Searches for SM Higgs Boson

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UC Berkeley 290e Seminar

Outline

- Introduction
- SM Higgs Search Strategies and Challenges
- Recent Results
- Future Prospects
- Conclusion

Disclaimer: Some of plots are taken from ICHEP10 and Higgs Hunting workshop in Orsay. The errors are mine.

Introduction

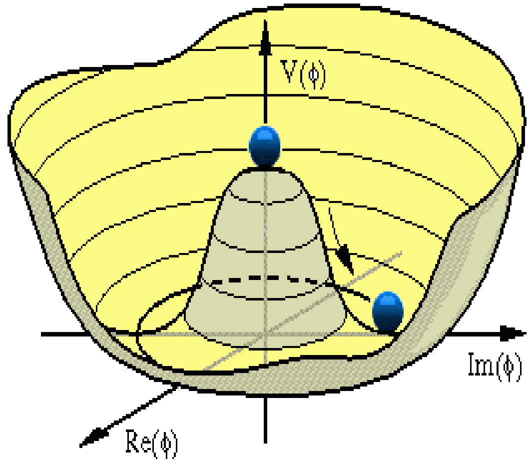
- The Higgs boson is the last unobserved particle postulated in the SM which help explain the origin of mass in the universe.
- Observation and measurement of the Higgs boson are longstanding key objectives to understand the mechanism of electroweak symmetry breaking.
- Not seeing a low mass Higgs guarantee's that there is new physics waiting to be found at LHC.
- New physics may influence the Higgs production and decay, it's crucial to observe as many of its properties as possible.
- Window of Opportunity: Tevatron with increased luminosity and time to improve analysis could add crucial information $H \rightarrow bb$ that is most difficult to observe at LHC.

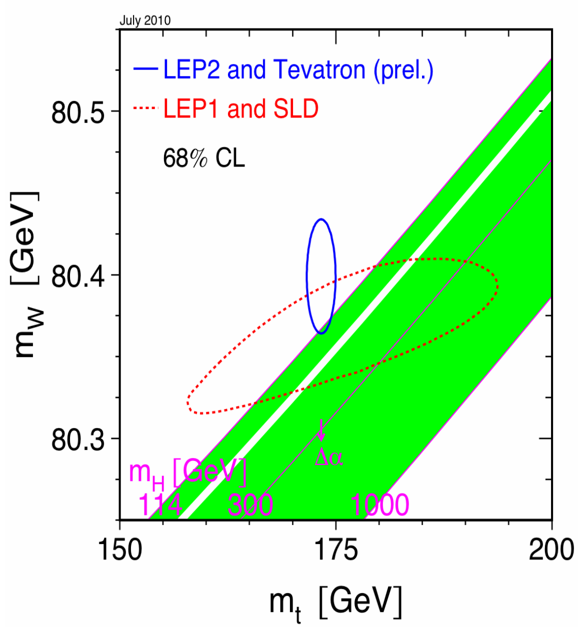
Recent Headlines

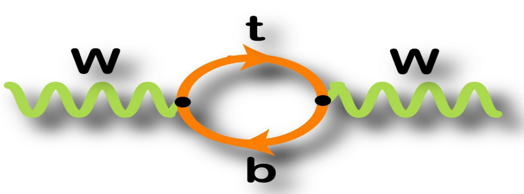
- “America Physicists Scrounge to Stay in ‘God Particle’ Race ’’ -- Science Insider
- “Fermilab urged to pursue ‘God’s particle’ ’’ --Chicago Sun-Time
- “Teams of Physicists Closing in on the ‘God Particle’ ’’ -- NY Time
- “Higgs boson discovery rumour denied by US lab’’ --BBC
- “Physicists get political over Higgs” -- Nature
- ...

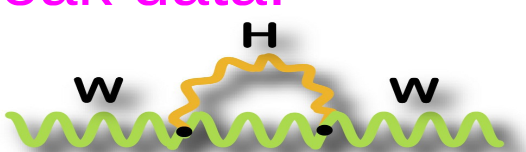
Higgs Mechanism

- Adds a scalar field to the gauge theory
- Predicts a scalar particle, Higgs boson
- W and Z boson gain mass through spontaneous symmetry breaking.
- Quark and Lepton gain mass through Yukawa coupling.
- No free parameters, all couplings known, except the Higgs mass.
- Testable via loop correlation using precision electroweak data.

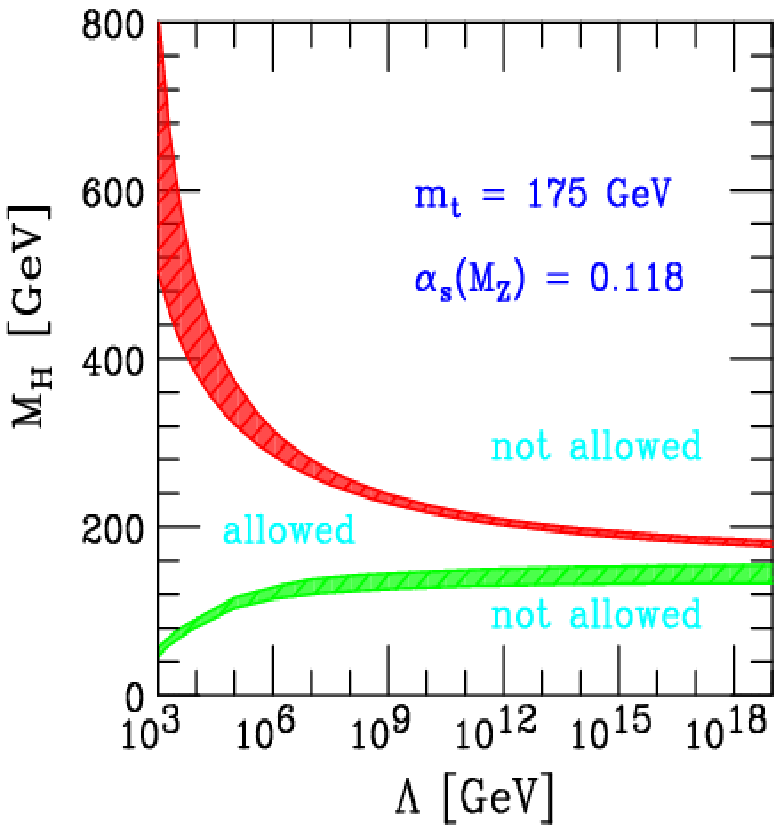


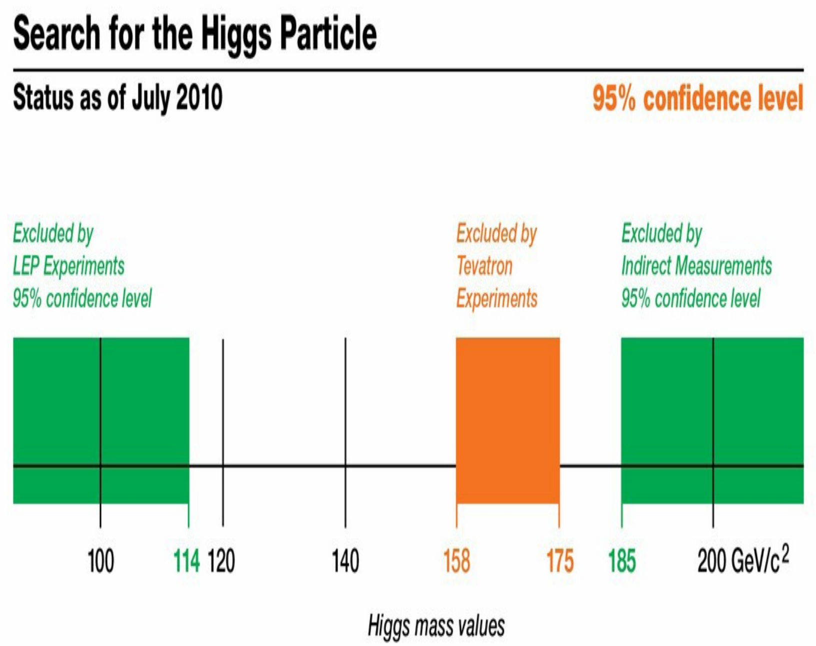






State of Art of Higgs Mass

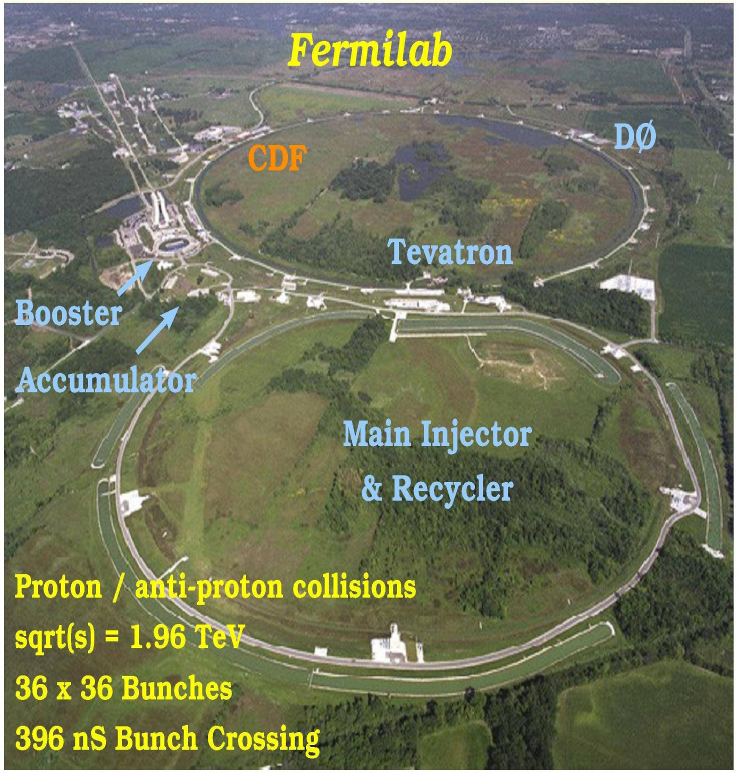




- **Theoretical Limits:** finite and positive Higgs couplings
- **Direct from LEP+Tevatron:** M_H>114.4 & Not[158,175] GeV/c^2
- **Indirect from EW data:** M_H<158 GeV/c^2 @ 95% CL

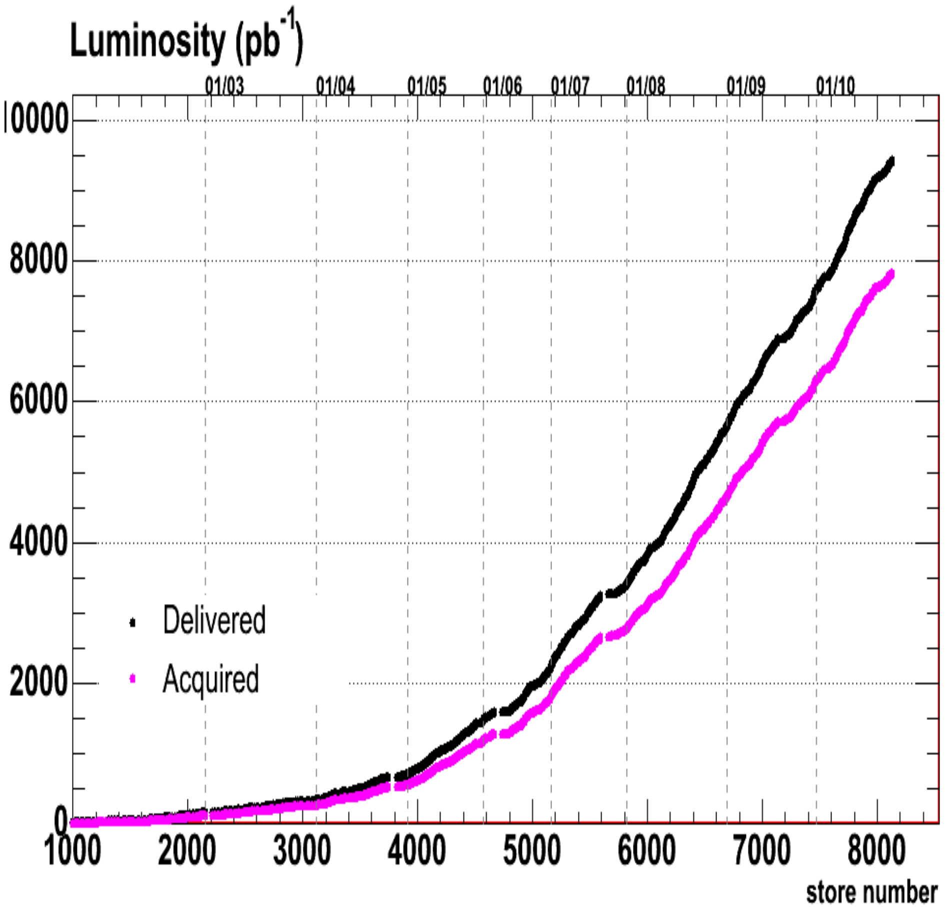
The Colliders

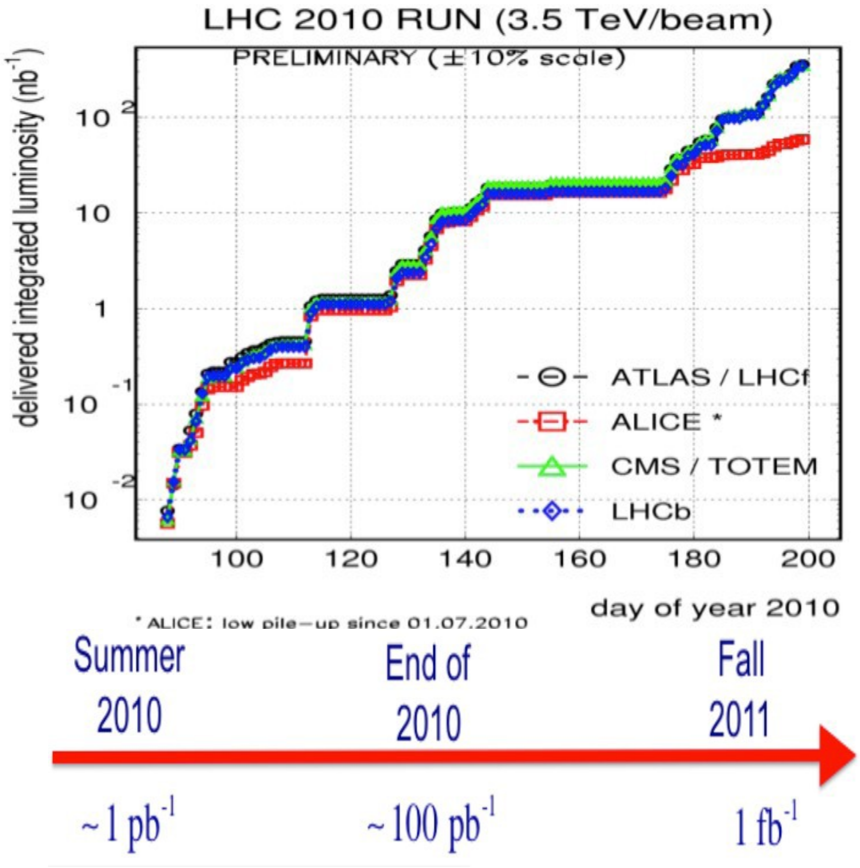
- Tevatron: p-pbar collision @ 1.96TeV
- LHC: p-p collision @ 7 TeV



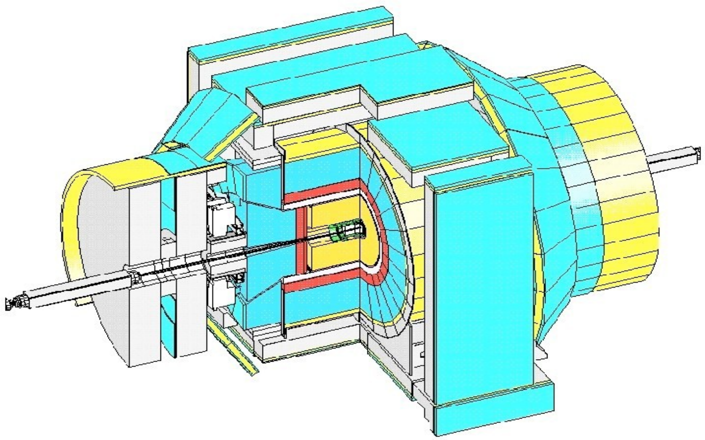
Integrated Luminosities

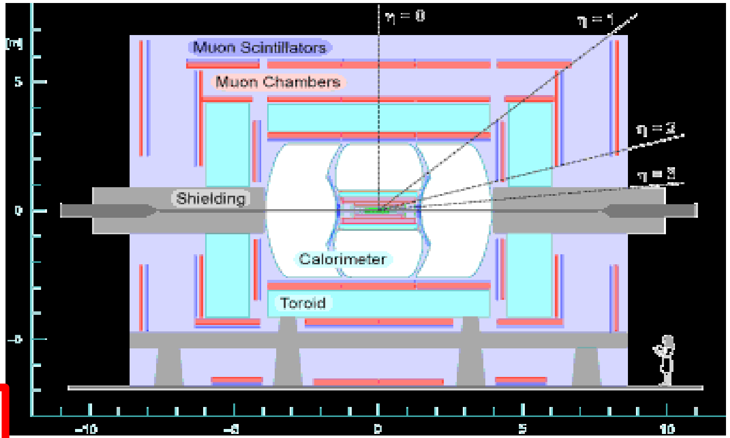
- Tevatron doing very well: Delivered ~10 fb^{-1} with L_{inst}> 4x 10^{32}.
- LHC making great progress: expect to deliver ~1 fb^{-1} by 2011.



