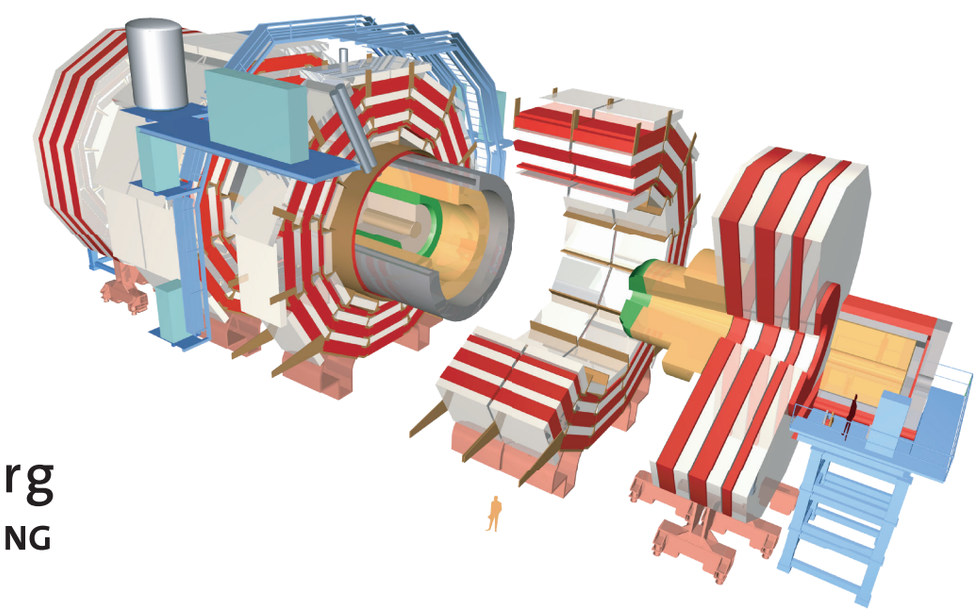
“Jets, Top, etc” in CMS

Moriond 2011 ~~summary~~ sneak preview

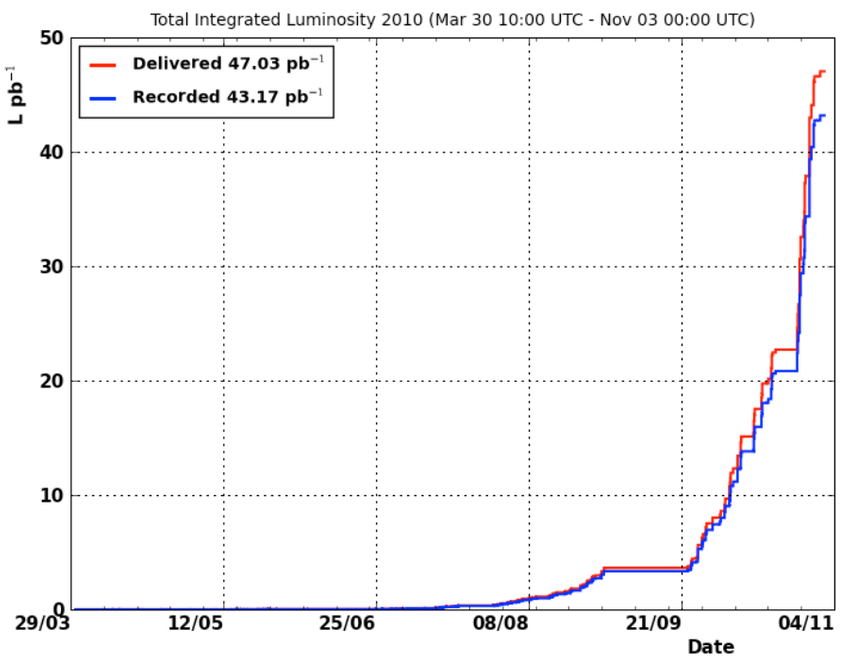
Martijn Gosselink



Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Run 2010

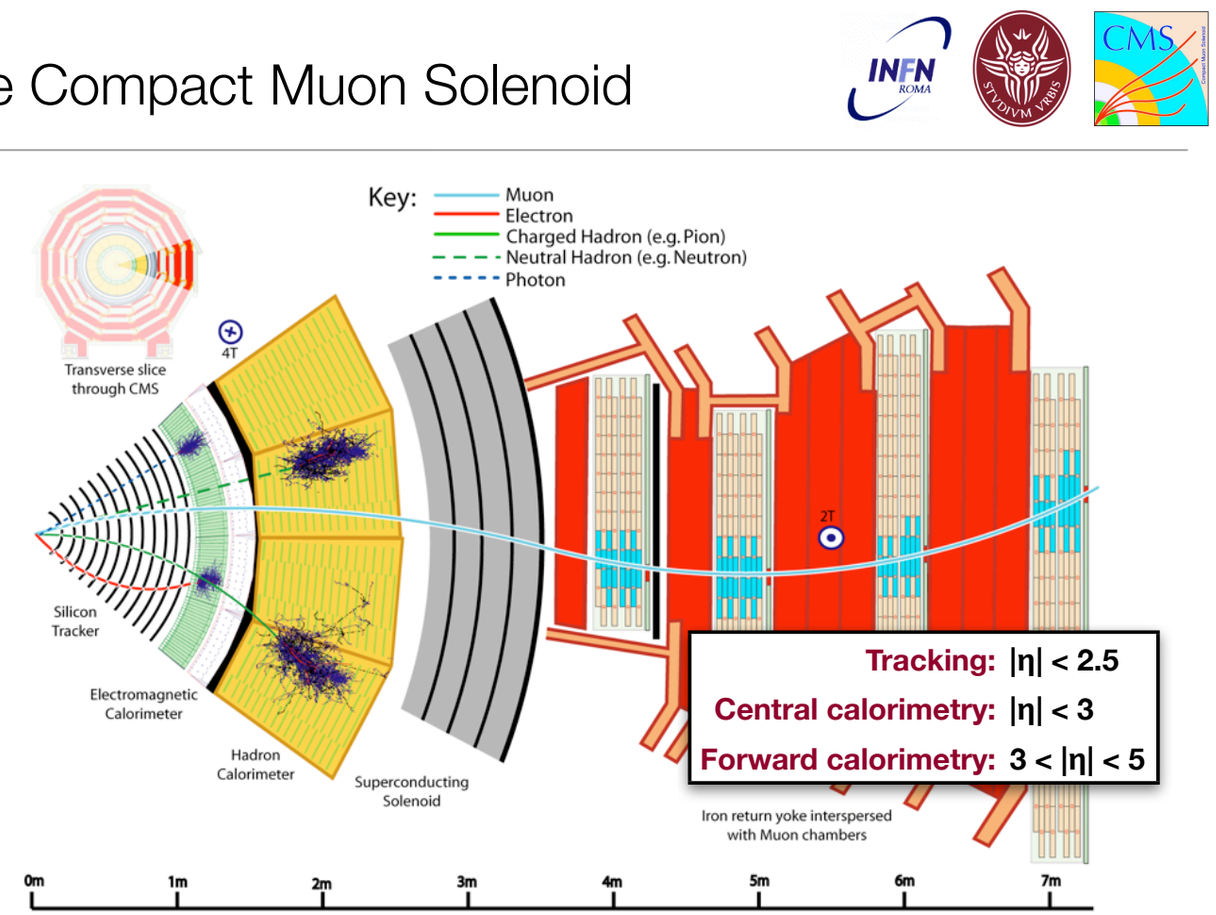
integrated luminosity



proton-proton: 7 TeV

35.9 pb^{-1}

4% uncertainty (was: 11%)



Overview

- Jets
- W/Z + jets
- Top Quark Physics

Francesco Pandolfi
Università di Roma 'Sapienza'
INFN Sezione di Roma

Vitaliano Ciulli
Università and INFN Firenze

Jasmin.Gruschke@cern.ch (KIT)

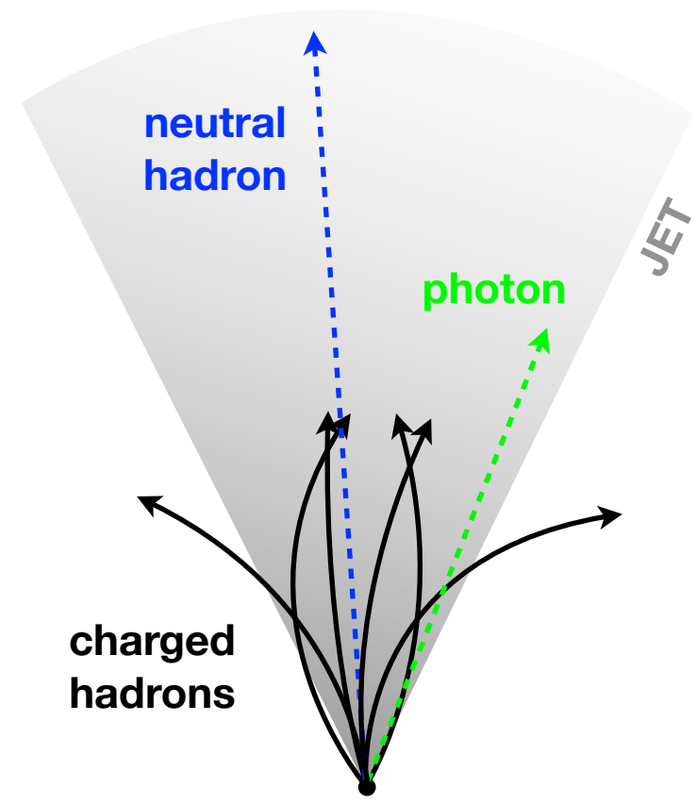
Jets

Jet Reconstruction at CMS

1. Calorimeter Jets: calorimeter towers

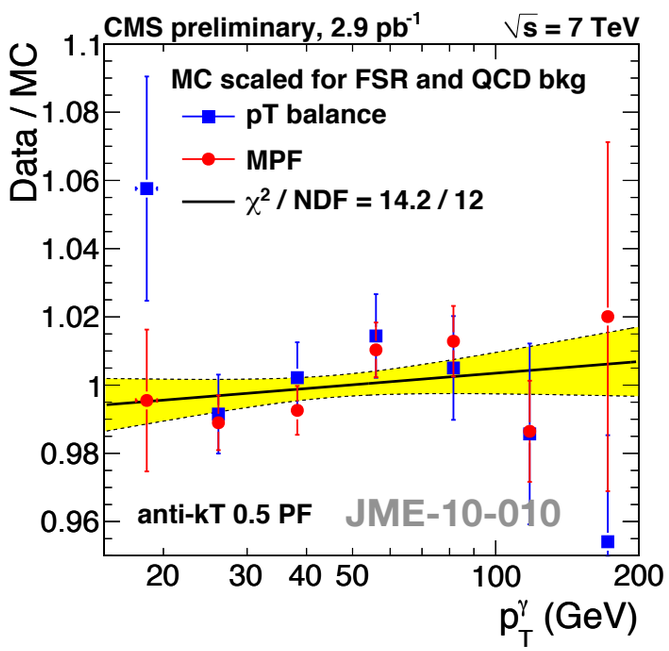
2. Jet Plus Tracks: correct for tracks

3. **Particle Flow:** particle candidates

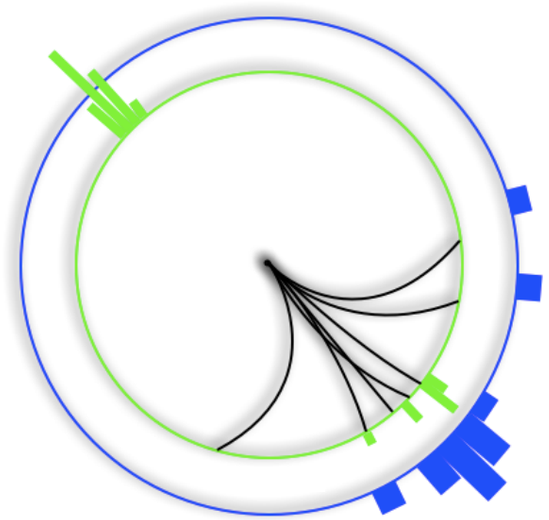


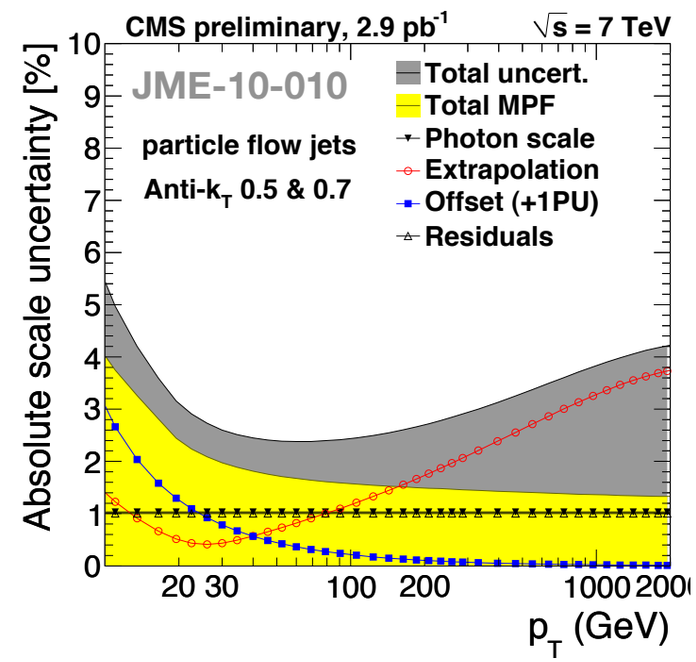
Jets

Jet Absolute Response



γ+Jet events:





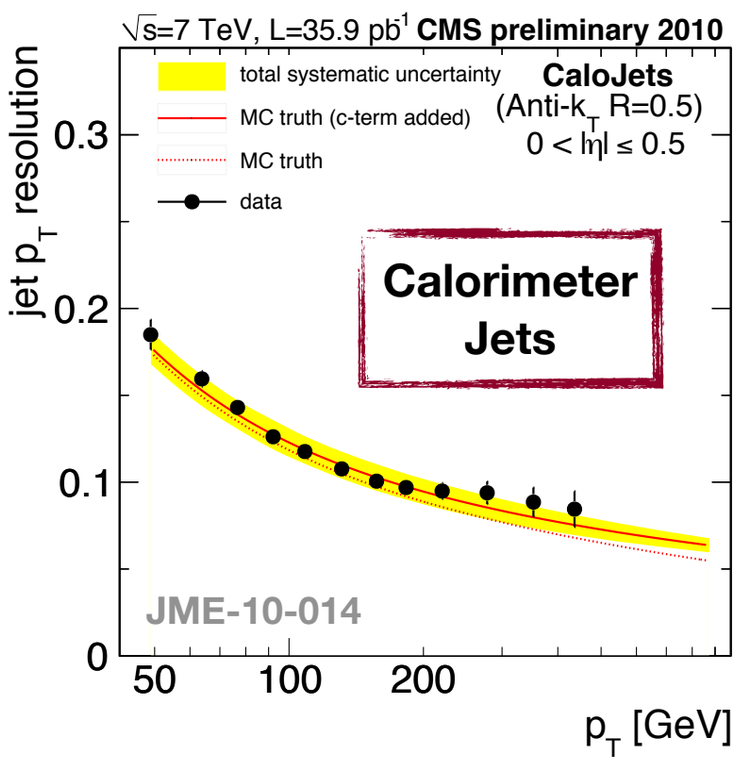
- Transverse plane balancing
  - Photon vs jet (p_T balance)
  - Photon vs missing E_T (MPF)
- Detector understood at few percent level already with 3 pb^{-1} of data
- Recent studies (36 pb^{-1}) show improvements

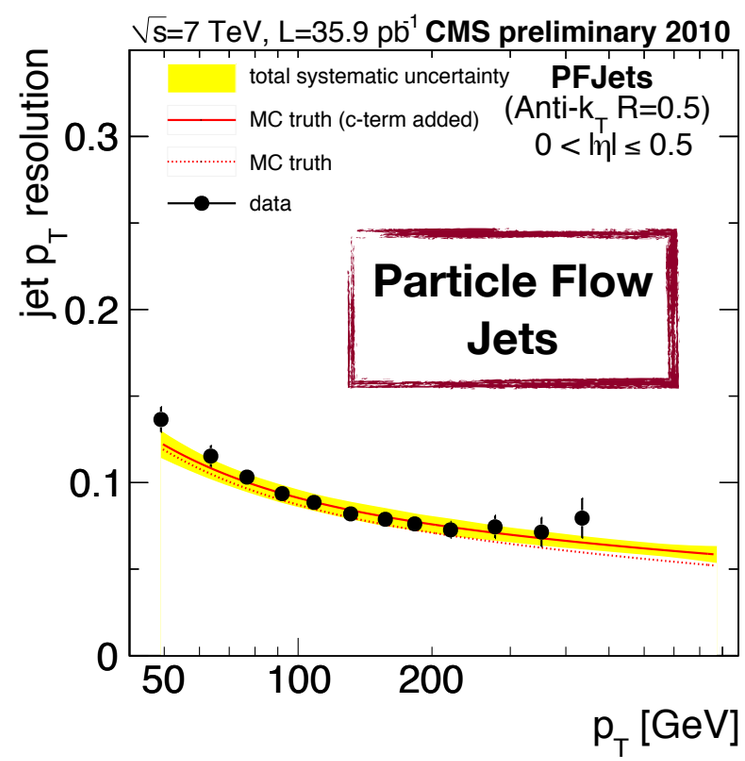
Jets

Jet Resolution Measurement

- Dijet asymmetry method:

$$\mathcal{A} = \frac{p_{\mathrm{T}}^{\mathrm{Jet1}} - p_{\mathrm{T}}^{\mathrm{Jet2}}}{p_{\mathrm{T}}^{\mathrm{Jet1}} + p_{\mathrm{T}}^{\mathrm{Jet2}}} \longrightarrow \frac{\sigma(p_{\mathrm{T}})}{p_{\mathrm{T}}} = \sqrt{2}\,\sigma_{\mathcal{A}}$$

