The Tevatron Search for a Low Mass Standard Model Higgs Boson

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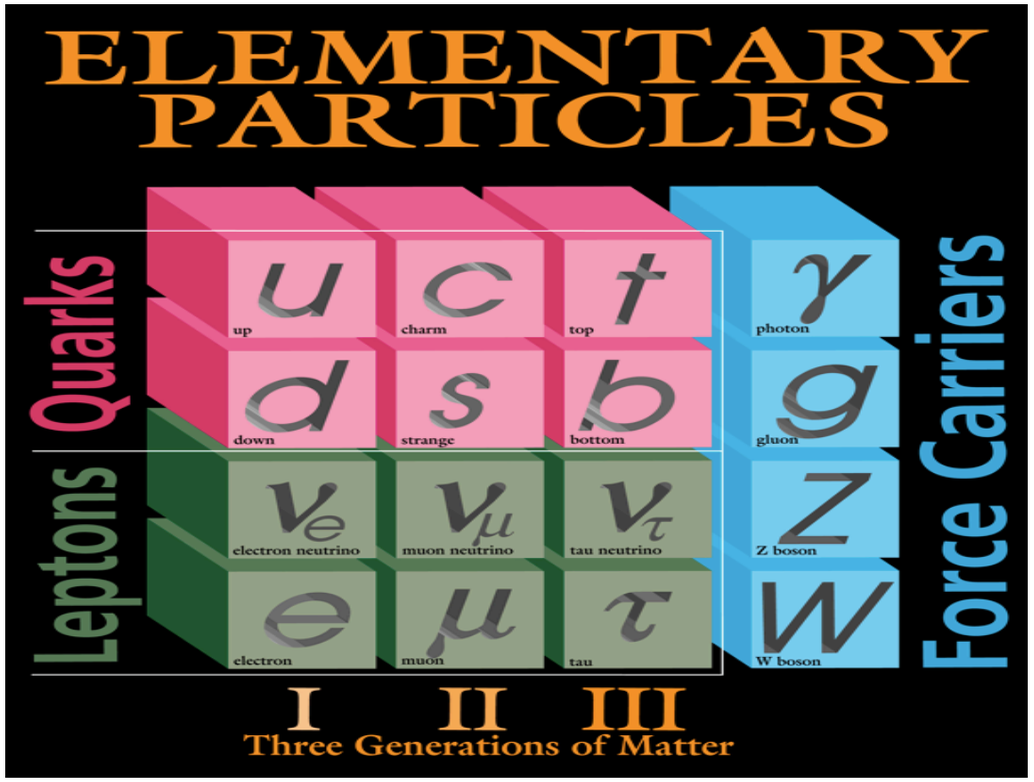
[On Behalf of the CDF and DØ Collaborations]

03/17/2010 Moriond-QCD

Introduction

- Standard Model :
  - Describes the fundamental constituents of matter and the interactions between them
  - No particle masses..



- Through the Higgs Mechanism :
  - $W^{\pm}$ and Z acquire mass, γ remains massless
  - Fermion masses can be generated
  - Predicts existence of the Higgs Boson

No experimental observation so far..

Mass not specified by theory

- Constraints on M_H from experiment :
  - Direct Searches by LEP Experiments ($Z^* \rightarrow ZH$) : M_H > **114.4** GeV/c^2 @ 95% CL

+

  - Fit to precision EW measurements (M_t,M_w, etc.) : $M_H \lesssim$ **186** GeV/c^2

The Tevatron

- proton anti-proton Collider
- Center of Mass Energy = 1.96 TeV
- ~ 1km Radius
- ~8 fb^{-1} delivered to each experiment
- Expect an additional 2-4 fb^{-1} by fall 2011
- Current Higgs results use up to 5.4 fb^{-1}

SM Higgs @ the Tevatron

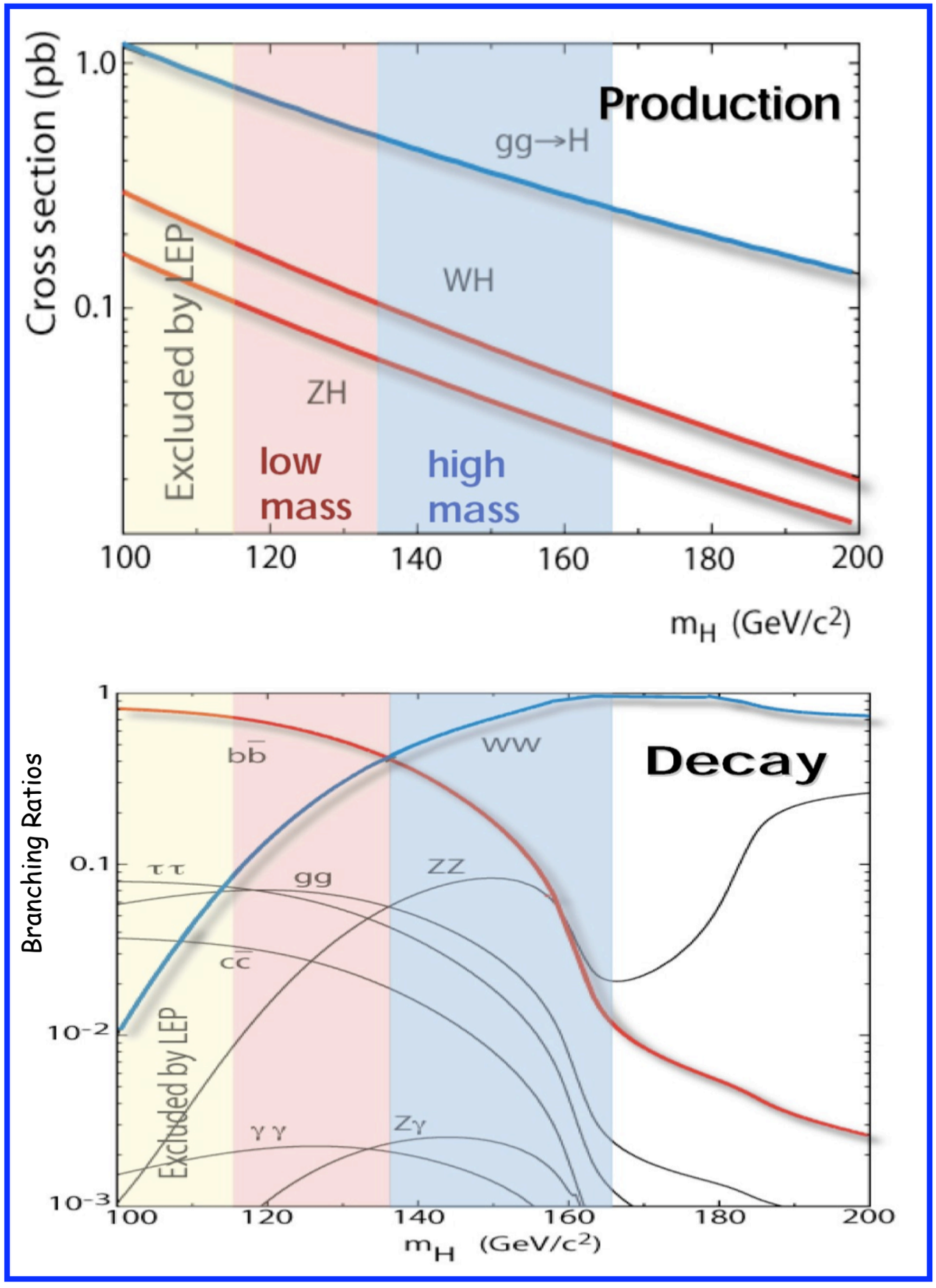
- Primary production modes are :
  - Direct production (gg → H)
  - Associated production (ZW,WH)

- For higher masses (MH > 135 GeV/c^2) mostly decays to W pairs

see talk by R. Bernhard

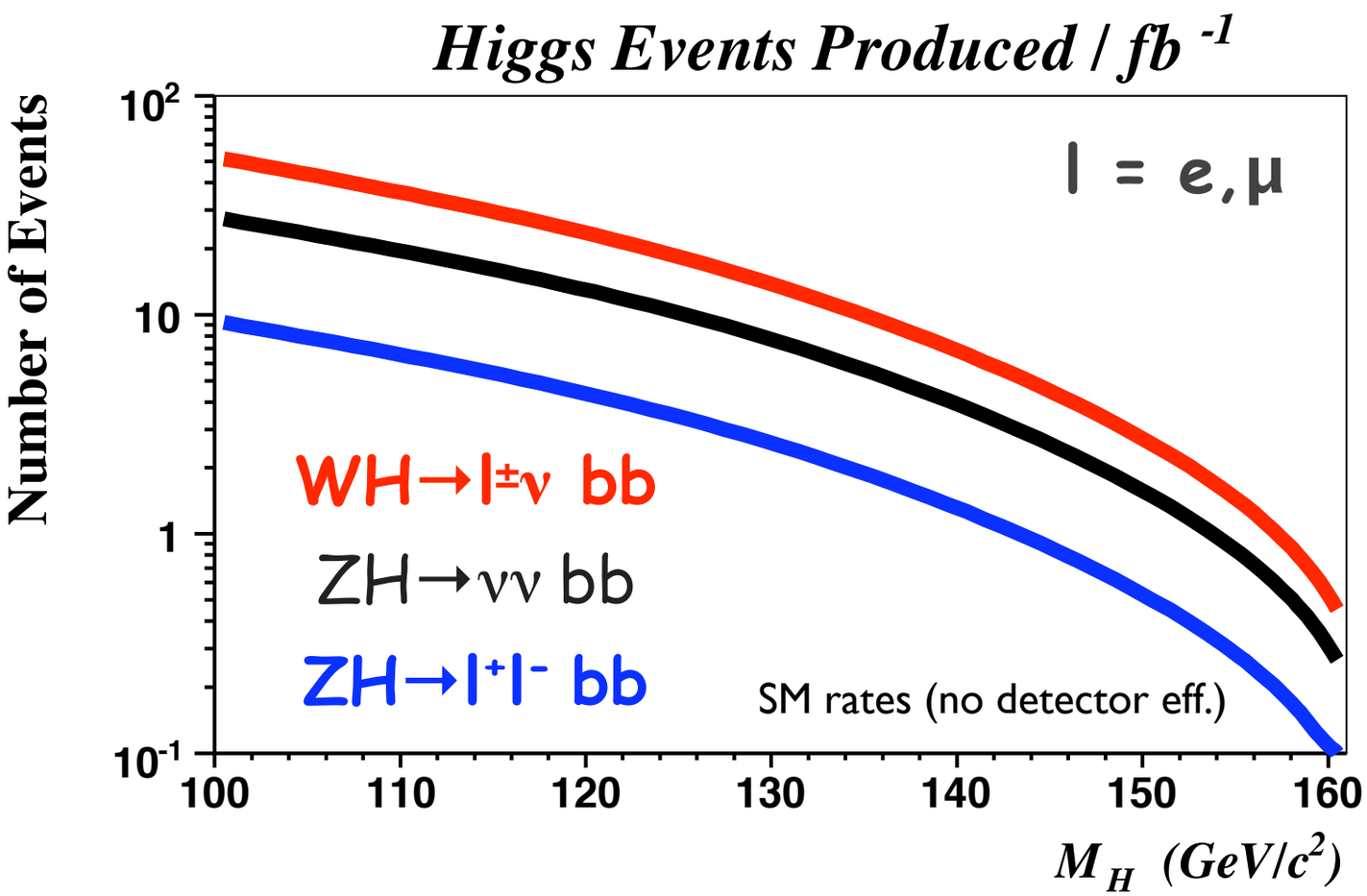
- For lower masses (MH < 135 GeV/c^2) main decay is **H → bb**

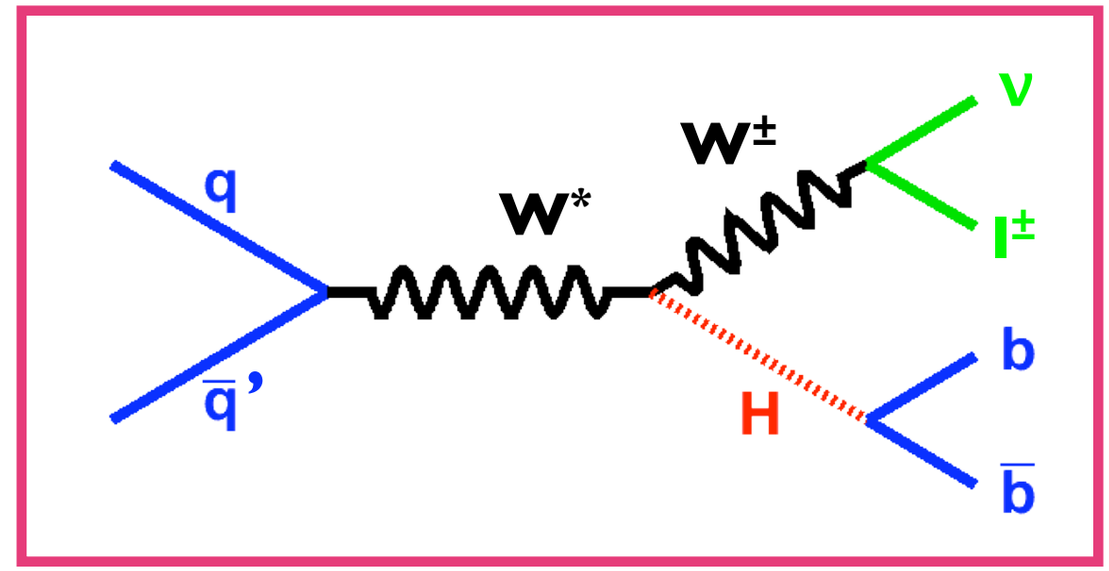
- At lower masses the dominant Higgs process (gg → H → bb) is overwhelmed by multi-jet background events, so we rely on WH/ZH modes.

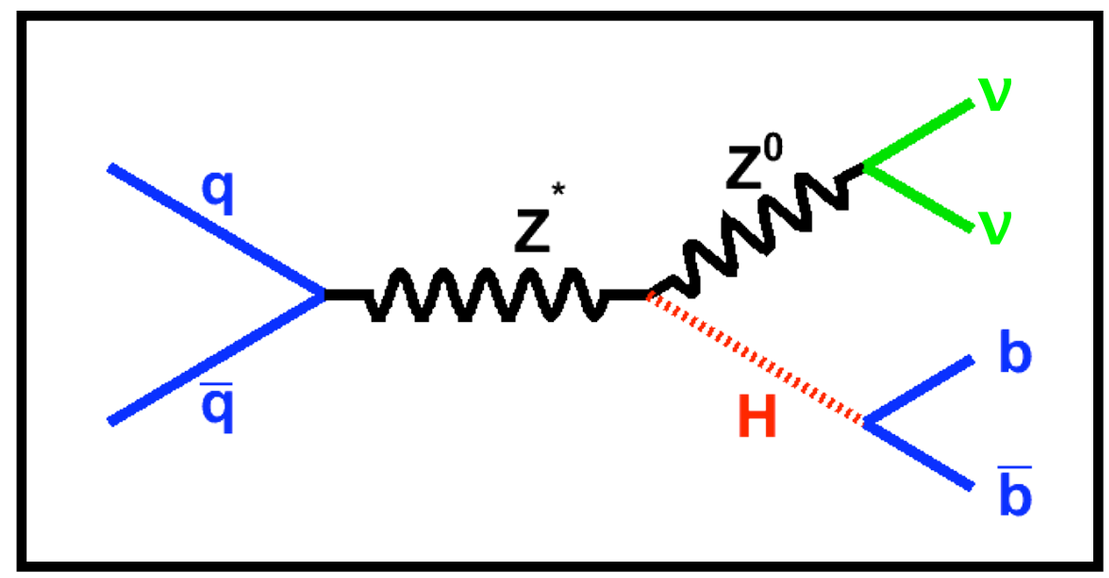


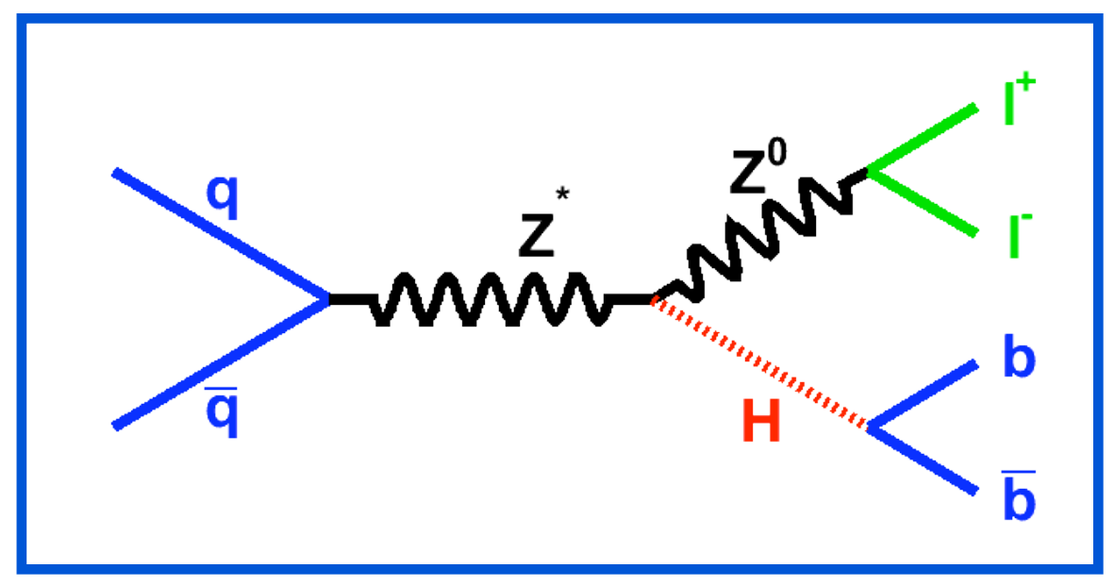
Main Tevatron Search Channels

- Focus of Tevatron low mass searches is Associated production followed by H → bb



