Measurement of $t\bar{t}$ Production Cross Section Using b-tagged Semileptonic Events

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Young Scientific Forum(4)

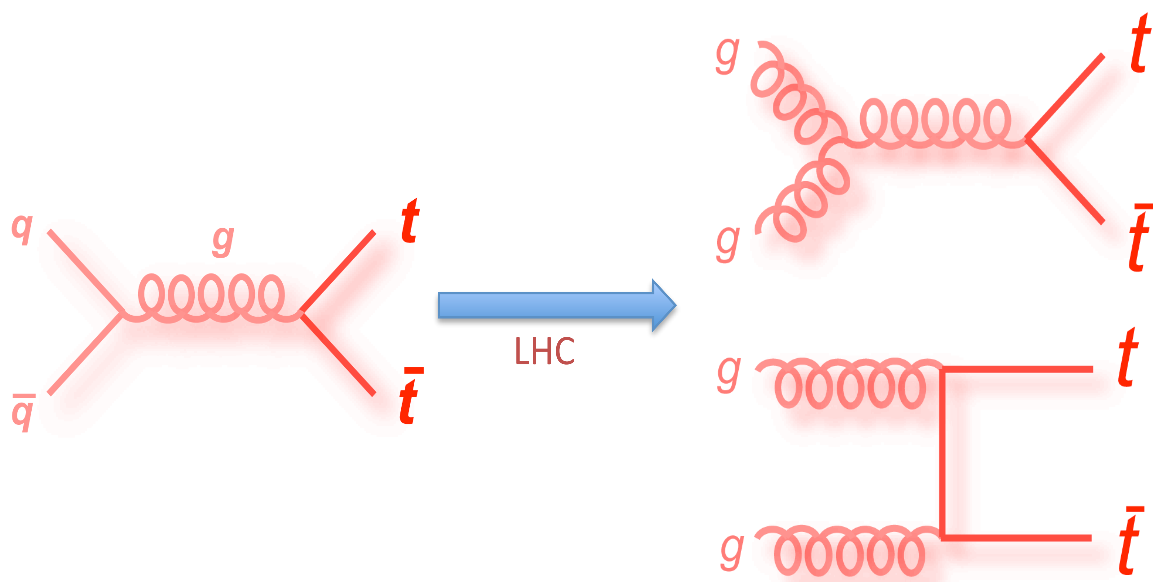
Rencontres de Moriond (EWK), La Thuile, AO, Italy

3-10 Mar, 2012

Introduction

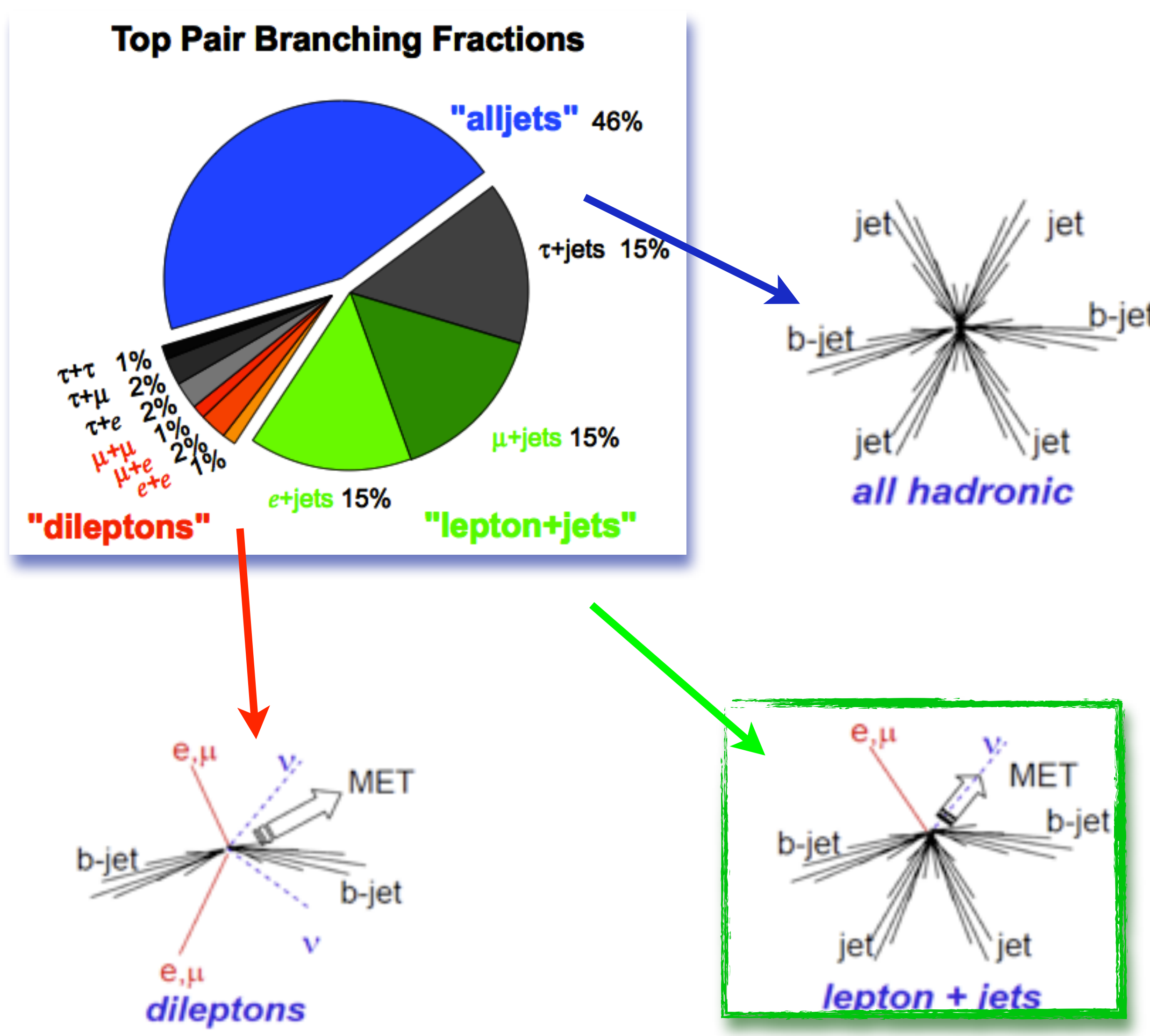
- Pair production
  - σ~7.5 pb (Tevatron 1.96 TeV ppbar)
  - σ~165 pb (LHC 7 TeV) Pair production

- Top Pair final state decays
  - Golden channels: lepton + jets and dilepton
  - Challenging channels: full hadronic, tau + mu

