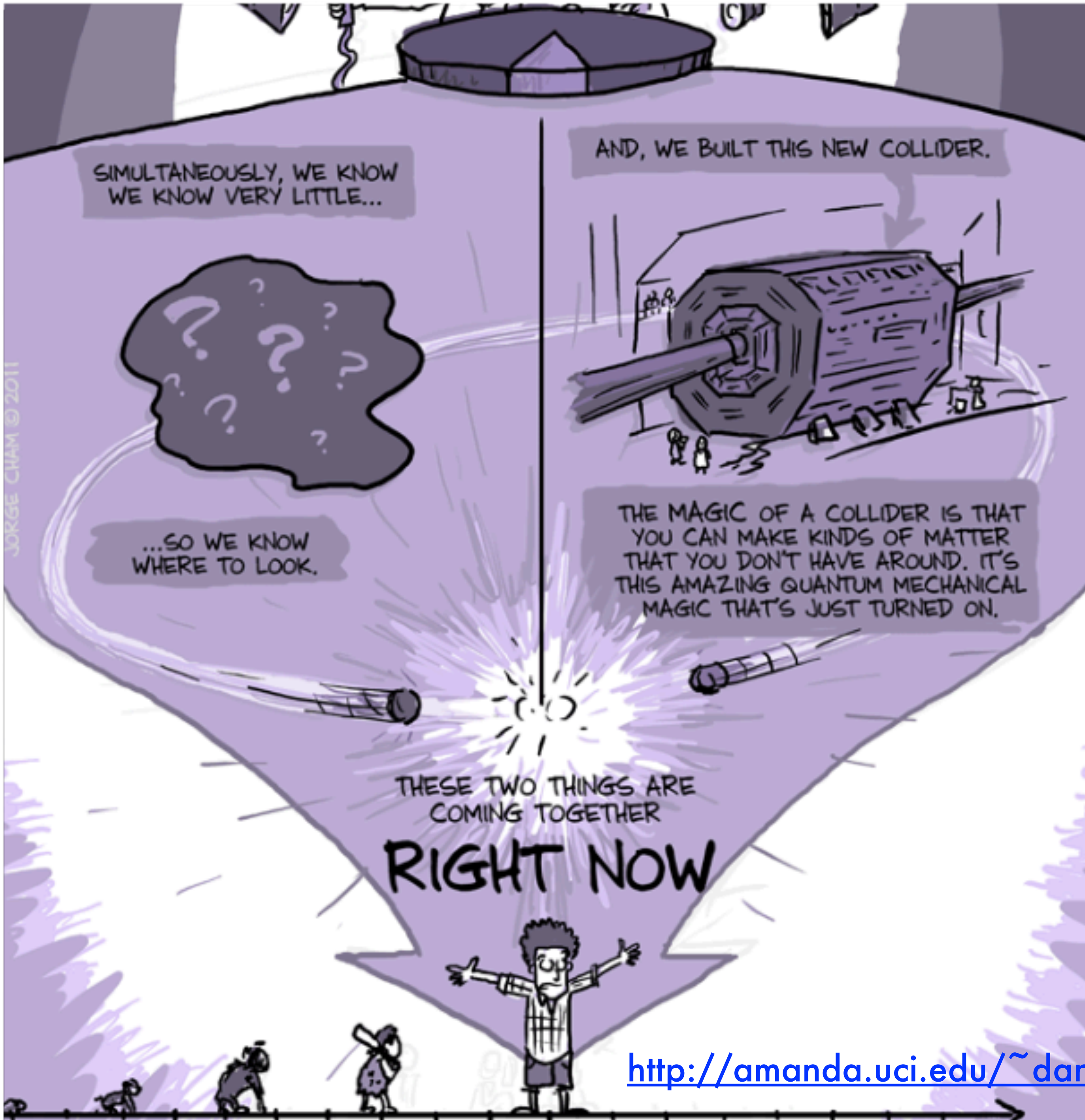
simple boosted objects and novel views of top

Featuring brand new ATLAS, CDF results!

Daniel Whiteson
UC Irvine

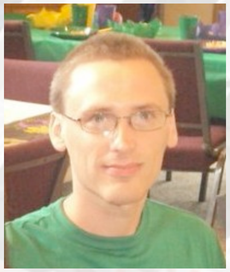
Seminar, UC Davis, Feb 2012



http://amanda.uci.edu/~daniel/comic.html

▶ **Whiteson**, ZZ->4l, 4l searches

Postdocs



Ning Zhou, SS 2l, SS tops, γ+MET ◀

▶ Andy Nelson, ZZ + searches

Grads

▶ Robert Porter, CDF SS dileptons

Michael Werth, t′ in OS dileptons 34/pb ◀

t′ in OS dileptons 1/fb

▶ Kanishka Rao, CDF top+MET

b′ in l+jets

t+j resonance (CDF+ATLAS)

resonances in top

Eric Albin, γ+MET ◀

Color Key
CONF
Published
In Review
Planned

Undergrads

▶ Johnny Ho, t+j resonance (ATLAS)

Jared Vasquez, CDF ZZ+met, t′ to OS dilep 5/fb ◀

Four younger students Z′ to gluons, resonances in top

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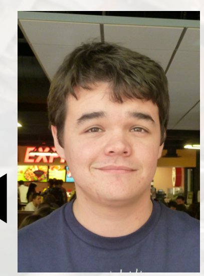

Johnny Ho, t+j resonance (ATLAS)

Jared Vasquez, CDF ZZ+met, t′ to OS dilep 5/fb

Four younger students Z′ to gluons, resonances in top

Outline

I. Introduction: experimental innovation

II. Simple boosted objects

III. Novel views of top quark events

VI. Concluding rant: open data

History of biology PhDs

1980s

Choose a
gene

Manually sequence <5

Crude comparisons

1990s

Choose a
set of genes

Automatically sequence 10s

Compare to databases of genes

2000s

Choose a
genome

Cheaply sequence 1M in < 1 week

Invent new analytics to compare genomes

Still don't understand correlation vs causation

History of experimental HEP PhDs

1980s

Choose a channel/signal

Enumerate backgrounds

Estimate backgrounds

Estimate uncertainties

Set limits

1990s

Choose a channel/signal

Enumerate backgrounds

Estimate backgrounds

Estimate uncertainties

Set limits

2000s

Choose a channel/signal

Enumerate backgrounds

Estimate backgrounds

Estimate uncertainties

Set limits

Of course advances have been made for each step

So what is modern?

New experimental tools

Sophisticated triggering

Multi-variate analysis/ Machine learning

jet flavor tagging

monopoles

lepton-jets

track-less jets

boosted objects

new resonances

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Theory papers

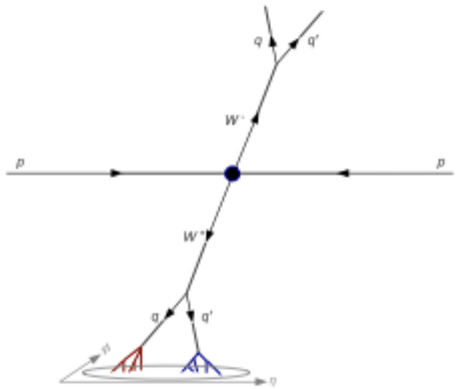
Identifying Boosted Objects with N-subjettiness

Jesse Thaler and Ken Van Tilburg

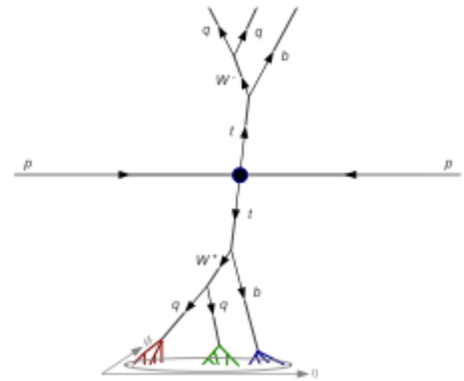
Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

E-mail: jthaler@jthaler.net, kvt@mit.edu

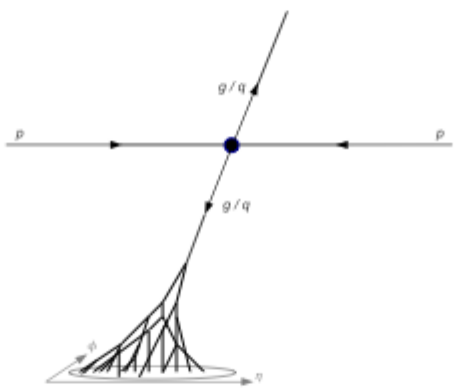
Counting sub-jets



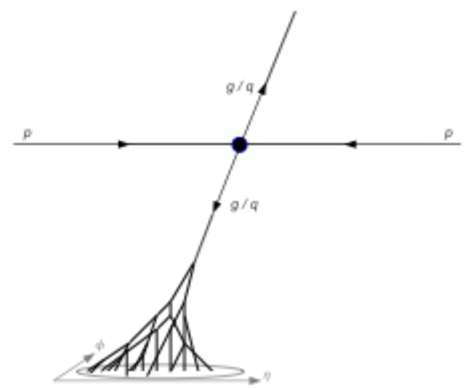
(a)



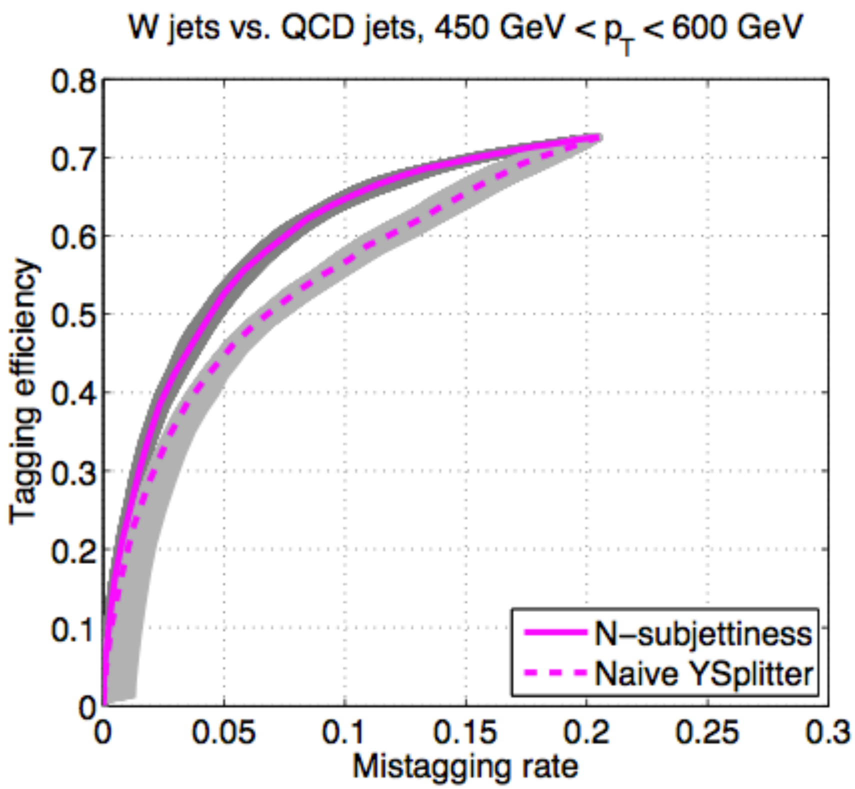
(a)

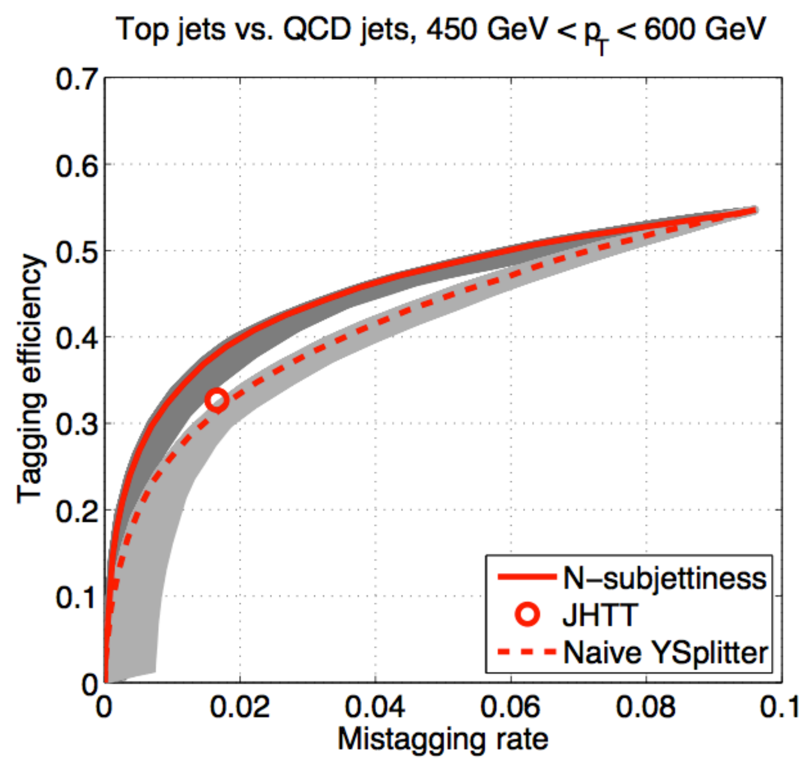


(c)



Performance





How realistic?

Hard process
→Pythia
→Toy Calorimeterization
→FastJet

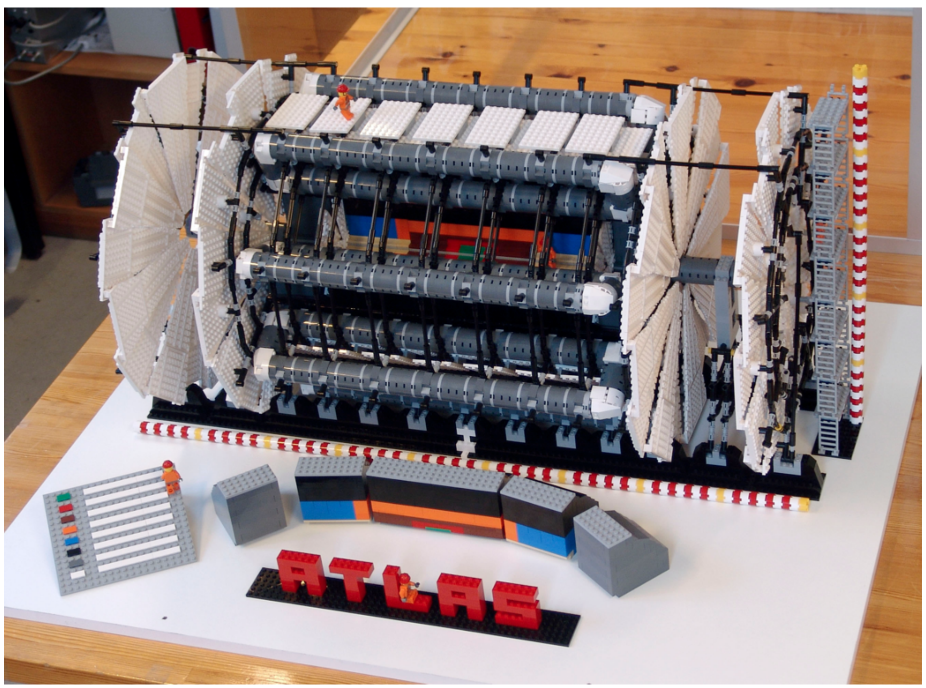
To partially simulate detector effects and to speed up jet reconstruction, observable final-state particles with $|\eta| < 4$ are collected into "calorimeter" cells arranged in a rectangular lattice with 80 rapidity (η) and 64 azimuth (ϕ) bins (corresponding to approximately 0.1×0.1 sized cells). The calorimeter momenta are interpreted as massless pseudo-particles with energy given by the calorimeter energy.

Play time

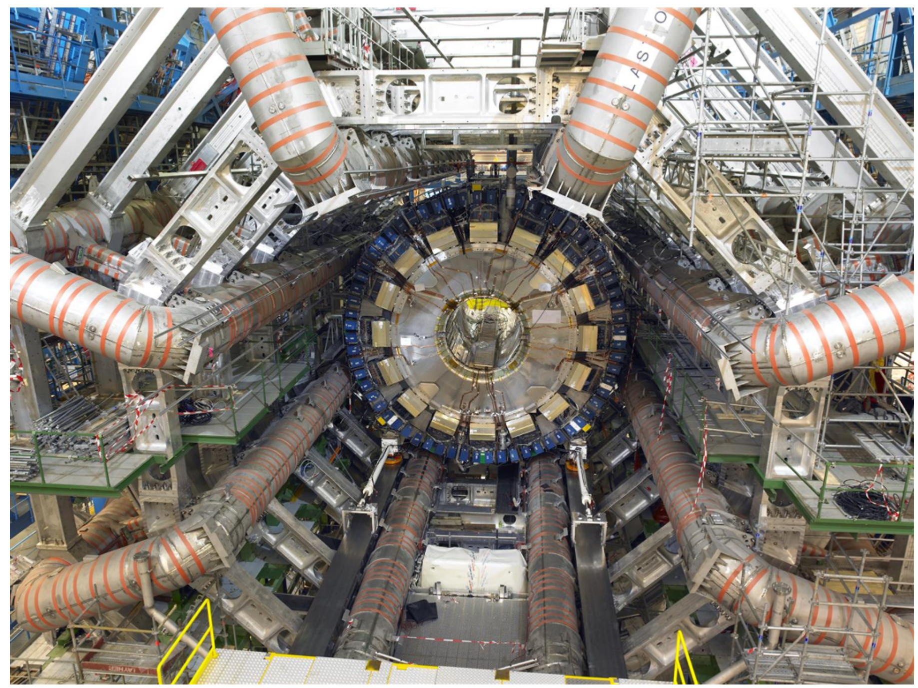
theory performance : results in data

=

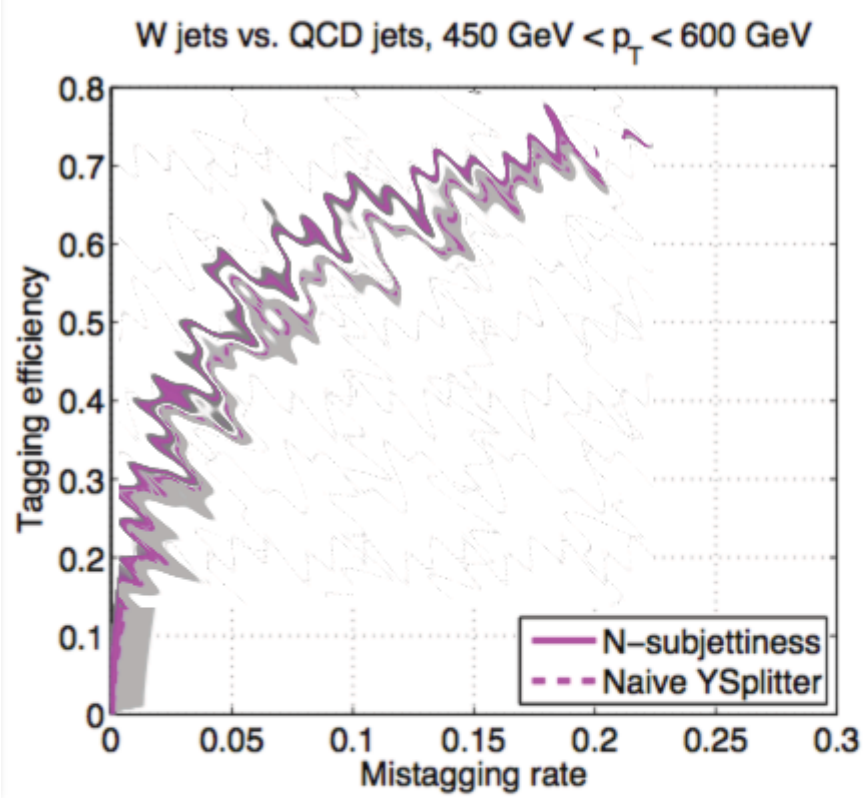
LEGO ATLAS : real ATLAS

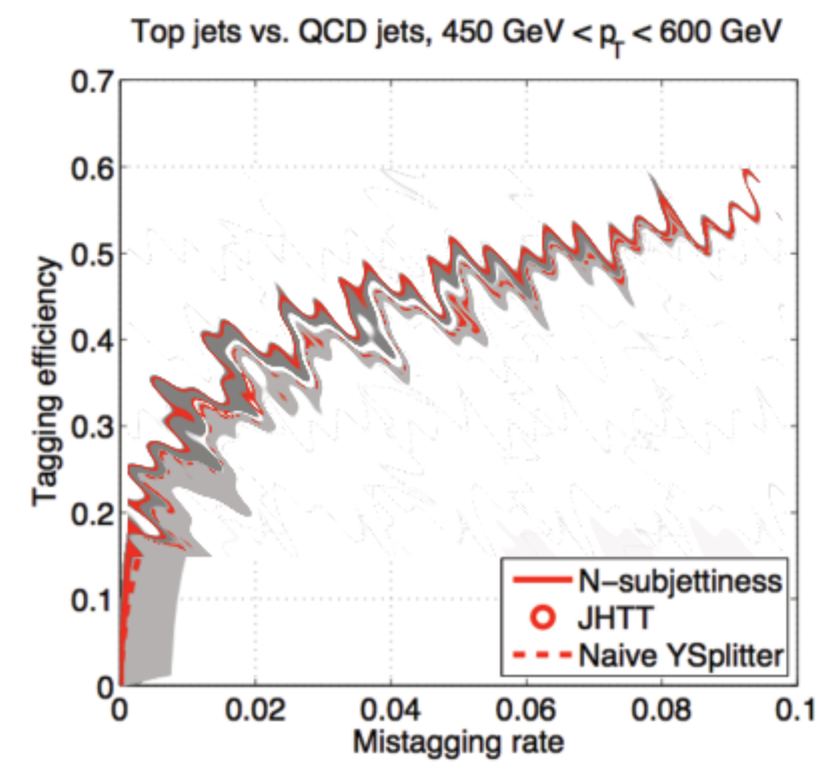


:



How I read these plots



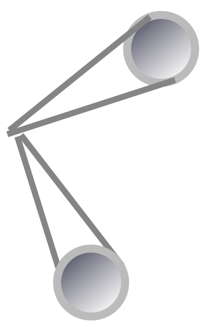


<u>Summary</u>: a lot of work for minor improvements which may be irrelevant

Simple approach

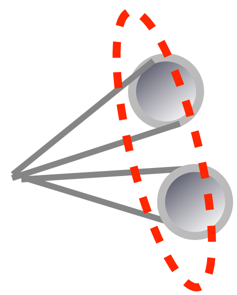
Do we need fatjets and subjets at all?

