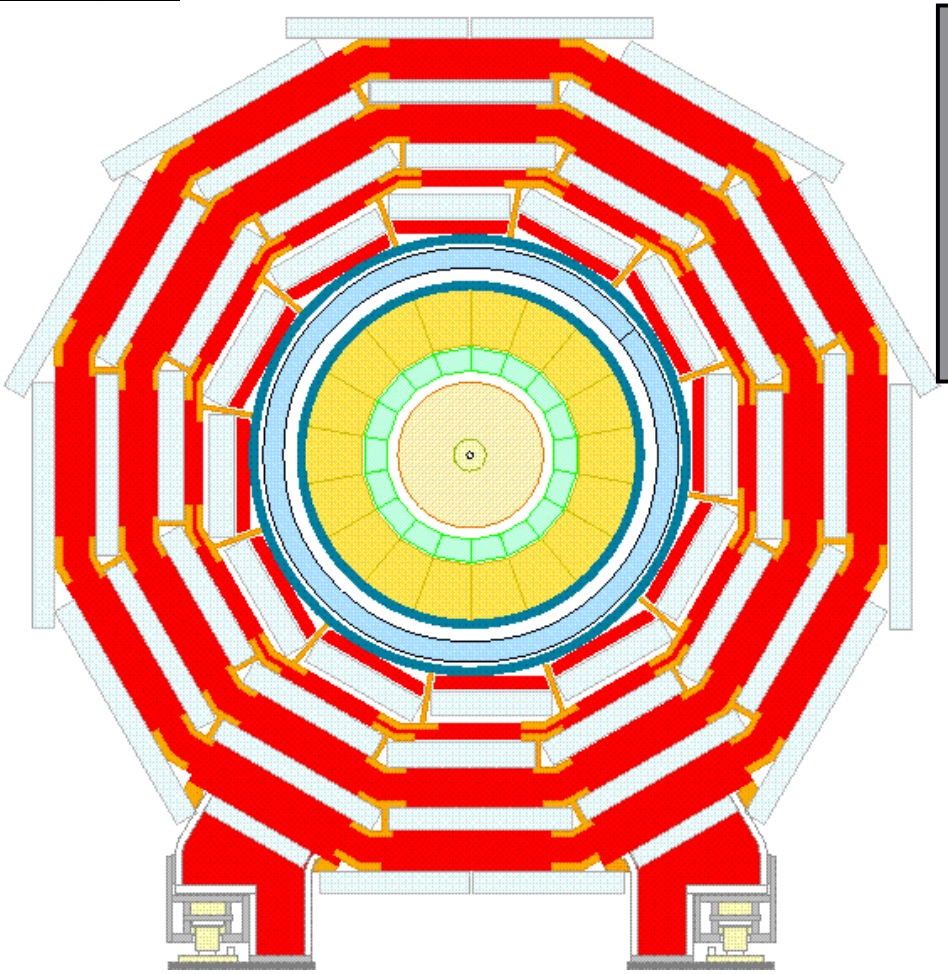
Top quark results using CMS data at 7 TeV

Karl M. Ecklund
Rice University
on behalf of the
CMS Collaboration

Compact Muon Solenoid



Transverse Slice

15 m

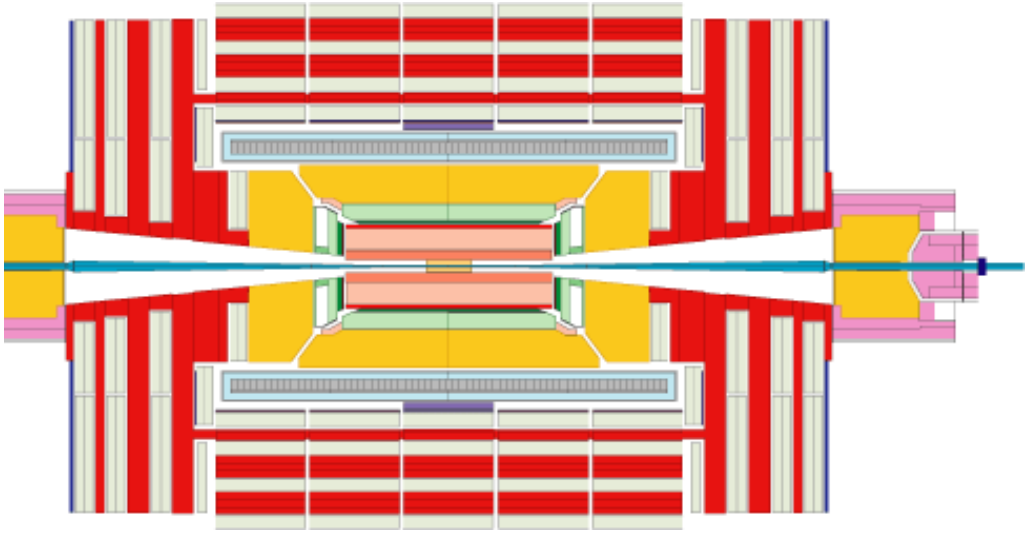
General Purpose Detector
- Precision Silicon Tracking
- EM Calorimeter
- Hadron Calorimeter
- 3.8 T Magnetic Field
- Muon Detectors

JINST 3 08004 (2008)

