# Search for Higgs bosons at Tevatron

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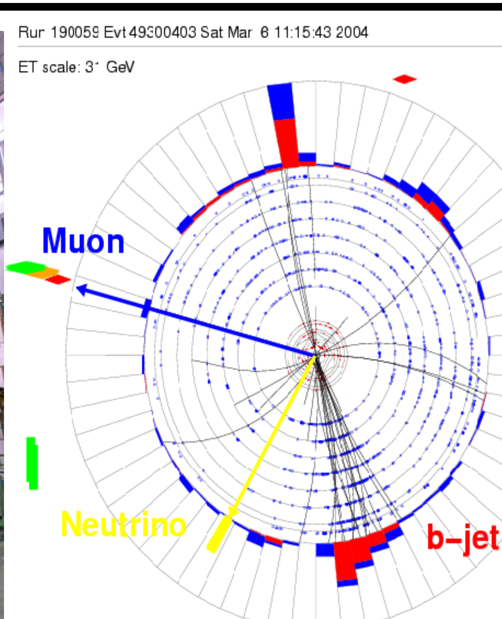
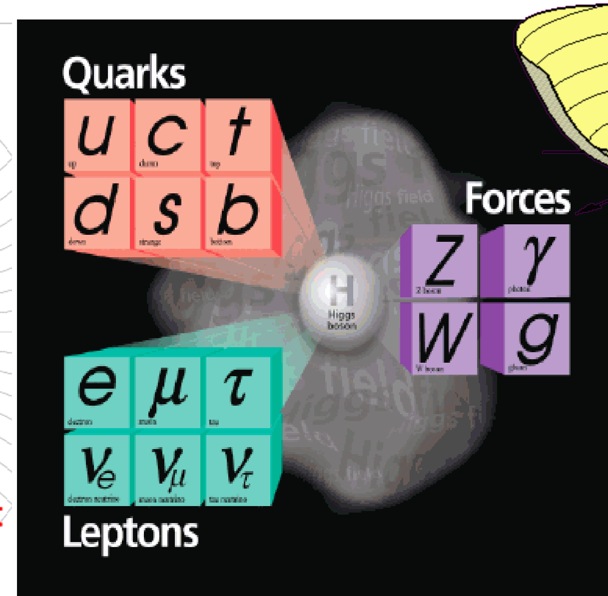
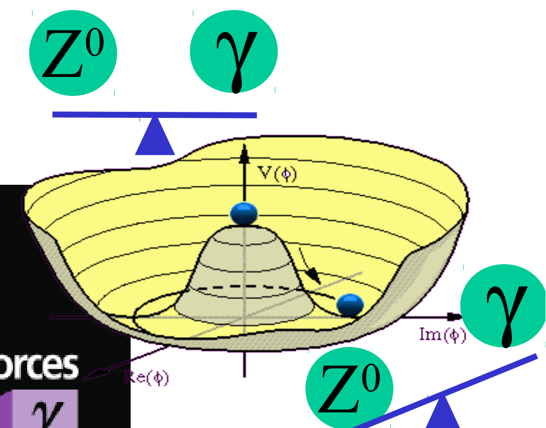
Outline :
- SM Higgs
  - techniques
  - results
- selected results Beyond SM