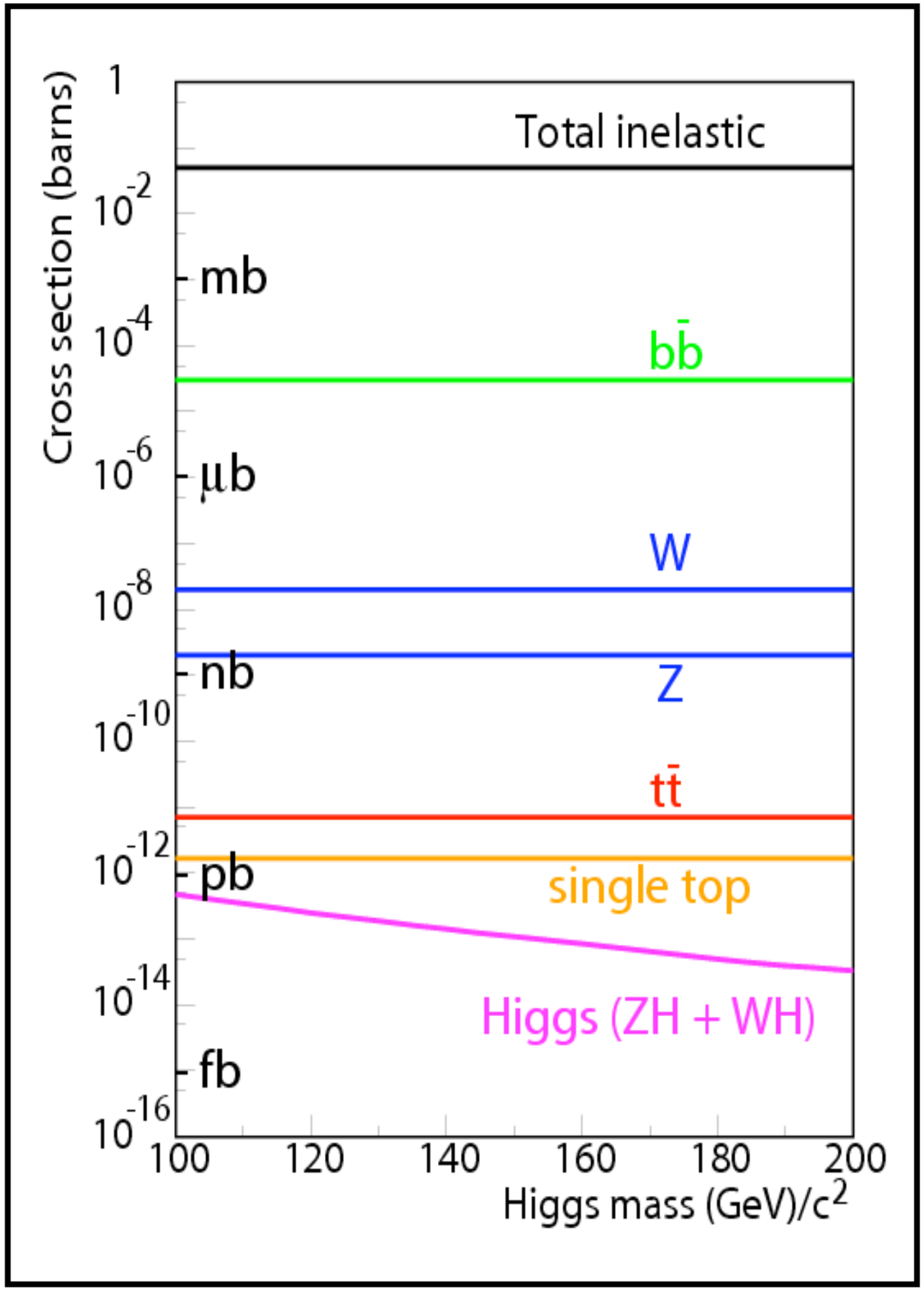






- Higgs events are rare ~ 1 Higgs / 10^{12} collisions

SM Backgrounds



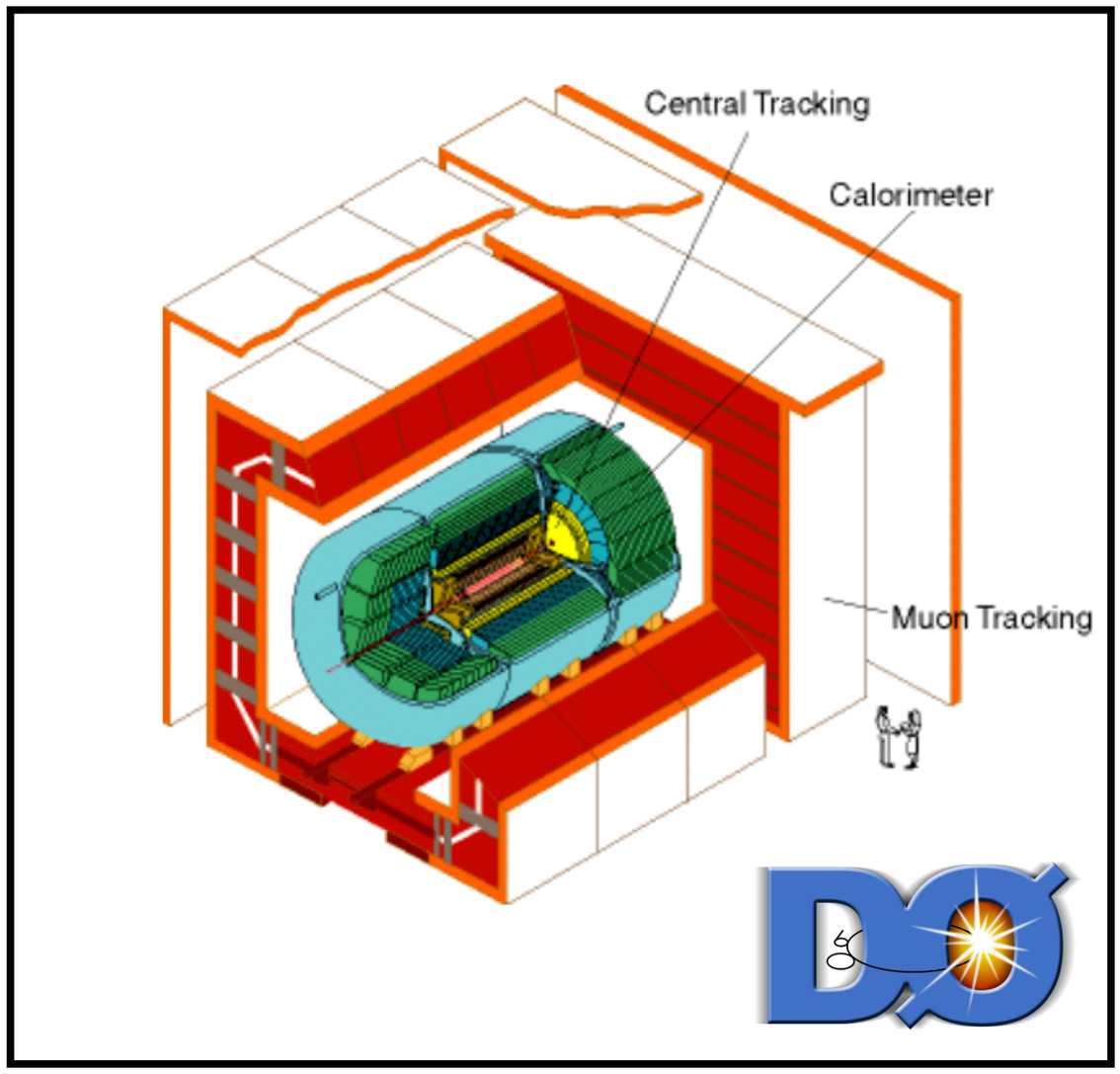
- While Higgs events are rare, backgrounds are plentiful...

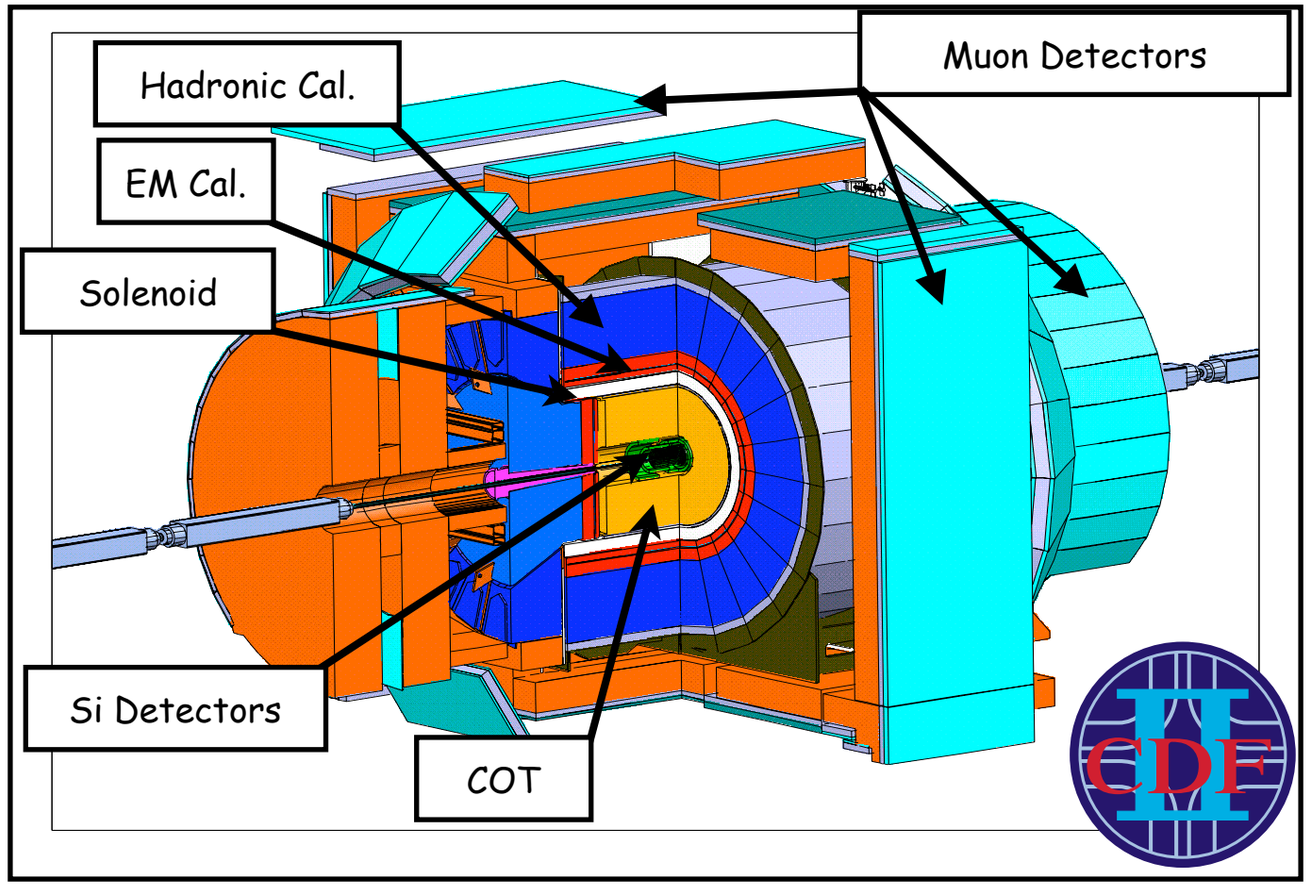
- In order to have any chance at observation/exclusion the Tevatron experiments search in **multiple Higgs final states** with the focus on increased **signal acceptance** and maximum **background discrimination**

- However, Tevatron experiments have observed rare processes, using techniques similar to those used in Higgs Searches; for example single top production.

DØ and CDF II

- Multi-purpose Detectors
  - Silicon Detectors critical for b-jet ID
  - Tracking : CDF Drift Chamber (COT)
    DØ Fiber Tracker
  - Calorimeters and Muon Detectors





- Advanced trigger systems to select 'interesting' events :
  - significant missing energy (ν)
  - high momentum charged particles ($e^{\pm}$,$\mu^{\pm}$)
  - energetic jets (b)

Low Mass Higgs Search Strategy

I. Maximize Signal Acceptance :

* exploit as much of your detector as possible
* additional triggers, relaxed lepton ID

II. Reduce background through b-jet ID :

* "b-tagging"
* reduces up to ~95% of light and c-jet backgrounds

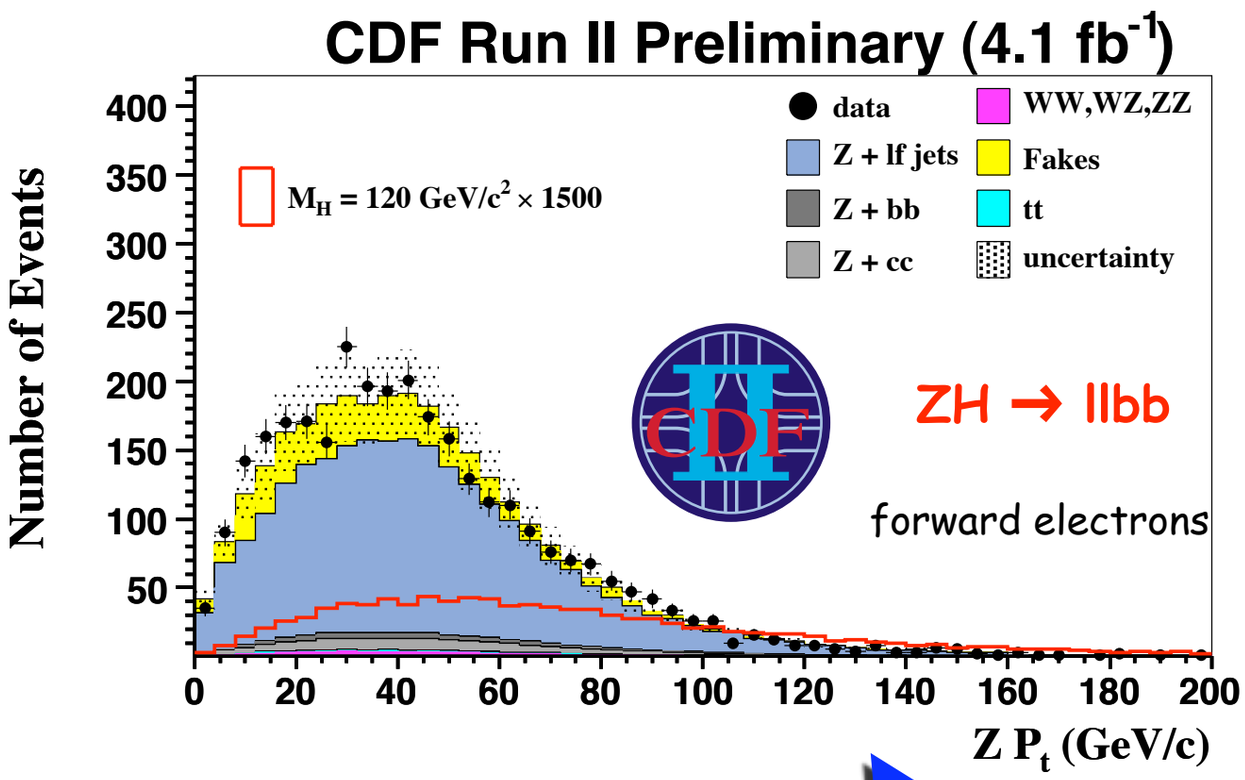
III. MultiVariate (MV) signal/background discrimination :

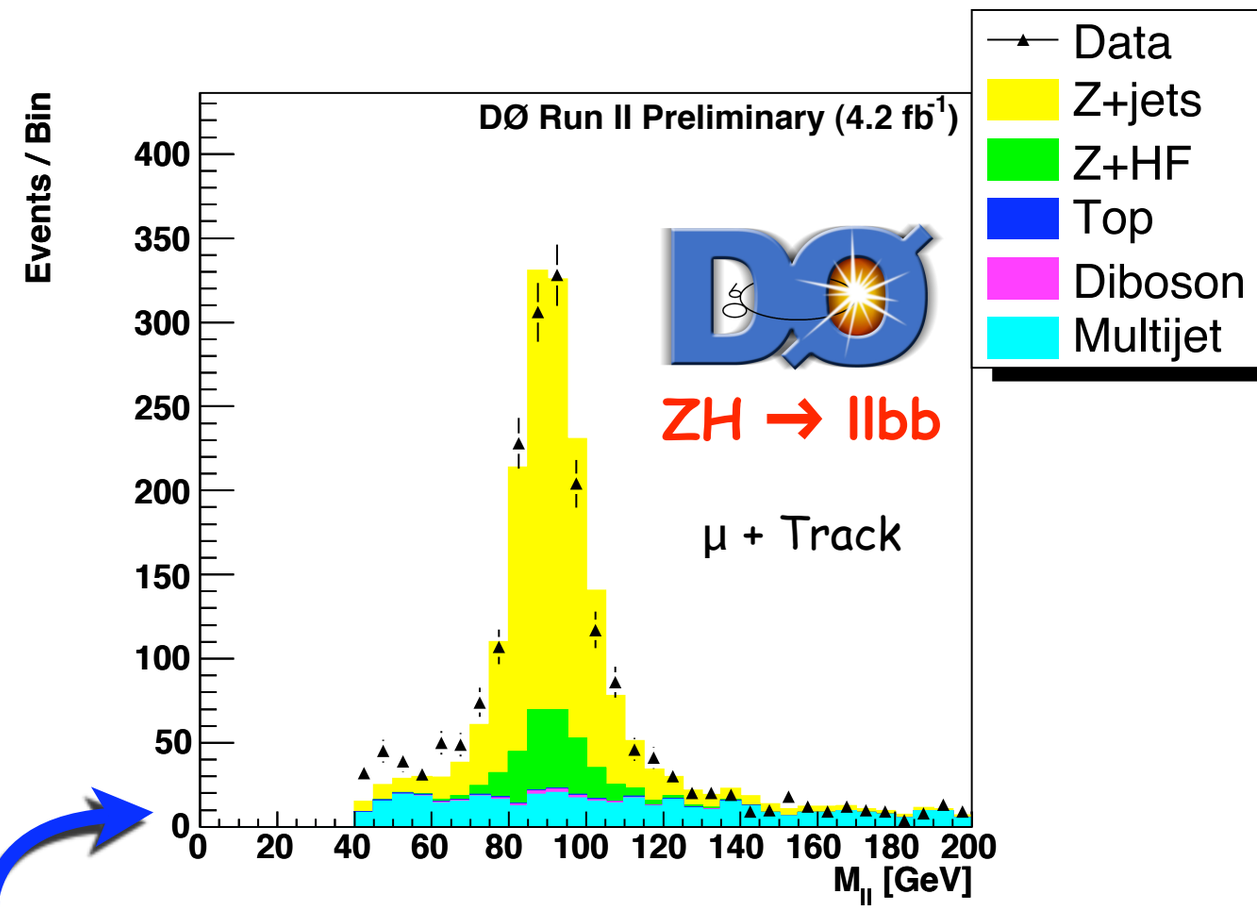
* Simultaneously utilize the combined S/B discriminating power of multiple quantities

* Output of MV classifier compared to model of SM backgrounds & Uncertainties

I. Increasing Signal Acceptance

- Example : **ZH → llbb**
  - * small expected signal - so acceptance is key
  - * reconstruction of Z and H resonances control background rates, allowing for loose selection requirements
- Additional Signal from expanded lepton identification : ~15% signal gain

