Search for the Higgs at the Tevatron

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Outline

Higgs boson

Tevatron

SM Searches

BSM searches

Conclusions

Higgs Boson

Makes the SM work

allows massive W & Z

allows fermion masses

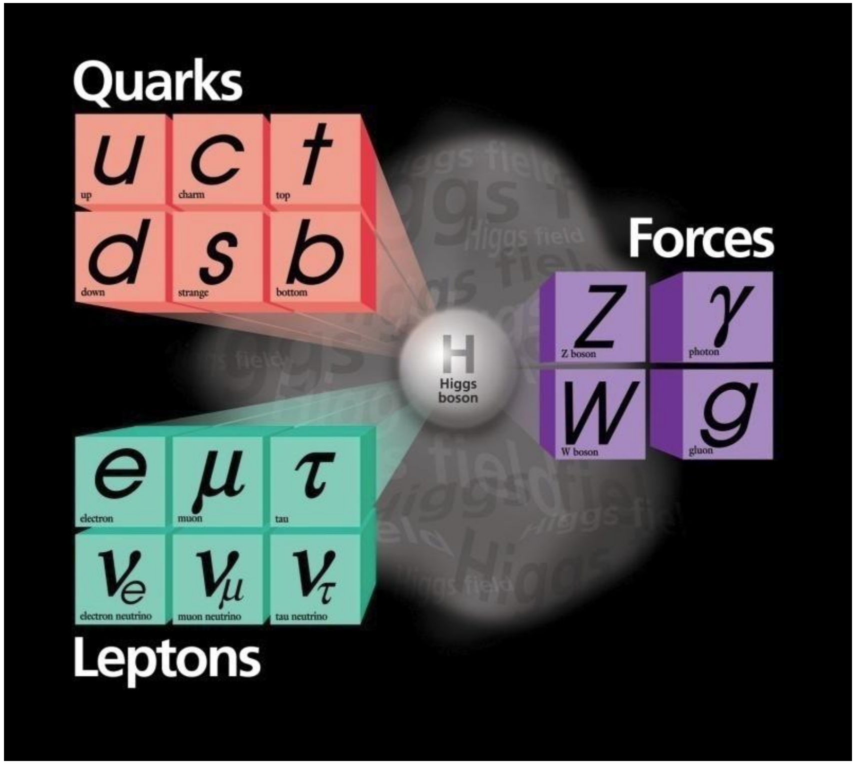
Testable prediction of Electroweak theory

Scalar Higgs Boson

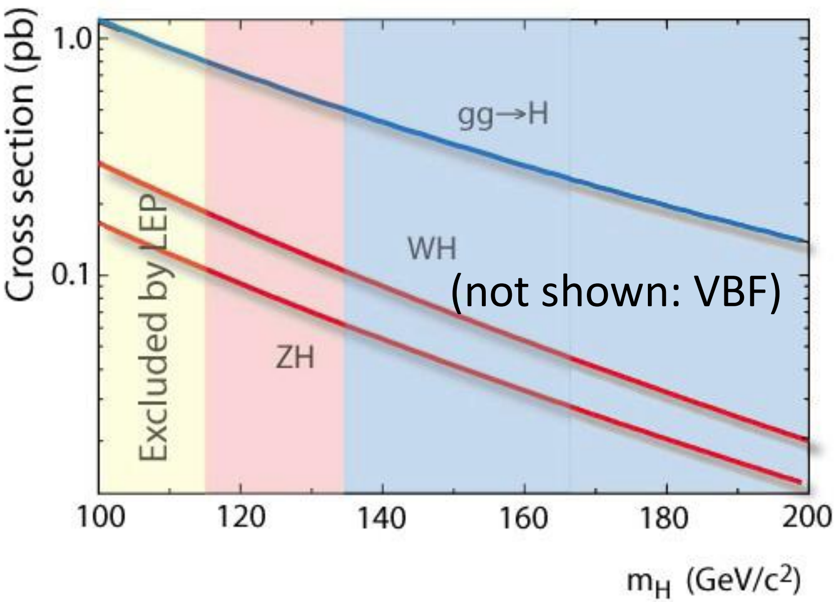
MSSM (2 doublet)

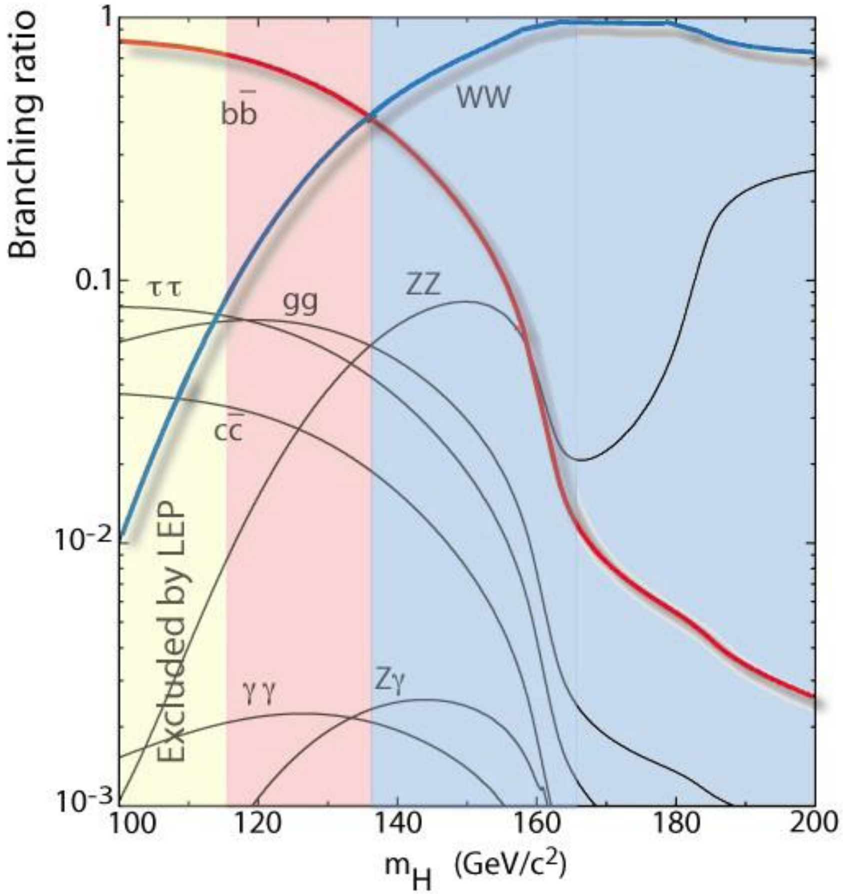
5 Higgs Bosons

(Explains very little)



Higgs Production and Decay





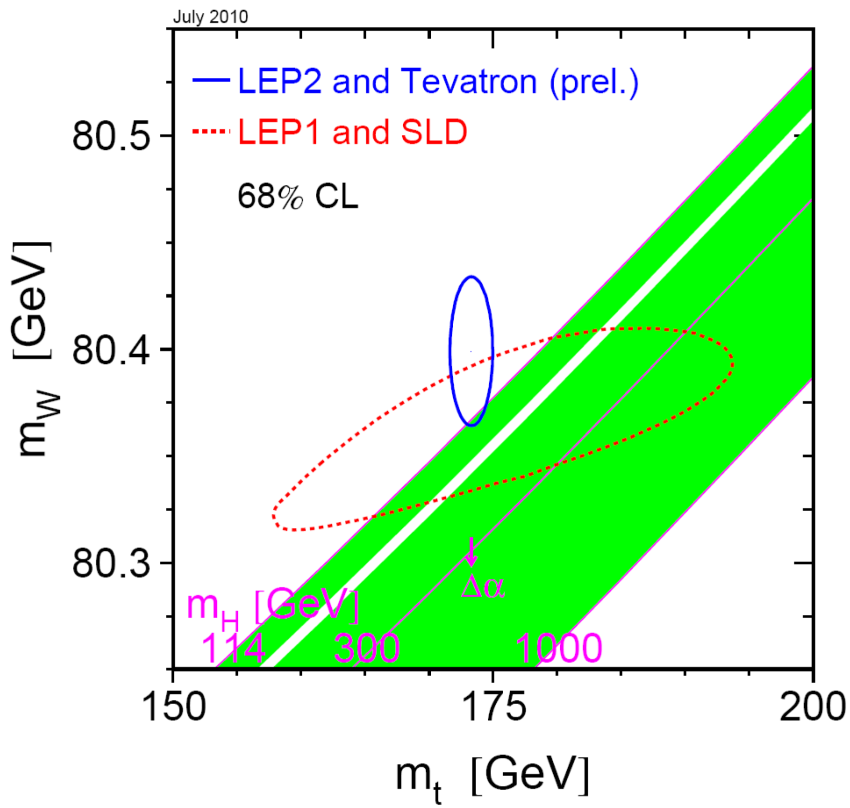
Gluon fusion dominates

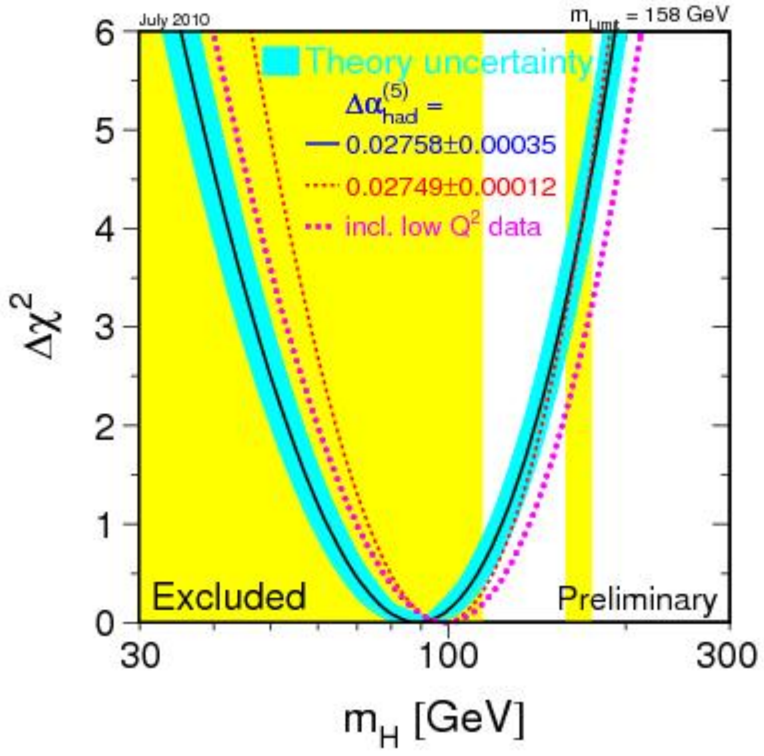
- difficult backgrounds
- triggering problematic

Associated production

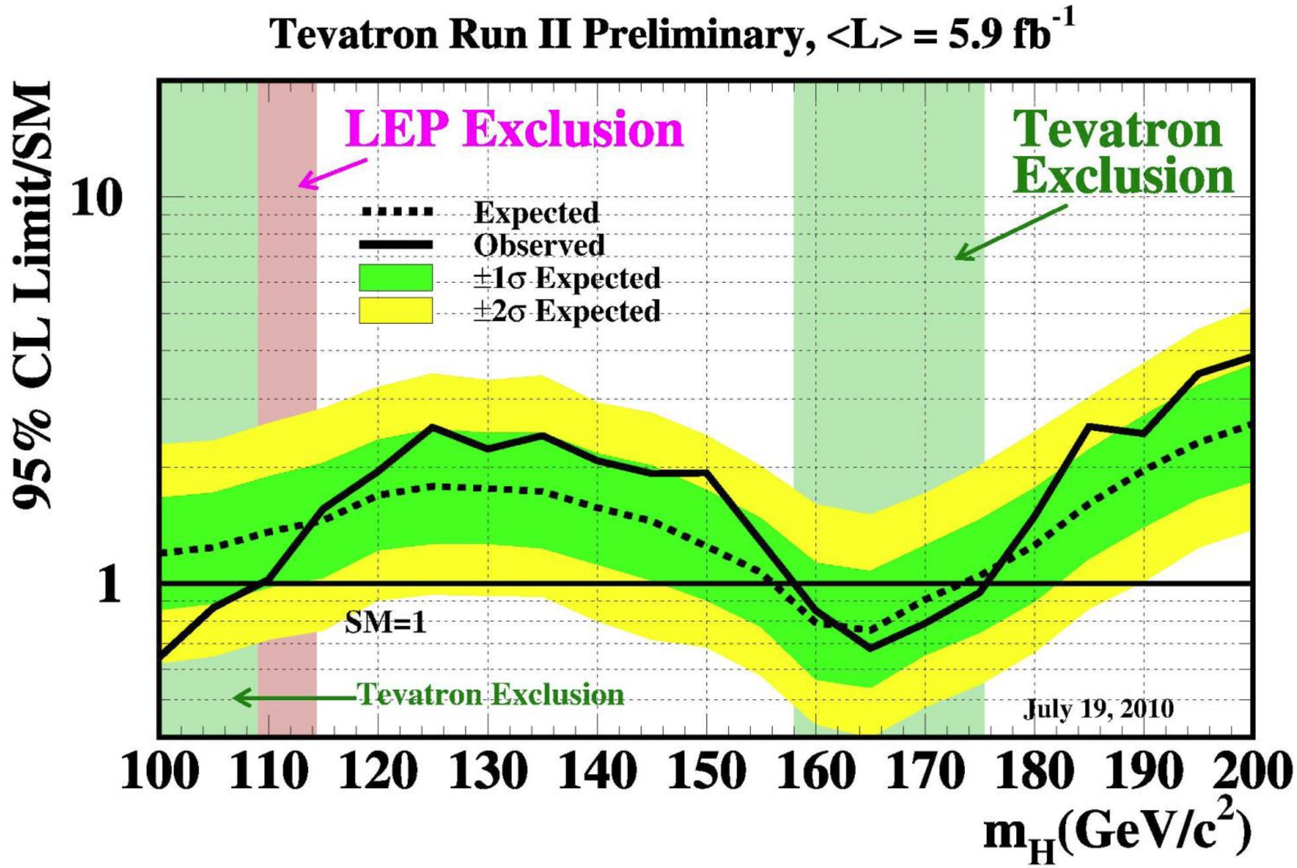
- lower rate
- clearer signature (leptonic decays of W/Z)

Higgs Constraints and Limits





Higgs Constraints and Limits



Tevatron limits as of last summer...

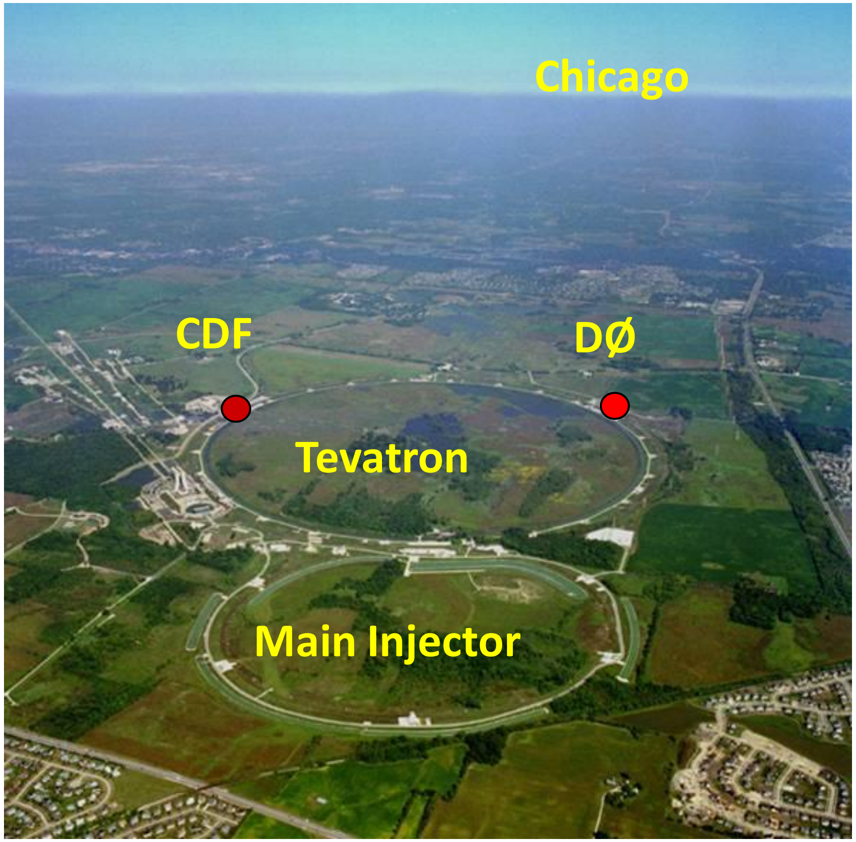
Tevatron

Proton-antiproton collider

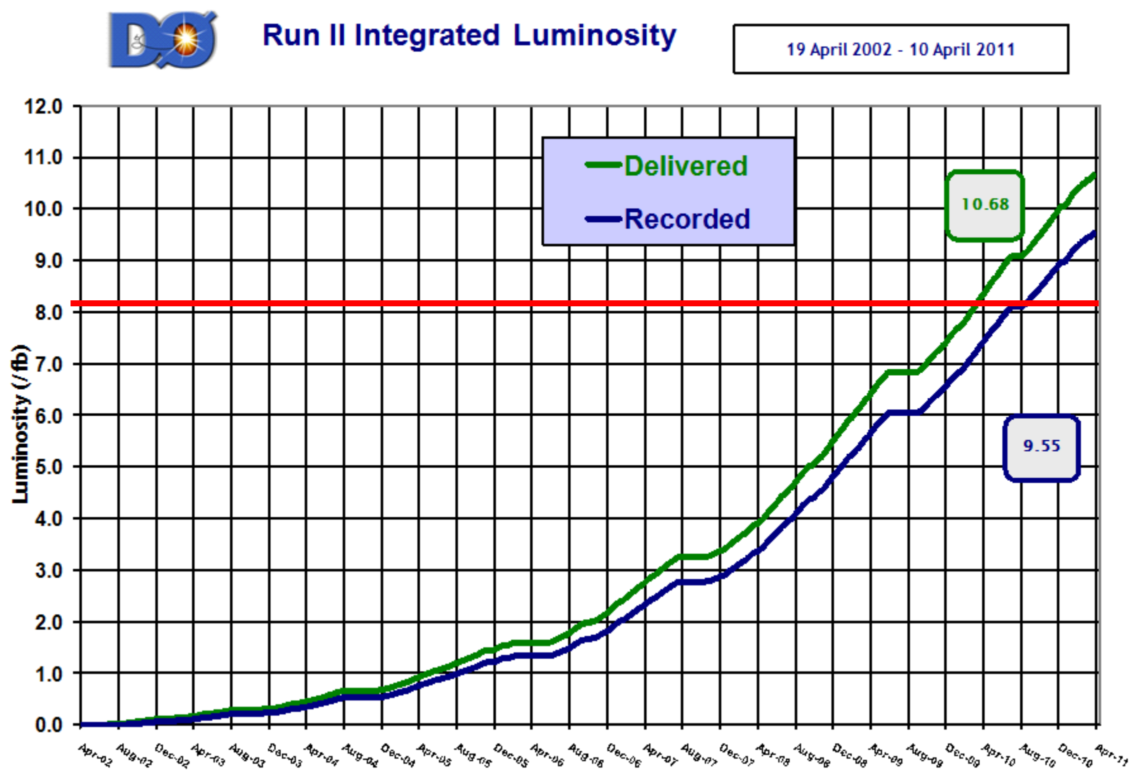
Centre of mass energy of 1.96 TeV

396ns bunch spacing

RunII will end later this year



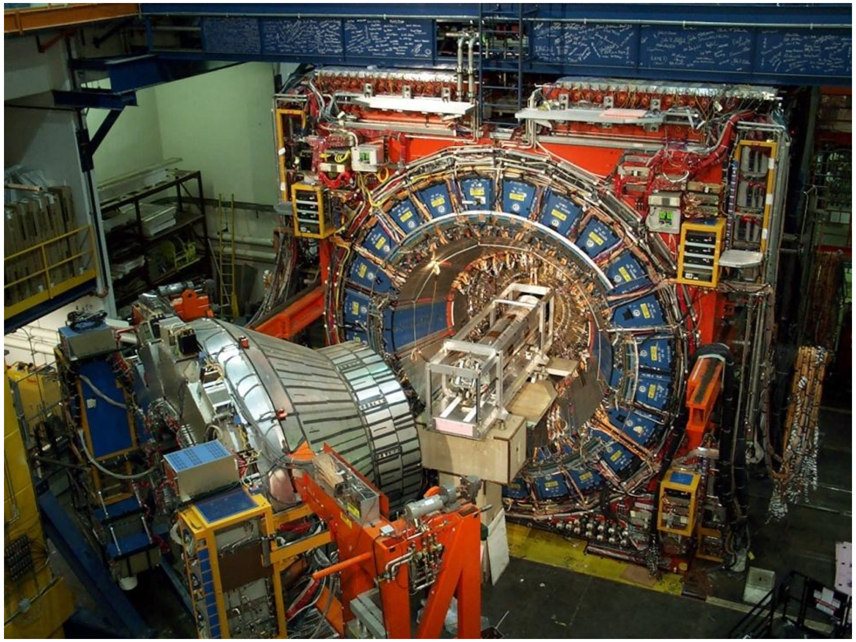
Luminosity



Project around 10fb^{-1} recorded lumi with running until September

Detectors

Silicon vertex detector
Wire drift chamber
Pb/Fe-scintillator calorimetry
Muon chambers



Silicon vertex detector
Scintillating fibre tracker
LAr-U calorimetry
Muon chambers

