Higgs Searches
Latest Results from the Tevatron

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on behalf of the CDF and DØ Collaborations

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Outline

Introduction

Challenges and analysis strategies

Low mass SM Higgs searches

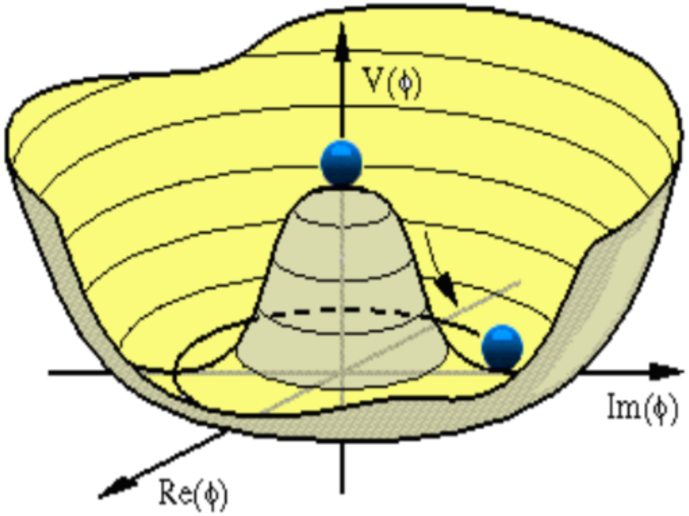
High mass SM Higgs searches

New combined Tevatron result

Conclusions

The Higgs Boson

In the Standard Model, the Higgs field is a complex scalar field, V(ϕ)



Through electroweak symmetry breaking, the gauge bosons (W, Z) acquire mass

A single Higgs boson with spin 0 appears. The only free parameter is its mass

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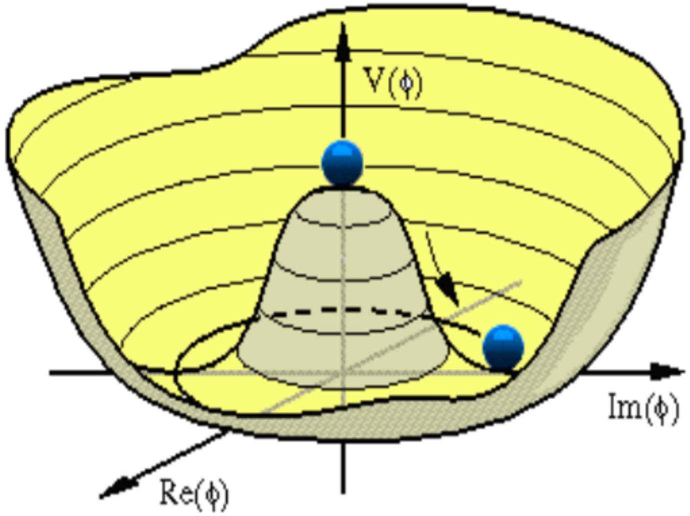
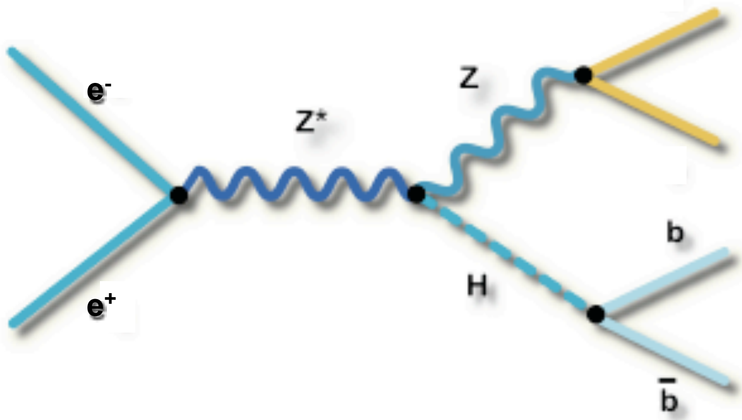


Through electroweak symmetry breaking, the gauge bosons (W, Z) acquire mass

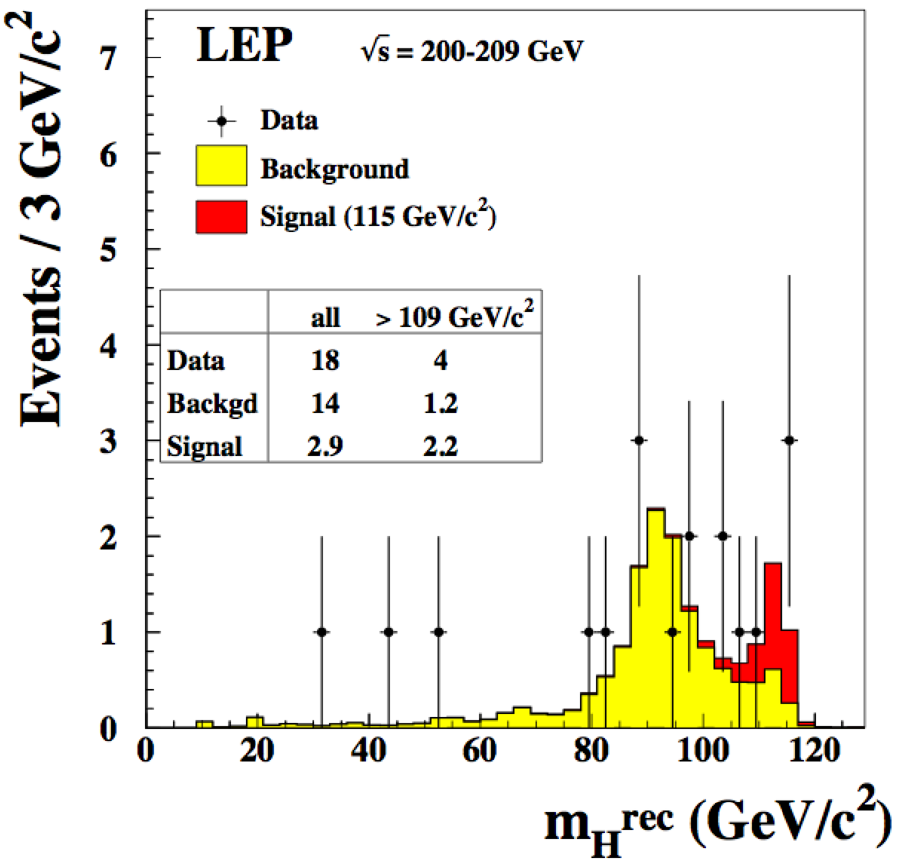
A single Higgs boson with spin 0 appears. The only free parameter is its mass

The Higgs particle is the only missing piece of the Standard Model

Higgs searches at LEP



$\sqrt{s} - m_Z = 206.6 - 91.2 = 115.4$ GeV

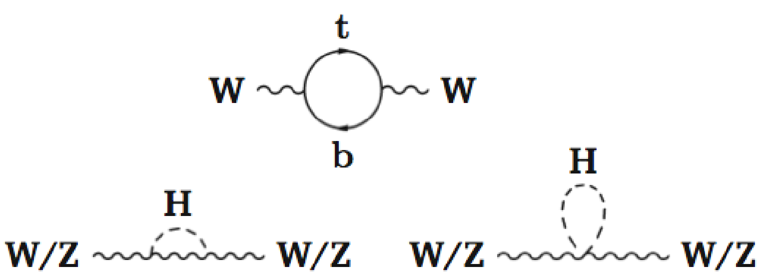


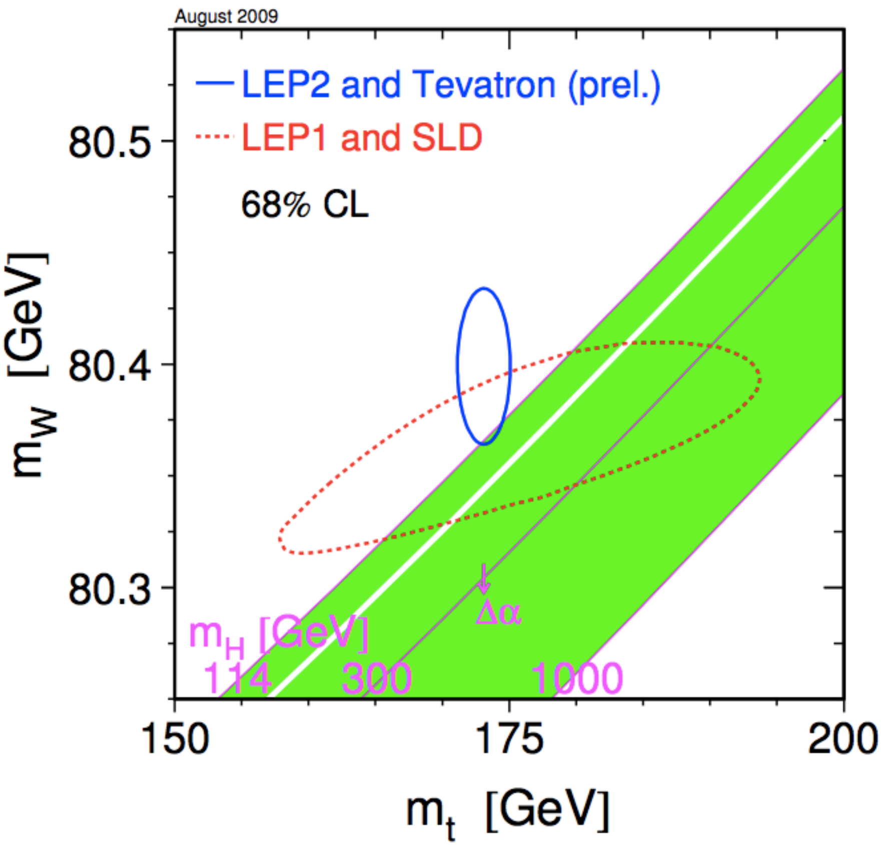
Excess around 115 not significant

$m_H \geq 114.4$ GeV @ 95% CL

Stalking the Higgs

The SM relates m_H, m_t, m_W via radiative corrections:





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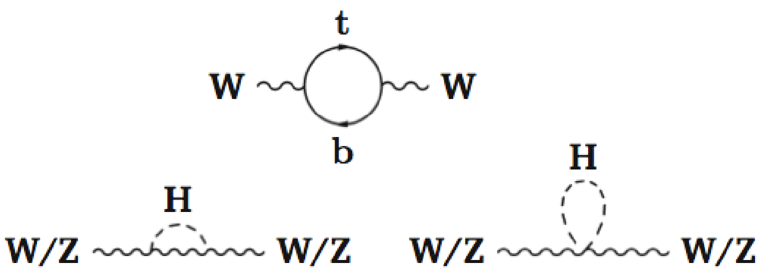
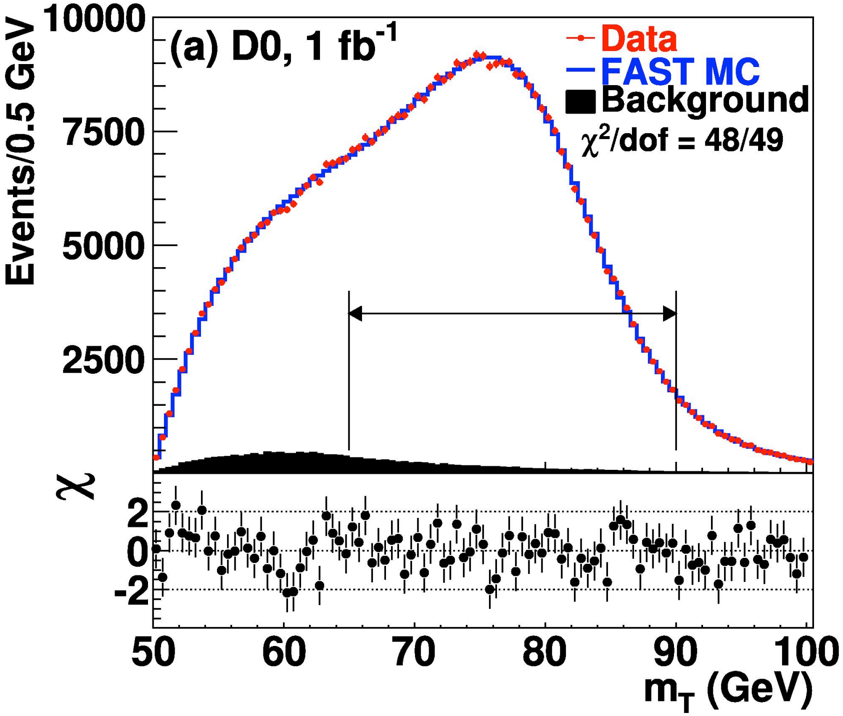


Combined top mass from CDF+DØ:
173.1 ± 1.3 GeV

Run II W mass measurements
DØ: 80.401 ± 0.043 GeV
CDF: 80.413 ± 0.048 GeV



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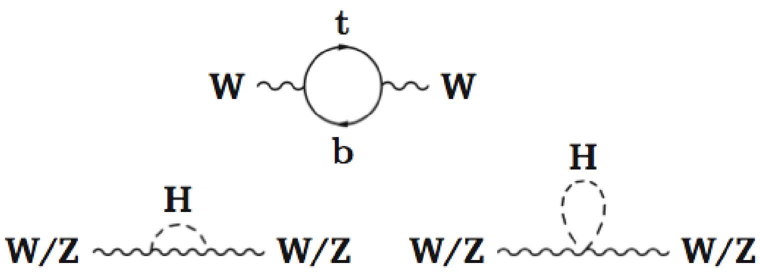
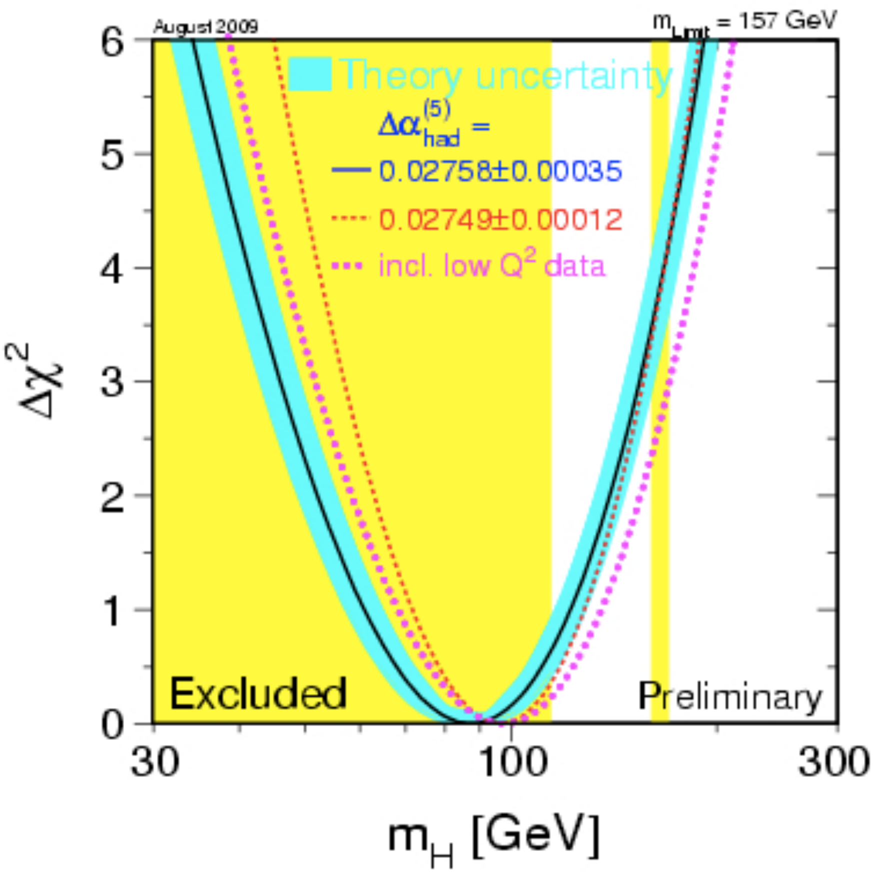


Indirect constraints on the Higgs boson mass from global EW fits:

m_H < 186 GeV @95%CL

(including the direct limit from LEP)



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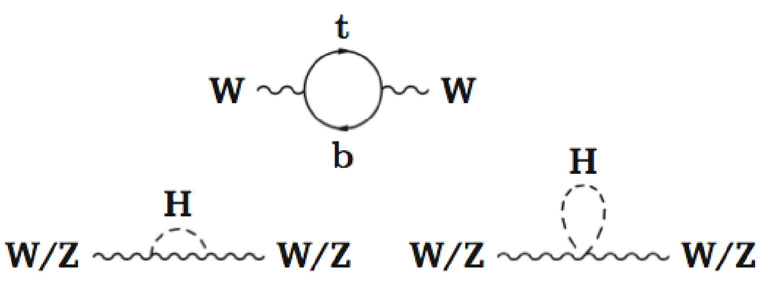

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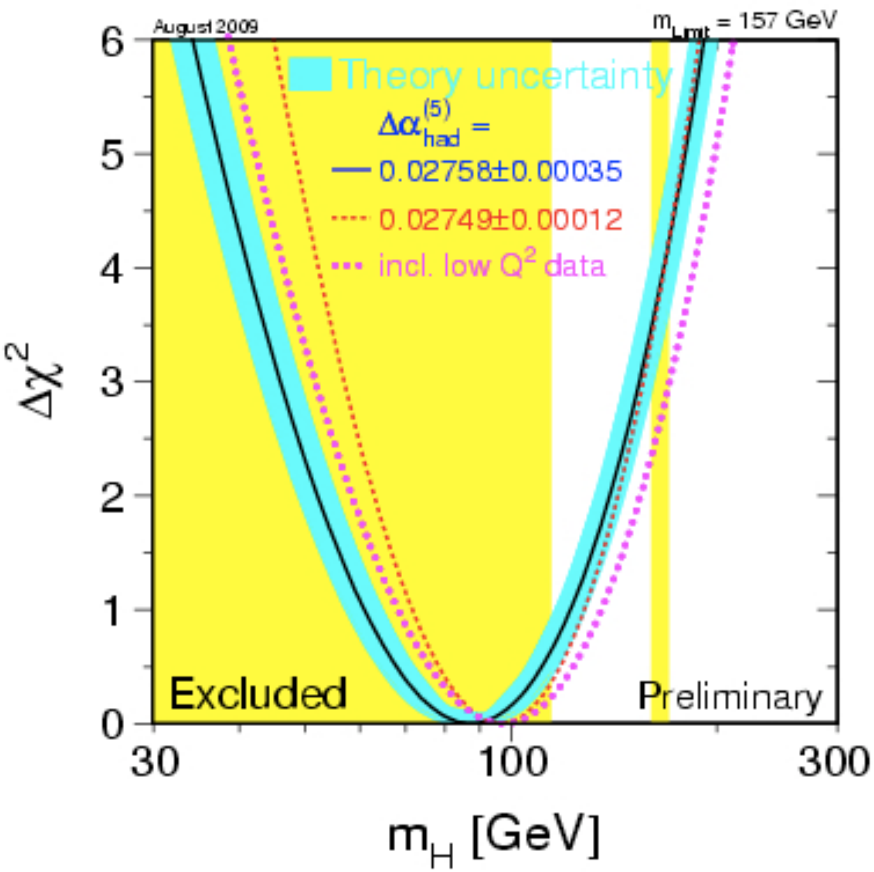
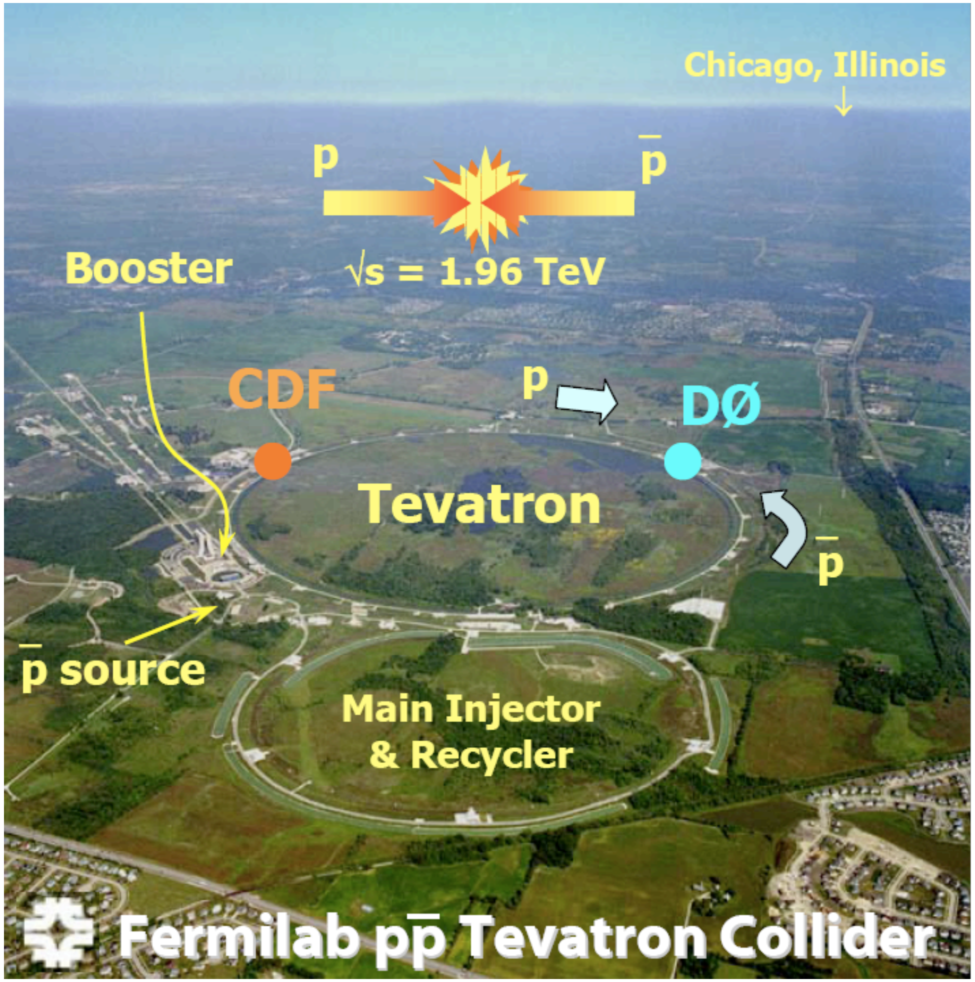
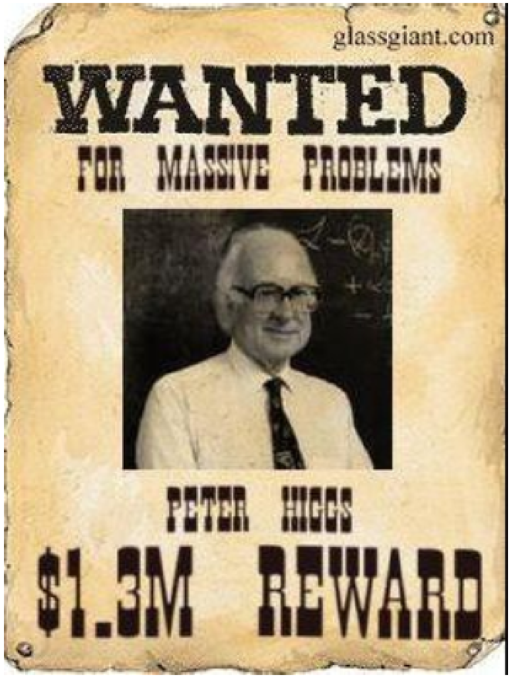


A light Higgs boson is around the corner (if the SM is correct)!

