



Search for a Higgs Boson Produced in Association with a Vector Boson Using Like-Sign Dilepton Events at CDF

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On behalf of CDF Collaboration

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Outline

1. *Introduction*
2. *Backgrounds*
3. *Multivariate Analysis (Boosted Decision Trees)*
4. *Results & Summary*

★ Higgs Boson is **only undiscovered elementary particle** in the Standard Model (SM).

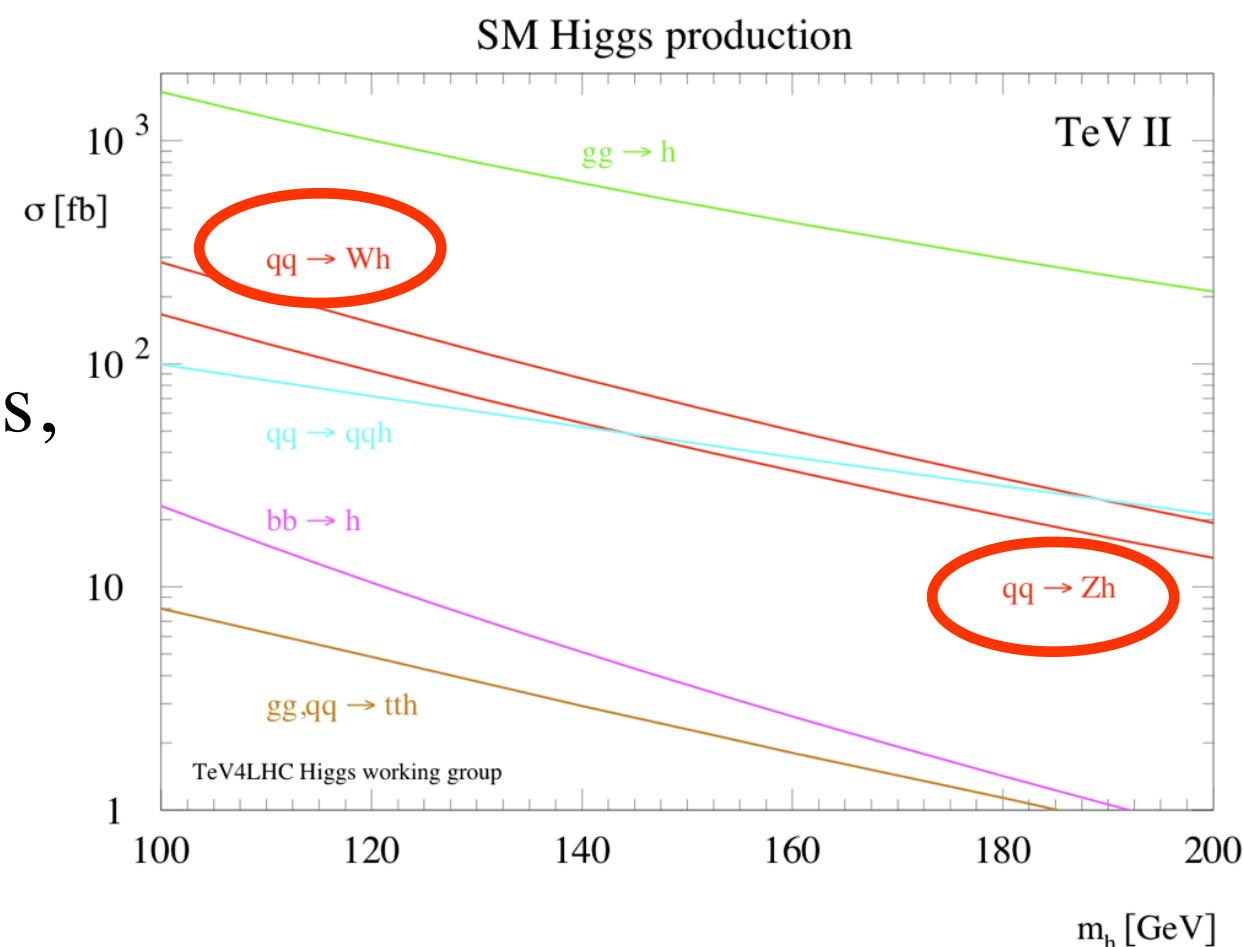
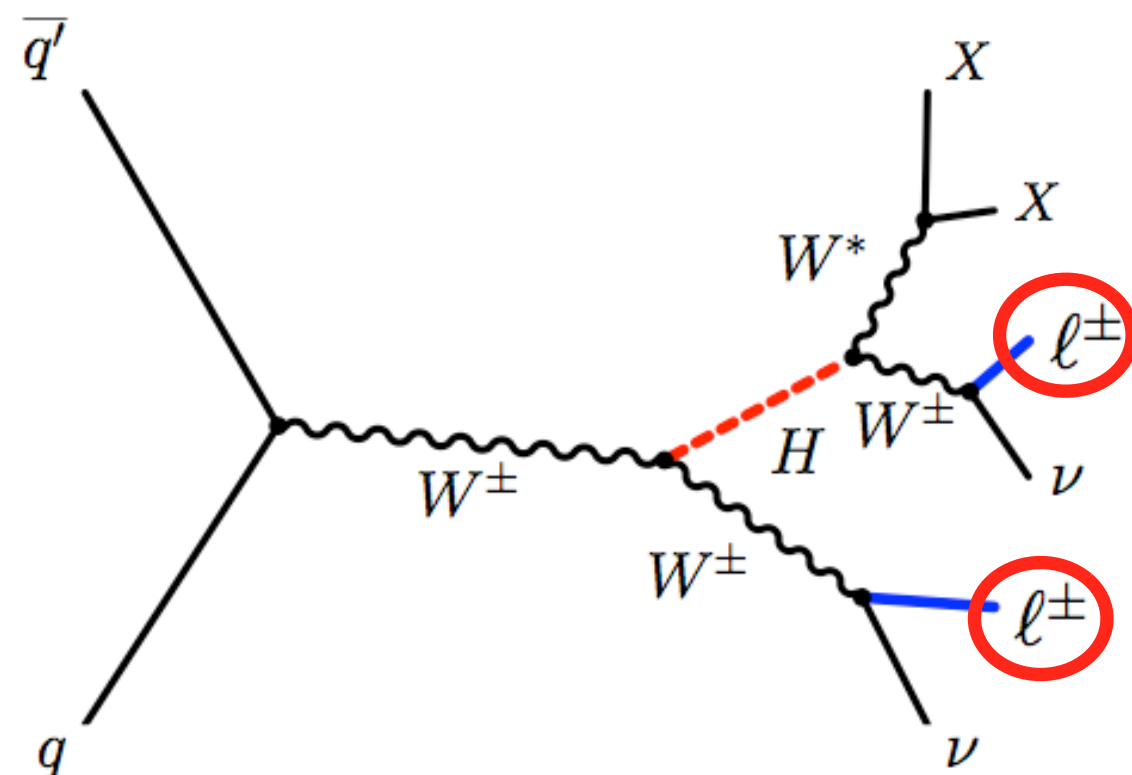
★ VH production is a strong channel at the Tevatron (relatively large cross section).

★ Final state with like-sign charge combination

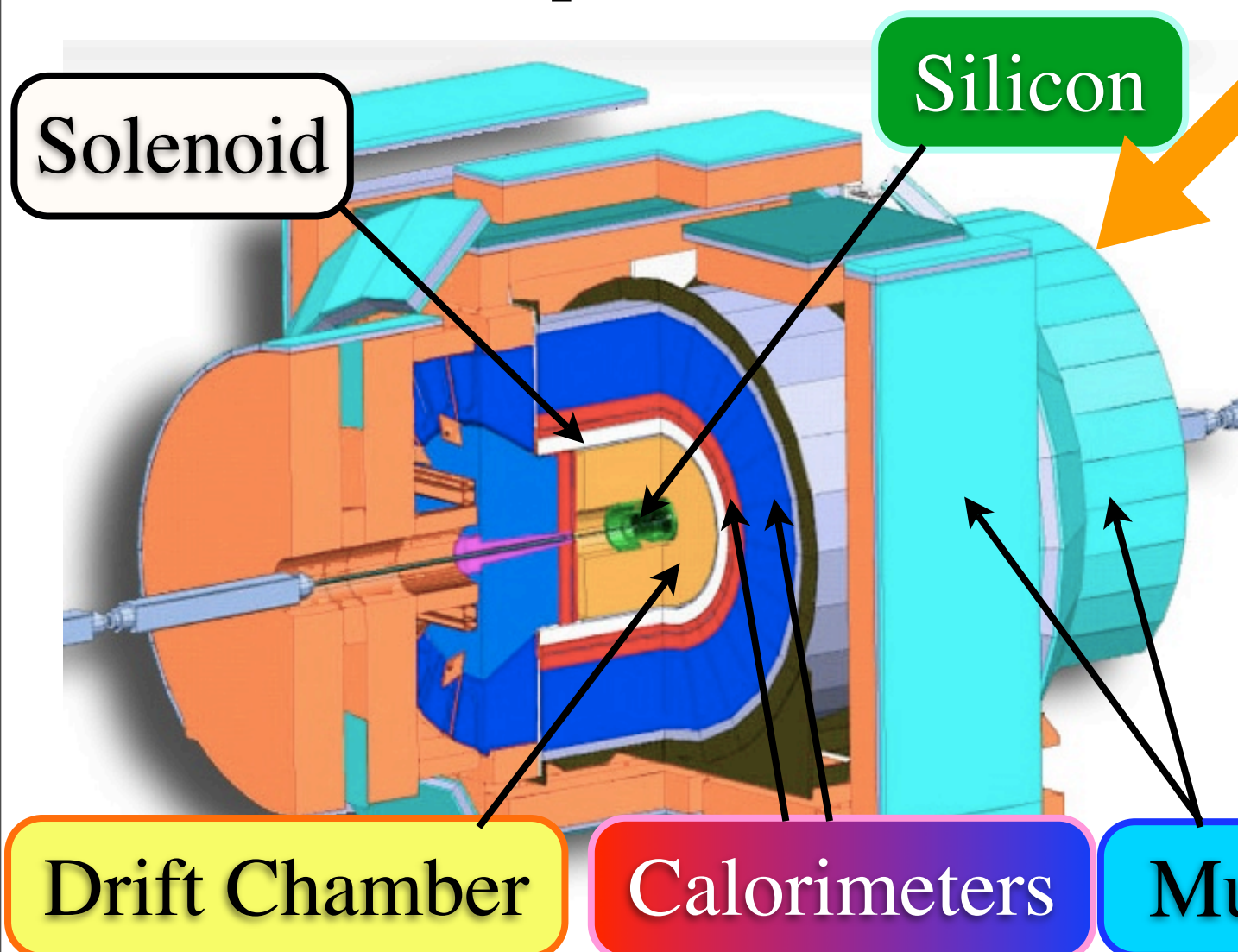
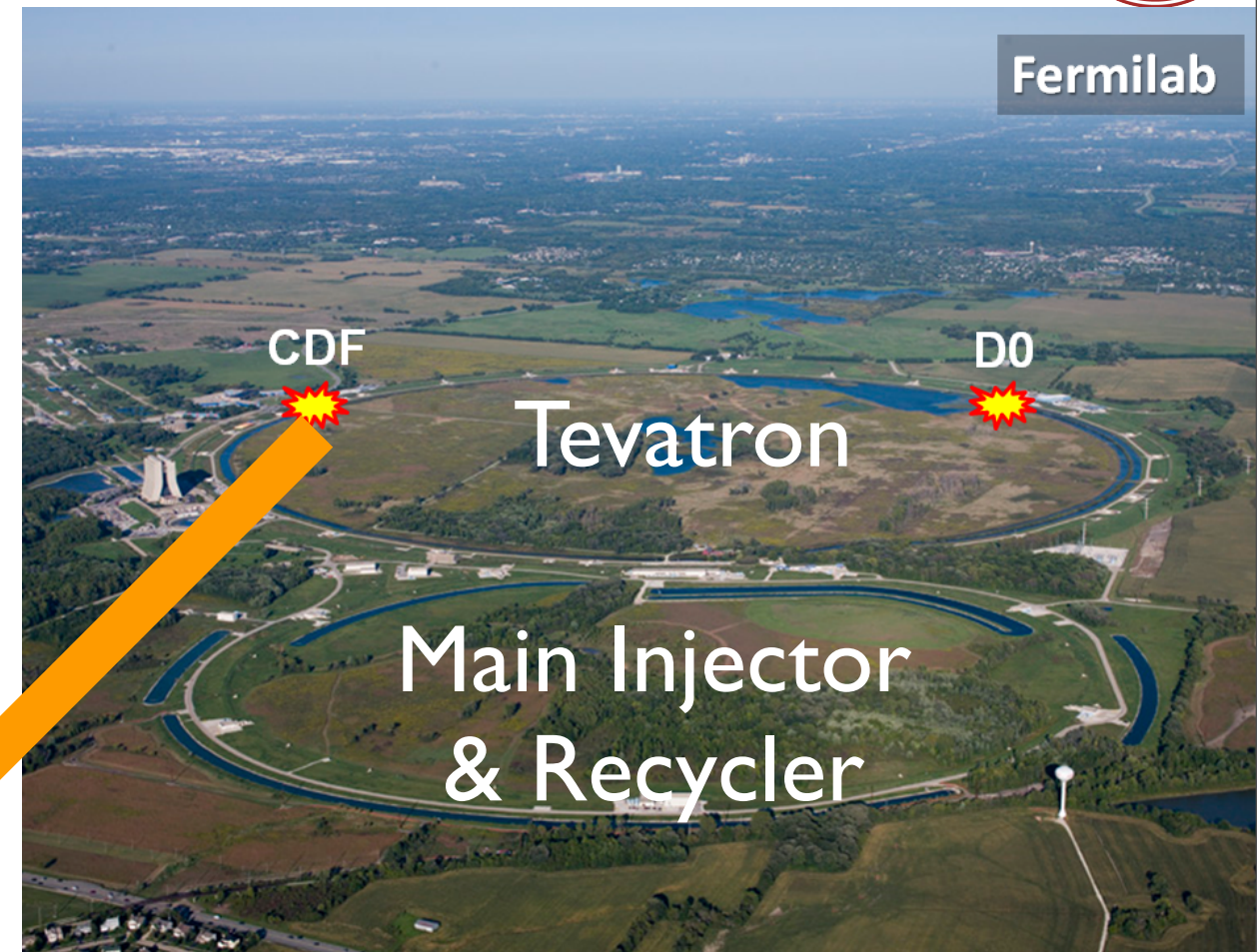
$$VH \rightarrow VWW \rightarrow \ell^\pm \ell^\pm + X$$

is very clean channel!

