

b' Searches in CMS

Yuan Chao
National Taiwan University

Beyond the 3 SM generation
at the LHC era Workshop
2008/09/04



Outlines

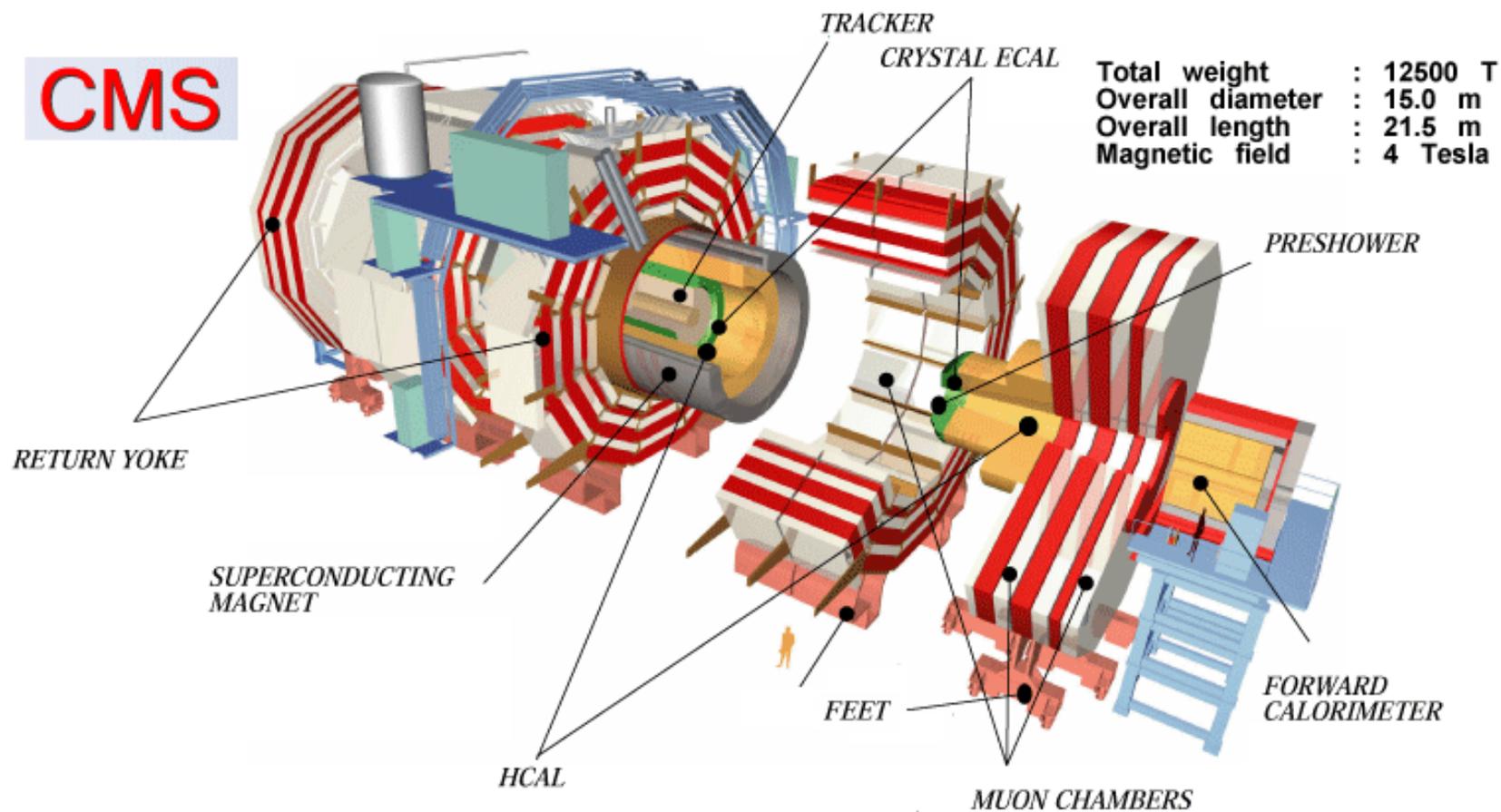
- Introduction
- Physics motivation
 - Hints from past studies
 - Current works from Tevatron
- Monte Carlo study
 - Signal
 - Backgrounds
- Summary and plans
- Future prospect





CMS Detector

- Compact Muon Solenoid
 - A general purposed detector





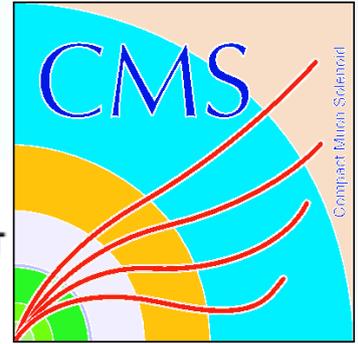
CMS Detector

- Compact Muon Solenoid
 - A general purposed detector

CMS



Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.5 m
Magnetic field : 4 Tesla



RETURN YOKE

SUPERCON. MAGNET

Key:

- Muon
- Electron
- Charged Hadron (e.g. Pion)
- - - Neutral Hadron (e.g. Neutron)
- - - Photon

4T

Silicon Tracker

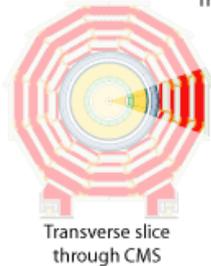
Electromagnetic Calorimeter

Hadron Calorimeter

Superconducting Solenoid

2T

Iron return yoke interspersed with Muon chambers



Transverse slice through CMS



Intro on 4th Generation Quarks

- The 4th generation: bottom-like b' and top-like t'
- Currently focus on b' decays:

Light b' scenario

- Larger x-section

- $b' \rightarrow cW, t^{(*)} W^{(*)}$

dominate:

