Top physics results from CMS

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On behalf of the CMS Collaboration

ICPP, June 2011, Istanbul, Turkey

Why top-quark is interesting ?

- Heaviest SM particle

  - m(top) = 173 ± 1.1 GeV (0.6%)

- Fundamental parameter of the SM

  - One of the most important inputs to the global electroweak fits

- New physics may preferentially couple to top

  - Search for new particles decaying into top pairs

- Top quark production forms background to many new physics searches

  - Understanding its properties, differential distributions etc. important

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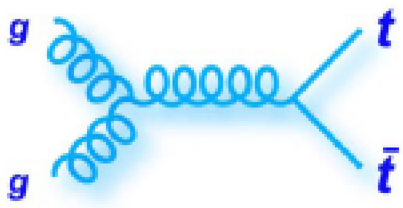
Outline

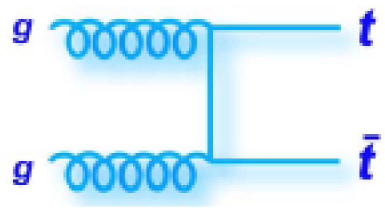
- Physics Objects for Top physics
- Measurements performed so far (L_{int} ~36 pb^{-1})
    - Top pair-production cross section
    - Top quark mass measurement
    - Single Top measurement
    - Charge Asymmetry
    - Top pair invariant mass & search for new physics
- Summary & Outlook

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

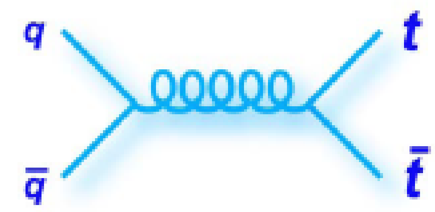
Top pair production

- Gluon fusion (dominant at LHC)



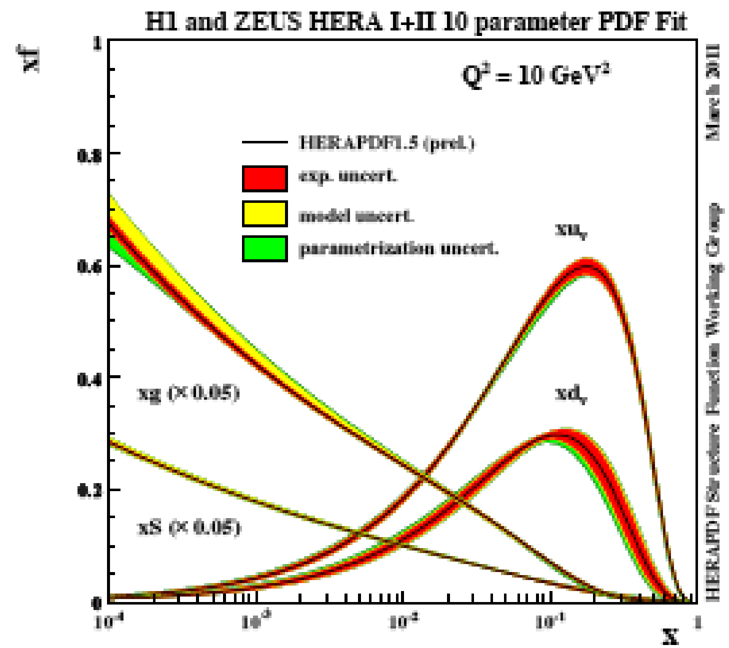


- Quark anti-quark annihilation

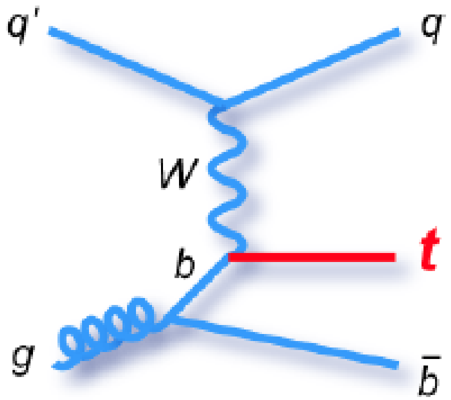


	LHC	TEVATRON
σ(tt) (pb)	163 ± 11	7.1 ± 0.4
gg	~ 85%	~ 10%
qq	~ 15%	~ 90%

- 20 times larger x-section: 250 pb^{-1} @ the LHC ~ 5 fb^{-1} @ the Tevatron
- Dominant production via gg fusion
- Probe different region of x-Bjorken

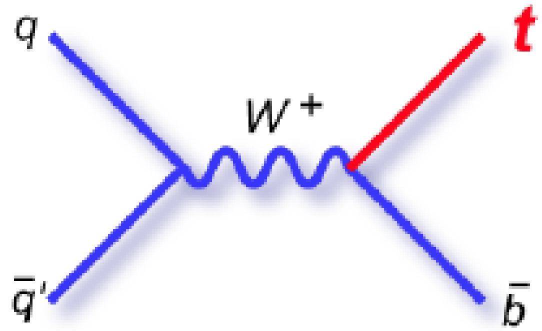


Single Top production



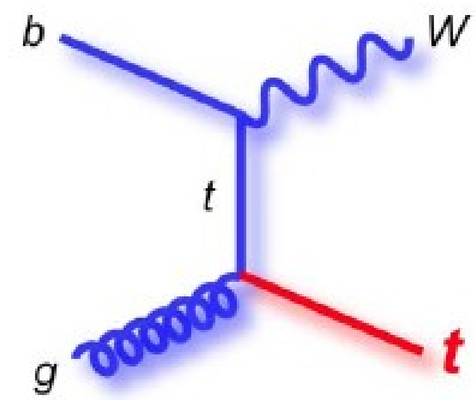
t-channel

∫ ~ 64 pb @7 TeV



s-channel

∫ ~ 4.6 pb @7 TeV



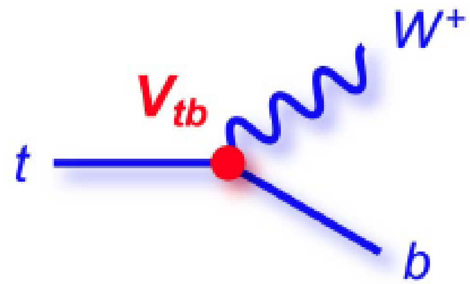
tW-channel

∫ ~ 15.6 pb @7 TeV

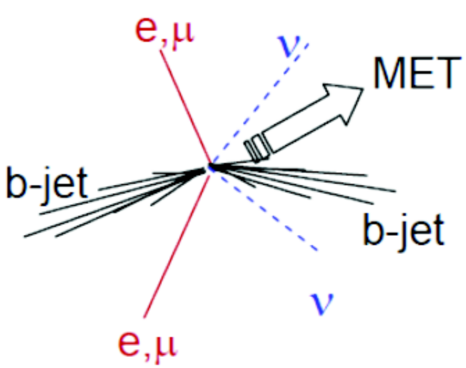
- Produced via electroweak interaction
- ~ 30 times larger x-section in t-channel @LHC than @ Tevatron
- ~ 70 % more *t* than anti-*t* *(charge asymmetry)*
- Difficult signature, large backgrounds from top pair production & V+jets

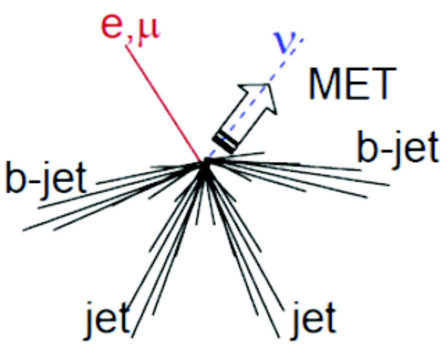
Top quark decays

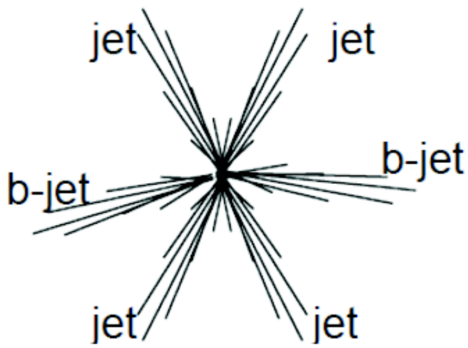
- Top decays almost exclusively to t->Wb



Top pair classification according to W decays







di-lepton channel

BR ~ 5 %
small background (Z+jets)

