Search for high mass standard model Higgs boson at Tevatron

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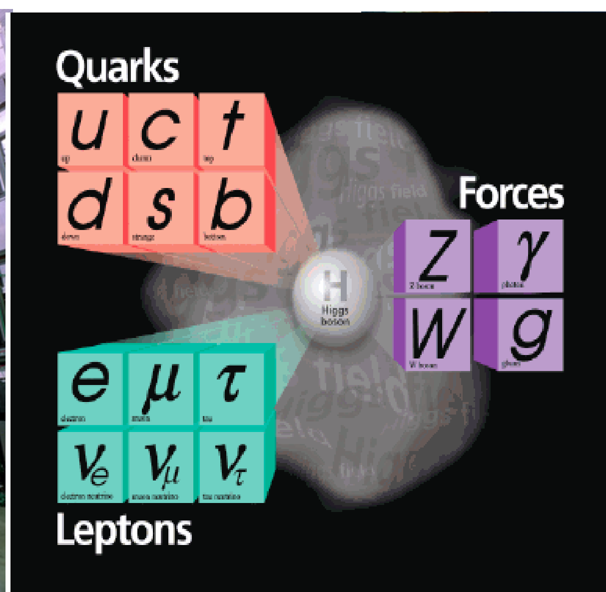
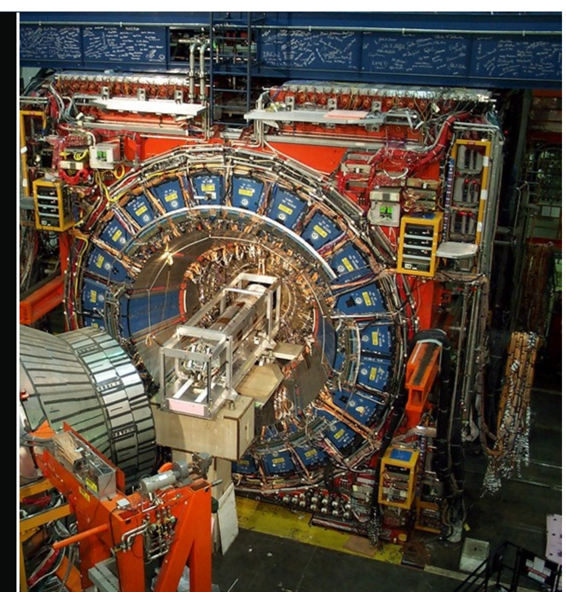
on behalf of the CDF and DØ collaborations

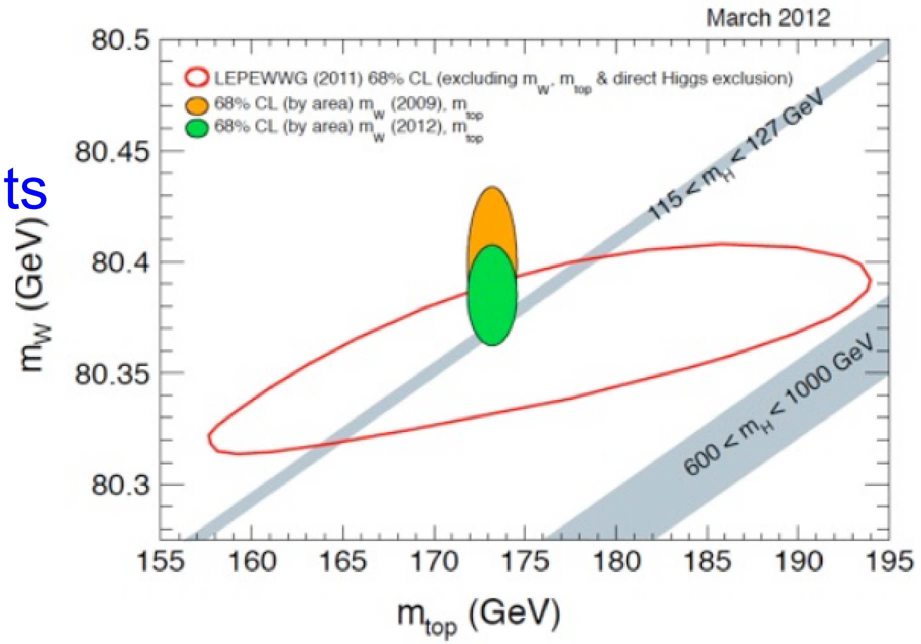




Where to look for SM Higgs boson ?

Indirect constraints from EW measurements

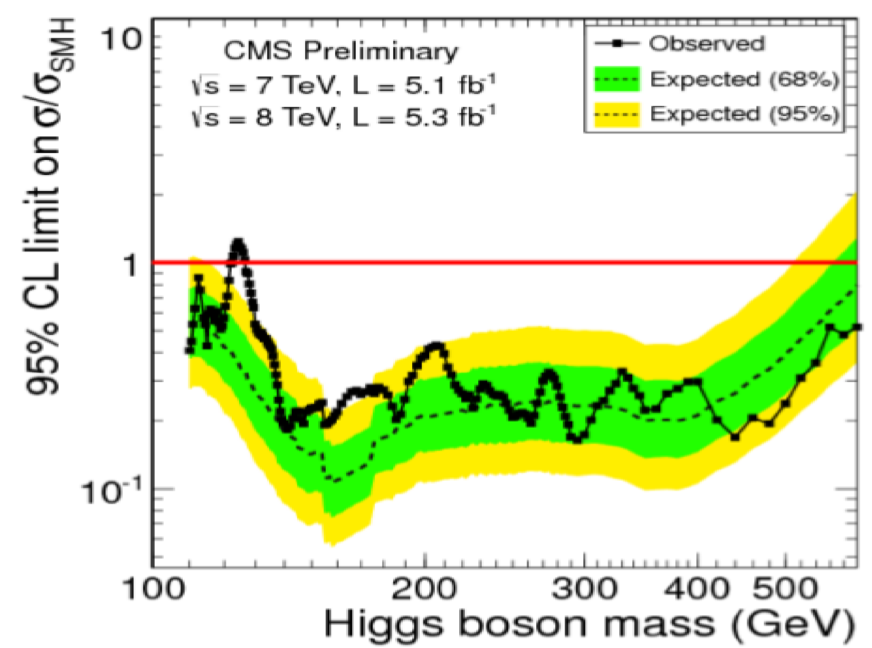
M_H < 152 GeV @95%



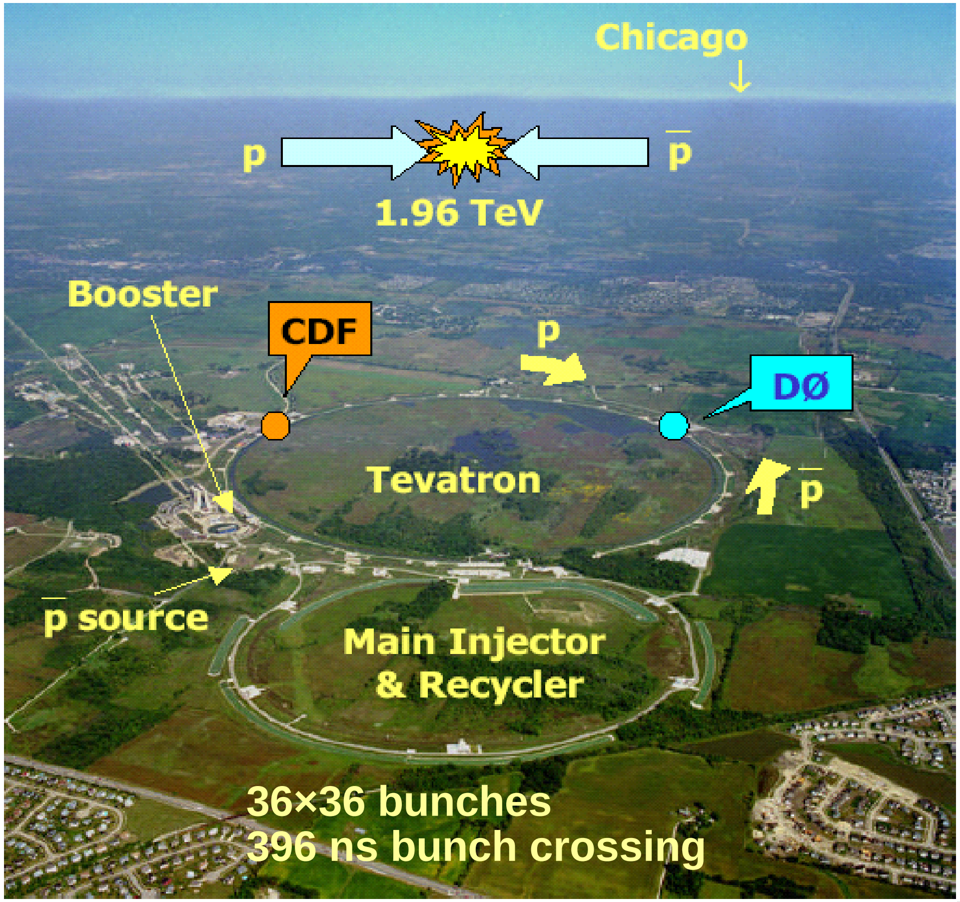
Direct constraints from LHC

122.5 GeV <M_H < 127 GeV @95%

July 4th : Observation of a Higgs-like particle @5σ by Atlas & CMS around 125 GeV



The Tevatron proton-antiproton collider



Run I (1993-1996)

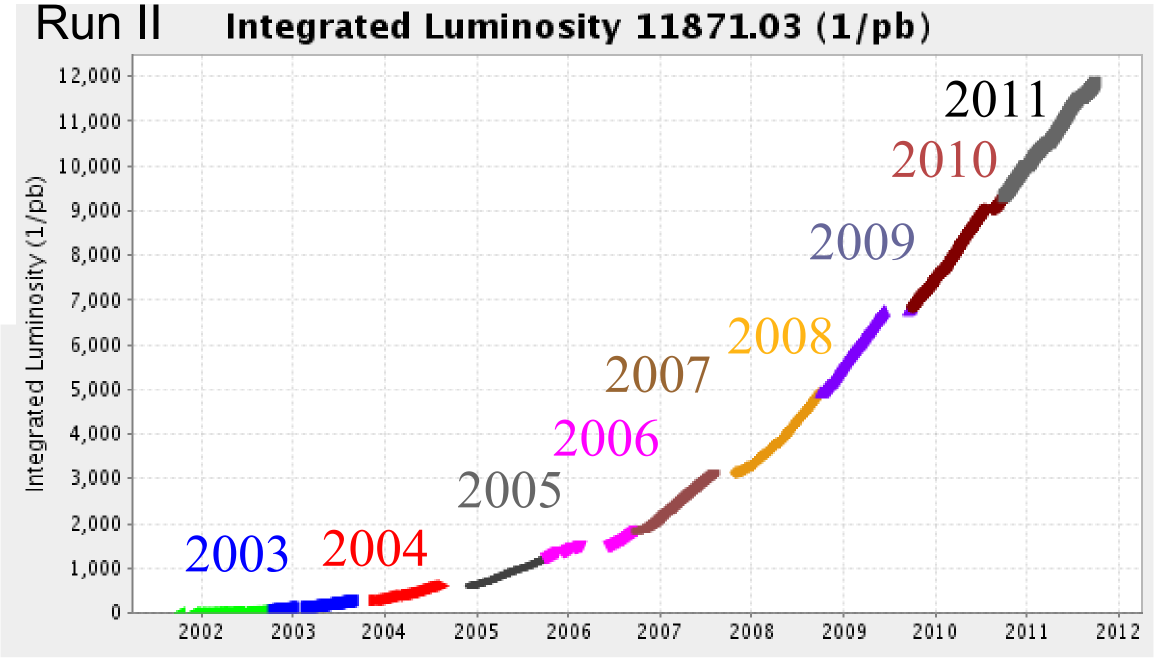
~120 pb^{-1} per experiment-top quark discovery

Run II: (2002-2011)

Shutdown 30 september 2011

~12 fb^{-1} delivered per experiment

~9.5 fb^{-1} for physics analysis

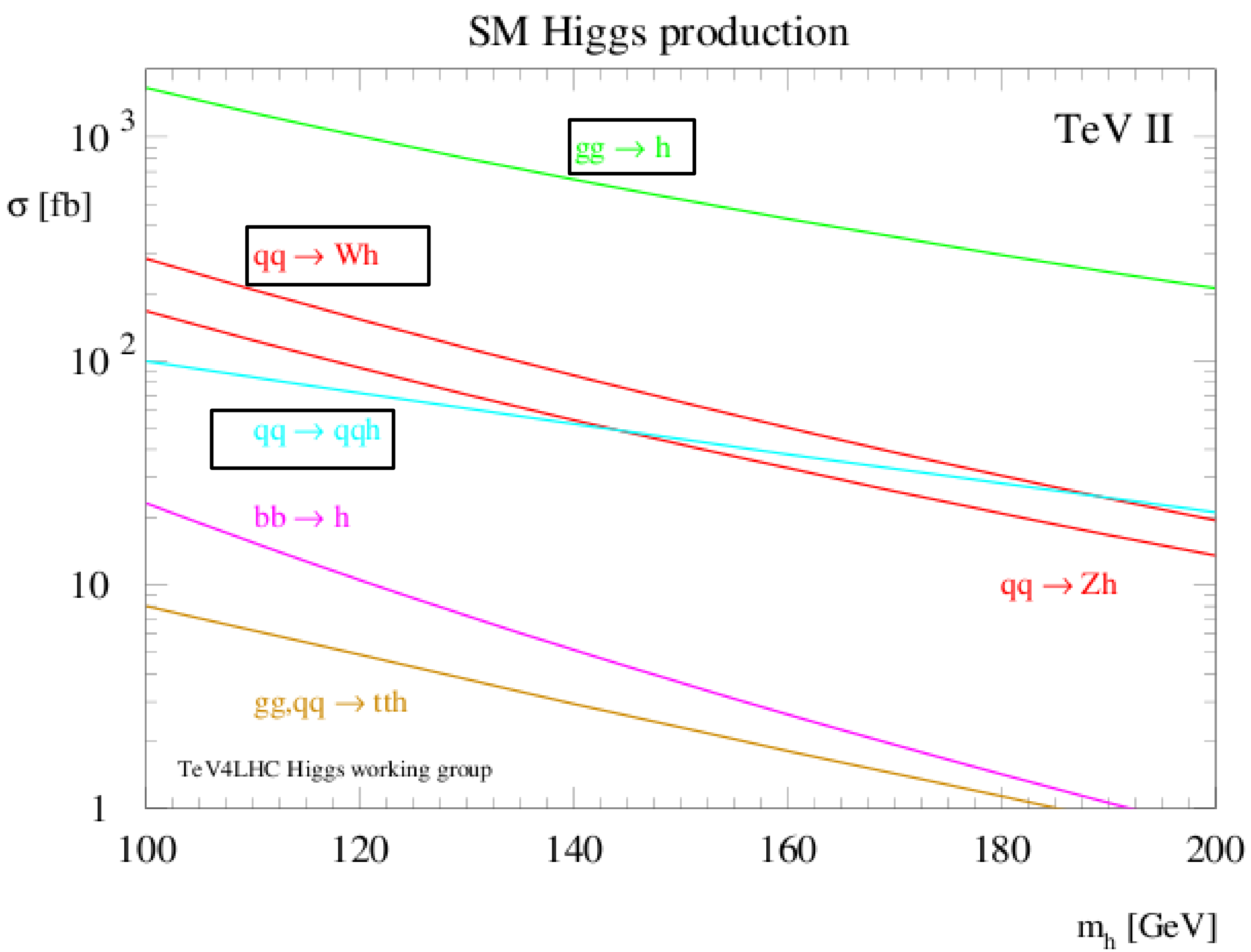


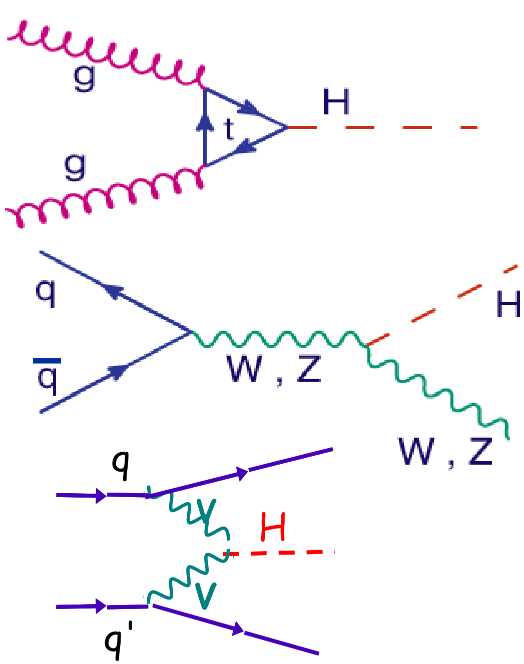
Most of the Higgs results today rely on the full data set

