dilepton channel
CMS PAS TOP-12-041

Monte Carlo simulations



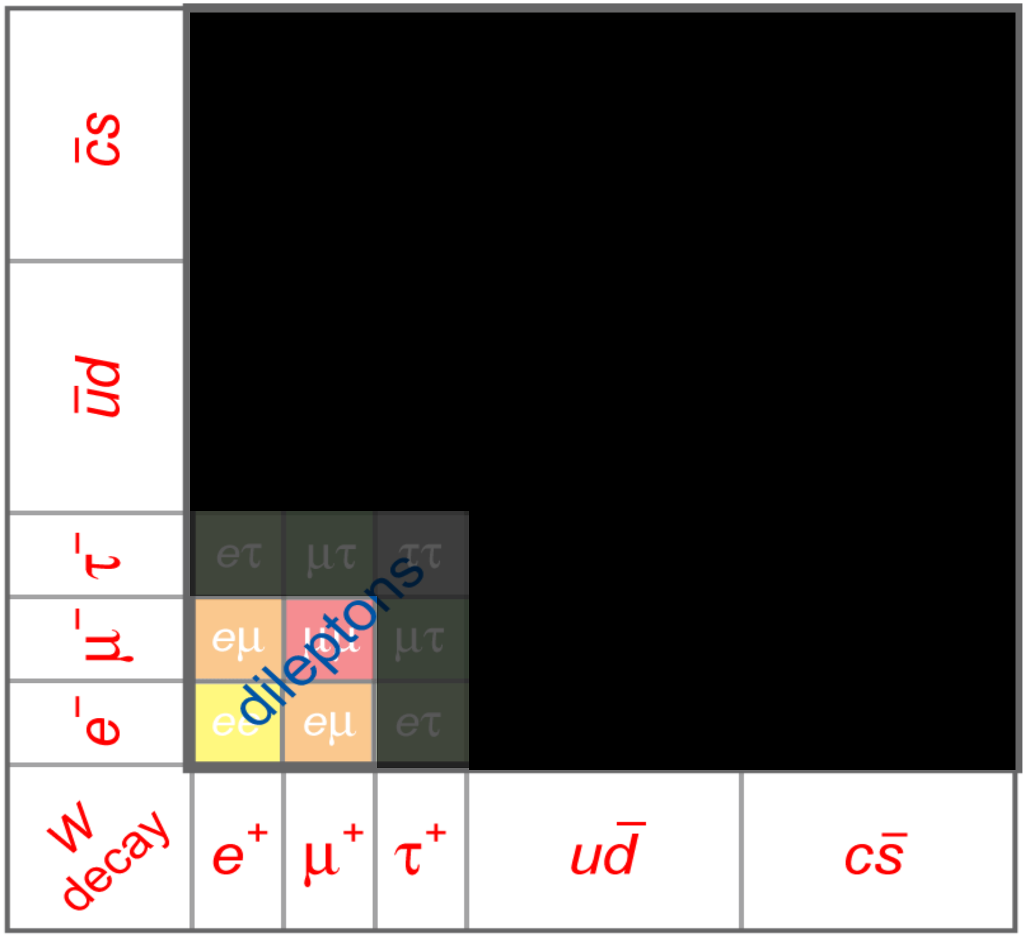
- $t\bar{t}$ signal:
  - ALPGEN + HERWIG (Vary renormalization/factorization and jet-parton matching scales)
  - ALPGEN + PYTHIA
  - POWHEG + PYTHIA
  - MC@NLO + HERWIG
  - ACERMC, SHERPA
- W/Z+jets ALPGEN + HERWIG
- Diboson HERWIG
- Single top ACERMC (*t*-channel) + MC@NLO (*Wt*- and *s*- channels)

- $\sigma^{th}_{tt} = 167^{+17}_{-18}$ pb (m_t = 172.5 GeV)



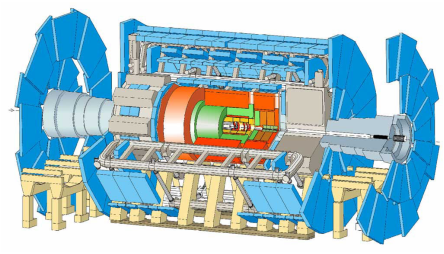
- $t\bar{t}$ signal:
  - MADGRAPH + PYTHIA (Vary renormalization/factorization and jet-parton matching scales)
  - POWHEG + PYTHIA
  - MC@NLO + HERWIG
- Z/γ^* MADGRAPH + PYTHIA
- W/Z+jets MADGRAPH + PYTHIA
- Diboson MADGRAPH + PYTHIA
- Single top POWHEG + PYTHIA

- $\sigma^{th}_{tt} = 165.6^{+11.6}_{-10.4}$ pb (m_t = 172.5 GeV)



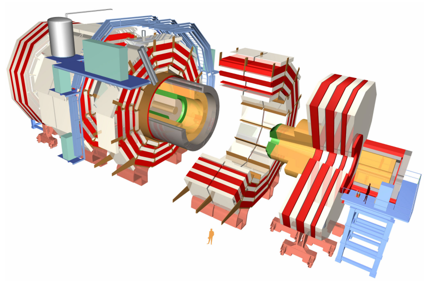
$\bar{c}s$
$\bar{u}d$
τ^-
μ^-
e^-
W decay
e^+
μ^+
τ^+
$u\bar{d}$
$c\bar{s}$
eτ
μτ
ττ
eμ
μμ
μτ
ee
eμ
eτ
dileptons

Event selection



- Electrons: p_T>25 GeV $|\eta|$<2.47
- Muons: p_T>25 GeV $|\eta|$<2.5
- Jets: p_T>25 GeV $|y|$<2.4

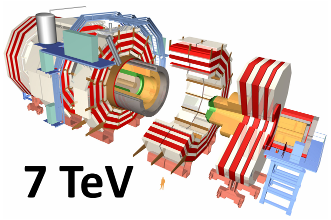
- Single lepton triggers
- Two opposite-sign leptons
- At least two jets
- At least two *b*-jets ($\varepsilon_{tagging} \approx$ 70%)
- E_t^{miss} > 40 GeV (*ee*, μμ)
- H_T > 130 GeV (*e*μ)
- Veto Z-boson and vector-meson regions (*ee*, μμ)



- Electrons: p_T>20 GeV $|\eta|$<2.4
- Muons: p_T>20 GeV $|\eta|$<2.4
- Jets: p_T>30 GeV $|\eta|$<2.4

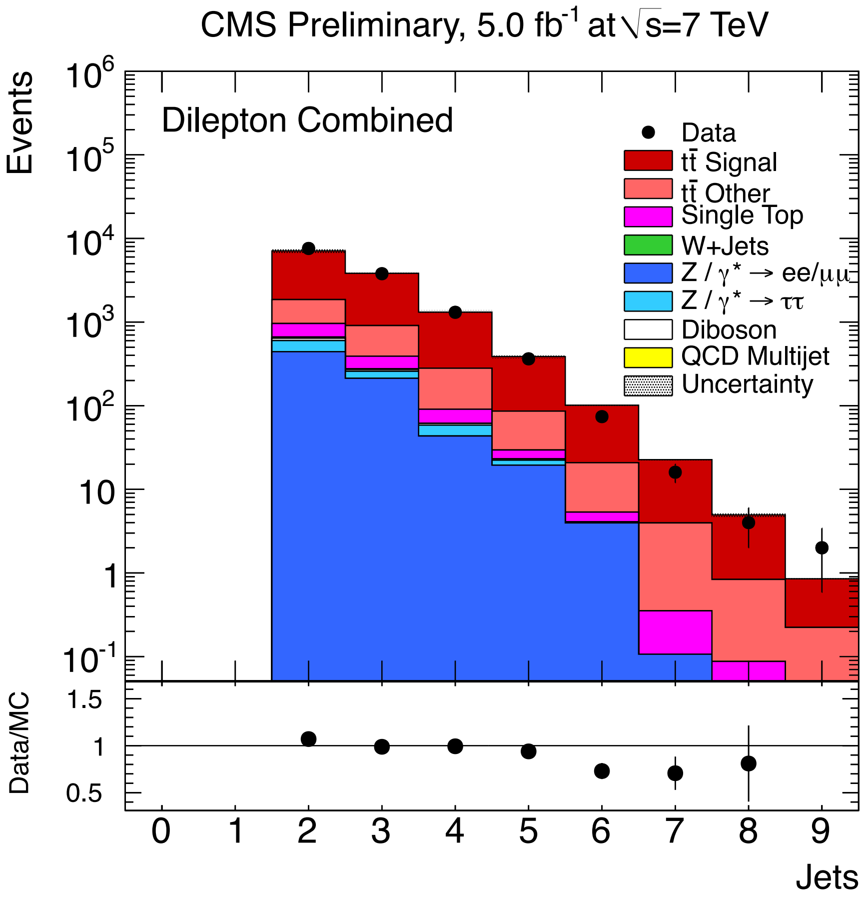
- Dilepton trigger
- At least two opposite-sign leptons
- At least two jets of which at least one is identified as *b*-jet ($\varepsilon_{tagging} \approx$ 80-85%)
- E_T^{miss} > 30 GeV (40 GeV)
- Use kinematic reconstruction to determine top-pair properties and identify 2 *b*-jet originating from decays of *t*-quarks

(value for 8 TeV data analysis)

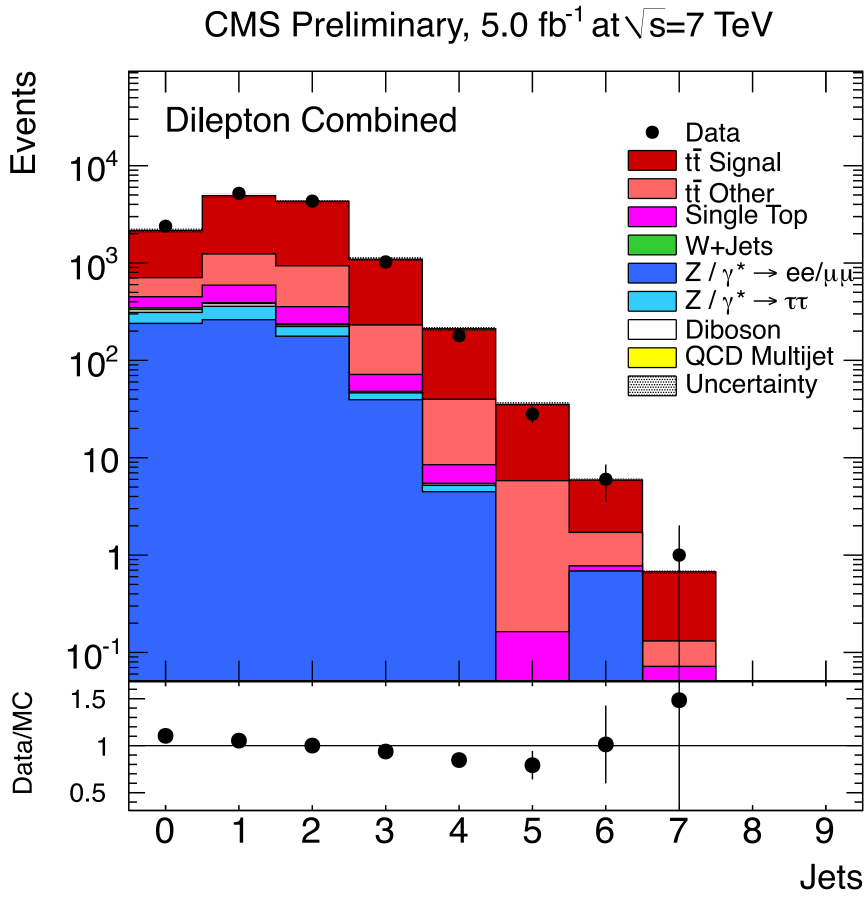


Jet multiplicity

[CMS PAS TOP-12-023]

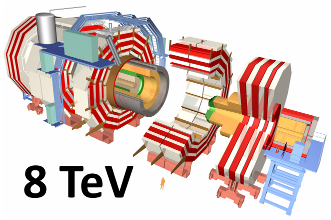


$p_T^{jet} \geq 30$ GeV



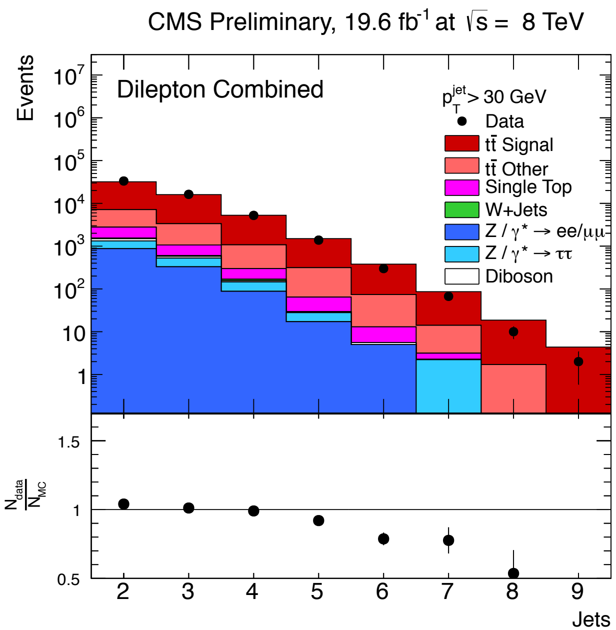
$p_T^{jet} \geq 60$ GeV

Good agreement data/Monte Carlo

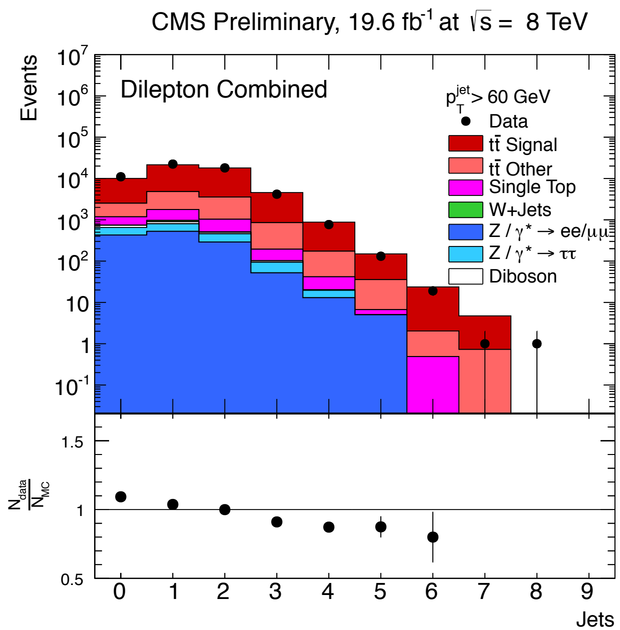


Jet multiplicity

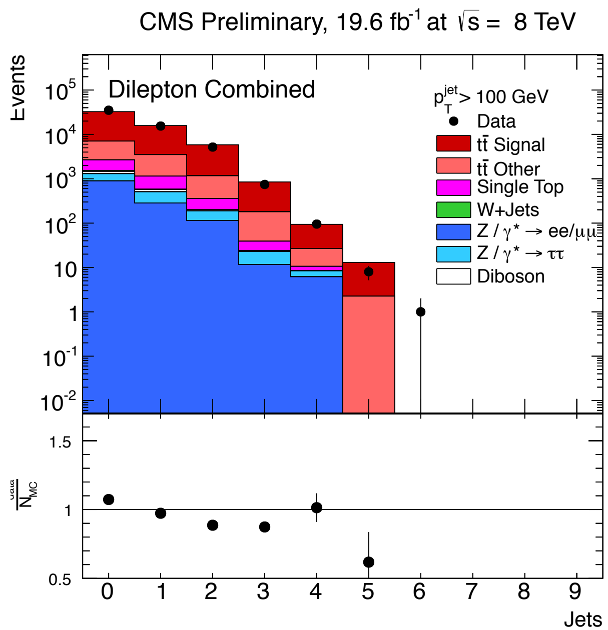
CMS PAS TOP-12-041



$p_T^{jet} \geq 30$ GeV

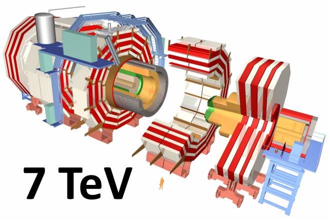


$p_T^{jet} \geq 60$ GeV



$p_T^{jet} \geq 100$ GeV

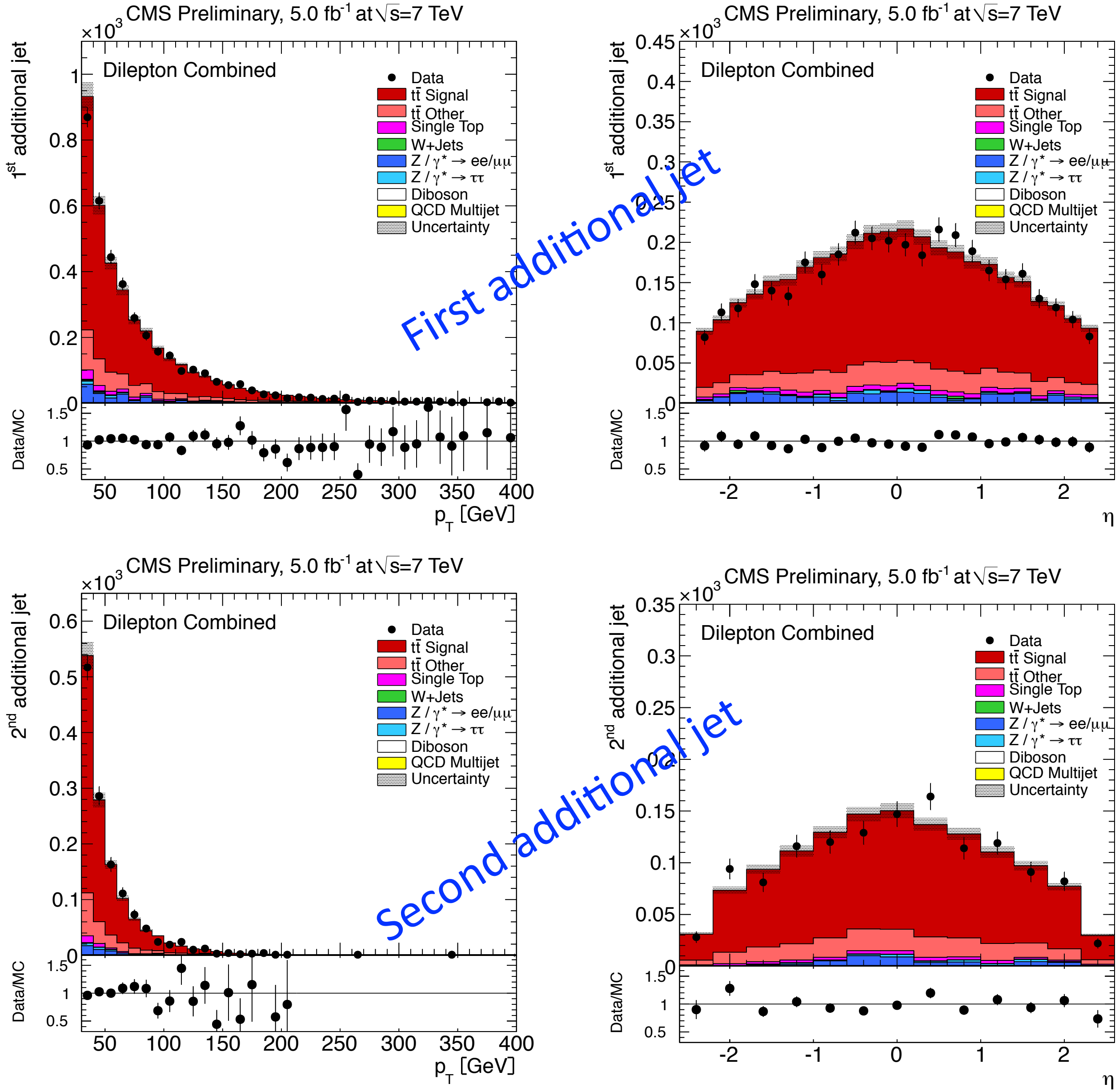
Simulation predicts slightly higher jet multiplicity than data



