Searches for diboson production with heavy-flavor jets in the final state at the Tevatron

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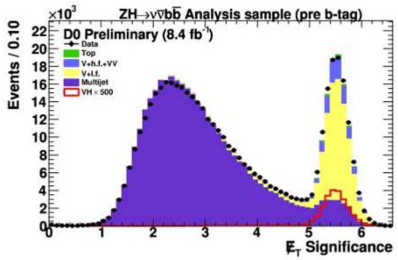
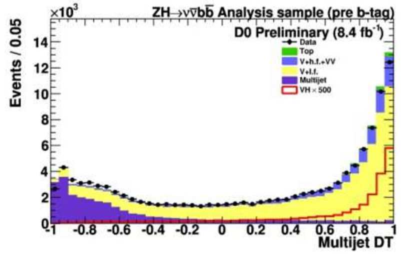
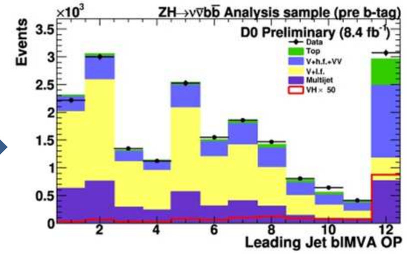
A typical Low-Mass Higgs search: MET + b-jets



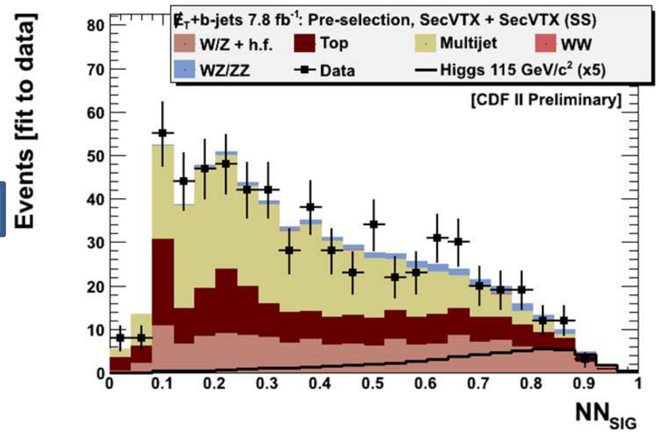
Kinematic event selection



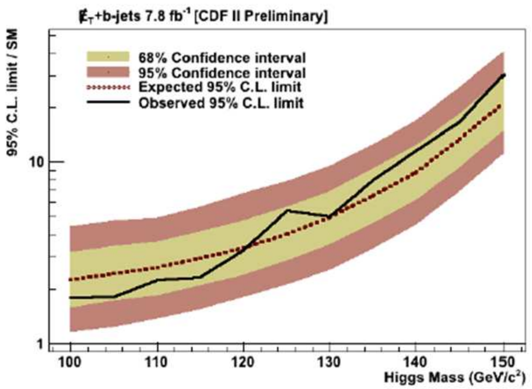
Multijet removal



b-tagging



Final discriminant
SVM, BDT, RF…



Statistical analysis
Log Likelihood Ratio (LLR)
Marginalization of nuisance parameters

This whole procedure should be validated with a known signal

Diboson search with Z $\to$ bb as a benchmark

Let's replace the Higgs we are searching for by a Z boson:

For (W/Z)H with mH = 115 GeV:

WH $\to$ lνbb:	**27 fb**	**(l=e,μ)**
ZH $\to$ llbb:	**5 fb**	**(ll=ee,$\mu\mu$)**
ZH $\to$ $\nu\nu$bb:	**15 fb**	
Total:	**46 fb**	

For (W/Z)Z:

WZ $\to$ lνbb:	**105 fb**	**(l=e,μ)**
ZZ $\to$ llbb :	**24 fb**	**(ll=ee,$\mu\mu$)**
ZZ $\to$ $\nu\nu$bb:	**73 fb**	
Total:	**202 fb**	

The cross section for diboson production is ~ 4.5 times larger than for (W/Z)H

But the dijet mass resolution is not sufficient to separate dijets from W and Z decays
=> WW $\to$ lνcs becomes a significant background
Furthermore, background level and related systematics are larger at these lower masses.
On the other hand, there is relatively more signal contribution from Z $\to$ cc than from H $\to$ cc

The observation of (W/Z)(Z $\to$ bb), using the same techniques as for the Higgs searches, is the ultimate benchmark for those searches at the Tevatron

Towards the benchmark at HCP'11…

WW+WZ in lν + HF jets:

	CDF note 10598	**(7.5/fb)**
	D0 publication in preparation	**(4.3/fb)**
WZ	**in lν + HF jets:**	
	D0 note 6220	**(7.5/fb)**
ZZ+ZW	**in ll + HF jets**	
	CDF note 10601	**(6.6/fb)**
	D0 note 6256	**(7.5/fb)**
WZ+ZZ	**in MET + HF jets:**	
	CDF note 10311 (arXiv:1108.2060 [hep-ex])	**(5.2/fb)**
	D0 note 6223	**(8.4/fb)**

Combination of (W→lν)bb, (Z→ll)bb, and (Z→νν)bb

	D0 note 6260	**(7.5 to 8.4/fb)**

For reference: diboson production cross sections used by the TeVNPHWG:
WW: 11.34 pb WZ: 3.22 pb ZZ: 1.20 pb (MCFM@NLO)

WW+WZ in lν+HF (1/2)

7.5/fb

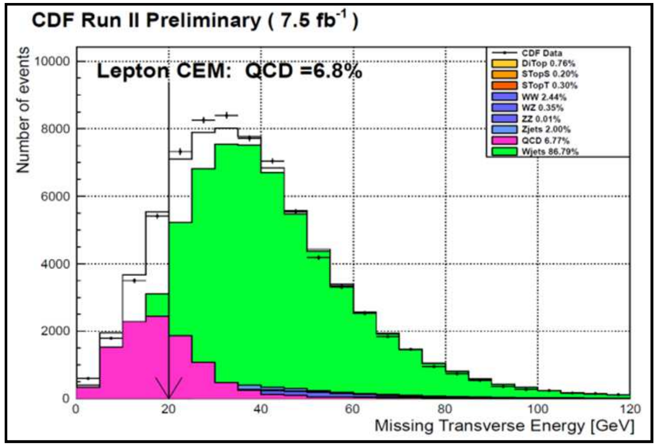
Selection:

