Higgs searches at the Tevatron

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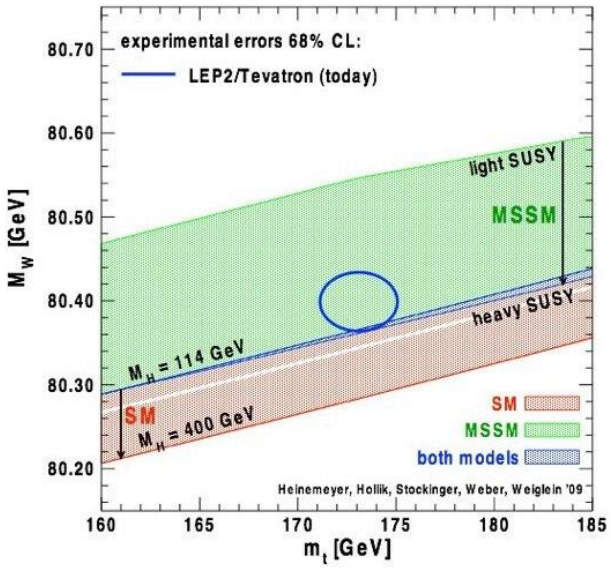
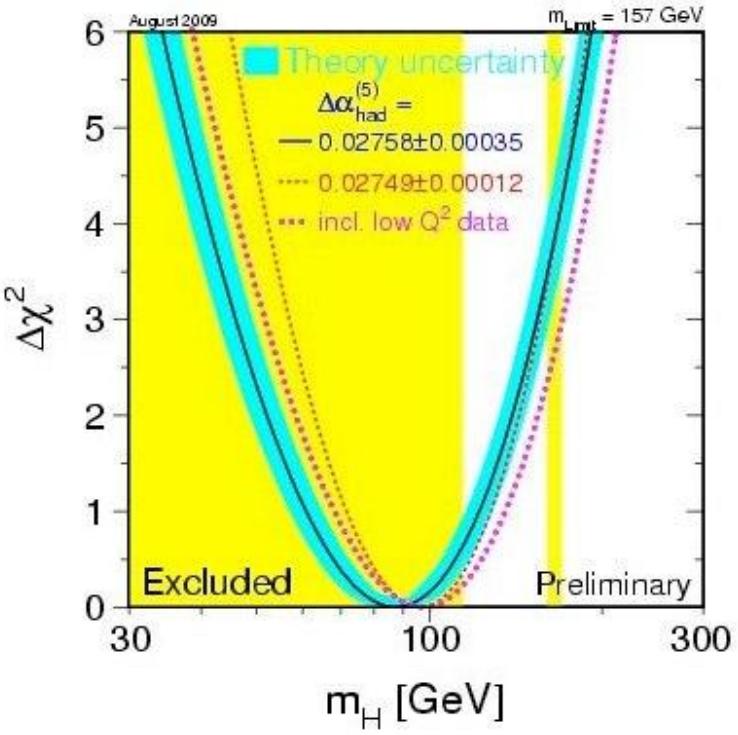
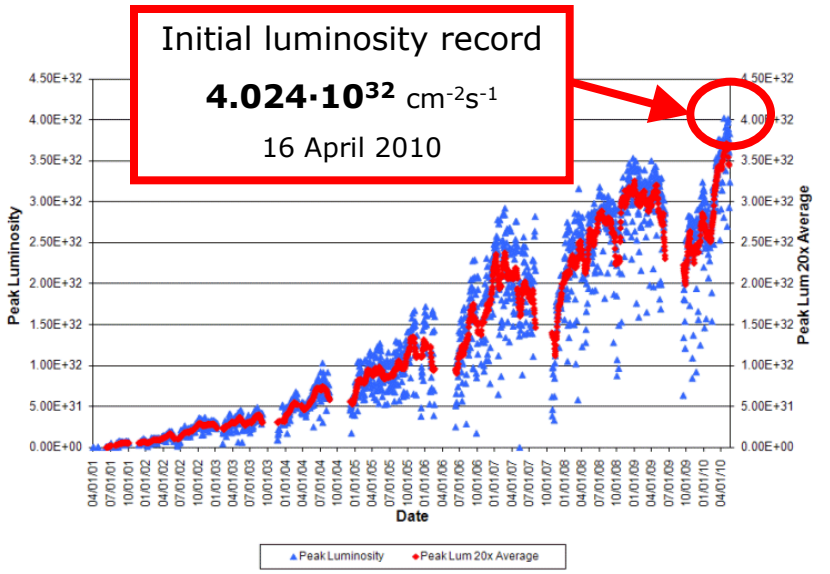
The Standard Model Higgs boson

- The Higgs boson is a key element of the Standard Model
- Theorized in 1964, but not yet observed
- Higgs mass is not predicted by SM
- Precise measurement @ Tevatron of m_t and m_W (indirect constraint)
- Direct exclusion of SM Higgs @ 95% CL:
  - Lep **$m_H > 114.4$ GeV/c²**
  - Tevatron **[162 ; 166] GeV/c²**

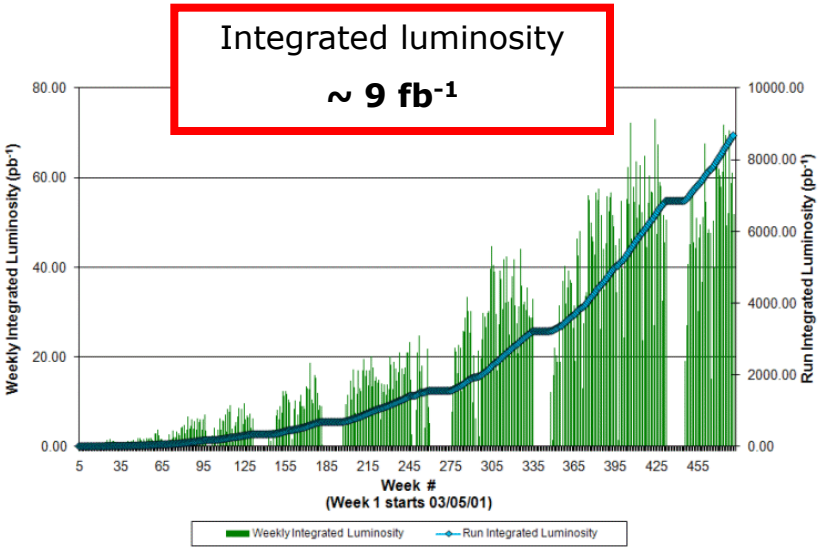




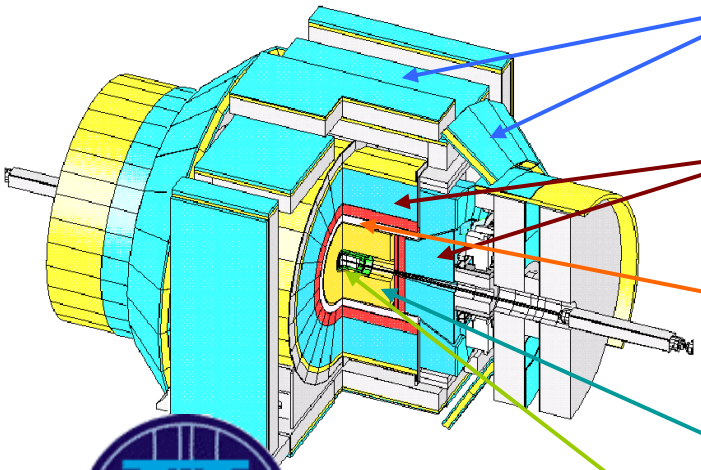
Tevatron



- ***p-$\bar{p}$*** collisions @ ***√s = 1.96 TeV***
- 2 interaction points: **CDF**, **DØ**
- delivered per experiment ~ ***9 fb^{-1}***
  (on tape ~ ***7 fb^{-1}***)
- reached ~ ***2 fb^{-1}*** per year
- running stable at high luminosity
- *Presented results up to **5.4 fb^{-1}***