★ Also, this channel can be investigated Beyond SM (e.g. Fermiophobic (FP) Higgs, which cannot couple to fermions.)



- ★ $\sqrt{s} = 1.96 \text{ TeV } p\bar{p}$ collisions at CDF and D0
- ★ Data taking was finished in last September
- ★ Delivered: $\sim 12 \text{ fb}^{-1}$
- ★ CDF Data taped: $\sim 10 \text{ fb}^{-1}$



* CDF Detector:
general purpose detector

- * Data: 9.4 fb^{-1} collected by CDF (Full Dataset)
 - ✓ (cf. APS April Meeting & Users Meeting (Poster): 7.6 fb^{-1})
- * Central leptons (Electron & Muon) + **Forward Muons**
- * Minimum kinematical requirement for the 1st and 2nd leptons
(maximizing signal acceptance)

✓ 1st lepton:

$$E_T(p_T) > 20 \text{ GeV}$$



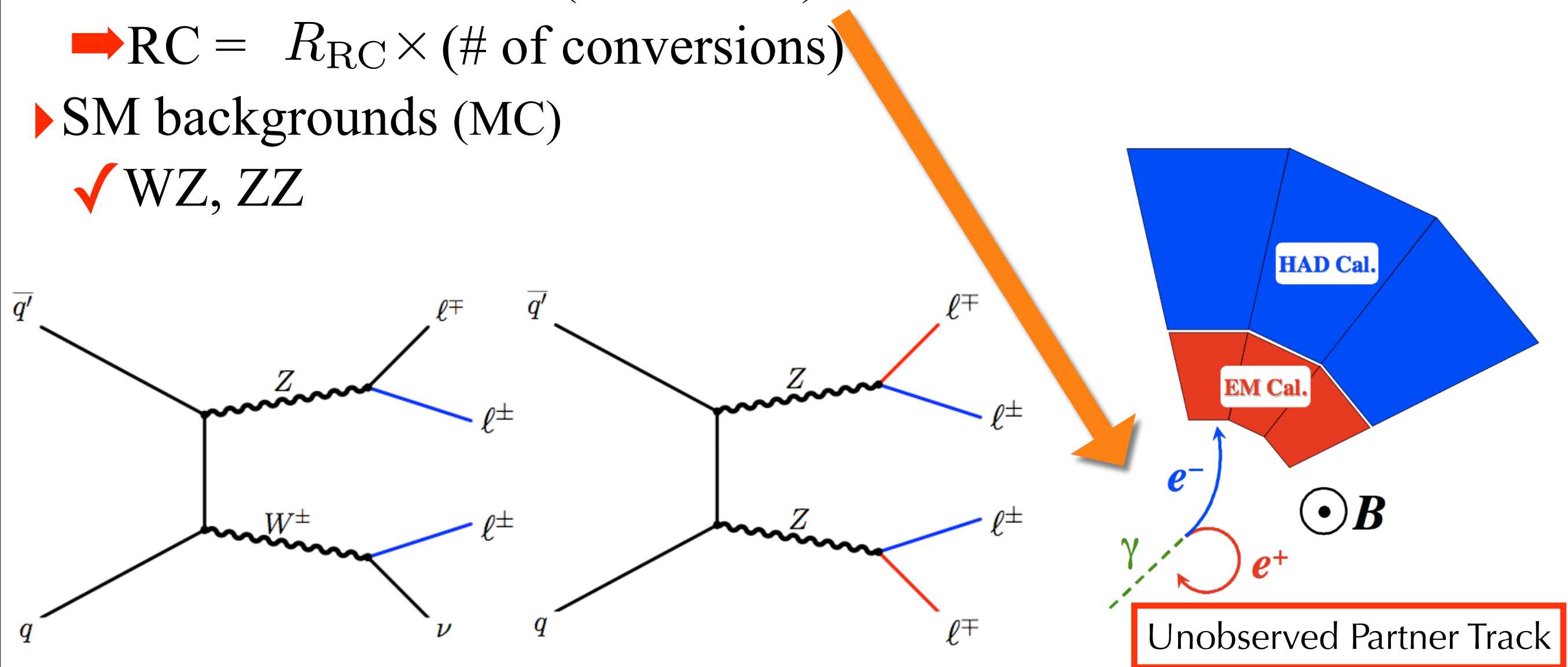
✓ 2nd lepton:

$$E_T^{\ell_2} > 6 \text{ GeV} \quad \& \quad p_T > 6 \text{ GeV}/c$$

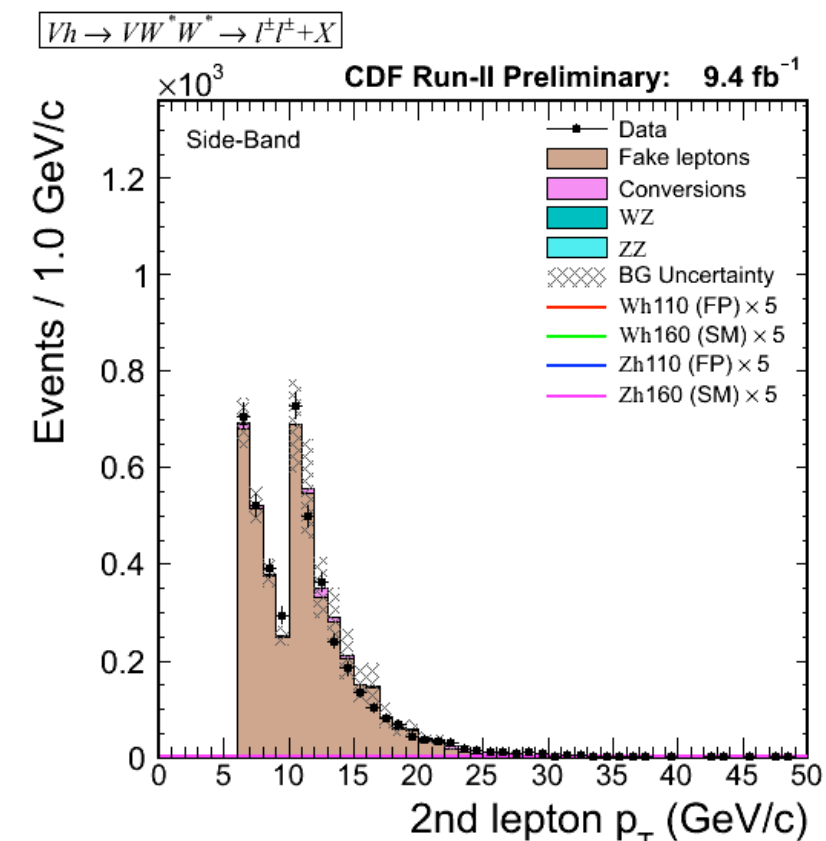
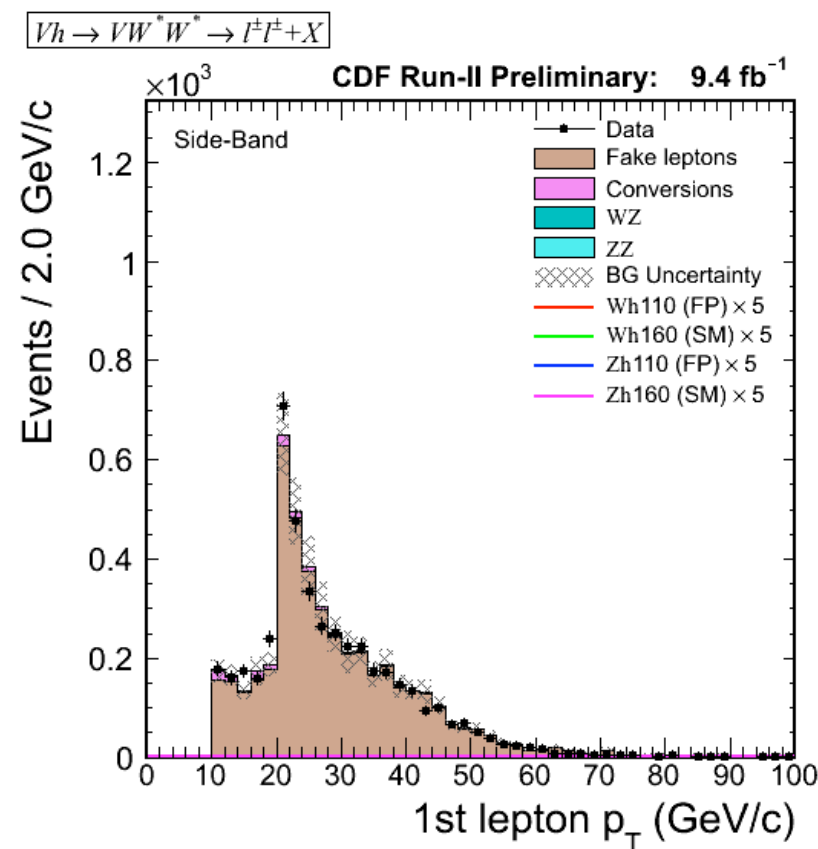
- * Isolation cuts
- * Track quality cuts (including silicon hits)
- * Lepton identification cuts based on likelihood method
- * Like-sign charge combination

- ▶ Fake leptons (data-driven)
 - ✓ Punch-through hadrons
 - ✓ Non-prompt leptons
 - ➡ Fake = $R_{\text{fake}} \times (\# \text{ of isolated tracks})$
- ▶ Residual Conversions (data-driven)
 - ➡ RC = $R_{\text{RC}} \times (\# \text{ of conversions})$
- ▶ SM backgrounds (MC)
 - ✓ WZ, ZZ

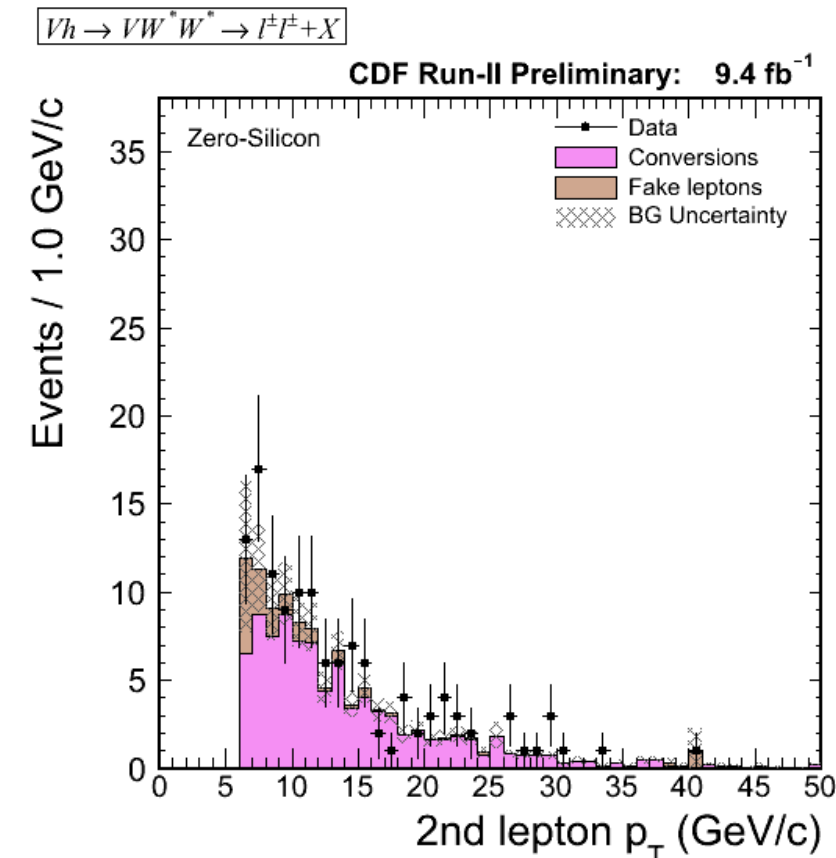
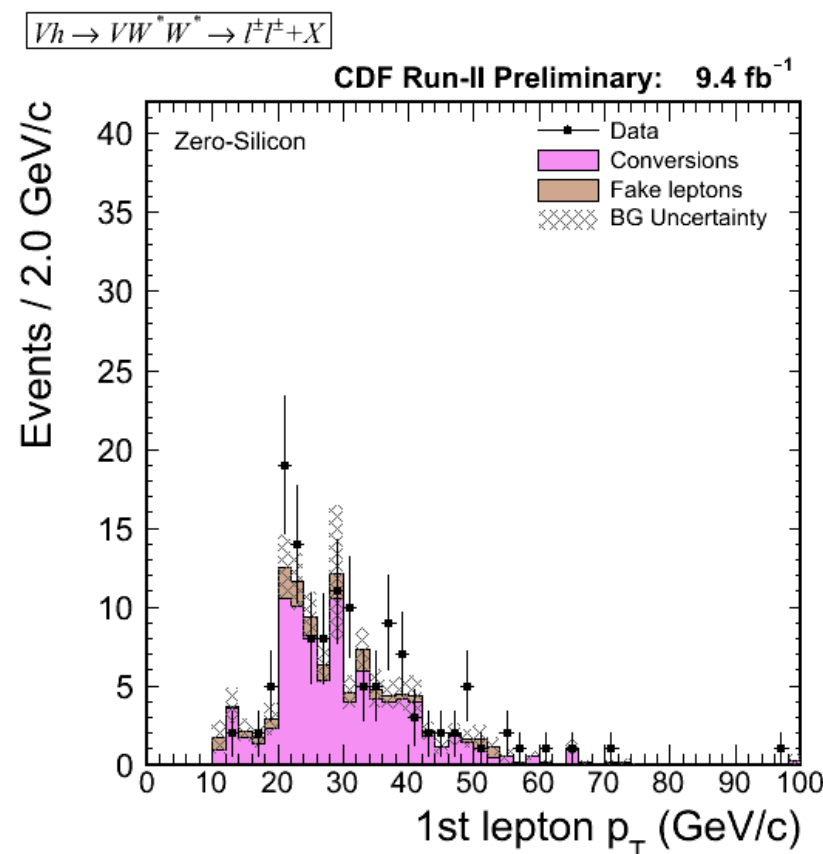
cf. New Perspectives 2011
I explained fake estimations in detail.



