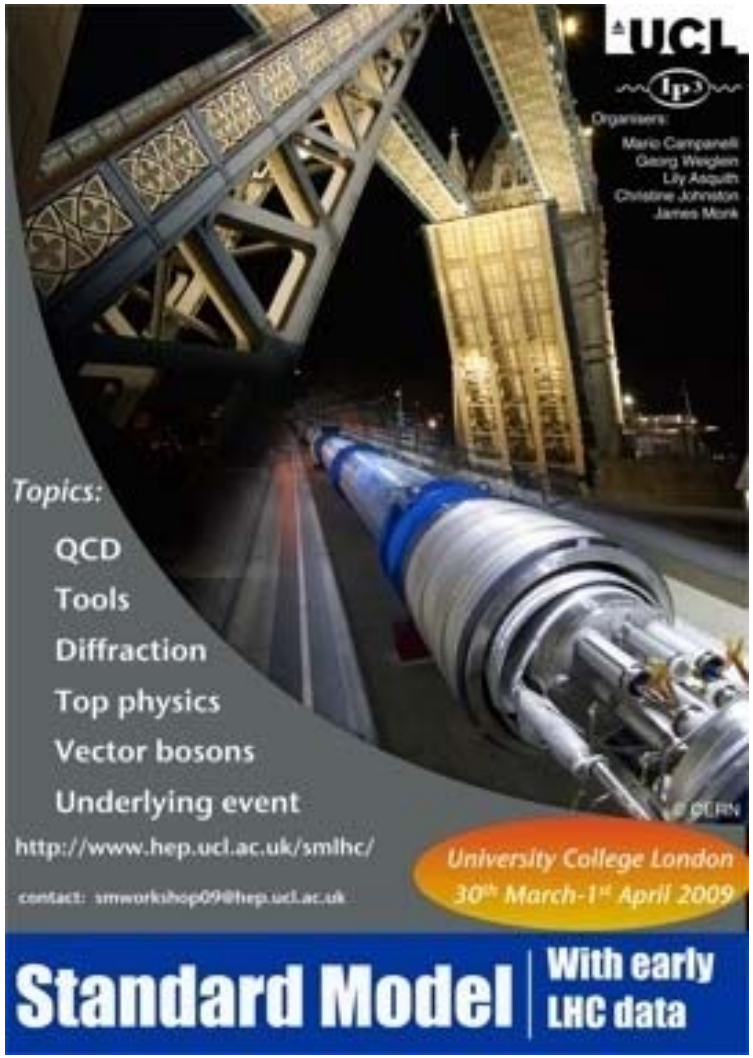
Early Top Quark Cross section measurements at the LHC



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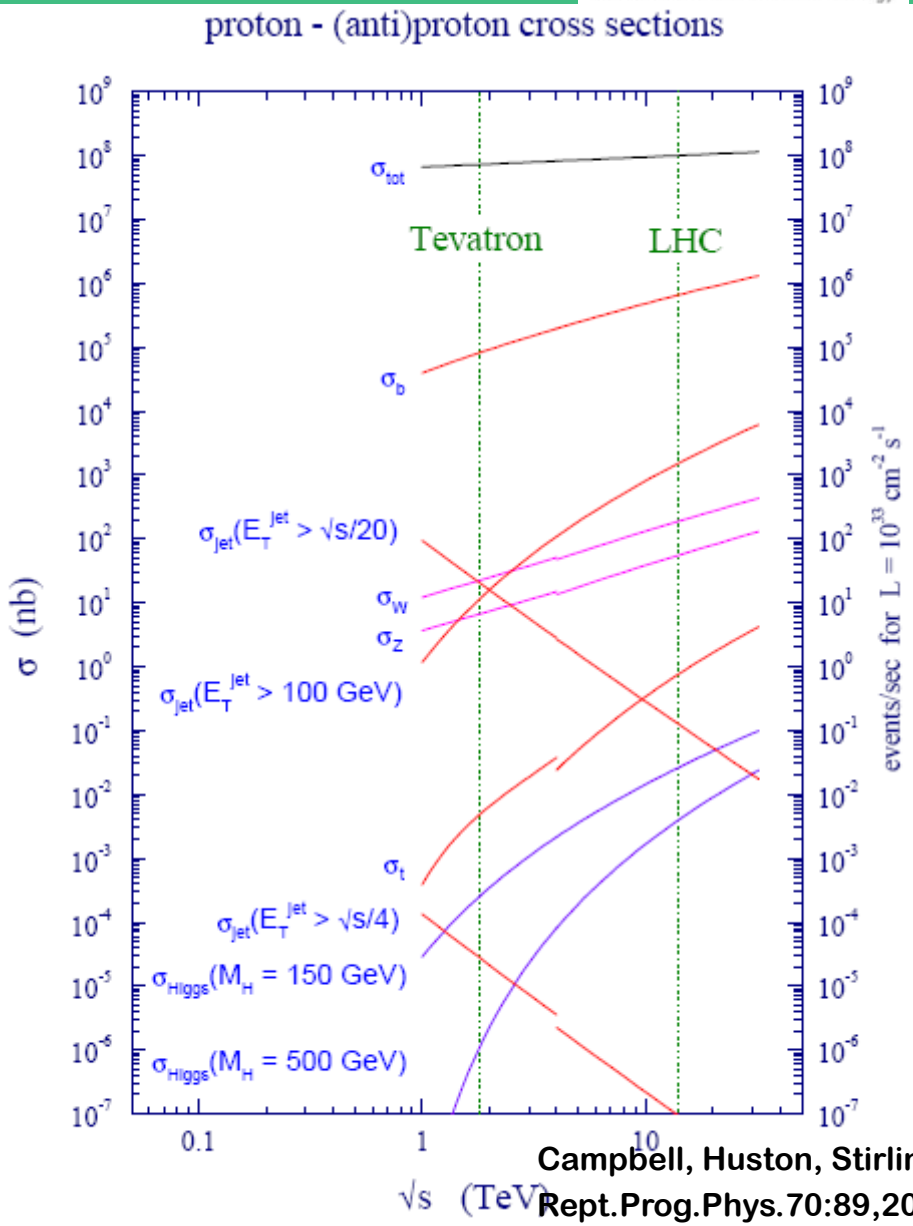
On behalf of CMS and ATLAS

Workshop on SM Physics with early LHC Data, UC London

31 March 2009

Introduction

- LHC opens new regime in rates and phase space for SM physics
  - ❑ QCD
  - ❑ W,Z bosons
  - ❑ Top quarks
- Standard model must be "rediscovered" before discoveries can be claimed
- Top is a background for new physics (e.g. SUSY)
- Top events will be produced so copiously that we can use them to understand the detector (JES, b-eff)



Campbell, Huston, Stirling, Rept.Prog.Phys.70:89,2007

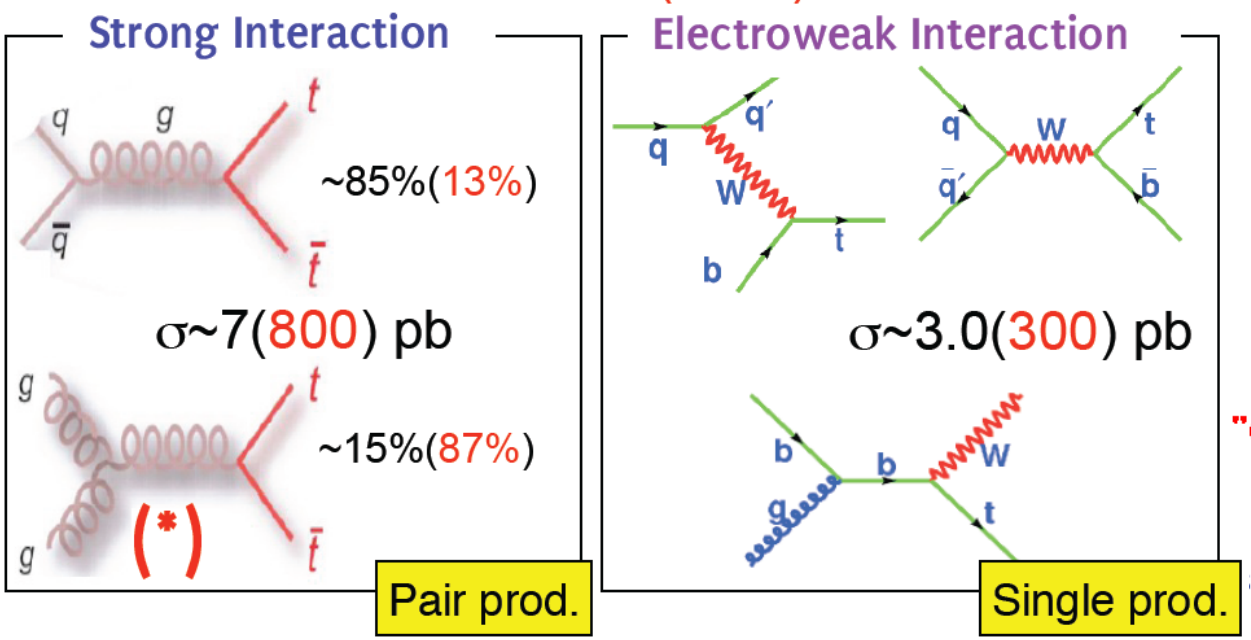
Top Cross Section at Tevatron and LHC

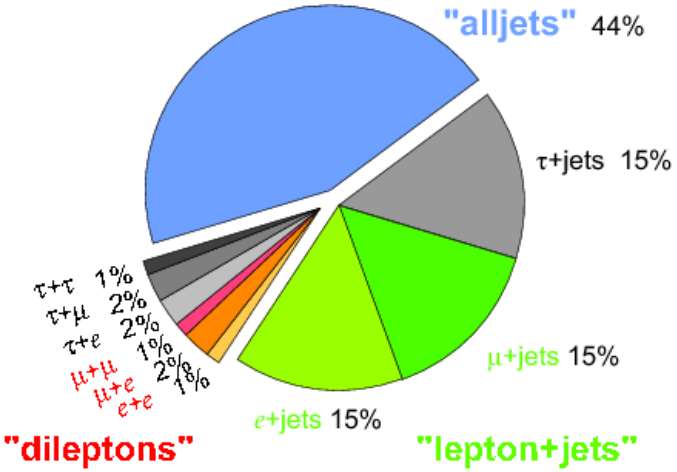
	Cross Section [pb]		
Process	**E(c.m.)=1.96 TeV**	**E(c.m.)=10 TeV**	**E(c.m.)=14 TeV**
ttbar	7.6+/- 0.4 +/- 0.4	414+/-40 +/-20 (x50)	908+/-83+/-30(x120)
Single-top s	0.88 +/- 0.12	5+/- 0.5 (x5)	10.7 +/- 1.0 (x10)
Single-top t	1.98 +/- 0.25	131+/- 7 (x60)	247 +/- 13 (x120)
Single-top tW	0.094 +/- 0.014	29 +/- 3 (x290)	56 +/- 6 (x560)

