Searches for High-Mass SM Higgs at the Tevatron

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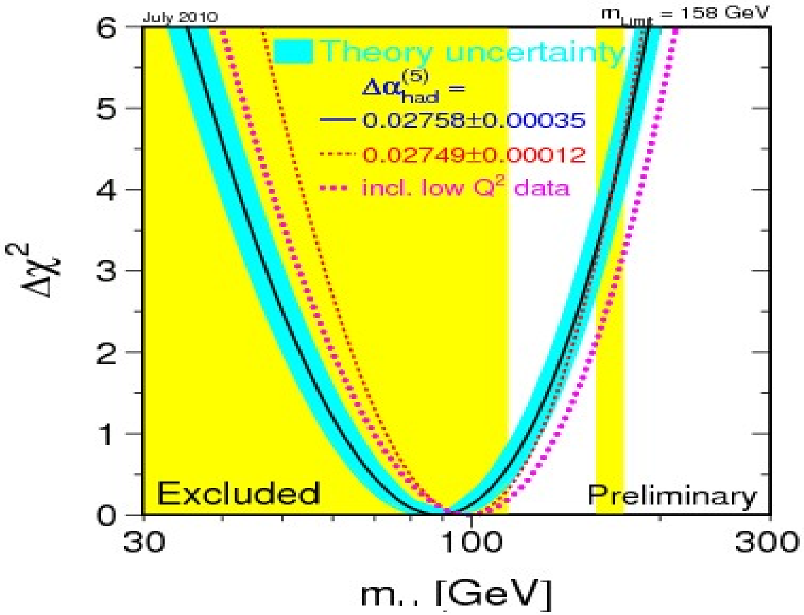
(on behalf of the CDF & D0 collaborations)

Moriond QCD 2011

Introduction

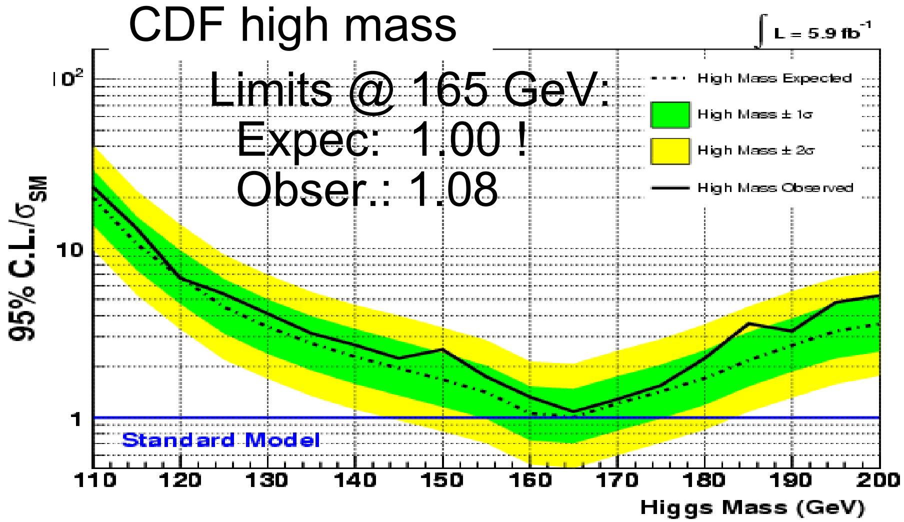
- Higgs mechanism explains EWSB in SM
- Higgs boson: last SM particle not yet experimentally observed
- Indirect EWK measurements + LEP: M_H < 185 GeV @ 95% CL



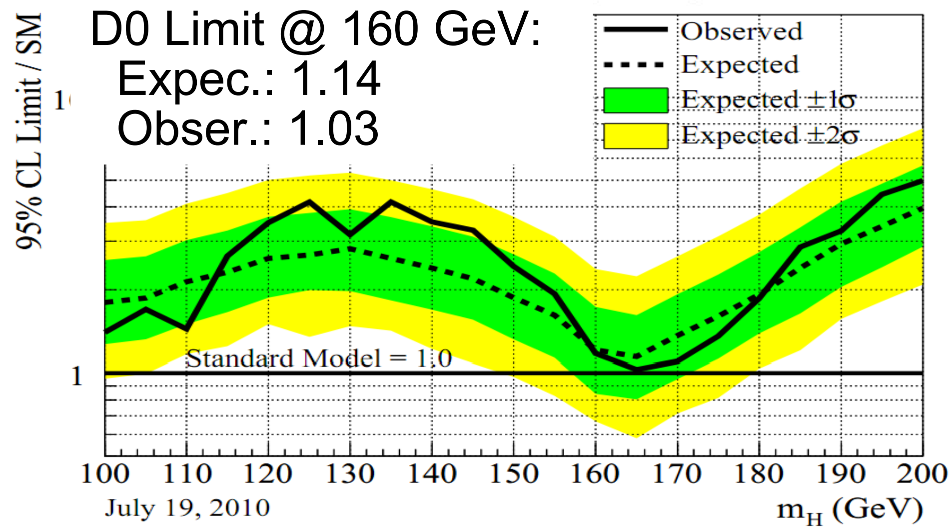
- Tevatron results from last summer:

CDF high mass

Limits @ 165 GeV:
Expec: 1.00 !
Obser.: 1.08

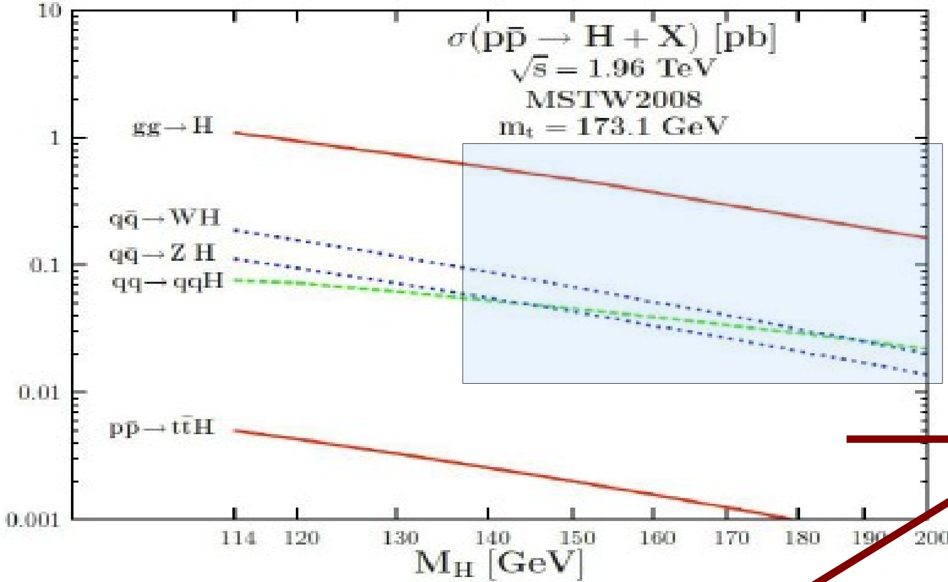


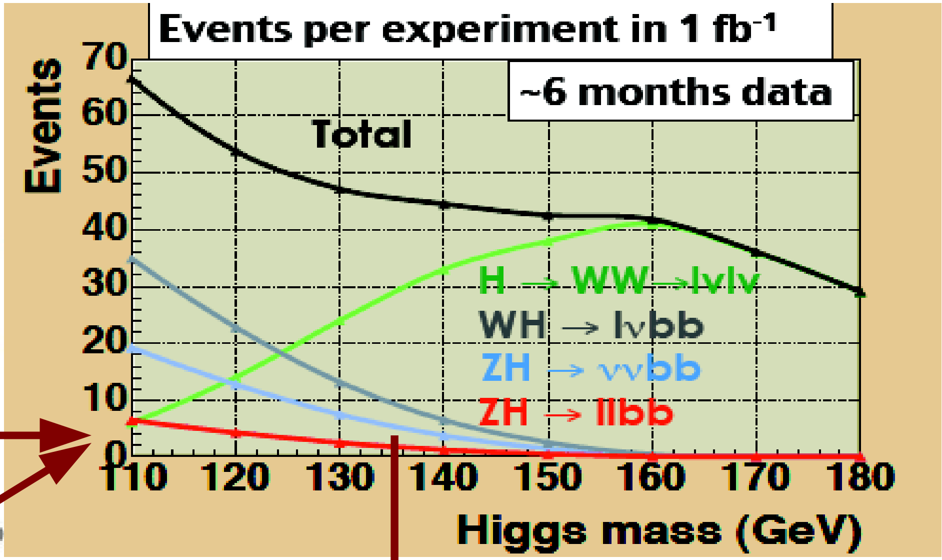
D0 Limit @ 160 GeV:
Expec.: 1.14
Obser.: 1.03

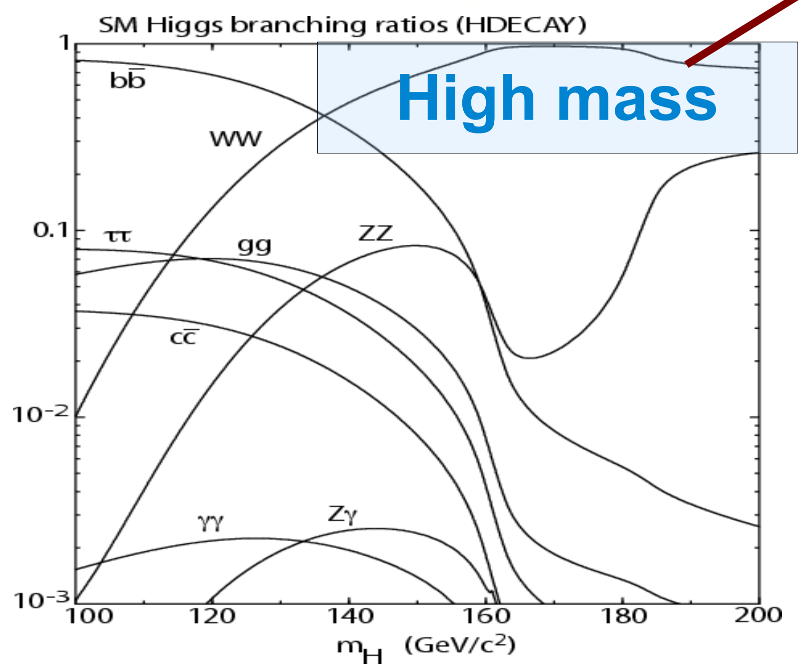


In combination, excluded m_H from 158 – 175 GeV (expec.: 156 – 173 GeV)

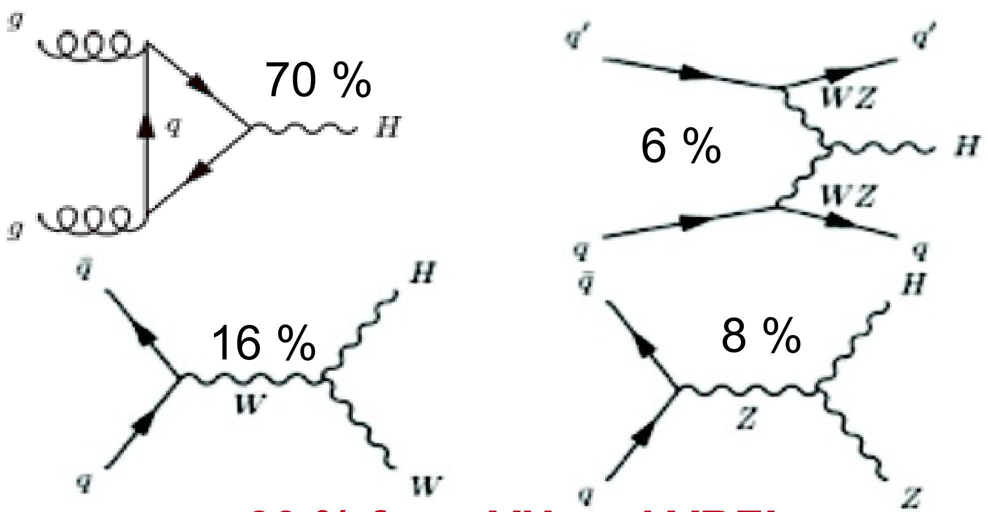
Production of high-mass Higgs at Tevatron