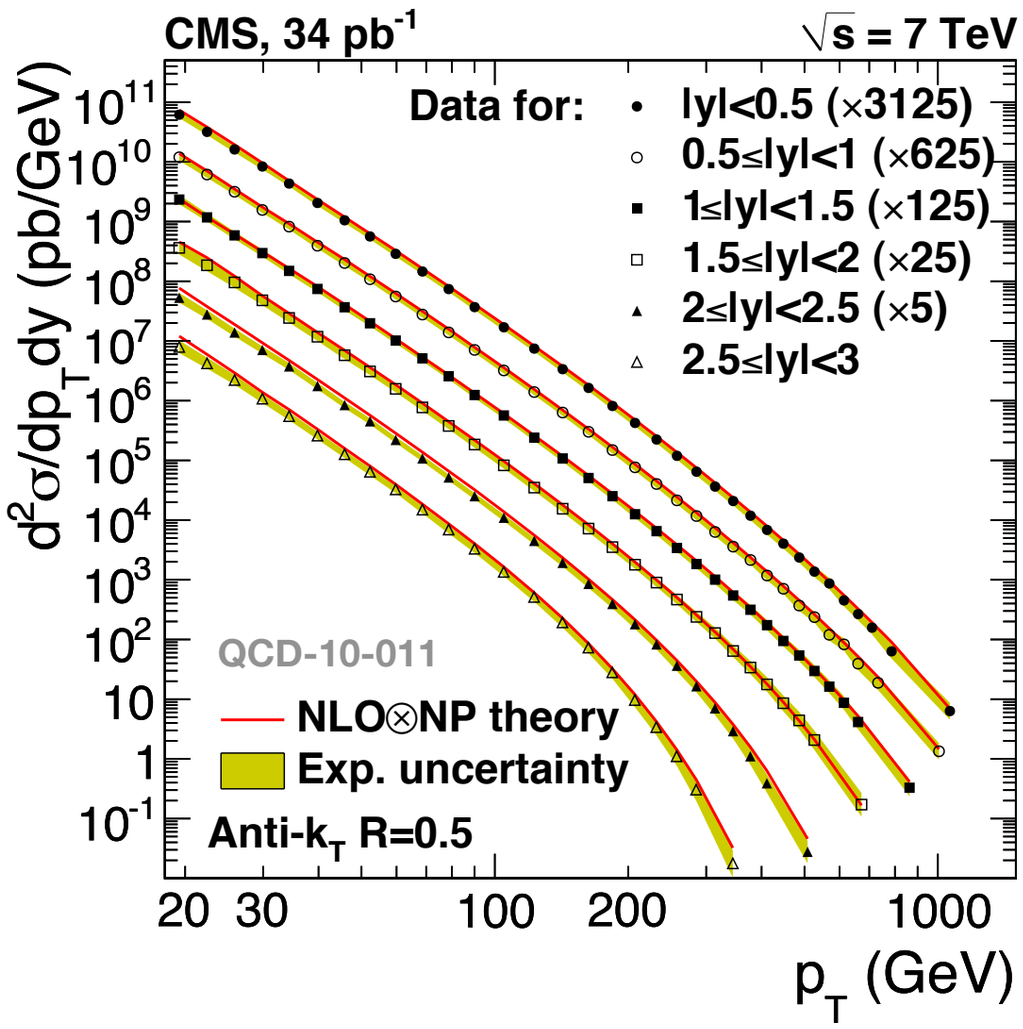




Jets

Inclusive Jet Cross Section

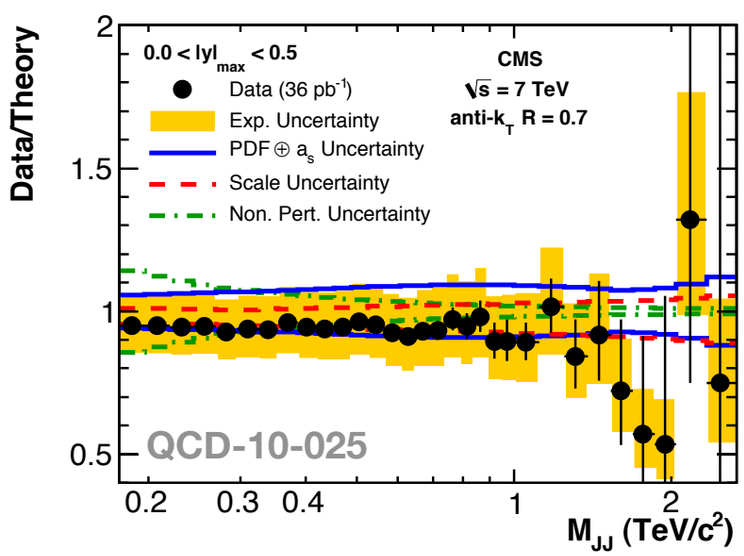
- Benchmark test of pQCD
- Extended previous results both at low and high p_T
  - From 18 GeV to over 1 TeV
- Six rapidity bins up to |y| = 3
- Data unfolded with resolution
- Good agreement with prediction over > 10 orders of magnitude

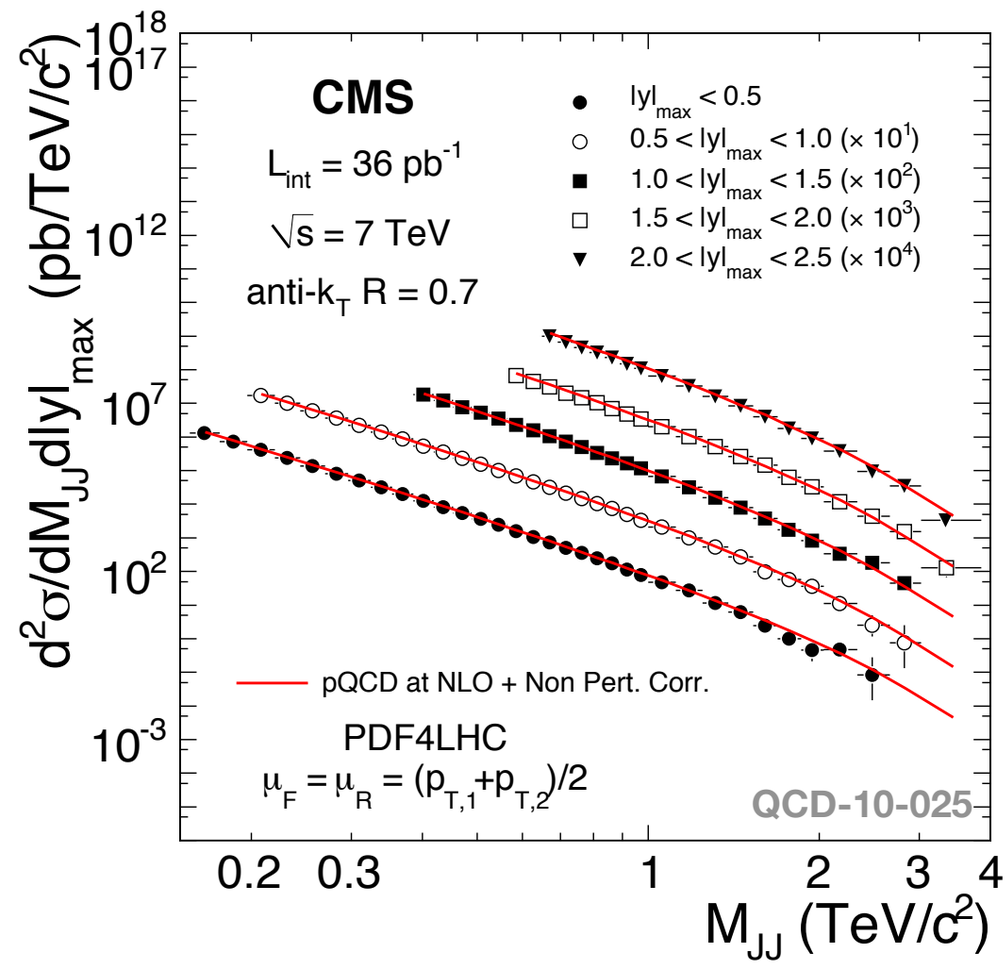


Jets

DiJet Cross Section vs Mass

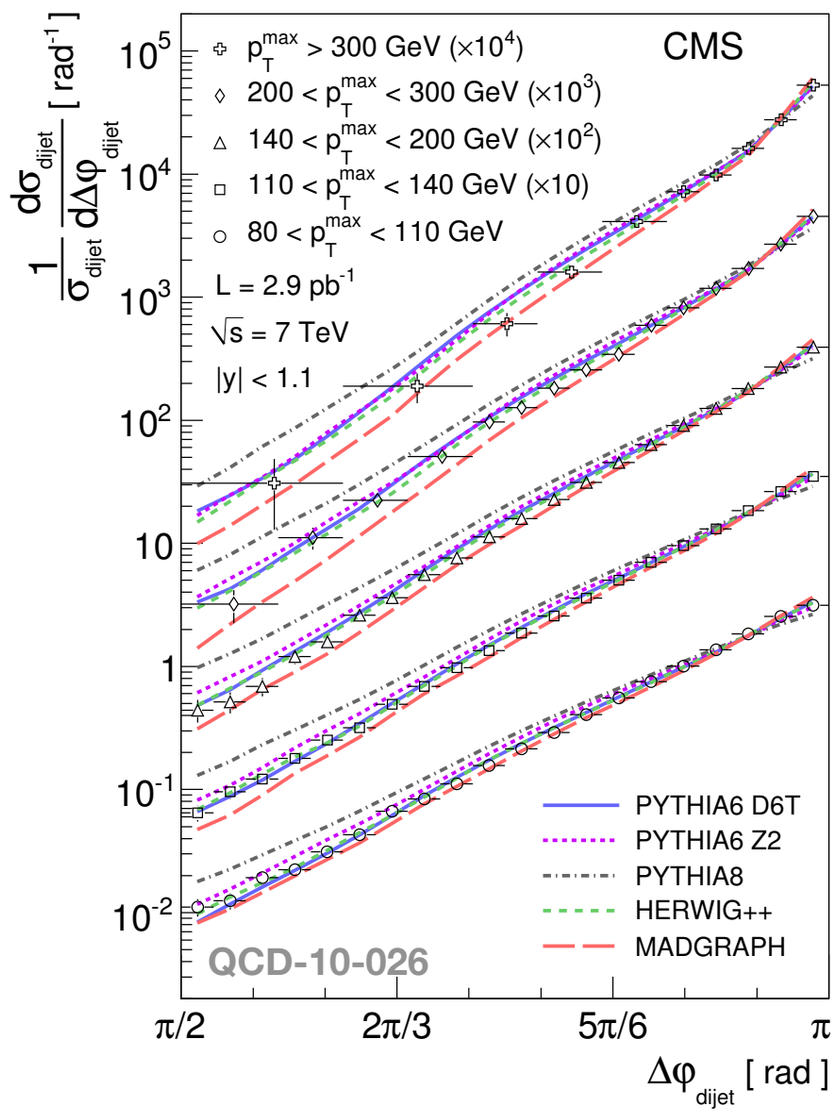
- Additional test of pQCD
- Background for 'bump hunting'
- Up to M_{JJ} = 3.5 TeV/c^2
- Data/theory compatible with inclusive jet measurement





Jets

DiJet Azimuthal Decorrelations



- Sensitive to high-order QCD radiation
  - Probes high jet multiplicities without measuring all jets
- Important test of MC description of multiple parton radiation
  - Fundamental in precision measurements and search for new physics
- Best description of the data: Pythia6 and Herwig++

Jets

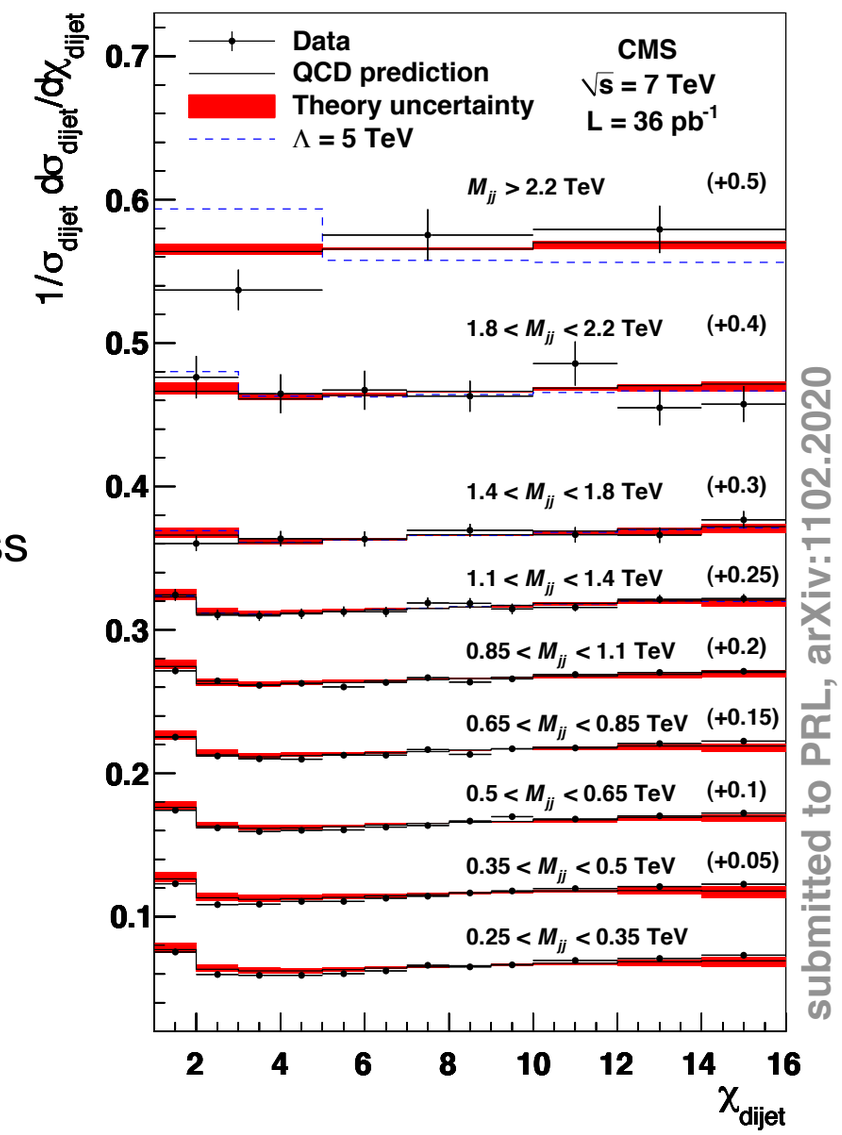
From pQCD Tests to Searches

See A. Harel's talk on monday

- Dijet angular analysis: exponential difference of jet rapidity gap:

$$\chi_{\mathrm{dijet}} = \exp(|y_1 - y_2|)$$

- Low dijet mass: stringent test of pQCD
- High mass: search for quark compositeness
  - Contact interactions (CI) enhance central dijet production ($\chi_{\mathrm{dijet}} \sim 1$)
- Data well described by QCD prediction
  - Excluding CI with $\Lambda < 5.6$ TeV



W/Z + jets

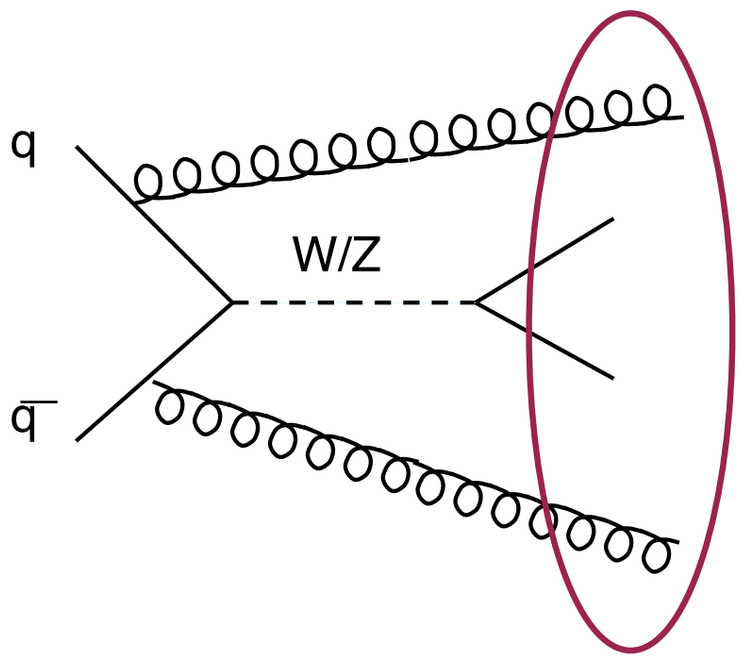


Diagram: ordinary QCD+EWK

But very challenging for NLO calculations very challenging if there are many jets

Recently done with up to 4(3) jets for W(Z)

Until now ME+PS Monte Carlo are the main tool for simulation therefore important to cross-check with data

Furthermore final state contains

- Jets
- Leptons
- Missing Et

=> major background to new physics

W/Z + jets

$W \rightarrow \mu\nu$ and $Z \rightarrow \mu\mu$ selection

Select events using single muon triggers with a P_T threshold in the range from 9 to 15 GeV

Requires one muon with:

- pT > 20 GeV, $|\eta|$ <2.1 and matched to the trigger
- Relative isolation $(\Sigma p_T\,(tk) + \Sigma E_T\,(had+em))/p_T < 15\%$
- Muon quality criteria to reject punch-through and decays in flight

If second muon is found with

- pT > 10 GeV, $|\eta|$ <2.4
- $60 < M_{\mu\mu}$ (GeV) < 120

=> event goes in the Z sample

Otherwise if

- $M_T > 20$ GeV

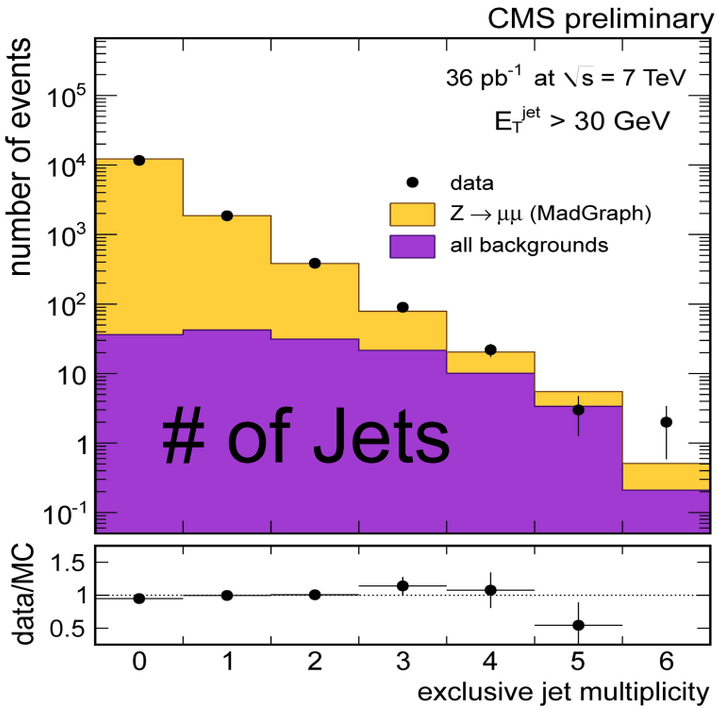
=> event goes in the W sample

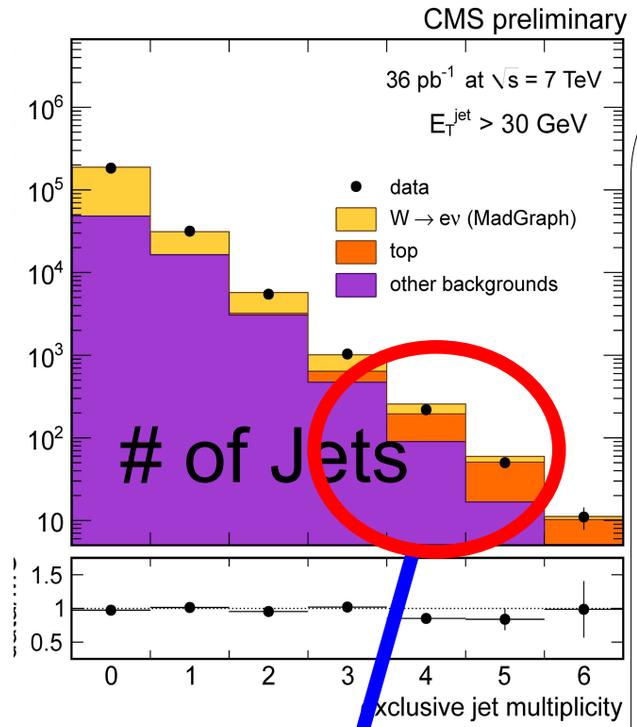
Results will be given inside acceptance

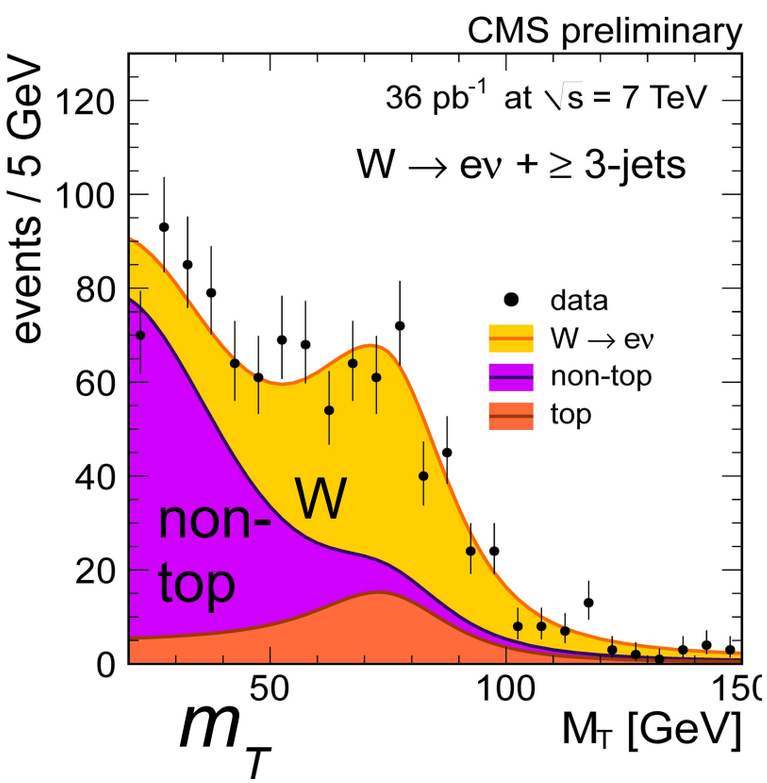
Looser cuts on the second leptons increase statistics and reduce efficiency dependence on the number of jets

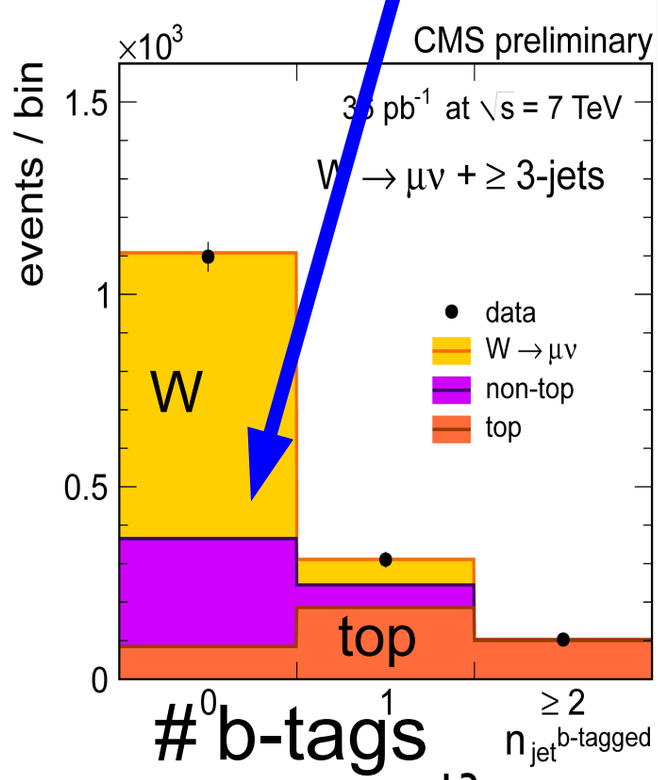
W and Z + Jets

- Additional selection variable: Jet with p_T > 30 GeV









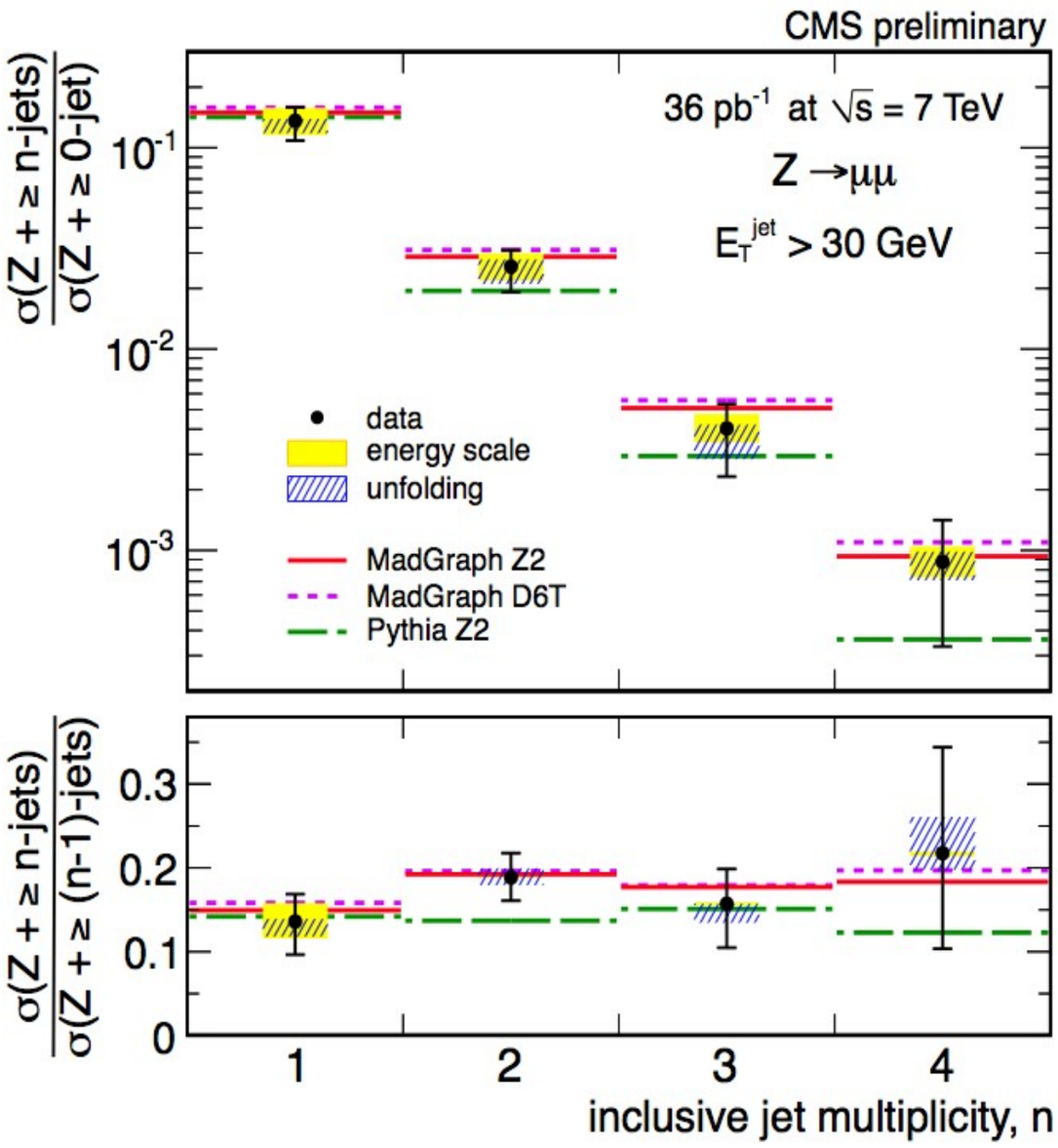
For W in a Jet bin:

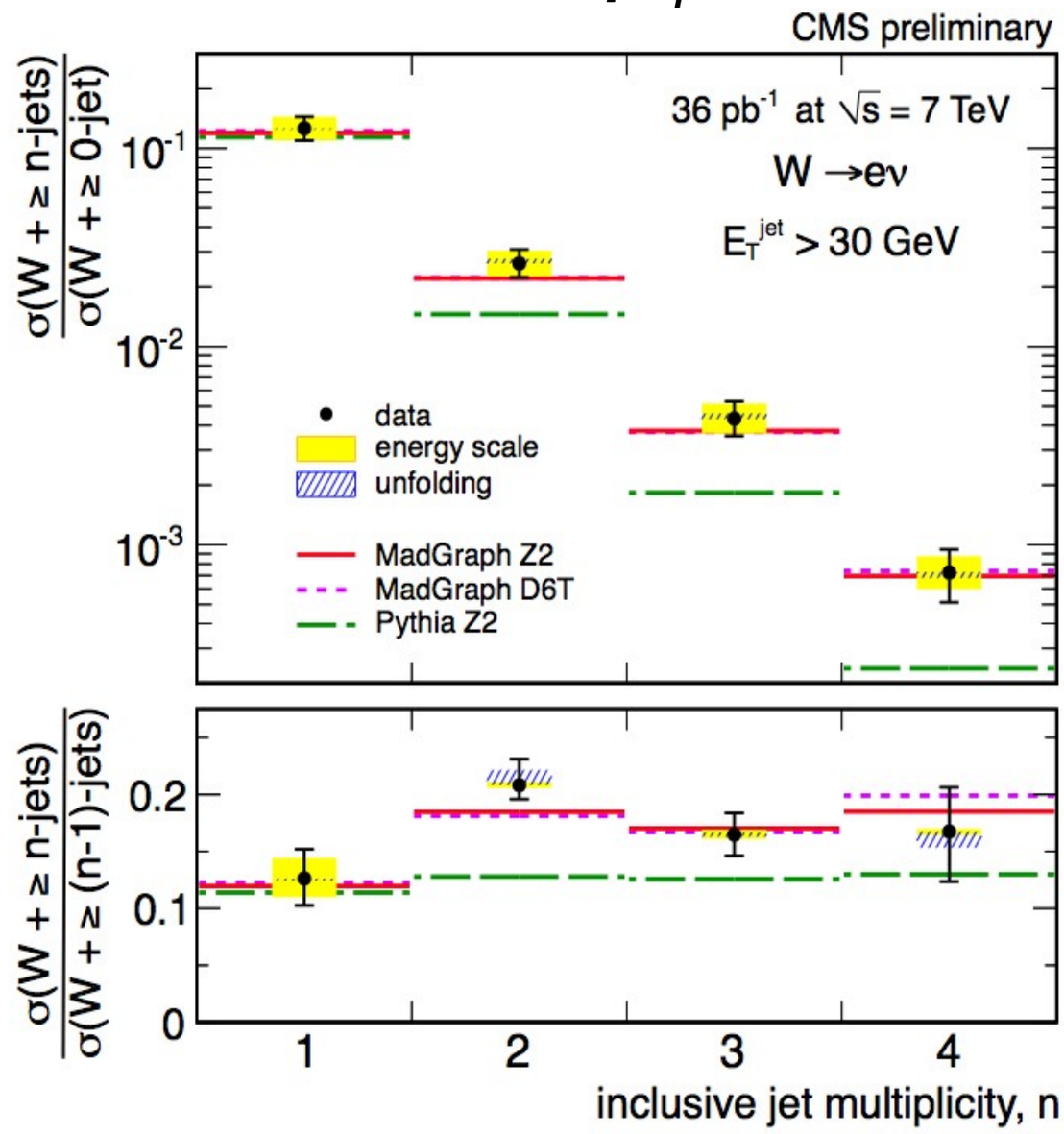
- tt large background
- B-jet tag as discriminant
- **2D fit M_T^W vs. $N_{B\text{-jets}}$**
- Parametric models in M_T^W
  - Fitted in control regions
- B-tag eff/purity from data

- Z+jets: similar to Z differential
- Jet multiplicity unfolded

W and Z + Jets Cont'd

- Additional selection variable: Jet with p_T > 30 GeV

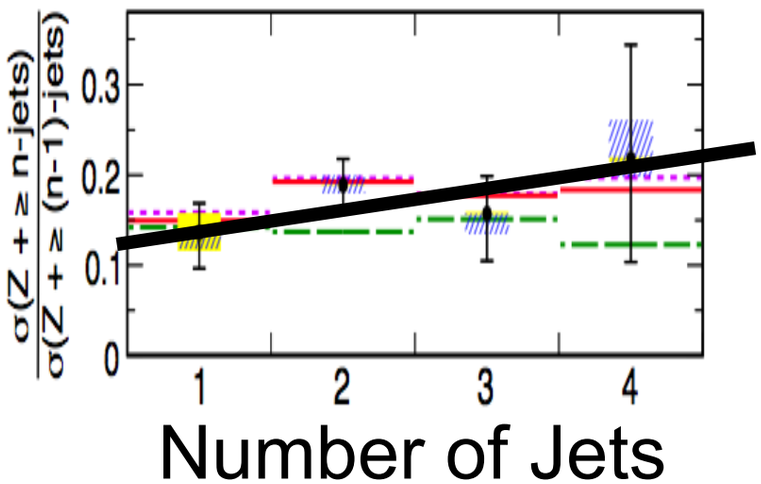




Boson + Jets follow matrix element MC scaling

Plots are normalized to the 0 jet bin

W/Z+Jets Scaling (Berends-Giele)

