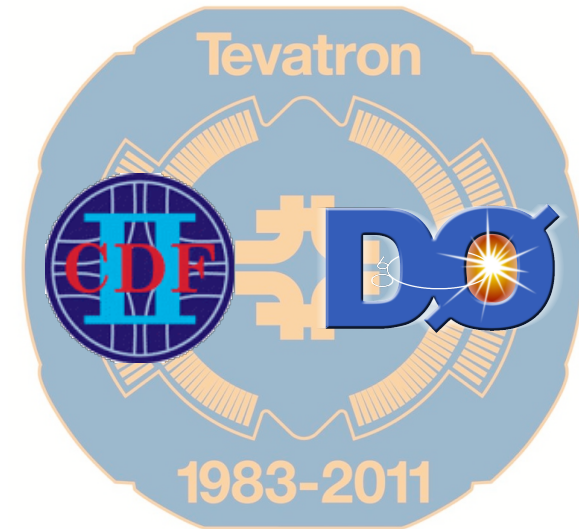
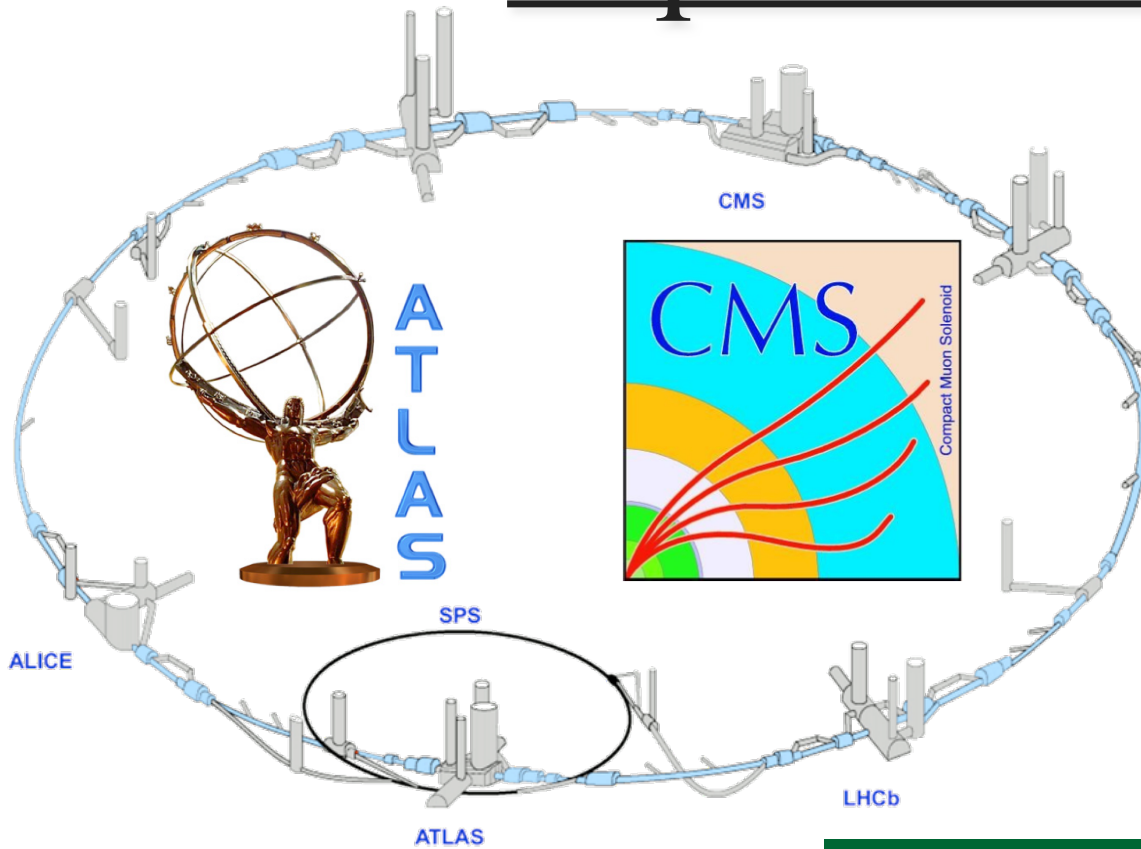


Top cross sections



MICHIGAN STATE
UNIVERSITY

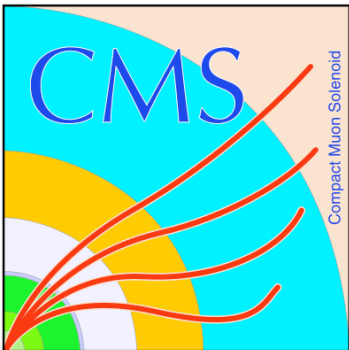
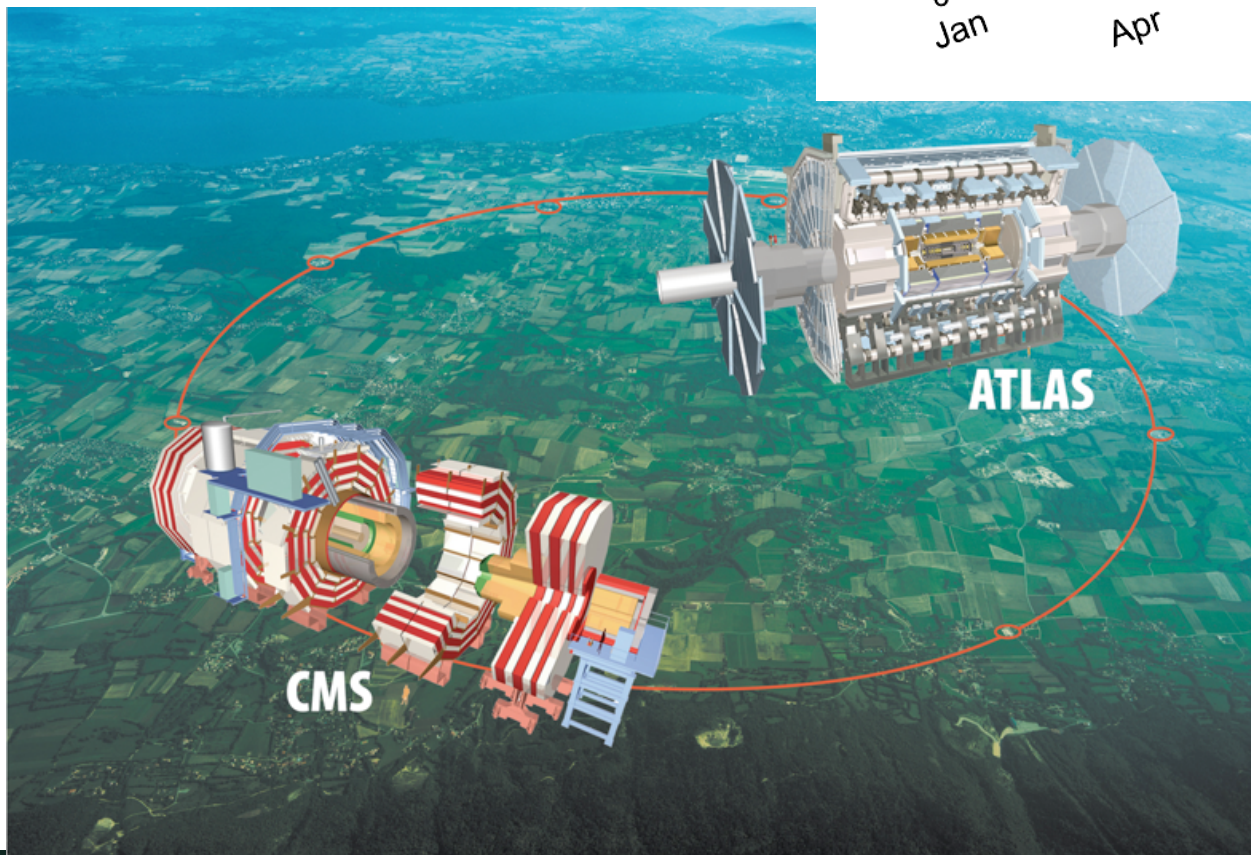
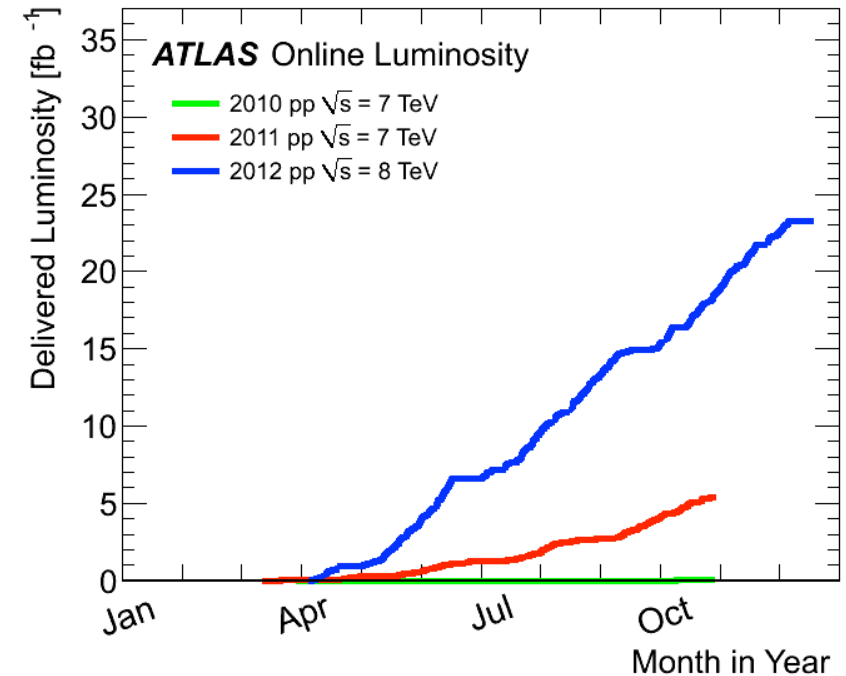
Reinhard Schwienhorst

Outline

- Top production
- Pair production
 - With jets
 - With boson
- Single top production
- New physics connected to top
- Conclusions

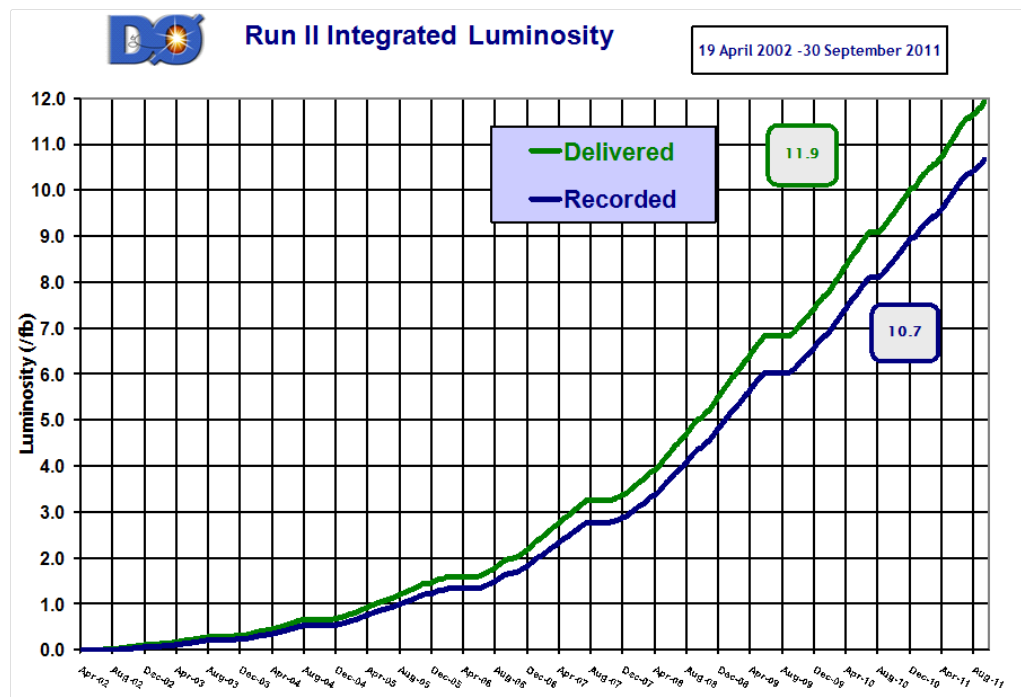
LHC machine

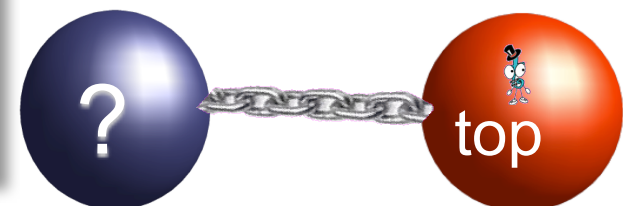
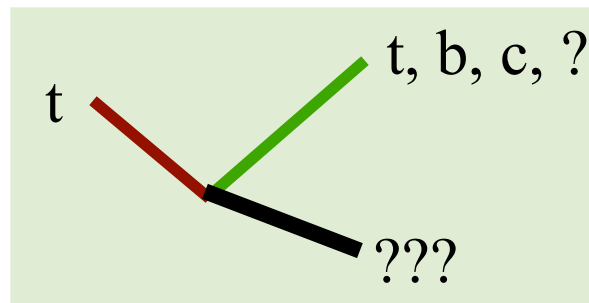
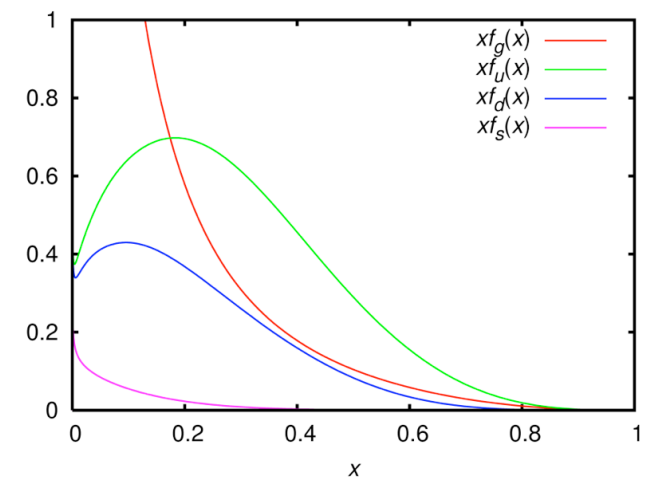
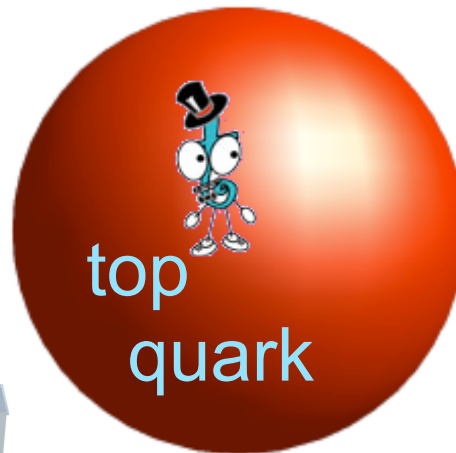
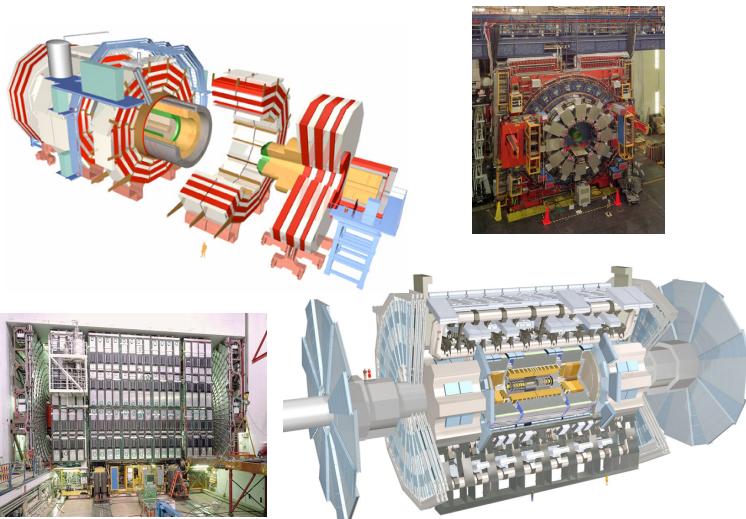
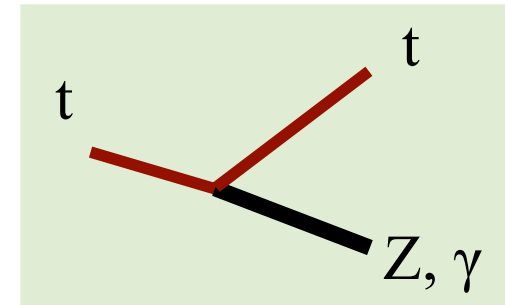
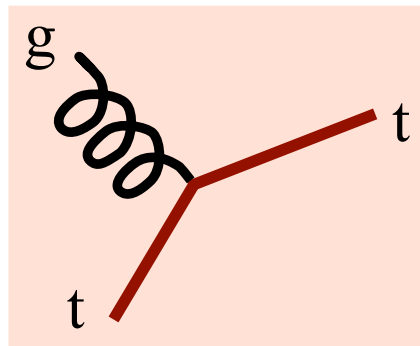
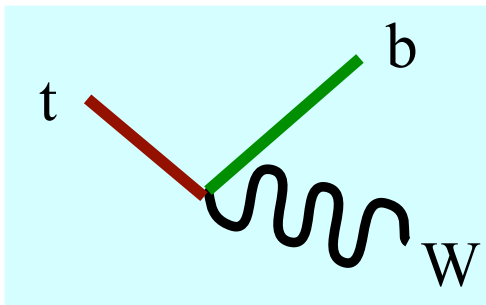
- proton-proton collider
- 7 TeV in 2011
- 8 TeV in 2012
- gluon-dominated initial states
 - top quark factory
 - > 5 M top pairs produced so far



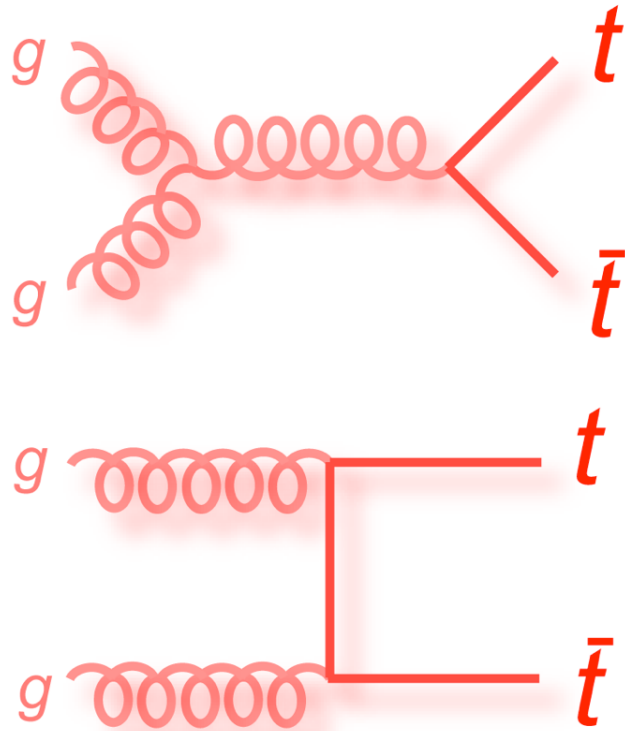
Tevatron collider in Run II

- proton-antiproton collider
 - quark-dominated initial states
 - CP asymmetries
- 1.96 TeV
- 12 fb⁻¹ delivered
- 10 fb⁻¹ recorded per experiment

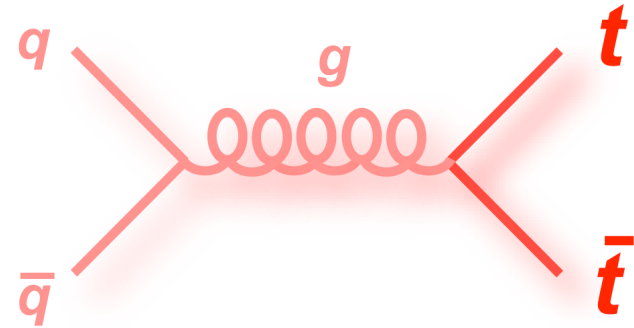




Top pair production



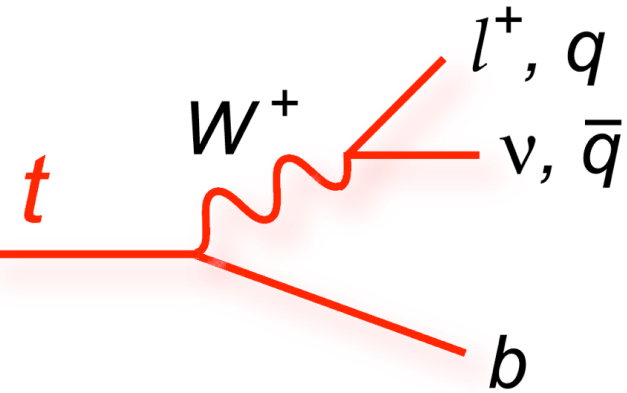
$\sim 87\%$ at 8TeV LHC



$\sim 85\%$ at Tevatron

- Measure cross section in all top decay modes
- Precision test of SM
 - Theory prediction at NNLO arXiv:1303.6254
- Large top quark samples for calibration

Top quark decay



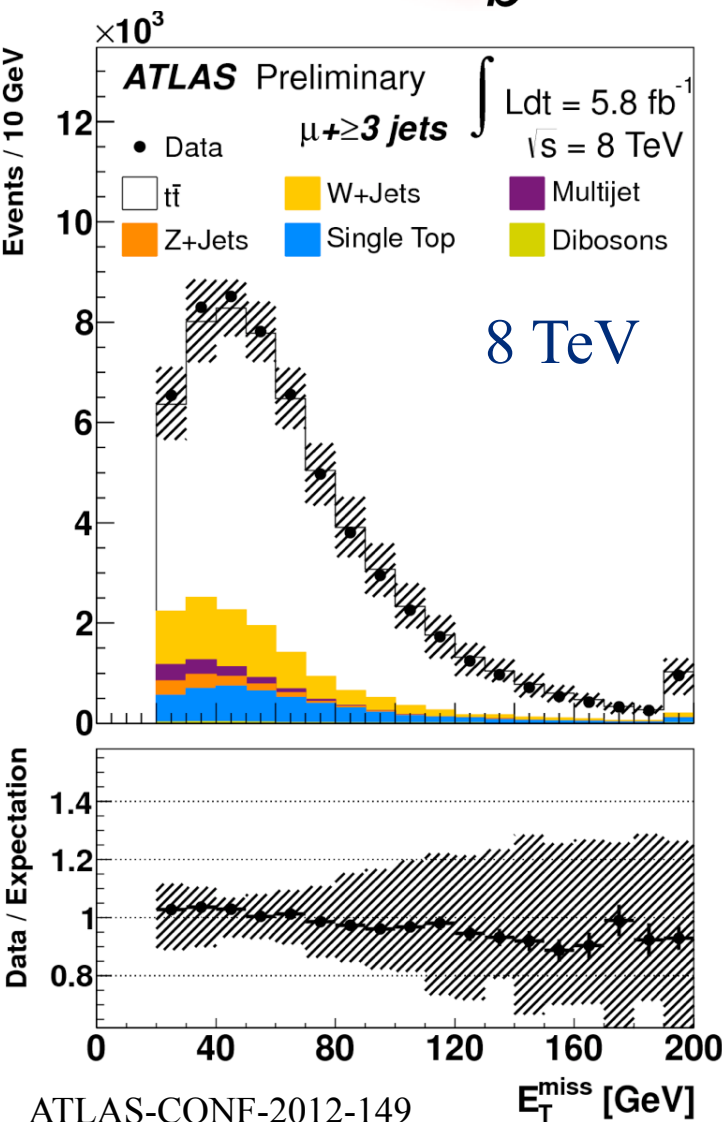
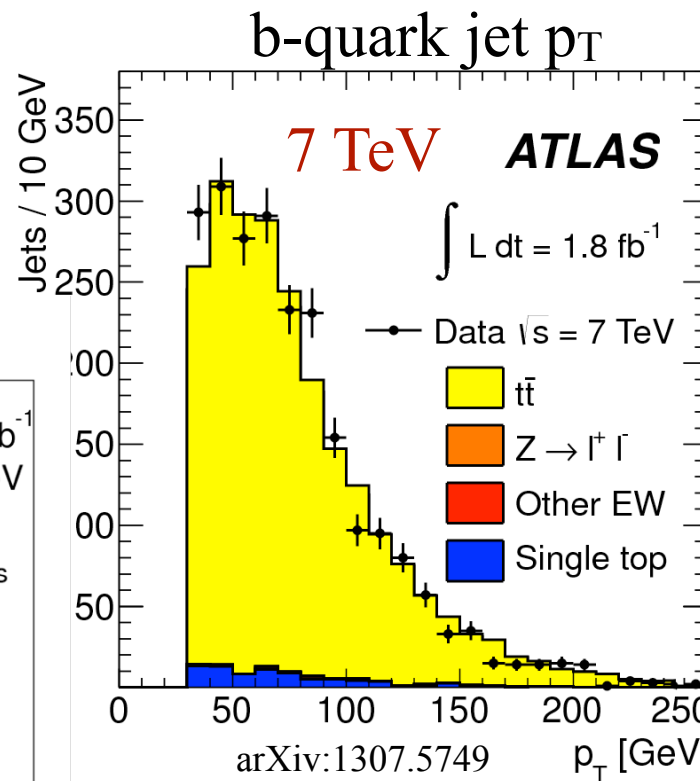
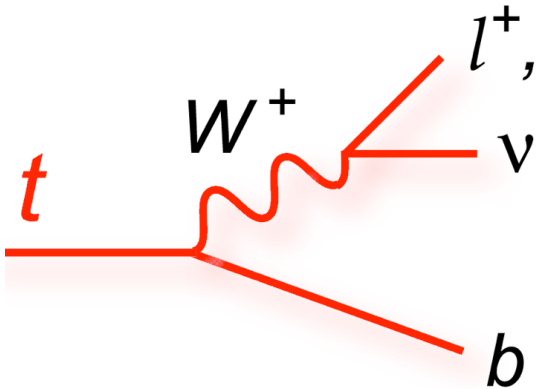
- b-tagging
- lepton isolation
- missing E_T
- tau identification
- 10^3 had tau evts

