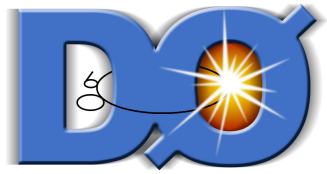


Searches for New Physics in the Top Quark Sector

Su-Jung Park
II. Physikalisches Institut
Georg-August-Universität Göttingen

GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

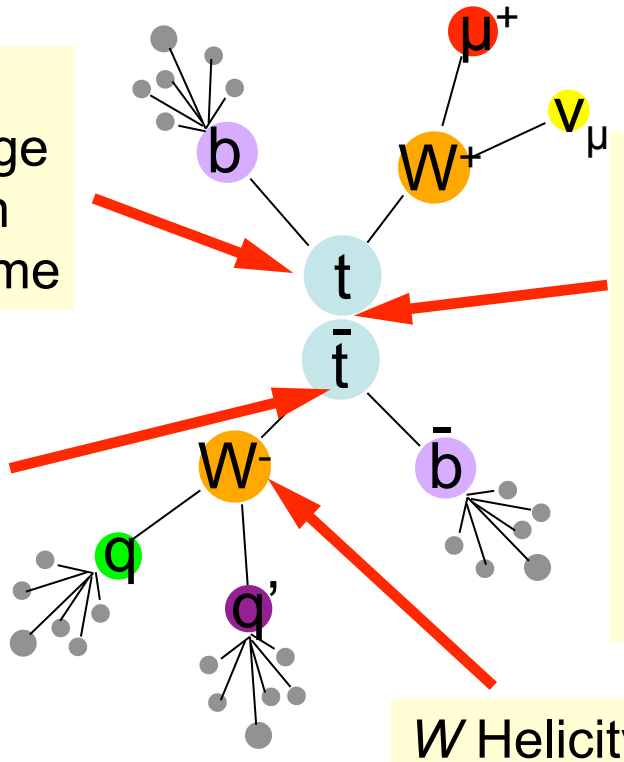
Overview

- Introduction
- Examples from Top Quark Production
  - $t\bar{t}$ Resonances
  - Differential Cross Section
- Examples from Top Quark Decay
  - Flavor Changing Neutral Currents
  - Cross Section Ratios
- More Possibilities
- Summary

Introduction

- Top quark provides various handles on new physics
- Many are covered by precisely measuring top quark, others require dedicated studies

Mass
Charge
Width
Lifetime



Production cross section
Kinematics
Resonance production
New particle
Associated production
Spin correlations
Charge asymmetry
Forward-backward asymmetry