SM HIGGS SEARCHES
HIGH MASS
LOW MASS

Search Strategy

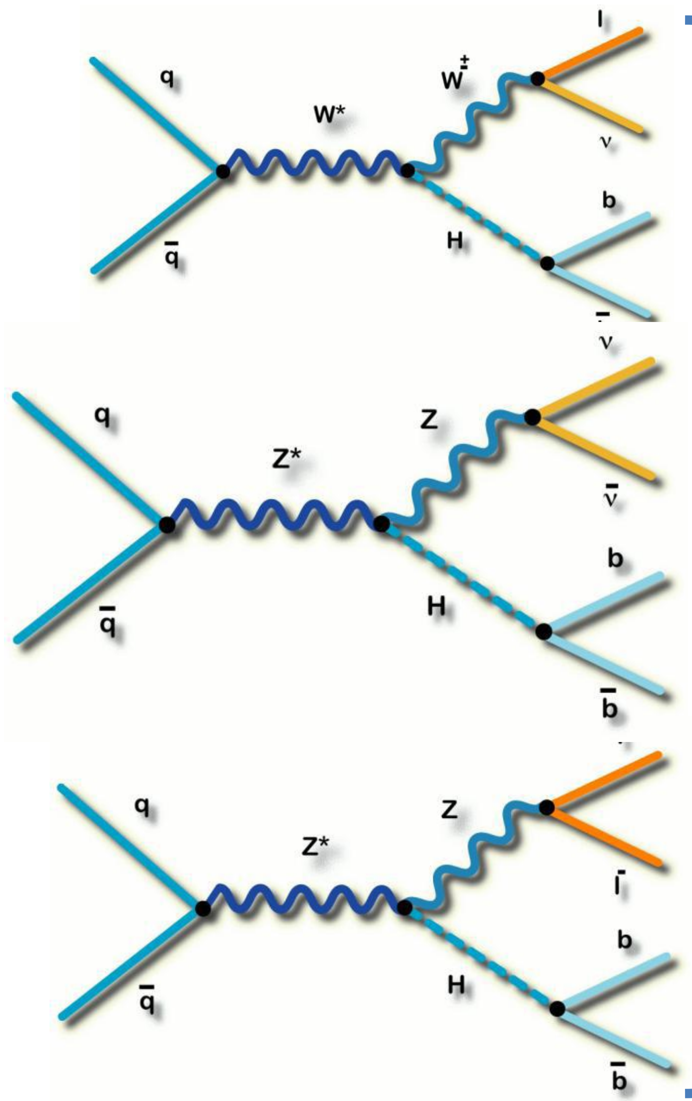
Analyze final states with clear signatures:

- electrons
- muons
- displaced vertices (b-jets)
- missing energy (neutrinos)

Combine as many channels as possible

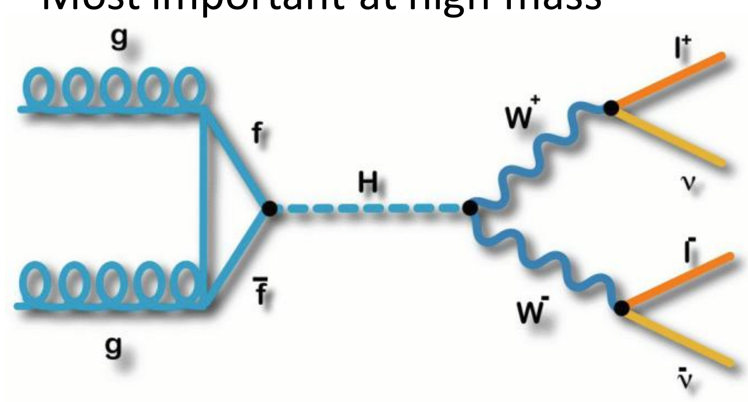
Combine across experiments

Search Strategy



Most important at low mass

Most important at high mass



Search Strategy

Channel	Luminosity (fb^{-1})	m_H range (GeV/c^2)
$WH \to \ell\nu b\bar{b}$ 2-jet channels 4×(TDT,LDT,ST,LDTX)	5.7	100-150
$WH \to \ell\nu b\bar{b}$ 3-jet channels 2×(TDT,LDT,ST)	5.6	100-150
$ZH \to \nu\bar{\nu}b\bar{b}$ (TDT,LDT,ST)	5.7	100-150
$ZH \to \ell^+\ell^- b\bar{b}$ 4×(TDT,LDT,ST)	5.7	100-150
$H \to W^+W^-$ 2×(0,1 jets)+(2+ jets)+(low-$m_{\ell\ell}$)+(e-τ_{had})+(μ-τ_{had})	5.9	110-200
$WH \to WW^+W^-$ (same-sign leptons 1+ jets)+(tri-leptons)	5.9	110-200
$ZH \to ZW^+W^-$ (tri-leptons 1 jet)+(tri-leptons 2+ jets)	5.9	110-200
$H + X \to \tau^+\tau^-$ (1 jet)+(2 jets)	2.3	100-150
$WH + ZH \to jjb\bar{b}$ 2×(TDT,LDT)	4.0	100-150
$H \to \gamma\gamma$	5.4	100-150

Channel	Luminosity (fb^{-1})	m_H range (GeV/c^2)
$WH \to \ell\nu bb$ (ST,DT,2,3 jet)	5.3	100-150
$VH \to \tau^+\tau^- b\bar{b}/q\bar{q}\tau^+\tau^-$	4.9	105-145
$ZH \to \nu\bar{\nu}b\bar{b}$ (ST,TLDT)	5.2-6.4	100-150
$ZH \to \ell^+\ell^- b\bar{b}$ (ST,DT,ee,$\mu\mu$,ee_{ICR},$\mu\mu_{trk}$)	4.2-6.2	100-150
$VH \to \ell^\pm\ell^\pm + X$	5.3	115-200
$H \to W^+W^- \to e^\pm\nu e^\mp\nu, \mu^\pm\nu\mu^\mp\nu$	5.4	115-200
$H \to W^+W^- \to e^\pm\nu\mu^\mp\nu$ (0,1,2+ jet)	6.7	115-200
$H \to W^+W^- \to \ell\bar{\nu}jj$	5.4	130-200
$H \to \gamma\gamma$	4.2	100-150
$t\bar{t}H \to t\bar{t}b\bar{b}$ (ST,DT,TT,4,5+ jets)	2.1	105-155

(As of summer 2010)

Search Strategy

Channel		Luminosity (fb^{-1})	m_H range (GeV/c^2)
$H \to W^+W^-$	$2\times$(0,1 jets)+(2+ jets)+(low-$m_{\ell\ell}$)+(e-τ_{had})+(μ-τ_{had})	7.1	110-200
$WH \to WW^+W^-$	(same-sign leptons 1+ jets)+(tri-leptons)	7.1	110-200
$ZH \to ZW^+W^-$	(tri-leptons 1 jet)+(tri-leptons 2+ jets)	7.1	110-200

Channel		Luminosity (fb^{-1})	m_H range (GeV/c^2)
$H \to W^+W^- \to l^\pm \nu l^\mp \nu$	(0,1,2+ jet)	8.1	115-200
$H \to W^+W^- \to \mu\nu\tau_{had}\nu$		7.3	115-200
$H \to W^+W^- \to \ell\bar{\nu}jj$		5.4	115-200
$VH \to \ell^\pm\ell^\pm + X$		5.3	115-200
$VH \to \tau^+\tau^- b\bar{b}/q\bar{q}\tau^+\tau^-$		5.3	105-200
$H \to \gamma\gamma$		8.2	100-150

Updated for combinations for Winter conferences 2011

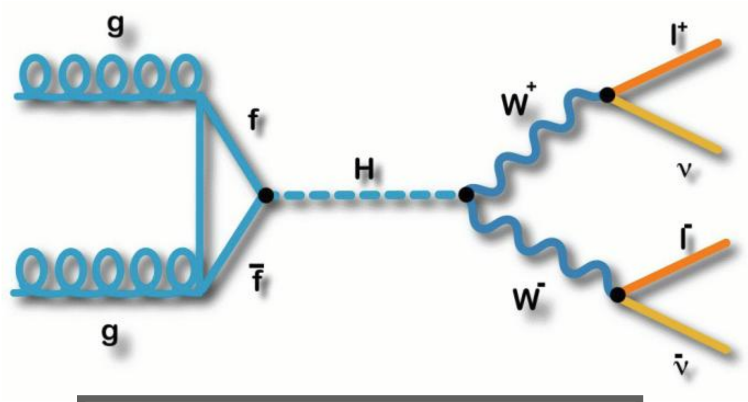
High Mass Searches

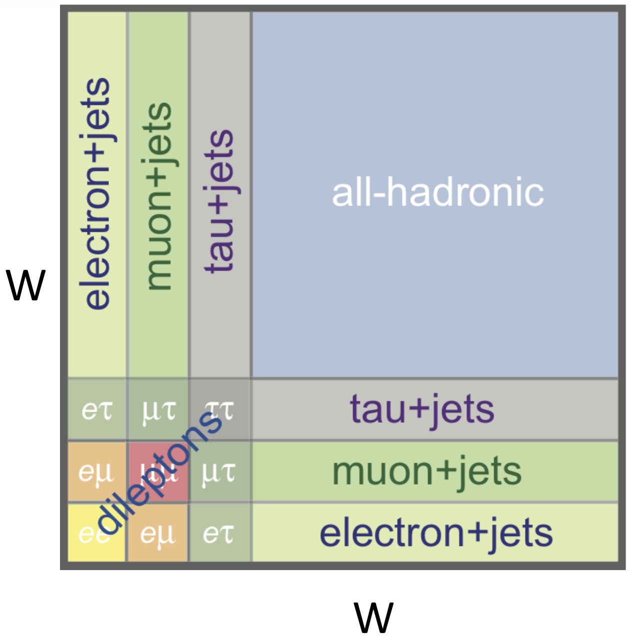
High mass: $m_H > 135$ GeV
Dominated by: $H \to WW$

Dilepton (e and μ): (~6%)
- most sensitive
- lowest background rate

Lepton + hadronic tau: (~4%)
- brings additional sensitivity
- larger backgrounds

Lepton + jets: (30%)
- lots more signal
- huge backgrounds



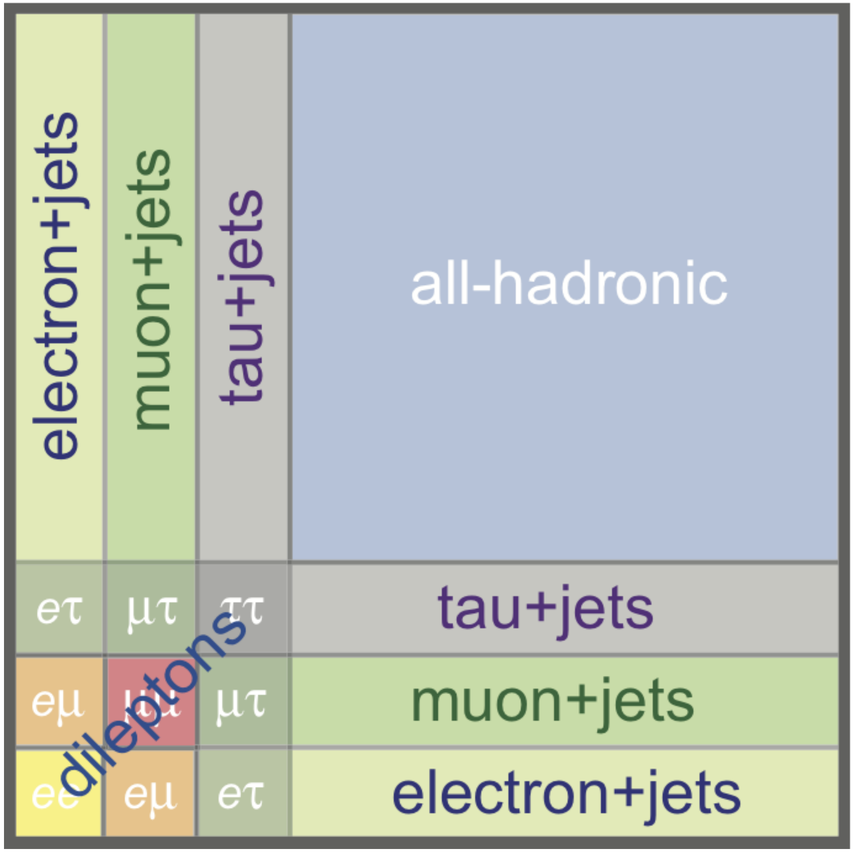


High Mass Searches

Separate in many sub-channels:

- lepton flavour/quality:
  - ee, eμ, μμ (D0)
  - high S/B, low S/B (CDF)
- lepton charge:
  - OS & SS
- jet multiplicity:
  - 0, 1 and >= 2
- low and high dilepton mass (CDF)

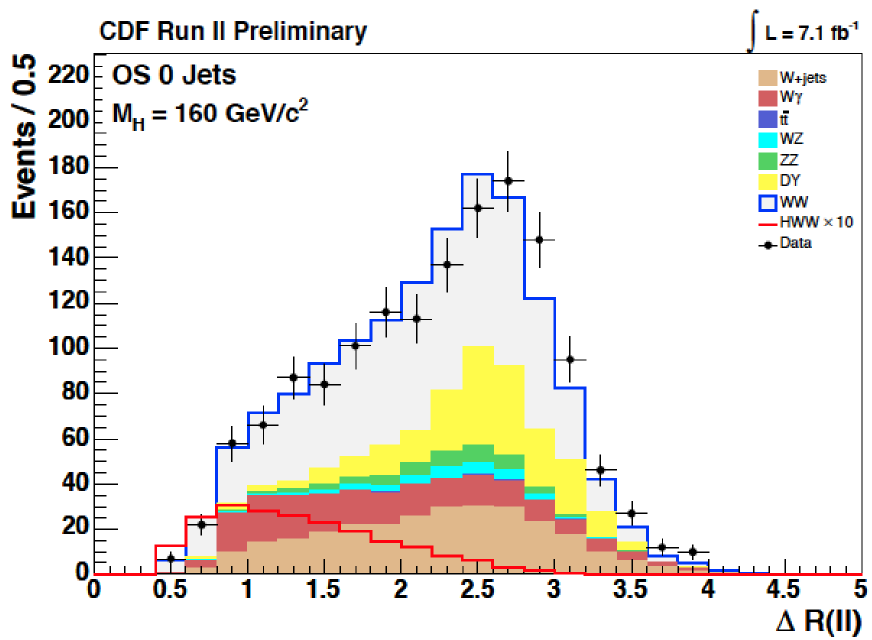
Use MVA techniques – optimised in each sub-channel

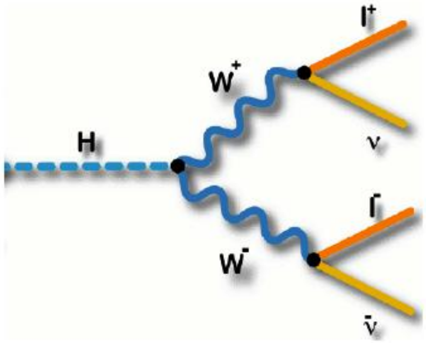


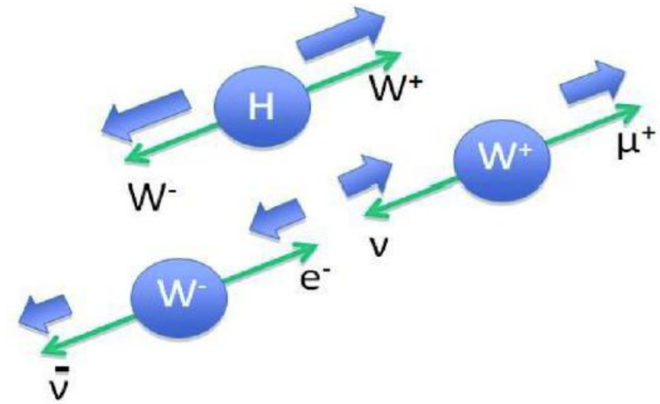
Dileptons

Select 2 OS leptons + Missing Energy

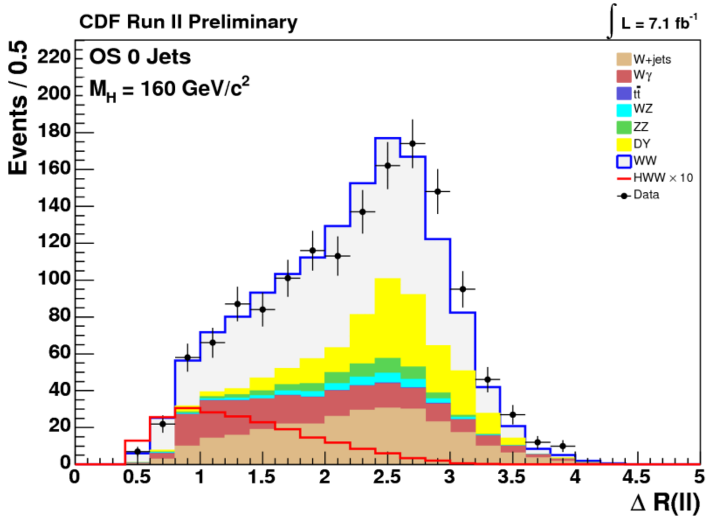
Spin 0 Higgs → difference in lepton opening angle from WW production







Dileptons: subchannels



CDF: 6 subchannels

- 0/1/2+ jets
- high/low S/B lepton categories
- di-lepton mass

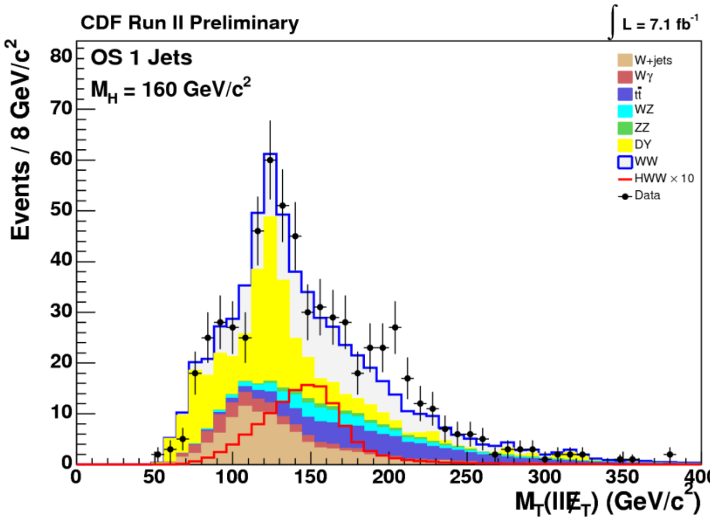
Dominant backgrounds:

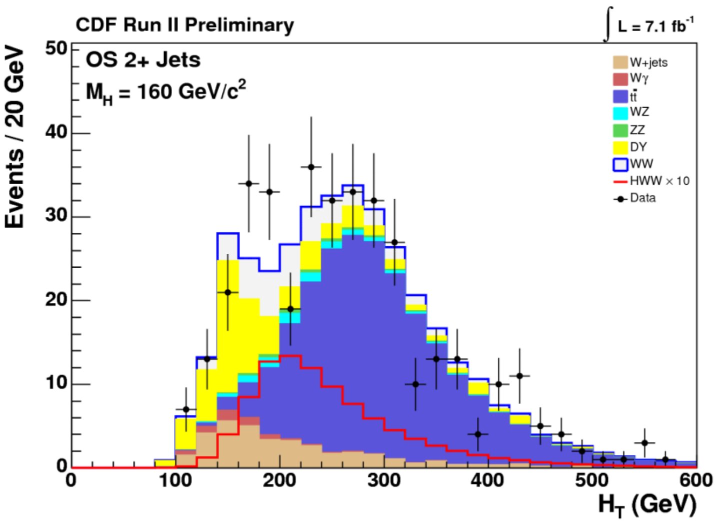
0j: WW

1j: DY and WW

2+j: top

Low dilepton mass: Wγ





Dileptons: subchannels

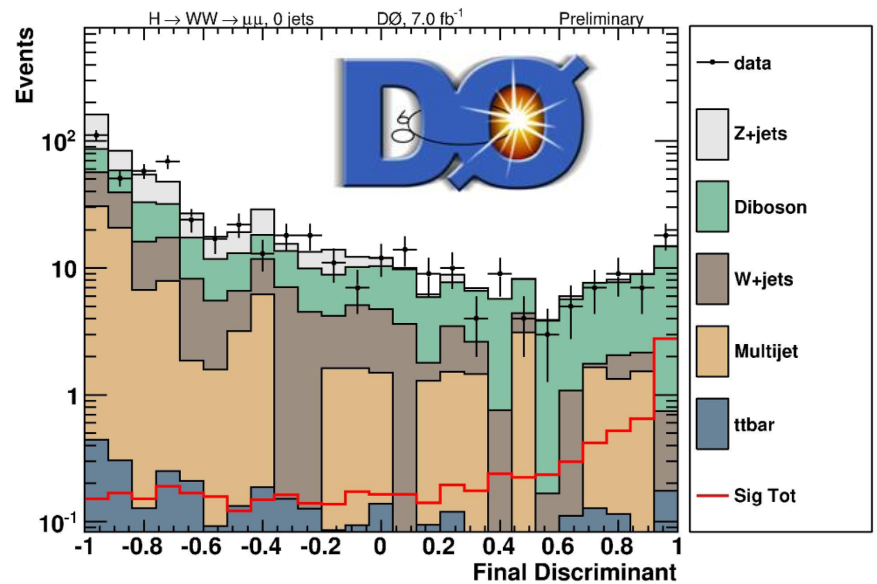
D0: 18 subchannels:

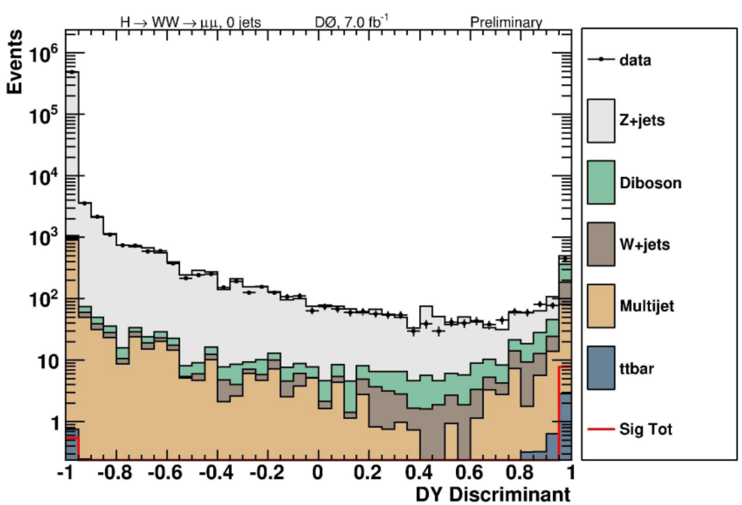
lepton flavour: ee, eμ, μμ

jet multiplicity: 0,1,2+

DT trained to suppress Z/γ*

Further DT trained to suppress other backgrounds





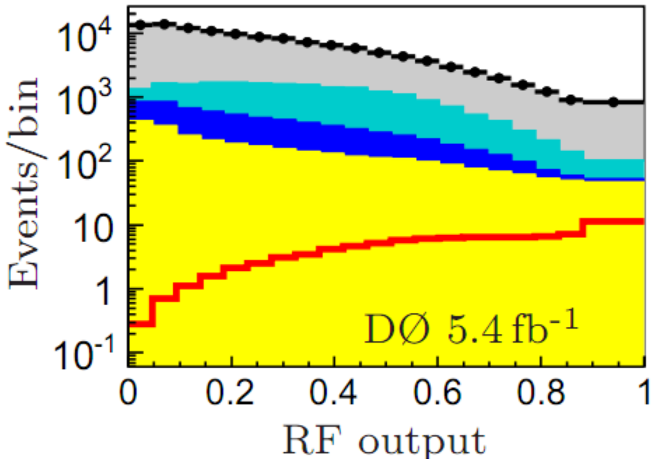
Dominant backgrounds:

ee – Z/γ* → ee

μμ – Z/γ* → μμ

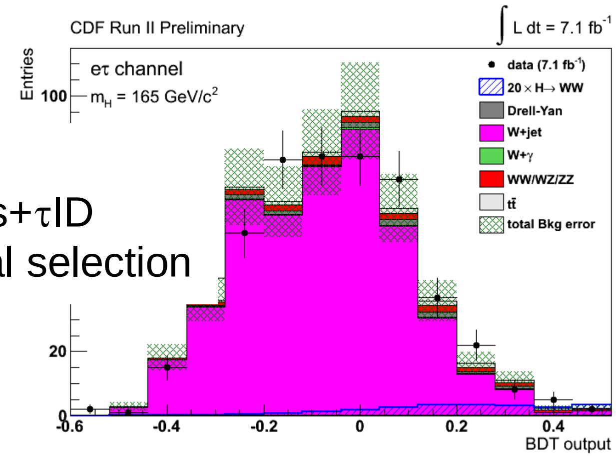
eμ – WW, W+jets

Other channels

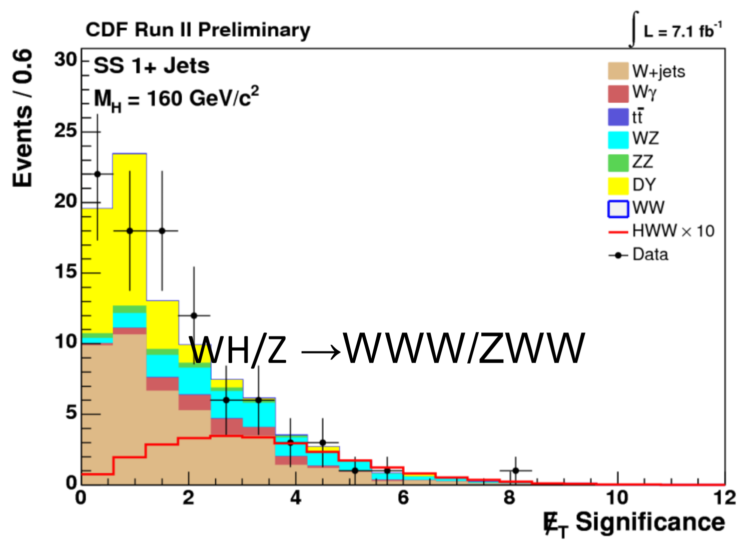


H→WW→lνjj
D0: huge W/Z+jets background
Random Forest selection
(CDF result coming soon)

H→WW→lντ$_{HAD}$ν
CDF: BDT kinematics+τID
D0: NN τID + NN final selection



CDF:
SS leptons + jets
3 trilepton channels



WH/Z →WWW/ZWW

D0:
SS leptons

Experimental Uncertainties

Generally uncorrelated across experiments

Many correlated across channels at a single experiment

- Lepton and jet selection efficiencies
- Jet energy scale
- QCD ISR/FSR effects
- Missing ET modeling

Theoretical Uncertainties I

Canonical scale variation κ=2

- Uncertainties taken from NNLO calculation - conservatively cover NLO and NNLO calculations

Investigations at NNNLO show no unexpected behaviour

Evaluated separately and correlated across jet categories and experiments

(7-33%)

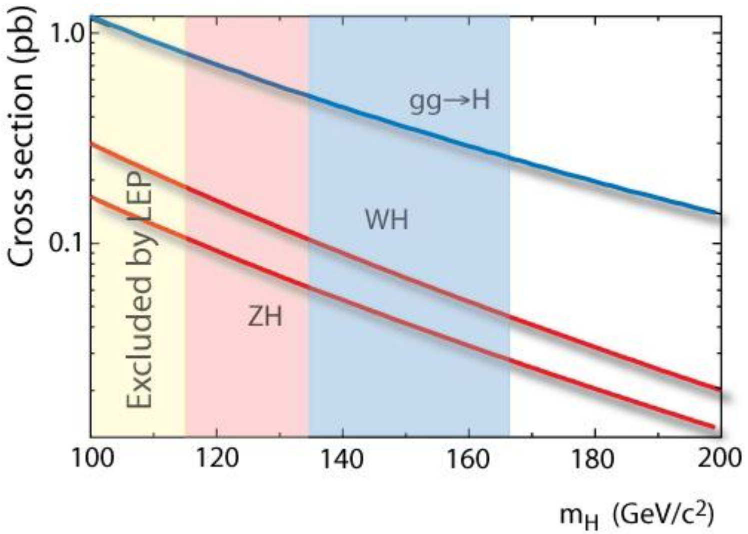
Included as uncertainties in the limit setting

gg→h dominant process

Grazzini, de Florian (arXiv:0901.2427)

Anastasiou, Boughezal, Periello (arXiv:0811.3458)

- resummed NNLL+NNLO



Theoretical Uncertainties II

MSTW2008 NNLO PDFs (Eur.Phys.J. C 63, 189)

Global parton fit including Tevatron jet data
(important for constraining high-x gluon)

Includes uncertainties on α_s following MSTW procedure

Follow prescription from PDF4LHC : ~factor 2 increase w.r.t. using MSTW08 errors alone. (2.5-30% @ m_h=160 GeV)

PDF depends on scale choice - effect included in scale uncertainties ensures correct correlations

Correlated across experiments and channels

Further details on combinations: **http://tevnphwg.fnal.gov**

Techniques: Limit setting

Two statistical approaches employed
Agreement better than 5% over all masses (average 2%)

1. Bayesian
   Flat prior for signal, credibility intervals
2. Modified frequentist
   Log-likelihood ratio, CLs = CLs+b/CLb

Operate on binned final discriminant distributions
Poisson statistics assumed for each bin
Systematics introduced as nuisance parameters
Impact of systematics mitigated with constraints from data

High Mass Summary

channel	Lumi	Exp. Limit
OS, 0j	7.1	1.52
OS, 1j	7.1	2.13
OS +2j	7.1	2.74
Low M_{ll}	7.1	10.6
SS	7.1	2.75
trileptons	7.1	4.9
$e/\mu+\tau_{HAD}$	7.1	13.1

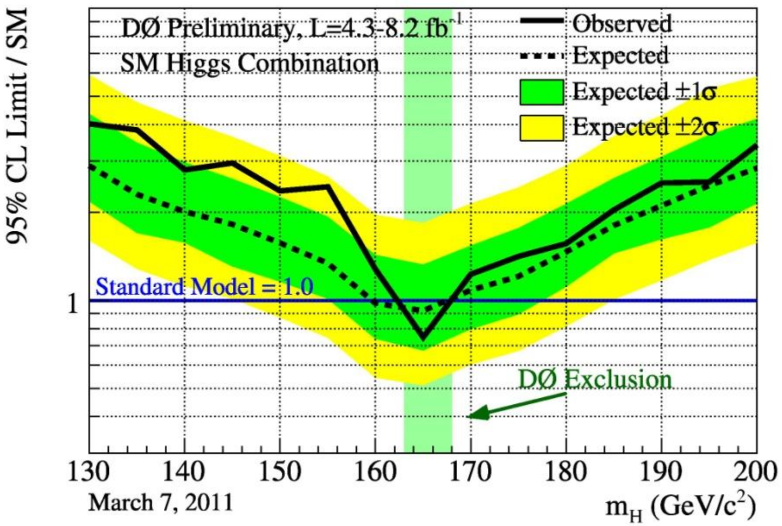
channel	Lumi	Exp. Limit
OS - eμ	8.1	1.26
OS - ee	8.1	2.29
OS - μμ	8.1	2.23
lνqq	5.4	5.1
SS	5.4	7.0
$e/\mu+\tau_{HAD}$ <=1j	7.3	7.8
$e/\mu+\tau_{HAD}$ >= 2j	7.3	12.3

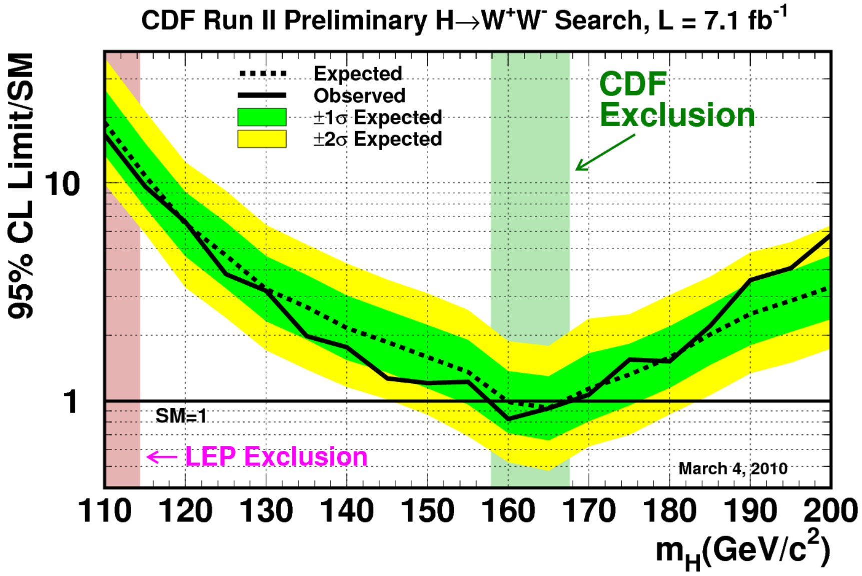
CDF: 12 channels – all updated

D0: 34 channels – added hadronic tau channels

Expected limits given for M_A = 165 GeV

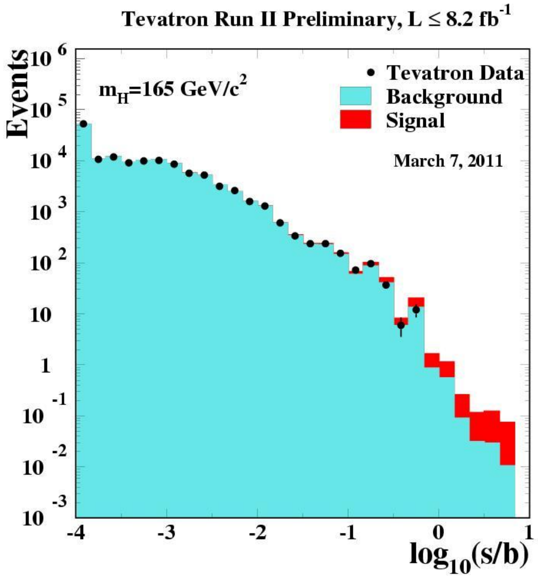
Results



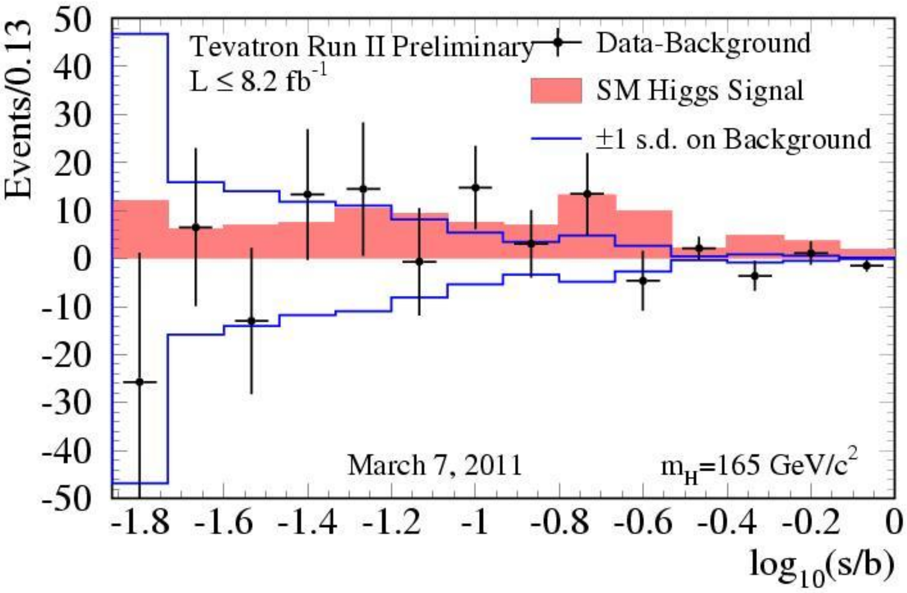


Combinations by experiment: single experiment exclusion from both CDF and D0

Results

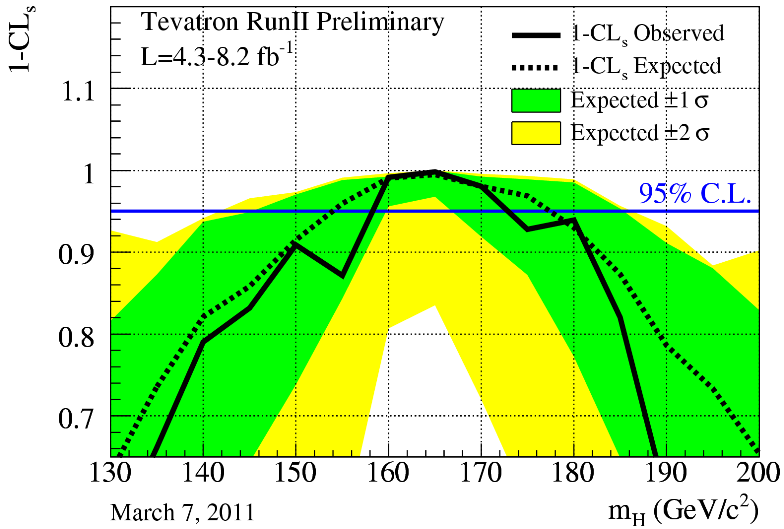


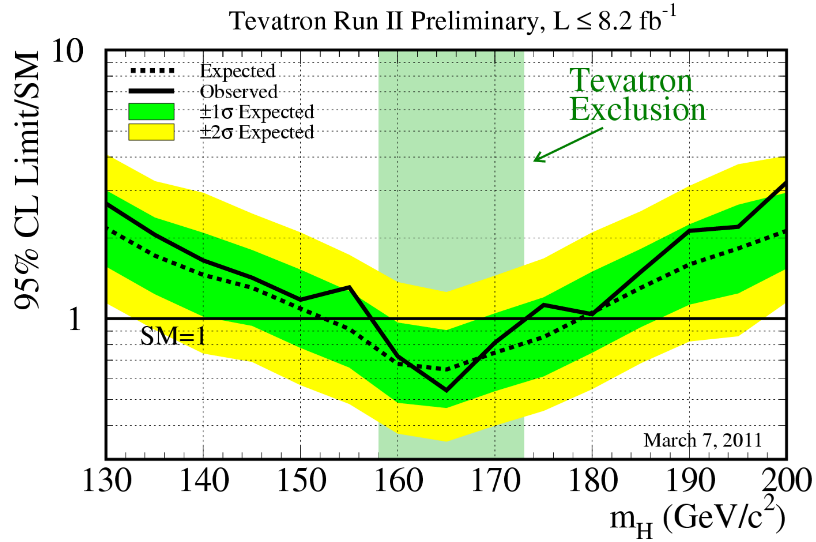
Tevatron Run II Preliminary, L ≤ 8.2 fb-1
Events
mH=165 GeV/c2
Tevatron Data
Background
Signal
March 7, 2011
log10(s/b)



Events/0.13
Tevatron Run II Preliminary
L ≤ 8.2 fb-1
Data-Background
SM Higgs Signal
±1 s.d. on Background
March 7, 2011
mH=165 GeV/c2
log10(s/b)

Combined Results



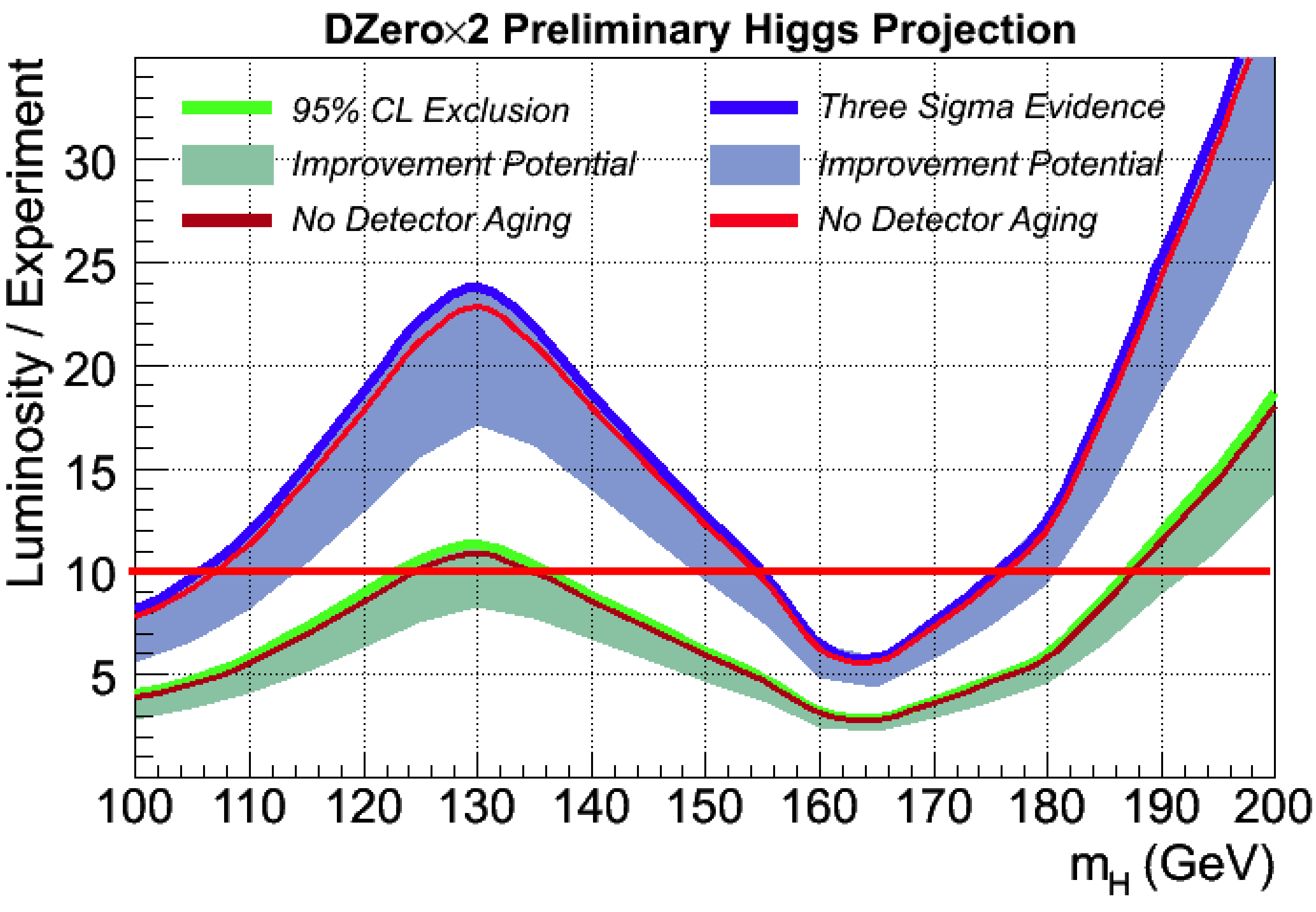


SM Higgs excluded at 95% CL for **158 < m_h < 173 GeV**

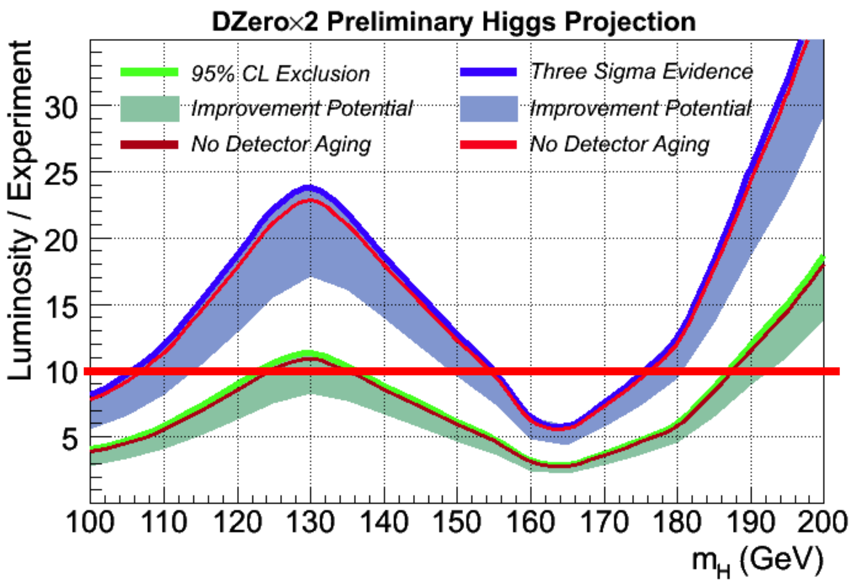
Expected exclusion at 95% CL **153 < m_h < 179 GeV**