Tevatron collider in Run II

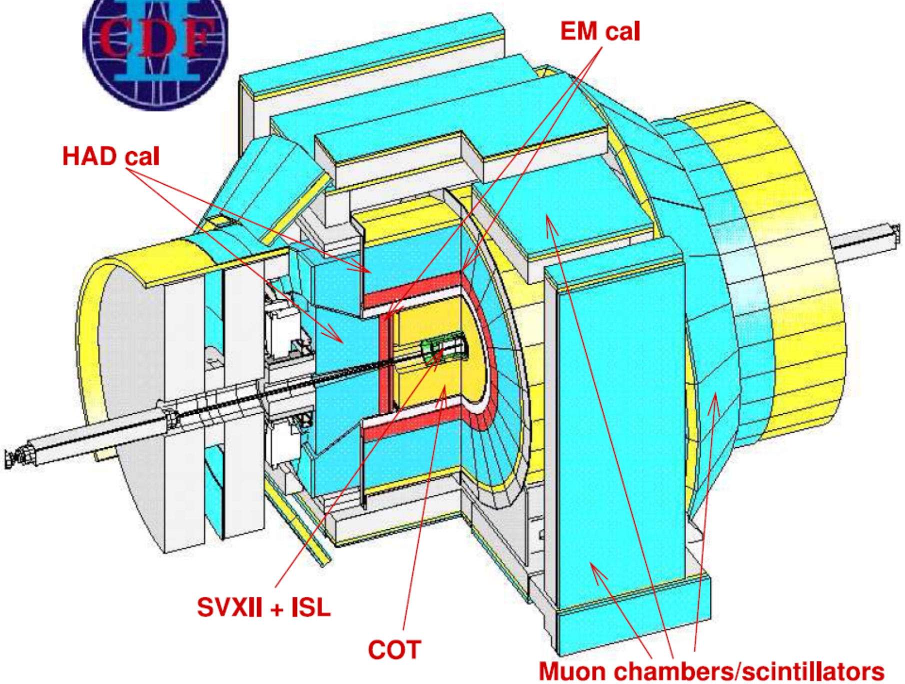


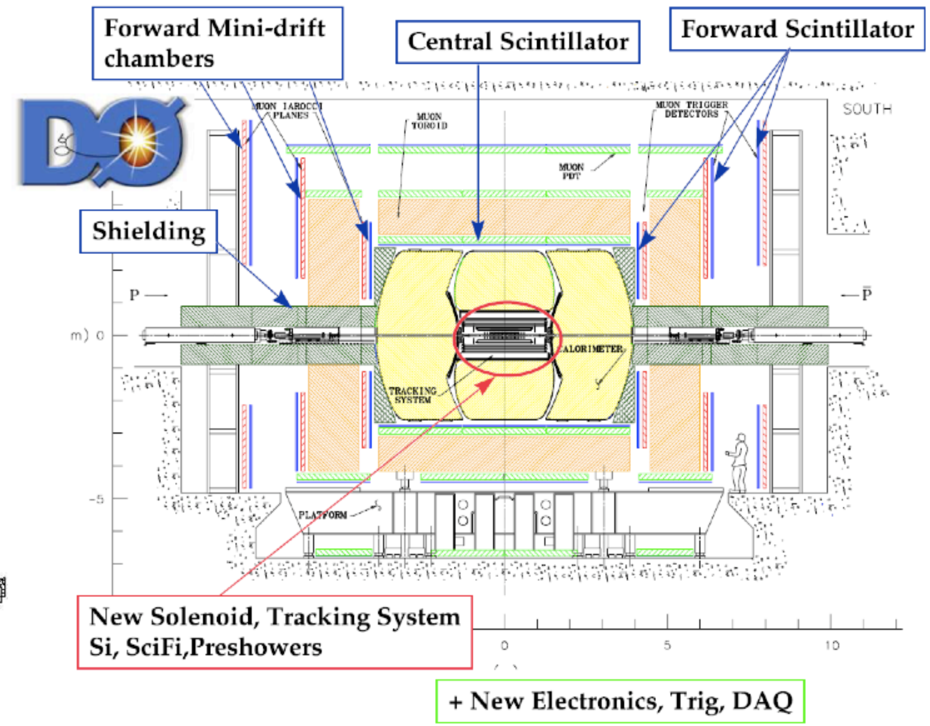


CDF and DØ experiments in Run II

Two General-Purpose Detectors:

Precision tracking
Hermetic calorimeter
Muon system



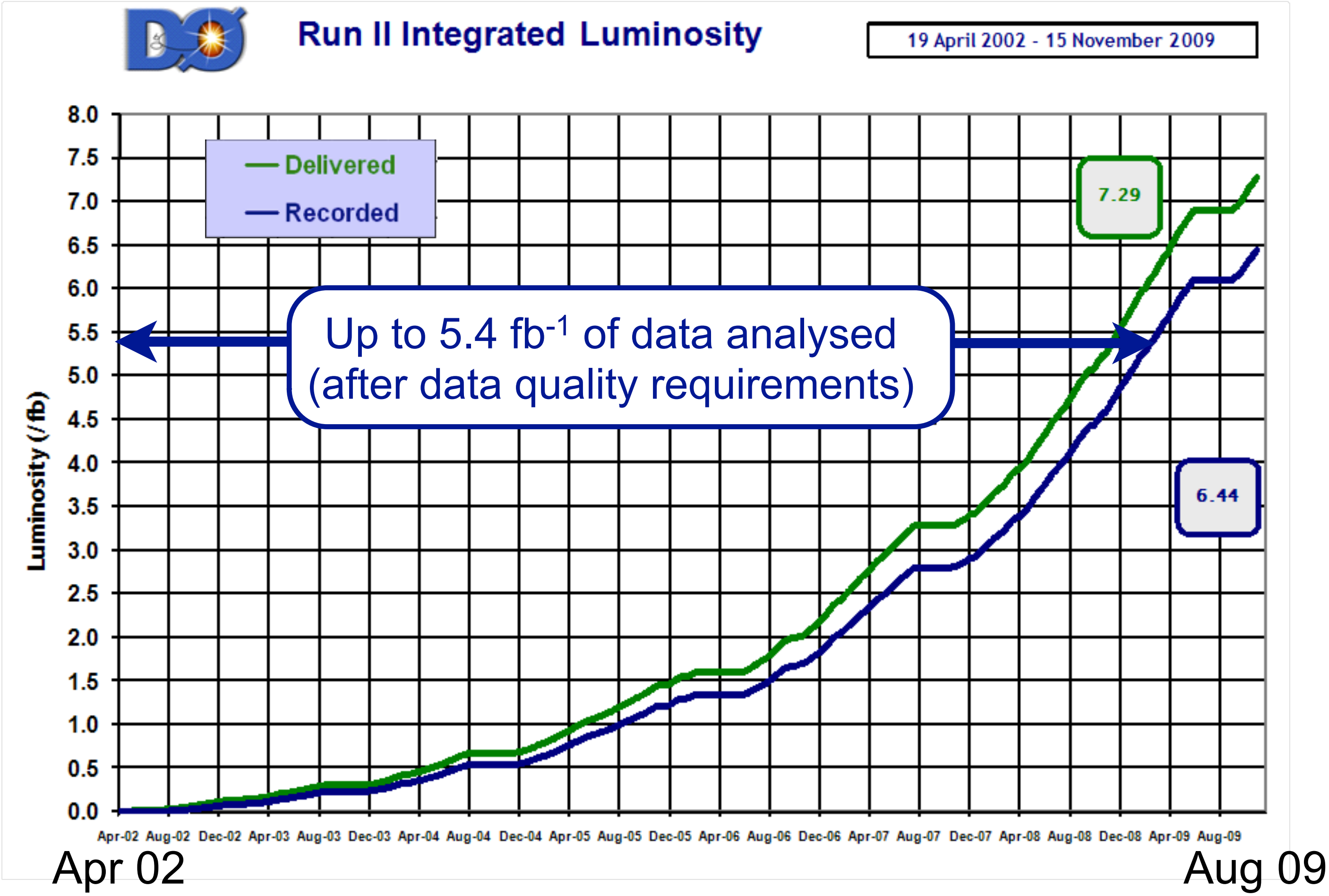


Both detectors are upgraded for Run II

Well understood, stable operation and data taking efficiencies ~90%

Data set

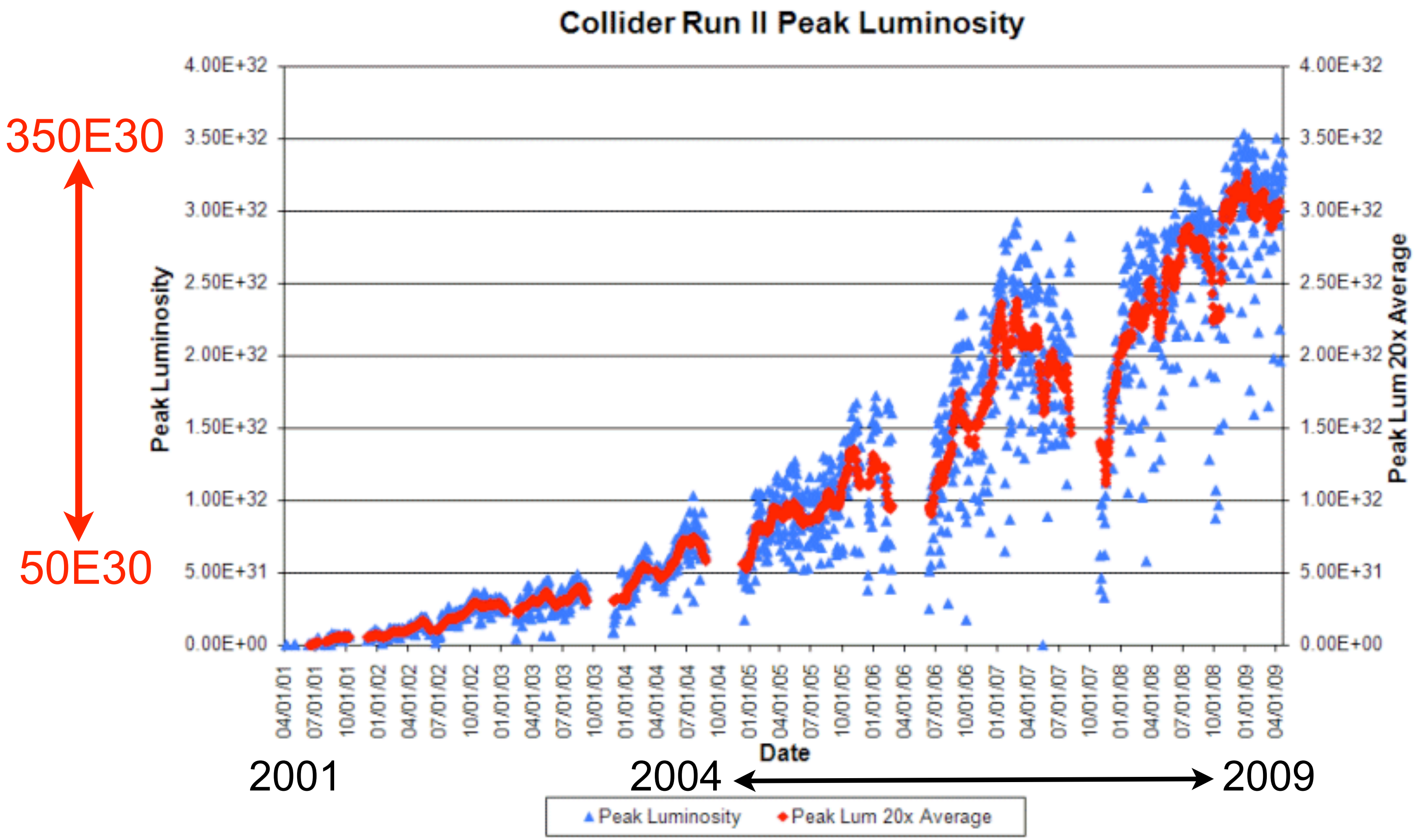
Tevatron delivers a data set equal to Run I (~100 pb^{-1}) every 2 weeks



Similar for CDF

Expected to ~double this luminosity by the end of Run II

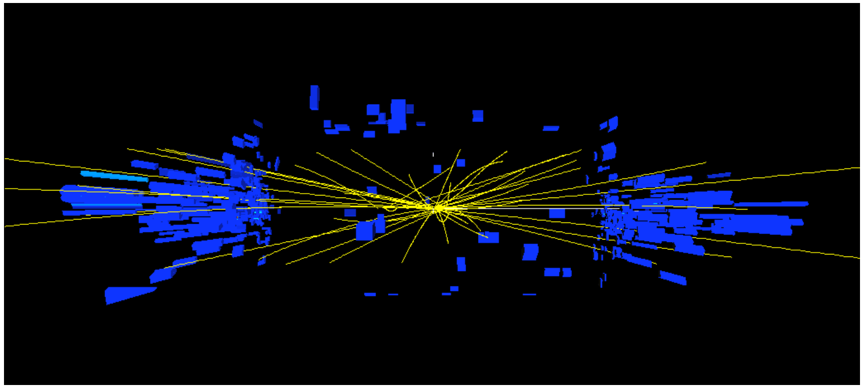
Tevatron performance



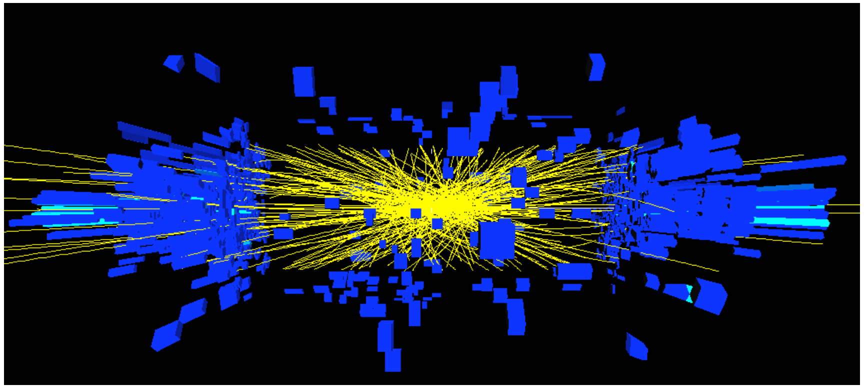
More data with higher instantaneous luminosities

Challenges of high luminosity

Event @ 60E30 cm^2s^{-1}



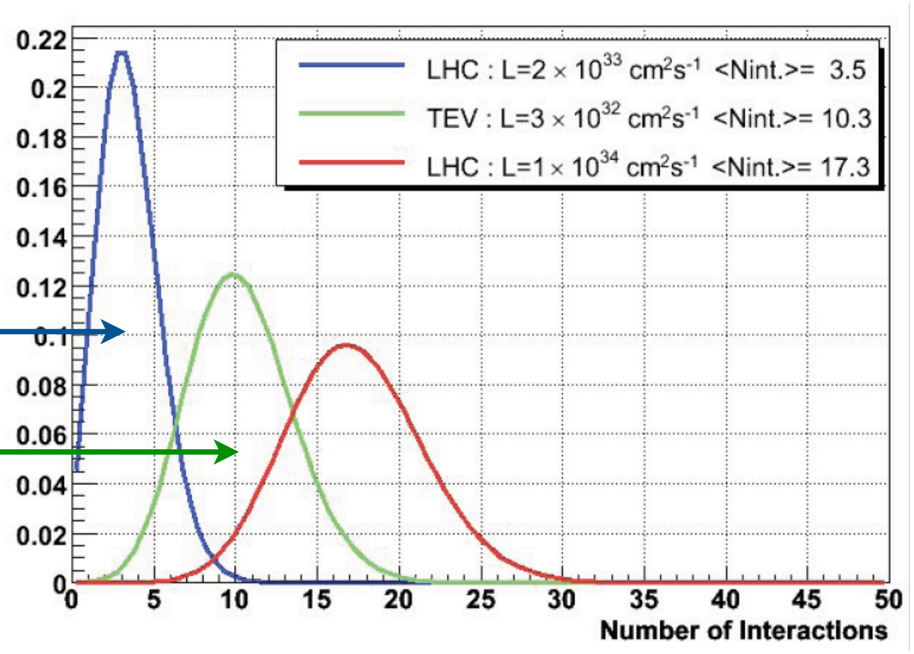
... and @ 240E30 cm^2s^{-1}



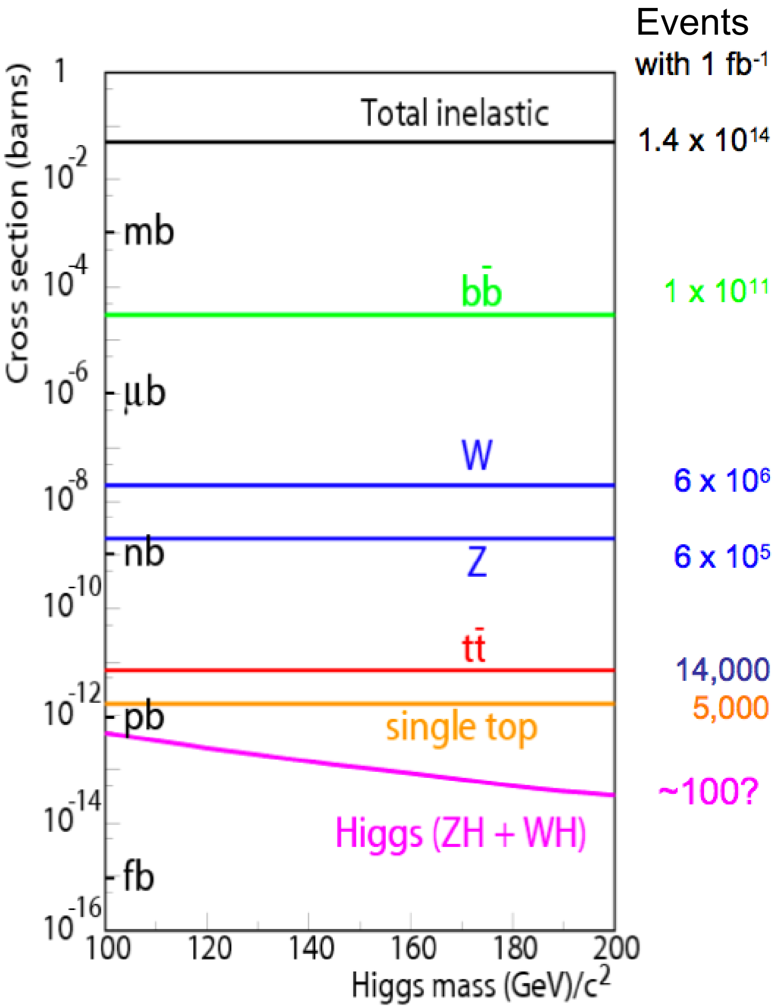
Average number of interactions:

LHC: initial "low" lumi run (L=2000E30 cm^2s^{-1}): <N>=3.5

TeV: (L=300E30 cm^2s^{-1}): <N>=10



Higgs production at the Tevatron



only one in ~10^{12} events
will be a Higgs boson

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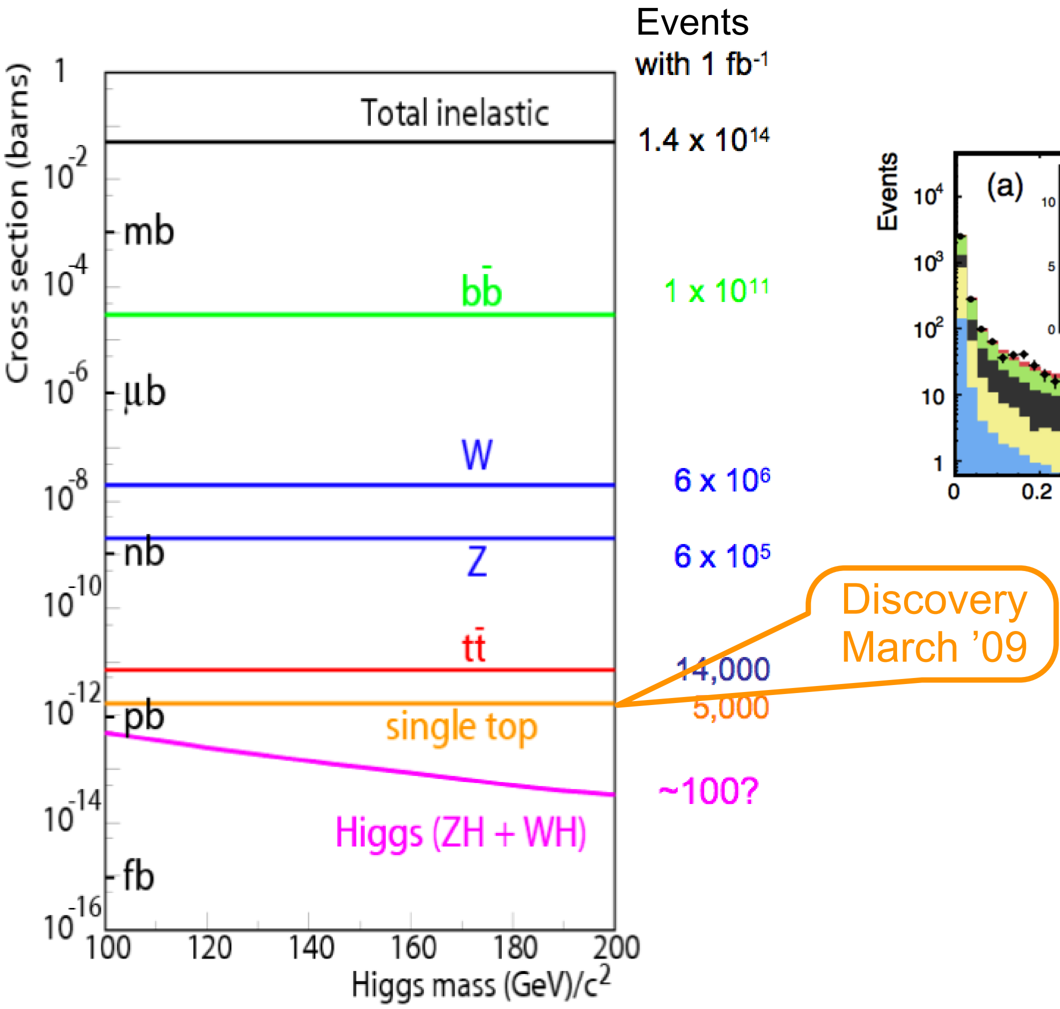
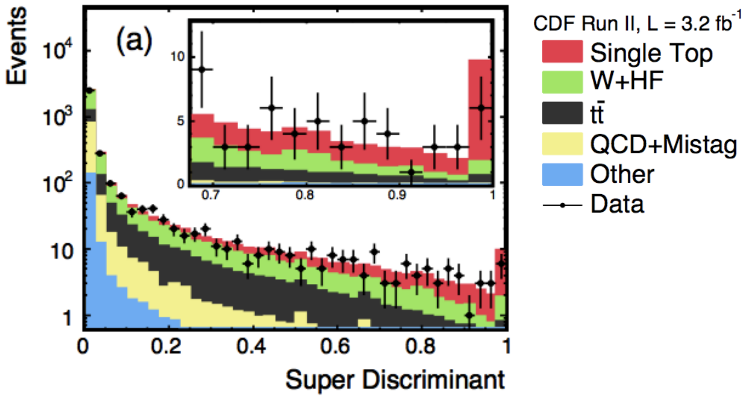
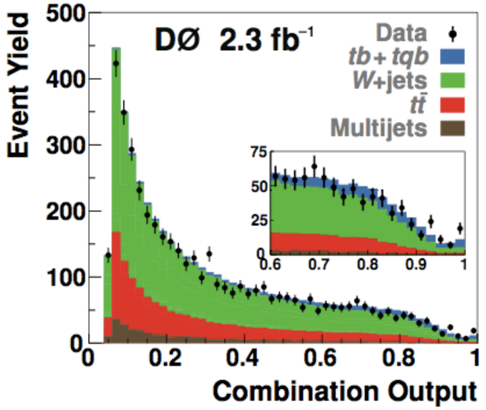


