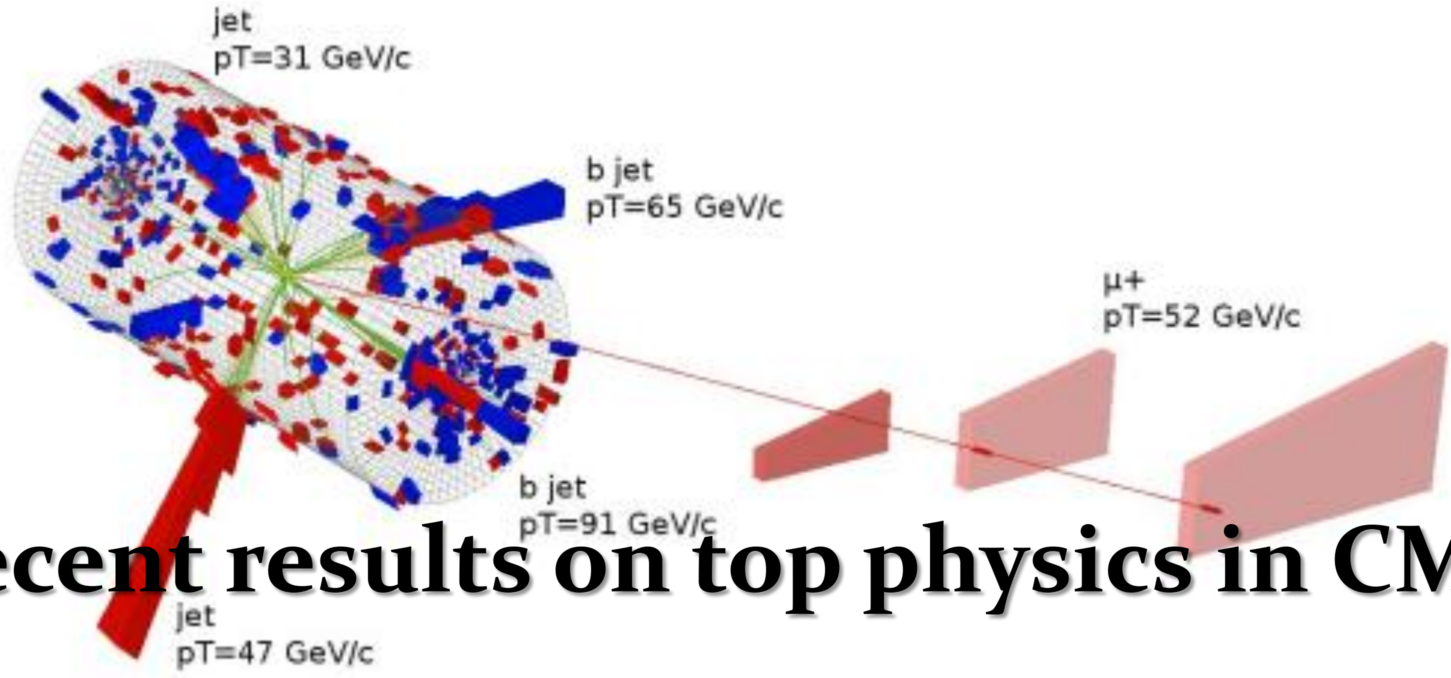

Recent results on top physics in CMS

Roberto Chierici (CNRS+CERN)

CERN PH – LHC Seminar
16th April 2012

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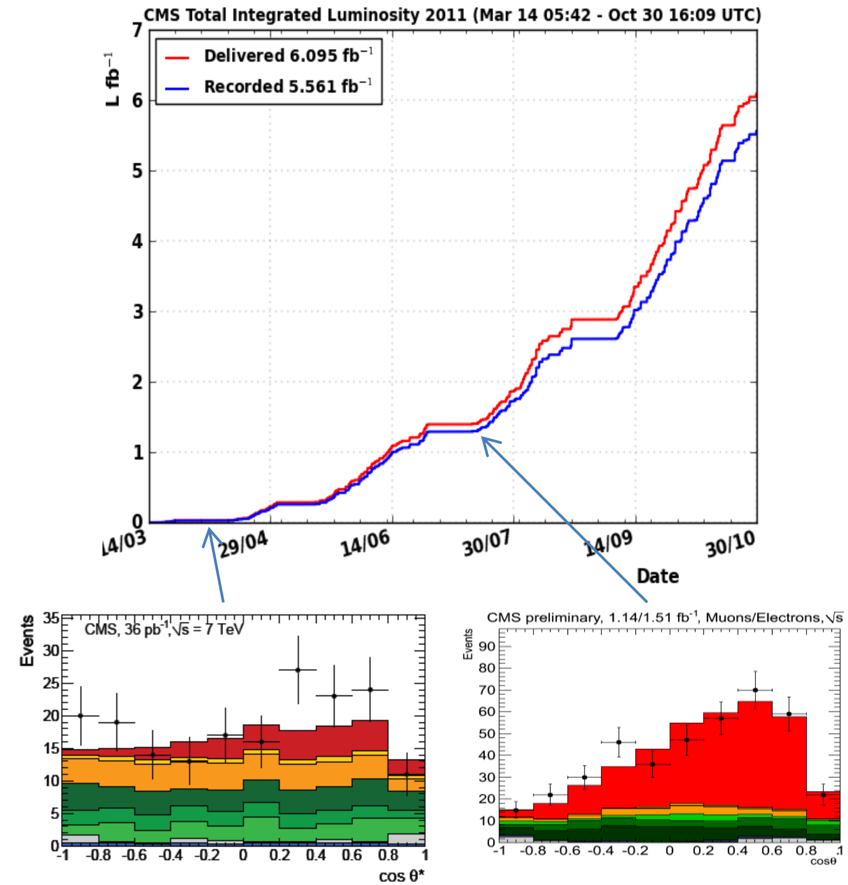
- Introduction
- Production cross section
- Differential cross section
- Top intrinsic properties
  - Mass, spin, couplings
- Single top production
- Top as a window to new physics
  - Selected topics

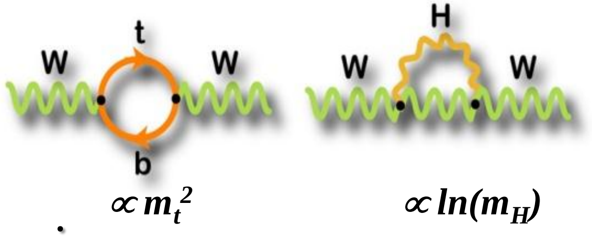


- While the overview aims to be complete, more emphasis will be put on recent/new results
- All CMS public results available from:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

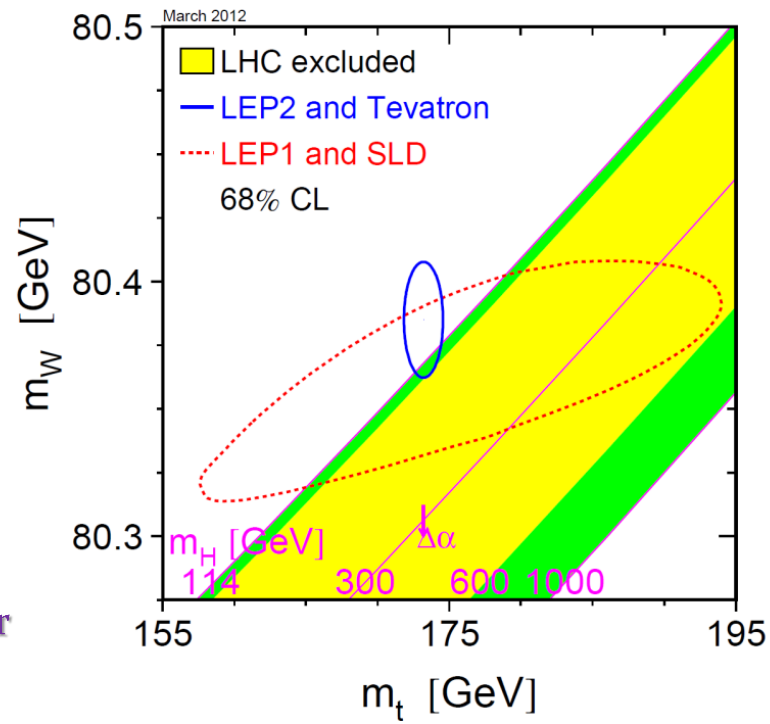
Introduction

Top physics

- Top physics is one of the main pillars of the physics program at the LHC
  - ➢ Direct access to fundamental parameter of the SM (m_t, V_{tb})
  - ➢ Direct probe of the EWSB sector (y_t~1!)
  - ➢ Other stringent tests of SM (QCD predictions in $d\sigma/dX$, constraints on couplings, CPT invariance,...)

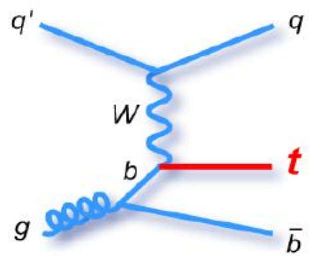


  - ➢ Privileged sector for the direct manifestation of new physics
    - o In production ($pp \to X \to tt$)
    - o In association ($pp \to tt+X$)
    - o In decay (H^+, FCNC,...)
  - ➢ Indirect probe for the presence of new physics
    - o charge asymmetries, spin structure, couplings
  - ➢ "The jackknife" for physics at the LHC
    - o All sub-detectors are involved in top reconstruction
    - o Helps understand (b)jet scale
    - o Helps understand b-tagging
    - o Constraints on PDFs
    - o Top physics may be an important background for searches



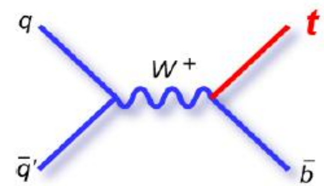
Top production at the LHC

- Top is produced in pairs (QCD) or singly (EWK)
- Single top EWK production happens via three main contributions



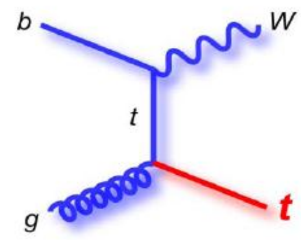
t-channel

$\sigma(7\ \text{TeV})\sim 64$ pb



s-channel

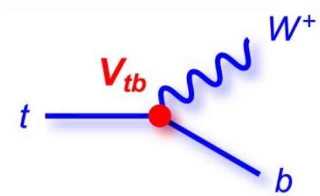
$\sigma(7\ \text{TeV})\sim 4.6$ pb



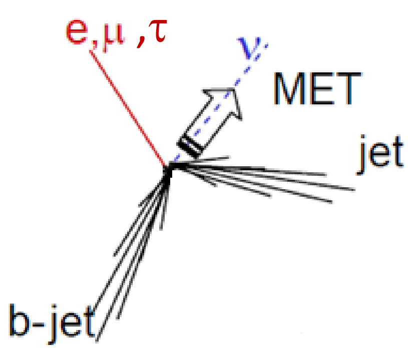
tW-channel

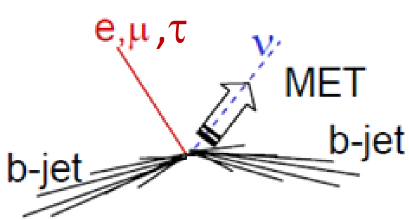
$\sigma(7\ \text{TeV})\sim 15.6$ pb

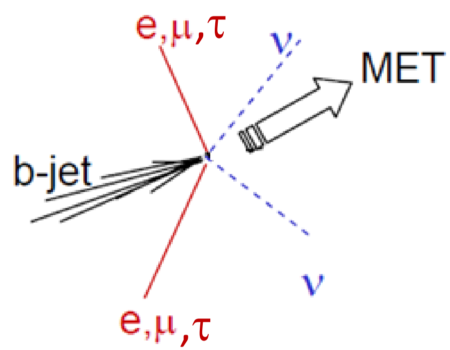
Kidonakis, NLO+NNLL
t-channel: PRD 83 (2011) 091503
s-channel: PRD 81 (2010) 054028
tW-channel: PRD 82 (2010) 054018



$V_{tb}\sim 1$







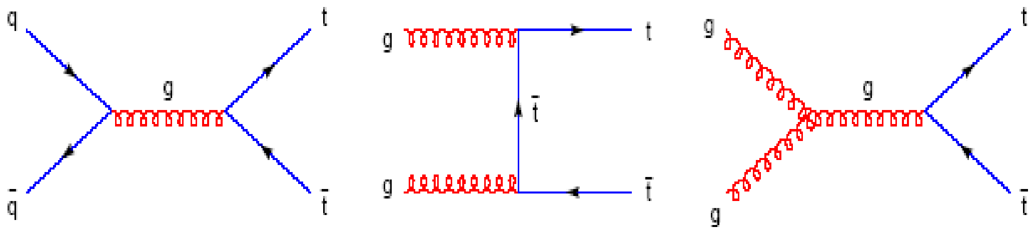
- Backgrounds
  - Top pair
  - W+(HF)jets
  - QCD

- Backgrounds
  - Top pair
  - W+(HF)jets
  - QCD

- Backgrounds
  - Top pair
  - Z+(HF)jets
  - QCD

Top production at the LHC

- Top pair QCD production happens mainly via gluon fusion

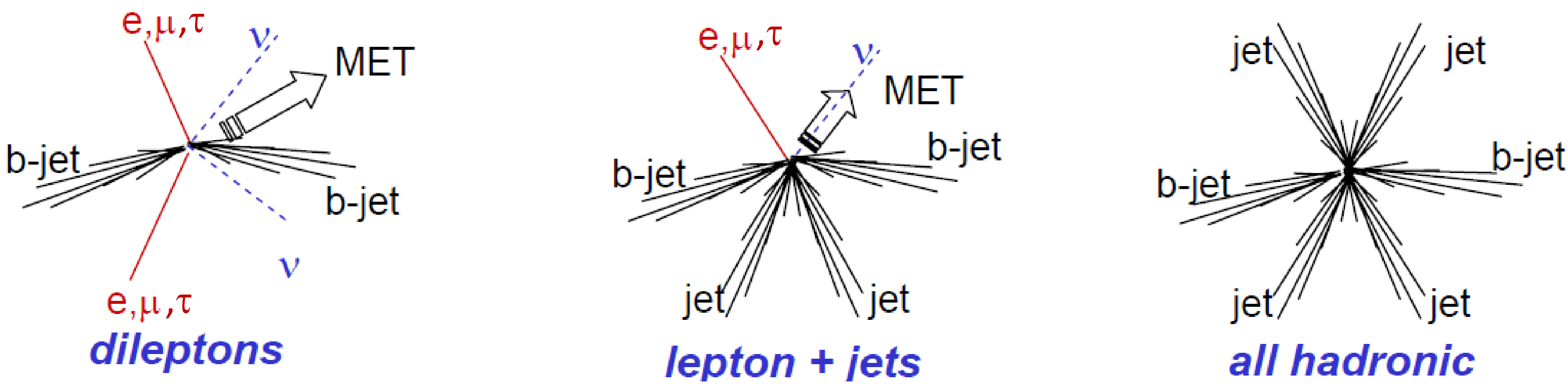


NLO (MCFM): $\sigma_{t\bar{t}}^{\mathrm{NLO}} = 158^{+23}_{-24}$ pb

approx. NNLO: $\sigma_{t\bar{t}} = 163^{+11}_{-10}$ pb

Kidonakis, PRD 82 (2010) 114030

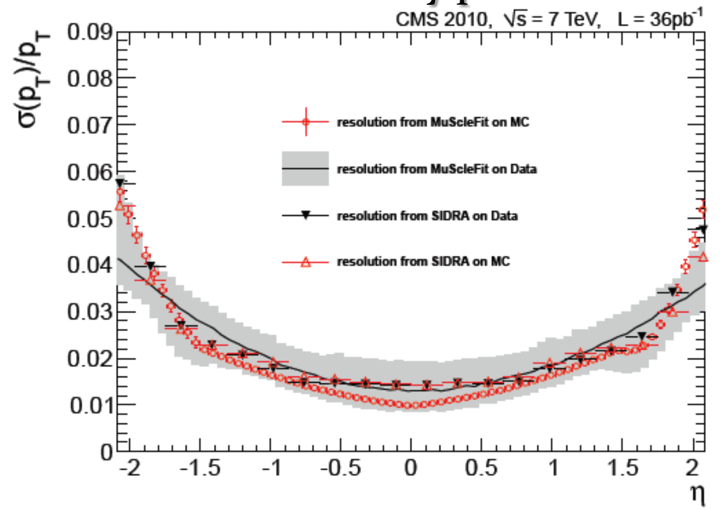
Langenfeld, Moch, Uwer, PRD80 (2009) 054009