CDF : ~7 events reconstr. in 1fb^{-1} @ 165 GeV:

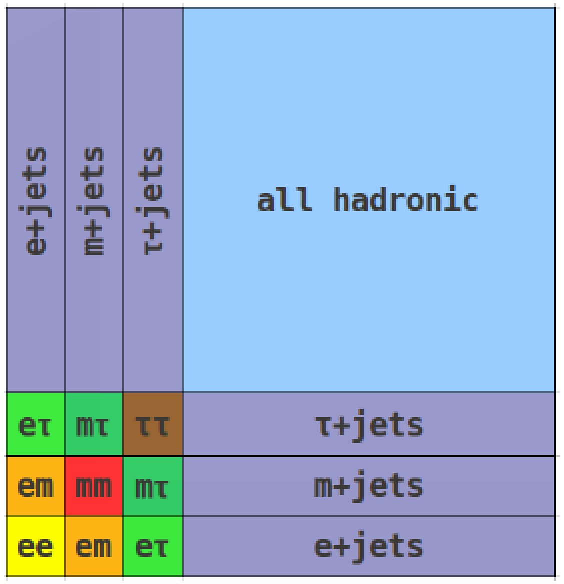


30 % from VH and VBF!

High mass analyses – overview

General analysis approach:

- **Select as much inclusive sample as possible**
  - All 4 main Higgs processes
  - All but all-hadronic WW decay channels
    ($ll\nu\nu$ –4%, $l\nu\tau_{HAD}\nu$–6%, $l\nu jj$-30%)
  - Basic selection very loose
    (Sig/Bckg: typically 1% – 3% at CDF for dileptons)

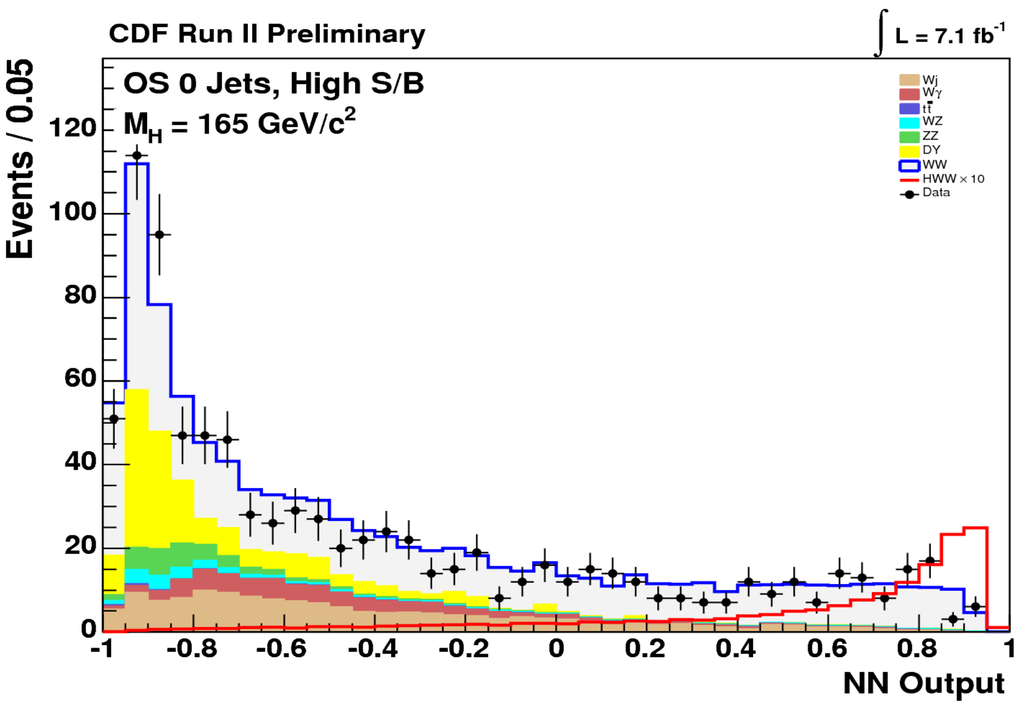


- **Separate sample into sub-channels**
  - Leptons: ee,$e\mu$,$\mu\mu$ (D0); High S/B, Low S/B (CDF)
  - Charge of leptons (OS and SS)
  - Number of jets: 0, 1, >= 2 Jets
  - Low and high dilepton mass – CDF

High mass analyses – overview (cont.)

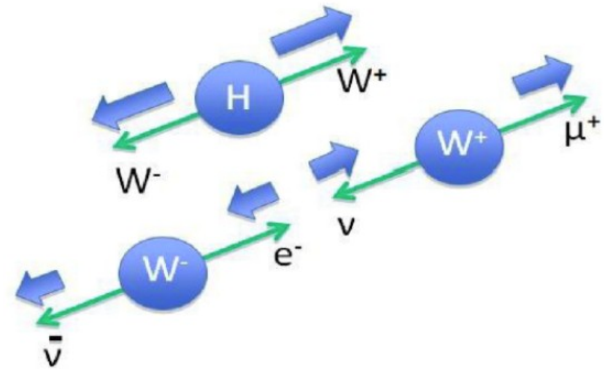
- **Separate signal from background by Multivariate techniques (MVA)**
  - Neural networks (NN), Boosted Decision Trees (BDT)
  - Optimize variables for each channel (typically ~10 variables)
  - ~20 – 30 % improvement comparing to optimized cut-based analysis

