Combined Higgs Searches at DZero

+ CDF & DØ

W&C, December 7th 2007

Gregorio Bernardi, LPNHE-Paris

for the DØ Collaboration

- **Standard Model Higgs Searches**
- **New results since Lepton-Photon (2007)**
- **Combination techniques**
- **Combination results:**
  DØ and CDF & DØ (released today)

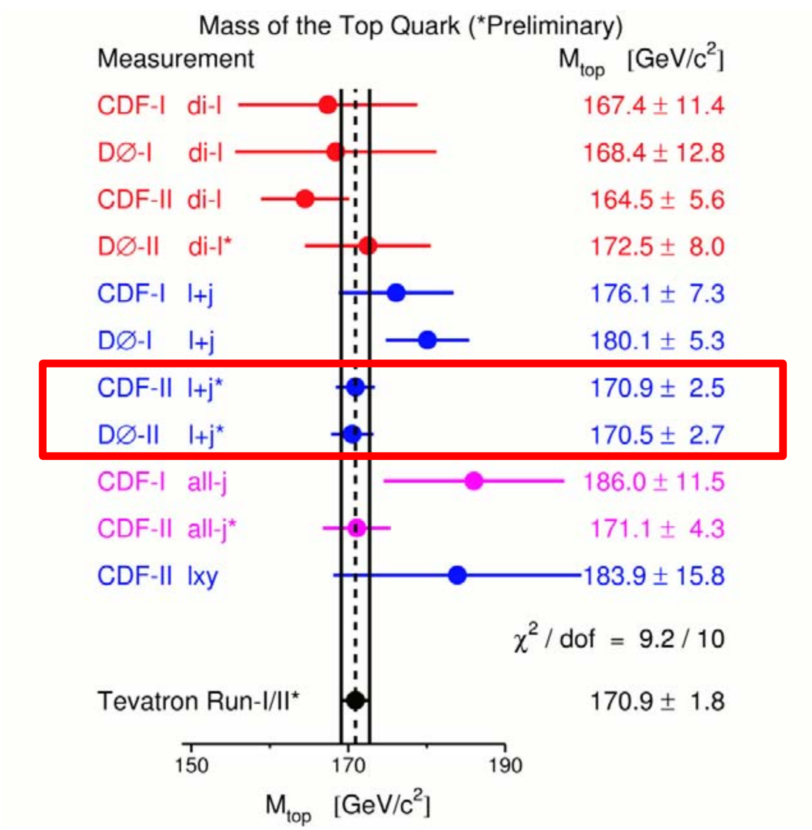
Special thanks to W. Fisher, T. Junk, W. Yao, TevNP-Higgs WG and all DØ and CDF colleagues

http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm

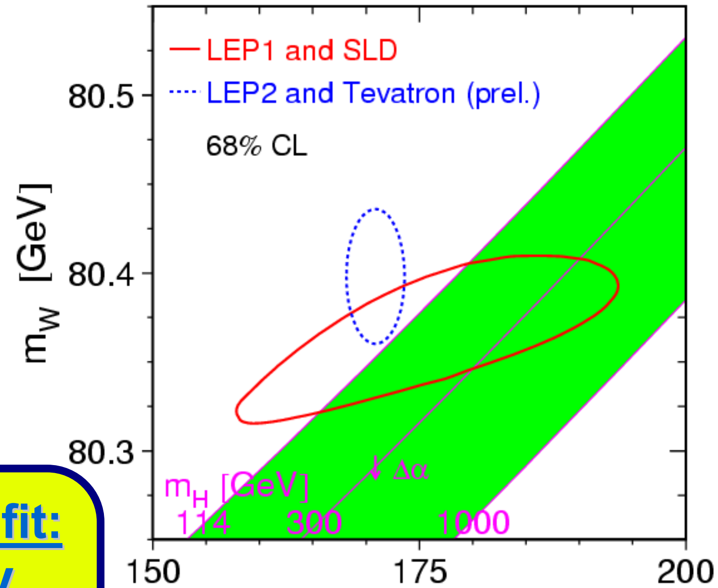
Experimental constraints on the Higgs Boson

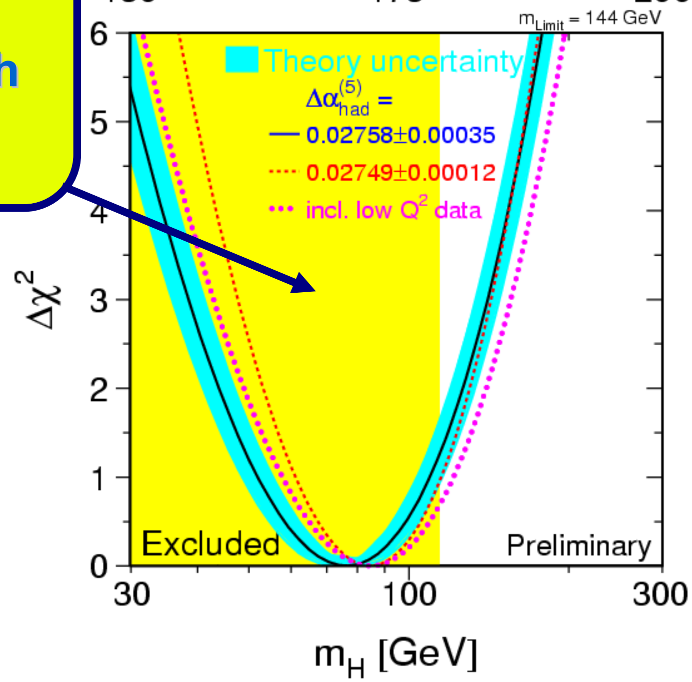
Indirect Constraints:
Top, W-boson masses

Direct searches at LEP II:
m_H>114.4 GeV @ 95% CL

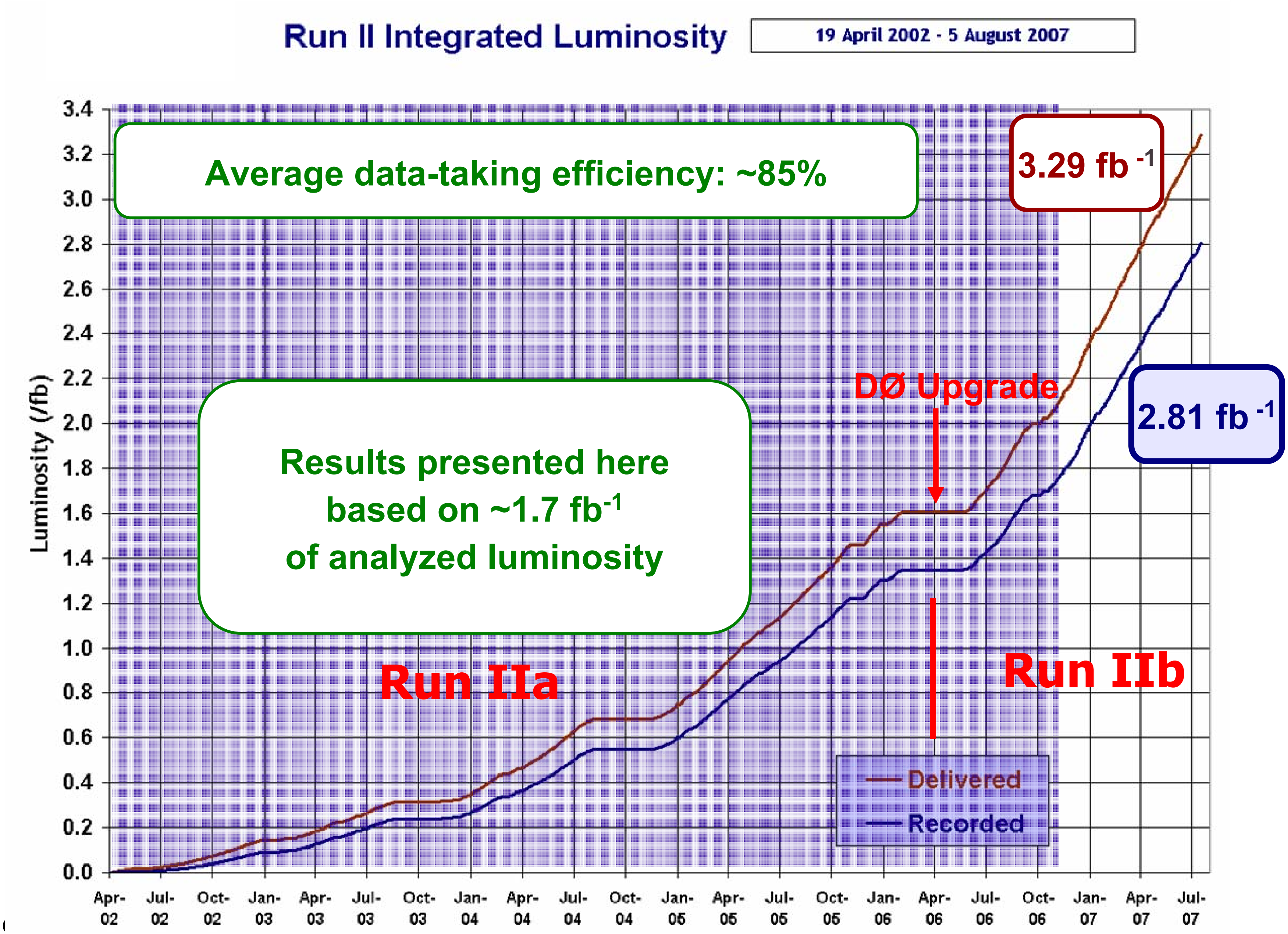


Precision EW fit:
m_H<144 GeV
(<182 GeV with LEPII Limit)





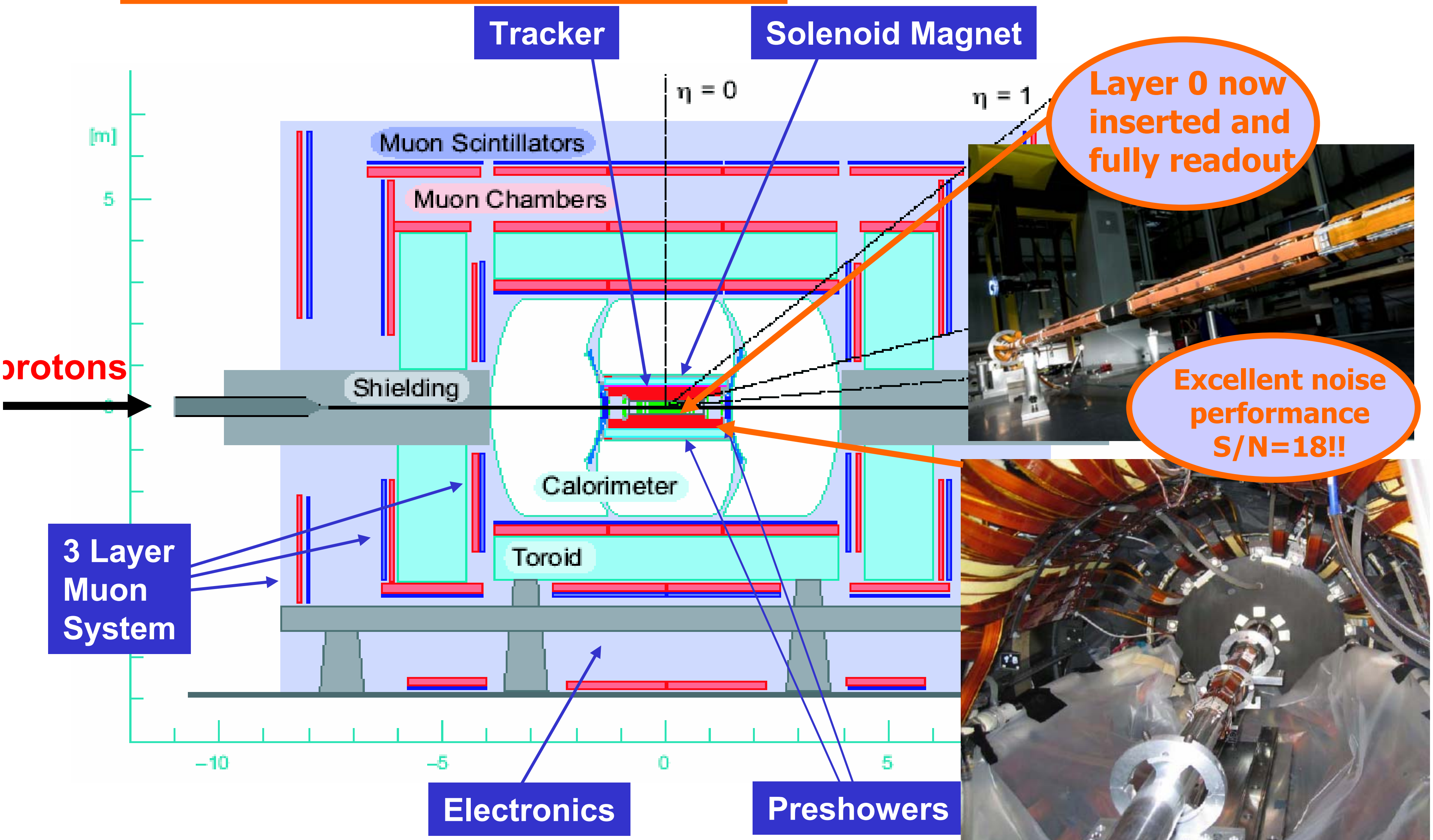
Dataset



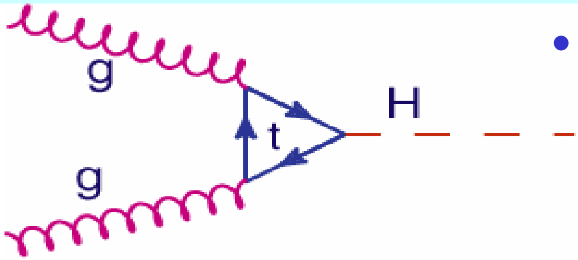
Run II Integrated Luminosity
19 April 2002 - 5 August 2007
Average data-taking efficiency: ~85%
3.29 fb -1
2.81 fb -1
DØ Upgrade
Results presented here based on ~1.7 fb-1 of analyzed luminosity
Run IIa
Run IIb
Delivered
Recorded
Luminosity (/fb)
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07

The Upgraded DØ detector in Run IIb

- Trigger: L1 Calorimeter trigger
- Silicon vertex detector: Layer 0

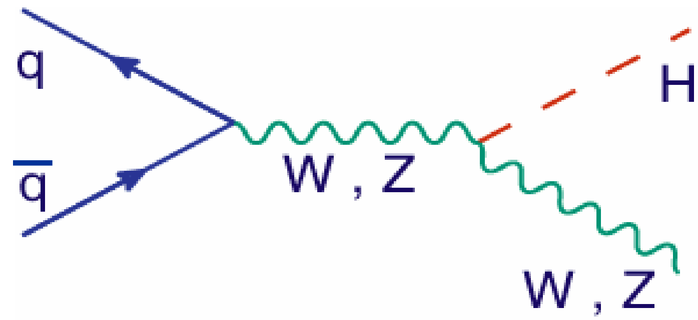


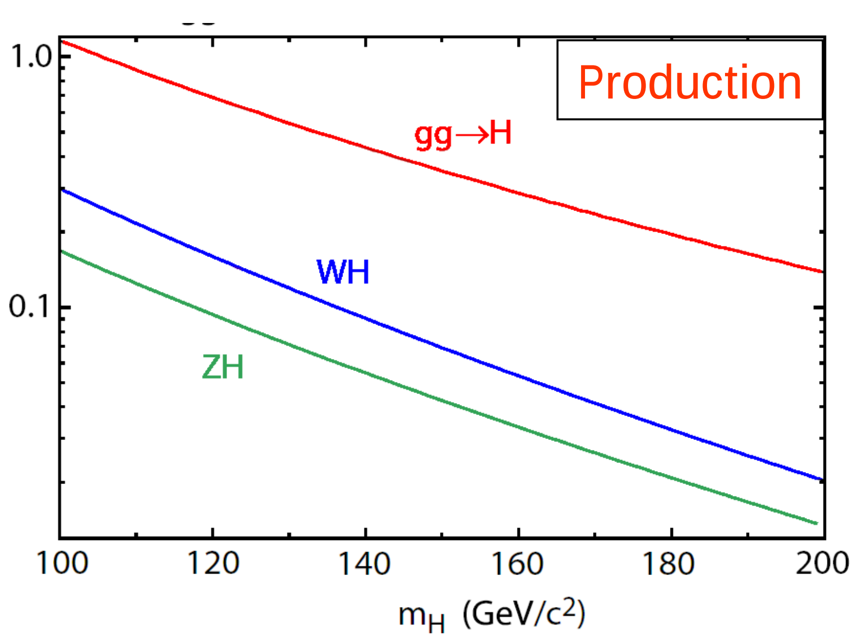
SM Higgs boson production & decays

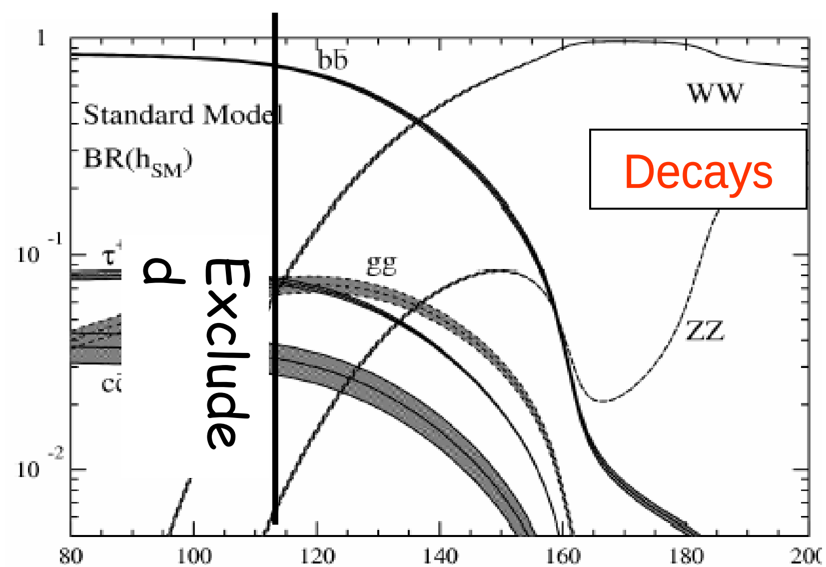


- **gg fusion**
  - Dominates at hadron machines
  - Usefulness depends on the Higgs decay channel

- **WH, ZH associated production**
  - Important at hadron colliders since can trigger on 0/1/2 high-p_T leptons and MET





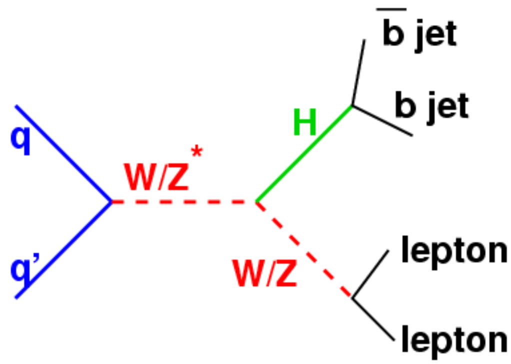


SM Higgs Searches at the Tevatron

Low mass (m_H <~135 GeV):
dominant decay:

$$H \to b\bar{b}$$

Use associated production modes to get better signal/background



$$q\bar{q}' \to WH \to \ell\nu b\bar{b}$$

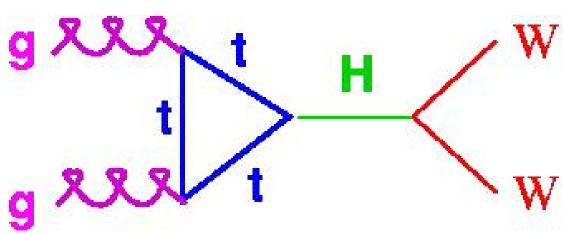
$$q\bar{q} \to ZH \to \ell^+\ell^- b\bar{b}$$

$$q\bar{q} \to ZH \to \nu\bar{\nu} b\bar{b}$$

Intermediate mass: $q\bar{q} \to WH \to WWW^{(*)}$

High mass (m_H>~135 GeV):
dominant decay:

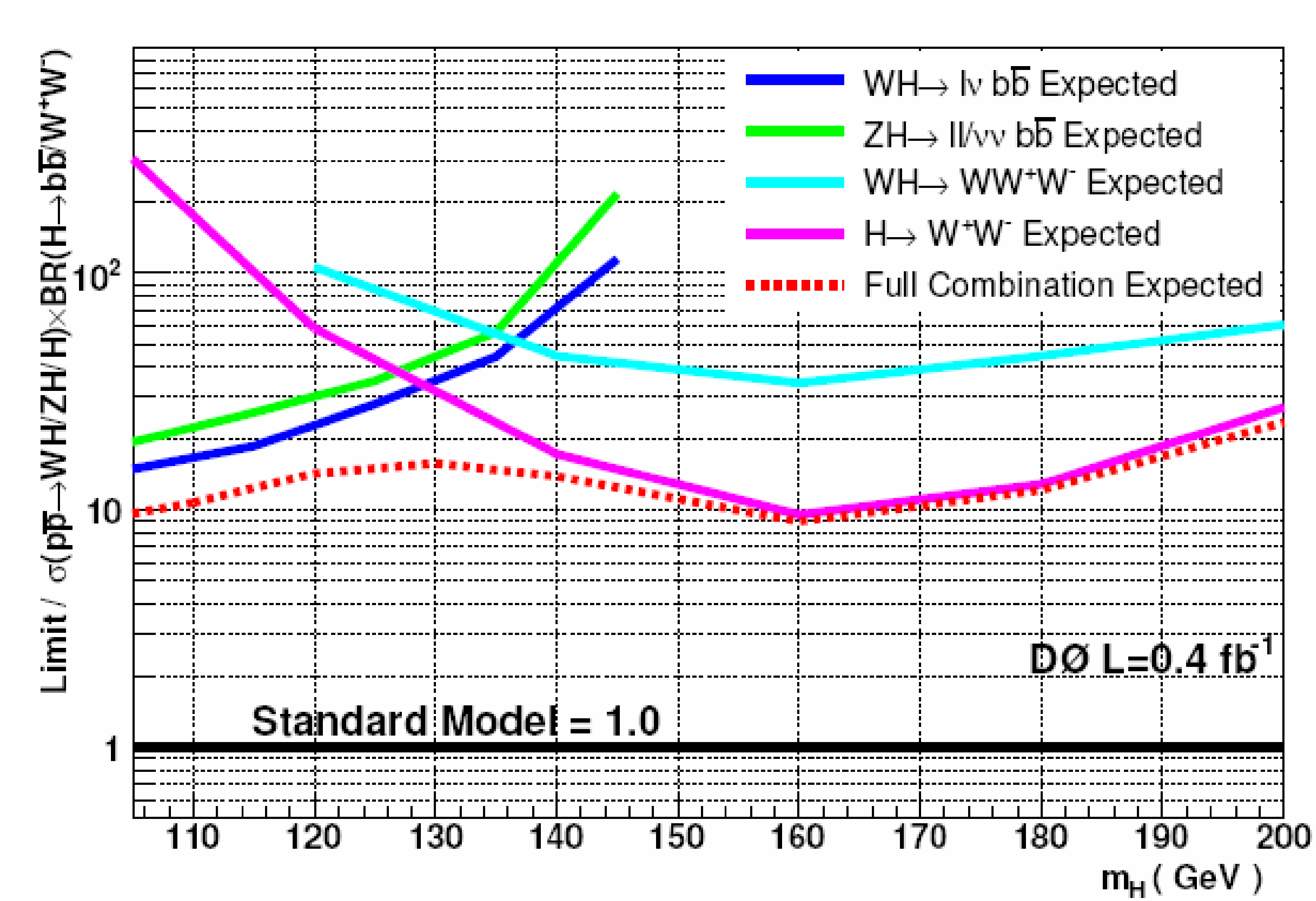
$$H \to WW^{(*)}$$



$$gg \to H \to WW \to \ell\nu\ell'\nu'$$

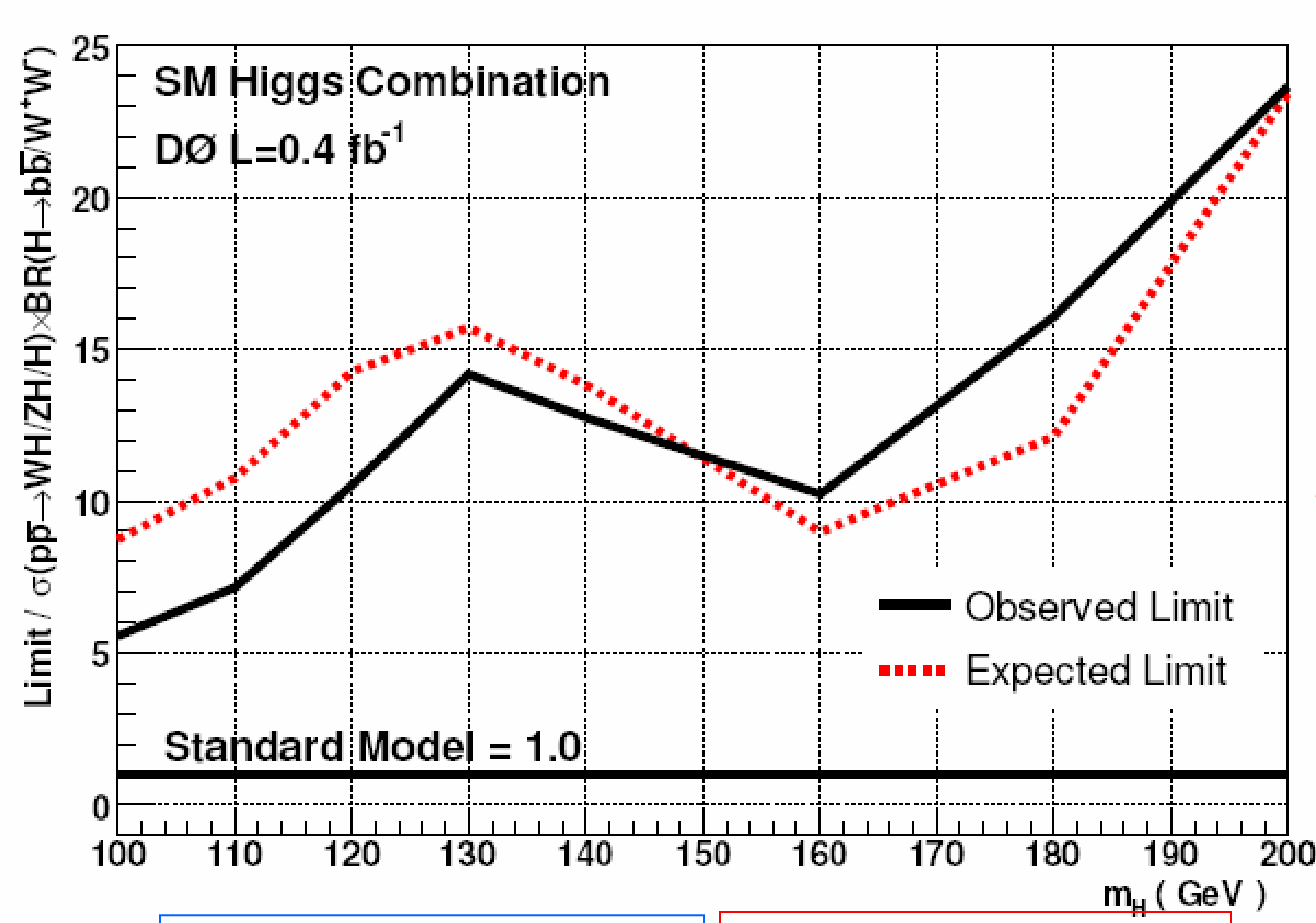
Comparison of expected limits/channel

based on 0.3-0.4 fb^{-1} of data



DØ combination, 0.4 fb^{-1}, arXiv:0712.0598, subm. to PLB

Combination with 0.4 fb-1 (→ PLB)



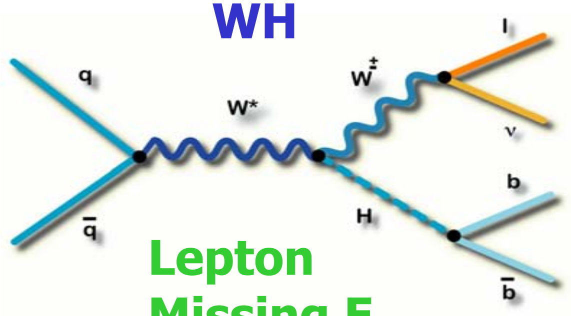
arXiv:0712.0598

@ 115 GeV (0.4 fb^{-1}) Expected/Obs	@ 160 GeV(0.3 fb^{-1}) Expected/Obs
12.1 / 8.5	9.0 / 10.2

All limits in this talk are given as ratios to SM cross-sections

SM Higgs Low mass searches: datasets/methods

WH

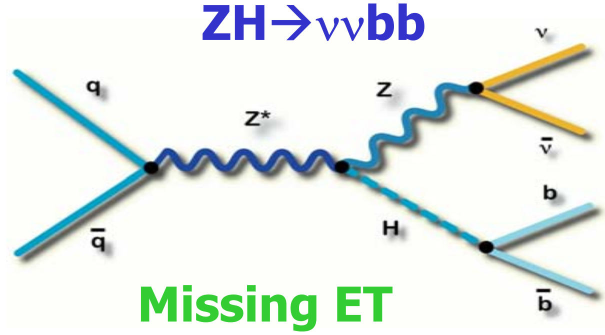


Lepton
Missing E_T
2 b-jets

1.7 fb^{-1}

LP-07

ZH→ννbb

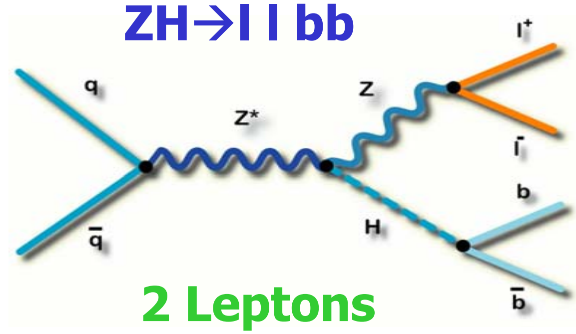


Missing ET
2 b-jets

0.9 fb^{-1}

Updated (NN)

ZH→l l bb



2 Leptons
2 b-jets

1.1 fb^{-1}

LP-07

Common to all analyses: b-tagging, Jet calibration & resolution, lepton-identification, Background cross-section

Differences: instrumental bckd, multivariate techniques

Neural Network b-tagger

All Higgs analyses uses Neural Network b-tagging algorithm

Asymmetric tagging:

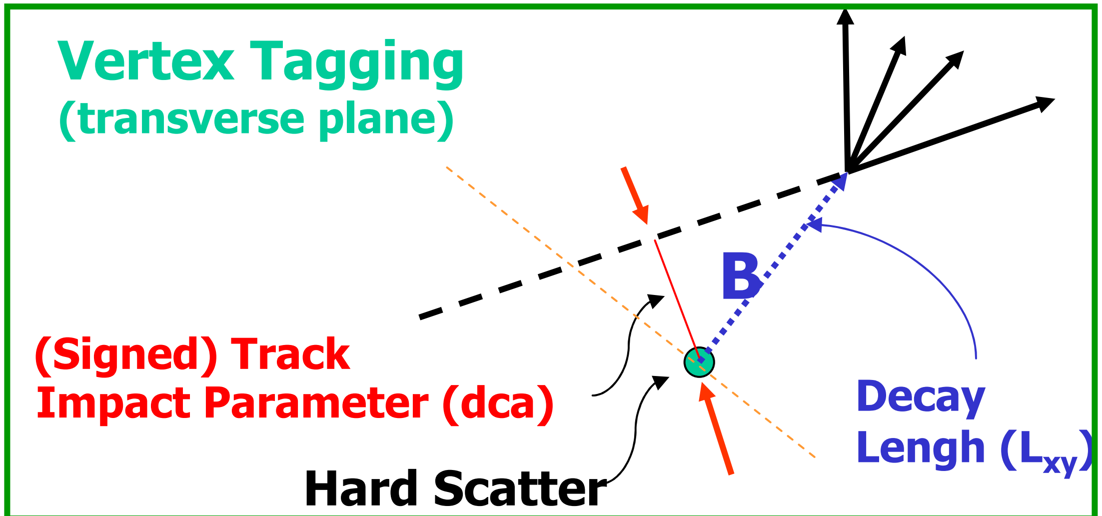
Tight tagging for Single Tag

Loose tagging for Double Tag

→ Large improvement compared to the individual taggers:

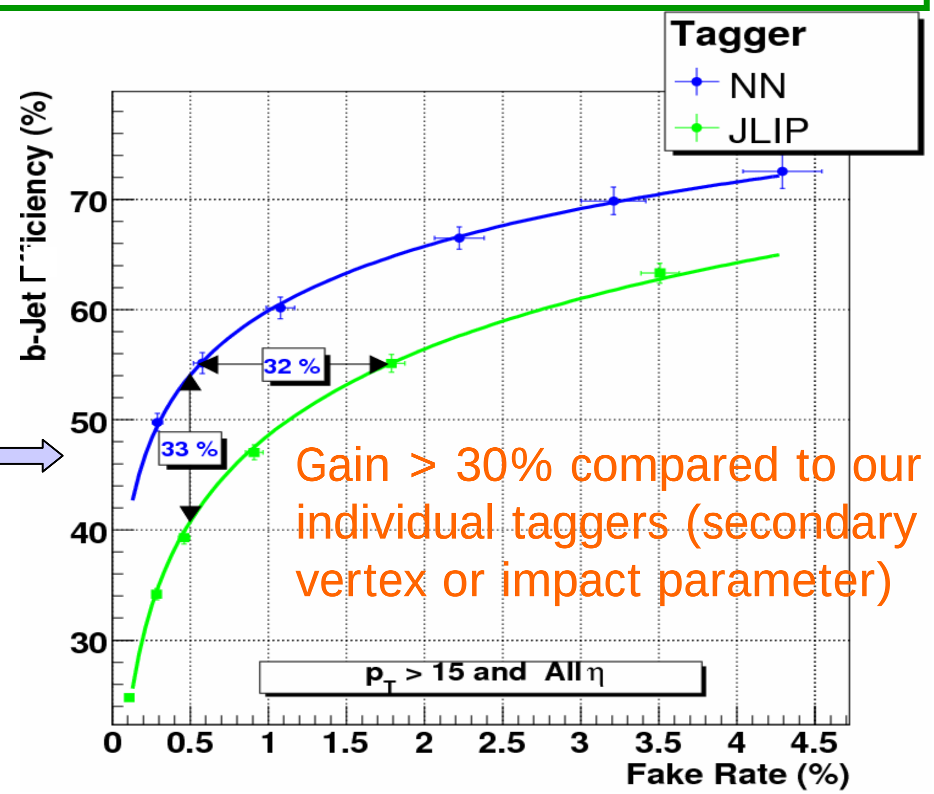
Loose → 72% b-tagging eff. 6% mistag

Tight → 50% b-tagging eff. 0.3% mistag



Combine in Neural Network:
- vertex mass
- vertex number of tracks
- vertex decay length significance
- chi2/DOF of vertex
- number of vertices
- two methods of combined track impact parameter significances

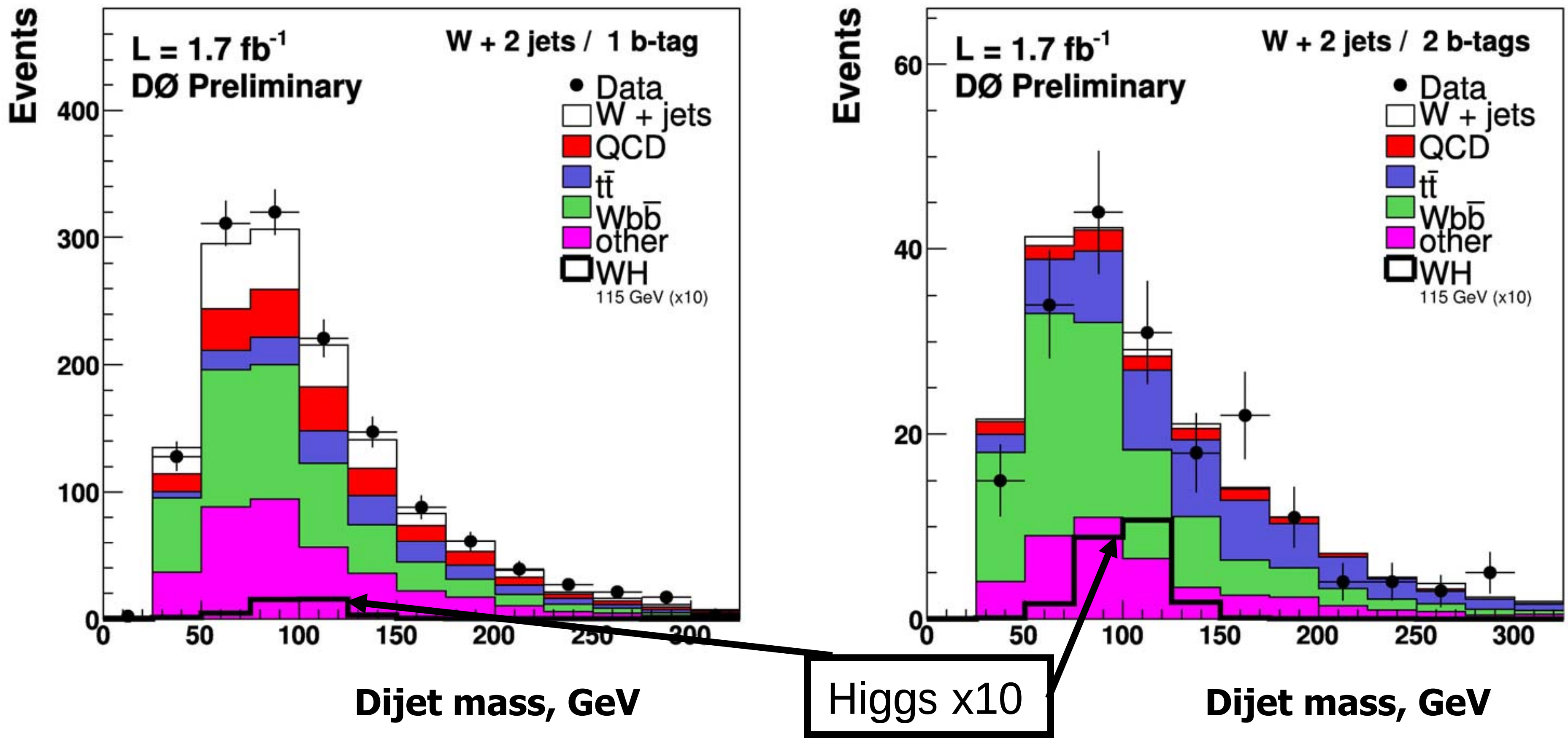
→ NN_{btag} →



WH→lν bb (l=e,μ): after b-tagging

Starting from a W+ 2 jet selection, apply NN_btagging → orthogonal samples

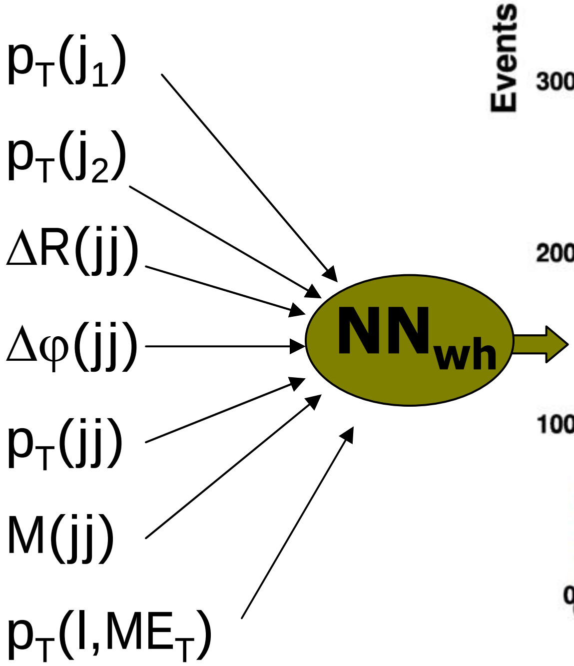
Exclusive single tag | **Double Loose tag**

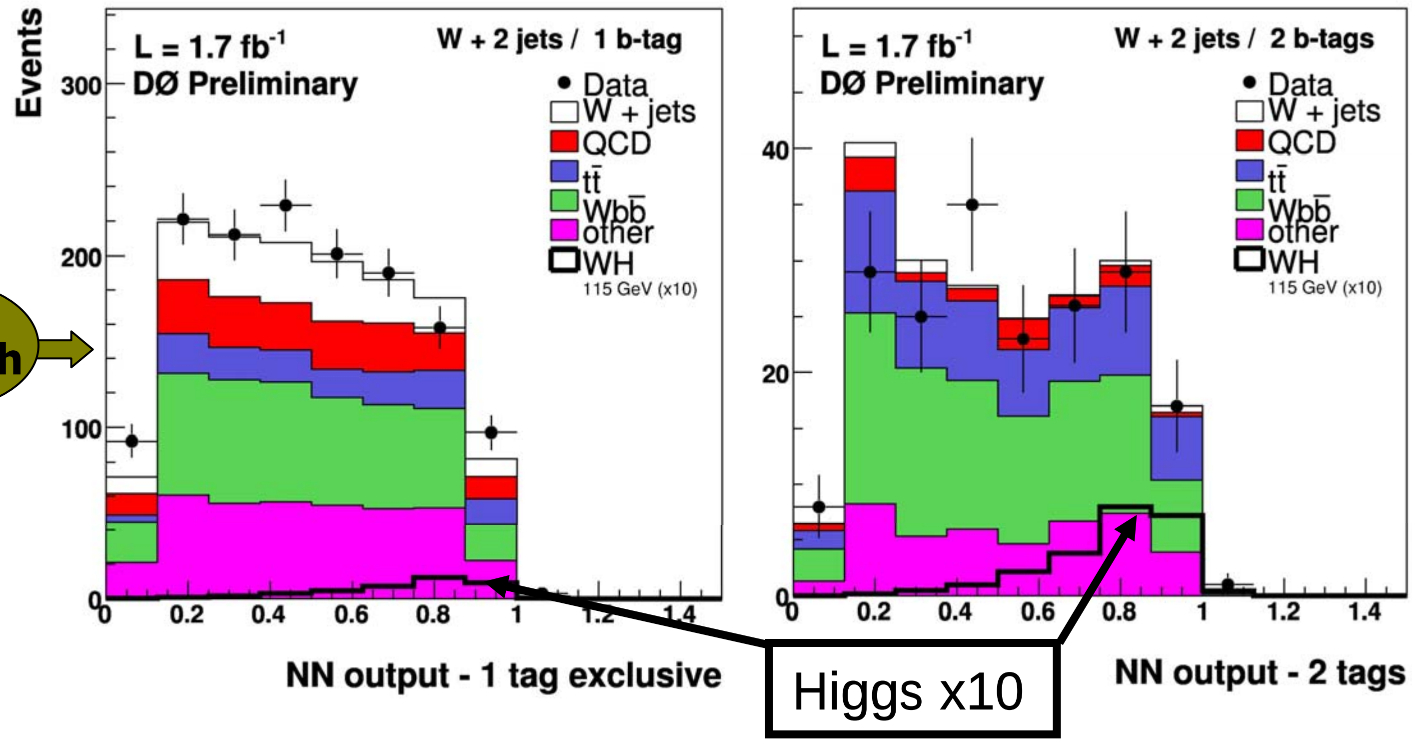


Backgrounds are measured one after the other (Wbb, Single Top), WZ with Z→bb remains the golden benchmark on which we can tune our analysis tools.

