(W/Z)Z with $Z \rightarrow bb$
using the DØ Higgs Framework

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Fermilab
(W/Z)Z at Tevatron

- Probe of the EWSB mechanism
  - Test of SM
  - Indirect searches for New Physics (xsec, kinematic, couplings)

\[
\sigma(W^\pm Z^0) = 3.22^{+0.20}_{-0.17}\text{(scale)}^{+0.11}_{-0.08}\text{(PDF)}\text{ pb}
\]

\[
\sigma(Z^0 Z^0) = 1.20^{+0.05}_{-0.04}\text{(scale)}^{+0.04}_{-0.03}\text{(PDF)}\text{ pb}
\]

- Ultimate test of experimental and statistical techniques used in the Higgs searches
VZ with $Z\rightarrow bb$ as Higgs Test

- $\sigma(VZ) \sim 4.5$ times larger than $\sigma(VH)$
- Lower masses
  - Dijet mass resolution doesn’t allow to separate dijets from $W$ and $Z$ decays: $WW(\rightarrow lvcs)$ becomes large background
  - Background rates and systematics increase at lower masses
  - Larger $Z\rightarrow cc$ contribution than $H\rightarrow cc$

### (W/Z)H ($m_H=115 GeV$)
- $WH\rightarrow lvbb$ 27fb
- $ZH\rightarrow llbb$ 5fb
- $ZH\rightarrow vvbb$ 15fb
- Sum 46fb

### (W/Z)Z
- $WZ\rightarrow lvbb$ 105fb
- $ZZ\rightarrow llbb$ 24fb
- $ZZ\rightarrow vvbb$ 73fb
- Sum 202fb
The Tevatron and DØ

- Central tracking: silicon vertex detector and fiber tracker in 2T field
- Calorimeter: hermetic coverage $|\eta|<4.2$, LqAr Calorimeter
- Muon System: excellent purity and coverage: $|\eta| < 2$

Results presented here based on $\sim 8.7 \text{ fb}^{-1}$ of recorded luminosity

Avg. data-taking efficiency: $>90\%$

$\sqrt{s} = 1.96 \text{ TeV}$
$\Delta t = 396 \text{ ns}$

Run I 1987 (92)-95
Run II 2001-11: 75x larger dataset increased energy

Typical average Luminosity:
$>300 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1}$
$\sim 50 \text{ pb}^{-1}$ per week

Delivered
Recorded

$12 \text{ fb}^{-1}$
$11 \text{ fb}^{-1}$

Run II Integrated Luminosity
Validation of Higgs-Methods

kinematic selection → multijet removal → b-tagging → final discriminant

statistical analysis

Björn Penning, ICHEP 2012, Melbourne 6th July 2012
Multivariate Methods

- Look at many variables simultaneously
- Choose well modeled, separating variables
- Neural Networks (NN), Decision Trees (DT)
- DT arboretum: Random Forest (RF)
- Typically see > 20% sensitivity improvement w.r.t. single best variable
b-tagging

- Long life-time of b-hadrons $\rightarrow$ displaced vertex
- DØ uses MVA, exploiting
  - information of displaced vertex, track impact and PV association probability
- Typically two orthogonal samples
  - Double Tag (DT)
  - Single Tag (ST)

\begin{align*}
\text{b-ID eff:} \\
\text{loose: } 80\% (10\%) \\
\text{tight: } 50\% (0.5\%)
\end{align*}
The observation of \((W/Z)(Z\rightarrow bb)\), using the same techniques as for the Higgs searches, is validation of the Higgs searches at the Tevatron

Only change: MVAs retrained using \((W/Z)Z\) as signal, WW still background
### Diboson Channel

#### Diboson \( l \nu bb \)
- high \( p_T e, \mu \)
- \( E_T^{\text{miss}} \)
- 2,3 jets
- BDT: 14 inputs

#### Diboson \( llbb \)
- lepton pair \( \sim M(Z) \)
- kinematic fit
- 2,3 jets
- RF: 19 inputs

#### Diboson \( \nu\nu bb \)
- large \( E_T^{\text{miss}} \)
- \( E_T^{\text{miss}} \) signific.
- \( \geq 2 \) jets
- BDT: 32 inputs

### Discriminating Variables

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Diboson Channel

Diboson \( l \nu bb \)

Diboson \( llbb \)

Diboson \( \nu \nu bb \)

Background Subtracted Distribution

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- Identical to Higgs searches too
- **Global fit to final discriminants** in all sub-channels
  - Theoretical uncertainties correlated
  - Experimental uncertainties (un-)correlated
- **Main uncertainties:** b-tagging, Jet Energy Scale and Resolution, heavy/light flavor ratio

**Combined analyses:** $M(jj)$
Combination

- Combining all three channels
- Maintaining proper correlation among channels

\[ \sigma^{MVA}_{WZ+ZZ} = (1.13 \pm 0.36) \times \sigma_{SM} \]

3.3\sigma Evidence (exp. 2.9\sigma)

SM@NLO:
\[ \sigma (WZ + ZZ) = 4.4 \pm 0.3 \text{ pb} \]
Summary

- Looking \((W/Z)Z\) with \(Z \rightarrow bb\) provides ultimate test for our Higgs searches

- Very ‘Higgs-like’ final state with comparable \(\sigma\)

- Using identical techniques as Higgs searches in validation of procedures and techniques

- Evidence for \((W/Z)Z\) with \(Z \rightarrow bb\) production
Backup
Towards Today’s Measurement

- High $p_T$ muon/electron + $E_T^{\text{miss}}$ + 2/3 jets
- b-tagging to enrich heavy flavor contributions
- Perform fit to Random Forest and $M_{jj}$ distribution
- Cross section measured in NT, ST, DT channels

Cross sections for $WW/WZ$ production in $l^+HF$ final states (b-tagging)

- High $p_T$ muon/electron + MET + 2 or 3 jets
- b-tagging to isolate heavy flavor (HF) jets contribution
- S/B separation: Random Forest (RF)
- MC/data fit to the RF output and $M_{jj}$ distributions
- Cross sections measured in 0, 1, 2 b-tag channels

$\sigma_{\text{RF}}^{WW+WZ} = 19.6^{+3.2}_{-3.0}\text{pb}$
$\sigma_{jj}^{WW+WZ} = 18.3^{+3.8}_{-3.6}\text{pb}$

$\sigma_{\text{RF}}^{WW+WZ} = 15.9^{+3.7}_{-3.2}\text{pb}$
$\sigma_{jj}^{WW+WZ} = 3.3^{+4.1}_{-3.3}\text{pb}$
FIG. 6: Results from the simultaneous fit of \( \sigma(WZ) \) and \( \sigma(ZZ) \). The plot shows the best fit value with 68% and 95% uncertainty ellipses and the NLO SM prediction.

FIG. 3: Comparison of the measured WZ and ZZ signals (filled histograms) to background-subtracted data (points) in the dijet mass distribution (summed over all channels) for the (a) ST, and (b) DT sub-channels; and (c) the sum of the ST and DT sub-channels. Also shown is the \( \pm 1 \) standard deviation uncertainty on the fit to background. Events with a dijet mass greater than 400 GeV are included in the last bin of the distribution.

FIG. 4: Distribution of VZ cross sections obtained from (a) background-only pseudo-experiments and (b) signal+background pseudo-experiments. The observed cross section from the data (vertical red line) is also shown.

FIG. 5: LLR distributions obtained from background-only and signal+background pseudo-experiments compared to the LLR obtained from the data.