Rare decays
Branching ratio
$|V_{tb}|$
Anomalous couplings

W Helicity

- Examples for unusual production and rare decays

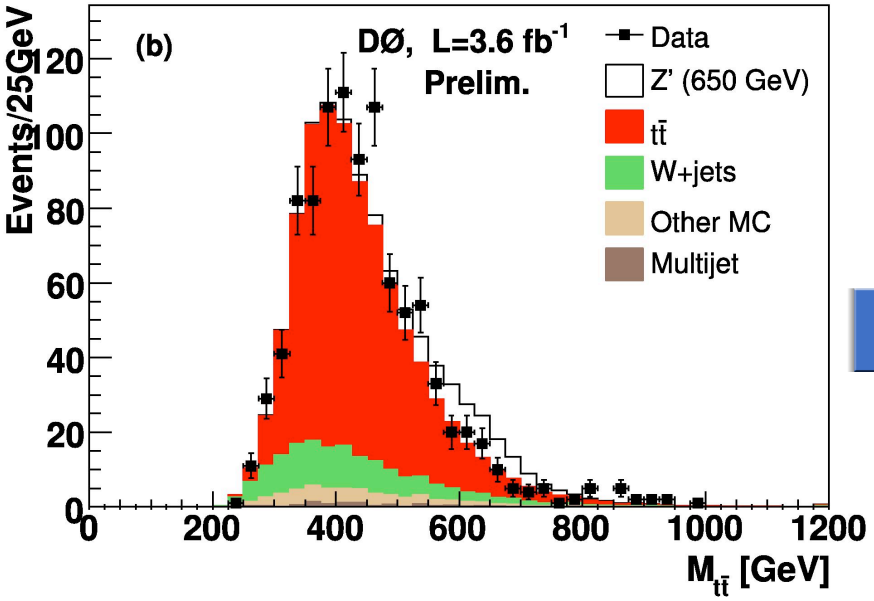
Unusual Production

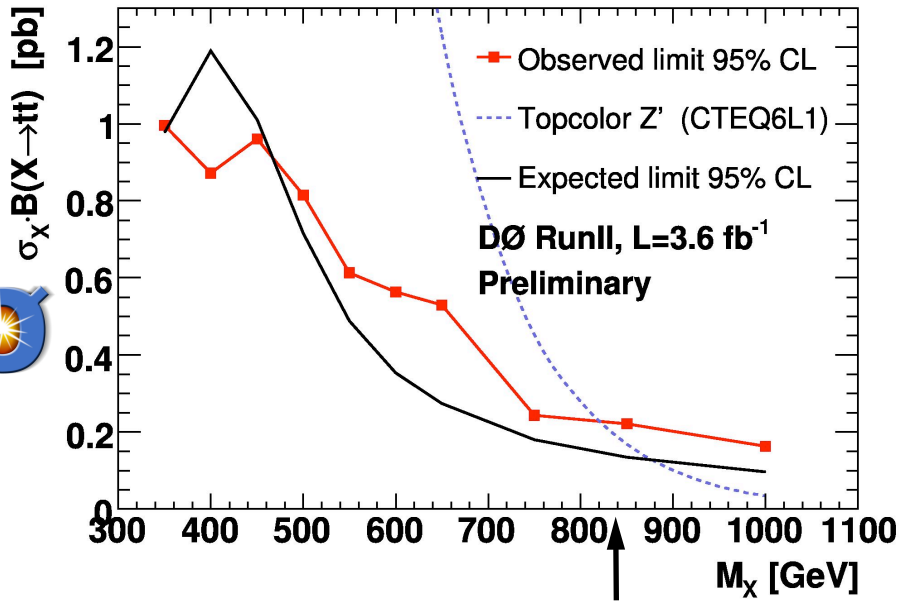
- Theory provides candidates for $t\bar{t}$ resonances
  - Massive *Z*-like bosons in extended gauge theories
  - Kaluza Klein excited states of gluons, weak bosons, gravitons
  - Axigluons
  - Massive gluon
  - Narrow leptophobic *Z´* in topcolor models

- Narrow resonances (independent of theory) should be visible as peak in invariant mass spectrum of $t\bar{t}$ pairs
- Additionally, the differential cross section as a function of the invariant mass can be calculated

Resonances@Tevatron

- Semileptonic decay channel (≥3 jets and ≥1 b-tag) in 3.6 fb^{-1}
- Reconstruct $M_{t\bar{t}}$ from up to four leading jets, lepton, neutrino (*W* mass constraint for p_z^{ν})
- Template method

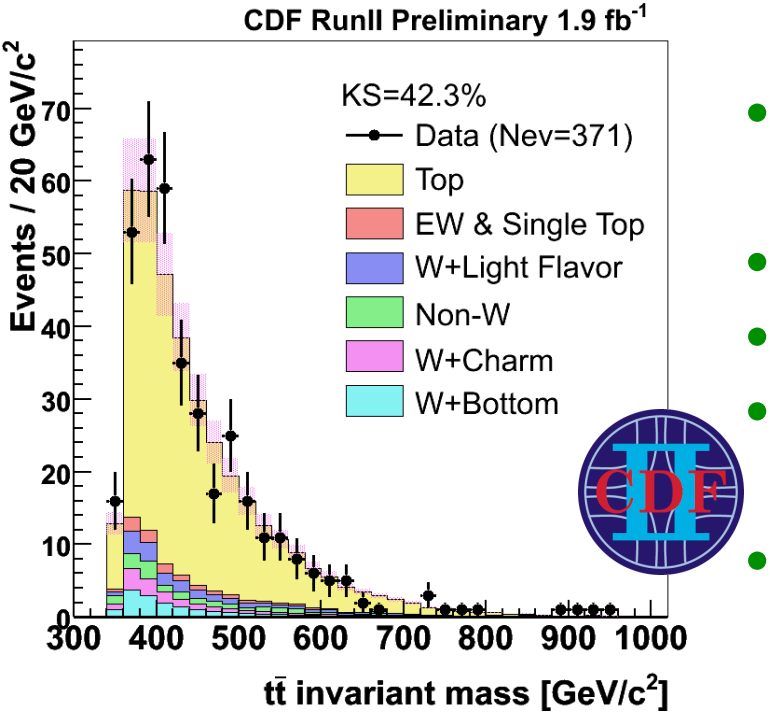




- For topcolor leptophobic Z´: $(\Gamma_{Z'} = 0.012 M_{Z'})$ $M_{Z'} > 820$ GeV
- Model-independent upper cross section limits

Resonances@Tevatron

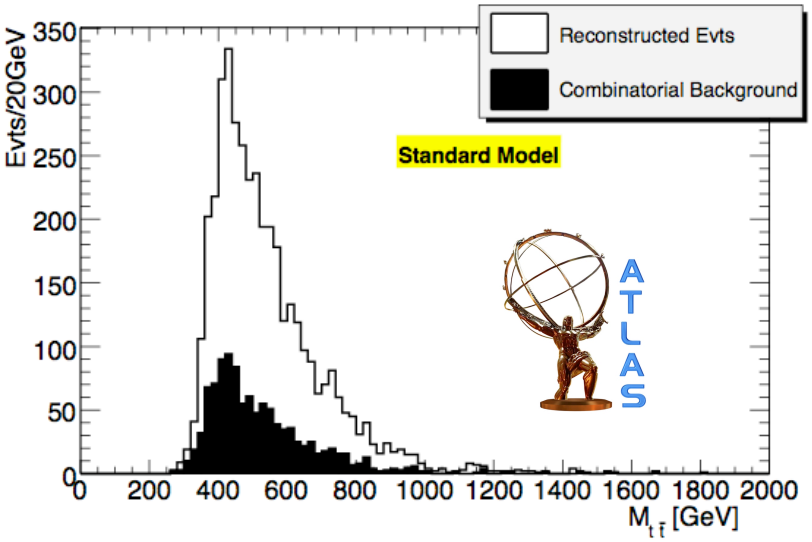
- Semileptonic decay channel (≥4 jets)
- Template method with 955 pb^{-1} (≥1 b-tag): χ^2 minimization to $t\bar{t}$ hypothesis, top mass as constraint => $M_{Z'} > 720$ GeV
- Matrix element + template method with 682 pb^{-1}: probability distribution for $M_{t\bar{t}}$ using differential $t\bar{t}$ cross section and transfer functions => $M_{Z'} > 725$ GeV