Small pT



Use narrow jets.

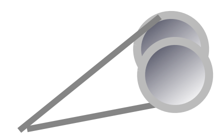
Medium pT



Use narrow jets.

Group jets in
fat cones

Large pT

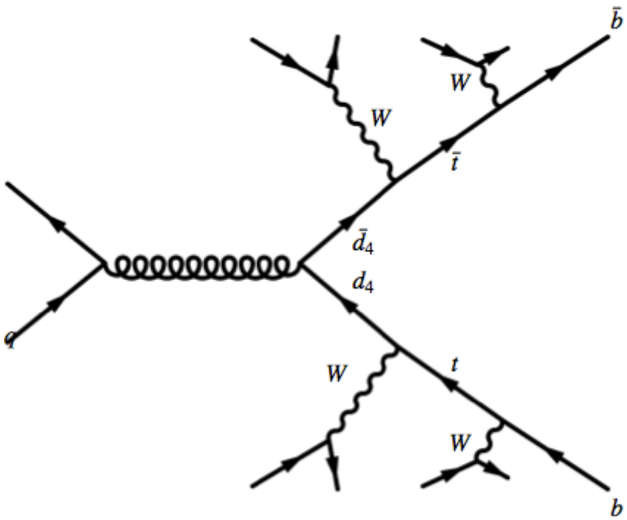


Use narrow jets.

Measure jet mass

b′→ttbar→l+jets

Heavy particles decaying to top+jets



Selection

One lepton (e or μ)

MET>20

At least **five** jets

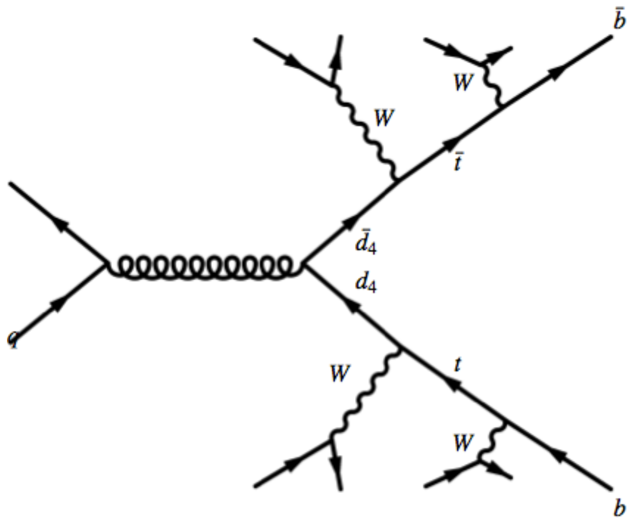
Dataset

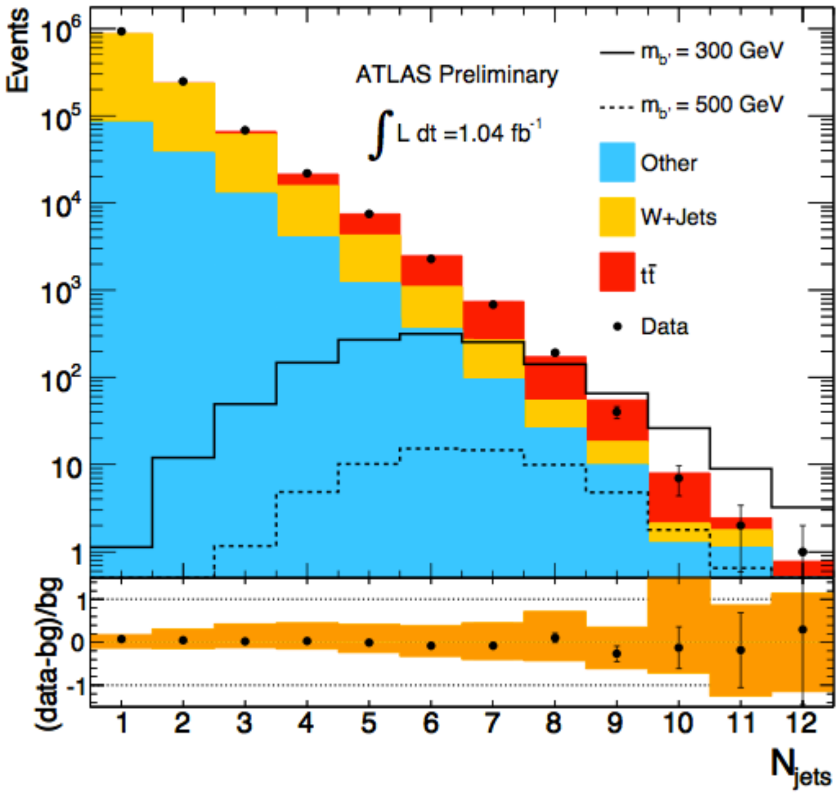
ATLAS 1/fb

Analysis done largely by a single grad student: Kanishka Rao, UCI

b′→ttbar→l+jets

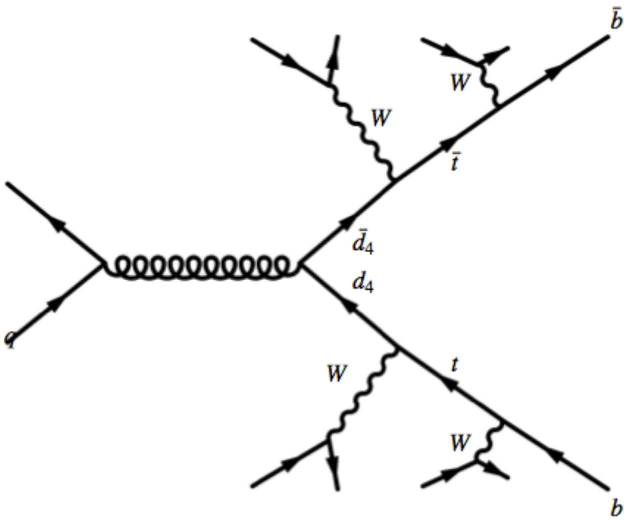
Heavy particles decaying to top+jets

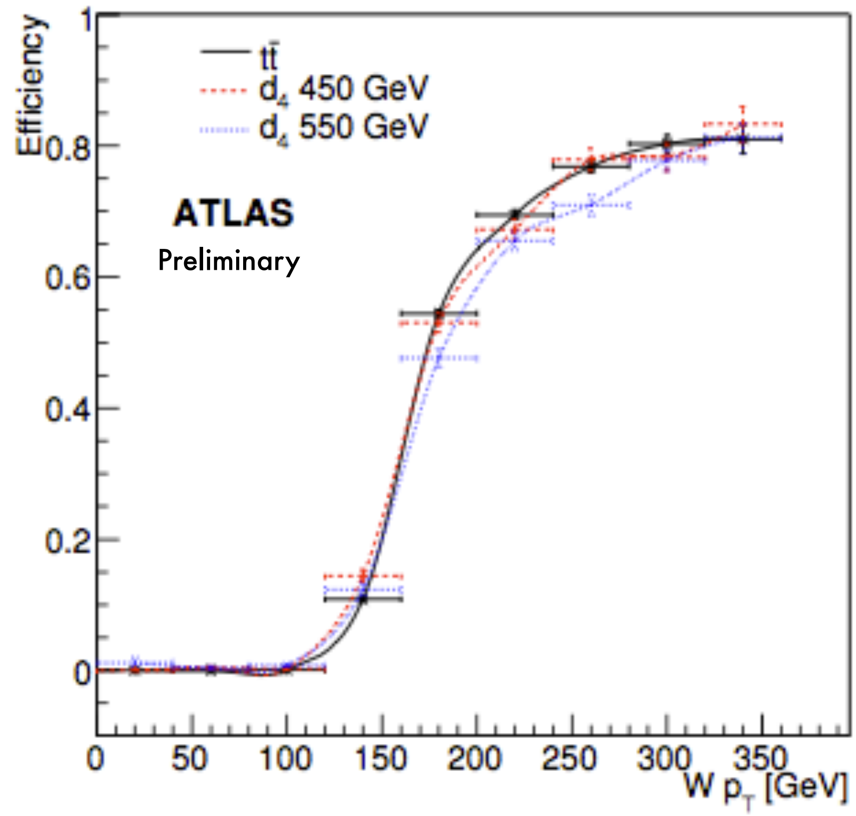


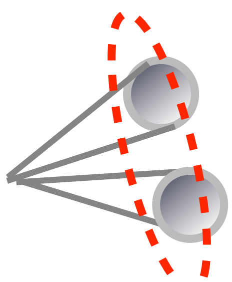


b′→ttbar→l+jets

Heavy particles decaying to top+jets **with boosted W's**

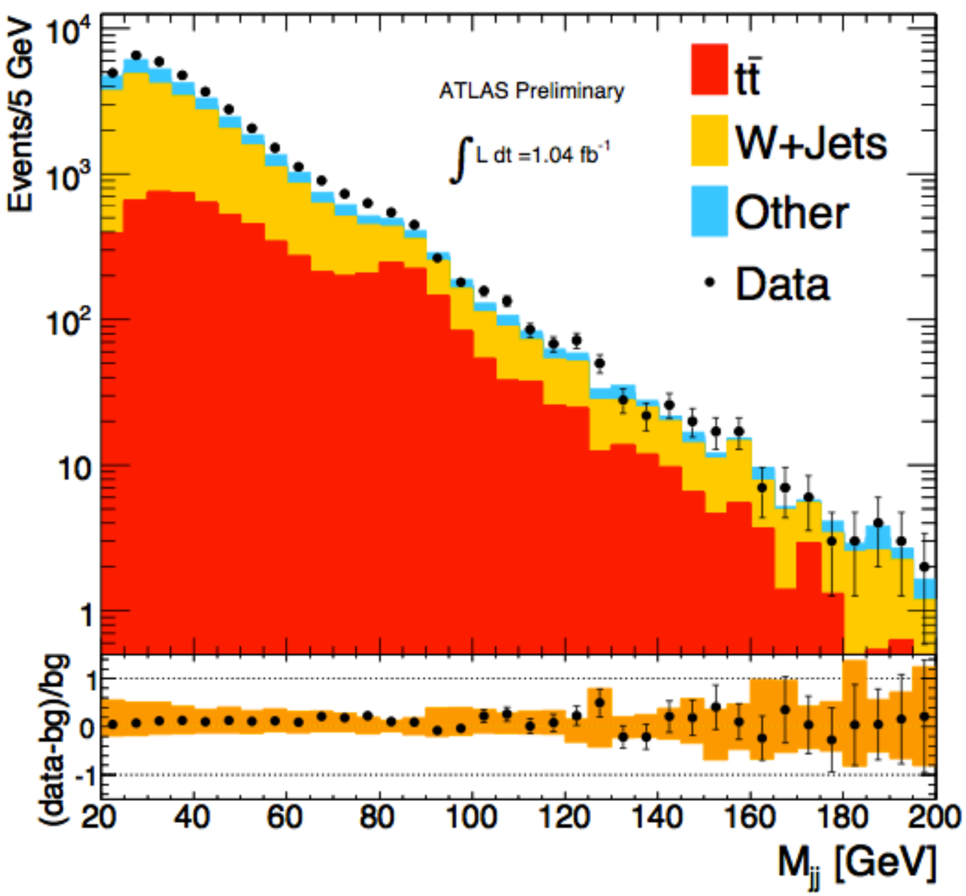


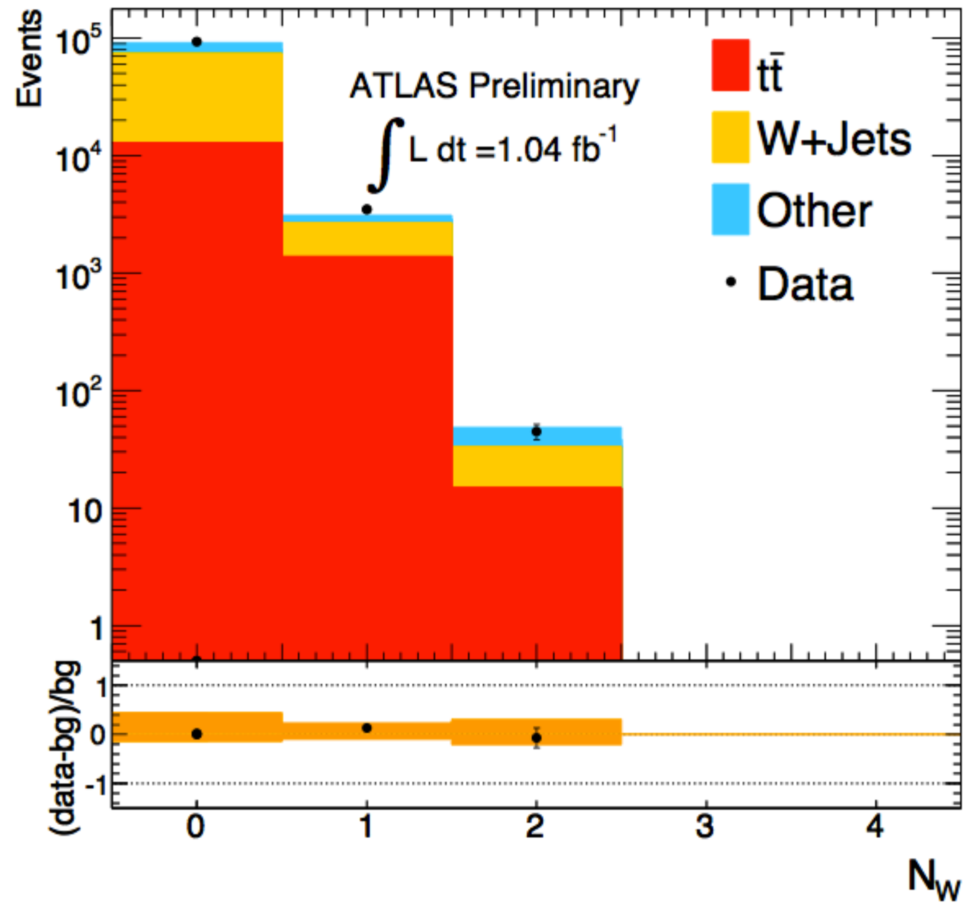




Find **standard jets** within a cone examine dijet mass

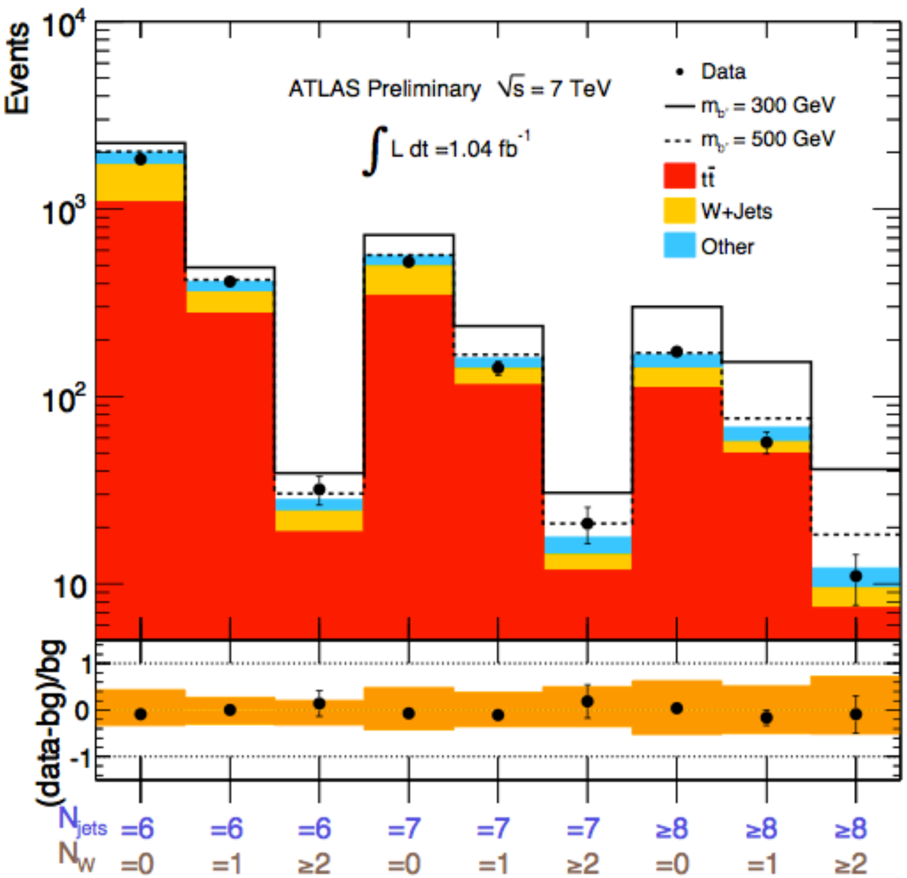
Validate in ttbar

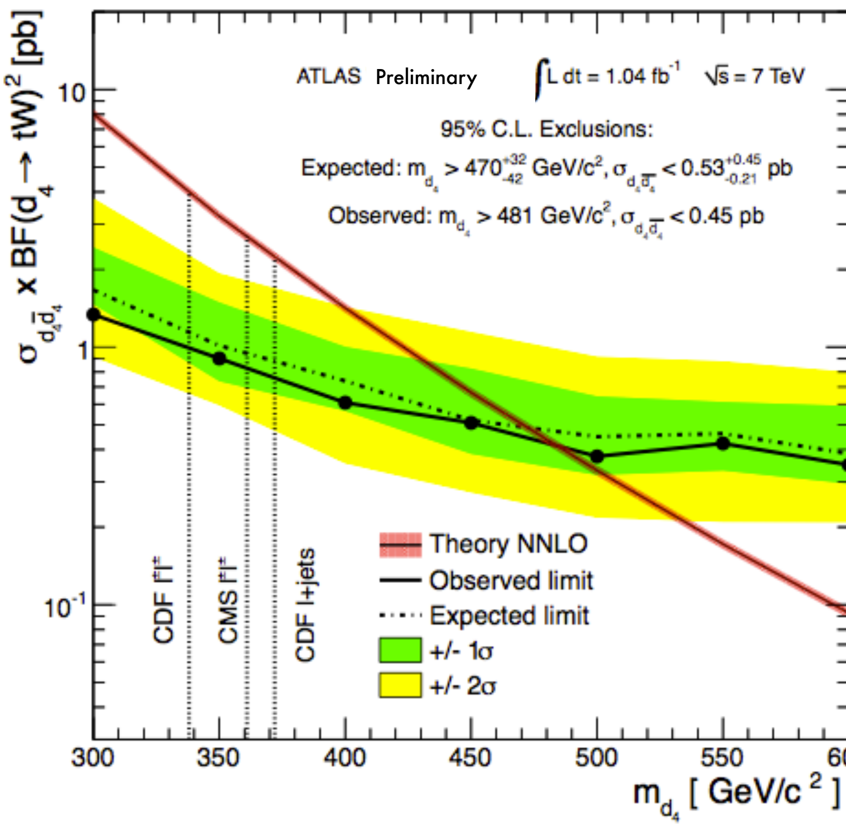




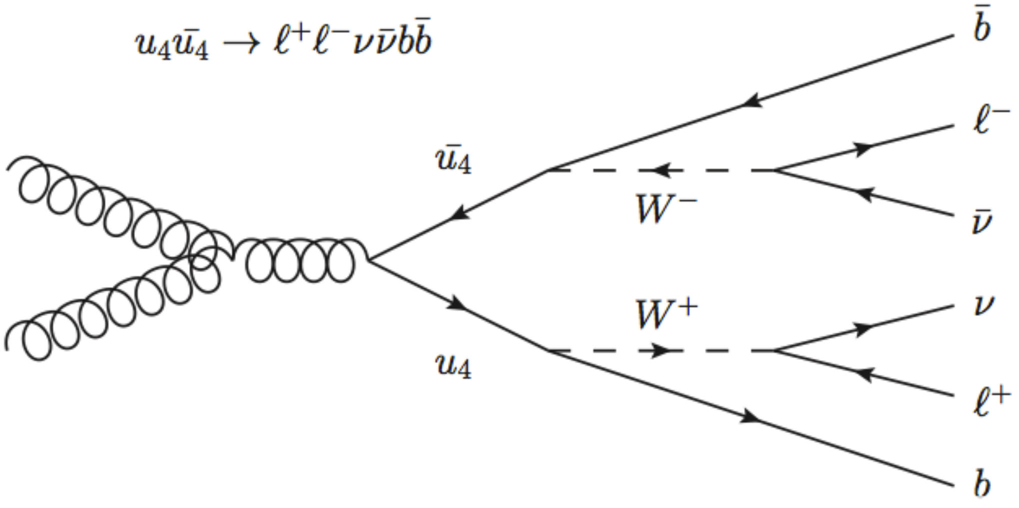
events with 3 or 4 jets

results


ATLAS Preliminary √s = 7 TeV
∫L dt =1.04 fb⁻¹
Data
m_b' = 300 GeV
m_b' = 500 GeV
tt̄
W+Jets
Other
Events
(data-bg)/bg
N_jets =6 =6 =6 =7 =7 =7 ≥8 ≥8 ≥8
N_W =0 =1 ≥2 =0 =1 ≥2 =0 =1 ≥2