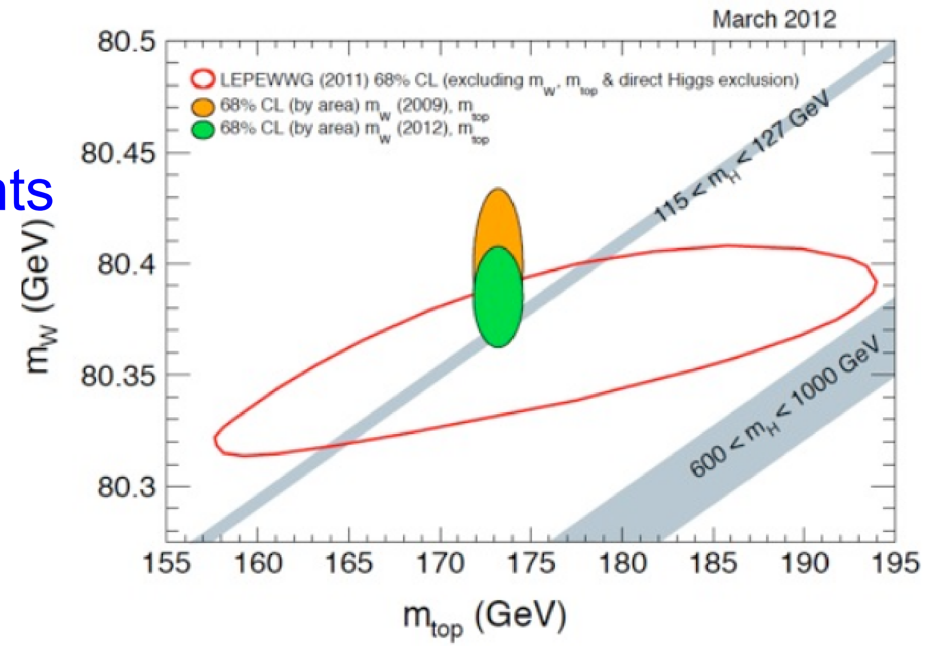



# Where to look for SM Higgs boson ?

Indirect constraints from EW measurements

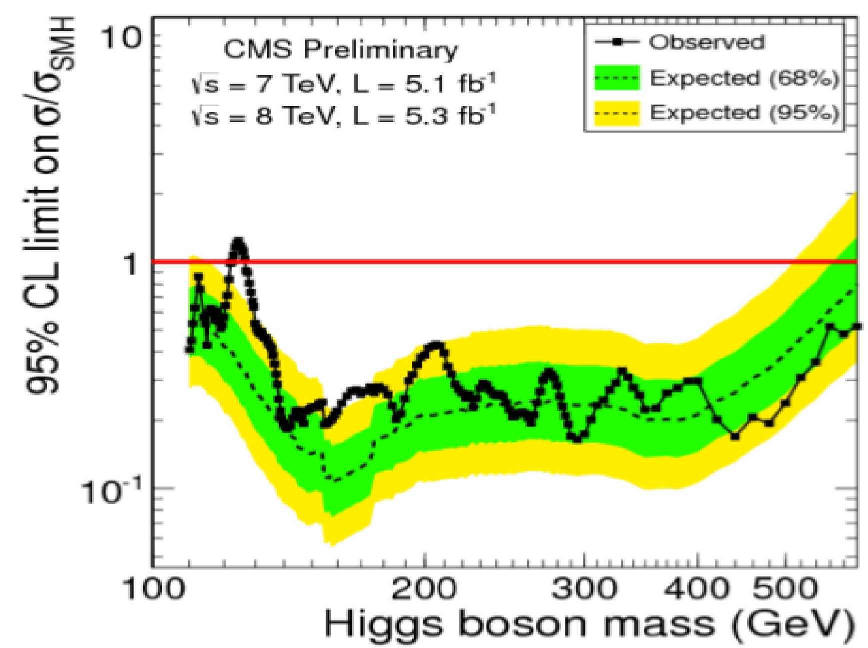
$M_H < 152$ GeV @95%