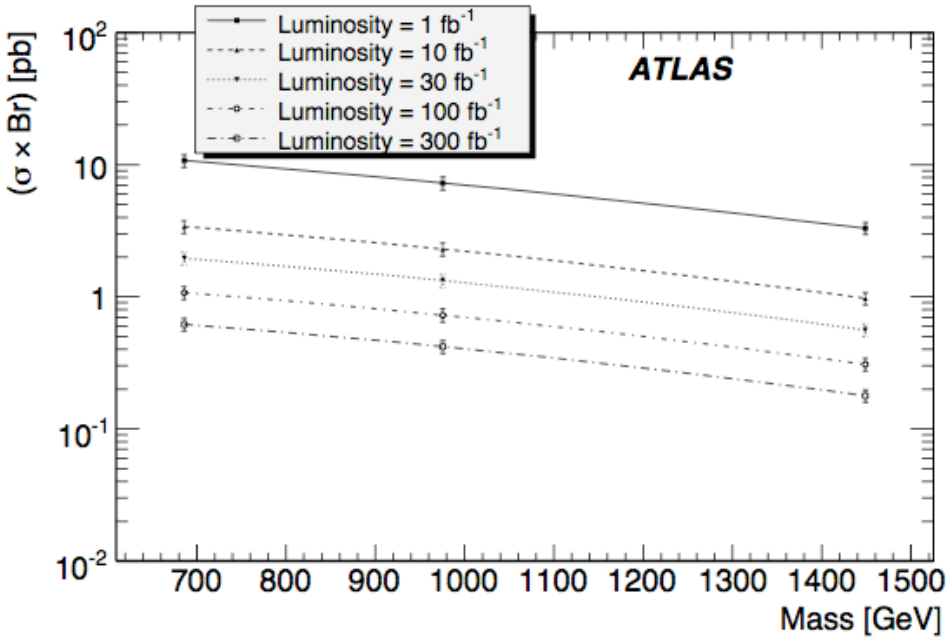
- Search for a massive gluon with 1.9 fb^{-1}
- Interference with $q\bar{q} \rightarrow t\bar{t}$ production
- Semileptonic channel (=4 jets, b-tags)
- Invariant mass distribution consistent with SM
- Limits on the coupling strength

Resonances@LHC

- Semileptonic decay channel (≥4 jets, =2 b-tags)
- Purely geometric method to minimize sensitivity to JES: closest jets form hadronic *W* + closest *b*-jet = hadronic top; on leptonic side use *W* mass constraint for p_z^{ν}