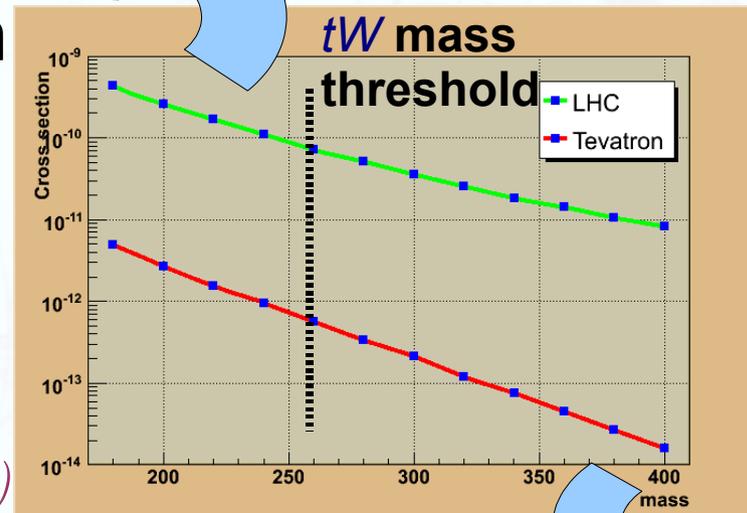
- Sizable $|V_{cb'}|$

$$b' \rightarrow cW \gg t^{(*)} W^{(*)}$$

- Suppressed $|V_{cb'}|$

$$b' \rightarrow cW \ll t^{(*)} W^{(*)}$$

- FCNC: bZ, bH



Heavy b' scenario

- Smaller x-section

- Wide mass coverage

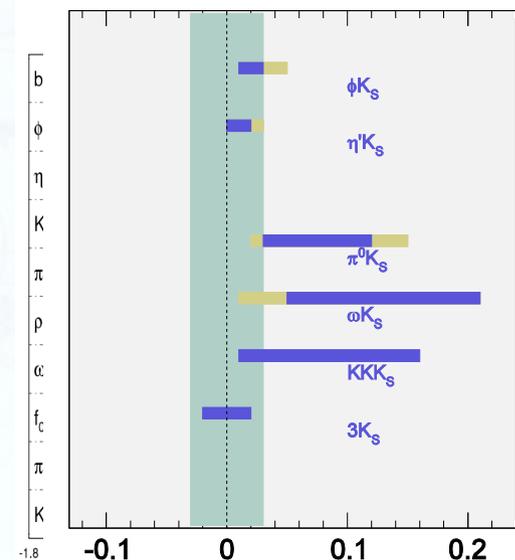
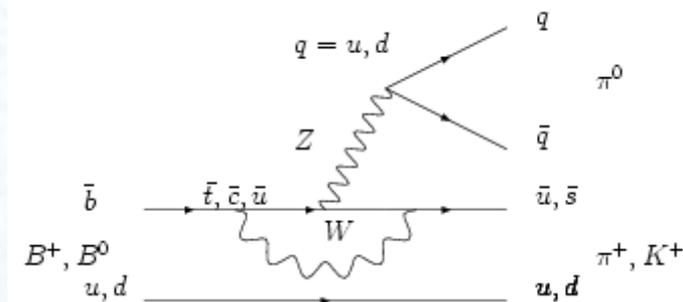
- $b' \rightarrow tW$ dominate

LHC has niche for both x-section and mass coverage!



Physics Motivation

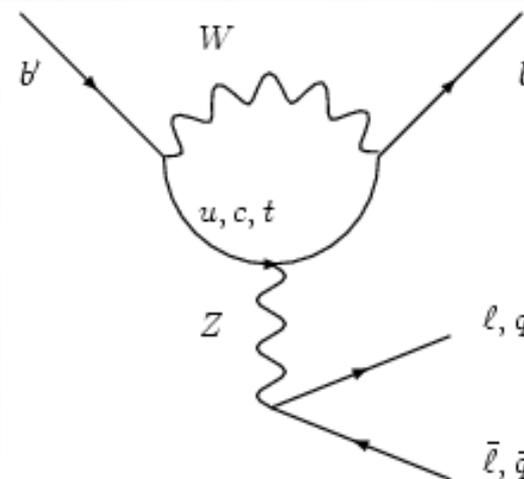
- Why still searching for b' :
- Hints from past works in B factories
 - The ΔA_{CP} on $B \rightarrow K\pi/K\pi^0$ DCPV
 - Highlight of ICHEP2004
 - Possible contribution from the **Z-penguin**
 - Recent publication in **Nature**
 - The $\Delta S < 0$ in $b \rightarrow sqq$ TCPV
 - Highlights sine first $S(\phi K_s)$
 - Tendencies show up in different $b \rightarrow sqq$ modes
 - Could be explained by introducing b'
- New results still coming from Tevatron
 - Different work groups continues studying in related topics
 - Not a closed file