• BR~10%	• BR~44%	• BR~46%
• Backgrounds	• Backgrounds	• Backgrounds
➢ Z+jets	➢ W+jets	➢ QCD
➢ Single top (tW)	➢ QCD	
➢ QCD	➢ Single top	

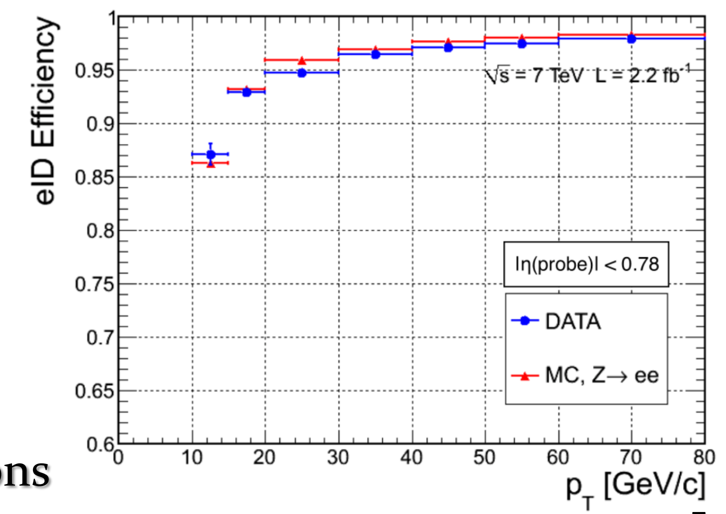
Detector objects: leptons

- All physics objects are essential for top physics: leptons, (b)-jets, MET
- Particle Flow reconstruction in CMS
  - Optimally combine all sub-detector information to reconstruct and identify particles



- Leptons (e,μ,τ) with p_T >20 $|\eta|$<2.5
  - Muon p_T resolution for top is 1-2%
  - ECAL resolution ~1% for top
    - Track matching to recover for brehmsstrahlung
- Excellent ID capabilities
  - Use redundancy of sub-detectors for muons
  - Shower shapes, H/E, conversion vetoes for electrons
- Isolation in tracker and calorimeters
  - Cut on relative isolation in a cone with ΔR=0.3

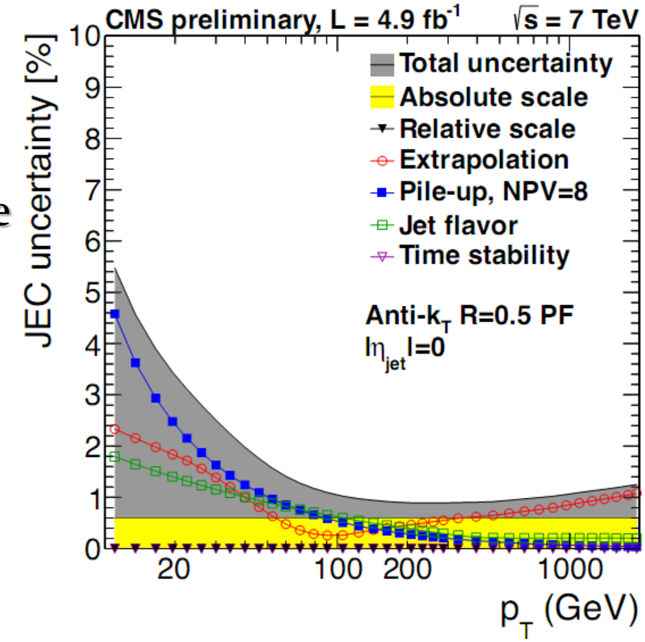
$$I^{\ell}_{\mathrm{Rel}} = \frac{E^{\ell}_{\mathrm{CH}} + E^{\ell}_{\mathrm{NH}} + E^{\ell}_{\gamma}}{p^{\ell}_{\mathrm{T}} \cdot c}$$

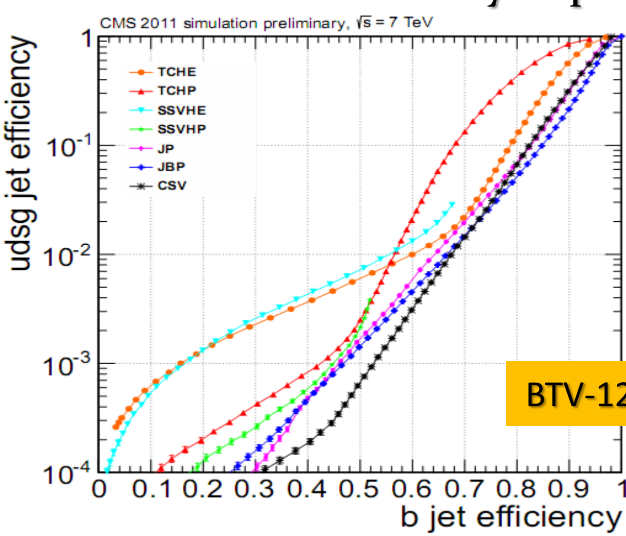


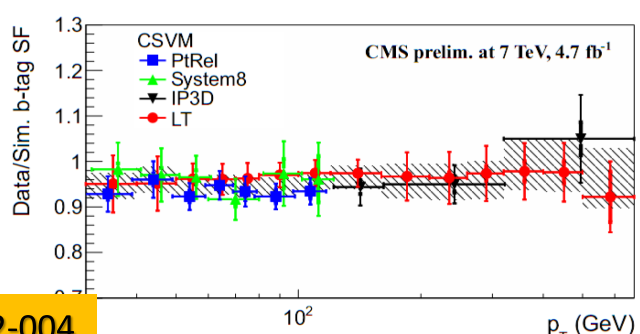
- Trigger largely based on leptons
  - Single/double (isolated) lepton
  - Lepton+jets at HLT are used for high PU conditions

Detector objects: jets, MET, b-tagging

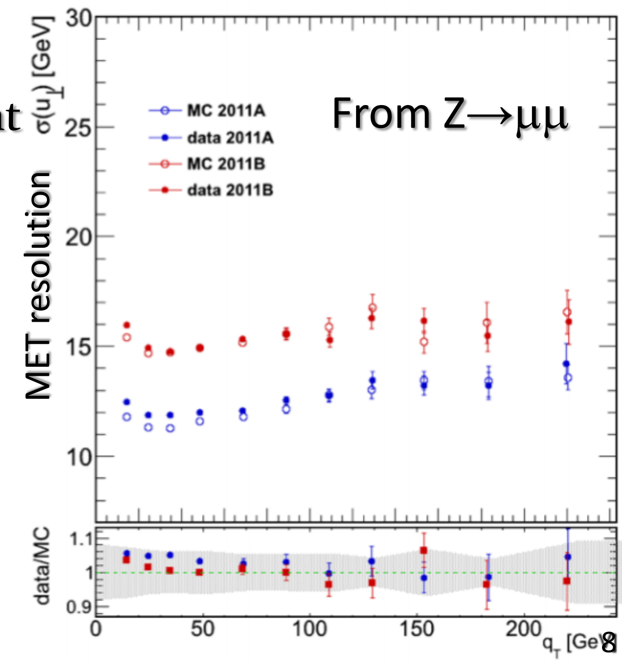
- Jets defined with anti-k_T algorithm with R=0.5
  - p_T>30 GeV $|\eta|$<2.5 (analysis dependent)
  - JES uncertainty via γ/Z+jets, ≤2% for most of the p_T range
  - JER about 10%
- b-tagging is optionally applied
  - Uses secondary vertices and/or IP information
  - Efficiencies and fake rates are calibrated by using data
  - Crosschecked in situ with top pair events
- Missing transverse energy
  - Requirement depends on analysis, from 20 to 60 GeV
  - Resolution vastly improved by the Particle Flow treatment





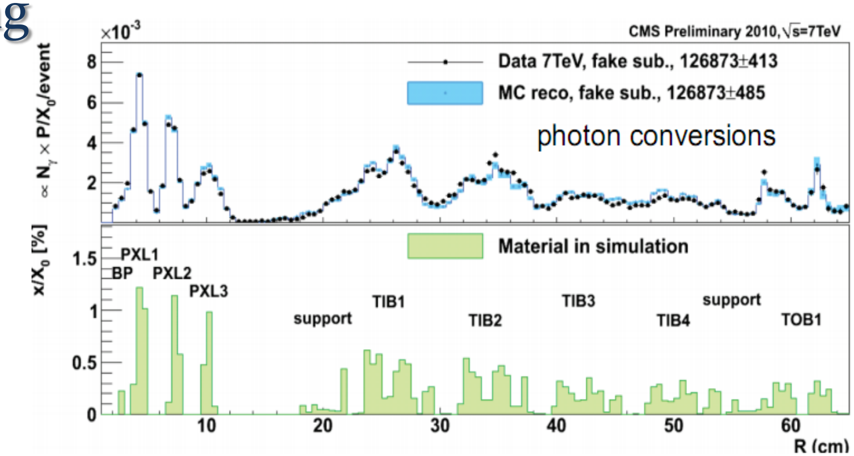


BTV-12-004

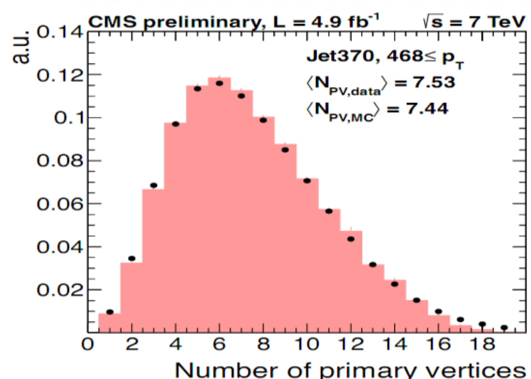


Simulation and Monte Carlo

- The reference generator for multi-leg final states is MadGraph$_{+PYTHIA}$
  - ➢ W/Z+Njets, N=0,…4, tt+Njets, N=0,…3, ME-PS matching with MLM
  - ➢ Flexibility for inclusion of new physics scenarios
  - ➢ Typically crosschecked vs NLO generators
- Other reference generators include NLO via POWHEG$_{+PYTHIA}$ and MC@NLO$_{+HERWIG}$
  - ➢ For both single top and top-pair description
- Systematic sources due to theory/modelling
  - ➢ Q^2 choice in the ME description
    - o also affects PS parameters
  - ➢ Choice of the ME-PS matching scale
  - ➢ PDFs, UE tunings

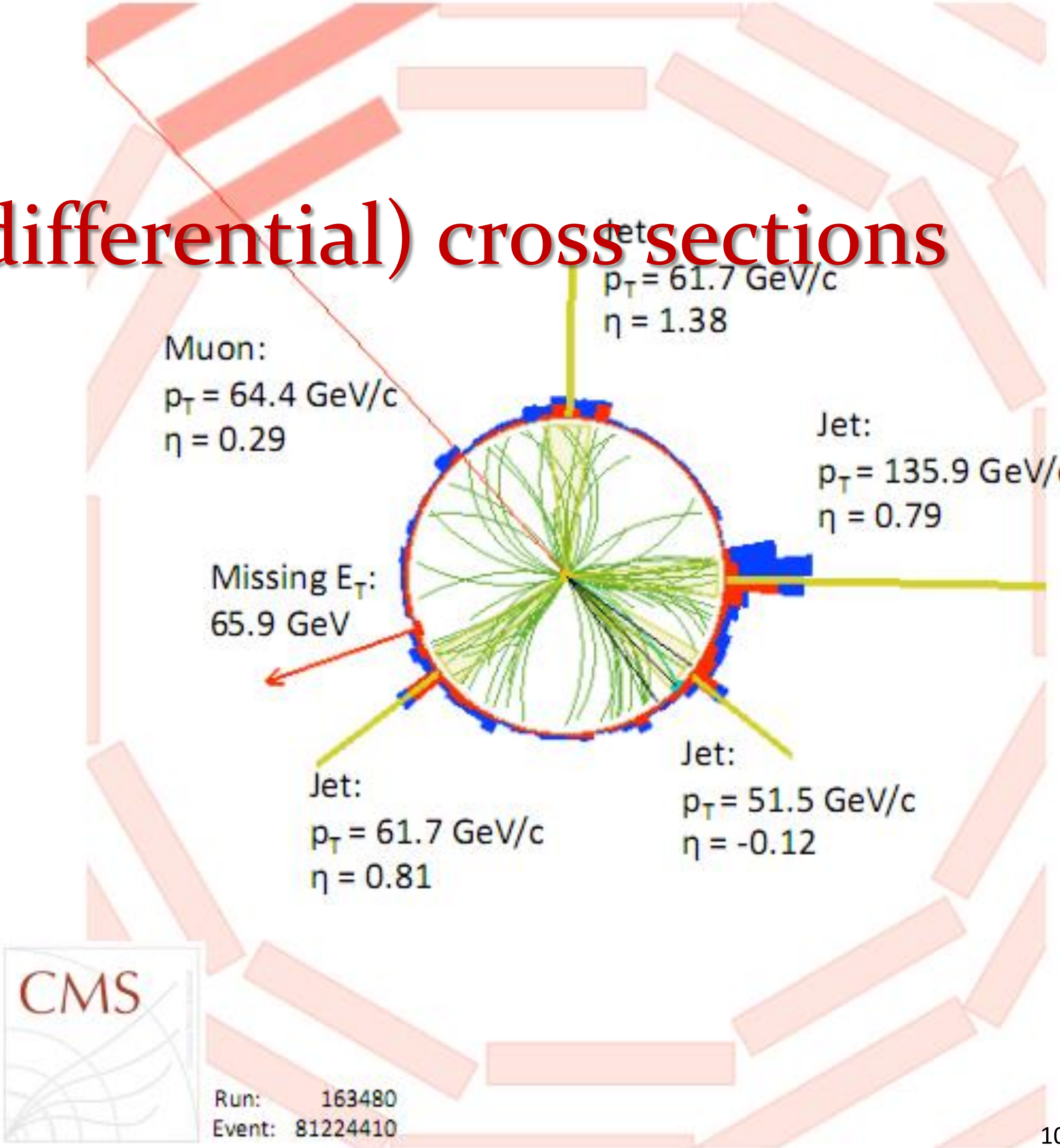


- Detector simulation via Geant4
  - ➢ Impressive accuracy of CMS simulation
  - ➢ In time and out of time pileup are added before the simulation of the electronics



reweight to match the PV distribution in data

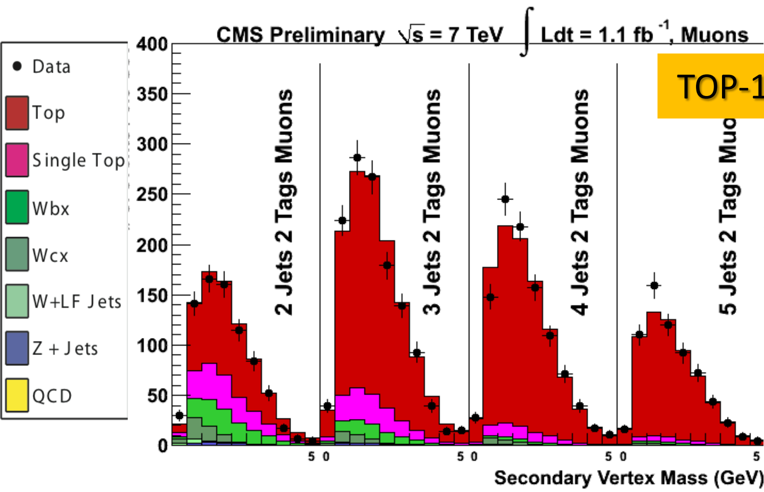
Top pair (differential) cross sections

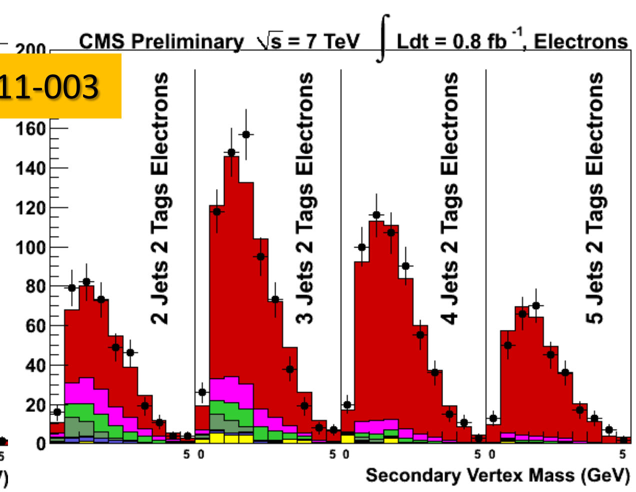


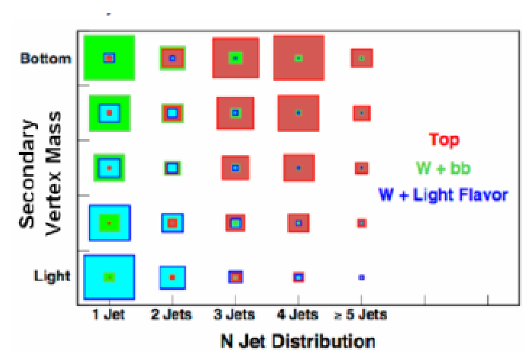
Cross section: hadronic channels

- ℓ+jets final states represent a good compromise between statistics and purity
  - ➢ 3D binned maximum likelihood fit: use secondary vertex mass, Njets, Nbtag
    - ○ W+HF normalization included in fit
    - ○ Systematic errors are treated as nuisance parameters (radiation parameters, JES, b-tag eff,...)