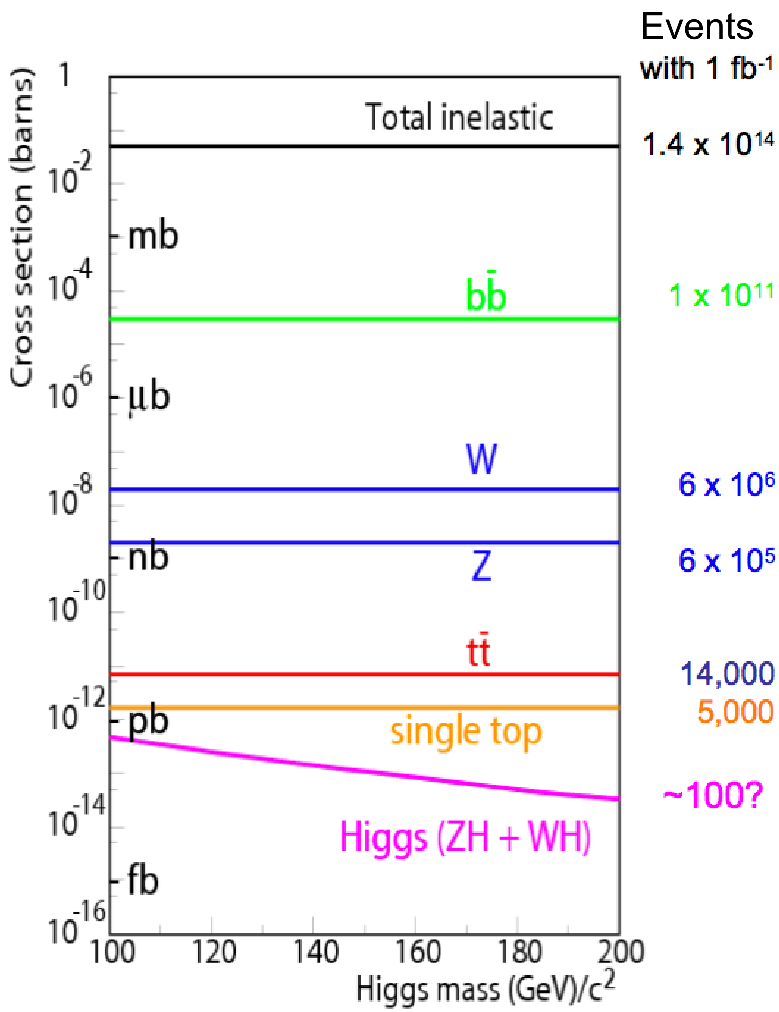


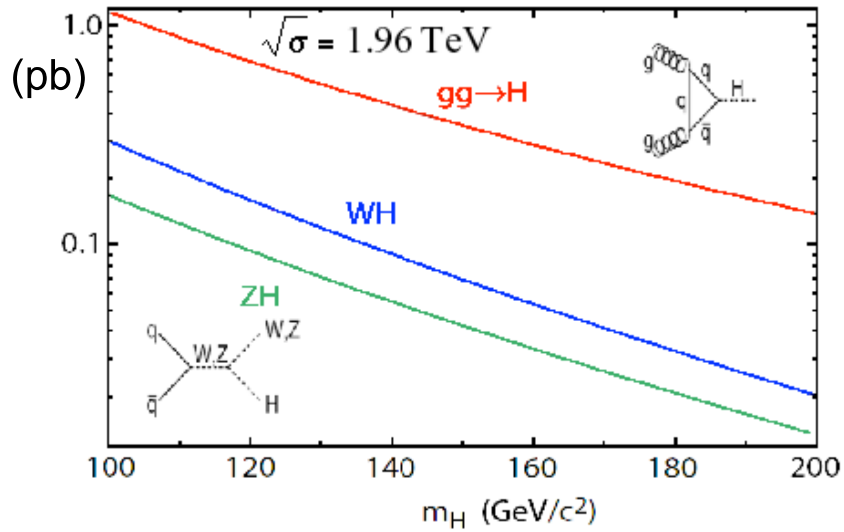


only one in ~10^{12} events will be a Higgs boson

[Phys. Rev. Lett. 103, 092001 (2009), Phys. Rev. Lett. 103, 092002 (2009)]

Higgs production at the Tevatron



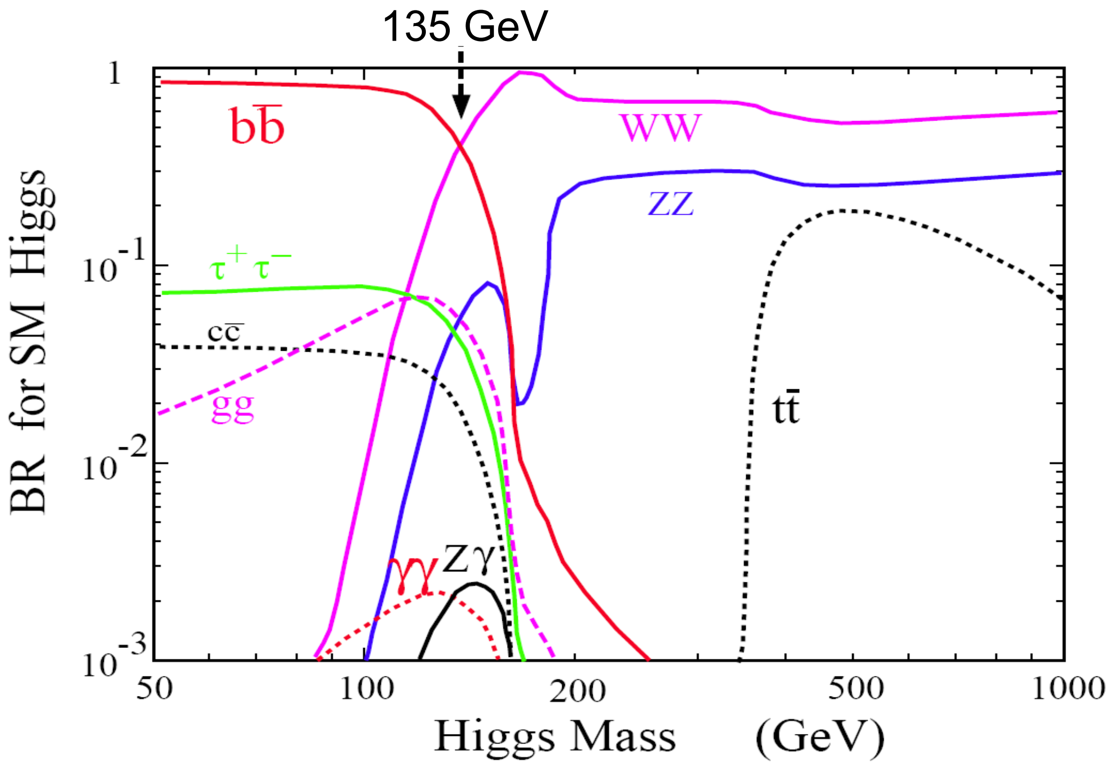


only one in $\sim 10^{12}$ events will be a Higgs boson

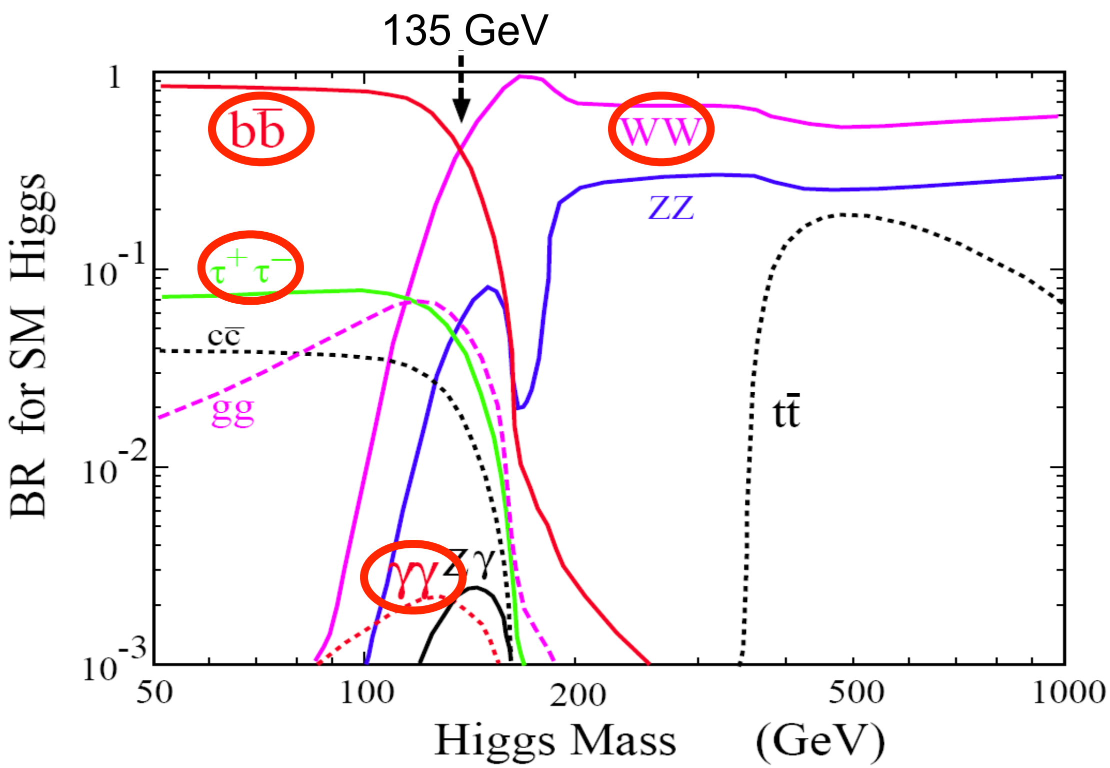
Higgs production cross sections are small: 0.1-1 pb, depending on m_H

Dominant production mode is gluon-gluon fusion

Higgs decays



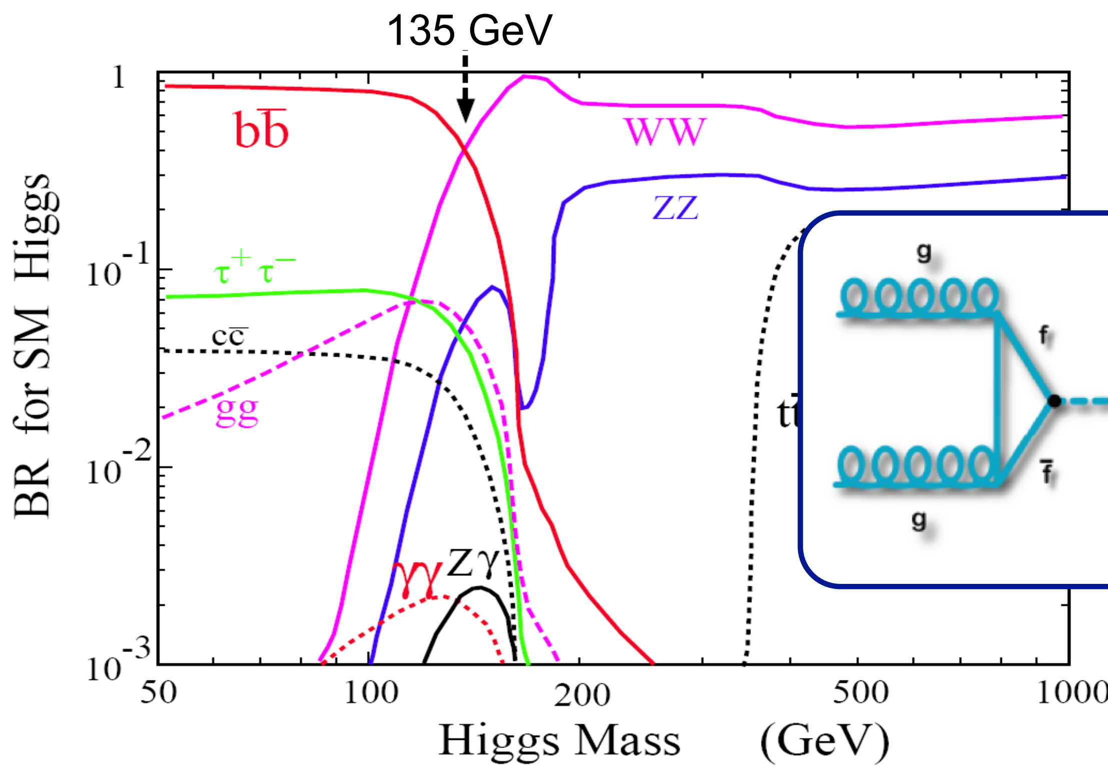
Search strategy at the Tevatron

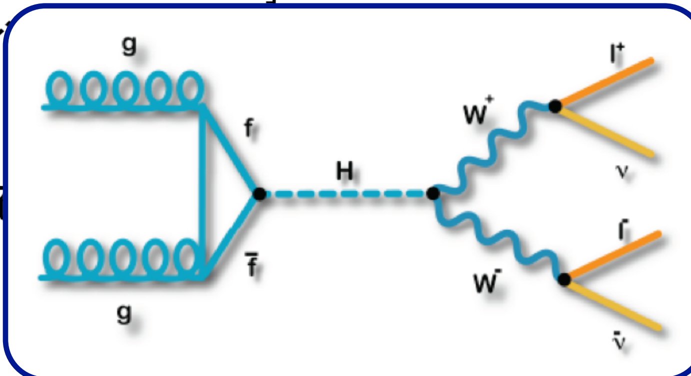


Investigate different production mechanisms and a large number of final states

→ Focus on the main search channels in this talk

Search strategy at the Tevatron

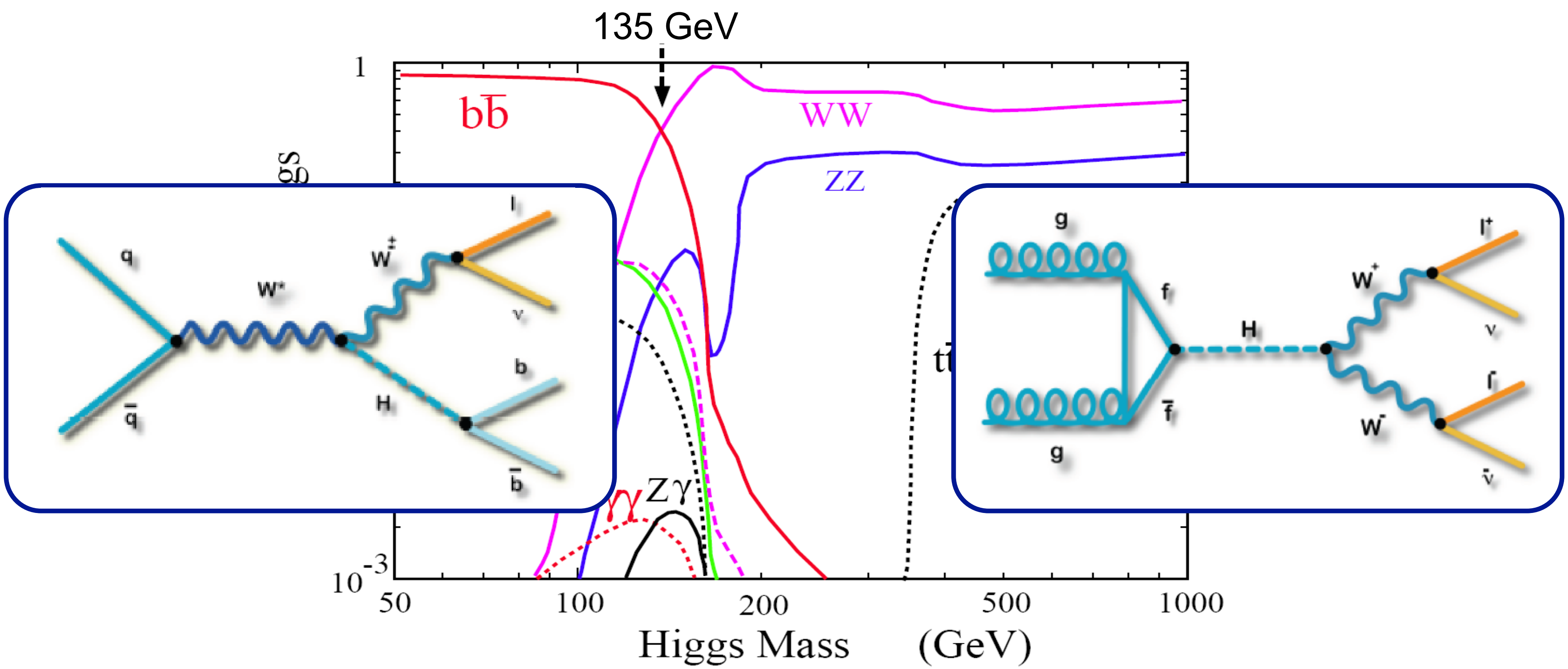




m_H > 135 GeV:

gg→H production with decay to WW

Search strategy at the Tevatron



$m_H < 135$ GeV:

Associated production WH and ZH with $H \rightarrow bb$ decay

$m_H > 135$ GeV:

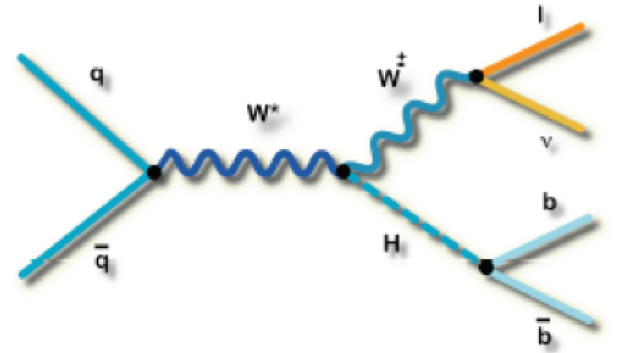
$gg \rightarrow H$ production with decay to WW

Updates since Moriond ‘09

Channel	CDF	DØ
$m_H < 135$ GeV		
$WH \rightarrow l\nu bb$	2.7 → 4.3 fb^{-1}	2.7 → 5.0 fb^{-1}
$WH \rightarrow \tau\nu bb$	---	0.9 → 4.0 fb^{-1}
$ZH \rightarrow llbb$	2.7 → 4.1 fb^{-1}	2.3 → 4.2 fb^{-1}
$ZH \rightarrow \nu\nu bb$	2.1 → 3.6 fb^{-1}	2.1 → 5.2 fb^{-1}
$XH \rightarrow \tau\tau jj$	2.0 fb^{-1}	1.0 → 4.9 fb^{-1}
$m_H > 135$ GeV		
$H \rightarrow WW \rightarrow l\nu l\nu$	3.6 → 4.8 fb^{-1}	3.0 - 4.2 → 5.4 fb^{-1}
$VH \rightarrow VWW \rightarrow ll+X$	3.6 → 4.8 fb^{-1}	1.1 → 3.6 fb^{-1}

Major updates on all the important search channels since the last Tevatron combination: analysis improvements + more data

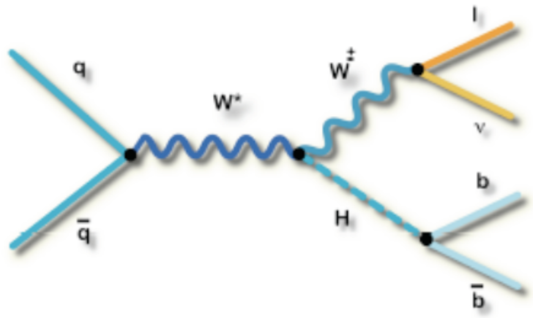
Searches for a low mass Higgs



m_H < 135 GeV:

Associated production WH and ZH with H→bb decay

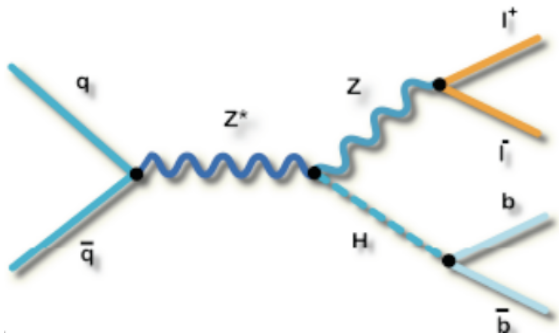
Main low mass search channels



MET+l+bb: $WH \rightarrow l\nu bb$

Large production cross section

Higher backgrounds than in $ZH \rightarrow llbb$

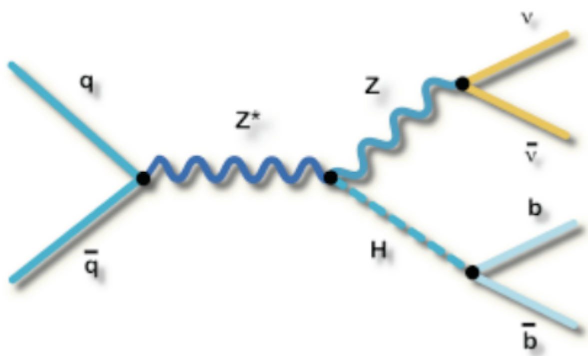


ll+bb: $ZH \rightarrow llbb$

Low backgrounds

Fully constrained

Small Higgs signal



MET+bb: $ZH \rightarrow \nu\nu bb$

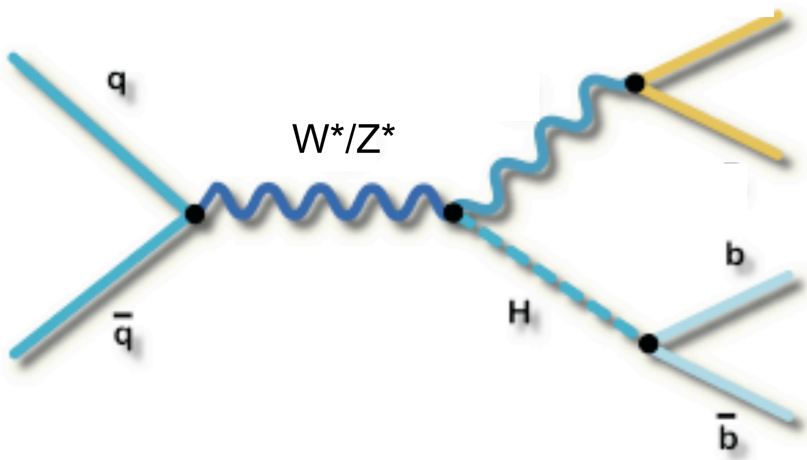
3x signal than in $ZH \rightarrow llbb$

(+$WH \rightarrow l\nu bb$ when lepton missing)

Large backgrounds that are difficult to handle

Signal and backgrounds

Experimental signature:



Missing transverse energy and/or isolated leptons

Two high p_T jets, acoplanar, b-tagged

Main backgrounds:

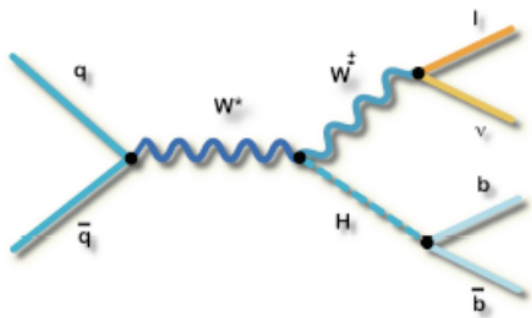
- SM Physics (from MCs): W/Z+jets, diboson, $t\bar{t}$ and single top
- Instrumental (from Data): Multijet events with mismeasured missing E_T or jets faking leptons

