New Physics Searches at CDF, with Top-Quarks and Higgs Bosons

Kanishka Rao
UC Irvine

SLAC Seminar
4/2/2013

Outline

- Big questions and particle colliders
- Formulating answers, analysis strategy
- Top-quark pair production asymmetry
- Chromophilic Z'
- Two Higgs doublet models

Big Questions

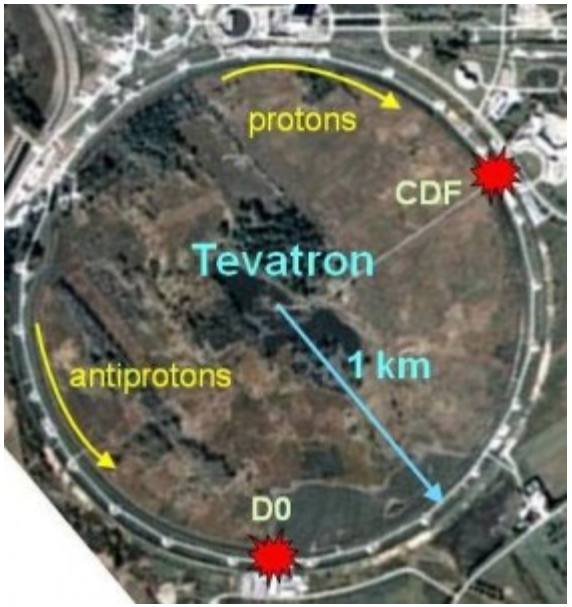
- Answering the big physics questions…
  - What is the world made up of?
  - Why do things have mass?
  - What is dark matter?
  - A theory of everything?

- To answer these big we have to go to the smallest, most fundamental entities

Particle Colliders

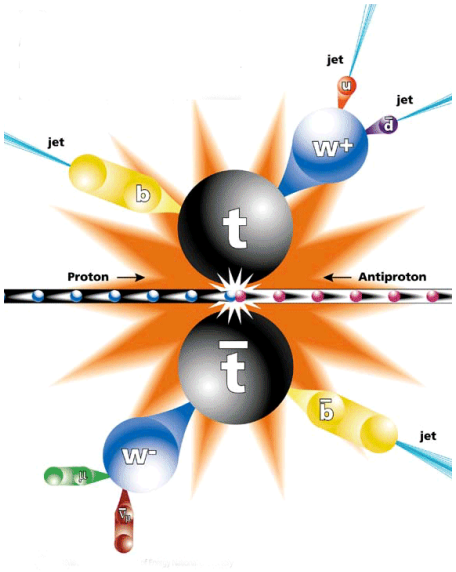
- Test current understanding – the Standard Model (SM)
- Deviations from the SM
  - New physics
- Multipurpose
  - Single dataset

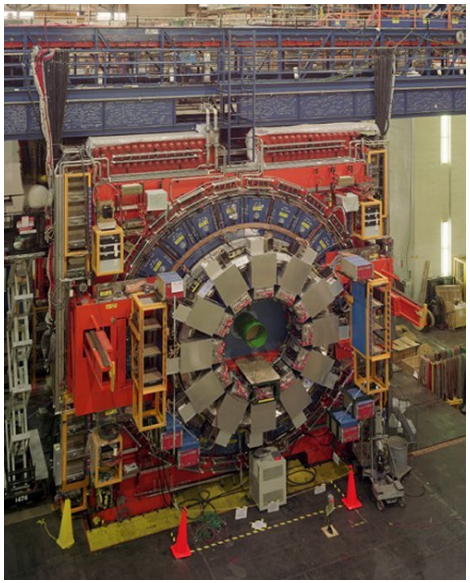
Tevatron, Fermilab



CDF Detector and Top-Physics

- CDF studies 2 TeV proton-antiproton collisions at the Tevatron
- Discovered the top-quark
- 100,000 top-quark pairs produced at Tevatron





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Analysis Strategy

- Many different models/ideas can be tested with the CDF dataset
- How do we answer as many relevant physics questions as possible?
  - Analysis strategy
- Do we need N independent experimental analyses to answer N physics questions ?

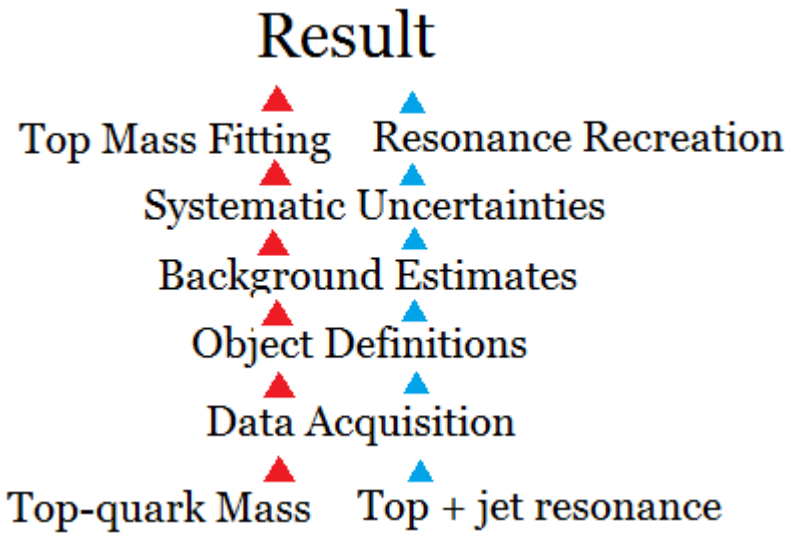
3 unrelated physics questions
(but maybe related analyses?)

{
- Top-quark pair production asymmetry
- A search for a chromophilic Z' boson
- Two Higgs doublet models

Analysis Strategy

- Do we need N experimental analyses to N answer physics questions ?
  - What is the mass of the top-quark?
  - Is there a new particle resonance that decays to a top-quark and a jet?

- 'Overlapping sub-problems'
  - Don't do the same thing twice
- We try to reuse existing tools and ideas for searches wherever possible



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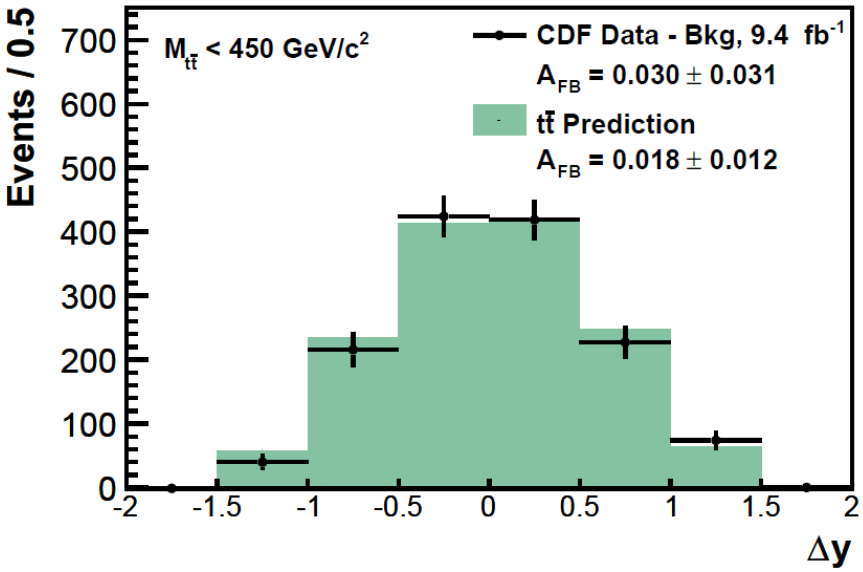
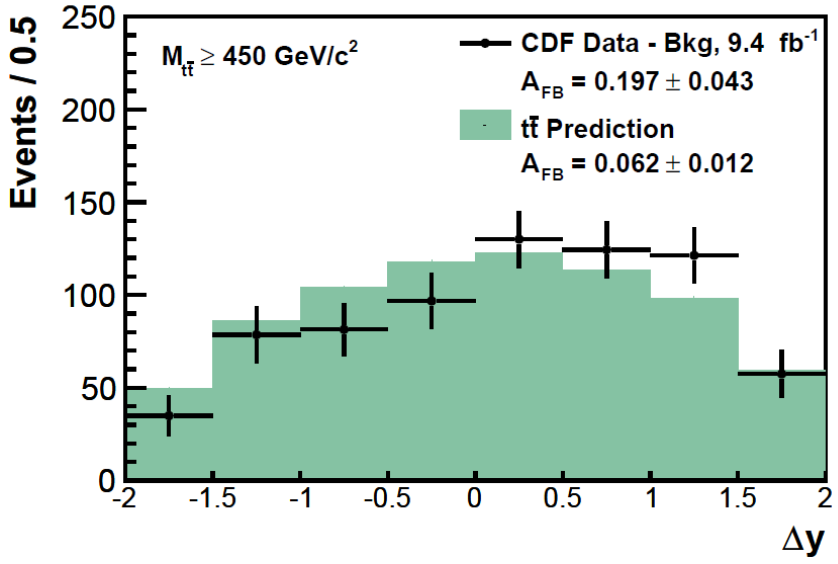
Top Forward-Backward Asymmetry

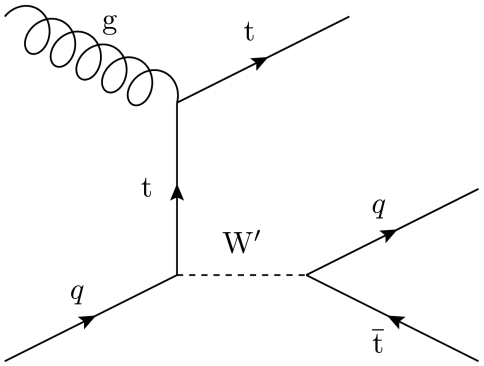
- CDF observed an asymmetry in top-quark pair production, 2011
- 3 sigma deviation observed with mass dependence
- Possible new physics effect?

