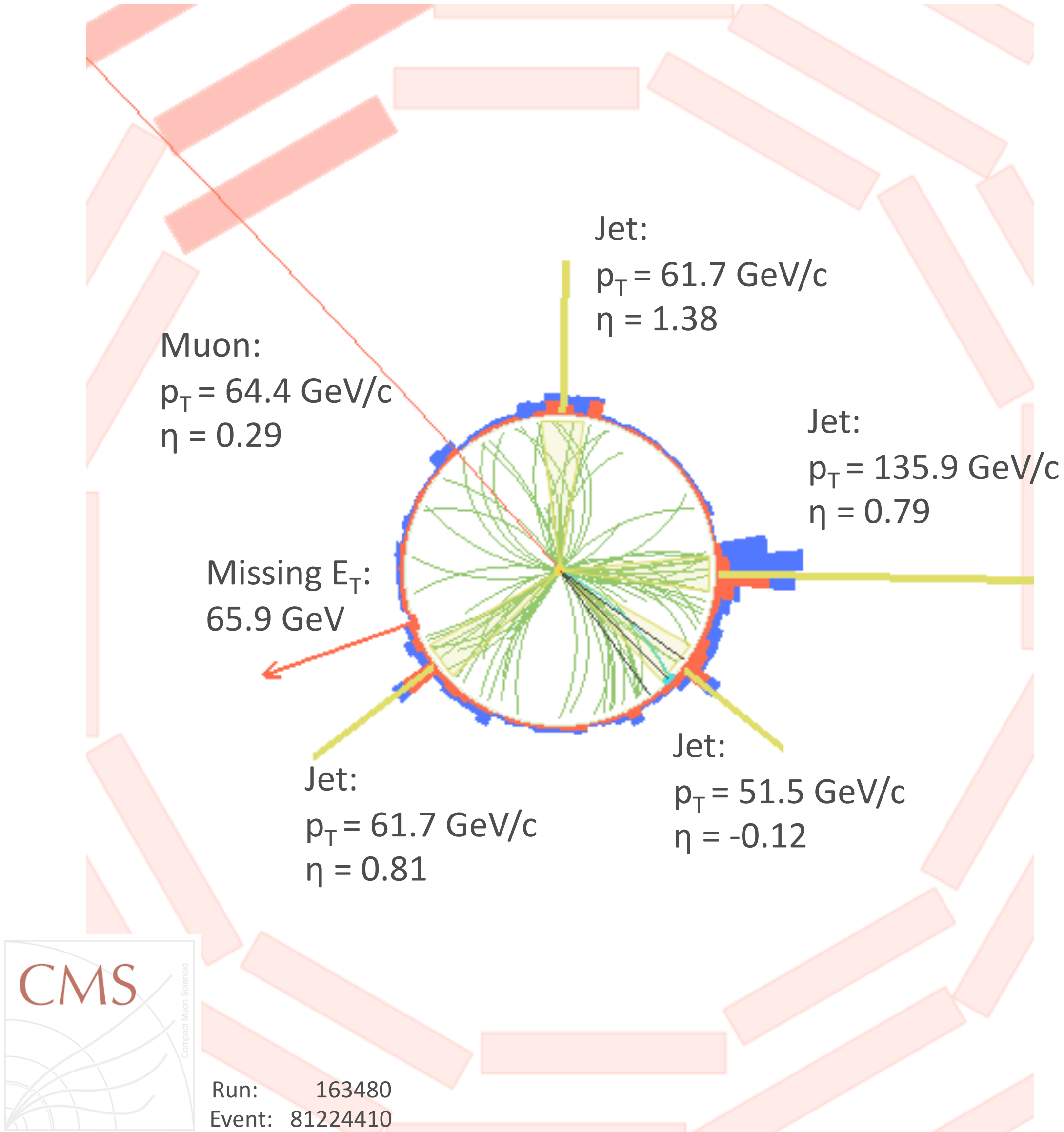
Top physics at CMS

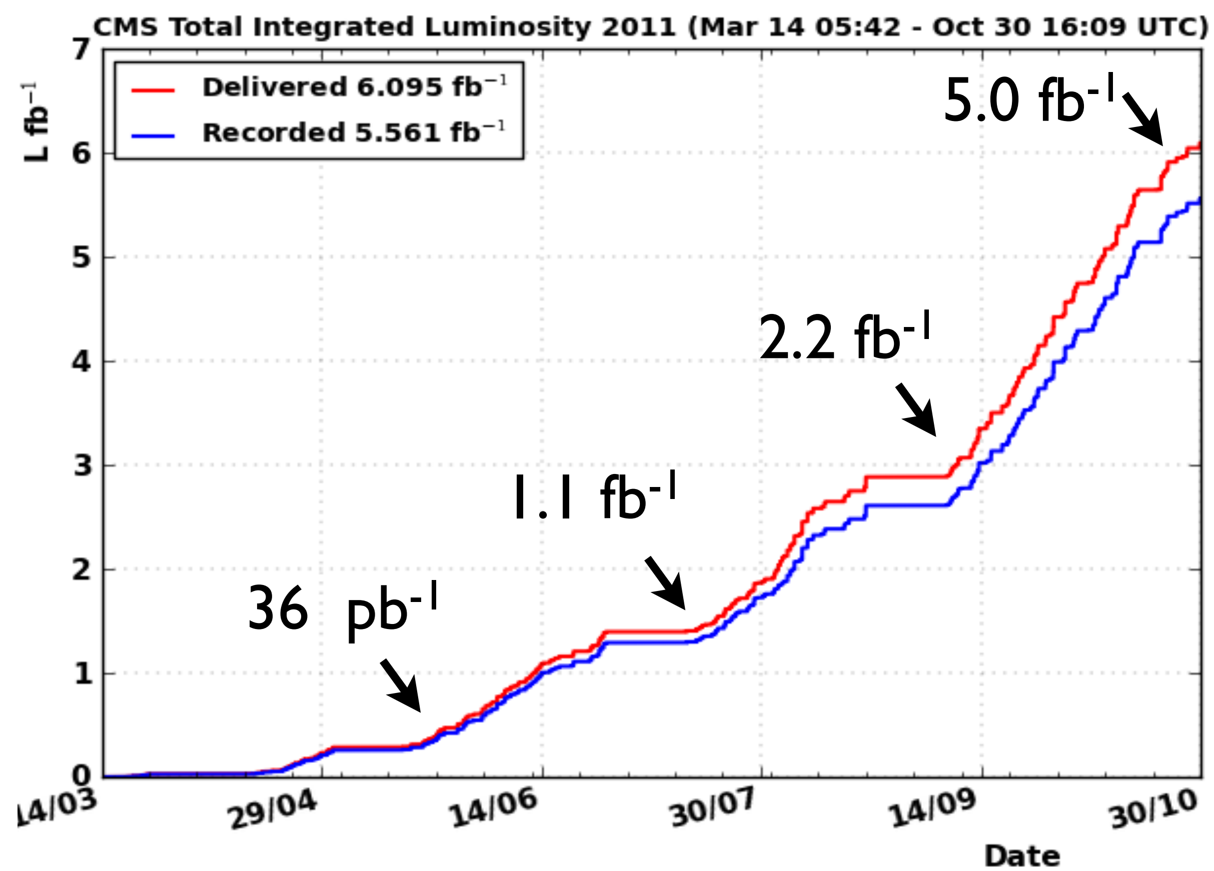


Tae Jeong Kim (Korea University)

On behalf of CMS collaboration
For ICFP 2012 at Kolymbari in Greece
15/06/2012

Introduction

- Outline
  - Motivation
  - Top production and decays
  - Physics Objects
  - Results
    - Top pair cross section
    - Differential cross section
    - Single top cross section
    - Top mass
    - Top quark properties
    - Search for ttbar resonance
    - Charge asymmetry

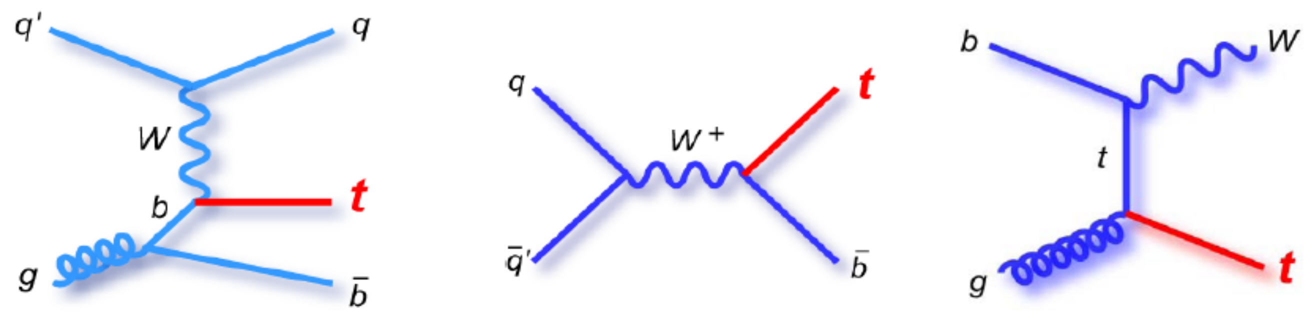


Motivation

- Top physics
  - Can give hints for EWSB.
    - Top mass is the heaviest SM particles.
  - Indirect search for Higgs and new physics.
  - Test of Perturbative QCD through precise measurement
    - direct access to fundamental SM parameters.
  - Main background for new physics
    - possible deviation due to new physics

Top production & decays

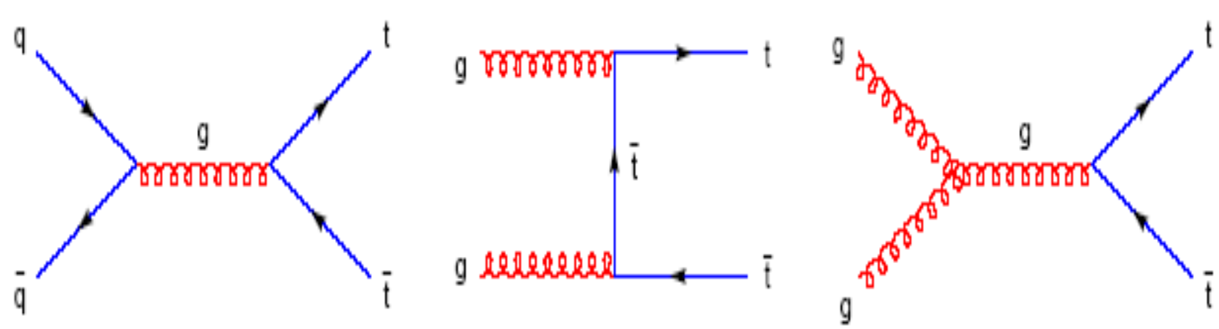
- Single top production



t-channel σ(7 TeV)~64 pb | s-channel σ(7 TeV)~4.6 pb | tW-channel σ(7 TeV)~15.6 pb

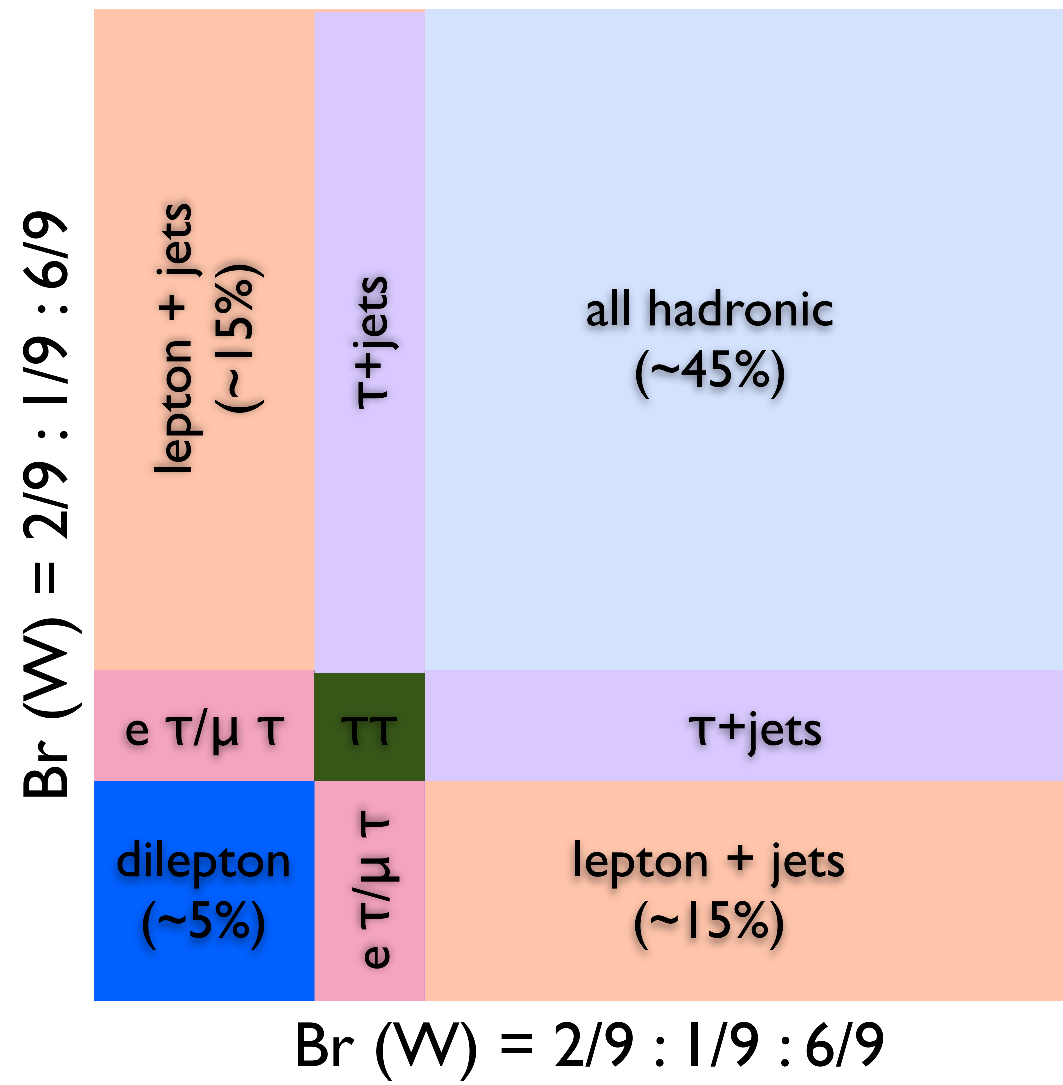
Kidonakis, NLO+NNLL
t-channel: PRD 83 (2011) 091503
s-channel: PRD 81 (2010) 054028
tW-channel: PRD 82 (2010) 054018

- Top pair production



NLO (MCFM): 158 pb
approx. NNLO: 163 pb
Kidonakis, PRD 82 (2010) 114030
Langenfeld, Moch, Uwer, PRD80 (2009) 054009

- Top decays



Physics Objects & MC sample

Muons	$\|\eta\| < 2.4$ (2.1), Particle-based isolation
Electrons	$\|\eta\| < 2.5$, (veto $1.44 < \|\eta\| < 1.57$), Particle-based isolation
Taus	charged hadrons + calorimeter informations (HPS algo.)
Jets	Particle-flow* jets (Anti-Kt with dR=0.5), $p_T > 30$ GeV
MET	opposite transverse direction of vector sum of all particles

