New Standard Model Higgs Results from DØ

Fermilab Joint Experimental-Theoretical Seminar

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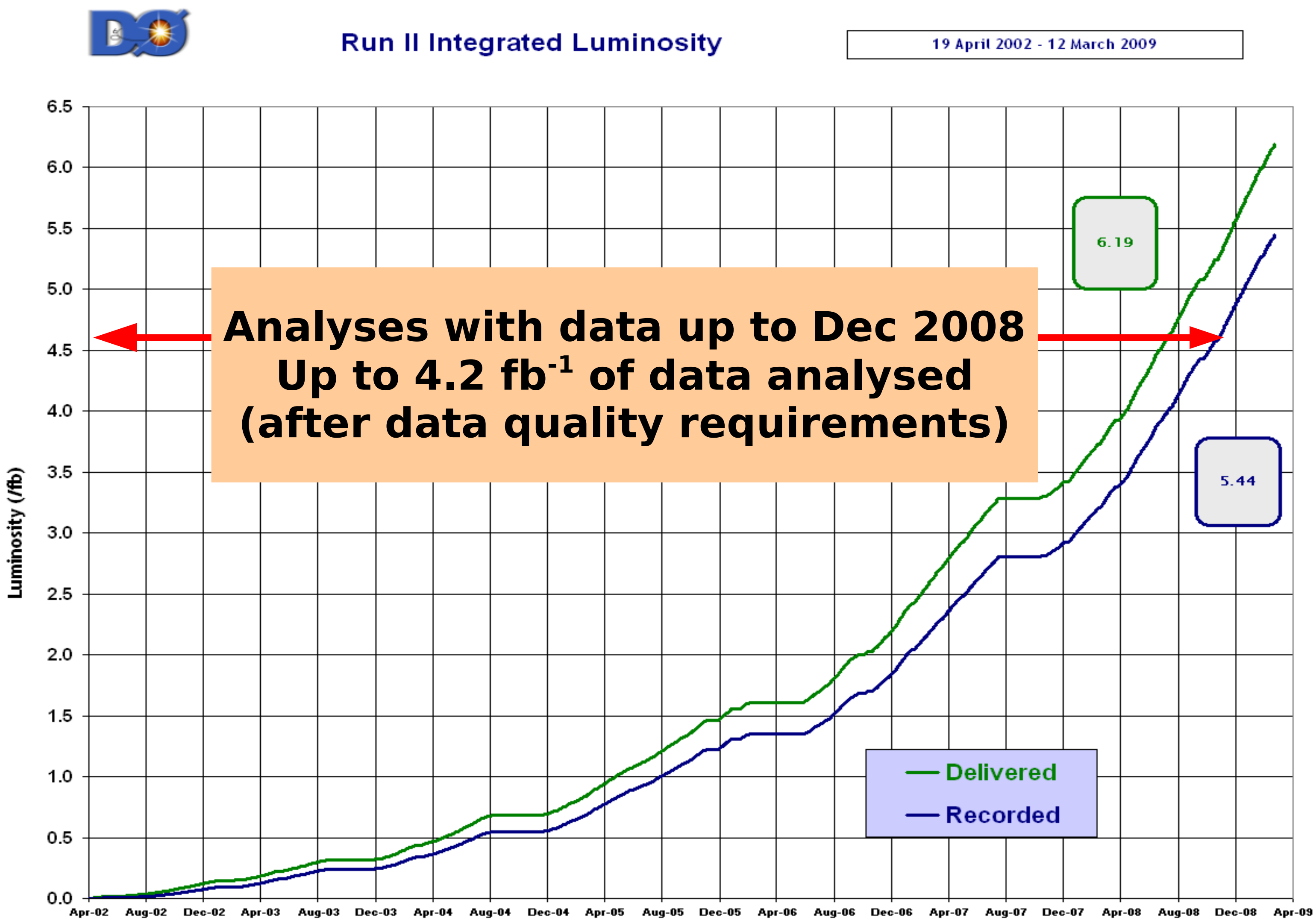
Many thanks to my DØ colleagues and to the TEVNPHG working group

Outline

- Introduction
  - Searching for the Higgs at Tevatron
- High mass region
  - $H \rightarrow WW$
- Low mass region
  - $WH \rightarrow l\nu bb$
  - $ZH \rightarrow llbb$
  - WH/ZH final states with τ
  - $H \rightarrow \gamma\gamma$
- Filling the gap
  - $WH \rightarrow WWW \rightarrow$ like-sign dileptons
- Combinations
  - DØ combination
  - Tevatron combination (low mass region)

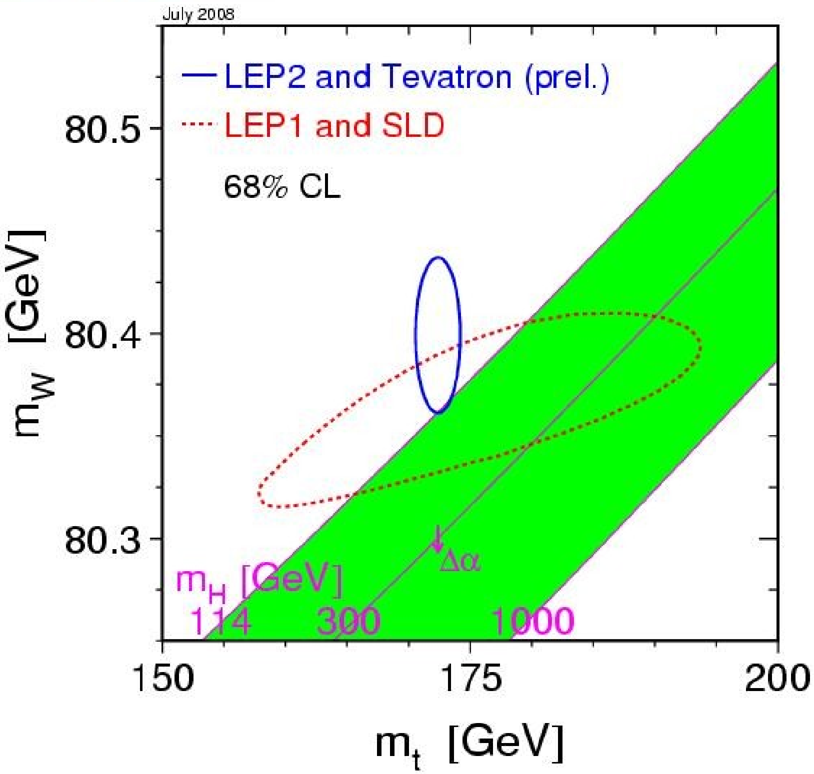
High mass CDF+DØ combination in the next presentation by Sergo Jindariani

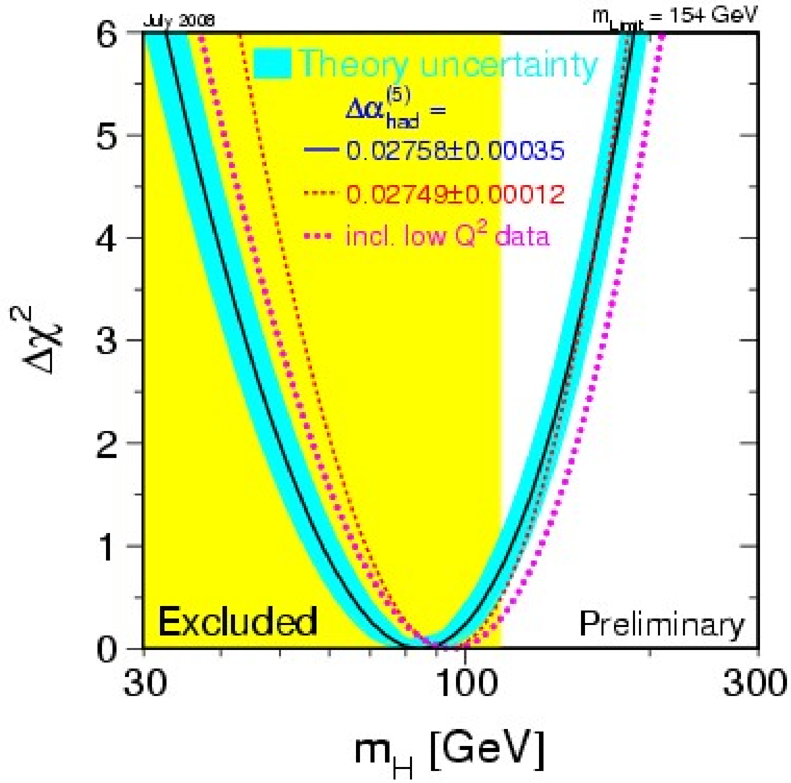
Thanks to the Beams Division



Analyses with data up to Dec 2008
Up to 4.2 fb^{-1} of data analysed
(after data quality requirements)

Higgs Searches at Tevatron





SM prefers light Higgs Boson: M_H< 154 GeV @ 95% C.L.

< 185 GeV with direct LEP limit

Indirect constraints on M_H limited by M_W precision

Focus search in 100-200 GeV range where Tevatron is sensitive

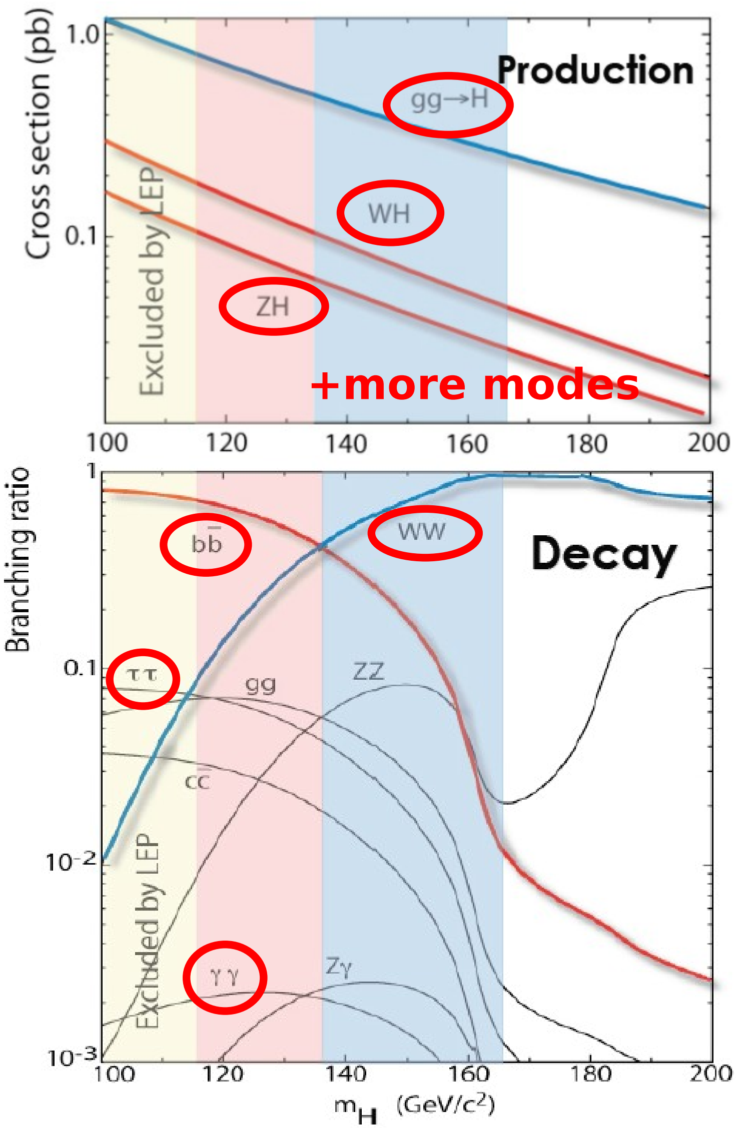
Higgs Searches at Tevatron

Investigate different production mechanisms and use multiple final states

Large list of analyses, particularly for low values of M_H

Open to surprises (non SM Higgs signal ?)