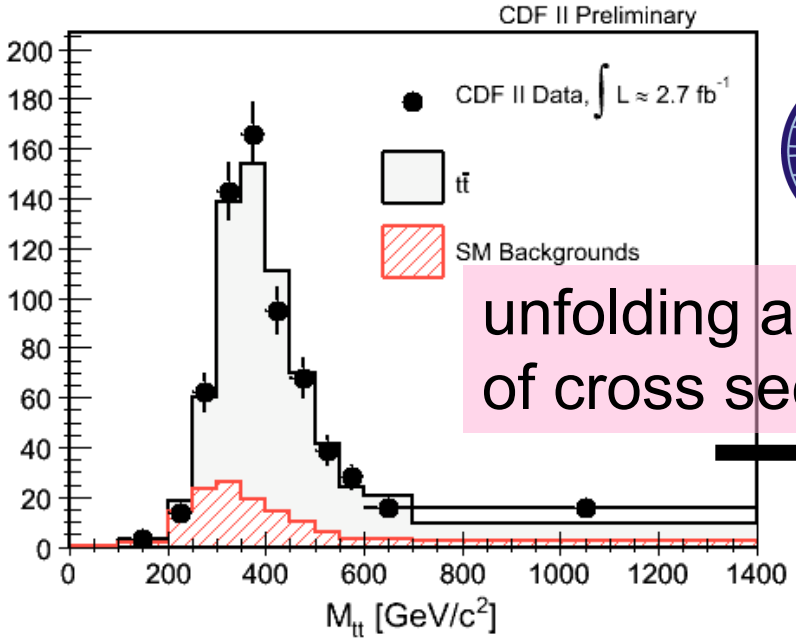


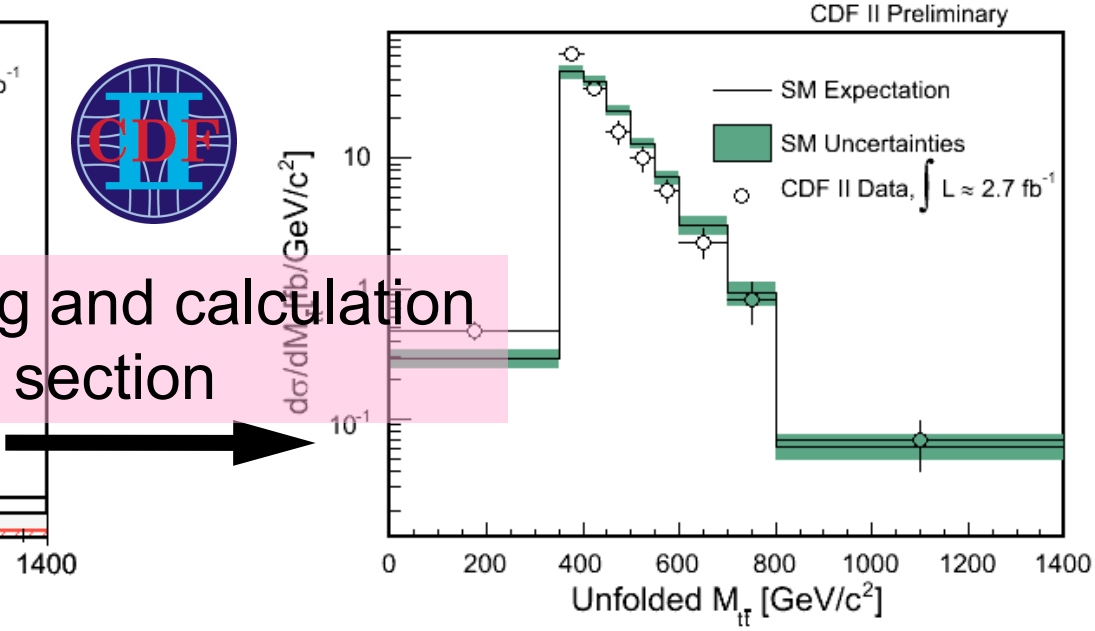
- Count SM $t\bar{t}$ in mass window twice the detector resolution
- => Discovery potential for narrow resonances



Differential Xsec@Tevatron

- Semileptonic decay channel (≥4 jets, ≥1 b-tag) in 2.7 fb^{-1}
- In-situ JES using hadronic *W*
- $M_{t\bar{t}}$ reconstruction with 4 leading jets, lepton and MET
- $M_{t\bar{t}}$ in 9 bins
- Unfolding for detector effects and acceptance
- No deviation from the Standard Model