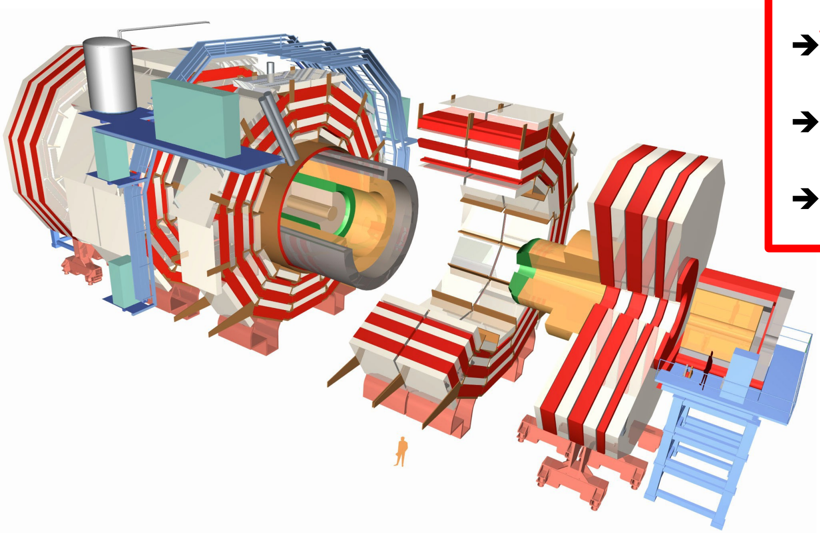


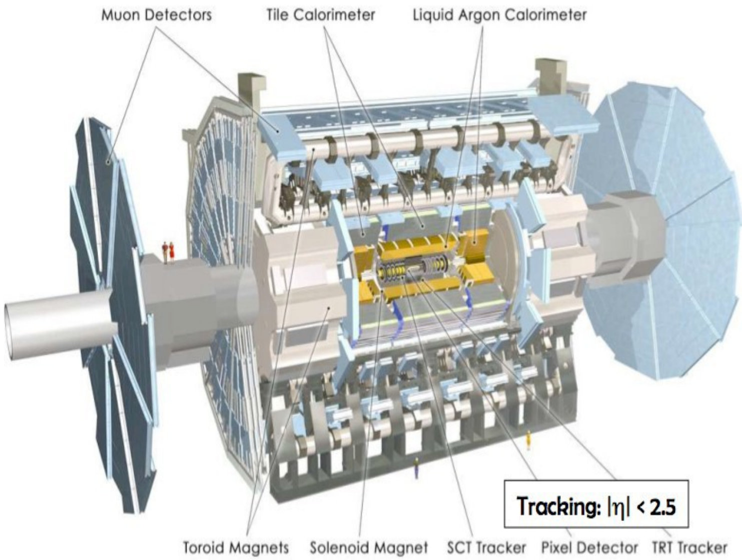
General-purpose Detectors



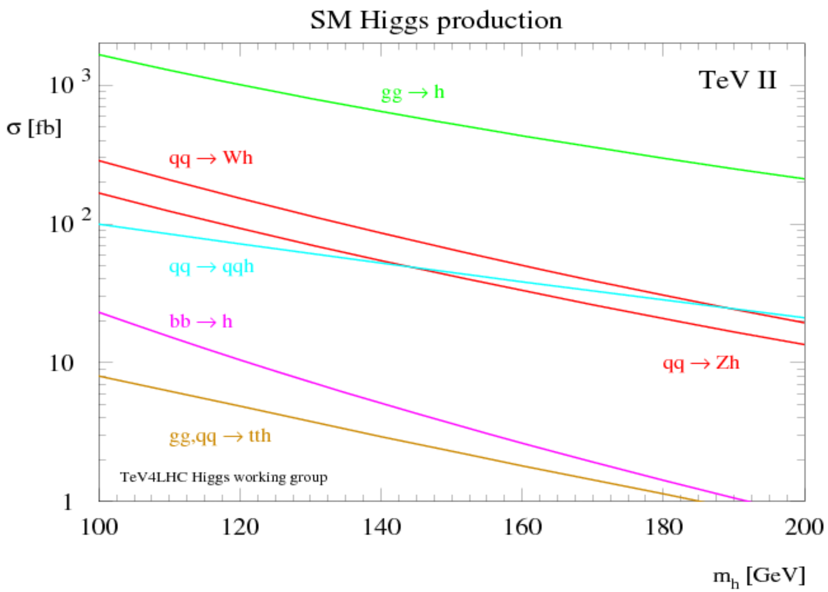


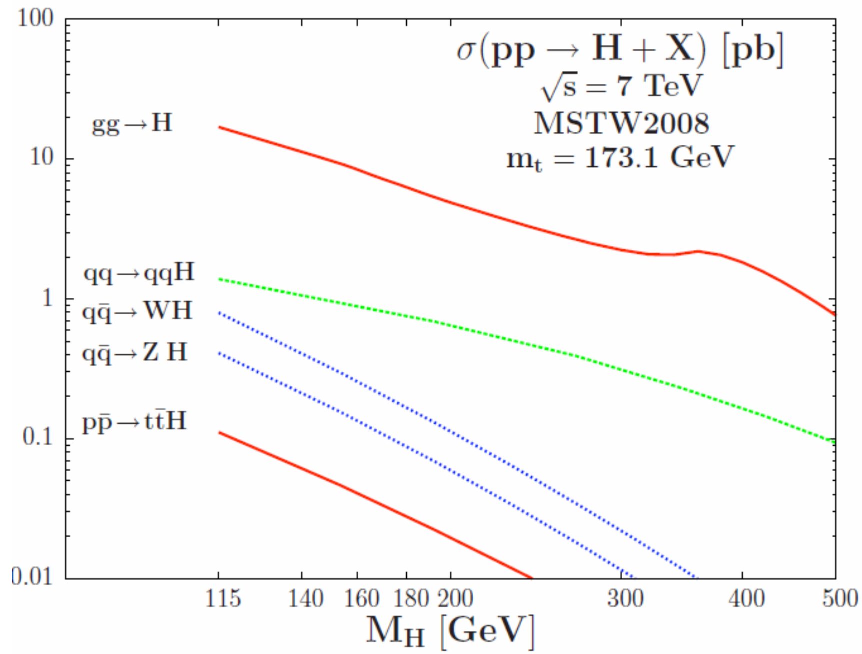
Excellet:
- Lepton ID
- Tracking
- Vertexing
- Jets
- Missing Et

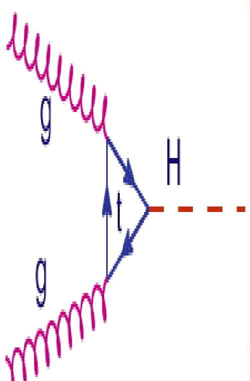


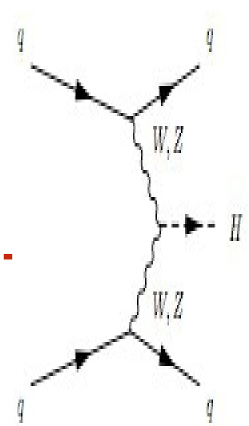


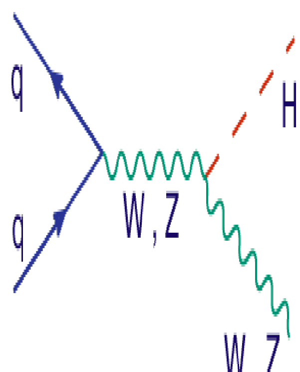
SM Higgs Production

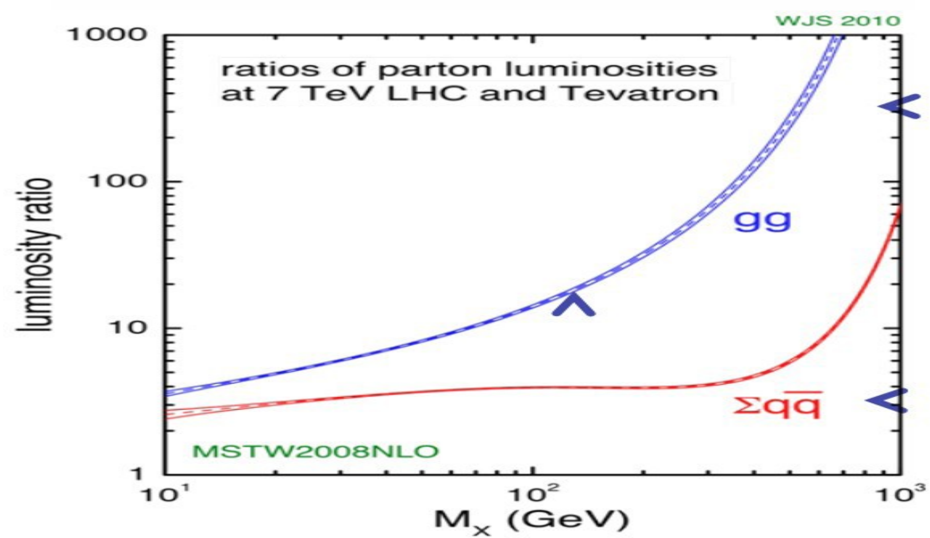




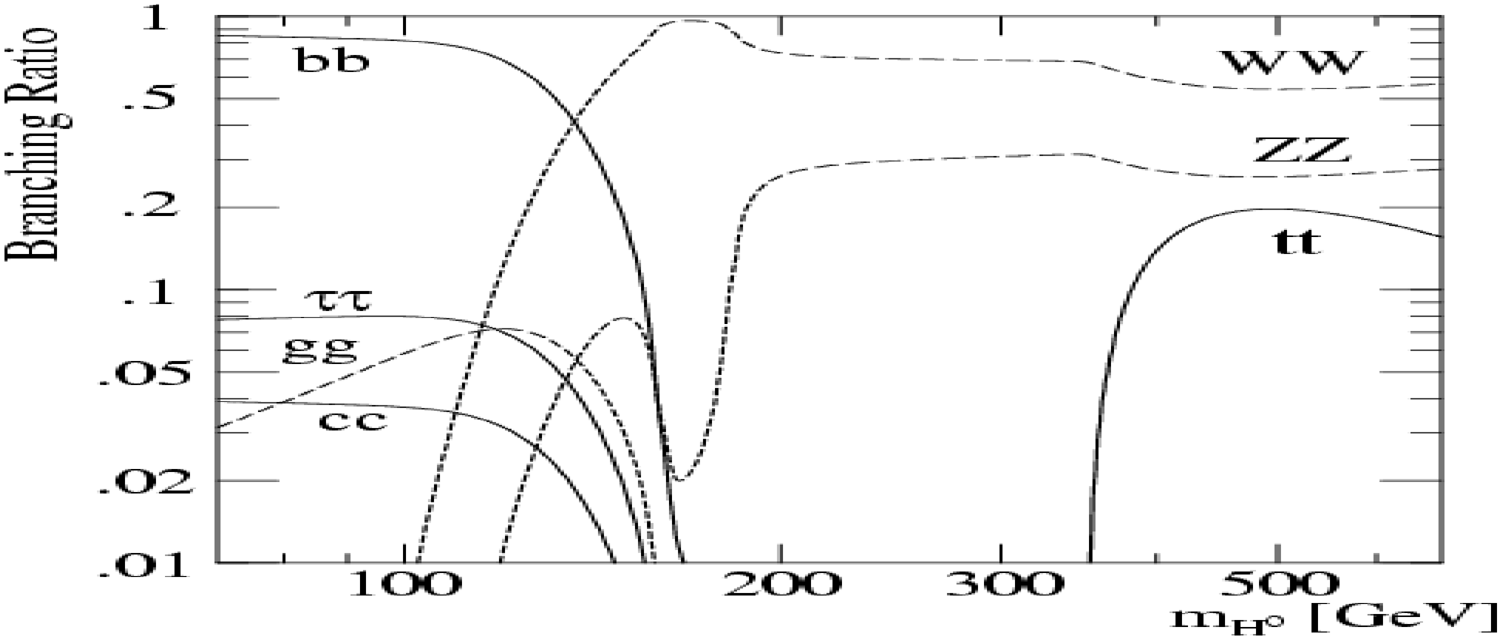








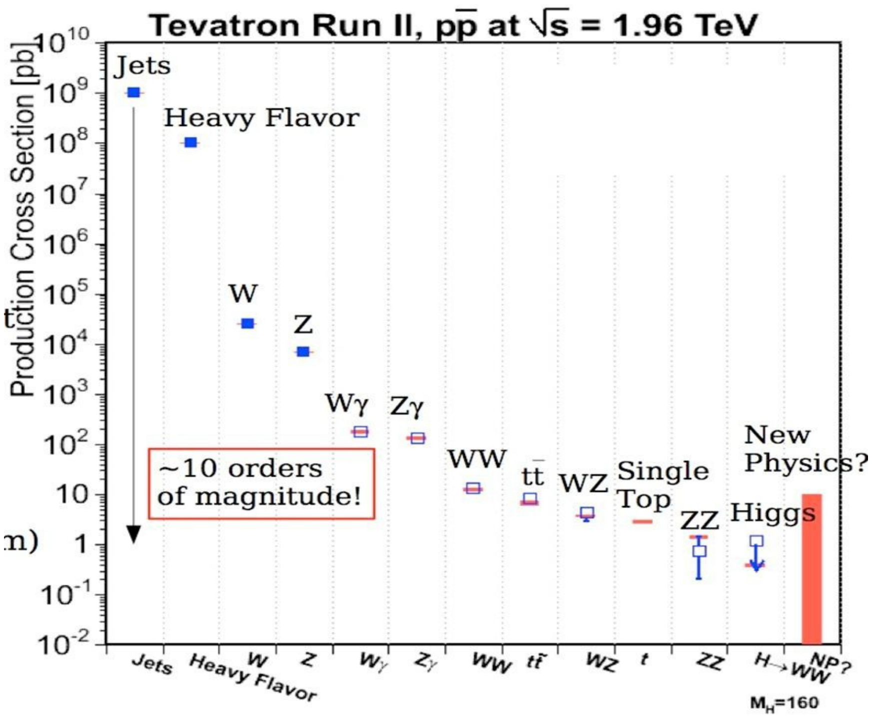
Higgs Decays

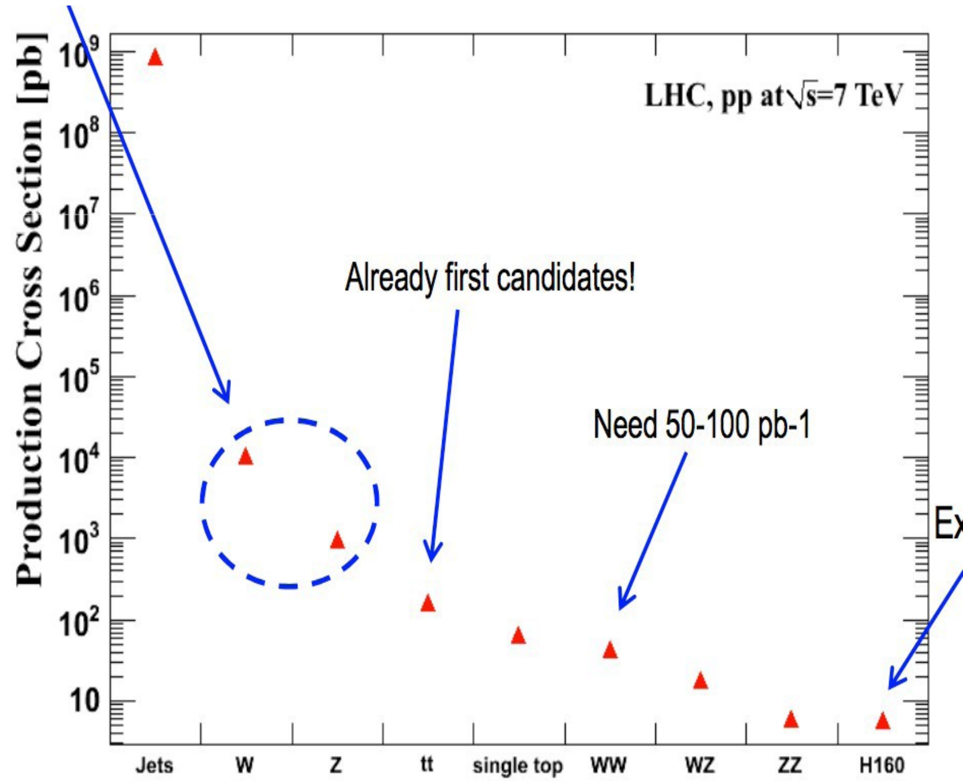


- MH<135 GeV: H→bb dominate
- qq→VH→lvbb, llbb, vvbb most accessible at Tevatron
- Difficult at LHC due to large ttbar bkgs, need to rely on H→γγ

- MH>135: H→WW* dominate
- Exploit large σ(gg→H)
- H→WW→lvlv: clean final states.
- Sweat spot for LHC (large σ).