Side-Band:
2nd lepton fails
Lepton ID Cuts
(Fake leptons rich)



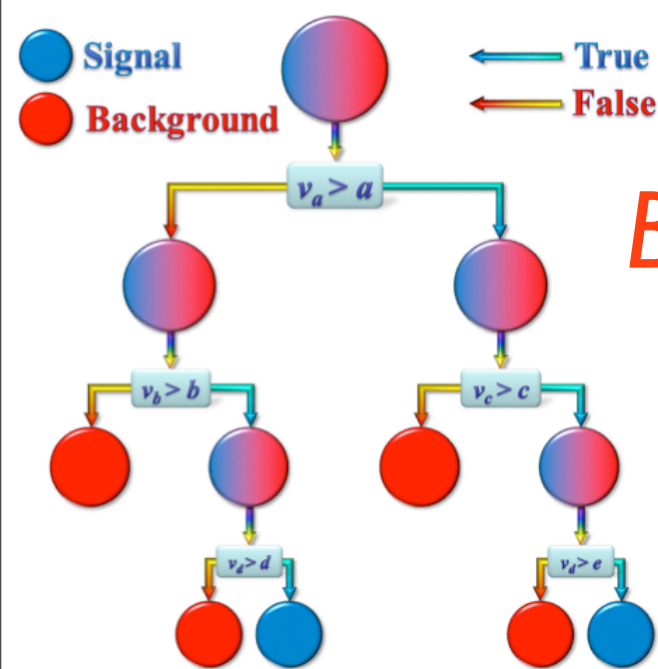
Zero Silicon:
2nd lepton has no
silicon hits
(Conversion rich)



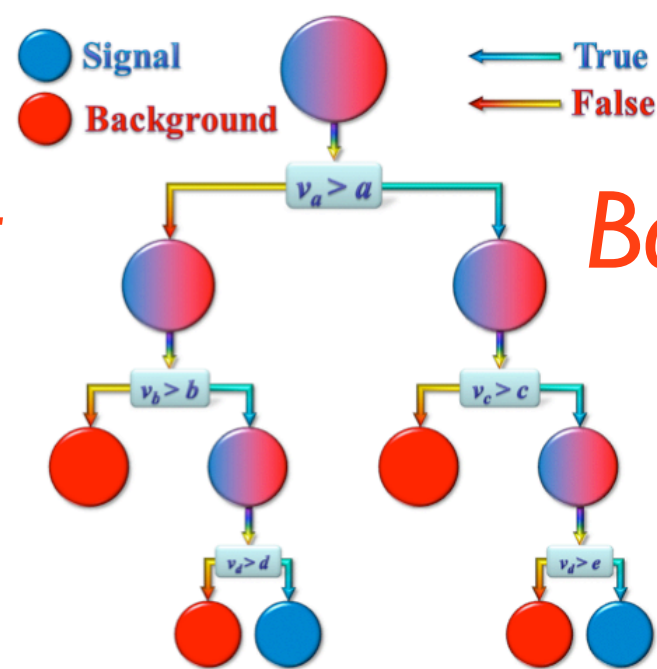
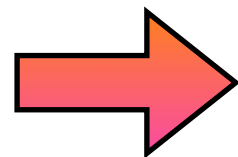
★ To get more sensitivity, we employ multivariate technique.

★ Boosted Decision Trees (BDT)

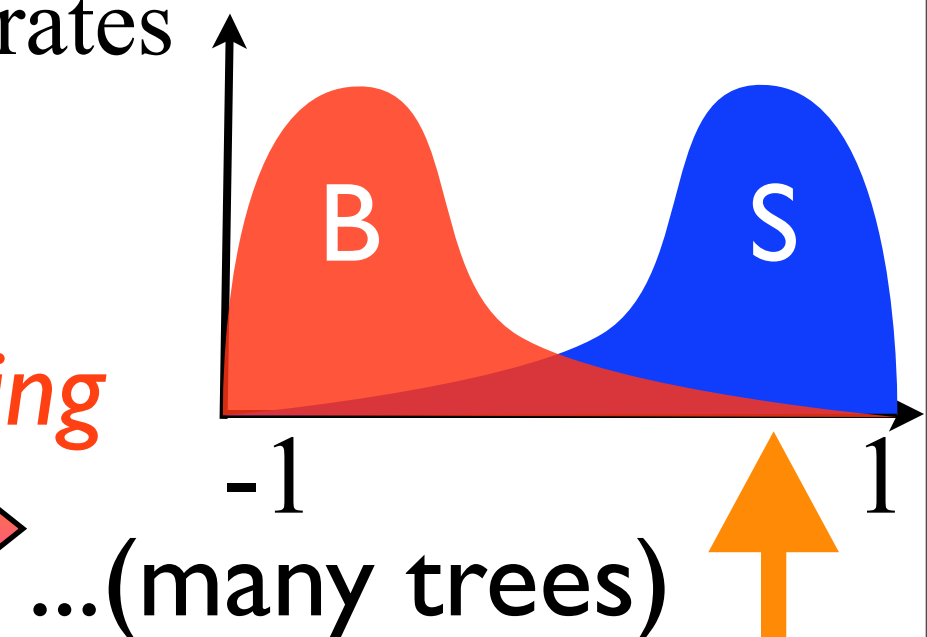
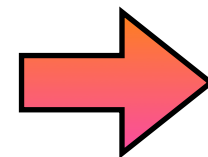
- ▶ True/False decision in each splitting (Decision Tree)
- ▶ Boosting can pick up misclassified events w/ weighting each event
- ▶ Output from many trees, combine w/ error rates



Boosting



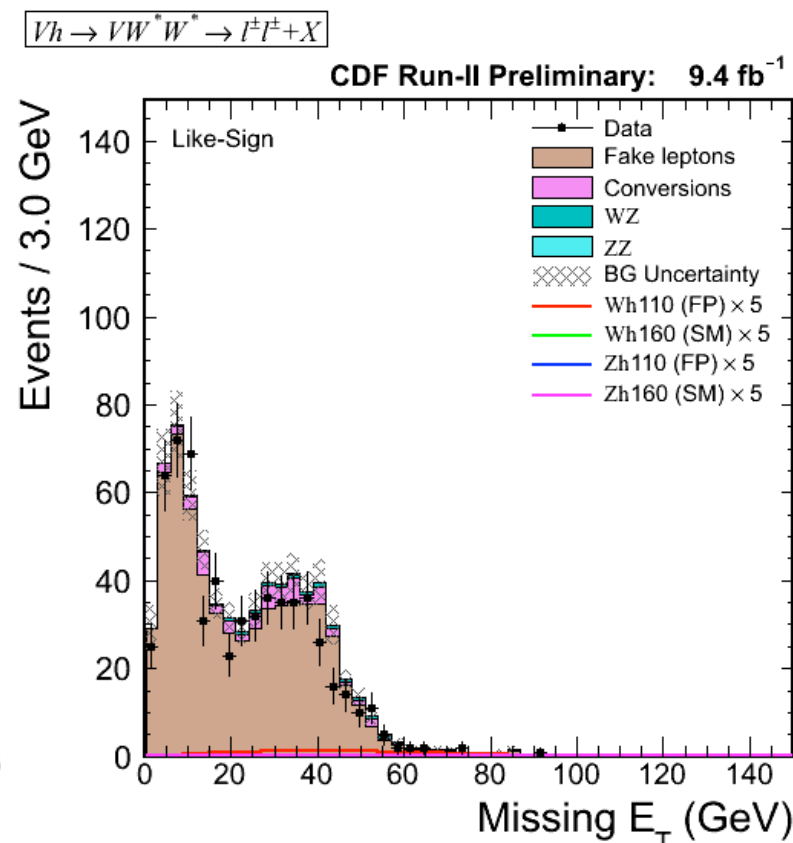
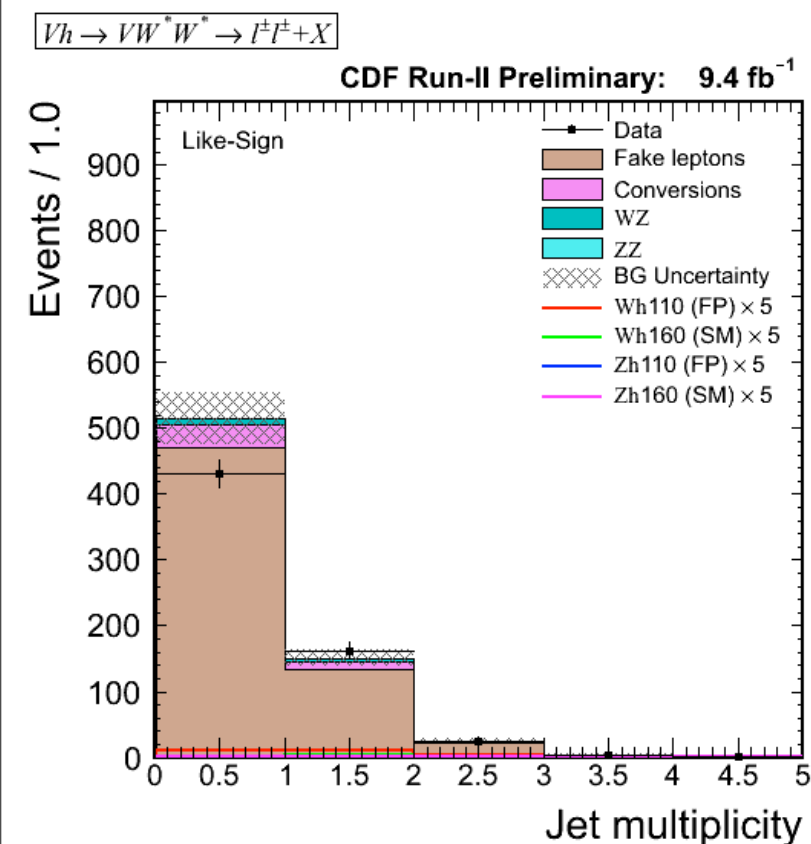
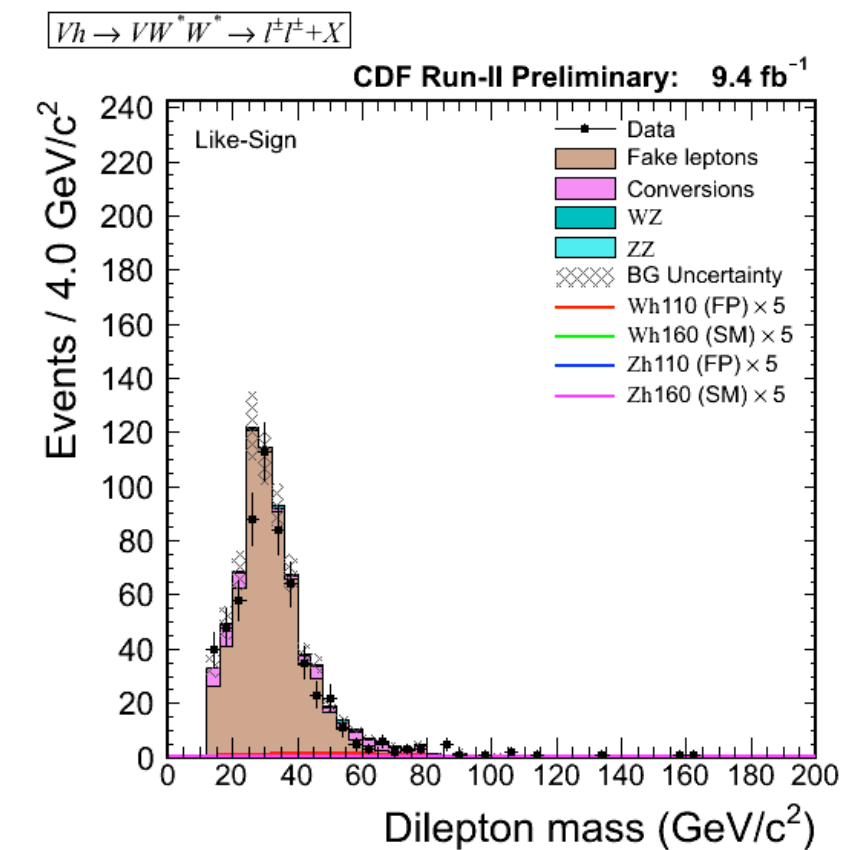
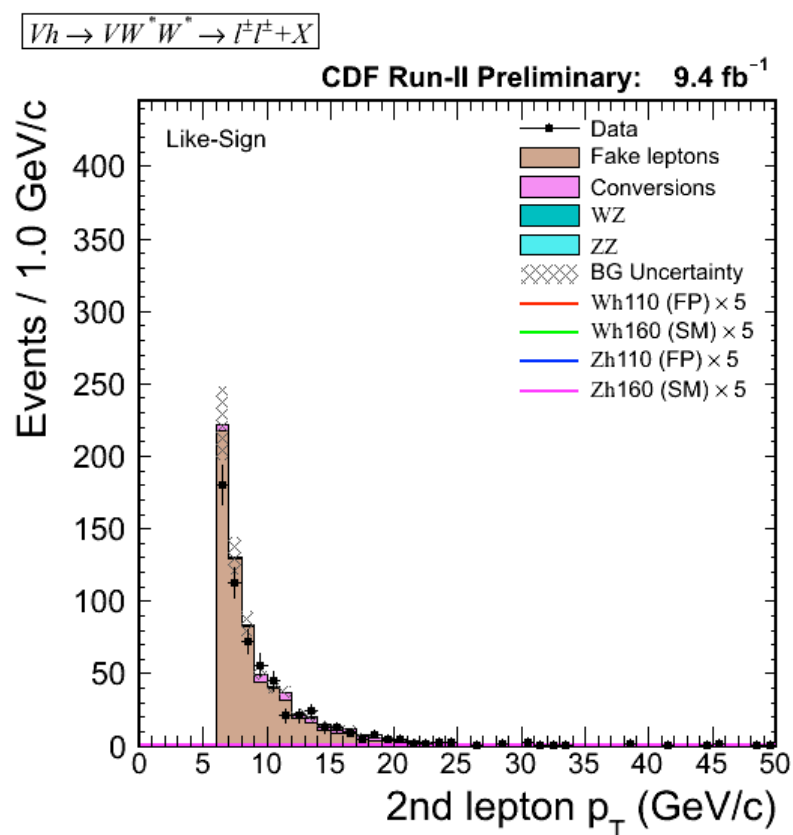
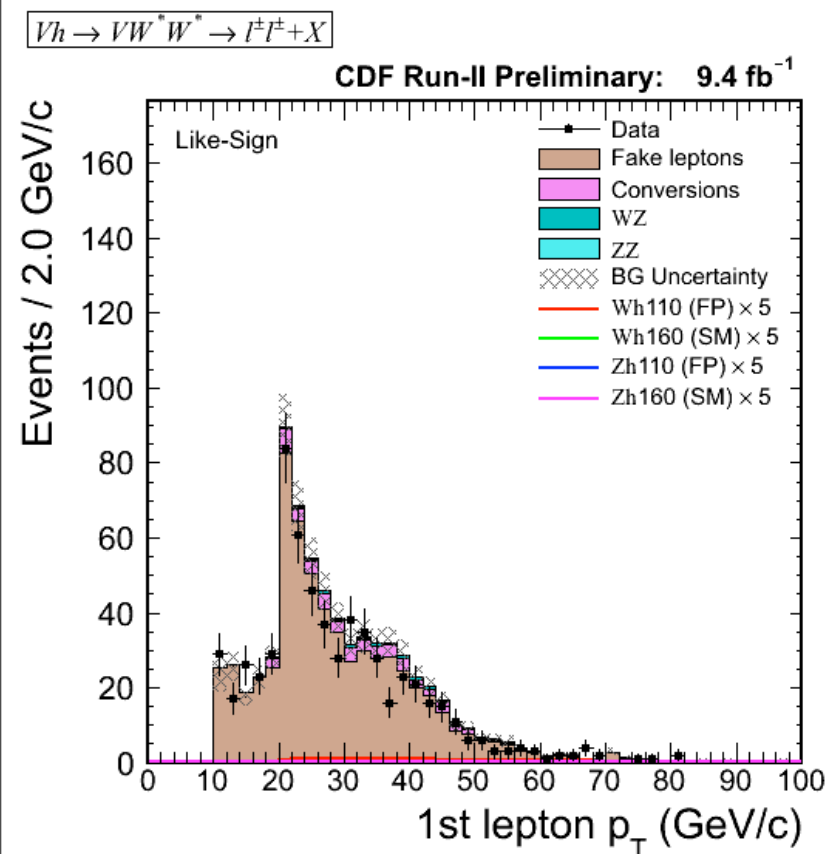
Boosting