1 e/μ (pT > 20 GeV), MET > 20 GeV, exactly 2 jets (pT > 20 GeV, |η| < 2)

Multijet rejection using an SVM

Remaining MJ and V+jets normalizations from a template fit to the MET distribution

At least one jet tagged by the SecVtx algorithm



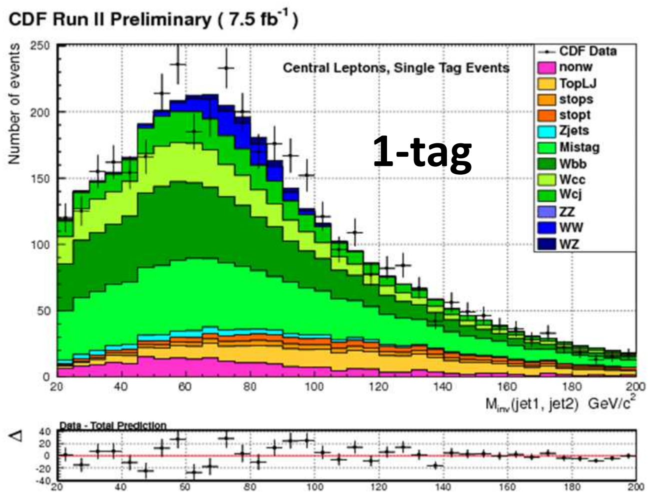
Yields	1-tag	2-tag
Signal	215	11
Backg.	5514	396
S/√B	2.9	0.6

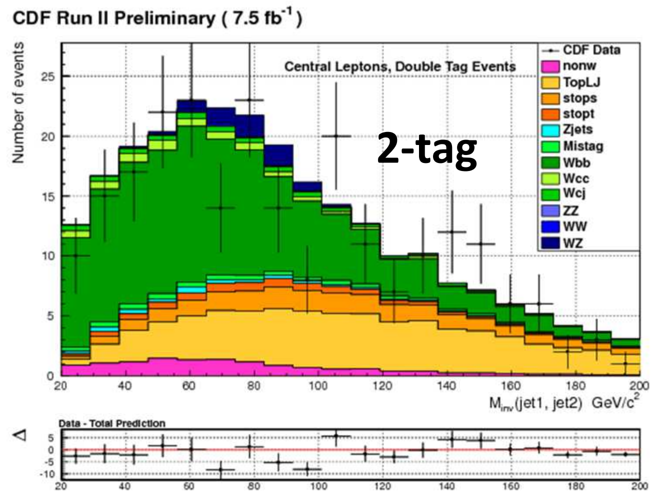
In 1-tag: WW ~74% of the signal
In 2-tag: WZ ~88% of the signal

Most of the sensitivity comes from W→cs in the 1-tag channel

WW+WZ in $l\nu$+HF (2/2)

Final discriminant: the dijet mass (1 and 2 tag, also lepton classes)

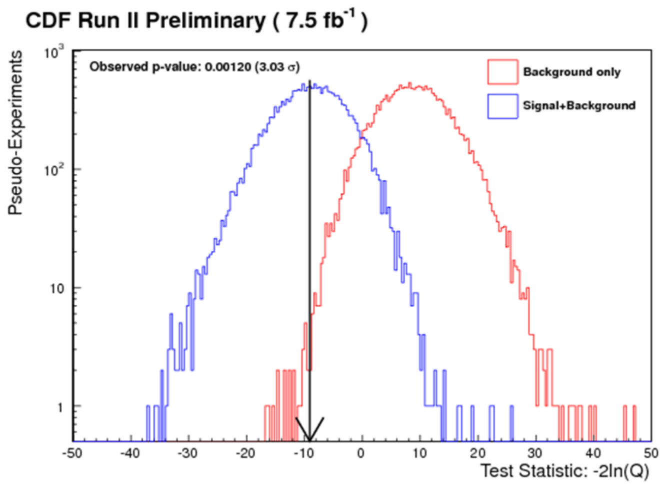




Statistical analysis:
WW/WZ ratio fixed as in the SM

3.0 S.D. from the B-only hypothesis
(3.0 expected)
Good agreement with S+B

σ (WW+WZ) = (1.1 +0.3 -0.4**) σ_SM**



WW+WZ in $l\nu$+HF (1/2)

4.3/fb

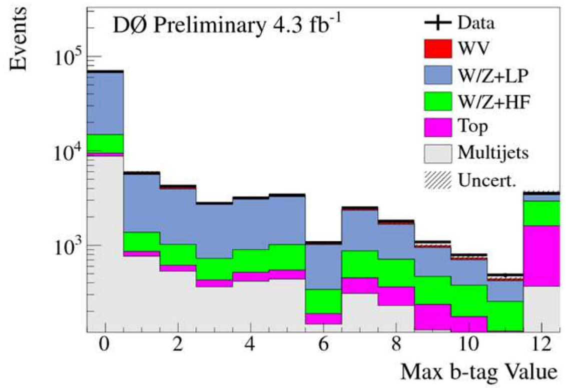
Selection:

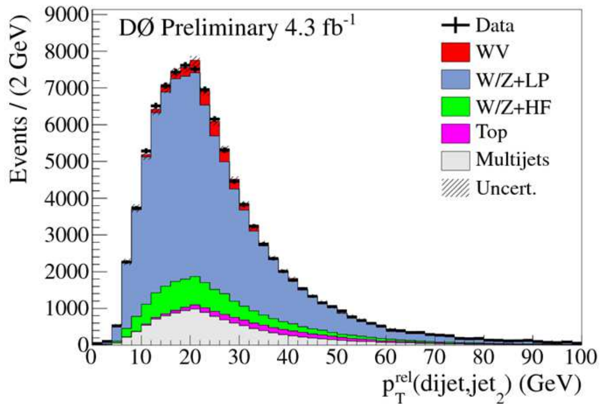
1e/μ (pT > 20/15 GeV), MET > 20 GeV, $\geq$ 2 jets (pT > 20 GeV, $|\eta|$ < 2.5)
m_T($l\nu$) > 40 GeV – 0.5MET ("triangle cut" against MJ background with fake leptons)