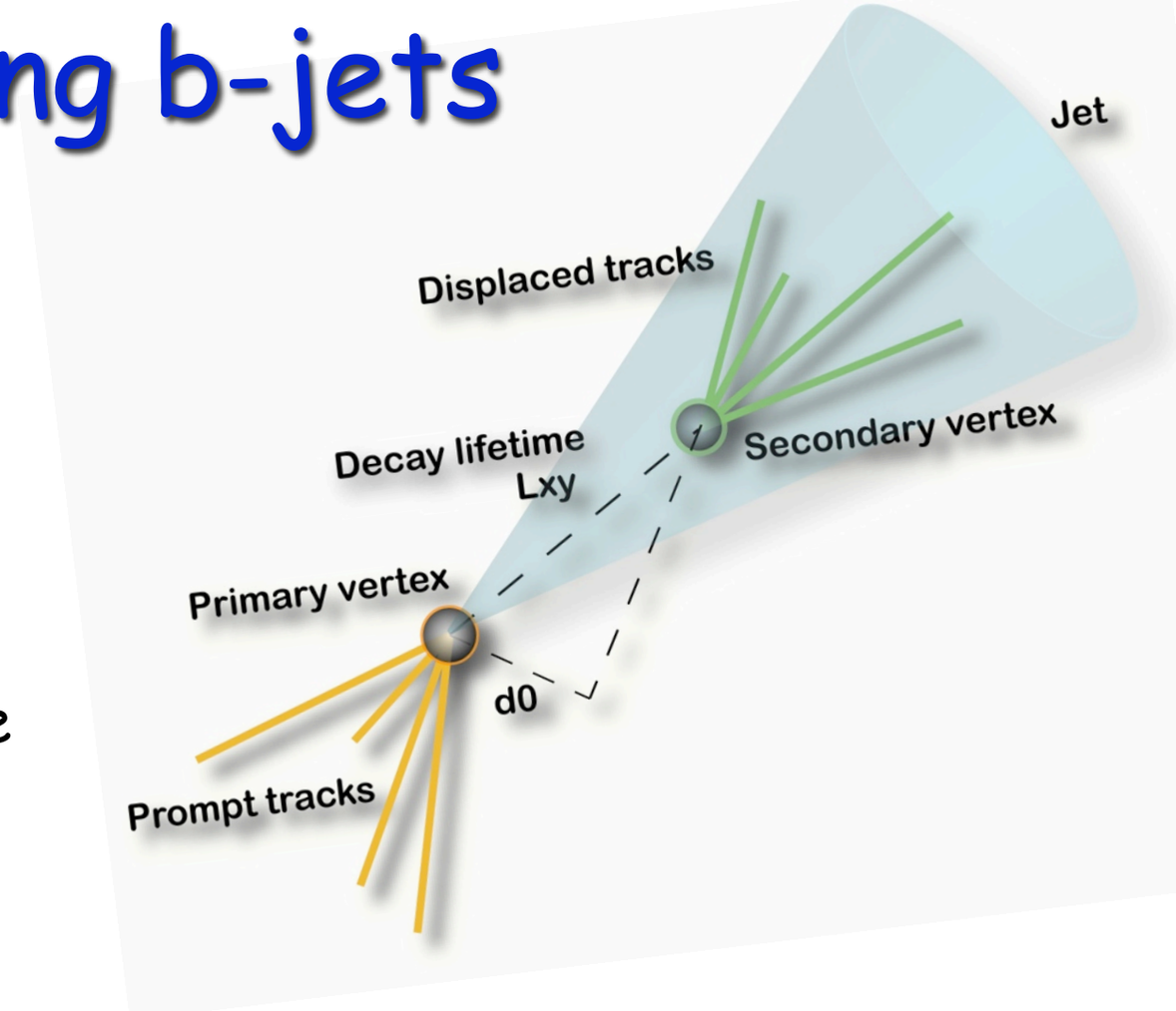


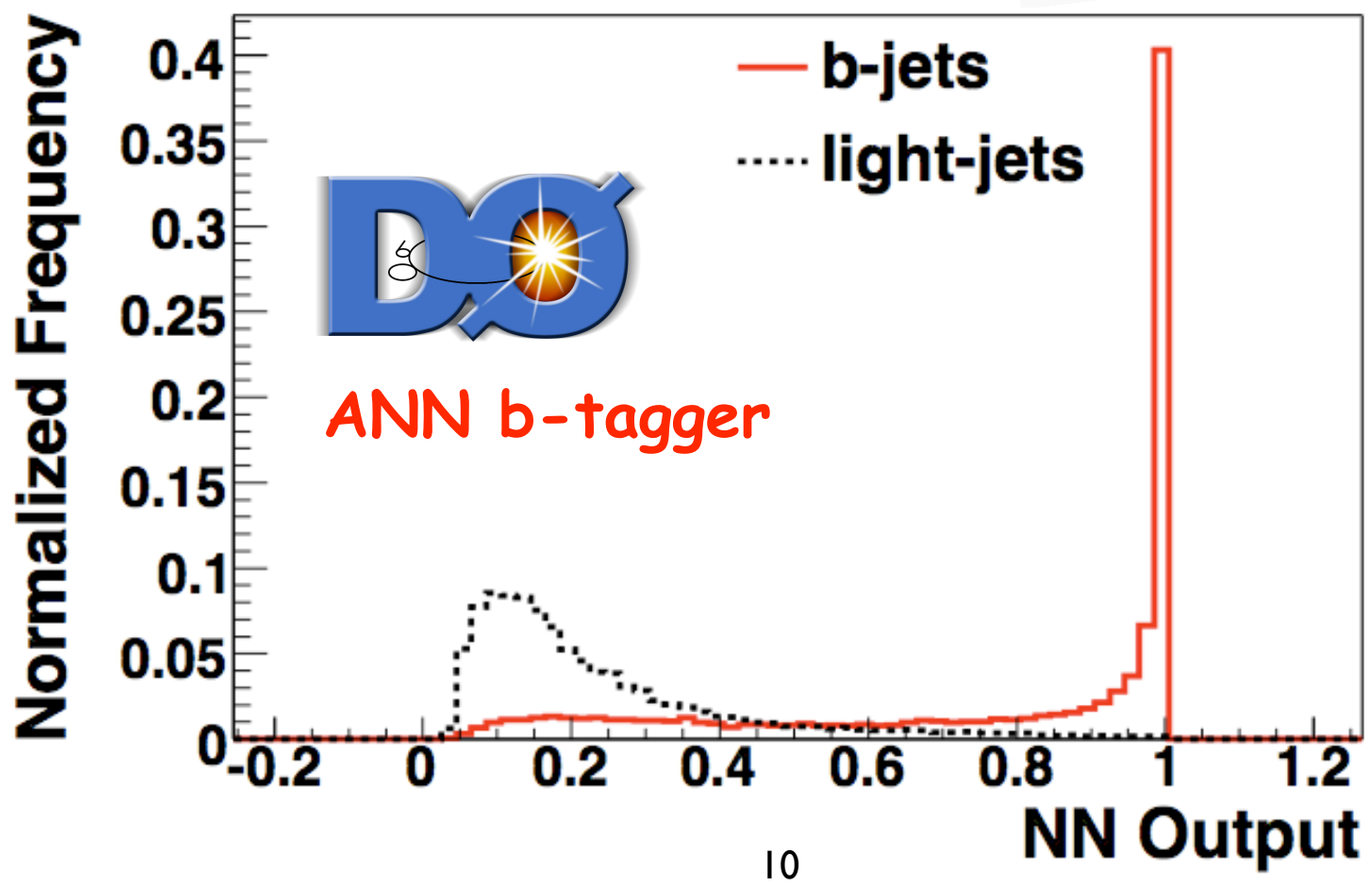


- * reconstruct Z candidates from two forward calorimeter deposits
- * reconstruct Z candidate from a μ and an isolated track
- * MV electron ID in regions of limited calorimeter coverage

II. Identifying b-jets

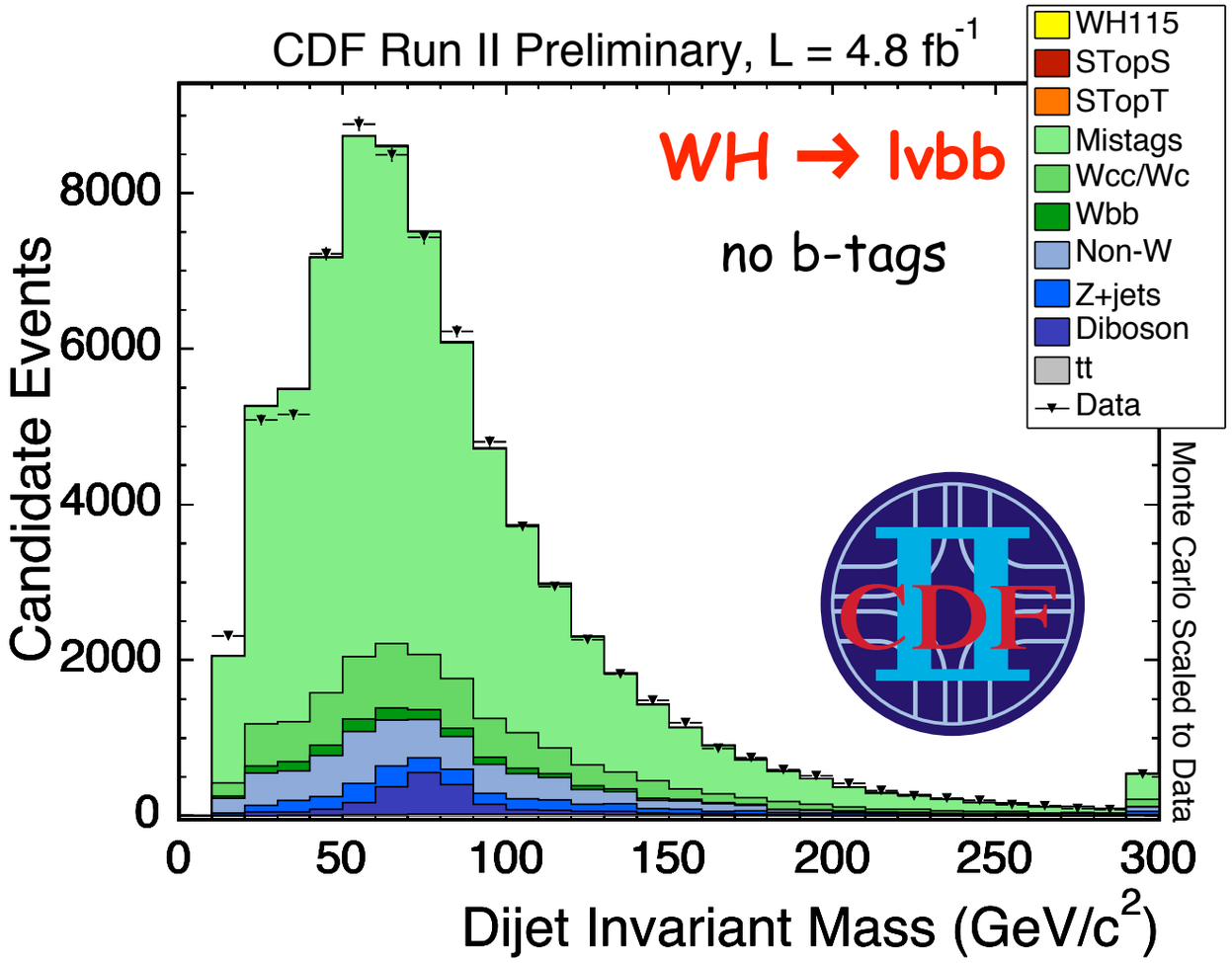
- b-tagging :
  - distinguish b-jets from c/light jets
  - Exploits long lifetime of b
  - Various algorithms available @ CDF & DØ
  - tag 50-60% of b-jets with ~1% lf tag rate



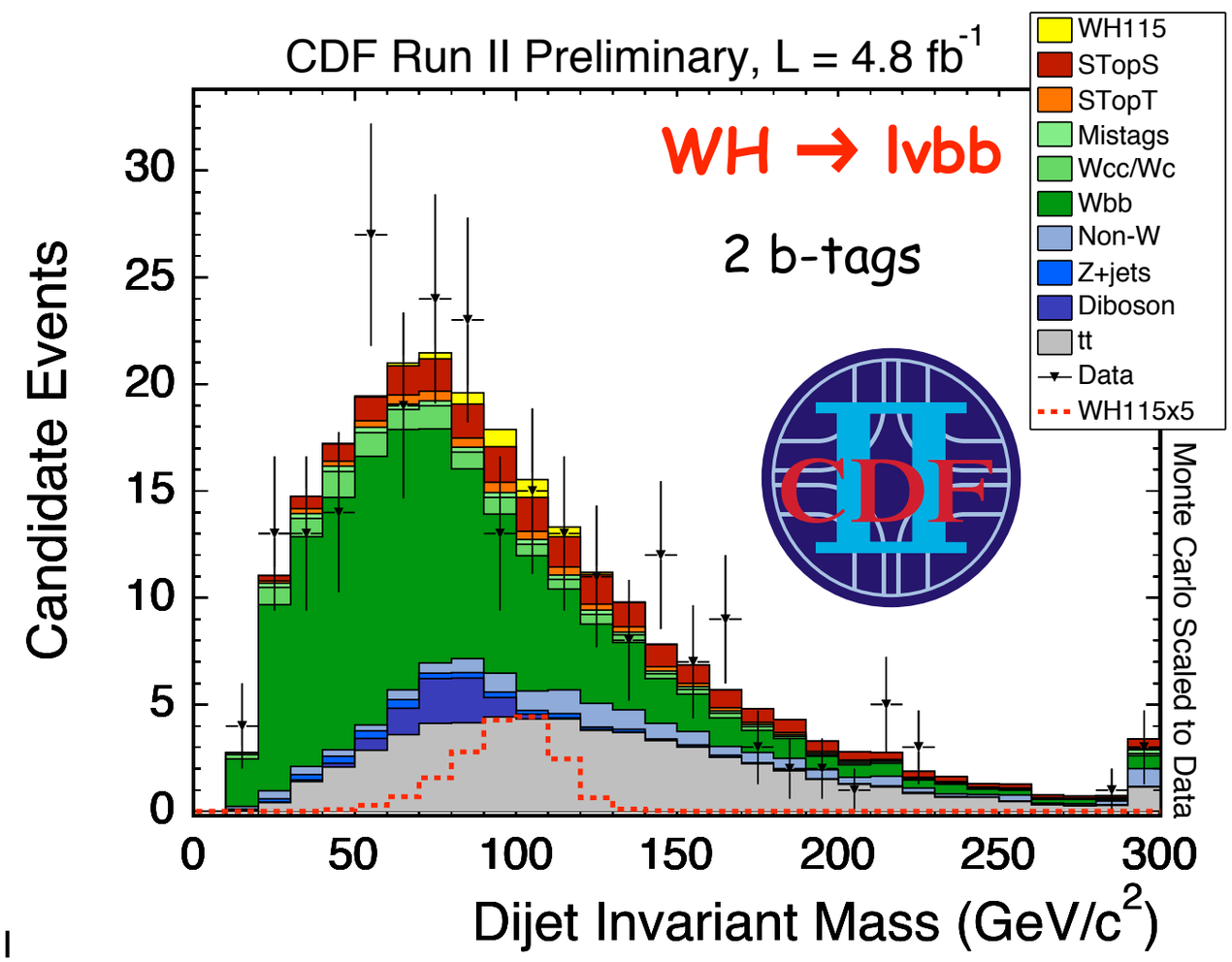


II. Identifying b-jets

- Example : **WH → lvbb**



* tagging both jets dramatically reduces background (W + lf jets)



III. Multivariate Techniques

- Common Multivariate Discriminants :
  - Artificial Neural Network (NN)
  - Boosted Decision Trees (BDT)
  - Matrix Element Probabilities (ME)

- Proven utility in Diboson & single top searches :
  - WW/WZ->lvjj observation/evidence :

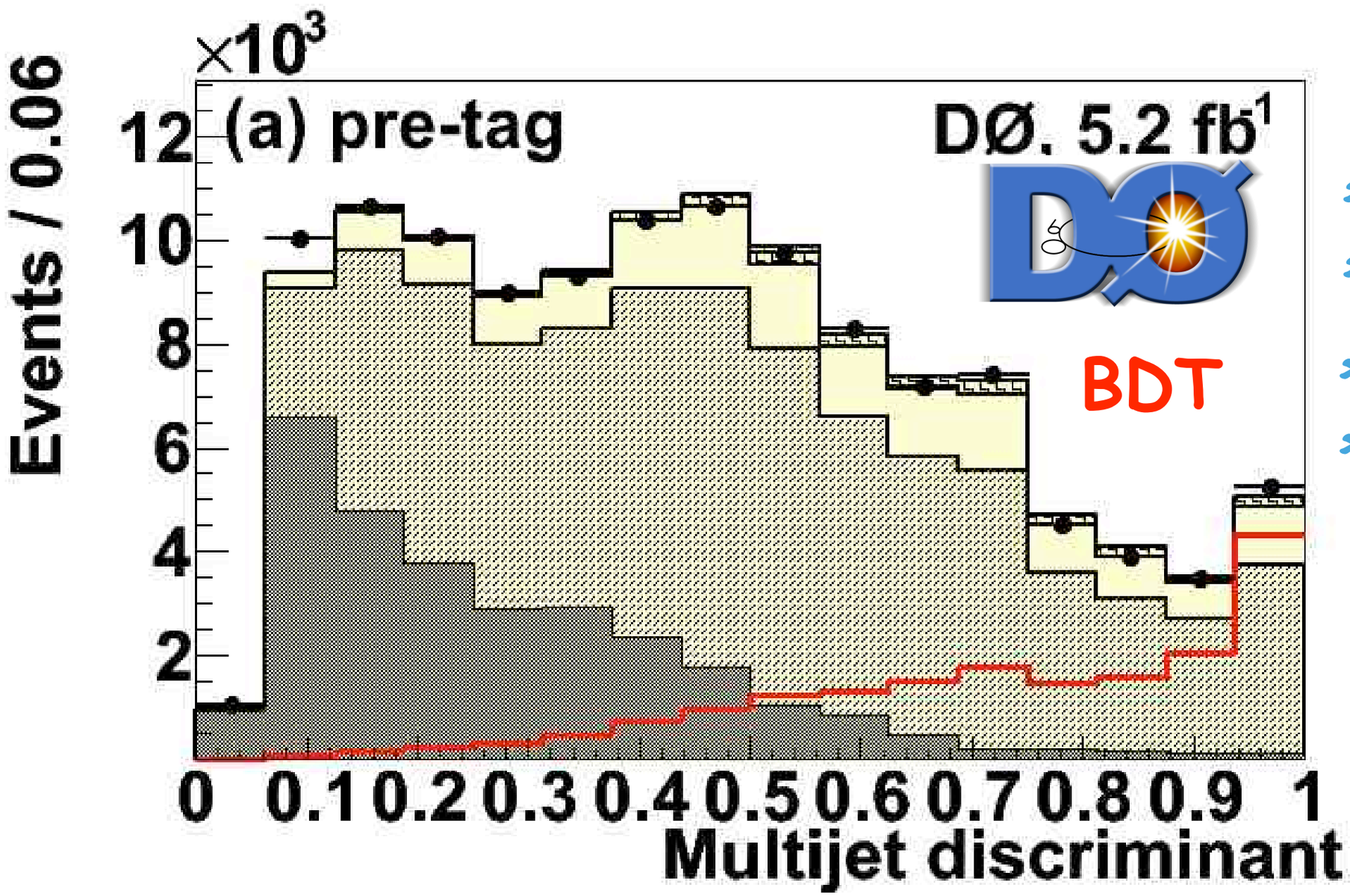
    Phys. Rev. Lett. **104**, 101801 (2010), arXiv:0911.4449v1
    Phys. Rev. Lett. **102**, 161801 (2009), arXiv.org:0810.3873

  - single top observation :

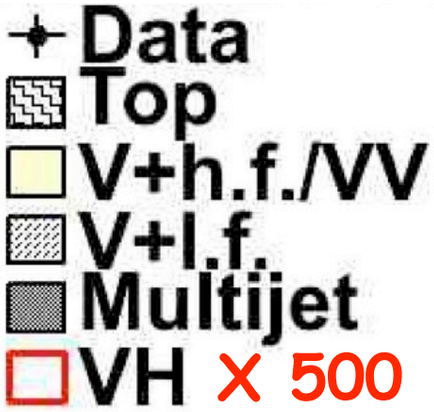
    Phys. Rev. Lett. **103**, 092002 (2009). arXiv: 0903.0885
    Phys. Rev. Lett. **103**, 092001 (2009) arXiv:0903.0850

III. Multivariate Techniques

- Example : **VH → ννbb (V= Z/W)**
  - multi-jet (QCD) backgrounds are large
  - BDT's separate VH from QCD
  - second set of MV discriminants employed for Signal vs. non-QCD bkg.