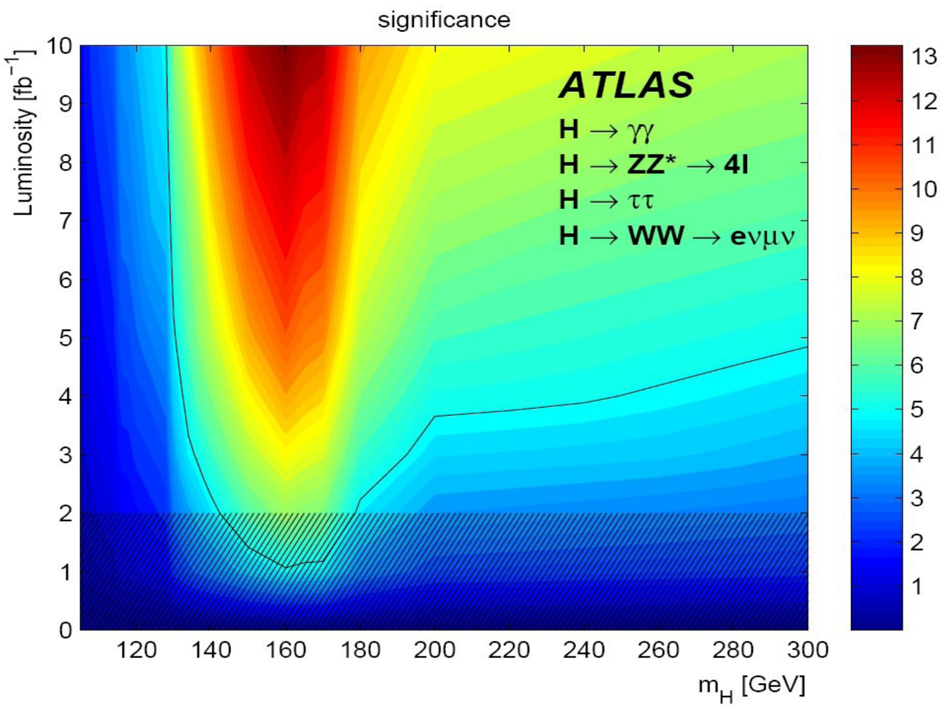
The Challenges

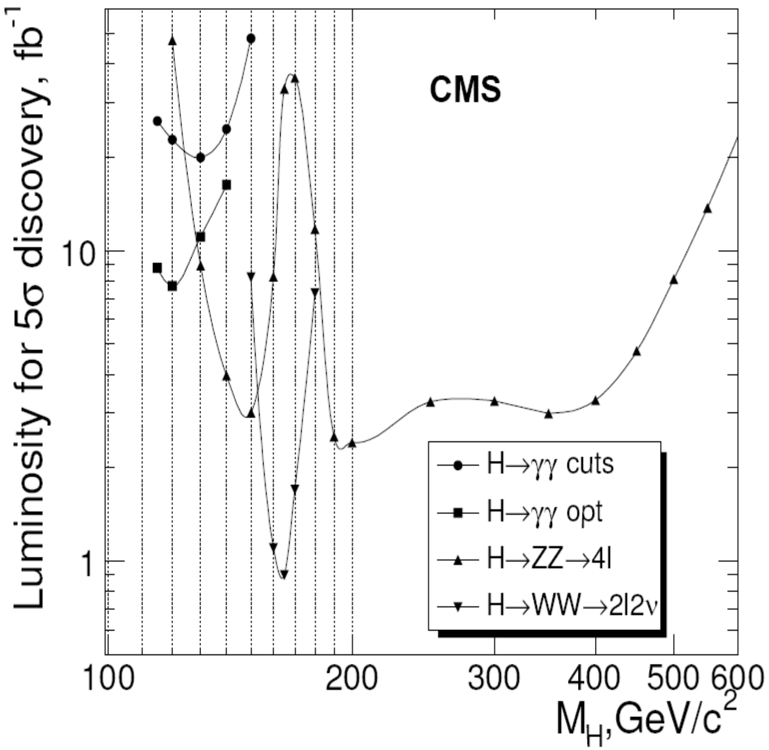




- Higgs production is a low rate process
- Backgrounds are many orders of magnitude larger
- Challenge: Separate Signal from large background

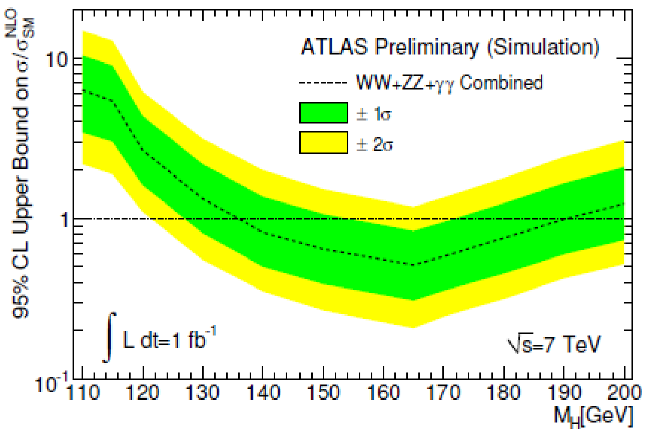
LHC Sensitivity @14 TeV

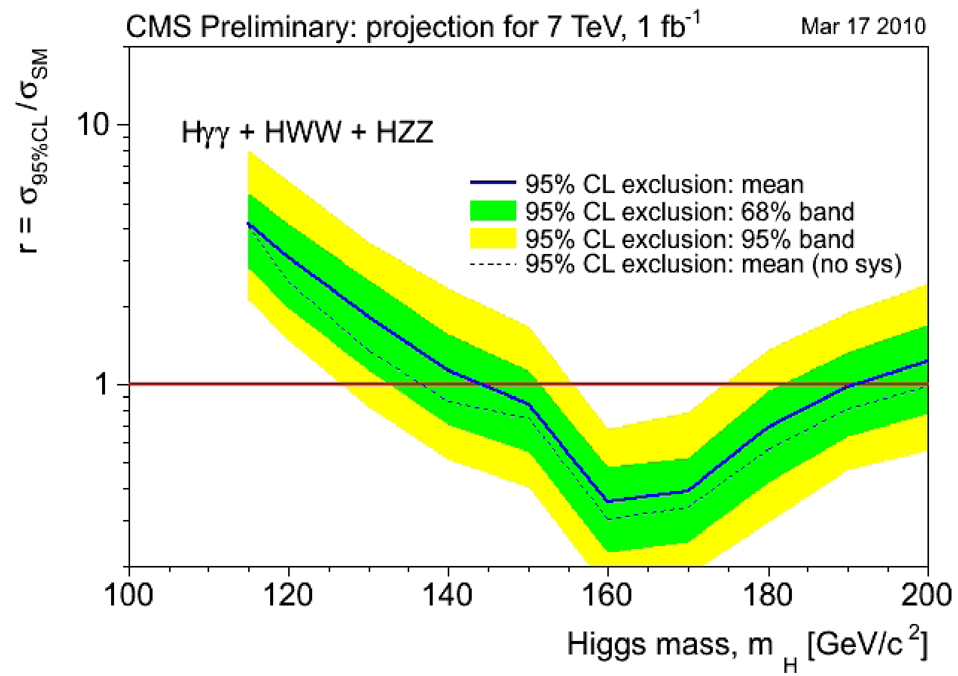


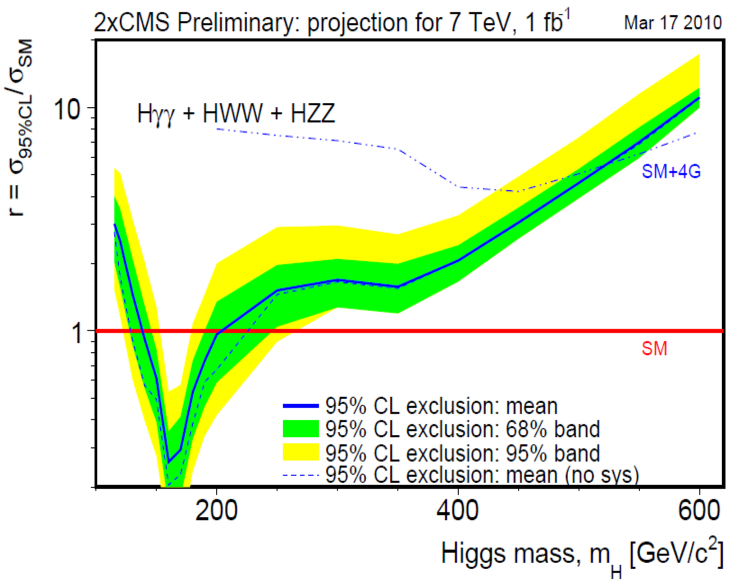


- With 10 fb^{-1}, 5sigma discovery for MH [115,500] GeV/c^2
- With 5 fb^{-1}, 5 sigma discovery for MH[130,450] GeV/c^2
- With 1-2 fb^{-1}, H→WW channel starts to play

What expected from LHC at 2012



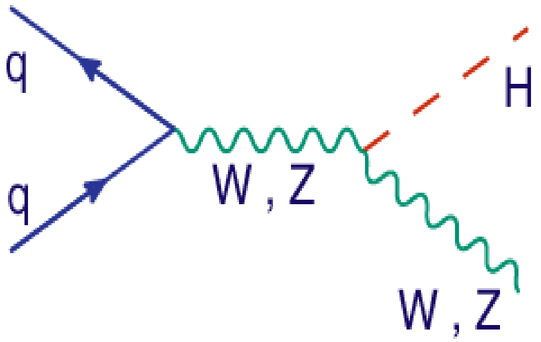




- Combining $H \to \gamma\gamma$, WW, ZZ.
- Projected exclusion limits assuming twice amount of data (ATLAS+CMS): $140 < M_H < 200$ GeV/c^2

Tevatron Higgs Search Strategies

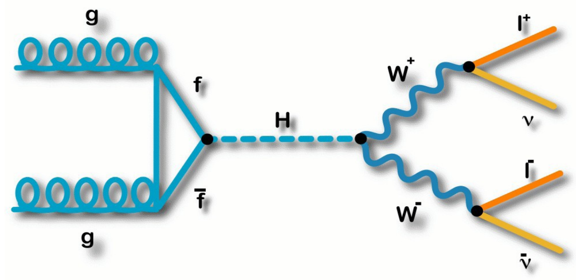
Event selections are similar for the corresponding CDF and D0 analyses.



•**Search for H→bb in association with W and Z:**

- Main low mass channels
- Identify Higgs as two jets with 1 or 2 btags
- W, Z identified as leptonic or hadronic decays

•**Search for H→WW→lνlν in inclusive production:**



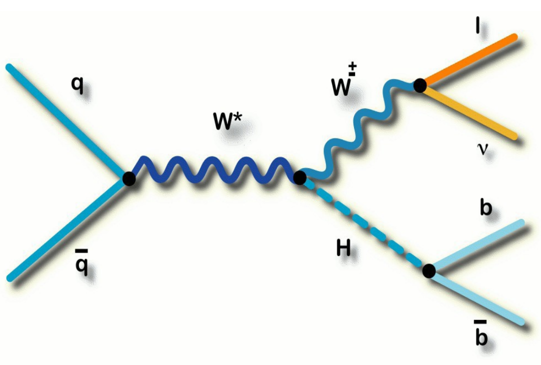
- Main high mass channel
- Selects on two charged leptons + missing et

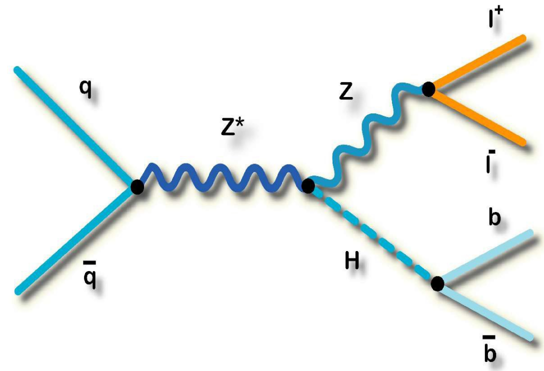
•**Search for H→ττ, γγ in inclusive production:**

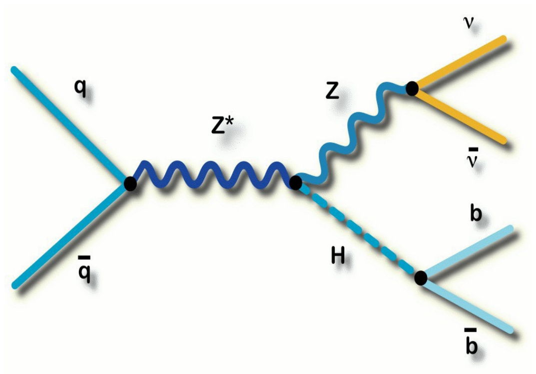
- Minor channels for Tevatron, but important for LHC
- Identify Higgs as a pair of τ or a pair of γ

•Employing “**no channel too small**” strategies to gain signal acceptances while reducing backgrounds with advanced analysis technique(**NN,ME,BDT**).

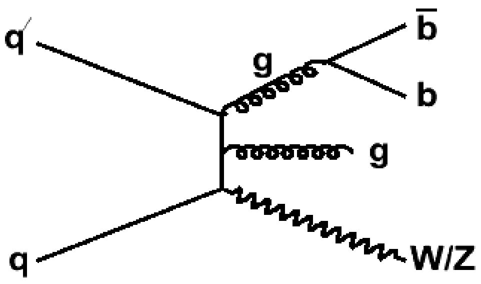
Low Mass Higgs Signitures

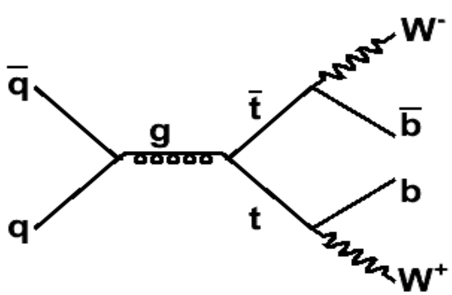


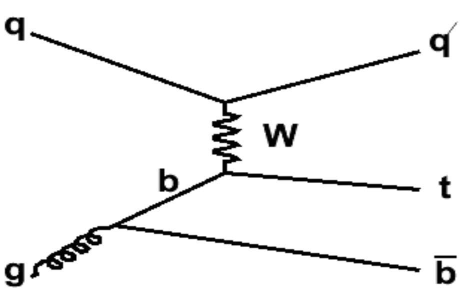




- Goal: search for dijet resonance H→bb
  - WH→lvbb: 1 lepton + met + 2b
  - ZH→llbb: 2 lepton + 2b
  - ZH→vvbb, WH→(l)vbb: 0 lepton + met+2b
- Major backgrounds: Vbb, ttbar, single top...

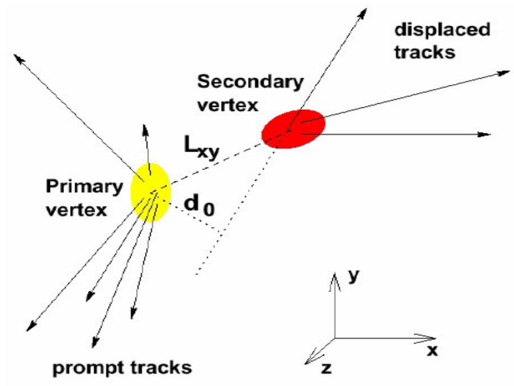


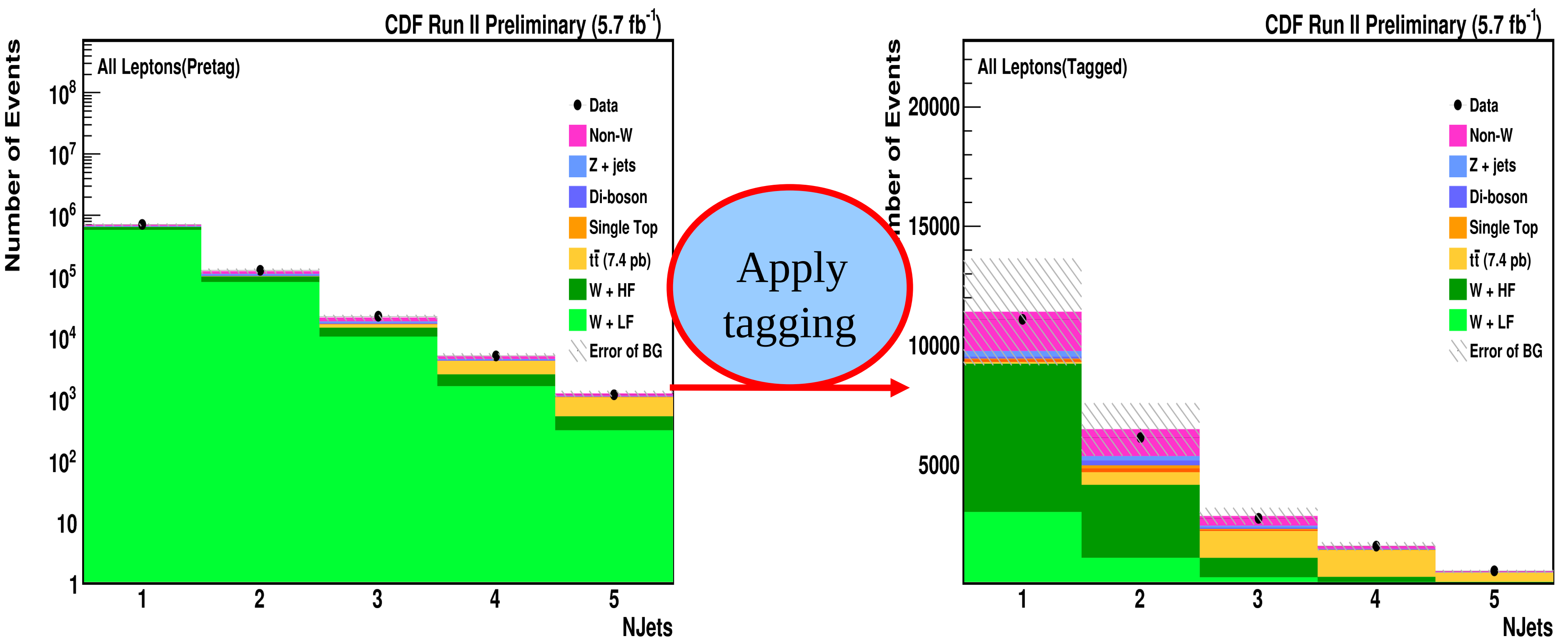




Identifying H→bb

- b-hadron are long lived: search for displaced tracks vertex inside the jet.
- Separate ttbar→lvbbjj, W+bb/Z+bb from W/Z+light flavor jets.