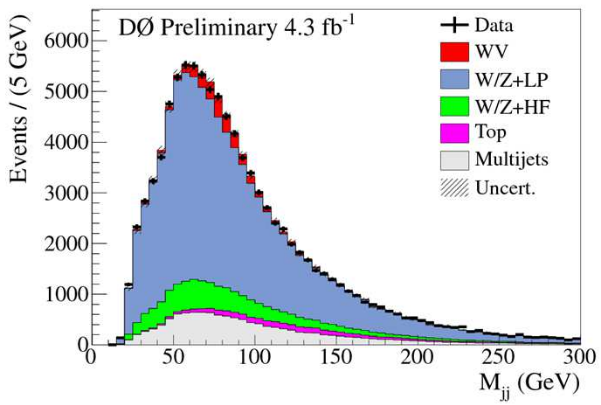
b-tagging:

12 b-NN operating points corresponding to increasing b purity
loosest operating point chosen to define 0, 1 and 2-tag samples
NN values used as input to the final discriminant

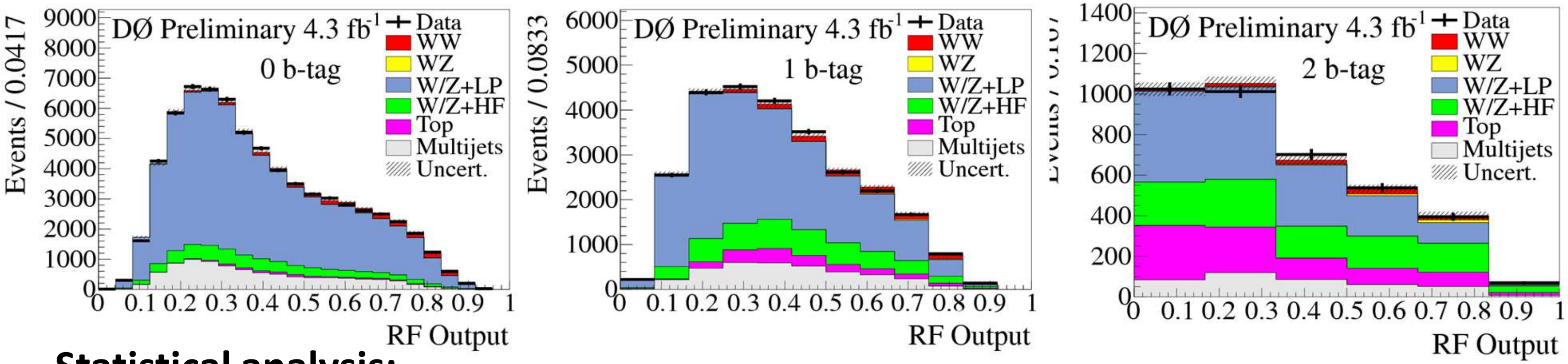
Final discriminant: RF (15 inputs)







WW+WZ in lν+HF (2/2)

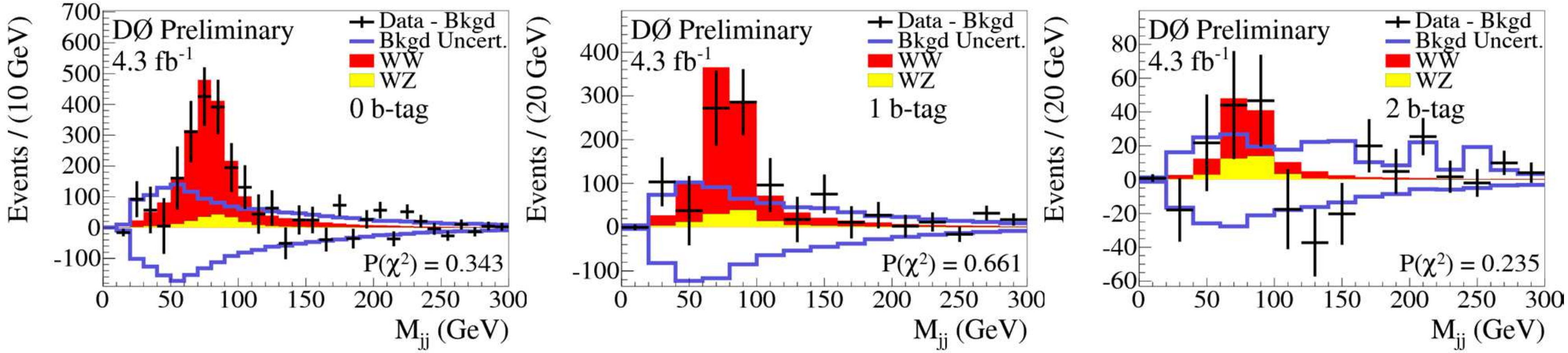


Statistical analysis:

WW/WZ ratio fixed as in the SM

8.0 S.D. from the B-only hypothesis (6.0 expected) **σ (WW+WZ) = (1.2 ± 0.2) σ_SM**

Good agreement with S+B



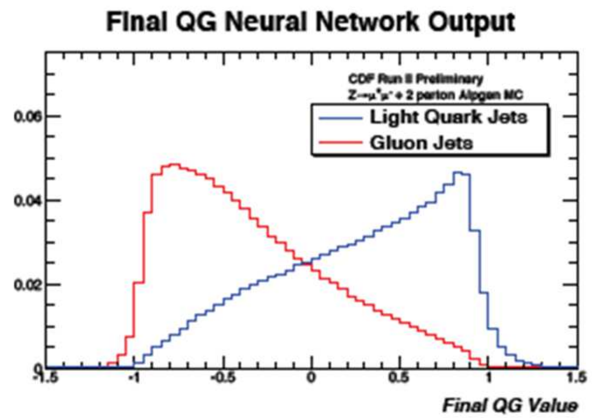
If WW is constrained to its SM value ± 7%, the fit yields σ (WZ) = (1.3 ± 0.6) σ_SM
and the significance of the WZ signal is 2.2 S.D (1.2 expected)