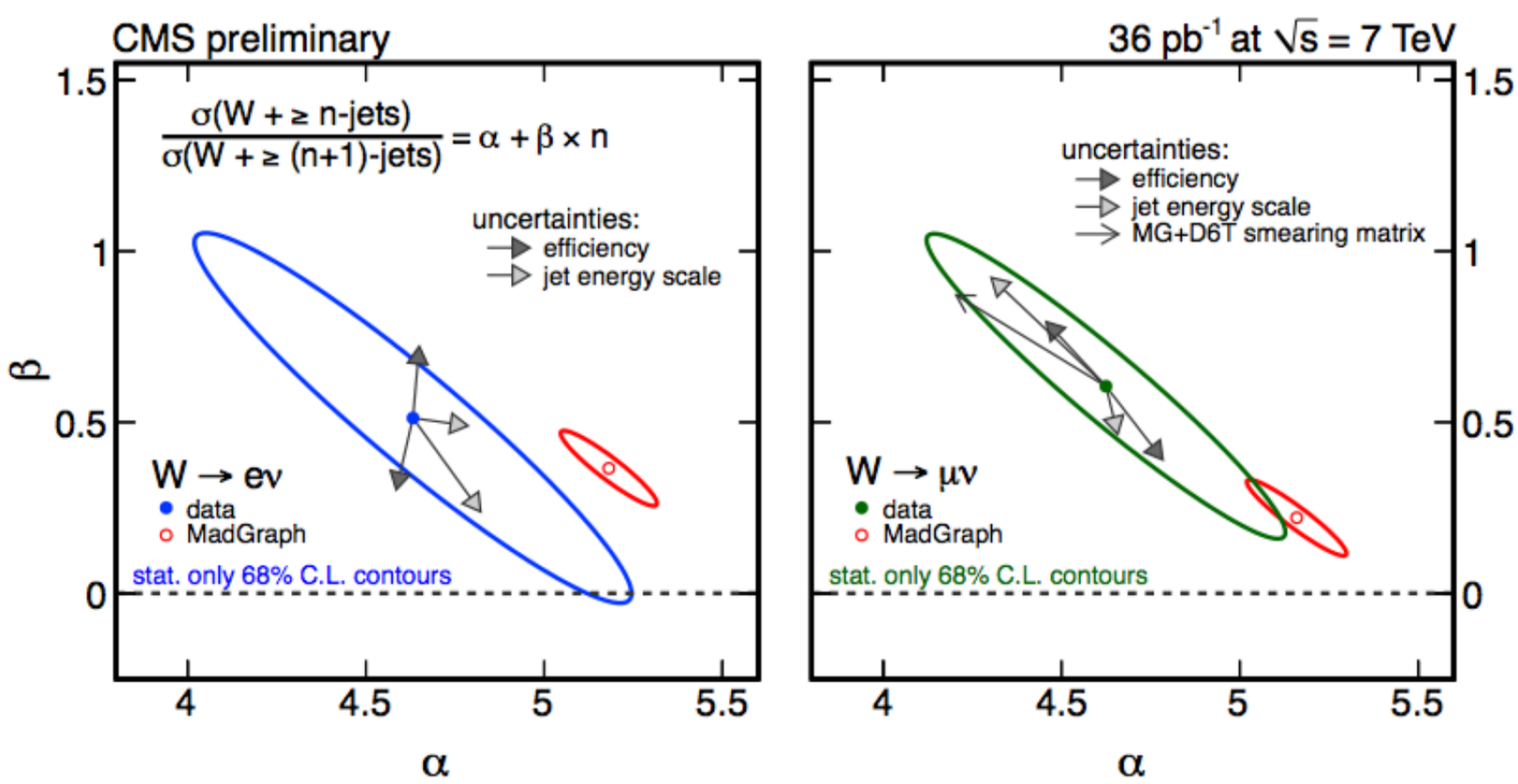


$$\frac{\sigma_n}{\sigma_{n+1}} = \alpha + \beta n$$

LO: strong coupling

>LO + phase space

- Fit to number of jets (simultaneous extraction)
  - Sensitive to expected QCD scaling ($\alpha = \alpha_{strong}$)



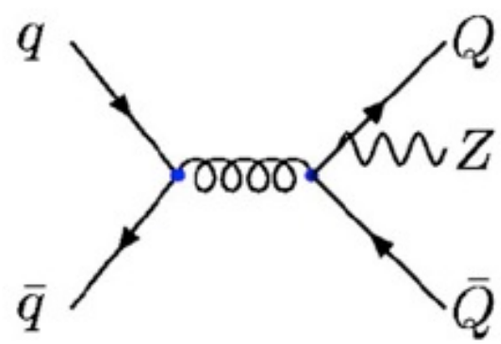
Lower than MC predicted

Still consistent

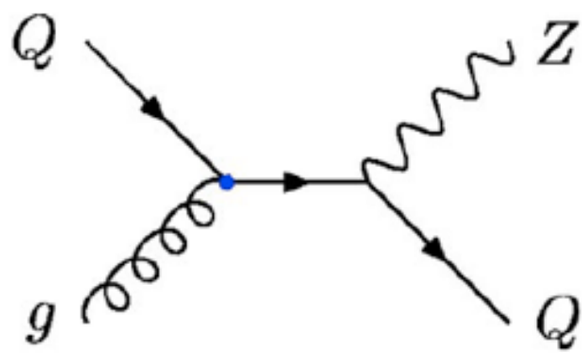
Z + b observation

Z+b is a benchmark channel for MSSM Higgs searches

Large theoretical uncertainty at NLO reflects in the 30% difference between fixed- and variable-flavor schema calculation, e.g.



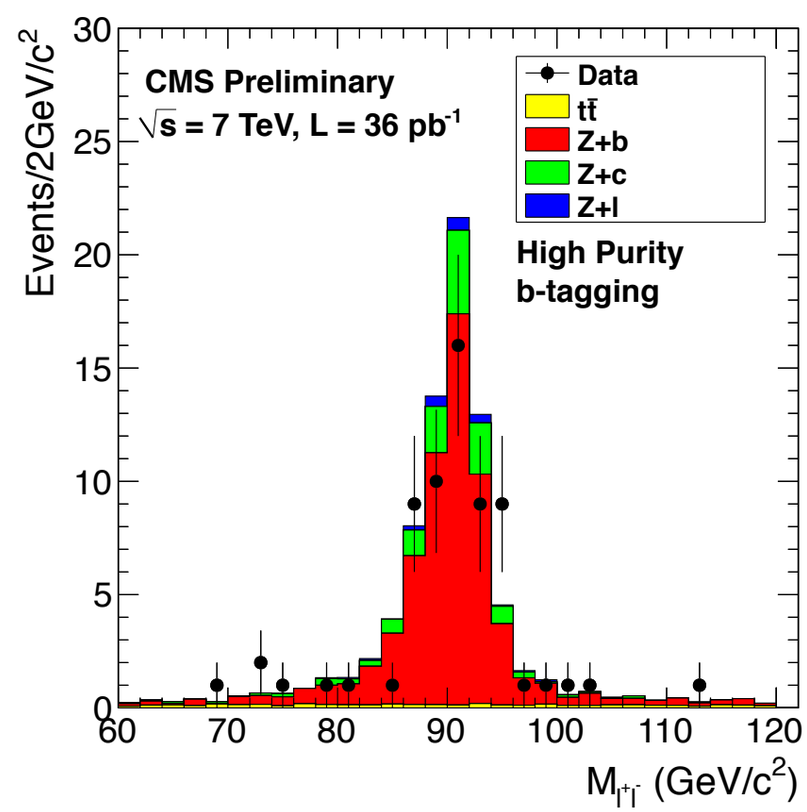
vs



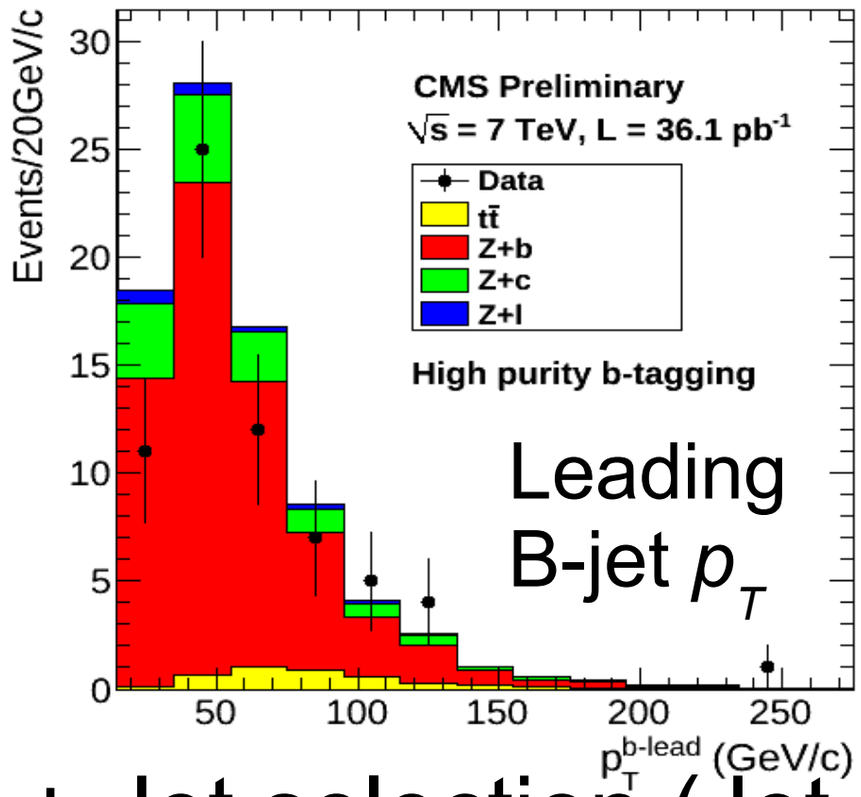
Events with a Z and at least one jet are selected if the jet has a secondary vertex

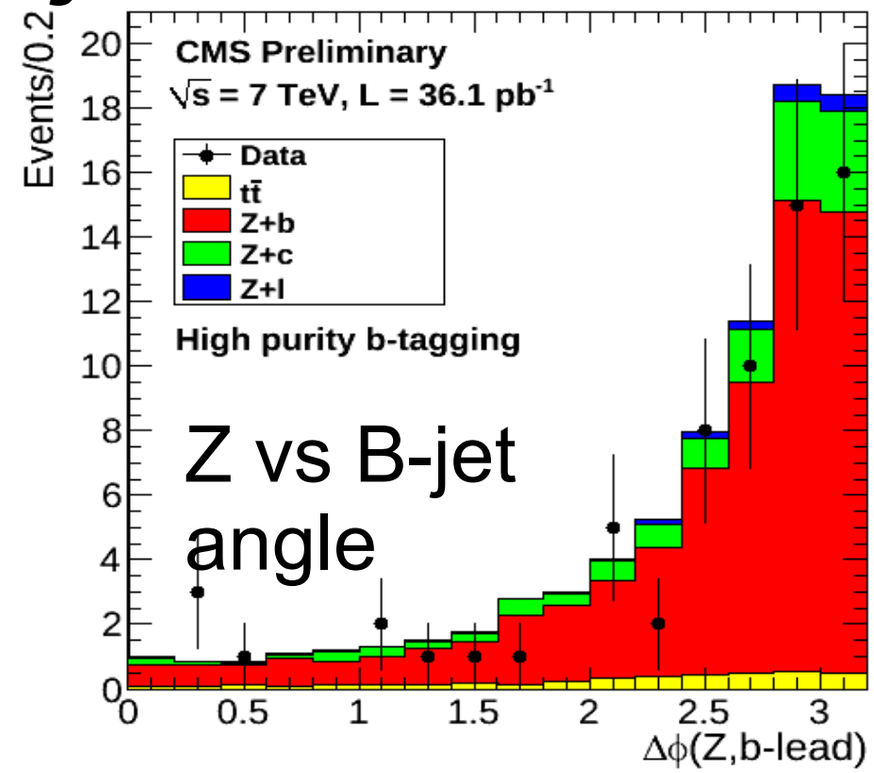
Two different vertex based b-tag have been used: high purity and high efficiency

A cut $ME_T < 40$ GeV is applied to reject top events



Z + b jets





- Z + Jet selection (Jet p_T > 25 GeV)
  - Cut on *MET* < 40 GeV to eliminate top background
  - Purity/Efficiency from fit to data(2nd vertex mass)

Ratio Z + b / Z + jet

	Electrons	Muons
Data	0.054±0.015	0.046±0.014
MC	0.043±0.005	0.047±0.005

Within kinematic range

Top Quark Physics

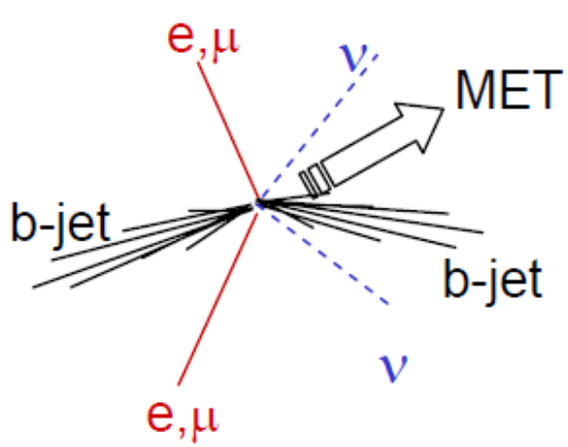
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

- $t\bar{t}$ Cross Section Measurement in the Lepton+Jets Channels w/o b-Tagging (TOP-10-002)
- $t\bar{t}$ Cross Section Measurement in the Lepton+Jets Channels with b-Tagging (TOP-10-003)
- $t\bar{t}$ Cross Section Measurement in the Dilepton Channels (TOP-10-005)
- Combination of $t\bar{t}$ Cross Section Measurements and Comparison with Theory Predictions (TOP-11-001)
- Single Top Quark Cross Section Measurement (TOP-10-008)
- Top Quark Mass Measurement in the Dilepton Channels (TOP-10-006)
- Charge Asymmetry Measurement (TOP-10-010)
- The $m(t\bar{t})$ Spectrum and Searches for New Physics (TOP-10-007)

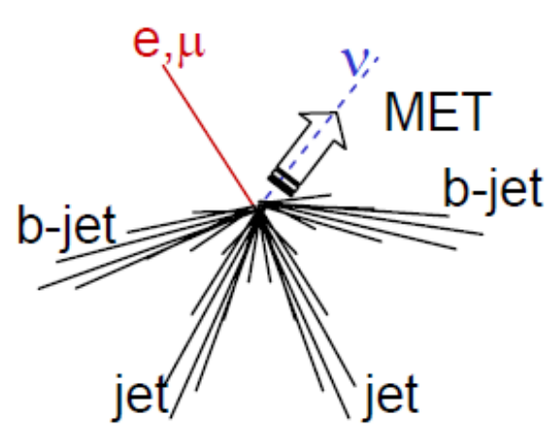
All presented results are obtained from the full 2010 pp dataset: $L = (36 \pm 1)\,\mathrm{pb}^{-1}$

tt^{bar} overview: selection criteria

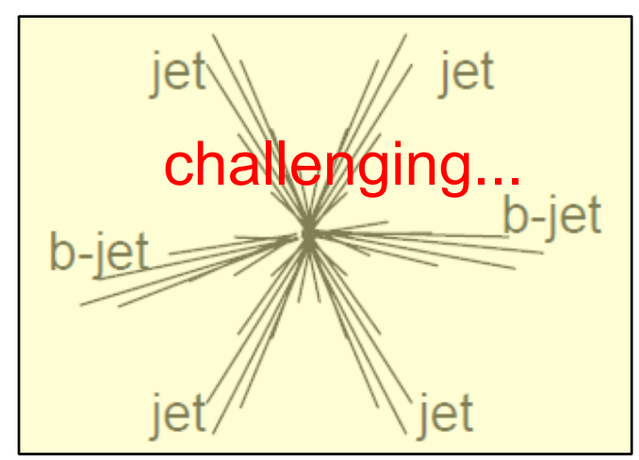
- Dileptons
  - 2m || 2e || em, isolated
  - At least 2 central jets
  - Z veto in 2m and 2e
  - High MET
  - B-tagging for supporting results
- Lepton+jets
  - 1m || 1e, isolated
  - At least 4 central jets
  - High MET
  - Alternative analyses w/ and w/o b-tagging



dileptons
(BR~5%)



lepton + jets
(BR~30%)