ATLAS Preliminary ∫L dt = 1.04 fb⁻¹ √s = 7 TeV
95% C.L. Exclusions:
Expected: m_d4 > 470 +32 -42 GeV/c², σ < 0.53 +0.45 -0.21 pb
Observed: m_d4 > 481 GeV/c², σ < 0.45 pb
CDF l±l±
CMS l±l±
CDF l+jets
Theory NNLO
Observed limit
Expected limit
+/- 1σ
+/- 2σ
σ × BF(d4 → tW)² [pb]
m_d4 [GeV/c²]

t′



Selection

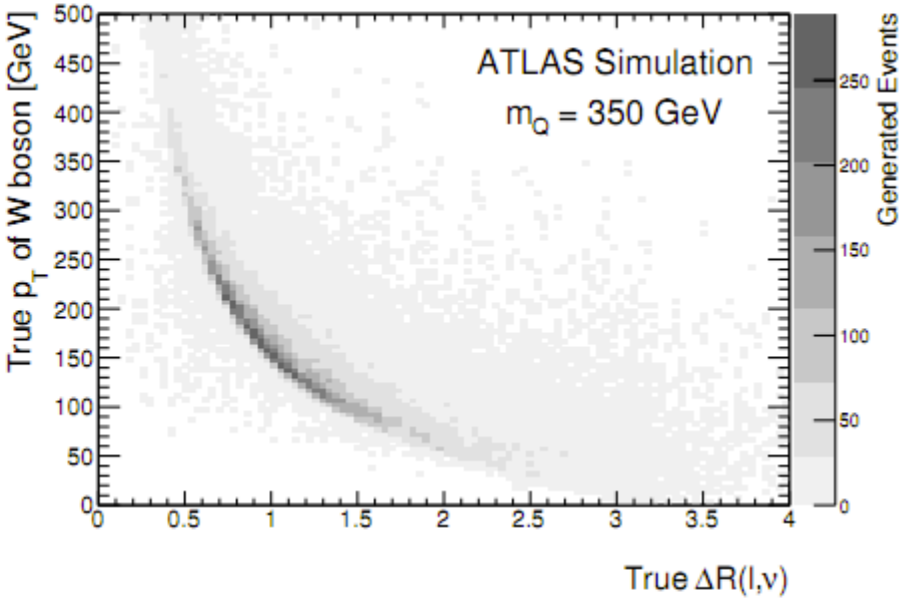
Two OS lepton (e or μ)
MET>60
At least two jets

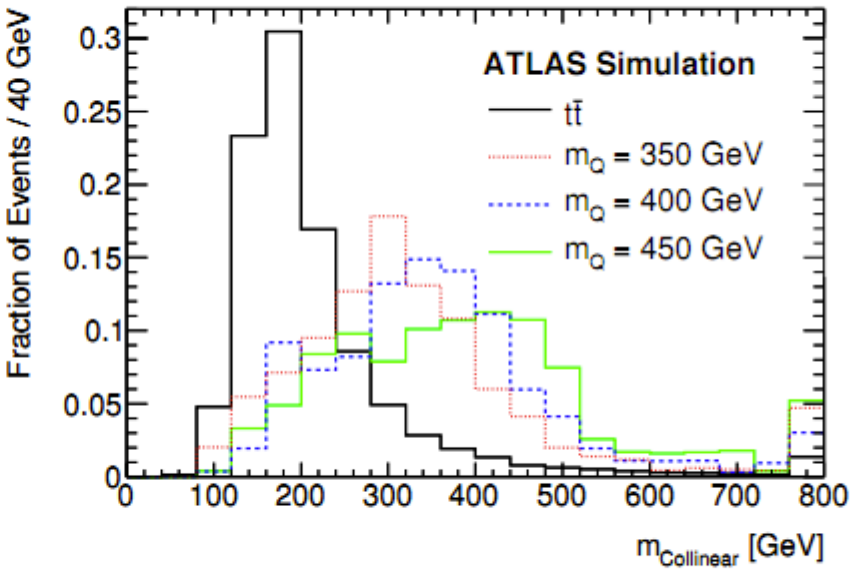
Dataset

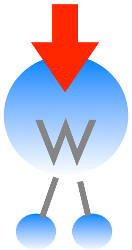
ATLAS 1/fb

Analysis done largely by a single grad student: Michael Werth, UCI

OS QQ->WqWq

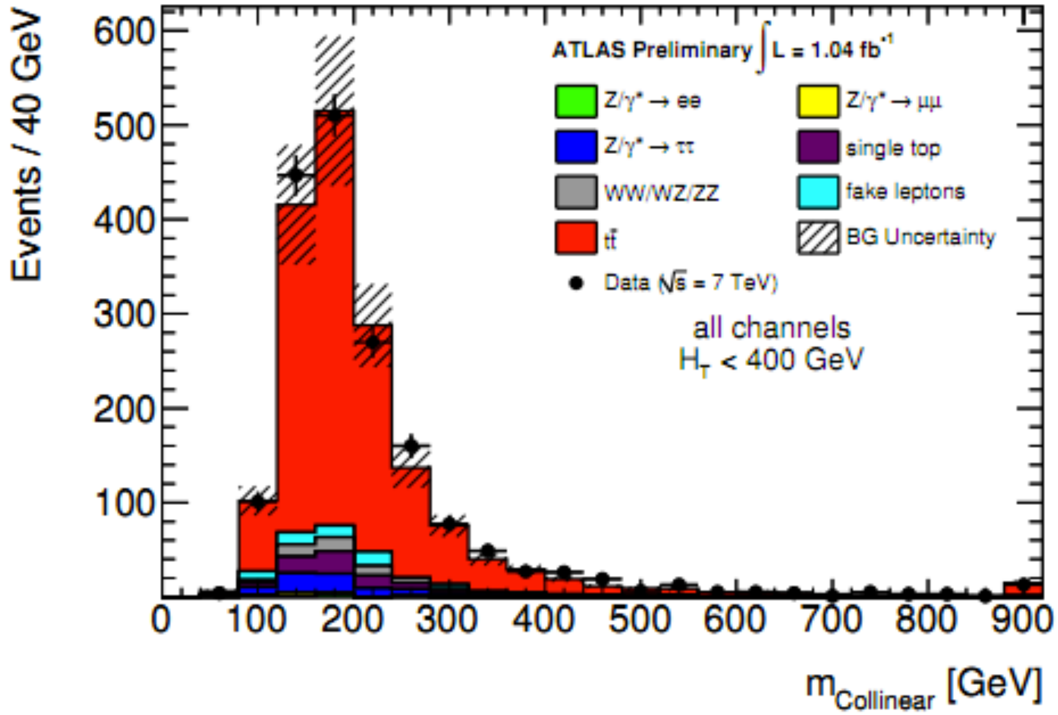




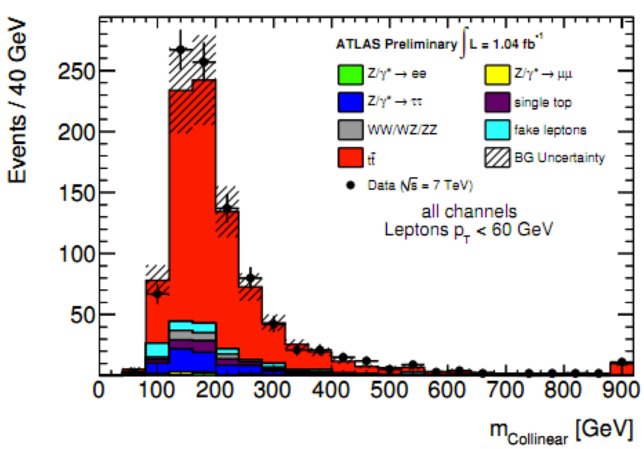


More W p_T means smaller opening angle between lepton and neutrino

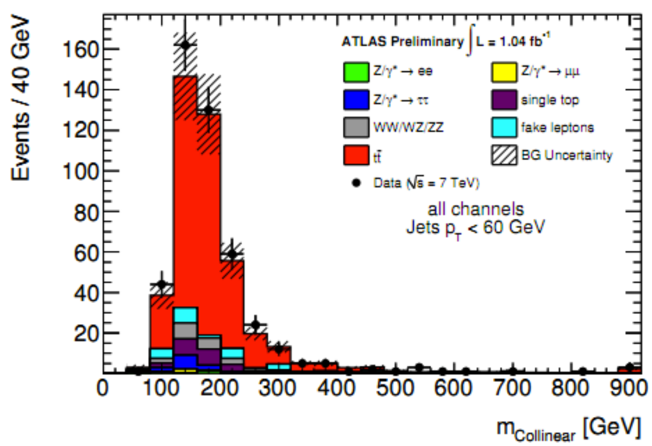
Validation



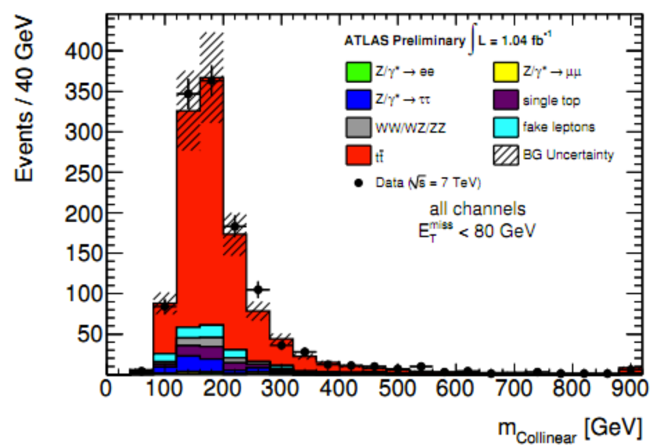
ATLAS Preliminary ∫L = 1.04 fb⁻¹
Z/γ* → ee
Z/γ* → μμ
Z/γ* → ττ
single top
WW/WZ/ZZ
fake leptons
tt̄
BG Uncertainty
Data (√s = 7 TeV)
all channels
H_T < 400 GeV
Events / 40 GeV
m_Collinear [GeV]



ATLAS Preliminary ∫L = 1.04 fb⁻¹
Z/γ* → ee
Z/γ* → μμ
Z/γ* → ττ
single top
WW/WZ/ZZ
fake leptons
tt̄
BG Uncertainty
Data (√s = 7 TeV)
all channels
Leptons p_T < 60 GeV
Events / 40 GeV
m_Collinear [GeV]

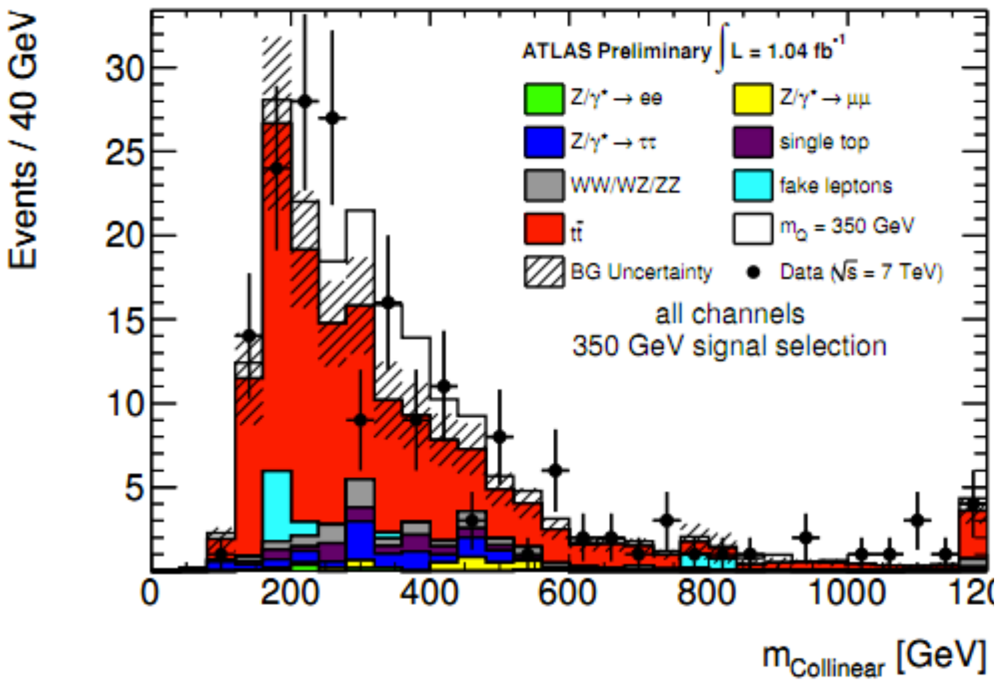


ATLAS Preliminary ∫L = 1.04 fb⁻¹
Z/γ* → ee
Z/γ* → μμ
Z/γ* → ττ
single top
WW/WZ/ZZ
fake leptons
tt̄
BG Uncertainty
Data (√s = 7 TeV)
all channels
Jets p_T < 60 GeV
Events / 40 GeV
m_Collinear [GeV]

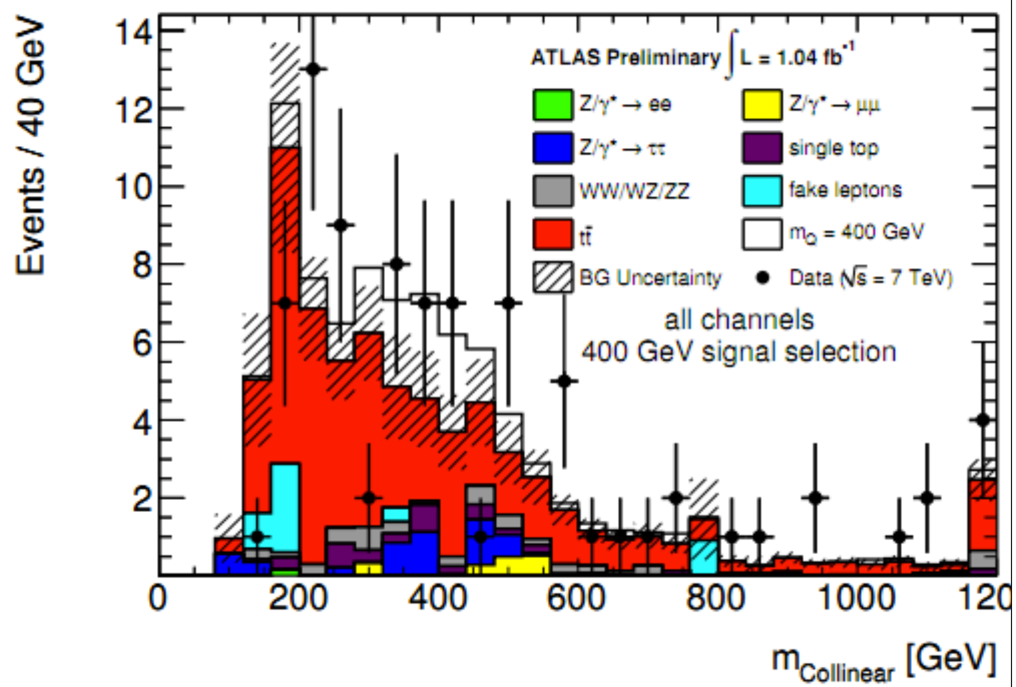


ATLAS Preliminary ∫L = 1.04 fb⁻¹
Z/γ* → ee
Z/γ* → μμ
Z/γ* → ττ
single top
WW/WZ/ZZ
fake leptons
tt̄
BG Uncertainty
Data (√s = 7 TeV)
all channels
E_T^miss < 80 GeV
Events / 40 GeV
m_Collinear [GeV]

OS QQ->WqWq



ATLAS Preliminary ∫L = 1.04 fb⁻¹
Z/γ* → ee
Z/γ* → μμ
Z/γ* → ττ
single top
WW/WZ/ZZ
fake leptons
tt̄
m_Q = 350 GeV
BG Uncertainty
Data (√s = 7 TeV)
all channels
350 GeV signal selection
Events / 40 GeV
m_Collinear [GeV]

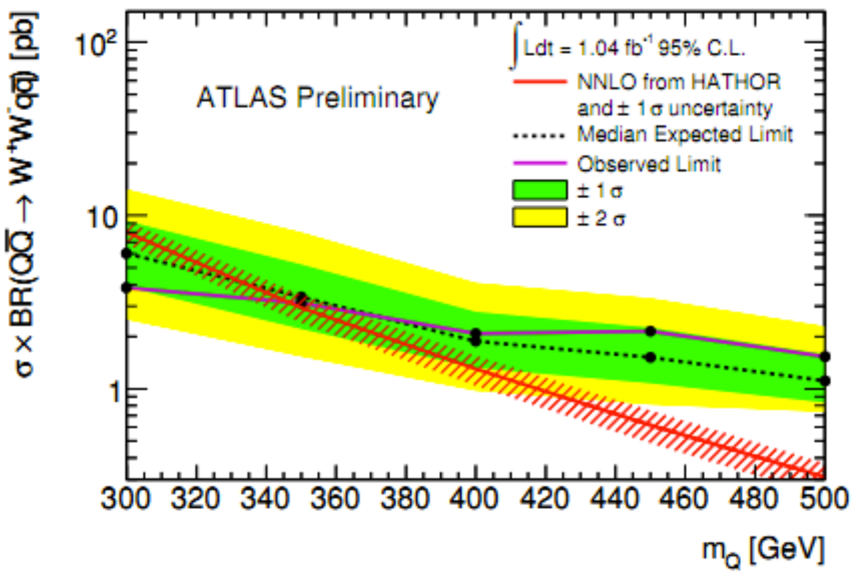


ATLAS Preliminary ∫L = 1.04 fb⁻¹
Z/γ* → ee
Z/γ* → μμ
Z/γ* → ττ
single top
WW/WZ/ZZ
fake leptons
tt̄
m_Q = 400 GeV
BG Uncertainty
Data (√s = 7 TeV)
all channels
400 GeV signal selection
Events / 40 GeV
m_Collinear [GeV]

Results

TABLE V. Expected background, expected signal and observed data in ee, $\mu\mu$, and $e\mu$ channels for $m_Q = 300 - 500$ GeV after final selection. The uncertainties shown include both statistical and systematic contributions.

m_Q (GeV)	Expected Background	Expected Signal	Observed Data
300	$300\ ^{+40}_{-40}$	$95\ ^{+14}_{-12}$	315
350	$148\ ^{+22}_{-18}$	$35\ ^{+5}_{-4}$	180
400	$75\ ^{+11}_{-10}$	$17.1\ ^{+2.5}_{-2.1}$	89
450	$49\ ^{+8}_{-6}$	$8.4\ ^{+1.2}_{-1.0}$	57
500	$30\ ^{+5}_{-4}$	$4.4\ ^{+0.6}_{-0.5}$	36



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Tops

Studied to death?

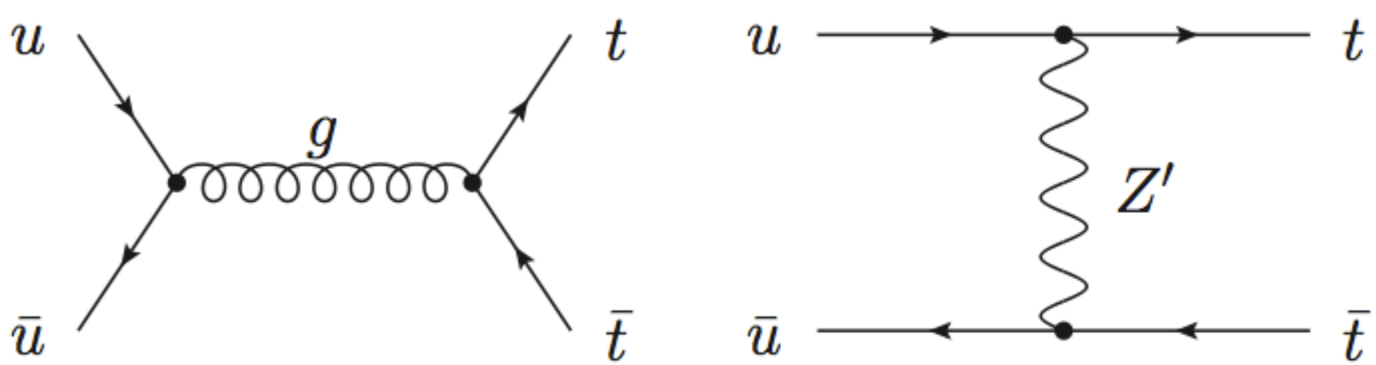
- M_t, V_{tb}, BRs, charge, total cross-section, W helicity. top width & lifetime, gg vs qq, X->tt, etc...

What is left?

