Higgs searches at the Tevatron

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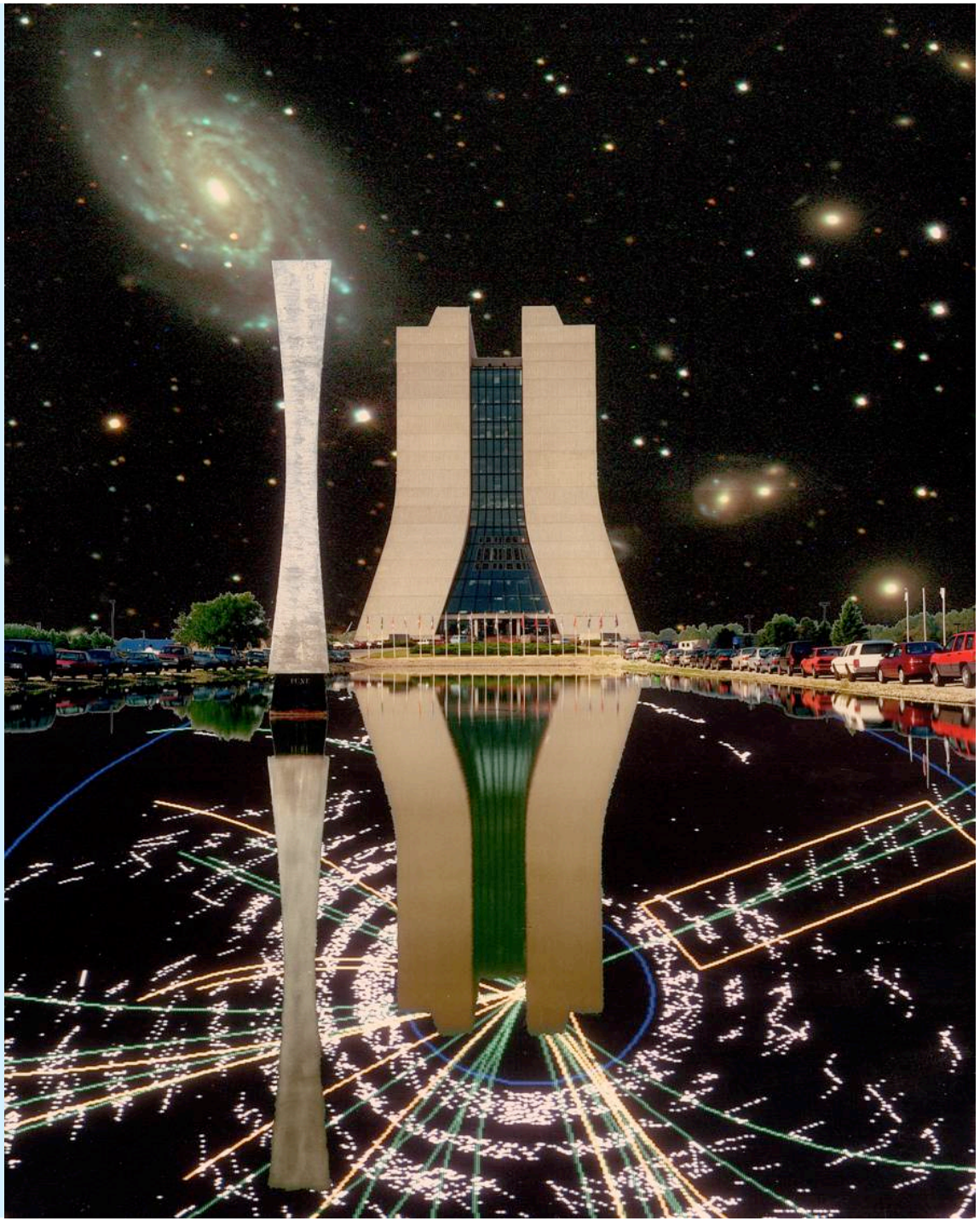
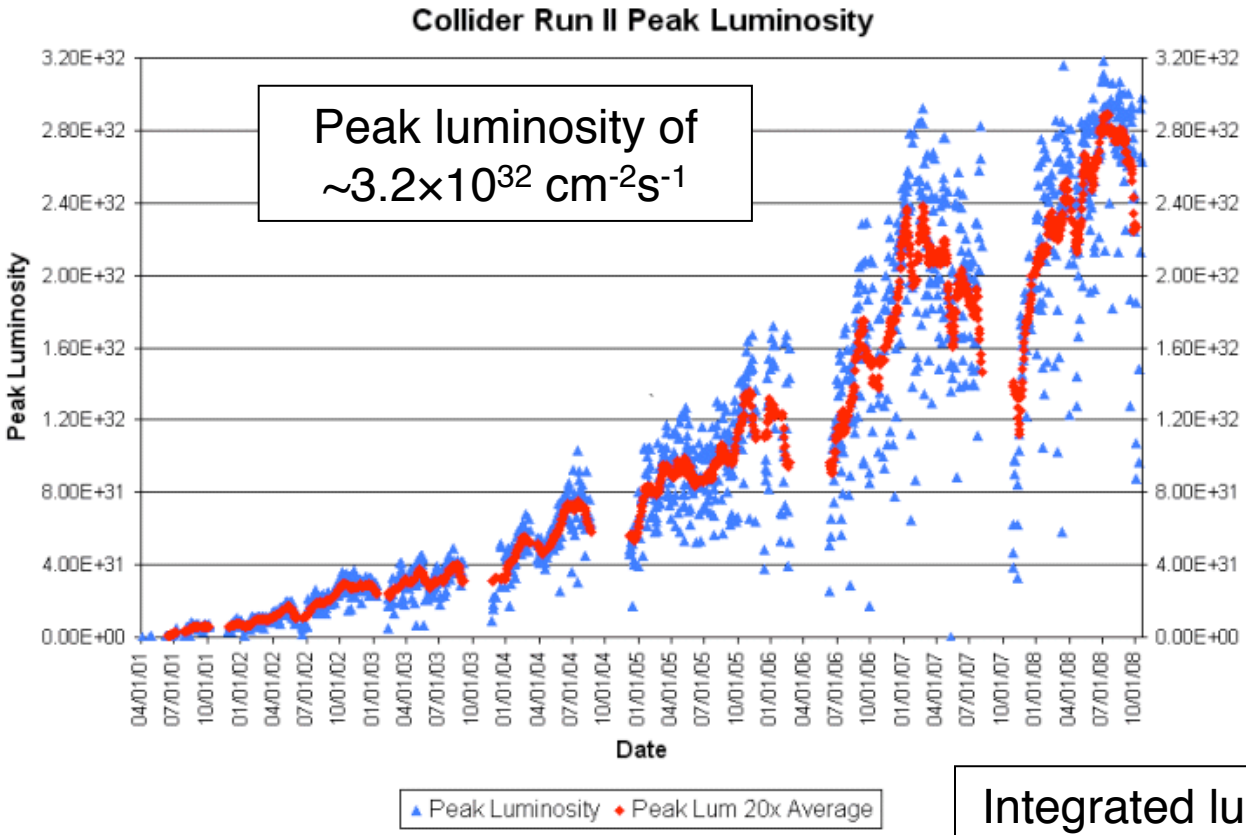
Outline

- **Introduction**
  - Tevatron, CDF, DØ
- **The SM Higgs**
  - WH → $\ell\nu bb$
  - ZH → $\ell\ell/\nu\nu bb$
  - H → WW* → $\ell^+\ell^-\nu\nu$
  - H → $\gamma\gamma$, H → $\tau\tau jj$, ttH
- **SUSY Higgs**
  - bh/bbh(→bb)
  - h → $\tau\tau$
- **Summary**