ZW+ZZ in ll+HF

6.6/fb

Selection:

ee/μμ (pT > 20 GeV), 76< M_ll < 106 GeV, ≥ 2 jets (pT > 20 GeV, |η| < 2)
Z pT > 10 GeV, MET < 25 GeV



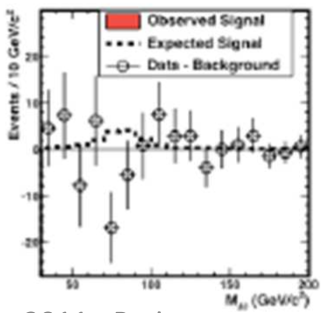
Define three samples:

HF based on "b-ness"
LF and gluon-rich no-tag
(based on q-g NN discriminant)

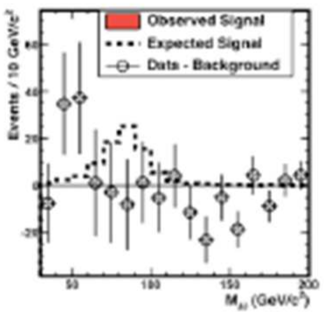
Yields	no-tag	LF-tag	HF-tag
Signal	80	87	16
Backg.	5690	3600	760
S/√B	1.1	1.5	0.6

Final discriminant:
the dijet mass in the three samples
(MC gluon JES adjusted by -2σ, based on Z+1-jet control sample)

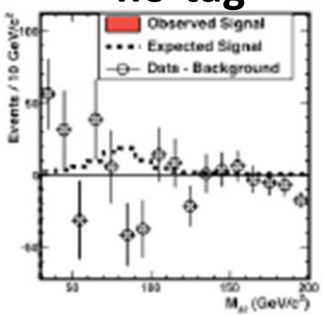
HF



LF



no-tag



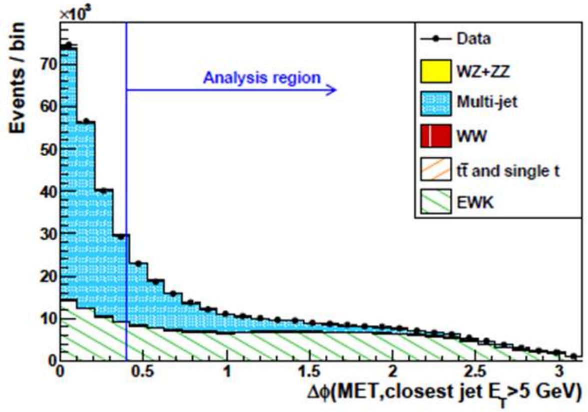
Not yet enough sensitivity
to observe a signal

WZ+ZZ in MET + HF (1/2)

5.2/fb

Selection:

MET > 50 GeV + MET significance cut, $\leq$ 1 e/μ,
$\geq$ 2 jets (pT > 20 GeV, $|\eta|$ < 2), $\Delta\phi$(MET,jets) > 0.4



Backgrounds:
V+jets shape from MC (corrected based on γ+jets)
Multijet model from $\Delta\phi$(MpT,MET) > 1 (MC subtracted)
Top and WW from MC

(0+1)-tag, and 2-tag samples based on "b-ness"

Yields	(0+1)-tag	2-tag
Signal	1330	52
Backg.	230100	1052
S/$\sqrt{B}$	2.8	1.6

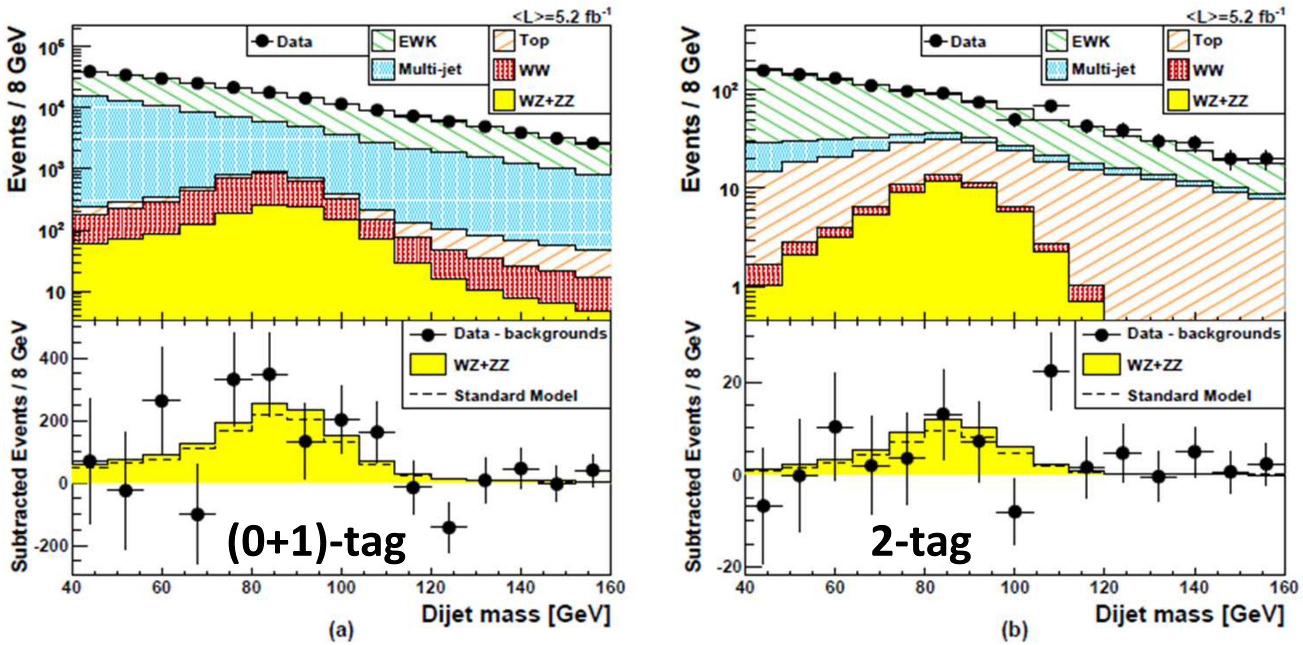
Post-fit results

Final discriminant:
the dijet mass in both samples

In the fit:
V+jets float independently in the two samples
WW constrained within 6%
WZ/ZZ ratio fixed as in the SM

