Top Quark Production at the LHC

Andrew Ivanov

Kansas State University

On behalf of the ATLAS and CMS Collaborations

FPCP 2012

University of Science and Technology of China, Hefei, AnHui, China

Large Hadron Collider

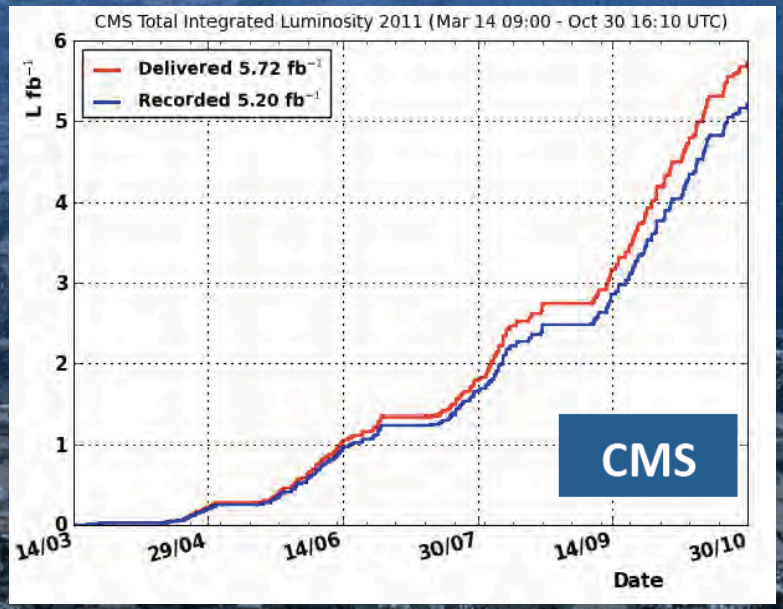
pp collisions at $\sqrt{s}$ = 7.0 TeV

Max. Inst. Lumi (2011)

~ 3.5 x 10^{33} $cm^{-2}s^{-1}$

Recorded Integrated Luminosity

~ 5.2 fb^{-1}



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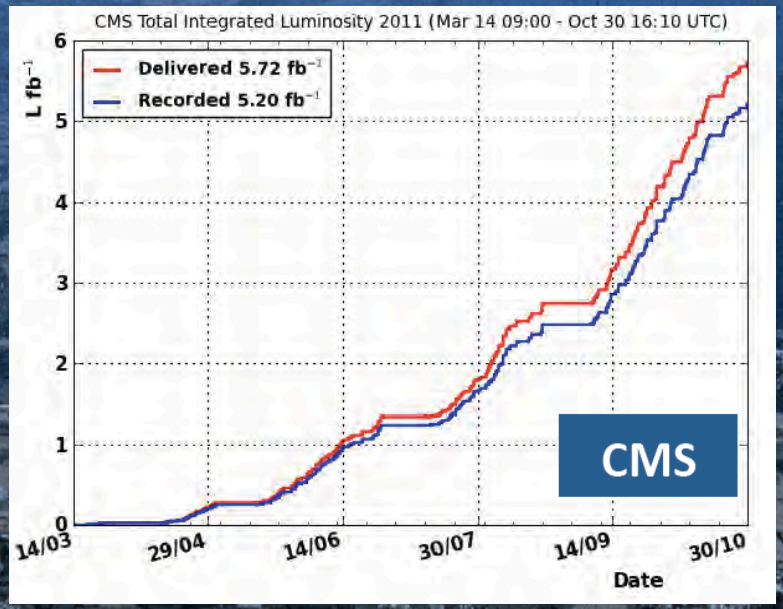
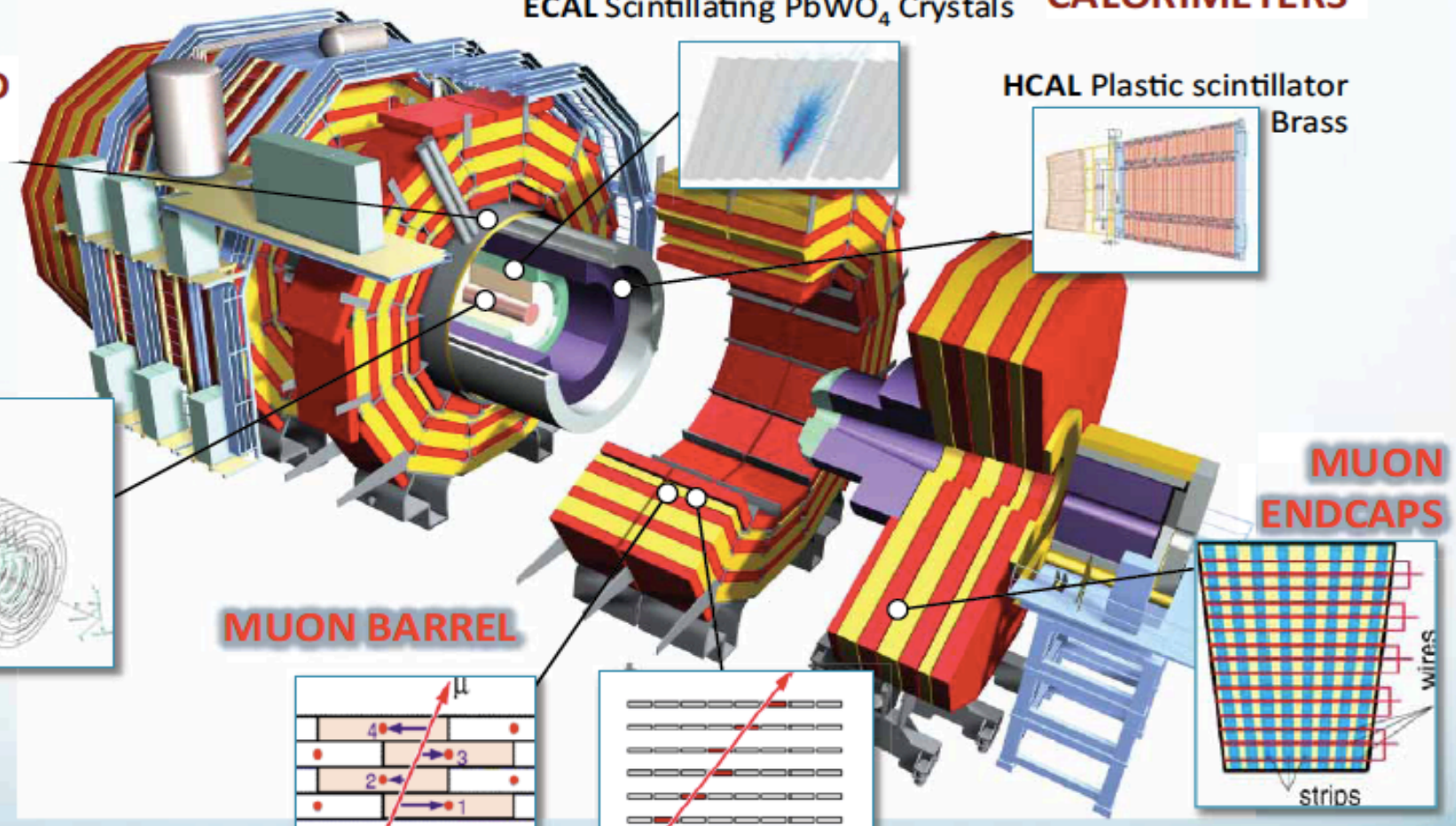


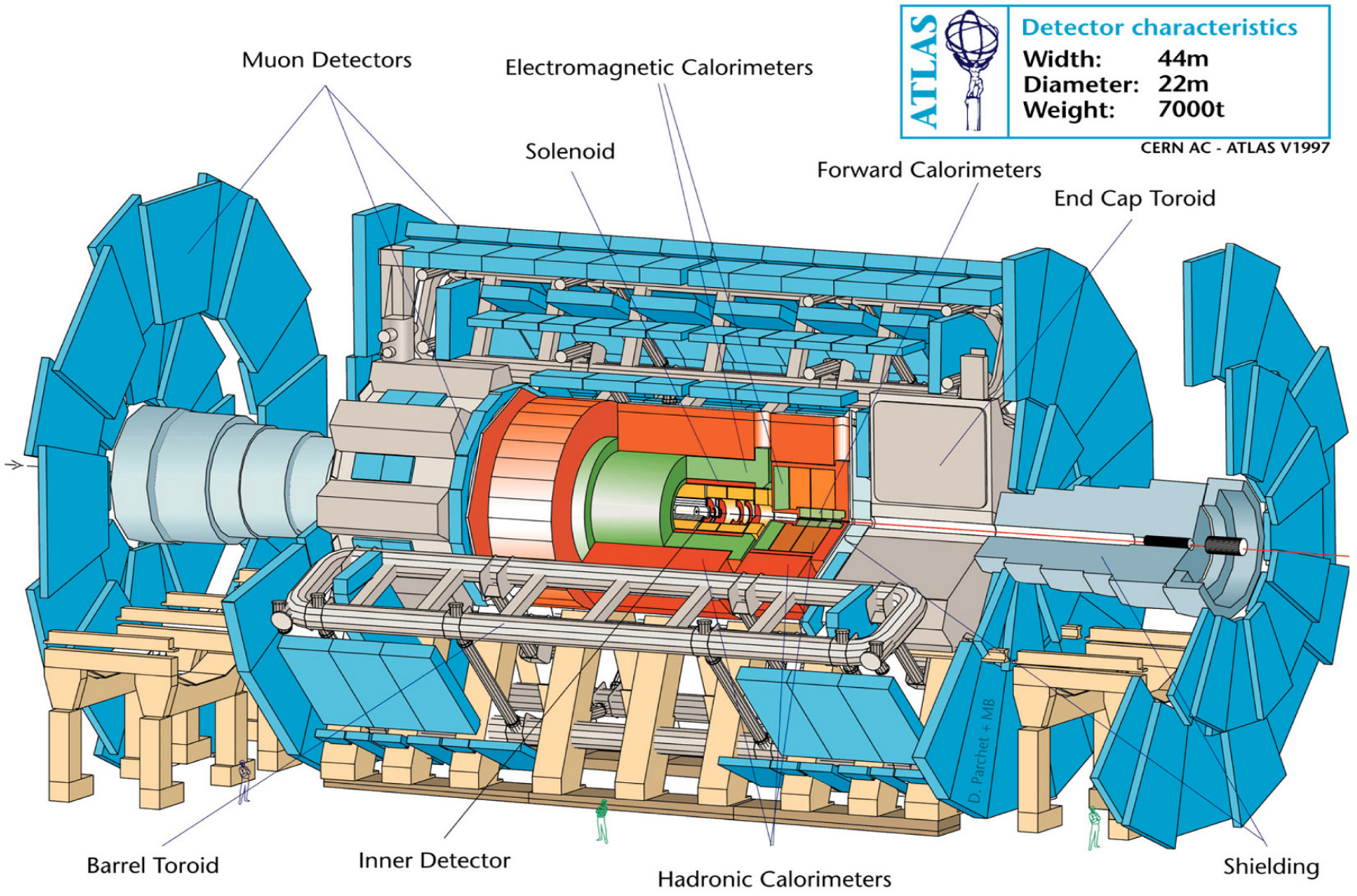
NOW: pp collisions at $\sqrt{s}$ = 8.0 TeV
Max. Inst. Lumi (2012)
~ 5.5 x 10^{33} $cm^{-2}s^{-1}$
Recorded Integrated Luminosity
~ 2 fb^{-1}
Goal : 20 fb^{-1} by the end of 2012
ATLAS Higgs Boson !..