Top Pair Decay Channels

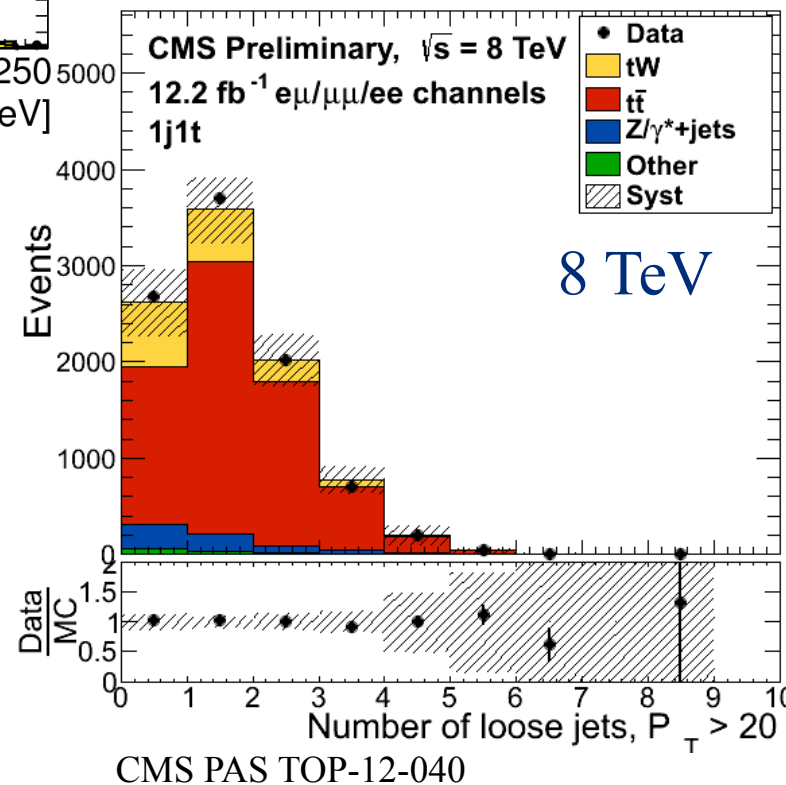
$\bar{c}s$	electron+jets	muon+jets	tau+jets	All-hadronic: large samples (10^6 evts) very large backgrounds	
$\bar{u}d$					
τ^-	$e\tau$	$\mu\tau$	$\tau\tau$		
μ^-	$e\mu$	$\mu\mu$	$\mu\tau$	Lepton+jets: large samples (10^5 evts) manageable backgrounds most common analysis channel	
e^-	ee	$e\mu$	$e\tau$		
W decay	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$

Dileptons:
very clean signature,
small rate (10^4 evts)

Top quark decay products

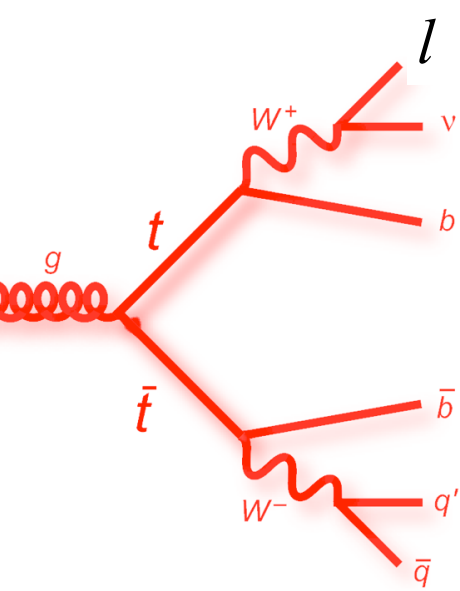


Dilepton jet multiplicity

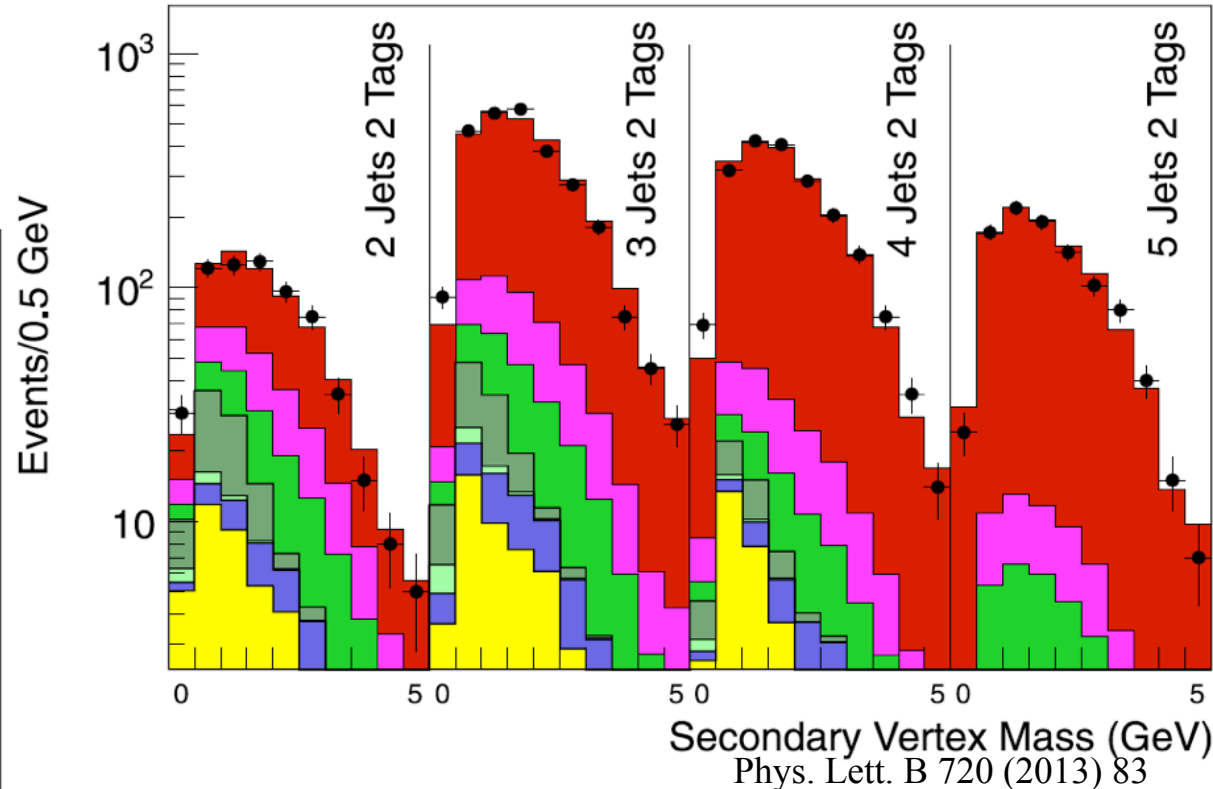


Lepton (e, μ) + jets cross section

Standard candle measurements at 7 TeV and 8 TeV

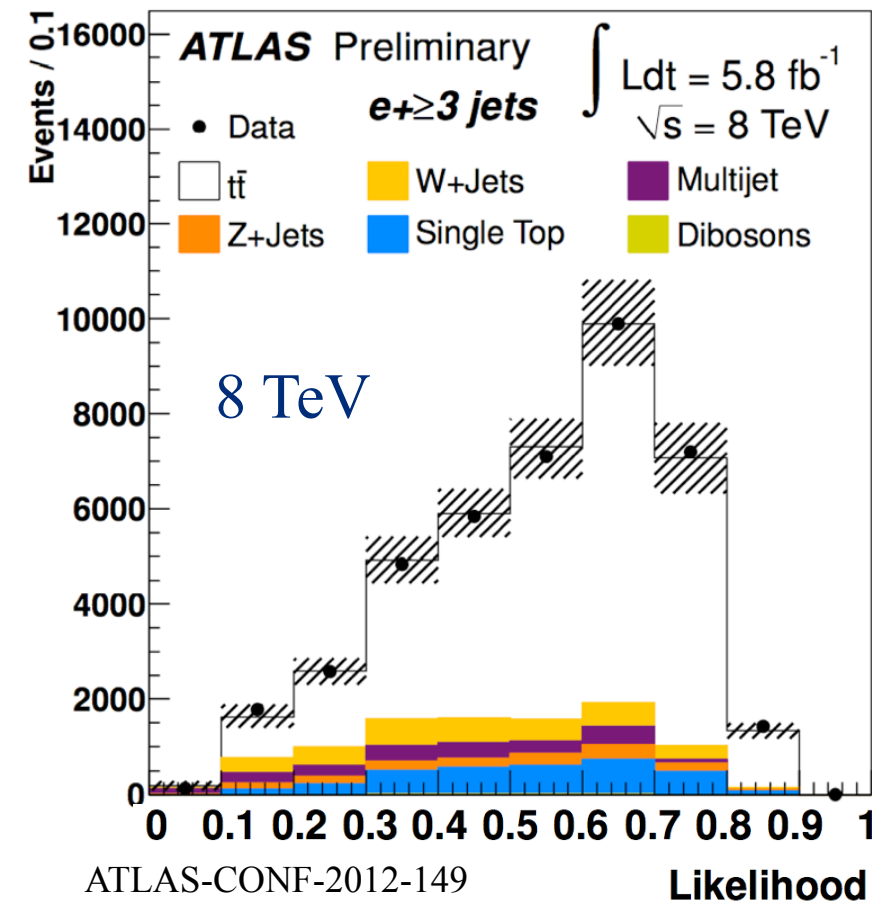


CMS $\sqrt{s} = 7$ TeV **7 TeV** 2.2 fb⁻¹ of Electron Data



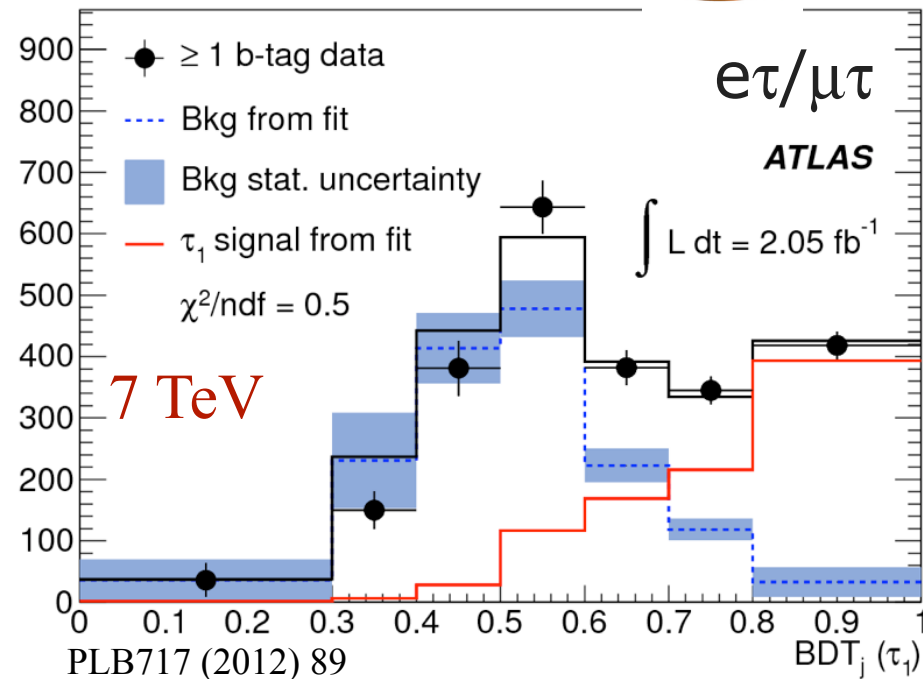
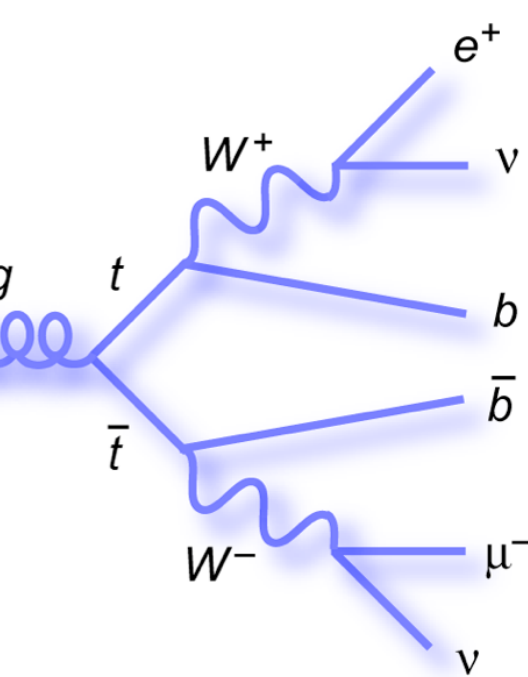
CMS (7 TeV): $\sigma = 158.1 \pm 2.1$ (stat) ± 10.2 (syst) ± 3.5 (lum) pb

ATLAS (8 TeV): $\sigma = 241 \pm 2$ (stat) ± 31 (syst) ± 9 (lum) pb

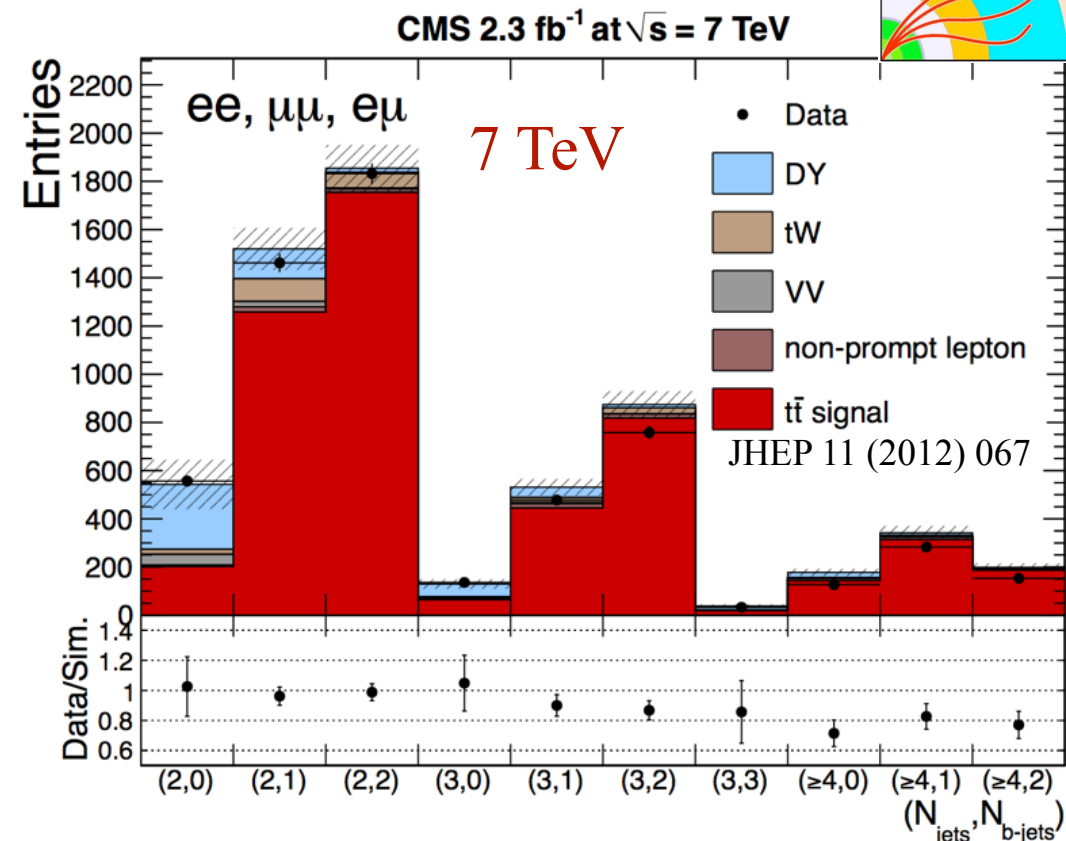


Dilepton cross section

- $ee/\mu\mu/e\mu$: Smaller backgrounds, smaller BR
- $e\tau/\mu\tau$: sensitive to rare decays, new physics



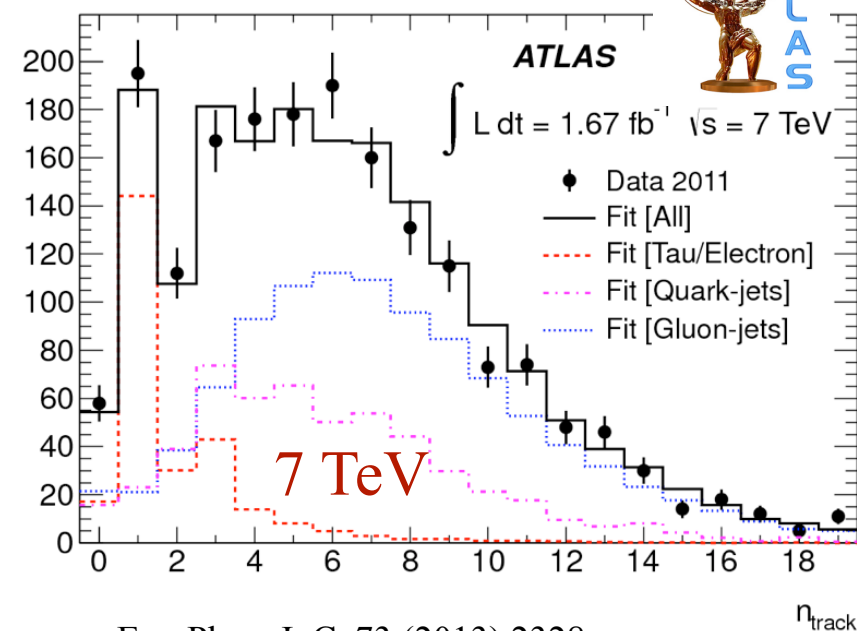
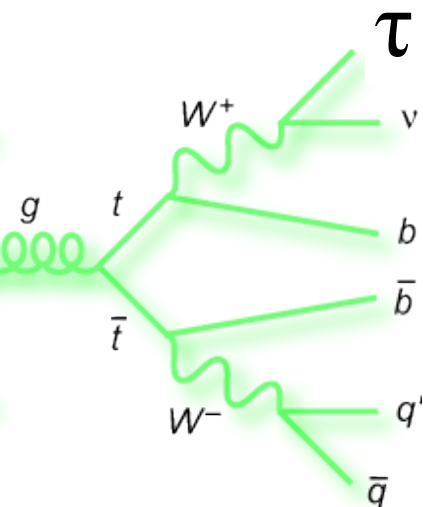
$$\sigma = 186 \pm 13 \text{ (stat)} \pm 20 \text{ (syst)} \pm 7 \text{ (lum)} \text{ pb}$$



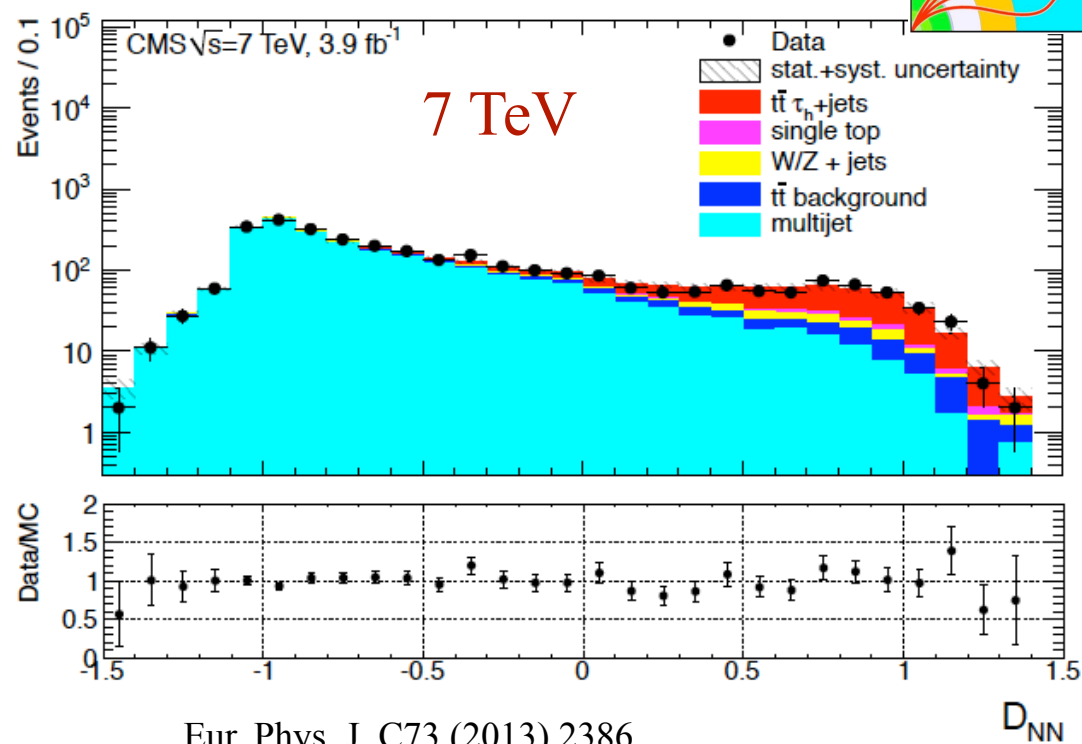
$$\sigma_{t\bar{t}} = 161.9 \pm 2.5 \text{ (stat.) } {}^{+5.1}_{-5.0} \text{ (syst.)} \pm 3.6 \text{ (lumi.) pb}$$

tau + jets

- Reconstruct hadronic tau
- Large multijets background
- Sensitive to new physics