lepton+jet channel

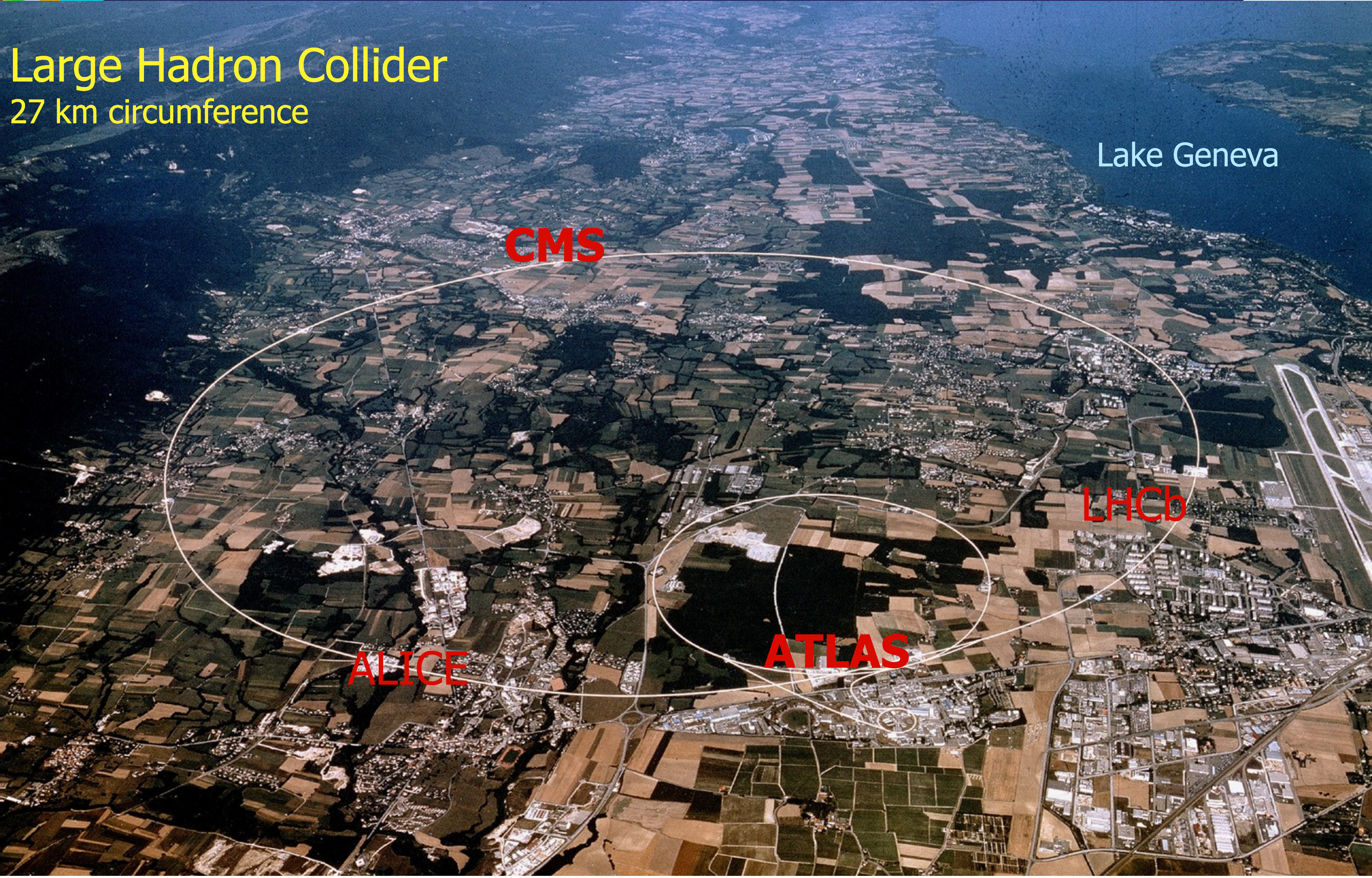
BR ~ 30 %
main background W+jets

Fully hadronic channel

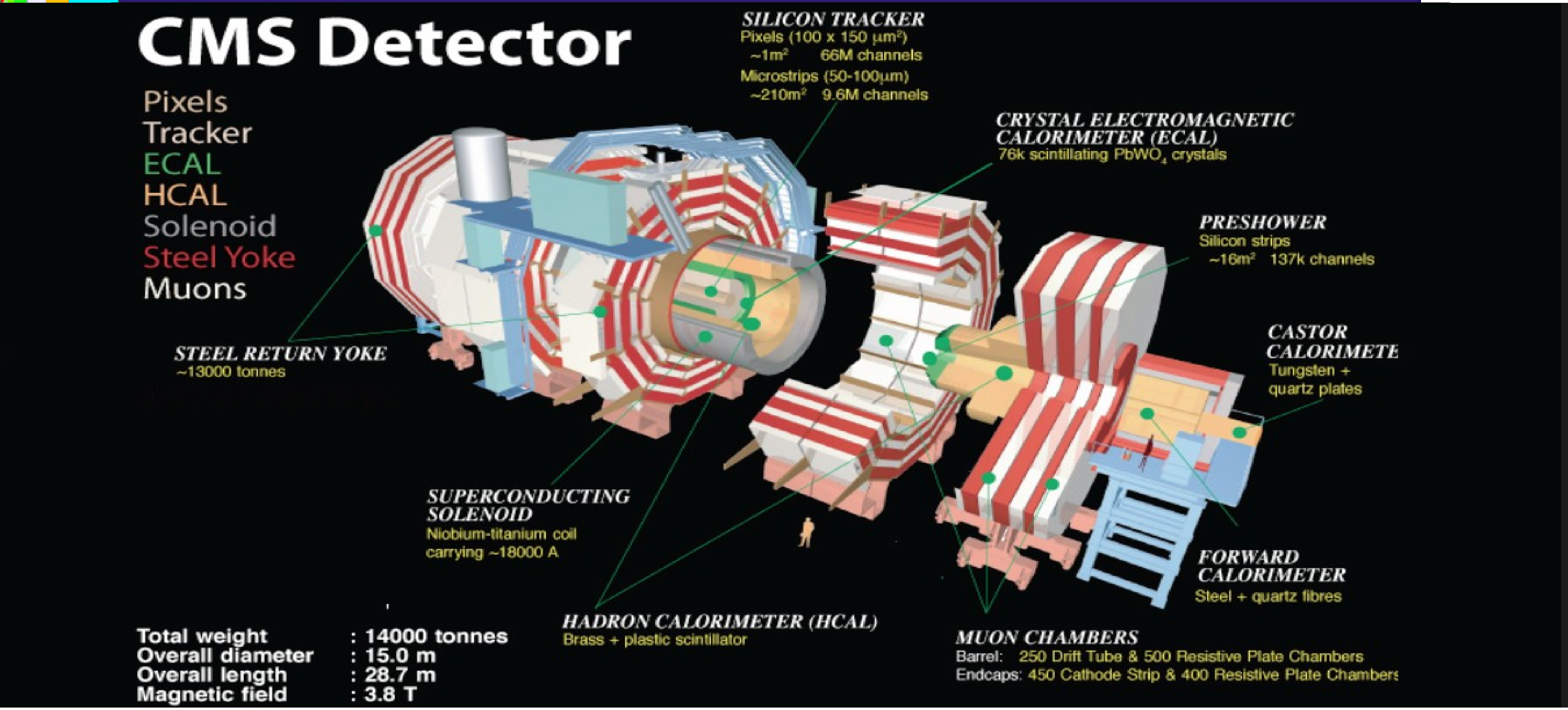
BR ~ 46 %
large background from QCD multi-jet

Analysis strategy is deriven by the W decays

Large Hadron Collider (LHC)



CMS Detector



Large Magnetic Field : 3.8 T

Large Si Tracker : precision: ~1% up to 100 GeV

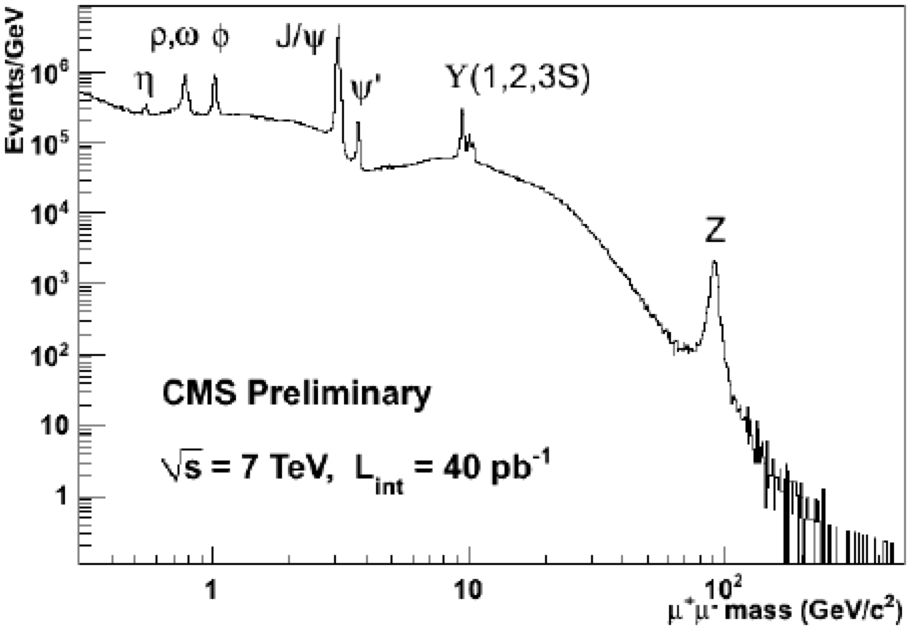
Precision PbWO4 EM Calorimeter: very good energy resolution for photons/electrons: <1% above 30 GeV

Hadron calorimeter has moderate jet energy resolution: ~10% above 100 GeV

Muon system: muon trigger and identification (also important for measuring TeV muons)

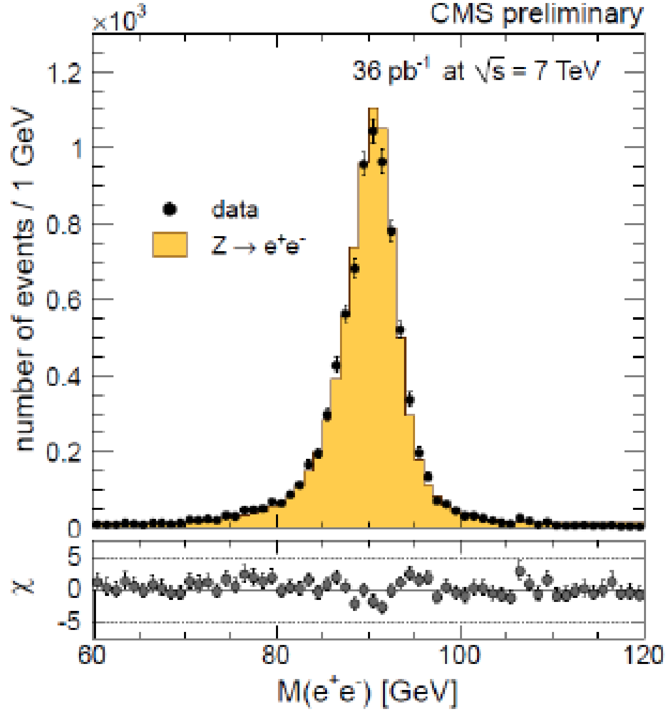
Ingredients for Top measurements

Muons



- Good p_T resolution ~1-2 %
- ID based on track fit quality & impact parameter

Electrons

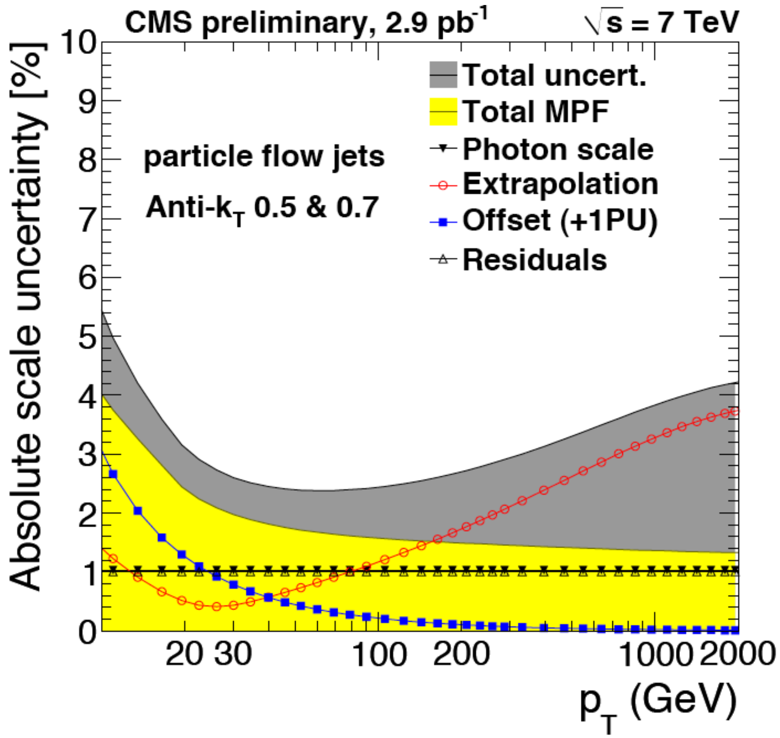


- Excellent ECAL resolution ~1%
- ID based on shower shape & H/E

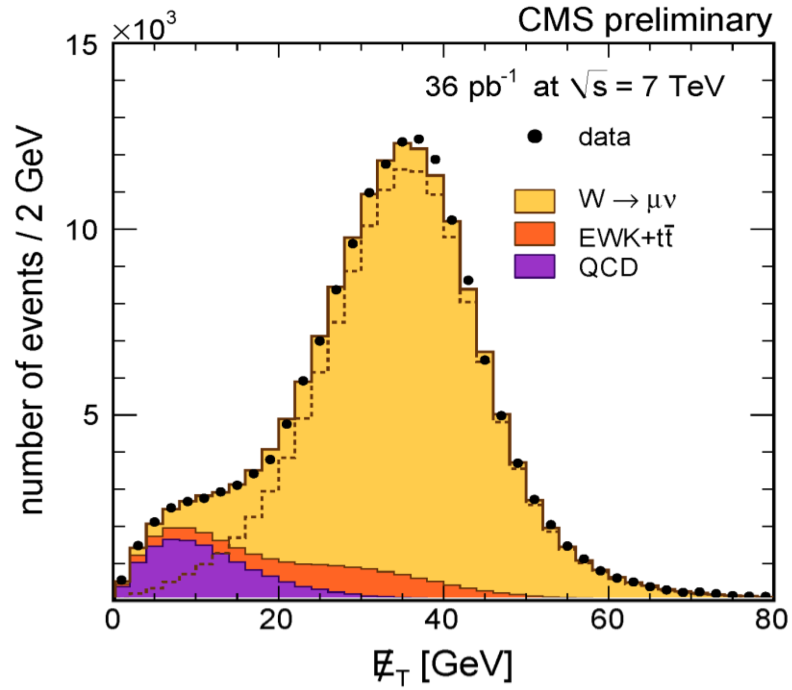
- Isolation of leptons is critical to distinguish prompt (W/Z) and non-prompt (QCD) leptons
- Typical uncertainty on the efficiency ~ 5%
- Key for triggering events for TOP analysis

Ingredients for Top measurements

Jets



Missing Transverse Energy (MET)



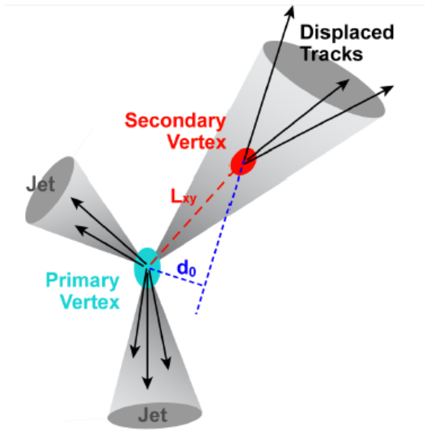
- Particle Flow(PF) objects for jet reconstruction; combine tracker/calorimeter/muon system measurements
- Most used algorithm :Anti-k_T (ΔR=0.5)

- Improved MET resolution with PF
- important for QCD/Z+jets rejection

- Uncertainty on the Jet energy scale depending on | /p_T ~3 to 5 %

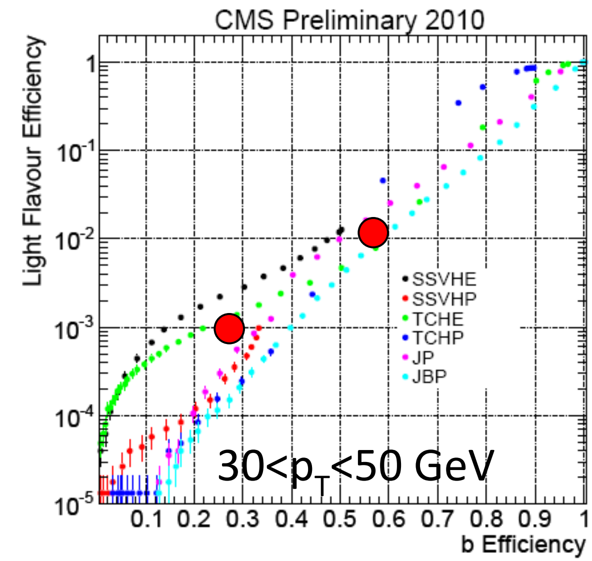
Ingredients for Top measurements

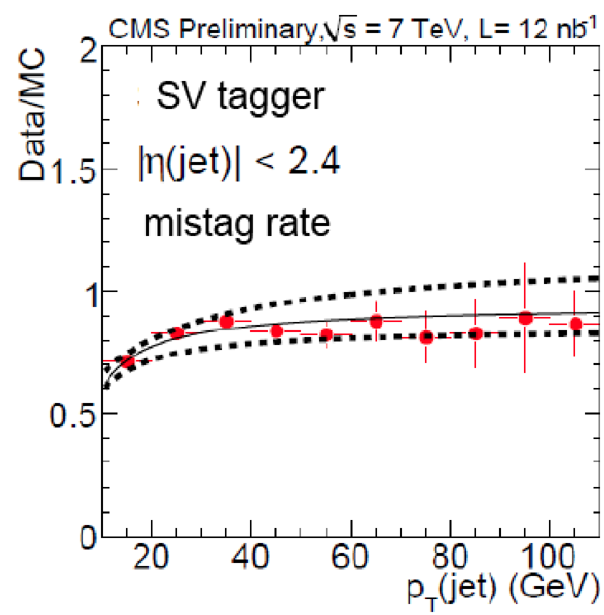
b-jet identification



"Track counting" tagger
Discriminator: IP significance of the n_{th} track

Secondary vertex tagger
Discriminator based on 3D flight distance



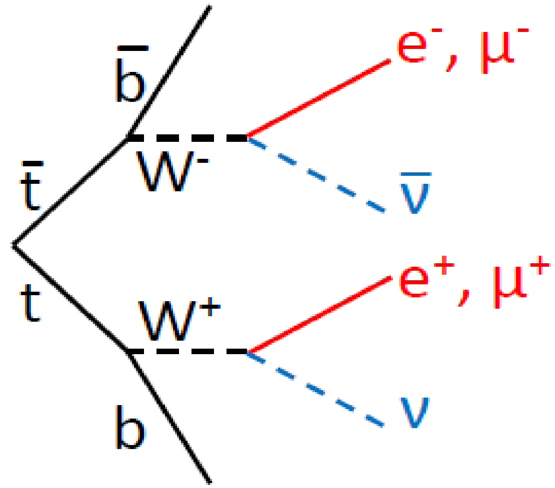


- Crucial ingredient : requires excellent tracker performance and alignment
- Data driven determination of the efficiency & mis-tag rate, Typical uncertainty on the efficiency is 10-15%