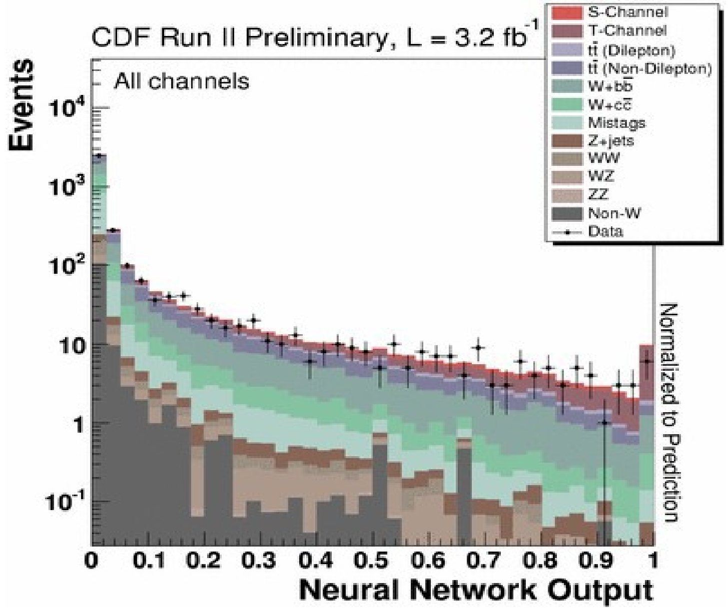


Advanced Multivariate Techniques

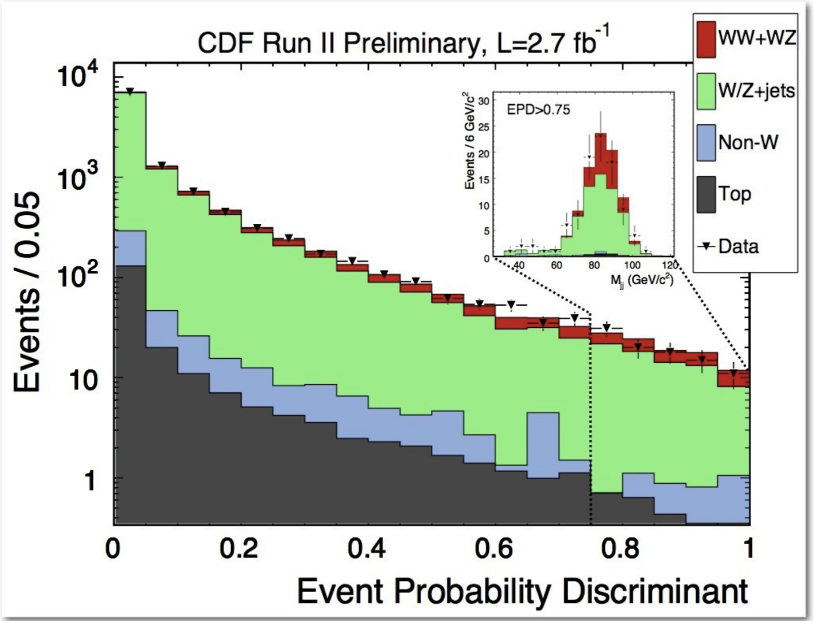
- In order to suppress large background, we use various advanced multivariate technique.
- LO Matrix Elements (ME): are used to calculate event probabilities and likelihood ratios.
- Neural network (NN): combine various kinematic variables, including ME into a final discriminant.
- Boosted Decision Tree (BDT): an alternative to NN
- Typical Improvement is ~25% respect to use a single variable, such as dijet mass.
- However, the primary gains in recent years mainly from improved signal acceptance: more triggers, looser lepton ID, better b-tagging...

Applications of Multivariate Methods

- Observation of single top: t+q→lνjj, similar to WH→lνbb
- $Xsec_{measured}=2.3^{+0.6}_{-0.5}$ pb
- NLO: xsec=3.46+-1.8 pb



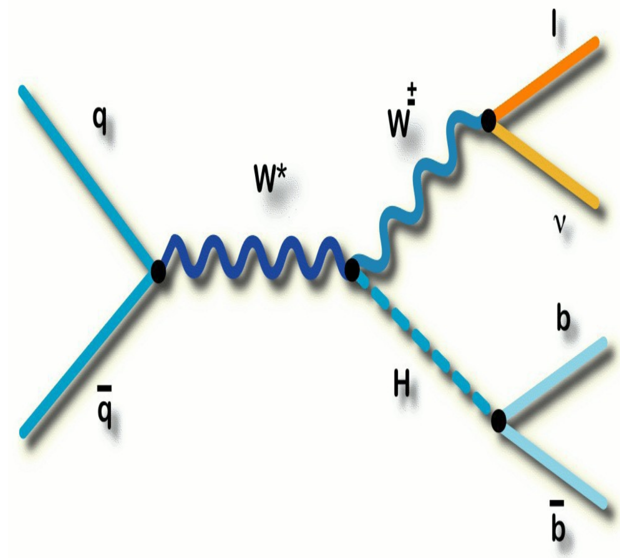
- Observation of WW+WZ→lνjj, similar to WH→lνbb
- $Xsec_{measured}=16.5^{+3.3}_{-3.0}$ pb
- NLO: Xsec =15.1+-0.8 pb

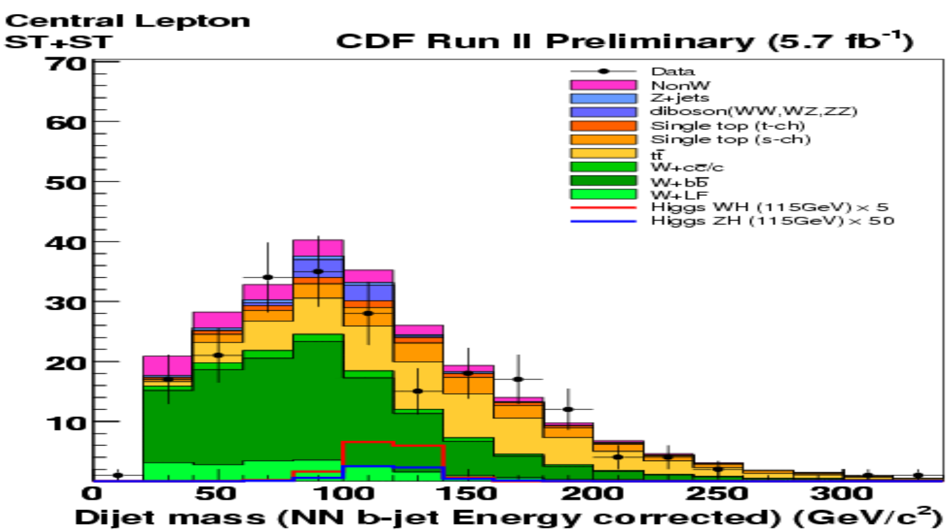


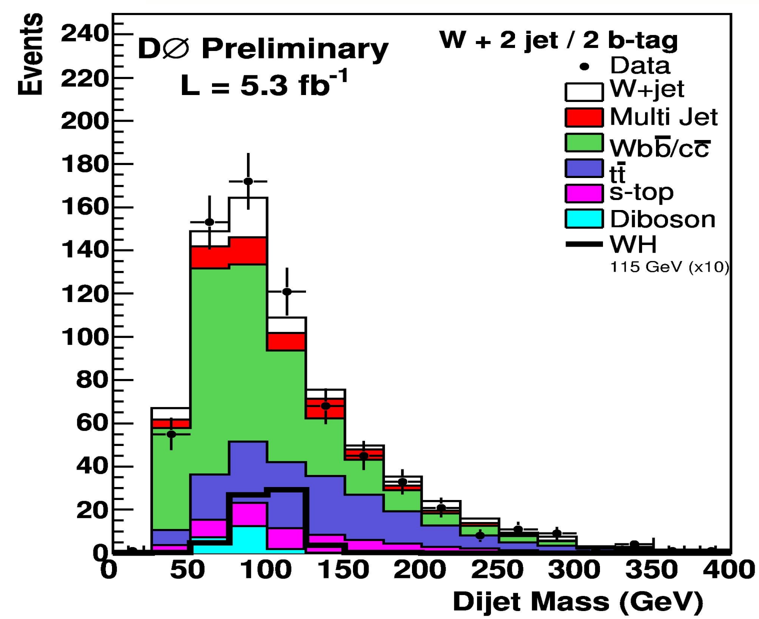
- Provide solid ground that these advanced tools do work to separate small signal from large backgrounds.

Search for WH→lνbb

- WH→lνbb is one of most sensitive channel for low mass Higgs.
- Easy to trigger on lepton, missing Et
- Requiring excellent b-tagging and di-jet mass resolution
- Expect 500 WH→lvbb@115 GeV with 10 fb^{-1} before acceptances

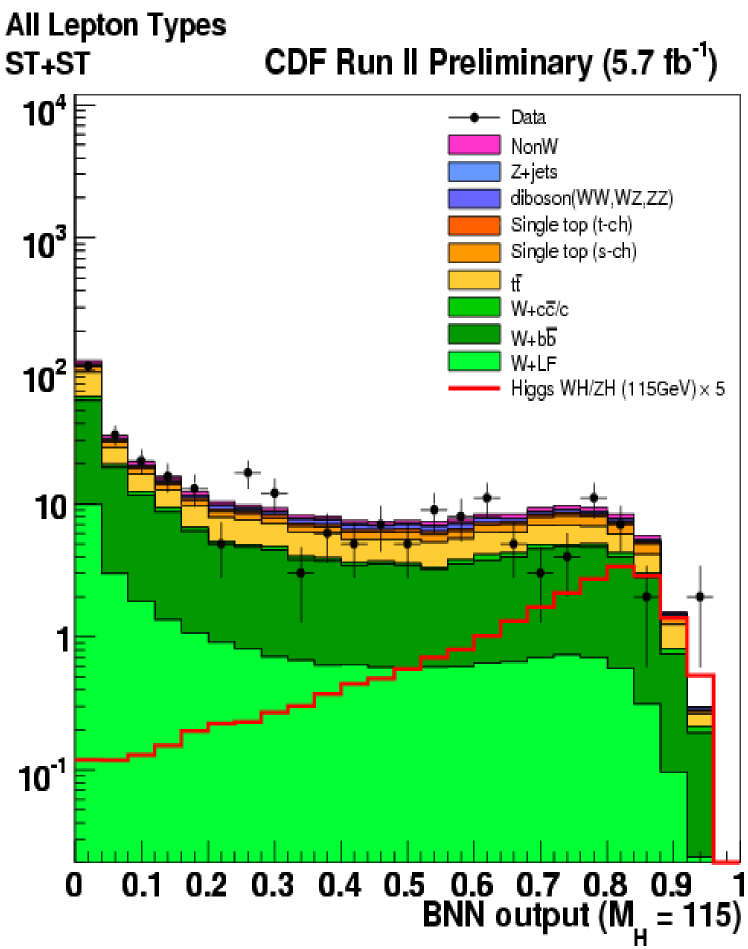


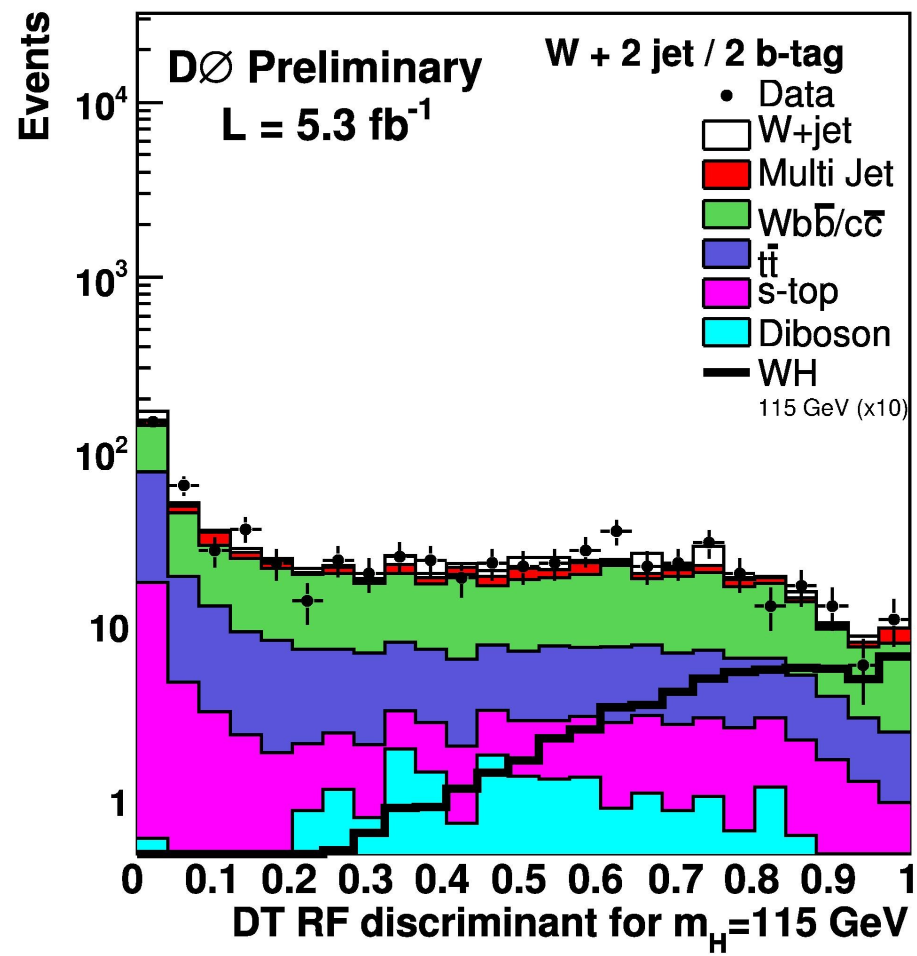




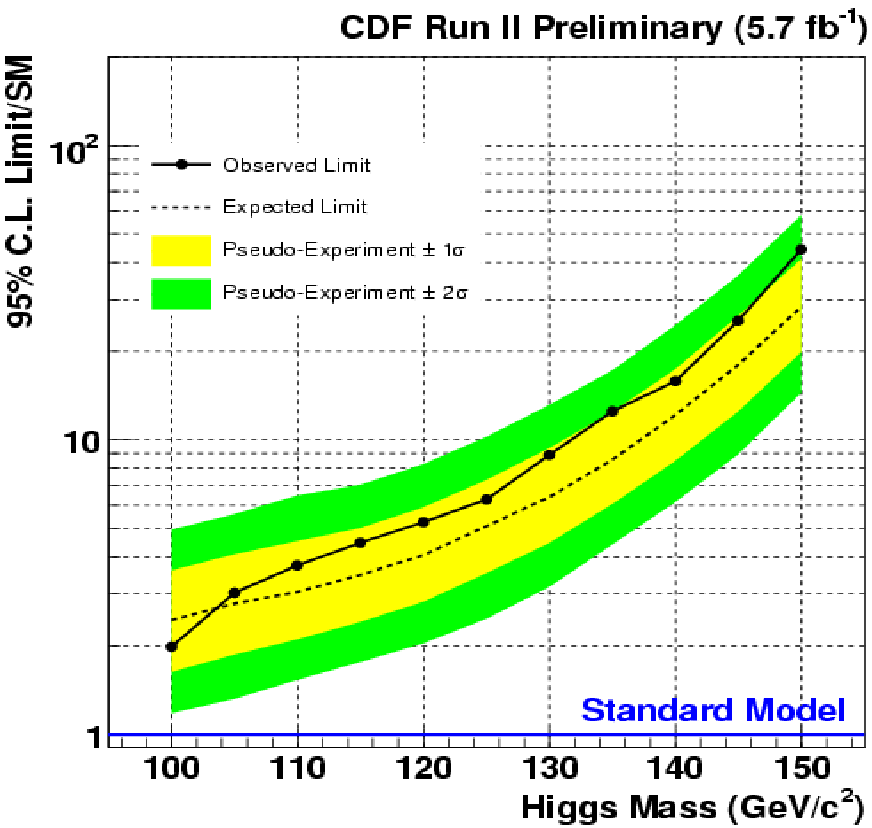
WH→lvbb Final Discriminants

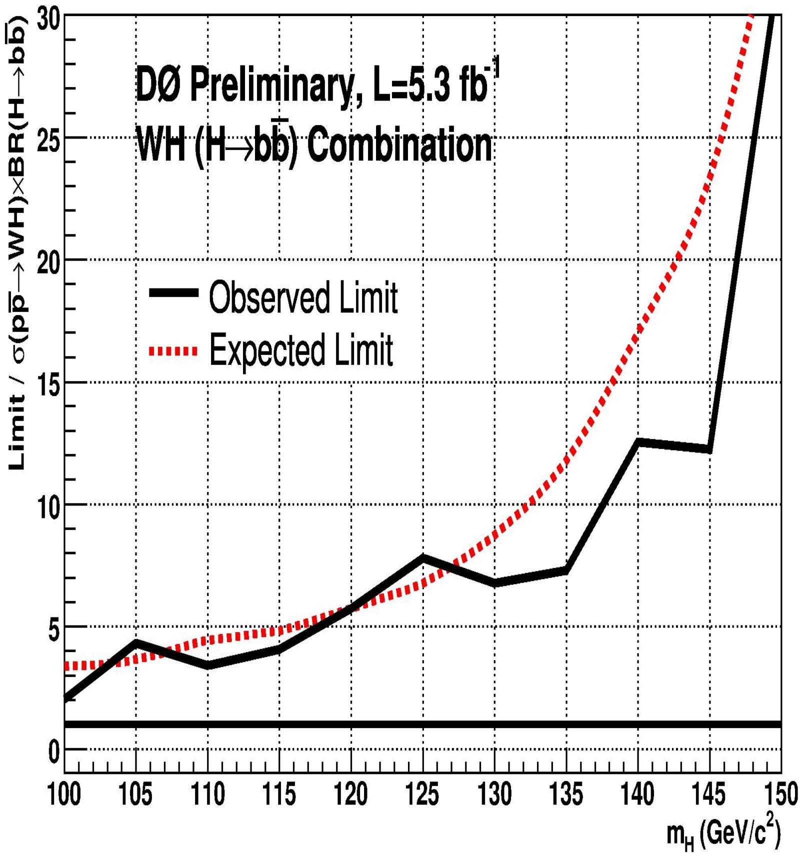
- CDF: use of a Bayesian NN(2jet) and ME(3jet)
- D0: combine kinematic into a Random Forest DT