Higgs production at the Tevatron

Production cross section (for 115< m_H<180 GeV)

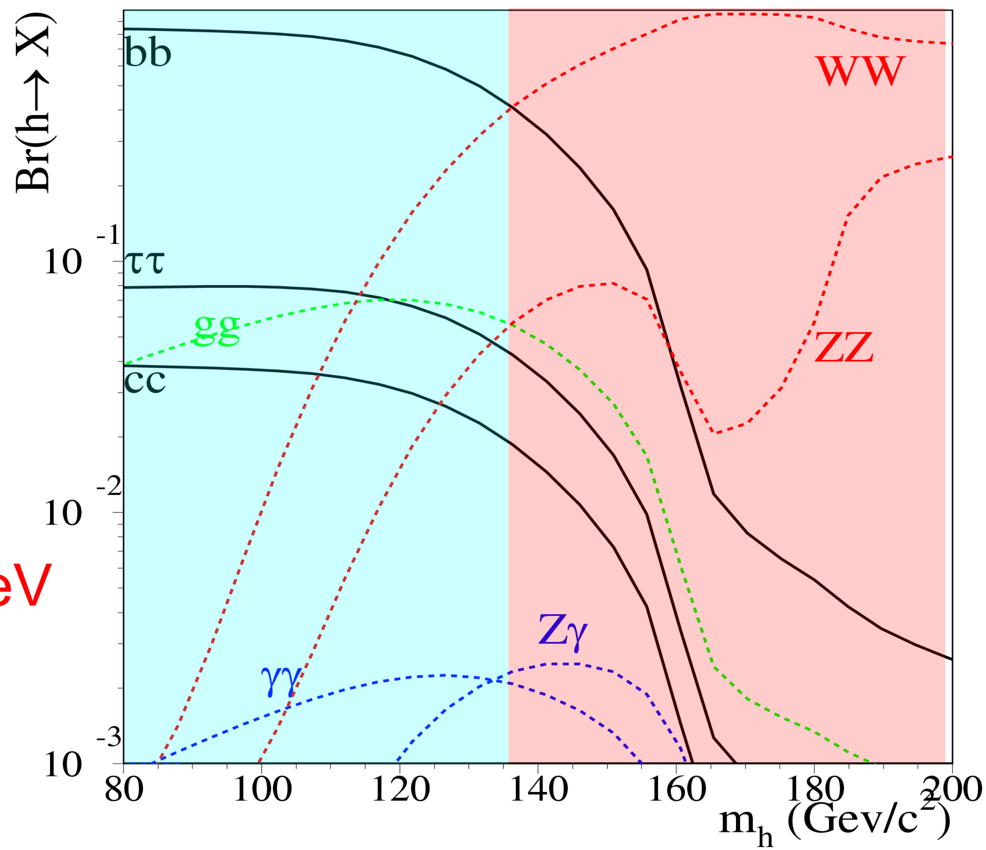
- In the 1.2-0.3 pb range for gluon fusion gg → H
- In the 0.2-0.03 pb range for WH associated vector boson production
- In the 0.08-0.03 pb range for the vector boson fusion qq → Hqq





Low Mass vs High Mass

Decay modes depends on the Standard Model Higgs boson mass.

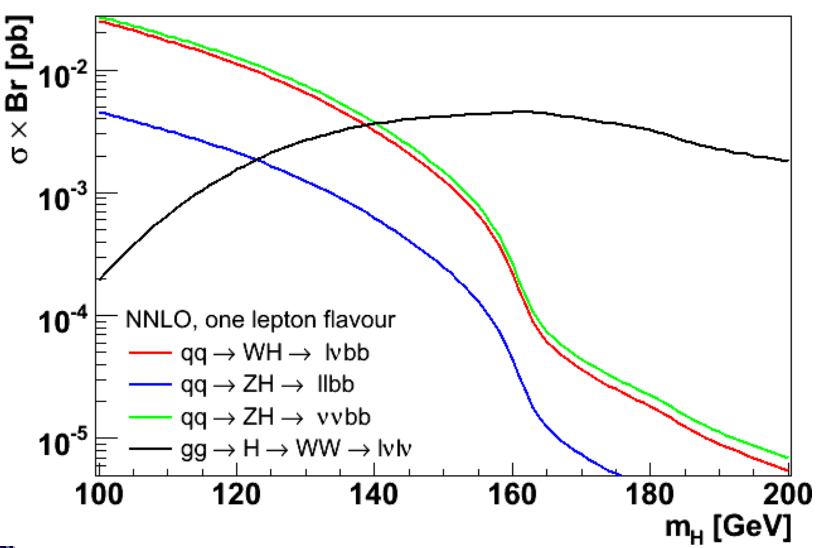


Searches at high mass:

- Look for W decay products
- Peak sensitivity just above threshold M_H~165 GeV

Low Mass vs High Mass channels:

comparable sensitivities for 125-130 GeV



m_H<135 GeV

$H \rightarrow b\bar{b}$

$H \rightarrow \tau\tau$

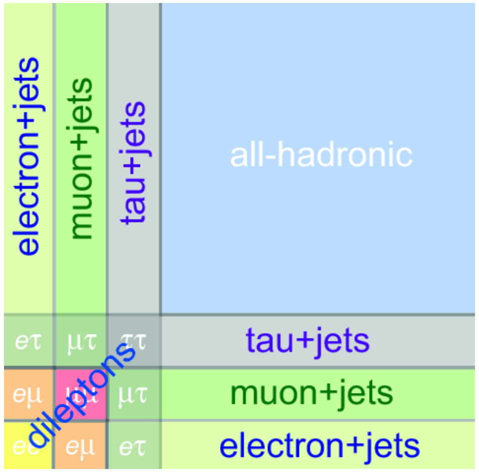
m_H>135 GeV

$H \rightarrow WW^*$

The different high mass channels

Overwhelming QCD background in hadron colliders:

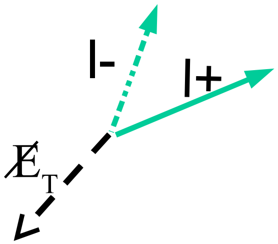
→ need for lepton and/or missing E_T signature



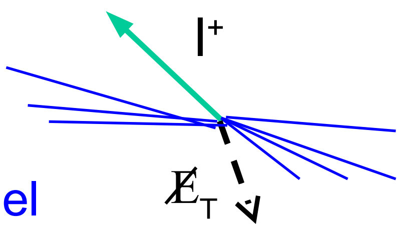
W vs W decays

Searches driven by H → WW

- Di-lepton of opposite signs (OS) + $\not{E}_T$
  - Clean signal, Small Br~6% (ee +eμ + μμ)

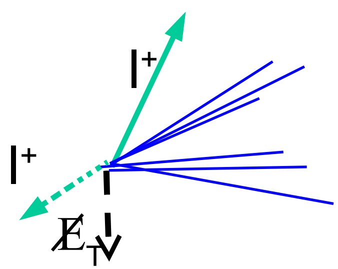


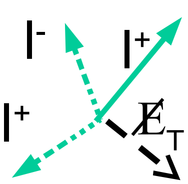
- Lepton+ tau+ $\not{E}_T$
  - Small Br~4% (eτ+ μτ)
  - Difficulty to reconstruct hadronic taus
- Lepton + $\not{E}_T$ + jets
  - Larger Br ~ 30% (e+jets, μ+jets)
  - Large W+jets background, hard to model

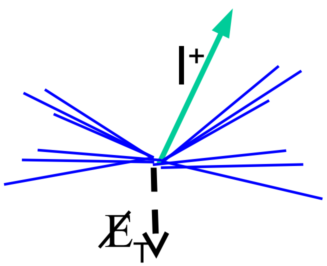


Also WH → W W W, ZH → Z W W

- Di-lepton of same sign + $\not{E}_T$
  - Clean signature, but small σxBr
- Trilepton + $\not{E}_T$
  - Clean signature, but small σxBr
- Lepton + $\not{E}_T$+ 4 jets : challenging

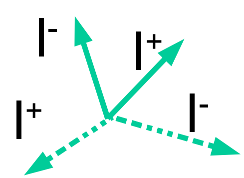




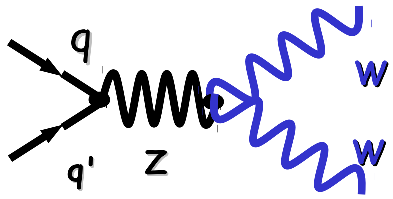


Also H → ZZ

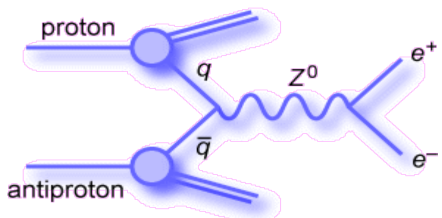
- 4 leptons are a clean but very rare signature



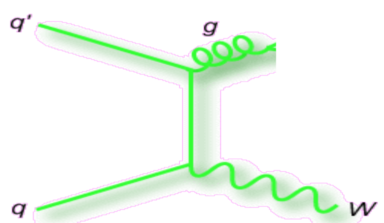
Backgrounds to Higgs



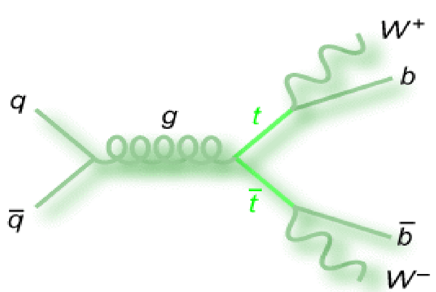
- Di-boson WW, WZ, ZZ
  - Can yield 1, 2, 3 or 4 real leptons
  - NLO calculation for cross-sections
  - WW = irreducible background for H $\rightarrow$ WW
    - NLO correction for p_T and di-lepton opening angle



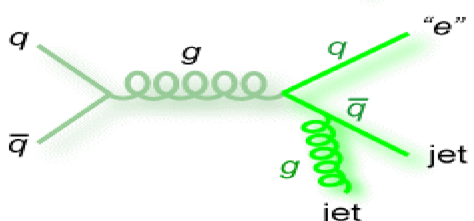
- Z+jets, Z+γ
  - Mismeasured jets or leptons yielding $\not{E}_T$
  - Jet or gamma faking a 3rd lepton
  - NNLO or data cross-sections, data-based corrections to model p_T(Z)



- W+jets, W+γ
  - Jet or γ faking lepton for multi-lepton signatures
  - W+jets background to semi hadronic signatures
  - Data driven correction



- Top pair
  - Two real W's from top decays
  - Cross-section normalized at NNLO



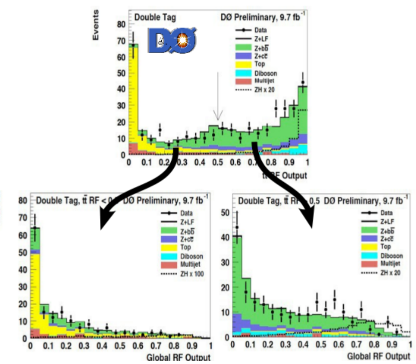
- QCD multijet events
  - Jets faking leptons
  - Mismeasured jets creating $\not{E}_T$

Search Strategy

Start with pre-selection of isolated high p_T leptonic events

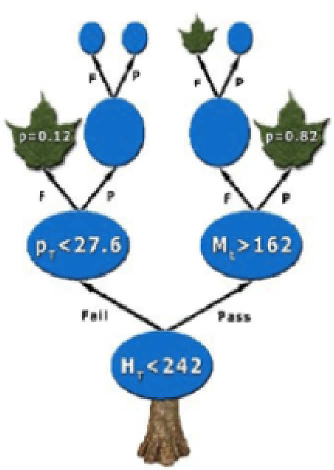
Try to maximize acceptance

- Many different lepton reconstruction categories, loose lepton-id
- Lower kinematic requirements
- Inclusive triggers when possible



Split analyses into subchannels

- Different signal/background to maximize discriminating power
- Sensitivity to different signal production mode
- Also gives more handles to control background level and systematic uncertainties

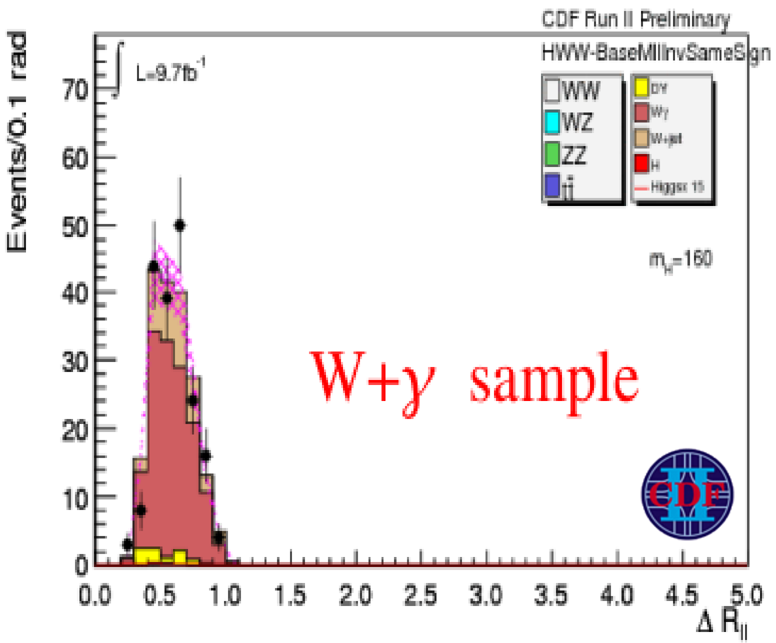


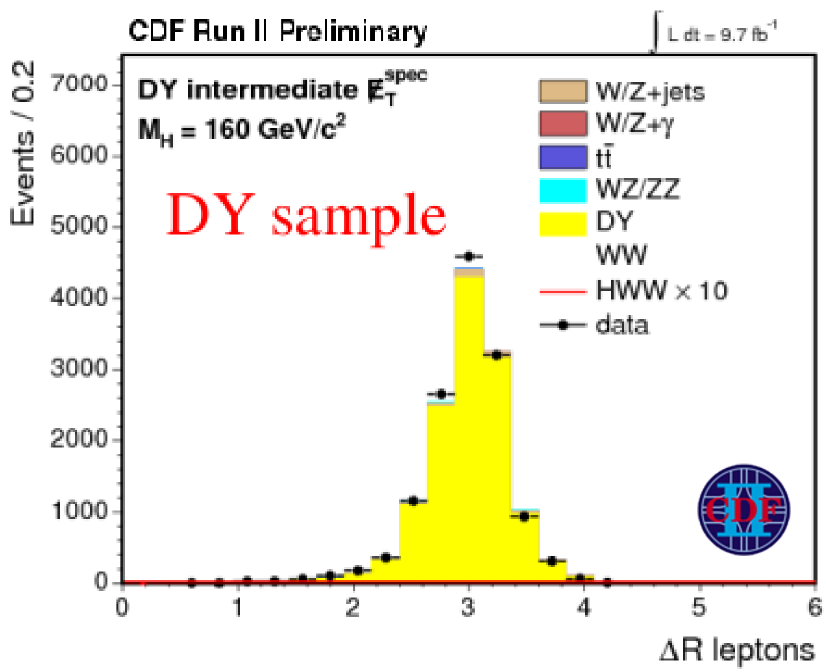
Multivariate techniques to maximize use of available information