CDF and DØ



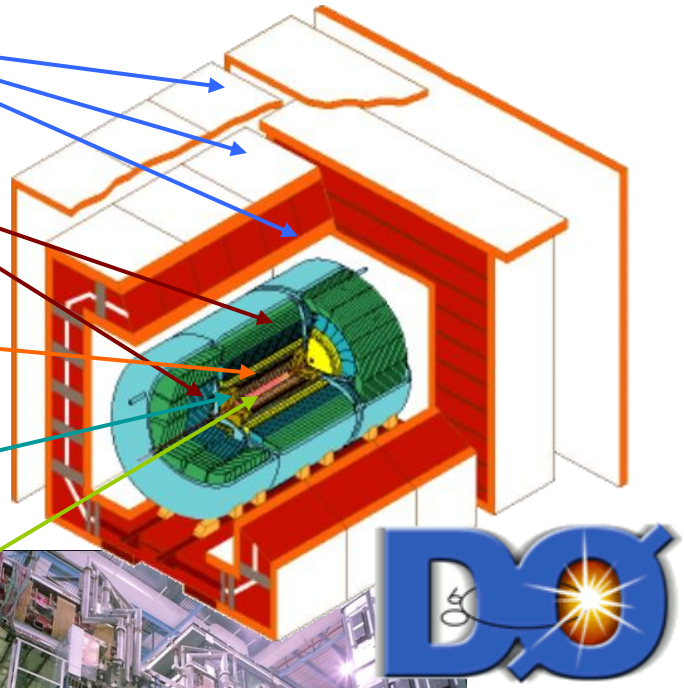
Muon system

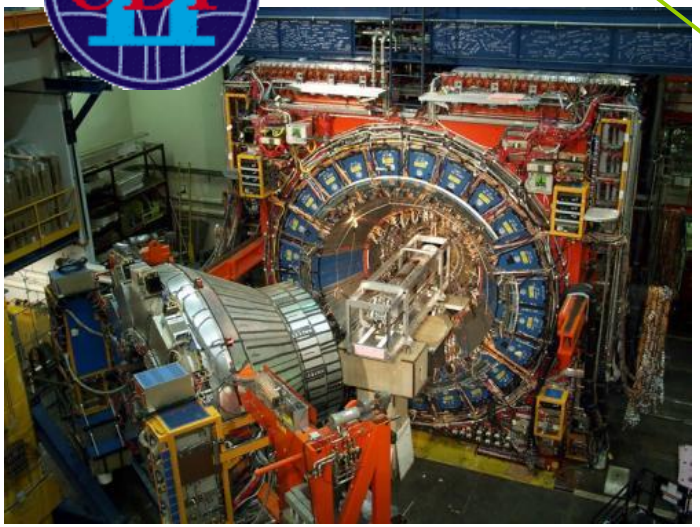
EM and Had calorimeters

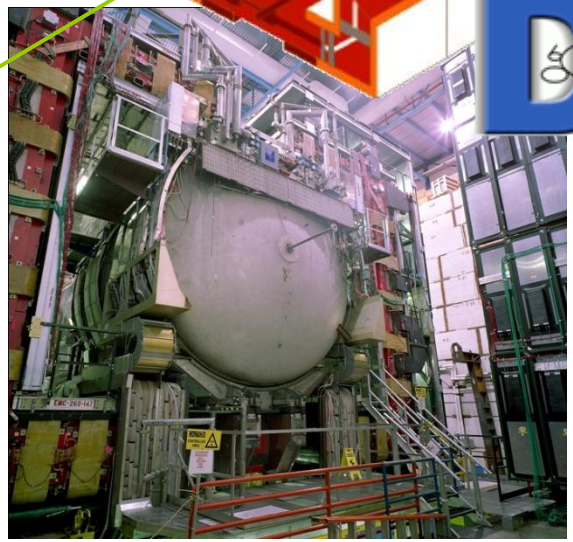
Solenoid

Tracker

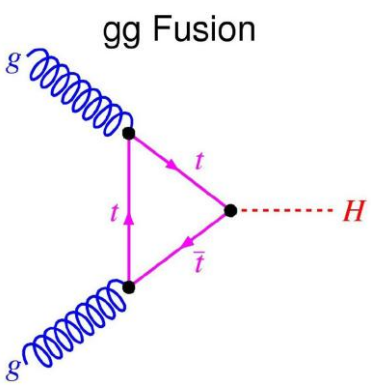
Silicon Vertex Detector

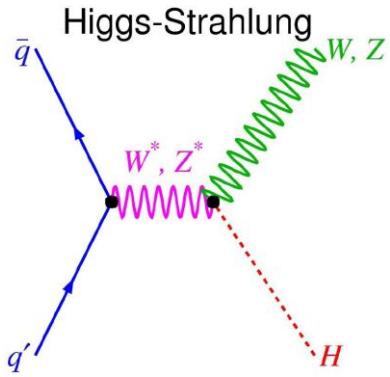


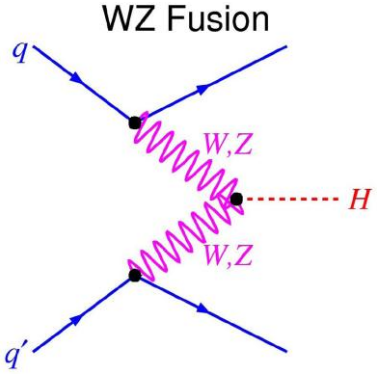


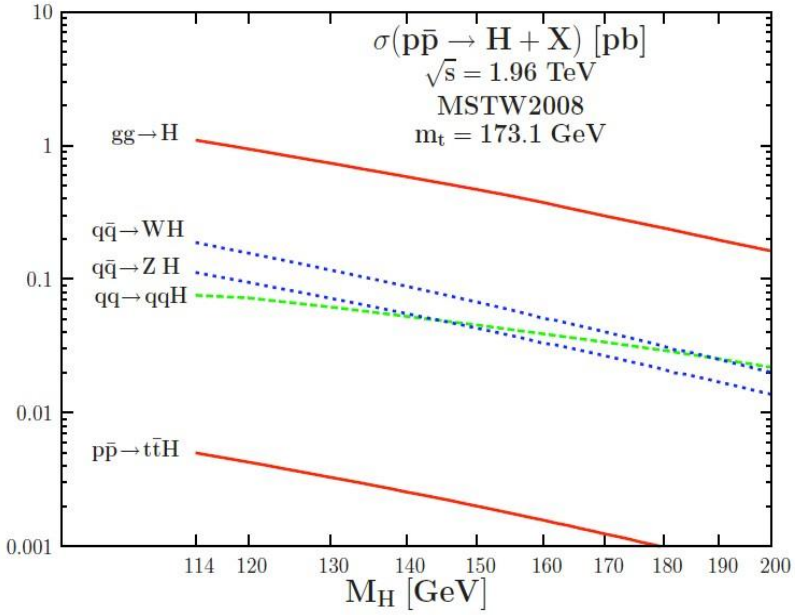


Higgs boson production at Tevatron







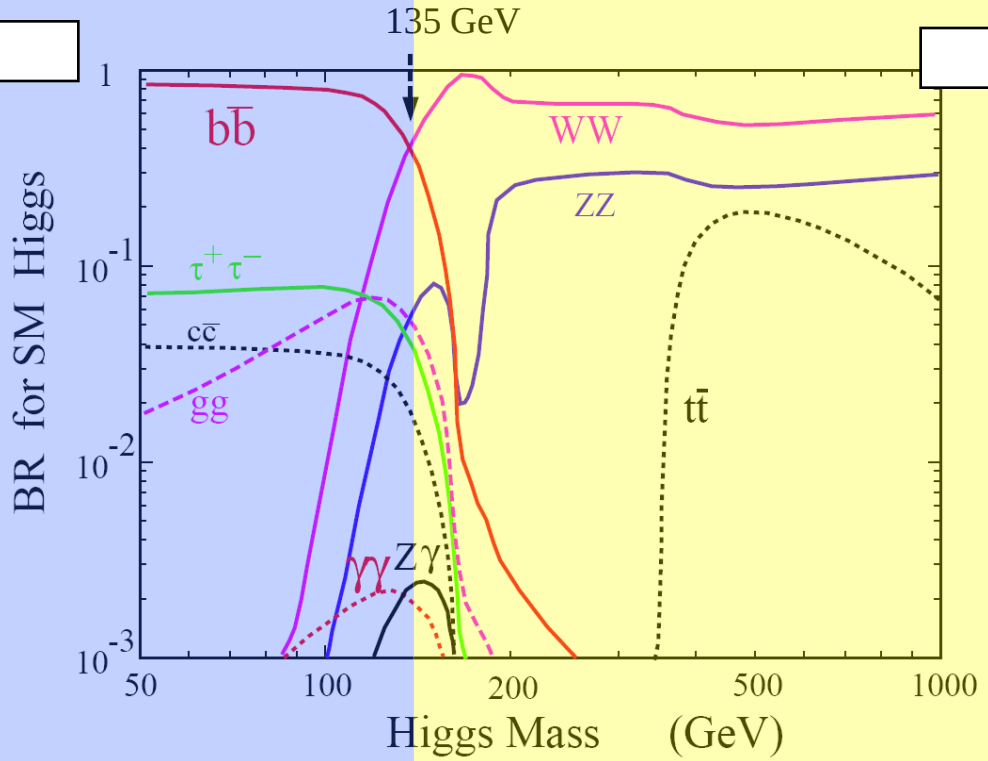


[pb]	m_H = 115 GeV/c^2	m_H = 165 GeV/c^2
Theoretical prediction		
σ(gg → H)	1.2	0.39
σ(qq → WH)	0.18	0.04
σ(qq → ZH)	0.11	0.03
σ(qq → qqH)	0.08	0.04
Measured at Tevatron		
σ(pp → Z)	261	
σ(pp → WW/WZ)	18.1	

Higgs boson decay

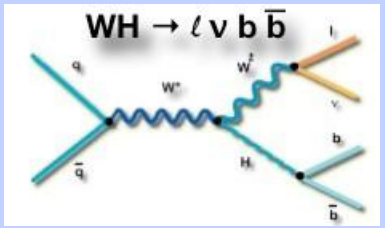
"Low mass" region

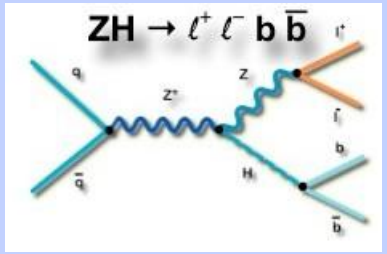
m_H = 115 GeV/c^2	
Decay	BR
H → bb	0.73
H → WW	0.08
