Single Top Production at CMS

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On behalf of the CMS Collaboration

(CIEMAT – Madrid)

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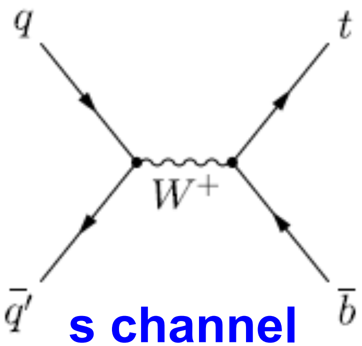
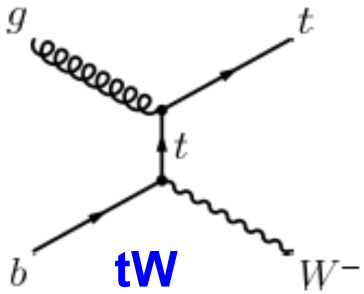
Introduction

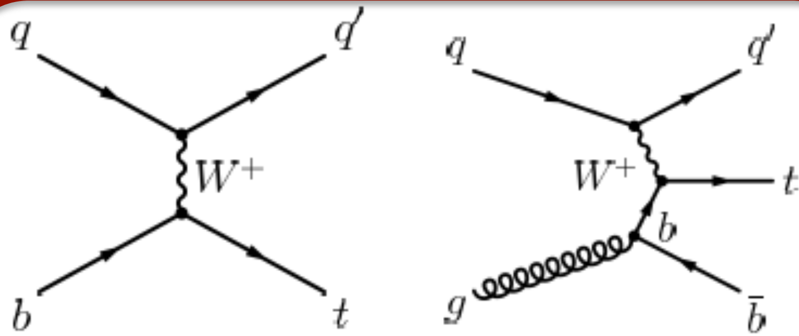
Possible ways of producing single-top in pp collisions:



s channel
(4 pb @ 7 TeV)



tW
(11 pb @ 7 TeV)



t channel SM NLO: 62 pb @ 7 TeV

The analysis: measurement of t-channel single top production

Other channels: treated as background

Use: top leptonic decay channels on CMS data at 7 TeV (36/pb)

Probing top electroweak interactions on new energy regime: x-section

- Also: access to V_{tb} coupling
- Profit from V-A structure of EWK interaction: tops almost 100% polarized
  - Polarization accessible via decay products

Analysis strategy

2D: angular analysis

2D fit to angular properties of the signal

Main backgrounds have very similar shapes

Result is robust against background composition

Minimum model dependence

BDT: multivariate analysis

Uses boosted decision tree

Exploits prior assumptions about the signal

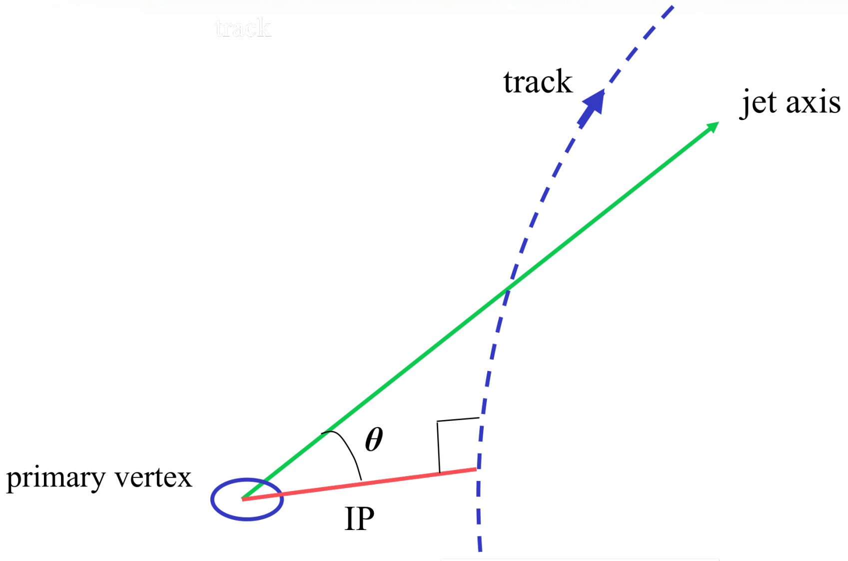
Uses much of the available event information (many variables)

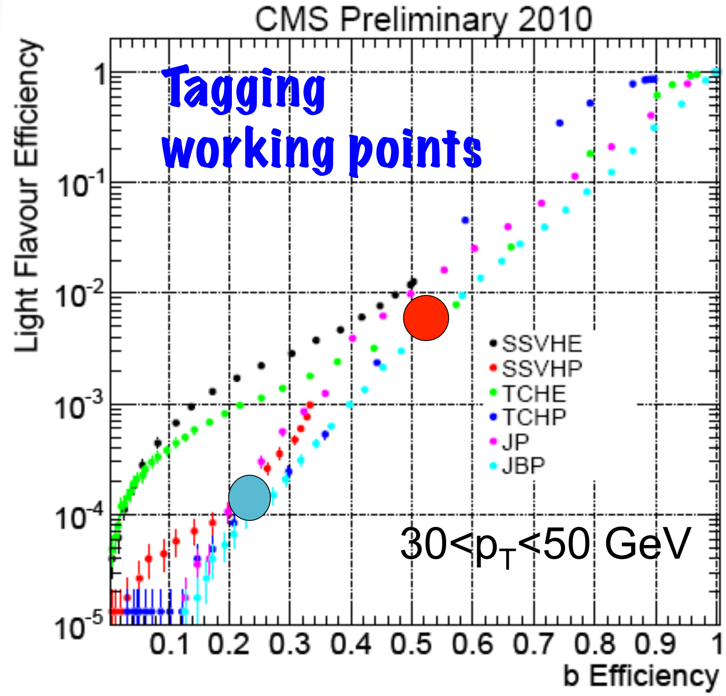
Maximum sensitivity

Final result: combination of the two analyses

Event selection + background

b-tagging
Common for both analysis





"Track counting tag" based on Impact Parameter (IP):

Tag → requirement on IP significance of the Nth- track: $IP/\sigma_{IP} > Tag_{cut}$

- **High Purity**: (N=3 ●) ~ low light-jets contamination, lower b-tag efficiency
- **High Efficiency**: (N=2 ●) ~ larger contamination, larger b-tag efficiency