➡ Constrain and test modelling of backgrounds in sideband regions

Lepton + missing E_T + 2 b-jets

First step: selection

Select 2 jets, missing E_T and isolated electron or muon

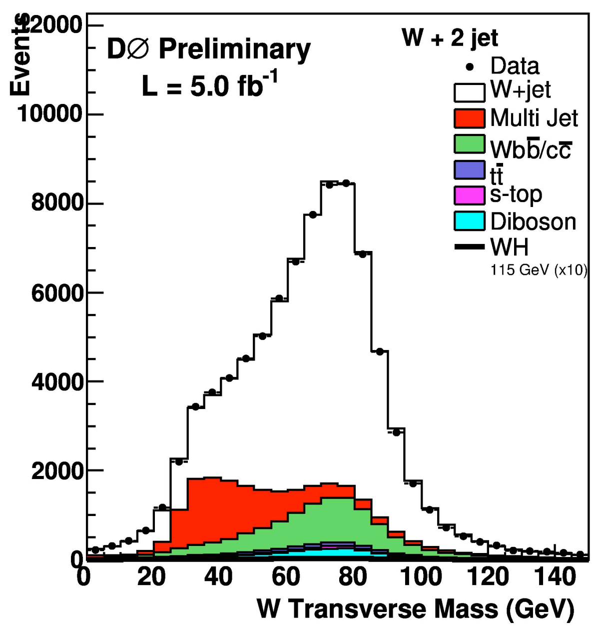


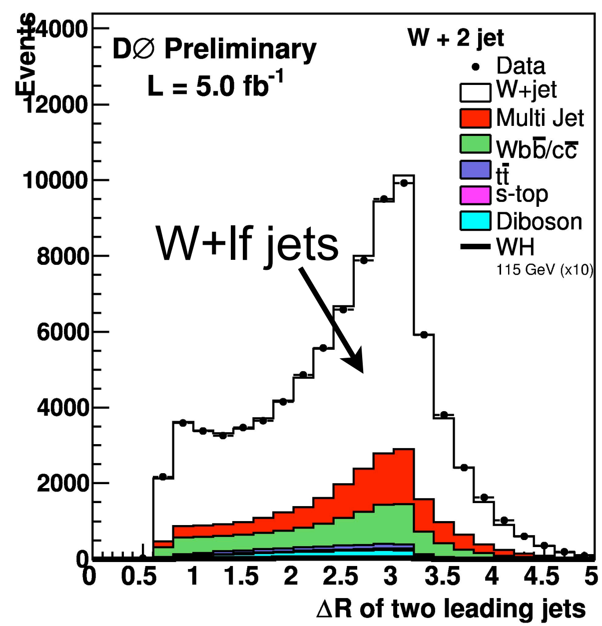
1 lepton + $\not{E}_T$

2 high p_T b-jets

Signal mainly

$WH \rightarrow l\nu bb$





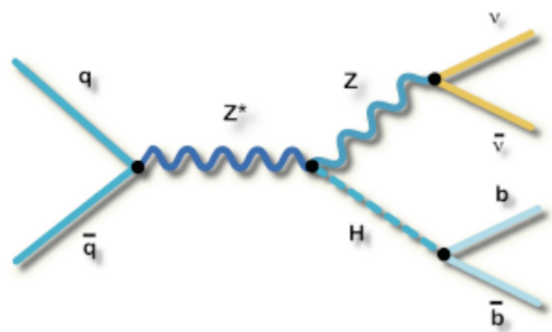
Large missing E_T + 2 b-jets

Select 2 jets and
large missing E_T

Signal from

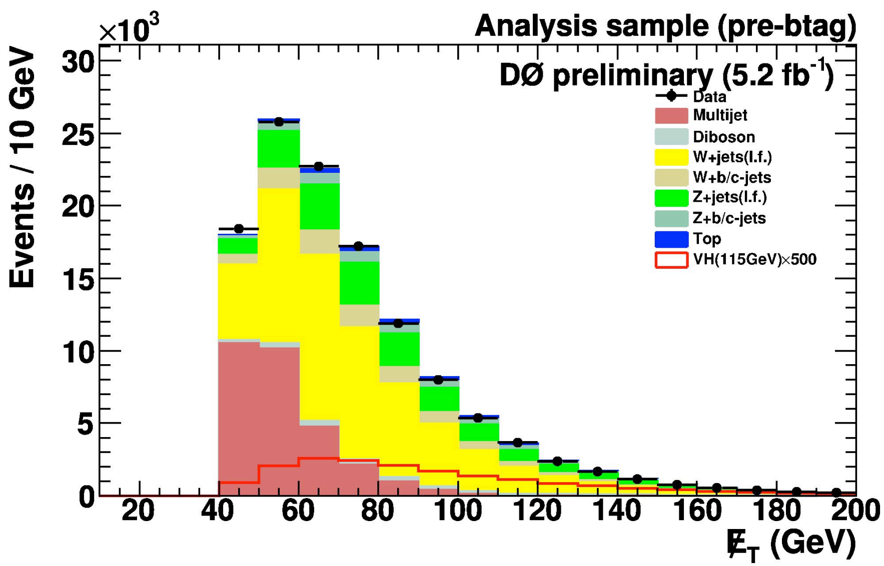
$ZH \rightarrow \nu\nu bb$

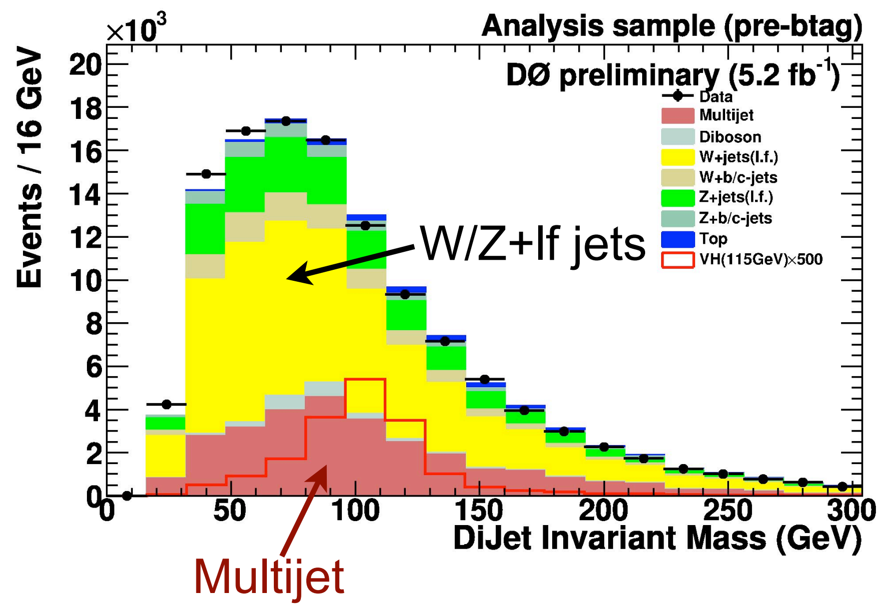
$WH \rightarrow \ell\nu bb$



large missing E_T

2 high p_T b-jets

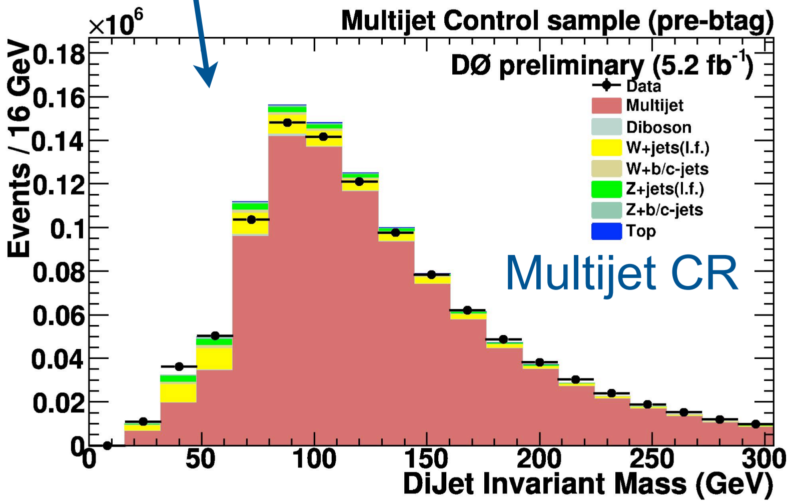


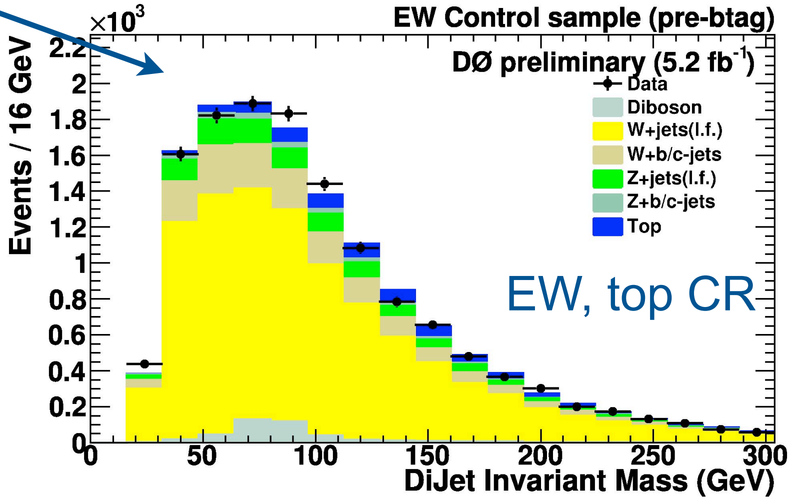


Control regions

Understand modelling of main backgrounds in control regions:

- Multijet enhanced: loosening missing E_T (and related variables)
- EW, top enhanced: require isolated lepton

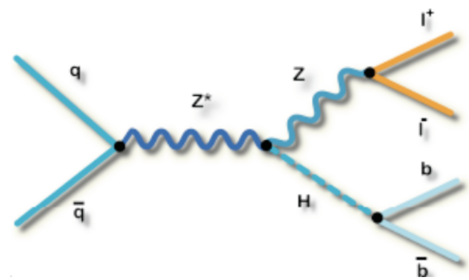




Similar control regions for other final states and heavy flavour enhanced samples

2 leptons + 2 b-jets

Select 2 jets and two isolated electrons/muons

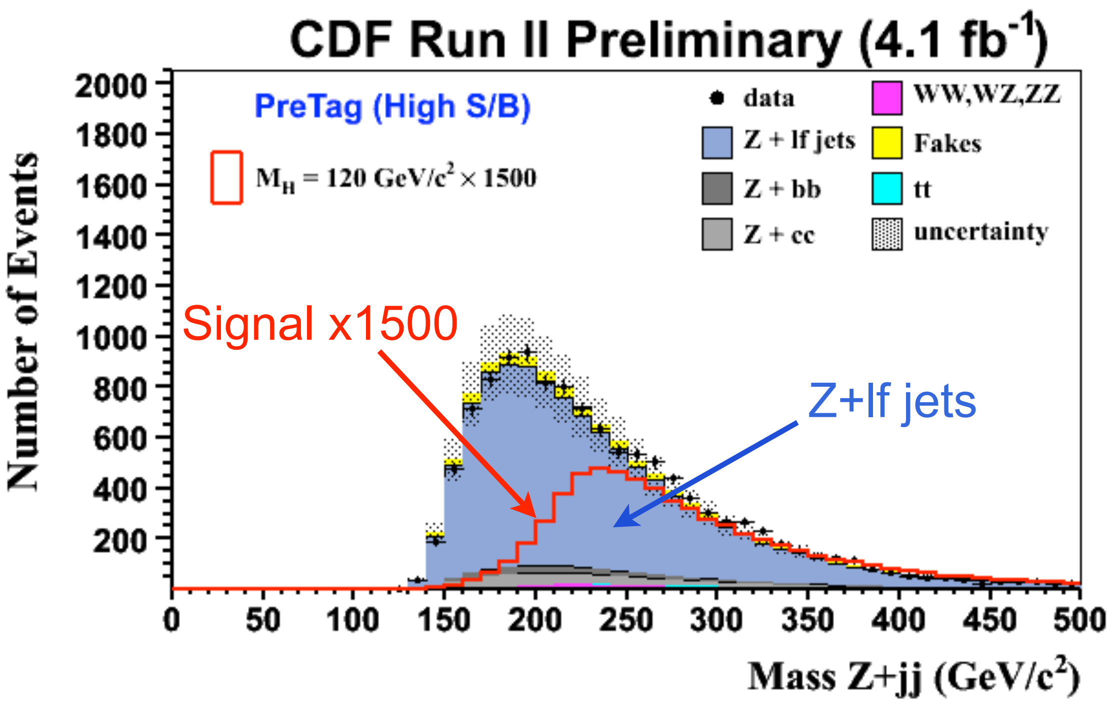


2 high p_T leptons

2 high p_T b-jets

Signal from

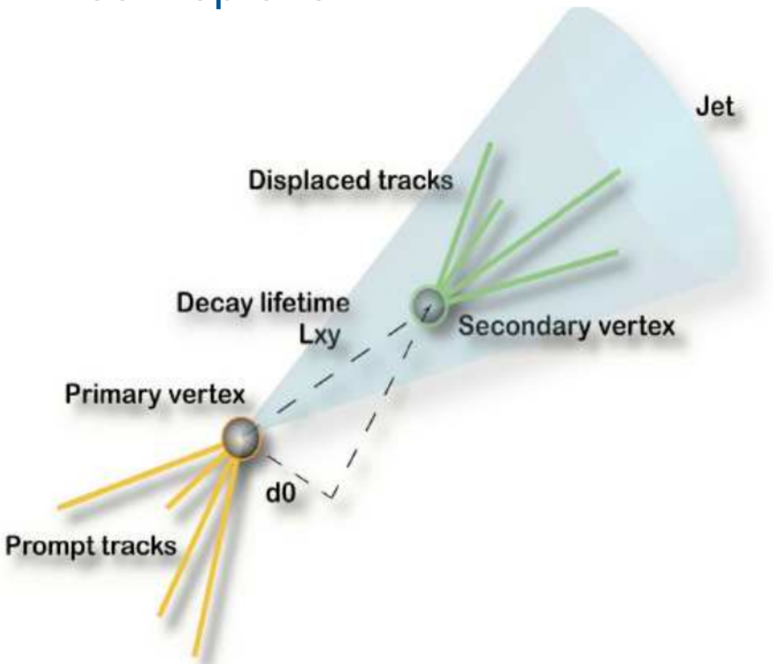
$ZH \rightarrow llbb$

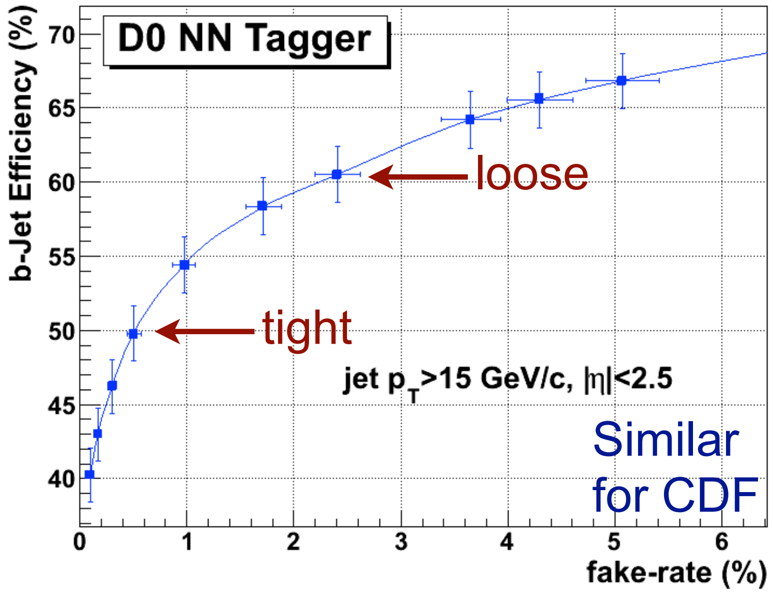


b-jet tagging

Second step: exploit B meson lifetime, mass, fragmentation and decay modes to separate b from light-quark jets

- secondary vertex
- track impact parameters
- vertex track multiplicity
- vertex mass
- soft leptons



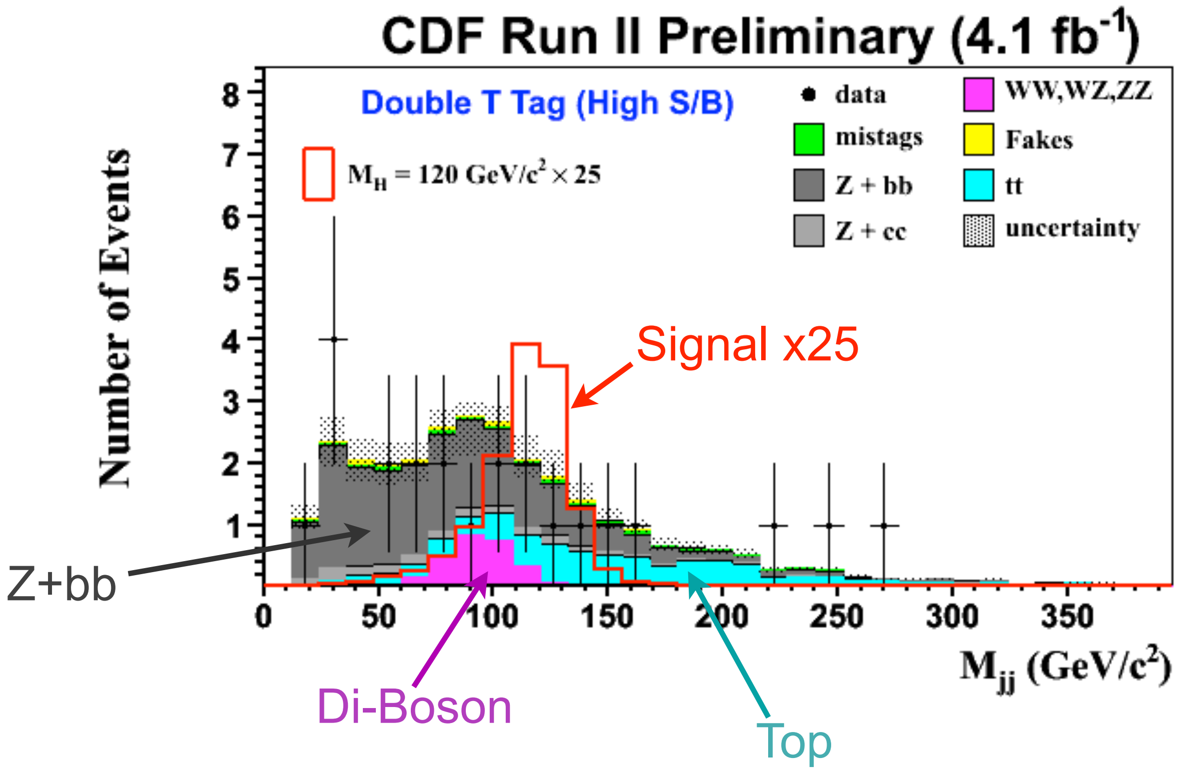


Use neural networks for optimal combination of tagging information

After b-tagging

Backgrounds dominated by: W/Z+bb, di-boson and top

Best discriminant: dijet invariant mass

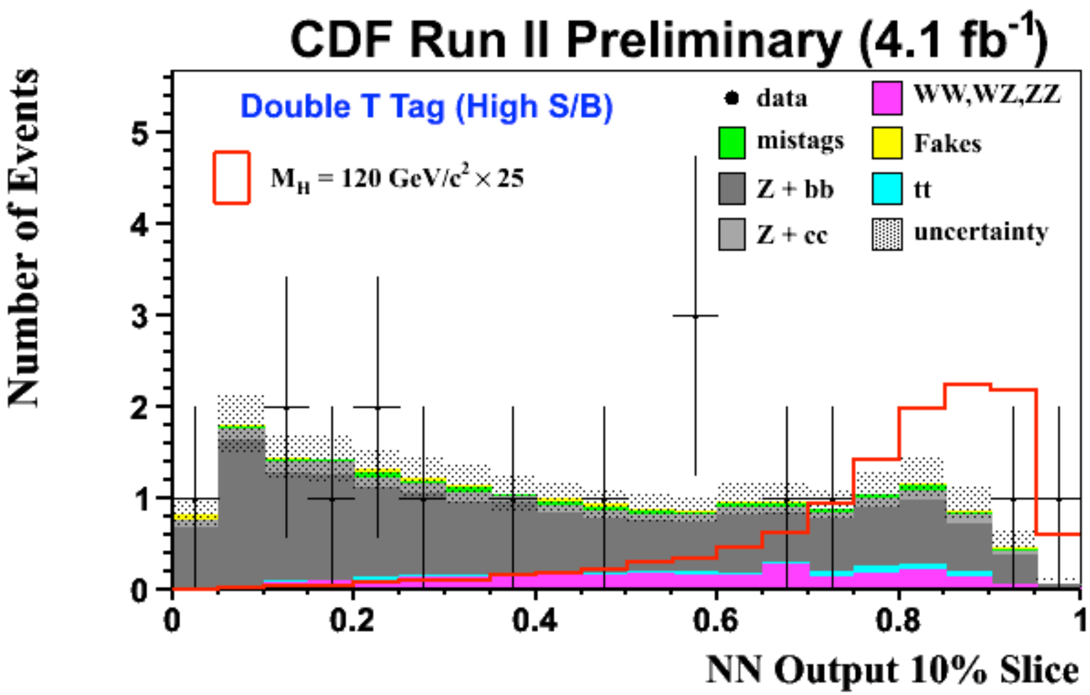


Final discrimination

Third step: Optimise separation using multivariate discriminant

Most common techniques:
Neural Network, Decision Tree and Matrix Element

- Exploit information from several final-state variables and their correlations



Searches for a low mass Higgs

1) basic selection
2) heavy flavour tagging
3) dijet mass
4) multivariate analysis

➡ Large efforts to improve in all areas

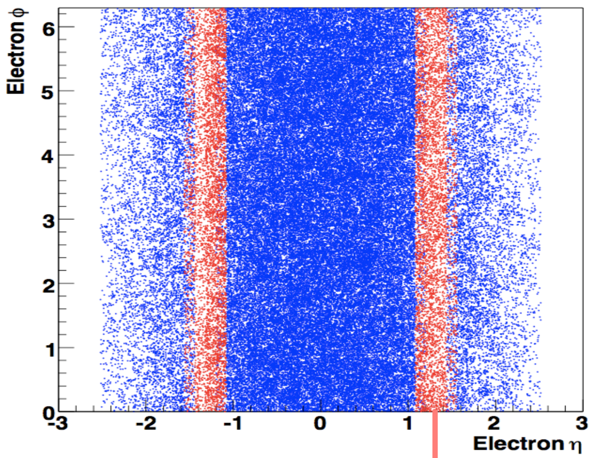
Selection

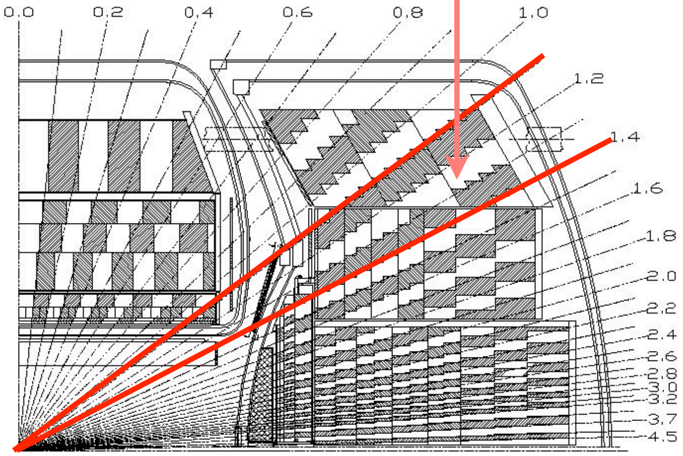
Increase signal acceptance:

- Relaxed cuts
- Improved lepton identification
- Add looser lepton definitions

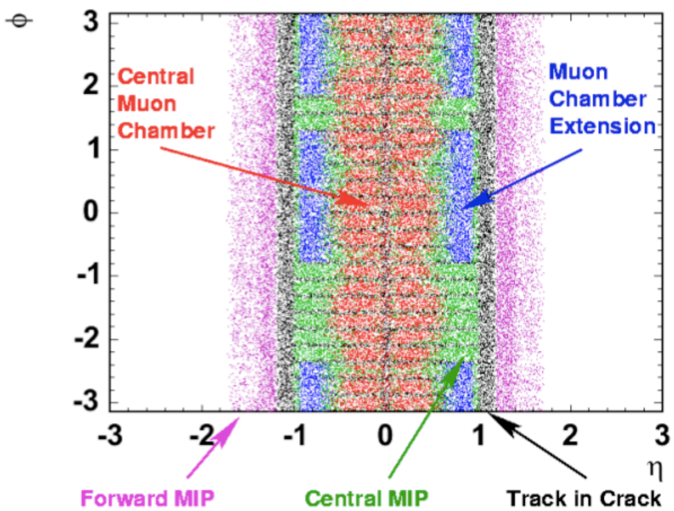
15-30% increase in signal yields

Electrons in inter-cryostat regions at DØ



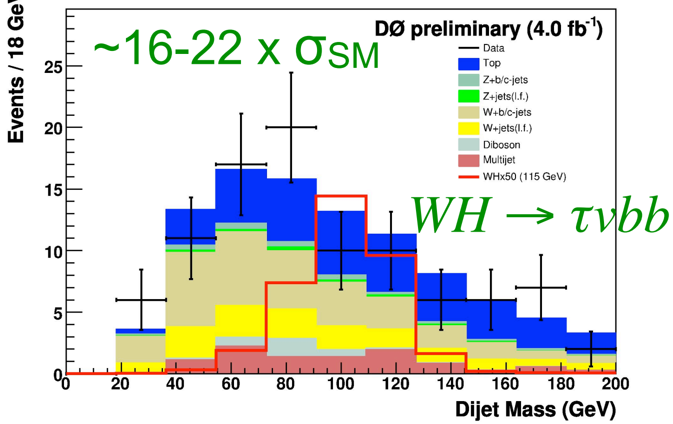


MIP's without hit in muon chambers at CDF

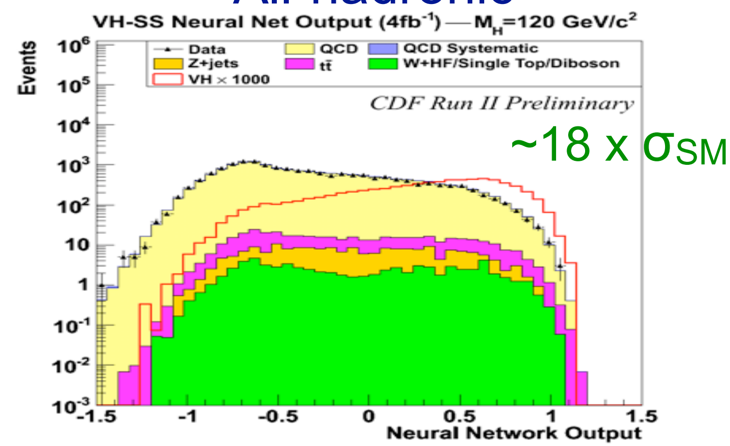


Adding sub-leading channels

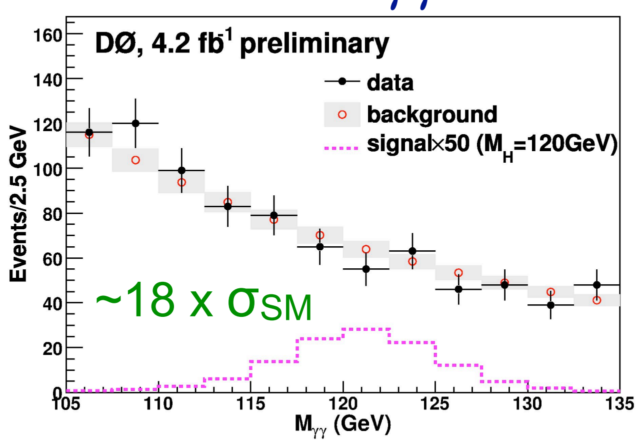
Final states with taus



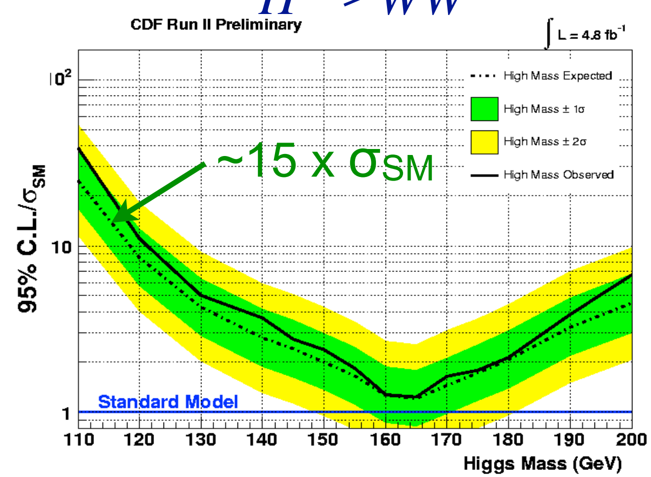
All-hadronic



$H \rightarrow \gamma\gamma$



$H \rightarrow WW$



Contribute 10-20% to overall sensitivity (depending on m_H)

b-tagging

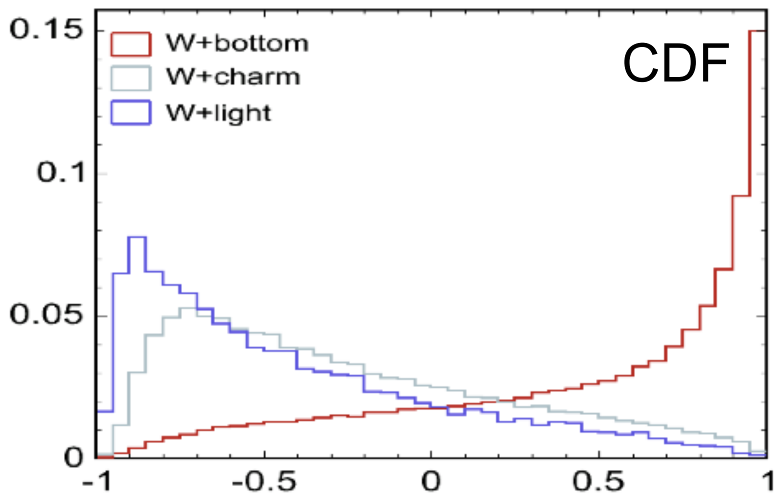
Improved b-tagging algorithms (b vs light jet discrimination)

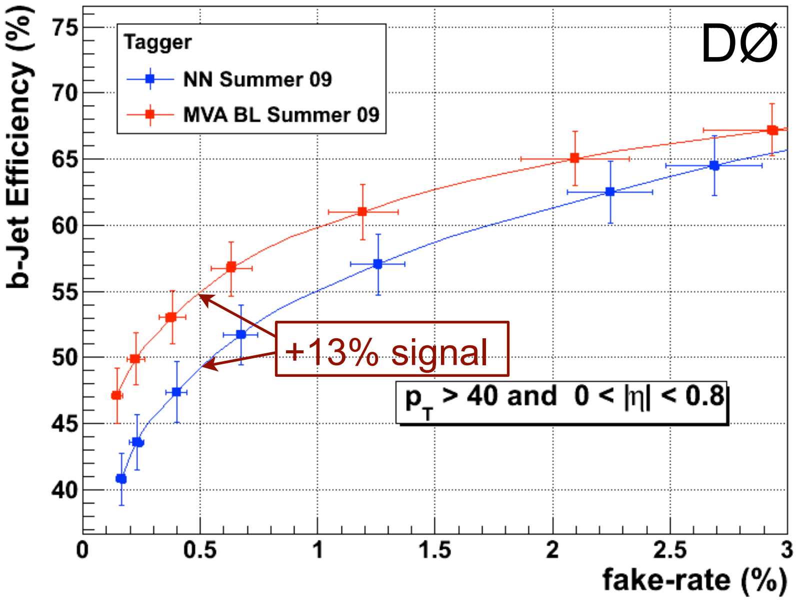
- 13% increase in b-jet efficiency at same fake rate

New, additional algorithms

- b vs. c discrimination
- b vs. bb (merged) discrimination

Not yet all used in recent Higgs results…





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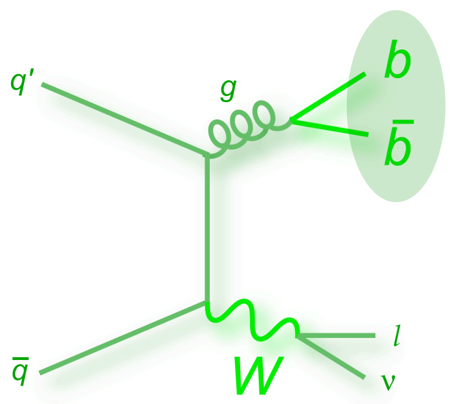
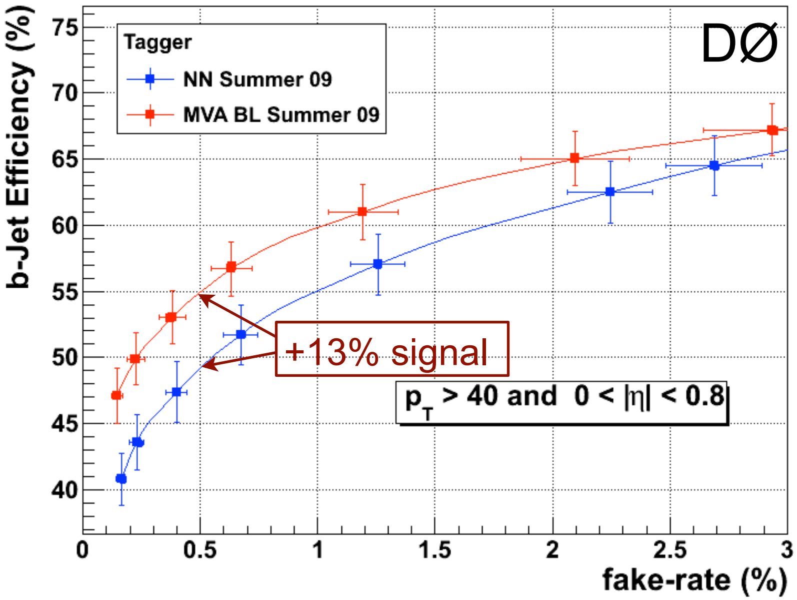


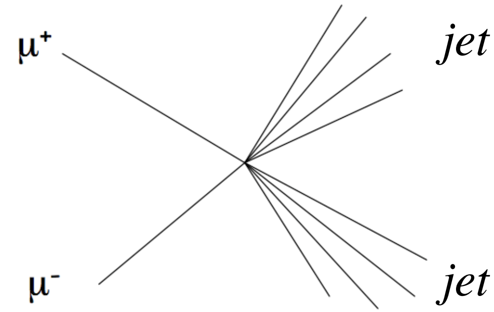


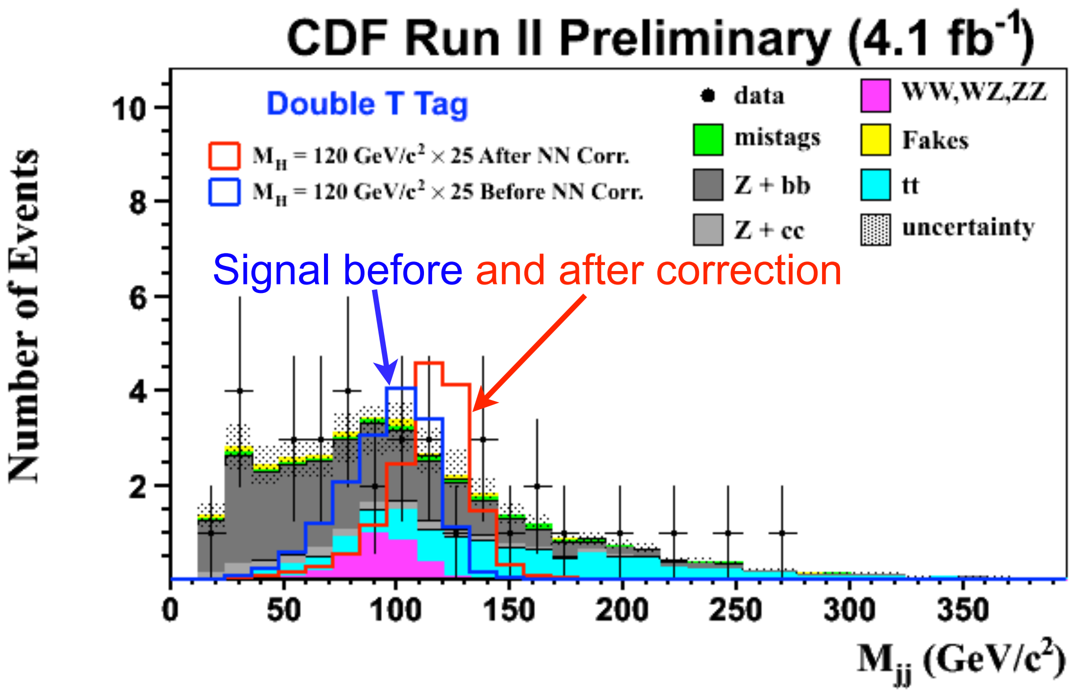
Dijet mass resolution (I)

Example: *ZH → llbb* fully reconstructed, no intrinsic missing E_T

➡ use constraints to improve di-jet mass resolution

Gives up to ~10% improvement in sensitivity

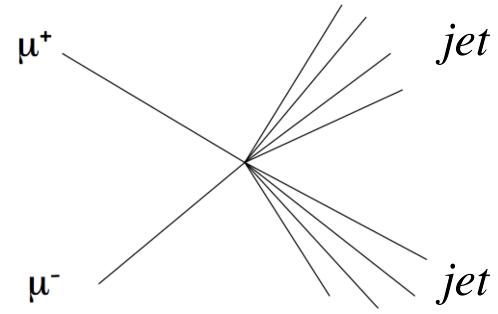




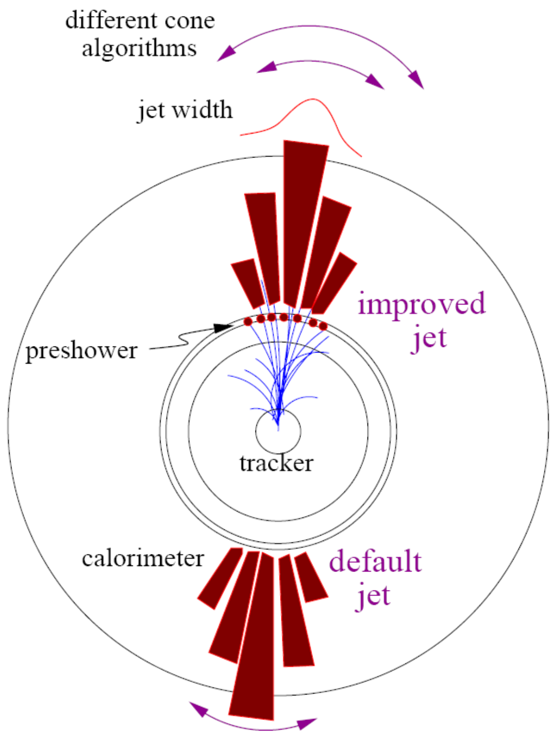
Dijet mass resolution (II)

Example: $ZH \rightarrow llbb$ fully reconstructed, no intrinsic missing E_T

➡ use constraints to improve di-jet mass resolution



Gives up to ~10% improvement in sensitivity



Example: $ZH \rightarrow \nu\nu bb$ (CDF)

Improve dijet mass resolution with information from the tracker

Up to ~10% improvement in sensitivity

Efforts ongoing to achieve further improvements in mass resolution

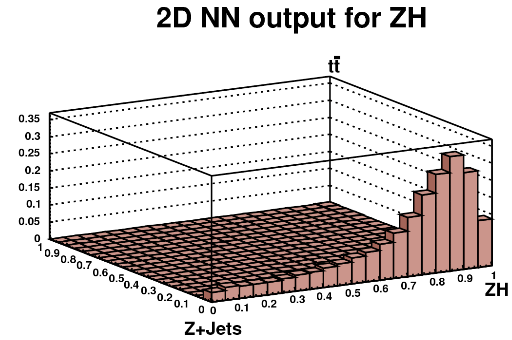
Multivariate discrimination

Use methods more effective

- Combination of several methods:

  e.g. matrix element likelihood as input in decision tree
- Separate training against different backgrounds
- 2D discriminant

Example: $ZH \rightarrow llbb$

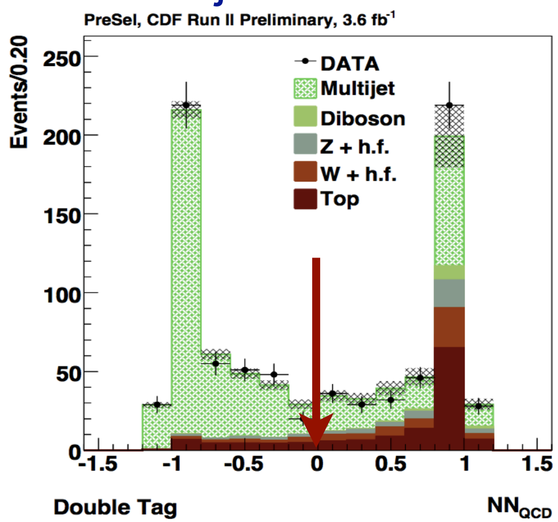


Typical sensitivity gain compared to single variable is 15-20%
Additional 5-10% from smart combinations

Example:
$ZH \rightarrow \nu\nu bb$

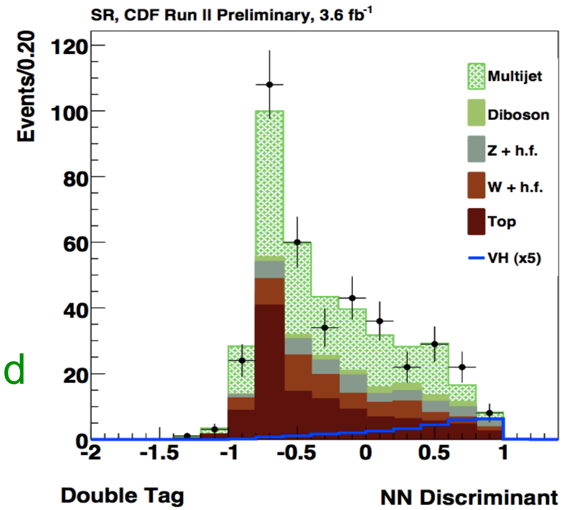
multijet discriminant

1st



final discriminant

2nd



Systematic uncertainties

Example: $ZH \rightarrow \nu\nu bb$. Relative uncertainties in %

Systematic Uncertainty	Type	Signal	Background
Jet Energy Scale	Shape & Norm	2.7	3.5
Jet Reco*ID	Shape & Norm	0.4	0.8
Jet Resolution	Shape & Norm	0.9	0.8
Cross Sections	Flat Norm	6.0	7.5
Mulit-jet Normalization	Flat Norm	–	1.5
Heavy Flavor Fraction	Flat Norm	–	9.8
Parton Distribution Function	Shape only	–	–
Vertex Confirmation	Shape & Norm	2.5	1.5
Taggability	Shape & Norm	3.6	3.3
b-Tagging	Shape & Norm	8.7	7.9
Trigger Efficiency	Shape & Norm	3.5	3.4
μ ID	Shape & Norm	1.1	1.5
EM ID	Shape & Norm	0.2	0.3
Alpgen MLM	Shape only	–	–
Alpgen Event Scale	Shape only	–	–
Alpgen Underlying Event	Shape only	–	–
Luminosity	Flat Norm	6.1	6.1

Total: ~15% ~20-25%

Shift jet quantities, measured efficiencies etc. by ±1σ and propagate through analysis

Main systematic uncertainties from b-tagging, cross section/luminosity and modelling of W/Z+hf jets background

Individual low mass results

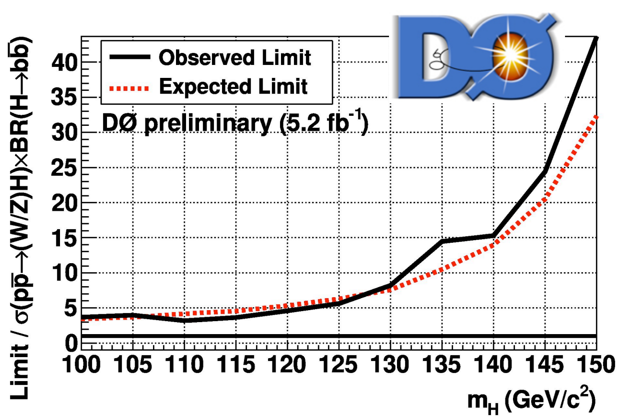
Limits on individual channels a factor of 4-8 away from SM cross section at m_H=115 GeV

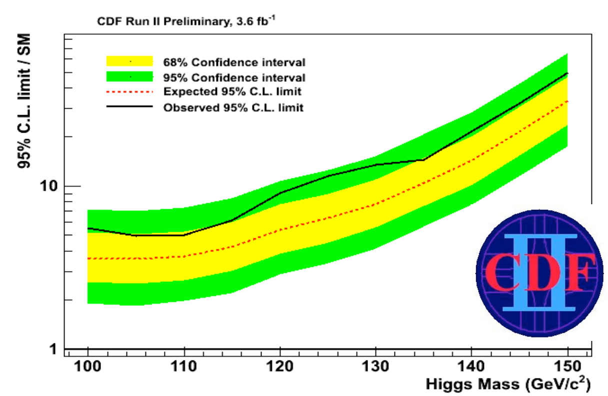
- Crucial to combine all contributing channels

Channel (w/o taus)	CDF *(exp / obs)*	DØ *(exp / obs)*
WH → lvbb	4.0 / 5.3	5.1 / 6.9
ZH → vvbb	4.2 / 6.1	4.6 / 3.7
ZH → llbb	6.8 / 5.9	8.0 / 9.1

Example limit for single channel:

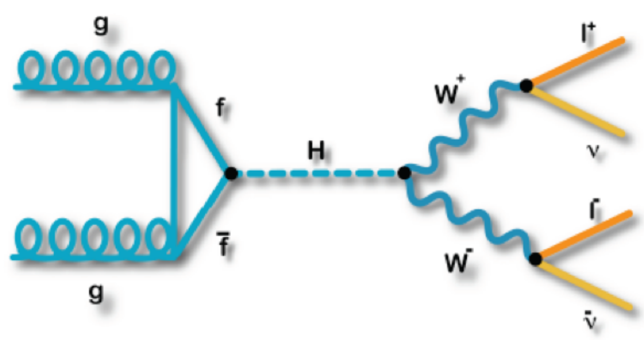
ZH → vvbb





At high discriminant values S/B typically 1/10 - 1/20 for the most sensitive low mass channels

Searches for a high mass Higgs



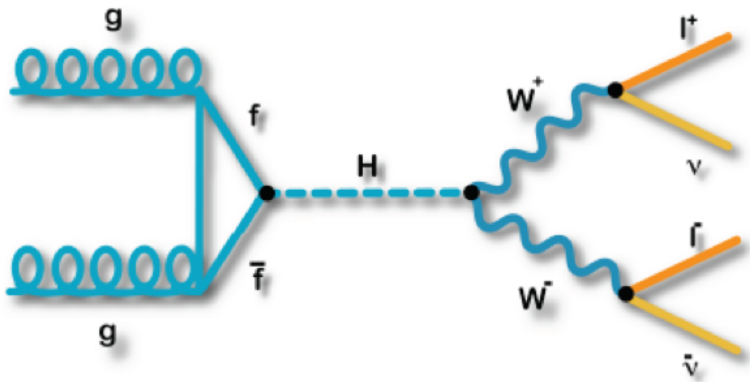
m_H > 135 GeV:

gg→H production with decay to WW

$H+X \rightarrow l^+l^- +$ missing E_T

Dominant decay for m_H>135 GeV: $H \rightarrow W^*W$

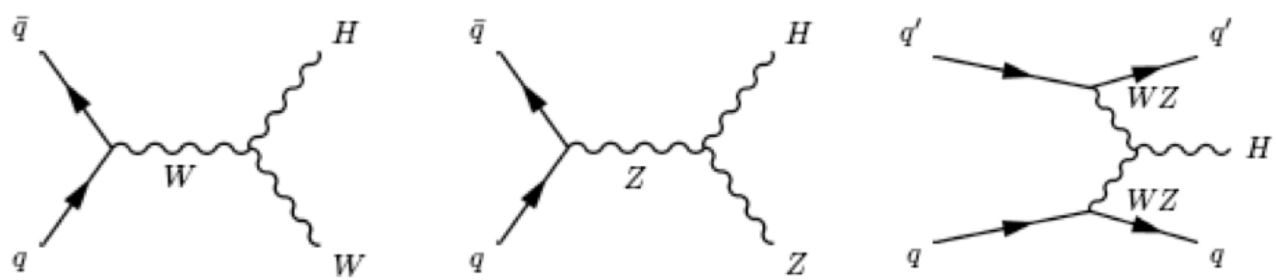
Clean environment can take advantage of $gg \rightarrow H$ production