WZ+ZZ in MET + HF (2/2)

Post-fit results



Significance: 1.9 S.D. (1.7 expected)

Good agreement with S+B

σ (WZ+ZZ) = (1.1 +0.7 -0.6**) σ_SM**

Sensitivity from both WZ and ZZ

The following mutually exclusive analyses are exact copies of the corresponding low-mass Higgs searches.

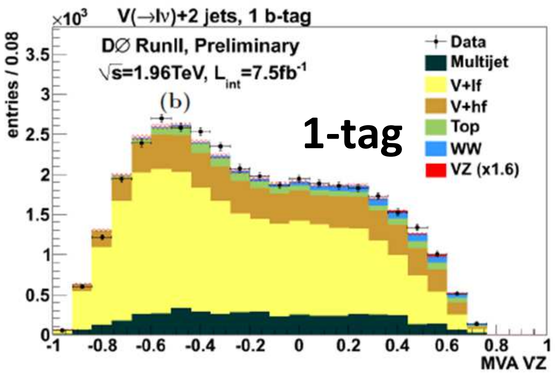
The only changes are the MVA trainings where the signal is now WZ+ZZ (instead of WH+ZH), while WW remains a background.

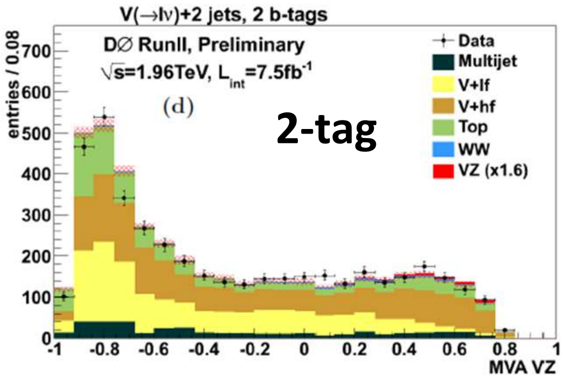
Hence, only minimal detail is given.

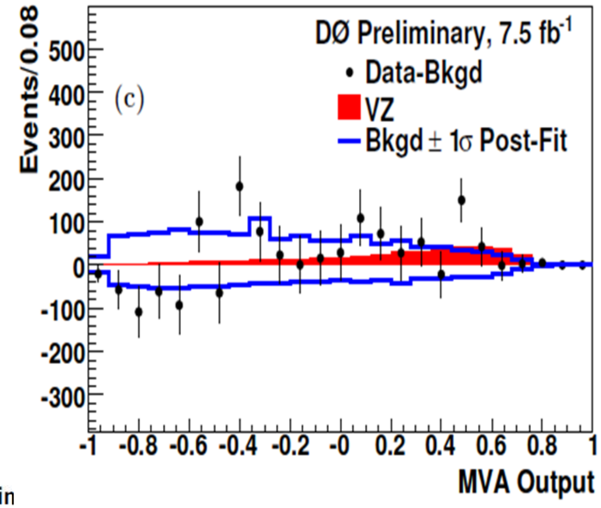
WZ in lν+HF

7.5/fb

Selection: e/μ + MET + 2 or 3 jets + m_T(lν) vs. MET "triangle cut"
Multijet background rejection using a BDT
Separation in 1 and 2-tag samples based on the loosest b-BDT operating point,
and inclusion of the b-BDT output in the final discriminant.
Final discriminant: BDT (14 inputs).

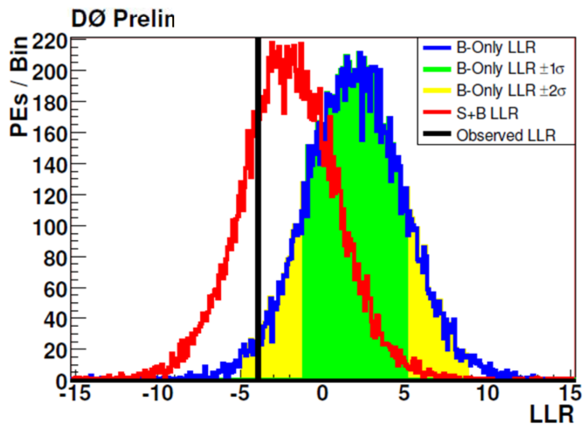






Post-fit results

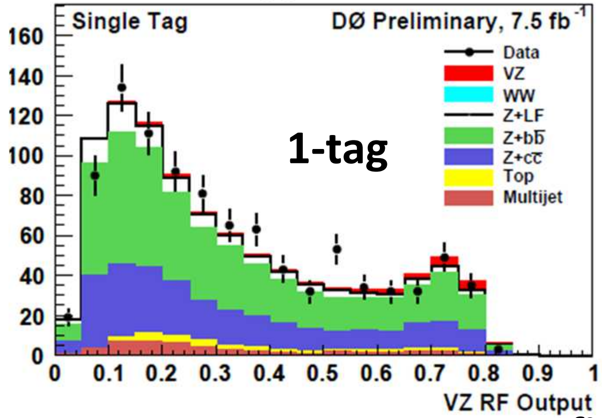
Statistical analysis:
WZ/ZZ ratio fixed as in the SM
2.2 S.D. from the B-only hypothesis
(1.4 expected)
σ(WZ+ZZ) = (1.6 ± 0.8) σ_SM
Sensitivity dominated by WZ