Eur. Phys. J. C, 73 (2013) 2328



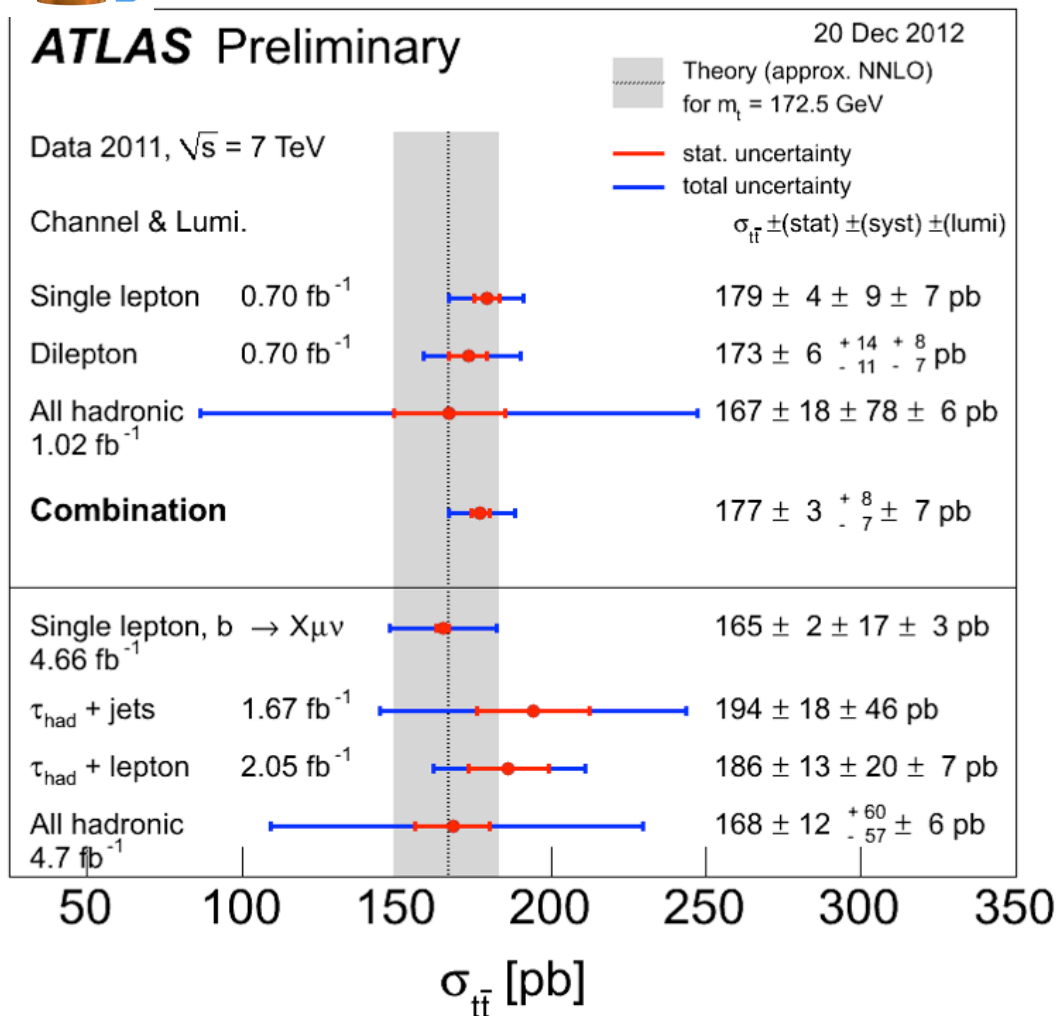
Eur. Phys. J. C73 (2013) 2386

$$\sigma = 152 \pm 12 \text{ (stat)} \pm 32 \text{ (syst)} \pm 3 \text{ (lum)} \text{ pb}$$

$$\sigma = 194 \pm 18 \text{ (stat)} \pm 46 \text{ (syst)} \text{ pb}$$

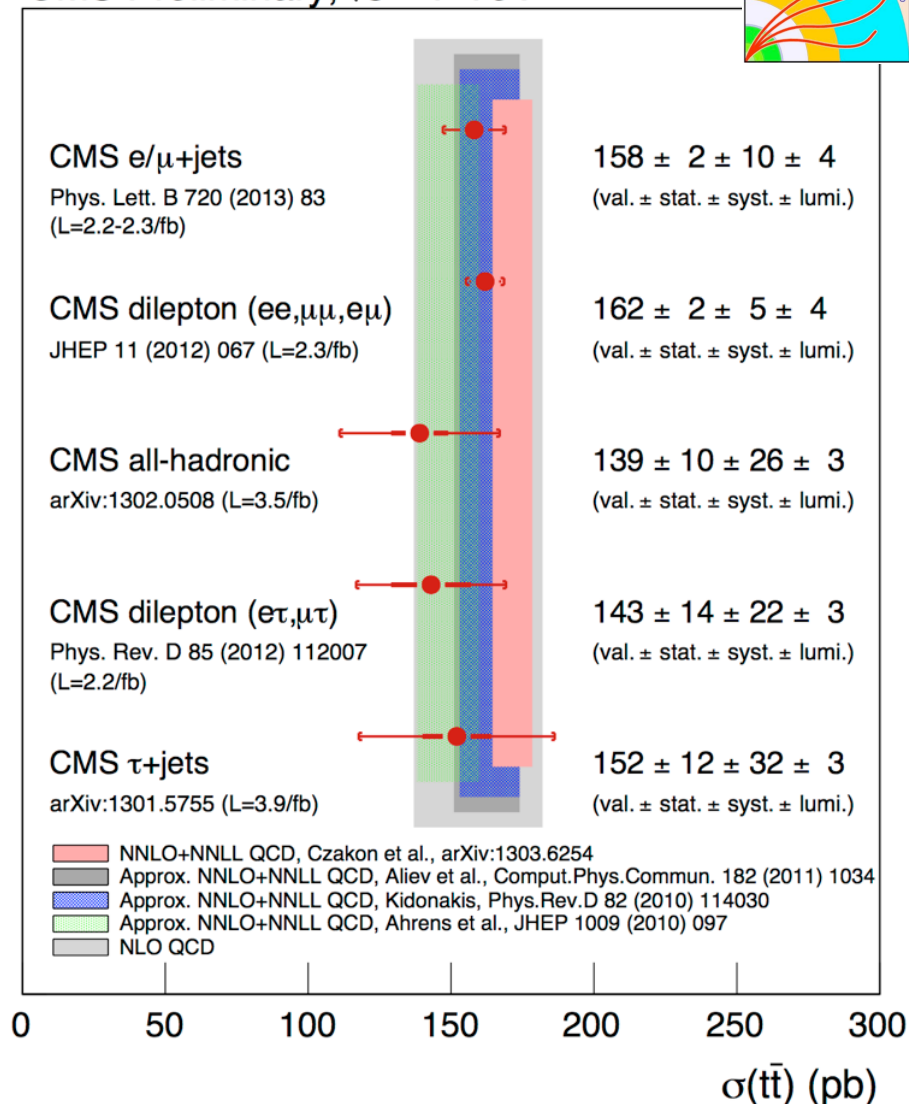


7 TeV precision results



- ATLAS: Measurements with full 7 TeV dataset in progress

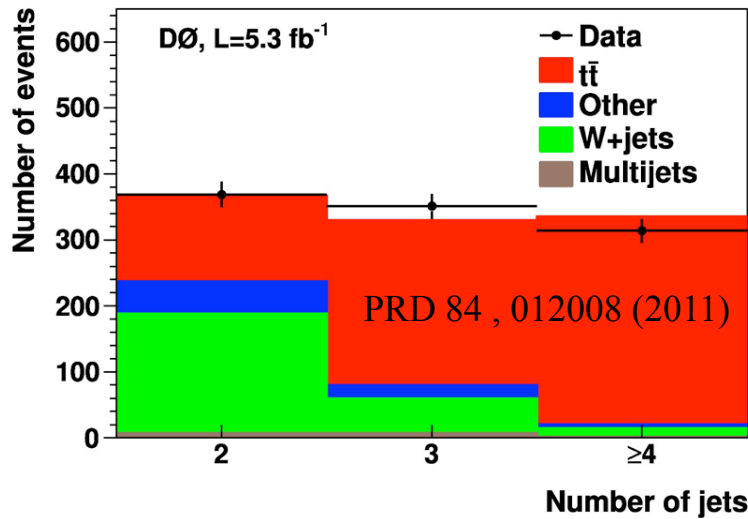
CMS Preliminary, $\sqrt{s} = 7$ TeV



- CMS: 7 TeV complete, focus on 8 TeV now

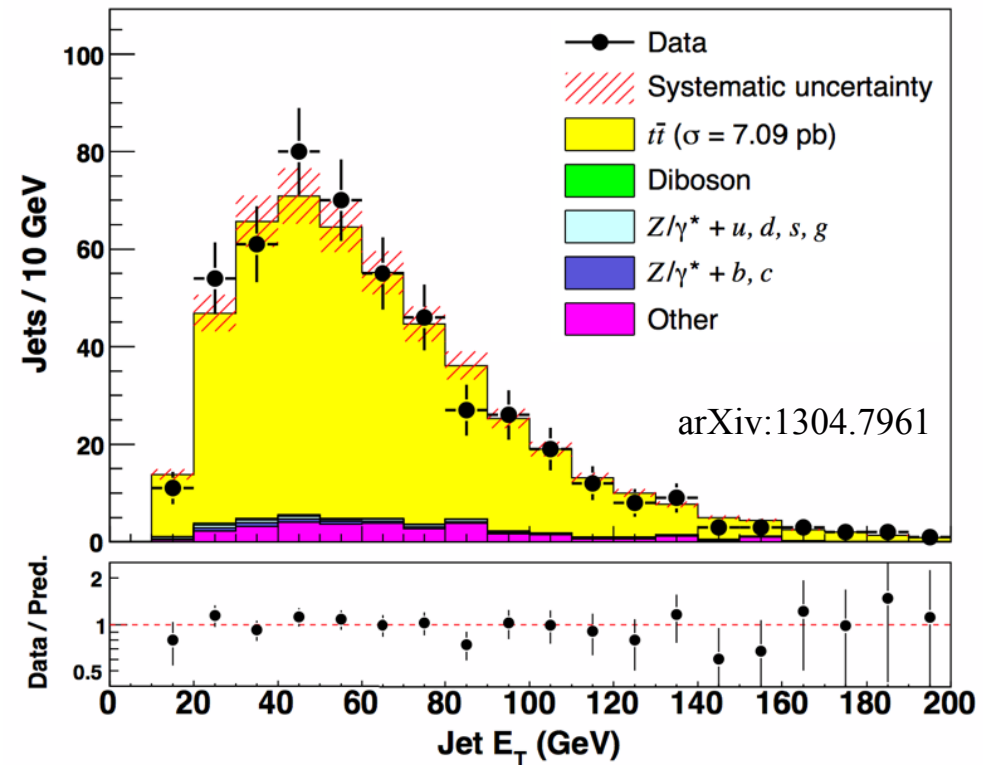
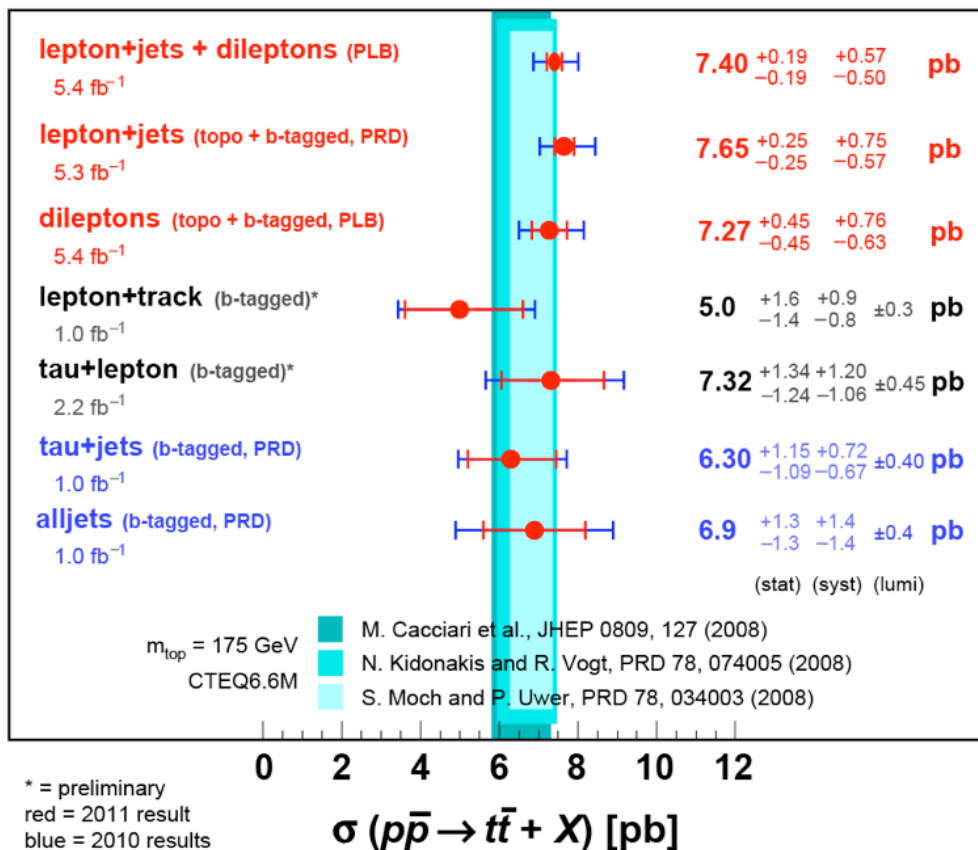


Tevatron cross section

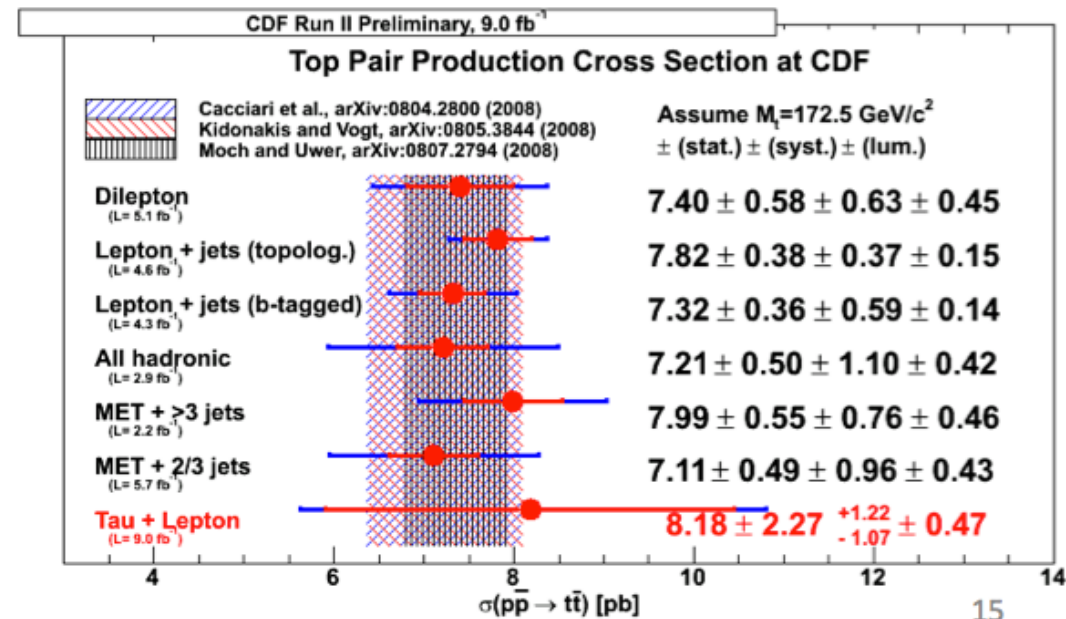


DØ Run II

July 2011

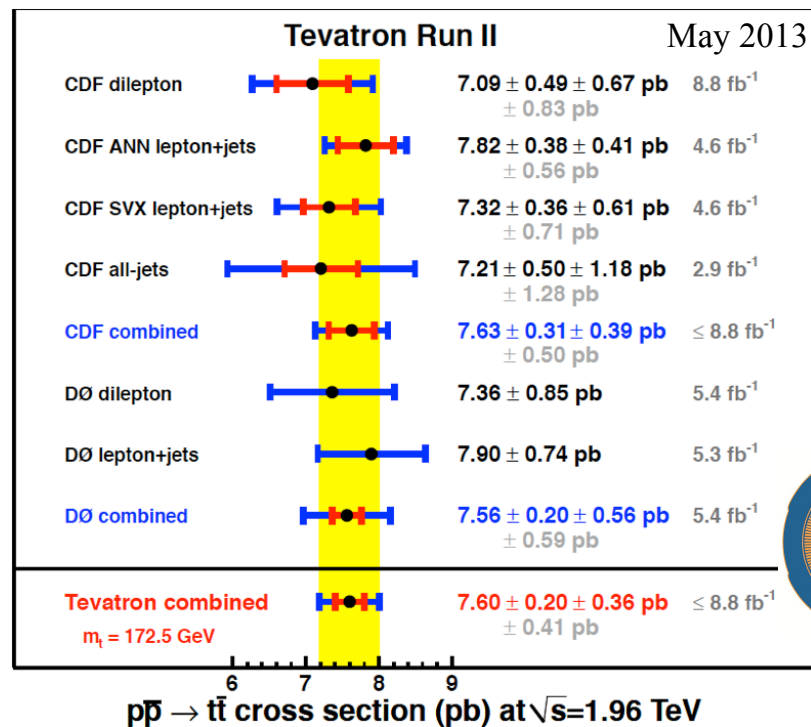
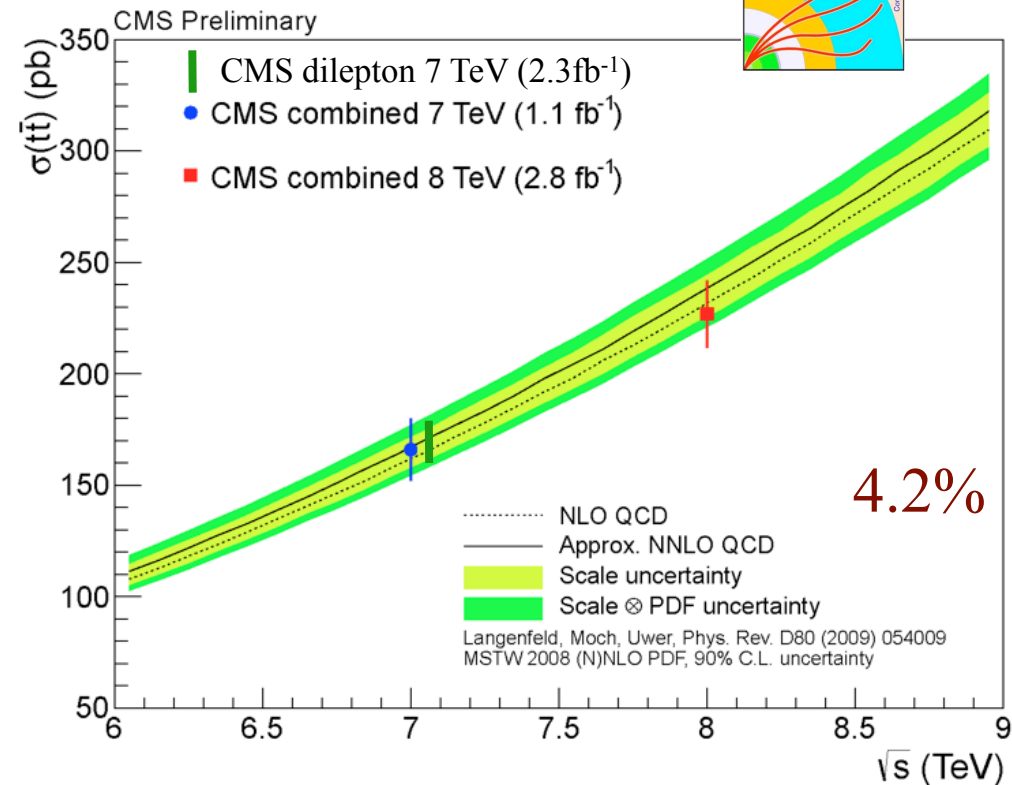
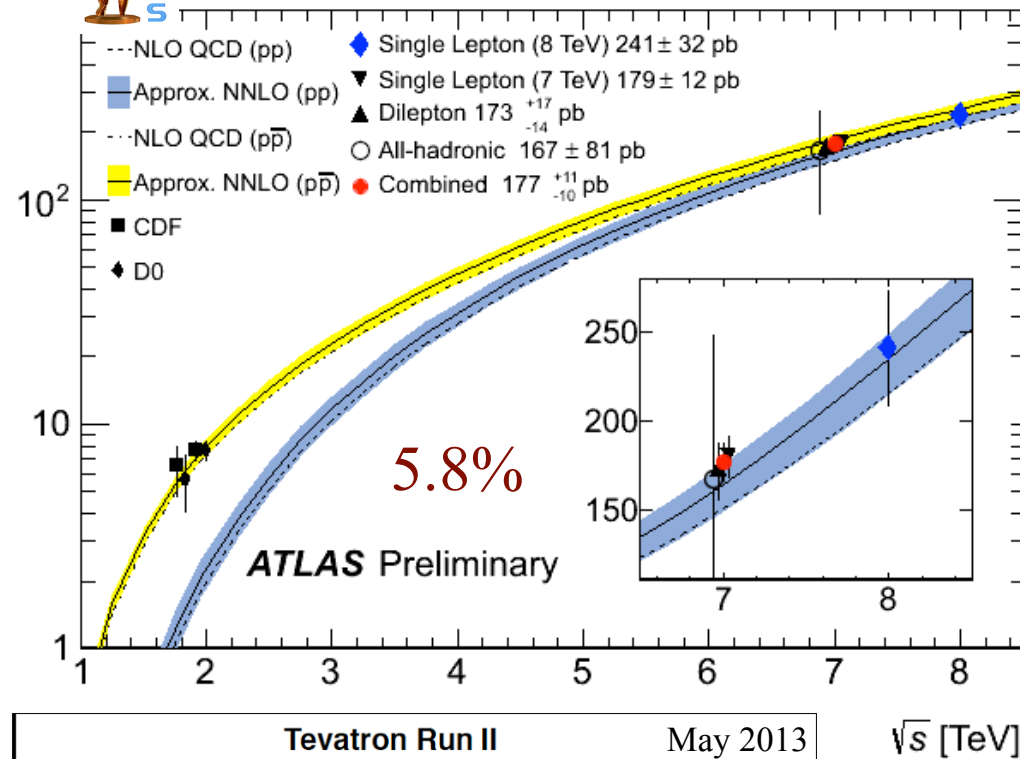
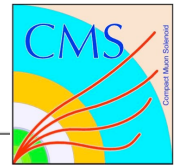


arXiv:1304.7961





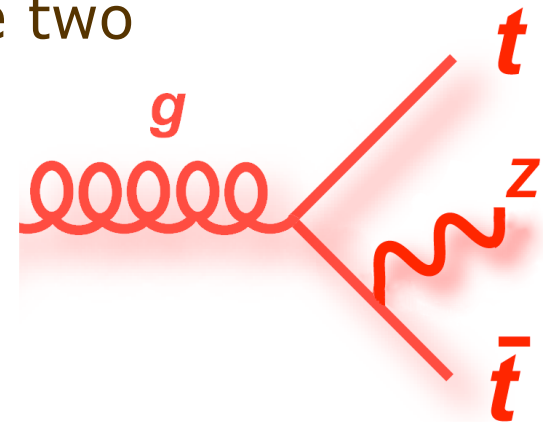
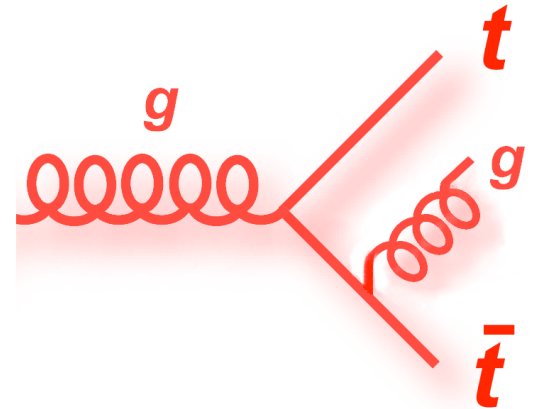
Cross section summary



- All final states explored
 - Except di-tau with hadronic decay
- Measurements to 5%
 - Equal experimental and theory errors

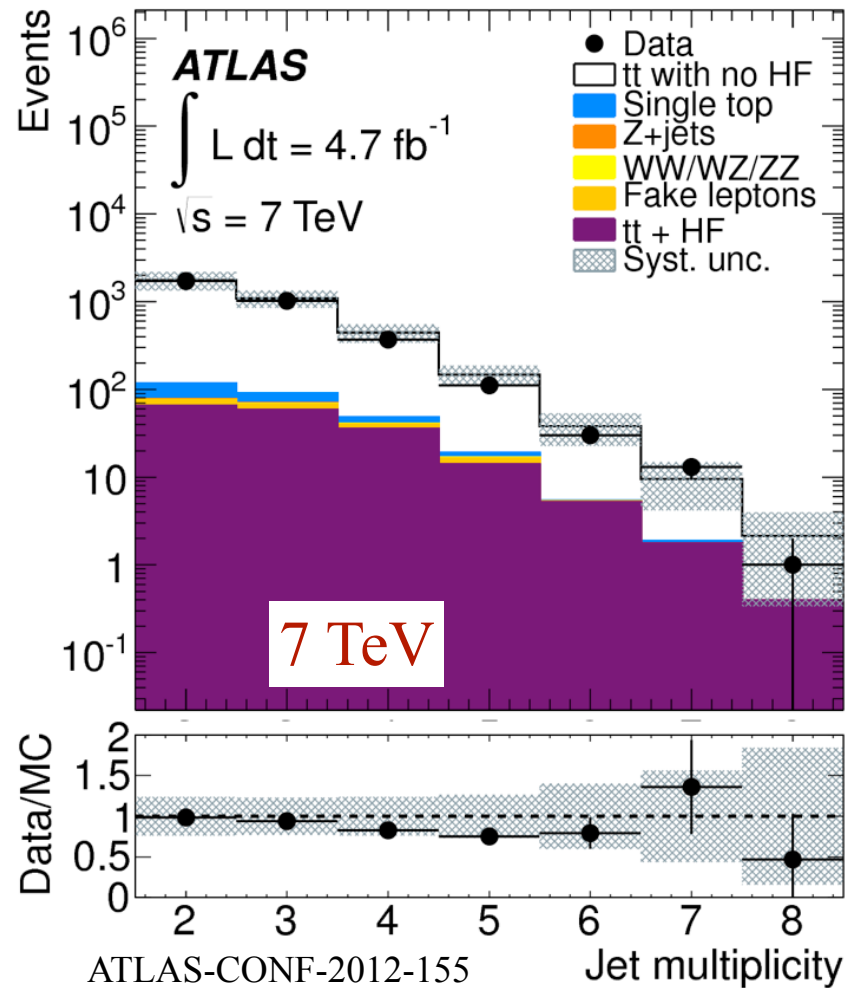
Top pair associated production

- In association with jets
 - Study jet multiplicity
 - Study flavor composition
 - Precision QCD tests
 - ISR/FSR modeling
 - Background to $t\bar{t}H$
 - Sensitive to new physics, new particles
- In association with bosons
 - Observe $t\bar{t}W$, $t\bar{t}Z$ production, separate the two
 - First measurement of top-Z coupling
 - Sensitive to anomalous weak couplings
 - Sensitive to new physics, new particles