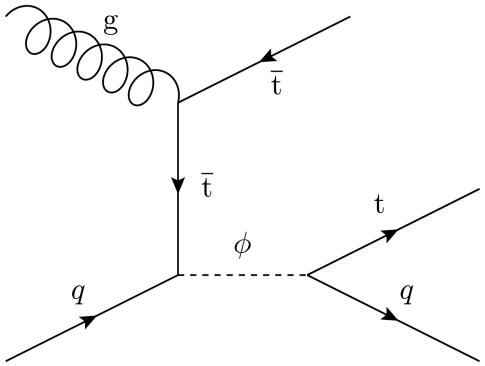




Top AFB – A New Physics Explanation
[http://arxiv.org/abs/1102.0018]

- New particles might interfere with top-quark pair production, causing the observed top AFB
- Then such new particles might also be produced





- A resonance, M, is produced in association with top (anti-top) and decays to anti-top (top) + u/d quark
- Final state is $t\bar{t}$ + light jet

Top + Jet Resonance Search: Analysis Details

CDF@ 2 with the full dataset
lepton + jets channel

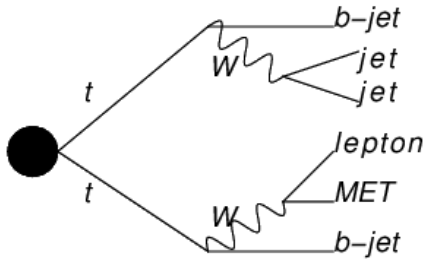
Selection:
Events with at least 5 jets and exactly 1 lepton
At least 1 b-tagged jet

Object Definitions:
Jets, pT > 20 GeV
Electrons, pT > 20 GeV
Muons, pT > 20 GeV
Clean up, MET cuts reduce multijet background

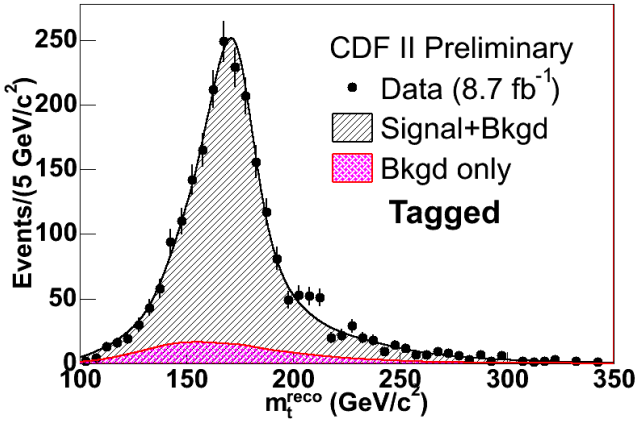
Major Standard Model Backgrounds
Top-quark pair production
W + jets

Resonance Recreation

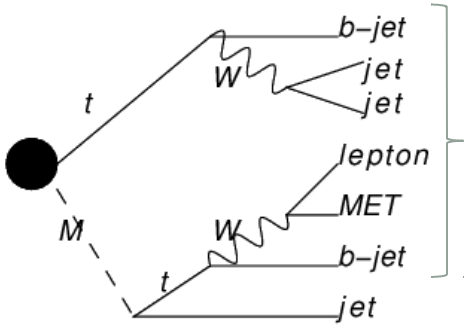
Top-quark pair recreation [previously solved]



Kinematic χ^2 fitter



Top + jet resonance production



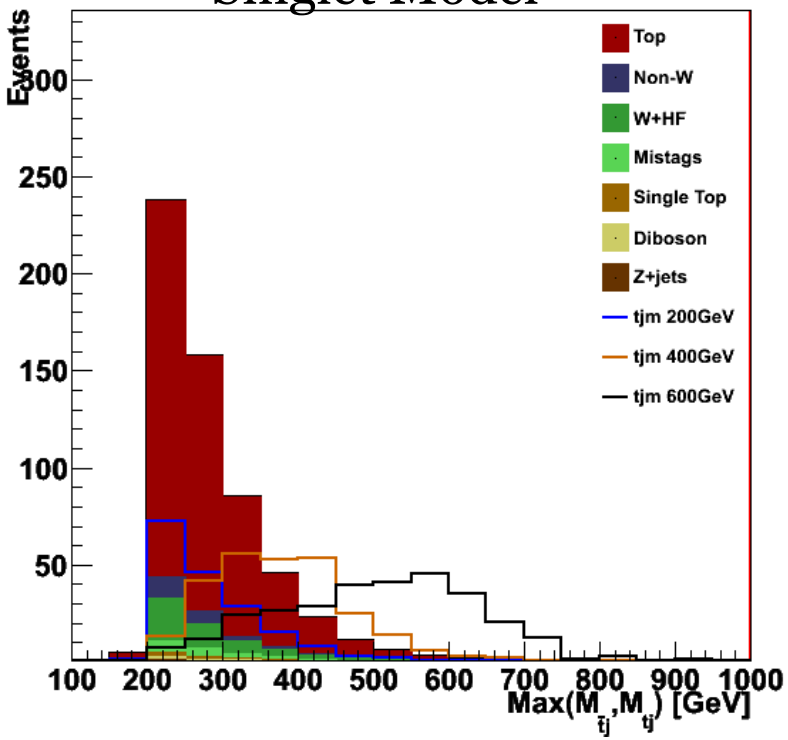
- Run fitter 5 times using 4 jets at a time
- Use the 4 jets that fit best to recreate top and anti-top
- Combine additional jet to recreate t+j and $\bar{t}$+j resonance

Resonance Recreation

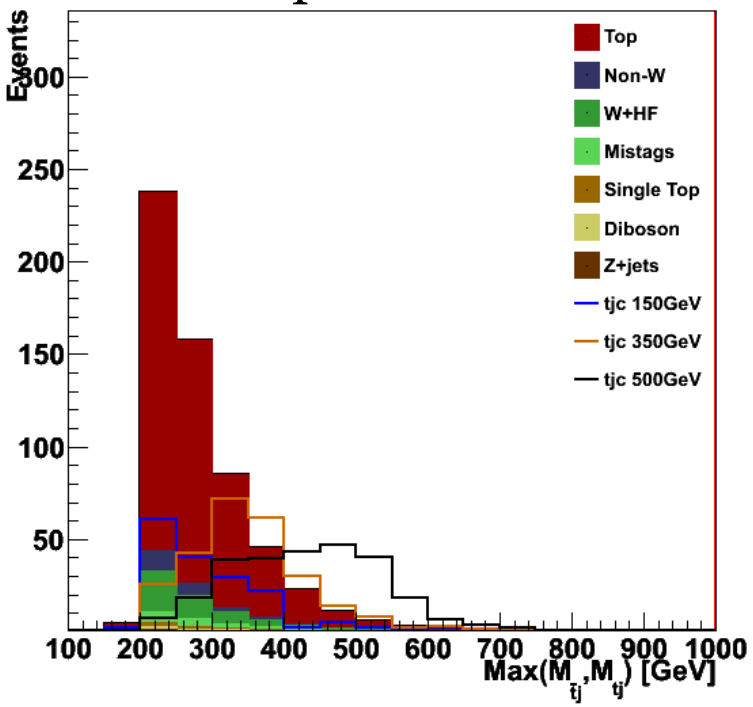
We use max(m_tj, m_j) to pick up the resonance

Signal will look like bump in this variable, mtj

Singlet Model



Triplet Model



Control Regions

Three general regions are used to validate background modeling:

= 4 jet, >= 1 tag This region validates $t\bar{t}$ modeling, signal is depleted in this region by the = 4 jet requirement. This region also validates tagged events.

>=5 jet, = 0 tag This region validated non-$t\bar{t}$ backgrounds (W+jets), signal is depleted due to 0 tag. This region also validates >= 5 jet events.

>=5 jet, >= 1 tag, HT < 225 GeV This region validates $t\bar{t}$+jet events, signal is reduced due to the HT cut. Low mass signal [~200 GeV] persists.

Signal Region

>=5 jet, >= 1 tag dominant background is $t\bar{t}$ ~ 85%

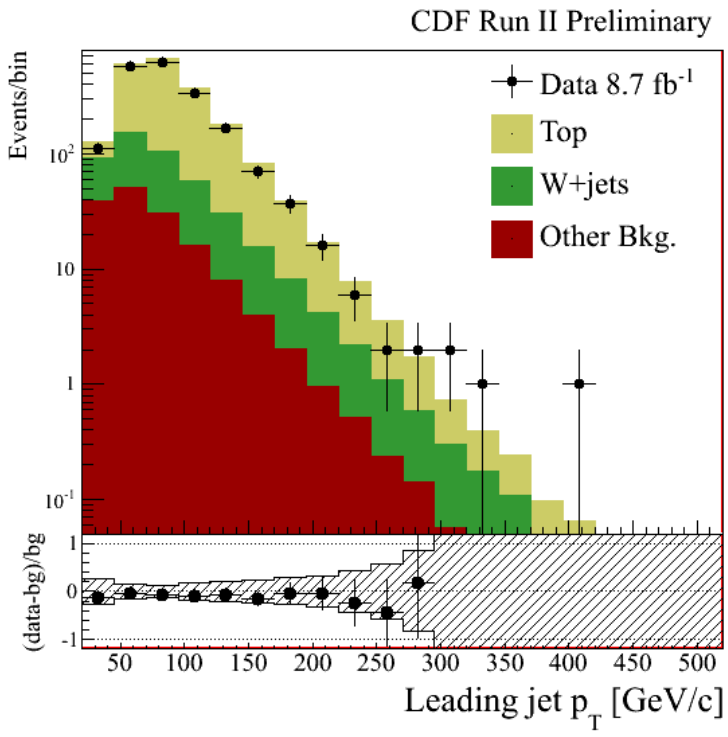
Standard Model Backgrounds

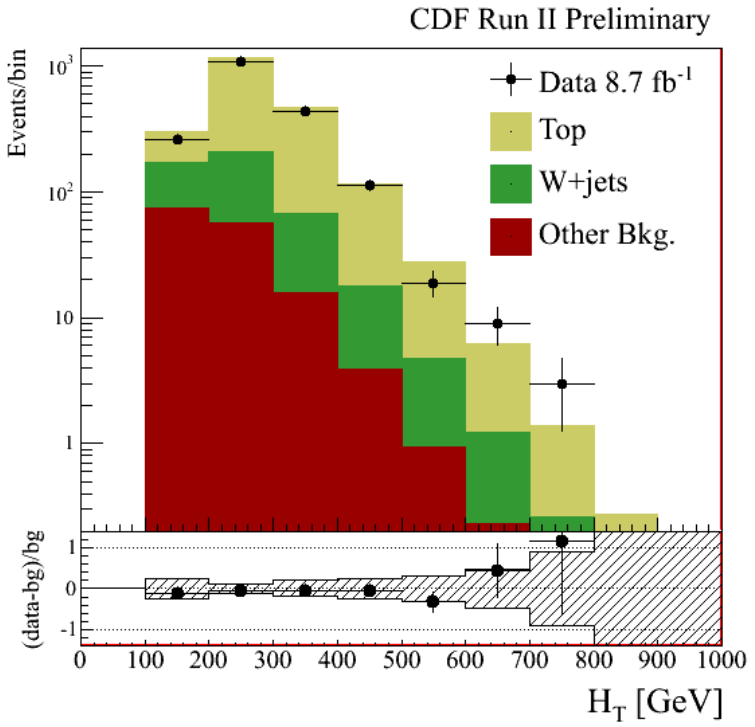
- Standard Model background processes are simulated by Monte Carlo
  - Top-quark pairs: simulated by PYTHIA ~ 80% of background events
  - W + jets: simulated by Alpgen+PYTHIA ~ 15% of background events
  - Z + jets, diboson, single top and fake estimates were also included

Background	total
$t\bar{t}$	550.6
W+jets	78.64
Z+jets	4.06
Diboson	4.40
S top	6.14
QCD	25.52
Total	669.2±89
Data	670
Signal 1 pb^{-1}:	
200 GeV	215.2
300 GeV	253.4
400 GeV	306.5
500 GeV	339.7
600 GeV	338.8
800 GeV	343.4