WH→lν bb (l=e,μ): Neural Net and Limits

Use neural network to separate signal from background
Fit the NN output





- **Limit @ M_H=115 GeV:**

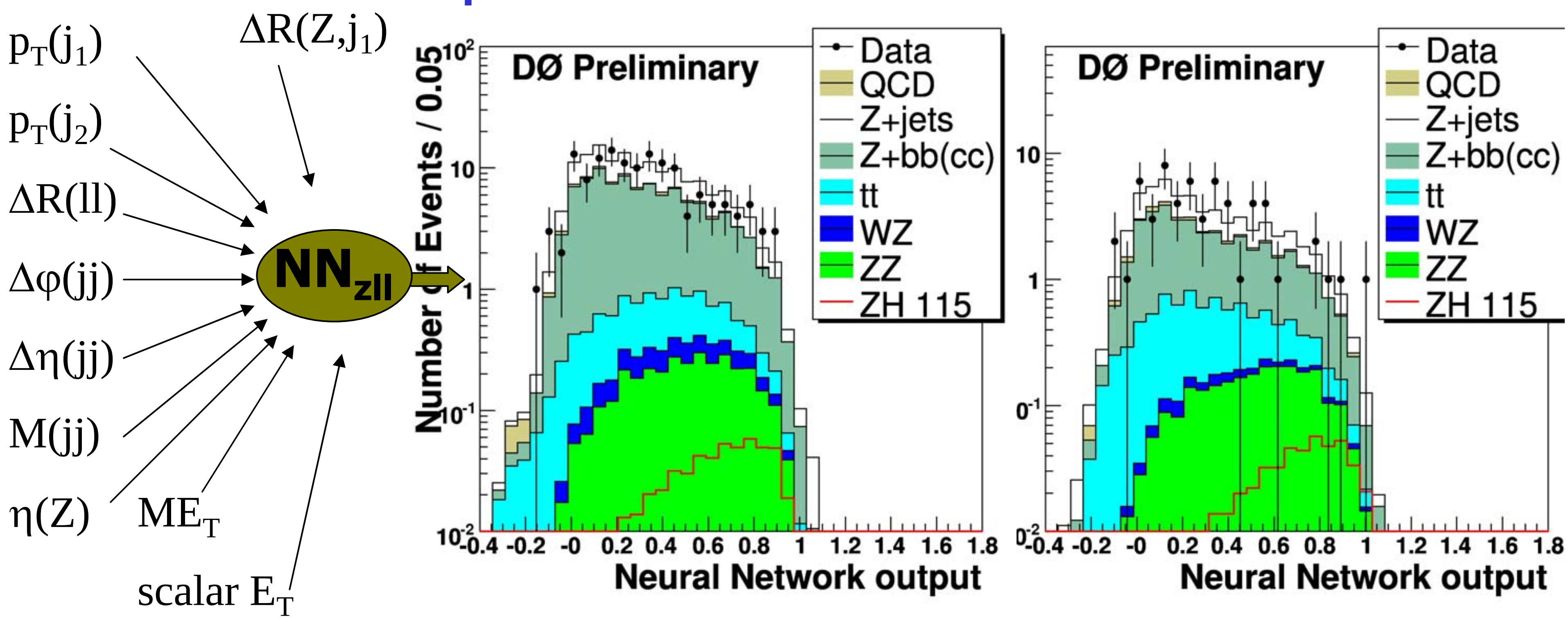
σ_{95}/SM, L=1.7 fb^{-1}= 9 (exp)/11(obs)

CDF L=1.7 fb^{-1}=10(exp)/10(obs)

Future improvements (short term):
include forward electrons and 3 jets sample. Improve NN with more backgd rejection and use Matrix Element approach

ZH→ll bb (l=e,μ): setting limits

- **Starting from a Z+ 1 or 2 b-jets selection**
- **Use neural network to separate signal from background**
- **Fit the NN output**



- **Limit @ M_H=115 GeV:**

σ_{95}/SM, 1.1 fb^{-1}=20(exp)/18(obs)

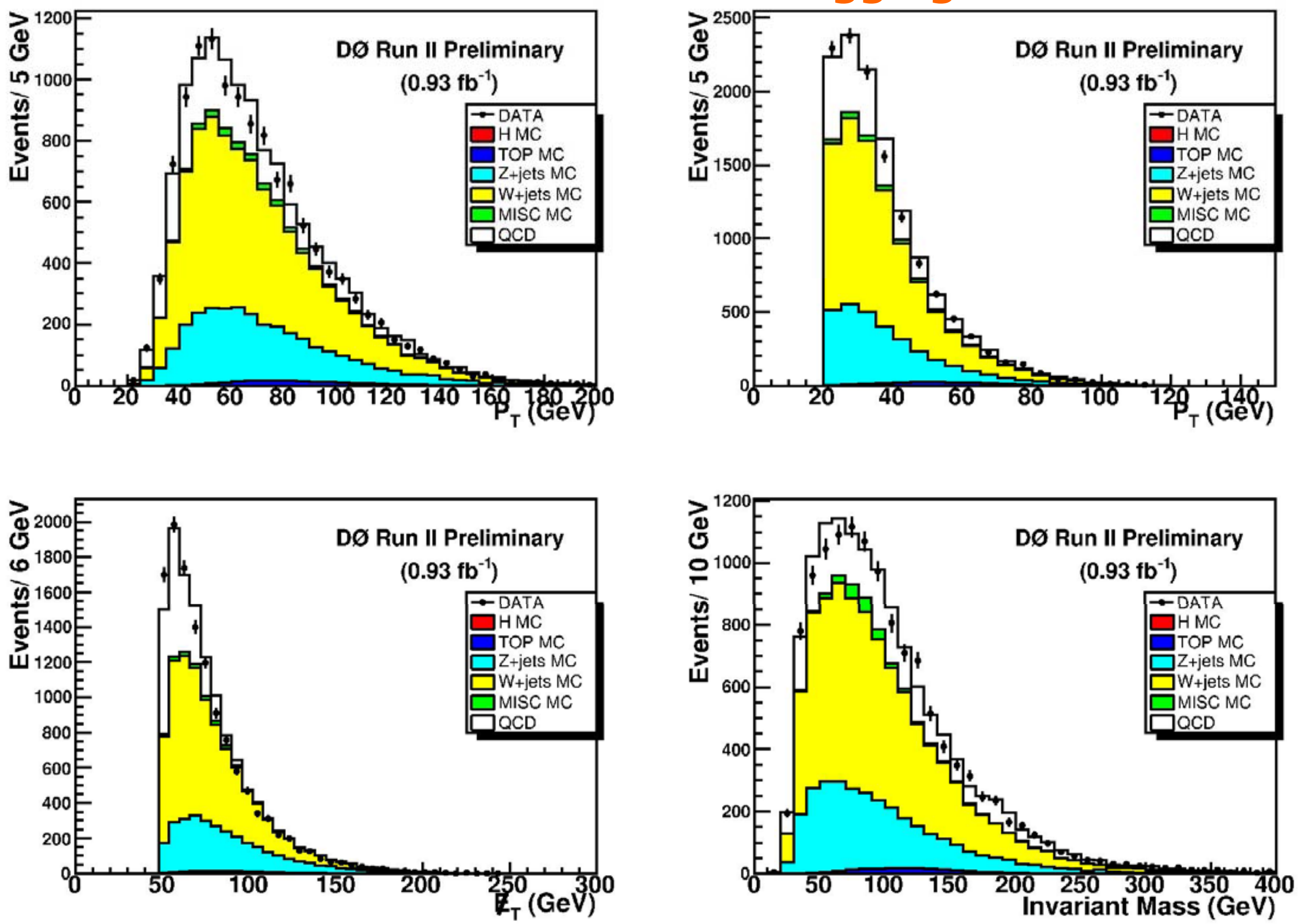
CDF, L=1.0 fb^{-1}=16(exp)/16(obs)

Future improvements (short term):
more efficient lepton-ID
Improve NN and use Matrix element approach

ZH→ νν bb / Update with Neural Net

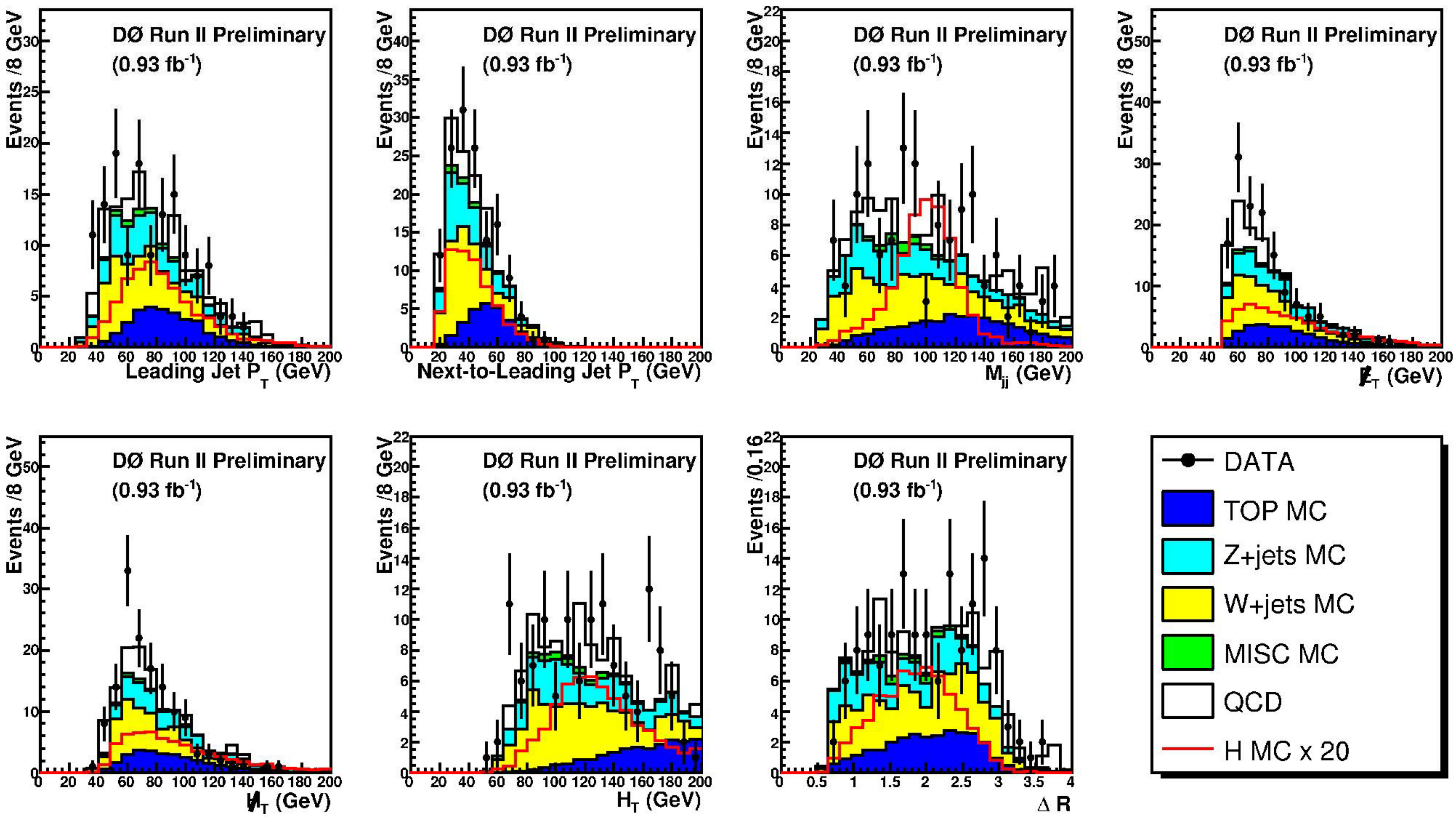
Starting from a Missing E_T (> 50 GeV) + jet selection

Distributions before b-tagging



Instrumental background and trigger are understood. Dominant physics background is W+jets with non reconstructed charged lepton

ZH→ νν bb / Update with NN (0.9 fb^{-1})

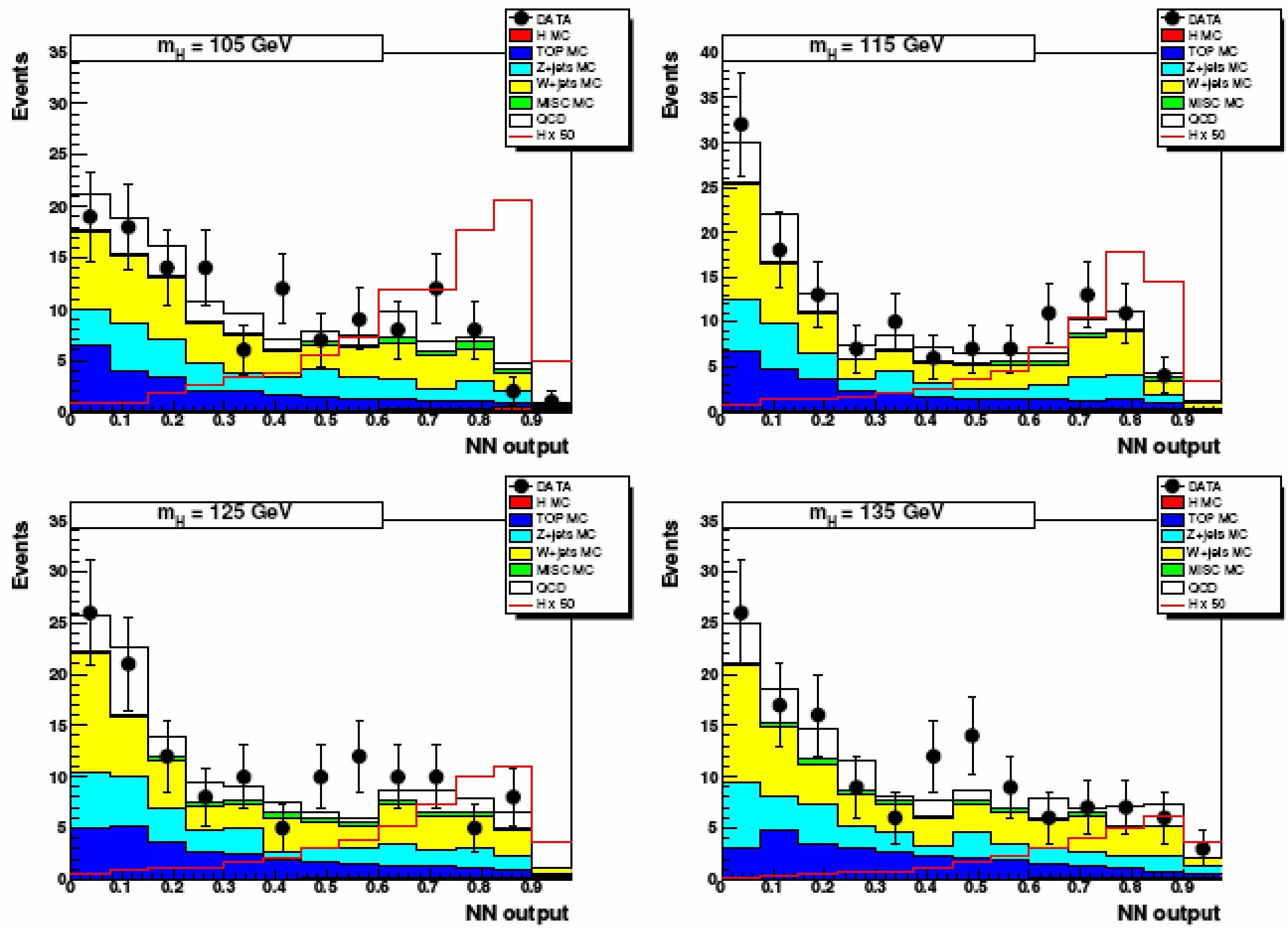


NN input variables, after double b-tag

$NN_{Z\nu\nu}$

➔ **Expected Limits improve by 20-30%**

ZH→ $\nu\nu$ bb / Update with NN (0.9 fb^{-1})



- **Limit @ M_H=115 GeV:**

σ_{95}/SM, 0.9 fb^{-1}= 12 (exp)/ 13(obs)

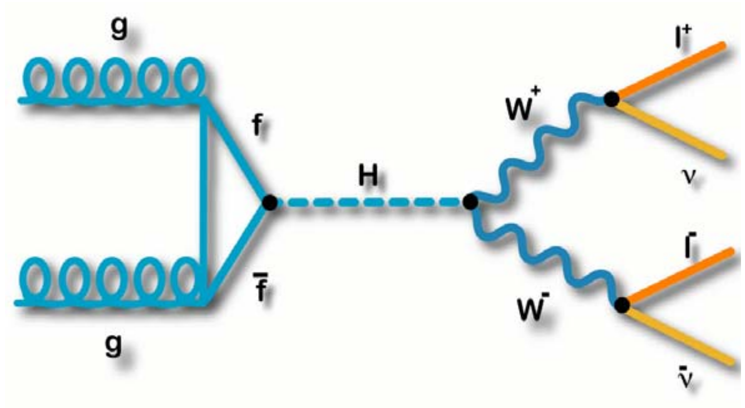
CDF, L=1.7 fb^{-1}= 10 (exp)/20(obs)

Future improvements (short term):
Improve QCD-multijet understanding. Improve Trigger efficiency (L1Cal RunIIb upgrade).
Use single-tag as well.

High mass SM Higgs

Main mode: gg → H → WW* → lν l′ν′ (l, l′=e,μ)

- two high p_T isolated leptons, missing E_T
- three main channels (ee, eμ, μμ)
- start probing other channels (μτ)



Can't reconstruct the Higgs mass (escaping ν's)

H→WW* is low background mode

Dibosons: main background

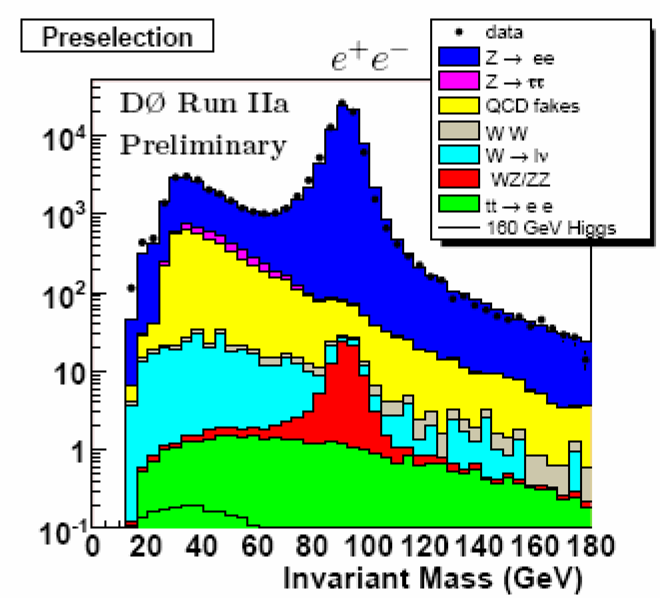
- WW* irreducible, separate from the signal based on angular correlation Δφ(l,l′) – Higgs is a scalar !

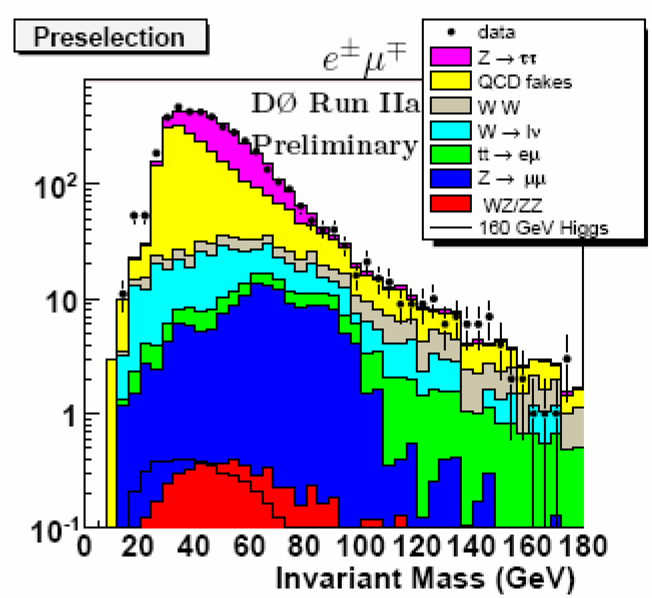
W+jets and multijets

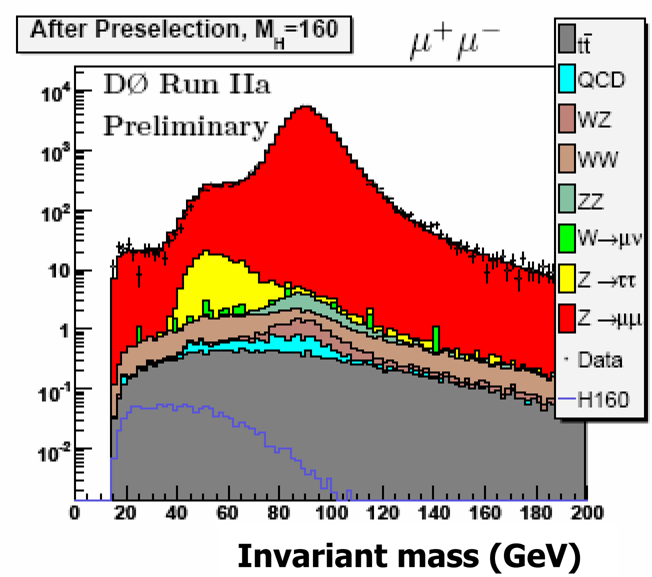
- need good lepton identification

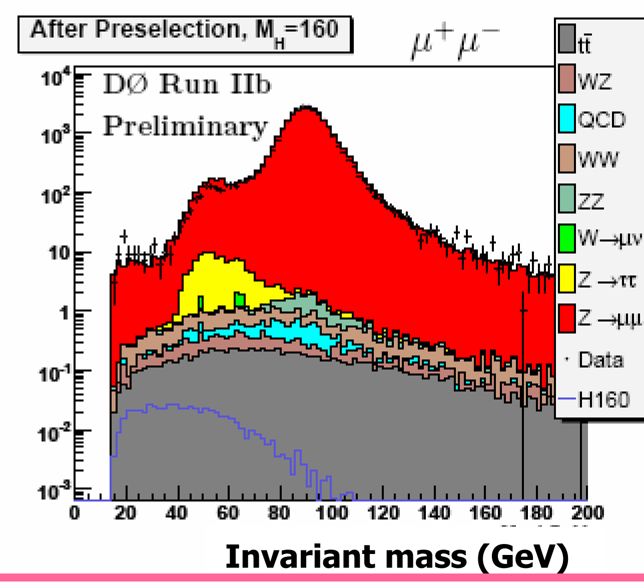
Z→ττ : specific for eμ channel and channels involving taus

H → WW: ee, eμ in Run IIa ; μμ in Run IIa & IIb







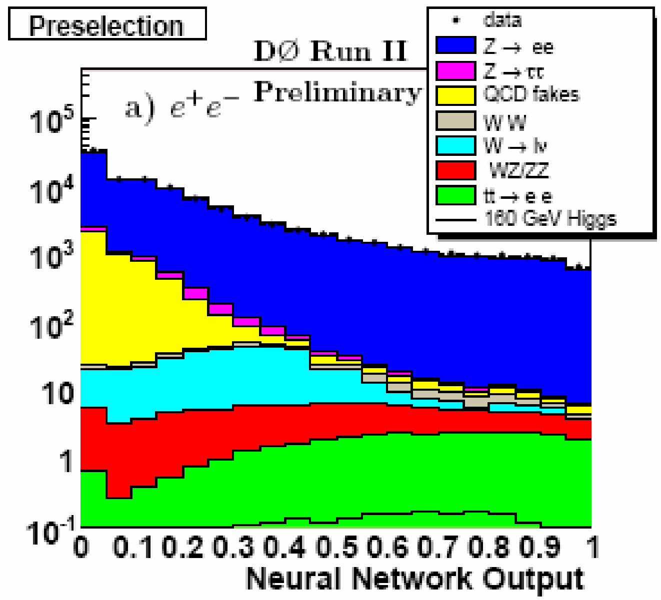


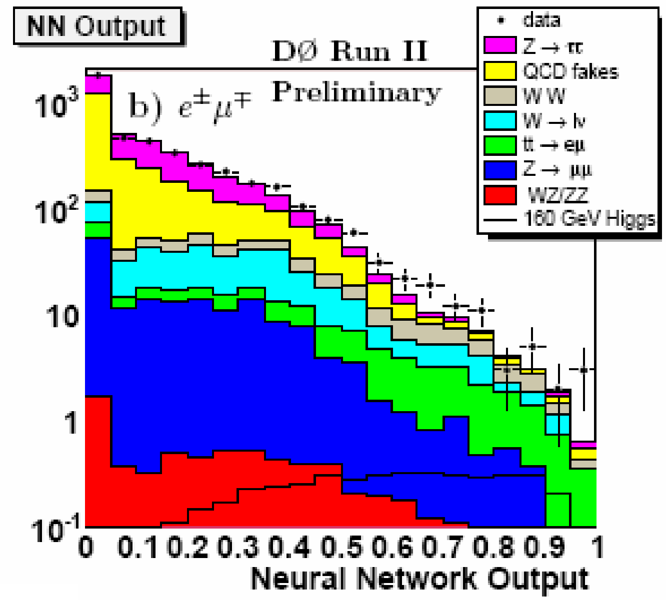
Run IIb

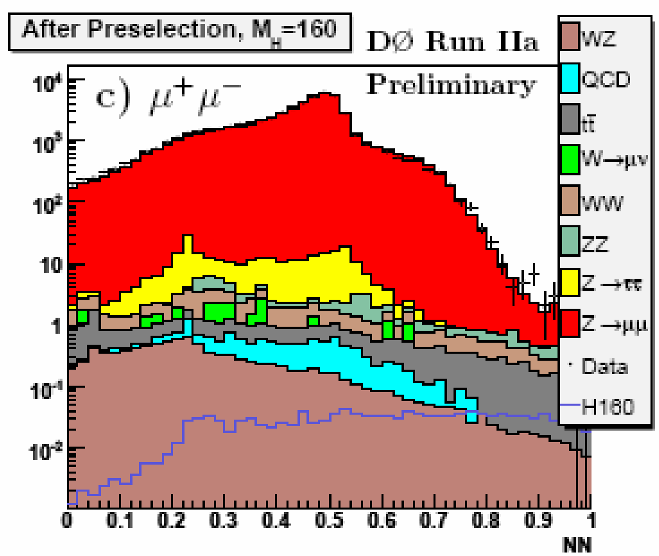
Similar detector performances

As Run IIa

H→ WW: Neural Net Output







p_T of the leading lepton,

p_T of the next-to-leading lepton,

NN$_{WW}$

invariant di-lepton mass,

angle between the two leptons,

missing transverse energy $\not\!\!E_T$,

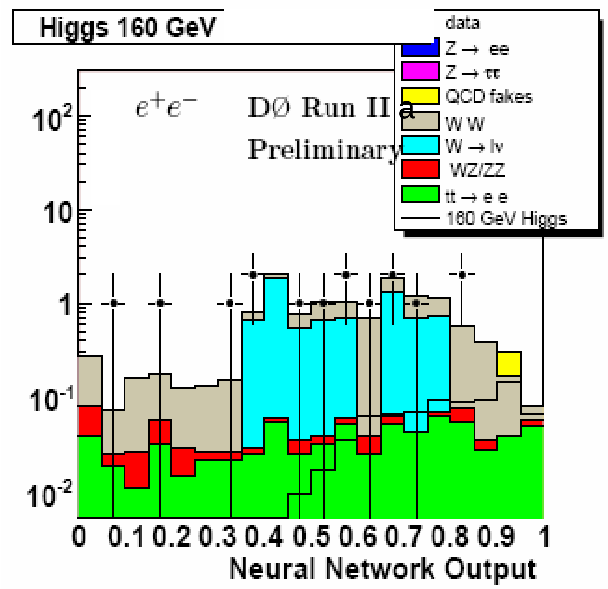
angle between the leading lepton and $\not\!\!E_T$,