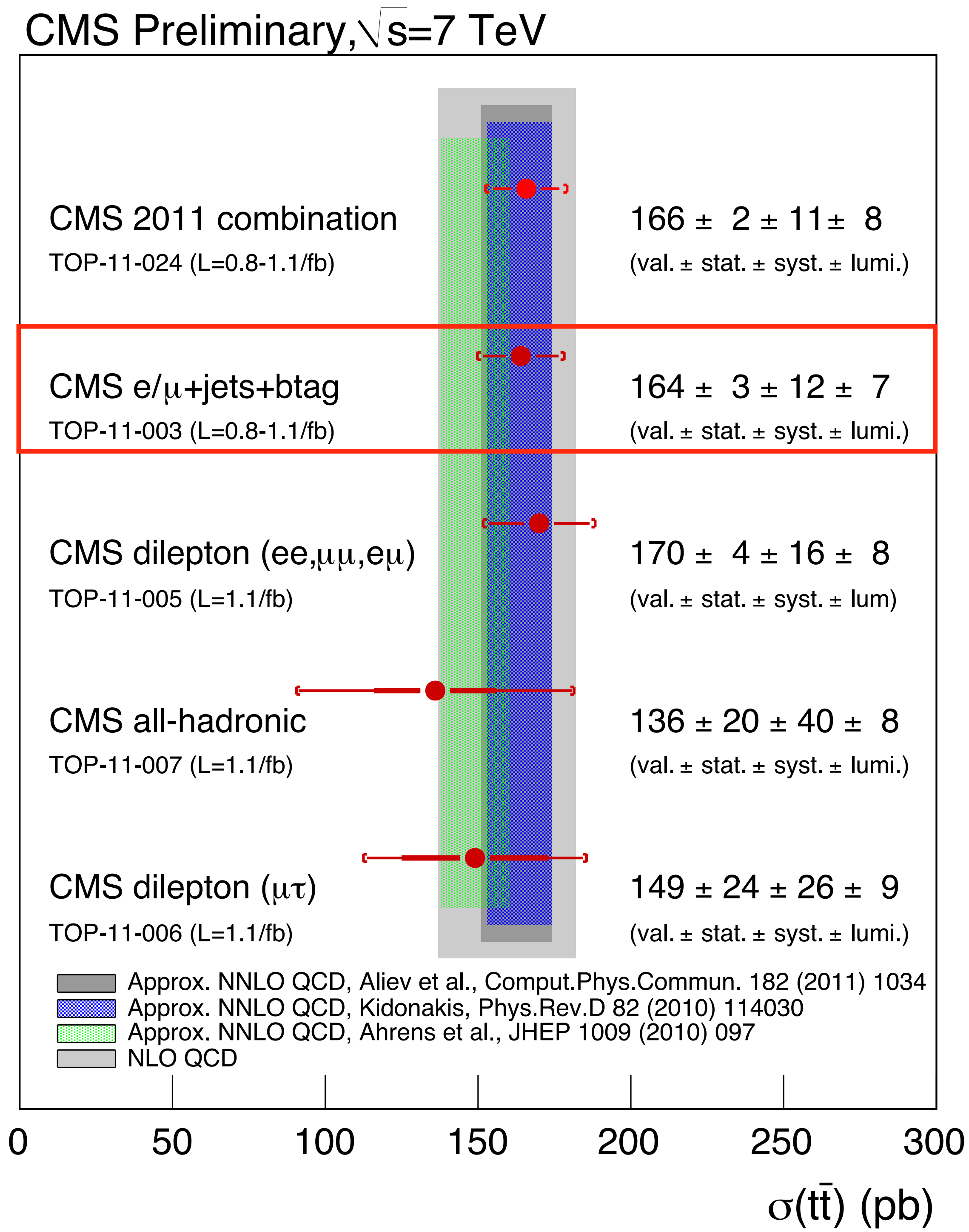


~90%(Tevatron)
~15%(LHC)

~10%(Tevatron)
~85%(LHC)



Cross-section Measurement



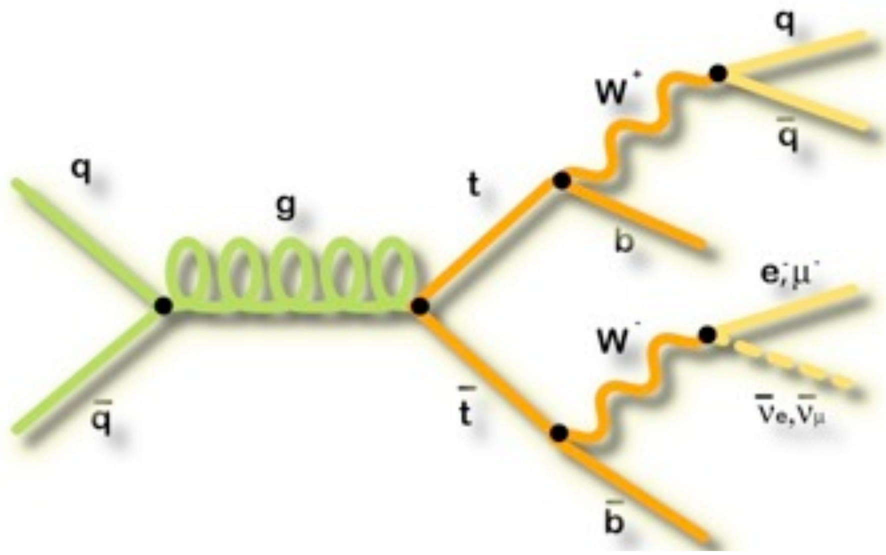
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Event Selection

- Triggers
  - Single Electron/Muon

- Electrons
  - Electron ID with 70% (95%) reconstruction efficiency (second electron for dilepton veto)
  - Relative isolation<0.01 and conversion rejection
  - $|\eta| < 2.5$, $P_T > 45$ GeV

- Muons
  - Global and tracker muon, relative isolation <0.125
  - $|\eta| < 2.1$, $P_T > 35$ GeV



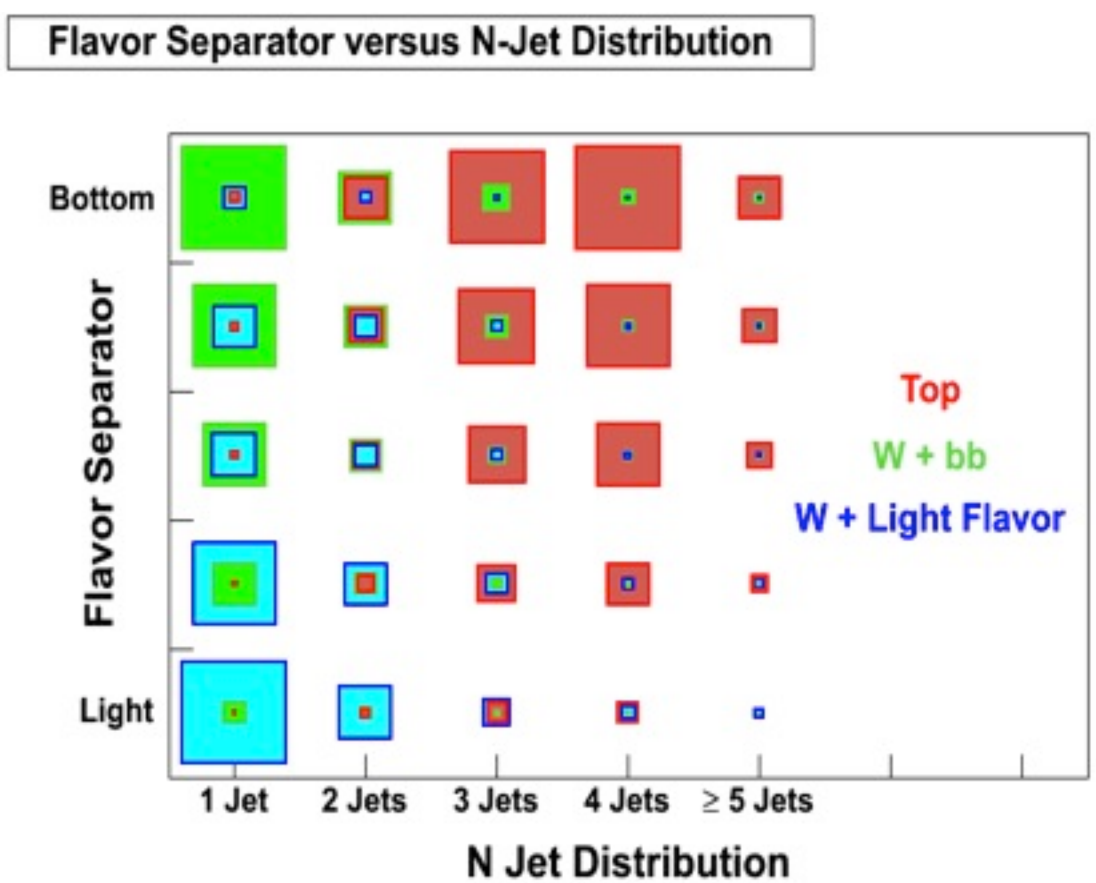
- Jets
  - anti-kT jet clustering algorithm with R=0.5
  - $P_T > 30$ GeV and $|\eta| < 2.4$, JetID
  - ≥ 1 btag jet using standard high efficiency tagger