Control Region: 4 jet, >=1 tag

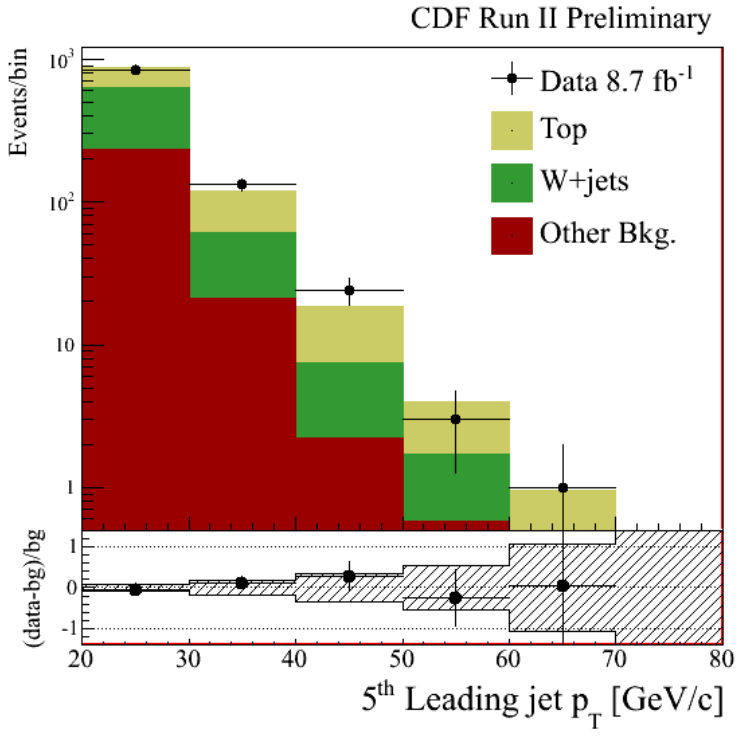
Top-quark pair modeling in 4 jet events

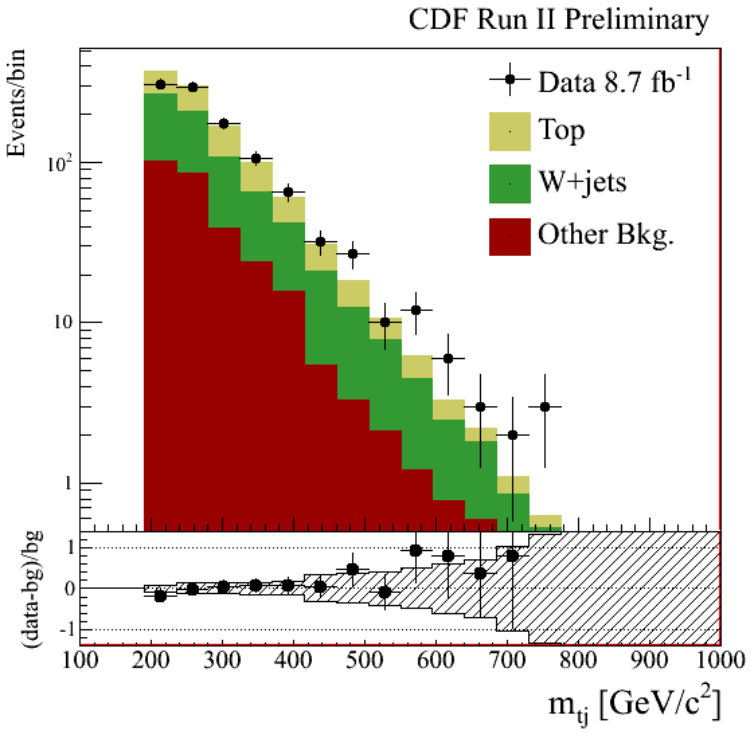




Control Region: 5 jet, =0 tag

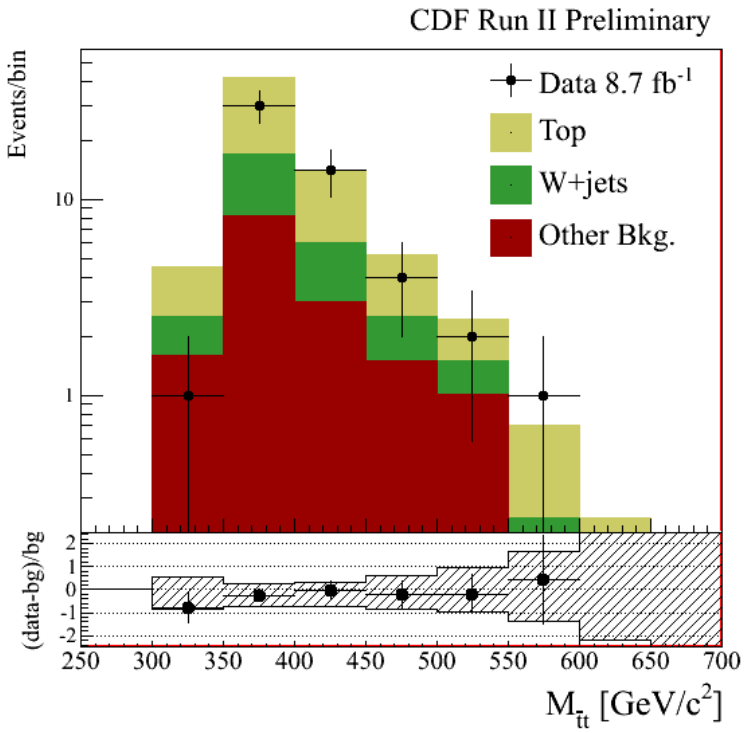
Top-quark pair and W+jets modeling in 5 jet events

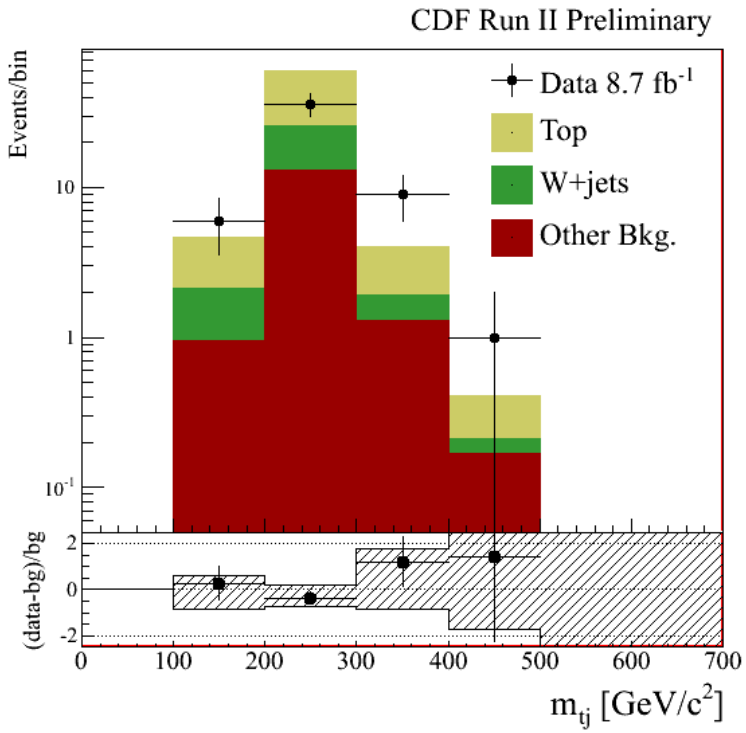




Control Region: 5 jet, low HT

Top-quark pair $t\bar{t}$ + jet in 5 jet events

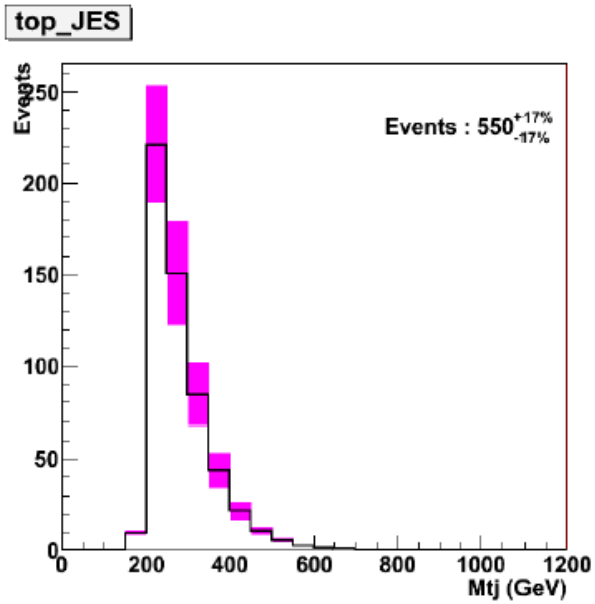


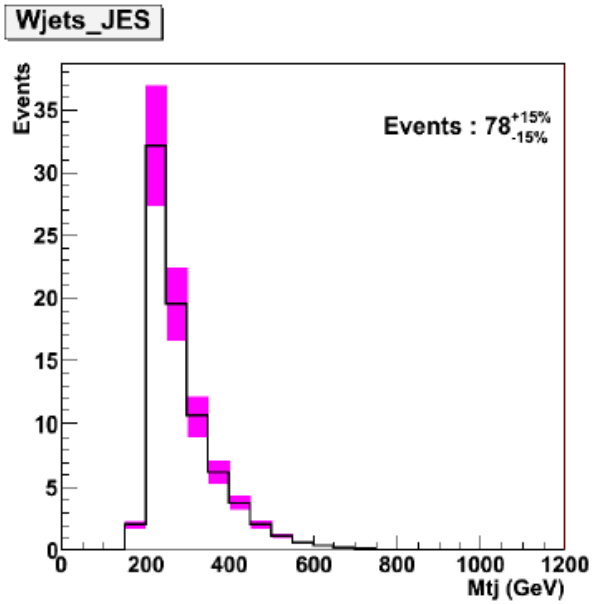


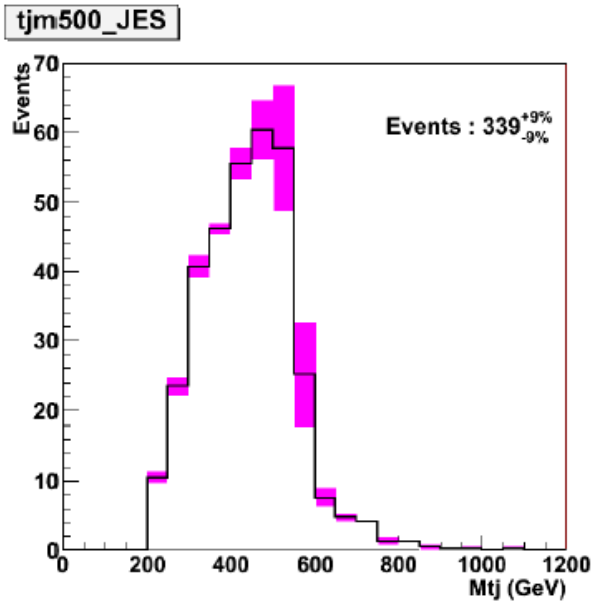
Systematic Uncertainties

Jet energy scale uncertainties are the dominant systematic

- Affects yield due to 5 jet requirement
- Affects reconstructed mass distributions