WH→lvbb Limits

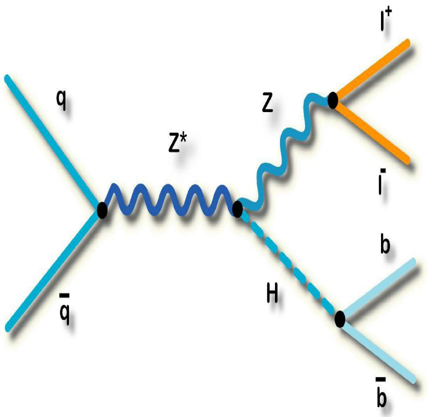


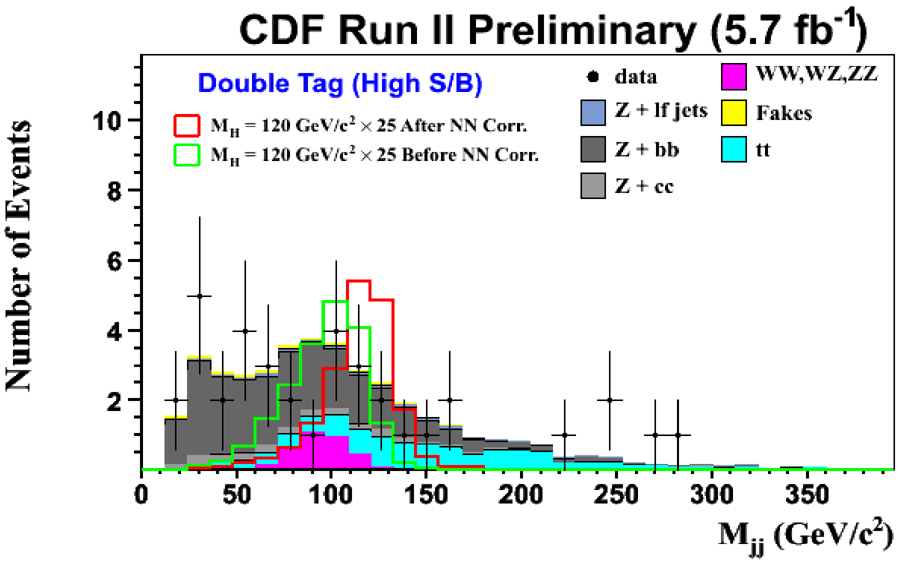


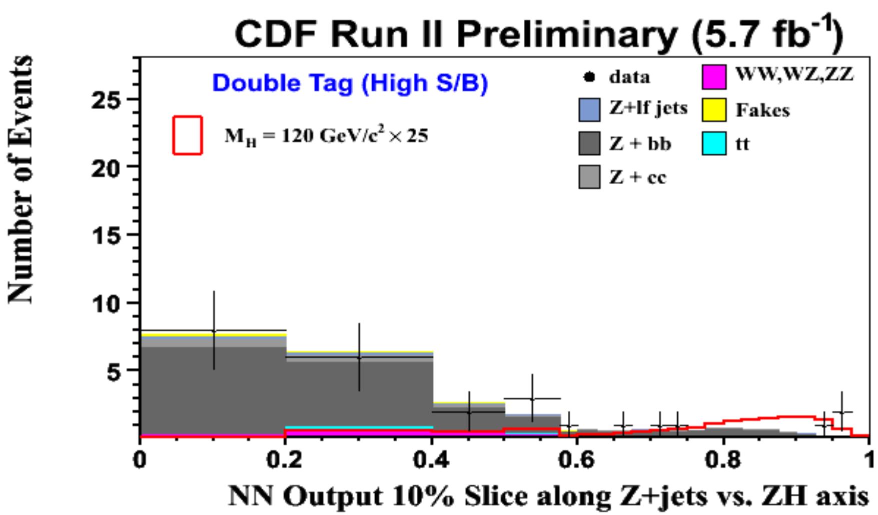
- Obs./exp. limits: 4.5/3.5(CDF) and 4.1/4.8(D0) @115 GeV
- Not competitive for a single channel, need to combine all channels and both CDF and D0.

Search for ZH→llbb

- Low event rate but clean signature
- Select two high Pt leptons (tight and loose)
- Split off 1 or 2 b-tags
- Improve dijet mass using met constrain
- NN train to separate ZH from top & Z+jets

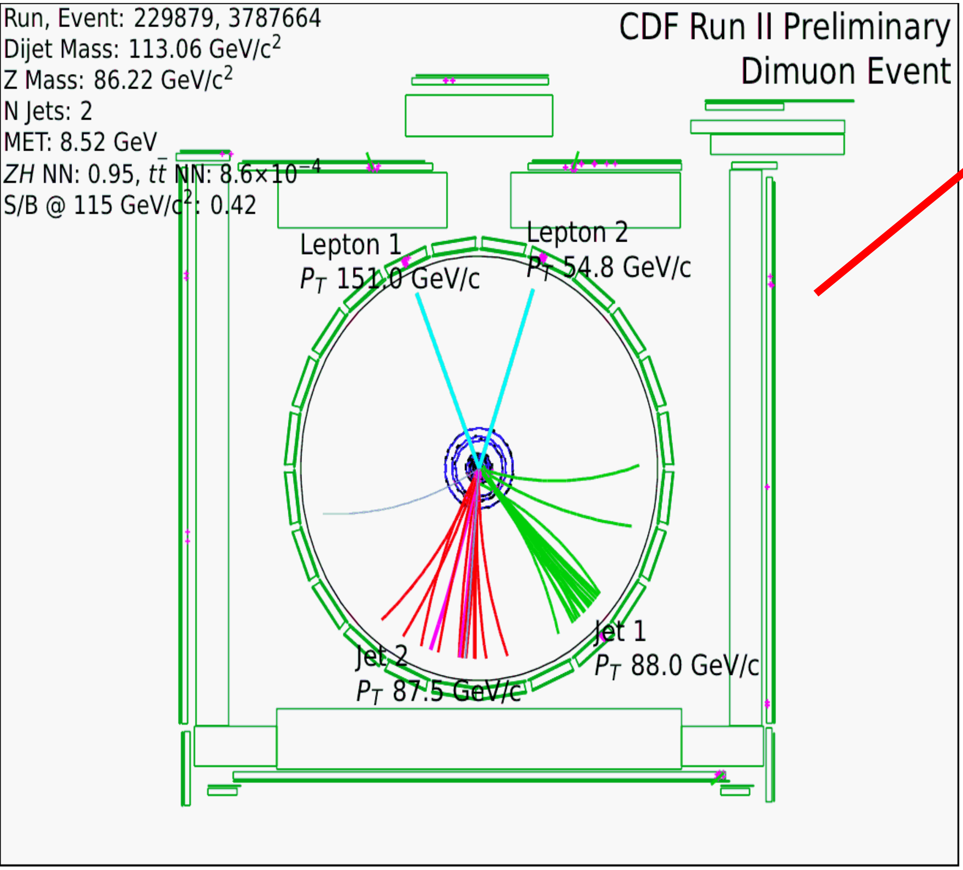




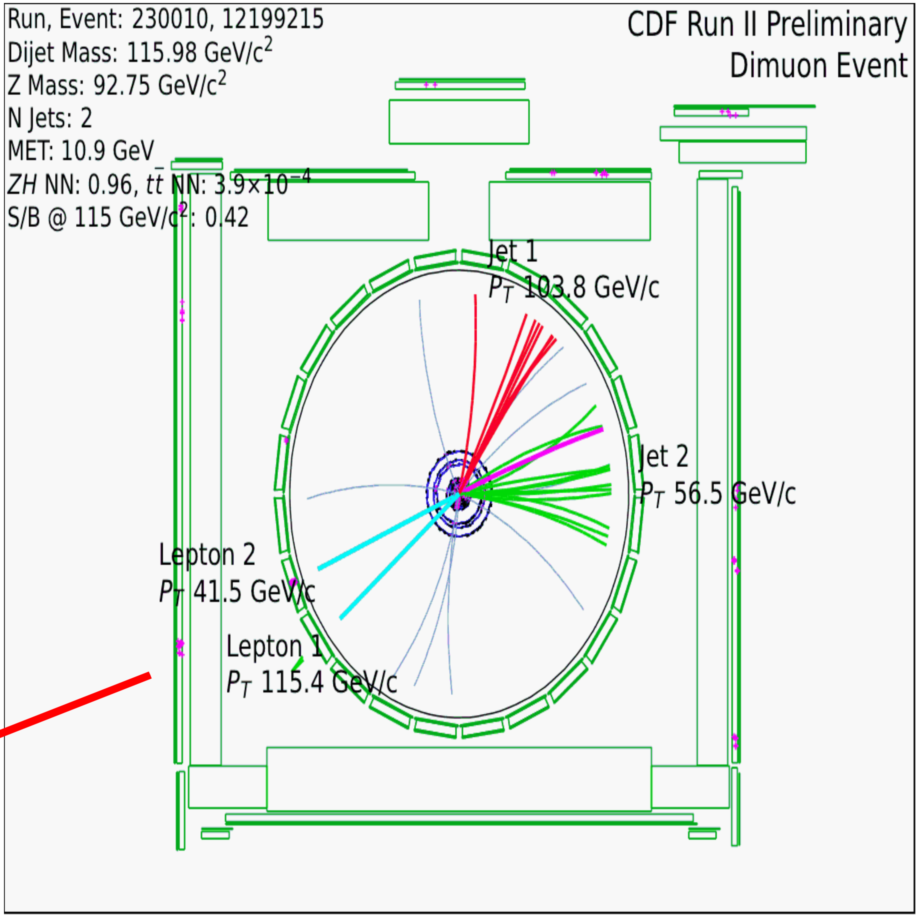


- Obs./exp. limits: 6.5/6.0(CDF) and 8.0/5.7(D0) @115 GeV

ZH→llbb Candidates



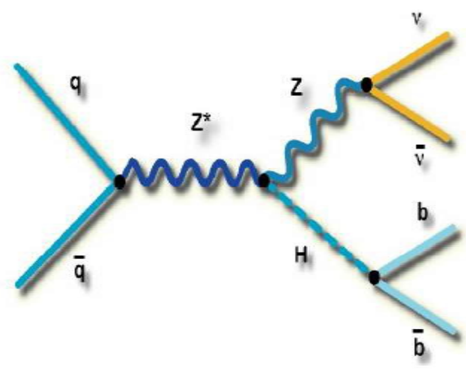
Dijet mass=113 GeV,
Z mass=86 GeV,
Met=8.5 GeV

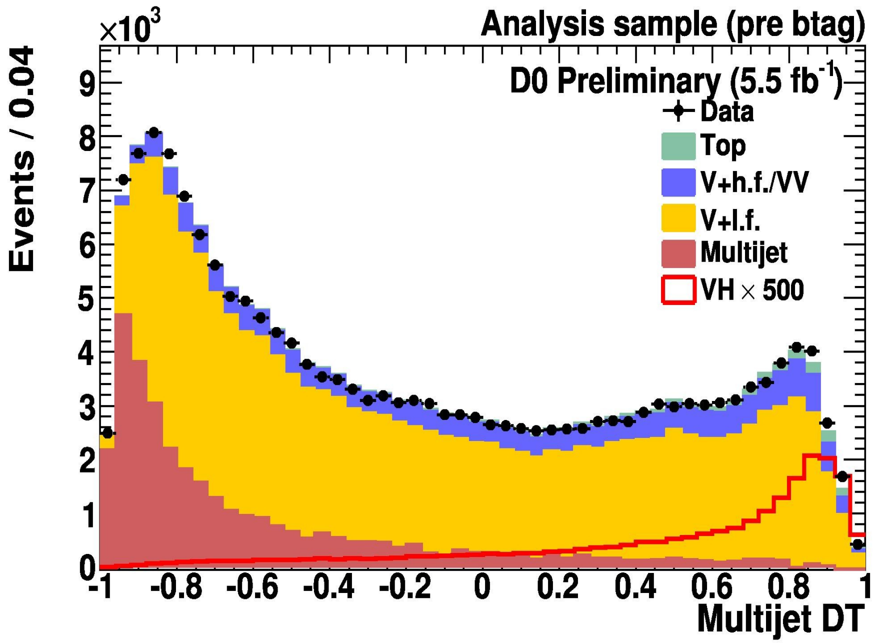


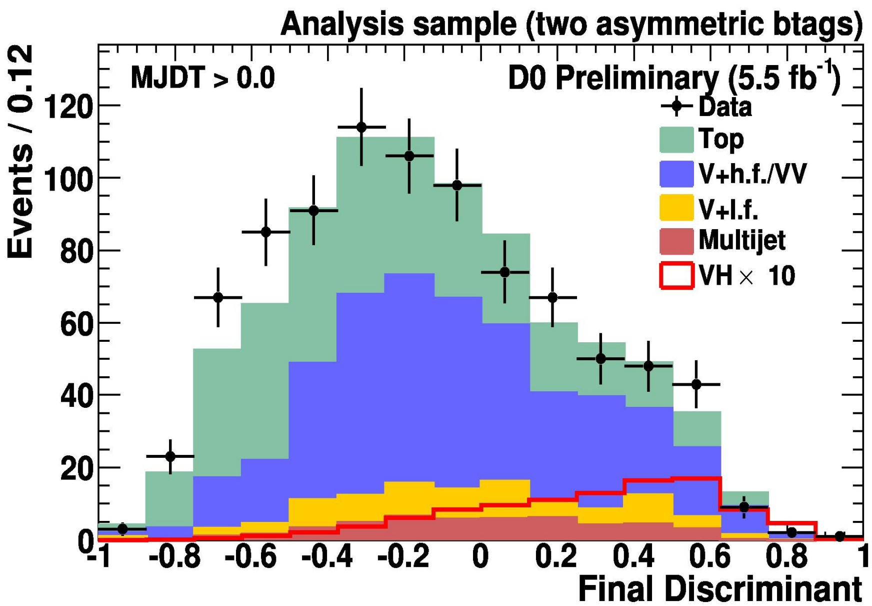
Dijet mass=116 GeV,
Z mass=92.8 GeV,
Met=11 GeV

Search for ZH→vvbb, WH→(l)vbb

- Large xsec*BR, but large QCD difficulty
- Require Met>50 GeV + 2jet
- Split off 1 or 2-btag
- Reject Multijets: track met, Δφ, met/σ



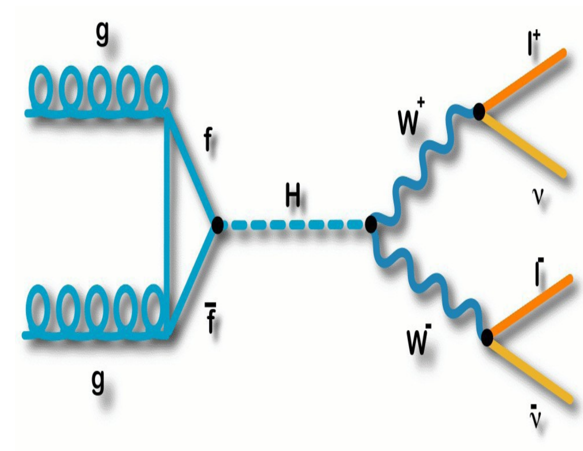


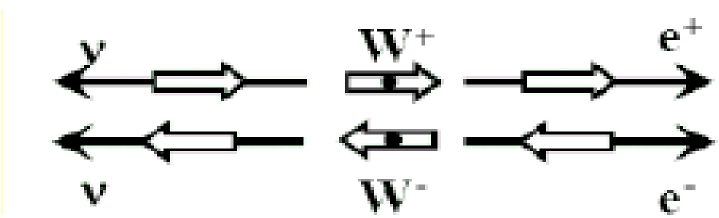


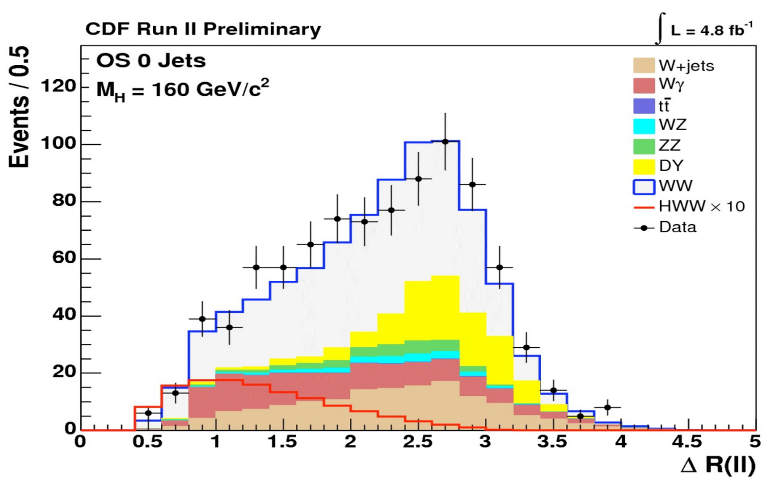
- Obs./exp. limits: 2.3/4.0(CDF) and 3.4/4.2(D0) @115 GeV