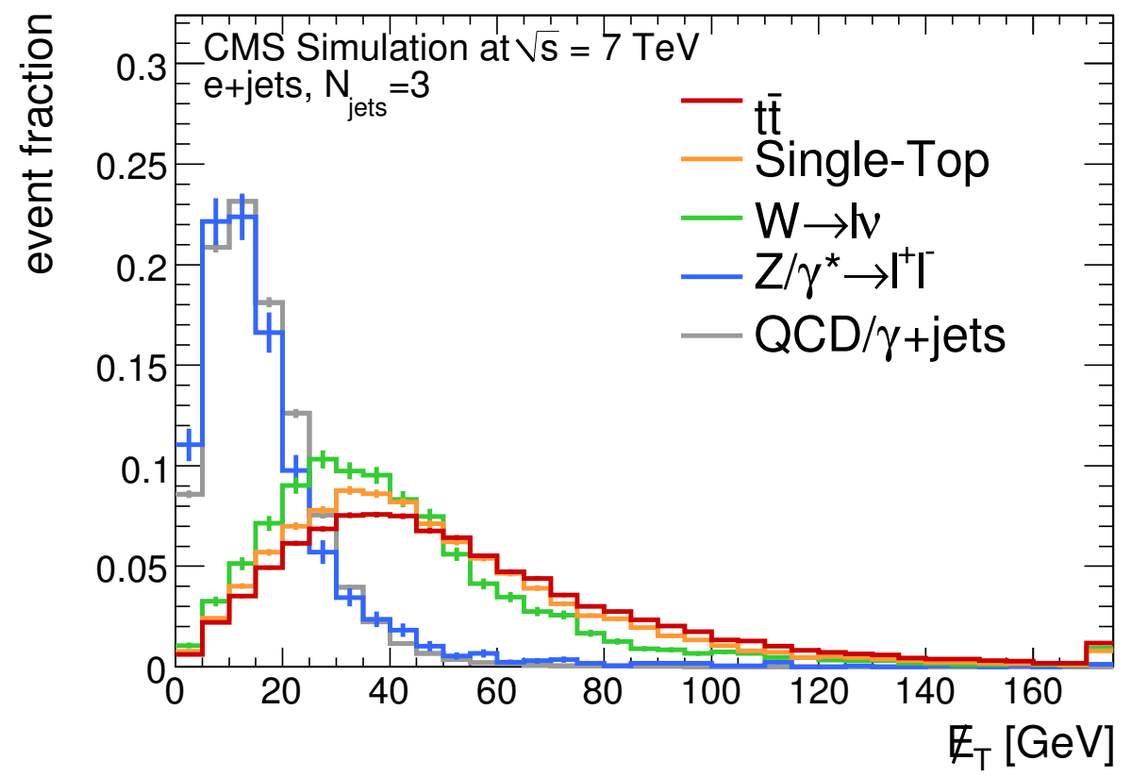


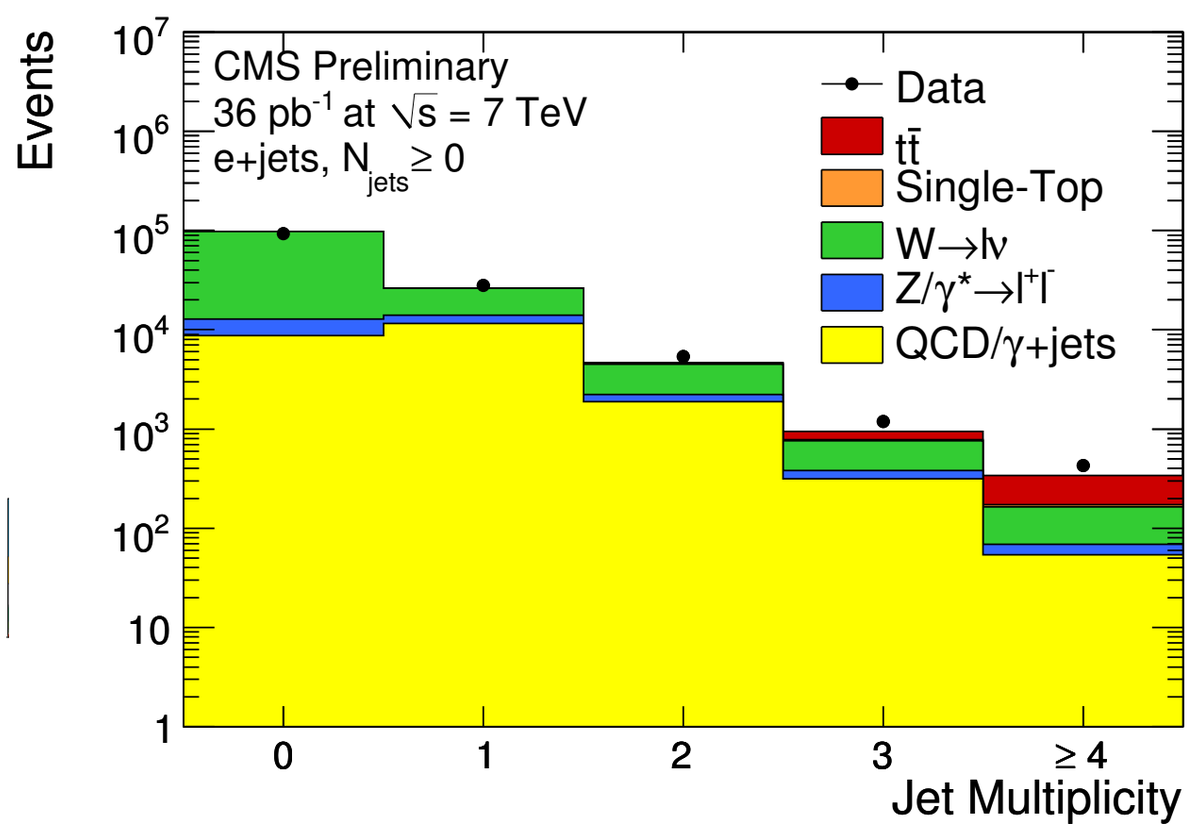
all hadronic
(BR~46%)

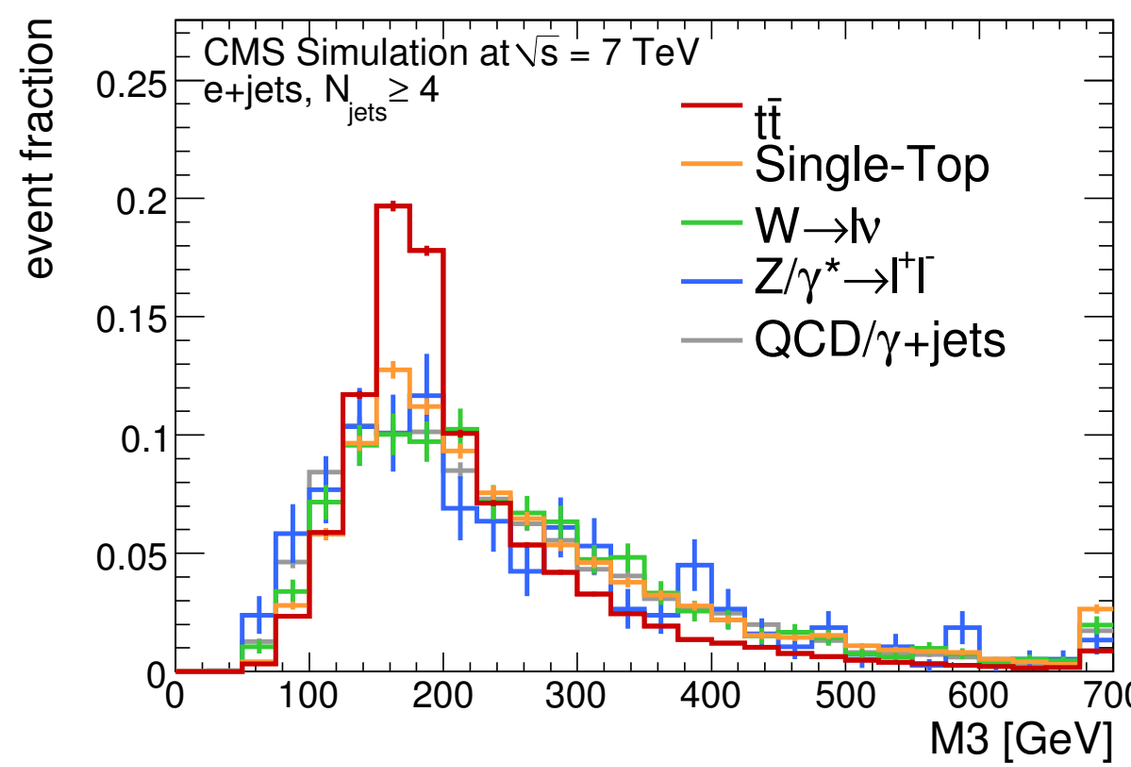
$t\bar{t}$ Cross Section in the Lepton+Jets Channels w/o b-Tagging (CMS-PAS TOP-10-002)

- Binned Likelihood Template Fit to $\not{E}_T$ and M3 (inv. mass of three jets with highest vectorial summed p_T) distributions
  - e+jets channel
  - μ+jets channel
  - Combined measurement in both channels
- Special Features:
  - Data-driven lepton selection and trigger efficiencies
  - Data-driven QCD template

e+jets Channel:

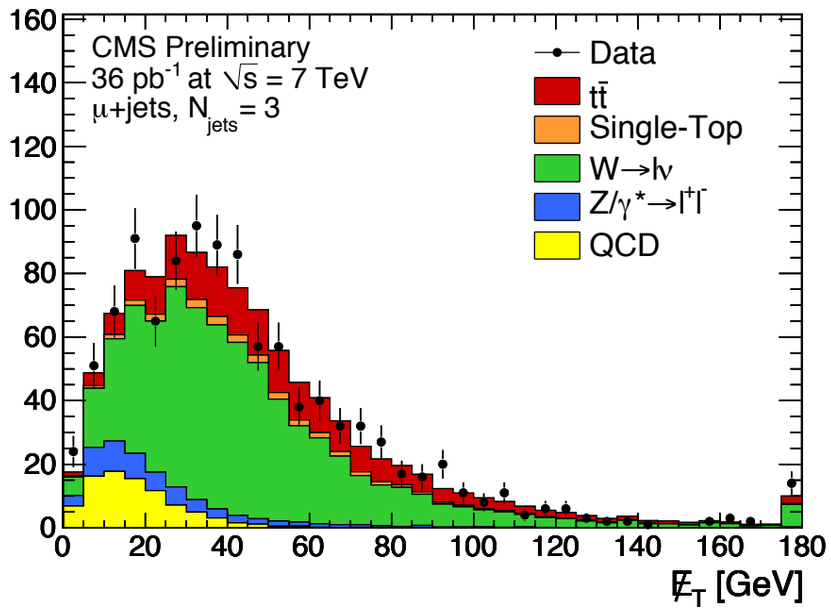


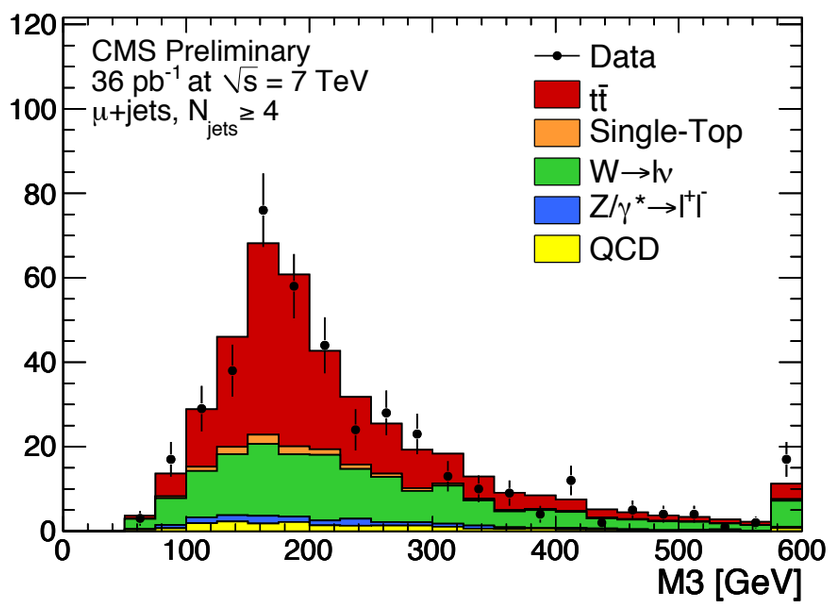




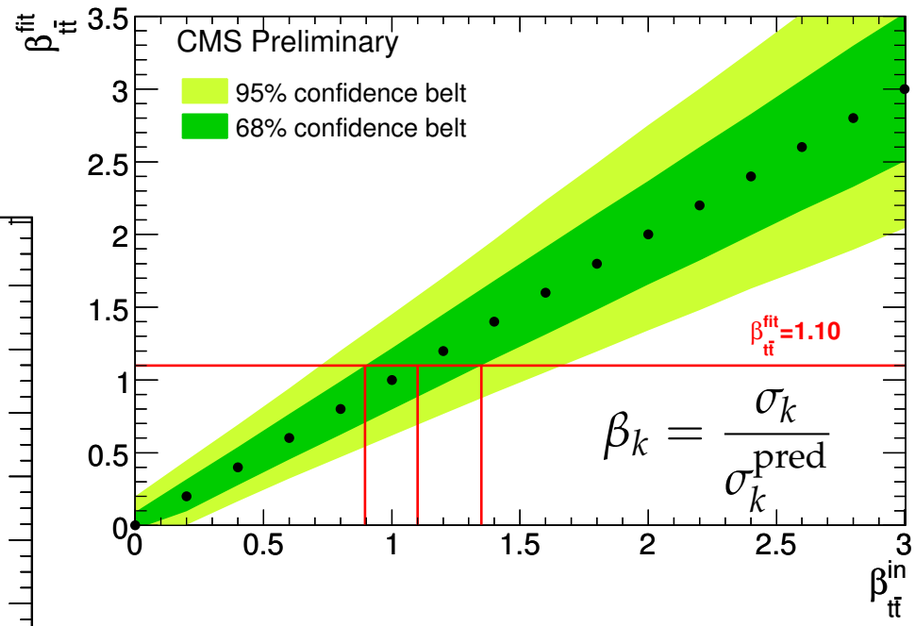
$t\bar{t}$ Cross Section in the Lepton+Jets Channels w/o b-Tagging (CMS-PAS TOP-10-002)

μ+jets Channel:





Combined Measurement:



e+jets Channel:

$$\sigma_{t\bar{t}} = 180^{+45}_{-38}(\text{stat.} + \text{syst.}) \pm 7(\text{lumi.})\ \text{pb}$$

μ+jets Channel:

$$\sigma_{t\bar{t}} = 168^{+42}_{-35}(\text{stat.} + \text{syst.}) \pm 7(\text{lumi.})\ \text{pb}$$

Combined Measurement:

$$\sigma_{t\bar{t}} = 173^{+39}_{-32}(\text{stat} + \text{syst}) \pm 7(\text{lumi})\ \text{pb}$$

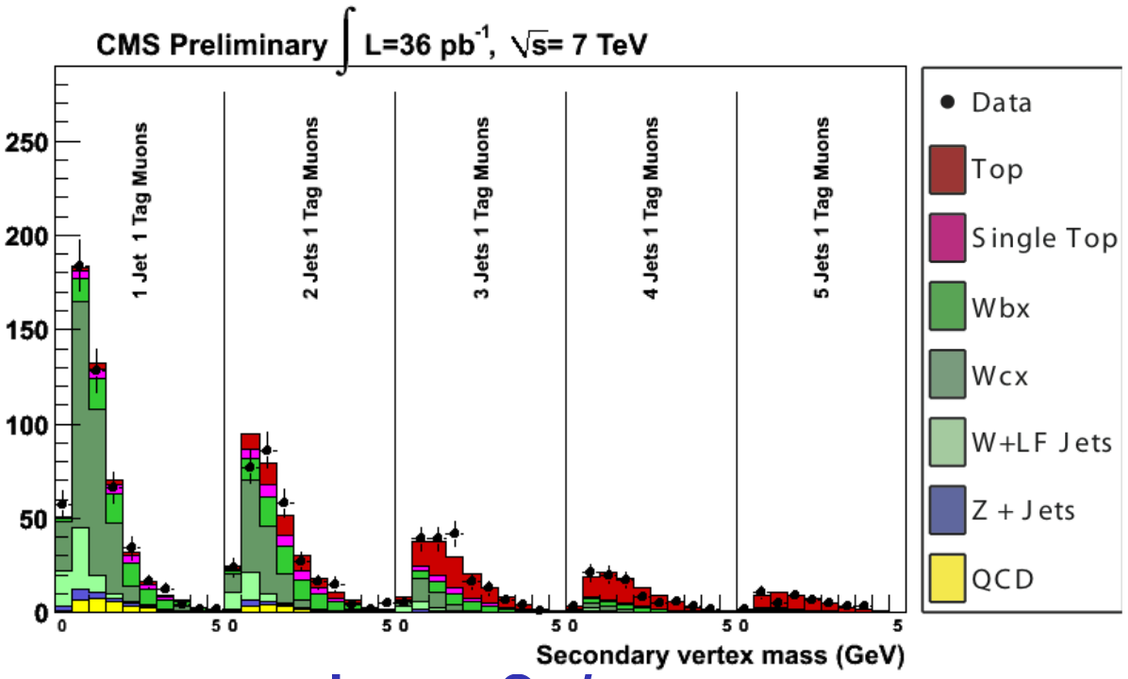
Combined Measurement:

	stat.+syst. uncertainty	
Stat.+bkg. uncertainty	−8.4%	+8.7%
JES	−17.6%	+20.3%
JER	−8.4%	+8.8%
ISR/FSR variation	−8.6%	+9.0%
Factorization scale	−10.6%	+11.2%
Matching threshold	−9.8%	+10.5%
Branching ratio	−8.6%	+8.9%
Efficiencies (from T&P)	−8.7%	+9.2%
QCD rate & shape	−8.9%	+9.1%
Lepton scale	−8.4%	+8.7%
PDF uncertainty	−8.5%	+8.7%
Pile-up	−9.3%	+9.3%
Total	−19.3%	+23.5%

$t\bar{t}$ Cross Section in the Lepton+Jets Channels with b-Tagging (CMS-PAS TOP-10-003)

Binned Likelihood Fit to the secondary vertex mass in the e+jets, μ+jets channel, and in the combination of both channels

μ+jets; 1 b-tag:



e+jets Channel:

$$\sigma_{t\bar{t}} = 158 \pm 14\ (\text{stat.}) \pm 19\ (\text{syst.}) \pm 6\ (\text{lum.})\ \text{pb}$$

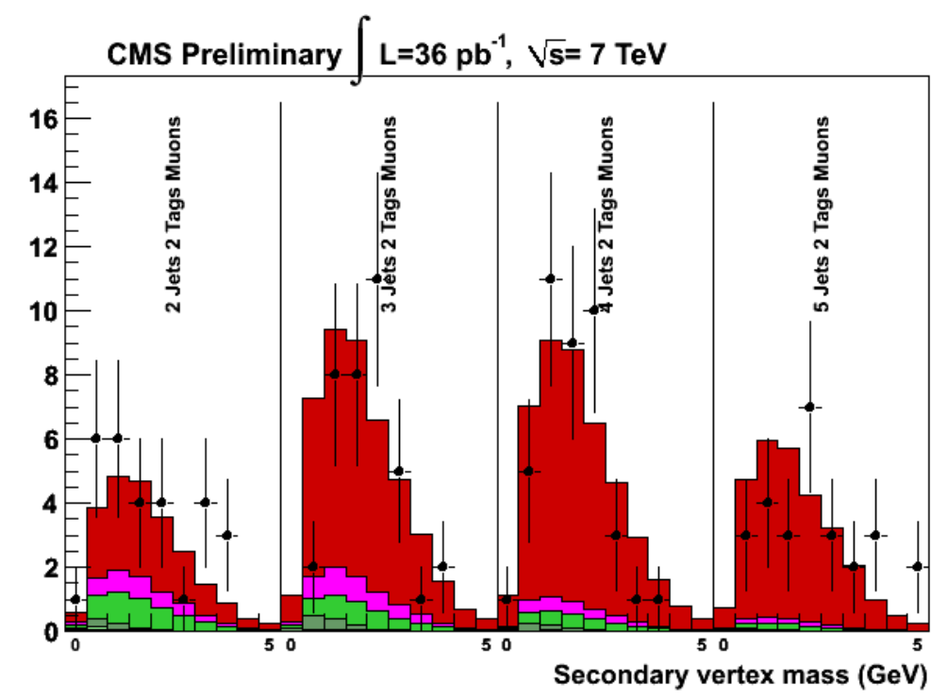
μ+jets Channel:

$$\sigma_{t\bar{t}} = 145 \pm 12\ (\text{stat.}) \pm 18\ (\text{syst.}) \pm 6\ (\text{lum.})\ \text{pb};$$