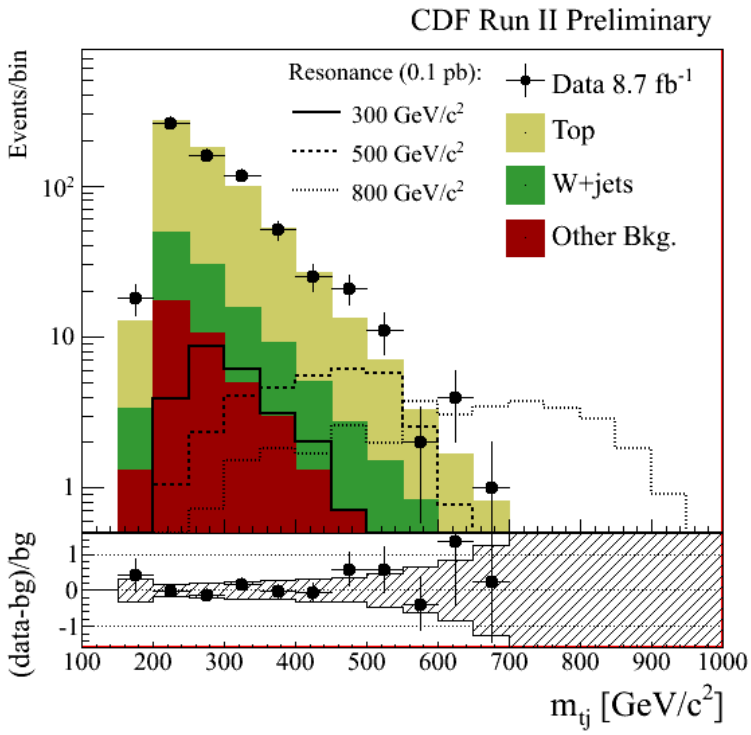


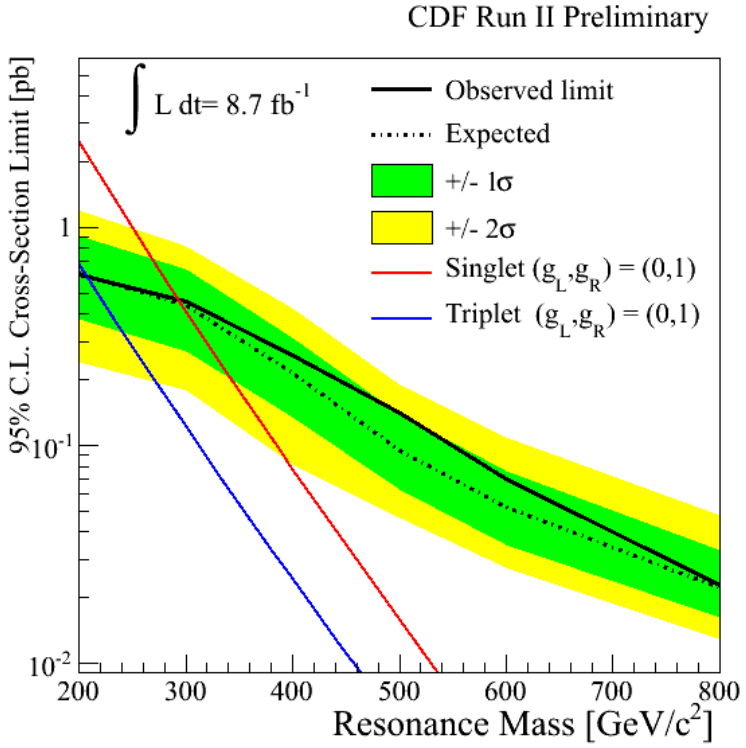


Signal Region and Limits

No excess observed, consistent with SM only hypothesis

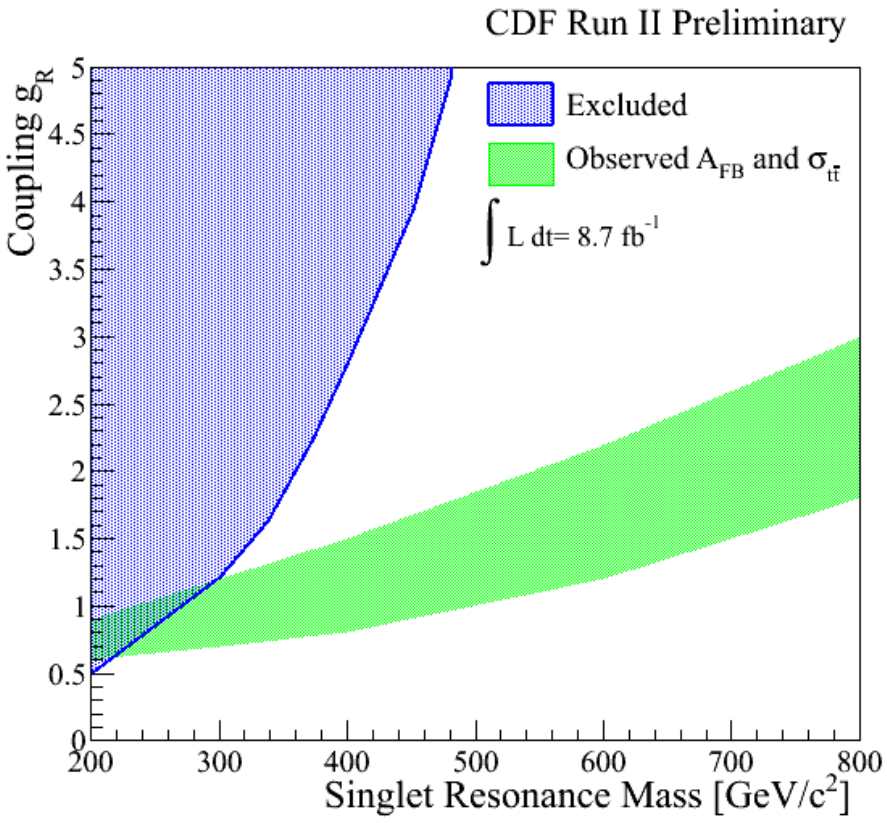
We set 95% CL exclusion limits on the cross-section of such resonances

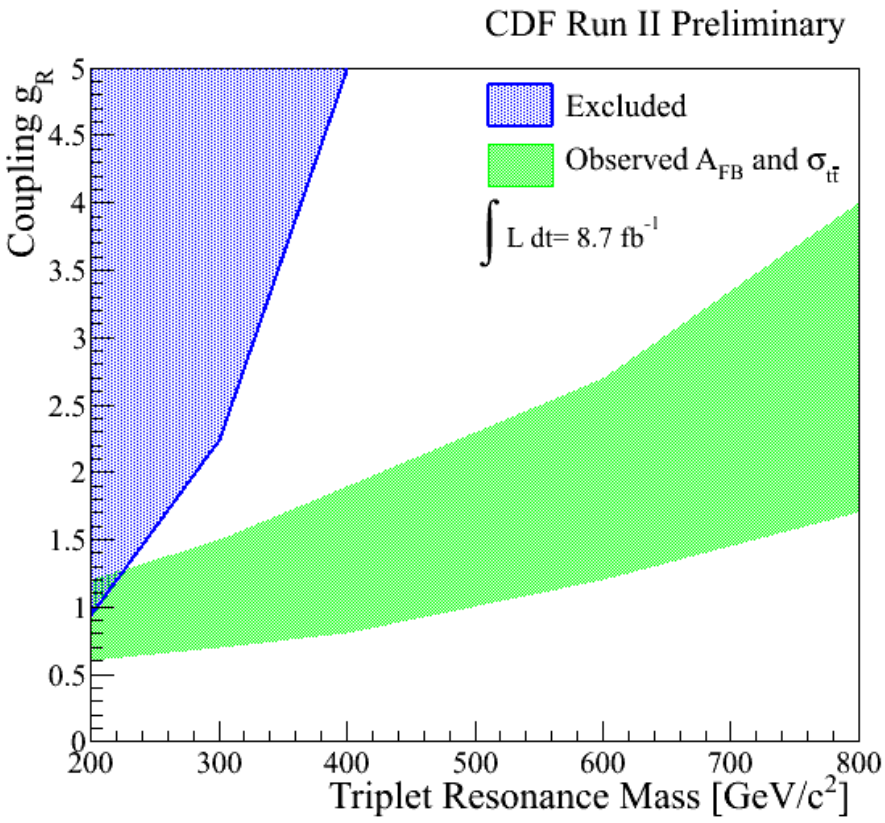




Limits on Model Space

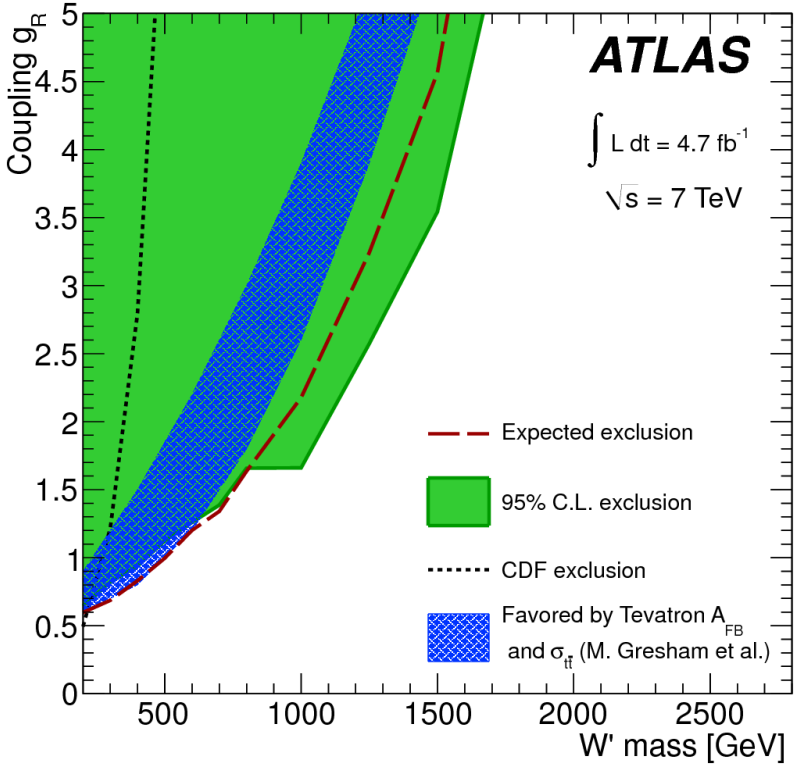
- A lot parameter space still left unexplored
- PRL, 2012 [http://arxiv.org/abs/1203.3894]

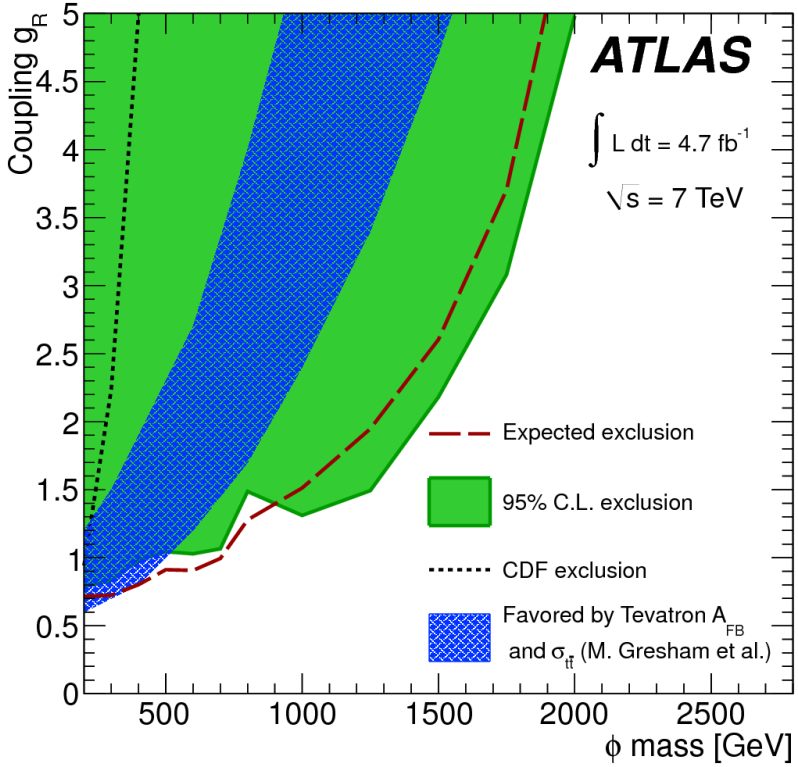




ATLAS Limits

- At ATLAS we managed to exclude the favorable mass-coupling space for such resonances





