Top Quark Physics with CMS

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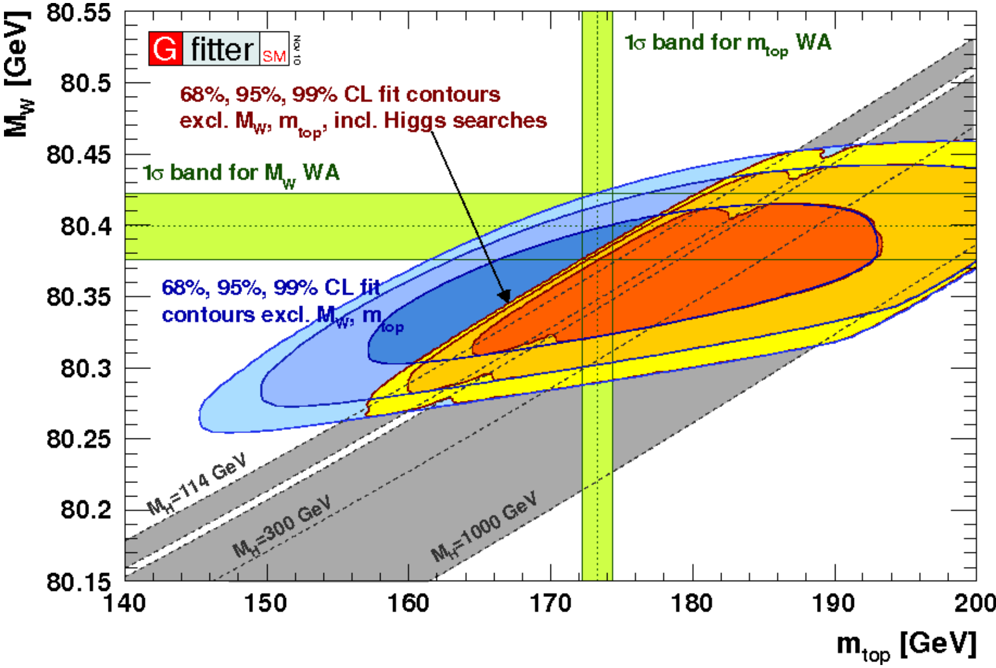
Outline

- Motivation & Introduction
- Physics Objects for Top
- MC Simulation
- Measurements performed so far:
  - Top pair cross section
  - Top mass, incl. lepton+jets channel **[NEW]**
  - Single top cross section
  - Top pair invariant mass & search for new physics
  - Charge Asymmetry
  - Search for same-sign top pairs **[NEW]**

- All CMS public results available from
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Why is Top Physics interesting?

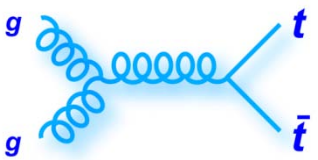
- Heaviest SM particle
  - o m(top)=173+/-1.1GeV (0.6%)
- Special role in EWK symmetry breaking?
- Sensitive to Higgs mass through EWK loop corrections
  - o Low Higgs mass peferred

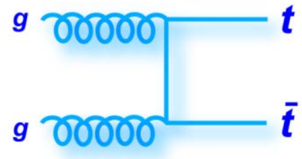


- New physics may couple preferentially to top
  - o e.g. search for new particles decaying into top (pairs) ➔ M(ttbar)
- The top quark may be special
  - o New physics may be hidden in e.g. spin structure
- Top production may be background to SUSY and other NP

Top quark pair production

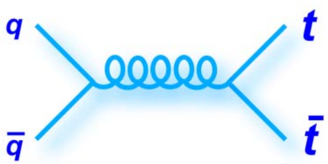
- Gluon fusion (dominant at LHC)

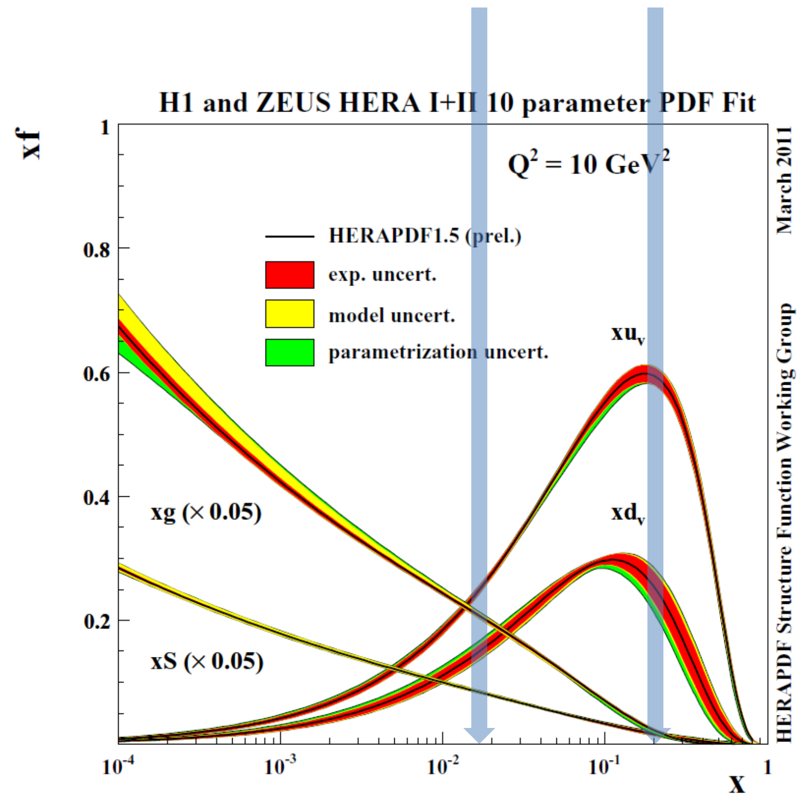




	LHC	Tevatron
gg	~85%	~10%
qq	~15%	~90%

- Quark-antiquark annihilation





- Total cross section at 7 TeV:
  - o NLO (MCFM) $\sigma_{t\bar{t}}^{\mathrm{NLO}} = 158^{+23}_{-24}\ \mathrm{pb}$
  - o approx. NNLO
    - Kidonakis, PRD 82 (2010) 114030

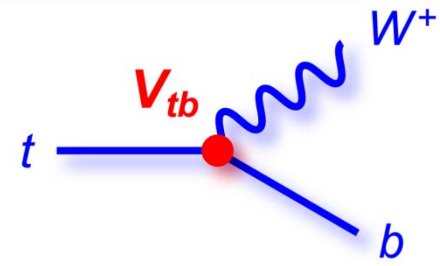
      $$\sigma_{t\bar{t}} = 163^{+11}_{-10}\ \mathrm{pb}$$

    - Langenfeld, Moch, Uwer, PRD80 (2009) 054009;
    - Aliev et al., CPC182 (2011) 1034

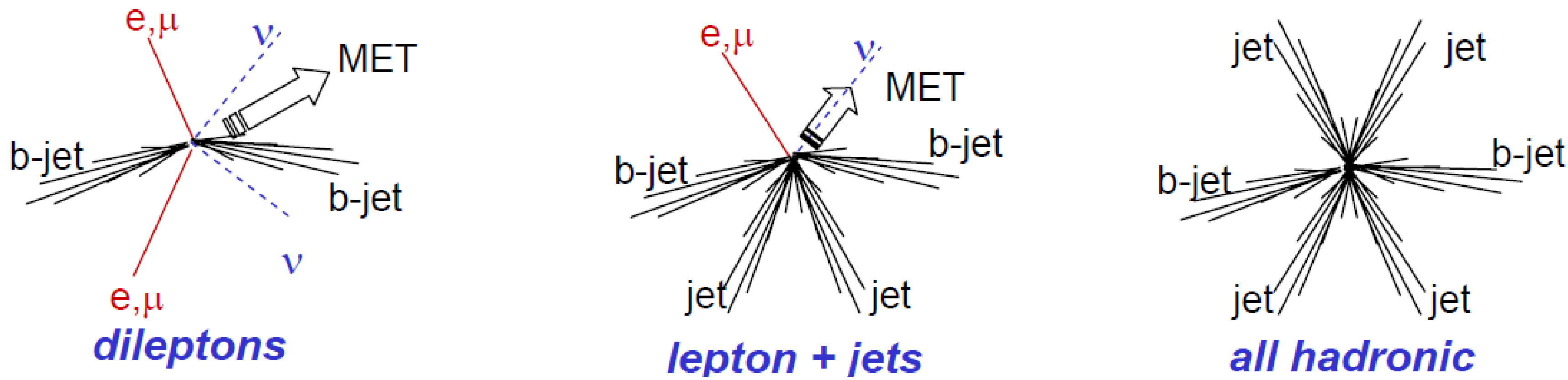
      $$\sigma_{t\bar{t}} = 164^{+10}_{-13}\ \mathrm{pb}$$

Top quark decays

- Top decays before it can hadronize
  - o almost exclusively t->Wb



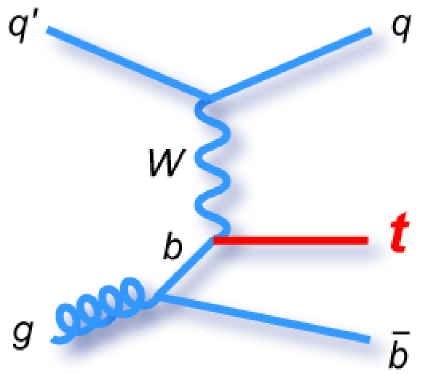
- Top pair event classification according to W decays



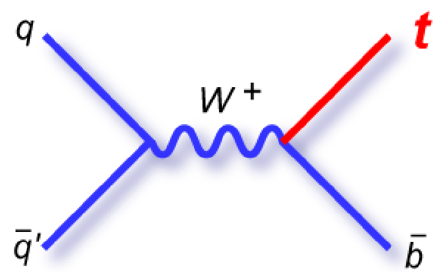
Branching ratio:	~5%	~30%	~46%
Backgrounds:	few (mainly Z+jets)	moderate (mainly W+jets)	huge (mainly QCD)

Single Top Production

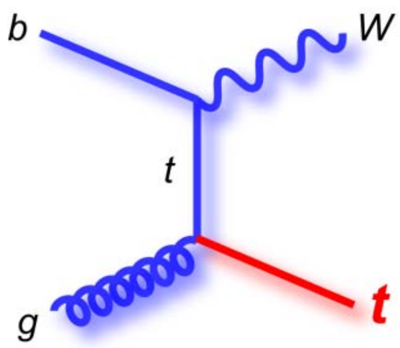
- Single top quarks are produced through electroweak interaction



t-channel



s-channel



tW-channel
(associated production)

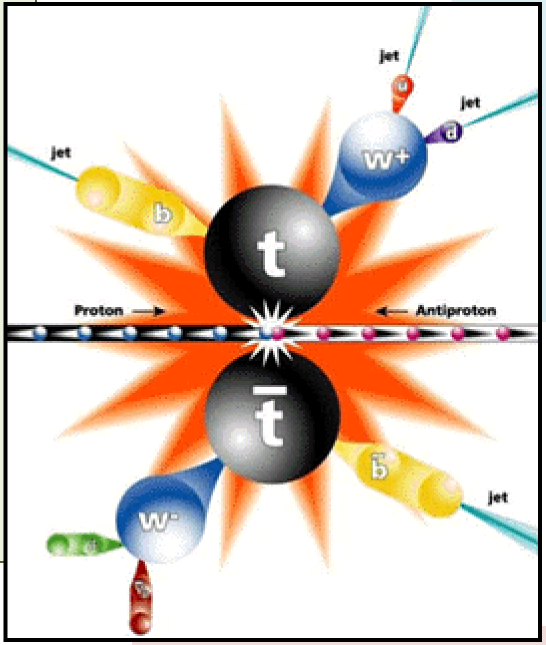
Cross section:	~64 pb	~4.6 pb	~15.6 pb

Kidonakis, NLO+NNLL
t-channel: PRD 83 (2011) 091503
s-channel: PRD 81 (2010) 054028
tW-channel: PRD 82 (2010) 054018

Difficult signature (fewer jets)
Large backgrounds from ttbar, V+jets
tW-channel interferes with ttbar at higher orders

LHC Top Physics Program

- Production
  - o Pair cross section (QCD)
  - o Single top cross section (EWK)
  - o Differential cross sections
    - Compare with theory
    - Validate ME+PS models
  - o Charge asymmetry
  - o Spin correlations



- Decay
  - o Branching ratios
  - o t->Wb / t->Wq
  - o W-helicity in top decays (W->tb coupling)

- Intrinsic Properties
  - o Mass (difference)
  - o Charge
  - o Lifetime

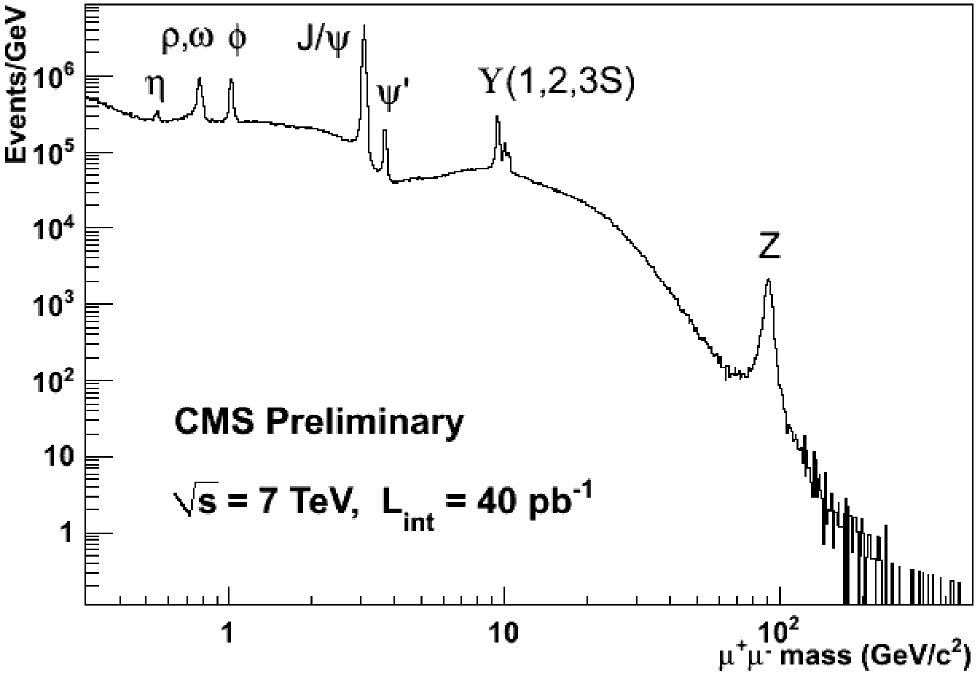
- New physics
  - o New particles decaying to top
  - o BSM top decays
  - o New physics with top-like signature

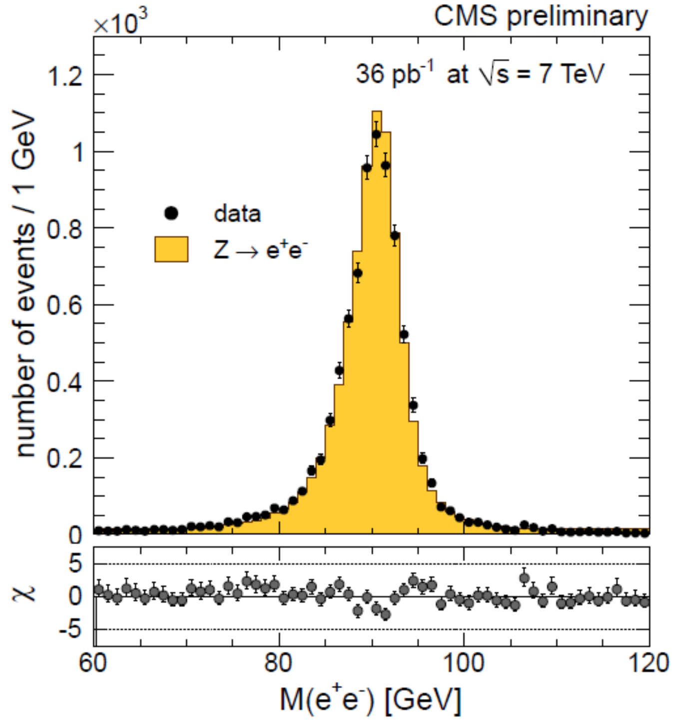
Physics Objects for Top Physics

- Electrons and muons (in future also taus)
  - o Identification with high efficiency & low fake rate
  - o Precise momentum measurement
  - o Isolation (identify leptons from W-decays, suppress QCD)
  - o Key for triggering top events
- Jets
  - o Precise measurement with small jet energy scale uncertainty
- Missing transverse energy (MET)
  - o Reconstruct transverse neutrino momentum
  - o Reject QCD, Z+jets background
- b-jet identification
  - o High efficiency (and low failure rate) to tag jets from b-quarks
  - o Helps with jet pairing (e.g. for top mass)

Top physics needs ~all physics objects well understood!