Combined Measurement:

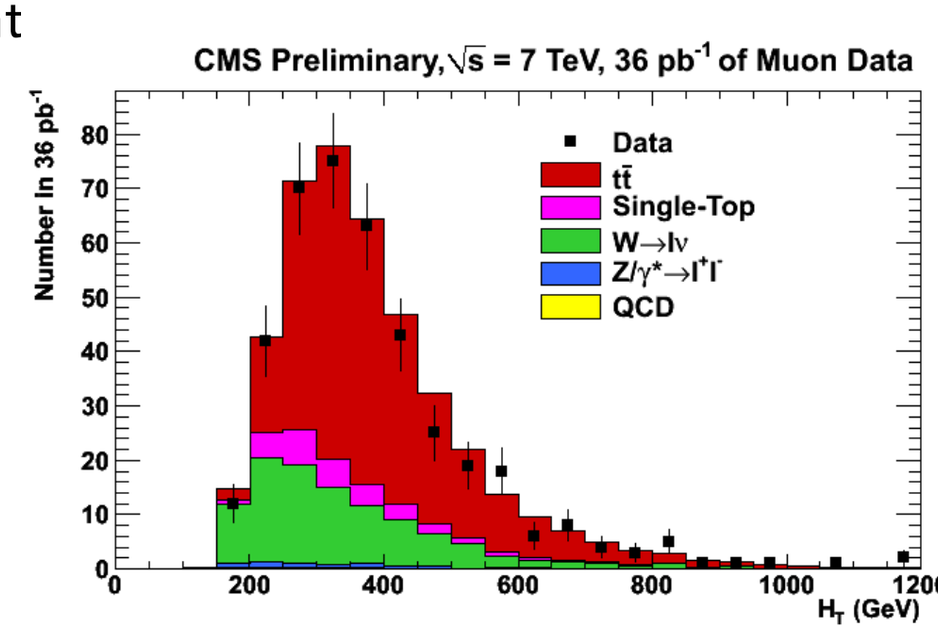
$$\sigma_{t\bar{t}} = 150 \pm 9\ (\text{stat.}) \pm 17\ (\text{syst.}) \pm 6\ (\text{lum.})\ \text{pb}.$$

μ+jets; 2 b-tags



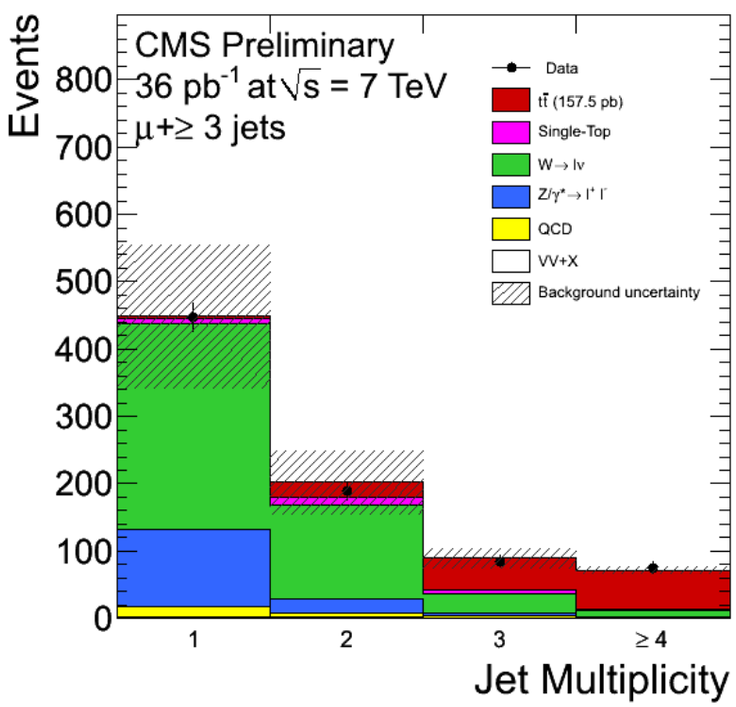
Profiling: most important systematics included as parameters, thus their impact reduced

μ+jets Channel:



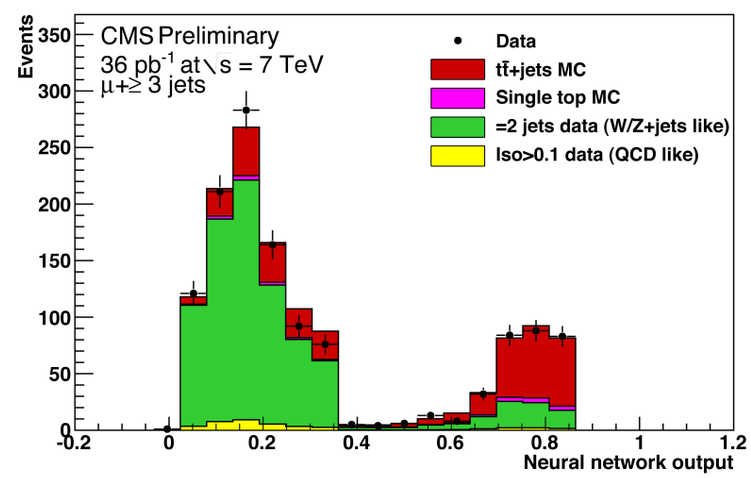
$t\bar{t}$ Cross Section in the Lepton+Jets Channels with b-Tagging (CMS-PAS TOP-10-003)

Source	Uncertainty (%)
Systematic uncertainties	
Lepton ID/reco/trigger	3
Unclustered E_T^{miss} resolution	< 1
$t\bar{t}$+ Jets Q^2-scale	2
ISR/FSR	2
ME to PS matching	2
PDF	3.4
Profile likelihood parameters	
Jet energy scale and resolution	7.0
b tag efficiency	7.5
W+Jets Q^2-scale	9.1
Combined	11.6



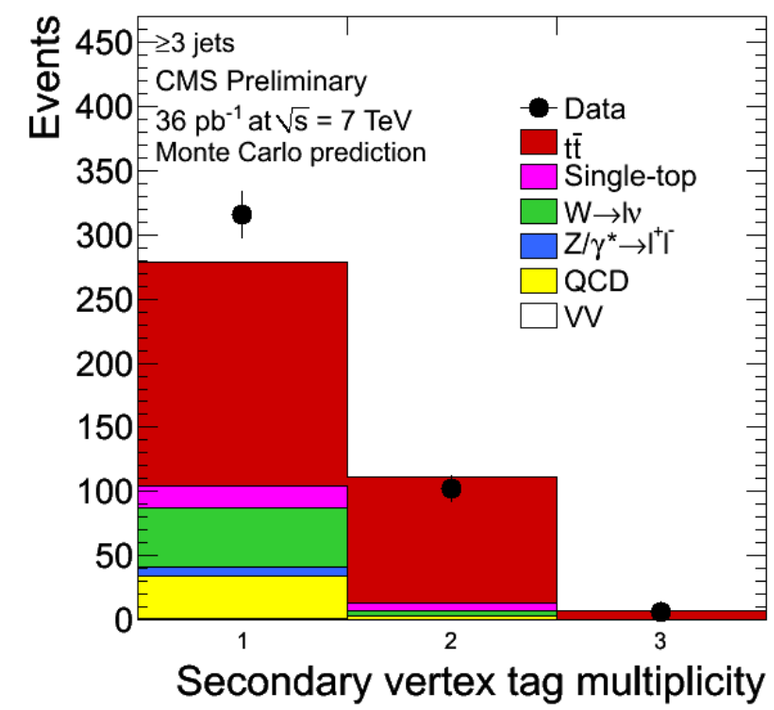
Jet multiplicity in muon channel with at least one muon-in-jet. The measured cross section is

$\sigma_{t\bar{t}} = 163 \pm 21\,(\text{stat.}) \pm 35\,(\text{syst.}) \pm 7\,(\text{lumi.})$ pb



Fit result of neural net analysis. The measured cross section is

$\sigma_{t\bar{t}} = 151 \pm 15\,(\text{stat.})\,^{+35}_{-28}\,(\text{syst.}) \pm 6\,(\text{lumi.})$ pb

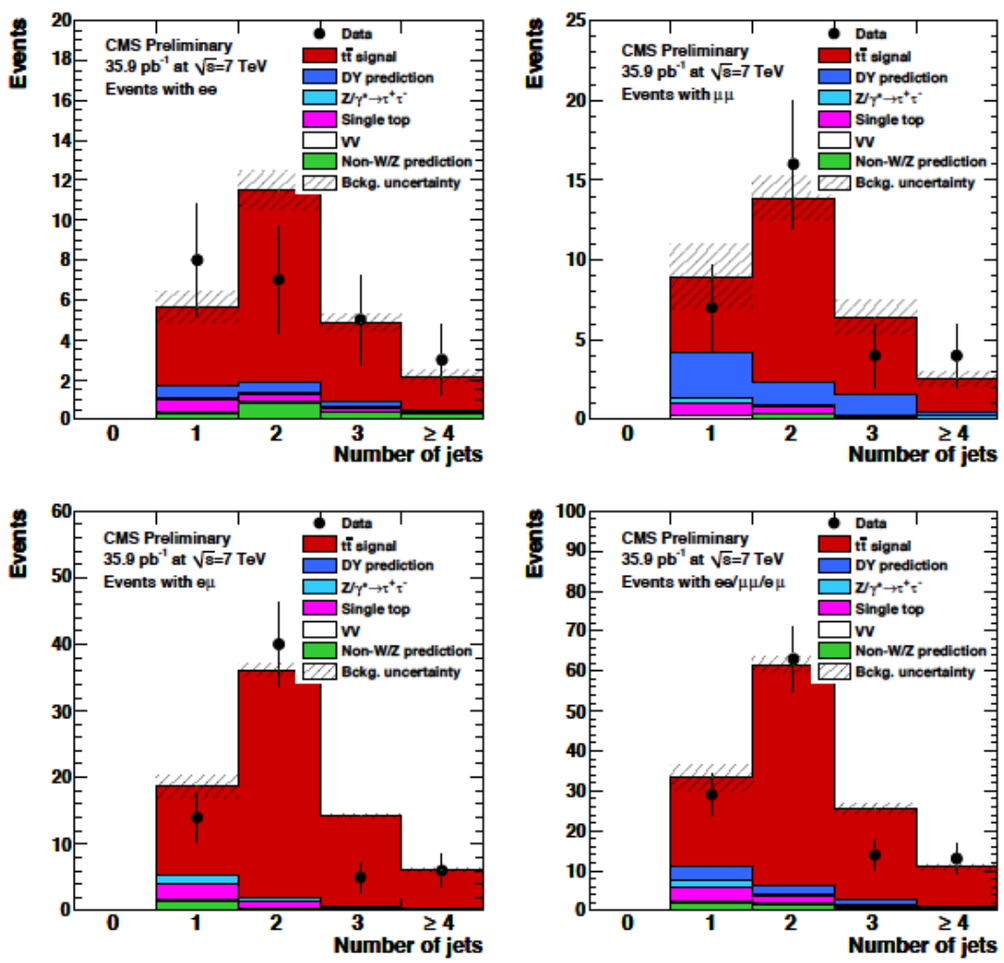


b-tag multiplicity in the electron channel. The measured cross section is

$\sigma_{t\bar{t}} = 169 \pm 13\,(\text{stat.})\,^{+39}_{-32}\,(\text{syst.}) \pm 7\,(\text{lumi.})$ pb

$t\bar{t}$ Cross Section in the Dilepton Channels (CMS-PAS TOP-10-005)

Event counting with dedicated data-driven techniques for the estimation of background contributions in the e^+e^-, the $\mu^+\mu^-$, and the $e^\pm\mu^\mp$ channels



3 channels:

e^+e^-, $e^\pm mu^\pm$, mu^+mu^-

3 selections

> 1 jet, no b-tag
> 1 jet, b-tag
= 1 jet, no b-tag

Final state	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
At least two jets, no b-tagging requirement			
Events in data	23	28	60
All backgrounds	5.5 ± 2.3	9.5 ± 4.3	6.7 ± 2.0
Total acceptance, %	0.259 ± 0.021	0.324 ± 0.025	0.928 ± 0.057
Cross section, pb	$189 \pm 52 \pm 29 \pm 8$	$159 \pm 45 \pm 39 \pm 6$	$160 \pm 23 \pm 12 \pm 6$
At least two jets, at least one b-jet			
Events in data	15	24	51
All backgrounds	2.3 ± 1.4	3.8 ± 2.0	3.0 ± 1.4
Total acceptance, %	0.236 ± 0.022	0.303 ± 0.028	0.857 ± 0.068
Cross section, pb	$150 \pm 46 \pm 22 \pm 6$	$186 \pm 45 \pm 25 \pm 7$	$156 \pm 23 \pm 13 \pm 6$
One jet, no b-tagging requirement			
Events in data	8	10	18
All backgrounds	2.1 ± 0.7	7.1 ± 4.3	4.9 ± 1.5
Total acceptance, %	0.058 ± 0.007	0.074 ± 0.008	0.183 ± 0.024
Cross section, pb	$282 \pm 135 \pm 45 \pm 11$	$107 \pm 119 \pm 163 \pm 4$	$200 \pm 65 \pm 35 \pm 8$

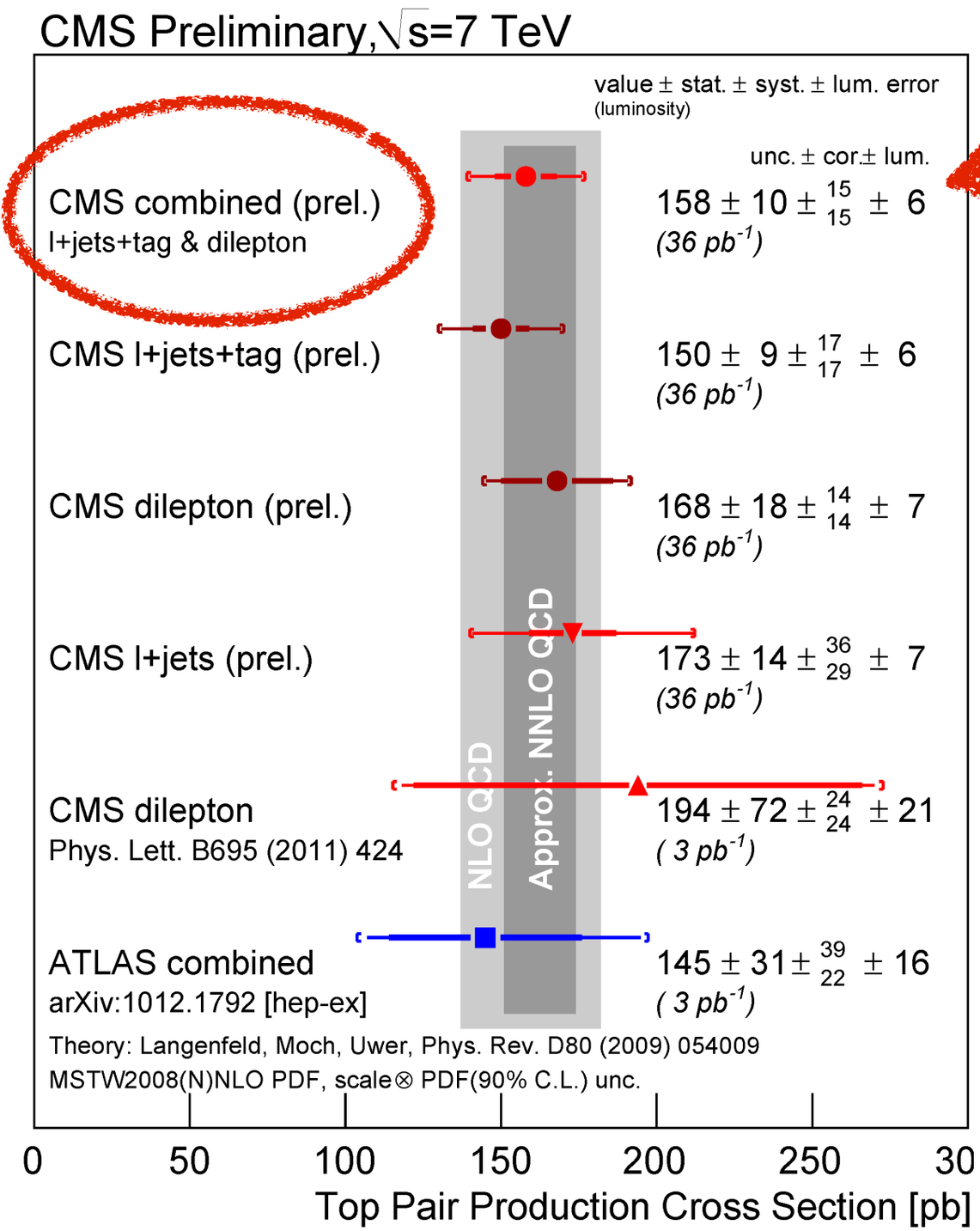
$$\sigma_{t\bar{t}} = 168 \pm 18\,(\text{stat.}) \pm 14\,(\text{syst.}) \pm 7\,(\text{lumi.})\ \text{pb}$$

$$\sigma_{t\bar{t}}/\sigma_{Z/\gamma^*} = 0.175 \pm 0.018\,(\text{stat.}) \pm 0.015\,(\text{syst.})$$