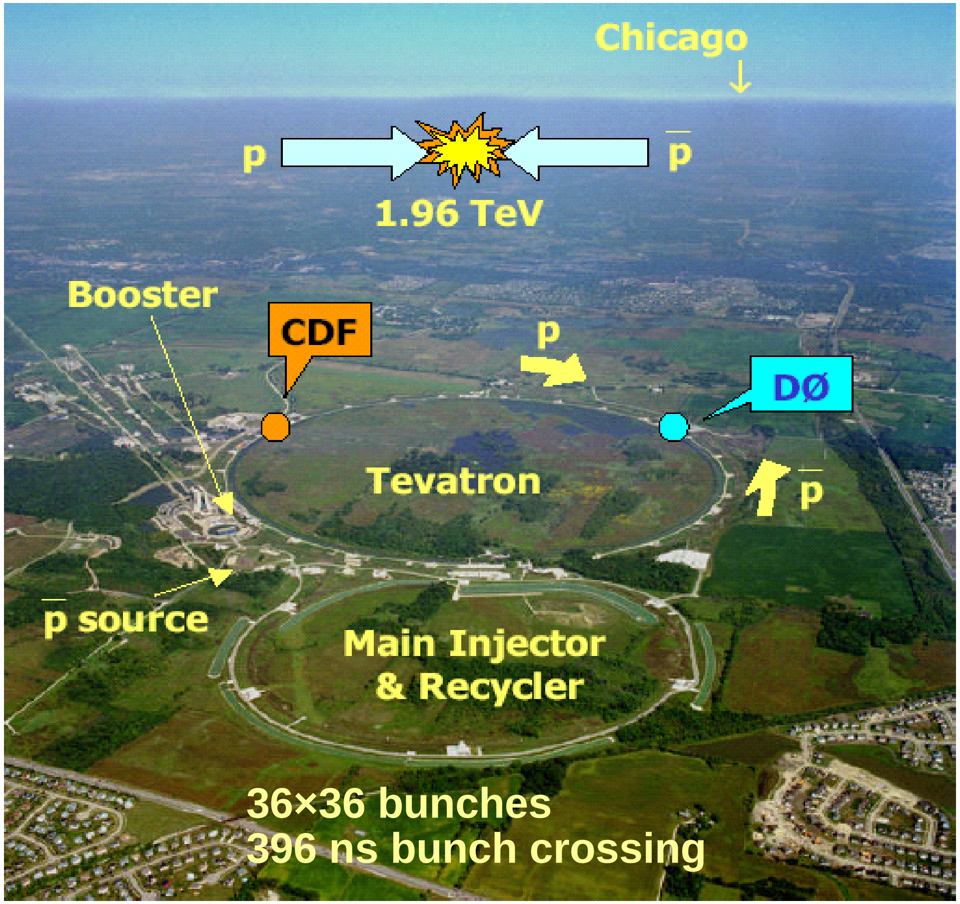

Direct constraints from LHC

122.5 GeV $< M_H <$ 127 GeV @95%

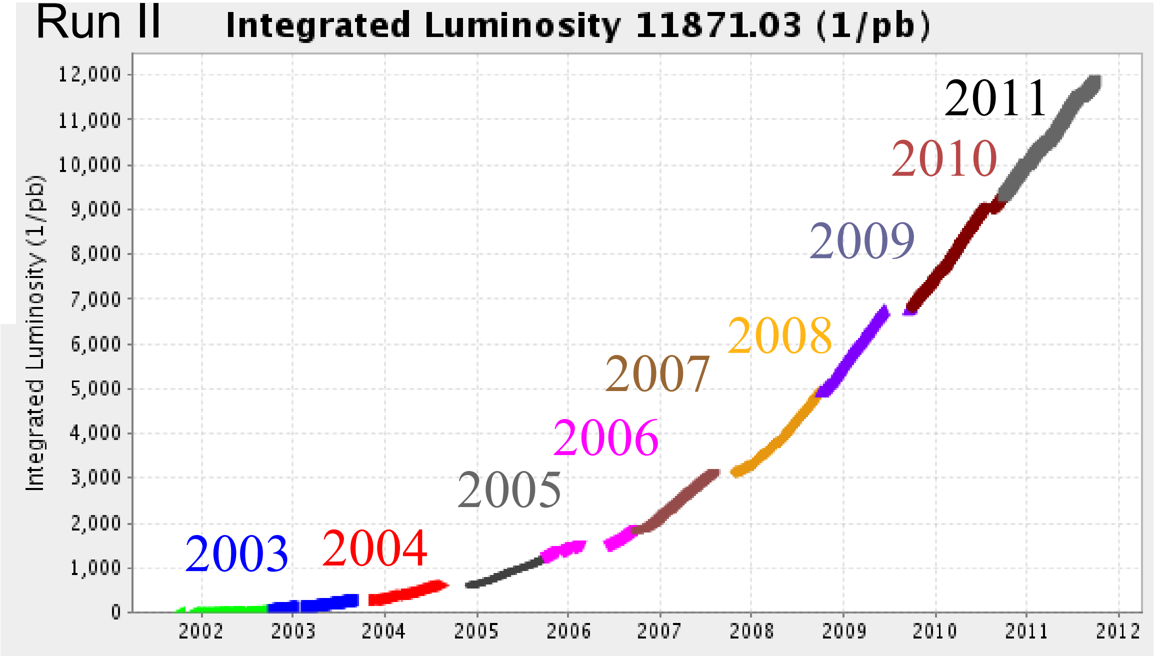
July 4th : Observation of a Higgs-like particle @5σ by Atlas & CMS around 125 GeV