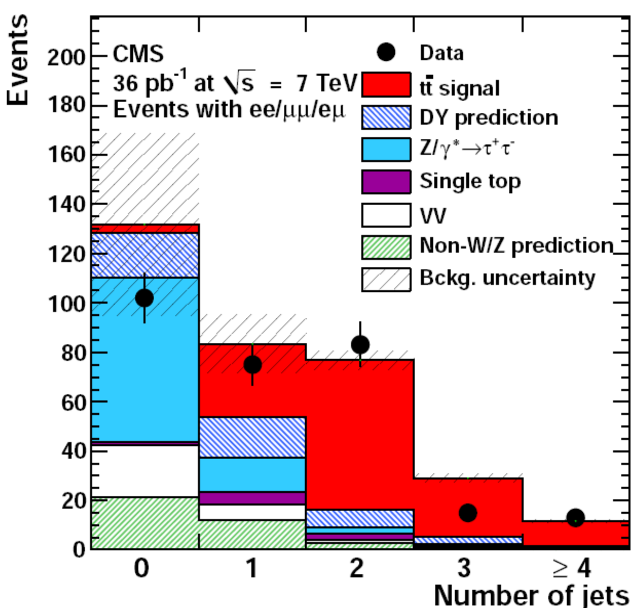
σ(tt): di-lepton channel

Signal selection

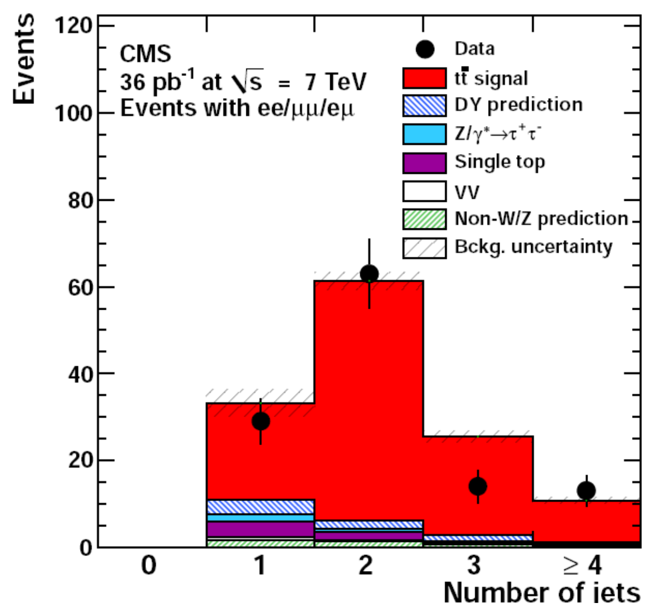
- Inclusive lepton triggers
- 2 Isolated leptons $p_T(\mu,e) > 20$ GeV
- Lepton id & conversion rejection, Eff. 99(90)% for $\mu(e)$
- Z boson veto $|M(\ell\ell)-M(Z)| > 15$ GeV
- MET > 30(20) GeV , p_T(Jets) > 30 GeV
- B-jet identification: Eff: ~80% , mis-tag rate: ~10%



≥ 0 b-tag **86 tops expected ≥ 2 jets**



≥ 1 b-tag : 79 tops expected



Very pure sample of Top events!!!

σ(tt): di-lepton : Results

- Simple counting experiment in three categories for each *ee*, μμ, *e*μ channels

- ≥ 2 jets, no b-tag
- ≥ 2 jets, at least 1 b-tag : more precise than without b-tag for the ee and μμ
- ≥ 1 jets, no b-tag : less precise but improves the combined result

Final state	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
At least two jets, no b-tagging requirement			
Events in data	23	28	60
All backgrounds	5.5 ± 2.3	9.5 ± 4.3	6.7 ± 2.0
Total acceptance, %	0.259 ± 0.021	0.324 ± 0.025	0.928 ± 0.057
At least two jets, at least one b-jet			
Events in data	15	24	51
All backgrounds	2.3 ± 1.4	3.8 ± 2.0	3.0 ± 1.4
Total acceptance, %	0.236 ± 0.022	0.303 ± 0.028	0.857 ± 0.068
One jet, no b-tagging requirement			
Events in data	8	10	18
All backgrounds	2.1 ± 0.7	7.1 ± 4.3	4.9 ± 1.5
Total acceptance, %	0.058 ± 0.007	0.074 ± 0.008	0.183 ± 0.024

Major backgrounds are estimated from data:

- Drell-Yan: rejected by Z veto, the residual background **is estimated from data using control samples (rejected events by** |M(ℓℓ)-M(Z)|)
- W+Jets, semi-lept. tt, QCD: include non-prompt leptons, **estimated from data using Tight-to-loose method , by measuring “fake” lepton probabilities in QCD multi-jet events**

σ(tt): di-lepton : Results

- Dominating systematic uncertainties:
  - Data driven background estimates
  - Jet energy scale
  - b-tagging efficiency

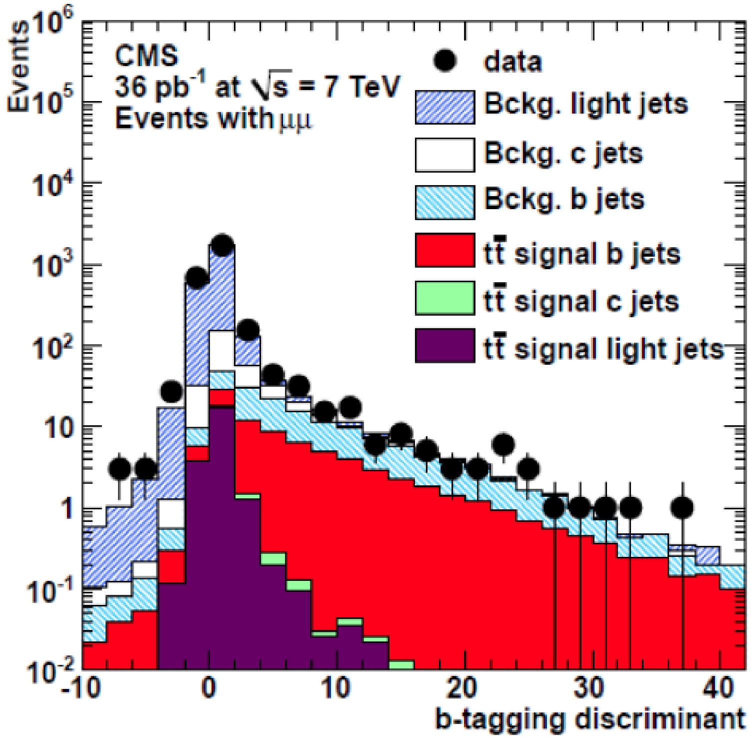
- In-situ determination of b-tagging efficiency
  - Use the relation between the efficiencies of ≥ 1 b-tag and ≥ 2 b-tag, $R_{2/1}$

$$R_{2/1}^{\mathrm{sim}} = (57.9 \pm 0.1)\%$$

$$R_{2/1}^{\mathrm{data}} = (60.8 \pm 7.5)\%$$

  - Good agreement is observed
    - 5% uncertainty is assigned to MC efficiency

b-tag discriminator: impact parameter significance of the second track



σ(tt): di-lepton : Results

Measured 9 individual cross sections are combined using the BLUE technique (Best Linear Unbiased Estimator) : **takes into account the correlations between different contributions to the measurements**

- Combined cross section (14% relative uncertainty)

$$\sigma_{t\bar{t}} = 168 \pm 18\ (stat.) \pm 14\ (syst.) \pm 7\ (lumi.)\ pb$$

4% uncertainty on the Luminosity

- Cross section ratio tt/Z

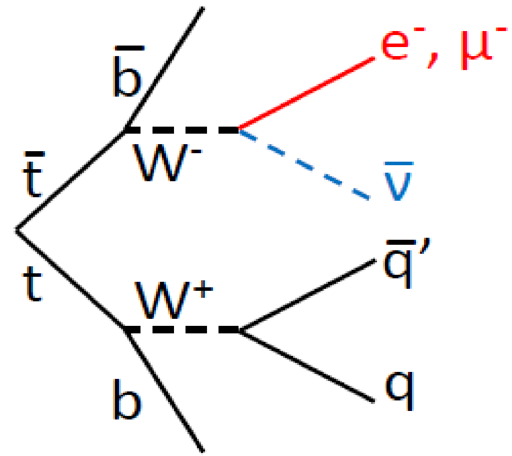
$$\frac{\sigma(\mathrm{pp} \to \mathrm{tt})}{\sigma(\mathrm{pp} \to \mathrm{Z}/\gamma^{\star} \to \mathrm{e^+e^-}/\mu^+\mu^-)} = 0.175 \pm 0.018\,(\mathrm{stat.}) \pm 0.015\,(\mathrm{syst.})$$

- 13 % uncertainty, comparable to uncertainty of SM prediction
- Only marginally better than the cross section uncertainty; dominating systematic uncertainties do not cancel; luminosity accounts only for 4%

σ(tt): lepton+jets channel

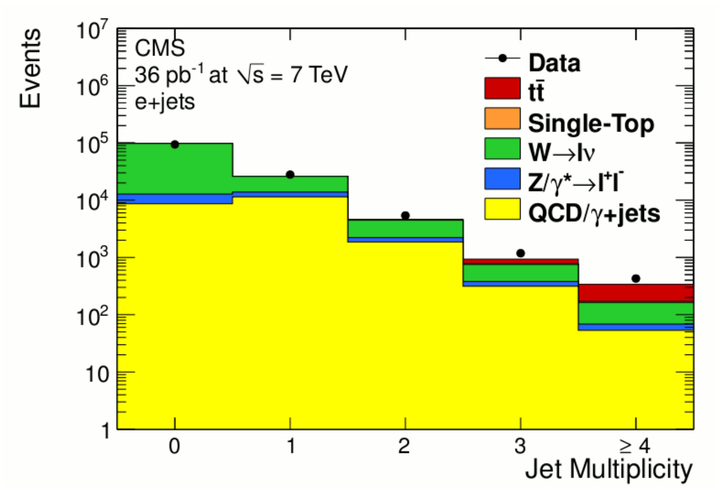
Signal selection

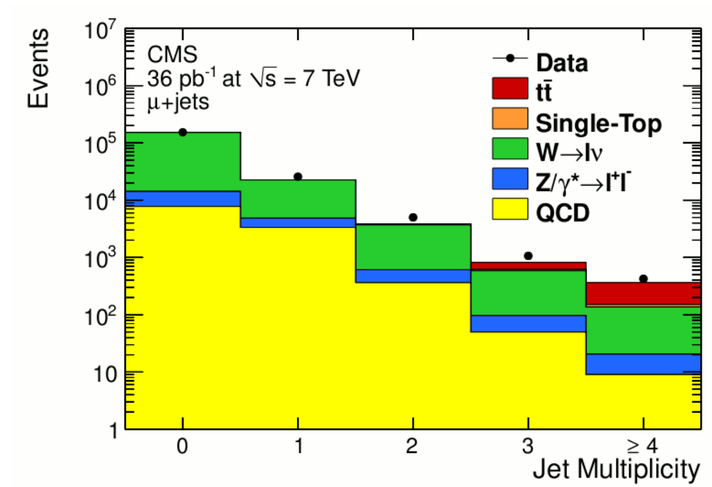
- Single lepton triggers
- Exactly 1 Isolated lepton p_T(⌠/e) > 20/30 GeV
- Lepton id & conversion rejection
- Veto events with a second loose lepton
- p_T(Jets) > 30 GeV



•Two analysis:

No b-tag (MET shape as discriminating variable) ; With b-tag (based on secondary vertex) , MET > 20 GeV





lepton+jets channel has larger BR but larger background

σ(tt):Lepton+Jets without b-tag

- Simultaneous template fit(binned likelihood) in two distributions to extract N(tt)