Error Rate α_1
First Tree T_1

Error Rate α_2
Second Tree T_2

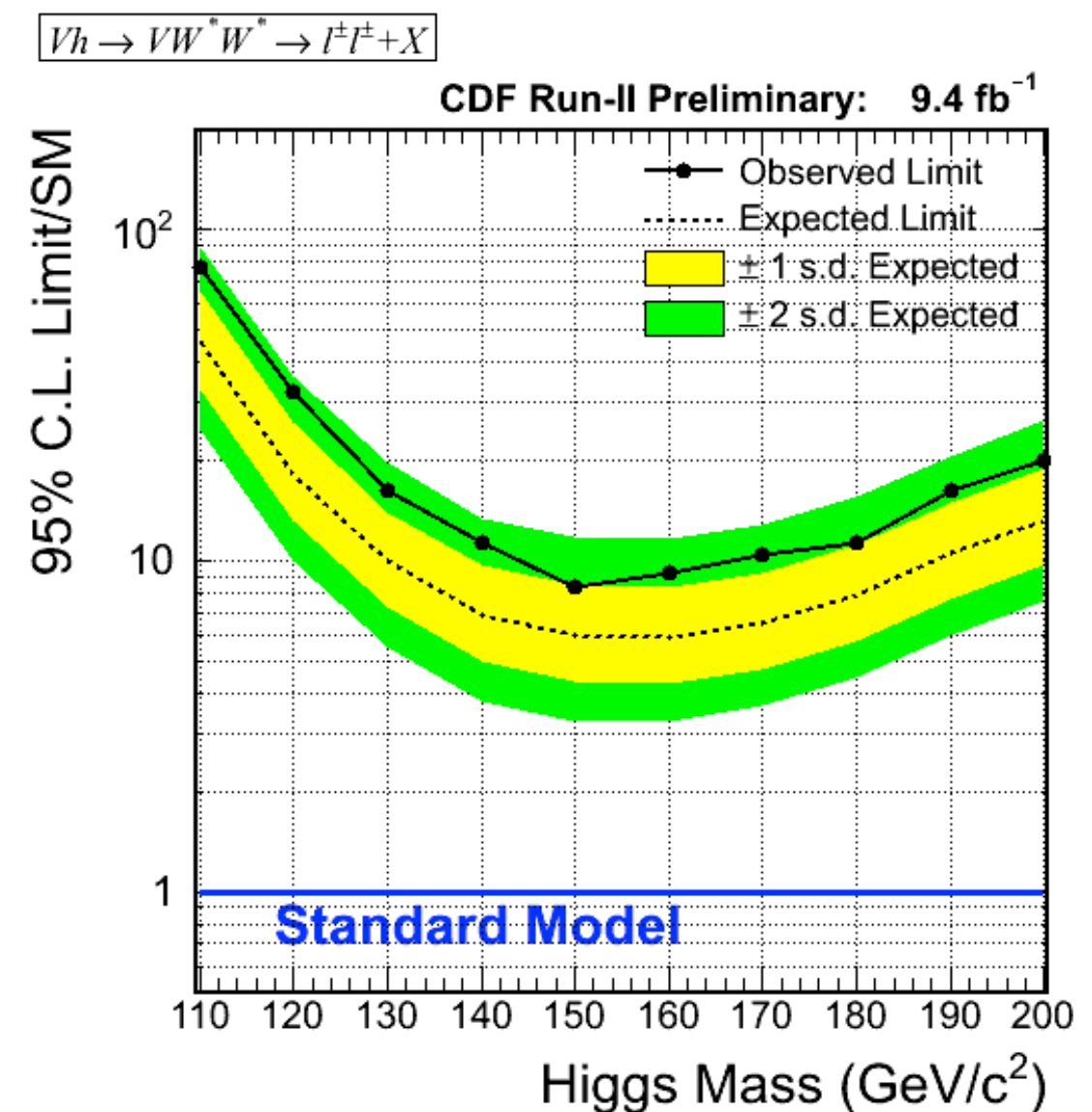
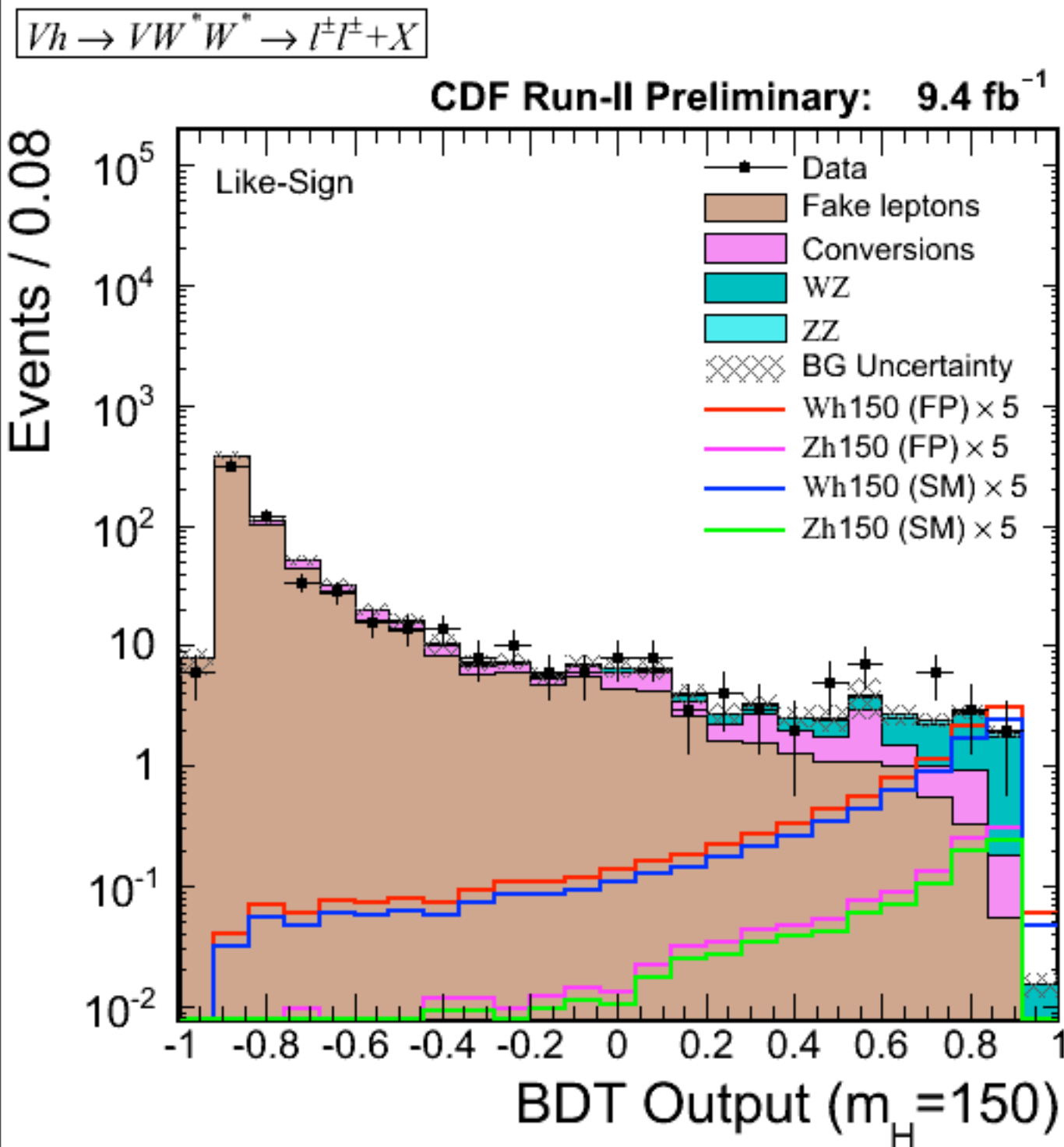
$$\text{Output} = \sum_n \alpha_n T_n$$



Other Input Variables

- Missing ET related
- Event Shape related

- No significant differences between data & expected backgrounds
- We set 95% Confidence Level limit on the SM Higgs