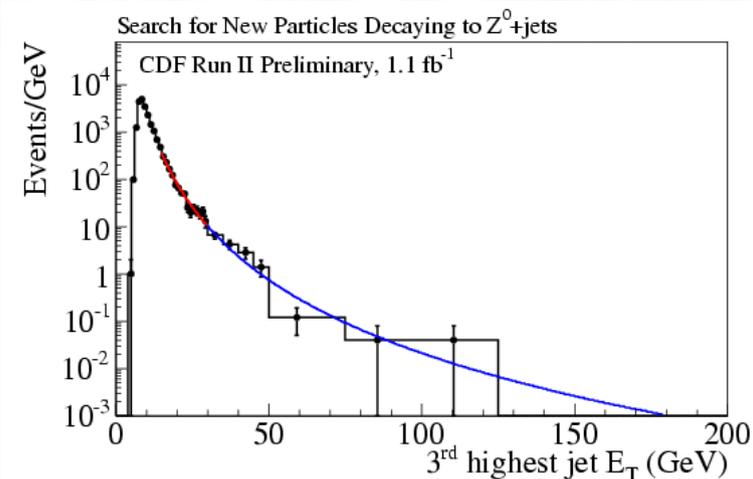


Search for New Particles to Z^0 +jets

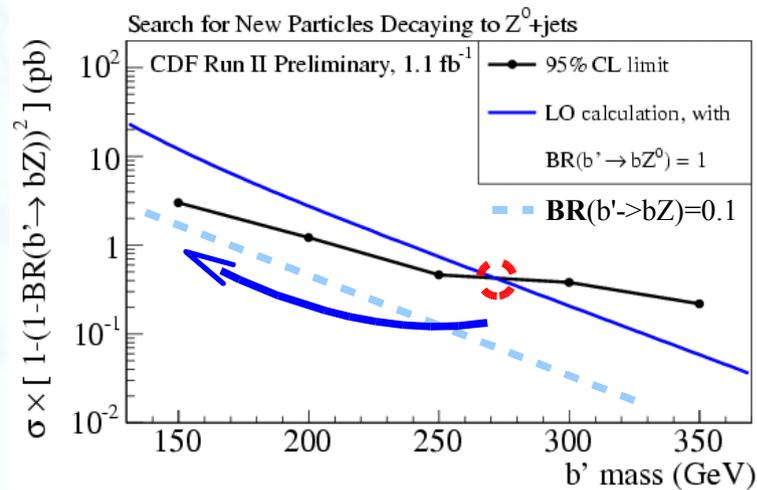
- CDF Run II data, 1.06/fb
 - $b'b'$ pair production
 - One Z leptonic decays
 - Check for the E_T of 3rd jet
- Assuming $\text{Br}(b' \rightarrow bZ)$: 100%
- b' mass > 268 GeV @ 95% C.L.



arXiv:0706.3264



Fit to 3rd-highest jet E_T jet distribution in Z +jet data.

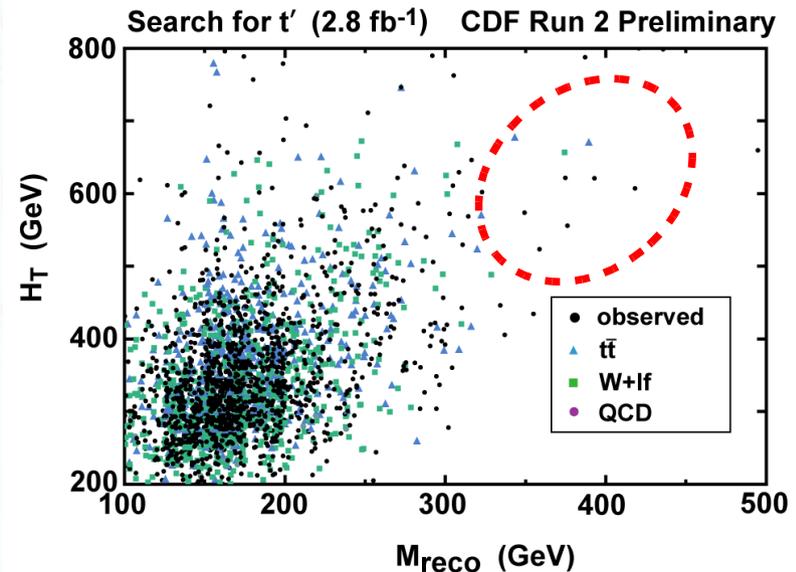
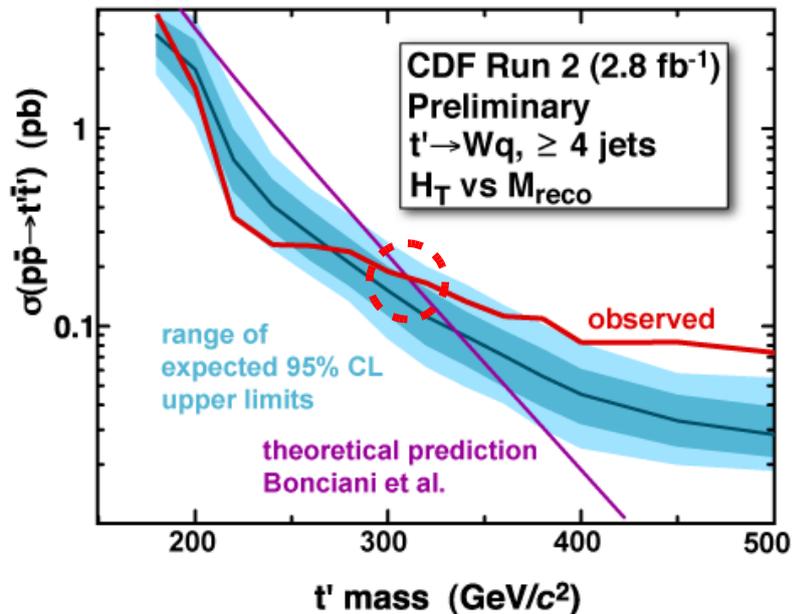


Cross section limit vs. mass.