For Top:
b-tag 2nd vertex
Electrons
Missing Energy
Muons

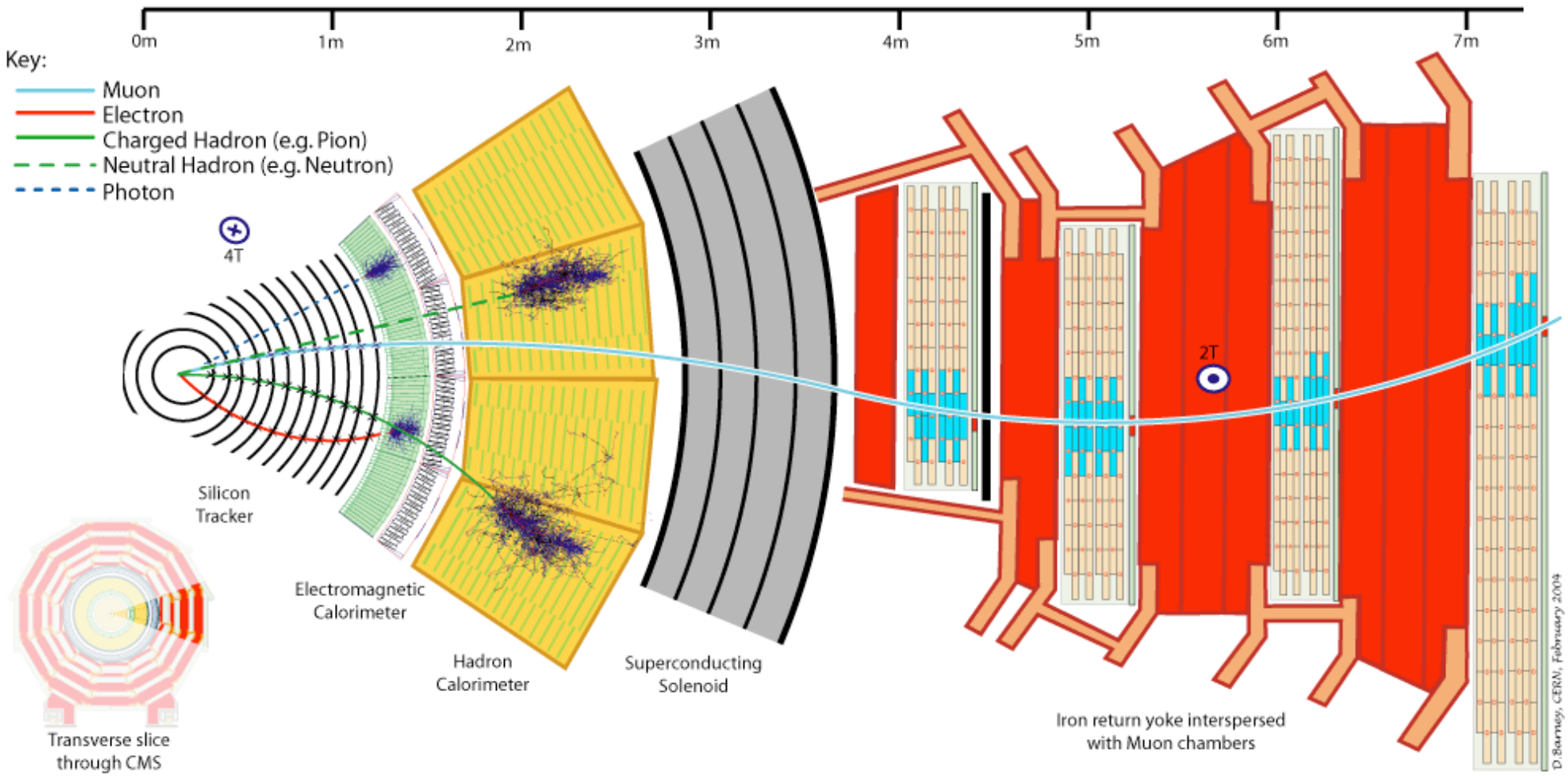
Integrated
Particle Flow
Reconstruction

Longitudinal Slice

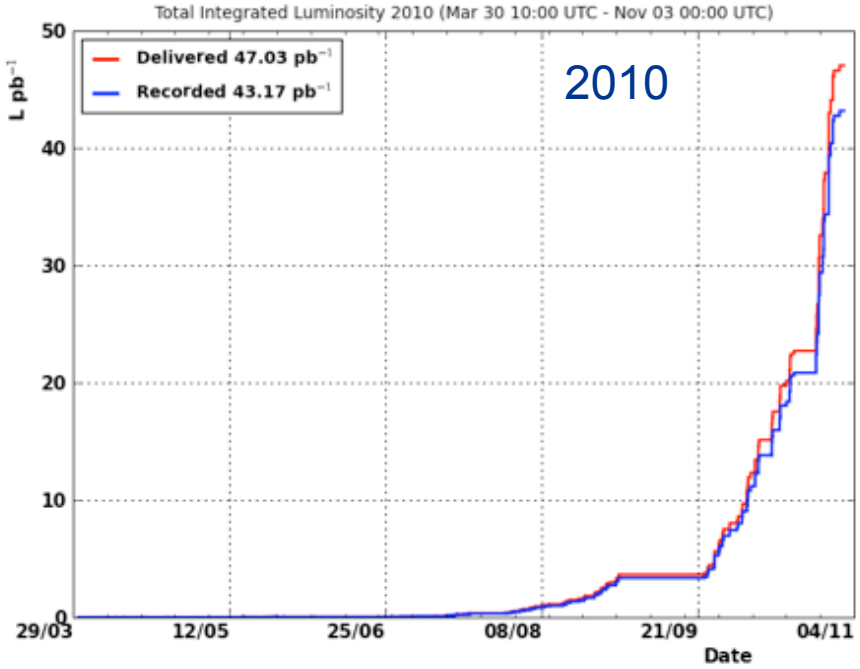


21 m

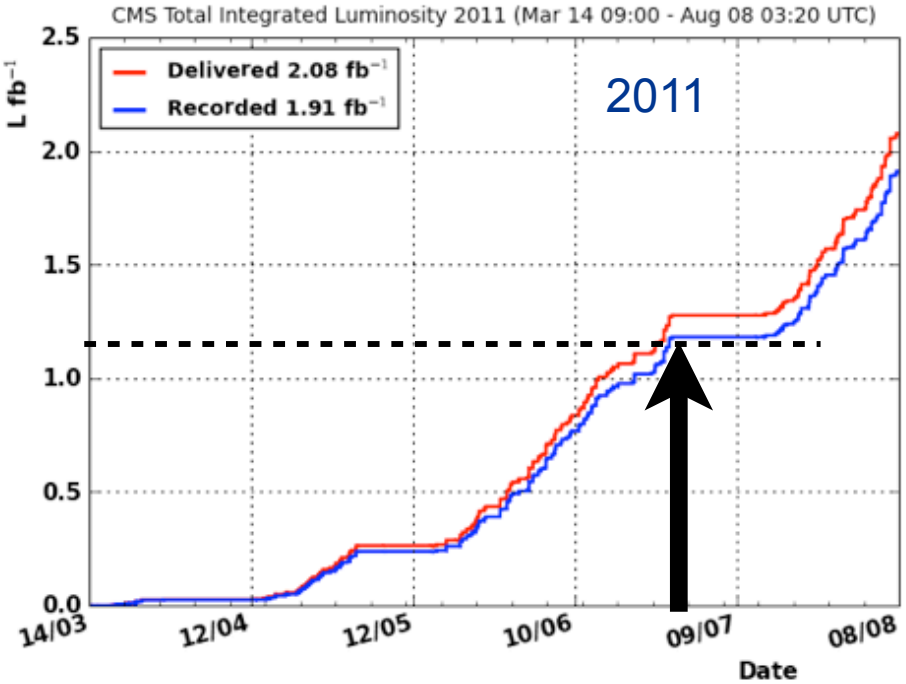
Transverse slice through CMS



CMS Data Samples



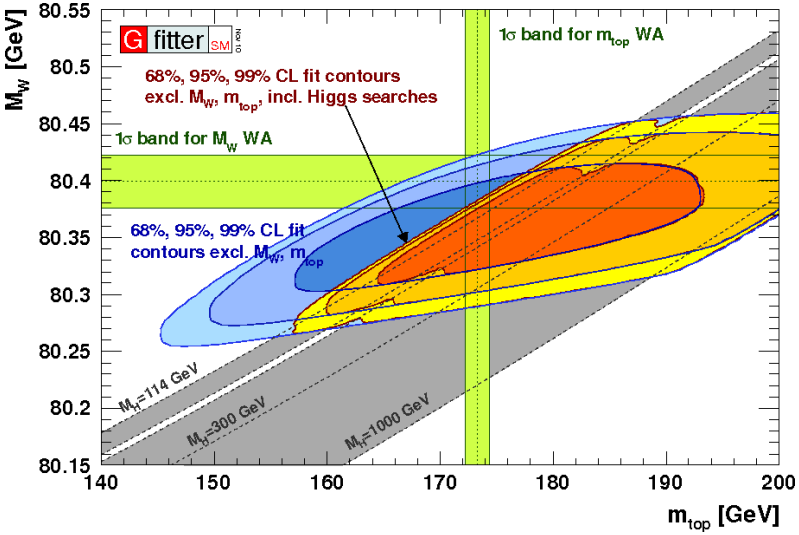
<u>2010 Dataset</u>
36 pb^{-1} for Top Analysis
(good: calorimeters, muon, tracking)



<u>2011 Dataset</u>
~1.0 fb^{-1} for Top Analysis available for EPS/DPF
Doubled again since restart of LHC Physics
Today Peak luminosity > 2 ×10^{33} cm^{-2} s^{-1}
Challenges for triggering on top samples

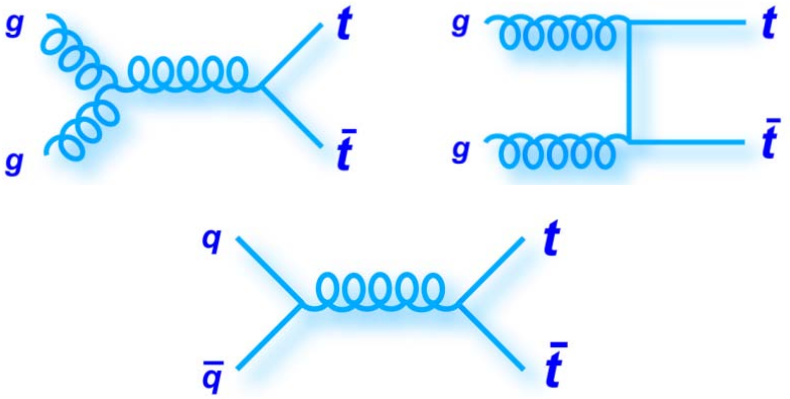
Motivation for Top Physics @ LHC

- Top is heavy
  - large Yukawa - perhaps a role in EWSB
  - loop corrections to Higgs mass (m_t^2)
- Precision measurements using top quarks
  - top production and decay
  - top properties can be probed for BSM physics
    - even if indirect, may be important confirmation of other discoveries!
  - LHC is a top factory - large samples available
    - 160 pb × 1000 pb^{-1} = 160 k t tbar pairs produced
    - kinematic reach beyond the Tevatron
- New Physics
  - preferential coupling to top?
  - new particles decaying to top (Z', 4th generation, ...)
  - new physics can modify top couplings