2 opposite charge high p_T leptons

missing E_T

Signal contribution also from $W/Z+H$, qqH production



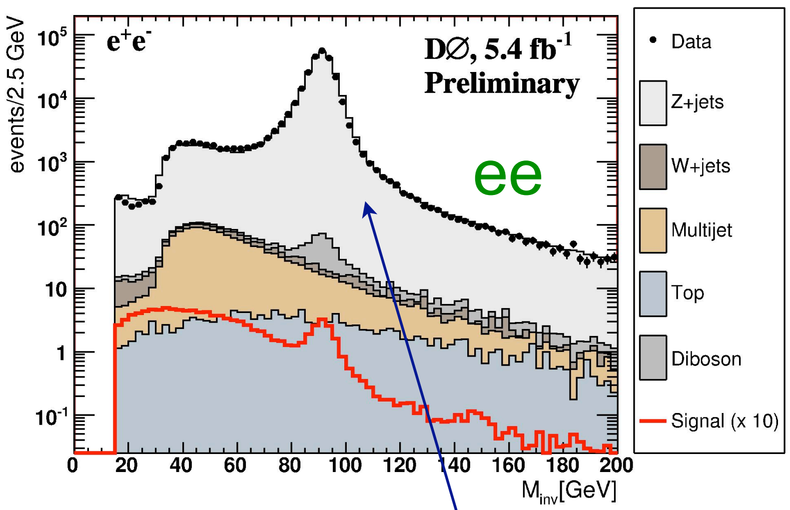
~ 35% more signal

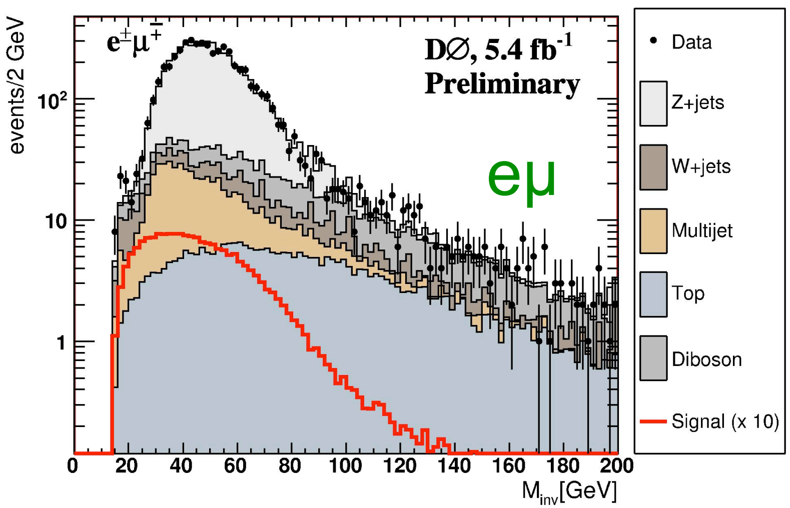
➡ Consider all sources of opposite charged di-lepton + missing E_T

Selection and backgrounds

Previously discussed improvements on lepton acceptance and multivariate discrimination essential

Preselection: two isolated, opposite charge, high p_T leptons





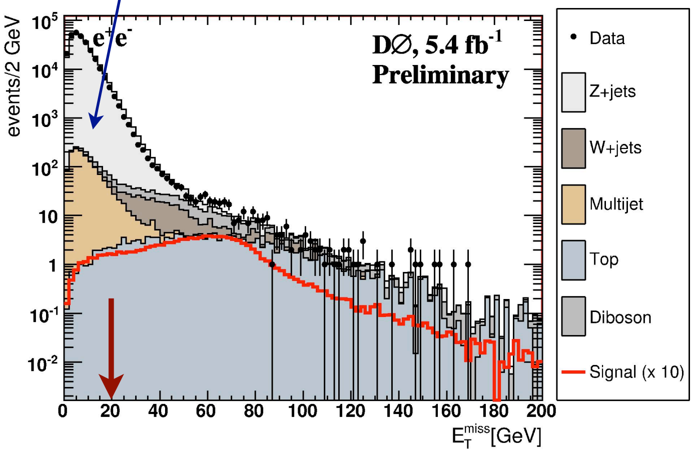
Backgrounds: Drell-Yan production (dominant background), diboson (*W*-pair production irreducible), top anti-top, W+jets/γ, multijet

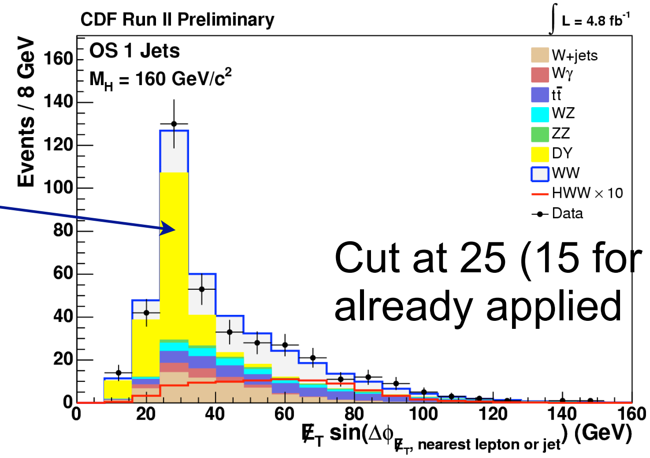
Signal and background cross sections normalized using highest-order calculations available (NLO or better). p_T(WW) and p_T(H) corrected to NLO

Verify background modelling in control regions

Analysis strategy

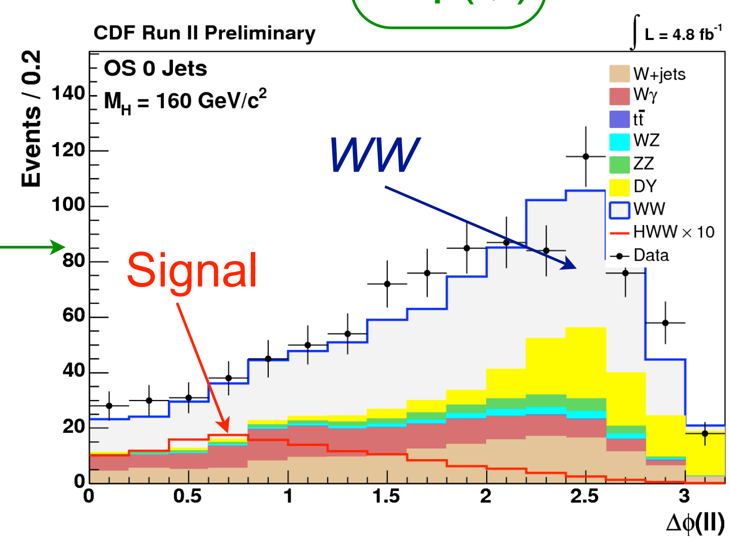
Dominant background from Drell-Yan production reduced using missing E_T and its significance

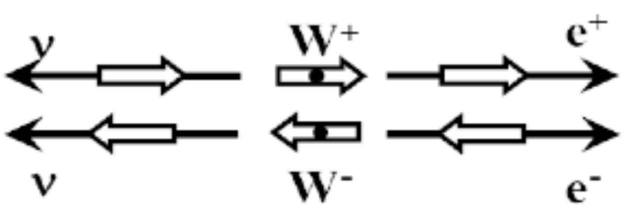




Δφ(l,l)

Spin correlation gives main discrimination against irreducible background from non-resonant SM *W*-pair production





Final discrimination

To increase sensitivity:

CDF: Neural Network with additional ME input for the 0-jet NN

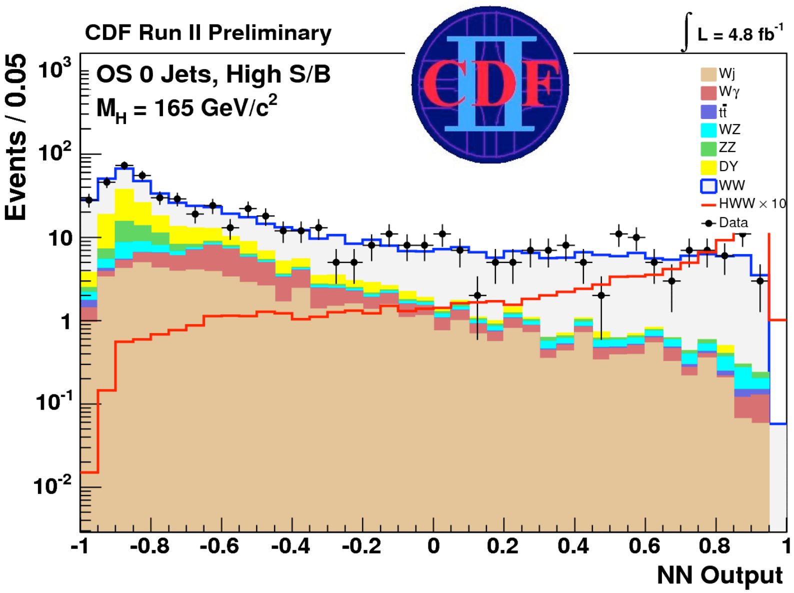
Split samples into loose/tight lepton ID and by jet multiplicity

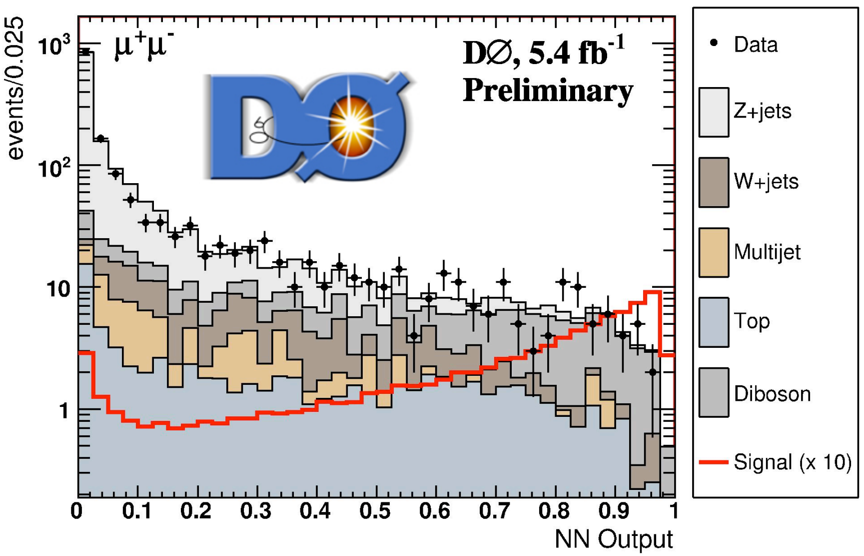
Veto events with tight b-tagged jet

DØ: Neural Network with 12 kinematic and topological input variables

Split the samples according to lepton flavour

Number of jets used as NN input

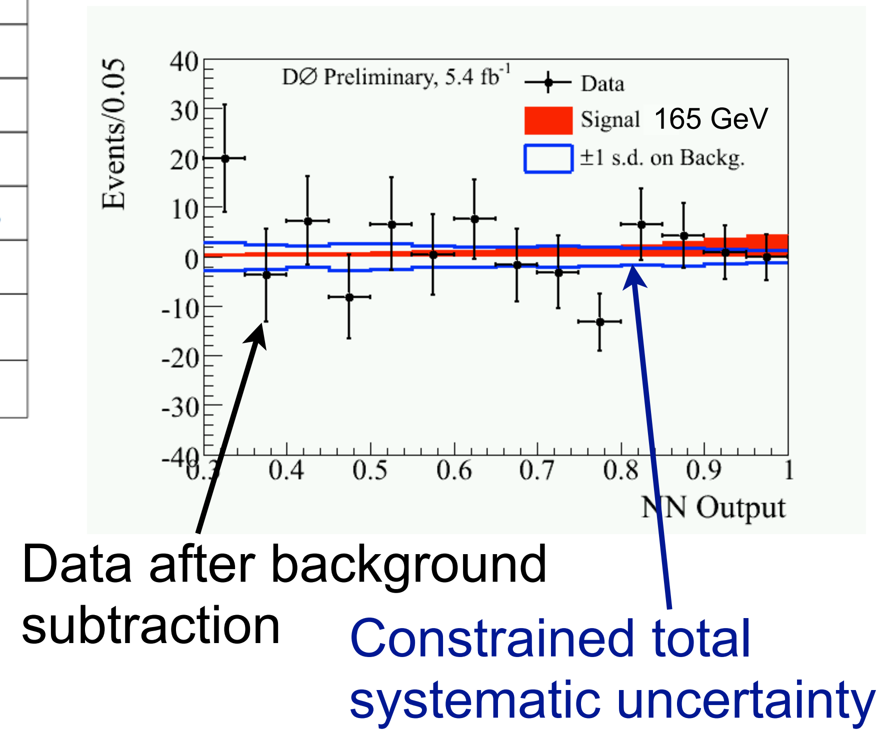




Systematic uncertainties

Relative uncertainties in %

Systematic Uncertainty	Type	Value
Jet Energy Scale	Shape & Norm	3-17
Jet ID Efficiency	Shape & Norm	6-18
Jet Resolution	Shape & Norm	2
Cross Sections	Flat Norm	6-10
Multijet Background	Flat Norm	2-20
Parton Distribution Function	Flat Norm	8
Lepton ID	Flat Norm	2.5-4
Lepton Momentum Scale	Shape & Norm	2-8
p_T of WW/H/Z	Shape & Norm	1-5
Luminosity	Flat Norm	6.1



Main systematic uncertainties:

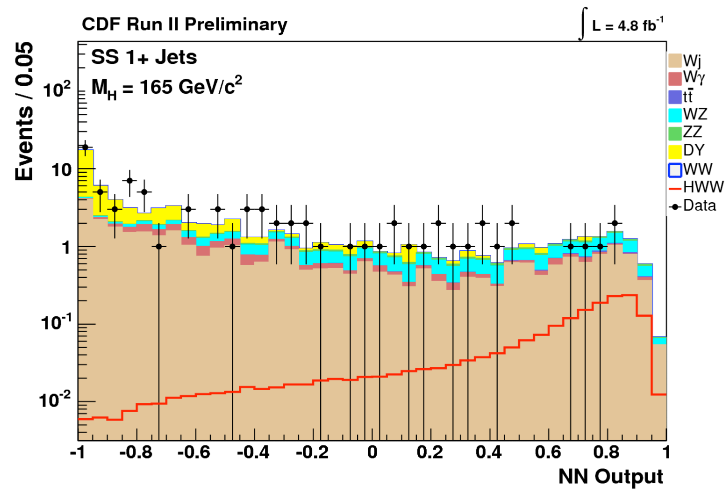
- Signal (total 10%): cross section, lepton ID/trigger
- Background (total 13%): cross sections, jet→lepton fake rate, jet ID/resolution/calibration

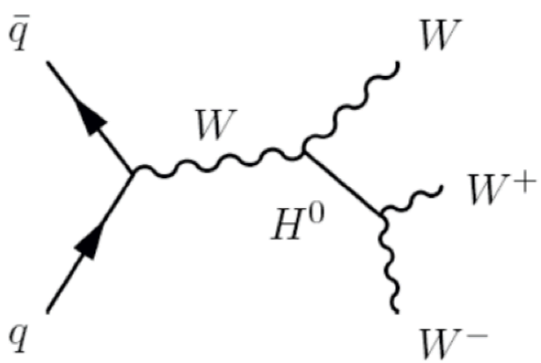
$VH \rightarrow VWW \rightarrow l^{\pm}l^{\pm}+X$

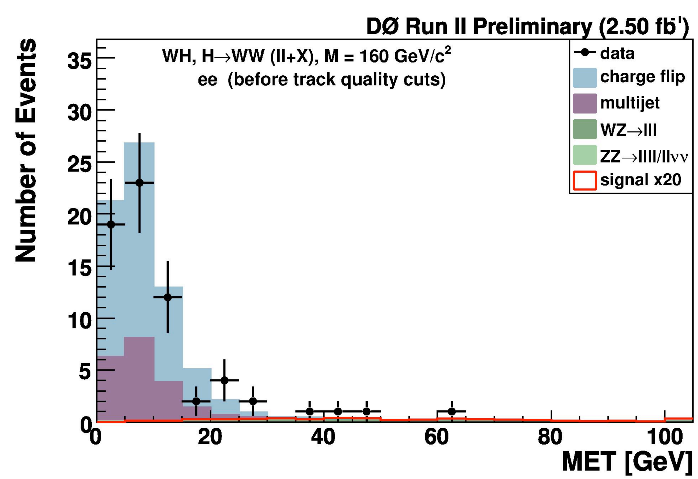
Important additional sensitivity from same charge dilepton selection

Search for associated production with $H \rightarrow WW$ decay

- Remove SM Physics backgrounds with like-sign lepton requirement and veto on additional leptons
- Main backgrounds due to lepton charge mis-ID and jets faking leptons
- Adds ~10% of sensitivity at high mass

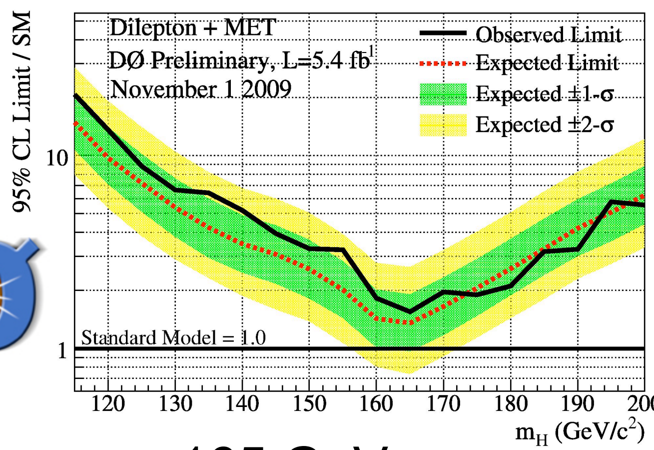




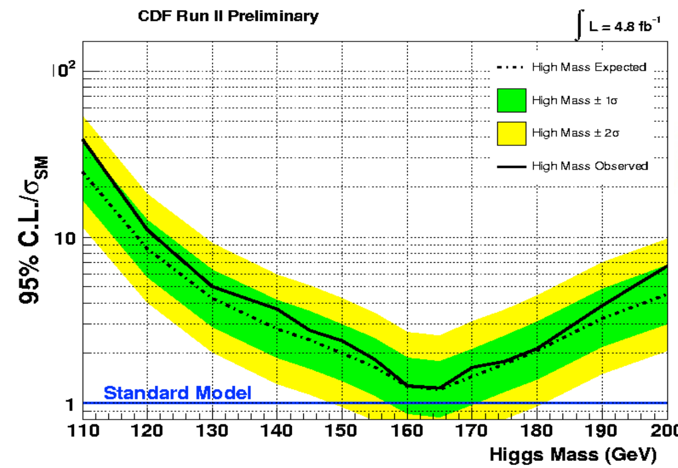


Dilepton + missing E_T results

Exclusion limits per experiment:



m_H=165 GeV (w/o same sign)
Exp/Obs: 1.36/1.55 x σ_{SM}



m_H=165 GeV
Exp/Obs: 1.21/1.23 x σ_{SM}

30 Higgs events expected per experiment in final selection

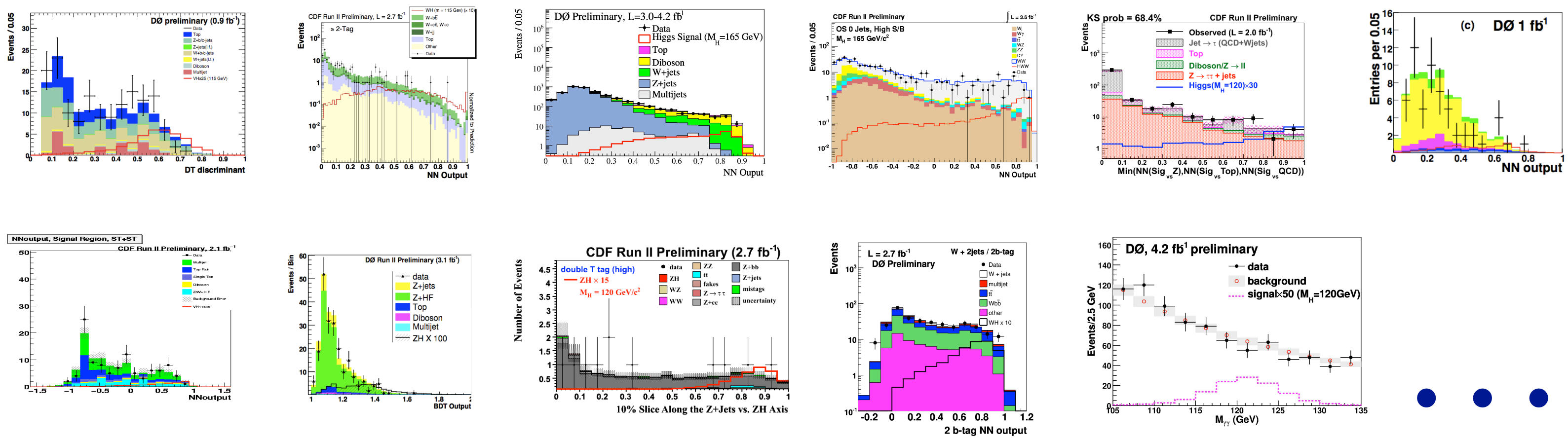
At high Neural Network values S/B close to 1

With additional luminosity and improvements (e.g. additional channels) expect single experiment exclusion around m_H = 165 GeV in the near future

Limit setting

Combine all channels from CDF and DØ for best sensitivity

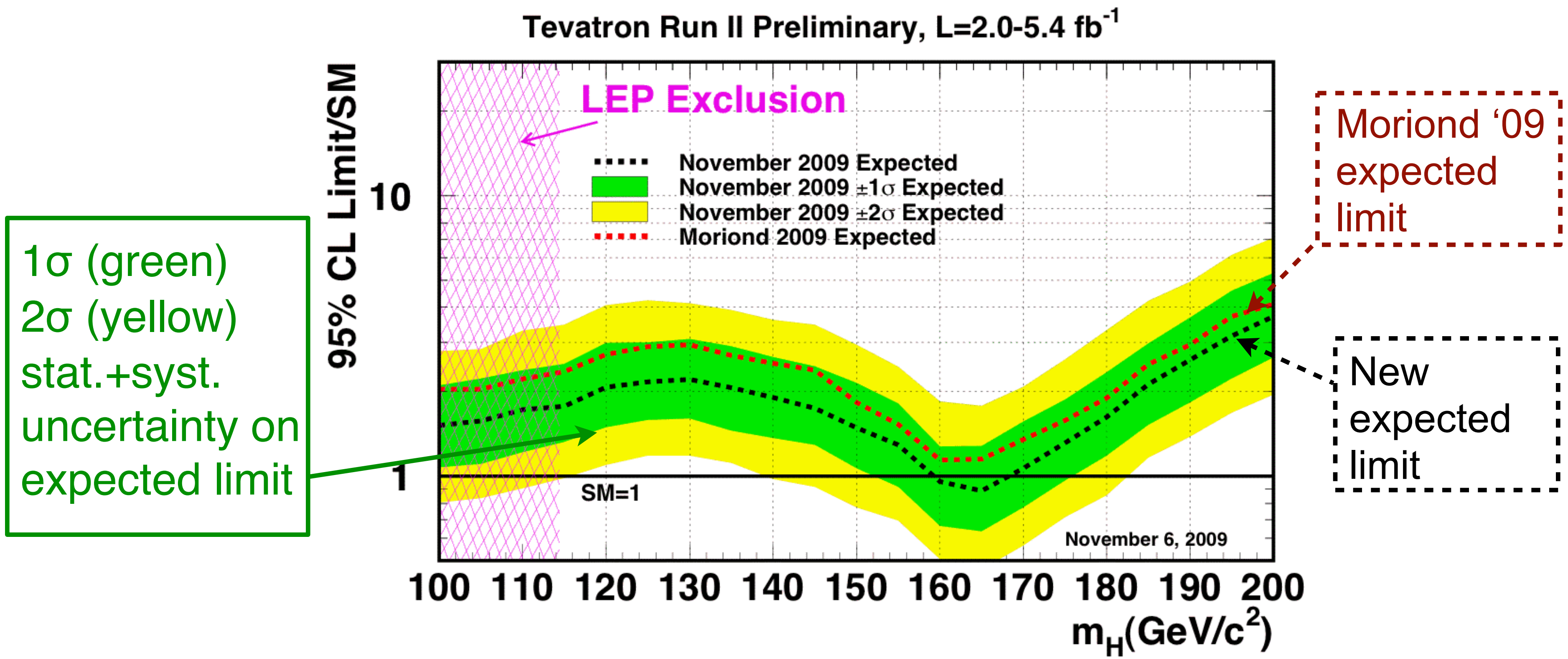
- Combining more than 30 different channels per experiment