- Decision trees (BDT), Neural Networks (NN), Matrix Element (ME)
- Trained for each subchannel and Higgs mass hypothesis.
- Input variables:
  - event topology, lepton kinematics, quality of leptons, jet content, Matrix Element discriminant, relation between lepton and $\not{E}_T$, relation between jets and $\not{E}_T$, b-tag of events (against top)
- Some analyses employ several MVA trained against different specific backgrounds

Use data as much as possible

- Instrumental background need to be determined on data
  - jets faking leptons, photon faking electrons, charge mis-measurements, Missing E_T
- Background enriched samples to tune or check modeling of specific background processes



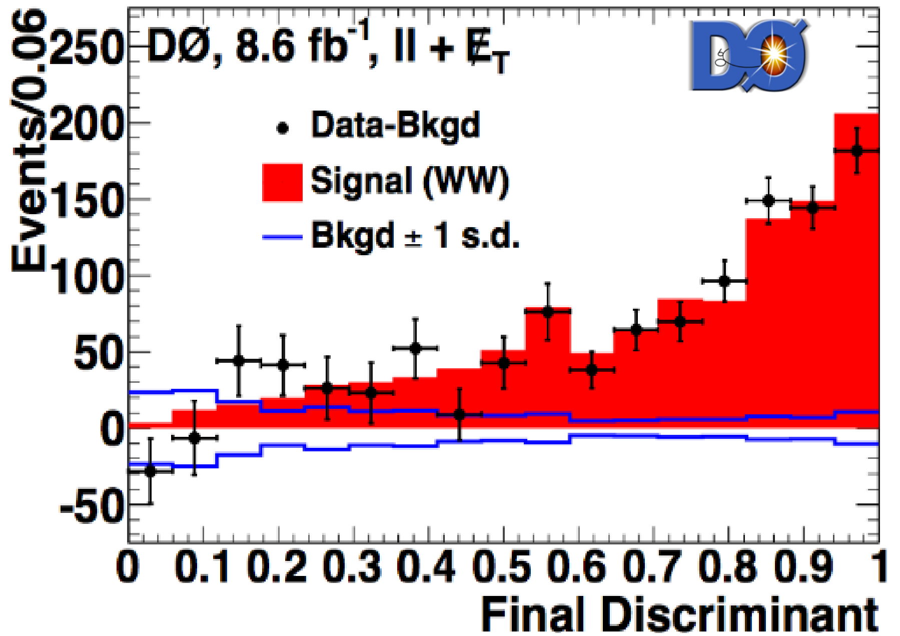


Validate methodology using data

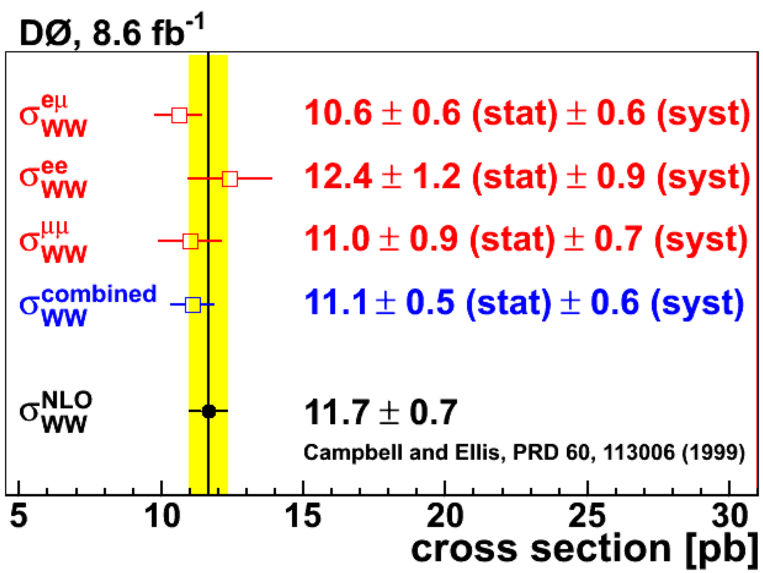
eg at DØ:

Measure $p\bar{p} \rightarrow WW \rightarrow l\nu\, l\nu$ cross-section

- Employ same analysis technique as in searches for $H \rightarrow WW \rightarrow l\nu l\nu$
  - Same subchannels
  - Same inputs to MVA
  - Train MVA to discriminate WW production
  - Similar treatment of systematic uncertainties

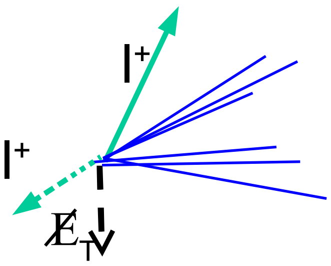


$H \rightarrow WW \rightarrow l\nu l\nu$ search with 8.6 fb^{-1}
submitted to PRD [arxiv:1207.1041]



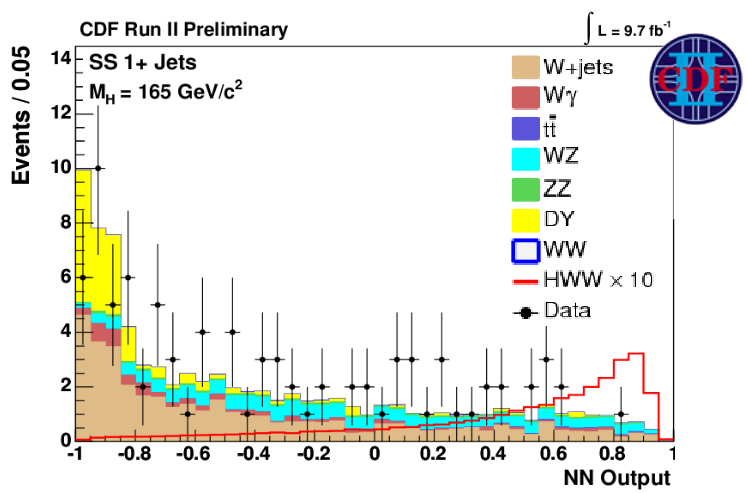
Measured cross-section: 11.1±0.8 pb
in agreement with NNLO prediction

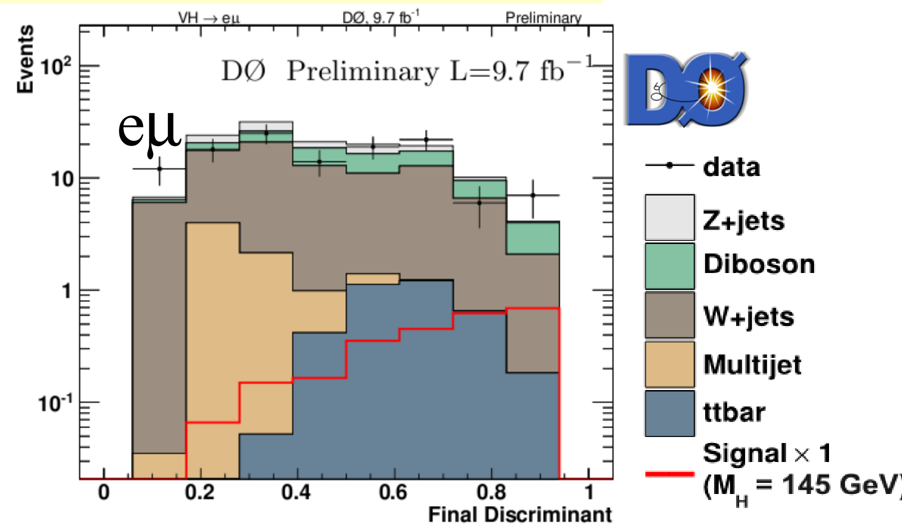
Same sign di-lepton + $\not\!\!E_T$ channels



Same sign signature mainly from WH → W W W

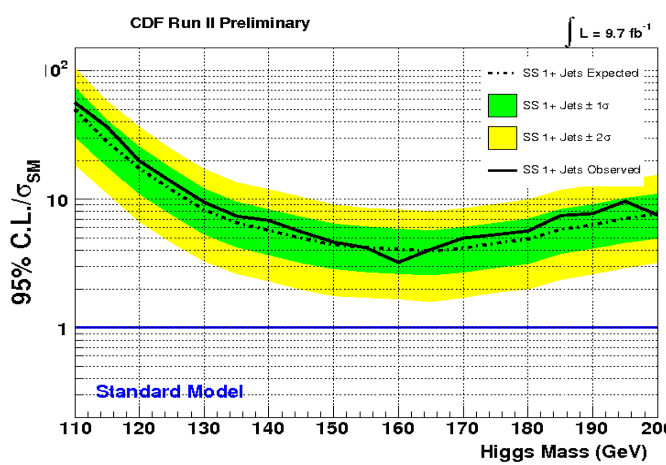
- 2 isolated high p_T leptons,Large missing E_T
- Same charge (require high quality track)
  - unlike Drell-Yan and WW background
- Presence of jets (CDF)

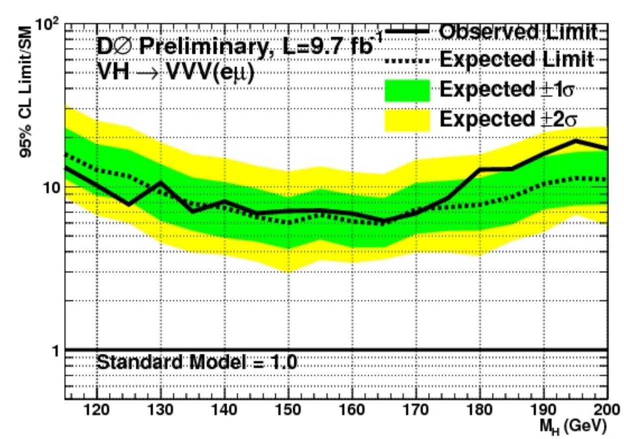




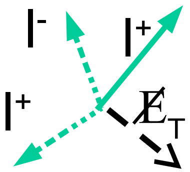
Limit derived from MVA distribution

sensitivity @125 GeV	
CDF	DØ
~12x σ_{SM}	~12x σ_{SM}



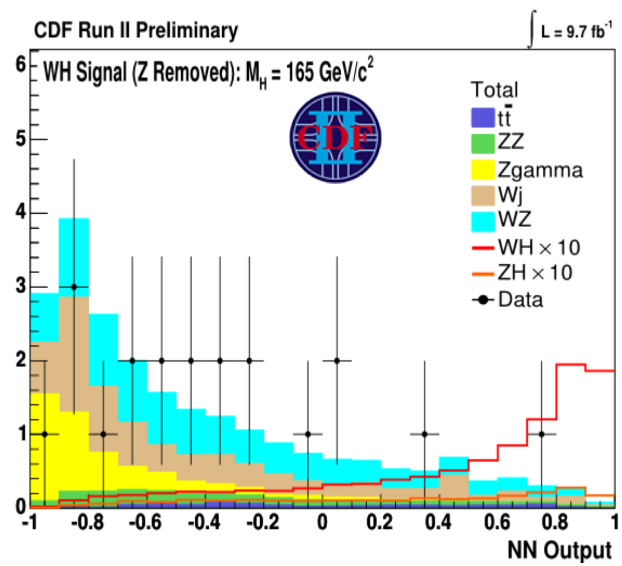


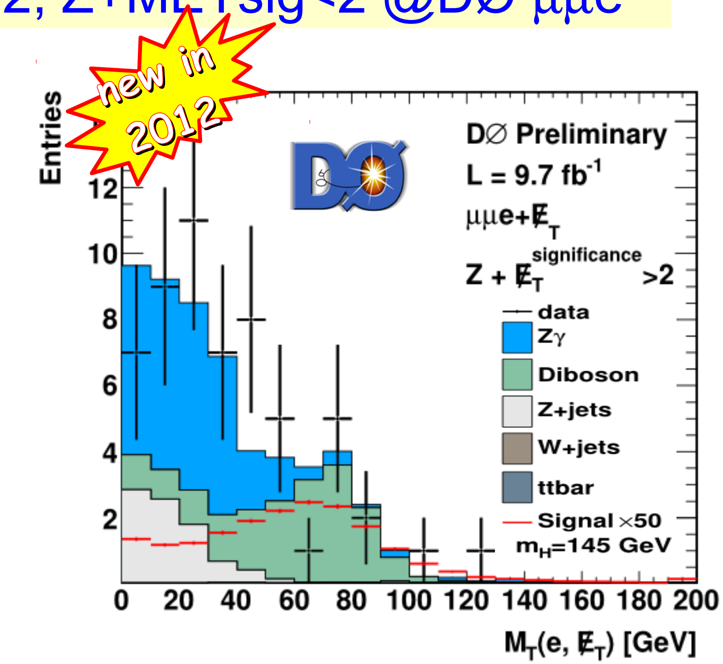
Tri-lepton channels



Signature: 3 isolated hight p_T leptons,Large missing E_T

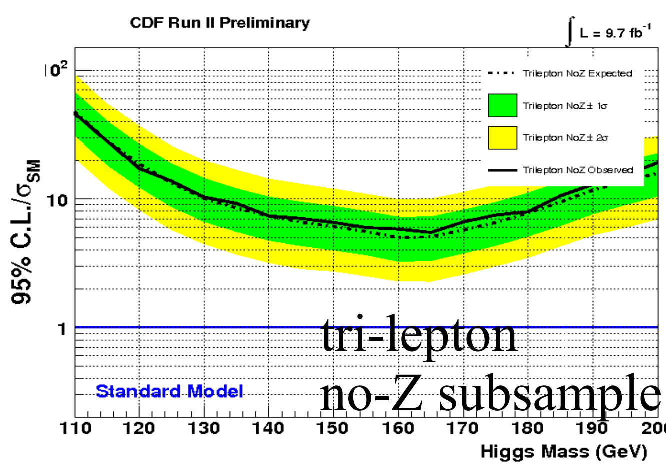
- Split into: non-Z, Z+1 jet, Z+2jet channels @CDF
- Split into: non-Z, Z+ METsig>2, Z+METsig<2 @DØ μμe