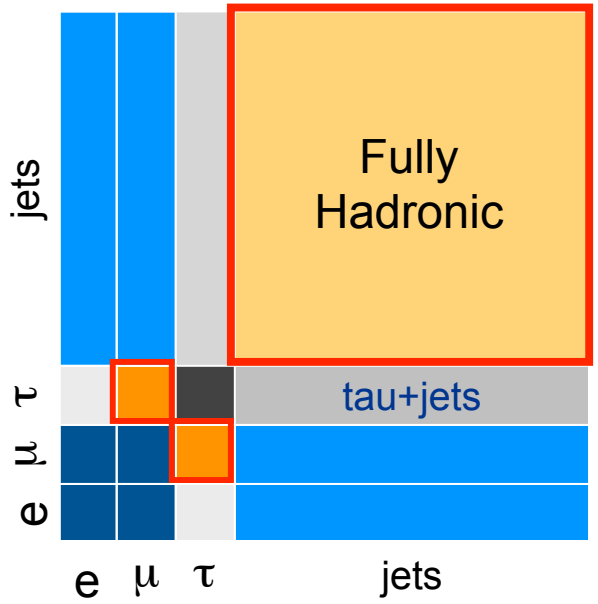


Top Pair Cross Section Measurements

- SM Production
  - gluon fusion ~85% LHC
  - $q\bar{q}$ annihilation ~15% LHC



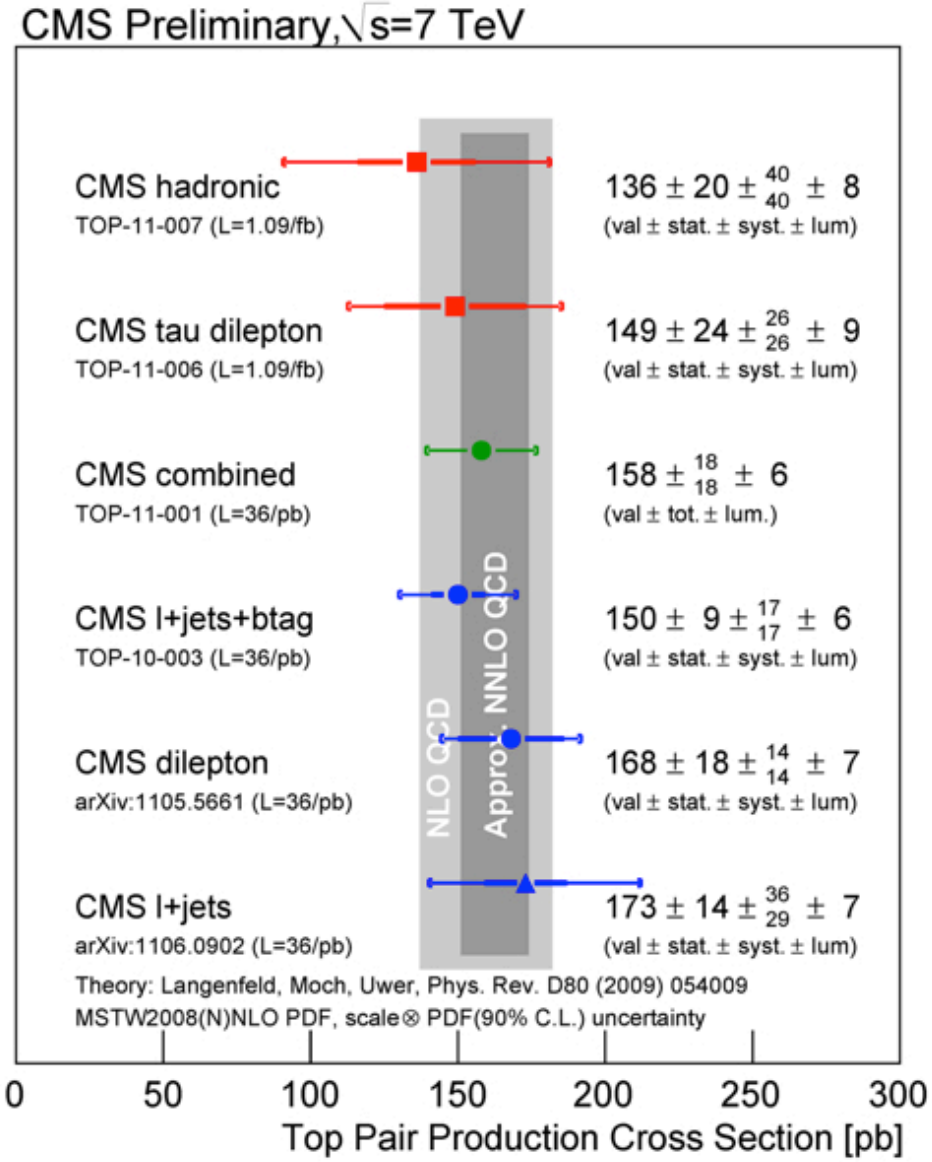
- SM cross sections
  - $\sigma_{NNLO}=163^{+11}_{-10}$ pb Kidonakis PRD 82 114030 (2010)
  - $\sigma_{NNLO}=164^{+10}_{-13}$ pb Langenfeld et al. PRD 80 054009 (2009) Aliev et al. CPC 182, 1034 (2011)
- SM Decay
  - Expect ~100% t→Wb ($|V_{tb}|\sim1$)
  - $t\bar{t}$ channels characterized by W decays
    - dilepton: $t\bar{t}\rightarrow W^+bW^-\bar{b}\rightarrow \ell^+\nu b\ell^-\bar{\nu}\bar{b}$
    - lepton+jets: $t\bar{t}\rightarrow \ell\nu bq_iq_j\bar{b}$
    - fully hadronic: $t\bar{t}\rightarrow q_iq_jbq_kq_l\bar{b}$

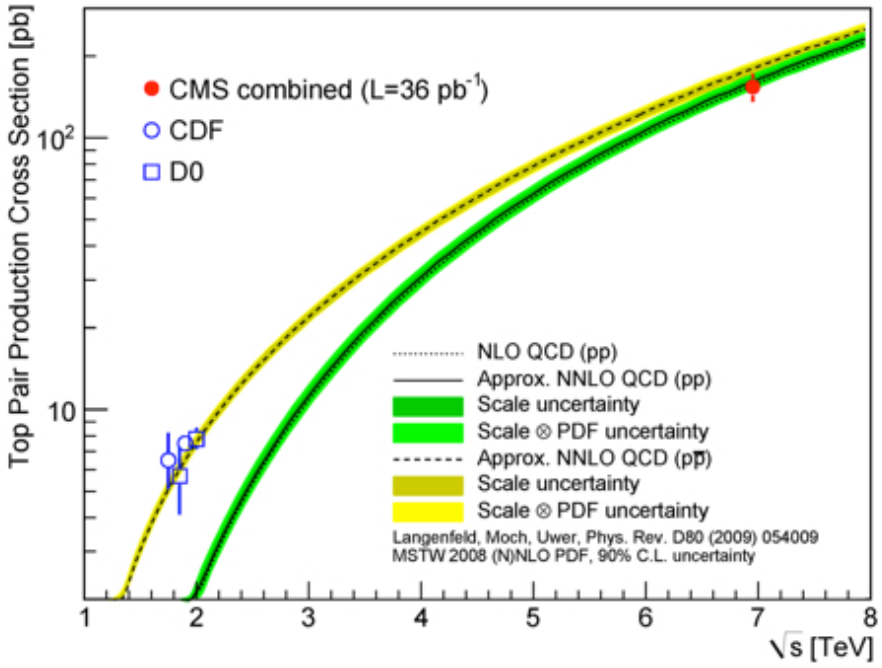


2010 Results (36/pb): dilepton, lepton+jets
New Results (1.09/fb): Fully hadronic, μτ

See S. Khalil talk for details (5pm)

Cross Section Summary





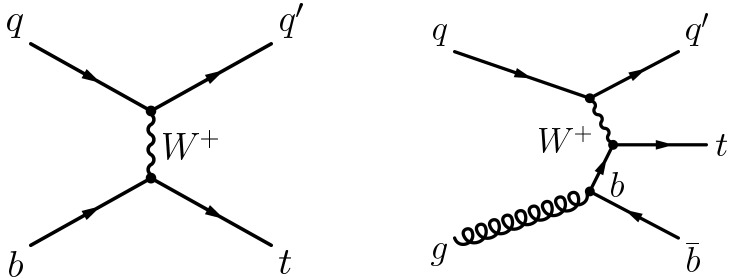
- Good agreement in varied channels
- Good agreement with NLO calculations

See S. Khalil talk for details (5pm)

Single Top Production

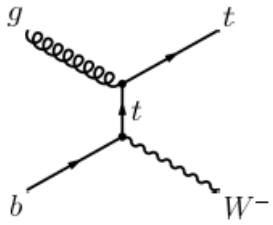
- Standard Model Production

t channel



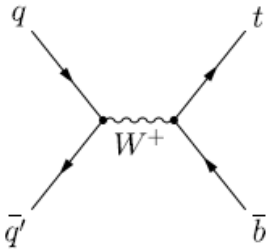
σ=62 pb

tW channel



σ=11 pb

s channel



σ=4 pb

- Probes New Physics through top couplings
  - non-SM production or decay
- Single top discovered at the Tevatron
- CMS Search for t-channel at 7 TeV
  - large cross section with distinctive signature
  - two searches with 2010 data (36/pb)