More than 50 different sources of systematic uncertainties are considered, and constrained in sidebands

Use different techniques to cross check calculations (Bayesian, modified frequentist) → Results agree within 5%

Improvements since last combination

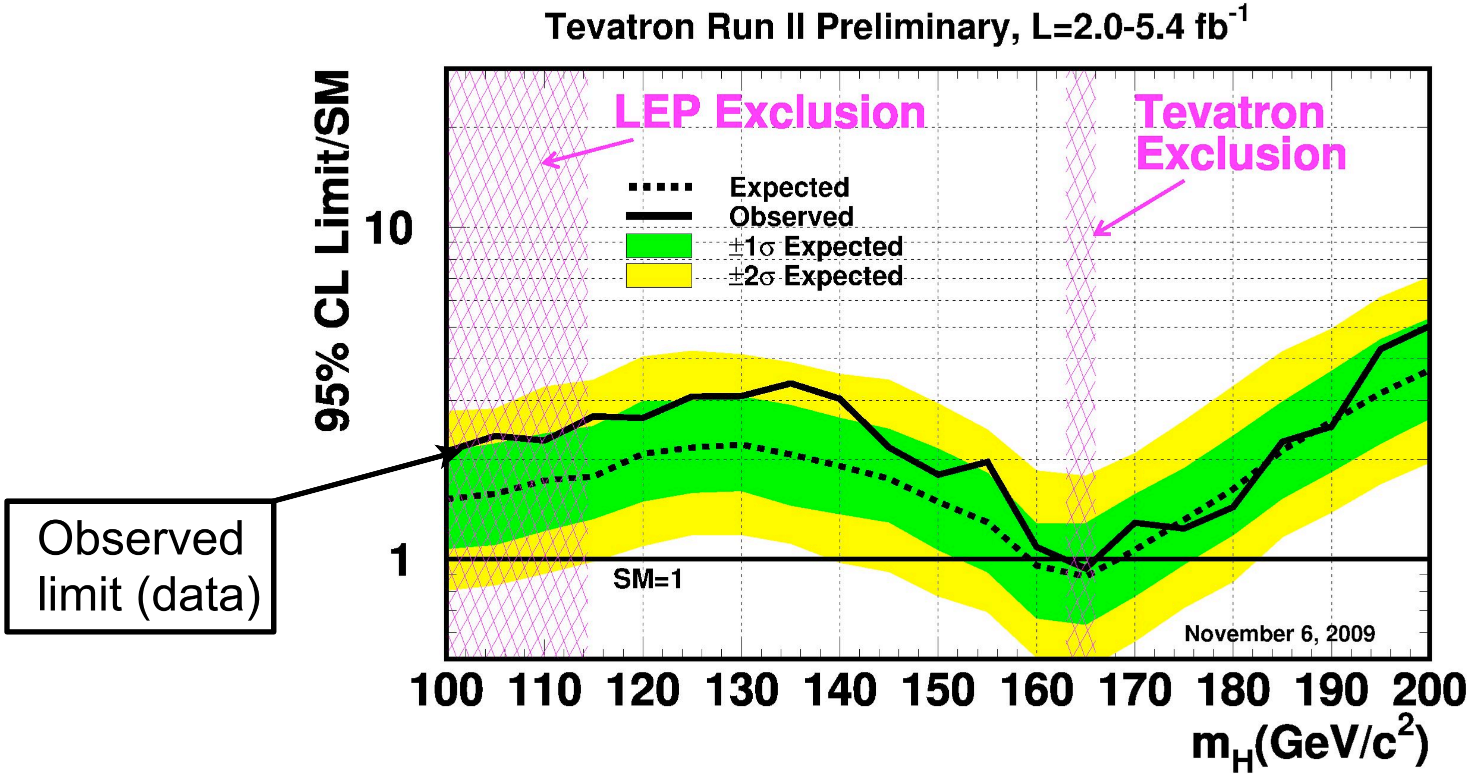


Significant improvements across the whole mass range

- First time also an expected exclusion range, from 159 to 168 GeV
- Better than 2.2 x σ_{SM} sensitivity for all mass points below 185 GeV

At m_H=115 GeV expected limit 1.8 x σ_{SM}

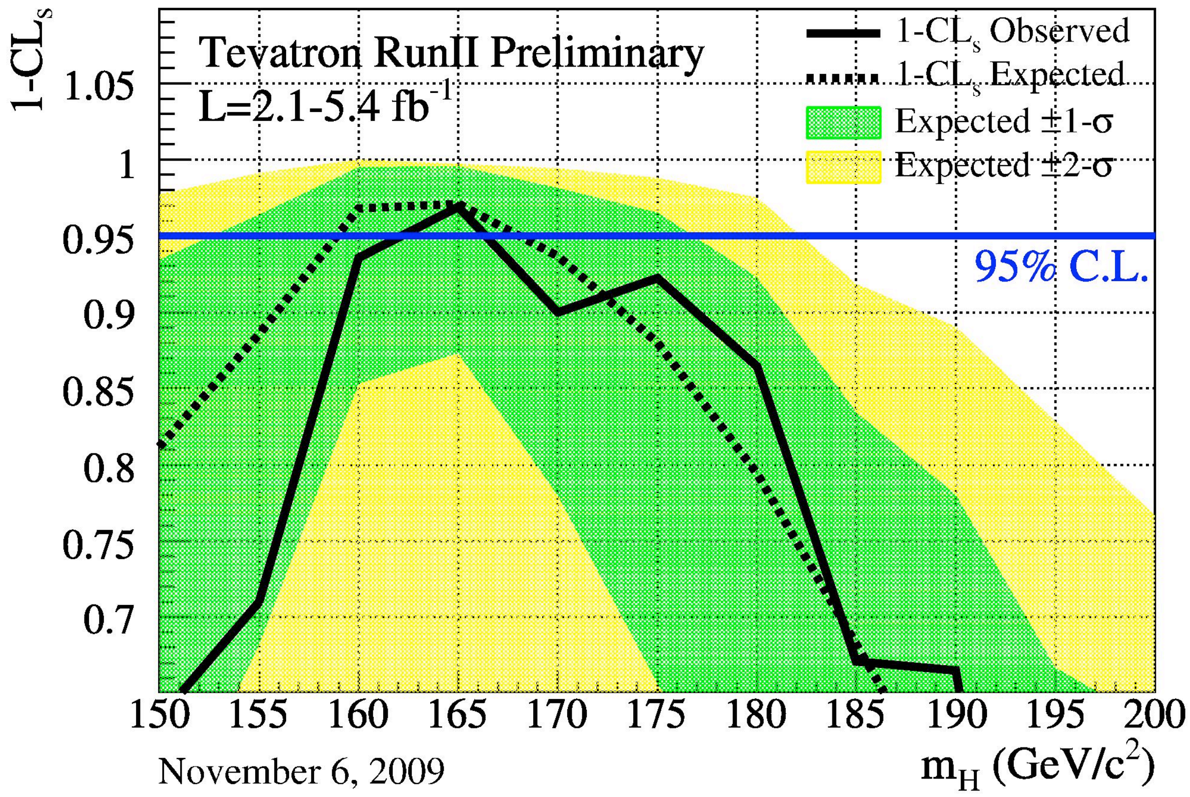
Combined Tevatron limits



Sensitivity increased with more data, observed exclusion slightly smaller than March 2009 (can fluctuate in any iteration)

New Higgs exclusion region 163-166 GeV at 95%CL

Combined Tevatron limits



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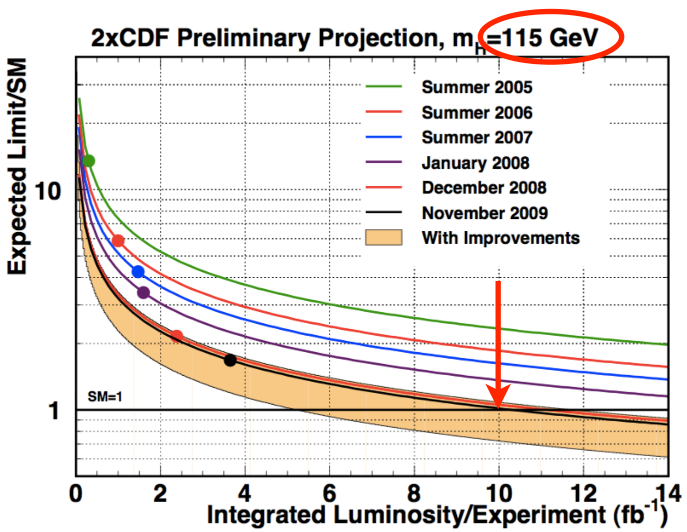
New Higgs exclusion region 163-166 GeV at 95%CL

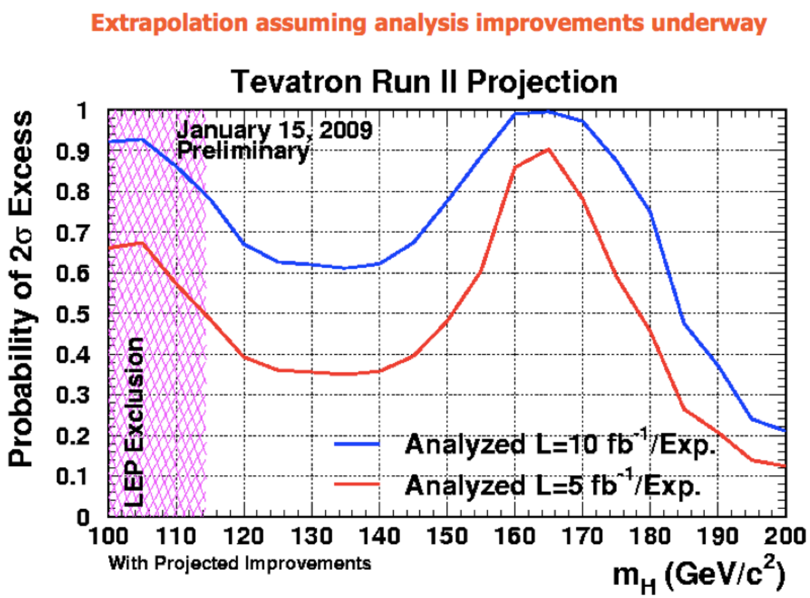
Tevatron Higgs reach

Expected to have 10 fb^{-1} of analyzed data per experiment at the end of Run II

- Roughly 2 times more than used in current Tevatron combination

With additional improvements and luminosity will be sensitive for the Higgs over the entire mass range preferred by EW fits





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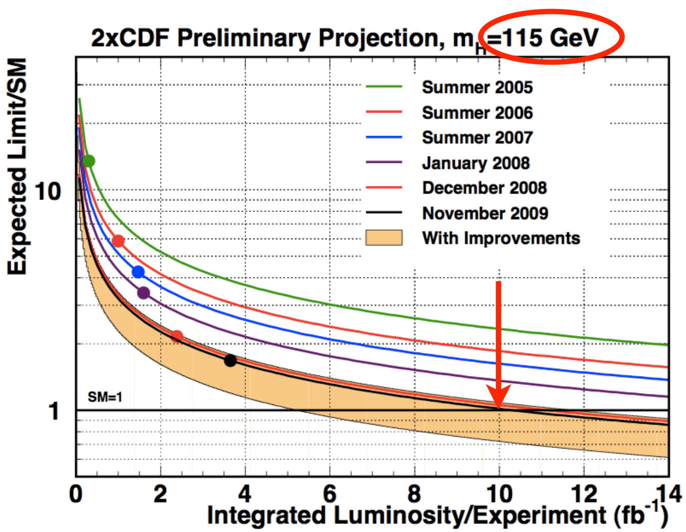
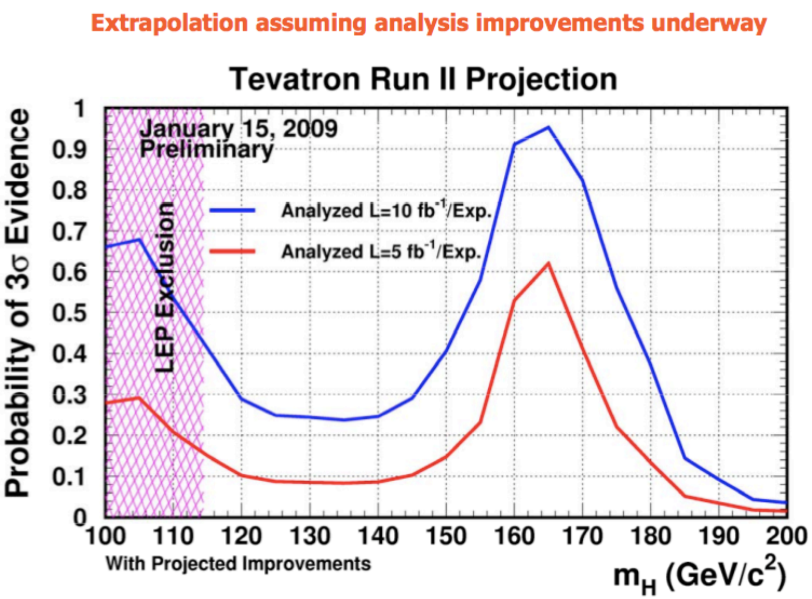
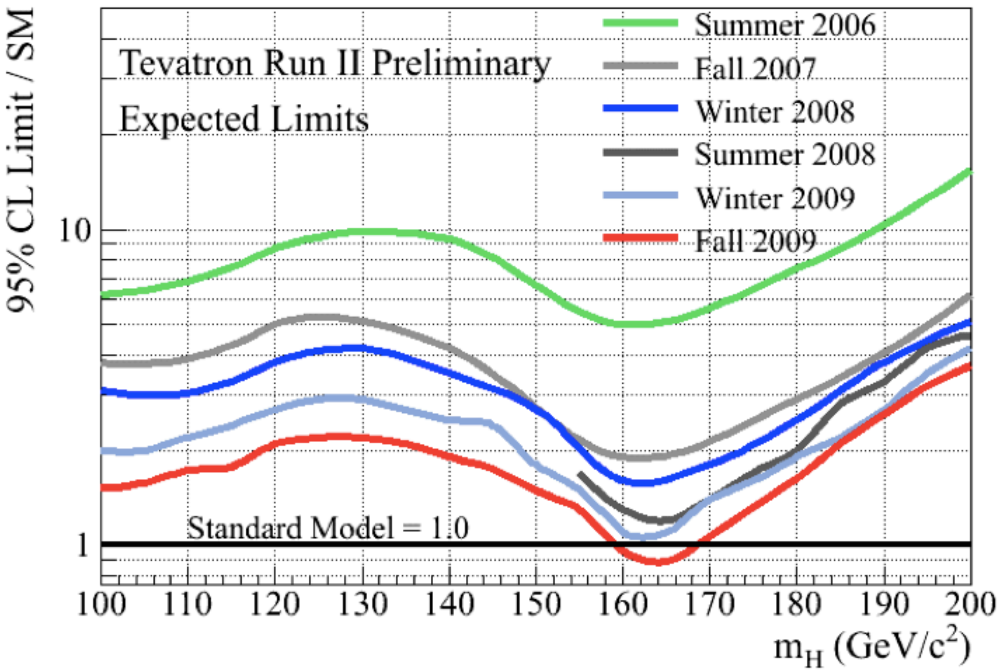




Conclusions

Our Higgs sensitivity rapidly improves, thanks to an excellent Tevatron performance and many detector, algorithm and analysis improvements!

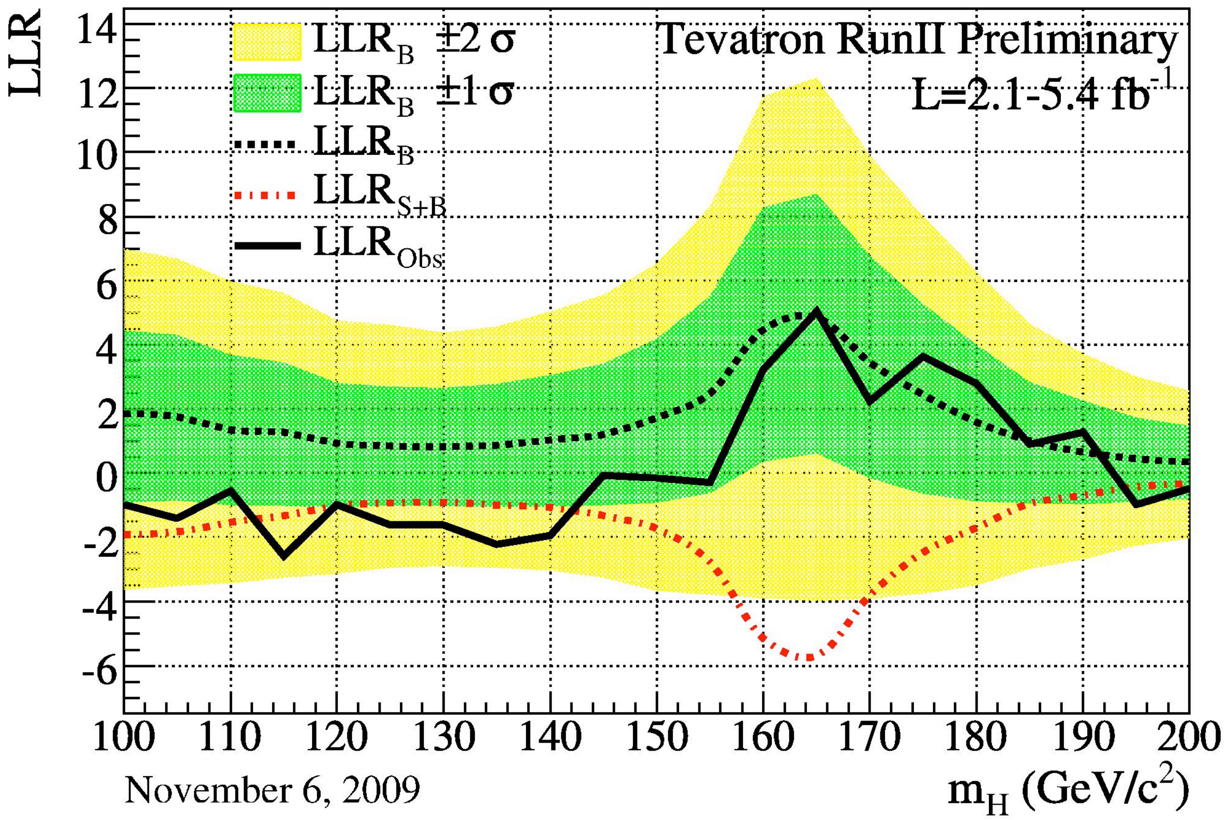


Today we have a first expected exclusion around 165 GeV and limits ~2 x σ_{SM} over the entire mass range preferred by EW fits

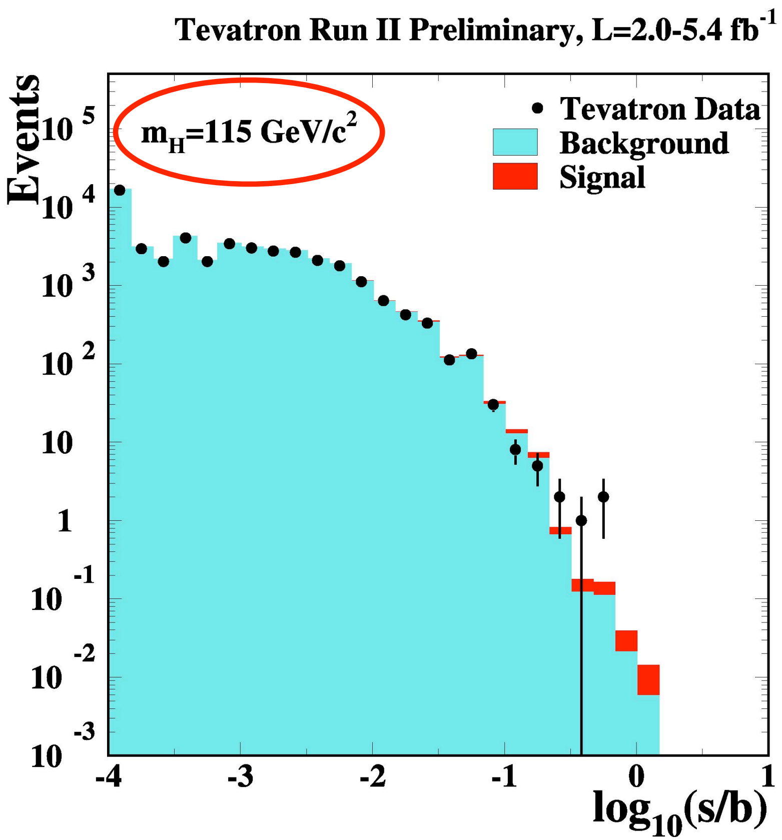
By the end of the Tevatron run expected to be sensitive for the SM Higgs over this entire mass range

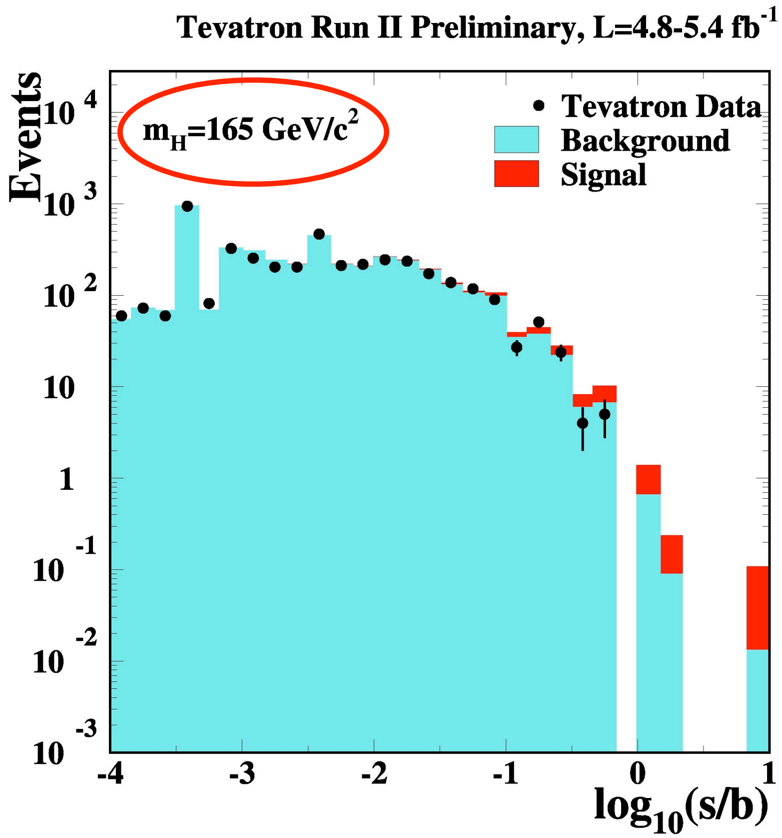
Backup slides

LLR


LLR
14
12
10
8
6
4
2
0
-2
-4
-6
100
110
120
130
140
150
160
170
180
190
200
LLR_B ±2 σ
LLR_B ±1 σ
LLR_B
LLR_{S+B}
LLR_{Obs}
Tevatron RunII Preliminary
$L=2.1\text{-}5.4\ fb^{-1}$
November 6, 2009
m_H (GeV/c^2)