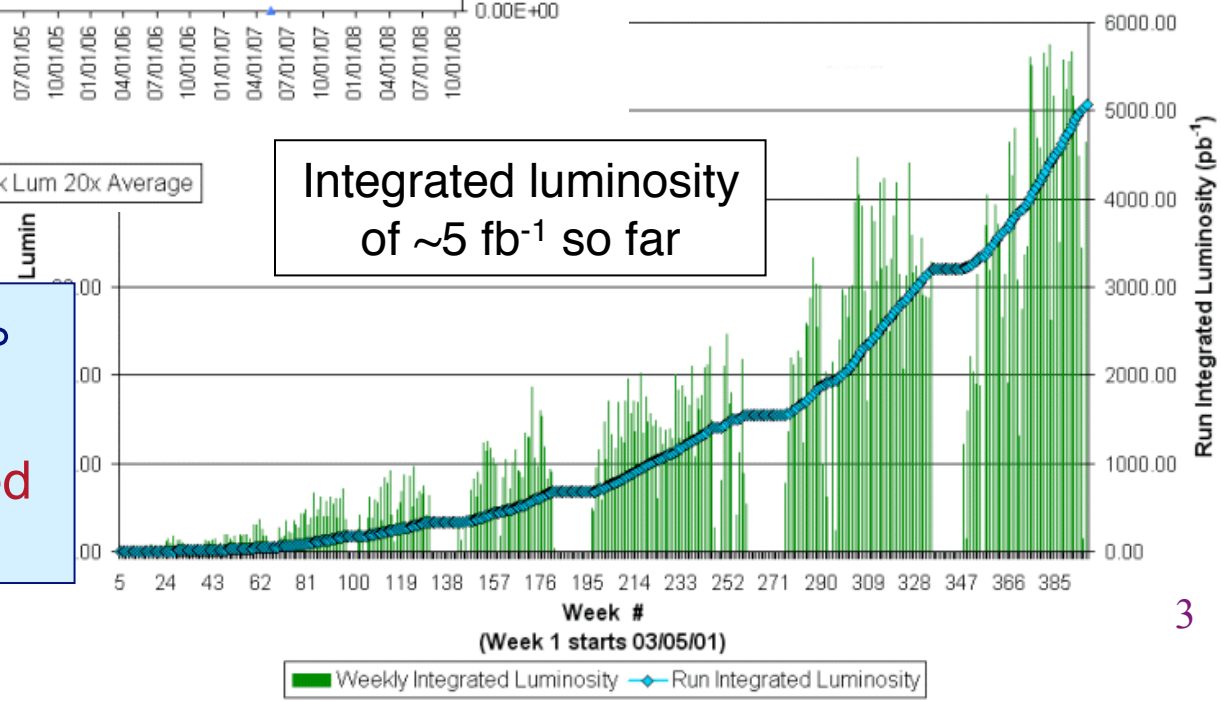


Tevatron peak and integrated luminosities, Oct. '08



Peak luminosity of ~3.2×10^{32} $cm^{-2}s^{-1}$

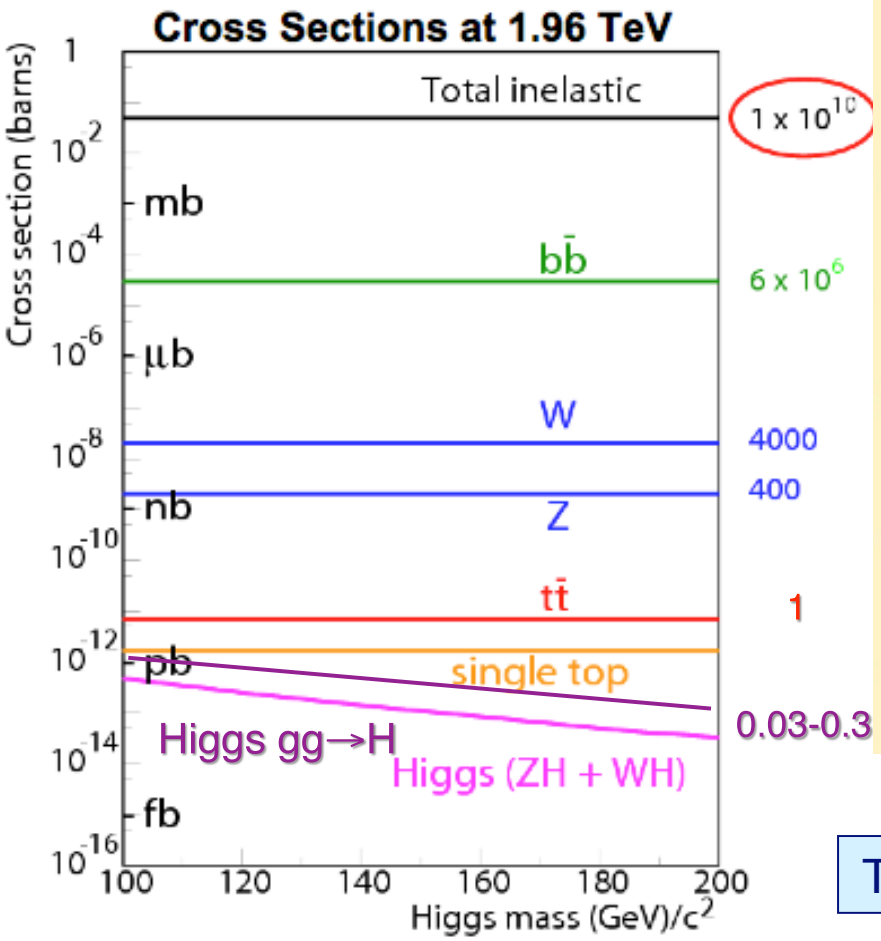
- Delivered integrated luminosity ~5 fb^{-1}
- Data set has doubled every year
- Expect ~ 8 fb^{-1} by the end of 2009

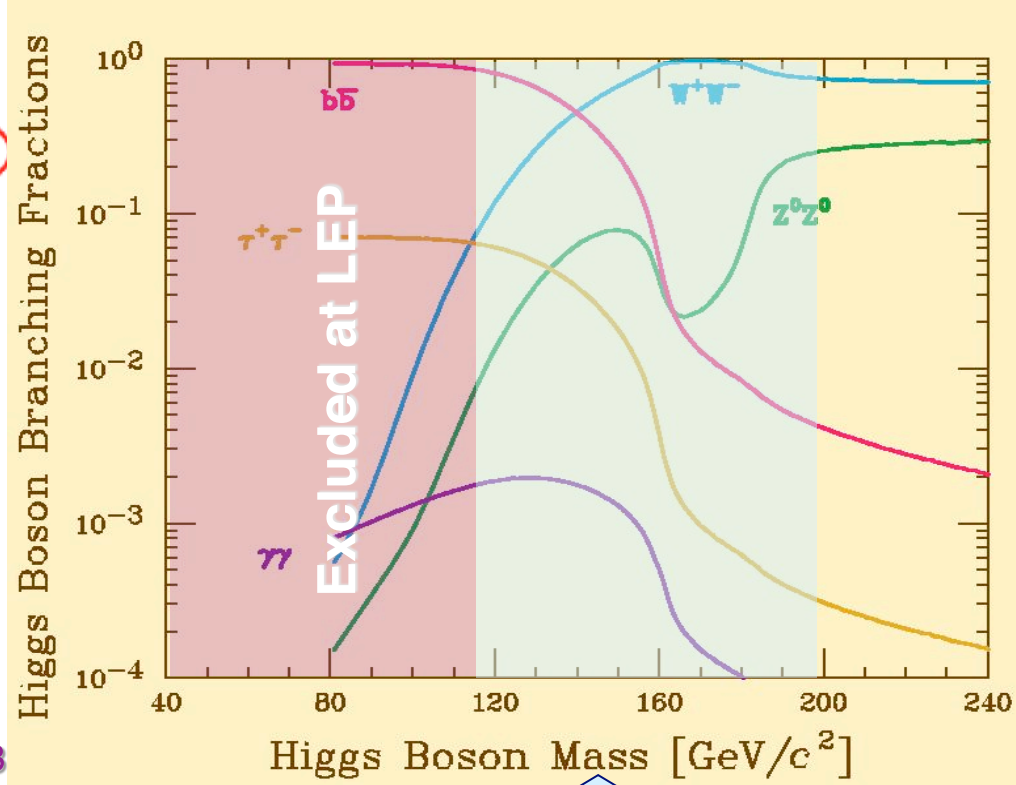


Integrated luminosity of ~5 fb^{-1} so far

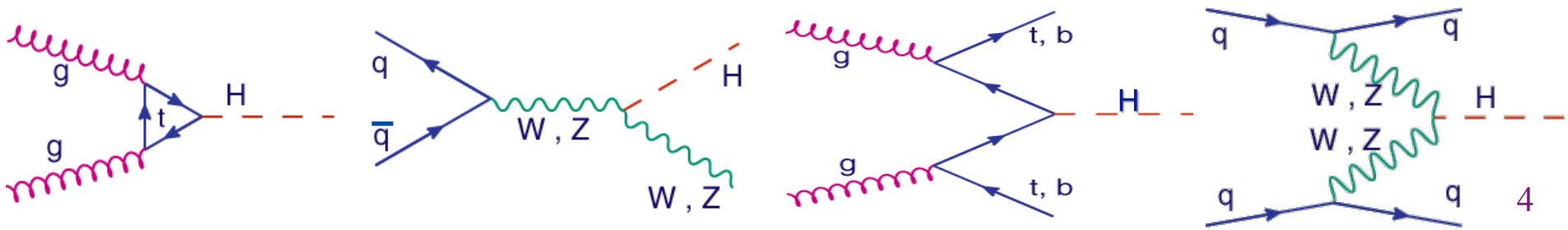
- CDF/DØ operate at ~ 90% efficiency
- Following results are based on 1 – 3 fb^{-1} of data

The SM Higgs boson production and decay



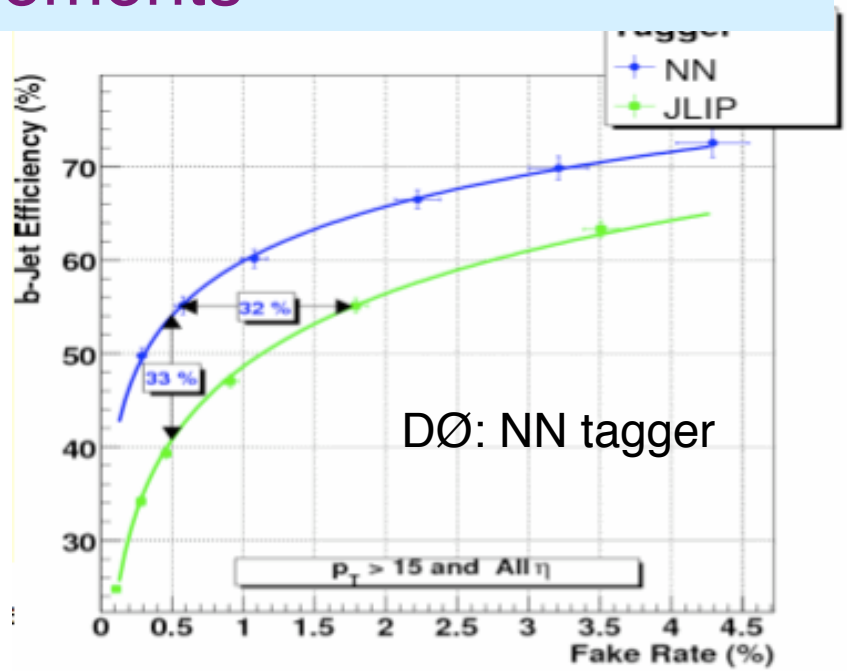


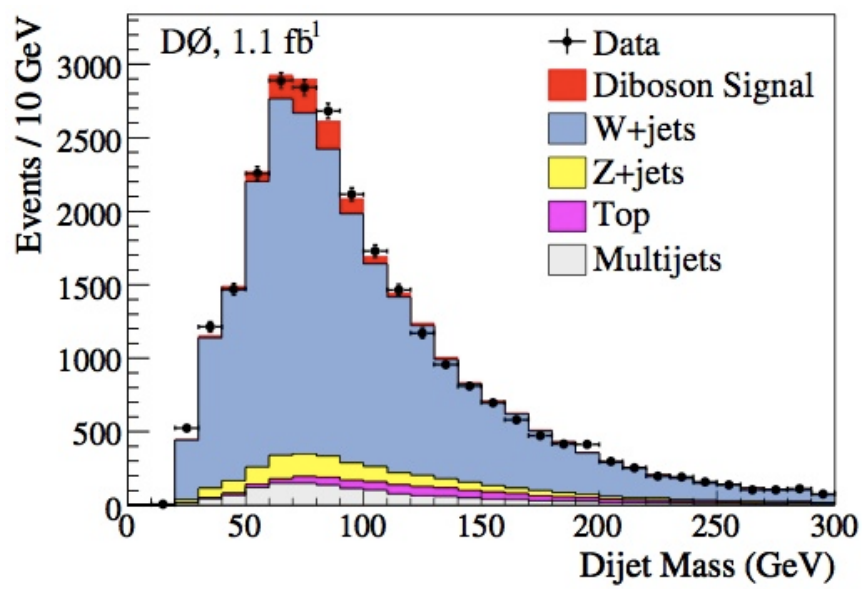
Tevatron can explore bb and WW decay modes