arXiv 1106.3052 CMS-PAS-TOP-10-008

See T. Speer talk for details 10 Aug

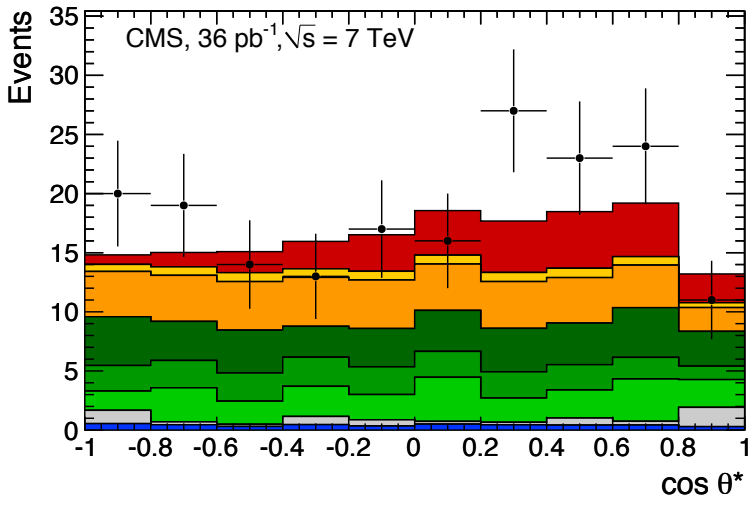
CMS Single Top t-channel

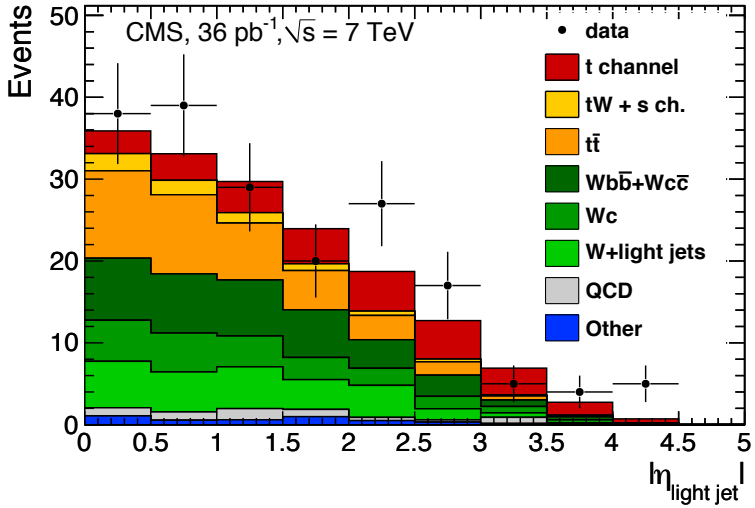
arXiv 1106.3052 CMS-PAS-TOP-10-008

- Event Selection
  - $t \to Wb$ with leptonic $W \to \ell\nu$ (e or μ)
    - lepton: $p_T > 20$ GeV muons and $p_T > 30$ GeV electrons
    - Neutrino from Missing ET: require $M_T > 40$ (50) GeV μ (e)
  - Exactly two anti-k_T jets (R=0.5) with $p_T > 30$ GeV $|\eta| < 5$
    - one jet b tagged with high purity tagger
- Two analysis methods:
  - 2D template fit in η_j and cos $\theta^*_{\ell j}$
    - t-channel signal has a non-central light jet & V-A predicts: $\frac{d\Gamma}{d\cos\theta^*} \propto 1 + A\cos\theta^*$
    - smaller model dependence
  - Multi-variate analysis using a boosted decision tree
    - 37 observables exploiting expected kinematics (W, top, b-jet,…)
    - higher sensitivity
- Backgrounds
  - QCD - modeled from data in control region using M_T
  - W+light jets - fit simultaneously or data-driven estimate
  - VQQ - MC normalized from top pair cross section analysis

Single Top Fits

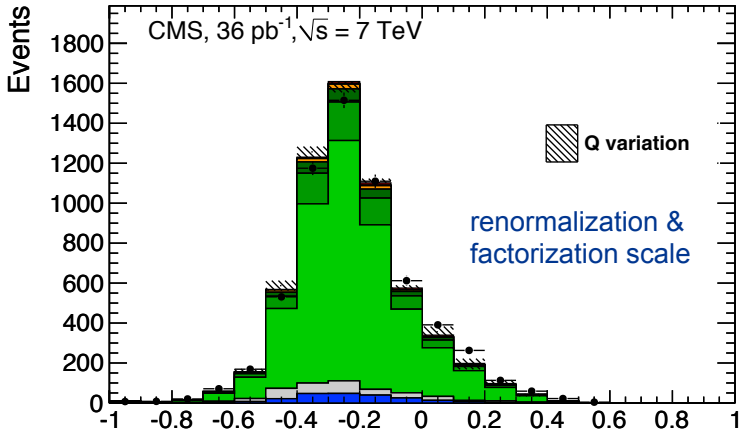
Projections of 2D Fit



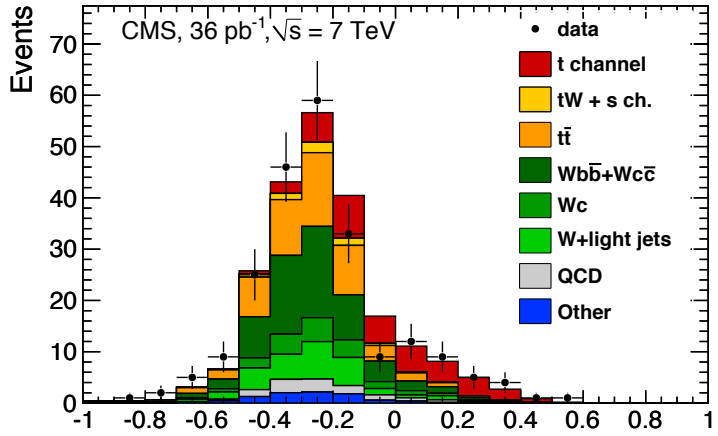


arXiv 1106.3052 CMS-PAS-TOP-10-008

Binned bdt discriminant



Good Agreement in
Control Region (no b-tag)



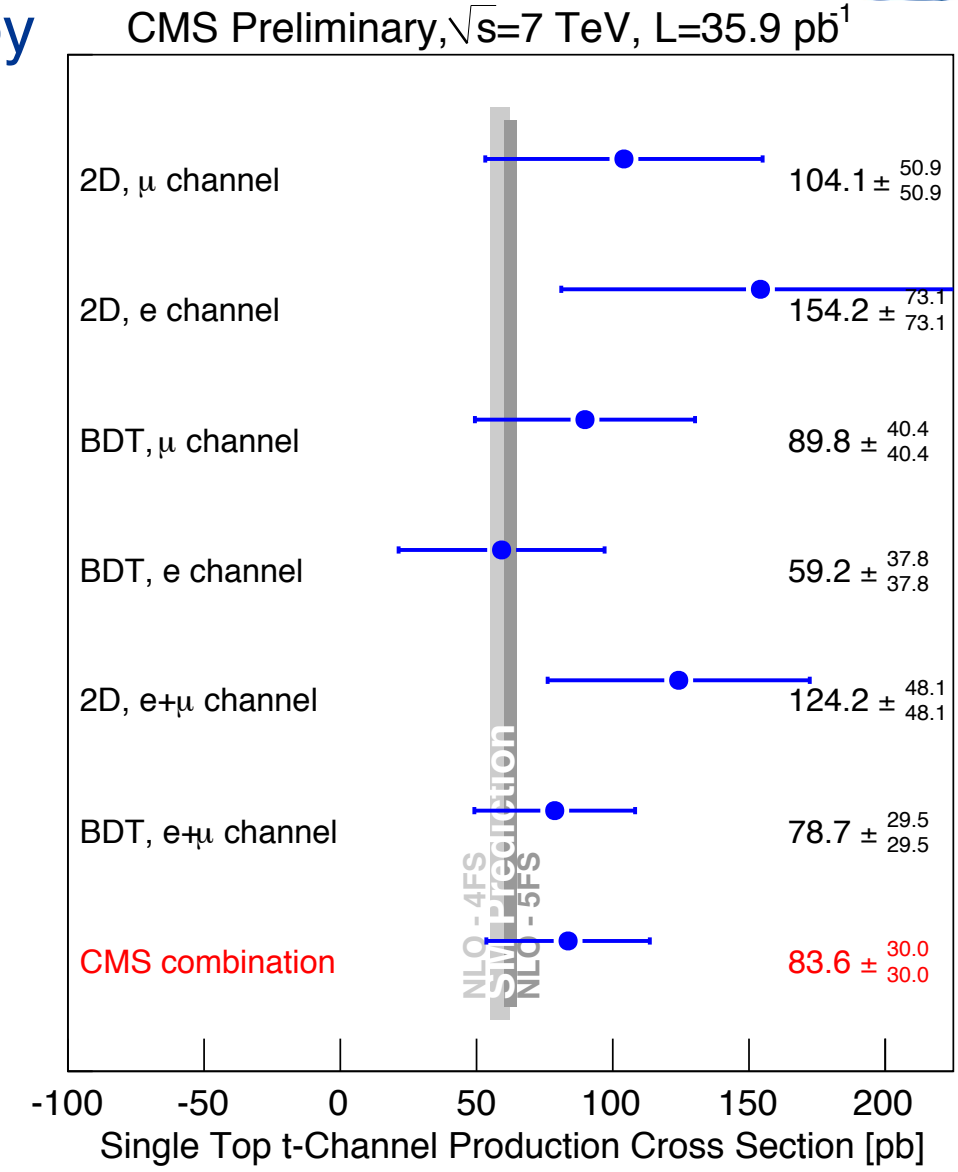
e and μ combined (b-tag)
Signal for t-channel single top

Both analyses find evidence for single top t-channel

Single Top Measurement (t-channel)