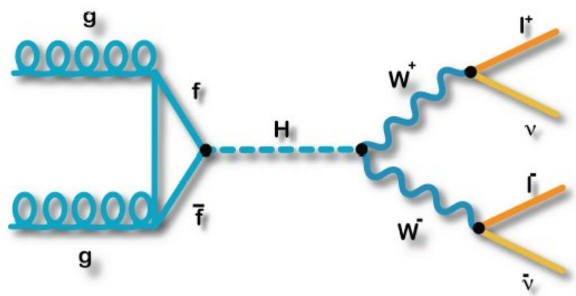
Advanced analysis techniques to identify signal in large background samples, advanced statistical techniques to interpret and combine results of searches



H+X→l^+l^-+missing E_T – 3.0-4.2 fb^{-1} (i)

Consider all sources of opposite sign dilepton plus missing E_T as signal, largest contribution from H→WW decay

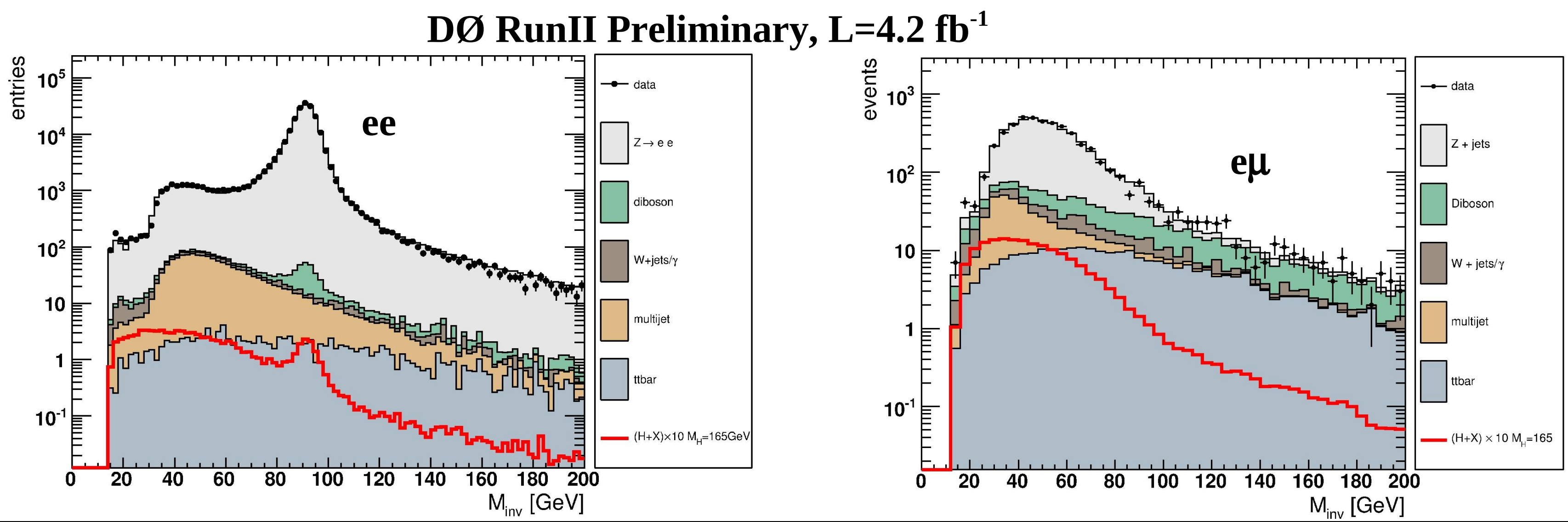
Select sample of dilepton (p_T>15 GeV) events (ee, eμ and μμ)



Background dominated by Drell-Yan/Z pair production

Reduced with missing E_T requirement

Irreducible background from non-resonant SM W pair production



$H+X \to l^+l^- + \text{missing } E_T$ (ii)

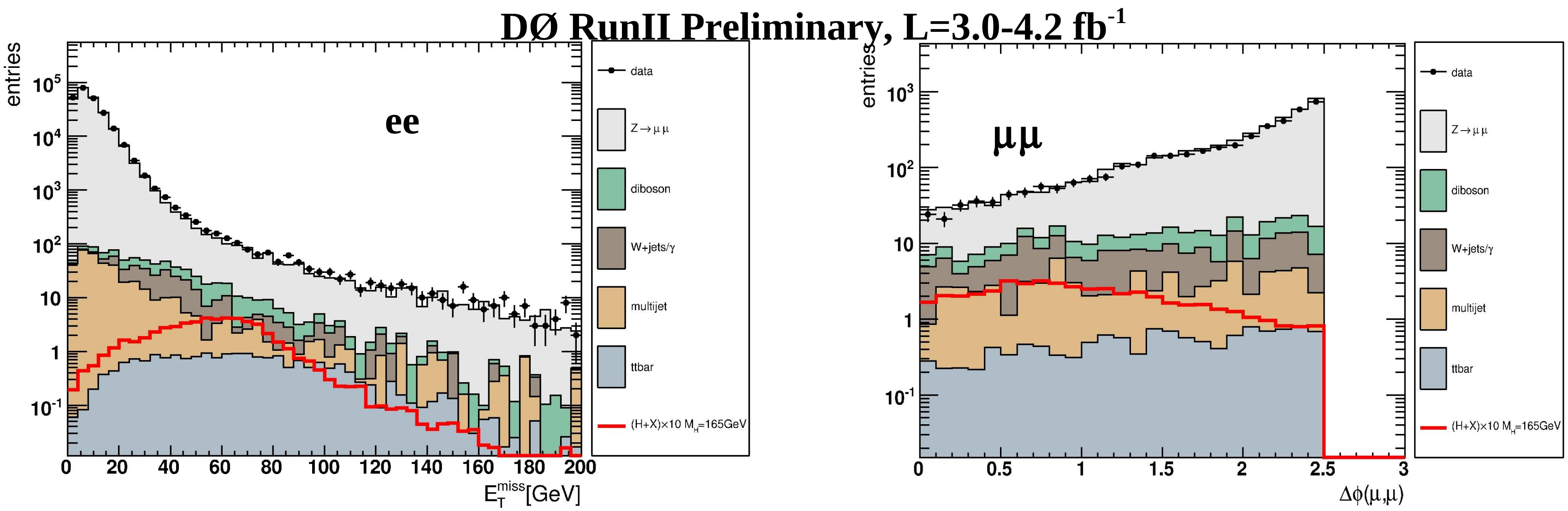
ee/eμ channel (4.2 fb^{-1}) - Z background rejected with cuts on:

- missing E_T and its significance
- minimal transverse mass

μμ channel (3.0 fb^{-1}) - use only:

- transverse momentum of μ pair (0 jet case), missing E_T (1 jet case)

Use difference in spin correlations to reduce WW background (opening angle of lepton pair)



H+X→l^+l^-+missing E_T (iii)

Final sample composition, input to NN discriminant:

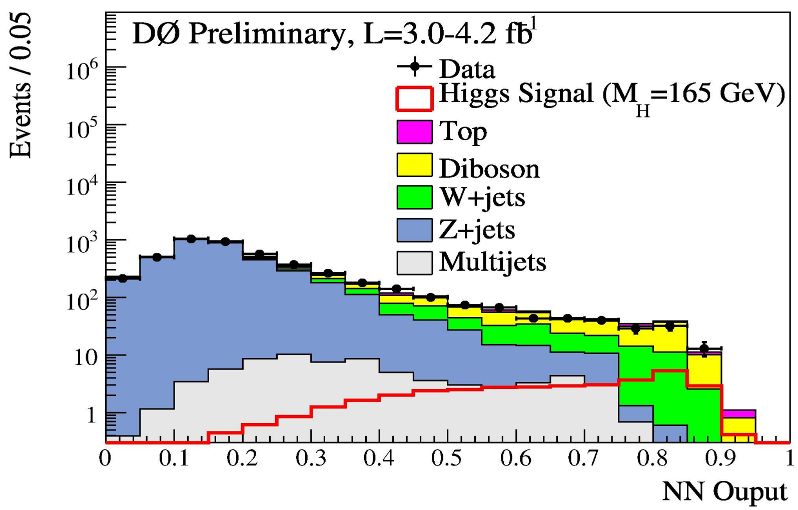
Channel	ee	eμ	μμ
Luminosity (fb^{-1})	4.2	4.2	3.0
Z	108	13	3987
Diboson	84	162	127
tt	40	82	13
W+jets	98	79	134
Multijets	2	1	64
Total Background	332	337	4325
Data	336	329	4084
Signal (M_H=165 GeV)	6.1	12.2	4.9

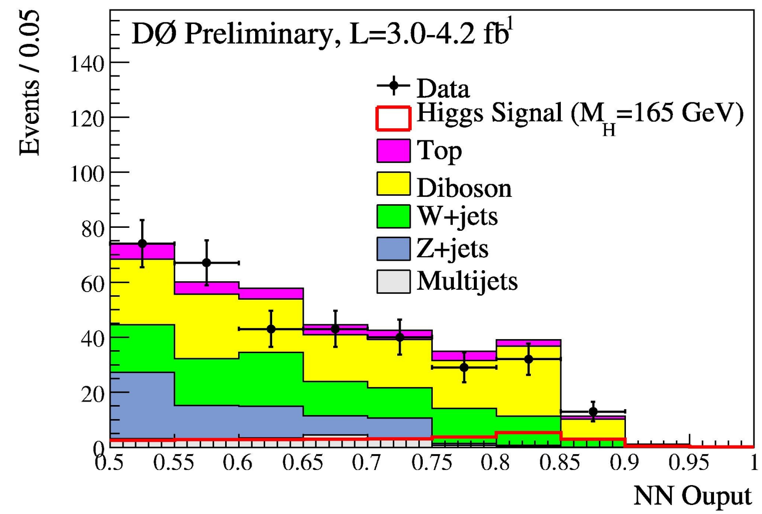
μμ channel: higher signal efficiency, more background

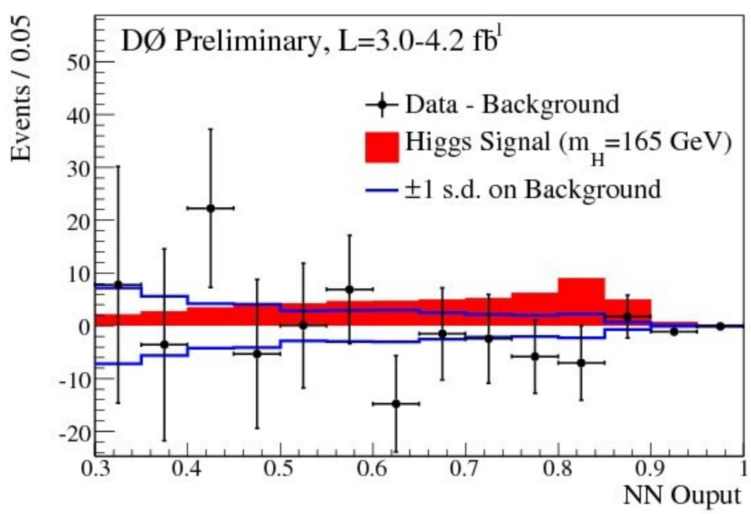
Main systematics:

- **Signal (total10%):**
  cross section, lepton ID/trigger efficiencies
- **Background (total 13%):**
  cross sections, jet efficiencies/resolution/calibration

$H+X \rightarrow l^+l^-$+missing E_T (iv)







NN discriminant greatly enhances S/B – reach level close to 1/3 at high NN values

Expected 165 GeV Higgs signal would be visible over background uncertainty

From the Data to the Limits

Not just counting experiments (low S/B), set limits:

- fit discriminant distributions with templates for B-only and S+B
- estimate maximum content of S
- compare with SM cross section

CDF & DØ: different limit setting procedures

- consistent within 5% on average

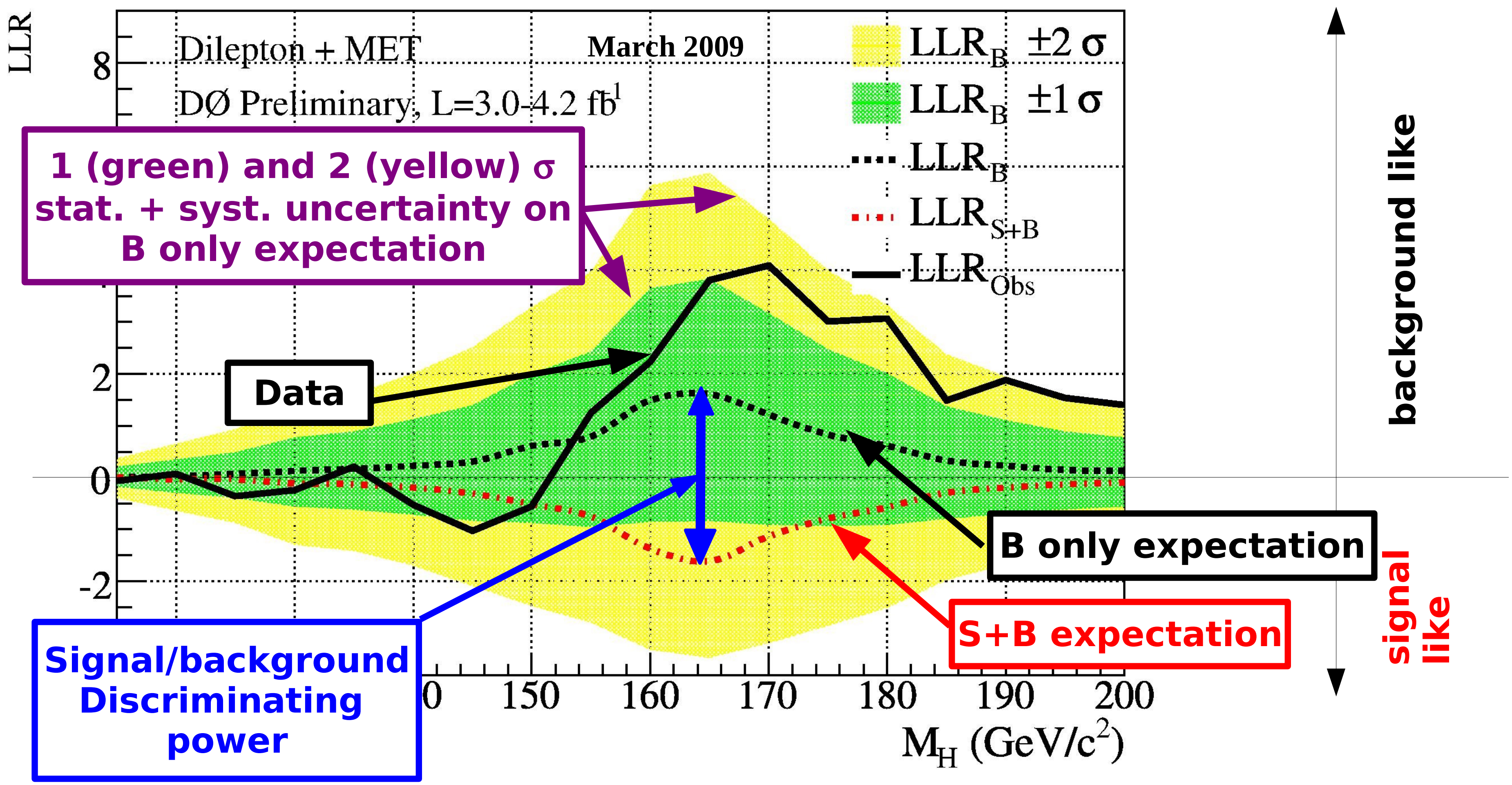
Systematic uncertainties float within Gaussian constraints:

- variations constrained in low S/B regions of discriminant

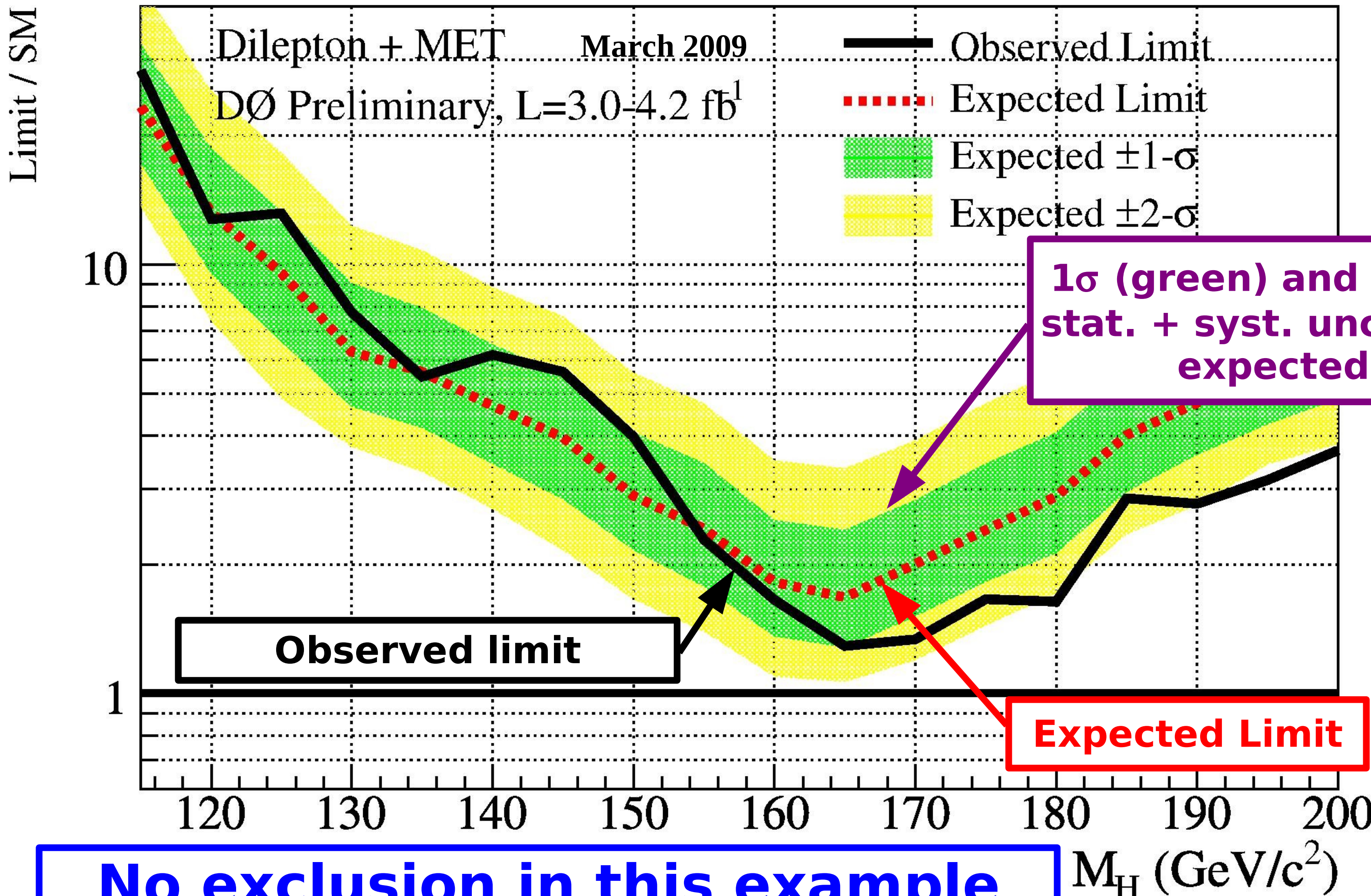
Consider both systematics affecting just the normalization of the backgrounds (efficiency of the signal) or also the shape of the discriminant:

- correlations within one experiment
- correlations between experiments (σ and luminosity)

LLR plots: allow combination of limits for different processes



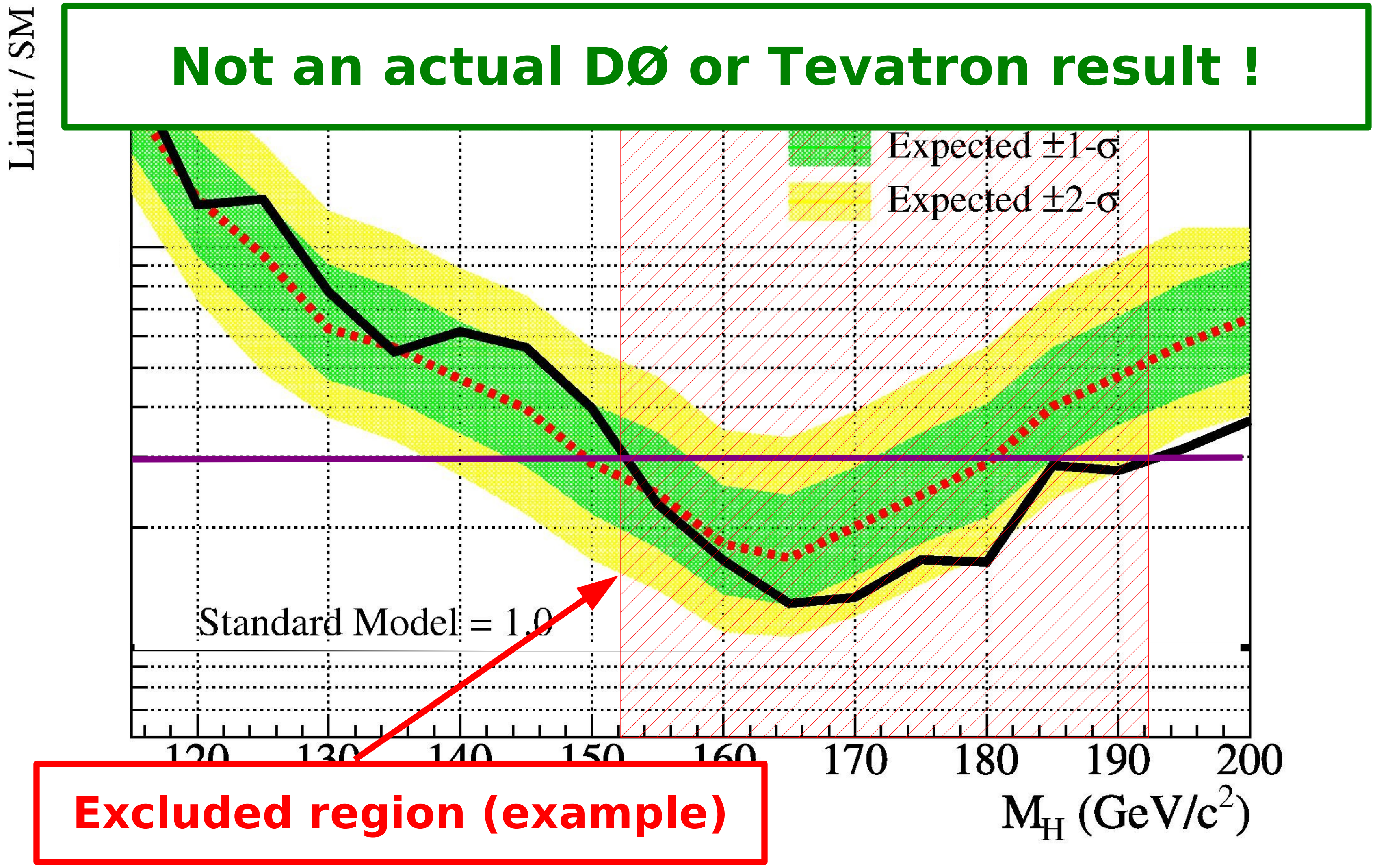
Reminder: Limit Plots



No exclusion in this example

Reminder: Exclusion Plots

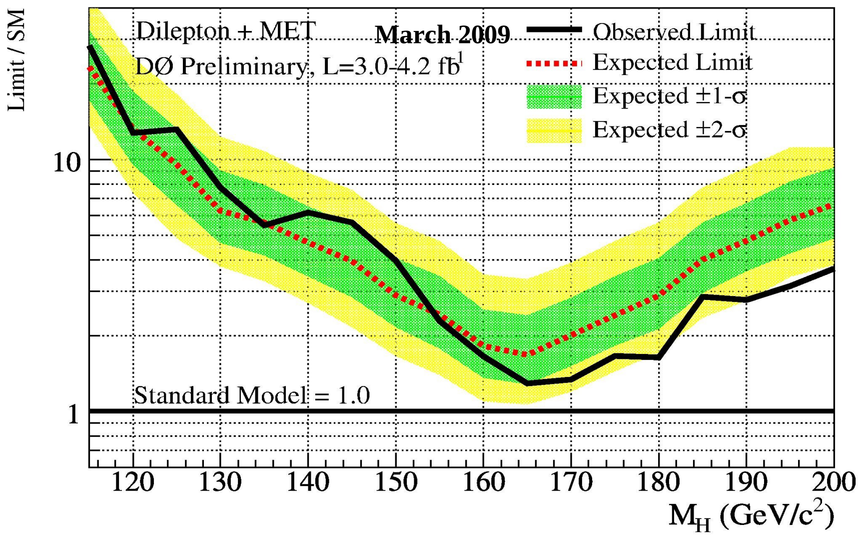
Not an actual DØ or Tevatron result !

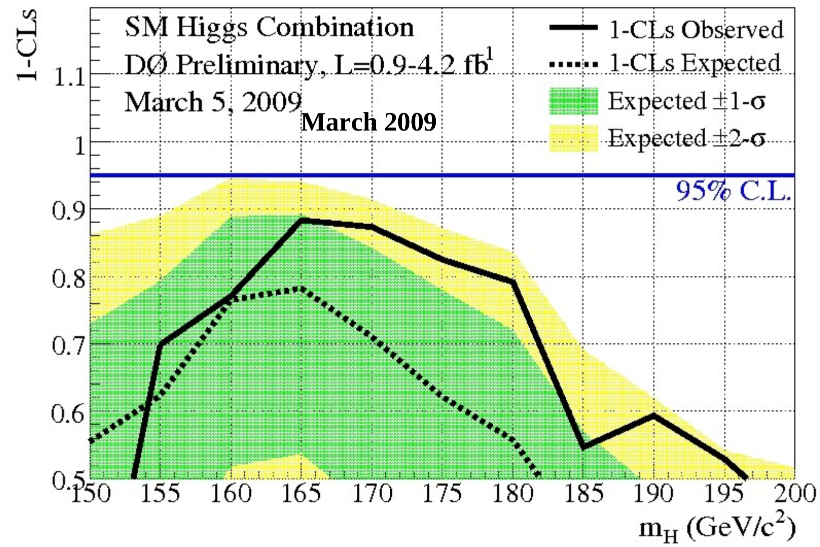


H+X→l^+l^-+missing E_T (ν)