- Understand A_{FB} anomaly
- Resonances inside top-like events

Afb

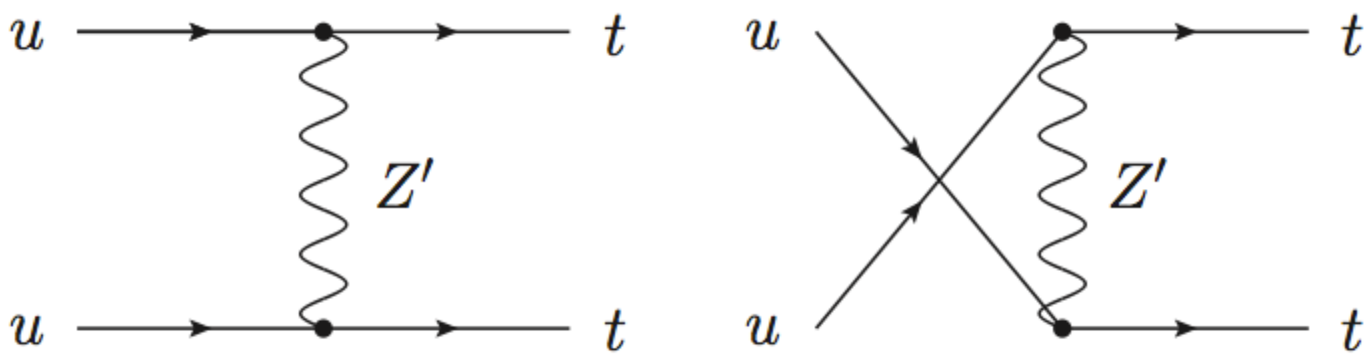
CDF's top A_{FB} can be explained



if there is a **new ttbar production** mechanism via t-channel Z′

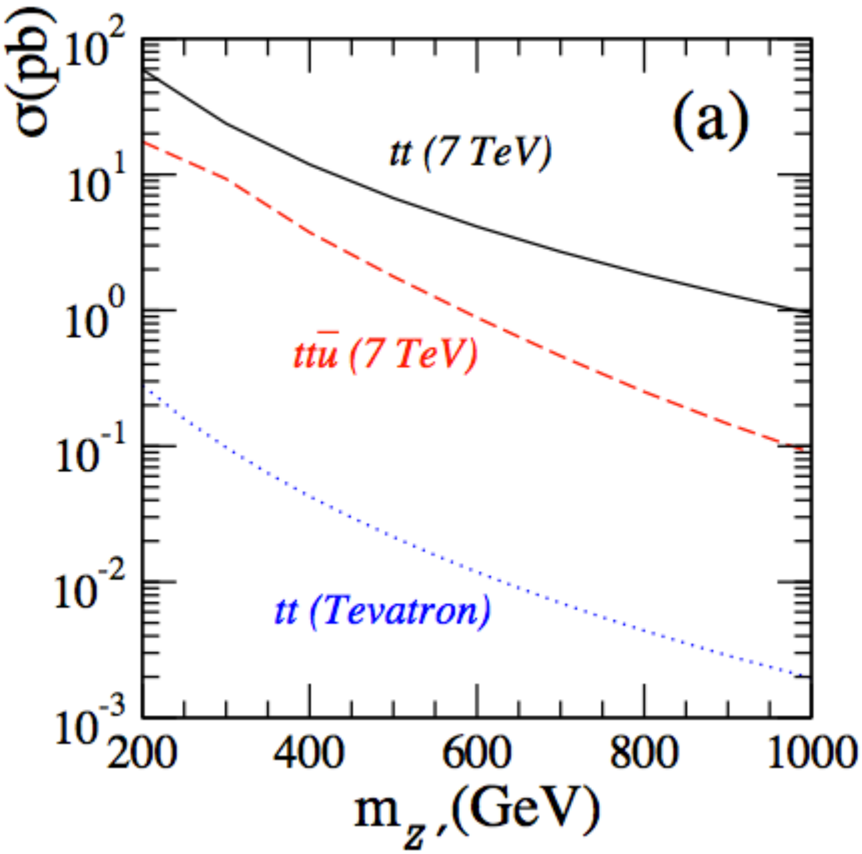
Testable hypothesis

Also predicts



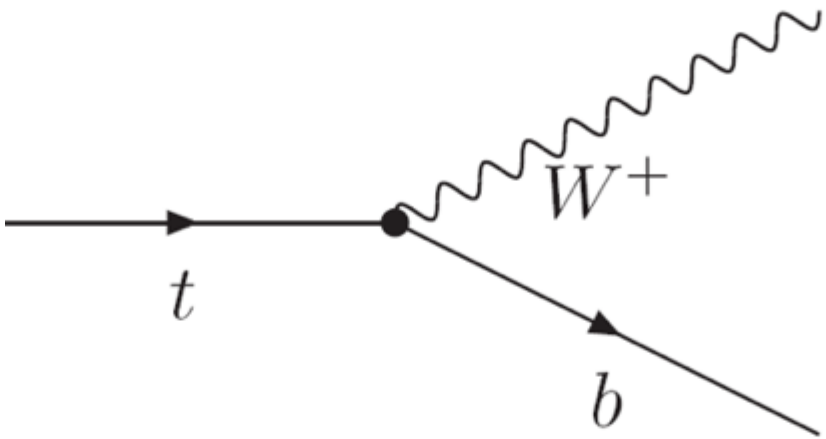
same-sign tops through MxFV coupling

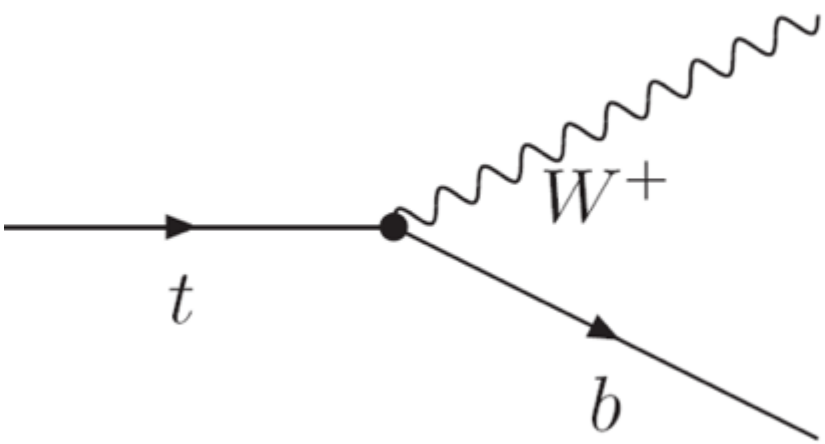
Rates



Testable at the Tevatron, enormous at the LHC

Same sign tops





Same-sign tops

Gives ss W's

Gives ss dileptons

LHC

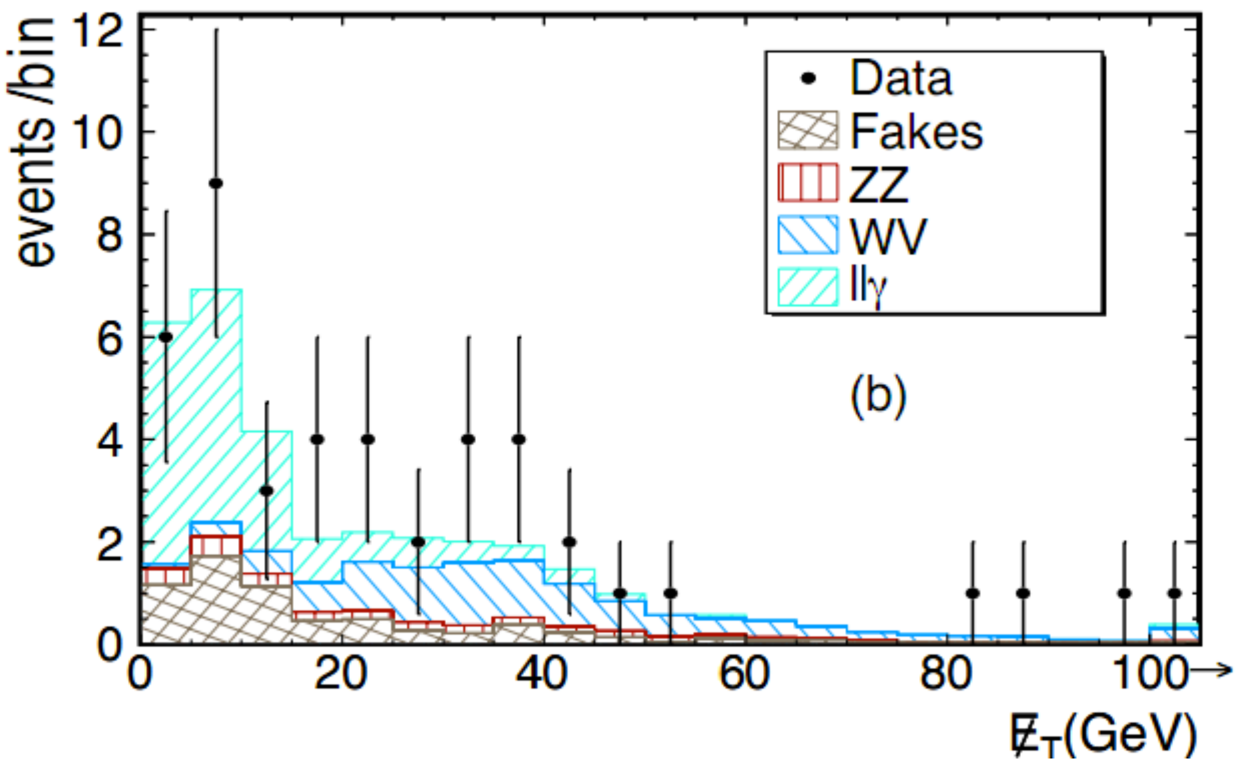
pp means ++ > - -

Smaller backgrounds

l+jets charge asymmetry

CDF like-sign dileptons

	$n_{\rm obs}$	$n_{\rm pred}$
$e_{\rm si}e_{\rm si}$	11	6.3±1.0
ee	3	1.3±0.3
$e_{\rm si}e$	9	9.1±1.8
$e_{\rm si}\mu$	11	6.8±0.8
$e\mu$	5	6.4±1.2
$\mu\mu$	5	3.2±0.3
Total	44	33.2±4.7



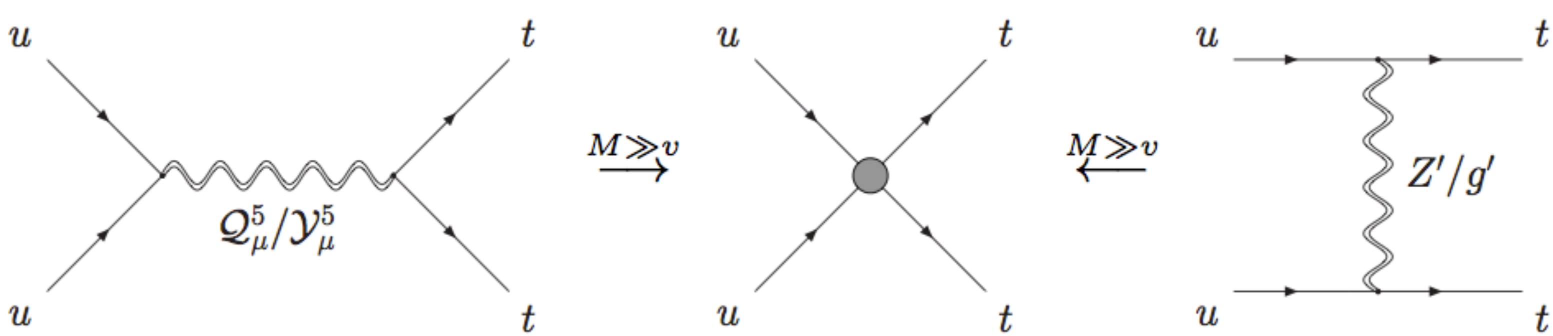
1/fb PRL 2007

ls dileptons 6.1/fb

CDF RunII Preliminary	6.1/fb
top quark pairs	0.1 ± 0.1
Z	26.6 ± 3.4
WW,WZ,ZZ	28.4 ± 2.0
W+gamma	16.2 ± 2.4
Fakes	51.6 ± 24.2
Total	123.0 ± 24.6
Data	145

same-sign tops

Many models



Use 4f effective operators

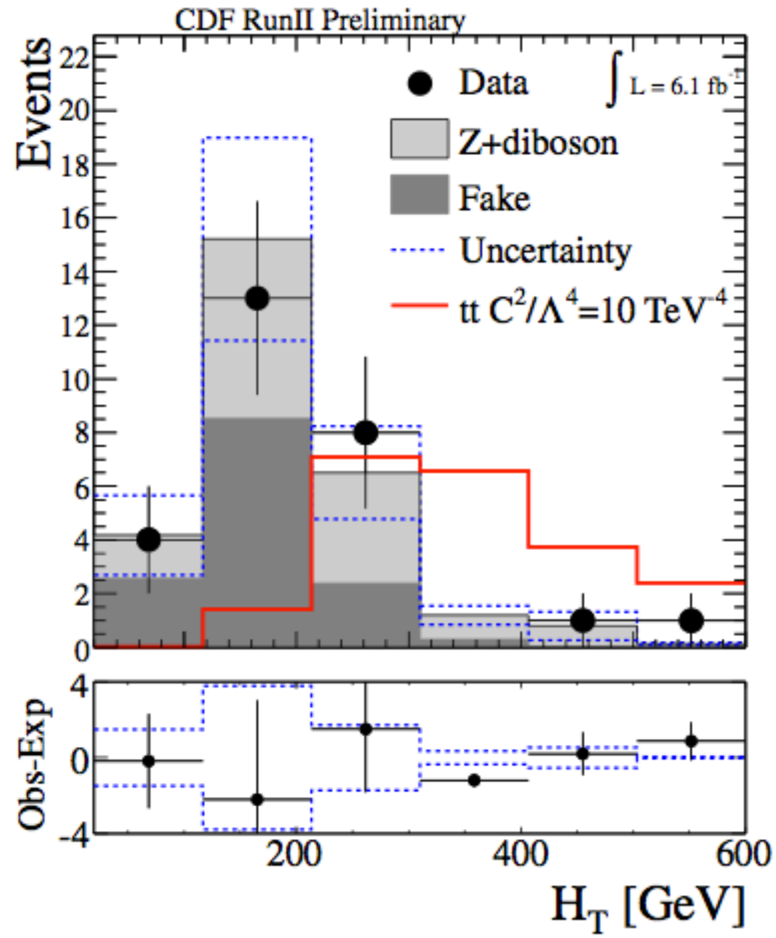
(LL,LR,RR) modes

same-sign leptons+2jets

Process	Total $\ell\ell$
$t\bar{t}$	0.1 ± 0.0
$Z \to \ell\ell$	5.9 ± 1.7
WW, WZ, ZZ	7.2 ± 0.5
$W(\to \ell\nu)\gamma$	0.9 ± 0.7
Fakes	13.8 ± 7.2
Total	28.0 ± 7.5
Data	27

coupling $|C|/\Lambda^2$

cross-section $\propto C^2/\Lambda^4$



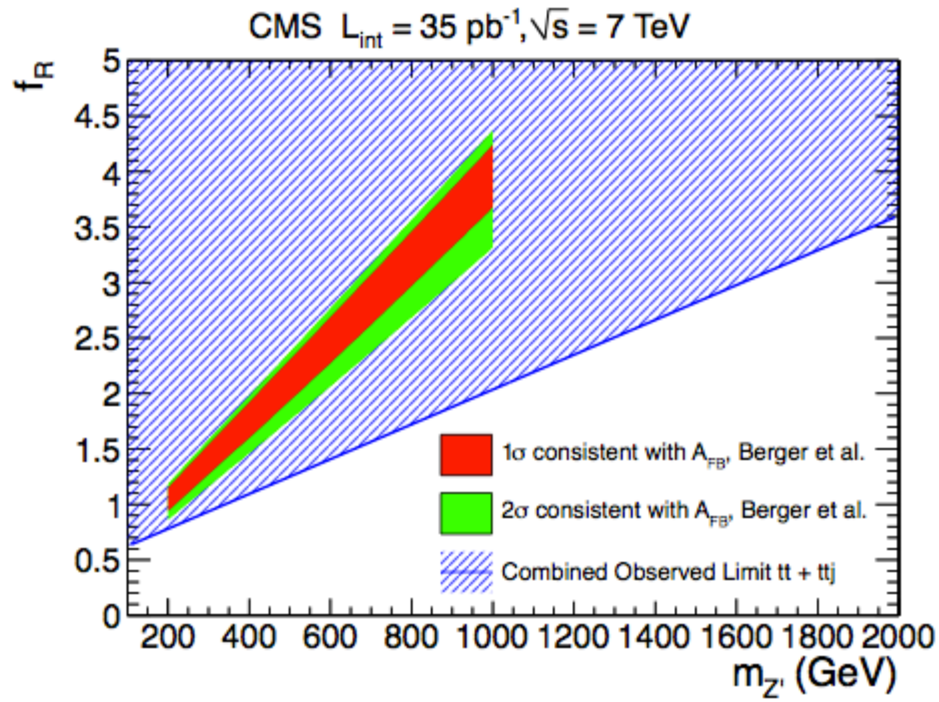
CMS

Expect

3.4 ±1.8

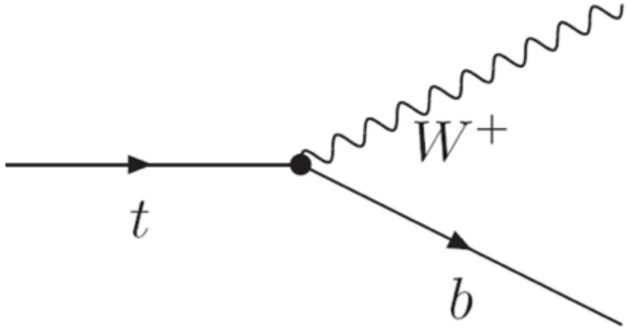
Observe

3



Rule out a bunch of Z models

ATLAS

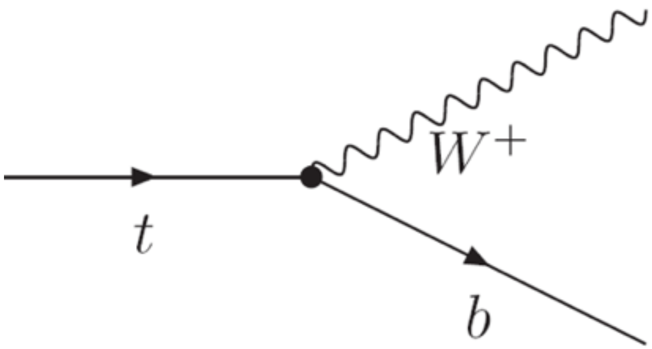


Selection

Two SS lepton (e or μ)

MET>40

At least two jets



Dataset

ATLAS 1/fb

Analysis led by
UCI postdoc : Ning Zhou

ATLAS

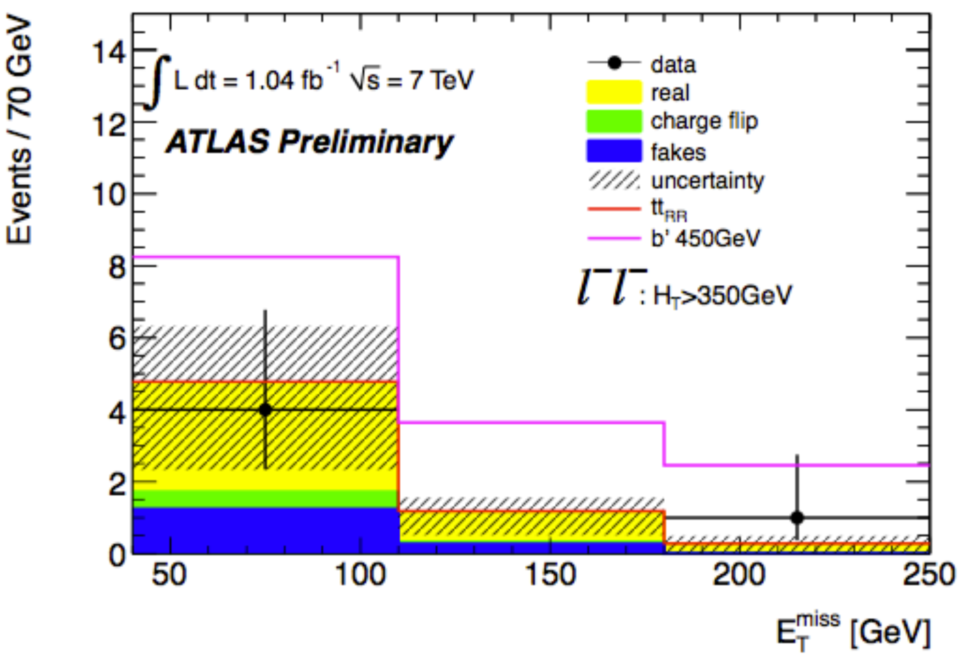
negative charge

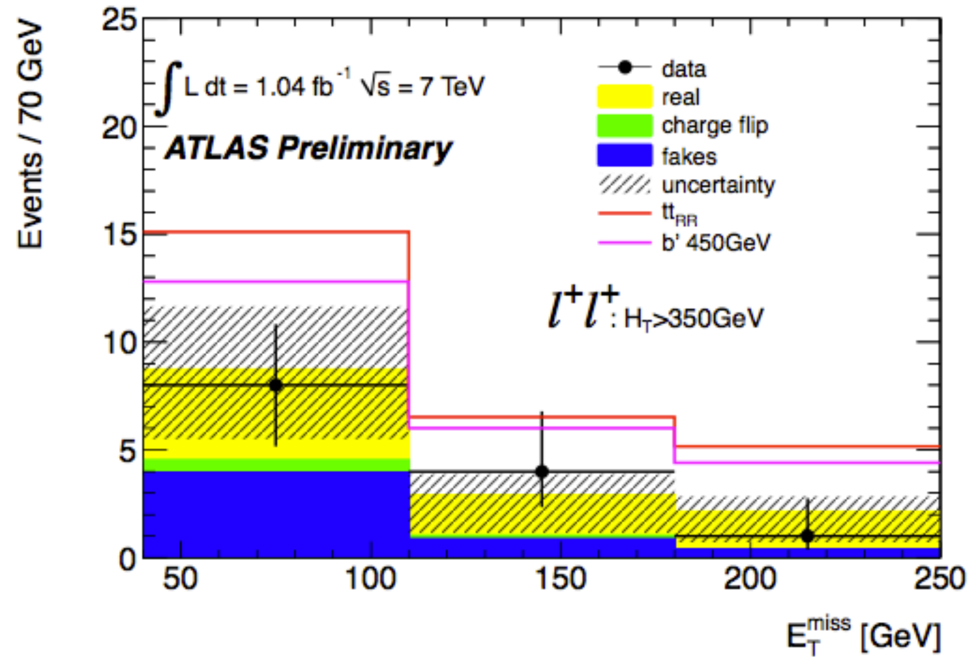
	e^-e^-	$\mu^-\mu^-$	$e^-\mu^-$
Fake	$0.2 \pm 0.3 \pm 0.1$	$0.7 \pm 0.3^{+0.6}_{-0.3}$	$0.5 \pm 0.2^{+0.7}_{-0.3}$
Charge flip	$0.3 \pm 0.1^{+0.3}_{-0.1}$	$0 \pm 0^{+0.01}_{-0}$	$0.3 \pm 0.1^{+0.2}_{-0.1}$
Real	$0.8 \pm 0.3^{+0.2}_{-0.5}$	$1.0 \pm 0.3^{+0.3}_{-0.6}$	$2.3 \pm 0.5^{+0.6}_{-1.8}$
Total	$1.4 \pm 0.4^{+0.3}_{-0.6}$	$1.7 \pm 0.4 \pm 0.7$	$3.1 \pm 0.6^{+1.0}_{-1.8}$
Data	1	2	2
tt_{LL}	$0.2 \pm 0.1 \pm 0.03$	$0.2 \pm 0.1 \pm 0.02$	$0.5 \pm 0.3 \pm 0.1$
tt_{LR}	$0.02 \pm 0.01 \pm 0.01$	$0.001^{+0.01}_{-0.001} \pm 0.001$	$0.02 \pm 0.02 \pm 0.01$
tt_{RR}	$0.5 \pm 0.3 \pm 0.1$	$0.1 \pm 0.1 \pm 0.2$	$0.8 \pm 0.3 \pm 0.1$
b' 450 GeV	$1.8 \pm 0.2 \pm 0.2$	$2.1 \pm 0.2 \pm 0.2$	$4.3 \pm 0.3 \pm 0.4$

positive charge

	e^+e^+	$\mu^+\mu^+$	$e^+\mu^+$
Fake	$0.8 \pm 0.6^{+0.2}_{-0.4}$	$1.0 \pm 0.3^{+0.6}_{-0.4}$	$3.3 \pm 1.1^{+1.6}_{-1.4}$
Charge flip	$0.3 \pm 0.1^{+0.3}_{-0.1}$	$0 \pm 0^{+0.01}_{-0.0}$	$0.4 \pm 0.1^{+0.3}_{-0.1}$
Real	$1.9 \pm 0.5^{+0.5}_{-1.4}$	$1.6 \pm 0.3^{+0.6}_{-0.9}$	$4.4 \pm 0.7^{+1.1}_{-3.0}$
Total	$3.0 \pm 0.8^{+0.6}_{-1.4}$	$2.6 \pm 0.4^{+0.9}_{-1.1}$	$8.1 \pm 1.3^{+2.1}_{-3.3}$
Data	2	1	10
tt_{LL}	$30.1 \pm 1.9 \pm 4.6$	$30.4 \pm 1.9^{+4.3}_{-4.4}$	$64.2 \pm 2.8^{+9.8}_{-9.9}$
tt_{LR}	$3.8 \pm 0.2 \pm 0.6$	$4.2 \pm 0.3 \pm 0.6$	$8.3 \pm 0.4 \pm 1.2$
tt_{RR}	$35.5 \pm 2.1 \pm 5.6$	$29.5 \pm 1.9 \pm 4.2$	$65.7 \pm 2.8 \pm 10.0$
b' 450 GeV	$1.8 \pm 0.2 \pm 0.2$	$2.7 \pm 0.2 \pm 0.3$	$5.0 \pm 0.3 \pm 0.6$

