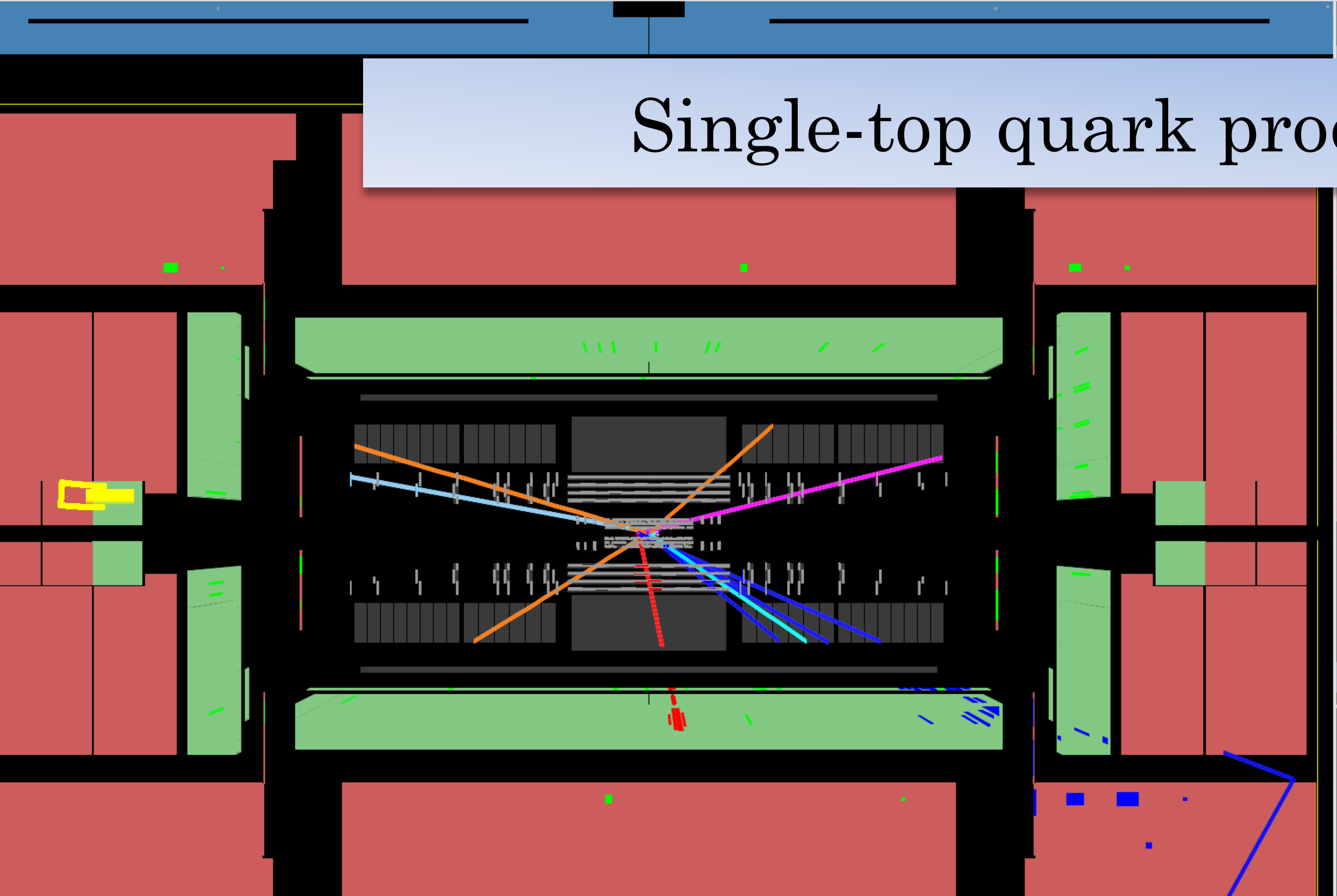
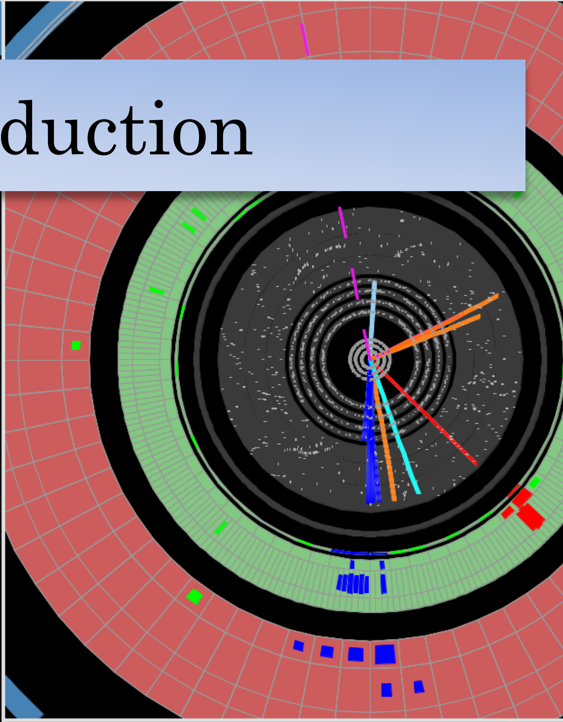
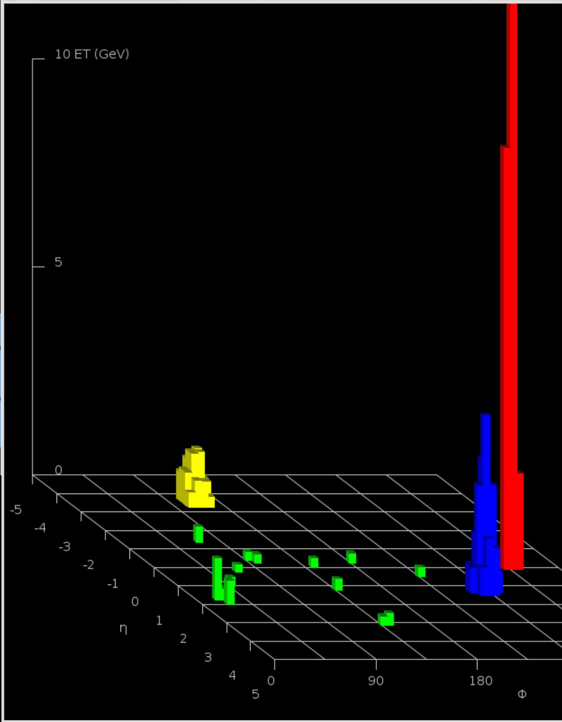
Single-top quark production







Dominic Hirschbühl

BERGISCHE UNIVERSITÄT WUPPERTAL

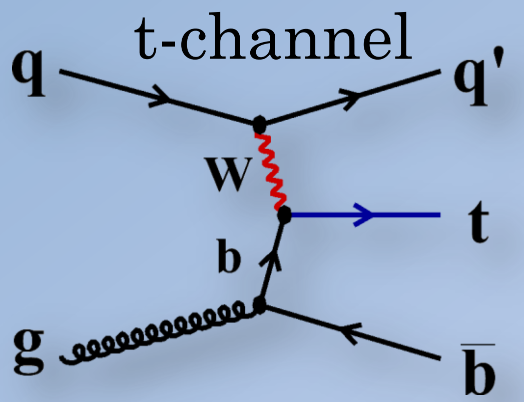
PHYSICS AT THE TERA SCALE Helmholtz Alliance

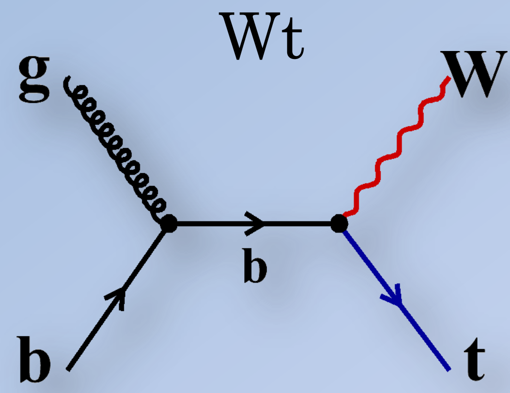
On behalf of the ATLAS,CDF,CMS and D0 collaborations