(Summer 2010 expected exclusion: 156 < m_h < 173 GeV)

Projections



Projections



Luminosity alone insufficient to get exclusion across mass range

Analysis improvements needed:

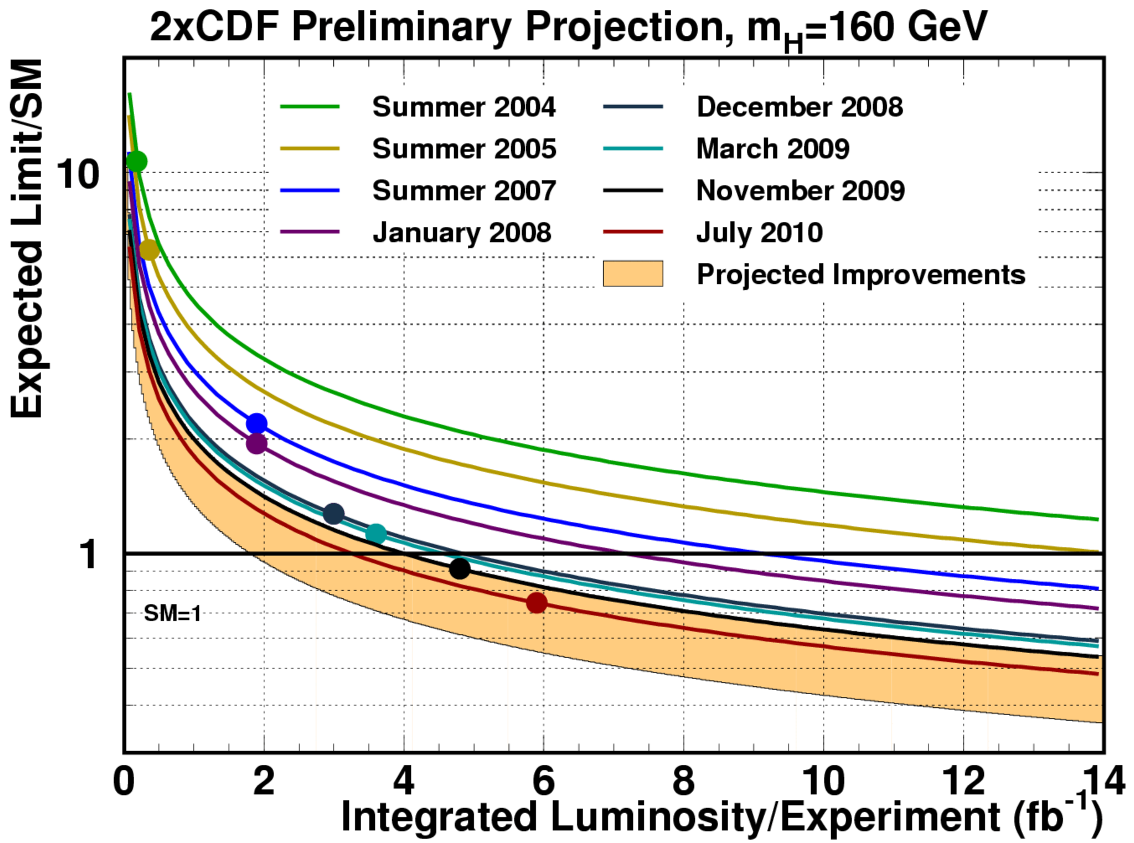
increase acceptance

add channels

advanced techniques

improved b-tagging

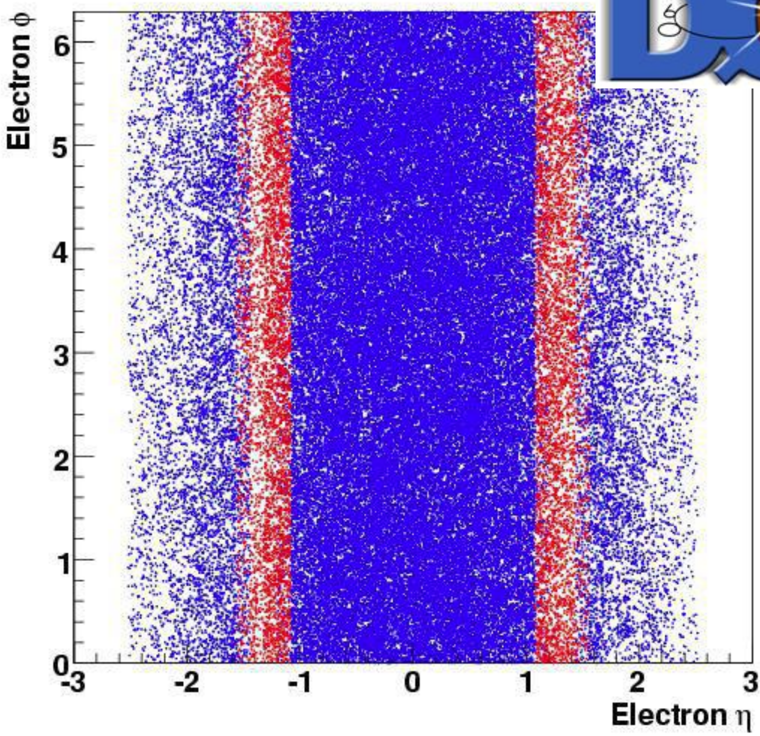
Projections

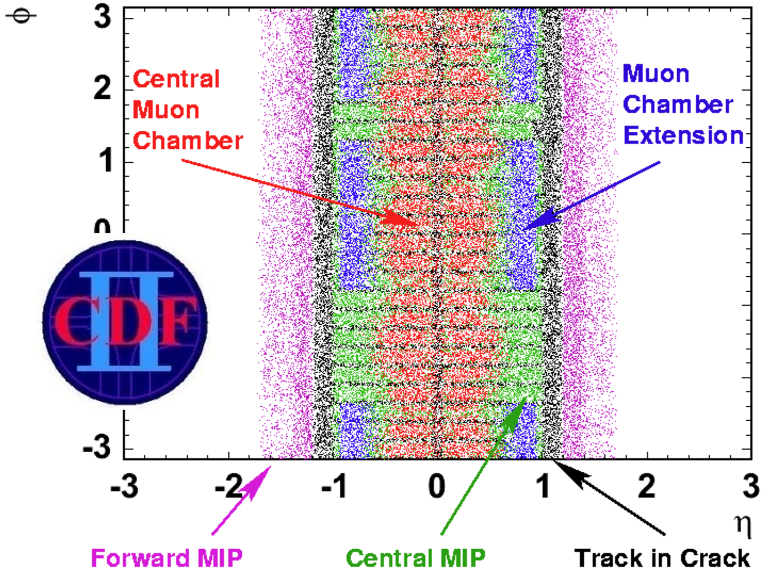


With each update sensitivity has improved beyond that from luminosity alone

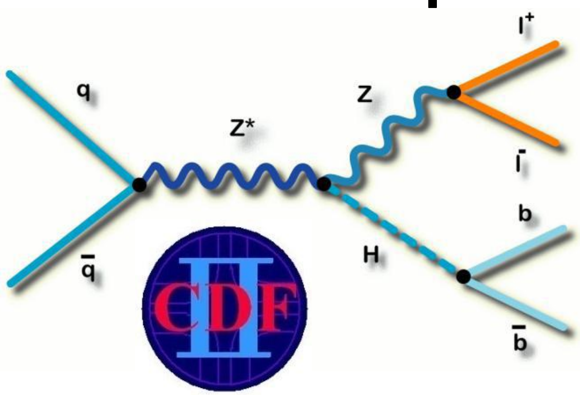
Acceptance

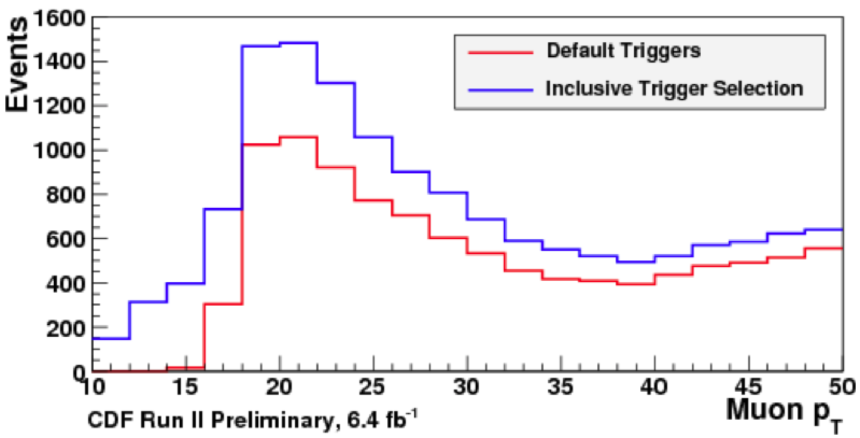
e.g. expand trigger and analysis acceptance for electrons and muons



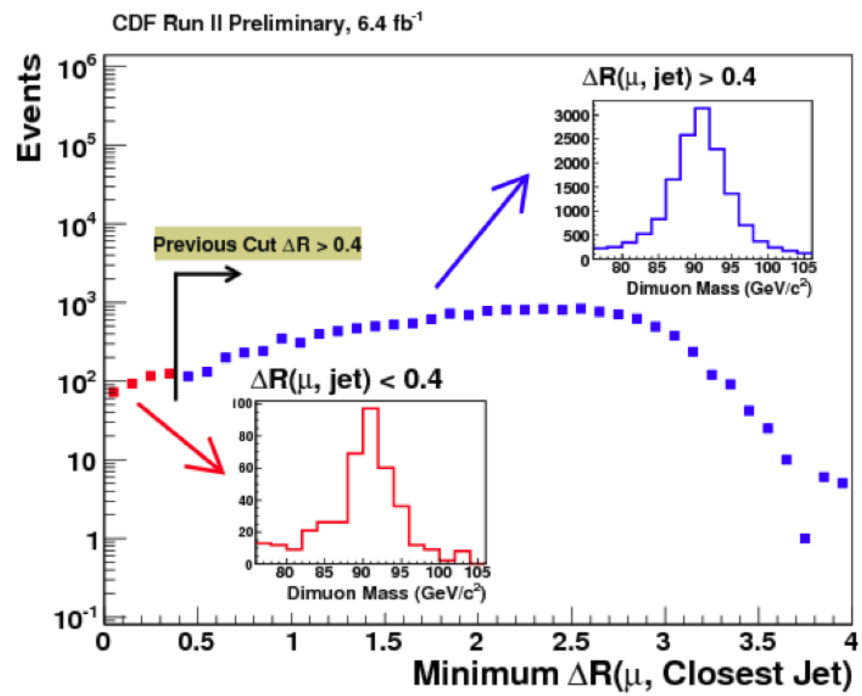


Acceptance and trigger improvements: ZH→μμbb



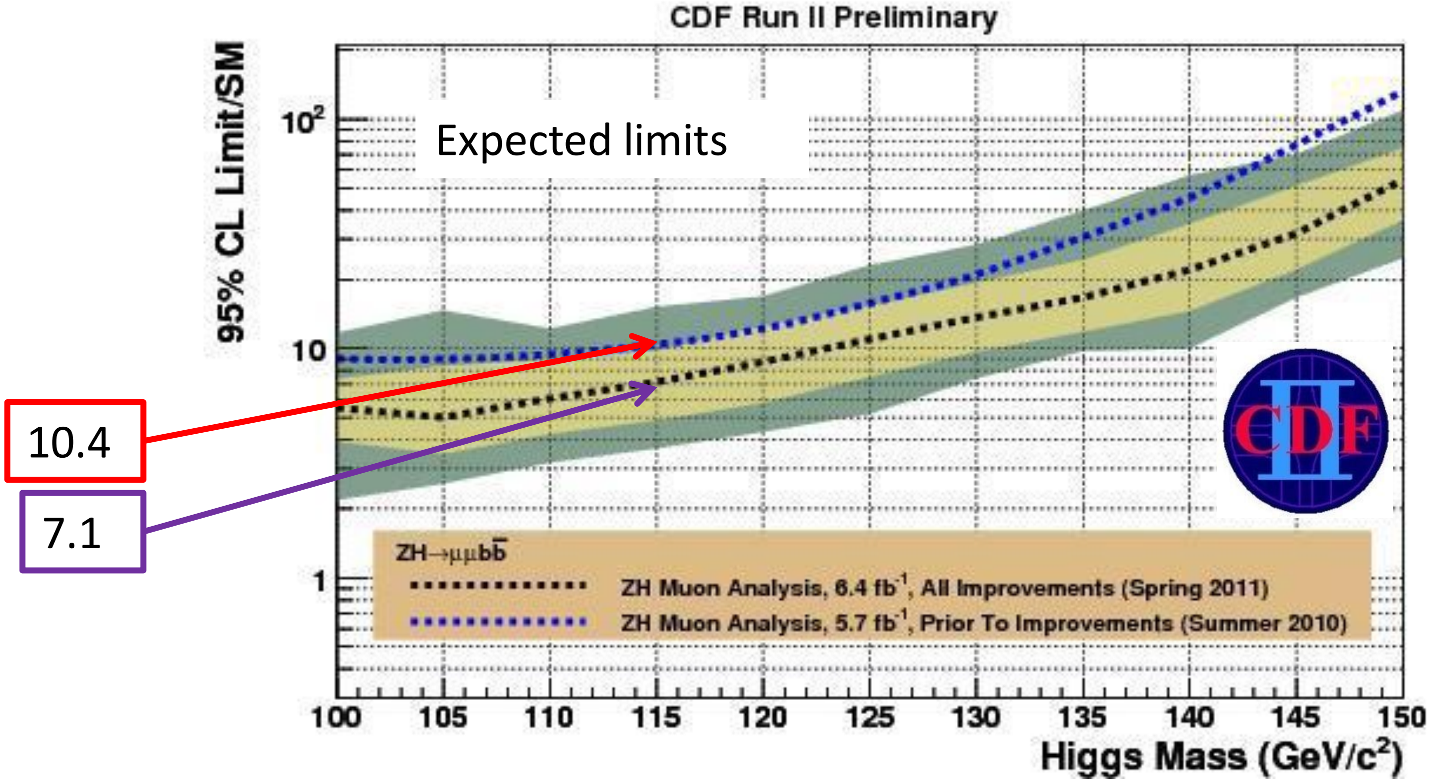


More inclusive trigger selection



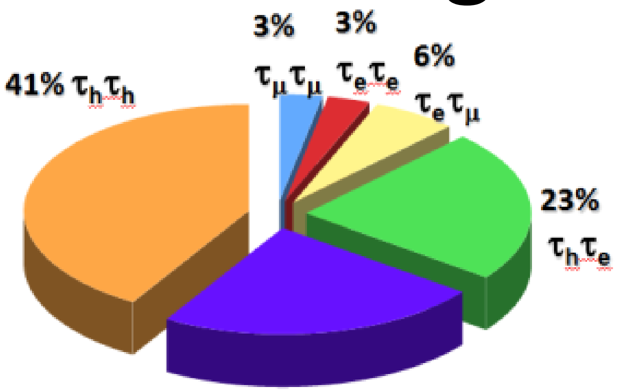
Relaxed kinematic cuts
+ NN selection

Improvements



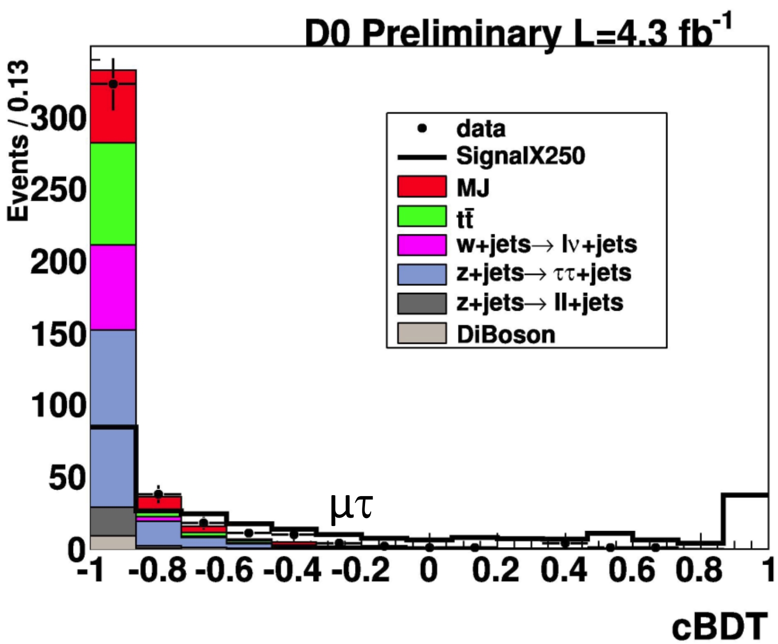
25% improvement beyond luminosity at 115 GeV!

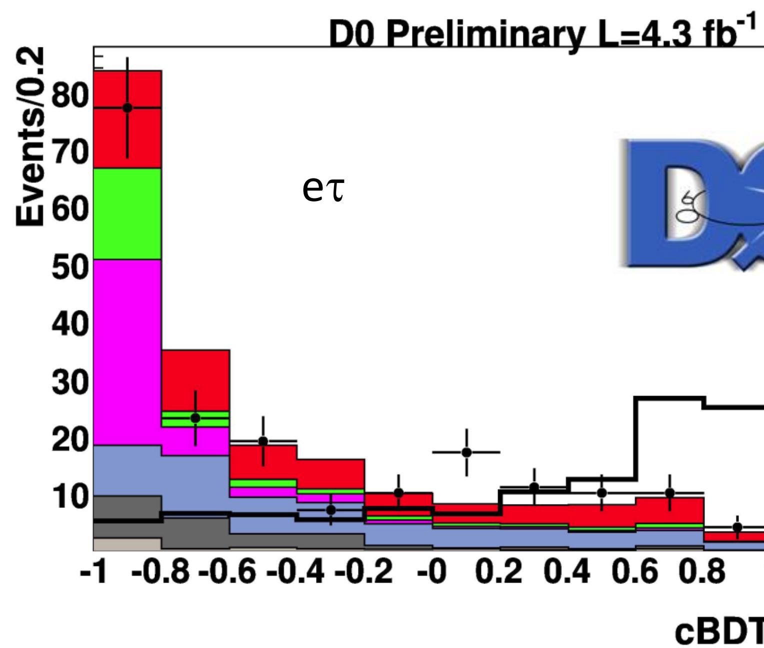
Adding channels: H⟶ττ+jets



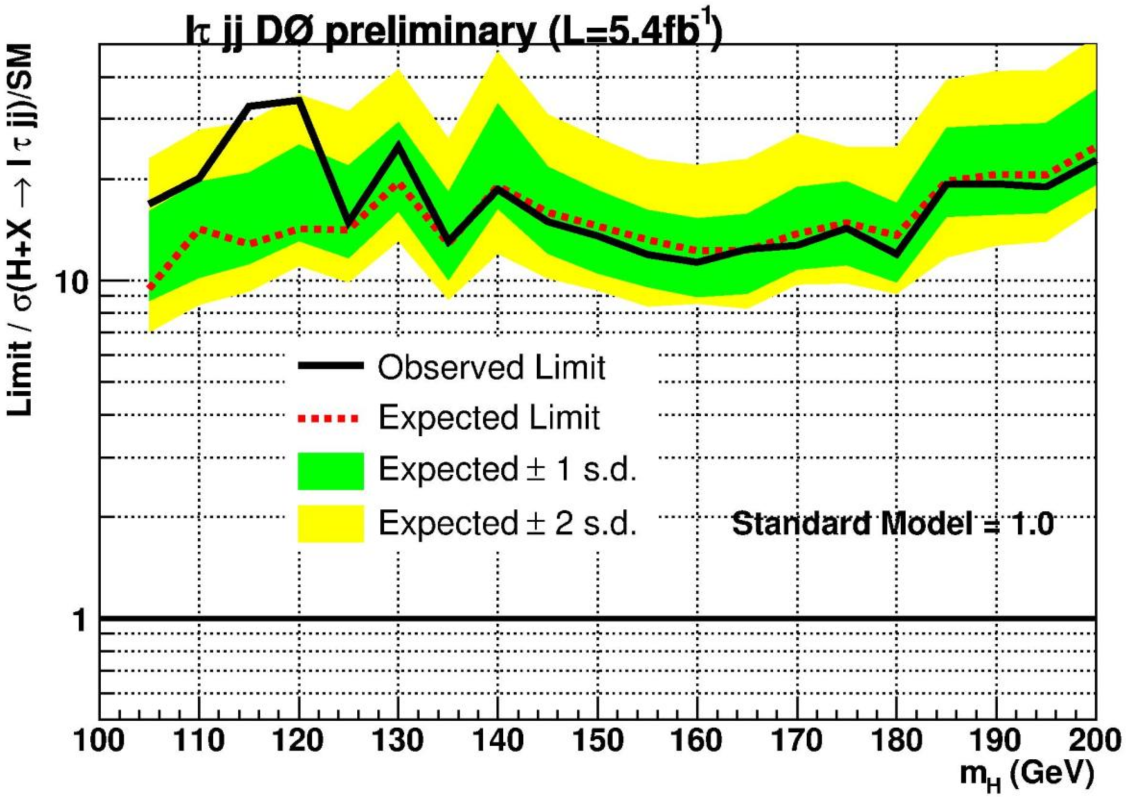
H⟶ττ+jets : look for one hadronic tau decay
+ one leptonic

