Search for rare Standard Model processes in the $E_T + b$-jets signature

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Why $E_T + b$-jets?

**Interesting signature in searching for both SM and BSM physics**

- $ZH \rightarrow \nu \nu b\bar{b}$ is one of the most sensitive decay modes for a low mass Higgs;
- $ZZ \rightarrow \nu \nu b\bar{b}$ is on the road to the Higgs;
- Sensitive to single top, mainly through hadronic $\tau$ decays;
- SUSY: $\tilde{b}\tilde{b} \rightarrow b\tilde{\chi}_0^0 \tilde{b}\tilde{\chi}_0^0$;
- Technicolor: $\rho^\pm_T \rightarrow Z\pi^\pm_T \rightarrow \nu \nu b\bar{q}$;

**Extra acceptance from W decays**

- Hadronic $\tau$ decays ($\tau$ ID not very efficient);
- Also, the $e/\mu$ acceptance is not very high;
- Thus, this signature collects 50% of the leptonic $W$ decays at CDF;
- So, we are sensitive to $WH \rightarrow \ell \nu b\bar{b}$, $WZ \rightarrow \ell \nu b\bar{b}$, and $\rho^\pm_T \rightarrow W^\pm \pi^0_T \rightarrow \ell \nu b\bar{b}$;
The Challenges

Final state limitations

▶ Many SM processes mimic the $E_T + b$-jets final state;
▶ Requires modeling for many backgrounds;

Different cause for $E_T$ in backgrounds

▶ EW backgrounds yield intrinsic $E_T$;
▶ QCD multi-jet yields instrumental $E_T$;

Pre-selection cuts are not enough for sensitive analysis

▶ We reject mis-measured events (with $E_T$ collinear to a jet), and require $b$-jets,
▶ Yet, we have low $S/B$: 1/50 (Single Top), 1/150 (WZ/ZZ), 1/500 (SM Higgs);
▶ We have to do something more to further reject the backgrounds;
Intrinsic $\not{E}_T$ vs. instrumental $\not{E}_T$

How we measure $\not{E}_T$

- Typically provided by the transverse energy imbalance ($\not{E}_T$) in the calorimeter;
- We also use the transverse momentum flow imbalance ($\not{p}_T$) from the spectrometer;
  - $\not{p}_T$ largely correlated with $\not{E}_T$ in presence of neutrinos (or $\tilde{\chi}^0$, etc.);
  - Very different for instrumental $\not{E}_T$: $\not{p}_T$ and $\not{E}_T$ either correlated or anti-correlated;

Exemple: $ZZ \rightarrow \nu\nu b\bar{b}$

- $[\not{E}_T \text{ aligned to } \not{p}_T]$ [Diagram of $ZZ \rightarrow \nu\nu b\bar{b}$]

Example: QCD $b\bar{b}$

- $[\not{p}_T \text{ is not aligned to } \not{E}_T]$ [Diagram of QCD $b\bar{b}$]
A Neural Network to reject QCD

We combine novel variables to identify instrumental $E_T$ and distinguish it from “real” $E_T$.

Adding more variables

Performance

Signal acceptance 90-95%
Multi-jet rejection $\sim 90\%$
Every input variable is validated in several control regions. The neural network output is also checked for mis-modeling.

**Performance**

- Signal acceptance: 90-95%
- Multi-jet rejection: ~90%

**S/B**

- Single Top: 1/20 (×2.5)
- WZ/ZZ: 1/50 (×3.0)
- SM Higgs: 1/200 (×2.5)
CDF Analyses in the $E_T+b$-jets signature

Single top production: part of observation


Single Top Quark Cross Section

- **CDF Lepton+jets**: $3.2 \text{ fb}^{-1}$
  - $2.17 \pm 0.56 \pm 0.55 \text{ pb}$

- **CDF MET+jets**: $2.1 \text{ fb}^{-1}$
  - $5.0 \pm 2.6_{-2.3} \text{ pb}$

- **DØ Lepton+jets**: $2.3 \text{ fb}^{-1}$
  - $3.94 \pm 0.88_{-0.88} \text{ pb}$

**Tevatron Combination** (Preliminary)
- $2.76 \pm 0.58_{-0.47} \text{ pb}$

$m_{\text{top}} = 170 \text{ GeV}$

CDF Run II, $2.1 \text{ fb}^{-1}$
CDF Analyses in the $E_T+b$-jets signature

Top pair production: Cross-check using well understood signal.
CDF Analyses in the $E_T + b$-jets signature

SM Higgs: among most sensitive low mass ($< 135$ GeV/$c^2$) channels

CDF Run II Preliminary, $5.7$ fb$^{-1}$

CDF Run II Preliminary, $5.7$ fb$^{-1}$

CDF Run II Preliminary, $<L> = 5.6-5.9$ fb$^{-1}$

LEP Excl.

95% CL Limit/SM

SM=1

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$E_T + b$-jets signature

September 17, 2011 8 / 9
An interesting channel for SM and BSM physics

- Many SM and BSM yield $\not{E}_T + b$-jets;
- This channel has very large acceptance;
- Very sensitive provided we get rid of the large QCD multijet-background;

A powerful tool to reject QCD multi-jet

- Novel combination of kinematic variables (exploits correlations);
- The technique is very generic: works with many different signals;
- It is as powerful as a lepton ID, in a channel with much larger acceptance;
- Made three SM analyses possible at CDF (and similarly at DZero);
- We plan to use this technique to measure $\sigma(WZ/ZZ \to \not{E}_T + b\bar{b})$;

Thank You
Backup Slides
Data-driven model and control regions

Data-driven model for multi-jet (MJ) production

- **Why?** Efficiency is so low that we would need a very large QCD Monte Carlo sample;
- **Data-driven method:** deriving a (4D) Tag-Rate-Matrix from QCD MJ sample (> 99.9%);
- Applying the matrix to the (pre-tag) data to get $b$-tagging probability for each event;
  - We apply the matrix to the Monte Carlo and subtract to avoid double counting;
- Excellent agreement in the shape. Normalization obtained from control region;

Control regions

- **TRM:** training sample for Tag-Rate-Matrix;
- **QCD:** cross-check for the data-driven model;
- **EWK:** cross-check for the EWK backgrounds (MC);
- **QCD Scale Factor Check:** derivation of the QCD MJ scale factor (~ 1);
- New: extra regions with high $NN$ output in pre-tag;
More on the QCD multi-jet (MJ) model

Components of multi-jet background

- The multi-jet background in the past analyses consisted mainly of QCD + EWK mis-tags;
- We are now using a new modeling in which the EWK mis-tags are modeled separately;

CDF Run II 5.7 fb$^{-1}$ Preliminary

- Top Pair
- Single Top
- Diboson
- Z+HF
- Z+LF
- Zbb
- W+HF
- W+LF
- Multijet
- Data
- Signal (x100)
Checking the modeling: Control Regions

- Every input to the NN is checked in more than 5 orthogonal control regions;
- We check both the data-driven and Monte Carlo modeling;
- Excellent agreement throughout;

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March, 17 2011 13