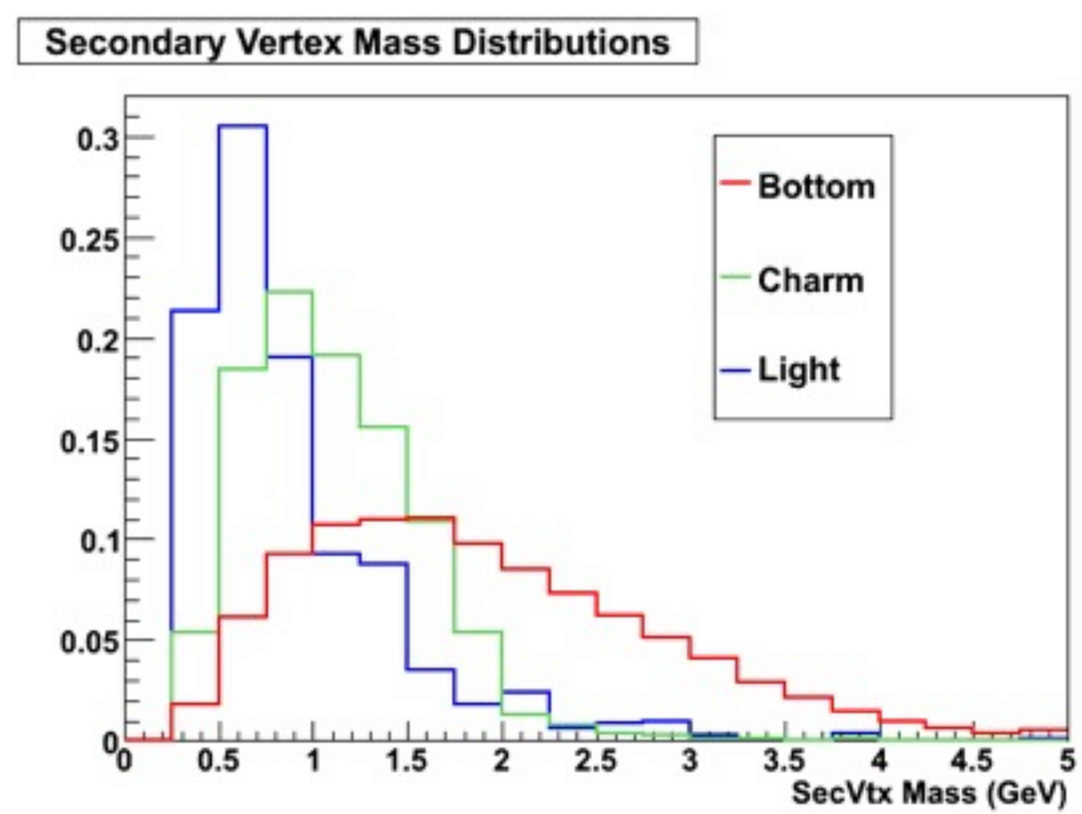
- MET
  - Negative sum of transverse momenta of all reconstructed particles
  - MET > 20.0 GeV

http://cdsweb.cern.ch/record/1386709?ln=en

Simultaneous Heavy Flavor and Top

- Discriminating variables
  - N-Jet distribution - Distinguish Top from Wbb
  - "Flavor separator" - Distinguish Wbb from W+charm and W+LF
    - Secondary vertex (secvtx) mass– invariant mass of tracks originating at identified secvtx
    - Good separation of bottom from charm and light flavor jets
- Perform a simultaneous 3D(N_{Jets}, N_{Tags}, secvtx mass) Maximum Profile likelihood Fit

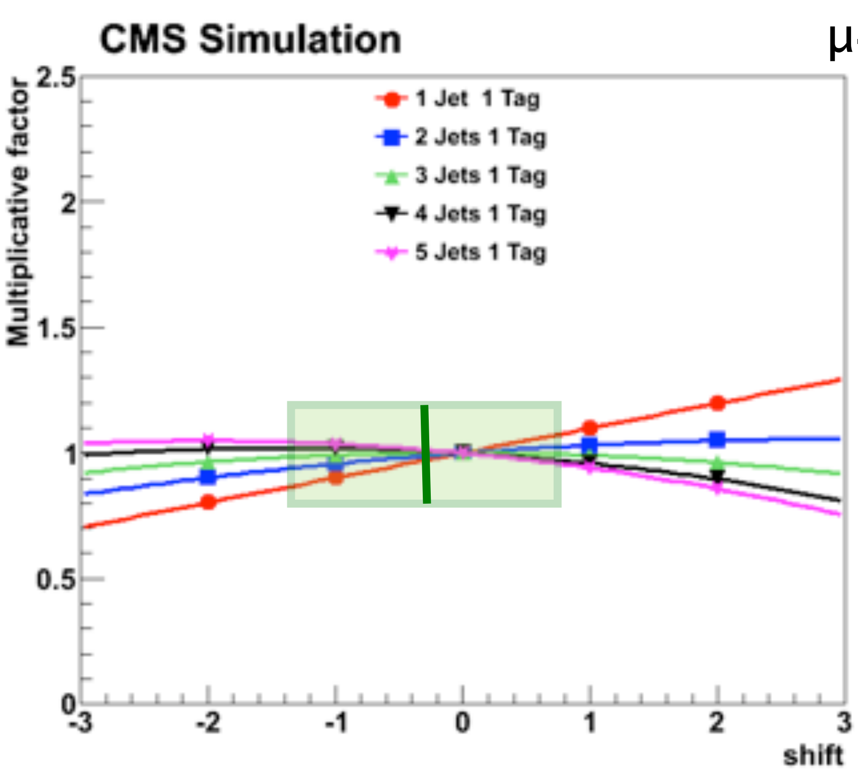




Systematic Uncertainties (1)

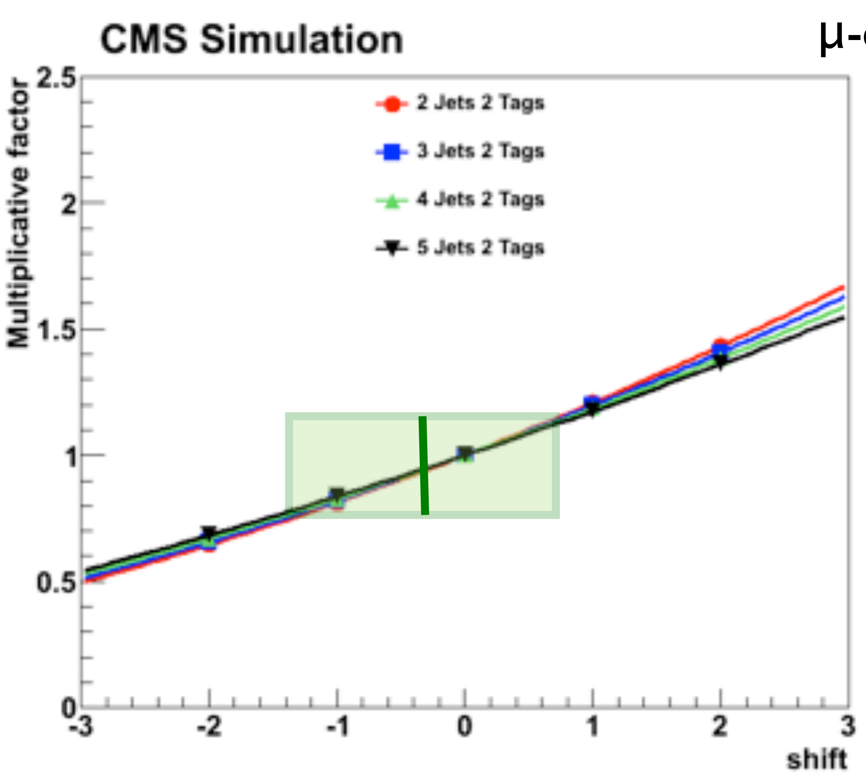
- How do we put systematic uncertainties into fitter?
  - Create and compare the nominal and shifted MC templates
- All functional forms are parameterized as polynomials
  - Generally 2nd order and are applied as multiplicative factors.
- For example: Able to extract btag efficiency in-situ
  - Use b-tagging efficiency and mistag SF constrained to 1.0 ±0.1