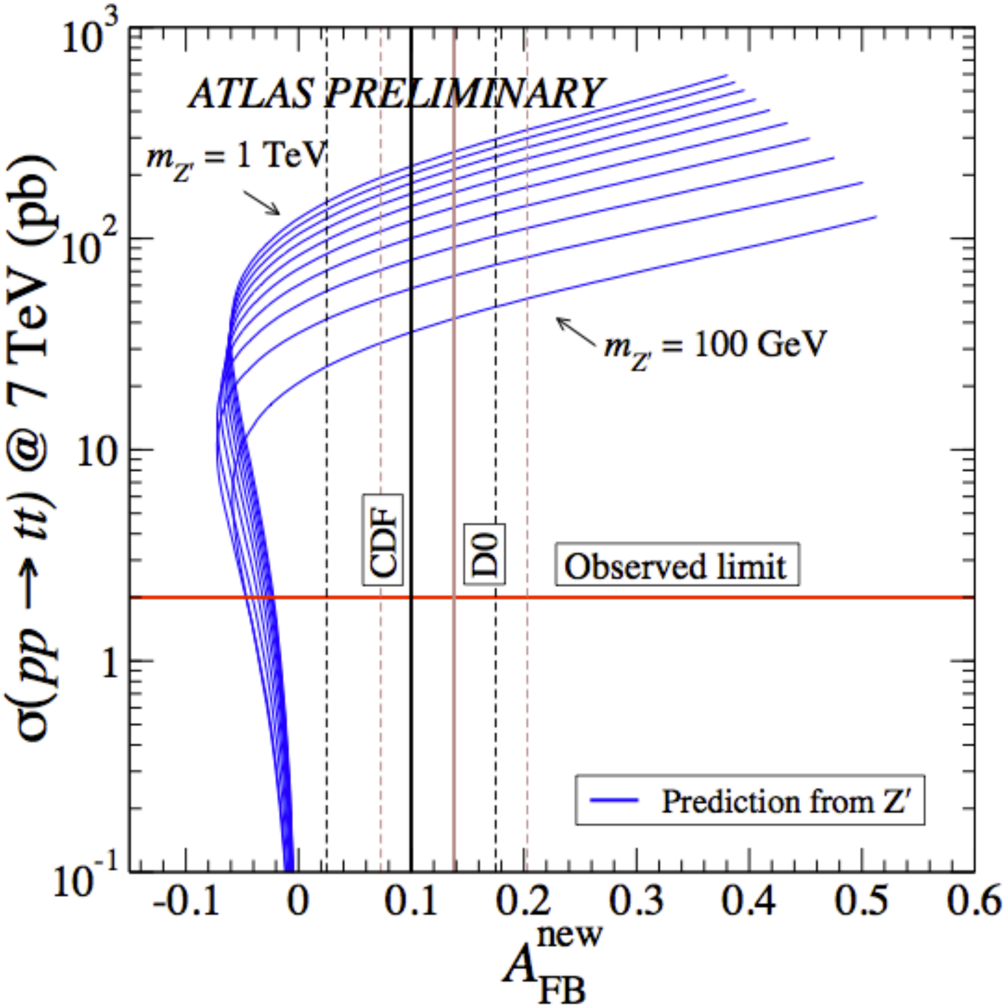
ATLAS

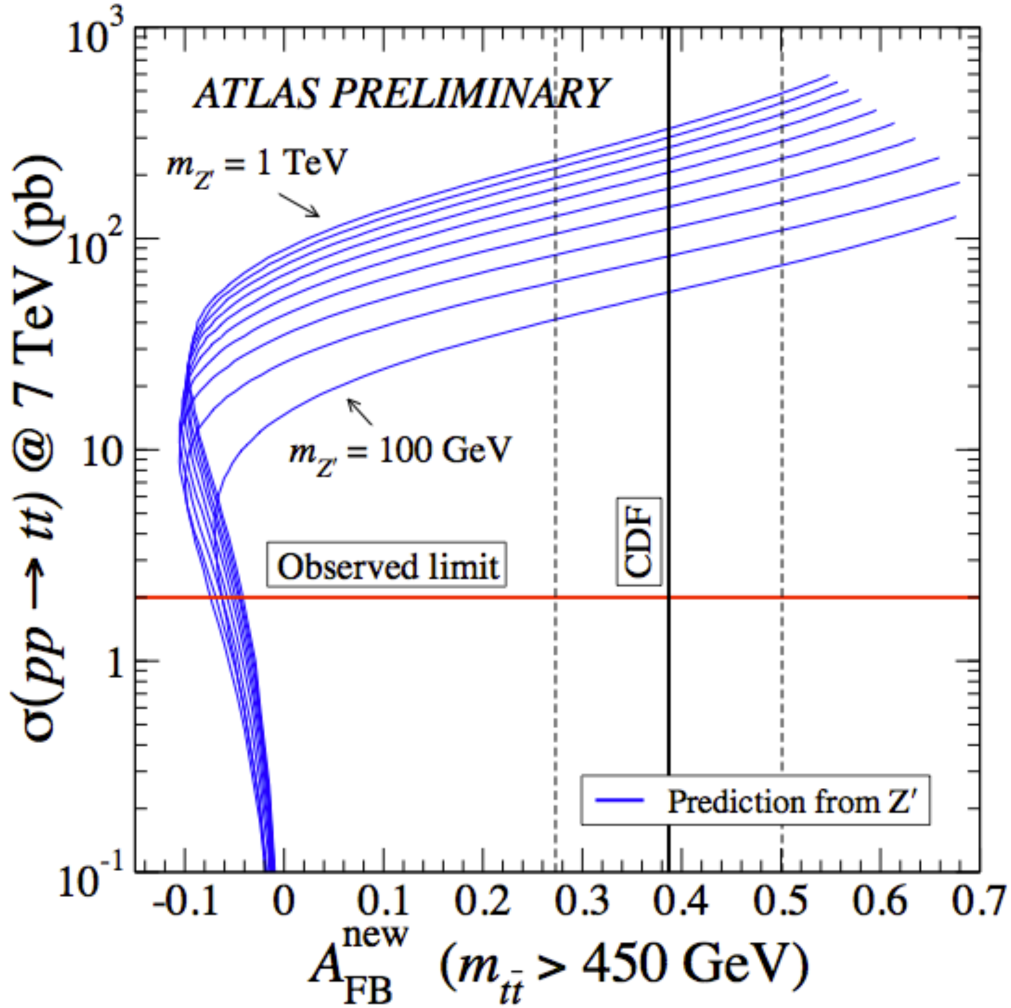




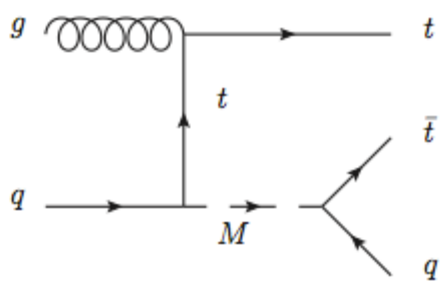
ATLAS sees a few events, but consistent with background.

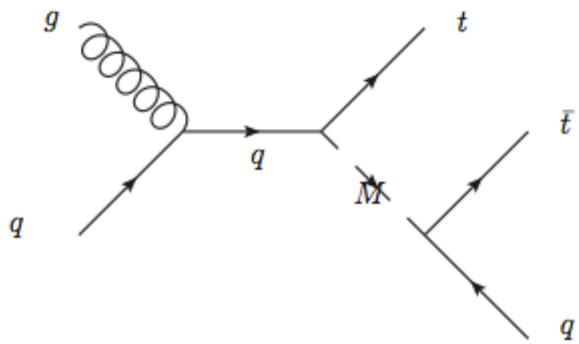
Interpretation

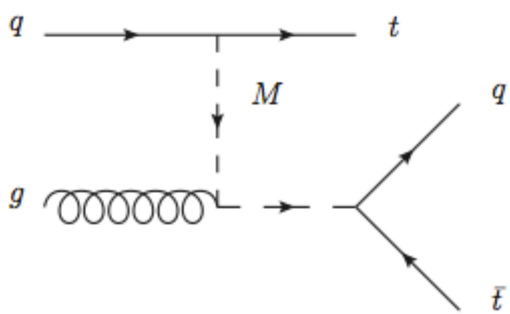




tt+u







M not self-conjugate, so no ss tops!

qg → Mt → (tbar +q) t → ttbar + q

Look for resonance in t+j

But...

<u>s- channel</u>: can't generate asymmetry to explain top A_{FB} measurement

<u>t- channel:</u>

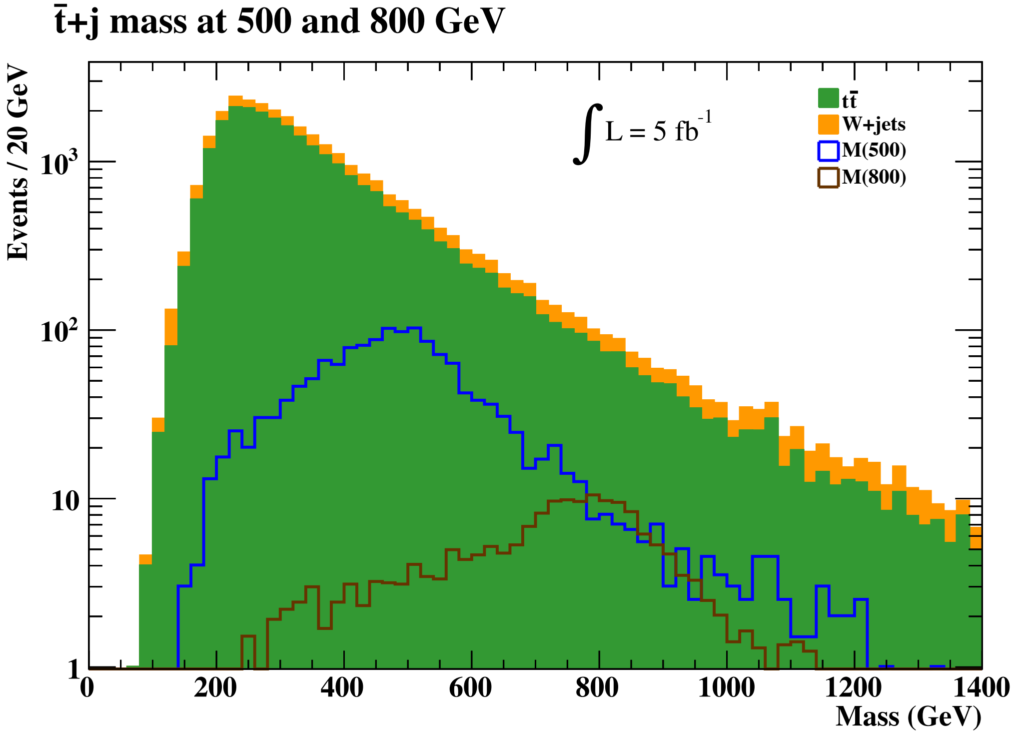
light mediators constrained by overall ttbar cross-sec

heavy mediators constrained by CDF invariant mass distribution

t+j resonance

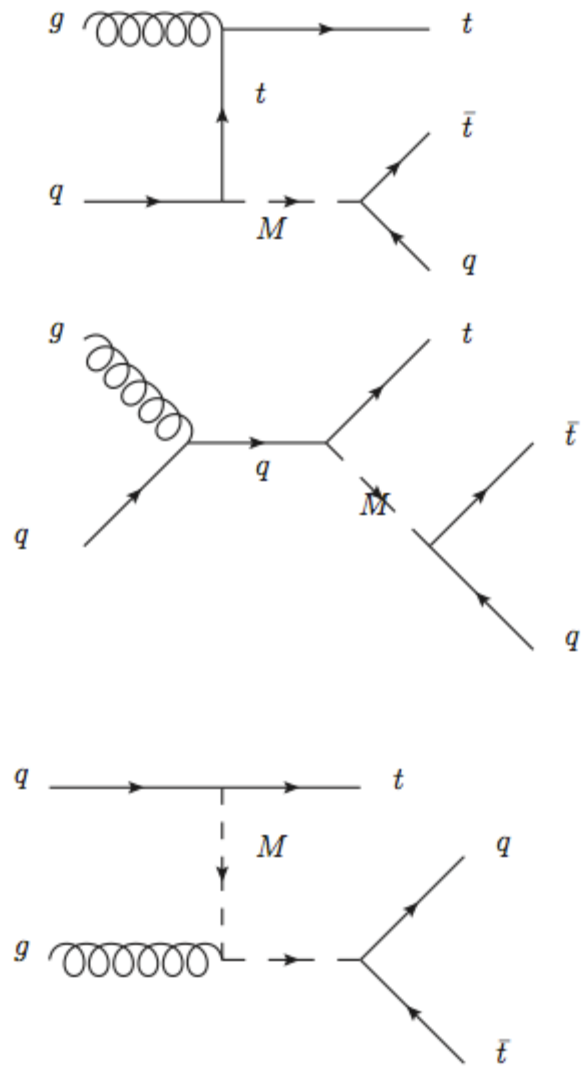
Resonance

t+j resonance has never been examined



Analysis done largely by a single grad student: Kanishka Rao, UCI

Selection & dataset



Selection

One lepton (e or μ)