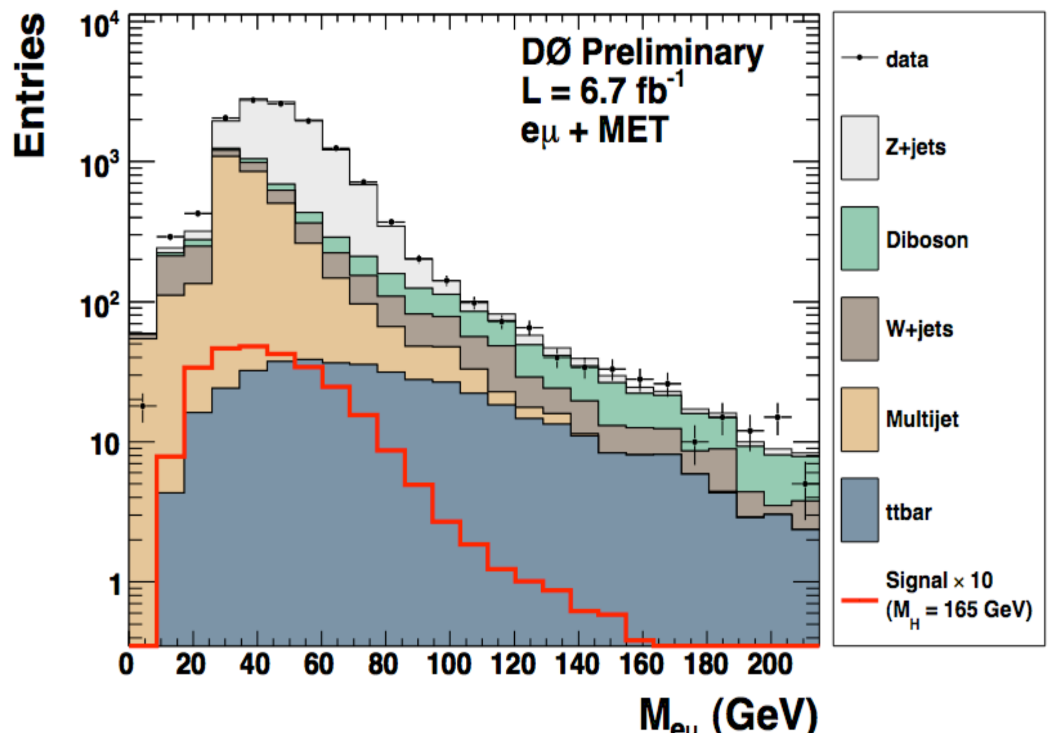
Search for H→WW→llνν

- Selecting dilepton+met,split of n jets.
- Key: maximizing lepton acceptance
- Combining Δφ(ll), Kinematic to MVA
- Most sensitive Higgs channel.



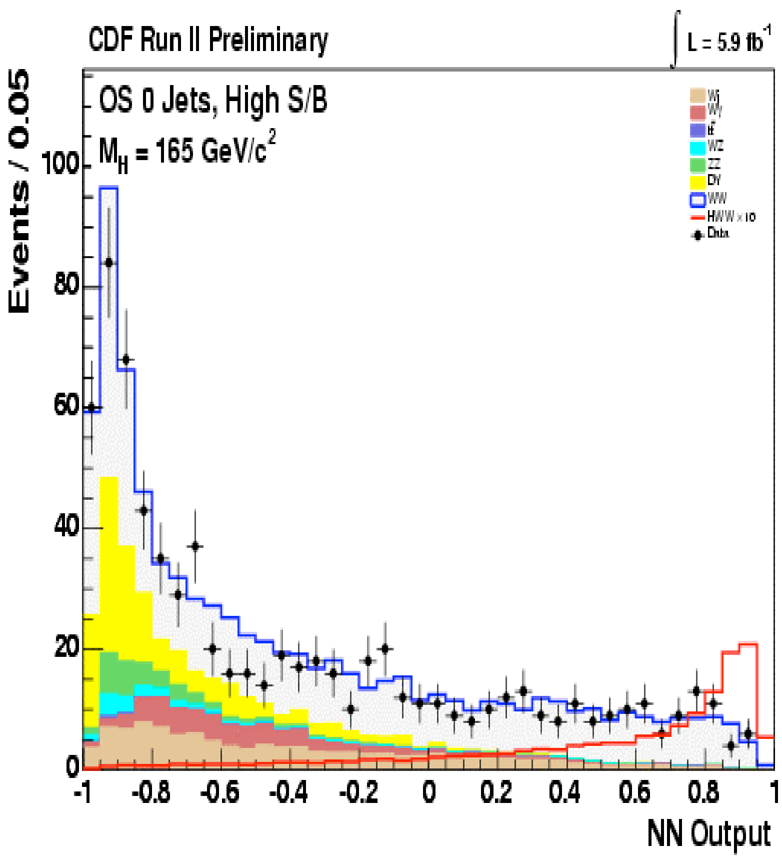


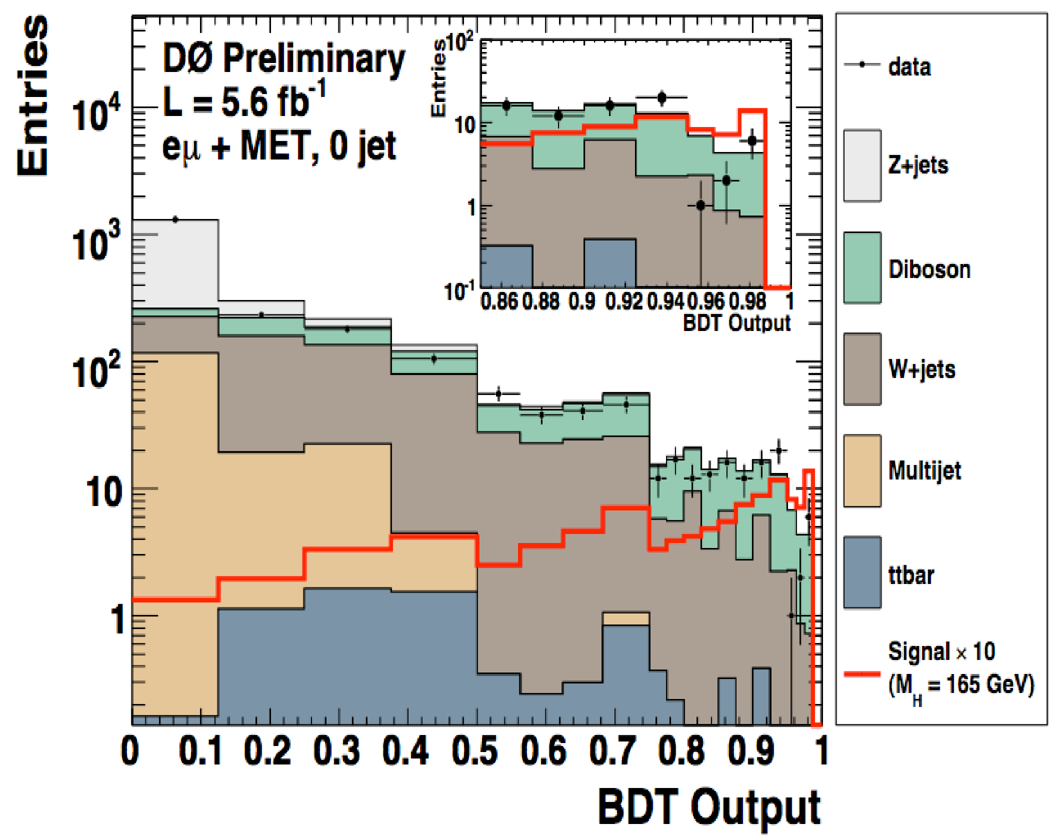




H→WW→llνν Final Discriminant

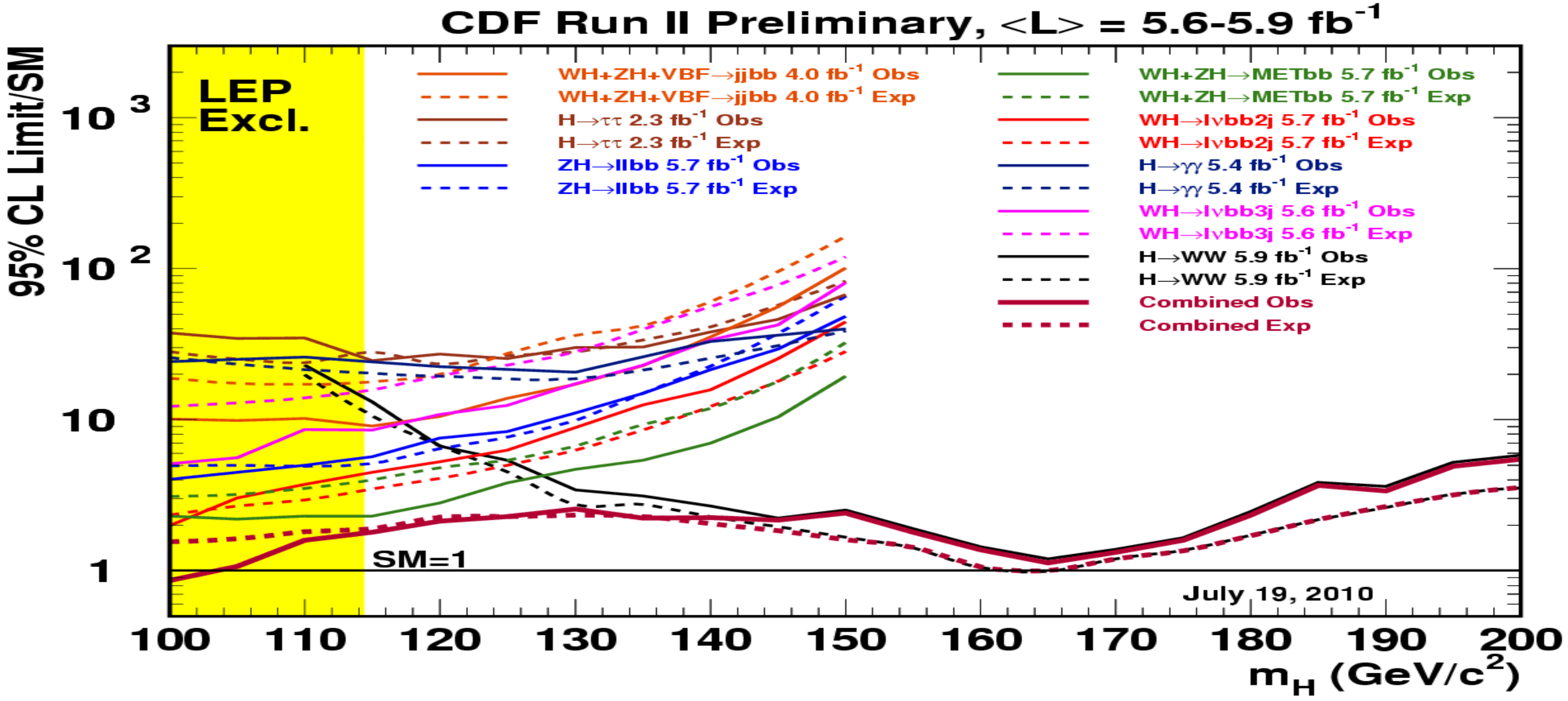
- CDF: Separate high and low S/B samples and 0,1,2 jets bins, train NN: dR, dφ, Ht, ME likelihood ratios(LRHWW, LRWW)
- D0: Incorporate jet selection, train DT: 15+ input variables.





Tevatron combination

- **Total 129 mutually exclusive final states (CDF:56 & D0:73).**
- **Both CDF & D0 see good agreement in all channels and combine statistically to improve the Higgs sensitivity.**



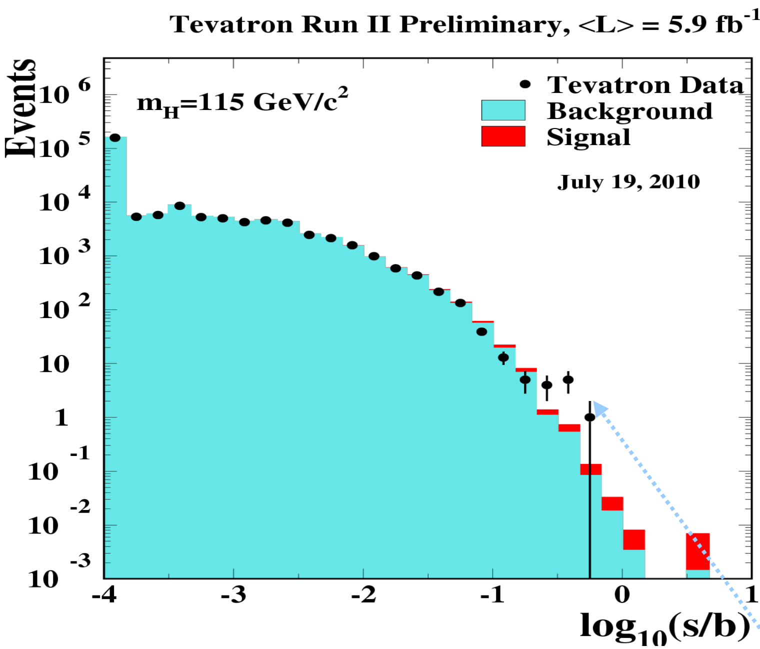
Systematic Uncertainties

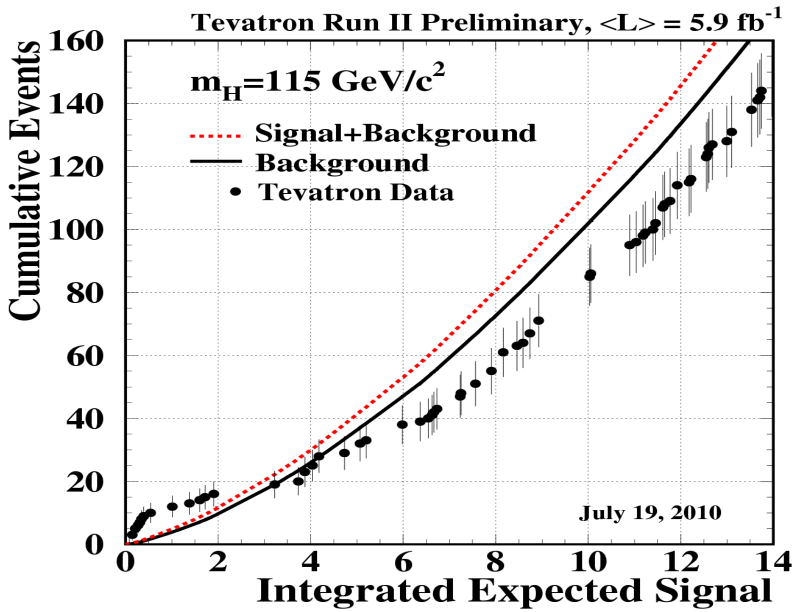
- Two types of systematics on estimated signal and background:
  - Rate systematics: only affect overall normalization
  - Shape systematics: change differential distribution, i.e. due to JES, MC modeling
- Systematics correlated between CDF and D0:
  - Integrated luminosity (4% correlated out of 6%)
  - Theoretical cross sections for signal and backgrounds (5-10%)
- Other Sources correlated within experiment:
  - Lepton ID, 2-4%
  - Btag SF, JES, FSR/ISR, 5-10%
  - Jet/Missing Et modeling
  - MC simulated backgrounds (W/Z+HF)
  - instrumental backgrounds(non-W, mistag)

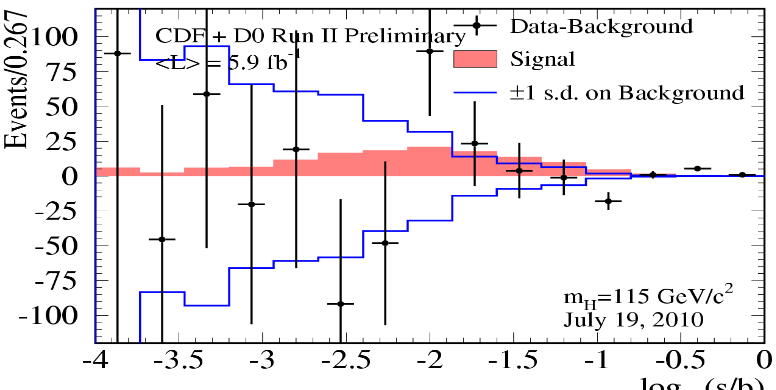
Combination Methods

- Two limit setting methods used and provide cross check(<10%).
- Using distributions of final discriminant, not just event yields.
- Using Poisson statistics for all bins.
- Systematic as nuisance parameters with truncated Gaussian.
- **Bayesian Method (CDF), integrating over likelihoods:**
  - based on credibility, uses a prior
  - “How likely is the real value below limit?”
- **Modified Frequentist Method (DØ), CLs test statistics:**
  - comparing 'b-only' & 's+b' hypotheses
  - based on coverage, using pseudo-experiments
  - “How likely is the limit above the real value?”