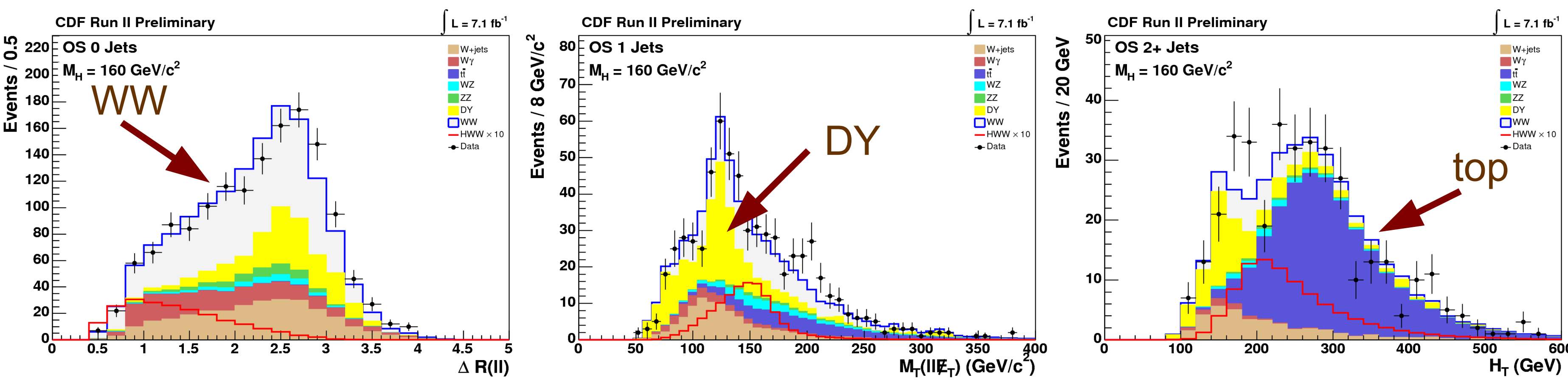
- **Set limits using MVA discriminants as an input**



$H \rightarrow WW \rightarrow l\nu l\nu$

- Most sensitive decay channel
- CDF:
  - Sub-channels (6) separated by
    - Number of jets (0,1 2+)
    - Dilepton categories (high/low S/B)
    - Dilepton mass
  - Dominant bckg: 0 jets region – WW; 1 jet – DY,WW; 2+ jets – top, low dilepton mass – Wγ
  - Strongest discriminants: opening angle between leptons (ΔR) – 0j,1j scalar sum of transverse momentum of all objects (H_T) – 2j

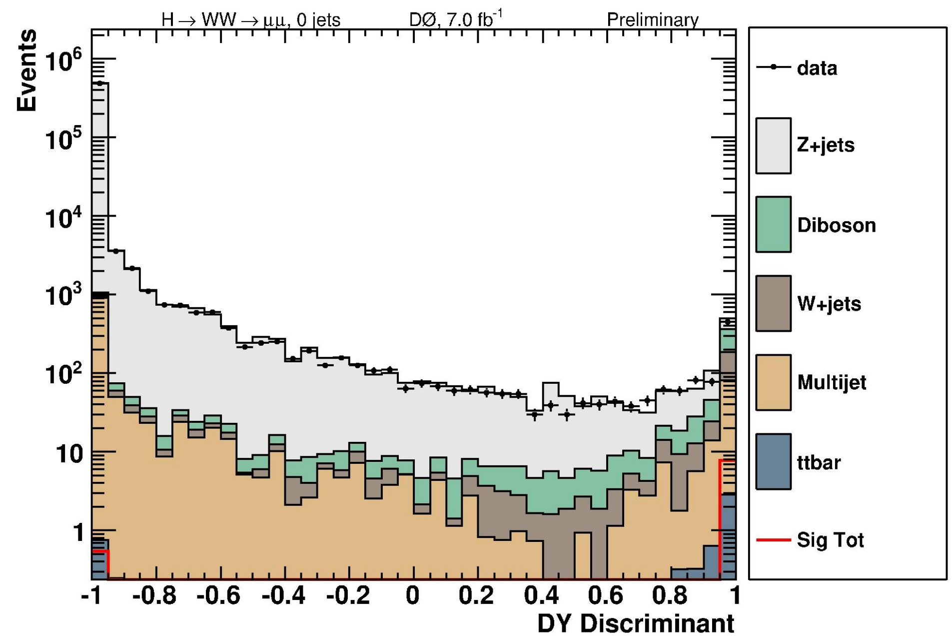


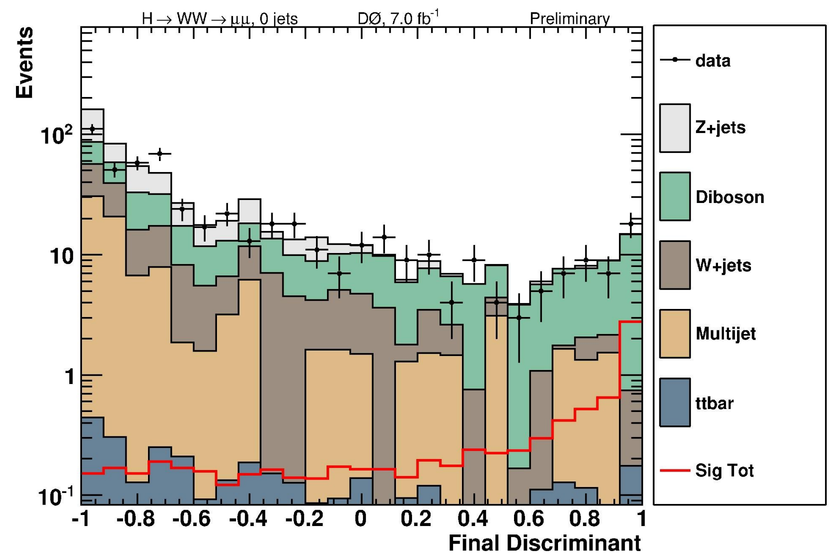


$H \to WW \to l\nu l\nu$

D0:

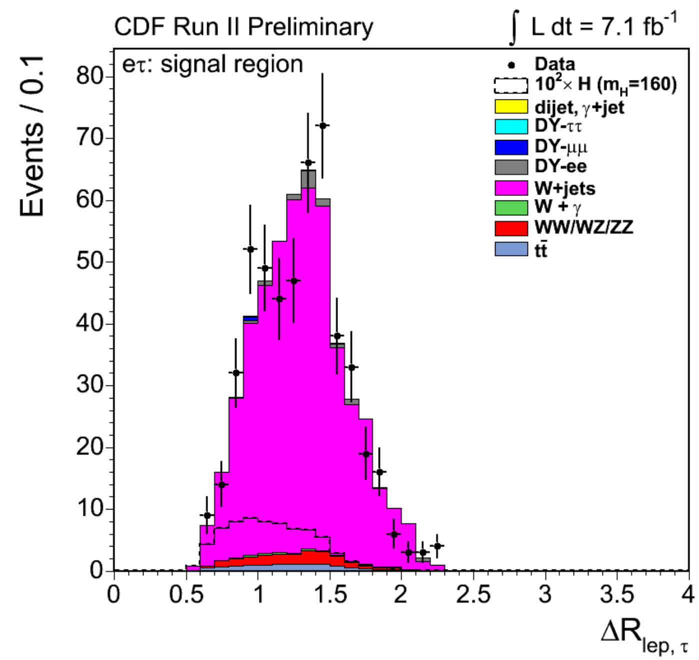
- Sub-channels (18) separated by
  - Lepton flavours (ee,eμ,μμ)
  - Number of jets (0,1 2+)
- Use DT discriminant to initially separate signal from Z/γ* (ee,μμ)
- Additional DT to better separate the remaining backgrounds
- After final selection, dominant bckg.:
  - ee – Z/γ* → ee
  - μμ – Z/γ* → μμ
  - em – WW, W+jets
- At the level of final selection: CDF+D0 ~100 signal events ! (m_H = 165 GeV)

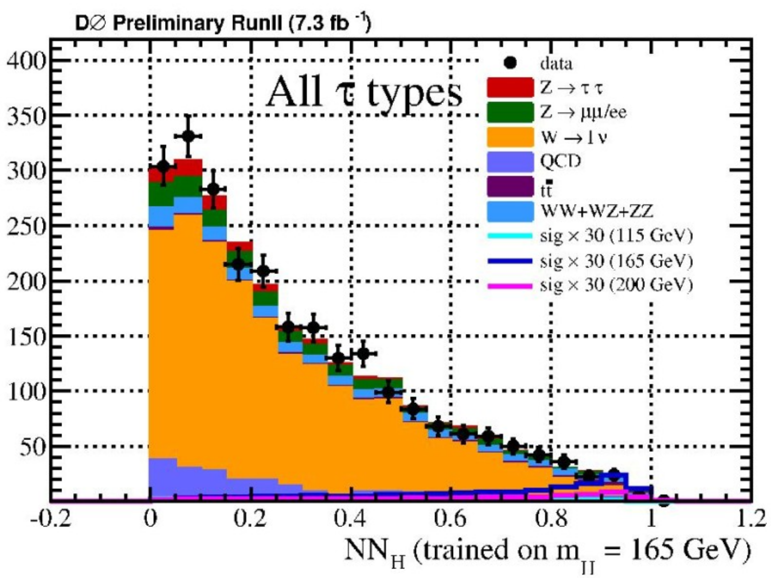


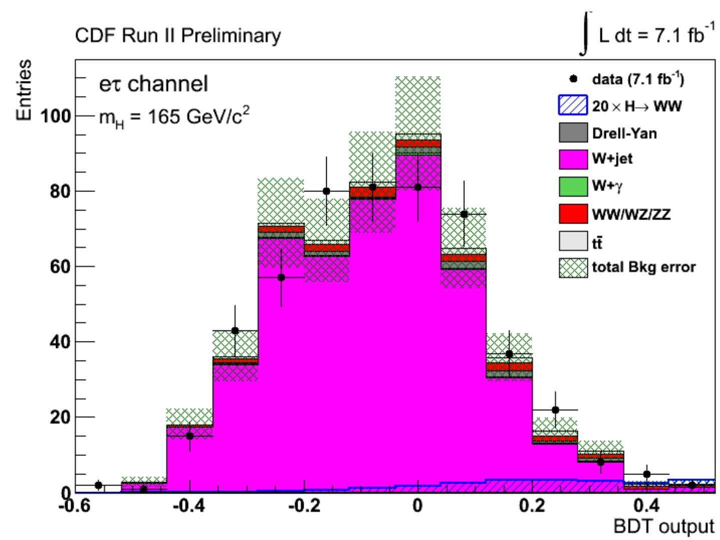


$H \rightarrow WW \rightarrow l\nu\tau_{HAD}\nu$

- CDF: $e\nu+\tau_{HAD}\nu$, $\mu\nu+\tau_{HAD}\nu$
- D0: $\mu\nu+\tau_{HAD}\nu$ +≤1 jet
  - $e/\mu\nu+\tau_{HAD}\nu$ + ≥2 jets
- Dominant bckg.: W+jets
- S/B = ~0.2 % (lower than dilepton)
- CDF: BDT use event kinematics together with τ identification variables
- D0: NN to identify real τ's before final NN