CMS Detector

weight: 12500 t
overall diameter: 15 m
overall length: 21.6 m

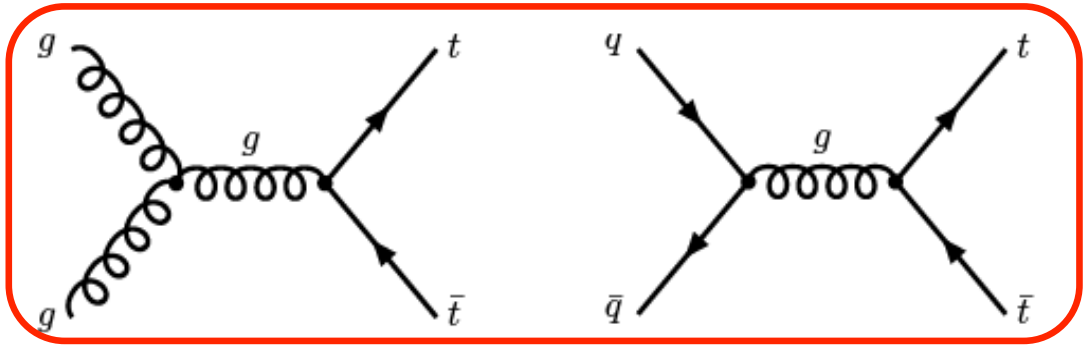


ATLAS Detector



Top Quark Production at LHC

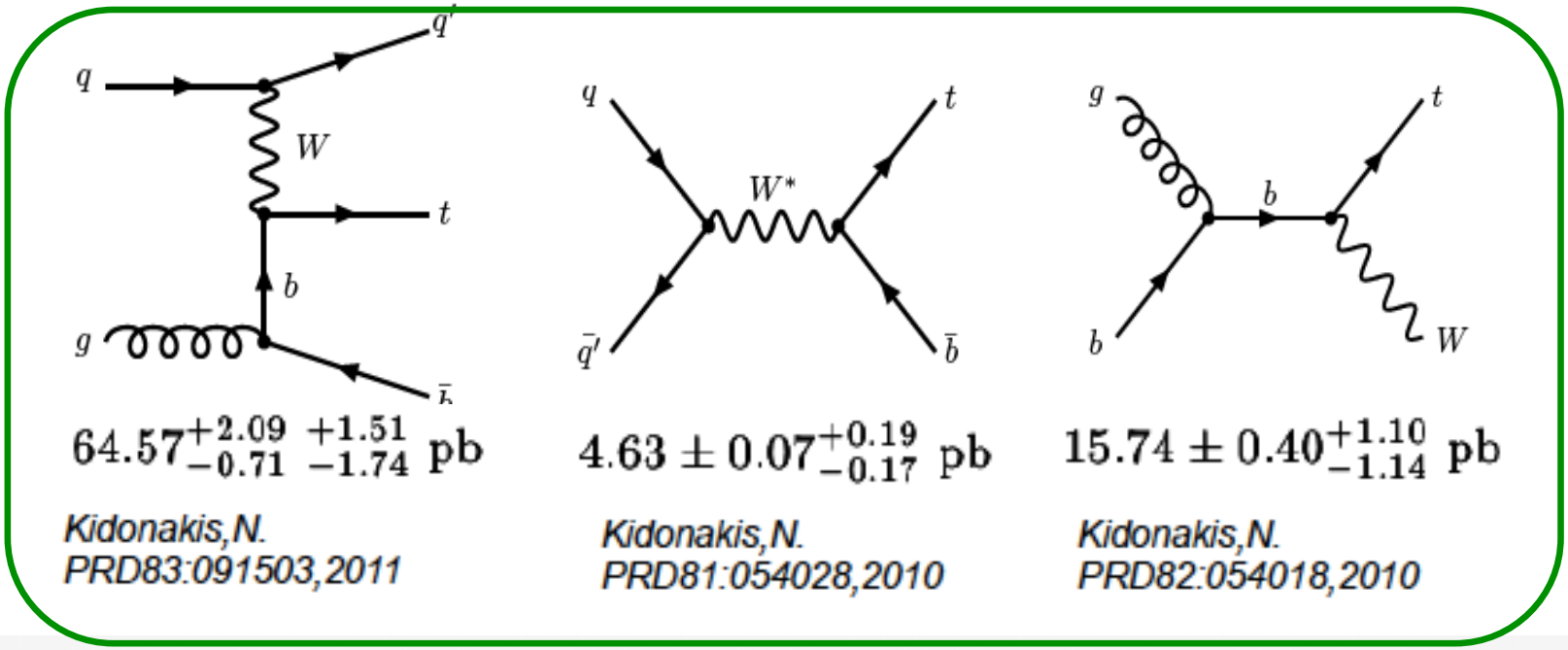
Top Quark Pair Production



165^{+11}_{-16} pb

Aliev, M. et al
arXiv/hep-ph:1007.1327

Single Top Production



$64.57^{+2.09\ +1.51}_{-0.71\ -1.74}$ pb

Kidonakis, N.
PRD83:091503, 2011

$4.63 \pm 0.07^{+0.19}_{-0.17}$ pb

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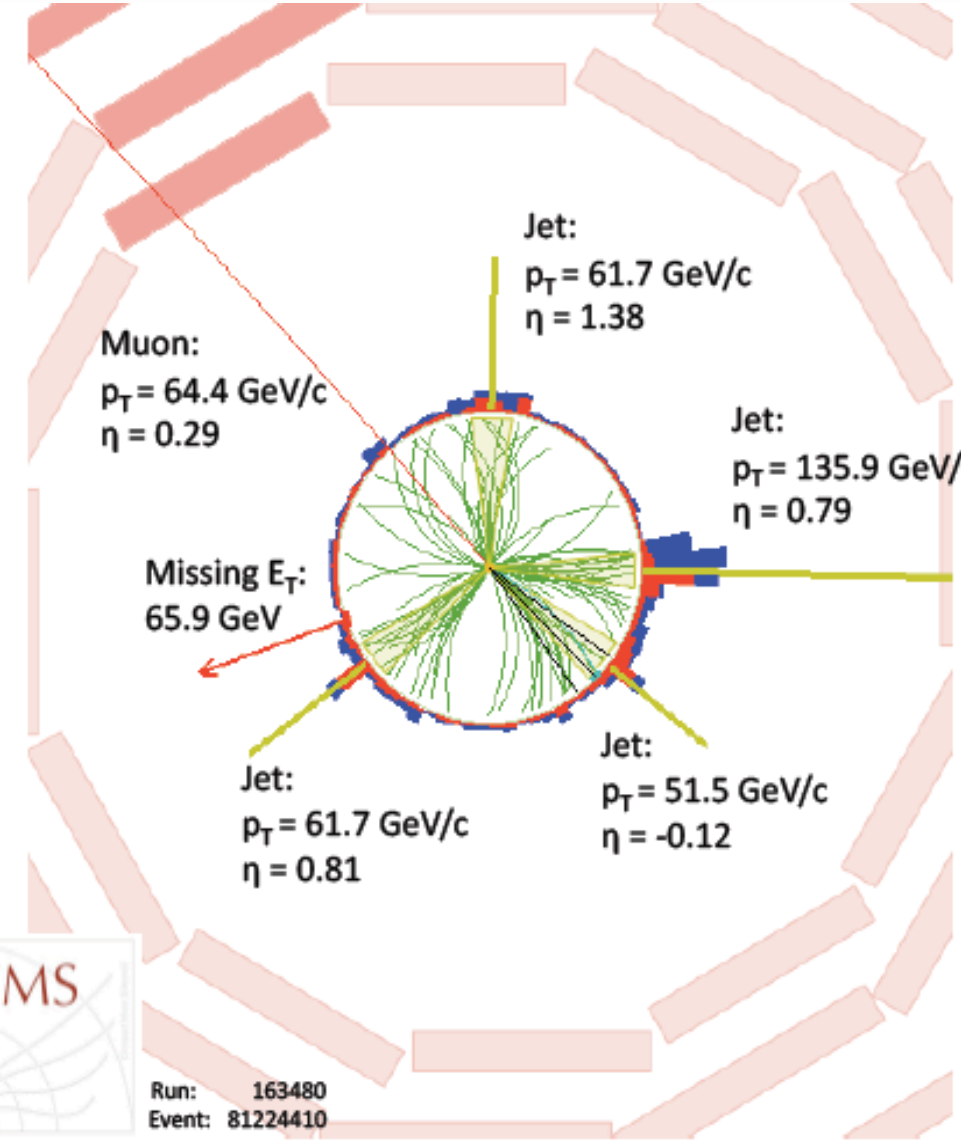
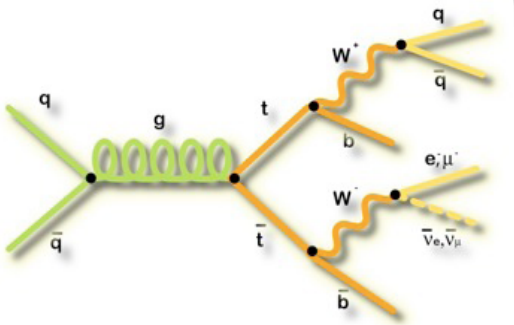
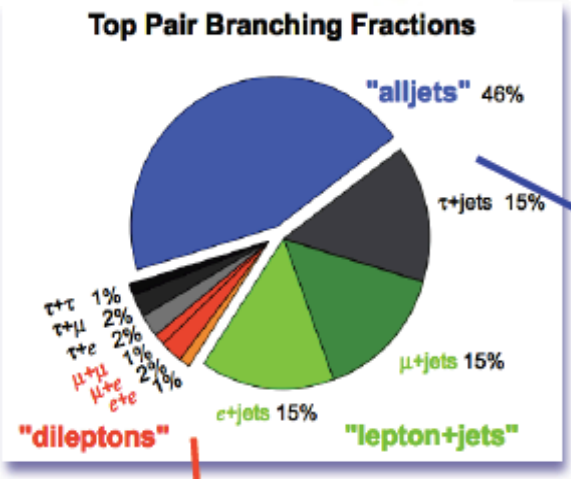
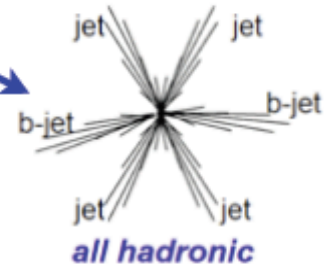
PRD82:054018, 2010

