Top Pair Differential Cross Sections Using the CMS Detector

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On behalf of the CMS collaboration

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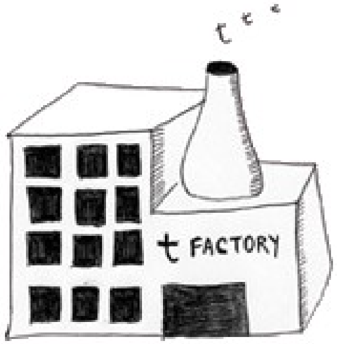
Overview



- LHC producing millions of tops per year
- A new era of precision physics
- Comprehensive set of measurements of differential top quark pair cross sections
  - Lepton p_T, η
  - Top p_T, y
  - Top pair p_T, y and $m(t\bar{t})$
  - Jet multiplicity and jet veto “gap fraction” distributions
  - $\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}j\bar{j})$

Motivation

- Verify the production and hadronisation mechanism through different decay channels
- Test of perturbative QCD
  - Different Generators
  - Constrain theory uncertainties

Different Monte Carlo Generators

ME	PS	Method	PDF
MadGraph	Pythia	ME+PS	CTEQ6L1
MC@NLO	Herwig	NLO	CTEQ6M
Powheg	Pythia	NLO	CTEQ6M

Renormalisation scale (up:×4, down:×0.25)

$Q^2 = m(\text{top})^2 + \sum p_T^2(\text{jets})$ (MadGraph)

$Q^2 = m(\text{top})^2$ (MC@NLO/Powheg)

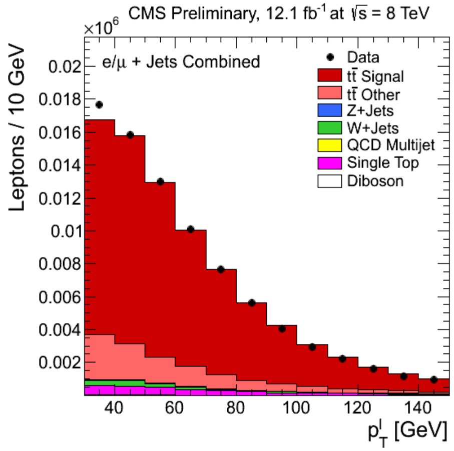
Parton Matching (up:×2, down:×0.5)
MadGraph nominal: 20 GeV
Contains up to 3 additional partons

- Window to new physics
- Background to ttH and many BSM searches

General Analysis Strategy

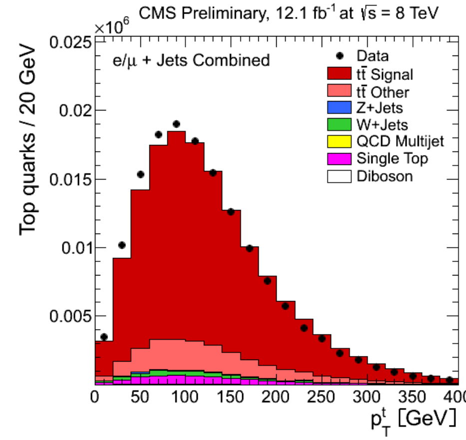
1. Event Selection

(get a very pure ~90% $t\bar{t}$ sample)



2. Kinematic Fit

Reconstruct the $t\bar{t}$ decay to obtain top quark kinematics



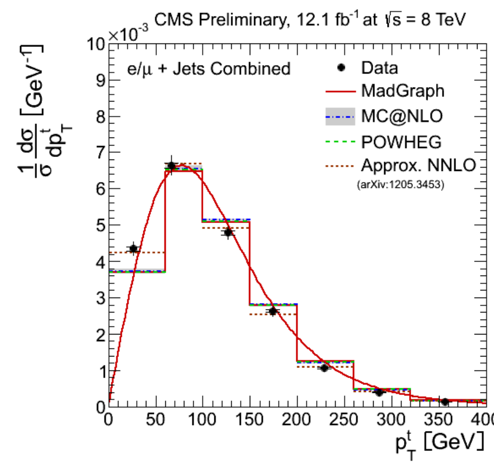
3. Background estimation/subtraction

Calculate the differential cross section

$$\frac{d\sigma_{tt}}{dN} = \frac{N^i_{data} - N^i_{bkg}}{\Delta^i_x \epsilon^i \mathcal{L}}$$

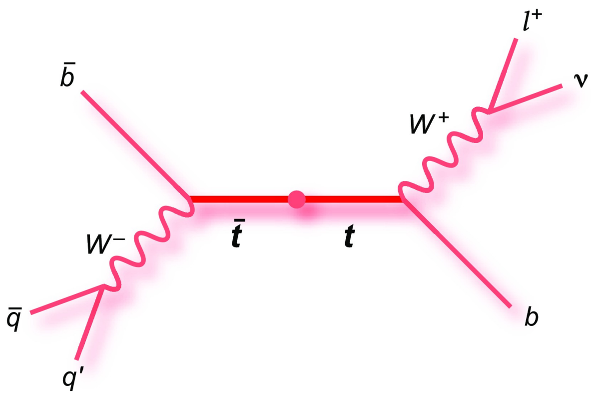
4. Unfolding

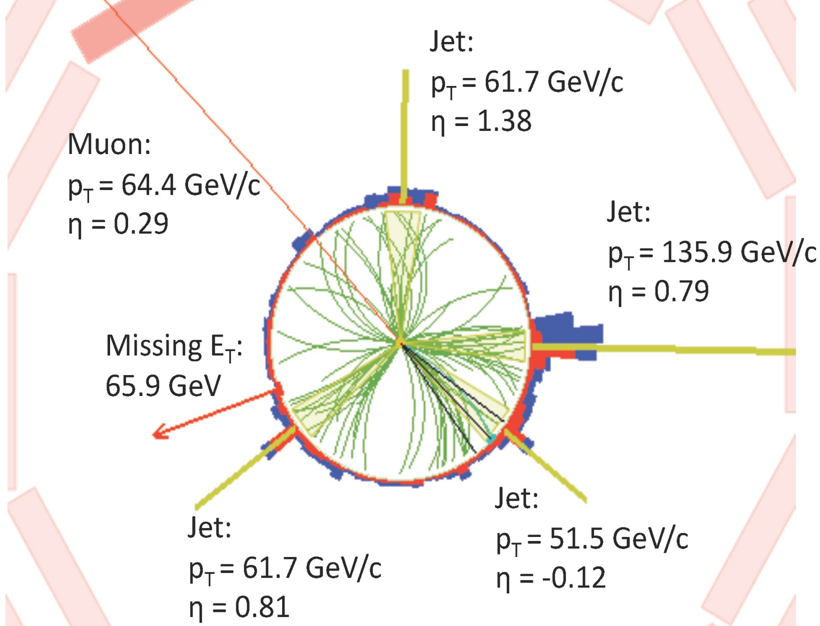
Detector and selection effects removed

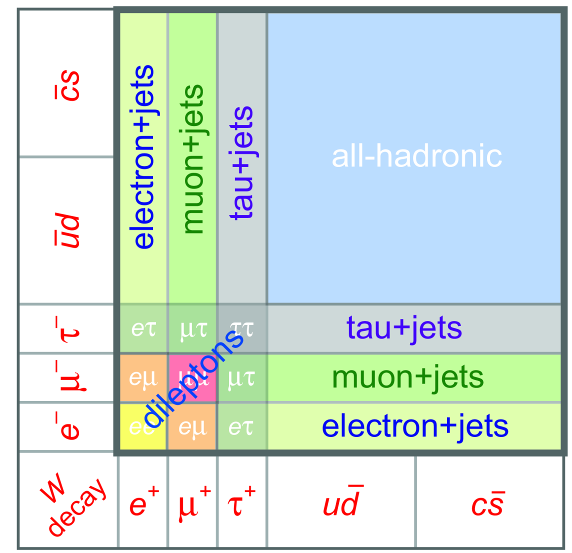


Can then compare with different Generators, models, experiments or with 7 TeV data

Typical Event Selections







Semileptonic channel (BR(e,μ)~34%)

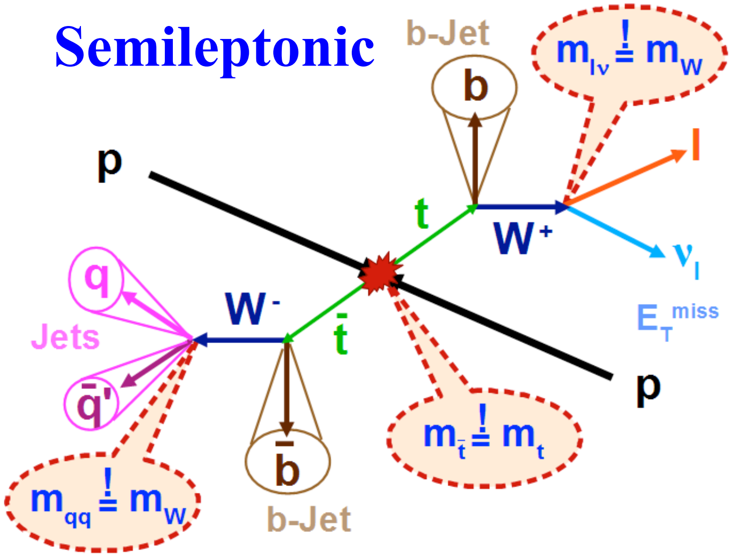
- High p_T > 30 GeV single isolated lepton (e or μ)
- Additional leptons vetoed
- ≥4 jets (p_T >30 GeV)
- ≥2 b-tags

Dilepton channel (BR(ee, μμ, eμ)~6%)

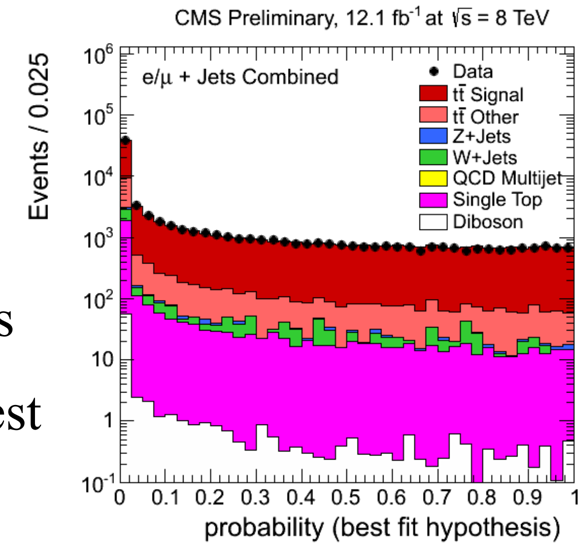
- Two opposite sign leptons(ee, μμ, eμ)
- $m(l^+l^-)$ > 12 GeV (QCD rej.)
- $|m(l^+l^-) – m(Z)|$ > 15 GeV (Z veto)
- ≥2 jets
- MET > 40 GeV (ee & μμ only)
- ≥1 b-tag