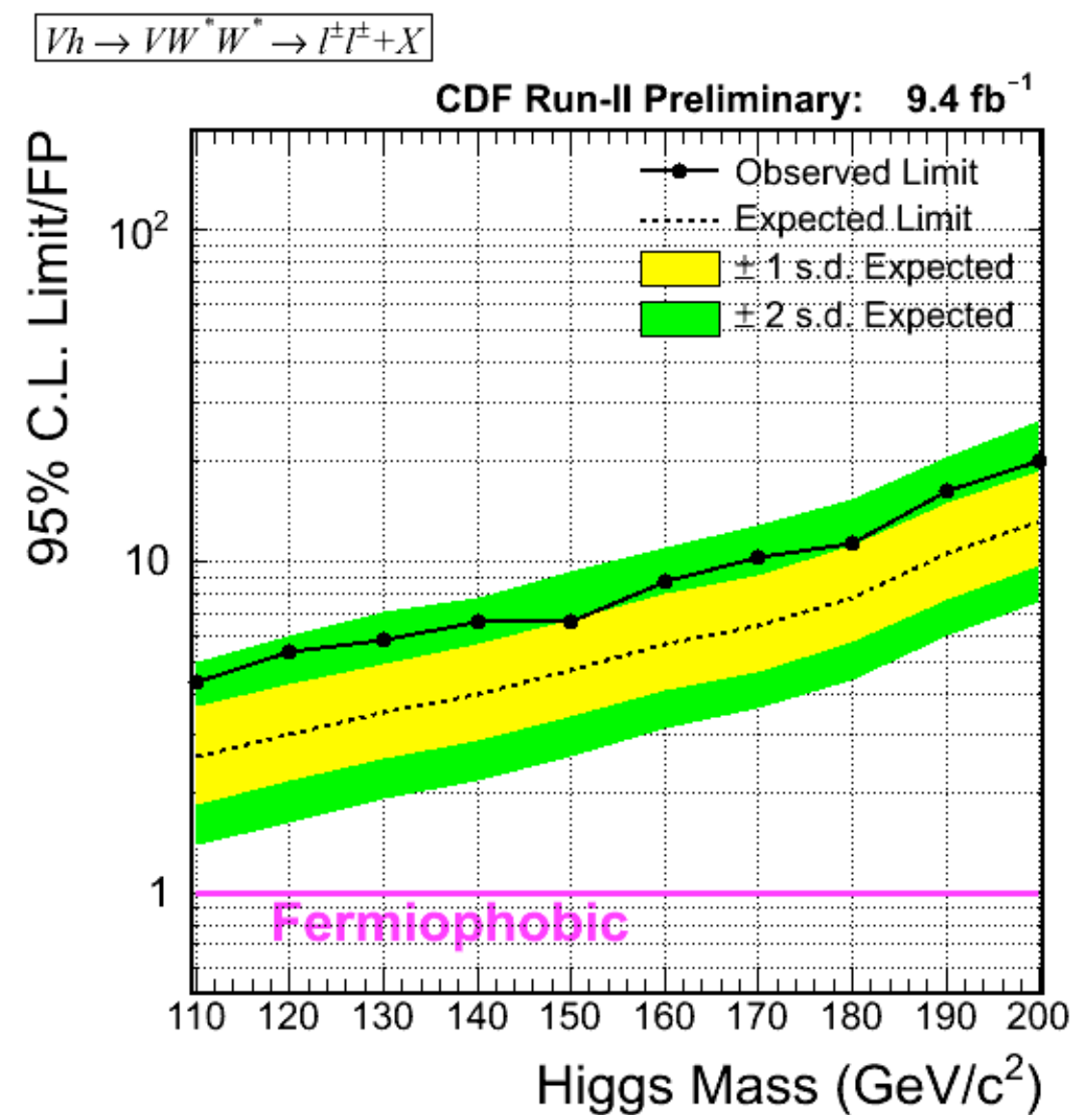
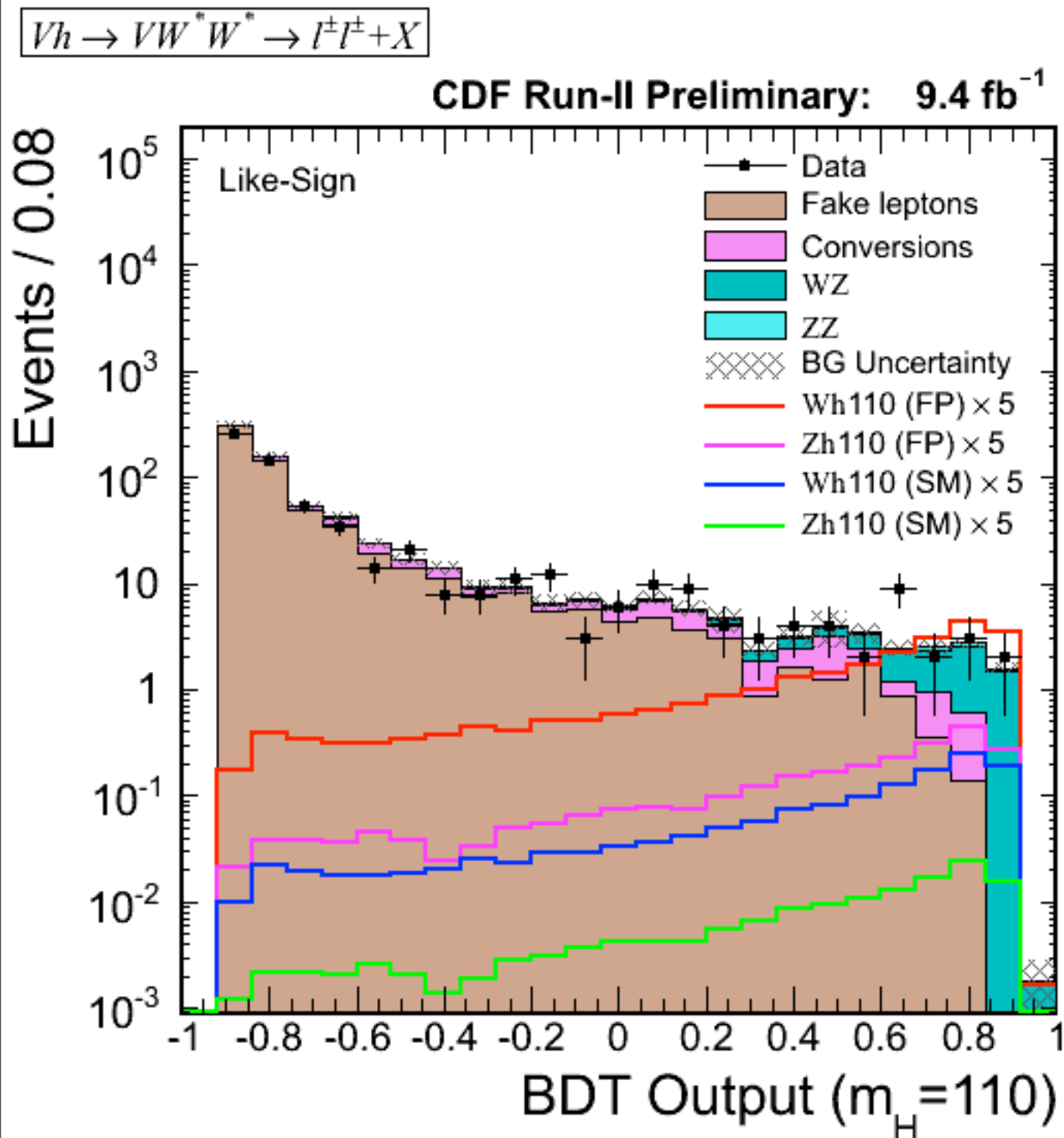
Observed limit: 8.3

Expected limit: 6.0

$$m_H = 150 \text{ GeV}/c^2$$

Results (Fermiophobic)

- No significant differences between data & expected backgrounds
- We set 95% Confidence Level limit on Fermiophobic Higgs



