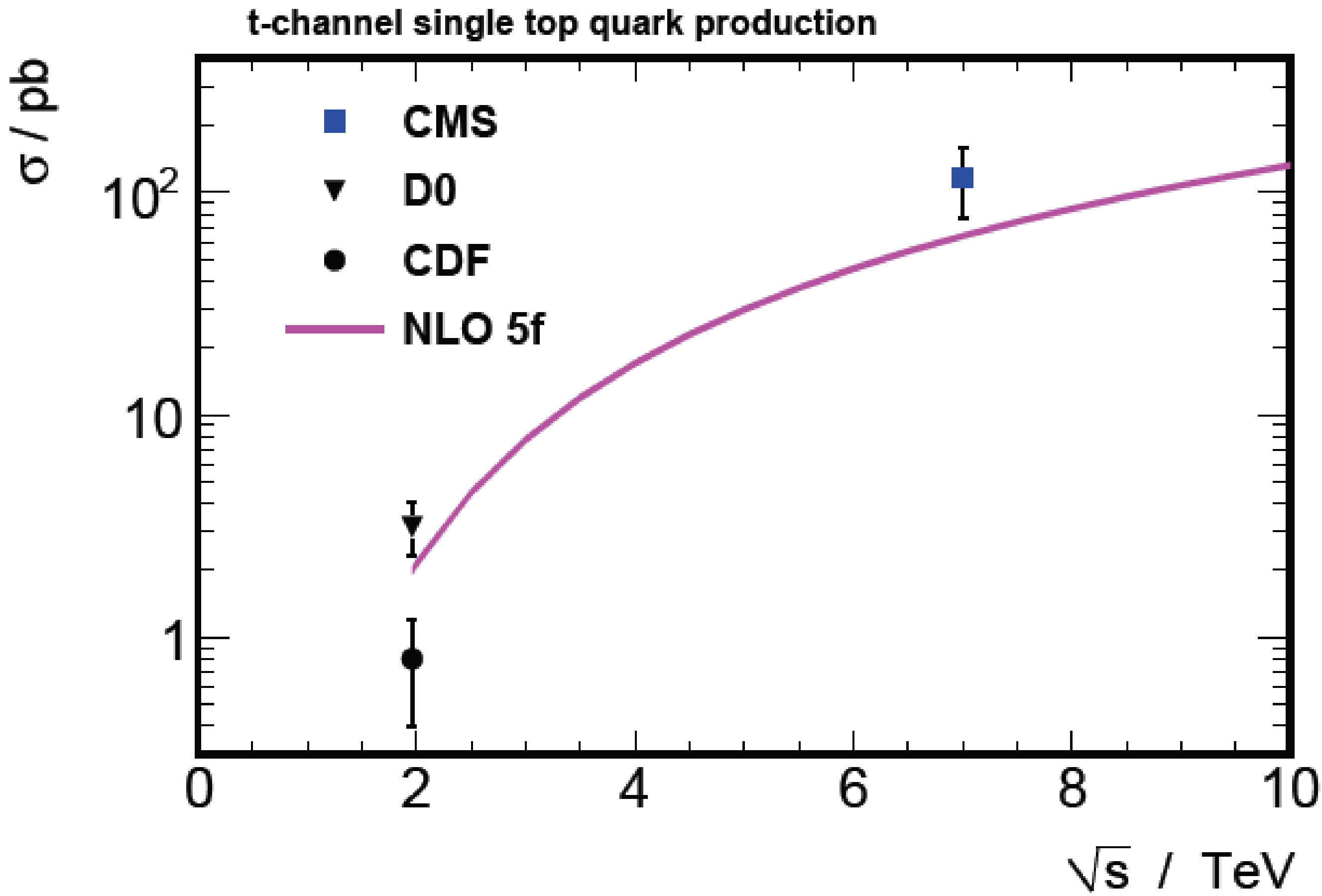
Single top at LHC: the first measurement

Andrea Giammanco (FNRS & CP3-UCL)



Preliminary result from **CMS-PAS-TOP-10-008**,
"Measurement of the single-top t-channel cross section at $\sqrt{s}$=7 TeV"

Acknowledgements: a team work

Cross sections
Chris Neu (Virginia)
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Top mass and properties
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Single top
Andrea Giammanco (Louvain)
Jennine Wagner-Kuhr (Karlsruhe)

The 3 subgroups of the CMS Top Physics Analysis Group

Main contributors to the "Moriond analysis":
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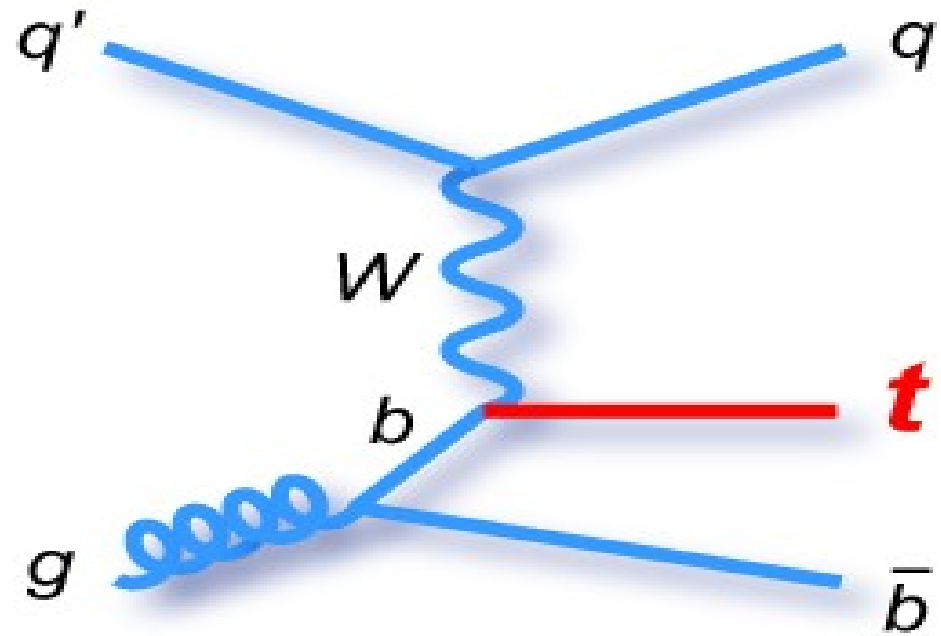
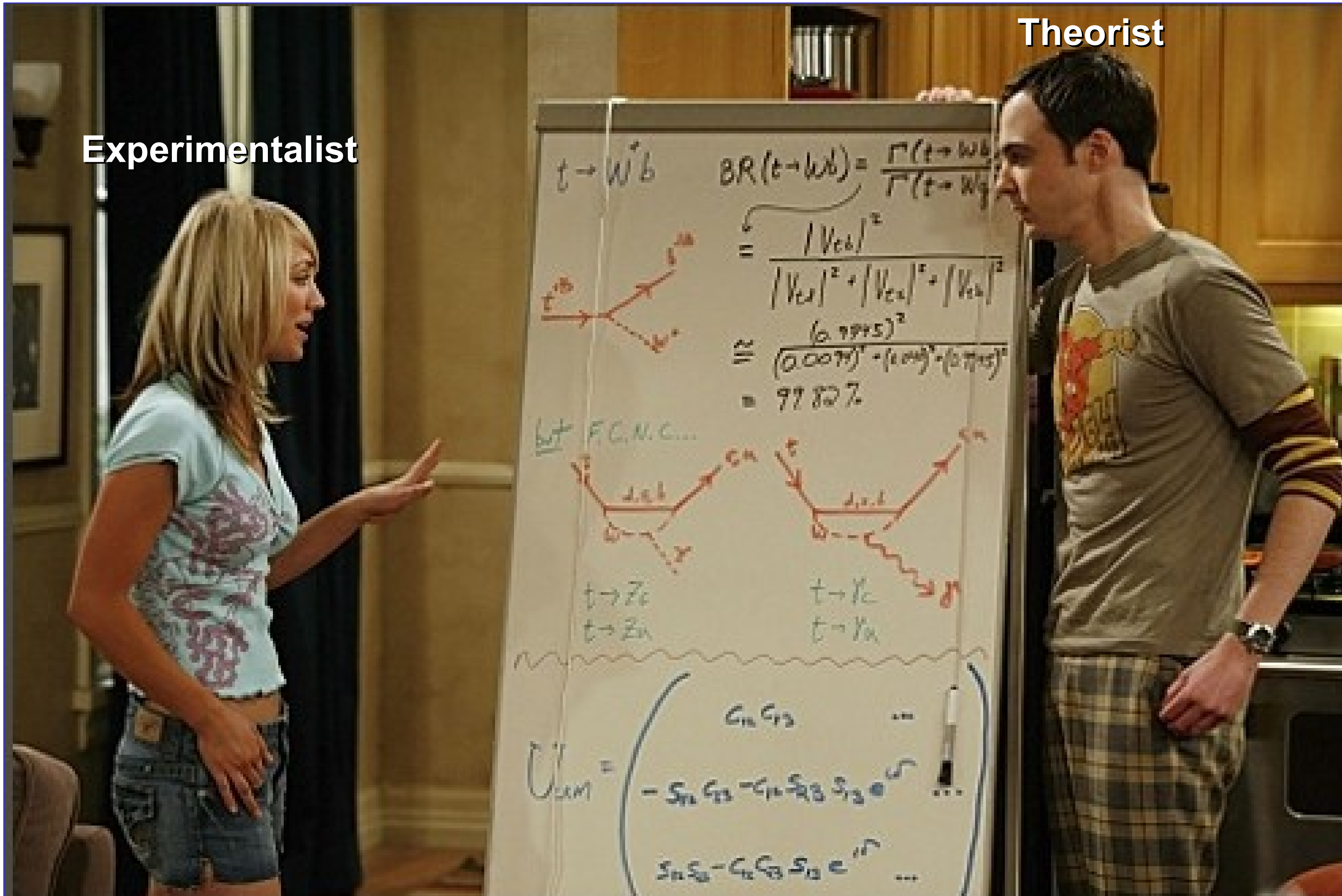
Jyothsna Komaragiri (Karlsruhe), Dmitri Konstantinov (Protvino)
heroic effort, they avoid the risk that while focusing on 2010 data we waste 2011 ones!

Outline

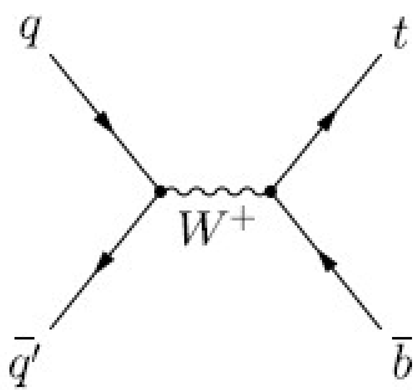
- **Theory**
  - Signal definition
  - Single top and CKM
- **Experimental setup**
  - LHC and CMS
  - Our data set
- **Single top analysis**
  - Event selection
  - Backgrounds *in situ*
  - 2D analysis
  - BDT analysis



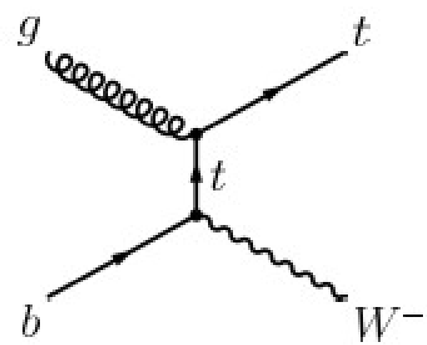
Part I: Theory



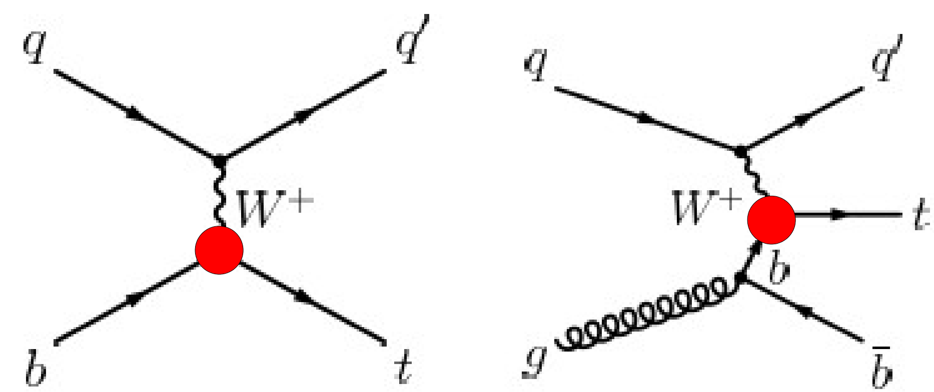
What we talk about, when we talk about single top



s channel
(4 pb @ 7 TeV)



tW
(11 pb @ 7 TeV)



t channel
(65 pb @ 7 TeV)

- Tevatron: >5σ in s+t (~1+2 pb)
  - Separate s/t results also appeared
  - tW negligible at 1.96 TeV
- LHC, 7 TeV: t channel dominant
  - s channel & tW are treated as backgrounds in this talk
- Goals (increasing statistics):
  - **Confirmation of Tevatron & First cross section @ 7 TeV**
  - Competitive constraint on $|V_{tb}|$ ⇒ limit on 4th quark family
  - FCNC, charged resonances, etc.; the three channels offer complementarity

The CKM matrix

$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix} .$$

- It is **unitary**, meaning that:
  - Any two rows or columns are orthogonal; verified in K and B exps
  - The scalar product of any row and any column by its own complex conjugate is **1**; if less $\Rightarrow$ evidence for new quarks
- Very precise direct measurements of the 1st and 2nd rows:
  - $|V_{ud}|$: from $0^+ \rightarrow 0^+$ β decays
  - $|V_{us}|$: mostly from semileptonic K decays
  - $|V_{ci}|$ (i=d,s): from D, D_s decays; $|V_{cd}|$ also from $\nu d \rightarrow \mu^- c$
  - $|V_{ib}|$ (i=u,c): from B decays

What do we know about the 3rd row

- First two rows + Standard Model + 3x3 unitarity ⇒

$$|V_{td}| \simeq 0.0069 - 0.0088$$

$$|V_{ts}| \simeq 0.0401 - 0.0418$$

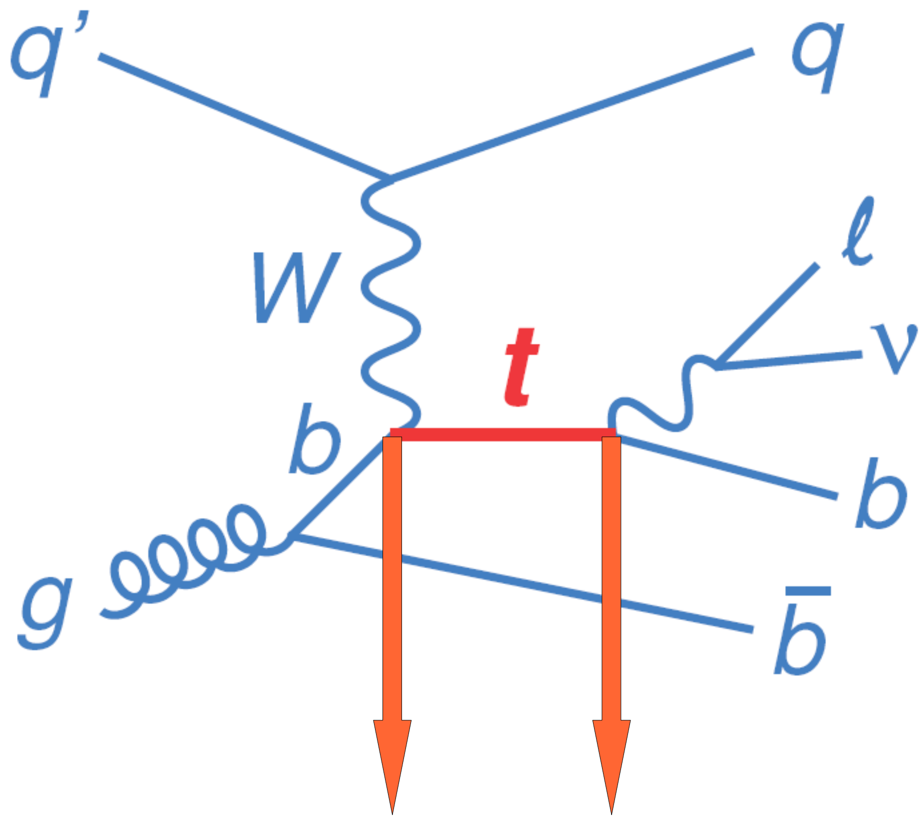
(at 2σ level)

$$|V_{tb}| \simeq 0.9990 - 0.9992$$

- Measurements of ΔM_{Bs} and ΔM_{Bd} constrain $|V_{td}/V_{ts}|$
- Measuring R measures $|V_{tb}|$ only if 3x3 unitarity is assumed

$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq(=d,s,b))} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

Single top and $|V_{tb}|$

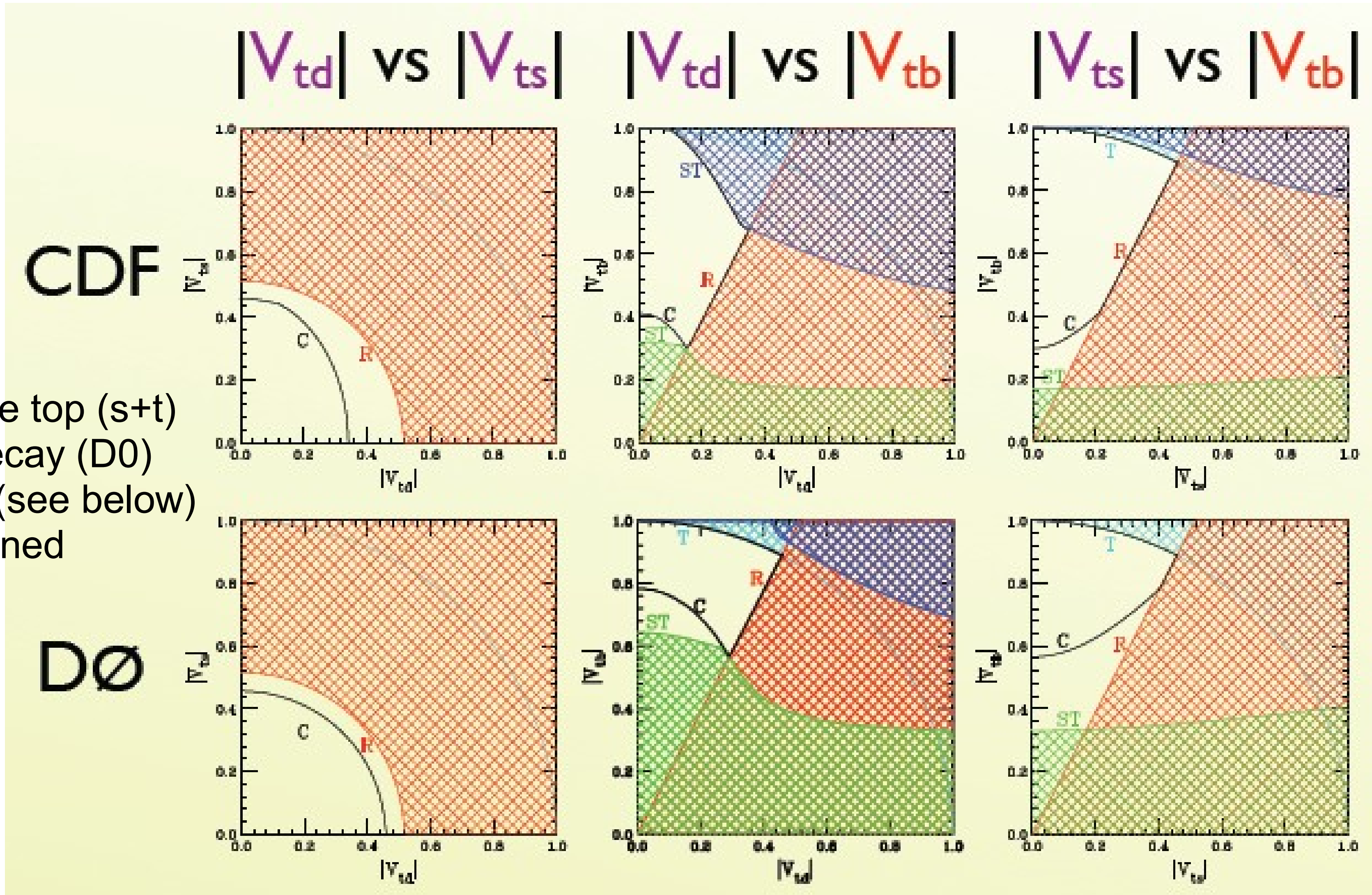


$\sigma(|V_{tb}|^2)\bullet R$

Popular simplifying assumption: $|V_{ti}| \ll |V_{tb}|$ ($i=d,s$) even if a 4th family exists, hence $R \sim 1$; but D0 limit $R > 0.79$ only implies $|V_{tb}| > 1.9\sqrt{|V_{td}|^2+|V_{ts}|^2}$

<u>For the moment</u> we have to live with this approximation, but ...

From an old CP3 paper...