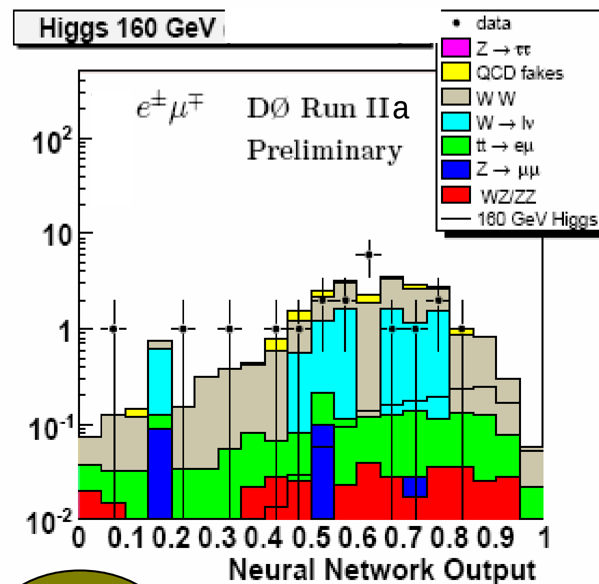
angle between the next-to-leading lepton and $\not\!\!E_T$,

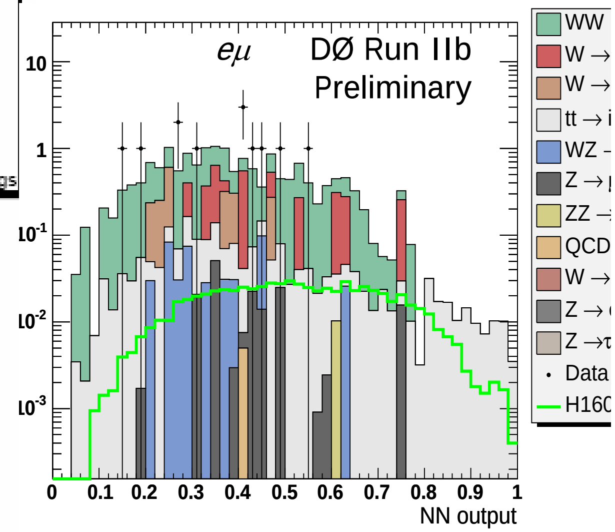
minimum transverse mass of the leptons and $\not\!\!E_T$,

sum of the lepton p_T and $\not\!\!E_T$.

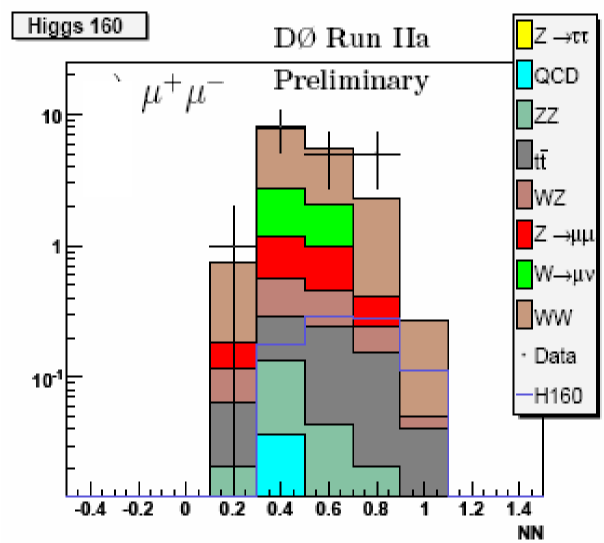
ee, eμ, μμ Run IIa, Run IIb, NNs outputs

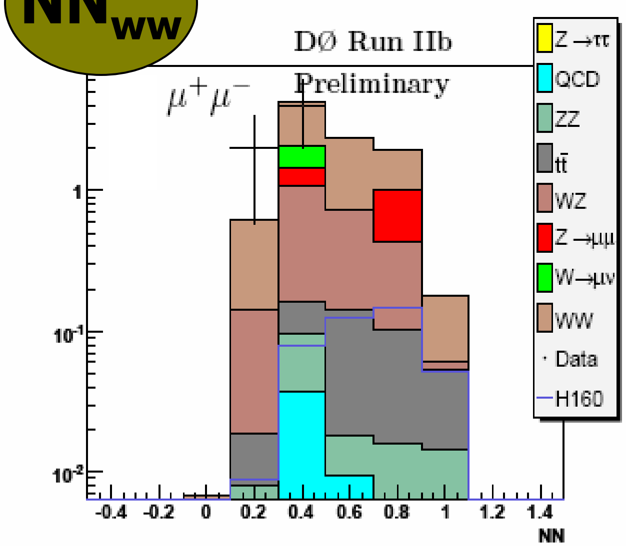


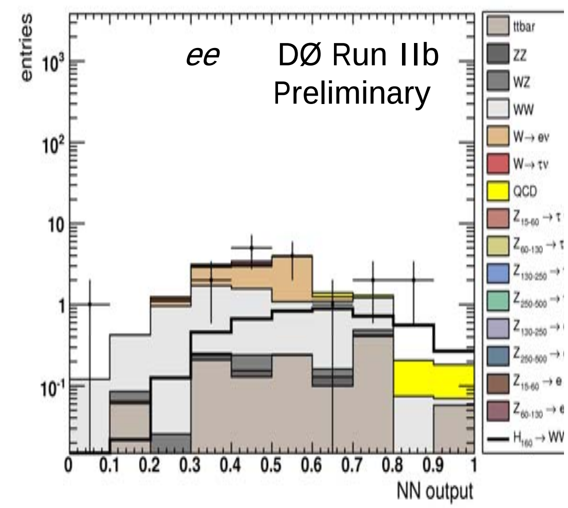




NN_{WW}



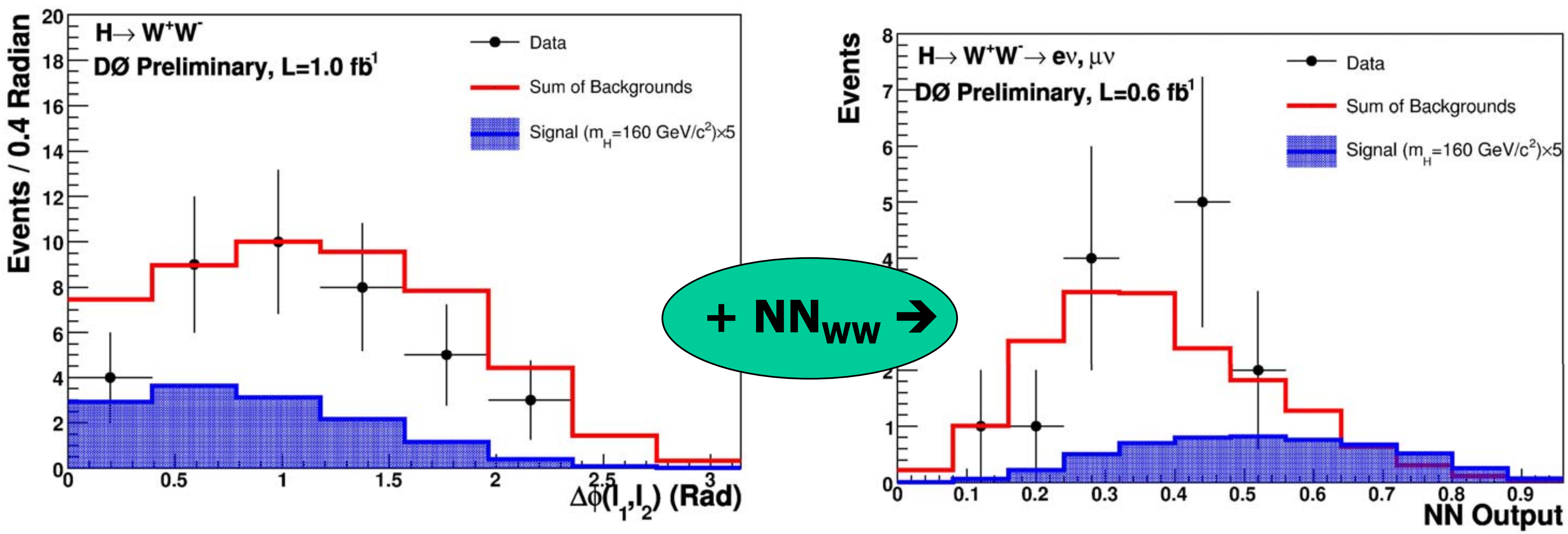




$H \rightarrow WW^* \rightarrow l\nu\ l'\nu'$: NN input/output

Variables used depend on the mass/channel

Significant improvement compared to Delta-Phi (>30%), with NN_{WW}



Combining the results

For the searches and to set limits, Tevatron experiments use generalized CL_s method (modified frequentist, DØ) and Bayesian methods (CDF), and cross-check each other.

Systematics, including correlations, are taken into account:

Main systematics (depending on channel):
- luminosity and normalisation
- QCD background estimates
- input background cross-sections
- jet energy scale and b-tagging
- lepton identification
- K-factors on W/Z+ Heavy Flavor

Limit setting approaches agree to within ~10%

Systematics: ZH-llbb / CDF vs DØ

CDF: Double Tag (DT) $ZH \to \ell\ell b\bar{b}$ Analysis

Contribution	Fakes	Top	WZ	ZZ	$Z+b\bar{b}$	$Z+c\bar{c}$	Z+mistag	ZH
Luminosity ($\sigma_{\mathrm{inel}}(p\bar{p})$)	0	4	4	4	4	4	0	4
Luminosity Monitor	0	5	5	5	5	5	0	5
Lepton ID	0	1	1	1	1	1	0	1
Fake Leptons	50	0	0	0	0	0	0	0
Jet Energy Scale (shape dep.)	0	$^{+0.1}_{-0.1}$	0	$^{+0.5}_{-3.0}$	$^{+3.1}_{-7.8}$	$^{+8.7}_{-0}$	0	$^{+0.3}_{-1.2}$
Mistag Rate	0	0	0	0	0	0	24	0
B-Tag Efficiency	0	16	16	16	16	32	0	16
$t\bar{t}$ Cross Section	0	20	0	0	0	0	0	0
Diboson Cross Section	0	0	20	0	0	0	0	0
$\sigma(p\bar{p} \to Z + HF)$	0	0	0	0	40	40	0	0
ISR (shape dep.)	0	0	0	0	0	0	0	$^{+4.6}_{+0.6}$
FSR (shape dep.)	0	0	0	0	0	0	0	$^{+5.3}_{+3.7}$

DØ: Double Tag (DT) $ZH \to \ell\ell bb$ Analysis

Contribution	WZ/ZZ	Zbb/Zcc	Zjj	$t\bar{t}$	QCD	ZH
Luminosity	6.1	6.1	6.1	6.1	0	6.1
EM ID/Reco eff.	4	4	4	4	0	4
Muon ID/Reco eff.	4	4	4	4	0	4
Jet ID/Reco eff.	2	1.5	2	1.5	0	1.5
Jet Energy Scale (shape dep.)	4	8	11	2	0	2
B-tagging/taggability	8	8	9	7	0	7
Cross Section	7	0	0	18	0	6
Heavy-Flavor K-factor	0	30	15	0	0	0
Instrumental-ZH-2	0	0	0	0	50	0

Limit Setting

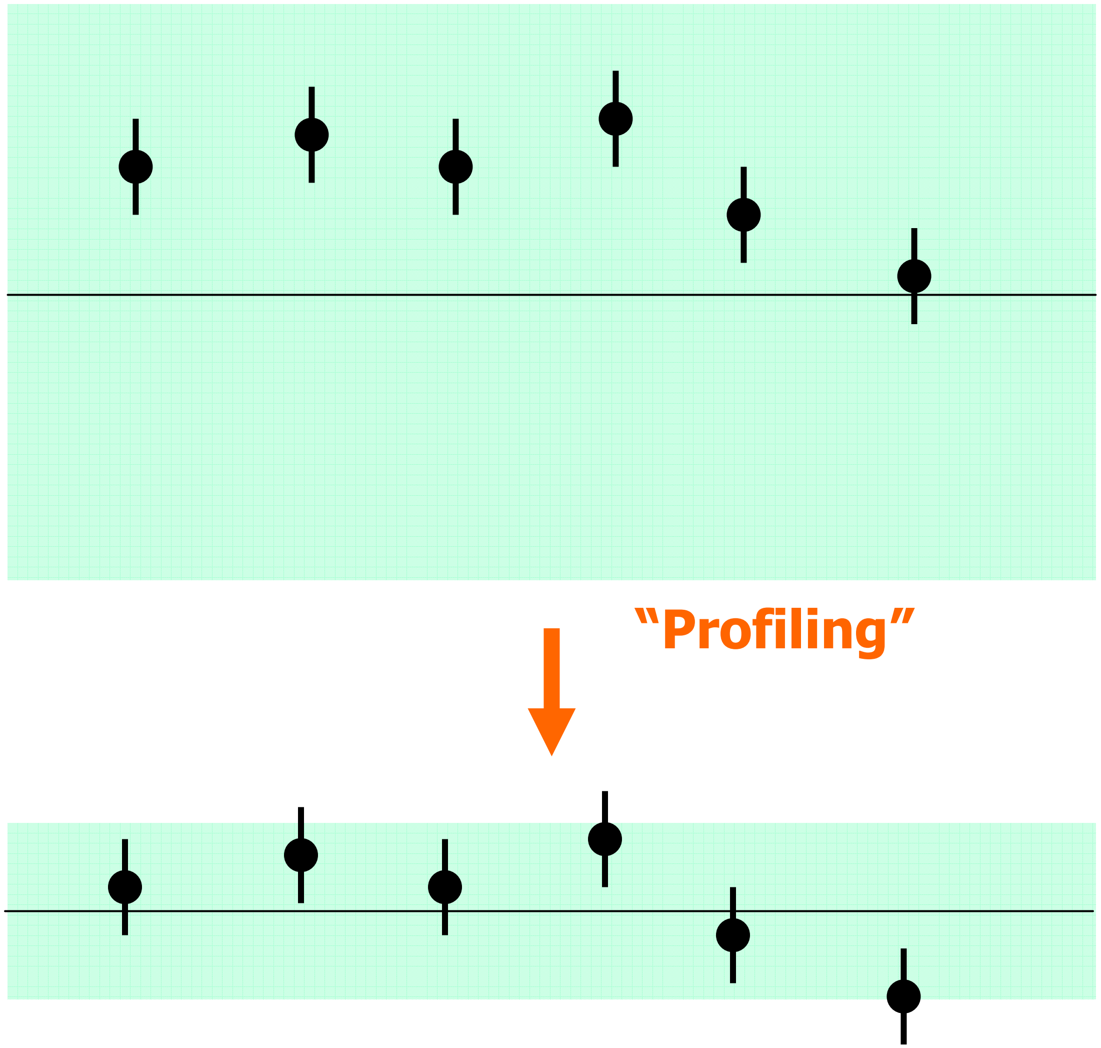
LEP: low background, small systematics
Tevatron: high background, large systematics (at low mass)

But SMALL signals in both cases
→Background only (b) and signal plus background (s+b) hypotheses are compared to data using Poisson likelihoods.

Systematic uncertainties are included in the likelihood, via gaussian smearing of the expectation ('profile likelihood').

New compared to LEP:
Background is constrained by maximising profile likelihood ('sideband fitting'), usefull in particular at low mass.

Constraining Systematics Uncertainties with Data



Background prediction
+ uncertainty

AKA side band fitting

Nuisance parameters introduced in the chi^2 of the fit allow shifting of central value of the background estimation

Systematic uncertainty width gets also constrained

Shape of the systematic is also taken into account

More on CL_S

- In the absence of signal, we set limits on Standard Model Higgs boson production
  - We calculate limits via the CLs prescription:

$$CL_s = \frac{CL_{s+b}}{CL_b}$$

  - Using a Log-Likelihood Ratio test statistic:

$$Q(\vec{s}, \vec{b}, \vec{d}) = \prod_{i=0}^{N_{Chan}} \prod_{j=0}^{N_{bins}} \frac{(s+b)_{ij}^{d_{ij}} e^{(s+b)_{ij}}}{d_{ij}!} / \frac{b_{ij}^{d_{ij}} e^{b_{ij}}}{d_{ij}!} \qquad LLR = -2 \times LogQ$$

d_{ij} refers to "data" for model being tested; **Observed events, or expected Background or Signal+Background**

- Distributions of simulated outcomes are populated via Poisson trial with mean values given by B-only or S+B hypotheses
  - Systematics are folded in via Gaussian marginalization
  - Correlations held amongst signals and backgrounds

CLs

- **Model repeated outcomes of the experiment via Poisson distribution**
  - **Simulate Signal+Bkgd and Bkgd-Only outcomes based on predictions**
  - **Uncertainties on nuisance parameters folded in via Gaussian smearing**
  - **Define frequentist confidence levels based on these simulated outcomes**

Black line: Observed LLR value

Determined by data measurment

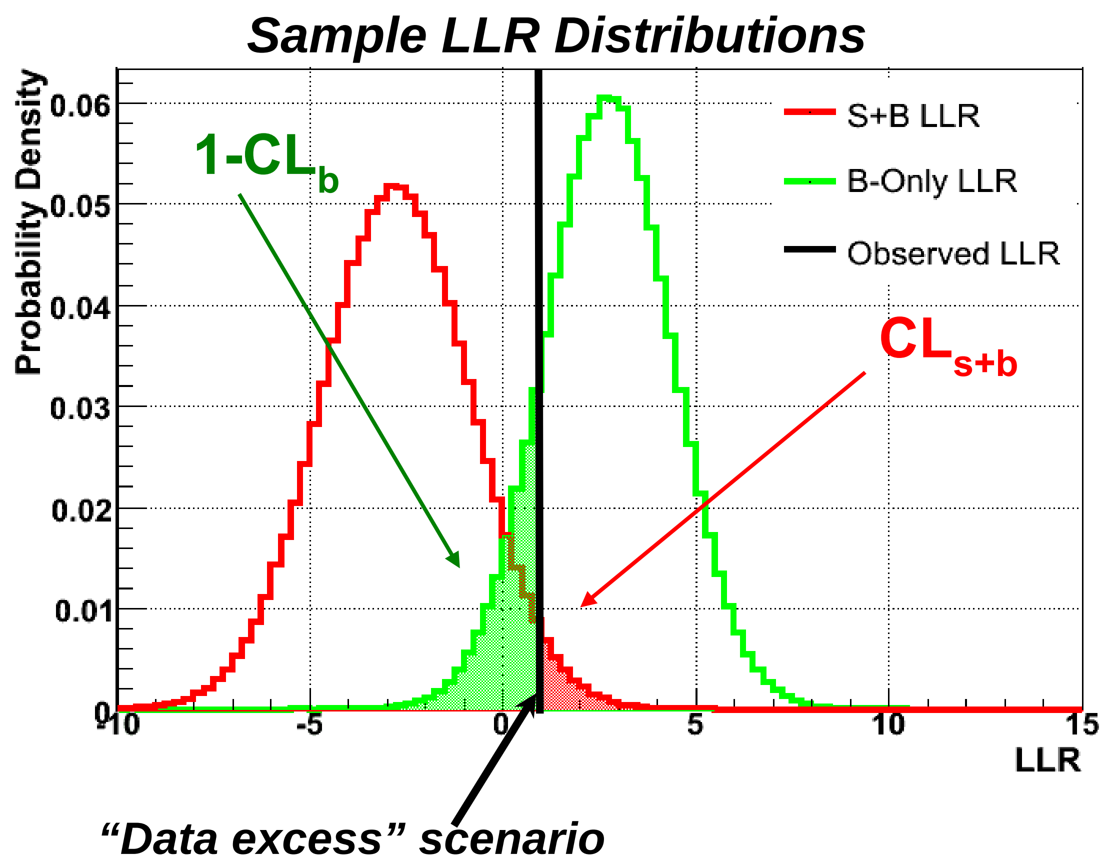
Green: Bkgd-only hypothesis

CL_b is region to right of LLR_{obs}

Equals ~50% for good bkgd/data agreement

Red: Signal+Bkgd hypothesis

CL_{s+b} is region to right of LLR_{obs}



CLs

- **Model repeated outcomes of the experiment via Poisson distribution**
  - **Simulate Signal+Bkgd and Bkgd-Only outcomes based on predictions**
  - **Uncertainties on nuisance parameters folded in via Gaussian smearing**
  - **Define frequentist confidence levels based on these simulated outcomes**