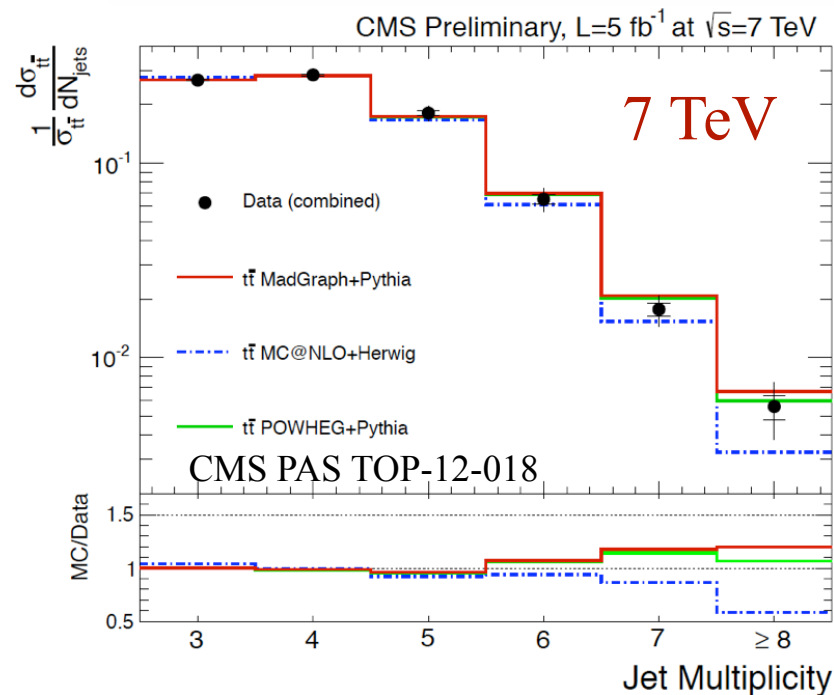
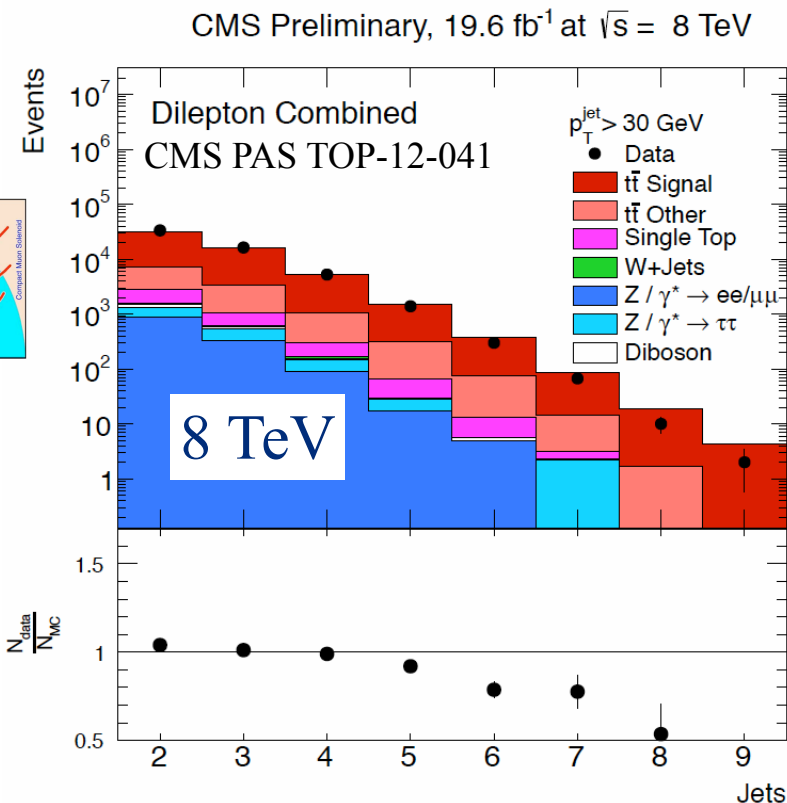




top + jets

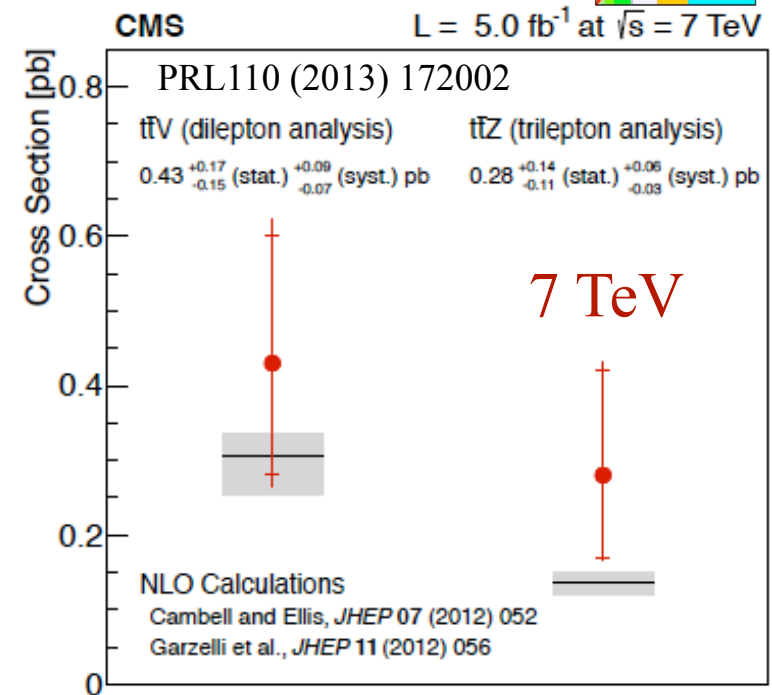
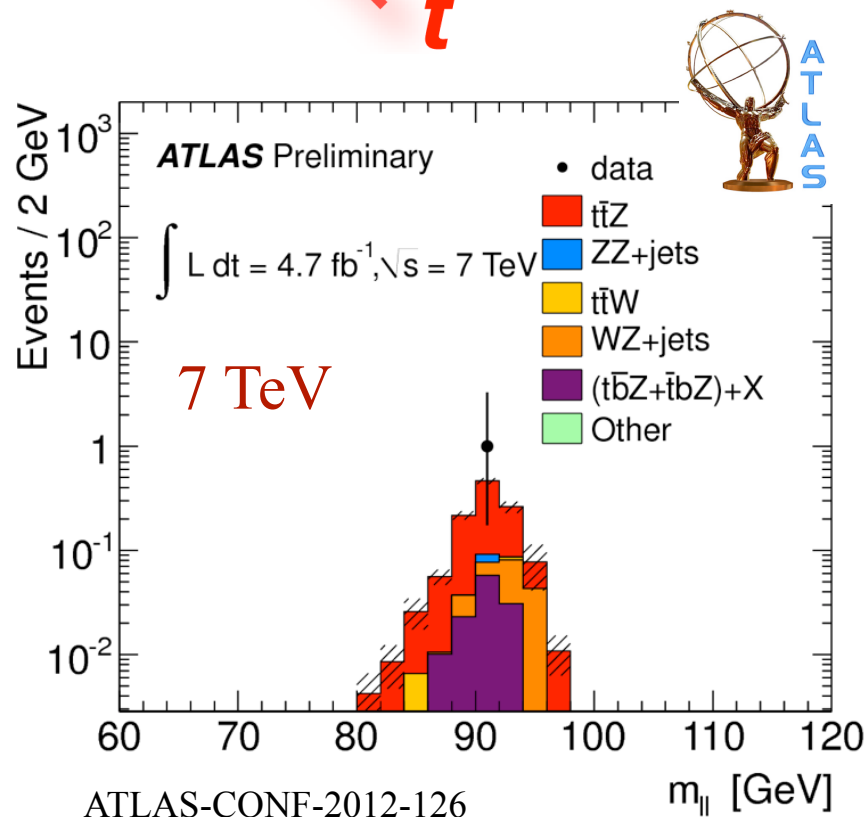
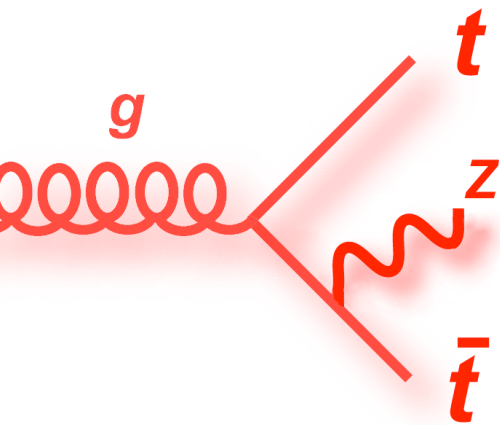


ATLAS: also flavor composition
 $R_{\text{HF}} = 7.1 \pm 1.3 \text{ (stat.) } ^{+5.3}_{-2.0} \text{ (syst.) } \%$
 arXiv:1304.6386



CMS: differential cross section

top pairs plus bosons



$$\sigma(ttV) = 0.43^{+0.17}_{-0.15} \text{ (stat.) } ^{+0.09}_{-0.07} \text{ (syst.) pb}$$

- 3 s.d. for ttZ+ttW combined
- 3.3 s.d for ttZ

- tt γ also from CDF CDF note 10270

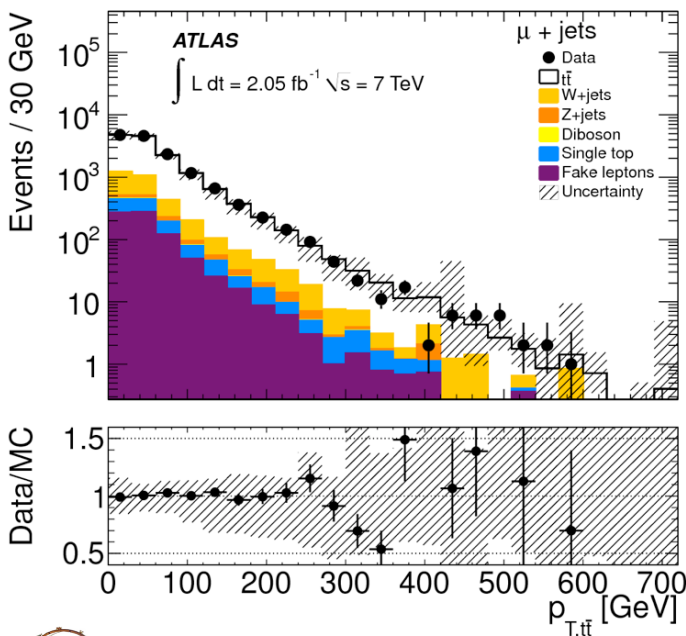
$$\sigma(tt\gamma) = 0.18 \pm 0.07 \text{ pb}$$

- 3 s.d.

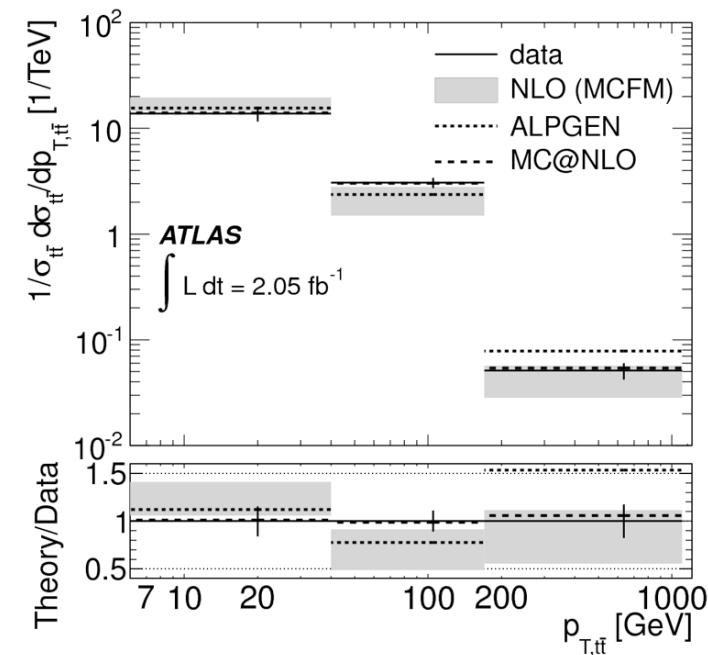
- Upper limit on ttZ at 7 TeV
- Also tt γ ATLAS-CONF-2011-153

Differential cross sections

- Compare kinematics in different theory models to data
 - Theory prediction at NLO and approx. NNLO Phys.Rev. D84 (2011) 011504
- Test QCD predictions beyond total rate
- Sensitive to new physics and modified couplings
- Constrain PDFs, generators, parton showering, etc



- Subtract background
- Correct for acceptance
- Unfold detector level to parton level



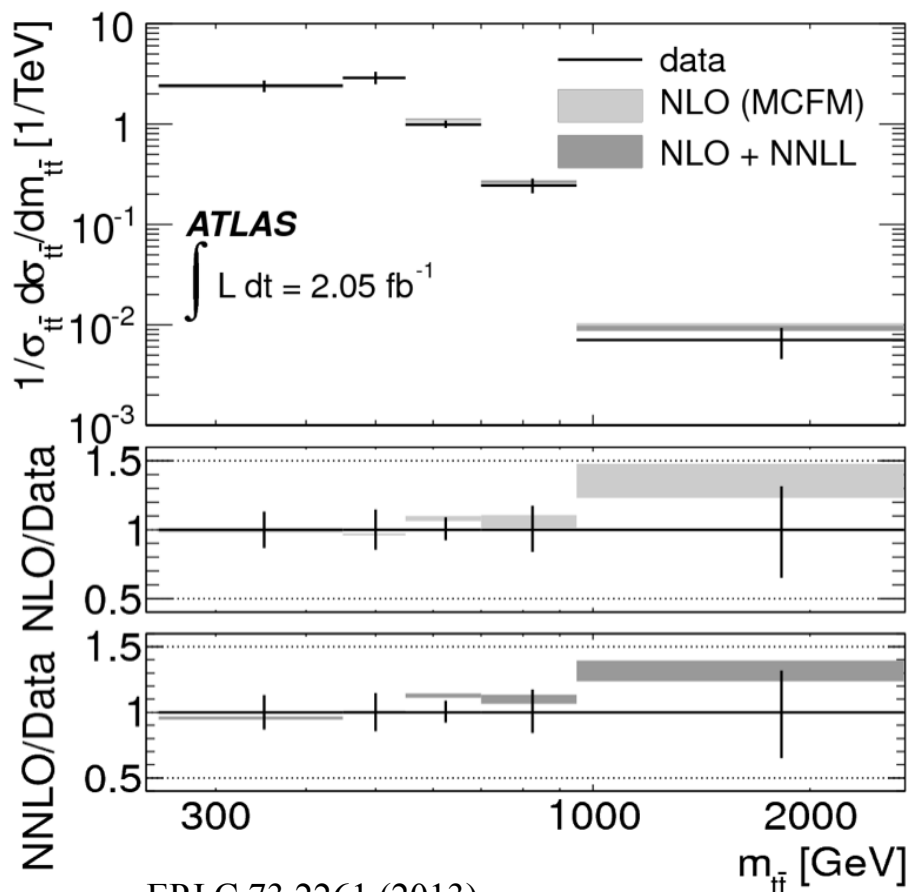
7 TeV

EPJ C 73 2261 (2013)



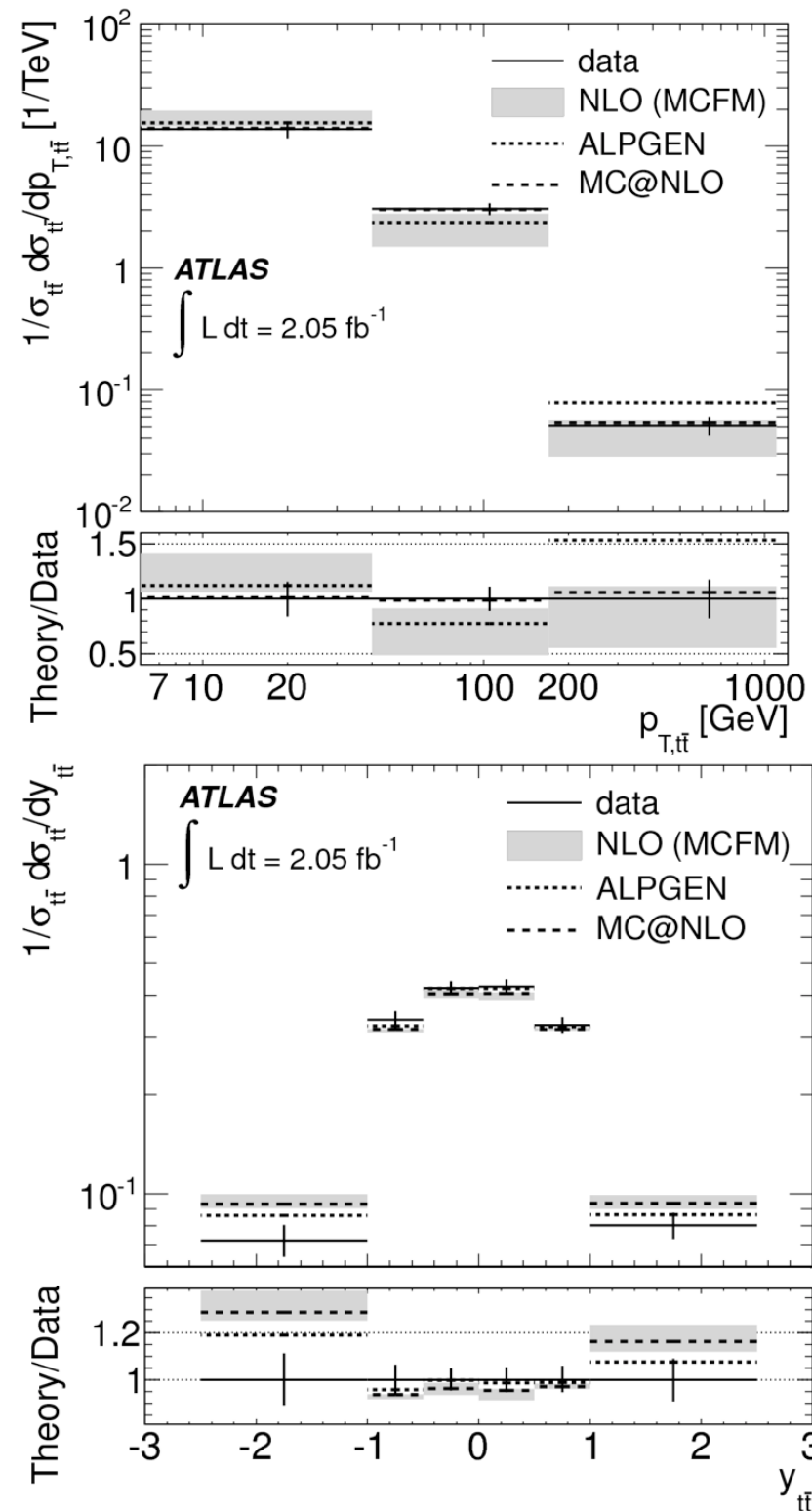
Differential XS

7 TeV



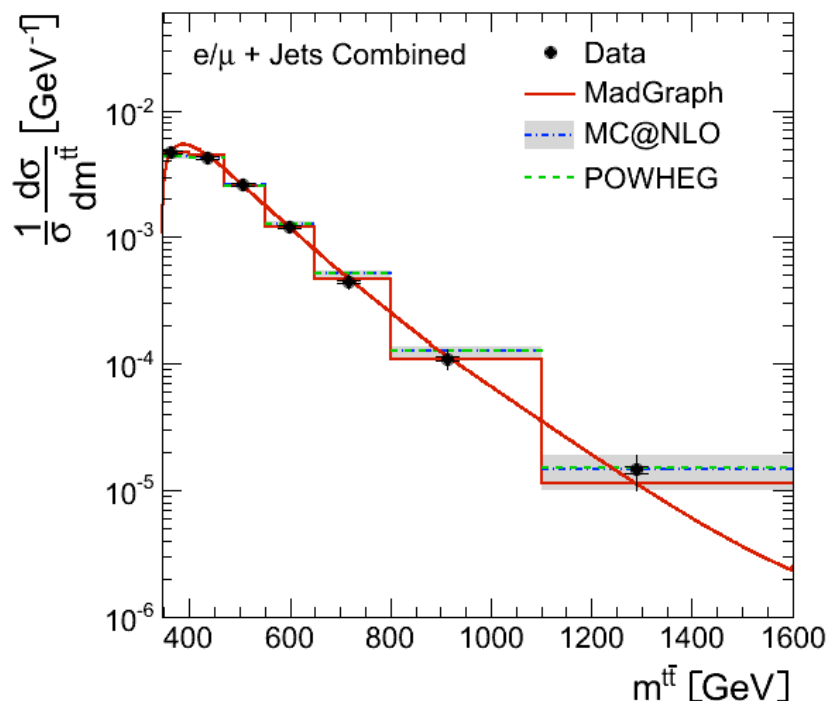
EPJ C 73 2261 (2013)

- Agreement with NLO within uncertainties
- Differential charge asymmetry → next talk



Differential XS at 8 TeV

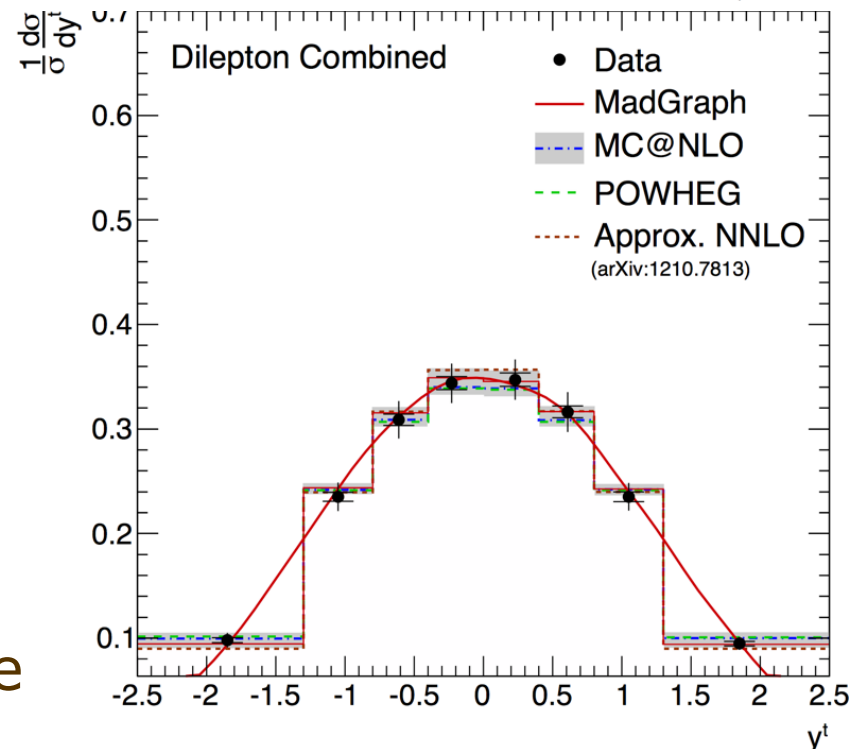
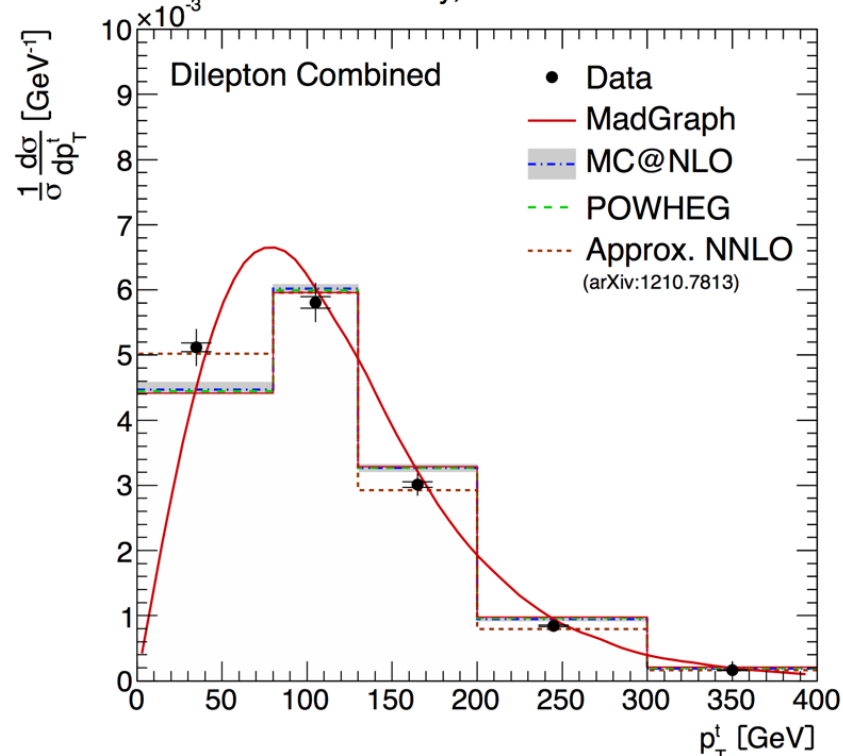
CMS Preliminary, 12.1 fb⁻¹ at $\sqrt{s} = 8$ TeV