- Combination of two analyses by BLUE (51% corr.)
  - $\sigma = 83.6 \pm 30_{(stat+syst)} \pm 3_{(lumi)}$ pb
- Combined significance 3.5σ
- In agreement with SM
- 95% CL Limit on $|V_{tb}|$
  - $|V_{tb}| > 0.62$ (0.68)
- Results accepted by PRL

  arXiv 1106.3052 CMS-PAS-TOP-10-008
- Work in progress with >1/fb of 2011 data, including s,tW channels



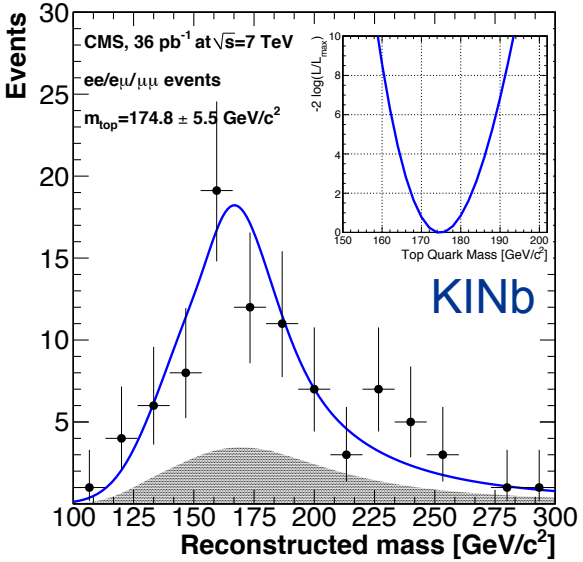
See T. Speer talk for details 10 Aug

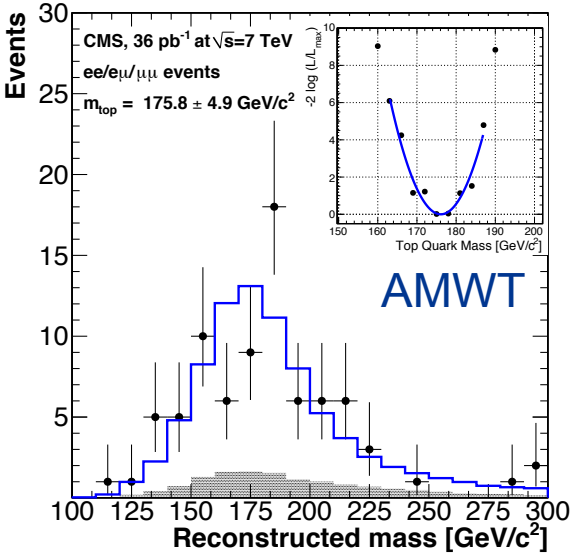
Top Mass in Dilepton Channel

Dilepton Channel 36 pb^{-1}

arXiv 1105.5661 CMS-TOP-11-002 (acc. by JHEP)

- Mass via two known techniques (Tevatron) with improvements
  - KINb
  - AMWT
- Careful systematics





(GeV/c^2)

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

Method	Measured m_{top} (in GeV/c^2)	Weight
AMWT	$175.8 \pm 4.9\,(\text{stat.}) \pm 4.5\,(\text{syst.})$	0.65
KINb	$174.8 \pm 5.5\,(\text{stat.})^{+4.5}_{-5.0}\,(\text{syst.})$	0.35
Combined	$175.5 \pm 4.6\,(\text{stat.}) \pm 4.6\,(\text{syst.})$	$\chi^2/\text{dof} = 0.040$ (p-value = 0.84)

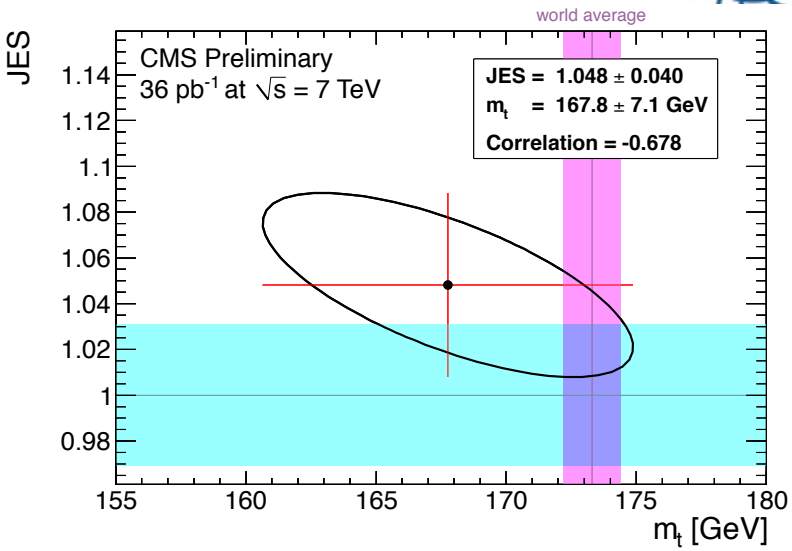
First top mass measurement from LHC

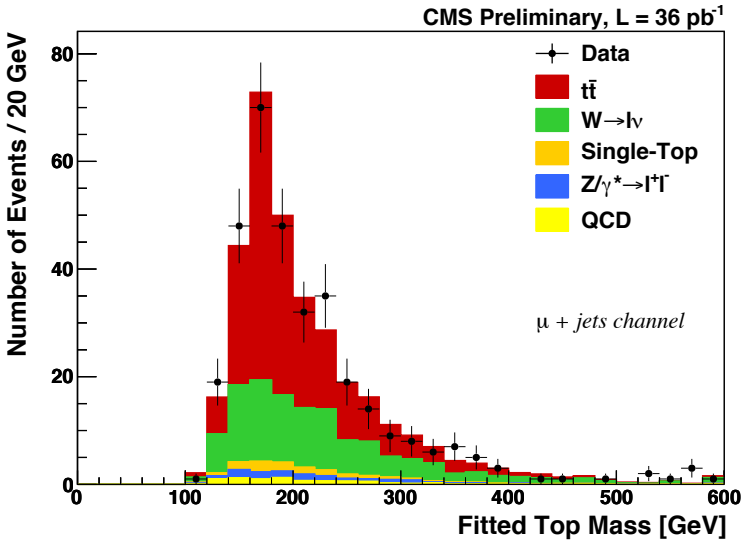
See A. Avetisyan talk for details 12 Aug

Top Mass in Lepton + Jets

Lepton+Jets Channel (36 pb^{-1})

- Again two methods CMS-PAS-TOP-10-006
  - Template Method
    - jointly with jet energy scale
    - 2 btags required; μ+jets
  - Ideogram Method
    - event-by-event likelihoods
    - best precision from kinematic fit taking all event information





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

Ideogram Result: e/μ+jets Preliminary

$$m_t = 173.1 \pm 2.1(\text{stat})^{+2.8}_{-2.5}(\text{syst}) \text{ GeV}.$$

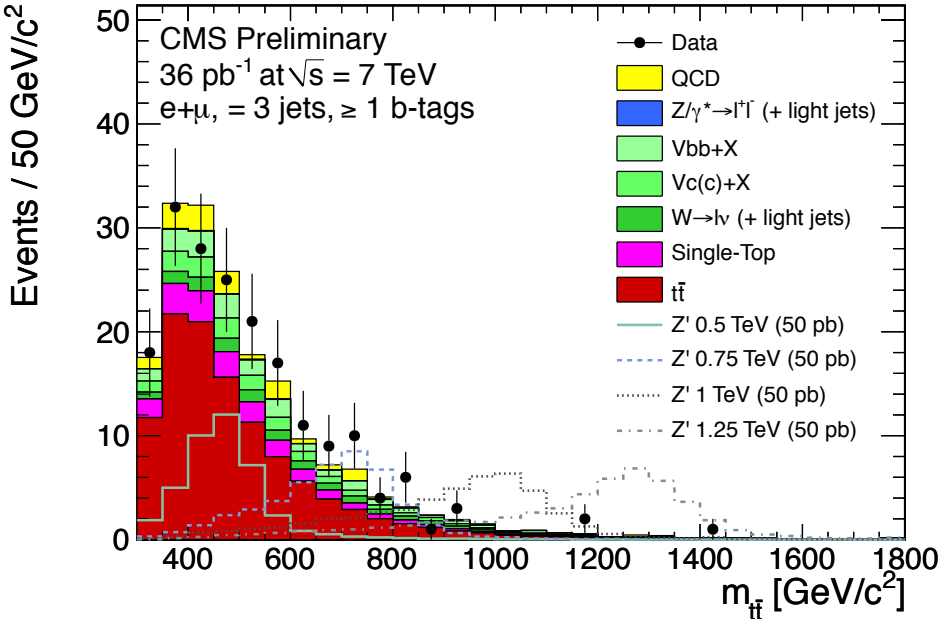
Combination with dilepton channel

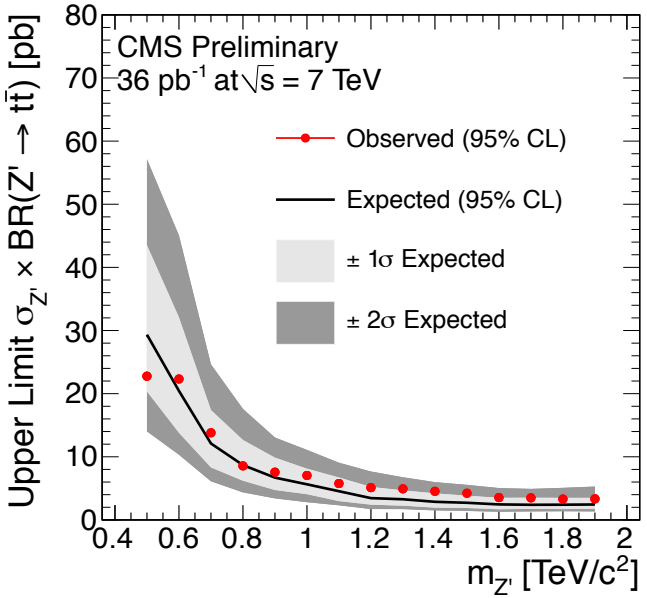
$$m_t = 173.4 \pm 1.9(\text{stat}) \pm 2.7(\text{syst}) \text{ GeV}.$$