Expected 95% C.L. Limit for M_H=165 GeV: 1.7*SM

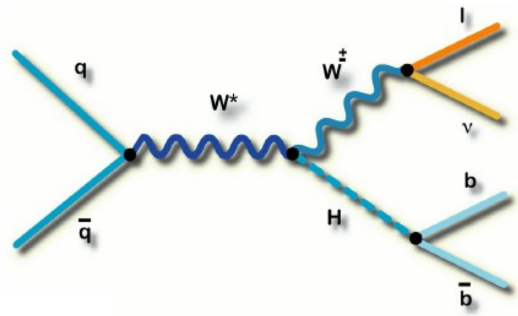
Observed: 1.3*SM





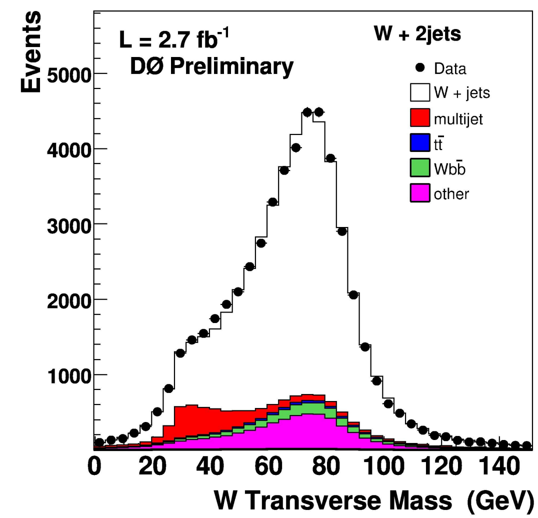
With additional luminosity / improvements in the analysis (matrix element added to the NN, additional channels) expect single experiment exclusion in the M_H≈165 GeV region in the near future

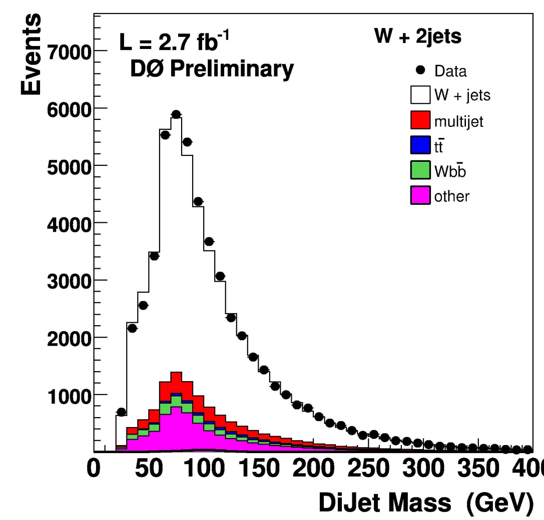
$l\nu bb$ final state -2.7 fb^{-1} (i)



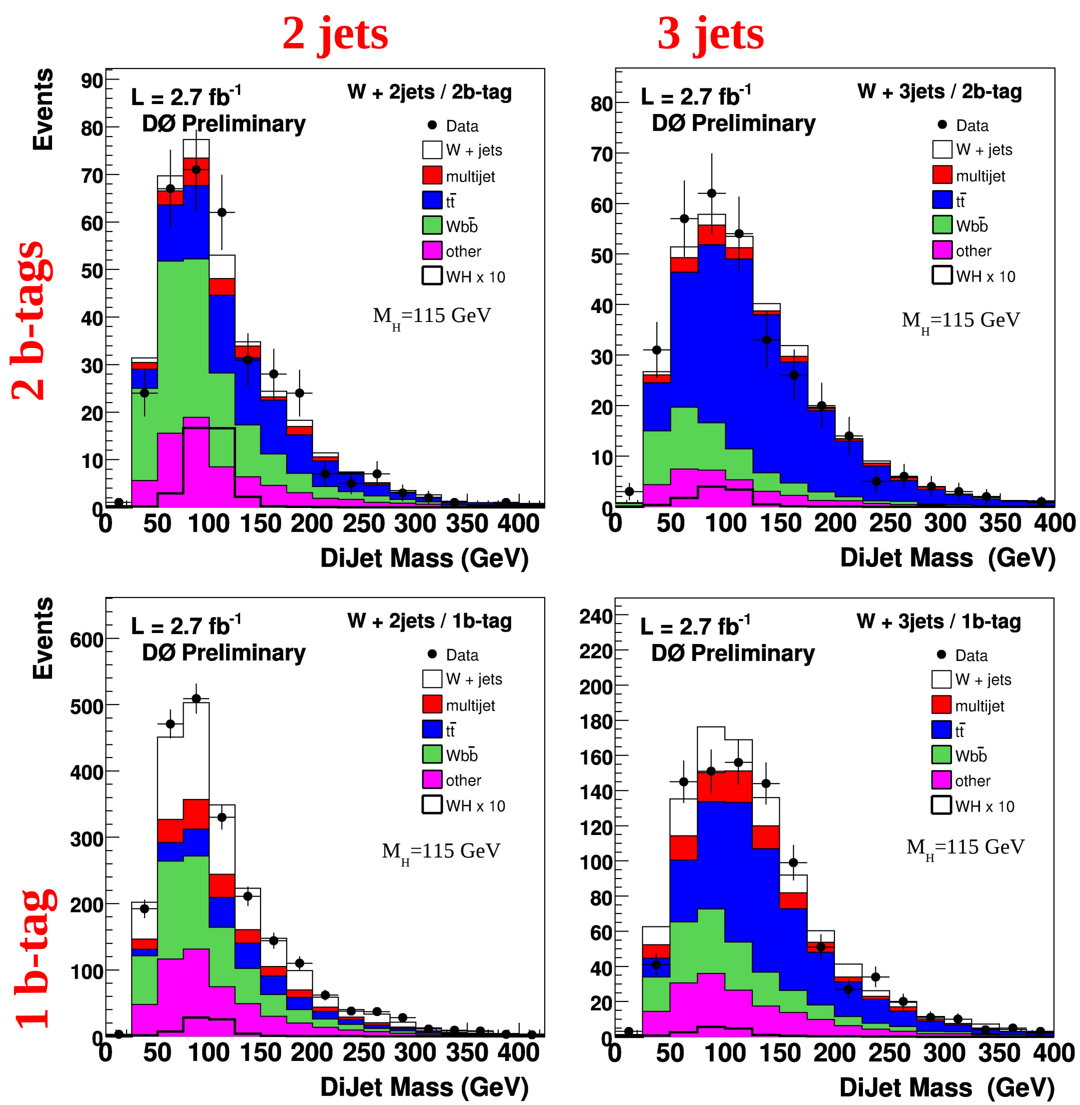
Most sensitive final state in low mass region:

- **WH (+ some ZH events with undetected lepton)**
- **Select W+2/3 jets sample (consider e,μ decays)**
- **Require b-tagging, two orthogonal samples (2 b-tags, 1 b-tag)**





lνbb final state (ii)



After b-tagging:

S/B: 1/100 – 1/1000

(2/2 b jets – 1/3 b jets)

Dijet invariant mass most discriminating quantity

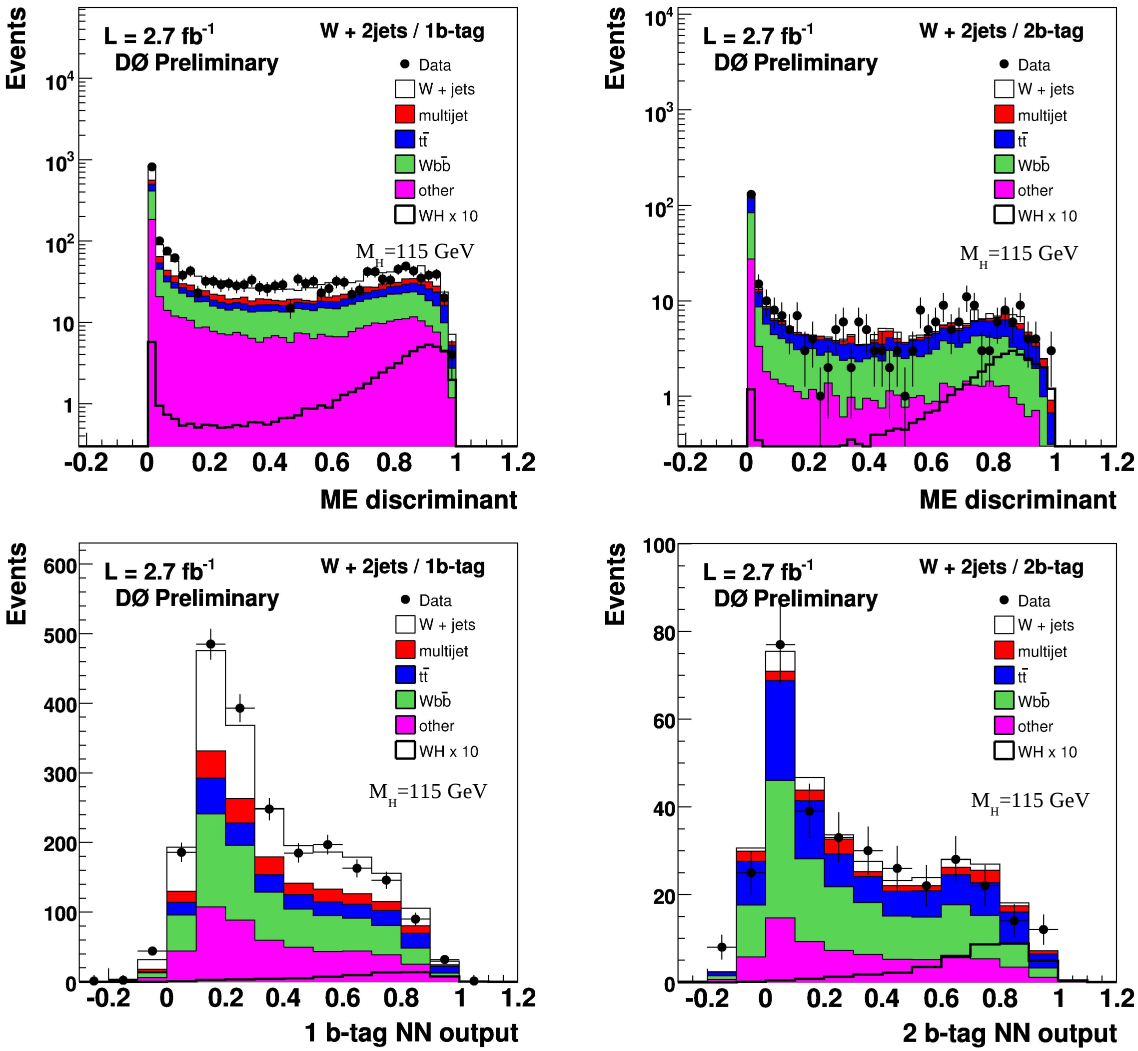
Include other kinematic variables in neural network (gain 15% in sensitivity)

Expect 13 signal events in total for M_H=115 GeV (3.8k events total)

Use dijet invariant mass for the 3 jet sample

lνbb final state (iii)

New: add matrix element discriminant in NN (+8% gain)

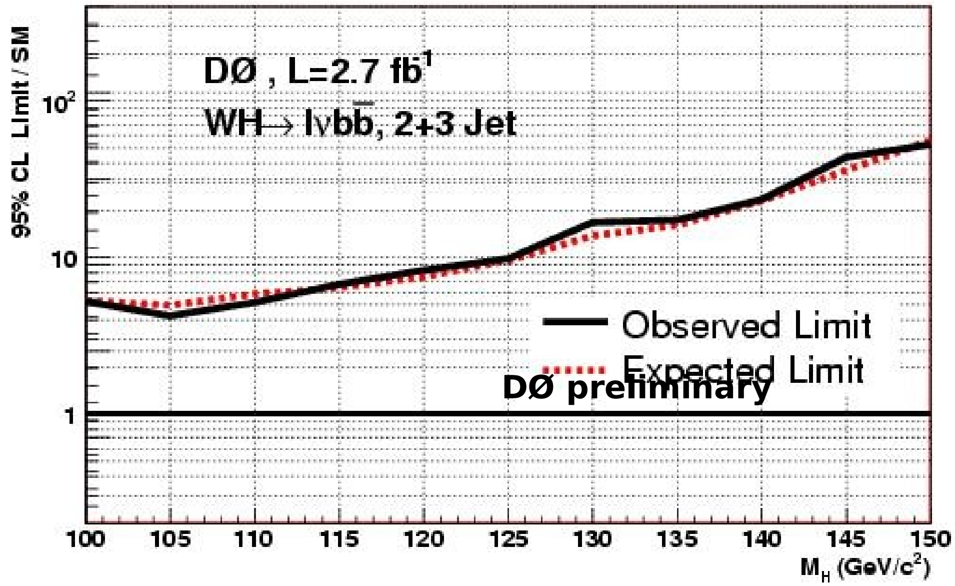


$$\frac{M(WH)}{M(WH)+M(Wbb)}$$

LO matrix elements, integrated over ν variables, detector resolution

High NN values: S/B improved to 1/20-1/10

lνbb final state (iv)



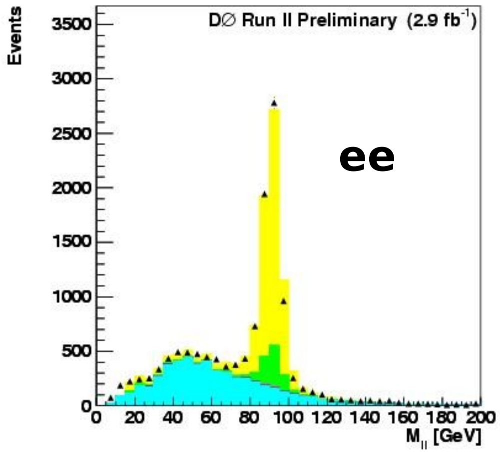
Observed (expected) limit at M_H=115 GeV: 6.7 (6.4) * SM