- multi-jet Region < 0.6
- Signal Region > 0.6
- rejects ~95% QCD
- retains ~70% VH



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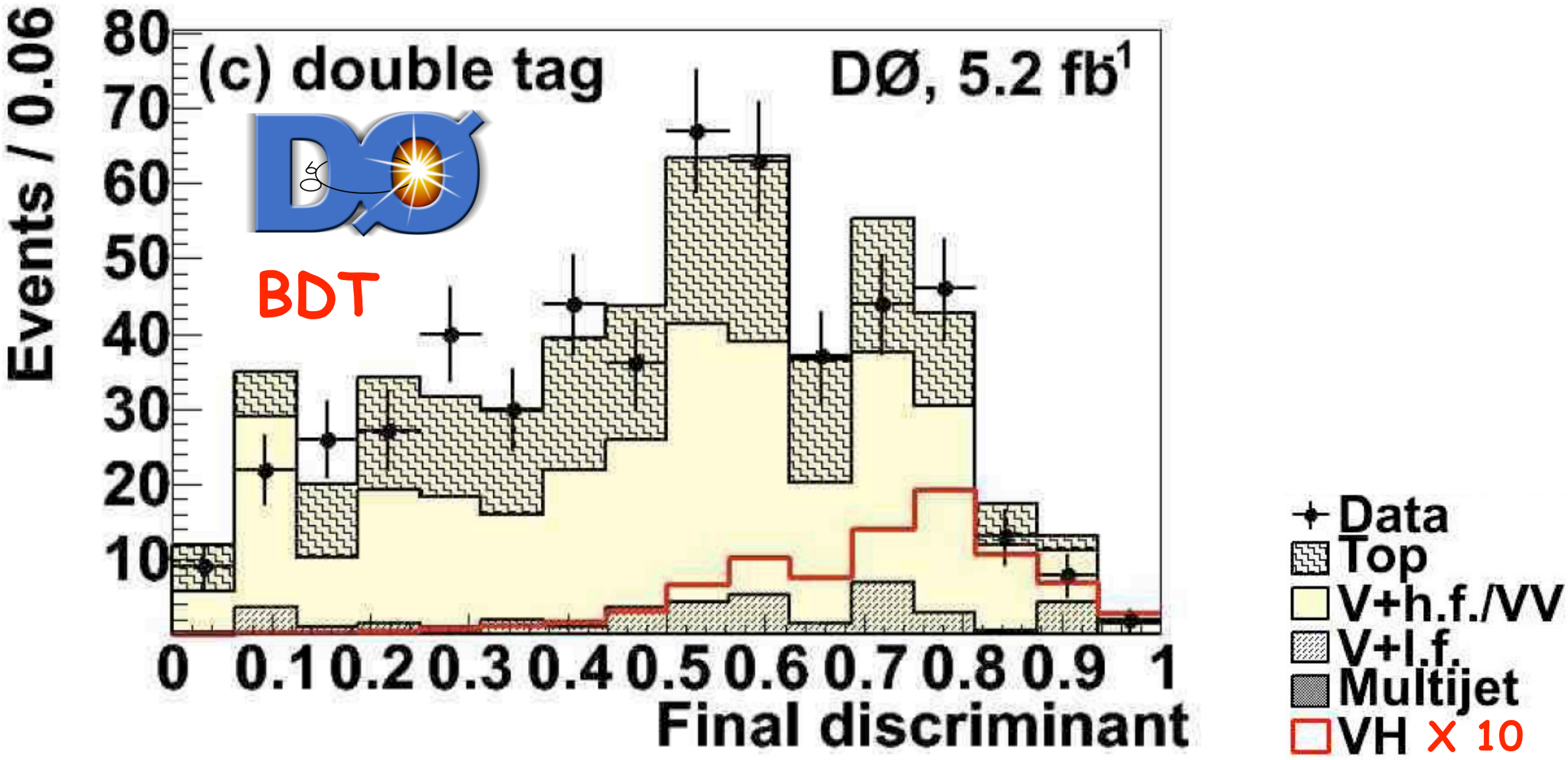

Results

- No signal-like excess over bkg. observed in any Tevatron Higgs mode
  - 95% CL upper limits on SM Higgs production
  - Combine **H → bb** searches with **H → τ τ**, **H → γ γ** & **H → WW** modes

Obs. (Exp) 95% CL upper limits / SM @ M_H = 115 GeV/c^2		
Channel	CDF II	DØ
$WH \to l^{\pm}\nu\ bb$	4.3 (3.8) in 4.3 fb^{-1}	6.9 (5.1) in 5.0 fb^{-1}
$VH \to \nu\nu\ bb$	6.1 (4.2) in 3.6 fb^{-1}	3.7 (4.6) in 5.2 fb^{-1}
$ZH \to l^{+}l^{-}\ bb$	5.9 (6.8) in 4.1 fb^{-1}	9.1 (8.0) in 4.2 fb^{-1}

http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm
http://www-cdf.fnal.gov/physics/new/hdg/Results.html

Results

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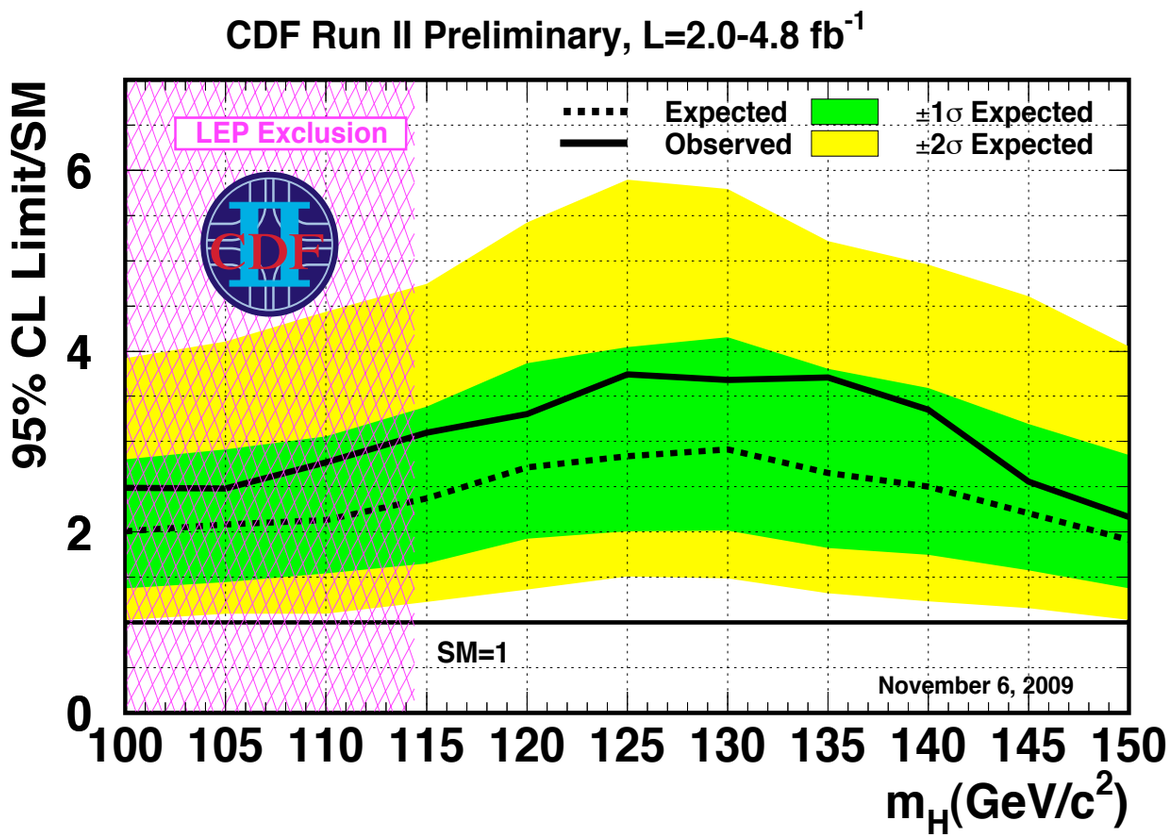
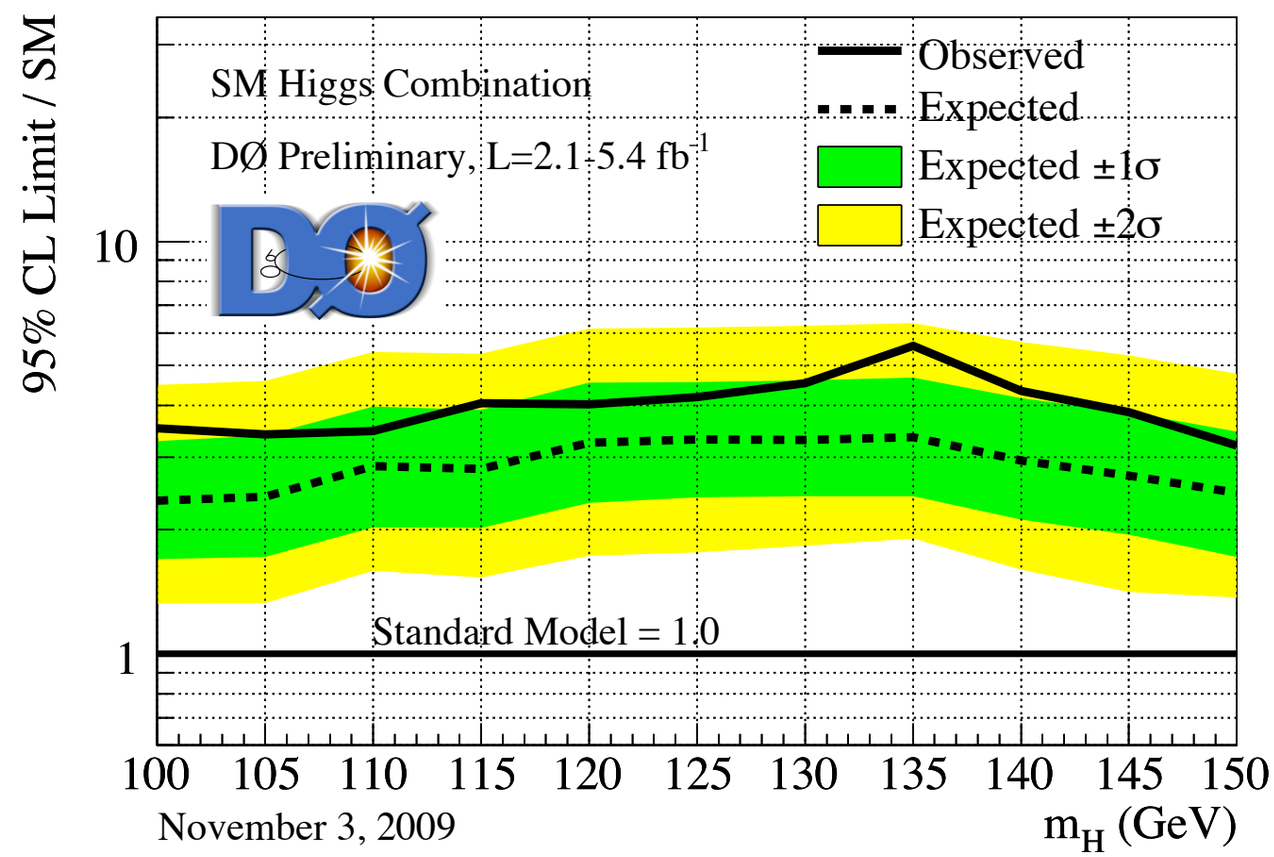




CDF 95% CL Upper Limits @ M_H = 115 GeV/c^2

Obs. → 3.1 X SM
Exp. → 2.4 X SM

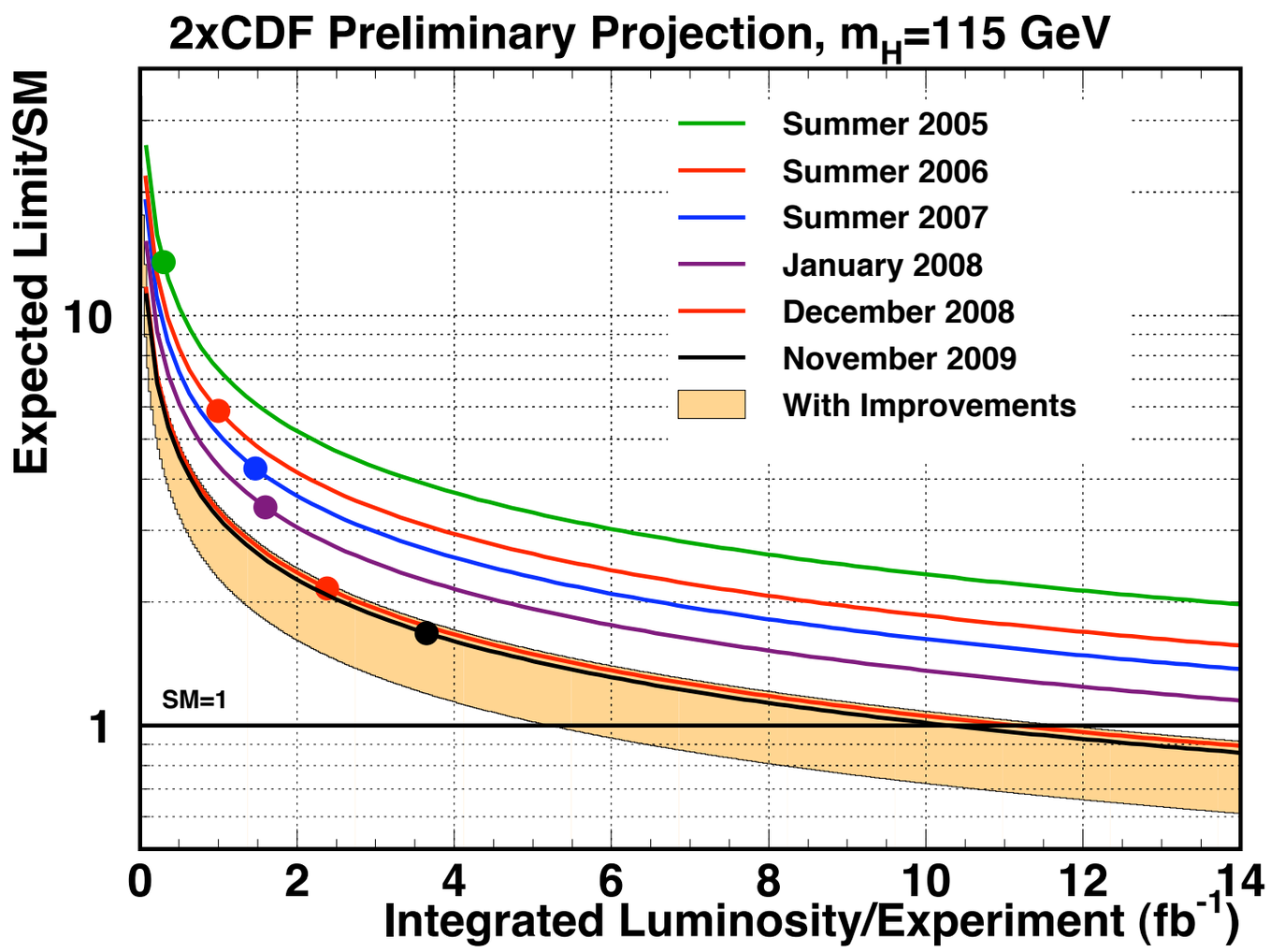
DØ 95% CL Upper Limits @ M_H = 115 GeV/c^2

Obs. → 4.0 X SM
Exp. → 2.8 X SM

Tevatron combination details in talk by W. Yao

Conclusions

- Average analyzed data sample ~ 4 fb^{-1} @ 115 GeV/c^2
- Tevatron will deliver 10-12 fb^{-1} per experiment by end of 2011
- Extrapolation of current results ~ SM sensitivity with 10 fb^{-1} per exp.

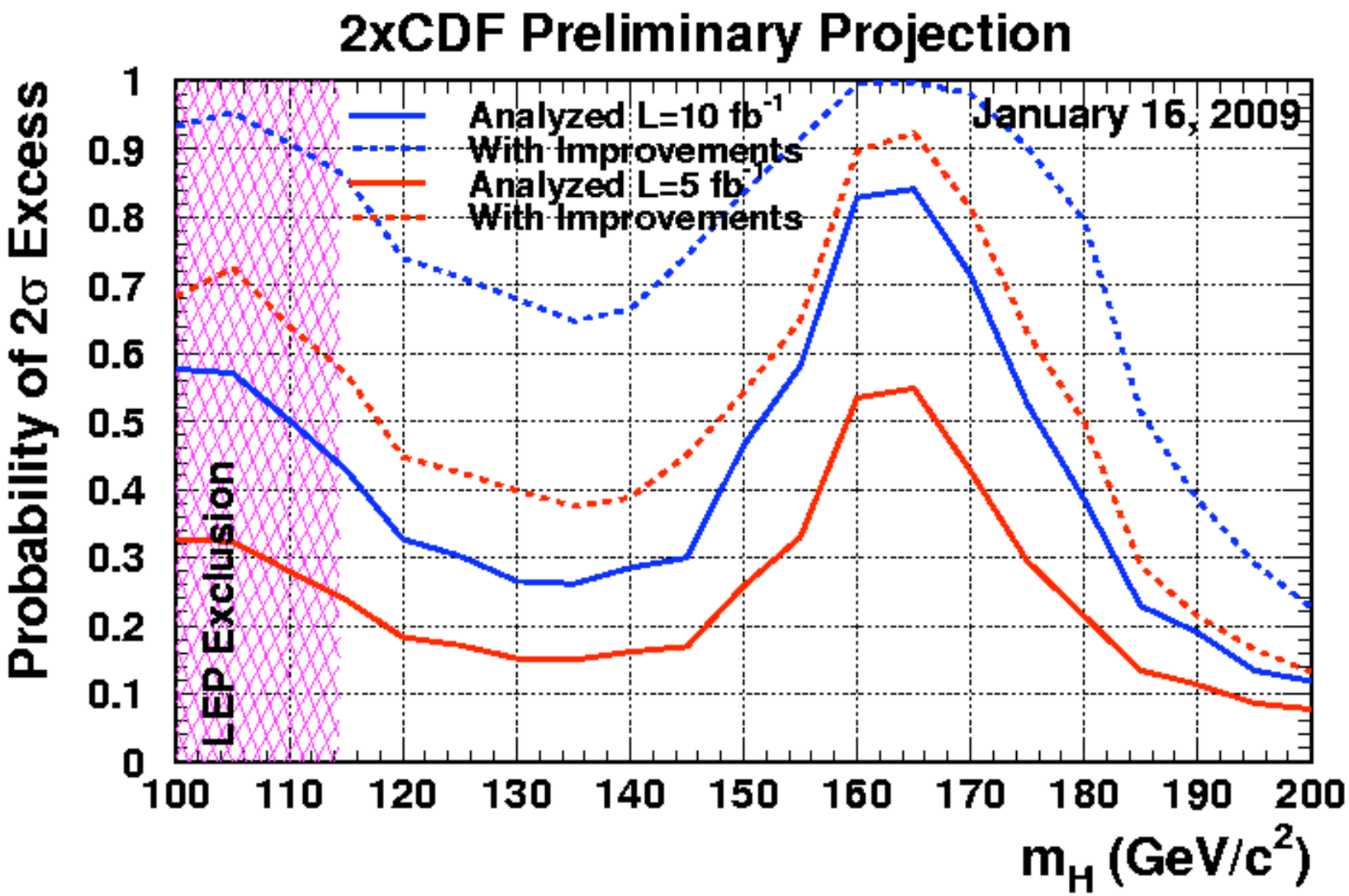


- Coming Soon ...
  - expanded e/μ selection
  - final states with τ's
  - better b-tagging
  - improved jet energy resolution
  - migration of improvements across channels