Top Pair Invariant Mass

CMS-PAS-TOP-10-007

- Resonance search in $t\bar{t}$
  - Z', Kaluza-Klein gluons, …
- "Low mass" analysis
  - following (e/μ)+jet reconstruction
  - 8 channels
    - 3 jets w/ b-tag
    - 4 jets w/ 0,1,2 tags
  - kinematic fit
  - simultaneous template fits
- No deviation from SM
  - limits on narrow Z'





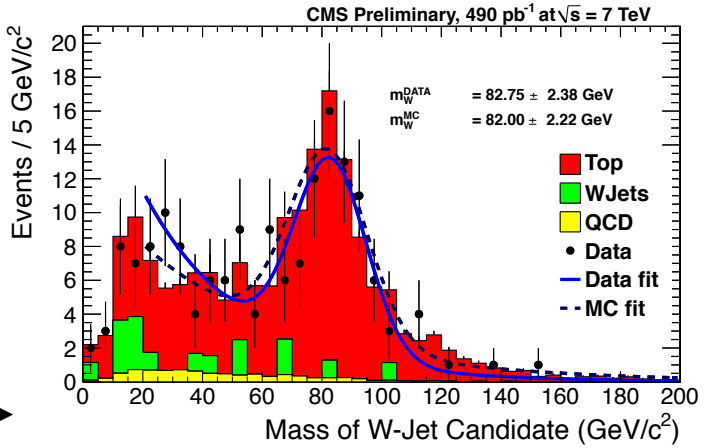
See S. Rappoccio talk for details 11 Aug

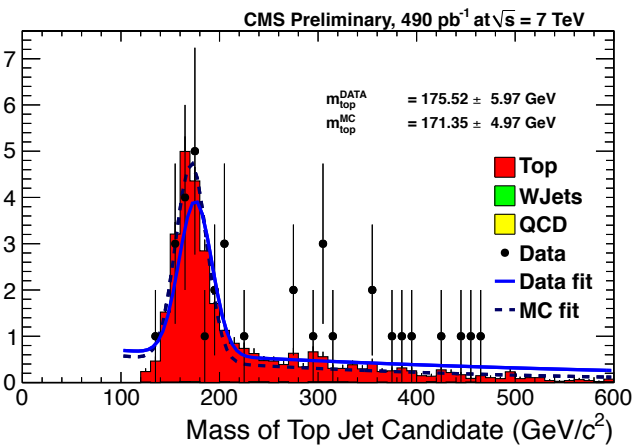
Top Pair Invariant Mass

CMS-PAS-EXO-11-006

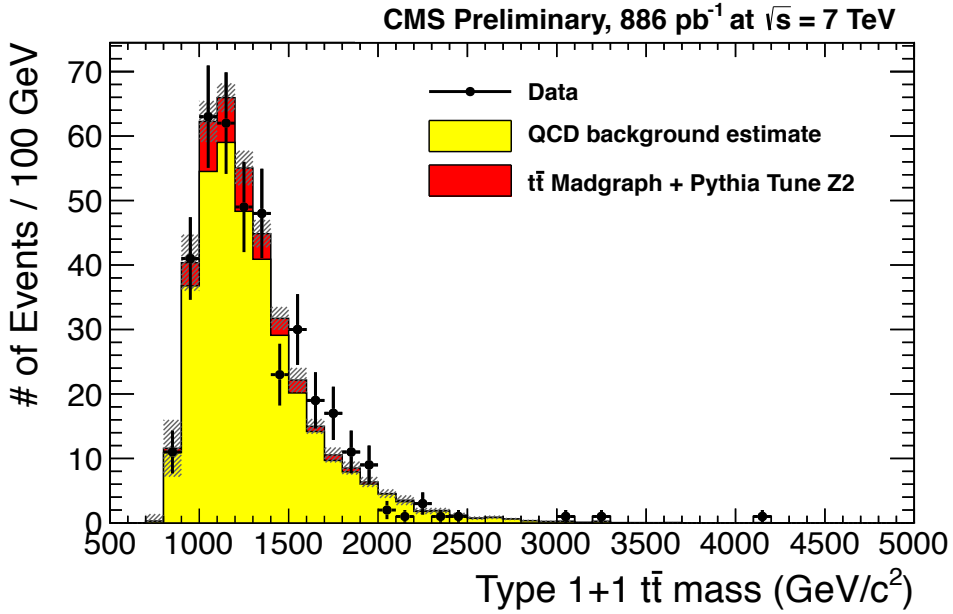
See S. Rappoccio talk for details 11 Aug

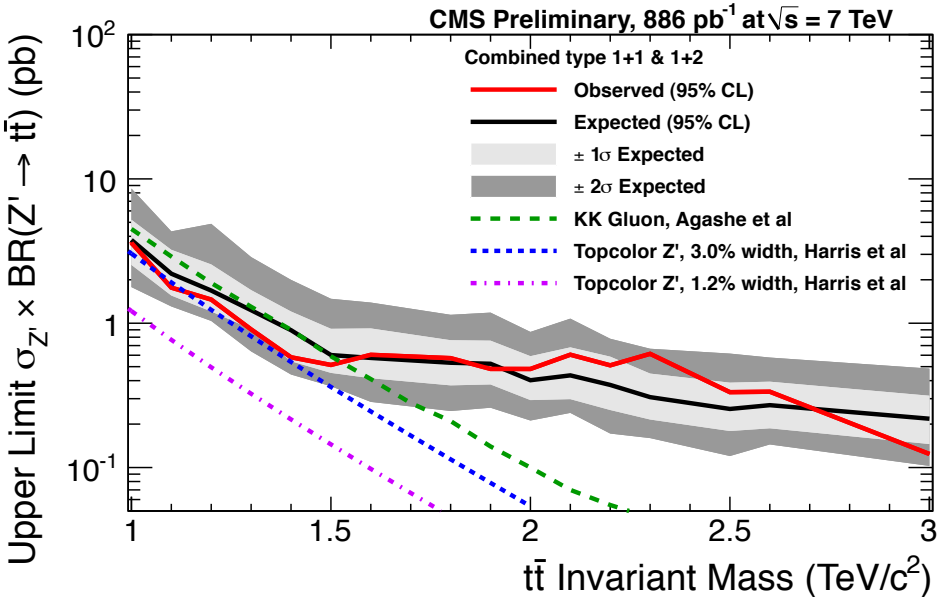
- High mass/boosted tops
  - fully hadronic channel
  - using jet substructure or top/W tagging
    - validated with boosted μ+jet sample