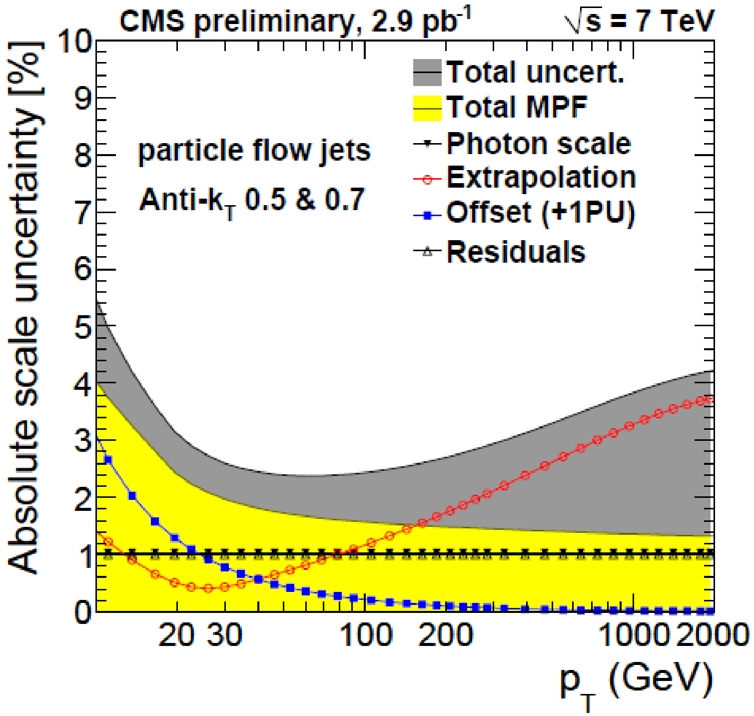
Electrons and Muons

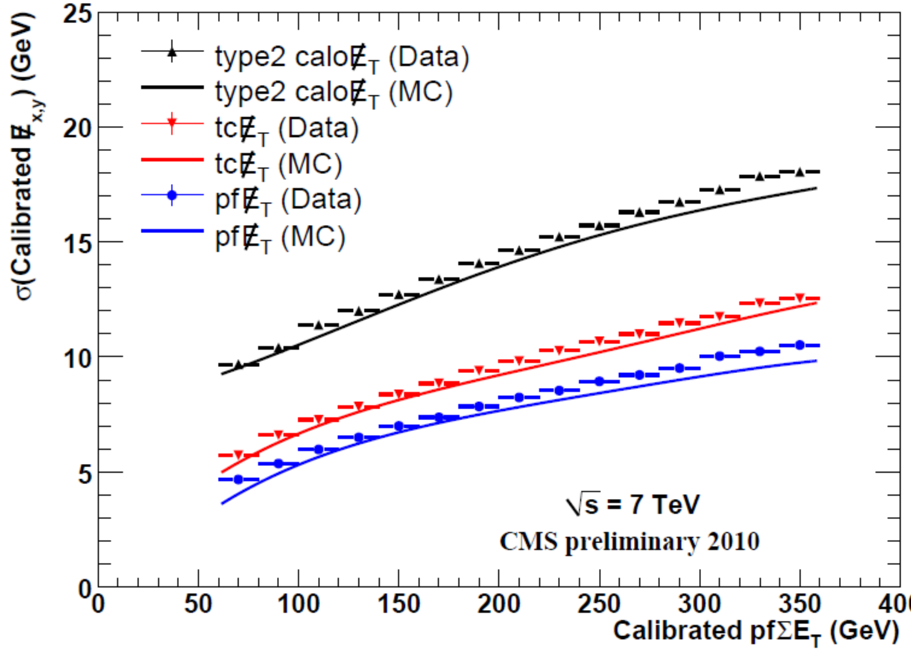




- Muon Pt resolution for Top 1-2% (tracker dominated)
- Good trigger and ID capabilities using redundant subdetectors
- Excellent ECAL resolution (~1% for TOP)
- Good track matching (fit accounting for Bremsstrahlung)
- ID based on shower shape, H/E, etc.

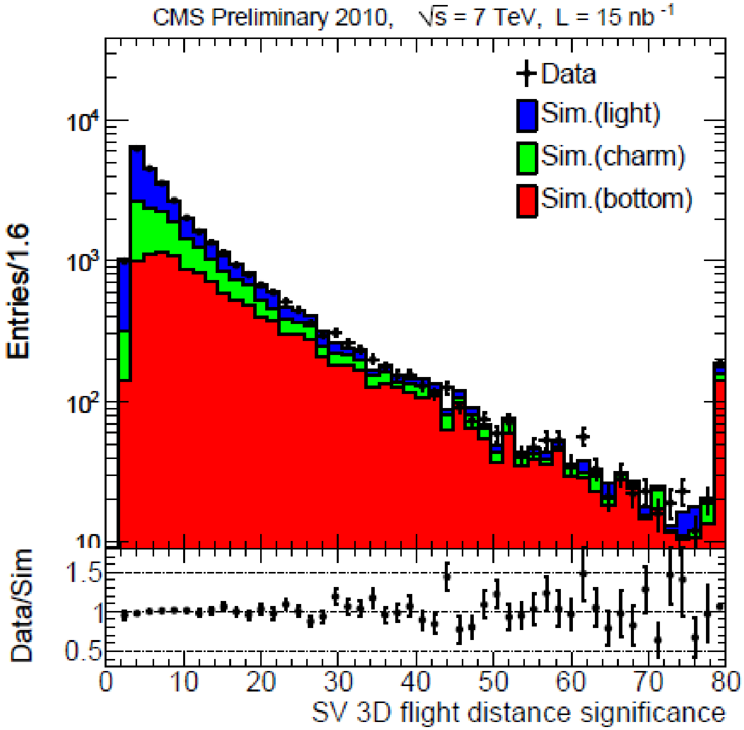
Jets and Missing Transverse Energy

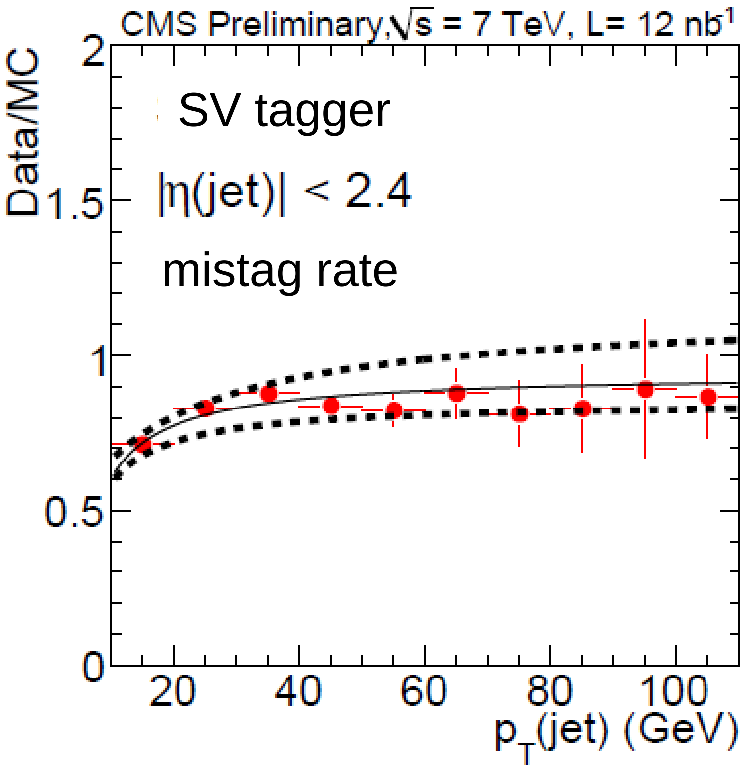




- Particle Flow (“PF”, calo&tracking&muons combined)
- Jets defined using anti-kT algo (dR=0.5)
- Jet energy scale uncertainty <3% for 30<Pt<200 GeV
- Jet Pt resolution 10-15%
- MET resolution vastly improved with PF

b-jet Identification





- Crucial ingredient: excellent tracker performance and alignment
- So far mostly use
  - Count tracks with large IP
  - Secondary vertex reconstruction

- Data-driven efficiency & mistag rate determination
- SF(Data/MC) close to unity
  - known to ~15-20% for b-eff
  - known to ~10% for mistag rate

MC Simulation and Theory Uncertainties

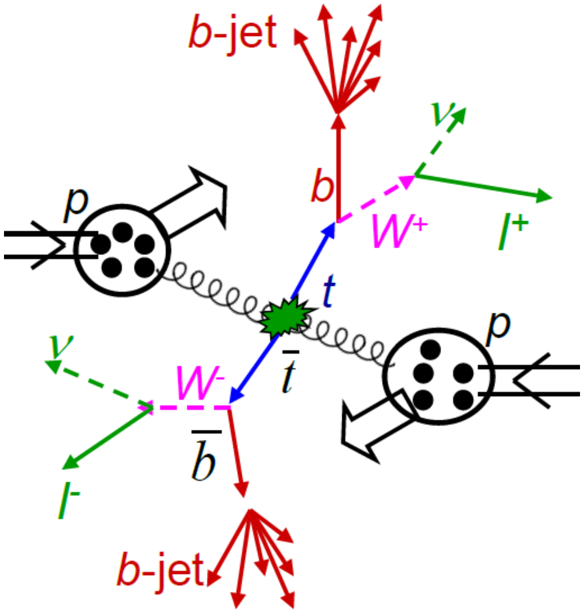
- Use MADGRAPH to simulate top signal and most important backgrounds (W/Z+jets)
  - Matrix elements with up to 3 (tt) or 4 (W/Z) extra jets
  - ME+PS matching using MLM prescription
  - Scales set as $Q^2 = M^2_{t,W,Z} + \sum P^2_{T,jets}$
  - Cross sections rescaled to inclusive (N)NLO values
- Dedicated samples to estimate modelling uncertainties, varying
  - scale Q by factors 2.0 and 0.5
  - amount of ISR/FSR radiation
  - matching thresholds by factors 2.0 and 0.5
  - MC@NLO as alternate signal generator

- Use data-driven backgrounds where possible

Outline

- Top pair cross section
- Top pass measurement
- Top pair invariant mass distribution
- Single top cross section
- Charge asymmetry
- Search for same-sign top pairs

Dilepton channel: Event selection



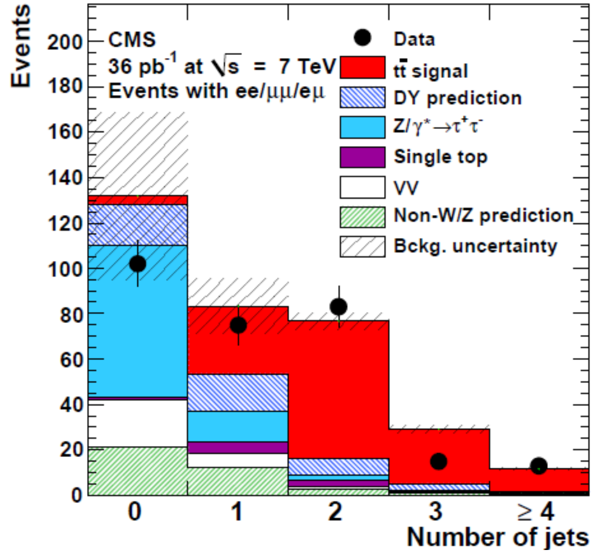
- Inclusive single lepton triggers
  - o muons (Pt>…15 GeV) and electrons (Pt>…22 GeV)
- Two isolated, opposite charge leptons (ee,mumu,emu)
  - o Pt>20 GeV, |eta|<2.4(mu),2.5(e)
  - o Good ID, conversion rejection for electrons, eff. 99(90)% for mu(e)
  - o Rel. isolation< 0.15

$$\text{Rel.isol.} = \frac{\sum_{R<0.3} p_T^{\text{track}} + \sum_{R<0.3} p_T^{\text{ECAL}} + \sum_{R<0.3} p_T^{\text{HCAL}}}{p_T(\text{lepton})}$$

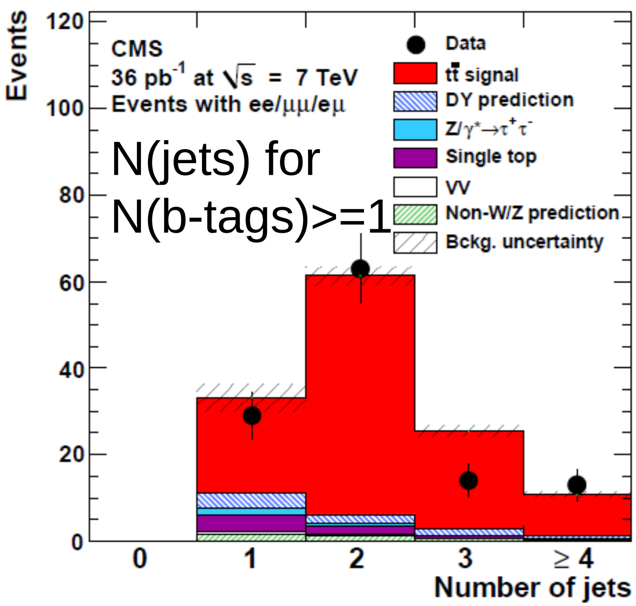
- Z-boson veto (ee,mumu)
  - o |M(ll)-M(Z)|>15 GeV
- Missing Et (MET)
  - o MET>30 (20)GeV in ll (ll')
- Jets
  - o Pt>30 GeV, |eta|<2.5
- b-jet identification
  - o Track-counting algorithm
  - o Here: eff ~80%, mistag rate 10%

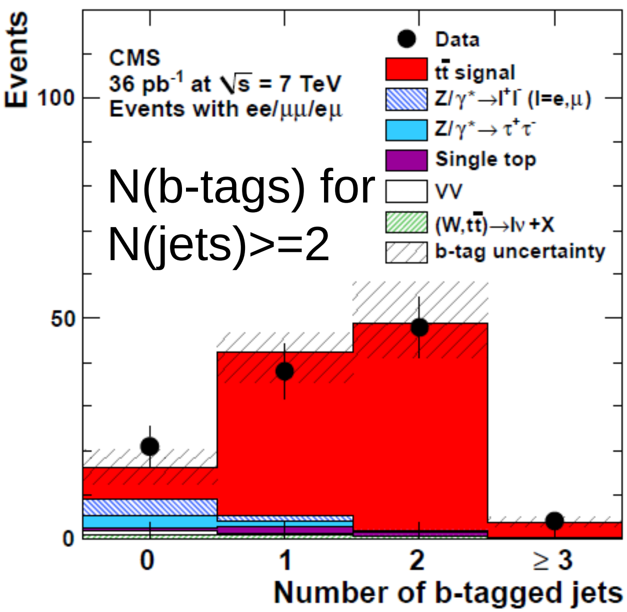
Top pair cross section in dileptons (arXiv:1105.5661)

Jet multiplicity before applying b-tagging



Hatched:
BG uncertainty





Very pure sample of top events!

Top pair cross section in dileptons (arXiv:1105.5661)

- Counting experiment, done in three categories (and each for ee,mumu,emu)
  - o 2 jets, >=0 b-tags
  - o 2 jets, >=1 b-tags (adds sensitivity for ee,mumu)
  - o 1 jet, >=0 b-tags (improves combined result)
- Important backgrounds from data
  - o Drell-Yan (after Z-veto)
    - N(in veto,data) *R(out/in,MC)
  - o Events with non-W/Z leptons (mainly QCD,W+jets)
    - "fakes" measured in QCD sample.

Final state	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
At least two jets, no b-tagging requirement			
Events in data	23	28	60
Simulated backgrounds	1.4 ± 0.3	1.5 ± 0.3	5.2 ± 1.2
$Z/\gamma^* \to e^+e^-/\mu^+\mu^-$	3.0 ± 1.8	7.4 ± 4.1	–
Non-W/Z	1.1 ± 1.4	0.6 ± 1.1	1.4 ± 1.6
All backgrounds	5.5 ± 2.3	9.5 ± 4.3	6.7 ± 2.0
Total acceptance $\mathcal{A}$ (%)	0.259 ± 0.021	0.324 ± 0.025	0.928 ± 0.057
Cross section (pb)	$189 \pm 52 \pm 29$	$159 \pm 45 \pm 39$	$160 \pm 23 \pm 12$
At least two jets, at least one b-jet			
Events in data	15	24	51
Simulated backgrounds	0.7 ± 0.2	0.8 ± 0.3	2.5 ± 0.7
$Z/\gamma^* \to e^+e^-/\mu^+\mu^-$	0.7 ± 0.7	2.6 ± 1.8	–
Non-W/Z	0.9 ± 1.2	0.3 ± 0.8	0.5 ± 1.1
All backgrounds	2.3 ± 1.4	3.8 ± 2.0	3.0 ± 1.4
Total acceptance $\mathcal{A}$ (%)	0.236 ± 0.022	0.303 ± 0.028	0.857 ± 0.068
Cross section (pb)	$150 \pm 46 \pm 22$	$186 \pm 45 \pm 25$	$156 \pm 23 \pm 13$
One jet, no b-tagging requirement			
Events in data	8	10	18
Simulated backgrounds	1.6 ± 0.4	1.9 ± 0.4	3.6 ± 0.9
$Z/\gamma^* \to e^+e^-/\mu^+\mu^-$	0.2 ± 0.3	5.2 ± 4.3	–
Non-W/Z	0.3 ± 0.5	0.1 ± 0.4	1.3 ± 1.3
All backgrounds	2.1 ± 0.7	7.1 ± 4.3	4.9 ± 1.5
Total acceptance $\mathcal{A}$ (%)	0.058 ± 0.007	0.074 ± 0.008	0.183 ± 0.024
Cross section (pb)	$282 \pm 135 \pm 45$	$107 \pm 119 \pm 163$	$200 \pm 65 \pm 35$

Top pair cross section in dileptons (arXiv:1105.5661)

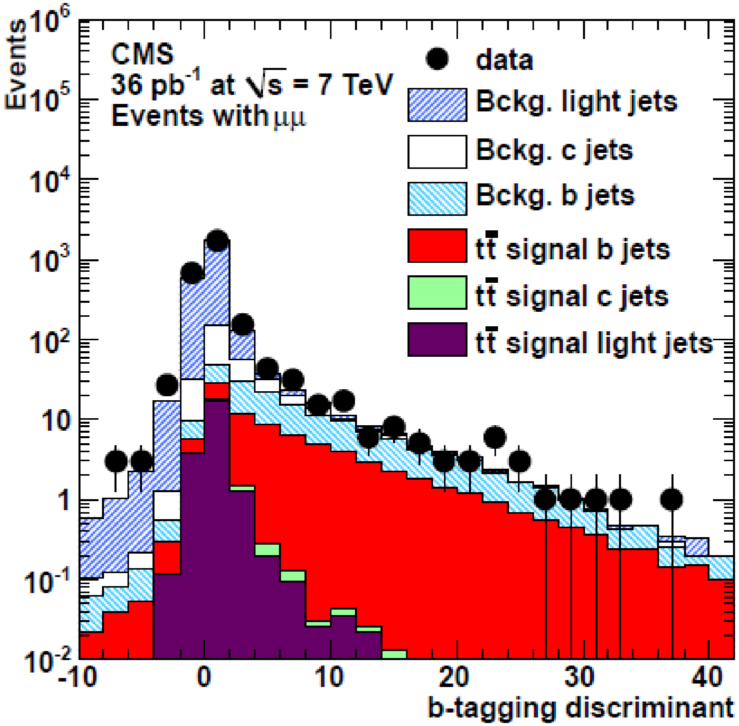
- Dominating systematics
  - o Data-driven background estimates
  - o Jet energy scale
  - o b-tagging efficiency

- In-situ determination of b-tagging efficiency
  - o b-tagging eff. related to ratio of >=2 tag / >=1 tag events $R_{2/1}$

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

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

  - o Good agreement observed
    - 5% uncertainty assigned to MC eff.