Kinematic Reconstruction

Semileptonic

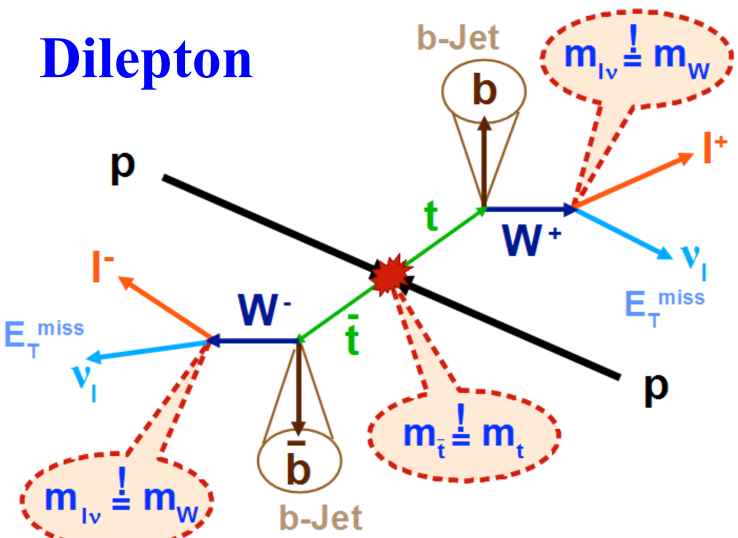


- Constrained system
- Vary 4-momenta of jets, lepton, and neutrino within resolutions
- Consider up to 5 leading jets
- Choose permutation with best fit hypothesis (min. χ^2)



$m(W) = 80.4$ GeV
$m(t) = m(\bar{t})$
Initial $p_z(\nu) = 0$

Dilepton



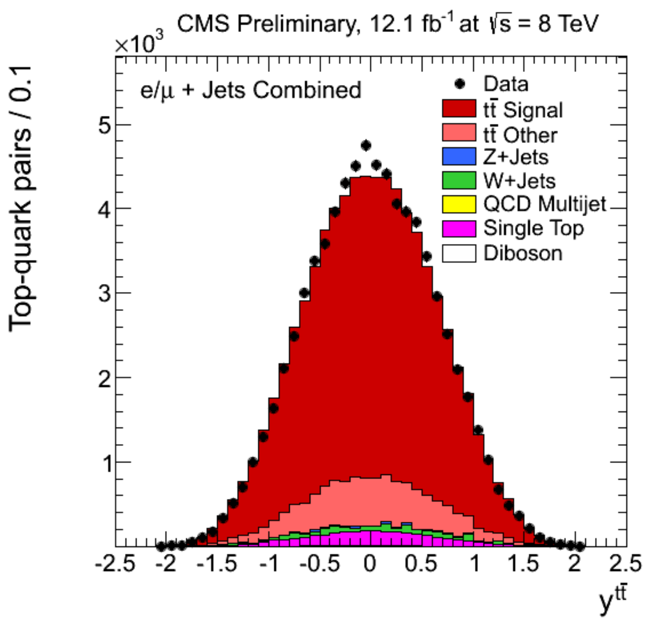
- Under-constrained system (2 neutrinos)
- Top mass varied from 100-300 GeV in 1 GeV steps
- All jets passing selection considered
- Solutions with multiple b-tags preferred

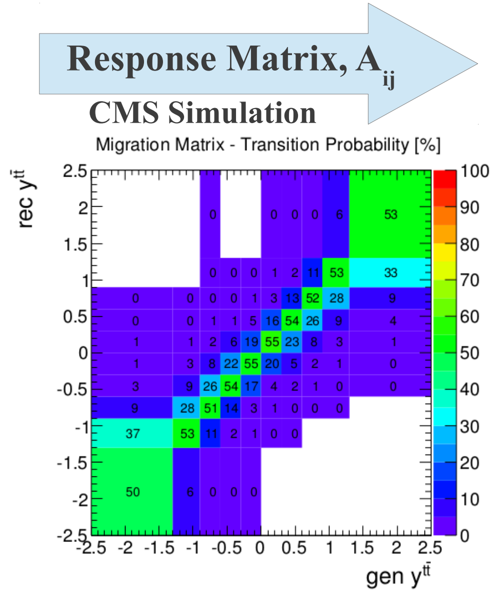
$p_{\nu 1}(x,y) + p_{\nu 2}(x,y) = MET$

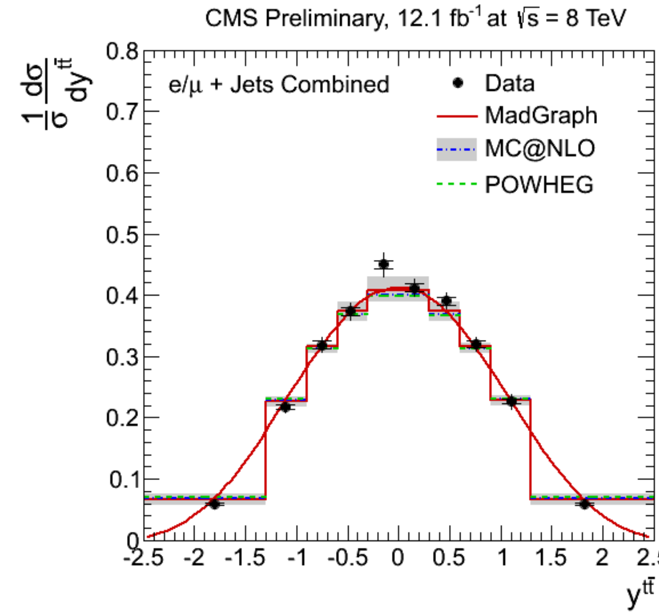
Both methods ~90% efficient

Unfolding

Correct for detector and selection effects







Binning Choice

Define two (purity and stability) variables sensitive to migration in and out of bins

$$p_i = \frac{N_{\text{rec\&gen,i}}}{N_{\text{rec,i}}} \qquad s_i = \frac{N_{\text{rec\&gen,i}}}{N_{\text{gen,i}}}$$

Require values of ~>0.4

Regularisation

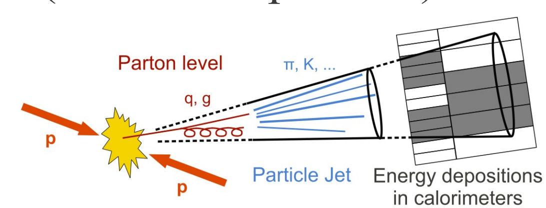
- Basic unfolding involves the simple inversion of the response matrix:

$$\mathrm{N}_{i,\text{unf}} = A_{ij}^{-1}\mathrm{N}_{j,\text{meas}}$$

- Regularisation is used to remove large statistical fluctuations (SVD)

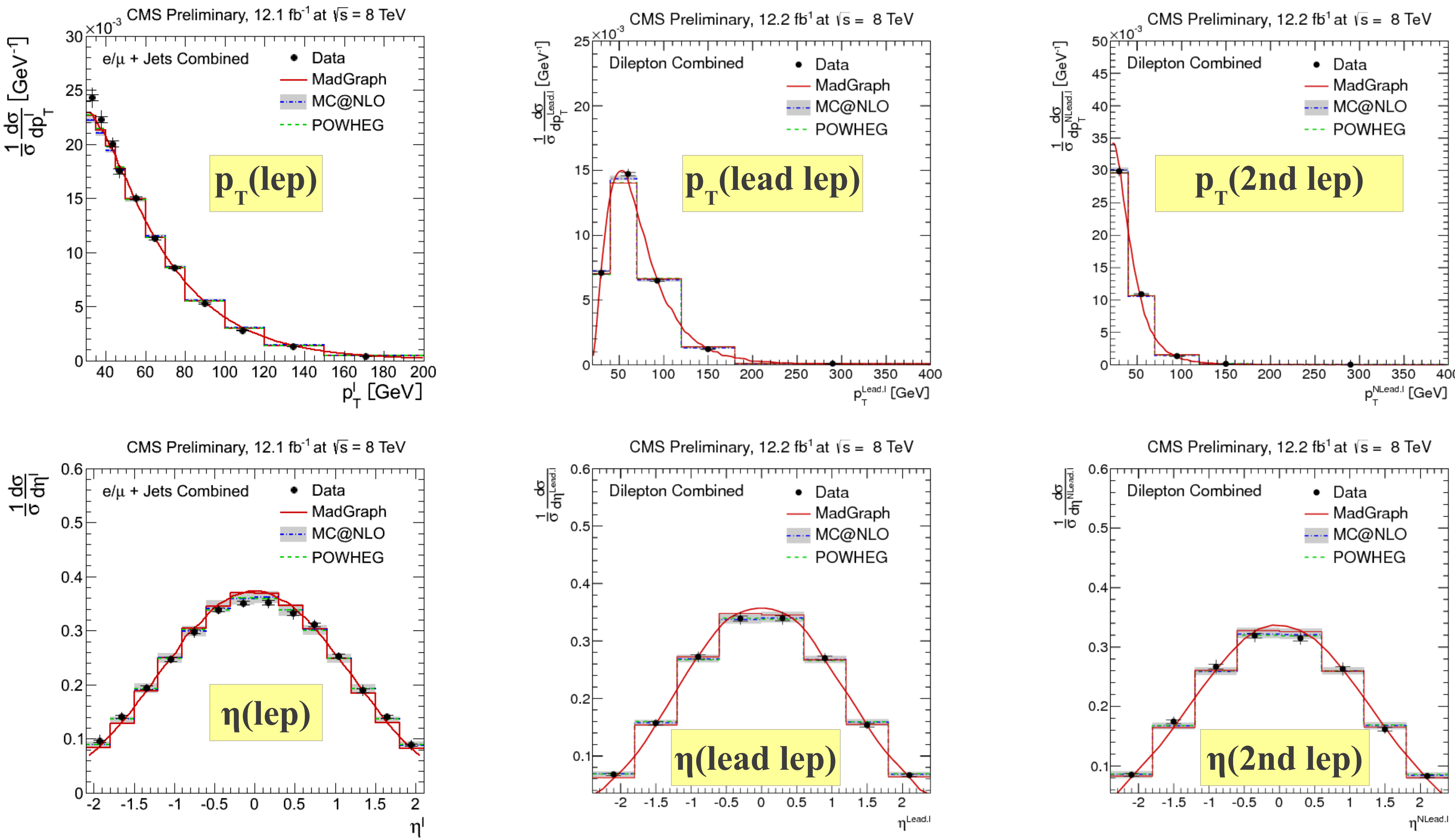
Phase Space definition

Can correct back to **parton** or **particle** level in **full** or **visible** phase space. (variable dependent)