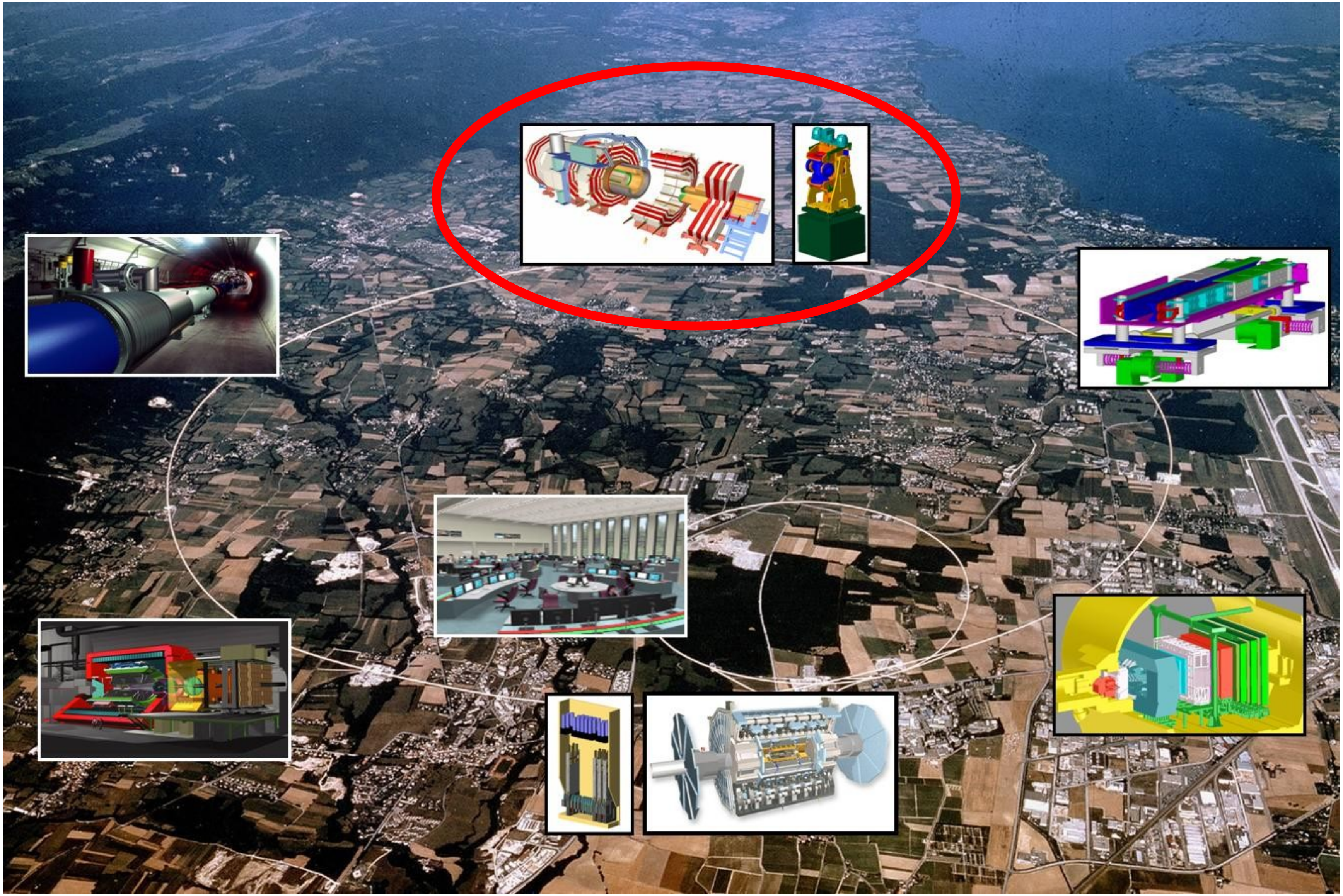


Alwall et al., Eur. Phys, J. C49 791 (2007) + updates

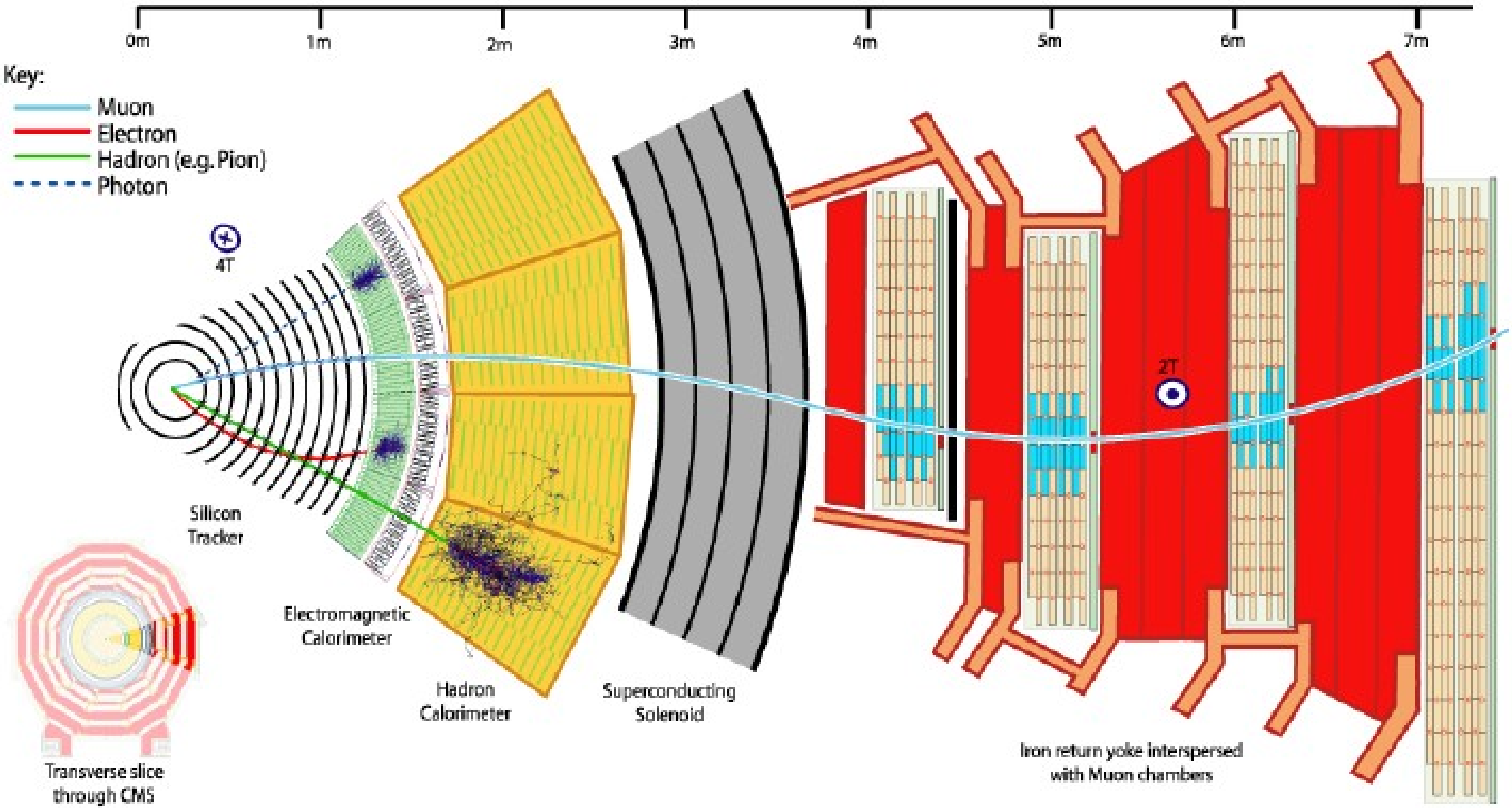
ST: single top (s+t)
R: top decay (D0)
T: trivial (see below)
C: combined

Simplifying assumption: no other new physics apart from new quarks
→ trivial constraint from Pythagoras' theorem

Part II: Experimental setup



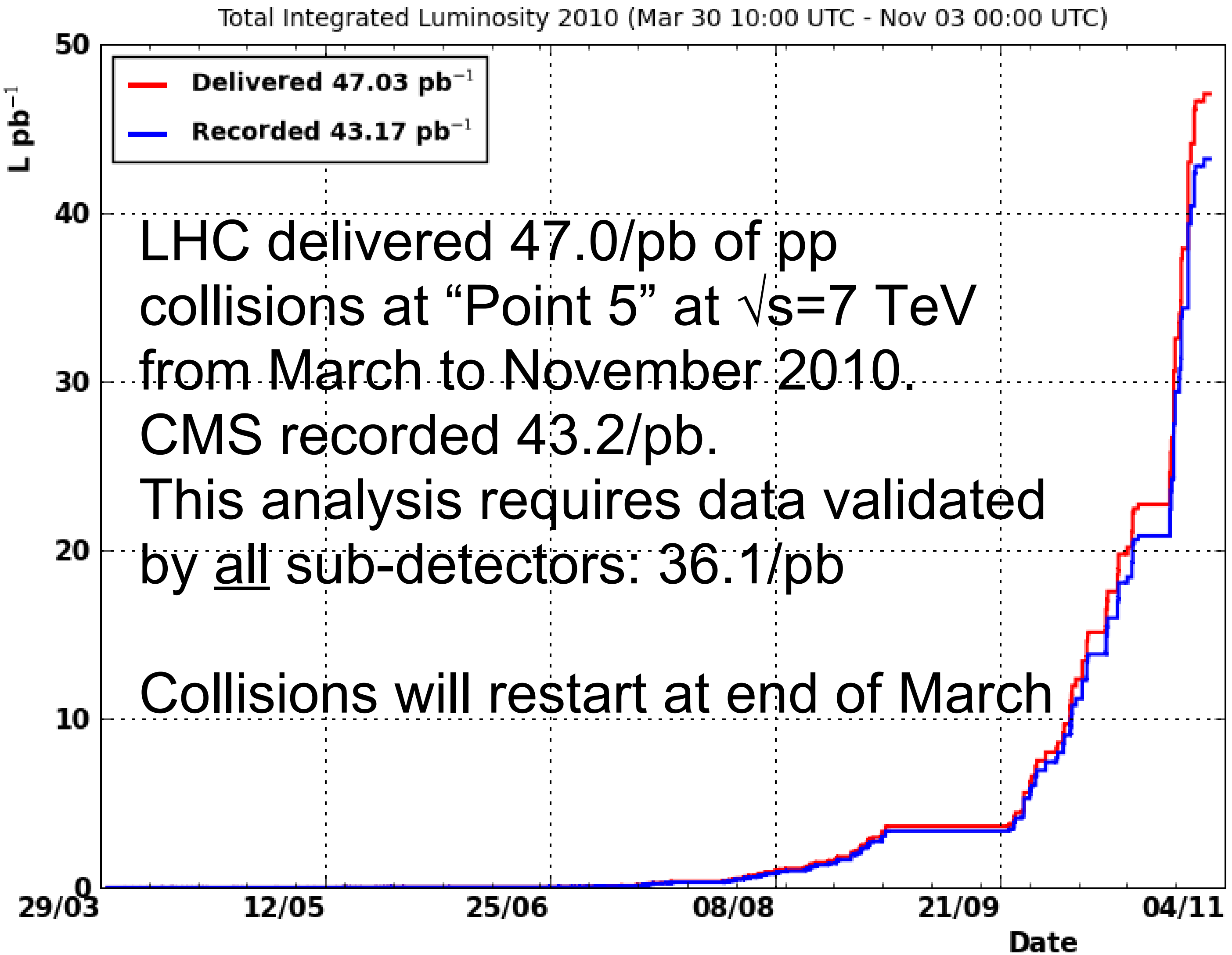
CMS detector: general concept



In→out: Si Pixels, Si Strips, EM calorimeter (PbWO), Hadron calorimeter (brass+scint.), Solenoid (3.8 T), Muon system (RPCs, drift tubes in barrel, CSCs in endcaps)

Neutrinos: no interaction → momentum imbalance → MET

Our current dataset



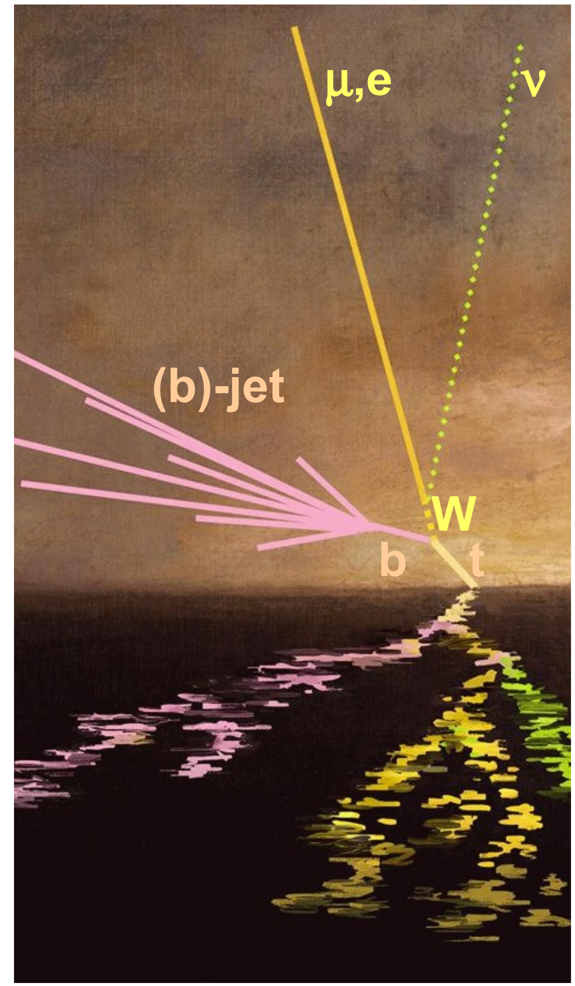
LHC delivered 47.0/pb of pp collisions at "Point 5" at $\sqrt{s}$=7 TeV from March to November 2010.

CMS recorded 43.2/pb.

This analysis requires data validated by <u>all</u> sub-detectors: 36.1/pb

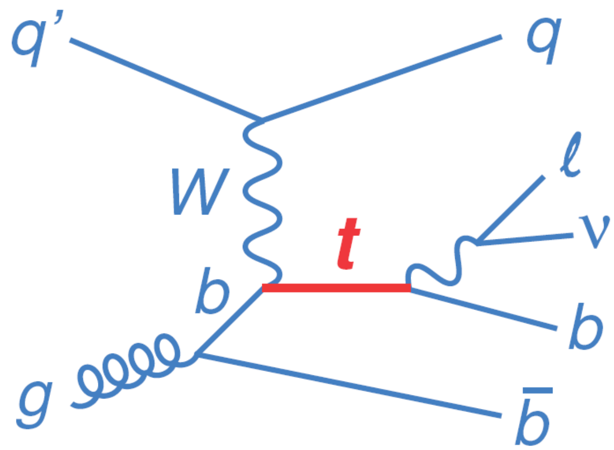
Collisions will restart at end of March

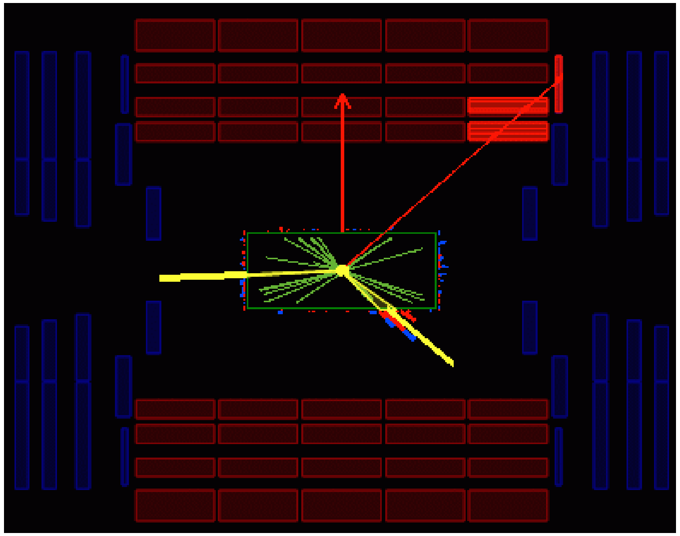
Part III: Single top search



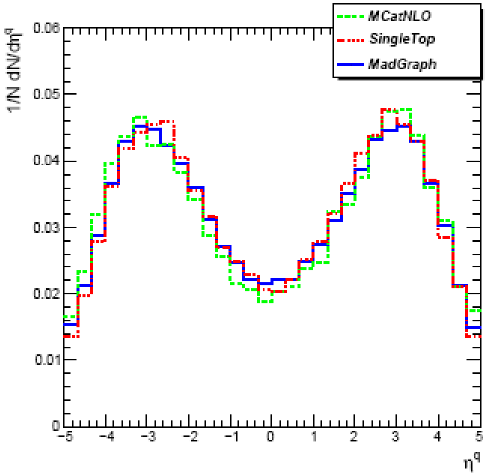
F. Ligabue & B.R. Haydon

Event selection: general idea





- Main features of t-channel events:
  - Real W from t ($m_t > m_W$)
    - decaying 2/9 of the times into l(=e,μ)+ν
  - Central b jet from t
  - Light jet from recoil, rather forward
  - Additional b jet has a very soft p_T spectrum

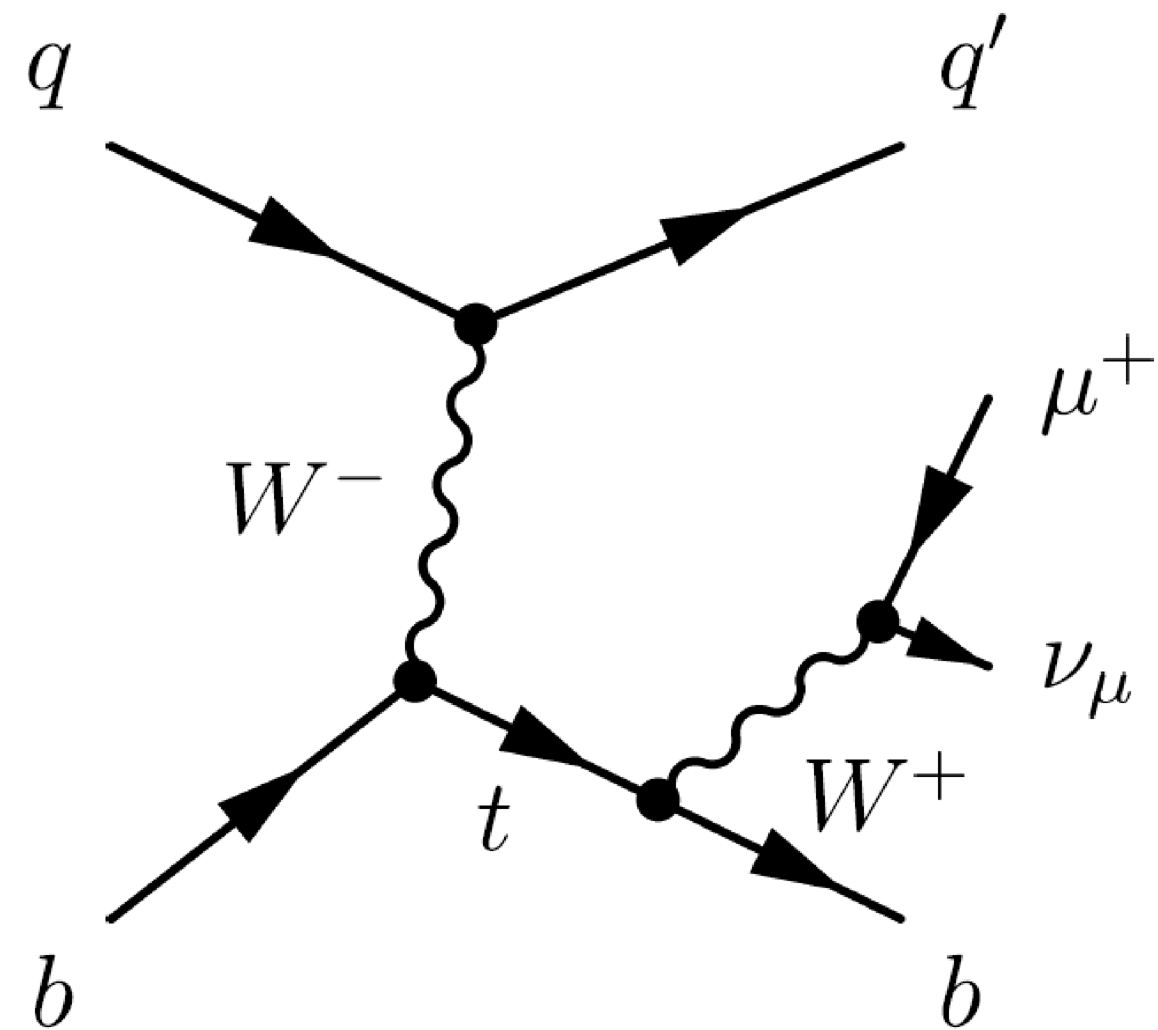


Two analyses

- Analysis #1 (2D), Naples-Louvain:
  - 2D fit to angular properties of the signal
  - Main backgrounds have very similar shapes → result is robust against background composition
  - This is the robust analysis; low model dependence
- Analysis #2 (BDT), Aachen:
  - Multivariate analysis (boosted decision tree)
  - Exploits prior knowledge of EW top quark production
  - This is the aggressive analysis; maximum sensitivity
- Both share a similar event selection

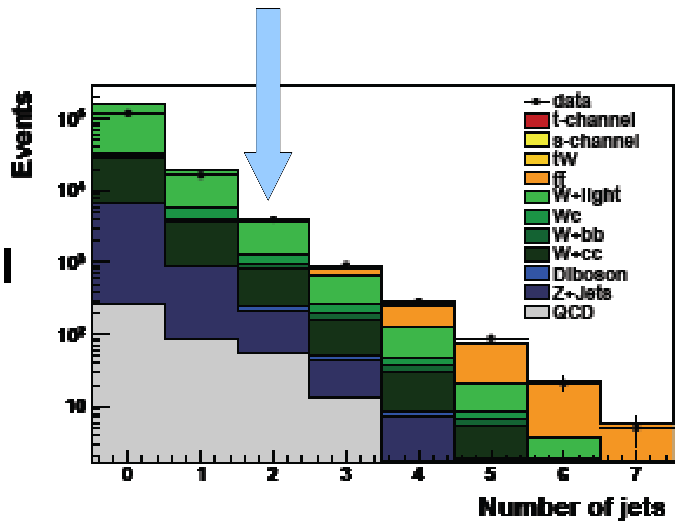
Event selection

- Trigger: single μ/e
- Single lepton, isolated
  - Di-lepton veto
  - Z veto (e channel only)
- Exactly 2 jets
  - far from the lepton
- At least 1 b jet
- Analysis-specific:
  - **2D:** veto on 2nd b jet
  - **BDT:** $\Delta\phi(j1,j2)<3$
- Last cut: $M_T(W)$

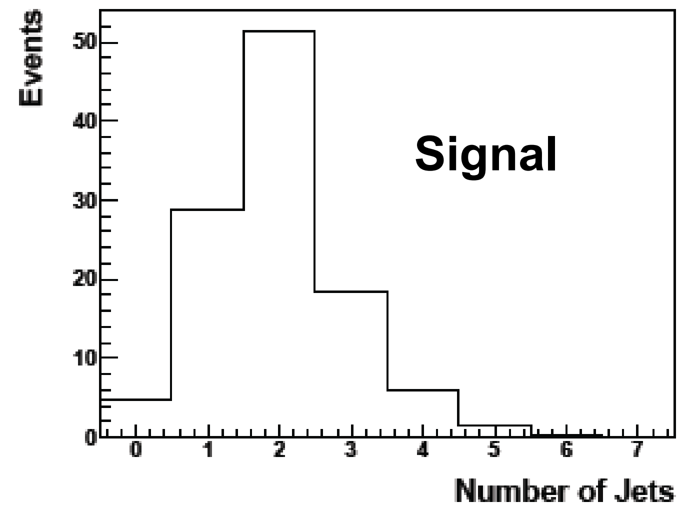


After 1l2j selection: a W-dominated sample

Muon channel

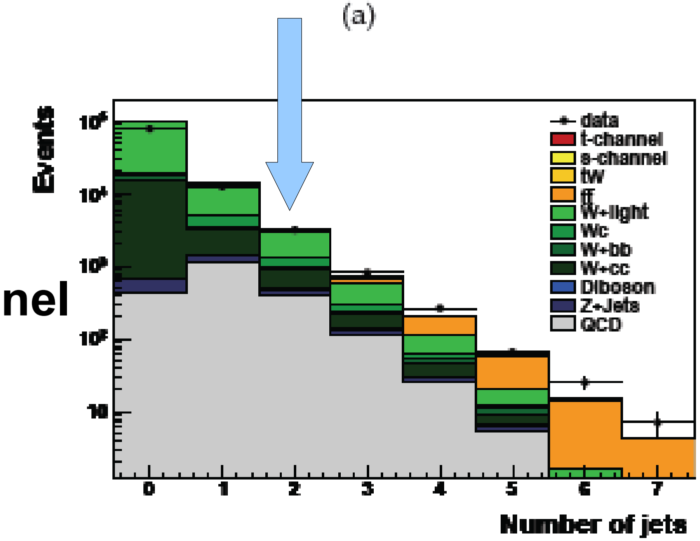


(a)

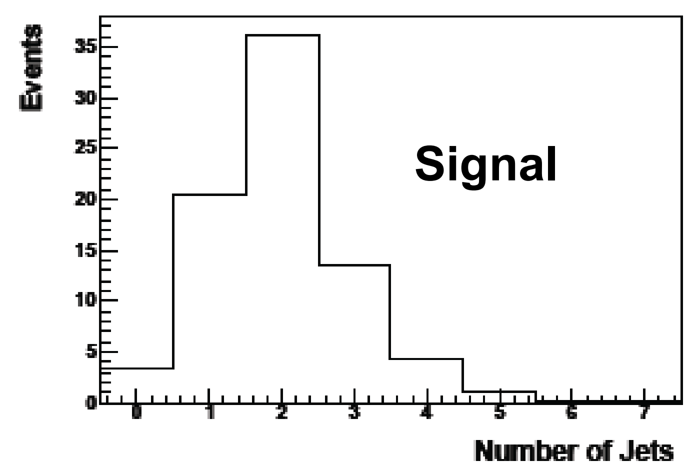


(b)

Electron channel



(c)

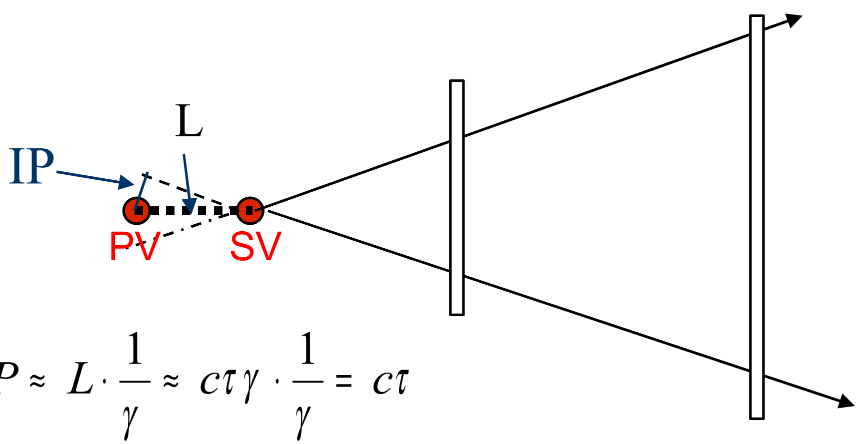


(d)

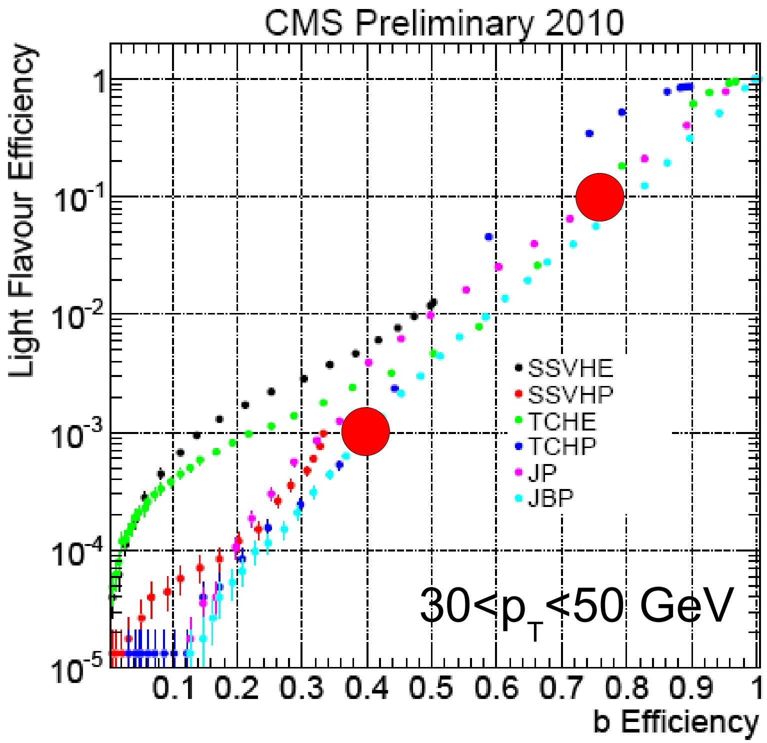
b tagging

- Based on Impact Parameter (IP)
  - "Track counting" (TC): require at least N tracks with IP/σ_{IP}>cut
  - High Purity TC: N=3, tight cut = 3.4 (~0.1% mistag prob.)
  - High Efficiency TC: N=2, loose cut = 1.7 (~10% mistag prob.)