Top pair cross section in dileptons (arXiv:1105.5661)

- Combined cross section (14% rel. uncertainty)

$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}}) = 168 \pm 18\,(\mathrm{stat.}) \pm 14\,(\mathrm{syst.}) \pm 7\,(\mathrm{lumi.})\ \mathrm{pb}$$

Here and elsewhere:
Luminosity error: 4%

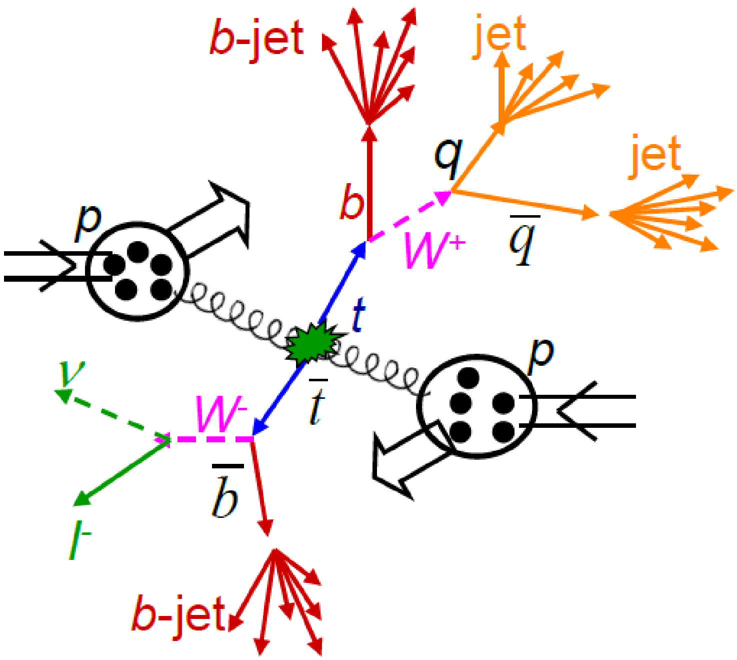
- Cross section ratio tt/Z
  - o Interesting quantity:
    - No luminosity uncertainty
    - anti-correlated PDF uncertainty in Z and tt
  - o Result:

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

  - o 13% uncertainty, comparable to uncertainty of SM prediction
  - o Only marginally better than cross section uncertainty (dominating systematics do not cancel; luminosity error only 4%)

Lepton+jets: Event selection

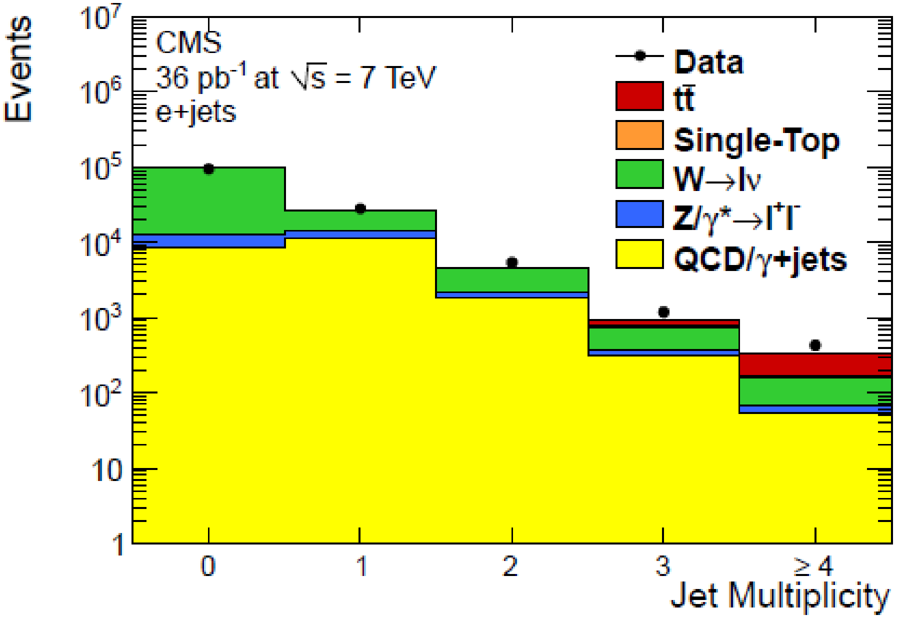
- Considered modes:
  - o e+jets, mu+jets
- Single lepton triggers used
- Exactly one isolated lepton
  - o Muons: Pt>20 GeV,|eta|<2.1
    - Rel. Isolation < 0.05
  - o Electrons: Pt>30 GeV, |eta|<2.5
    - Rel. Isolation, conversion veto
- Jets
  - o Pt>30 GeV, |eta|<2.4

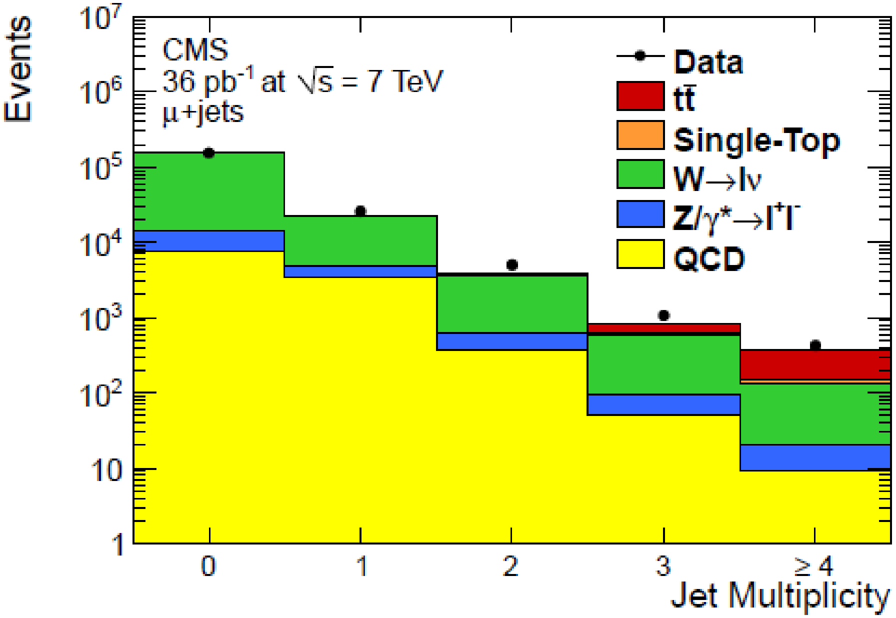


- Analysis without b-tagging
  - o Use MET shape as discriminating distribution
- Analysis with b-tagging
  - o MET>20GeV
  - o SV tagging algorithm

Top pair cross section in l+jets without b-tagging (arXiv:1106.0902)

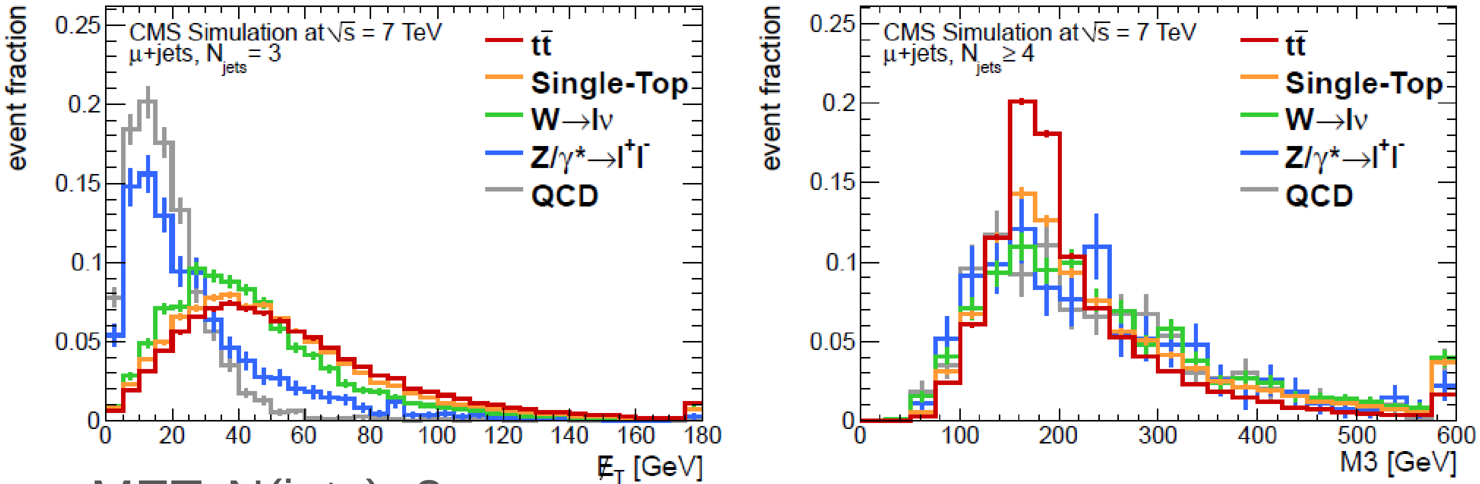
- Event counts vs jet multiplicity





Top pair cross section in l+jets without b-tagging (arXiv:1106.0902)

- Method: simultaneous template fit in two distributions to extract N(ttbar)

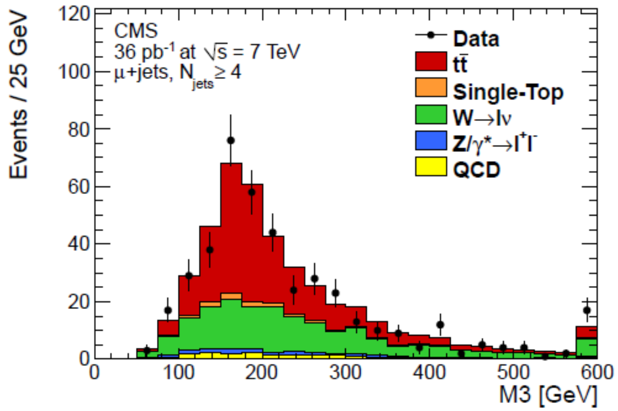


  - MET: N(jets)=3
    - separates mainly backgrounds without true MET (QCD,Z+jets) from events with MET (top, W+jets)
  - M3: N(jets)>=4
    - Mass of three jets maximising vectorially summed Pt
    - Separate top from backgrounds
  - Templates from MC, except QCD (control regions from data)

Top pair cross section in l+jets without b-tagging (arXiv:1106.0902)

- Cross section extraction:

	$\beta_{t\bar{t}}$	$N_{t\bar{t}}$	$N_{single\text{-}top}$	N_{W+jets}	N_{Z+jets}	N_{QCD} e+jets	N_{QCD} μ+jets
predicted	1.00	733 ± 116	72 ± 4	1069 ± 77	138 ± 10	367 ± 27	58 ± 4
fitted	$1.10^{+0.25}_{-0.21}$	806^{+183}_{-154}	76 ± 22	1475 ± 86	184 ± 51	440 ± 44	113 ± 31



MC scaled to fit result (muons, >=4 jets)

Systematics

	combined result	
	stat.+syst. uncertainty	syst. only
Stat. uncertainty	$^{+8.7\%}_{-8.4\%}$	–
JES	$^{+20.3\%}_{-17.6\%}$	$^{+18.3\%}_{-15.5\%}$
Factorization scale	$^{+11.2\%}_{-10.6\%}$	$^{+7.1\%}_{-6.5\%}$
Matching threshold	$^{+10.5\%}_{-9.8\%}$	$^{+5.9\%}_{-5.0\%}$
Pileup	$^{+9.3\%}_{-9.3\%}$	$^{+3.3\%}_{-4.0\%}$
ID/reconstruction	$^{+9.2\%}_{-8.7\%}$	$^{+3.0\%}_{-2.3\%}$
QCD rate & shape	$^{+9.1\%}_{-8.9\%}$	$^{+2.7\%}_{-2.9\%}$
ISR/FSR variation	$^{+9.0\%}_{-8.6\%}$	$^{+2.3\%}_{-1.8\%}$
JER	$^{+8.8\%}_{-8.4\%}$	$^{+1.3\%}_{-0.0\%}$
PDF uncertainty	$^{+8.7\%}_{-8.5\%}$	$^{+0.0\%}_{-1.3\%}$
Total	$^{+23.5\%}_{-19.3\%}$	$^{+21.8\%}_{-17.4\%}$

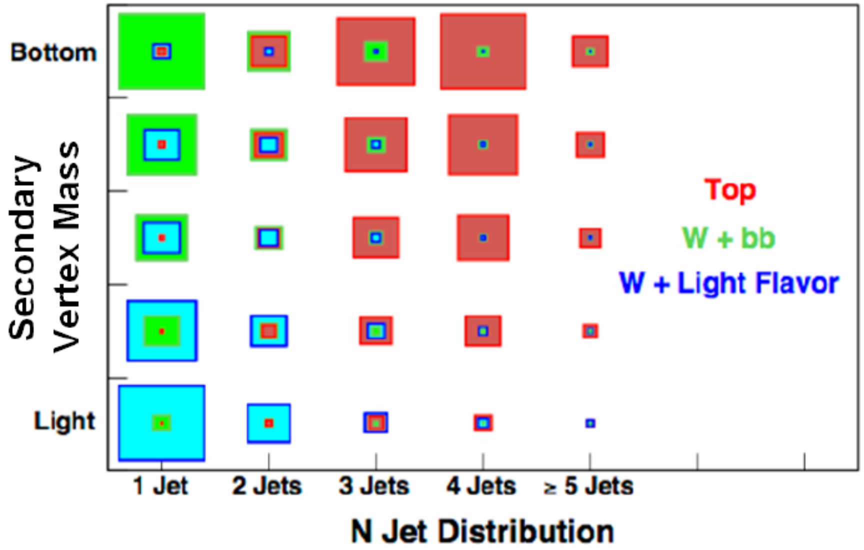
e+jets $\sigma_{t\bar{t}} = 180^{+45}_{-38}(\text{stat.} + \text{syst.}) \pm 7(\text{lumi.})\,\text{pb}$

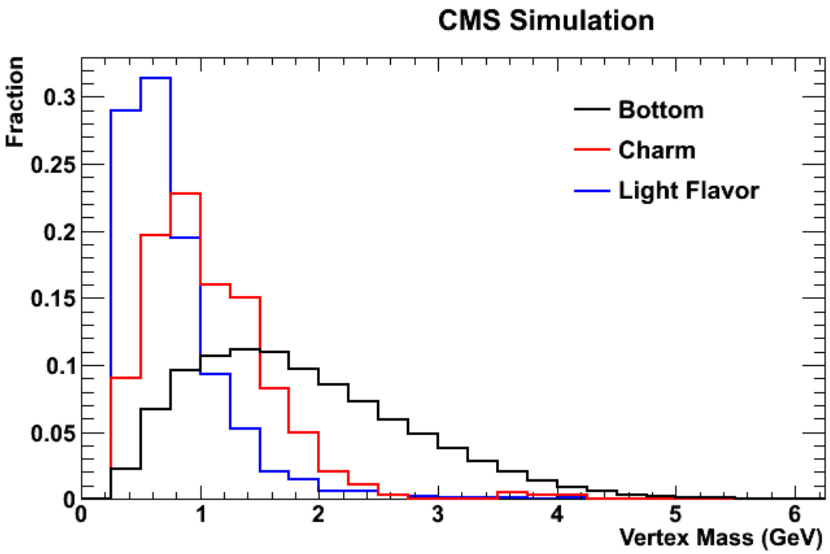
mu+jets $\sigma_{t\bar{t}} = 168^{+42}_{-35}(\text{stat.} + \text{syst.}) \pm 7(\text{lumi.})\,\text{pb}$

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

Top pair cross section in l+jets with b-tagging (TOP-10-003)

- Use events with >=1 b-tag
  - o Secondary vertex (SV) algorithm
- Template fit of SV mass in 2D N(jets), N(tags) plane
  - o Separation of signal and various backgrounds