Tevatron low-Mass Candidate Summary

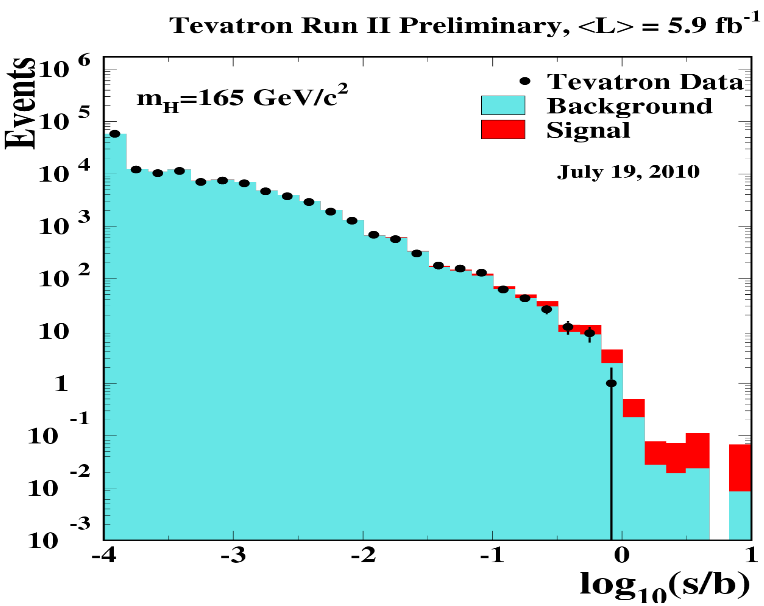


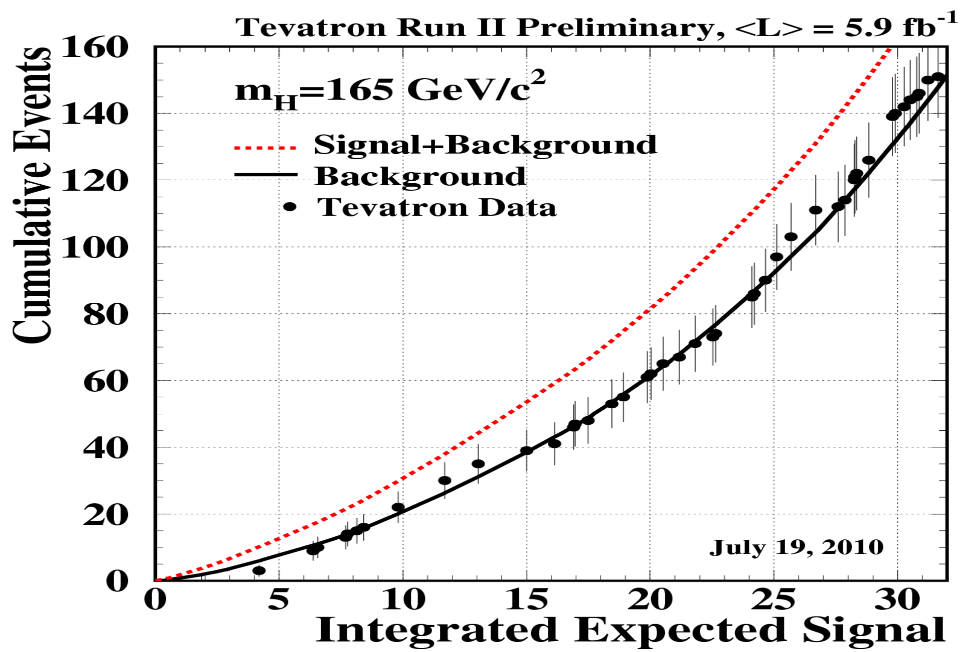


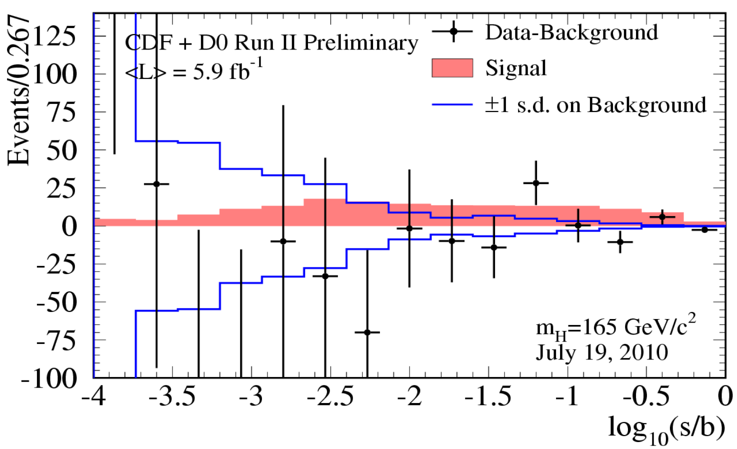


- Data with similar S/B may be added without lose sensitivity.
- Data: 5 evts with 0.8 bkg S/B=0.5.
- Fluctuations:excess and deficit averages out.

Tevatron high-mass Candidate Summary



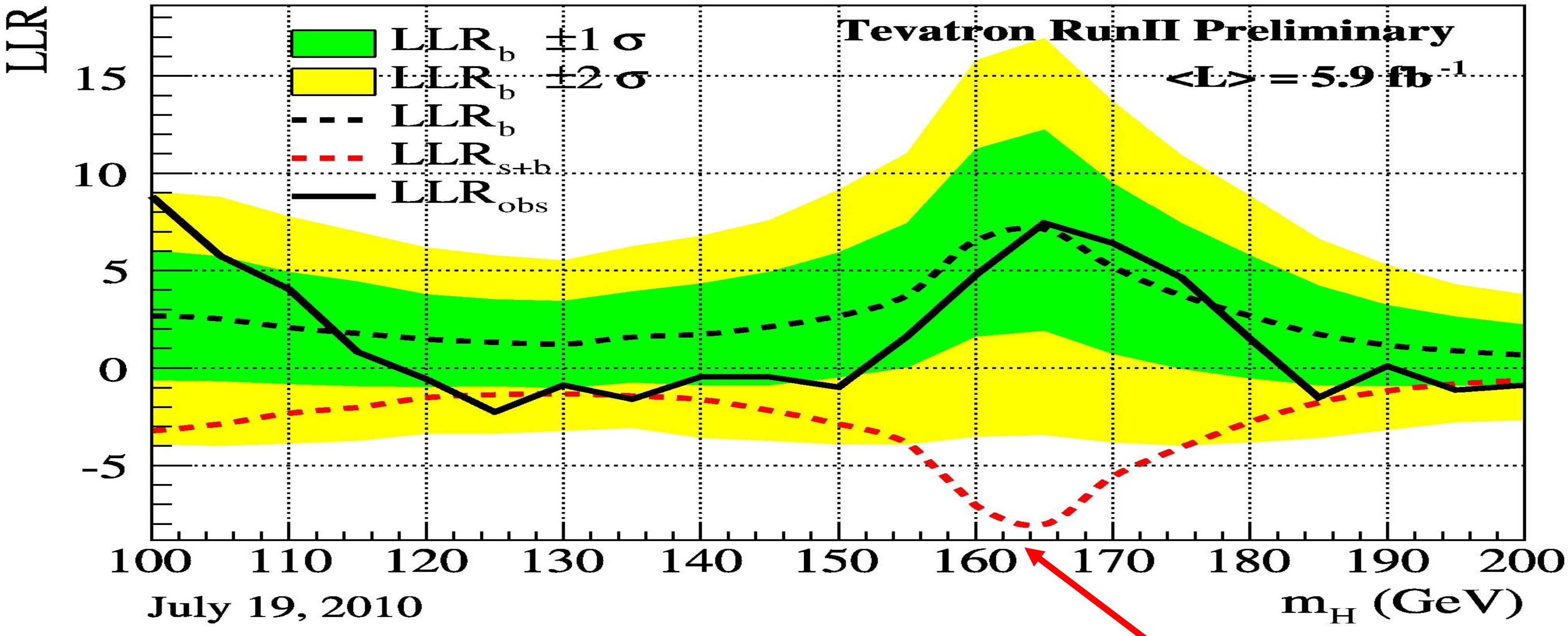




- Data with similar S/B may be added with no loss in sensitivity
- No excess of events observed in the highest S/B bins

Tevatron Sensitivity

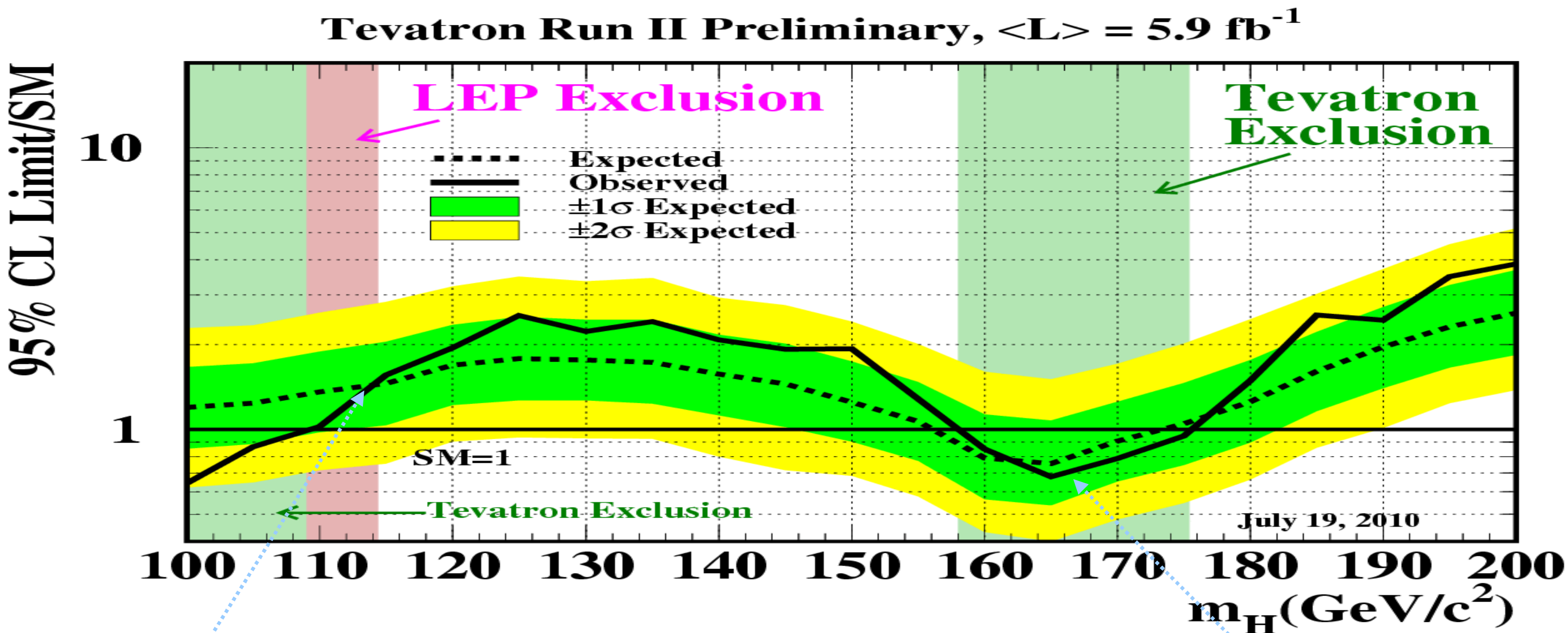
- **Log-likelihood Ratios (LLR): LLR_b, LLR_{s+b}, LLR_{obsv}**
- **Separation between LLR_b and LLR_{s+b} is the search sensitivity**



We could be seeing a ~ 3 σ excess if Higgs was at 165 GeV!

Tevatron Combination

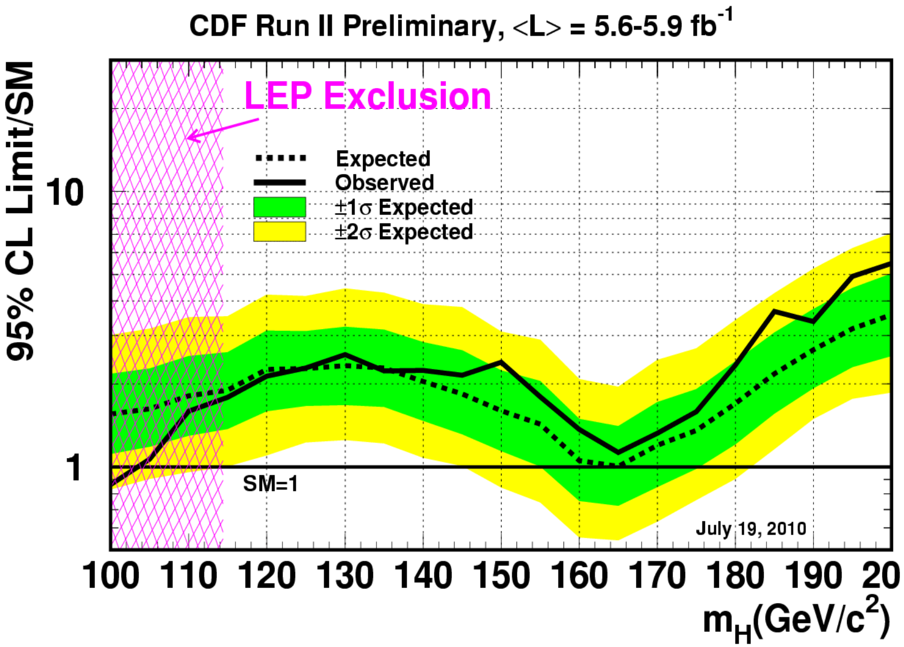
- **Combining CDF and D0 for maximum sensitivity.**
- Set 95% CL exclusion: 158<MH<175 & 100<MH<109 GeV.

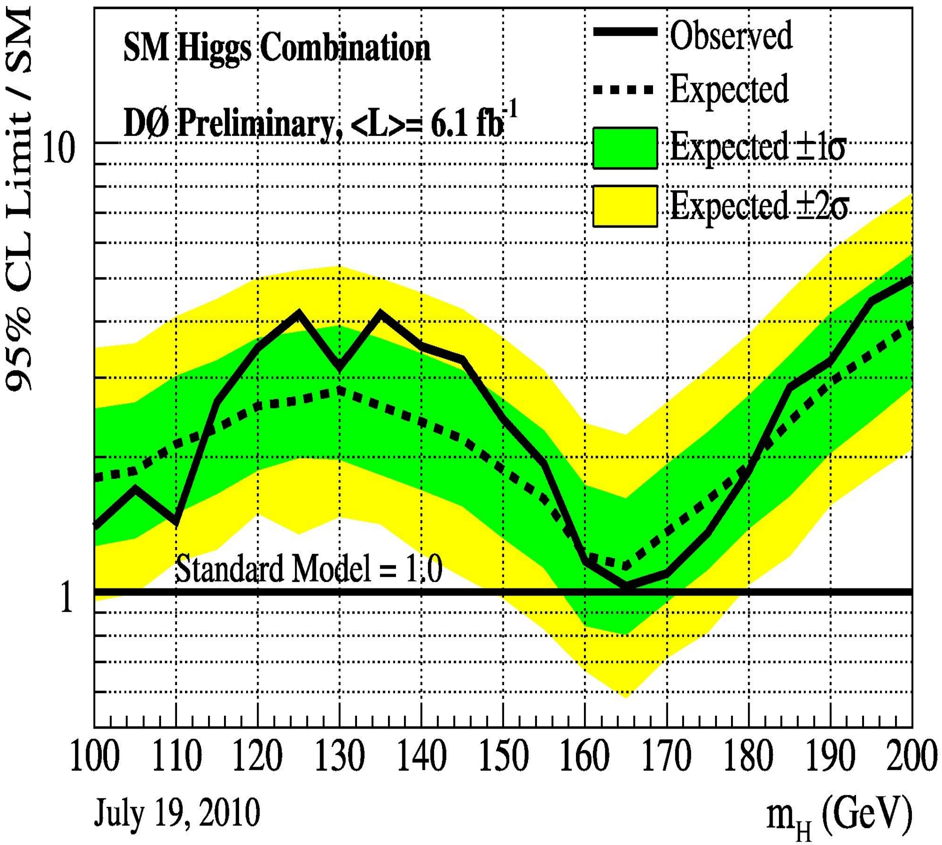


M_H=115 GeV: 1.56/1.45(Obs/Exp)

M_H=165 GeV: 0.68/0.76(Obs/Exp)