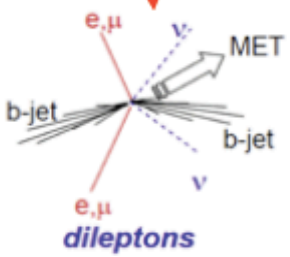
Top Pair Events at LHC

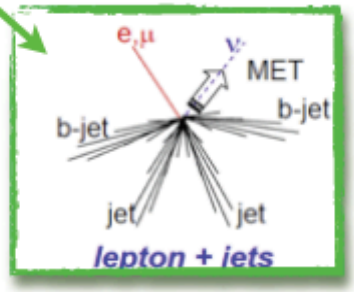






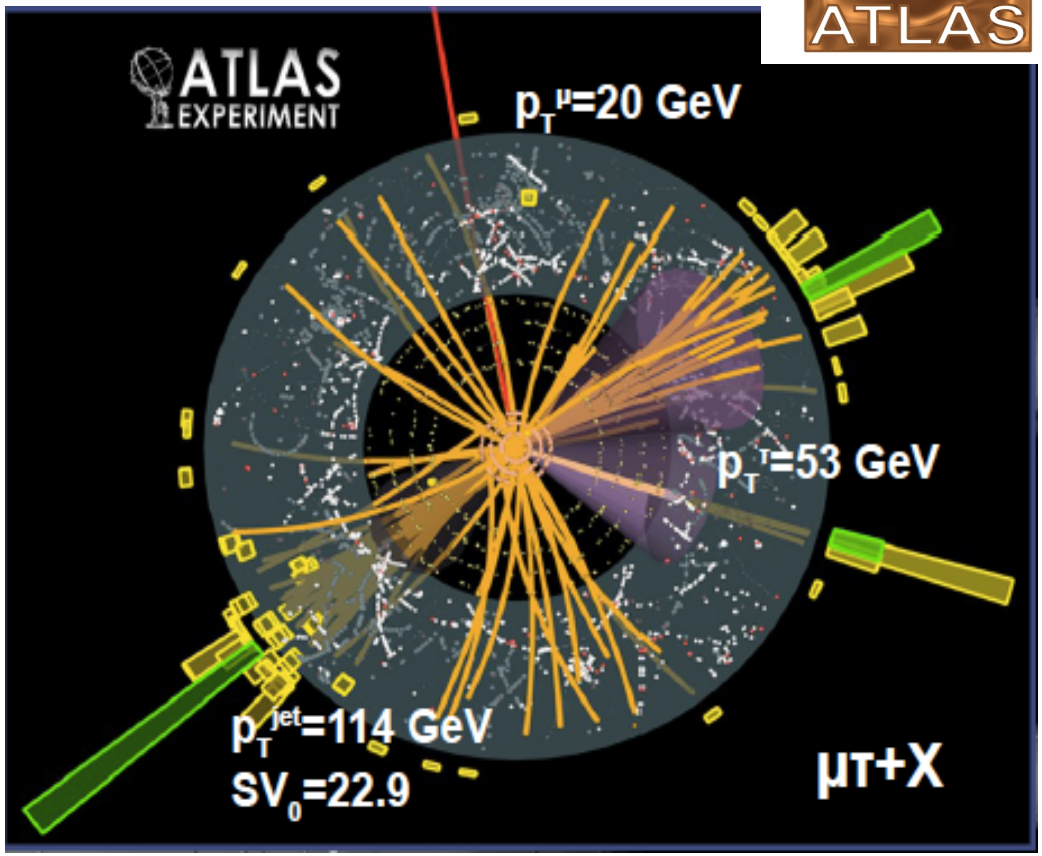




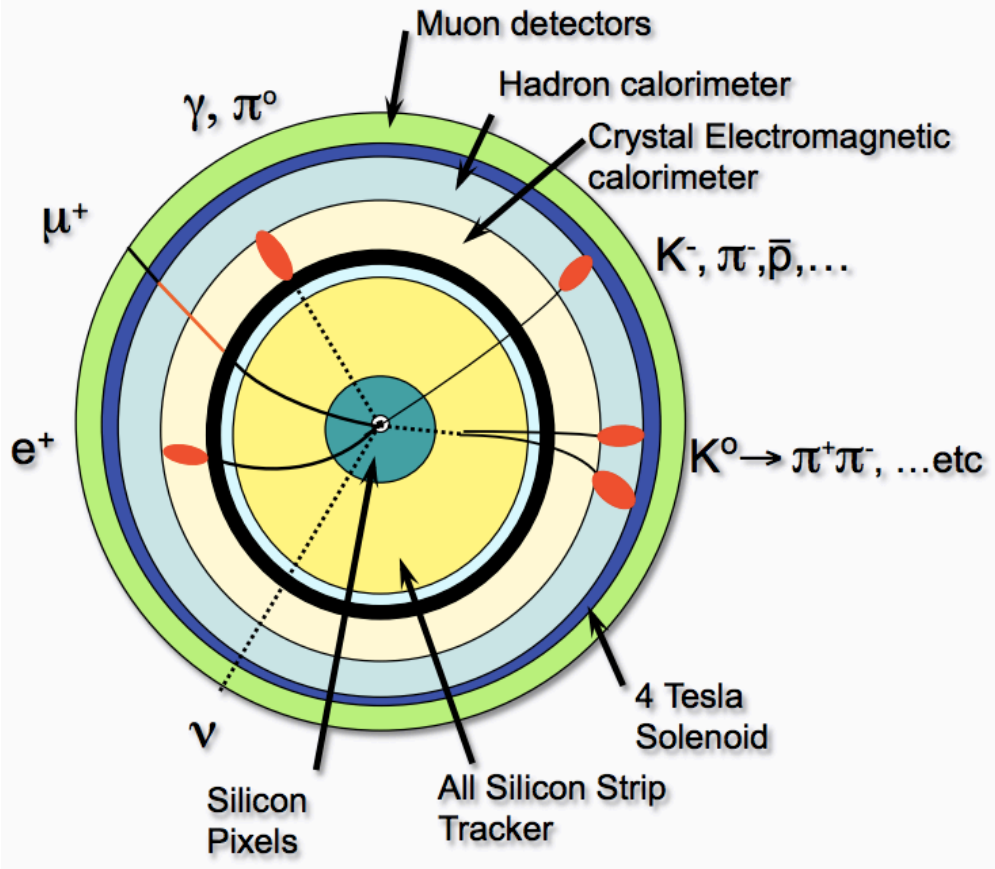


Top Pair Events at LHC

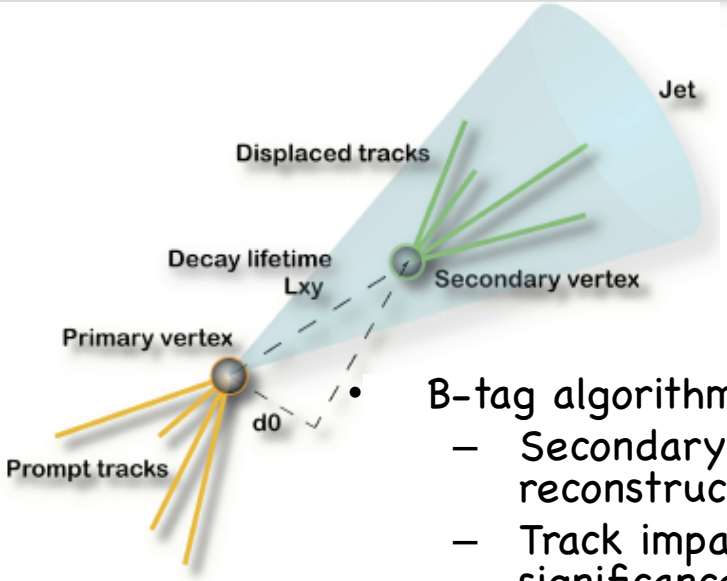
- Trigger
  - Single/double (isolated) leptons (plus hadronic activity)
- Jets
  - Anti-k_T algorithm with cone 0.4 ATLAS (0.5 CMS)
  - p_T > 20 ATLAS (30 CMS) GeV,
  - $|\eta|$ < 2.5 ATLAS (2.4 CMS)
  - B-tagging (optional)
- Leptons (e, μ, τ)
  - with p_T > 20 ATLAS (30 CMS) GeV, $|\eta|$ < 2.5
  - Isolation: Calo/Track ATLAS, Particle Flow CMS
- Missing transverse energy
  - optional m_{TW}



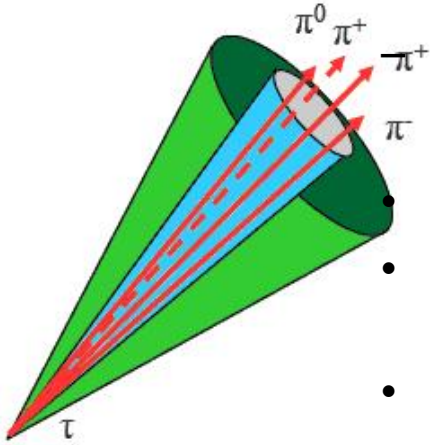
Particle Identification



- CMS employs Particle Flow algorithm by performing global e, μ, γ, charged or neutral hadron reconstruction



- B-tag algorithms based on
  - Secondary vertex reconstruction
  - Track impact parameter significance
  - JetFitter(ATLAS) – decay chain reconstruction
  - Combination

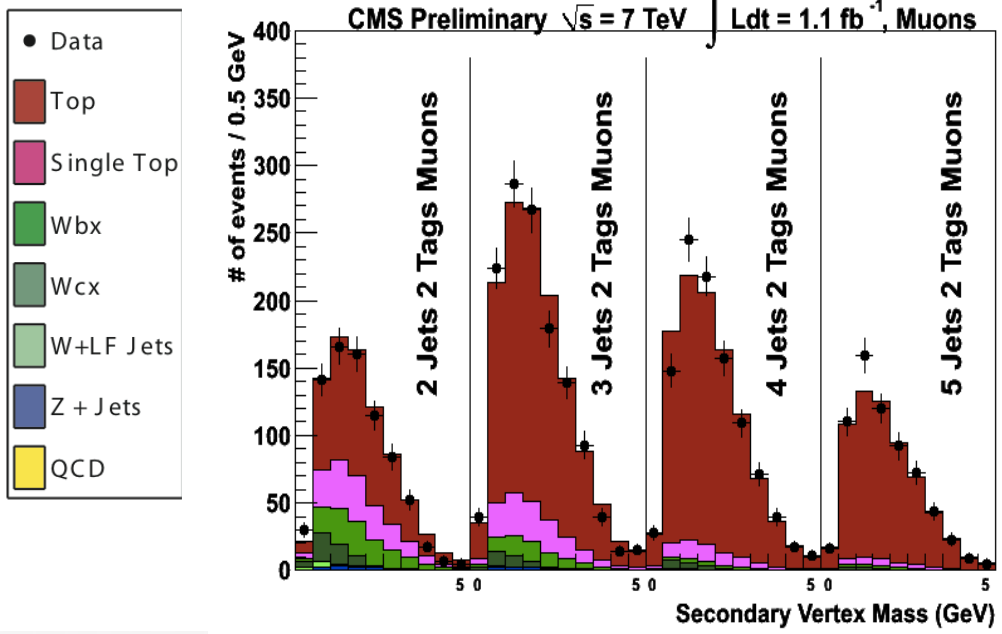


- τ_h ID
- Boosted Decision Tree (ATLAS)
- Hadron + Strip – particle flow (CMS)