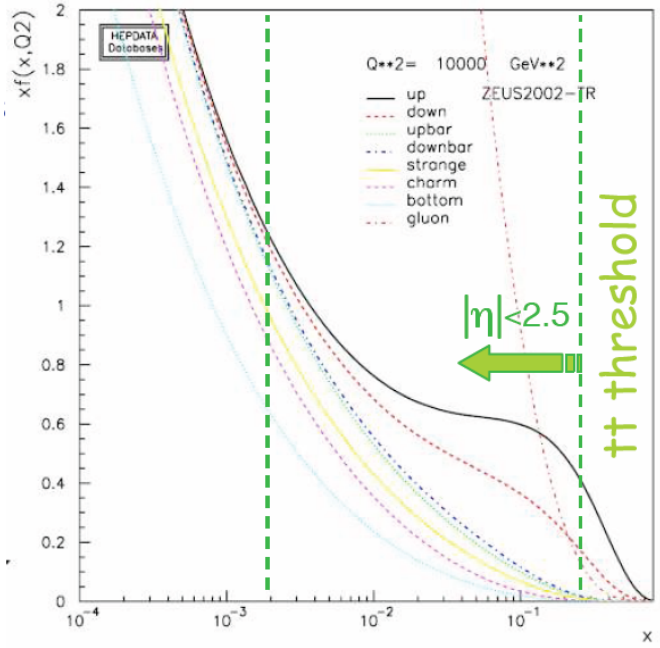
- **Top pair production:**
  - M. Cacciari et al.:
    - JHEP 0809 (2008) 127 [arXiv:0804.2800]
  - N. Kidonakis, R. Vogt:
    - Phys.Rev. D78 (2008) 074005 [arXiv:0805.3844]
  - S. Moch, P. Uwer:
    - Nucl.Phys. (Proc.Suppl.)183 (2008) 75-80 [arXiv:0807.2794]
    - Phys.Rev. D78 (2008) 034003 [arXiv:0804.1476]
  - P. Nadolski et al. (CTEQ):
    - Phys. Rev. D78 (2008) 013004 [arXiv:0802.0007]
- **Single top:**
  - B.W. Harris et al.
    - Phys.Rev. D66 (2002) 054024 [hep-ph/0207055]
  - T. Tait (tW)
    - Phys. Rev. D61 (2000) 034001 [hep-ph/9909352]
  - Z. Sullivan
    - Phys. Rev. D70 (2004) 114012
  - N. Kidonakis,
    - Phys. Rev. D74 (2006) 114012
  - J. Campbell et al.,
    - [arXiv:0903.0005]

Top Quark Physics at the LHC

Tevatron (LHC)



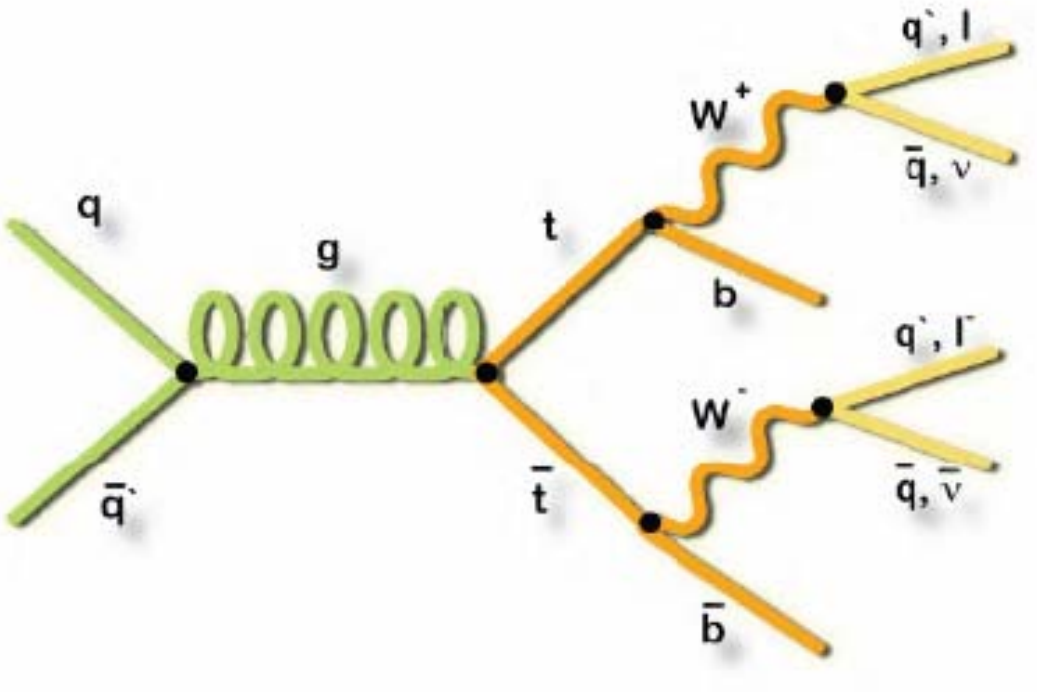




- **LHC will be "top factory"**
  - **9M ttbar events per 10fb-1 (1 year @ 14 TeV)**
  - **80K ttbar events in 2009-2010 run (200 pb-1 @ 10 TeV)**

Top Quark Physics (cont.)

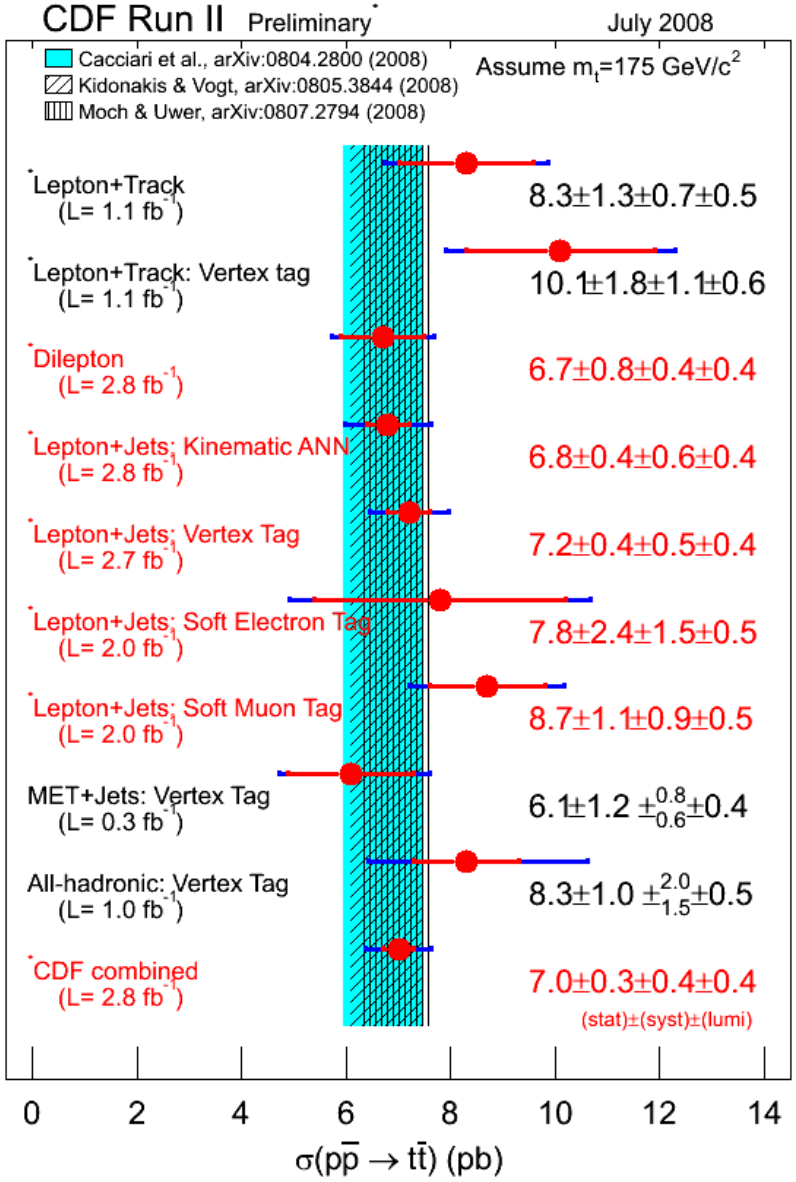
- **LHC Top Physics Program**
  - "Rediscovery" and cross section at LHC energies
  - Single top production
  - Differential cross sections, validate MC (background for searches)
  - Properites (mass, spin, charge..)
  - Ttbar resonances (Z' etc.)
  - New physics in top decays

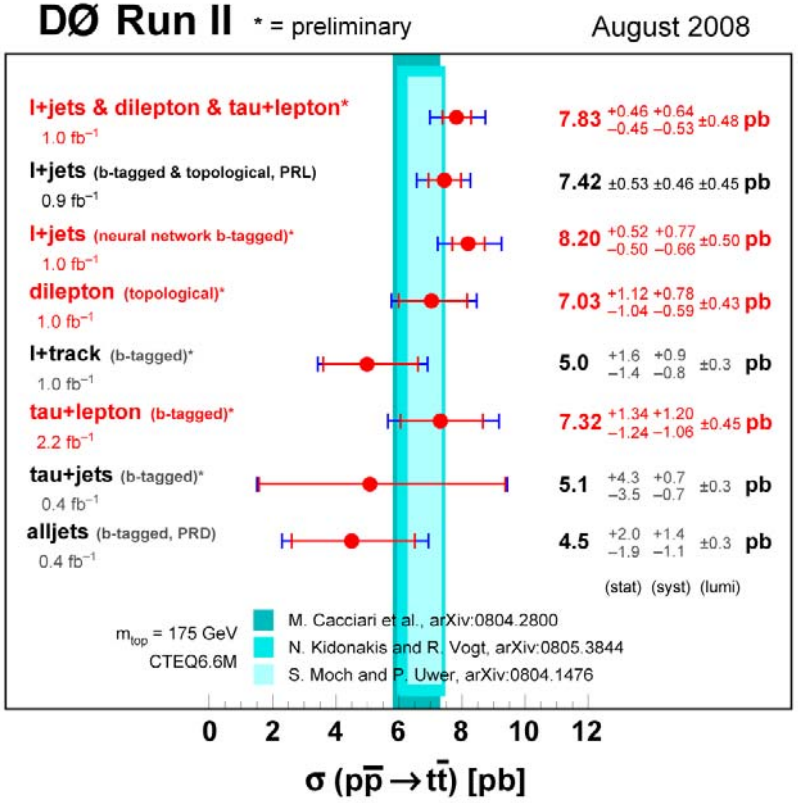


- **In the beginning, focus on channels with leptonic W decay(s)**
  - Dilepton channel
    - Two leptons, >=2 jets, MET
  - Lepton+jets channel
    - One lepton, >=4 jets, MET
  - "Easier" w.r.t. trigger, QCD background