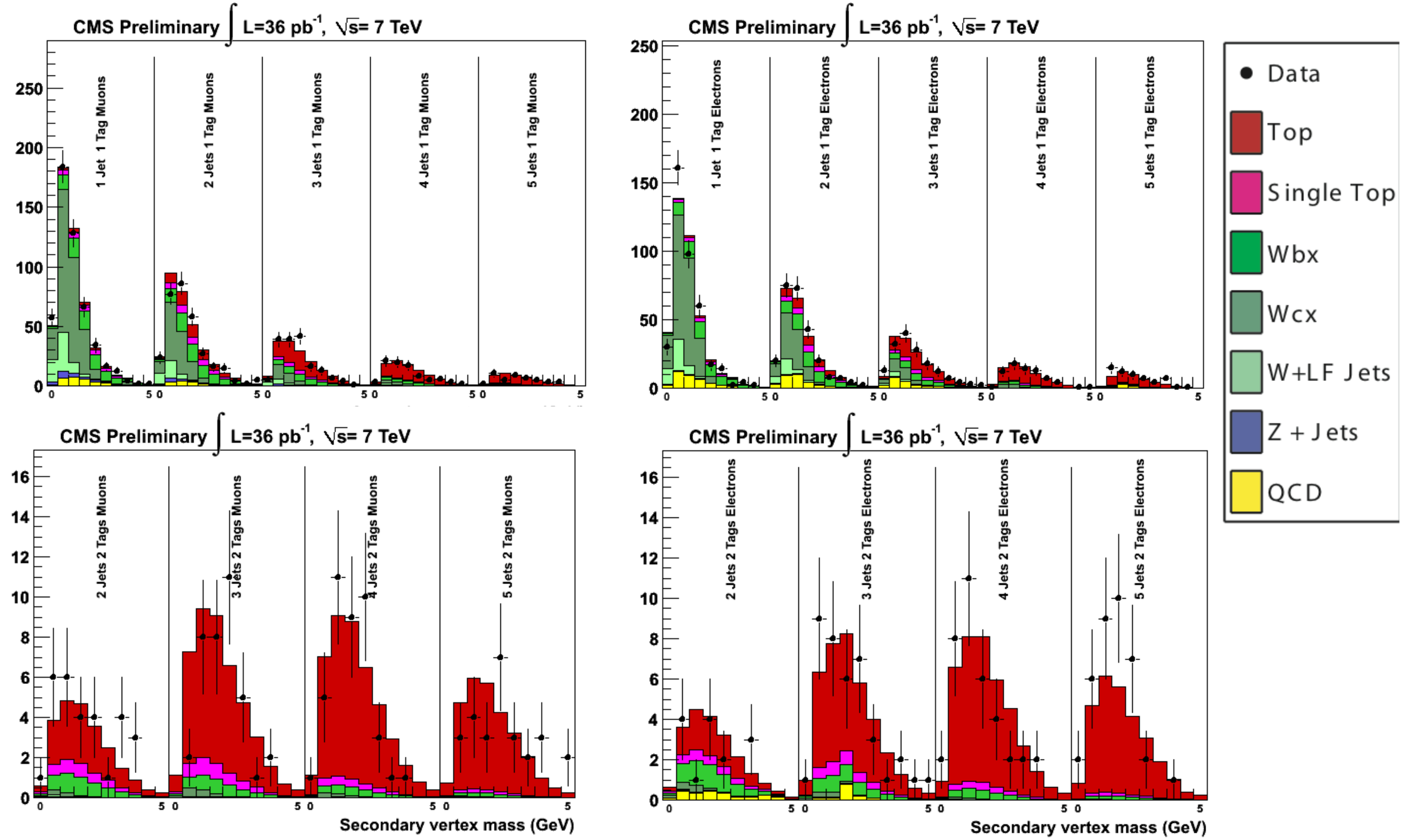




- Most important systematics fitted in situ (nuisance parameters in profile likelihood)
  - o Jet energy scale
  - o B-tag efficiency
  - o W+jets ren./fac. scale

Top pair cross section in l+jets with b-tagging (TOP-10-003)

- Fit result: SV mass distributions in 5(4) 1(2)-tag bins per channel (e+jets, mu+jets)



Top pair cross section in l+jets with b-tagging (TOP-10-003)

Obtained result for BG normalizations :

BG scale factor	Fit result
W+b scale factor (w.r.t. MC sc. to incl. NNLO)	1.9 +0.6-0.5
W+c-jets scale factor (w.r.t. MC sc. to incl. NNLO)	1.4 +/- 0.2

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

JES/ b-tag SF consistent with input, but uncertainty reduced!

Systematic uncertainties extracted in the fit

Result:

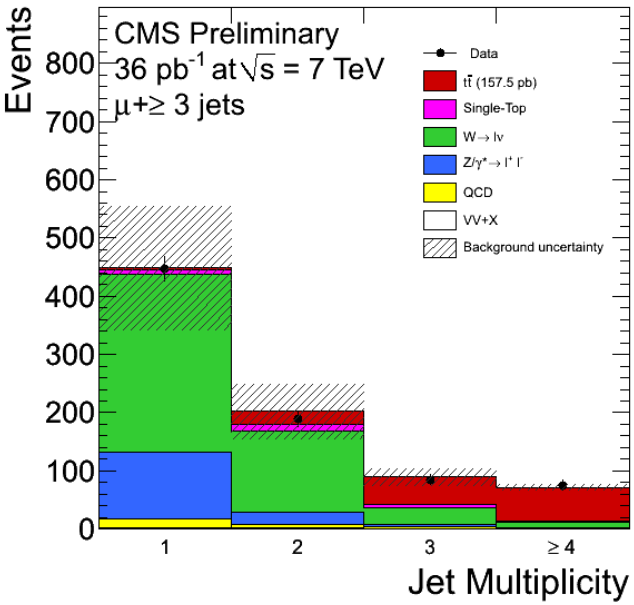
$$\sigma_{t\bar{t}} = 150 \pm 9\,(\text{stat.}) \pm 17\,(\text{syst.}) \pm 6\,(\text{lumi.})\text{ pb}$$

Total uncertainty 13%

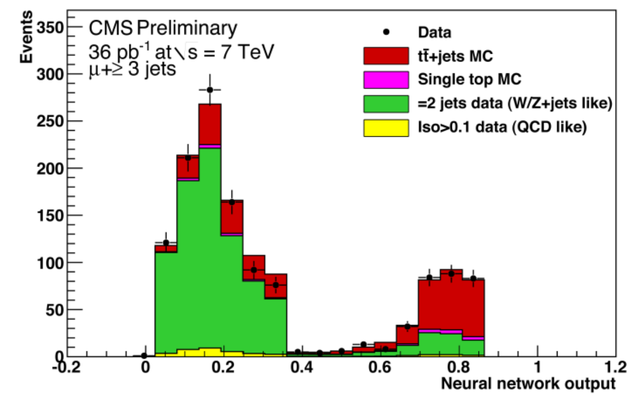
Cross check analyses

- Soft muon tagging in mu+jets
  - o Orthogonal method to identify b-jets
  - o Suffers from reduced efficiency
- Counting experiment in e+jets
  - o Use Berends scaling to estimate W+jets background
- Neural network analysis in mu+jets
  - o Variables: dR(jet1,jet2), eta(muon), b-tag
- All in good agreement!

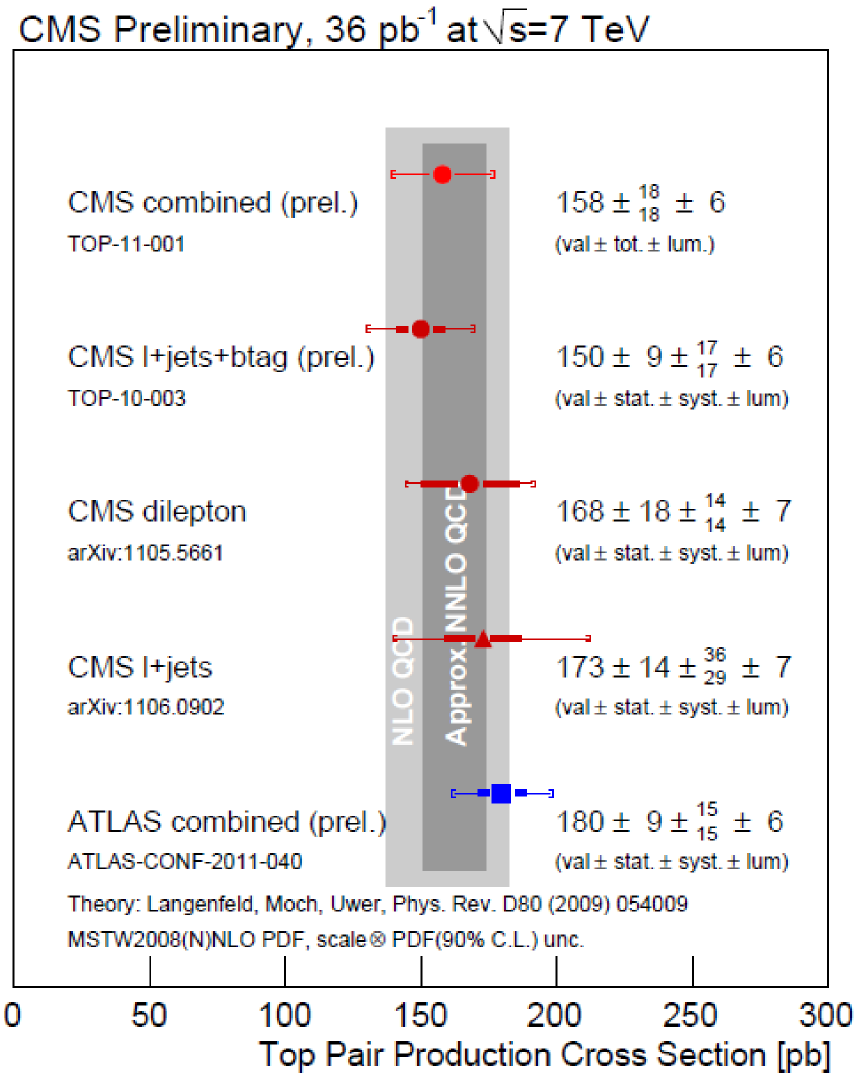
Jet multiplicity for events with >=1 soft muon tag

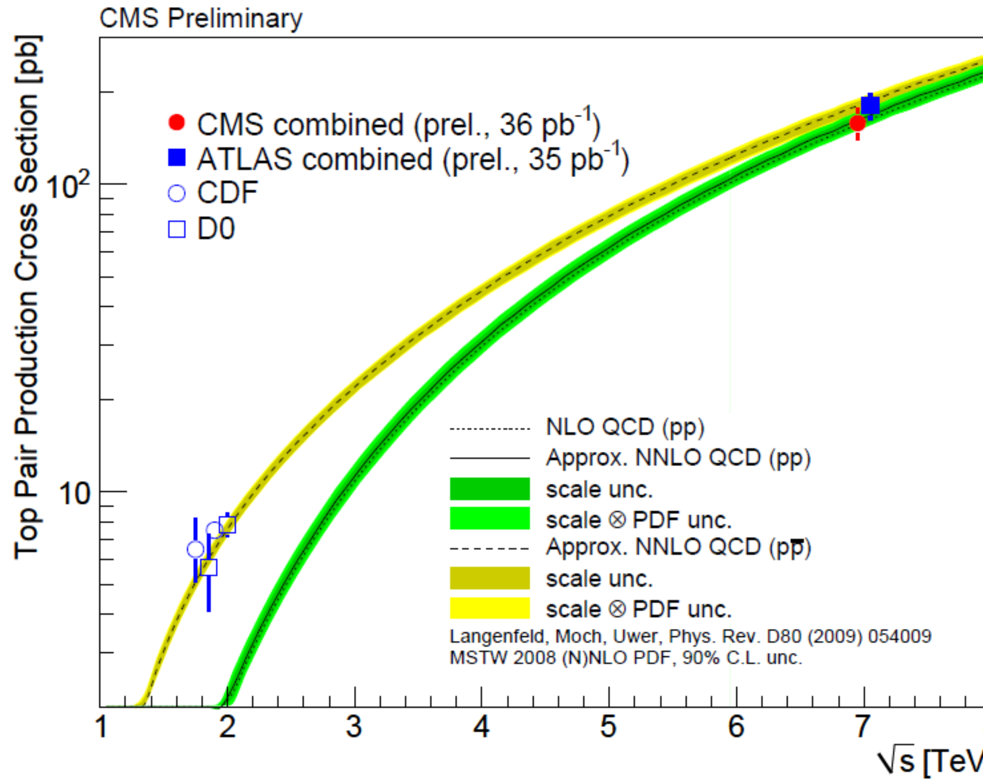


NN discriminant



Cross section combination



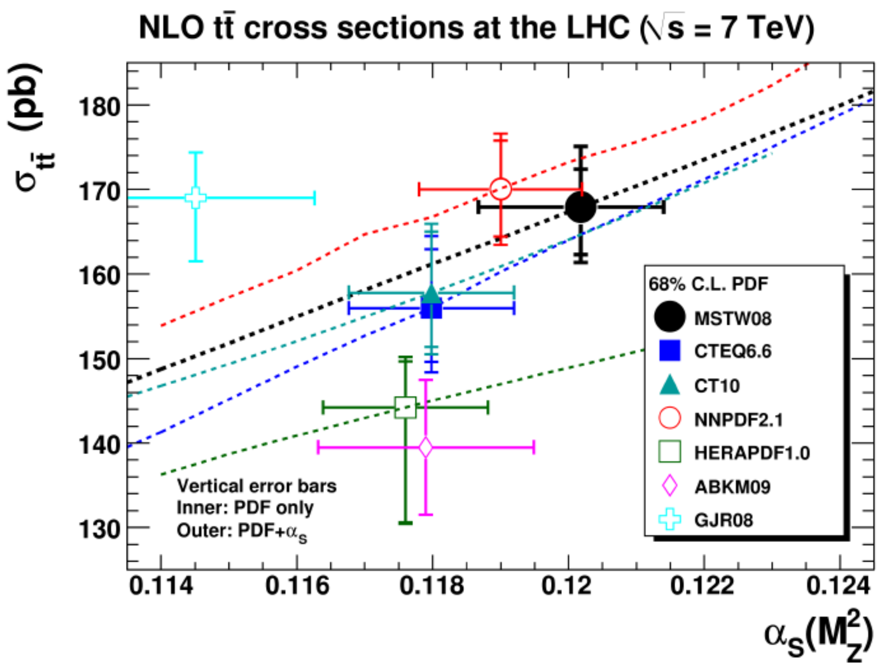


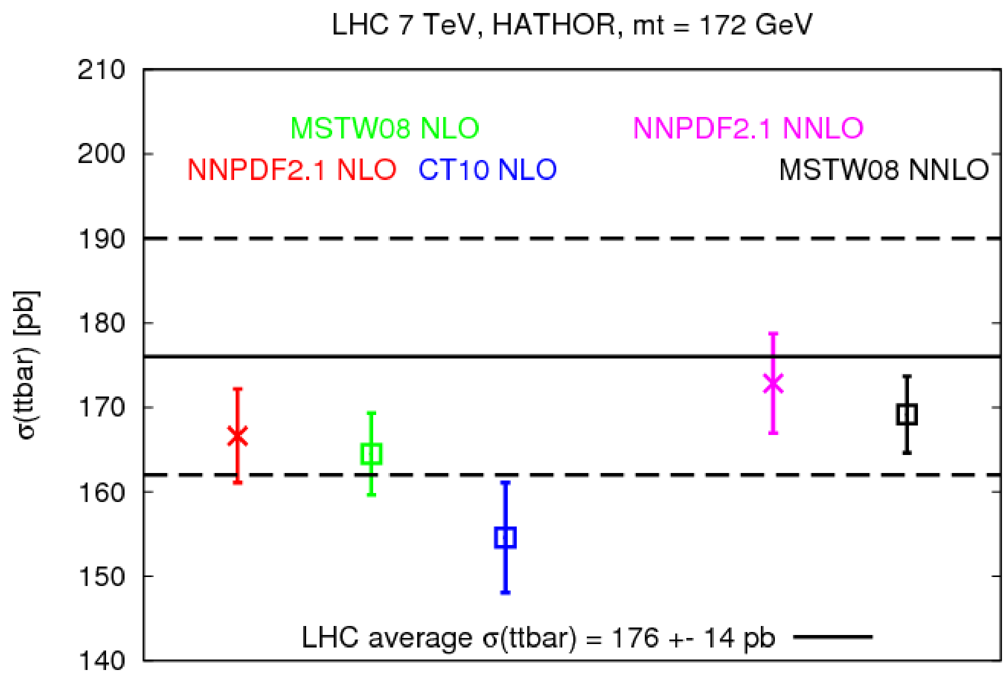
Precision of CMS combination 12%

Very good agreement with theory
Already more precise than NLO!