Event selection

(*) Lepton RelIso = (sum trkE+calE)/p_T in a cone R=0.3 around the lepton axis

2D : robustness

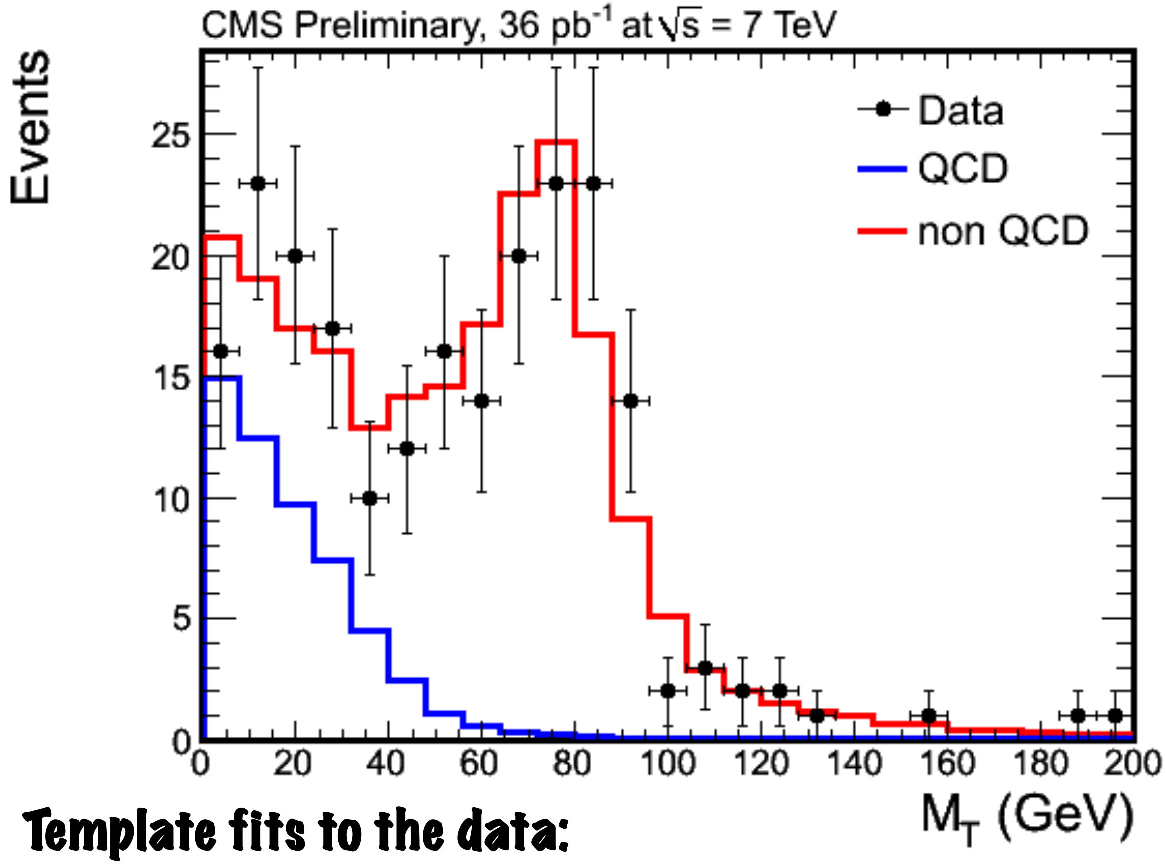
- **Exactly one isolated lepton:**
  - ✓ muon: p_T>20 GeV
    electron: p_T>30 GeV
  - ✓ muon: RelIso < 0.05 (*)
    electron: RelIso < 0.1
- **Exactly 2 jets (p_T>30 GeV, |η|<5)**
  - ✓ Exactly one b-tagged jet *(high purity tagger)*
  - ✓ Event vetoed if 2nd b-tagged jet is found *(high eff tagger)*
- **W transverse mass:**
  - ✓ muon ch: $M_T(W)$>40 GeV
  - ✓ electron ch: $M_T(W)$>50 GeV

BDT: efficiency

- **Exactly one isolated lepton:**
  - ✓ muon: p_T>20 GeV
    electron: p_T>30 GeV
  - ✓ muon: RelIso < 0.1 (*)
    electron: RelIso < 0.1
- **Exactly 2 jets (p_T>30 GeV, |η|<5)**
  - ✓ Exactly one b-tagged jet *(high purity tagger)*
  - ✓ $\Delta\phi$(j1,j2)<3 *(to avoid poor data/MC agreement in the back-to-back region)*
- **W transverse mass:**
  - ✓ muon ch: $M_T(W)$>40 GeV
  - ✓ electron ch: $M_T(W)$>50 GeV

Background estimation using data

When multi-jet events fake a reconstructed t→Wb



QCD (multijets) background

W transverse mass:
no jacobian peak on QCD sample

→Adjust signal/bkg using shape

→ N(data) = aN(QCD) + bN(signal)

Template fits to the data:

signal shape from Monte Carlo simulation
in the signal: real leptons are isolated

QCD shape: from data, sample selected failing analysis isolation criteria : 0.2<RelIso<0.5
reconstructed leptons failing isolation criteria are most probably jets faking the signal

Background estimation

When W+light -jet events fake a reconstructed t→Wb

W+light jets background

- Same procedure as for QCD - used to estimate **W+light jets in 2D analysis**
- **(In BDT multivariate analysis, W+light bkg** treated as nuisance parameter in the fit**)**

Other backgrounds

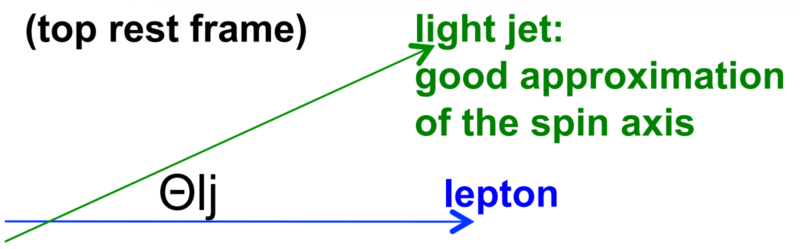
- **Background estimation from all other sources:**

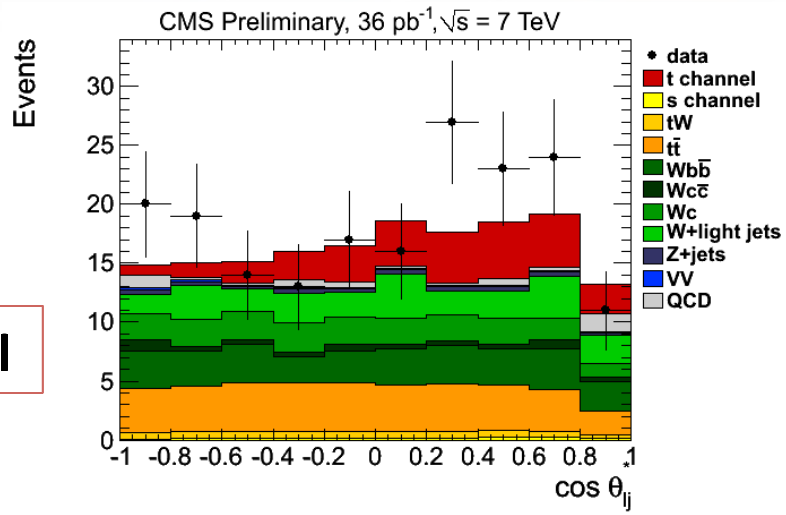
  shapes and relative contributions from Monte Carlo simulation

  normalization estimated individually in the two analyses

2D analysis

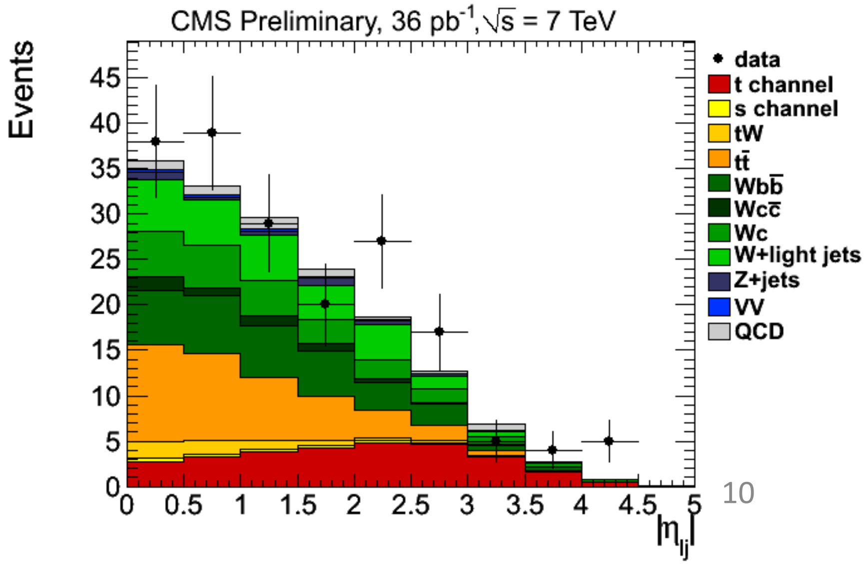
2D analysis

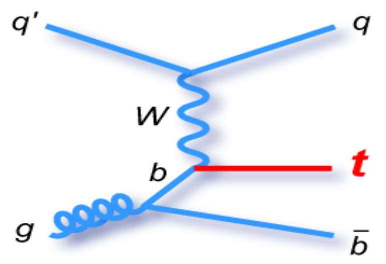




Angle Θ_{lj} : flat bkg , increasing signal

Rapidity η_{lj} : decreasing bkg, increasing signal





Shown here for mu+e channels together

Individual distributions very similar (backup)