CDF and D0 Individual Combinations

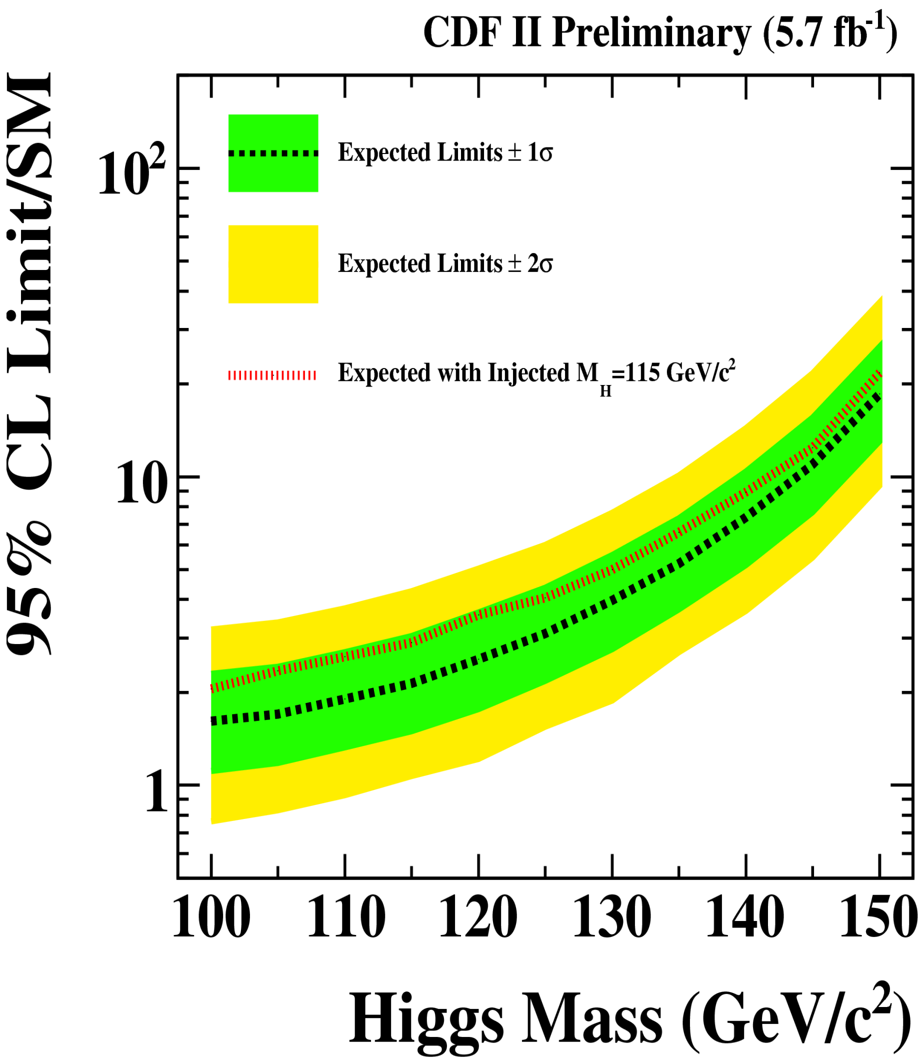




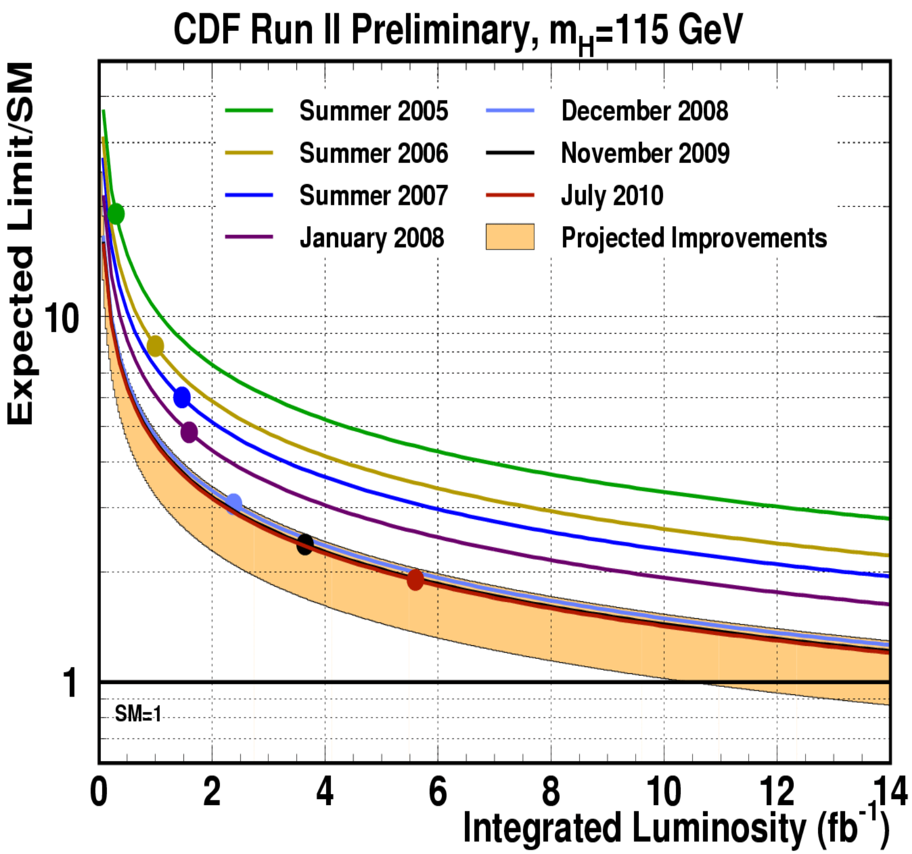
- CDF and D0 close to achieve individual exclusion @ 165 GeV.
- The limit is close to 2 x SM @ 115 GeV.

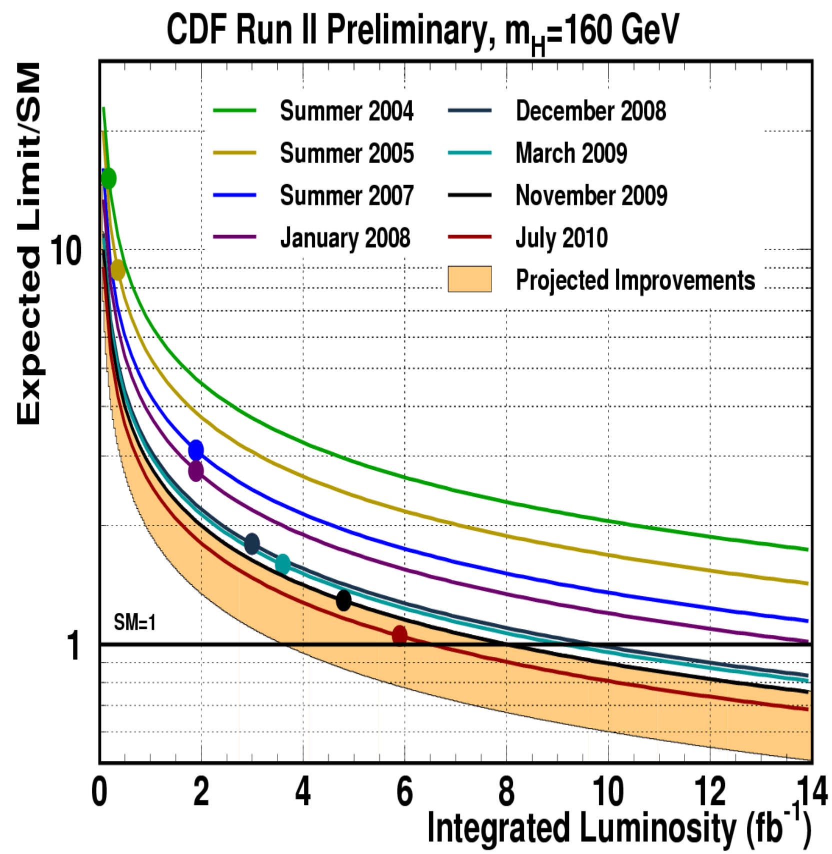
Studies of Injecting a Signal at mH=115 GeV

- Injecting Higgs signal into pseudoexperiments for low-mass channels (VH→lvbb, llbb, vvbb).
- If Higgs exist, we would observed the limit 1 σ higher than expected where Higgs signal is absent.
- More pronounced with other channels and D0 included as well.



Analysis Improvements over Time





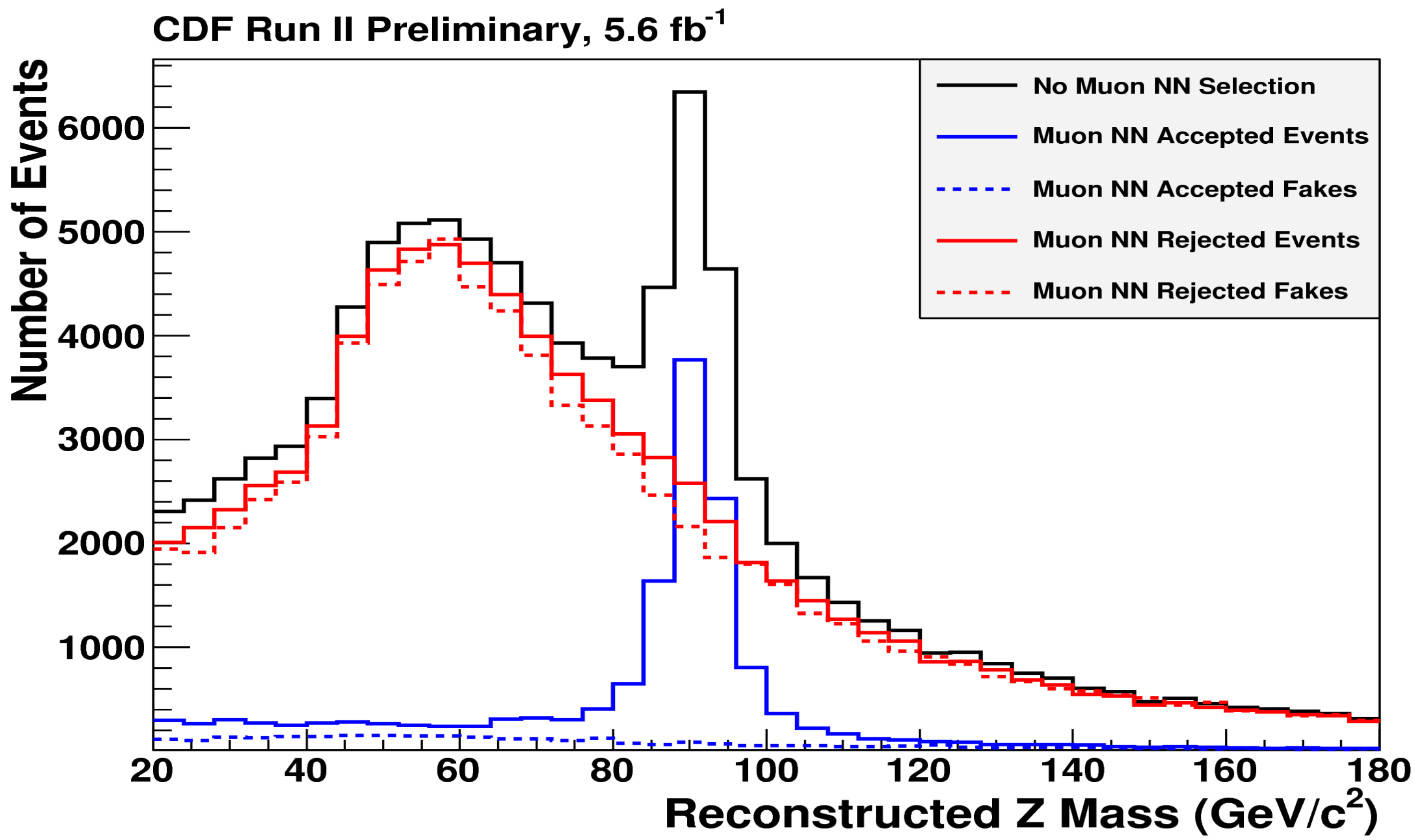
- Achieved & projected expected limit on the SM Higgs over time.
- Sensitivity has been improved more than a factor of 2 since 2005

Sensitivity Improvements

Type	Projected improvements	WHlvbb, %	ZHllbb, %	VHMETbb, %
TRIGGERS	Single stub muons	5	3	NO
	Complete OR	5	3	8
	Multivariate turn-on curves	5	DONE	5
LEPTON ID	Multivariate elec ID	10	10	NO
	Multivariate muon ID	5	DONE	NO
OTHER	Relaxed cuts	2	DONE	2
	Track-based variables	5	2	DONE
	Color flow	3	3	3
B-TAGGING	NN B-tags	DONE	6	6
	NN flavor separator	DONE	DONE	5
	Soft-electron b-tag	5	5	5
	Silicon clustering algorithm	15	15	15
JET EN RESOL.	Track + CAL	3	1	DONE
	B-specific NN	DONE	1	3
	PI-0 corrections	5	1	5
TOTAL	All improvements	90%	60%	70%

- Still rooms to improve for the low mass searches.
- ~50% gain required to reach projected sensitivity

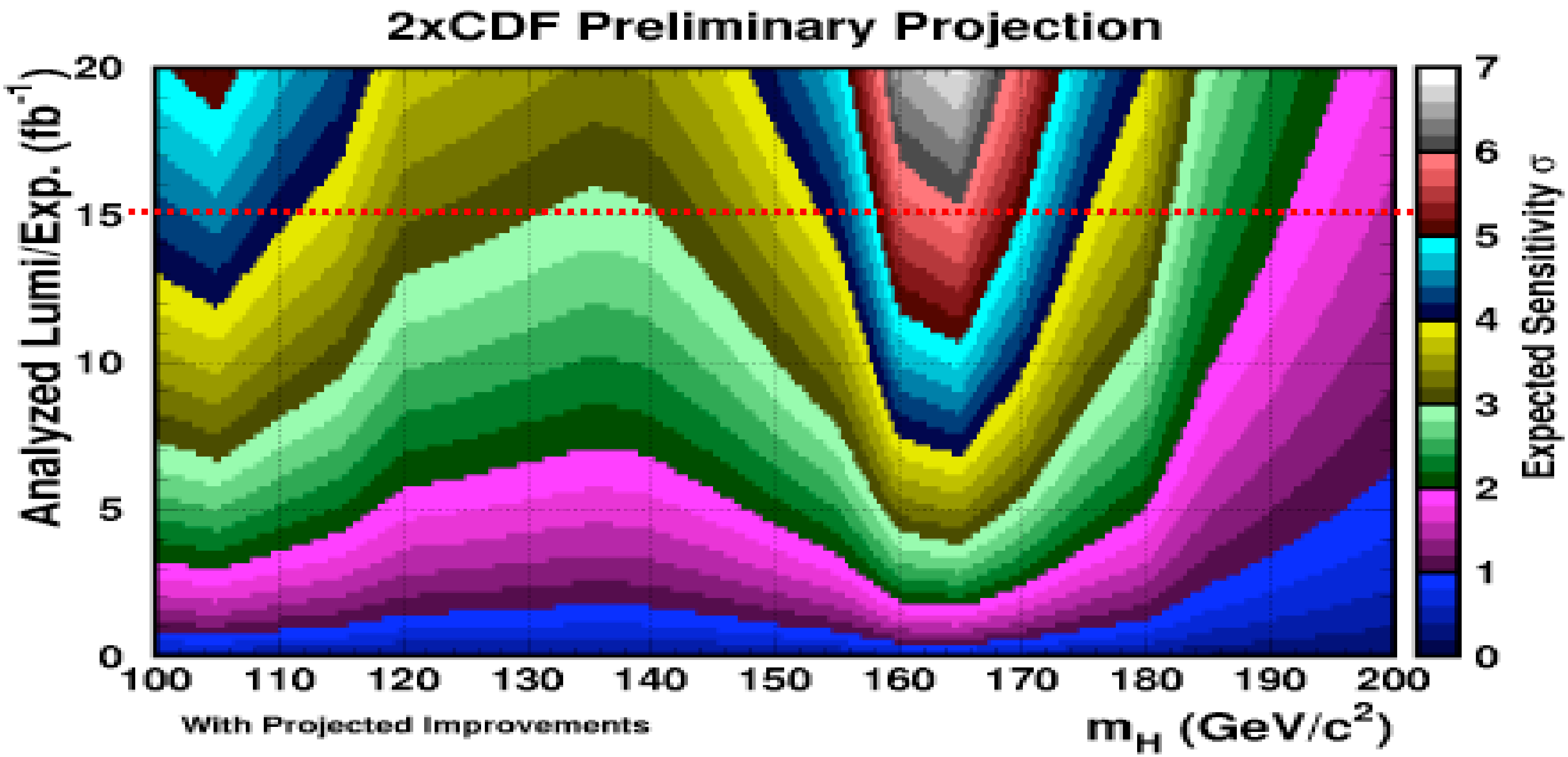
CDF Multivariate Lepton ID



- Improve lepton identification using multivariate technique.
- Adds previously unused leptons to gain acceptance.

Tevatron Prospects

- With 3 additional years of running, the Tevatron can reach >3 sigma expected sensitivity for m_H<180 GeV/c^2.



Conclusion

- Tevatron is performing very well and is testing for SM Higgs.
- LHC is doing great for the first data and will accumulate soon enough data to test for SM Higgs boson.
- "No channel too small" strategy seems work well for both CDF &D0 and the Higgs sensitivity will continue to improve over time.
- With 3 additional years of running, the Tevatron can reach >3 σ expected sensitivity for $114<m_H<185$ GeV/c^2
- Finding evidence for a low mass Higgs→bbbar is essential to understanding EWSB in the SM – complement to LHC program
- This is exciting time to hunt for the Higgs boson.