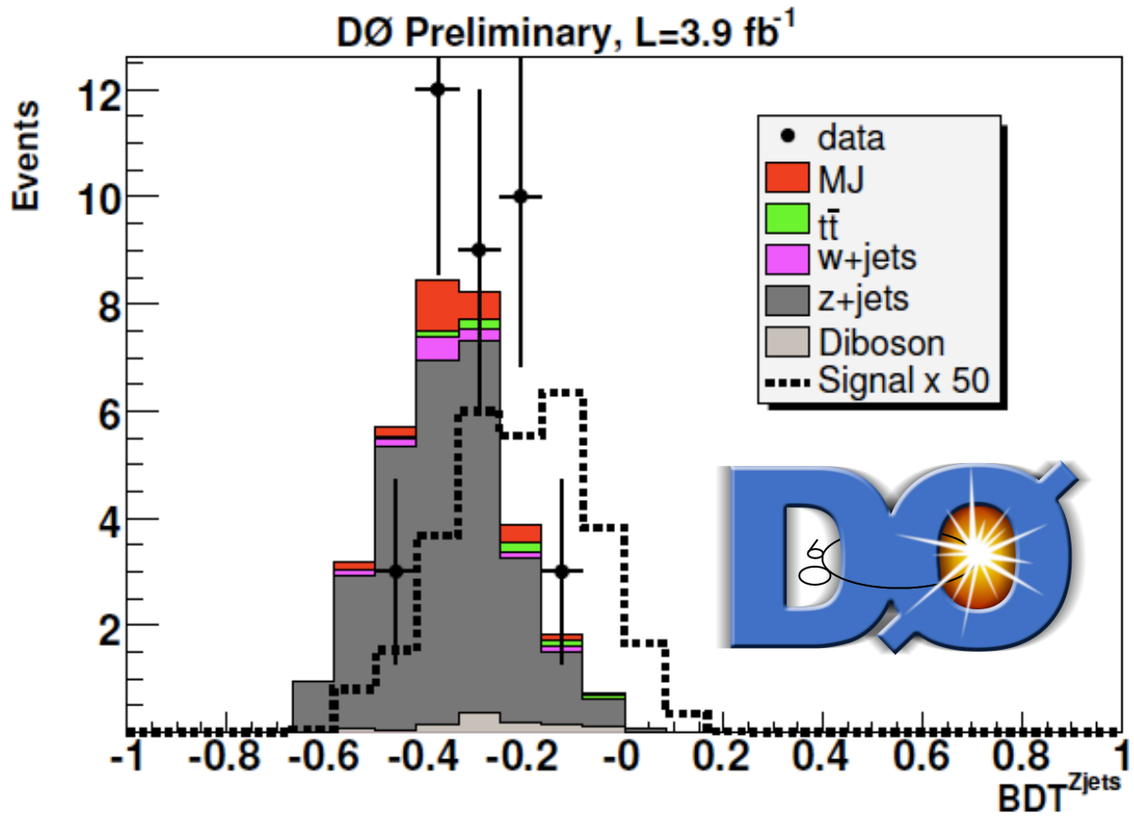
Backup

m_H (GeV/c^2)	$\sigma_{gg\to H}$ (fb)	σ_{WH} (fb)	σ_{ZH} (fb)	σ_{VBF} (fb)	$B(H \to b\bar{b})$ (%)	$B(H \to \tau^+\tau^-)$ (%)	$B(H \to W^+W^-)$ (%)
100	1861	286.1	166.7	99.5	81.21	7.924	1.009
105	1618	244.6	144.0	93.3	79.57	7.838	2.216
110	1413	209.2	124.3	87.1	77.02	7.656	4.411
115	1240	178.8	107.4	79.07	73.22	7.340	7.974
120	1093	152.9	92.7	71.65	67.89	6.861	13.20
125	967	132.4	81.1	67.37	60.97	6.210	20.18
130	858	114.7	70.9	62.5	52.71	5.408	28.69
135	764	99.3	62.0	57.65	43.62	4.507	38.28
140	682	86.0	54.2	52.59	34.36	3.574	48.33
145	611	75.3	48.0	49.15	25.56	2.676	58.33
150	548	66.0	42.5	45.67	17.57	1.851	68.17
155	492	57.8	37.6	42.19	10.49	1.112	78.23
160	439	50.7	33.3	38.59	4.00	0.426	90.11
165	389	44.4	29.5	36.09	1.265	0.136	96.10
170	349	38.9	26.1	33.58	0.846	0.091	96.53
175	314	34.6	23.3	31.11	0.663	0.072	95.94
180	283	30.7	20.8	28.57	0.541	0.059	93.45
185	255	27.3	18.6	26.81	0.420	0.046	83.79
190	231	24.3	16.6	24.88	0.342	0.038	77.61
195	210	21.7	15.0	23	0.295	0.033	74.95
200	192	19.3	13.5	21.19	0.260	0.029	73.47

σ(ZH,WH,VBF) from TeV4LHC Higgs working group at http://maltoni.home.cern.ch/maltoni/TeV4LHC/SM.html
MCFM + HDECAY


2xCDF Preliminary Projection
Analyzed L=10 fb^{-1}
With Improvements
Analyzed L=5 fb^{-1}
With Improvements
January 16, 2009
LEP Exclusion
Probability of 2σ Excess
m_H (GeV/c^2)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
100
110
120
130
140
150
160
170
180
190
200

channel : $H \rightarrow \tau\tau$



DØ 95% CL Upper Limits

for

Mh = 115 GeV/c^2

Obs. ➔ 27 X SM

Exp. ➔ 15.9 X SM

$gg \rightarrow H, \quad H \rightarrow \tau^+\tau^- \; + \; 2$ additional jets (denoted GGF)

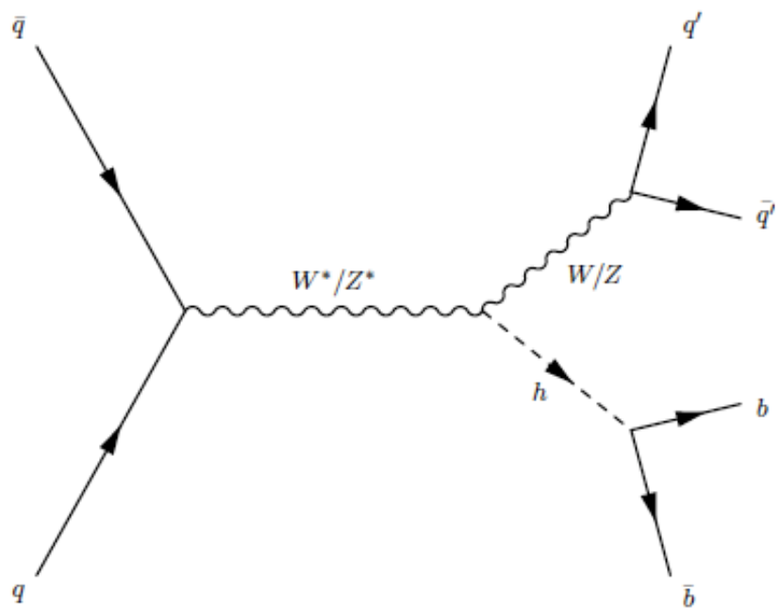
$q\bar{q} \rightarrow Hq\bar{q} \quad H \rightarrow \tau^+\tau^-$ (denoted VBF)

$p\bar{p} \rightarrow ZH, \quad Z \rightarrow \tau^+\tau^-, \quad H \rightarrow q\bar{q}$ (denoted ZH)

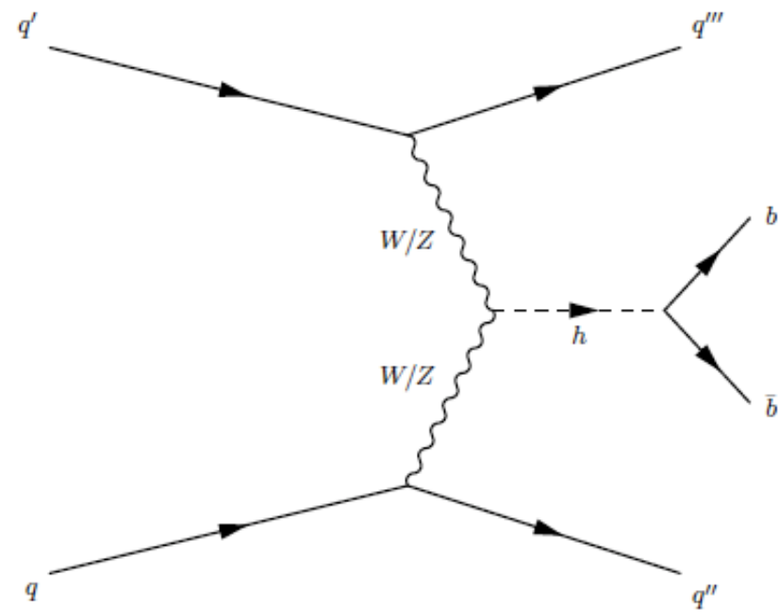
$p\bar{p} \rightarrow HZ, \quad H \rightarrow \tau^+\tau^-, \quad Z \rightarrow q\bar{q}$ (denoted HZ)

$p\bar{p} \rightarrow HW, \quad H \rightarrow \tau^+\tau^-, \quad W \rightarrow q\bar{q}'$ (denoted HW)

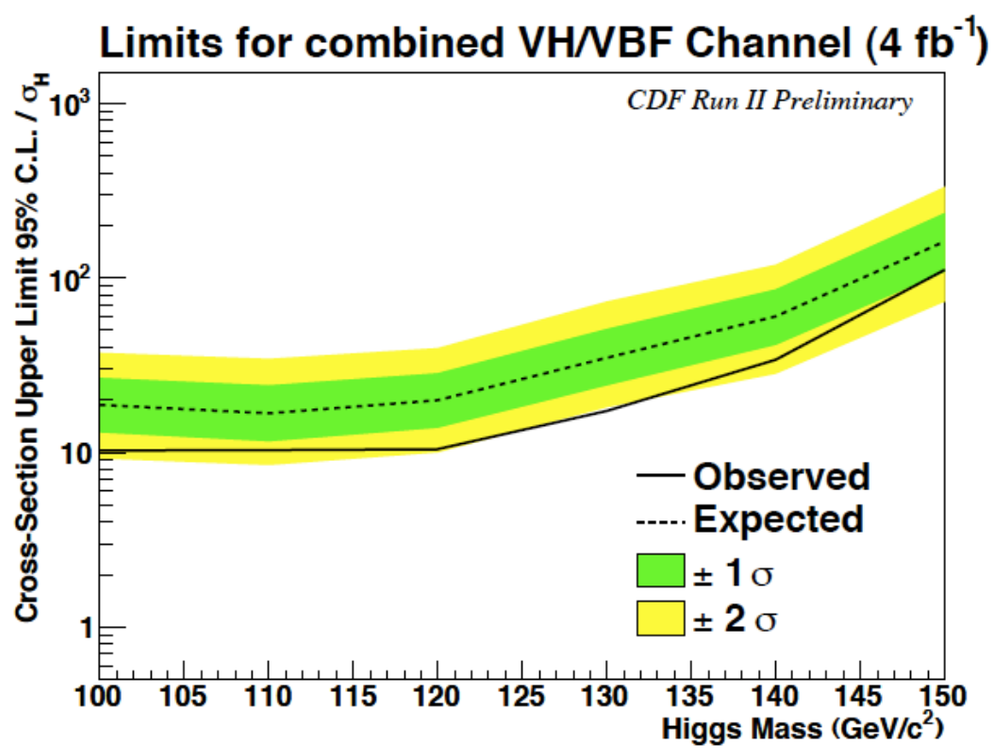
channel : "all hadronic"



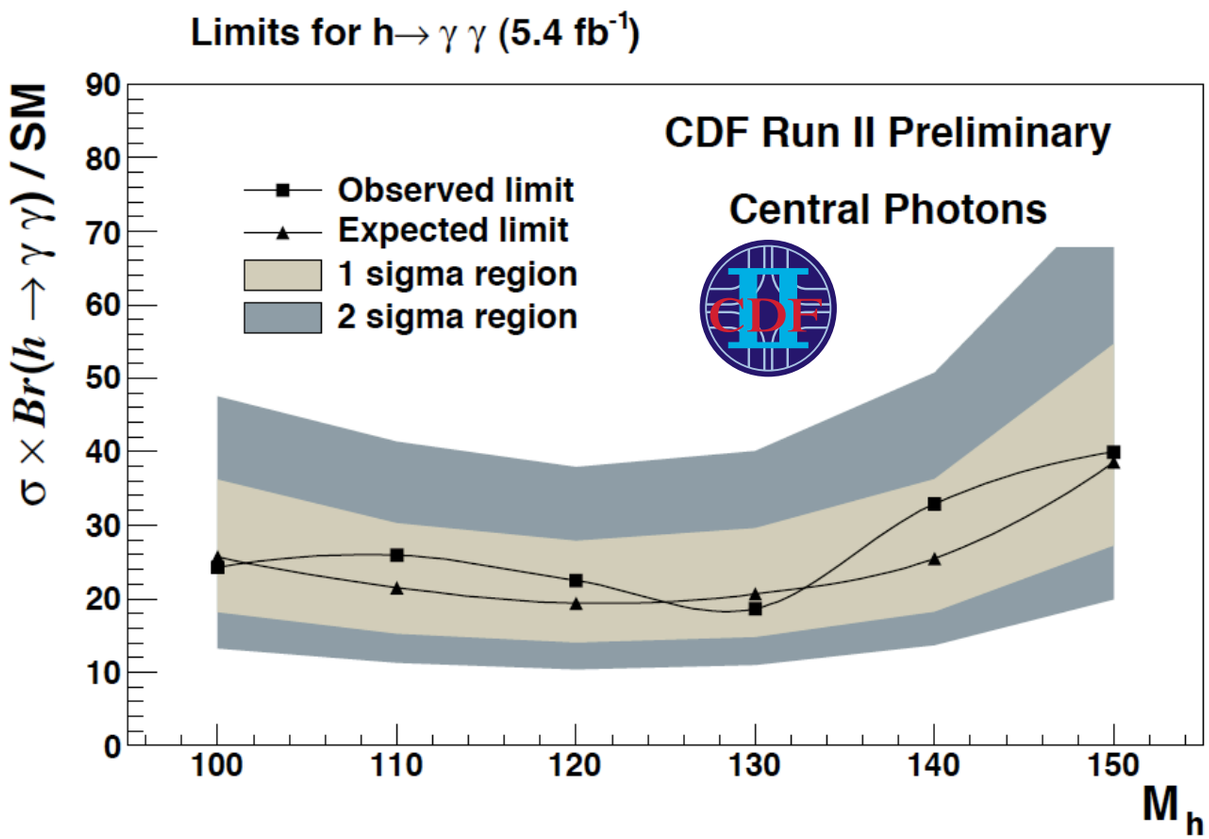
(a)Production and decay mode of the $W/ZH \rightarrow b\bar{b}qq$ channel

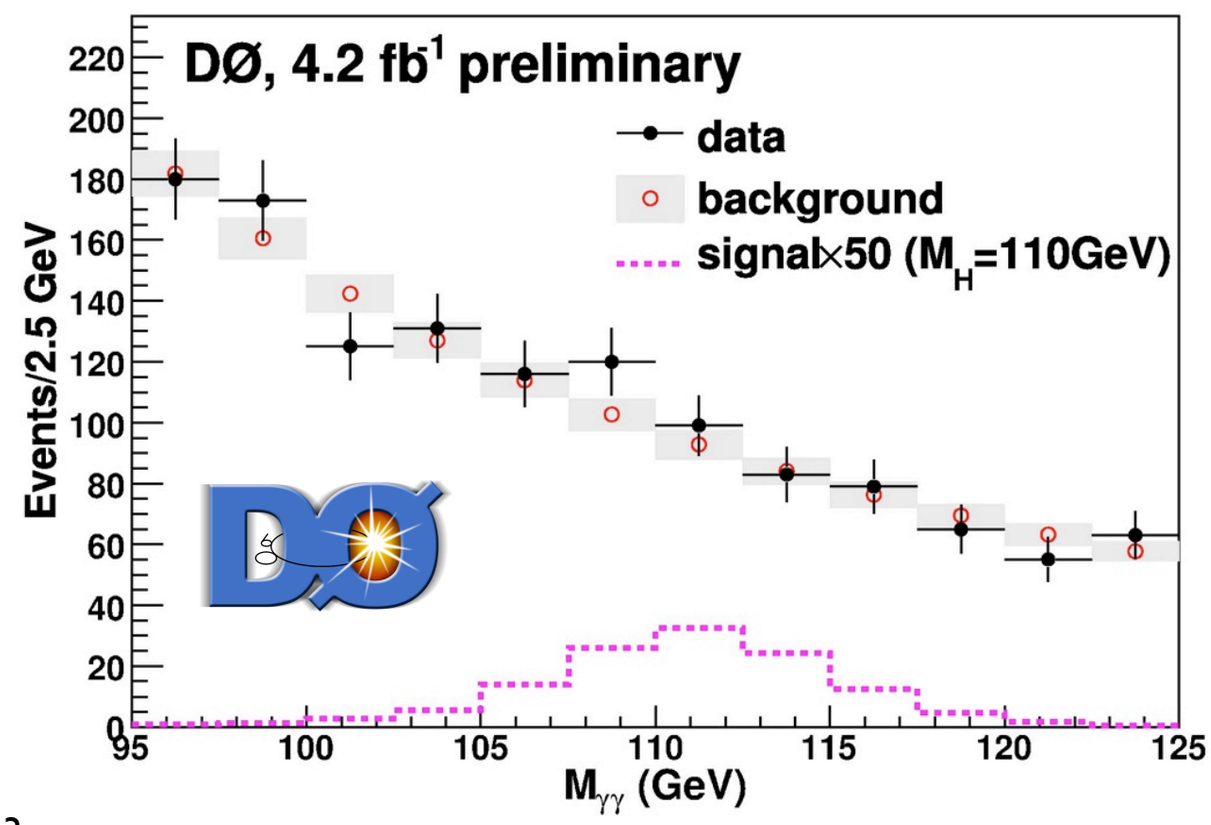


(b)Higgs boson production via vector boson fusion process.



channel : H→γγ


Limits for h→ γ γ (5.4 fb-1)
CDF Run II Preliminary
Central Photons
Observed limit
Expected limit
1 sigma region
2 sigma region
σ × Br(h → γ γ) / SM
M h


DØ, 4.2 fb-1 preliminary
data
background
signal×50 (MH=110GeV)
Events/2.5 GeV
Mγγ (GeV)