p_T and η of additional jets

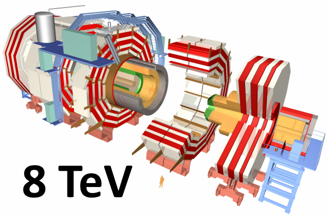
CMS PAS TOP-12-023

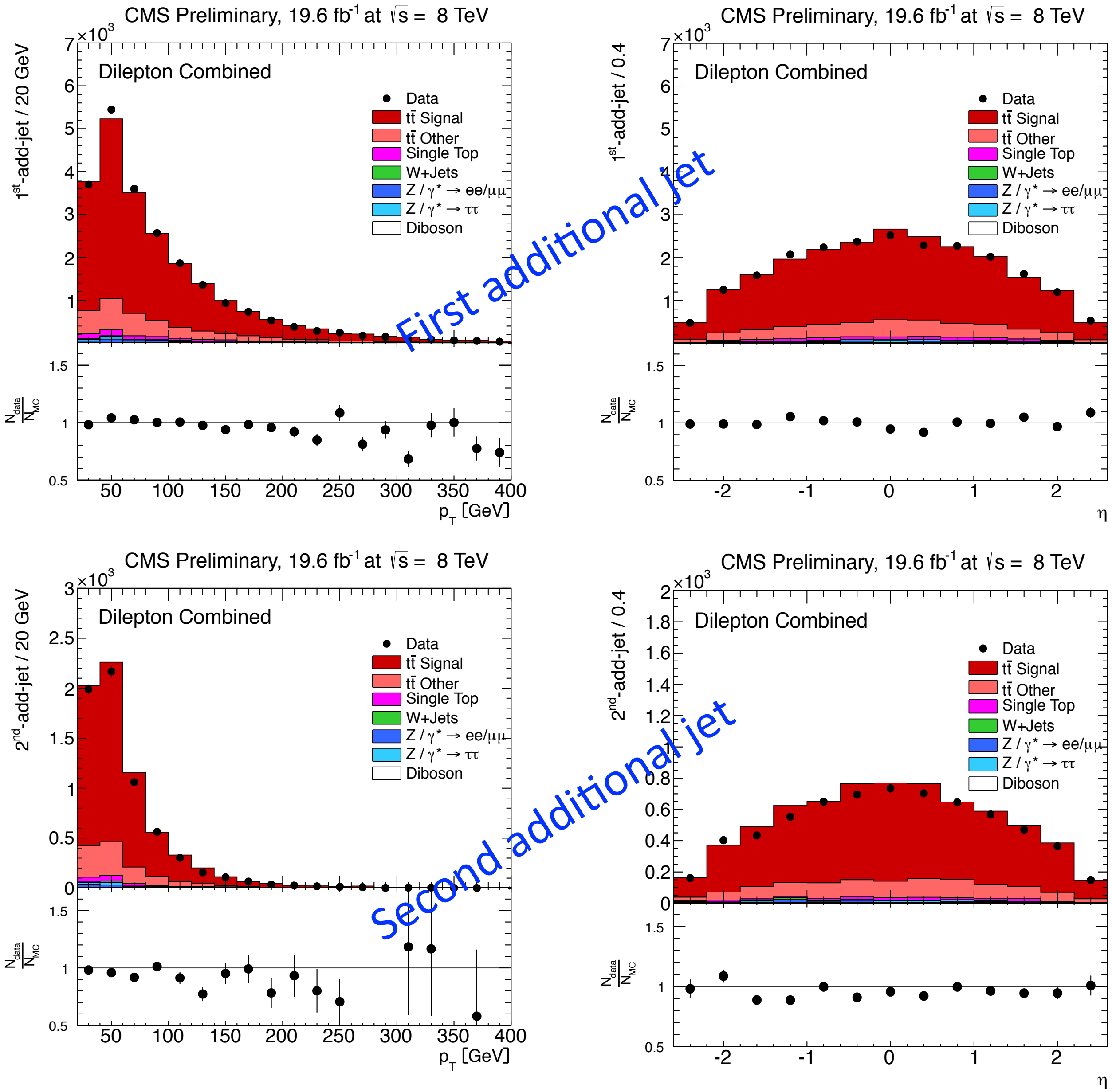
Data well described by simulation



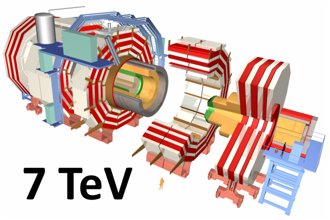
p_T and η of additional jets

[CMS PAS TOP-12-041]





Data well described by simulation



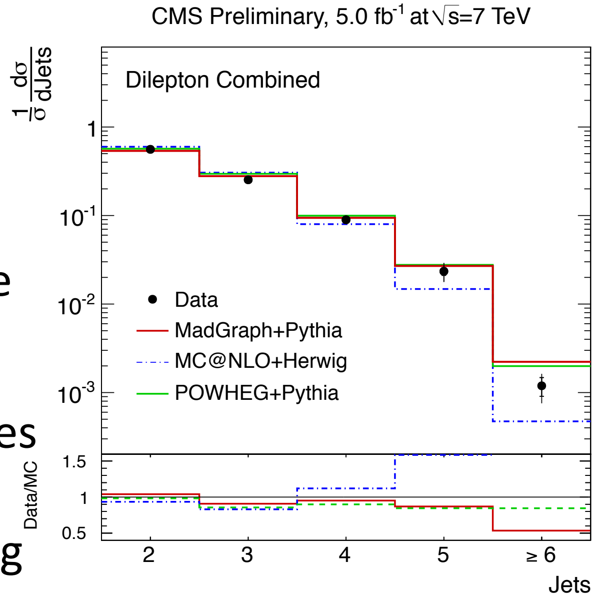
Differential cross-section

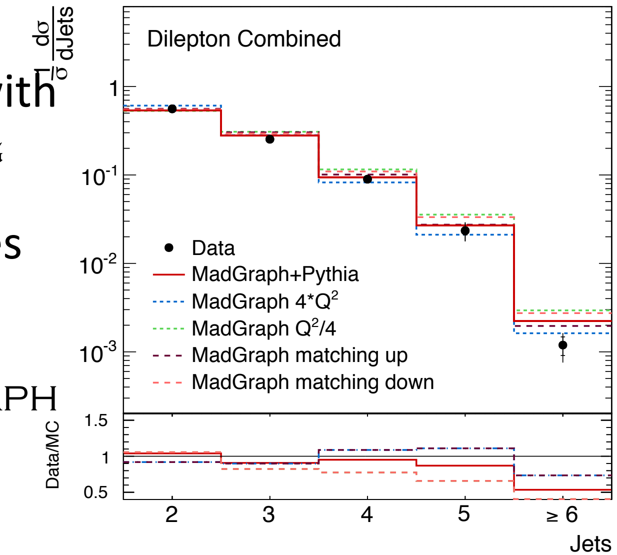
[CMS PAS TOP-12-023]

$$\frac{d\sigma_{t\bar{t}}}{dN} = \frac{N^i_{data} - N^i_{bkg}}{\Delta^i_x \varepsilon^i L}$$

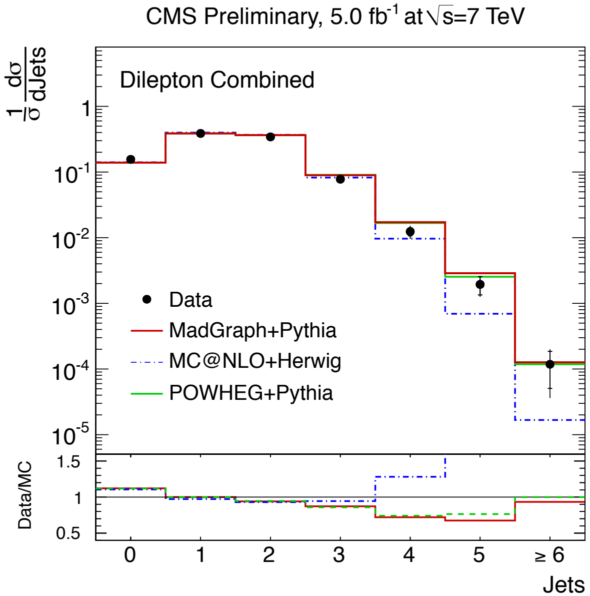
- Normalised dividing by the total cross-section
- Trigger/detector efficiencies and resolutions corrected using a regularised unfolding method
- Reasonable agreement with MadGraph and Powheg
- Mc@Nlo underestimates large jet multiplicities
- Larger scales in MadGraph improve data description above three jets

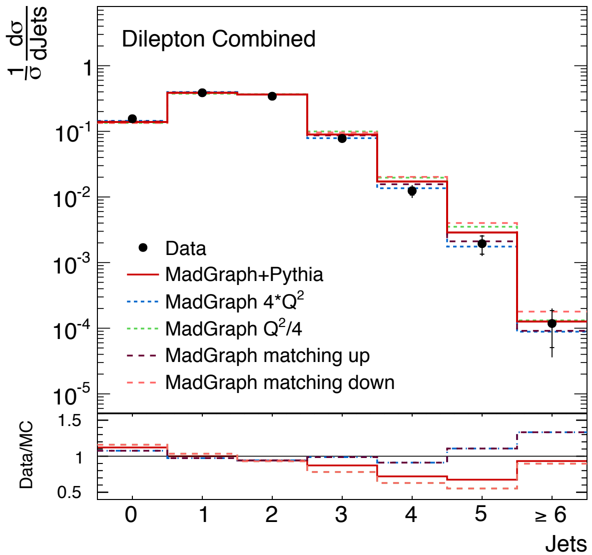
$p_T^{jet} \geq 30$ GeV

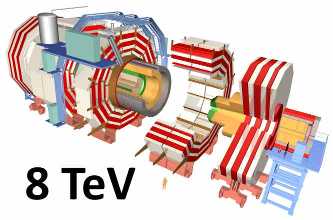




$p_T^{jet} \geq 60$ GeV



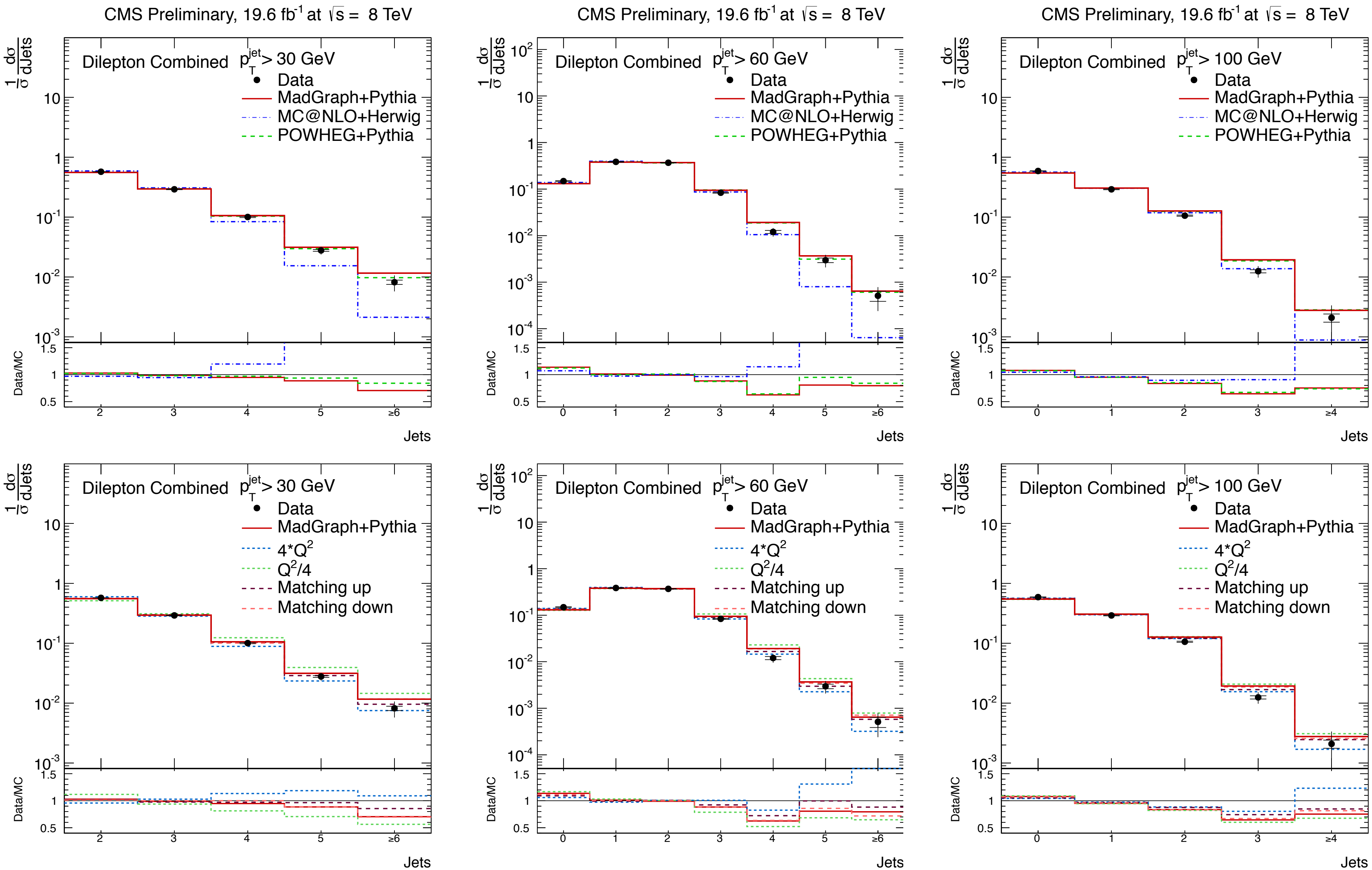


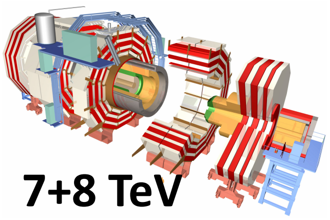


Differential cross-section

CMS PAS TOP-12-041

$p_T^{jet} \geq 30$ GeV $p_T^{jet} \geq 60$ GeV $p_T^{jet} \geq 100$ GeV





Differential cross-section systematic uncertainties

CMS PAS TOP-12-023
CMS PAS TOP-12-041

- Q^2 and matching scales
- Hadronisation and color reconnection models
- PDF uncertainties
- Backgroung yields (±30%) range for 0.5% to 2%

- JES and JER
- b-tagging efficiency around 0.5%
- Pile-up (vary cross-section by 8% (5%)) amounts to 0.3%
- Lepton trigger and identification negligible
- Kinematic reconstruction conservatively estimated to be 2%
- Top mass uncertainty effect below 1 %