H → ττ	0.07

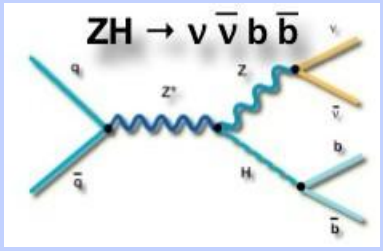


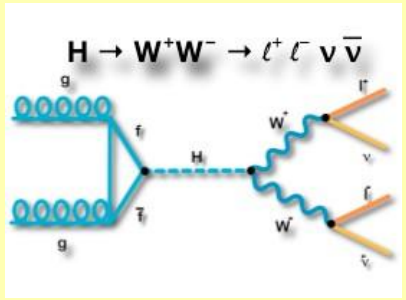
"High mass" region

m_H = 165 GeV/c^2	
Decay	BR
H → bb	0.01
H → WW	0.96
H → ττ	0.02



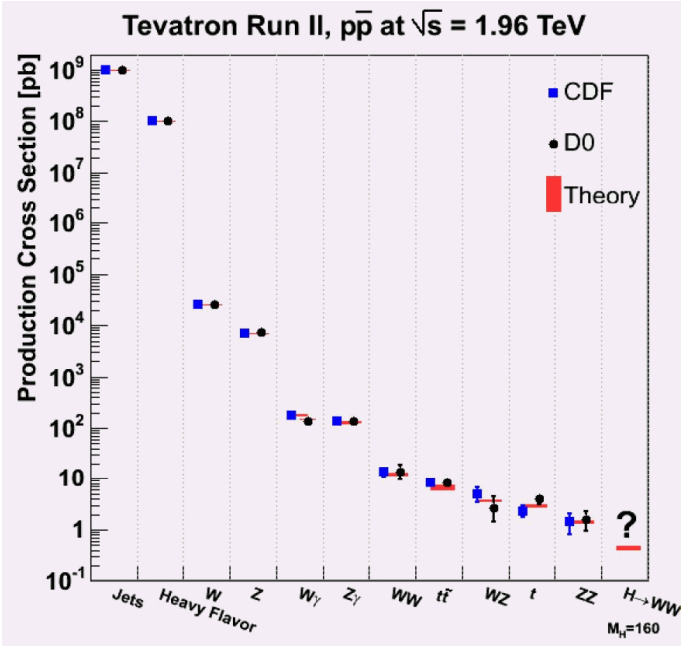


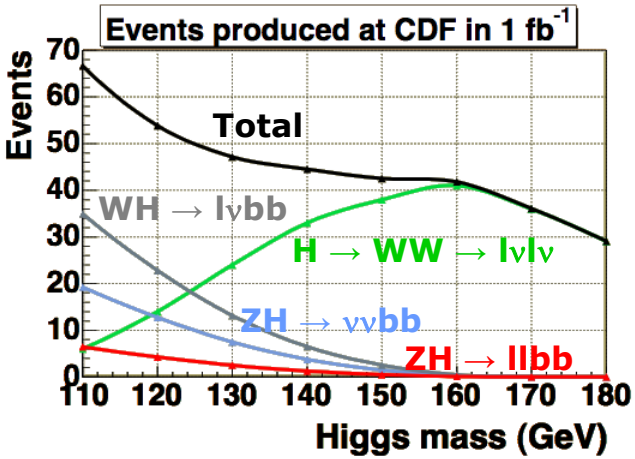




Search strategy

- CDF and DØ are measuring processes with $\sigma \sim 1$ pb: *the Higgs search is hard but not impossible!*
- *Dominant decay mode* - increase statistics
- *Leptonic final states* - increase S/B
- No single channel can reach the needed sensitivity: ***combine*** as many as possible!
- ***Divide*** analysis samples in sub-categories to optimize S/B

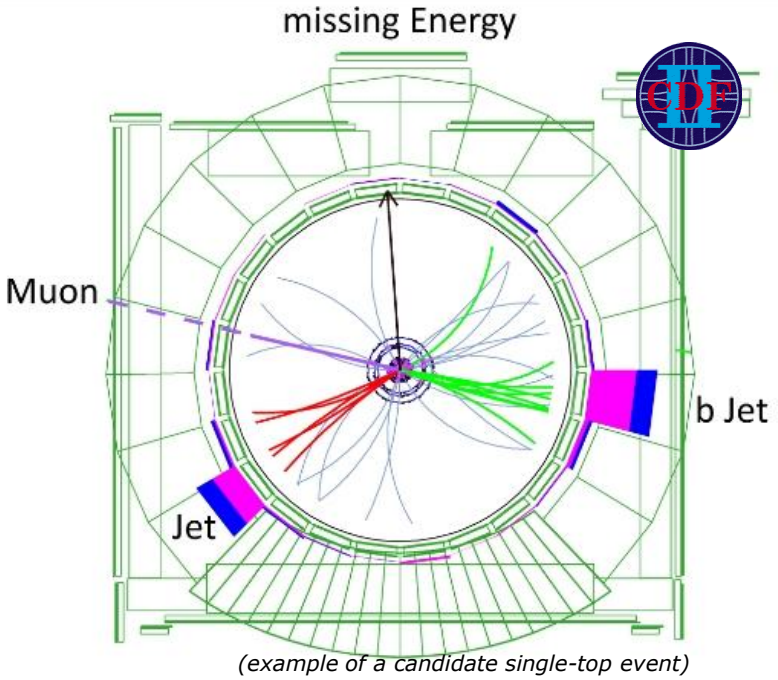




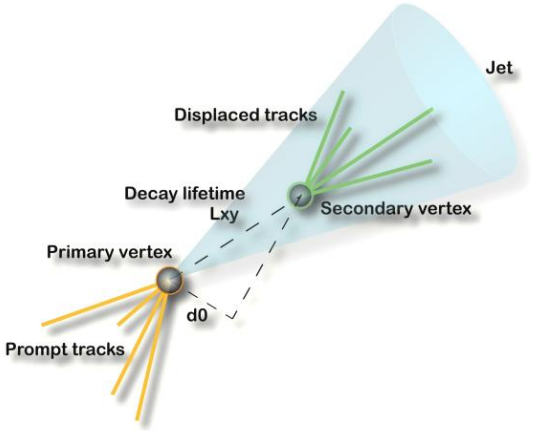
Channel	events/fb @ 115	events/fb @ 165
WH → lνbb	28	0.1
ZH → ννbb	16	0.07
ZH → llbb	5	0.02
H → WW → lνlν	9	38
Total	58	38