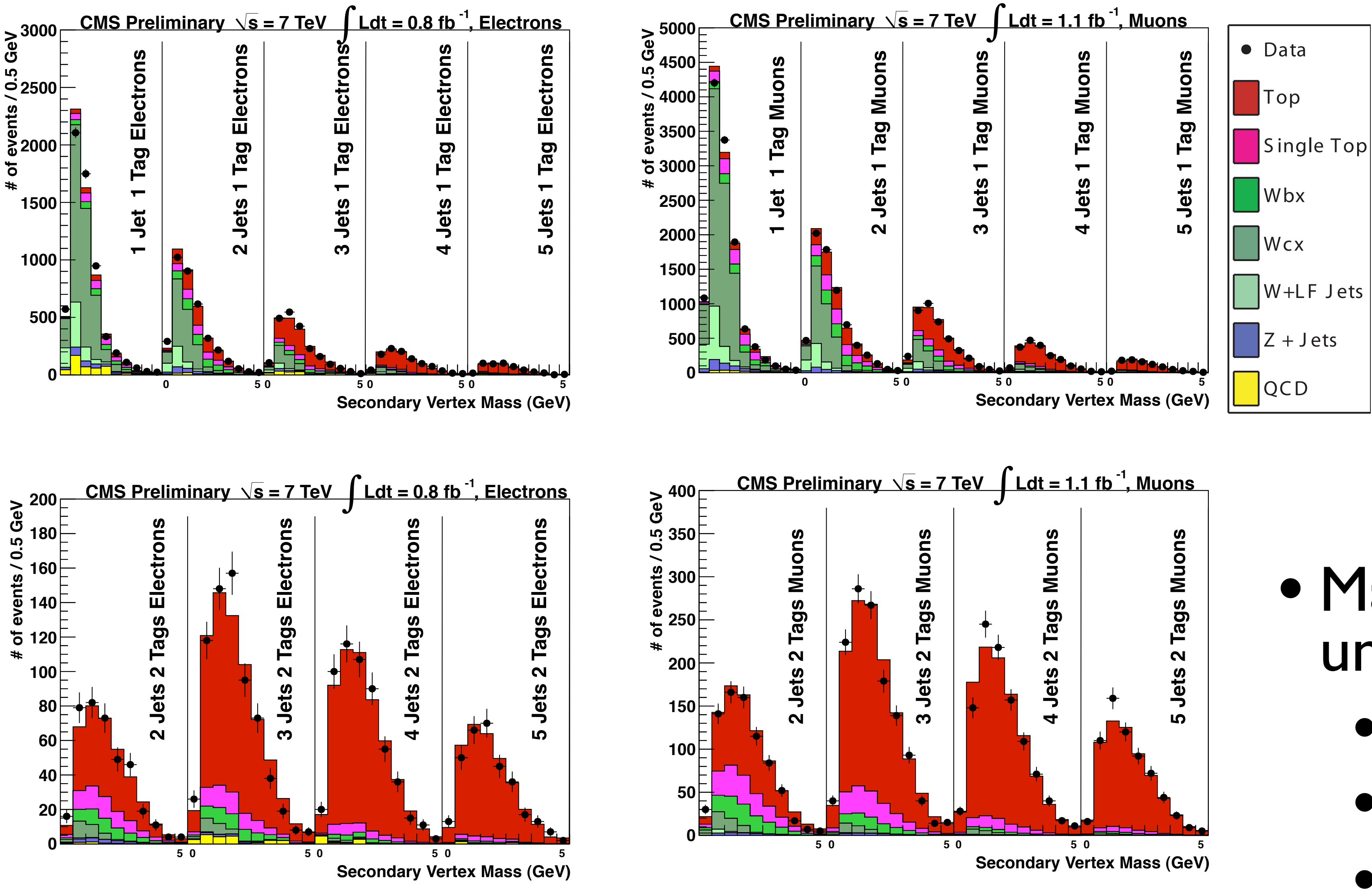
- Top signal sample
  - MadGraph with matrix elements up to three additional partons
  - POWHEG for single top production.
  - ME are matched with Pythia for Parton showering (PS)
  - Top mass 172.5 GeV
  - use NLO 157.5 pb for normalization.
  - TAUOLA for tau decay

*Combines all information from all sub-detectors and reconstruct all particles: charged hadrons, photons, neutral hadrons, muons and electrons which are used for jet and MET reconstruction as well as for isolation requirement.

Lepton+jets

TOP-11-003

- Binned profile likelihood fitting
- Fitting to secondary vertex mass distribution in 1 b-tag and 2 b-tag jet bins



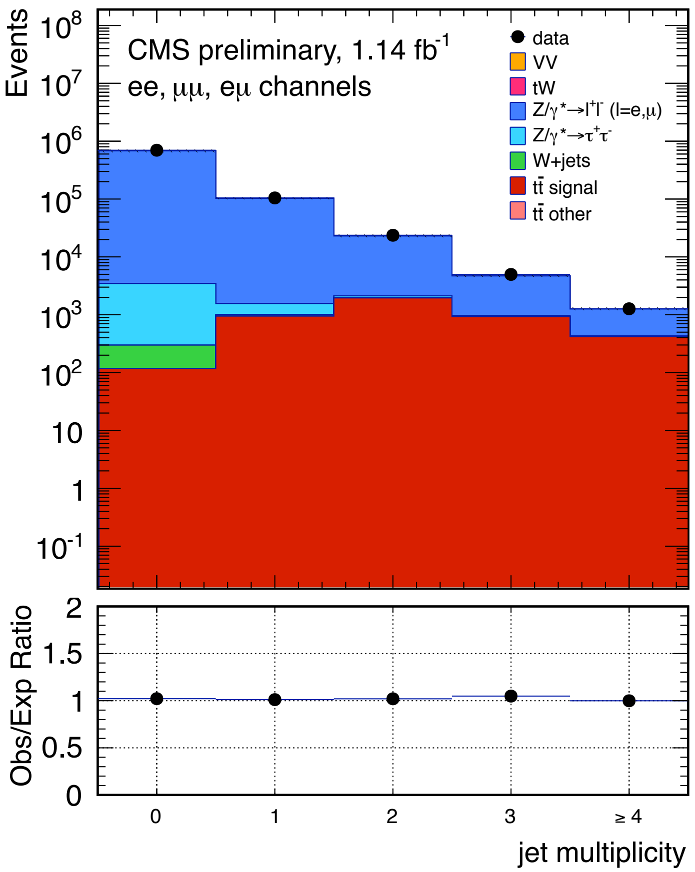
- Event selection
  - Only one isolated lepton : $p_T > 45/35$ GeV (e/μ)
  - MET > 20/30 GeV (e/μ)
  - b-tag (secondary vertex)
- QCD shape is from non-isolated data.

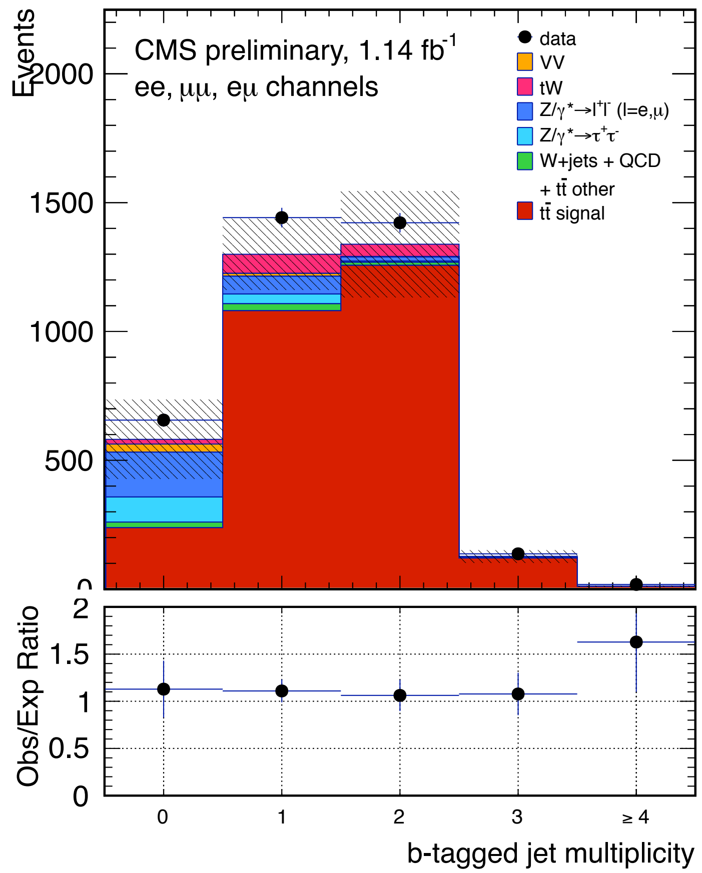
- Main systematic uncertainties included in fit
  - W + jets Q^2
  - b-tagging efficiency
  - JES

σ(comb.)=164.4±2.8(stat.)±11.9(syst.)±7.4(lumi.) pb

Dilepton

TOP-11-005





- Event Selection
  - Two opposite sign isolated leptons $p_T > 20$ GeV
  - $M_{ll} > 12$ GeV & $|M_{ll} - 91| > 15$ GeV (ee/μμ)
  - At least two jets $p_T > 30$ GeV
  - MET > 30 GeV (ee/μμ)
  - One b-tagging
- Data-driven way
  - Lepton efficiency
  - DY and QCD

- Counting method
- BLUE (Best Linear Unbiased Estimator) method for combination of three decay modes

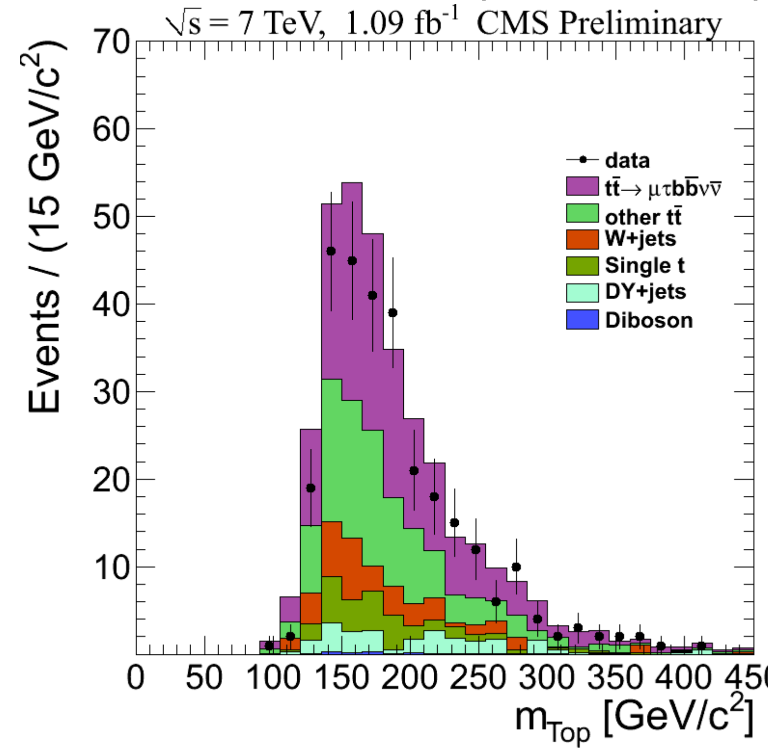
$\sigma = 169.9 \pm 3.9(\text{stat.}) \pm 16.3(\text{syst.}) \pm 7.6(\text{lumi.})\text{pb}$

Tau decay mode

- Tau identification (hadronic tau decay)
  - Hadrons plus strips (HPS) combining charged hadrons and EM particles in strips in calorimeter to take into account π^0
- tau+lepton decay mode
  - H^+ (<top mass) can contribute.
  - Data-driven background estimation
    - The jet can fake tau jet → fake rate.
    - Take average over two estimates from
      - QCD (gluon jet) + W+jets(quark jet)

σ=148.7±23.6(stat.)±26.0(syst.)±8.9(lumi.)pb

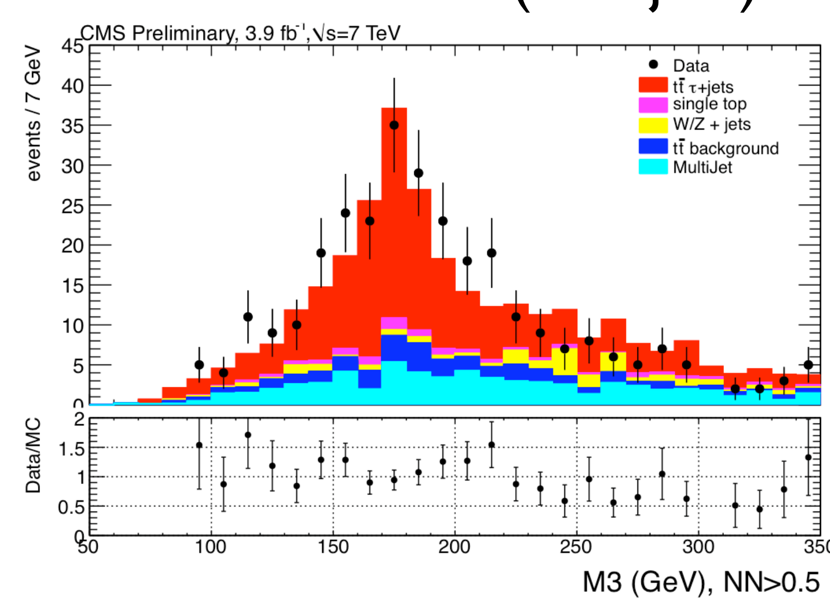
TOP-11-006 (muon+tau)



- tau+jet decay mode (not for combination yet)
  - 4 jets are required.
  - QCD background is from data.
  - NN method

σ=156±12(stat.)±33(syst.)±3(lumi.)pb

TOP-11-004 (tau+jets)



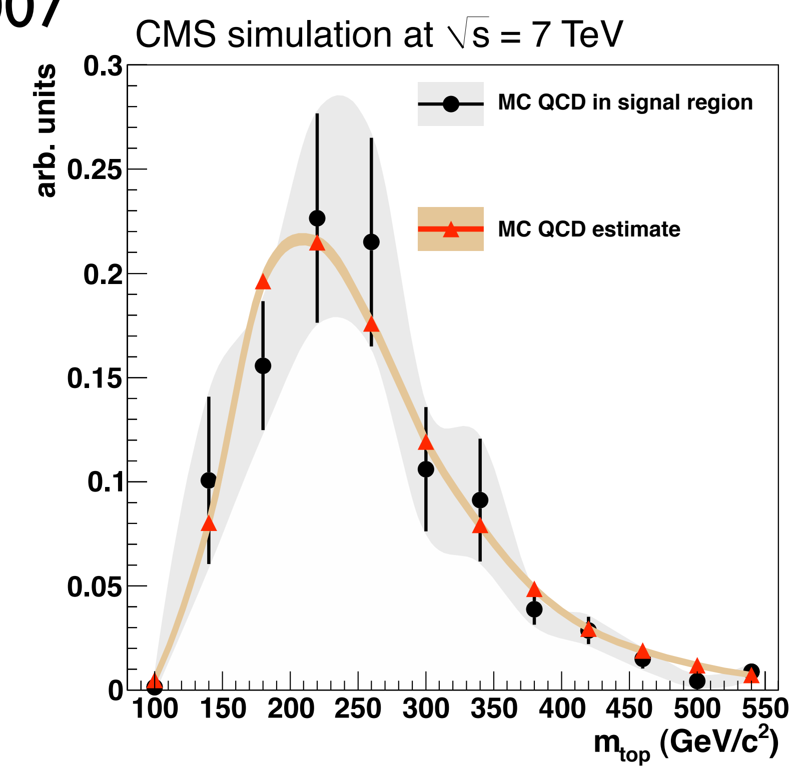
Hadronic decay

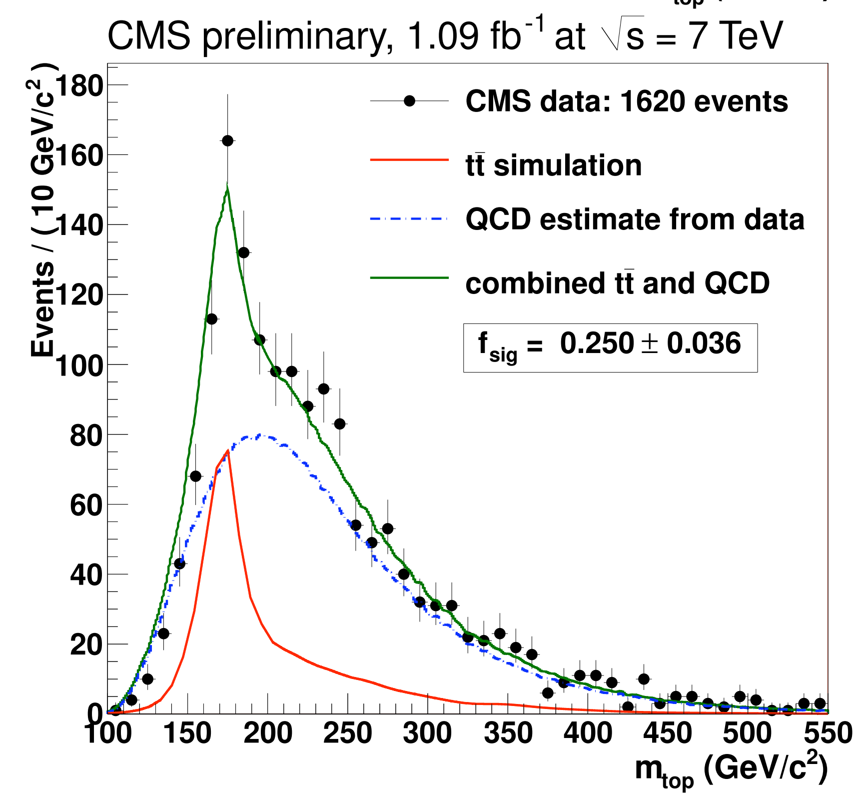
TOP-11-007

- Branching ratio is large ~ 45 %
  - suffer from large multi jet background
- Event selection
  - 6 jets are required
  - at least two b-tagged jets
- QCD contribution from data
  - scale factor from non b-tagged jet sample (more than 6 jets) to b-tagged jets as a function of p_T and η.

- Uncertainty mainly from
  - b-tagging
  - jet energy scale
  - background estimation.