Definition of IP:

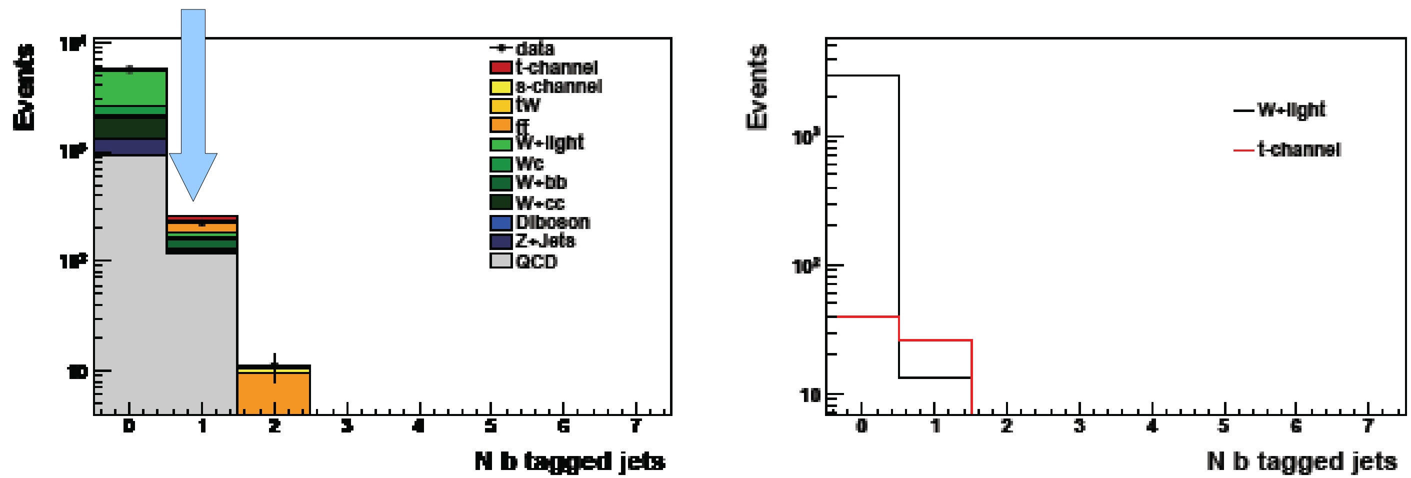


$$IP \approx L \cdot \frac{1}{\gamma} \approx c\tau\gamma \cdot \frac{1}{\gamma} = c\tau$$



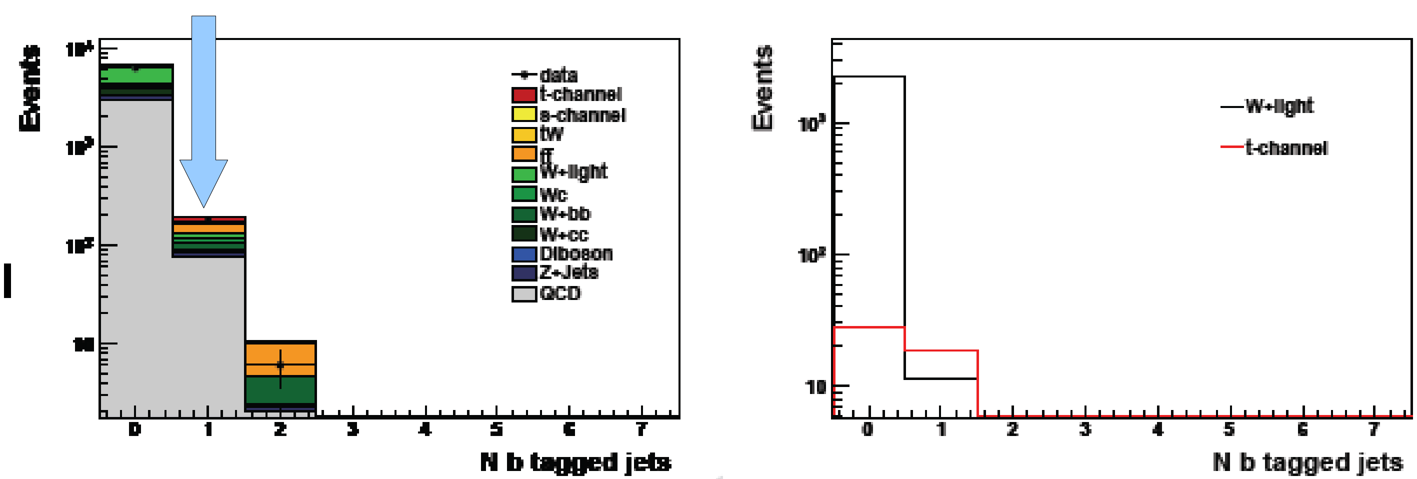
Getting rid of W+light jets: tight b tagging

Muon channel



(a) (b)

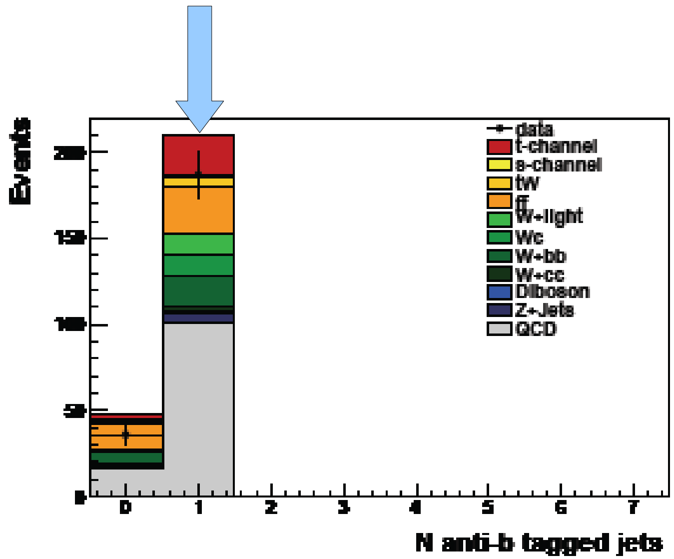
Electron channel

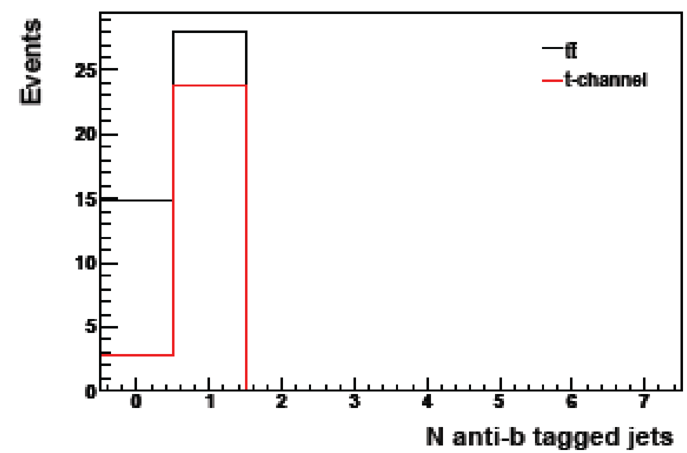


We count jets that pass the tight threshold on b tagging

Signal has 1 b: loose anti-b-tagging

Muon channel

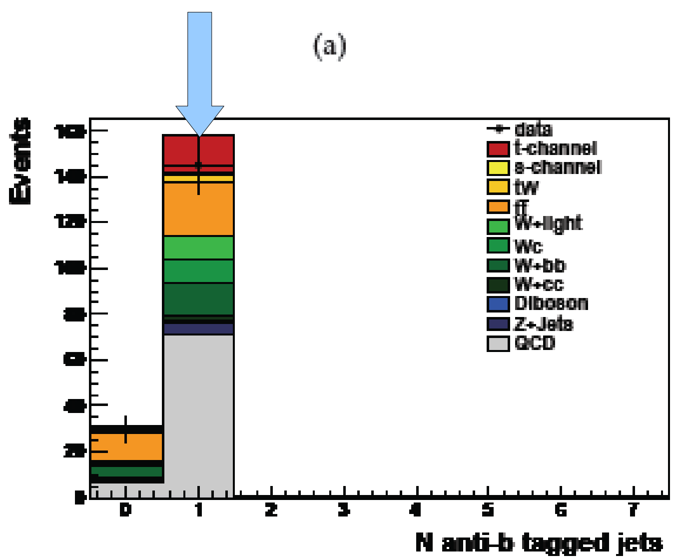


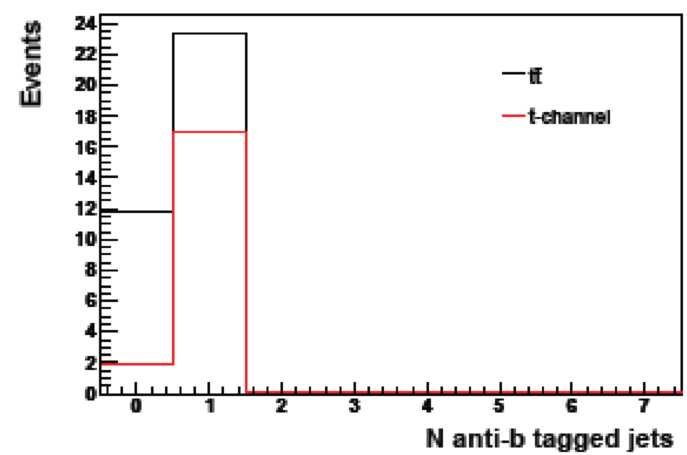


(a)

(b)

Electron channel

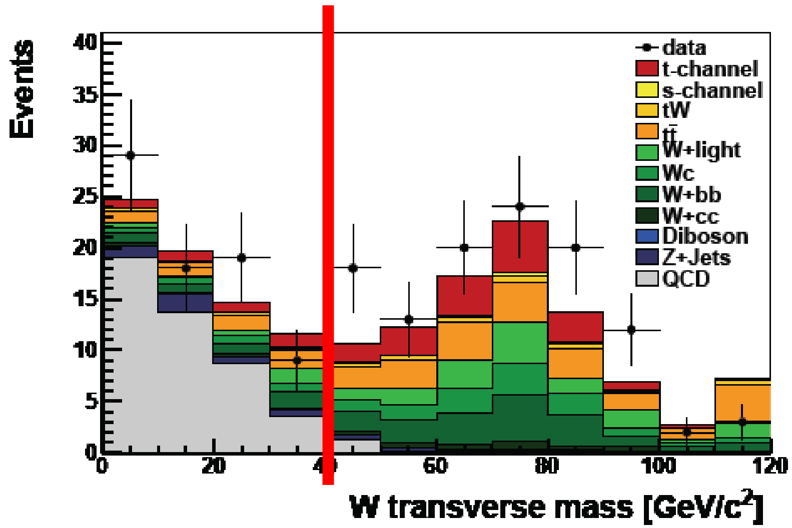




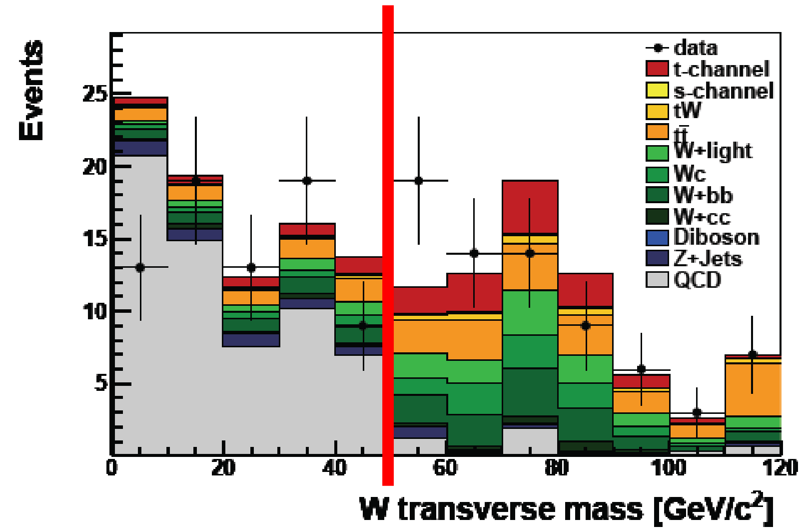
We count jets that fail the loose threshold on b tagging

Invariant transverse mass (M_T):
QCD has no Jacobian peak at the W mass

$$M_T = \sqrt{(p_{T,l} + p_{T,\nu})^2 - (p_{x,l} + p_{x,\nu})^2 - (p_{y,l} + p_{y,\nu})^2}$$



Muon channel: M_T>40 GeV

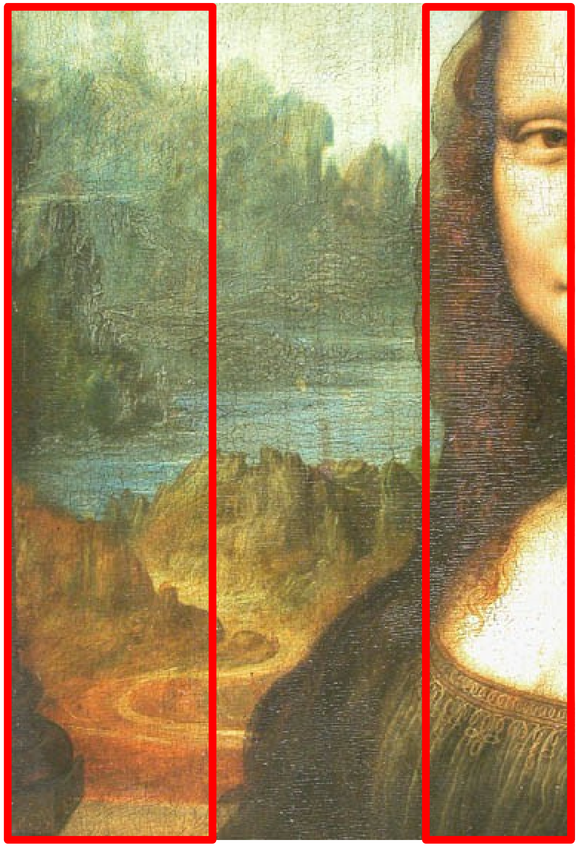


Electron channel: M_T>50 GeV

This is our <u>last cut</u>: our bkg estimations from data are based on M_T.
Cut was chosen(*) in a blind data-driven way after fitting(**) the QCD component in the 1l2j sample (no b tagging) with 15/pb, then **frozen**

(*) figure-of-merit = $W/\sqrt{[W+QCD+(k*QCD)^2]}$, with k=50%; (**) fit strategy explained later

Background estimations



Control region **Analysis region**

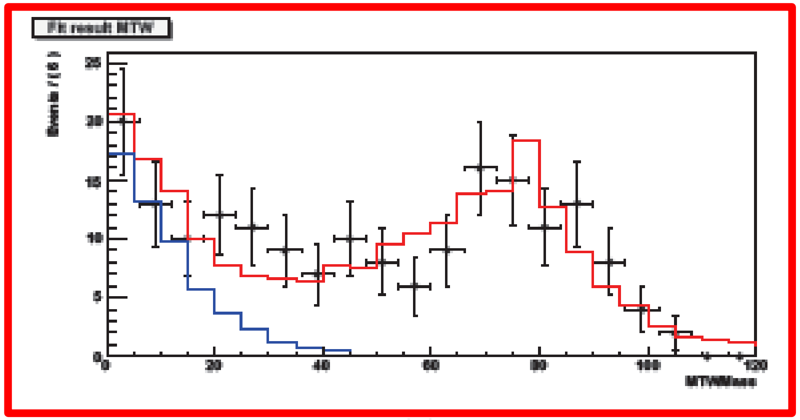
Q: How much water is behind Mona Lisa's head?

A: define a region with very little Mona Lisa, then extrapolate (with some reasonable assumption)

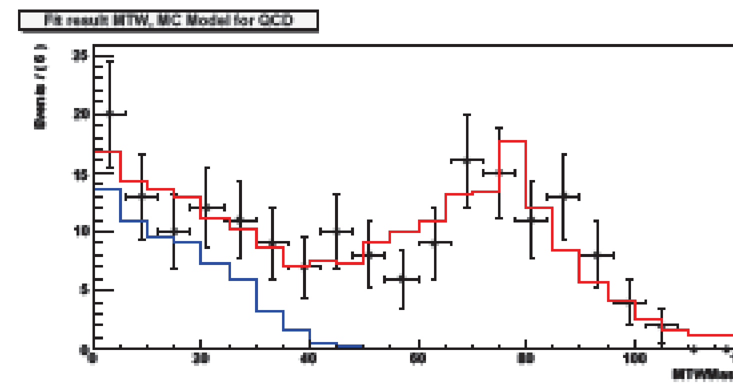
QCD estimation

QCD template: orthogonal data (anti-isolated) **QCD template from pre-tag MC**

Muon channel:
fit range [0,∞]

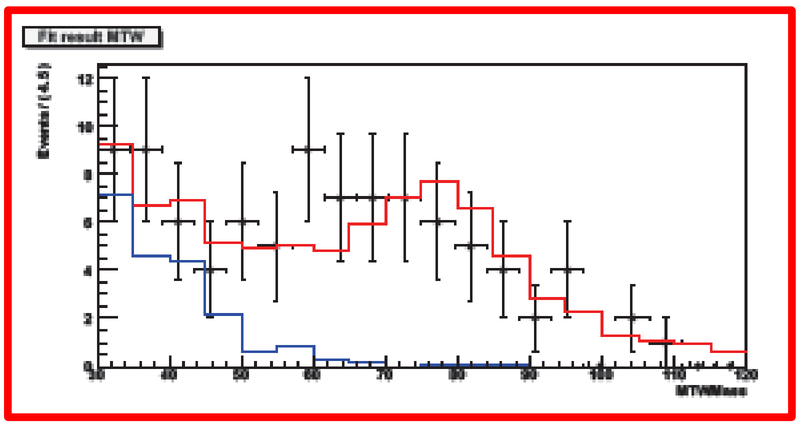


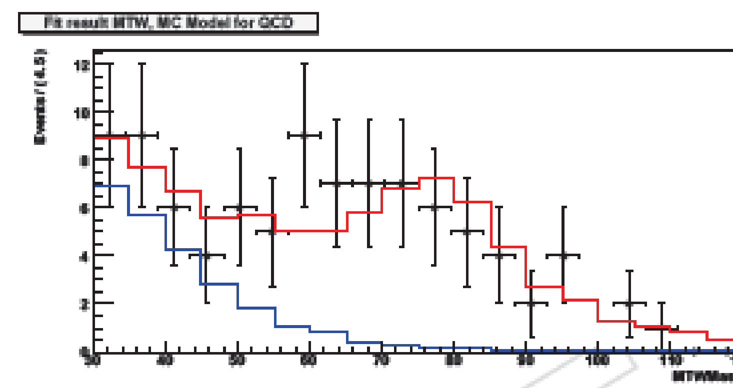
(a)



(b)

Electron channel:
fit range [30,200]



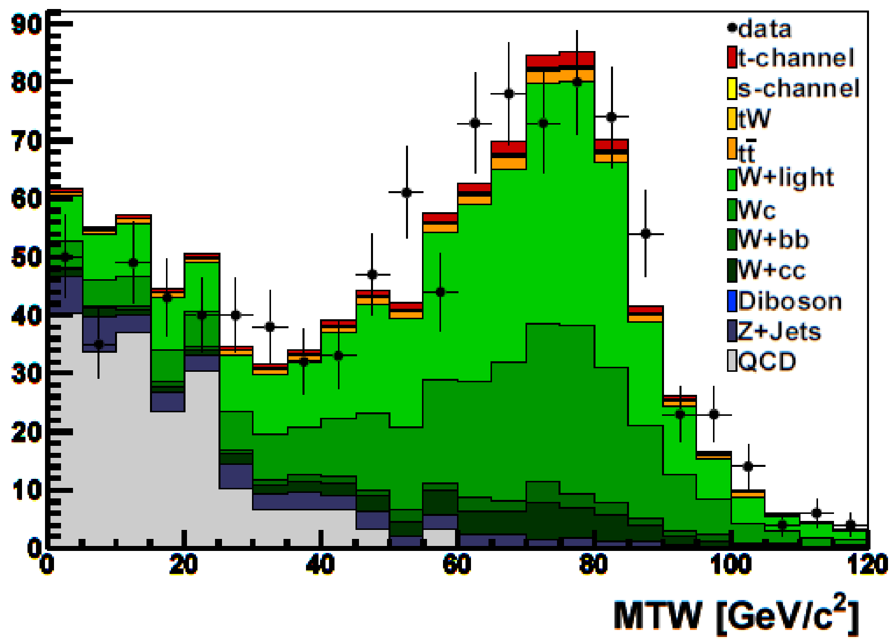


Most non-QCD processes share the same shape in M_T: total "non-QCD" category is kept floating in the fit, with template taken from MC; the "QCD" category is also floating, with template from an orthogonal sample with inverted isolation, >99% pure in QCD (isolation and MT have negligible correlation in the fitted range). Systematic error taken from changing QCD template (right) and fit range.