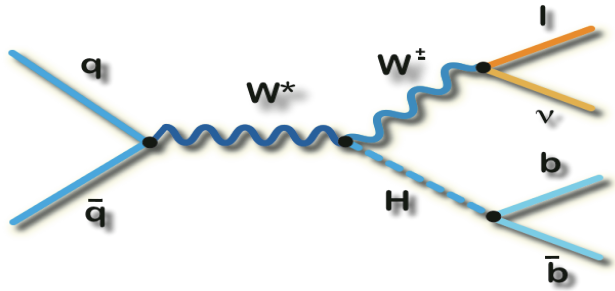
Recent improvements

- Better trigger algorithms
- b-tagging: ~60% efficiency at ~1% mis-tagging rate
- Di-jet mass resolution (CDF)
  - Combine calorimeter and tracking information
  - NN based jet energy corrections
- Recover the acceptance losses
- Precise measurements of the bkgd. and reference (low x-section) processes
  - W/Z+jets, W/Z+b-jets, ZZ→ℓℓ/ννℓℓ, single top, WW/WZ→ℓν+jets
- Tuning of the corresponding MC event generators
- Extensive use of multivariate analysis techniques (NN, ME, DT, …)

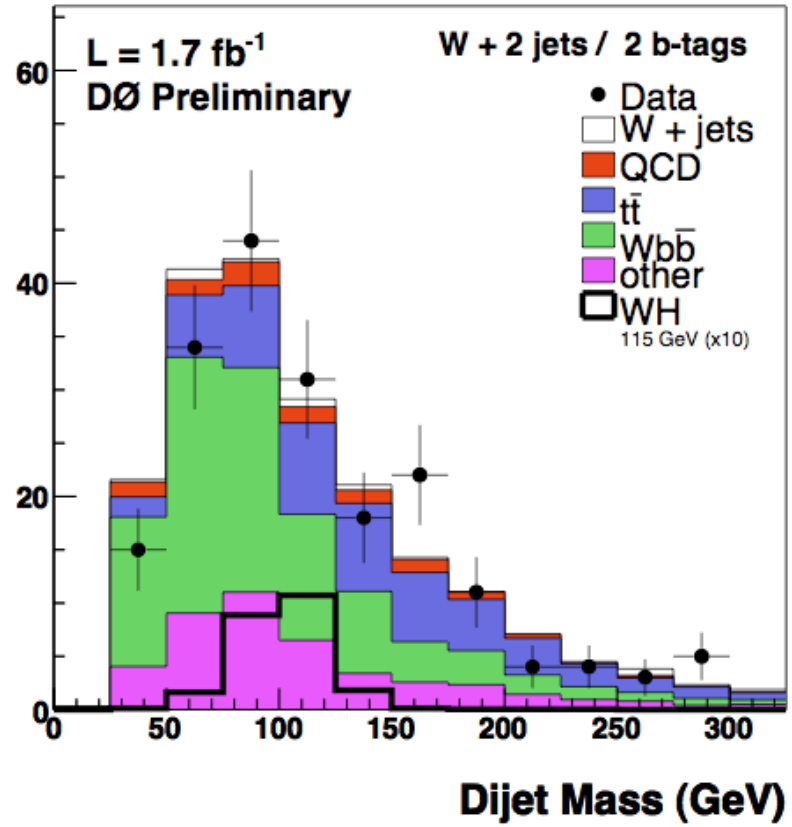


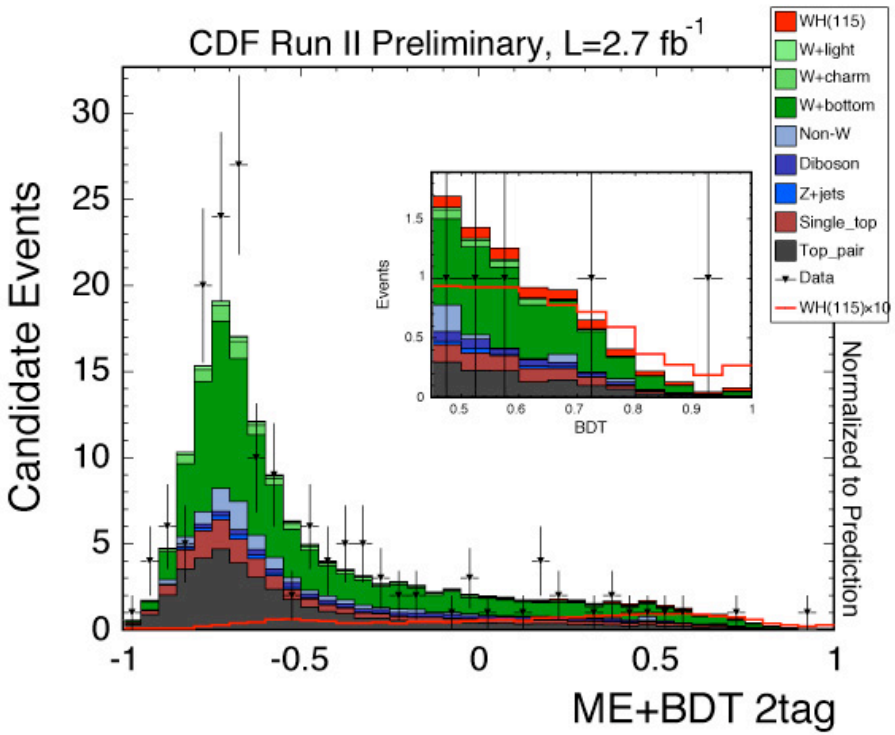


WH → ℓνbb channel



- Signature: high p_T lepton, MET and b jets
- Bkgd.: W+bb/qq, (single) top, non-W/QCD
- Normalize the dominant W+bb bkgd. in control regions; shape from MC



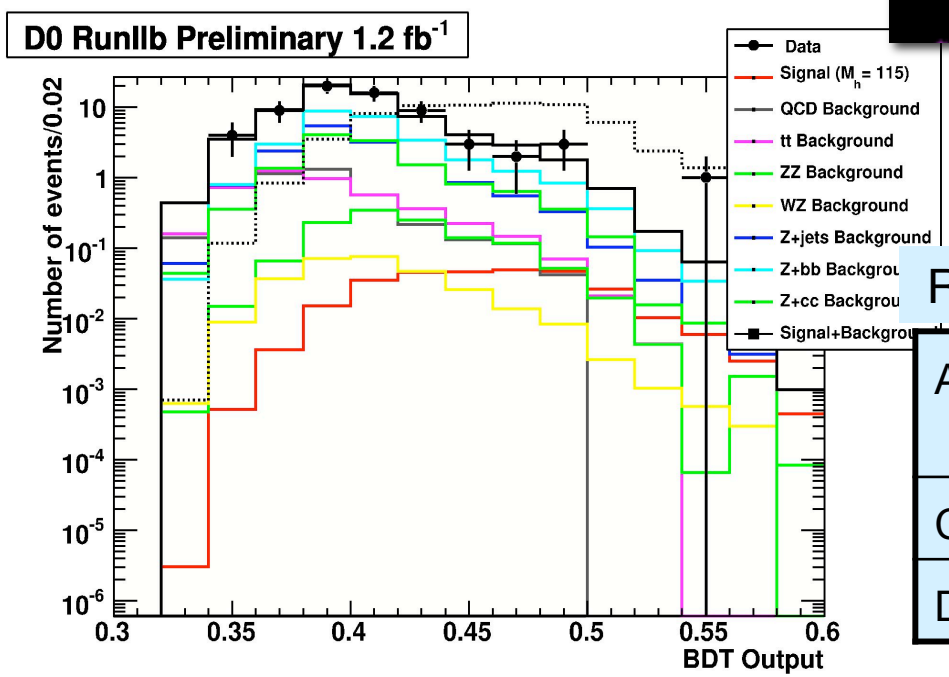


Results for m_H = 115 GeV: 95% CL limit/SM

Analysis	Lum (fb^{-1})	Higgs events	Exp. limit	Obs. limit
CDF ME+BDT	2.7	7.8	5.6	5.7
DØ NN	1.7	7.5	8.5	9.3

ZH → ℓℓbb channel

- Two high p_T leptons plus b jets → clean signature → can loosen object ID requirements
  - Loose b-tagging operating point
  - Isolated tracks and calorimeter only electrons
- The dominant bkgd.: Z + b jets