- MET in the 3 jets subsample : separates bkg without true MET

- M3 in the ≥ 4 jets sample mass of the 3 jets maximizing the vect. summed p_T

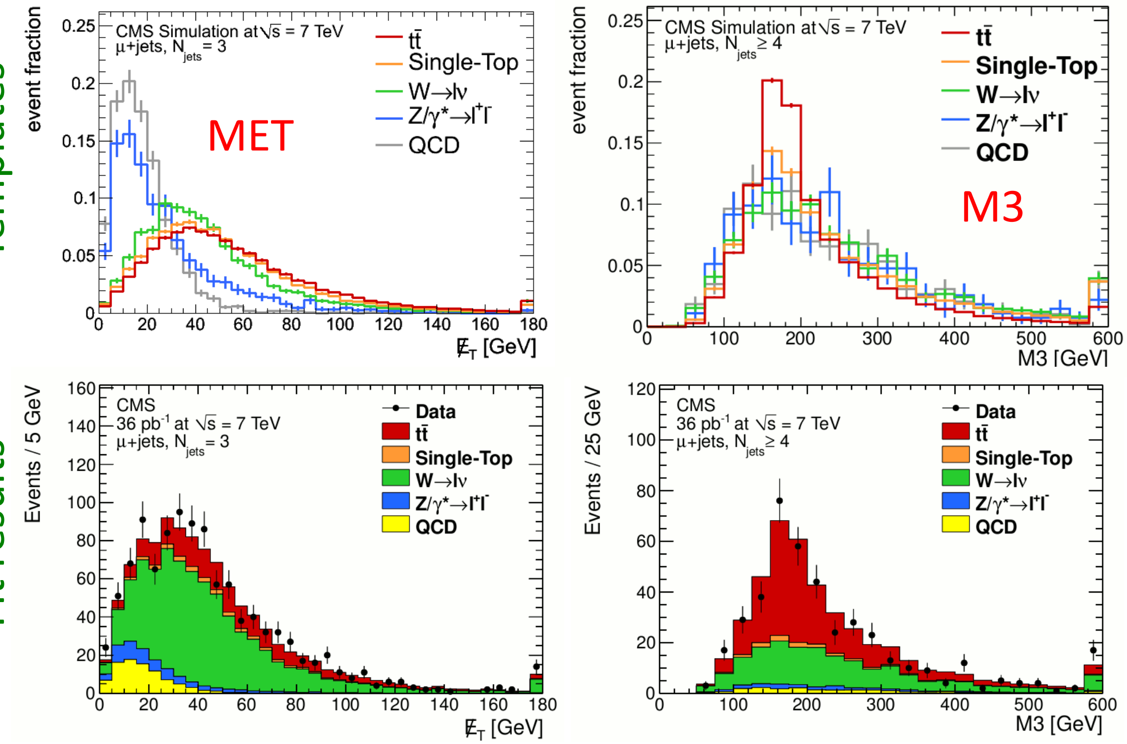
- Templates are from MC except for QCD multi-jet that is obtained from data: leptons failing Iso, id and d0 cuts

3 jets

≥4 jets

Templates

Fit results



Results after combining m+jets and e+jets measurements:

$$\sigma_{t\bar{t}} = 173^{+39}_{-32}(\mathrm{stat}+\mathrm{syst}) \pm 7(\mathrm{lumi})\ \mathrm{pb}$$

Dominant syst. uncertainties :Jet energy corrections (18 %), factorization scale (7%)

σ(tt): Lepton+Jets with b-tag

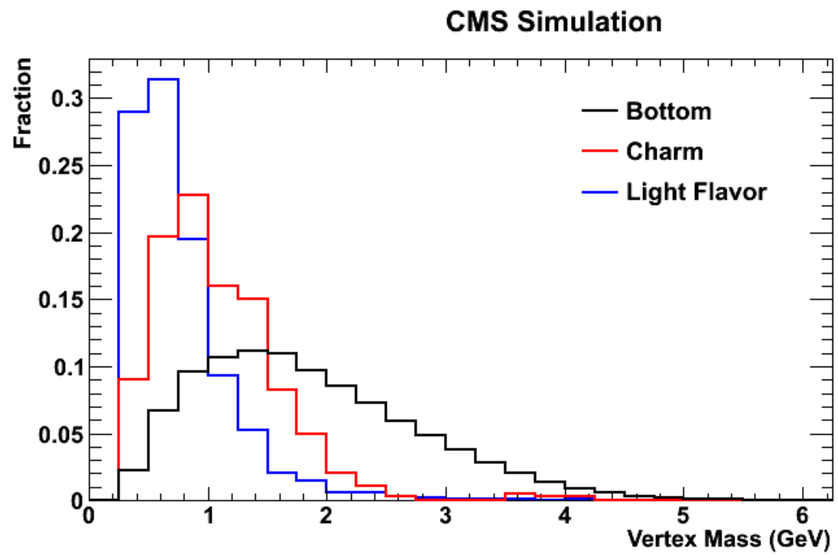
- Use events with at least 1 jet b-tagged (54% efficiency, 1.5 % mis-tag)

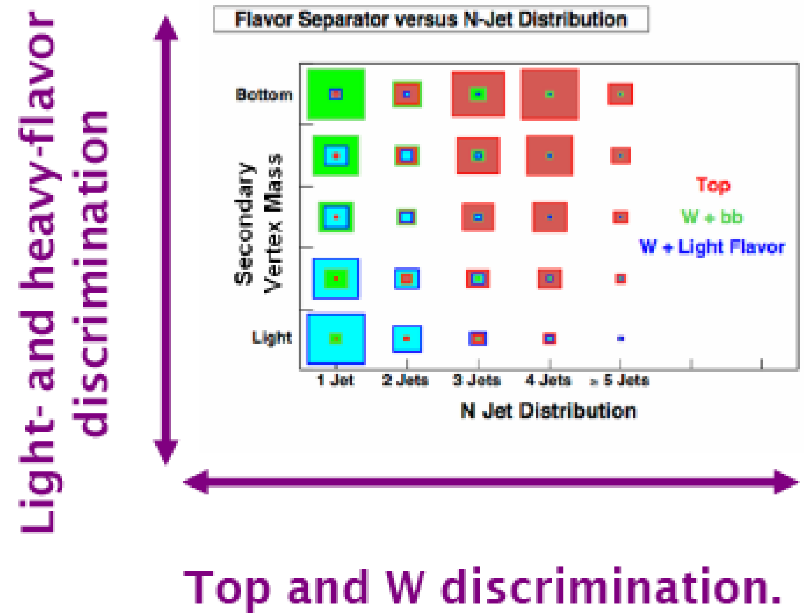
- Use “Secondary Vertex mass” as a decimator for light-quark and b-quark jets

- Defined as the mass resulting from the sum of the four-vectors of the tracks originating from the SV.

- Split the selected events sample into 1 b-tag and 2 b-tag samples

- Consider distributions in jet multiplicities for muon and electron channels separately

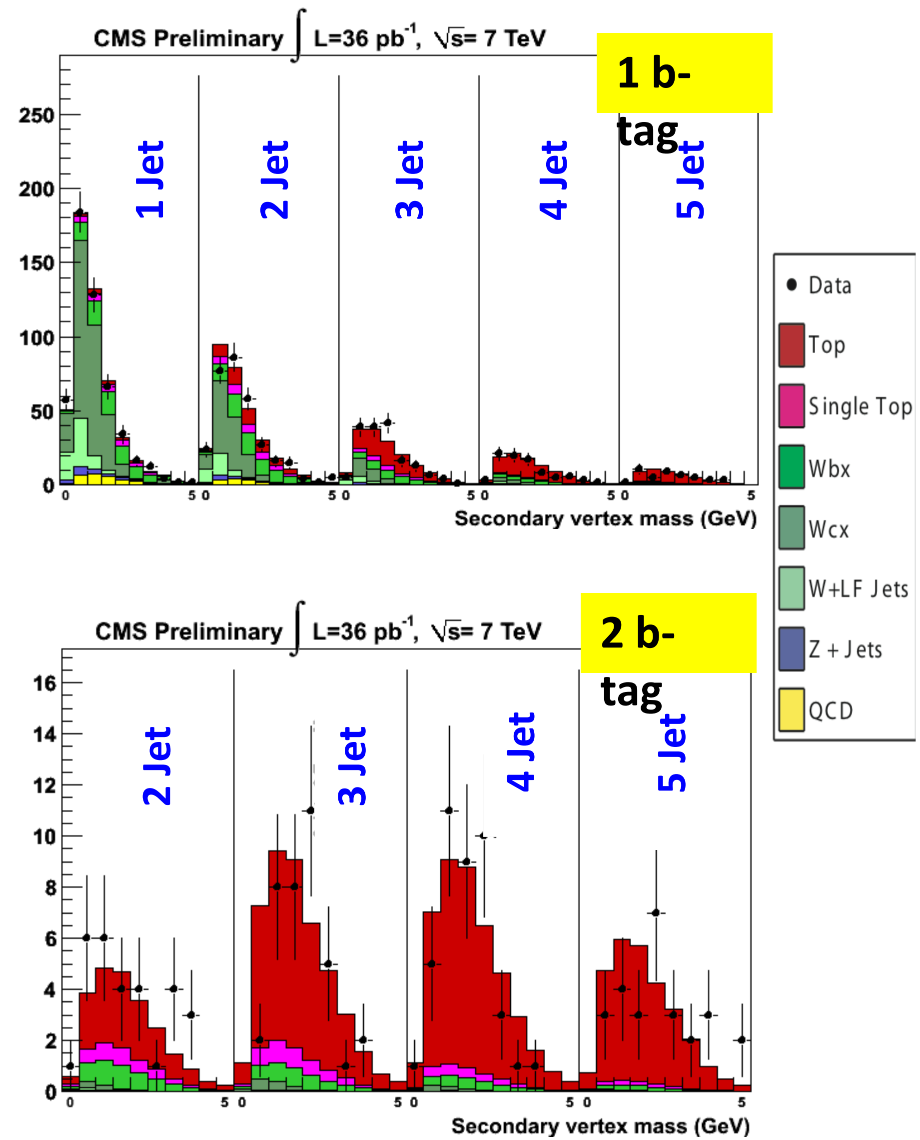




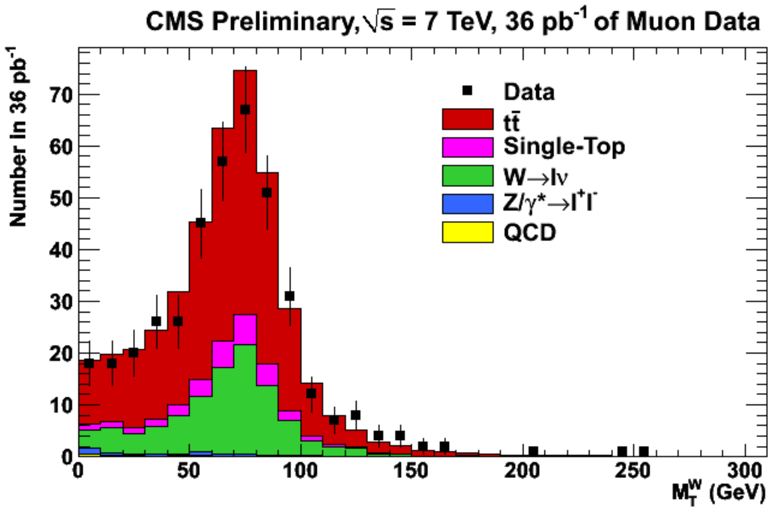
σ(tt): Lepton+Jets with b-tag

- **Simultaneous profile likelihood fit in 18 subsamples:**
  - 2 lepton flavours (*e*, μ)
  - [1-5] jet mult. with 1 b-tag
  - [2-5] jet mult. with ≥ 2 b-tag
- **Constrain the normalization of some of the bkg. to be within the large range of th. uncert.**
- **Most important systematics fitted in situ (taken as nuisance parameters in profile likelihood)**
  - Jet energy scale,
  - B-tag efficiency
  - Renormalization/factorization (Q^2) scale uncertainty

Secondary Vertex mass distribution in (muon channel)



σ(tt): Lepton+Jets with b-tag



Transverse mass distribution of the reconstructed W in μ + jets channel (1-btag & ≥ 3jets)

- Each background and the signal distribution is normalized according to the fit result:
  - Scale factor (W+b) = 1.9 ± 0.6
  - Scale factor (W+light) = 1.4 ± 0.2

- Good agreement between data & fit results

Combined Cross section:

13 % uncertainty

$$\sigma_{t\bar{t}} = 150 \pm 9\ (\text{stat.}) \pm 17\ (\text{syst.}) \pm 6\ (\text{lumi.})\ \text{pb}$$