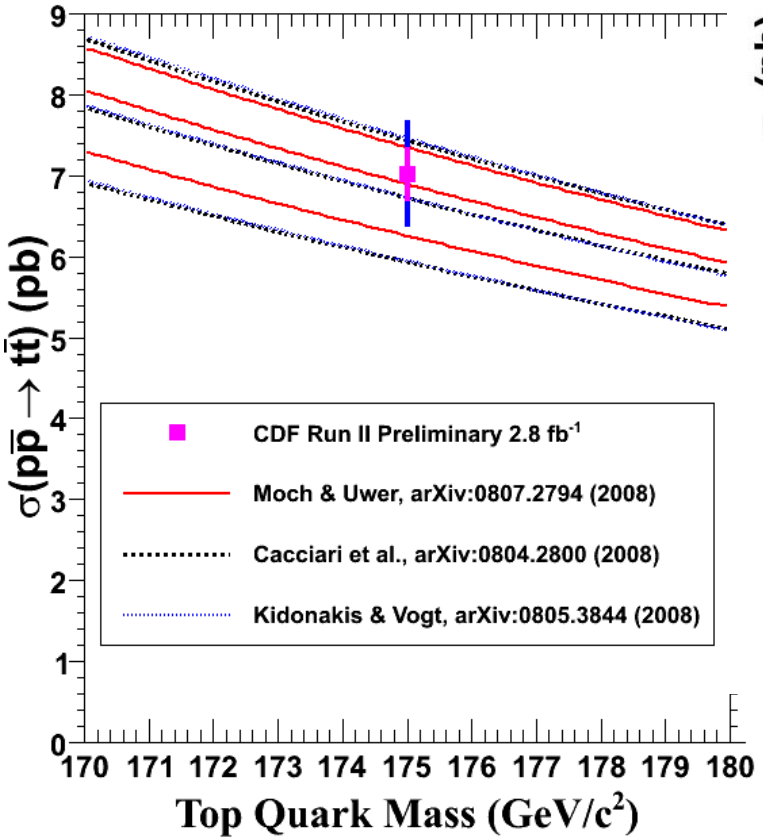
- **Ttbar events as commissioning tool**
  - Understanding of most physics objects required (leptons, jets, MET, b-tagging)
  - Use to constrain JES and b-tag efficiency

Tevatron Measurements, Summer 2008

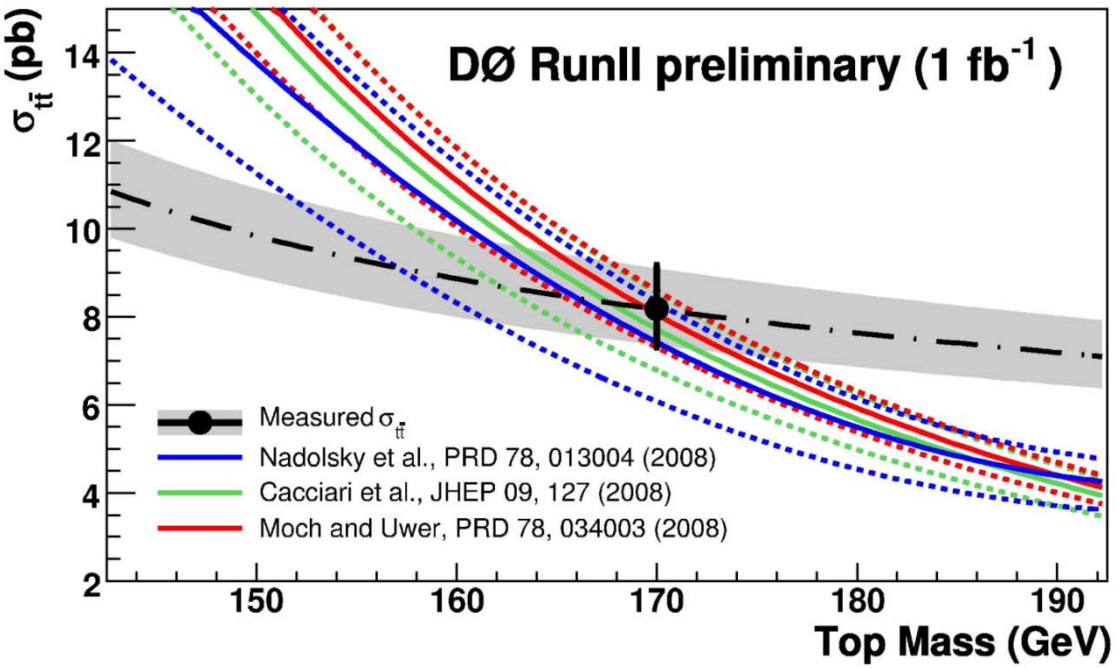




CDF and D0 Combinations



CDF Note 9448



D0 Note 5907

- Good agreement CDF vs D0
- Good agreement with theory

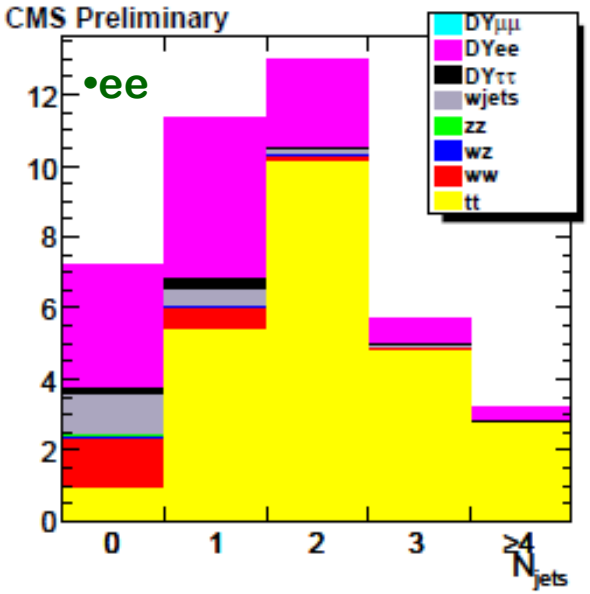
Dilepton channel (CMS)

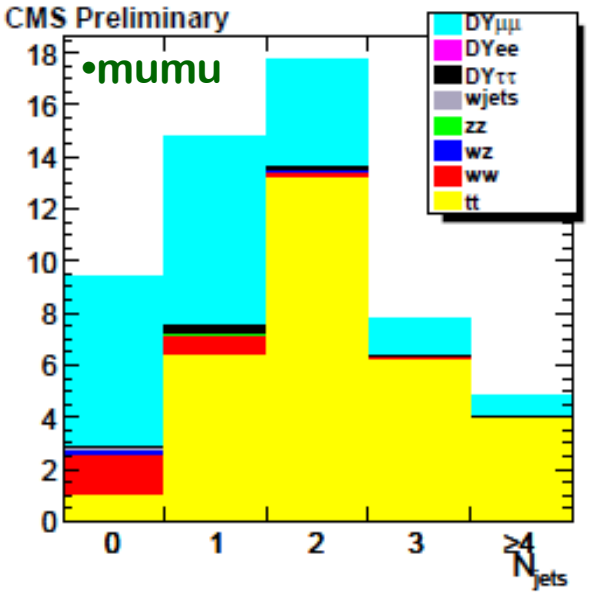
- 2 isolated leptons (ee,mumu, emu), Pt>20 GeV
  - ❑ DY veto
- MET>20/30 GeV
- >=2 jets, Et> 30 GeV
- No b-tagging

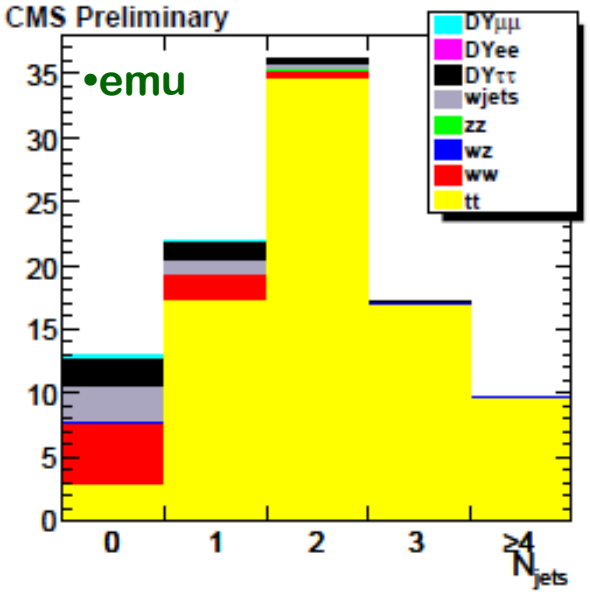
- For 10pb-1 expect 10% stat error combined

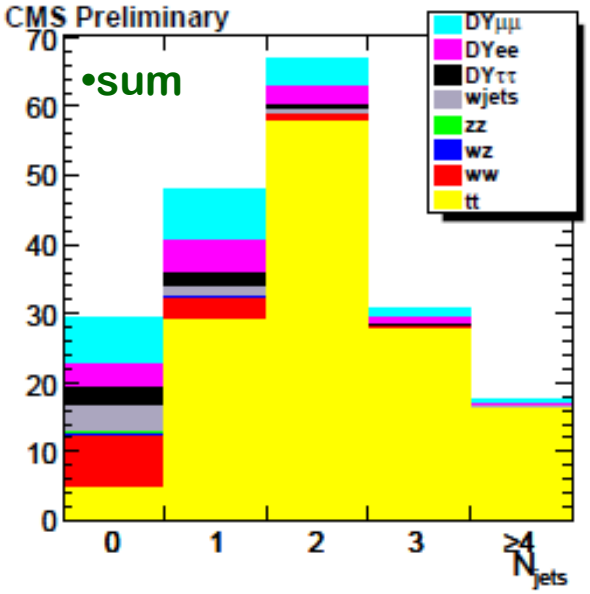
- If MET cannot be controlled, do emu only (stat err. 13%)

CMS PAS TOP-08-001





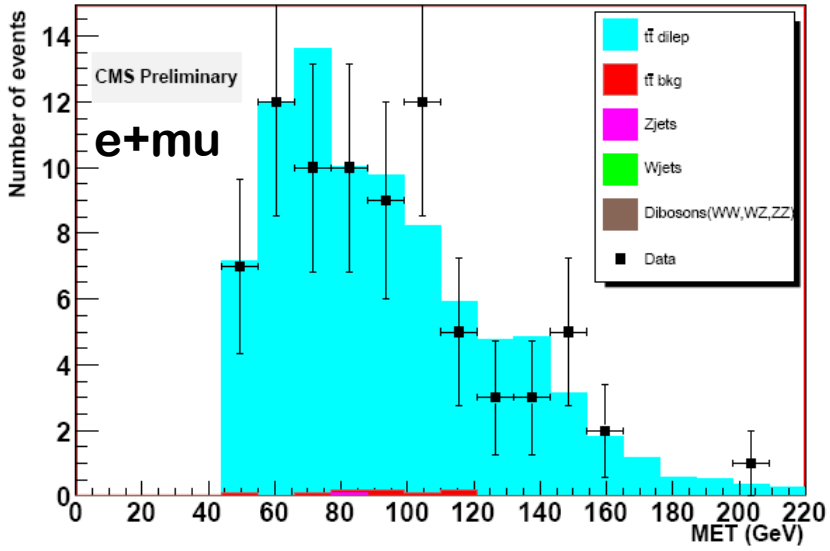


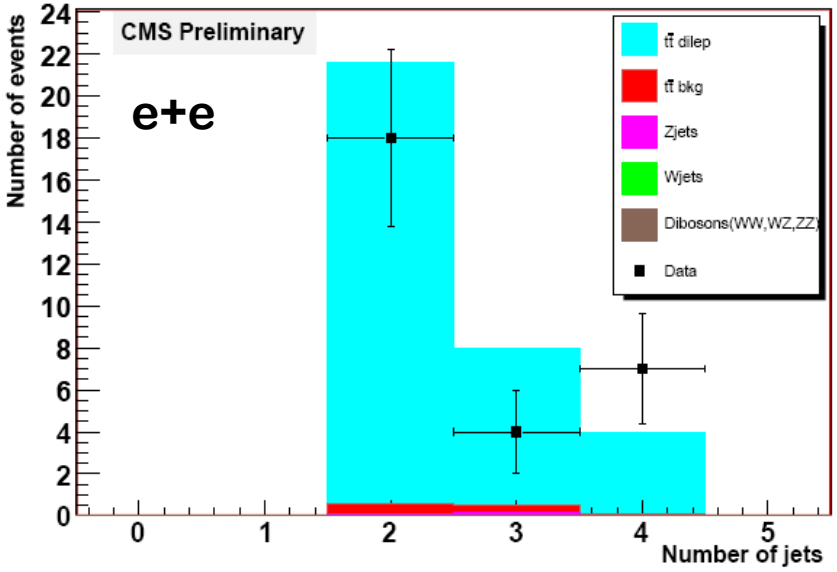


Dilepton channel (CMS cont.)