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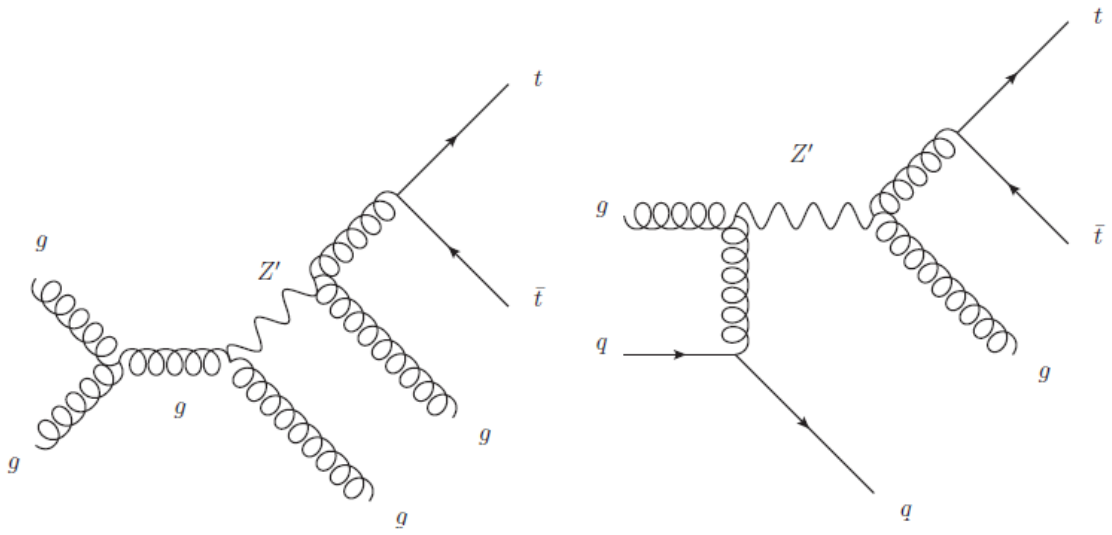
- Chromophilic Z'
- Two Higgs doublet models

A Chromophillic Z'
[http://arxiv.org/abs/1202.4014]

- Several new physics scenarios predict suppressed couplings of a Z' to fermions
- This paper considers a special case of Z' coupling to SU(3) only
- Z' → two body decays are suppressed, only three body decays possible



- Z' resonance in $t\bar{t}$ + jet

Chromophilic Z' Search: Analysis Details

CDF@ 2 with the full dataset
lepton + jets channel

Selection:
Events with at least 5 jets and exactly 1 lepton
At least 1 b-tagged jet

Object Definitions:
Jets, pT > 20 GeV
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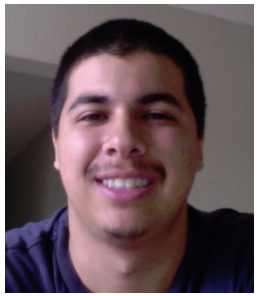
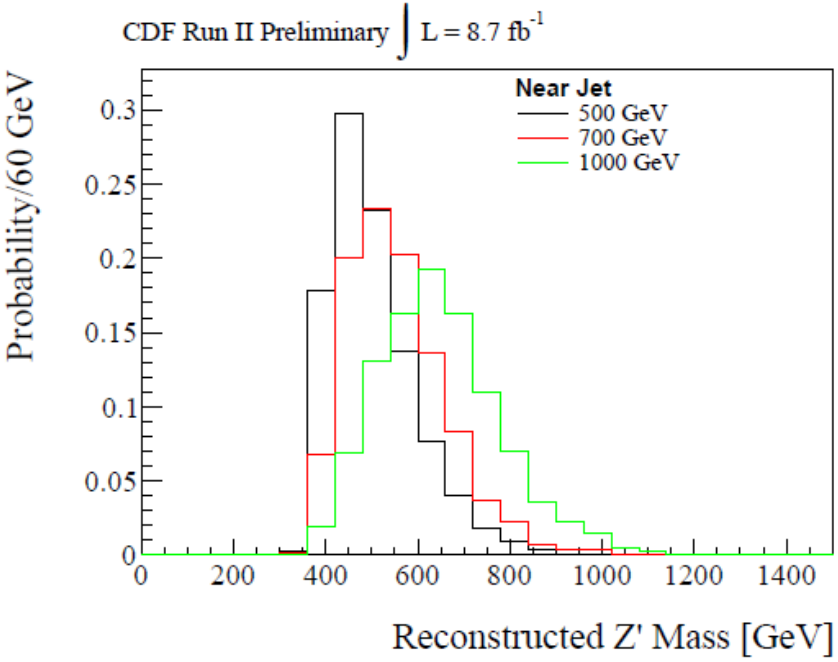


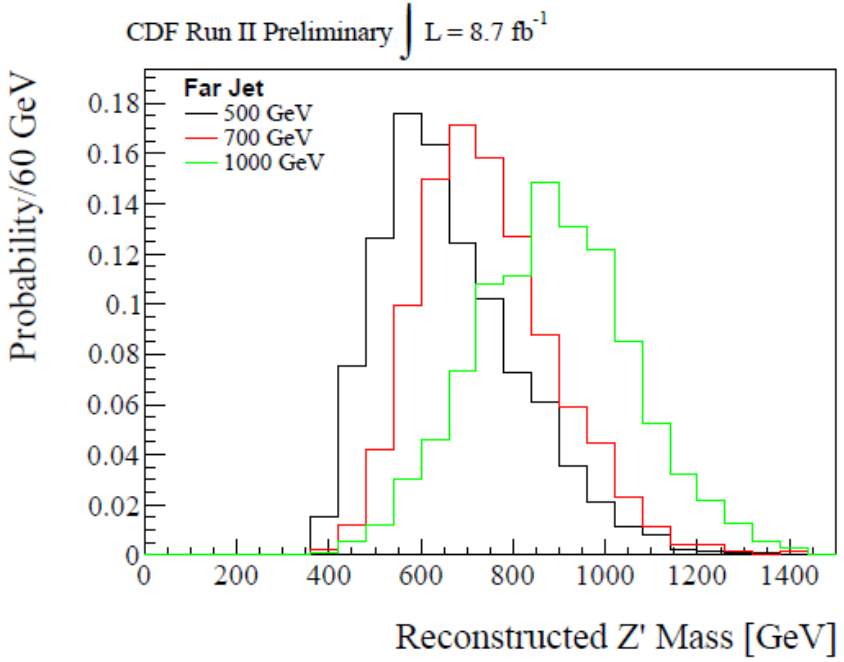
Mazin Khader+
Mike Yen

Major Standard Model Backgrounds
Top-quark pair production
W + jets

Resonance Recreation

- We use the top kinematic χ^2 fitter to find which 4 jets best fit a $t\bar{t}$ topology
- We estimate $dR(jet,t\bar{t}) \times pT_{jet}$ for all remaining jets
  - Smallest – 'near jet' reconstruction
  - **Largest – 'far jet' reconstruction**



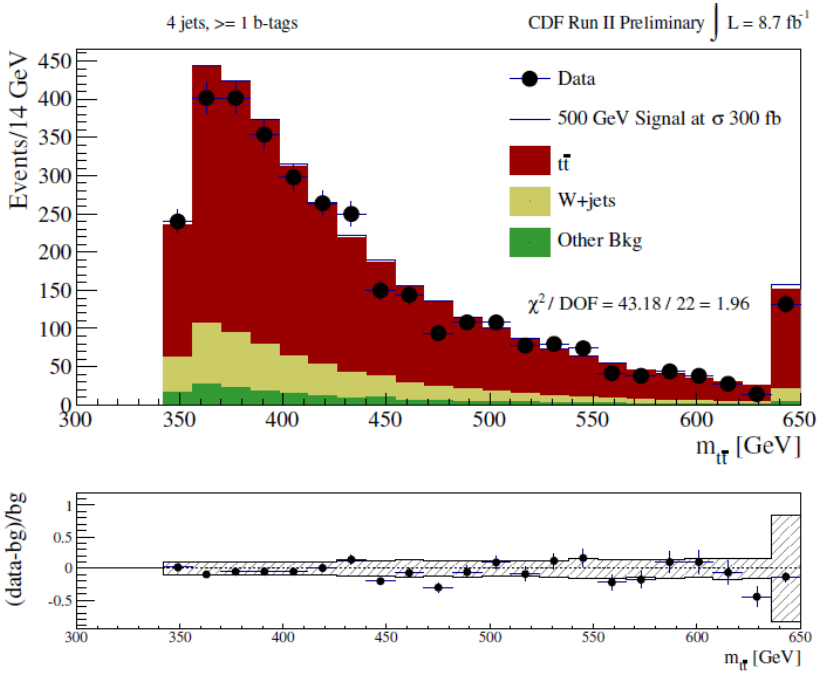


Background Validation

We validate the Monte Carlo modeling of the SM backgrounds in control regions

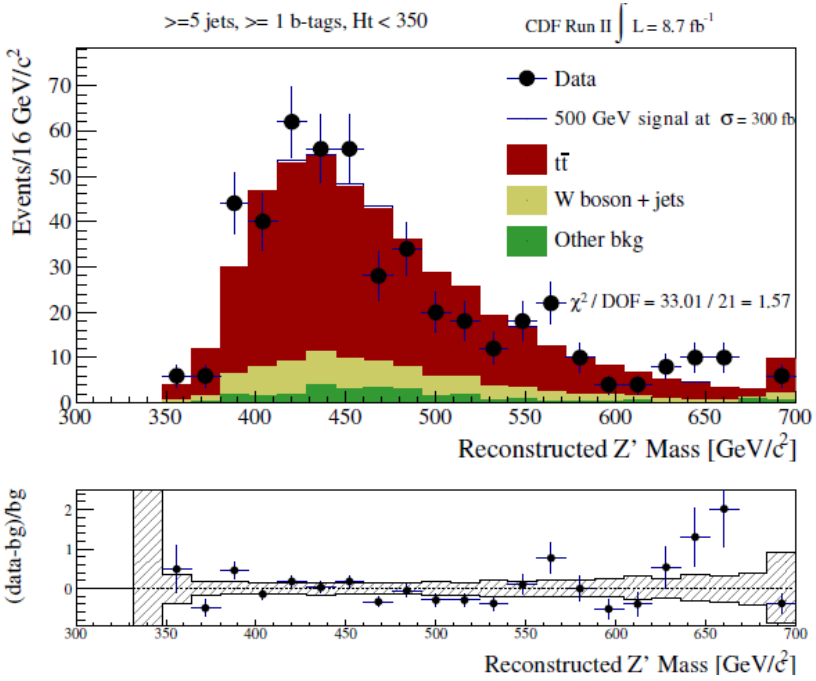
Top-quark pair production and W + jets processes are the major backgrounds