CMS PAS TOP-12-027

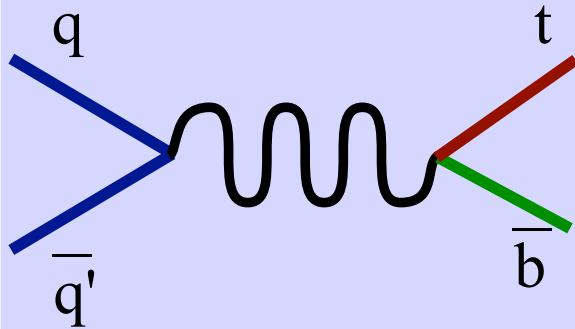
- Agreement with NLO within uncertainties
 - Top p_T softer than predicted
- Also available as p_T , η for top
 - and for lepton, b in visible phase space

CMS Preliminary, 12.2 fb⁻¹ at $\sqrt{s} = 8$ TeV

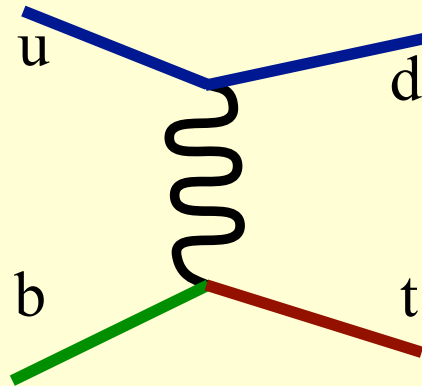


Single top production

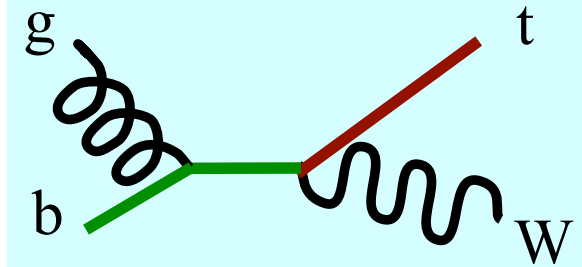
s-channel



t-channel



Associated production



Tevatron:

$$\sigma_{\text{tot}} = 3 \text{ pb}$$

LHC:
(7 TeV)

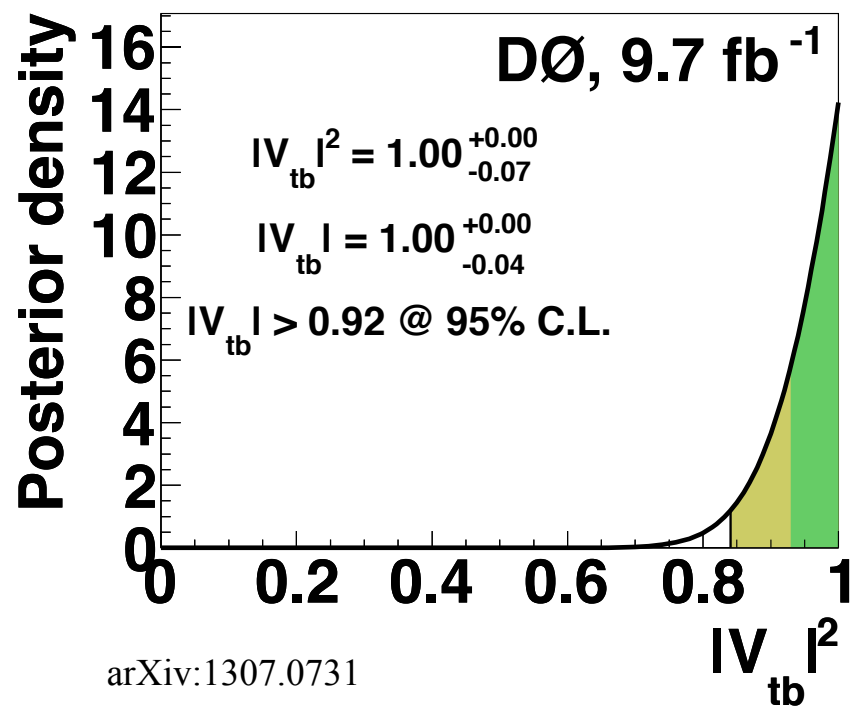
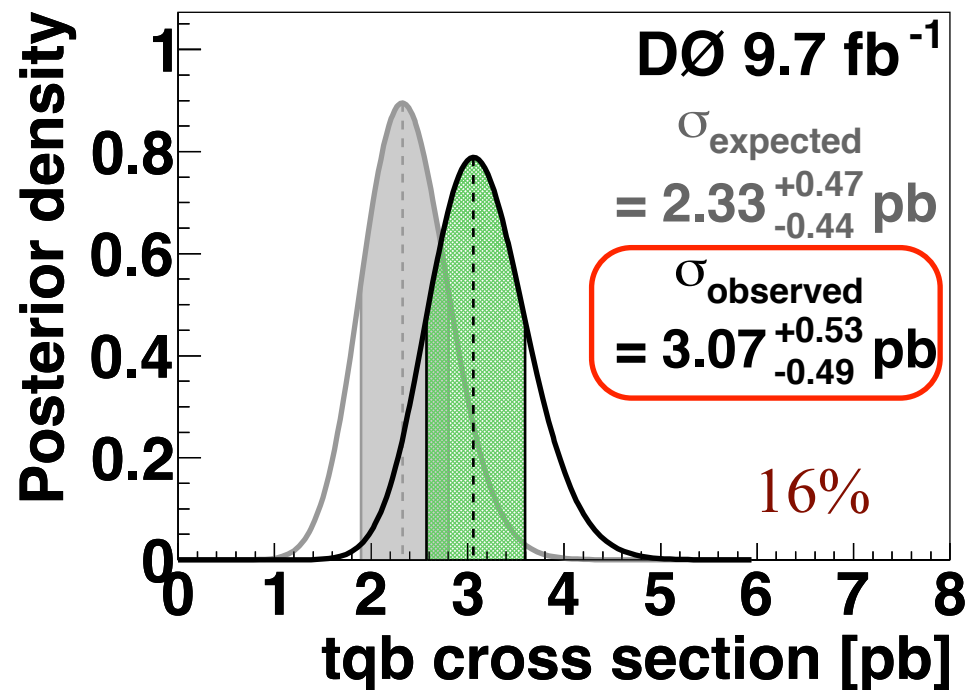
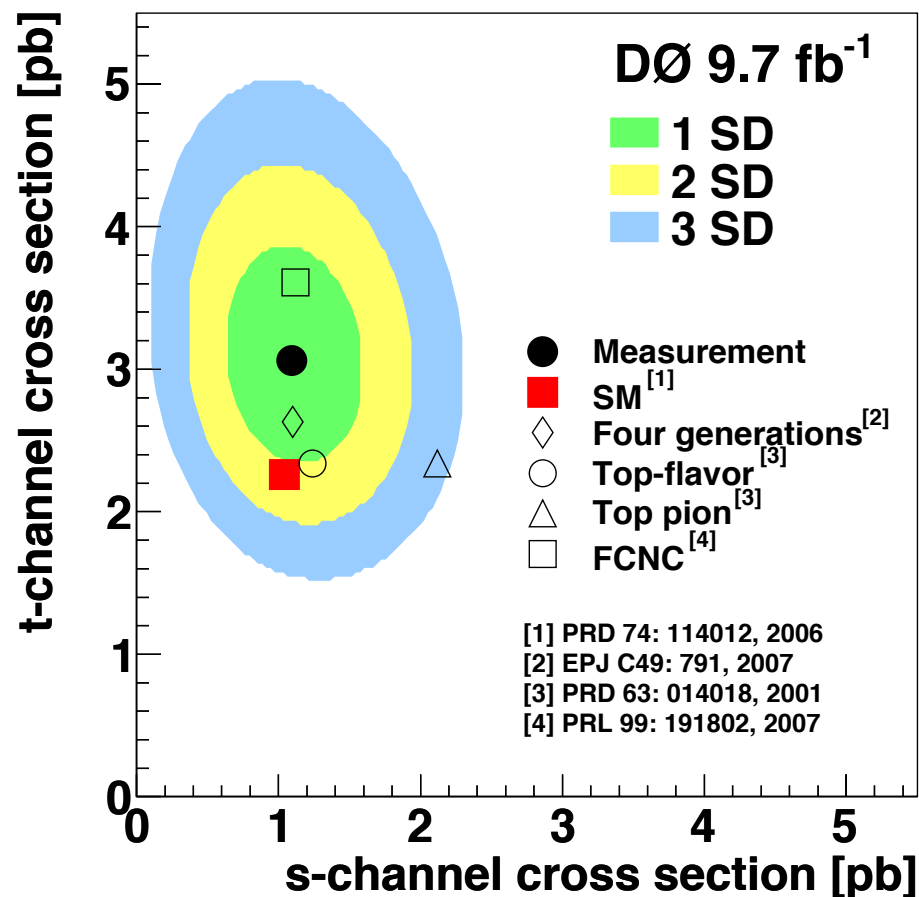
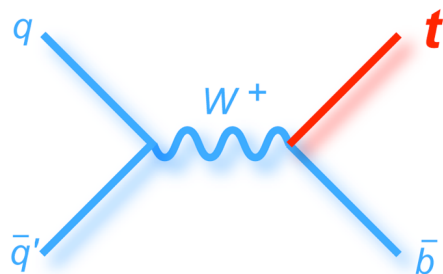
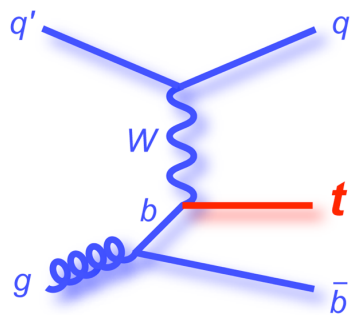
$$\sigma_{\text{tot}} = 76 \text{ pb}$$

LHC:
(8 TeV)

$$\sigma_{\text{tot}} = 114 \text{ pb}$$

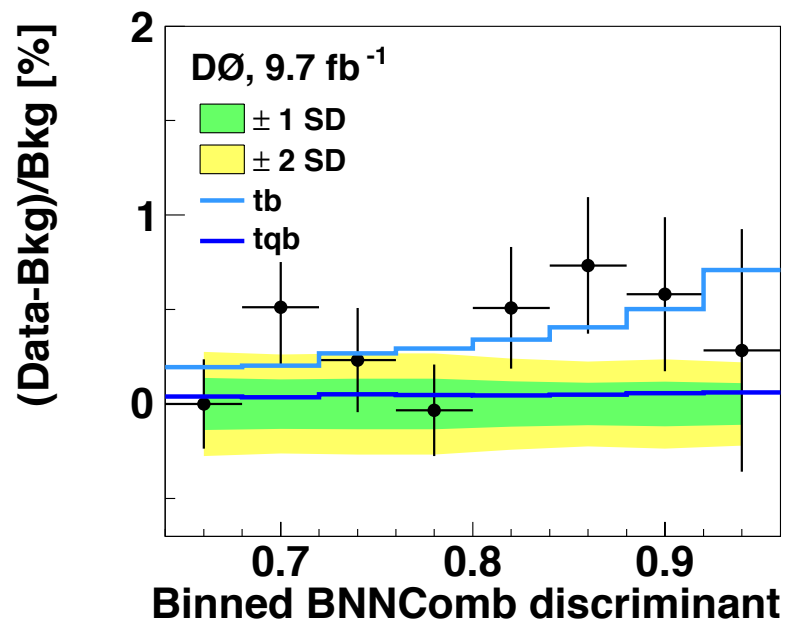
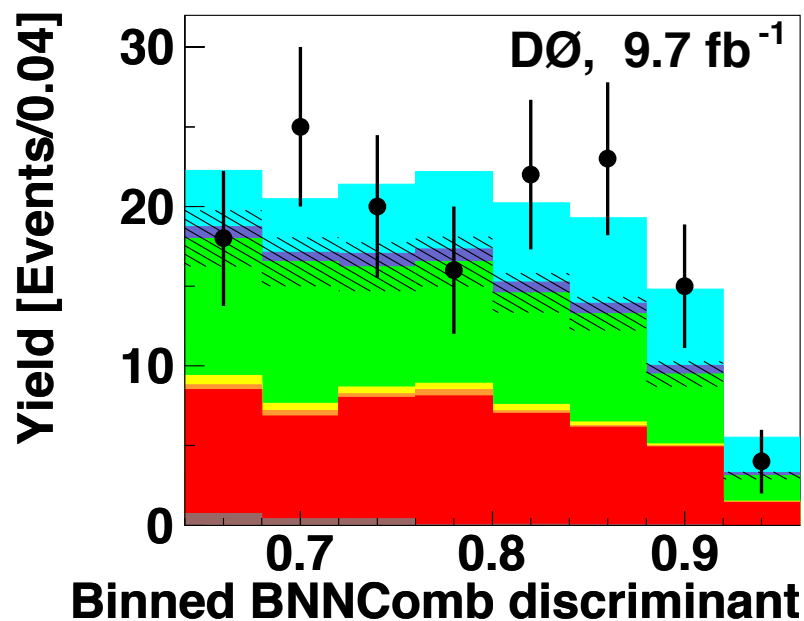
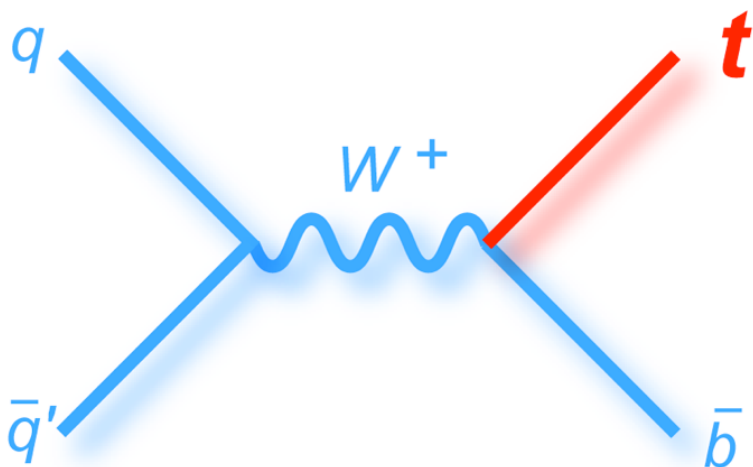


Single top quark production



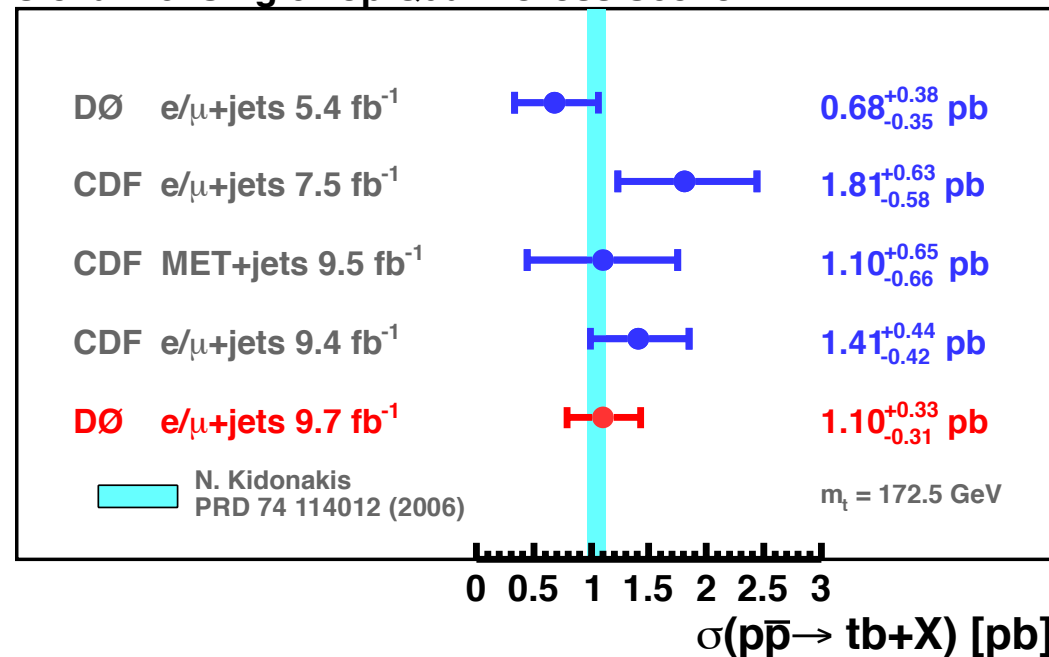
arXiv:1307.0731

s-channel single top



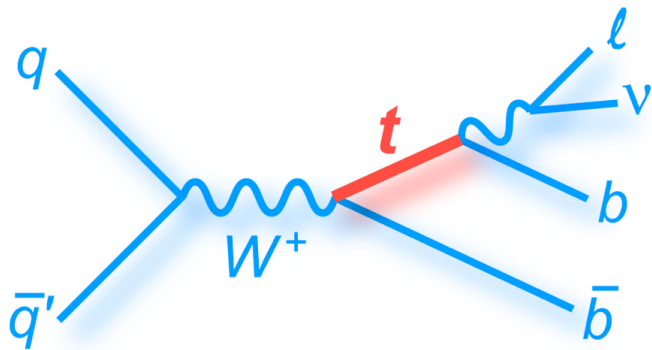
- 3.7 s.d. significance
- very difficult at LHC

s-channel Single Top Quark Cross Section

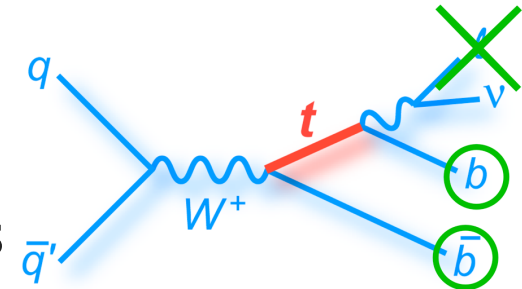


arXiv:1307.0731

s-channel single top

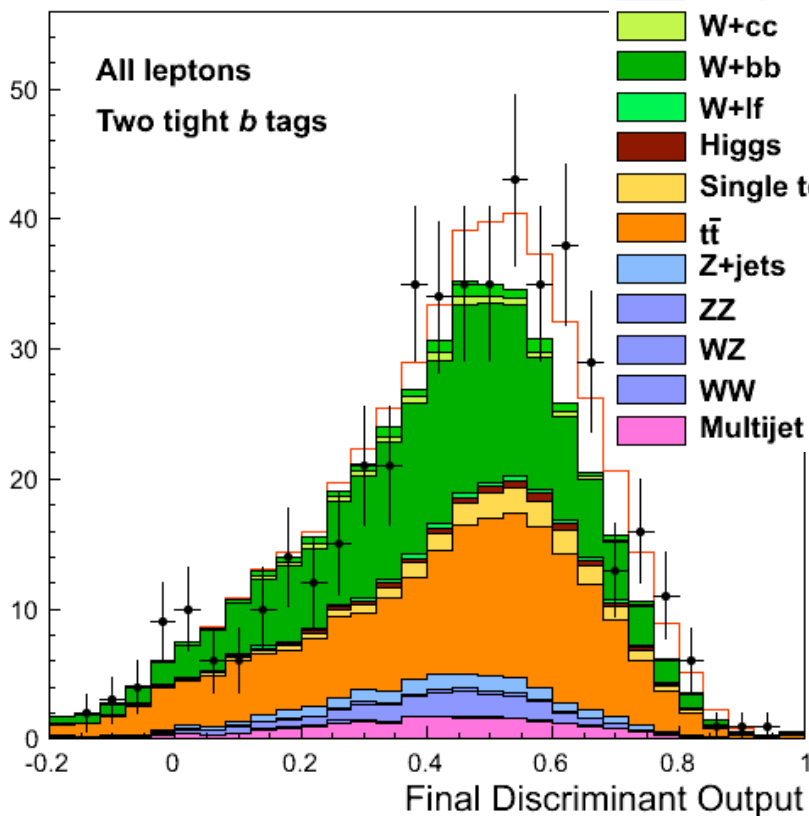


- Resolved lepton and MET+jets channels
- Based on Higgs analysis
- TeV combination in progress



CDF Run II Preliminary (9.4 fb⁻¹)

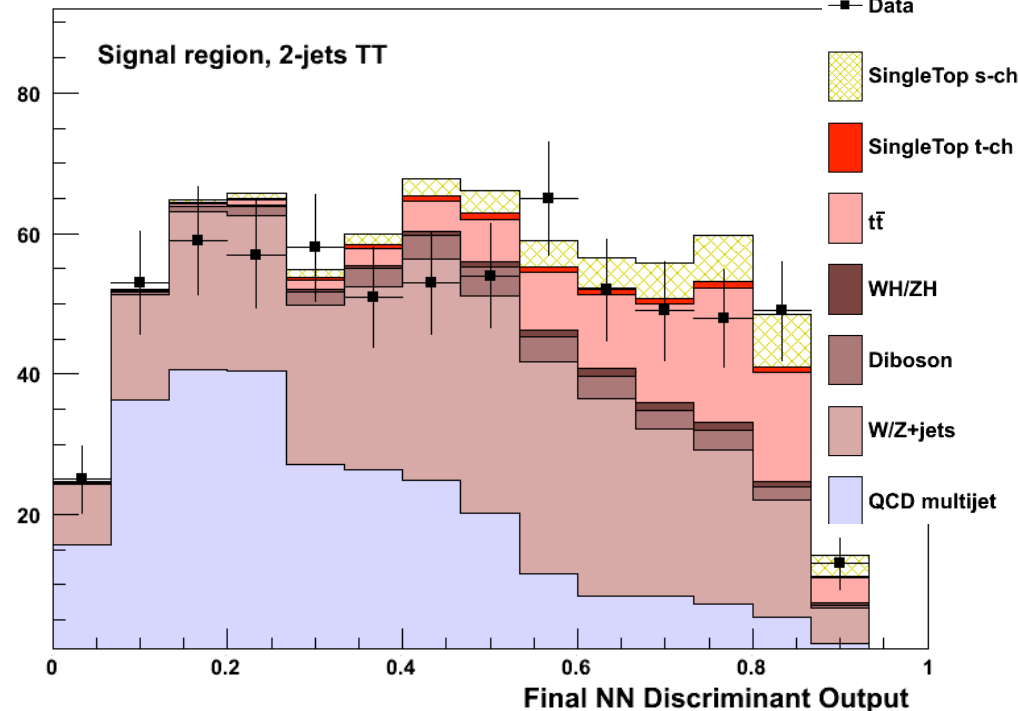
Number of events



- Data
- Single top (s-ch)
- W+cj
- W+cc
- W+bb
- W+lf
- Higgs
- Single top (t & Wt)
- t $\bar{t}$
- Z+jets
- ZZ
- WZ
- WW
- Multijet

Single Top s-channel in $\cancel{E}_T$ +jets, CDF Run II Preliminary, L = 9.5 fb⁻¹

Events/0.07

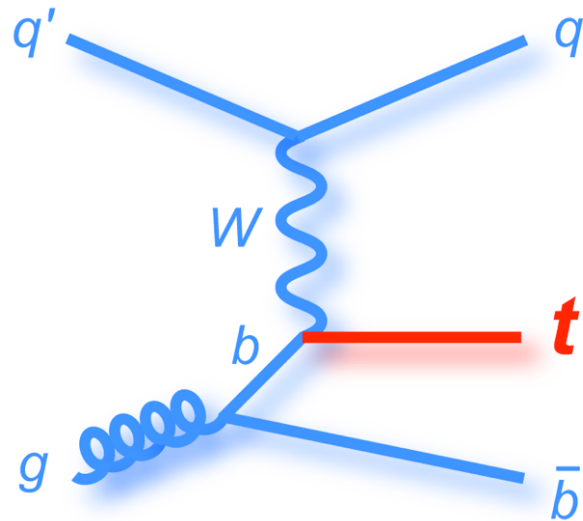


$$\sigma = 1.10 \pm 0.66 \text{ pb}$$

• 3.7 s.d. significance

$$\sigma_{\text{Obs}}^{s\text{-ch}} = 1.41^{+0.44}_{-0.42} \text{ pb}$$

LHC single top production

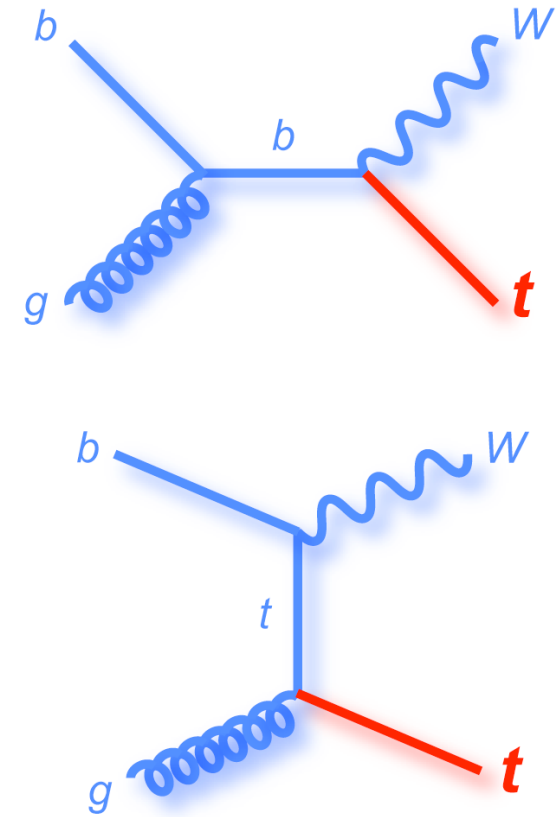


t-channel

$$\sigma = 87.5 \pm 2.8 \text{ pb at 8 TeV}$$

Kidonakis, arXiv:1205.3453

- Measure cross section for top and anti-top
 - PDFs
- CKM matrix element $|V_{tb}|$
- Spin correlation, CP violation
- Single-top factory