- Analysis with b-tagging
  - Misalignment included
- Event selection
  - 2 isol. Leptons (e or mu), Pt>20 GeV, DY veto
  - MET>50 GeV
  - 2 b-jets, Pt>30 GeV
- Almost bkd. free due to tight cuts
  - 160 signal events in 100 pb-1
  - Very small background
- Cross section from event counting, ~8% stat error

CMS PAS TOP-08-002





Dilepton channel (ATLAS)

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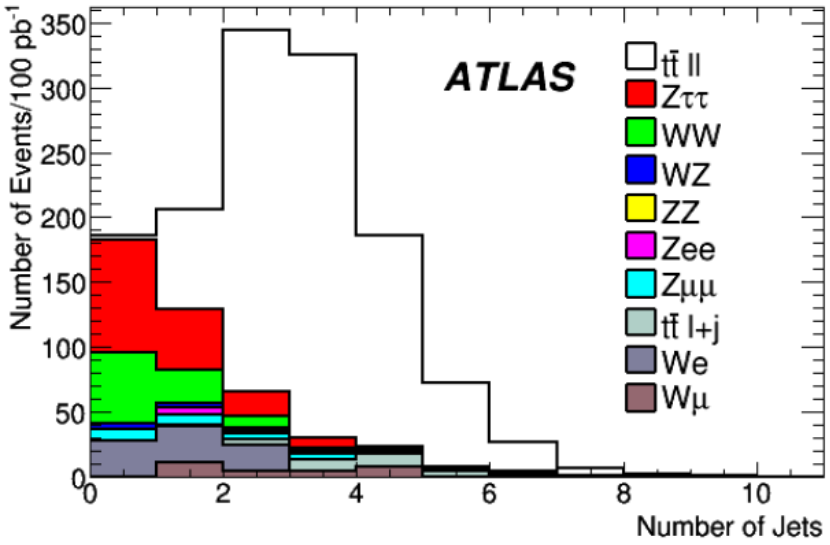
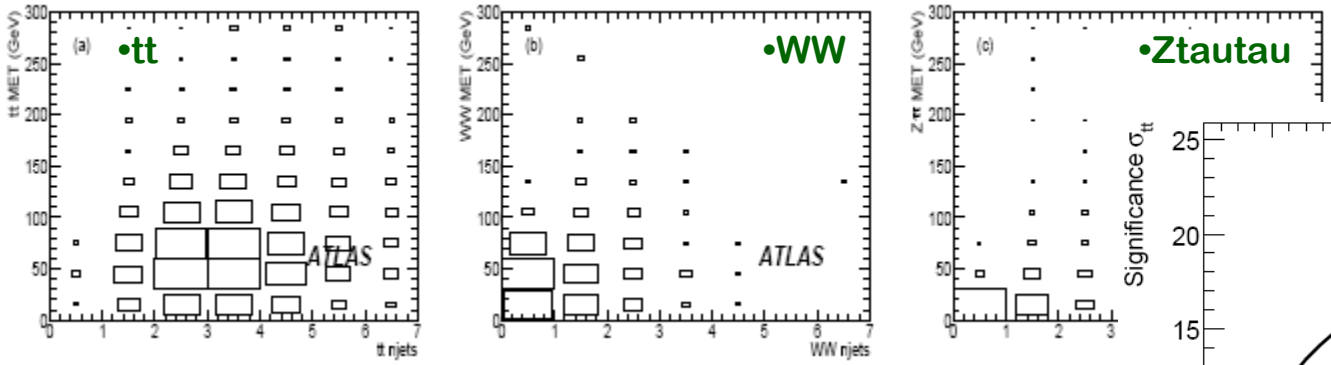
- **Event selection:**
  - 2 leptons, pt> 20 GeV
  - Jets with Et> 20 GeV
  - MET>30 GeV, DY veto

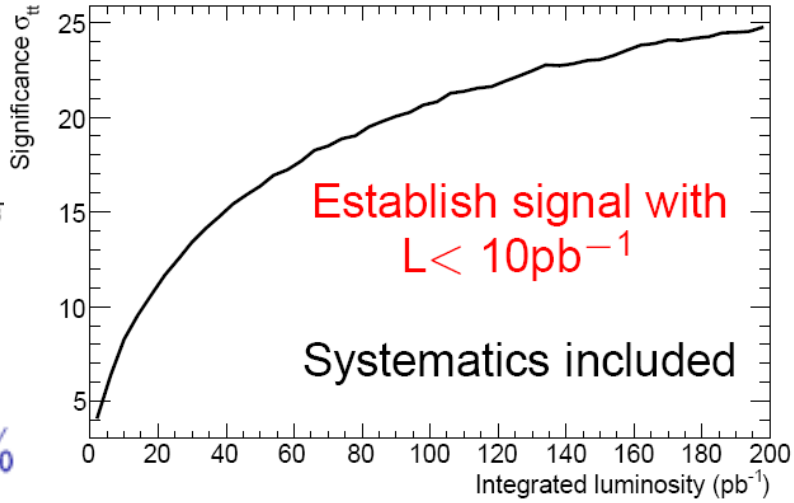


- **Cross section measurement**
  - Fit MET vs Njets templates for signal and background



  - Expected precision for 100 pb-1 (incl. syst.):

$$\Delta\sigma/\sigma = (4(\text{stat}) \pm 4(\text{sys}) \pm 2(\text{pdf}) \pm 5(\text{lumi}))\%$$

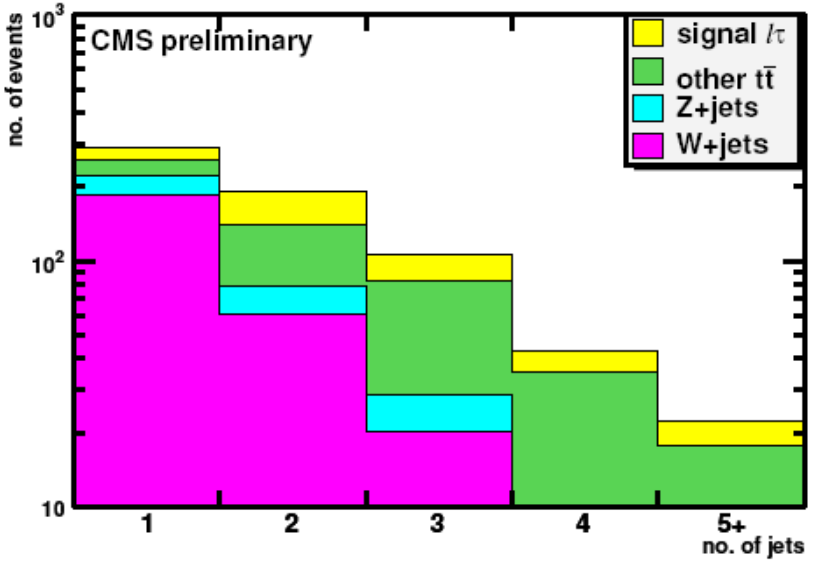


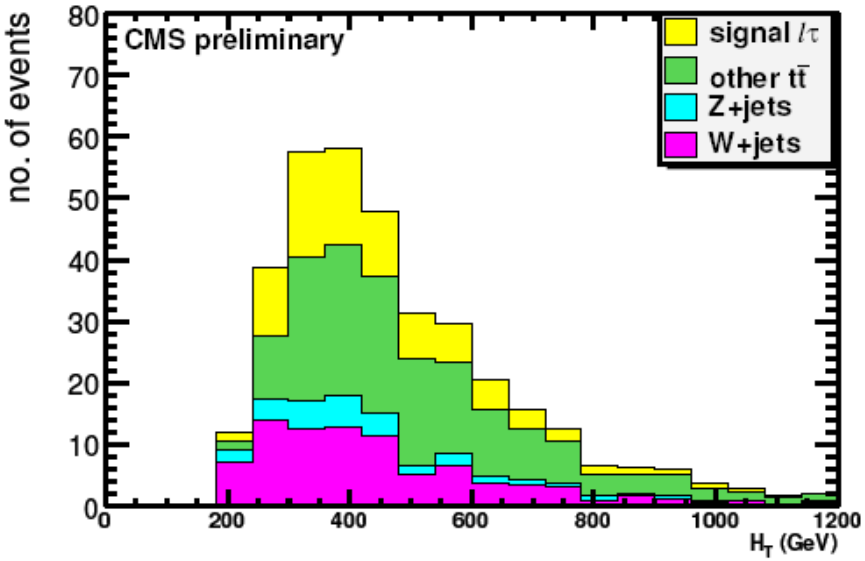
Dilepton-tau (CMS)

- e+tau and mu+tau final state considered
  - Tau candidate, Pt(track)>20 GeV
  - e or mu, Pt>20 GeV
  - >= 2 jets, Pt>30 GeV, MET>60 GeV
  - No b-tagging included yet
- Evaluate tau fake rate from data using multijet samples
- Event yield for 100pb-1:

CMS PAS TOP-08-004

	e+tau	mu+tau	other tt	W+jets	Z+jets	S/B
1-prong	32	41	105	56	23	0.4
3-prong	6	7	55	33	4	0.14