- Luminosity cancels in ratio

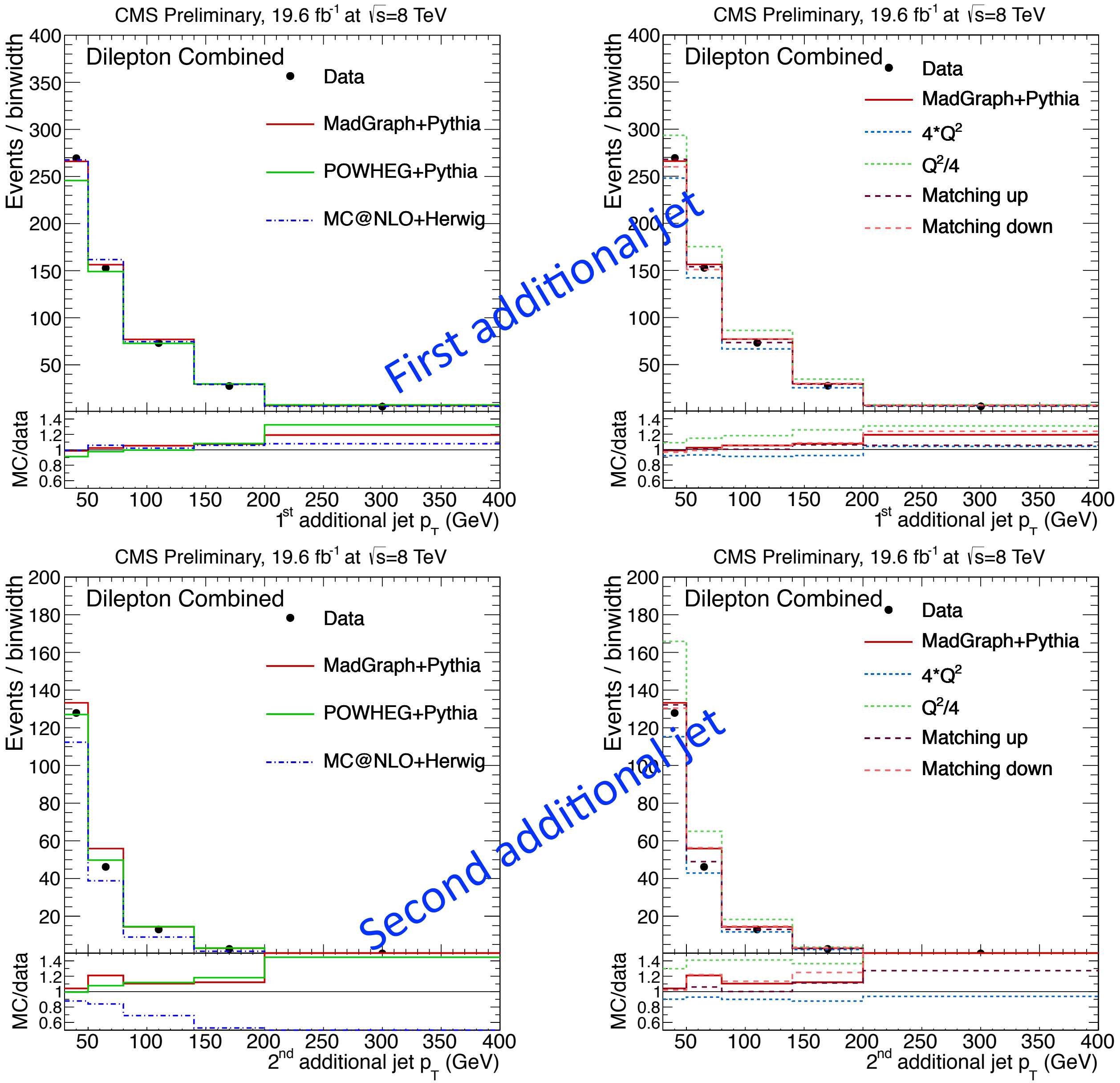
- Total systematic uncertainty from 3% (low multiplicity bins) to ~20% in 5 or more jets bin (dominated by statistics of modified MC samples)

p_T of additional jets in signal

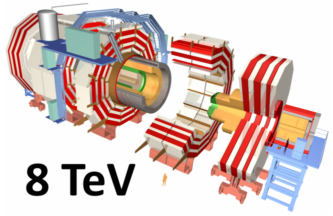
CMS PAS TOP-12-041

8 TeV

- Variations on jet-matching scale no significant effect
- Variations on Q2 large effect on yields
- MC@NLO second jet yield too low

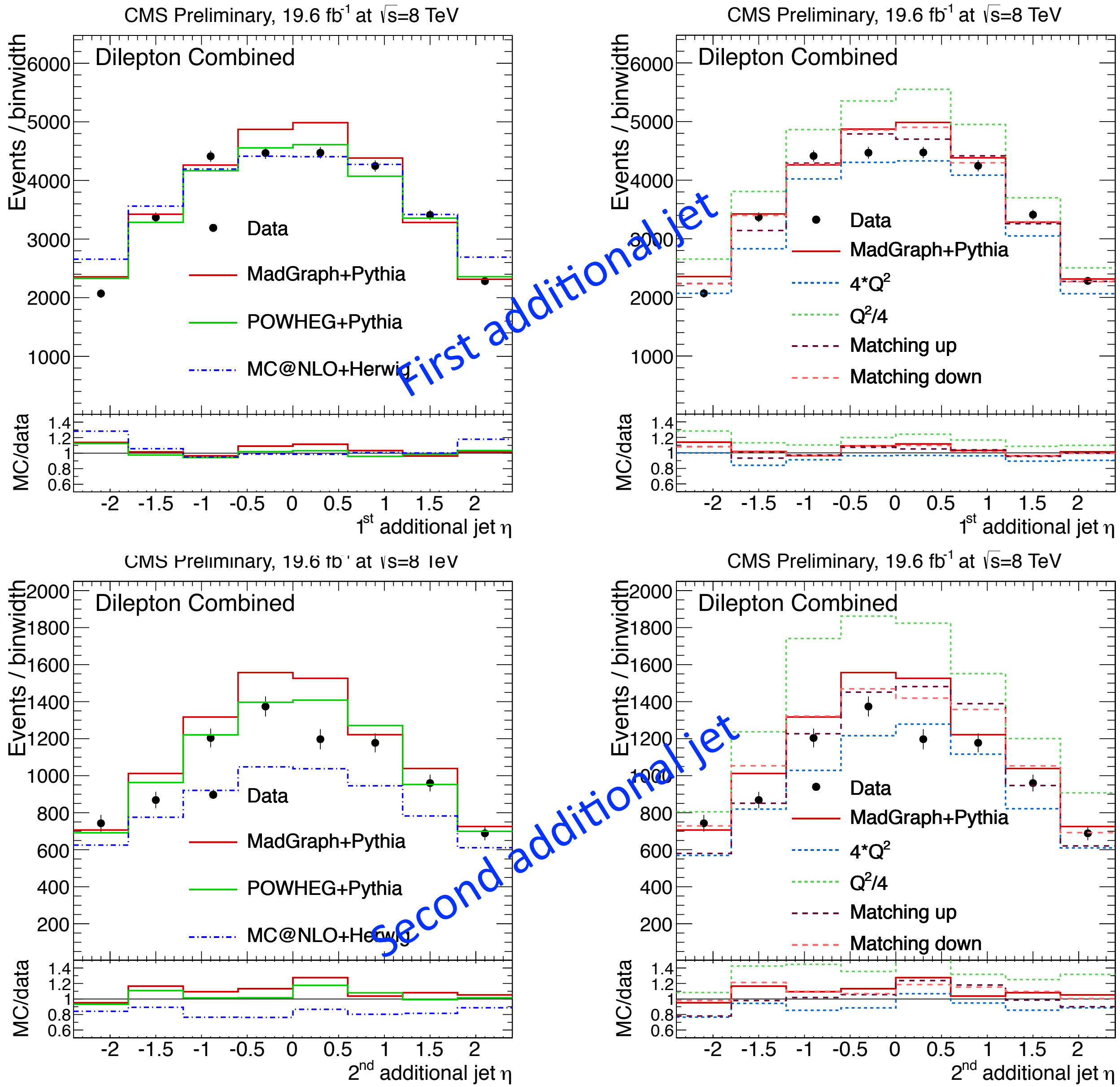


CMS PAS TOP-12-041



η of additional jets in signal

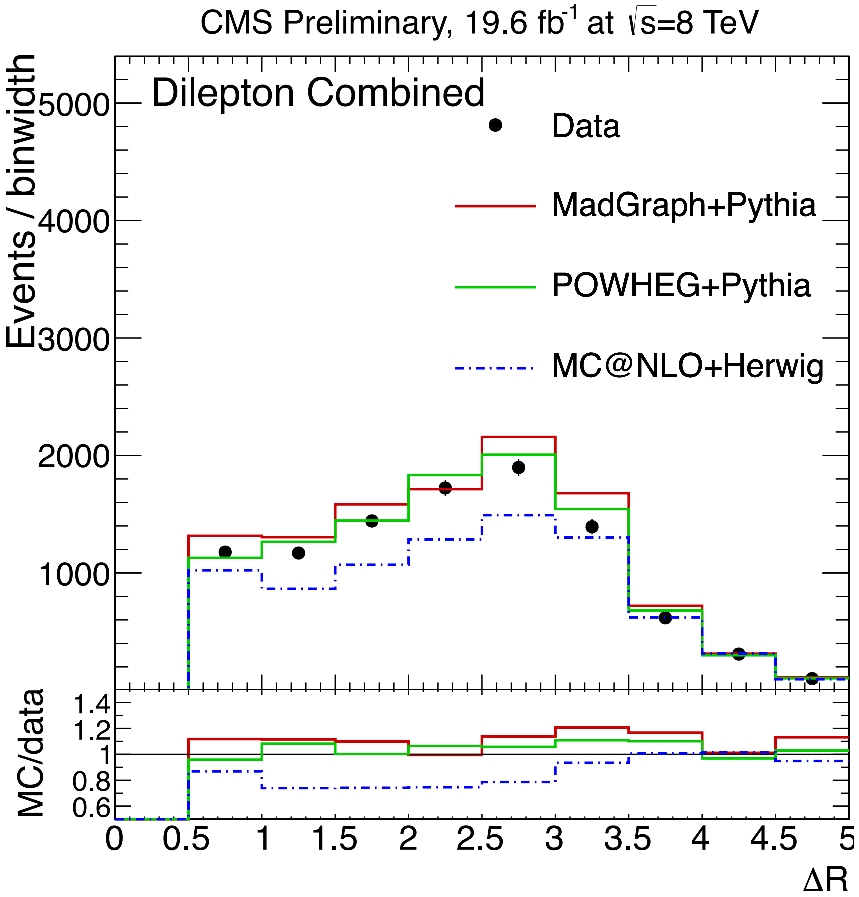
- Variations on jet-matching scale no significant effect
- Variations on Q2 large effect on yields
- MC@NLO second jet yield too low

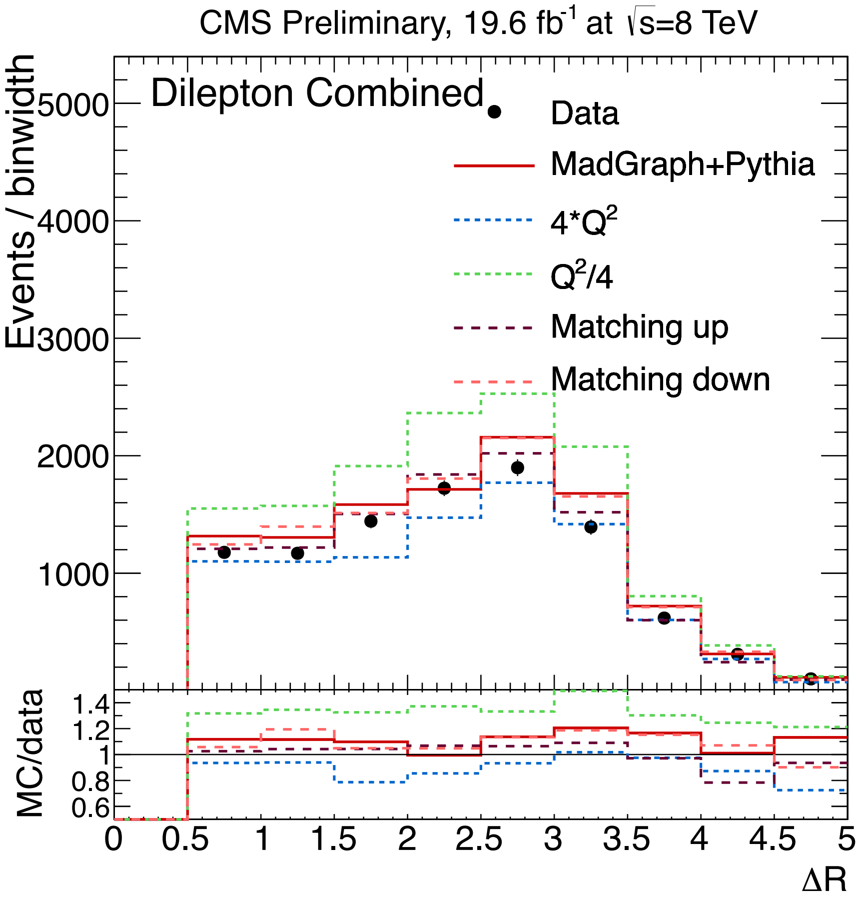


ΔR between additional jets in signal

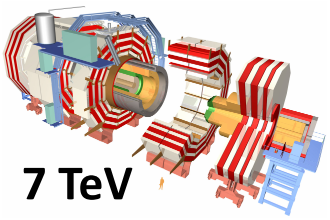
8 TeV

CMS PAS TOP-12-041





MC@NLO ΔR yield too low

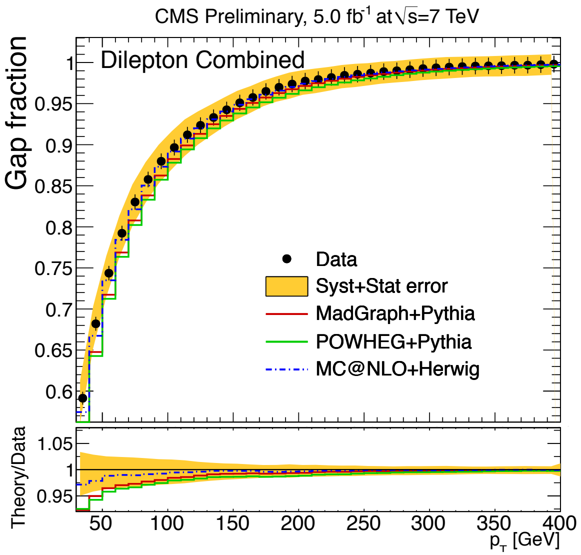


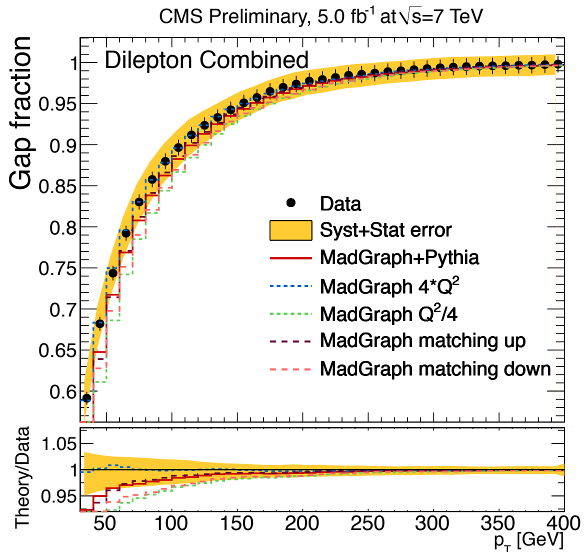
Additional jet gap fraction

[CMS PAS TOP-12-023](CMS PAS TOP-12-023)

events without additional jets above threshold

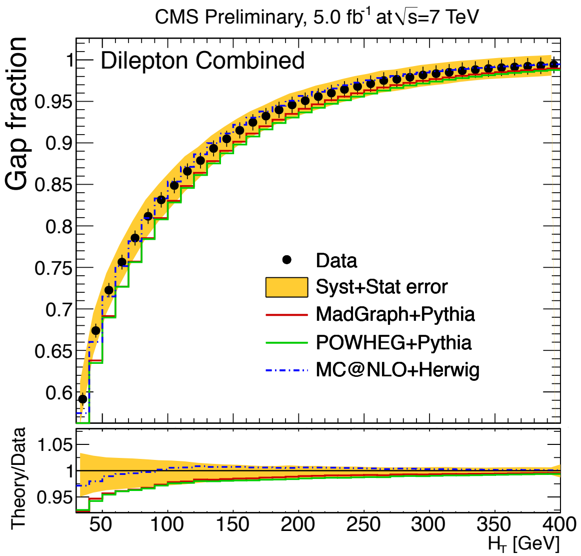
$$f(p_T) = \frac{N(p_T)}{N_{total}}$$

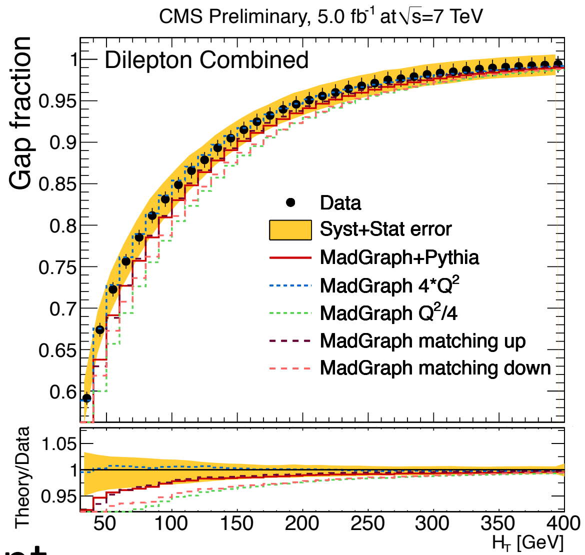




events with H_T below threshold

$$f(H_T) = \frac{N(H_T)}{N_{total}}$$

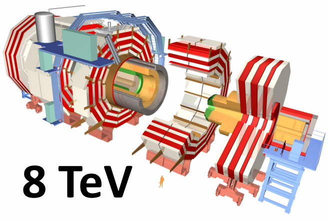


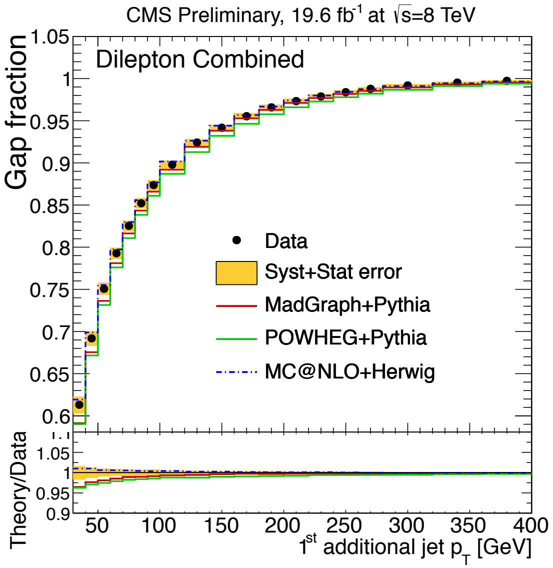


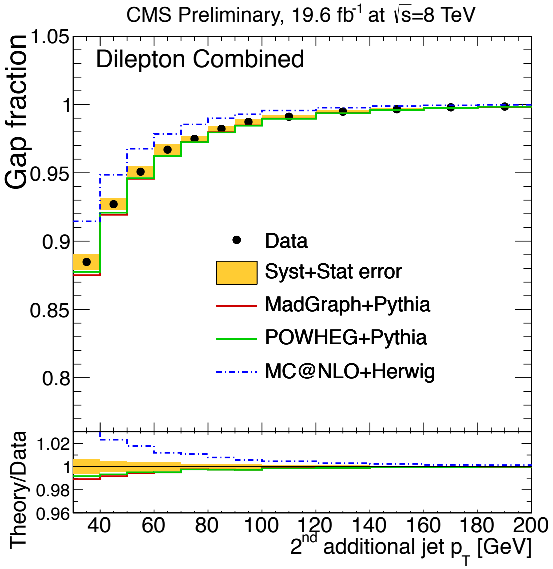
- Better described by MC@NLO + HERWIG
- Increasing Q^2-scale in MADGRAPH improves agreement