$\sigma = 136 \pm 20(\text{stat.}) \pm 40(\text{syst.}) \pm 8(\text{lumi.})\,\text{pb}$





Unbinned maximum likelihood fit

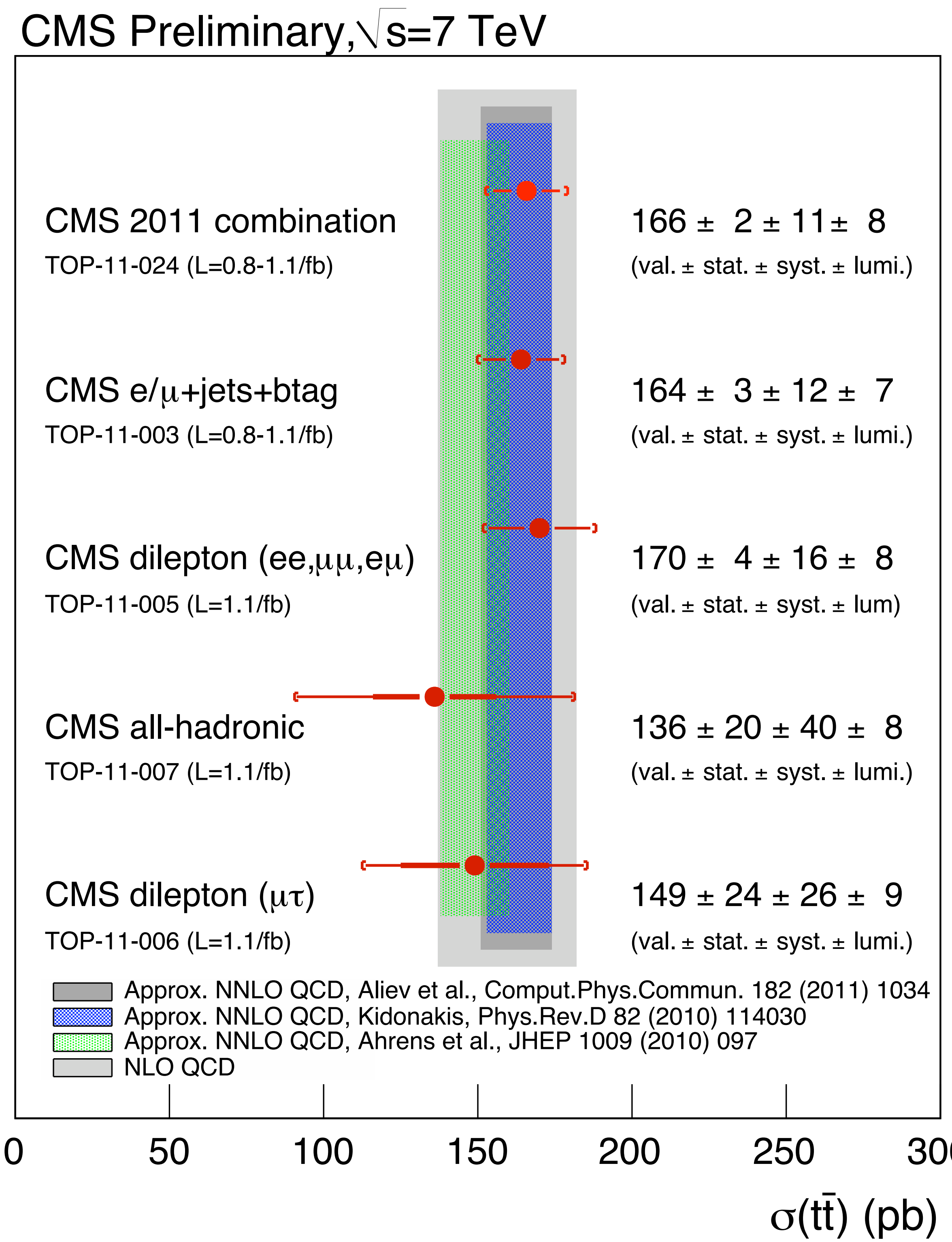
Combined cross section

TOP-11-024

- All possible decay channels are combined.
- Binned Likelihood fitting method.
- Take counting method analysis (dilepton) and unbinned analysis (hadronic decay) as one bin.
- Blue method is also used as cross check.

$\delta\sigma/\sigma$ = 8%

$$\sigma_{t\bar{t}} = 165.8 \pm 2.2(\text{stat.}) \pm 10.6(\text{syst}) \pm 7.8(\text{lumi.})\ \text{pb}$$



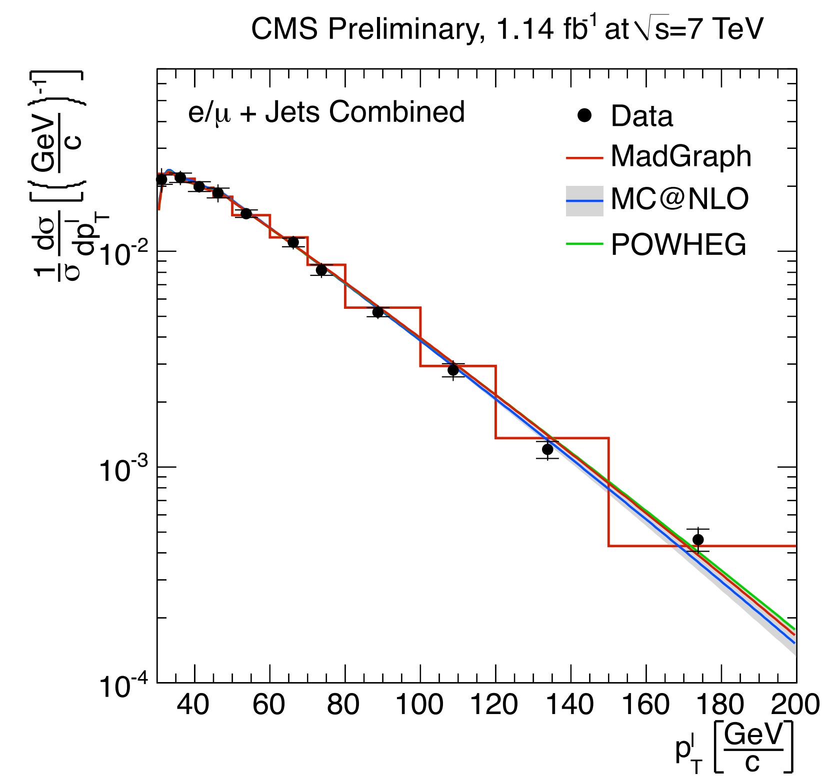
Differential cross section

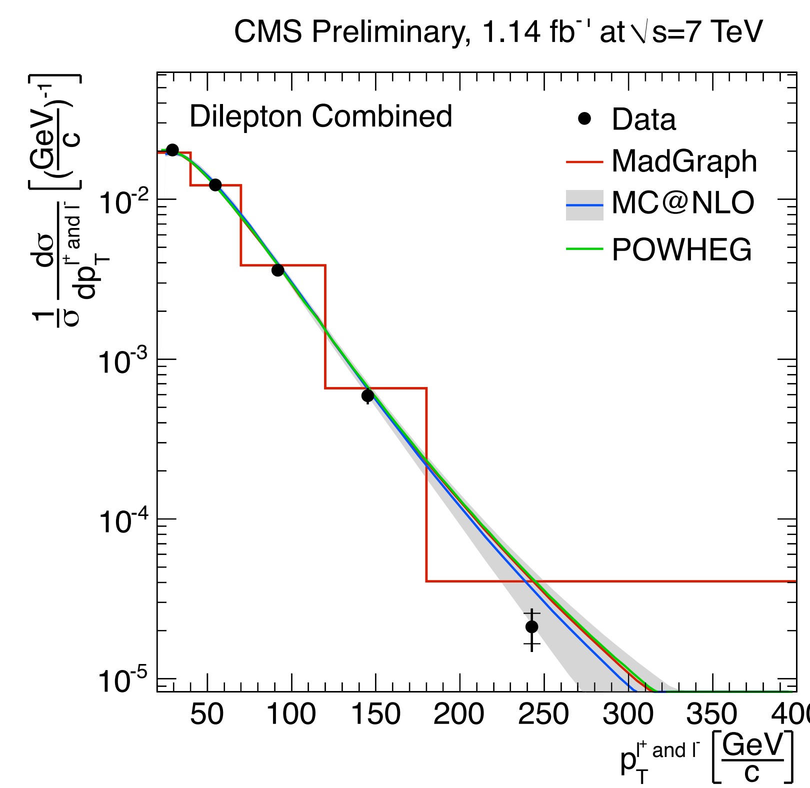
TOP-11-013

- Test pQCD in all kinematic variables of lepton, top quark and ttbar system.
- Sensitive to new physics.
- Dilepton and lepton+jets
- Normalized differential cross section.

$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{N^i_{\mathrm{Data}} - N^i_{\mathrm{BG}}}{\Delta^i_{\mathrm{X}}\epsilon^i L}$$

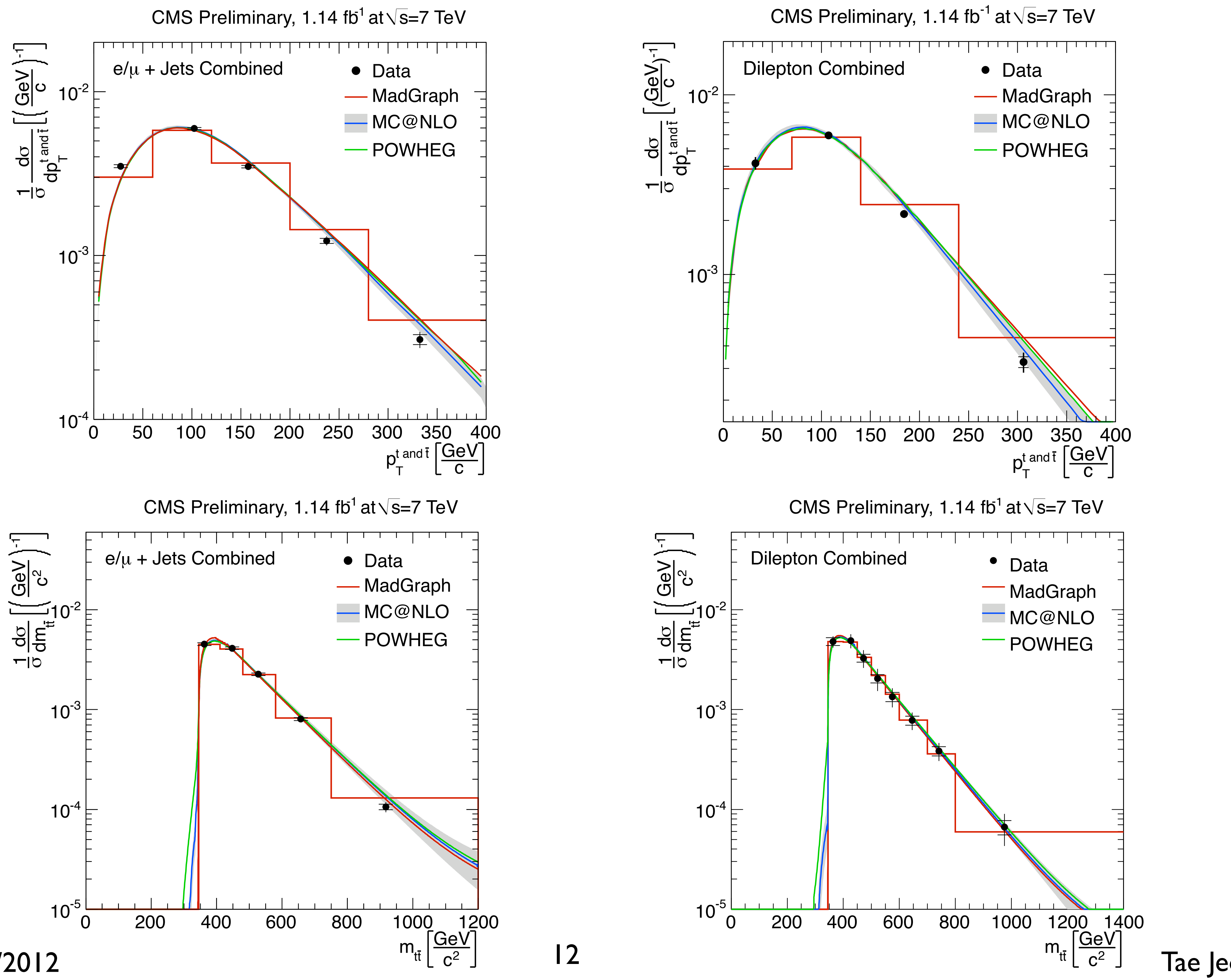
- Full kinematic reconstruction or four momentum sum (dilepton M_{tt})
- Bin by bin or SVD unfolding method
- Unfolding at parton level
- Systematic uncertainties
  - shape uncertainties
  - hadronization uncertainty





Differential cross section

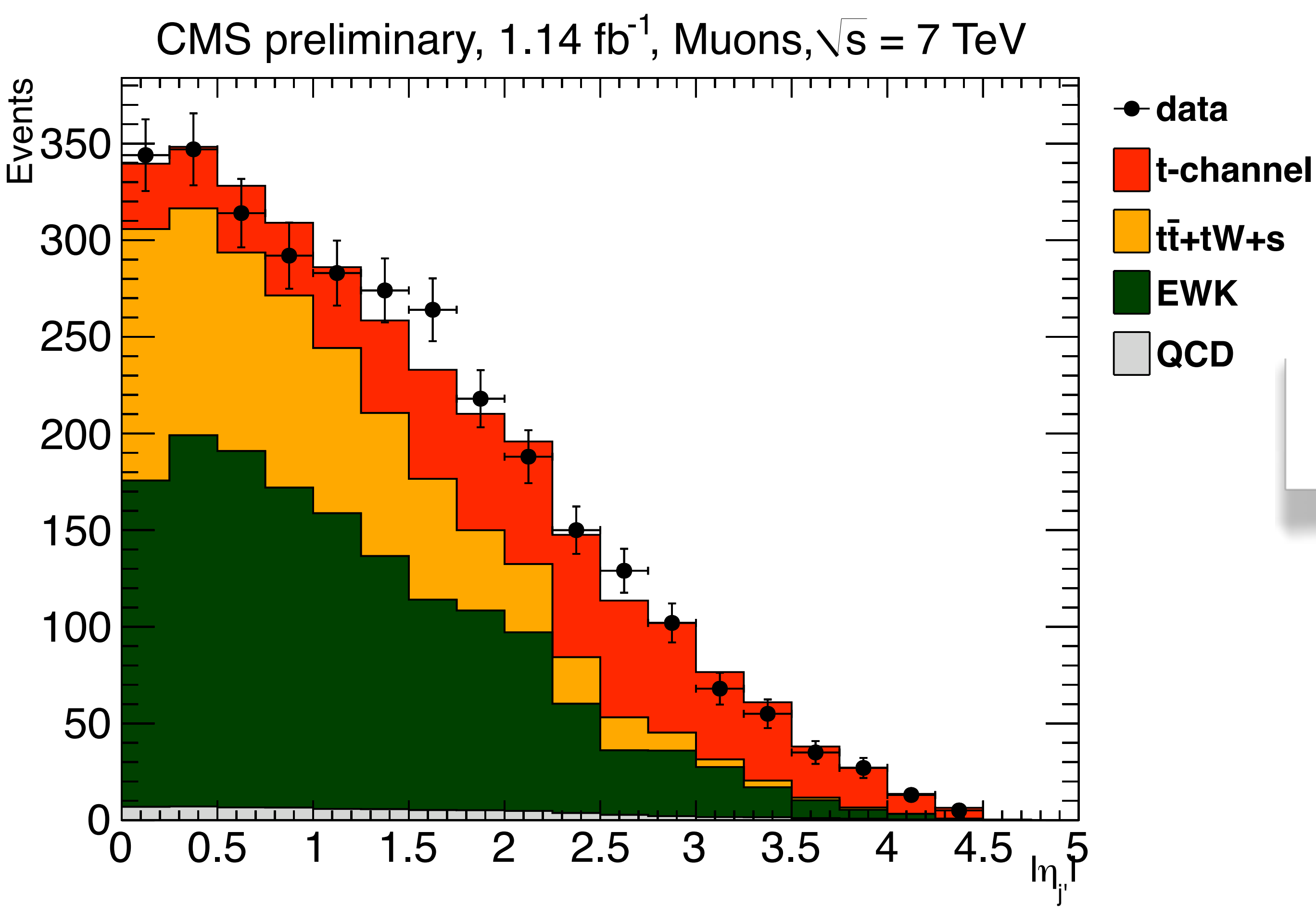
- Top quark distribution - Excellent agreement!