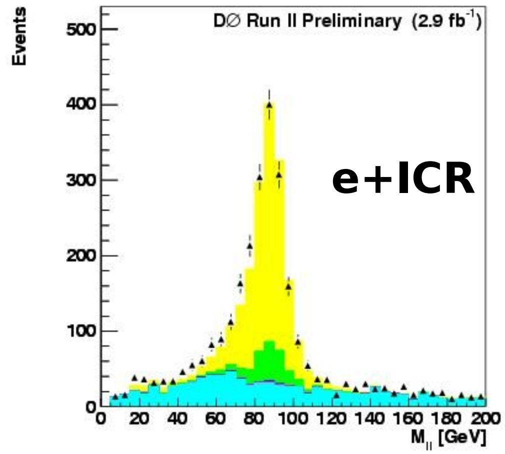
Improves over published result (1.1 fb^{-1}) 11.4 (10.7) * SM

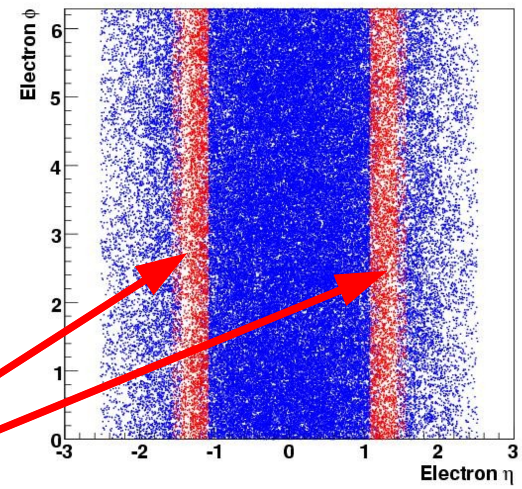
Main systematic uncertainties:

- **Signal (15% tot): cross section, b-tagging probabilities, ID efficiencies**
- **Background (25-30%): normalization of W+heavy flavors (HF) samples, b-tagging, modeling W+jets background**

ee/μμbb final states - 4.1 fb^{-1} (i)

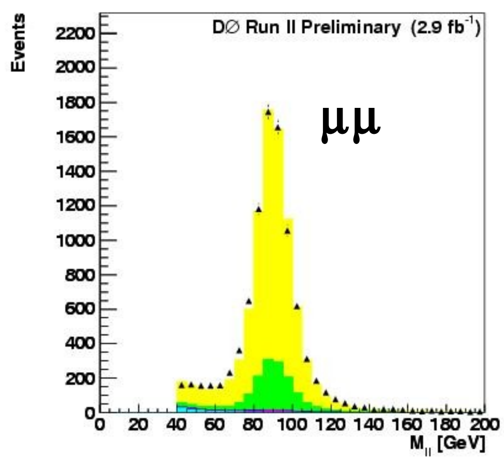


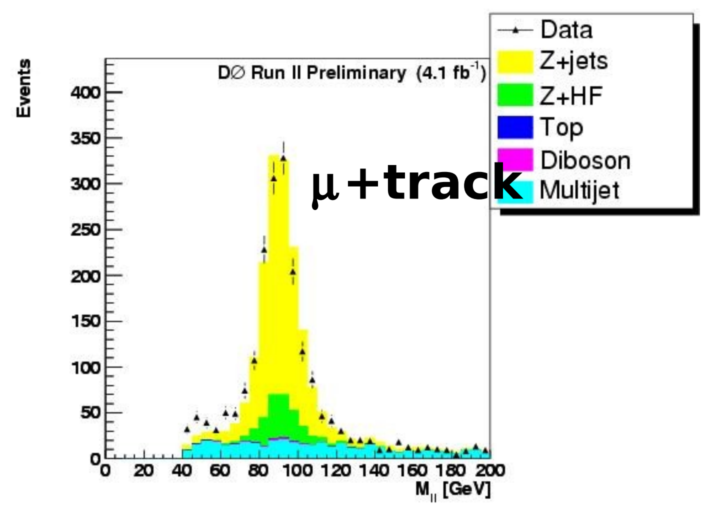




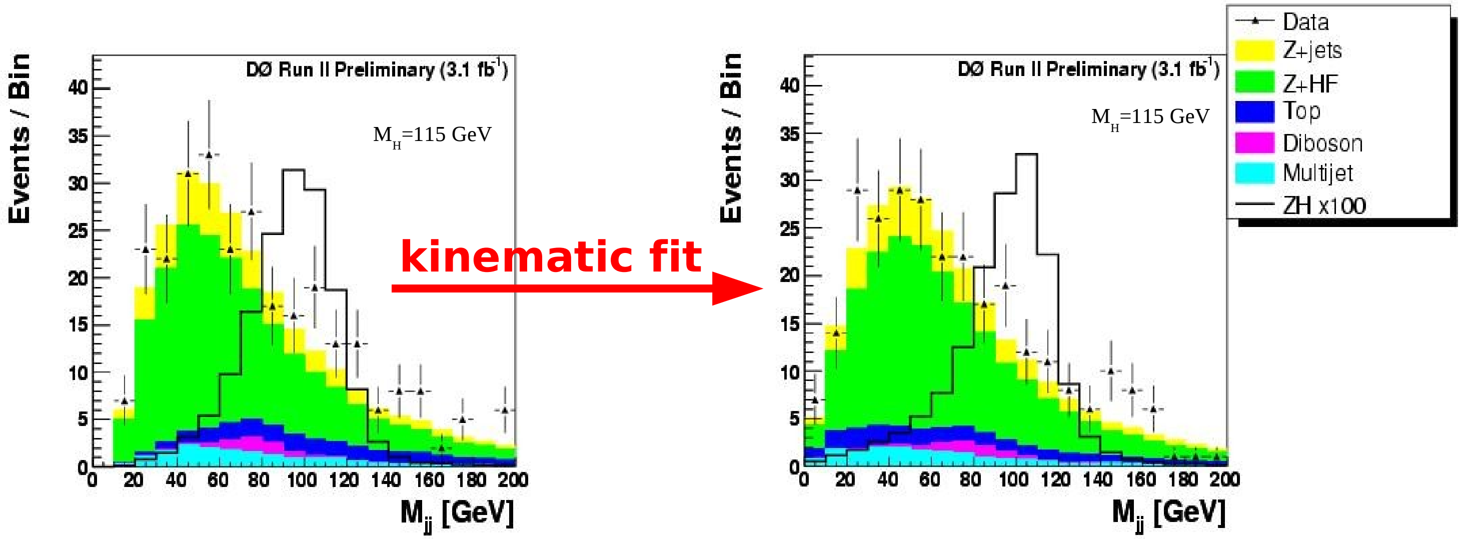
Increase sample by 15% by using

- **Electrons in inter-cryostat regions (identified as τ)**
- **Events with muon + isolated track**





ee/μμbb final states (ii)



Use kinematic fit (constrain the lepton pair to the M_Z and transverse momentum conservation in ZH system)

Improve dijet invariant mass resolution by 4%, improve limit (based on dijet invariant mass discriminant) by 8%

Push non-resonant background to lower invariant masses

One of many improvements in Higgs searches

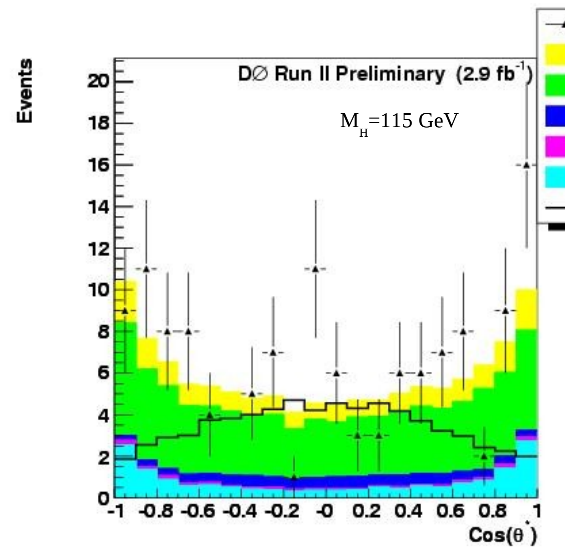
ee/μμbb final states (iii)

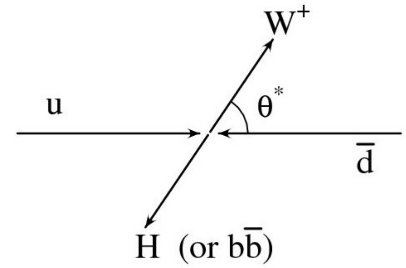
Not (yet) using matrix element information in final discriminant (boosted decision tree)

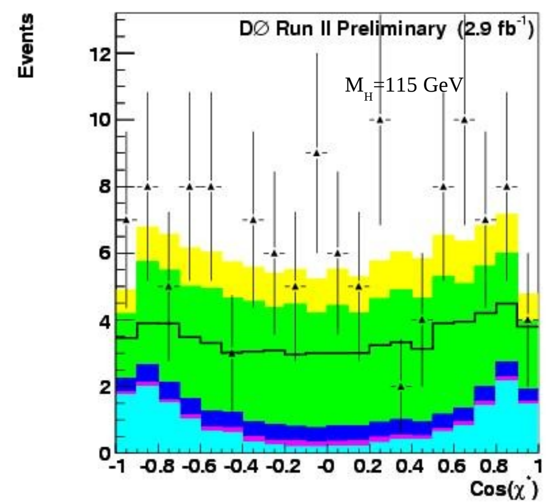
Using instead spin correlations between Z and g→bb (or H→bb) system

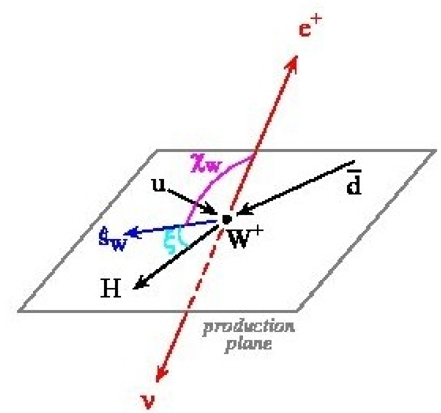
Replace spin correlations with angular correlations of decay products

Proposed by Parke/Veseli PRD60 093003 (1999)

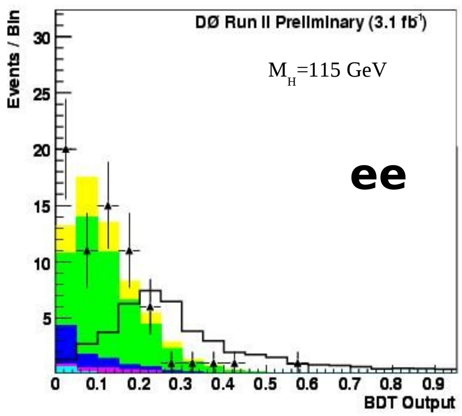


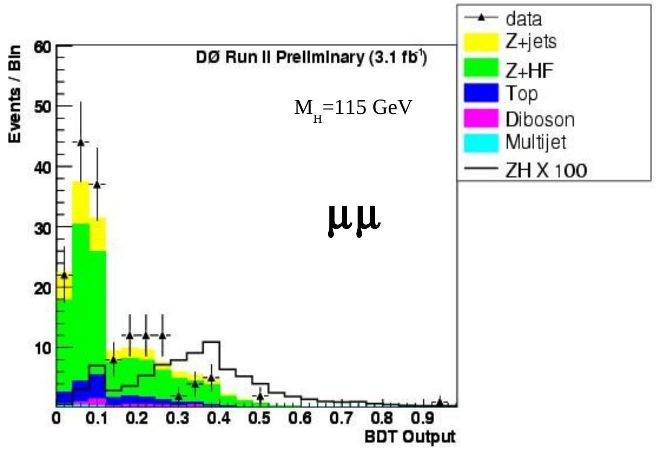






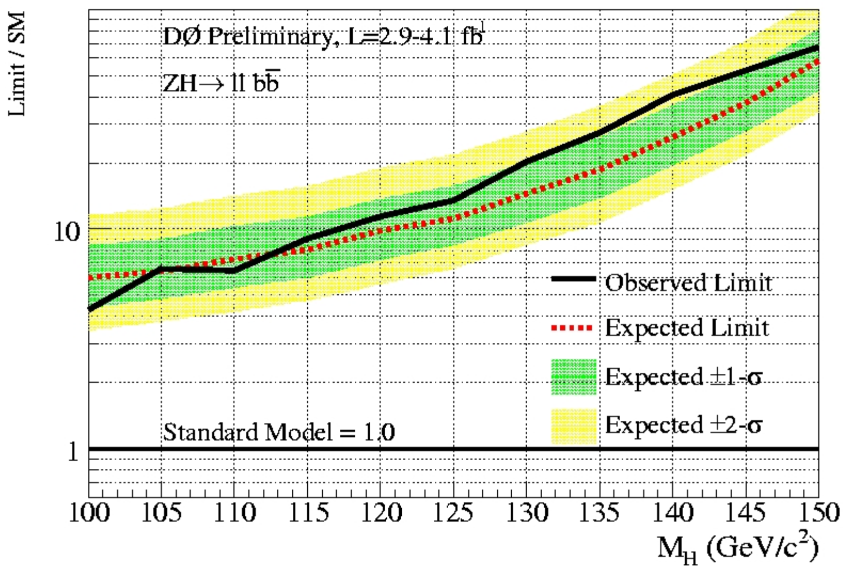
ee/μμbb final states (iv)