2D analysis

- **In each channel:** fit simultaneously Θlj and η distributions
- **Free parameters: signal and background normalizations**
- **Once number of signal events N_s is determined,**

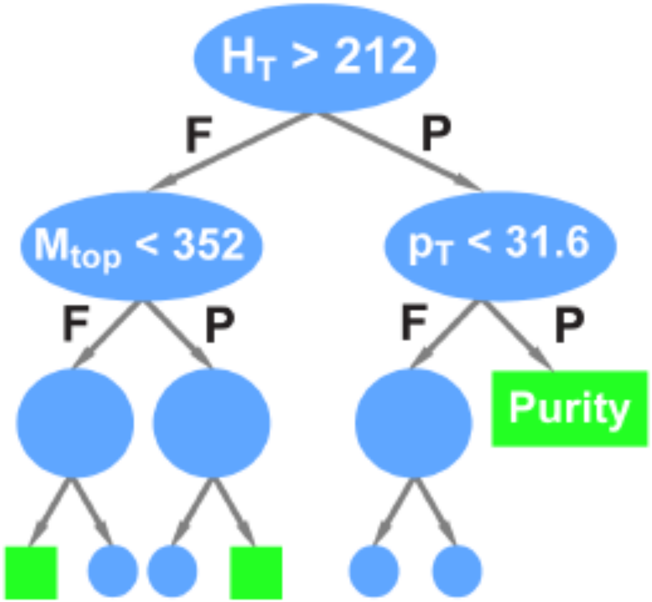
$$\sigma = \frac{N_s}{\epsilon \cdot B(t \to \ell \nu b) \cdot L}$$

  - efficiencies estimated from Monte Carlo simulation
  - $B(t \to l\nu b) = 0.1080$
  - $\mathscr{L} = 36.1\ pb^{-1}$

Boosted Decision Tree analysis

Boosted Decision Trees

Decision Tree (example):



Signal-like event: weight=+1

Background-like: weight=-1

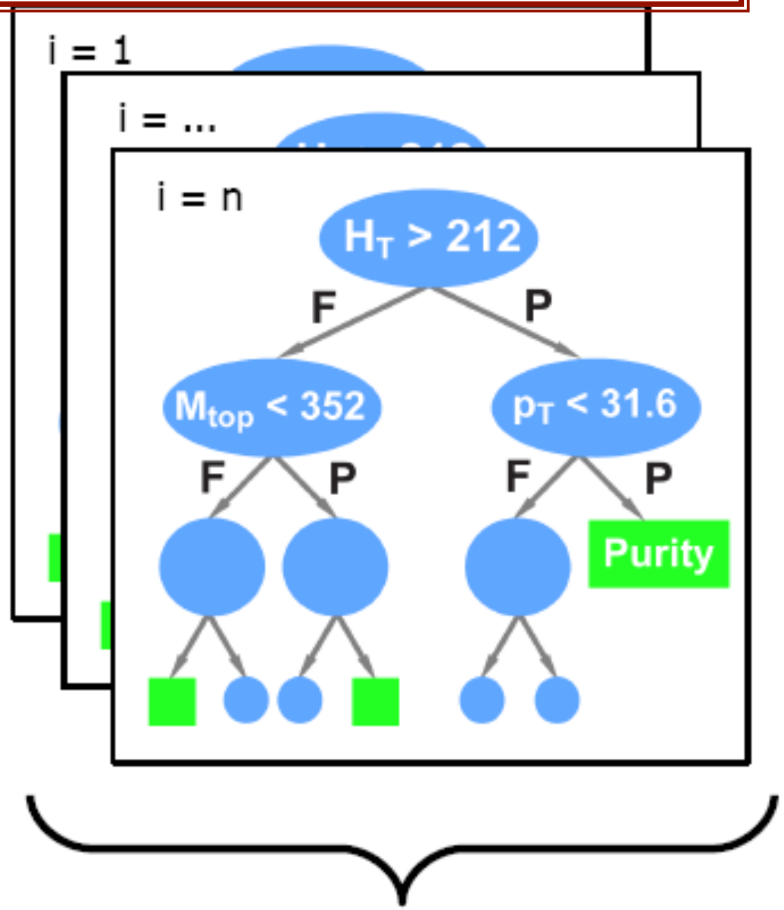
(cuts are for illustration only)

Reweight misclassified events

→

n boosting Cycles

(weight trees by their error rates)



weighted majority vote

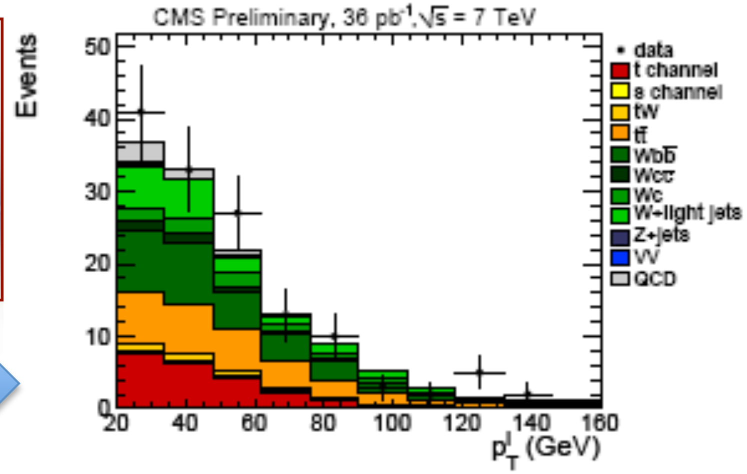
$$y_{Boost}(\vec{x}) = 1/N_{trees} \cdot \sum_{i}^{N_{trees}} ln(\alpha_i) \cdot h_i(\vec{x})$$

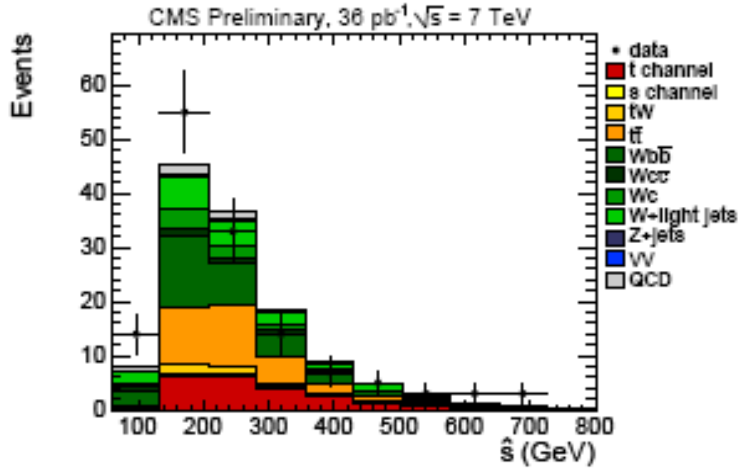
BDT inputs

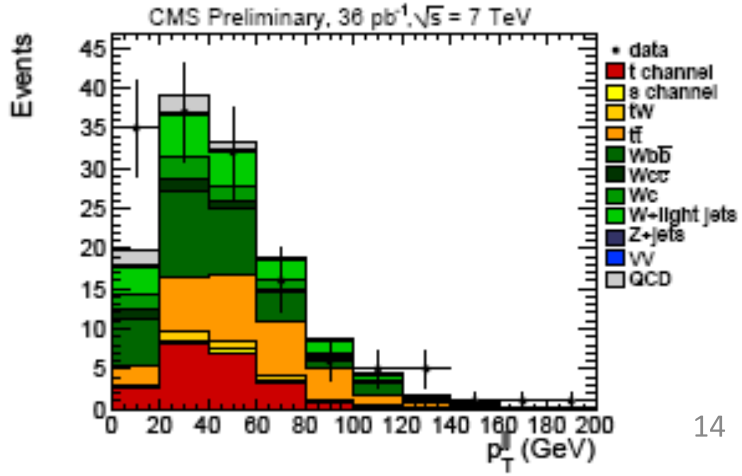
37 inputs in 5 categories:

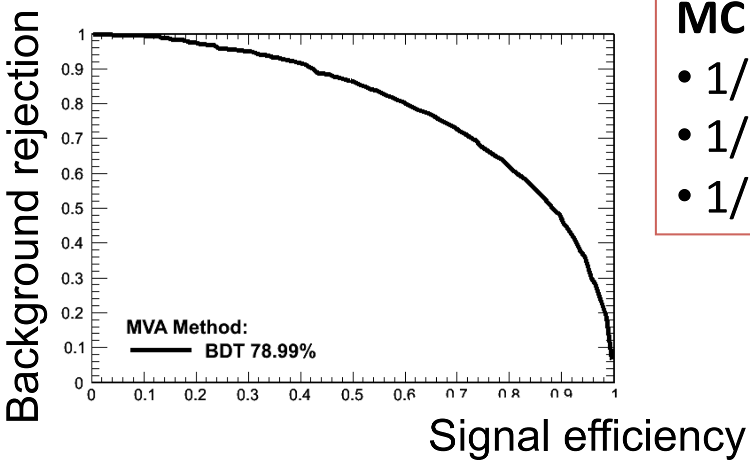
Examples

- **Kinematics** of final-state objects
- **Correlations** of final-state objects
- **Properties** of reconstructed **W, t, t+q**
- **Angular distribs.** of light jet wrt W,t,t+q
- **Global event properties**



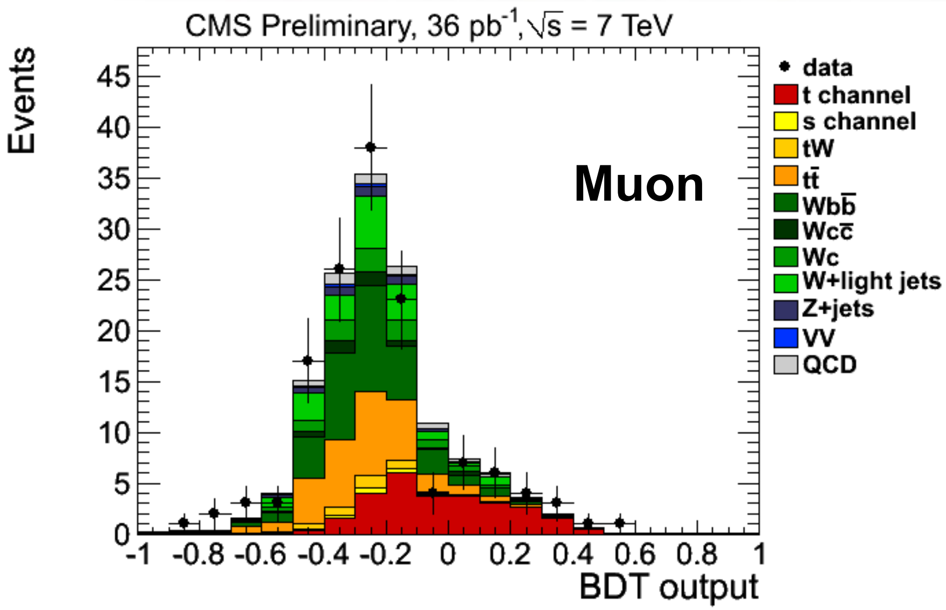


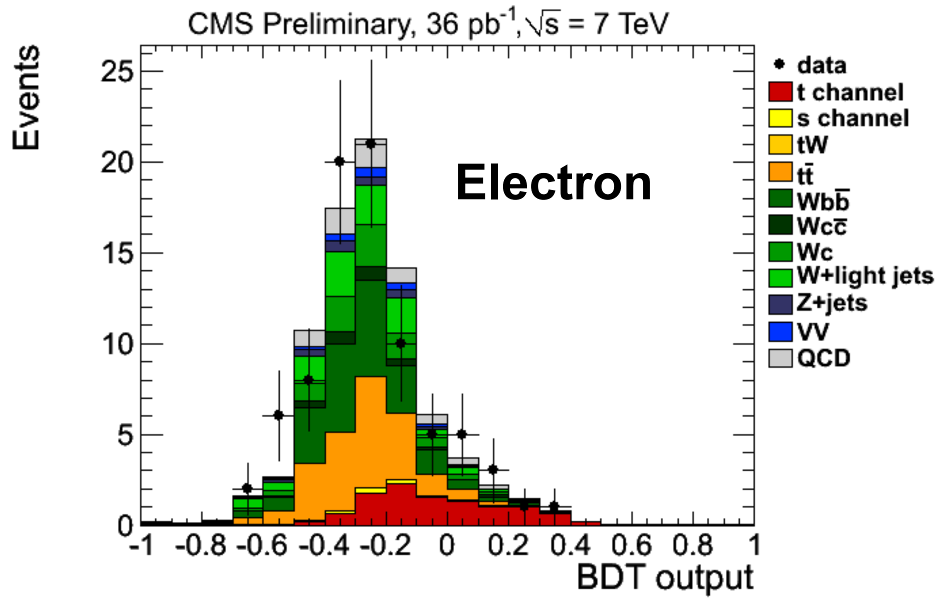


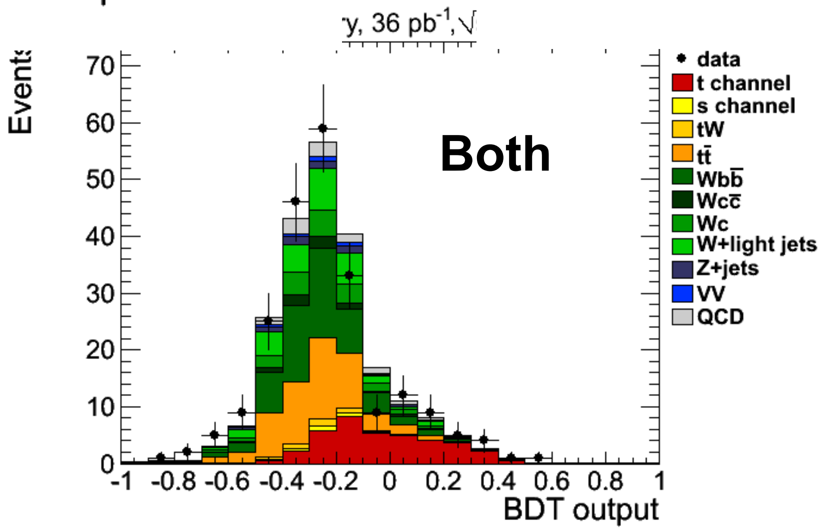


MC sample split:
- 1/3 evaluation
- 1/3 BDT training
- 1/3 testing output

BDT output


CMS Preliminary, 36 pb^{-1}, $\sqrt{s}$ = 7 TeV
Events
Muon
data
t channel
s channel
tW
$t\bar{t}$
$Wb\bar{b}$
$Wc\bar{c}$
Wc
W+light jets
Z+jets
VV
QCD
BDT output