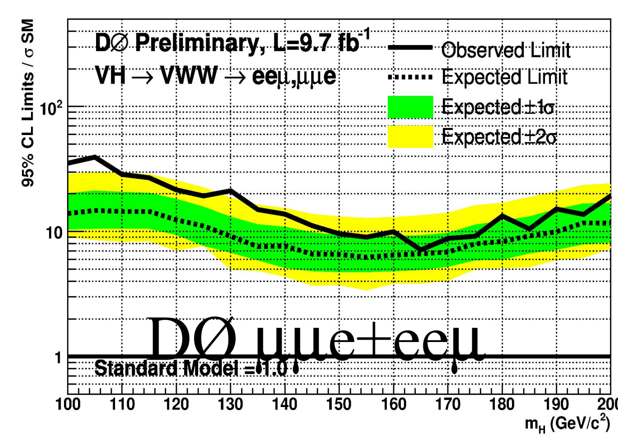




Limits derived from MVA distribution

sensitivity @125 GeV	
CDF	DØ
~13x σ_{SM}	~11x σ_{SM}

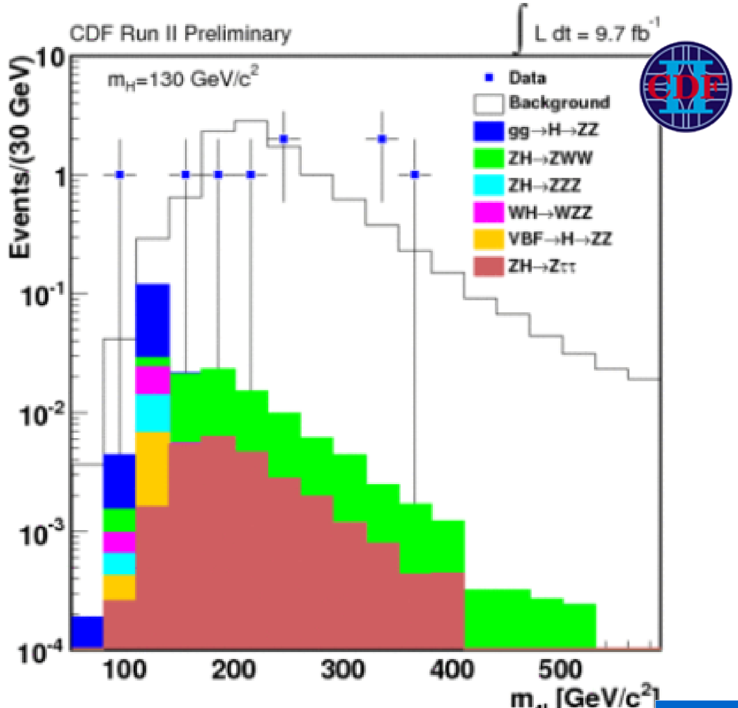


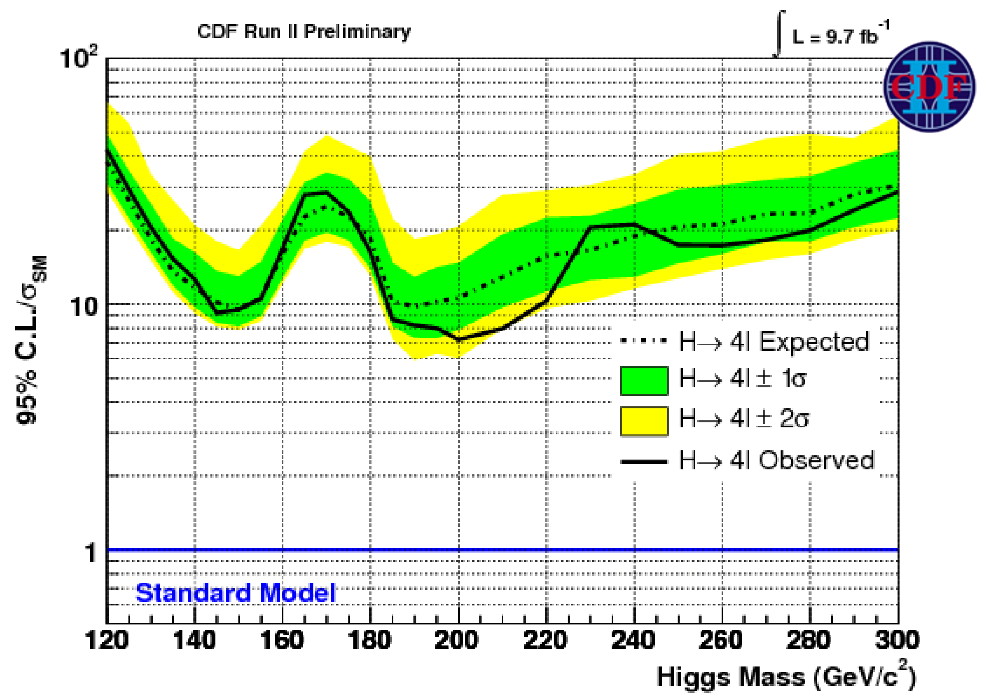


4 leptons @CDF

Rare signature because of small Branching ratios.
Larger non resonant ZZ production as main background

- Eg for M_H=130 GeV :
  - Expect 0.2 signal vs 11 bkg events
    0.1 from H →ZZ →l l l l
    0.1 from ZH → ZWW →l l l l ν ν, ZH → l l ττ

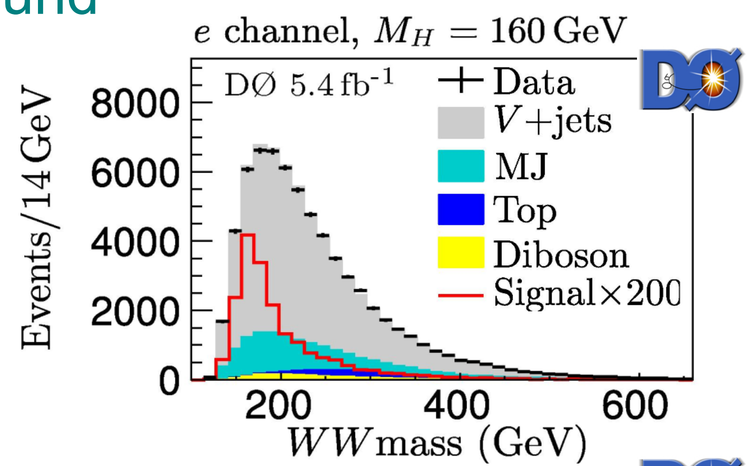




sensitivity	
@125 GeV	@145 GeV
~30 x σ_{SM}	~ 10x σ_{SM}

$H \rightarrow WW \rightarrow l\nu jj$ and $VH \rightarrow VWW \rightarrow l\nu jjjj$ @DØ

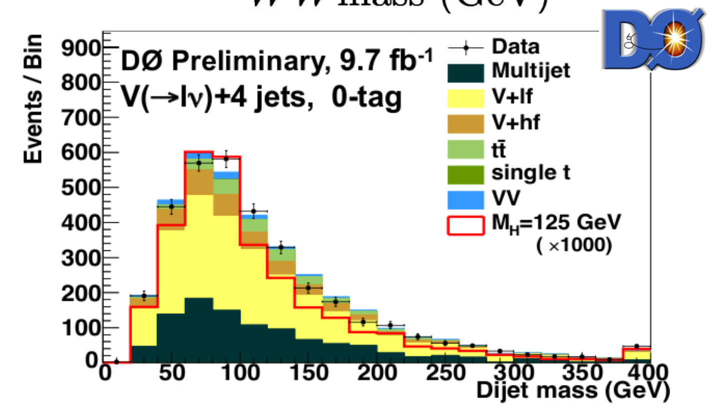
Challenging analyses with large W+jets background



$H \rightarrow WW \rightarrow l\nu jj$ 5.4 fb^{-1} PRL 106, 171802(2011)

- W mass constraint to reconstruct neutrino p_Z
  - Full reconstruction of the kinematic
  - Enhance sensitivity for M_H>160 GeV

new in 2012

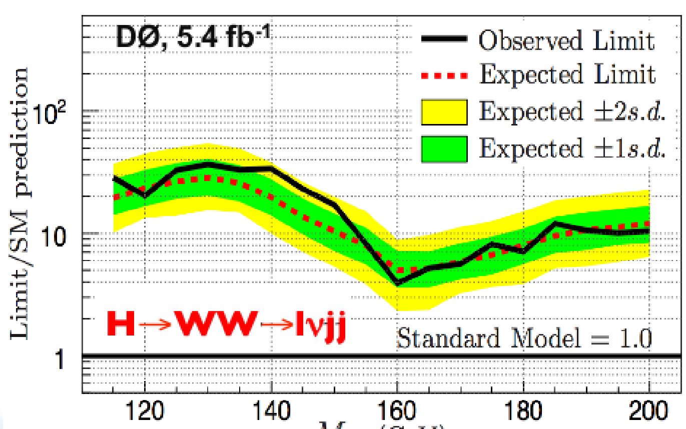


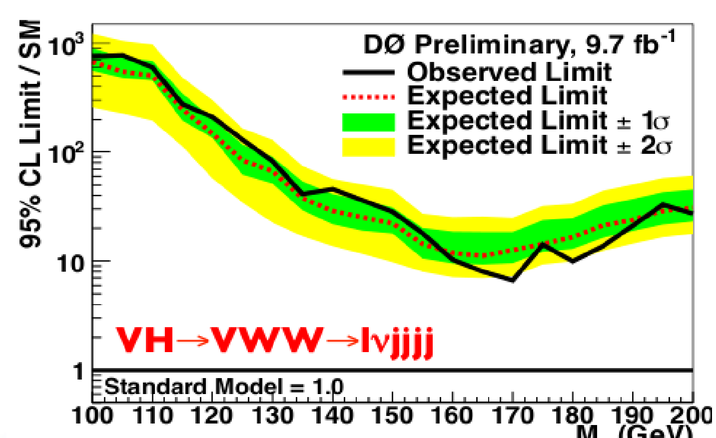
$VH \rightarrow VWW \rightarrow l\nu jjjj$

- Part of the "low mass" $WH \rightarrow l\nu bb$ analysis
  - 4-jet bin (0 and 1 tag) sensitive to high mass Higgs

Limits derived from MVA distribution

sensitivity @125 GeV	
lνjj	lν jjjj
~ 25 x σ_{SM}	~80 x σ_{SM}

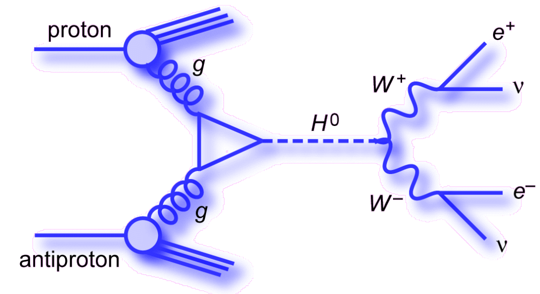


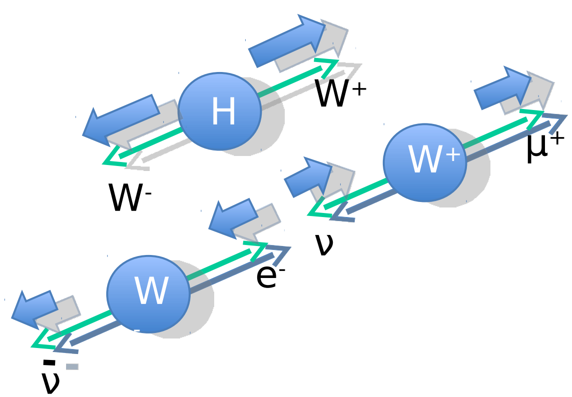


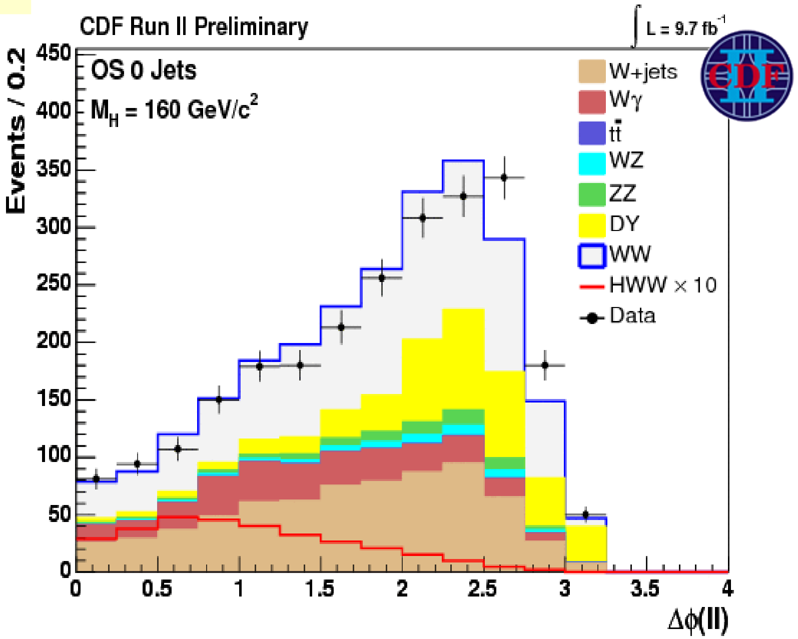
OS di-lepton + $\not{E}_T$ channels

Opposite Sign Signature:

- 2 isolated high p_T leptons, opposite signs
  - Unlike W+jets and QCD background
- Large missing E_T
  - Unlike Drell-Yan background
- Higgs is scalar at rest + V-A interaction
  - The leptons tend to be collinear
  - Small $\Delta\phi(l,l)$
  - Unlike WW background



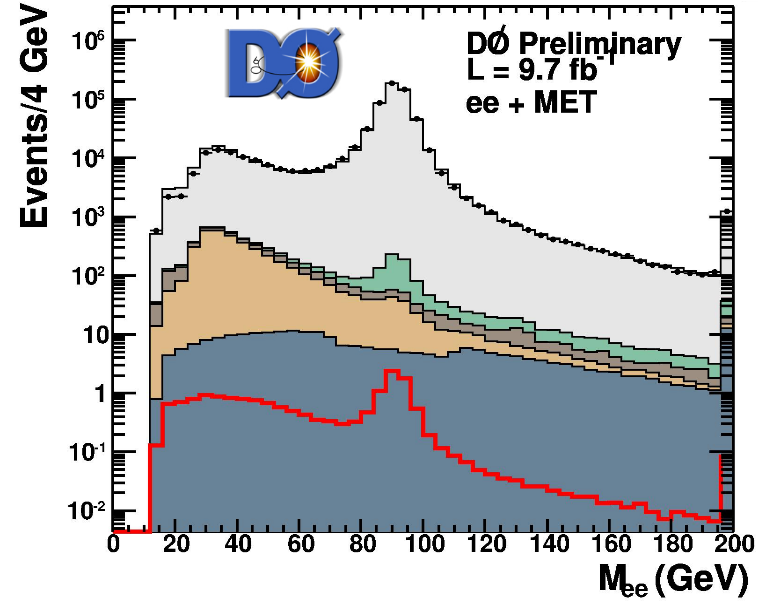


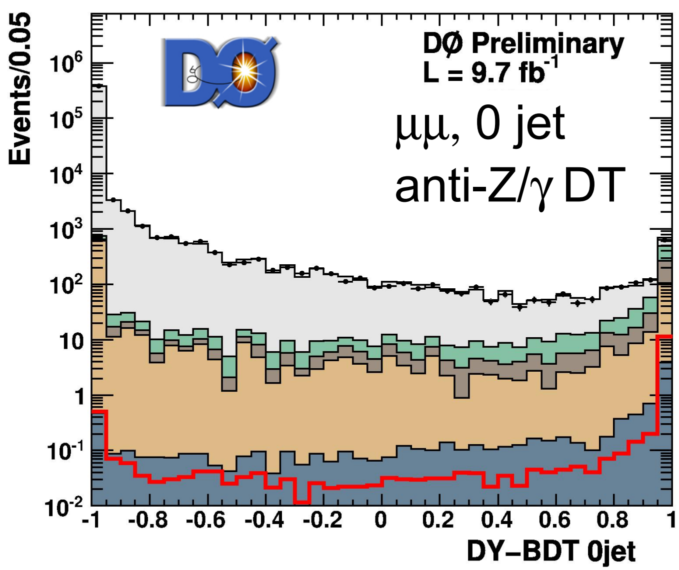


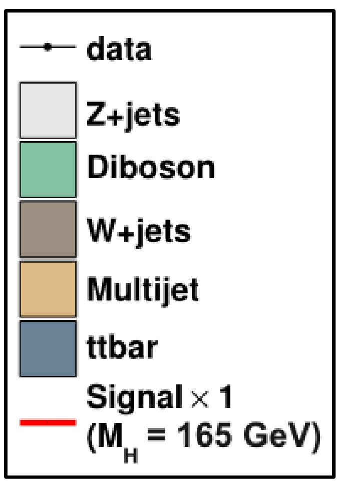
OS di-lepton + $\not\!\!E_T$ selection

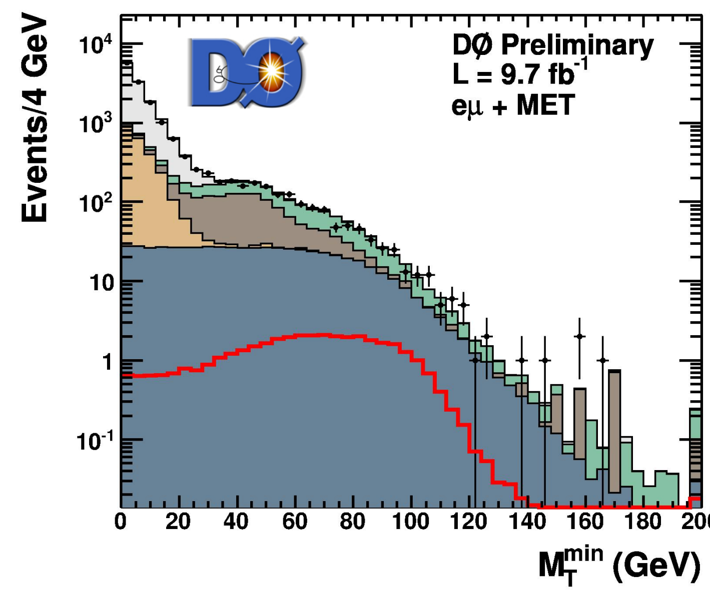
Get rid of the dominant Z/γ background.