Search for Heavy Top $t' \rightarrow Wq$ Events

- CDF Run II data, 2.8/fb
 - Decay channel: $t't' \rightarrow W(l'\nu) + 4\text{-jets}$
 - Veto: cosmic ray, $Z \rightarrow ll$
- Template method for M_T recon. based on best χ^2 -fit:
 - Observables: t' mass (M_{recon}) & total trans. energy (T_H)
 - t' mass > 311 GeV at 95% CL (previous 256 GeV with 760/pb)





Study Overview

- **b' mass assumption:**

- **Light b' scenario**

$$b'b' \rightarrow bZcW, bZt^{(*)}W^{(*)}, bZbZ, cWcW$$

- **Heavy b' scenario**

$$b'b' \rightarrow tWtW, tWcW$$

- **Leading order x-section (Pythia LO)**

| | Light b' | | | | Heavy b' | | | | |
|-------------------------------|------------|--------|-------|------|------------|------|------|------|--|
| M(b') GeV | 200 | 225 | 250 | 300 | 350 | 400 | 450 | 500 | |
| X-section pb | 264.29 | 149.59 | 89.25 | 34.9 | 16.3 | 8.05 | 4.36 | 2.45 | |

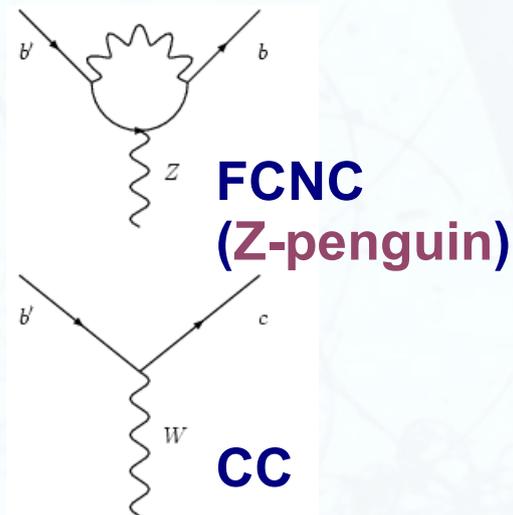
*Sub-branching fraction **not** included

- **Considered decay channels**

- $Z \rightarrow ll ; W \rightarrow l\nu, \text{Jets} (l \equiv e, \mu)$

- **Chosen final states: (cleanest mode with large sub-BR)**

$$3L+4J, 2L(++/--)+6J (tWtW)$$





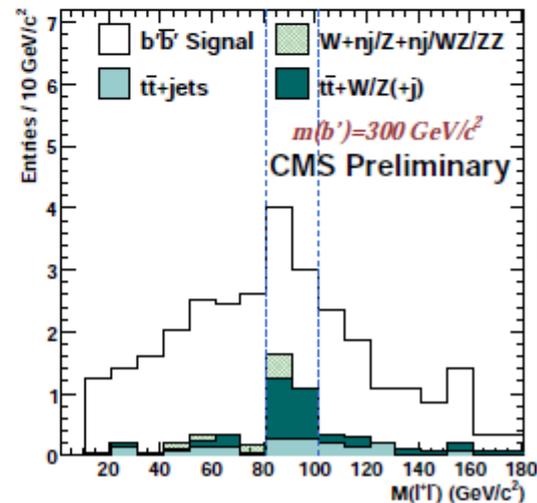
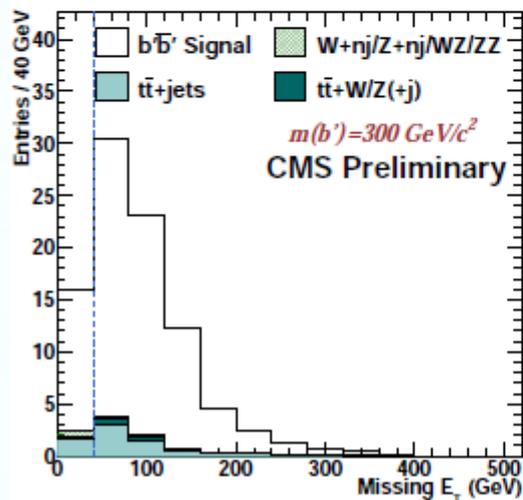
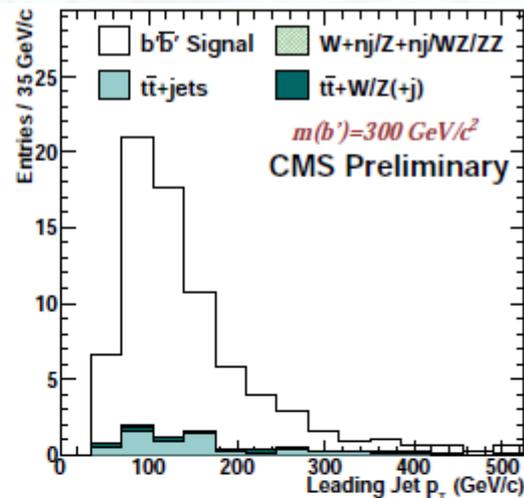
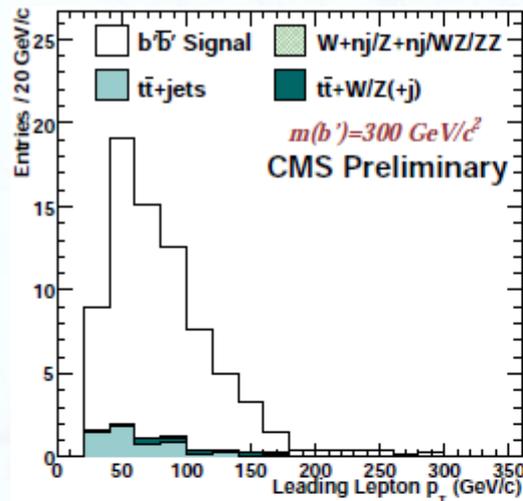
Object Selection

- **High level trigger:** single electron, muon trigger
- **Four types of objects are used**
 - **Electron:** built from ECAL super clusters with pixel matched trk
 - Kinematical selections, official Identification, Track isolation
 - **Muon:** reconstructed from local, stand-alone and global
 - Kinematical selections, Track isolation
 - **Calo Jets:** Iterative Cone 0.5 algorithm
 - Kinematical selections with Jet Energy Correction
 - **MET:** determined from calorimetric measurements
 - Kinematical selections with Jet Correction
 - **Muon** Correction
- **Event signature:**
 - $2L(ss)+N(\text{Jet})\geq 4$
 - $3L+N(\text{Jet})\geq 2$