PDF sensitivity

NLO (Graeme Watt)





NNLO (Juan Rojo)

- Starting to become sensitive to PDF differences
- Similarly interesting for ttbar/Z ratio
  - PDF uncertainties anti-correlated

Outline

- Top pair cross section
- Top pass measurement
- Top pair invariant mass distribution
- Single top cross section
- Charge asymmetry
- Search for same-sign top pairs

Top mass in Dileptons (arXiv:1105.5661)

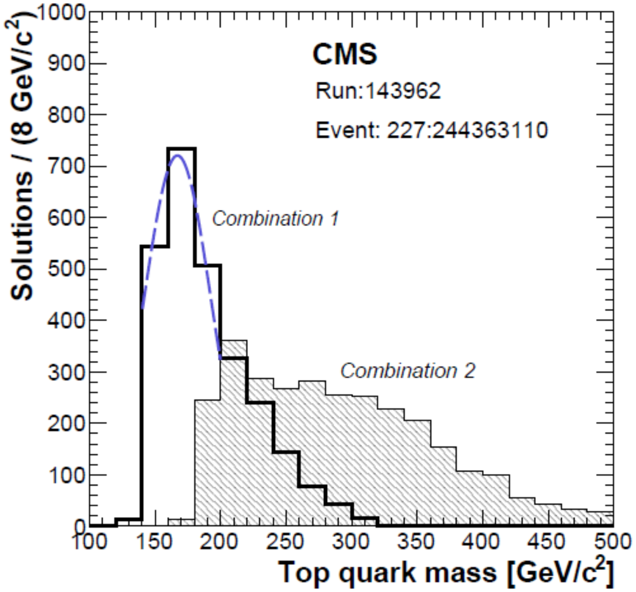
- Event selection similar to cross section measurement
  - o No b-tagging requirement, but b-likeness used in jet assignment
- 2 methods to deal with underconstrained system

o Analytical Matrix Weighting Technique (AMWT)

- Assign weight for each solution based on PDF, kinematics
- For each event, take m(top) with highest sum of weights
- Based on MWT method from D0: PRL 80 (1998) 2063

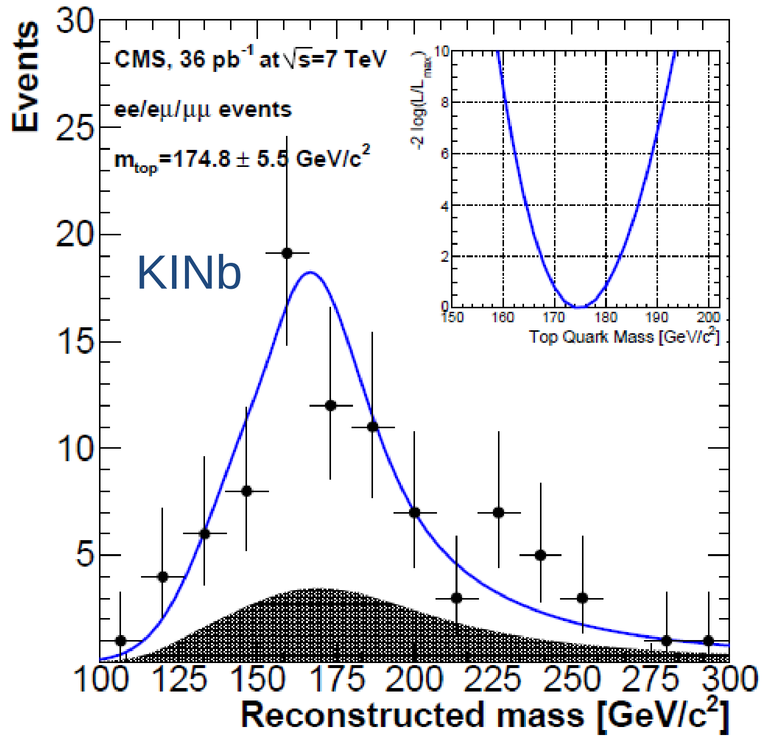
o KINb Method

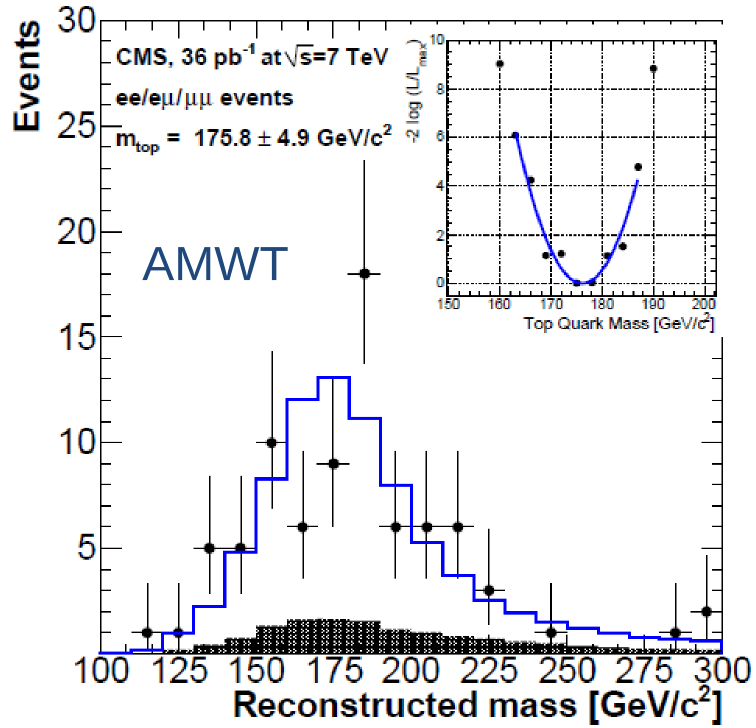
- Pz(tt) drawn from MC distribution
- Accept solution with lowest m(ttbar)
- Chose combination with largest number of solutions
- m(top) from Gaussian fit around peak of solutions
- Based on KIN method from CDF: PRD 73 (2006) 112006



Top mass in Dileptons (arXiv:1105.5661)

- Mass extraction
  - maximum likelihood fit of mass distributions to templates for signal and background
  - Methods linear in m(top) and unbiased after calibration





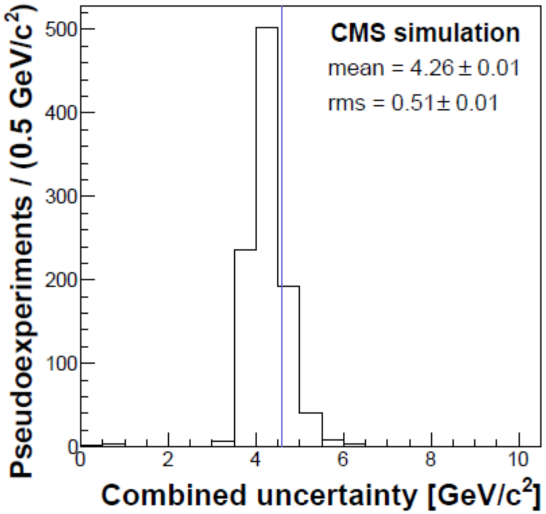
Top mass in Dileptons (arXiv:1105.5661)

- Systematic uncertainties
  - Dominated by jet energy scale, pile-up and UE

Source	KINb	AMWT
Overall jet energy scale	+3.1/−3.7	3.0
b-jet energy scale	+2.2/−2.5	2.5
Lepton energy scale	0.3	0.3
Underlying event	1.2	1.5
Pileup	0.9	1.1
Jet-parton matching	0.7	0.7
Factorisation scale	0.7	0.6
Fit calibration	0.5	0.1
MC generator	0.9	0.2
Parton density functions	0.4	0.6
b-tagging	0.3	0.5

- Two results are combined
  - Correlations taken into account

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

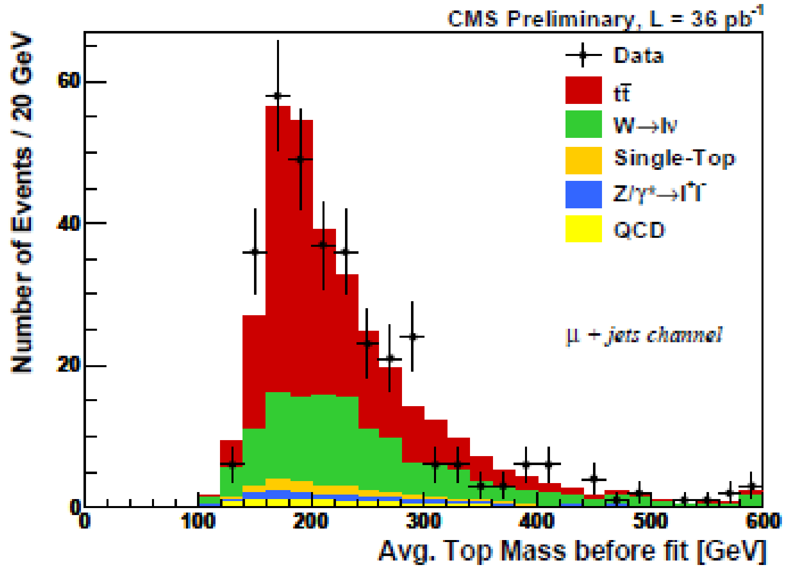


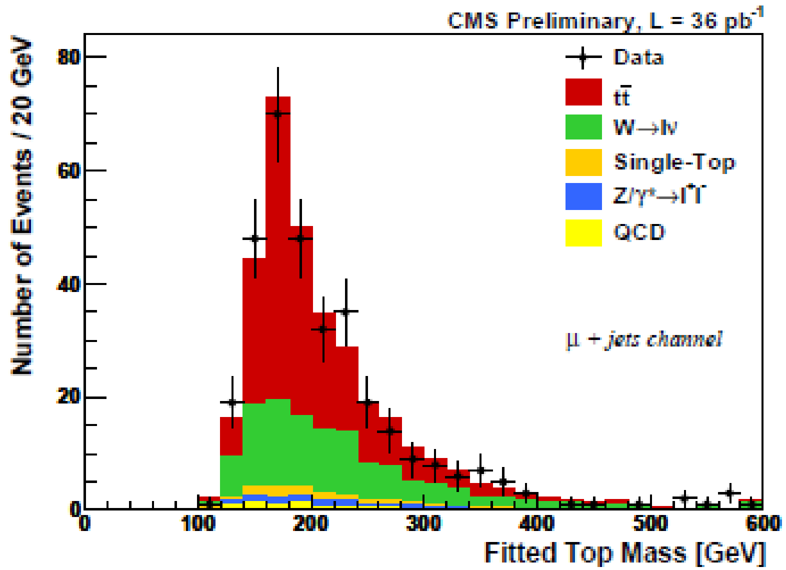
First m(top) measurement at LHC
Good agreement with world average 173.3+/-1.1GeV
Precision not much worse than TEV dilepton

Top mass in lepton+jets (PAS TOP-10-009)

NEW!

- Using the “Ideogram method” (DELPHI,D0,CDF)
- Event selection as for cross section analysis
  - o signal fraction ~55% for >=4 jets
- Kinematic fit
  - o Constrained fit requiring m(t)=m(tbar) applied to up to 24 jet combinations per event



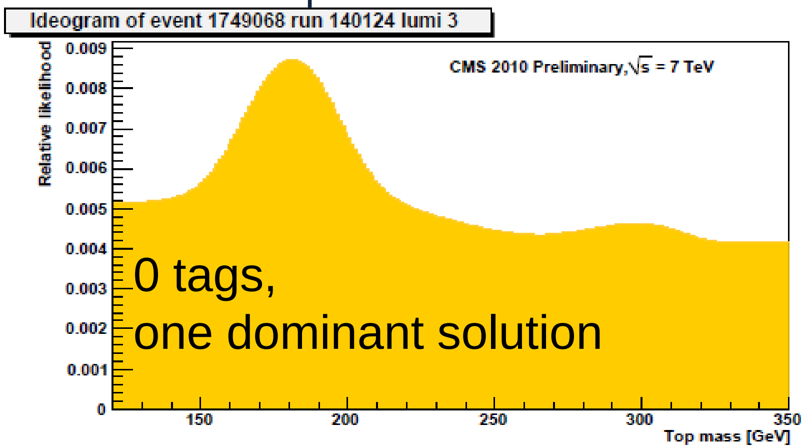


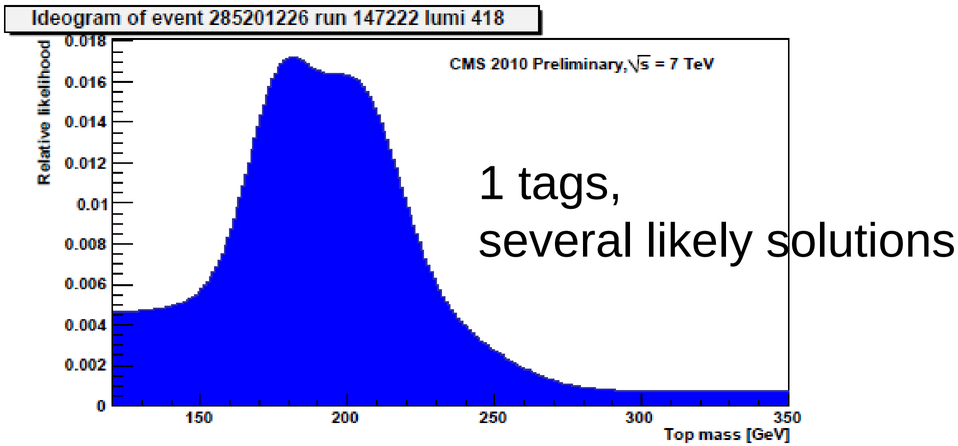
Top mass in lepton+jets (PAS TOP-10-009)

- Event likelihood (== Ideogram)

$$\mathcal{L}_{event}\left(x|m_t, f_{t\bar{t}}\right) = f_{t\bar{t}} P_{t\bar{t}}\left(x|m_t\right) + \left(1 - f_{t\bar{t}}\right) P_{bkg}\left(x\right)$$

  - o x: observables (fitted mass & uncertainty, chi^2, N-btags)
  - o Signal probability density $P_{t\bar{t}}\left(x|m_t\right) = P_{t\bar{t}}\left(n_{btag}\right) \cdot P_{t\bar{t}}\left(x_{mass}|m_t\right)$
    - Sum over permutations and indiv. Weights (correct perm.: analytical function; wrong perm: shape from MC)
    - Consistency of b-tags folded in
  - o Background probability density $P_{bkg}\left(x\right)$
    - Shape from MC simulation

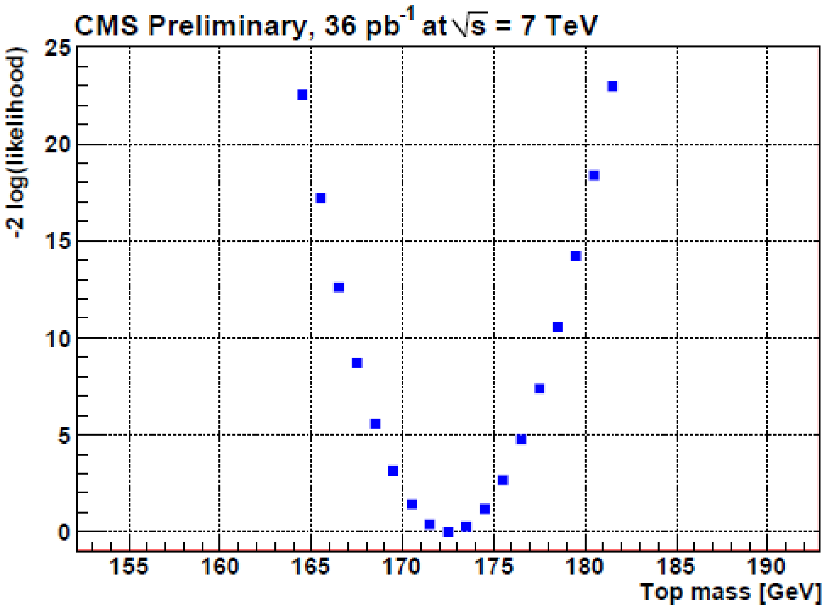




Top mass in lepton+jets (PAS TOP-10-009)

- Construct sample likelihood and minimize

$$\mathcal{L}_{\text{sample}}(m_t, f_{t\bar{t}}) = \Pi_j \mathcal{L}_{\text{event},j}(m_t, f_{t\bar{t}})$$

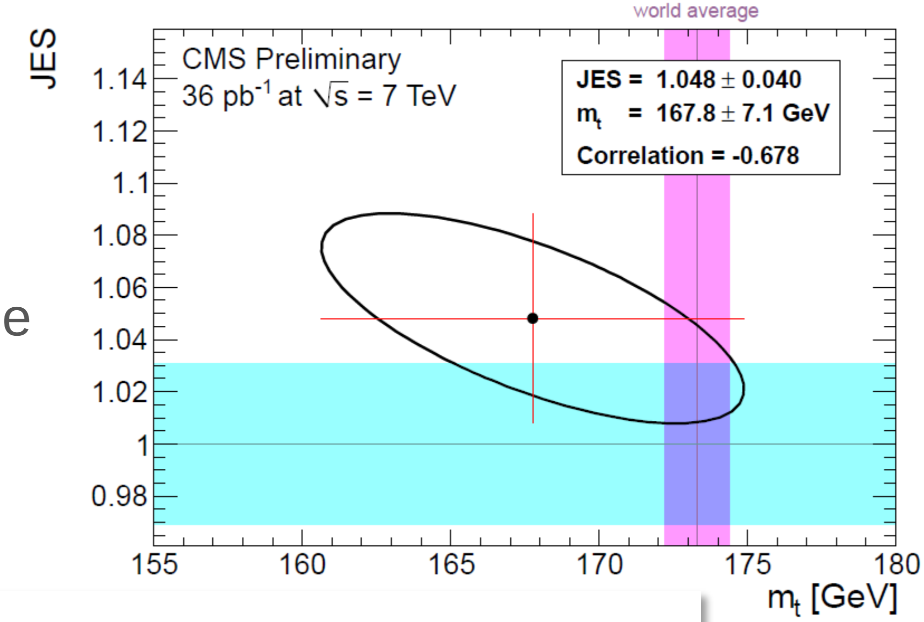


- Systematics
  - o Dominated by jet energy scale

Source	Ideogram analysis δm_t (GeV)
JES (overall data/MC)	+2.4-2.1
JES p_T and η dependence	-
light vs b-jet scale	-
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

Top mass in lepton+jets (PAS TOP-10-009)

- Cross check: simultaneous measurement of m(top) and JES
  - o Template method in 2-tag sample
  - o using M3 and M2 (mass of untagged jets)



- Central result:

$$m_t = 173.1 \pm 2.1(\text{stat})^{+2.4}_{-2.1}(\text{JES}) \pm 1.4(\text{other syst}) \ \text{GeV}$$

  - o Factor two more precise than ATLAS!