D0 update adds eτ final state
and extra luminosity



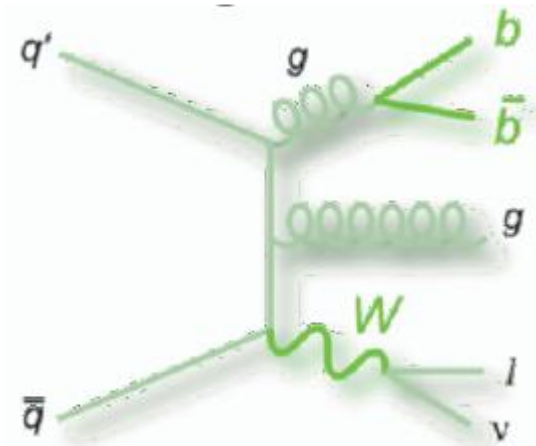


Adding channels

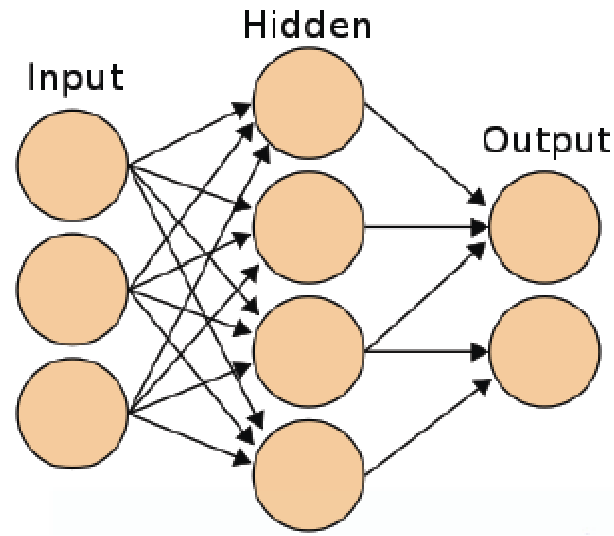


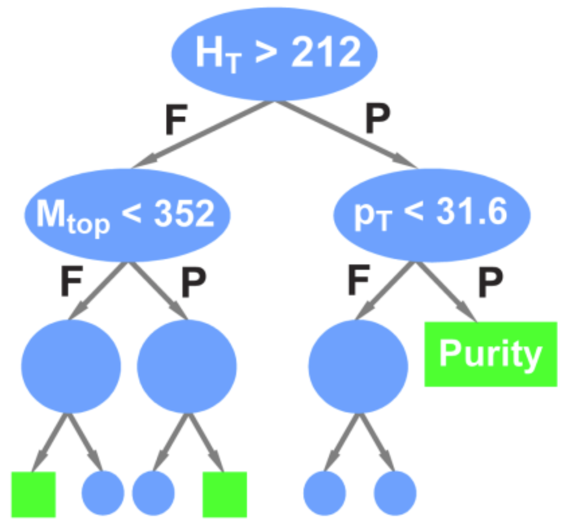
15% improvement beyond luminosity alone

Advanced techniques: Multivariate analysis



Neural networks
 - the old workhorse





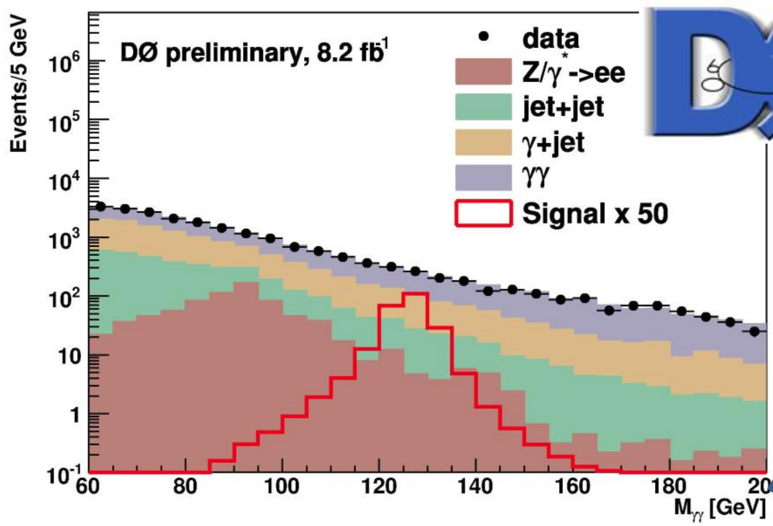
Matrix elements
 - use differential cross sections of signal and major backgrounds to estimate signal likelihood

Boosted decision trees
Random forests

 - gain by recovering events removed in traditional "cut-based analyses"

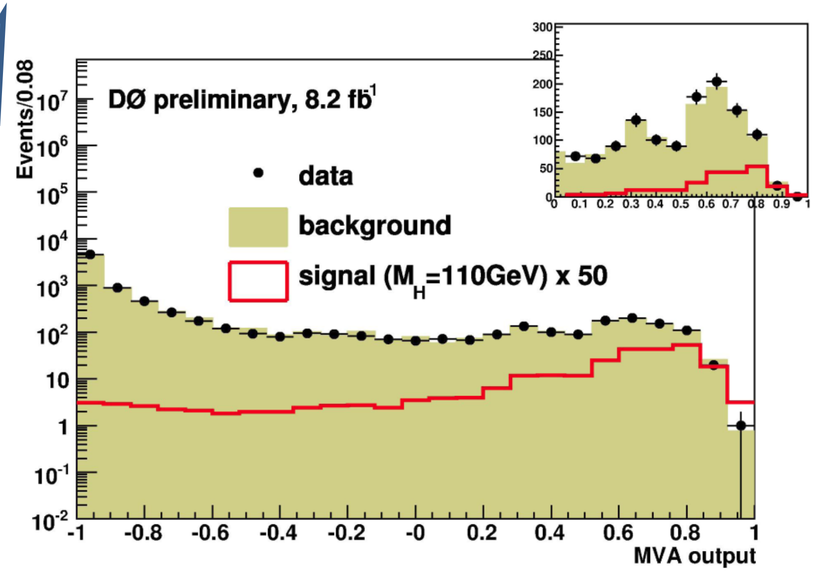
Use discriminant distribution (rather than say invariant mass or other kinematic dist.)

Multivariate techniques: H→γγ

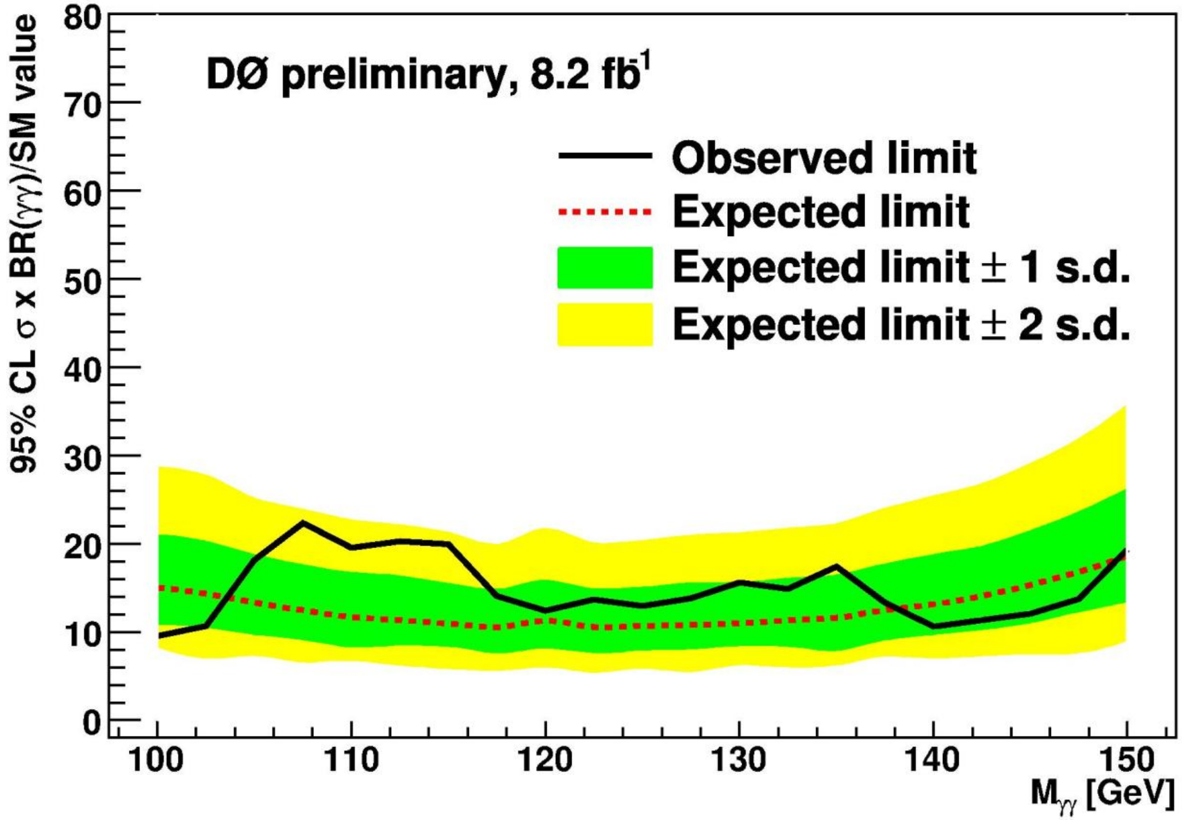


Previous version of analysis (4.2fb^{-1}) – used γγ-invariant mass distribution

Update (8.2fb^{-1}) uses decision tree distribution



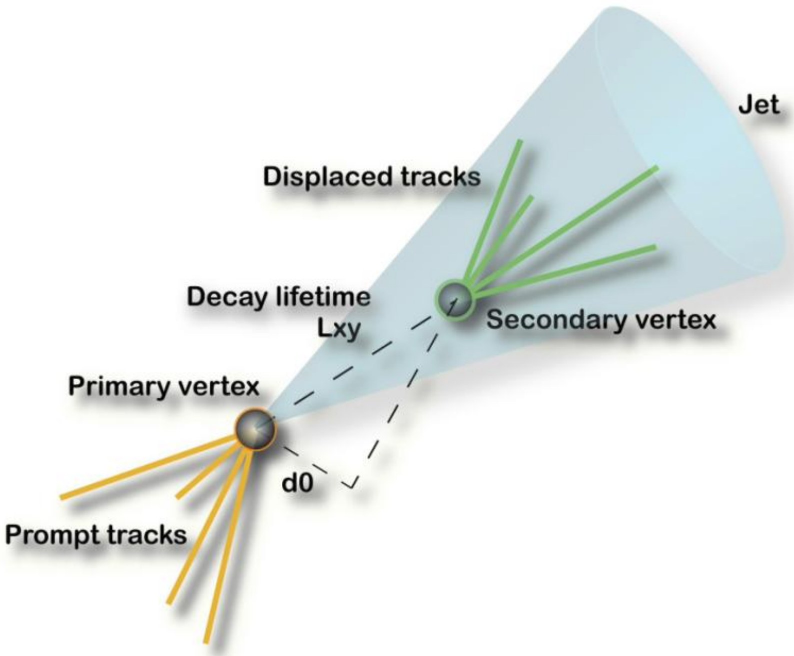
Multivariate techniques: H→γγ

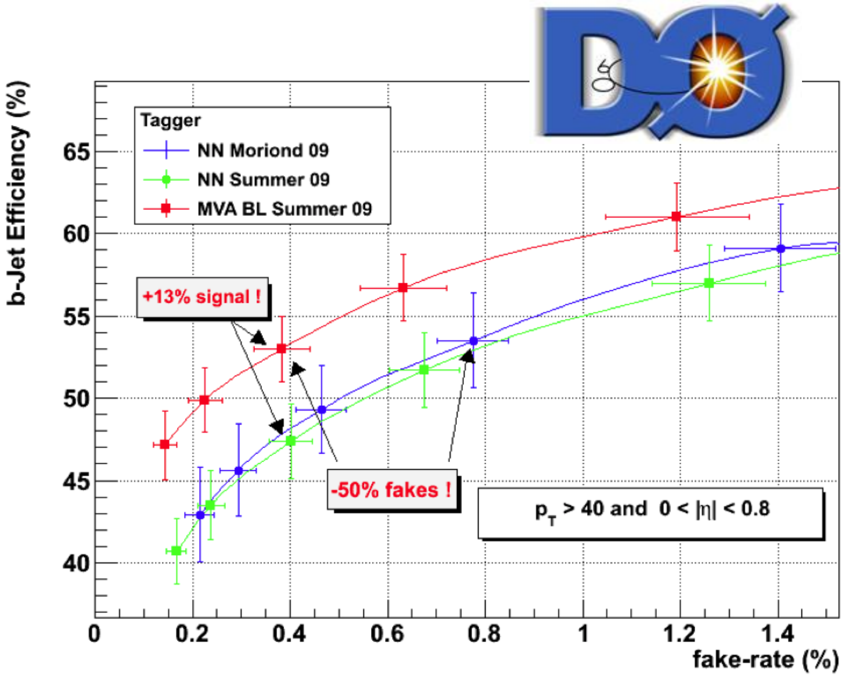


~20% increase in sensitivity beyond luminosity increase alone

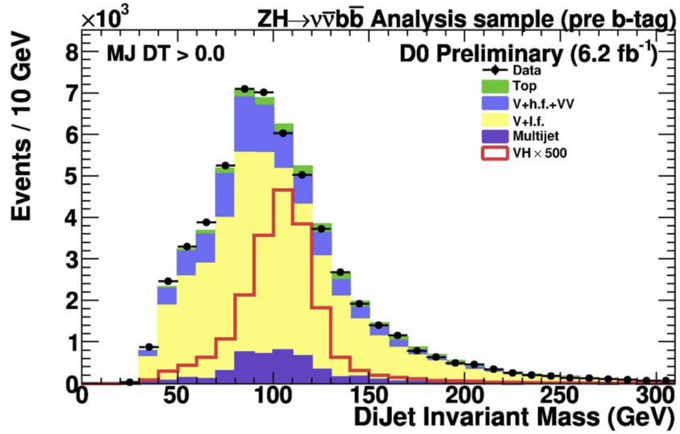
Improved b-tagging

Since H→bb dominant at low mass – b-jet identification critical



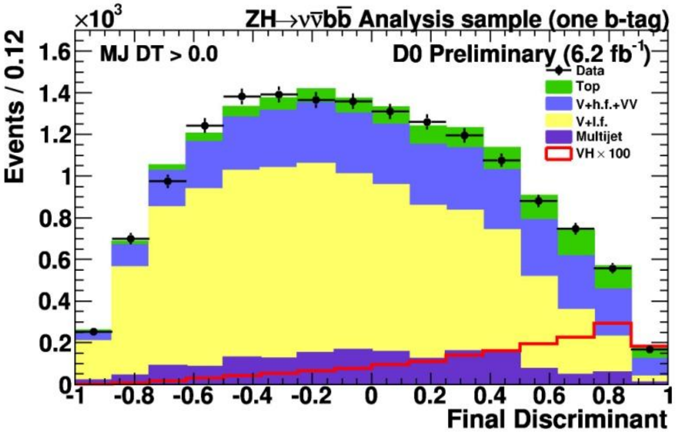


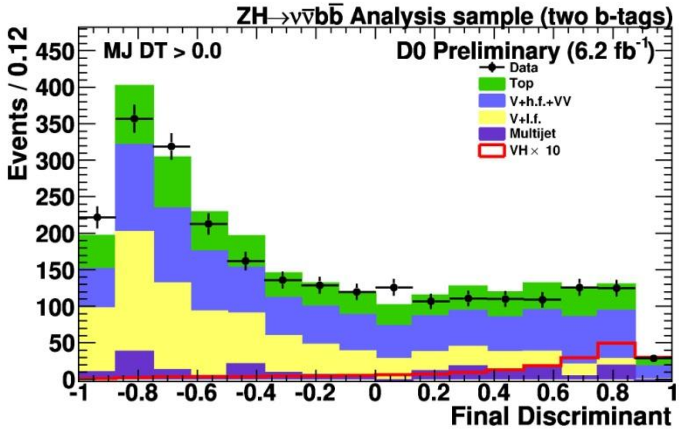
Improved b-tagging: ZH→ννbb



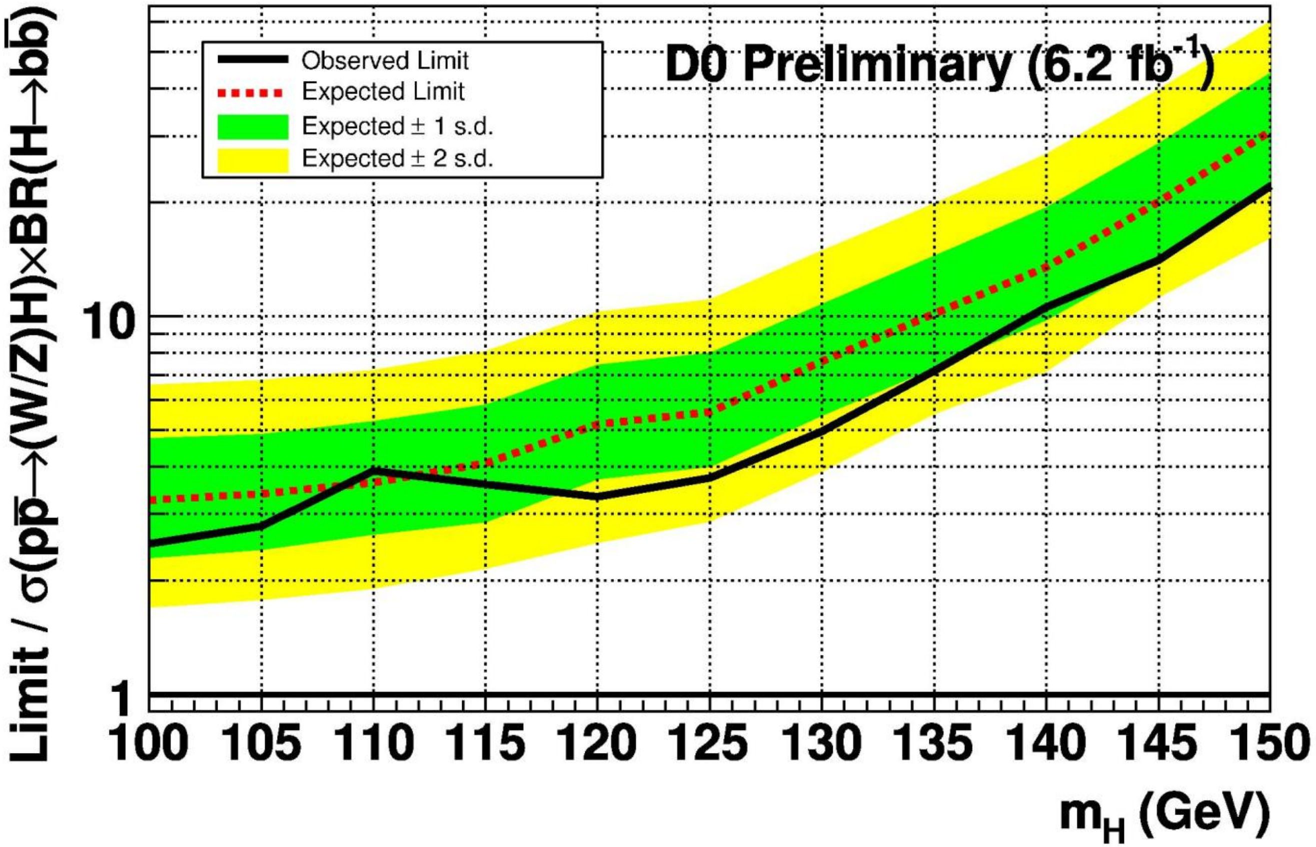
b-tagging improves discrimination

b-tagging discriminant input into final analysis discriminant





Improved b-tagging: ZH→ννbb



MVA b-tagging + use of MVA in final discriminant -> 15% improvement over luminosity alone

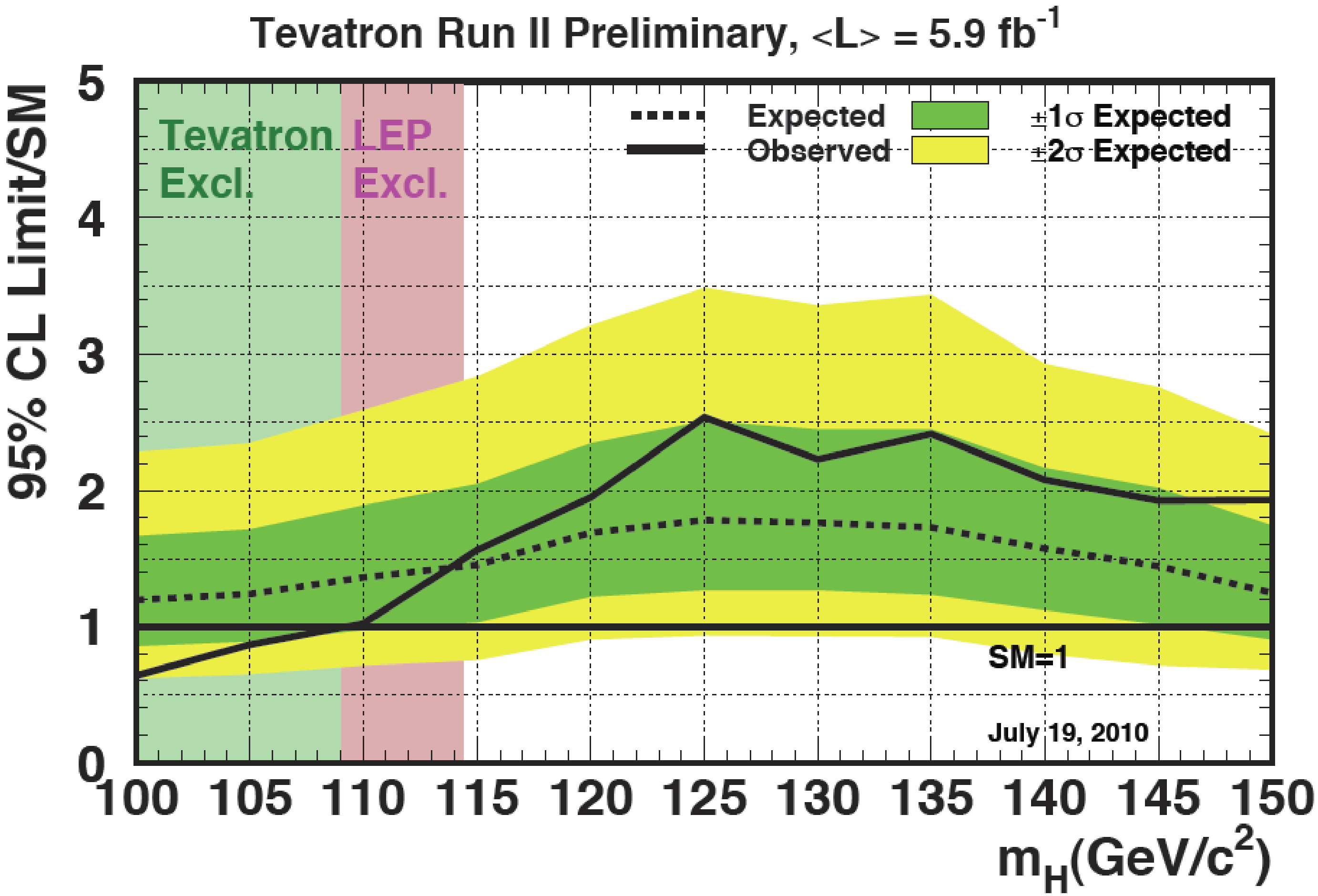
Low Mass Searches

	CDF Searches		D0 Searches	
	Lumi	Exp. Limit	Lumi	Exp. Limit
$WH \rightarrow l\nu bb$	5.7	3.5	5.3	4.8
$ZH \rightarrow \nu\nu bb$	5.7	4.0	6.4	4.2
$ZH \rightarrow llbb$	5.7	5.5	4.2-6.2	5.7
$VH/VBF \rightarrow bbjj$	4.0	17.8		
$H/VH/VBF \rightarrow \tau\tau jj$	2.3	24.5	4.9	15.9
$H \rightarrow \gamma\gamma$	4.2	20.8	4.2	18.5
$ttH \rightarrow ttbb$			2.1	45.3