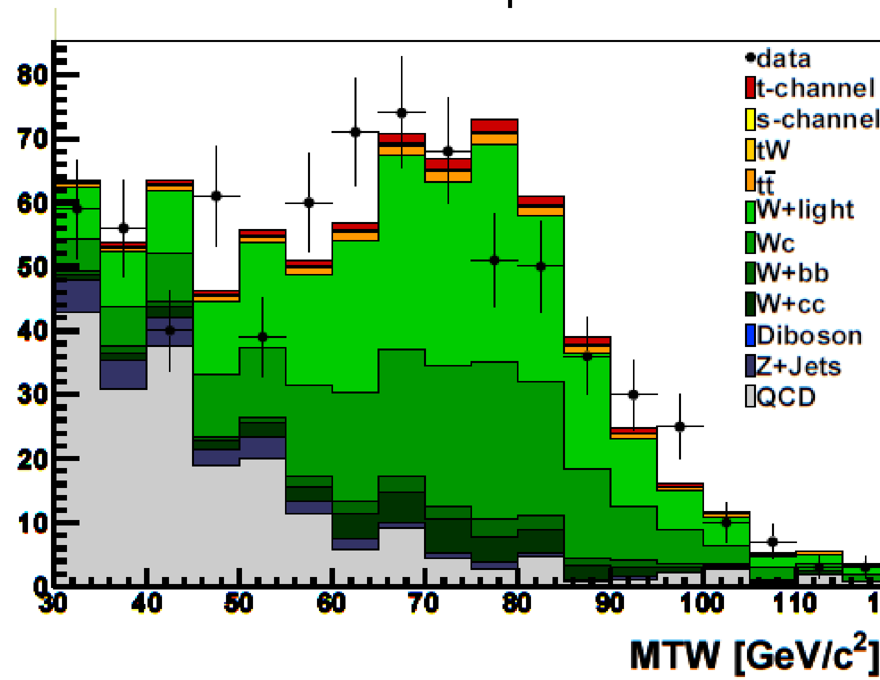
W+light jets estimation

Orthogonal sample: 2-jet bin, 1j passes the loose b-tagging but fails the tight one, the other jet fails loose b-tagging

Muon channel



Electron channel: M_T>30 GeV



- 3 categories: QCD, W+light jets, “all the rest”
- We leave QCD and W+light jets normalization floating, “all the rest” constrained.
- Again, we take the QCD template from the same selection but anti-isolation.
- We use MC shape for all other channels.
- We use the result from another study (TOP-10-003) for the normalization of ttbar and W+heavy flavour partons. All other backgrounds are fixed to SM prediction.

Expected yield

Process	μ channel	e channel
single top, t channel	17.6 ± 0.2	11.2 ± 0.1
single top, s channel	0.90 ± 0.01	0.62 ± 0.01
single top, tW	3.10 ± 0.05	2.41 ± 0.04
WW	0.29 ± 0.01	0.23 ± 0.01
WZ	0.24 ± 0.01	0.17 ± 0.05
ZZ	0.018 ± 0.001	0.011 ± 0.001
$W+$ light partons	18.2 ± 5.5 (†)	11.6 ± 3.5 (†)
$Z + X$	1.7 ± 0.5 (†)	1.6 ± 0.5 (†)
QCD	0.6 ± 0.3 (†)	$2.6^{+3.4}_{-2.6}$ (†)
$V + Q\bar{Q}$ & Wc	33.3 ± 16.6 (‡)	23.6 ± 11.8 (‡)
$t\bar{t}$	20.3 ± 3.6 (‡)	15.6 ± 2.8 (‡)
Total background	78.6	58.4
Signal + background	96.2	69.6
Data	112	72

Estimated from MC
(error: MC statistics)

Estimated *in situ*
(Z+X: scaled as W+l.j.)

Scaled to the cross sections from another "Moriond analysis" (error from there)

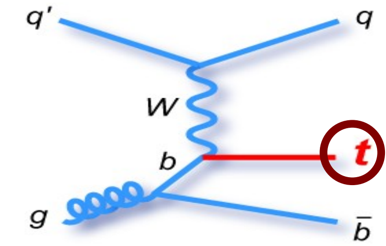
The last step

Some observables, for 36 pb^{-1} of data passing full selection

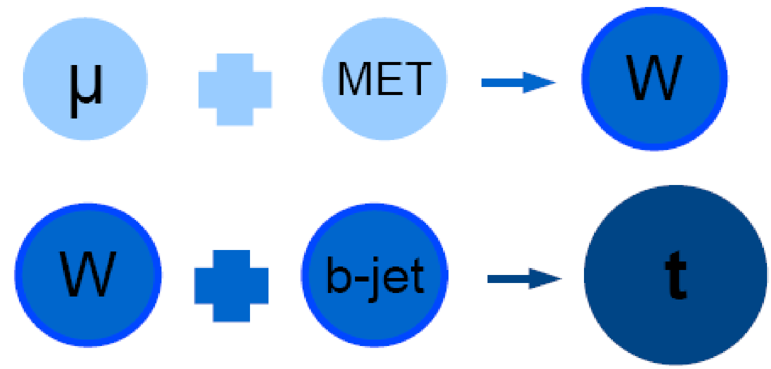
Cross section

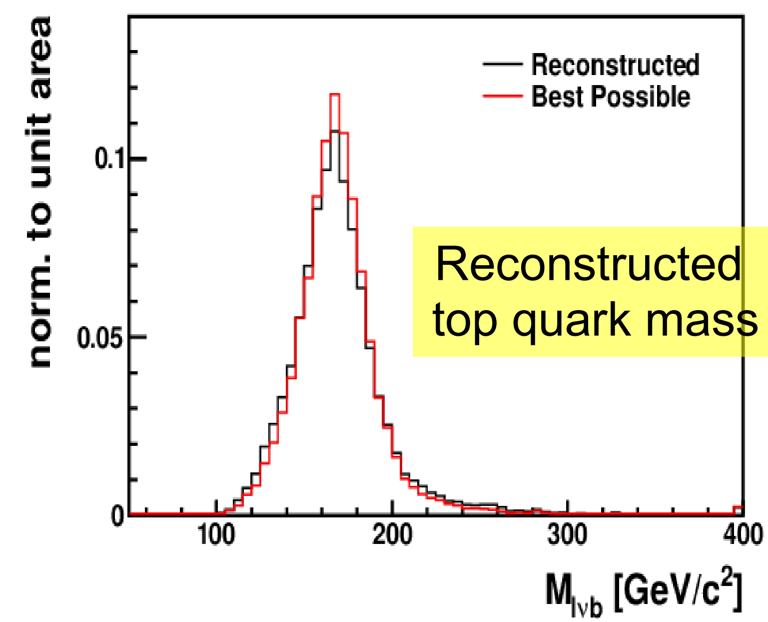
We have two machineries: a simple fit to 2 robust observables, and a fit to a multivariate discriminant (Boosted Decision Tree) designed to squeeze as much information as possible from the selected events

Top quark reconstruction



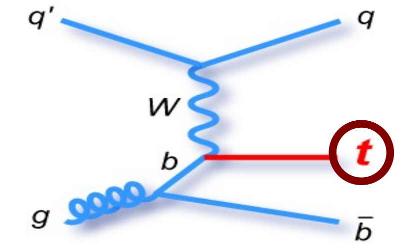
- W boson reconstruction:
  - W mass constraint
  - 2nd order equation in $P_{z,\nu}$
  - Complex solutions (22% of sel.evts.)
    - Forcing $M_T = M_W \rightarrow Img(P_{z,\nu})=0$
  - Two real solutions (78% of sel.evts.)
    - Pick the one with smallest $P_{z,\nu}$
    - correct in 60% of cases
- Pairing with a b:
  - Just take the b-tagged jet
  - Correct in 92.6% of selected events



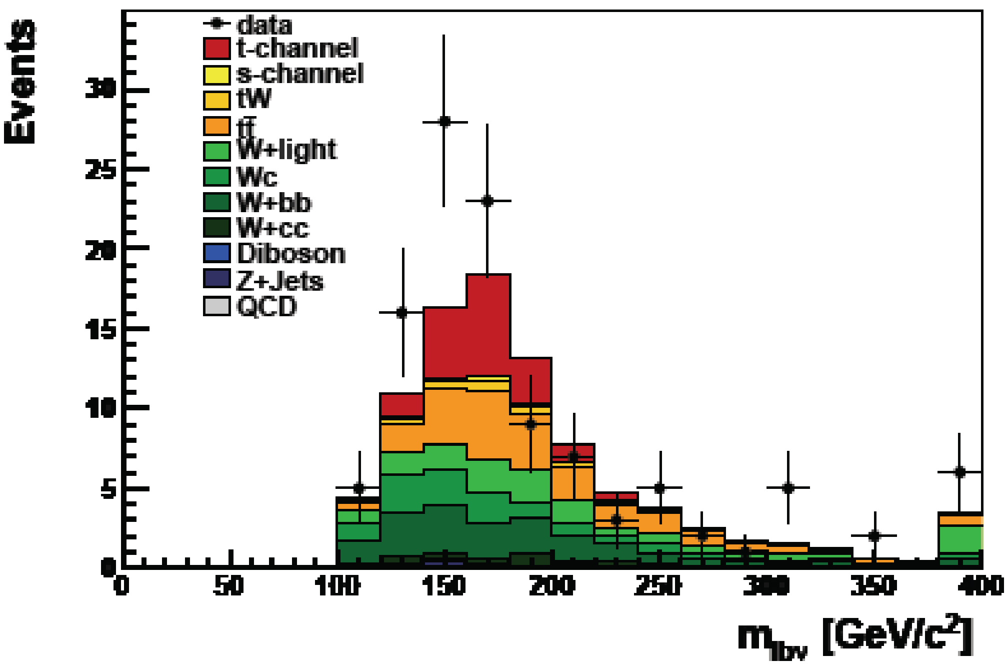


"Best possible" means minimal distance (ΔR) of ν_{reco}, b_{reco} from ν_{true}, b_{true}

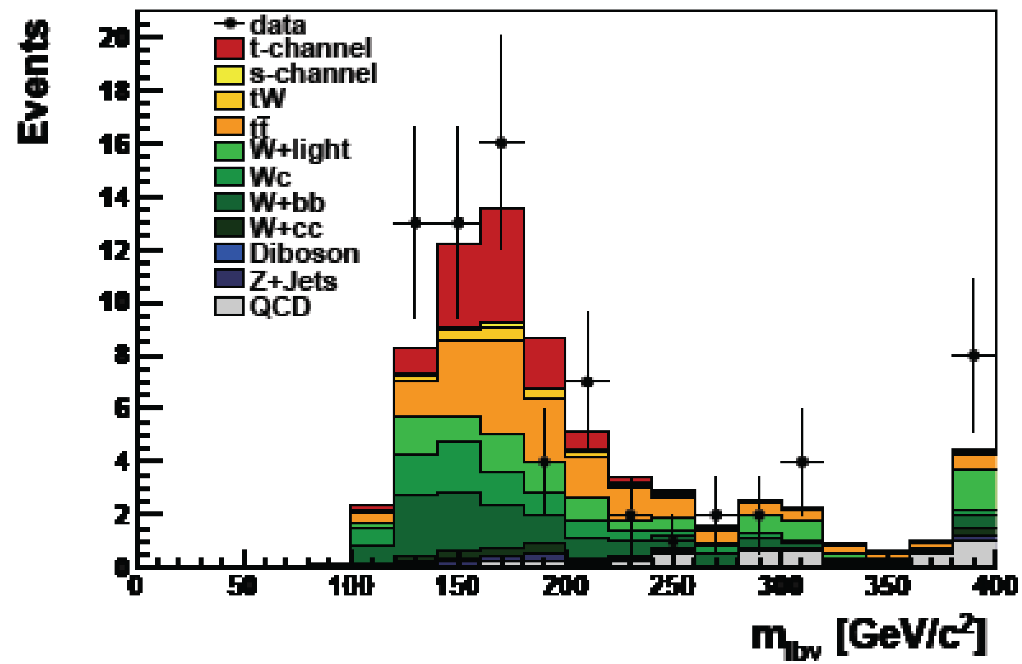
Smoking gun #1: there is a peak at ~M_{top}



Muon channel

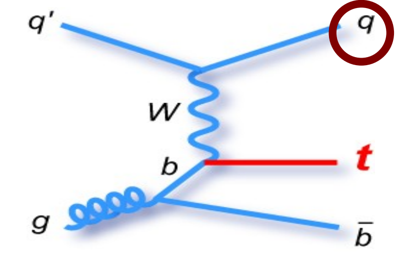


Electron channel

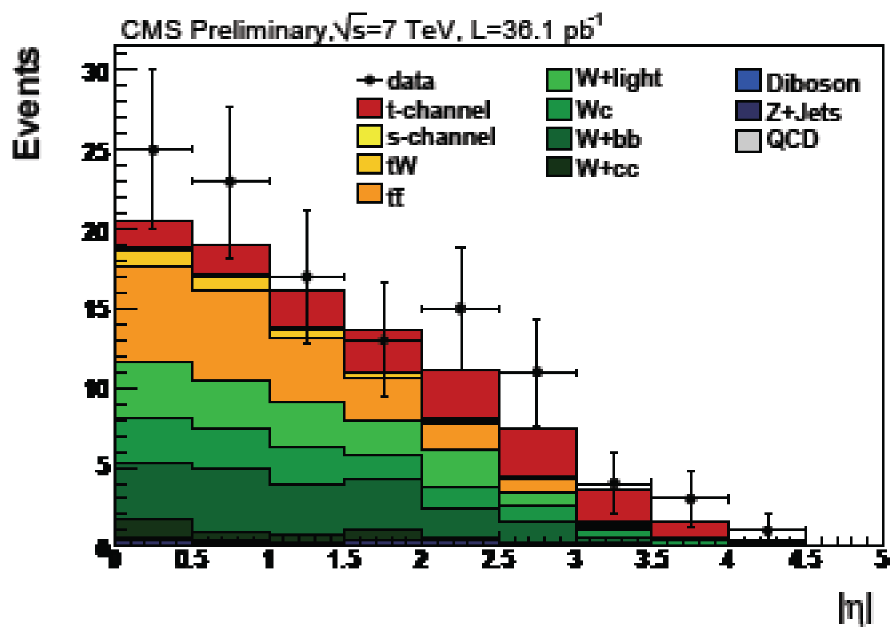


We explored the possibility to use this observable in our fits in a previous MC study. Not competitive until we have a very good precision on jet energy corrections.

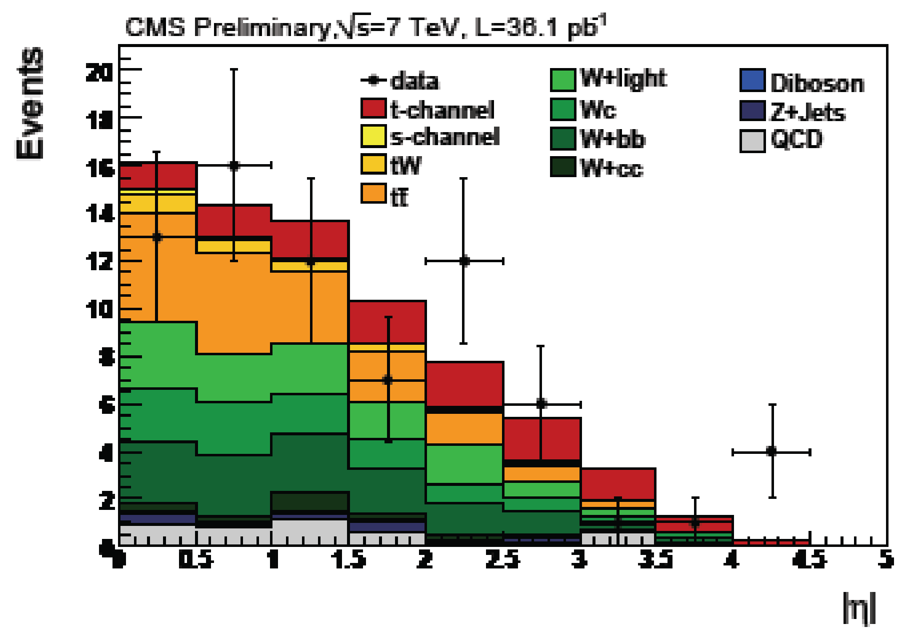
Smoking gun #2: recoil quark



Muon channel

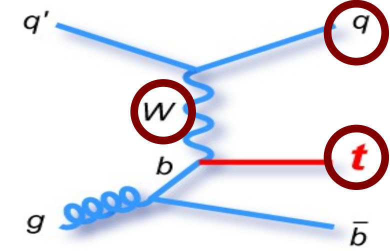


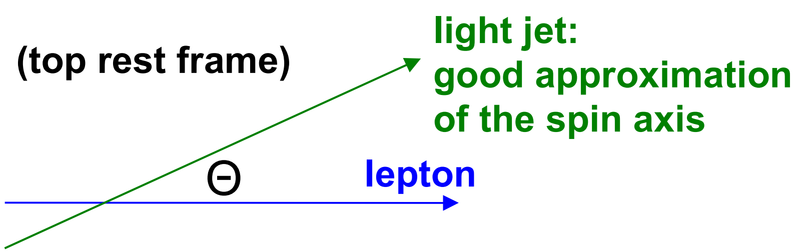
Electron channel



Pseudorapidity of the jet failing the loose b tagging.

Smoking gun #3: this top quark is polarized



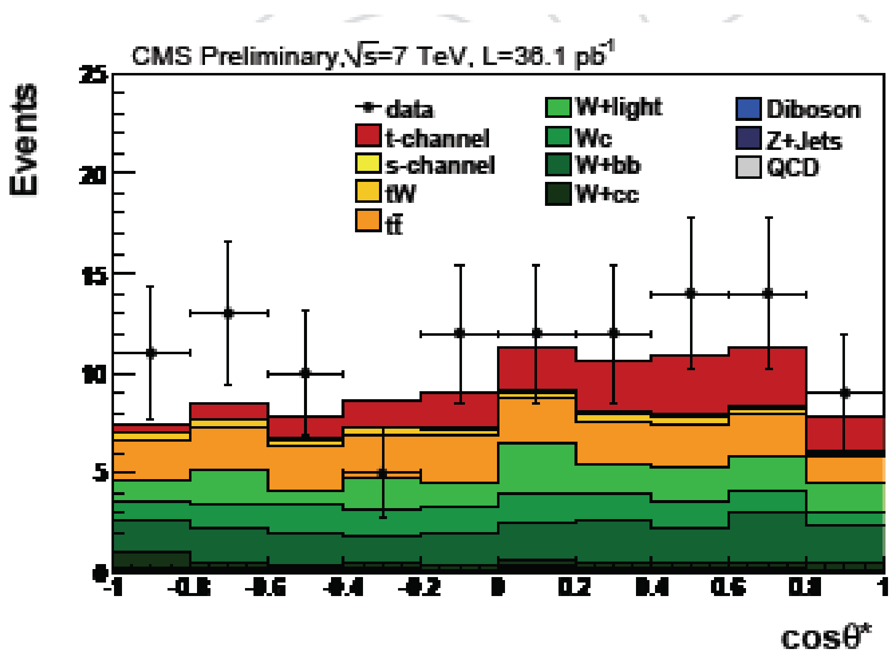


Most characteristic feature of single top events, stemming from the V-A nature of the Wtb coupling

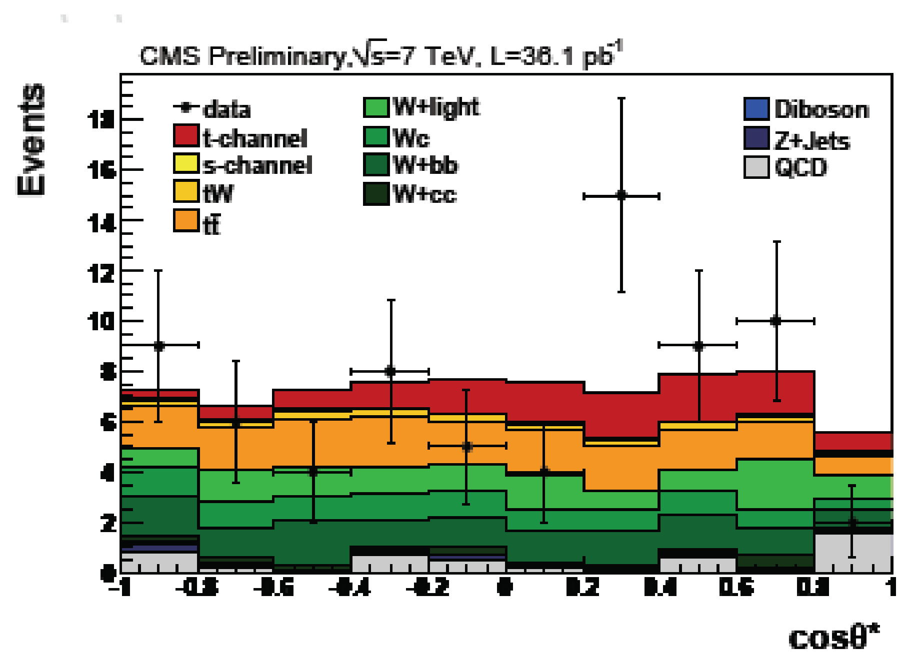
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{1}{2}(1 + A\cos\theta^*)$$

A = 1 for charged leptons

Muon channel



Electron channel



2D analysis: fit to $|\eta_{lj}|$ and $\cos\theta_{lj}^*$

Unbinned maximum likelihood fit to the dataset using the function:

$$L(N_s,N_b|cos\theta_1^*,...,cos\theta_n^*,\eta_1,...,\eta_n) =$$
$$= e^{-(N_s+N_b)} \cdot (N_s+N_b)^n \prod_{k=1}^{n} \frac{1}{N_s+N_b}\left(N_s \cdot P_s(cos\theta_k^*,\eta_k) + N_b \cdot P_b(cos\theta_k^*,\eta_k)\right)$$

- Two free parameters: N_s and N_b
- N_s and N_b are the number of events for signal (S) and overall background (B)
- P_s and P_b are the signal and background distribution functions.

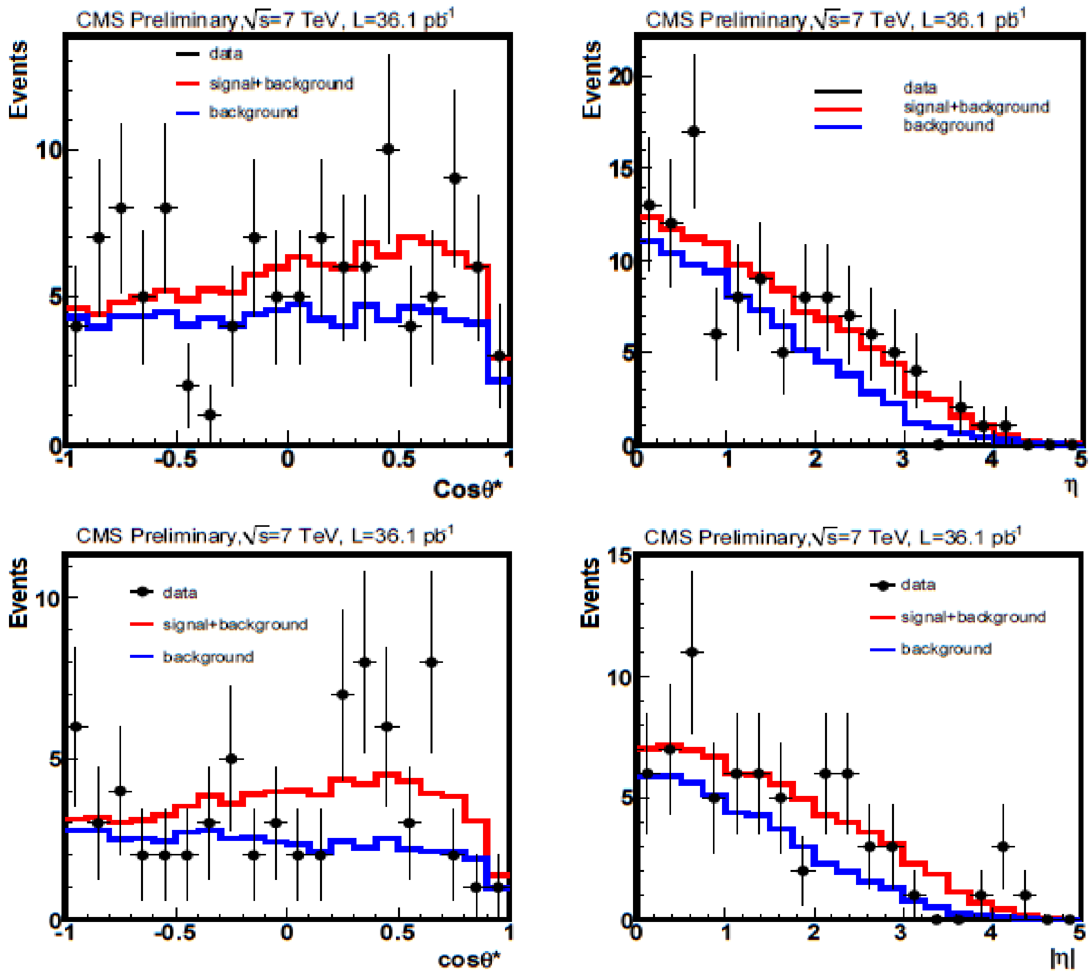
Correlation between $\cos\theta^*$ and η is ~6% for the signal and O(%) for all backgrounds, accounted for as systematics.
Background templates are parametrized as product of 1D templates.