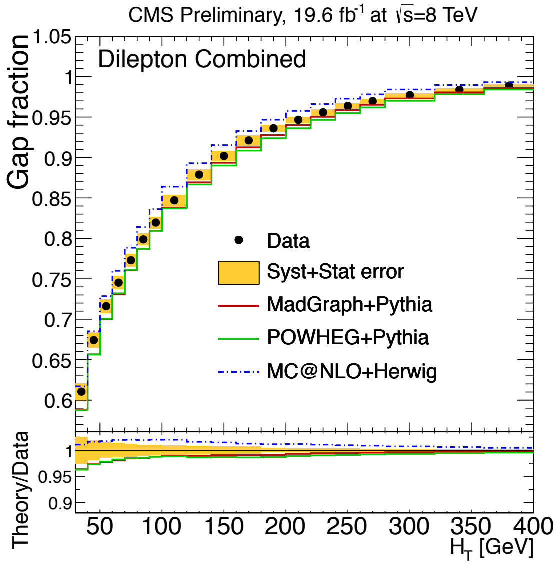
[CMS PAS TOP-12-041](#)

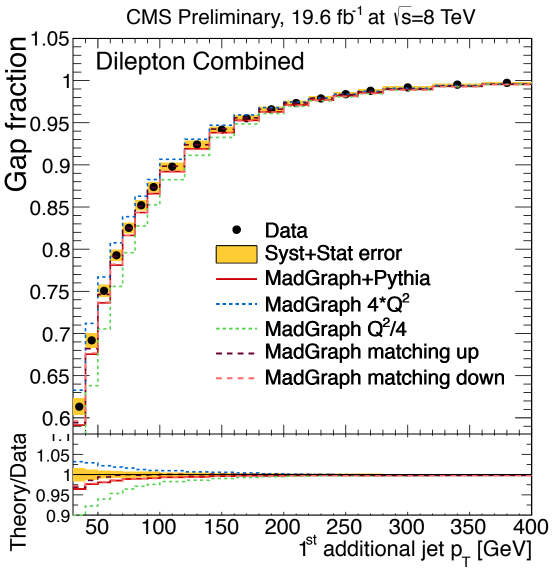
Additional jet gap fraction

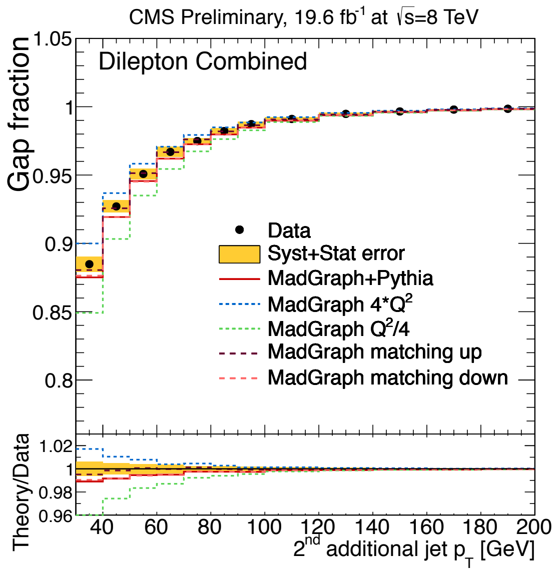


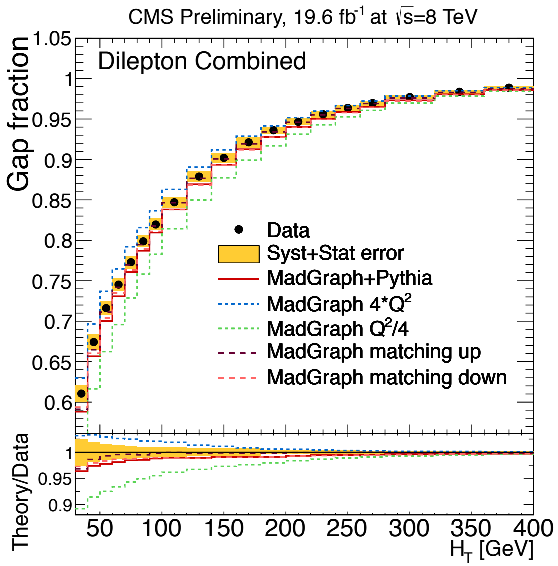






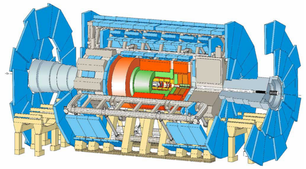






Additional jet gap fraction

Eur. Phys. J C (2012) 72-2043



7 TeV

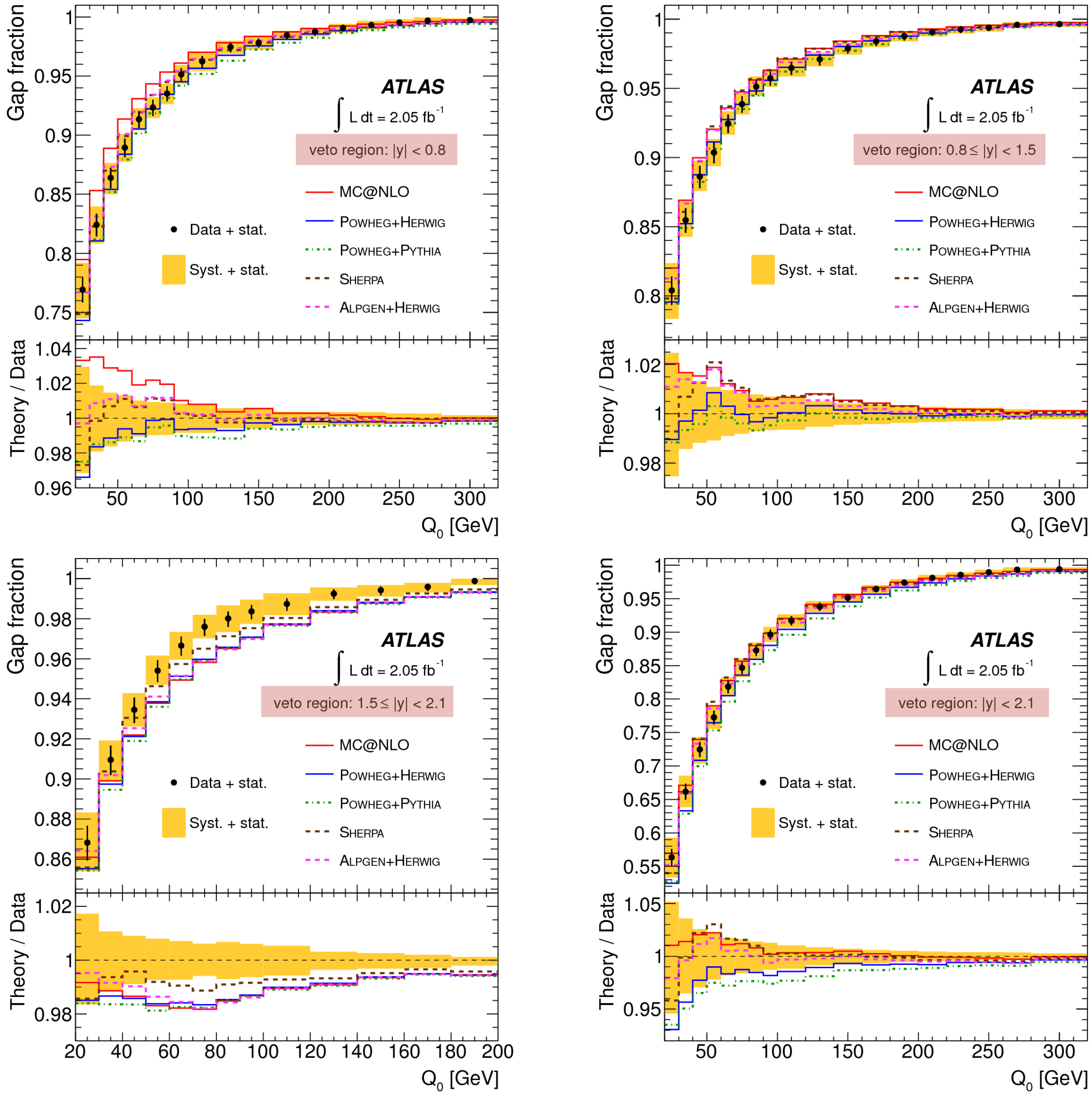
$$f(Q_0) = \frac{n(Q_0)}{N}$$

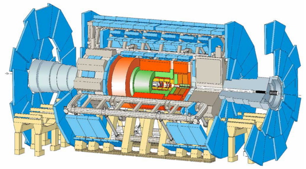
events without additional jets above given p_T

- Mainly sensitive to the leading-p_T emission acompanying the $t\bar{t}$ system
- Apply correction fraction for detector effects:

$$C(x) = \frac{f^{truth}(x)}{f^{reco}(x)}$$

- Resonable agreement in full rapidity interval (|y|<2.1)
- No simulation agrees in the most forward region ⟶ too much jet activity predicted
- MC@NLO predicts too little jet activity in central region





[Eur. Phys. J C (2012) 72-2043](#)

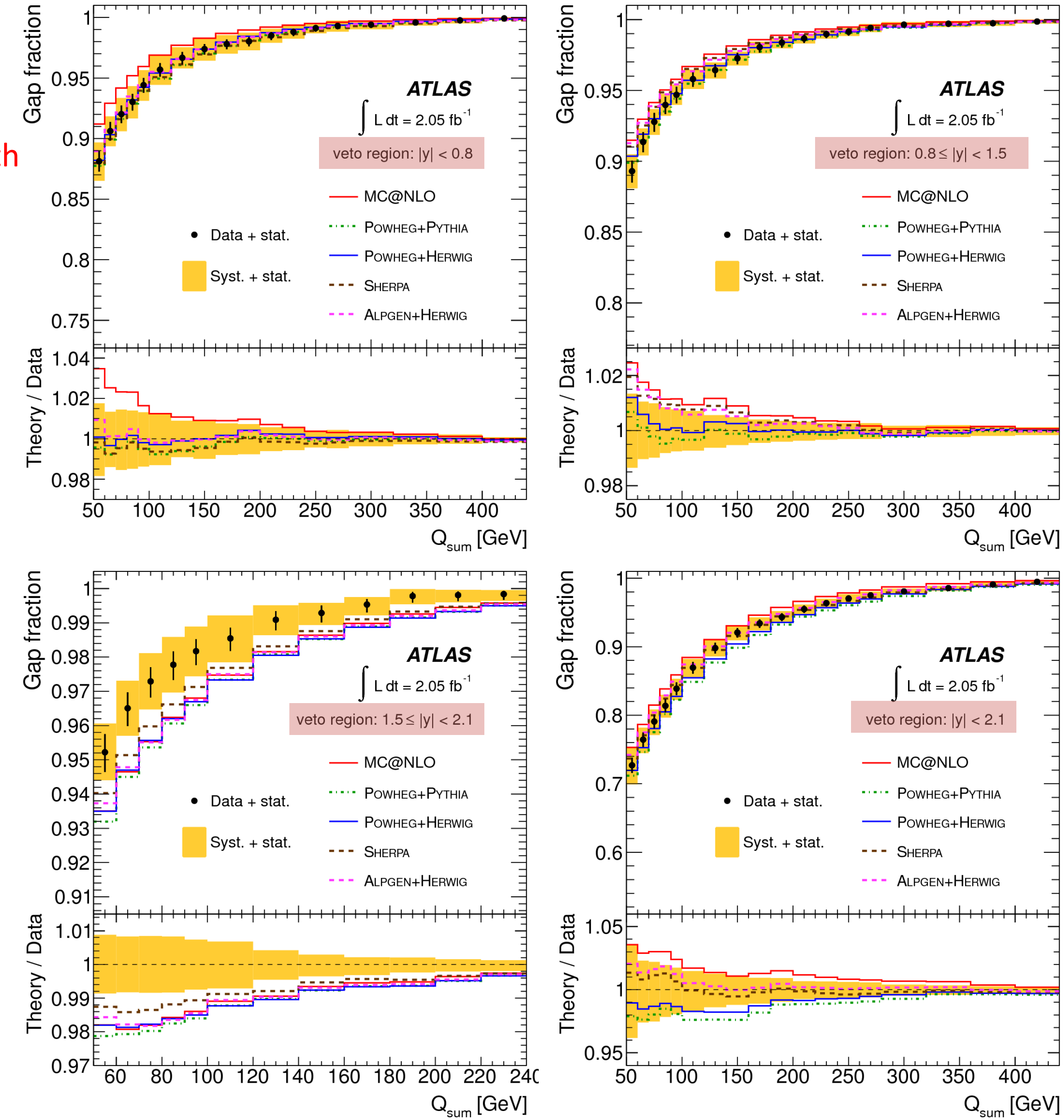
Additional jet gap fraction

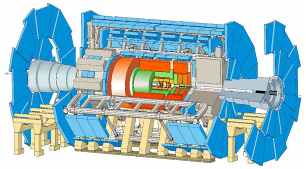
7 TeV

$$f(Q_{sum}) = \frac{n(Q_{sum})}{N}$$

events with H_T below threshold

- Sensitive to all emissions acompanying the $t\bar{t}$ system
- Gap fraction lower than for Q_0 case probing quark and gluon radiation beyond first emission
- Differences between data and theory similar to the Q_0 case





Additional jet gap fraction

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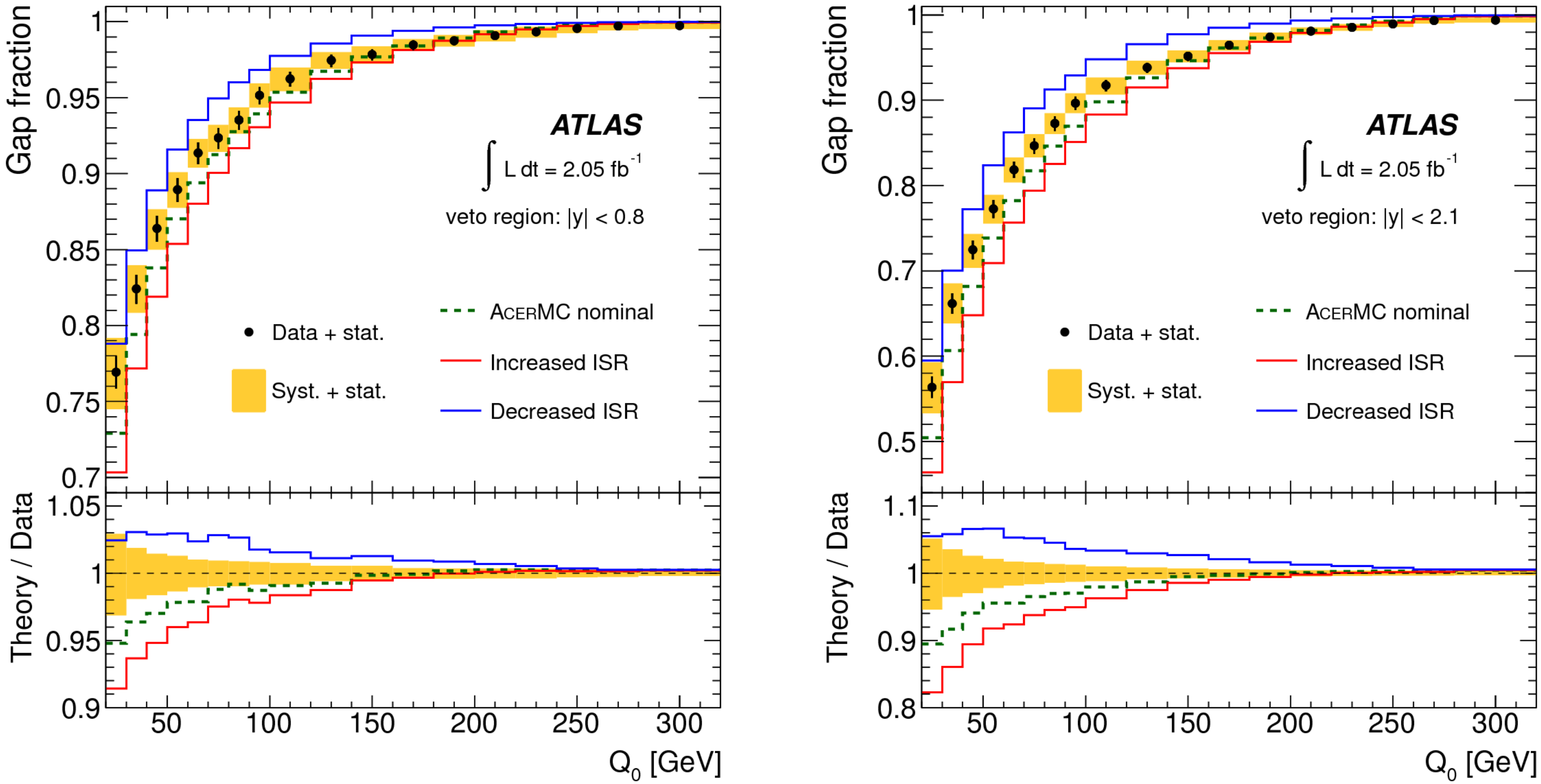
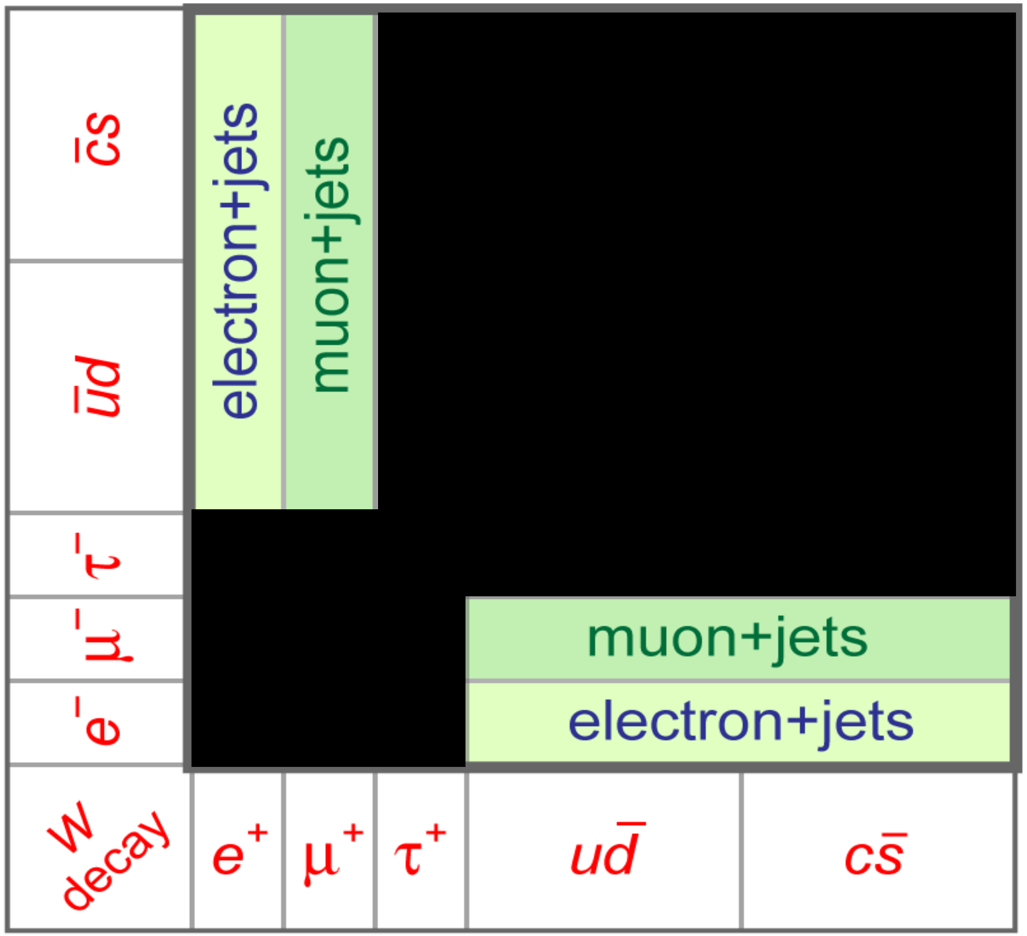
7 TeV