Black line: Observed LLR value

Determined by data measurment

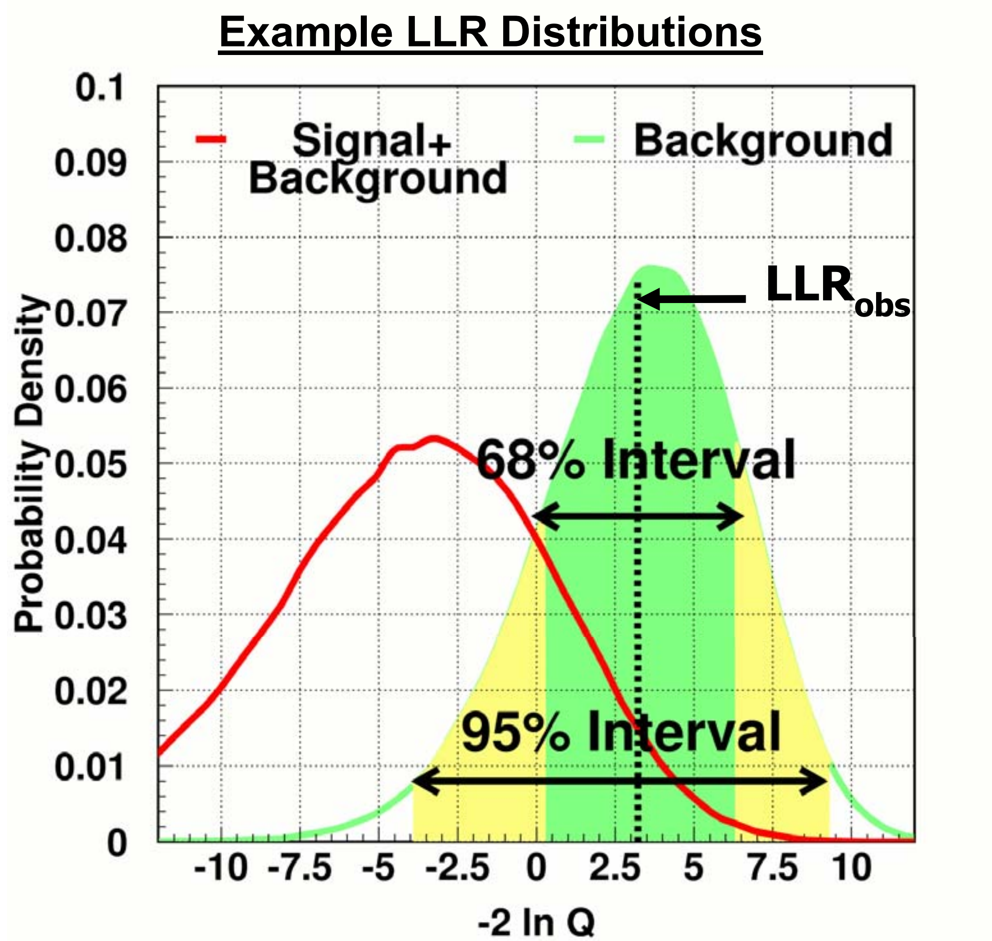
Green: Bkgd-only hypothesis

CL_b is region to right of LLR_{obs}

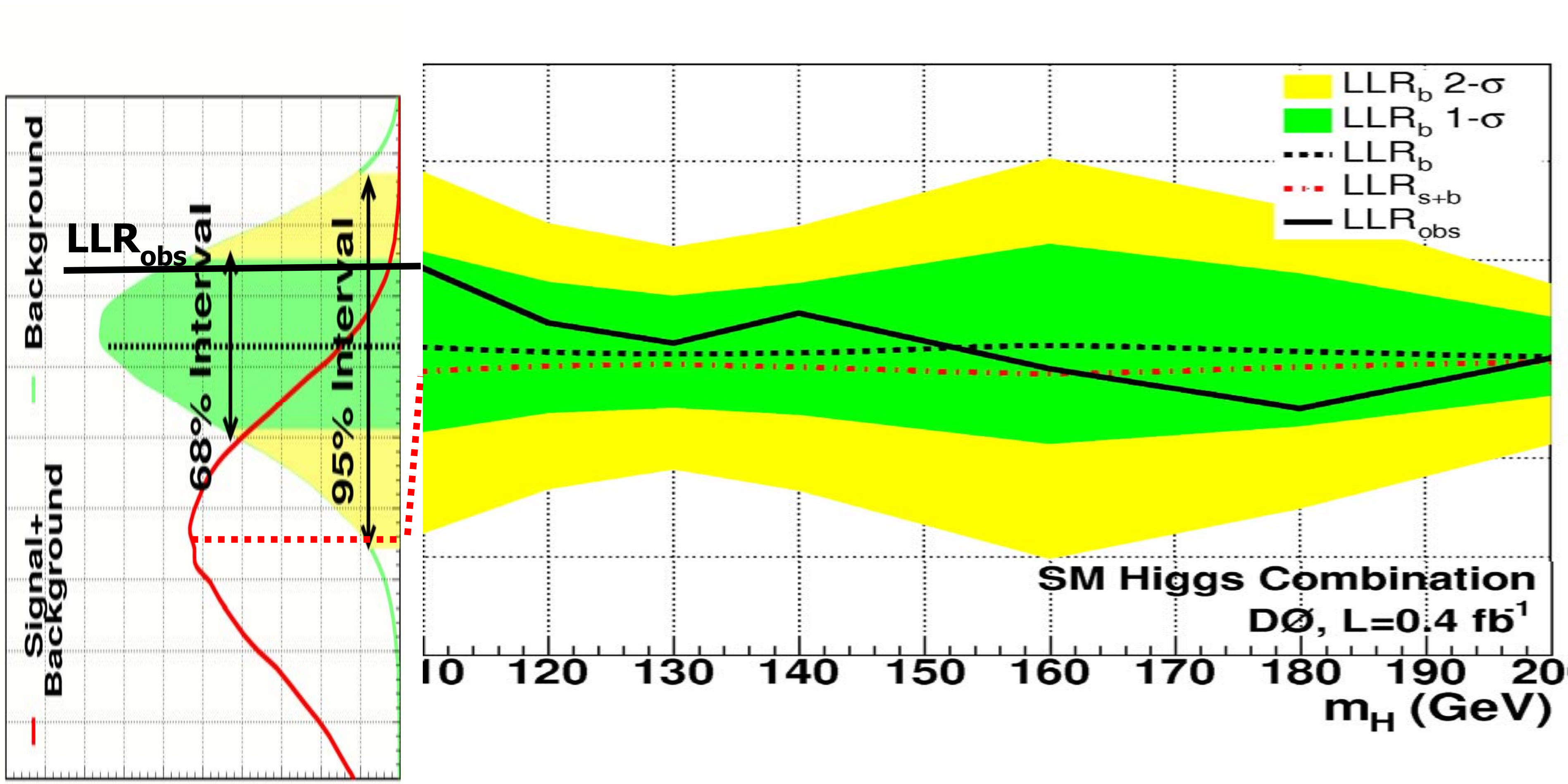
Equals ~50% for good bkgd/data agreement

Red: Signal+Bkgd hypothesis

CL_{s+b} is region to right of LLR_{obs}

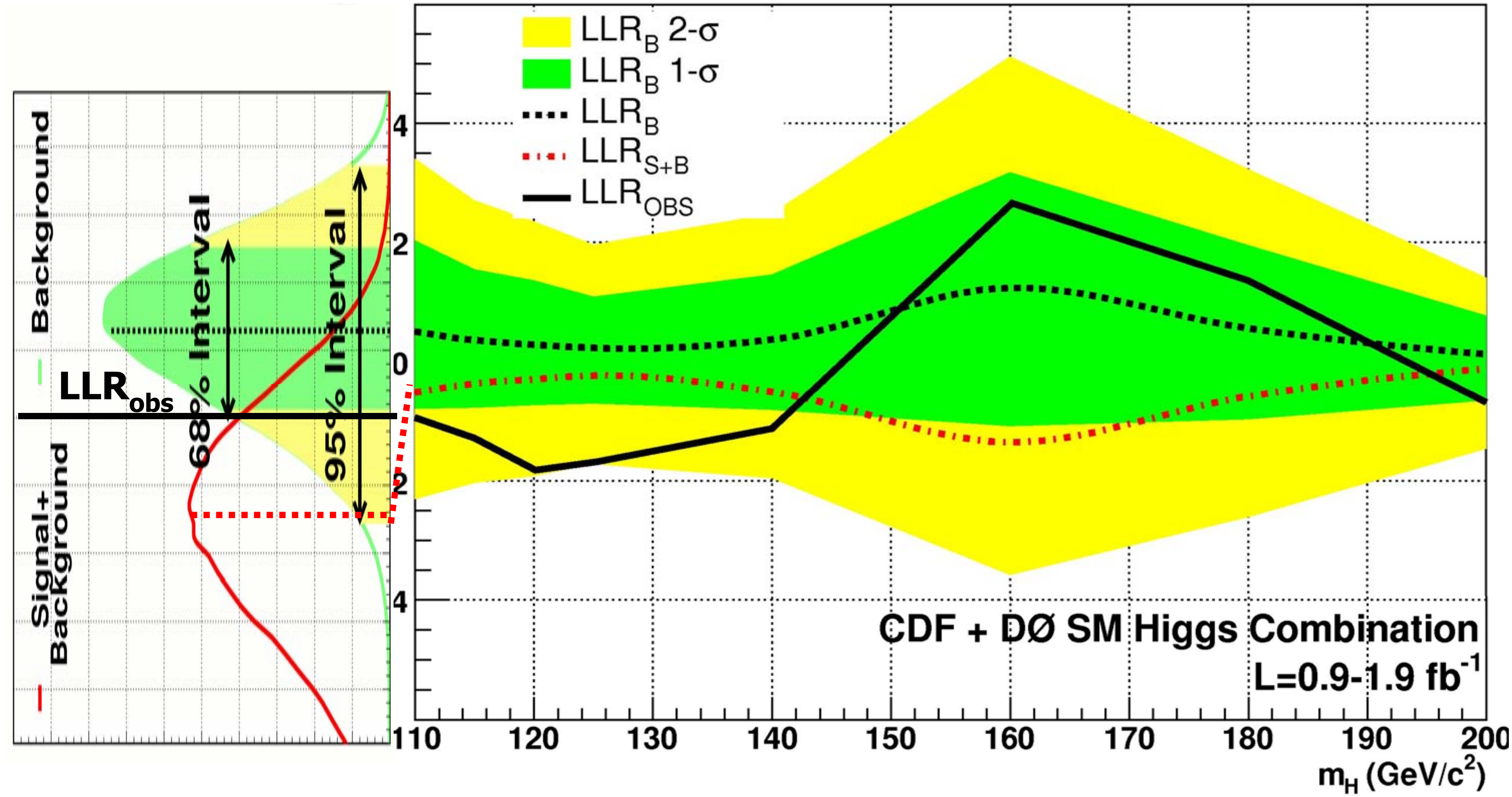


CL_b and CL_{s+b} projections vs Mass



D0 combination, 0.4 fb^{-1} **arXiv:0712.0598**

CL_b and CL_{s+b} projections vs Mass



CDF+DØ combination, 0.9-1.9 fb^{-1}

More details later

Profile Likelihood

- To counteract the degrading effects of systematic uncertainties, we actually integrate over the Profile Likelihood distributions
  - Obtained by fitting MC expectations to "data" for each outcome
  - Capitalizes on shape and statistics of data to constrain background fluctuations
- Must define the best fit of our MC model to data
  - **Assume:** $B_i \rightarrow B_i \prod_k (1+\sigma_i^k \rho_k)$

    Where ρ_k has a mean of 0 and width of 1

Marginalizing!

Minimize Poisson estimator by varying nuisance parameters ρ_k

$$\chi^2 = 2\sum_i (B_i - D_i) - D_i \ln\left(\frac{B_i}{D_i}\right) + \sum_k \rho_k^2$$

Different approaches for CL_S Profiling

Starting from the basics distributions (no systematics), how to proceed to optimize our sensitivity?

Simples approach: include systematics as a smearing effect on the background and signal → large impact on the sensitivity since systematics are sometimes overestimated, full info of the data not used.

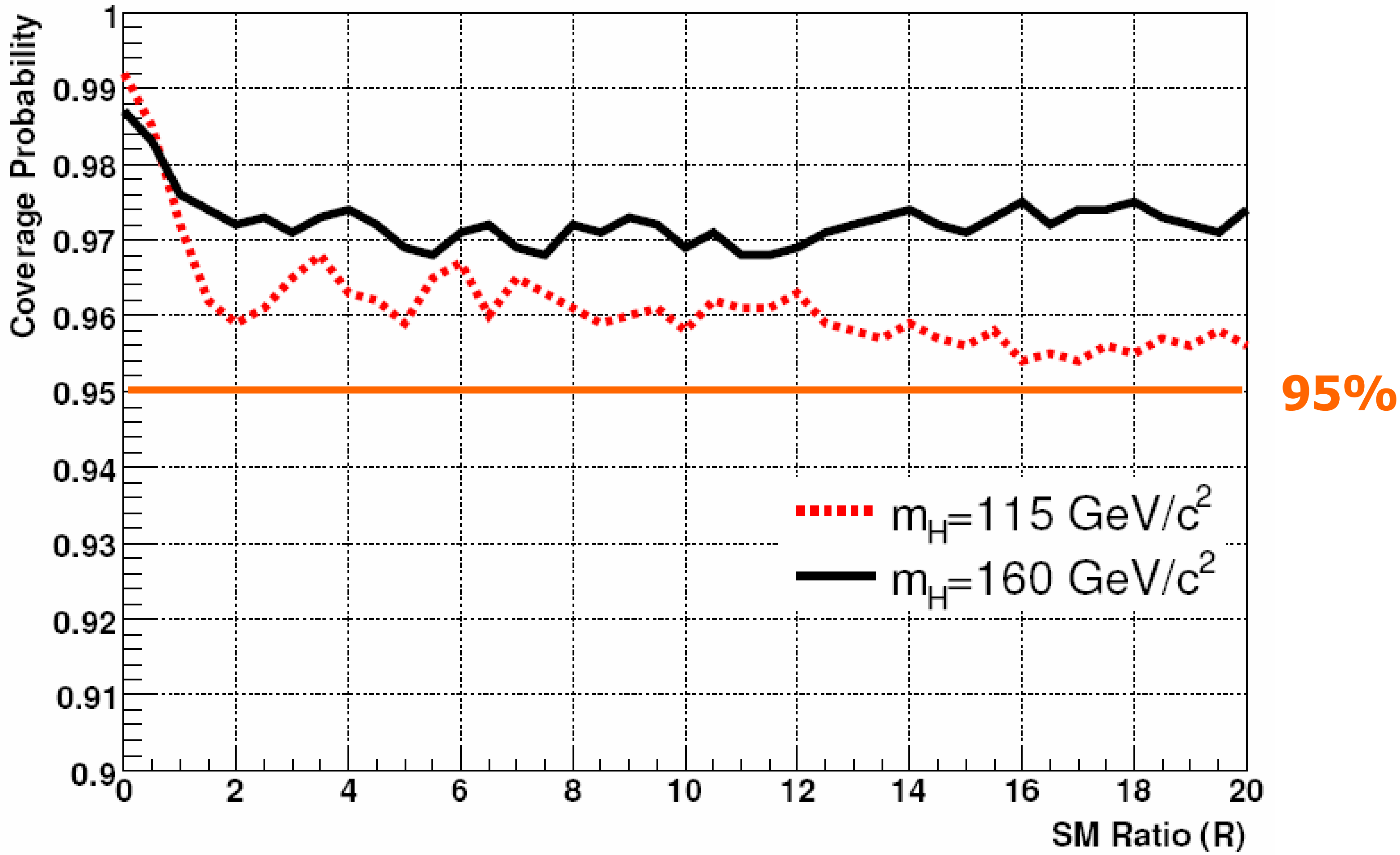
To reduce the impact of systematics two possibilities were investigated

A) Constrain the systematics by doing two fits on each data or pseudo-data sets: one assumes S+B hypothesis, the other Background-only. (called Double-Fitting)

B) do only one fit assuming B-only, only on the bins with a small signal contamination (Log(1+s/b) < 0.015, i.e. less than ~4% of signal. (called Single-Fit/growing-window ,→ window grows when scaling up the signal to check how much more signal we need to be sensitive to a SM Higgs).

Method B is slightly more performant than A, still maintaining appropriate coverage, so we use method B in the following

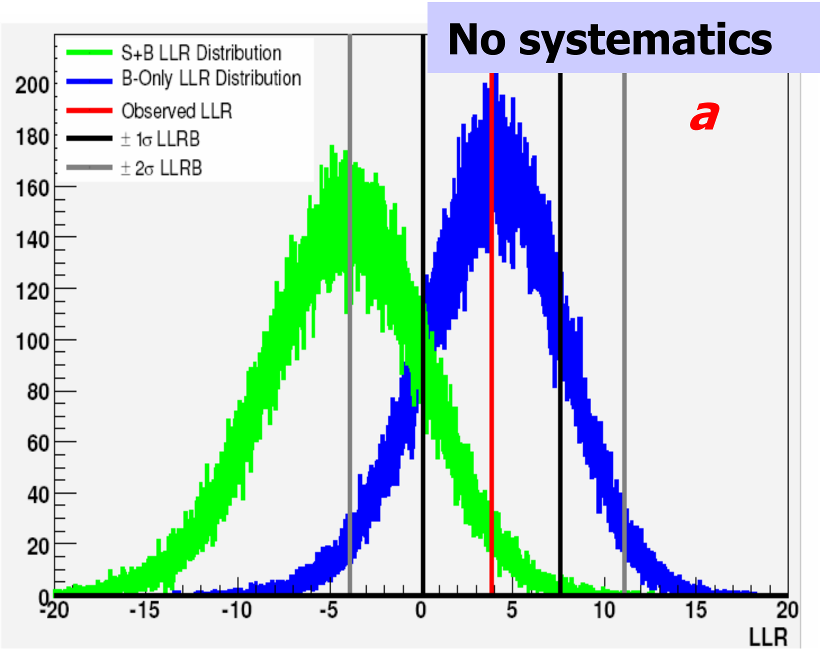
Frequentist Coverage of CL_s

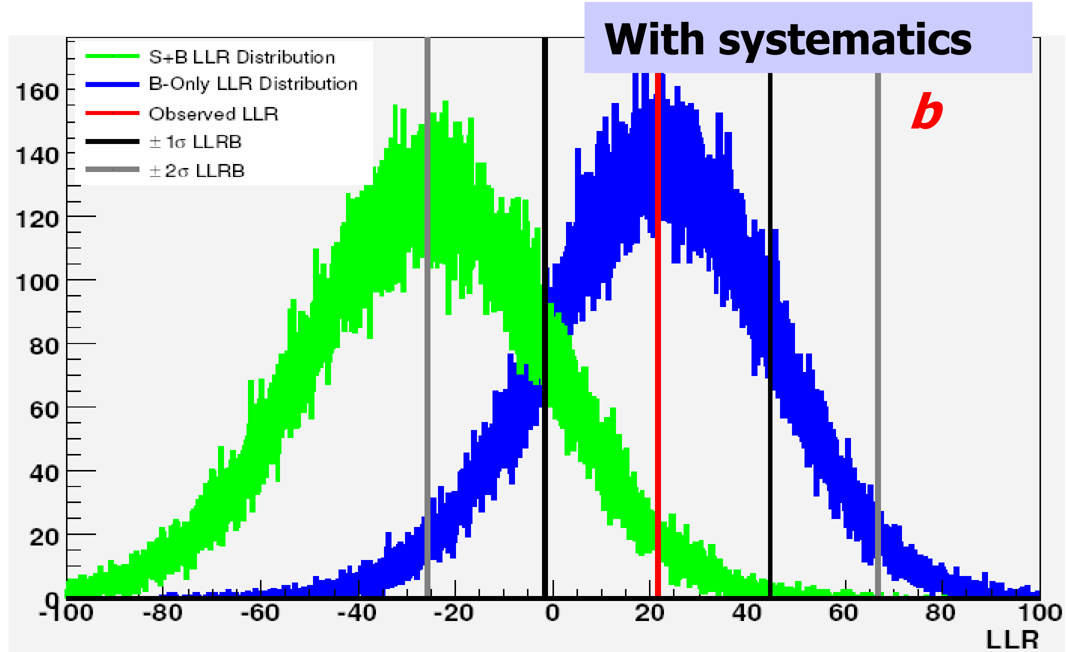


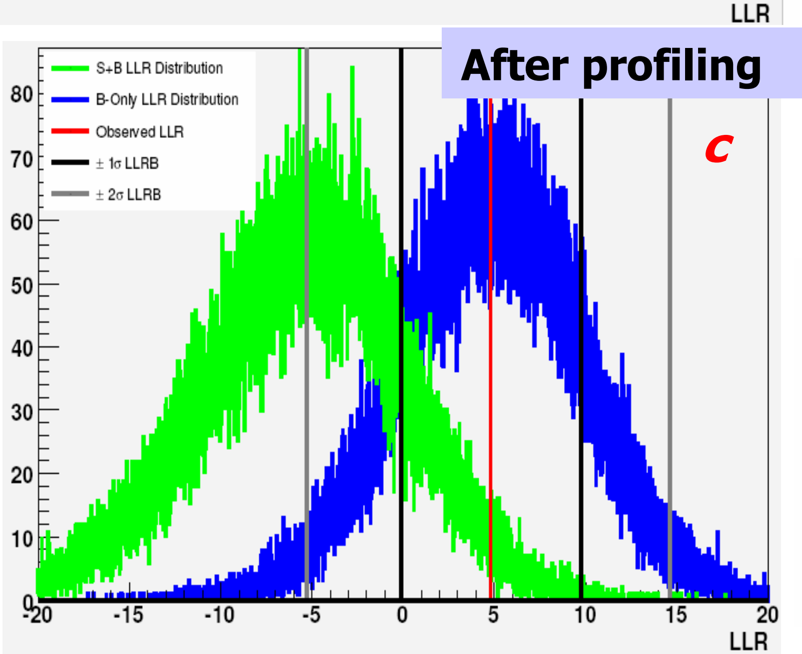
As obtained on full D0 combination (Lepton-photon 07) CL_S with growing window.