μ-channel, ≥1 tag



Measured: 97± 1 %

μ-channel, ≥2 tag



Btag group measurement of 95 ± 1 % is covered in our 1σ interval

Systematic Uncertainties (2)

Quantity	Constraint (%)
b-tag Efficiency Scale Factor	100 ± 10
b-tag Mistag Scale Factor	100 ± 10
Jet energy scale relative to nominal	100 ± 3 (η,p_T dependent)
W+jets renormalization/factorization scales	100^{+100}_{-50}
W+jets background normalization	unconstrained
QCD background normalization	100 ± 100
Single-top background normalization	100 ± 30
Z+jets background normalization	100 ± 30

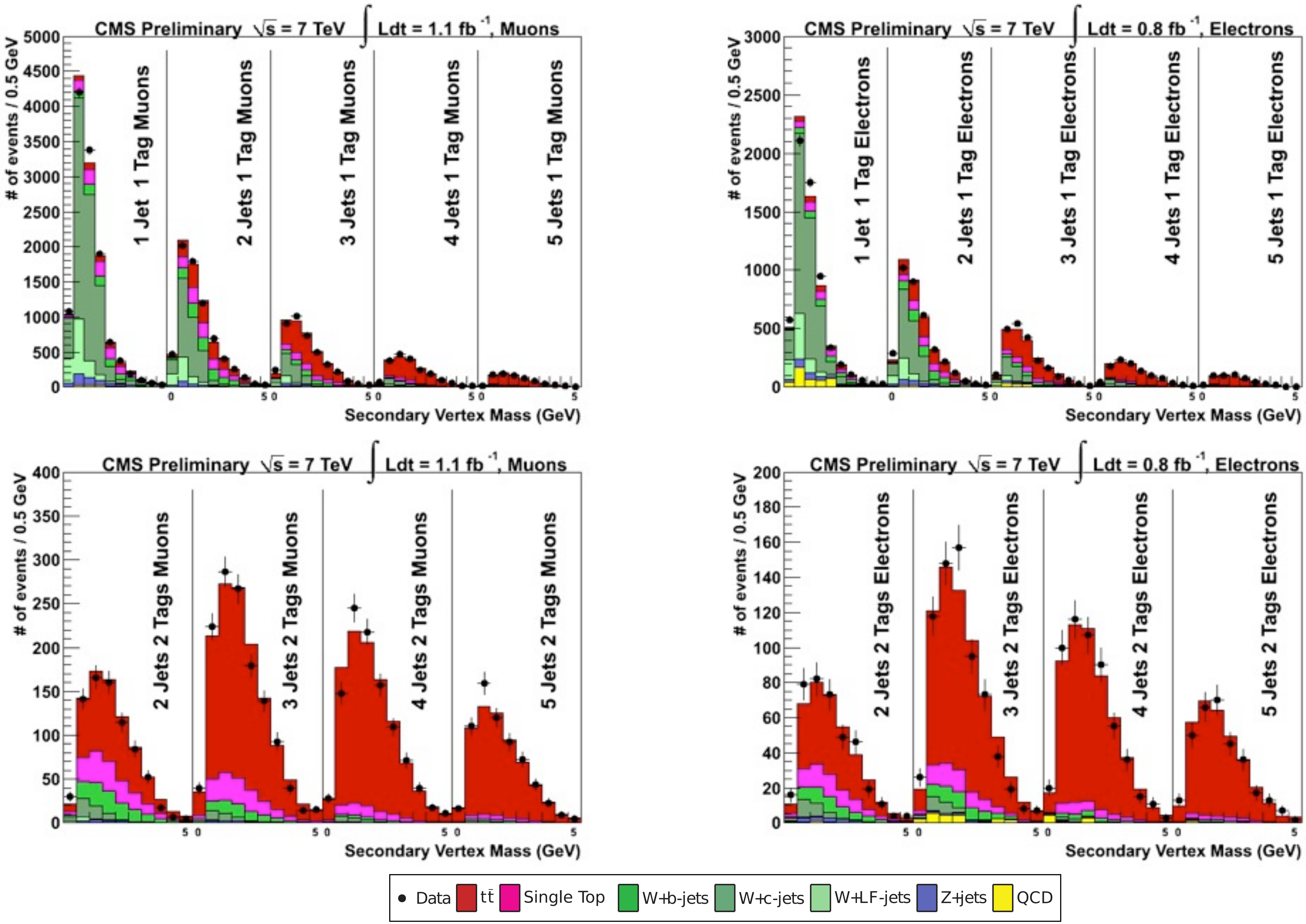
systematic uncertainties covered in fit

Source	Muon Analysis	Electron Analysis	Combined Analysis
Quantity	Uncertainty (%)		
Lepton ID/reco/trigger	3.4	3	3.4
$\not\!\!E_{\mathrm{T}}$resolution due to unclustered energy	< 1	< 1	< 1
$t\bar{t}$+jets Q^2 scale	2	2	2
ISR/FSR	2	2	2
ME to PS matching	2	2	2
Pile-up	2.5	2.6	2.6
PDF	3.4	3.4	3.4
Profile Likelihood Parameter	Uncertainty (%)		
Jet energy scale and resolution	4.2	4.2	3.1
b-tag efficiency	3.3	3.4	2.4
W+jets Q^2 scale	0.9	0.8	0.7
Combined	7.8	7.8	7.3

systematic uncertainties not covered in fit

Important! The full result is not the sum of the squares. Have to account for correlations (fitter does this automatically)

Results



CMS Preliminary $\sqrt{s}$ = 7 TeV $\int$ Ldt = 1.1 fb^{-1}, Muons
1 Jet 1 Tag Muons
2 Jets 1 Tag Muons
3 Jets 1 Tag Muons
4 Jets 1 Tag Muons
5 Jets 1 Tag Muons
# of events / 0.5 GeV
Secondary Vertex Mass (GeV)
CMS Preliminary $\sqrt{s}$ = 7 TeV $\int$ Ldt = 0.8 fb^{-1}, Electrons
1 Jet 1 Tag Electrons
2 Jets 1 Tag Electrons
3 Jets 1 Tag Electrons
4 Jets 1 Tag Electrons
5 Jets 1 Tag Electrons
# of events / 0.5 GeV
Secondary Vertex Mass (GeV)
CMS Preliminary $\sqrt{s}$ = 7 TeV $\int$ Ldt = 1.1 fb^{-1}, Muons
2 Jets 2 Tags Muons
3 Jets 2 Tags Muons
4 Jets 2 Tags Muons
5 Jets 2 Tags Muons
# of events / 0.5 GeV
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CMS Preliminary $\sqrt{s}$ = 7 TeV $\int$ Ldt = 0.8 fb^{-1}, Electrons
2 Jets 2 Tags Electrons
3 Jets 2 Tags Electrons
4 Jets 2 Tags Electrons
5 Jets 2 Tags Electrons
# of events / 0.5 GeV
Secondary Vertex Mass (GeV)
Data
$t\bar{t}$
Single Top
W+b-jets
W+c-jets
W+LF-jets
Z+jets
QCD

Results

Channel	luminosity	Measurement
μ+jets	1.1/fb	163.2 ± 3.4 (stat.) ± 12.7 (syst.) ± 7.3 (lum.)pb
e+jets	0.8/fb	163.0 ± 4.4 (stat.) ± 12.7 (syst.) ± 7.3 (lumi.) pb
combine	0.8-1.1/fb	164.4 ± 2.8 (stat.) ± 11.9 (sys.) ± 7.4 (lumi.) pb