- Data driven QCD bkgd



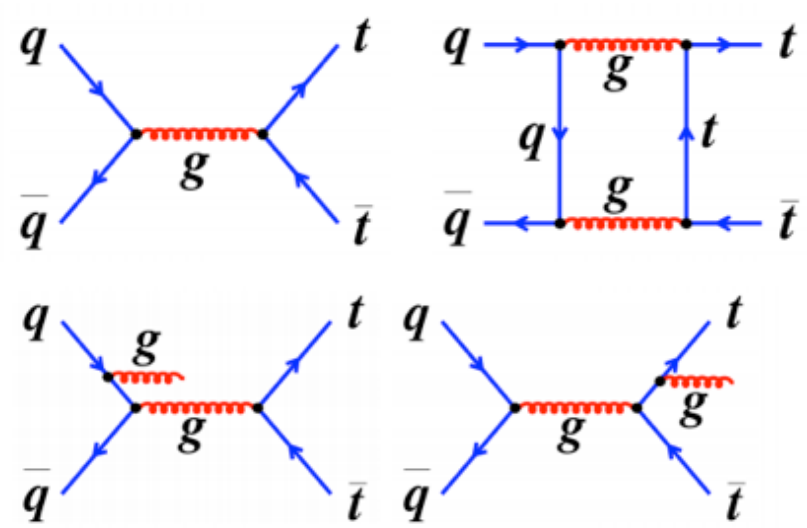


Limit on KK Gluons M>1.5 TeV

Top Charge Asymmetry

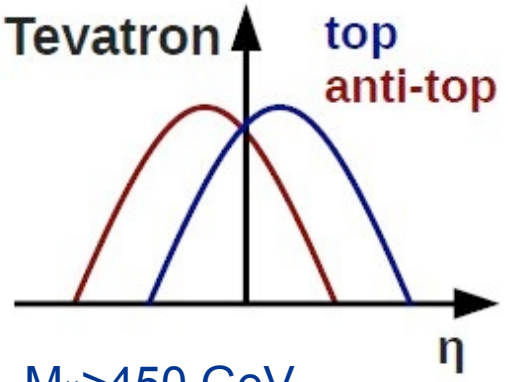
$$A_C = \frac{N^+ - N^-}{N^+ + N^-}$$

Top - Anti Top asymmetries
from interference of
LO, box, radiative diagrams



Look at pseudorapidity or rapidity difference

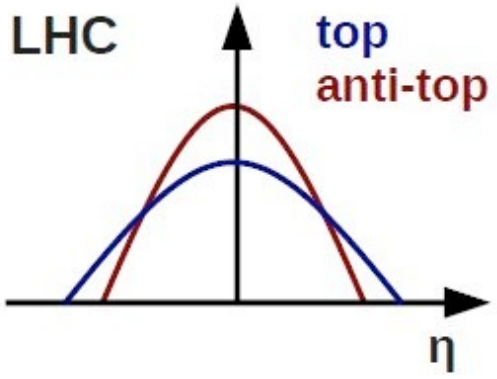
<u>Forward-backward</u>
Observed by D0 & CDF
D0 PRL 100 142002 (2008)
CDF PRL 101, 202001 (2008)
arXiv 1101.0034



~2σ Larger than SM; Esp. M_{tt}>450 GeV
Perhaps new physics? Axigluons?

<u>"Width" difference</u>
CMS 36/pb
CMS-PAS-TOP-10-010

Now updated to 1.09/fb
CMS-PAS-TOP-11-014



SM Prediction
Tevatron ~5%
LHC ~1% (dilution from gg production)

Kuhn & Rodrigo PRL 81, 49 (1998)
(updated for pdfs, m_{top})

See M. Segala talk for details 12 Aug

Top Samples for A_C

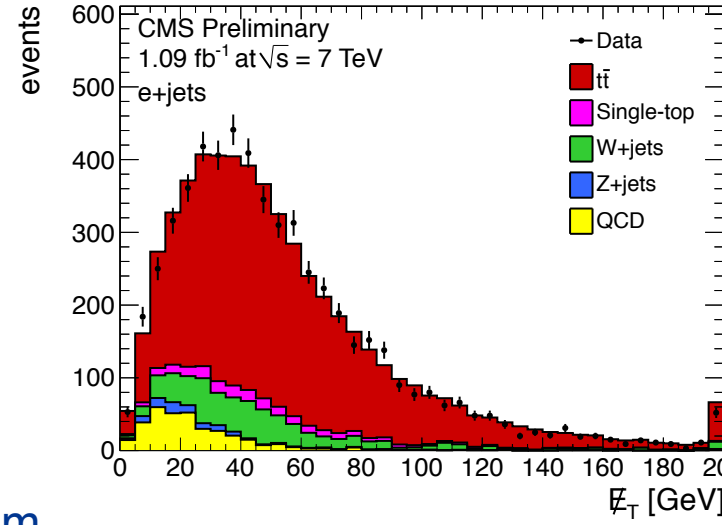
CMS-PAS-TOP-10-010

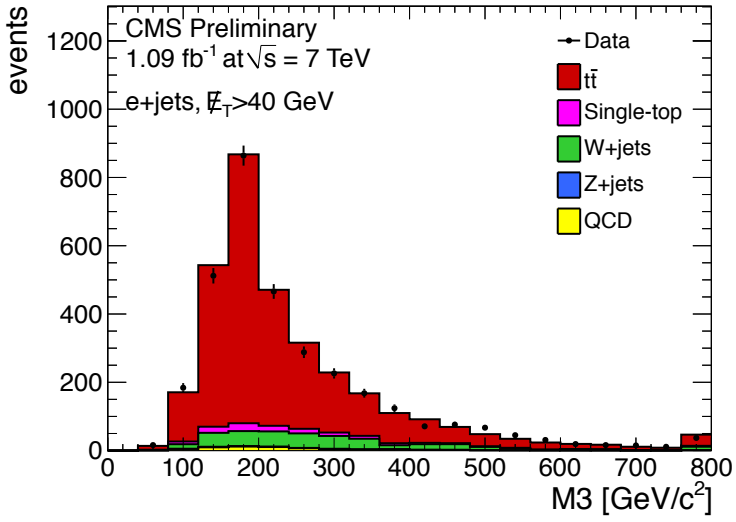
Lepton + Jets Discrimination from
- ≥1 b-tagged jet (new)

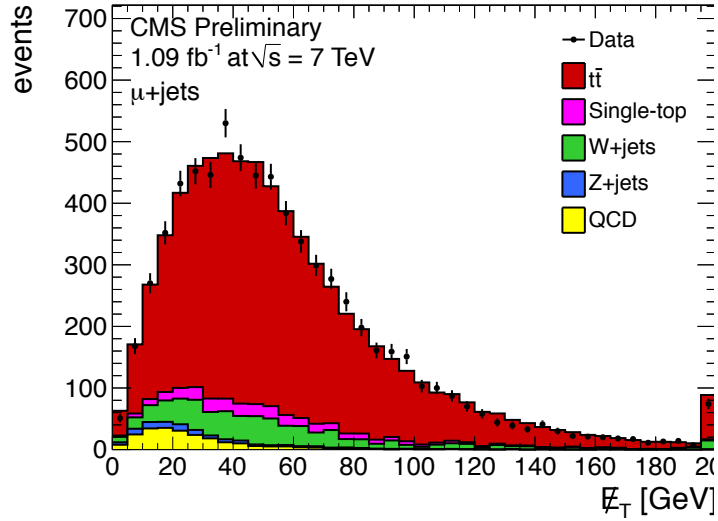
& Template fits to
- Missing ET
- M3 as M_{top} estimator