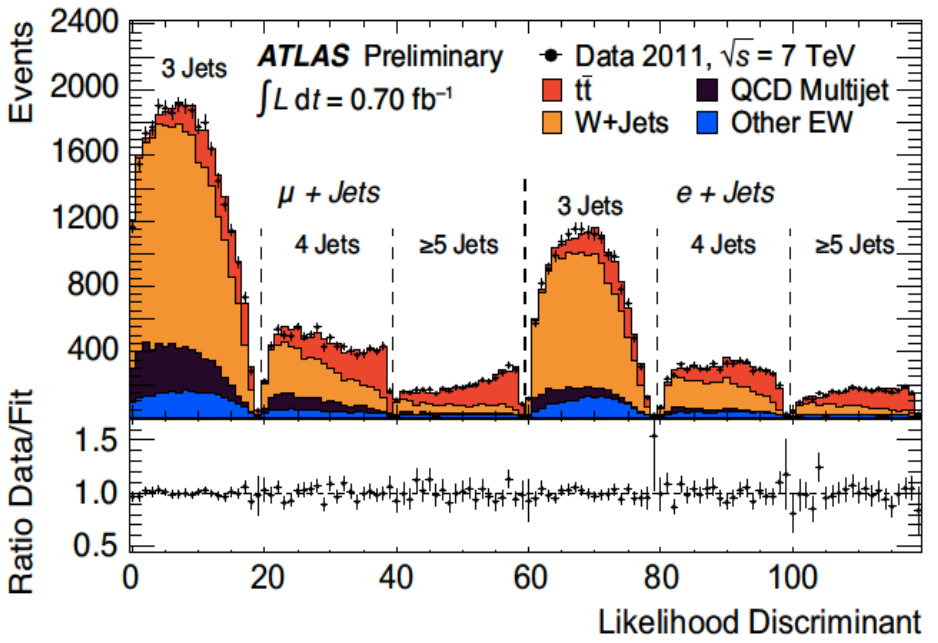
Lepton + Jets Channel

- Simultaneous likelihood fit across different jet multiplicities
- CMS: Secondary vertex mass, split into # of jets(1-4,>=5), b-tags(1,>=2)
- ATLAS: Likelihood discriminant (lepton η, leading jet p_T, aplanarity, etc.), split into # of jets (3,4,>=5)
- Main background: W+jets (light/heavy flavor)

σ_{tt} =164.4±2.8(stat.)±11.9(syst.)±7.4(lumi) pb



σ_{tt} =179.0±3.9(stat.)±9.0(syst.)±6.6(lumi) pb

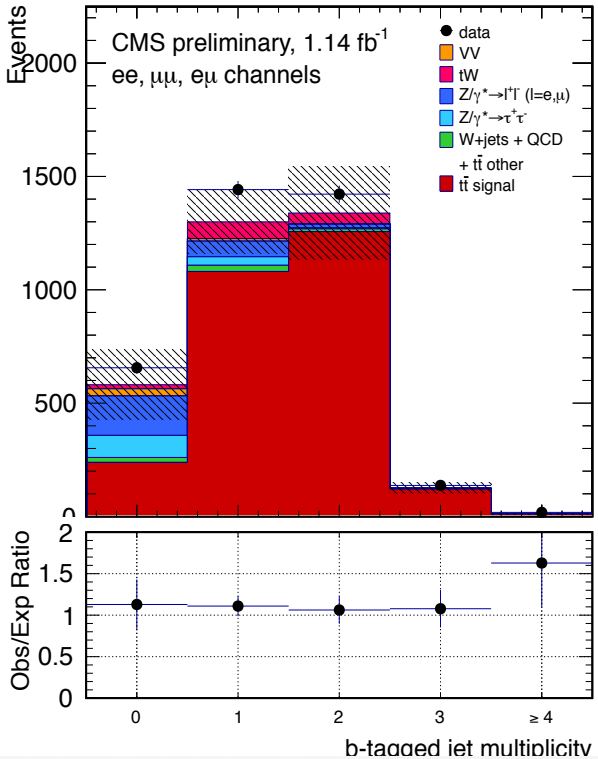


Dilepton Channel

- Clean channel, small backgrounds: DY + jets, W+jets via mis-idenitified second lepton
- Likelihood fit using different di-lepton categories: ee, μμ, eμ, (ATLAS also eTL, μTL) with and without b-tagging

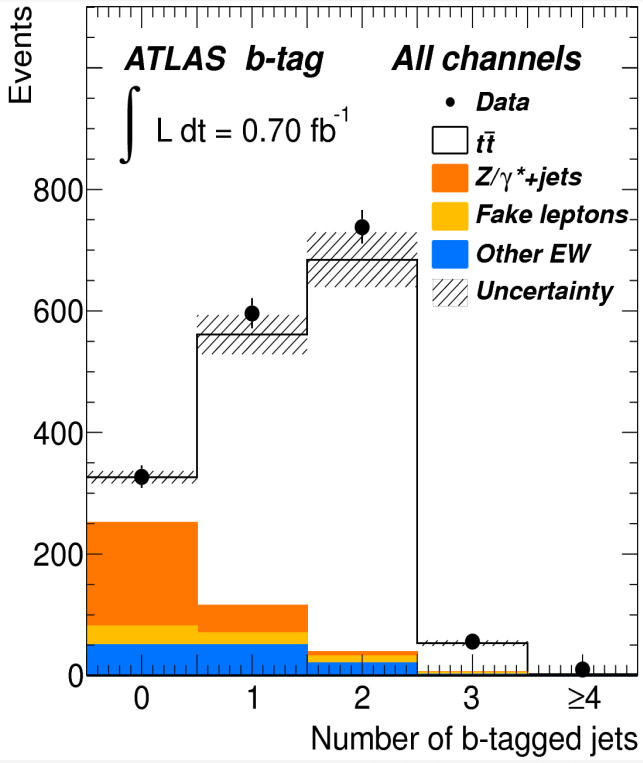
σ_{tt} =169.9±3.9(stat.)±16.3(syst.)±7.6(lumi) pb

σ_{tt} =176±5(stat.)$^{+14}_{-11}$(syst.)±8(lumi) pb



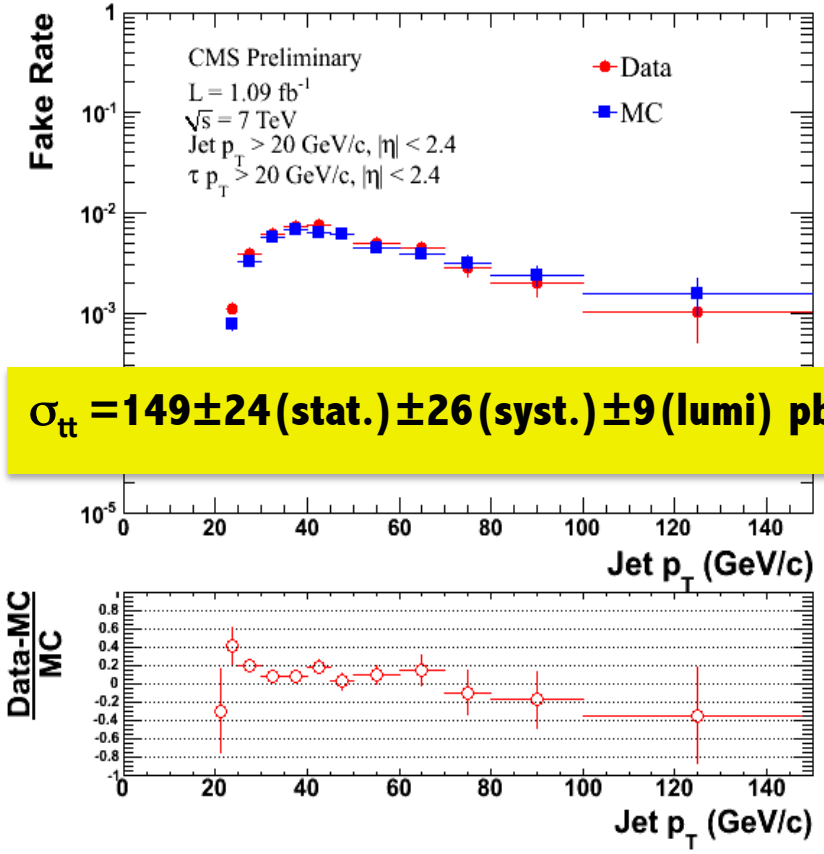
CMS: combine ee, μμ, eμ, using BLUE

Lyons, Gibaut, Clifford, NIM A270 (1988) 110



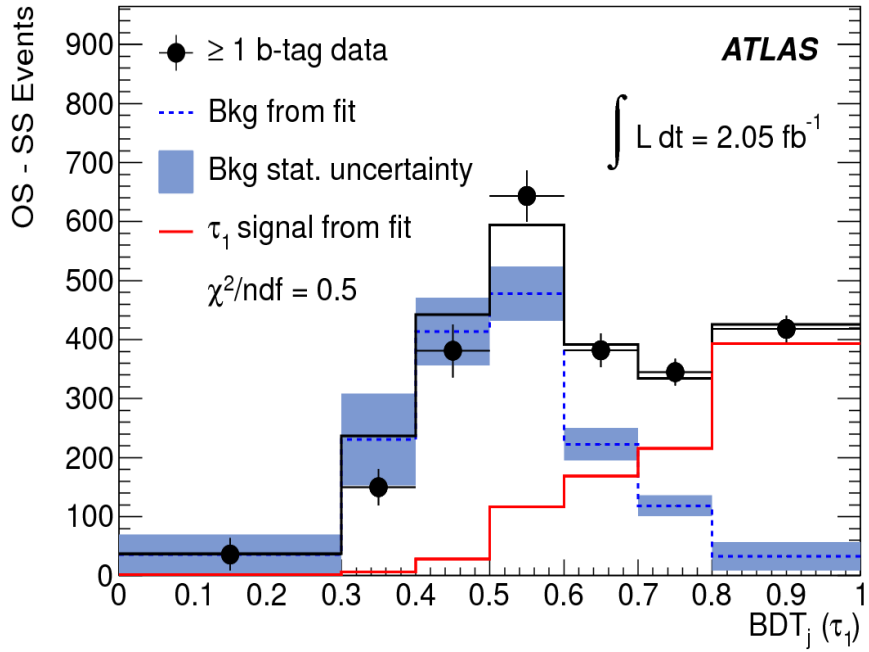
τ_h + e/μ Channel

- Hadronic τ identification (ATLAS: BDT, CMS: hadron+strips HPS τ ID)
- ATLAS eliminates ``fake τ'' background from gluon and b-jets by subtracting OS-SS events
- Use W+ 1 jet and 0 b-tag control regions to evaluate ``fake τ'' from quark jets
- Extract cross section from BDT shape separately for one and three-prong τ.
- CMS: Matrix method, evaluate p_T, η -dependent fake rate from multi-jets and W +>=1 jet events



σ_{tt} =149±24(stat.)±26(syst.)±9(lumi) pb

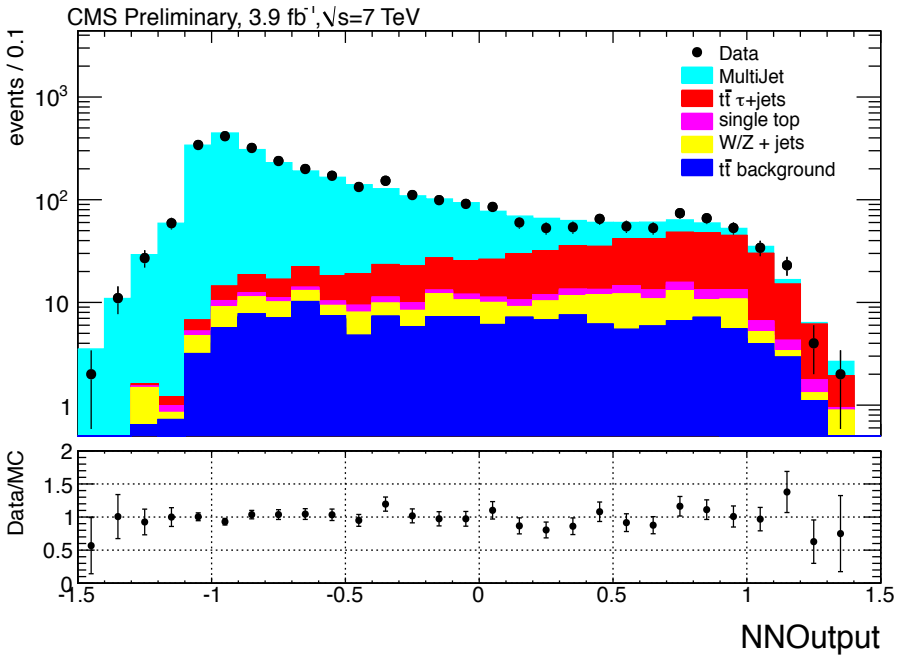
σ_{tt} =186±13(stat.)±20(syst.)±7(lumi) pb