➔ Adequate coverage. (Double-Fitting is a bit more conservative: coverage 1-2% higher, limits obtained 5-10% less sensitive)

Effects of Profiling (CL_s)



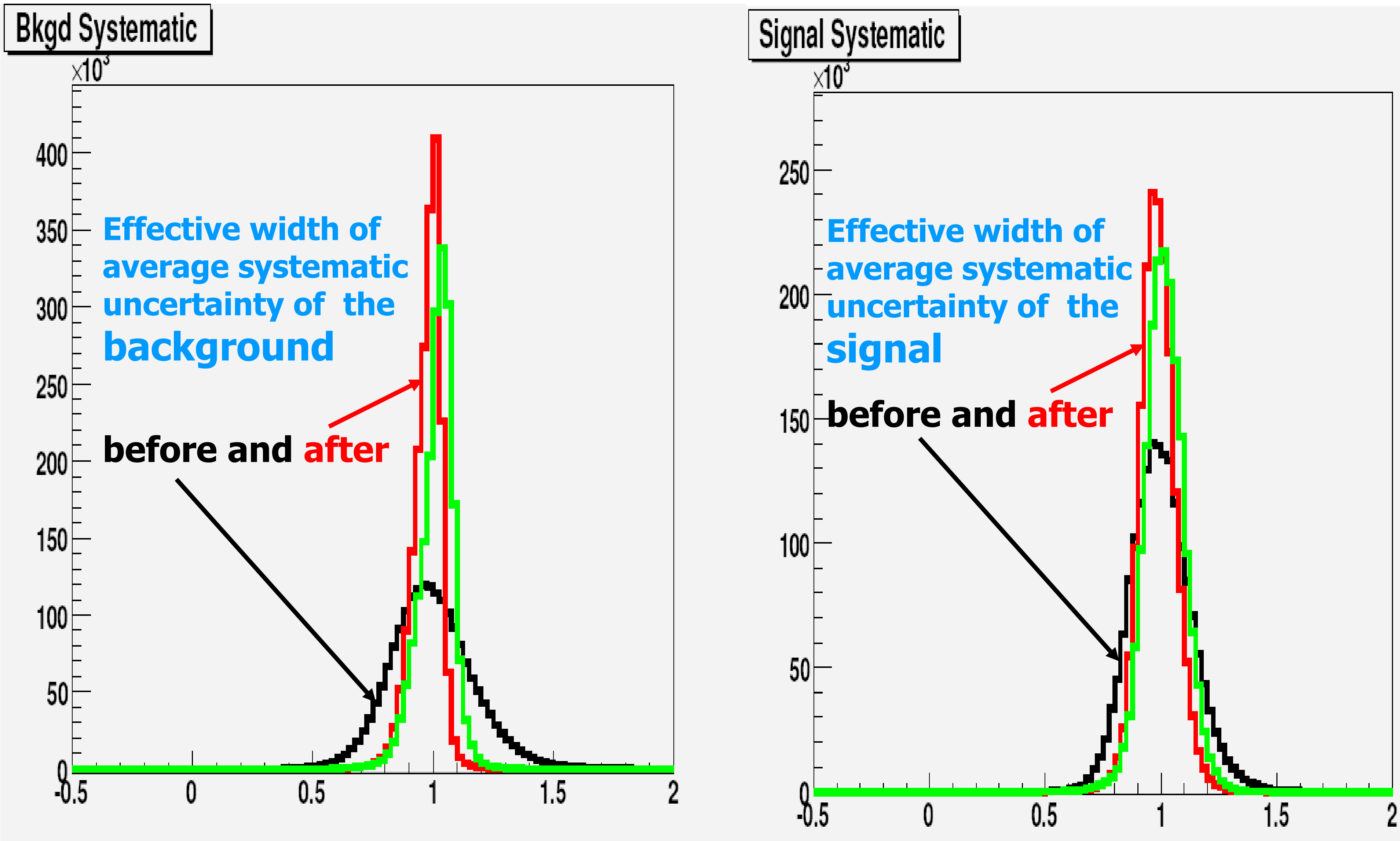




Toy example: Data is set to expected background, signal scaled up to to 95% exclusion, differently for these 3 cases:

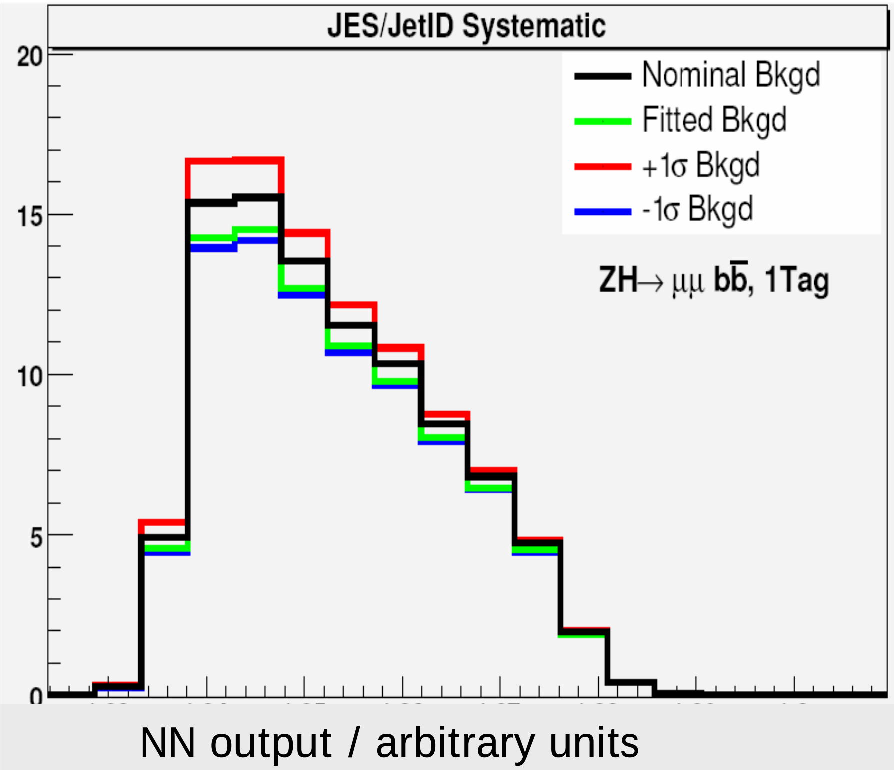
		95% CL Limit	Coverage Probability		CL_b
No Systematics	a	14.2	0.978		0.981
Standard Systematics	b	37.5	0.982		0.987
Double-Fitting		16.9	0.955		0.976
Single-Fit, Fixed Window		14.1	→ 0.925	Bad!	0.958
Single-Fit, Growing Window	c	15.3	0.948		0.976

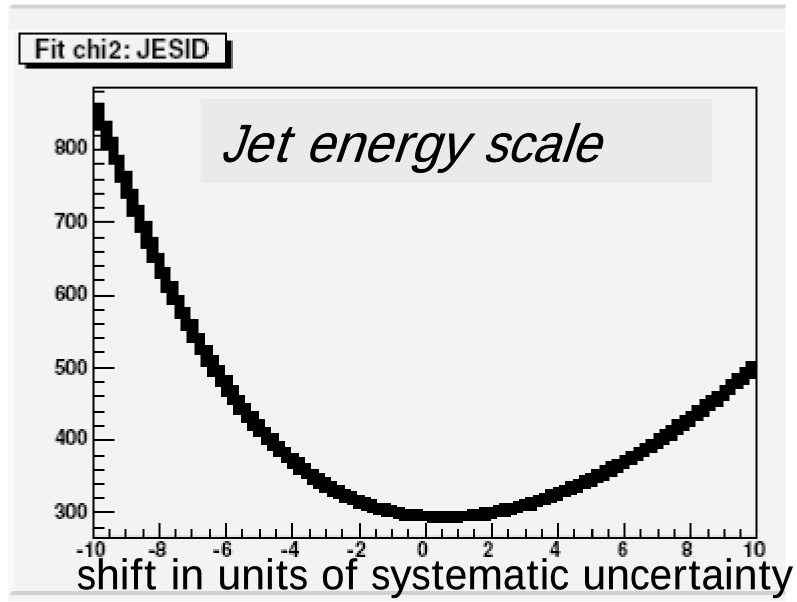
Effects of Systematics Profiling

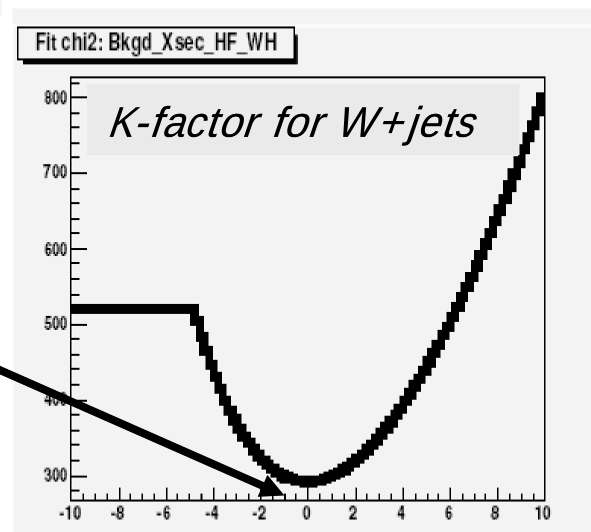


The per-bin fluctuations in the background model before fitting ([redacted]), after the S+B fitting ([redacted]), and after the B-Only fit ([redacted]). The values in the histogram represent the ratio to the nominal background prediction per bin.

Best fit for Jet energy scale, for K-Factor



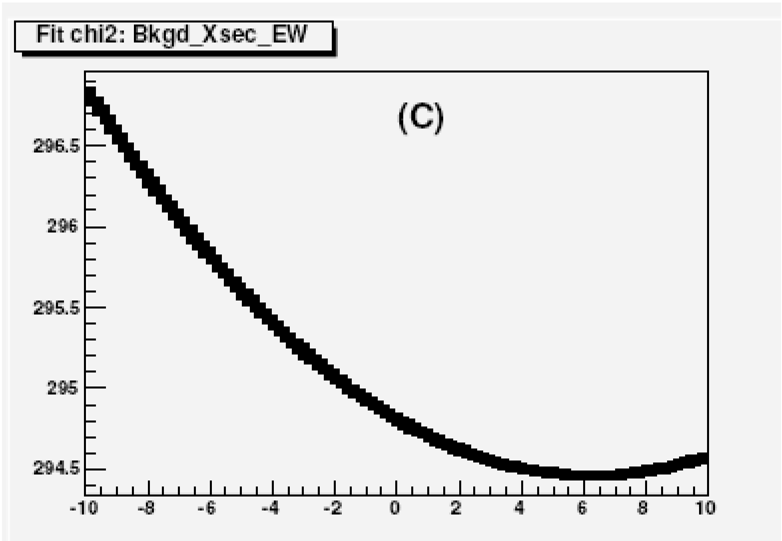




χ^2 Response Function
Minimum: 0.0
RMS: 0.367

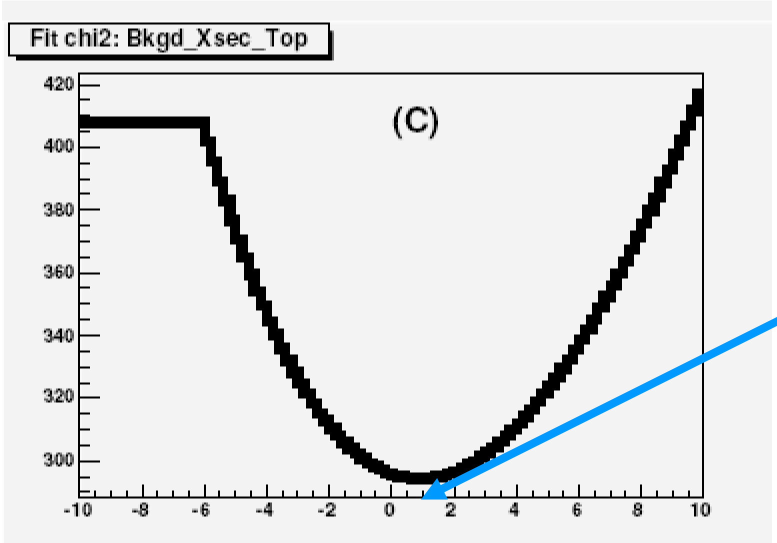
Chi² for K-factor of W+jets, centered at 0 we got it right!

RMS<<1 ➔ systematic overestimated



shift in units of systematic uncertainty

WW cross section is barely constrained. Shallow minimum. Rate too small to impact the fit.

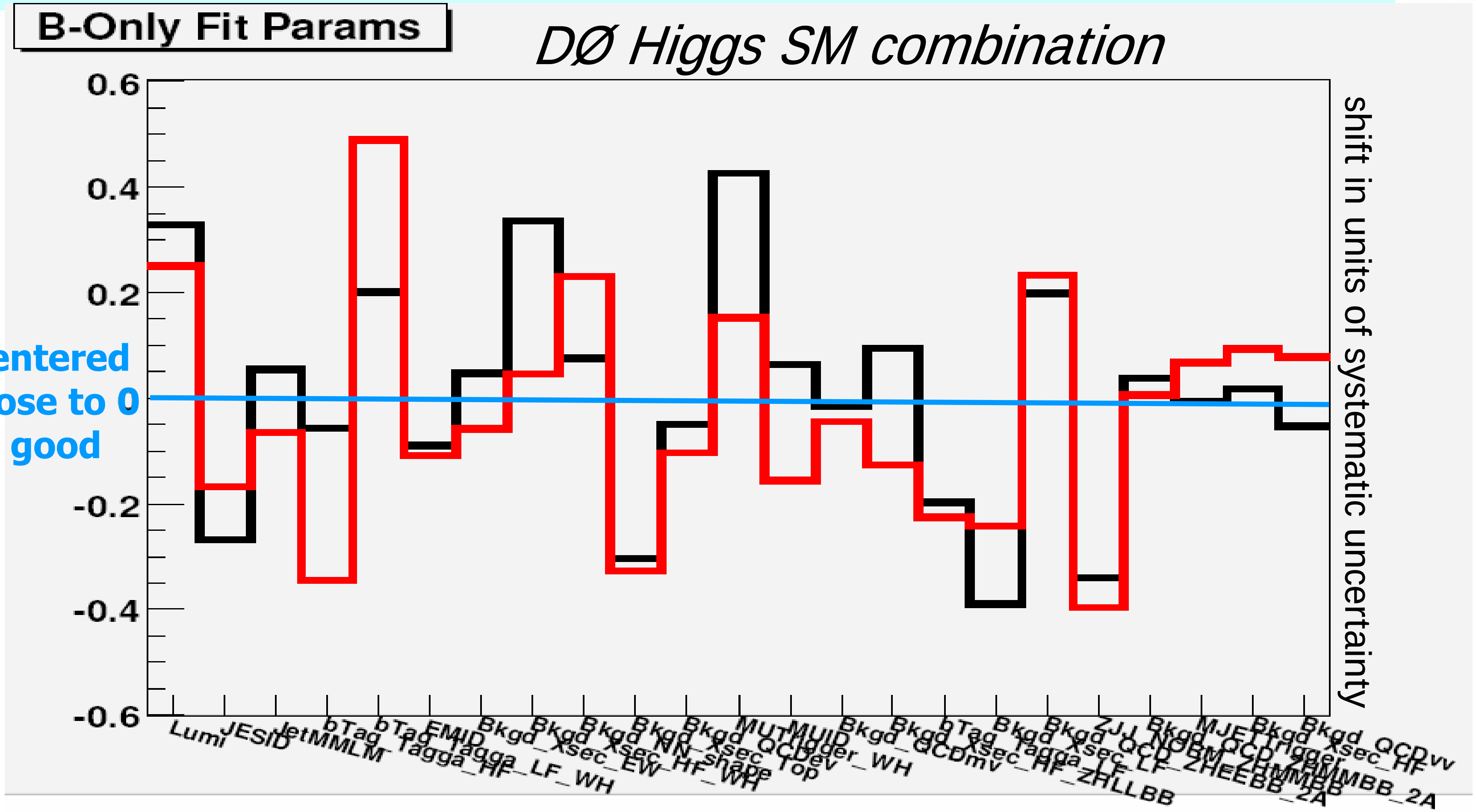


shift in units of systematic uncertainty

Top-antiTop cross section can be constrained. Minimum found at ~+1 sigma(15%)

Understandable since we use cross-section computed for m_{top}=175 GeV, i.e a bit too low.

Best fit for nuisance parameters



Centered close to 0 → good

No smoking gun after all the checks, proceed to derive combined limit…

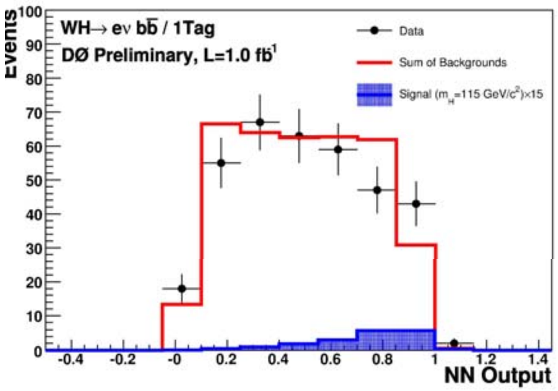
…and let's also keep in mind that we will be able to test the "evidence potential" of the method with WZ/ZZ where Z→bb, i.e. identical final state as WH and ZH

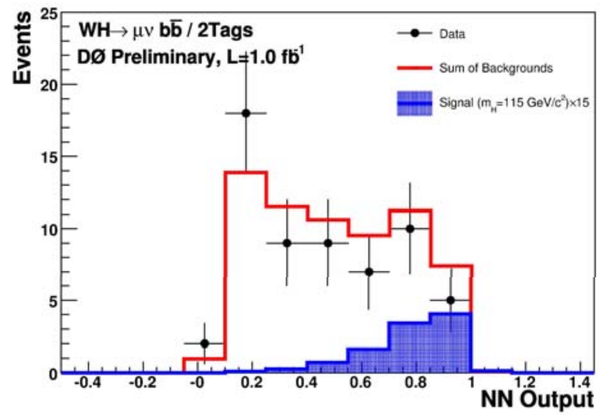
Combining the Results

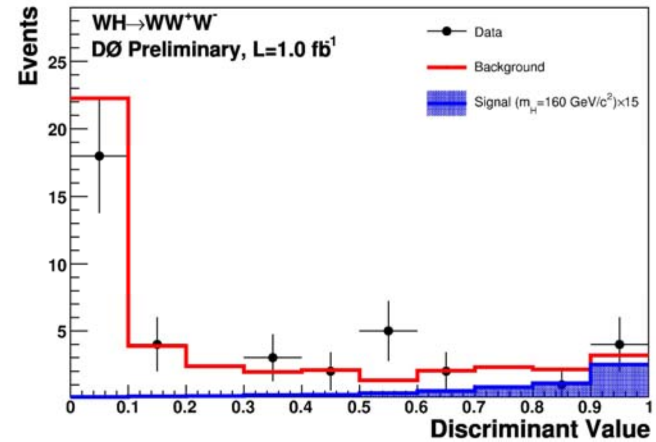
Channel	Lumi /Technique	Final state	#chan.
WH→lν bb	**1.7 fb^{-1} / NN**	**e/μ, 1b/2b**	**2*(2+2)**
ZH→ll bb	**1.1 fb^{-1} / NN**	**e/μ, 1b/2b**	**2+2**
ZH→νν bb	**0.9 fb^{-1} / NN**	**Z→νν, W→łν (2b)**	**2**
H→WW*	**1.7 fb^{-1} /NN**	**ee, eμ, μμ**	**2*3**
WH→WWW*	**1 fb^{-1} / 2D LHood**	**ee, eμ, μμ**	**3**

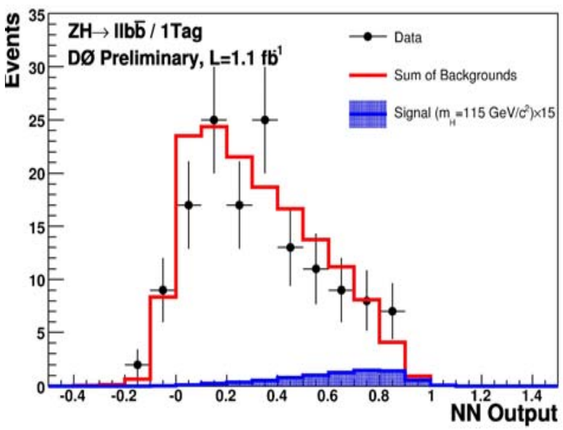
Total of 23 DØ channels combined (tau-channels not included yet)

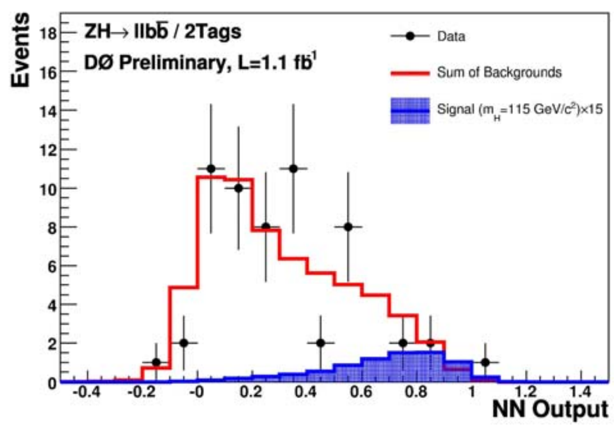
Final variables used for the Combination