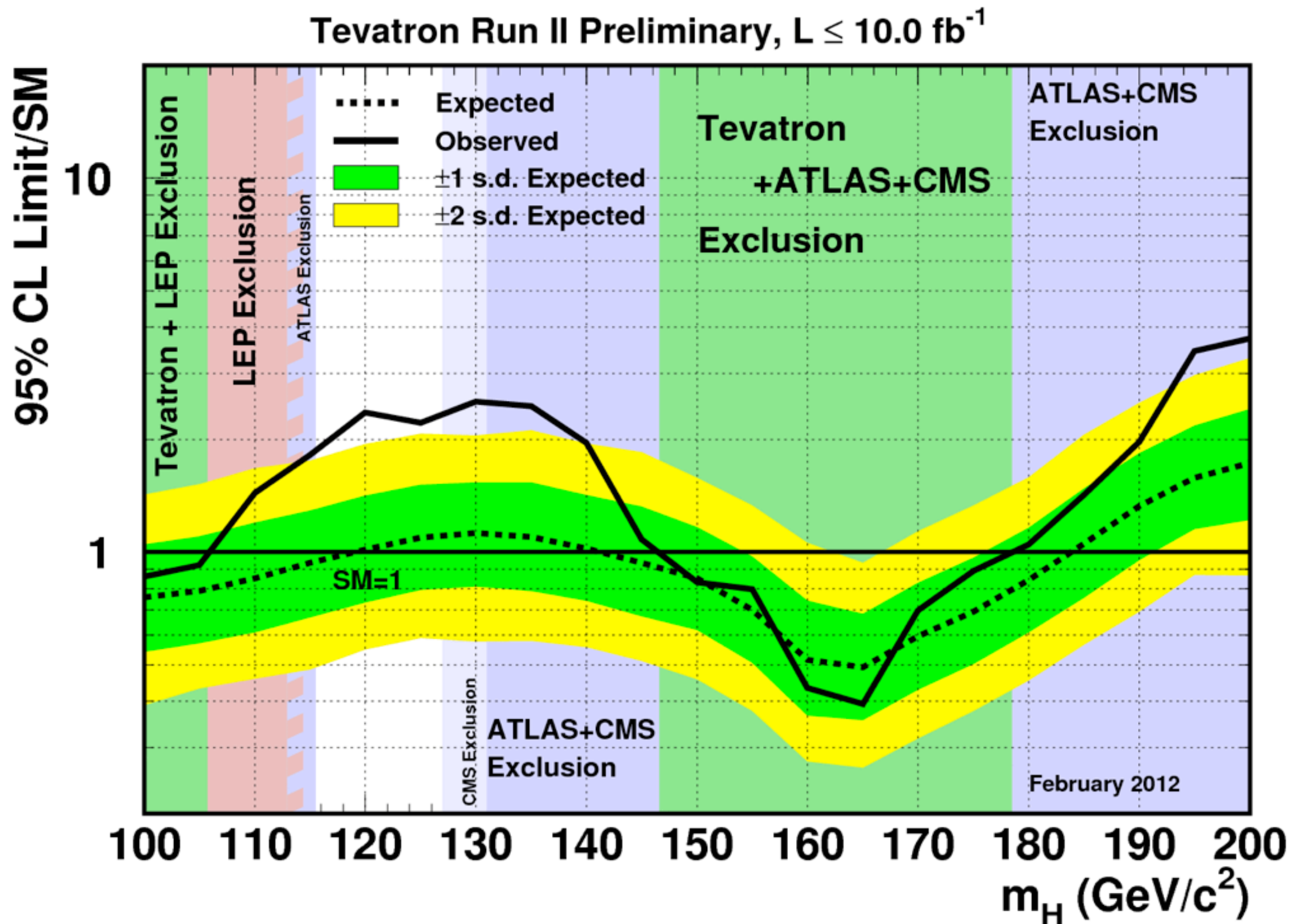
Observed limit: 4.4

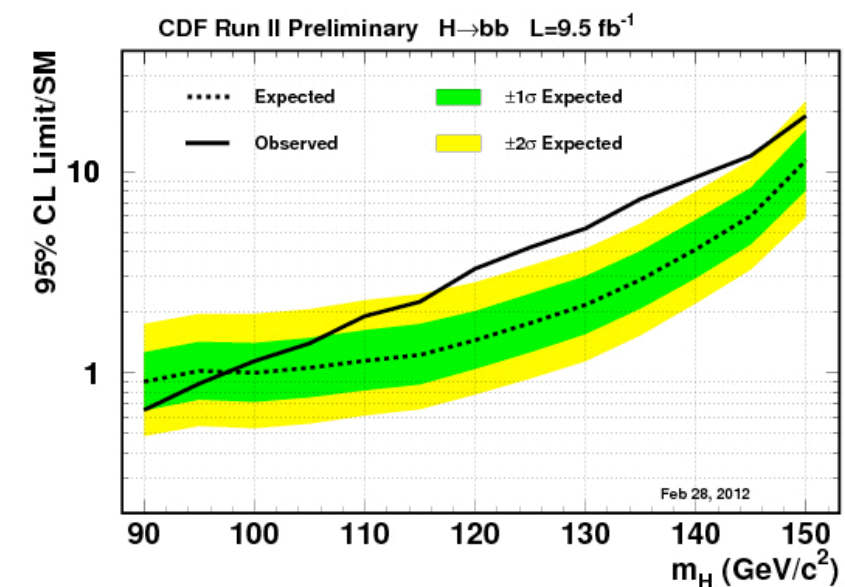
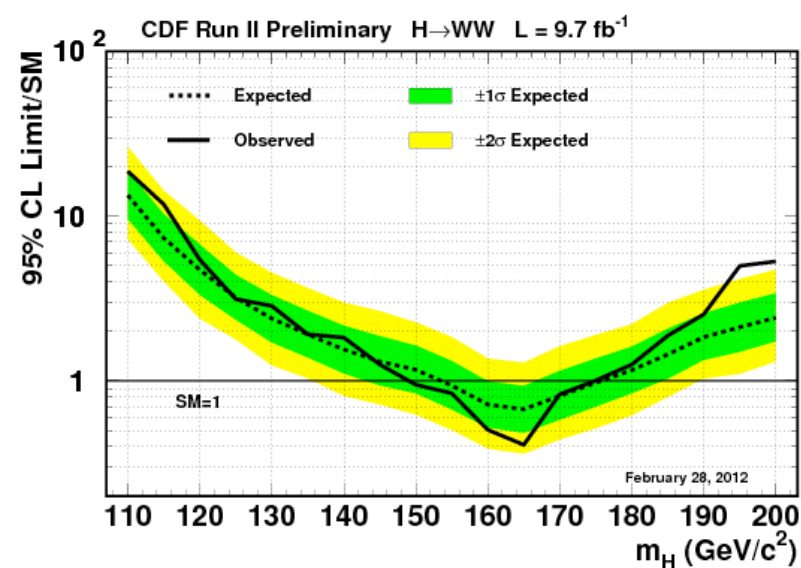
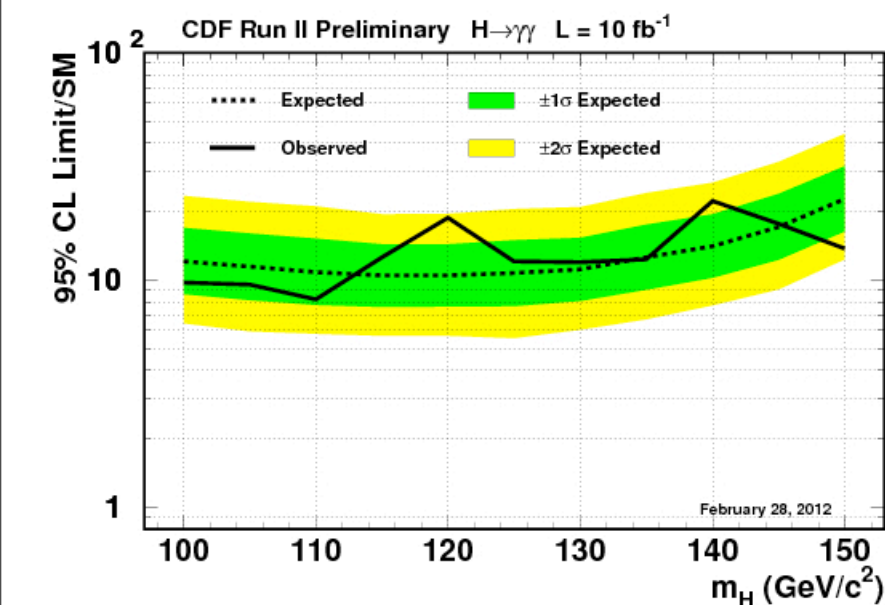
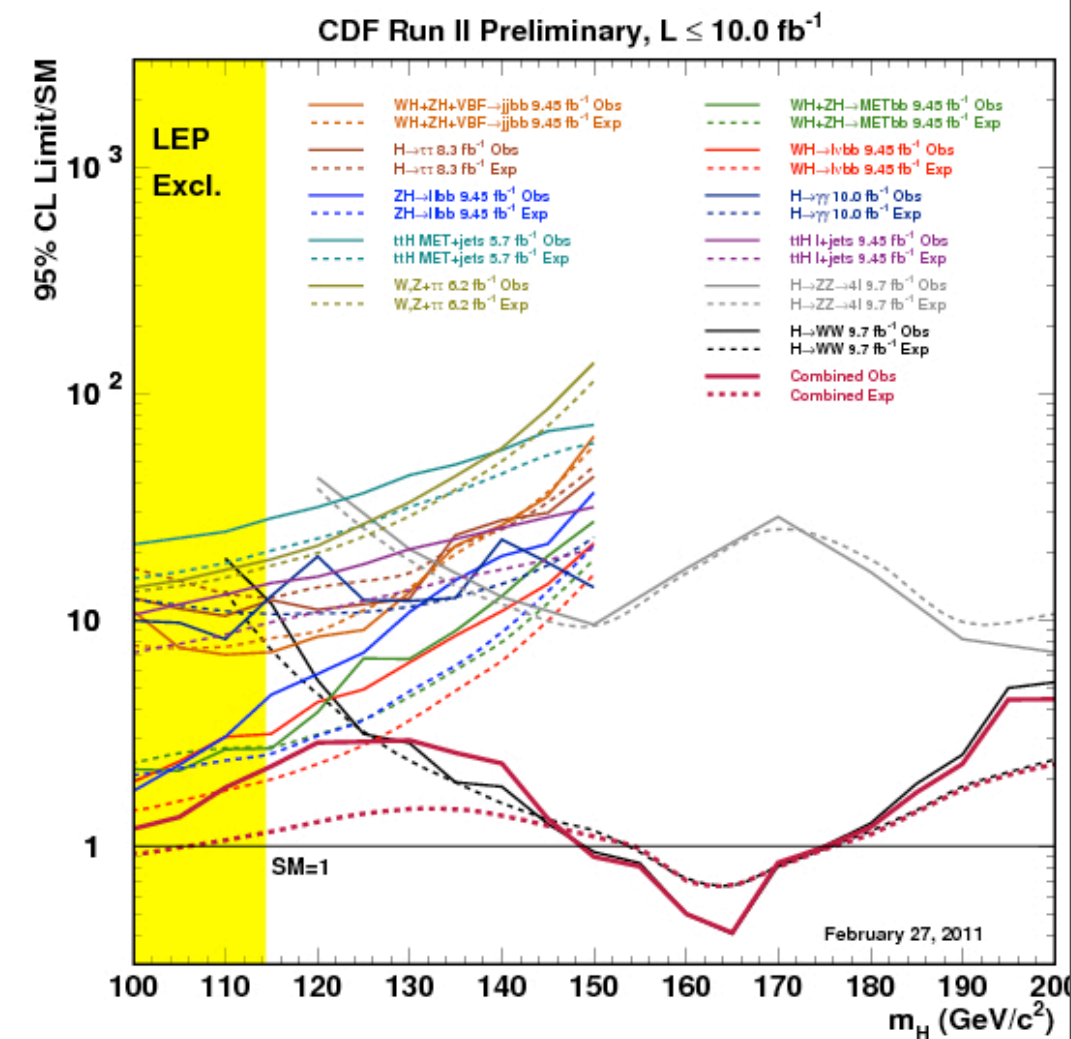
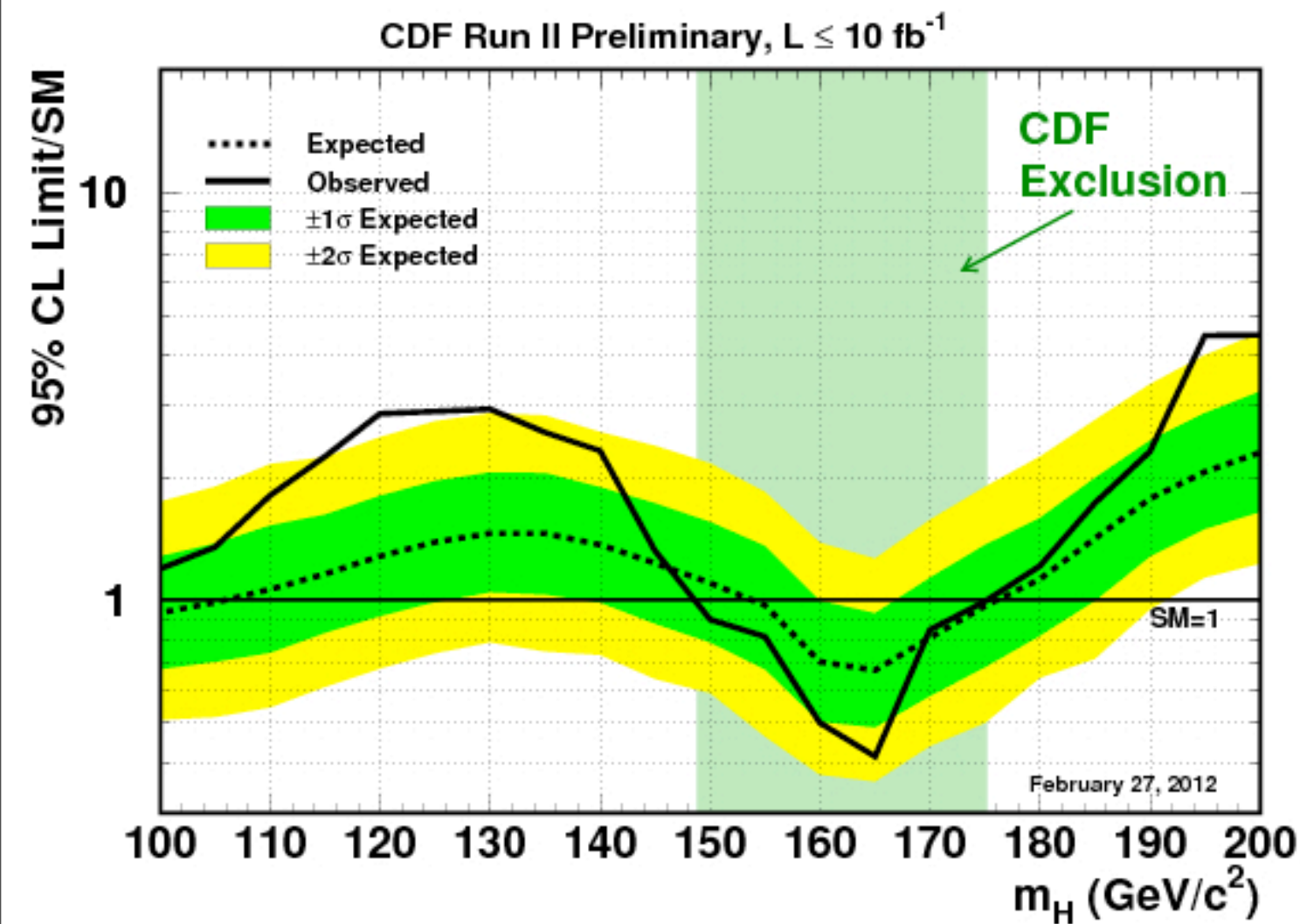
Expected limit: 2.6

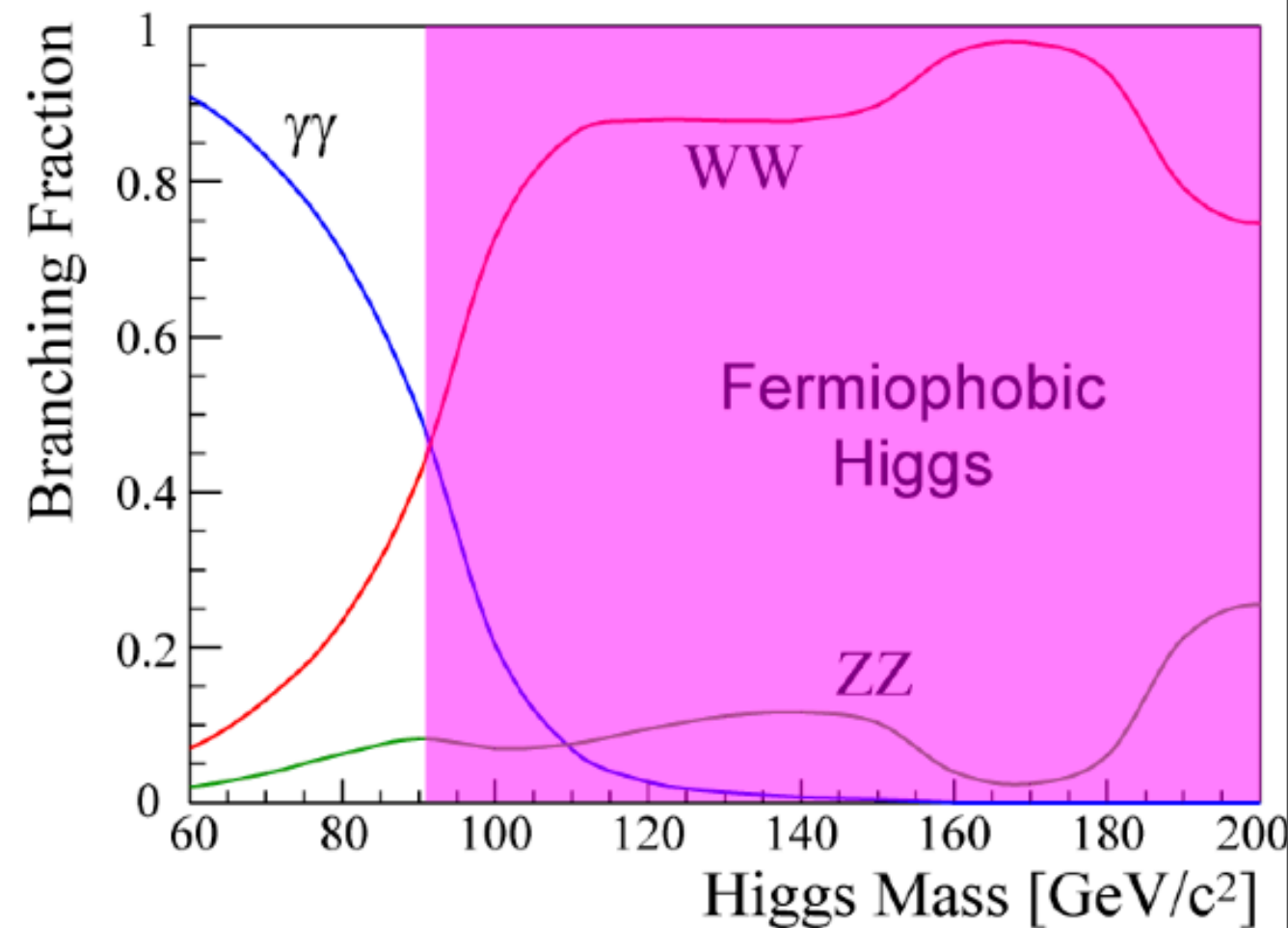
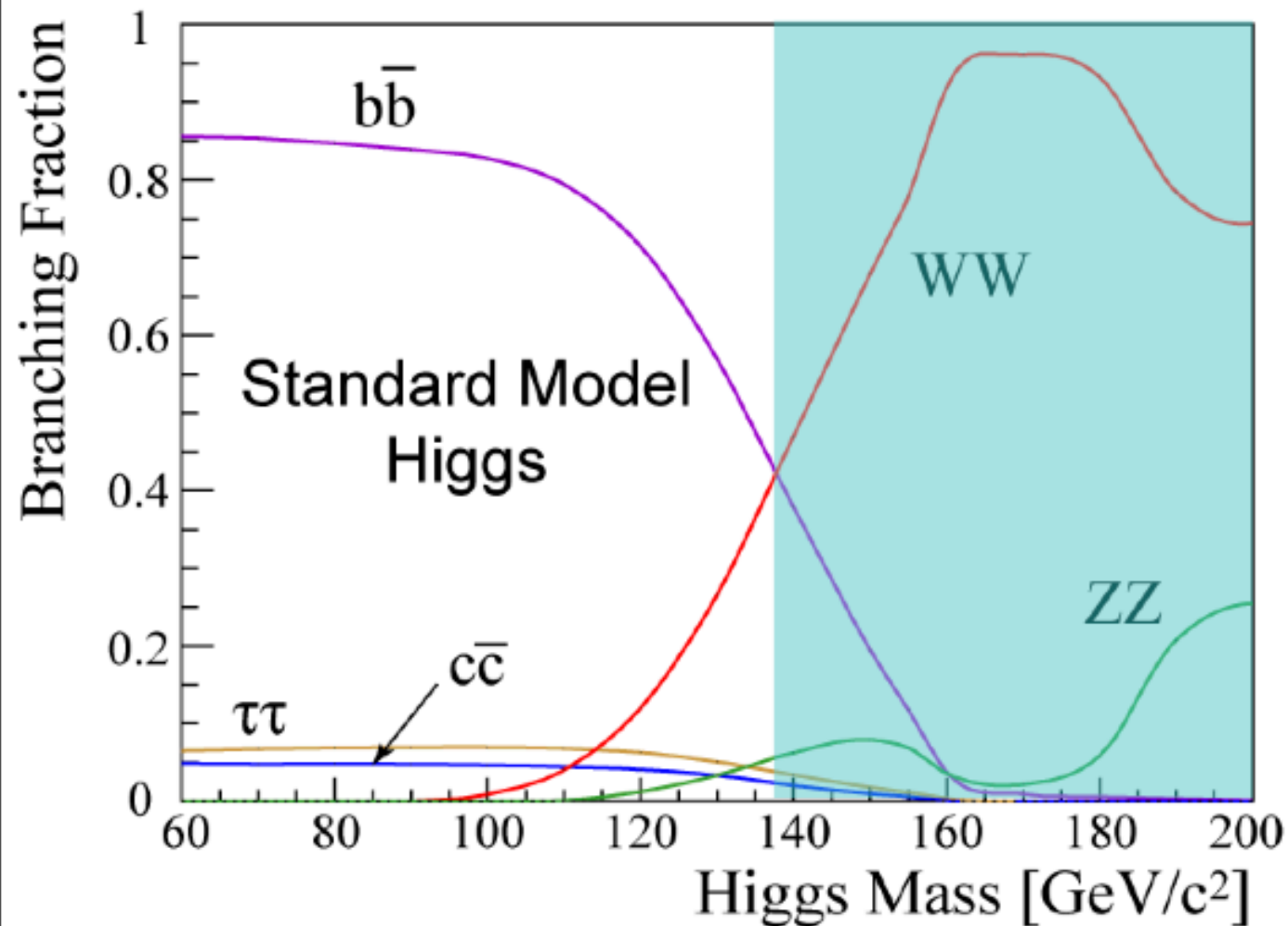
$$m_{h_{FP}} = 110 \text{ GeV}/c^2$$