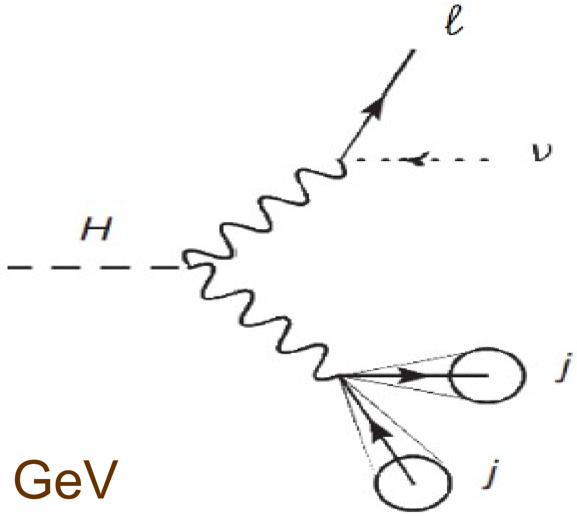


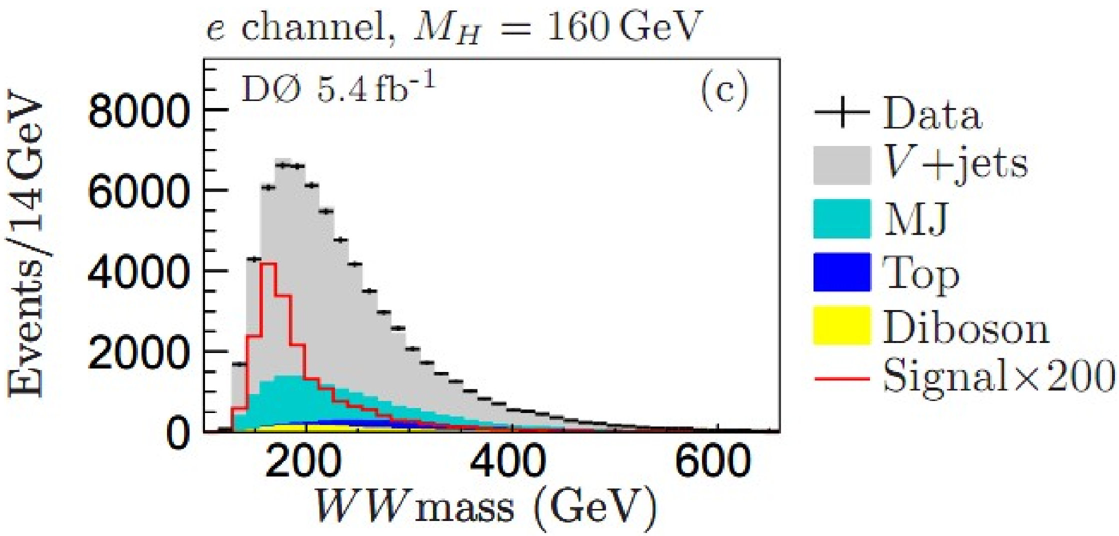


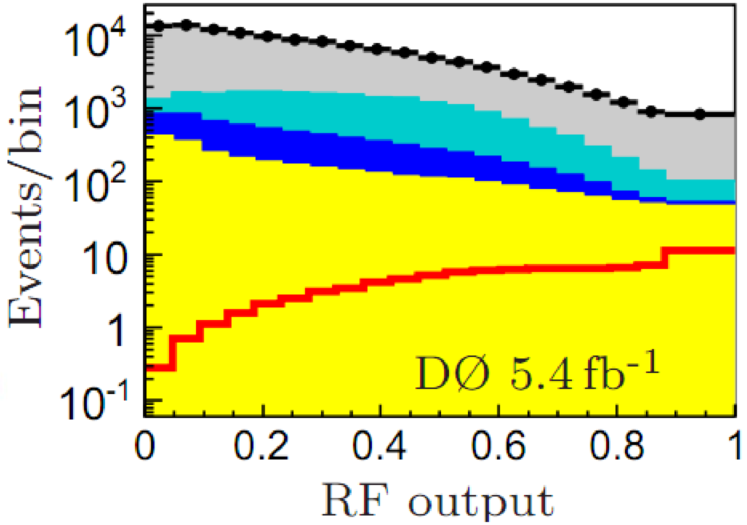


$H \to WW \to l\nu jj$

- D0: $e/\mu\ \nu$ jj
- Factor of ~6 increase in BR
- ~ 90 signal events @ M_H = 160 GeV !
- Dominant bckg. huge: W/Z+jets (~100k ev.!)
- Nice constraint :
  using W mass → get p_z of neutrino
  → possible to estimate Higgs mass for M_H >160 GeV
- CDF result expected for the summer