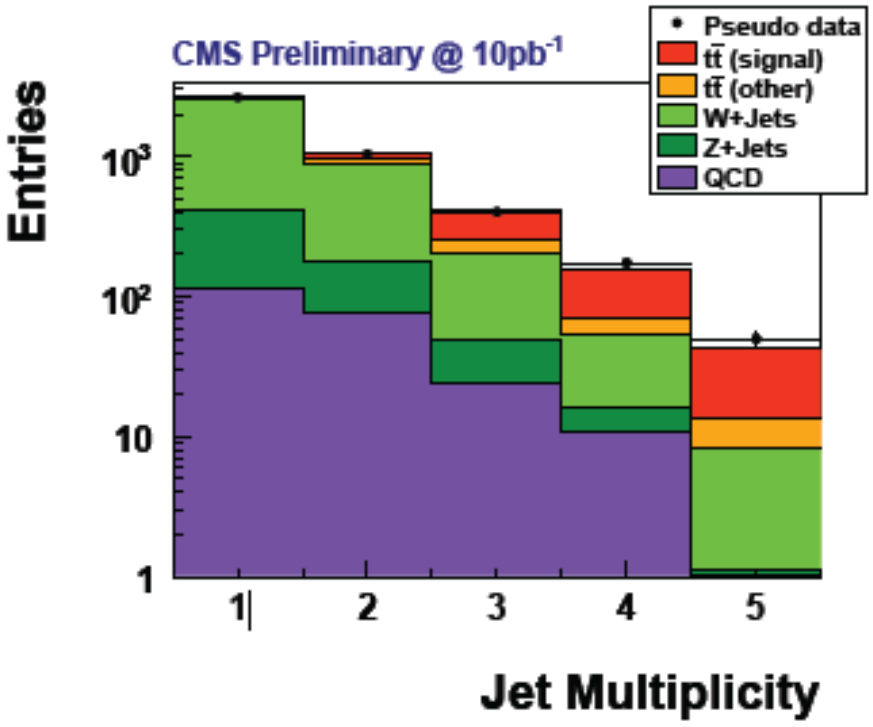


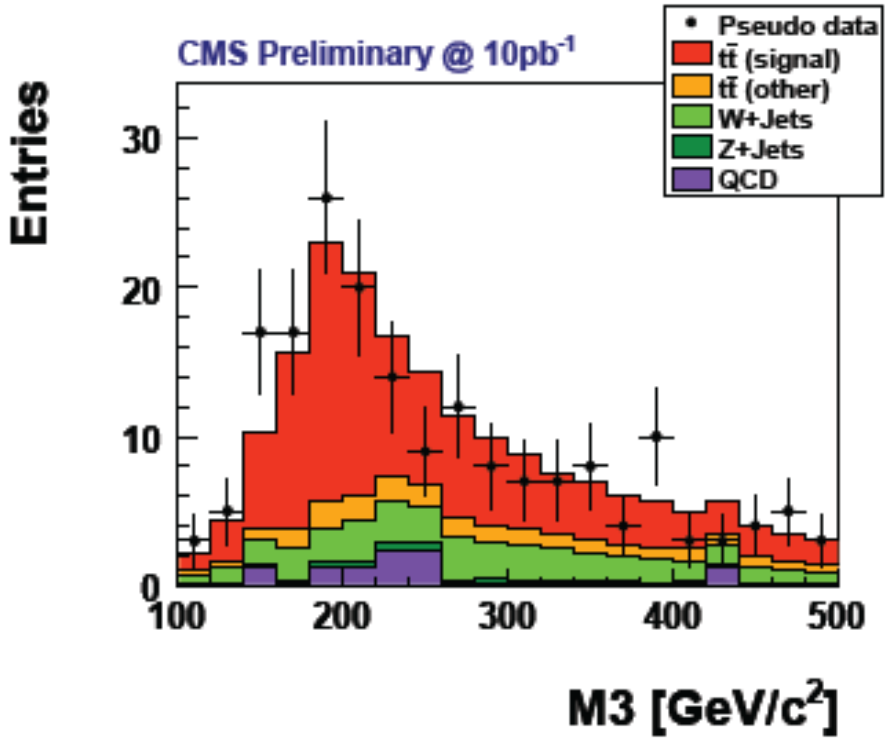
Muon+Jets (CMS)

- **Simple and robust event selection**
  - ❑ **One tightly isolated muon, Pt>30 GeV**
  - ❑ **At least 4 jets, Et>65,40,40,40 GeV**
- **No b-tagging, no MET**
- **For 10 pb-1: expect 128 / 90 signal / background events**

CMS PAS TOP-08-005

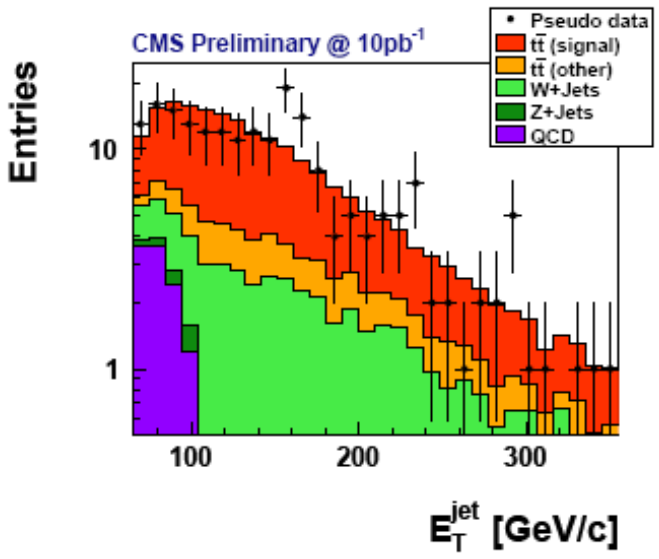
Inv. Mass of 3 jets with highest vec.sum. Pt

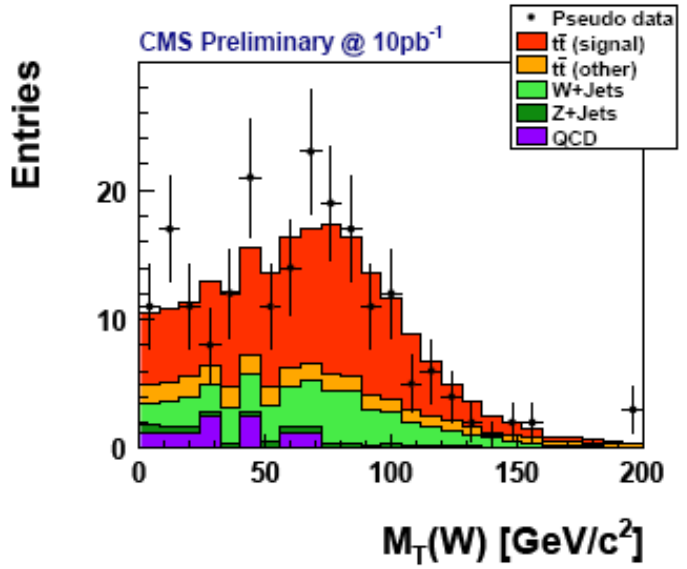


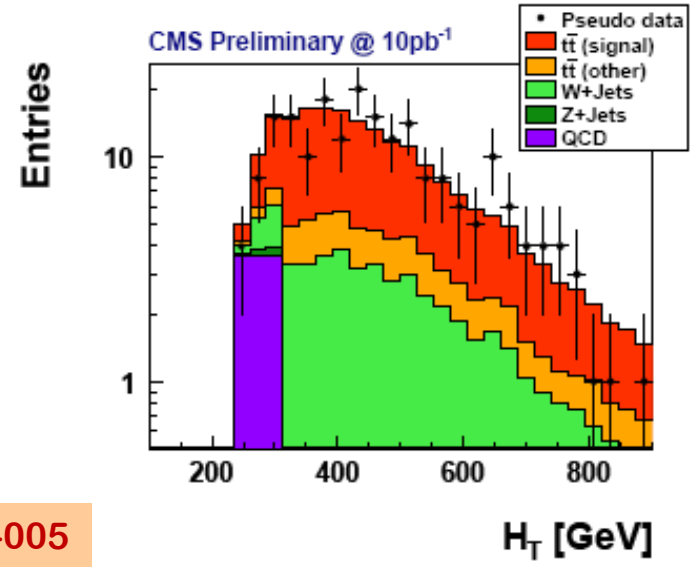


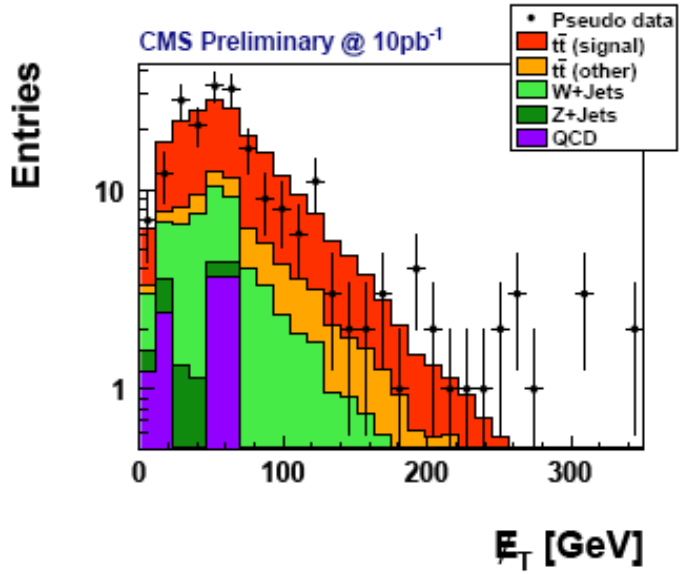
Muon+Jets (cont.)

- **Differential distributions**
- **Pseudo-data corrsponding to 10pb-1**
- **First rough validation of MC models possible**









CMS PAS TOP-08-005

Lepton+Jets (ATLAS)

- **ATLAS event selection for 100pb-1**
  - One lepton (e or mu) with Pt>20 GeV
  - MET > 20 GeV
  - >=4 jets with Et>40,40,40,20 GeV
  - W-mass constraint
- **Optionally**
  - Top mass window
  - B-tagging

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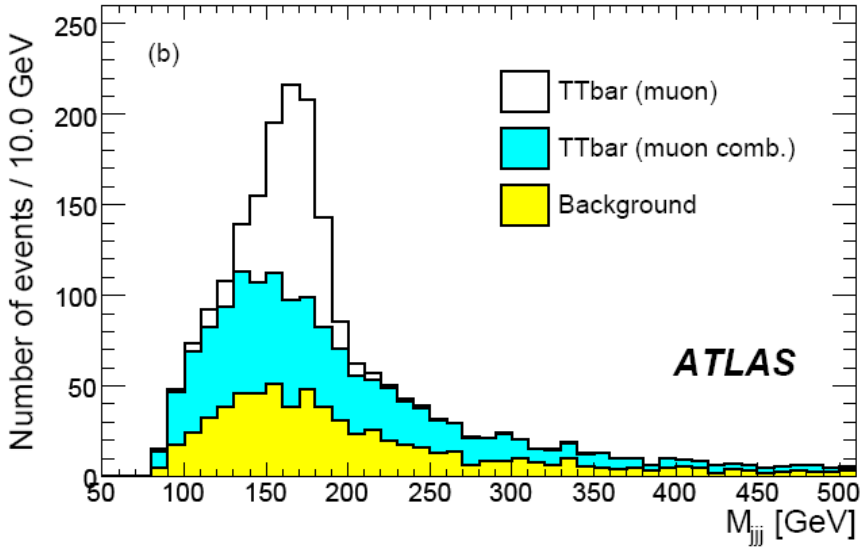

QCD not included in Bkgd.
"comparable to W+jets"

Muon analysis						
Sample	default	W const.	m_t win	W const. + $\lvert\eta\rvert < 1$	W const. + 1 b-tag	W const. + 2 b-tag
Signal	3274	1606	755	386	403	280
Background	1497	495	143	84	42	14
S/B	2.2	3.2	5.3	4.6	9.6	20.1

Lepton+Jets (ATLAS, cont.)