Object Selection

- Kinematical distributions of the objects



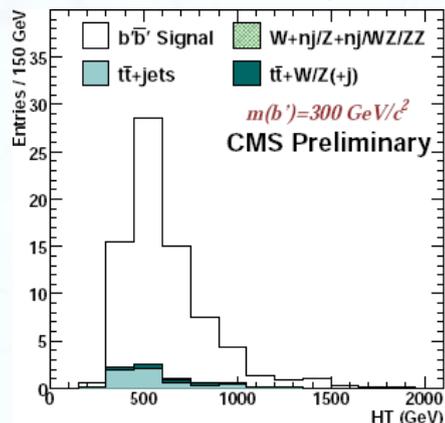


Event Selection

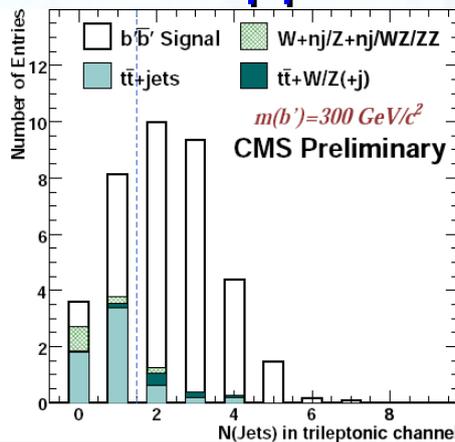
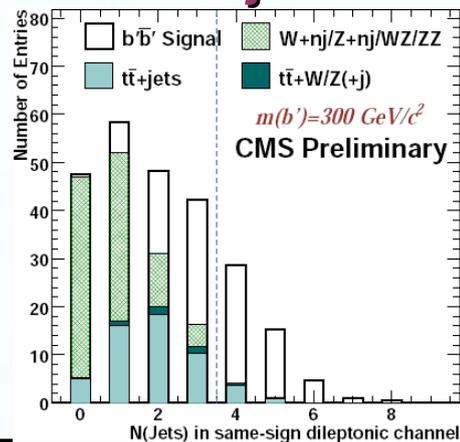
- Observables

- HT: trans. energy sum of all interested daughters

$$H_T \equiv \sum p_T(\text{Jets}) + \sum p_T(\text{leptons}) + \text{MET}$$



- Number of jets: a direct cut applied





MC Study

- Generated with a Fast sim

| Process | Xsec (pb) | Size | Generator |
|---------------------|-----------|-------|-----------|
| b'b'→tWtW (300 GeV) | 34.9 | 40K | Pythia |
| b'b'→tWtW (400 GeV) | 8.05 | 40K | Pythia |
| b'b'→tWtW (500 GeV) | 2.45 | 40K | Pythia |
| ttW | 0.65 | 6K | CompHEP |
| ttW+j (pT>10 GeV) | 1.23 | 6K | CompHEP |
| ttZ | 1.01 | 6K | CompHEP |
| ttZ+j (pT>10 GeV) | 2.4 | 4K | CompHEP |
| ttWW | 0.01 | 64K | CompHEP |
| ttH(→WW) | 0.21 | 4K | Pythia |
| WZ | 51.5 | 50K | Pythia |
| ZZ | 15.5 | 50K | Pythia |
| tt+jets | 694 | 1.03M | Madgraph |
| Z+jets | 7000 | 1.73M | Madgraph |
| W+jets | 60000 | 4.4M | Madgraph |

Plus
>10M bb+jets
and QCD samples



MC Study

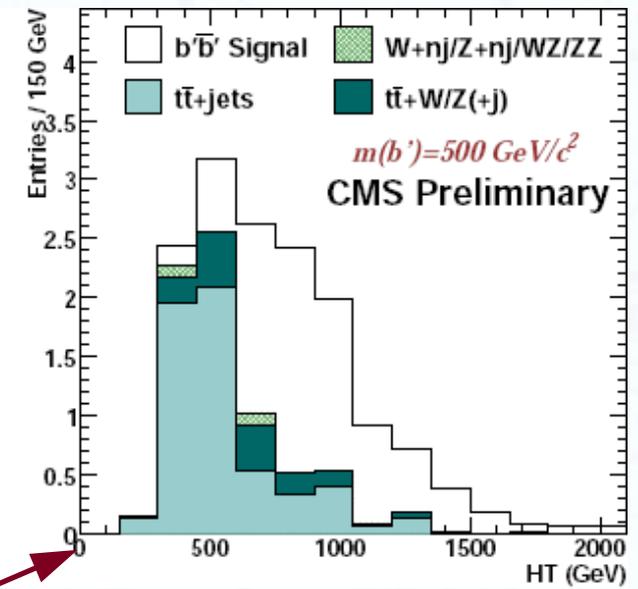
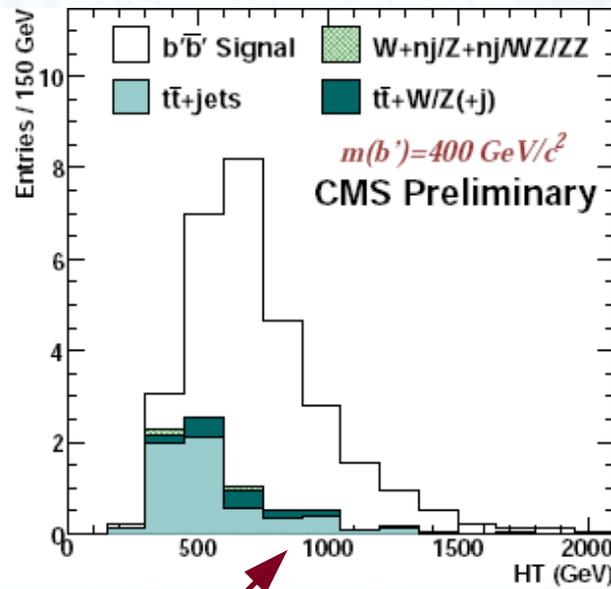
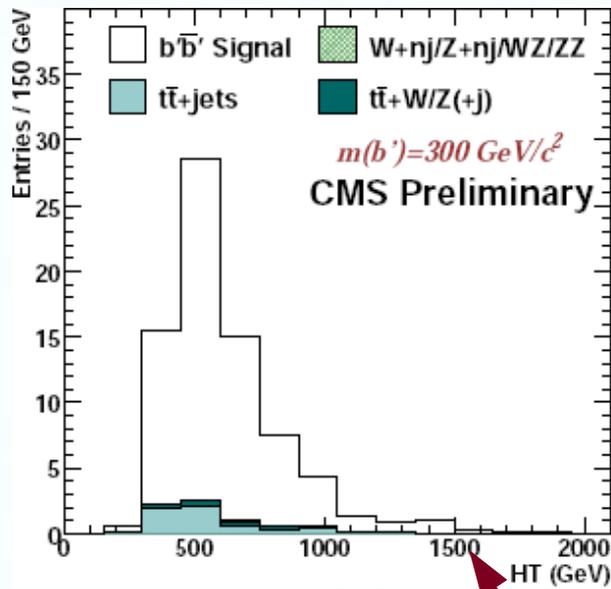
- Assuming $b', \bar{b}' \rightarrow tW$ 100%, with LO calculation
- Normalized to 100/pb Luminosity