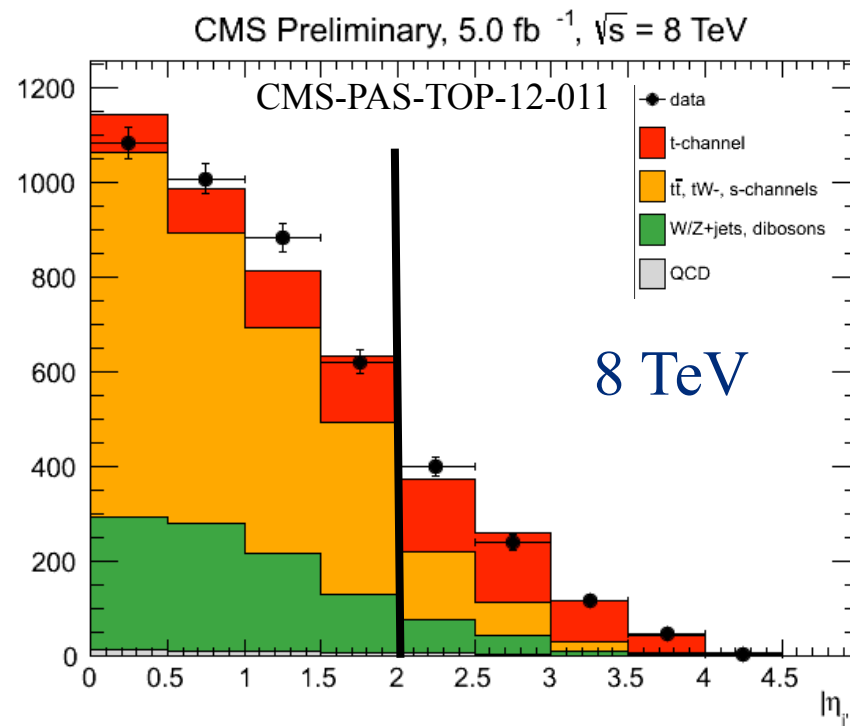
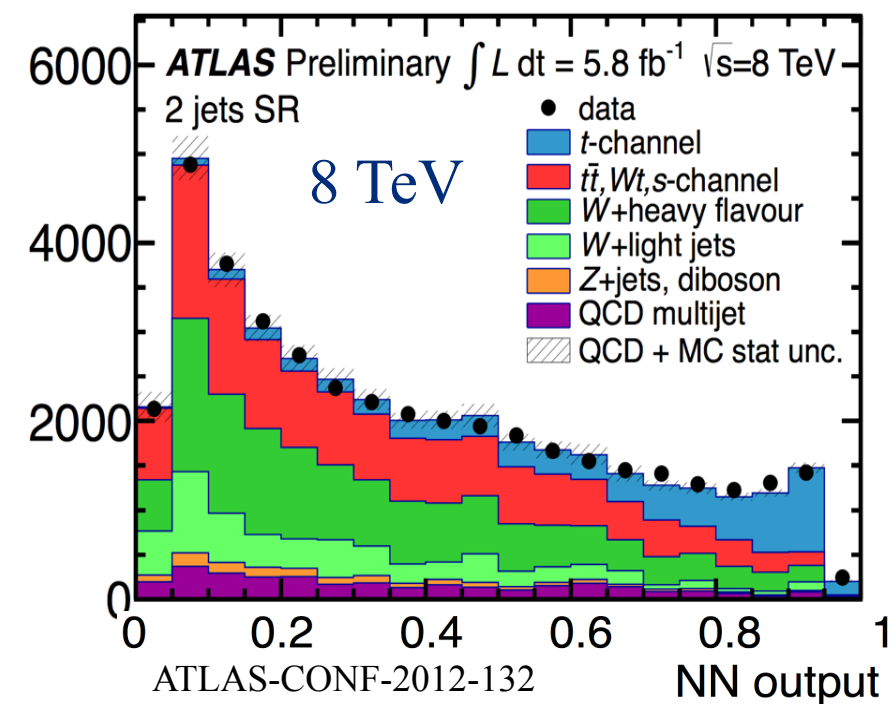
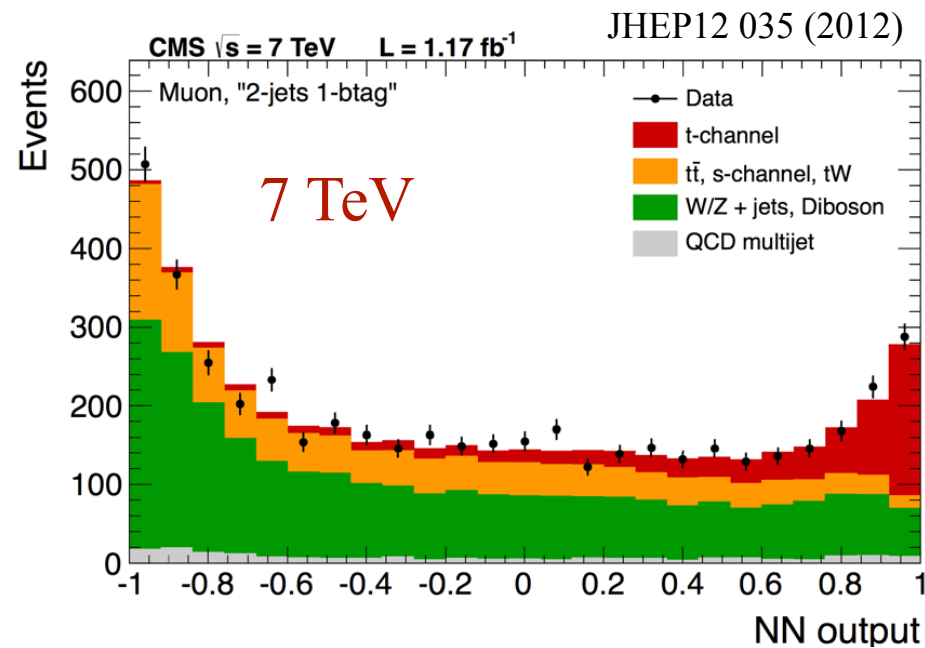
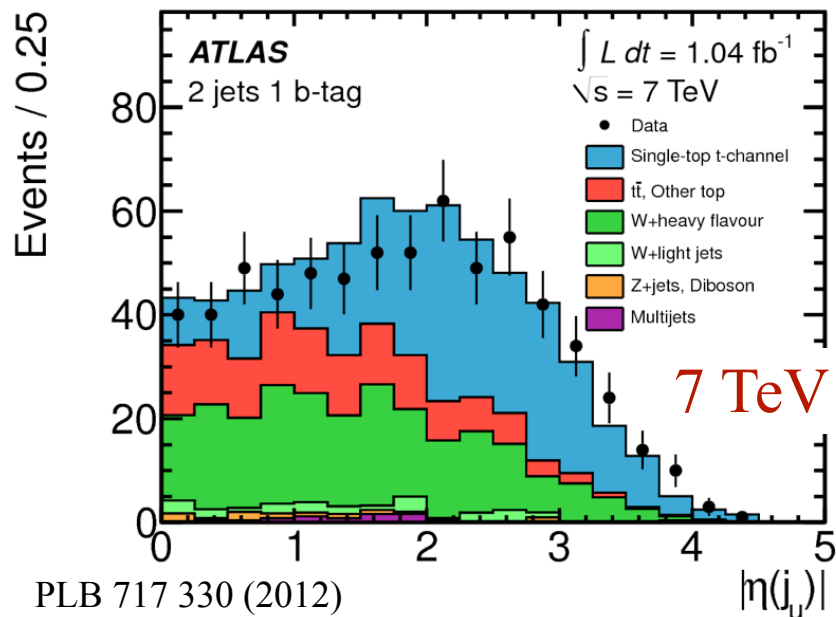


Wt associated production

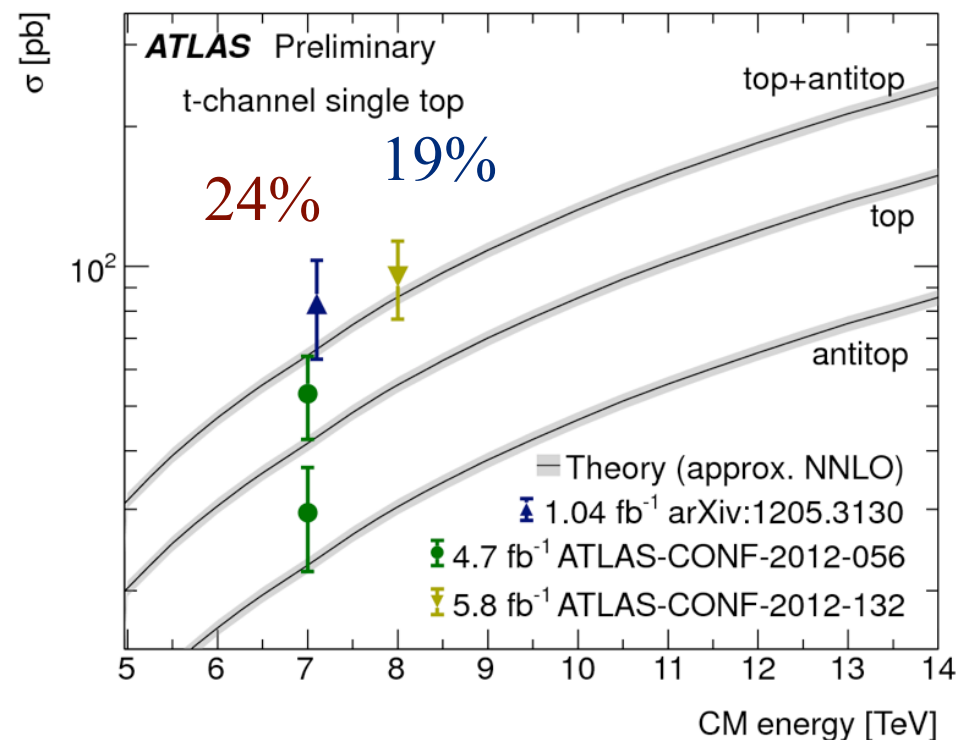
$$\sigma = 22.4 \pm 1.5 \text{ pb at 8 TeV}$$

Kidonakis, PRD82 054018 (2010)

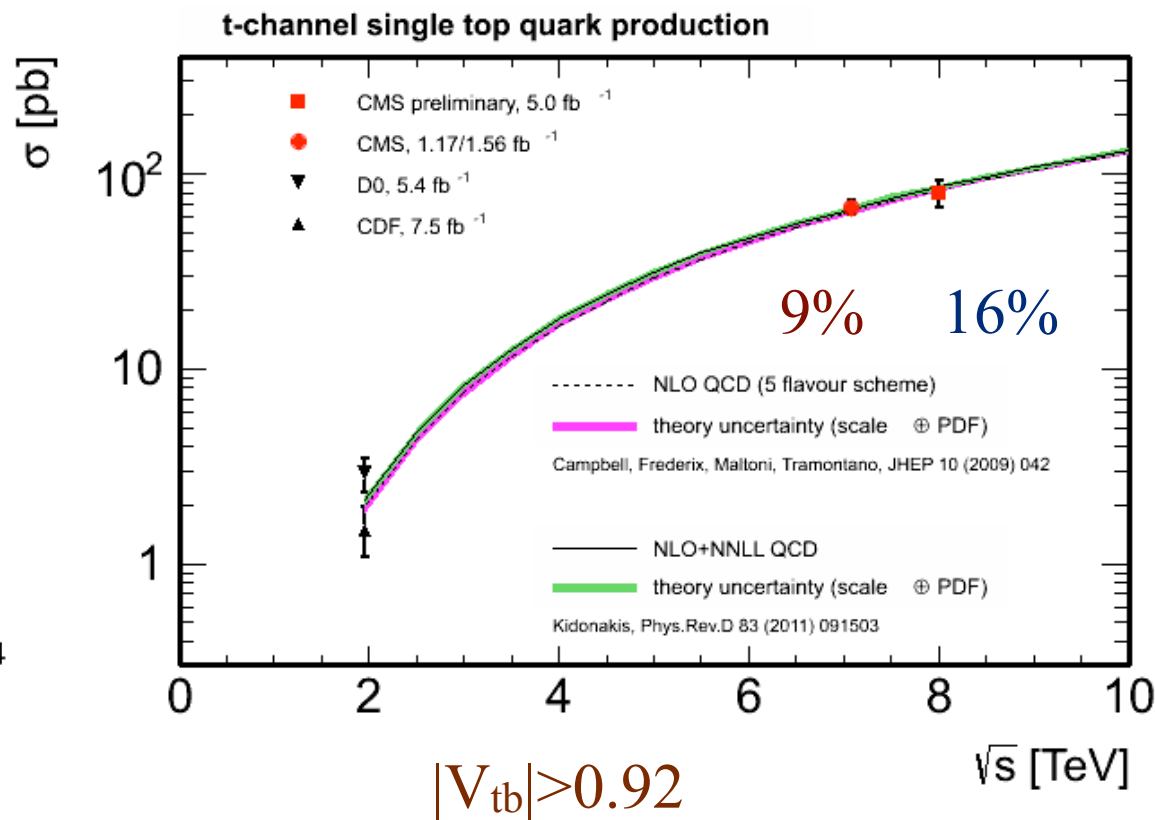
- s-channel: only upper limit so far
ATLAS-CONF-2011-118



t-channel cross section



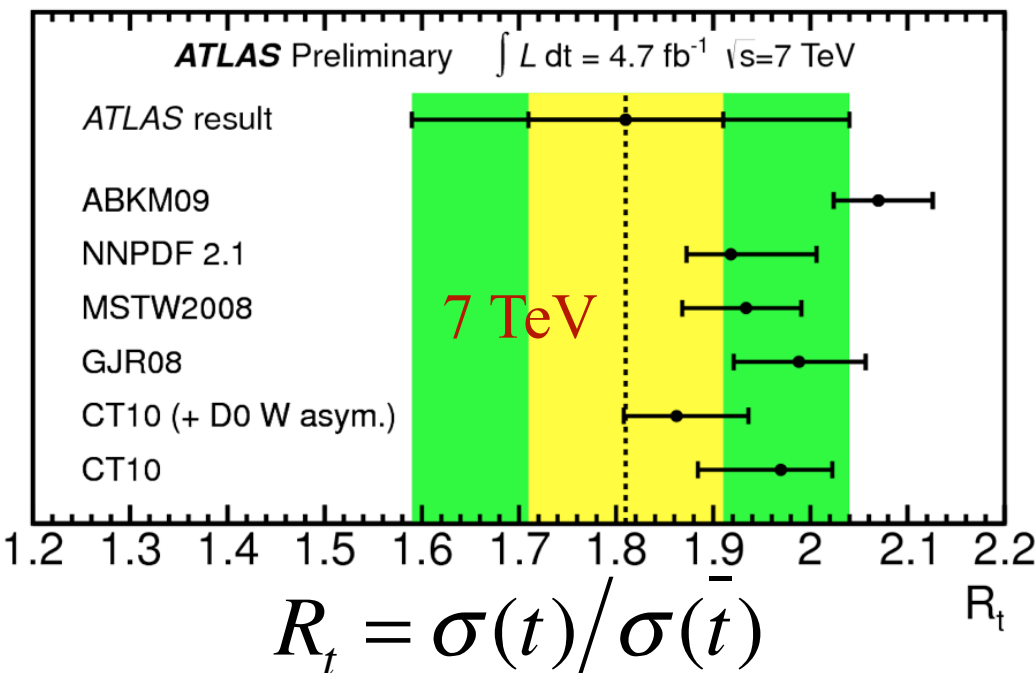
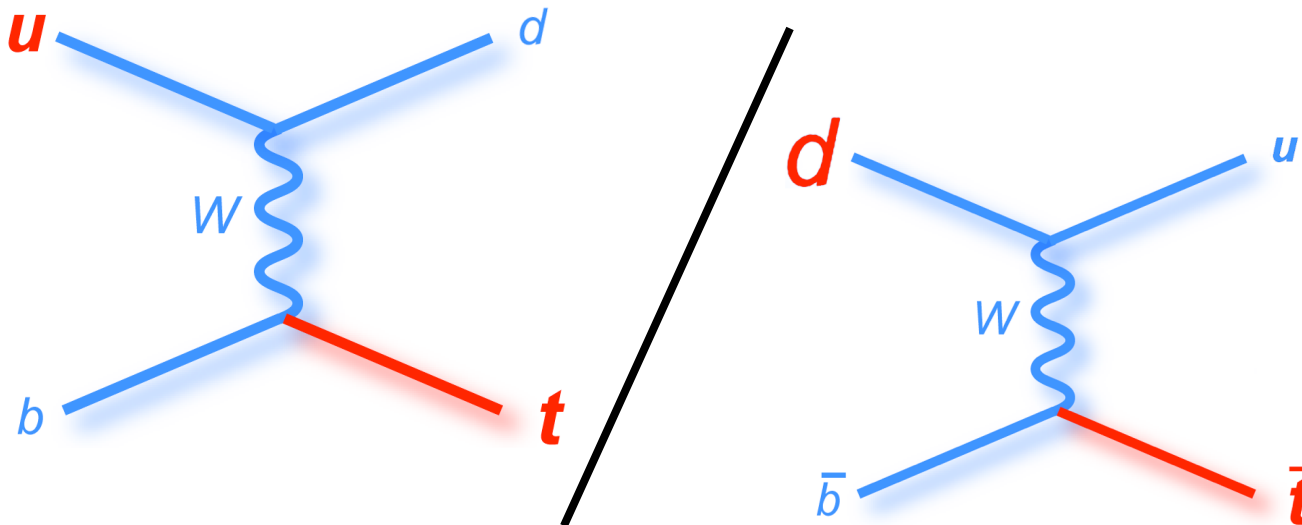
$|V_{tb}| > 0.80$



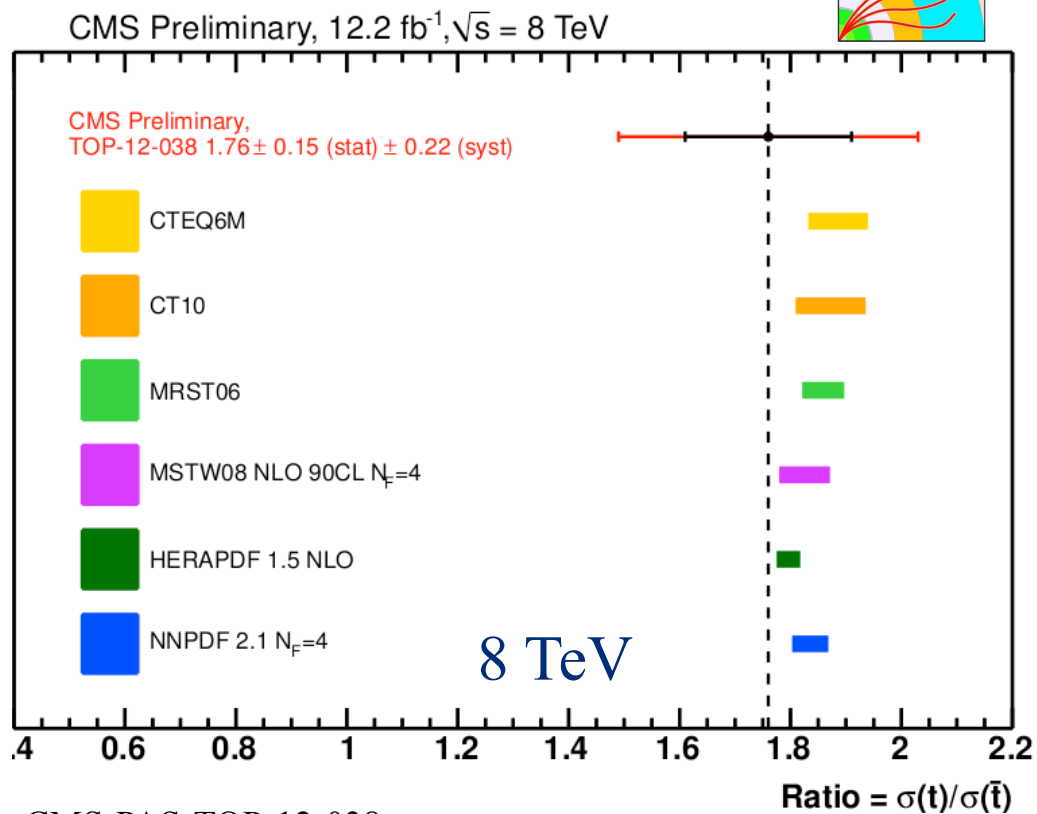
$|V_{tb}| > 0.92$

- Precision single top physics (CMS uncertainty < 10%)
 - Dominated by systematic uncertainties
- Updates with full 7 TeV and 8 TeV datasets in progress

top/anti-top ratio in t-channel

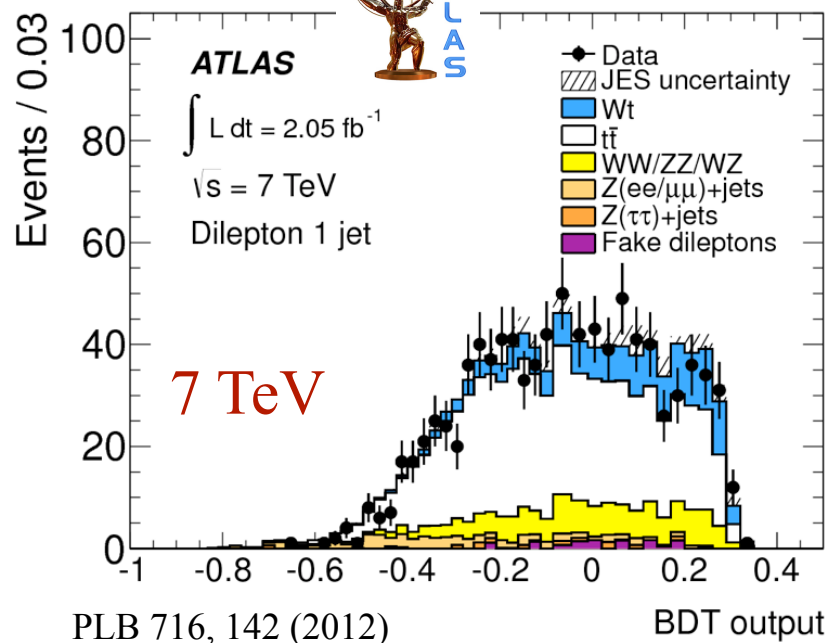
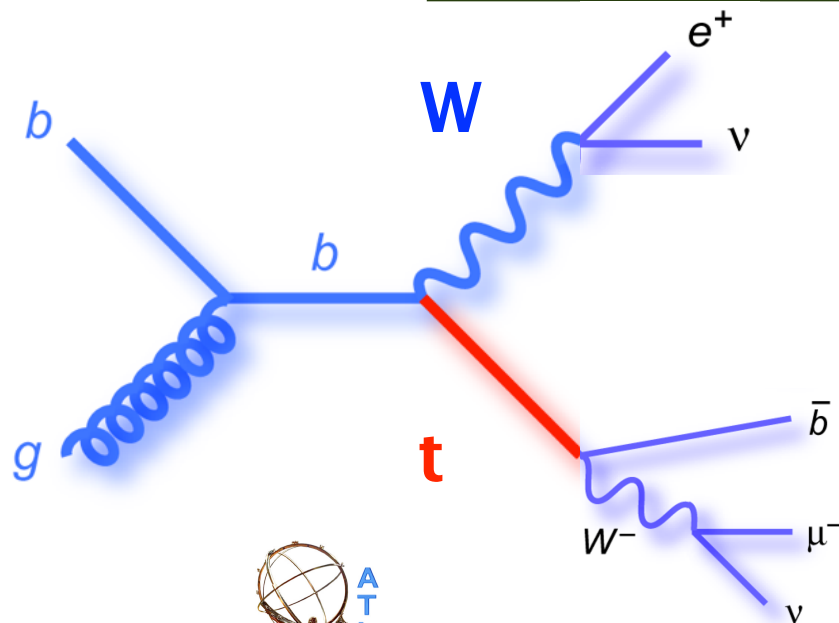