Tools

- ***Leptons***
  - electrons and muons (clear signature at hadron colliders)
  - several categories to increase acceptance
  - dedicated algorithms for taus
- ***Jets***
  - cone algorithms
  - jet energy corrected to account for detector effects, clustering algorithm, multiple interactions, …
- ***Missing Transverse Energy (MET)***
  - calorimeter energy imbalance on the transverse plane
  - accounts for neutrinos
- ***b-tagging***
  - techniques used to identify jets originating from a b quark, exploiting its properties (long lifetime, high mass, leptonic decay)
  - main algorithms: secondary vertex, JetProbability, NN
- ***Multivariate techniques*** *used to combine as much information as possible to enanche S/B discrimination*
  - Artificial Neural Networks (NN)
  - Boosted Decision Trees (BDT)
  - Matrix Element (ME)



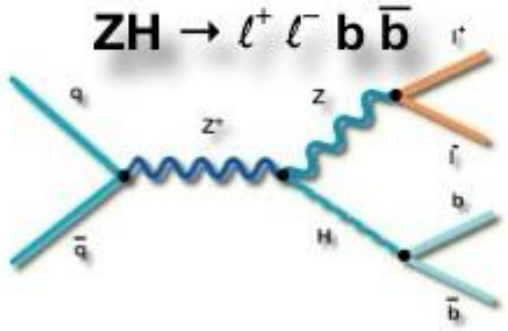
(example of a candidate single-top event)

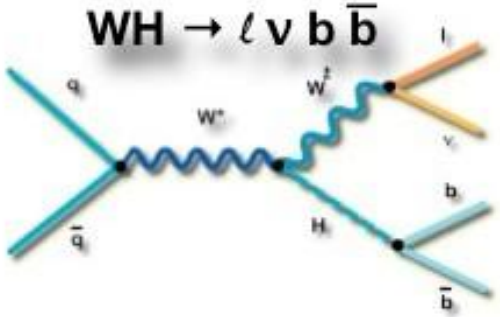


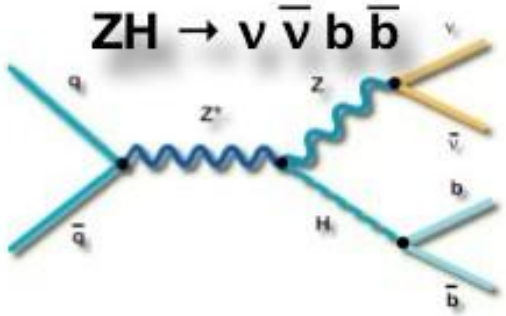
Low mass searches

- gg->H->bb has the biggest cross section, but is not valuable because of the overwhelming multijet background

- Associated production has smaller cross section, but provide clearer signature







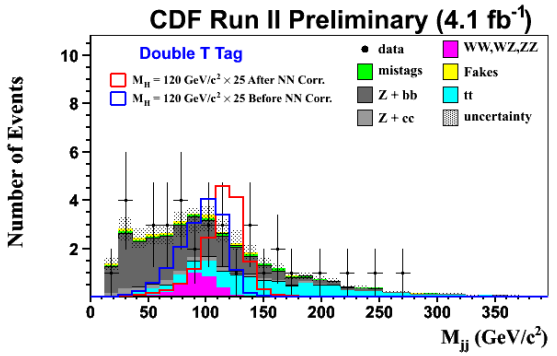
ZH → llbb

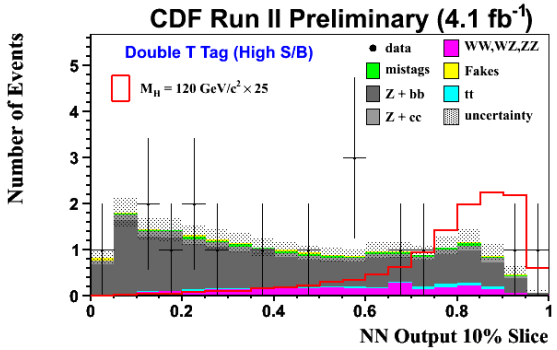
- ***Cleanest mode - low statistics***

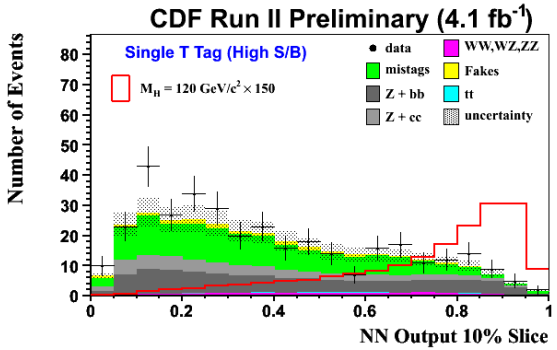
- ***Event selection:***
  - Z candidate reconstructed in the e^+e^- or $\mu^+\mu^-$ channel;
  - ≥ 2 jets.
- ***Analysis technique:***
  - ***specific jet energy correction*** (NN based) for MET, to improve M_{jj} resolution;
  - 6 sub-samples according to Z reconstruction, quality and b-tagging;
  - ME and NN for final discriminant.

- ***DØ final discriminant by a BDT***

MH = 115 GeV/c²	expected limit ($x\sigma_{SM}$)	observed limit ($x\sigma_{SM}$)
DØ 4.2 fb^{-1}	**8.0**	**9.1**
CDF 4.1 fb^{-1}	**6.8**	**5.9**







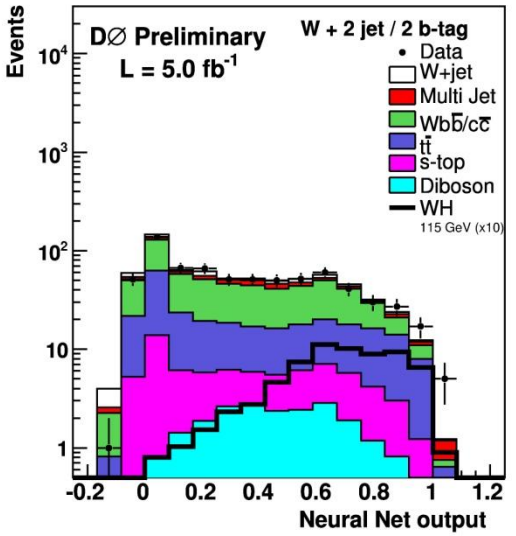
WH → lνbb

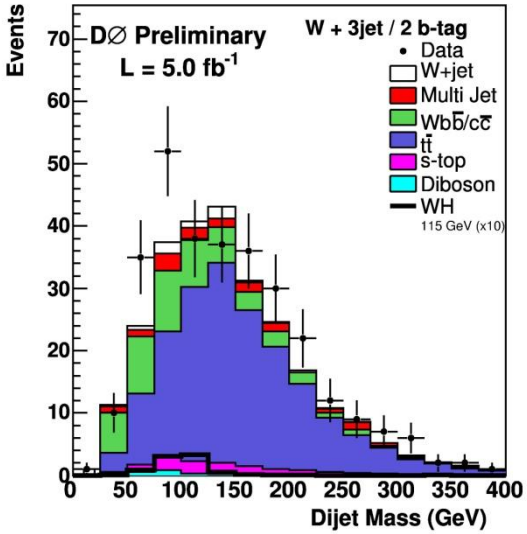
- ***Best compromise between signal yeld and background level***

- ***Event selection:***
  - W candidate reconstructed with an high-P_T e or μ plus MET;
  - 2 or 3 jets.
- ***Analysis technique:***
  - 8 sub-samples according to lepton channel, # of jets and b-tagging;
  - NN discriminant for W+2 jets sample;
  - di-jet invariant mass for w+3 jets.