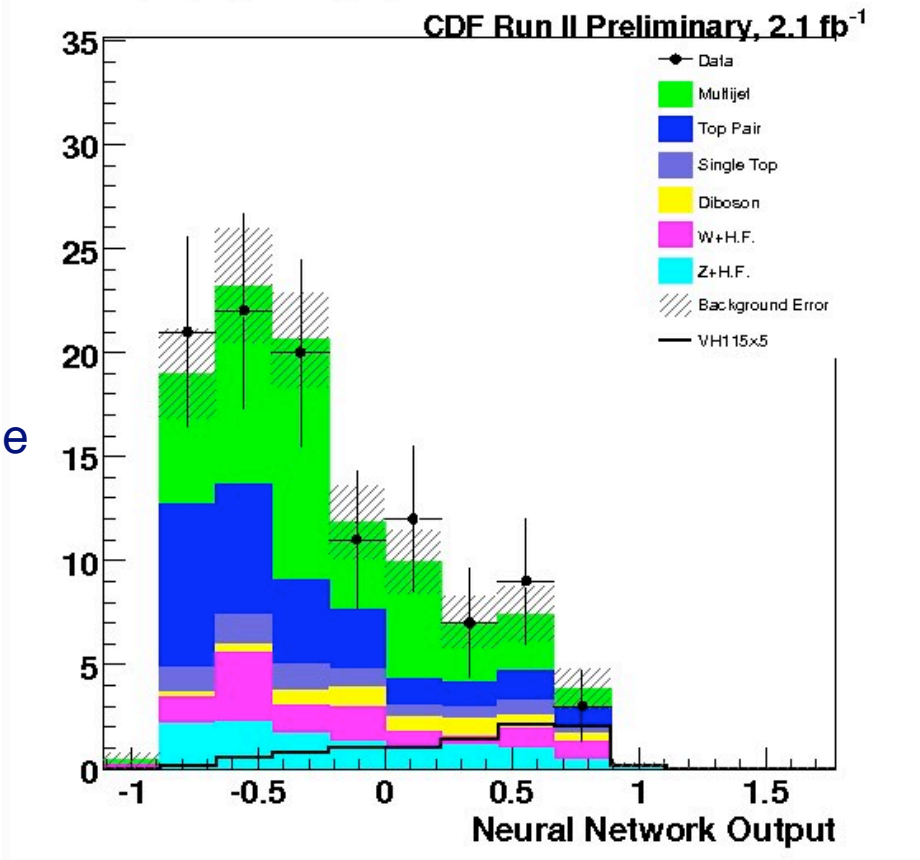


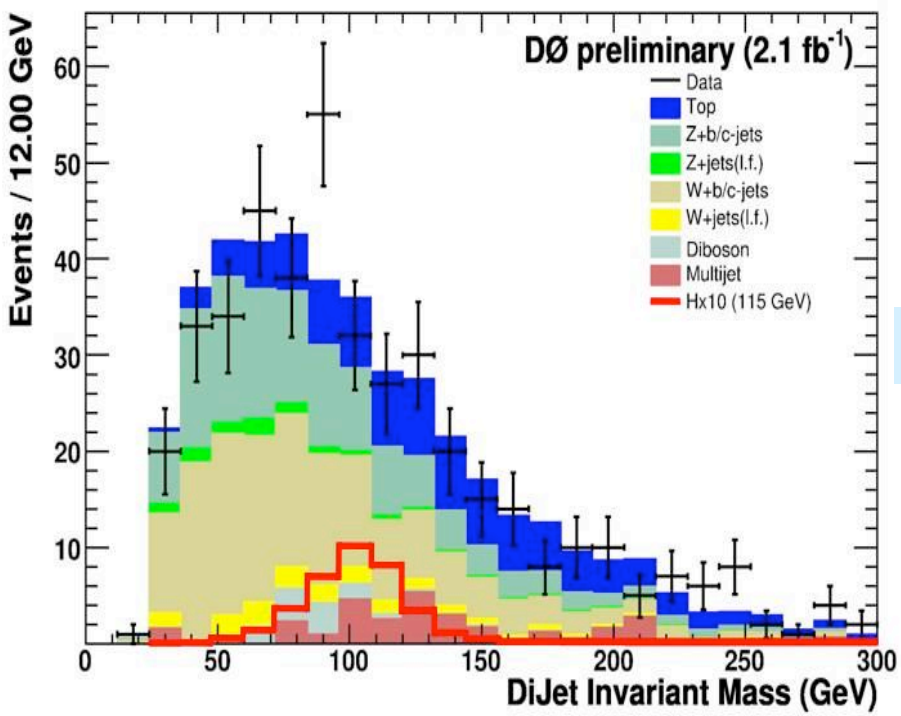
Results for m_H = 115 GeV: 95% CL limit/SM

Analysis	Lum (fb^{-1})	Higgs events	Exp. limit	Obs. limit
CDF NN	2.4	1.8	11.8	11.6
DØ NN,BDT	2.3	2.0	12.3	11.0

ZH → ννbb channel

- ZH→ννbb, WH→ℓνbb (ℓ not detected)
- Signature: MET and b jets
- Bkgd: W/Z+(b-)jets, top, instrumental/ QCD (b-)jets
- QCD background determined from data
  - Use missing p_T built from tracks to define control regions





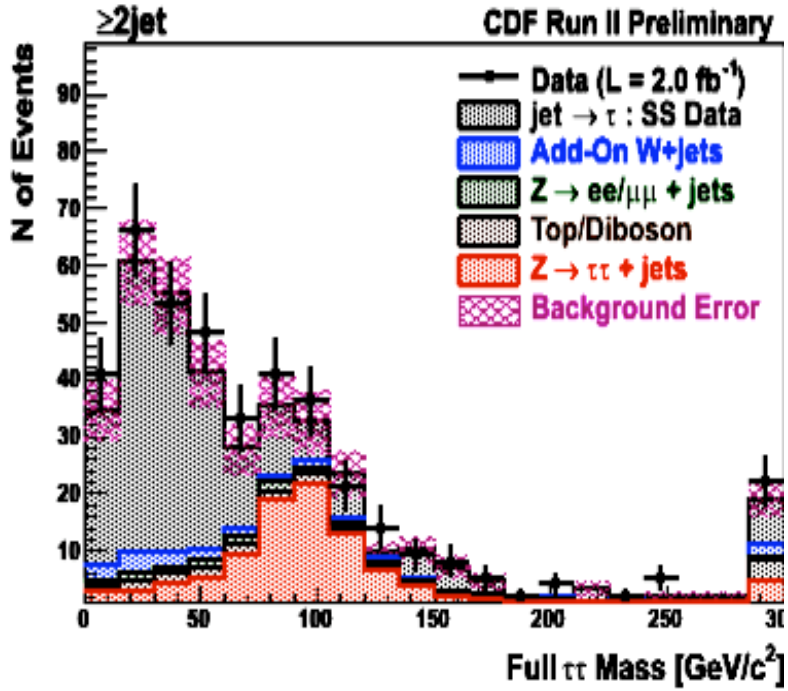
Results for m_H = 115 GeV: 95% CL limit/SM

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.1	7.3	6.3	7.9
DØ BDT	2.1	3.7	8.4	7.5

A word of encouragement for LHC (1)

CDF: H → τ τ + 2 jets

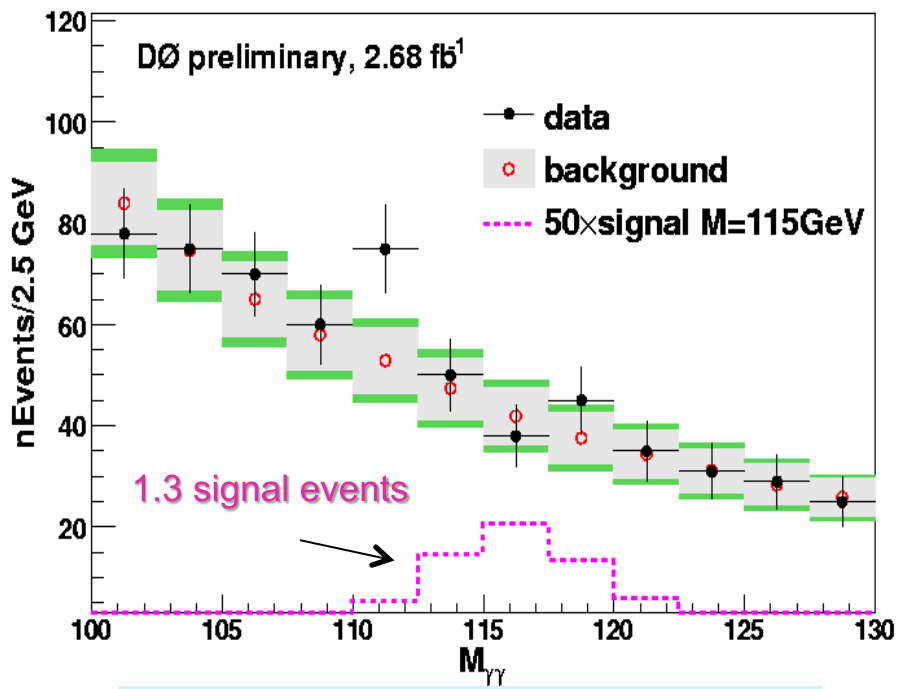
- Simultaneous search in W/ZH, VBF and ggH channels
- 1 had τ + 1 opp. sign lepton
- Train 3 Neural Networks: H vs Z, H vs tt and H vs QCD



95% CL limit in σ×B/SM
30.5 (24.8) at m_H=115 GeV

DØ: H → γγ

- NN-based photon identification
- Bkgd.: γγ direct production (60%) and γ+jet/di-jets (data driven)
- Look for excess in di-photon mass spectrum

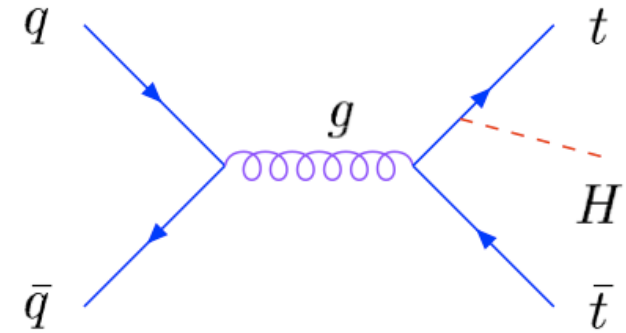


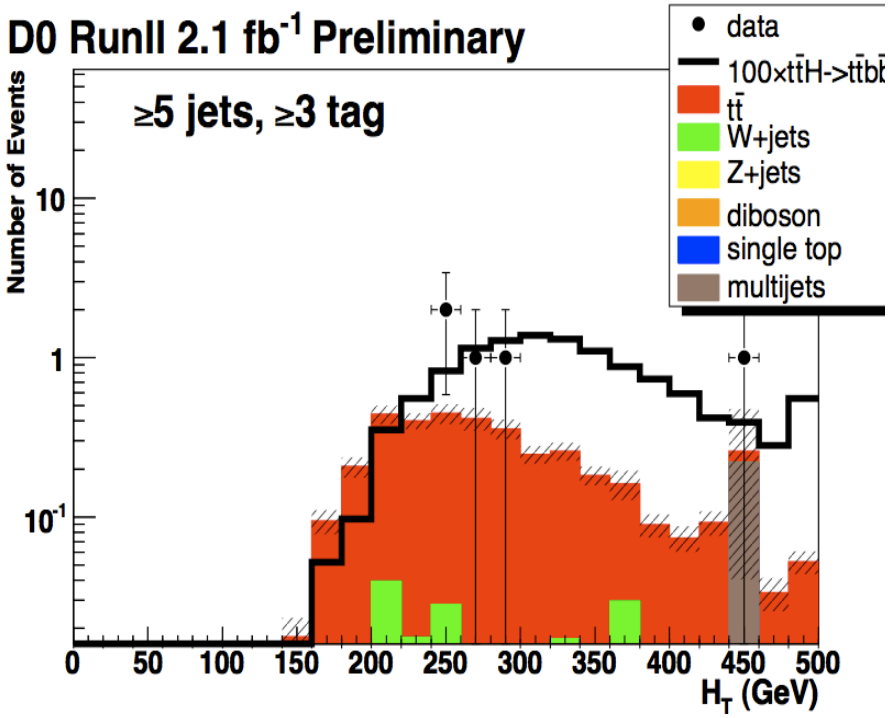
95% CL limit in σ×B/SM
30.8 (23.2) at m_H=115 GeV