- Use kinematics, in particular $\not\!\!E_T$ based variables that ensure $\not\!\!E_T$ is significant and not due to mismeasured object
- DØ (ee, μμ) employs Decision Trees trained against Z/γ









- Typically: - O(1000) events remains at this stage for each sub-selection
  - S/B is of order O(1/100)

OS di-lepton + $\not\!\!E_T$ selection

Get rid of the dominant Z/γ background.

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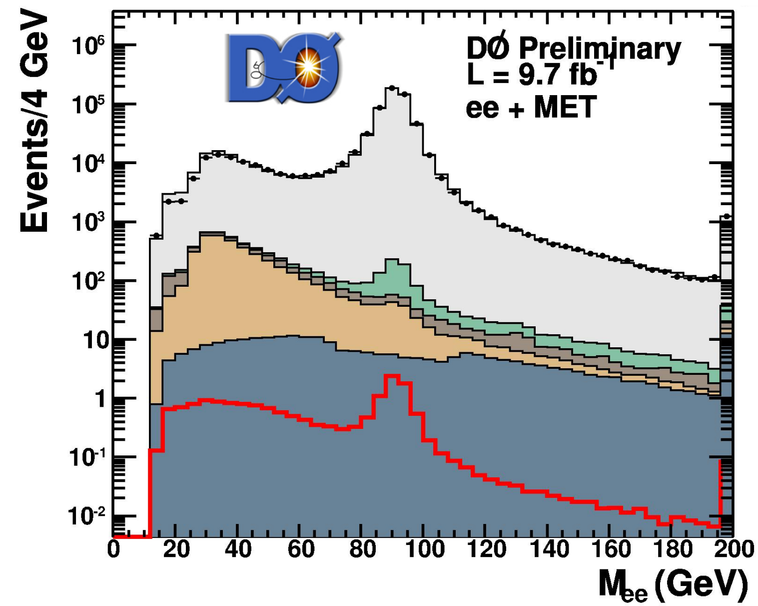

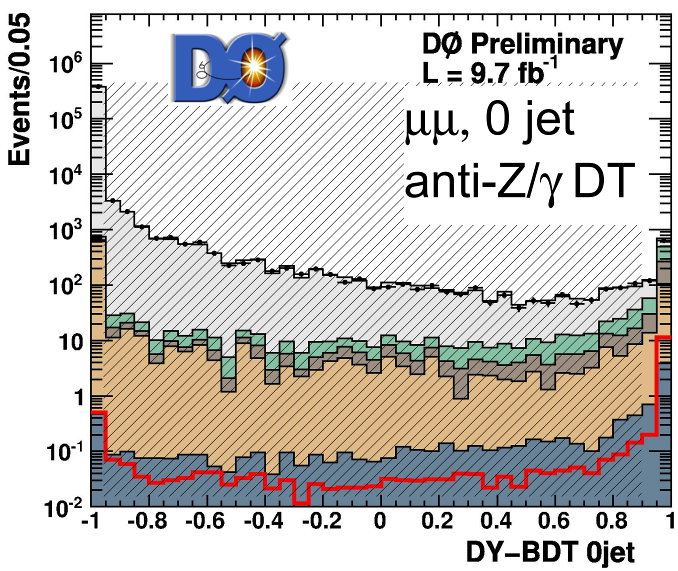

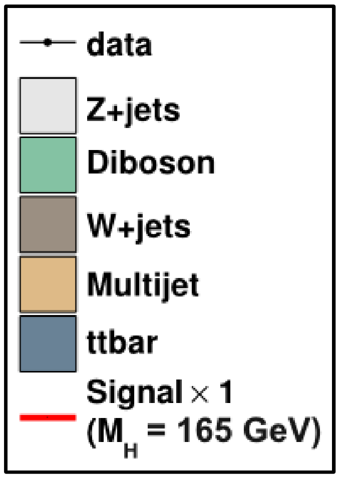

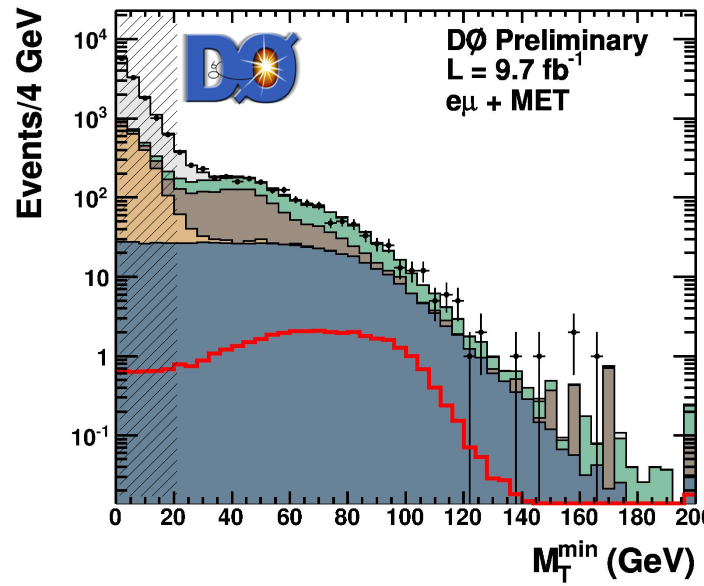

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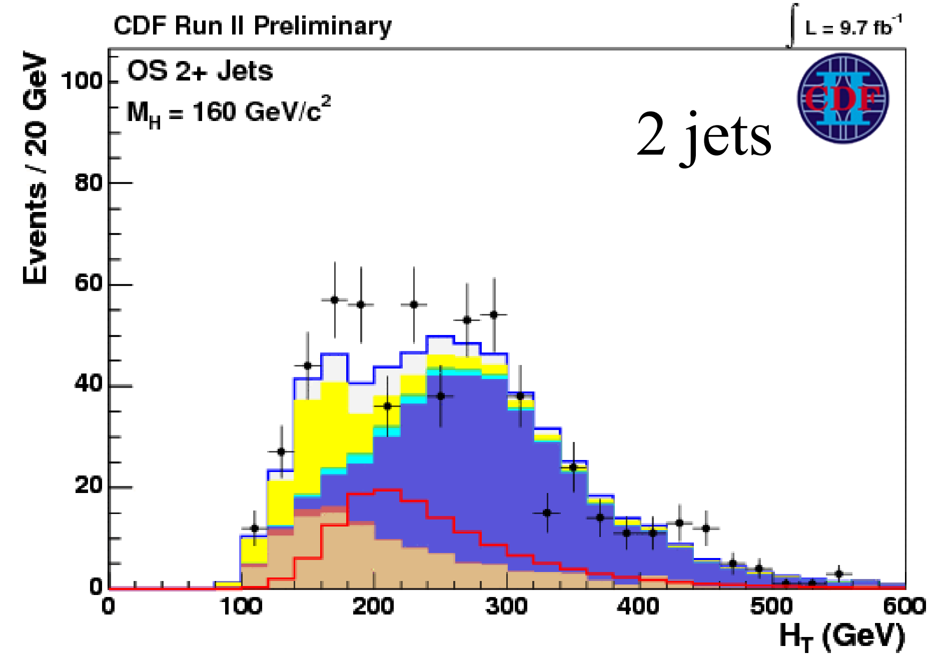
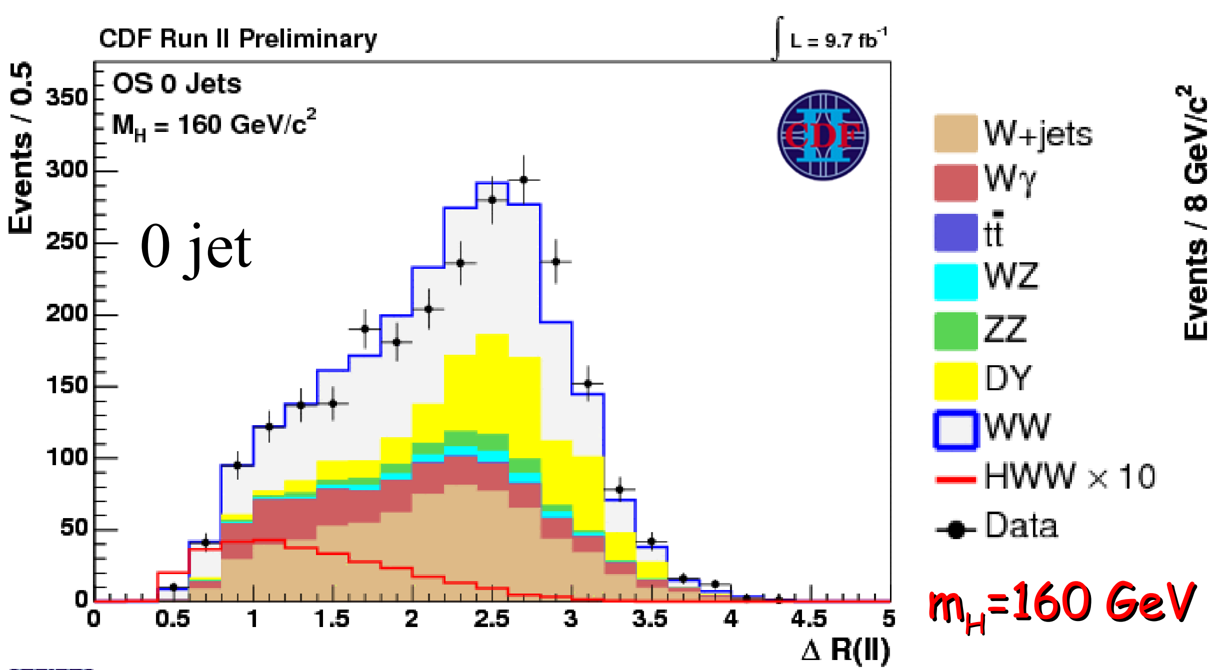
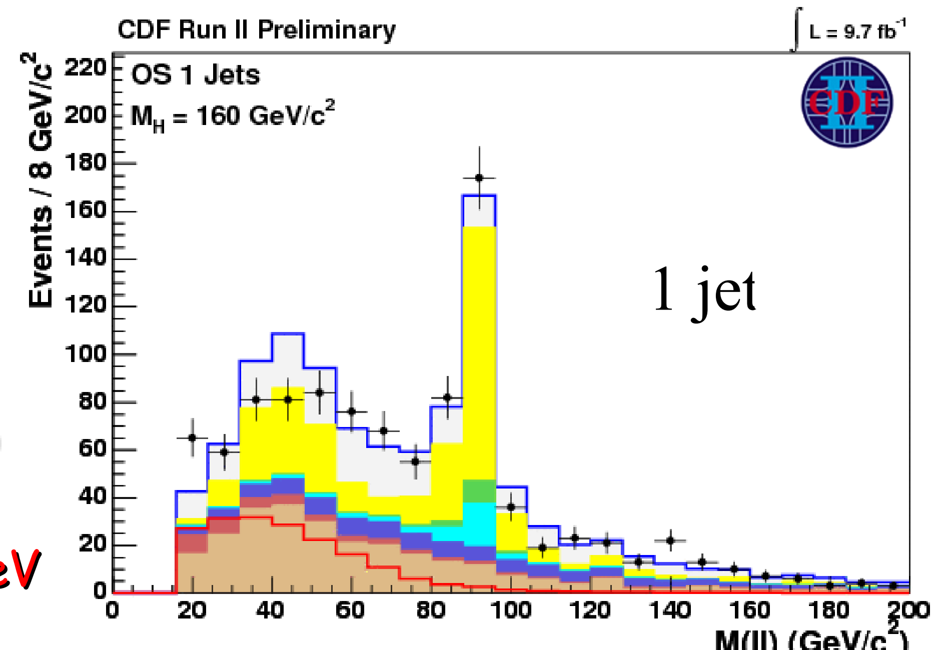
Di-lepton + $\not\!\!E_T$ (OS) : subchannels

Split according to jet multiplicity (CDF+DØ)

- Better sensitivity to H+jets final states: qqH, WH, and ZH
  - important for lower masses
- Each multiplicity bin correspond to a different dominant background
  - 0 jet: WW
  - 1 jet: WW + Z/γ
  - ≥2 jets: top pairs





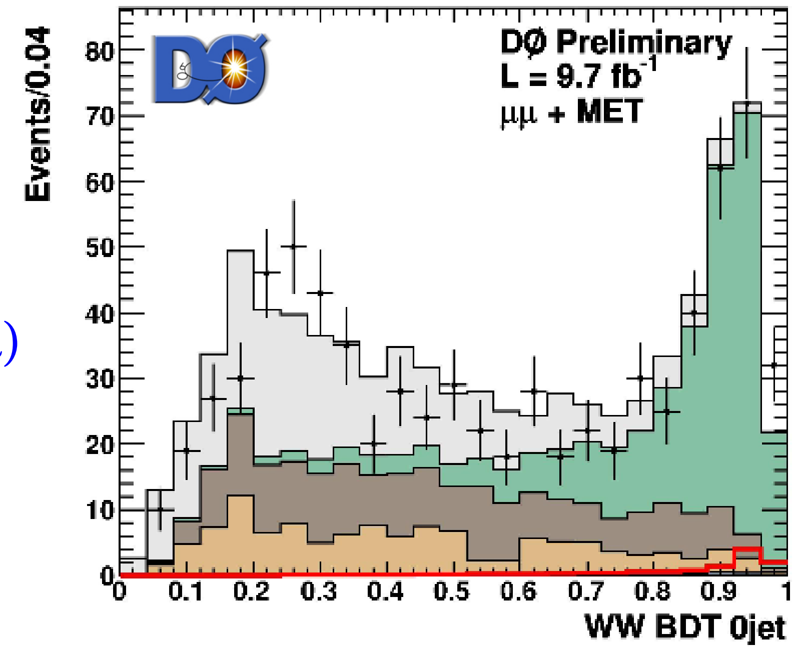


Di-lepton + $\not\!\!E_T$ Subchannels

Split analysis according to :

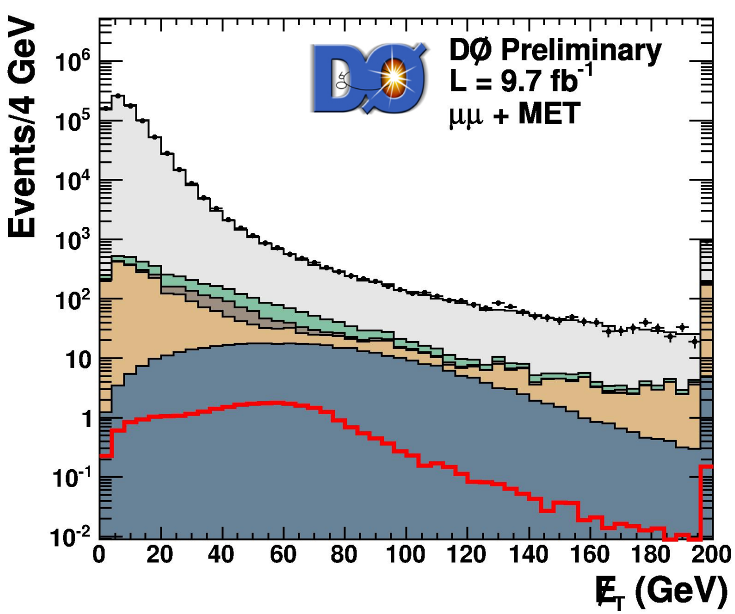
- Lepton flavor: ee, eμ, μμ (DØ)
- Signal purity based on lepton quality (CDF)
- Low (<16 GeV) di-lepton mass (CDF)
- Enriched/Depleted WW samples thanks to a dedicated WW-BDT discriminant (DØ ee, μμ)