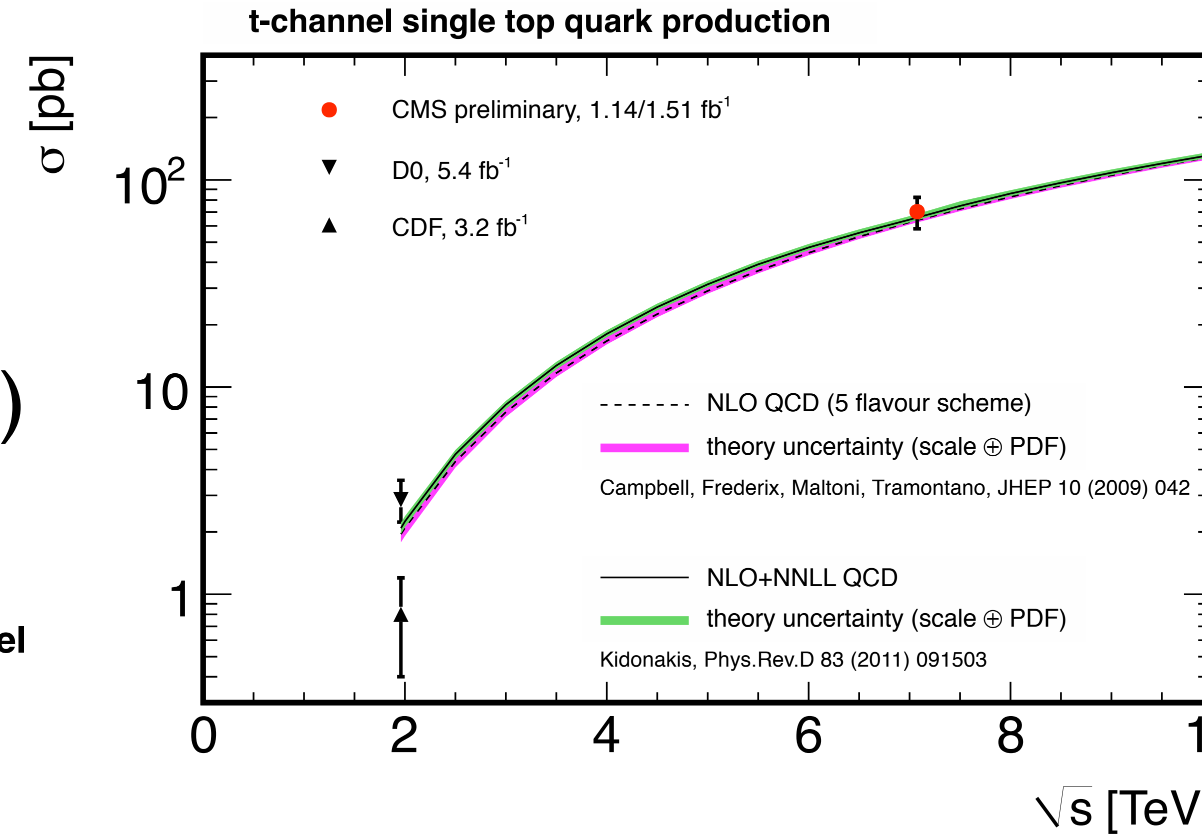


Single top (t-channel)

TOP-11-021

- Event selection
  - one isolated e ($p_T > 30$ GeV) or μ ($p_T > 20$ GeV)
  - 2 jets, MET > 30 GeV, $|\eta| < 5.0$
  - one "tight" b-tag
  - transverse $M_W > 40$ GeV
- Extract signal from a fit to angular distribution η of light jet (forward region)





$$\sigma_{t-\mathrm{ch.}} = 70.2 \pm 5.2(\mathrm{stat.}) \pm 10.4(\mathrm{syst.}) \pm 3.4(\mathrm{lumi.})\ \mathrm{pb}$$

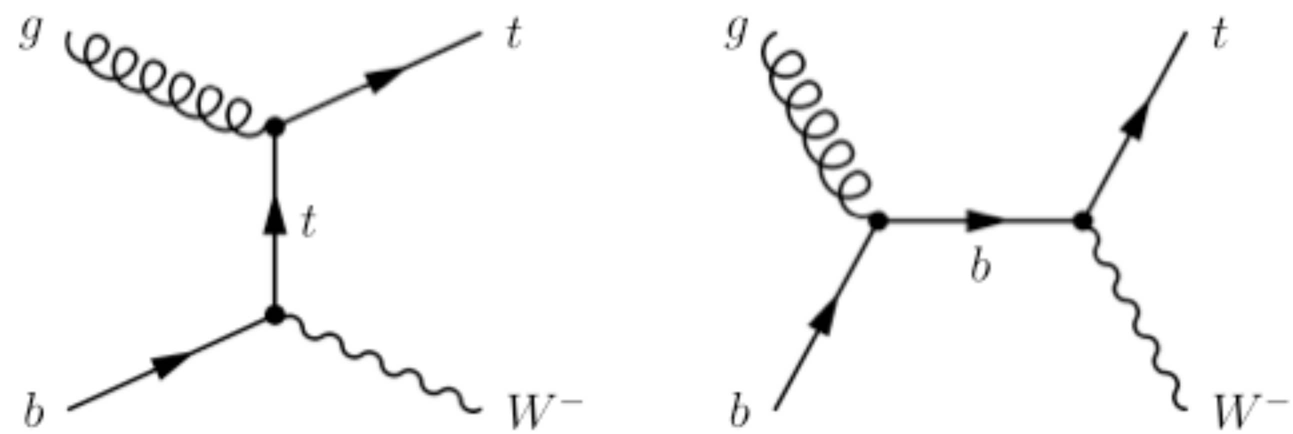
- Direct measurement of $|V_{tb}|$

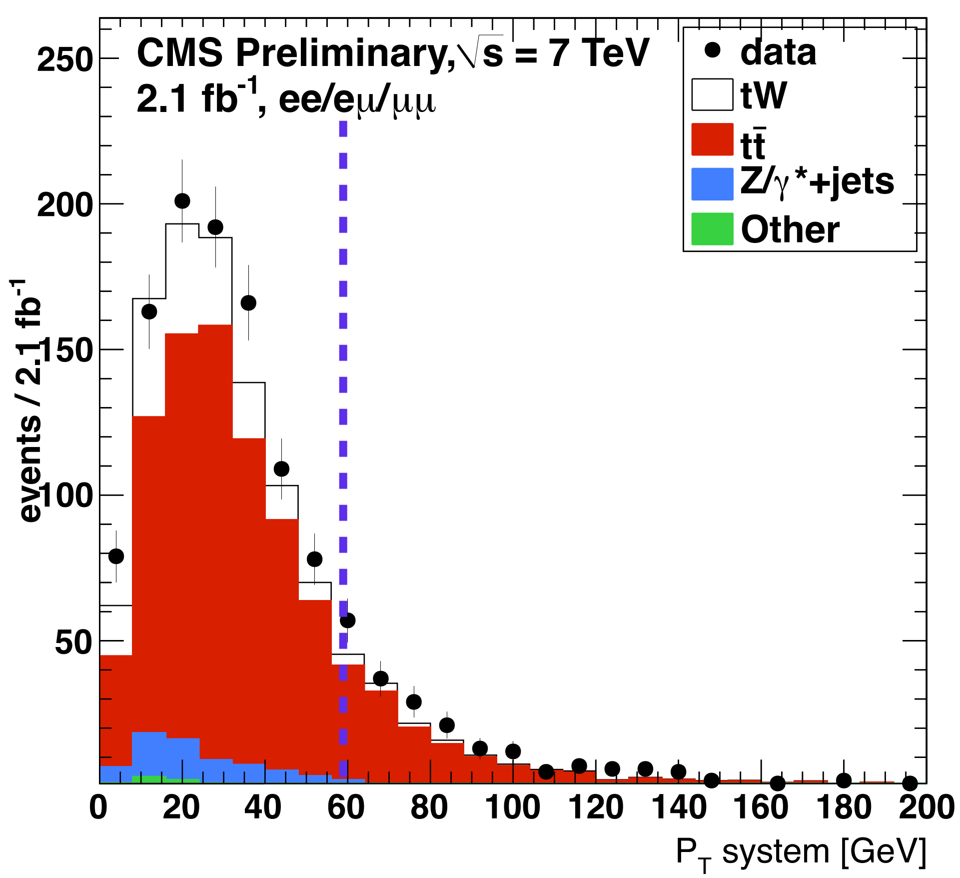
$$|V_{tb}| = \sqrt{\frac{\sigma_{t-\mathrm{ch.}}}{\sigma^{\mathrm{th}}_{t-\mathrm{ch.}}}} = 1.04 \pm 0.09\,(\mathrm{exp.}) \pm 0.02\,(\mathrm{th.})$$

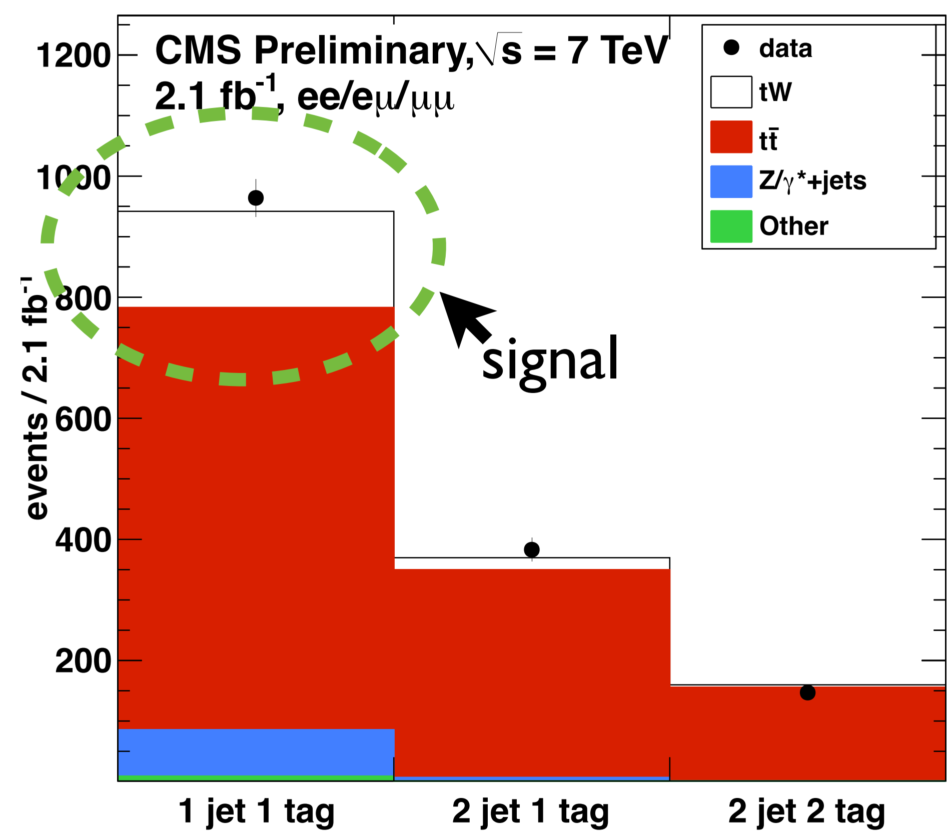
Single top (tW production)

TOP-11-022

- Events selection
  - similar to dilepton event selection.
  - second b-jet is vetoed.
  - requirement on p_T of system (< 60GeV)
- Use maximum likelihood fit







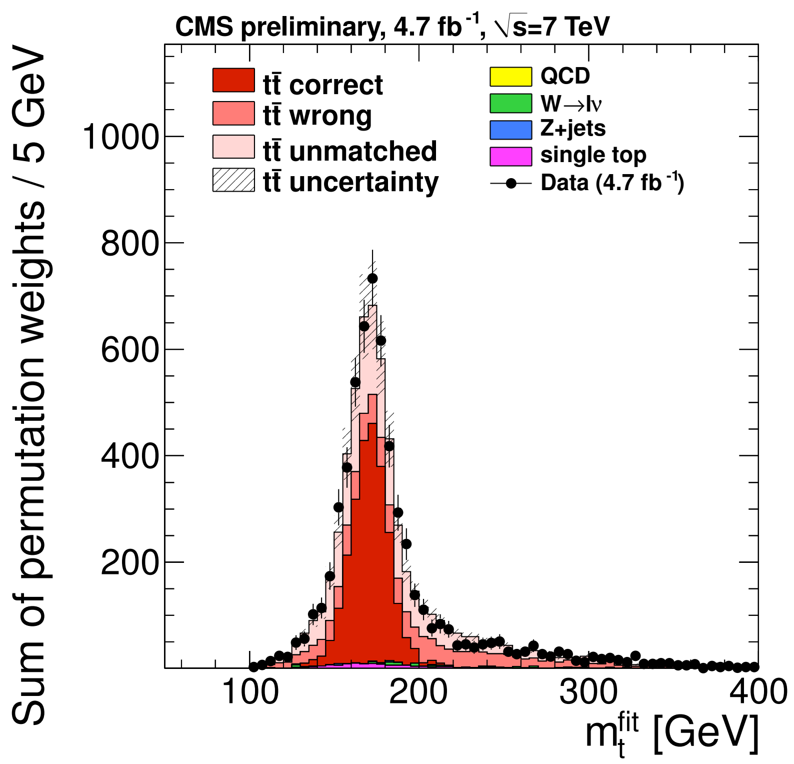
22^{+9}_{-7} (stat $\oplus$ syst) pb

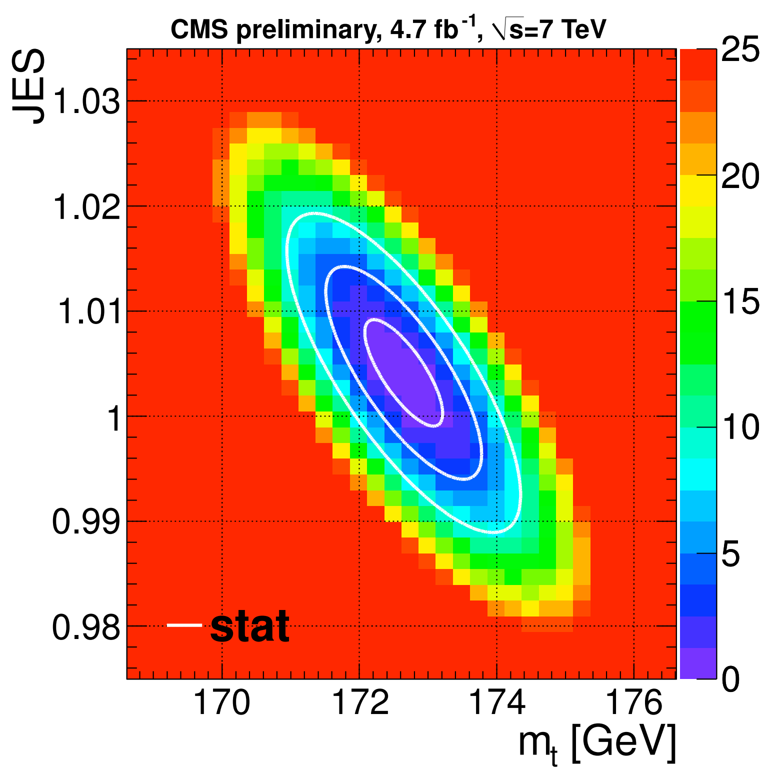
- Observed significance = 2.7 σ

Mass measurement in muon+jets

TOP-11-015

- Muon+jets
- Likelihood method considering all jets permutations and b-tagging information.
- Top quark mass and JES are obtained simultaneously.
- b-JES uncertainty is dominant.