- ***CDF uses ME technique***

MH = 115 GeV/c^2	expected limit ($x\sigma_{SM}$)	observed limit ($x\sigma_{SM}$)
DØ 5.0 fb^{-1}	***5.1***	***6.9***
CDF 4.8 fb^{-1}	***3.9***	***4.4***

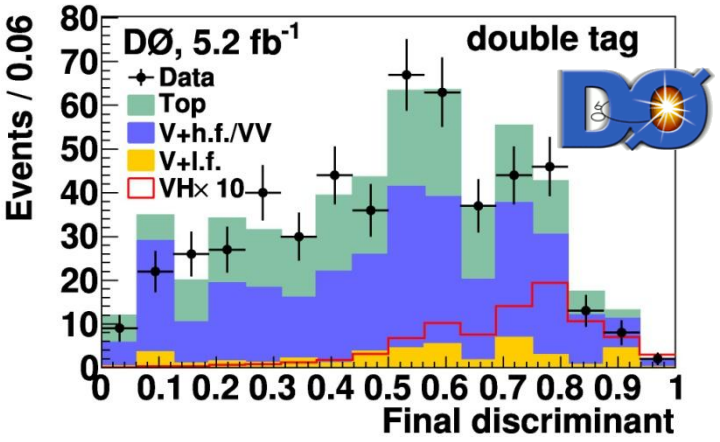


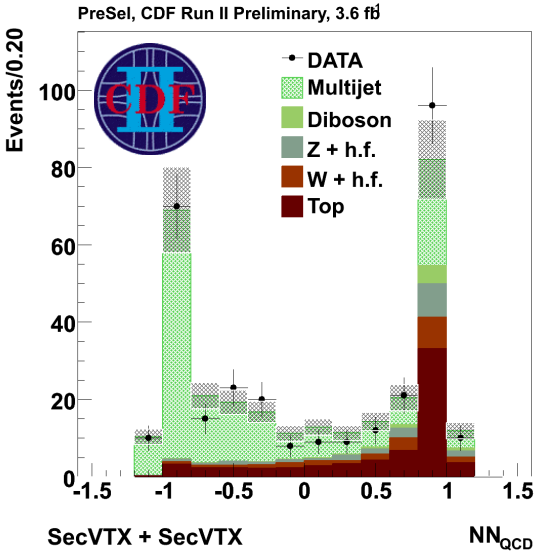


ZH → ννbb and WH → (l)νbb

- ***Good signal acceptance - huge background***
- *Sensitive to ZH → νν bb and ZH → llbb, WH → lν bb (when the charged lepton is not reconstructed)*

- ***Event selection:***
  - large MET;
  - 2 or 3 jets.
- ***Analysis technique:***
  - NN trained to cut down the multijet background;
  - 3 b-tagging categories;
  - final NN discriminant.

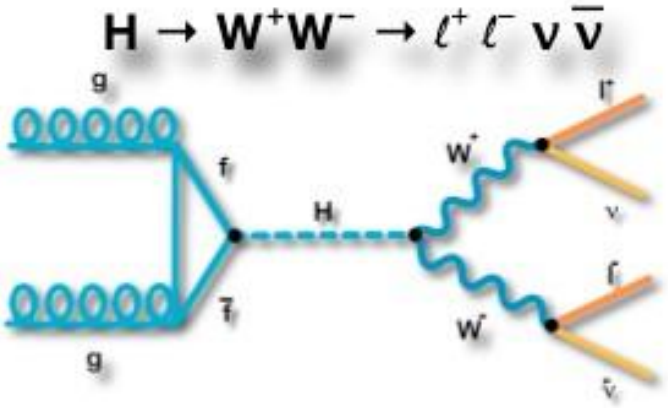




MH = 115 GeV/c²	expected limit ($x\sigma_{SM}$)	observed limit ($x\sigma_{SM}$)
DØ 5.2 fb^{-1}	***4.6***	***3.7***
CDF 3.6 fb^{-1}	***4.2***	***6.1***

High mass searches

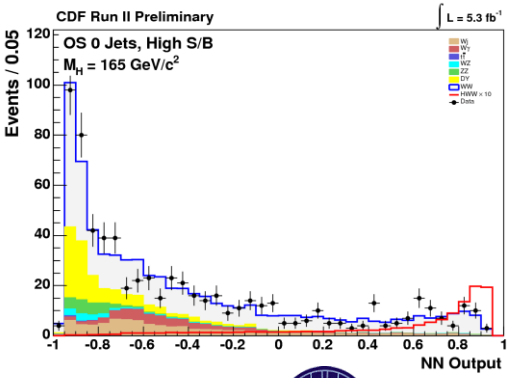
- $H \rightarrow WW$ has the biggest branching ratio for $m_H > 135$ GeV/c^2
- Clear lepton signature from W decay
- Sensitive to gluon-gluon fusion, with acceptance also for WH and ZH

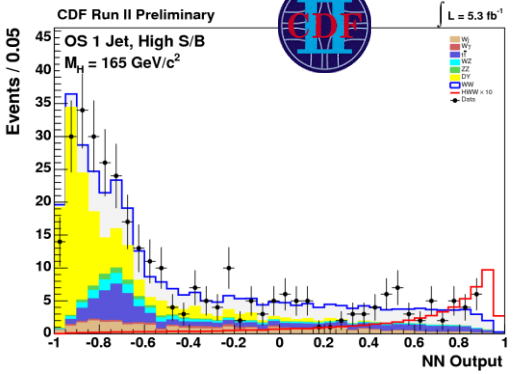


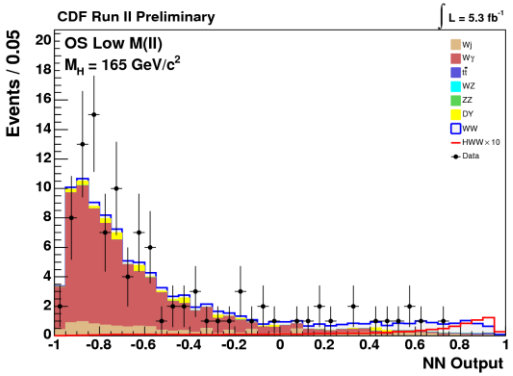
MH = 165 GeV/c^2	expected limit ($x\sigma_{SM}$)	observed limit ($x\sigma_{SM}$)
DØ 5.4 fb^{-1}	***1.36***	***1.55***
CDF 5.3 fb^{-1}	***1.03***	***1.13***

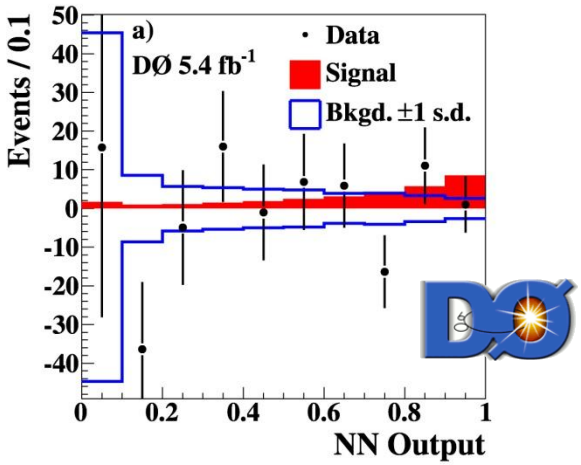
H → WW* → lνlν

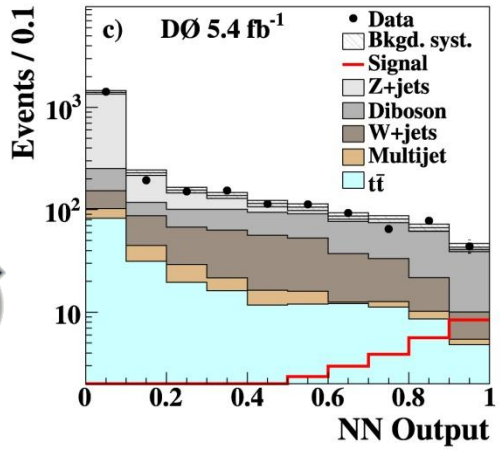
- ***Event selection:***
  - 2 leptons (e or μ) - also τ decaying to e or μ enter the sample;
  - large MET.
- ***Analysis technique:***
  - extended leptons categories;
  - 5 orthogonal sub-samples to optimize S/B;
  - opposite sign leptons sub-sample divided also according to jet multiplicity;
  - M_{ll} < 16 GeV/c^2 category;
  - 2 same sign leptons (acceptance for WH⟶WWW*, ZH⟶ZWW*);
  - CDF 5 final NN discriminant;
  - DØ 3 final NN combined in single discriminant.