W+light jets and QCD templates from orthogonal data.

Results, 2D analysis

μ

e



$$\sigma = 98.9 \pm 37.3(stat.)\,^{+30.4}_{-23.7}(syst.) \pm 11.0(lumi.)\ \text{pb} \qquad \text{muon channel}$$

$$\sigma = 142.0 \pm 50.9(stat.)\,^{+27.8}_{-21.4}(syst.) \pm 15.6(lumi.)\ \text{pb} \qquad \text{electron channel}$$

$$\sigma = 116.7 \pm 32.2(stat.)\,^{+25.2}_{-19.9}(syst.) \pm 12.9(lumi.)\ \text{pb} \qquad \text{combined}$$

Systematics

Systematics	σ up,down
Central value	116.7 $\pm$ 32.2 (stat) (27 %) pb
W+light partons rate	+1.2 -1.0 %
$W + Q\bar{Q}$ rate	-1.6 +4.0 %
$W + c$ rate	-4.7 +3.3 %
$t\bar{t}$ rate	+1.2 -1.3 %
QCD rate	+3.2 -1.7 %
b-tagging efficiency	-15.2 +21.7%
b-tagging mistag	-0.3 +0.4%
JES (+ corr. $E_{\mathrm{T}}^{\mathrm{miss}}$)	-1.9 +6.2 %
Unclustered $E_{\mathrm{T}}^{\mathrm{miss}}$	-2.3 +5.5 %
Z+jets rate	$\pm$ 0.2 %
VV rate	$\pm$ 0.1 %
Single top s channel rate	-0.2 +0.2 %
Single top tW channel rate	+0.5 -0.5 %
η_{lj}-cos θ^*_{lj} correlation	-0.5 %
SingleTop (Z2) - MadGraph ($D6T$)	+9.0 %
W+light partons model	-6.4 %
Pile up	+3.5 %
Q^2	+11 -3.4 %
ISR, FSR	+0.06 -0.7 %
$D6 - Z2$	+5.8 %
Total Systematics	-19.9 +25.2

This is going to improve soon

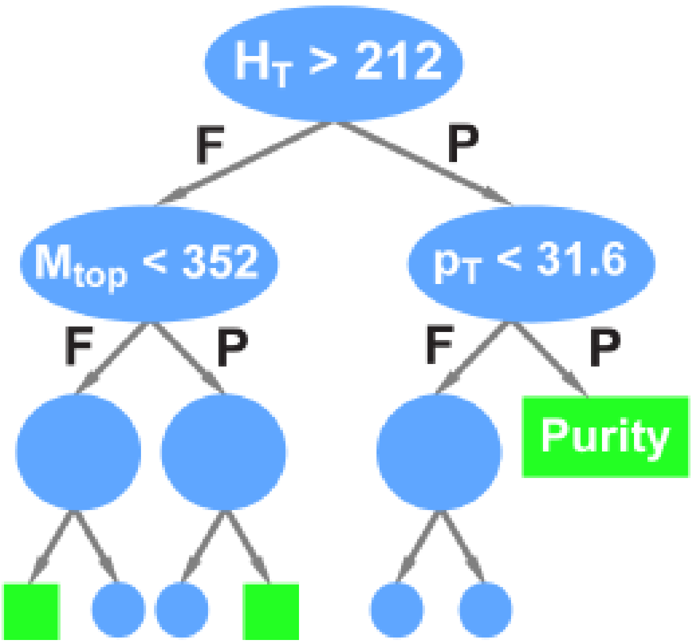
Signal model

Main uncertainty on bkg model

Boosted Decision Tree concept

(numbers are for illustration only)

Decision Tree (example):



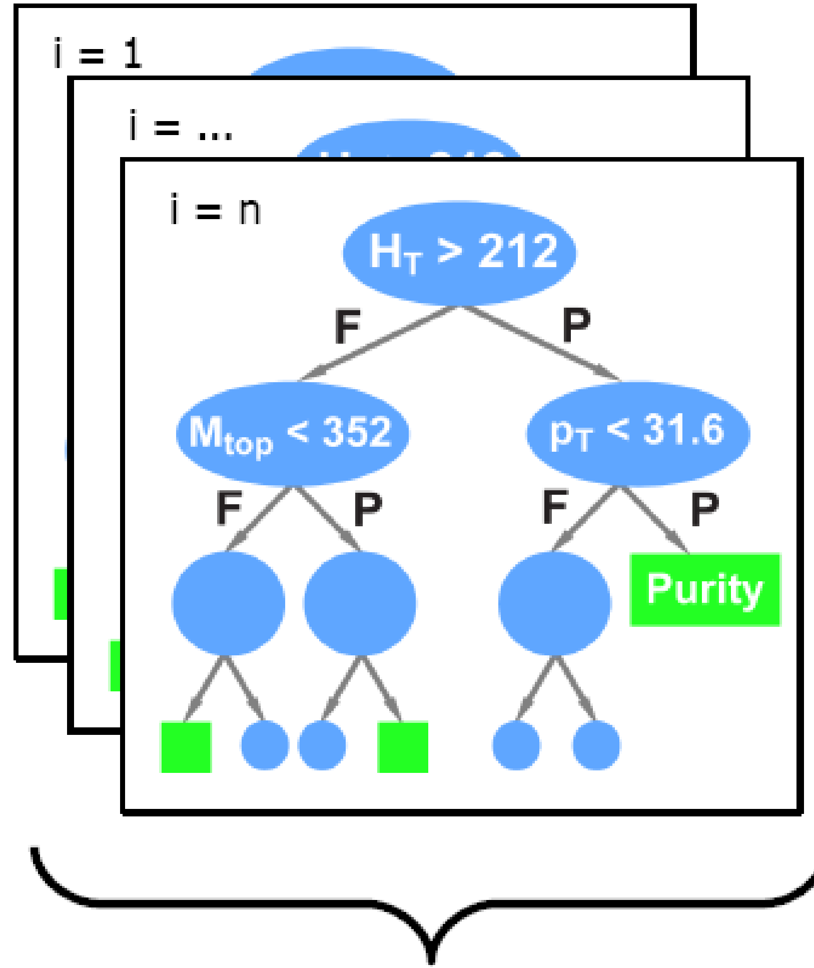
Signal-like event: weight=+1

Background-like: weight=-1

Reweight
misclassified events

n boosting
Cycles

(here you need MC)

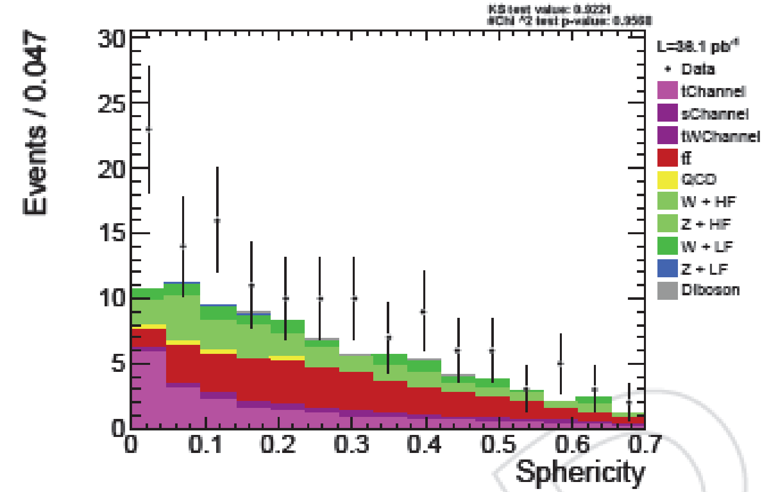


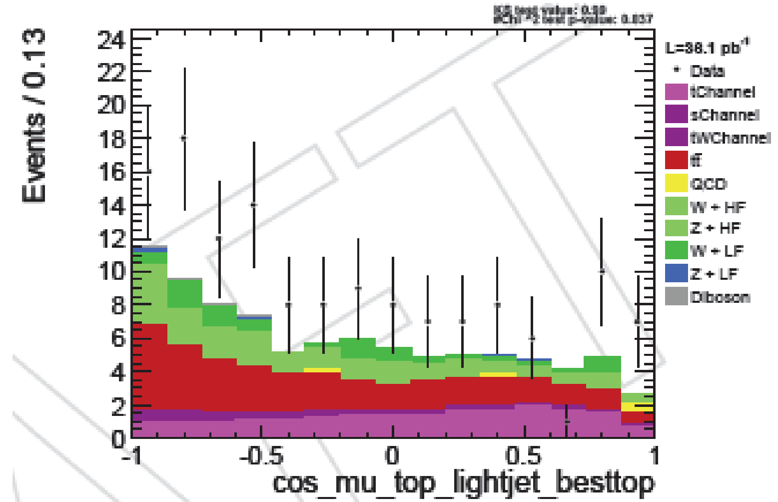
weighted majority vote

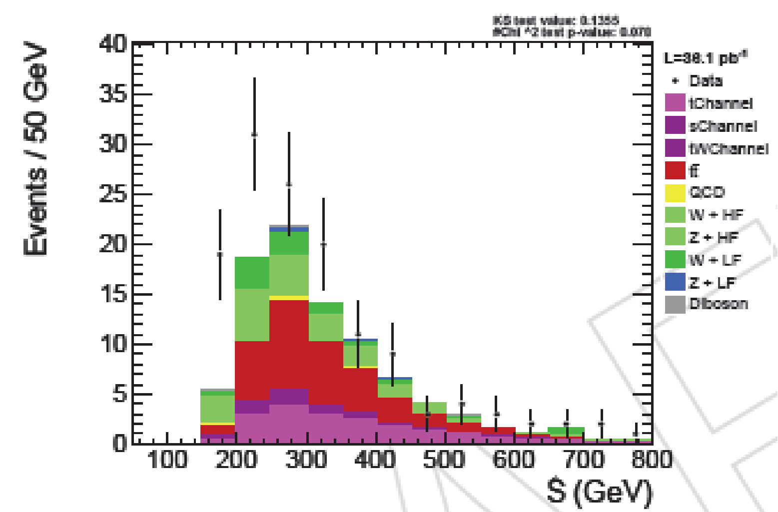
$$y_{Boost}(\vec{x}) = 1/N_{trees} \cdot \sum_{i}^{N_{trees}} ln(\alpha_i) \cdot h_i(\vec{x})$$

Inputs

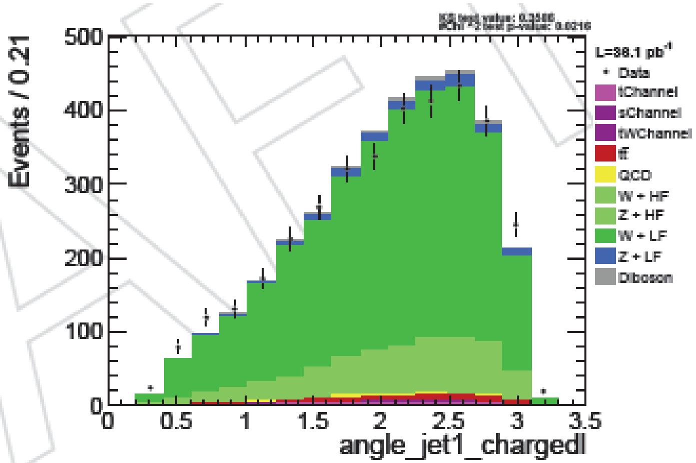
- 37 inputs (*) in 5 categories:
  - Kinematics of final-state objects (l,j,MET)
  - Correlations between final-state objects
  - Properties of reconstructed W, t, t+q
  - Angular distributions of l,j wrt W, t, t+q
  - Global event properties (sphericity, sum of p_T, ...)
- (*) yes, this is a lot, but see next slide

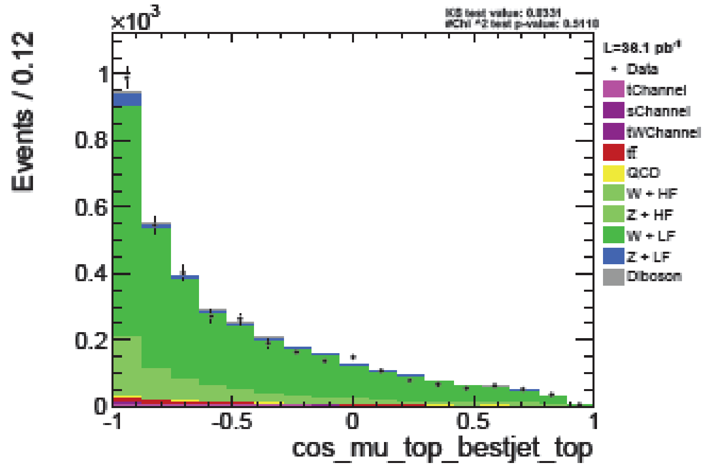


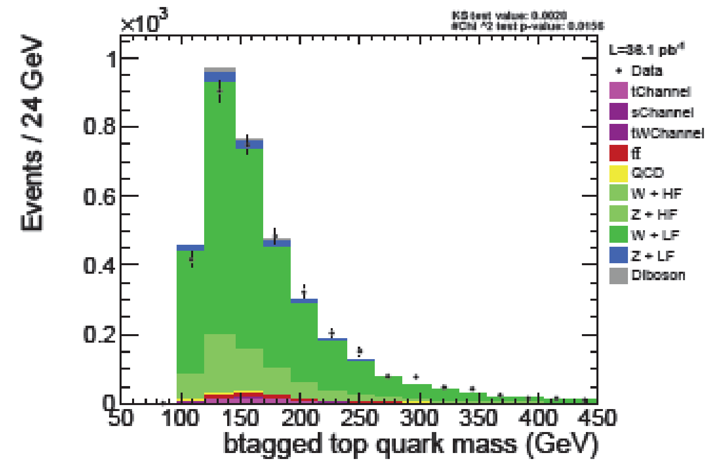




“37 inputs? You must be joking!”

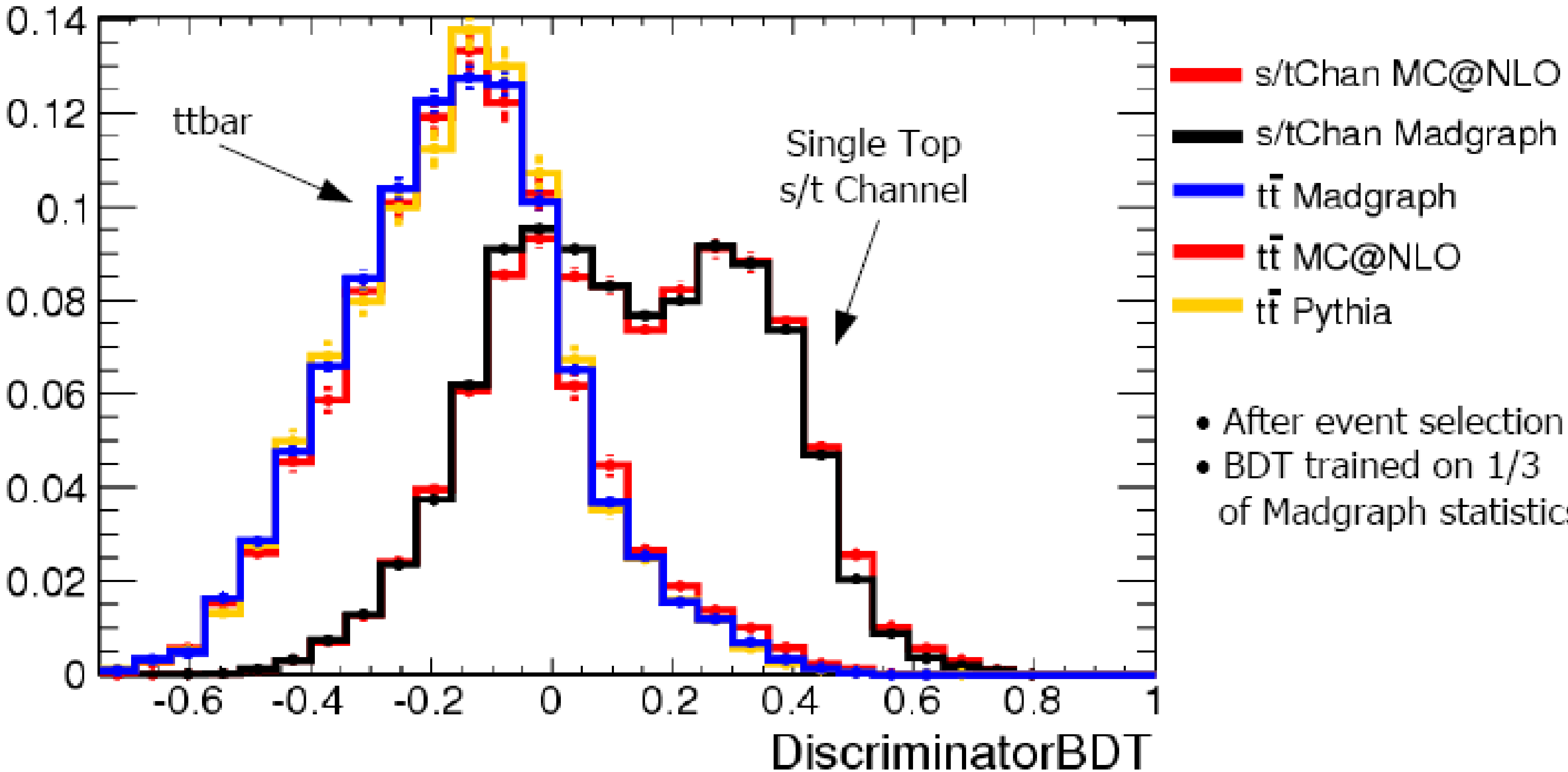






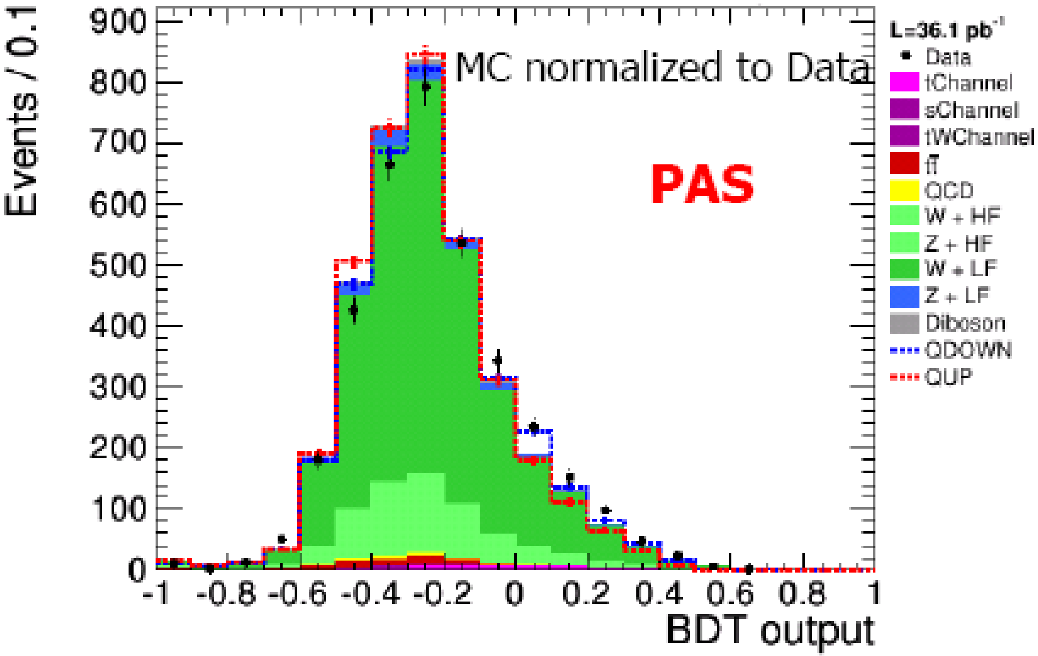
- Well, we validated all the 37!
  - ...at the small cost of the additional cut $\Delta\phi(j1,j2)<3$ needed to improve the data-MC agreement in the W+light jets control region
  - We then found that our W+jets MC was buggy, and the correct MC setting shows a remarkable agreement even without this cut
  - But all samples for systematics were done with these settings...
- A Kolmogorov-Smirnov test was done, including the main systematics, obtaining a flat distribution → our W+light jets model is appropriate for describing data at the current precision

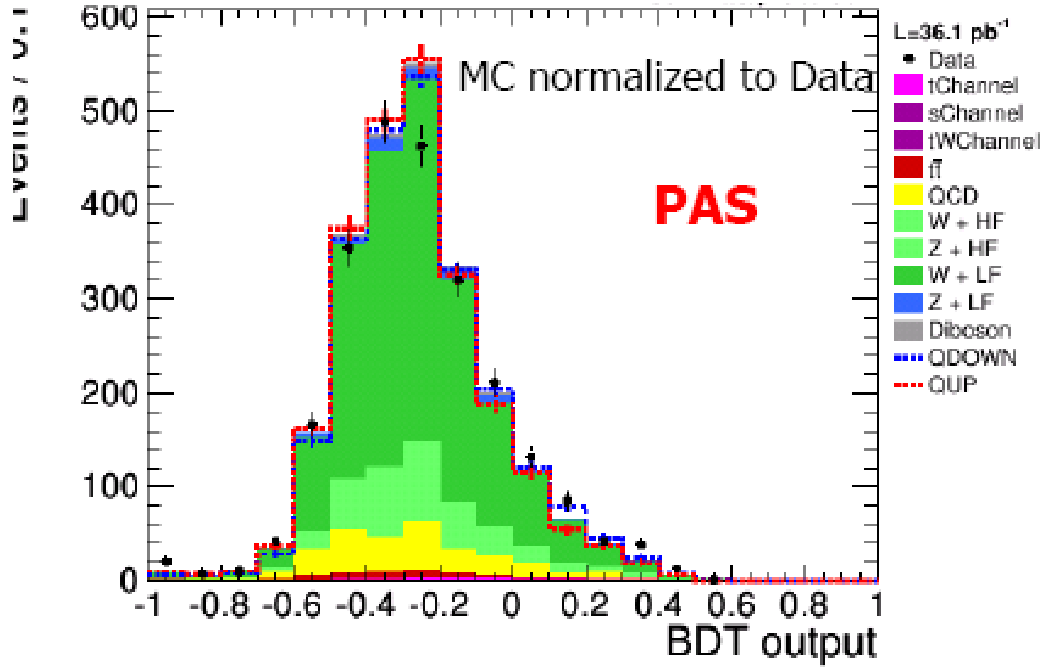
Robustness of our BDT: signal and ttbar models