Top-quark pairs dominated region

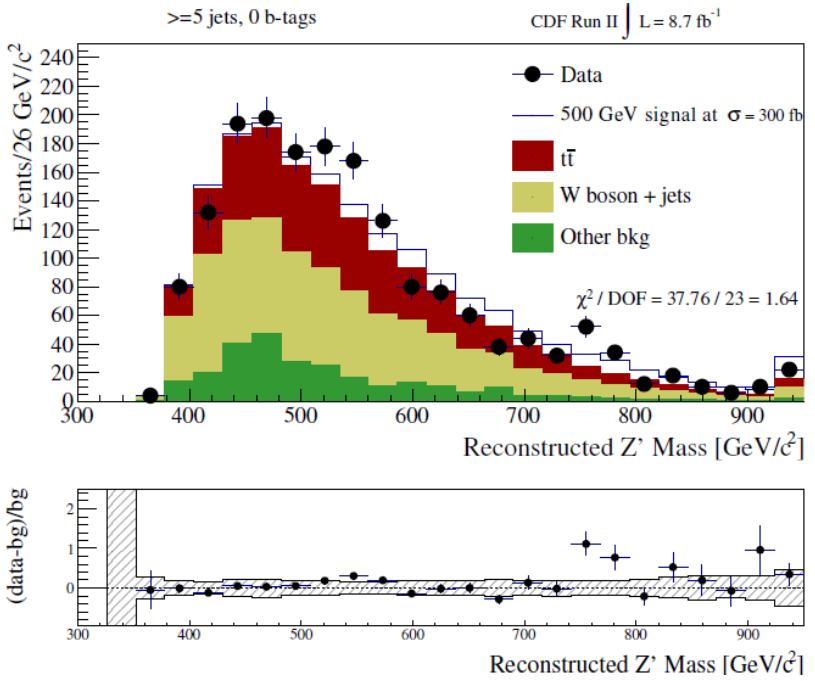


Background Validation

Top-quark pairs dominated region

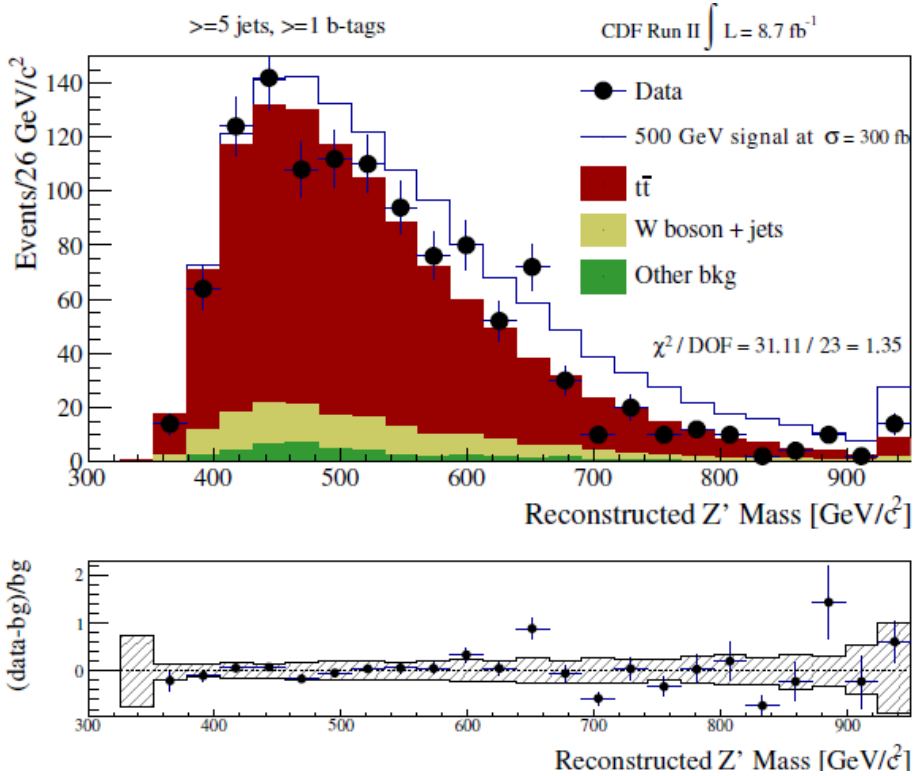


Top-quark/W + jets region



Signal Region

Data is consistent with SM only hypothesis

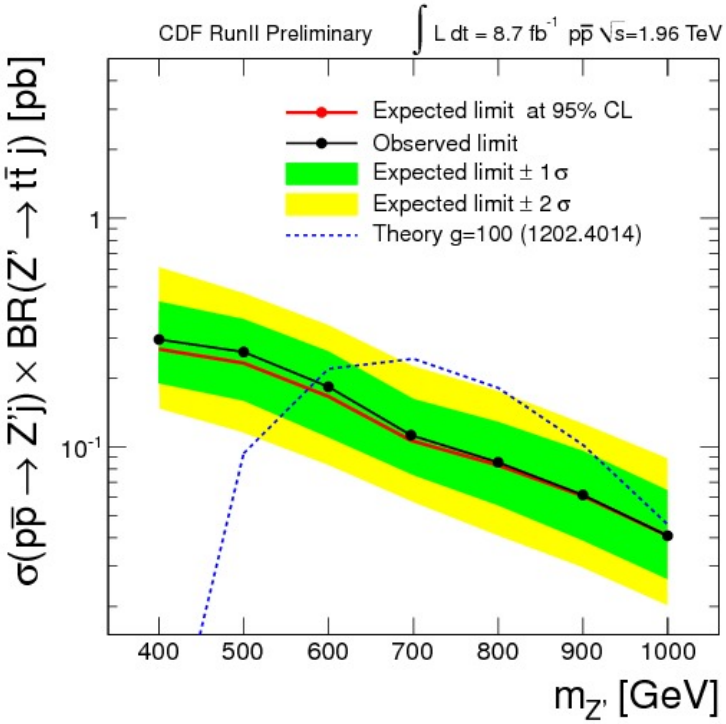


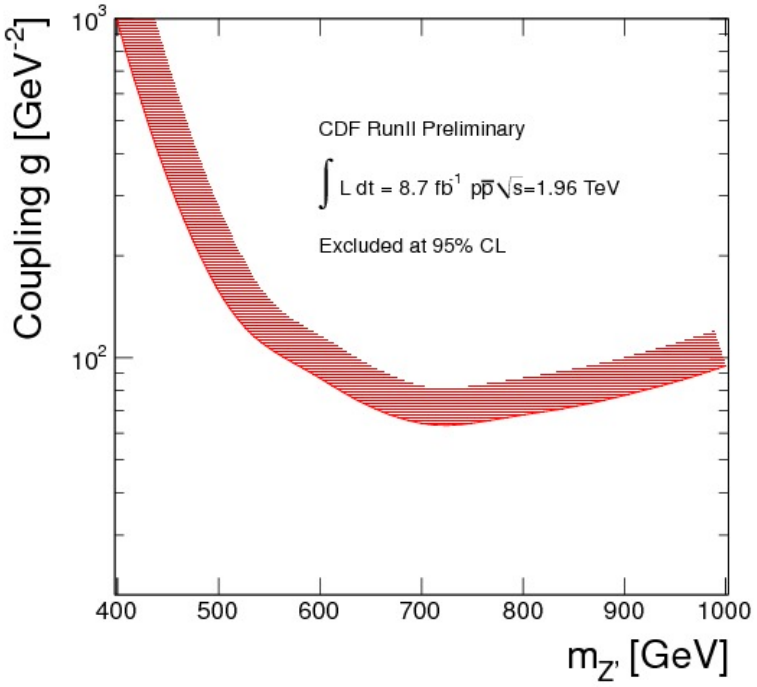
CDF Run II Preliminary 8.7 fb^{-1}			
	e+jets	μ+jets	total
$t\bar{t}$	206 ± 44	271 ± 61	477 ± 103
W+jets	31 ± 10	36 ± 12	67 ± 21
Single Top	2 ± 1	3 ± 1	6 ± 2
Z+jets	1 ± 1	2 ± 1	3 ± 1
Diboson	2 ± 1	2 ± 1	4 ± 1
QCD	11 ± 11	< 1	11 ± 11
Total	254 ± 47	314 ± 62	568 ± 105
Data	261	325	586
Signal at $\sigma = 300$ fb:			
500 GeV/c^2	55 ± 2	89 ± 4	144 ± 7

Table 4: Expected background and signal and observed yields in the $t\bar{t}$+jet region, with at least five jets, at least one b-tag and missing tansverse energy greater than 20 GeV.

Limits

We set 95% CL limits on the cross-section, and limit the model-space
PRD, 2012 [http://arxiv.org/abs/1210.5686]





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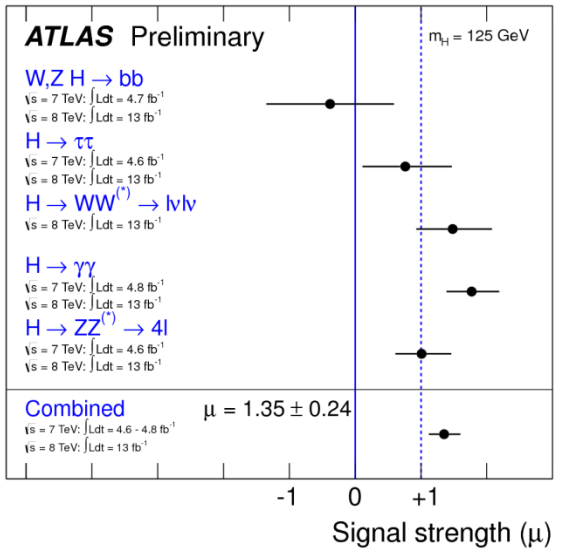
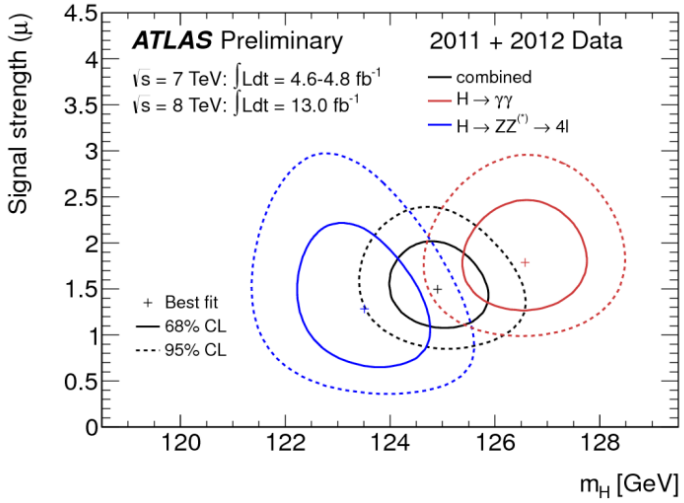
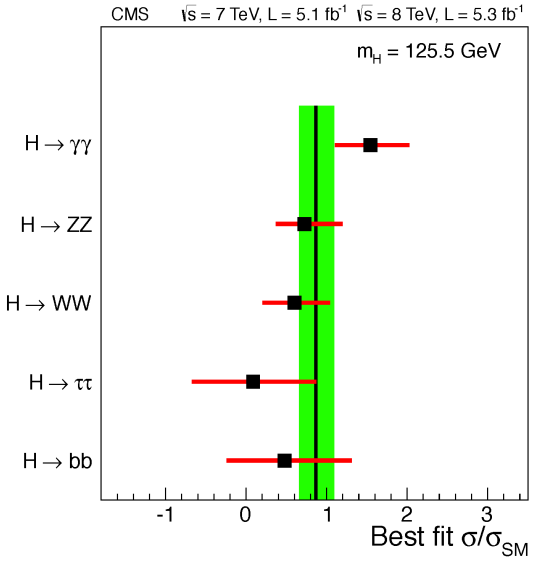
Higgs Searches

- We have a newly discovered boson at the LHC at 125 GeV!
- First task is to measure its properties
- What if it is not the SM Higgs?
  - Best case scenario
  - ATLAS and CMS both see a larger di-photon signal
  - Mass difference at ATLAS?