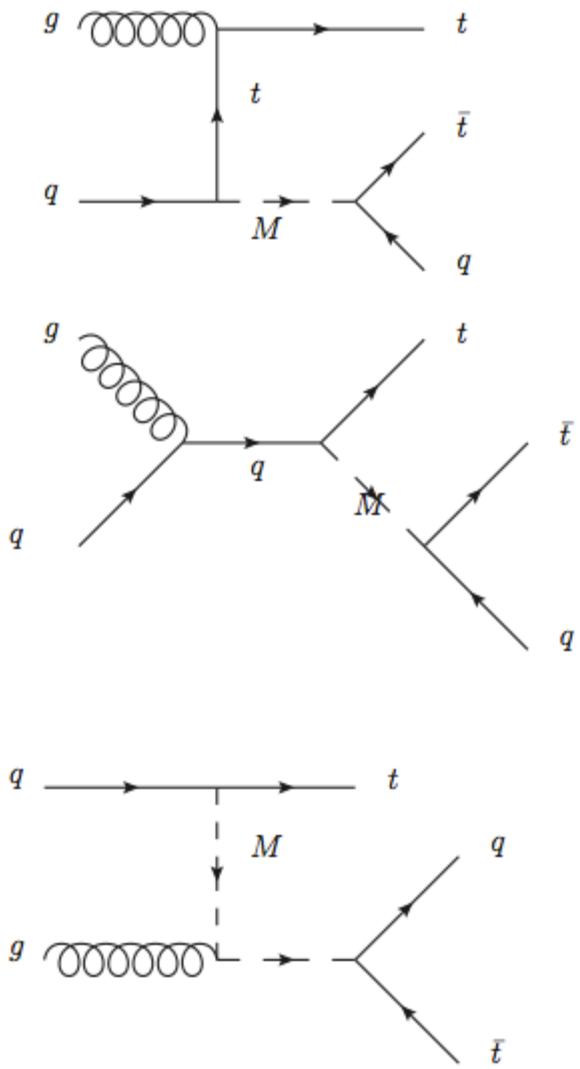
MET>20

At least five jets

Dataset

CDF 8.7/fb

Reconstruction



<u>Identify top, antitop</u>

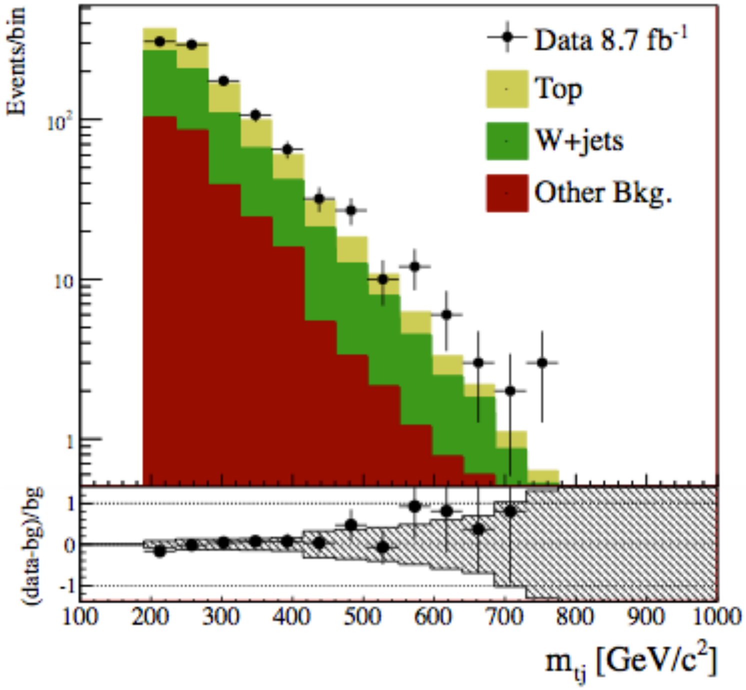
use standard kinematic fitter

<u>Choose additional jet</u>

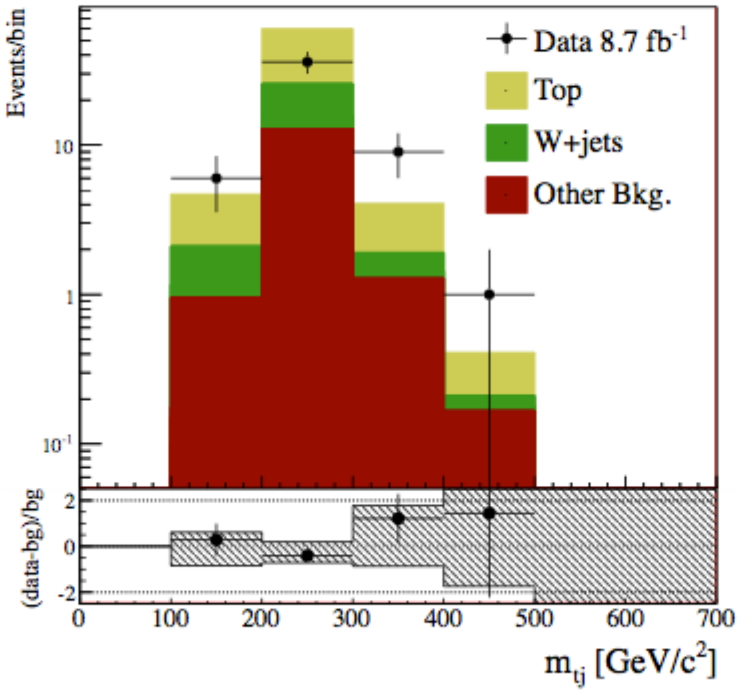
maximize m_{tj}

Validation

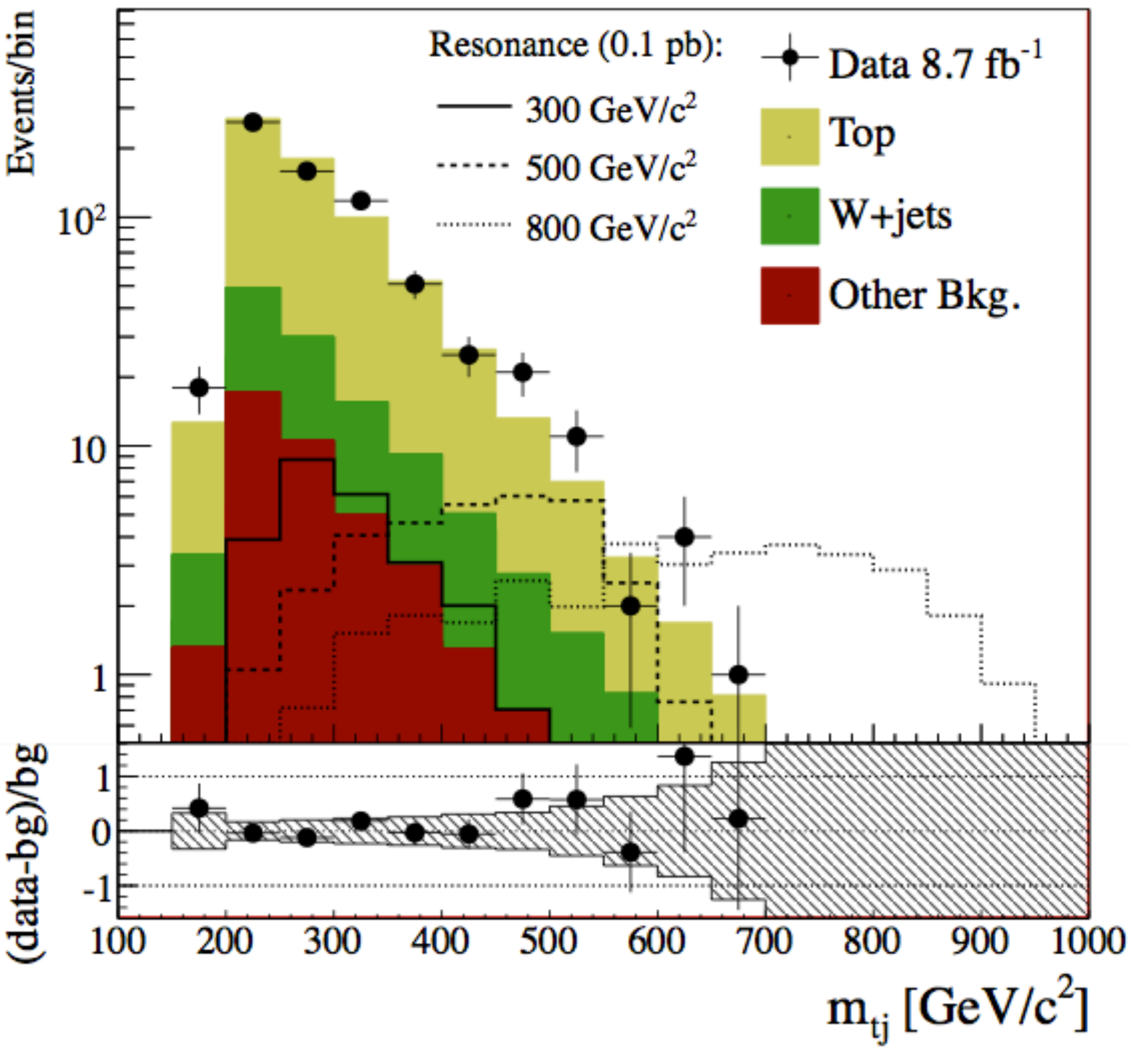
5-jet, 0tag



5-jet, 1tag, low HT

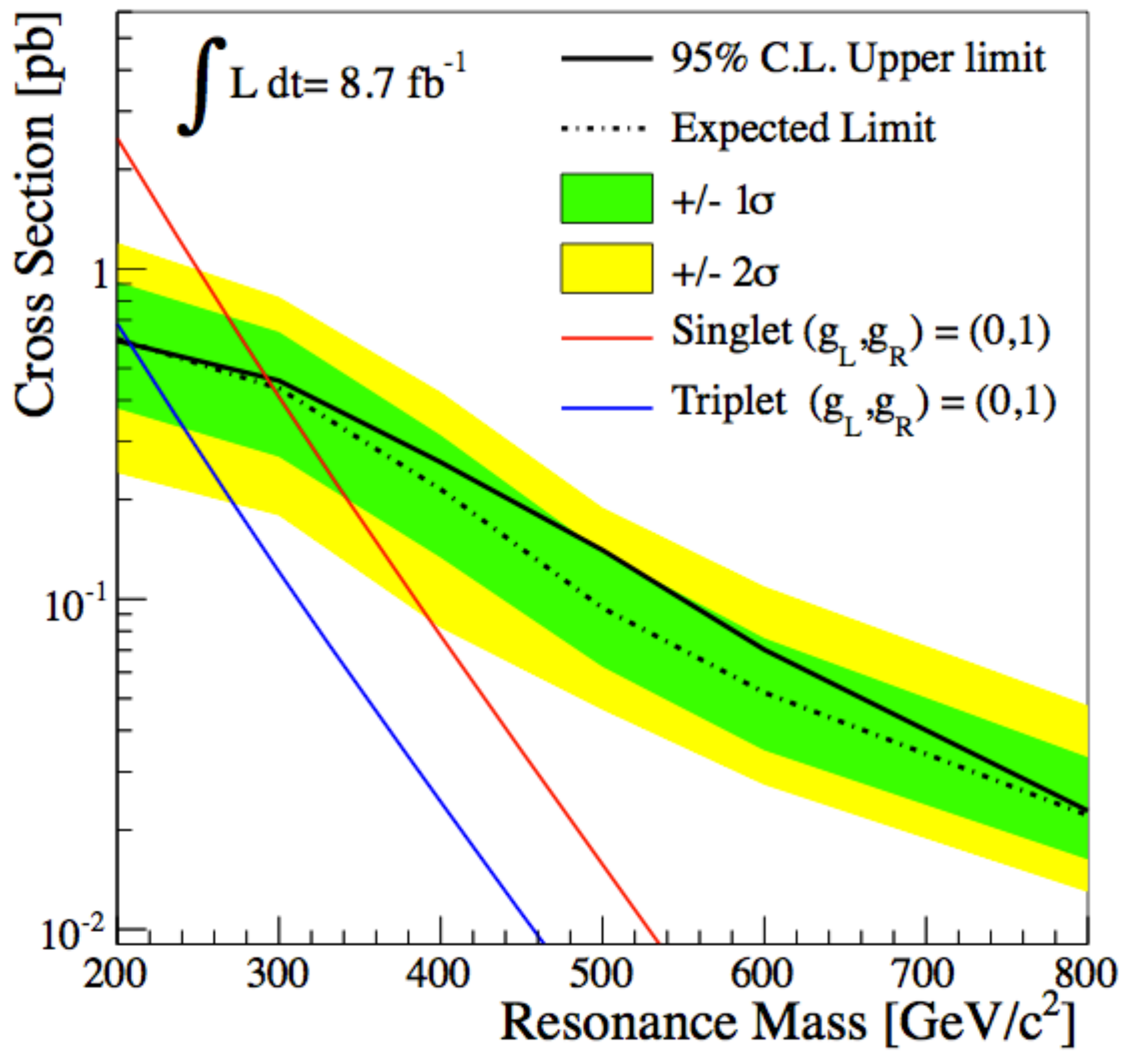


CDF t+j



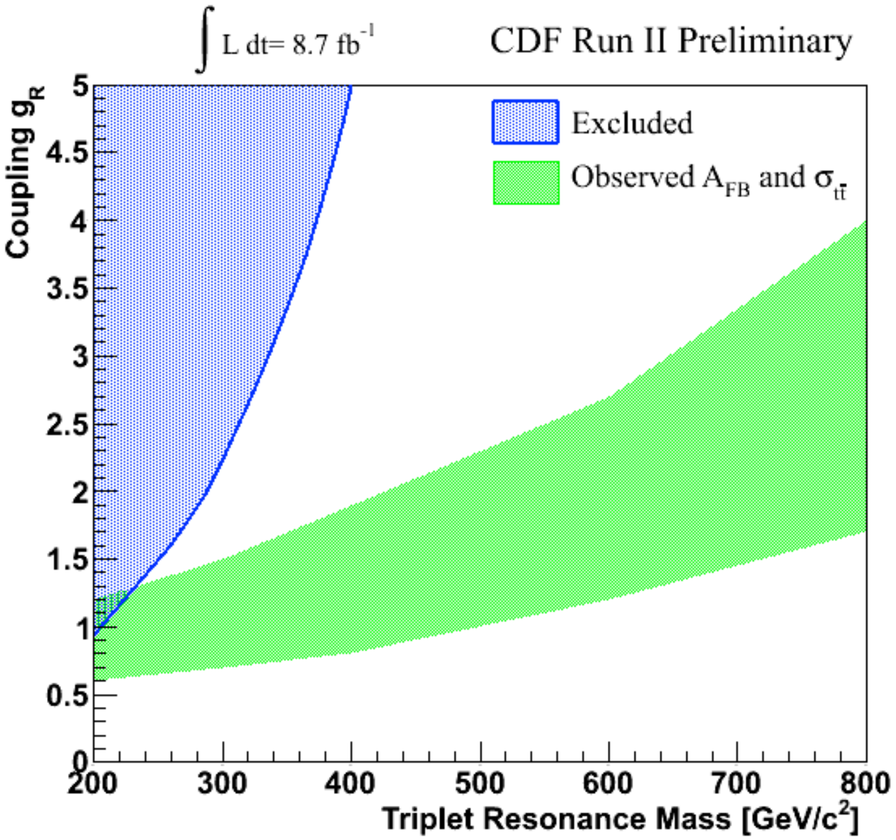
Resonance (0.1 pb):
300 GeV/c²
500 GeV/c²
800 GeV/c²
Data 8.7 fb⁻¹
Top
W+jets
Other Bkg.
Events/bin
(data-bg)/bg
m_tj [GeV/c²]

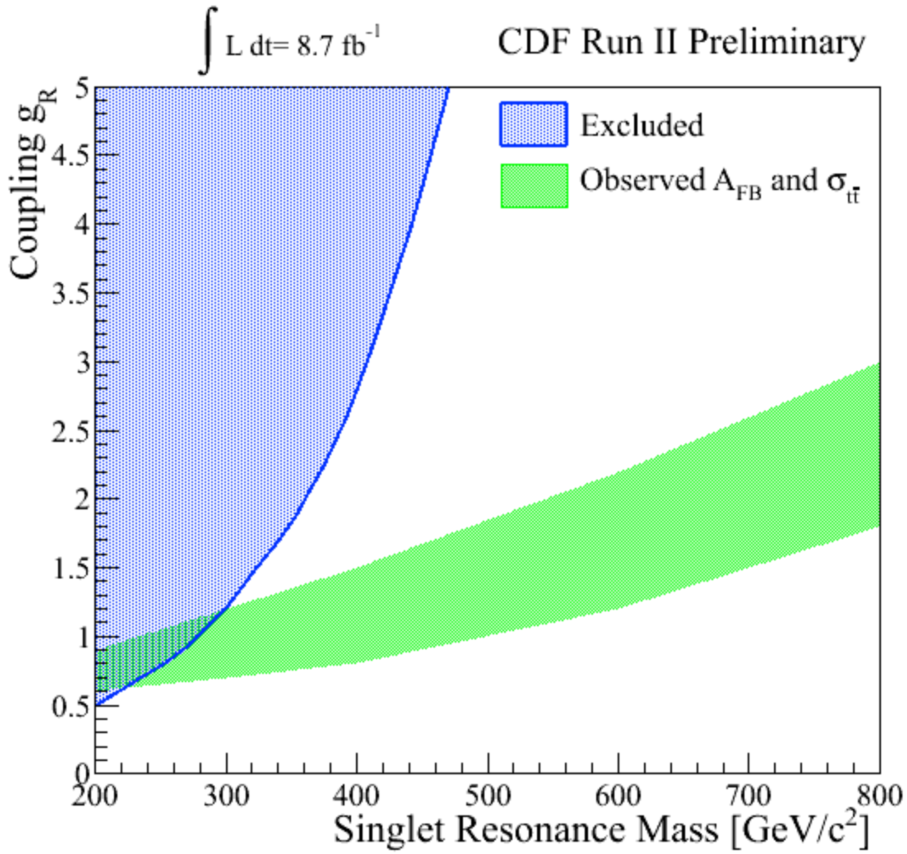
CDF ttj



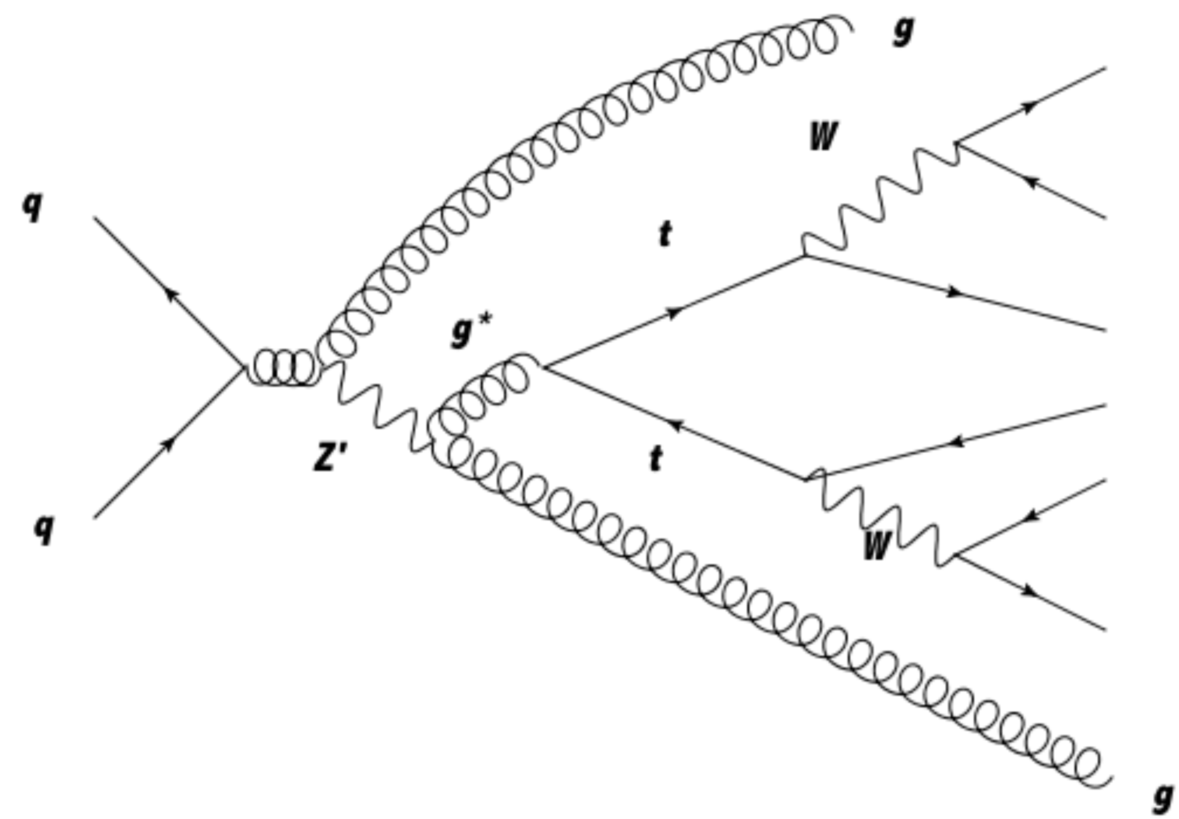
Analysis done largely by a single grad student: ***Kanishka Rao, UCI***

Interpretation



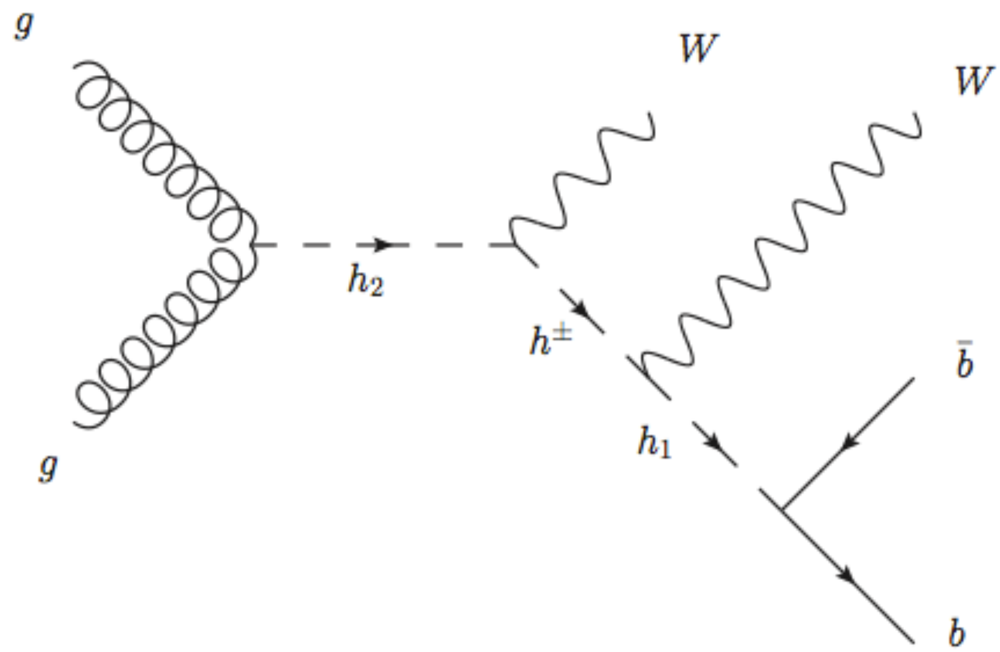


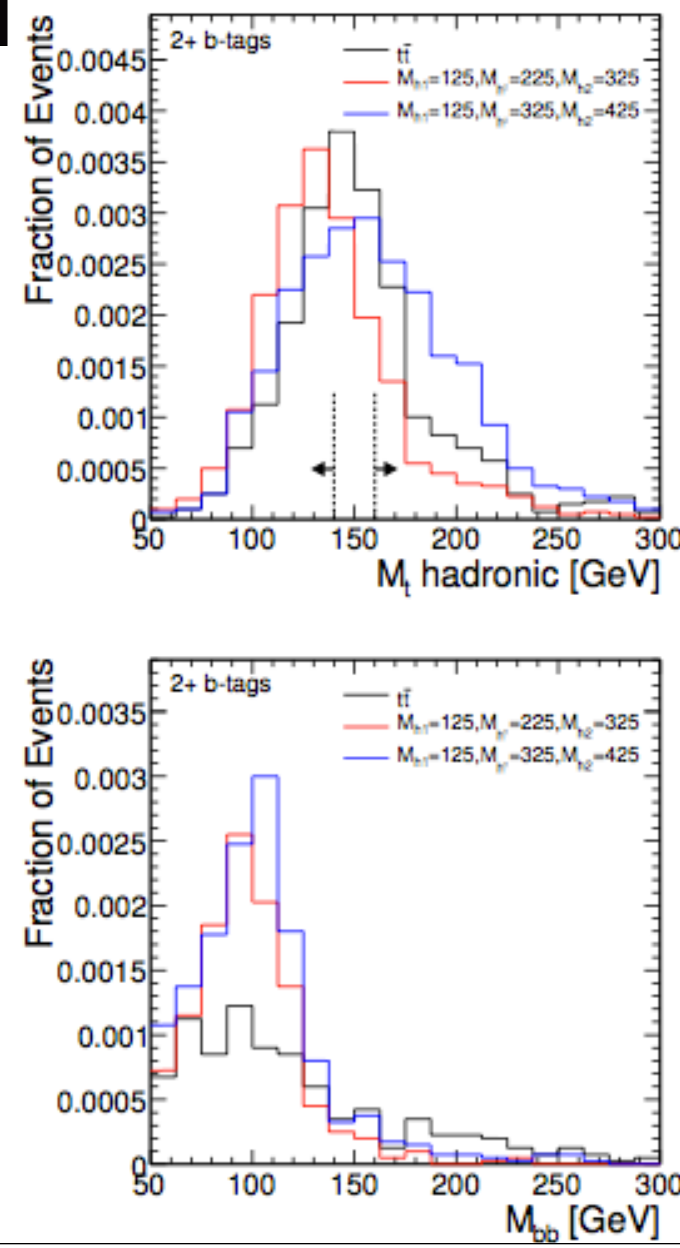
Z'->gg giving ttj resonance



With Alwall, Rajaraman (to appear)

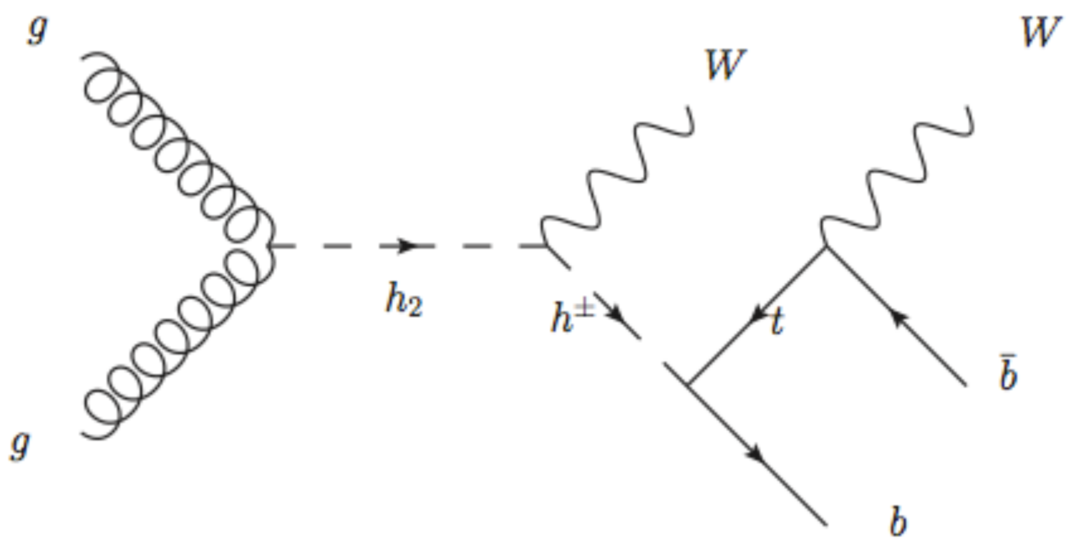
Higgs in WWbb

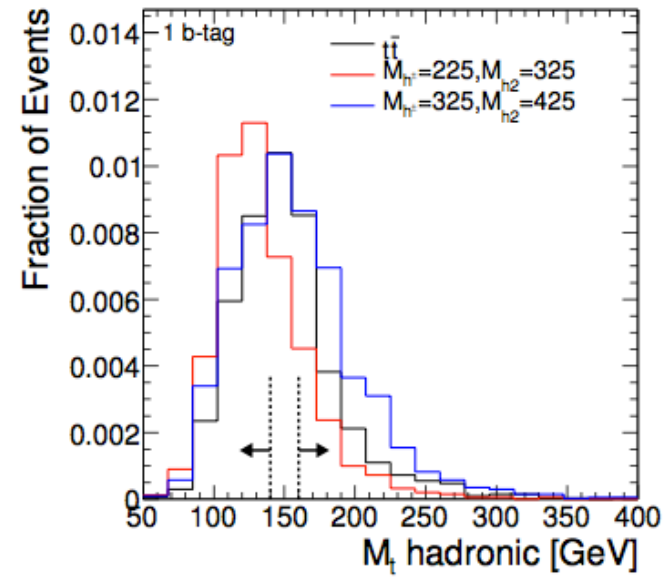


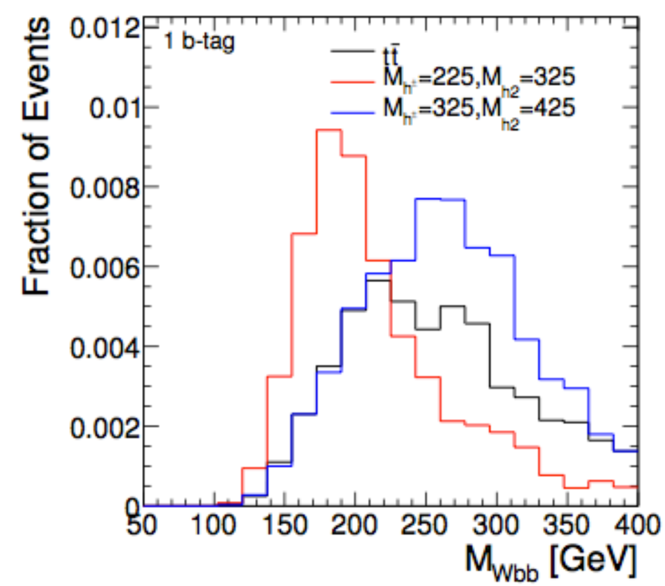


With Evans, Luty, Kilminster (**arXiv:1201.3691**)

Higgs in WWbb







With Evans, Luty, Kilminster (**arXiv:1201.3691**)

Outline

I. Introduction: experimental innovation

II. Simple boosted objects

III. Novel views of top quark events

VI. Concluding rant: open data

Open data

“big learn”: machine learning in big data

Lots of smart people & good ideas

Few real applications (Netflix)

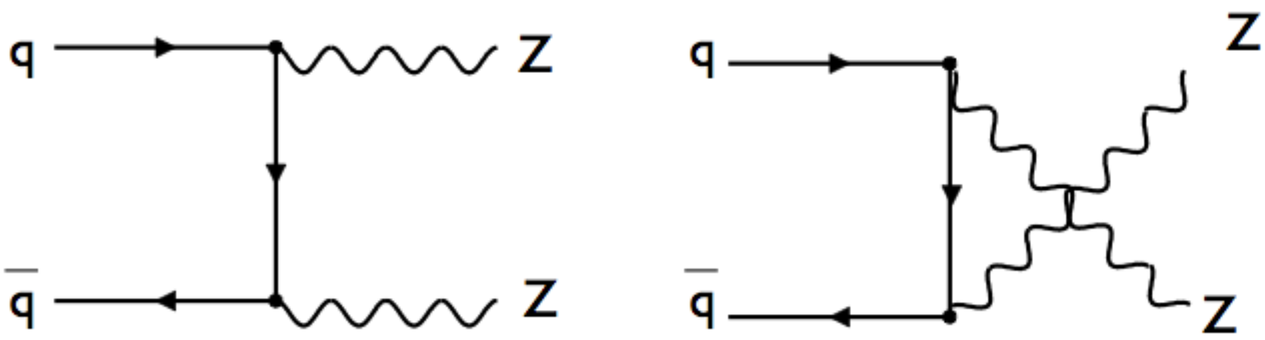
Number of people who wanted to work on HEP

after my talk: > 25

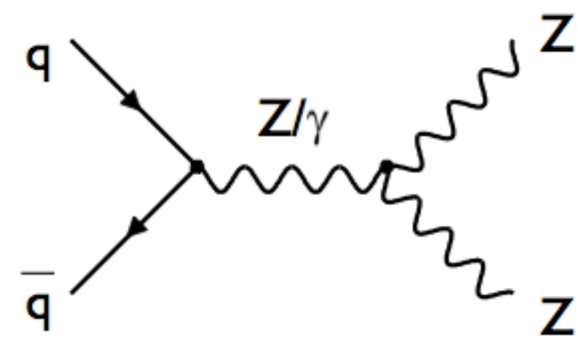
after I said the data is not public: 0

That's it!