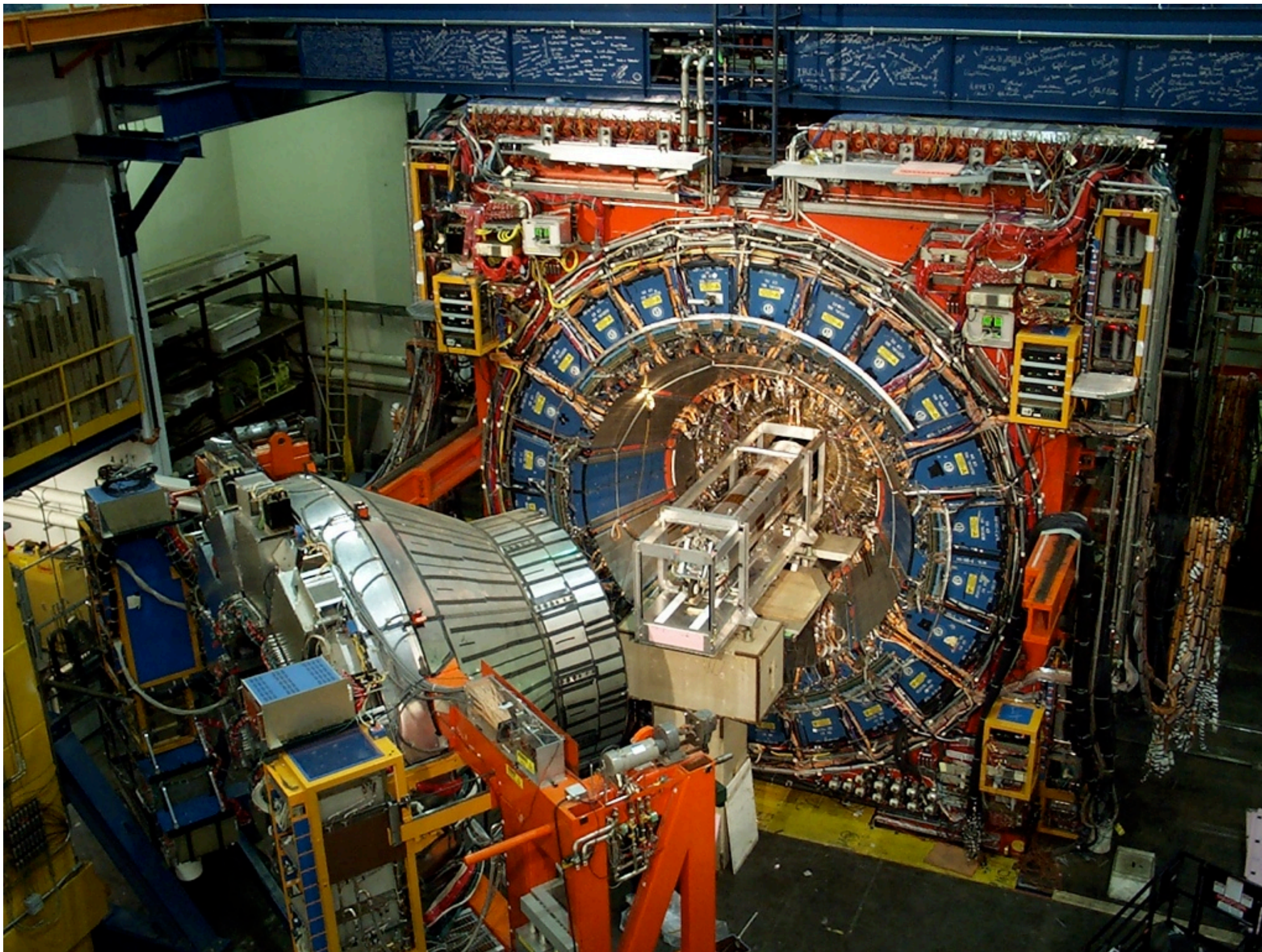
- ❖ Data 9.4 fb^{-1} used for Higgs search (Full dataset)
- ❖ No significant discrepancies between data & expected
- ❖ BDT method applied to get more sensitivity, and we get the 95% C.L. Limit:
 - ➡ **8.3** \times (SM Higgs 160) (Expected limit: **6.0**)
 - ➡ **4.4** \times (FP Higgs 110) (Expected limit: **2.6**)
- ✓ More Like-Sign Dilepton Events
 - ✓ WZ/ZZ Measurements
 - ✓ Like-Sign Characteristic Search
 - ✓ etc. (If you have something, please let me know :-))

Back Up

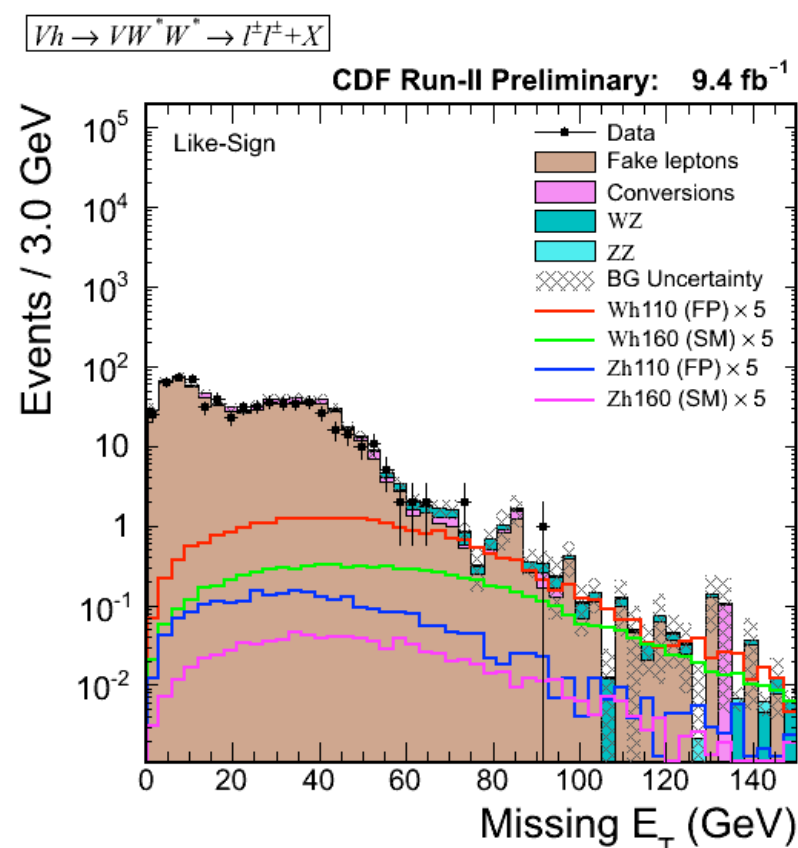
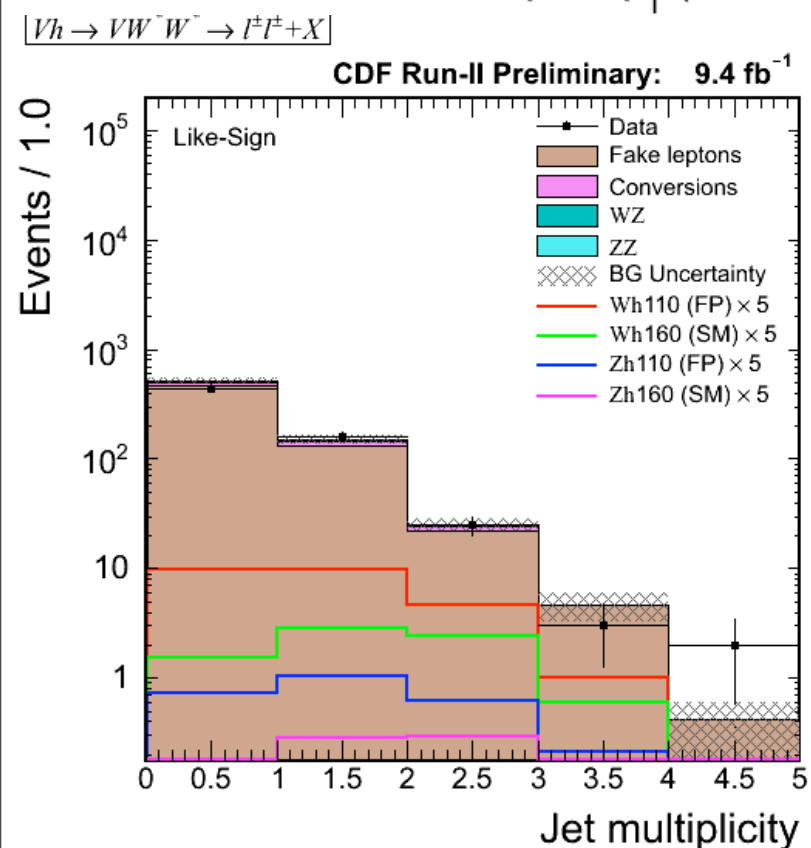
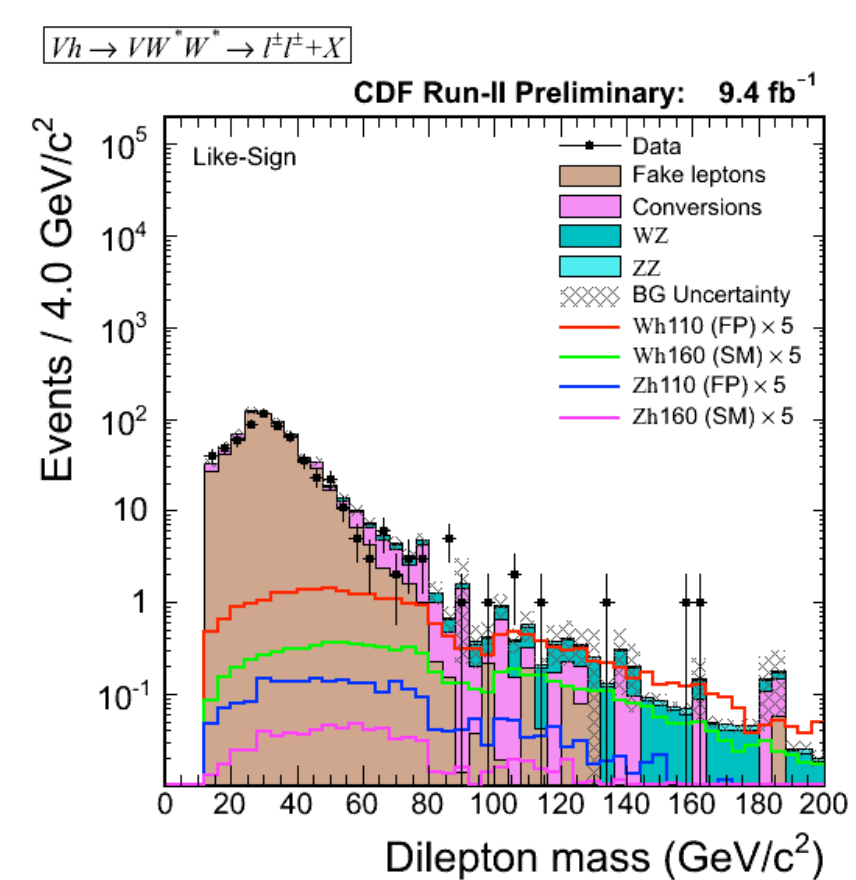
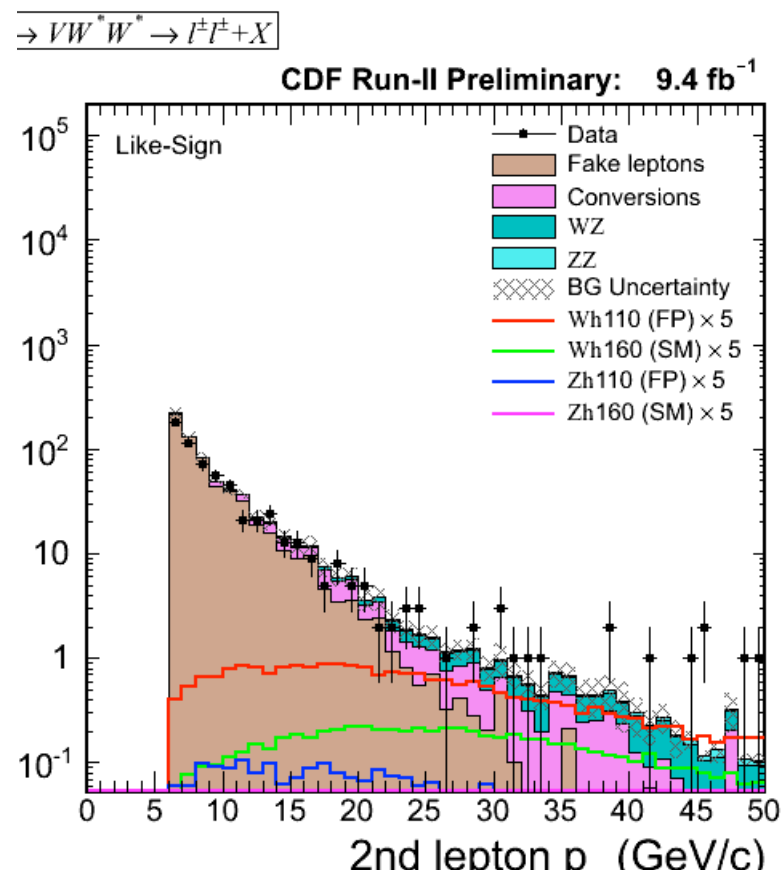
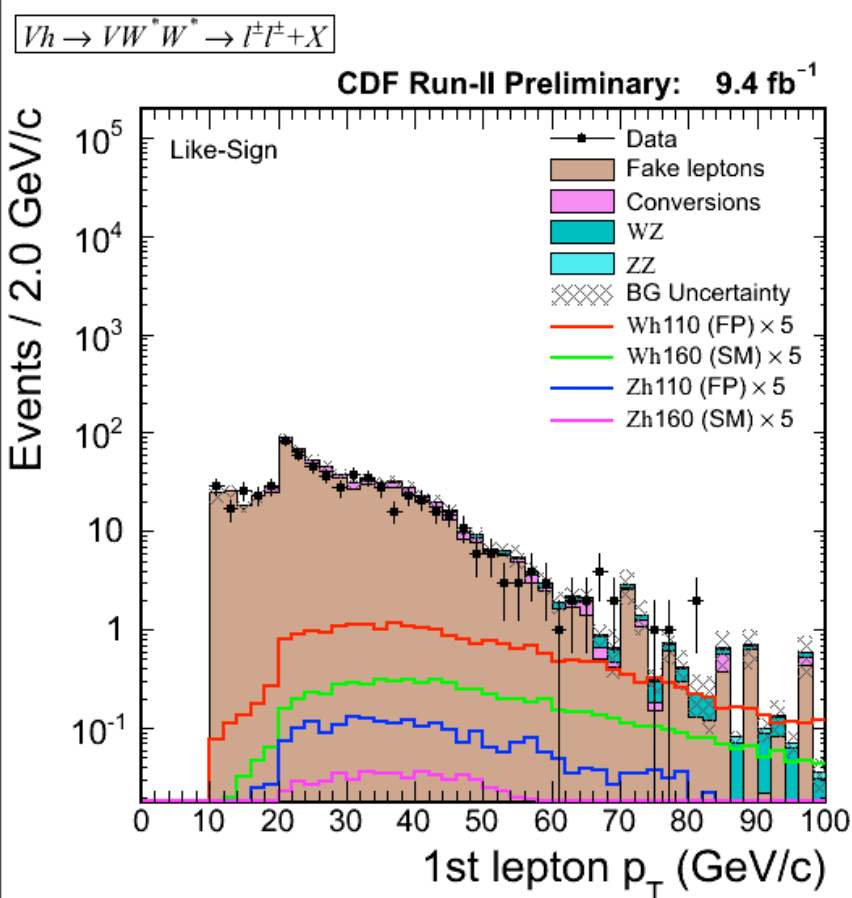