- Btag SF
  - 96.7 ± 1 %
- Jet Energy Scale:
  - 99.2 ± 1.2 % of the nominal in agreement with 100%
- W+Jets Q^2:
  - 9 ± 10 % in agreement with the nominal value
- W+b-jets:
  - K=1.2 ± 0.3 * SM expectation
- W+c-jets:
  - K=1.7 ± 0.1 * SM expectation

Extra material

Results

Fit factors	
Top	$164.2^{+6.1}_{-5.9}$
SingleTop	$1.44^{+0.27}_{-0.27}$
Wbx	$1.21^{+0.28}_{-0.27}$
Wcx	$1.66^{+0.06}_{-0.06}$
Wqq	$0.58^{+0.08}_{-0.07}$
ZJets	$1.34^{+0.29}_{-0.29}$
Fit Shifts	
Q2	$0.09^{+0.10}_{-0.10}$
btag	$-0.33^{+0.11}_{-0.11}$
jes	$-0.28^{+0.39}_{-0.40}$
lftag	$0.11^{+1.00}_{-1.00}$
qcdConstr_1j_el	$0.60^{+0.34}_{-0.33}$
qcdConstr_1j_mu	$-0.78^{+0.25}_{-0.26}$
qcdConstr_2j_el	$-0.65^{+0.27}_{-0.26}$
qcdConstr_2j_mu	$-1.36^{+0.63}_{-0.63}$
qcdConstr_3j_el	$1.27^{+0.59}_{-0.59}$
qcdConstr_3j_mu	$0.09^{+0.86}_{-0.86}$
qcdConstr_4j_el	$-0.21^{+0.38}_{-0.36}$
qcdConstr_4j_mu	$0.19^{+0.85}_{-0.85}$
qcdConstr_5j_el	$-0.46^{+0.45}_{-0.44}$
qcdConstr_5j_mu	$-0.20^{+0.98}_{-0.98}$

uncorrected

σ(Top) in pb

fraction of SM

shift from nominal value [σ]

constrained to 0 ± 1

shift from nominal value [σ]

100% uncert.

constrained to 0 ± 1

Results (Correlation Matrix)

	Top	SingleTop	Wbx	Wcx	Wqq	Zjets	Q2	btag	jes	lftag
Top	1.000	-0.285	-0.180	0.288	0.032	0.074	-0.135	-0.627	-0.835	0.002
SingleTop	-0.285	1.000	-0.731	0.049	0.047	-0.041	0.069	-0.104	0.134	-0.006
Wbx	-0.180	-0.731	1.000	0.068	0.123	-0.145	0.295	0.195	0.269	-0.002
Wcx	0.288	0.049	0.068	1.000	0.053	0.034	0.673	-0.428	-0.204	-0.011
Wqq	0.032	0.047	0.123	0.053	1.000	-0.139	0.311	-0.058	-0.048	-0.763
ZJets	0.074	-0.041	-0.145	0.034	-0.139	1.000	0.129	0.000	-0.100	0.002
Q2	-0.135	0.069	0.295	0.673	0.311	0.129	1.000	-0.022	0.231	-0.016
btag	-0.627	-0.104	0.195	-0.428	-0.058	0.000	-0.022	1.000	0.460	-0.011
jes	-0.835	0.134	0.269	-0.204	-0.048	-0.100	0.231	0.460	1.000	0.003
lftag	0.002	-0.006	-0.002	-0.011	-0.763	0.002	-0.016	-0.011	0.003	1.000

Simple Fit For Top Cross Section

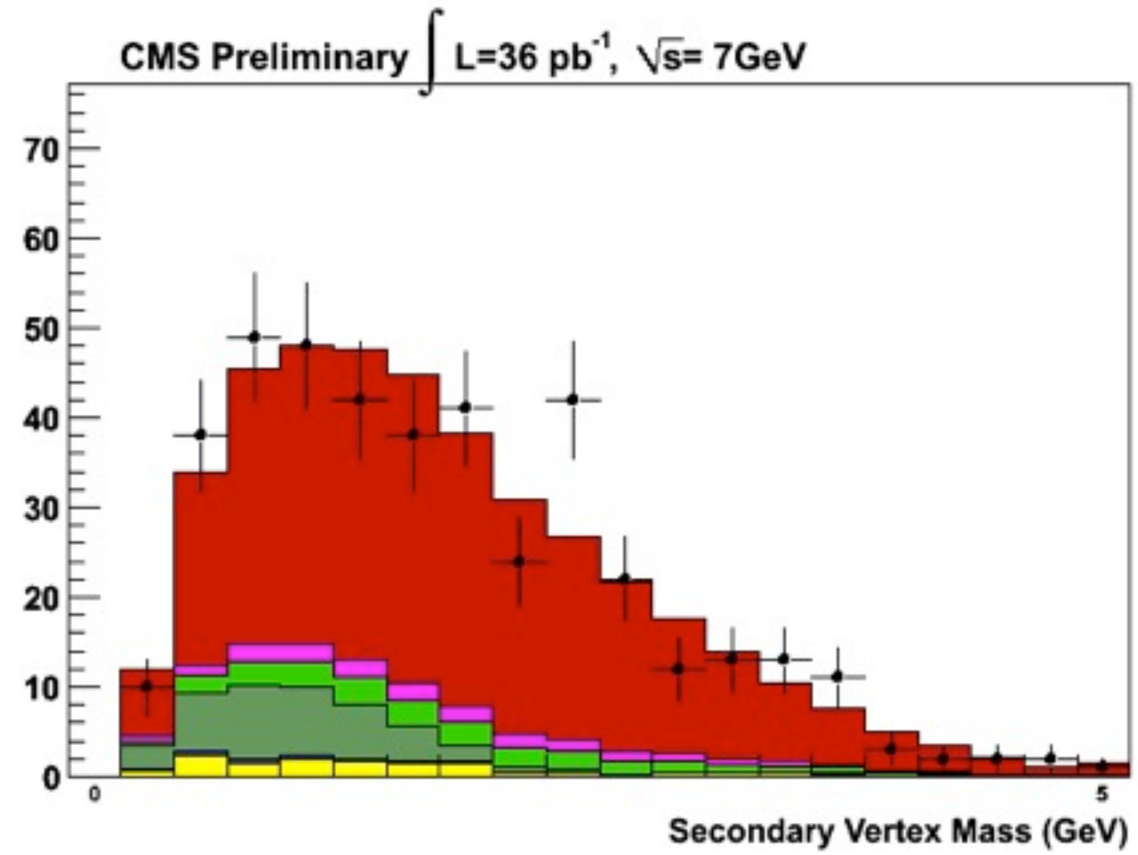
- Take all events (electrons and muons) with
  - $\geq$ 4 jets
  - $\geq$ 1 b-tag
- Put secondary vertex mass of leading b jet into fit.
- Constrain
  - Wbb (200% ± 200% SM)
  - Single top (100% ± 30% SM)
  - QCD (to MET fits ± 100%)
- Result:
  - σ_{tt} = 150 ± 17 (stat + Wbb)

    ± 11 (Btag) ± 11 (JES)

    ± 9 (Syst) pb

    = 150 ± 22 pb

Most of this is due to uncertainties on Wbb!



Theory value $\sigma_{top\ pair}$ = 157 pb.

How Can We Reduce Uncertainties due to Wbb, B-tagging, and JES?

Simultaneous Fit

- Fit separately lepton flavor (electron,muon), number of jets (1, 2, 3, 4, ≥ 5), and number of tags (1, ≥ 2).
- Fitter maximizes Poisson likelihood P(N_{pred}|Data) for each bin.
  - It needs to understand how much of each sample (e.g., top) is there for each lepton flavor, jet, and tag region.
- For example, top:

Top cross section (floats in fit)

MC prediction of events for a given lepton, jet, tags region

$$\boxed{\mathcal{N}_{\text{pred}_{t\bar{t}}}(\text{lepton, jet, tag})} = \boxed{\sigma_{t\bar{t}} \cdot MC_{\text{pred}}(\text{lepton, jet, tag})} \cdot \boxed{P^{\text{Btag}}_{N_{t\bar{t}}}(\text{lepton, jet, tag}|\mathcal{R}_{\text{Btag}})} \cdot P^{\text{JES}}_{N_{t\bar{t}}}(\text{lepton, jet, tag}|\mathcal{R}_{\text{JES}}) \cdot \ldots$$

Number of predicted top pair events for a given lepton, jet,tag region

Polynomial function that describes fractional change to prediction as a function of R_{btag} . Always define to be exactly 1 when R_{btag} =0.