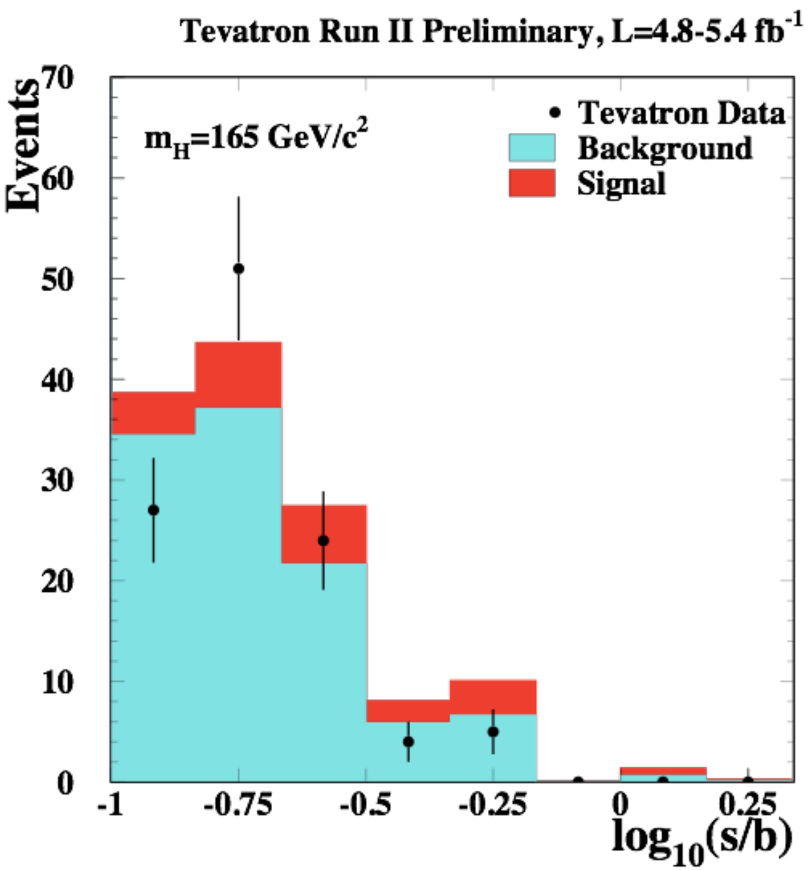
Distribution of different s/b bins





Distribution of different s/b bins

$\log_{10}$s/b,	Signal,	Bkgr,	Data
-1.083	7.86	96.45	90
-0.916	4.19	34.44	27
-0.75	6.52	37.09	51
-0.583	5.80	21.62	24
-0.416	2.22	5.84	4
-0.25	3.41	6.61	5
-0.083	0	0	0
0.083	0.71	0.64	0
0.25	0.14	0.09	0



Dilepton + missing E_T analysis

Changes since Moriond 2009

CDF:

- Increased dataset from 3.6 to 4.8 fb^{-1}
- Likelihood based central electron ID
  - 10% improvement in efficiency with same fake rate
- Additional triggerable muon categories
- Low M*ll* analysis
- gg→H cross section systematic uncertainty depends on Njets

DØ:

- Increased dataset in ee and eμ channels from 4.2 to 5.4 fb^{-1} and in μμ channel from 3.0 to 5.4 fb^{-1} (adding higher jet multiplicities in μμ)
- New Neural Network
  - Now with Njets distribution and enhanced W+jets content in training
- Small changes in selection and systematics
- Small changes in background modeling

Both experiments with ~20% improvement in expected sensitivity

Selected control samples, H → WW analysis

TABLE VIII: Expected and observed yields in the $W\gamma$ control sample.

CDF Run II Preliminary	$\int \mathcal{L} = 4.8$ fb^{-1}
$M_H = 165$ GeV$/c^2$	
$t\bar{t}$	0.0035 ± 0.0005
DY	1.49 ± 0.36
WW	0.101 ± 0.012
WZ	0.255 ± 0.037
ZZ	0.020 ± 0.003
W+jets	7.1 ± 1.7
$W\gamma$	66.8 ± 8.0
Total Background	76 ± 8
$gg \to H$	0.0089 ± 0.0015
Total Signal	0.0089 ± 0.0015
Data	67

$W\gamma$ Control Region

TABLE IX: Expected and observed yields in the $t\bar{t}$ control sample.

CDF Run II Preliminary	$\int \mathcal{L} = 4.8$ fb^{-1}
$M_H = 165$ GeV$/c^2$	
$t\bar{t}$	166 ± 28
DY	1.24 ± 0.41
WW	0.62 ± 0.14
WZ	0.131 ± 0.018
ZZ	0.135 ± 0.018
W+jets	2.81 ± 0.76
$W\gamma$	0.070 ± 0.017
Total Background	171 ± 28
$gg \to H$	0.053 ± 0.037
WH	0.096 ± 0.012
ZH	0.131 ± 0.017
VBF	0.0135 ± 0.0022
Total Signal	0.293 ± 0.049
Data	159

$t\bar{t}$ Control Region

TABLE X: Expected and observed yields in the W+jets control sample.

CDF Run II Preliminary	$\int \mathcal{L} = 4.8$ fb^{-1}
$M_H = 165$ GeV$/c^2$	
$t\bar{t}$	0.0006 ± 0.0002
DY	64.2 ± 19.5
WW	0.104 ± 0.027
WZ	7.04 ± 0.96
ZZ	0.550 ± 0.075
W+jets	58.9 ± 17.7
$W\gamma$	12.2 ± 2.8
Total Background	143 ± 27
WH	0.162 ± 0.021
ZH	0.011 ± 0.001
Total Signal	0.173 ± 0.023
Data	147

W+Jets Control Region

TABLE XI: Expected and observed yields in the Drell-Yan control sample.

Category	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jets	Total	Data
$e\ e$	10.8	65.6	62.0	3.1	184005.4	2.7	1018.1	185167.6	178866.0
$e\ \mu$	10.4	0.2	0.1	2.4	143.1	0.7	150.3	307.2	171.0
$\mu\ \mu$	10.0	52.1	51.8	2.7	141437.9	0.0	710.5	142265.0	140413.0
e trk	8.6	19.8	19.3	2.4	53663.4	0.9	812.9	54527.2	49582.0
μ trk	5.7	14.9	14.5	1.6	40513.6	0.1	544.5	41094.7	38903.0
Total:	45.5	152.5	147.7	12.1	419763.4	4.3	3236.2	423361.7	407935.0

Cross section calculations

Using up-to-date cross section calculations (arXiv:hep-ph/0607308 except where noted):

- gg→H: NNLL QCD, b quark contribution at NLO, 2 loop ewk corrections, changed since last Summer (arXiv:0901.2427 [hep-ph]), newer PDF set, consistent choice of α_s, 10% uncertainty
  - +12% at M_H=100 GeV
  - -8% at M_H=200 GeV
  - -4% at M_H=170 GeV
- WH/ZH: NNLO in QCD, NLO ewk, 5% uncertainty
- Vector boson fusion: NLO QCD, 10% uncertainty

CDF and DØ using common values (and correlated uncertainties) for cross sections of background processes: tt and single top (10%), diboson production (6%)

W/Z+jets(heavy flavour): considered uncorrelated (constrainted from data)

Multijet background: estimated from data (uncorrelated)

Limit setting

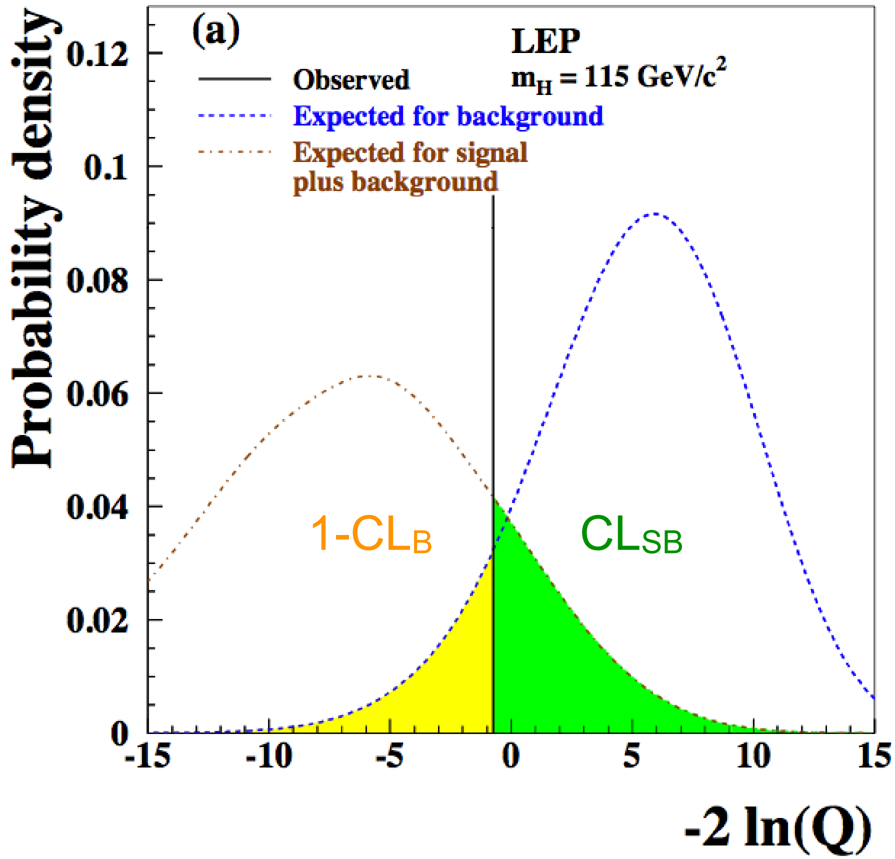
Construct MC toy experiments for background only or signal plus background hypotheses

- Incorporate systematic uncertainties through Gaussian smearing

Evaluate the statistical significance with a Poisson log likelihood ratio (obtain probability densities)

$$Q(m_H) = \frac{L_{s+b}}{L_b}$$

$1-CL_B$: probability for a signal like fluctuation of the background



Excess around 115 slightly more s+b like

$m_H \geq 114.4$ GeV @ 95% CL

Limit setting

Full combination of all channels from CDF and DØ for best sensitivity

- Combining ~30 different channels per experiment
- More than 50 different sources of systematic uncertainties are considered

LEP:	low background, small systematics
Tevatron/LHC:	high background, large systematics

Degrading effect of systematic uncertainties larger at the Tevatron

Similar methods for limit settings as used at LEP, but counteract the degrading effects from uncertainties via “Profile Likelihood” technique

$$Q(m_H) = \frac{L_{s+b}}{L_b}$$

← Likelihood now a function of nuisance parameters

Background is constrained by maximising profile likelihood (‘sideband fitting’)

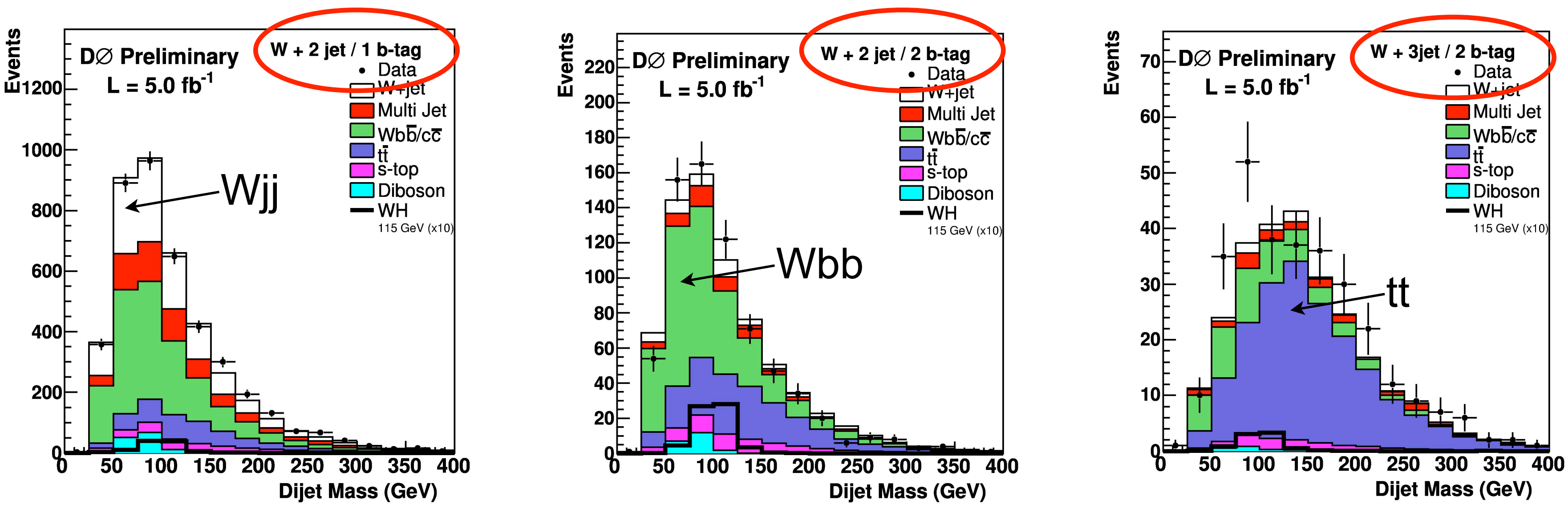
Maximise benefit from S/B variations

Split data into several sub-samples with different S/B to increase sensitivity

- Tight/loose lepton definitions
- Number of jets
- Number of tagged jets
- b-tagging operating point

➡ Different sample compositions increase multivariate discrimination

Example: $WH \rightarrow l\nu bb$

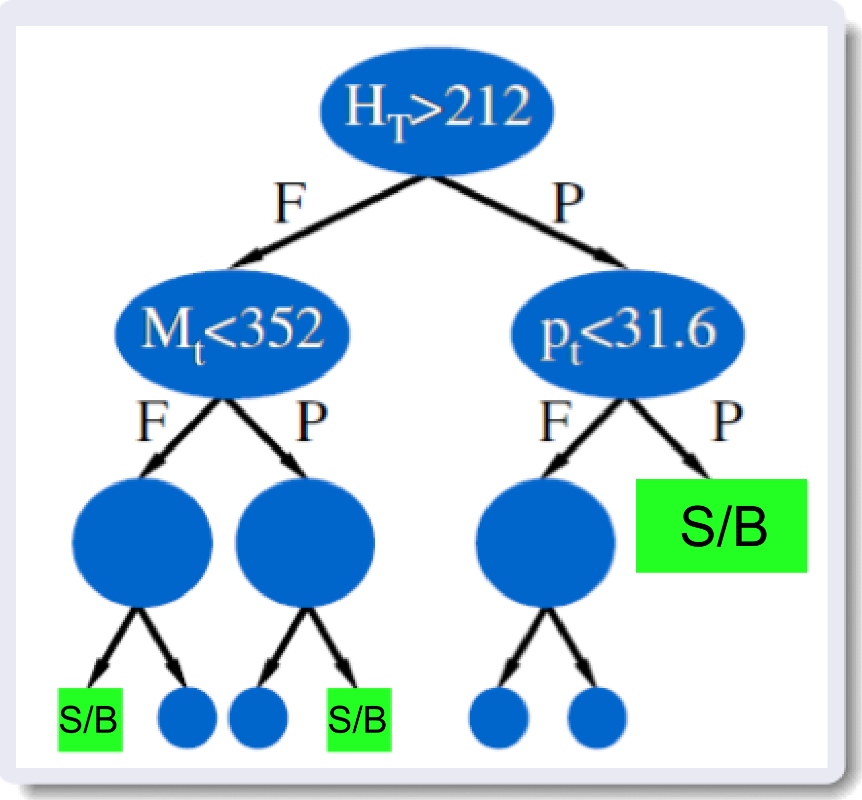


Decision Trees

Train

- Start with all events (first node)
- For each variable, find the splitting value with best separation between children (best cut).
- select best variable and cut and produce Failed and Passed branches
- Repeat recursively on each node
- Stop when improvement stops or when too few events left. Terminal node = leaf.

Idea: recover events that fail criteria in cut-based analysis



Matrix elements

- Use the 4–vectors of all reconstructed leptons and jets
- Use matrix elements of main signal and background diagrams to compute an event probability density for signal and background hypotheses.
- Goal: calculate a discriminant:

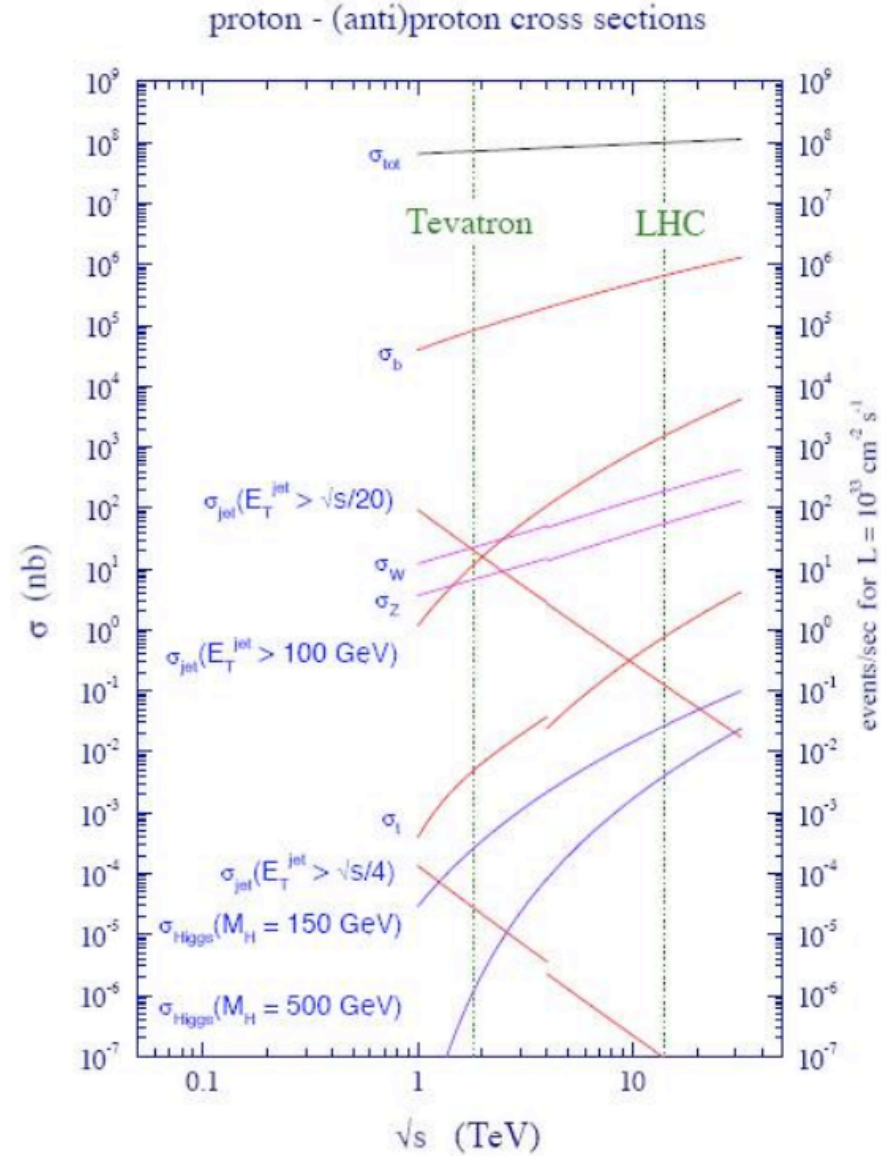
$$D_s(\vec{x}) = P(S|\vec{x}) = \frac{P_{Signal}(\vec{x})}{P_{Signal}(\vec{x}) + P_{Background}(\vec{x})}$$

- Define P_{Signal} as properly normalized differential cross section

$$P_{Signal}(\vec{x}) = \frac{1}{\sigma_S} d\sigma_S(\vec{x}) \quad \sigma_S = \int d\sigma_S(\vec{x})$$

Signal and background rates

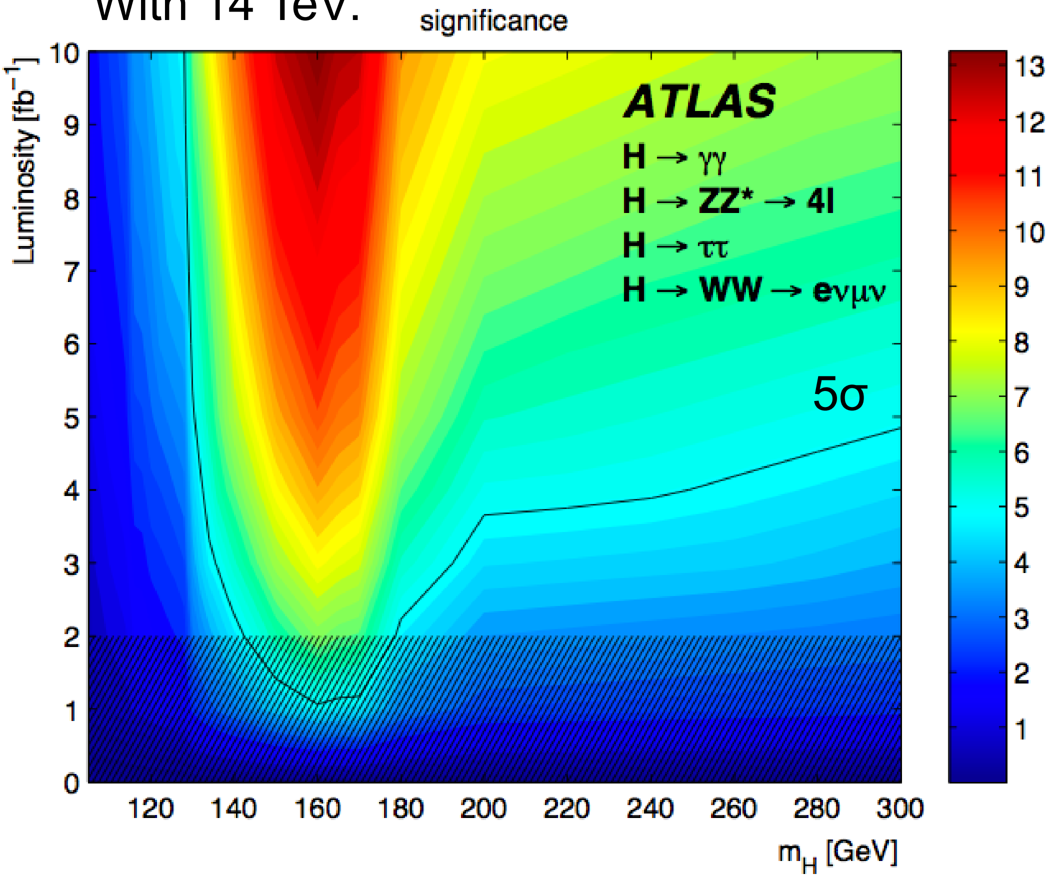
From the Tevatron to the LHC:



LHC discovery potential

ATLAS as an example, similar conclusions from CMS

With 14 TeV:



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m_H > 130 GeV

Main channels $H \to WW$ and $H \to ZZ$

Discovery with few fb^{-1} up to masses favourable by the SM possible

m_H < 130 GeV

Main channels $H \to \gamma\gamma$ and $H \to \tau\tau$

Challenging, a few years of running may be needed