# The Tevatron proton-antiproton collider



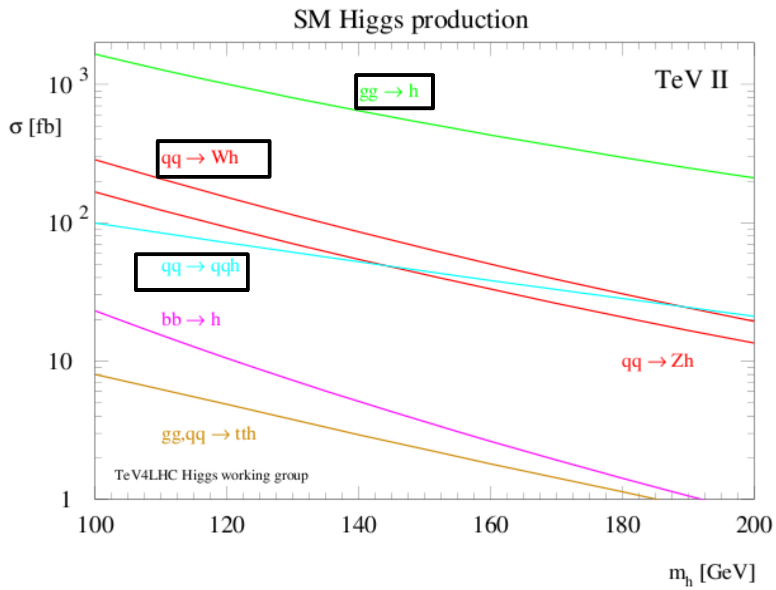

Run I (1993-1996)
~120 $pb^{-1}$ per experiment-top quark discovery
Run II: (2002-2011)
Shutdown 30 september 2011
~12 $fb^{-1}$ delivered per experiment
~9.5 $fb^{-1}$ for physics analysis