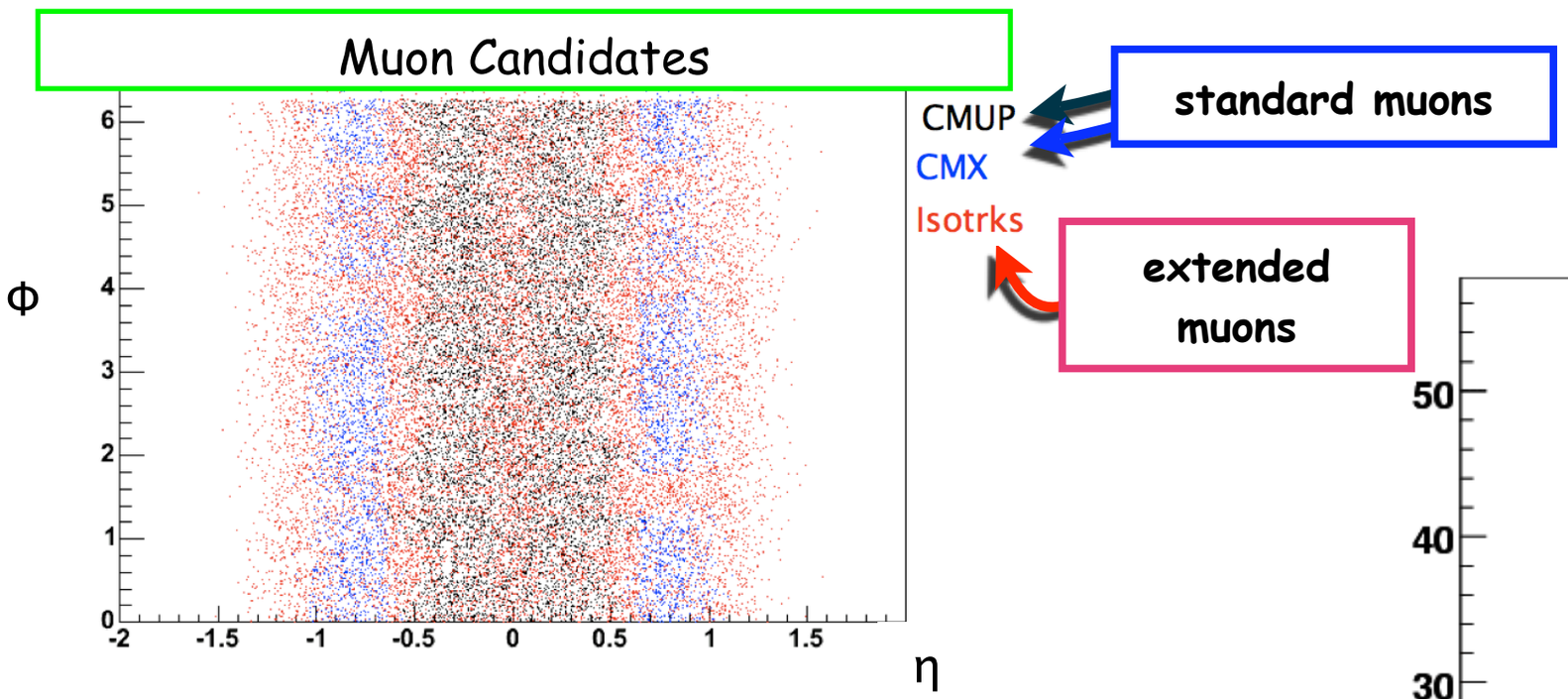
channel : WH→lνbb

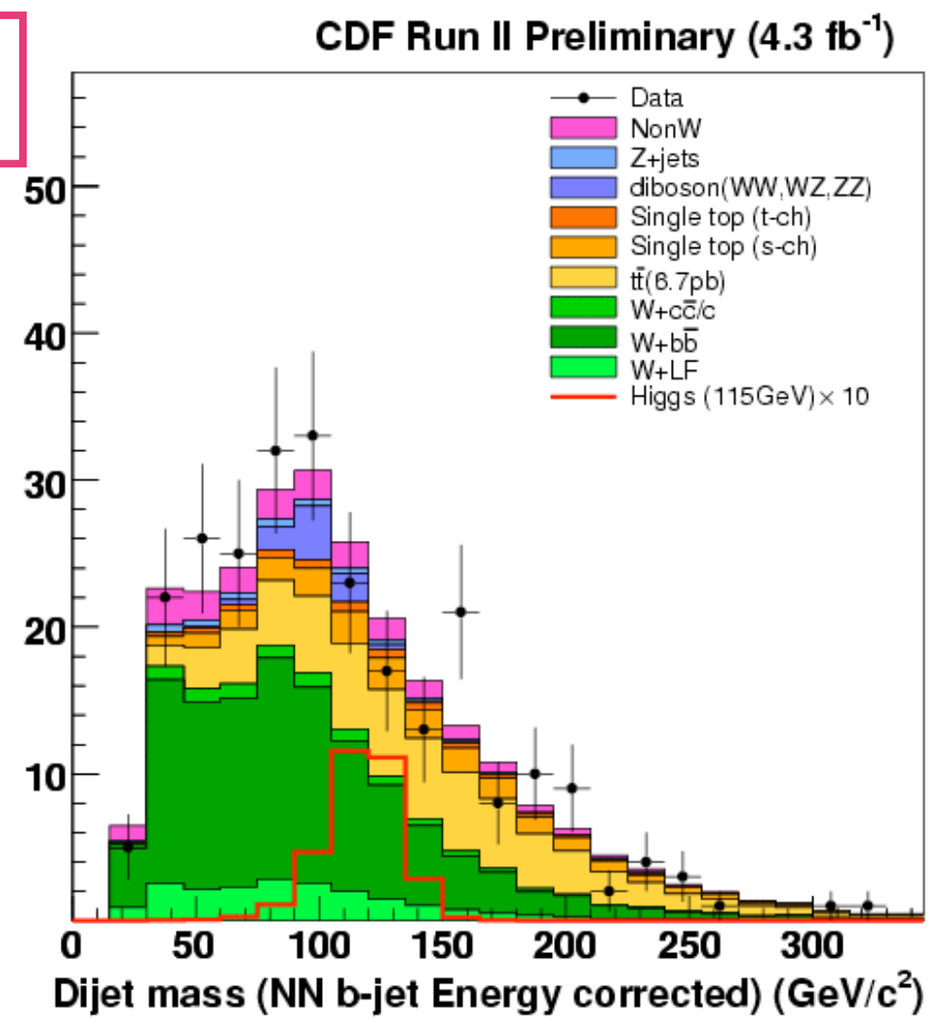
- Basic event selection :

  1 high Pt muon/electron or isolated track (P_t is > 90% of Σ P_t nearby tracks)

  2 energetic jets + significant missing E_t

  at least 1 jet "b-tagged"

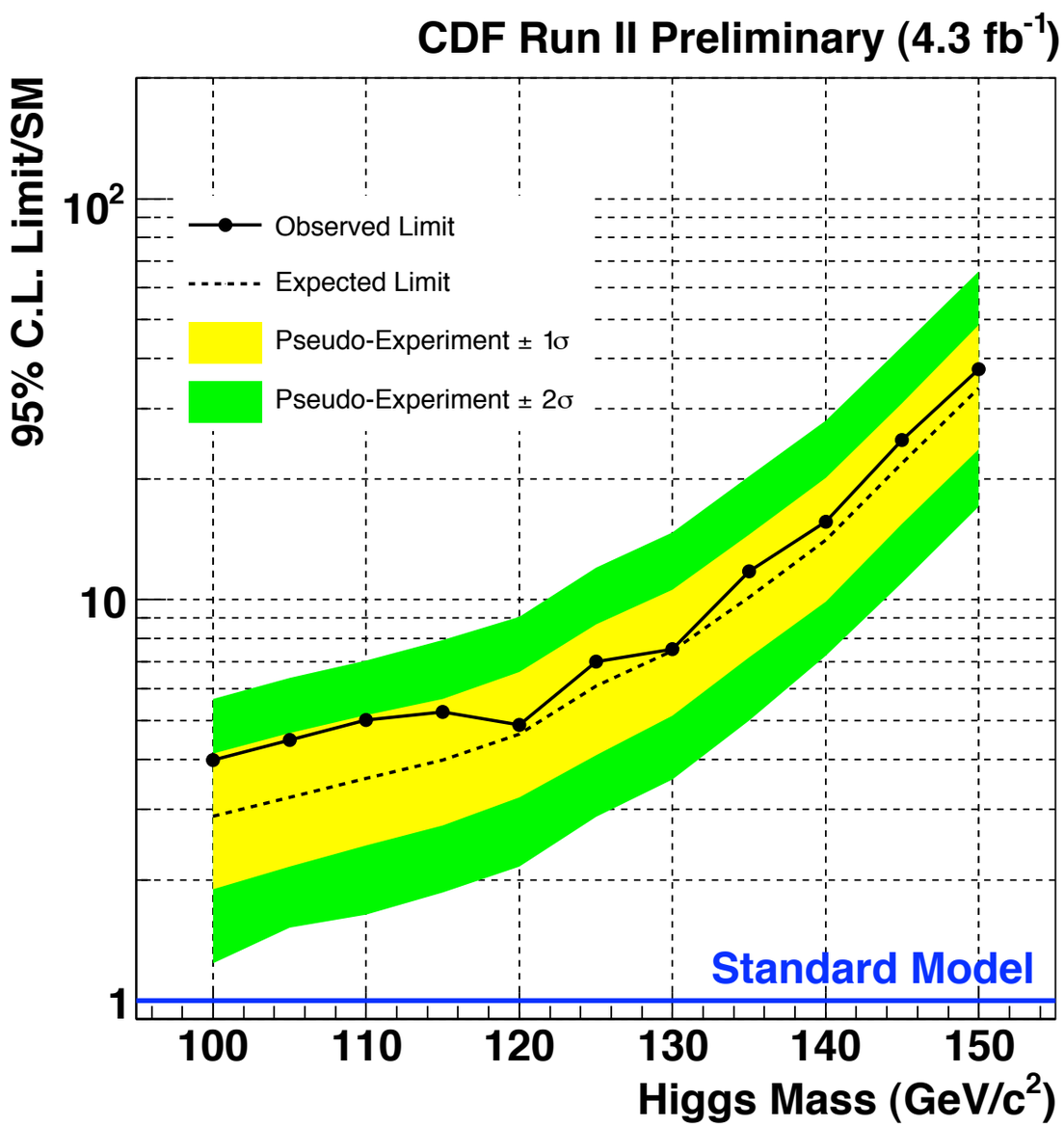


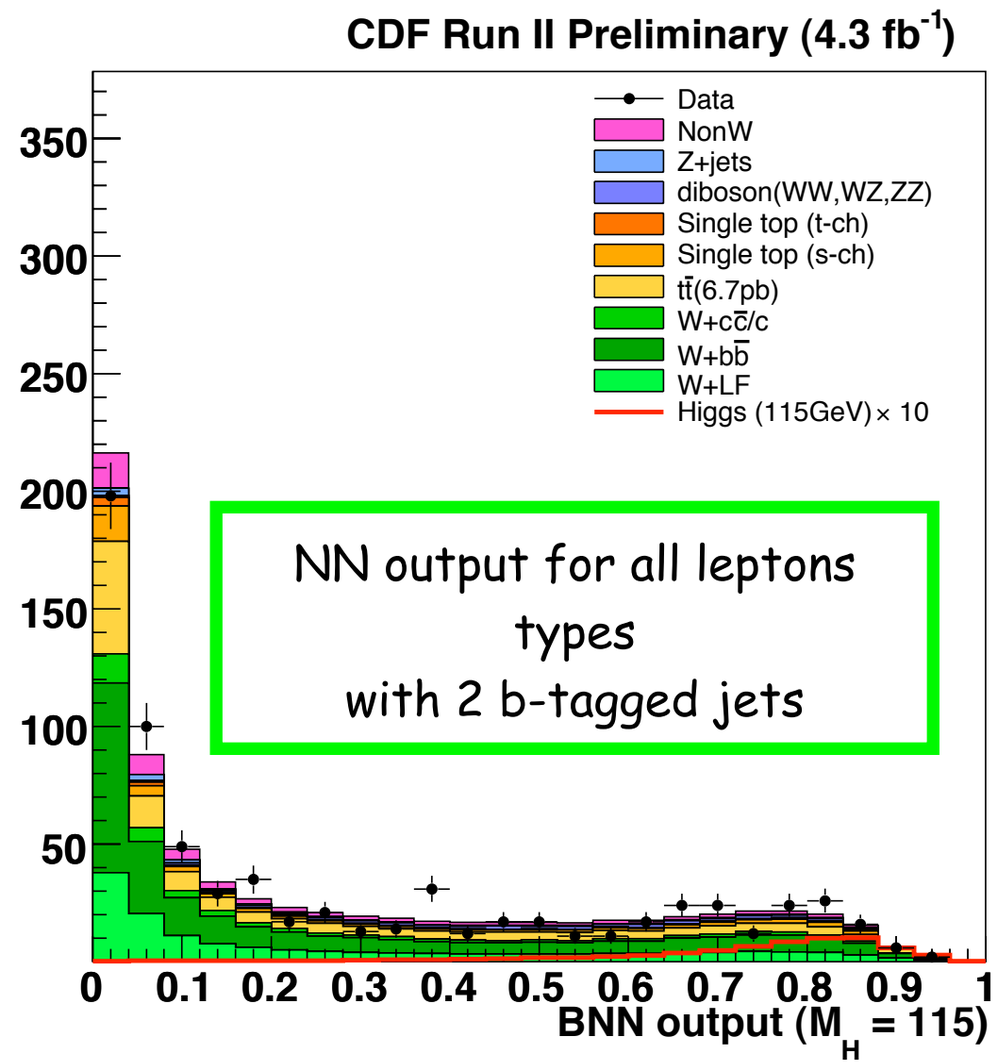


- Changes since March 2009:
  - New NN based corrections to b-jet energies
    - similar to ZHllbb jet energy corrections
  - Additional events from a MET (40) trigger
  - NN based b-tagging

channel : WH→lνbb

- Results :





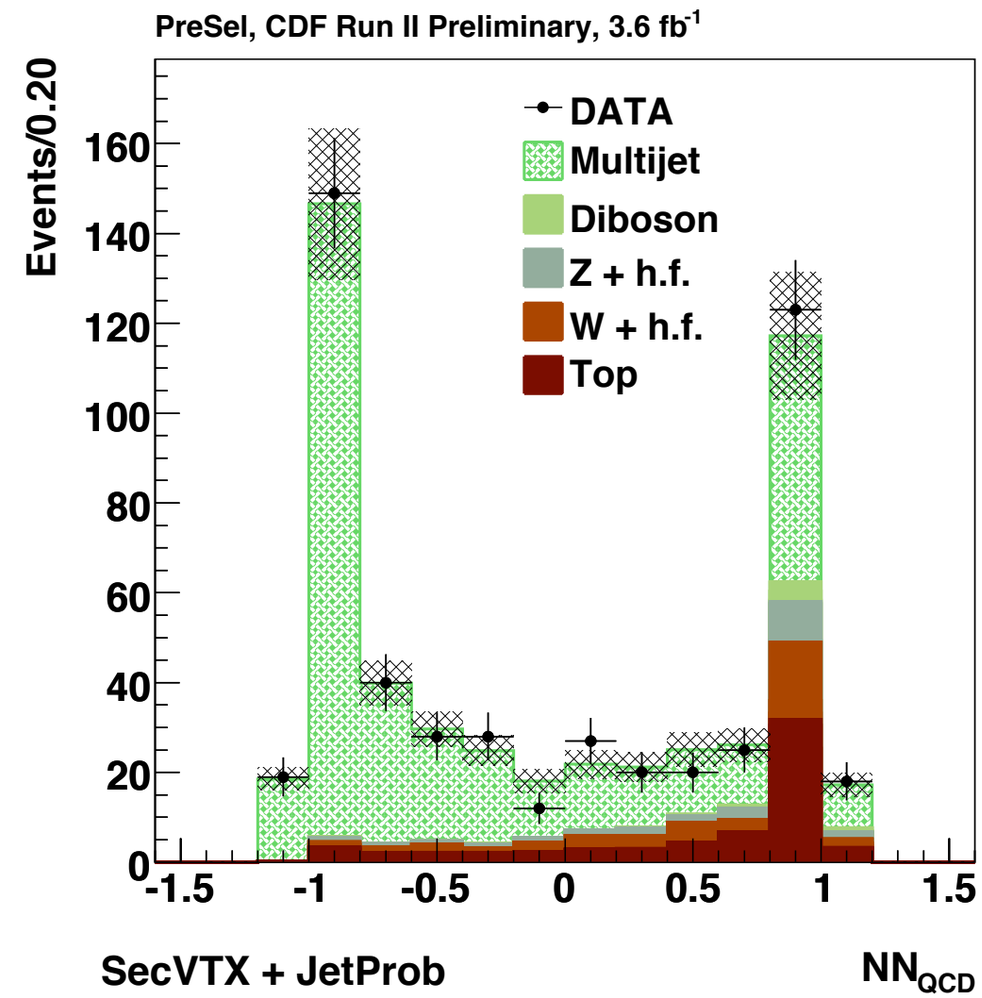
NN output for all leptons types
with 2 b-tagged jets

CDF Limits for Mh = 115 GeV/c^2
4.3 fb-1
Obs. → 5.3 X SM Prediction
Exp. → 4.0 X SM Prediction

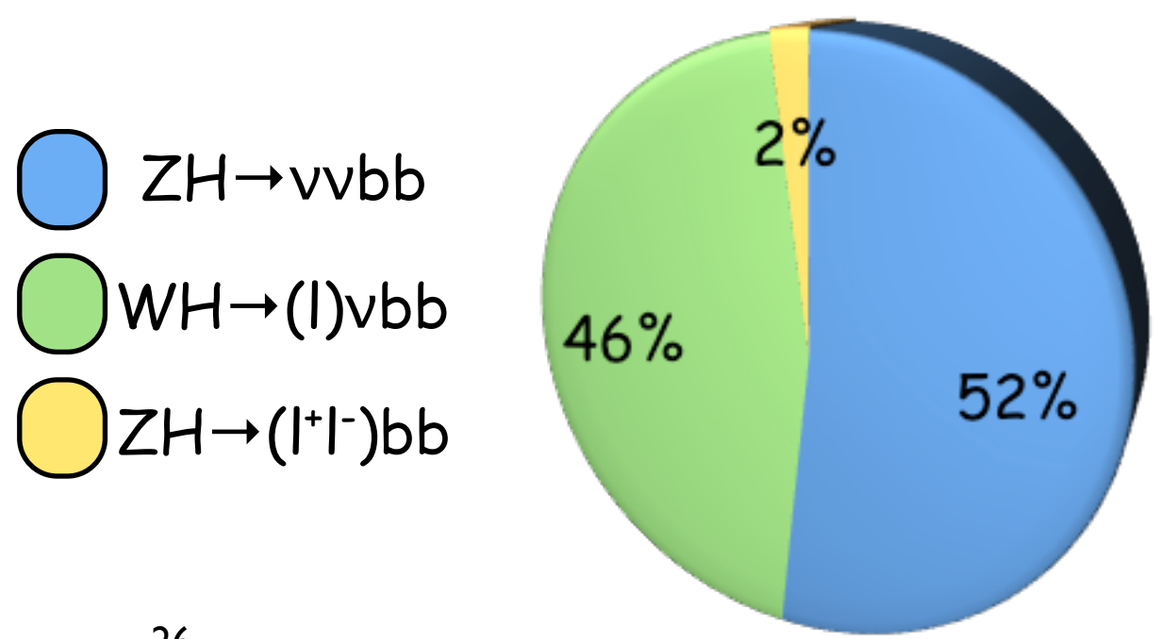
- Parallel ME based analysis also in the works, expected to combine with NN search

channel : VH→ννbb

- Basic event selection :
  - high missing Et > 50 GeV
  - 2 energetic jets
  - at least 1 jet "b-tagged"
- NN event selection :
  - Designed to reject QCD
  - Cut at NN_out > 0 keeps 95% of Signal while removing 68% Bkg.