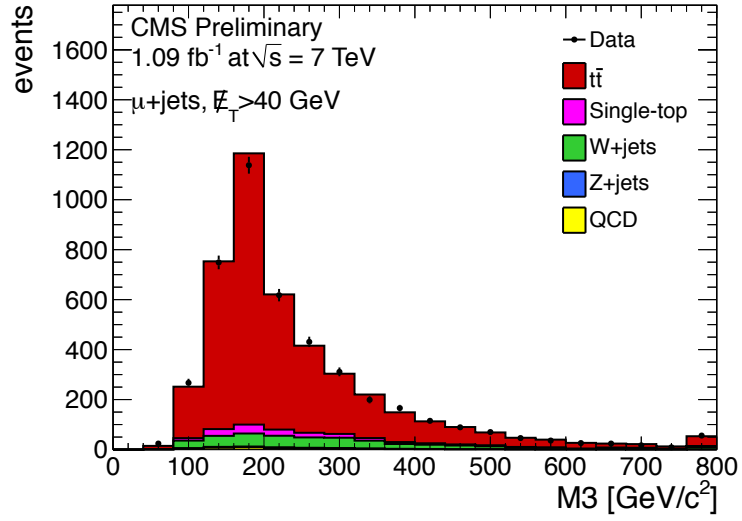
Clean top sample

Best jet combination from Likelihood using
- kinematics
- btagging
- m_t, m_W





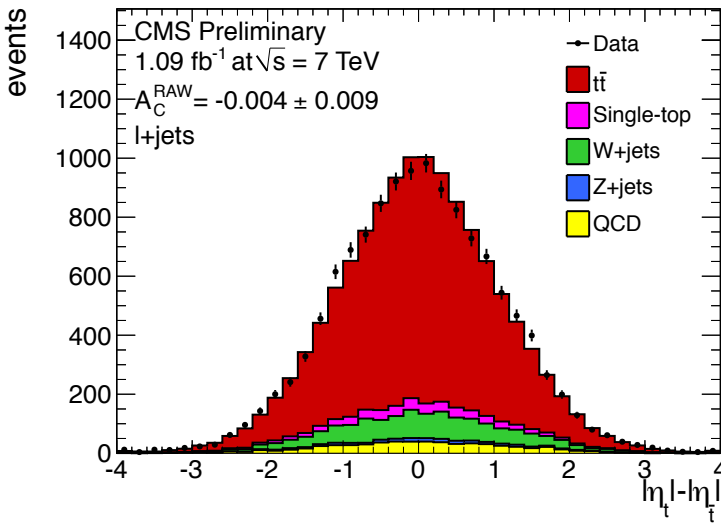


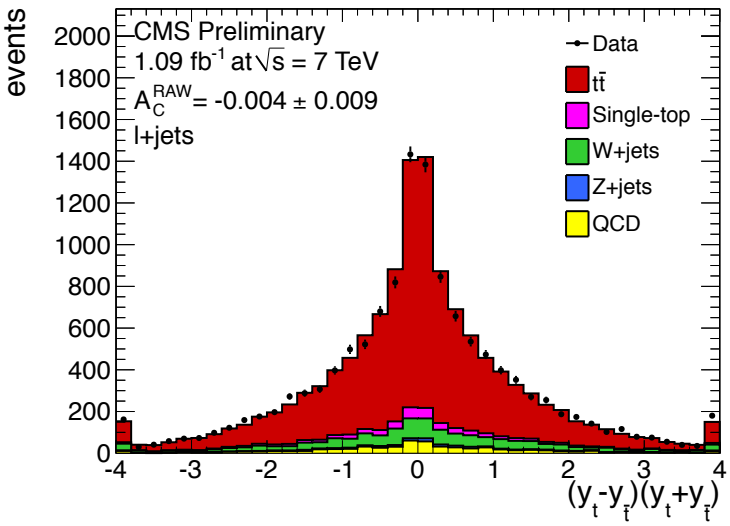


M3 = invariant mass of 3 jets with max vector sum of p_T

Raw and Unfolded Asymmetry

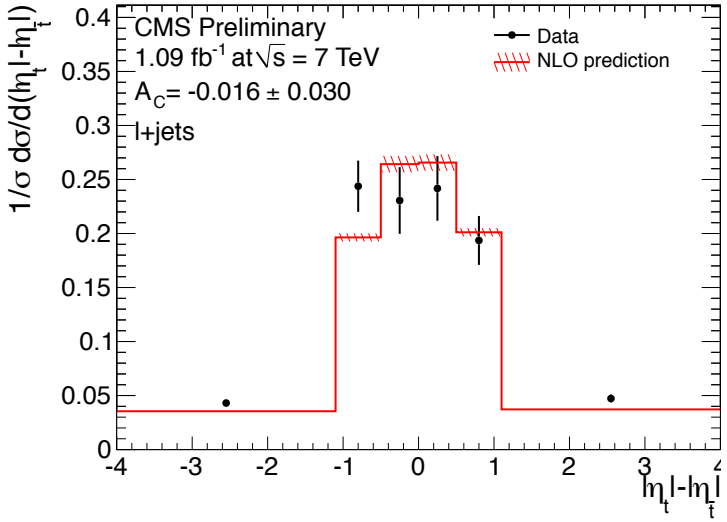
CMS-PAS-TOP-10-010

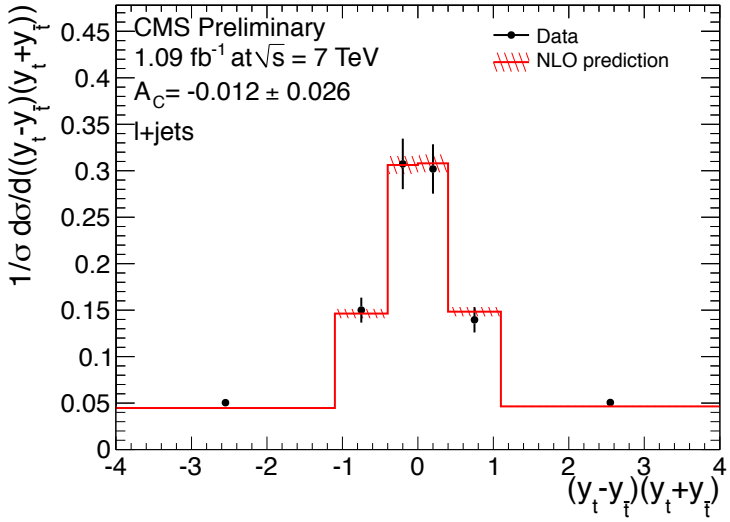




Raw asymmetry is background-subtracted
Then unfolded for acceptance & resolution effects

Observable	Raw A_C	BG-subtracted A_C	Unfolded (and corrected) A_C
$\Delta\lvert\eta\rvert$	-0.004 ± 0.009	-0.009 ± 0.010	$-0.016 \pm 0.030^{+0.010}_{-0.019}$
$\Delta(y^2)$	-0.004 ± 0.009	-0.007 ± 0.010	$-0.013 \pm 0.026^{+0.026}_{-0.021}$





Top Charge Asymmetry Results

CMS-PAS-TOP-10-010

CMS Measurement 1.09/fb

$$A_C^{\eta} = -0.016 \pm 0.030\ (\text{stat.})^{+0.010}_{-0.019}(\text{syst.})$$

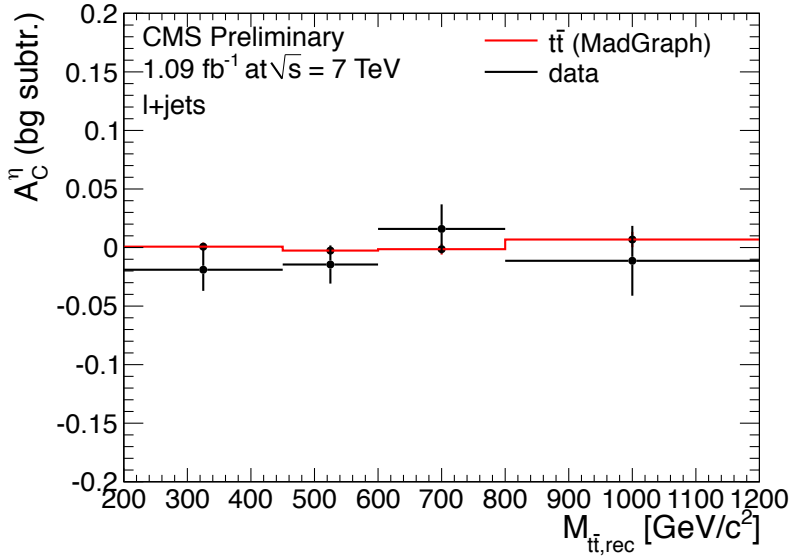
$$A_C^{y} = -0.013 \pm 0.026\ (\text{stat.})^{+0.026}_{-0.021}(\text{syst.})$$

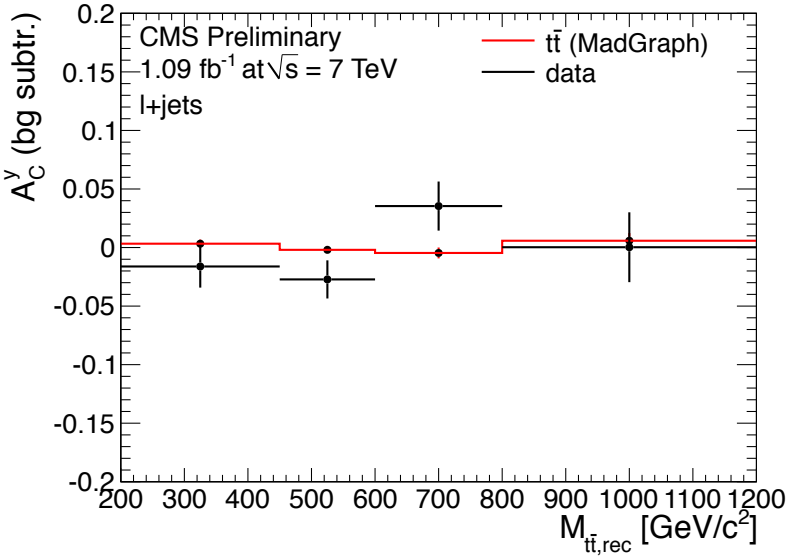
SM Expectation

$$A_C^{\eta} = 0.013 \pm 0.001$$

$$A_C^{y} = 0.011 \pm 0.001$$

- No significant difference from SM
  - No trends versus tt invariant mass (not yet unfolded in $M_{t\bar{t}}$)





See M. Segala talk for details 12 Aug

Summary & Conclusion

- Large samples of top quarks produced and analyzed
  - Cross sections in agreement with (N)NLO SM predictions
    - Channels: dilepton (including τ), lepton+jets, fully hadronic
  - Single top: evidence seen at SM level for t-channel EWK production
  - Future: differential cross sections
- Top mass measurement
  - dilepton and lepton + jet channels at ~2% level
- Top samples used to probe for BSM physics
  - Search for peaks in M(t tbar) - high M sensitivity beyond Tevatron
    - new jet substructure analysis in fully hadronic channel
  - Charge asymmetry consistent with SM (needs statistics)
  - And more properties to come: Wtb couplings, charge, ...
- Analysis of > 1 fb^{-1} in progress (updates coming soon)

CMS Top Presentations at DPF

- See dedicated CMS talks for additional analysis details
  - Top pair cross section - S. Khalil 9 Aug @ 5 pm
  - Single Top measurement - T. Speer 10 Aug @ 2 pm
  - New physics M(t tbar) - S. Rappoccio 10 Aug @ 5:30 pm
  - M_{top} - A. Avetisyan 12 Aug @ 8:40 am
  - t tbar Charge Asymmetry - M. Segala 12 Aug @ 9:40 am