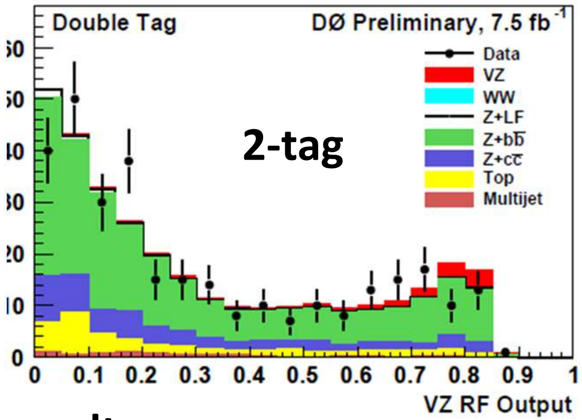


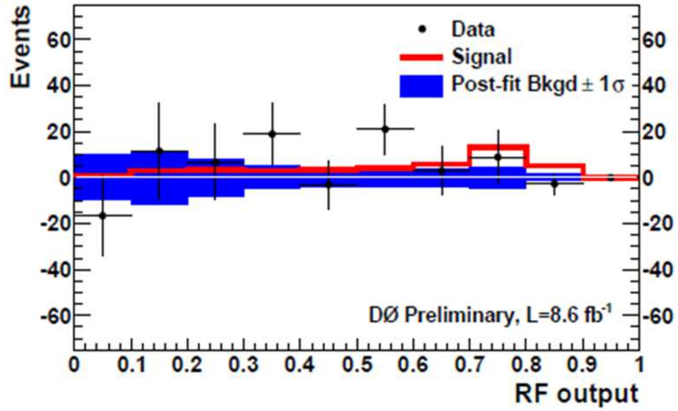
ZZ in ll+HF

7.5/fb

Selection: ee/μμ in Z-mass window + 2 or 3 jets
Separation in 1 and 2-tag samples
based on a tight and a loose b-BDT operating point: T&L and T&!L
Kinematic fit
Final discriminant: RF (19 inputs).

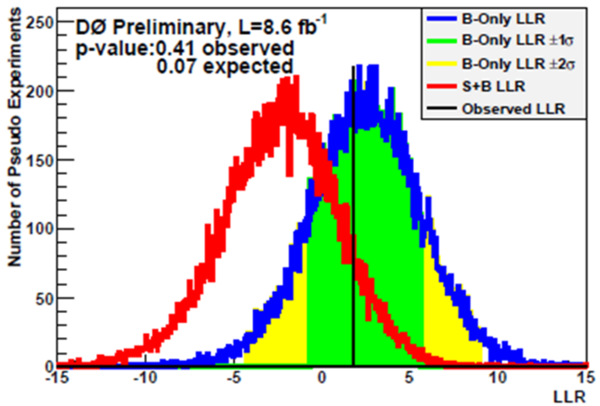






Post-fit results

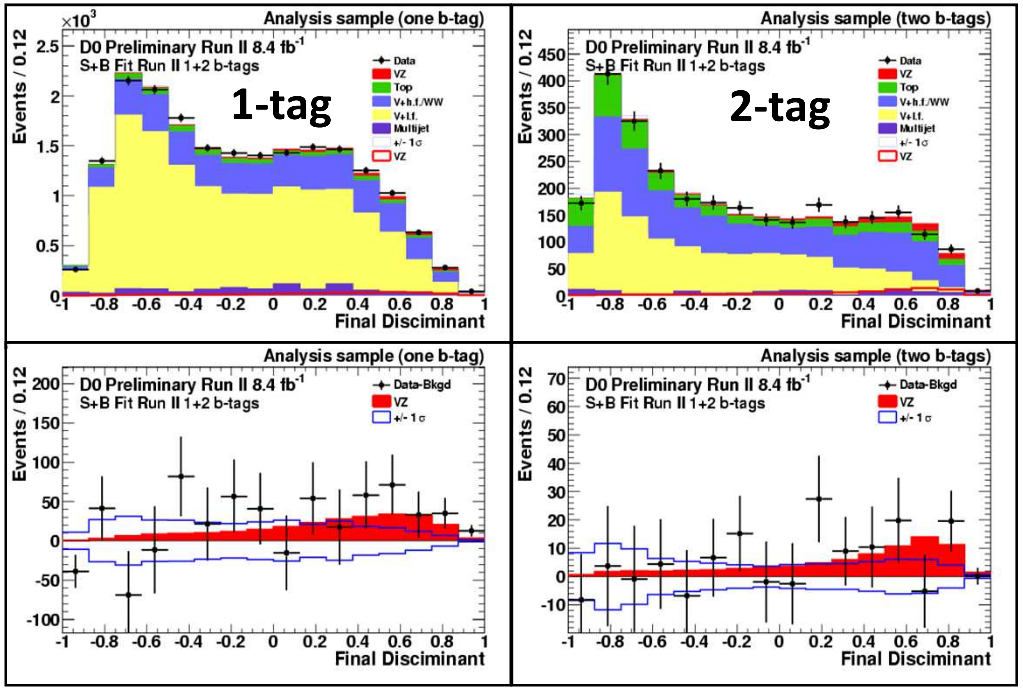
Statistical analysis:
WZ/ZZ ratio fixed as in the SM
0.1 S.D. from the B-only hypothesis
(1.5 expected)
σ(WZ+ZZ) = (0.1 ± 0.6) σ_SM
Sensitivity dominated by ZZ



WZ+ZZ in MET+HF

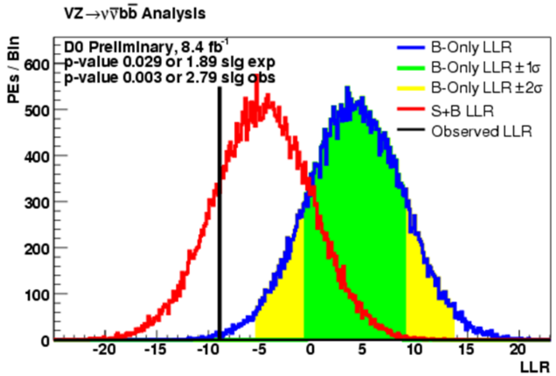
8.4/fb

Selection: large MET + MET significance + 2 acoplanar jets + e/μ veto
Multijet background rejection using a BDT
Separation in 1 and 2-tag samples based on the loosest b-BDT operating point,
and inclusion of the b-BDT output in the final discriminant.
Final discriminant: BDT (32 inputs !).