| Process | Yield | | |
|---|--------------|--------|--------|
| | Same-sign 2L | 3L | Sum |
| $b'\bar{b}', M(b') = 300 \text{ GeV}/c^2$ | 44.7 | 23.6 | 68.2 |
| $b'\bar{b}', M(b') = 400 \text{ GeV}/c^2$ | 14.6 | 7.6 | 22.2 |
| $b'\bar{b}', M(b') = 500 \text{ GeV}/c^2$ | 5.1 | 2.9 | 8.0 |
| $t\bar{t} + \text{jets}$ | 4.7 | 1.0 | 5.7 |
| $t\bar{t}W(+j)$ | 0.43 | 0.32 | 0.73 |
| $t\bar{t}Z(+j)$ | 0.31 | 0.38 | 0.68 |
| $t\bar{t}W^+W^-$ | 0.020 | 0.014 | 0.035 |
| Z+jets | < 0.4 | < 0.4 | < 0.4 |
| W+jets | < 1.4 | < 1.4 | < 1.4 |
| ZZ | < 0.03 | < 0.03 | < 0.03 |
| WZ | < 0.10 | 0.21 | 0.21 |
| Background Sum | 5.4 | 1.9 | 7.3 |



Signal Estimation

- Assuming $b', \bar{b}' \rightarrow tW$ 100%
- Normalized to 100/pb Luminosity



| $M(b')$ | 300 (GeV) | 400 (GeV) | 500 (GeV) |
|---------------|-----------|-----------|-----------|
| $b'b$ LO Xsec | 34.9 pb | 8.05 pb | 2.45 pb |
| Signal Yield | 68.2 | 22.2 | 8.0 |
| Bkg. Yield | 7.3 | 7.3 | 7.3 |

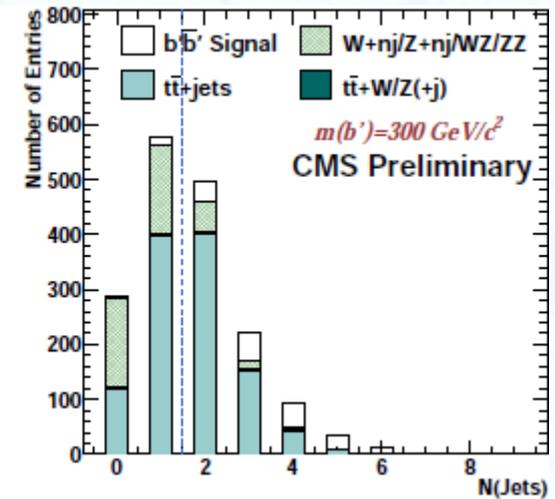
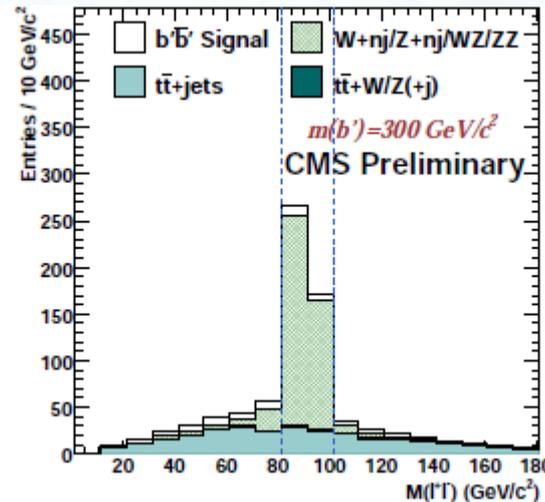
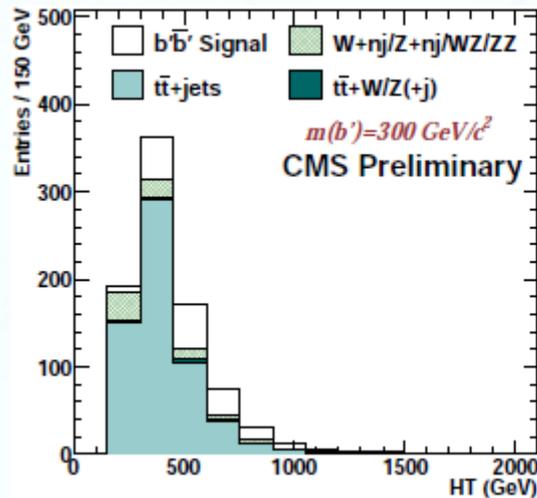
← Background is the same.