$$\sigma_{t\bar{t}} = 164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst}) \pm 7.4(\text{lum.})\ \text{pb}$$

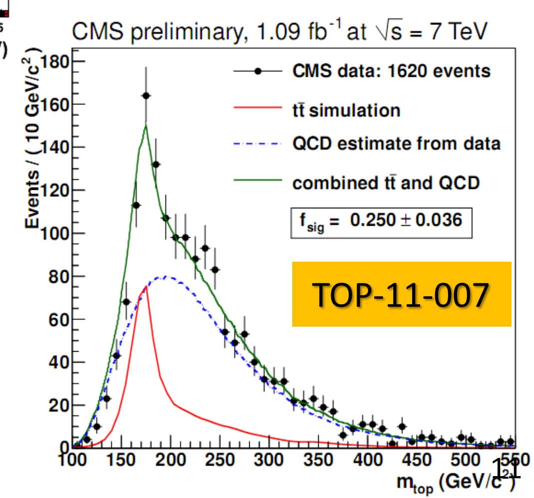






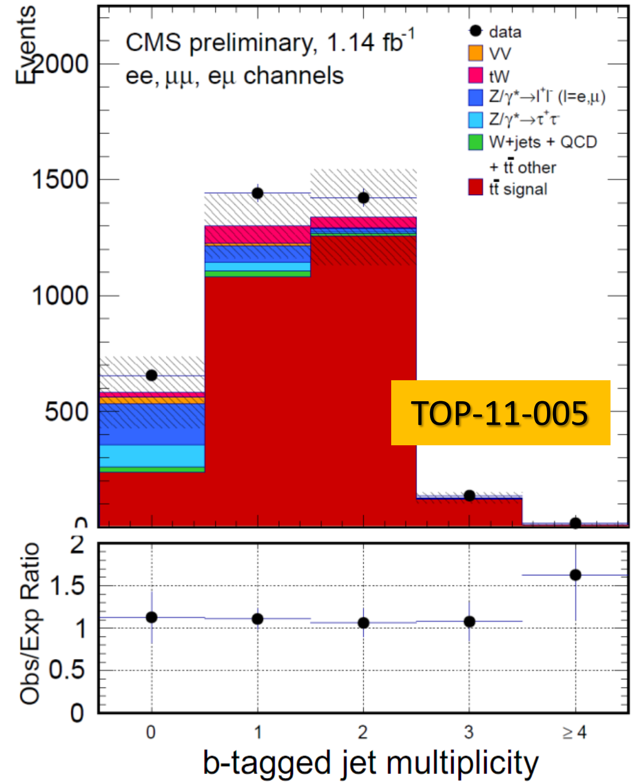
- Fully hadronic channel fully dominated by QCD
  - ➢ In situ determination of the QCD component
  - ➢ Template fit to m_t to extract the cross-section

$$\sigma_{t\bar{t}} = 136 \pm 20\ (\text{stat.}) \pm 40\ (\text{sys.}) \pm 8\ (\text{lumi.})\ \text{pb}$$

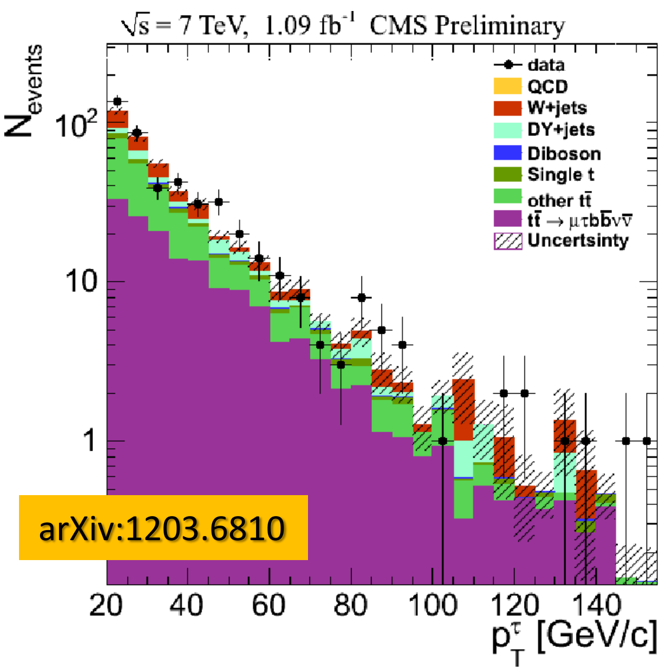


Cross section: leptonic channels

- Di-lepton (e, μ) are particularly background free
  - ➢ Counting experiment performed in three categories of number of jets and number of b-tags
    - (2j,>=0 btags; 2j,>=1btags; 1j, >=2 btags)
  - ➢ DY background completely data-driven
  - ➢ Cross section extraction driven by the very clean e+μ channel



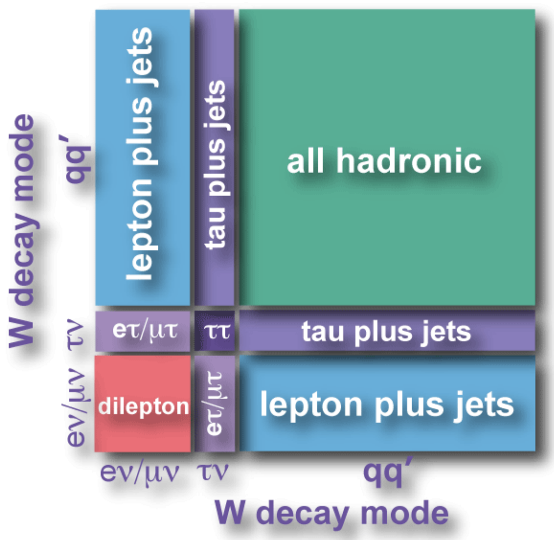
$$\sigma_{t\bar{t}} = 169.9 \pm 3.9 \text{ (stat.)} \pm 16.3 \text{ (syst.)} \pm 7.6 \text{ (lumi.)pb}$$



- Di-lepton with τ
  - ➢ Tau-fake leptons determined from data by using QCD events
  - ➢ First top pair cross section measurement at the LHC involving τ

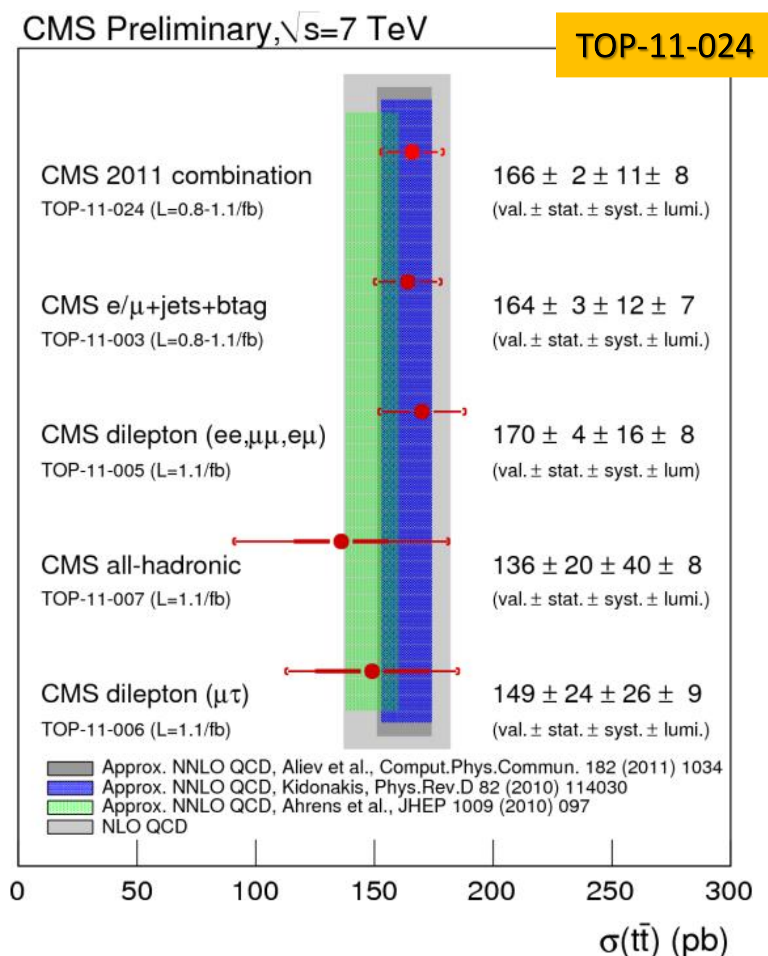
$$\sigma_{t\bar{t}} = 148.7 \pm 23.6\text{(stat.)} \pm 26.0\text{(syst.)} \pm 8.9\text{(lumi.) pb}$$

Cross section combination



- All top pair final states are (being) investigated
  - ➢ ℓ(e,μ)+jets, ℓℓ(all but ττ)+jets and fully hadronic final states in the combination.
  - ➢ τ+jets in the works…

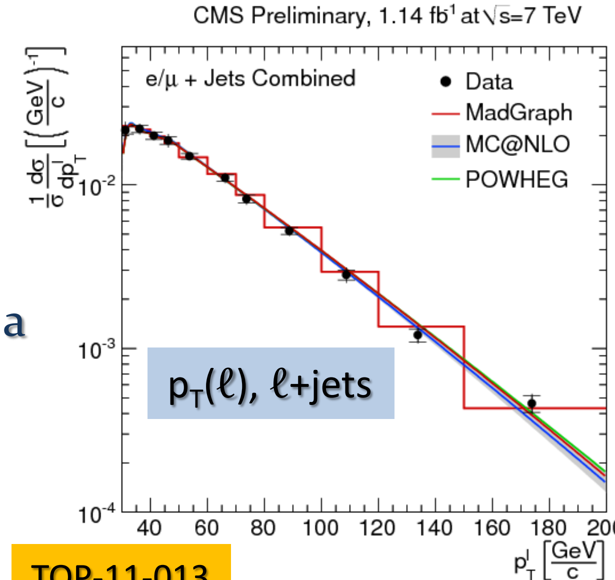
- The combination is performed via a likelihood formulation
  - ➢ Counting experiment are expressed as individual bins
  - ➢ Experimental uncertainty close to 8%
  - ➢ Challenging approximate NNLO computations !
  - ➢ Even more stringent in perspective with more precise estimation of the luminosity
    - ➢ Error on luminosity down to 2.2%



Top pair differential cross sections

- First measurement of normalized differential cross-sections in top pair production at 7TeV
  - Important test of pQCD
  - Sensitive to new physics
  - Event selections similar to the total cross section analyses

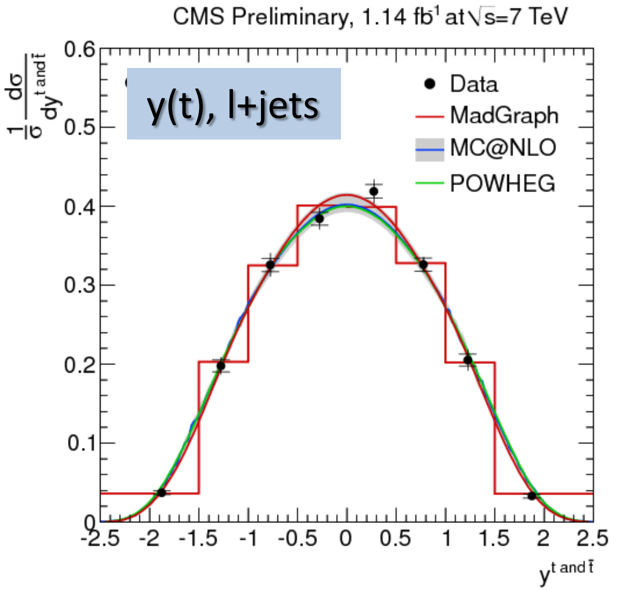
$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{N^i_{\mathrm{Data}} - N^i_{\mathrm{BG}}}{\Delta^i_{\mathrm{X}}\epsilon^i L}$$

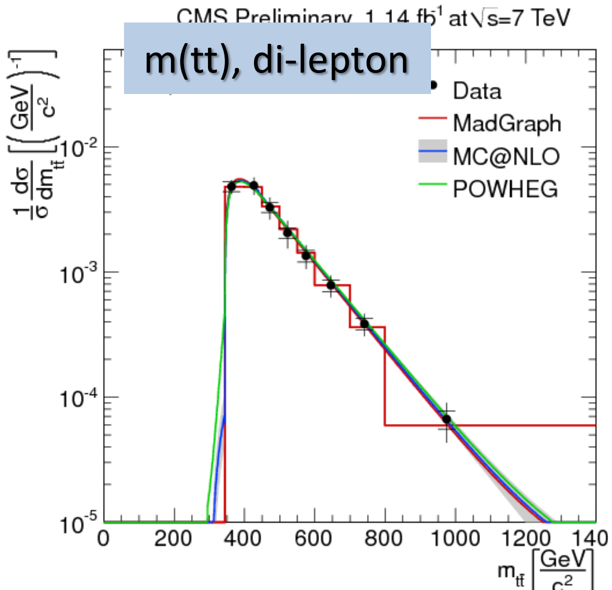


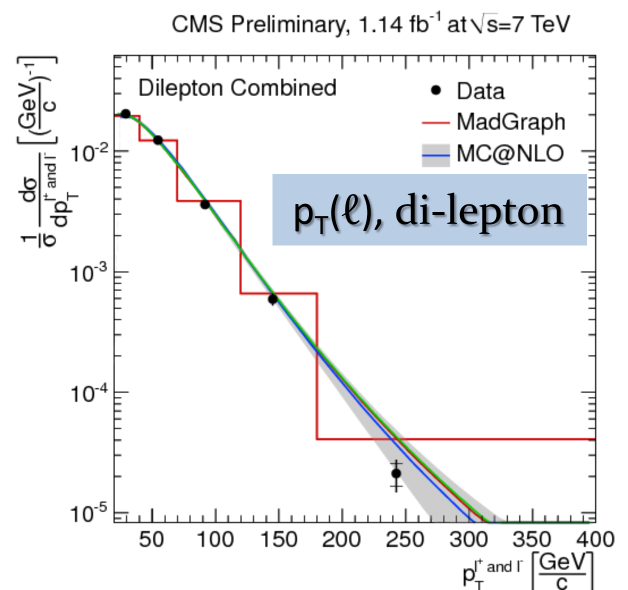
TOP-11-013

- Full kinematics reconstructed via kinematic fit (ℓ+jets) or a probabilistic reconstruction of neutrinos (di-leptons)

- Unfolding to parton level
  - Via bin-by-bin correction or full unfolding (SVD)
  - Look at variables involving leptons, tops, top pairs