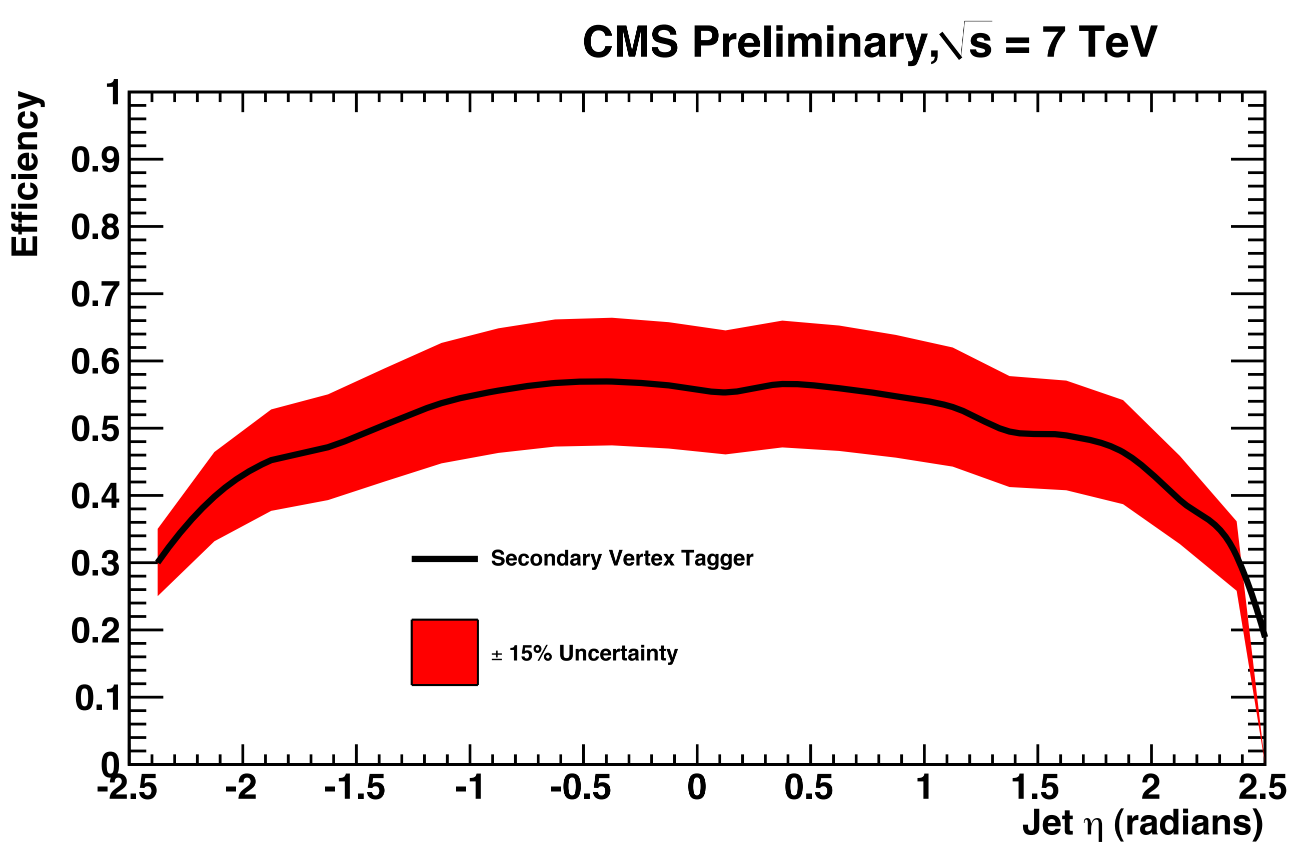
Nuisance parameter for the B-tagging

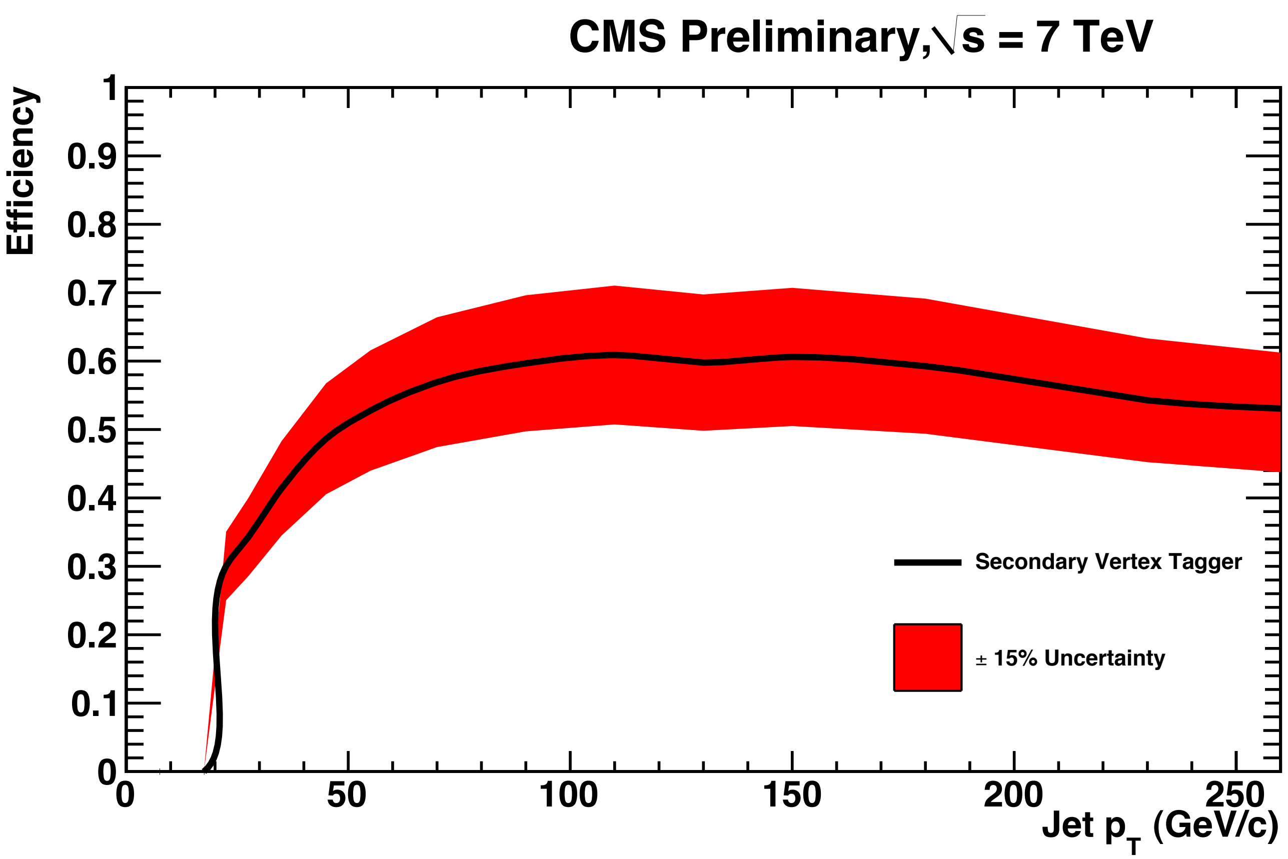
b-Tagging Efficiency in Data

- Weight the tag jets in simulation

$$\mathcal{W} = \begin{cases} S_{btag} & \text{heavy flavor jet tagged during simulation} \\ 0 & \text{heavy flavor jet not tagged during simulation} \\ S_{\text{mis}} & \text{light flavor jet} \end{cases}$$