Data Driven Analysis

- Two-box method:

- A control region (opposite-signed 2L) is used
- Other selection criteria are remained the same



- Background estimated with iteration method

- $N_B = N_B^{\text{control}} \times R_B = (N^{\text{control}} - N_S^{\text{control}}) \times R_B$,
- $N_S = N - N_B$,
- $N_S^{\text{control}} = N_S / R_S$



Systematics

- Summary of systematic uncertainties

| $M(b')$ (GeV/c^2) | 300 | 400 | 500 |
|--------------------------------------|--------|--------|---------|
| Integrated luminosity | 11.1% | 11.1% | 11.1% |
| Non-prompt and fake leptons | +7.3% | +19.4% | +51.2% |
| Background cross sections | -17.1% | -46.9% | -124.4% |
| Jet energy scale | 1.0% | 3.0% | 8.1% |
| Jet efficiency | 11.2% | 14.0% | 27.4% |
| MET | 5.1% | 5.0% | 7.8% |
| Leptons | 30.4% | 19.7% | 20.8% |
| Pile-ups | 2.4% | 2.5% | 2.7% |
| PDF | 1.0% | 1.3% | 2.0% |
| MC Statistics | 5.3% | 7.2% | 8.7% |
| Sum: systematics | 4.3% | 7.7% | 19.8% |
| Statistics (100 pb^{-1}) | +36% | +35% | +67% |
| Sum: syst. + stat. | -39% | -55% | -132% |
| | 15% | 28% | 57% |
| | +39% | +45% | +88% |
| | -42% | -62% | -144% |



Systematics

- **Integrated luminosity:**
 - 10% in the normalization.
- **Non-prompt and fake leptons:**
 - vary the background ratios from half to double.
- **Background cross sections:**
 - tt+jets (10%), tt+bosons (20%), di-bosons (20%),
 - +100% for the processes that are not included (tt + H, bb+jets, and QCD multi-jets).
- **Jet energy scale:**
 - 7% per jet.
- **Jet reconstruction efficiency:**
 - assign 10% of the events to have an additional jet or to lose one jet.



Systematics (cont.)

- **Missing transverse energy:**
 - apply $1\sigma(\text{MET})$ shift on the distributions.
- **Pile-up jets:**
 - a comparison between the samples with and without pile-up simulations.
- **Lepton identification, isolation, and trigger:**
 - 1% per lepton
- **Parton distribution function (PDF):**
 - re-weighting the events according to the uncertainty PDF sets.
- **Monte Carlo statistics.**



Significance

- Significance estimated for 100/pb

| b' Mass | 300 GeV/ c^2 | 400 GeV/ c^2 | 500 GeV/ c^2 |
|---------------------------|----------------------|----------------|----------------|
| $b'b'$ LO cross section | 34.9 pb | 8.05 pb | 2.45 pb |
| Expected signal yield | 68.2 | 22.2 | 8.0 |
| Expected background yield | $7.3^{+10.5}_{-4.8}$ | | |
| S_{12} | 7.5σ | 2.0σ | 0.0σ |
| S_{cP} | N/A | 2.1σ | 0.0σ |

Definition:

- S_{12} :

$$2\sqrt{N_{\text{sig}} + N_{\text{bgr}}} - \sqrt{N_{\text{bgr}} + D_{\text{bgr}}} \sqrt{(N_{\text{bgr}} + D_{\text{bgr}})/(N_{\text{bgr}} + S_{\text{bgr}}^2 + D_{\text{bgr}})}$$

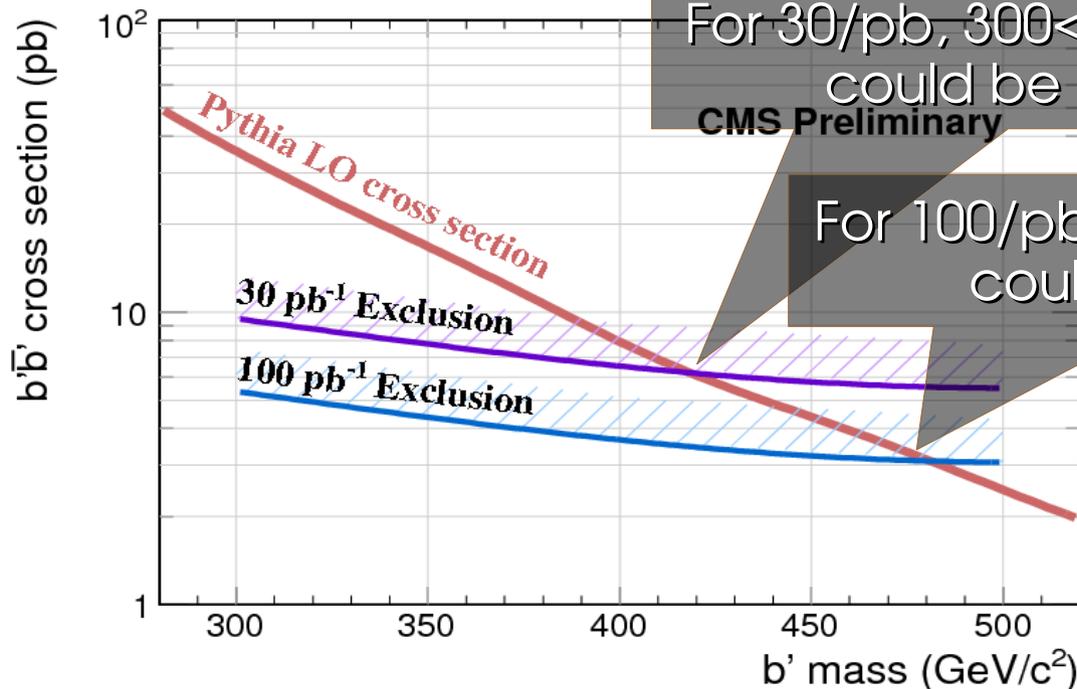
- S_{cP} : $\beta = \frac{1}{\sqrt{2\pi}} \int_{S_{cP}}^{\infty} e^{-\frac{x^2}{2}}$, where $\beta = \sum_{i=s+b}^{\infty} \frac{b^i e^{-b}}{i!}$ (recommended)