Post-fit results

Statistical analysis:
WZ/ZZ ratio fixed as in the SM
2.8 S.D. from the B-only hypothesis
(1.9 expected)
σ(WZ+ZZ) = (1.5 ± 0.5) σ_SM
Sensitivity shared by ZZ ($Z \to \nu\nu$)
and WZ ($W \to l\nu$ with missed lepton)



Combination of the WZ/ZZ D0 searches

The exact same techniques are used as for the Higgs combinations.

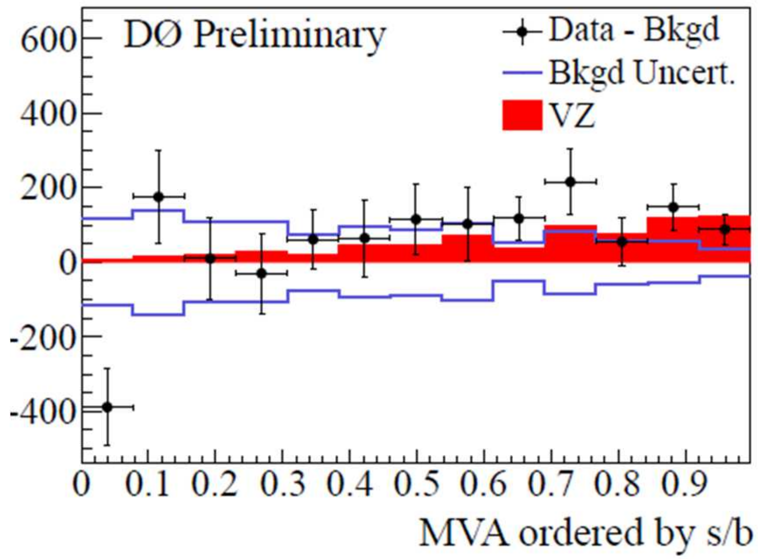
Global fit to the final discriminants in all sub-channels
Theoretical uncertainties correlated.
Experimental uncertainties (un-)correlated as appropriate.

Main uncertainties:

Heavy/Light ratio in (W/Z)+jets
Object reconstruction and identification
Jet energy calibration and resolution
b tagging

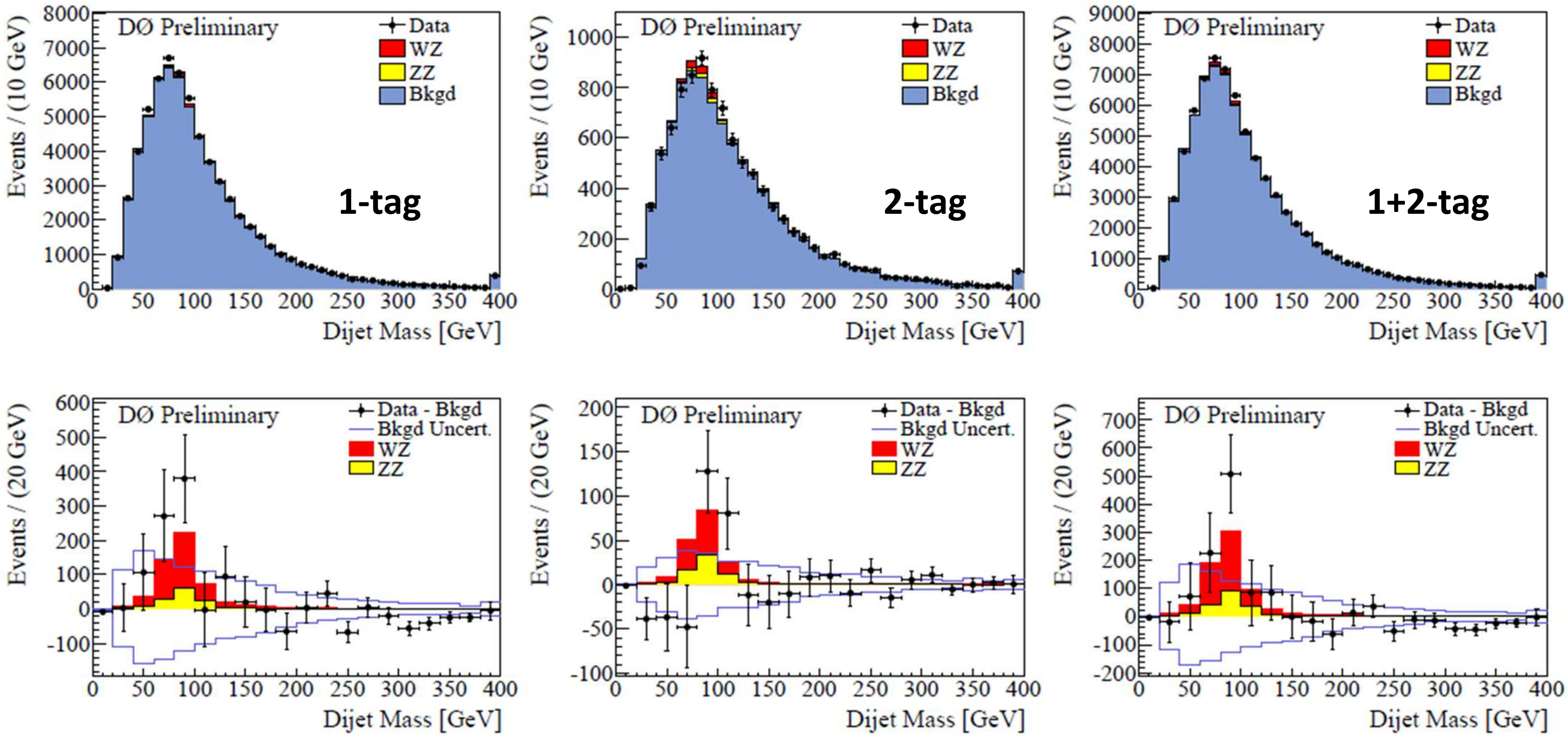
This shows the background subtracted final discriminant after the combined fit.
The WZ/ZZ ratio has been fixed as in the SM

The bins of the individual discriminants have been regrouped according to s/b, and summed in a single distribution.