- After event selection
- BDT trained on 1/3 of Madgraph statistics

Robustness of our BDT: W+light jets control sample

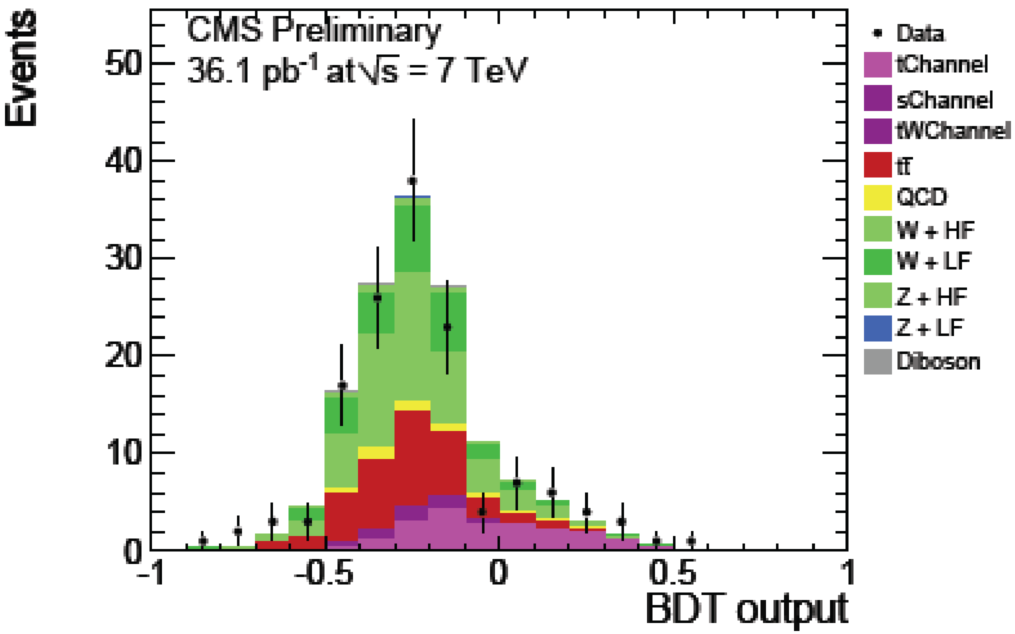


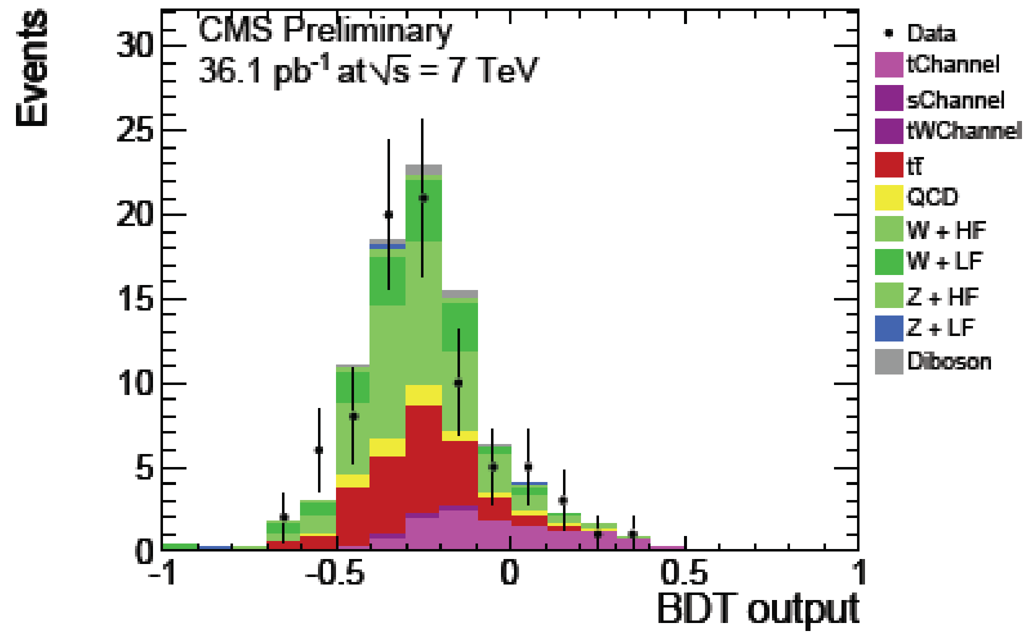


Muon Channel:
KS test probability: 20.1%

Electron Channel:
KS test probability: 13.6%

BDT results





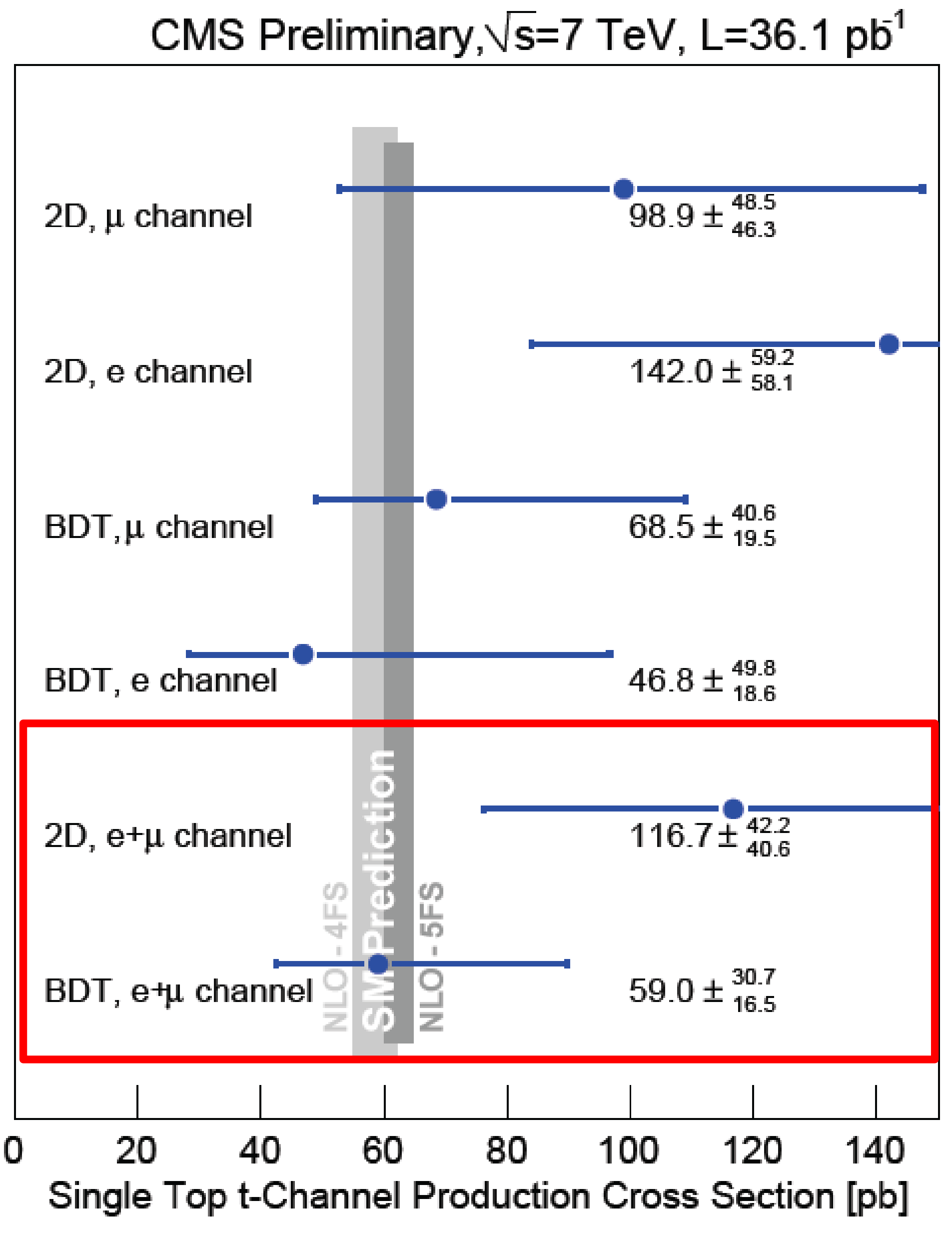
Note: the backgrounds here fluctuate individually within Gaussian constraints

$$\sigma^{BDT} = 68.5^{+40.6}_{-19.5}(total)\ \text{pb} \qquad \text{muon channel}$$

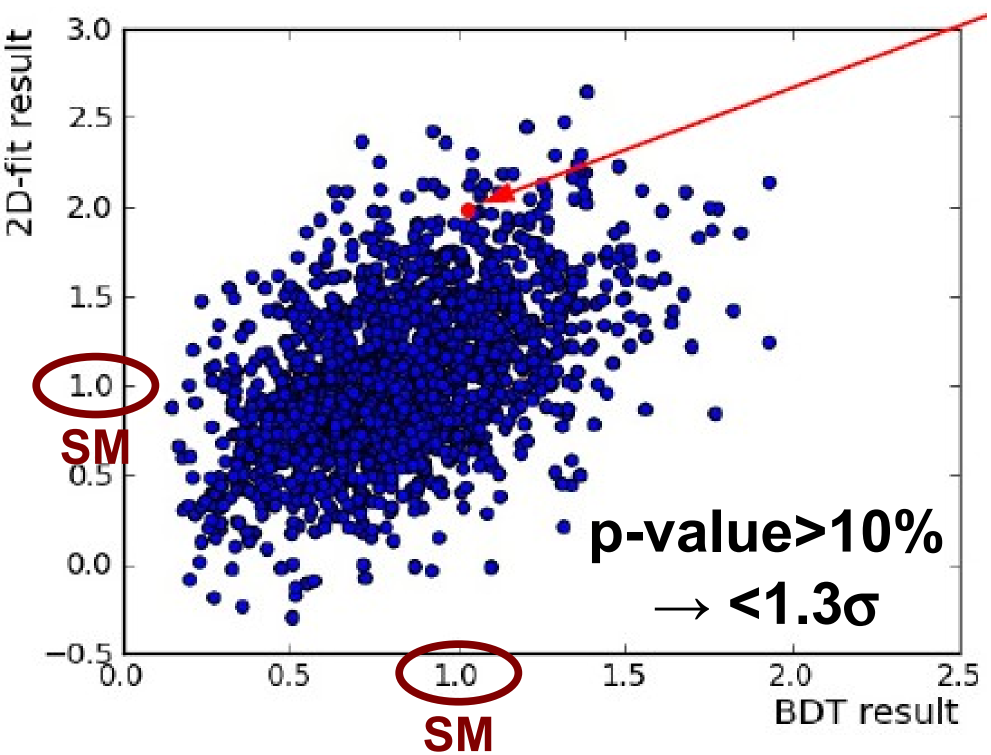
$$\sigma^{BDT} = 46.8^{+49.8}_{-18.6}(total)\ \text{pb} \qquad \text{electron channel}$$

$$\sigma^{BDT} = 59.0^{+30.7}_{-16.5}(total)\ \text{pb} \qquad \text{combined}$$

Are the results compatible?



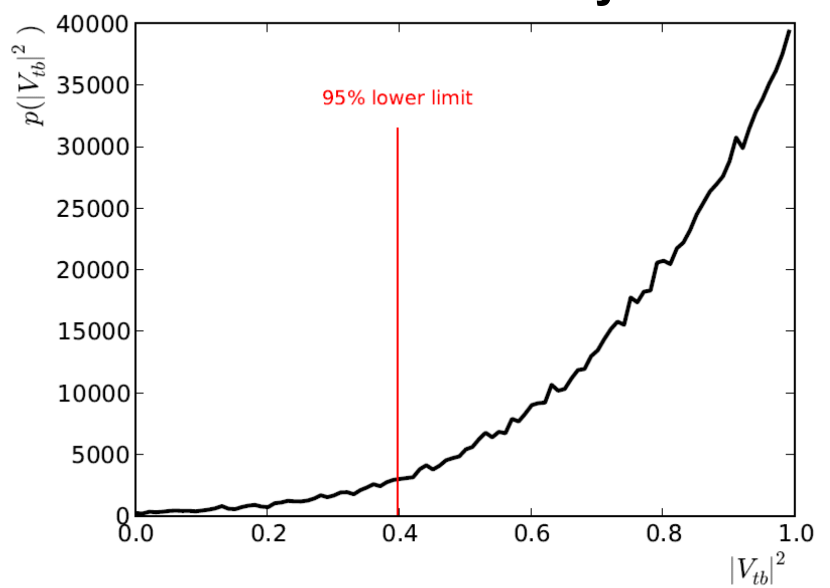
Just taking the quoted error bars underestimates the disagreement. The two selections are correlated (~50% overlap), and the fitted observables are correlated as well. We performed <u>toy experiments</u>:



Limit on $|V_{tb}|$, with some assumptions

- A limit à la Tevatron is straighforward:
  - Under the assumption that $|V_{td}|,|V_{ts}|<<|V_{tb}|$
  - ...and therefore R~1
  - ...which means that $|V_{tb}|^2 = \sigma(\text{exp})/\sigma(\text{SM})$, i.e., we have already measured it!
  - We have to consider the error on σ(SM)
- We also follow Tevatron on another assumption:
  - Flat prior $0<|V_{tb}|^2<1$
  - Rationale for this: flat in the physical observable (σ), not the fundamental one

From the 2D analysis:

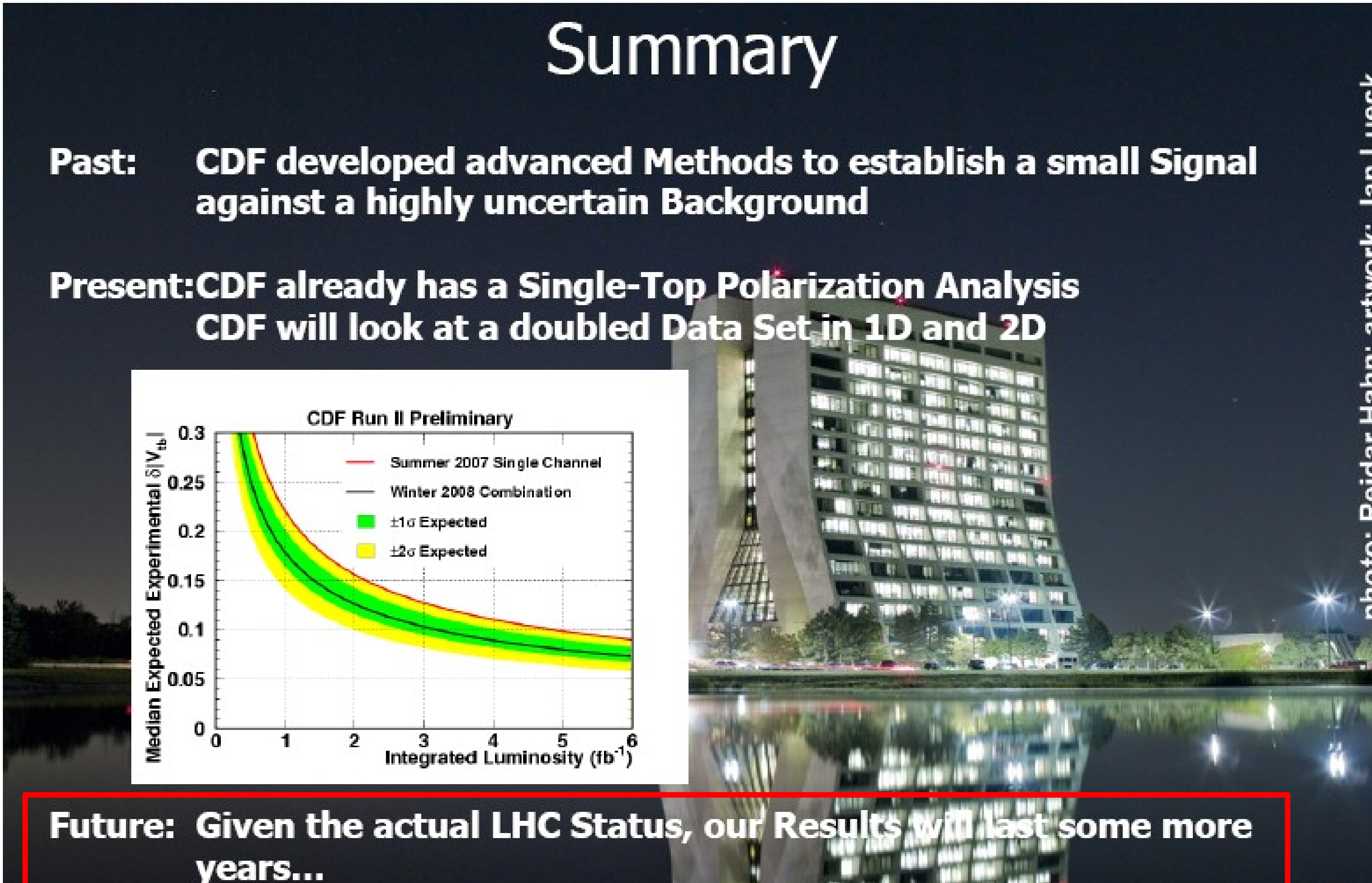


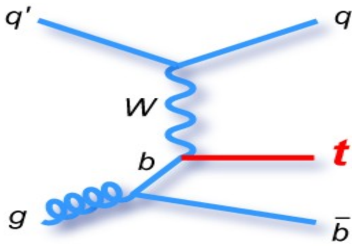
$|V_{tb}|^2 > 0.4$ @ 95%CL

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

Tevatron: > 0.77 @ 95%CL

8 months ago, at TOP2010...





Conclusions

- We measured the single top cross section in t channel at 7 TeV for the first time, with two complementary analyses
- Another impressive achievement of LHC: it took 15 years for Tevatron to go from top quark observation to single top, a few months for us
  - Nevertheless, it was not just “brute force”: making single top an analysis “for early data” required a long preparation and some original ideas
  - Historical recollection: in our kick-off meeting in Apr.2008, we wondered whether the same precision with ~1000/pb @ 14 TeV was realistic!

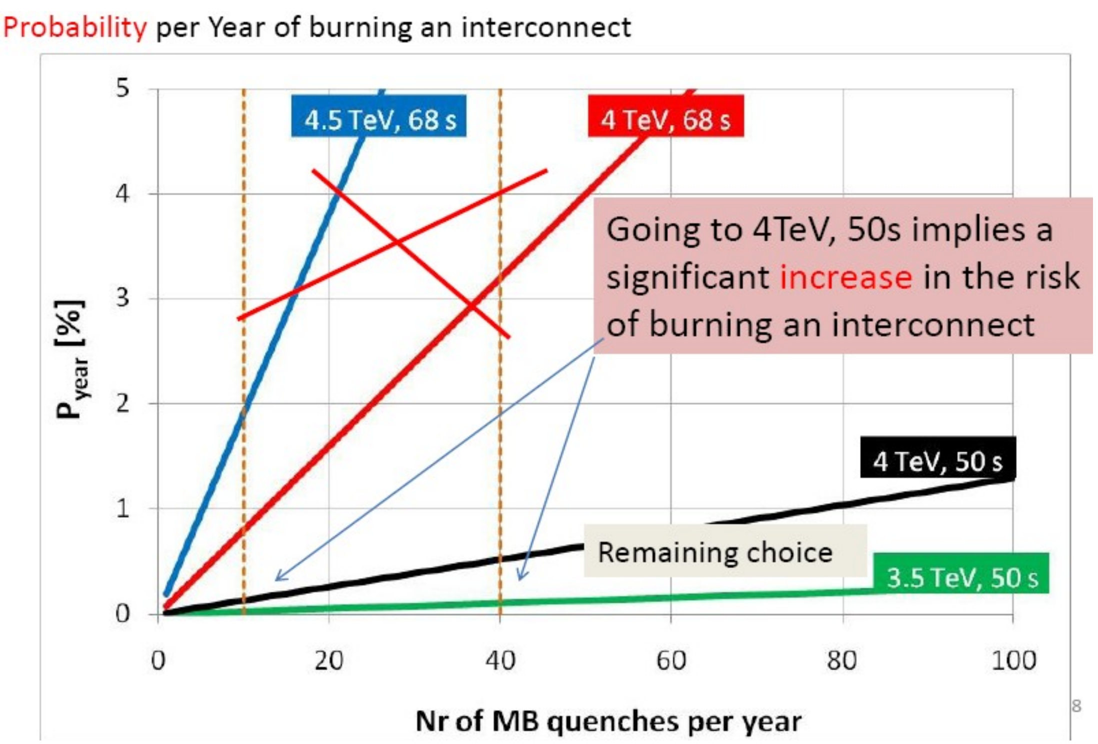
Thanks for you attention!