ATLAS-CONF-2012-056

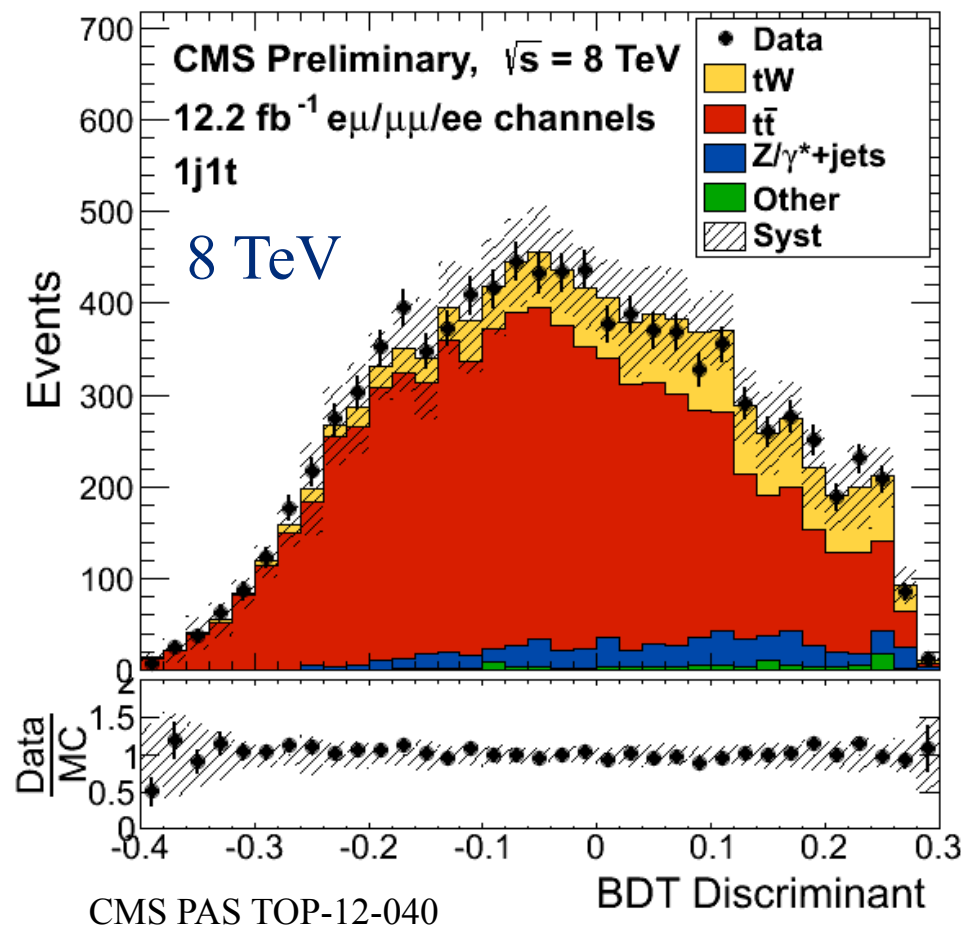


CMS-PAS-TOP-12-038

Wt associated production

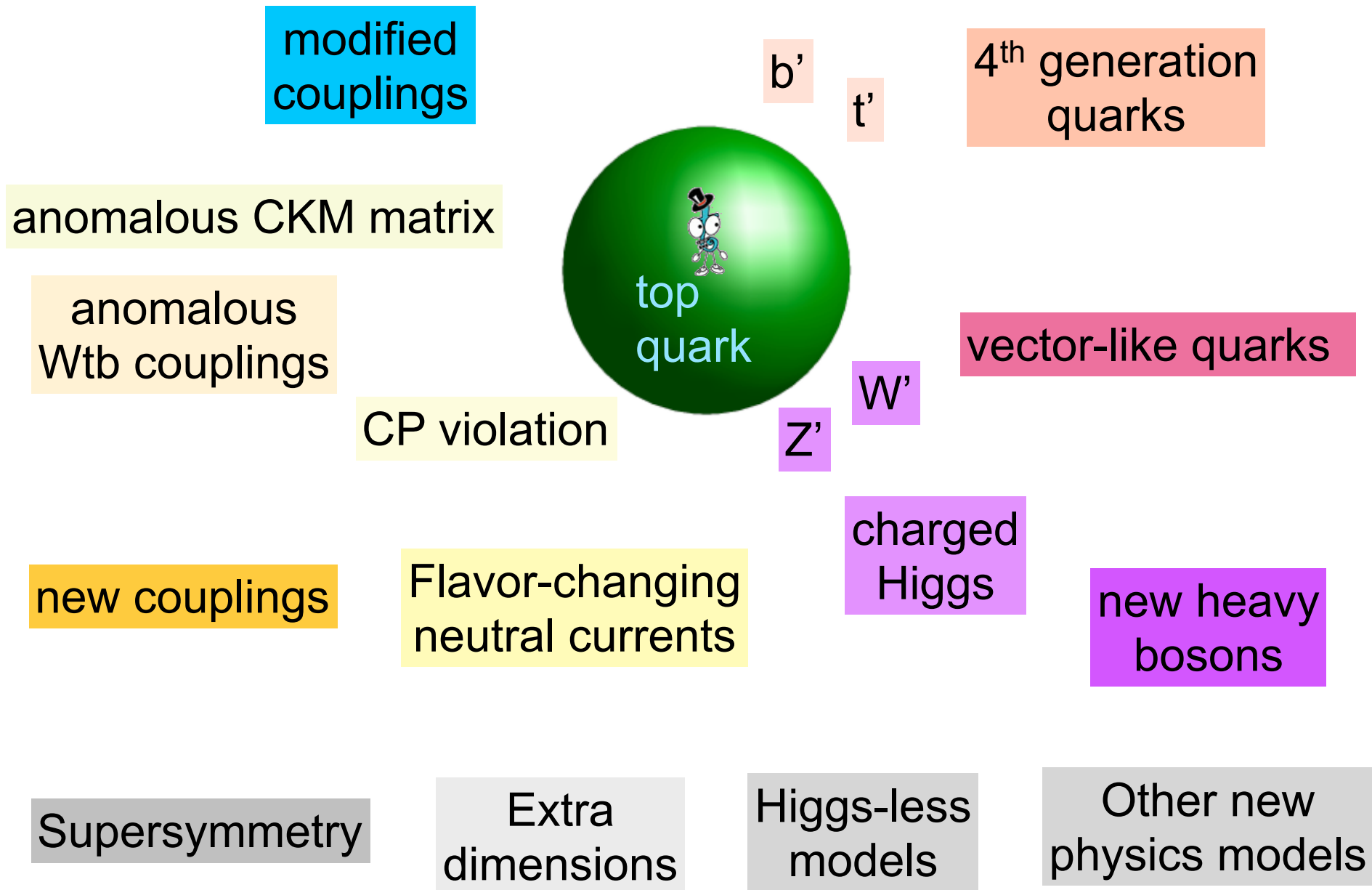


$\sigma = 16.8 \pm 2.9 \text{ (stat)} \pm 4.9 \text{ (syst) pb}$
 3.3 s.d. evidence

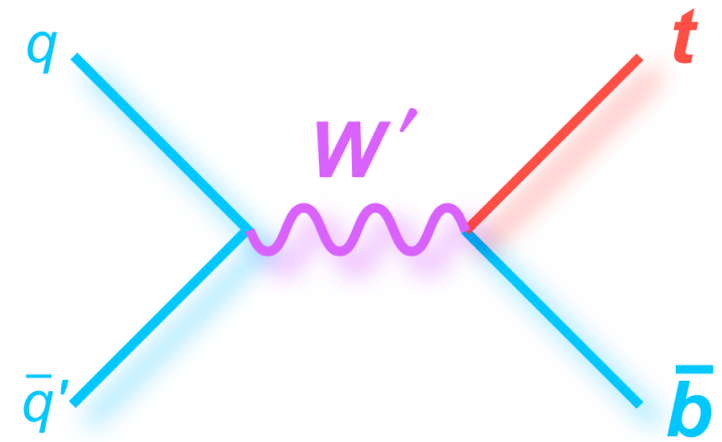
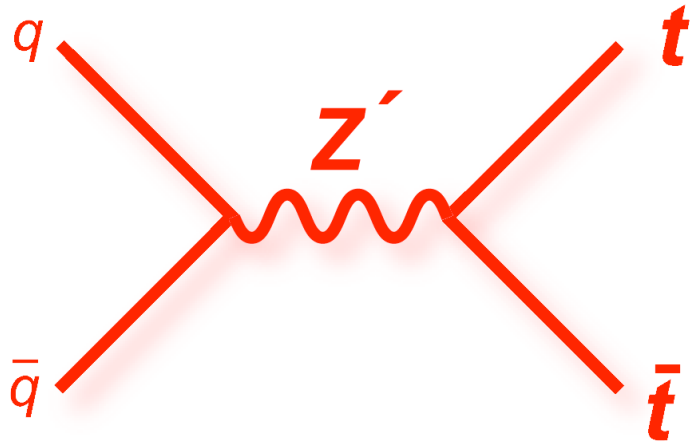


8 TeV:
 $\sigma = 23.4 \pm 5.5 \text{ pb}$
 6.0 s.d. observation
 7 TeV: 4 s.d. evidence

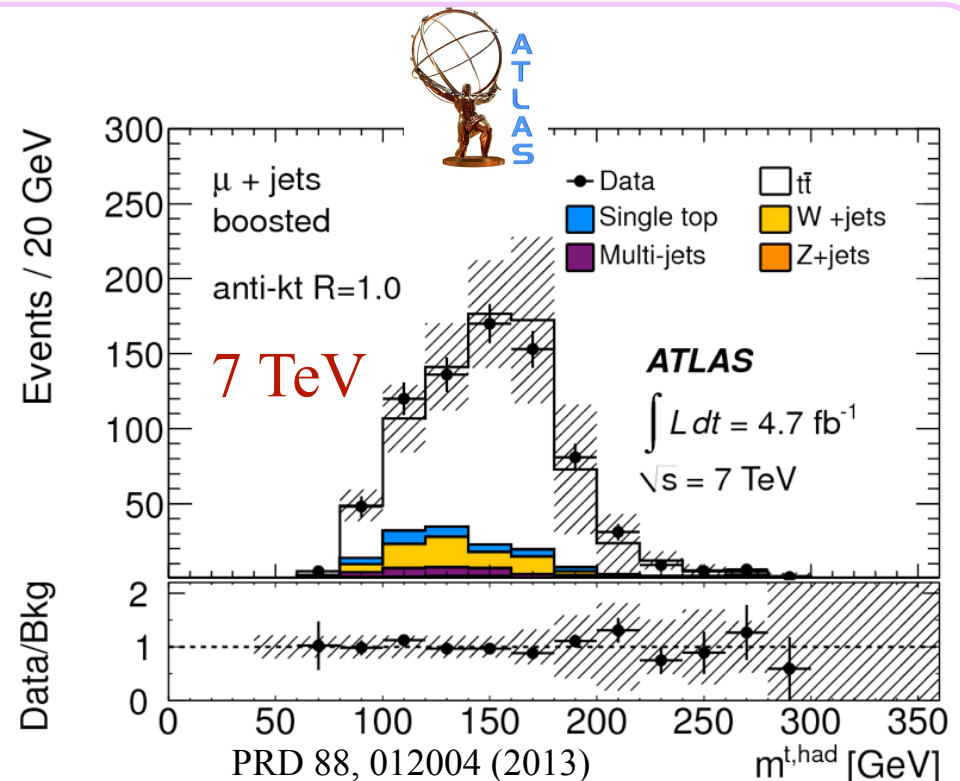
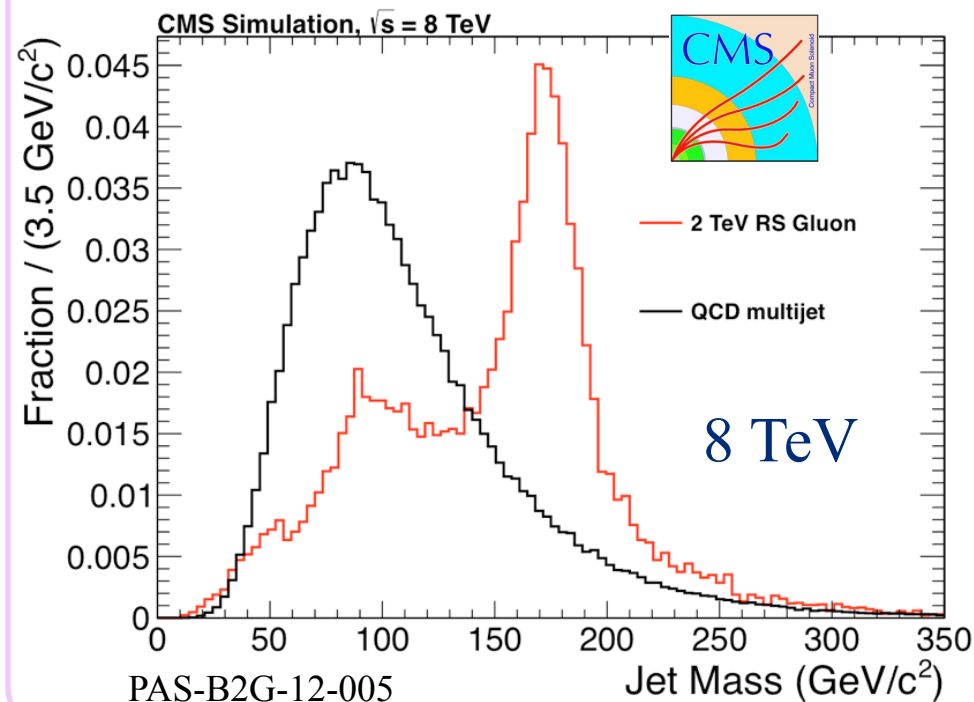
Searches for new physics



Heavy resonance searches

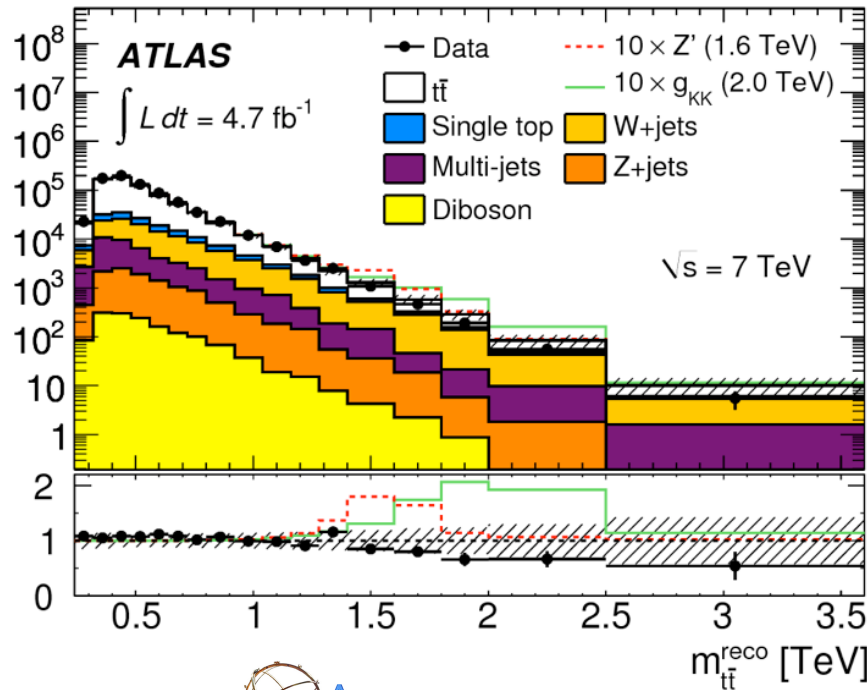


- Searches in lepton+jets and all-jets
- Limits on Z' , W' , KK gluon
- Boosted top techniques



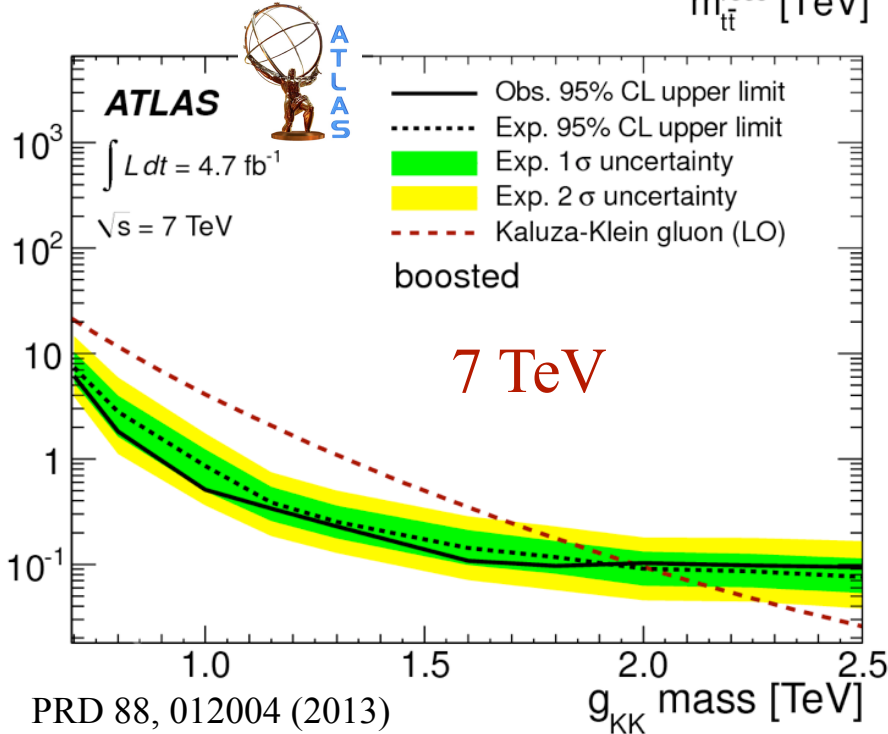
High-mass resonance search (Z', KK gluon)

Events / TeV

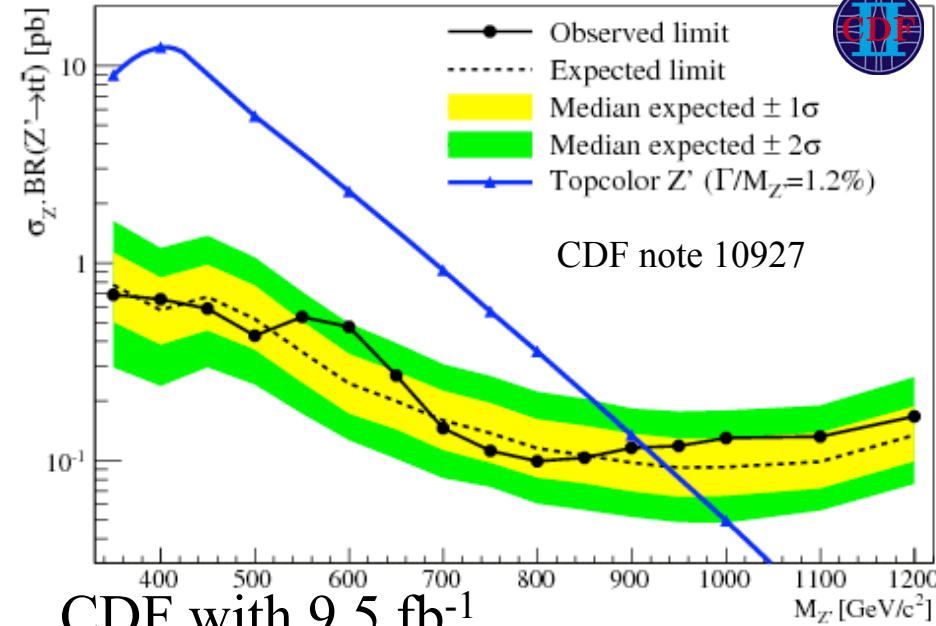


Data/Bkg

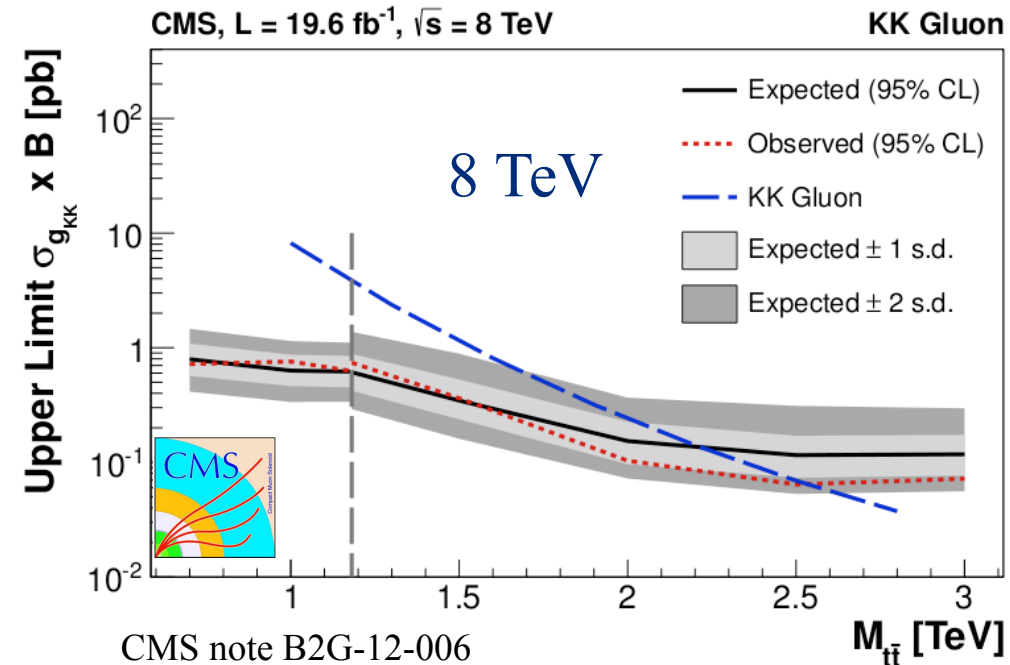
$\sigma_{g_{KK}} \times \text{BR}(g_{KK} \rightarrow t\bar{t}) [\text{pb}]$



PRD 88, 012004 (2013)



CDF with 9.5 fb^{-1}
 low-mass sensitivity

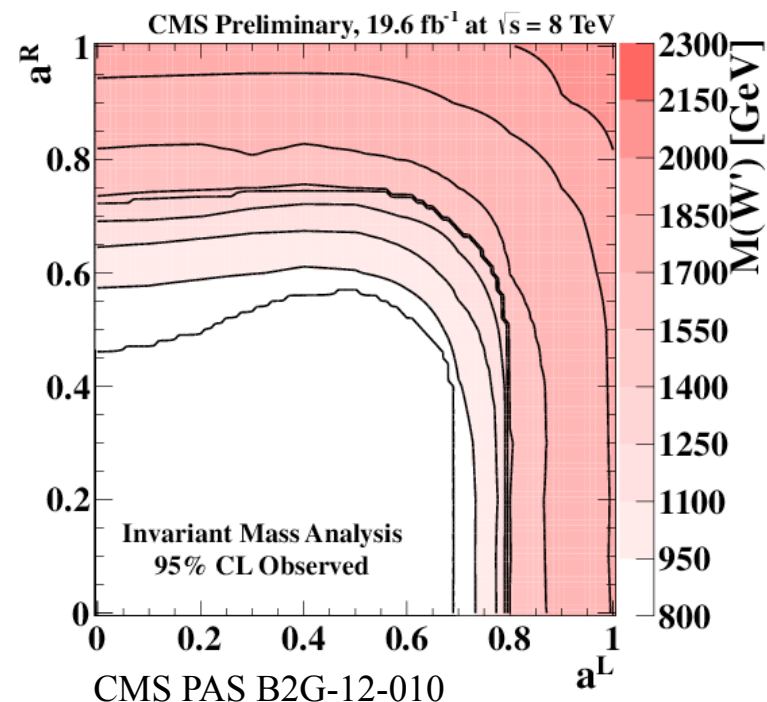
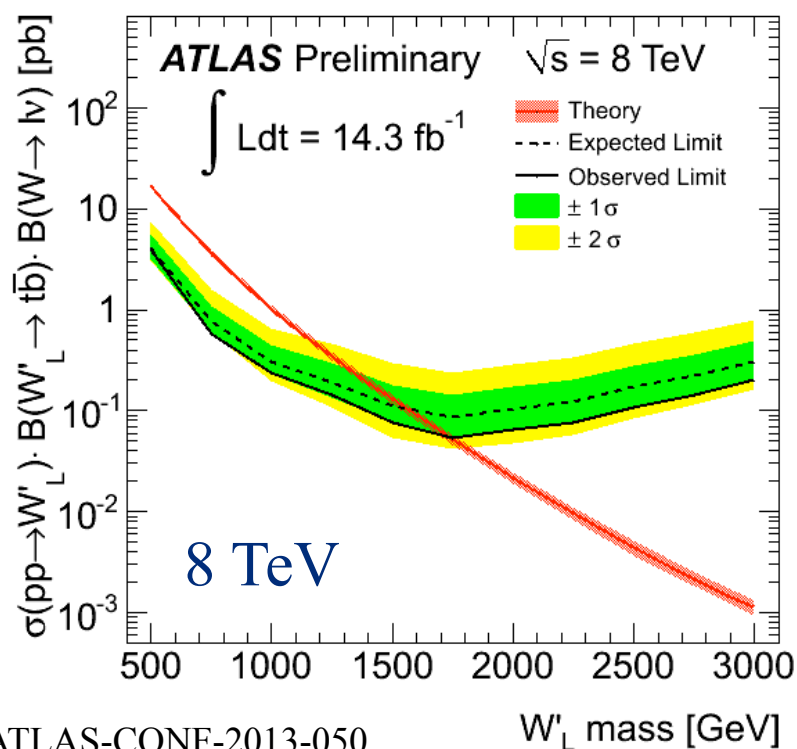
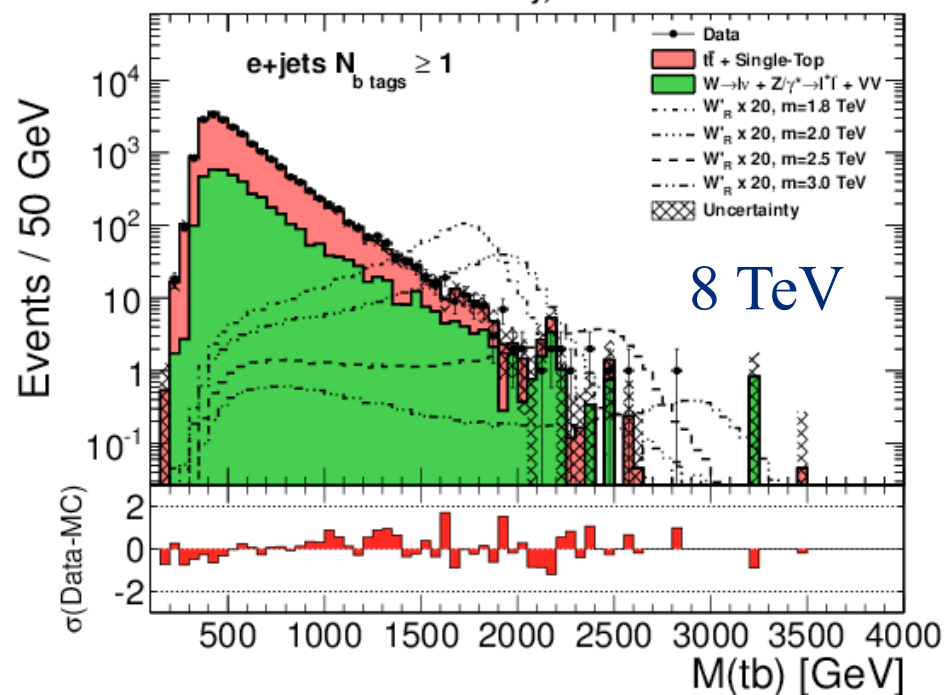