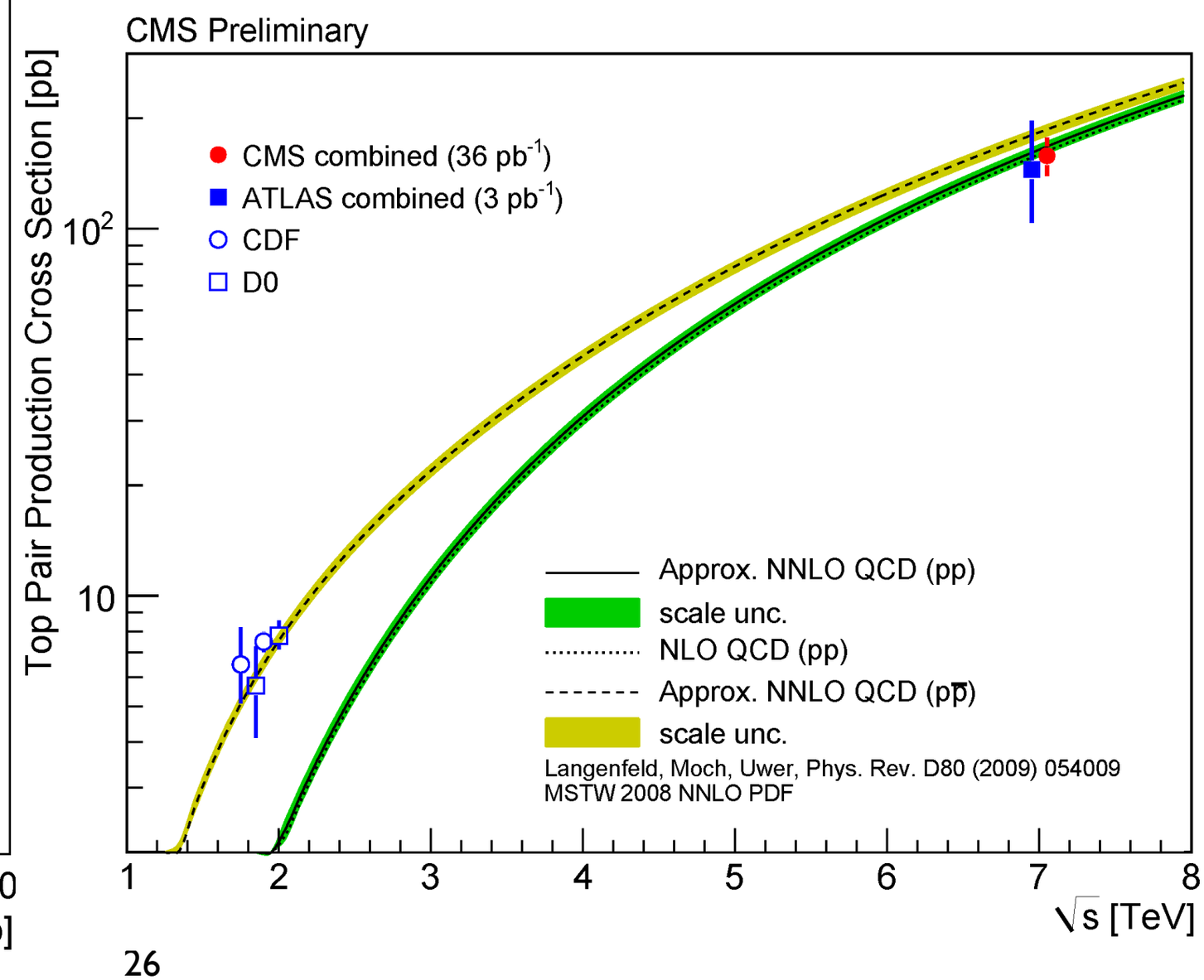
$t\bar{t}$ Cross Section in the Dilepton Channels (CMS-PAS TOP-10-005)

	$N_{jet} = 1$		$N_{jet} \geq 2$	
Source	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$
Lepton selection	1.91/1.30	1.11	1.91/1.30	1.11
Energy scale	−3.0	−5.5	3.8	2.8
Lepton selection model	4.0	4.0	4.0	4.0
Branching ratio	1.7	1.7	1.7	1.7
Decay model	2.0	2.0	2.0	2.0
Event Q^2 scale	8.2	10	−2.3	−1.7
Top-quark mass	−2.9	−1.0	2.6	1.5
Jet and $\not{E}_T$ model	−3.0	−1.0	3.2	0.4
Shower model	1.0	3.3	−0.7	−0.7
Pileup	−2.0	−2.0	0.8	0.8
Subtotal (before tags)	11.2/11.1	13.1	8.0/7.9	6.2
b tagging ($\geq$ 1 b tag)			5.0	5.0
Subtotal with tags			9.5/9.4	8.0
Luminosity	4	4	4	4

Combination of $t\bar{t}$ Cross Section Measurements and Comparison with Theory Predictions (CMS-PAS TOP-11-001)

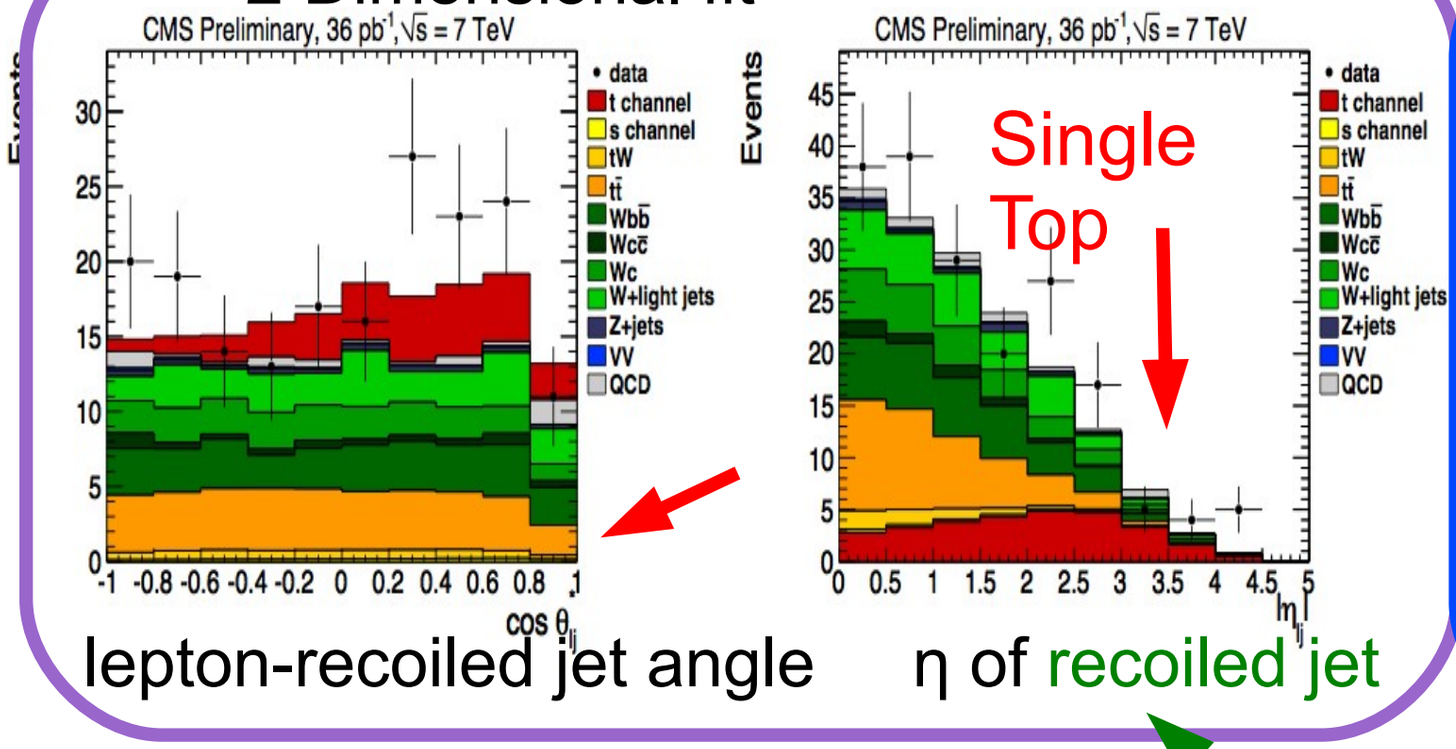


$$\sigma_{t\bar{t}}^{\mathrm{CMS}} = (158 \pm 19)\ \mathrm{pb}$$



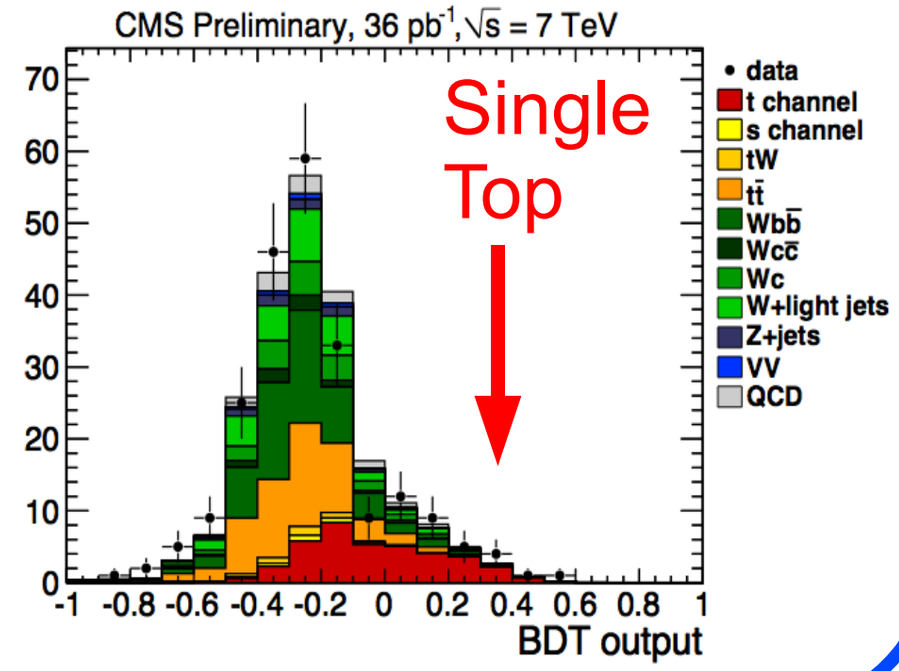
Single Top Cross Section

2 Dimensional fit

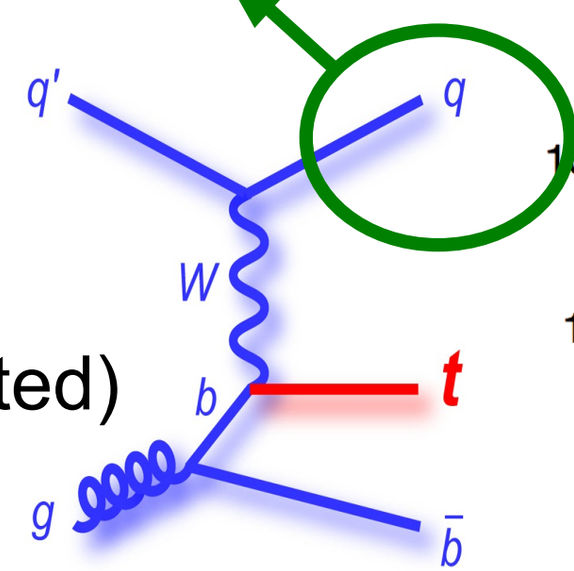


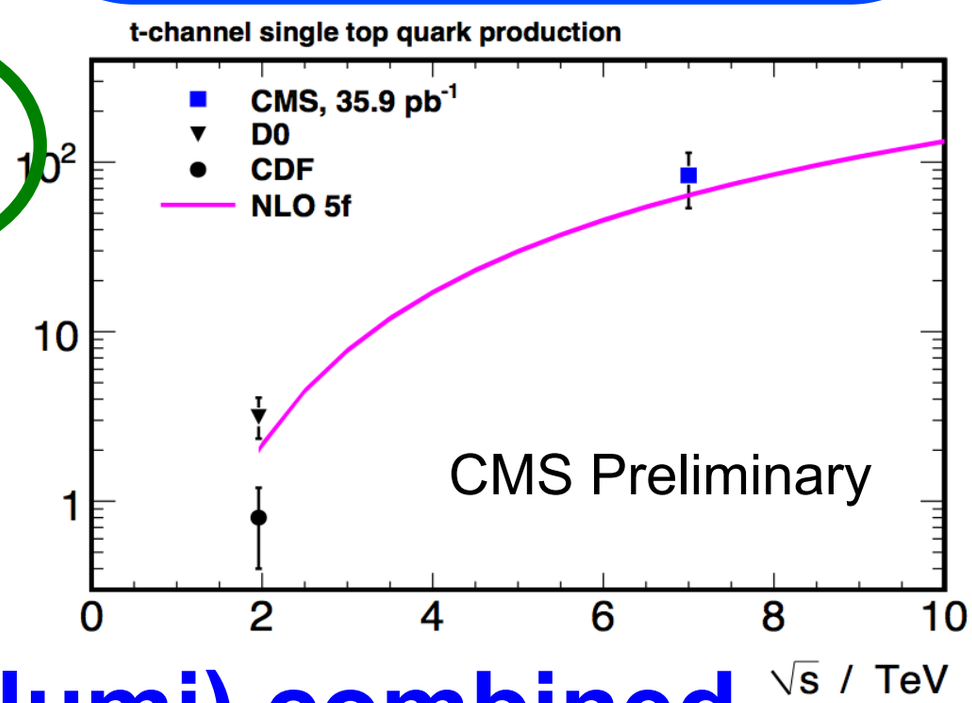
lepton-recoiled jet angle η of recoiled jet

Fit to Boosted decision tree



- W+2 jet selection
  - Lepton + *MET* + 2 jets
  - Require 1 b-tag
- Significance meas(expected)
  - 2D: 3.7(2.1) sigma
  - BDT: 3.5(2.9) sigma

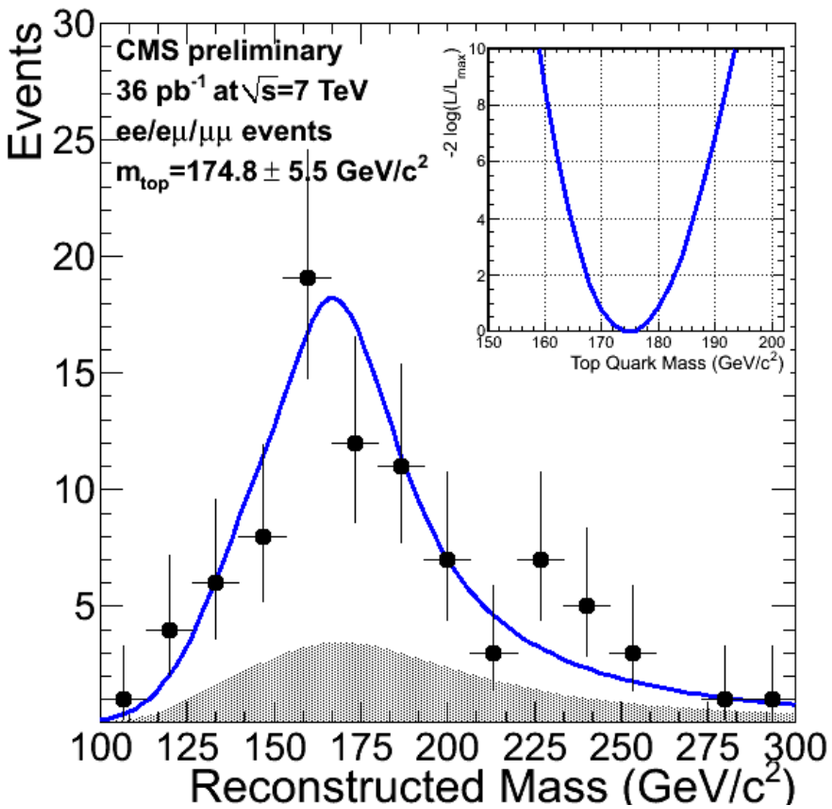


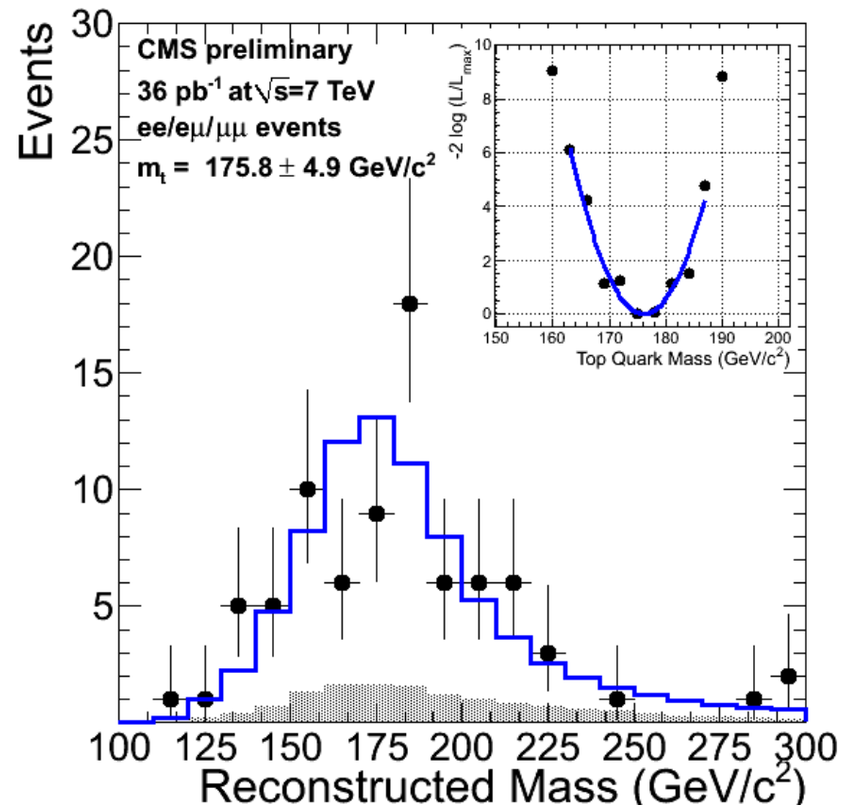


83.6±29.8(stat+sys)±3.3(lumi) combined

Top Quark Mass Measurement in the Dilepton Channels (CMS-PAS TOP-10-006)