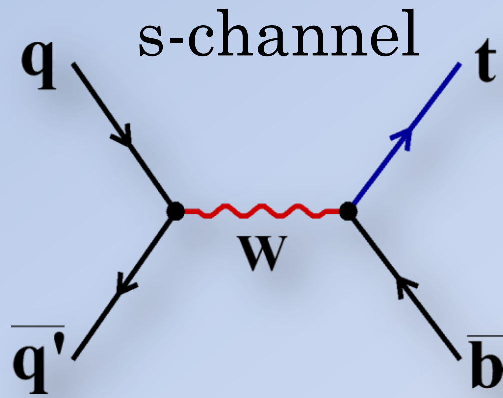
SM@LHC - Copenhagen

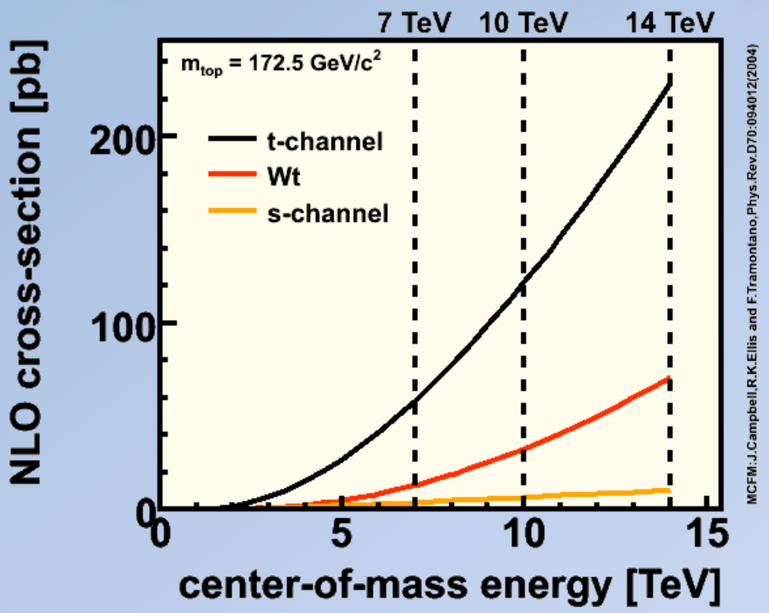
11.04.2012

Production of single top quark events









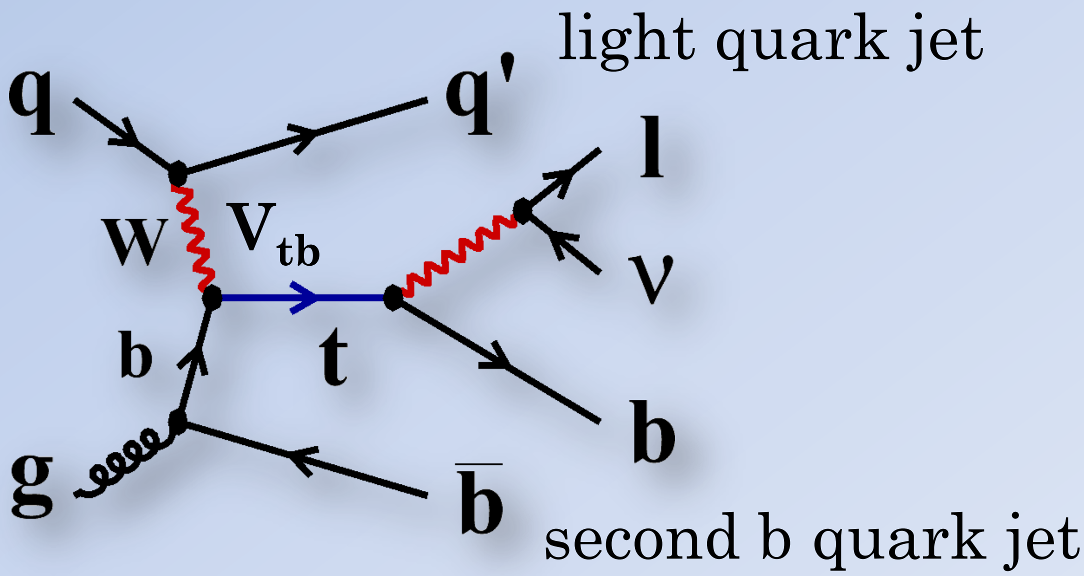
Cross sections	1.96 TeV m_t = 173 GeV	7 TeV m_t = 172.5 GeV
t-channel	2.1 ± 0.1 pb	64.6 ± 2.4pb
Wt	0.25 ± 0.03 pb	15.7 ± 1.1 pb
s channel	1.05 ± 0.05 pb	4.6 ± 0.2 pb

Single-top-quark and antiquark cross sections are different for t- and s-channel at the LHC!

Calculations by N. Kidonakis:
Phys.Rev.D83 (2011) 091503, Phys.Rev.D82 (2010) 054018,2010, Phys.Rev.D81 (2010) 054028
at NLO + NNLL resummation ($NNLO_{approx}$)

Motivation

- Test of standard model predictions
  - Establish all three production channels
  - Cross section ∝ $|V_{tb}|^2$
    - Test of the unitarity of the CKM Matrix
    - Hints for existence of a 4th generation
  - Test of the b-quark structure function: DGLAP evolution
  - t-channel cross section ratio @ LHC is sensitive to the top quark/anti-top quark ratio in PDFs
  - Test V-A structure of Wtb vertex, i.e top quark polarization.



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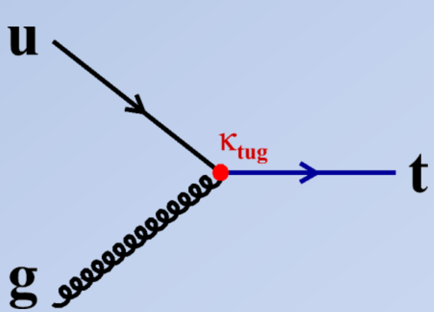
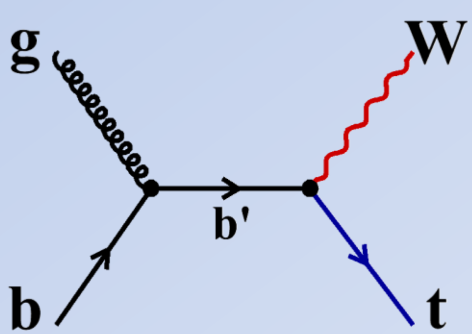
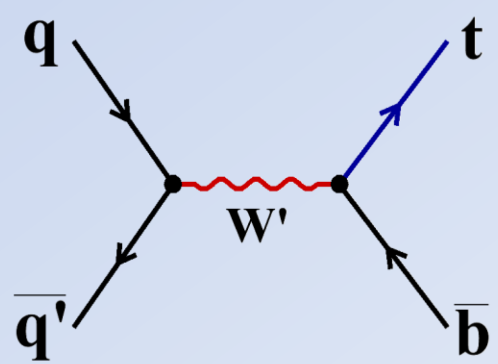
- Probe and preparation for searches for new physics
  - anomalous Wtb couplings
  - charged heavy Bosons W', H+ etc.
  - 4^{th} generation fermions b'
  - FCNC, Monotops







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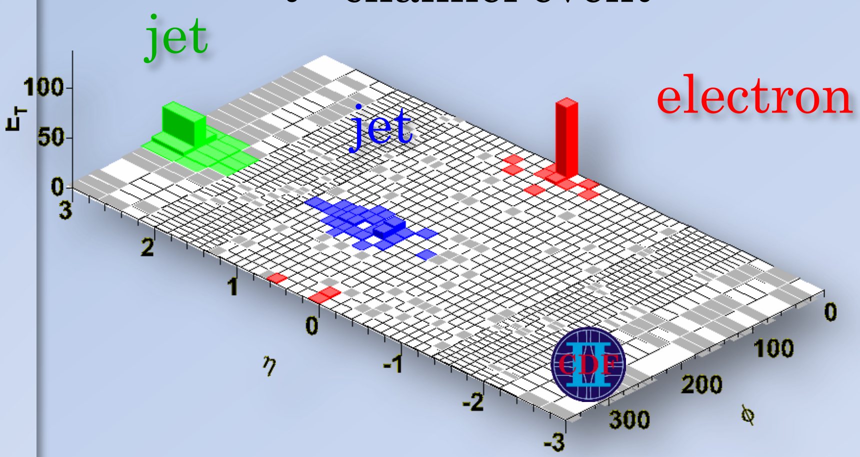
  - 4^{th} generation fermions b'
  - FCNC, Monotops

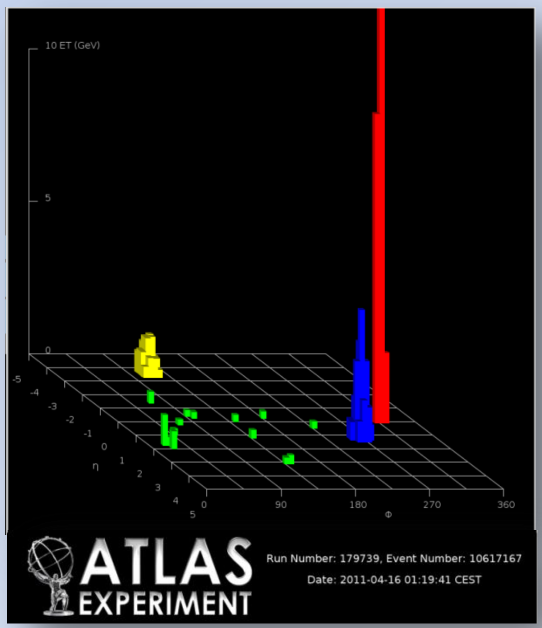
- Single top as a complementary environment
  - Different color structure, fewer reconstruction ambiguities
  - Redo measurements of top properties:
    m_t, W polarization in top decay, …

Single top event selection

- Lepton selection (electron / muon):
  - Isolated
  - Also some acceptance from leptonic tau decays
- Jets
  - Anti-k_T algorithm @ LHC
  - Cone algorithm @ Tevatron
  - |η|: within tracker acceptance for Wt & s-channel
  - including forward calorimeters for t-channel
  - Identification of b-quark jets
  - Number of jets: 2 - 4
- Missing transverse energy
- QCD multijet veto

t - channel event



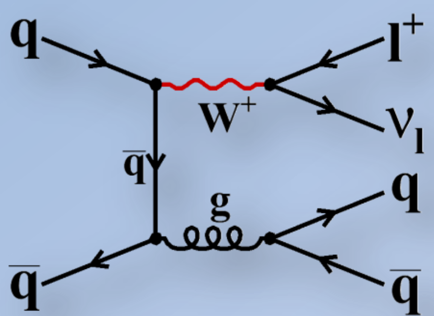


Background processes

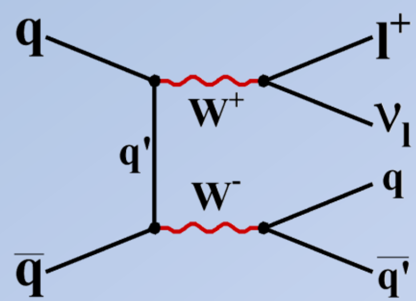
Event signature:

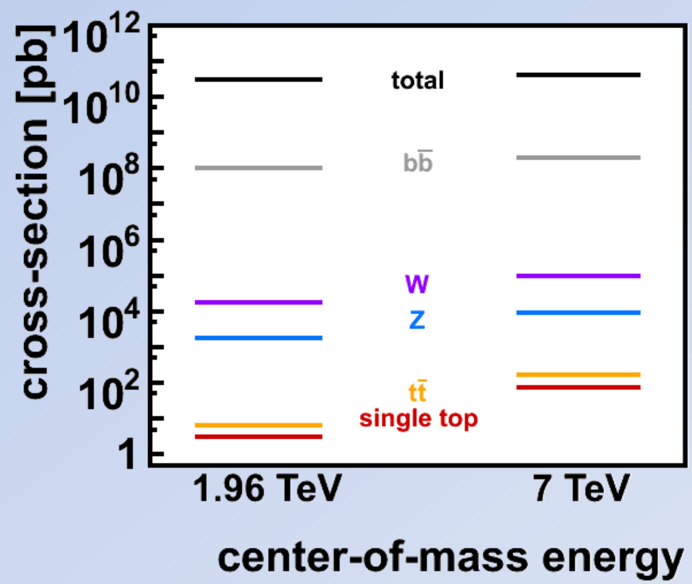
- One (lepton+jets) or two (di-lepton) **real W bosons**
- One high-P_T central **b-jet** (from top quark)

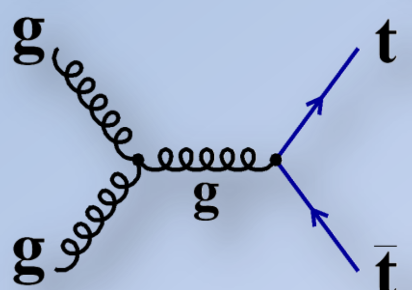
W/Z + HF pairs



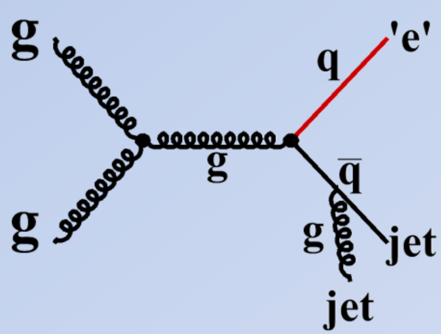
WW/WZ/ZZ







top-quark-antiquark pair production



QCD multijets
("fake" leptons)

Background estimation - strategy

Using MC acceptance and modeling

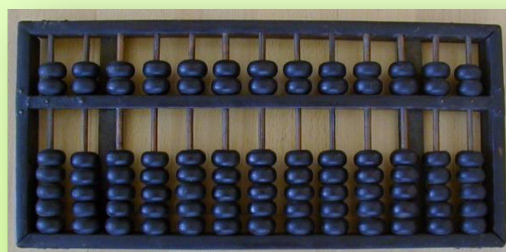
$$N = \sigma \cdot \varepsilon \cdot \mathcal{L}$$

Using MC modeling but normalization from data

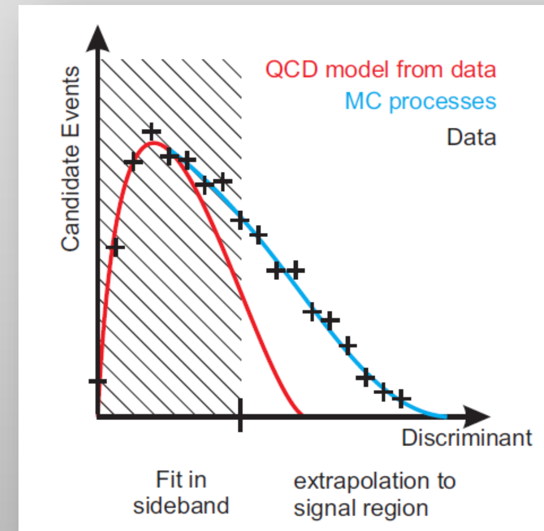
$$N^{pretag}_{W+jets} = N^{pretag}_{data} - N^{pretag}_{qcd} - N^{pretag}_{MC}$$

$$N^{tag}_{\Phi,n} = N^{pretag} F^{pretag}_{\Phi,n} P^{tag}_{\Phi,n} .$$

$$\begin{aligned} N^{tag}_{data-bkg,2} &= N^{pretag}_{data-bkg,2} \cdot (F^{pretag}_{bb,2} \cdot P^{tag}_{bb,2} + k^{pretag}_{cctobb} \cdot F^{pretag}_{bb,2} \cdot P^{tag}_{cc,2} + F^{pretag}_{c,2} \cdot P^{tag}_{c,2} + \\ &+ F^{pretag}_{l,2} \cdot P^{tag}_{l,2}) = N^{pretag}_{data-bkg,2} \cdot (k^{pretag}_{bb1to2} \cdot F^{pretag}_{bb,1} \cdot P^{tag}_{bb,2} + k^{pretag}_{cctobb} \cdot k^{pretag}_{bb1to2} \cdot F^{pretag}_{bb,1} \cdot P^{tag}_{cc,2} \\ &+ k^{pretag}_{c1to2} \cdot F^{pretag}_{c,1} \cdot P^{tag}_{c,2} + k^{pretag}_{l1to2} \cdot F^{pretag}_{l,1} \cdot P^{tag}_{l,2}). \end{aligned}$$

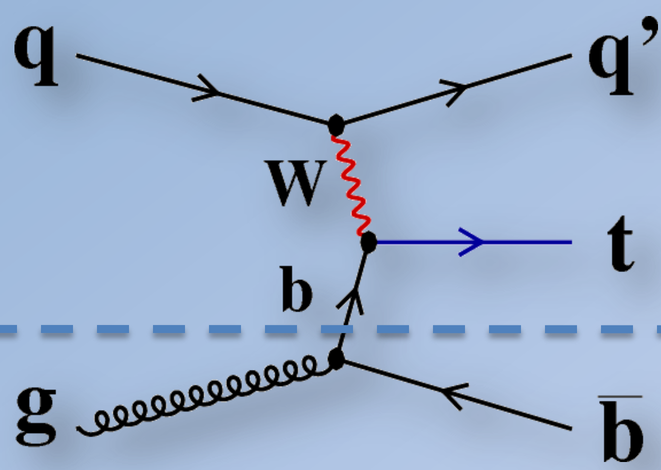


Using modeling and normalization from data (Mostly „fake“ backgrounds)



Similar approaches of all 4 experiments – details are different

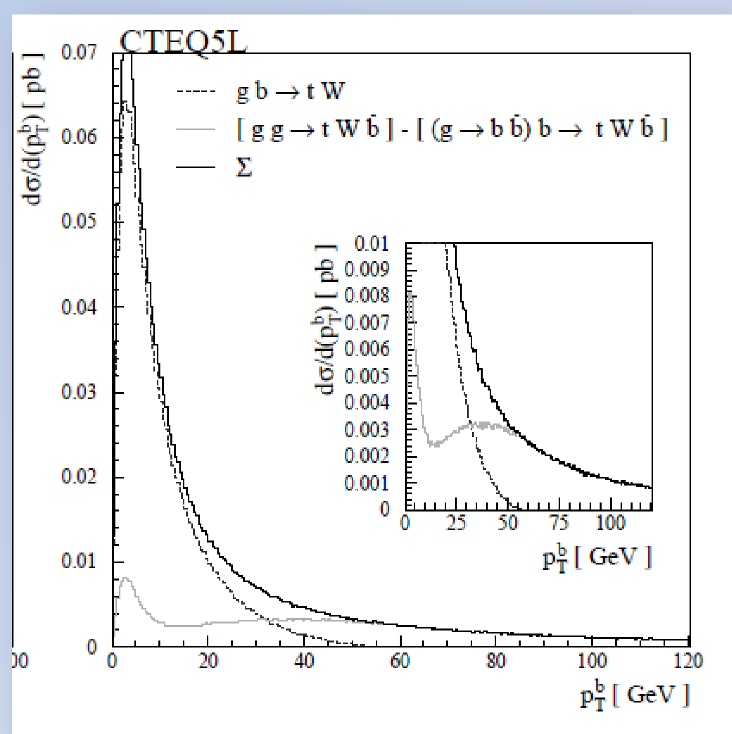
Signal modeling – t - channel

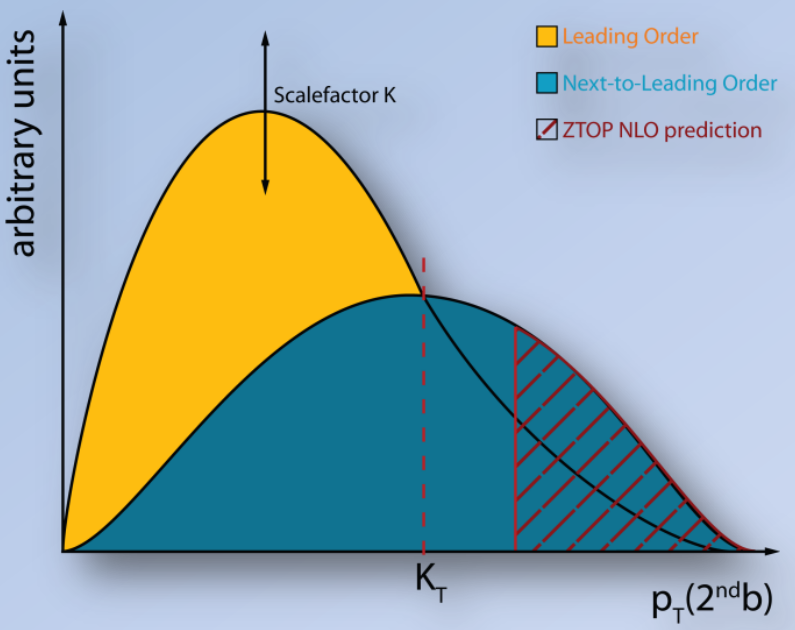


Model:

- CompHEP + Pythia
- AcerMC + Pythia
- Powheg +Pythia

AcerMC – ACOT method



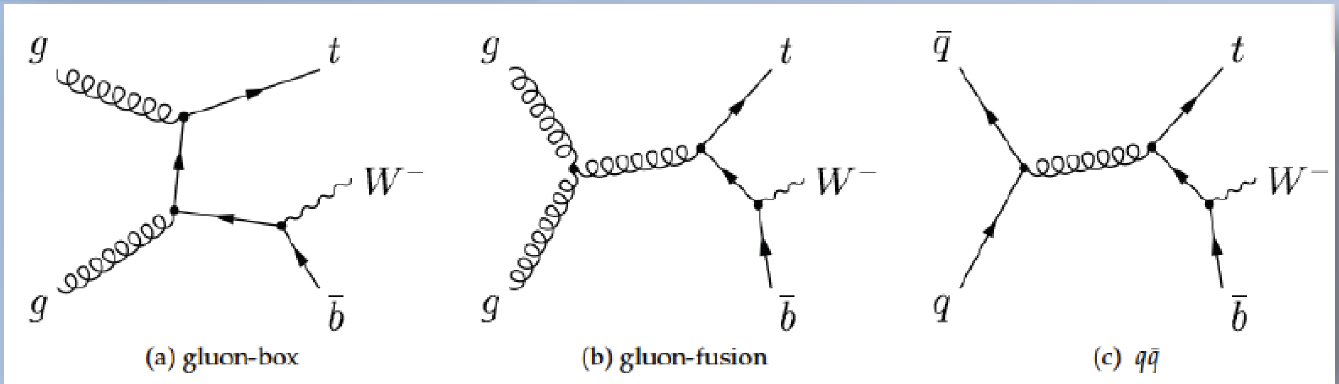


Comphep – Matching of second b

Signal modeling – Wt production

The definition of the tW process mixes with top-pair production @ NLO.

Model:
MC@NLO + Herwig
Powheg + Pythia

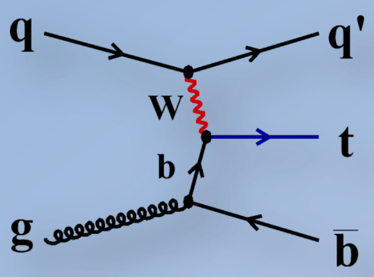


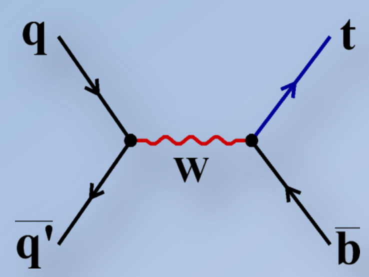
Two possible solutions:

- The “diagram removal” approach (DR):
  All ambiguous diagrams at NLO are excluded from the definition of signal (chosen as default)
- The “diagram subtraction” approach (DS):
  Subtracts a gauge-invariant term, cancelling locally the contribution of ttbar diagrams

The differences between the methods are small at the end of the analysis chain and taken as a systematic uncertainty.

t- and s-channel single top quark production

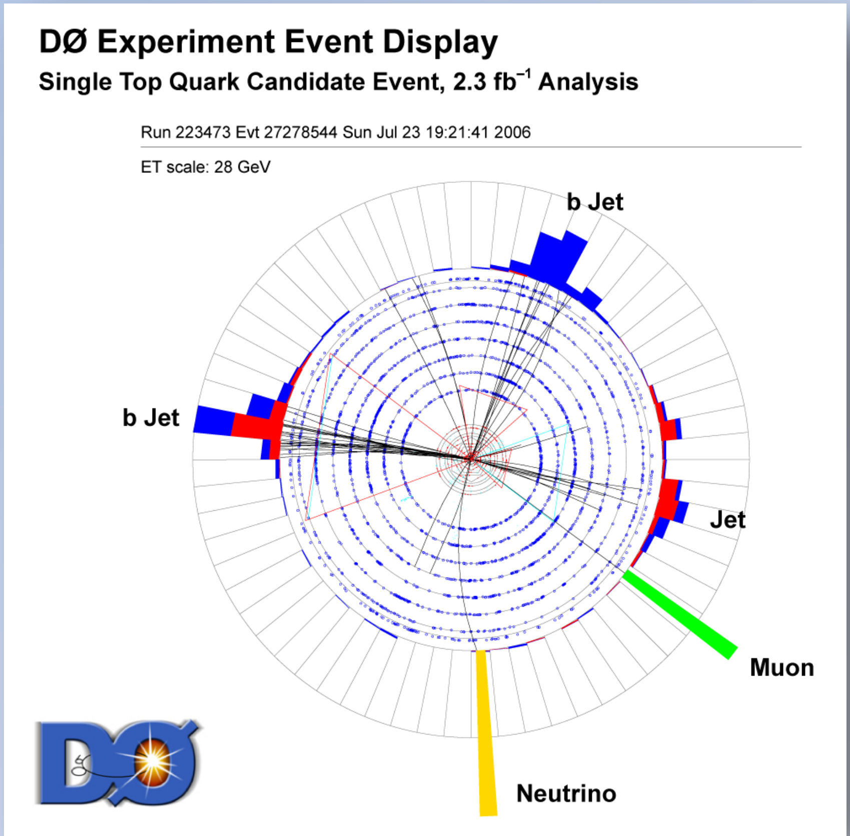




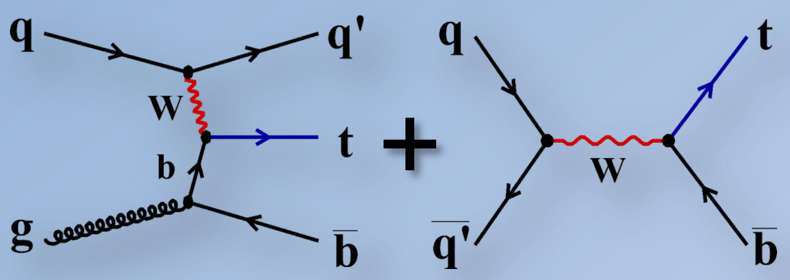
- Combined search (t+s channel)
- 2 D search (t- vs. s-channel)