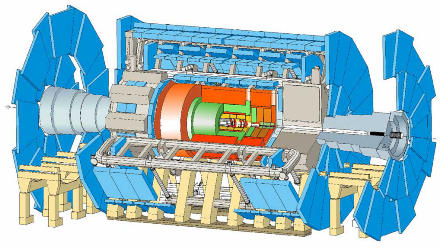


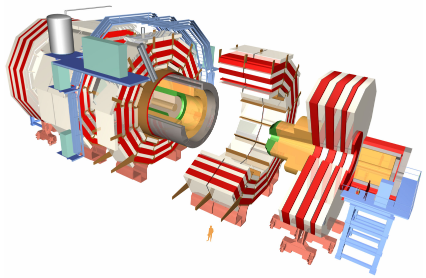
- Comparison to AcerMC + Pythia predictions after increasing/decreasing ISR
- Data within predictions but band twice larger than experimental precision



$\bar{c}s$
$\bar{u}d$
τ^-
μ^-
e^-
electron+jets
muon+jets
muon+jets
electron+jets
W decay
e^+
μ^+
τ^+
$u\bar{d}$
$c\bar{s}$

Event selection



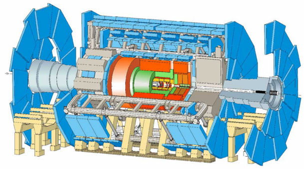


- Electrons: p_T>25 GeV |η|<2.47
- Muons: p_T>25 GeV |η|<2.5
- Jets: p_T>25 GeV |η|<2.5

- Single lepton triggers
- Exactly one isolated lepton matching trigger
- Veto events with other leptons with p_T>15 GeV
- At least three jets of which at least one is identified as *b*-jet ($\varepsilon_{tagging} \approx 70\%$)
- E_T^{miss} > 30 GeV
- $m_T(W)$ > 35 GeV

- Electrons: p_T>30 GeV |η|<2.5
- Muons: p_T>30 GeV |η|<2.1
- Jets: p_T>35 GeV |η|<2.4

- Single electron+3 jets or single muon trigger
- Exactly one isolated lepton
- At least three jets of which at least two are identified as *b*-jets ($\varepsilon_{tagging} \approx 80$-$85\%$)



7 TeV

Background estimation

ATLAS-CONF-2012-155

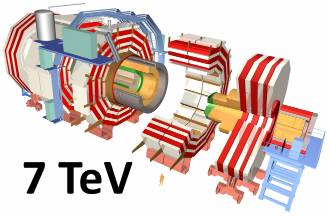
- Use W charge asymmetry to obtain normalisation before *b*-tagging

$$N^{pretag}_{W+jets} = \left(N^{+}_{data} - N^{-}_{data}\right)\frac{r_{MC}+1}{r_{MC}-1} \quad \text{where} \quad r_{MC} = \frac{\sigma(pp \to W^{+})}{\sigma(pp \to W^{-})}$$

- Normalisation obtained separately for W+3jet, W+4jet and W+≥5jets
- Add flavour fractions and *b*-tagging probabilities to get W+jets after *b*-tagging

- Get QCD multijet background (both shape and normalisation) from data using matrix method
- In electron channel use looser electron identification and no isolation and E_T^{miss}<20 GeV as control region
- Use two different control regions (low $m_T(W)$ and large muon impact parameter w.r.t. primary vertex) in muon channel

- Other contributions from MC



Background estimation

CMS PAS TOP-12-018

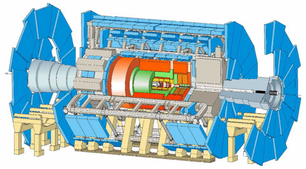
- Correct W+jets normalization from data
- Use W charge asymmetry measurement
- Apply full event selection except *b*-tagging

$$N^{pretag}_{W+jets} = \left(N^{+}_{data} - N^{-}_{data}\right)\frac{N^{MC}_{W^{+}} + N^{MC}_{W^{-}}}{N^{MC}_{W^{+}} - N^{MC}_{W^{-}}}$$

- Finally apply *b*-tagging

- Get QCD multijet background from data
- Invert lepton relative isolation criteria ($0.3 < I_{rel} < 1.0$)
- Drop *b*-tagging requirement
- Split into ≤ 1 *b*-tag and ≥2 *b*-tag regions. Get normalisation from first region and shape from E_T^{miss} distribution in second one

- Other contributions from MC



7 TeV

Systematic uncertainties

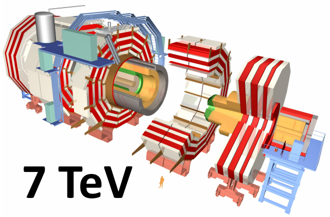
ATLAS-CONF-2012-155

- Signal PDF, parton shower modelling, ISR/FSR, signal generator
- W+jets normalisation (7 to 15%)
- Heavy flavours fraction (25%)
- W+jets shape
- QCD multijet normalisation (50%(20%) in the electron(muon) channel)
- Other backgrounds cross-section (4-8% single top and 4%+24% per jet in Z+jets)

- JES (varies between 1.5% and 8% + 2.5% bJES) increases from 3 to 40% with N_{jet}
- JER (jets smeared by 2-20%)
- Jet reconstruction efficiency (3% at most)
- b-tagging efficiency and primary vertex requirement
- Lepton trigger, reconstruction and selection efficiency
- E_T^{miss}

- Luminosity 3.9%

•Total uncertainty 13.4% (11.1%) in the electron (muon) channel. Reaches 54.4% (61.0%) in the $N_j \geq 8$ bin



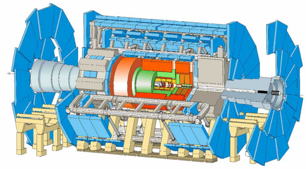
Systematic uncertainties

CMS PAS TOP-12-018

- Q^2 and matching scales range from 2.5% to 35%
- PDF uncertainties range from <2% to 10%
- W+jets background uncertainties (heavy flavour corrections, bkg subtraction)
- QCD background (choice of isolation cut, uncertainty of fit)
- Background yields from MC (±30%)

- JES and JER (varies between 2% and 10%) range from 1.5% to 14%
- b-tagging efficiency <5%
- Pile-up <5%
- Trigger efficiency <5%
- Lepton identification and isolation <5%

- Luminosity cancels in ratio



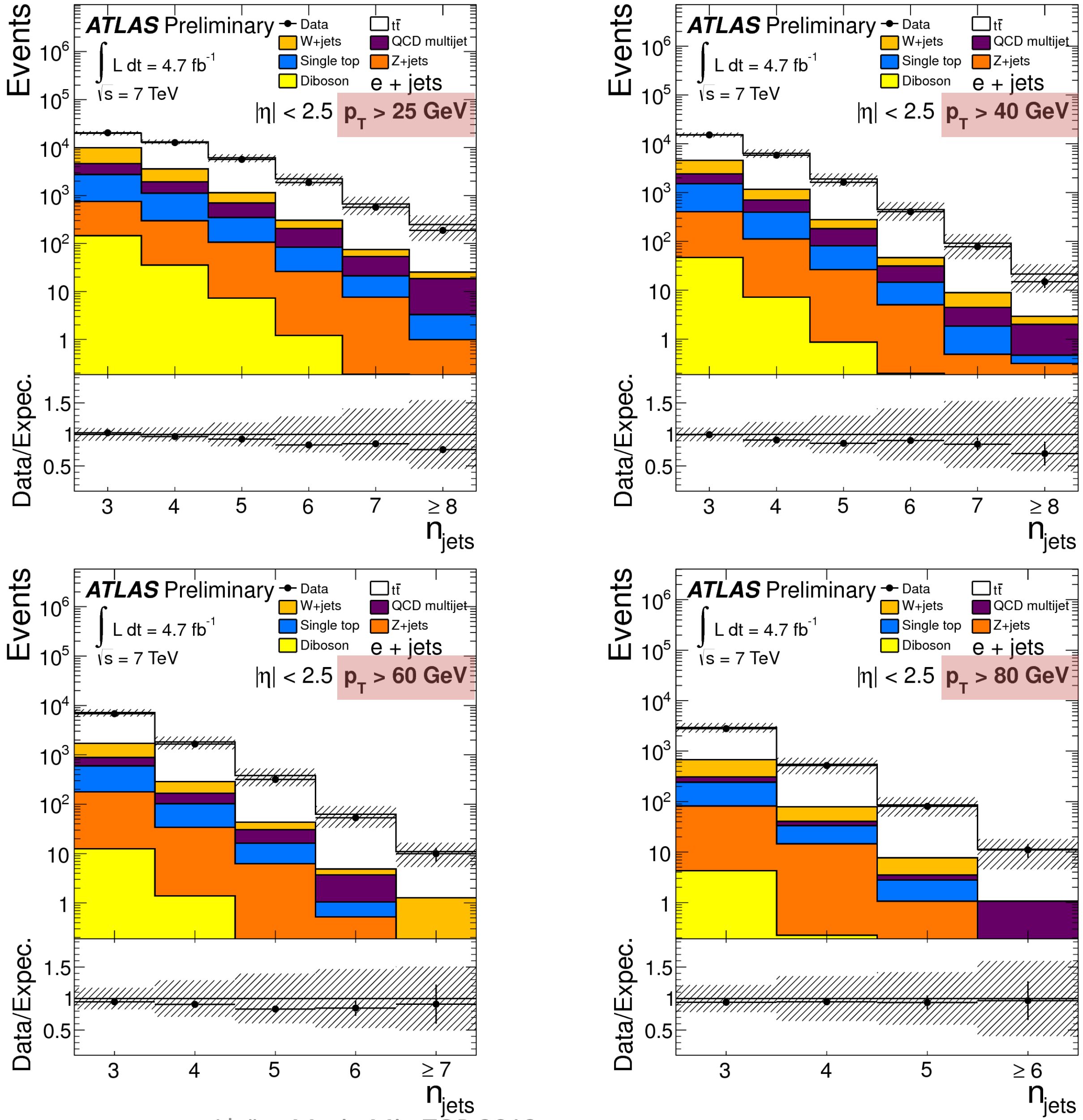
7 TeV

Jet multiplicity

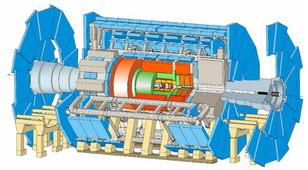
ATLAS-CONF-2012-155

e + ≥3 jets

Prediction agrees with observation



ATLAS-CONF-2012-155

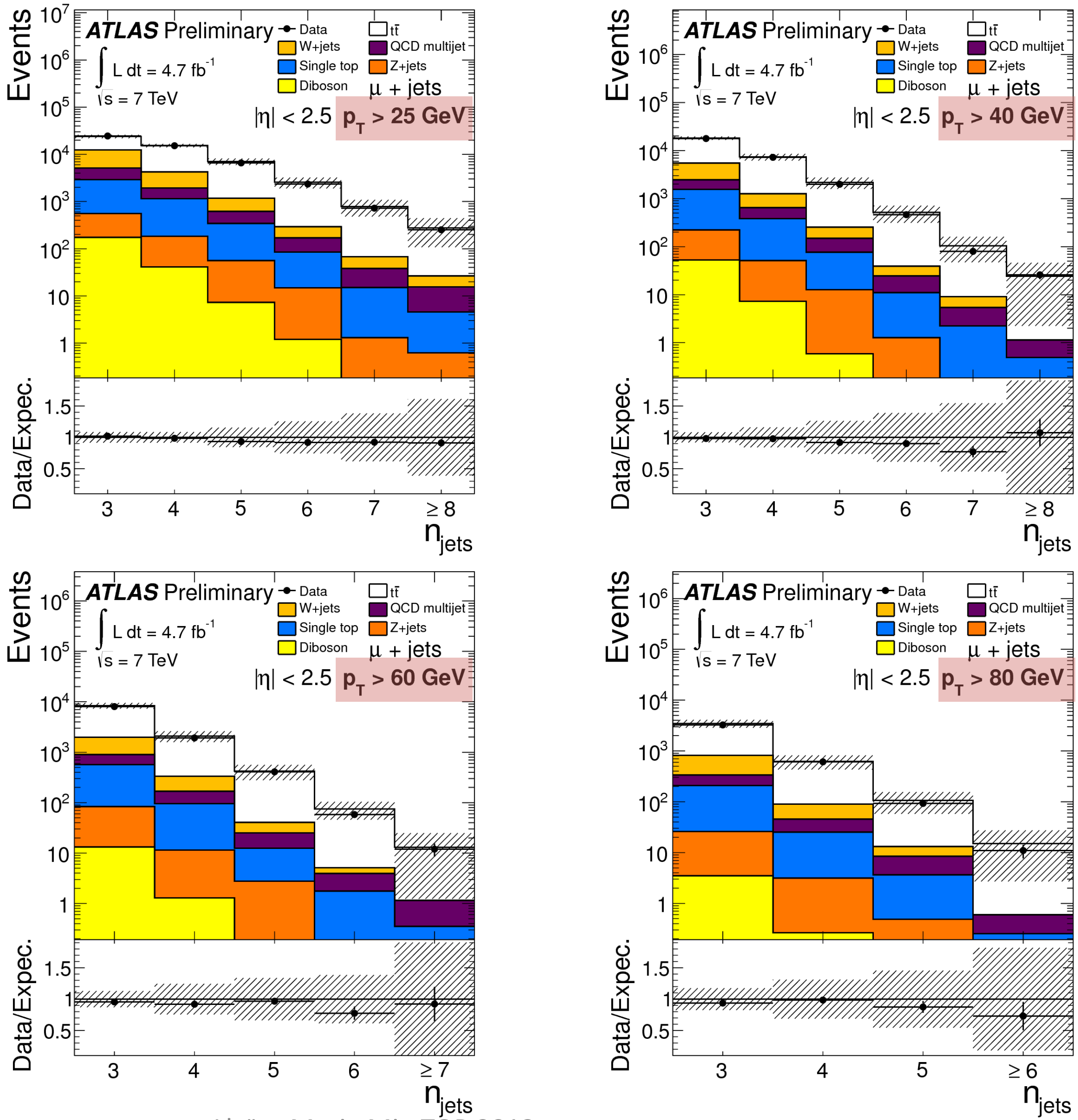


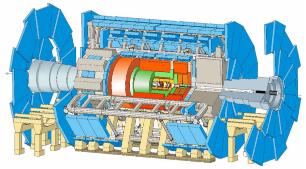
7 TeV

Jet multiplicity

μ + ≥3 jets

Prediction agrees with observation





7 TeV

Correction to particle level

[ATLAS-CONF-2012-155]

Jet resolution and reconstruction correction

Acceptance for selection efficiency

Background contribution

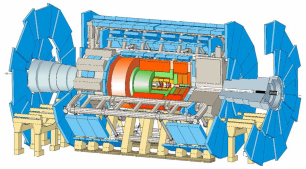
$$\vec{N}_{part} = \vec{f}_{part!reco} \cdot M^{reco}_{part} \cdot \vec{f}_{reco!part} \cdot \vec{f}_{accpt} \cdot (\vec{N}_{reco} - \vec{f}_{bkg})$$