<http://cmsdoc.cern.ch/~bityukov/signif/signif.html>



Exclusion Limit

- Assuming $b', \bar{b}' \rightarrow tW$ 100%
- An exclusion limit set at 95% C.L. if null signal observed in data
- Bayesian method is used for null hypothesis tests including systematical uncertainties.



For 30/pb, 300 < M(b') < 420 GeV could be excluded.

For 100/pb, 300 < M(b') < 480 GeV could be excluded.



Summary

- An analysis on the 4th gen. heavy b' with CMS FastSIM
 - Selection criteria optimized with GA
 - Background estimated with data driven method
 - Systematical uncertainties studied
- Results are promising for $M(b') \sim 300 \text{ GeV}$
 - Expecting 68.2 signal and 7.3 background with 100/pb data
 - S/N ~ 9.3 , significance $\sim 7.5\sigma$
- Excluding $M(b') < 480 \text{ GeV}$ if null signal seen @ 95 C.L.
- Studies on other channels like light b' are under going



Future Prospect

- **Covering the wide possible b' mass range**

- **Rich b' decay search channels:**

- **Light b' modes:**

- $b'b' \rightarrow bZbZ$
- $b'b' \rightarrow bZcW$
- $b'b' \rightarrow cWcW$
- $b'b' \rightarrow cWt^*W^*...$

- **Heavy b' modes:**

- $b'b' \rightarrow bZtW$
- $b'b' \rightarrow tWtW$
- $b'b' \rightarrow cWtW...$

- **A complete study is needed**



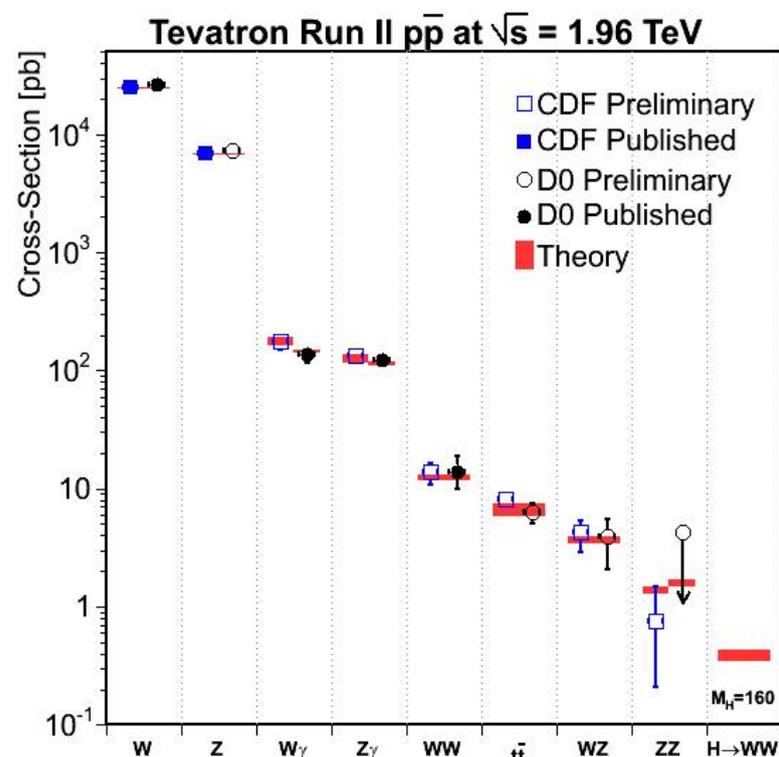


Thank YOU!



First Observation of WZ and Search for ZZ

- CDF Run II data, 1.9/fb
 - Decay channel: $WZ \rightarrow l'\nu l l$
 - Compare data vs. MC background
- $\sigma(WZ) = 4.3 + 1.4 / -1.1$ (stat.+syst.) pb
 - NLO expect 3.7 ± 0.3 pb
- $\sigma(ZZ) = 1.4 + 0.7 / -0.6$ pb
 - NLO expect 1.4 ± 0.1 pb
- $D\emptyset$ also sees significant ZZ
- Relate to $b'b' \rightarrow WZ + \text{jets}$
 - No obvious extra jets from the event display
 - Genuine WZ events
 - Heavier b' mass?





Selection Criteria

Selection cuts used in heavy b' study:

- **Trigger:** “HLT1ElectronRelaxed” + “HLT1MuonNonIso”.
- **Electron:** $p_T > 20$ GeV/c, $|\eta| < 2.5$, Official EID (robust),
Trk. isol. $\sum p_T^{trk} / p_T^{Ele} < 0.2$ (cone $R = 0.02 \sim 0.6$)
- **Muon:** $p_T > 20$ GeV/c, $|\eta| < 2.0$,
Track isolation $\sum p_T^{trk} < 3.0$ (cone $R < 0.3$)
- **CaloJets:** $p_T > 35$ GeV/c, $|\eta| < 2.4$ (Jet ene. correction)
- **MET** > 40 GeV (Jet ene. correction, muon corrected)
- **Z veto:** $M(l^+ l^-) = 80 \sim 100$ GeV/c²
- **W boson: no direct requirements**
 - min. 3 leptons or same-signed 2 leptons + jets