Lepton differential cross sections

8 TeV (12.2 fb^{-1})

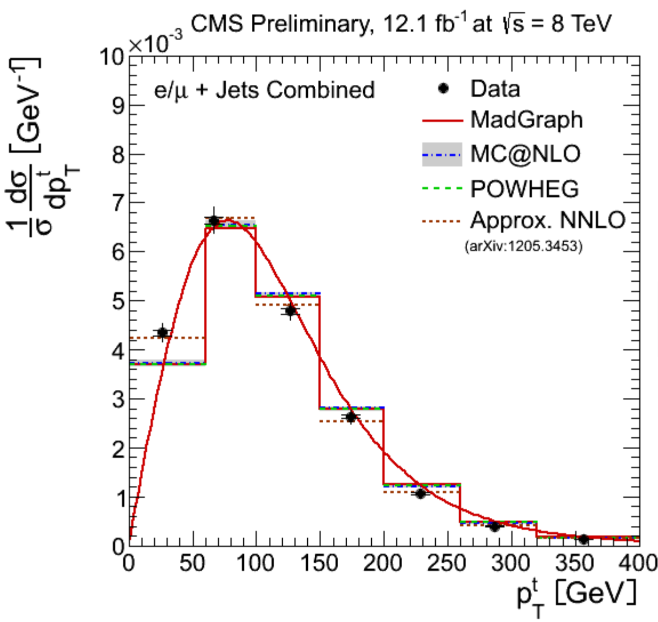


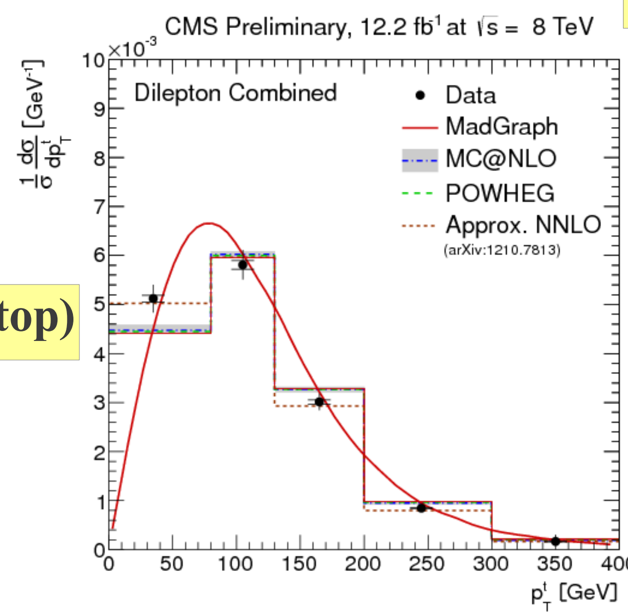
Measurements in the visible phase space

Top differential cross sections

8 TeV ($12.2\ fb^{-1}$)

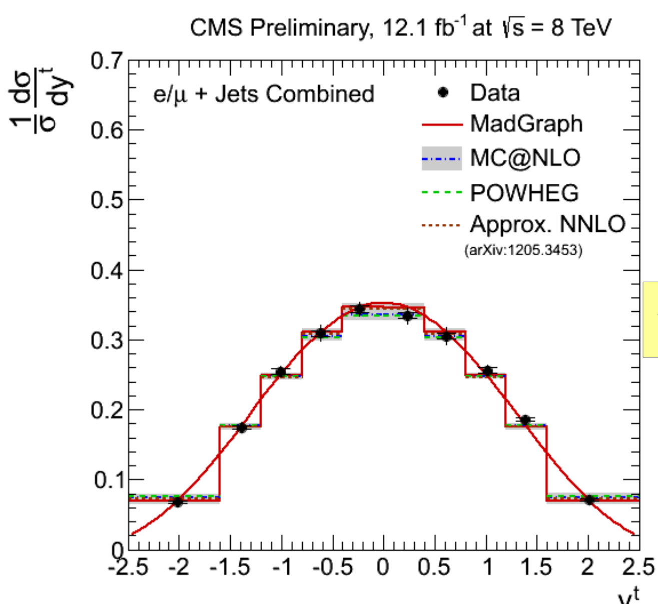
p_T(top)

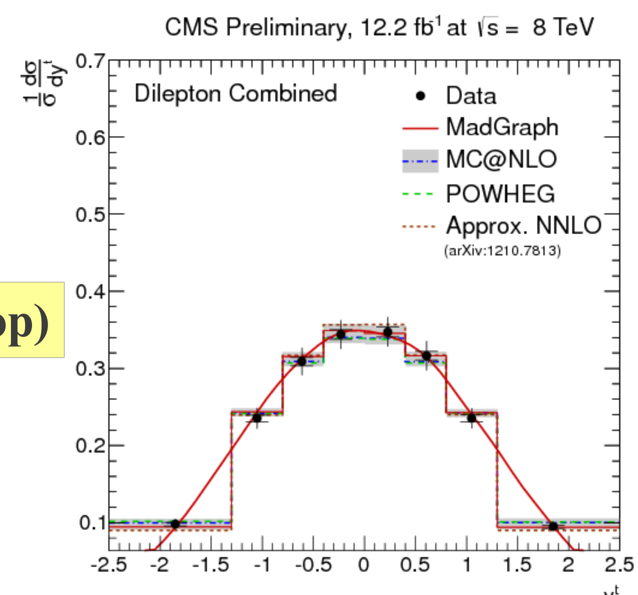




Approximate NNLO gives the best description of p_T(top) distribution

y(top)