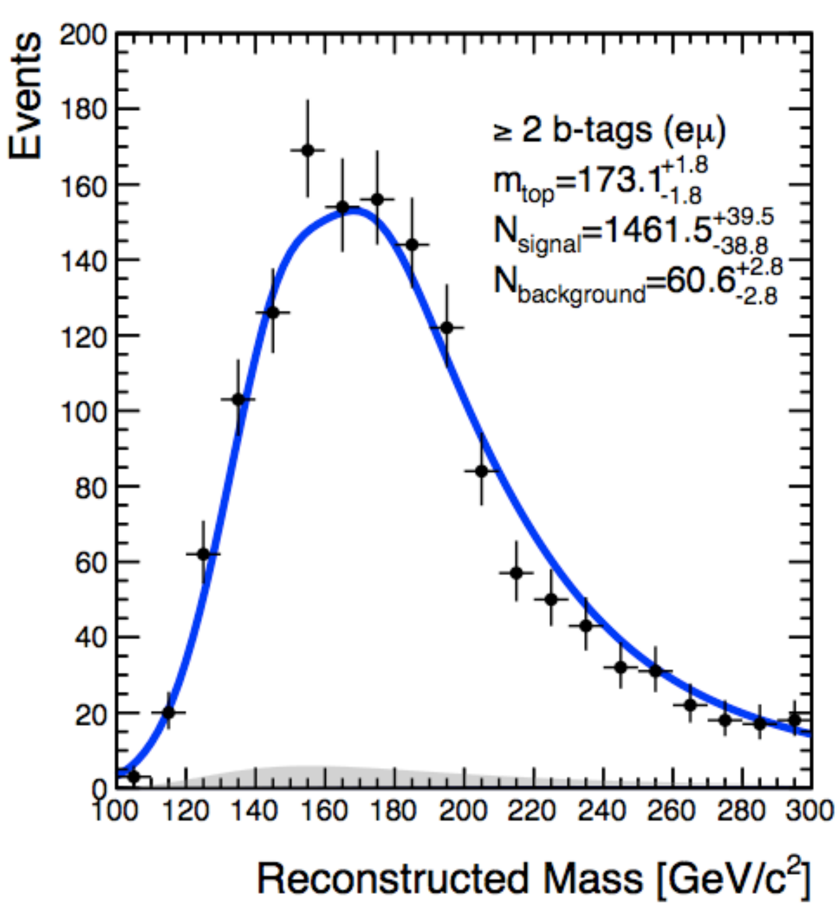
	δ_{m_t} (GeV)	δ_{JES}
Calibration	0.15	0.001
b-tagging	0.17	0.002
b-JES	0.66	0.000
p_T- and η-dependent JES	0.23	0.003
Jet energy resolution	0.21	0.003
Missing transverse energy	0.08	0.001
Factorization scale	0.76	0.007
ME-PS matching threshold	0.25	0.007
Non-$t\bar{t}$ background	0.09	0.001
Pile-up	0.38	0.005
PDF	0.05	0.001
Total	1.18	0.012

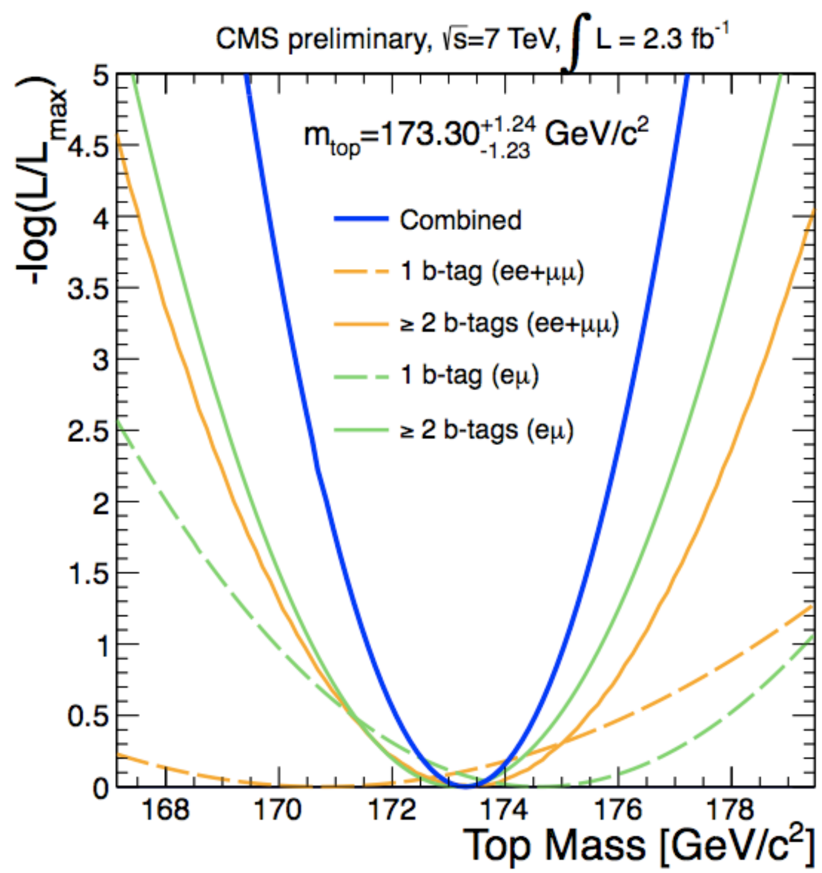
$$m_t = 172.64 \pm 0.57\ (\text{stat+JES}) \pm 1.18\ (\text{syst})\ \text{GeV}$$
$$\text{JES} = 1.004 \pm 0.005\ (\text{stat}) \pm 0.012\ (\text{syst})$$

Mass measurement in dilepton

TOP-11-016

- Reconstruct the top quark using KINb method.
  - based on energy-momentum conservation.
- To find solution, z component of ttbar system is varied.
- The lowest invariant mass when the two top masses is less than 3 GeV.
- Fitting to reconstructed top mass with signal shape linear functions of m_t.





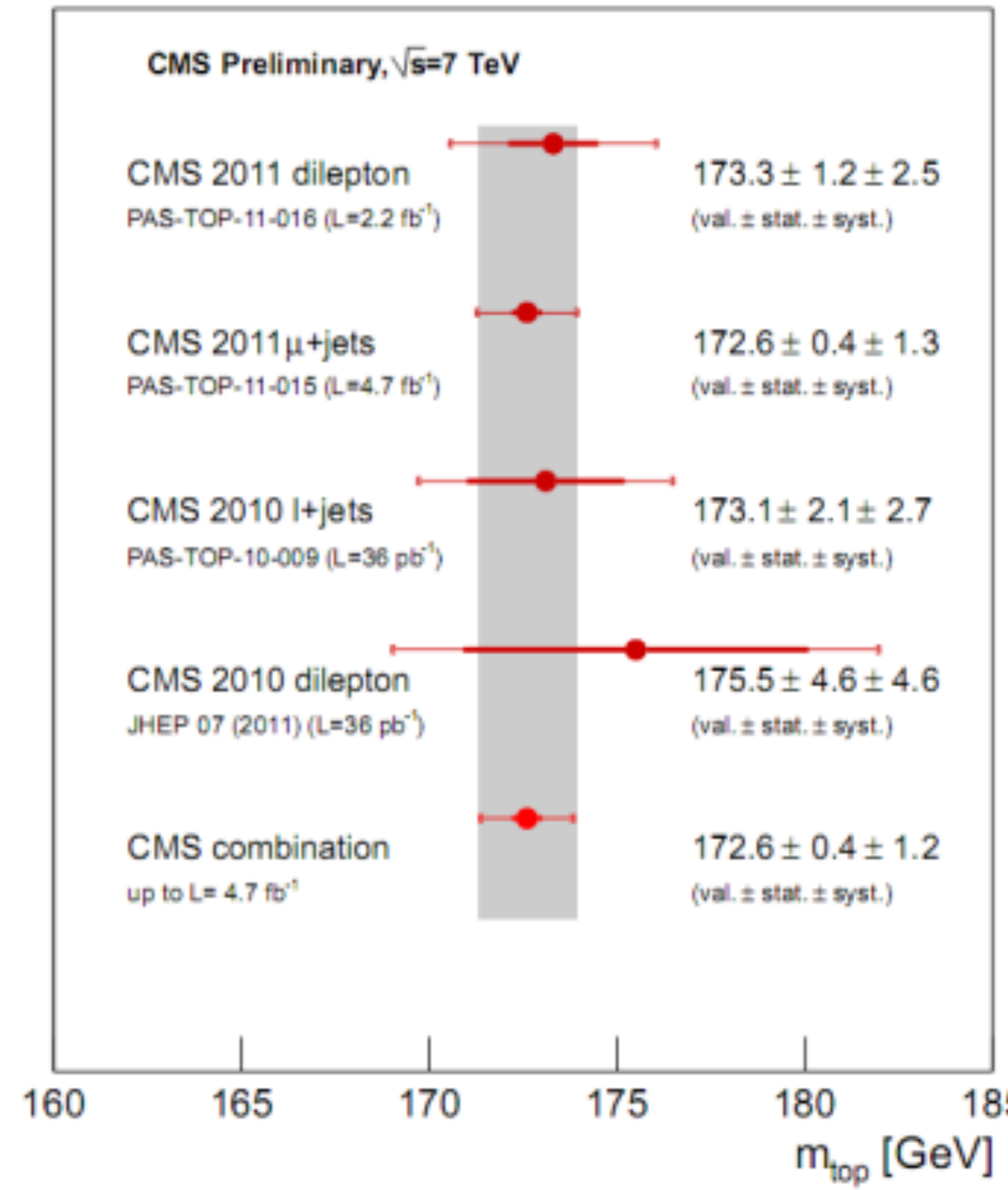
Source	Δm_{top} (GeV/c^2)
JES	$^{+1.90}_{-2.00}$
flavor-JES	$^{+1.08}_{-1.13}$
JER	± 0.30
LES	$^{+0.12}_{-0.18}$
Unclustered E_T^{miss}	± 0.43
Fit calibration	± 0.40
DY normalization	± 0.40
Factorization scale	± 0.41
Jet parton matching scale	± 0.65
Pile-up	± 0.19
b-tagging uncertainty	± 0.30
mis-tagging uncertainty	± 0.43
MC generator	± 0.14
PDF uncertainty	± 0.39
Total	$^{+2.52}_{-2.63}$

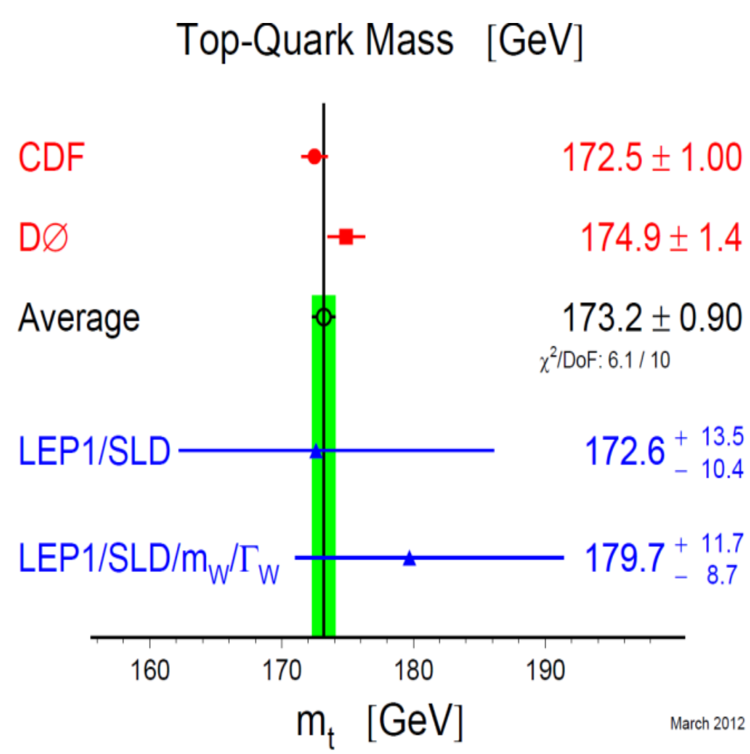
$$m_{top} = 173.3 \pm 1.2(\text{stat.})^{+2.5}_{-2.6}(\text{syst.})\ \text{GeV}/c^2$$

Mass combination

TOP-11-018

- Combining four results from dilepton and lepton+jets in 2010 and 2011.
- Use BLUE method for the combination.
  - The weight goes to the lepton+jets channel
- Competitive with Tevatron result
- Towards LHC and world combination in process.





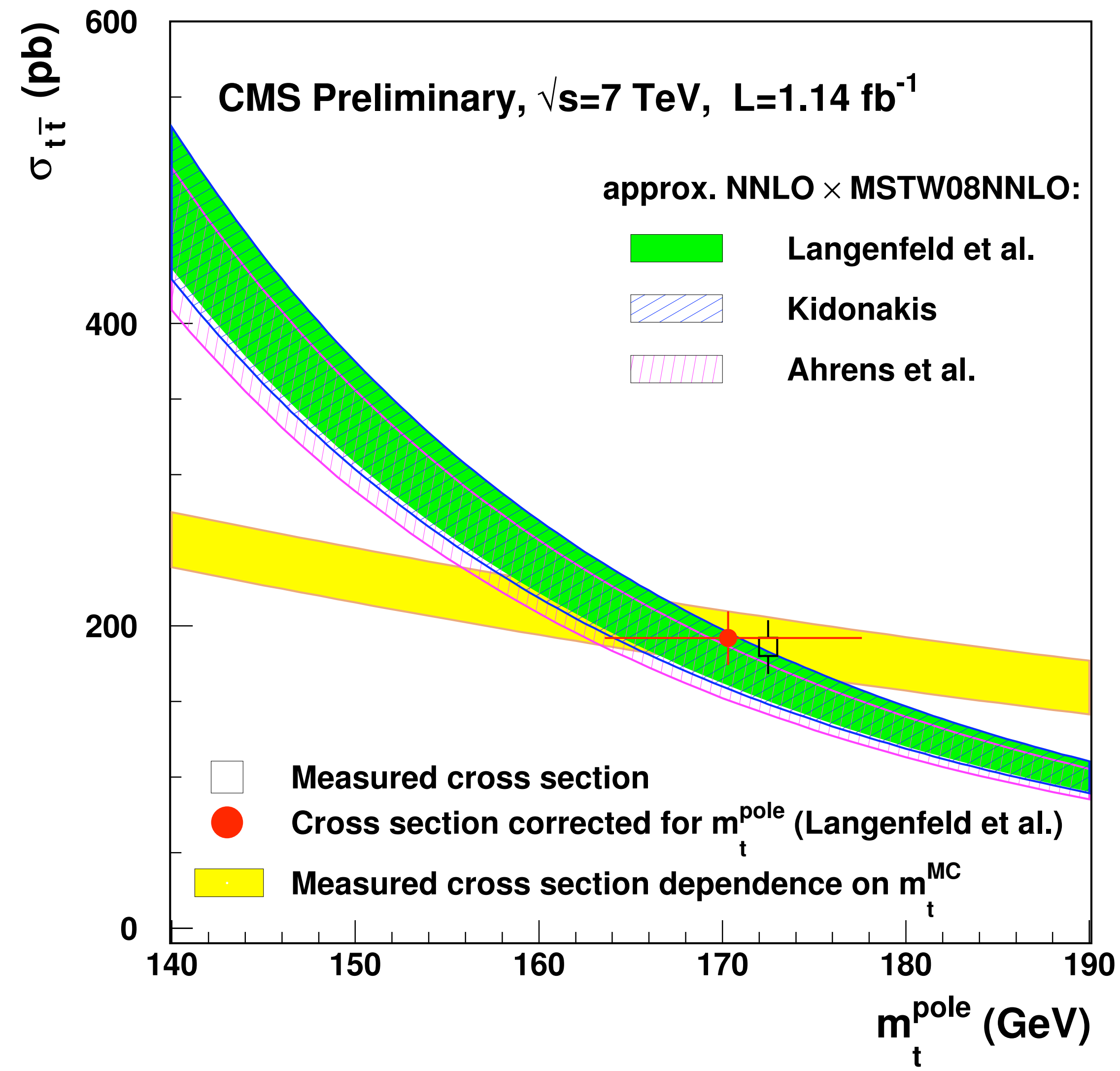
$$m_{top} = 172.6 \pm 0.4\ (\text{stat.}) \pm 1.2\ (\text{syst.})\ GeV/c^2$$

Top mass from cross section

TOP-11-008

- The cross section, σ_{tt} depends on MC top mass.
- Therefore, we can extract top mass from cross section measurement.
- Used cross section is from dilepton decay mode.
- Extract both pole mass and MS mass.
  - Pole mass is close to MC top mass.
  - Joint likelihood fitting to extract mass.

$$L(m_t) = \int f_{\text{exp}}(\sigma_{t\bar{t}}|m_t) f_{\text{th}}(\sigma_{t\bar{t}}|m_t) d\sigma_{t\bar{t}}$$



- Dependence on the PDFs.
  - 1-2 GeV
- Extracted top mass not competitive with the direct measurement.