- **Two methods to extract cross section studied**

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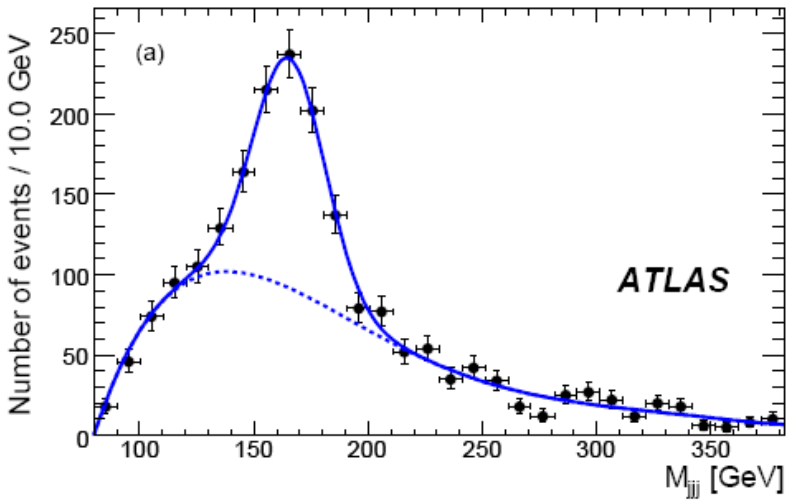
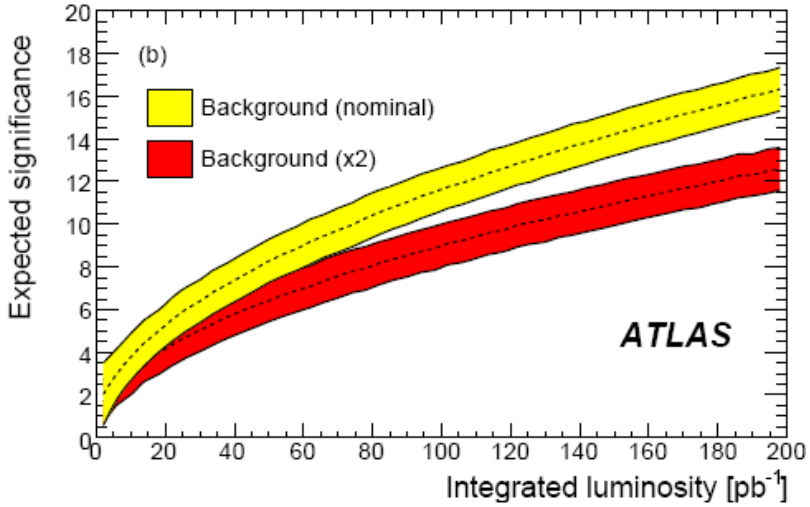
  - ❑ **Event counting**
    - o Requires understanding and normalization of backgrounds
  - ❑ **Maximum likelihood to three-jet inv. Mass distribution**
    - o Less sensitive to background normalization
    - o Requires well understood top mass peak



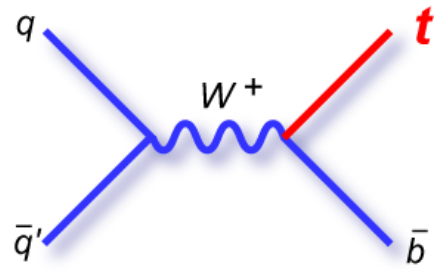


$$\text{Likelihood method:} \quad \Delta\sigma/\sigma = (7(\text{stat}) \pm 15(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$$

$$\text{Counting method:} \quad \Delta\sigma/\sigma = (3(\text{stat}) \pm 16(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$$

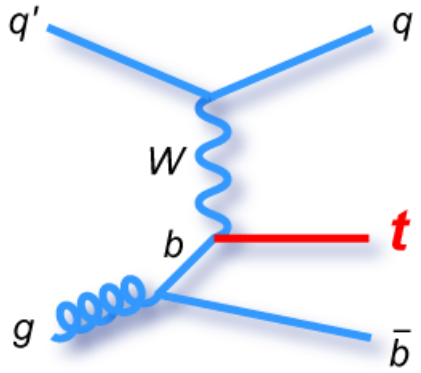
Single Top Production

- **Single top quarks produced at high rate at LHC**
  - ❑ **Direct measurement of Vtb**
  - ❑ **Search for non-SM contributions (W', H+)**



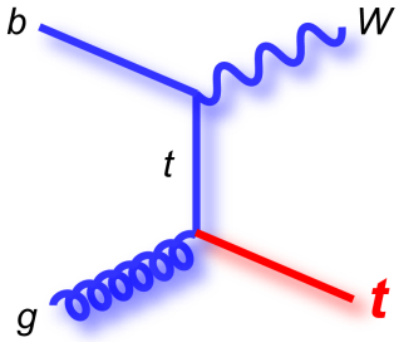
s-channel

- **Experimentally challenging**
  - ❑ **Low jet mult. than ttbar: larger W+jets, QCD bgkd.**
  - ❑ **tW-channel: large ttbar bkgd.**
  - ❑ **Low S/B, need sophisticated analysis techniques**



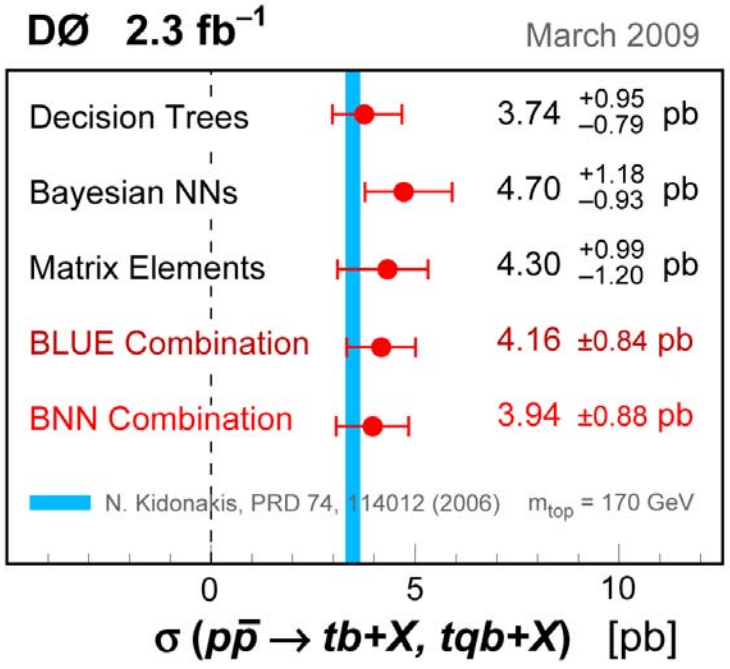
t-channel

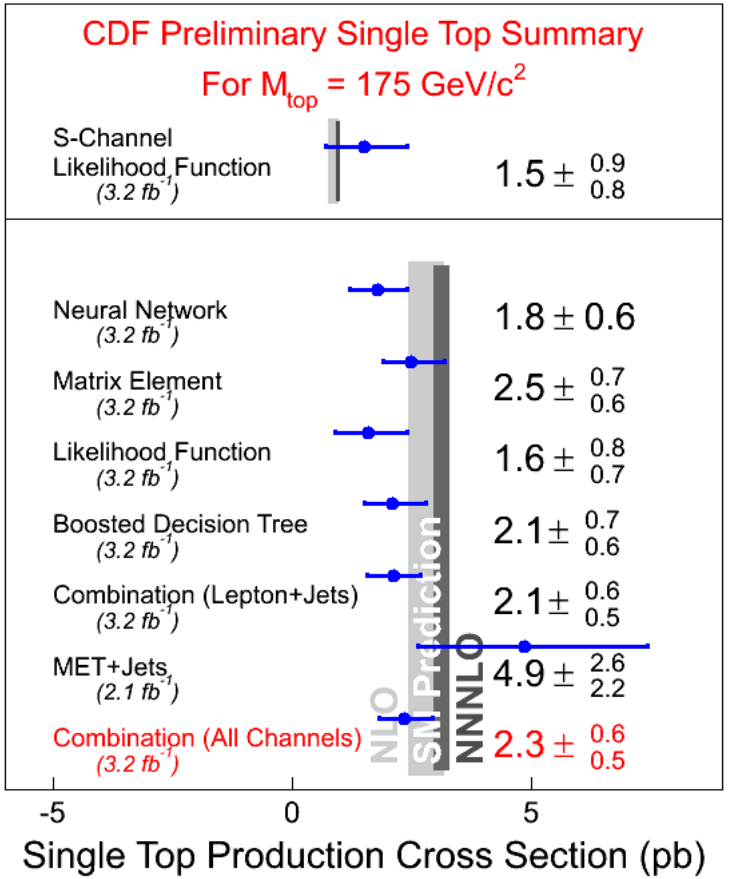
- **5σ observation just announced by CDF+D0**
  - ❑ **D0: [arXiv:0903.0850]**
  - ❑ **CDF: [arXiv:0903.0885]**

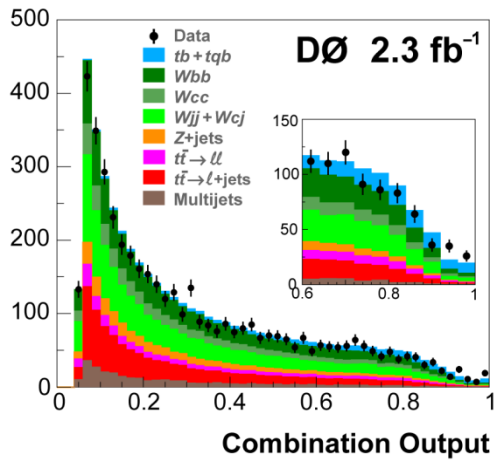


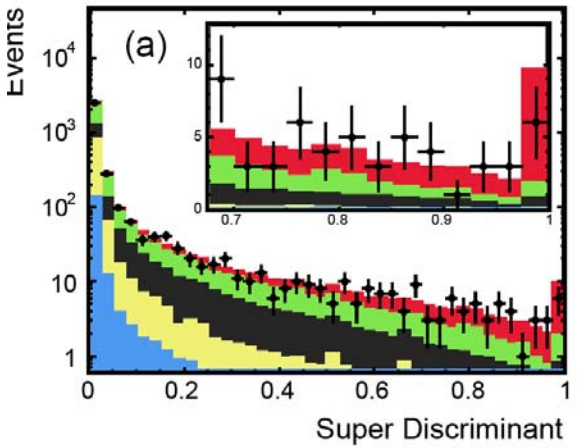
tW-channel

Single top 5σ observation









CDF: $|V_{tb}| = 0.91 \pm 0.11(\text{exp}) \pm 0.07(\text{th})$

DØ: $|V_{tb}| = 1.07 \pm 0.12$

Single top (ATLAS)