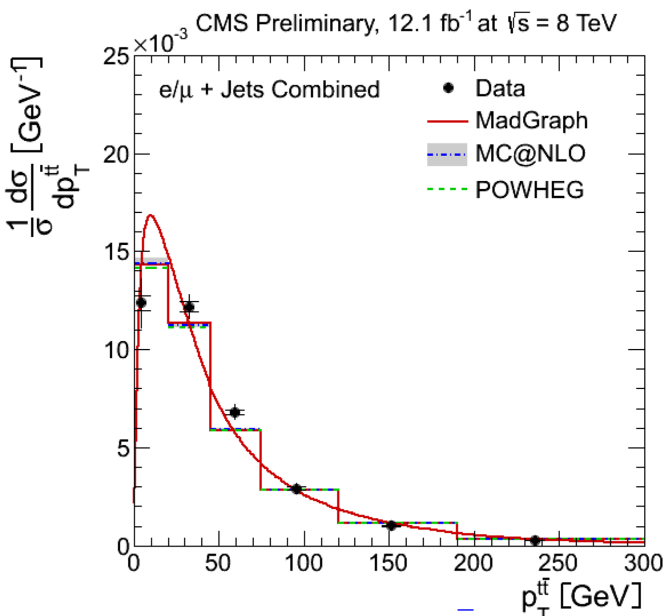


Good agreement with all predictions

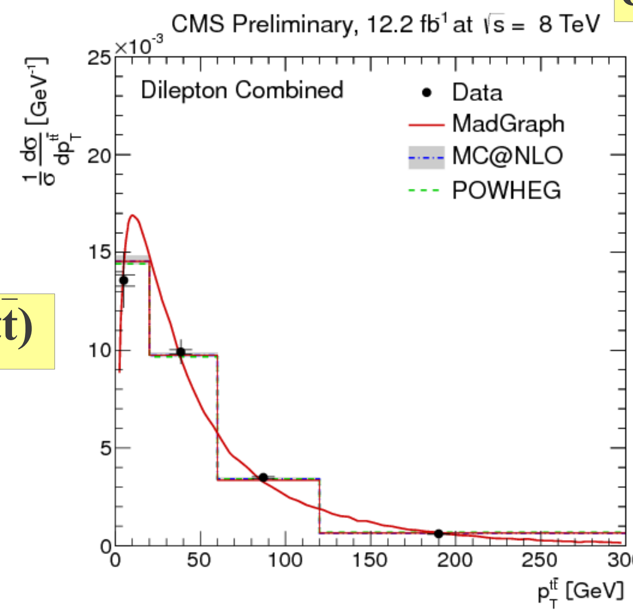
Measurements in the full phase space

Top pair differential cross sections

8 TeV (12.2 fb^{-1})

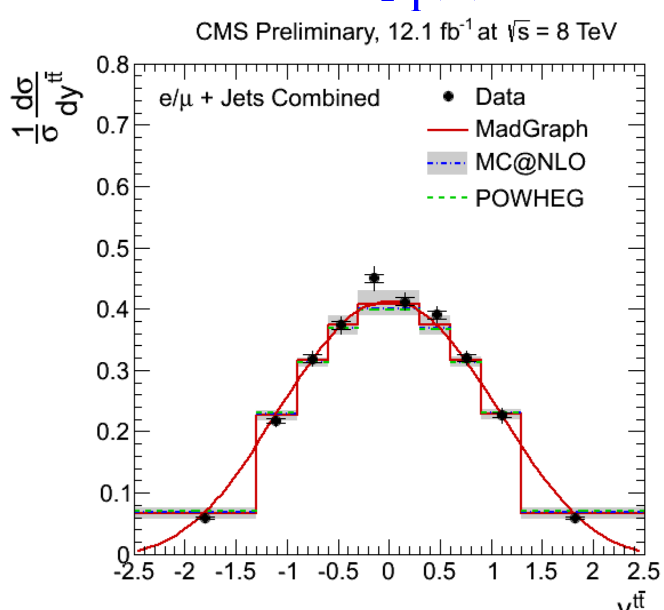


$p_T(t\bar{t})$

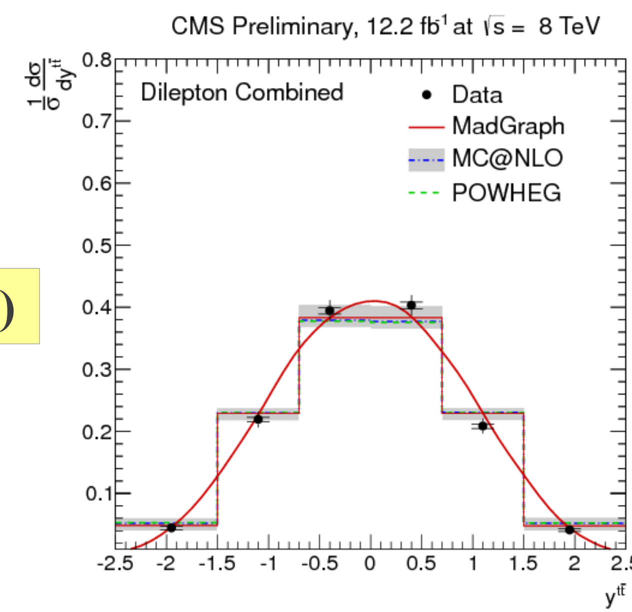


Consistent observations between dilepton and semileptonic channels

$p_T(t\bar{t})$ sensitive to higher order effects



$y(t\bar{t})$



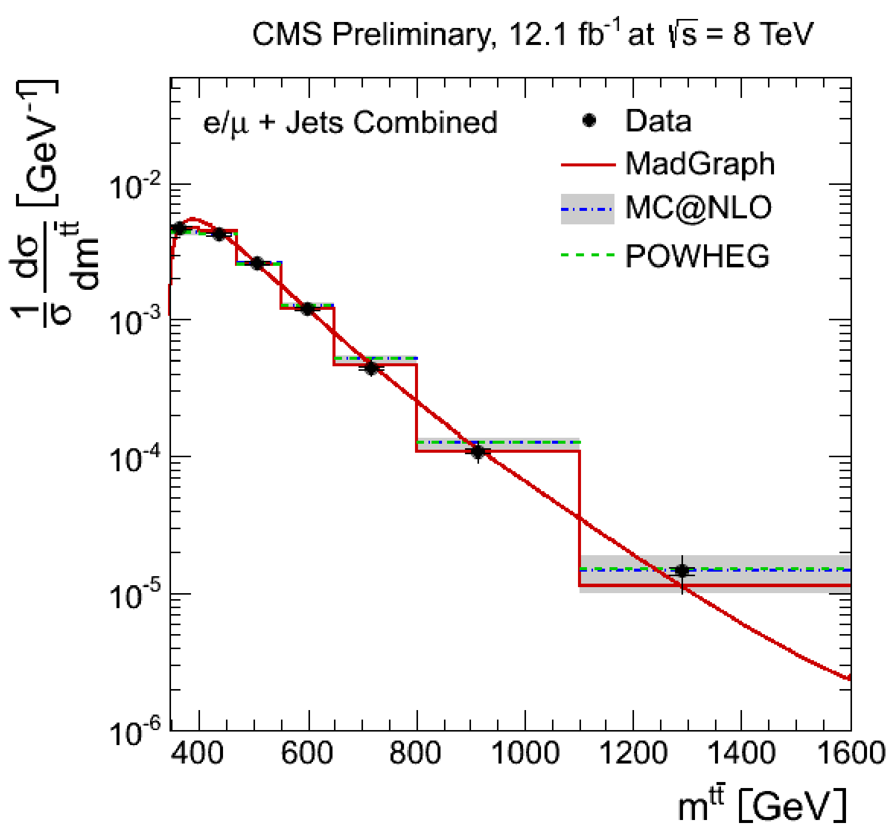
Typical precision 5-10% per bin

Main systematics: Jet energy scale (JES), model (Q^2 and Hadronisation)

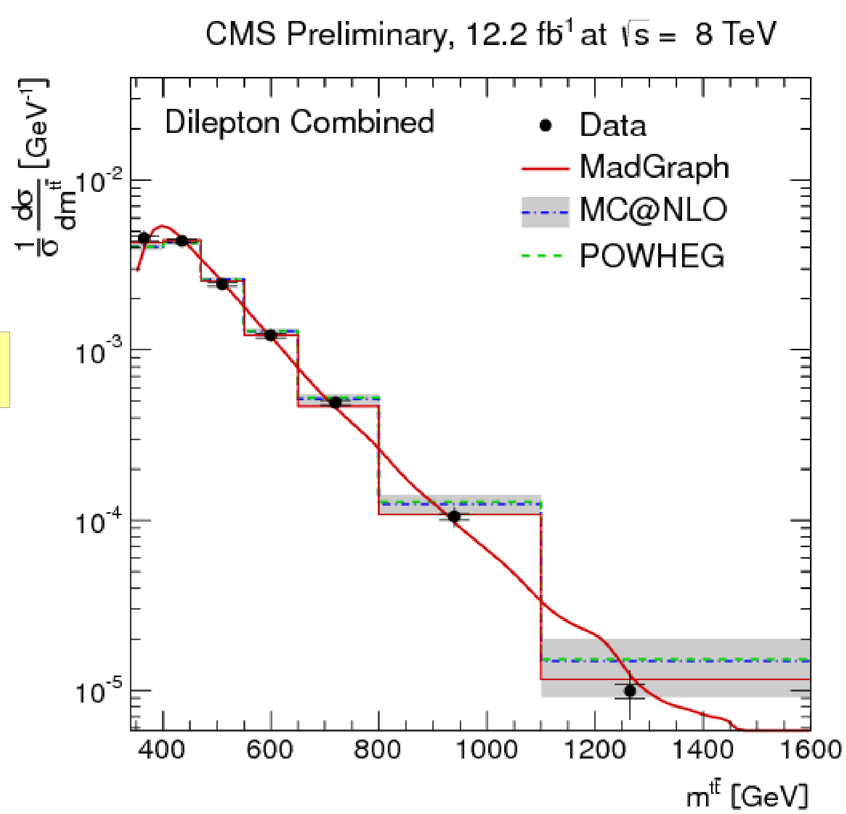
$y(t\bar{t})$ sensitive to the gluon distribution

m($t\bar{t}$) differential cross sections

8 TeV (12.2 fb^{-1})



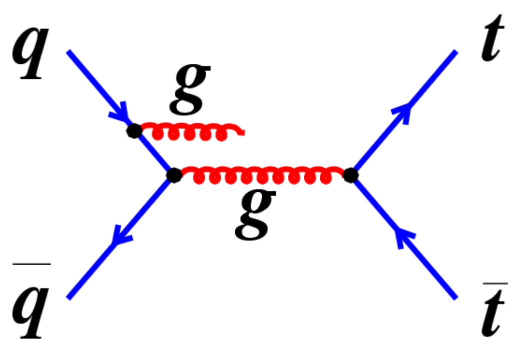
m($t\bar{t}$)

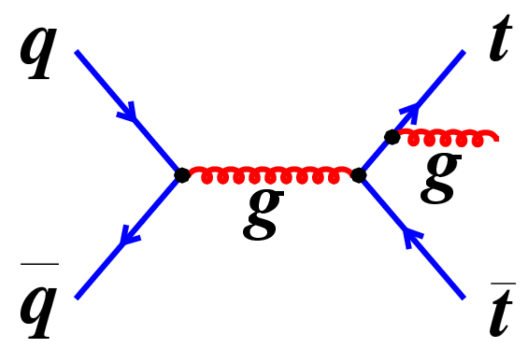


Sensitive to resonances and an important background for all new searches

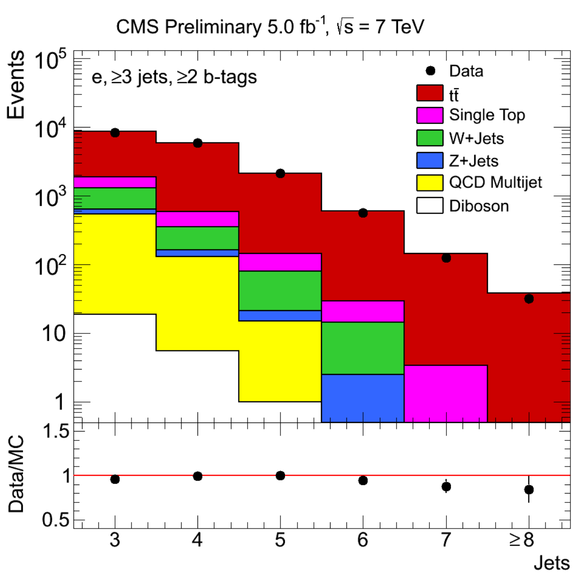
$t\bar{t}$+Jets

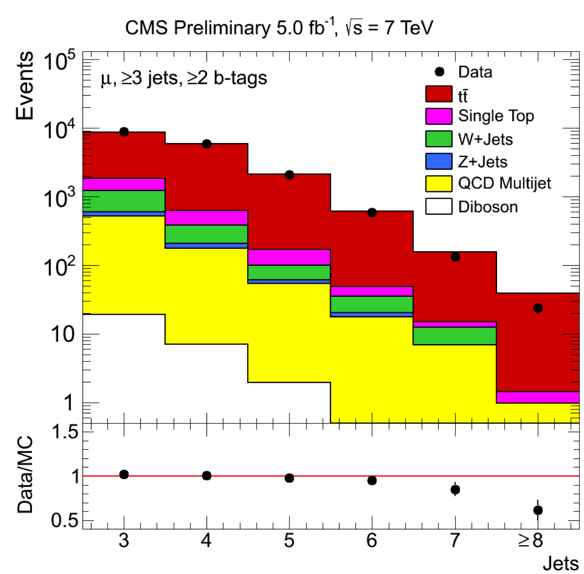
- A large fraction of $t\bar{t}$ events contain additional radiation (~50%)
- These studies are a good way of constraining ISR/FSR