Only Tevatron

- t-channel search → all 4 experiments
- s-channel search → only ATLAS

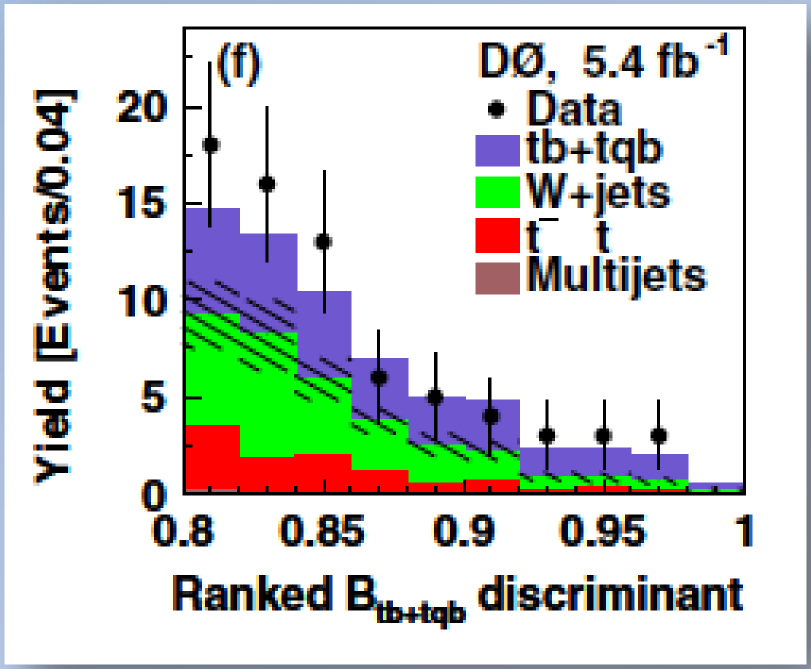


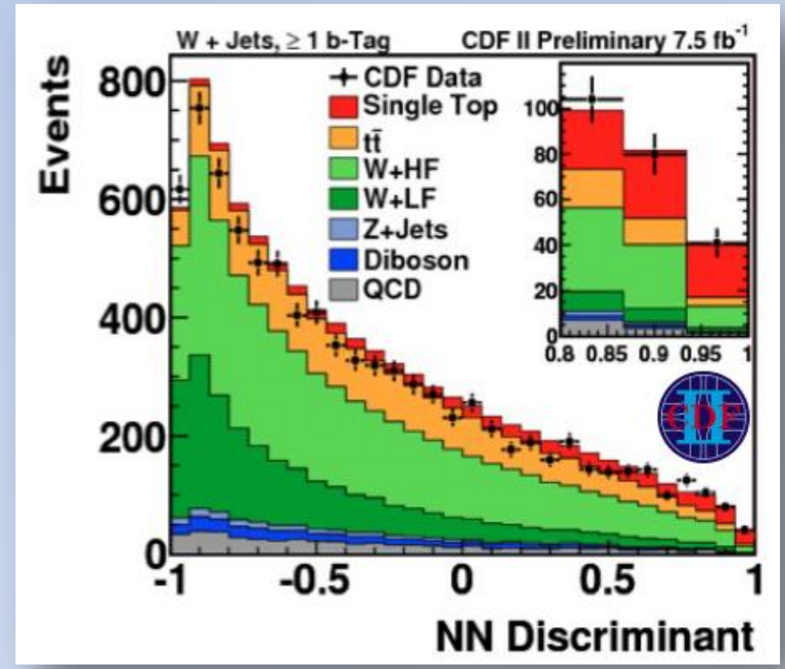
Combined (s+t) - channel analyses



SM: σ_{s+t} = 3.49 pb

- Using SM ratio between s- and t-channel
- Three MVA techniques combined to super-discriminants.
  One powerful neural network
- Statistical analysis:
  - Bayesian method

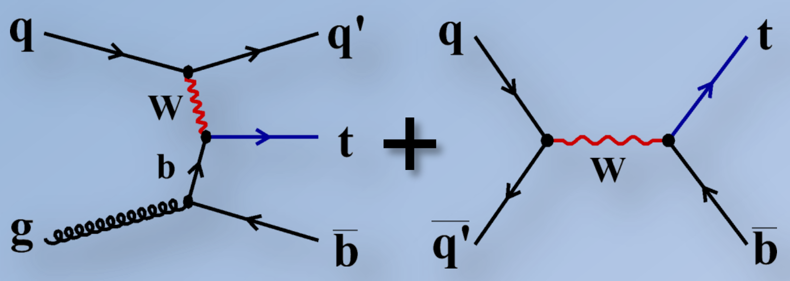




$\sigma_{s+t} = 3.43\ ^{+0.73}_{-0.74}$ (stat. + syst.) pb
relative unc.: +21% / -22%

$\sigma_{s+t} = 3.04\ ^{+0.57}_{-0.53}$ (stat. + syst.) pb
relative unc.: +19% / -17%

Combined (s+t) - channel analyses



SM: $\sigma_{s+t} = 3.49$ pb

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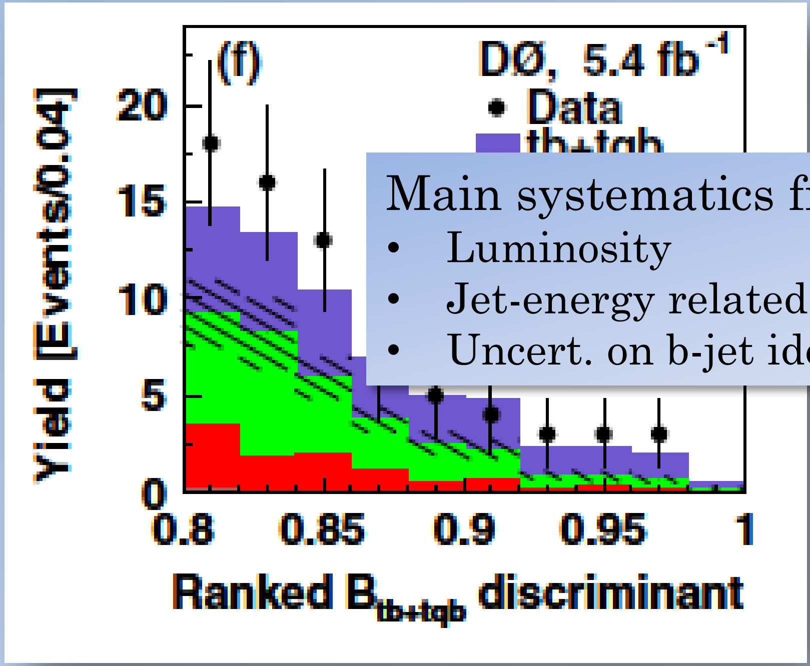

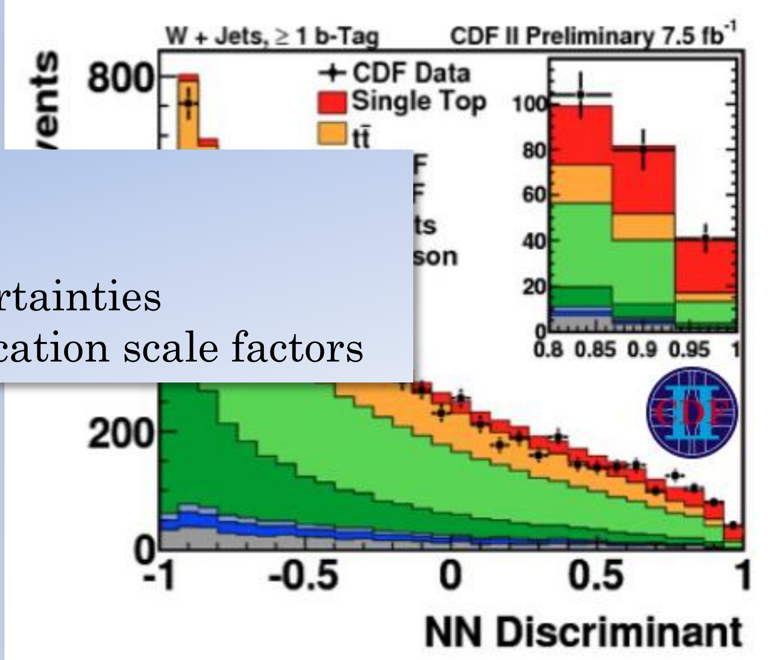

Main systematics from:
- Luminosity
- Jet-energy related uncertainties
- Uncert. on b-jet identification scale factors

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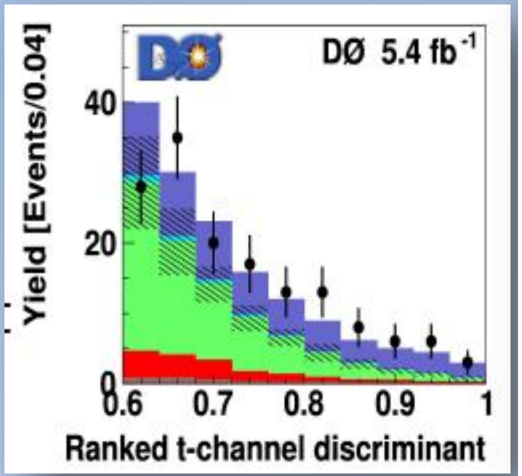
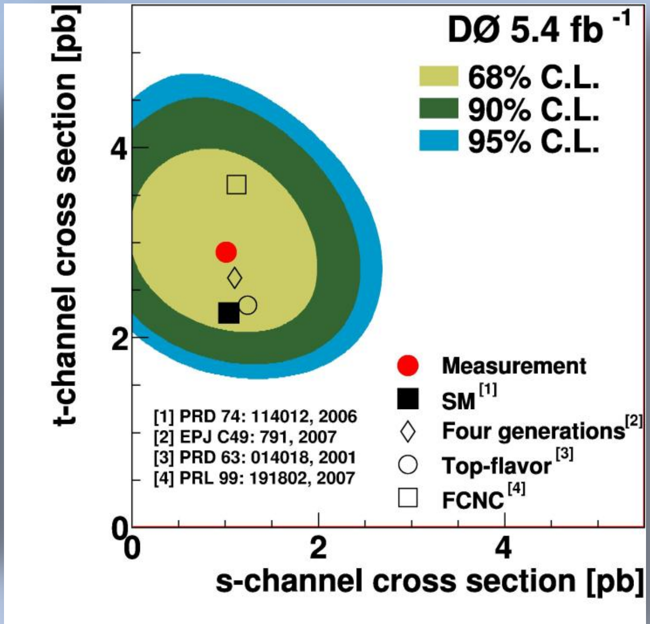
relative unc.: +21% / -22%

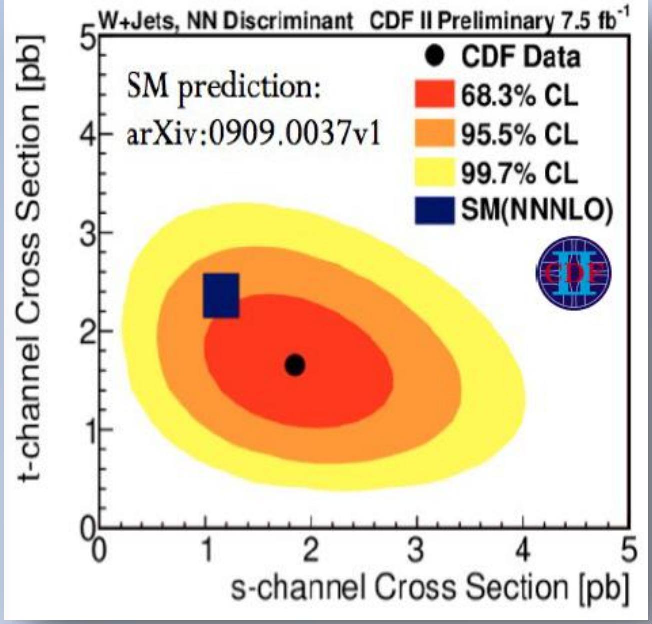
$\sigma_{s+t} = 3.04\,^{+0.57}_{-0.53}$ (stat. + syst.) pb
relative unc.: +19% / -17%

t- and s-channel @ Tevatron

- Measure both channels simultaneously
- Separate trainings for t- and s-channel (only D0)