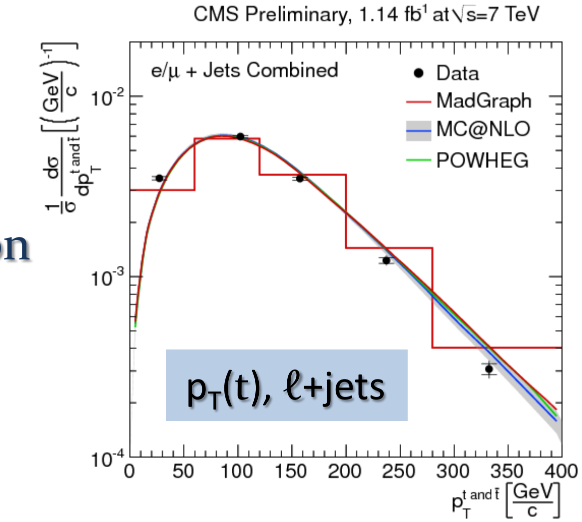


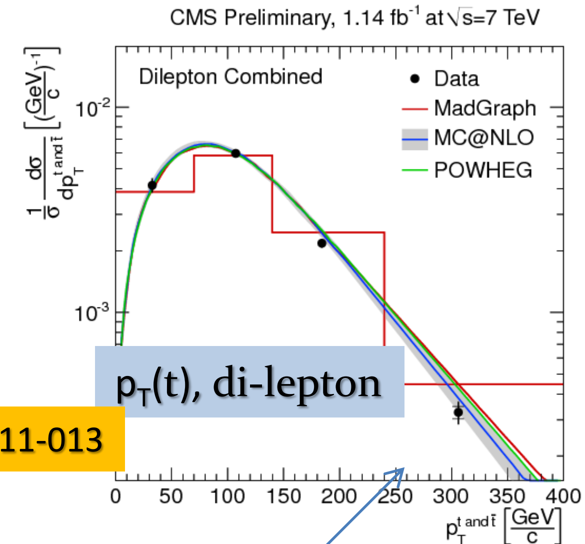


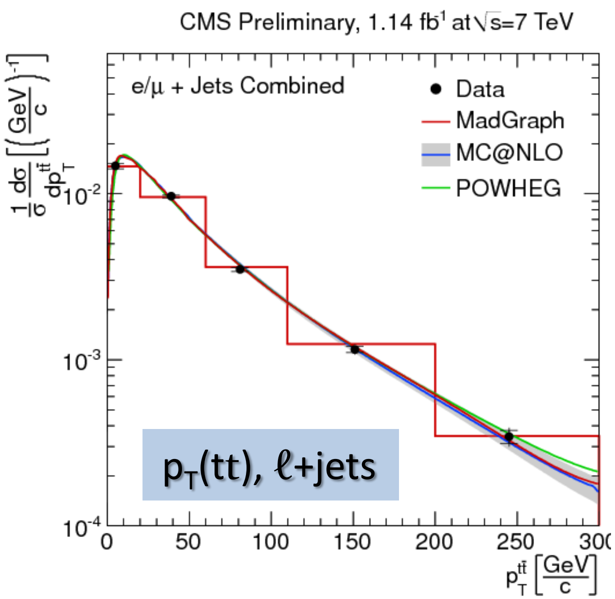


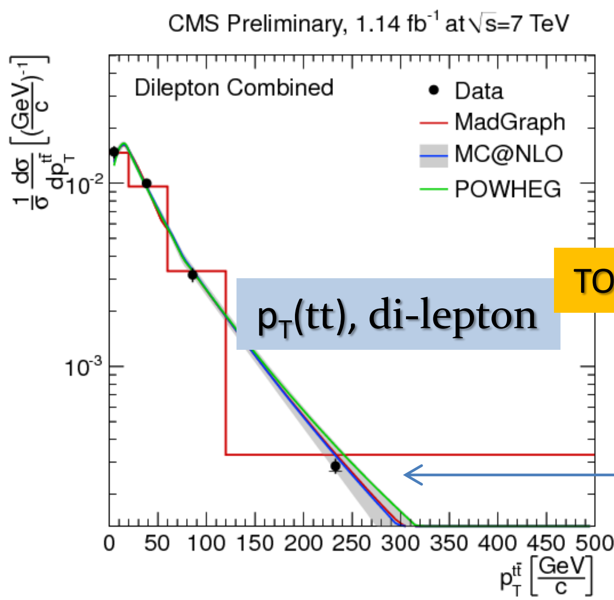
Top pair differential cross sections

- Binning optimized for purity (migration in bin i) and stability (migration out of bin i)
- Top quark distributions essential for e.g. studies on radiation
- Systematic errors (only shape uncertainties important)
  - ➢ Most important are background knowledge, radiation and hadronisation uncertainties
- Excellent agreement with predictions
  - ➢ Compare with both ME-PS matched and NLO codes



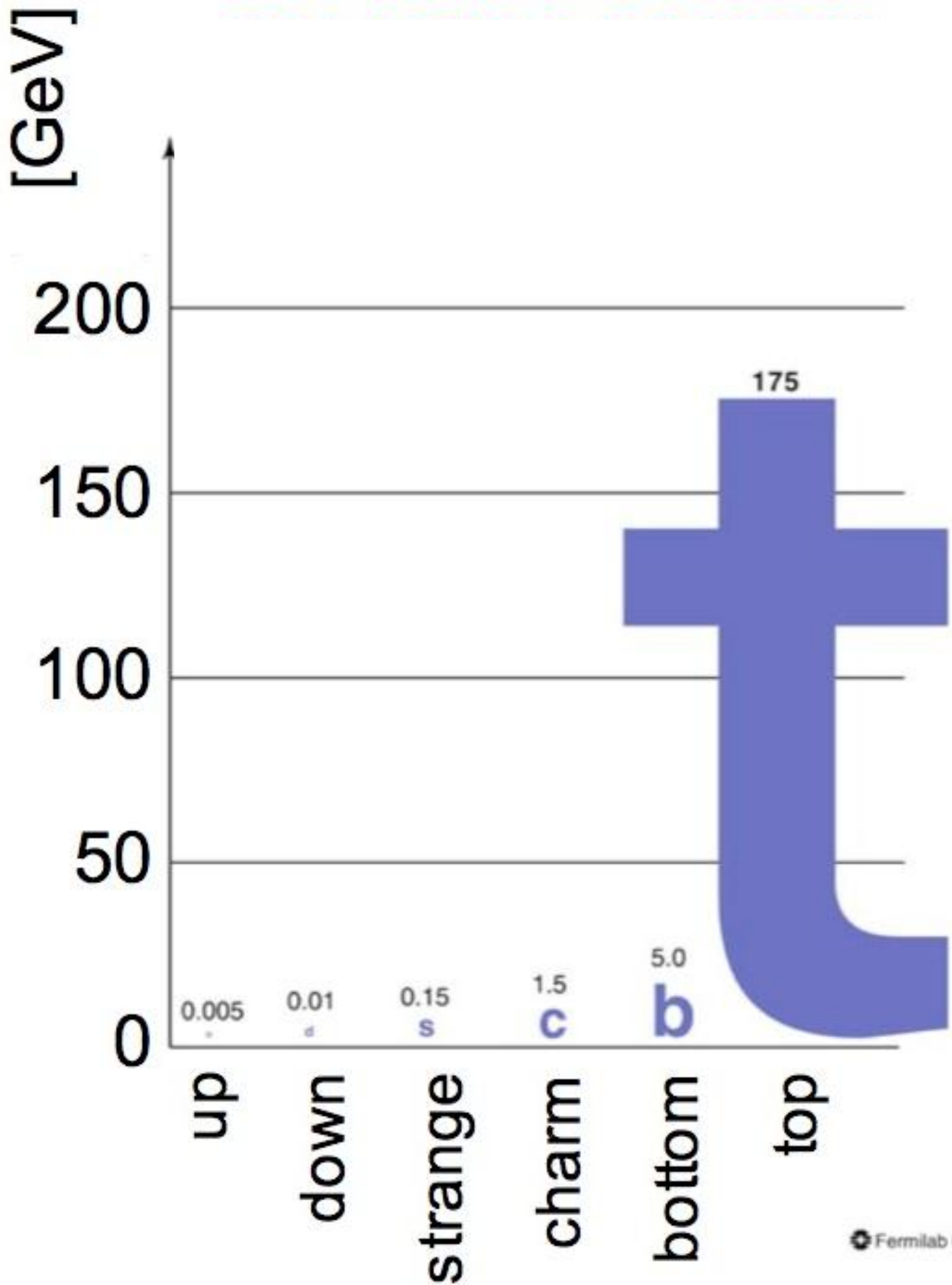






TOP-11-013

Horizontal bin center correction for showing the data
Lafferty, Wyatt, NIM A 355 541-547

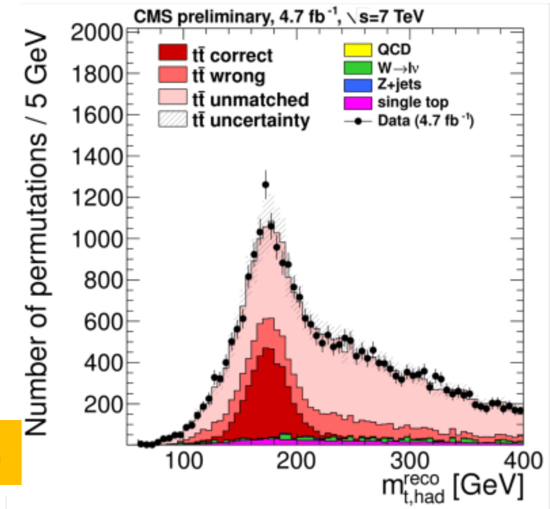


op properties

Top mass in ℓ+jets

- Top mass reconstructed via kinematic fits using the event kinematics
  - ➢ Likelihood method considering all jets permutations and b-tagging information
  - ➢ Need of PDFs per permutation as a function of m_t and JES. Calibration on MC.

$$\mathcal{L}_{event}\left(x|m_t,f_{t\bar{t}}\right) = f_{t\bar{t}}P_{t\bar{t}}\left(x|m_t\right) + \left(1-f_{t\bar{t}}\right)P_{bkg}\left(x\right)$$



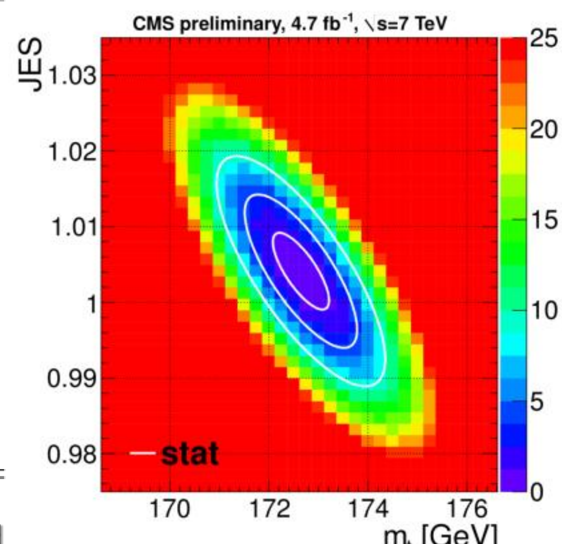
- Measurement dominated by systematic uncertainties
  - ➢ JES –also fit in situ– and (conservative) theory errors

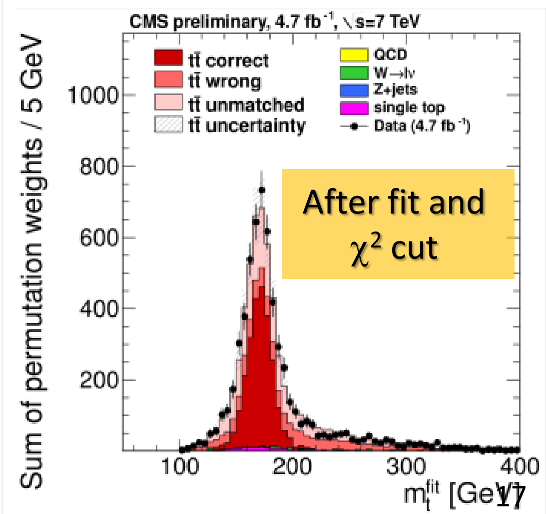
$$\begin{aligned} m_t &= 172.64 \pm 0.57\,(\text{stat+JES}) \pm 1.18\,(\text{syst})\ \text{GeV} \\ \text{JES} &= 1.004 \pm 0.005\,(\text{stat}) \pm 0.012\,(\text{syst}) \end{aligned}$$

TOP-11-015

	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

CR error not included





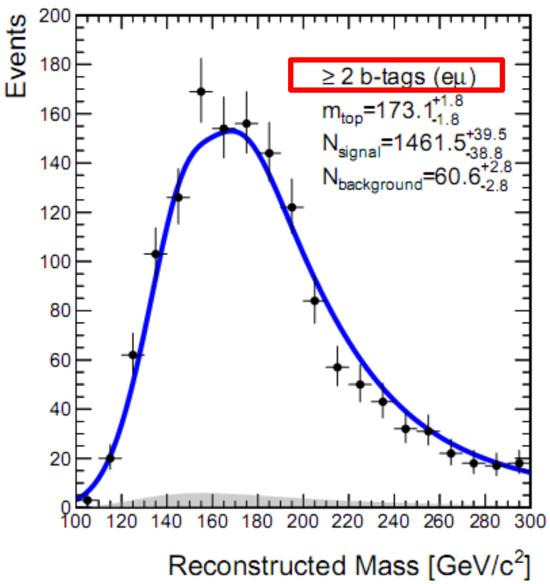
Top mass in di-leptons

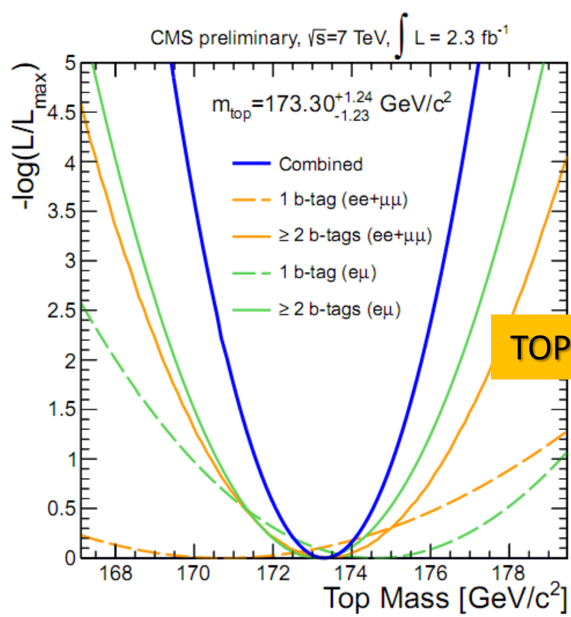
- Selection similar to the cross section measurement, plus additional MET cut for ee, μμ.
  - DY shapes taken from data in the low MET region
- Reconstruct the event kinematics by using the KINb method
  - Numerically solve the equations for kinematics. Count number of solutions compatible within resolution with the event kinematics. The most likely value for m is the estimator for m_t
  - Maximum likelihood fit of the resulting distribution for ee, μμ, eμ, 1 and 2 b-tags in the event
  - Method linear in m_t and unbiased after calibration
- Measurement dominated by JES uncertainty
  - Most precise to date in the dilepton channel

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

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

CR error not included





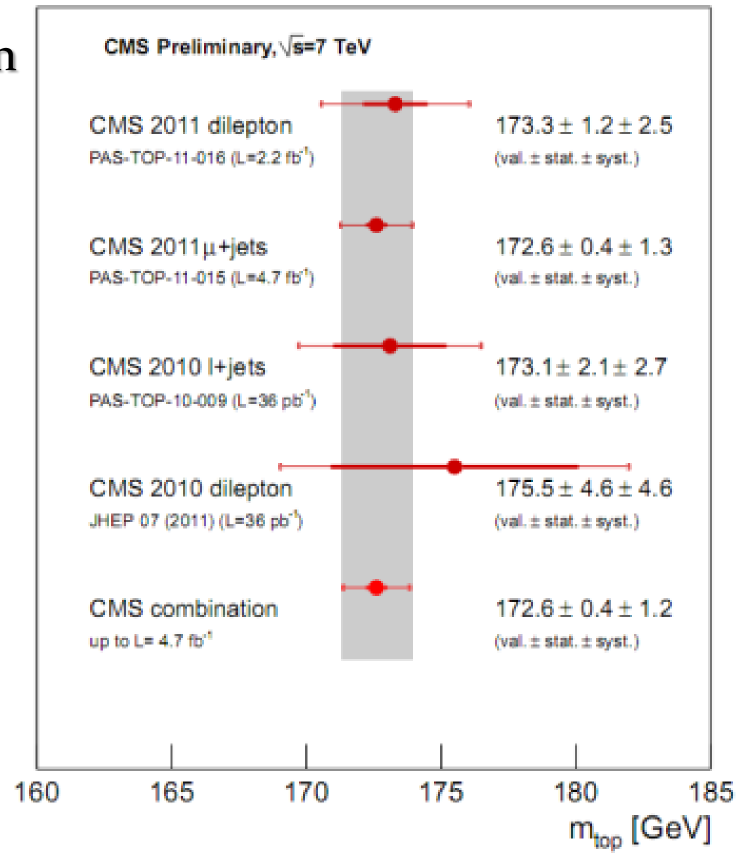
TOP-11-016

Top mass combination

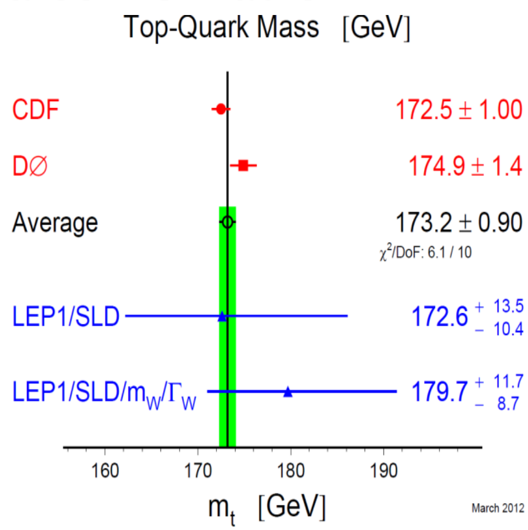
- In both di-lepton and ℓ+jets channel, the CMS m_t measurements are competitive with the corresponding ones at the Tevatron
- Use BLUE for the CMS combination, with detailed categorization of systematic errors according to their correlations
  - ➢ Combination dominated by the ℓ+jets channel
  - ➢ Results very robust against changes in correlation values/categories