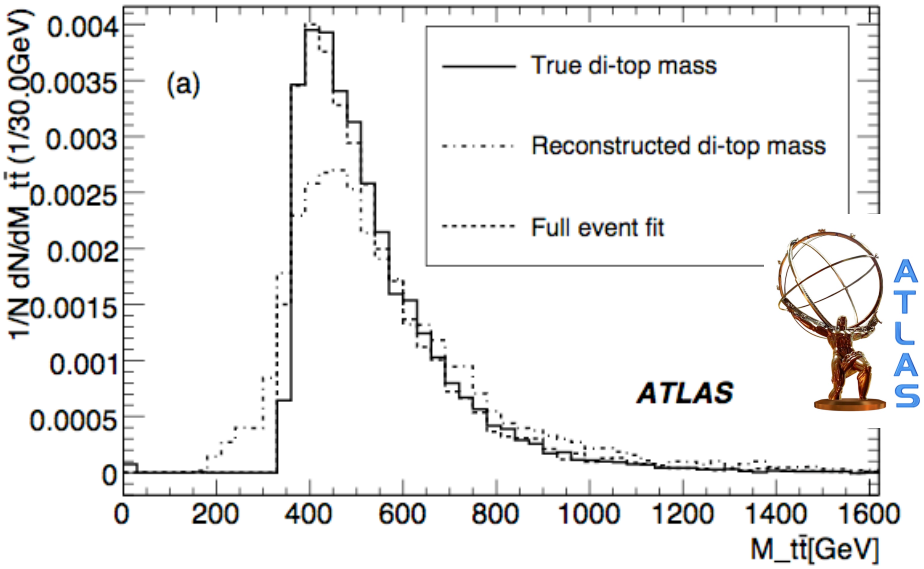


unfolding and calculation of cross section

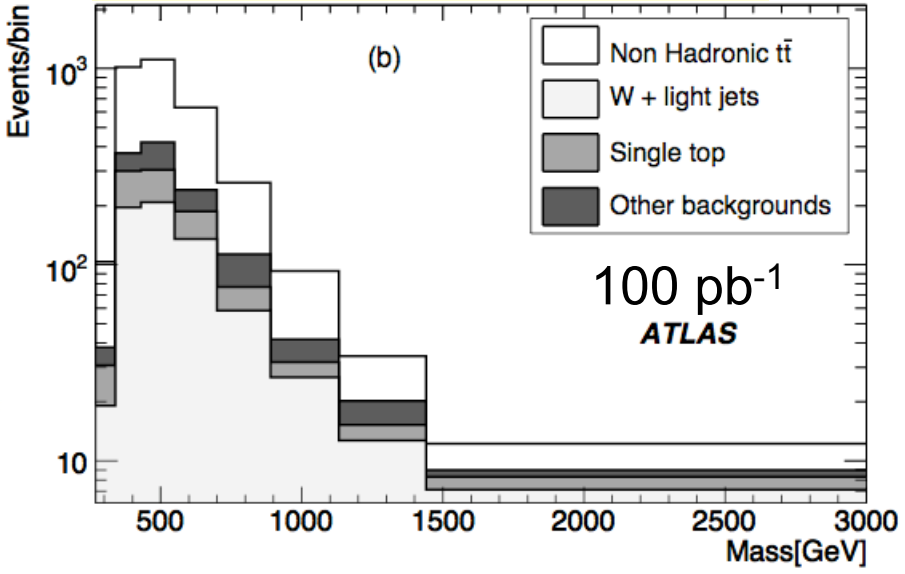
Differential Xsec@LHC

- Semileptonic decay channel (≥4 jets)
- Full least squares fit with *W* and top mass constraints OR simple reconstruction with leptonic *W* (by *W* mass constraint) plus 4 jets
- Expected mass resolution 5-9% for 200-850 GeV, bin size twice the mass resolution

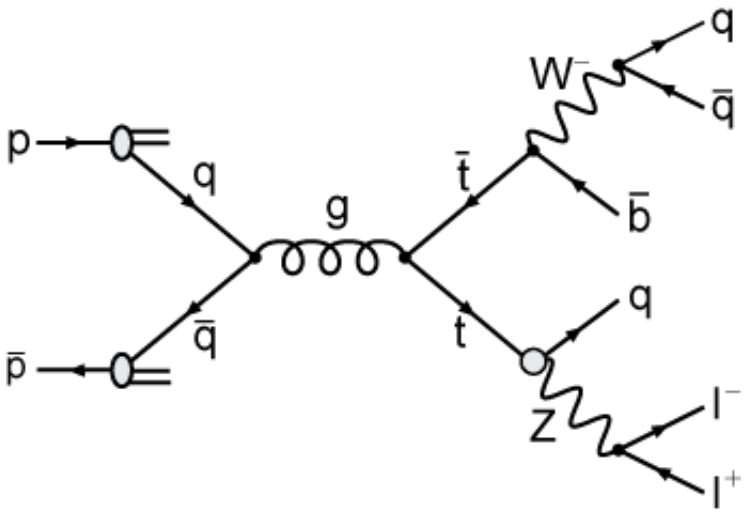
Comparison of fits

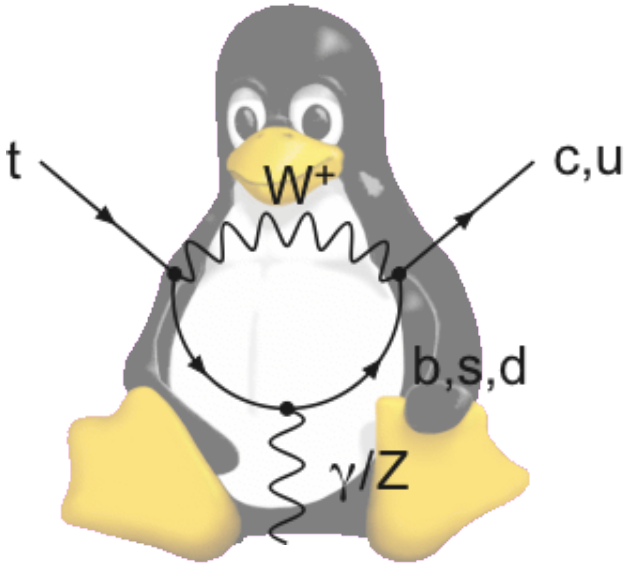


Mass spectrum (full fit)



Rare Decays





- Flavor Changing Neutral Currents (FCNC) highly suppressed in Standard Model: $\mathcal{B}(t \to Zq) = \mathcal{O}(10^{-14})$
- For some BSM models (e.g. SUSY) $\mathcal{B}(t \to Zq)$ up to $\mathcal{O}(10^{-4})$
- Similar for $t \to gq$ and $t \to \gamma q$

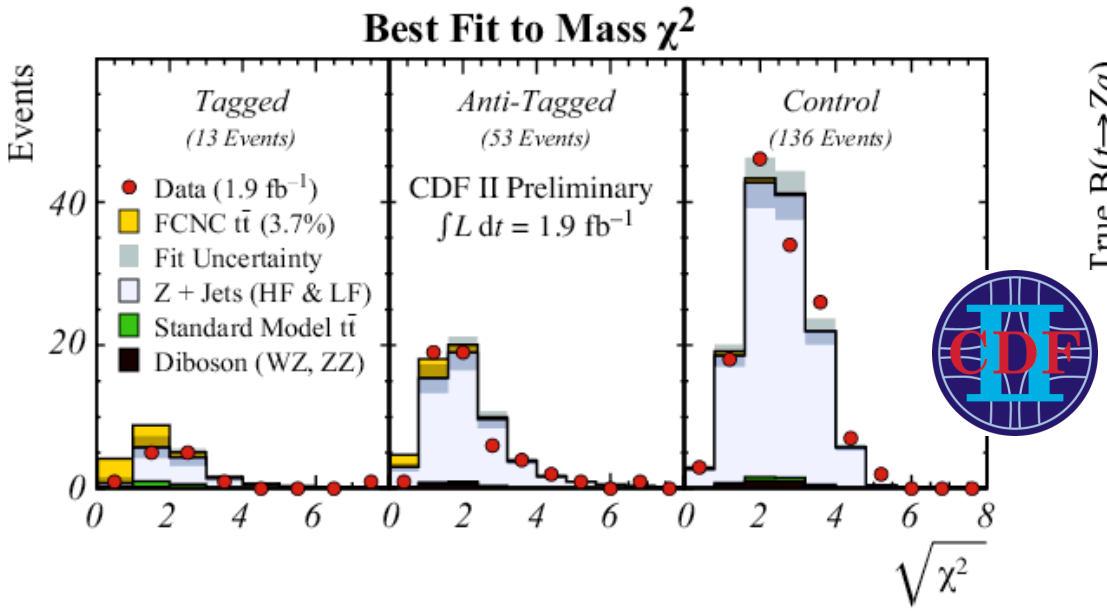
- Decay $t \to H^+ b$ could enhance τ or (semi)hadronic channels