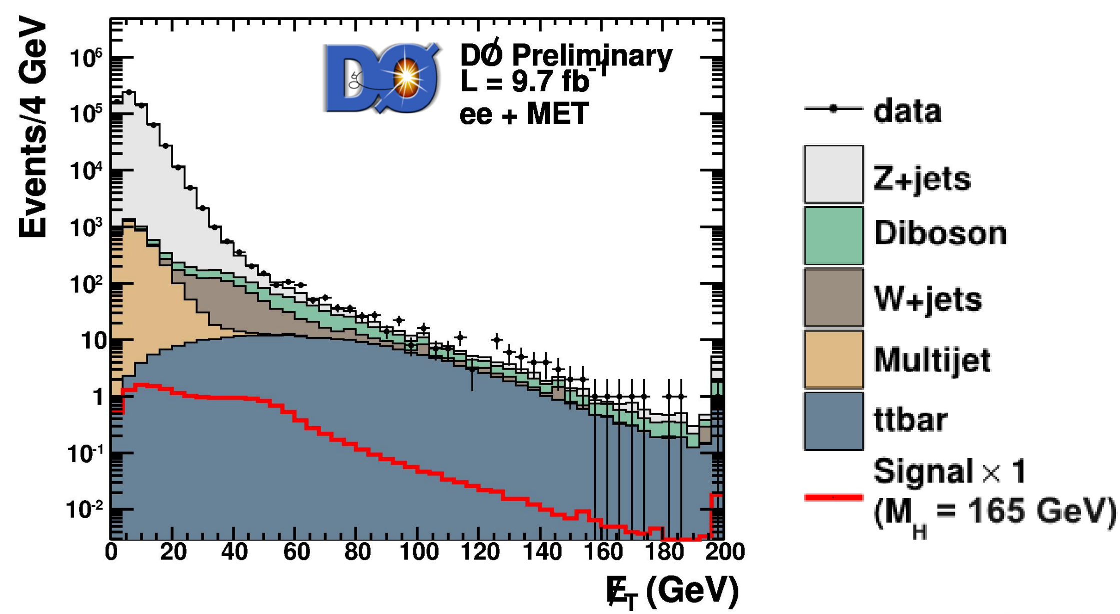
new in 2012



Different instrumental (fake) background
Different background composition
Different lepton momentum resolution

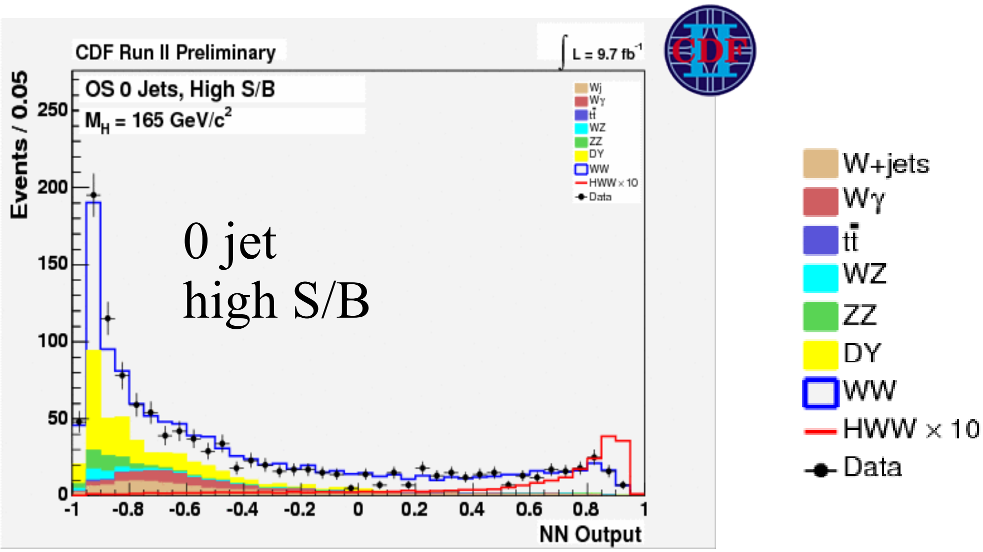
- typically 4% for electrons, 10% for muons at D0

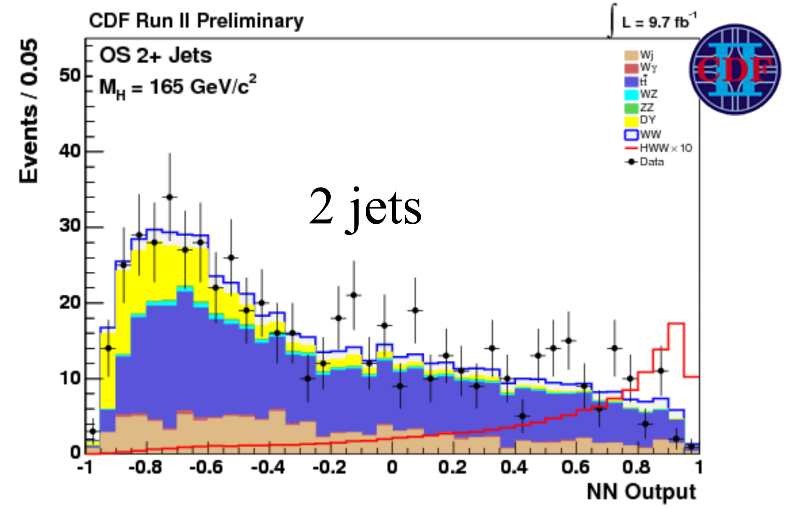


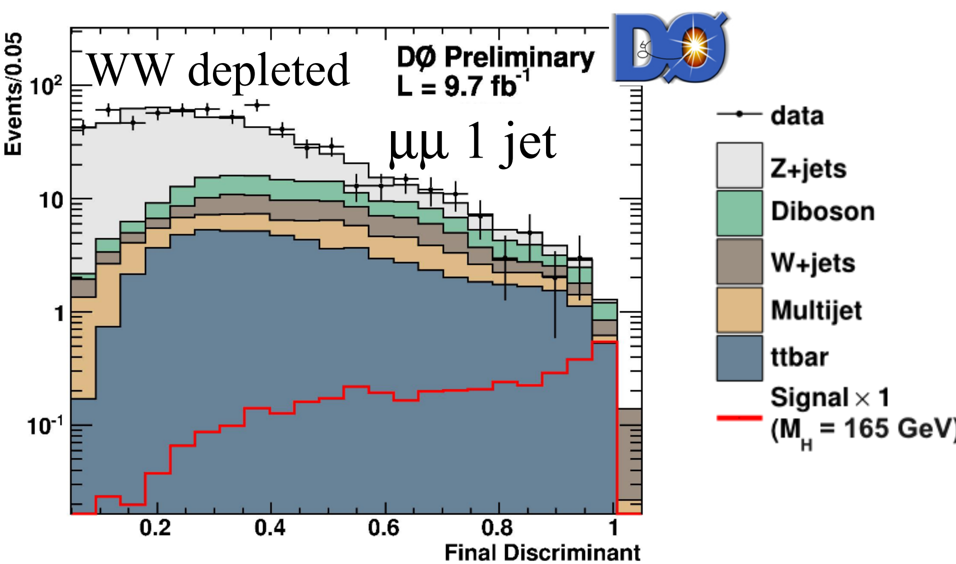


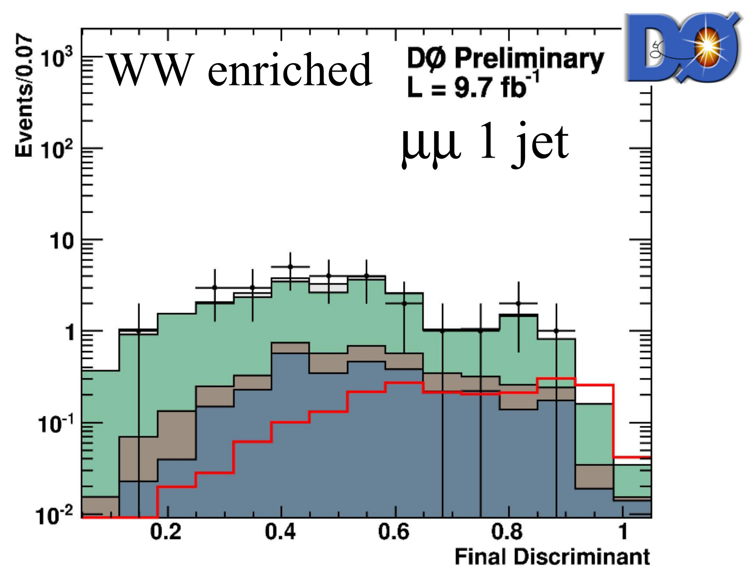
OS di-lepton channels: multivariate analysis

MVA outputs are inputs for statistical analysis of data







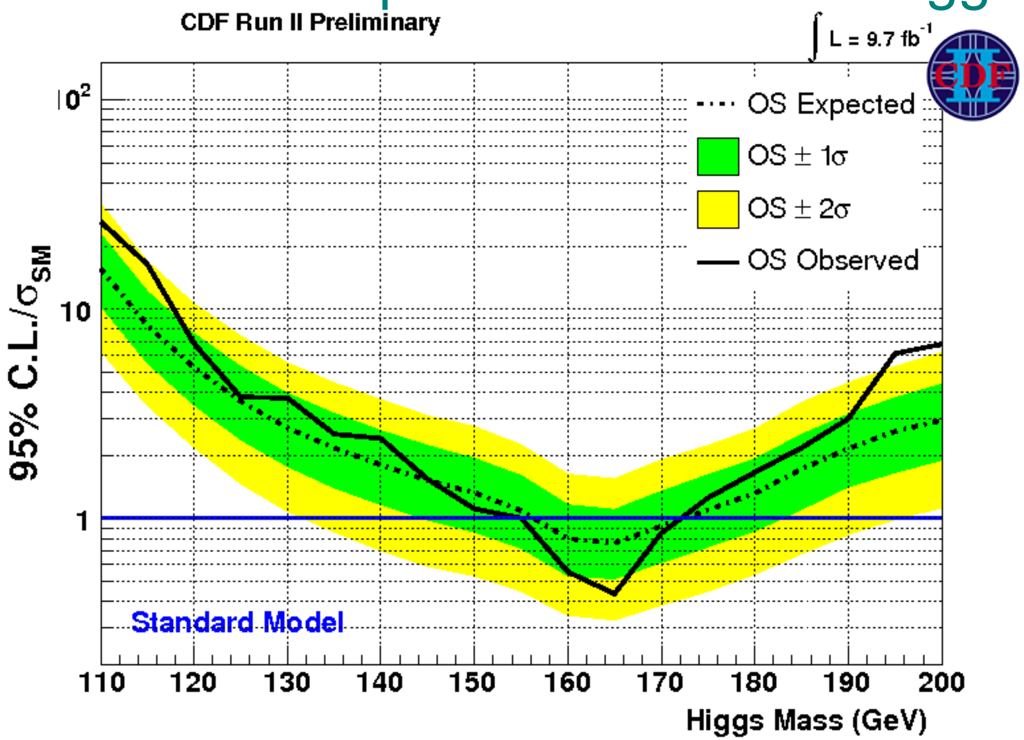


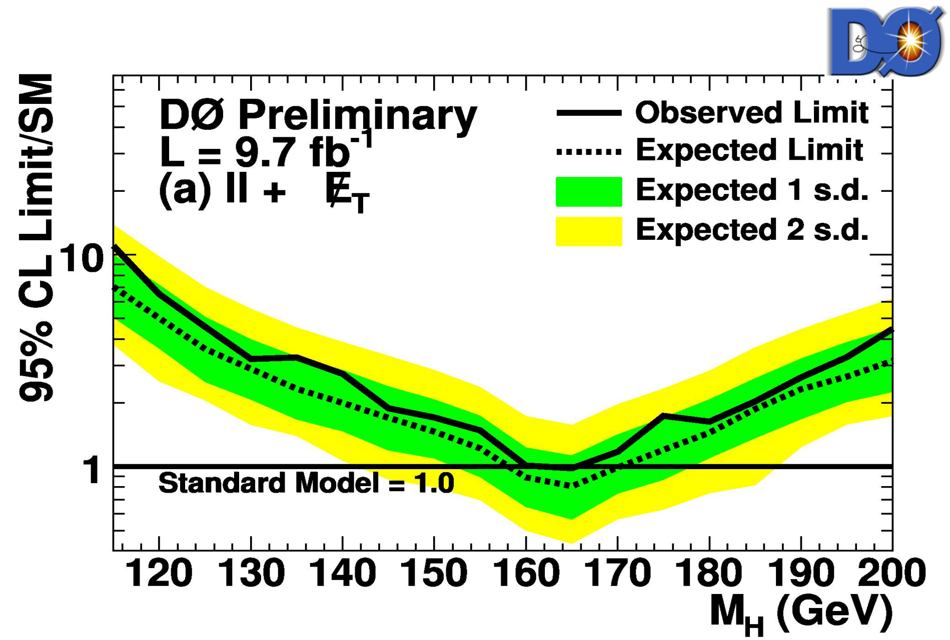
+ many others ...

No excess above background
→ derive limits

OS di-lepton results

- Both experiments achieve Higgs sensitivity with this channel only





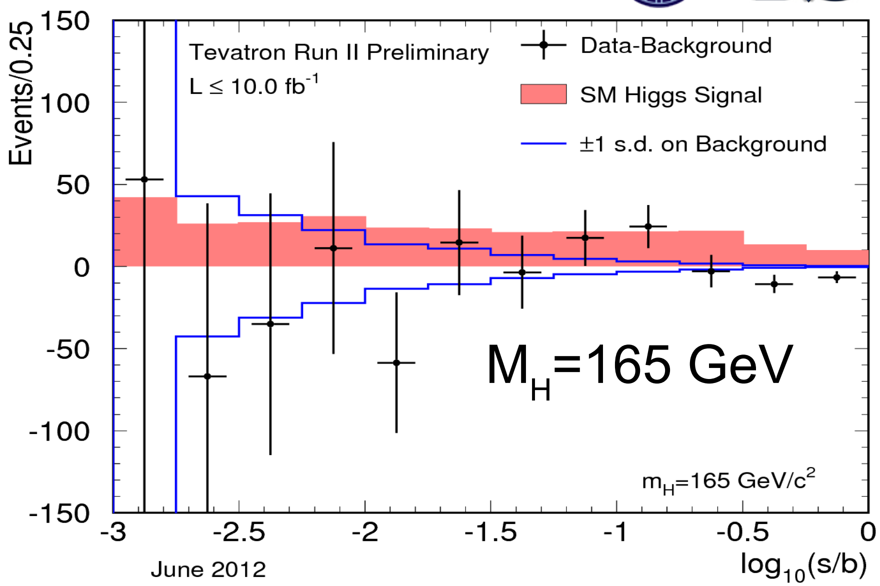
95% CL exclusion		
	CDF	DØ
Expected exclusion	[157,172] GeV	[159,170] GeV
Actual exclusion	[155,172] GeV	165 GeV
Sensitivity @ 125 GeV	3.6 x σ_{SM}	3.6 x σ_{SM}

Systematic uncertainties

Main systematics	Signal	Bkg
Lepton id +trigger	2-5%	2-5%
Lepton/jet fakes	-	14-50%
charge mis-id		20-40%
Luminosity	5.9%	6.1%
Jet calibration	5-17%	3-30%
$\not{E}_T$ modeling	-	~20%
pT(Z) pT(W) pT(WW)pT(H)	1.5%	1-5%
Cross-sections	(VBF,VH) 5-10%	6-10%
gg → H production Scale PDF	(jet dependent) 7-33% 7.6-30%	-