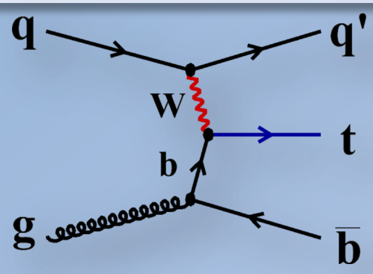


$\sigma_s = 0.98 \pm 0.63$ pb (rel. unc.: ± 64%)
$\sigma_t = 2.90 \pm 0.59$ pb (rel. unc.: ± 20%)
First observation of t-channel alone with 5.5 σ

$\sigma_s = 1.81\ ^{+0.63}_{-0.58}$ pb
relative unc.: +35% / -32%

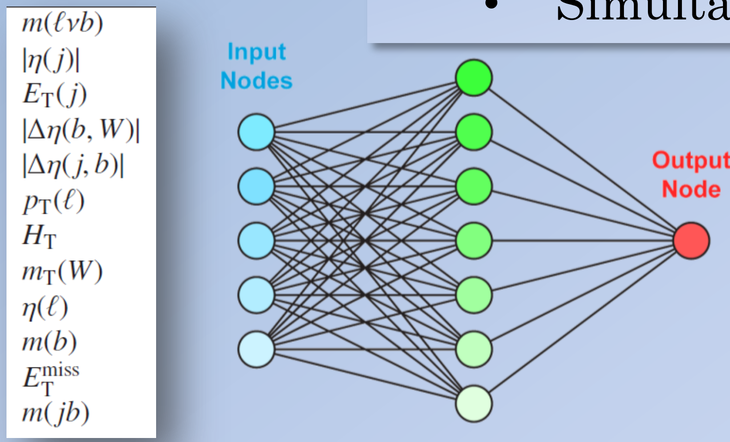
$\sigma_t = 1.49\ ^{+0.47}_{-0.42}$ pb
relative unc.: +32% / -28%

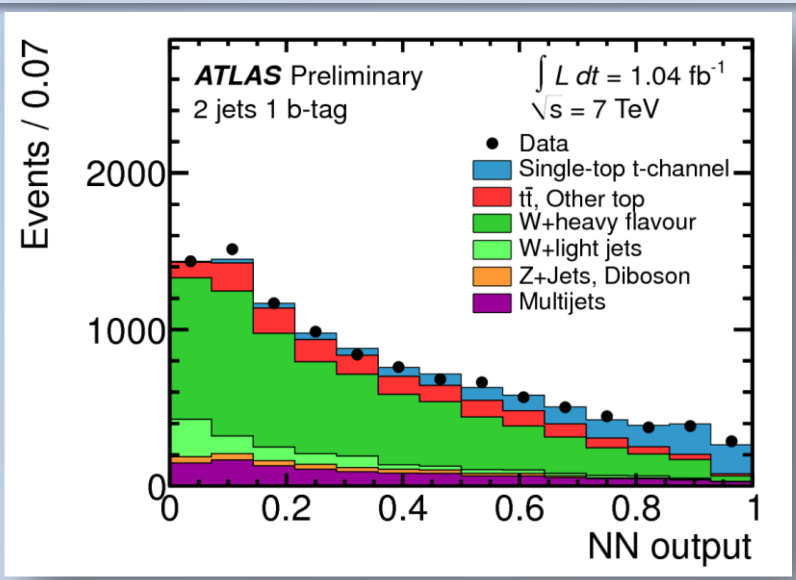
t-channel @ LHC



SM: $\sigma_t = 64.6$ pb

- Uses 1.04 fb^{-1} of 2011 data set.
- Neural Network based discriminant.
- Statistical analysis:
  - Maximum likelihood fit using the full output distribution
  - Simultaneous determination of background rates





Observed cross section:

$\sigma_t = 83 \pm 4$ (stat.) $^{+20}_{-19}$ (syst.) pb

relative unc.: +24% / -23%

From cut based analyses:

$\sigma(t) = 59 \pm 6$ (stat.) $^{+17}_{-16}$ (syst.) pb

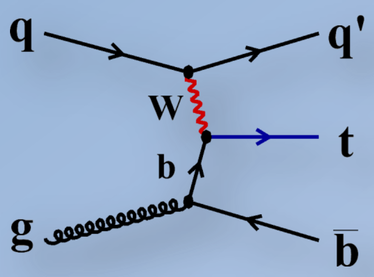
$\sigma(\bar{t}) = 33 \pm 5$ (stat.) $^{+12}_{-11}$ (syst.) pb

Main systematics from:

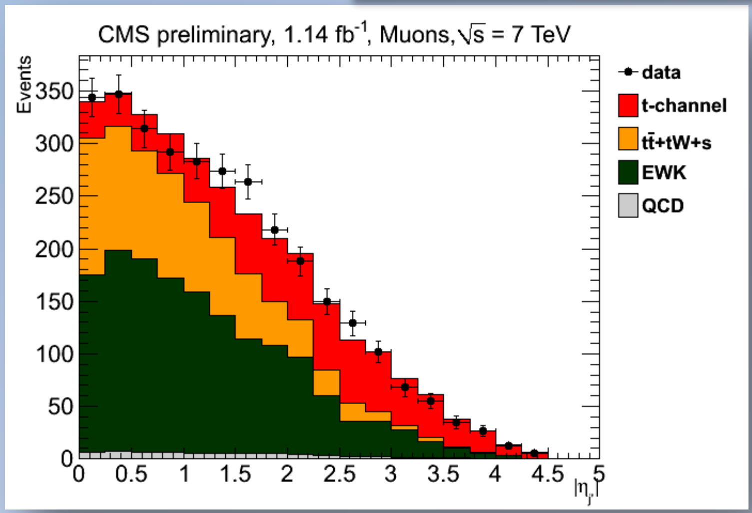
- ISR / FSR modeling ±14%
- b-tagging efficiency ±13%

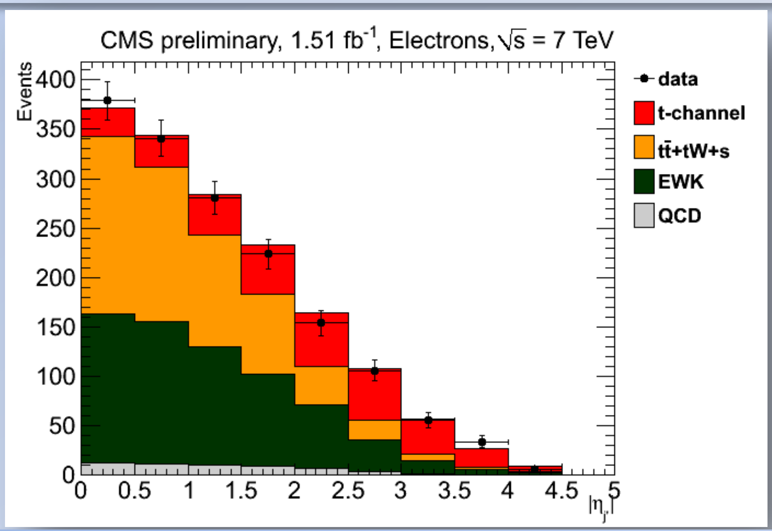
Observed significance 7.2 σ

t-channel @ LHC



- Uses 1.14 fb^{-1} (muons), 1.51 fb^{-1} (electrons) of 2011 data
- Cut on reconstructed top-quark mass:
  $130 < m(l\nu b) < 220$ GeV
- Single discriminate variable $|\eta|$ light jet
- Main background (W+jets) determined in side band
- Statistical analysis:
  - Maximum likelihood fit to $|\eta|$ light jet





Main systematics from:

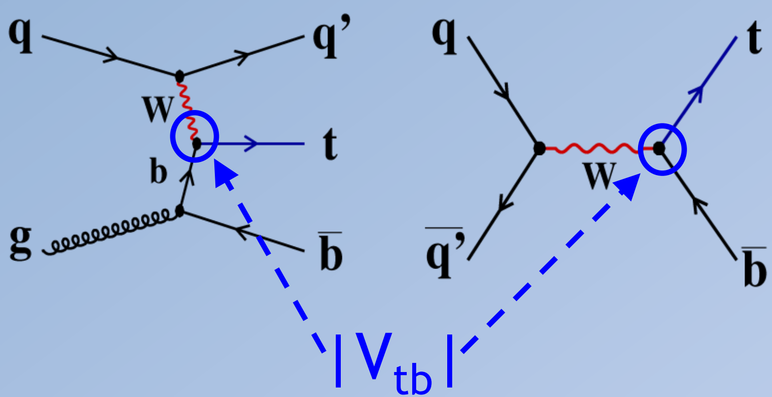
- Jet energy scale +9.2% / -6.2%
- W+heavy flavour extr. ±7.1%
- Q^2 - tchannel ±7.0%