Updated since last summer

Latest results and updates:
http://www-cdf.fnal.gov/physics/new/hdg/Results.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

Low Mass Combination



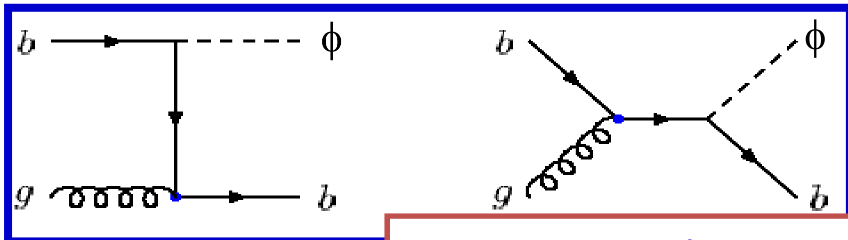
No new combination for Winter conferences – expect updates by Summer

NEW RESULTS IN BSM HIGGS

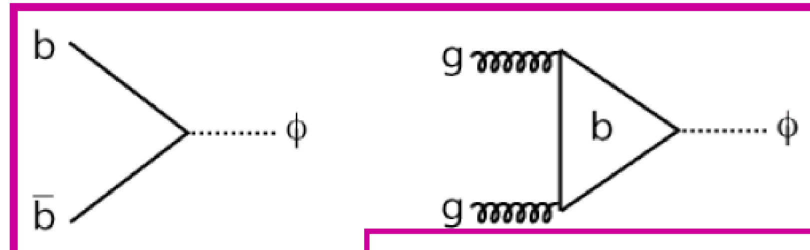
MSSM Neutral Higgs

Enhancement to “down-type” fermions

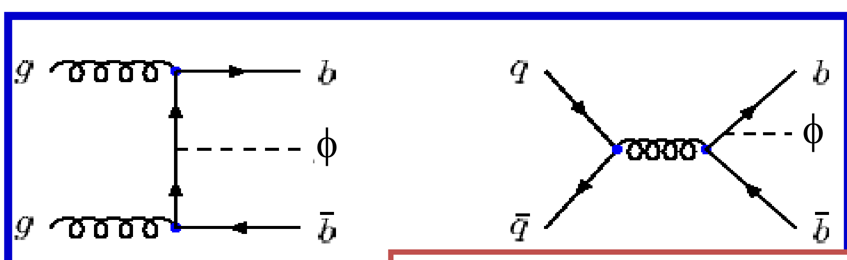
BR(ϕ→bb) ~ 90%
BR(ϕ→ττ) ~ 10%



bϕ → 3b/bττ



ϕ → ττ



bbϕ→ 4b/bbττ

ϕ→ττ

clean signatures but low BR

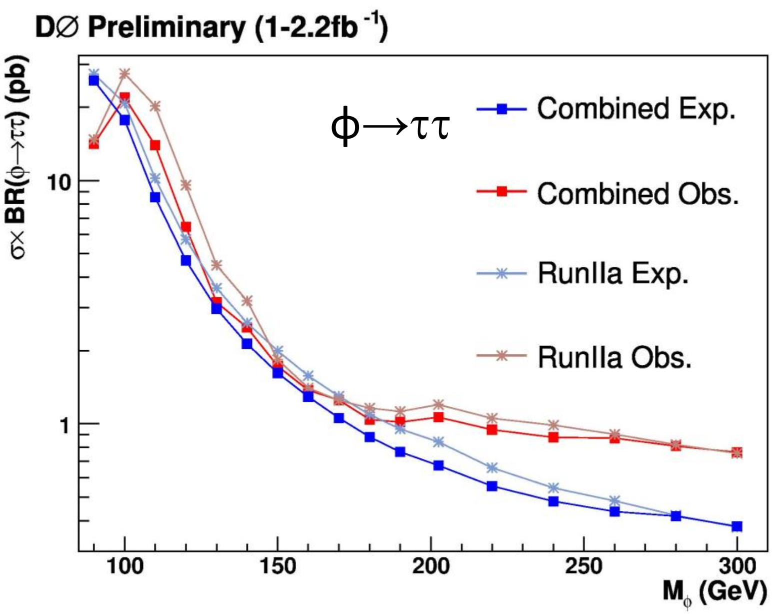
bϕ→bττ

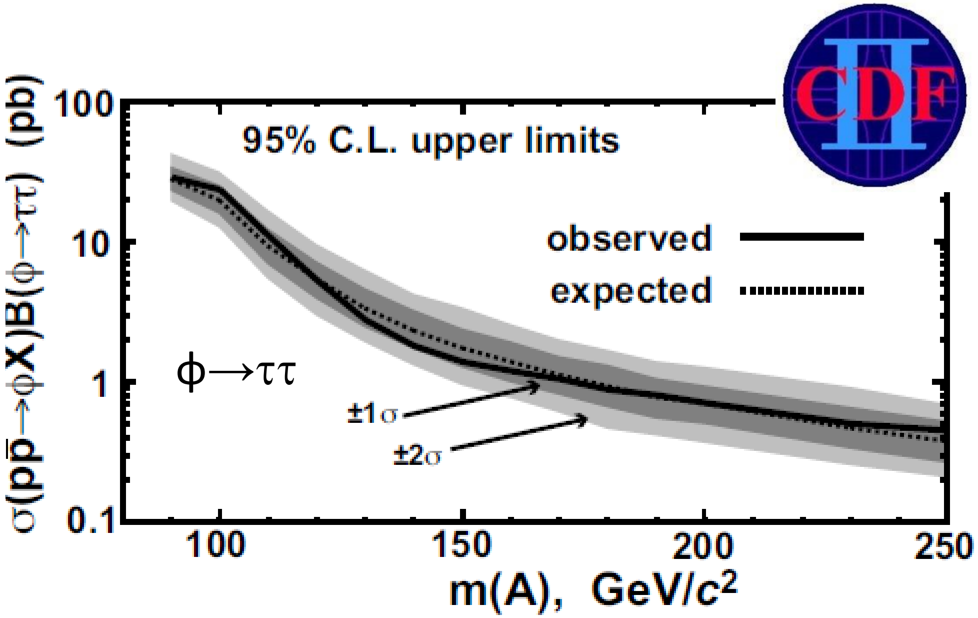
reduced backgrounds
added sensitivity at low mA

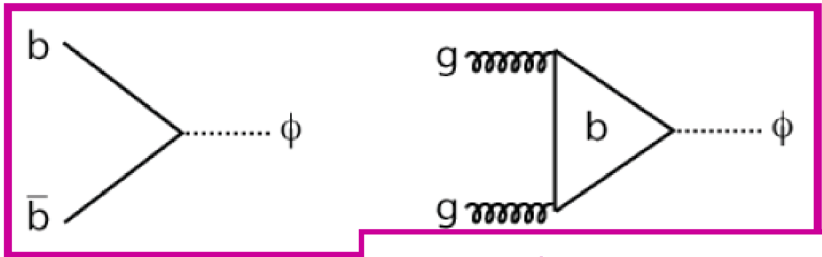
bϕ→bbb

large background
high BR

Inclusive Searches



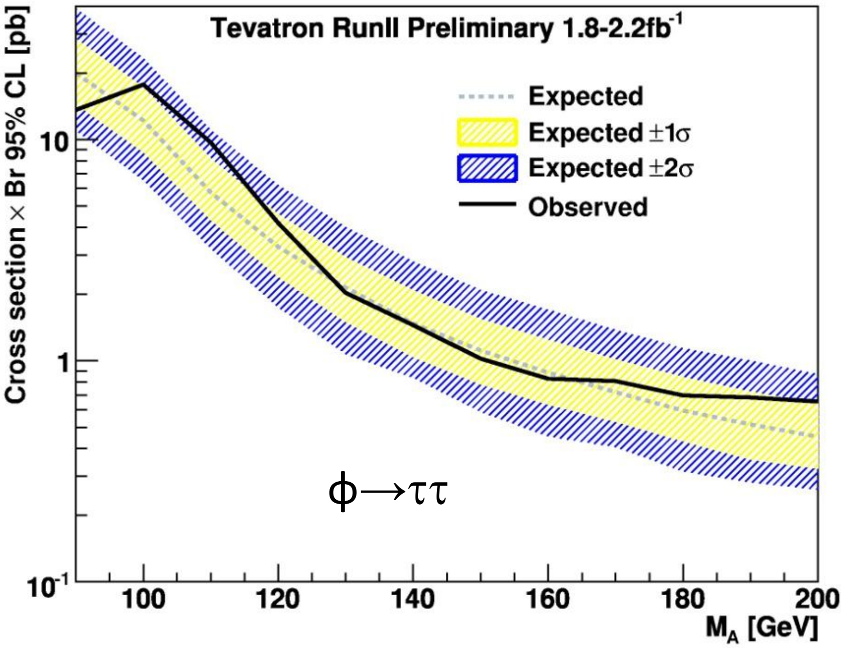


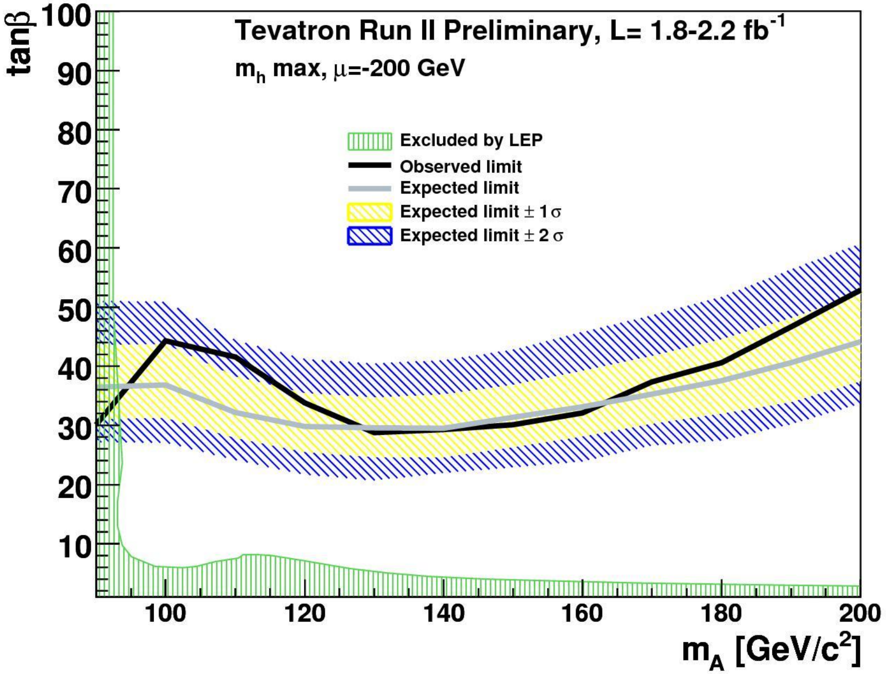


$\phi \to \tau\tau$

Inclusive Searches

Tevatron combination

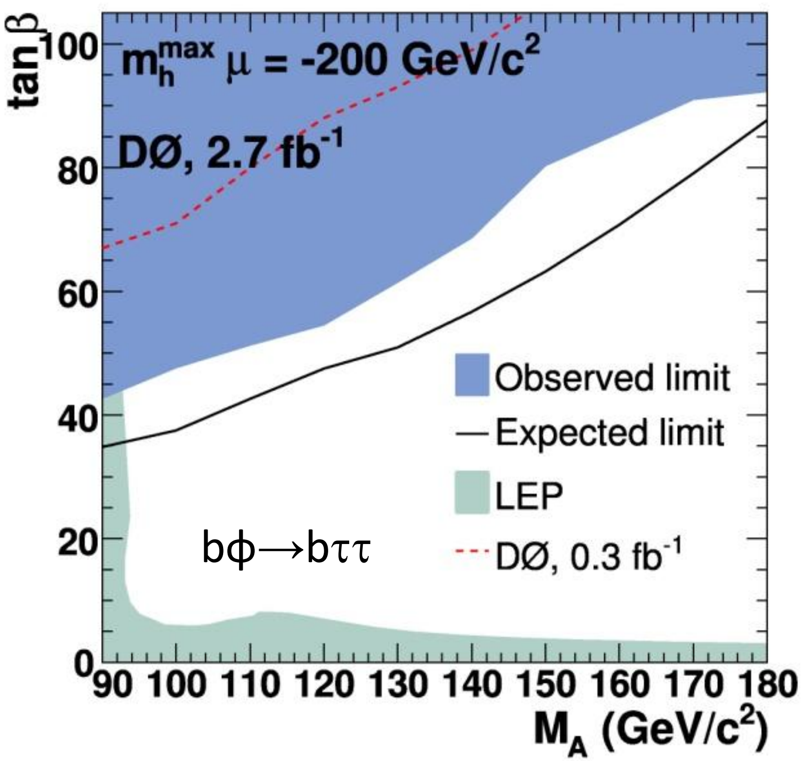




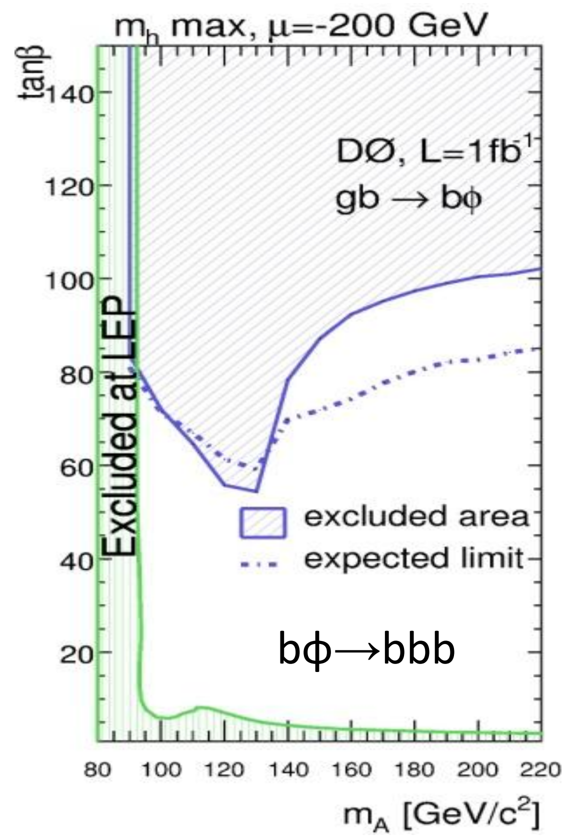
http://arxiv.org/abs/1003.3363v3

Exclusive Searches

Published results from DØ



Phys. Rev. Lett. **104**, 151801 (2010)



Phys. Rev. Lett. **101**, 221802 (2008)

Searches in tau final states

$b\phi \rightarrow b\tau_\mu\tau_{had}$

4.3 fb^{-1} integrated luminosity

Collected with single muon trigger

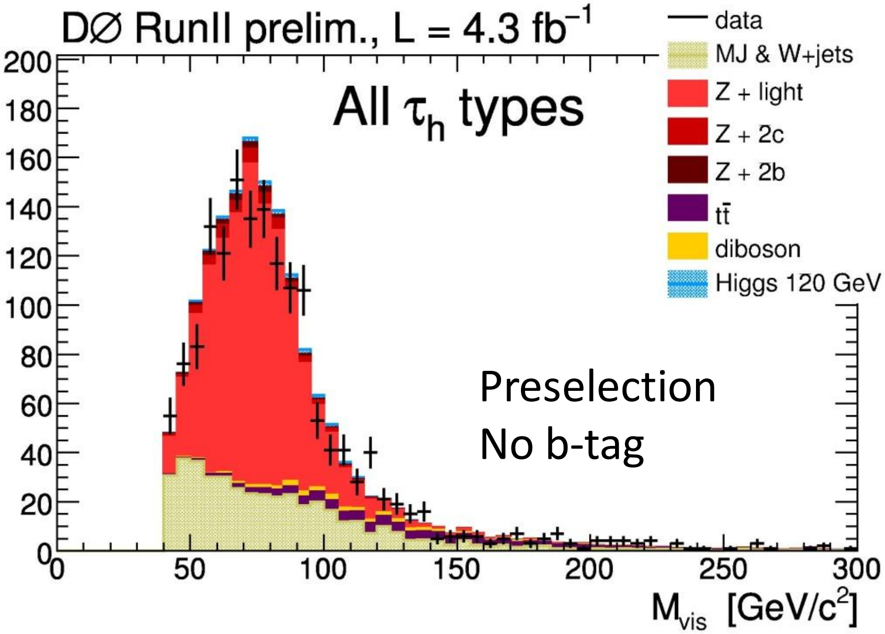
Complementary to $\phi \rightarrow \tau\tau$ and $b\phi \rightarrow bbb$

Dominant backgrounds:

- $Z \rightarrow \tau\tau$ + jets
- top pairs
- multi-jet (QCD + W+jets)

Event selection:

- Single isolated muon
- Opposite sign τ_{had}
- 1 loose b-tagged jet (ε ~ 71%)

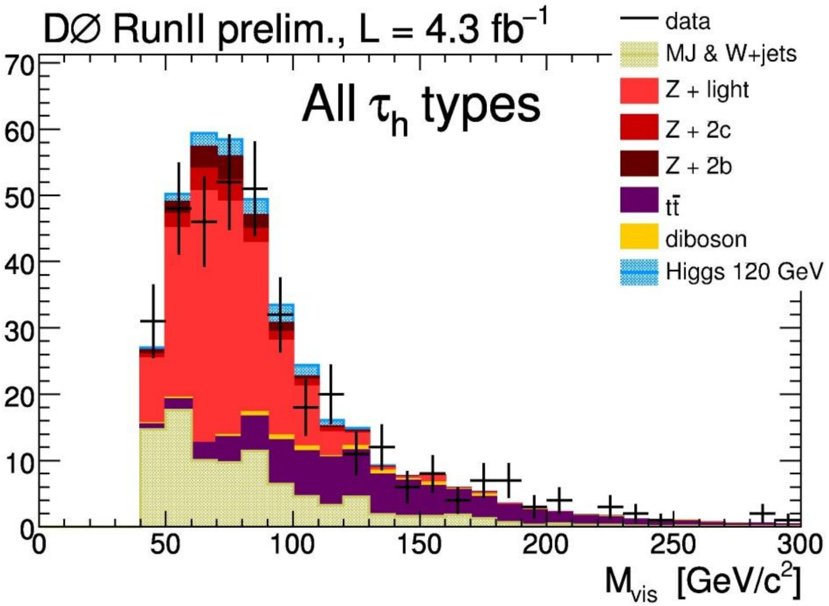


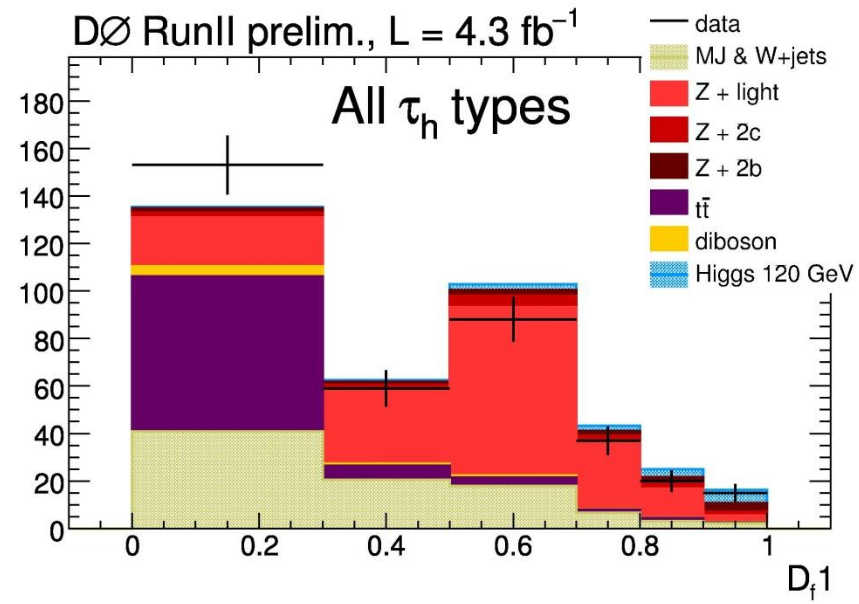
$$m_{\mathrm{vis}} = \sqrt{\left(p^{\tau_1} + p^{\tau_2} + \not{E}_T\right)^2}$$