The 2HDM Framework

- 2 Higgs doublet Models (2HDM), a minimal extension of the discovery
  - Are there two Higgs doublets instead of one?
  - Few new particles, charged Higgs or more neutral Higgs bosons
  - Similar to SUSY as it's a class of models rather than a single model
  - Provide a rich, relevant and vastly unexplored phenomenology

- We can interpret many hints of BSM physics
  - "*Mass-degenerate Higgs bosons at 125 GeV in the Two-Higgs-Doublet Model*", Haber et al, [1211.3131]
    - Two nearly degenerate Higgses might explain the observed di-photon excess
    - Will also explain a mass difference

2HDM Search: Analysis Details

CDF@ 2 with the full dataset
lepton + jets channel

Alan Truong

Selection:
Events with at least 4 jets and exactly 1 lepton
At least 1 b-tagged jet

Object Definitions:
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Clean up, cuts reduce multijet background

Adam Johnstone

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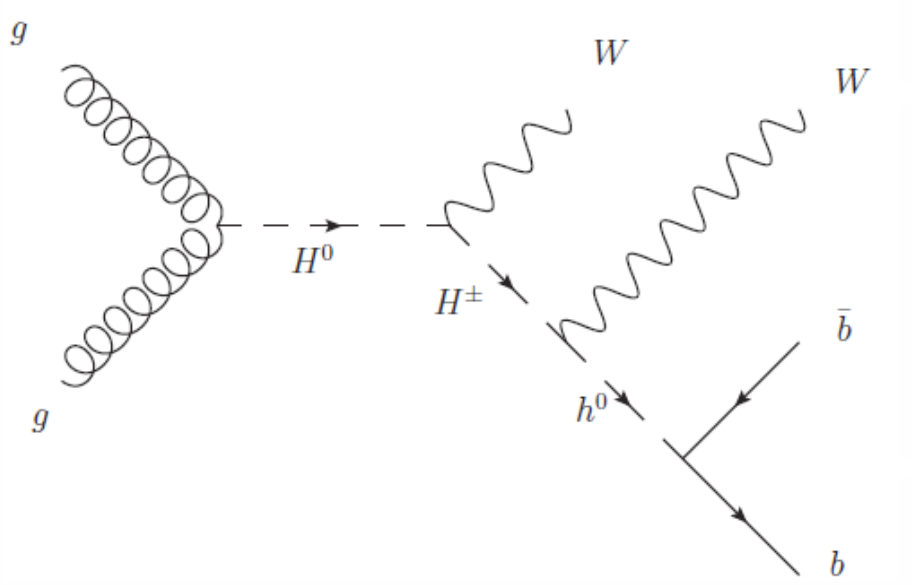
W + jets

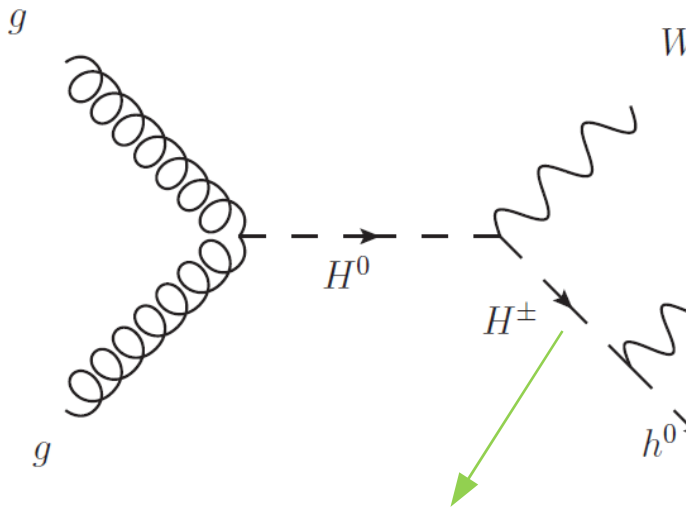
2HDM: Simplified Model Approach

- We searched for one such 2HDM cascade at CDF



- Searched for a Higgs cascade to a final state bbWW
- Three different Higgs masses
- 3 Higgs bosons, lightest one fixed at 125 GeV

Cascade Reconstruction



Lepton

Assume MET is from neutrino

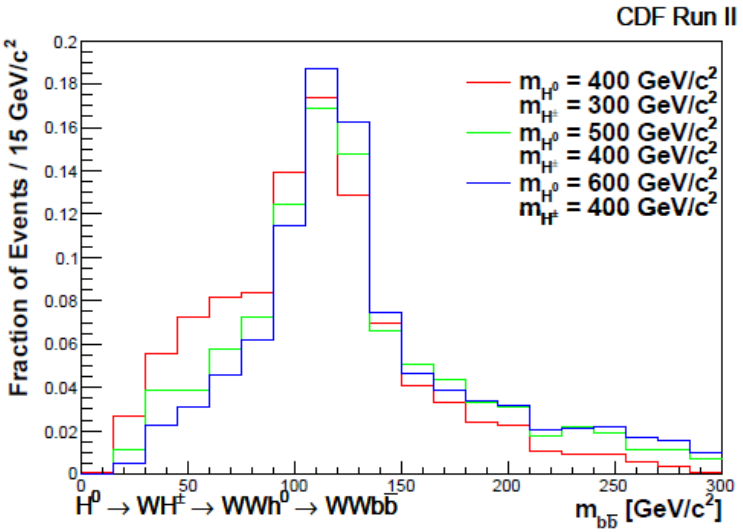
Jets with M ≈ 80.4

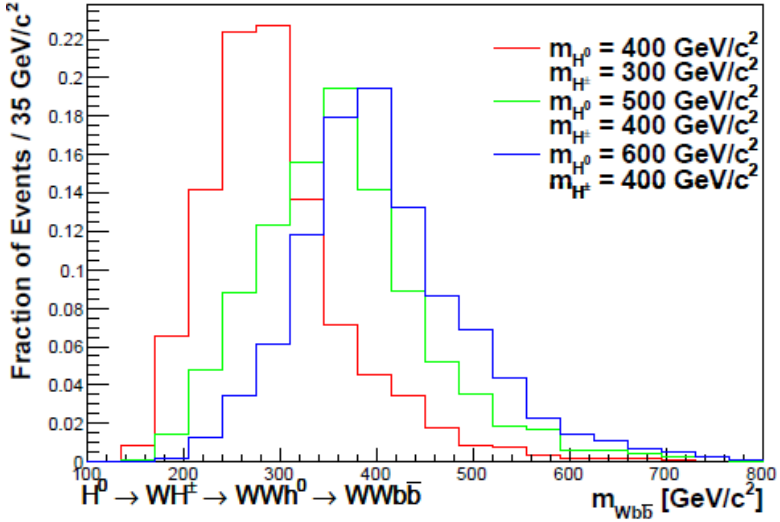
B-tagged jet

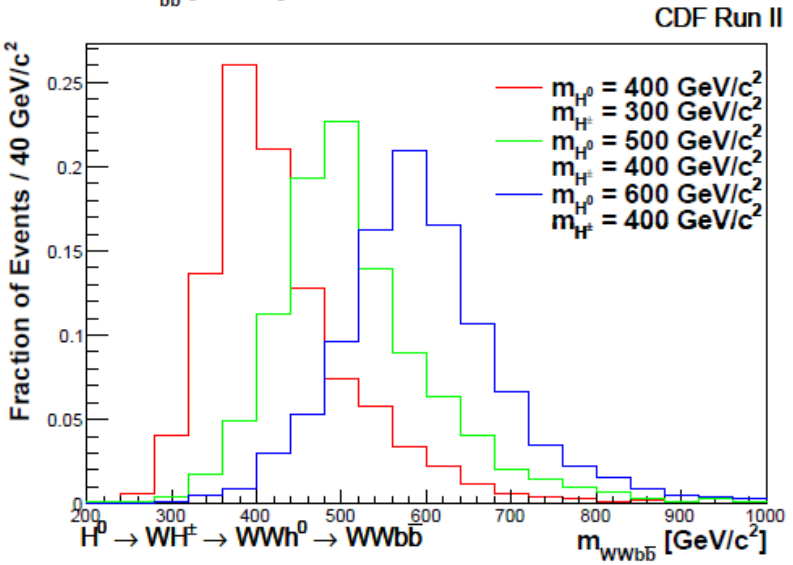
B-tagged jet/
largest pt non W jet

bbW is chosen using the W that gives the largest mass

Higgs Reconstructions







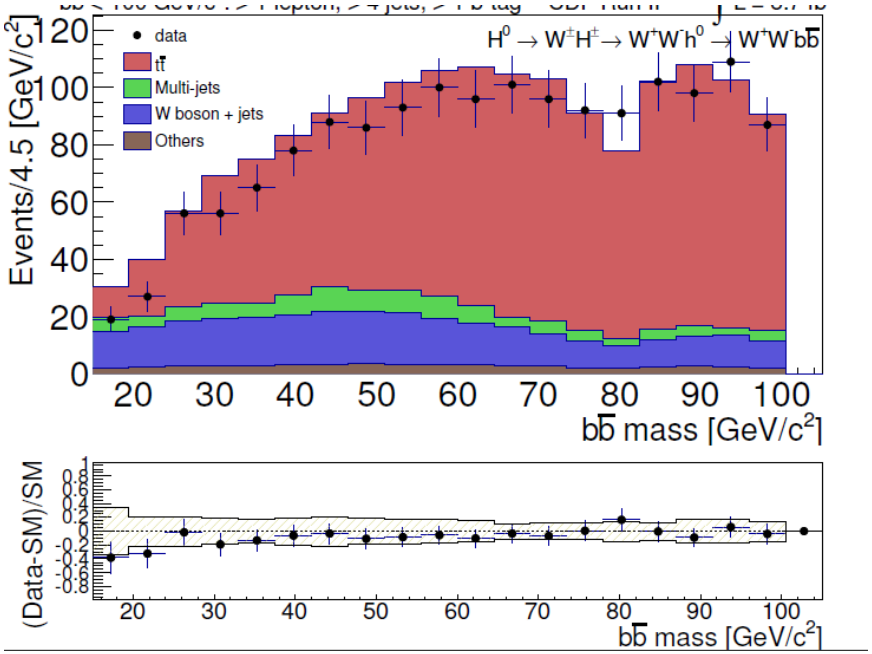
Analysis Strategy

- We scan in the two free model parameters
  - Heavy and intermediate Higgs boson masses
- Unique signal regions are defined for each signal mass point
  - Cut on reconstructed heavy and intermediate Higgs boson mass