Efficiency in Data

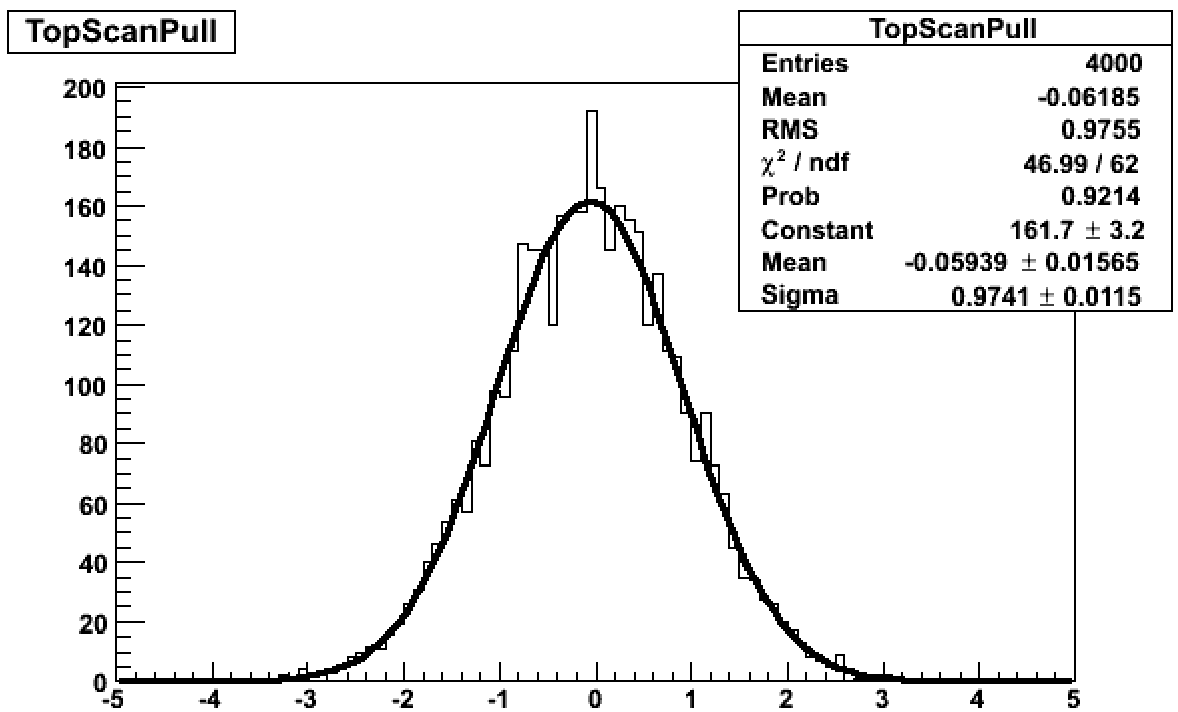




Coverage

- How do we know that the fitter doesn’t get lost somewhere?
- We run pseudo-experiments to determine 15%, 50% and 84% points for various pull distributions
- We correct for these small under coverage/bias

	Fitted values			PE Corr. [σ]			Corr. values		
		+ Err	- Err	Bias	+Err	-Err		+Err	-Err
Electron	162.4	8.9	-8.3	-0.06	1.04	1.01	163.0	9.3	-8.4
Muon	162.9	7.9	-7.7	-0.03	1.01	1.03	163.2	8.0	-7.9
e+mu	164.2	6.1	-5.9	-0.03	1.01	1.03	164.4	6.2	-6.1



Top pull distribution for the combine Mu+Ele channel generated with Q2 systematic uncertainty

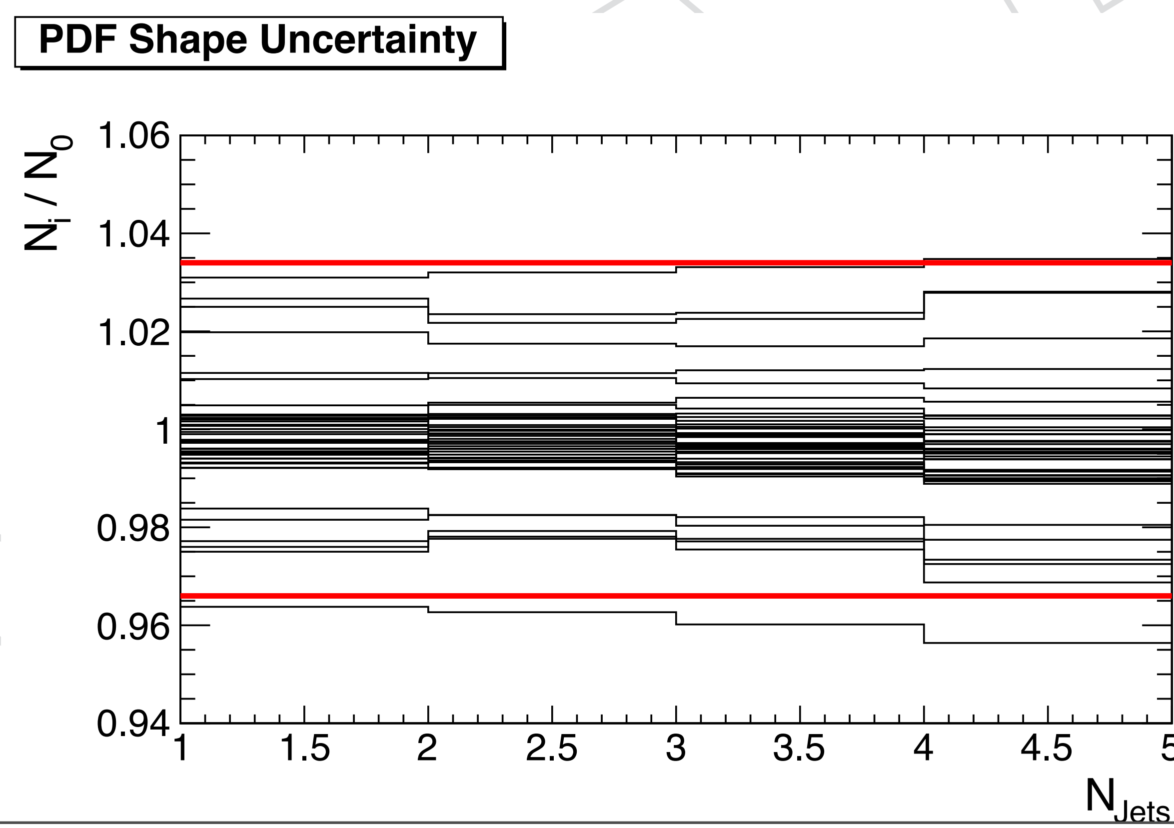
PDF Uncertainty

- Examine the uncertainties in the PDF set CTEQ6M (default) which are defined in PDF set CTEQ61
- The systematic uncertainty on the acceptance is estimated (1.004, 0.997)

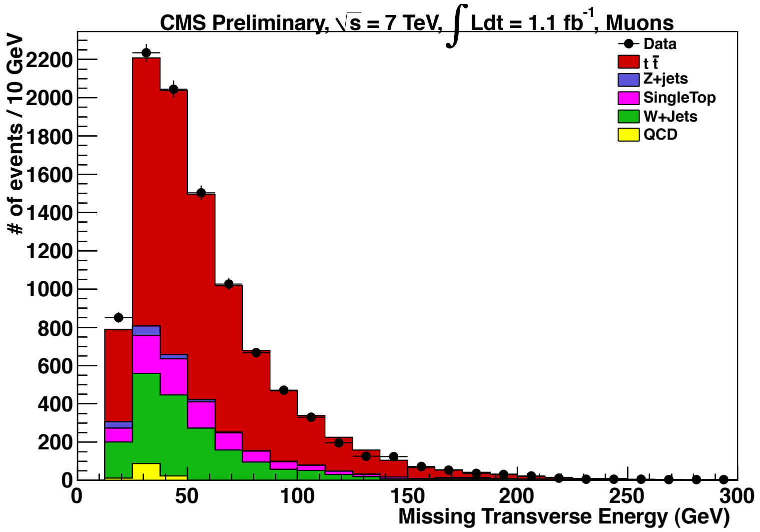
$$\Delta = \frac{1}{N_{events}} \sum_{events} \left[\sum_{i=1}^{22} \left(\frac{\mathrm{PDF}^i_+}{\mathrm{PDF}_0} \right)^2 + \sum_{j=1}^{22} + \left(\frac{\mathrm{PDF}^j_-}{\mathrm{PDF}_0} \right)^2 \right]$$