- All channels (t,s,tW) studied, using various strategies (cut based, likelihood, BDT,…)
- Common preselection:
  - ❑ Exactly one lepton (e or mu), Pt>30 GeV
  - ❑ 2, 3 or 4 jets with Pt>30 GeV, one b-jet

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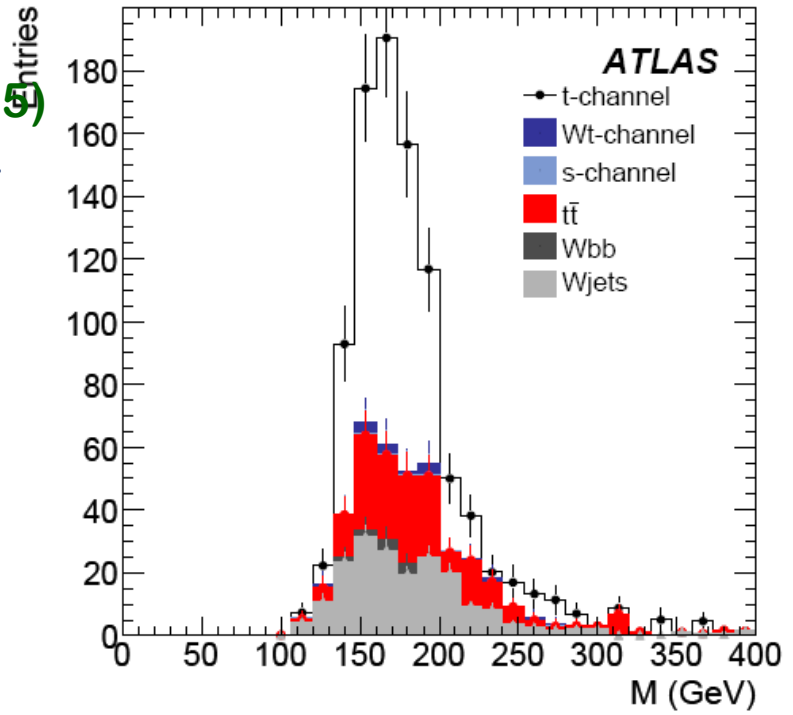
- t-channel (1fb-1):
  - ❑ Cut-based (b-jet Pt>50 GeV, light $|\eta|$>2.5)
    - o N(sig.)=1460, S/B=0.37, S/sqrt(B) = 23.4
  - ❑ Multivariate analysis (BDT)
    - o N(sig.)=542, S/B=1.3

$$\frac{\Delta|V_{tb}|}{|V_{tb}|} = \pm 11\%_{stat+sys} \pm 4\%_{theo} = \pm 12\%$$



Single top (ATLAS)

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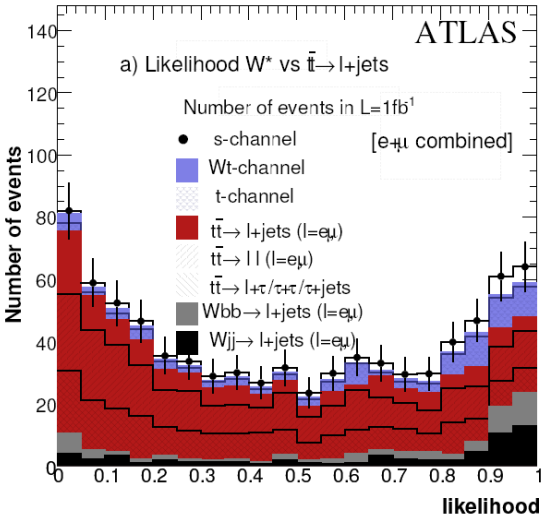
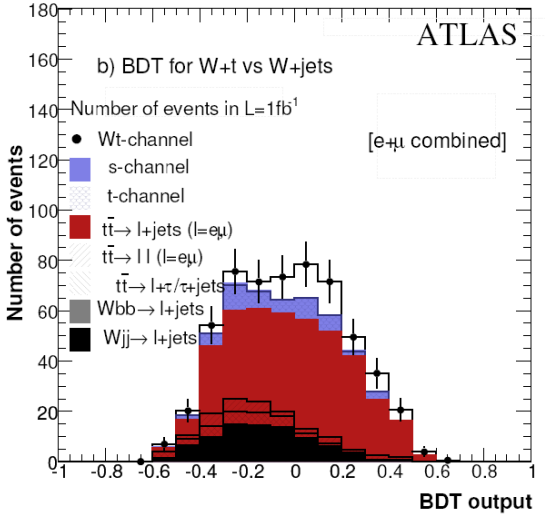
- **s-channel:**
  - 2 b-jets, no other light jets, lepton, MET
  - Topological cuts
  - 5 Likelihood functions for sig. vs bkgd.
    - N=15 in 1fb-1, S/B=0.2
    - Systematic error 95 (48)% with 1 (10) fb-1
  - 3σ evidence may be achievable with 30 fb-1



- **tW-channel:**
  - Exactly 1 b-jet, with Pt>50 GeV, topological cuts
  - Multivariate analysis (BDT)
    - 60 / 20 / 7 events in 2 / 3 / 4 jet bins in 1fb-1
    - S/B= 0.35 … 0.46
  - δσ/σ = 21% (stat.) +/- 48% (syst.) for 1 fb-1
  - δσ/σ = 6.6% (stat.) +/- 19% (syst.) for 10 fb-1



Conclusions

- **Results shown here based on 14 TeV simulations**
  - **10 TeV updates in progress, expect results for summer conf's**
  - **naïve scaling: needed lumi x2**

- **Top cross section road map with "early" LHC data**
  - **2009-2010 running @ 10 TeV:**
    - **20-50 pb-1: first ttbar dilepton, lepton+jets cross sections**
    - **50-200 pb-1: refined ttbar (with b-tagging), first look at single top t-ch.**
  - **Beyond 2010:**
    - **200-1000 pb-1: single top t-channel, ttbar all-jets**
    - **1-10 fb-1: single top tW-channel**
    - **>10 fb-1: single top s-channel**

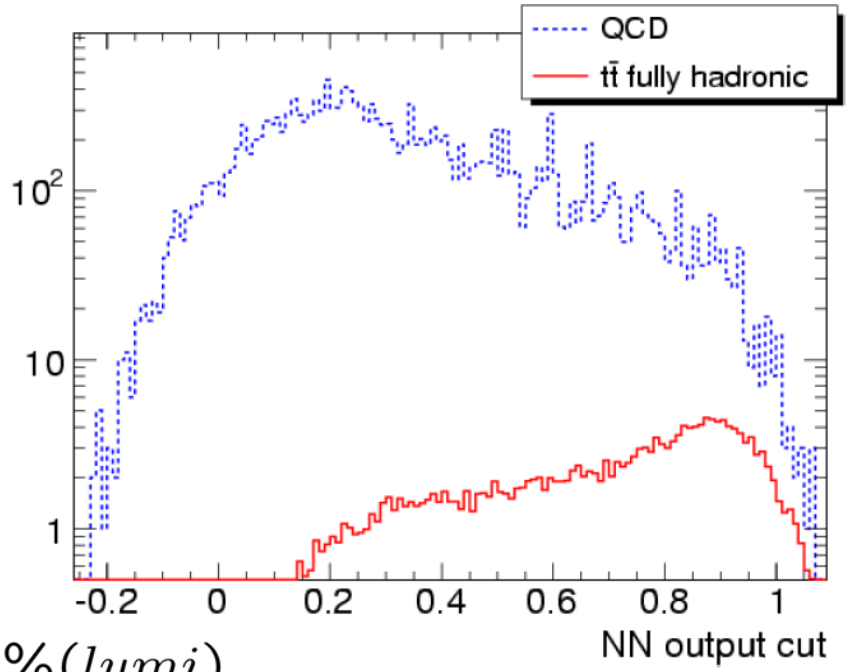
- **Top physics @ LHC is a …**
  - **Tool to understand the detector**
  - **Benchmark of the SM at LHC energies**
  - **Milestone en route to discoveries**

Backup Slides

Fully hadronic (CMS)

- **Base event selection for 1 fb-1:**
  - ❑ Dedicated b-tag multijet trigger
  - ❑ 6 jets, Pt>30 GeV
  - ❑ Topological cuts, b-tagging
- **1 (2) b-tags results in S/B = 1/17 (1/9)**
- **Improvement with Neural Net**
  - ❑ 1 (2) b-tags: S/B=1/7 (1/3)

Selection	Requirement	$\sigma\epsilon_{t\bar{t}}$ [pb]	$\sigma\epsilon_{QCD}$ [pb]	S/B	$S/\sqrt{S+B}$ ($\mathcal{L}=1$ fb^{-1})	$\epsilon_{t\bar{t}}$ (%)
Trigger	HLT jet+b-tagging	38	11600	1/300	11.1	16.8
Event	$6 \le N_{jet} \le 8$	35	7900	1/225	12.4	15.5
	$E_T \ge 30$ GeV	15	930	1/60	15.4	6.6
	centrality ≥ 0.68	9.9	324	1/33	17.1	4.4
	aplanarity ≥ 0.024	9.0	251	1/28	17.7	4.0
	$\sum_3 E_T \ge 148$ GeV	9.0	229	1/25	18.4	4.0
b-tagging	1 b-tag	8.6	148	**1/17**	21.7	**3.8**
	2 b-tag	6.0	54	**1/9**	24.1	**2.7**



CMS Note 2006/077

$$\Delta\sigma/\sigma = 3\%(stat.) \pm 20\%(syst.) \pm 5\%(lumi)$$

Single Top (CMS)

- **Results from 2006 PTDR (14 TeV)**
  - ❑ Update for 10 TeV in progress …

- **t-channel results for 10 fb^{-1}:**
  - ❑ Optimized event selection (S/N~1.34)
    - o Lepton Pt>20 GeV
    - o MET > 40 GeV
    - o Light jet p_T>40 GeV, $|\eta|$>2.5
    - o B-jet p_T>35 GeV, $|\eta|$<2.5
    - o Topological cuts

N_{evt}=2400

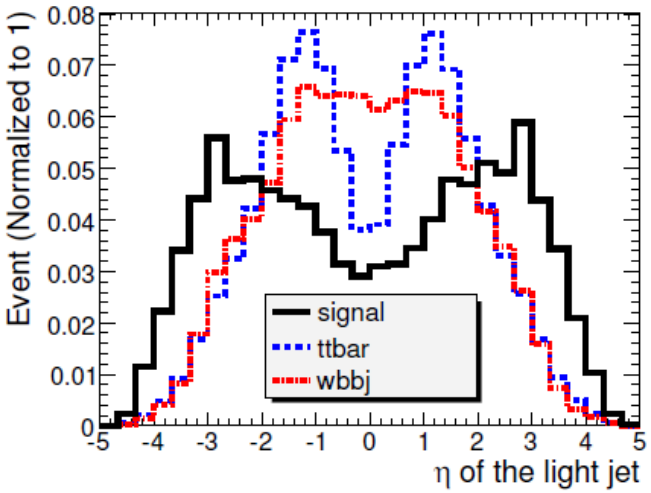
$\Delta\sigma/\sigma$ = 2.7 (stat.) $\pm$ 8.1 (syst.) $\pm$ 5 (lumi) %