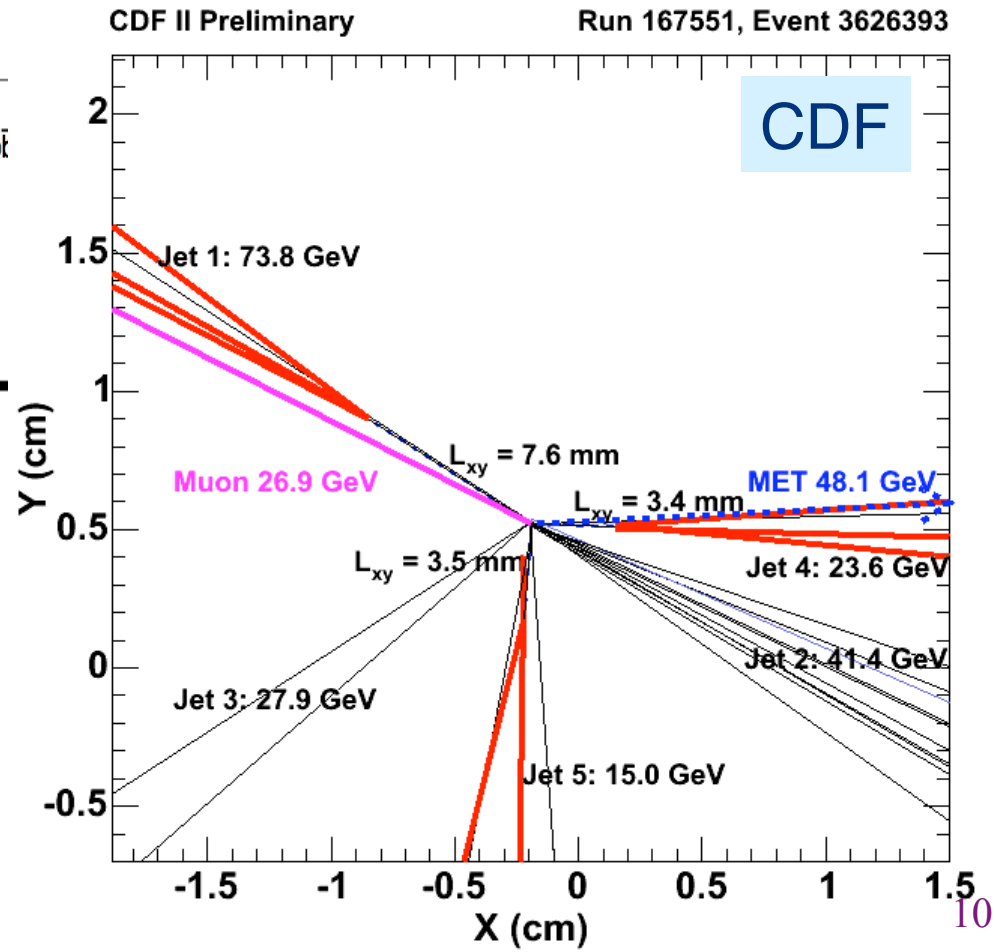
A word of encouragement for LHC (2)

DØ: ttH → ℓνbbbbqq

- 1 lepton + MET + ≥5 jets
- Treat number of b-tags separately
- Employ jets scalar sum (H_T) discriminant to extract signal



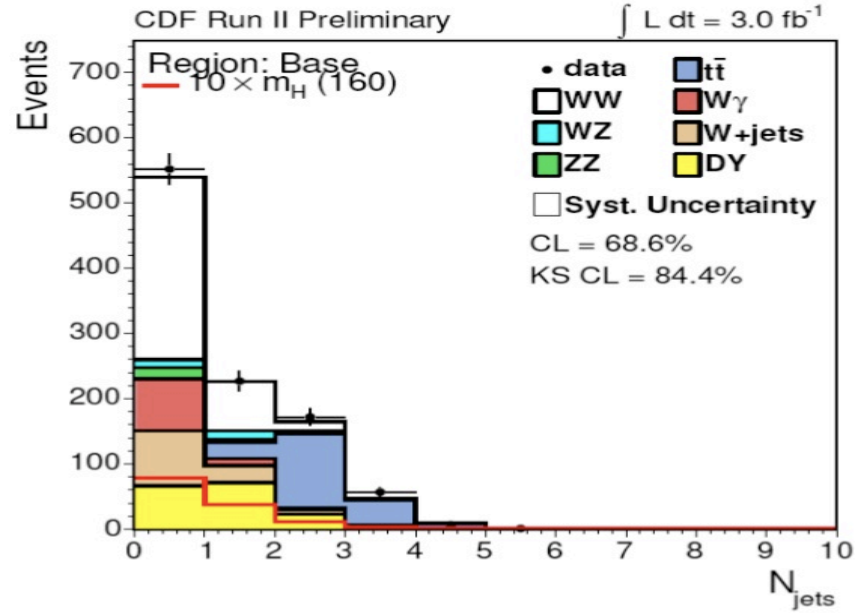


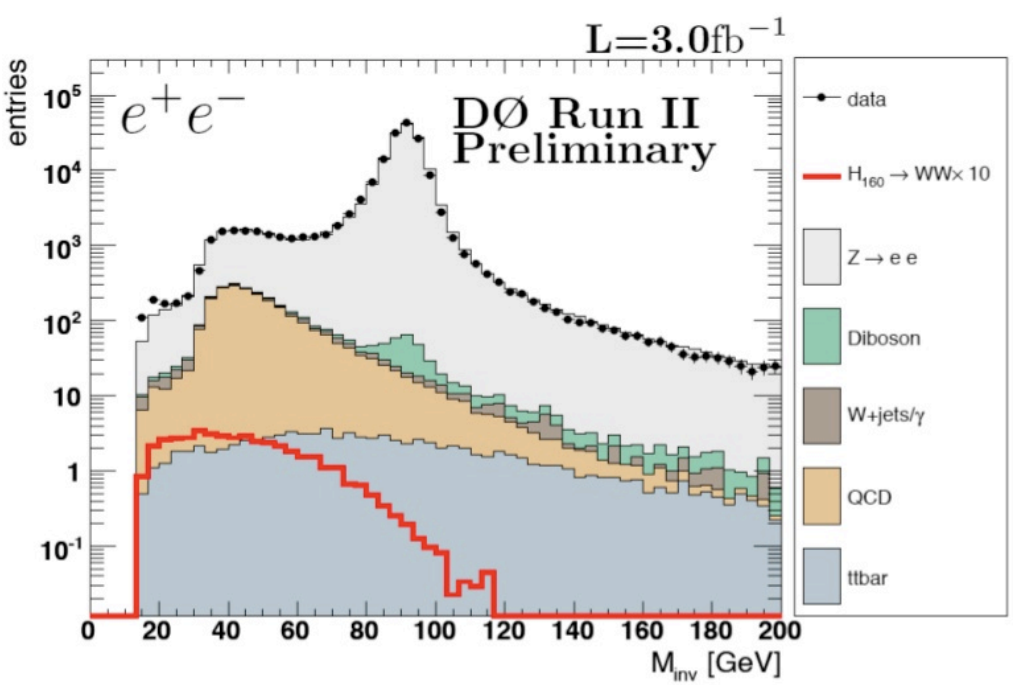


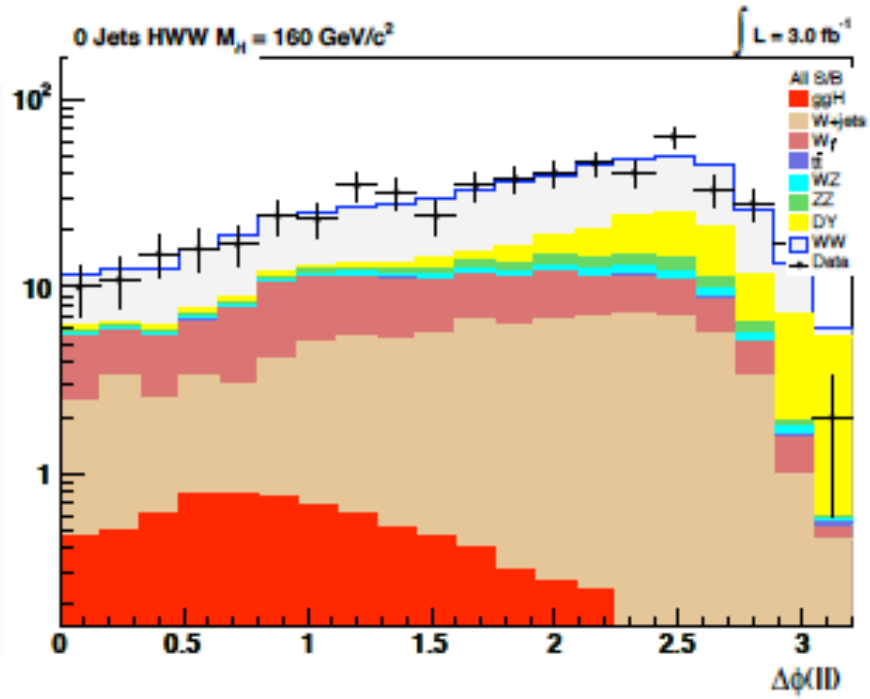
95% CL limit in σ×B/SM
63.9 (45.3) at m_H=115 GeV

H → WW* → ℓνℓν channel

- Employ all production mechanisms
  gg→H, W/ZH and VBF
- Signatures: two high p_T leptons + MET + 0-/1-/2-jets
- Bkgd. strongly depends on the number of jets in final state/process:
  WW, WZ, ZZ, W+γ/jets, DY, top