Events passing jet multiplicity requirement at particle level but not at reco level

Events passing jet multiplicity requirement at reco level but not at particle level

Total number of reconstructed events

- N_{reco}, f_{bkg}, f_{accpt} and $f_{reco!part}$ depend on the reconstructed jet multiplicity
- N_{part} and $f_{part!reco}$ are functions of the particle-jet multiplicity
- f_{accpt} range is 1.8-1.9 (1.4-1.5) for the electron (muon) channel
- $f_{reco!part}$ for three reconstructed jets varies between 0.9-0.75
- M_{part}^{reco} values range 0.5-0.9 off-diagonal and 0.5-0.7 in diagonal
- $f_{part!reco}$ consistent with unity when 5 or more jets are present

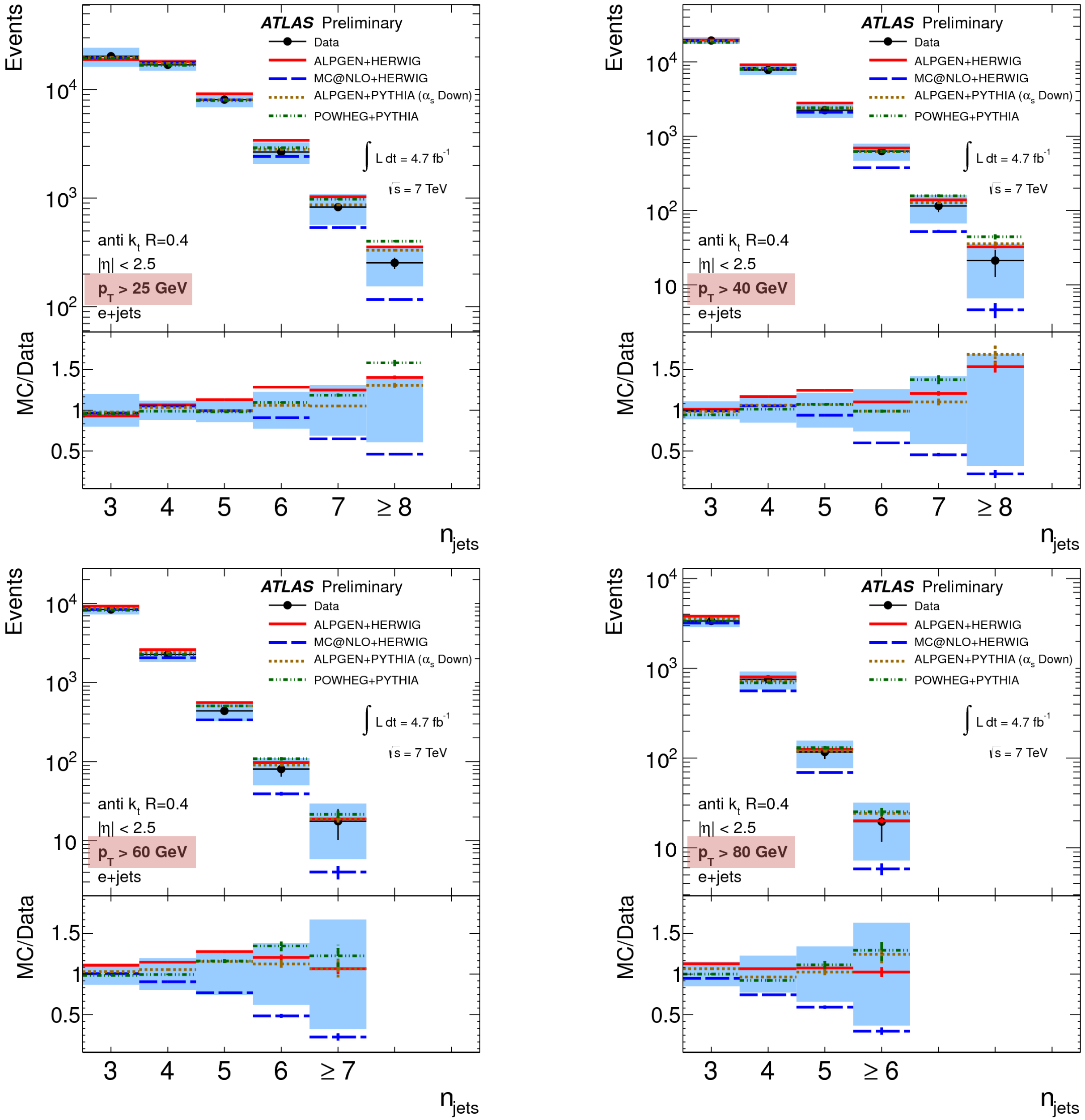


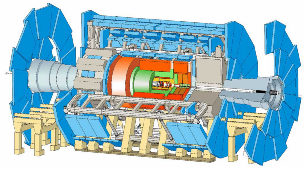
7 TeV

Particle-jet multiplicities

ATLAS-CONF-2012-155

e + ≥3 jets



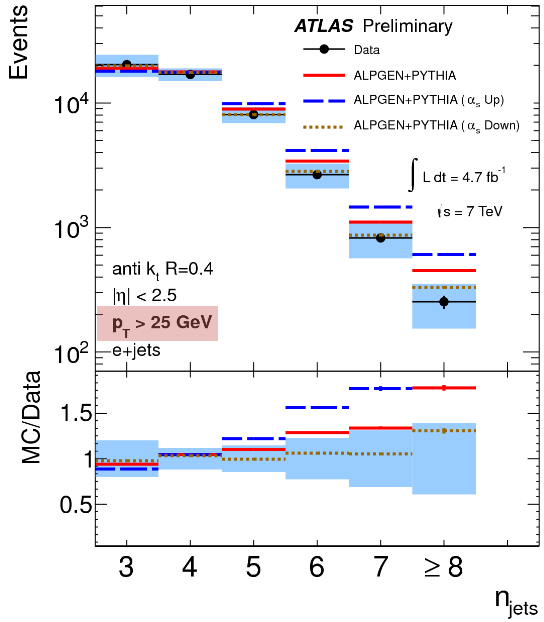


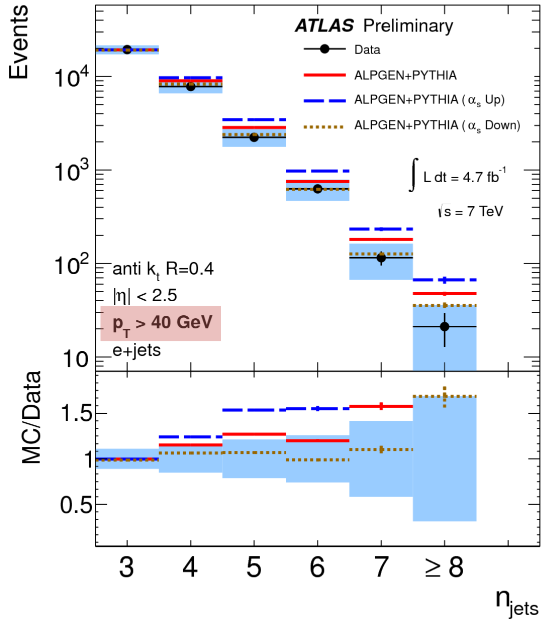
7 TeV

Particle-jet multiplicities

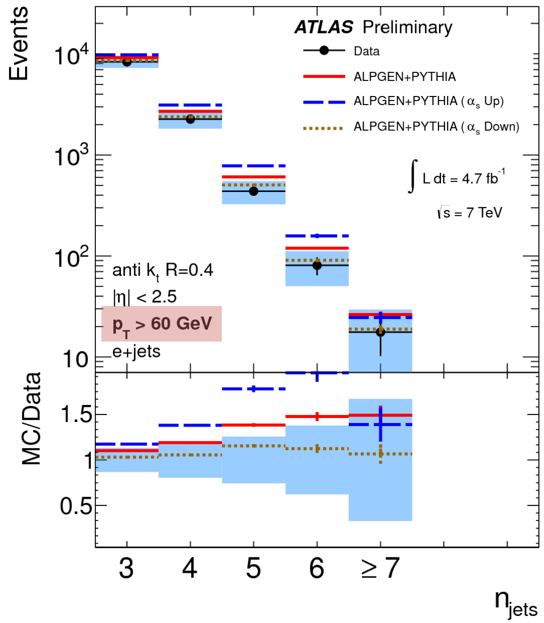
ATLAS-CONF-2012-155

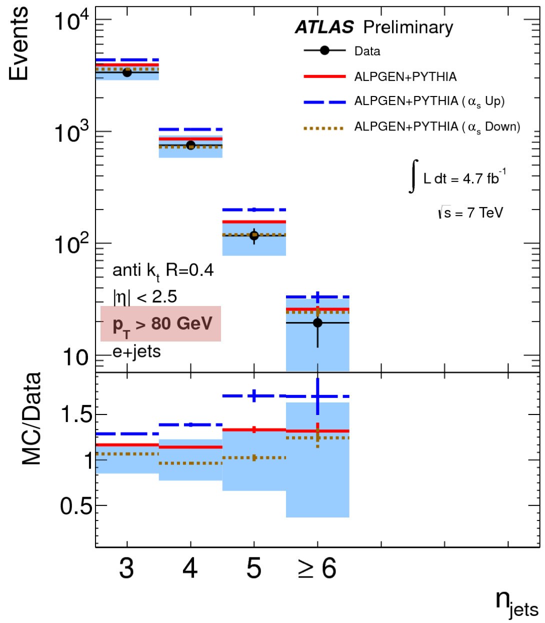
e + ≥3 jets

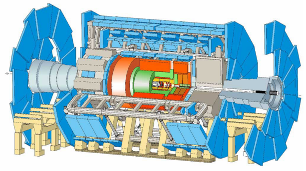




α_S-down variation most closely describes data





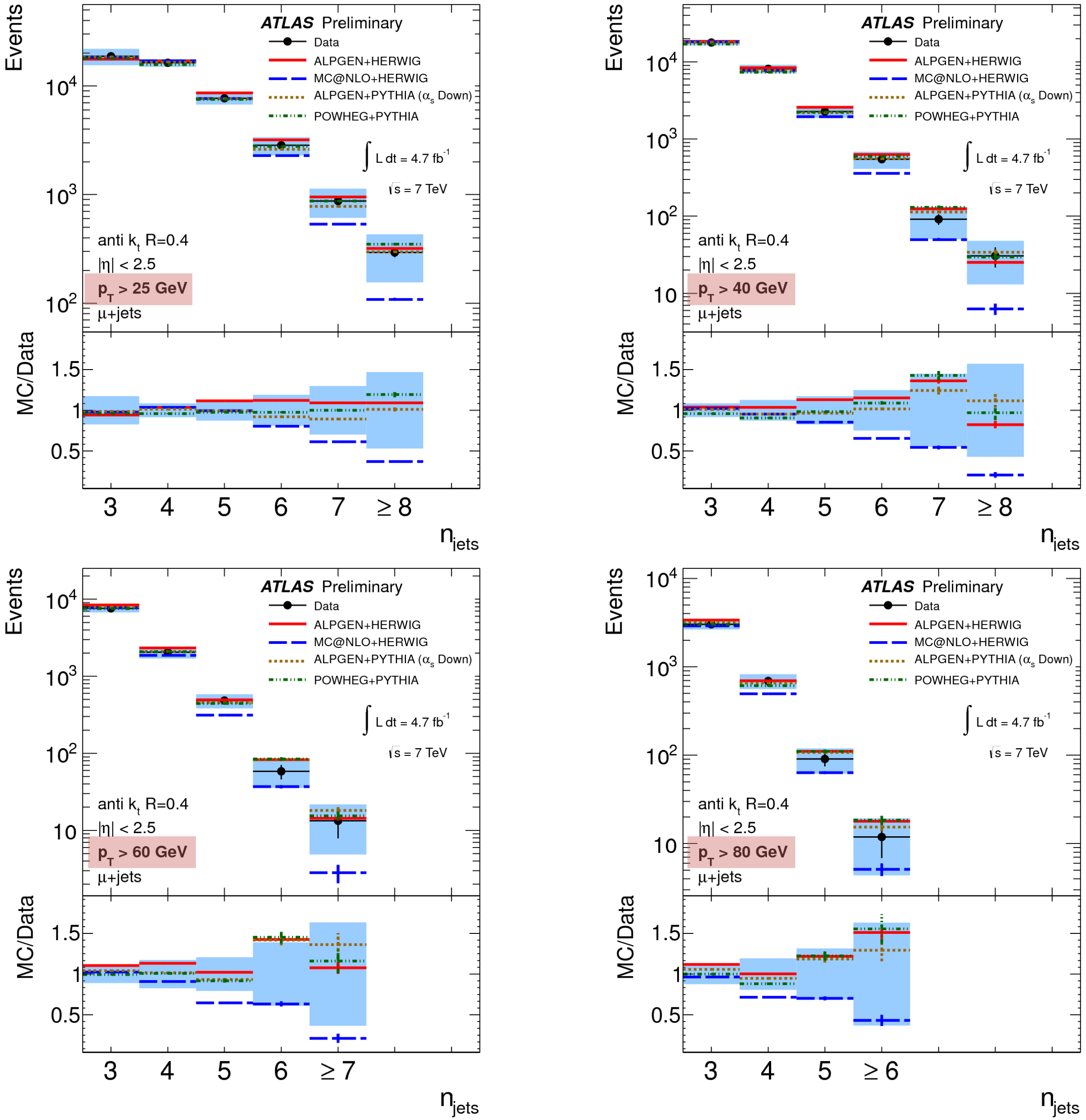


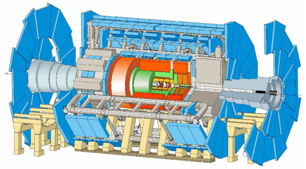
7 TeV

Particle-jet multiplicities

ATLAS-CONF-2012-155

μ + ≥3 jets



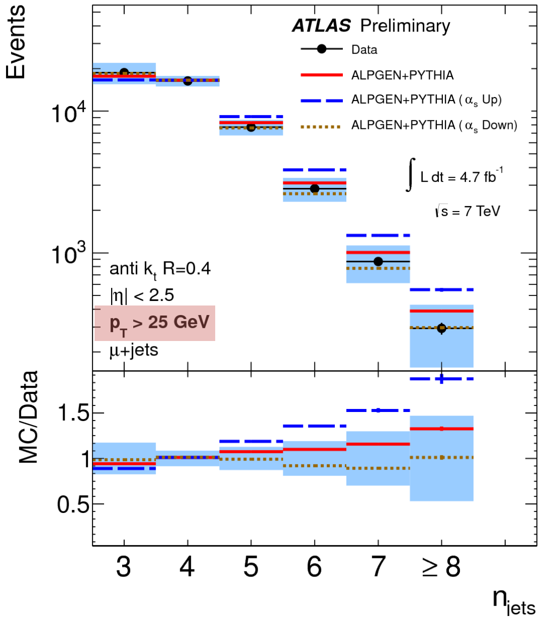