Searches in tau final states

Train NNs to discriminate against top and multi-jet backgrounds

NN b-tagger suppresses Z+jets background



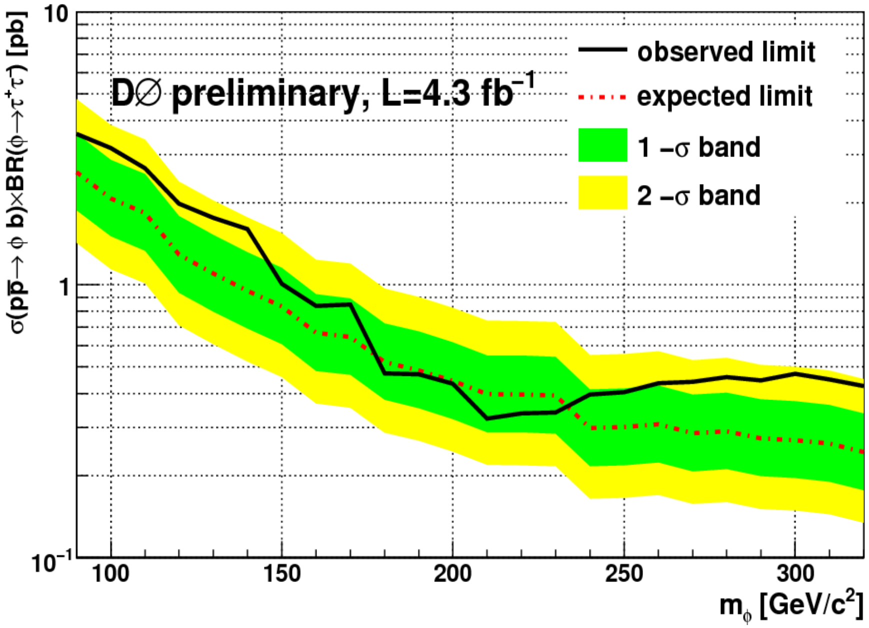


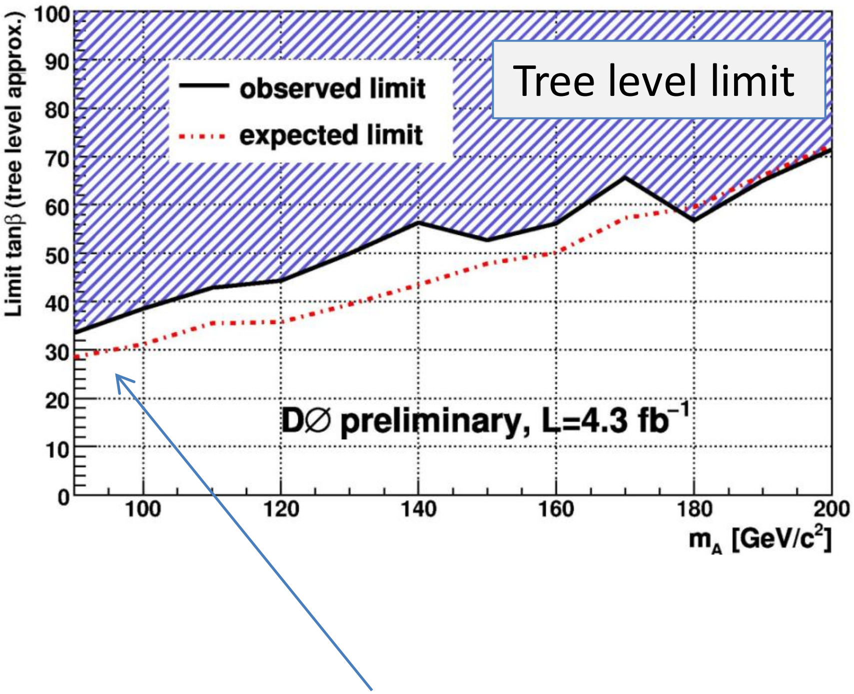
Combine all NNs into single discriminant

Final discriminant = geometric mean of 3 NN outputs

$b\phi \rightarrow b\tau_{\mu}\tau_{had}$ limits

4.3 fb^{-1} preliminary results





Limits set using “CLs” method

Most stringent limit at low M_A

Searches with b-quarks

New result with 5.2fb^{-1} data

Fermilab-Pub-10-446-E

Search for neutral Higgs bosons in the multi-b-jet topology in 5.2 fb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

V.M. Abazov,[35] B. Abbott,[72] B.S. Acharya,[29] M. Adams,[48] T. Adams,[46] G.D. Alexeev,[35] G. Alkhazov,[39]
A. Alton,[a 60] G. Alverson,[59] G.A. Alves,[2] L.S. Ancu,[34] M. Aoki,[47] Y. Arnoud,[14] M. Arov,[57] A. Askew,[46] B. Åsman,[40]

Phys. Lett. B 698, 97(2001)

arxiv.org:1011.1931

Major improvements since previous 1fb^{-1} publication

5x more data

Extended mass range: 90-300 GeV

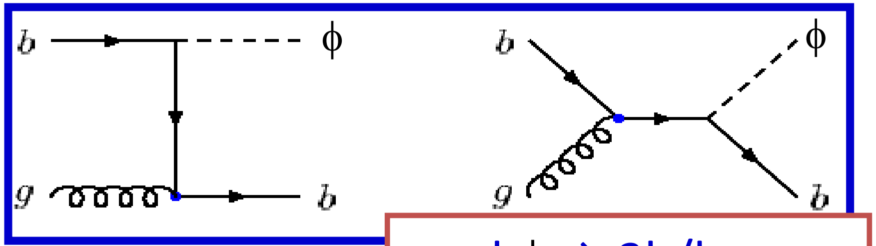
Larger MC samples

Expanded and improved treatment of systematics

- e.g. b-tagging

Re-analyzed old 1fb^{-1} data set

Searches with b-quarks



bφ → 3b/bττ

5.2fb-1 collected with jet triggers – making use of lifetime information

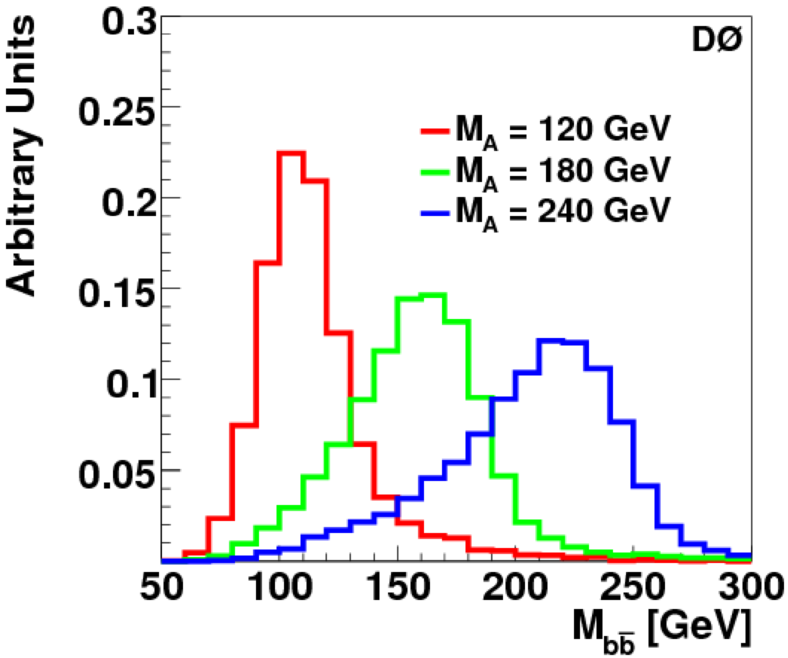
3 or 4 jets, 3 must be b-tagged

Kinematic likelihood (D) used to select best jet pairing, + cut to suppress background

Very large multi-jet background

Challenging to model
→ data driven method

Multijet cross sections not well predicted
→ float normalisation



Background Modelling

2D correction: likelihood vs invariant mass

$$S^{exp}_{3\mathrm{Tag}}(\mathcal{D}, M_{bb}) = \frac{S^{MC}_{3\mathrm{Tag}}(\mathcal{D}, M_{bb})}{S^{MC}_{2\mathrm{Tag}}(\mathcal{D}, M_{bb})} S^{data}_{2\mathrm{Tag}}(\mathcal{D}, M_{bb}).$$

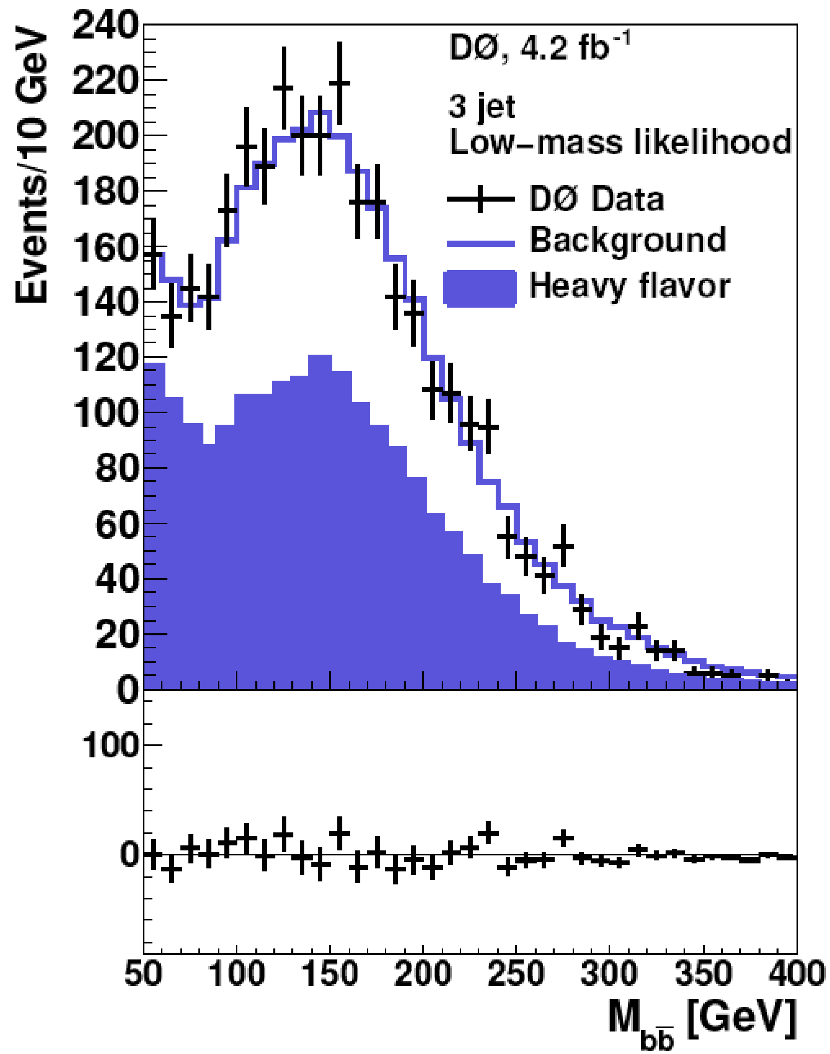
3 b-tag background

MC correction factor

2 b-tag data

Predict background shape from 2-tagged data with correction from MC

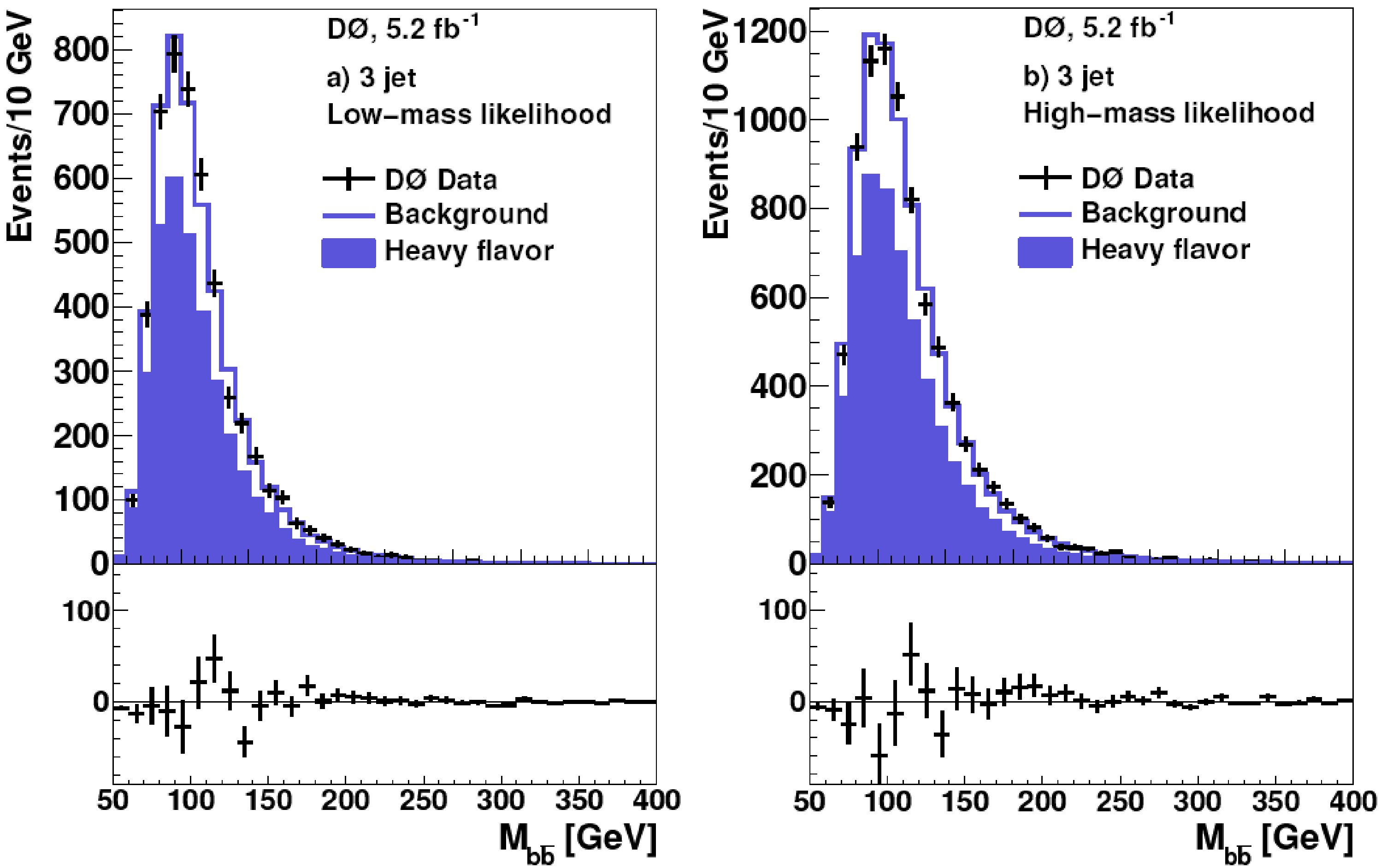
MC composition extracted from fit to data



Validate model in sideband

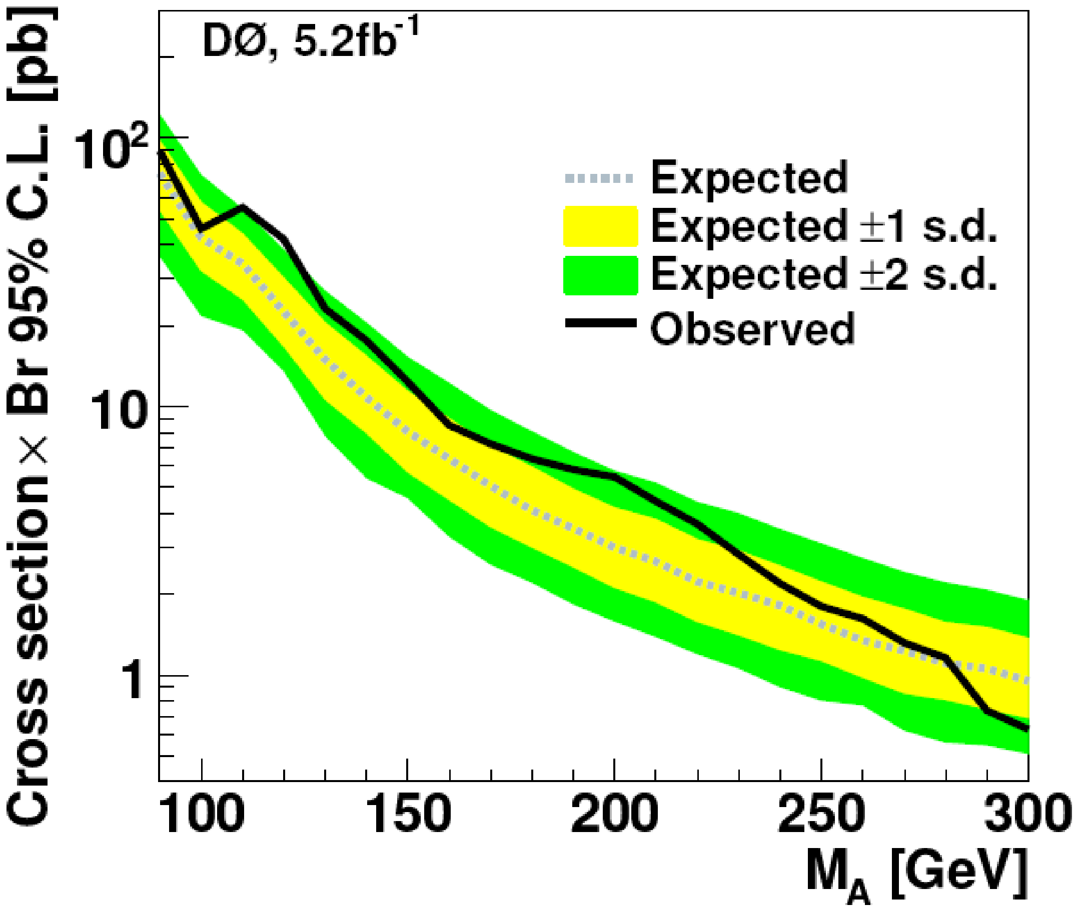
Mass distributions

Di-jet invariant mass distribution used as input for the limit setting



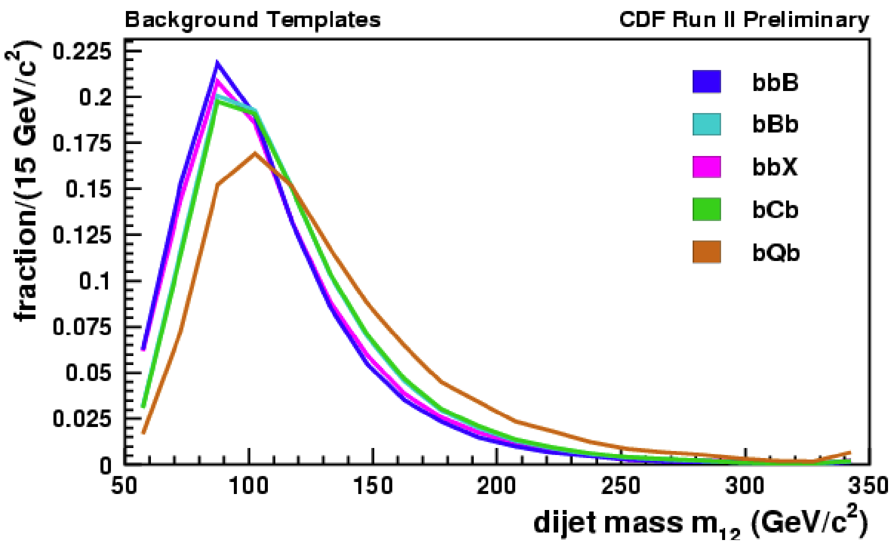
D > 0.65, background normalised to data

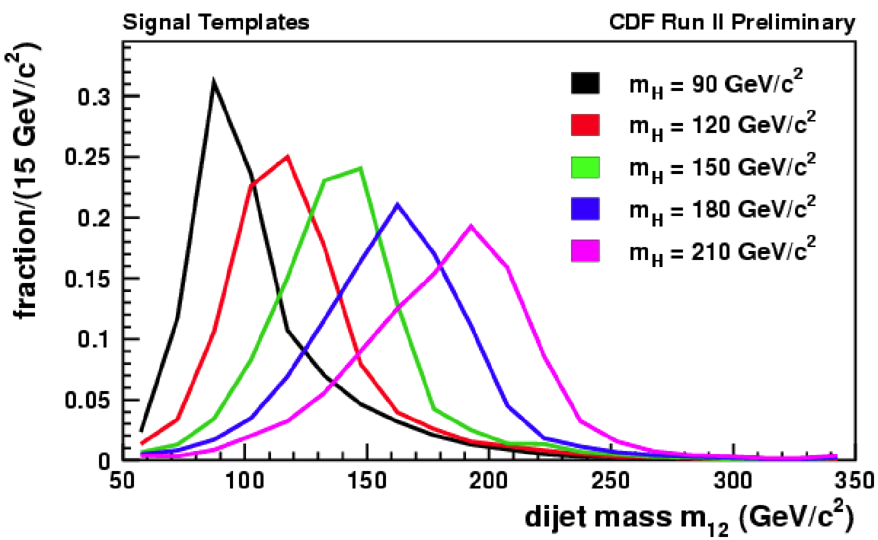
Results



DØ, 5.2fb^{-1}
Expected
Expected ±1 s.d.
Expected ±2 s.d.
Observed
Cross section × Br 95% C.L. [pb]
10^2
10
1
100
150
200
250
300
M_A [GeV]