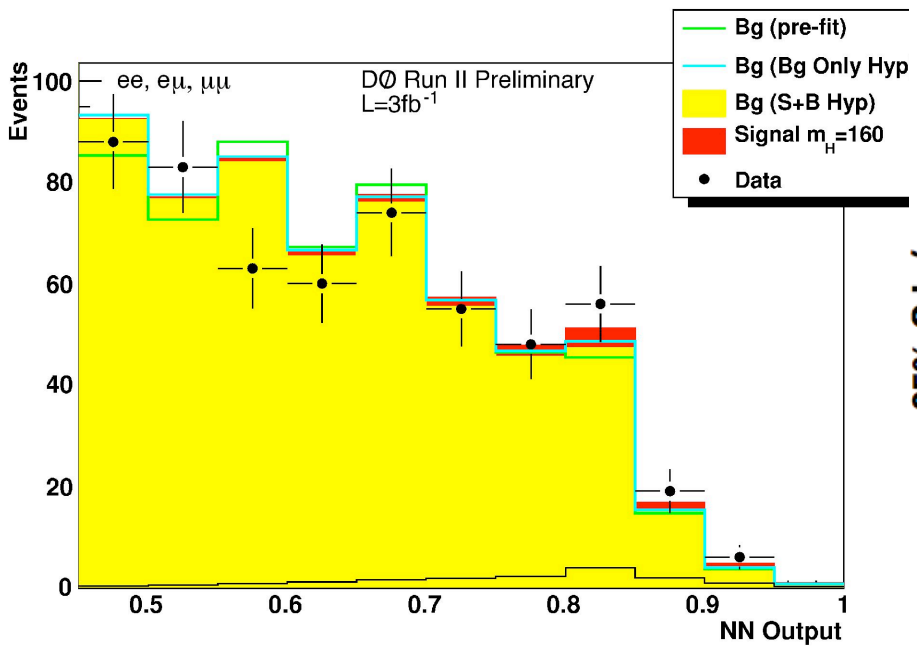


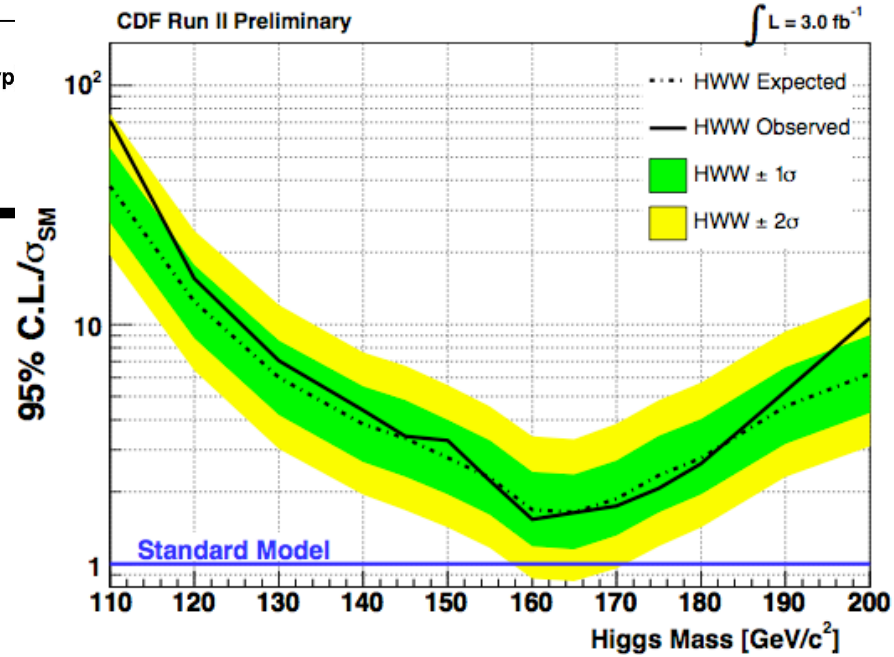




H → WW* → ℓνℓν limits

- Most promising channel to probe the SM Higgs





Results for m_H = 165 GeV: 95% CL limit/SM

Analysis	Lum (fb^{-1})	Higgs events	Exp. limit	Obs. limit
CDF ME+NN	3.0	17.2	1.6	1.6
DØ NN	3.0	15.6	1.9	2.0

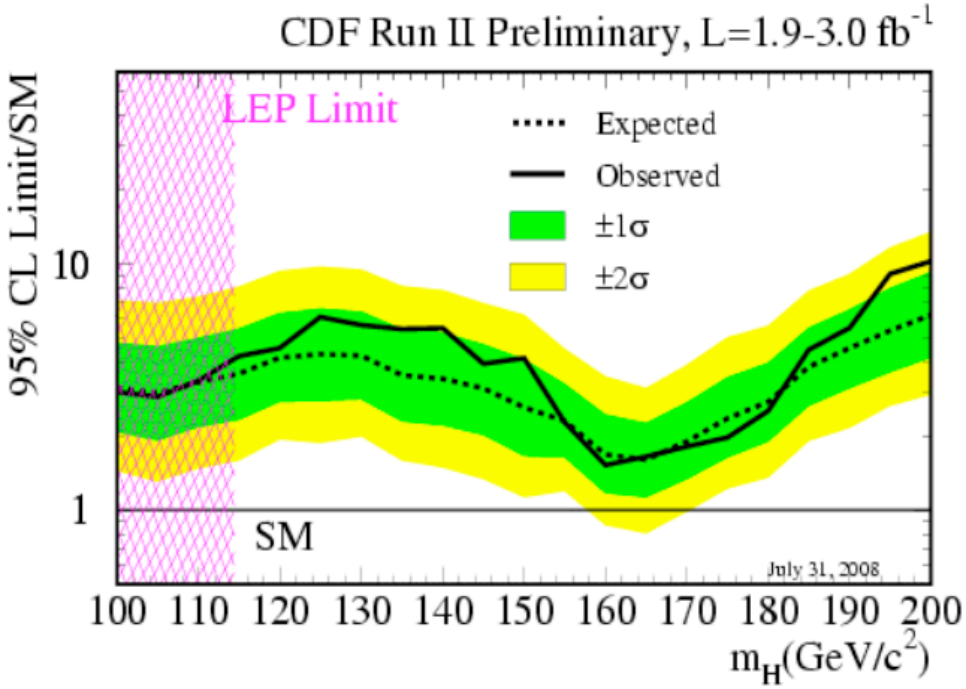
H → WW systematic uncertainties

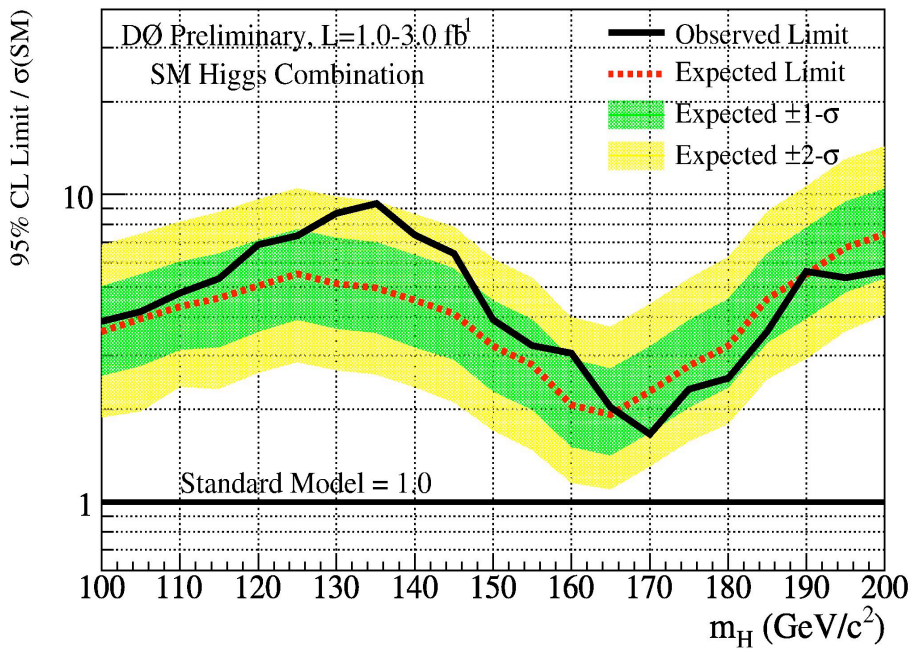
CDF: $H \to WW \to \ell^{\pm}\ell'^{\mp} + 0$ Jets Analysis

Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet	$gg \to H$	WH	ZH	VBF
Cross Section											
Scale								10.9%			
PDF Model								5.1%			
Total	*10.0%*	*10.0%*	*10.0%*	15.0%	5.0%	10.0%		12.0%			
Acceptance											
Scale (leptons)								2.5%			
Scale (jets)								4.6%			
PDF Model (leptons)	1.9%	2.7%	2.7%	2.1%	4.1%	2.2%		1.5%			
PDF Model (jets)								0.9%			
Higher-order Diagrams	**5.5%**	**10.0%**	**10.0%**	10.0%	**5.0%**	**10.0%**					
Missing Et Modeling	1.0%	1.0%	1.0%	1.0%	20.0%	1.0%		1.0%			
Conversion Modeling						20.0%					
Jet Fake Rates											
(Low S/B)							21.5%				
(High S/B)							27.7%				
MC Run Dependence	3.9%			4.5%		4.5%		3.7%			
Lepton ID Efficiencies	2.0%	1.7%	2.0%	2.0%	1.9%	1.4%		1.9%			
Trigger Efficiencies	2.1%	2.1%	2.1%	2.0%	3.4%	7.0%		3.3%			
Luminosity	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%		5.9%			

- Shape systematic evaluated for
  - Scale variations, ISR, gluon pdf, Pythia vs. NL0 kinematics, jet energy scale for signal and backgrounds. Included in limit setting if significant.
  - Systematic treatment developed in collaboratively between CDF and DØ