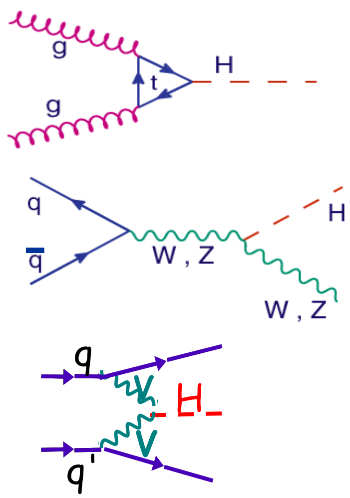



Most of the Higgs results today rely on the full data set

# Low Mass vs High Mass at Tevatron

search modes depends on the mass



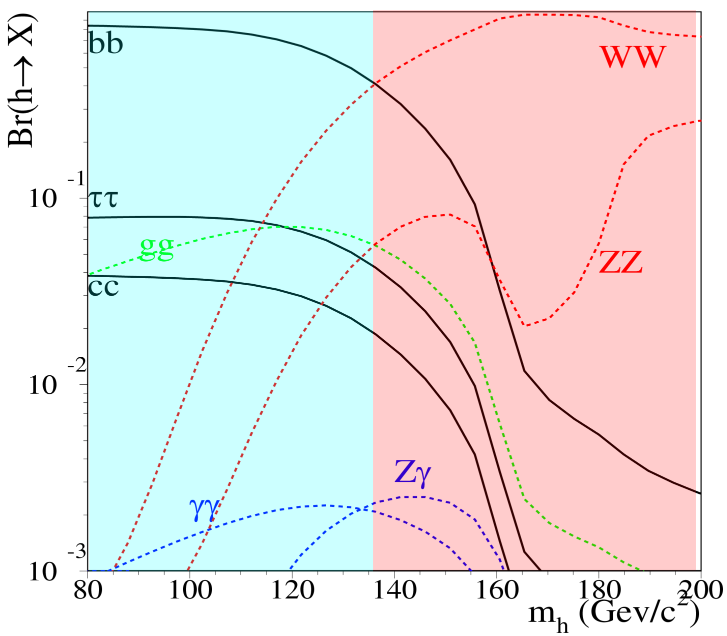




$m_H$<135 GeV
$H \to b\bar{b}$
$H \to \tau\tau$

$m_H$>135 GeV
$H \to WW^*$

Low Mass vs High Mass channels:
comparable sensitivities @130 GeV

VH → V bb modes
→ the most sensitive @125 GeV



# Tevatron analyzers are still improving results

## Updates for Summer 2012

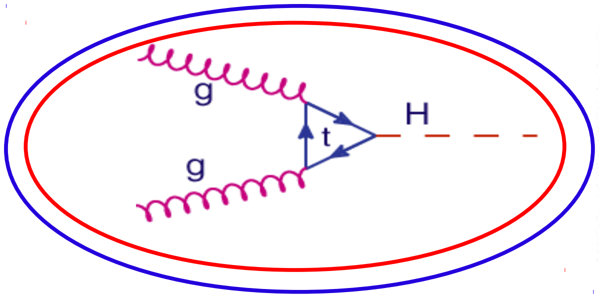
| Search Mode | Changes |
|---|---|
| $H \to W^+W^-$ | D0 (technique + new data) |
| $H \to \gamma\gamma$ | D0 (technique) |
| $ZH \to l^+l^-bb$ | D0 (technique) CDF (minor changes) |
| $WH \to l\nu bb$ | D0 (technique) |
| $VH \to \nu\nu bb$ | D0 (technique) CDF (minor changes) |

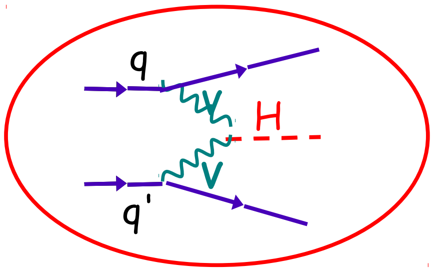
**~10-15% gain in sensitivity for channels with improved technique since last update in Moriond 2012**

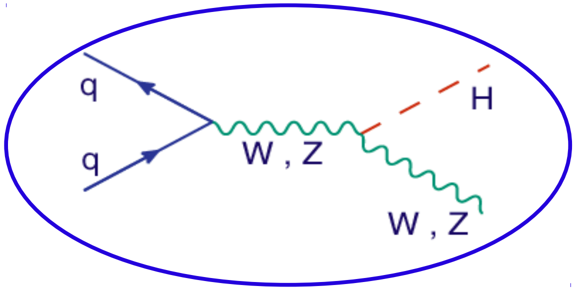
# Complementarity between LHC and Tevatron