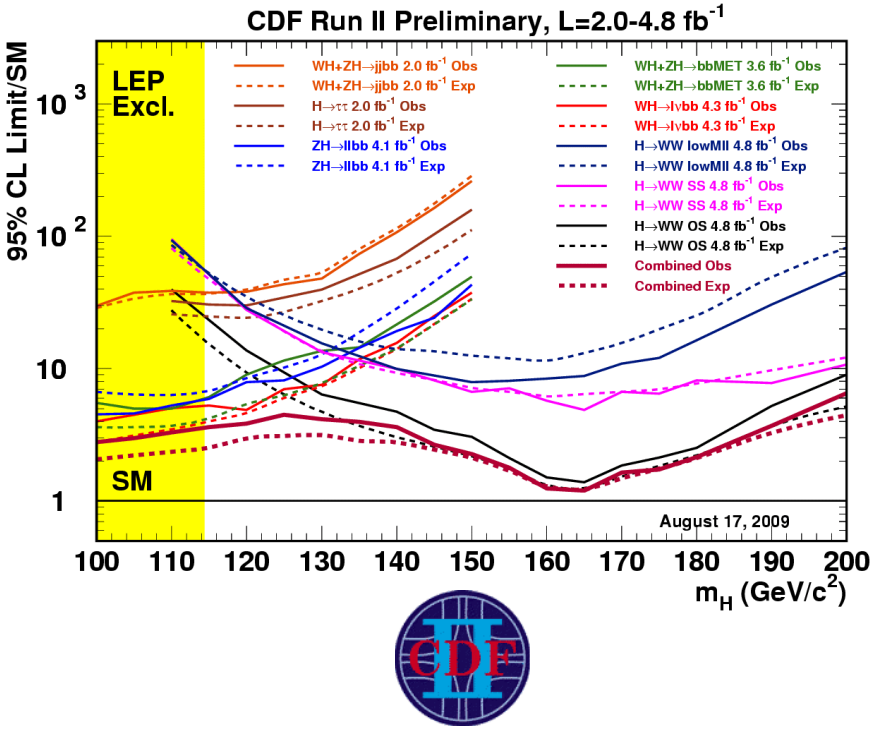


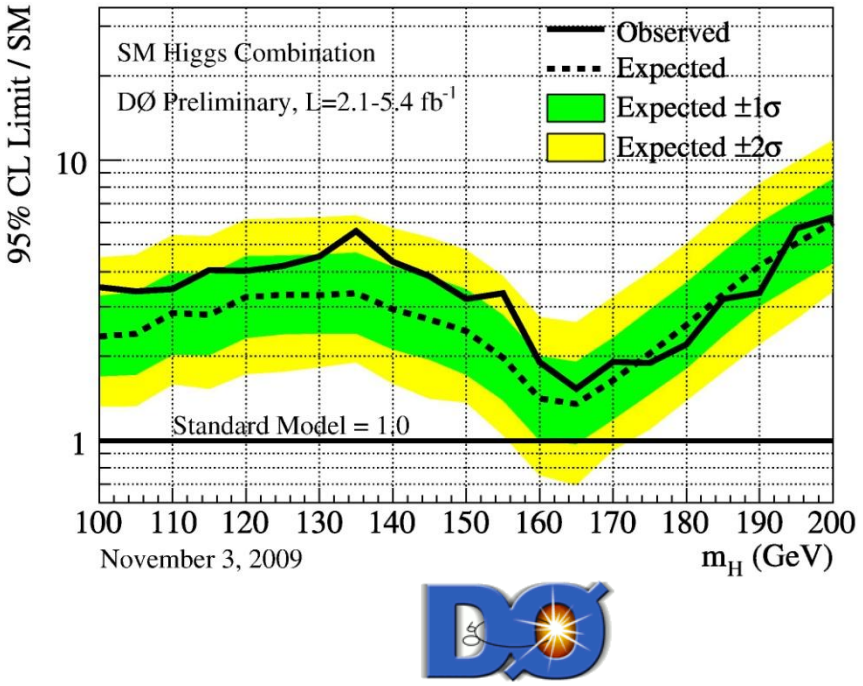




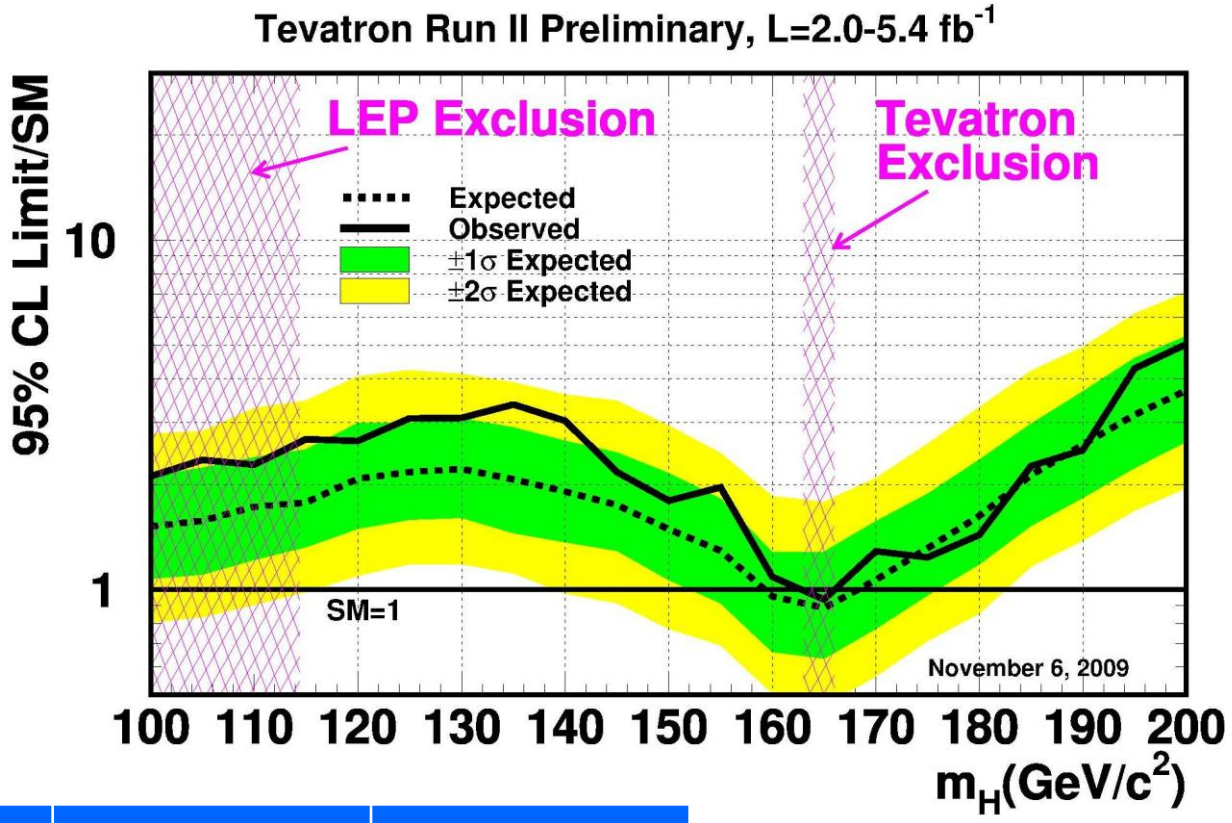
Limit combination

- In order to maximize sensitivity each experiment combines the results for different analyses.
- Systematics uncertainties are taken into account in the combination procedure, and their correlations are treated consistently.