ATLAS result in l+jets:
169.3 +/- 4.0 +/- 4.9 GeV
World average:
173.3 +/- 1.1 GeV

- Combined measurement with dileptons

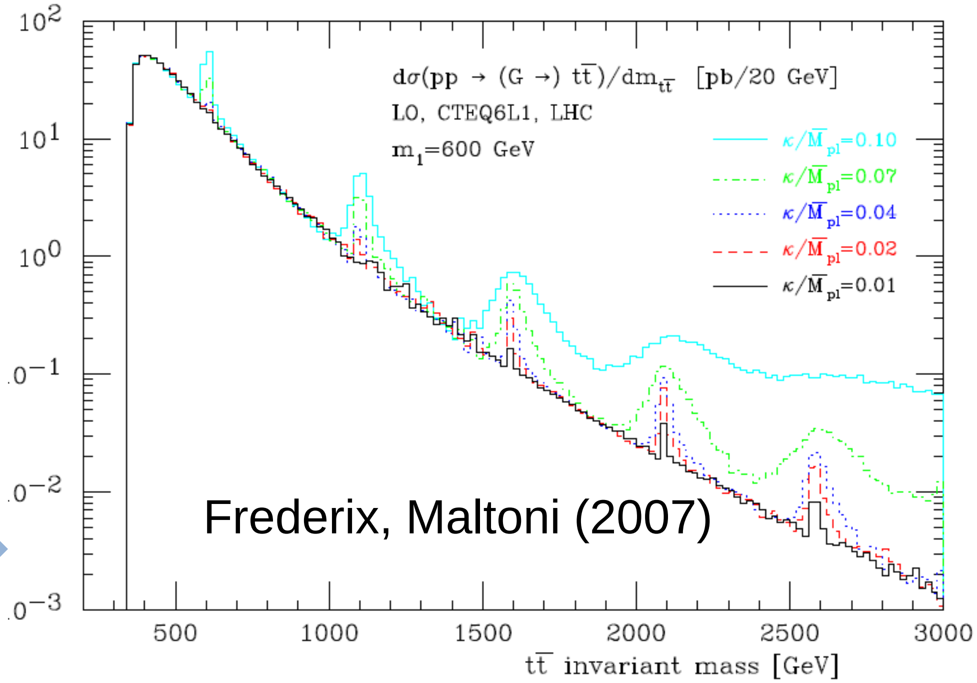
$$m_t = 173.4 \pm 1.9(\text{stat}) \pm 2.7(\text{syst}) \ \text{GeV}$$

Outline

- Top pair cross section
- Top pass measurement
- Top pair invariant mass distribution
- Single top cross section
- Charge asymmetry
- Search for same-sign top pairs

Top pair invariant mass (TOP-10-007)

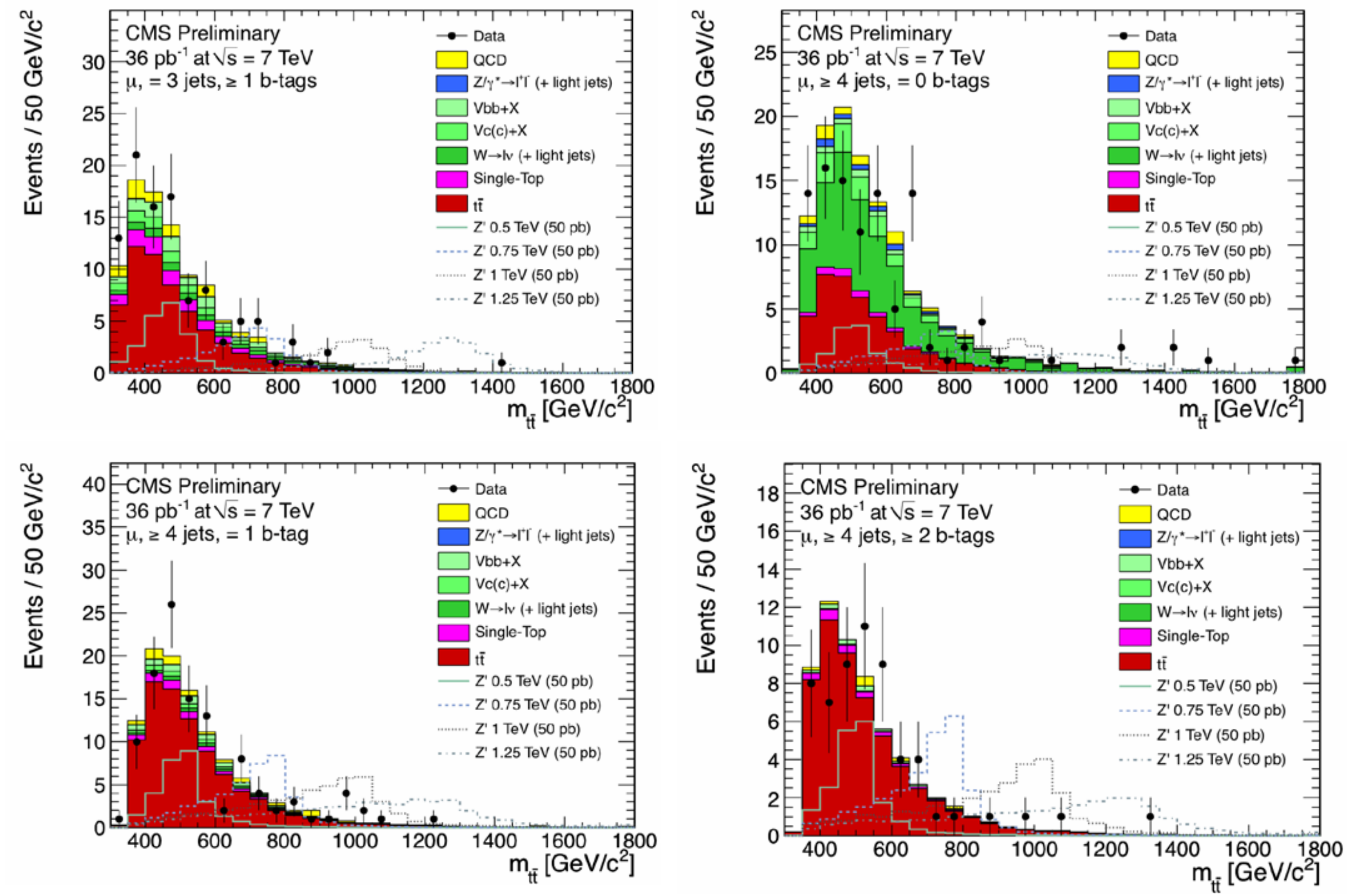
- Search for new particles decaying into top pairs
  - o Spin 0 (e.g. MSSM Higgs)
  - o Spin 1 (e.g. Technicolor, Topcolor Z' bosons)
  - o Spin 2 (KK graviton excitations)



- Distortions in m(ttbar) shape also predicted in other models

- Reconstruction:
  - o Standard reconstruction at low mass
  - o At high mass jets, leptons close by (due to top quark boost) ➔ "top tagging"

Top pair invariant mass (TOP-10-007)

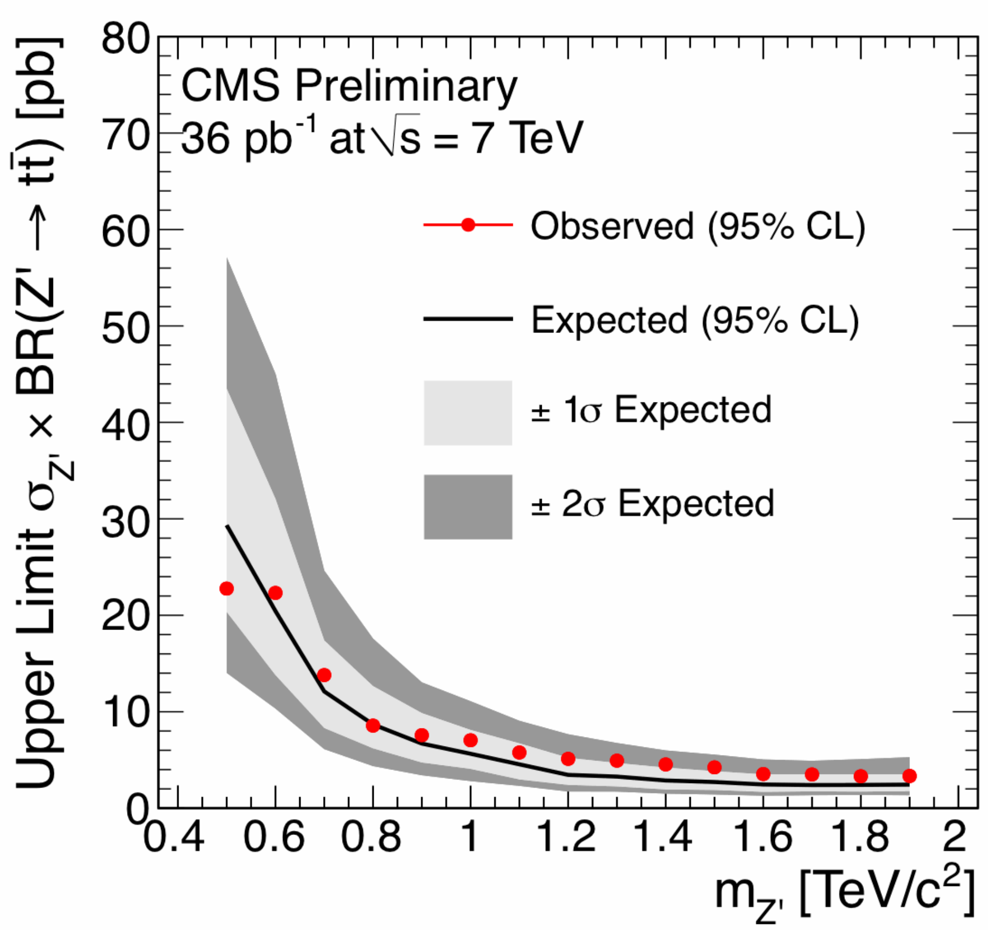


Here:
mu+jets only

- Categorize events in N(jets), N(tags), e/mu
- Fit templates of SM backgrounds and narrow Z' signal
  - o Systematics included as nuisance parameters modifying template shapes & normalizations

Top pair invariant mass (TOP-10-007)

- Derive 95% CL upper limit
- Limit presented in (cross section x BR) of a narrow Z'
  - Not tied to a specific Z' model
- Exclusion possible for models predicting ~10pb for M(Z')~1 TeV



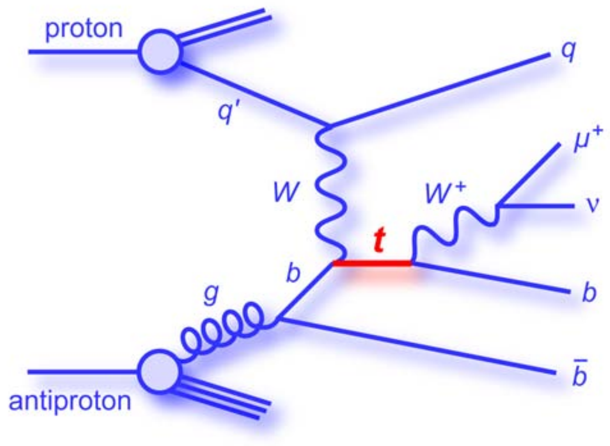
Even more interesting with 2011 data
Working on dedicated high-mass analyses ("top tagging") …

Outline

- Top pair cross section
- Top pass measurement
- Top pair invariant mass distribution
- Single top cross section
- Charge asymmetry
- Search for same-sign top pairs

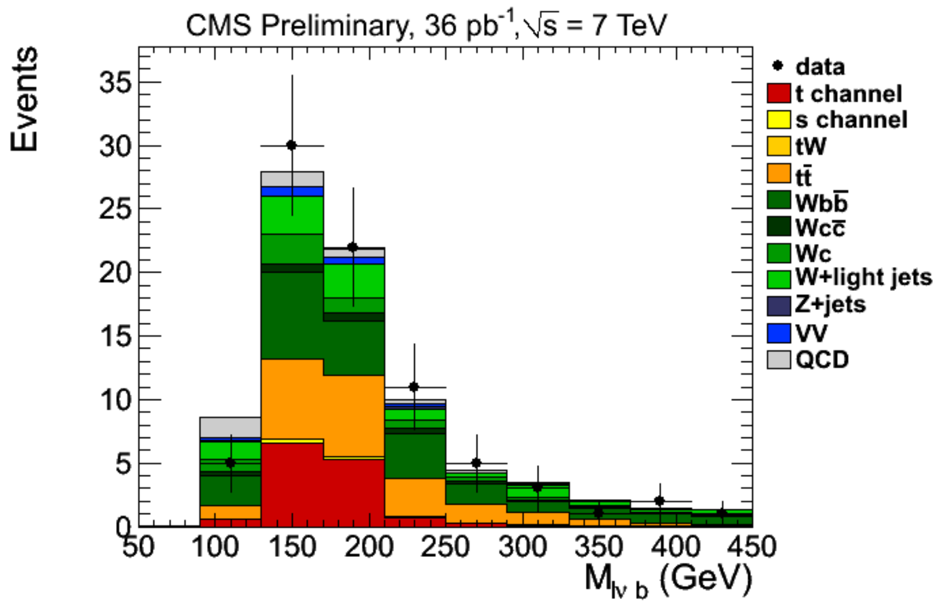
t-channel single top cross section (TOP-10-008)

- Selection of single top events
  - o 1 isolated electron (Pt>30 GeV) or muon (Pt>20 GeV)
  - o 2 jets, Et>30 GeV, |eta|<5.0
    - One "tight" b-tag
    - One "loose" b-veto (2D ana)
  - o transv. W mass > 40(50) GeV



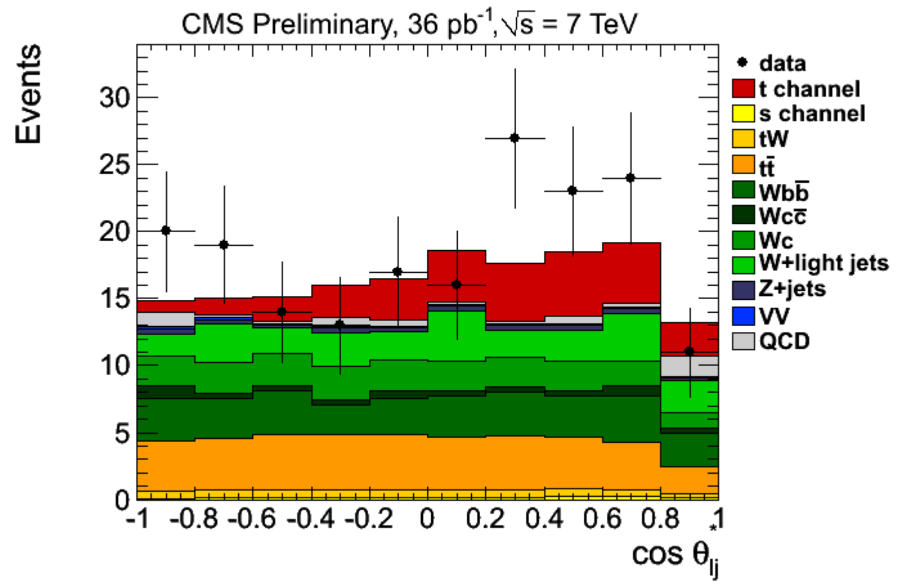
- Reconstruct m(top) using W mass constraint

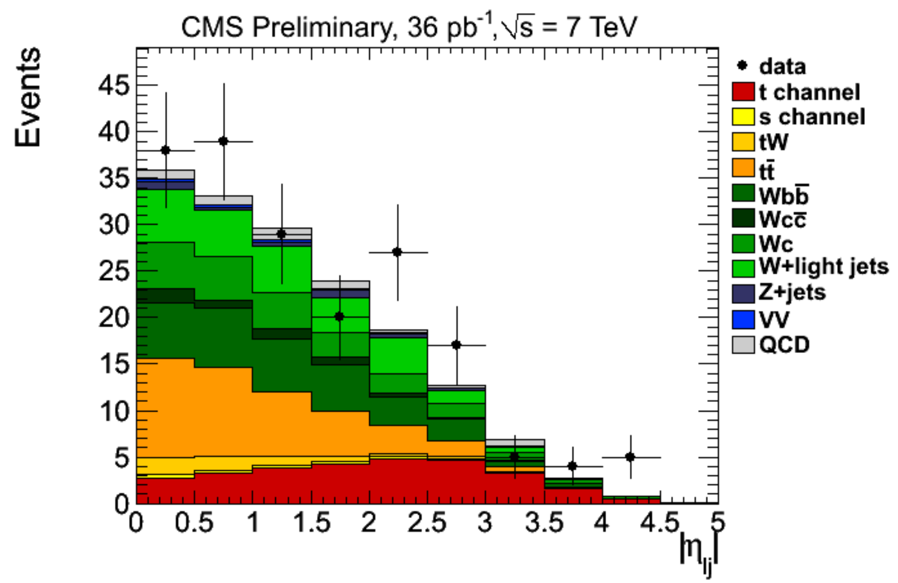
- Small S/B: 2 complementary methods:
  - o 2D analysis
  - o Boosted Decision Tree analysis



Single top cross section (TOP-10-008)

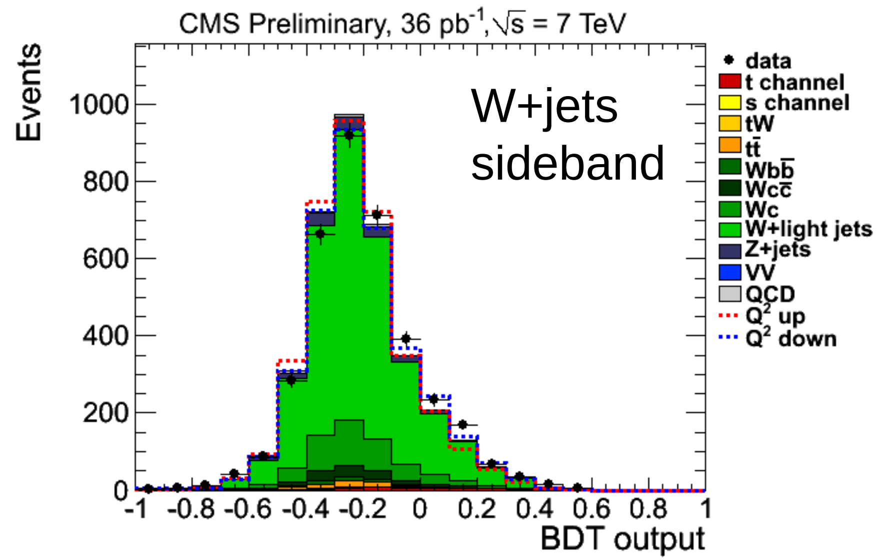
- 2D analysis
  - o Simultaneous fit to 2 discriminating variables
  - o Angle between l and light jet:
    - exploiting almost 100% left handed polarization of top quark
  - o Rapidity of light jet:
    - Recoil jet
  - o W+light shape from data
  - o Robust against BG composition
- Minimum model dependence