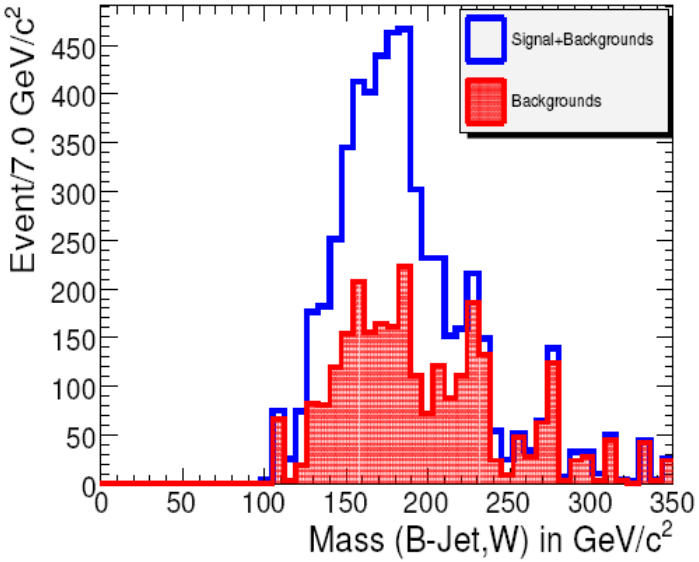
- **Other channels:**
  - ❑ s-channel

$\Delta\sigma/\sigma$ = 18 (stat.) $\pm$ 31 (syst.) $\pm$ 5 (lumi) %

  - ❑ tW-channel

$\Delta\sigma/\sigma$ = 7.4 (stat.) $\pm$ 18 (syst.) $\pm$ 5 (lumi) %





CMS Notes 2006/084 and 086

ATLAS l+jets

- **Systematics**

Source	Likelihood fit		Counting method (elec)	
	Electron (%)	Muon (%)	Default (%)	W const. (%)
Statistical	10.5	8.0	2.7	3.5
Lepton ID efficiency	1.0	1.0	1.0	1.0
Lepton trigger efficiency	1.0	1.0	1.0	1.0
50% more W+jets	1.0	0.6	14.7	9.5
20% more W+jets	0.3	0.3	5.9	3.8
Jet Energy Scale (5%)	2.3	0.9	13.3	9.7
PDFs	2.5	2.2	2.3	2.5
ISR/FSR	8.9	8.9	10.6	8.9
Shape of fit function	14.0	10.4	-	-

ATLAS single top t-channel

- **Systematics**

Source	Analysis of 1 fb^{-1}		
	Variation	Cut-based	BDT
Data Statistics		5.0%	5.7 %
MC Statistics		6.5 %	7.9%
Luminosity	5%	18.3 %	8.8%
b-tagging	5%	18.1 %	6.6%
JES	5%	21.6%	9.9%
Lepton ID	0.4%	1.5 %	0.7%
Trigger	1.0%	1.7 %	1.7%
Bkg x-section		22.9%	8.2%
ISR/FSR	+7.2 -10.6%	9.8 %	9.4%
PDF	+1.38 -1.07%	12.3 %	3.2%
MC Model	4.2%	4.2 %	4.2%
Total		45%	22%

Single top s-channel

- **Event yield**

Events in $1\,\mathrm{fb}^{-1}$	e channel	μ channel	e + μ combined
s-channel	6.3 ± 0.7	9.1 ± 0.8	15.4 ± 1.0
t-channel	negl.	1.7 ± 1.7	1.7 ± 1.7
Wt-channel	1.8 ± 1.0	negl.	1.8 ± 1.0
$t\bar{t} \rightarrow l + \text{jets}$	7.6 ± 2.6	7.7 ± 3.5	15.3 ± 4.4
$t\bar{t} \rightarrow ll$	6.0 ± 2.6	6.0 ± 2.6	12.0 ± 3.8
$t\bar{t} \rightarrow l + \tau$	6.8 ± 3.4	14.5 ± 4.1	21.3 ± 5.3
$Wb\bar{b}$+jets	10.0 ± 3.2	7.0 ± 2.6	17.0 ± 4.1
W+jets	6.2 ± 1.2	7.3 ± 2.1	13.5 ± 2.4
WZ + WW	negl.	negl.	negl.
Total Bkg	36.8 ± 5.8	45.9 ± 6.6	82.7 ± 8.6
S/B	17.3%	19.8%	18.7%
$S/\sqrt{B}$	1.0	1.3	1.7
$\sqrt{S+B}/S$	1.0	0.8	0.6

ATLAS single top s-channel

- **Table of systematics**

Source of uncertainty	Analysis for 1 fb^{-1} Variation	$\Delta\sigma/\sigma$	Analysis for 10 fb^{-1} Variation	$\Delta\sigma/\sigma$
Data Statistics		64%		20%
MC Statistics		29%		
Luminosity	5%	31%	3%	18%
b-tagging	5%	44%	3%	25%
JES	5%	25%	1%	5%
Lepton ID	1%	6%	1%	6%
Bkg x-section	10.3%	47%	3%	16%
ISR/FSR	9%	52%	3%	17%
PDF	2%	16%	2%	16%
b-fragmentation	3.6%	19%	3.6%	19%
Total Systematics		95%		48%

ATLAS single top tW-channel

- **Event yield for cut-based selection**

Events in $1\,\mathrm{fb}^{-1}$	2 jets (1b1j)	3 jets (1b2j)	4 jets (1b3j)
Wt-channel	435 ± 16	164 ± 10	40 ± 5
t-channel	1218 ± 47	94 ± 13	58 ± 11
s-channel	42 ± 2	5 ± 0.6	0.6 ± 0.2
$t\bar{t} \rightarrow l + \text{jets}$	1260 ± 38	664 ± 27	240 ± 16
$t\bar{t} \rightarrow \text{dilepton}$	291 ± 18	50 ± 7	17 ± 4
$t\bar{t} \rightarrow l + \tau$	428 ± 22	55 ± 8	17 ± 5
W+jets	2983 ± 71	207 ± 19	38 ± 6
$Wb\bar{b}$+jets	137 ± 33	13 ± 3	6 ± 2
TOTAL bkg	6359 ± 232	1088 ± 74	377 ± 42
S/B	6.8%	15.0%	10.6%
$S/\sqrt{B}$	5.4	5.0	2.1
$\sqrt{S+B}/S$	0.19	0.21	0.51

ATLAS single top tW-channel

- **Event yields BDT analysis**

Events in 1fb^{-1}	2 jet (1b1j)	3 jet (1b2j)	4 jet (1b3j)
Wt-channel	58.0 ± 5.8	20.9 ± 3.5	6.6 ± 2.0
t-channel	10.2 ± 4.2	negl.	1.7 ± 1.7
s-channel	1.4 ± 0.3	negl.	negl.
$t\bar{t} \rightarrow all\,jet$	negl.	negl.	negl.
$t\bar{t} \rightarrow l + jet$	56.3 ± 8.2	41.8 ± 6.3	13.7 ± 3.4
$t\bar{t} \rightarrow dilepton$	1.7 ± 1.2	negl.	negl.
$t\bar{t} \rightarrow l + \tau$	negl.	negl.	negl.
W+jets	92.1 ± 8	3.2 ± 1.4	0.2 ± 0.1
$Wb\bar{b}$+jets	3.9 ± 3.9	negl.	negl.
Total bkg	165.6 ± 9.2	45.1 ± 6.3	15.6 ± 3.4
S/B	35.0%	46%	36.2%
$S/\sqrt{B}$	4.5	3.1	1.7
$\sqrt{S+B}/S$	0.25	0.39	0.71

ATLAS single top tW-channel

- **Systematics**

Source of uncertainty	Analysis for 1 fb^{-1} Variation	$\Delta\sigma/\sigma$	Analysis for 10 fb^{-1} Variation	$\Delta\sigma/\sigma$
Data Statistics		20.6%		6.6%
MC Statistics		15.6%		
Luminosity	5%	20%	3%	7.9%
b-tagging	5%	16%	3%	6.6%
JES	5%	11%	1%	1.5%
Lepton ID	1%	2.6%	1%	2.6%
Bkg x-section	12.5/10%(*)	23.4%	3%	9.6%
ISR/FSR	9%	24.0%	3%	7.8%
PDF	2%	5.2%	2%	5.2%
b-fragmentation	3.6%	9.4%	3.6%	9.4%
Total Systematics		48%		19.4%

FCNC (ATLAS)

- **Event selection**

Channel	$t\bar{t} \to bWq\gamma$	$t\bar{t} \to bWqg$	$t\bar{t} \to bWqZ$
Pre-selection	$= 1\ell$ ($p_T > 25$ GeV) $\geq 2j$ ($p_T > 20$ GeV) $= 1\gamma$ ($p_T > 25$ GeV) $\not{p}_T > 20$ GeV	$= 1\ell$ ($p_T > 25$ GeV) $= 3j$ ($p_T > 40, 20, 20$ GeV) $= 0\gamma$ ($p_T > 15$ GeV) $\not{p}_T > 20$ GeV	$= 3\ell$ ($p_T > 25, 15, 15$ GeV) $\geq 2j$ ($p_T > 30, 20$ GeV) $= 0\gamma$ ($p_T > 15$ GeV) $\not{p}_T > 20$ GeV
Final selection	$p_{T\gamma} > 75$ GeV	$E_{vis} > 300$ GeV $p_{Tg} > 75$ GeV $m_{qg} > 125$ GeV $m_{qg} < 200$ GeV	$2\ \ell$ same flavour, oppos. charge
Trigger	e22i, mu20 or g55	e22i or mu20	e22i or mu20

- **Bkg. Yields / signal eff. For 1 fb-1:**

	e	μ	ℓ
$t\bar{t} \to bWq\gamma$:			
Total	$(4.4 \pm 0.6) \times 10^2$	$(2.2 \pm 0.6) \times 10^2$	$(6.5 \pm 0.7) \times 10^2$
Signal %	3.6 ± 0.2	4.1 ± 0.2	7.6 ± 0.2
$t\bar{t} \to bWqZ$:			
Total	$(0.3 \pm 0.6) \times 10^2$	$(0.1 \pm 0.6) \times 10^2$	$(1.3 \pm 0.6) \times 10^2$
Signal %	1.4 ± 0.1	2.5 ± 0.1	7.6 ± 0.2
$t\bar{t} \to bWqg$:			
Total	$(11.0 \pm 0.3) \times 10^3$	$(8.3 \pm 0.2) \times 10^3$	$(19.3 \pm 0.4) \times 10^3$
Signal %	1.3 ± 0.1	1.5 ± 0.1	2.9 ± 0.1