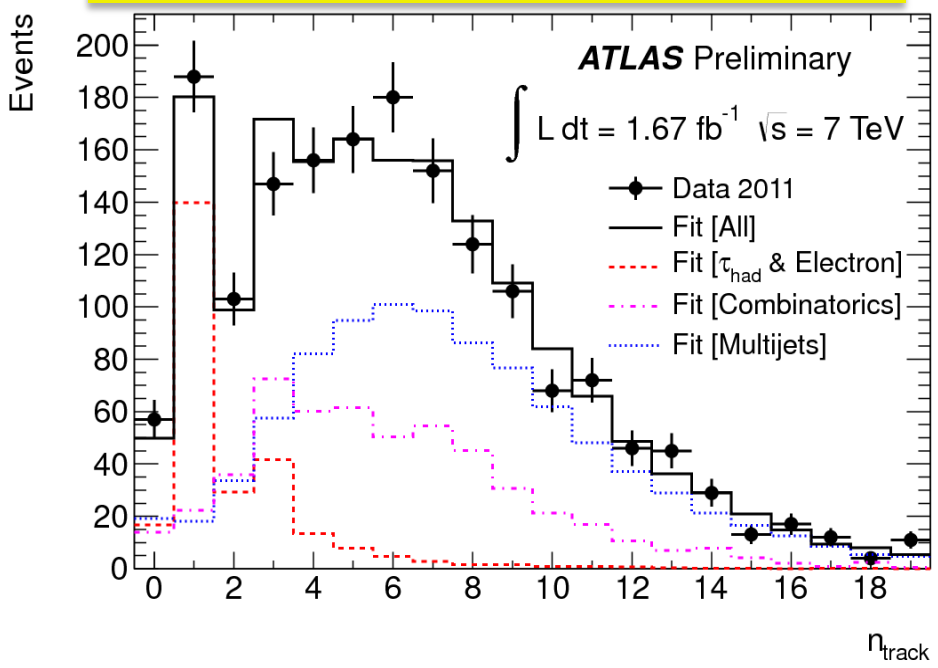
τ_h+ jets Channel

- CMS: HPS τ ID, train ANN: H_T, Aplanarity, $q(\tau)$. $|\eta(\tau)|$, E_T^{miss}, $\Delta\phi$ (τ, E_t^{miss}), M(jets, τ), χ^2, constraining W and top quark masses
- ATLAS: Clean sample by requiring large met significance, >= 5 jets, >=2 b-tags
- Discriminate τ_h from jets based on charged track multiplicity
- QCD multi-jet (gluons) shape is obtained from data side-band region, lower met significance; ttbar(μ+jets) from data used to obtain quark-jet shape

σ_{tt} =156±12(stat.)±33(syst.)±3(lumi) pb



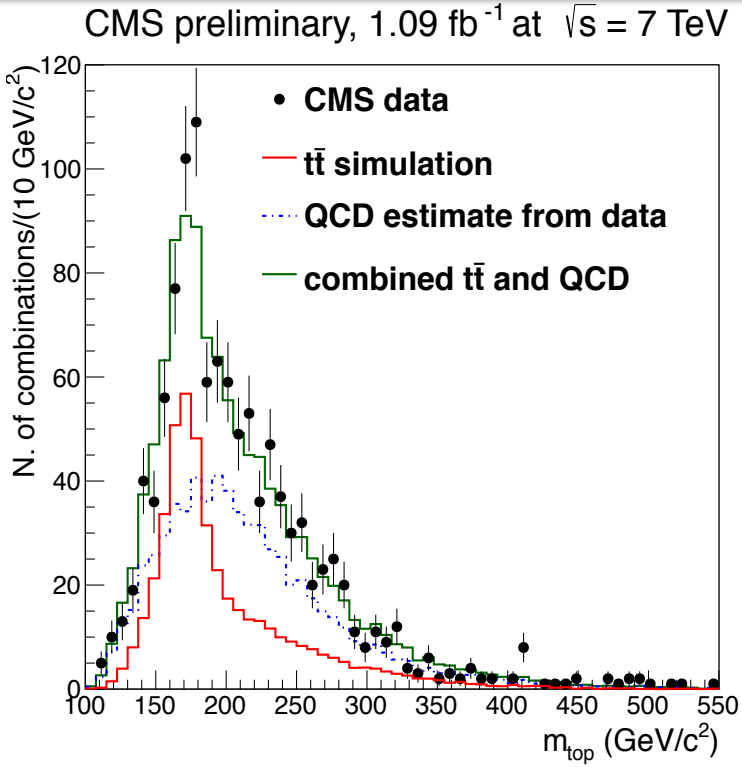
σ_{tt} =200±19(stat.)±43(syst.) pb



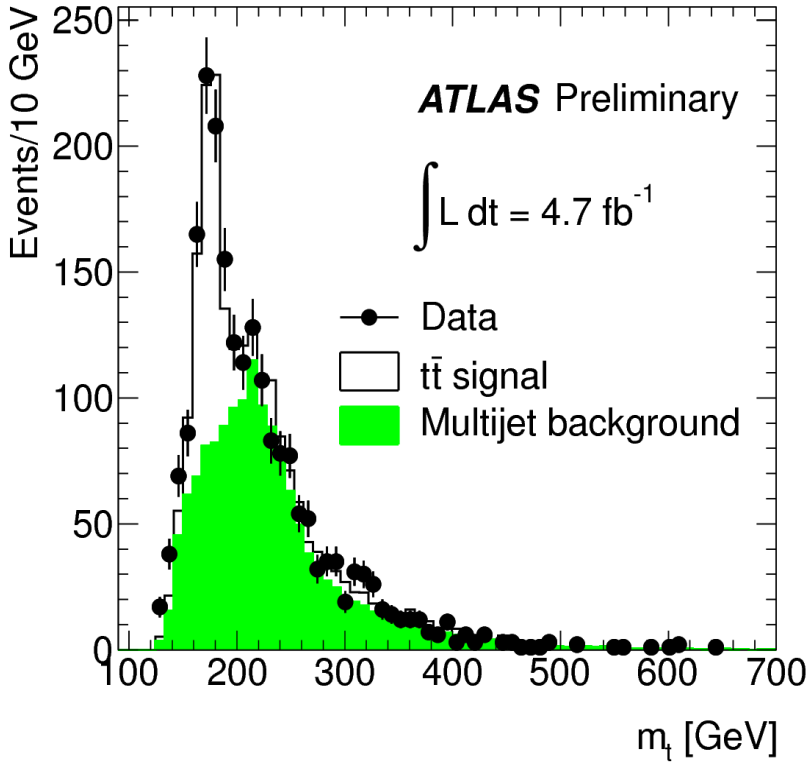
All-hadronic Channel

- Multi-jet trigger, >=2 b-tags using combination of high purity taggers
- Fit to reconstructed top quark mass using χ^2
- Multi-jet shape is taken from 0 b-tag region, corrected for b-tag p_T, η - dependent efficiency