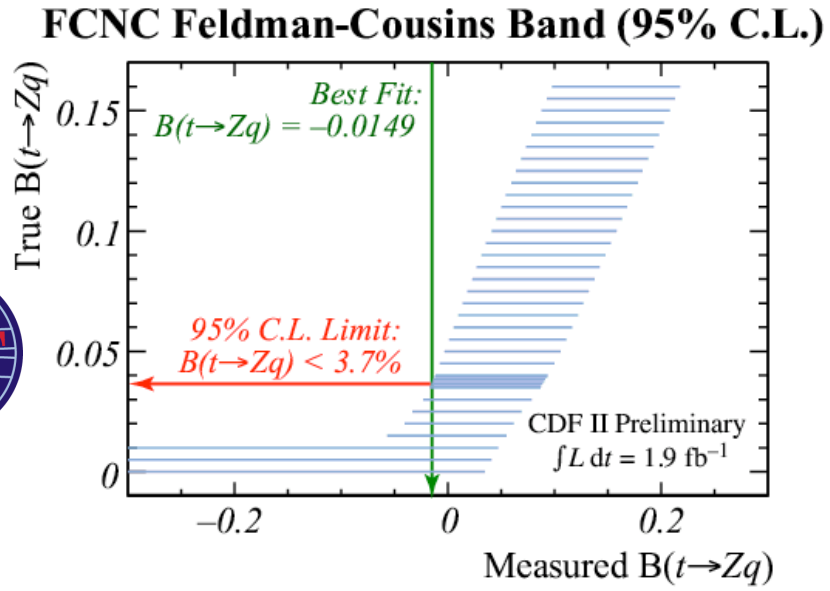
FCNC@Tevatron

- Direct search for $t \to Zq$ with leptonic Z candidate + ≥4 jets
- Two signal regions (0 b-tag, ≥1 b-tag) and a control region

$$\chi^2 = \left(\frac{m_{W,\mathrm{rec}} - m_{W,\mathrm{PDG}}}{\sigma_W}\right)^2 + \left(\frac{m_{t\to Wb,\mathrm{rec}} - m_t}{\sigma_{t\to Wb}}\right)^2 + \left(\frac{m_{t\to Zq,\mathrm{rec}} - m_t}{\sigma_{t\to Zq}}\right)^2$$

- Template fit to measured mass χ^2 => $\mathcal{B}(t \to Zq) < 0.037$



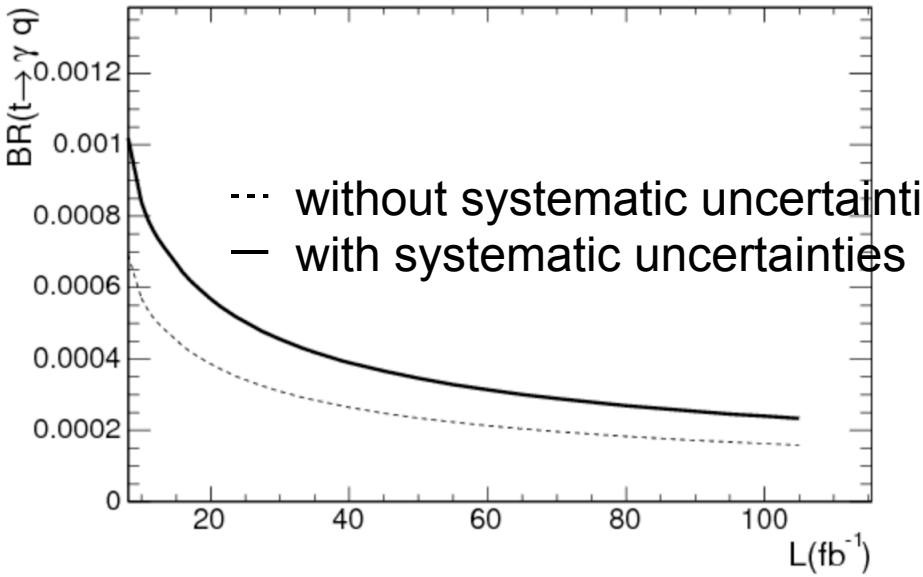


- Limits on $\mathcal{B}(t \to Zc, gc, \gamma c)$ of 0.11-0.13 from indirect search