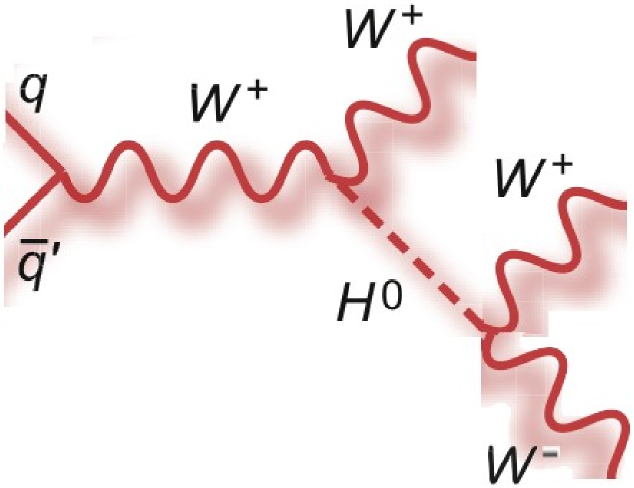


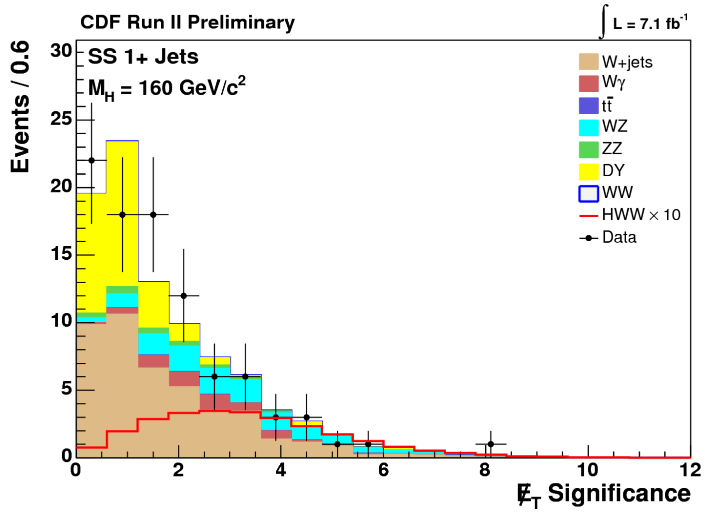


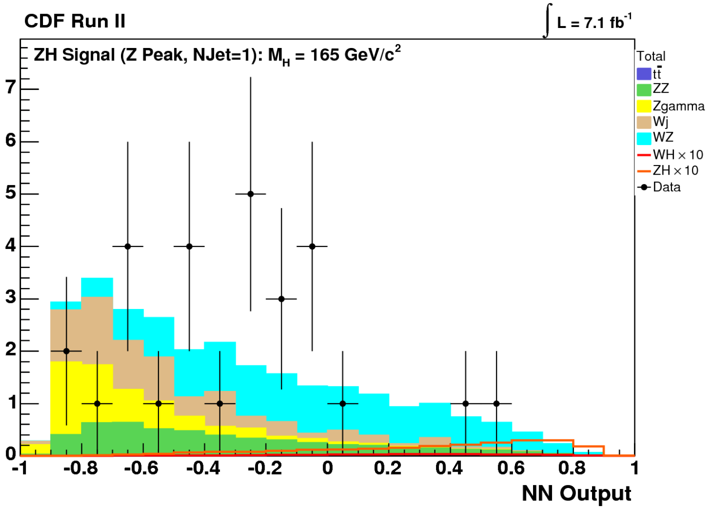


WH, ZH → WWW, ZWW

- CDF:
  - same-sign (1+ jets)
  - 3 trilepton channels (no-Z, in-Z+1jet, in-Z2+j)
- D0:
  - same-sign channels – ee, μμ, eμ
- Advantage: relat. high S/B (trileptons > 3%)
- Disadvantage: small number of events
- Dominant bckg.:
  - Same-sign: W+jets
  - Trileptons: WZ, Z+jets







Summary of sub-channels

- CDF – 12 mutually exclusive channels
  - All channels updated, minor improvements (e.g. updated x-sec. for VH)
- D0 – 34 mutually exclusive channels
  - Added hadronic τ events
- Expected limits at m_H = 165 GeV:

channel	Lum	expec.
CDF:		
OS - 0jet	7.1	1.52
OS - 1jet	7.1	2.13
OS - +2jets	7.1	2.74
low $M_{\ell\ell}$	7.1	10.6
SS	7.1	2.75
trileptons	7.1	4.9
$e/\mu + \tau_{HAD}$	7.1	13.1

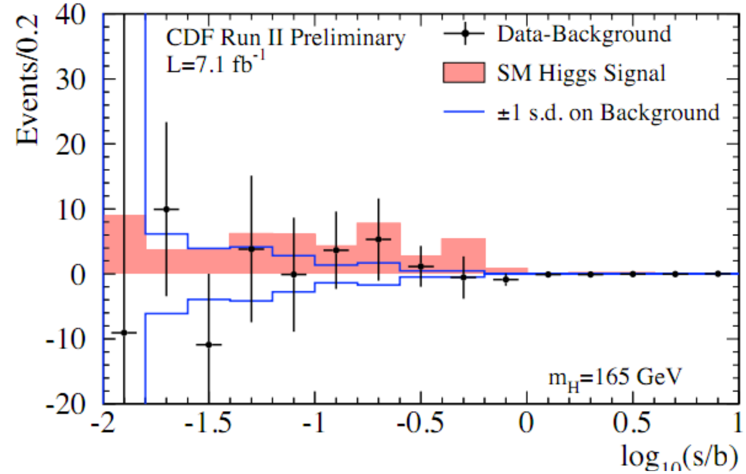
channel	Lum	expec.
D0:		
OS - $e\mu$	8.1	1.26
OS - ee	8.1	2.29
OS - $\mu\mu$	8.1	2.23
$\ell\nu qq$	5.4	5.1
SS	5.4	7.0
$e/\mu\tau_{HAD}$	7.3	7.8
$e/\mu\tau_{HAD}2 + jets$	4.3	12.3