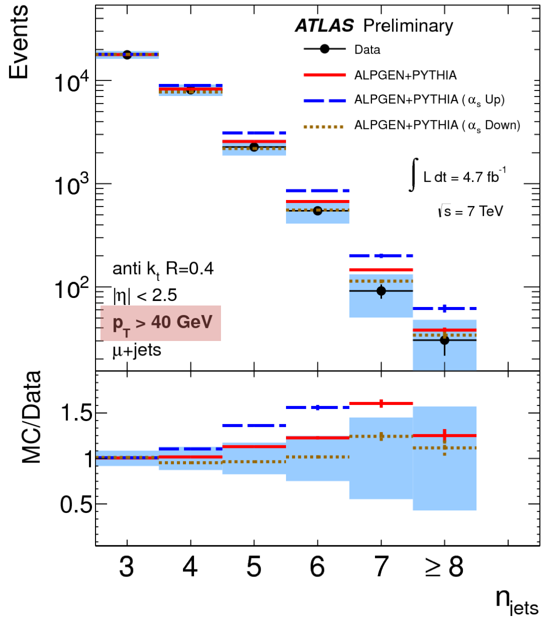
Particle-jet multiplicities

ATLAS-CONF-2012-155

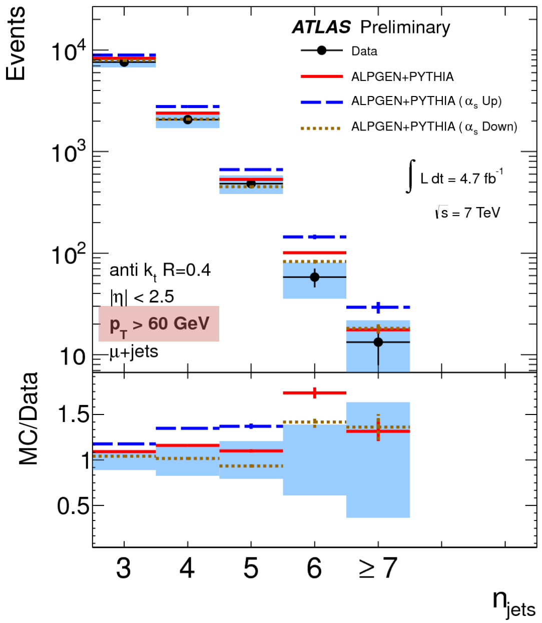
7 TeV

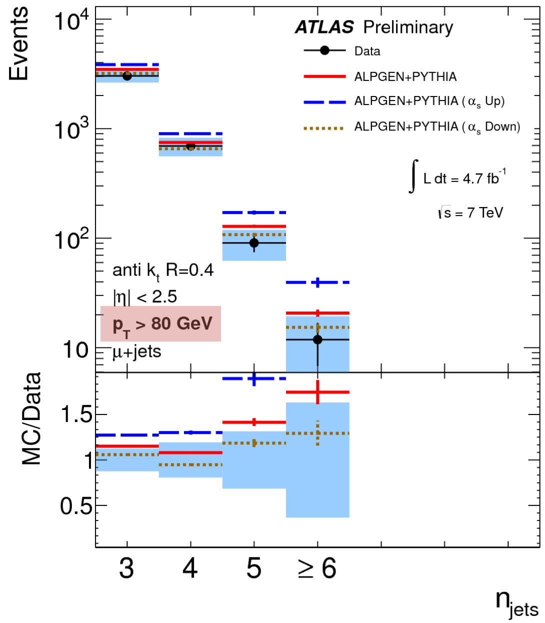
μ + ≥3 jets

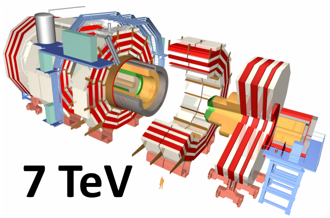




α_S-down variation most closely describes data

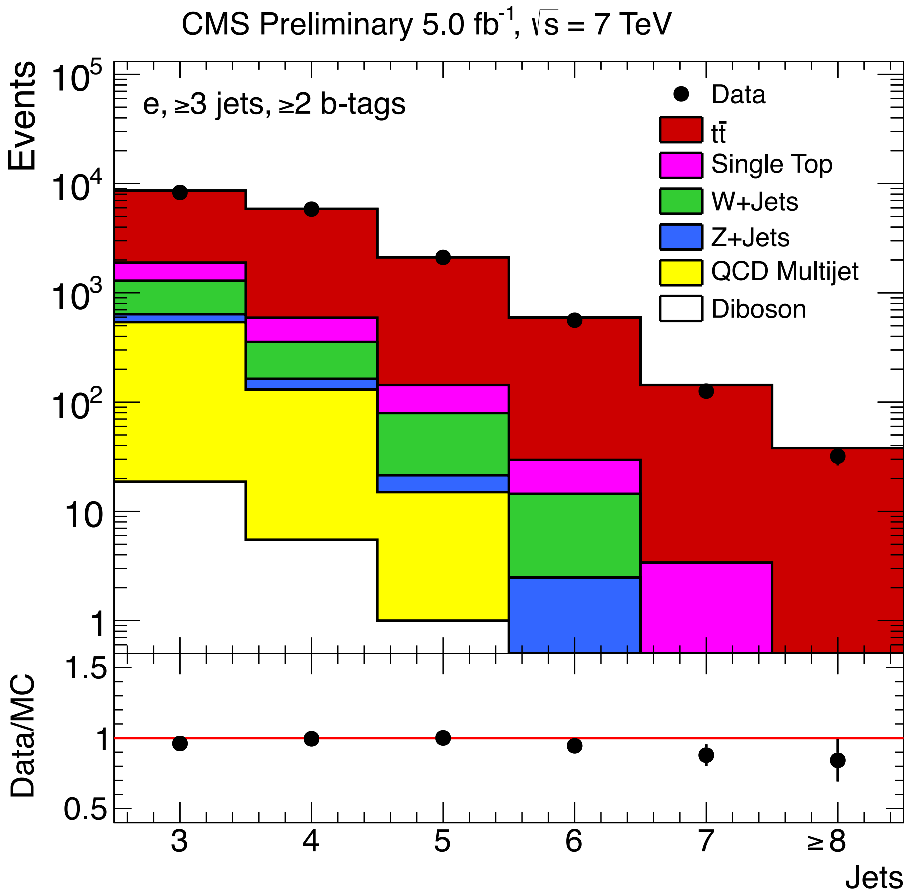


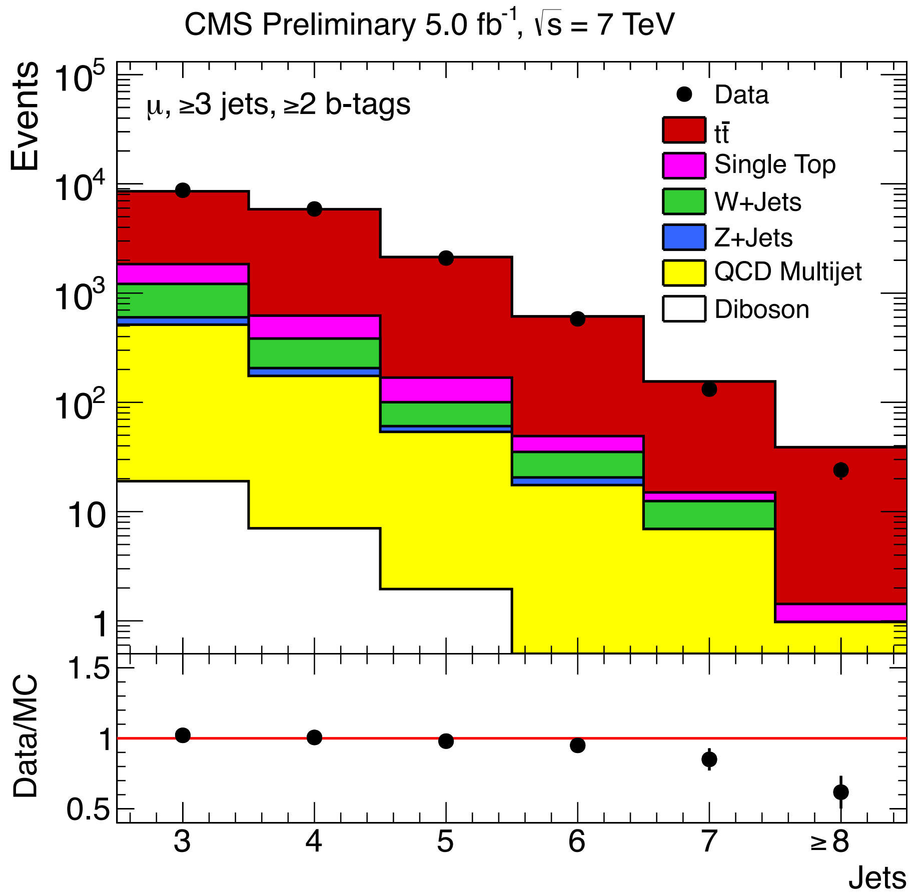




Jet multiplicity

[CMS PAS TOP-12-018]





e + ≥3 jets

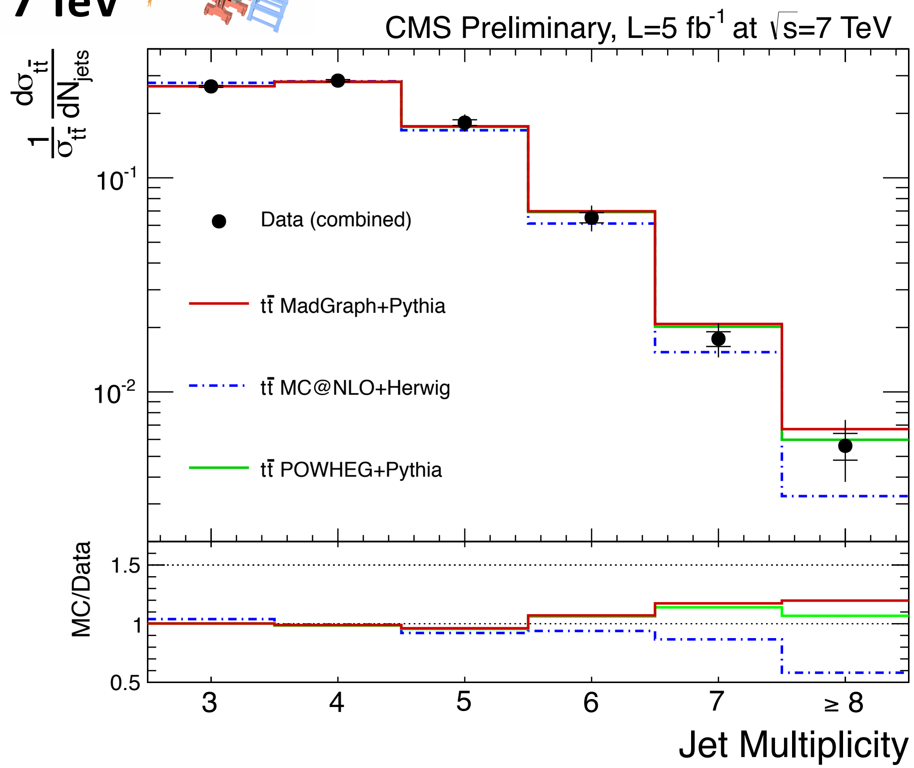
μ + ≥3 jets

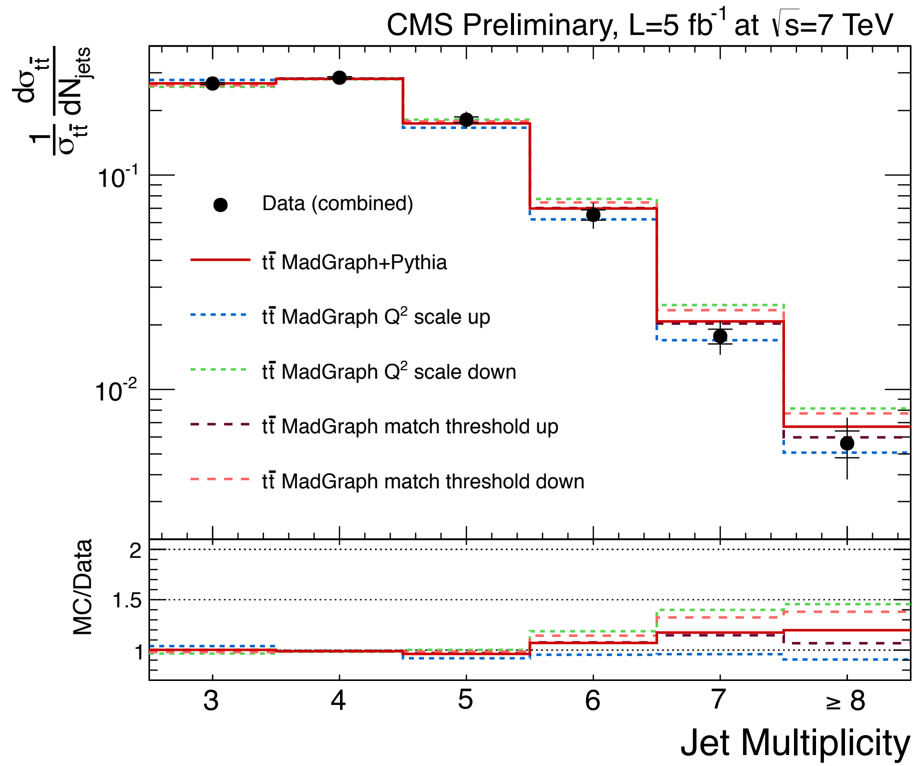
Prediction agrees with observation

Differential cross-section

CMS PAS TOP-12-018

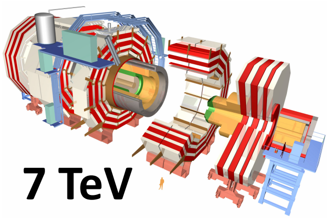
7 TeV





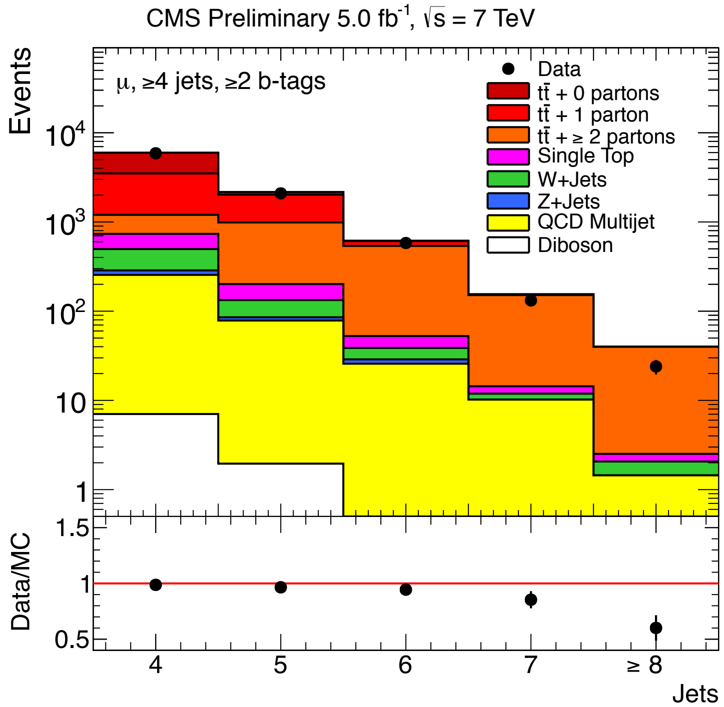
$$\frac{d\sigma_{t\bar{t}}}{dN} = \frac{N^i_{data} - N^i_{bkg}}{\Delta^i_x \varepsilon^i L}$$ where $\varepsilon^i = \frac{N^i_{rec}}{N^i_{gen}}$ and Δ^i_X the bin width

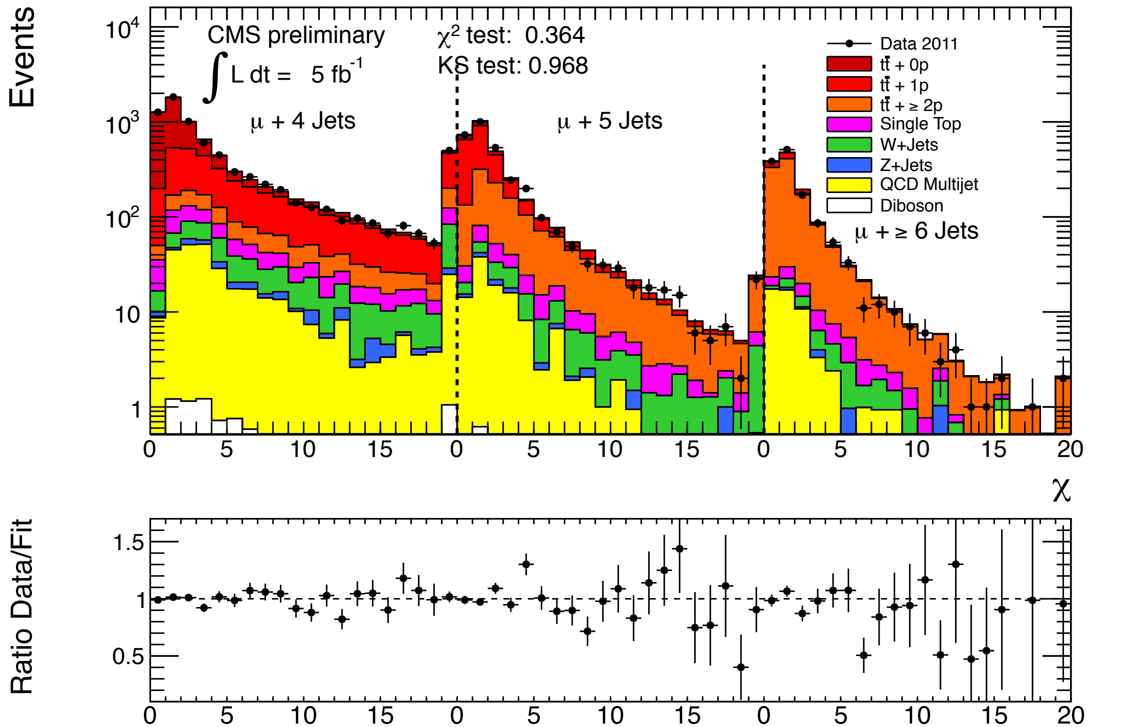
- Normalised dividing by the total cross-section
- Good agreement with MadGraph and Powheg
- Mc@Nlo underestimates large jet multiplicities



Differential cross-section in number of additional partons

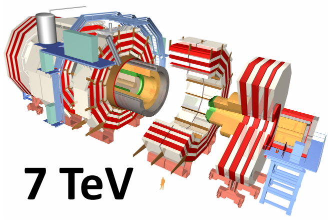
CMS PAS TOP-12-018





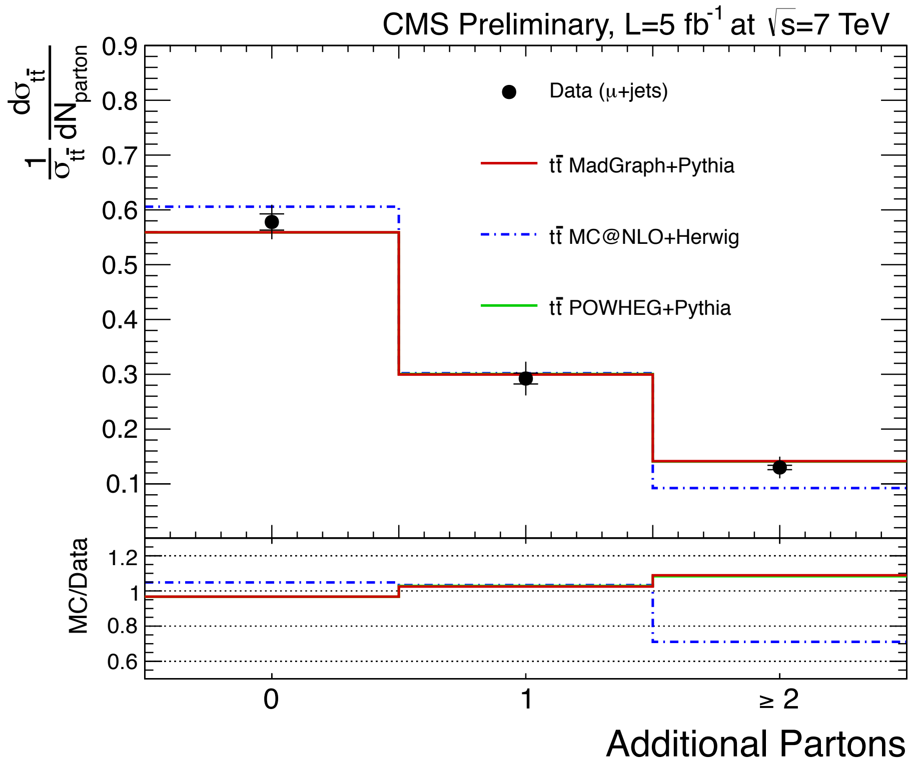
- Split $t\bar{t}$ contribution according to number of additional partons
- Use p_T>30 GeV $|\eta|$<2.4 jets with ΔR>0.5 from any $t\bar{t}$ decay product