The theory errors → scales, PDFs and α_S (m_Z)

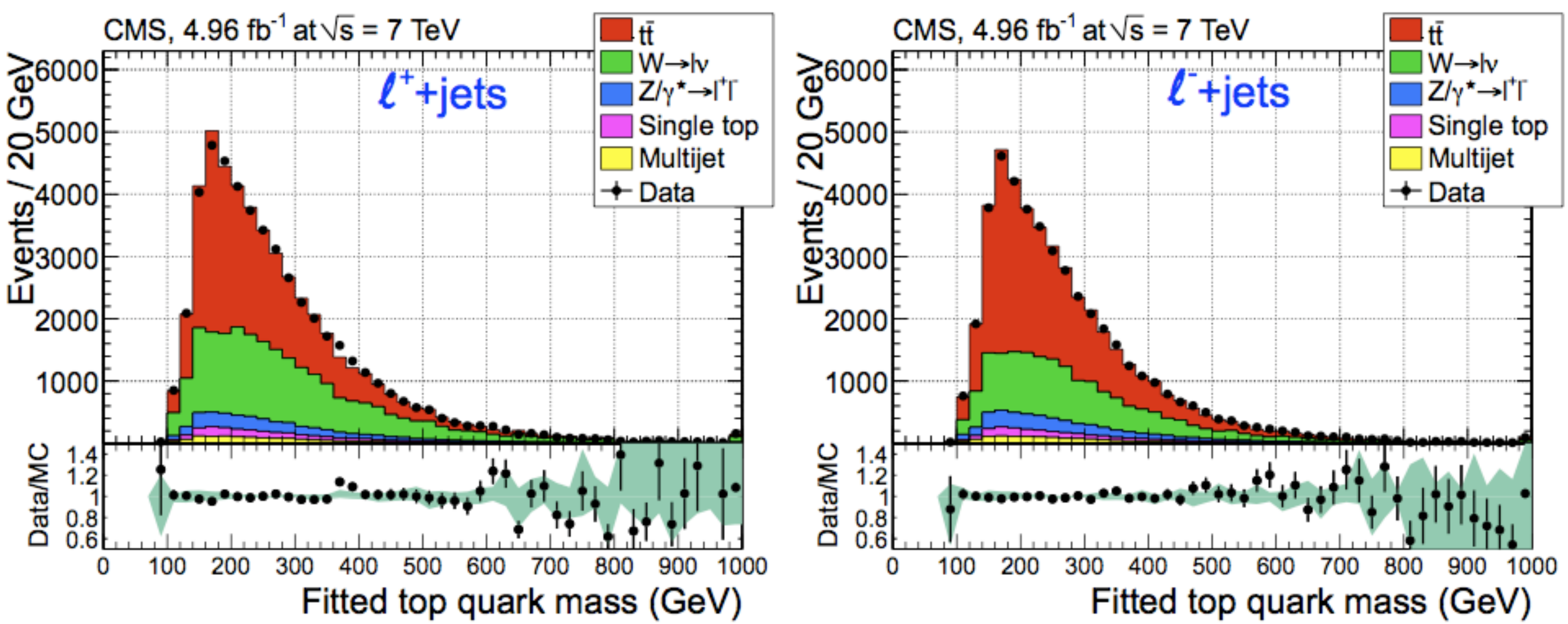
Approx. NNLO × MSTW08NNLO	m_t^{pole} / GeV	$m_t^{\overline{\text{MS}}}$ / GeV
Langenfeld et al. [7]	$170.3^{+7.3}_{-6.7}$	$163.1^{+6.8}_{-6.1}$
Kidonakis [8]	$170.0^{+7.6}_{-7.1}$	–
Ahrens et al. [9]	$167.6^{+7.6}_{-7.1}$	$159.8^{+7.3}_{-6.8}$

Top-antitop mass difference

arXiv:1204.2807

- CPT appears to be conserved in nature.
  - The mass of any particles must equal that of its anti-particles.
- Lepton+jets channel.
- Split the sample according to the charge of the lepton.
- Kinematic fit is used.
  - the same method for top mass reconstruction .
- World's best measurement so far.

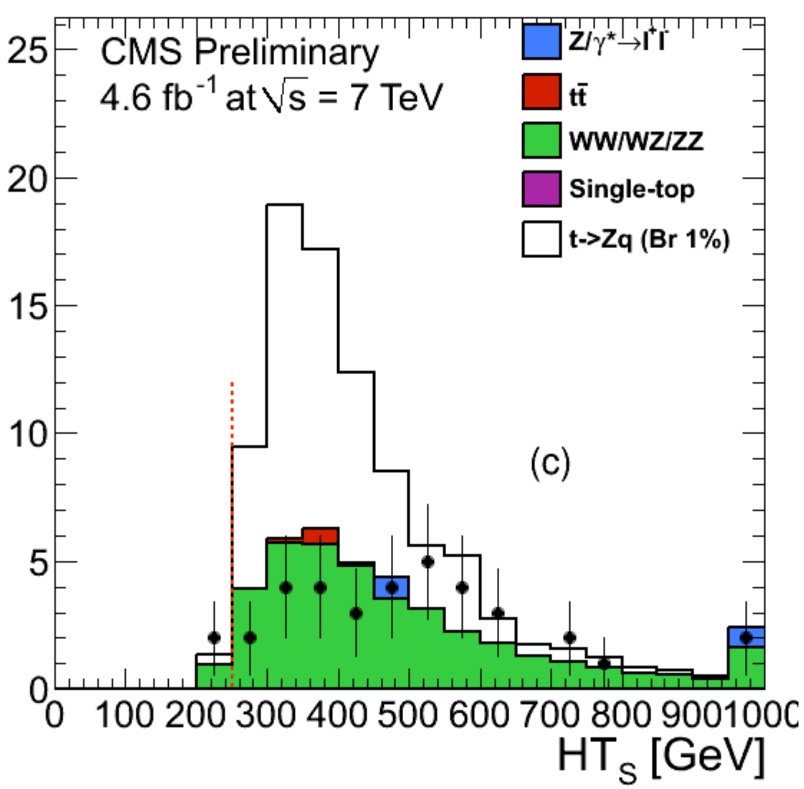
$$\Delta m_t = -0.44 \pm 0.46 \text{ (stat.)} \pm 0.27 \text{ (syst.) GeV}$$

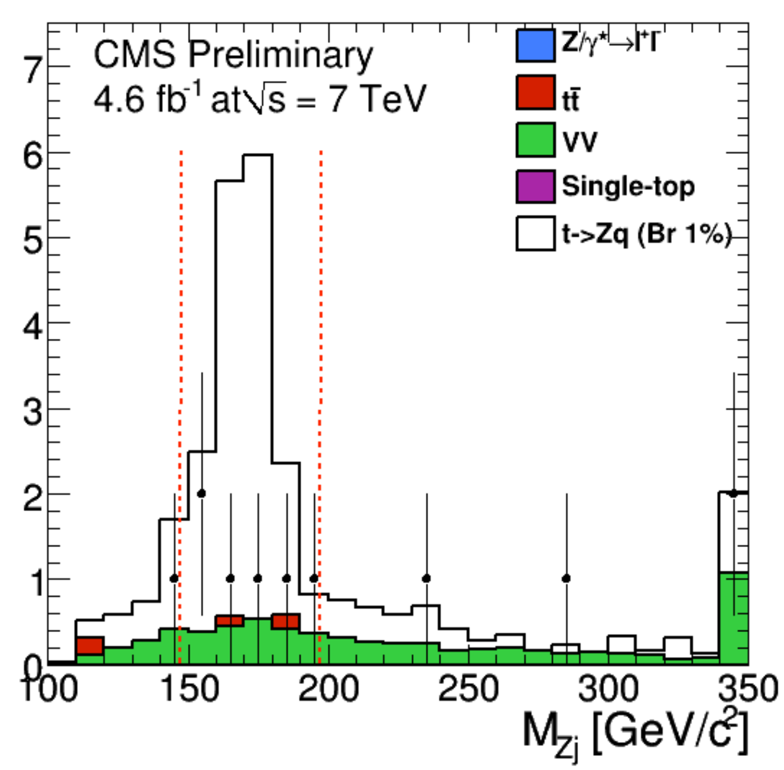


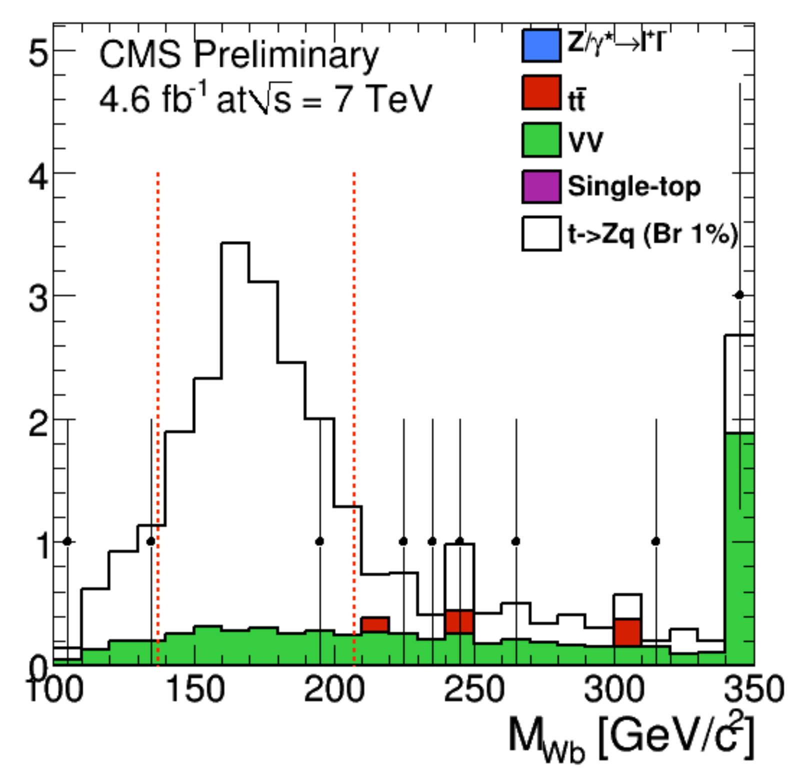
FCNC search

TOP-11-028

- t → Wb ~100% in SM
- BSM enhances t → Zq
- Event selections
  - three leptons (p_T > 20 GeV) veto on fourth lepton
  - two jets, MET > 30 GeV
  - M_{Zj} , M_{Wj} near top mass
  - b tagging or HT_S
- The branching ratio of t → Zq larger than 0.34 % is excluded at 95%.



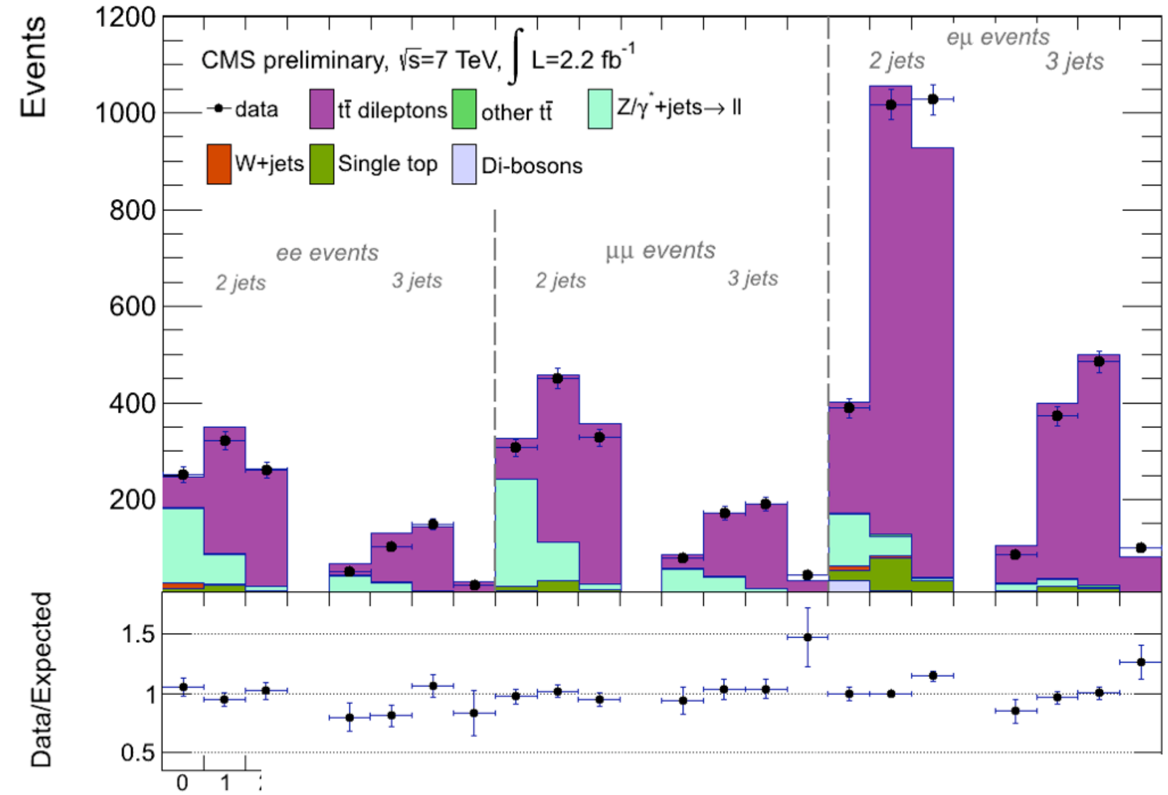




B(t→Wb)/B(t→Wq)

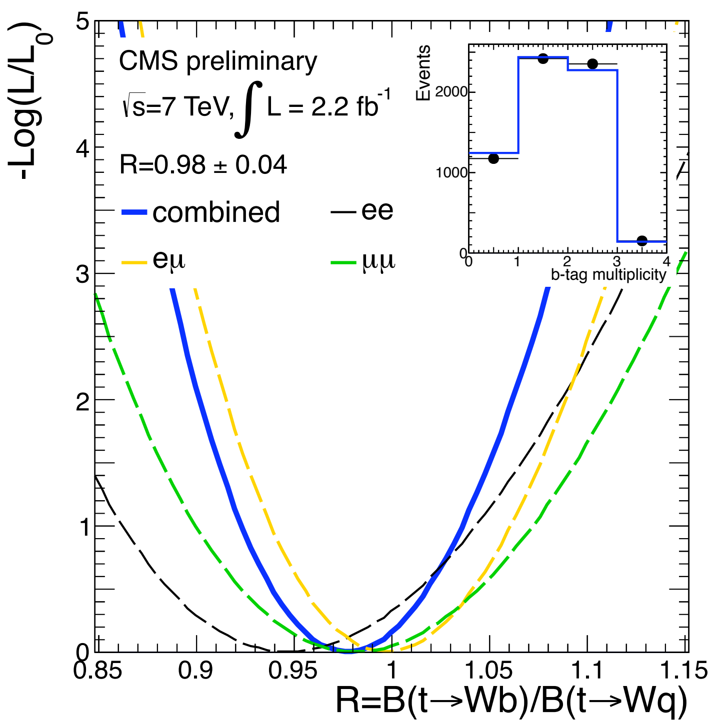
- t→Wb ~100%
- Event selection
  - Two isolated leptons
  - MET > 30 GeV for ee, μμ
- factorize b-tagging multiplicity
  - as a function of R, ε_b, ε_q
  - ε_b, ε_q are obtained from QCD

TOP-11-029



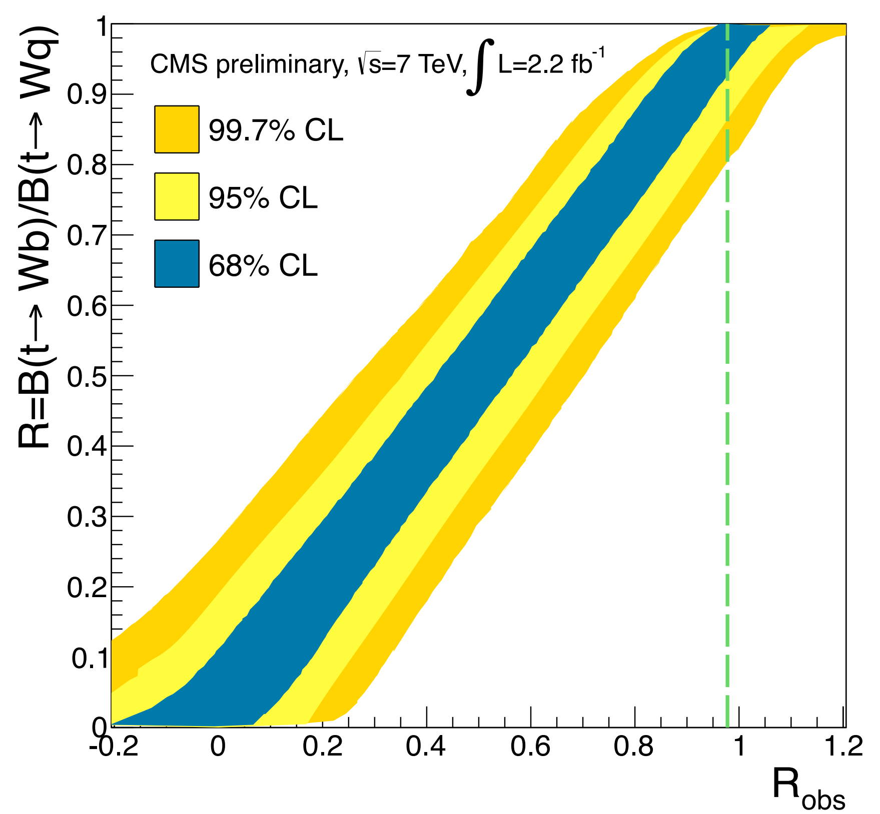
two jets example : reconstructed from top quark and selected as two b-jets. →

$$P_k = R^2\varepsilon_b^2 + 2R(1-R)\varepsilon_b\varepsilon_q + (1-R)^2\varepsilon_q^2$$



$$R = 0.98 \pm 0.04$$

R >0.85 at 95% C.L.