3b @ CDF

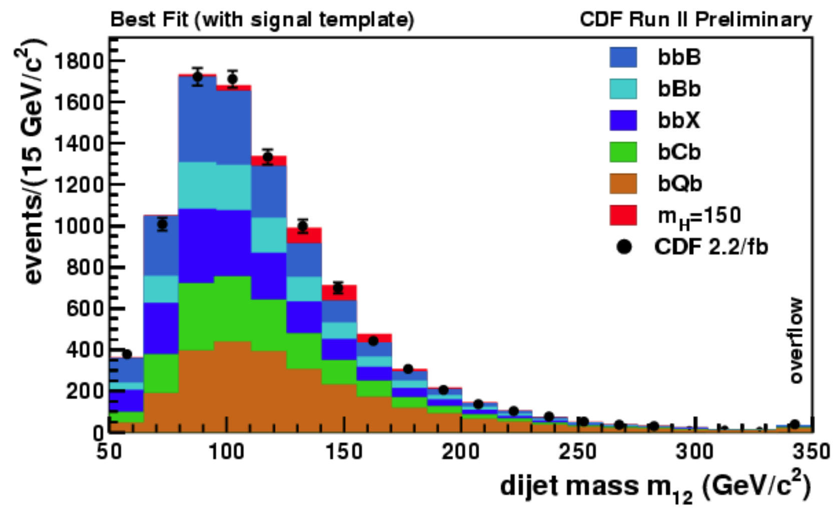




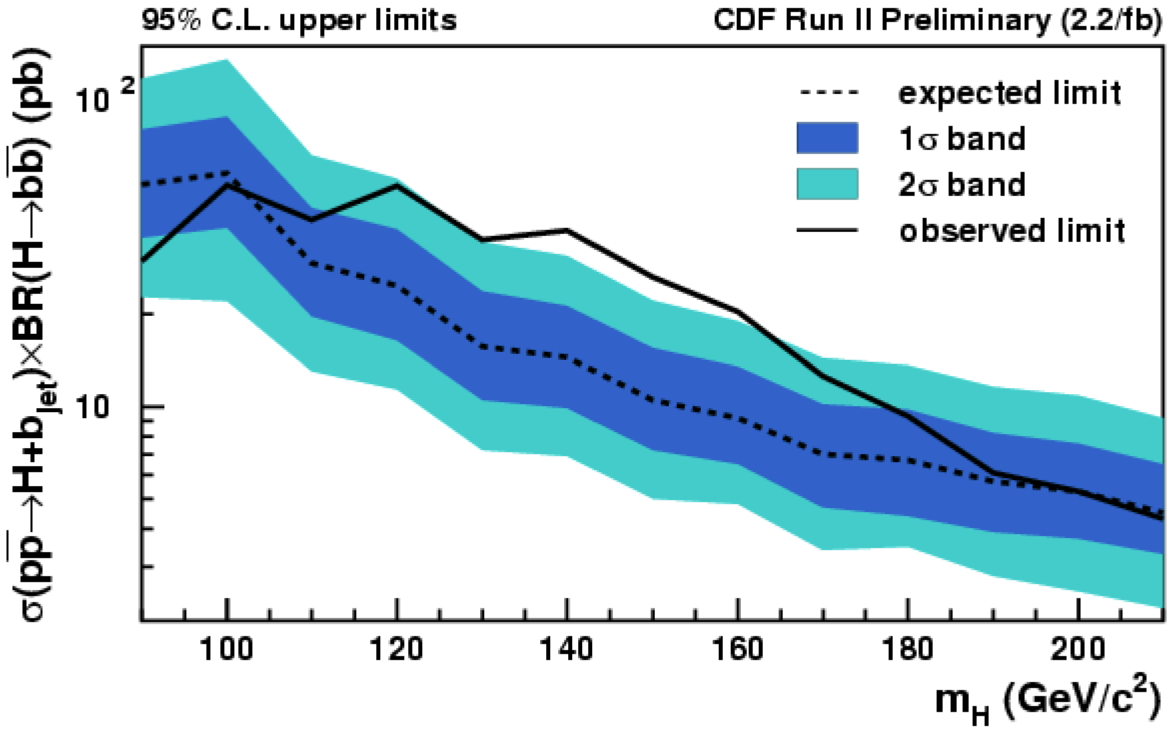
Select events with 3 b-tagged high pt jets

Form invariant mass of leading pair

Additional discriminant based on secondary vertex masses

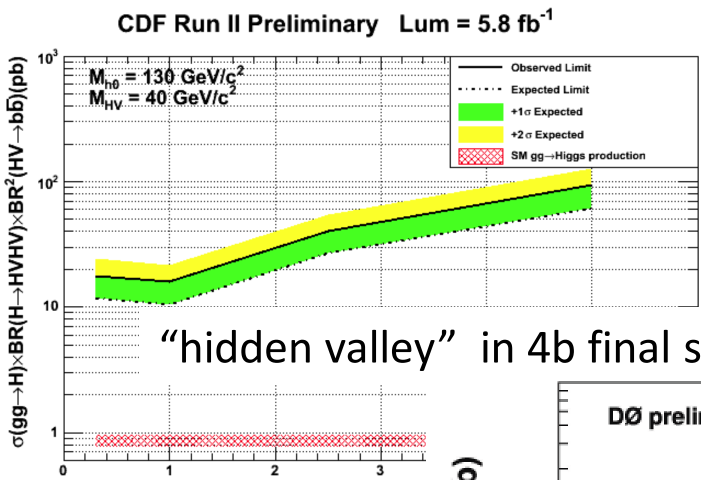


Results



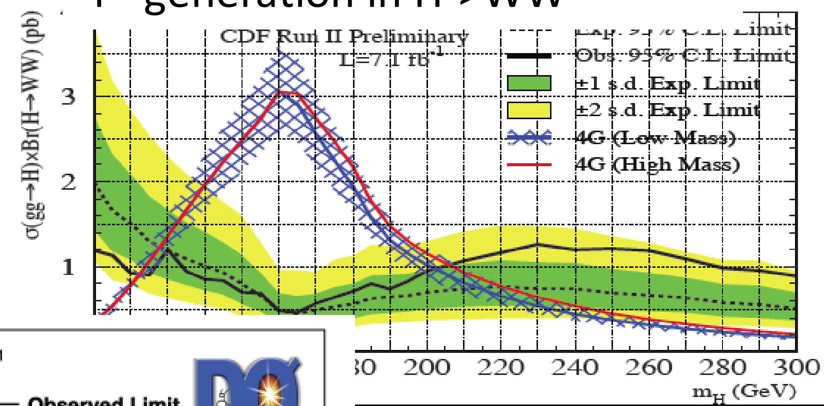
95% C.L. upper limits
CDF Run II Preliminary (2.2/fb)
expected limit
1σ band
2σ band
observed limit
$\sigma(p\bar{p}\rightarrow H+b_{jet})\times BR(H\rightarrow b\bar{b})$ (pb)
10^2
10
100
120
140
160
180
200
m_H (GeV/c^2)

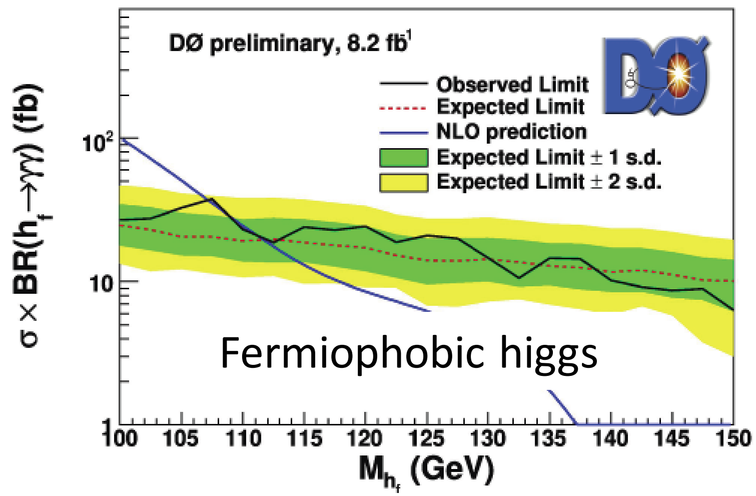
Many other results



“hidden valley” in 4b final state

4th generation in H->WW





Fermiophobic higgs

Latest results and updates:
http://www-cdf.fnal.gov/physics/new/hdg/Results.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

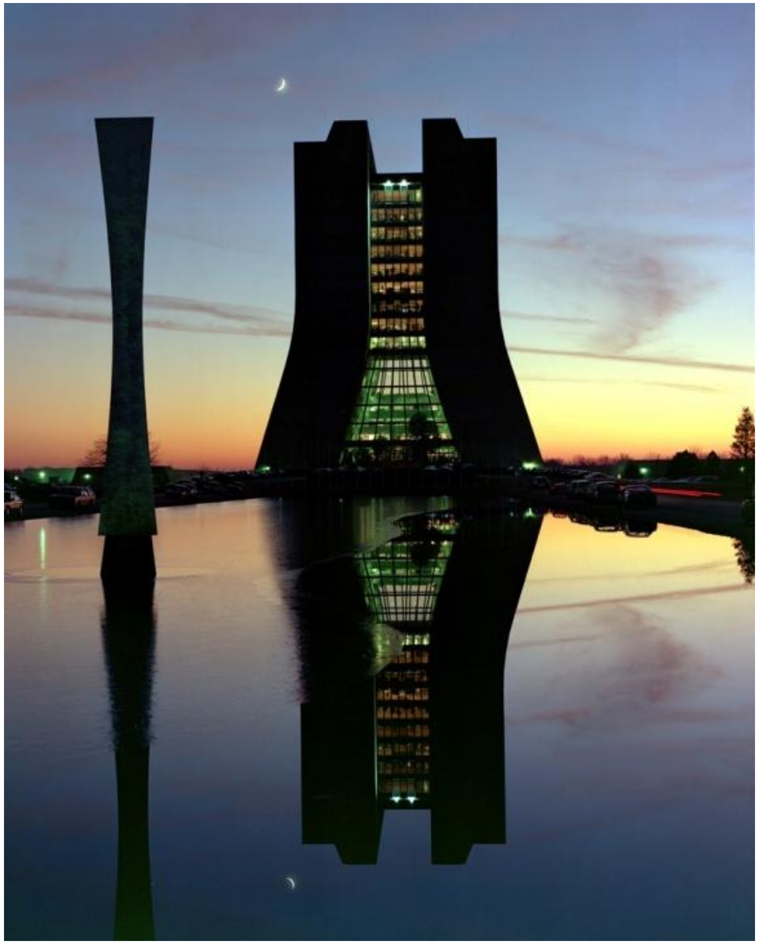
Conclusions

Rich programme of Higgs searches SM and BSM

Full data set + analysis improvements means possible exclusion $M_H < 190$ GeV

Updates and full combination expected this Summer

Sensitivity to BSM physics! Still some excitement left in the last days of Tevatron



BACKUP

Introduction

- In a conference talk it is not possible to discuss our analysis in depth. This talk is meant to clarify some of the details that feed into the calculation of the Tevatron Higgs limits.
- The Tevatron Higgs mass exclusion range is by its nature a probabilistic statement. All uncertainties must be treated properly, accounting for correlations, in order to obtain an accurate result.
- We choose theoretical inputs for our Higgs search limits that represent the consensus of the theoretical community. Picking extreme choices for these inputs would be biased and lead to over-coverage.

Derived from talk presented by M. Buehler at La Thuile 2011

Scale Variations (μ_R & μ_F)

- Is our treatment of assessing cross section uncertainties due to scale variations reasonable?

- We obtain our gluon fusion production cross sections from:

  D. de Florian, M. Grazzini, Phys. Lett. **B674**, 291-294 (2009). [arXiv:0901.2427 [hep-ph]].

  C. Anastasiou, R. Boughezal, F. Petriello, JHEP **0904**, 003 (2009). [arXiv:0811.3458 [hep-ph]].

- We use a scale variation of a factor of 2 from the central value ($\mu=m_H/2$) to estimate the magnitude of potential contributions from higher-order processes

- The authors confirmed that higher order corrections to these cross sections are small and that the standard $\kappa=2$ scale variations are perfectly reasonable for assigning uncertainties

- Another recent, independent publication argues for even smaller scale uncertainties than those being currently assigned in our searches:

  V. Ahrens, T. Becher, M. Neubert *et al.*, Eur. Phys. J. **C62**, 333-353 (2009). [arXiv:0809.4283 [hep-ph]];

  V. Ahrens, T. Becher, M. Neubert *et al.*, [arXiv:1008.3162 [hep-ph]].

- **Yes, our treatment is sufficient and supported by the theoretical community**

Additional Theoretical Uncertainties

- Should there be an additional theoretical uncertainty assigned to our gluon fusion cross sections coming from the effective field theory (EFT) approach used to integrate electroweak contributions from heavy and light loop particles?
- Such an uncertainty is already included:

  C. Anastasiou, R. Boughezal, F. Petriello, JHEP **0904**, 003 (2009). [arXiv:0811.3458 [hep-ph]].

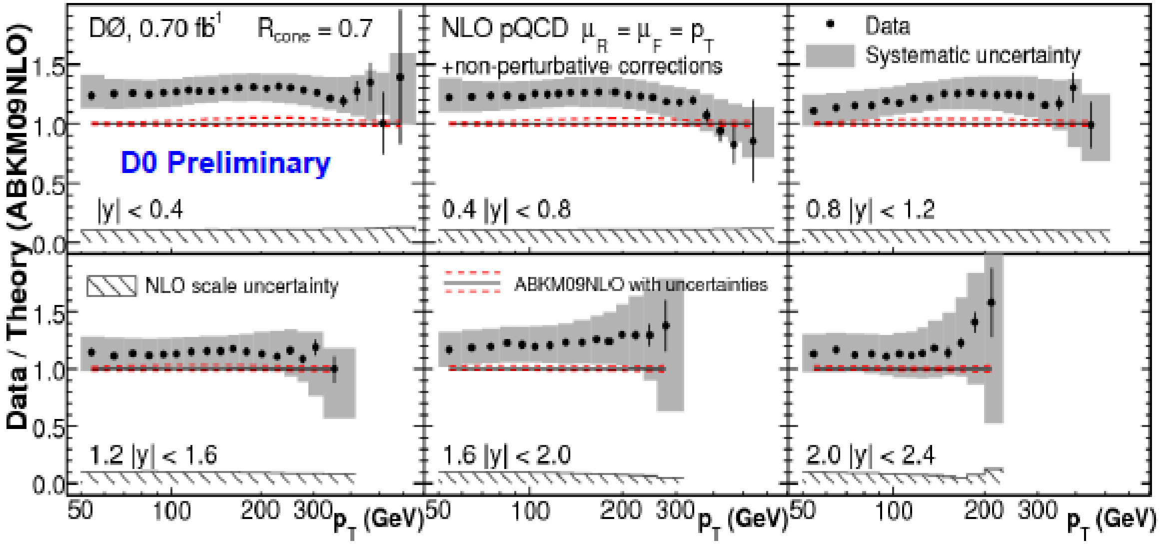
- Uncertainties on the gluon fusion cross section used in Tevatron Higgs searches incorporate a ~2% level component to account for this effect
- The same authors find that when they entirely remove corrections from light quark diagrams (clearly too conservative), the total cross section changes by less than 4%
- **Our current treatment of EFT effects is on solid ground**

PDF Uncertainties

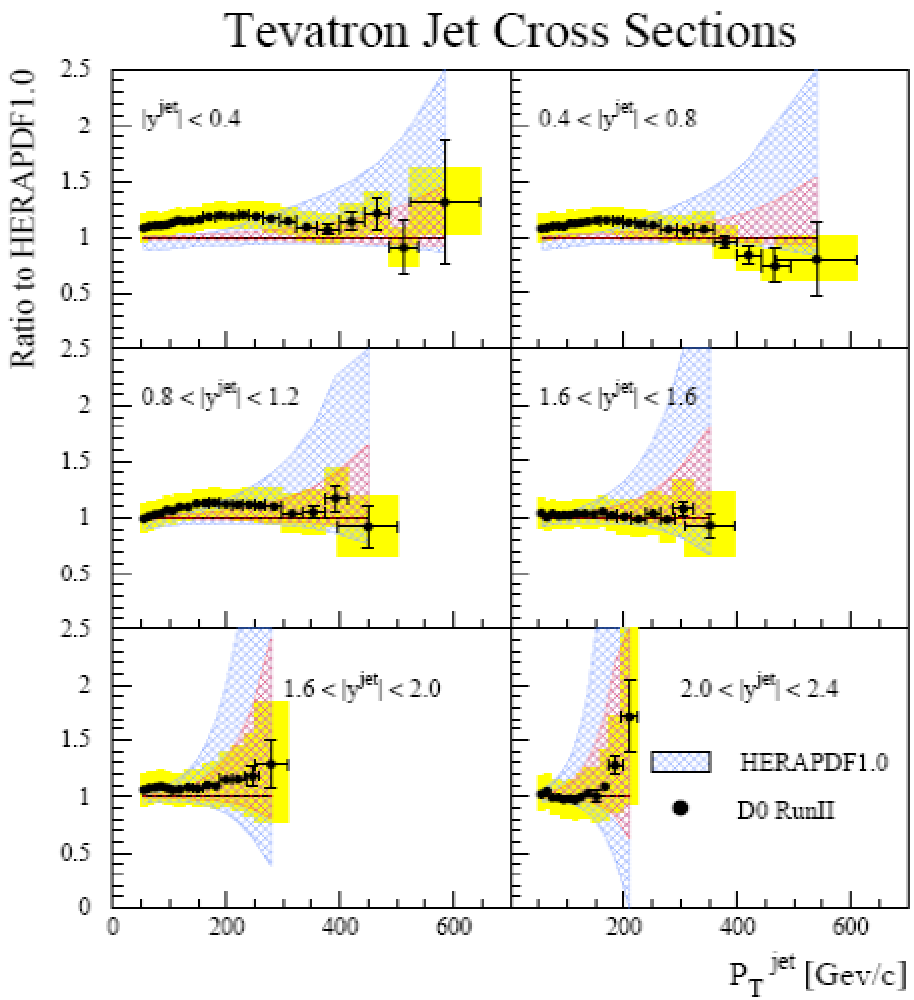
- Should our PDF uncertainties account for observed differences in cross sections obtained using our default MSTW model and ABKM/HERAPDF models?
- See Juan Rojo's talk on "Recent Developments and Open Problems in Parton Distributions" in the Tuesday afternoon session
- ABKM09 & HERAPDFs do not include Tevatron data, which provide the best constraints on the relevant high-x gluon distributions at Tevatron energies
- A comparison of high E_T Tevatron data with ABKM09 & HERAPDF shows large disagreement:

ABKM09 at the Tevatron:
Ratio of D0 High-ET jet cross-section to ABKM09 prediction (Data vs central PDF value)

(→ Uncertainty on ABKM Prediction)



PDF Sets



HERAPDF1.0 at the Tevatron:
Ratio of D0 High-ET jet cross section to HERAPDF1.0 prediction (Data vs central PDF value)

→ Total PDF uncertainty
→ Experimental PDF uncertainty
→ Systematic experimental error

- Our choice is also consistent with recommendations by the PDF4LHC working group, which is charged to provide guidance to experiments with respect to the use of PDF sets: http://www.hep.ucl.ac.uk/pdf4lhc/
- **Our PDF uncertainties are appropriate**

H1 & Zeus collaborations:
https://www.desy.de/h1zeus/combined_results/benchmark/tev.html

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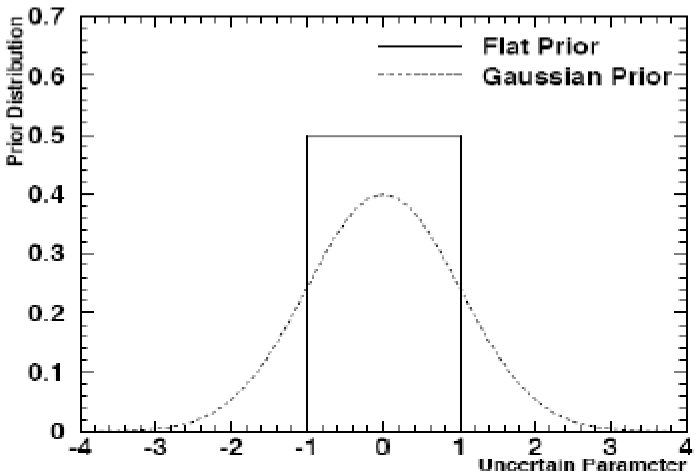
Treatment of Theoretical Uncertainties

- Most theoretical uncertainties are rather loosely stated. They are interpreted in terms of a maximum range of variations (*flat prior*)
- We treat theoretical uncertainties as gaussian (*gaussian prior*)
- Are we underestimating our uncertainties?
- We use the maximum bound as 1σ. This means we allow even larger variations than the given bounds. (See figure)
- We also tested the flat prior approach and found no significant change in our limits
- **We are not underestimating our uncertainties**



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Emulation of Tevatron Limit Calculation

- Care needs to be taken when trying to emulate Tevatron limits
- Correlations between different input channels need to be properly taken into account:
  - Our limit calculation uses these correlations to constrain the backgrounds
  - Our backgrounds are better constrained by the data, as compared to the theory. This can be viewed as a measurement of the true rate and the a posteriori uncertainty is an experimental determination of the true error.
- An estimation of the sensitivity increase due to MVA is not straightforward:
  - Our pre-selection cuts are kept as loose as possible to maximize signal acceptance and cannot be interpreted as an optimized cut-based analysis
  - MVAs are used to separate signal from background
  - To estimate MVA sensitivity gains: compare fully optimized cut-based results with MVA results
  - MVAs typically improve limits by ~30% over optimized cut-based
- Impact of theoretical uncertainties:
  - Theoretical uncertainties are statistically accounted for together with other systematics
  - Increasing theoretical cross section uncertainties is not equivalent to decreasing the central prediction

Conclusion

- Our Higgs limits are based on standard practices of the HEP community and the base assumptions that meet a consensus
- We are happy that our results on Higgs boson searches have captured the interest of the HEP theory community
- We welcome the scrutiny that comes with producing such important results
- **The Higgs limits obtained by the Tevatron are sound and indicate exclusion of the Higgs boson with masses between 158 and 175 GeV at the 95% CL**

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