Observed cross section:

$$\sigma_t = 70.2 \pm 5.2\,(\text{stat.}) \pm 10.4\,(\text{syst.}) \pm 3.4\,(\text{lumi.})\,\text{pb}$$

relative unc.: ± 17%

Vtb measurements



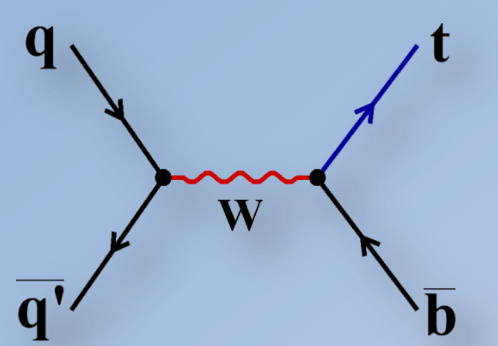
- Using cross section result measure $|V_{tb}|$
- Assume Standard Model (V-A) coupling and $|V_{tb}| >> |V_{ts}|, |V_{td}|$
  (Consistent with BR($t \rightarrow Wb$) measurements)

$$|V_{tb,meas}|^2 = \frac{\sigma_{meas}}{\sigma_{SM}} \cdot |V_{tb,SM}|^2$$

Experiment	Channel	$\vert V_{tb} \vert$	rel. exp. precision
CDF & DØ discovery ($3.2\ fb^{-1}$ & $2.3\ fb^{-1}$)	s+t channel	0.88 ± 0.07 (exp.) ± 0.07 (theo.)	8.0%
CDF ($7.5 fb^{-1}$)	s+t+Wt	0.96+-0.09 (exp.) +- 0.05 (theo.)	9.4%
DØ ($5.4\ fb^{-1}$)	t-channel	$1.02\ ^{+0.10}_{-0.11}$ (exp. + theo.)	+8.7% / -9.9%
CMS ($1.14\ fb^{-1}$ / $1.51\ fb^{-1}$)	t-channel	1.04 ± 0.09 (exp.) ± 0.02 (theo.)	8.7%
ATLAS ($1.04\ fb^{-1}$)	t-channel	$1.13\ ^{+0.14}_{-0.13}$ (exp. + theo.)	11.9%

Combination of CMS & ATLAS results are in progress.

s-channel – analysis

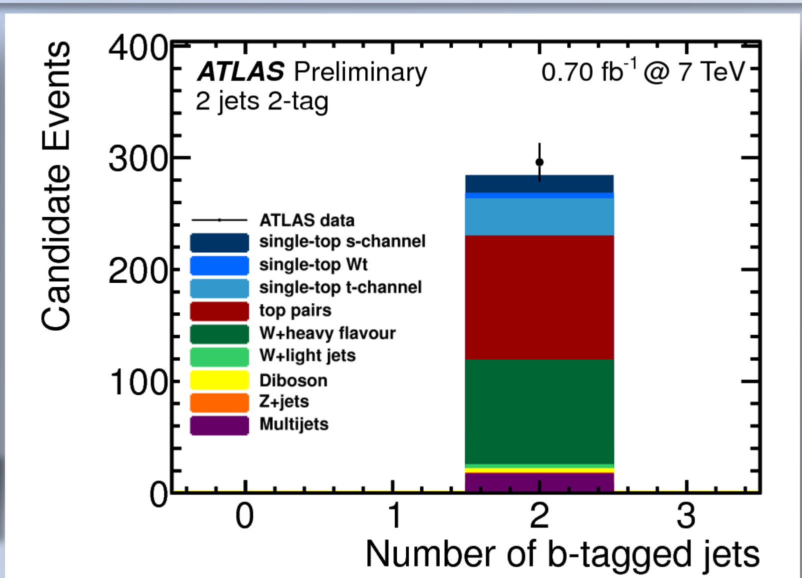


ATLAS-CONF-2011-118

- Smallest cross section of single top processes
- First analysis @ ATLAS with 0.7 pb^{-1}
- Cut based analyses
- Rate of main background (W+jets) estimated in data
- Statistical analysis: Profile likelihood

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

Cuts are optimized including systematics



Main systematics from (effect on xs unc.):

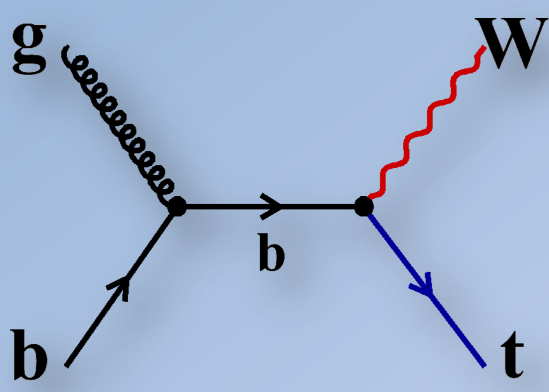
- MC Statistics ± 70%
- MC generator modeling +20%/-60%
- Luminosity ± 50%

Observed limit @ 95% C.L.

$\sigma_{s\text{-channel}} < 26.5$ pb

SM: $\sigma_s = 4.6$ pb

Wt channel



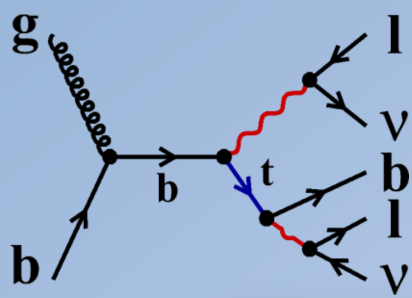
Two channels according to W decay modes:

- **Dilepton channel**
  both Ws: $W \to e\nu$ or $W \to \mu\nu$
  $\to$ 2 charged leptons, E_T^{miss}, 1 b-jet

- **Lepton + jets channel**
  $W \to e\nu$ or $W \to \mu\nu$ + $W \to qqbar$
  $\to$ 1 charged lepton, E_T^{miss},
  1 b-jet + 2 light quark jets

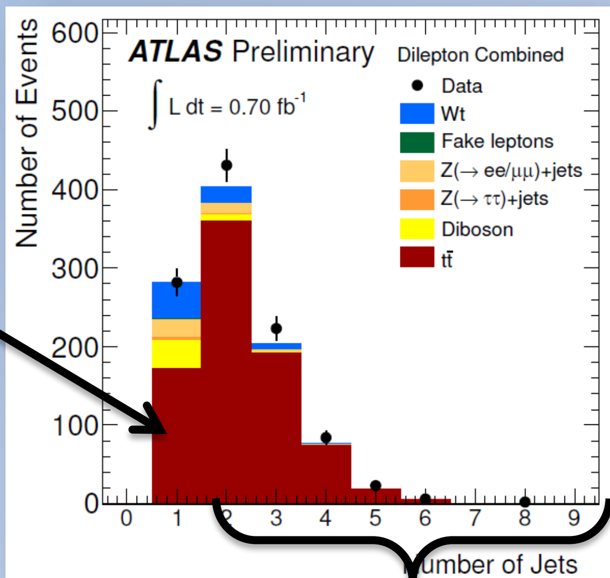
CONF note with 35 pb-1 (lepton+jets)
ATLAS-CONF-2011-027
CONF note with 0.70 fb-1 (dilepton)
ATLAS-CONF-2011-104
Physics Analysis Summary (dilepton)
CMS PAS TOP-11-022

Wt dilepton analysis @ ATLAS

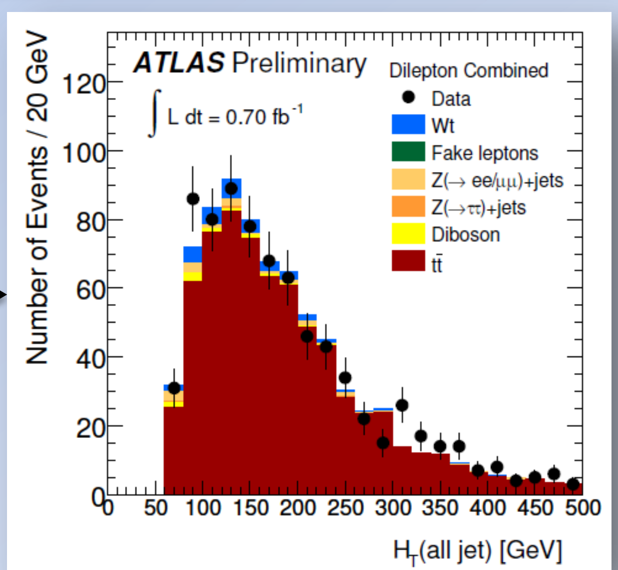


- Cut & count analysis
- Main background (ttbar) estimated using scale factor from side band
- Statistical analysis: Profile likelihood

Signal sample



Top-antitop background region



Main systematics from:

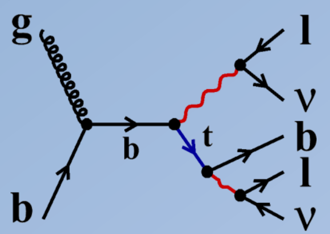
- Jet energy scale ±35%
- Jet energy resolution ±31%
- Jet reconstruction eff. ±31%

Observed cross section (significance 1.2σ):