Two analysis techniques based on template fits: fully kinematic analysis (left) and analytical matrix weighting technique (AMWT, right)





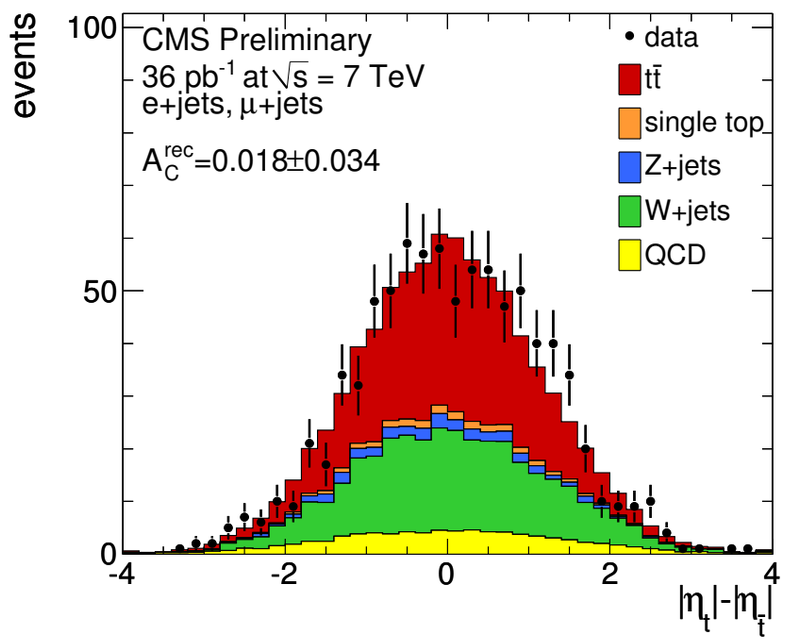
The shaded area corresponds to the background-only shapes; PIPs show the LLH as functions of m_{top}

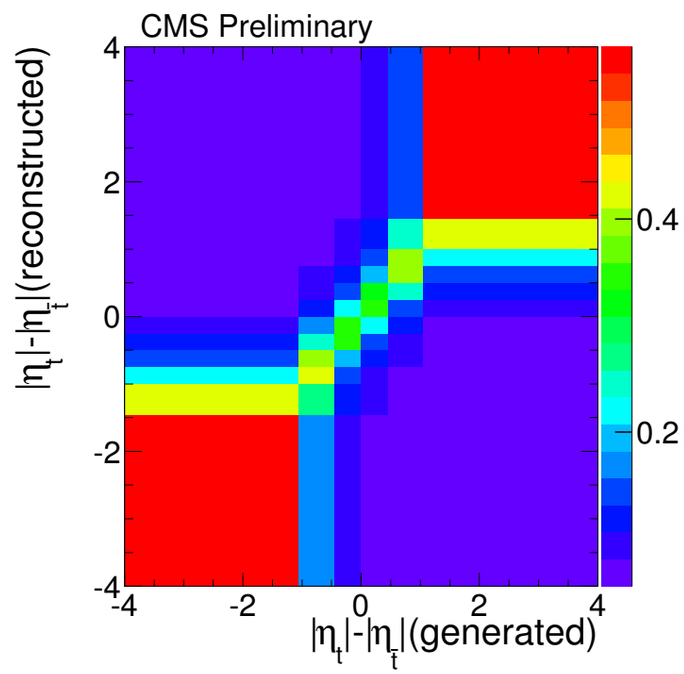
$$m_{top} = 175.5 \pm 4.6\,(\text{stat.}) \pm 4.6\,(\text{syst.})\ \text{GeV}/c^2$$

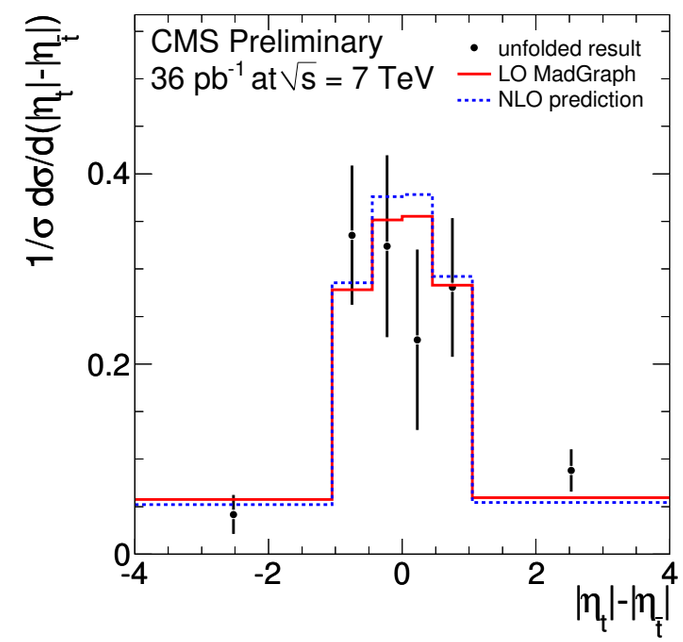
Source	KINb	AMWT	Correlation factor	Combination
jet energy scale	+3.1/-3.7	3.0	1	3.1
b-jet energy scale	+2.2/-2.5	2.5	1	2.5
Underlying event	1.2	1.5	1	1.3
Pileup	0.9	1.1	1	1.0
Jet-parton matching	0.7	0.7	1	0.7
Factorization scale	0.7	0.6	1	0.6
Fit calibration	0.5	0.1	0	0.2
MC generator	0.9	0.2	1	0.5
Parton density functions	0.4	0.6	1	0.5
b-tagging	0.3	0.5	1	0.4

Charge Asymmetry Measurement (CMS-PAS TOP-10-010)

- At the Tevatron: Deviation $> 3\sigma$ from SM predicted $A_{FB} \sim 5\%$
- At the LHC: Initial state symmetric (pp collider!) $\rightsquigarrow$ charge asymmetry (visible in $|\eta_t| - |\eta_{\bar{t}}|$)
- Expected asymmetry is small $A_C = 0.0130(11)$ [Ferrario, Rodrigo, et. al.], however, BSM like a Z' or an axigluon could show up



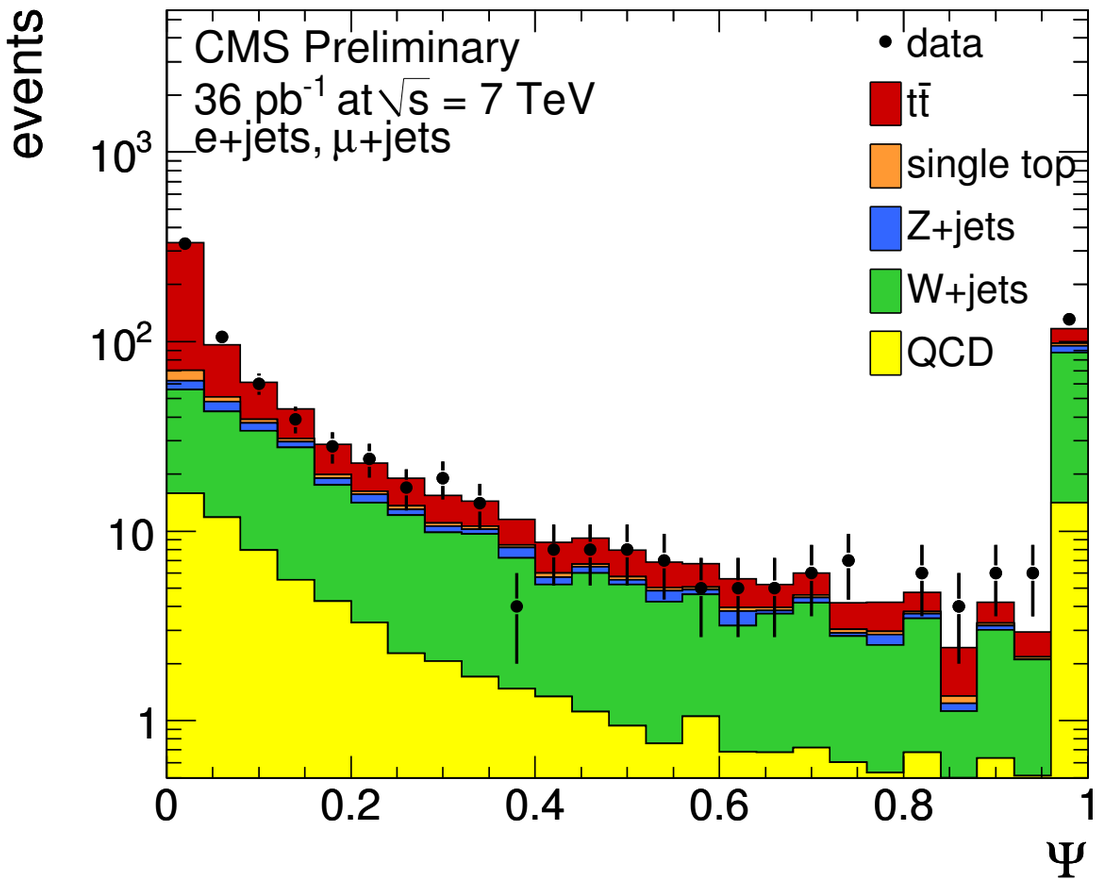




$$A_C = 0.060 \pm 0.134\,(\text{stat.}) \pm 0.026\,(\text{syst.})$$

Charge Asymmetry Measurement (CMS-PAS TOP-10-010)

Reconstruction of the $t\bar{t}$ system:

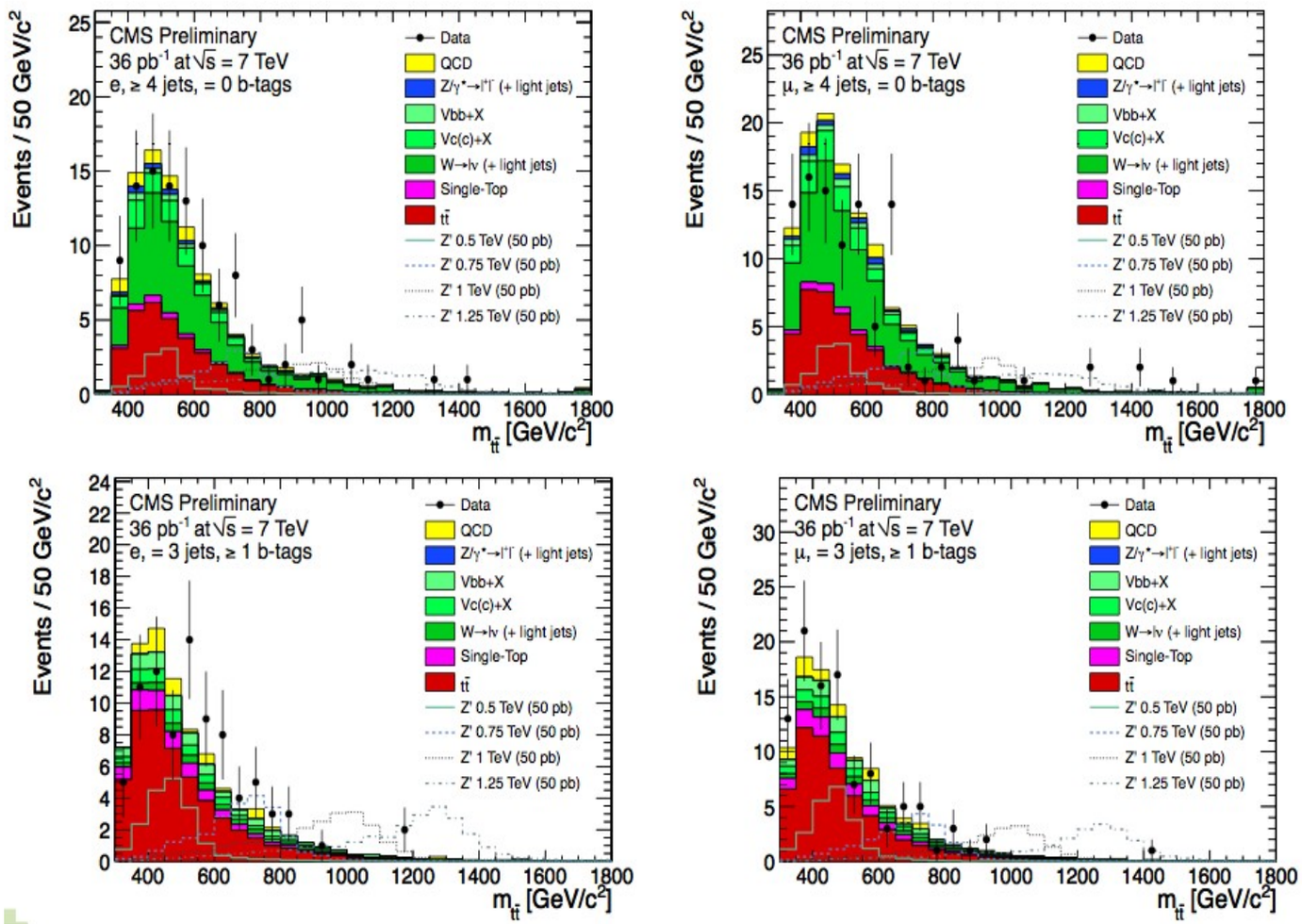


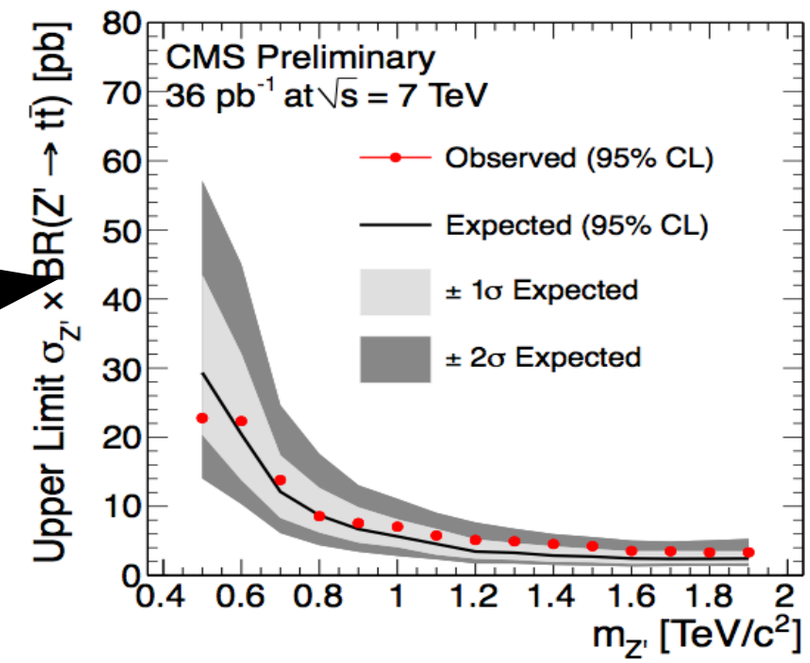
source of systematic	positive shift in A_C	negative shift in A_C
jet energy scale	0.017	-
jet energy resolution	0.007	-0.006
Q^2 scale	0.003	-0.007
ISR/FSR	0.005	-0.0006
matching threshold	0.004	-0.006
PDF	0.004	-0.011
b tagging	0.007	-
lepton efficiency	0.017	-0.018
QCD model	0.005	-0.005
overall	±0.026	

$$\Psi = \chi^2(1 - P_b(x_{b_{had}}))(1 - P_b(x_{b_{lep}}))P_b(x_{q_1})P_b(x_{q_2}).$$

$$\chi^2 = \frac{(m^{\text{b.p.}}_{\text{t,had}} - m^{\text{rec}}_{\text{t,had}})^2}{\sigma^2_{m_{\text{t,had}}}} + \frac{(m^{\text{b.p.}}_{\text{t,lep}} - m^{\text{rec}}_{\text{t,lep}})^2}{\sigma^2_{m_{\text{t,lep}}}} + \frac{(m^{\text{b.p.}}_{\text{W,had}} - m^{\text{rec}}_{\text{W,had}})^2}{\sigma^2_{m_{\text{W,had}}}}$$

Measurement of m_{tt}





- Measurement of m_{tt} translates to Z' search
- Limit extrapolated from from 4 separate channels
  - Lepton + 4/3 Jets w/ and w/o b-tag
  - Vary results by predicted σ w/unc → extrapolate limit

2011 run

Bring it on!