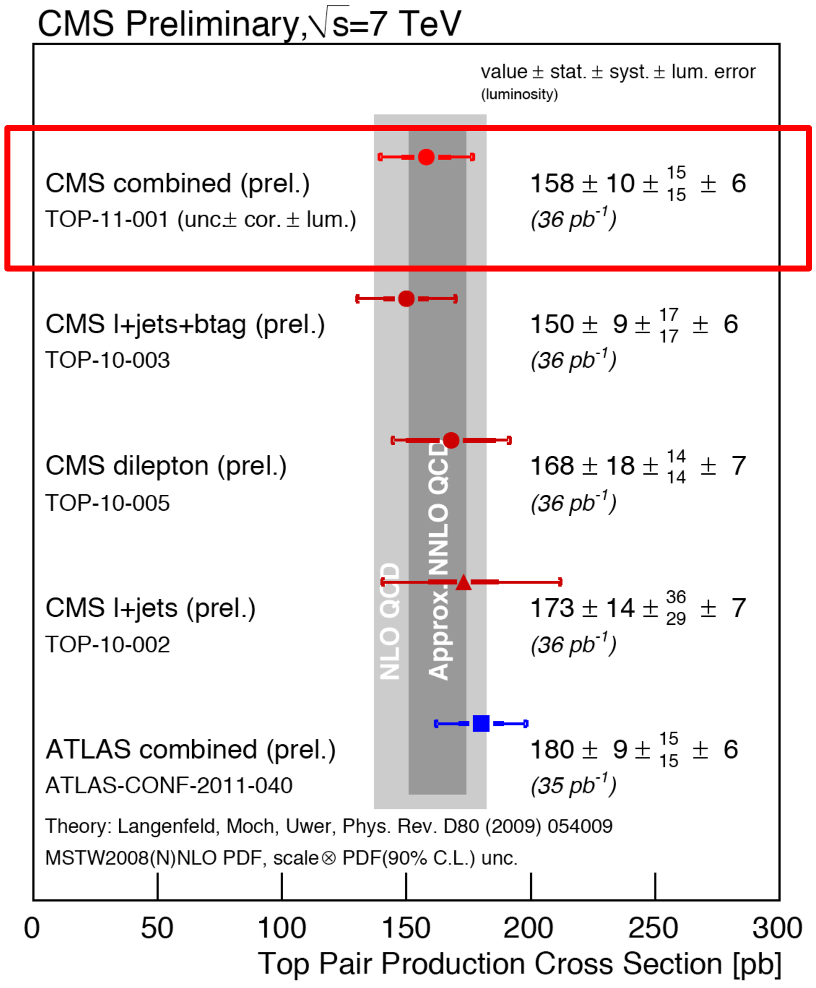
Source	Uncertainty (%)
Systematic uncertainties	
Lepton ID/reco/trigger	3
Unclustered E_T^{miss} resolution	< 1
$t\bar{t}$+ Jets Q^2-scale	2
ISR/FSR	2
ME to PS matching	2
PDF	3.4
Profile likelihood parameters	
Jet energy scale and resolution	7.0
b tag efficiency	7.5
W+Jets Q^2-scale	9.1
Combined	11.6

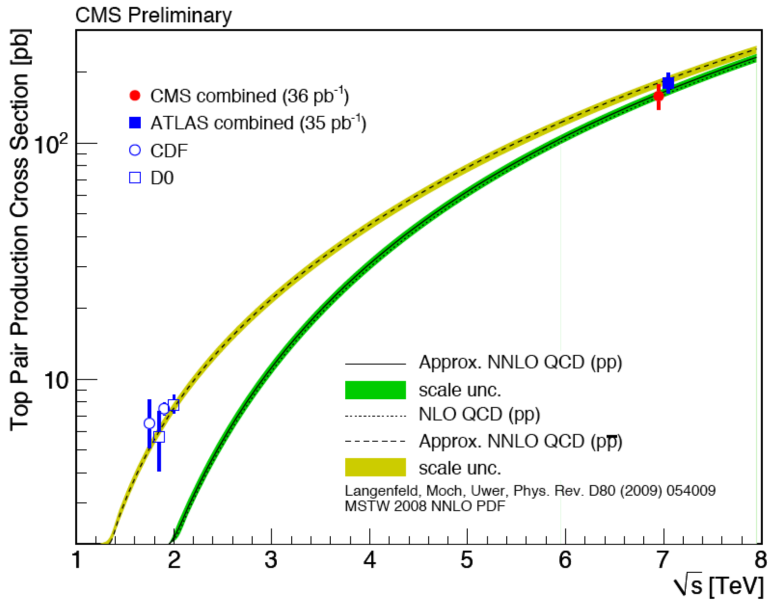
Systematic uncertainties extracted in the fit

Combined σ(tt)

CMS combined result using the BLUE technique:

$$\sigma_{t\bar{t}} = 158 \pm 10\ (unc.) \pm 15\ (cor.) \pm 6\ (lumi.)\ pb$$ ***12% precision***





- **Consistent with the theoretical tt cross section at approximate NNLO :**

  σtt (HATHOR) = 164^{+10}_{-13} pb   σtt (Kidonakis) = 163^{+11}_{-10} pb

- **Better experimental precision than the NLO theory uncertainty**

Top mass measurement

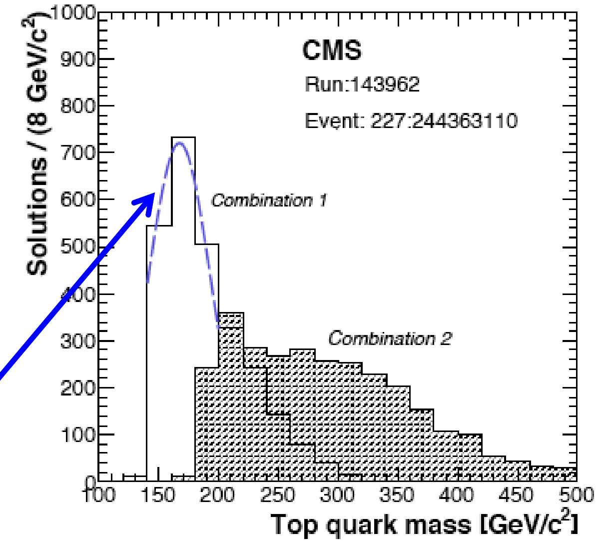
- Top mass has been measured with good precision at the TEVATRON in various decay channels using various techniques , **m_t = 173.3 ± 1.1 GeV**

- CMS performed measurements of the top mass using 2010 data in two decay modes
  - Di-lepton channel ($bb\ell\nu\ell\nu$)
    - Benefit from high purity of di-lepton events
    - Lower statistics, but very clean
    - Two different complementary methods used to measure the mass
  - Lepton + jets channel ($bbjj\ell\nu$)
    - Large branching ratio
    - Reasonable S/B ratio and well understood kinematics
    - Ideogram method used to measure the mass
- Results combined using BLUE method

M(top) measurement: di-lepton

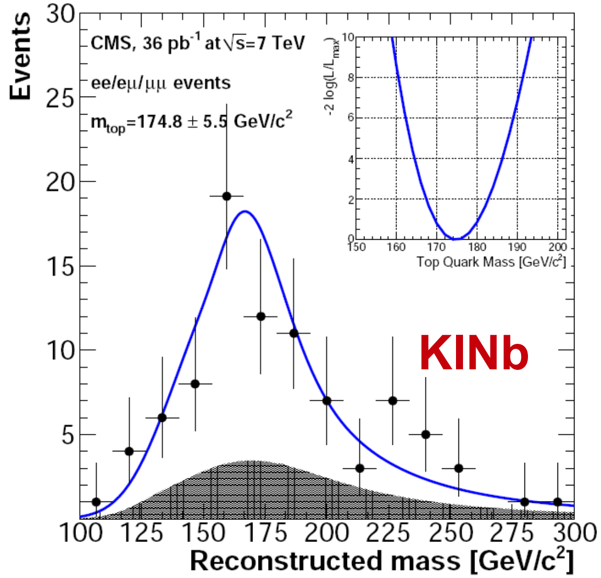
- Similar event selection as for the x-section measurement:
  - No b-tag req., but is used for jet assignment (16% improvement)
  - 102 selected events, MC(tt)= 92
  - For each top pair measure 4 particles + MET (6 unknown) :
  - 5 constraints : Transverse momentum conservation; $M_w = M(\ell\nu)$; $M_{top} \sim M_{anti\text{-}top}$

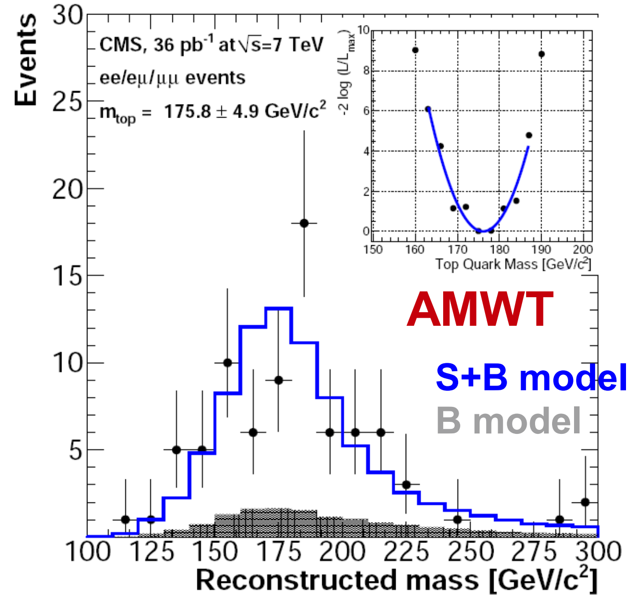
- **Two methods to deal with underconstrained system:**
  - **Analytical Matrix Weighting Technique (AMWT)**
  - Solve kinematic equations analyticaly for fixed values of M_{top}[100 - 300]GeV/c^2
  - With 2 possible lepton-jet assignment up to 8 solutions for the neutrino momenta for a given M_{top}
  - Weights assigned to each solutions according to PDF
  - Take the M_{top} value with the highest sum of weights
  - **Fully kinematics analysis (KINb)** :
    - Numerical solutions to the kinematics equations for each lepton-jet assignment per event, up to 4 solutions
    - p_z(tt) taken from simulation (10^4 iterations)
    - Smear jet energy/MET scales according to resolutions
    - Accept solutions if $\Delta m_{top} < 3$ GeV/c^2
    - Extract the top mass with a gaussian fit to m_{top}distribution



M(top) measurement: di-lepton

- Likelihood fits to data to extract m_t from the mass distributions





Systematic uncertainties are dominated by the Jet Energy Scale (2-3 %)

Method	Measured m_{top} (in GeV/c^2)
AMWT	$175.8 \pm 4.9(stat) \pm 4.5(syst)$
KINb	$174.8 \pm 5.5(stat)^{+4.5}_{-5.0}(syst)$
combined	$175.5 \pm 4.6(stat) \pm 4.6(syst)$

4% precision

M(top) measurement: Lepton+Jets

- Same event selection as for the x-sec measurement (S/B ~0.5 for Njet ≥ 4)

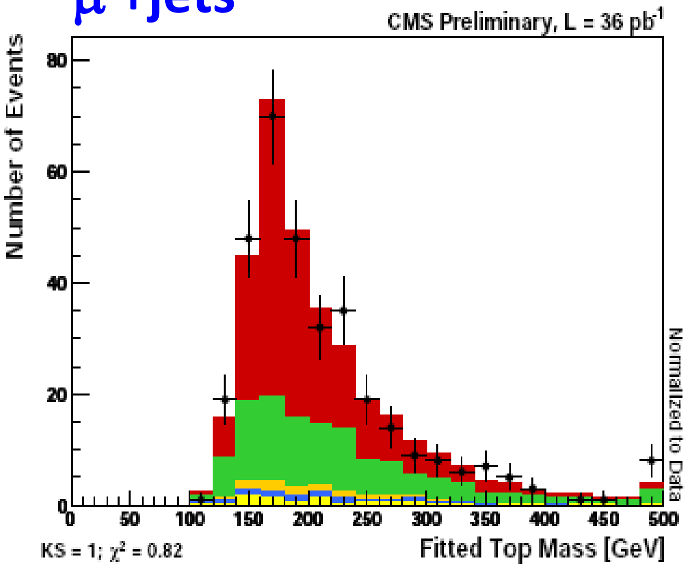
Ideogram technique (also used in D0/CDF)

- Constrained kinematic fit by requiring $M_{top} = M_{anti\text{-}top}$
  - Input: 4-momenta of the lepton and 4 jets , MET and the resolutions
  - Event likelihood as a function of the top quark mass hypothesis
  - Takes into account all possible jet assignments (each permutation weighted by χ^2)
  - Include b-tag into account

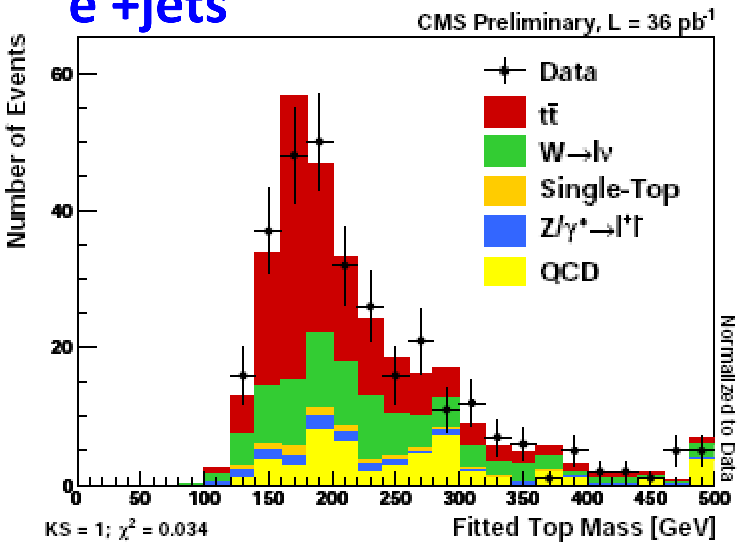
NEW

A joint likelihood fit over all events is used to the extract the value of the M_{top}