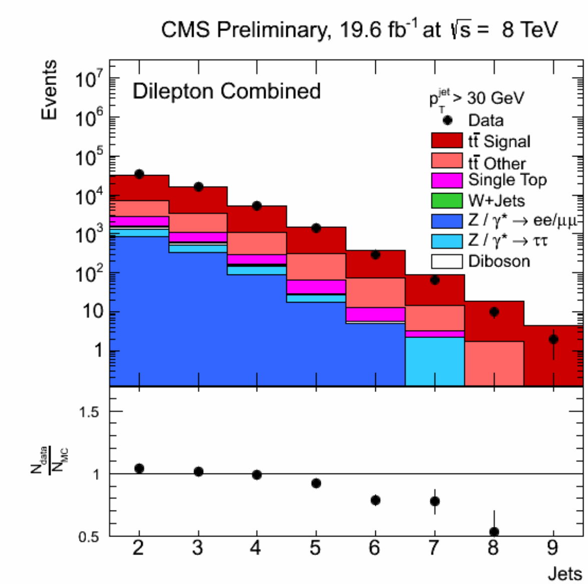




Jet multiplicity after event selection







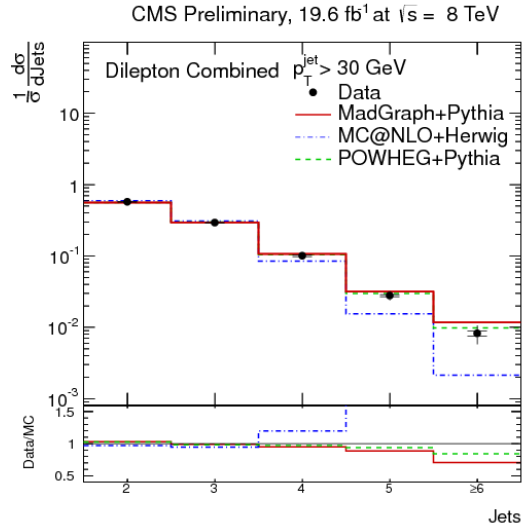
Jet Multiplicity

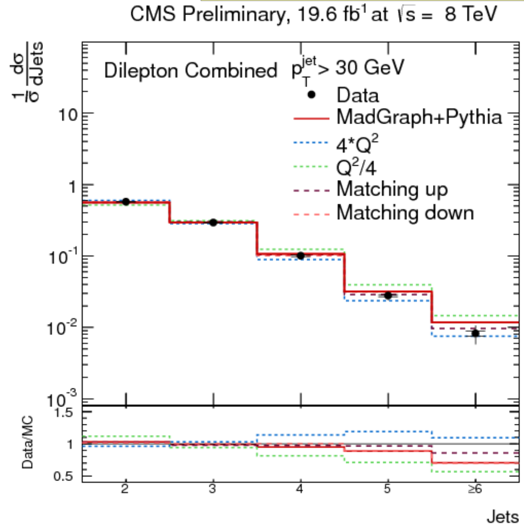
8 TeV (19.6 fb^{-1})

Dilepton channel

- Kinematic fit used
- Additional jets defined as those not identified as part of $t\bar{t}$ system

TOP-12-041





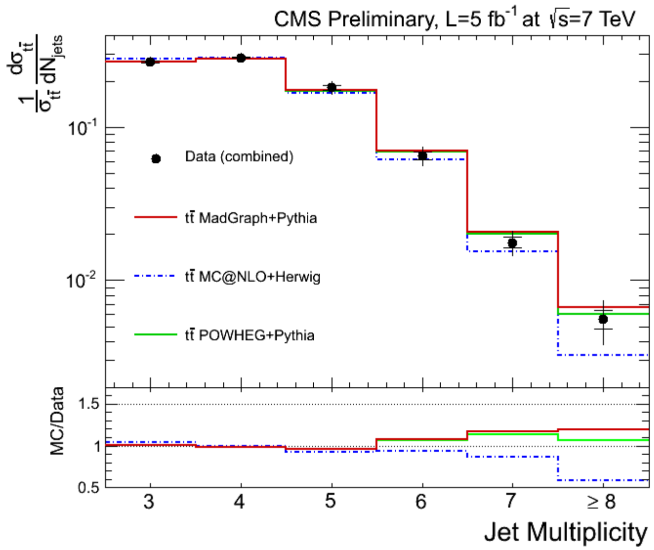
Main systematics: Jet energy scale (JES), model (Q^2 and Hadronisation)

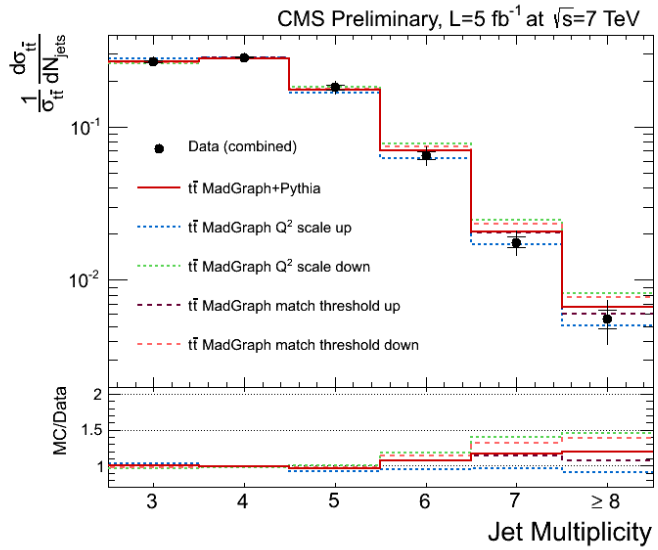
7 TeV (5 fb^{-1})

Semileptonic channel

- Cut and count analysis with data driven BG estimation
- Bin-by-bin unfolding applied

TOP-12-018





Jet veto "Gap Fraction"

8 TeV (19.6 fb^{-1})

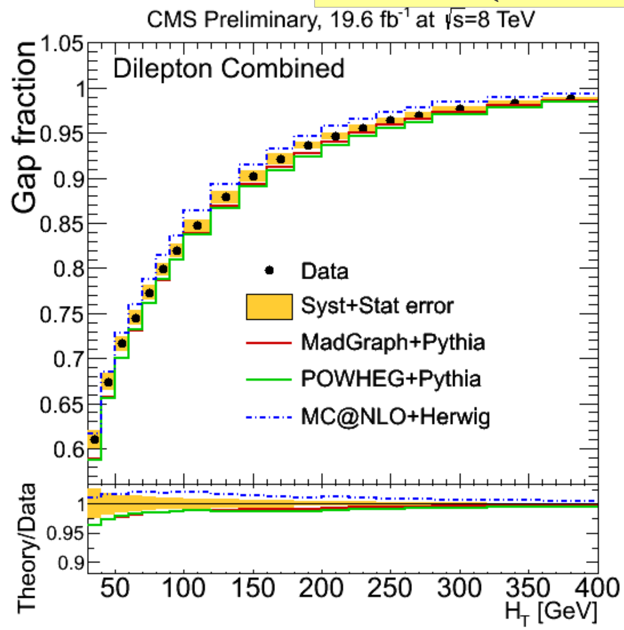
- The fraction of events that do not contain an additional jet above a certain p_T or H_T threshold

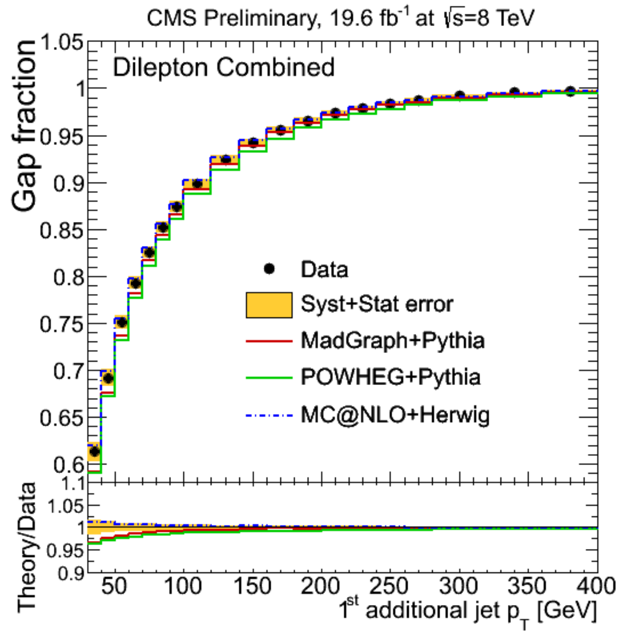
$$f(p_T) = \frac{N(p_T)}{N_{total}}$$

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

- H_T defined as sum of p_T of additional jets
- P_T/H_T of leading additional jet varied from 35 GeV to 380 GeV

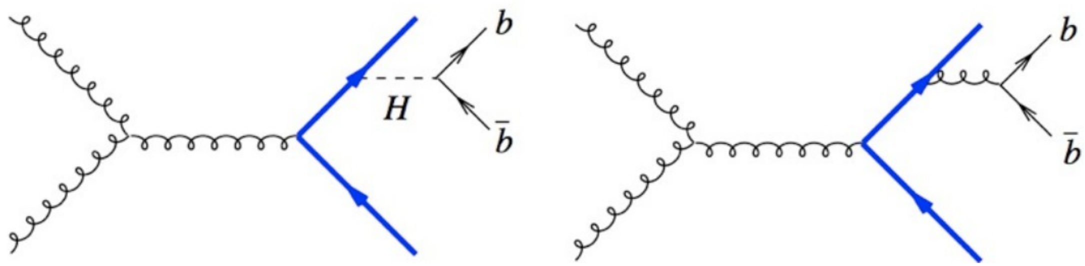
Main systematics: JES, background

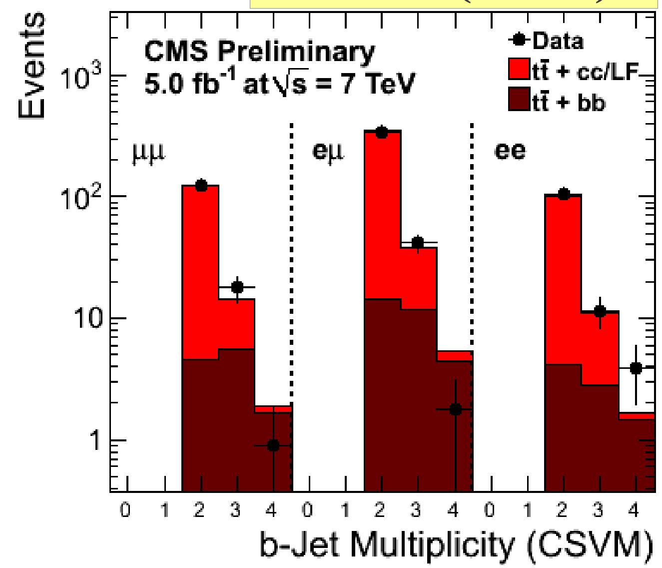




$\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}j\bar{j})$ Measurement

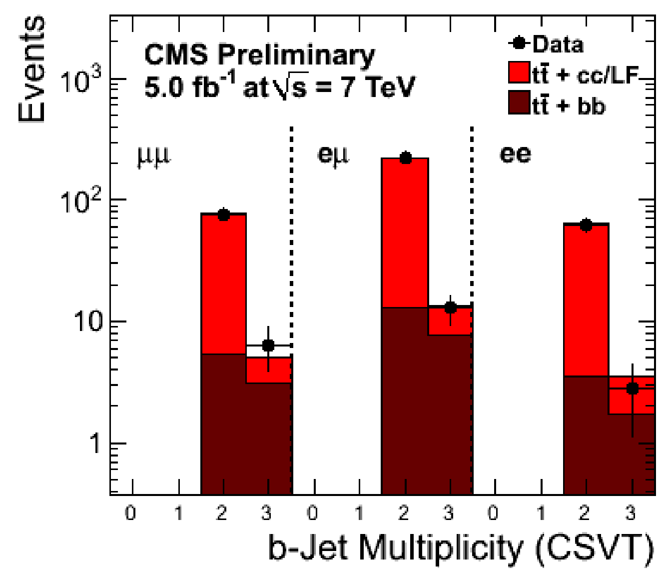
7 TeV (5 fb^{-1})