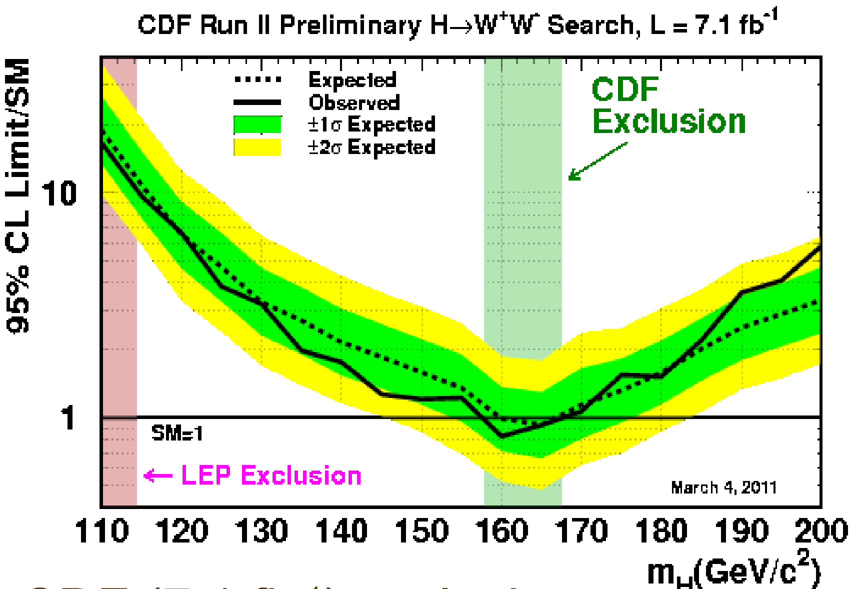
Systematic uncertainties

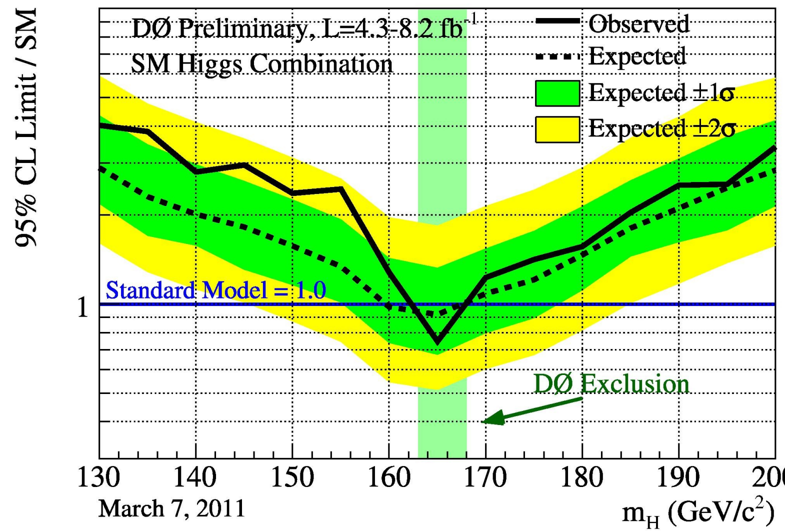
- Careful evaluation of many (~ 20 / experiment) experimental and theoretical uncertainties
- Both rate and shape uncertainties
- Taking into account correlations across the sub-channels
- Limits presented as ratio to SM → take into account uncertainties on theoretical cross-sections
- Largest experimental uncertainties:
  - Acceptance change due to higher order diagrams – 10%
  - Jet energy scale – varied by process: 3% – 25%
  - Luminosity – 6%
  - Lepton reconstruction efficiency 2 - 5%
- Largest theoretical uncertainties:
  - cross-section uncertainty – typically 5 – 10 %
  - gg → H exception – overall ~20% uncertainty
    - in 2+jets channel: 33% (scale), 29.7%(PDF)
      - A new NLO calculation: Campbell et al. – PRD81, 074023 (2010)
- **Overall effect: degrading the limits by 15 – 20 %**

Higgs limits

- No excess above background
  → set limits
- Only high-mass channels included
- MVA templates used as inputs for limit setting procedure







CDF (7.1 fb^{-1}) exclusion:
expected: 159 – 168 GeV
observed: 158 – 168 GeV

D0 (8.2 fb^{-1}) exclusion:
expected: 160 – 168 GeV
observed: 163 – 168 GeV

First single experiment exclusions from Tevatron!

Conclusions

- Updated results from last summer
- Another milestone achieved – **both experiments reached exclusion sensitivity individually**
- Major improvements expected for summer
  - Additional channels
  - Better object identification, etc.
- Unfortunately, no Tevatron running beyond 2011 → final dataset ~10 fb^{-1}
  - Aiming for full mass range Higgs sensitivity

BACKUP

Input Higgs Boson Production Cross Sections

m_H (GeV)	$\sigma_{gg\to H}^{NNLL}$	σ_{WH}	σ_{ZH}	σ_{VBF}	$\mathrm{Br}_{\mathrm{H\to WW}}$
110	1.385	0.212	0.126	0.085	0.046
115	1.216	0.175	0.104	0.079	0.083
120	1.072	0.150	0.090	0.073	0.136
125	0.949	0.130	0.079	0.067	0.208
130	0.843	0.112	0.069	0.062	0.294
135	0.751	0.097	0.060	0.058	0.391
140	0.671	0.085	0.053	0.053	0.492
145	0.601	0.074	0.047	0.049	0.592
150	0.539	0.064	0.041	0.046	0.689
155	0.484	0.056	0.036	0.042	0.789
160	0.432	0.049	0.031	0.039	0.905
165	0.384	0.044	0.028	0.037	0.959
170	0.344	0.039	0.025	0.034	0.964
175	0.310	0.034	0.023	0.032	0.958
180	0.279	0.030	0.020	0.029	0.933
185	0.252	0.027	0.018	0.027	0.845
190	0.228	0.024	0.016	0.025	0.787
195	0.207	0.021	0.014	0.024	0.759
200	0.189	0.019	0.013	0.022	0.743

Expected and Observed Limits versus Higgs Mass – CDF

m_H (GeV/c^2)	obs (Limit/SM)	-2σ exp (Limit/SM)	-1σ exp (Limit/SM)	Median exp (Limit/SM)	$+1\sigma$exp (Limit/SM)	$+2\sigma$exp (Limit/SM)
110	16.61	9.87	13.43	18.94	26.77	37.33
115	9.62	5.85	7.73	10.75	15.17	21.25
120	6.60	3.32	4.61	6.49	9.06	12.43
125	3.81	2.40	3.29	4.66	6.59	9.19
130	3.20	1.71	2.32	3.26	4.60	6.42
135	1.98	1.39	1.92	2.69	3.78	5.21
140	1.76	1.16	1.54	2.16	3.05	4.28
145	1.27	1.02	1.35	1.87	2.60	3.59
150	1.21	0.86	1.14	1.59	2.23	3.12
155	1.22	0.69	0.96	1.36	1.90	2.61
160	0.83	0.53	0.71	0.99	1.37	1.88
165	0.92	0.48	0.66	0.93	1.30	1.79
170	1.07	0.62	0.81	1.14	1.66	2.39
175	1.55	0.70	0.95	1.32	1.83	2.50
180	1.52	0.87	1.15	1.58	2.20	3.05
185	2.21	1.07	1.46	2.02	2.76	3.72
190	3.58	1.34	1.81	2.51	3.49	4.79
195	4.06	1.50	2.07	2.88	3.96	5.35
200	5.77	1.74	2.38	3.33	4.64	6.39

Future prospects for high-mass Higgs at Tevatron