CMS Preliminary, 36 pb^{-1}, $\sqrt{s}$ = 7 TeV
Events
Electron
data
t channel
s channel
tW
$t\bar{t}$
$Wb\bar{b}$
$Wc\bar{c}$
Wc
W+light jets
Z+jets
VV
QCD
BDT output


Events
Both
data
t channel
s channel
tW
$t\bar{t}$
$Wb\bar{b}$
$Wc\bar{c}$
Wc
W+light jets
Z+jets
VV
QCD
BDT output

Results

Results

Signal and Background yields at 36/pb

Process	2D, μ channel	2D, e channel	BDT, μ channel	BDT, e channel
single top, t channel	17.6 ± 0.7 (†)	11.2 ± 0.4 (†)	17.6 ± 0.7 (†)	10.7 ± 0.5 (†)
single top, s channel	0.9 ± 0.3	0.6 ± 0.2	1.4 ± 0.5	1.0 ± 0.3
single top, tW	3.1 ± 0.9	2.4 ± 0.7	3.8 ± 1.1	< 0.1
WW	0.29 ± 0.09	0.23 ± 0.07	0.32 ± 0.10	0.23 ± 0.07
WZ	0.24 ± 0.07	0.17 ± 0.05	0.33 ± 0.10	1.5 ± 0.4
ZZ	0.018 ± 0.005	0.011 ± 0.003	0.020 ± 0.006	< 0.1
$W+$ light partons	18.2 ± 5.5	11.6 ± 2.3	8.4 ± 4.2	7.0 ± 3.5
$Z + X$	1.7 ± 0.5	1.6 ± 0.3	0.7 ± 0.2	0.05 ± 0.03
QCD	0.6 ± 0.3	$2.6^{+3.4}_{-2.6}$	4.9 ± 2.5	5.3 ± 5.3
$VQ\bar{Q}$	20.4 ± 10.2	14.1 ± 7.1	17.6 ± 8.8	11.7 ± 5.8
Wc	$12.9\ ^{+12.9}_{-6.5}$	$9.4\ ^{+9.4}_{-4.7}$	$9.2\ ^{+9.2}_{-4.6}$	$5.9\ ^{+5.9}_{-2.9}$
$t\bar{t}$	20.3 ± 3.6	15.6 ± 2.8	34.9 ± 4.9	22.9 ± 3.2
Total background	78.6 ± 15.2	58.4 ± 11.0	82.4 ± 13.1	55.9 ± 10.2
Signal + background	96.2 ± 15.3	69.6 ± 11.0	100.0 ± 13.2	66.6 ± 10.2
Data	112	72	139	82

Results

Systematic uncertainties

uncertainty	correlation	impact on 2D −	2D +	BDT −	BDT +
statistical only	60	52		39	
shared shape/rate uncertainties:					
ISR/FSR for $t\bar{t}$	100	−1.0	+1.5	< 0.2	< 0.2
Q^2 for $t\bar{t}$	100	+3.5	−3.5	+0.3	−0.4
Q^2 for V+jets	100	+5.7	−12.0	+2.6	−4.5
Jet energy scale	100	−8.8	+3.6	−5.1	+1.2
b tagging efficiency	100	−19.6	+19.8	−15.2	+14.6
MET (uncl. energy)	100	−5.7	+3.7	−3.9	−0.5
shared rate-only uncertainties:					
$t\bar{t}$ (±14%)	100	+2.0	−1.9	+0.5	−0.6
single top s (±30%)	100	−0.4	+0.5	−0.4	+0.4
single top tW (±30%)	100	+1.1	−1.0	< 0.2	< 0.2
$Wb\bar{b}$, $Wc\bar{c}$ (±50%)	100	−3.0	+2.9	+1.7	−1.9
Wc ($^{+100\%}_{-50\%}$)	100	−3.0	+6.1	−2.4	+4.4
Z+jets (±30%)	100	−0.6	+0.7	+0.4	−0.2
electron QCD (BDT: ±100%, 2D: $^{+130\%}_{-100\%}$)	50	+2.9	−3.7	−1.7	+1.7
muon QCD (BDT: ±50%, 2D: ±50%)	50	< 0.2	< 0.2	−2.1	+2.1
signal model	100	−5.0	+5.0	−4.0	+4.0
BDT-only uncertainties:					
electron efficiency (±5%)	0	—	—	−1.4	+1.4
muon efficiency (±5%)	0	—	—	−3.6	+3.5
V+jets (±50%)	0	—	—	−1.5	< 0.2
2D-only uncertainties:					
muon W+light (±30%)	0	−1.4	+1.4	—	—
electron W+light (±20%)	0	−0.6	+0.7	—	—
W+light model uncertainties	0	−5.4	+5.4	—	—

b-tagging with 36/pb:

~20% uncertainty 2D
~15% uncertainty BDT

b-tagging with 0.5/fb:

Secondary-Vertex – based taggers instead of Track-Counting (?)

. Needs more statistics
. Stable against pile-up
. Better efficiency :: purity
. More precision

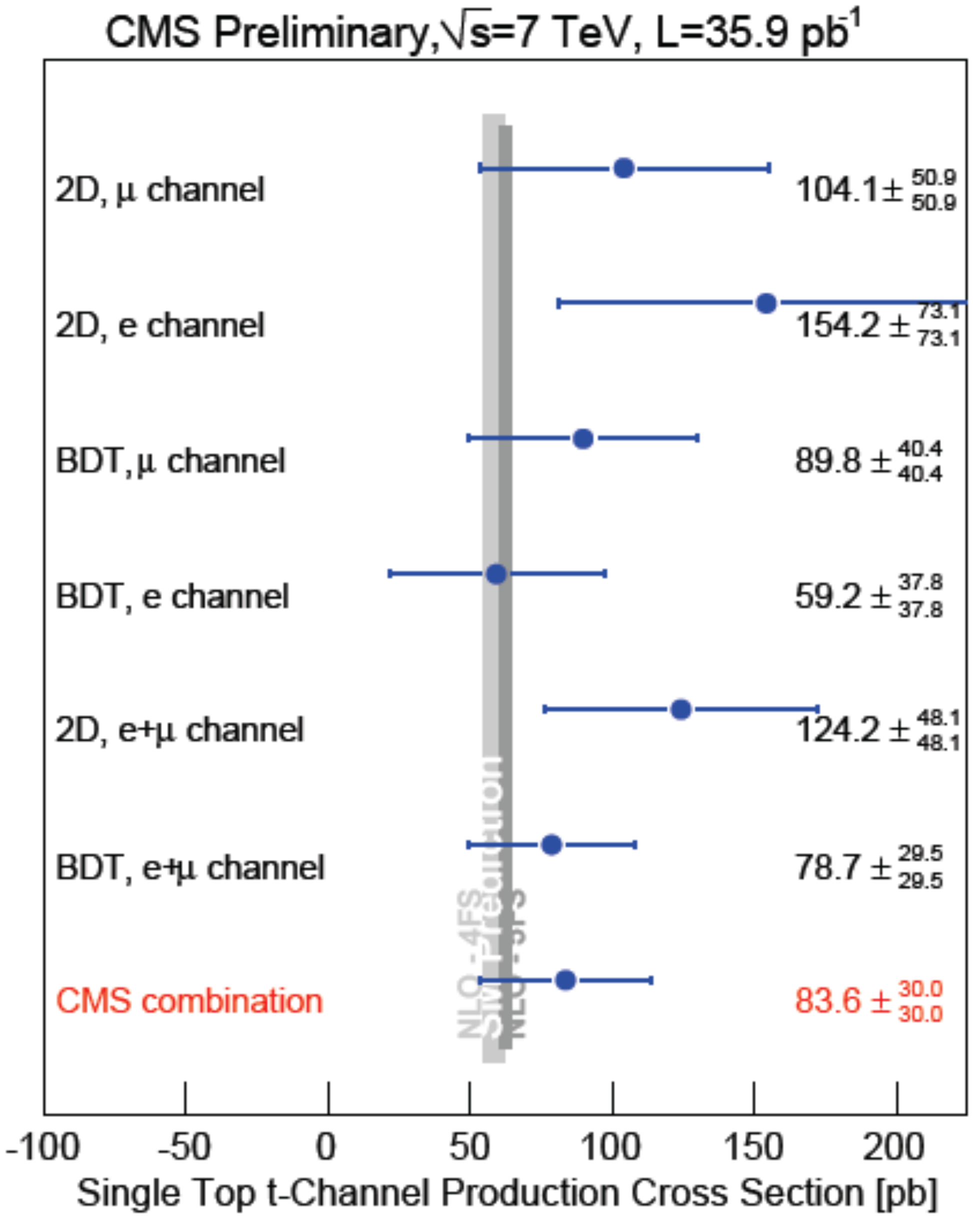
There is still room for improvement in the new data