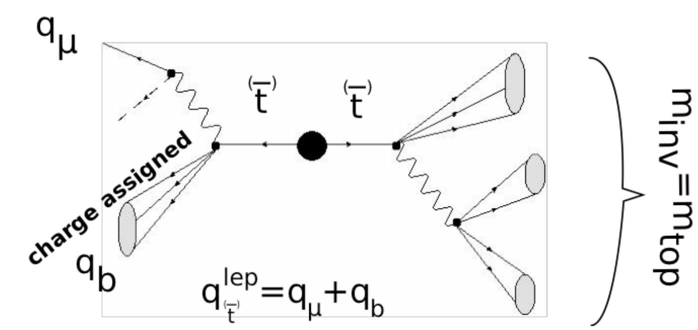
Top quark charge

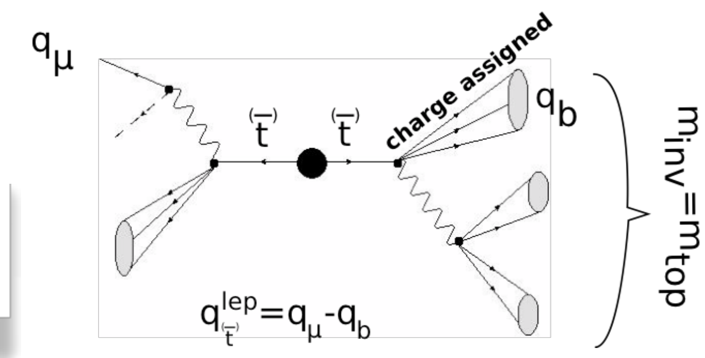
TOP-11-031

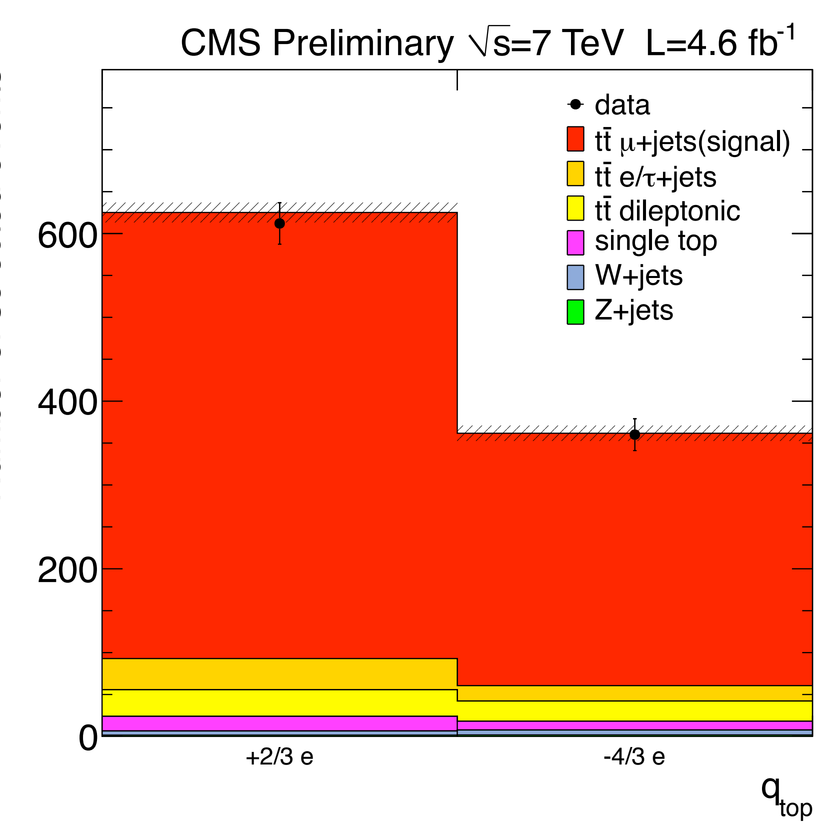
- Top charge +2/3.
- Assign top charge
  - muons from W + soft muons from B-hadrons
- Take into account wrong charge assignment.
  - b-enriched data sample.
- Exclude scenario with an exotic top quark (A=-1).

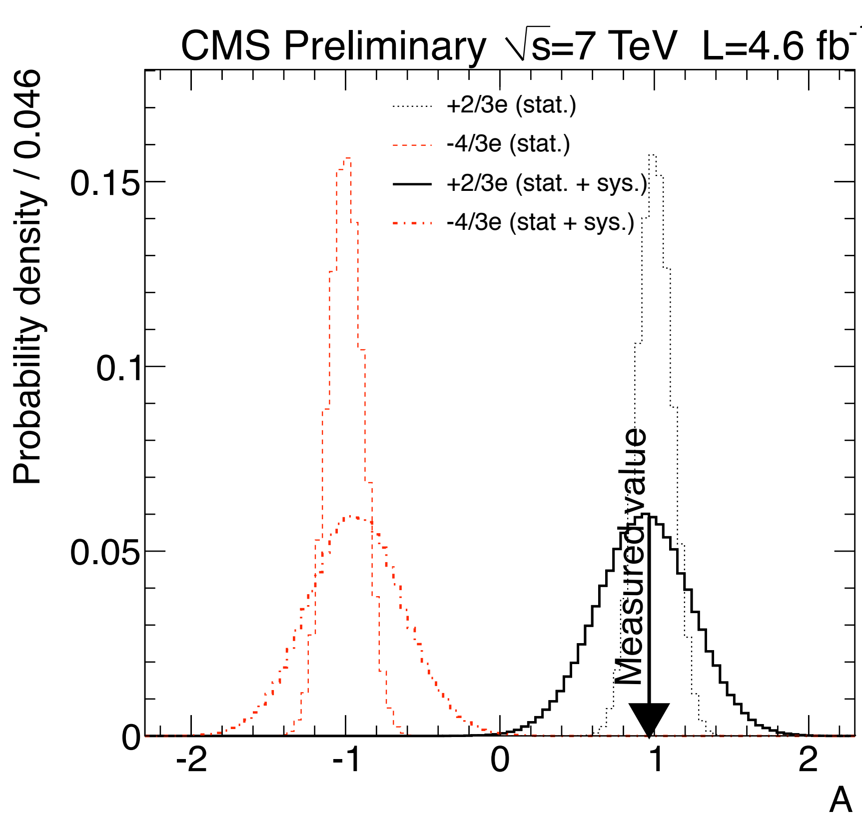
$$A = \frac{N_{SM} - N_{XM}}{N_{SM} + N_{XM}}$$

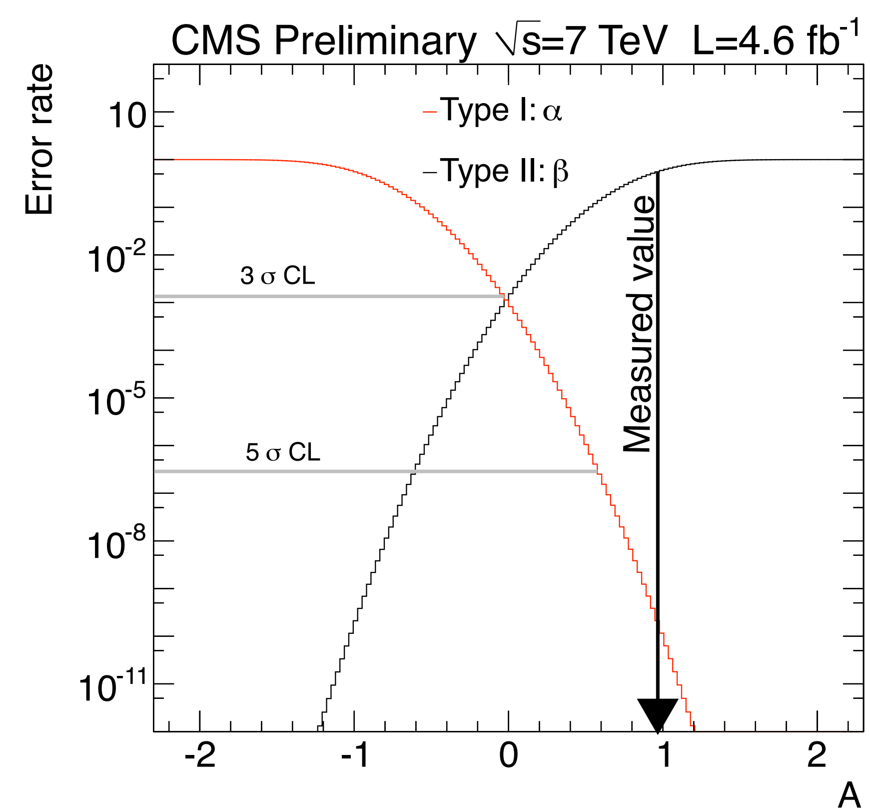
$$A_{\mathrm{meas}} = 0.97 \pm 0.12_{\mathrm{stat}} \pm 0.31_{\mathrm{syst}}$$



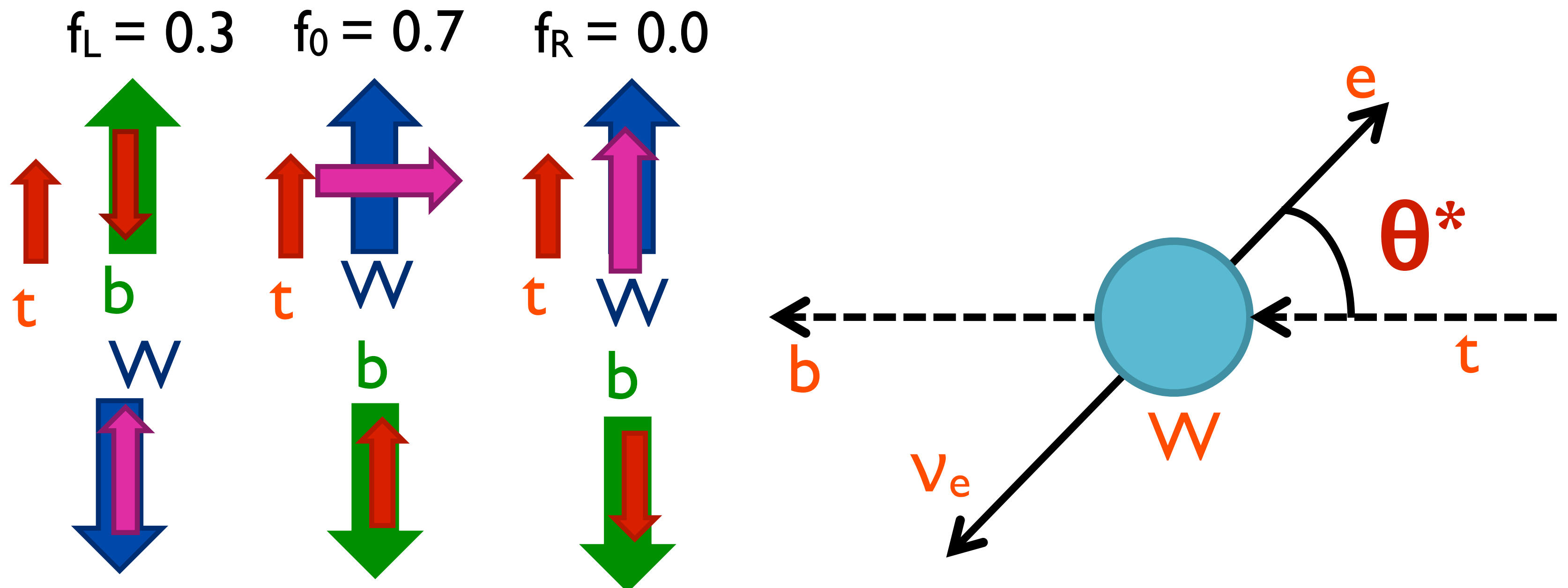


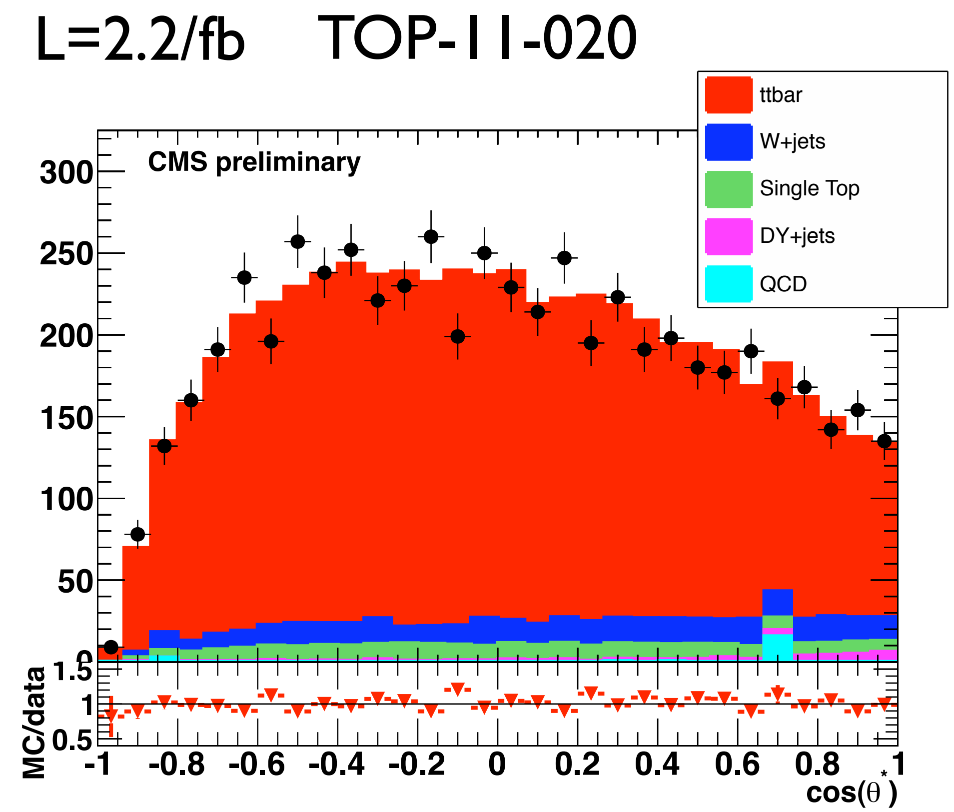






W polarization

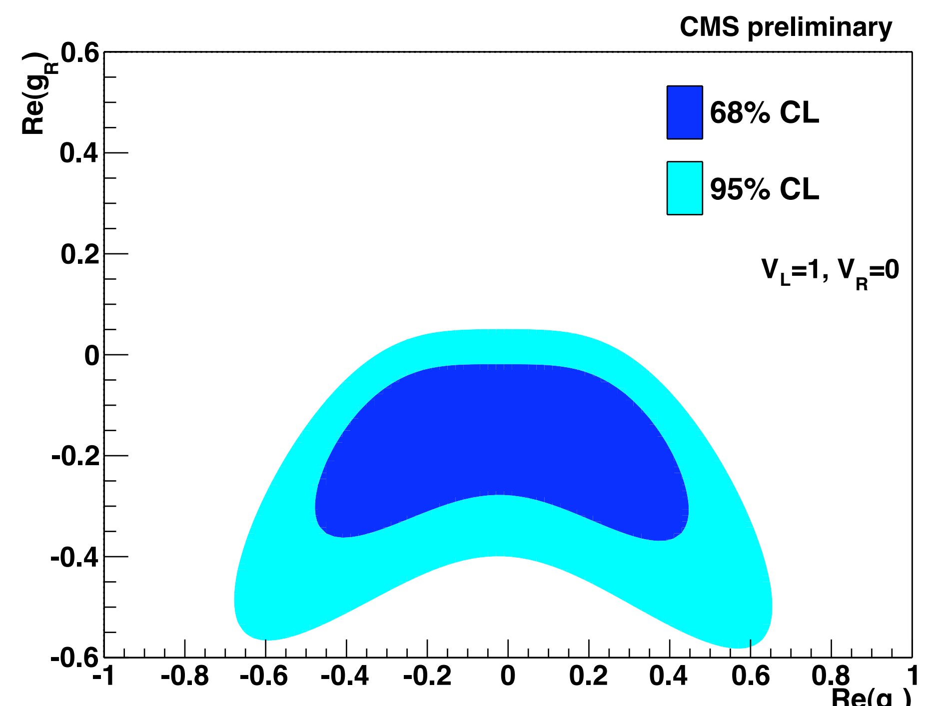




- cosθ* : angles between lepton in W rest frame and W momentum in top rest frame.
- The polarization fraction was extracted by fitting to data conθ* distribution with two types of fitting.
  - $F_R = 0$ and F_R = Free parameter.

$$F_0 = 0.567 \pm 0.074(\text{stat.}) \pm 0.047(\text{syst.})$$
$$F_L = 0.393 \pm 0.045(\text{stat.}) \pm 0.029(\text{syst.})$$
$$F_R = 0.040 \pm 0.035\ (\text{stat.}) \pm 0.044(\text{syst.})$$

  - Used to constrain anomalous Wtb couplings.