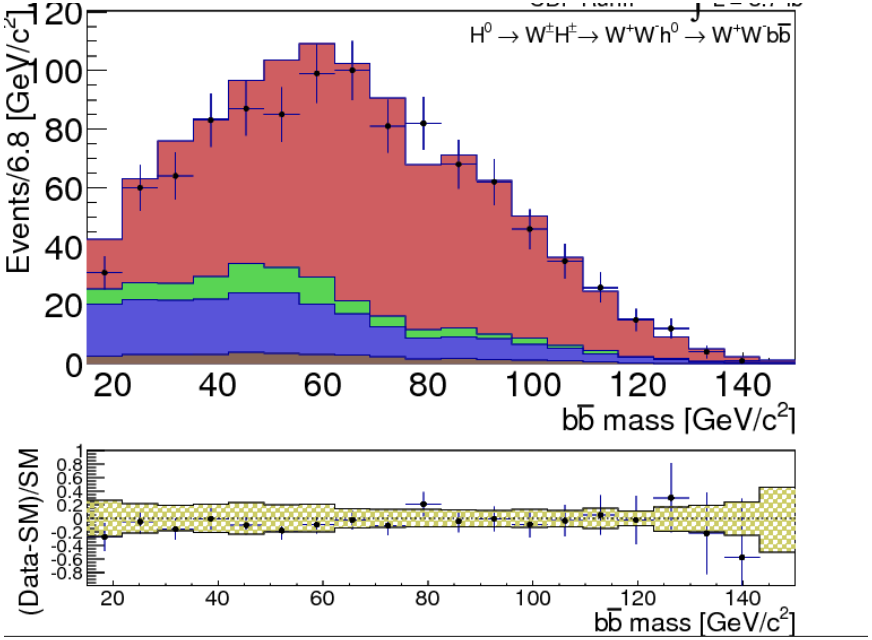
(m_{H^0}, m_{h^+})	m_{h^+} Cut	m_{H^0} Cut	Acceptance
325, 225	> 175	> 275	4.4%
400, 300	> 225	> 325	4.6%
425, 225	> 200	> 375	5.1%
500, 300	> 200	> 450	5.1%
500, 400	> 350	> 450	4.4%
525, 225	> 100	> 500	5.3%
600, 300	> 200	> 550	5.1%
600, 400	> 350	> 550	4.5%
700, 400	> 325	> 650	4.8%
700, 600	> 450	> 650	3.5%
725, 225	> 425	> 700	3.0%
800, 300	> 275	> 750	4.7%
800, 600	> 475	> 725	4.4%
900, 400	> 450	> 775	6.5%
900, 600	> 475	> 800	5.0%
1100, 600	> 475	> 975	4.8%

Control Region Modeling

Low m_bbWW Region (<450 GeV)

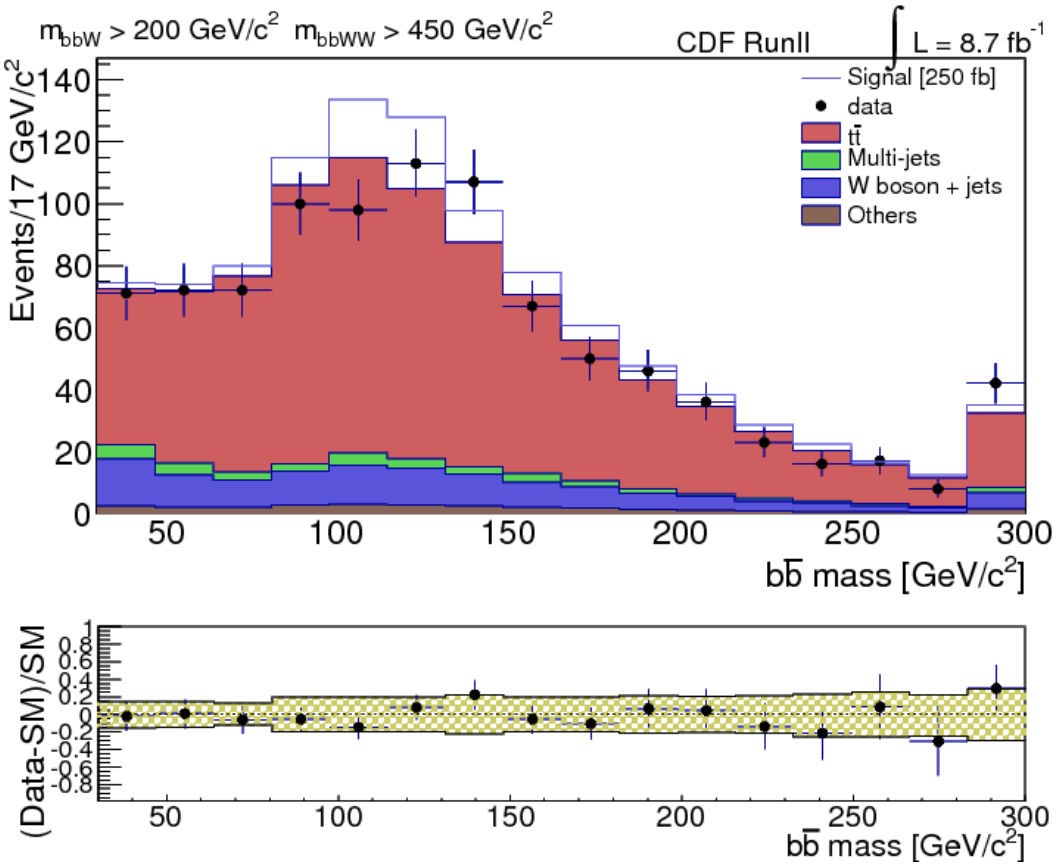


Low m_bbW Region (<250 GeV)



Signal Region

Signal mass point: 500, 300 GeV



Signal Regions

Signal mass point: 600, 300 GeV

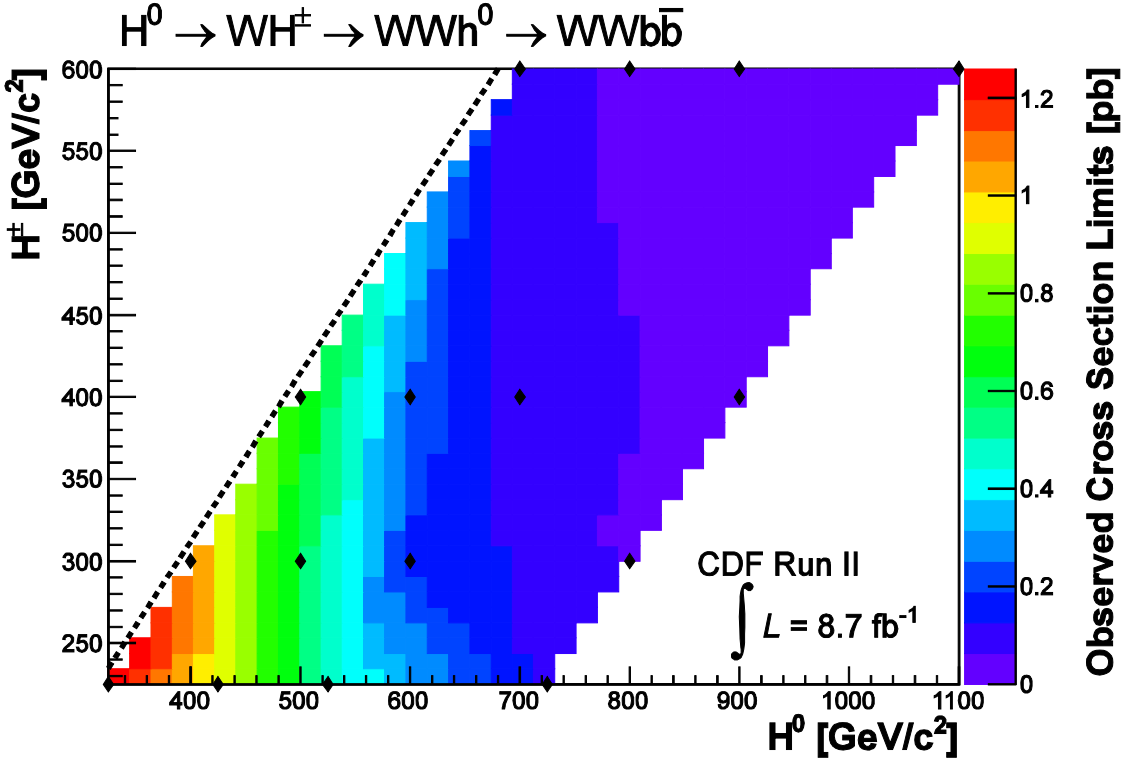
CDF Preliminary $\int \mathcal{L} = 8.7$ fb^{-1}

Process	ℓ+jets	μ+jets	e+jets
$t\bar{t}$	282.8^{+70}_{-70}	172.4^{+40}_{-40}	110.4^{+30}_{-40}
QCD	12.9 ± 20	0.0 ± 10	12.9 ± 10
W+HF	32.4^{+10}_{-20}	20.3^{+9}_{-10}	12.1^{+7}_{-10}
W+LF	18.5^{+10}_{-20}	11.4^{+7}_{-10}	7.1^{+6}_{-10}
Diboson	3.3 ± 0.3	2.0 ± 0.2	1.3 ± 0.2
Z+jets	3.5 ± 0.4	2.2 ± 0.2	1.3 ± 0.1
Total	358.4^{+70}_{-70}	211.2^{+40}_{-40}	147.2^{+30}_{-40}
Data	337	194	143
Signal	391.3 ± 30	241.6 ± 20	149.7 ± 20

Table for signal point $b\bar{b}WW$ 600 GeV and $b\bar{b}W$ 300 GeV with requirements at least 4 jets, at least 1 b-tagged jet, $b\bar{b}W$ greater than 200 GeV, $b\bar{b}WW$ greater than 550 GeV.

Result

- Data was found to be consistent with Standard model expectation, set limits in mass space
- PRL, 2012 [http://arxiv.org/abs/1212.3837]
- Ongoing effort at ATLAS ~ result coming soon



Commonalities

- Although all three analyses followed independent analysis paths/reviewers at CDF at different times, they shared several features

- Searches for new physics in the lepton + jets channel, with 4 or 5 jets and at least 1 b-tag
  - Same dataset
  - Background estimate sharing
  - Similar validation regions

- Required topology reconstruction
  - Reconstruction methodology sharing
  - Reusing the the top kinematic fitter

- Constrain new physics processes
  - Similar limit setting procedures

Conclusion

- We employed a strategy of sharing of analysis resources
- We completed three analyses at CDF in the top-quark sector
  - A search for top + jet resonance
  - A search for a chromophilic Z'
  - A search for a two Higgs boson cascade

Back Up

Top+j Kinematic Fitter

- An example with 700 GeV