- Test of perturbative QCD, BG to Higgs physics
- Perform a template fit of B-jet multiplicity in semileptonic channel
- DY BG estimated from data
- Most systematics cancel in ratio

B-tag scale factors and Q^2 dominant systematics



$$\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj) = 3.6 \pm 1.1(stat.) \pm 0.9(sys.)\%$$

Summary

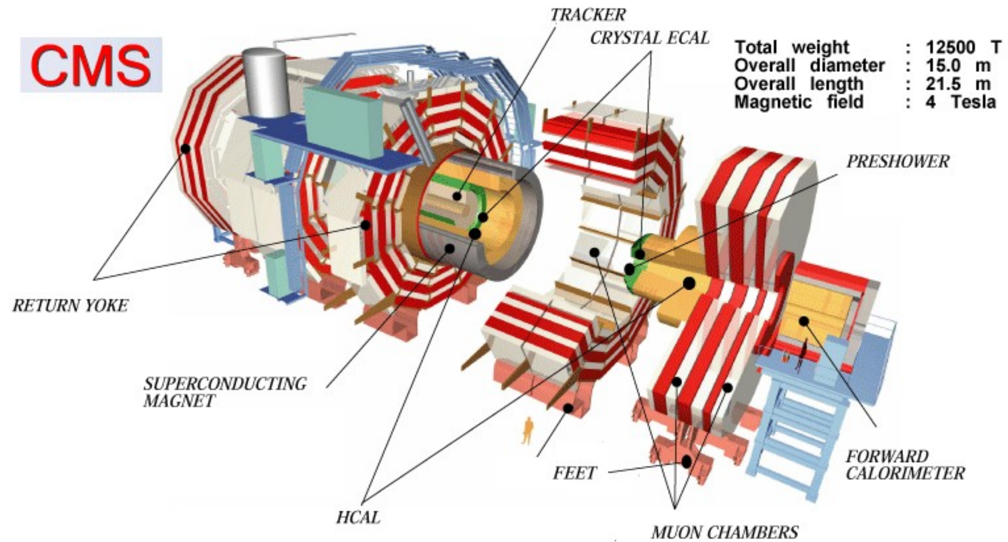
- CMS has produced many top pair differential cross section results on both 7 and 8 TeV datasets
- Precision now good enough to start discriminating between different generators and parameter choices
- Most measurements show a good agreement with SM predictions
- Aim is now to further improve precision by reducing systematics

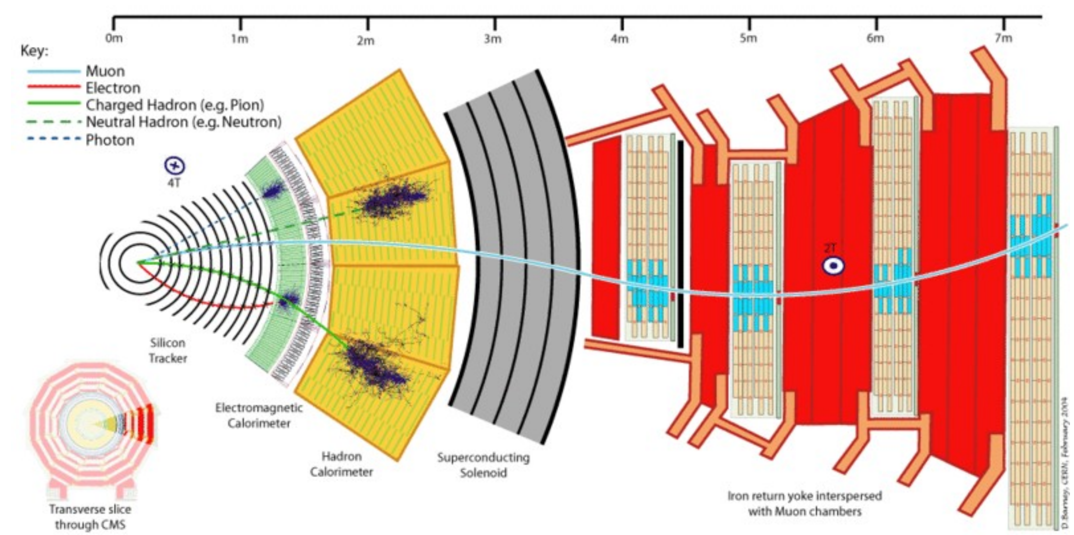
Thanks for your attention!

Backup slides

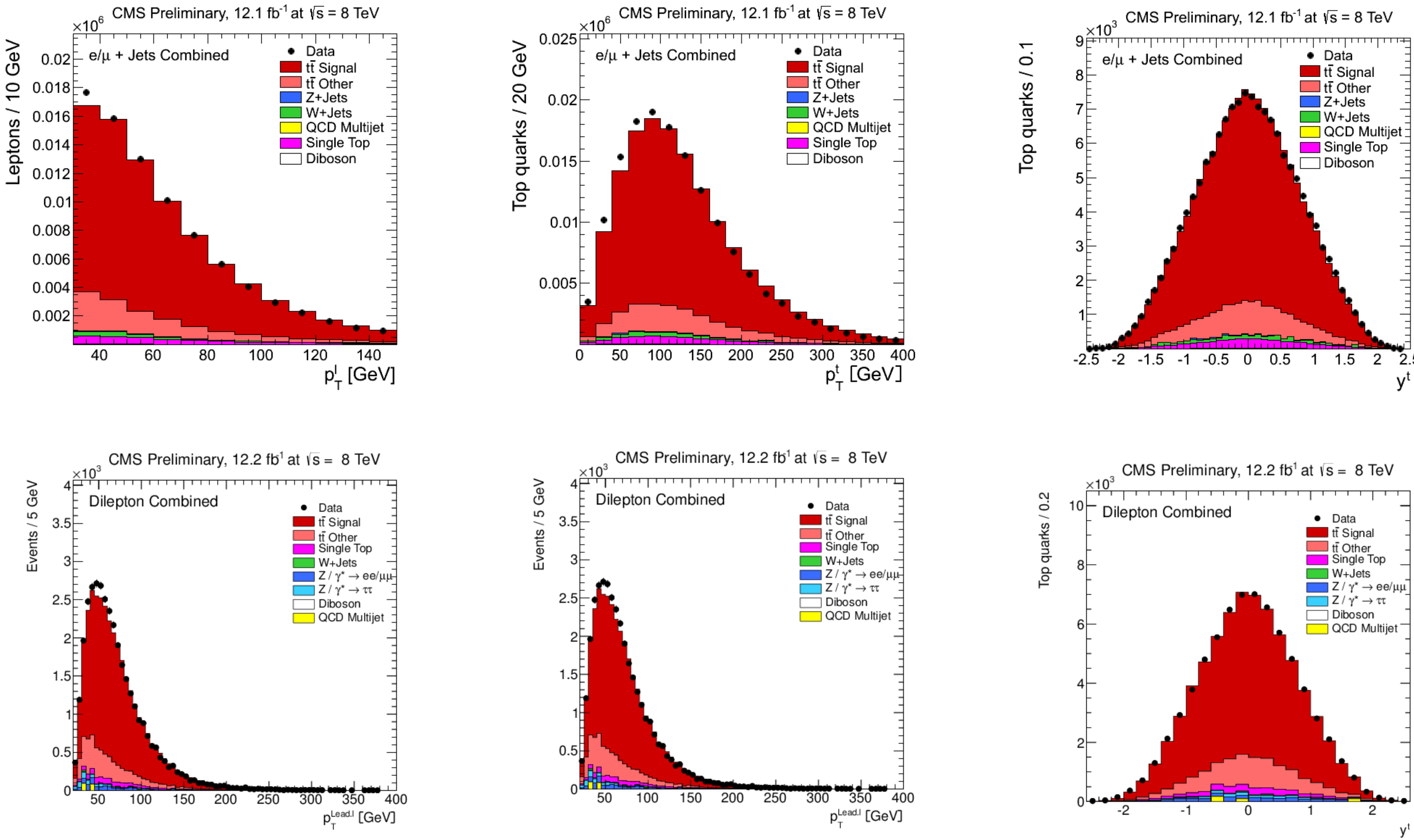
The CMS Detector and Object Reconstruction

- Embedded 3.8 T solenoid
- Trackers, ECAL and HCAL within solenoids field volume
- Muon chambers outside
- All parts of detector used to reconstruct events (particle flow)





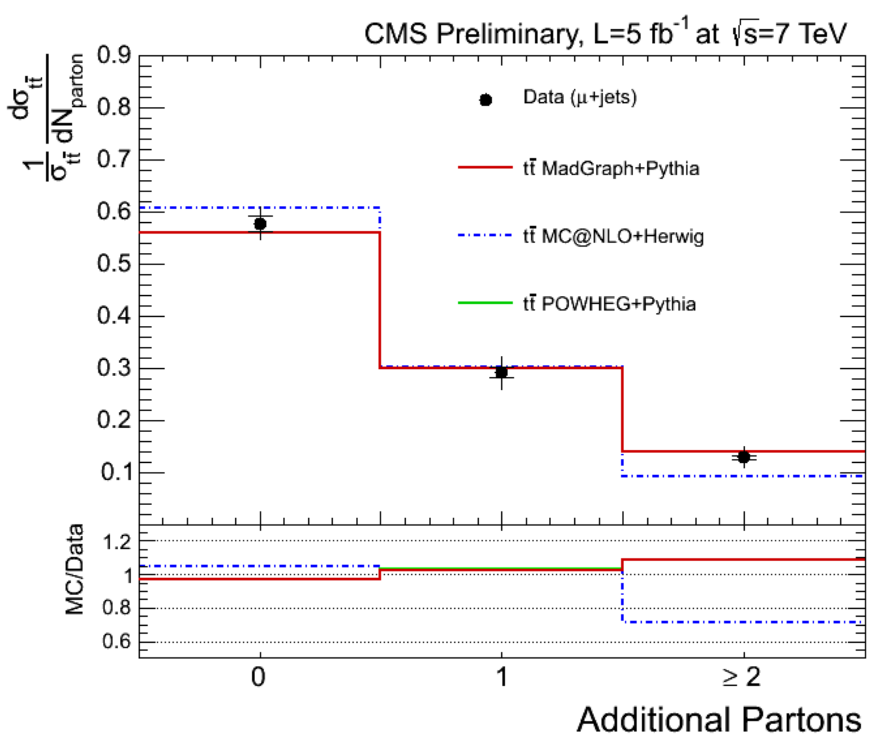
Some key variables after event selection