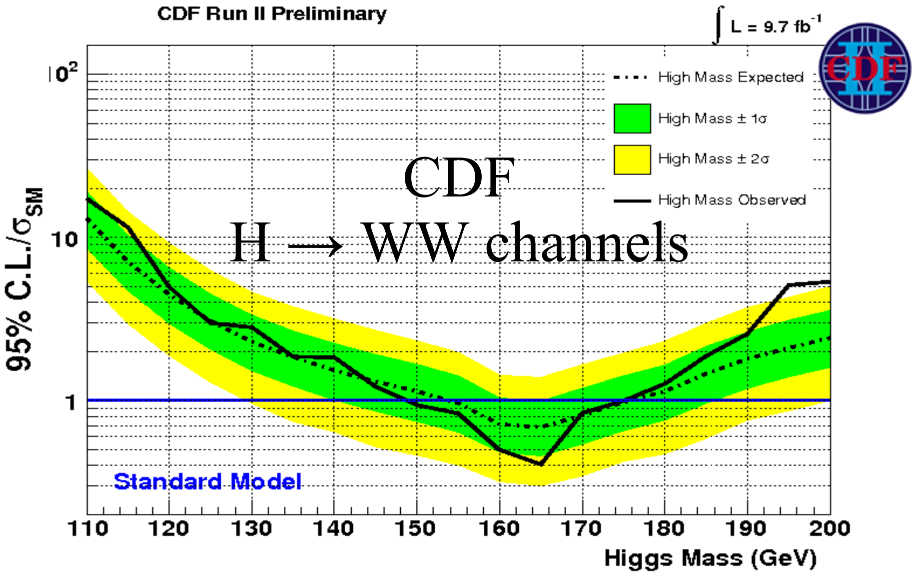
Uncertainties have a sizable impact

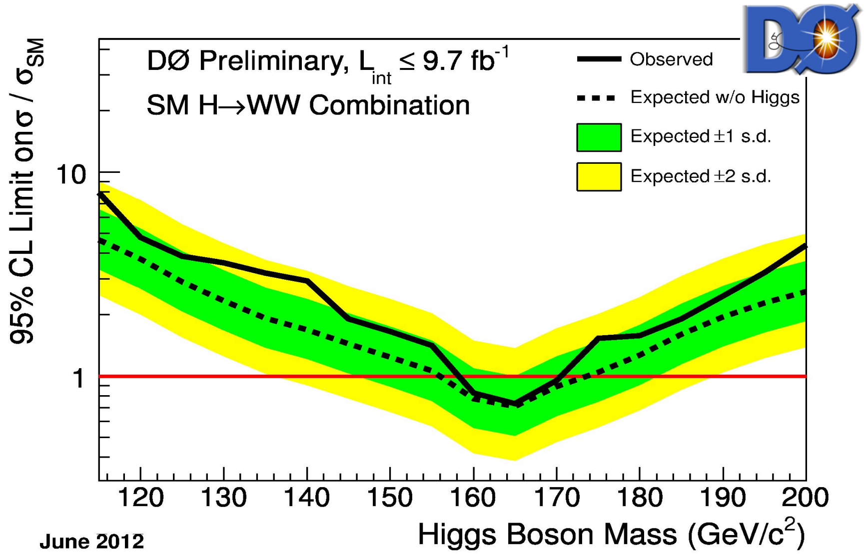
- Flat: affect overall normalization
- Shape: modify output of final discriminant
- Have to account of correlations among channels and experiments
- Impact is reduced thanks to constraints from background dominated region
- Degrade sensitivity by ~15-25%



Results from both experiments

Each experiment alone is sensitive to sizable mass range ~165 GeV





95% CL exclusion		
	CDF	DØ
Expected exclusion	[154,176] GeV	[157,173] GeV
Actual exclusion	[149,175] GeV	[158,170] GeV
Sensitivy @ 125 GeV	3.1 x σ_{SM}	3.2 x σ_{SM}

- For low masses [120-140] GeV: results from DØ show some slight excess
- A Higgs particle of 125 GeV, would create on average a ~1σ excess around [120-150] GeV

Summary/Conclusion

- CDF and DØ first achieved combined sensitivity to high mass Higgs in 2008
- Since then:
  - More data
  - More channels
  - Continuous improvements in analysis techniques
  - Still room for a few more improvements before final publication
- Each experiment is now probing @95% CL a sizable mass range of ~[155,175] GeV

- @125 GeV
  - Individual exclusion sensitivity is around 3.2 x SM
  - CDF+DØ results are not inconsistent with a Higgs of 125 GeV
    - No Large deviation relative to background-only hypothesis
    - DØ alone sees 1 to 1.5 sigma excess in the range [120-150] GeV
- Stay tuned:
  - See next talks for the contributions of low mass channels
  - See next talk for the combined CDF/DØ results
- More details:
  - CDF:http://www-cdf.fnal.gov/physics/new/hdg/Results.html
  - DØ: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Backup slides

DØ and CDF limits

D0 $H \rightarrow WW$

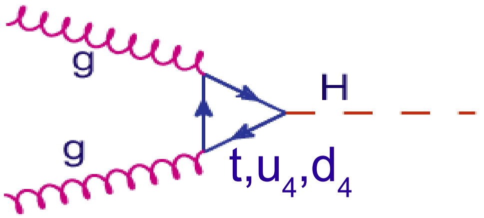
m_H	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
Expected:	5.81	4.37	3.20	2.57	2.09	1.81	1.54	1.31	1.10	0.79	0.72	0.91	1.07	1.32	1.68	2.05	2.43	2.80
Observed:	10.59	5.87	4.59	3.18	3.42	2.76	1.89	1.63	1.41	0.80	0.74	0.99	1.60	1.35	1.87	2.37	3.02	3.98

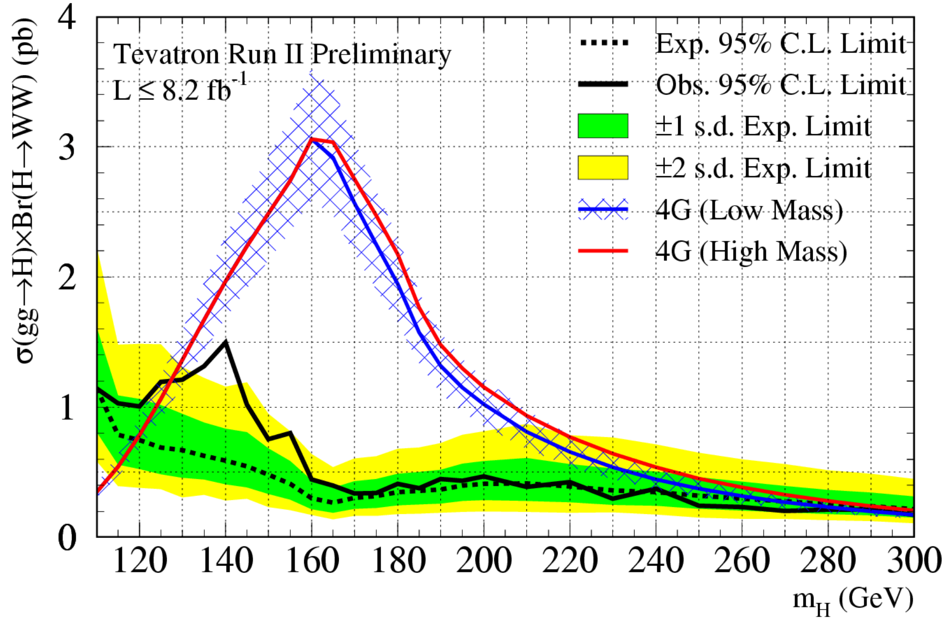
CDF $H \rightarrow WW$

High Mass	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
$-2\sigma/\sigma_{SM}$	5.39	2.95	1.88	1.29	0.96	0.74	0.64	0.52	0.46	0.40	0.32	0.30	0.34	0.42	0.47	0.58	0.75	0.86	1.00
$-1\sigma/\sigma_{SM}$	8.61	4.71	2.97	2.05	1.52	1.22	1.01	0.86	0.74	0.64	0.48	0.46	0.54	0.65	0.75	0.96	1.18	1.40	1.59
Median/σ_{SM}	**13.06**	**7.07**	**4.47**	**3.08**	**2.29**	**1.85**	**1.53**	**1.31**	**1.13**	**0.96**	**0.71**	**0.69**	**0.81**	**0.97**	**1.13**	**1.46**	**1.80**	**2.10**	**2.42**
$+1\sigma/\sigma_{SM}$	19.03	10.25	6.51	4.49	3.34	2.67	2.24	1.91	1.66	1.41	1.03	0.99	1.19	1.41	1.65	2.15	2.63	3.10	3.57
$+2\sigma/\sigma_{SM}$	26.57	14.32	9.21	6.28	4.62	3.75	3.17	2.69	2.32	1.97	1.43	1.39	1.65	1.95	2.31	2.99	3.71	4.30	4.99
Observed/σ_{SM}	**17.28**	**11.52**	**4.96**	**2.98**	**2.81**	**1.85**	**1.84**	**1.22**	**0.94**	**0.83**	**0.50**	**0.40**	**0.84**	**0.99**	**1.26**	**1.87**	**2.56**	**5.10**	**5.33**

Higgs search within 4th generation model

- New heavy generation of quarks
  - ggH coupling is multiplied by 3 compared to SM
  - Production is enhanced by 9
- Search in di-lepton +MET channel can be recycled
  - Some analysis tuning required because of extended mass reach (eg $\Delta\phi(l,l)$ cut not applicable when W's are boosted)



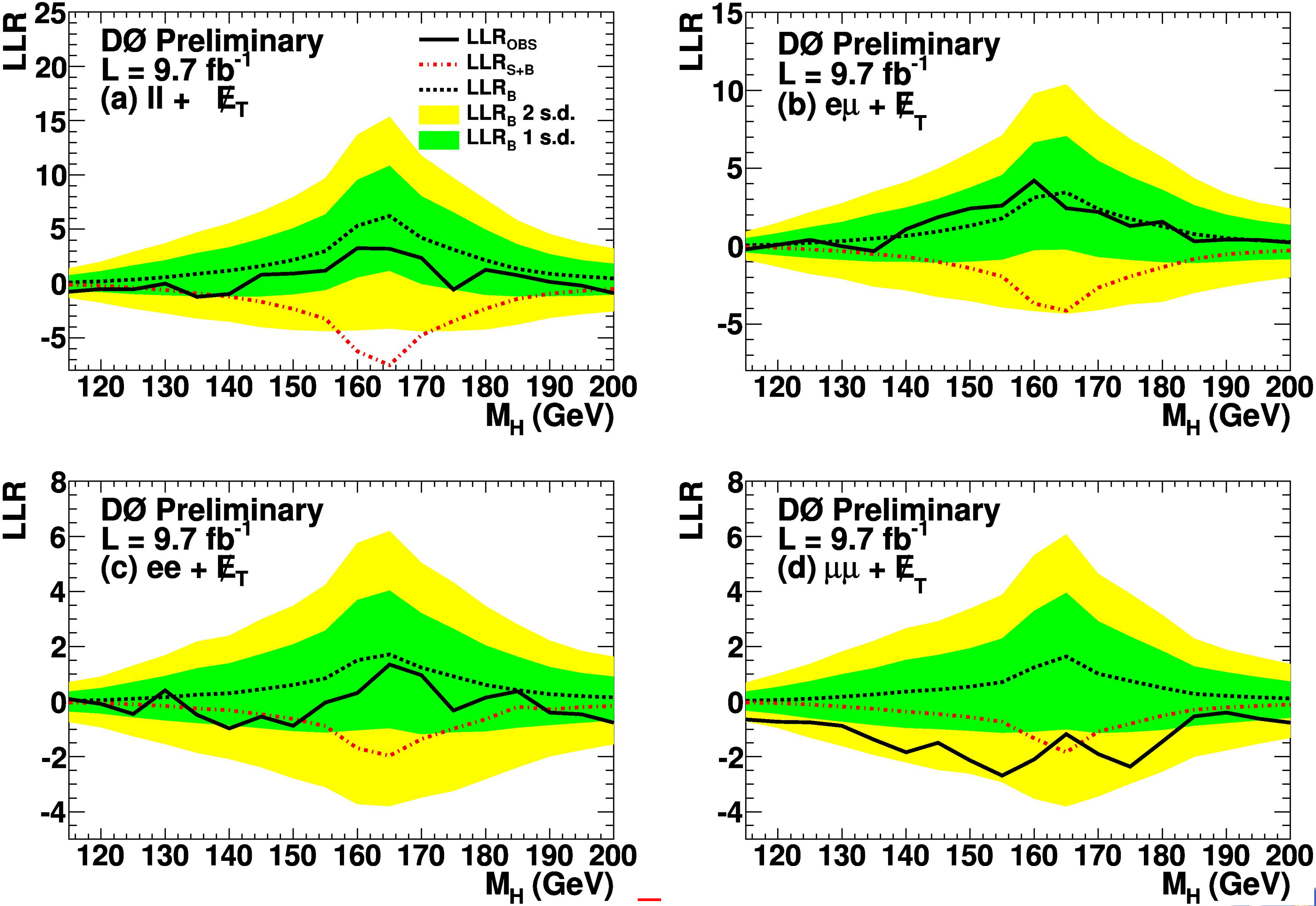


CDF only 8.2 fb^{-1} (summer 11) 123<m_H<215 GeV @95%CL

DØ only 8.1 fb^{-1} (summer 11) 140<m_H<240 GeV @95%CL

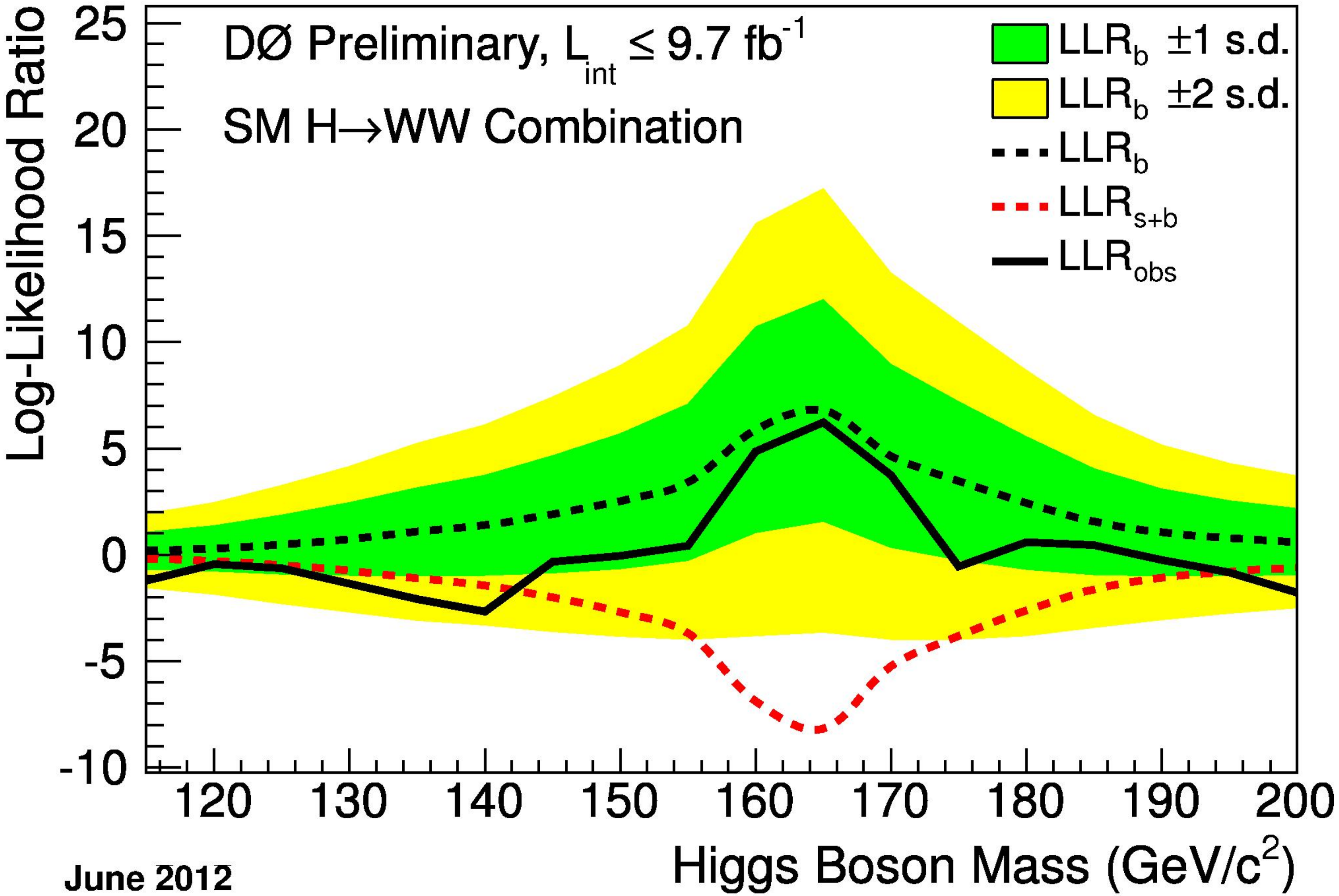
Combined result (summer 11) 124<m_H<286 GeV @95%CL