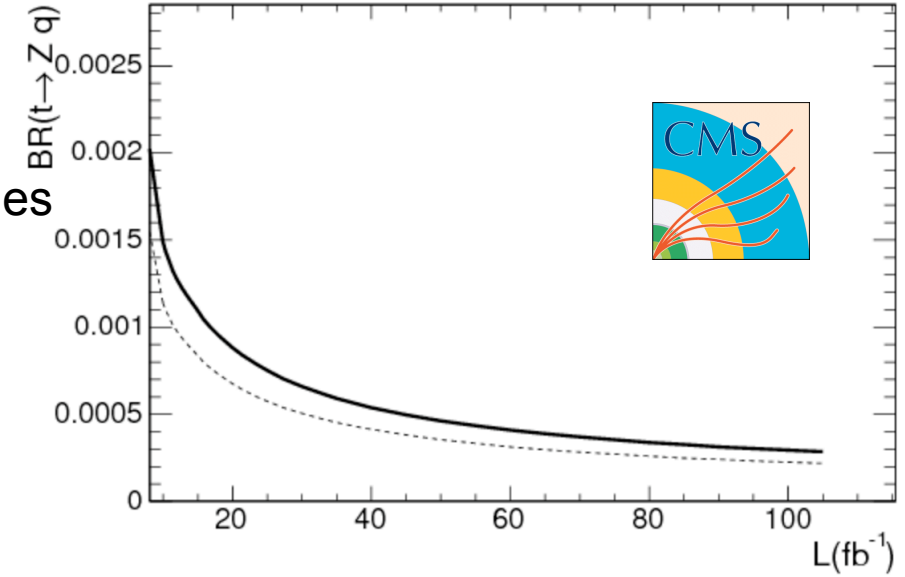
FCNC@LHC

- $t \to \gamma q, Zq$ (high background for *gq*)
- Only leptonic (*e*/μ) decays of *Z* and *W*
- Photon or $e^+e^-/\mu^+\mu^-$, light jet; isolated lepton, MET, b-jet; mass constraints on FCNC top, angle between tops
- Biggest background is SM $t\bar{t}$
- Discovery potential:

$t \to \gamma q$

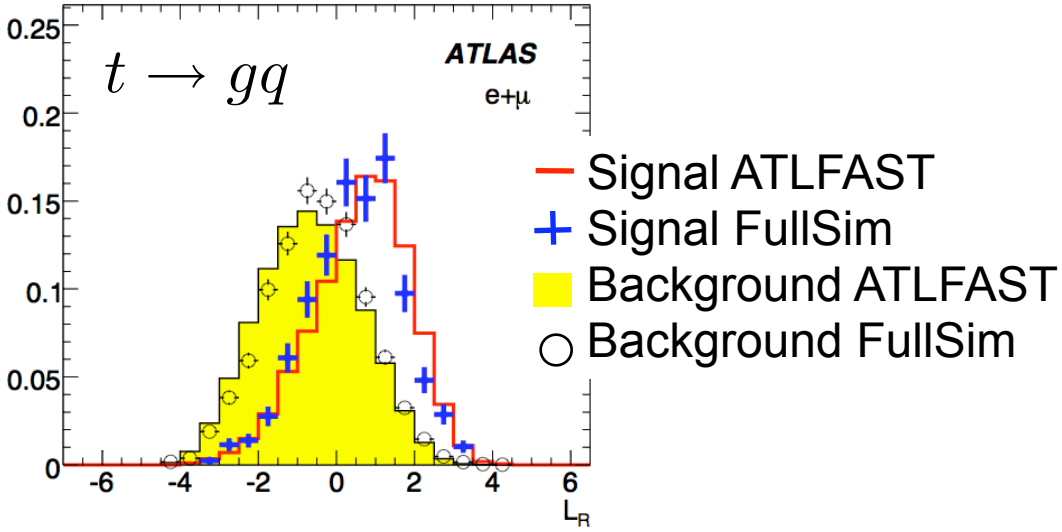


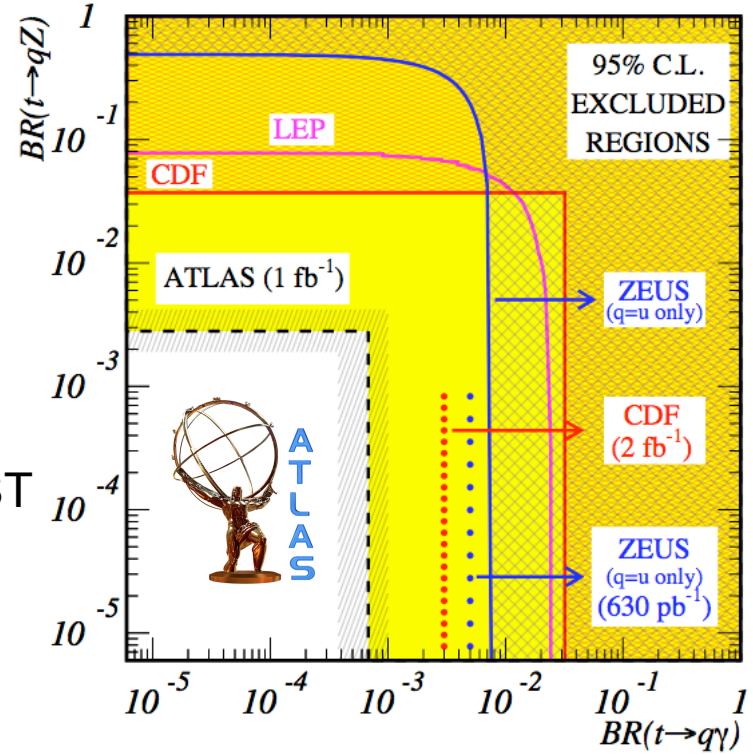
$t \to Zq$



FCNC@LHC

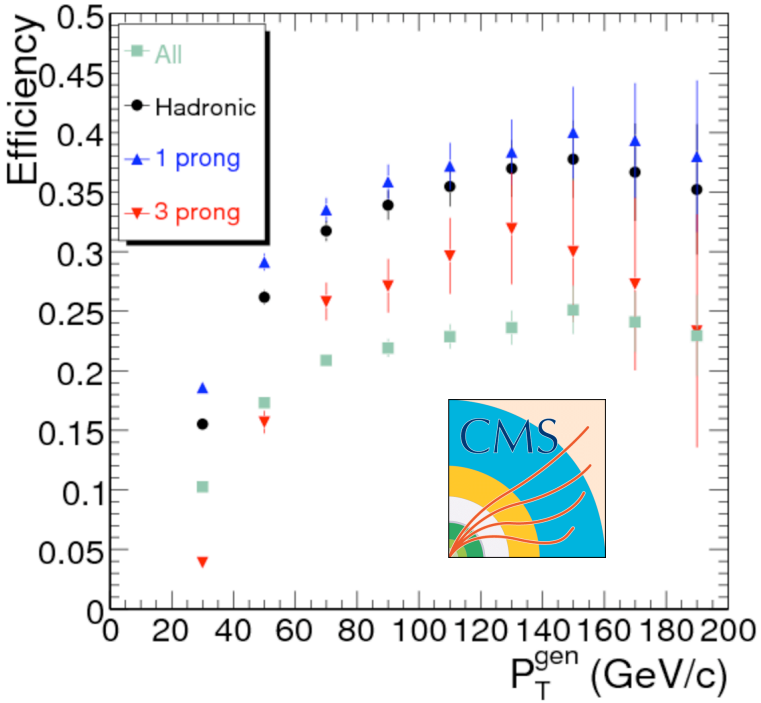
- $t \to Zq, gq, \gamma q$
- Only leptonic (e/μ) decays of *Z* and *W*
- Orthogonal selections, no b-tagging used
- Biggest backgrounds SM $t\bar{t}$, *W*+jets, *Z*+jets
- Mass χ^2 to choose neutrino solution and jet combination
- Use likelihood-based discriminants
- Expected sensitivity for 1 fb^{-1}

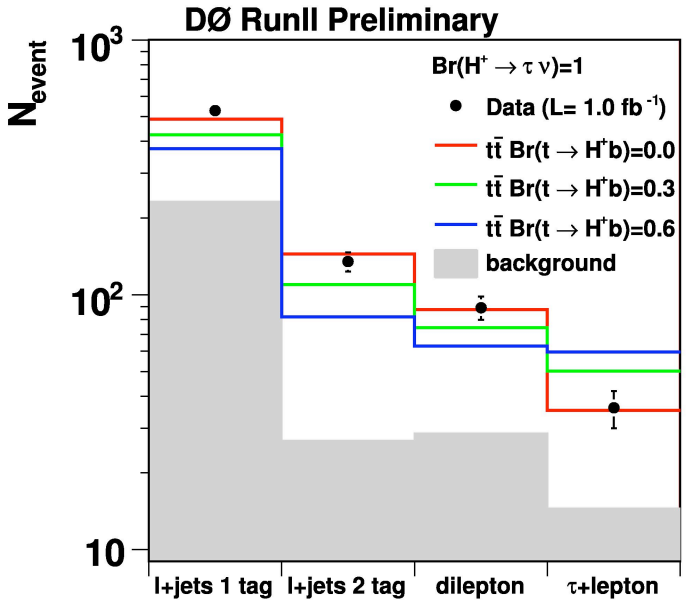




Cross Section Ratios

- Compare $t\bar{t}$ cross sections in different channels
- Ratios cancel many uncertainties
- $t \to H^+ b \to \tau^+ \nu b$ would enhance τ channels (see plot)
- $t \to H^+ b \to c\bar{s}b$ would enhance hadronic channels
- => Limits on those decays





- τ Decays of $t\bar{t}$ explored at LHC
- $t\bar{t}$ in τ still needs to be discovered!

More Possibilities

- Other feasible searches in the top sector
- Charged Higgs ($t \rightarrow H^{+} b$)
- Scalar top quarks with top signature ($\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ or $\tilde{t}_1 \rightarrow \tilde{\chi}_1^{+} b$)
- Associated production of Higgs ($t\bar{t}H \rightarrow t\bar{t}b\bar{b}$)
- Massive *t´* quark ($t' \rightarrow Wq$)
- Invisible decays of the top quark

- Single top
  - Charged Higgs ($H^{+} \rightarrow t\bar{b}$)
  - $W' \rightarrow tb$ resonance
  - FCNC production ($u(c) + g \rightarrow t$)

Summary

- Top quark excellent window to new physics
- Many exciting analyses are prepared for LHC
- Even more are possible...