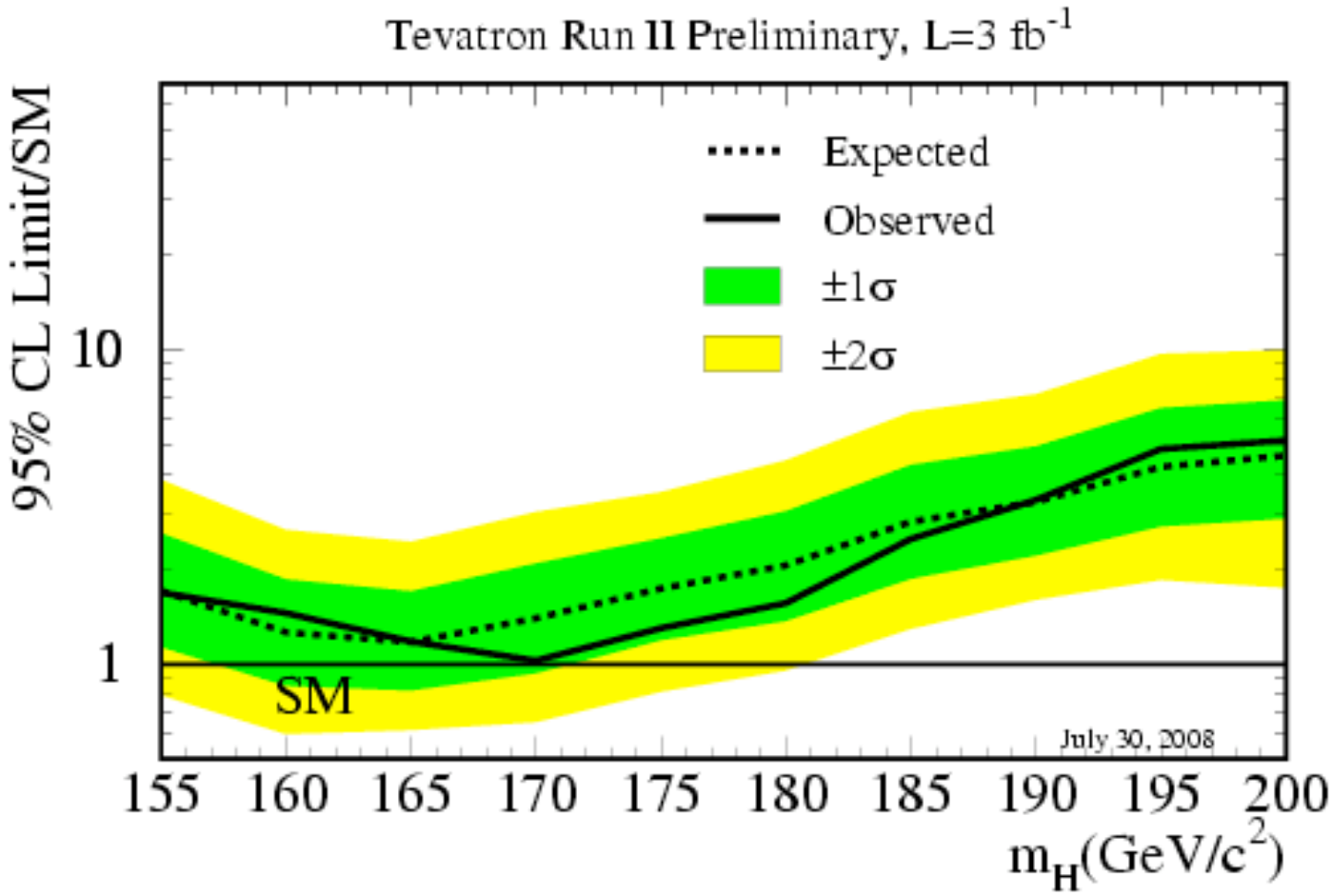
CDF/DØ, full mass range





- Expected sensitivity of CDF and DØ combined: < 3×SM at 115 GeV

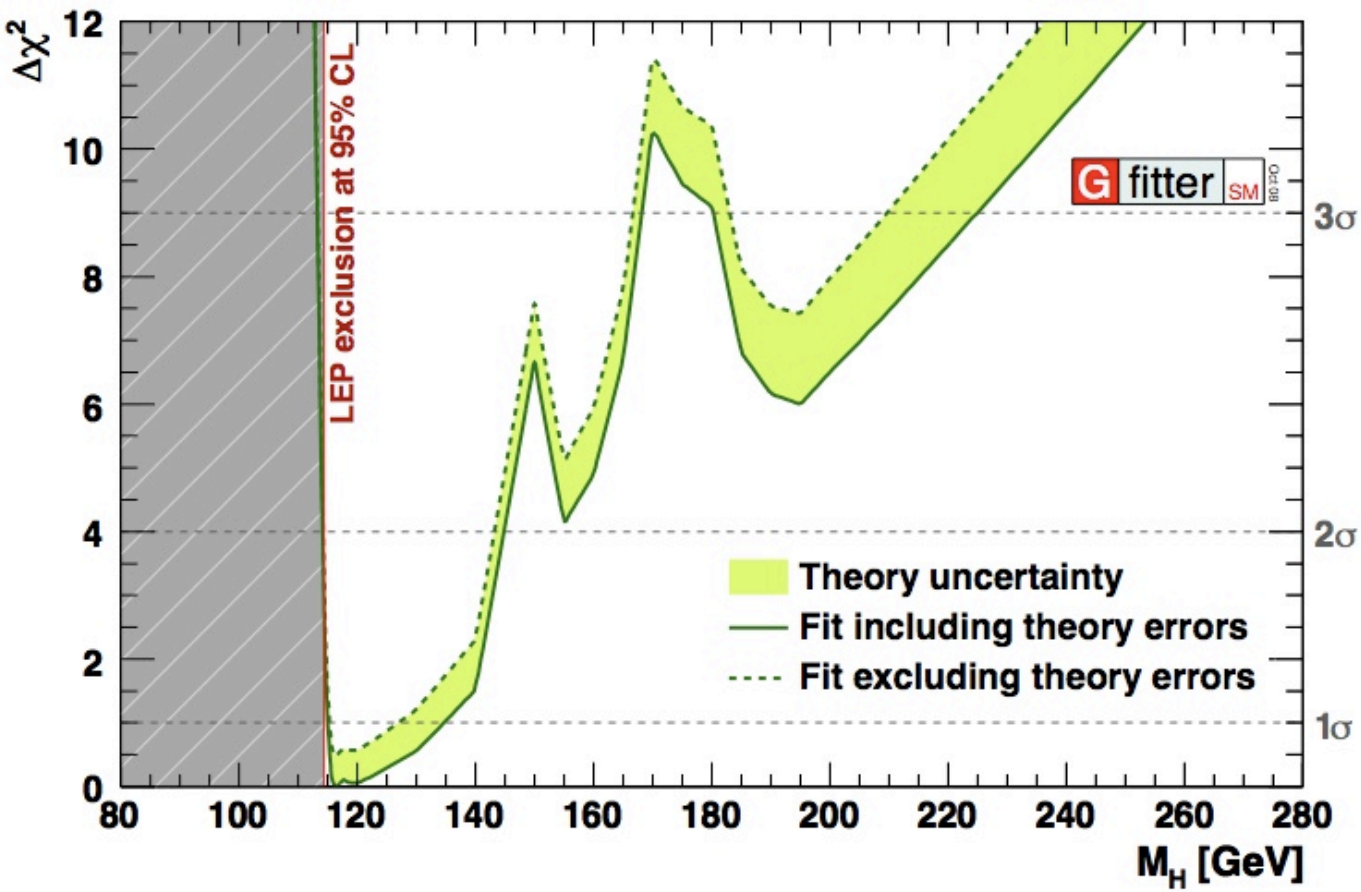
Combined limits: high mass



- Low mass combination difficult/time consuming due to ~70 channels/analyses
- At m_H = 170 GeV: expect 1.4, observe 1 event

Impact on the global SM Higgs fit

- Gfitter Group, arXiv:0810.3664 [hep-ph]
  - Includes constraints from LEP and Tevatron (Summer '08)



- Central value for the Higgs mass: $M_H = 116.4^{+18.3}_{-1.3}$ GeV

Searches for SUSY Higgs bosons

- In MSSM have two Higgs doublet fields
  - H_u (H_d) couple to up- (down-) type fermions
  - The ratio of their VEV's
    $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
  - 5 Higgs particles after EWSB
    h, H, A, H^+, H^-
  - h is "guaranteed" to be light
    $m_h <\sim 130\text{-}140$ GeV

- At large $\tan\beta$, coupling to down-type quarks, i.e. b's, is enhanced wrt SM
  - At tree level $\sim \tan\beta$ → production cross section rise as $\tan\beta^2$

- CP conservation is assumed in the following analyses

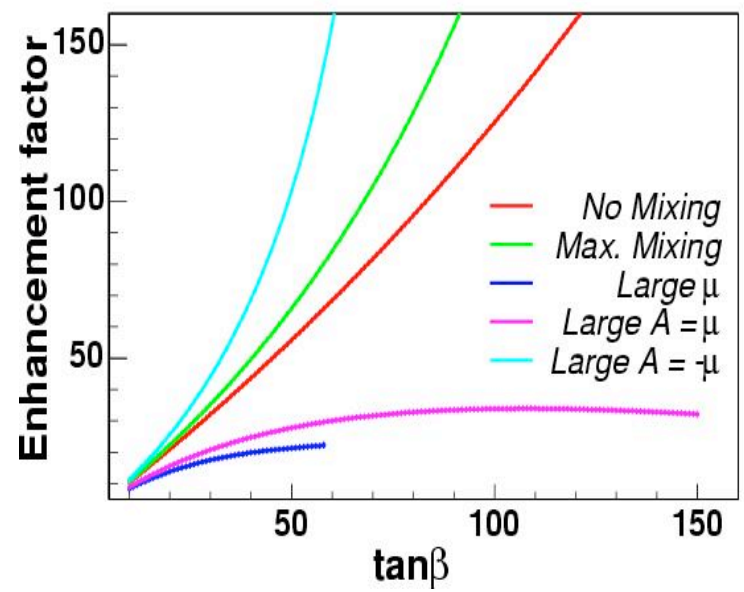
- NLO QCD calculations for bh/bbh production are available

Loop level corrections to x-section and BR

$$\sigma \times BR_{SUSY} = 2 \times \sigma_{SM} \times \frac{\tan\beta^2}{(1+\Delta_b)^2} \times \frac{9}{[9+(1+\Delta_b)^2]}$$

$$\text{with} \quad \Delta_b = \frac{\Delta h_b}{h_b} \times \tan\beta$$

Function of various SM/ SUSY parameters: $X_t = A_t - \mu\cot\beta$, μ, M_g, M_q, etc.