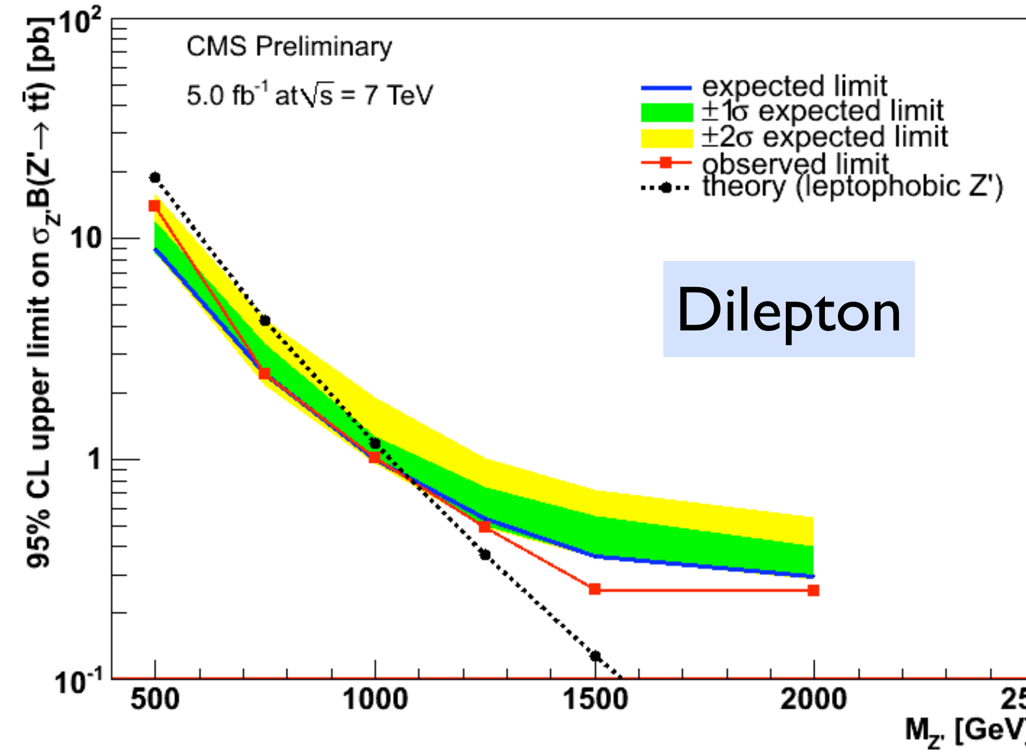


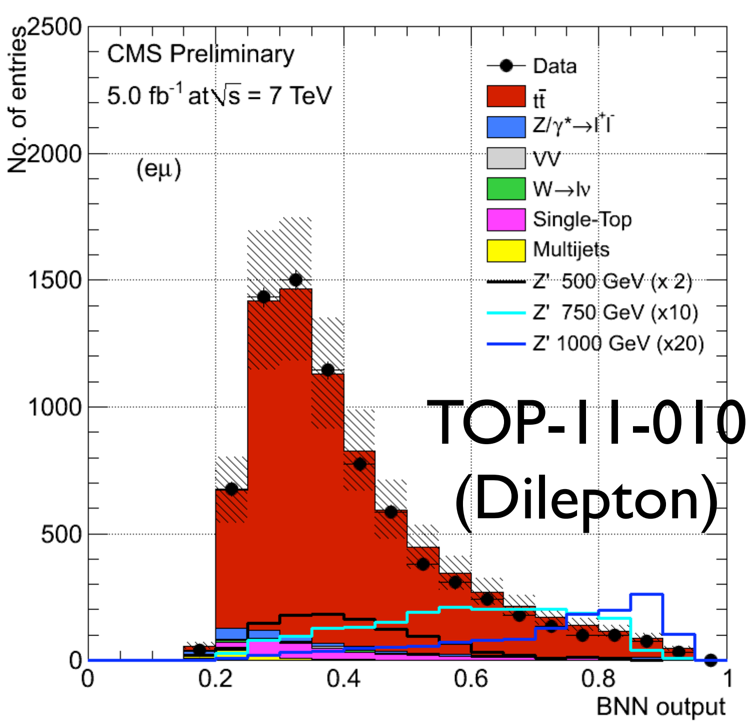
$$\mathcal{L}_{tWb} = \mathcal{L}_{tWb}^{\rm SM} - \frac{g}{\sqrt{2}}\bar{b}\Big[(V_L P_L + V_R P_R)\gamma^\mu + \frac{i\sigma^{\mu\nu}q_\nu}{m_W}(G_L P_L + G_R P_R)\Big]tW_\mu$$

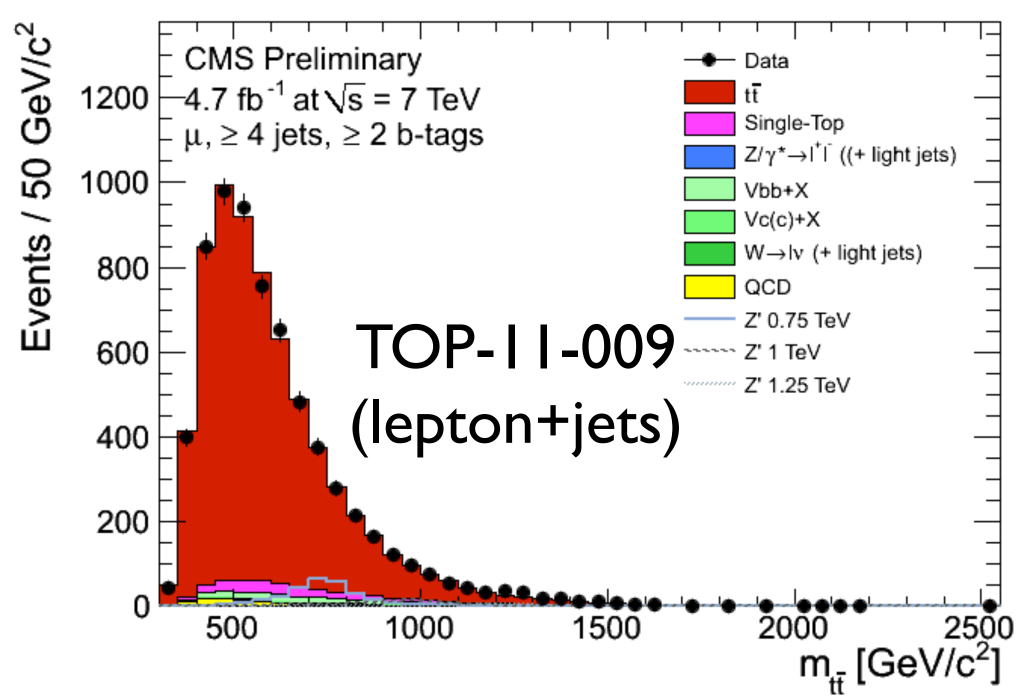
in the SM : $V_L=1, V_R=0, G_L=0, G_R=0$

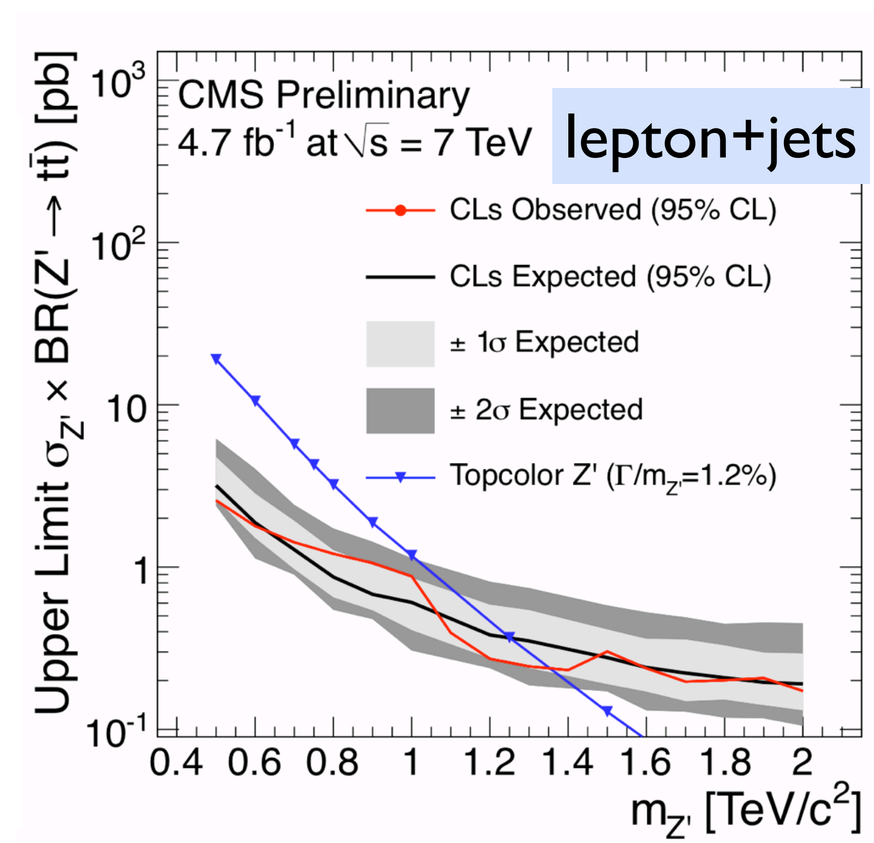
New physics in m(tt) resonance

- The resonance decaying into top pairs are predicted by several models.
- Dilepton
  - Standard dilepton event selection.
  - NN method to improve significance
- Lepton + jets
  - full event reconstruction.
  - Fitting together different Njets, b-tags.





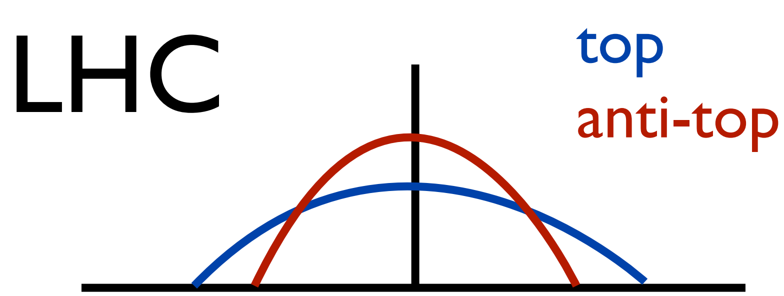




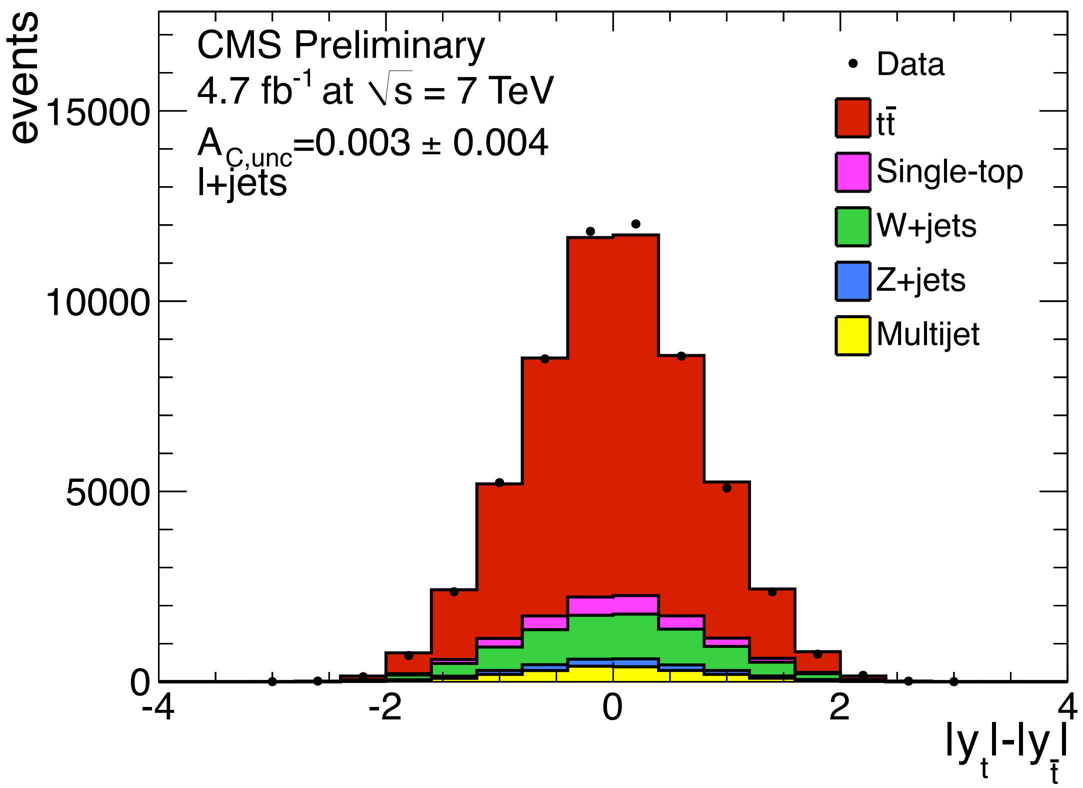
Charge Asymmetry

TOP-11-030

- CDF has already observed 3.4 sigma deviation with respect to SM above 450 GeV.
- Could be explained by possible new exchange particles in t-channel from various theory paper.
- Charge asymmetry is sensitive to this additional production mode.
- Event selection follows l+jets analysis requiring 4 jets and one b-tag.

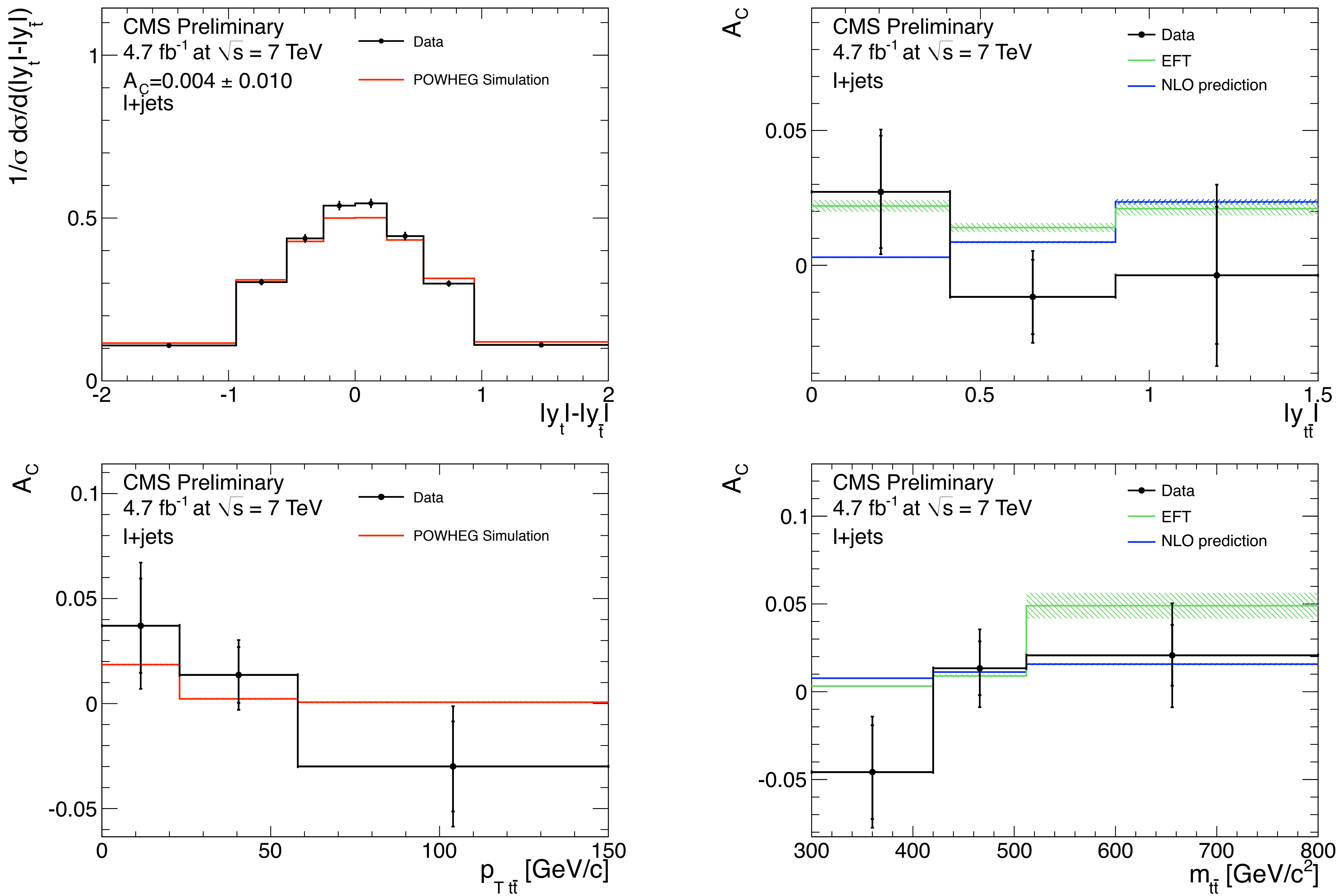


$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$



$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

Charge Asymmetry



- Regularized unfolding inclusive and differential A_c
- No deviation found so far!

Conclusion

- CMS has produced precise measurements.
  - in most of all possible decay modes
  - including differential cross section
  - starting to constrain theory.
- All measurements are consistent with SM
  - no hints for new physics yet.
- 2012 year will be more interesting.
  - more differential distribution.
  - Improve to reduce systematic uncertainty.
    - constrain theory uncertainty using data.
  - searching for new physics in top decays.

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