Schedule of our group

- Get approval by CMS (< March 9)
  - Moriond 2011: 1st result by CMS (and ATLAS?)
- Somewhen between April and June:
  - New data, get statistical error < systematic error
  - First paper submitted for publication
- And then:
  - Out-compete Tevatron on (model-dependent) $|V_{tb}|$ limits
  - Differential cross sections
  - Charge asymmetry
  - Combine with a precise R, set first model-independent $|V_{tb}|$ limits
  - First tW observation (in the World, not only at LHC)

LHC plans for 2011 and beyond

- Chamonix Workshop (Jan. 24-28, 2011)
  - Energy will stay at 7 TeV
  - We will run through 2012; L=1-8/fb
  - Technical stop: 2013-2014

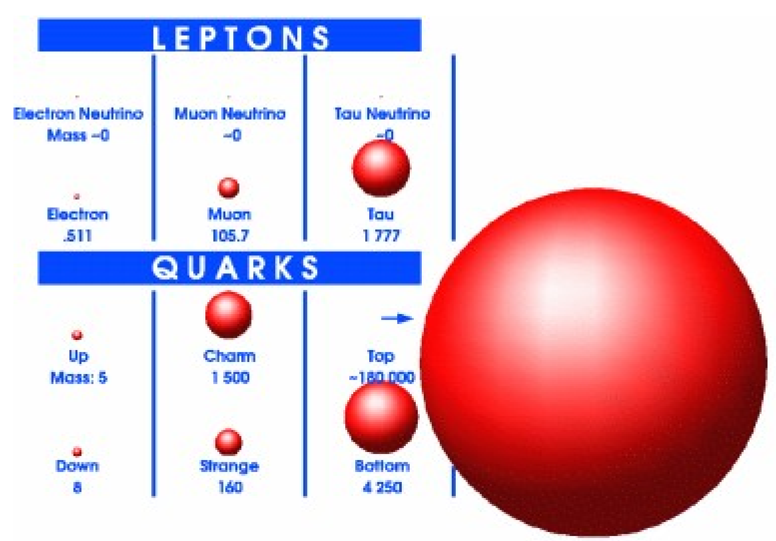


Digresssion: *a 4th family? Wasn't it excluded since long time?*

Electroweak precision data [LEPEWWG]

– Particle Data Group:
  An extra generation of ordinary fermions is excluded at the 6σ level on the basis of the S parameter alone... [Erler & Langacker]
  This result assumes that...any new families are degenerate [Erler & Langacker]
  Just as our 3rd generation??? [Holdom; Kribs, TP, Spannowsky, Tait]

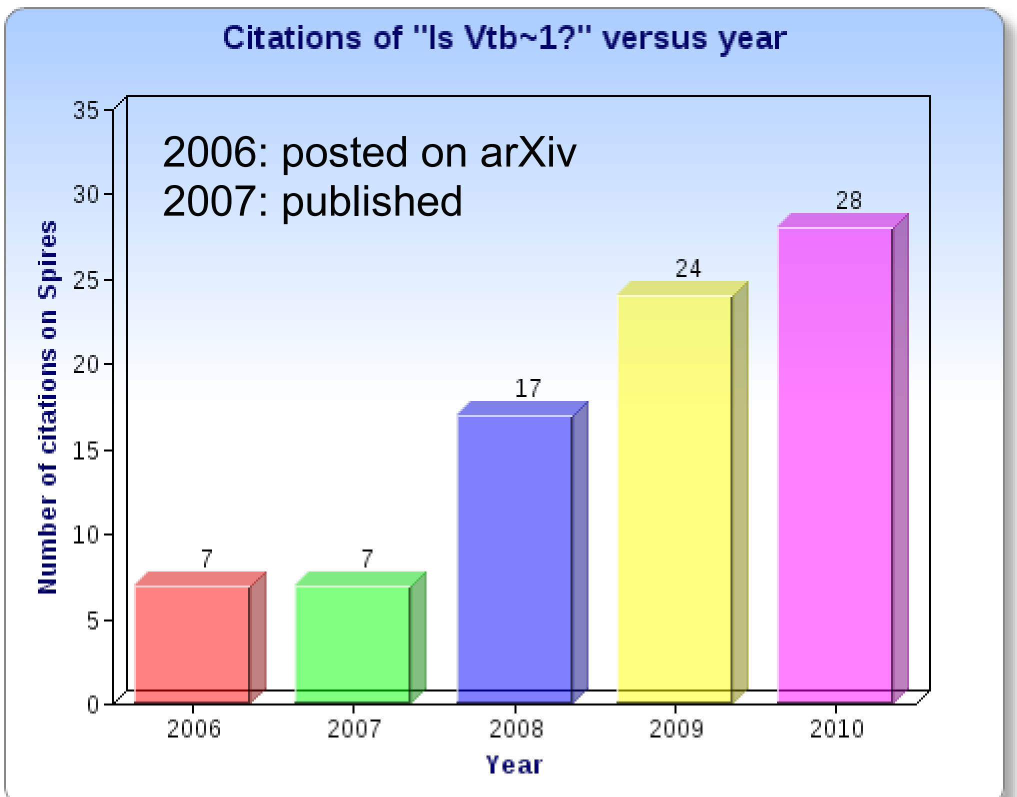
Flame-bait by Tilman Plehn

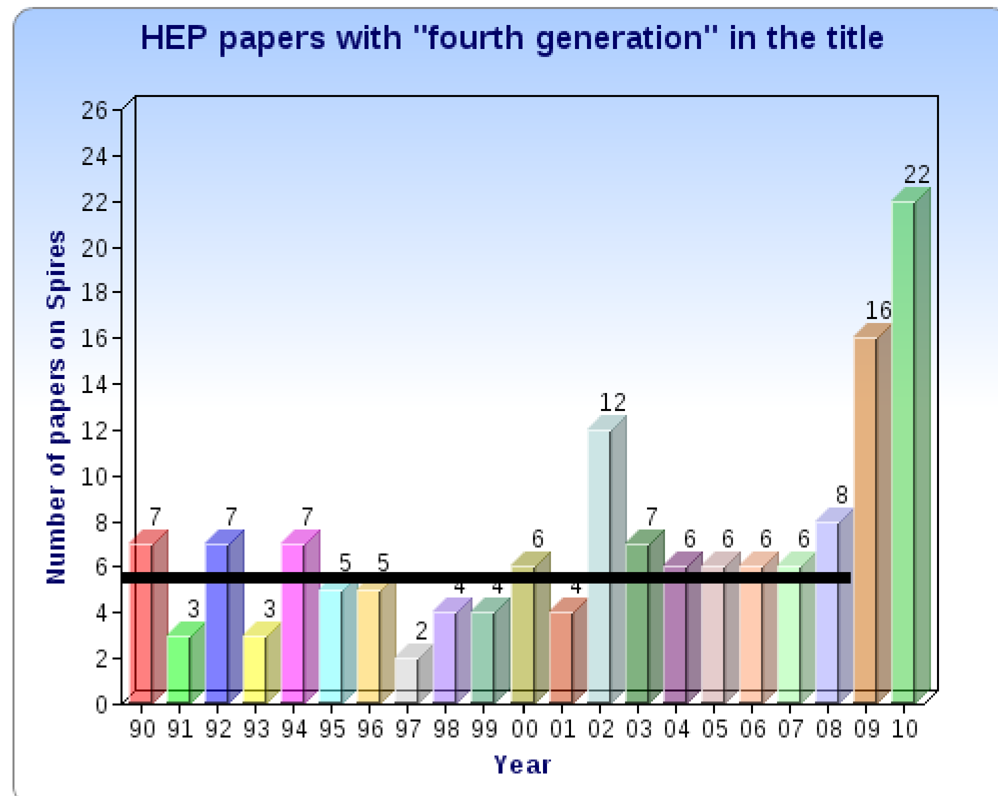


A small change in the Zeitgeist...

Particle Data Group:
An extra generation of ordinary fermions is excluded at the 6σ level on the basis of the S parameter alone... [Erler & Langacker]

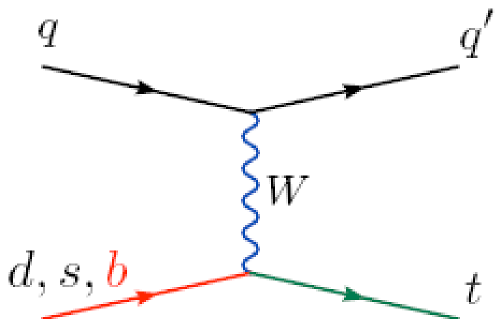
This result assumes that...any new families are degenerate [Erler & Langacker] !!!





Our humble paper revamped the interest of the community for new fermion generations.
Several dedicated workshops in the last 3 years! (Next one at DESY, September)

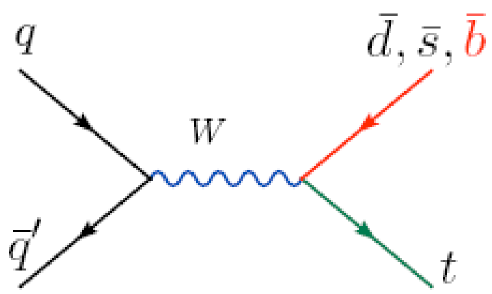
Direct constraints on $|V_{ti}|$, Tevatron



$$\sim |V_{td}|^2\sigma_d^{\text{t-ch}} + |V_{ts}|^2\sigma_s^{\text{t-ch}} + |V_{tb}|^2\sigma_b^{\text{t-ch}}$$

Enhancement due to large *d* and *s* densities

By the way: for the same reason, this is a good place to look for FCNC (*u* density)



$$\sim (|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2)\sigma^{\text{s-ch}}$$

Signal becomes similar to t-channel (only 1 *b*-jet)

Very simplified meta-analysis of Tevatron results (we will be able to do it more properly with direct access to CMS data):

$$\sigma_{1b\text{-tag}} = R\left\{\sum_{i=b,s,d} |V_{ti}|^2\sigma_i^{\mathrm{t-ch}} + 2(|V_{td}|^2 + |V_{ts}|^2)\sigma^{\mathrm{s-ch}}\right\}$$

$$\sigma_{2b\text{-tag}} = R\,|V_{tb}|^2\,\sigma^{\mathrm{s-ch}}$$

$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq(=d,s,b))} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

Direct constraints on $|V_{ti}|$, LHC

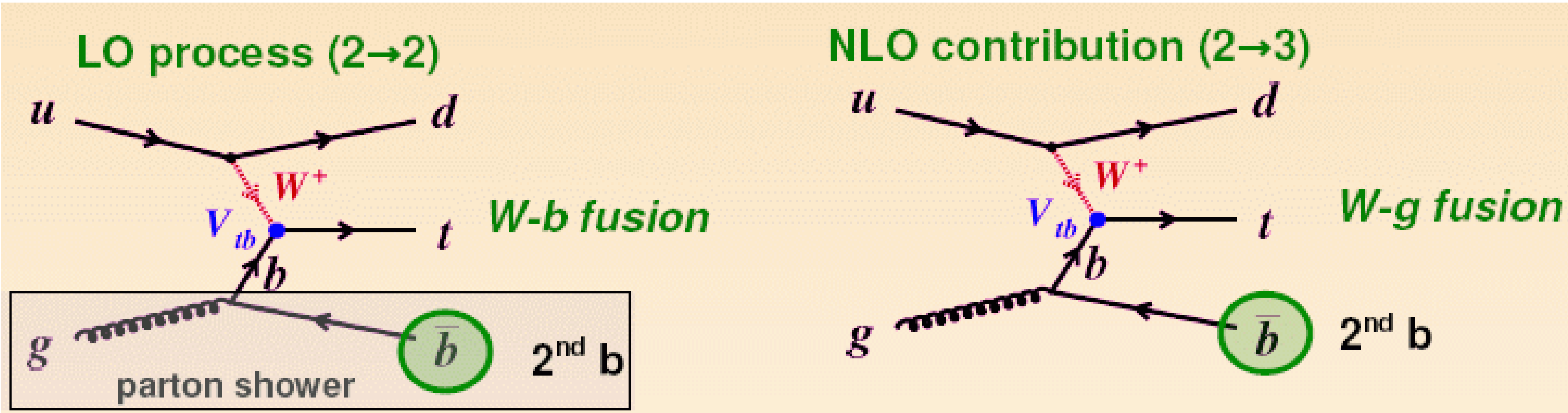
$$\sigma_{1b\text{-tag}} = R\left\{\sum_{i=b,s,d} |V_{ti}|^2 \sigma_i^{t-\mathrm{ch}} + \cancel{2(|V_{td}|^2 + |V_{ts}|^2)\sigma^{s-\mathrm{ch}}}\right\}$$

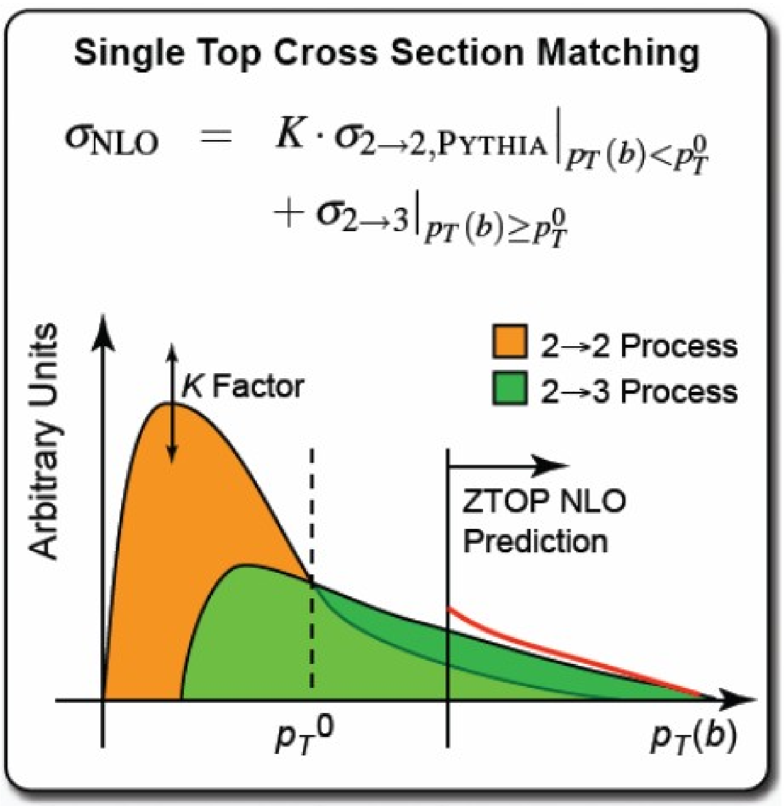
$$\cancel{\sigma_{2b\text{-tag}} = R\,|V_{tb}|^2\,\sigma^{s-\mathrm{ch}}}$$

$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq(=d,s,b))} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

- At LHC, $\sigma^{s\text{-ch}} \ll \sigma^{t\text{-ch}}$
  - The 3rd channel, tW, is non negligible now; but it's “1b” too
- 2 measurements (σ: single top, and R: from $t\bar{t}$) for 3 unknowns: top-only constraint of the entire 3rd row impossible
  - but we can use $|V_{td}/V_{ts}|$ from ΔM_{Bd} and ΔM_{Bs}

Signal model: 2→2 / 2→3 matching





- Matching in p_T of the associated b
- Original idea: E.Boos, L.Dudko, V.Savrin, CMS NOTE 2000/065 (*SingleTop* gen.)
- Used in CDF (*MadGraph*), D0 (*SingleTop*)
- CMS implementation on top of *MadGraph*
  - ✓ Cross-validated with *SingleTop* and *MC@NLO* (internal note AN2009/024)

The 4 exceptional events

Table 26: The 4 events with the largest value of η_{lj} in the electron decay channel. N_{PV} is the number of reconstructed primary vertices.

	Run	LS	Event	η_{lj}	$\cos\theta^*_{lj}$	$M_{l\nu b}$ (GeV/c^2)	M_T (GeV/c^2)	N_{PV}	JPT/ tcMET sel.?	BDT sel.?	BDT discr.
A	142928	446	107153746	4.04	0.43	167.0	94.0	1	Yes	Yes	0.31
B	143322	72	65704296	4.08	0.45	215.6	64.0	1	Yes	No	-
C	148829	160	157981253	4.31	-0.86	156.6	66.2	4	No	No	0.17
D	148864	355	415092519	4.11	-0.23	151.9	58.8	3	No	Yes	0.27

Table 27: Properties of the highest-η selected jets in the Hadron Forward calorimeter.

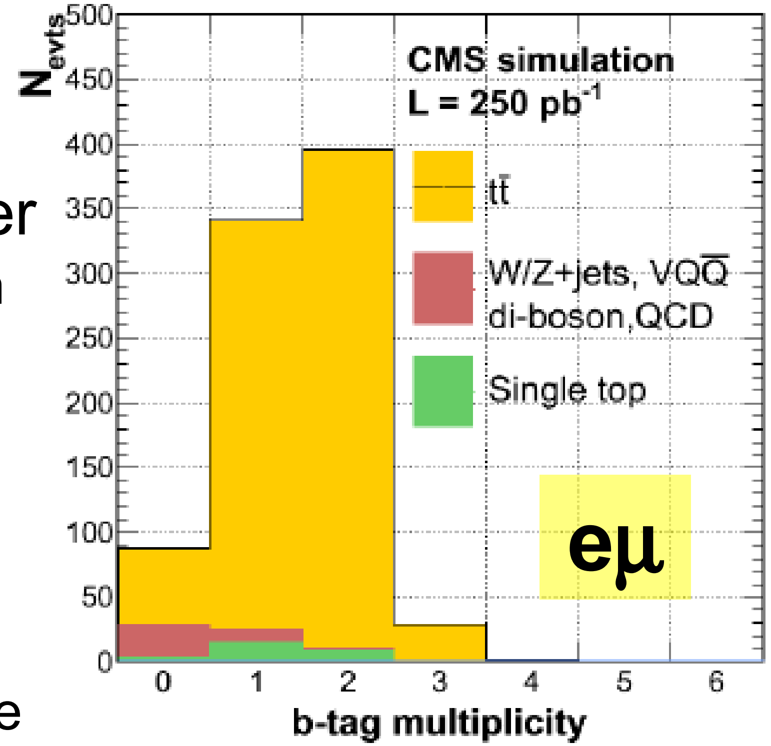
	Run	LS	Event	Hadronic energy (GeV)	EM energy (GeV)	Hadronic multiplicity	EM multiplicity
A	142928	446	107153746	1503.9	45.6	14	7
B	143322	72	65704296	961.0	13.1	14	4
C	148829	160	157981253	1965.9	15.7	20	3
D	148864	355	415092519	860.2	24.2	12	4

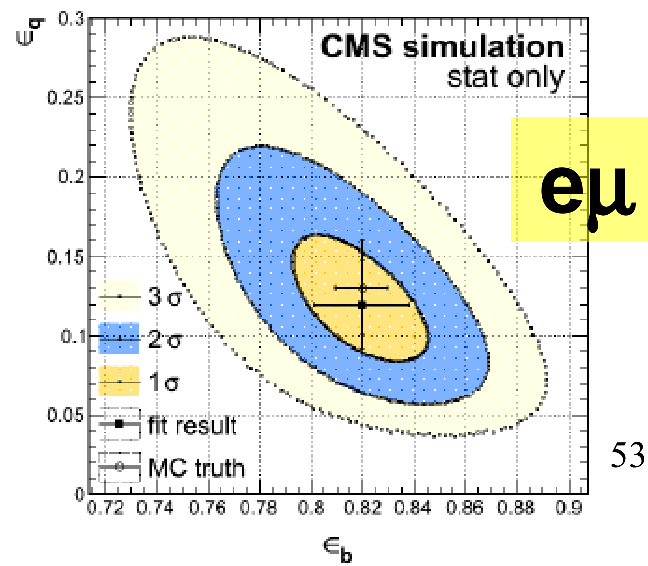
Events A and D are ranked as 2nd and 4th most signal-like events by the BDT.
Event C, if it passed the selection, would be ranked as 7th.
Event B fails BDT selection because PF2PAT treats the electron as a jet.
Event C fails BDT and JPT selections because one of its jets has 27.3 GeV according to PF2PAT and 26.9 GeV according to JPT (30.2 GeV in vanilla-PF).
Event D fails JPT selection because one of its jets has 29.8 GeV in JPT (31.1 GeV in PF)

b tagging efficiency or R=BR(t→b)

PAS TOP-09-001 (2l)
PAS TOP-09-007 (1l)

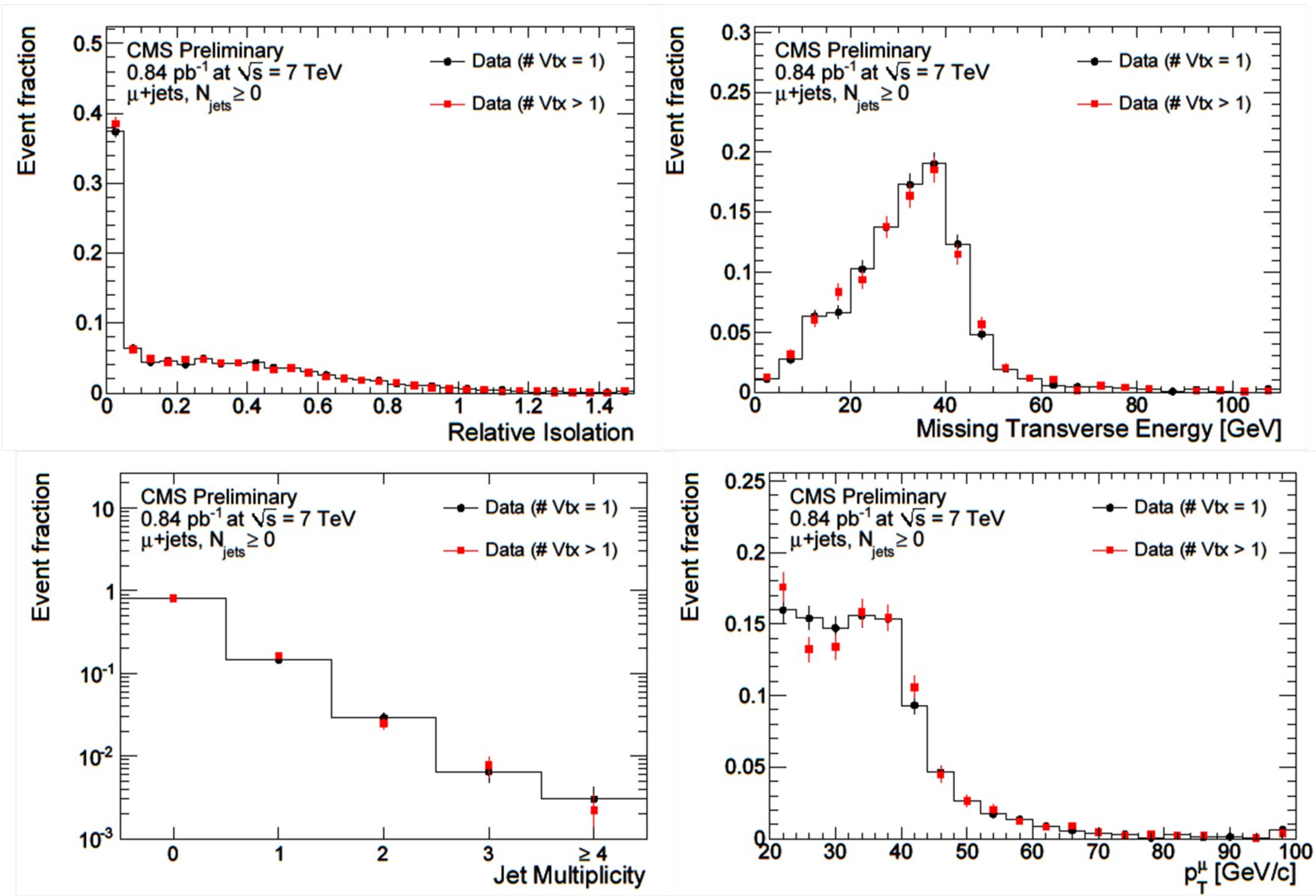
- Start from the standard selection and count the jets above some threshold in some b-tagger
  - A fit to this distribution yields ε_b, with the assumption of SM (R~1), or R if ε_b is estimated independently
  - In this slide a loose b-tagging working point is used, for a combined IP-based algorithm
- In the eμ channel, non-tt background is small
  - The challenge is the *internal* bkg: one b is missed, and a radiation (/pile-up/fake) jet is taken in his place
  - Methods exist to estimate it from the same data
  - Situation is much worse in the l+jets channels
- 250/pb @ 10 TeV: ΔR/R=±2%(stat)±9%(syst)
  - **→~500/pb @ 7 TeV to compete with Tevatron**
  - Dominated by b-tagging uncertainty
  - $\Delta\varepsilon_b/\varepsilon_b$=±1-3%(stat)±4%(syst) if R=1, depending on the threshold and on the tagger