DØ OS subchannels

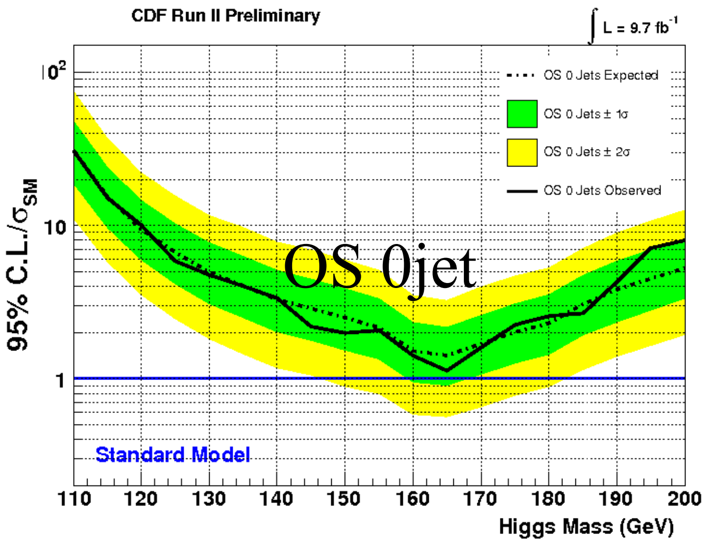


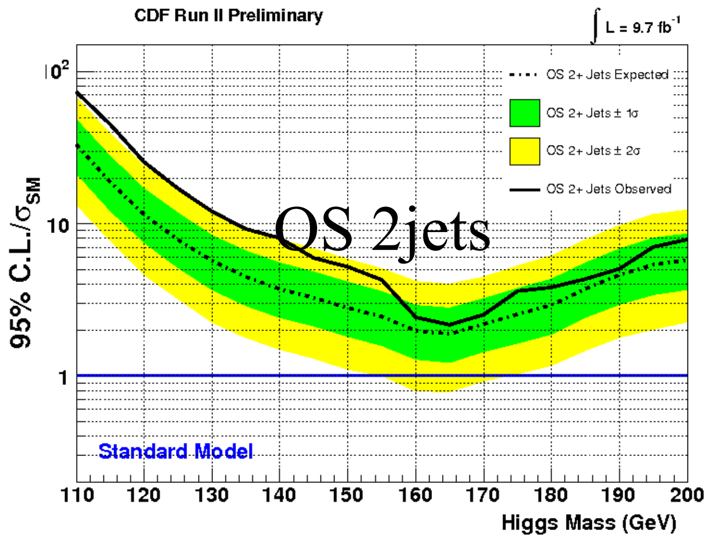
DØ H → WW

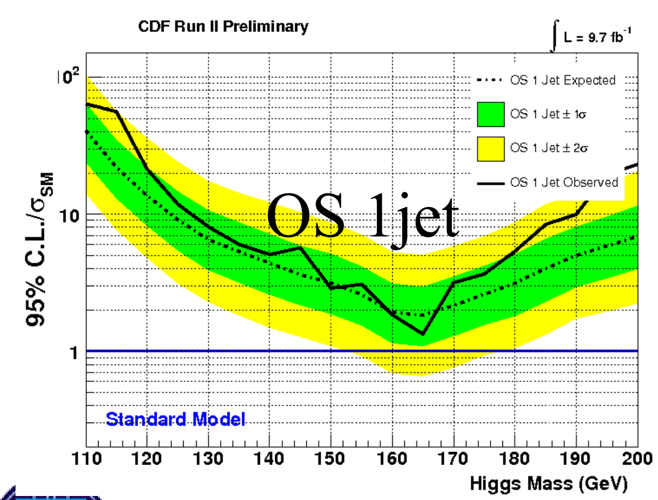
Slight [1σ -1.5σ] excess at low mass

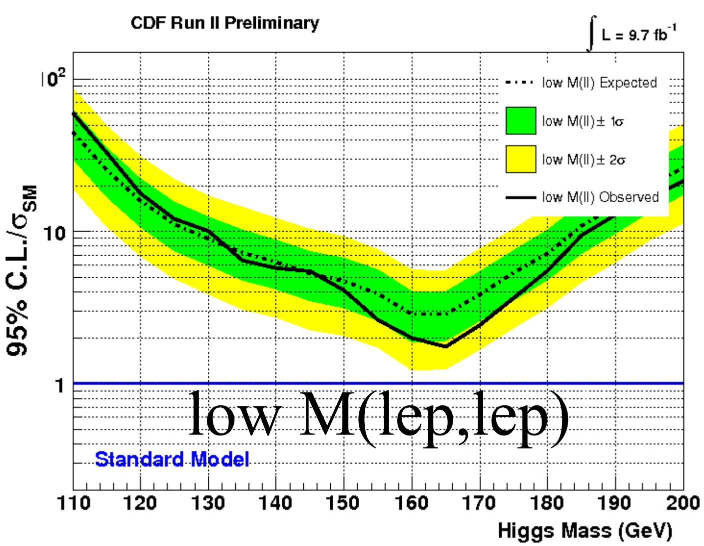


H → WW CDF subchannels









Di-lepton channels: new in 2012

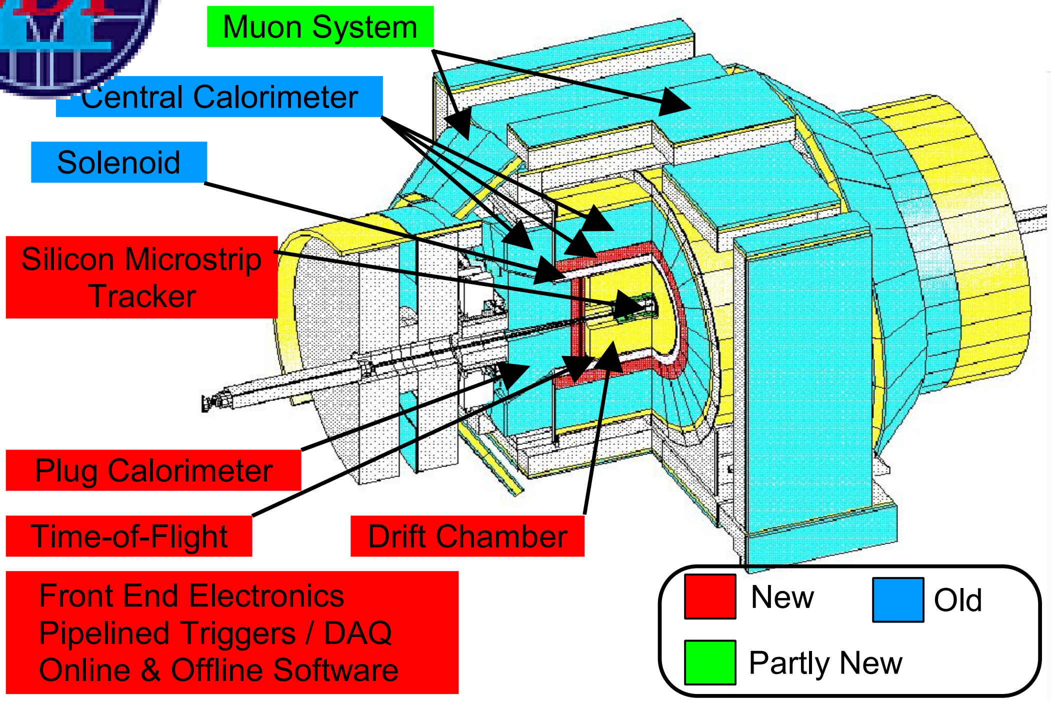
CDF

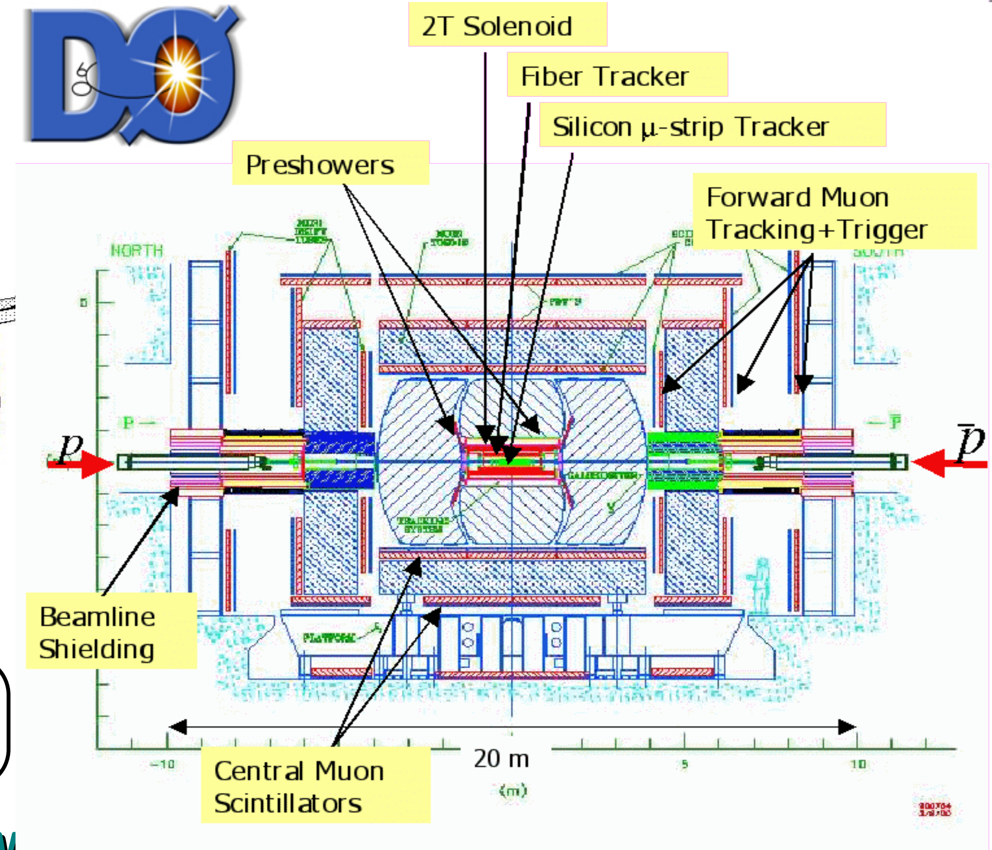
- More data, typically 20%

DØ

- More Data, typically 20%
- Opposite sign channels : ee , $\mu\mu$
  - Improved electron ID
  - split into enriched/depleted WW background region
  - O(10%) improvement
- New Tri-lepton analyses
  - split into three regions : non Z, Z+MET, Z+low MET, for $\mu\mu e$

Tevatron Experiments at RunII





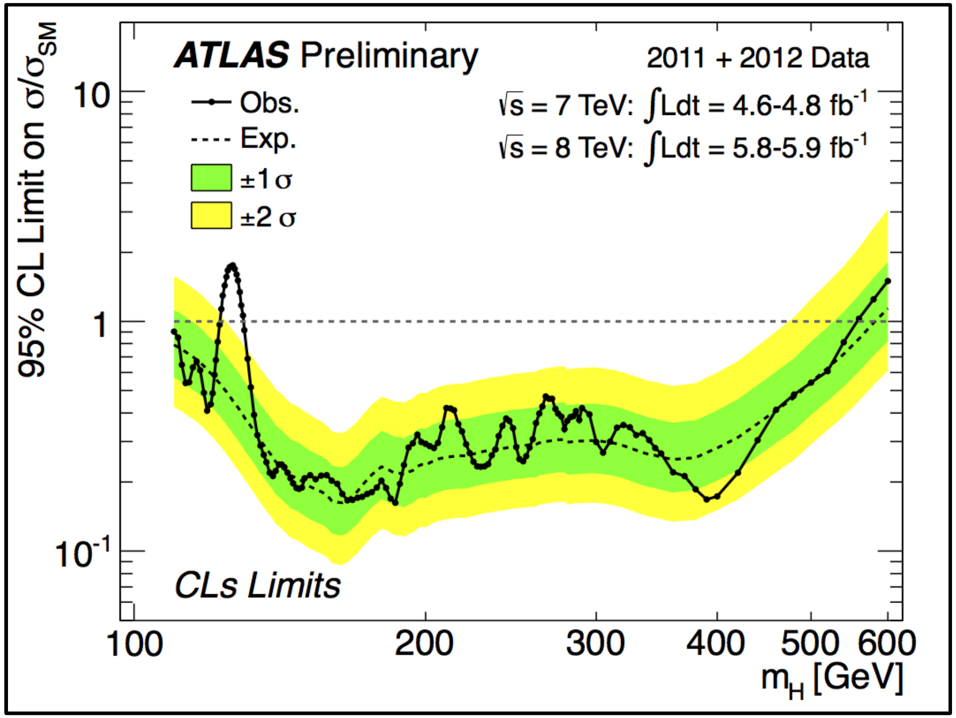
New
- silicon detector
- Drift chamber
- TOF PID system

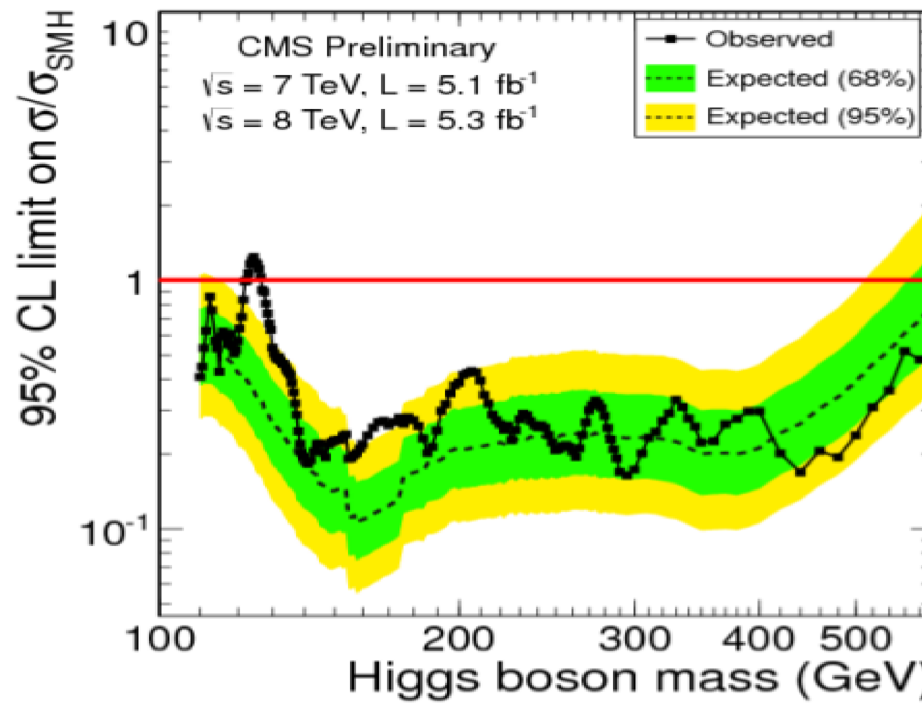
Upgraded
- Calorimeter
- DAQ/trigger
- displaced-vertex trigger

New
- Tracking in B-field
- Silicon detector
- fiber tracker

Upgraded
- Calorimeter, muon system
- DAQ/trigger
- RunIIb: Silicon layer 0, Cal Trigger

Recent LHC results





- Summer 11: LHC started to exclude a large range at high mass
- Winter 12: Remaining allowed region became narrower
  - Hints of an excess around 125 GeV
- July 4th 2012, updated results:
  - Searches exclude a large mass range up to 600 GeV
  - Only allowed region around 125 GeV
  - Observation of a Higgs-like particles @5 sigma claimed by Atlas & CMS around 125 GeV

gg →H (μ_R,μ_F) scale uncertainties

- Vary independently ggH +0jet, ggH+1jet, ggH+2jets scale uncertainties (s0, s1,s2).
- Account for migration between jet multiplicity bin.

	s0	s1	s2
0 jet	0.134	-0.230	0.0
1 jet	0.0	0.35	-0.127
2+jet	0.0	0.0	0.33