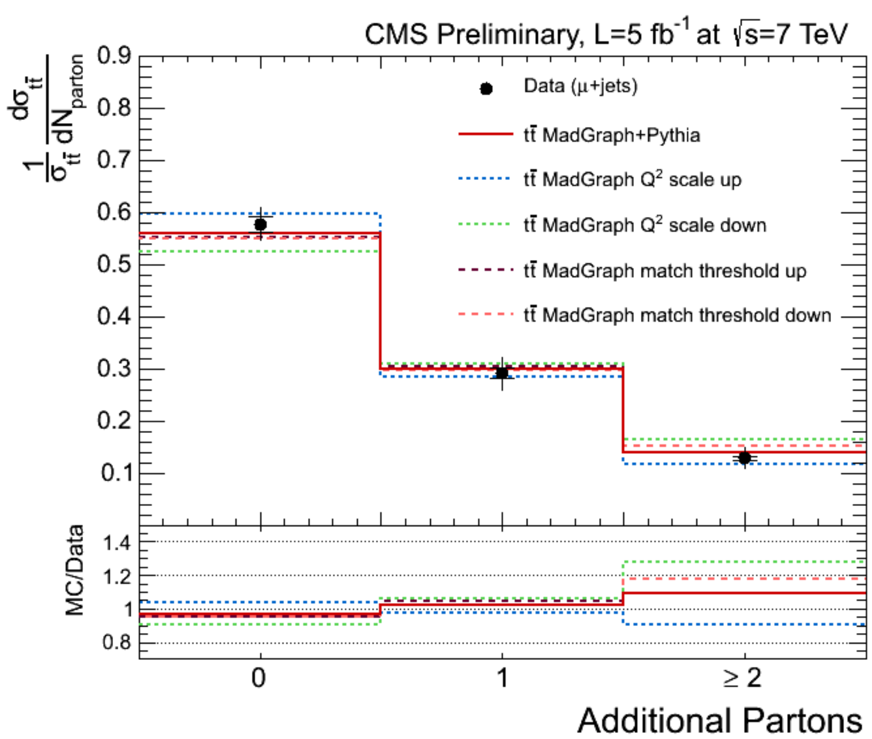


Parton multiplicity

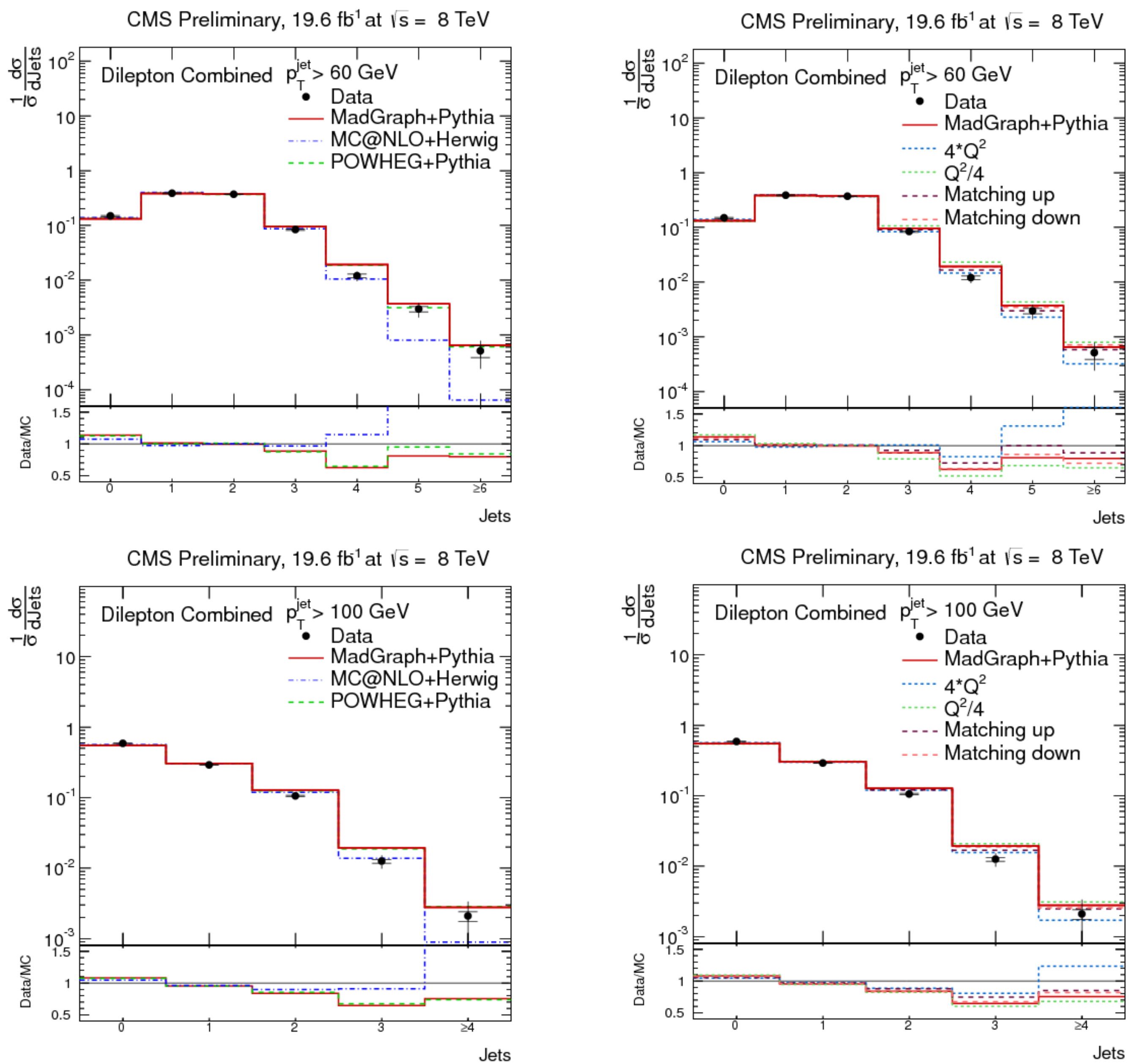
- Performed in μ+jets channel using a kinematic fit
- Extract parton multiplicities using a template fit of the χ^2

Main systematics: Jet energy scale (JES), model (Q^2 and Matching threshold)