$\sigma_{Wt} = 14.4\ ^{+5.3}_{-5.1}\ \text{(stat.)}\ ^{+9.7}_{-9.4}\ \text{pb}$

SM: $\sigma_t = 15.7$ pb

Wt dilepton analysis @ CMS

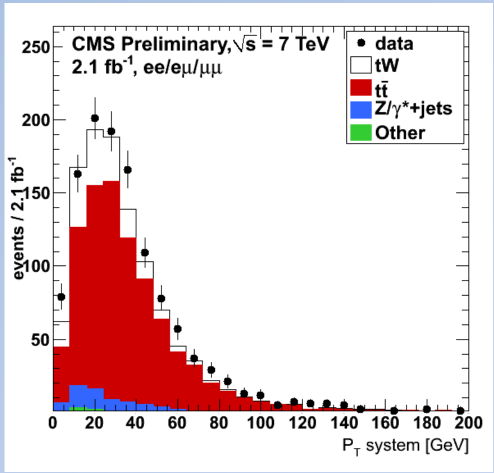


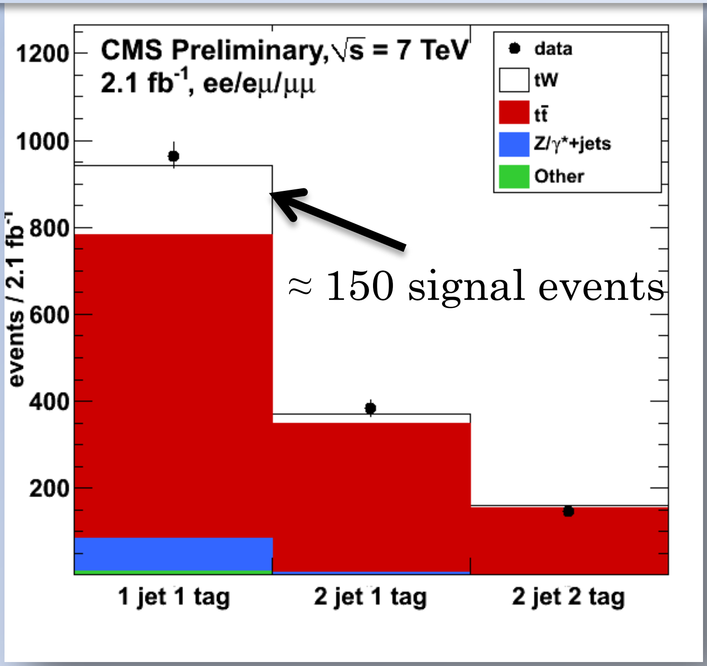
- Cut & count analysis
- Main background (ttbar) fitted simultaneously, together with b-tagging efficiency
- Statistical analysis: Profile likelihood

Additional cuts:

P_T system < 60 GeV

H_T > 160 GeV (only eμ channel)





Main systematics from:

- B-tagging
- Factorization/Renormalization scale
- DR/DS schema

Observed cross section :

$\sigma_{Wt} = 22\ ^{+9}_{-7}$ (stat.+syst.) pb

Significance 2.7σ

SM: σ_t = 15.7 pb

New physics searches

Previous analyses

- FCNC single top quark production
  - σ_{FCNC} < 17.3 pb @ 95% C.L.
  - BR($t \rightarrow ug$) < $5.7 \cdot 10^{-5}$, BR($t \rightarrow cg$) < $2.7 \cdot 10^{-4}$

  submitted to PLB: arXiv:1203.0529
- W'
  - m(W') > 863 .. 916 GeV *PLB 699, 145 (2011)*
  - m(W'_R) > 1.13 TeV
- Charged Higgs
  - m(H+) = 180–185 GeV and tan(β) = 20–70

    PRL 102, 191802 (2009)
- Monotop
  - σ < 0.5 pb @ 95% C.L.

    for a dark-matter particle mass of 0-150 GeV/c²

    arXiv:1202.5653
- Anomalous couplings
  - One-dimensonal limits assuming $|V_{tb} \cdot f_{L_V}| = 1$

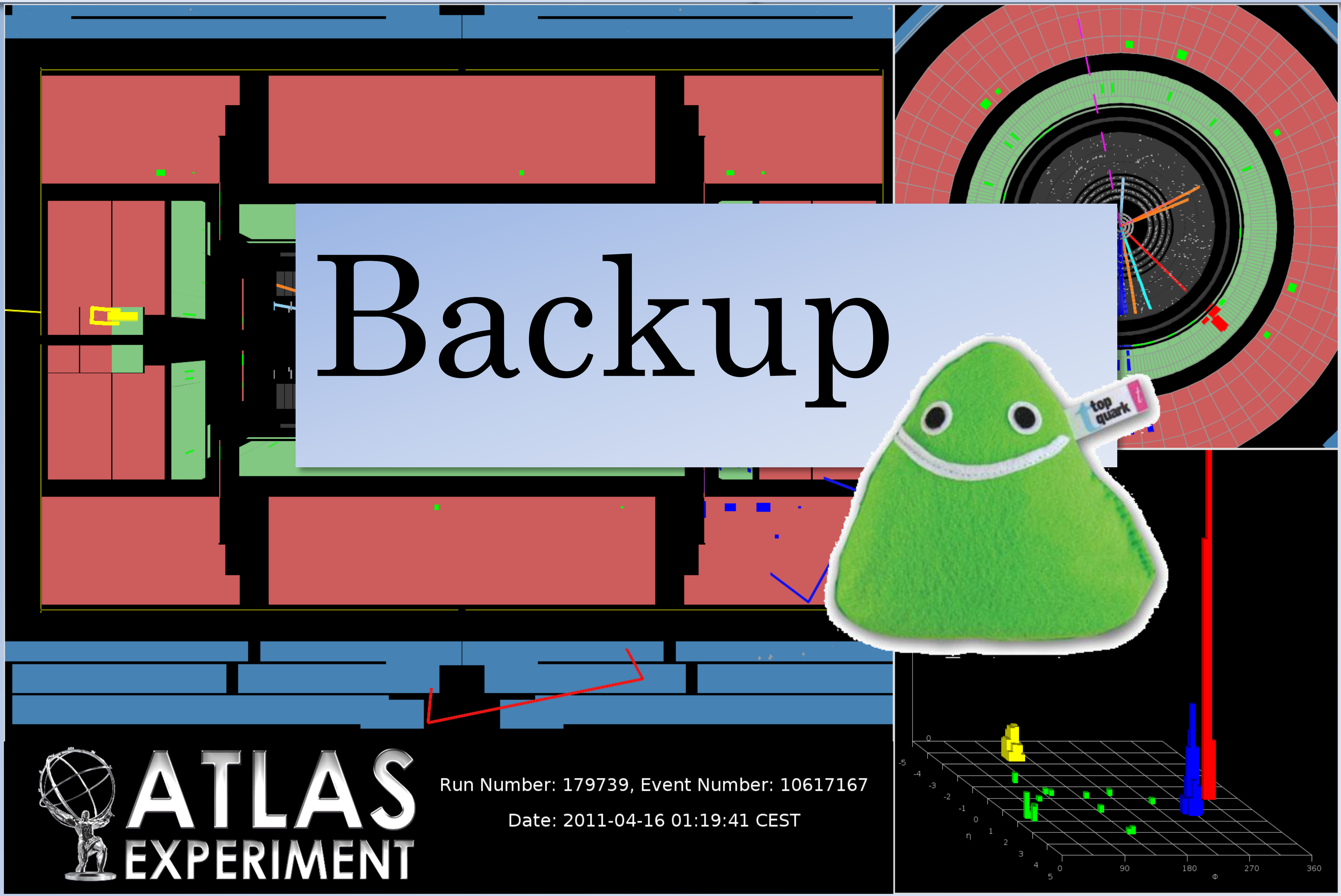
    $|V_{tb} \cdot f_{L_T}|^2 < 0.11$ $|V_{tb} \cdot f_{R_V}|^2 < 0.50$ $|V_{tb} \cdot f_{R_T}|^2 < 0.05$

    Phys.Lett. B708 (2012) 21-26

Summary / Conclusion

- Full suite of SM single top analyses performed
- All measurements are in agreement with the SM expectations
- Starting to enter the precision measurement regime
- Questions:
  - How to evaluate generator uncertainties?
    - 4-flavour vs. 5 flavor schema?
  - We would like to have an updated version of the 2D comparison made by Tait&Yuan 2000 of s-channel vs. t-channel including new physics models there.
  - Which precision measurements would you like to see to help nail down predictions for other /new physics.

Backup



Backup
ATLAS EXPERIMENT
Run Number: 179739, Event Number: 10617167
Date: 2011-04-16 01:19:41 CEST
top quark

Monte carlo samples

Process	CDF	D0	ATLAS	CMS
t-channel	Powheg+ Pythia	Comphep+Pythia	AcerMC+Pythia Wt: MC@NLO	Powheg+Pythia
Wt	Powheg+ Pythia		AcerMC+Pythia Wt: MC@NLO	Powheg+Pythia
s-channel	Powheg+ Pythia	Comphep+Pythia	AcerMC+Pythia Wt: MC@NLO	Powheg+Pythia
tt	Pythia	Alpgen+Pythia	MC@NLO + Herwig	Madgraph+Pythia
W+jets	Alpgen +Pythia	Alpgen+Pythia	Alpgen+Herwig	Madgraph+Pythia Data
Z+jets	Alpgen +Pythia	Alpgen+Pythia	Alpgen+Herwig	Madgraph+Pythia
WW,WZ,ZZ	Pythia	Pythia	Herwig	Pythia