Results

Significances

Analysis, channel	expected	observed
2D, μ-channel	$1.7^{+1.1}_{-1.0}$	2.5
2D, e-channel	$1.3^{+1.0}_{-1.1}$	3.1
2D, combined	$2.1^{+1.0}_{-1.1}$	3.7
BDT, μ-channel	$2.4^{+0.9}_{-1.0}$	3.1
BDT, e-channel	2.0 ± 1.0	1.9
BDT, combined	$2.9^{+1.0}_{-0.9}$	3.5

Results



Limits on $|V_{tb}|$:

Unconstrained measurement:

Assumption: $|V_{td}|,|V_{ts}| \ll |V_{tb}|$

$\Rightarrow$ BR($t \rightarrow b$)~1

$\Rightarrow$ **$|V_{tb}|^2 = \sigma(exp)/\sigma(SM)$**

$|V_{tb}|=1.16\pm0.22(exp)\pm0.02(th.)$

Constrained limit:

(flat prior $0 \leq |V_{tb}|^2 \leq 1$)

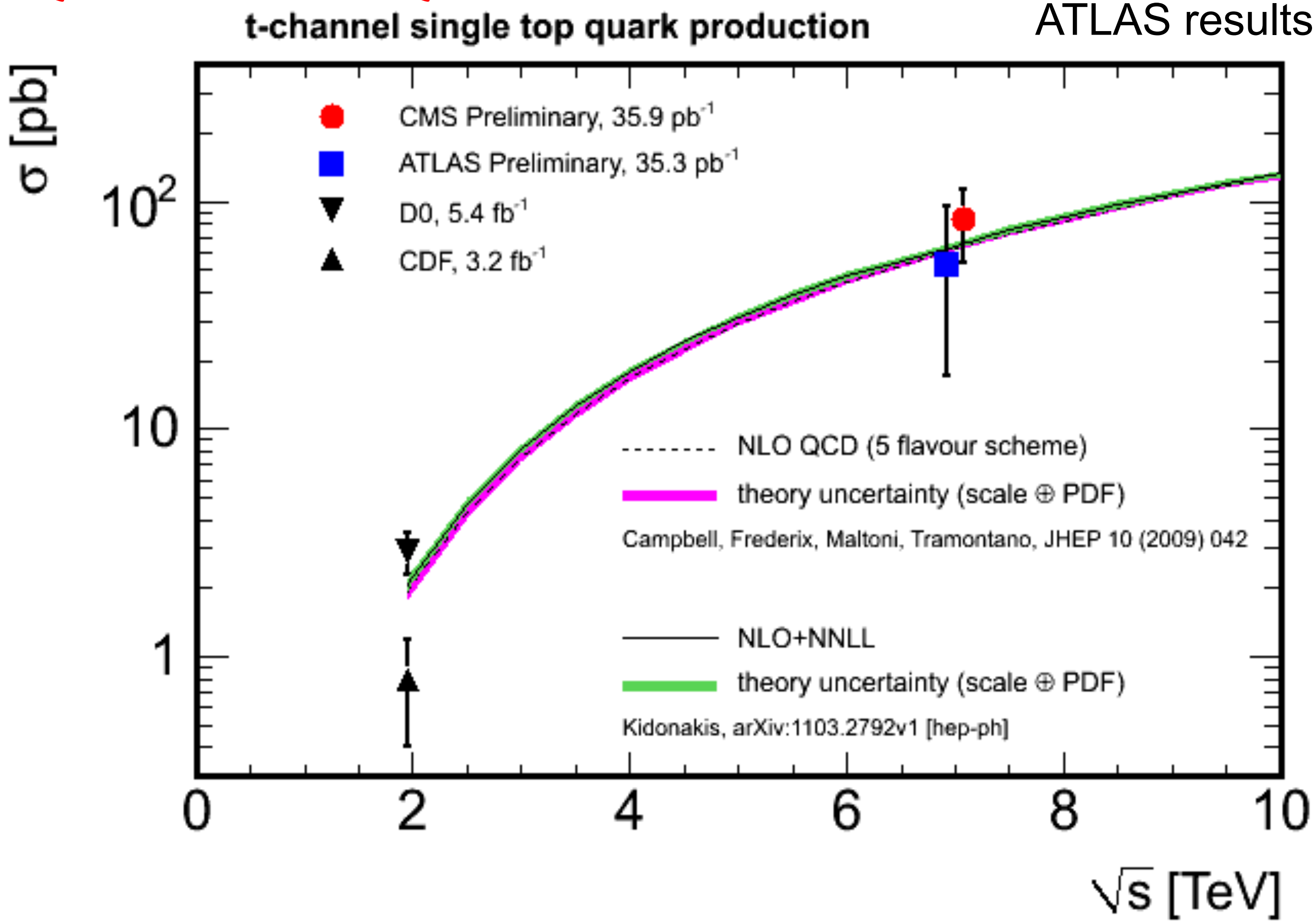
2D: $|V_{tb}| > 0.63$ @ 95%CL

BDT: $|V_{tb}| > 0.69$ @ 95%CL

Results

Comparison to other experiments

Comparison with more recent ATLAS results (156/pb) in backup



Conclusions

Concluding thoughts

Single Top production in the t-channel measured for the first time at the LHC

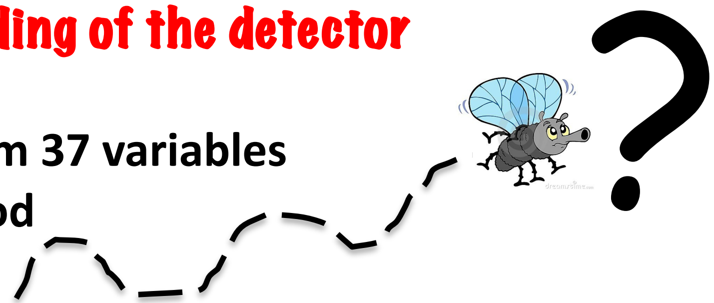
Precision: 36% in $\mathscr{L}$=36/pb of pp data at 7 TeV

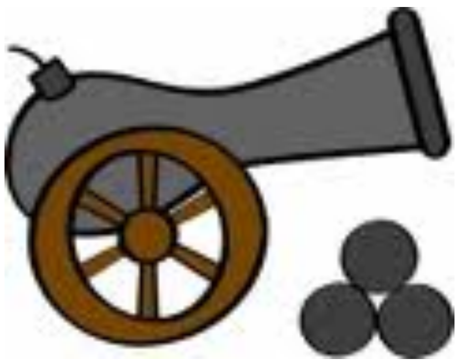
Results consistent with the Standard Model

Rather elaborated analysis

only possible with an excellent understanding of the detector

. 2D : uses angular properties of top decay
. BDT : uses pretty complete event information from 37 variables
. Combination: exploits the strength of each method