σ_{tt} =136±20(stat.)±40(syst.)±8(lumi) pb

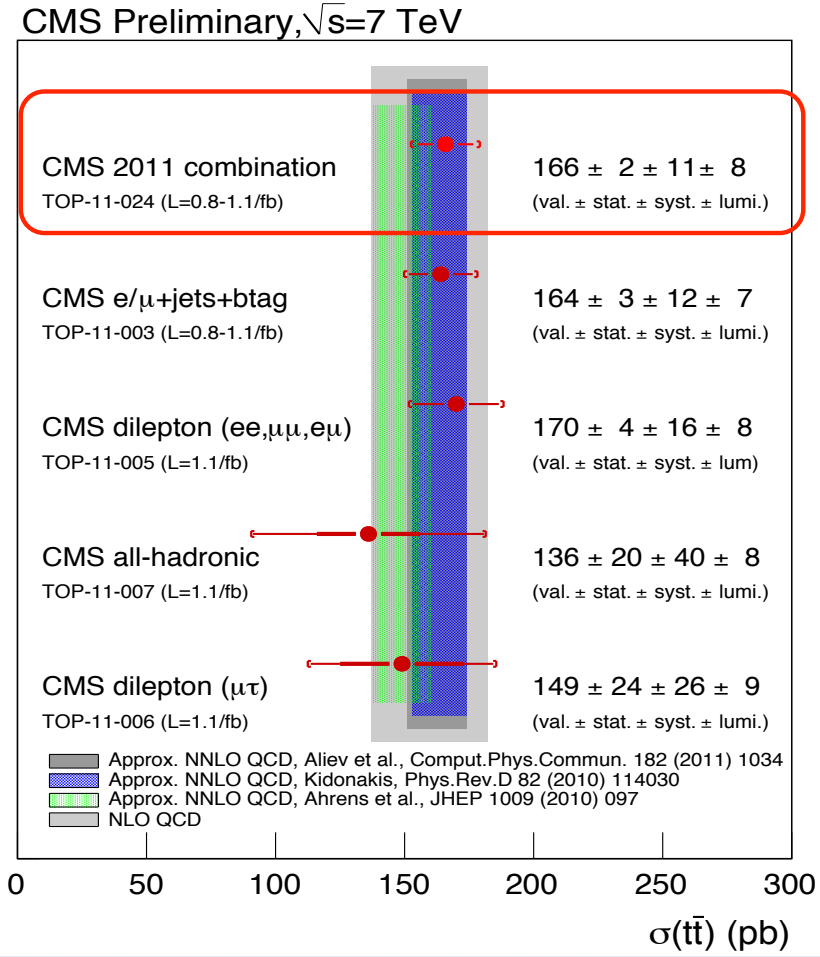


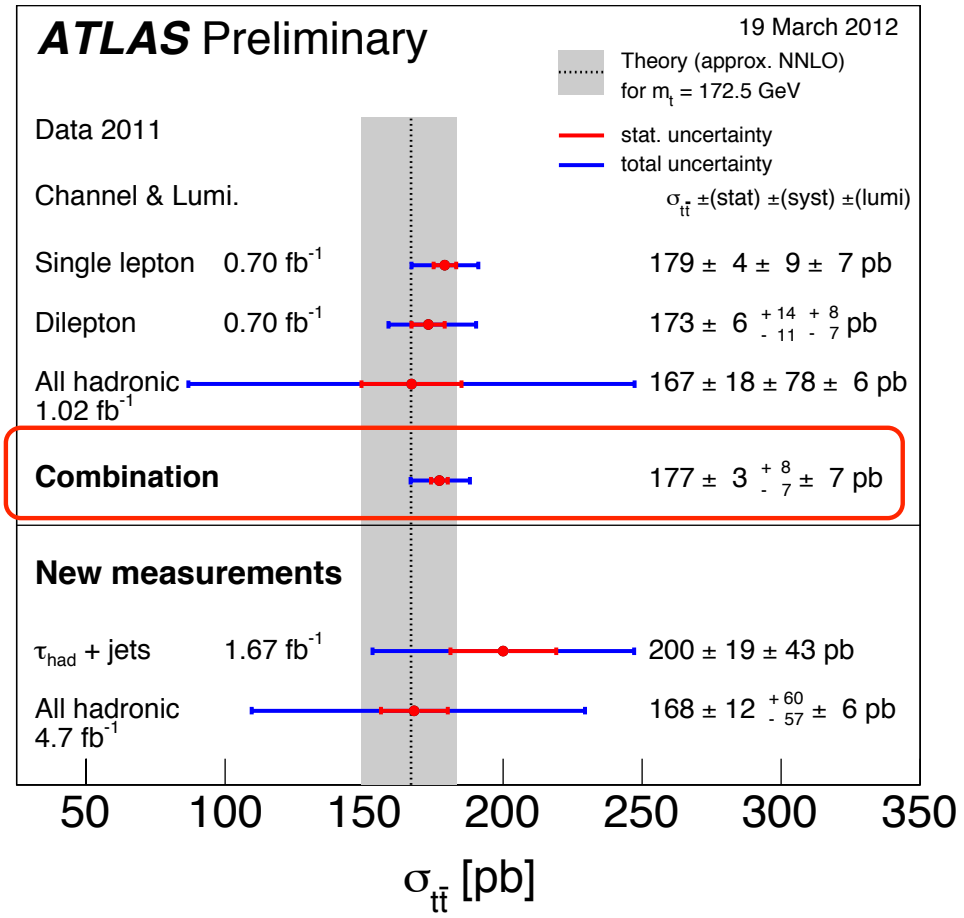
σ_{tt} =168±12(stat.)±60(syst.)±6(lumi) pb



Cross Section Combination

- CMS: Dil and All-Had channels added to single lepton channel likelihood
- ATLAS: Single lepton channel likelihood is approximated as multi-variate Gaussian
- Combined likelihood is formed from single lepton, dil and all-had channels

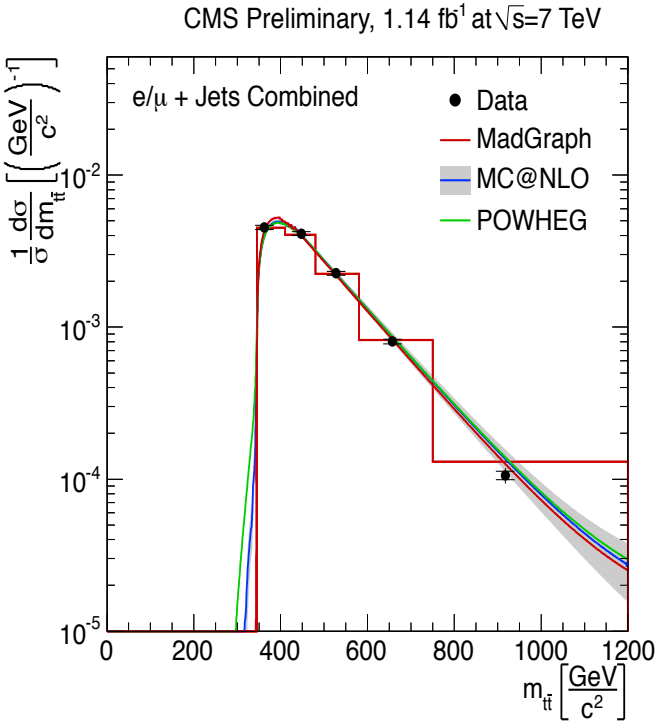


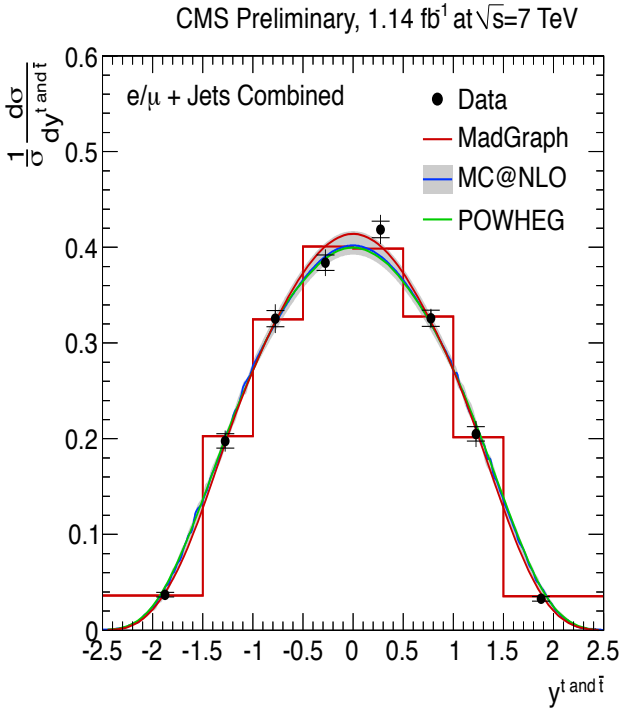


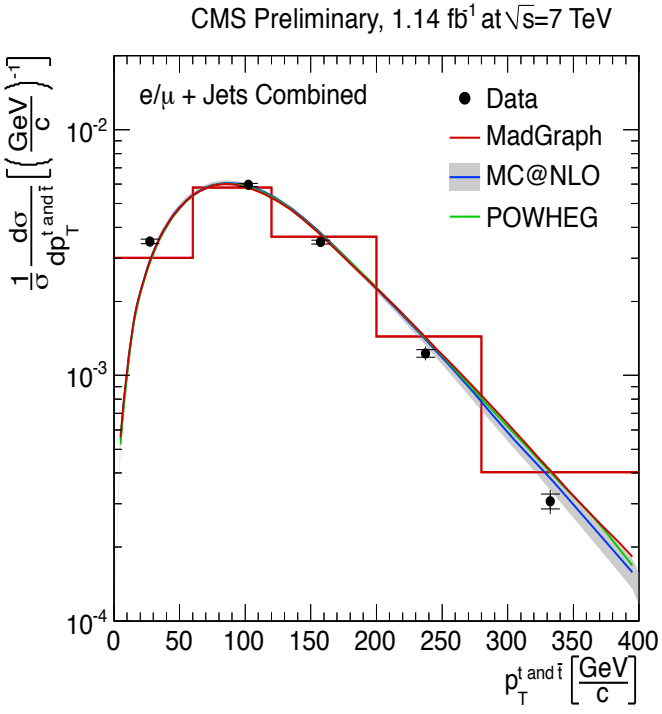
Differential Cross Section

$$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}}{dX}$$

- Measure cross section as a function of transverse momentum, (pseudo-)rapidity, invariant mass of final state leptons, reconstructed top quarks, tt system
- tt events are reconstructed by imposing kinematic constraints
- In DIL channel due to under-constraint, correct solution is found by most probable neutrino energy spectrum and prioritizing b-tagged jets over un-tagged
- Differential distributions are obtained by unfolding using Singular Value Decomposition method (A. Hoecker, V. Kartvelishvili, NIM A 372 (1996) 469)

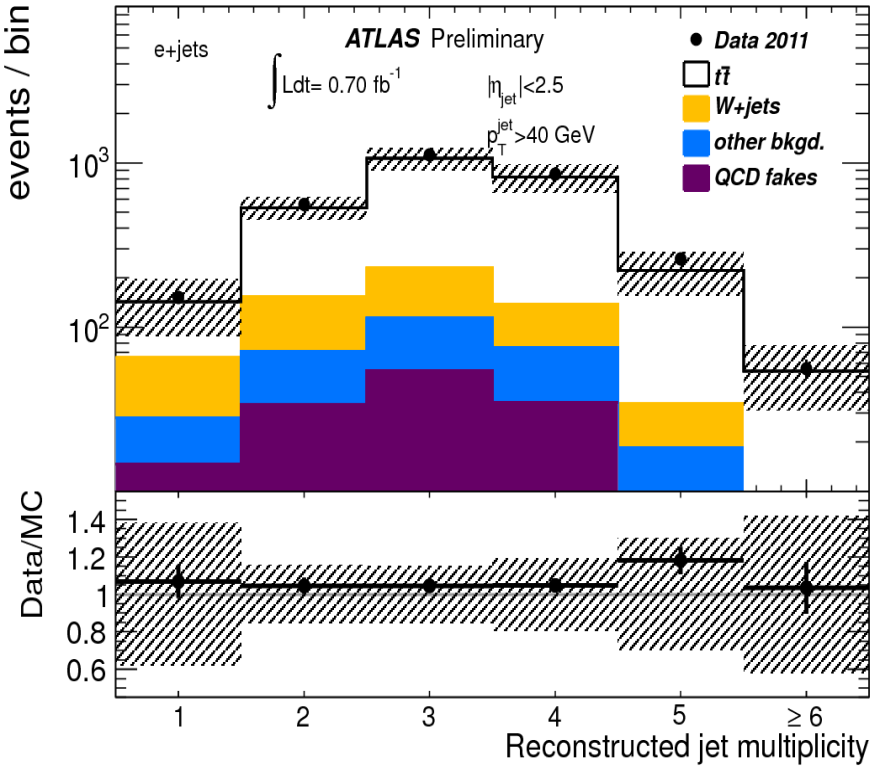


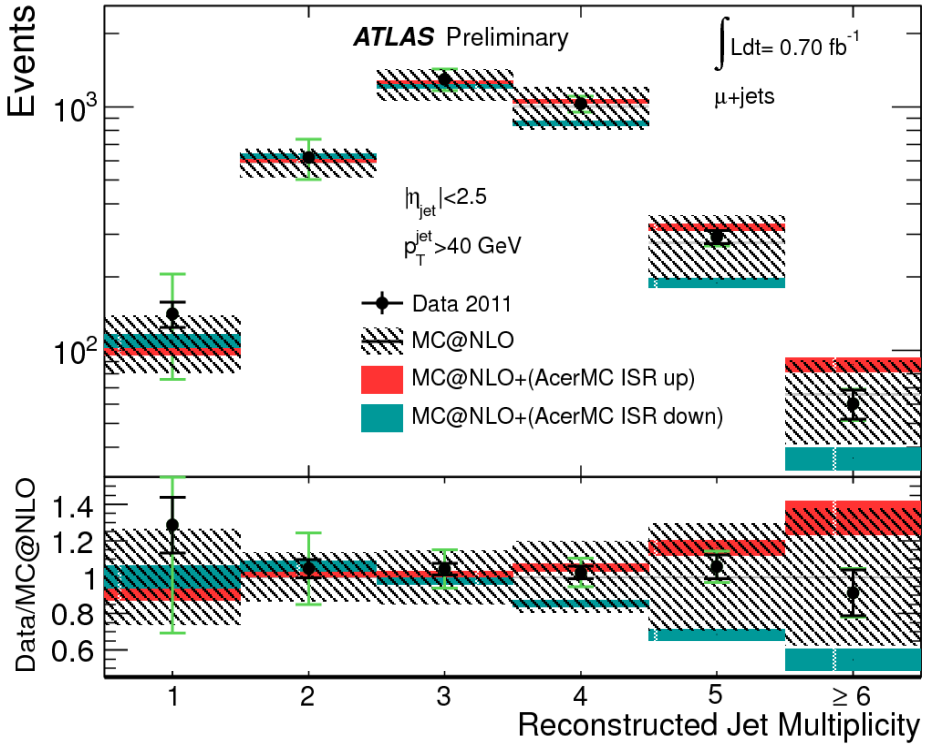




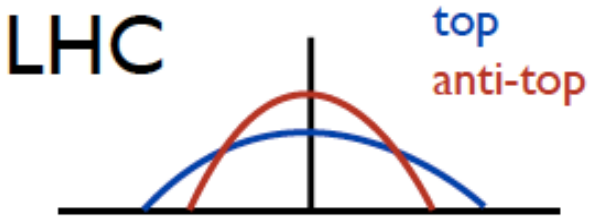
Jet Multiplicity Measurement

- Measurement performed in e(μ)+jets channel
- Jet multiplicities are reconstructed with 40 and 60 GeV thresholds
- No deviation from MC@NLO
- Jet multiplicity spectrum is cross-checked wrt different MC ISR variations using AcerMC
- Within current uncertainties no distinction between ISR models can be made