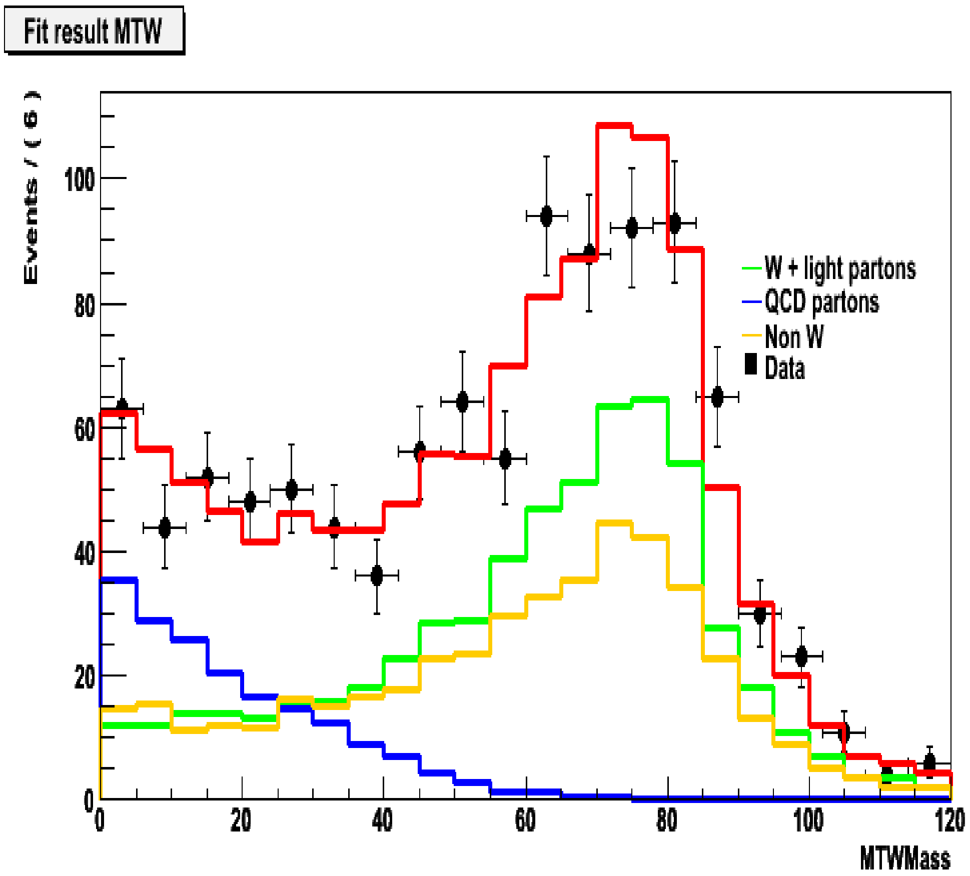
Sensitivity to pile-up

CMS-TOP-10-004

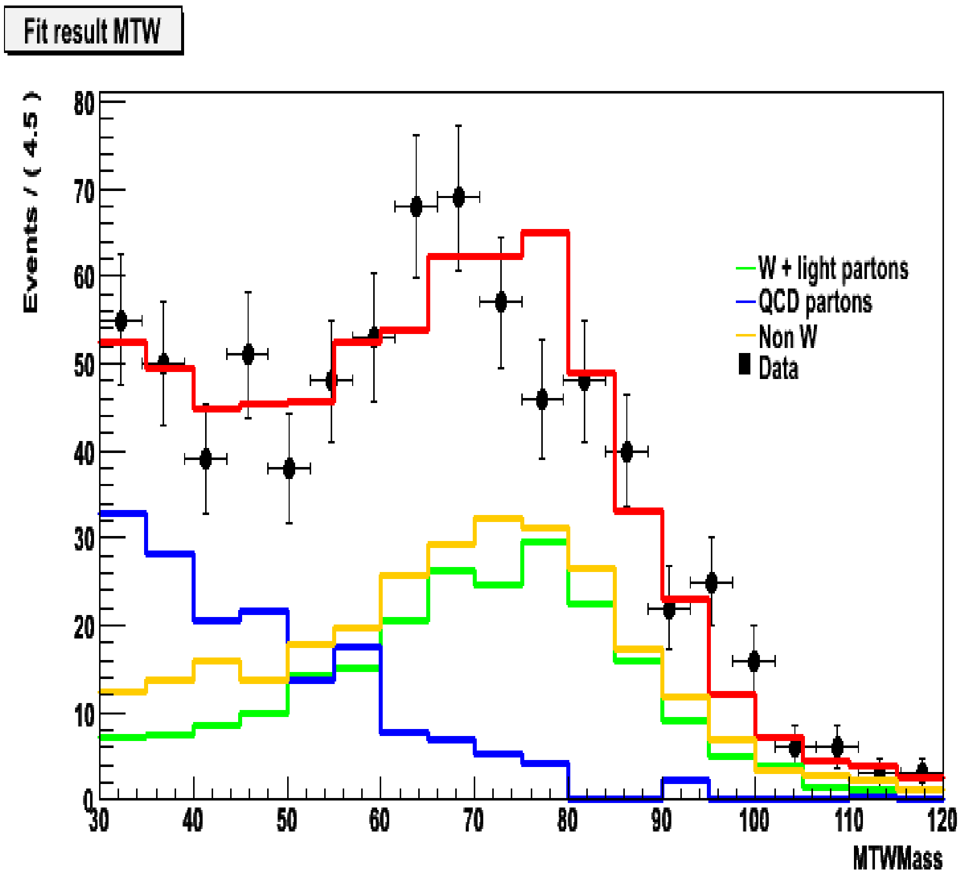


W+light partons estimation

Muon channel



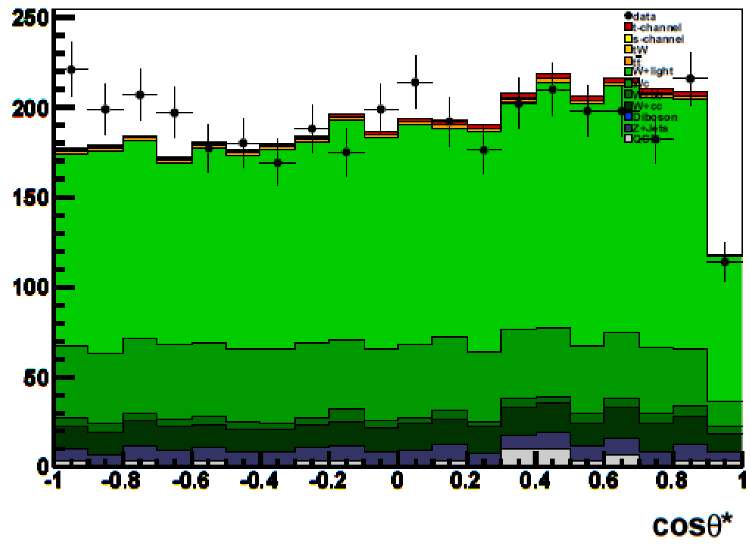
Electron channel: M_T>30 GeV



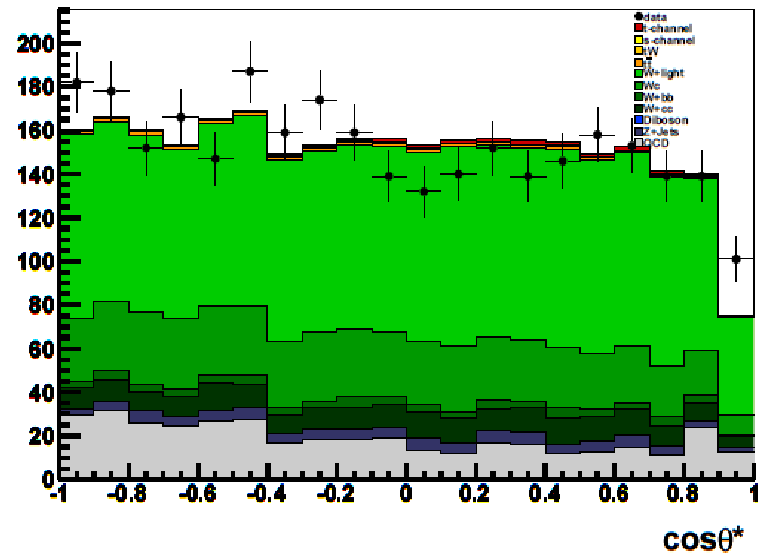
Template extraction: W+light jets enriched control sample

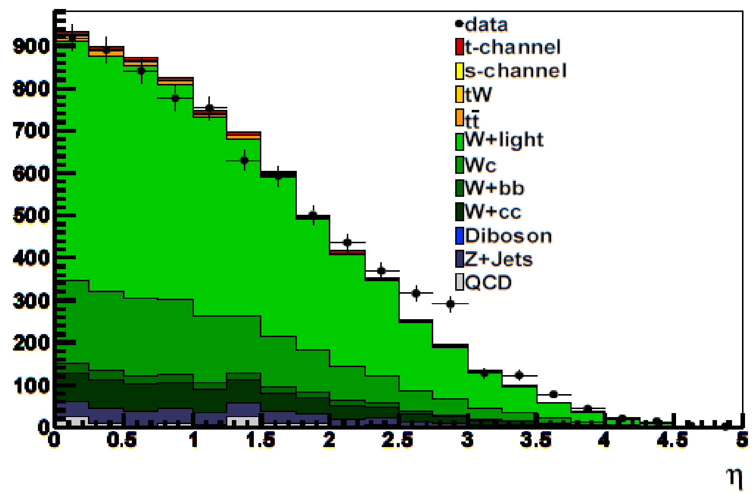
- 2-jet bin, both anti-b-tagged; M_T > 40 (50) GeV
- top quark reconstruction: use jet with highest-b-tag value

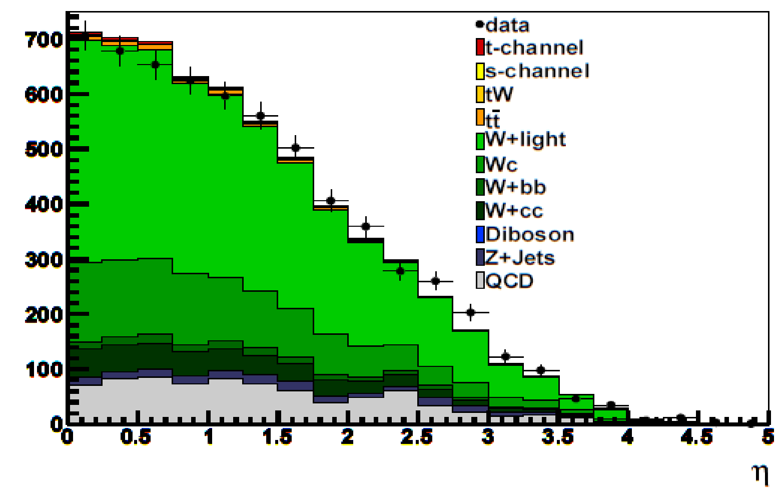
Muon channel



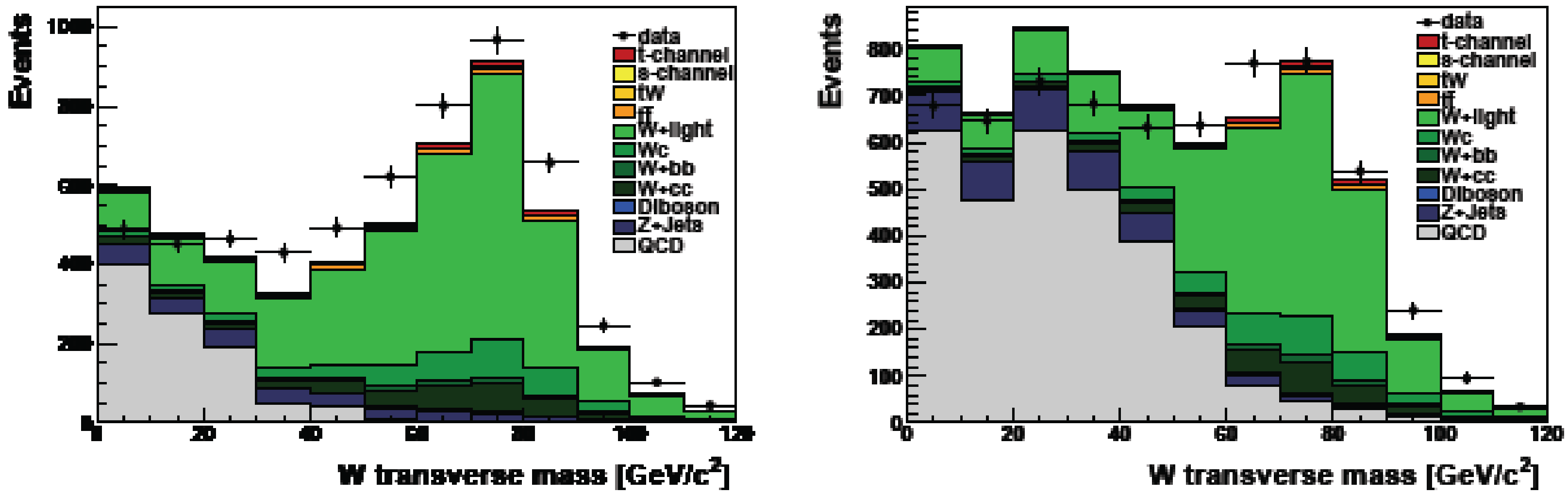
Electron channel







Choice of the M_T cut



(a) (b)

Figure 6: Transverse mass after the entire selection minus the M_T cut and the b-tagging requirements (a muons, c electrons).

Fit to separate variables

Fit variables	Signal yield ± statistics	cross section ± stat (pb)
$\cos\theta^*_{lj}, \eta_{lj}$	27.7 ± 11.2	100.6 ± 40.6
$\cos\theta^*_{lj}$	19.7 ± 20.7	71.6 ± 75.2
η_{lj}	28.8 ± 13.3	104.3 ± 48.3

Table 22: Results for 2D, $\cos\theta^*_{lj}$ only and η_{lj} only fits in the muon channel.

Fit variables	Signal yield ± statistics	cross section ± stat (pb)
$\cos\theta^*_{lj}, \eta_{lj}$	25.9 ± 9.5	142.0 ± 52.0
$\cos\theta^*_{lj}$	26.8 ± 15.2	147.1 ± 83.4
η_{lj}	24.9 ± 10.8	136.4 ± 58.7

Table 23: Results for 2D, $\cos\theta^*_{lj}$ only and η_{lj} only fits in the electron channel.

MC comparison, AN2009/024 (14 TeV samples)

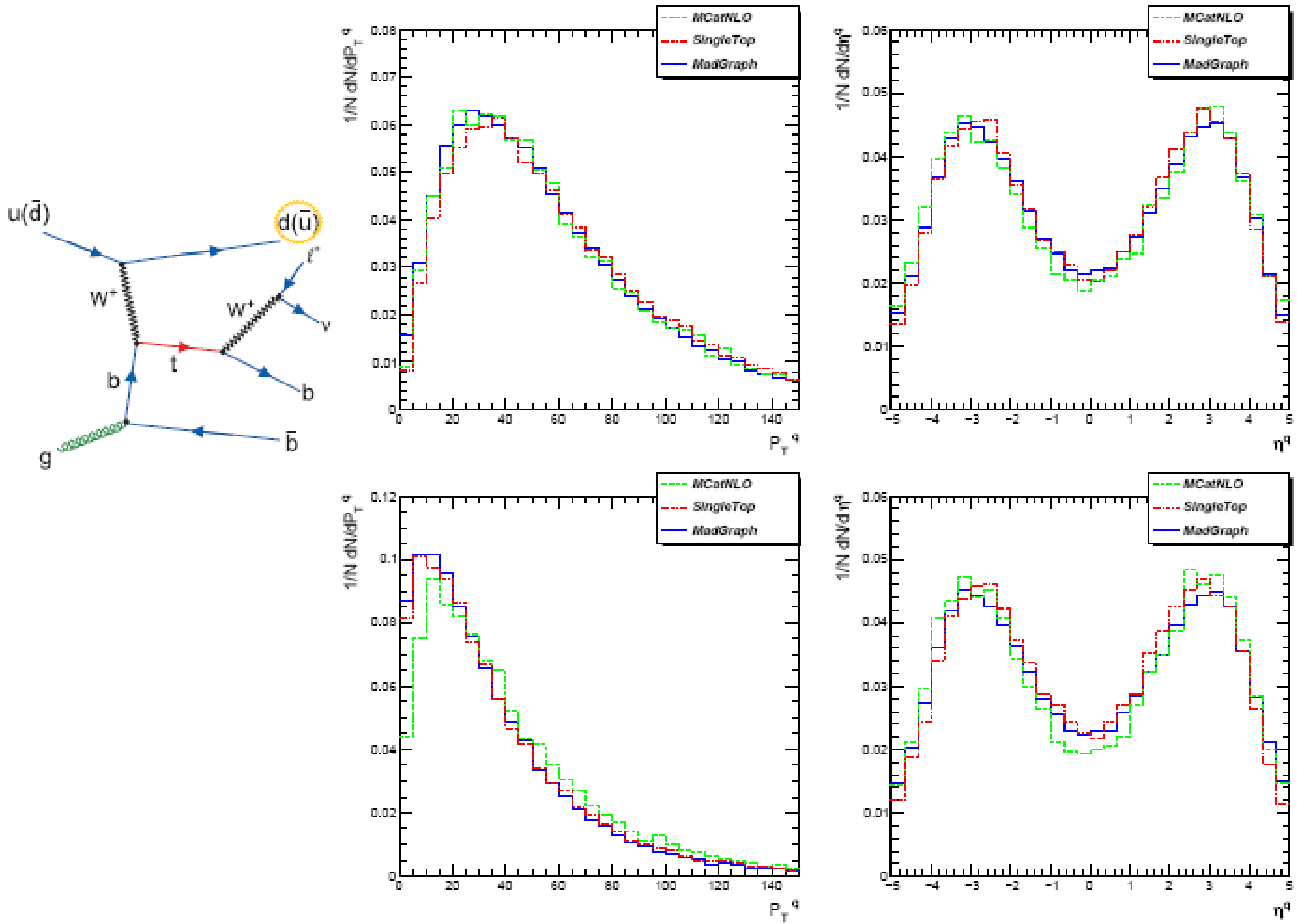
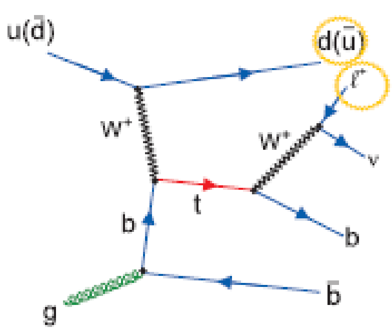


Figure 4: Distributions of p_T and η of the light quark q before simulation of Final State Radiation (top row) and after its simulation (bottom row).

MC comparison, AN2009/024 (14 TeV samples)



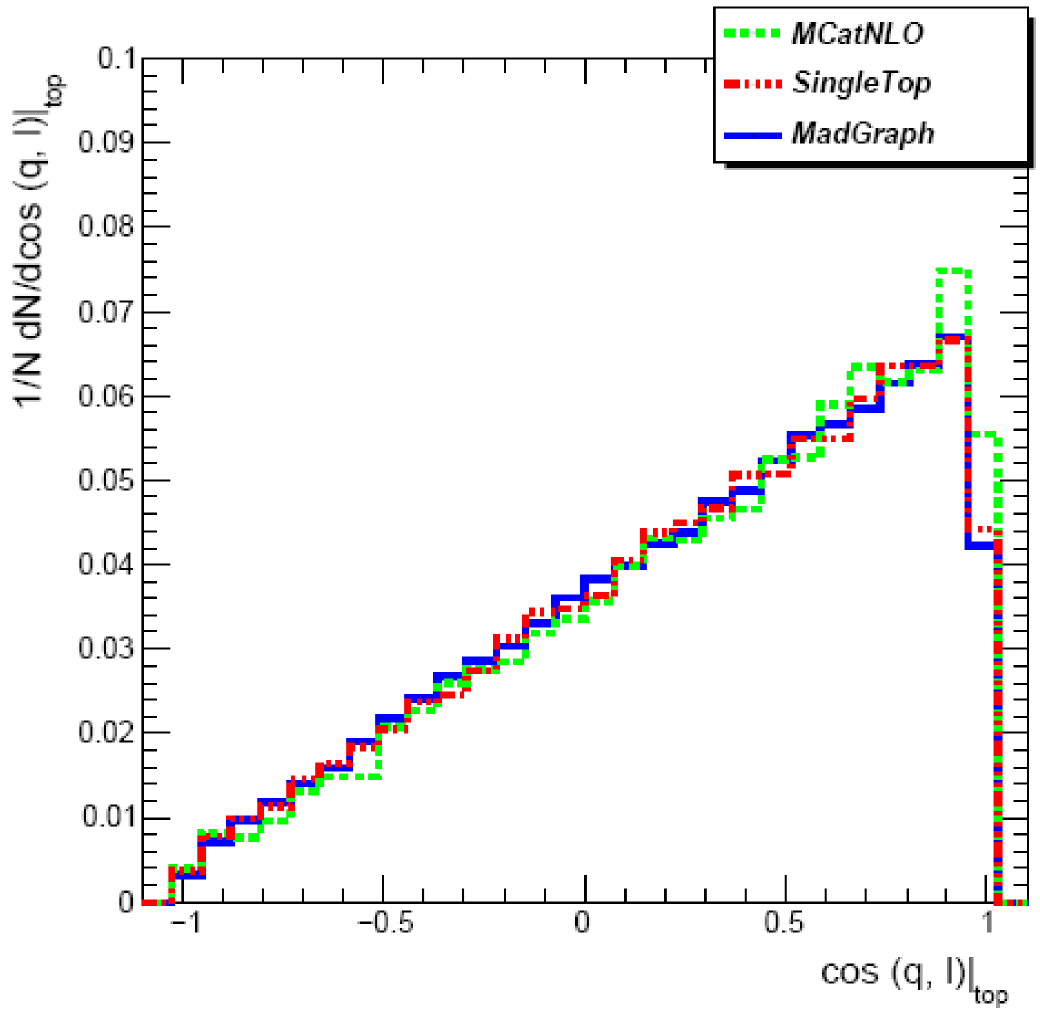
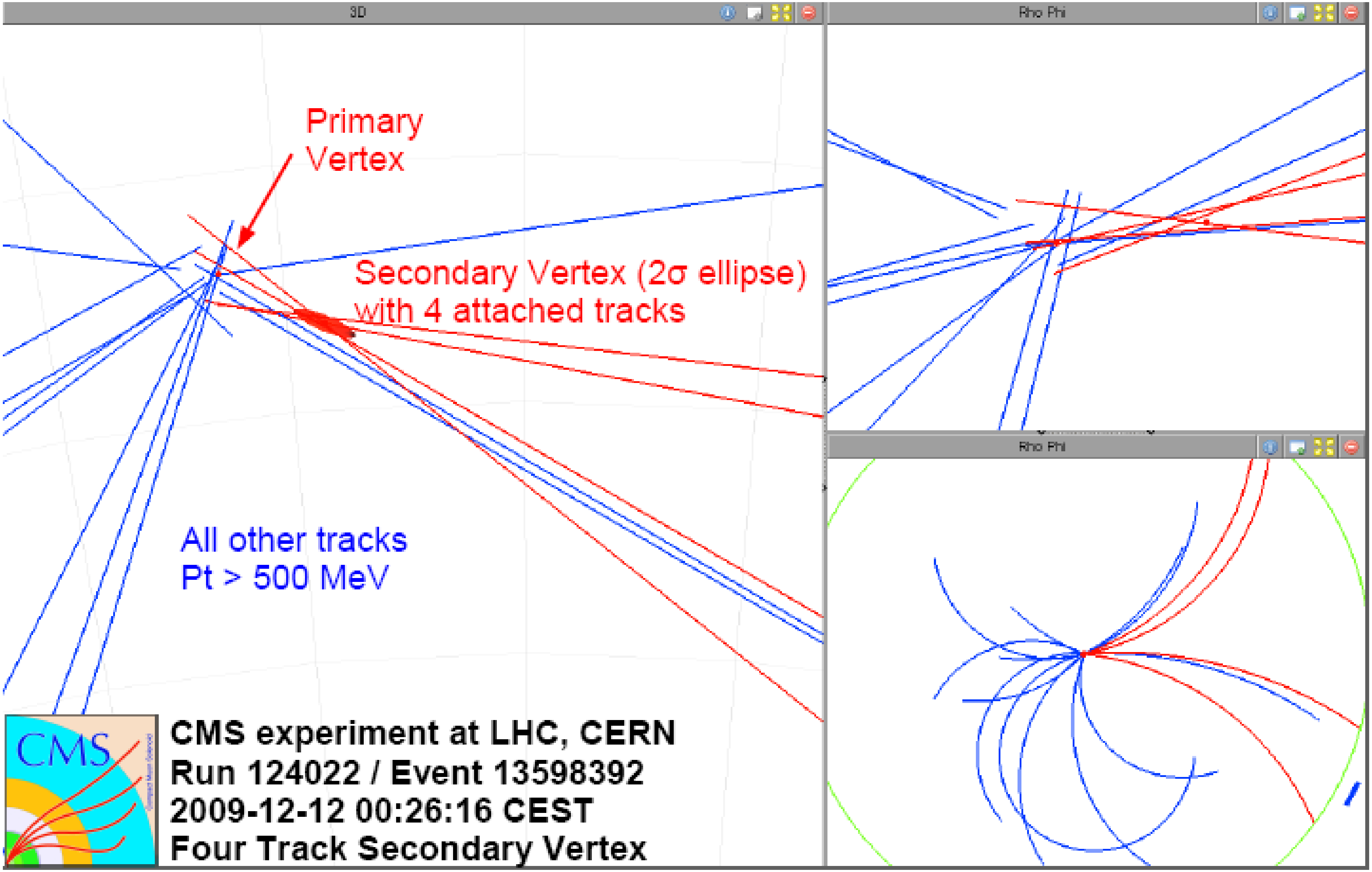


Figure 8: Distributions of the cosine of the angle between lepton and light quark in the rest frame of top quark. This variable reflects the spin correlations in the production of the top quark and its decay.


3D
Rho Phi
Rho Phi
Primary
Vertex
Secondary Vertex (2σ ellipse)
with 4 attached tracks
All other tracks
Pt > 500 MeV
CMS
CMS experiment at LHC, CERN
Run 124022 / Event 13598392
2009-12-12 00:26:16 CEST
Four Track Secondary Vertex