Input Variables (Selected, Log)



- Estimated by using data & MC
- Residual conversion rate:

$$R_{\text{resco}} = \frac{1 - \varepsilon_{\text{conv}}}{\varepsilon_{\text{conv}}} \quad \varepsilon_{\text{conv}}: \text{conversion tagging eff.}$$

- Split to

$$\varepsilon_{\text{conv}} = \varepsilon_{\text{rel}}(p_T) \times \varepsilon_{\text{abs}}$$

- Relative part: high- p_T region fitting \rightarrow low- p_T compared to obsp level with data (p_T relative eff. part).
- Absolute part is derived by using CES method.

- MetSpec:

- ➡ Missing E_T if $\Delta\phi(\text{MET}, \text{lepton or jet}) > \pi/2$
- ➡ Missing E_T times $\sin(\Delta\phi(\text{MET}, \text{lepton or jet}))$ if $\Delta\phi(\text{MET}, \text{lepton or jet}) < \pi/2$

- Sphericity:

- ➡ To look at event shapes.
- ➡ Sphericity tensor:

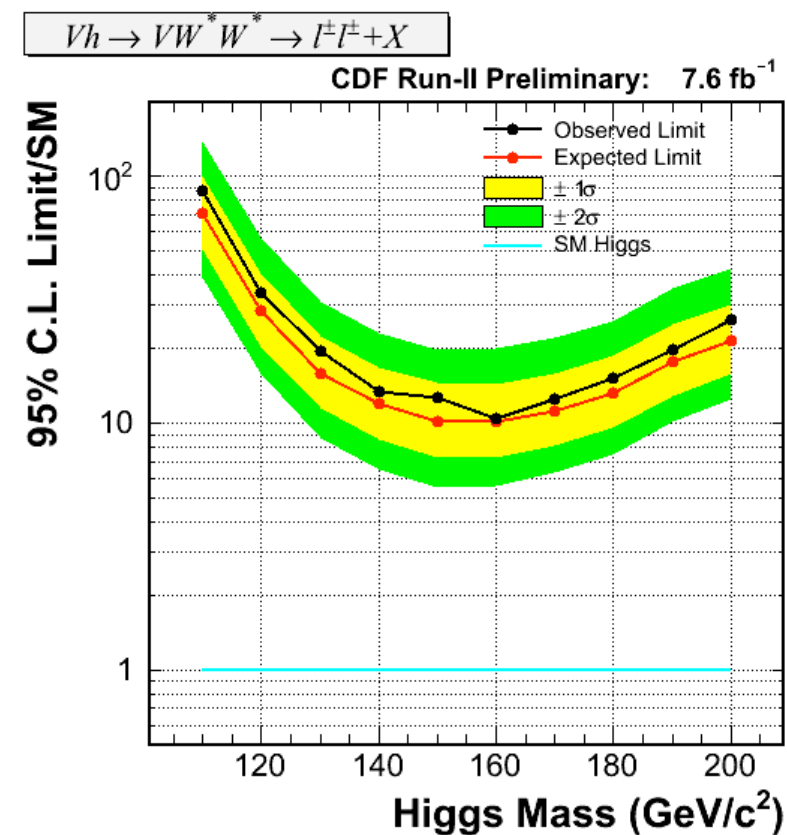
$$S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i |\mathbf{p}_i|^2}$$

- ➡ Eigenvalues $\lambda_1, \lambda_2, \lambda_3$ $\lambda_1 \geq \lambda_2 \geq \lambda_3, \lambda_1 + \lambda_2 + \lambda_3 = 1$

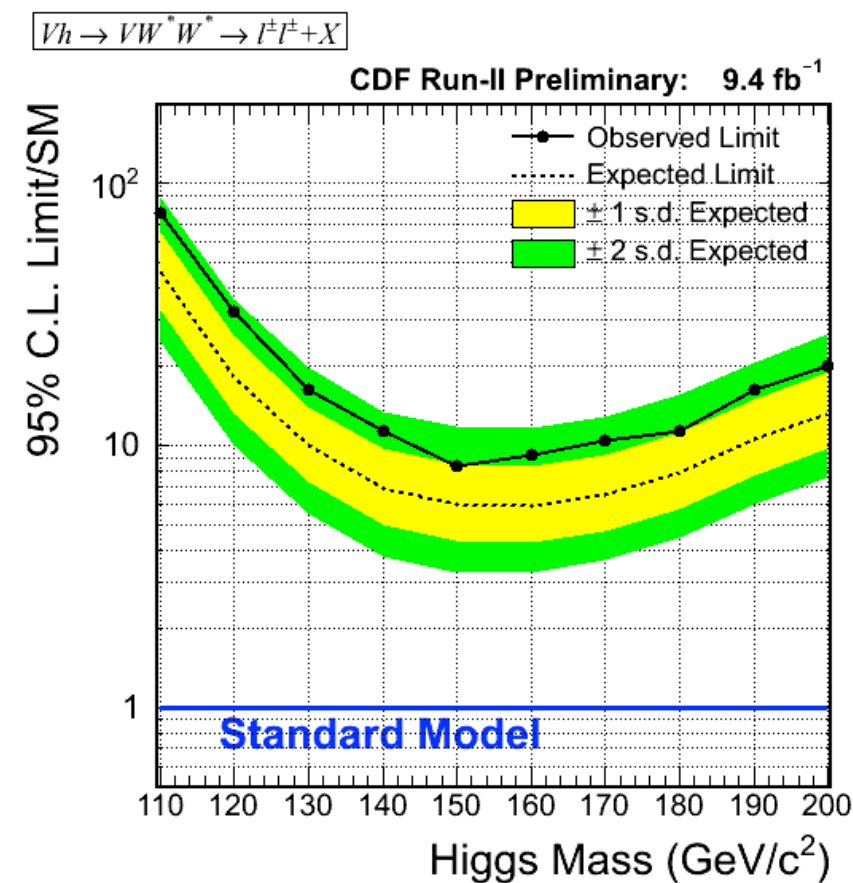
- ➡ Sphericity:

$$S = \frac{3}{2}(\lambda_2 + \lambda_3)$$

$Vh \rightarrow VW^*W^* \rightarrow l^\pm l^\pm + X$							CDF Run-II Preliminary: 7.6 fb^{-1}	
Mass (GeV/c^2)	(Expected limit)/SM					(Observed limit)/SM		
	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$			
110	38.7	50.3	70.4	99.6	138.5	87.0		
120	15.8	20.5	28.5	40.4	56.3	33.8		
130	8.8	11.4	15.8	22.4	30.9	19.4		
140	6.5	8.5	12.0	16.9	23.3	13.5		
150	5.5	7.3	10.1	14.5	19.9	12.7		
160	5.6	7.3	10.2	14.5	20.0	10.5		
170	6.3	8.2	11.3	16.0	22.2	12.6		
180	7.5	9.6	13.3	18.8	25.8	15.1		
190	10.1	12.9	17.8	25.3	35.3	19.9		
200	12.5	15.8	21.6	30.4	42.5	26.4		



$Vh \rightarrow VW^*W^* \rightarrow l^\pm l^\pm + X$							CDF Run-II Preliminary: 9.4 fb^{-1}	
Mass (GeV/c^2)	(Expected limit)/SM					(Observed limit)/SM		
	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$			
110	24.9	32.8	45.8	65.1	89.0	77.2		
120	10.0	13.2	18.3	26.1	36.2	32.5		
130	5.5	7.2	10.0	14.1	19.9	16.4		
140	3.8	5.0	6.9	9.7	13.4	11.4		
150	3.3	4.3	6.0	8.5	11.8	8.3		
160	3.3	4.3	5.9	8.4	11.6	9.2		
170	3.7	4.7	6.5	9.2	12.9	10.4		
180	4.5	5.7	7.9	11.2	15.6	11.4		
190	6.0	7.7	10.6	15.0	20.8	16.4		
200	7.6	9.7	13.3	18.9	26.5	20.2		



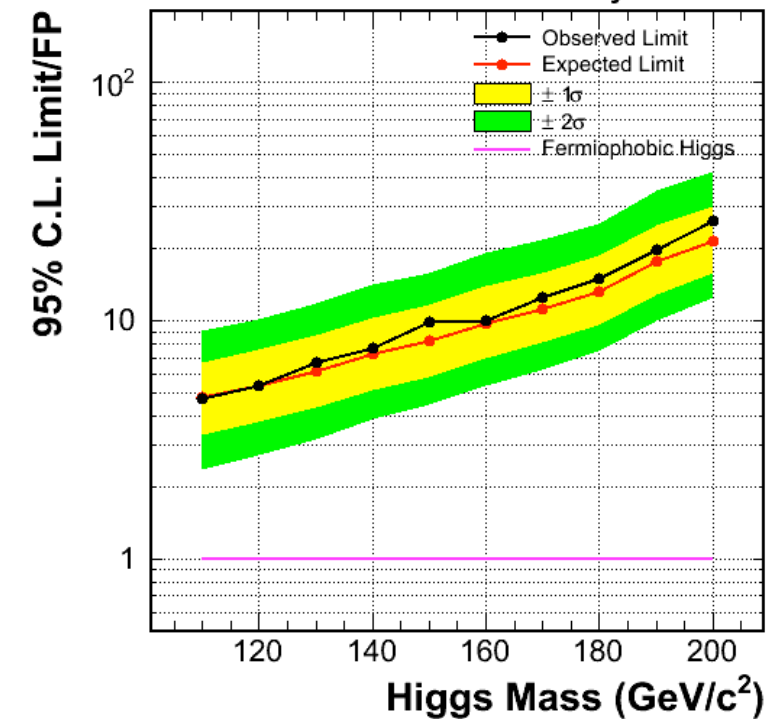
Fermiophobic Higgs Limit

$$Vh \rightarrow VW^*W^* \rightarrow l^\pm l^\pm + X$$

 CDF Run-II Preliminary: 7.6 fb^{-1}

Mass (GeV/c^2)	(Expected limit)/FP					(Observed limit)/FP
	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$	
110	2.4	3.3	4.8	6.7	9.1	4.7
120	2.8	3.8	5.4	7.6	10.2	5.3
130	3.2	4.3	6.2	8.7	11.8	6.6
140	3.9	5.1	7.3	10.2	14.1	7.7
150	4.5	5.8	8.2	11.7	15.8	9.9
160	5.3	7.0	9.8	13.9	19.3	10.0
170	6.2	8.1	11.2	15.8	21.8	12.4
180	7.4	9.5	13.2	18.7	25.6	15.0
190	10.1	12.9	17.8	25.3	35.2	19.9
200	12.4	15.8	21.6	30.4	42.4	26.4

$$Vh \rightarrow VW^*W^* \rightarrow l^\pm l^\pm + X$$

 CDF Run-II Preliminary: 7.6 fb^{-1}


$$Vh \rightarrow VW^*W^* \rightarrow l^\pm l^\pm + X$$

 CDF Run-II Preliminary: 9.4 fb^{-1}

Mass (GeV/c^2)	(Expected limit)/FP					(Observed limit)/FP
	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$	
110	1.4	1.9	2.6	3.7	5.0	4.4
120	1.6	2.2	3.0	4.3	6.0	5.3
130	1.9	2.5	3.5	4.9	7.0	5.8
140	2.2	2.9	4.0	5.6	7.8	6.6
150	2.6	3.4	4.7	6.7	9.3	6.6
160	3.1	4.1	5.6	8.0	11.1	8.8
170	3.6	4.7	6.4	9.1	12.8	10.3
180	4.4	5.7	7.8	11.1	15.5	11.3
190	6.0	7.7	10.6	15.0	20.7	16.3
200	7.5	9.7	13.3	18.9	26.5	20.1

$$Vh \rightarrow VW^*W^* \rightarrow l^\pm l^\pm + X$$

 CDF Run-II Preliminary: 9.4 fb^{-1}