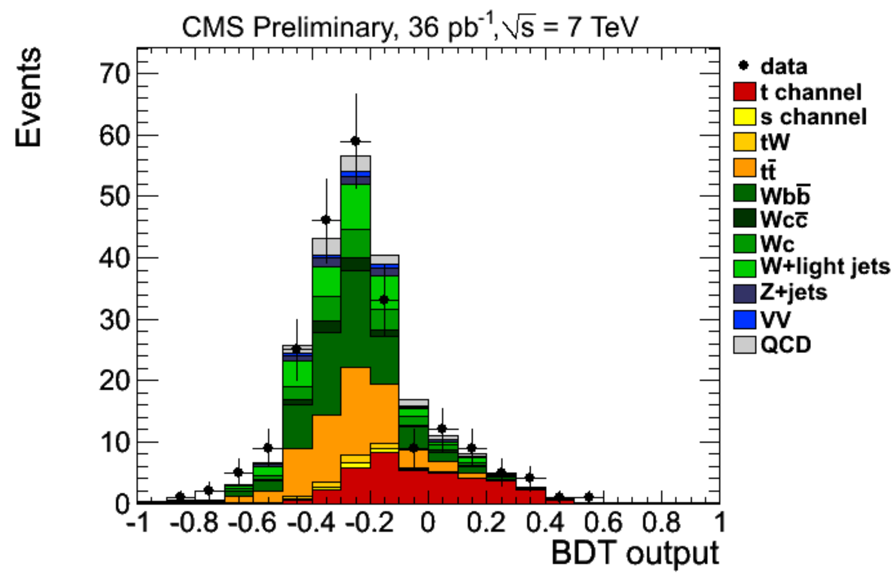




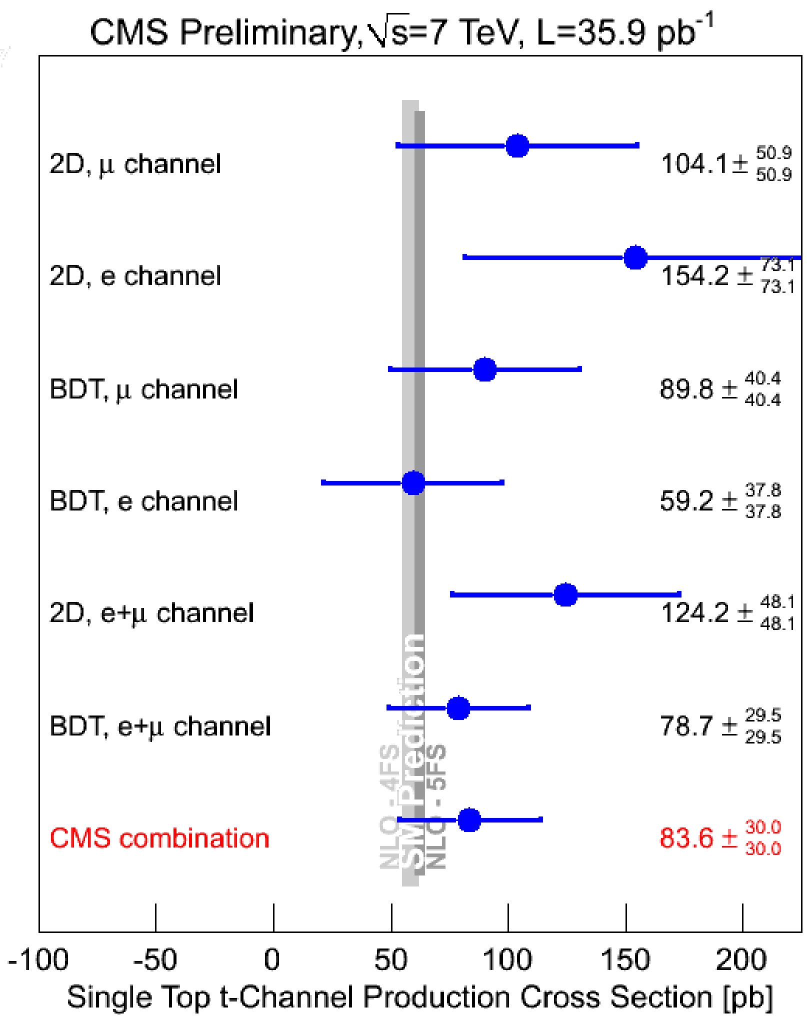
Single top cross section (TOP-10-008)

- Boosted Decision Tree (BDT) Analysis
  - o 37 well modeled input variables
    - Object kinematics & correlations, W & t properties, angular distributions, global event variables
  - o Cross section from fit to BDT output
    - Systematics included via nuisance parameters
- Maximum sensitivity





Single top cross section (TOP-10-008)



Observed (expected) sensitivity:
-2D ana: 3.7 (2.1) sigma
-BDT ana: 3.5 (2.9) sigma

- Measurement of CKM matrix element Vtb:

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

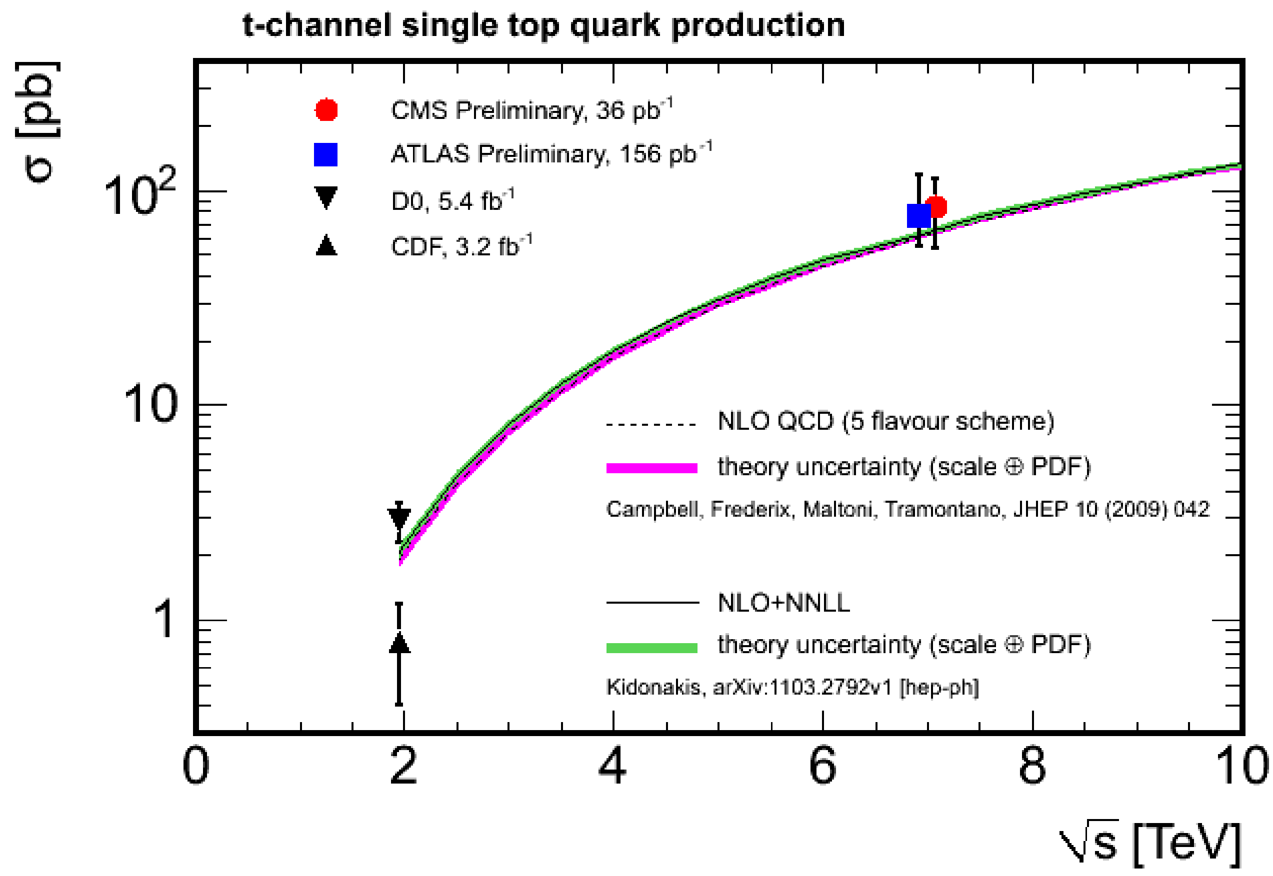
[CDF+D0: 0.88+/-0.07]

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

$|V_{tb}| > 0.69$ @95% CL (BDT analysis)

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

Single top cross section (TOP-10-008)



ATLAS:
76 +41/-21 pb

First single top cross section measurement in pp collisions
First measurement without use of MVA
33% precision with just 2010 data

Outline

- Top pair cross section
- Top pass measurement
- Top pair invariant mass distribution
- Single top cross section
- Charge asymmetry
- Search for same-sign top pairs

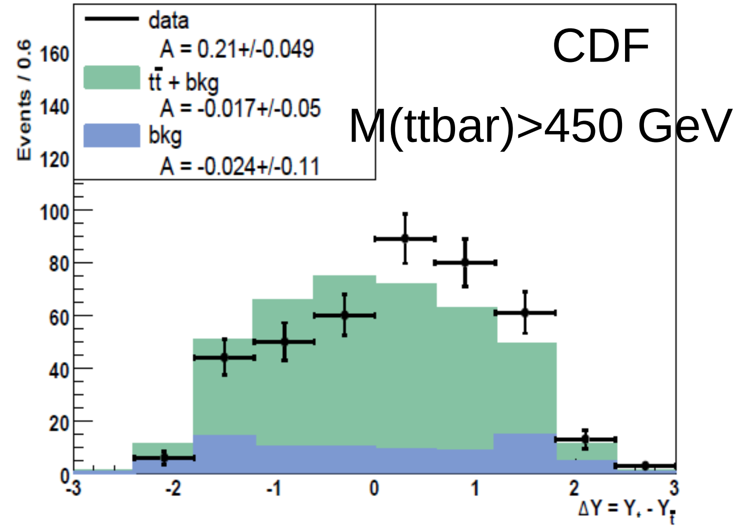
Forward-backward asymmetry

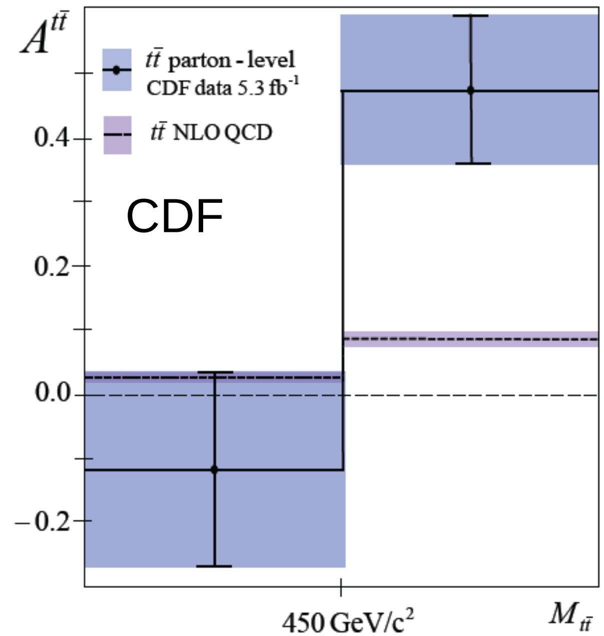
- ttbar forward-backward asymmetry in ppbar collisions

$$\Delta y = y_t - y_{\bar{t}}$$

$$A^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

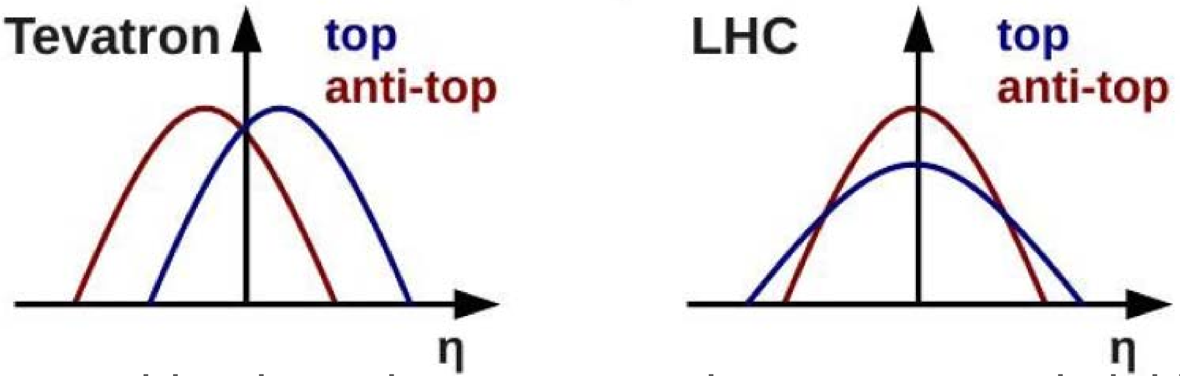
  - o LO: no asymmetry in SM
  - o NLO, small asymmetry
    - interference of diagrams that differ under charge conjugation
- Measured asymmetry larger than predicted
  - o esp. at high M(ttbar) mass
  - o e.g. CDF, arXiv:1101.0034: 3 sigma effect for M>450 GeV!





Forward-backward asymmetry

- New particles produced via pp->X->ttbar could increase the measured asymmetry
  - o Axigluons, new weak bosons, extra dimensions
- Models must accommodate measured cross section and M(ttbar) spectrum
- From Tevatron to LHC



  - o No forward-backward asymmetry due to symmetric initial state
  - o But: quarks have on average more momentum than anti-quarks
  - o Boost difference, resulting in small central-decentral asymmetry
    - Diluted due to ~85% gg initial states

Charge Asymmetry (TOP-10-010)

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

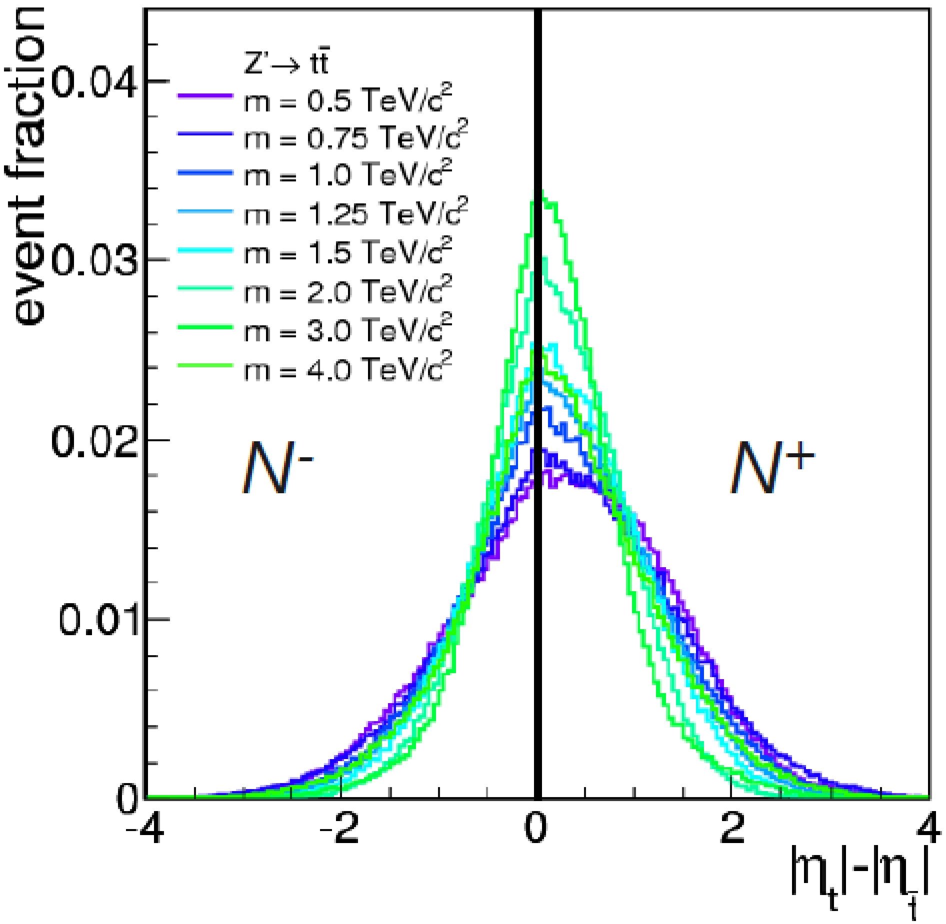
$$A_C = \frac{N^+ - N^-}{N^+ + N^-}$$

  - N+(-) is number of events where it is positive (negative)
- SM Prediction (G. Rodrigo)

  A_C=0.0130(11)
- Tevatron measurement

  A_C=0.04 to 0.05
- Z' with mass ~1TeV:

  A_C-A_C^{SM}~-0.02, -0.03

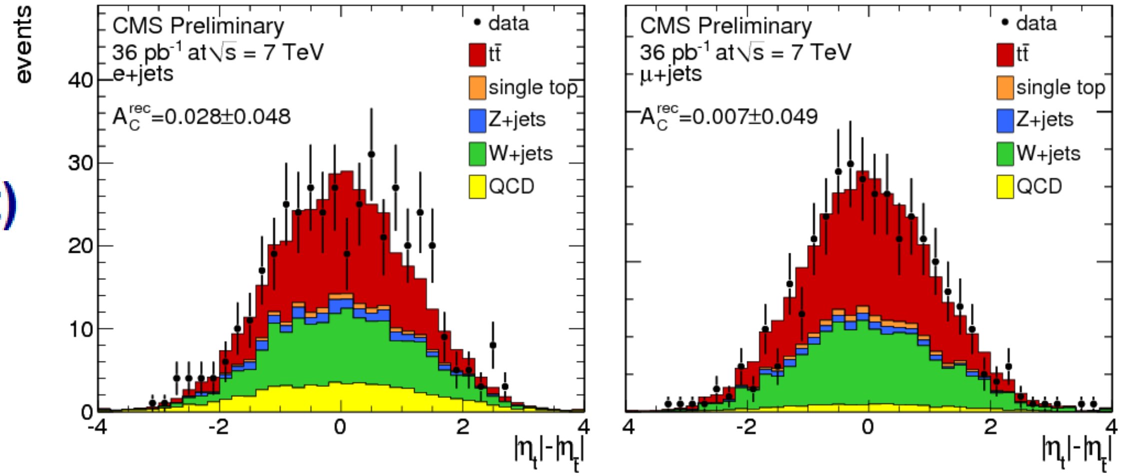


- Initial measurement of Ac performed in lepton+jets events

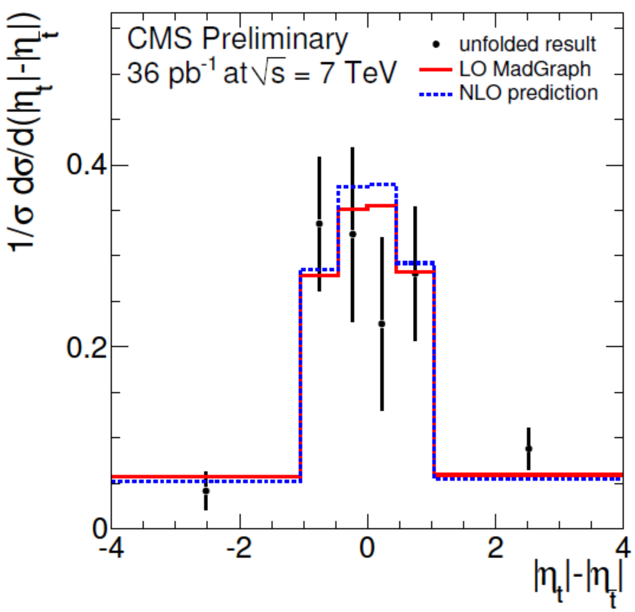
Charge Asymmetry (TOP-10-010)

- Raw asymmetry

A_C^{rec}=0.018±0.034(stat)



- Unfolded asymmetry



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	

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

Expect same sensitivity as Tevatron with ~1/fb
Will also do Ac vs M(ttbar)

Outline

- Top pair cross section
- Top pass measurement
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- Single top cross section
- Charge asymmetry
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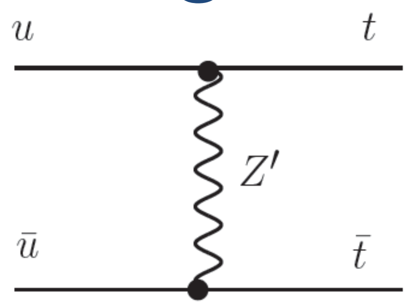
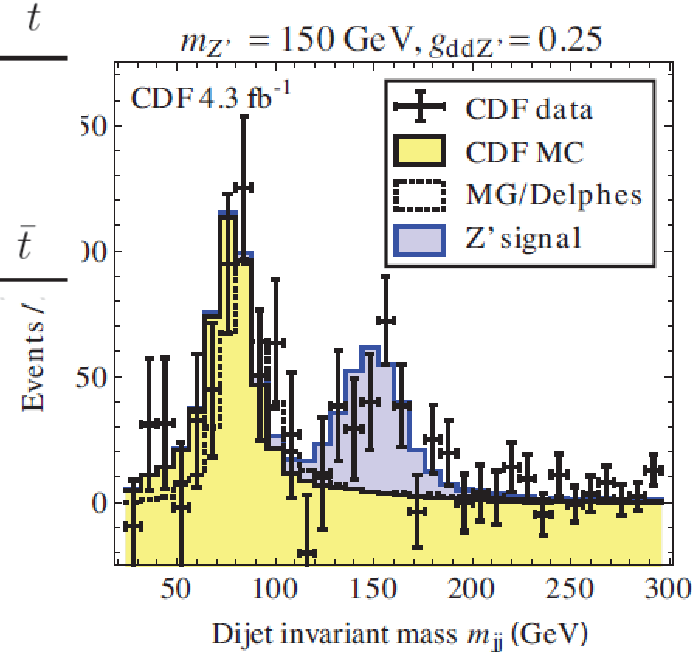
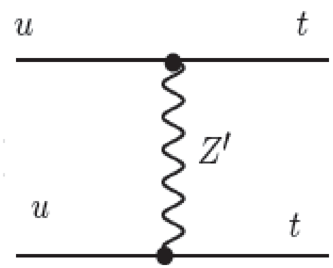
Afb and same-sign Top Pairs

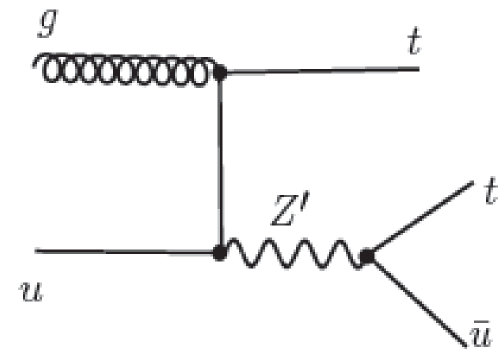
- FCNC in top sector could explain Afb at Tevatron
  - o t-channel exchange of Z’ coupling to u and t [S. Jung et al., …]





- Could also explain CDF Wjj bump (which D0 does not see…)
  - o [Buckley et al.; Jung et al.; Fox et al., Cheung et al., …]
- Should manifest as same-sign top pair production
  - o esp. viable at pp machine





- ➔Search for same sign tops in CMS data
  - o Consider model of Berger et al. (arXiv:1101.5625)

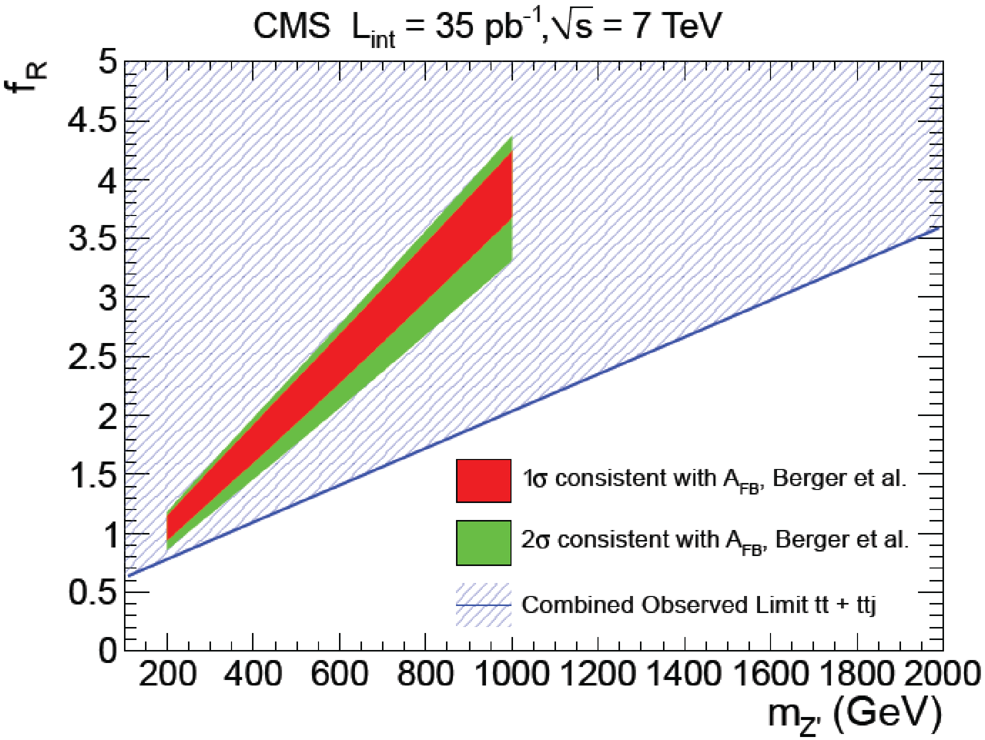
Same-sign Top search

- Event selection similar to std. dilepton top pair selection,but:
  - o 2 positively charged leptons (search for pp->tt)
- Result with 35/pb of 2010 data:
  - o 2 events (SM: 0.9+/-0.6)

NEW!

- Considered Model (Berger et al.):

$$\mathcal{L} = g_W \bar{u} \gamma^\mu (f_L P_L + f_R P_R) t Z'_\mu + h.c.$$



- Turn into limit on pp->tt(j) vs f_r and M(Z')
- Exclude parameter space favoured by Tevatron Afb, xsection measurements!

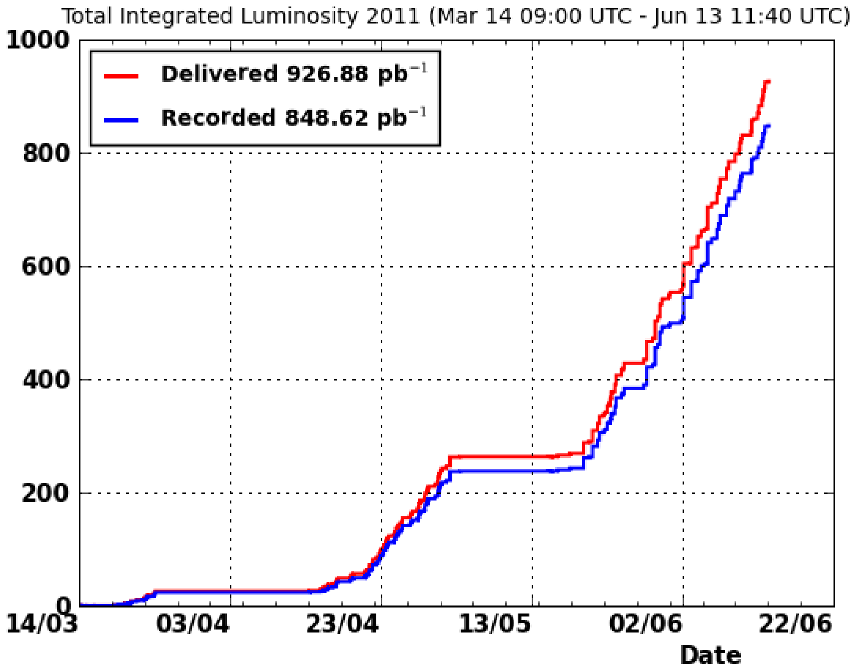
Summary

- First CMS Top physics results using 2010 data
- Already in the first year of data taking, we have:
  - Measured top pair production cross section to 12%
  - Measured t-channel Single Top cross section to 36%
  - Measured top mass to 3.3 GeV (2%)
  - Excluded a narrow Z' for M=1TeV, X.S.*BR=10pb
  - Made an intial measurement of the charge asymmetry
  - Excluded large parameter space for like-sign top pairs

- Impressive list which shows that
  - CMS detector is very well prepared for top physics, and for discoveries!

Outlook

- Several results already limited by systematics
- Challenges for 2011 analyses:
  - o reduce impact of Jet energy scale & b-tag.eff. (in situ!)
  - o Large number of pile-up events
  - o Triggering top events getting ever more challenging



- Many new results for summer conferences in the pipeline
  - o Hadronic & tau channels
  - o More differential measurements
  - o Top properties
  - o Focus on new physics in Top sector

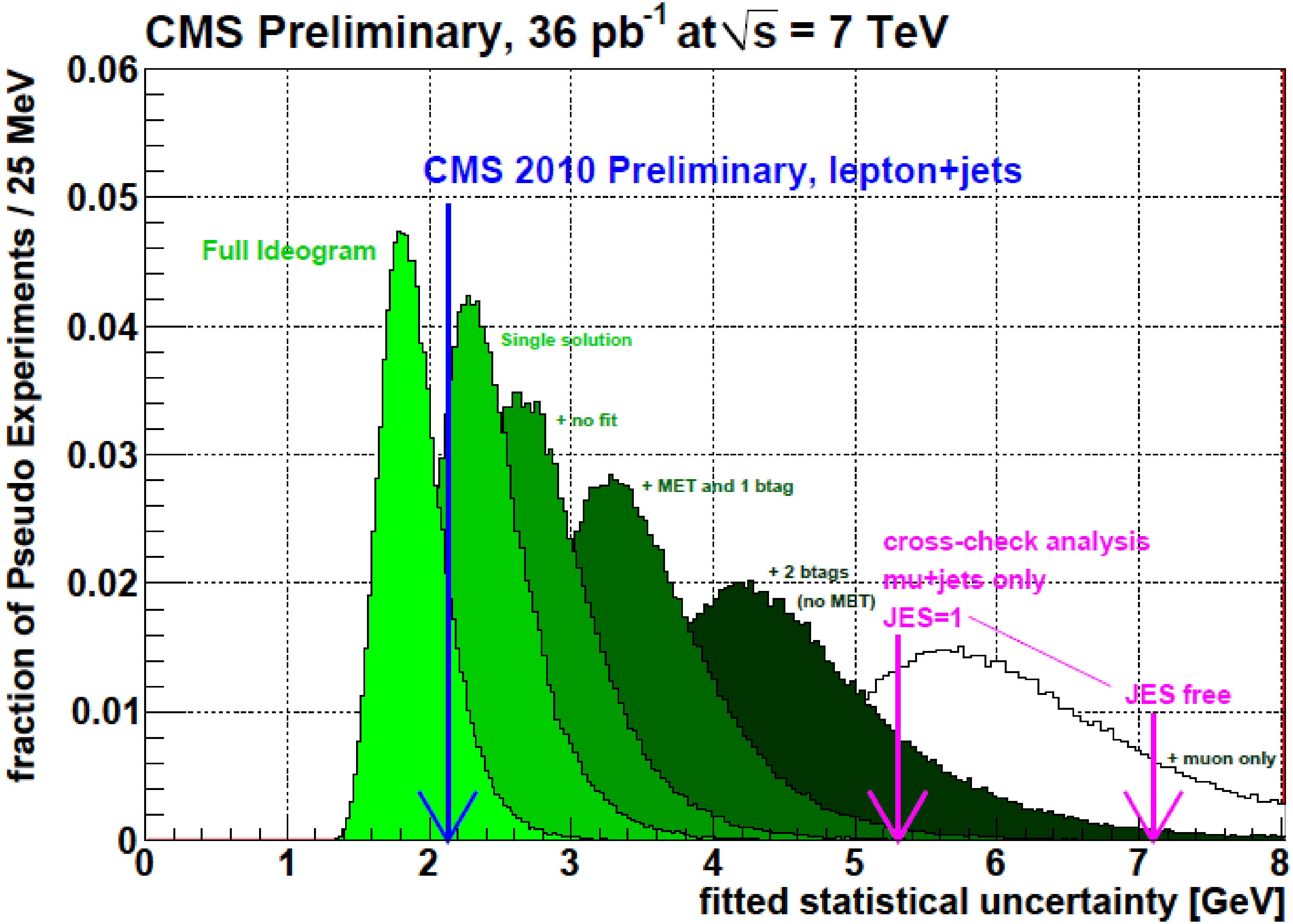

Top
Quark

BACKUP

Dilepton cross section systematics

Source	$N_{\text{jet}} = 1$ $e^+e^- + \mu^+\mu^-$	$N_{\text{jet}} = 1$ $e^\pm\mu^\mp$	$N_{\text{jet}} \geq 2$ $e^+e^- + \mu^+\mu^-$	$N_{\text{jet}} \geq 2$ $e^\pm\mu^\mp$
Lepton selection	1.9/1.3	1.1	1.9/1.3	1.1
Lepton selection model	4.0	4.0	4.0	4.0
Hadronic energy scale	−3.0	−5.5	3.8	2.8
Pileup	−2.0	−2.0	0.8	0.8
b tagging ($\geq$ 1 b tag)			5.0	5.0
Branching ratio	1.7	1.7	1.7	1.7
Decay model	2.0	2.0	2.0	2.0
Event Q^2 scale	8.2	10	−2.3	−1.7
Top quark mass	−2.9	−1.0	2.6	1.5
Jet and $\not{E}_T$ model	−3.0	−1.0	3.2	0.4
Shower model	1.0	3.3	−0.7	−0.7
Subtotal without b tagging	11.2/11.1	13.1	8.0/7.9	6.2
Subtotal with b tagging			9.5/9.4	8.0
Luminosity	4.0	4.0	4.0	4.0

Lepton+Jets top mass



Top mass combination

	Dileptons	Lepton+jets	Correlation factor	Combination
Measured m_t	175.5	173.1		173.4
Statistical Uncertainty	4.6	2.1	0	1.9
Breakdown of Systematic Uncertainty:				
Jet energy scale (correlated part)	2.25	2.25	1	2.3
Jet energy scale (uncorrelated part)	3.28	n/a	0	0.4
Jet energy resolution	0.5	0.1	1	0.1
Lepton energy scale	0.3	n/a	0	0.0
Missing p_T scale	0.1	0.4	1	0.4
Pile-up	1.0	0.1	1	0.2
b-tagging	0.4	0.1	1	0.1
Background	0.1	0.5	0	0.4
Parton density function	0.5	0.1	1	0.2
MC generator	0.4	n/a	0	0.0
Underlying event	1.4	0.2	1	0.3
ISR/FSR	0.2	0.2	1	0.2
Jet-parton scale	0.7	0.4	1	0.4
Factorization scale	0.6	1.1	1	1.0
Fit calibration and MC statistics	0.3	0.1	0	0.1
Total Systematic Uncertainty	4.6	2.7		2.7
Combination weight	12%	88%		

Single Top Systematics

uncertainty	correlation	impact on 2D −	impact on 2D +	impact on BDT −	impact on 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	—	—