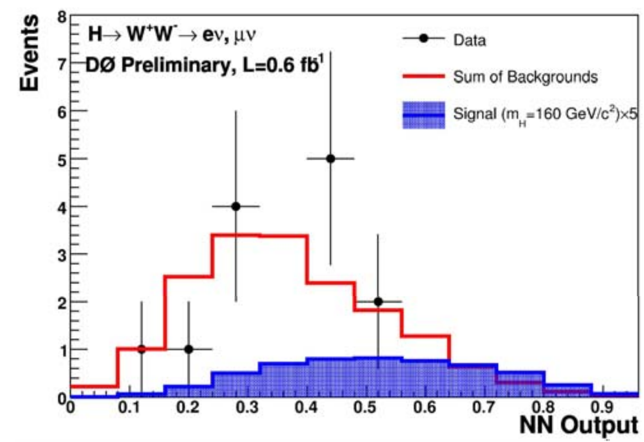


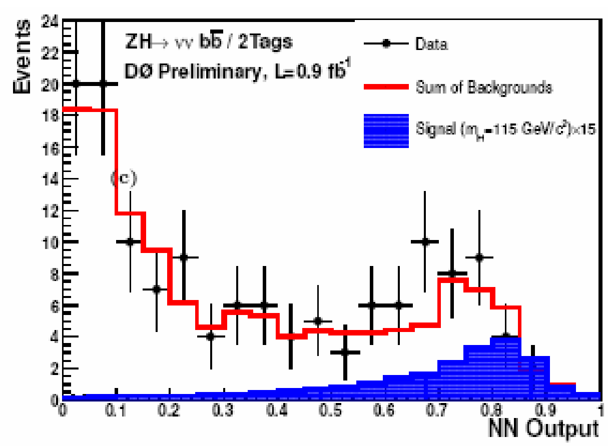


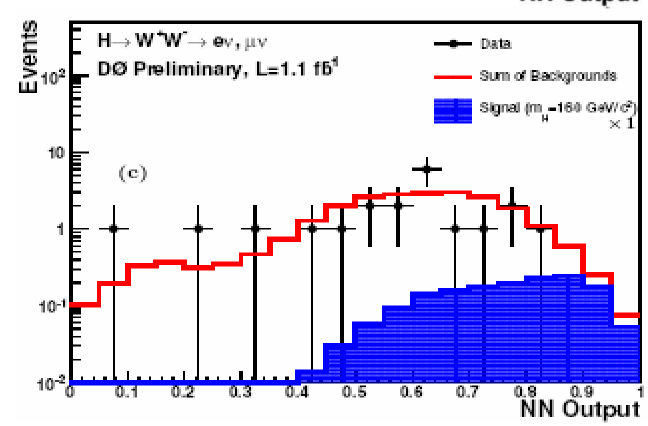




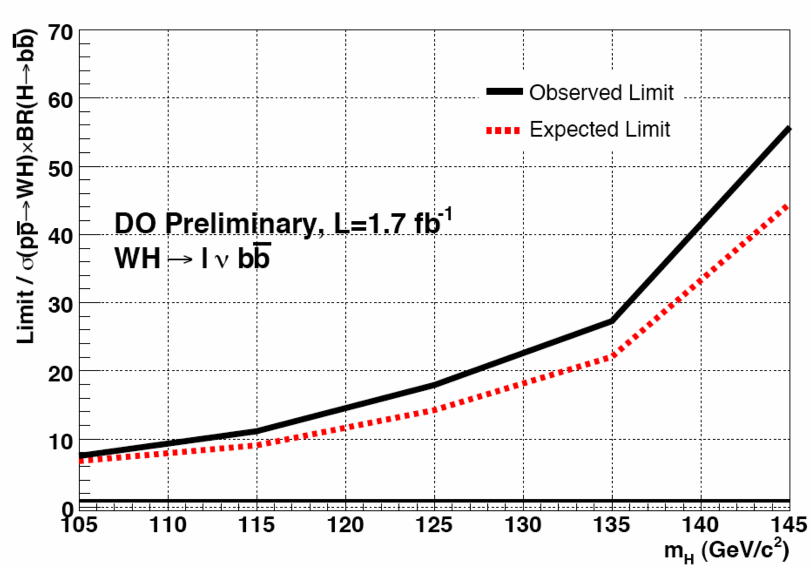


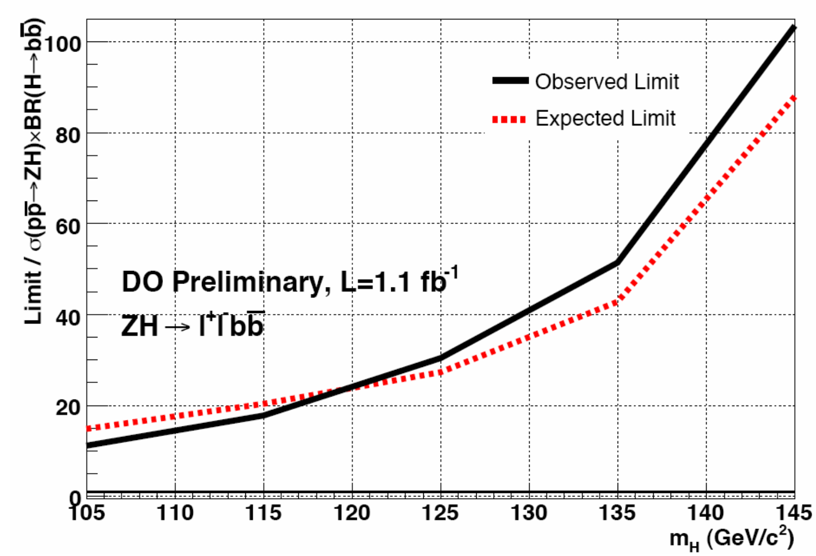


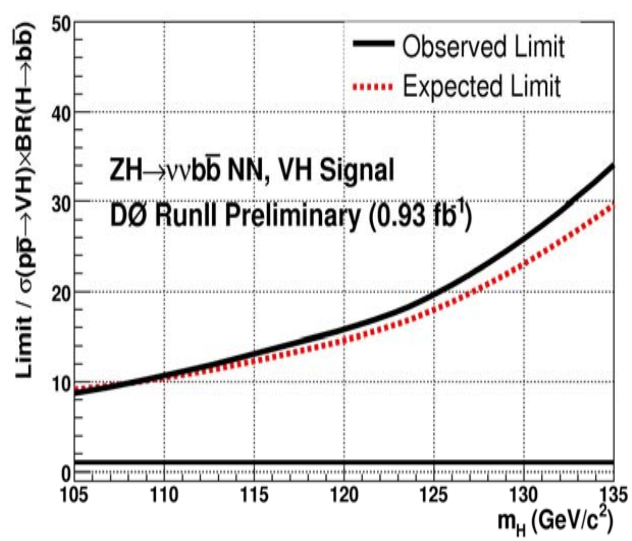


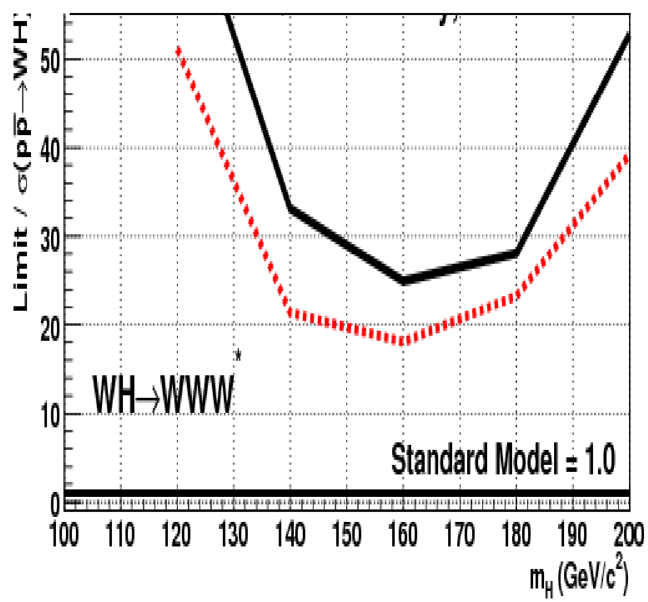


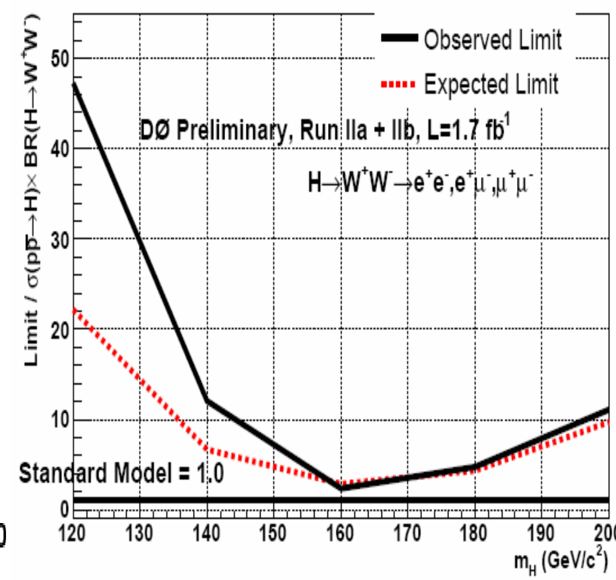
DØ Channels


Observed Limit
Expected Limit
DO Preliminary, L=1.7 fb-1
WH → l ν bb̄
Limit / σ(pp̄→WH)×BR(H→bb̄)
mH (GeV/c2)


Observed Limit
Expected Limit
DO Preliminary, L=1.1 fb-1
ZH → l+l-bb̄
Limit / σ(pp̄→ZH)×BR(H→bb̄)
mH (GeV/c2)


Observed Limit
Expected Limit
ZH→ννbb̄ NN, VH Signal
DØ RunII Preliminary (0.93 fb-1)
Limit / σ(pp̄→VH)×BR(H→bb̄)
mH (GeV/c2)


WH→WWW*
Standard Model = 1.0
mH (GeV/c2)


Observed Limit
Expected Limit
DØ Preliminary, Run IIa + IIb, L=1.7 fb-1
H→W+W-→e+e-,e+μ-,μ+μ-
Standard Model = 1.0
Limit / σ(pp̄→H)× BR(H→W+W-)
mH (GeV/c2)

New DØ SM Higgs Limits

- For m_H=115, expected (observed) 95% CL relative to σ_{SM} = 5.7 (6.4)
- For m_H=160, expected (observed) 95% CL relative to σ_{SM} = 2.8 (2.6)

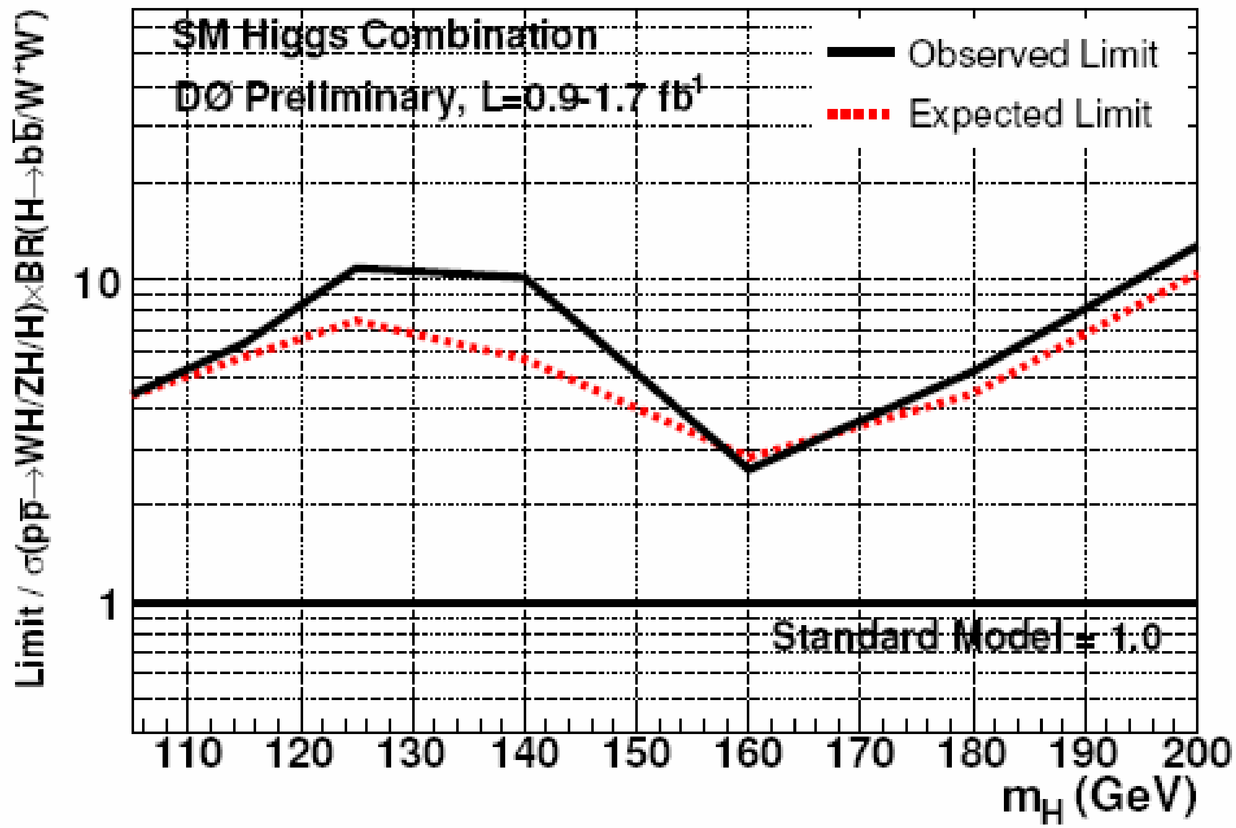
0.9-1.7 fb^{-1} analyzed,

Equivalent

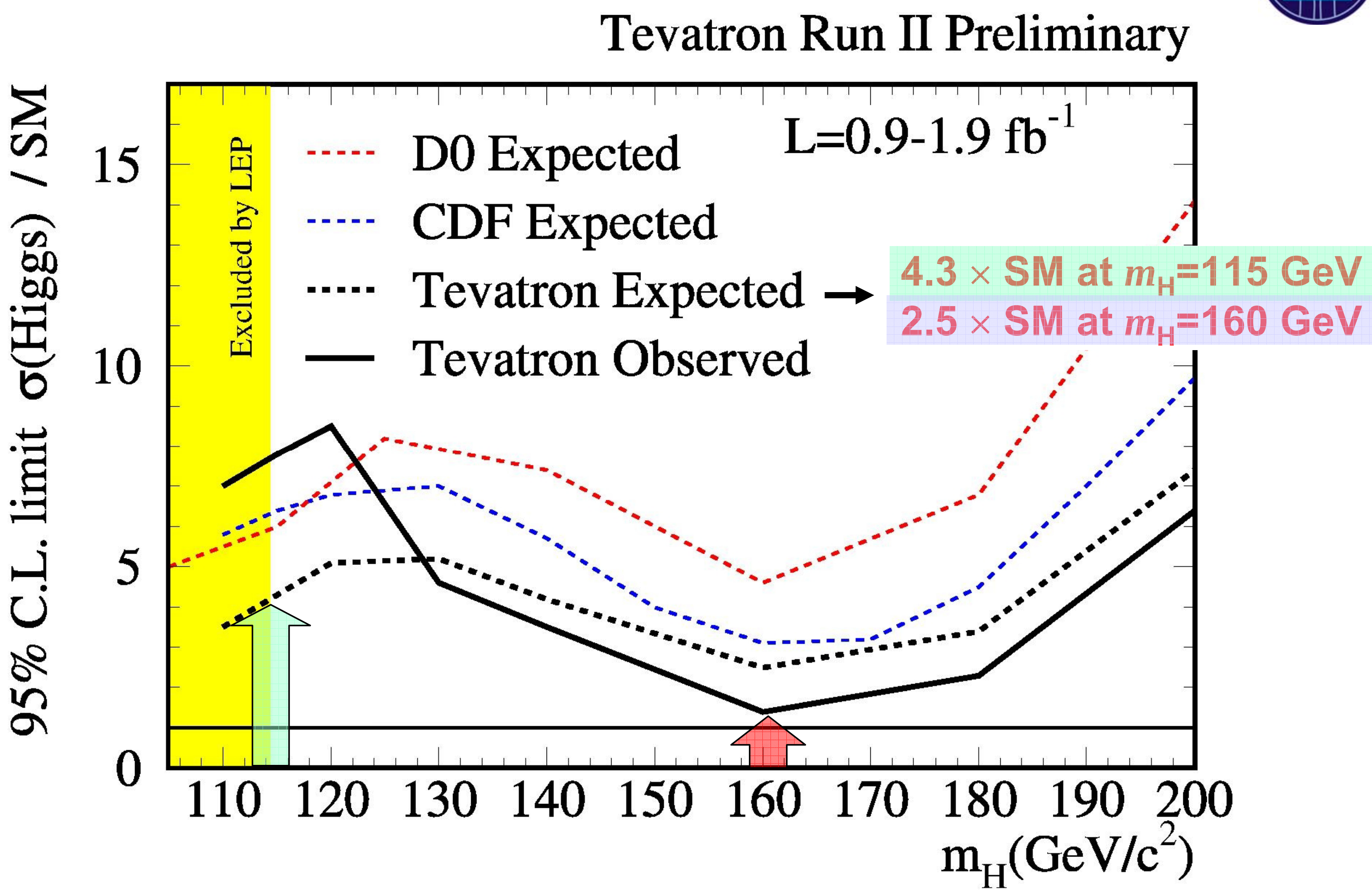
To 1.3 fb^{-1}
@ low mass,

To 1.7 fb^{-1}
@high mass

New results added since Lepton-Photon 07



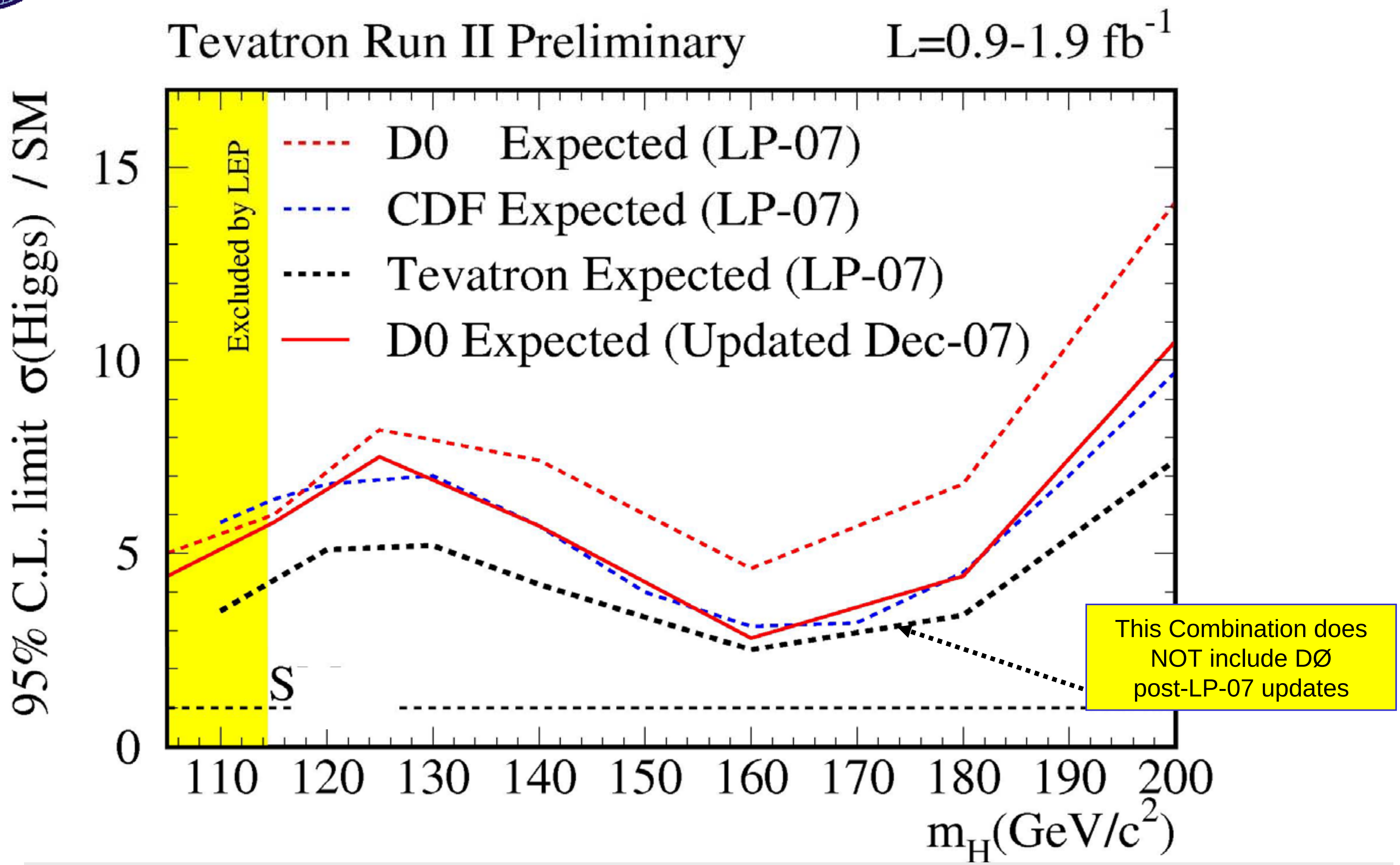
CDF+ DØ @ Lepton-Photon 2007



Observed limit at m_H= 160 Gev: 1.4 x SM

➔ Downward fluctuation compared to the expected

After LP-07 : DØ Updates



With latest updates of DØ (ZH→nunubb with NN, H→WW, more statistics and NN), CDF and DØ expected limits are the same at high mass. (Situation essentially unchanged at low mass)

CDF+ DØ @ Today

CDF Note 8961
DØ Note 5536

Combined CDF and DØ Upper Limits on Standard Model Higgs-Boson Production

Version 4.9 as of December 7, 2007

The TEVNPH Working Group*

for the CDF and DØ Collaborations

We combine results from CDF and DØ searches for a standard model Higgs boson (H) in $p\bar{p}$ collisions at the Fermilab Tevatron at $\sqrt{s} = 1.96$ TeV. With 1.0-1.9 fb^{-1} of data collected at CDF, and 0.9-1.7 fb^{-1} at DØ, the 95% C.L. upper limits on Higgs production are a factor of 6.2 (1.4) higher than the SM cross section for a Higgs mass of m_H =115 (160) GeV/c^2. Based on simulation, the expected upper limit should be 4.3 (1.9). These results extend significantly the individual limits of each experiment.

Several Approaches used

CDF uses a Bayesian approach

- Use Bayesian posterior probability
- Assume flat prior density for the number of Higgs events

- Combined Binned Poisson Likelihood:

$$\mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) = \prod_{i=1}^{N_C} \prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}} / n_{ij}!$$

- Combined Posterior Density Function:

$$p(R|\vec{n}) = \int d\vec{s} \int d\vec{b} \mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) \times s_{tot} / \int dR \int d\vec{s} \int d\vec{b} \mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) \times s_{tot}$$

DØ uses the CLs Method

the CL_S confidence interval is a normalization of CL_{S+B}

CL_{S+B} = signal + bkgd hypothesis, CL_B = bkgd only hypothesis

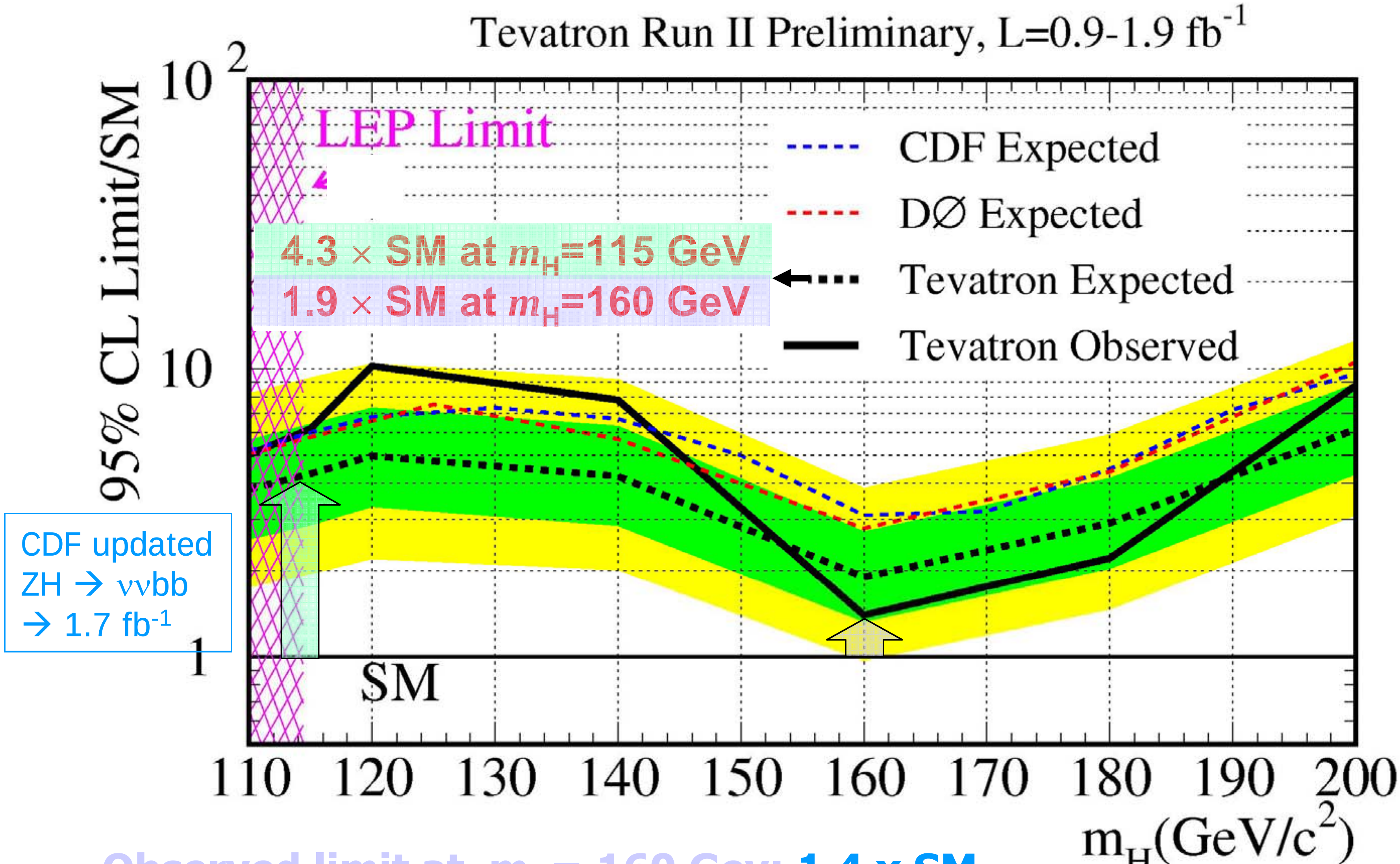
$CL_S = CL_{S+B}/CL_B$: CL_{S+B} & CL_B are defined using a “test statistic”

Test statistic used is the Log-Likelihood Ratio (LLR=-2 ln Q)

generated via Poisson statistics **($Q=e^{-(s+b)}(s+b)^d/e^{-b}b^d$) s,b,d=sig.,bkd,data)**

Tevatron Higgs combination is done with both methods
➔ they give results compatible within ~10%.