About 3.5 candidates in data, S/B≈1/300
(σ∗BR(ZH)≈0.15σ*BR(WH))

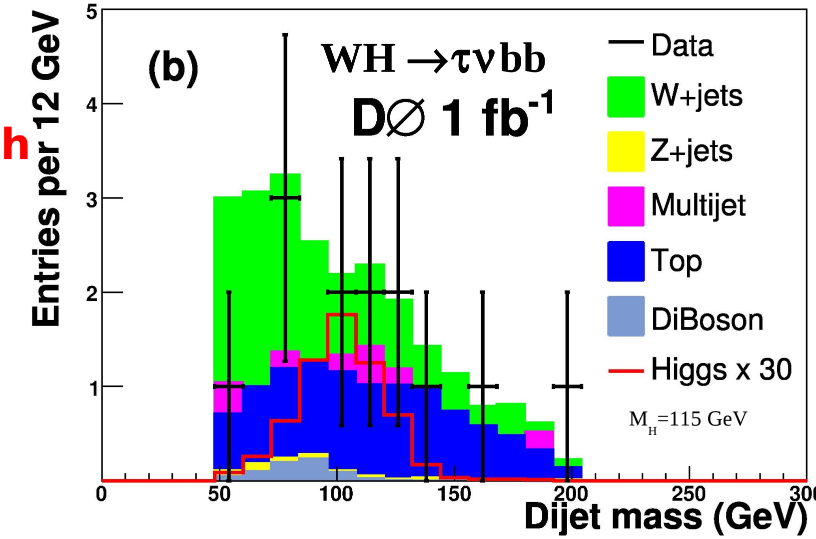
Observed (expected) limit at M_H=115 GeV: 9.1 (8.0) * SM

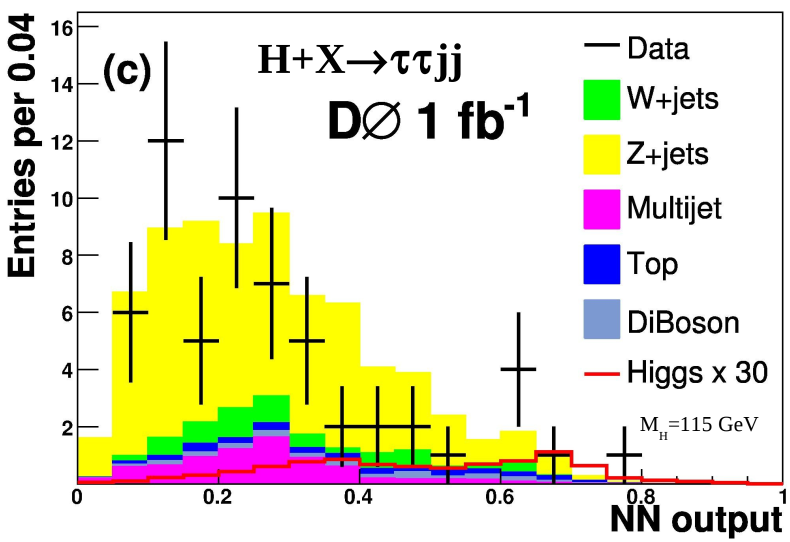


Final states with taus- 1 fb^{-1}

Two analyses: 1) τνbb

- Sensitive to WH (ZH with missing τ)
- Background dominated by W+jet(s) with misidentified τ
- 0.2 candidate events,
- S/B≈1/100





2) ττqq final states (1 τ→μ decay, 1 τ→hadrons)

- Sensitive to ZH (Z→ττ ,and H→ bb) W/ ZH (V→ qq and H→ττ) plus vector boson/gluon fusion (with H→ττ)
- Expect 0.7 events, S/B≈1/500

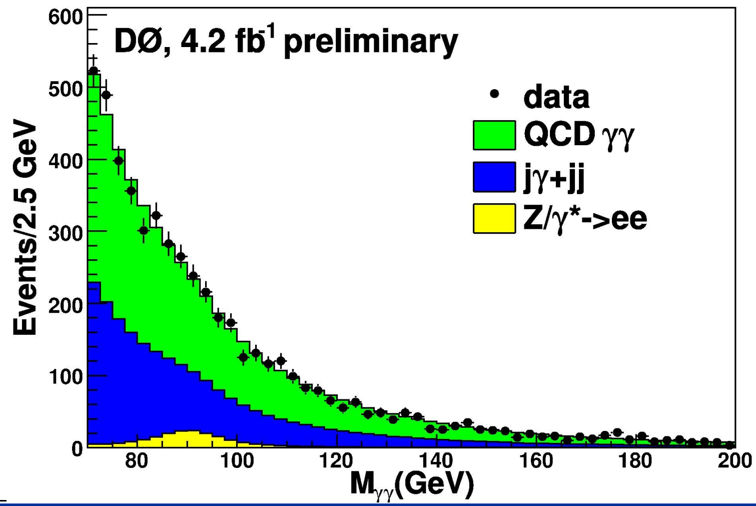
Combination of the two analyses for M_H=115 GeV:

observed limit 27*SM @ 95% C.L. (expected: 28*SM)

$H \rightarrow \gamma\gamma$ - 4.2 fb^{-1} (i)

Small branching fraction ($2*10^{-3}$), look for gluon fusion production

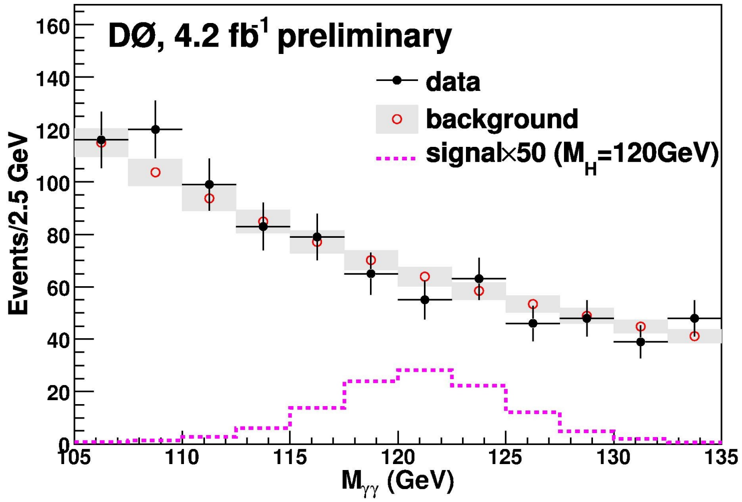
- Require 2 high E_T (>25 GeV) photons in central calorimeter
- Estimate Drell Yan background from MC using measured track inefficiency
- Estimate dijet/photon+jet background (with misidentified photons) from data
- Photon ID efficiency from data ($Z \rightarrow l^+l^-\gamma$ events)
- Remaining data assumed to be direct diphoton production (irreducible background, 60% of total sample)

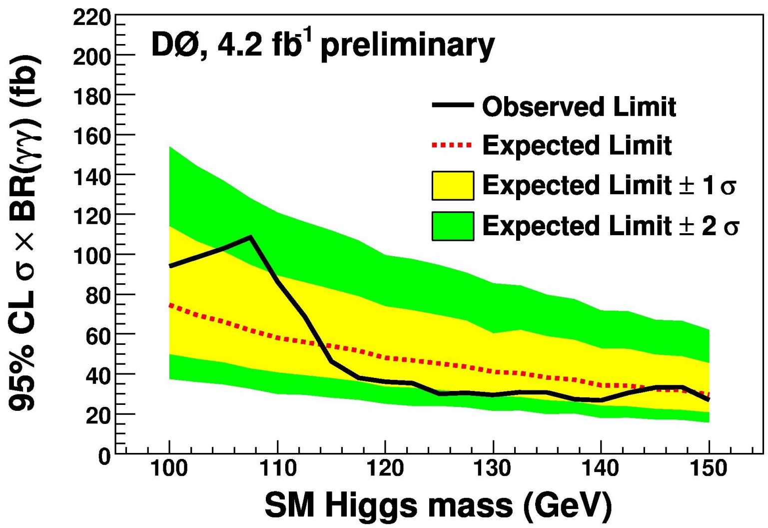


H→γγ (ii)

Signal efficiency taken from MC (considering data/MC differences)

Shape of irreducible γγ background obtained from fit in sideband region (ignore window ±15GeV from test mass)





Peaking signal compensates for low S/B (1/400)

Expect 2.5 events @ M_H=115 GeV

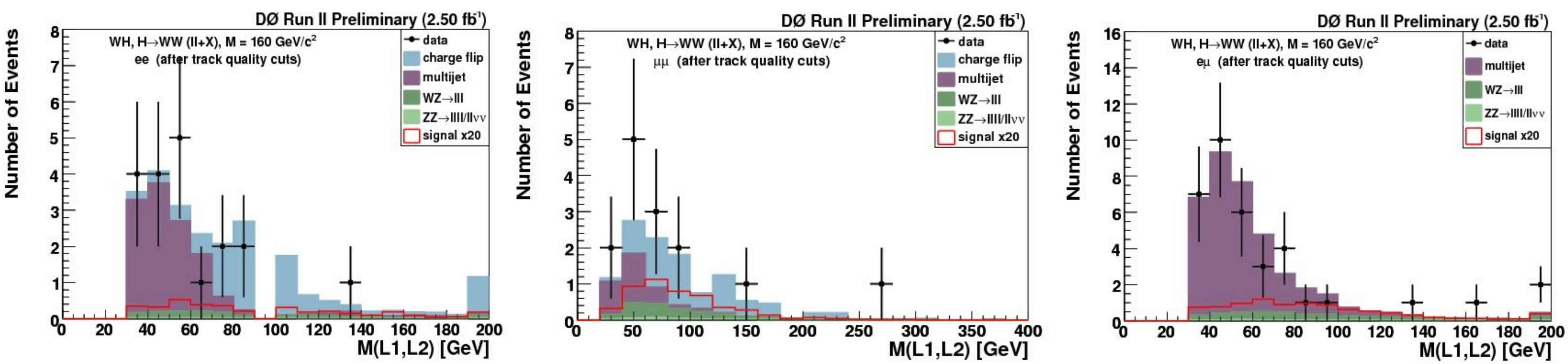
Limit for M_H=115 GeV: 18*SM (exp.), 16*SM (obs.)

Limit does not degrade for increasing M_H

WH→like-sign dileptons – 2.5 fb^{-1}(i)

Important analysis in the intermediate (130-150 GeV) mass region

- **Search for associated production, WH→WWW→$l^{\pm}\nu l^{\pm}\nu$+X decay**
- **Remove physics backgrounds with likesign dilepton requirements, vetos on additional leptons**
- **Instrumental background: misidentified leptons, charge misassignments (ee/μμ final states)**
- **Sample selection: like charge high p_T lepton pair, track quality cuts**



WH→like-sign dileptons (ii)

Charge misidentification probability and multijet background extracted from data

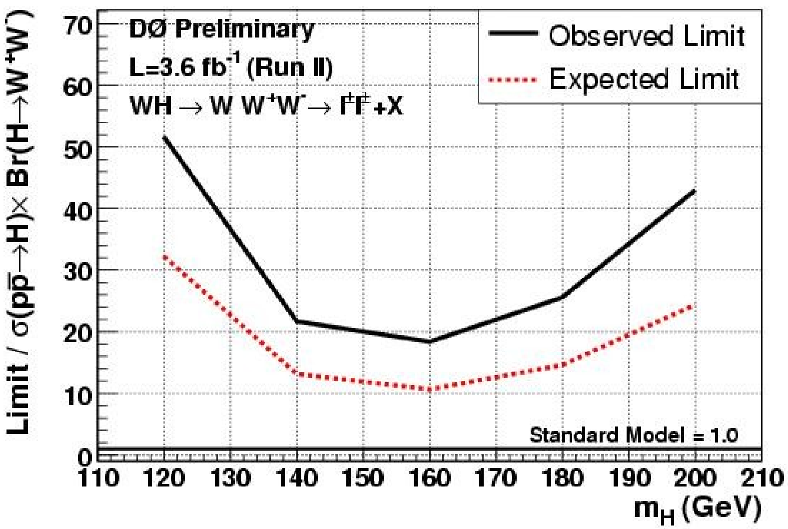
Different discriminants for each lepton pair final state:

- **Only 68 events in final sample (75 expected)**
- **For M_H=120 GeV expect 0.24 signal events**

Limit setting (combined with RunIIa 1.1 fb^{-1} analysis):

For M_H=120 (160) GeV:

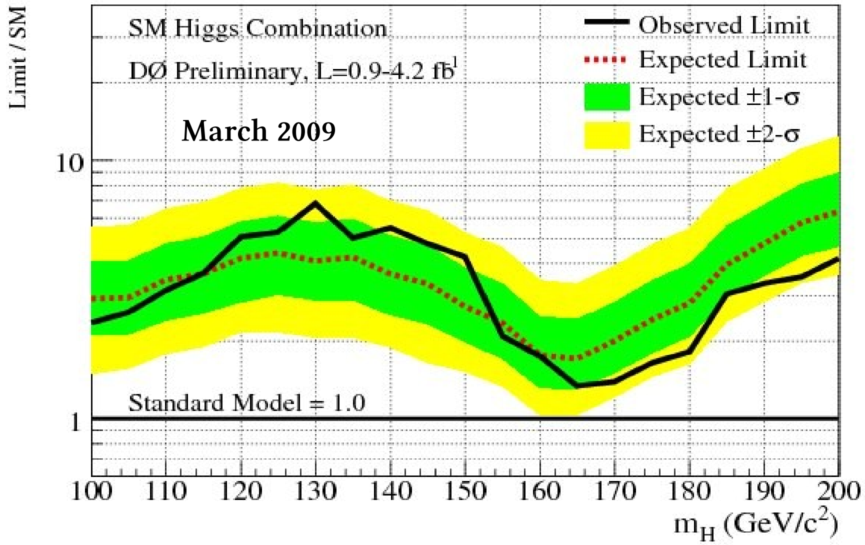
Expected: 32*SM (11*SM)
Observed: 52*SM (18*SM)

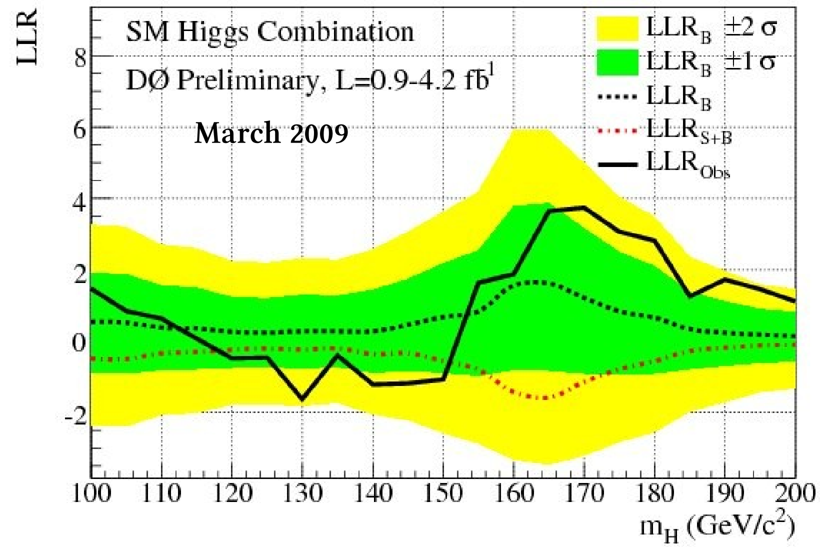


Combination of DØ searches

Combine all analyses presented today, plus:

- **$ZH \to \nu\nu bb$ (2.1 fb^{-1}, update to 4.1 fb^{-1} soon)**
- **ttH (2.1 fb^{-1})**





Expected limit at M_H=115 GeV (95% C.L.): 3.8*SM

Observed limit: 3.6*SM

Expected limit at M_H=165 GeV (95% C.L.): 1.7*SM

Observed limit: 1.3*SM

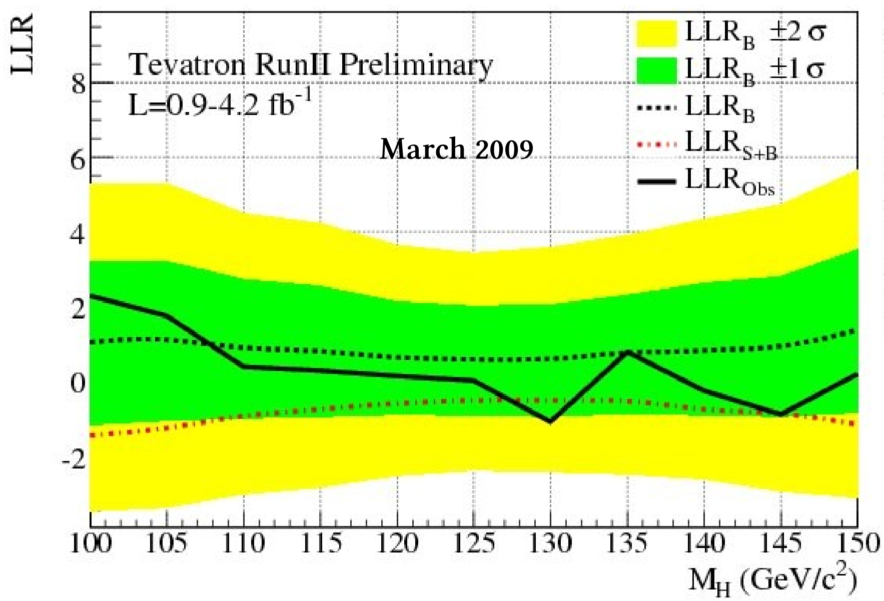
Tevatron Higgs Combination

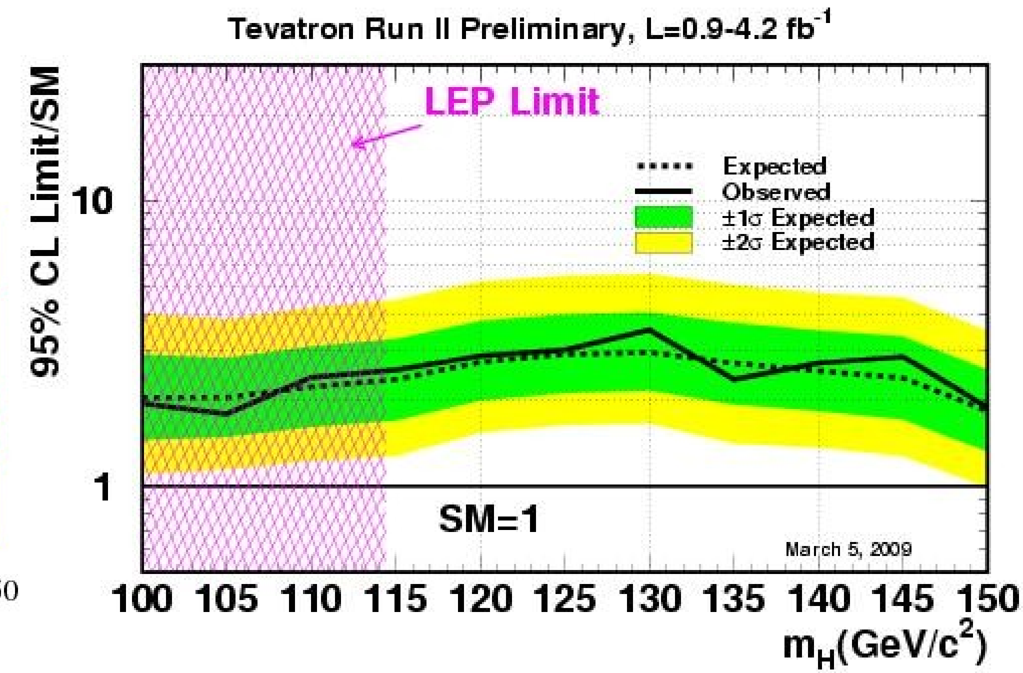
CDF inputs to Tevatron combination

Channel	Luminosity (fb^{-1})	M_H range (GeV)
$WH \to l\nu bb$	2.7	100-150
$ZH \to \nu\nu bb$	2.1	100-150
$ZH \to llbb$	2.7	100-150
$H \to WW$	3.6	110-200
$WH \to$ likesign dileptons	3.6	110-200
$H+X \to \tau\tau +$ 2 jets	2.0	100-150
$WH+ZH \to jjbb$	2.0	100-150

DØ inputs as for internal DØ combination
but llbb and WH→ like-sign dileptons analyses
restricted to only 1.1 fb^{-1} of data

Tevatron Combination Low M_H





For the Tevatron combination:

@ M_H=115 GeV expected limit 2.4*SM, observed 2.5*SM

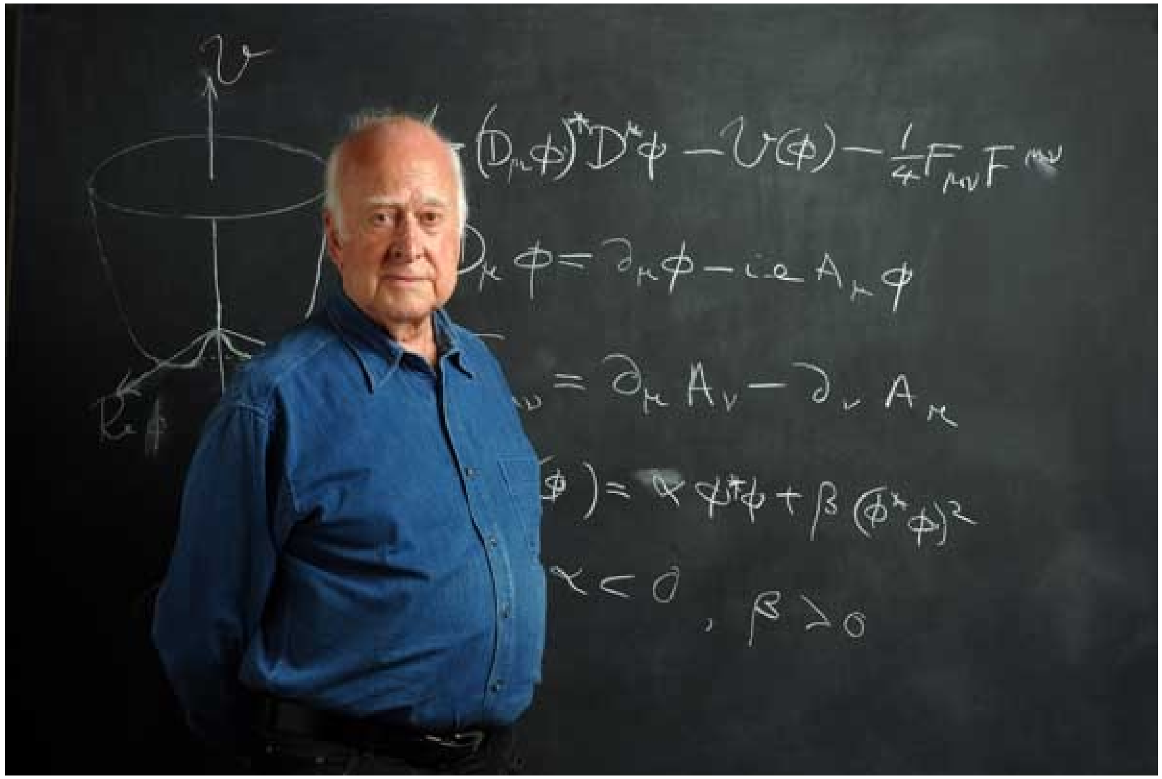
Effective luminosity for current analyses in CDF+DØ combination: 2.55 fb^{-1}

Conclusions

Progress made over last few months
- Increased luminosity
- Improvements in analyses resulting in
  - Increased signal efficiency
  - Better signal / background separation

Sadly no signal yet

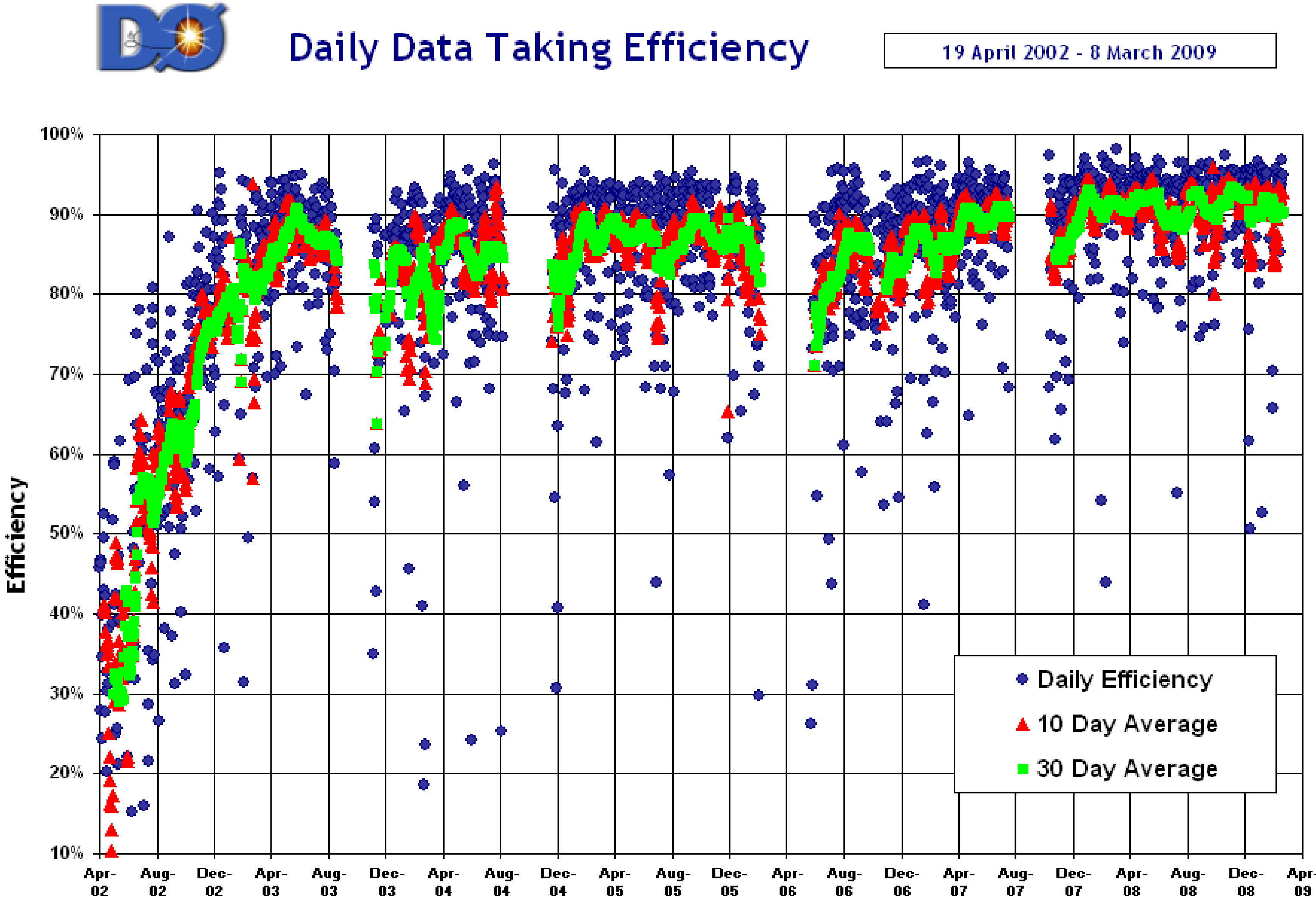
In addition
- High mass Tevatron combination in the next talk
- With additional luminosity and further improvements in analysis Tevatron will be sensitive to SM Higgs over the entire mass range preferred by electroweak fits