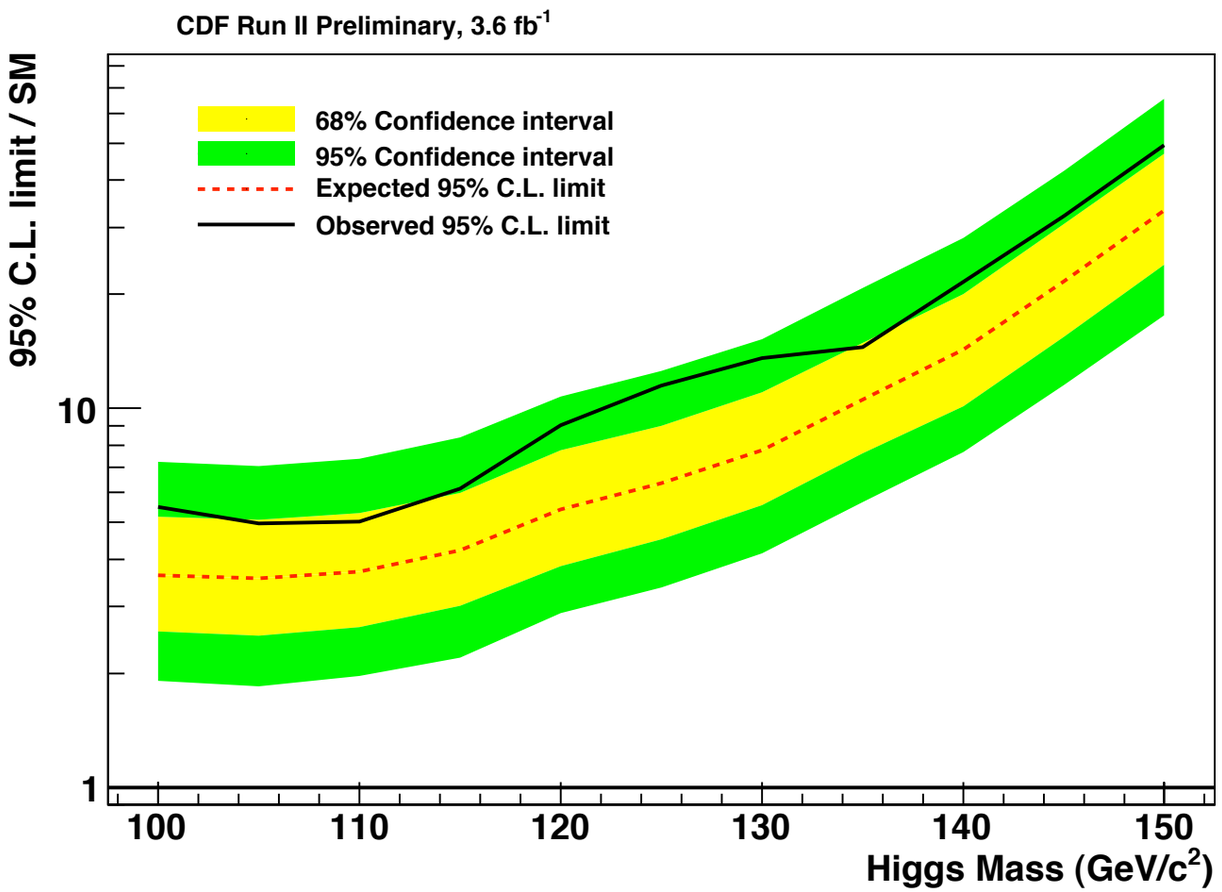


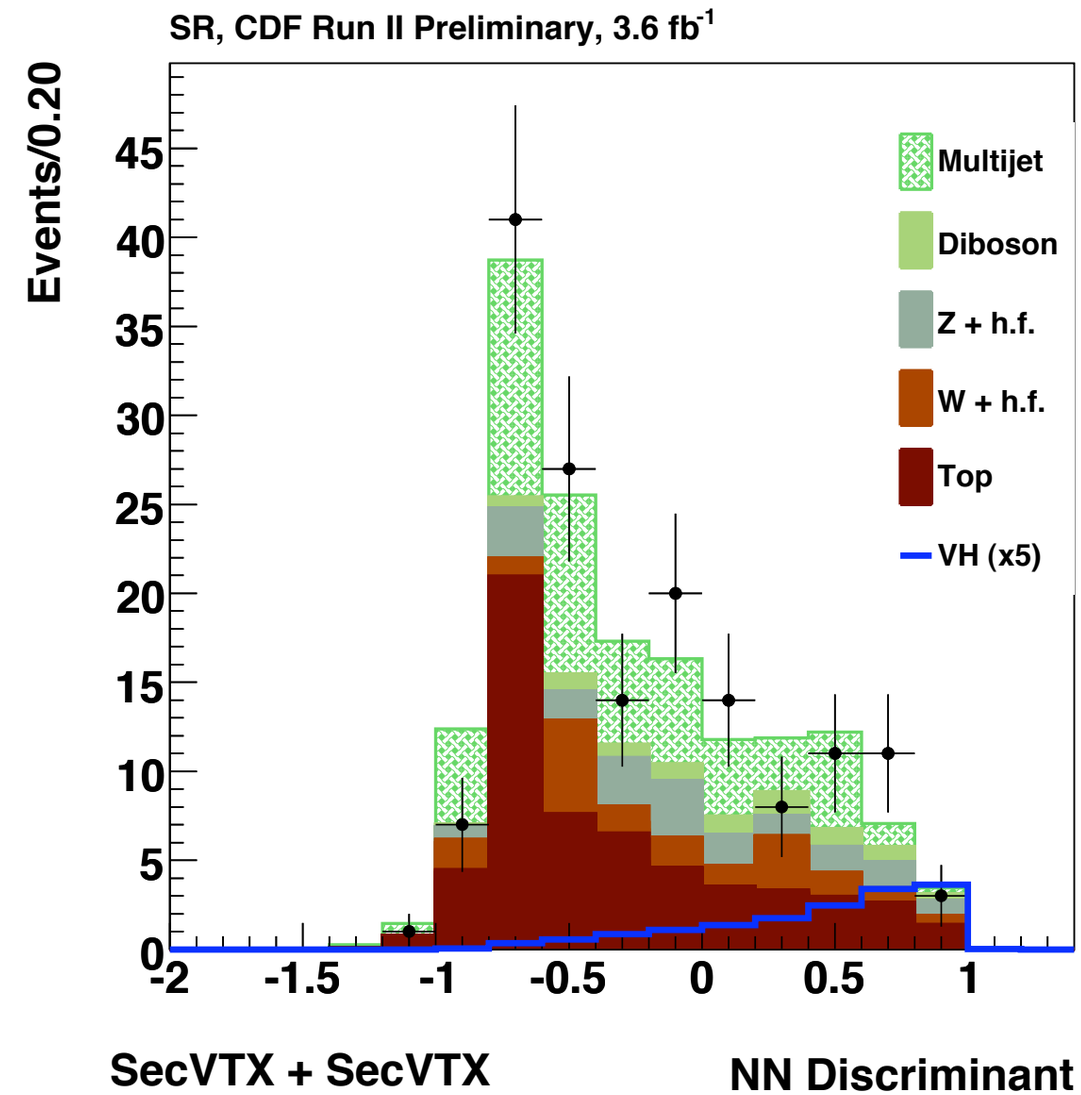
- Picks up "missed" WH→lνbb and ZH→l^+l^-bb events :



channel : VH→ννbb

- Results :

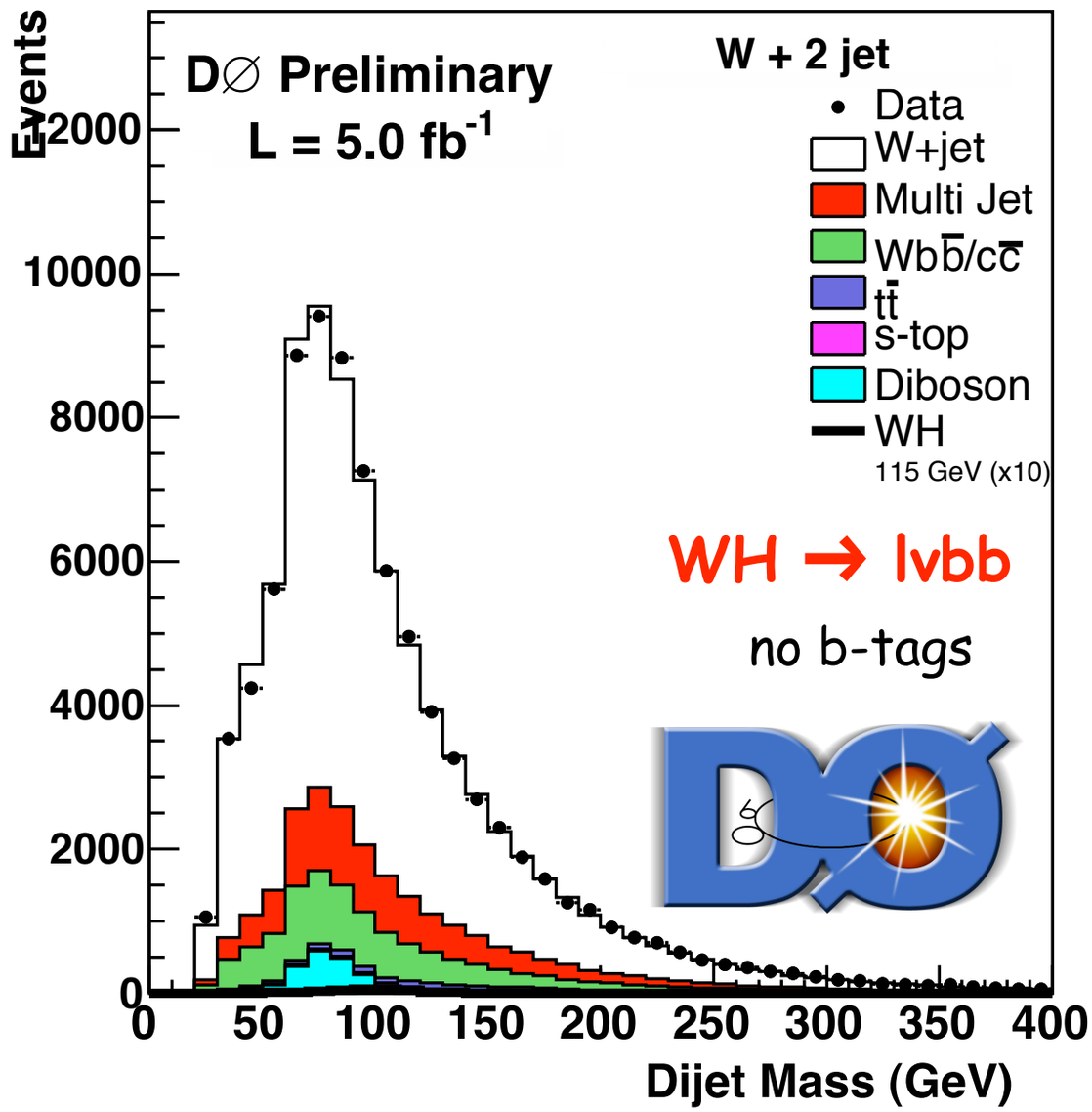




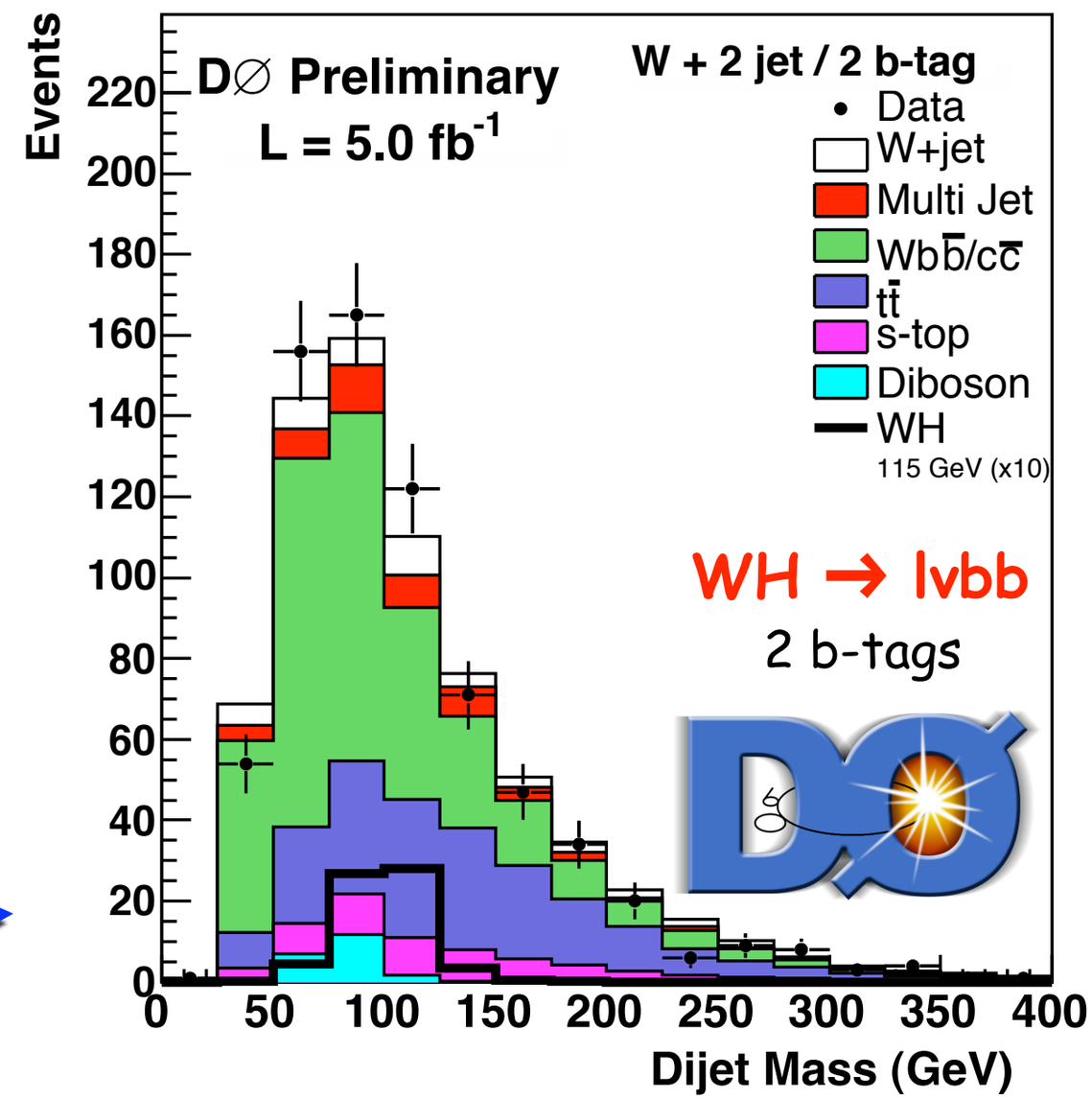
CDF Limits for Mh = 115 GeV/c^2
3.6 fb-1
Obs. → 6.1 X SM Prediction
Exp. → 4.2 X SM Prediction