Lepton-Photon 2007 + latest updates



Observed limit at m_H= 160 Gev: 1.4 x SM

→SM Higgs could be excluded @ 160 GeV in 2008

Projection assumptions: High mass Higgs

- Since 2005, our high Higgs mass experimental sensitivity has improved by a factor of 1.7 (i.e. taking out gain due to luminosity)
  - NN discriminants
  - Lepton acceptance

- For 2010, we estimate an additional improvement in analysis sensitivity by a factor of 1.4
  - increased lepton efficiency (10% per lepton)
  - multivariate analyses (~30% in sensitivity)

- Potential improvements not included in estimate
  - add τ channels
  - ...

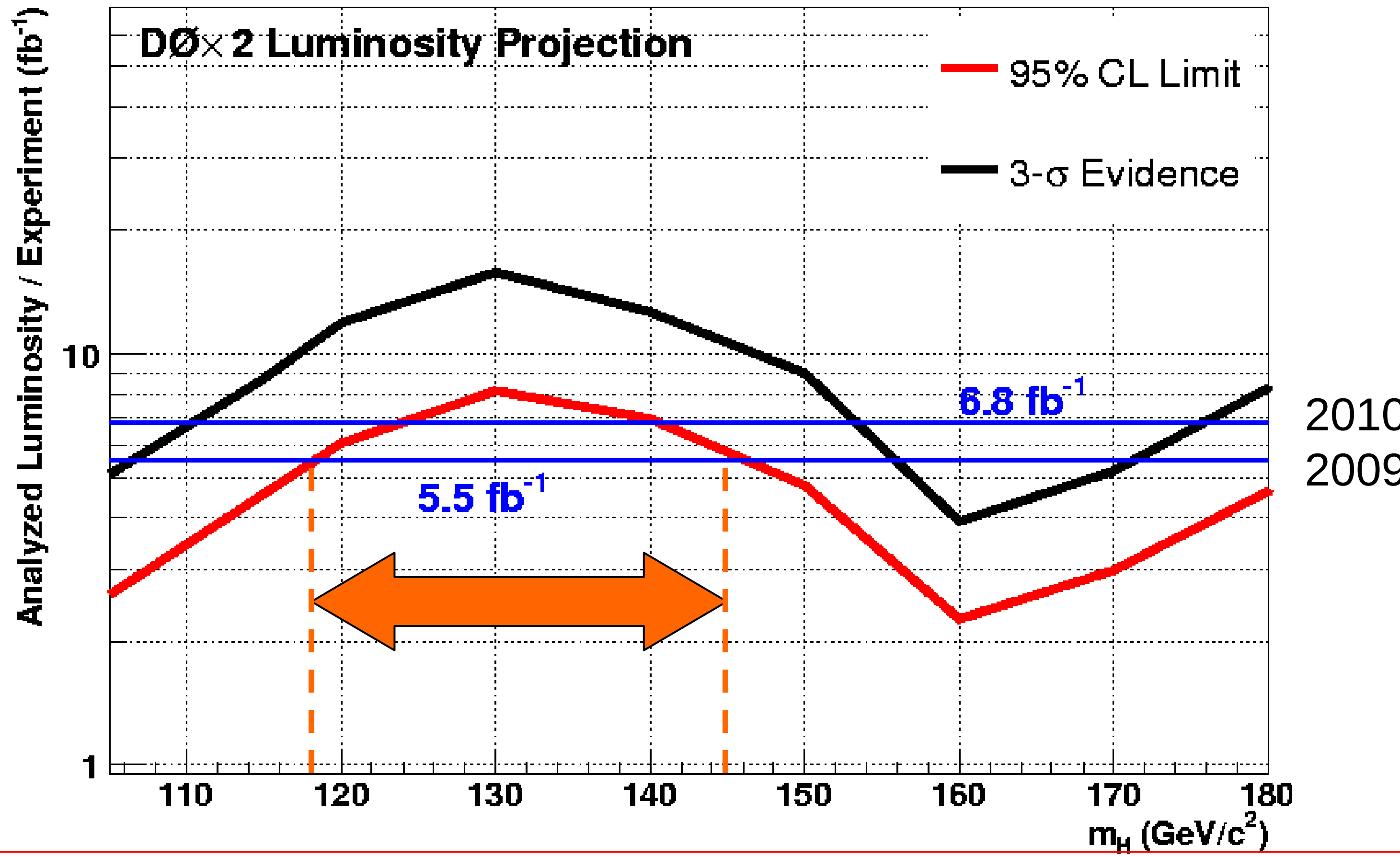
Sensitivity and Projections – M_H = 115 GeV

- Since 2005, our analysis sensitivity has improved by a factor of 1.7 beyond improvement expected from sqrt(luminosity)
  - Acceptance/kin. phase space/Trigger efficiency
  - Asymmetric tagging for double b-tags
  - b-tagging improvements (NN b-tagging)
  - improved statistical techniques/event NN discriminant
  - → for channel with largest effort applied (WH) factor was 2.1

- For 2010, we estimate that we will gain an additional factor of 2.0 beyond improvement expected from sqrt(luminosity)
  - add single-b-tag channel to ZH→ννbb
  - include forward electrons, and 3-jet sample in WH
  - b-tagging improvements
    - Layer 0 (~8% per tag efficiency increase)
    - add semileptonic b-tags (~5% per tag efficiency increase)
  - Di-jet mass resolution (18% to 15% in σ(m)/m)
  - increased lepton efficiency (10% per lepton)
  - improved/additional multivariate techniques (~20% in sensitivity)

Median expected Higgs sensitivity

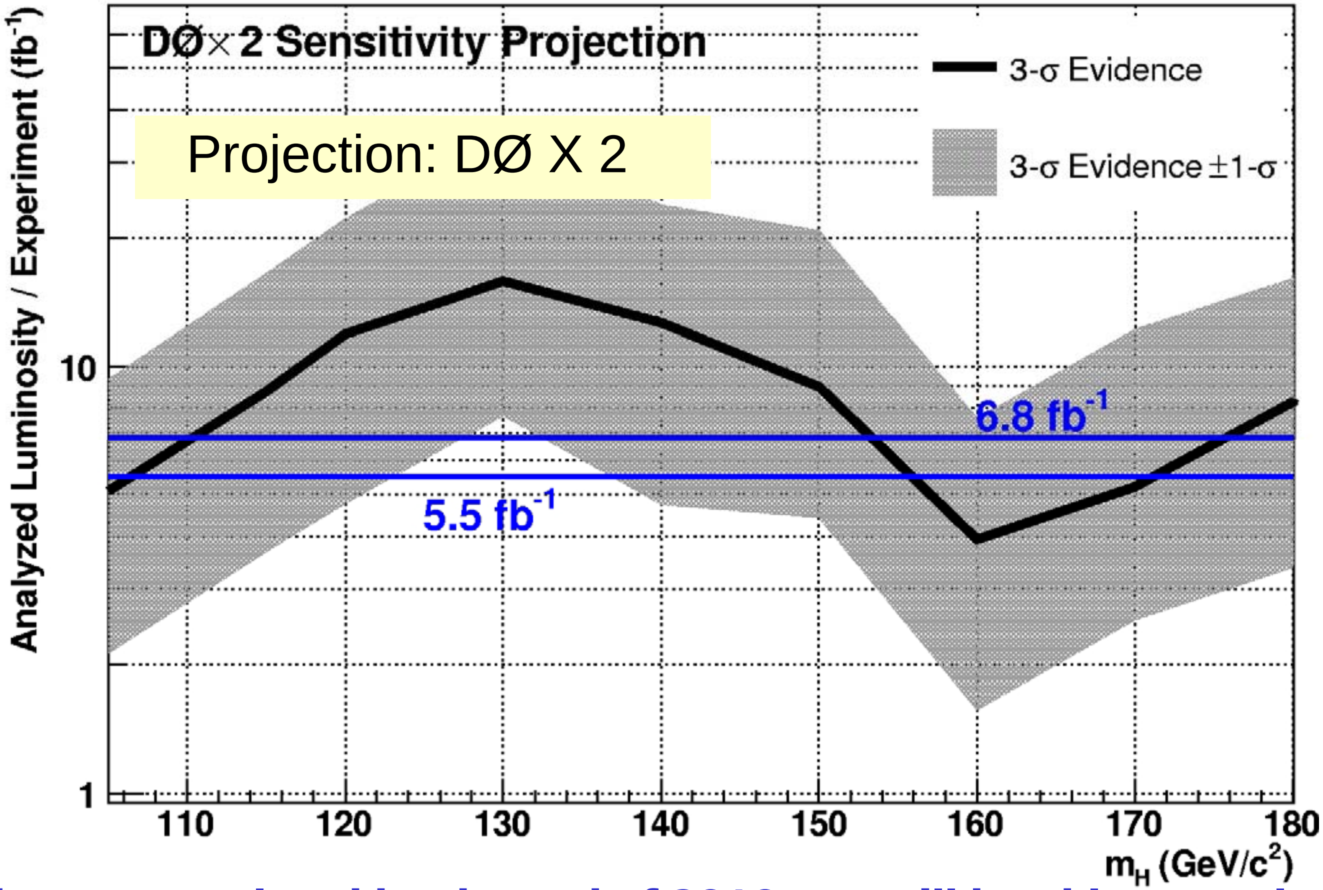
Assumes two experiments



By the time LHC produces Physics (end 2009) Precision EW measurements + Tevatron could allow SM Higgs only with mass between 118 and 145 GeV definitely only a light Higgs boson, which will take several years to be found at LHC (needs 5 fb^{-1}) → LHC/Tevatron complementarity H→ γγ vs H→ bb

Higgs sensitivity, 3-σ evidence

Assumes two experiments



2010
2009

- With data accumulated by the end of 2010, we will be able to explore much of the SM Higgs mass region allowed by the constraints from precision measurements and LEP direct exclusion
  - Expected 95% CL exclusion over whole allowed range, (except possibly around 130 GeV) - assuming the Higgs does not exist at these masses
  - Three-sigma evidence for a Higgs possible over almost entire range, and probable for the low end and high end.

Conclusion

New Higgs analysis became available and keep coming in, large common effort in both collaborations

Combining our many SM Higgs channels is becoming mature, inside DØ and CDF and between the two collaborations. Different methods allow to optimize sensitivity and spot mistakes.

Further improvements in front of us:

CDF – DØ unification of systematic uncertainties treatment.

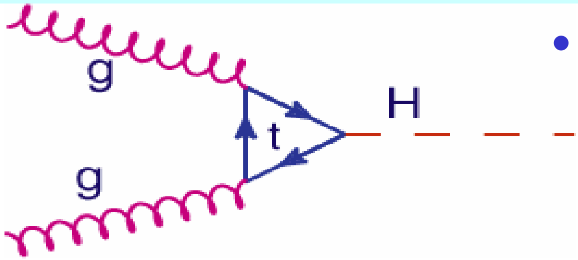
Finer m_H binning for next iteration.

2008 should allow us to go beyond LEP w.r.t SM Higgs, in particular at 160 GeV

2008 will also teach us how well we perform at low mass, with the golden WZ/ZZ (Z→bb) benchmark

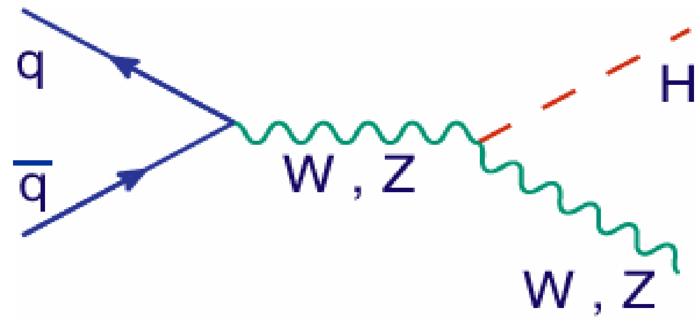
2009-2010 will also be most exciting years.

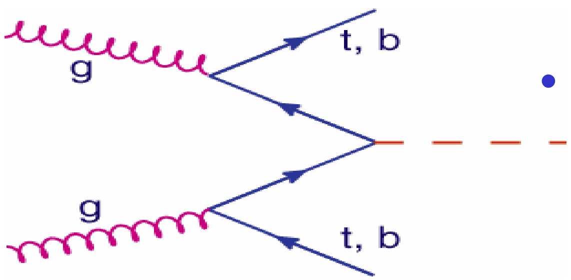
SM Higgs boson production



- **gg fusion**
  - **Dominates at hadron machines**
  - **Usefulness depends on the Higgs decay channel**

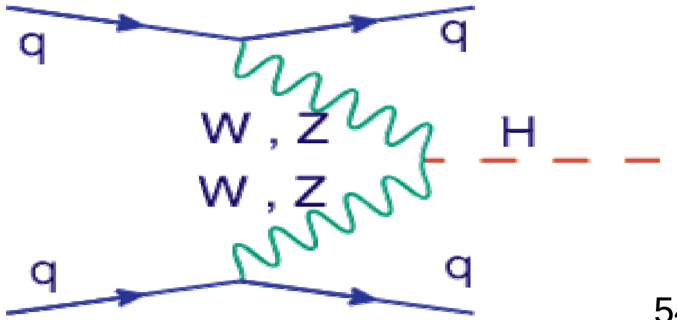
- **WH, ZH associated production**
  - **Important at hadron colliders since can trigger on 0/1/2 high-p_T leptons and MET**





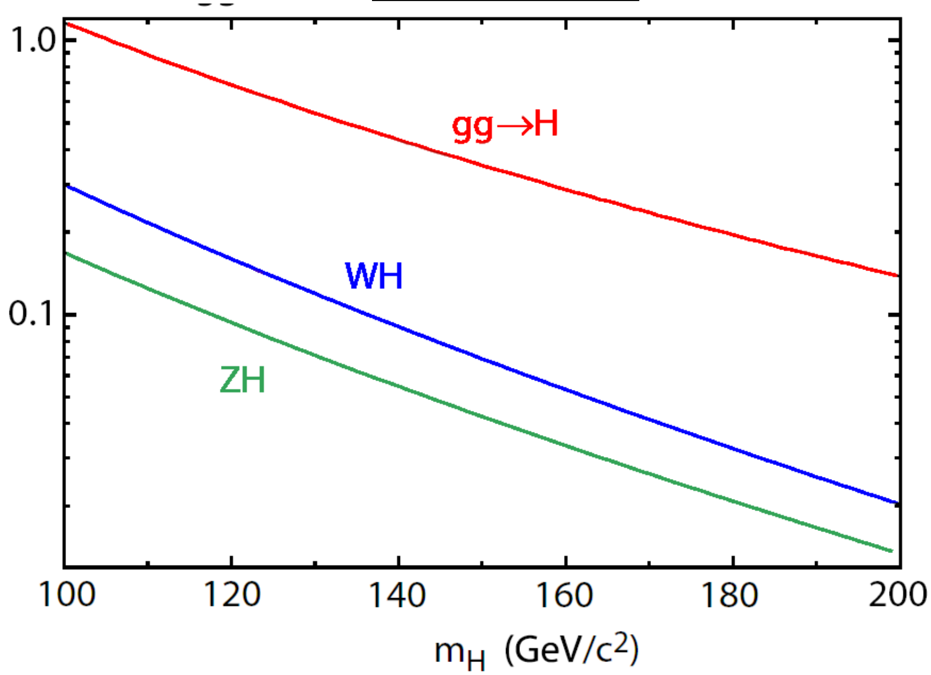
- **ttH and bbH associated production**
  - **High-p_T lepton, top reconstruction, b-tag**
  - **Low rate at the Tevatron**

- **Vector Boson Fusion**
  - **Two high-p_T forward jets help to "tag" event**
  - **Important at LHC, being studied at DØ**

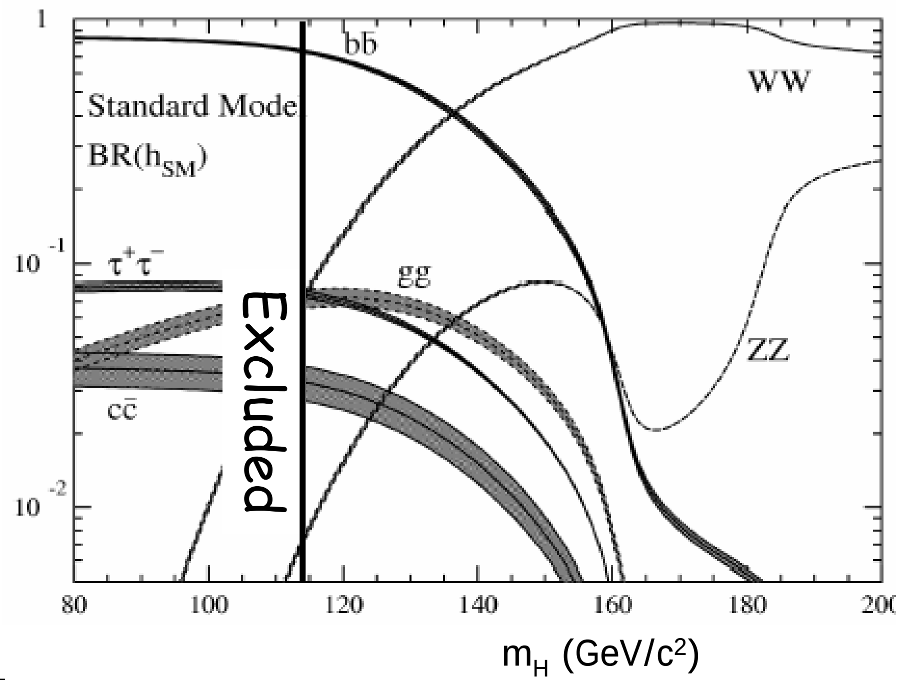


SM Higgs Production and Decays

Production



Decays



Production cross section (m_H 115-180)
→ in the 0.8-0.2 pb range for gg → H
→ in the 0.2-0.03 pb range for WH associated vector boson production

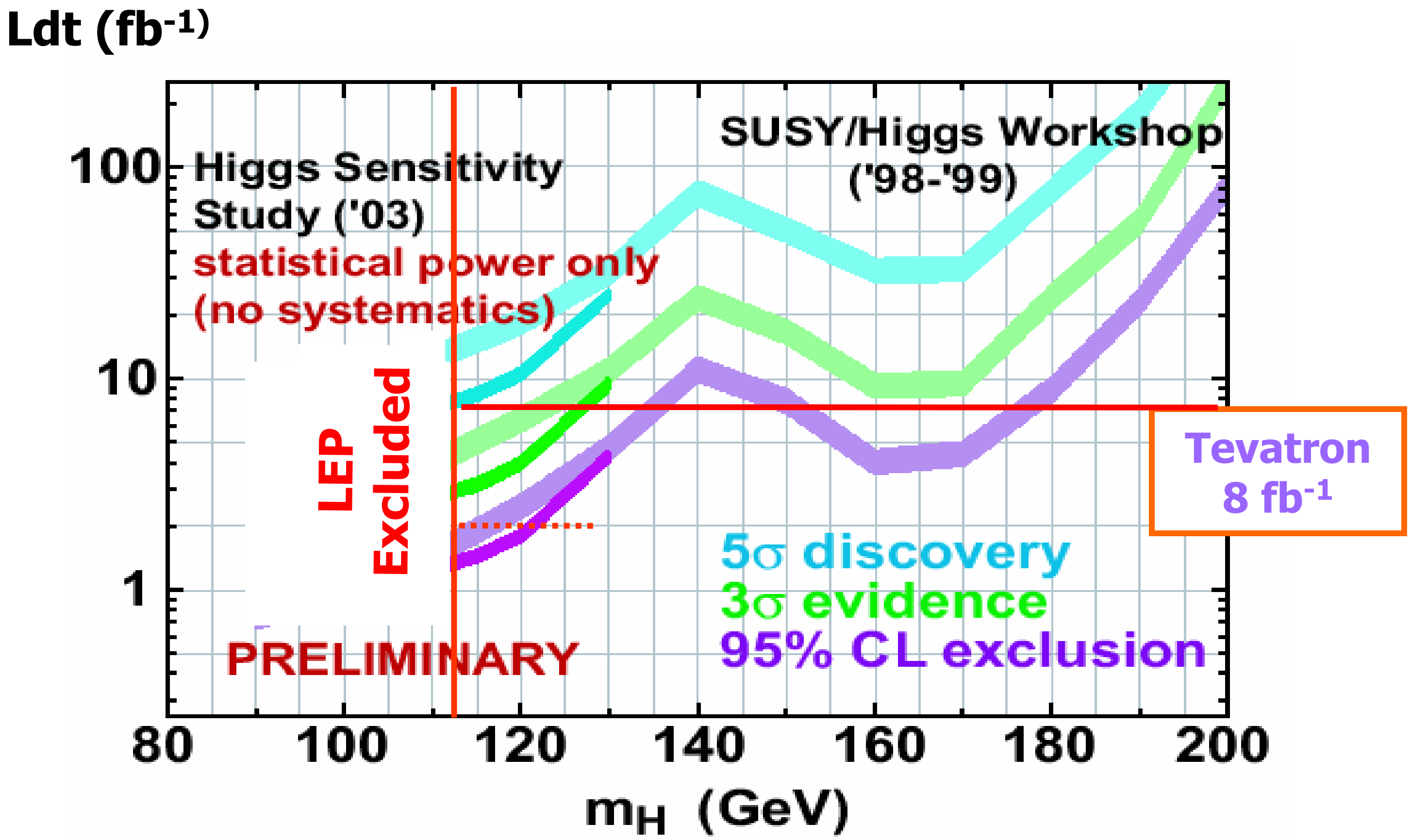
Dominant Decays
→ $b\bar{b}$ for M_H < 135 GeV
→ WW* for M_H > 135 GeV

Search strategy:

M_H <135 GeV: associated production WH and ZH with H→bb decay
Backgrounds: top, Wbb, Zbb…

M_H >135 GeV: gg →H production with decay to WW* or WH→WWW*
Backgrounds: WW, DY, WZ, ZZ, tt, tW, ττ

Tevatron SM Higgs Search: Outlook



In earlier studies, the Tevatron sensitivity in the mass region above LEP limit (114 GeV) was estimated to start at ~2 fb^{-1}

with 8 fb^{-1}: exclusion would be 115-135 GeV & 145-180 GeV,

Now, we are:

→ optimizing analysis techniques, understanding detectors better

→ measuring SM backgrounds (ttbar, Zbb, Wbb, WW, single top!)

→ Placing first Combined Higgs limits and compare to the prospects