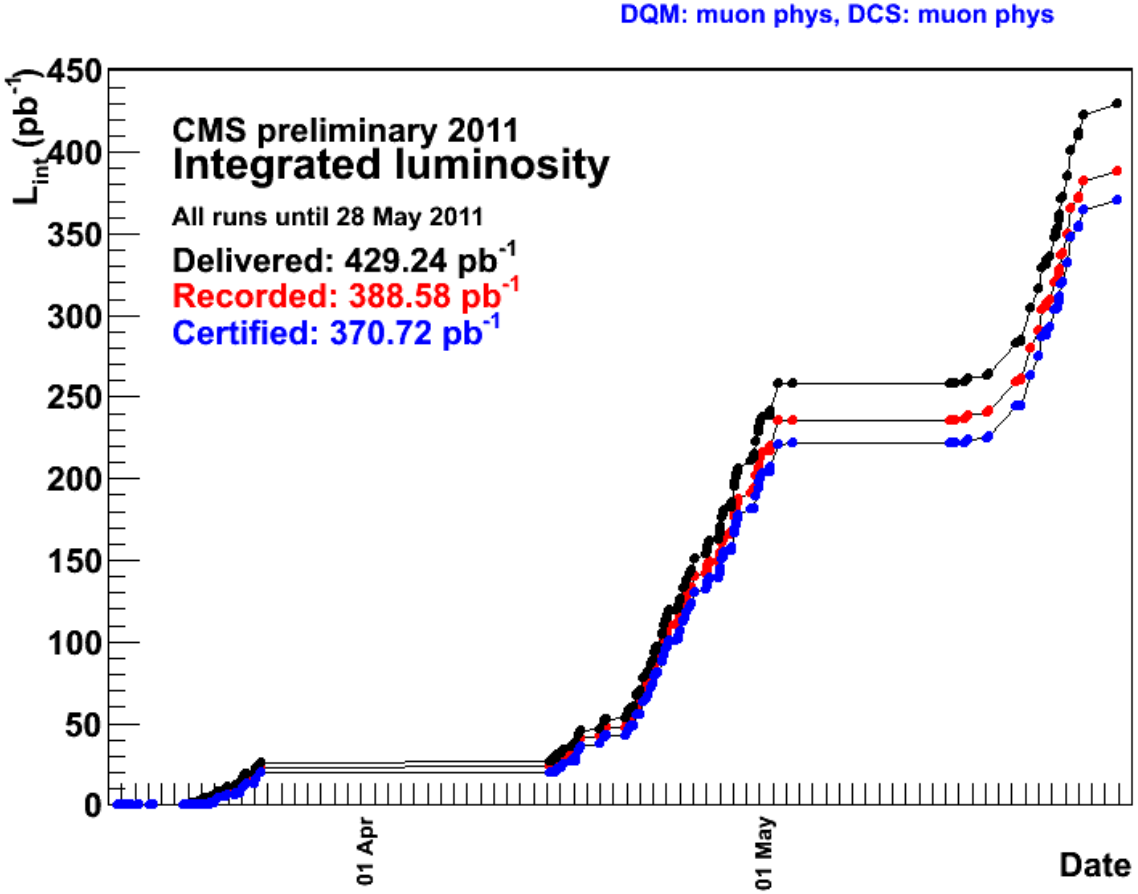




It would have been **impossible to achieve the precision** of the combination measurement on a simple cut-and-count analysis within current statistics

Concluding thoughts

Integrated Luminosty until May/2011



Single-top x-section t-channel:

Tevatron: σ =2 pb

→ Results p.18 for $\mathscr{L}$ ~ 5/fb

LHC: σ = 64.3 pb

→ bkg doesn't grow as fast

→ better S/B for same Nr tops

→ surpasses Tevatron at ~$\mathscr{L}$/32 ~ 0.16/fb

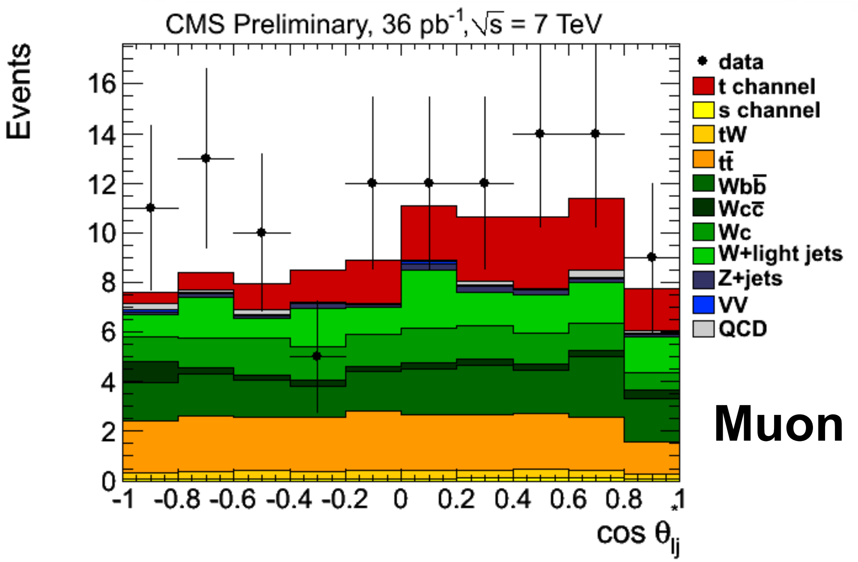
(experiment's efficiencies apart)

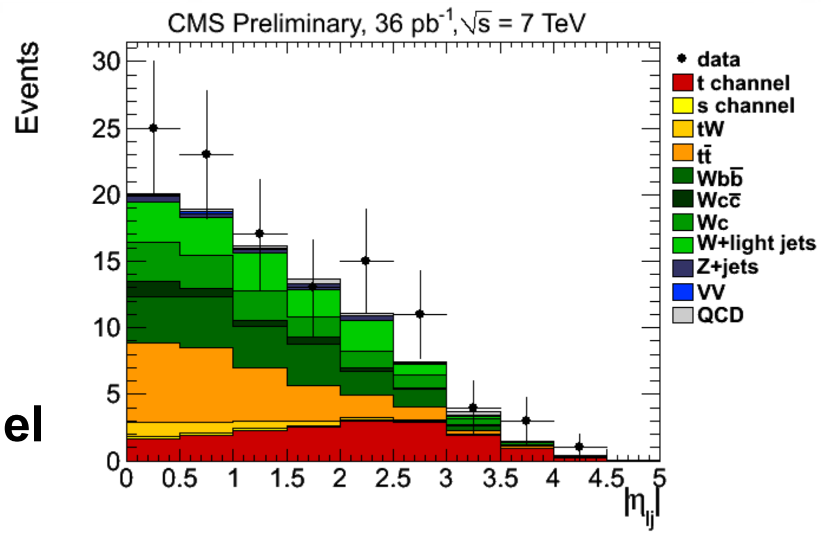
… basically NOW !

2011 is the *year of the top* at the LHC!