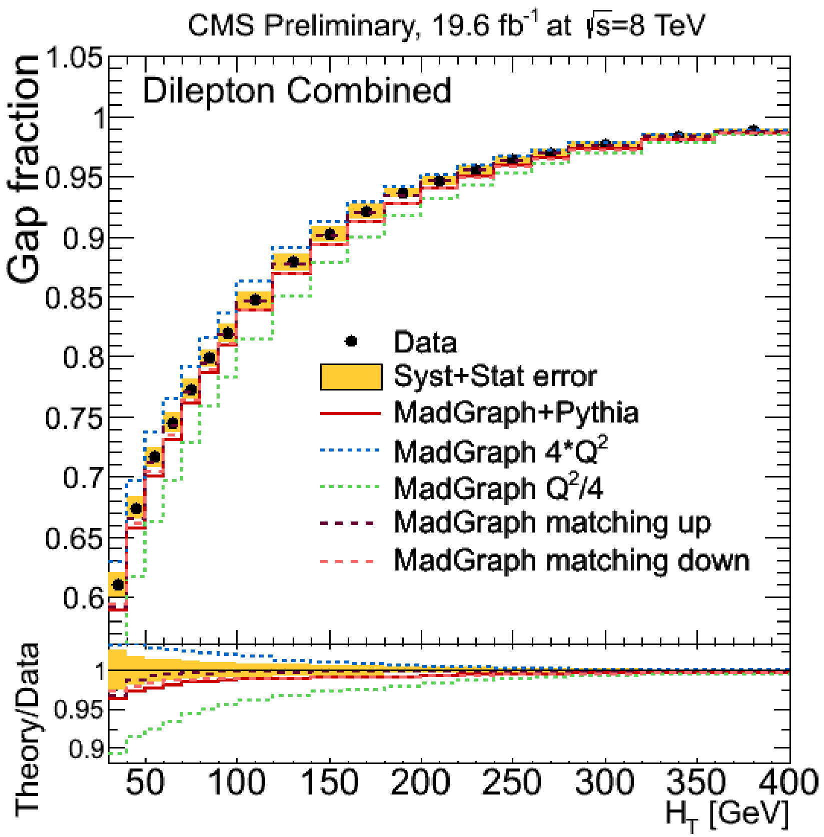


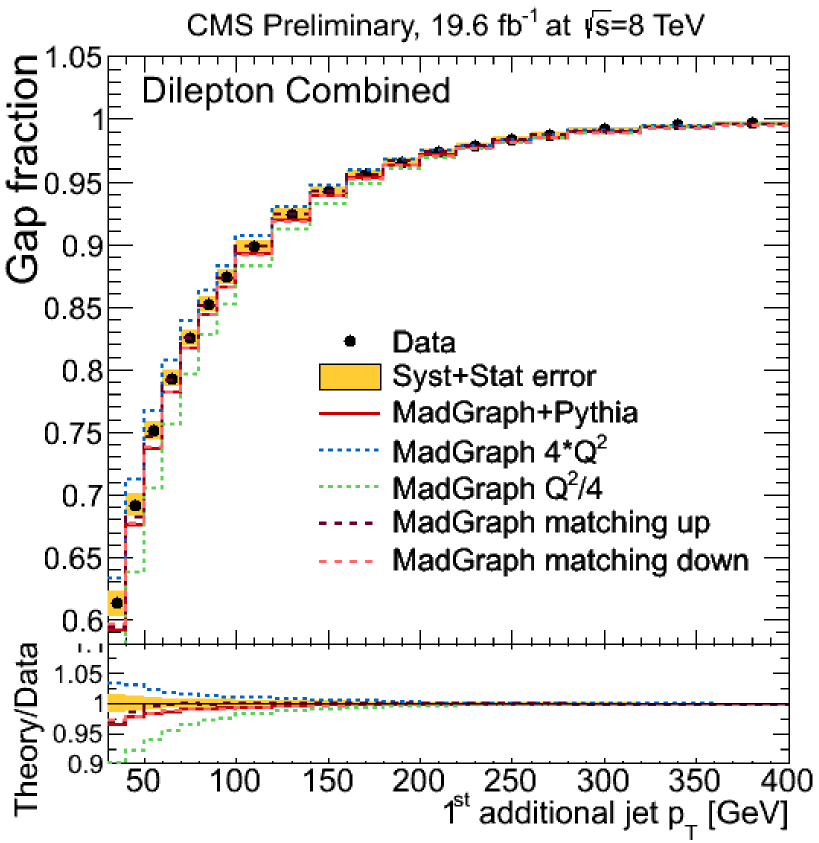


Jet multiplicity at different jet p_T cuts

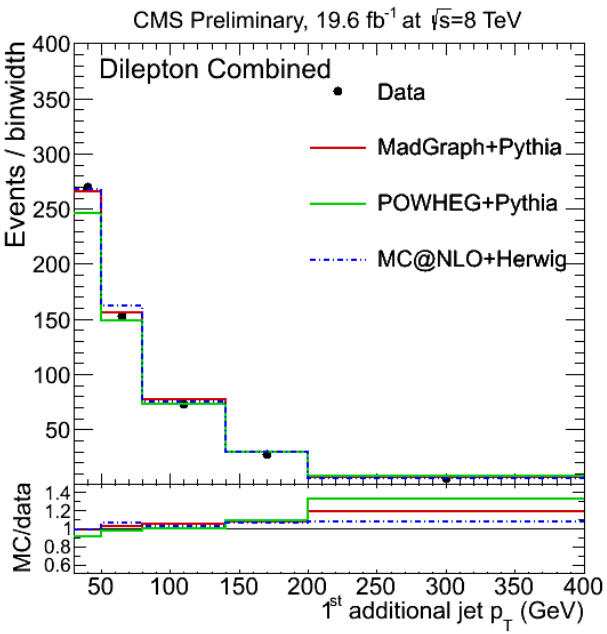


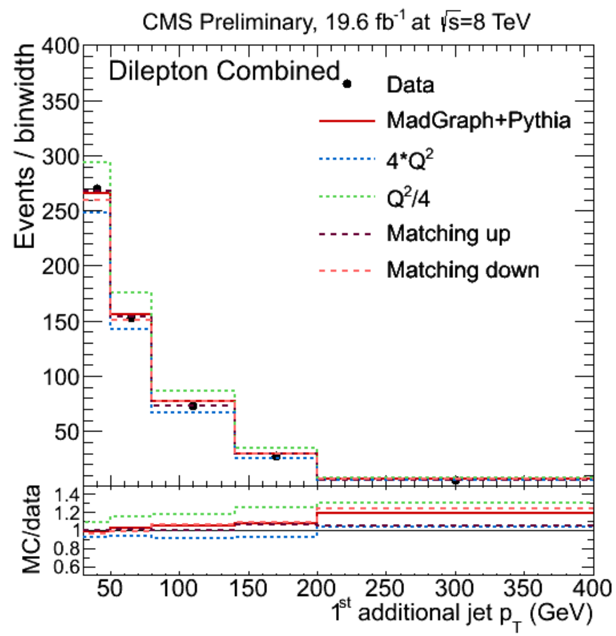
Jet veto “Gap fraction”

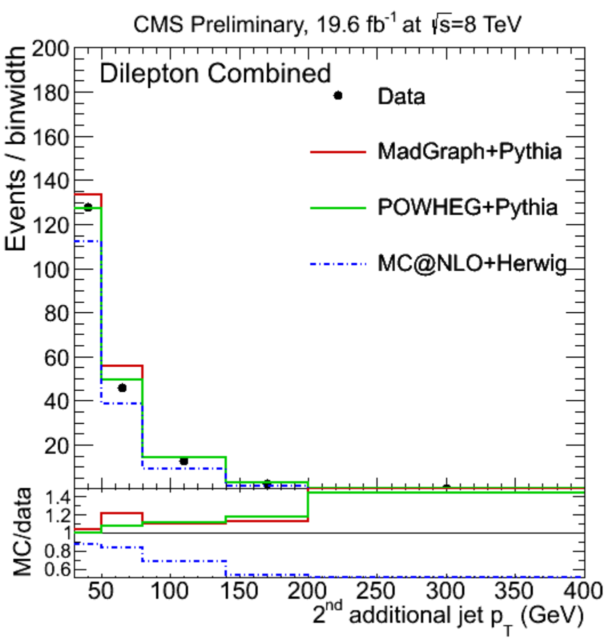


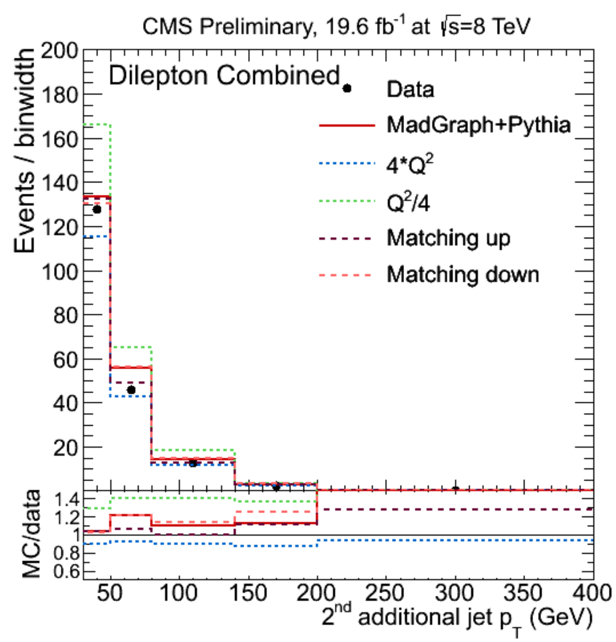


Additional jet kinematics



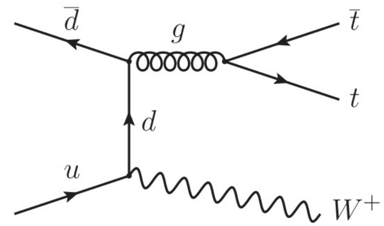


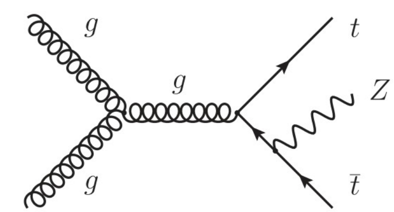




First measurement of $t\bar{t}Z/V$ couplings

7 TeV (5 fb^{-1})

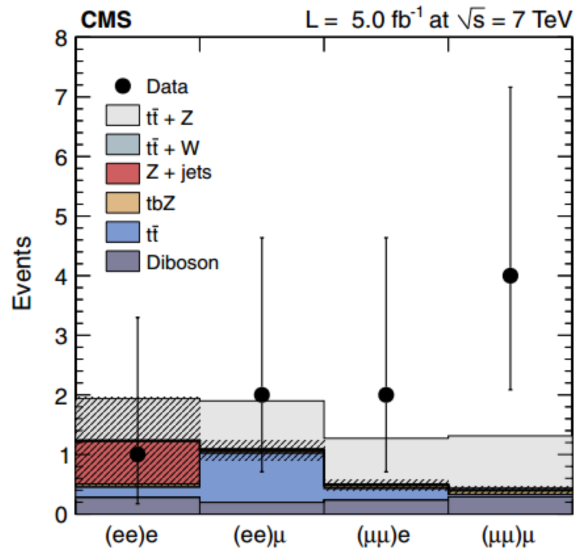


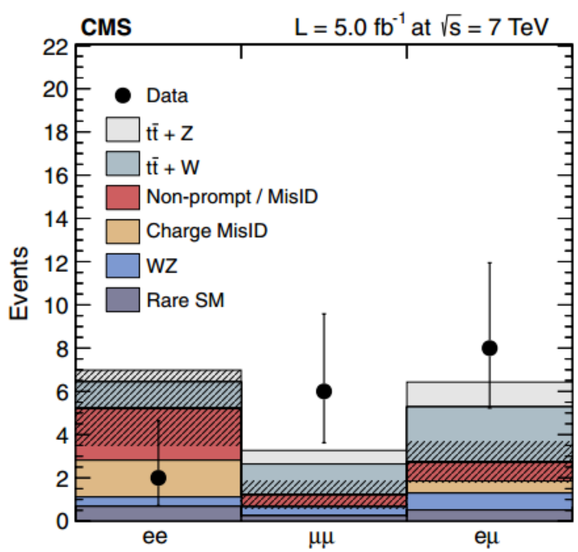


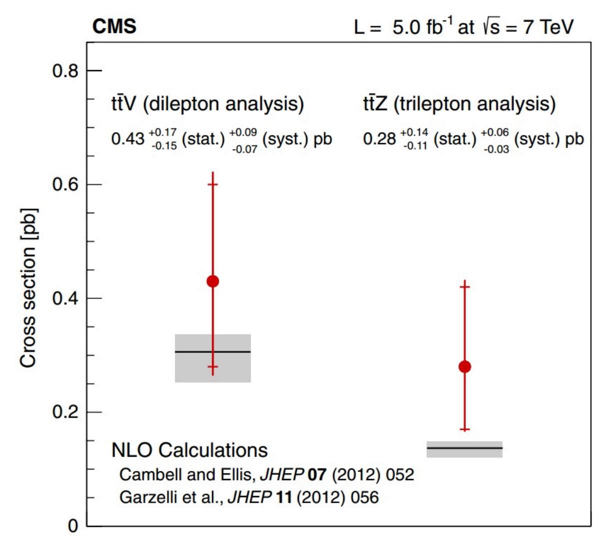
- Select tri-lepton($t\bar{t}Z$) and same sign dilepton($t\bar{t}V$) events

  Main BG: DY+non-prompt lepton (estimated from data)

- BG from Higgs negligible







arXiv:1304.5783