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

TOP-11-018



- Towards LHC and world combination
  - ➢ Work ongoing in the TOPLHCWG
  - ➢ In contact with the TEVEWWG



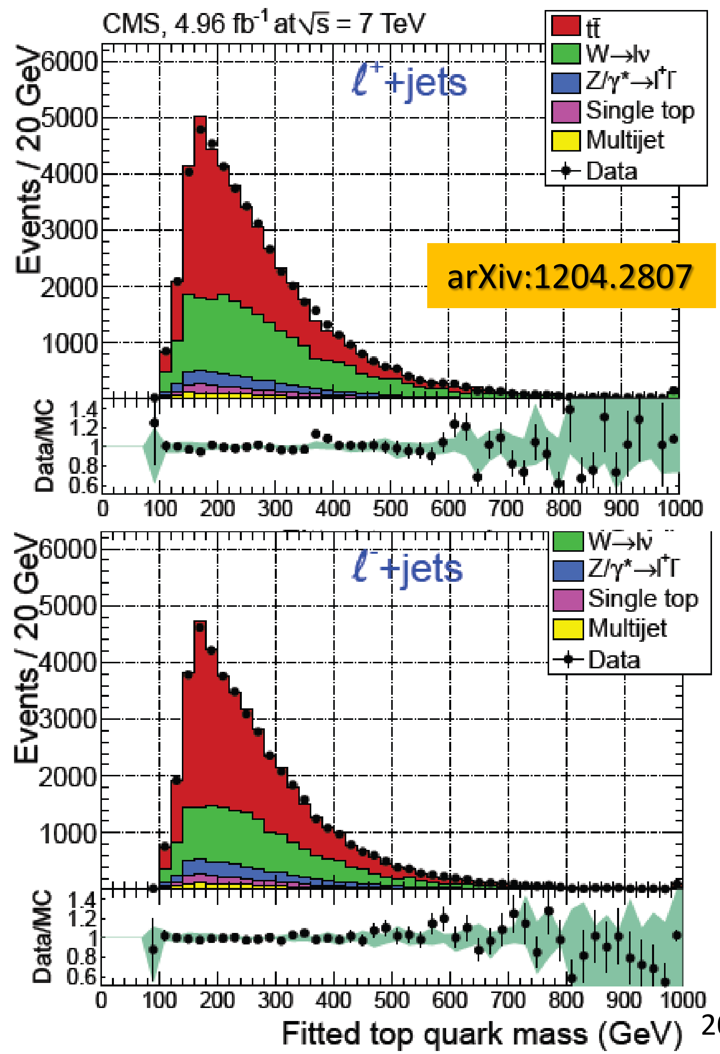
Top-antitop mass difference

- Test CPT invariance in the top sector
  - Reconstruction of the hadronic side: compare ℓ^++jets and ℓ^-+jets events
  - Use kinematic fit, and an event-per-event likelihood for ℓ^- and ℓ^+ separately
    - Same method of the top mass extraction

- Most systematic effects cancel out
  - Measurement is statistically limited
  - World's best so far, and consistent with the SM
  - Consistency also between e and μ channel

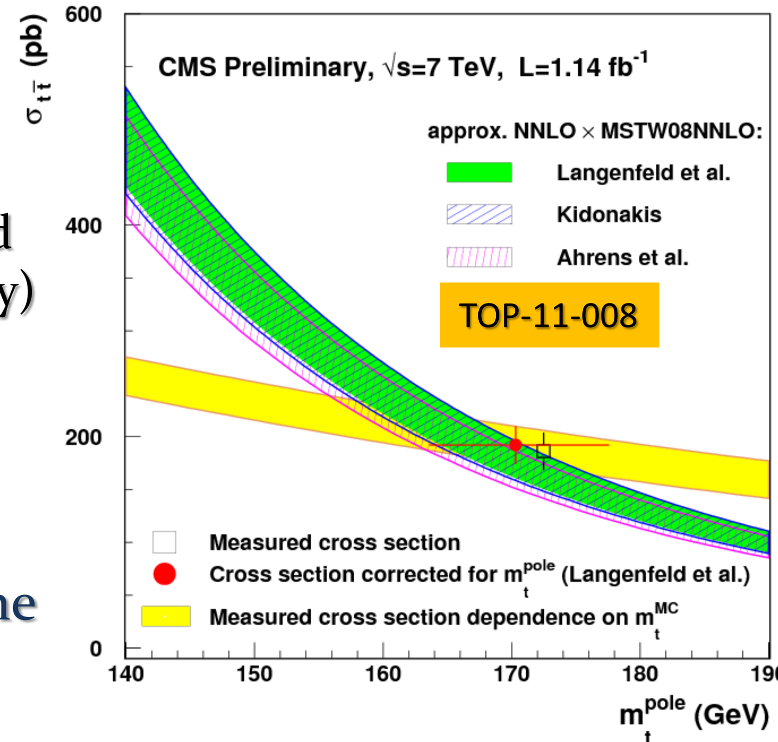
$$\Delta m_t = -0.44 \pm 0.46\ (\text{stat.}) \pm 0.27\ (\text{syst.})\ \text{GeV}$$

Source	Estimated effect (GeV)
Jet energy scale	$0.04 \pm \mathbf{0.08}$
Jet energy resolution	$0.04 \pm \mathbf{0.06}$
b vs. $\bar{\text{b}}$ jet response	$\mathbf{0.10} \pm 0.10$
Signal fraction	$\mathbf{0.02} \pm 0.01$
Difference in W^+/W^- production	$\mathbf{0.014} \pm 0.002$
Background composition	$\mathbf{0.09} \pm 0.07$
Pileup	$\mathbf{0.10} \pm 0.05$
b-tagging efficiency	$\mathbf{0.03} \pm 0.02$
b vs. $\bar{\text{b}}$ tagging efficiency	$\mathbf{0.08} \pm 0.03$
Method calibration	$0.11 \pm \mathbf{0.14}$
Parton distribution functions	**0.088**
Total	0.27



Top mass from cross section

- Use the dependence of σ_{tt} on m_t to infer the latter from the σ_{tt} measurement
  - ➢ Need full dependence of the acceptance of the analysis on m_t.
  - ➢ First extraction realized for the measurement in the di-lepton channel
- Theory errors include scales, PDFs, $\alpha_S(m_Z)$
- Extract both pole mass and $\overline{\text{MS}}$ mass
  - ➢ Pole mass directly related to what measured in direct reconstruction (~1 GeV uncertainty)
- Moderate dependence on the used PDFs
  - ➢ 1-2 GeV: the used value of α_S is crucial
- Extracted top mass not competitive with the direct determination



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]	$167.6^{+7.6}_{-7.1}$	$159.8^{+7.3}_{-6.8}$

W helicity and top couplings

- Measure θ^*_ℓ, the angle between the lepton and the b direction (in the W rest frame)
  - $d\sigma/d\cos\theta^*_\ell$ reflects 3 possible polarizations of the W. Sensitive to anomalous tWb couplings

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*_\ell} = \frac{3}{8}(1+\cos\theta^*_\ell)^2 F_R + \frac{3}{8}(1-\cos\theta^*_\ell)^2 F_L + \frac{3}{4}\sin^2\theta^*_\ell F_0$$

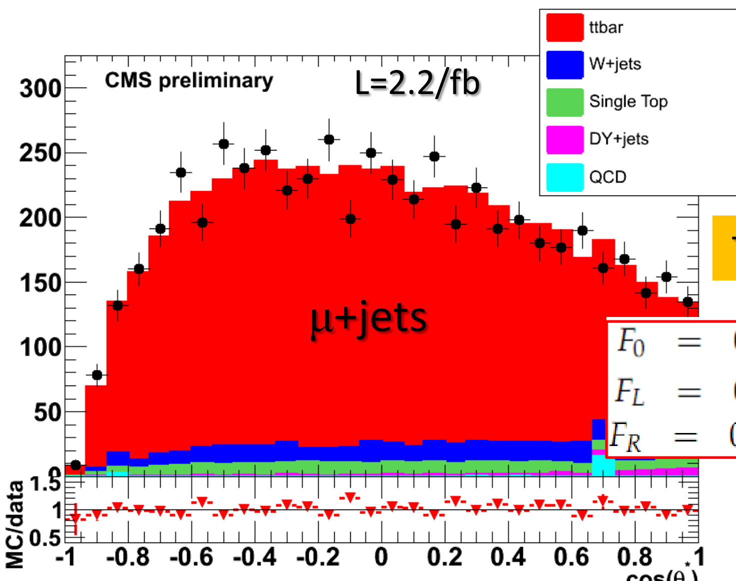
$$F_R = 4.1\times 10^{-4}$$
$$F_L = 0.301$$
$$F_0 = 0.698$$

- The polarization fractions can be extracted by a fit to data
  - Fit performed with and without the assumption of F_R=0
  - Main systematic errors represented by JES and theory uncertainties/W+jets normalisation

- Helicity fractions can be translated to constrain anomalous couplings and NP operators

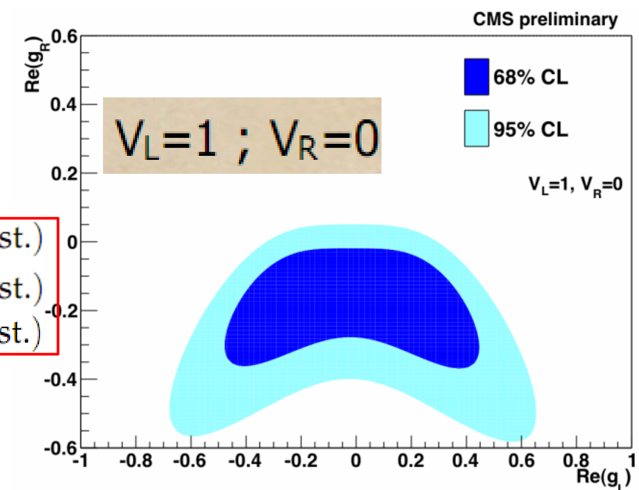
0 in the SM

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



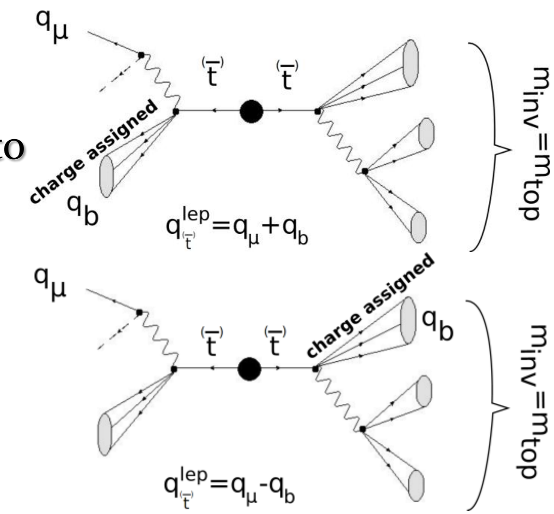
TOP-11-020

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



Constraints on the top charge

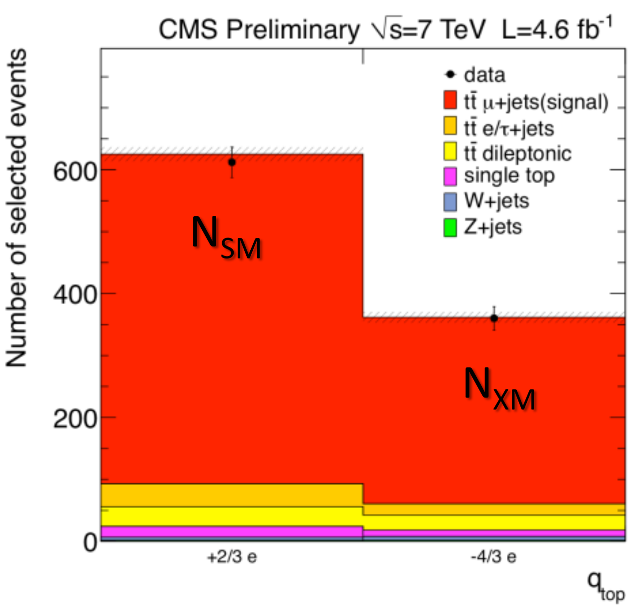
- Assign charge from semi-leptonic b decays
  - ➢ Minimize wrong charge assignment (e.g. B→D) by using p_{Trel} to optimize efficiency and purity
  - ➢ Performance measured in QCD b-bbar events
- Reconstruct hadronic top by using the knowledge of m_t
- Limit exotic scenario from asymmetry in charge categories
  - ➢ N_{SM} and N_{XM} are described by PDFs using signal/bckg

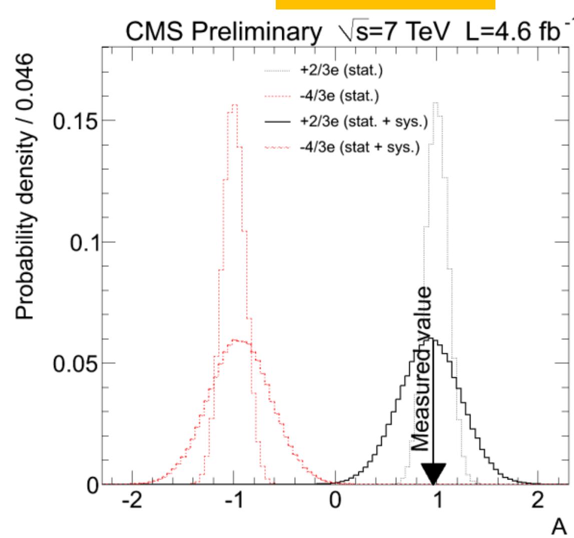


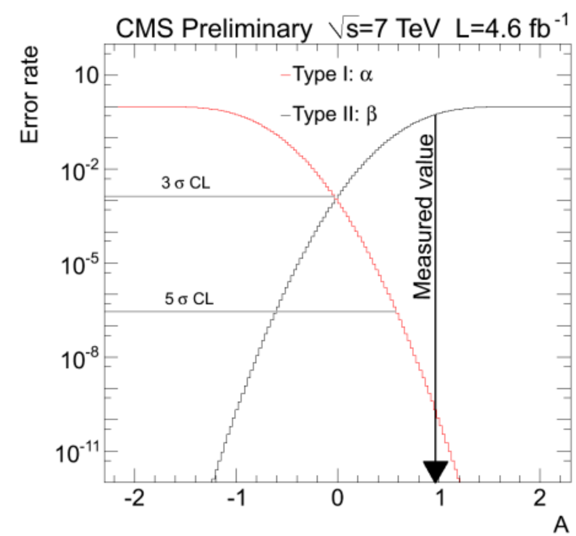
$$A_{\mathrm{meas}} = 0.97 \pm 0.12_{\mathrm{stat}} \pm 0.31_{\mathrm{syst}}$$