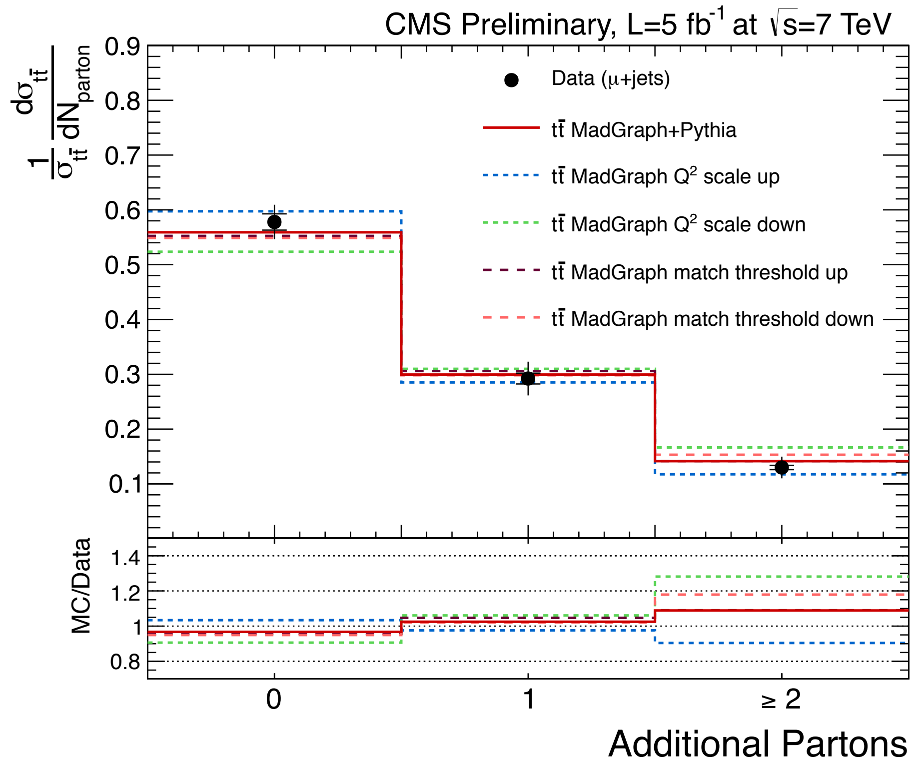
$$\chi = \sqrt{\left(\frac{m^{rec}_{W\,had} - m^{true}_{W\,had}}{\sigma_{W\,had}}\right)^2 + \left(\frac{m^{rec}_{t\,had} - m^{true}_{t\,had}}{\sigma_{t\,had}}\right)^2 + \left(\frac{m^{rec}_{t\,lep} - m^{true}_{t\,lep}}{\sigma_{t\,lep}}\right)^2}$$



Differential cross-section in number of additional partons

[CMS PAS TOP-12-018]





- Excellent agreement with MadGraph and Powheg
- Precision of the measurement significantly better than scales variation

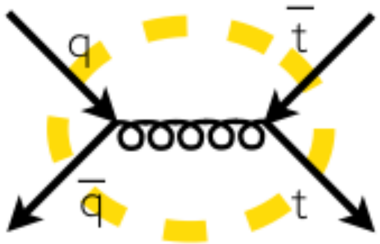
Summary

- $t\bar{t}$ jet multiplicity measurements useful to test theoretical predictions and to look for BSM signals
- Globally, good agreement data/MC found, but:
  - MC@NLO + HERWIG produces too little jet activity at high jet multiplicities
  - Some indication that data prefer a lower α_S (higher scale) for the multi-leg generators (ALPGEN, MADGRAPH)
- Jet multiplicity measurements limited by systematic uncertainties
- At large jet multiplicities data have large statistical errors, limiting the ability to constrain models

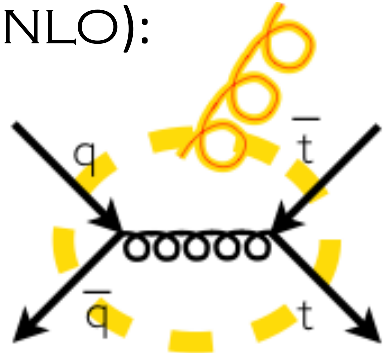
Back up

Monte Carlo simulations

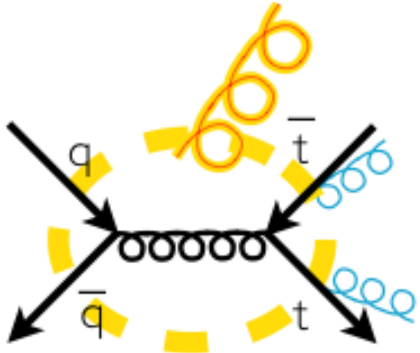
- **NLO + PS** (PowHeg, MC@NLO):



$t\bar{t}$ @ NLO

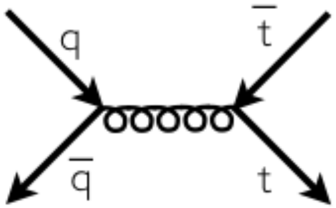


+ 1 jet @ LO

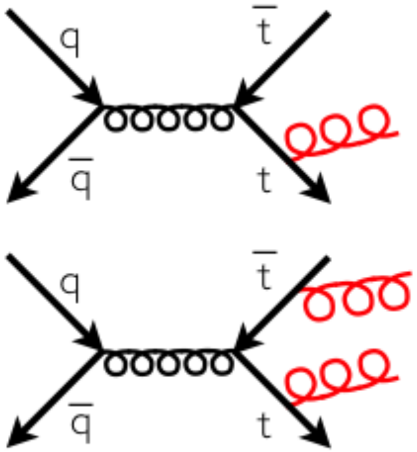


+ more jets from PS

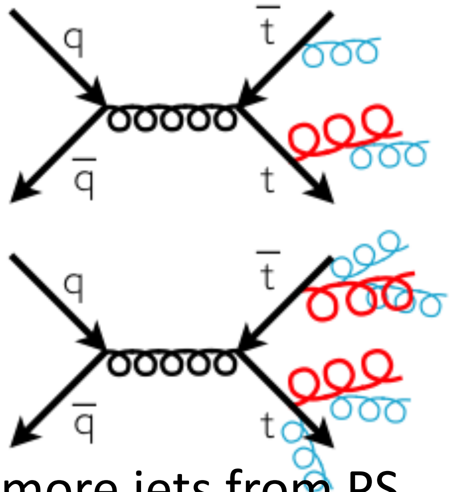
- **Multi-leg + PS** (Alpgen, MadGraph, Sherpa):



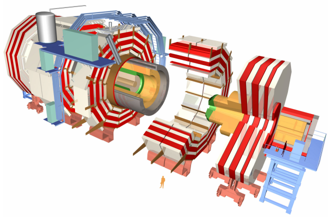
$t\bar{t}$ @ LO



+ 1 jet @ LO
+ 2 jets @ LO



+ more jets from PS



Monte Carlo simulations

- $t\bar{t}$ MadGraph v5.110 (M.E.@ tree level + up to 3 additional partons) + Pythia v6.424 with MLM matching scheme + Pythia Z2 tune for underlying event ($m_t^2+\Sigma p_T^2$(jet) Q^2 scale and CTEQ6L1 PDF) *Kidonakis*

- $t\bar{t}$ PowHeg r1380 + Pythia Z2 tune (CTEQ6M PDF)

- $t\bar{t}$ MC@NLO v3.41 + Herwig v6.520 (CTEQ6M PDF)

- Z/γ^* (NNLO)

- Single top PowHeg v1.0 + Pythia (NLO+NNLL) *Kidonakis*

- W+jets MadGraph v5.1.1 + Pythia v6.424 (NNLO)

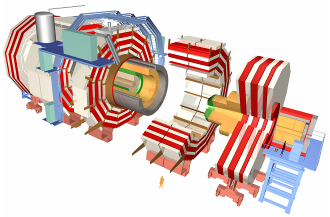
- Z+jets MadGraph v5.1.1 + Pythia v6.424 (NNLO) *Melnikov + Petriello*

- Diboson MadGraph v5.1.1 + Pythia v6.424 (NNLO) *Campbell et al.*

- QCD multijets (LO) *Sjöstrand*

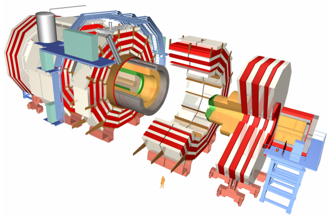
Monte Carlo simulations

- $t\bar{t}$ ALPGEN (CTEQ6L1 PDF) v2.13 (M.E.@ tree level + up to 5 additional partons) + HERWIG v6.520 with MLM matching scheme *Aliev et al.*
- $t\bar{t}$ POWHEG (CTEQ6.6 PDF) + PYTHIA (AUET2B-CTEQ6L1 tune)
- $t\bar{t}$ MC@NLO (CTEQ10 PDF) + HERWIG + JIMMY (AUET1 tune) for UE
- $t\bar{t}$ ALPGEN v2.14 (CTEQ5L) + PYTHIA (Peruggia tune)
- $t\bar{t}$ SHERPA (up to 3 additional partons, KKW matching scheme)
- $t\bar{t}$ ACERMC (MRS2007L) PDF) + PYTHIA + UE tune AMBT1
- Single top t-channel ACERMC *Kidonakis*
- Single top Wt, s-channels MC@NLO *Kidonakis*
- W/Z+jets ALPGEN v2.13 (CTEQ6L1) + HERWIG (up to 5 additional partons)
- Diboson HERWIG



Dilepton events kinematic reconstruction

- To determine top-quark pair kinematic properties and identify two *b*-jets
- Constraints:
  - Balance of two neutrinos transverse momentum
  - W invariant mass of 80.4 GeV
  - $m_{top} = m_{antitop}$
- Resolve ambiguities by prioritising event solutions with two or one *b*-jets over solutions with jets without *b*-tag
- Choose solution with most probable neutrino energies according to simulation among physical solutions
- Discard events with no physical solution (11% @7TeV and 12% @8 TeV)



Regularised unfolding method

- Trigger and detector efficiencies and resolutions might cause events migrations across bin boundaries and statistical correlations among neighboring bins

- Build response matrix to account for these effects using MadGraph

- Use generalised inverse of response matrix to obtain unfolded distributions from measured distributions by applying a χ^2 technique

- Apply smoothing prescription (regularisation) to avoid non-physical fluctuations

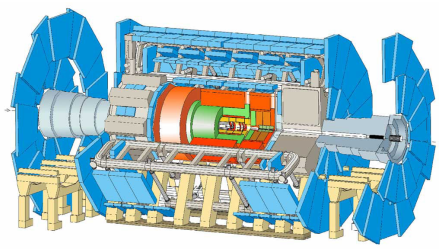
- Regularisation level determined individually for each distribution

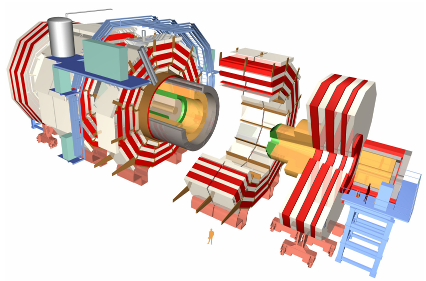
- Purity (p) and stability (s) typically around 50%, which guarantees than the bin-to-bin migrations are small enough to perform the measurement

$$p = \frac{N^i_{gen\&rec}}{N^i_{rec}} \qquad s = \frac{N^i_{gen\&rec}}{N^i_{gen}}$$

A. Hoecker and V. Kartvelishvili, "SVD Approach to Data Unfolding", Nucl. Inst. Meth. **A372** (1996) 469
V. Blobel, "An unfolding method for high energy physics experiment", arXiv:0208022

Event selection





- Electrons: p_T>25 GeV $|\eta|$<2.47
  E_T^{con}<3.5 GeV
- Muons: p_T>25 GeV $|\eta|$<2.5
  E_T^{con}<4 GeV p_T^{con}<4 GeV
- Jets: p_T>25 GeV $|y|$<2.4

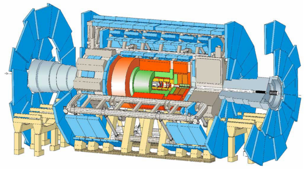
- Single lepton triggers
- Two opposite-sign leptons
- At least two jets
- At least two *b*-jets ($\varepsilon_{tagging} \approx 70\%$)
- E_T^{miss} >40 GeV (*ee*, μμ)
- H_T>130 GeV (*e*μ)
- Veto Z-boson and vector-meson regions (*ee*, μμ)

- Electrons: p_T>20 GeV $|\eta|$<2.4 I_{rel}<0.17 (0.15)
- Muons: p_T>20 GeV $|\eta|$<2.4 I_{rel}<0.20 (0.15)
- Jets: p_T>30 GeV $|\eta|$<2.4

$$I_{rel} = \frac{\sum p_T^{all-lepton}}{p_T^{lepton}}$$

- Dilepton trigger
- At least two opposite-sign leptons
- At least two jets of which at least one is identified as *b*-jet ($\varepsilon_{tagging} \approx$ 80-85%)
- E_T^{miss} > 30 GeV (40 GeV)
- Use kinematic reconstruction to determine top-pair properties and identify 2 *b*-jet originating from decays of *t*-quarks

(values for 8 TeV data analysis)



7 TeV

$t\bar{t}$+jets cross-section

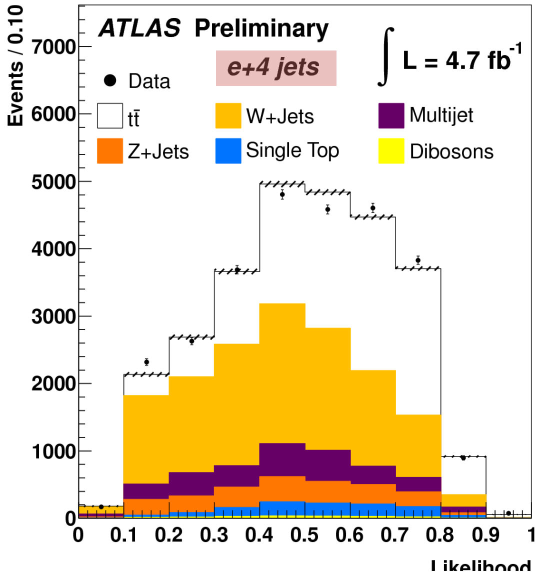
ATLAS-CONF-2012-083

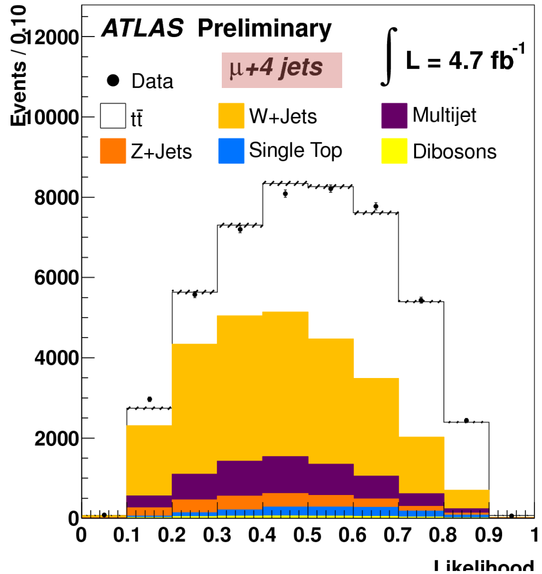
- Build likelihood with lepton η and aplanarity

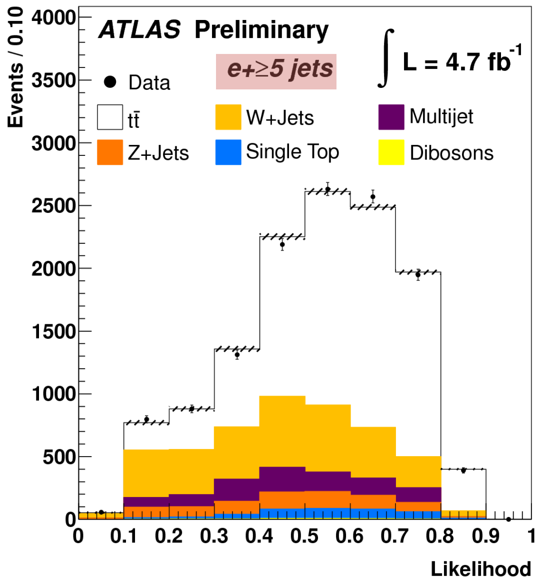
$$LHW_i = \frac{L_i^s}{L_i^s + L_i^b}$$

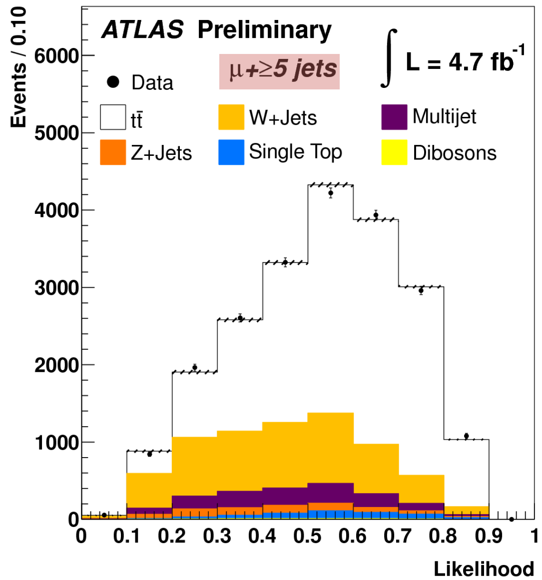
- Fit data to signal + background templates

$\sigma_{ttj} = 102 \pm 2_{stat}$ pb









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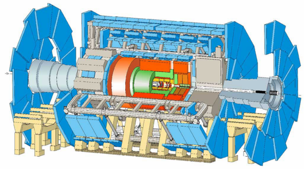

Additional jet gap fraction

7 TeV

$$f(Q_0) = \frac{n(Q_0)}{N}$$

events without additional jets above given p_T