4 charged leptons

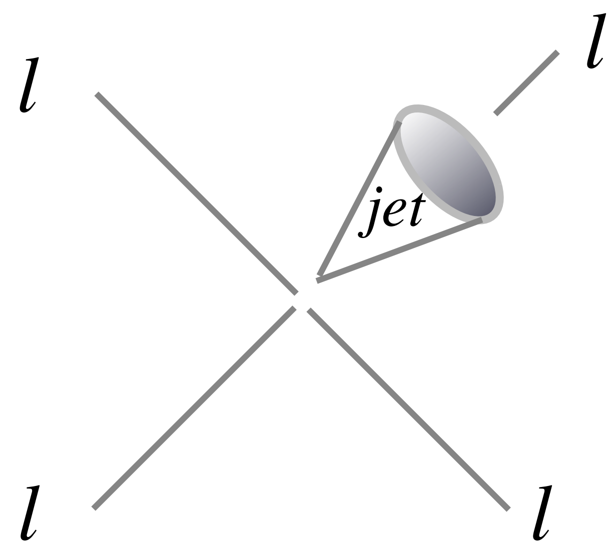


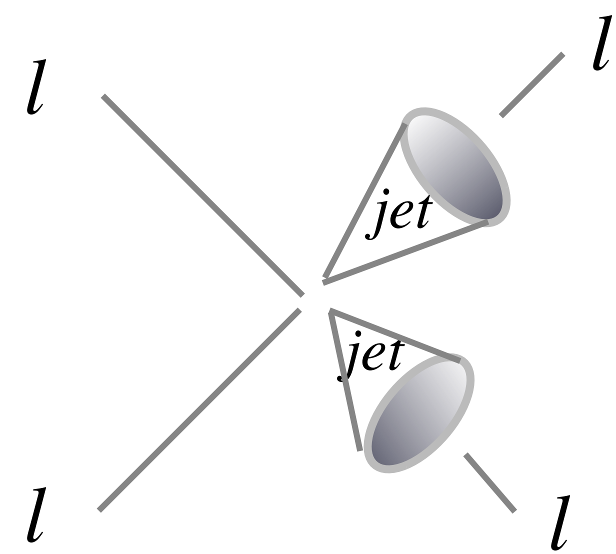
Standard Model Production



SM Forbidden

Backgrounds?





WZ+jet

Z+jet
tt → ll bb νν

Lepton types

Final State	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell^+\ell^-$
Observed	2	8	2	12
Bkg(data-driven)	$0.01^{+0.03+0.05}_{-0.01-0.01}$	$0.3^{+0.9}_{-0.3} \pm 0.3$	$< 0.01^{+0.03}_{-0.01}$	$0.3^{+0.9+0.4}_{-0.3-0.3}$
Expected ZZ	1.57±0.03±0.11	3.09±0.04±0.06	4.5±0.1±0.2	9.1±0.1±0.3

Table 2: Summary of observed events, total background contributions and expected signal in the individual four-lepton and combined channels. The first error is statistical while the second is systematic. The uncertainty on the luminosity is not included. The errors on the background estimates span the 68% confidence interval, which is not symmetric about the best estimate because the background cannot be negative.

PRL 2011

Lepton types

Final State	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell^+\ell^-$
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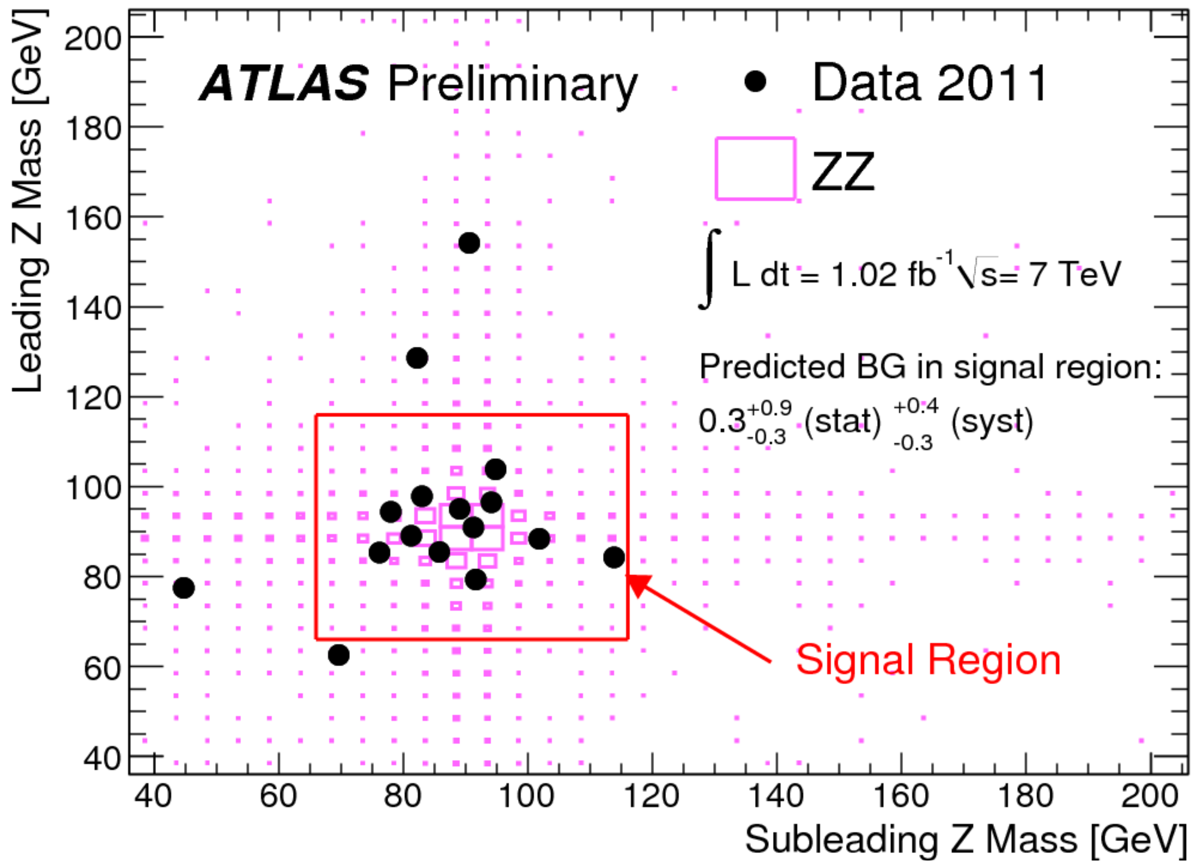
PRL 2011

Mass distribution



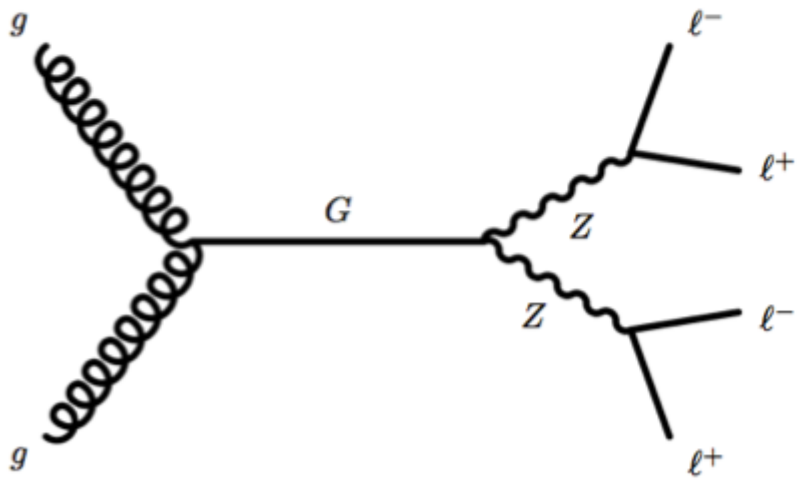
$$\sigma_{ZZ}^{\text{tot}} = 8.5^{+2.7}_{-2.3}\ (\text{stat.})\ {}^{+0.4}_{-0.3}\ (\text{syst.})\ \pm 0.3\ (\text{lumi.})\ \text{pb.}$$

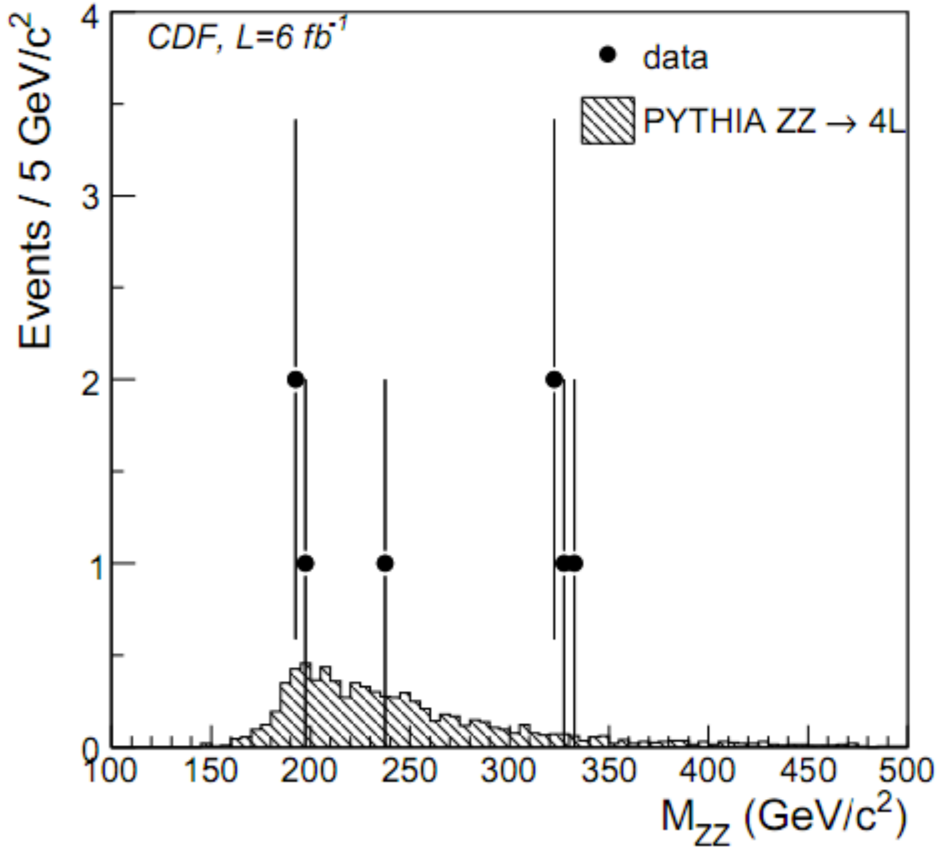
$$\sigma^{\text{NLO}} = 6.5^{+0.3}_{-0.2}$$

PRL 2011

Campbell, Ellis, Williams, JHEP 07, 018 (2011).

ZZ resonances?



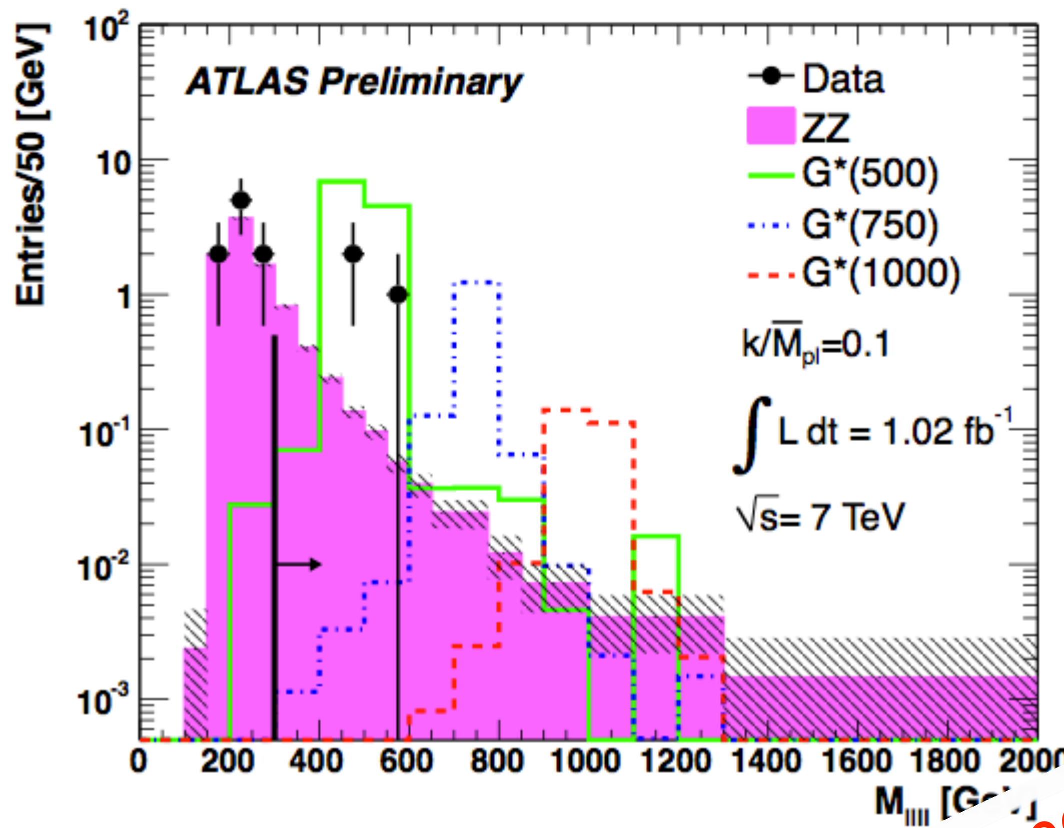


Exp: 5.5

Obs: 8

ATLAS ZZ resonances

Process	Total
ZZ	$1.85 \pm 0.11 \pm 0.09$
Fakes	$0.02^{+1.03}_{-0.01}{}^{+0.75}_{-0.02}$
Total Bkg.	$1.87^{+1.04}_{-0.11}{}^{+0.75}_{-0.09}$
Data	3
G(350 GeV)	$71 \pm 3 \pm 4$
G(500 GeV)	$12 \pm 0.5 \pm 0.6$
G(750 GeV)	$1.5 \pm 0.08 \pm 0.07$
G(1000 GeV)	$(2.7 \pm 0.2 \pm 0.1) \times 10^{-1}$
G(1250 GeV)	$(6.6 \pm 0.4 \pm 0.3) \times 10^{-2}$
G(1500 GeV)	$(1.9 \pm 0.1 \pm 0.1) \times 10^{-2}$



CONF 2011
Paper in review

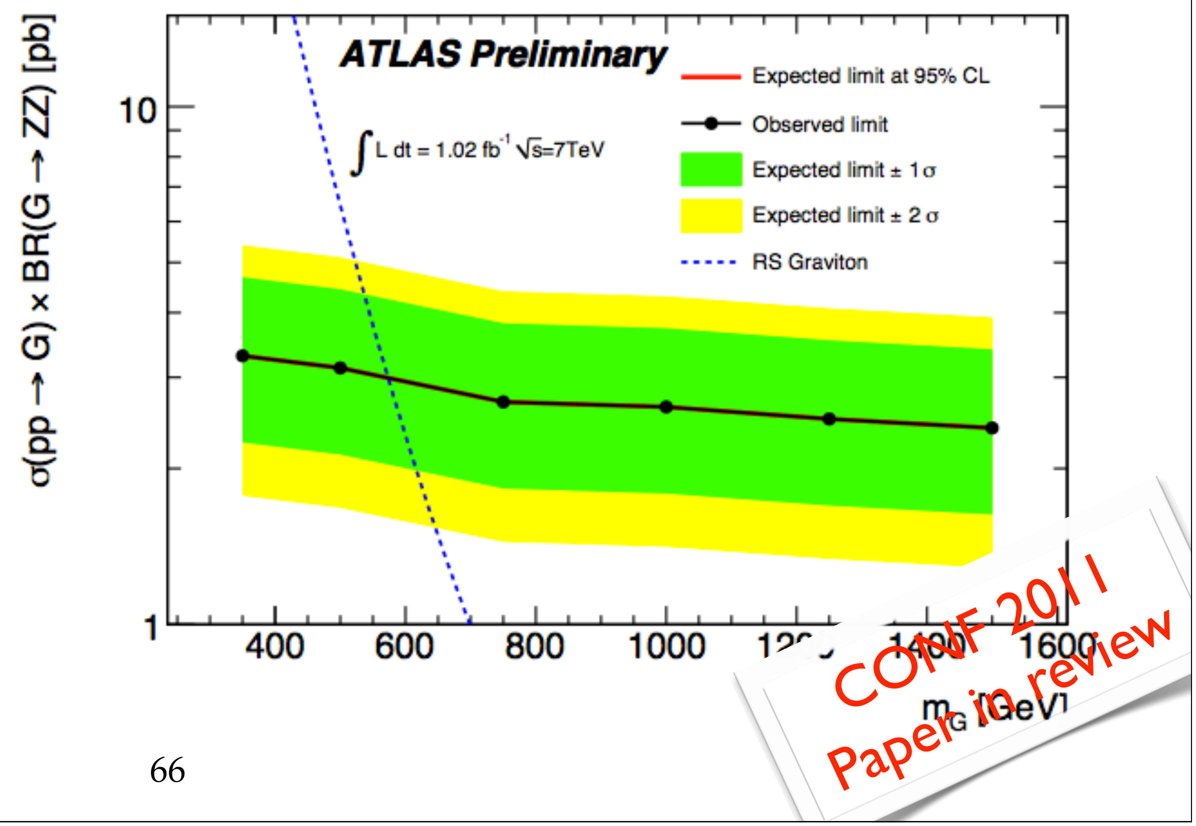
fiducial limits

$$\sigma_{ZZ\ \mathrm{fid}} < \frac{N_{ZZ}}{\epsilon_{ZZ} \times BF(ZZ \to \ell\ell\ell\ell) \times \mathcal{L}} = \frac{5.7}{0.61 \times 0.010 \times 1.02\ \mathrm{fb}^{-1}} = 0.92\ \mathrm{pb}$$

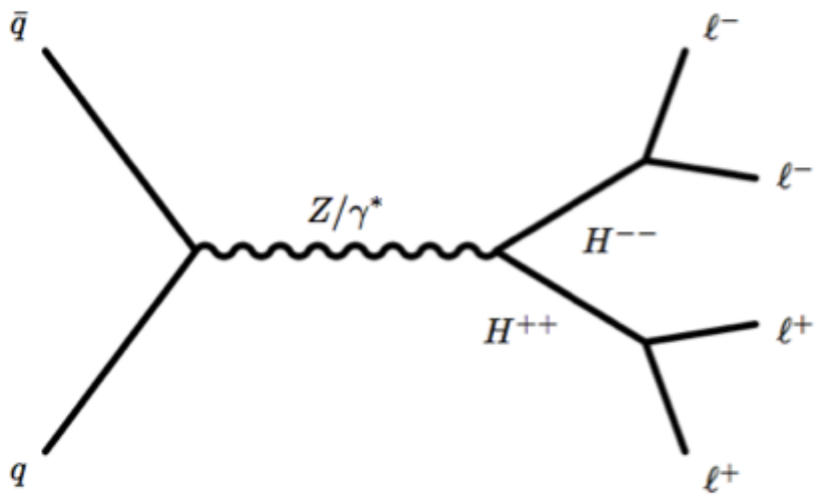
fiducial limits

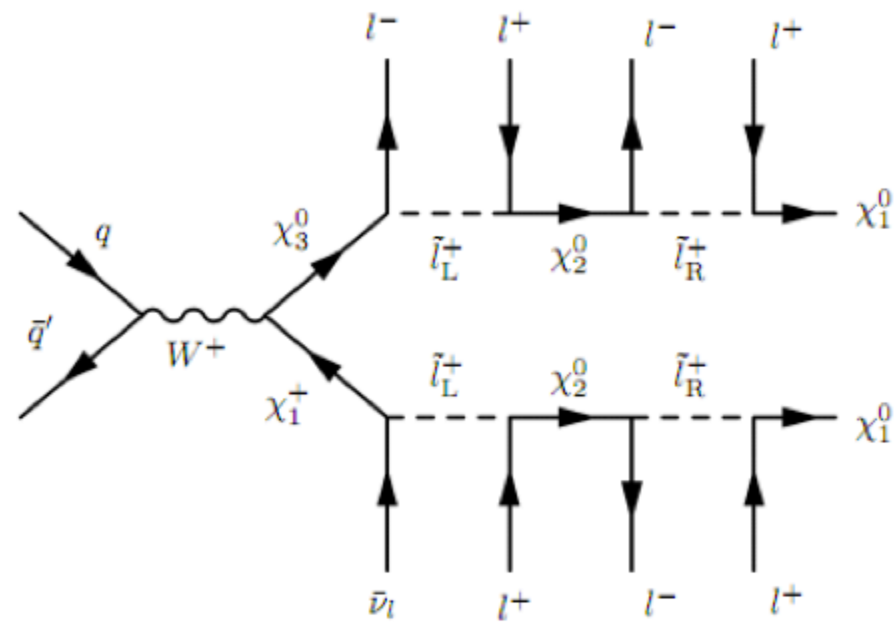
$$\sigma_{ZZ\ \mathrm{fid}} < \frac{N_{ZZ}}{\epsilon_{ZZ} \times BF(ZZ \to \ell\ell\ell\ell) \times \mathcal{L}} = \frac{5.7}{0.61 \times 0.010 \times 1.02\ \mathrm{fb}^{-1}} = 0.92\ \mathrm{pb}$$