Charge Asymmetry



$$A_C = \frac{N^+ - N^-}{N^+ + N^-}$$

- QCD predictions:

$A_c^{\Delta y} = 0.0115 \pm 0.0006$

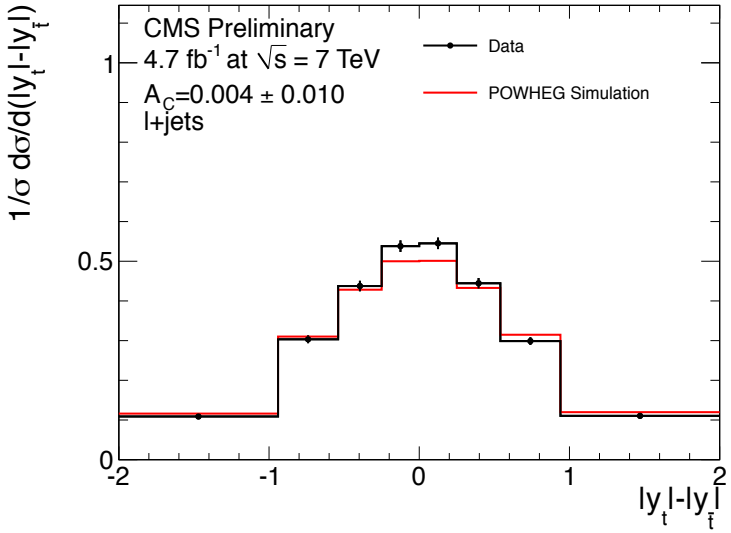
- CDF reported ~ 3.4 sigma deviation in forward-backward asymmetry for m(tt) > 450 GeV
- At LHC the charge asymmetry manifests itself in different rapidity widths of top/anti-top quarks
- Explore

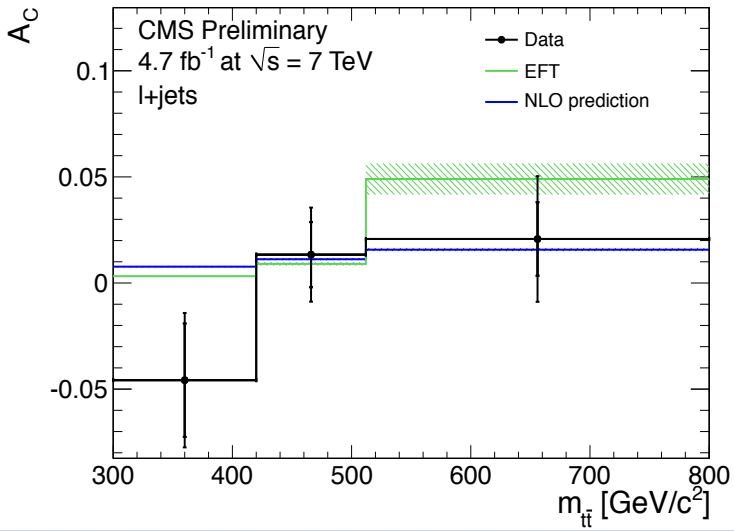
$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

- tt events are reconstructed by imposing W/top mass constraints and requirement that b-tagged jet matches jet from top decay
- Reconstructed distributions are corrected to true distributions via a regularized unfolding procedure [CMS] (Blobel arXiv: hep-ex/0208022), Bayesian unfolding [ATLAS] (Agostini NIM A 362 (1995) 487), which correct for bin-to-bin migration and efficiency effects

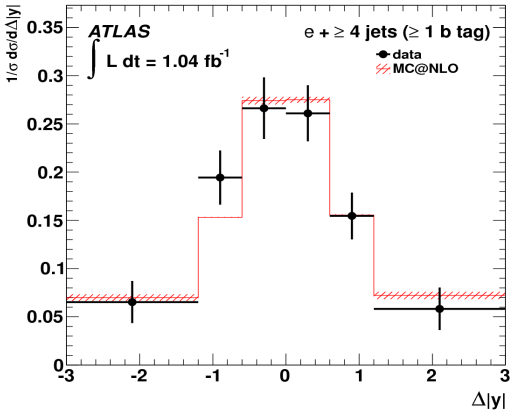
Charge Asymmetry

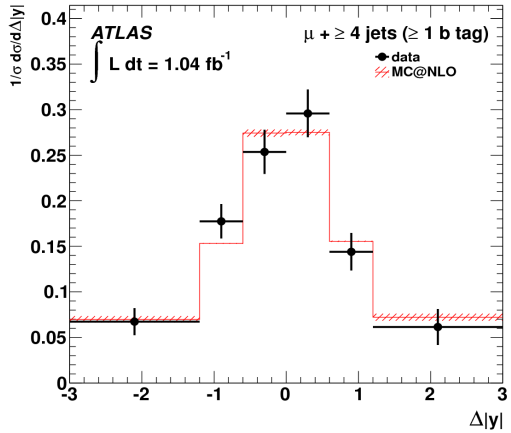
$A_C = 0.004 \pm 0.010\,(stat.) \pm 0.012\,(syst.)$





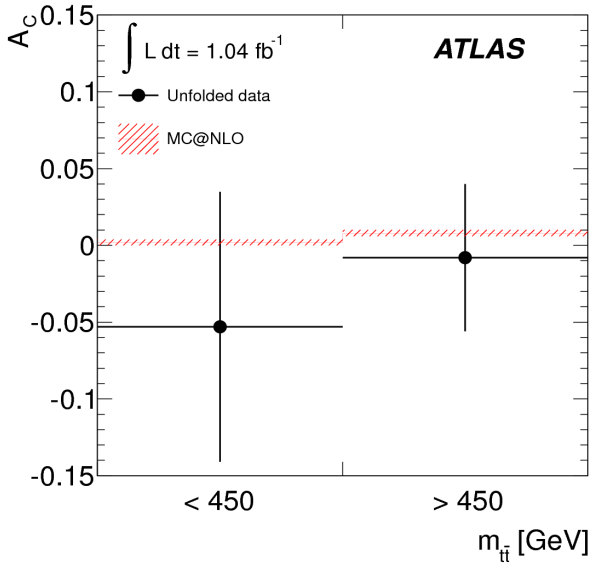
$A_C = -0.018 \pm 0.028\,(stat.) \pm 0.023\,(syst.)$





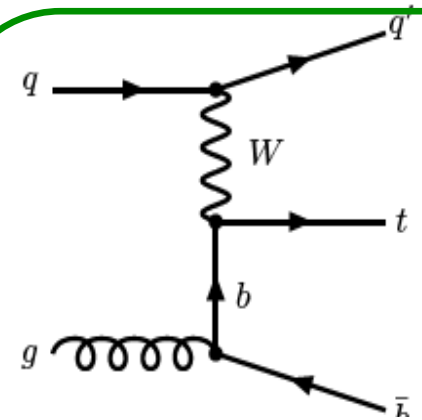
Consistent with Standard Model !

$A_C^{\Delta y} = 0.0115 \pm 0.0006$



Single Top at LHC

Single Top Production



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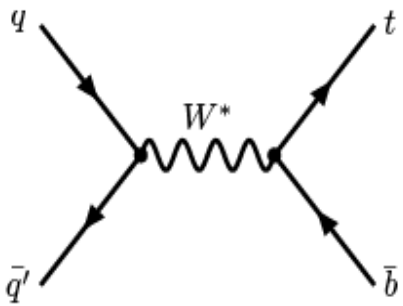

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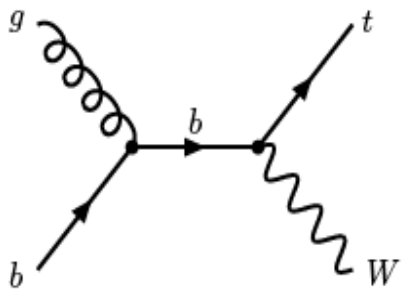

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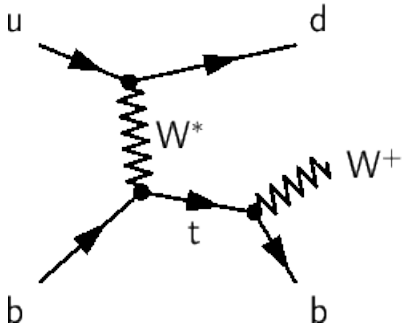
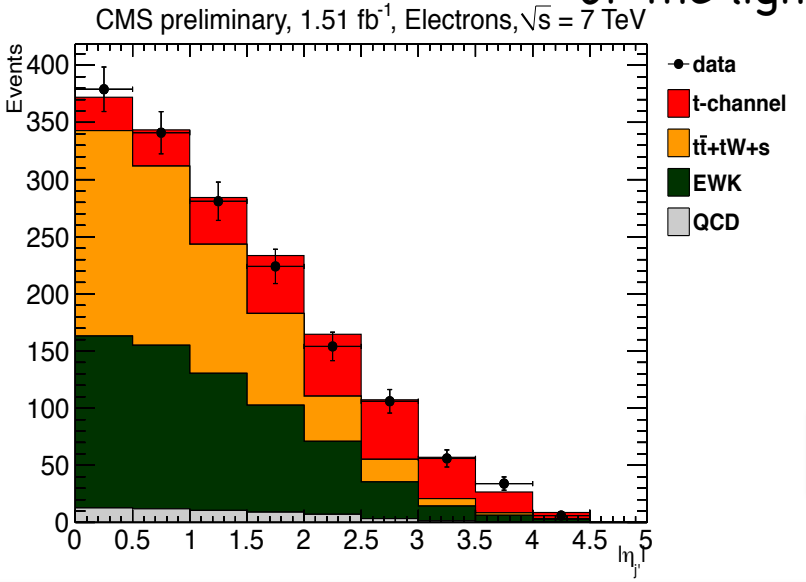
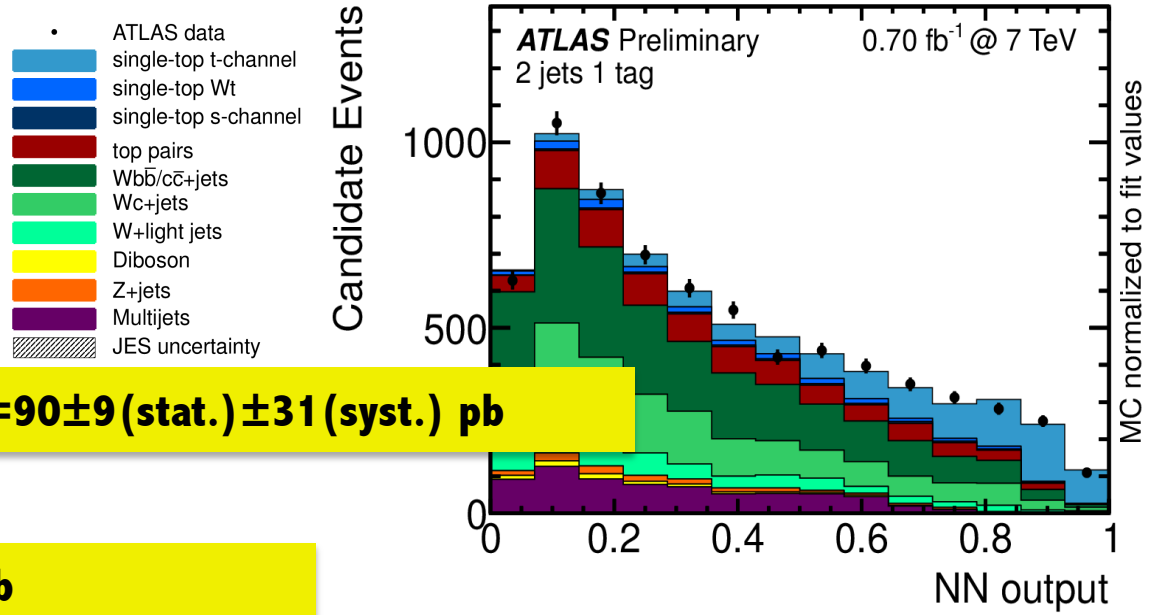
- Weak Interaction : Test of Wtb Vertex
- Measurement of V_{tb}
- Can be used to measure the b-quark parton distribution function (PDF)