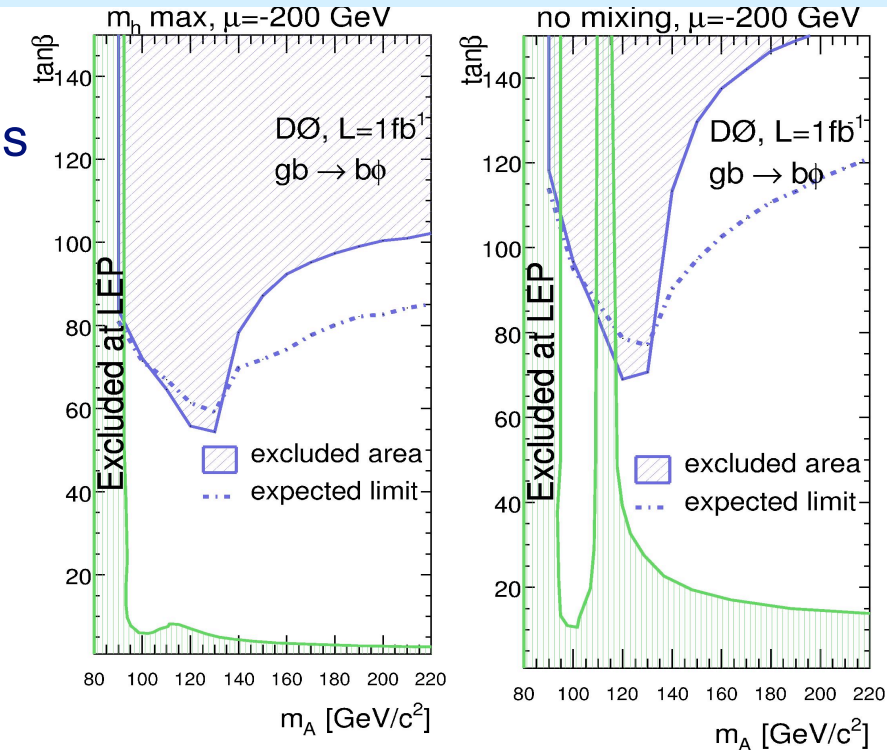
MSSM higgs

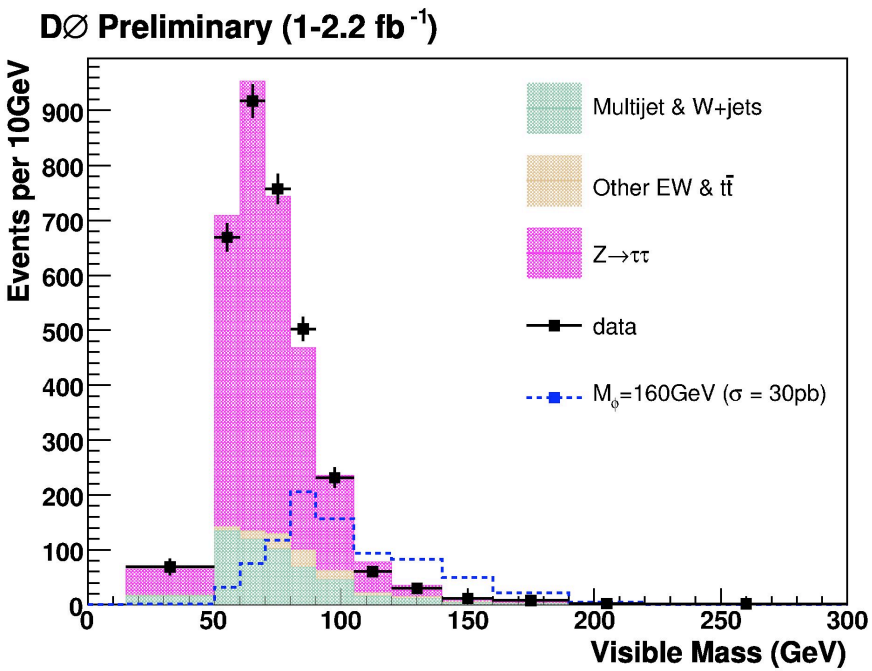
Associated production with b quarks

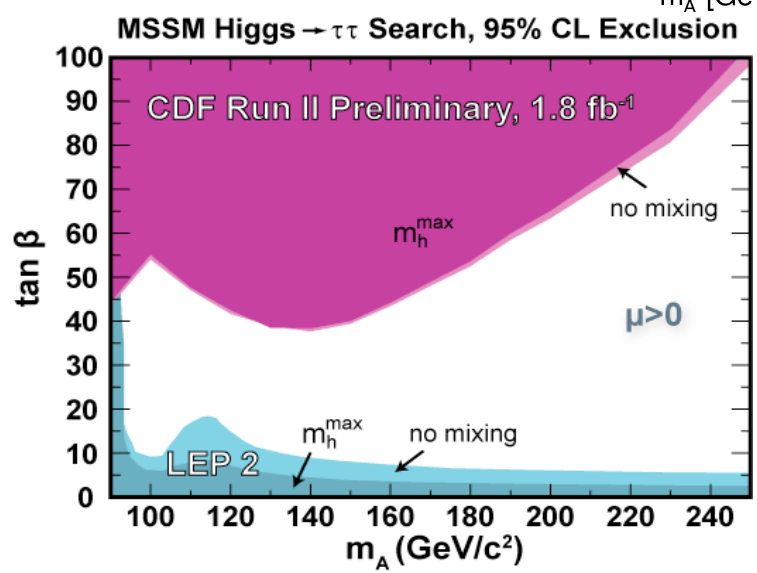
- DØ: bh/bbh(→bb) → ≥3 jets in final states
  - Require ≥ 3 b-tagged jets
  - Bkgd. evaluated from MC and data

Inclusive production

- CDF and DØ: h → ττ → $e\tau_h$, $\mu\tau_h$, or eμ
  - Look for excess in m_{vis} (= mass of visible τ decay products and missing E_T) spectrum



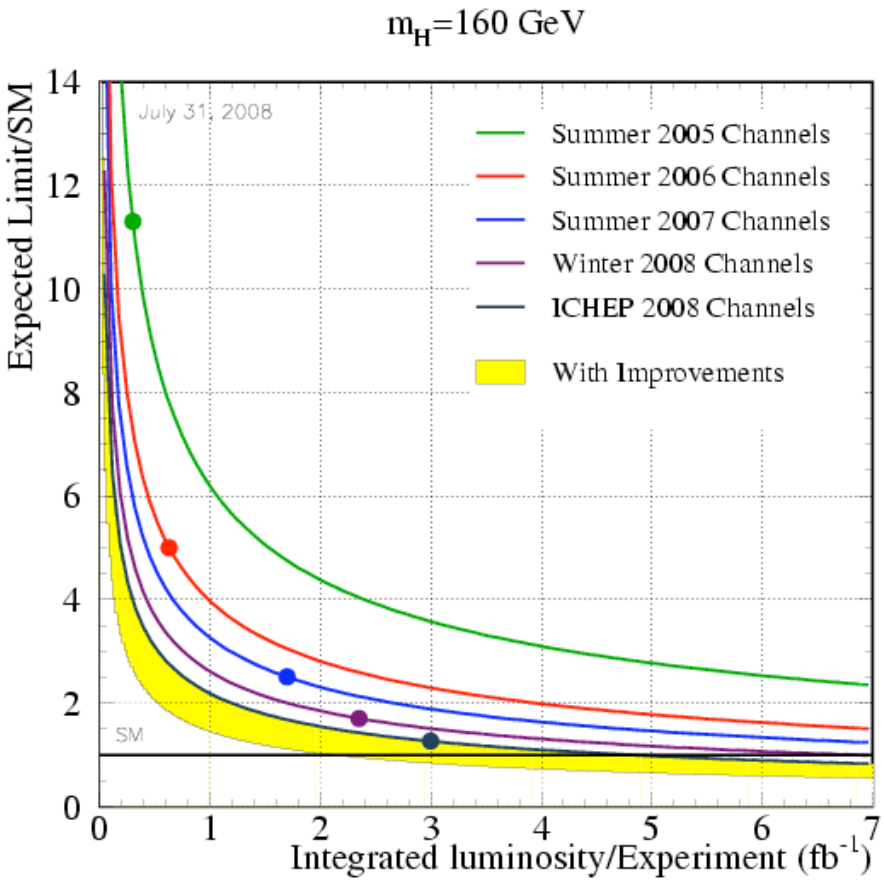
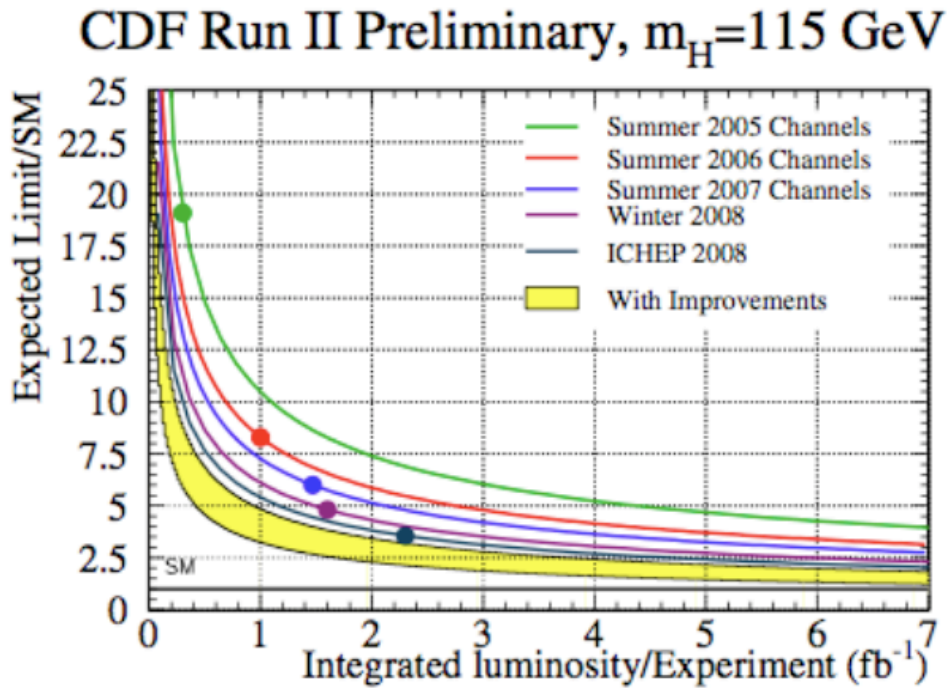




Summary

- Tevatron, CDF and DØ are performing very well
- Many improvements to the analyses techniques have been made recently, more in the works
- Precise measurements of various (low x-section) processes relevant to Higgs searches have been done
- Higgs physics at the Tevatron has entered an exciting phase
  - Significantly impacts the global SM fit
  - Complements LHC's reach in a very interesting mass region

Backups

Projections

- High/low mass analyses
  - Data make us smarter