Identifying b-jets

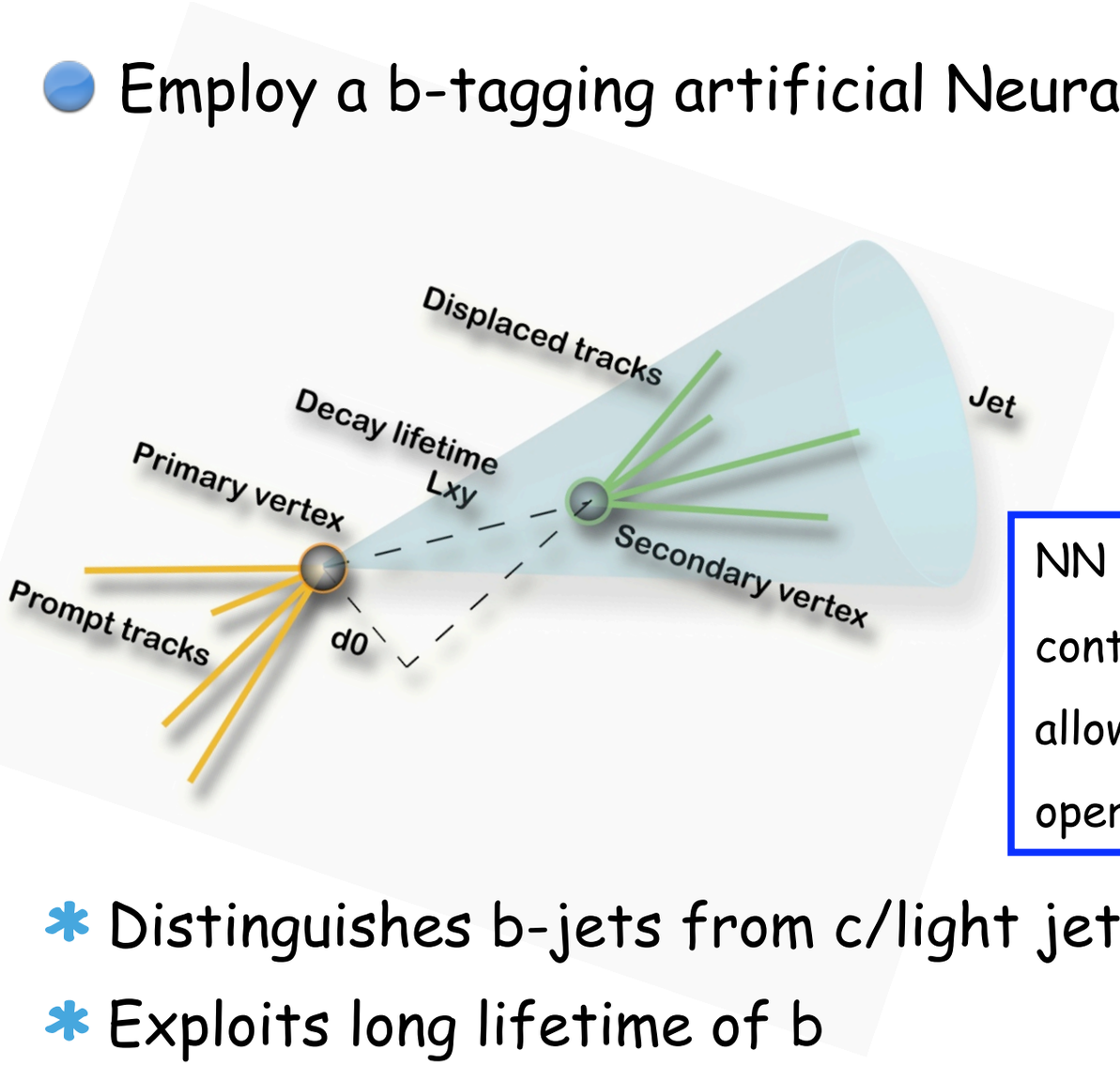
- Example : **WH → lνbb**

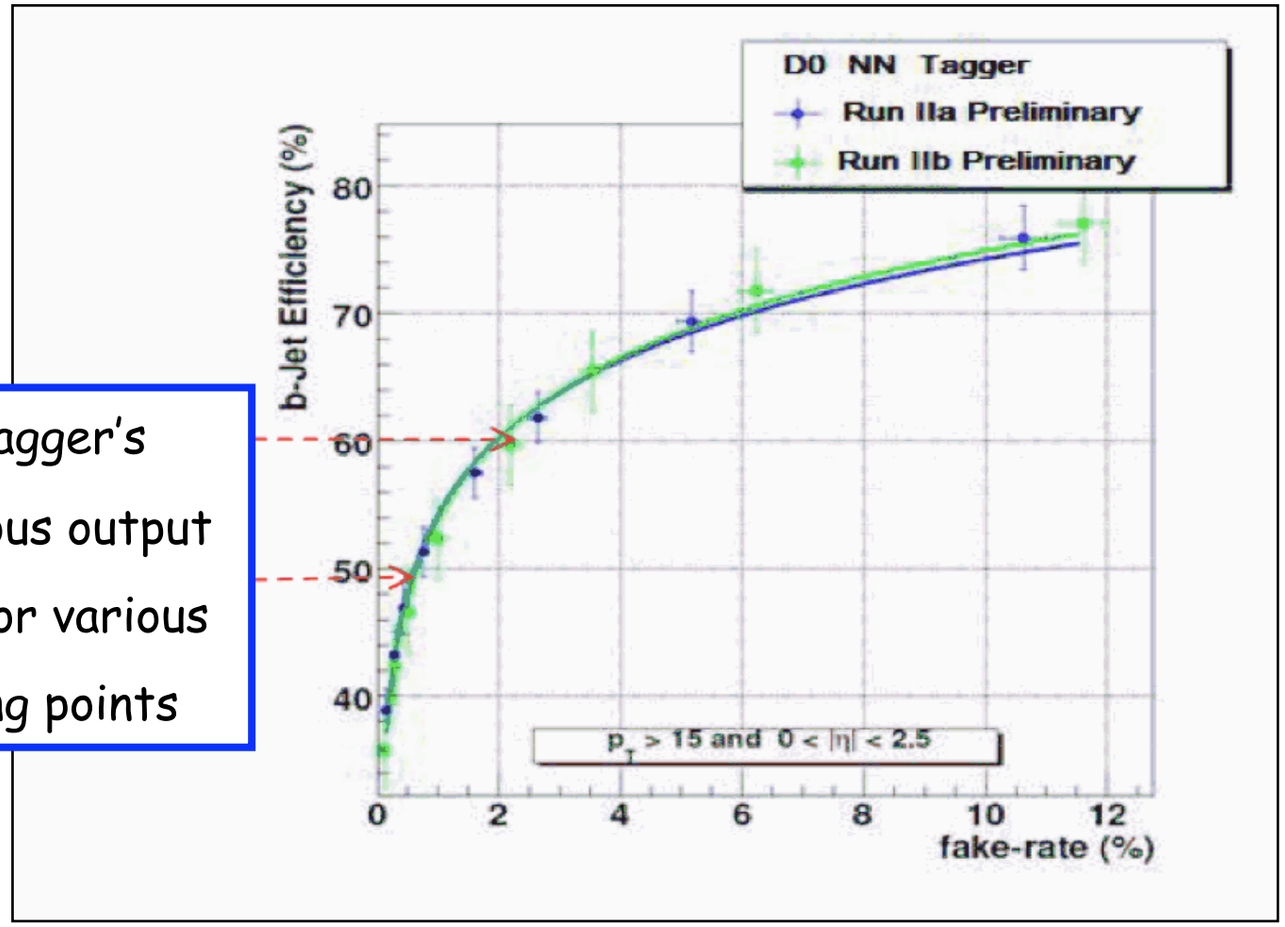


- tagging both jets dramatically reduces background (W + lf jets)
- S/√B enhanced to ~0.3



- Employ a b-tagging artificial Neural Network





NN b-Tagger's continuous output allows for various operating points

- Distinguishes b-jets from c/light jets
- Exploits long lifetime of b
- Various operating points

Tight : 50% eff. with 0.5% fake rate

Loose : 72% eff. with 4% fake rate

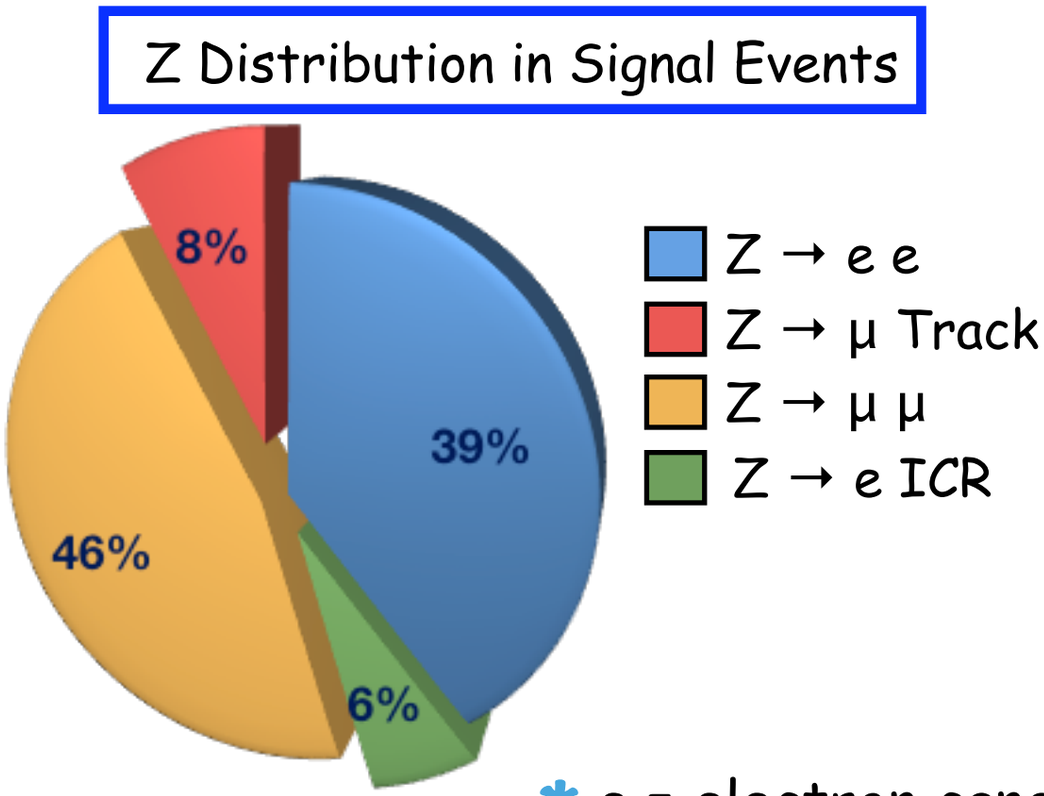
b-tagging rejects about 95% of Z+jets background !

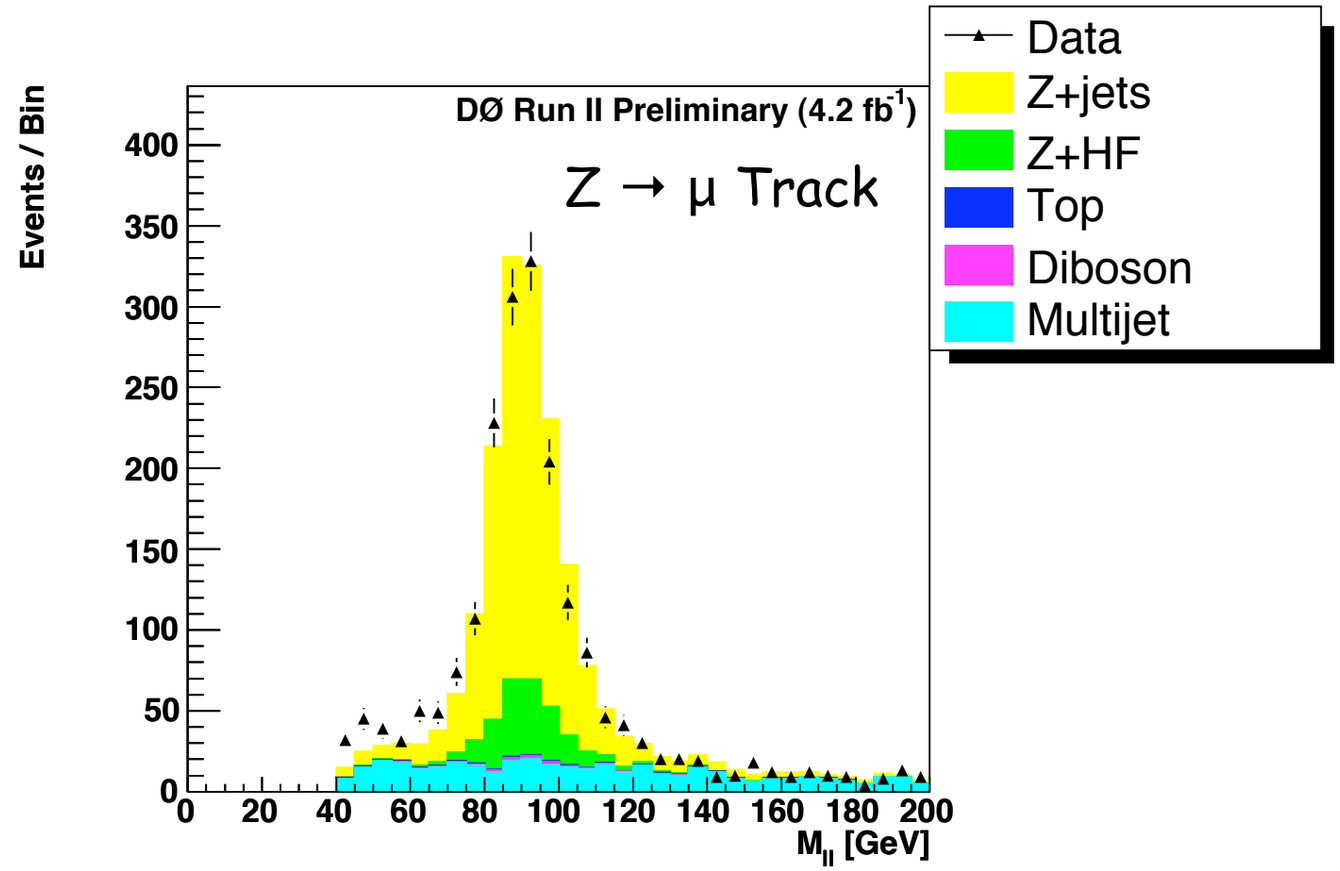
Two Final Tag Categories :

1 Jet passing Tight NN b-tag requirement

2 Jets passing Loose NN b-tag requirement

- Define four Z classes depending on lepton types and locations in the detector



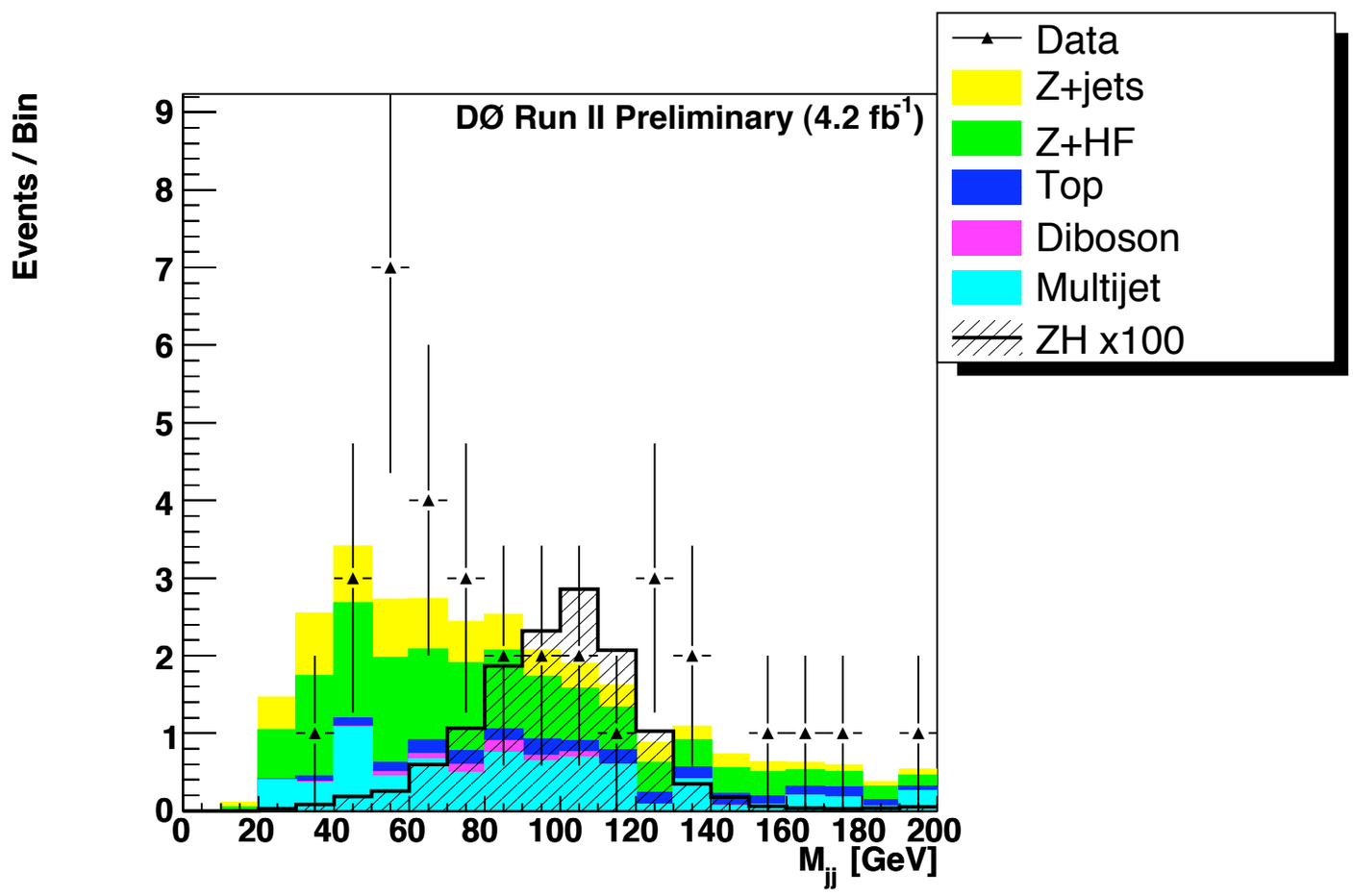


- e = electron candidate passing calorimeter cuts
- ICR = loose electron reconstructed from Track + Jet using a NN
- μ = muon candidate passing muon/track cuts
- Track = loose muon candidate reconstructed from track

- Net gain of ~15% more signal Z's by using Track and ICR loose lepton types

The D0 Approach :

- D0 performs a **Kinematic χ^2 fit** to improve signal discrimination
- lepton/jet energies and angles are allowed to float within detector resolution, to minimize χ^2 under the constraints
  - dilepton mass = Z mass +/- Z width
  - P_t of dilepton + dijet system is constrained to zero +/- 7 GeV

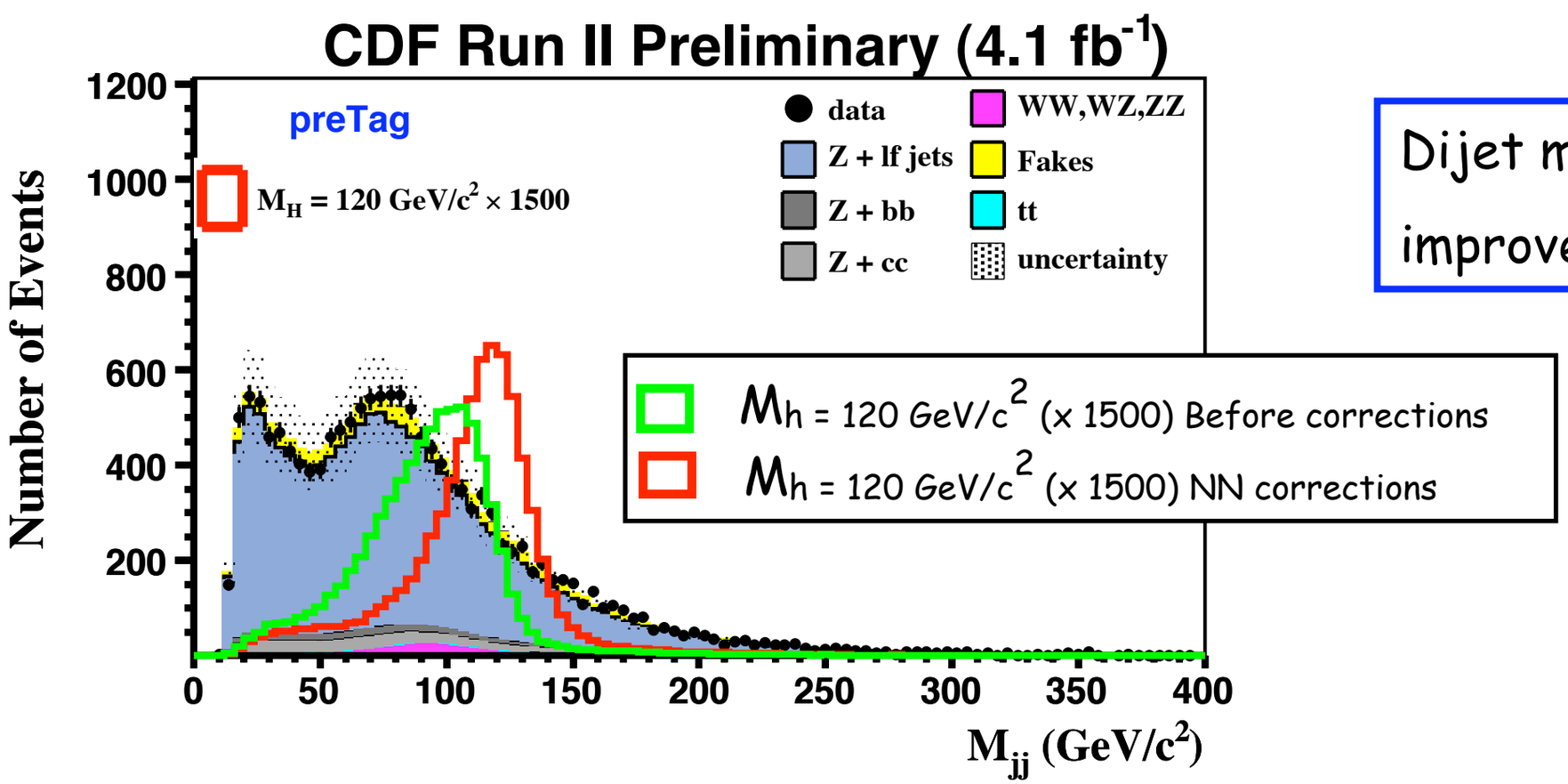


Dijet mass resolution similar to that of CDF

- No Neutrinos in signal final state ➔ Missing Energy is mostly due to mis-measured jet Energies
- Improved jet energy resolution enhances the discriminating power of jet based kinematic distributions

The CDF Approach :

- CDF Employs a **NN derived function** to correct jet energies for missing E_t
- The NN returns correction factors for the jets depending on the orientation and magnitude of missing E_t and jets



Dijet mass resolution improves from 18 to 12%