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

TOP-11-031

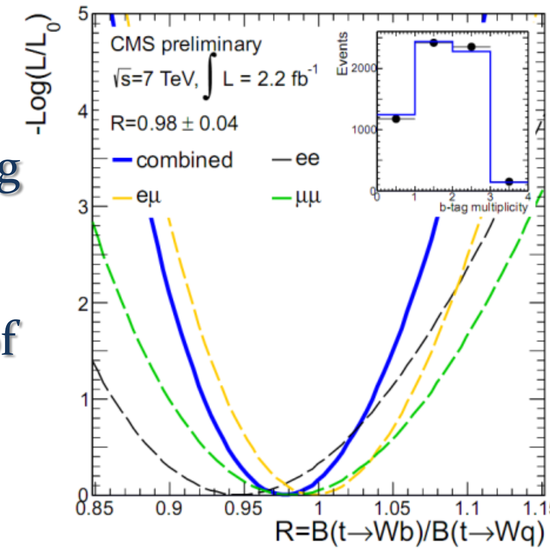


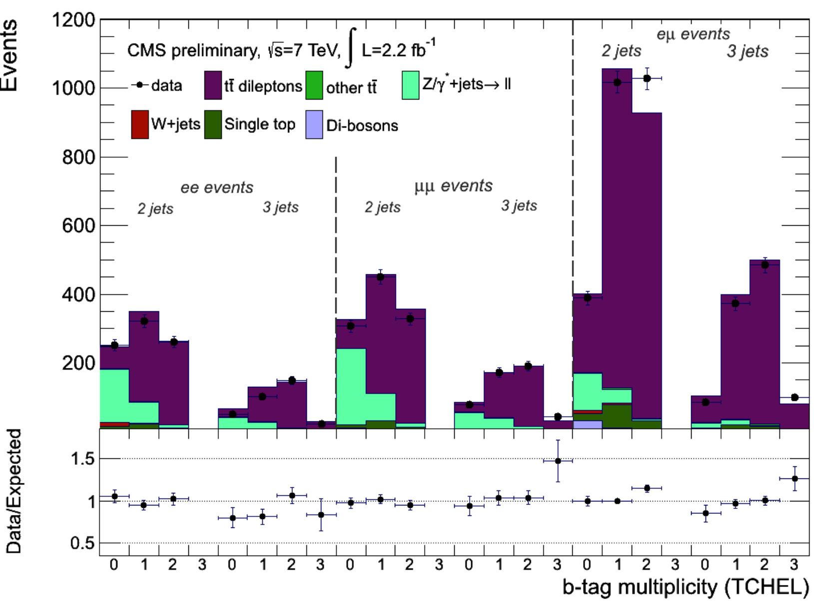




$R = BR(t \to Wb) / \Sigma_k BR(t \to Wq_k)$

- Use di-lepton events with standard selection
  - ➢ DY background entirely data driven
- Estimate Wq contribution from wrong assignments by using data driven approach which uses sidebands in m(qℓ)
- b-tagging multiplicity is then parameterized as a function of R, ε_b, ε_q, (combinatorial) backgrounds
  - ➢ Also dividing in ee, μμ, eμ and 2, 3 jets events
  - ➢ Fit R assuming ε_b from b production in di-jets
  - ➢ Determine F-C frequentist interval after profiling of all nuisances

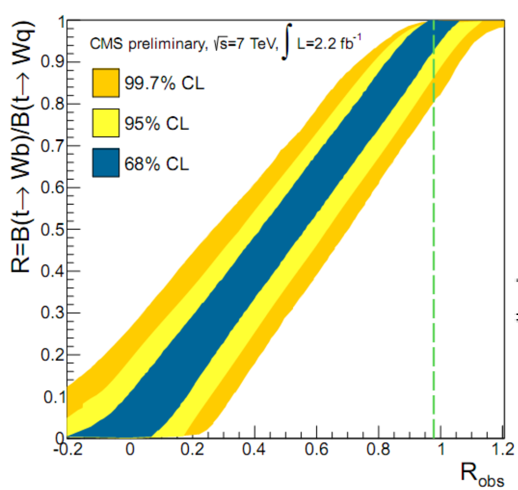




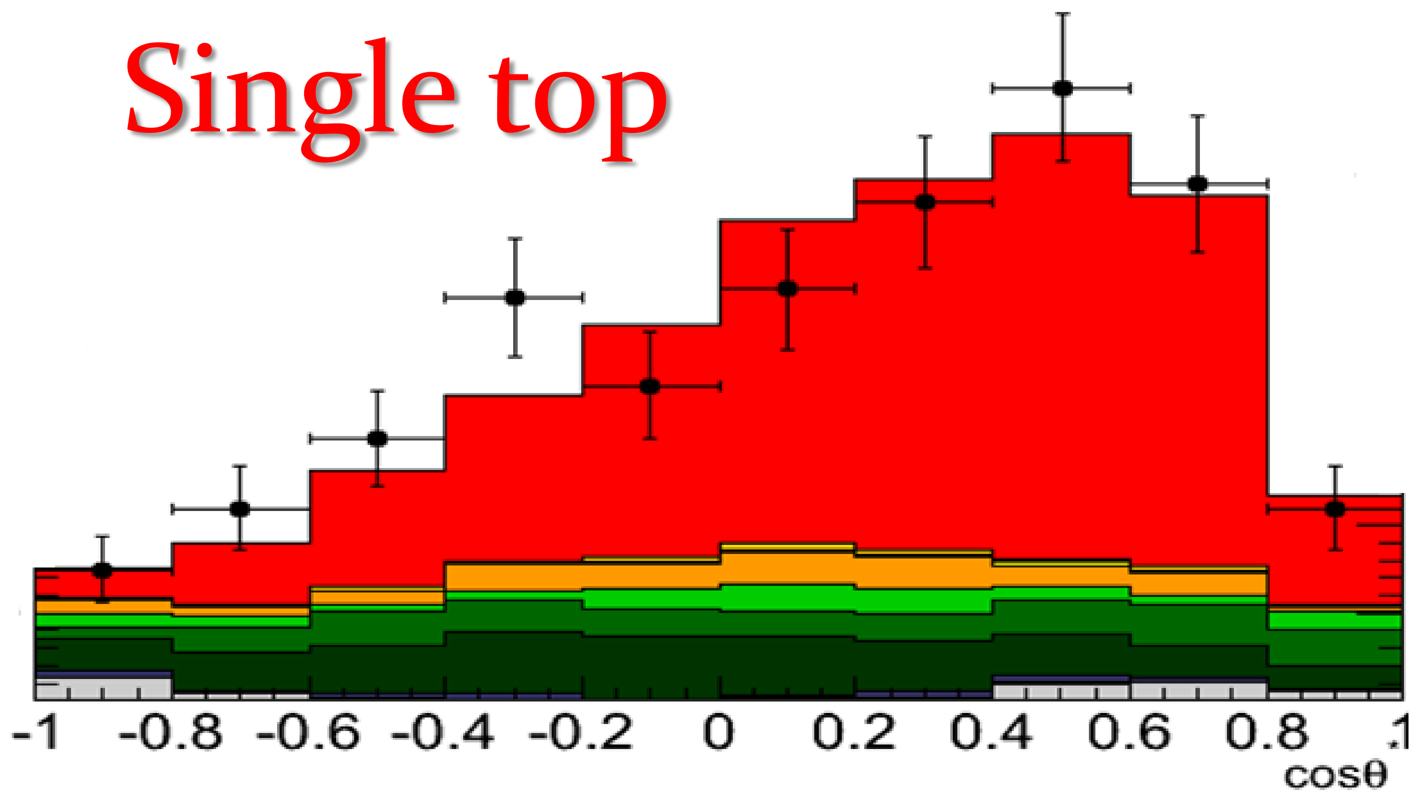
TOP-11-029

$R = 0.98 \pm 0.04$

$R > 0.85$ at 95% C.L.



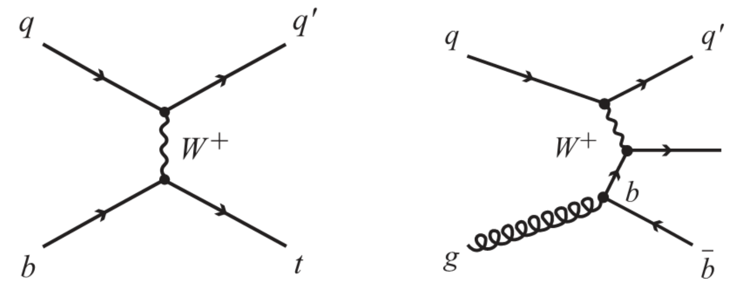
Source	Uncertainty
ε_b	0.031
ε_q	0.011
Jet energy scale	0.002
Jet energy resolution	0.004
Pile-up	0.006
Q^2	0.023
Jet-parton matching scale	0.011
DY contamination	0.012
$t\bar{t}$ contribution	0.002
Total	0.044



Single top
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
cosθ

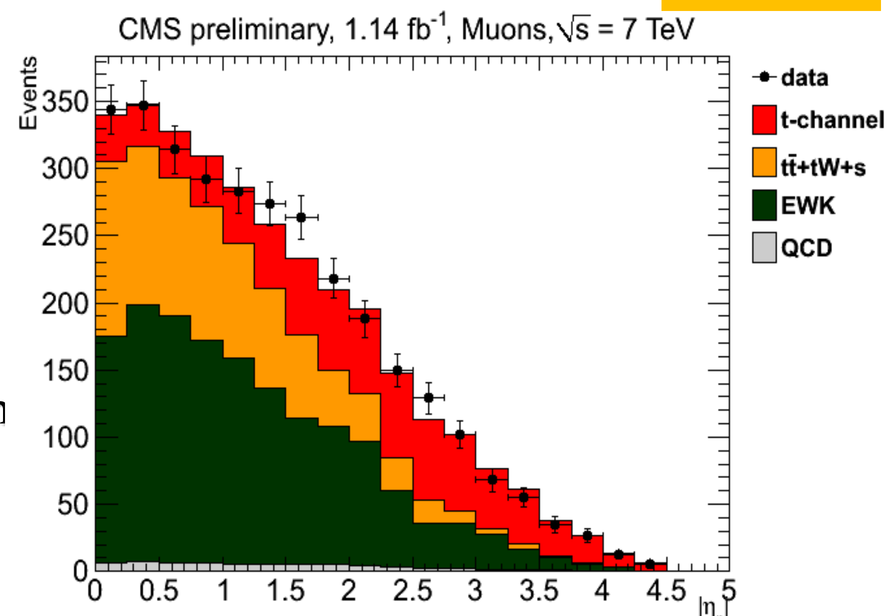
Single top - t-channel

- Select events with one isolated lepton, one b-tagged jet, one forward jet
  - 1 isolated e (p_T>30 GeV) or μ (p_T>20 GeV)
  - 2 jets, E_T>30 GeV, $|\eta|$<5.0
  - One "tight" b-tag
  - Transverse W mass > 40(50) GeV



- Cross section is extracted from a fit to the angular variable η_ℓ
  - All background rates and shapes are taken from control regions in data
    - QCD from fits to low m_T, MET
    - Top pair from the 3 jets, 2 b-tag sample
    - W+light jets from 2 jets and anti b-tag
    - W+HF via fit of sidebands in m(ℓbν)

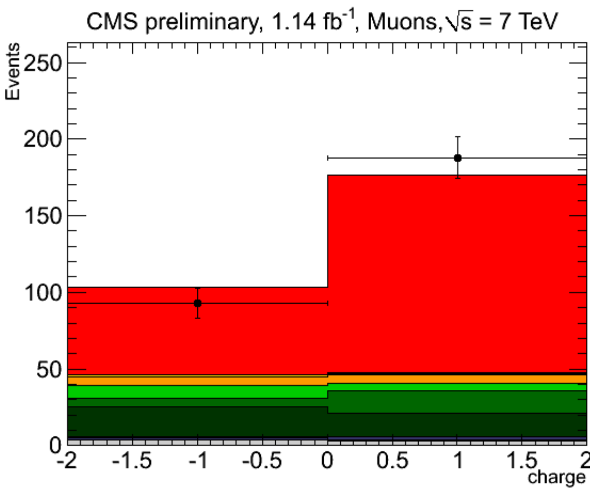
TOP-11-021

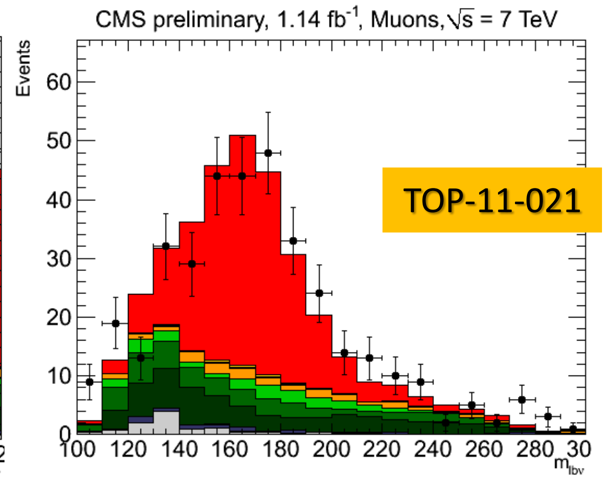


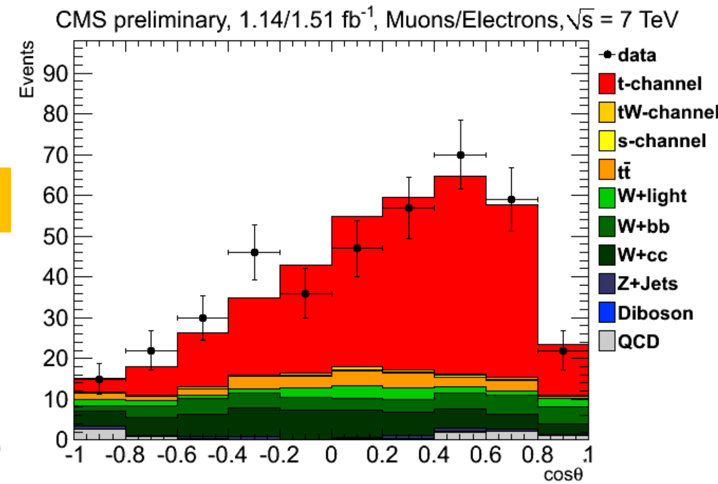
- Main systematic errors
  - JES
  - Background knowledge from data-driven methods

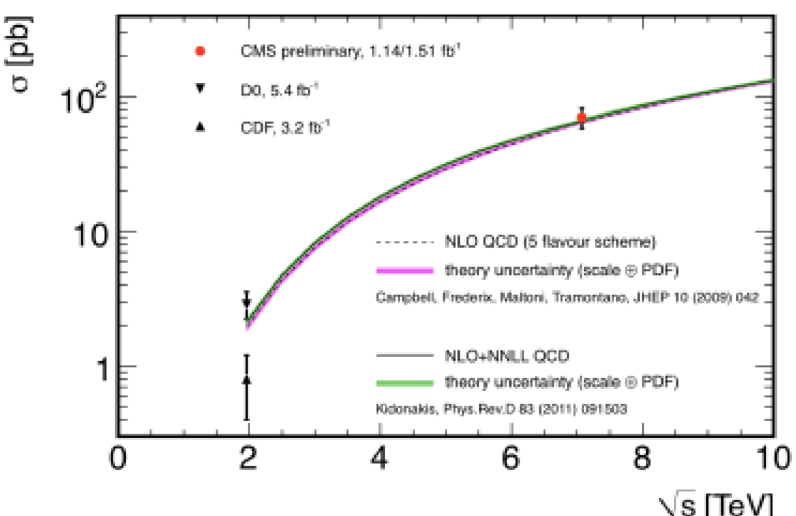
Single top - t-channel

- Excellent agreement in differential distributions after the fit:
  - Charge ratio: $N(\ell^+) \sim 1.9 N(\ell^-)$
  - Angular and mass distributions







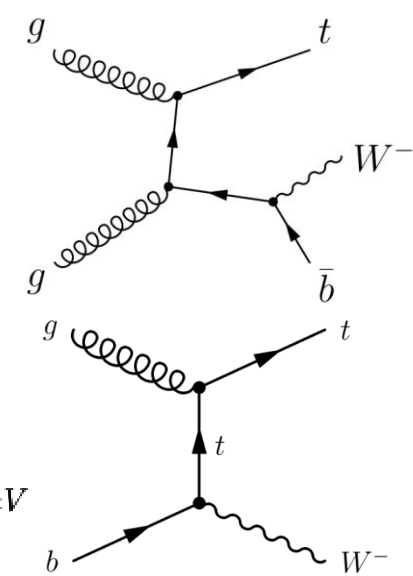


$$\sigma_{t-\mathrm{ch.}} = 70.2 \pm 5.2(\mathrm{stat.}) \pm 10.4(\mathrm{syst.}) \pm 3.4(\mathrm{lumi.})\ \mathrm{pb}$$

- $|V_{tb}|$ can be derived by assuming $|V_{td}|, |V_{ts}| << |V_{tb}|$

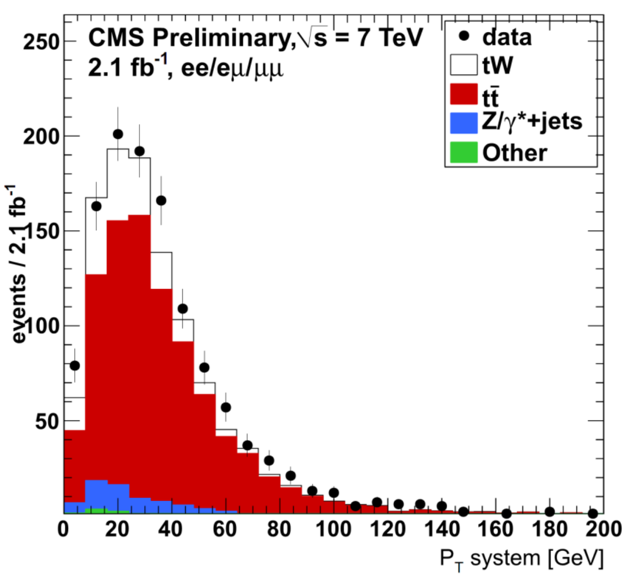
$$|V_{tb}| = \sqrt{\frac{\sigma_{t-\mathrm{ch.}}}{\sigma^{\mathrm{th}}_{t-\mathrm{ch.}}}} = 1.04 \pm 0.09\,(\mathrm{exp.}) \pm 0.02\,(\mathrm{th.})$$