Combined Tevatron limit



95 % CL observed limit ($x\sigma_{SM}$)	m_H = 115 Gev/c^2	m_H = 165 Gev/c^2
DØ	***2.8***	***1.4***
CDF	***2.4***	***1.2***

CDF + DØ combination

95% CL exclusion for $162 < m_H < 166$ GeV/c^2

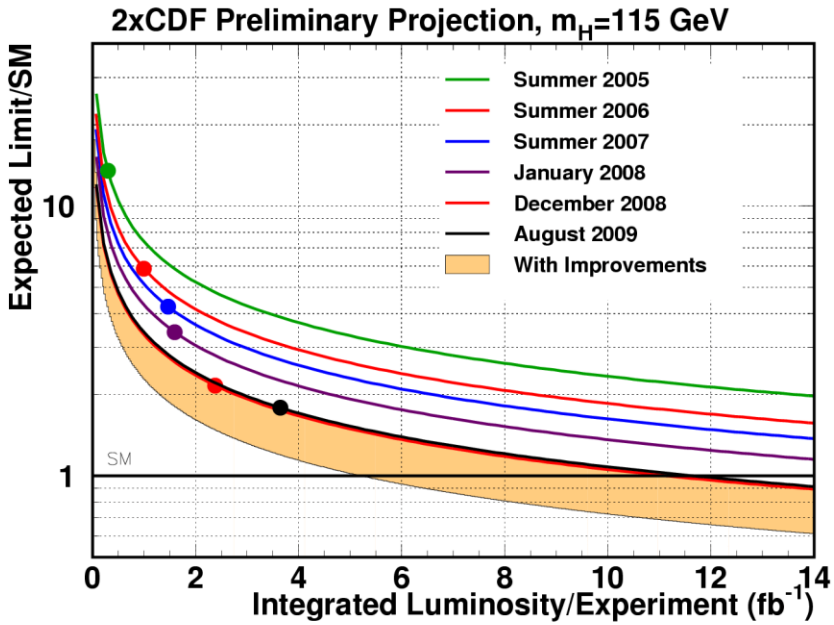
[PhysRevLett.104.061802]

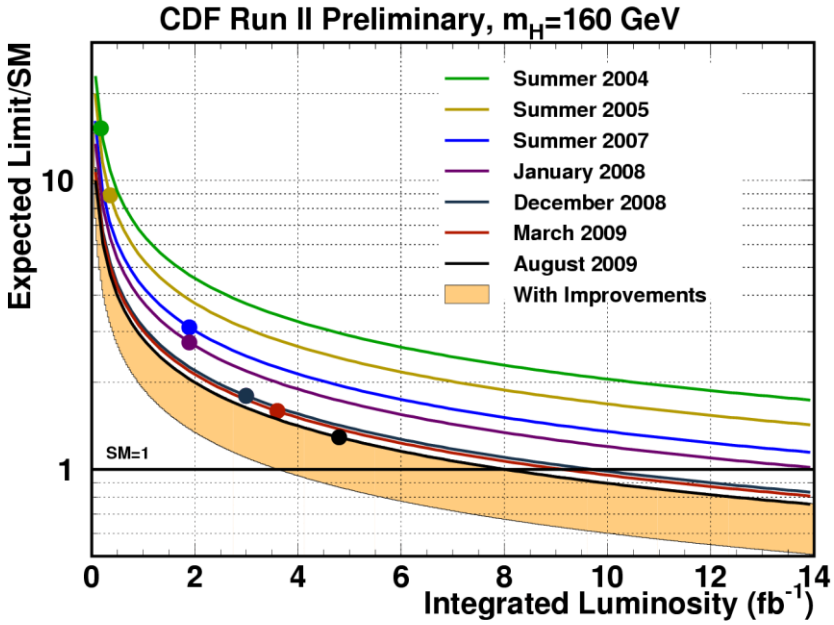
Conclusions and perspectives

- Tevatron is expected to deliver ~ 12 fb^{-1} by the end of 2011 per experiment (~ 2 fb^{-1} delivered to each experiment per year).
- CDF and DØ are pursuing a direct search for the SM Higgs boson in the $115 < m_H < 200$ GeV/c2 mass range.
- Also search for BSM Higgs.
- Experimental sensitivity continue to increase with the application of more sophisticated techniques.