Single top resonance searches



CMS Preliminary, 19.6 fb⁻¹ at $\sqrt{s} = 8$ TeV

- lepton+2b final state
- W' with left-handed and right-handed couplings
- Cuts (CMS), MVA (ATLAS) to optimize sensitivity
- Limit as function of W' couplings

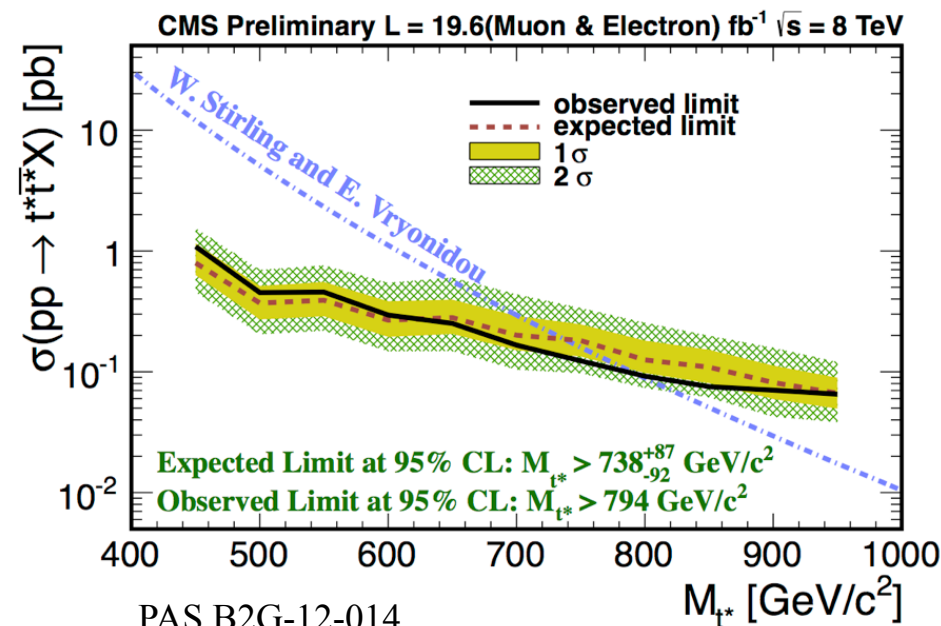
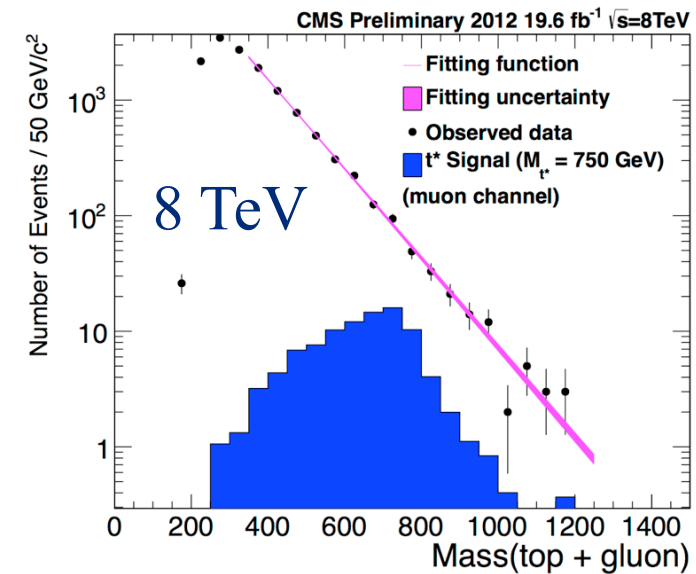
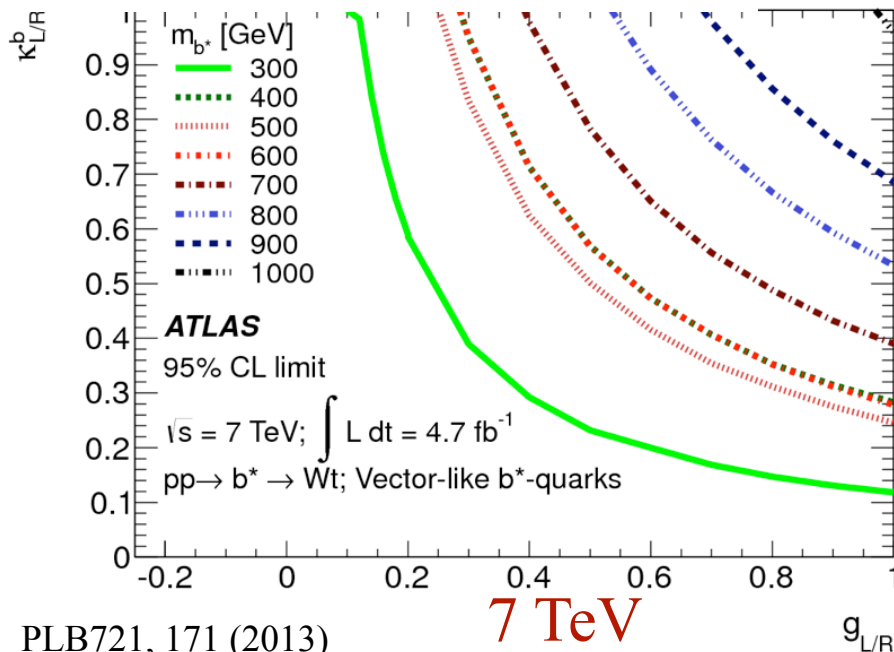
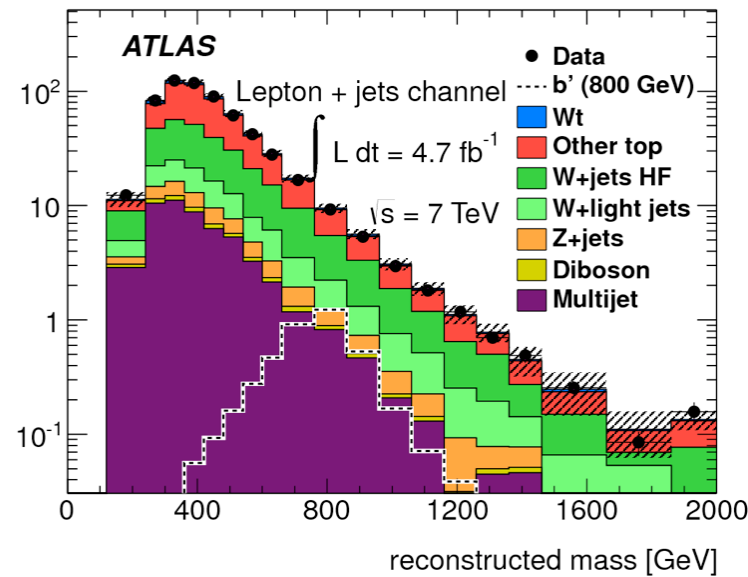


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Excited quark searches

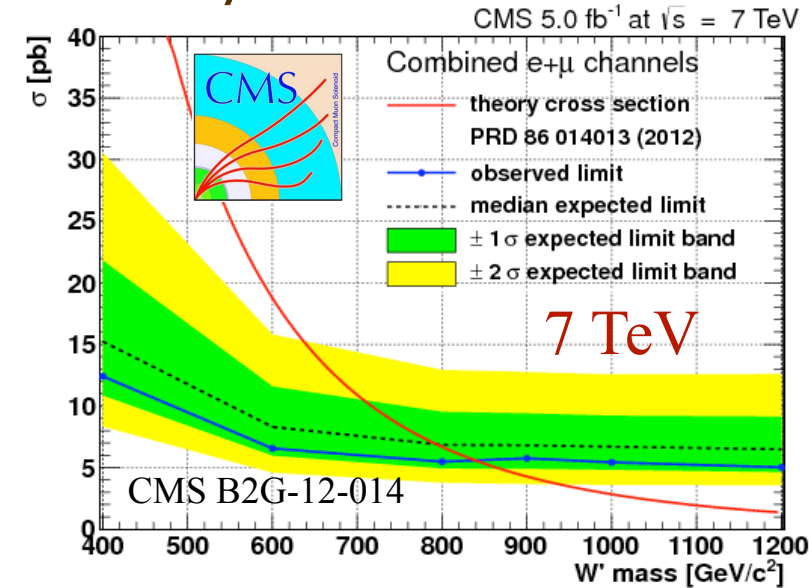
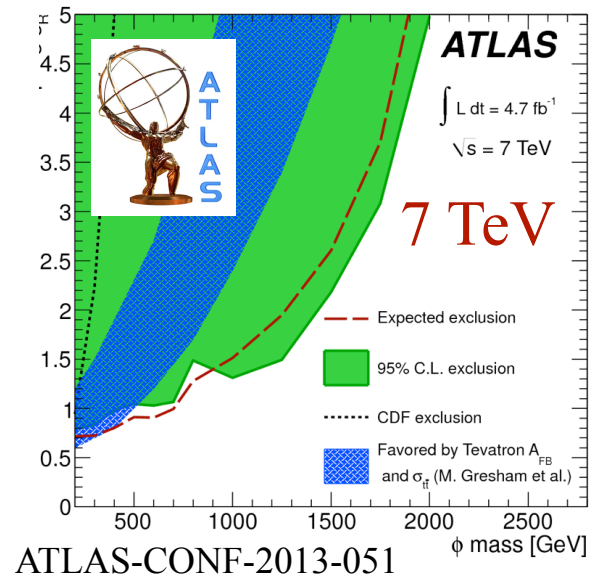
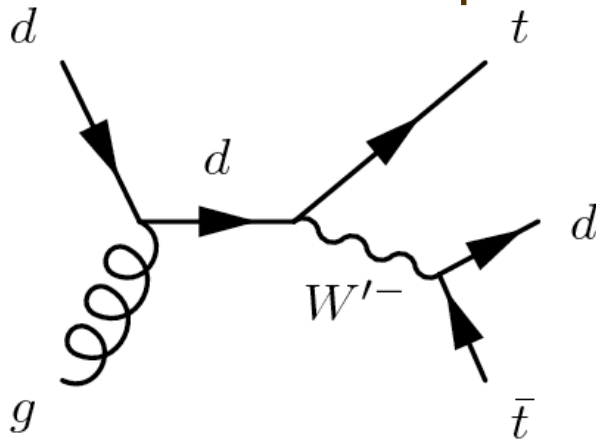
- Single production of b^* with vector-like-quark decay to Wt

- Pair production of t^* with decay to tg

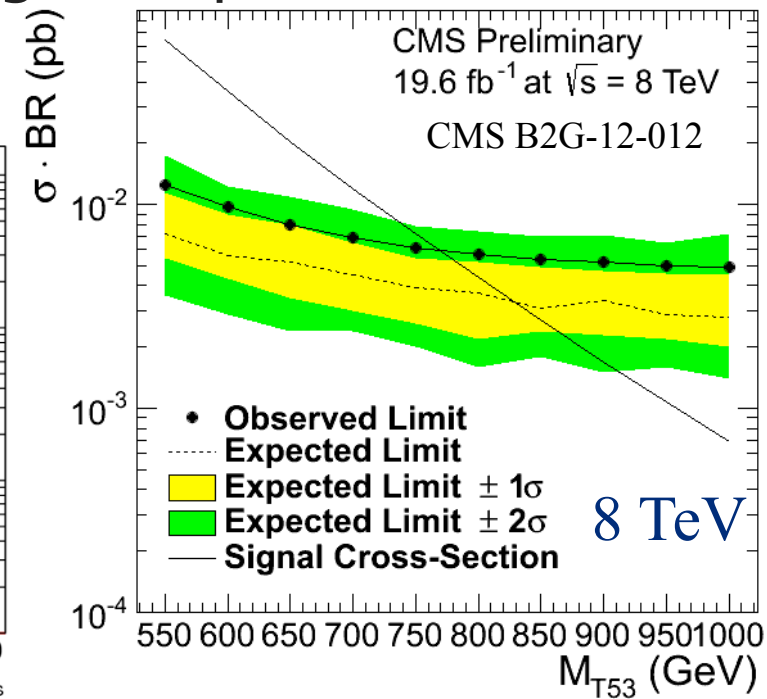
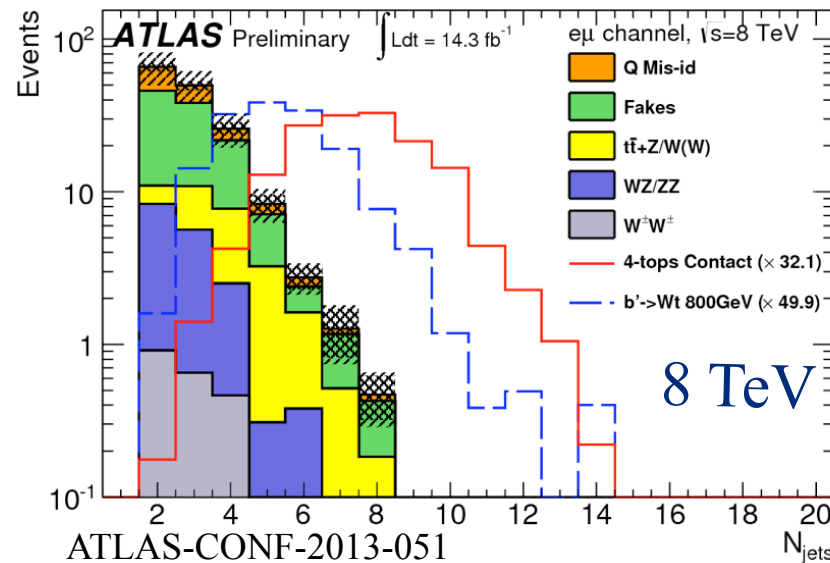
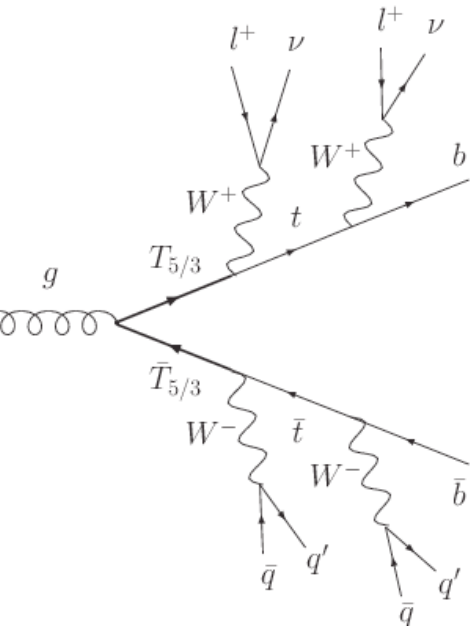


Other searches

- W' or Φ coupling only to top $\rightarrow$ top pair + jet signature
 - Possible explanation for Tevatron A_{FB} anomaly



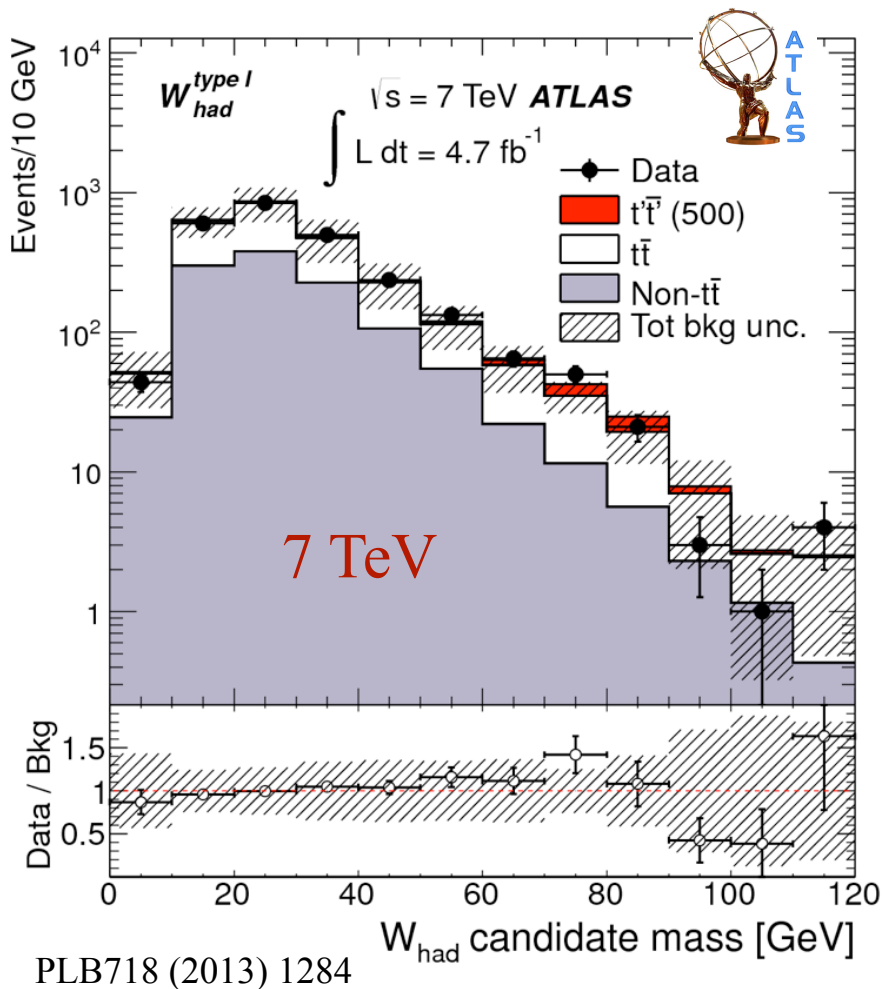
- b' or $5/3$ charge top partner decaying to top and W
 - Same-sign dilepton top signature



Top partner searches

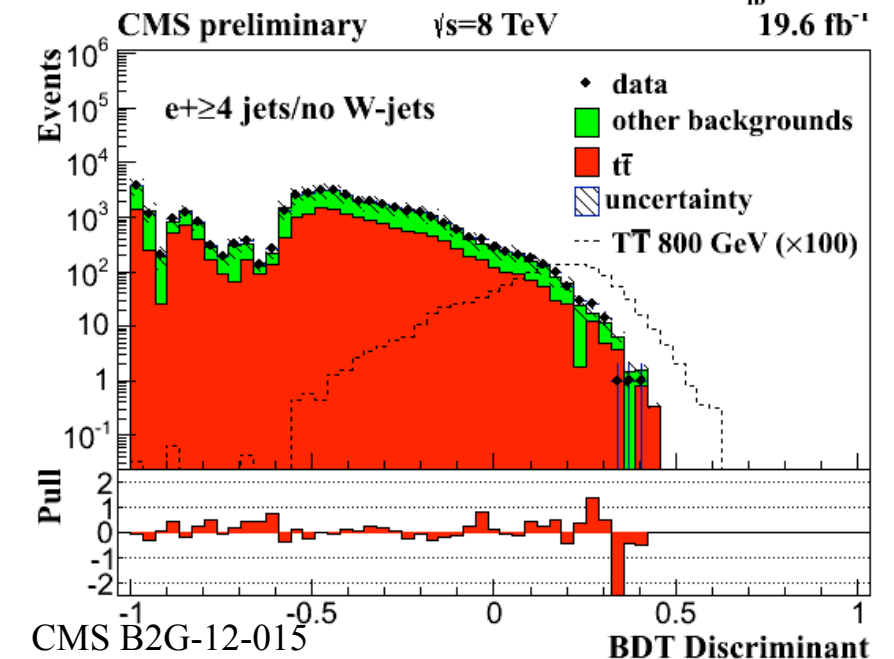
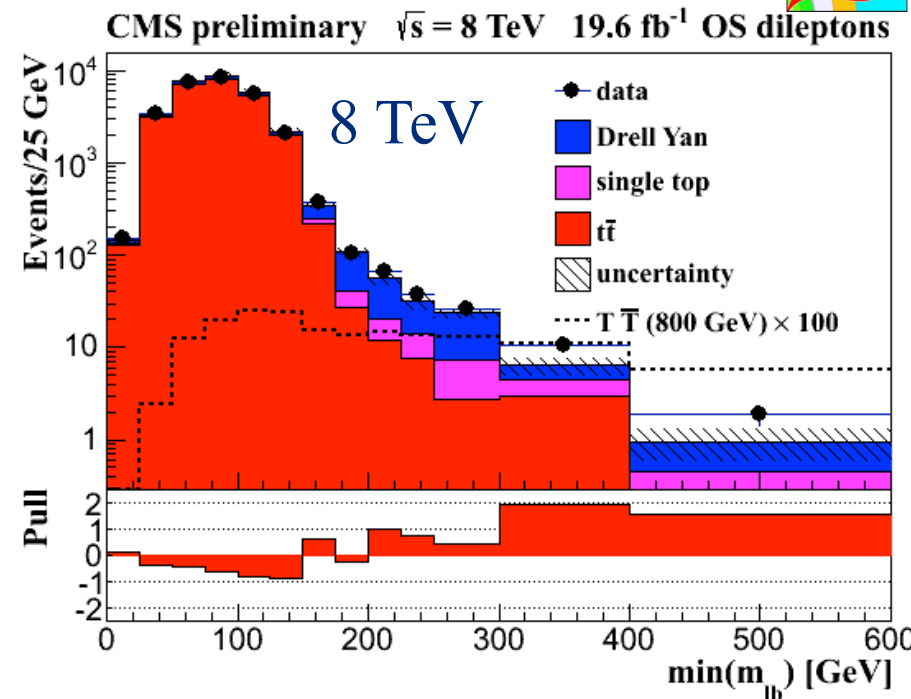


- Pair produced t' decaying to Wb



$m_{t'} > 656 \text{ GeV}$ ($BR(t' \rightarrow Wb) = 100\%$)

- Complete picture of fourth generation and vector-like quark searches in exotics talk on Saturday



$m_{t'} > 700 \text{ GeV}$ ($BR(t' \rightarrow Wb) = 100\%$)

Conclusions/Outlook

- LHC is producing lots of top quark results
 - Precision measurements
 - First observation of SM processes
 - Many searches for new physics connected to top
- Tevatron continues providing valuable physics
 - Cross section combinations
 - Single top
 - Well understood detectors
- Cross section measurements for top pairs and single top are critical for understanding LHC physics, detectors, MC, theory

Top at PIC

- EW session:
 - Precision EW fits
- QCD session:
 - Jet physics at high- $p_T \rightarrow$ boosted top jets
 - Higher-order QCD corrections - $t\bar{t}$ at NNLO
- Higgs session:
 - Higgs production
 - Top Yukawa coupling
- Heavy flavor sessions:
 - Top in loops
- Searches session:
 - Searches in top final states
 - Top coupling to new physics

Thanks!

- ATLAS top physics results:
<http://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults>
- CMS top physics results:
<http://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP>
- Tevatron physics for the informed public
http://www.fnal.gov/pub/today/frontier_science_result
- CDF top physics results:
<http://www-cdf.fnal.gov/physics/new/top/top.html>
- DØ top physics results:
<http://www-d0.fnal.gov/Run2Physics/top/>