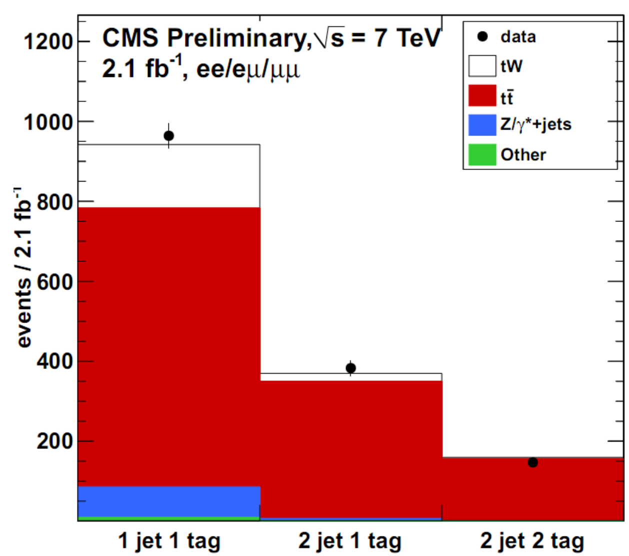
Single top – tW production



- Same as top pair at NLO
  - ➢ Subtraction schemes needed to properly define the observable
- Signature similar to di-lepton top pair (one b-jet less)
  - ➢ 2nd b-jet veto is applied for signal region
  - ➢ Add conditions on the p_T of the system $|\sum_{leptons} \vec{p}_T + \vec{p}_T^{\,b-jet} + \vec{E}_T^{miss}| < 60\ GeV$
  - ➢ Categorize events to constrain the tt component and ε_b
- Use maximum likelihood fit for σ(tW):
  - ➢ Observed significance is 2.7σ (expected 1.8+/-0.9 σ)

22^{+9}_{-7} (stat ⊕ syst) pb

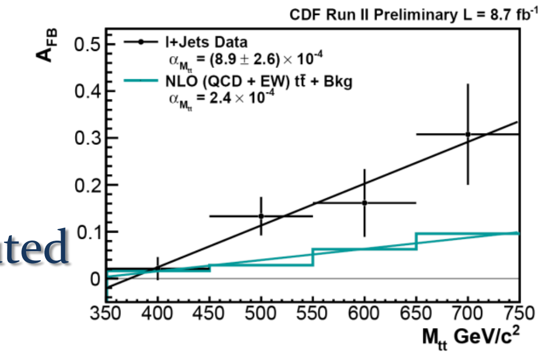




TOP-11-022

Looking for something beyond the SM

Charge asymmetries

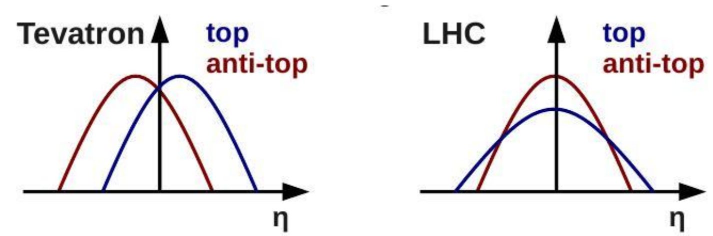


arXiv:1101.0034, arXiv:0712.0851

- Tevatron observes anomalous charge asymmetries
- Different definition is possible at the LHC, but asymmetry diluted

$$\frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} \qquad \Delta|y| = |y_t| - |y_{\bar{t}}|$$

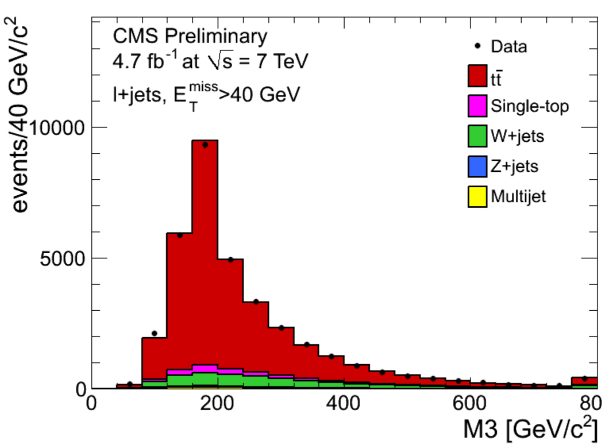
- Need a full event reconstruction
  - ➢ Use ℓ+jets events, the top charge is correlated to that of the lepton
  - ➢ Use W mass constraint for the neutrino
  - ➢ Use top kinematics to solve combinatorial

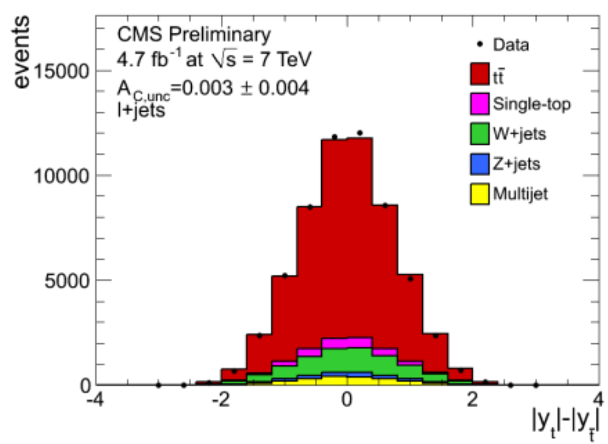


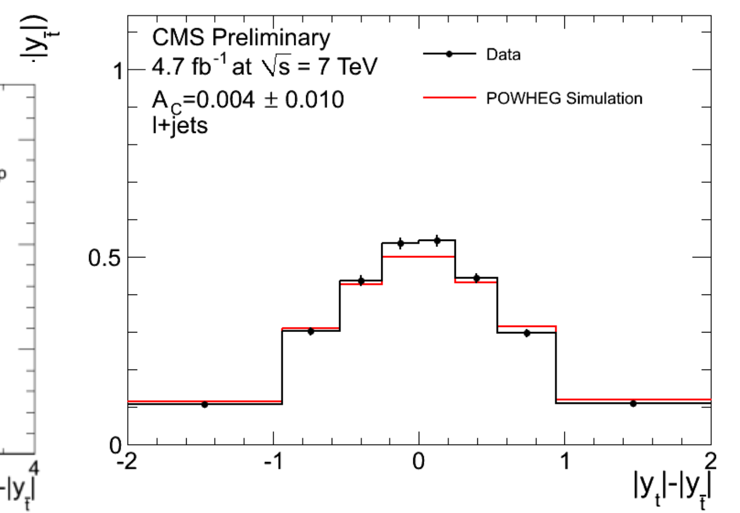
Uncorrected	0.003 ± 0.004 (stat.)
BG-subtracted	0.001 ± 0.005 (stat.)
Final corrected	0.004 ± 0.010 (stat.) ± 0.012 (syst.)
Theory prediction (SM)	0.0115 ± 0.0006

- Results are unfolded
  - ➢ Via regularized matrix inversion
  - ➢ Method tested to be linear and unbiased

TOP-11-030



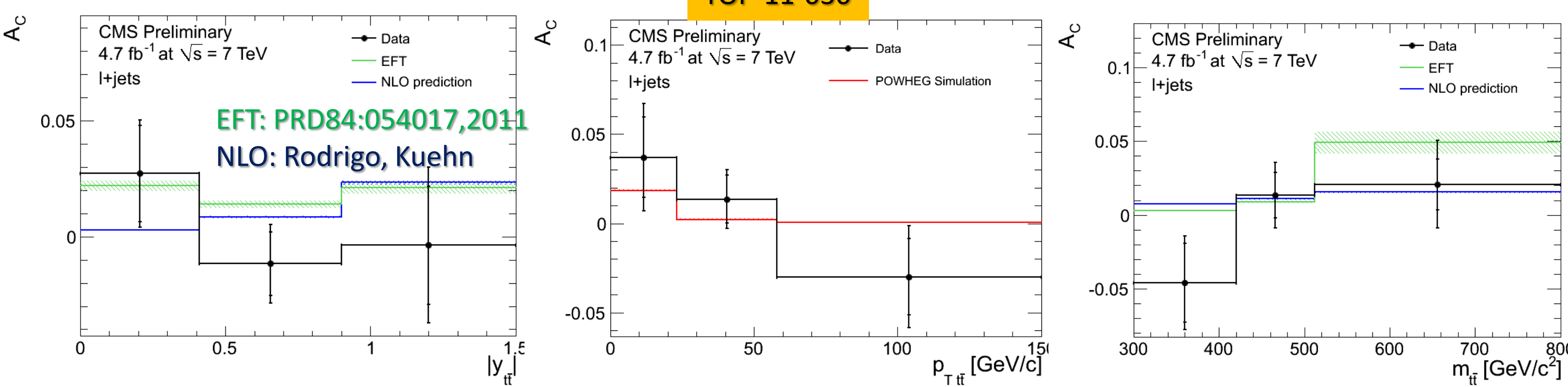




Differential asymmetries

- In many new physics scenarios the charge asymmetry depends on phase space
  - ➢ High mass/p_T regimes enhance the quark annihilation part of the initial state
- Measure A_c differentially as a function of p_T, y or invariant mass of the top pair system
- Full 2D regularized unfolding after background subtraction
  - ➢ Method tested to be linear in distortion function of the second unfolded variable
- Good agreement found between data and SM expectations within uncertainties
  - ➢ Main systematics errors are given by the unfolding itself and lepton ID efficiency
  - ➢ Results also compared with EFT predictions
    - Anomalous axial coupling of gluons to quarks: capable to explain the Tevatron anomaly

TOP-11-030

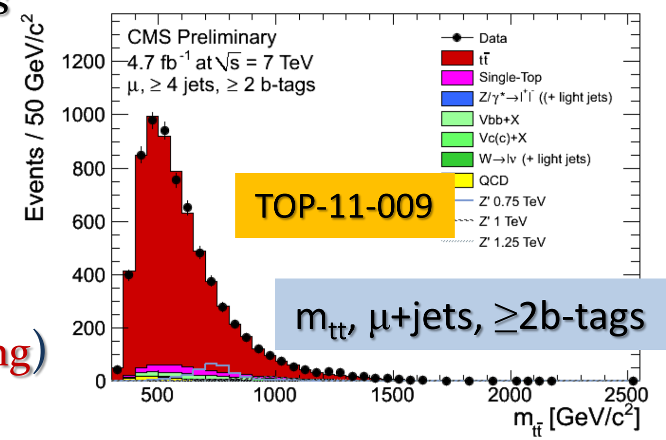


New physics in production: resonances

- Several models of new physics predict resonances decaying into top pairs

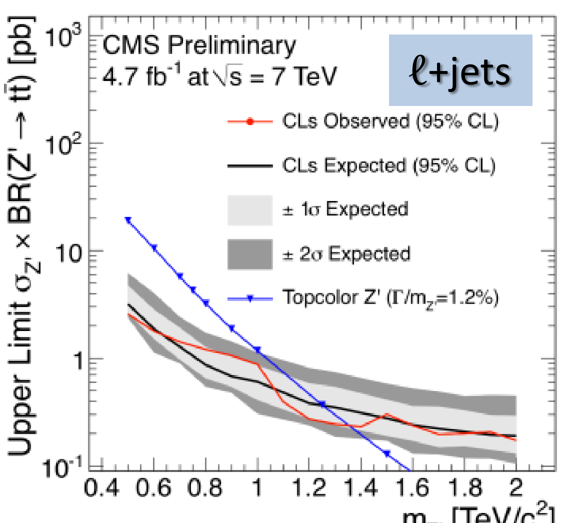
Topcolor/Technicolor Z'
Higgses
KK excitations

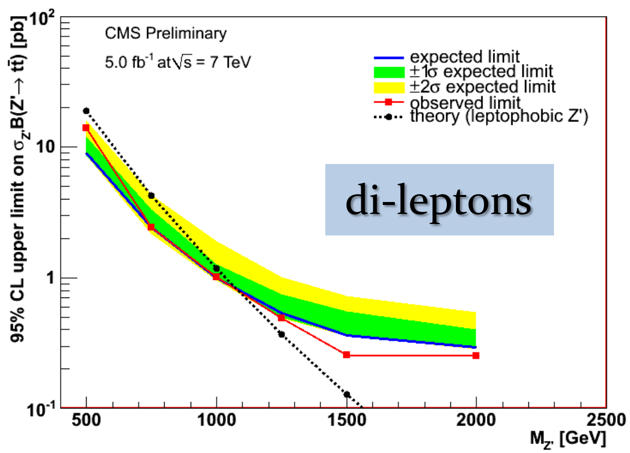
- ℓ+jets events: full event reconstruction
  - Jet pairing by χ^2 association (correct in ~70%)
  - Multi-jet and W+jets background from data control regions
  - Fit together different Njets, b-tag categories

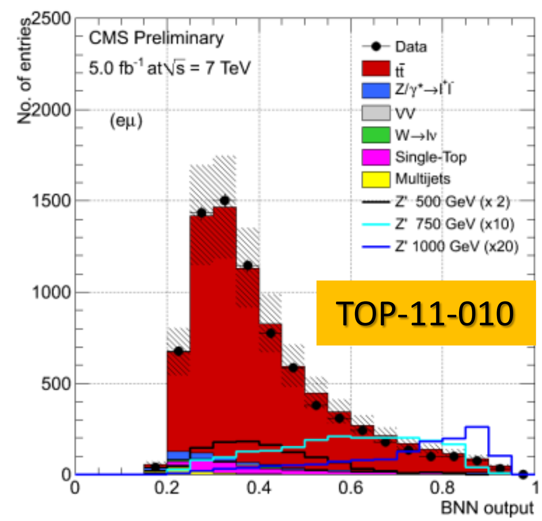


- Di-leptons: use a NN approach to best separate S and B
  - Uses information from jets, leptons, MET

- Systematic errors include shape (JES, b-tag, theory modelling) and rate (efficiencies, background yields) changing ones



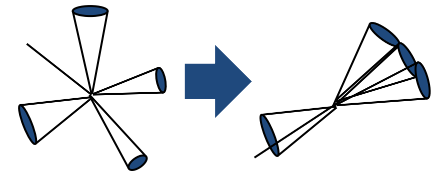


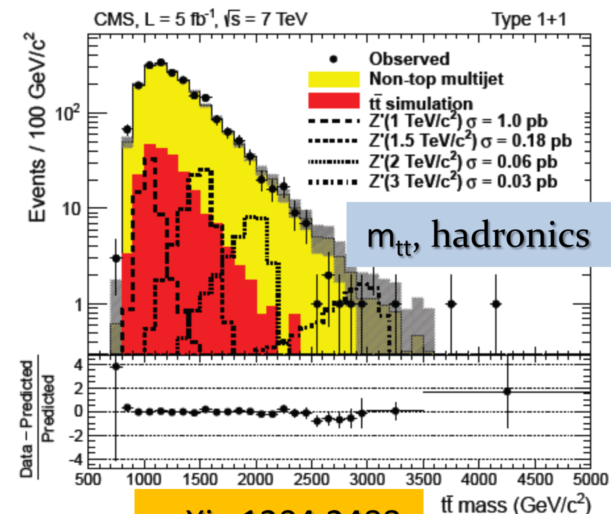


CL$_S$ criterion, LR= $-2\ln\frac{\mathcal{L}(\text{data}\,|\,\mu=0,\vec{\sigma})}{\mathcal{L}(\text{data}\,|\,\hat{\mu},\vec{\sigma})}$

New physics in production: high boosts

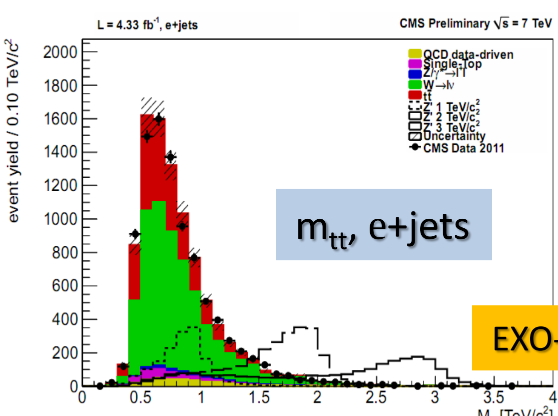
- Advanced techniques for top tagging in case of jet merging
  - ➢ Essential for hadronic channels at high mass/boosts
  - ➢ C-A modified algorithm finding jet substructures compatible with top kinematics
  - ➢ Entirely calibrated by using QCD data