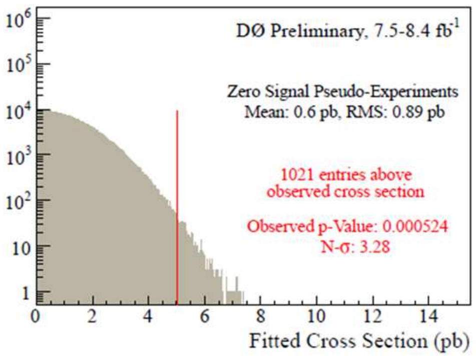
Combination of the WZ/ZZ D0 searches

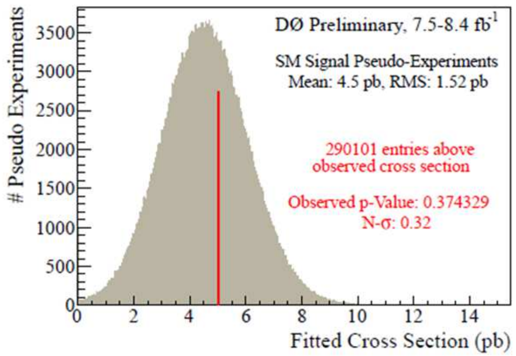
Post-fit (to the DT outputs) dijet mass distributions

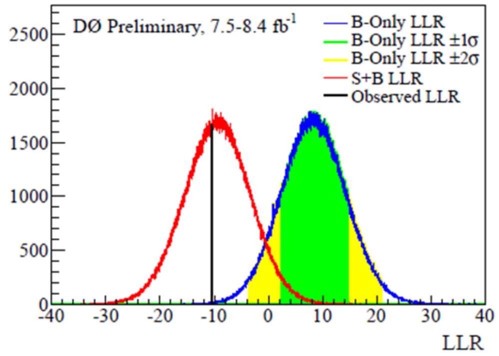


Post-fit (to the DT outputs) background-subtracted dijet mass distributions

Combination of the WZ/ZZ D0 searches







Evidence for WZ and ZZ production in final states with b-tagged jets:

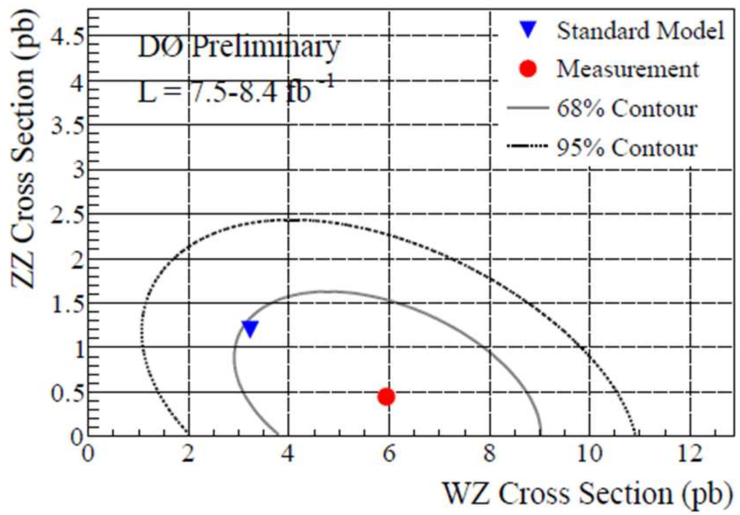
3.3 S.D. from the B-only hypothesis (2.9 expected)

Good agreement with S+B

σ(WZ+ZZ) = (1.13 ± 0.36) σ_SM

A fit was also performed where WZ and ZZ are allowed to float idependently:

σ(WZ) = (1.8 ± 0.5) σ_SM
σ(ZZ) = (0.4 ± 1.1) σ_SM



Summary

A number of analyses have recently addressed the search for diboson production with heavy-flavor jets in the final state

WW+WZ in $l\nu$+HF:

- CDF: **3.0 S.D. evidence for WW+WZ combined (7.5/fb)**
- DØ: **2.2 S.D. from background for WZ (4.3/fb)**

WZ+ZZ in MET+HF:

- CDF: **1.9 S.D. from background (5.2/fb)**

DØ: **The following analyses are "recycled" low-mass Higgs searches:**

WZ	**in $l\nu$+HF:**	**2.2 S.D. from background**	**(7.5/fb)**
ZZ	**in ll+HF:**	**0.1 S.D. from background**	**(7.5/fb)**
WZ+ZZ	**in MET+HF:**	**2.8 S.D. from background**	**(8.4/fb)**

DØ: **Combination of the three above:**

3.3 S.D. evidence for WZ+ZZ combined

(2.9 expected)

σ(WZ+ZZ) = (1.13 $\pm$ 0.36) σ_SM

These analyses have provided a direct validation of the procedures and techniques used in the searches for a low-mass Higgs boson at the Tevatron

Backup slides

b/c/light composition of the WZ+ZZ signal in the final sample of the D0 MET+HF analysis

- In the 1-tag channel:
  - bb : 16%
  - cc : 19%
  - cs : 23%
  - Rest: 41%
- In the 2-tag channel:
  - **bb : 60%**
  - cc : 22%
  - cs : 8%
  - Rest: 9%
- Remember that this is for the loosest b-tagging operating point, and that the b-tagging values are used as inputs to the final discriminant.