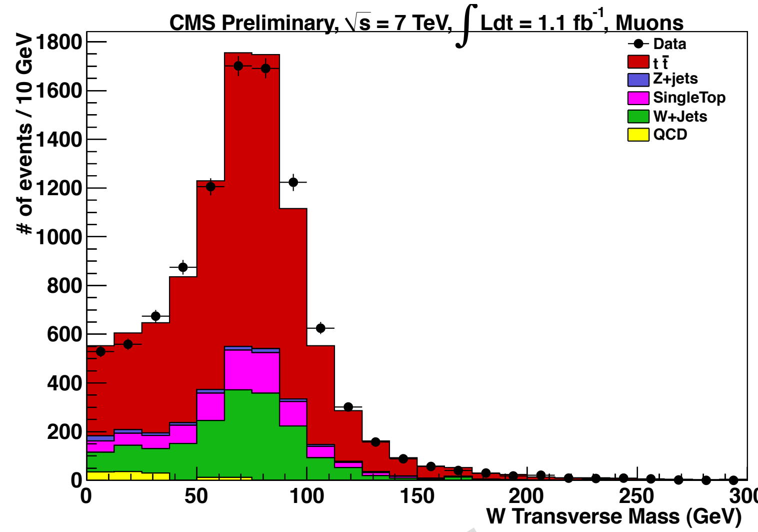
PDF uncertainty eigenvector weights

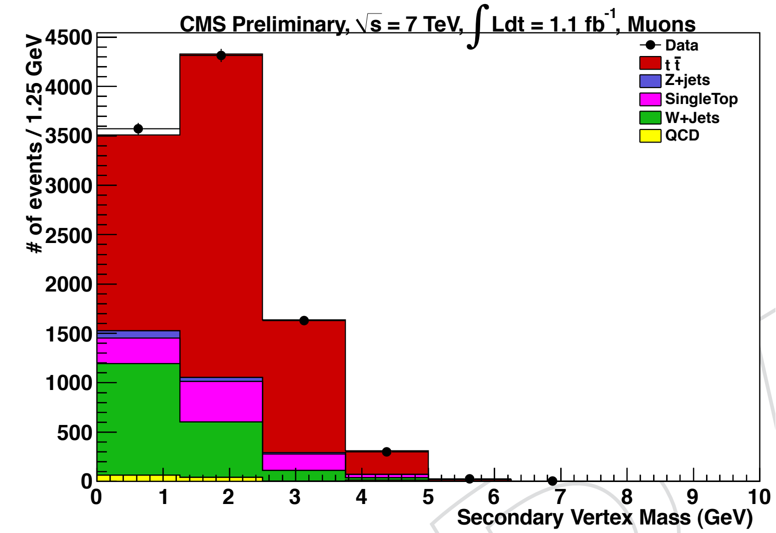
- The additional uncertainty due to Njets shape is estimated by examining the ratio between each of the Njet distribution corresponding to 44 eigenvectors in CTEQ61 and the nominal
- A flat 3.4% uncertainty for the 68% C.L. brackets the variation seen conservatively

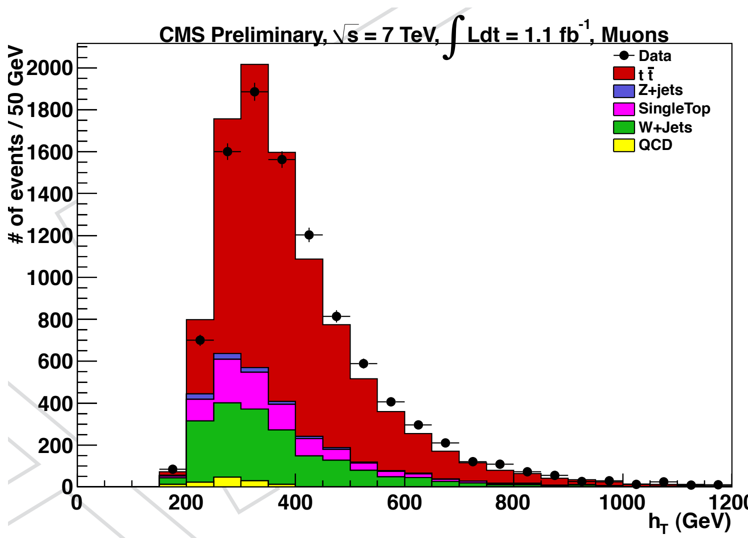


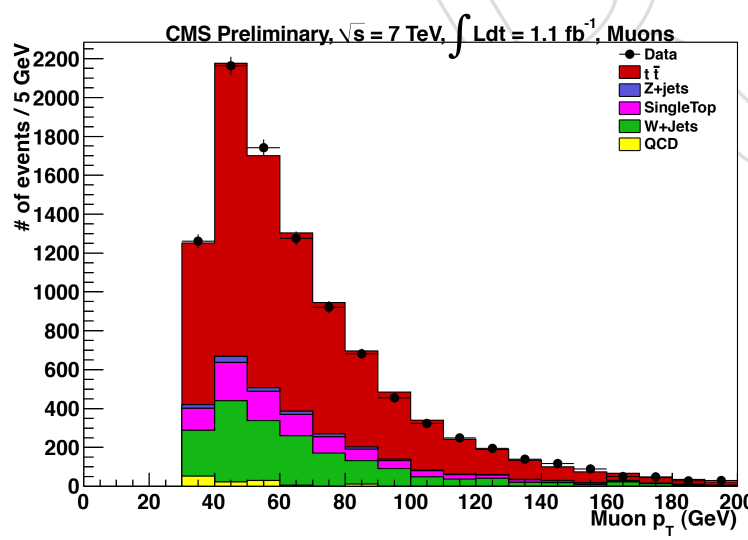
μ+jets kinematic distributions

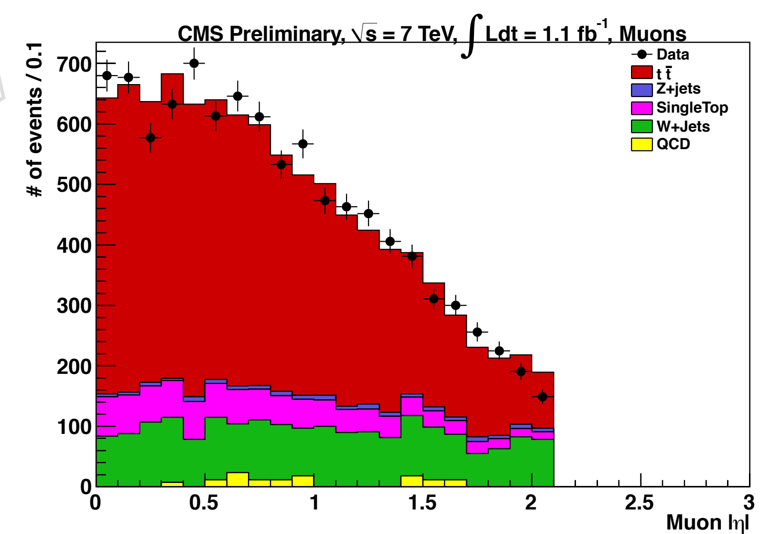












e+jets kinematic distributions