μ +jets



e +jets



Top quark mass combination

Top mass from Lepton+jet channel (Systematics dominated by jet energy scale):

$$m_{top} = 173.1 \pm 2.1\ (stat.)^{+2.8}_{-2.5}(syst.) GeV/c^2$$

ATLAS result in lepton+jet channel $m_t = 169.3 \pm 4.0 \pm 4.9\ GeV/c^2$

Factor two more precision than ATLAS

- Combined top quark mass (di-lepton & Lepton+jet) Use BLUE method: Statistical uncertainty not correlated, almost all systematics correlated

2% precision

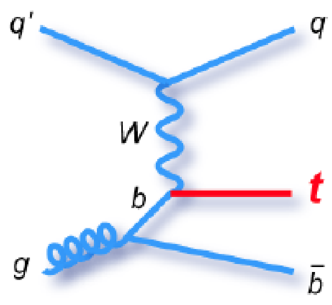
$$m_t = 173.4 \pm 1.9(\mathrm{stat}) \pm 2.7(\mathrm{syst})\ \ \mathrm{GeV}$$

Good agreement with world average $M_{top} = 173.3 \pm 1.1\ GeV/c^2$

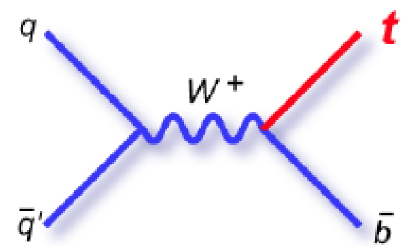
Single Top Search

Hunts Needle in a Haystack

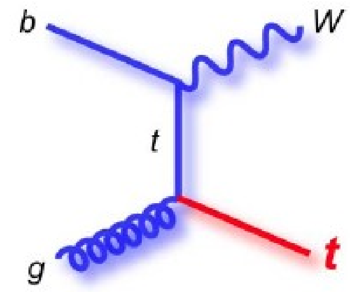
Single Top I



t-channel
$\sigma \sim$ 64 pb @7 TeV



s-channel
$\sigma \sim$ 4.6 pb @7 TeV



tW-channel
$\sigma \sim$ 15.6 pb @7 TeV

- Measure the single top production cross section via t-channel;
- Other channels considered as background
- Use W->$\ell\nu$, (ℓ= μ/e) , 2 b-jets , 1 lepton , MET

Event selection:

- 1 isolated lepton p_T(μ/e) >20(30) GeV
- 2 jets with p_T >30 GeV
- 1 b-tagged jet, events with second b-jet vetoed
- M_T(W) > 40 (50) GeV for muon(electron) channel

Single Top -II

Two complementary methods are deployed

2D: angular analysis

- 2D fit to angular properties of the signal
- Main backgrounds have similar shapes
- Result is robust against background composition

Minimum model dependence

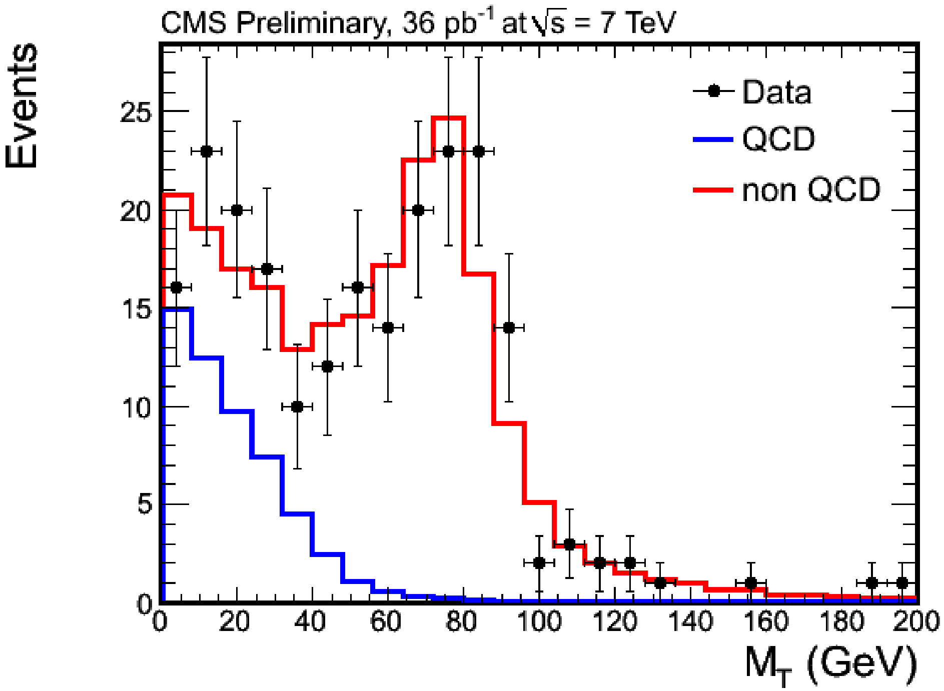
BDT: Multivariate analysis

- Uses boosted decision tree
- Exploits prior assumptions about the signal
- Uses all available information

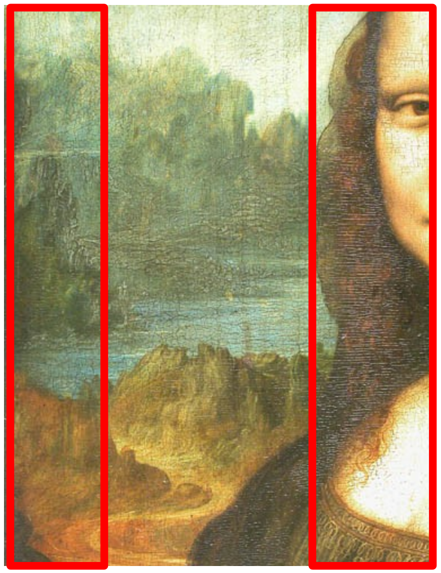
Maximum sensitivity

Final result: combination of the two results

channel, BDT



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



Control region

Analysis region

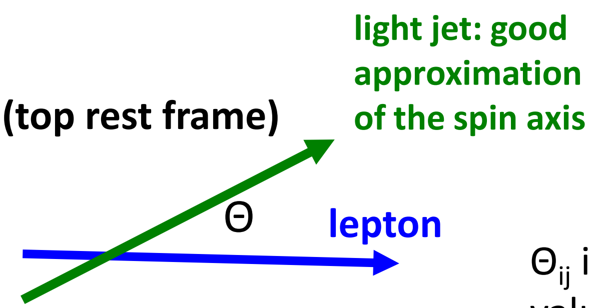
A: define a region with very little Mona Lisa, then extrapolate (with some reasonable assumption)

- Template fit, 2 components: QCD and non-QCD, both unconstrained
- "non-QCD" templates from MC
- "QCD" template from an **orthogonal sample** with **anti-isolation**

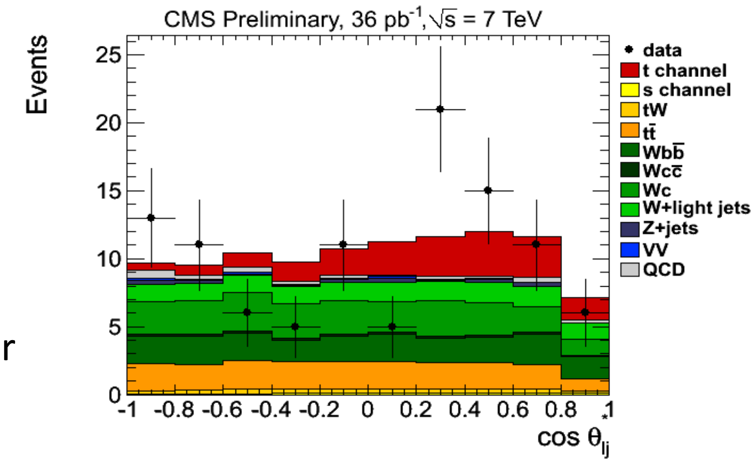
- Same method used in 2D for W+light estimation; BDT treats W+light rate as a nuisance parameter in the fit
- Other bkg: shapes and relative contributions from MC , normalizations estimated separately in two methods

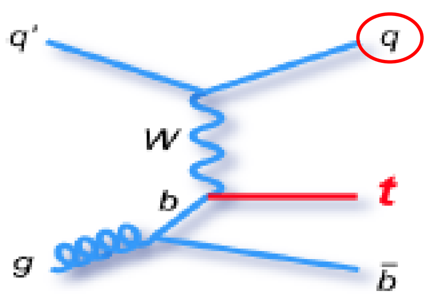
2D analysis: single top is polarized

Exploit almost 100% left handed polarization of top

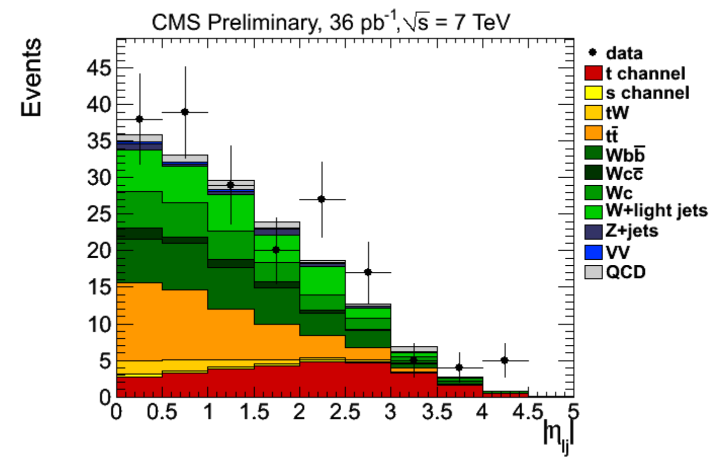


Θ_{lj} is flat for the background, smaller values are favored in signal





pseudorapidity of the recoil quark; (jet that fails the b-tag)
Backgrounds are more central



- **Perform a simultaneous fit to Θ_{lj} and η_{lj} distributions**
- Free parameters: signal and background yields
- Once the number of signal is extracted;

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

ε: estimated from MC
B(t -> lνb)= 0.1080

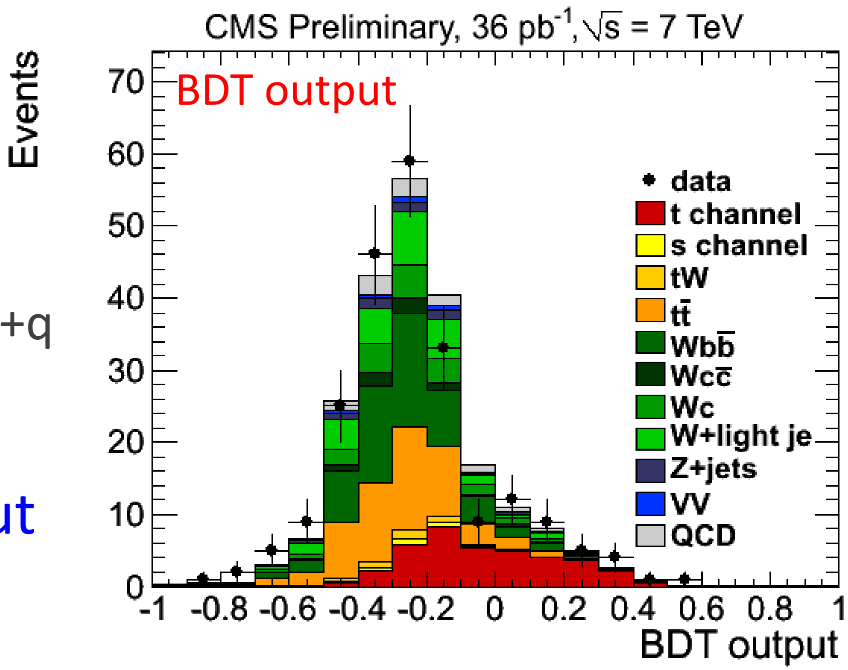
Boosted Decision Tree(BDT)

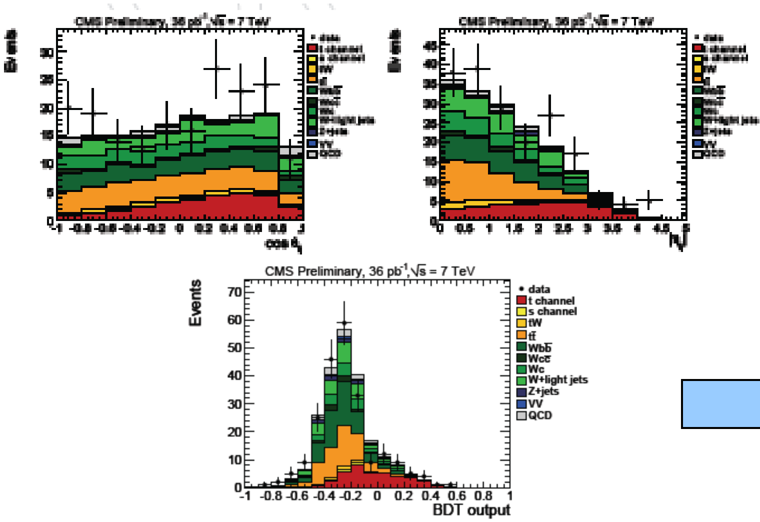
BDT:

Fully exploits signal topology, maximizes significance

Combines a given set of signal-background discriminating variables into one single classifier

- 37 well modeled input variables
  - Kinematics of final state objects
  - correlations of the final state objects
  - properties of the reconstructed W,t, t+q
  - Angular distributions of light jet w.r.t W, t, t+q
  - Global event properties
- Cross section from the fit to BDT output
  - Systematics included via nuisance parameters





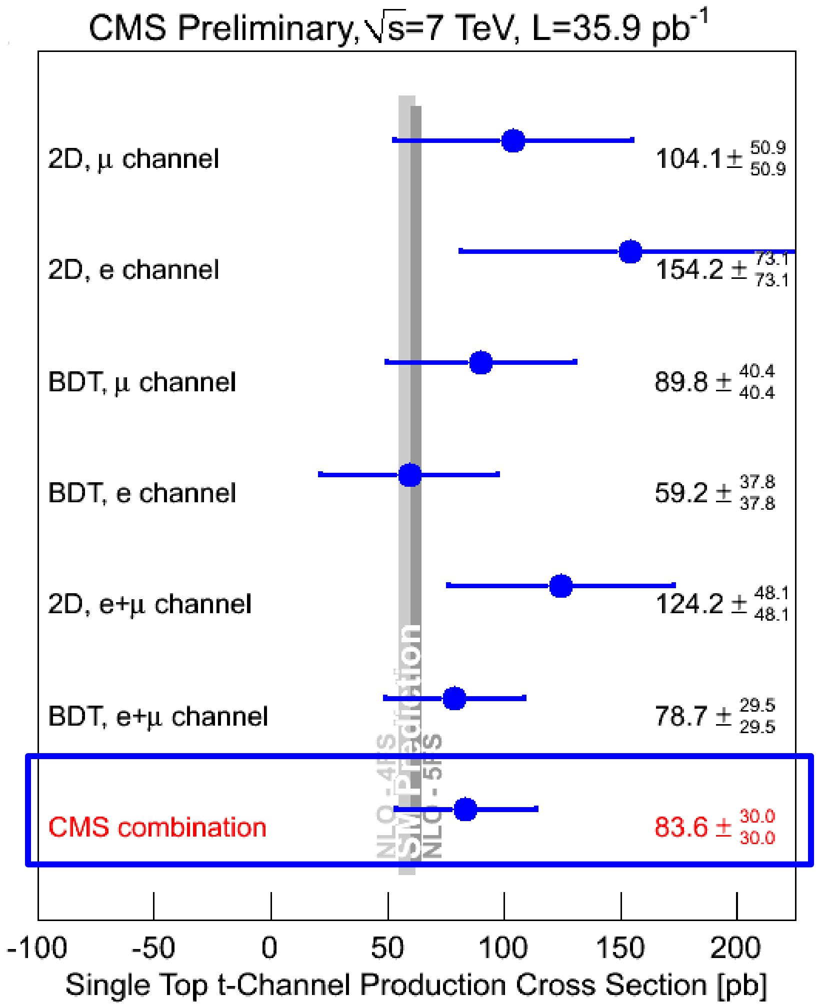
Final cross section

Combined single Top cross section

CMS combined result : almost all systematics fully correlated, 51% correlation in statistical uncertainty

$$\sigma_t = 83.6 \pm 29.8\ (stat. + syst.) \pm 3.3\ (lumi.) pb$$

36% precision

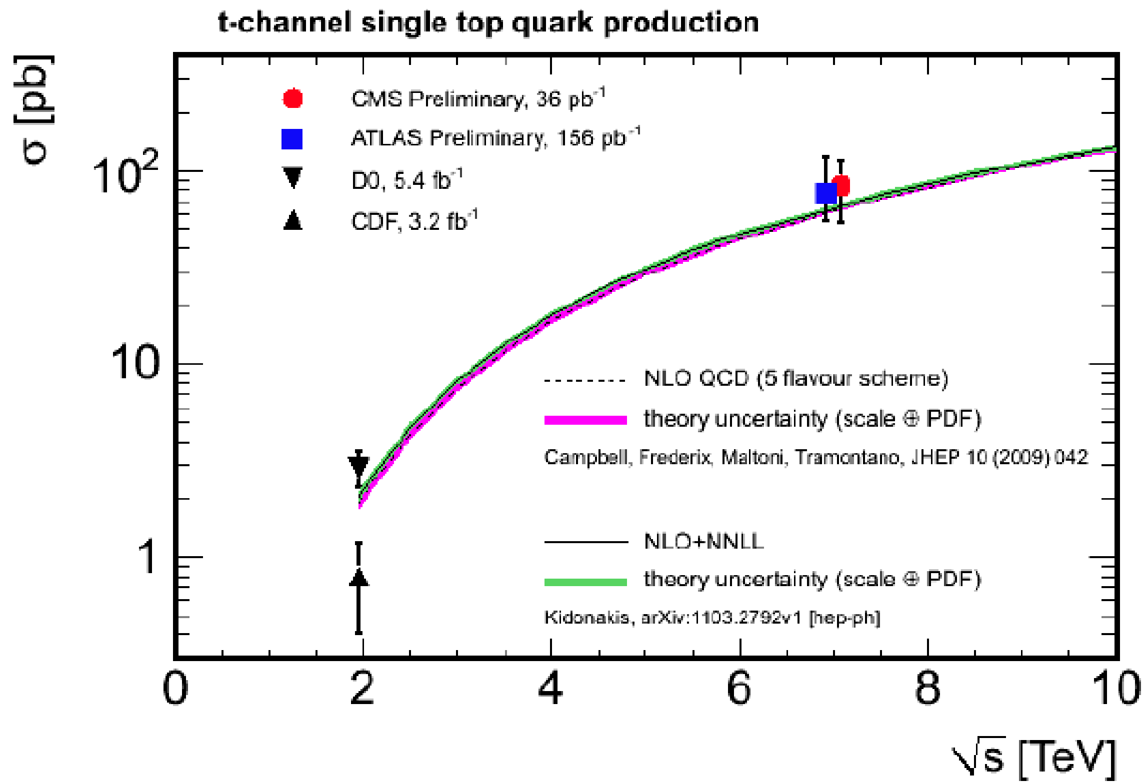


Dominant systematic uncertainty is due to b-tagging 20(15) % for 2D(BDT)

Limits on $|V_{tb}|$

- Unconstrained limit:
  - Assumption: $|V_{td}|, |V_{ts}| \ll |V_{tb}|$
    $\Rightarrow$ $|V_{tb}|^2 = \sigma(exp)/\sigma(SM)$
  - 2D: $|V_{tb}| = 1.41 \pm 0.27(exp) \pm 0.03(th.)$
    BDT: $|V_{tb}| = 1.12 \pm 0.21(exp) \pm 0.02(th.)$
- Constrained limit (i.e., flat prior $0 < |V_{tb}|^2 < 1$)
  - 2D: $|V_{tb}| > 0.63$ @ 95%CL,
    BDT: $|V_{tb}| > 0.69$ @ 95%CL

Combined single Top cross section



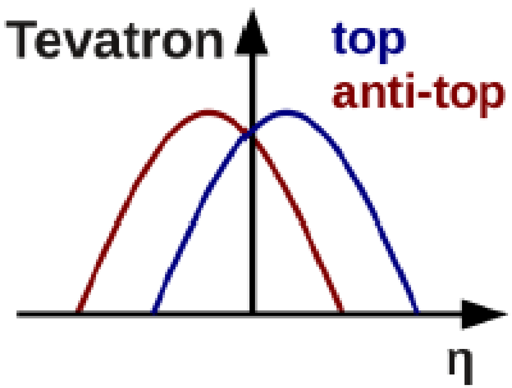
First single top cross section measurement in pp collisions

33% uncertainty achieved with 36 pb^{-1}

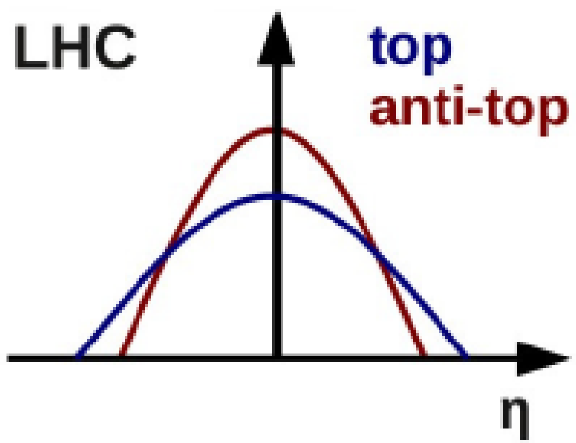
Charge asymmetry

- Allows for searches of new production mechanisms of top pairs
- Any deviation from SM prediction would be a possible indicator of BSM top production (Z', axigluons…)

- **Tevatron: proton-anti proton collider**
  - forward-backward (FB) asymmetry
  - Deviation > 3σ from SM predicted A_{FB} ~ 5%



- **LHC: proton-proton collider**
  - No FB asymmetry due to symmetric initial state
  - But quarks have on average more momentum than anti-quarks
  - Boost difference resulting in a small asymmetry in centrality ($|\eta_t| - |\eta_{\bar{t}}|$)
  - diluted due to 85% gg initial state



Charge asymmetry

- Variable used :

$|\eta_t| - |\eta_{\bar{t}}|$

$$A_C = \frac{N^+ - N^-}{N^+ + N^-}$$

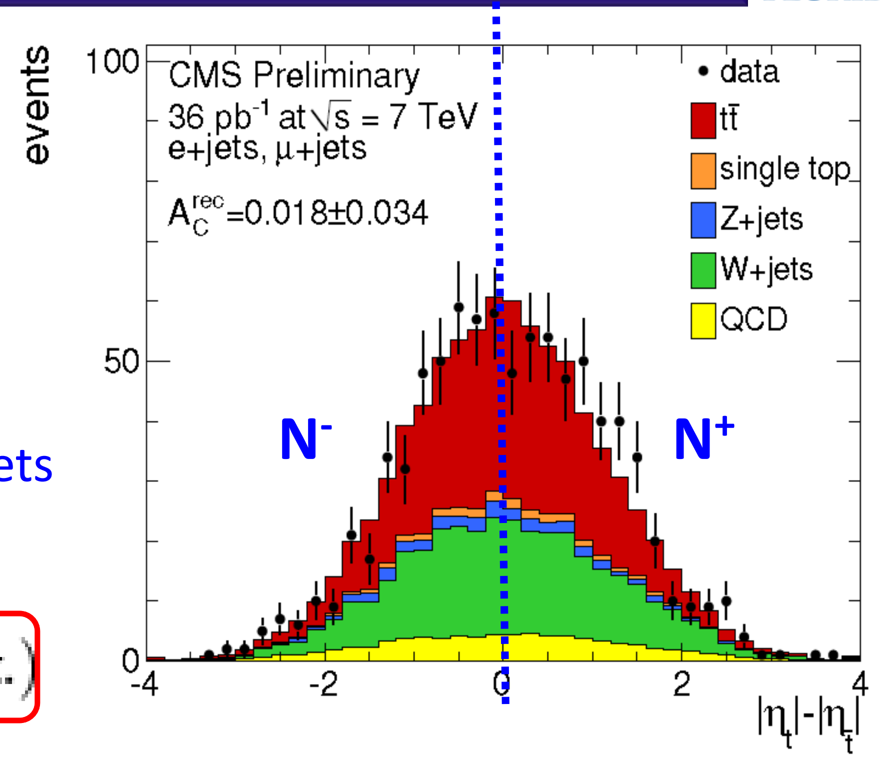
- Measured charge asymmetry in lepton + jets channel

$$A_C = 0.060 \pm 0.134(\text{stat.}) \pm 0.026(\text{syst.})$$

- Consistent with the SM prediction:

$$A_C = 0.0130 \pm 0.0011$$

- Expect same sensitivity as Tevatron with ~1fb^{-1} of data

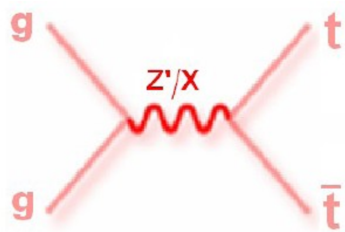


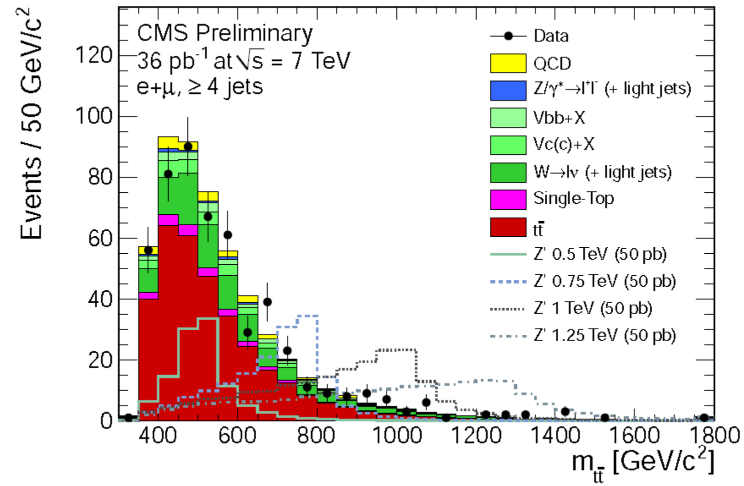
source of systematic	positive shift in A_C	negative shift in A_C
jet energy scale	0.017	-
jet energy resolution	0.007	-0.006
Q^2 scale	0.003	-0.007
ISR/FSR	0.005	-0.0006
matching threshold	0.004	-0.006
PDF	0.004	-0.011
b tagging	0.007	-
lepton efficiency	0.017	-0.018
QCD model	0.005	-0.005
overall	±0.026	