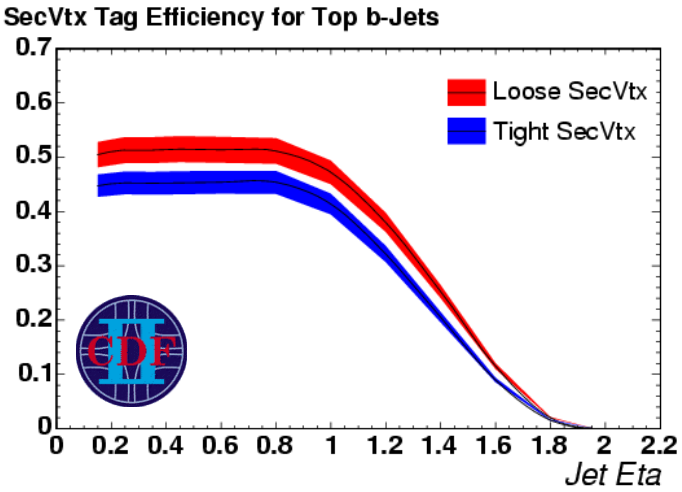
Backup

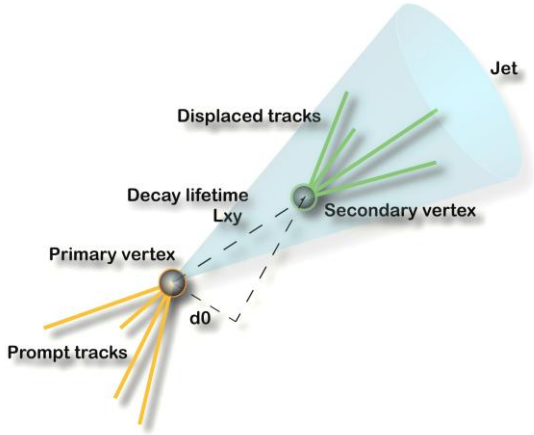
Improvements

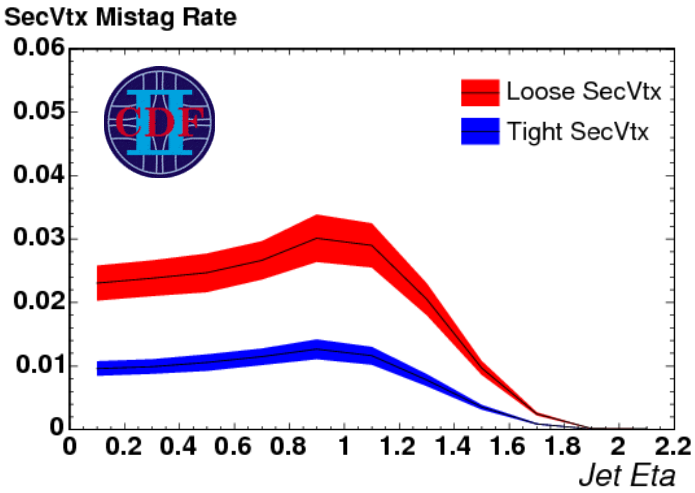


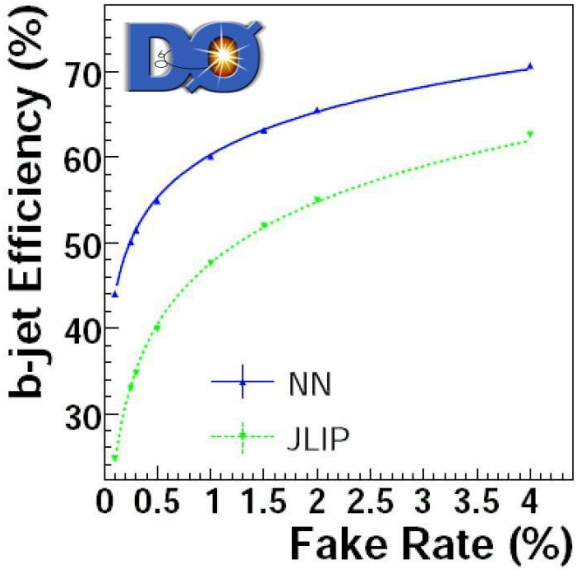


b-tagging

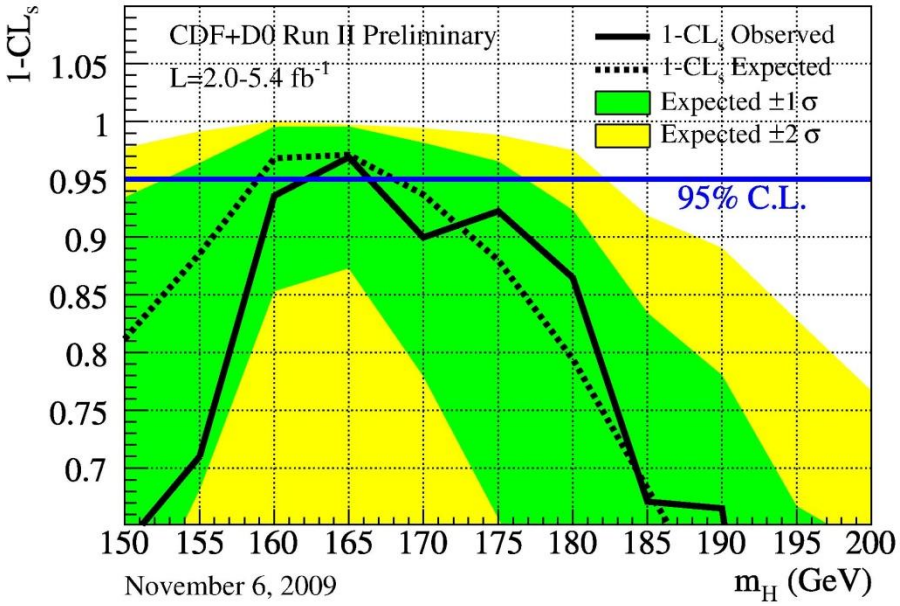

SecVtx Tag Efficiency for Top b-Jets
Loose SecVtx
Tight SecVtx
CDF II
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2
Jet Eta

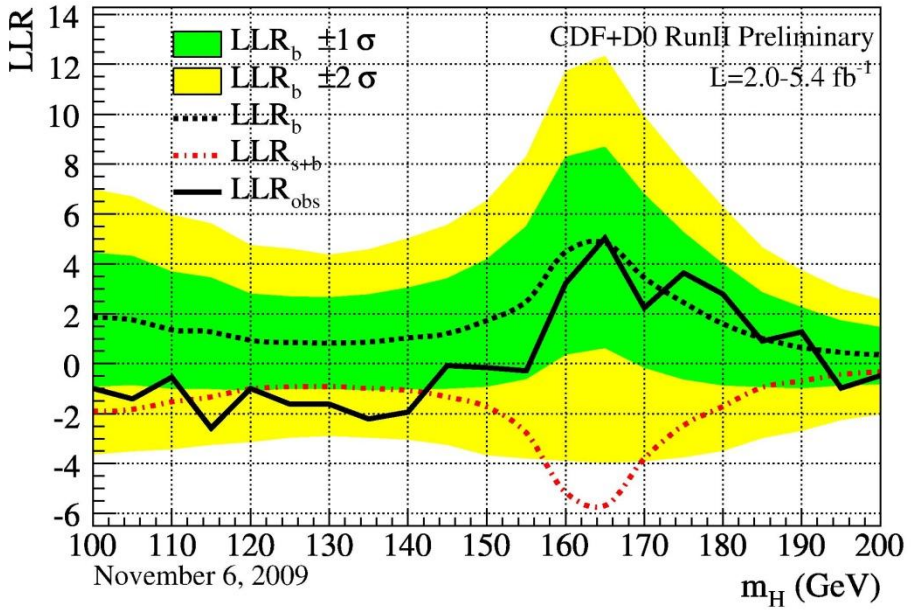

Jet
Displaced tracks
Decay lifetime
Lxy
Secondary vertex
Primary vertex
d0
Prompt tracks


SecVtx Mistag Rate
Loose SecVtx
Tight SecVtx
CDF II
0.06
0.05
0.04
0.03
0.02
0.01
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2
Jet Eta

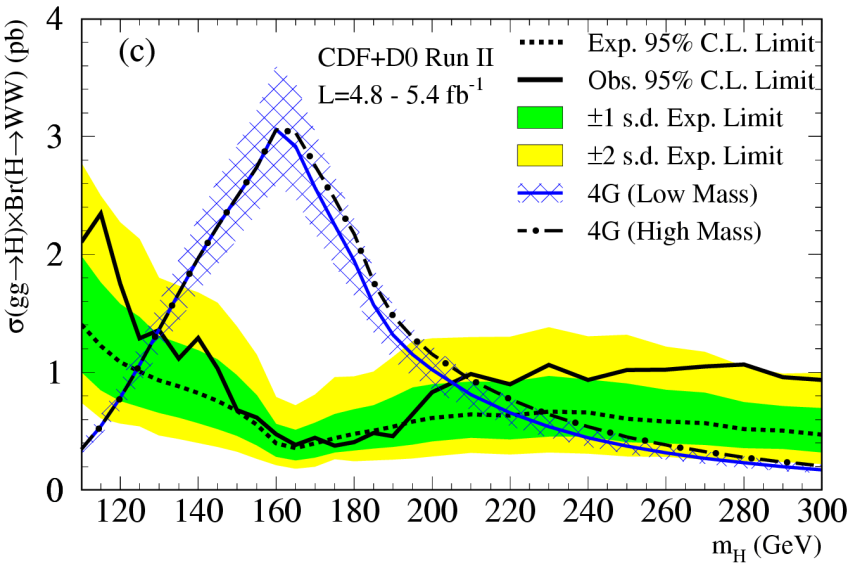

b-jet Efficiency (%)
70
60
50
40
30
NN
JLIP
0 0.5 1 1.5 2 2.5 3 3.5 4
Fake Rate (%)

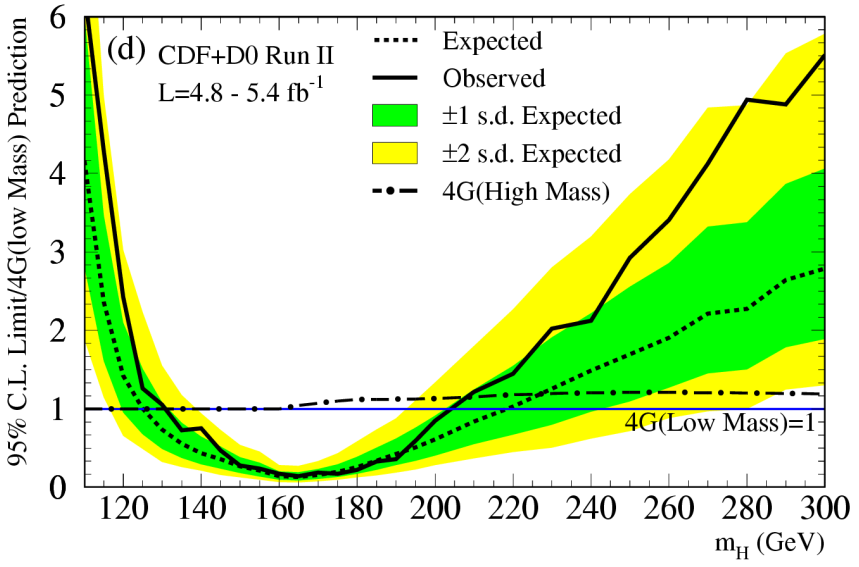
Combined Tevatron limit





4G


(c)
CDF+D0 Run II
L=4.8 - 5.4 fb-1
Exp. 95% C.L. Limit
Obs. 95% C.L. Limit
±1 s.d. Exp. Limit
±2 s.d. Exp. Limit
4G (Low Mass)
4G (High Mass)
σ(gg→H)×Br(H→WW) (pb)
mH (GeV)


(d)
CDF+D0 Run II
L=4.8 - 5.4 fb-1
Expected
Observed
±1 s.d. Expected
±2 s.d. Expected
4G(High Mass)
4G(Low Mass)=1
95% C.L. Limit/4G(low Mass) Prediction
mH (GeV)