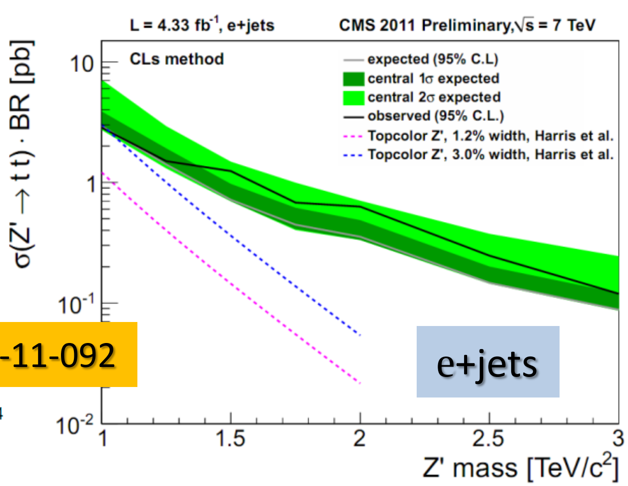


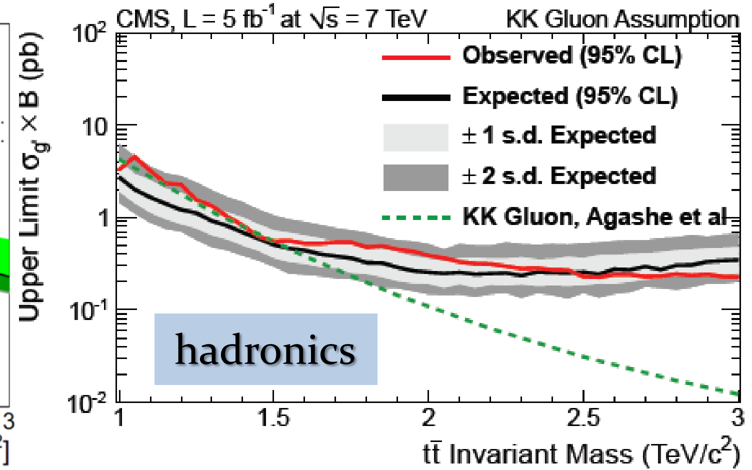
arXiv:1204.2488

- Also alternative ℓ+jets analyses which increase sensitivity at very high masses
  - ➢ No lepton isolation conditions, at least two jets
  - ➢ No direct reconstruction if more jets, top constructed favoring back to back configurations



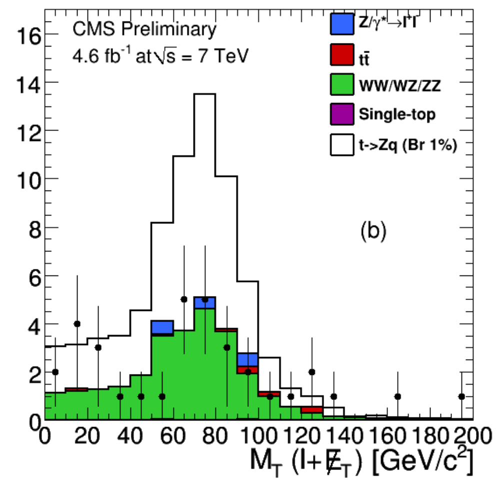
EXO-11-092

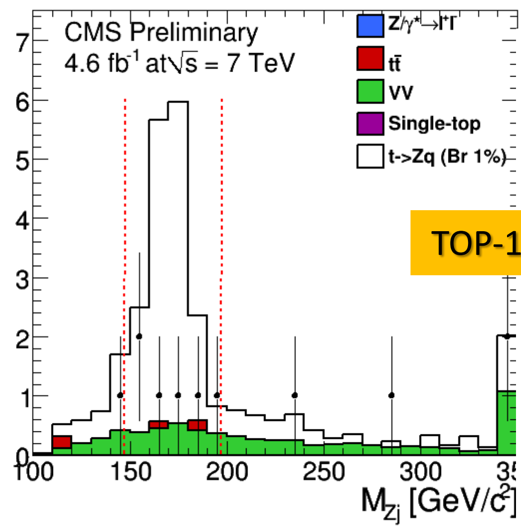




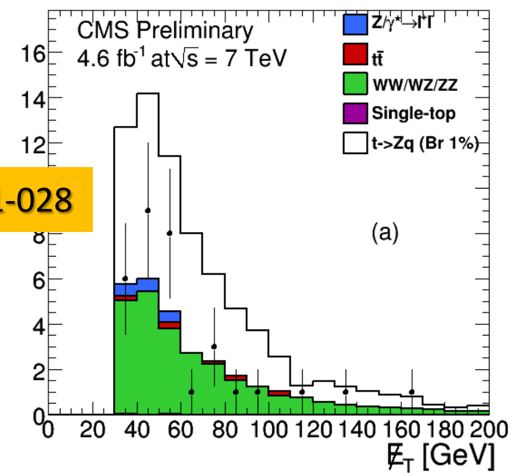
New physics in decays: FCNC

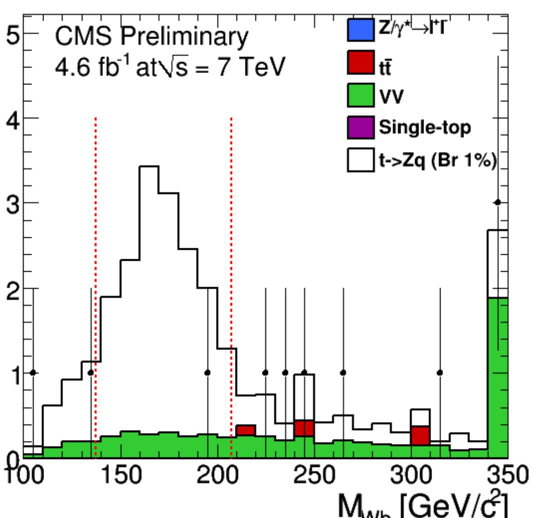
- At LO FCNC is highly suppressed: BR SM$(t \rightarrow qZ)_{NLO}$~10^{-14}
  - NLO corrections from BSM can enhance the BR by a factor of 10^{10}
- Search in top decays: $t \rightarrow qZ \rightarrow q\ell^+\ell^-$
  - Tri-lepton events (two from Z), very clean signature, but small BR
- Selection also requires two jets, MET>30GeV, veto on 4th lepton.
  - Full kinematics specified from χ^2 fit or using m_W and MET constraints
  - Either HT_S or b-tagging are used to further reduce the background
  - No excess observed





TOP-11-028





Signal Selection	HT_S-cut Based	b-tag Based
Total background prediction (data driven)	$16.2 \pm 3.9 \pm 2.6$	$0.6 \pm 0.1 \pm 0.1$
Data	11	0
Expected limit at the 95% CL	$Br(t \rightarrow Zq) < 0.42\%$	$Br(t \rightarrow Zq) < 0.34\%$
Observed limit at the 95% CL	$Br(t \rightarrow Zq) < 0.39\%$	$Br(t \rightarrow Zq) < 0.34\%$

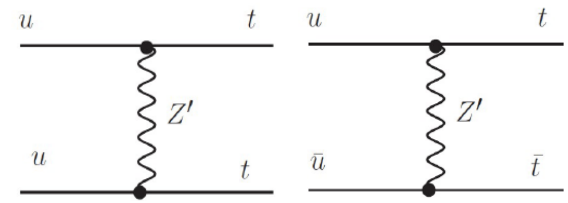
$HT_S = \Sigma p_{T\ell} + \Sigma E_{Tj} + \not{E}_T$

(world best)

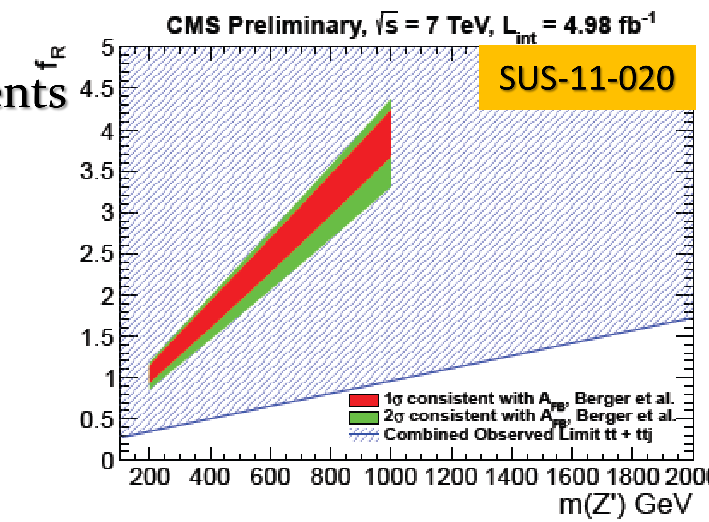
Other new physics compatible with top pairs

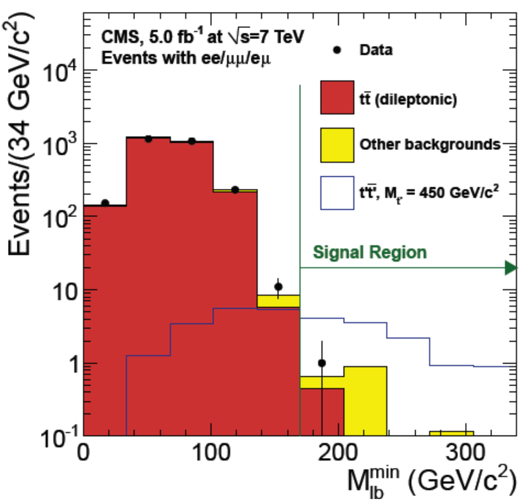
- Z' model could explain the Tevatron A_{FB} asymmetry
  - ➢ Search for two same sign leptons and at least two b-tagged jets with MET

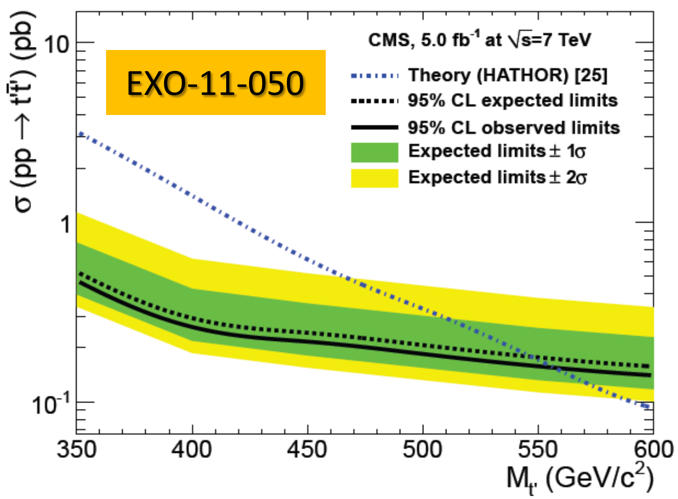
Berger et al., PRL106(2011), 201801



- Heavy top like quark decays $t'\bar{t}' \to bW^+\bar{b}W^-$
  - ➢ Look beyond the m(ℓb) endpoint in di-lepton events



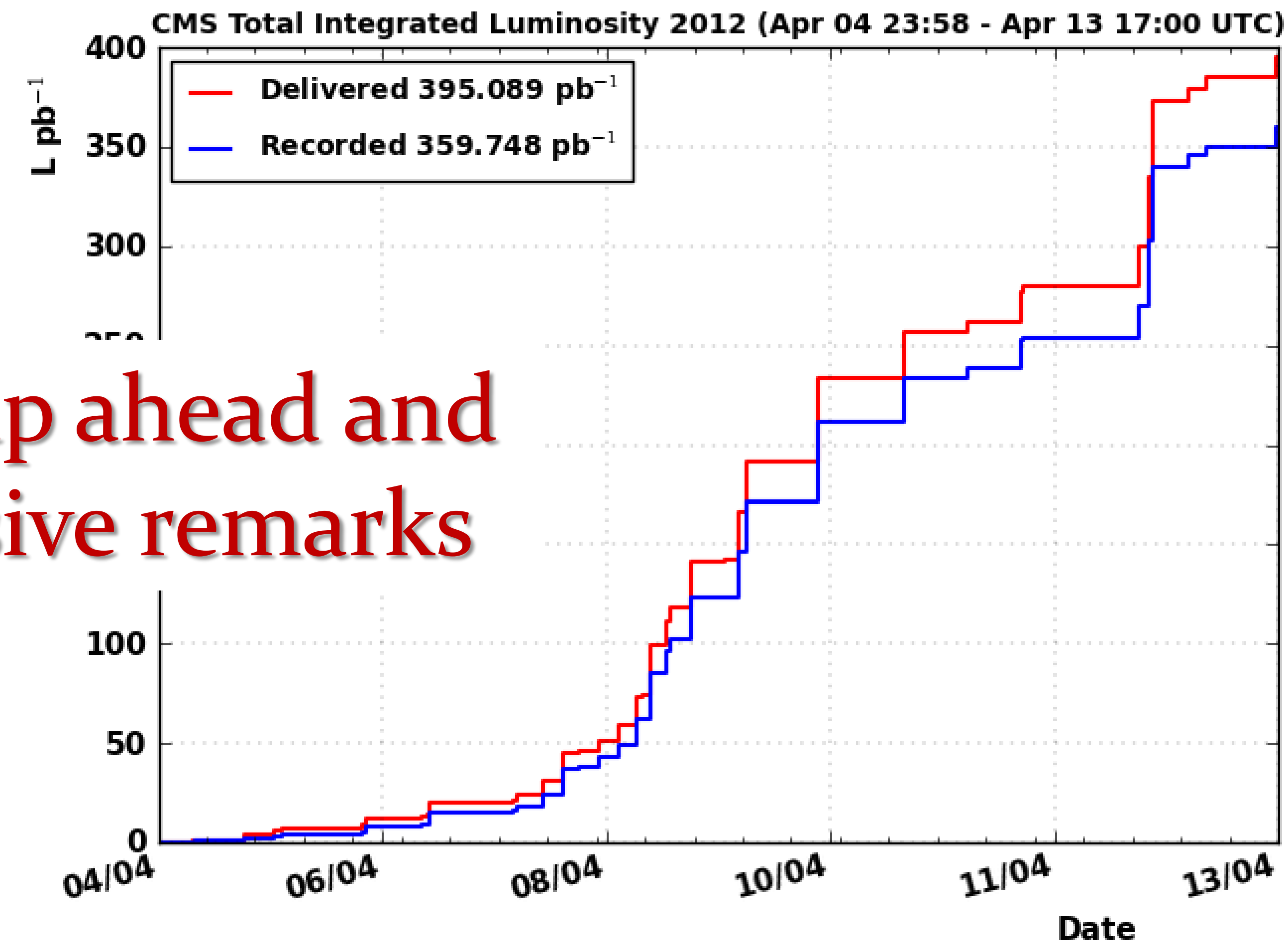




- Other searches involving fourth generation are investigated in CMS
  - ➢ Examples are $b'\bar{b}' \to tW^-\bar{t}W^+$ and $T\bar{T} \to tZ\bar{t}Z$
  - ➢ May lead to spectacular signatures with tt+multilepton final states

EXO-11-036

arXiv:1109.4985



Roadmap ahead and conclusive remarks

Top in the year of the Scalar Boson

Process	σ(8 TeV)/σ(7 TeV)
Top pair	~1.5
Single top t-ch	~1.3
Single top tW	~1.5
Single top s-ch	~1.2

- Consolidate the top sector at 8 TeV
  - Total and differential cross sections.
    - Double ratios tt/Z(8TeV)/tt/Z(7TeV)
  - Monitor distributions sensitive to new physics
- New ideas in the high statistics/precision regime
  - Alternative methods for determining the top mass
    - Favour methods presenting systematic errors uncorrelated with standard reconstruction
  - Constraining systematic errors by using data
    - Study Colour Reconnection effects, constrain theory uncertainties on radiation by using data
  - Let us go doubly differential (e.g. $m_t(X)$; $A_C(Y)$)
    - Select phase space regions where the sensitivity to the main systematic errors is reduced
  - "Environmental" studies of top-pair: tt+X !
    - Study couplings to bosons, and test signatures of new physics in association
- Other ongoing work in CMS/top
  - Top spin correlations, top finite width effects
  - Single top s-channel and differential distribution
  - Global fit to the Wtb vertex (top pair and single top measurements)
  - Contribute to the combination efforts ongoing in the TOPLHCWG

Conclusions

- Last year has been crucial for top physics
  - From a handful of events to a deep testing of the top sector
  - The realm of differential distributions
- CMS has been doing great…
  - Very competitive analyses in the top sector
  - We start to challenge theory predictions
- …and the Standard Model looks healthier than ever
  - No hints of new physics yet
- This year will be even more crucial for top physics
  - Doubly differential distributions
  - In situ constraints of theory systematic uncertainties
  - Study the environment in association to top pair events
  - Find hints of physics beyond the Standard Model ?