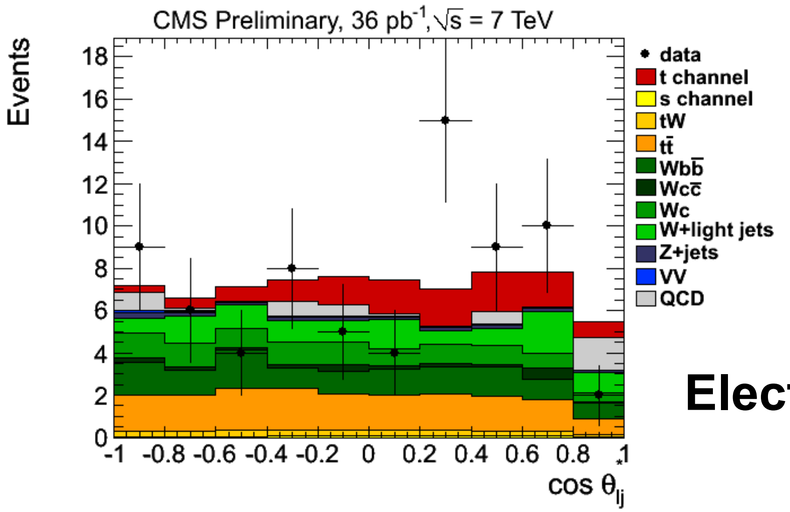
Backups

Input variables in 2D analysis

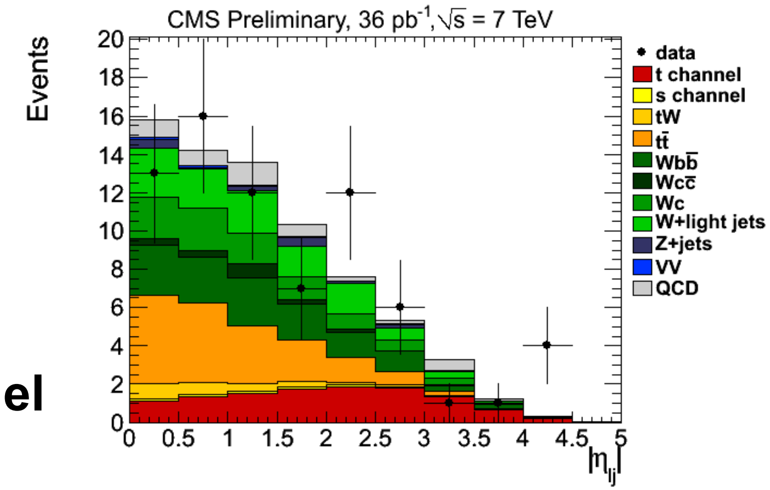




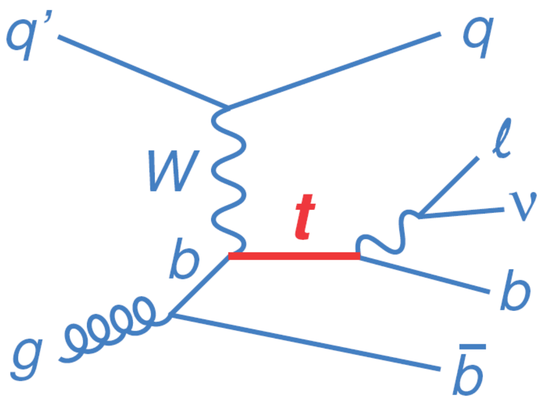
Muon channel

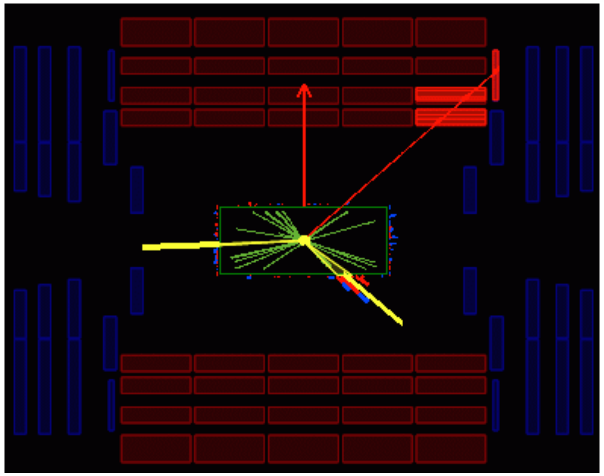


Electron channel



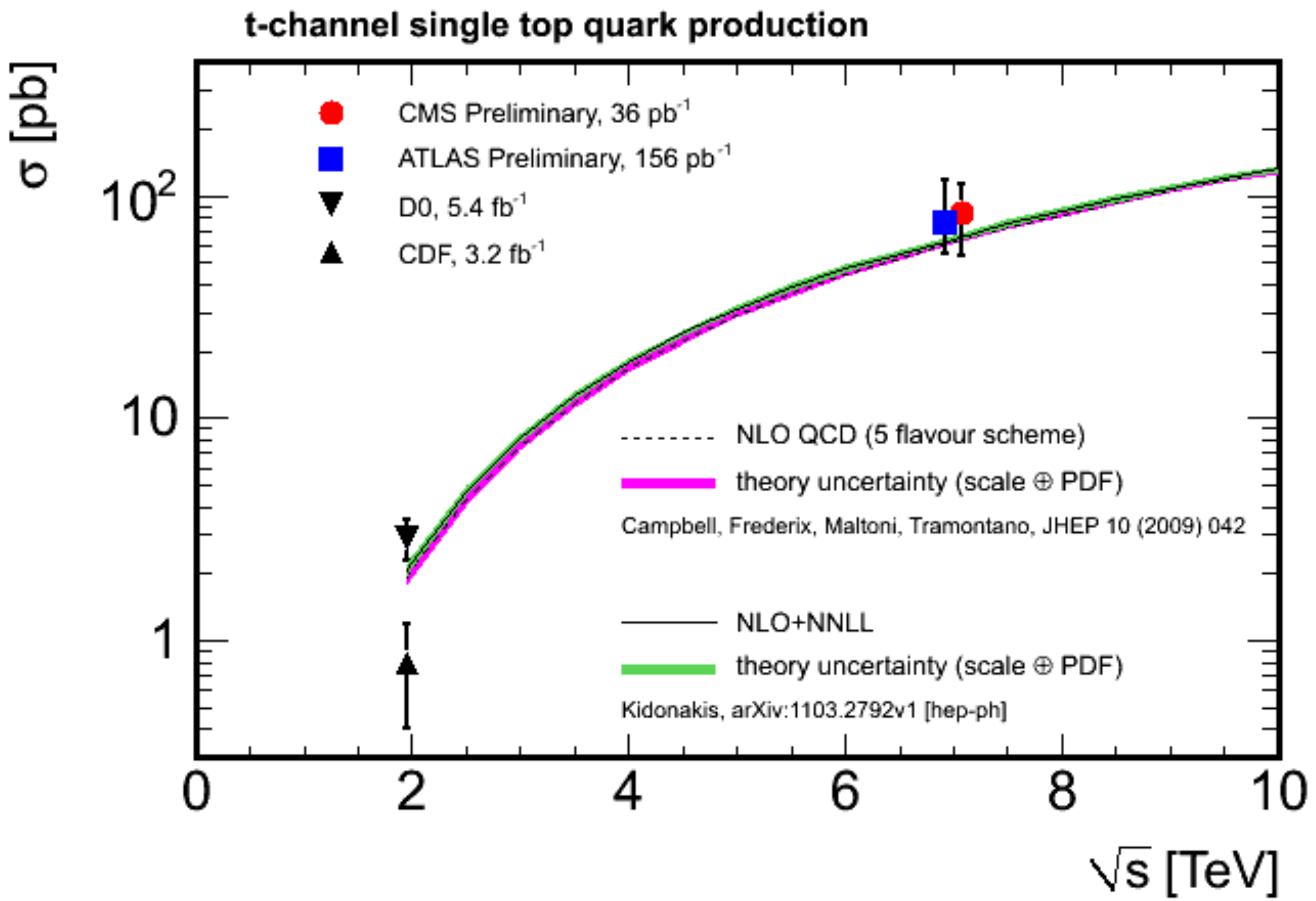
Expected signal





- Real W from t ($m_t > m_W$)
  - decaying 2/9 of the times into l(=e,μ)+ν
  - lν peak at the W mass (jacobian peak on transverse plane, page 7)
- Central b jet from top
  - lνb peak at the top mass
- Light jet from recoil in the forward direction
- Additional b jet: very soft p_T spectrum

Comparison with ATLAS updated results



CMS 36/pb

ATLAS 156/pb