Single Top t-Channel



- Event Selection: = 1 isolated lepton (e or μ)
- 2 (and 3 :ATLAS) jets (= 1 b-tagged)
- Missing E_T > 25(35) GeV and $m_T(W)$ > 60(40) GeV
- Other jet and b-tagging multiplicities used as control regions
- CMS: Max Likelihood fit to pseudo-rapidity of the light (untagged jet)
- ATLAS: Construct ANN from pseudo-rapidity of the light (untagged jet), reconstructed top quark mass, transverse energy of the light jet



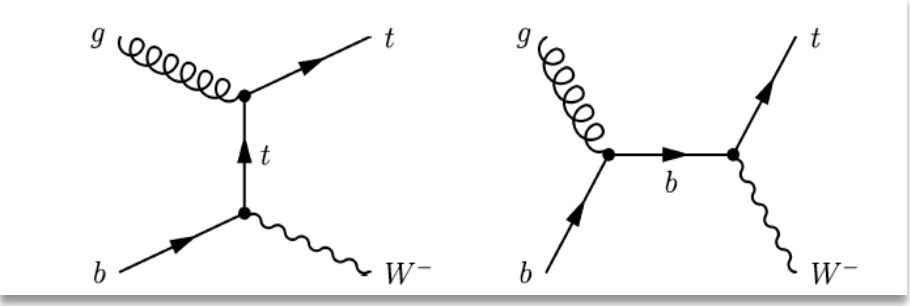


σ_t =90±9(stat.)±31(syst.) pb

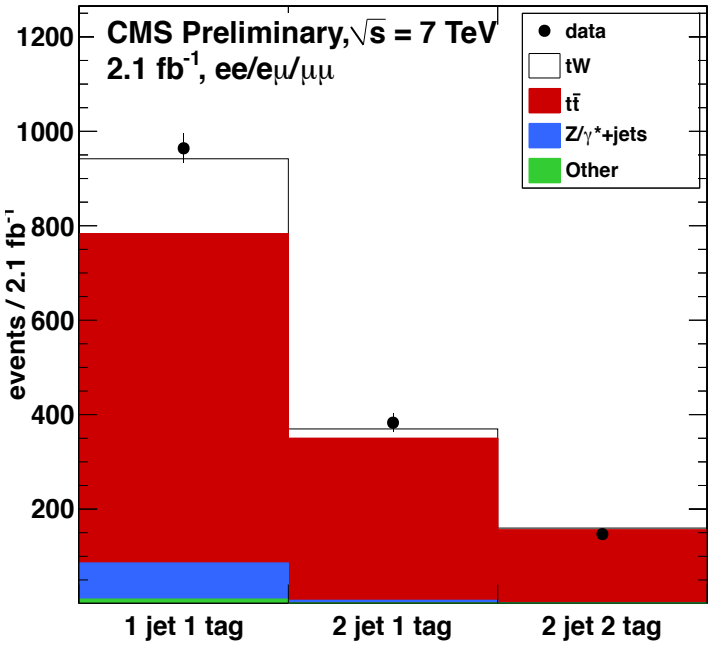
σ_t =70.2±5.2(stat.)±10.4(syst.)±3.4(lumi) pb

$|V_{tb}|$ = 1.04 ±0.09(exp.)±0.02(th.)

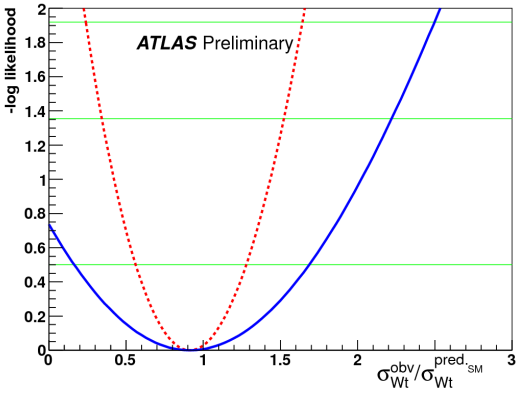
Single Top tW-Channel



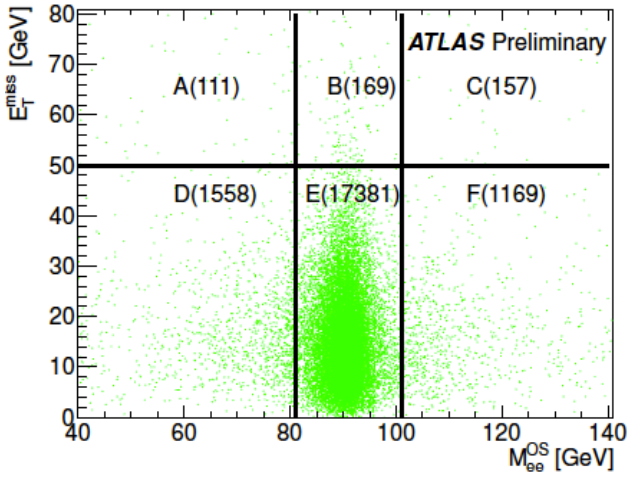
- Selection: 2 leptons
- Missing E_T , = 1 b-tagged jet
- Z-veto, reject ee, μμ in m_{ll} = [81,101]
- Main Backgrounds: Z+jets, ttbar
- ttbar is measured in the control regions (> =2 jets, 1 or 2 b-tags) and extrapolated into the signal region
- Z+jets is estimated using data-driven method by evaluating the number of events in MC "leaking" out of Z-mass window



σ_t =22±9 pb, at 2.7 σ

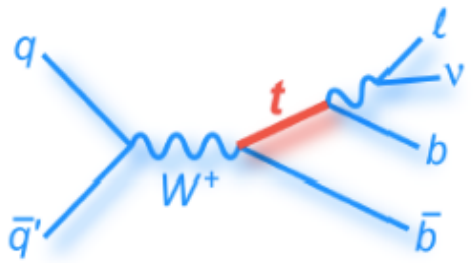


σ_t < 39 pb, at 1.2 σ



$$N^{predicted}_{A/C} = N^{data}_{D/F} \times (N^{data}_{B} / N^{data}_{E})$$

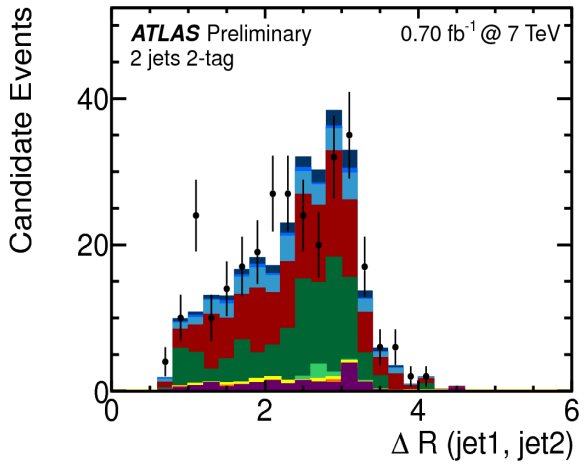
Single Top s-Channel



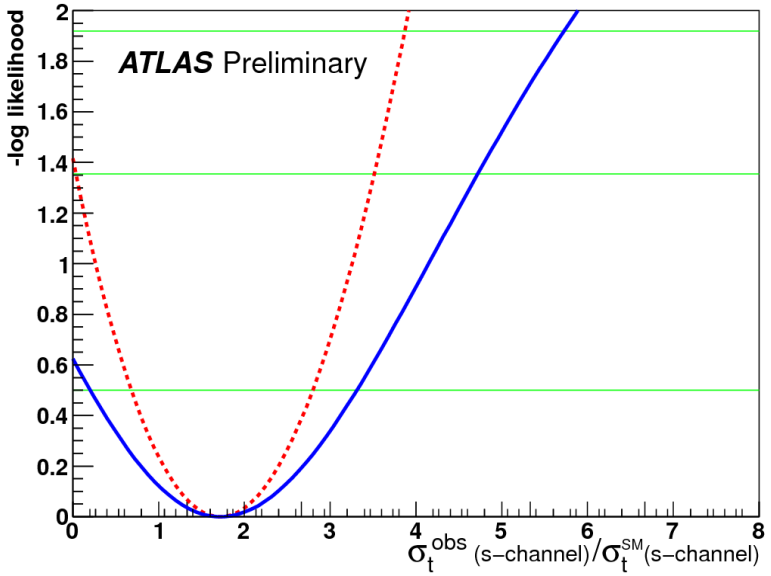
- Selection: 1 leptons
- Missing E_T >25 GeV, 2 jets >= 1 b-tagged
- m_{TW} > 60 GeV – E_T^{Miss}
- Cut-Based Analysis: Signal significance is improved after each step

Selection	Signal	Background	$S/\sqrt{B}$
Preselection Only	104	153802	0.26
Number of tagged jets=2	18	415	0.88
$30< m_{top,jet2} <247$ GeV/c^2	17	349	0.91
$p_T(jet1, jet2) <189$ GeV/c	17	346	0.91
$m_T(W) <111$ GeV/c	17	318	0.95
$0.43< \Delta R(b-jet1, lepton) <3.6$	17	308	0.97
$123< m_{top,jet1} <788$ GeV/c^2	17	302	0.98
$0.74< \Delta R(b-jet1, b-jet2) <4.68$	16	269	0.98

σ_t < 26.5 pb



- Final Selection:
- S-chan: 16 ± 6
- Total Exp. 285 ± 17
- Obs. 296



Conclusions

- CMS and ATLAS performed many precision inclusive and differential ttbar cross section measurements using various channels including all-hadronic and taus
- Measurements are systematically limited, starting to constrain theory
- Charge asymmetry measurement is consistent with SM

- Single Top:
  - Precision measurement of t-channel cross sections
  - Measurement of $|V_{tb}|$ at 10% level
  - Significance of tW-channel is close to 3 σ
  - First upper limit on s-channel

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Thank You !