Search for tt resonances

- **Search for heavy narrow resonances decaying into a tt pair in lepton+jets final state**

  → can modify the m(tt) spectrum from SM predictions

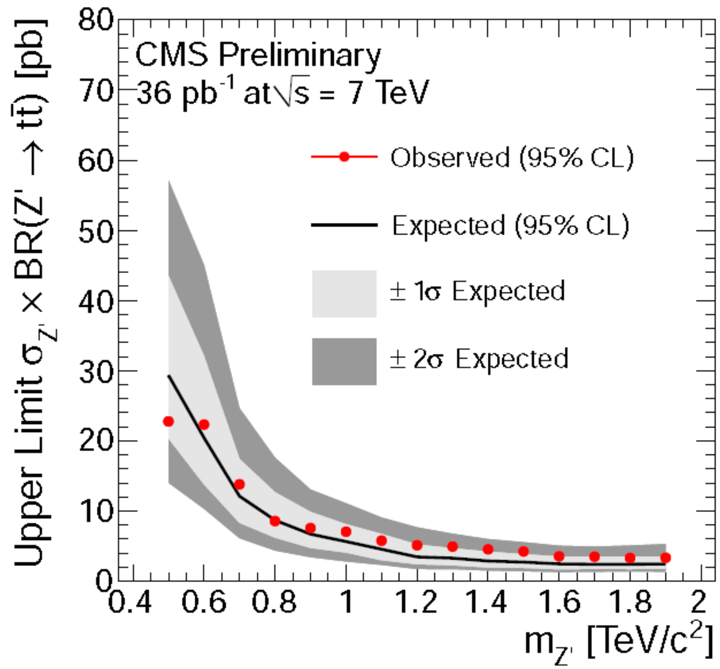




- Reconstruction of the m(tt) system

  → kinematic fit to improve the resolution

- data-driven & MC templates for all relevant processes
- Likelihood template fit to m(tt)



- **Good agreement in m(tt) with SM**

  Upper limits set for model-independent narrow-width Z' resonance production at 95% CL

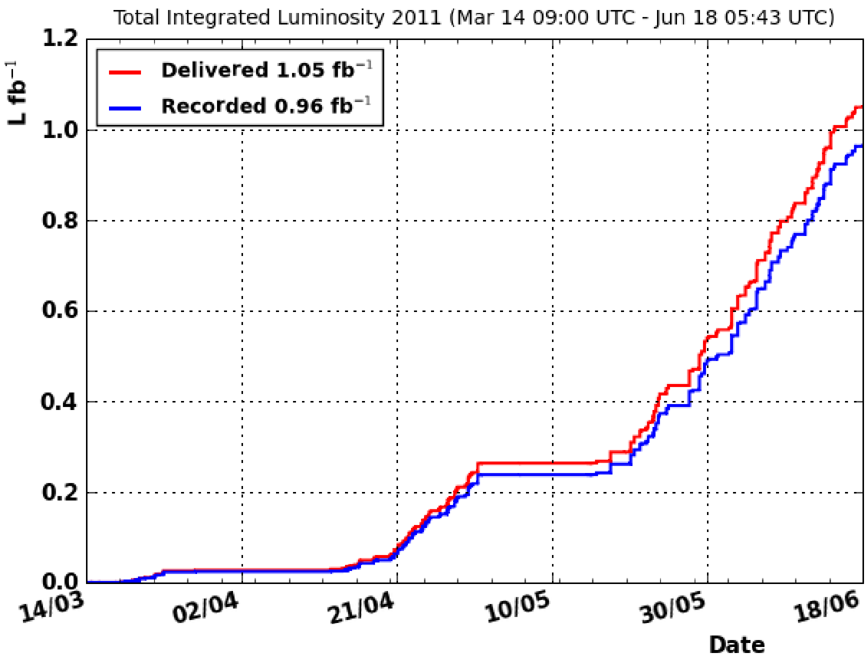
- **Comparable to Tevatron, particularly at higher masses**

Summary

- CMS performed excellent measurements of top-quark properties
- With only 36 pb^{-1} :
  - Top pair production cross section with 12%
  - t-channel single top cross section with 36%
  - Measured top mass with 3.3 GeV (2%)
  - Excluded a narrow Z' for M=1 TeV, x-sec*BR= 10pb
  - First measurements of charge asymmetry
  - Excluded large parameter space for like-sign top pairs (not included in this presentation)

Summary & Outlook

- Several results are already limited by systematics
- possible improvements/challenges in 2011 analysis
  - reduce the impact of
    - Jet energy scale uncertainties
    - b-tagging efficiency
  - Large number of pile-up
  - Triggering top events is becoming a challenge



- Many more results to come soon !

BackUp

Systematic uncert. on TOP mass measurement

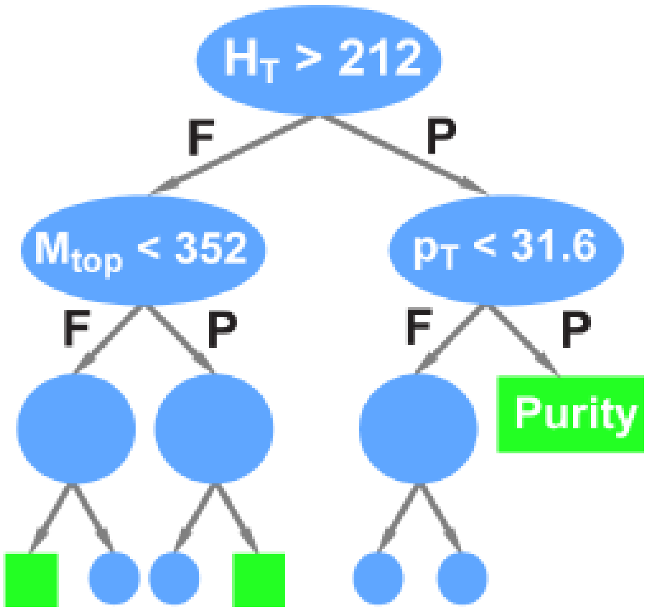
Largest source: JES!

Source	Ideogram analysis δm_t (GeV)
JES (overall data/MC)	+2.4-2.1
JER (10% effect)	0.07
MET (10% effect)	0.4
Factorization scale	1.1
ME-PS matching threshold	0.4
ISR/FSR	0.2
Underlying event	0.2
Pile-up effect	0.1
PDF	0.1
Background	0.5
B-tagging	0.05
Fit calibration statistics	0.1
Total systematic uncertainty	+2.8- 2.5

- Signal and background fraction and composition:
  - Change the signal fraction for lepton+jets ensemble by ± 20%.
  - Vary heavy flavor fraction in W+jets ± 100%
  - Use the expected sample composition instead of only using W+jets.

Boosted Decision Tree concept

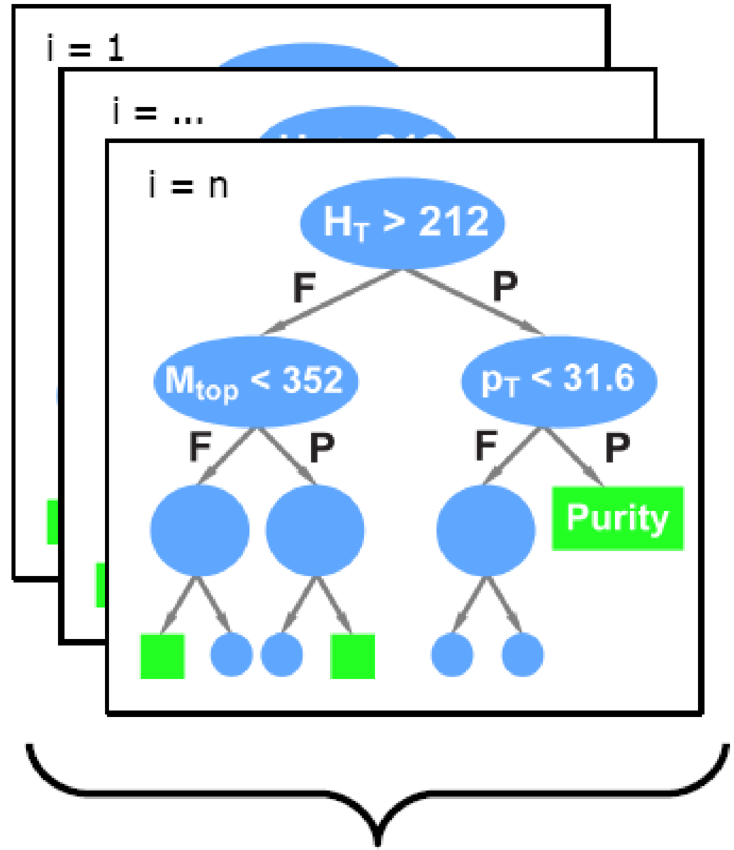
Decision Tree (example):



Reweight misclassified events

n boosting Cycles

(weight trees by their error rates)



weighted majority vote

Signal-like event: weight=+1

Background-like: weight=-1

(cuts are for illustration only)

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

Combination of Single TOP x-sec

- We use the Best Linear Unbiased Estimator
  - Assumptions of Gaussianity and linearity are approximately fulfilled (main uncertainties do)
  - Statistical correlation (60%) estimated with toy exps
  - 100% correlation for all common systematics, apart from QCD yield ~50%; varied within 0% and 100%, no impact
  - Weights found by minimizing the total error

$$\sigma^{2D} = 124.2 \pm 33.8(stat.)^{+30.0}_{-33.9}(syst.) \pm 5.0(lumi.)\ \text{pb}$$

$$\sigma^{BDT} = 78.7 \pm 25.4(stat.)^{+13.2}_{-14.6}(syst.) \pm 3.1(lumi.)\ \text{pb}$$

$$\sigma = 83.6 \pm 29.8(stat. + syst.) \pm 3.3(lumi.)\ \text{pb} \qquad \text{combined}$$

$$|V_{tb}| = \sqrt{\frac{\sigma^{exp}}{\sigma^{th}}} = 1.16 \pm 0.22(exp) \pm 0.02(th)$$

Single Top: W+jets estimation

Two control regions, both orthogonal to signal region

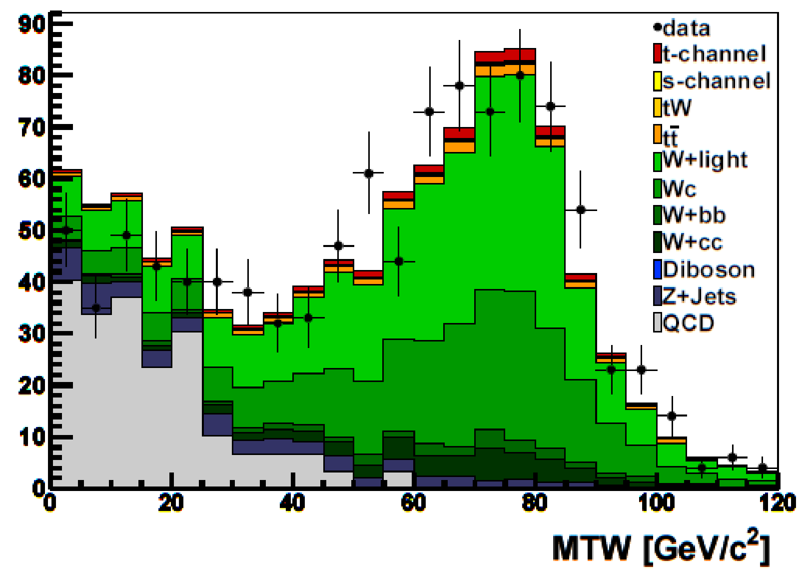
- **A:** no tight b-tag
- **B (⊂ A):** no tight b-tag, 1 loose b-tag and 1 anti-b-tag

Fit with 3 components:

- W+light partons (shape from MC)
- QCD (unconstr., shape from anti-iso)
- Others (fixed to expectations)

This is applied only in the 2D analysis; the BDT treats this rate as a nuisance parameter in the fit and marginalises it

Muon channel, region B



Process	*SF* from region *A*	*SF* from region *B*
μ channel	1.02 ± 0.03	1.27 ± 0.09
e channel	0.97 ± 0.04	1.05 ± 0.11

We take the central values from B, ±30% (μ), ±20% (e)
But the shapes of the 2D fit variables will be taken from A

Predicted event yields

Process	2D, μ channel	2D, e channel	BDT, μ channel	BDT, e channel
single top, t channel	[redacted]	[redacted]	[redacted]	[redacted]
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	[redacted]	[redacted]	[redacted]	[redacted]
$Z + X$	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
$VQ\bar{Q}$	[redacted]	[redacted]	[redacted]	[redacted]
Wc	[redacted]	[redacted]	[redacted]	[redacted]
$t\bar{t}$	[redacted]	[redacted]	[redacted]	[redacted]
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

Theory

In situ

Dedicated analysis

Although at this step we have a better S/B than CDF/D0, simple cut-and-count is clearly hopeless with this level of knowledge of the main backgrounds. But we can do better.