Graviton Mass [GeV]	Theory [pb]	Fiducial Acceptance	Selection Efficiency
350	41.70	27%	61%
500	6.45	28%	63%
750	0.69	31%	66%
1000	0.13	32%	66%
1250	0.03	33%	67%
1500	0.01	35%	66%



Anomalous 4l

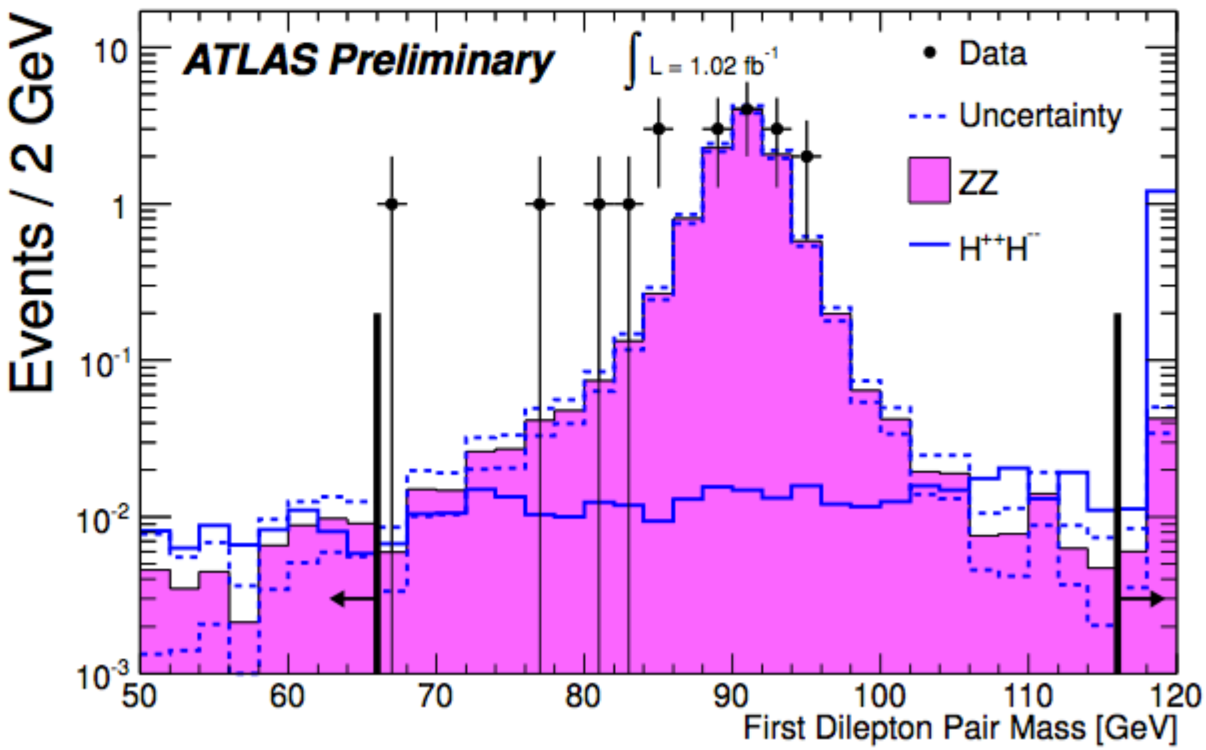




Many Leptons at the LHC from the NMSSM

Vernon Barger,[1] Gabe Shaughnessy,[2,3] and Brian Yencho[1]

Anomalous 4l



Process	Total
ZZ	$0.10 \pm 0.01 \pm 0.01$
Fakes	$0.61^{+1.25}_{-0.61}{}^{+0.91}_{-0.51}$
Total Bkg.	$0.71^{+1.25}_{-0.61}{}^{+0.91}_{-0.51}$
$H^{\pm\pm}_{200}$	$1.27 \pm 0.04 \pm 0.03$
Data	0

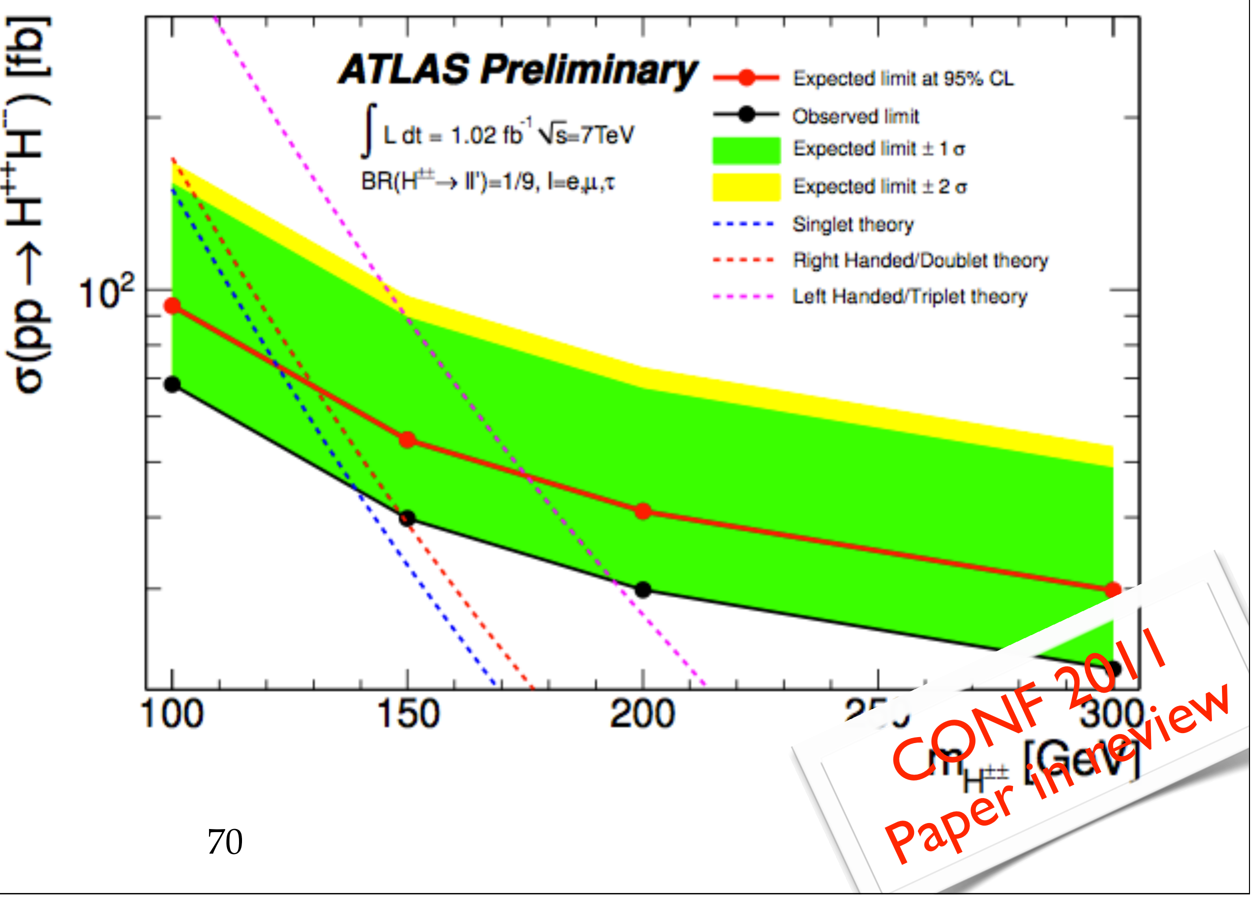
fiducial limits

$$\sigma_{4\mathrm{l\ fid}} < \frac{N_{4\ell}}{\epsilon_{\mathrm{non-ZZ}} \times \mathcal{L}} = \frac{3.0}{0.62 \times 1.02\ \mathrm{fb}^{-1}} = 4.7\ \mathrm{fb}$$

fiducial limits

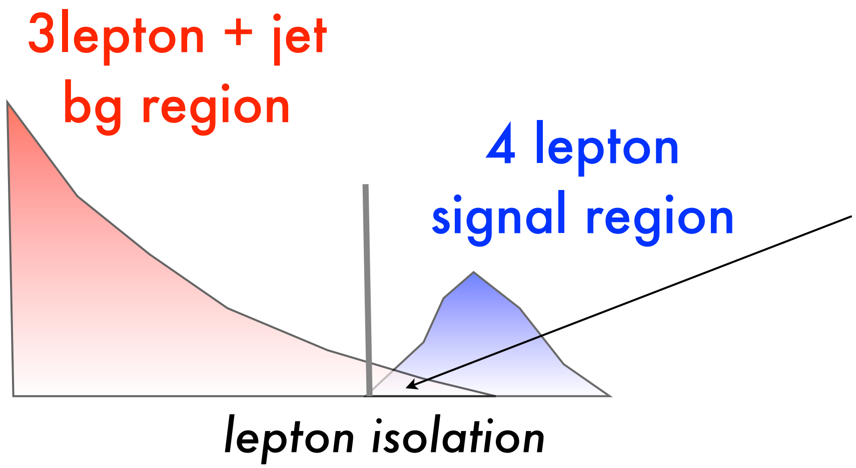
$$\sigma_{4l\ fid} < \frac{N_{4\ell}}{\epsilon_{non-ZZ} \times \mathcal{L}} = \frac{3.0}{0.62 \times 1.02\ fb^{-1}} = 4.7\ fb$$

$H^{\pm\pm}$ Mass [GeV]	Fiducial Acceptance	non-ZZ Selection efficiency
100	7%	62%
150	12%	66%
200	16%	67%
300	22%	67%



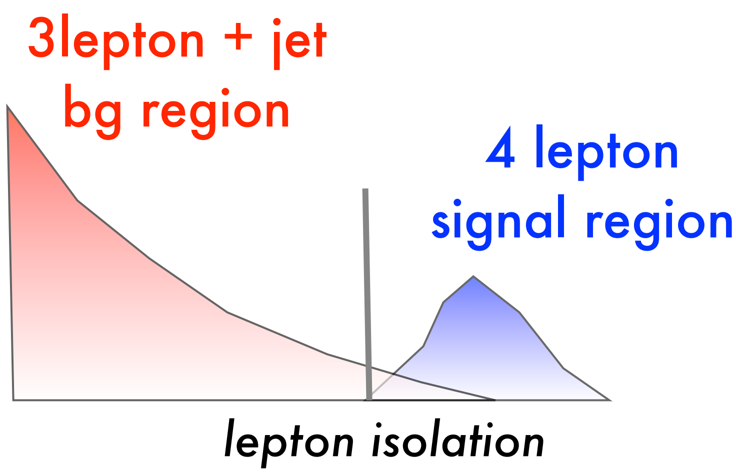
Backup

Background strategy

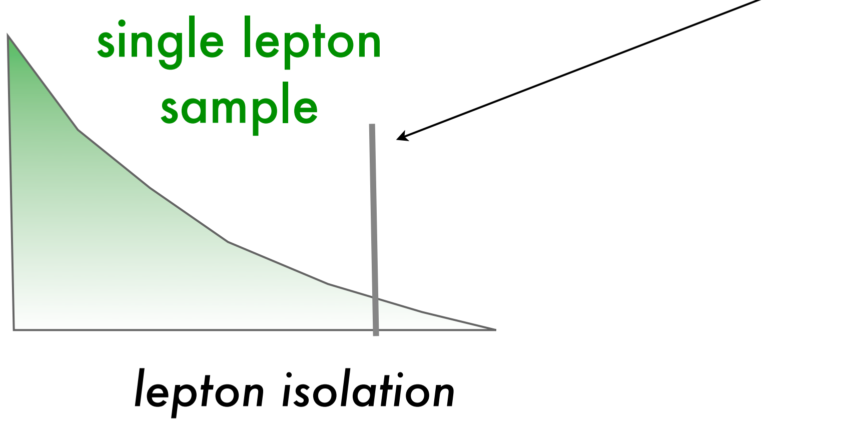


Need to know the size of this tail

Background strategy

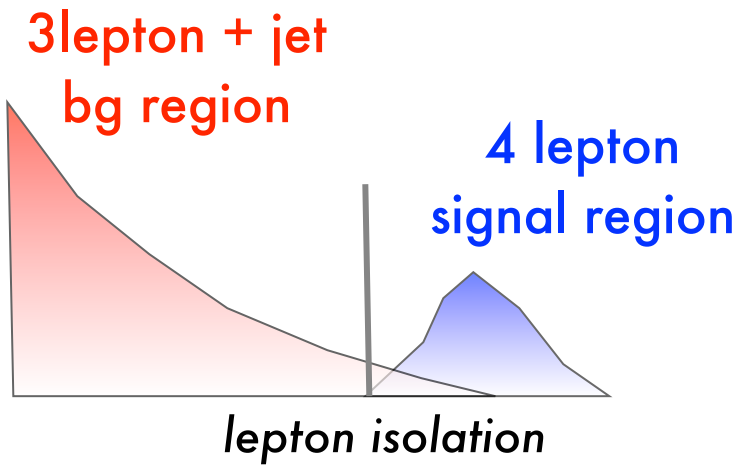


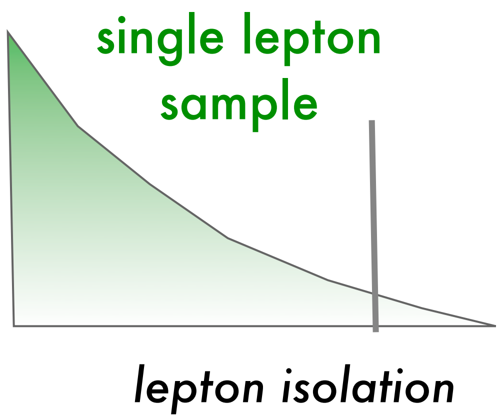
Find the same shape in a different sample



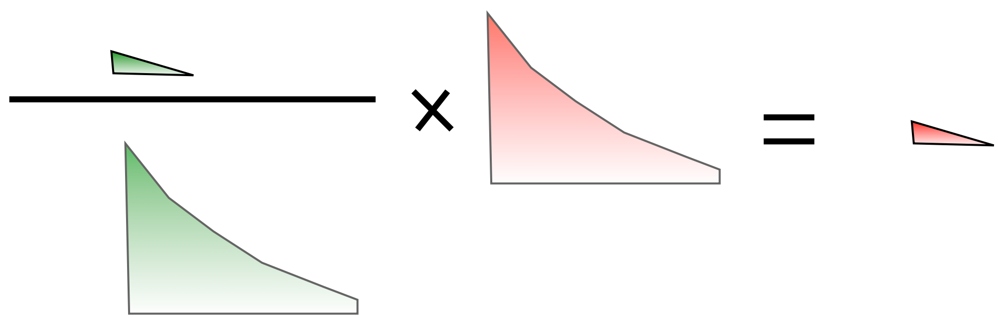
Measure fraction that pass threshold

Background strategy





Use fake rate
to extrapolate



FR x 3l+j = 4l bg

systematic uncertainties

<u>Lepton efficiencies</u>

electron efficiencies (7% in eeee)

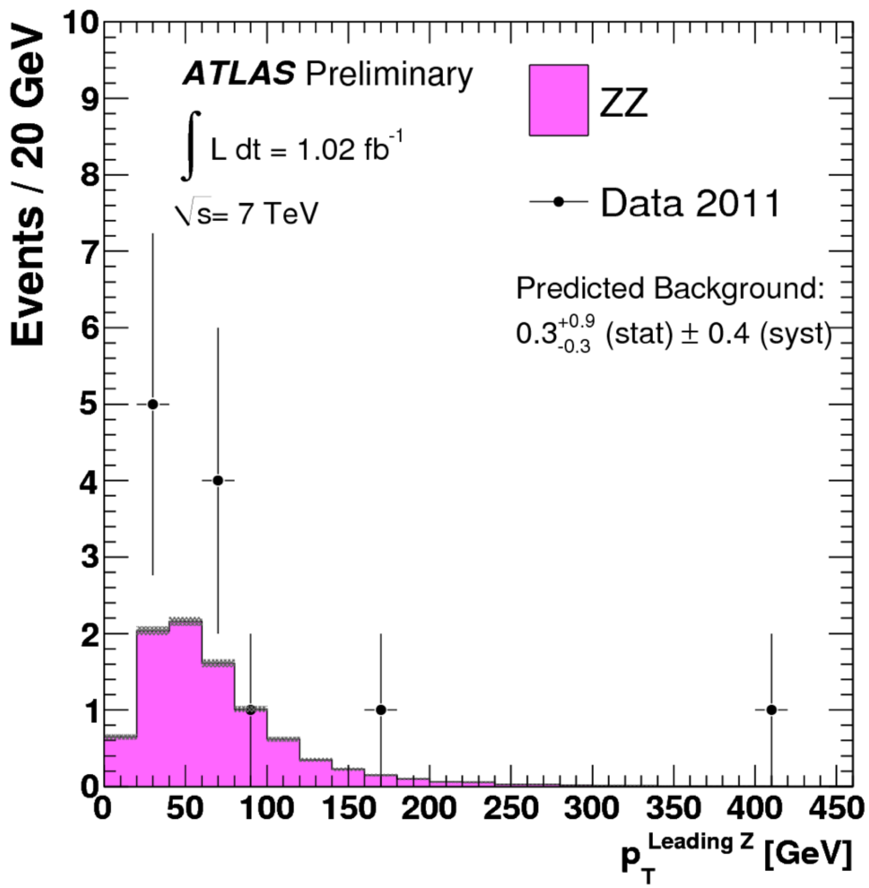
muon efficiencies (2% in μμμμ)

<u>Fake background</u> (up to 80%)

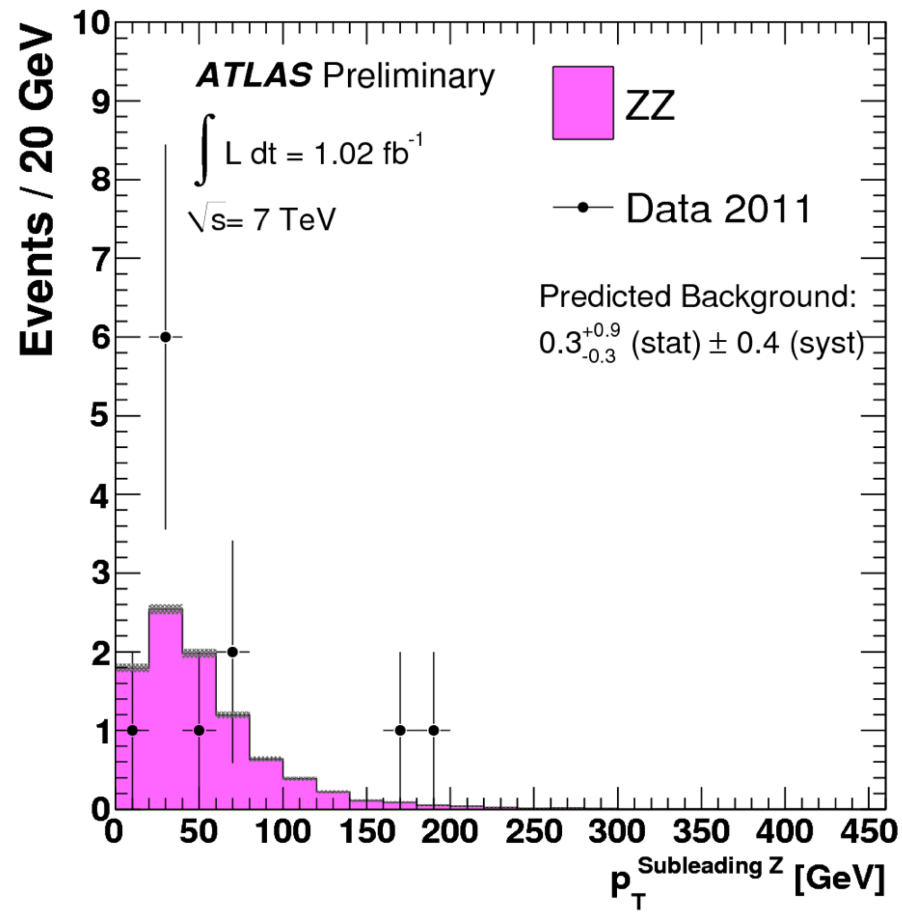
Light/heavy flavor composition

quark/gluon composition

Z momenta



ATLAS Preliminary
∫ L dt = 1.02 fb⁻¹
√s= 7 TeV
ZZ
Data 2011
Predicted Background:
0.3 +0.9 -0.3 (stat) ± 0.4 (syst)
Events / 20 GeV
p_T Leading Z [GeV]



ATLAS Preliminary
∫ L dt = 1.02 fb⁻¹
√s= 7 TeV
ZZ
Data 2011
Predicted Background:
0.3 +0.9 -0.3 (stat) ± 0.4 (syst)
Events / 20 GeV
p_T Subleading Z [GeV]