Let's put this Higgs guy on a commemorative T-shirt

BACKUP MATERIAL

Great Detector Performance



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

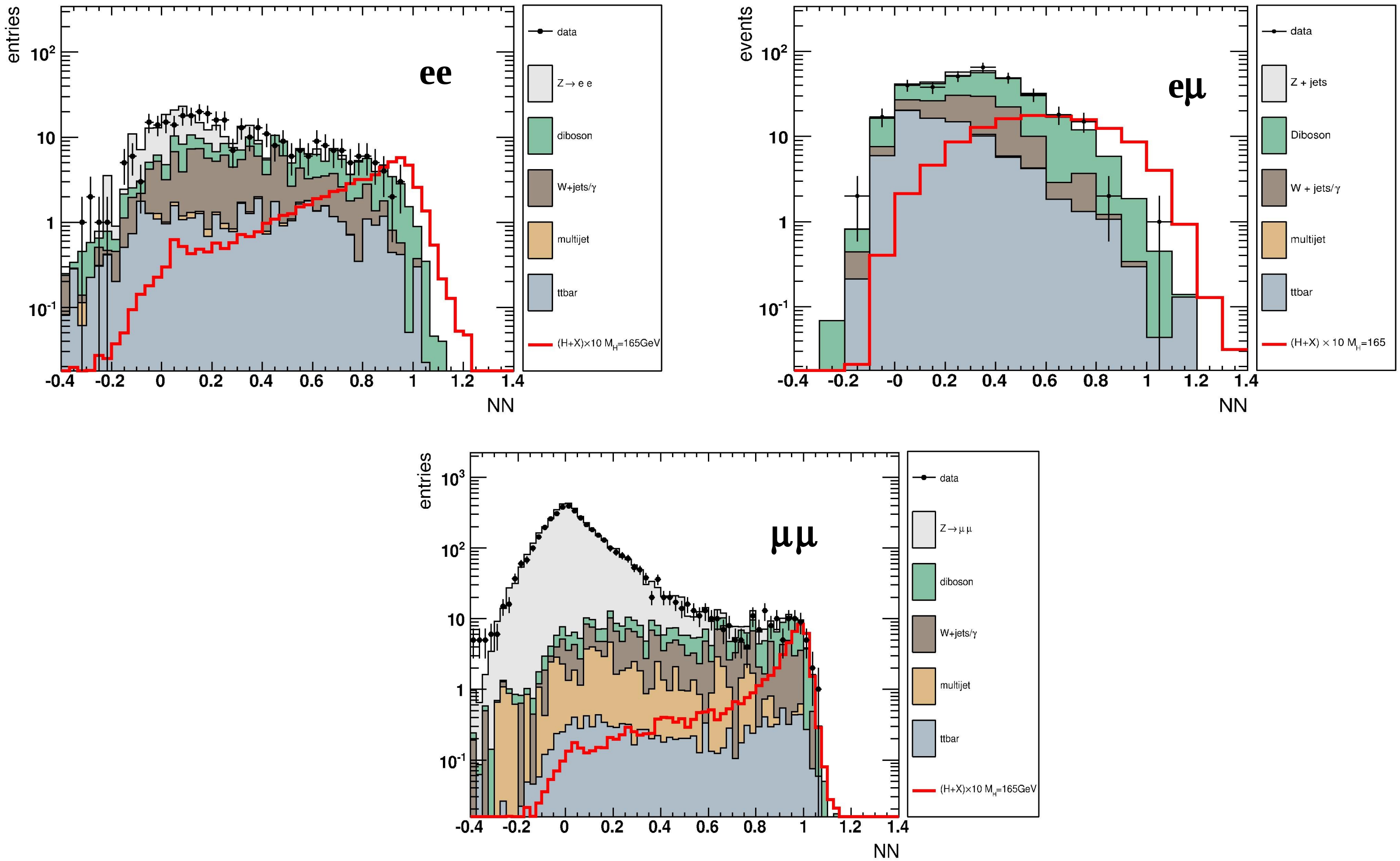
CDF and DØ using common values (and correlated uncertainties) for cross sections of background processes: tt and single top (10%), diboson production (6%)

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

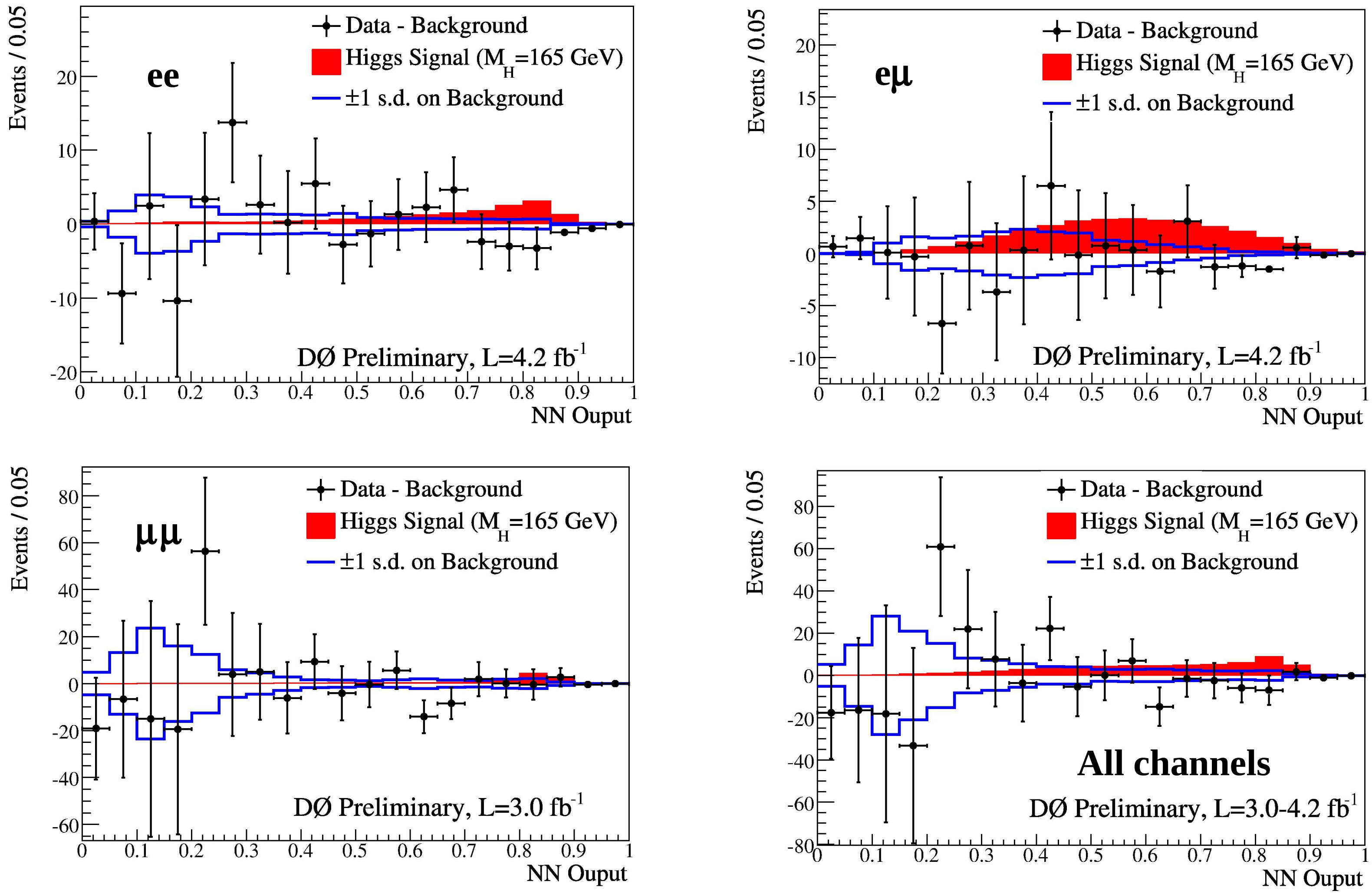
$H+X \rightarrow l^+l^-$+missing E_T

Reach S/B in range 1/10-1/1 for the highest NN values

DØ RunII Preliminary, L=3.0-4.2 fb^{-1}



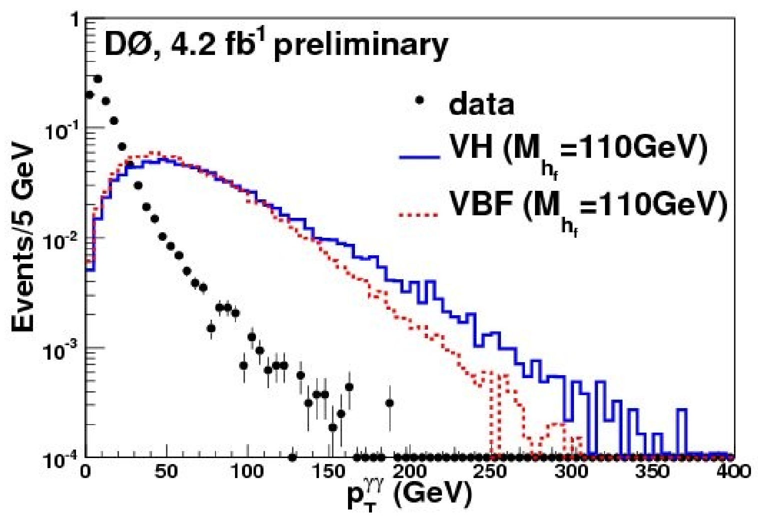
$H+X \rightarrow l^+l^- + \text{missing } E_T$

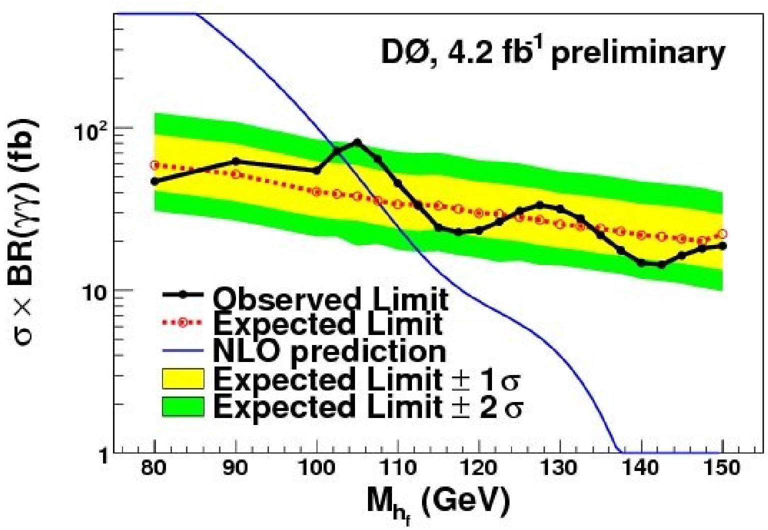


H→γγ BSM interpretation

Look for fermiophobic Higgs:

- **Higgs produced in association with W/Z or via vector boson fusion only, large p_T**
- **Enhance S/B by rejecting low p_T photon pairs (factor 4)**
- **Exclude M_H<102.5 GeV (expect 107.5 GeV)**
- **Cross section limits 70% better than for SM analysis**
- **Reached single LEP experiment sensitivity, 2 GeV away from LEP combination**
- **Combination with H→WW analysis(es) in the future**





Tevatron Combination Low M_H