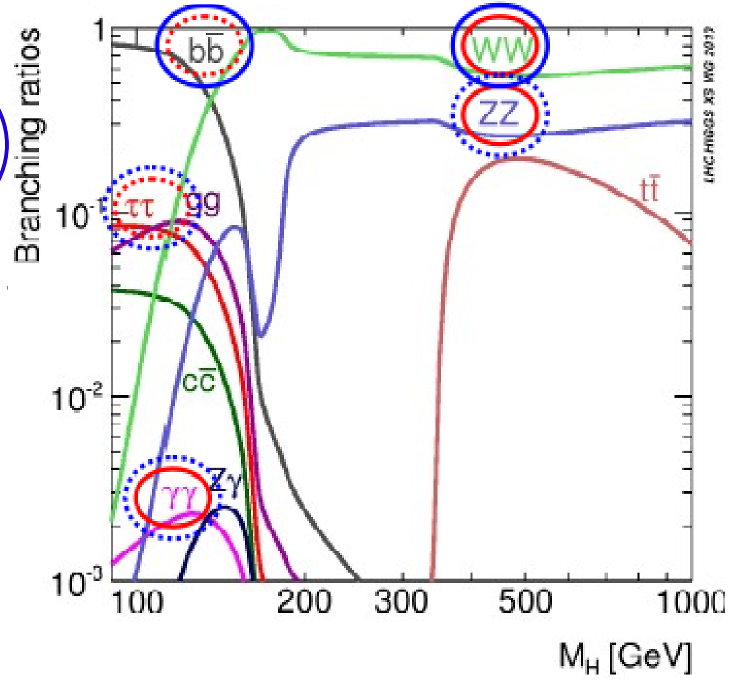
The name of the game now: **Probe new particle's couplings**

Tev vs LHC: Main sensitivity from different production mechanisms and decay modes




Main mode

Supporting mode

**LHC**

**Tevatron**

Tevatron main modes:

- VH→V bb, H → WW

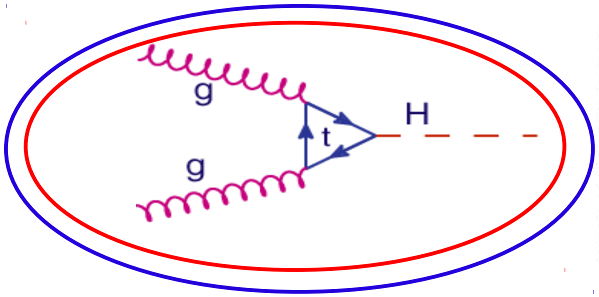
LHC main modes:

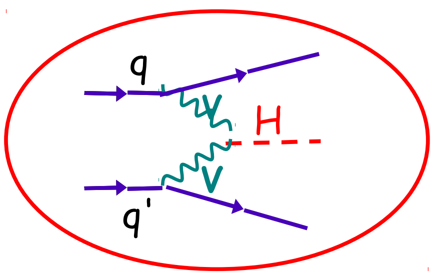
- H → γγ, qqH → qqττ, H→ZZ, H → WW

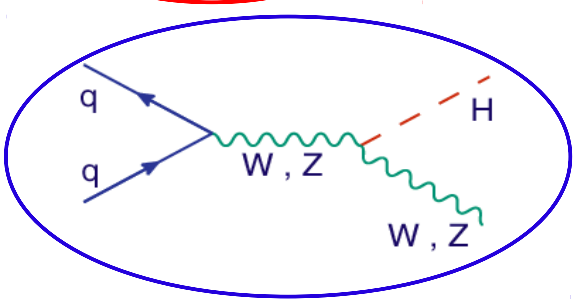
# Complementarity between LHC and Tevatron

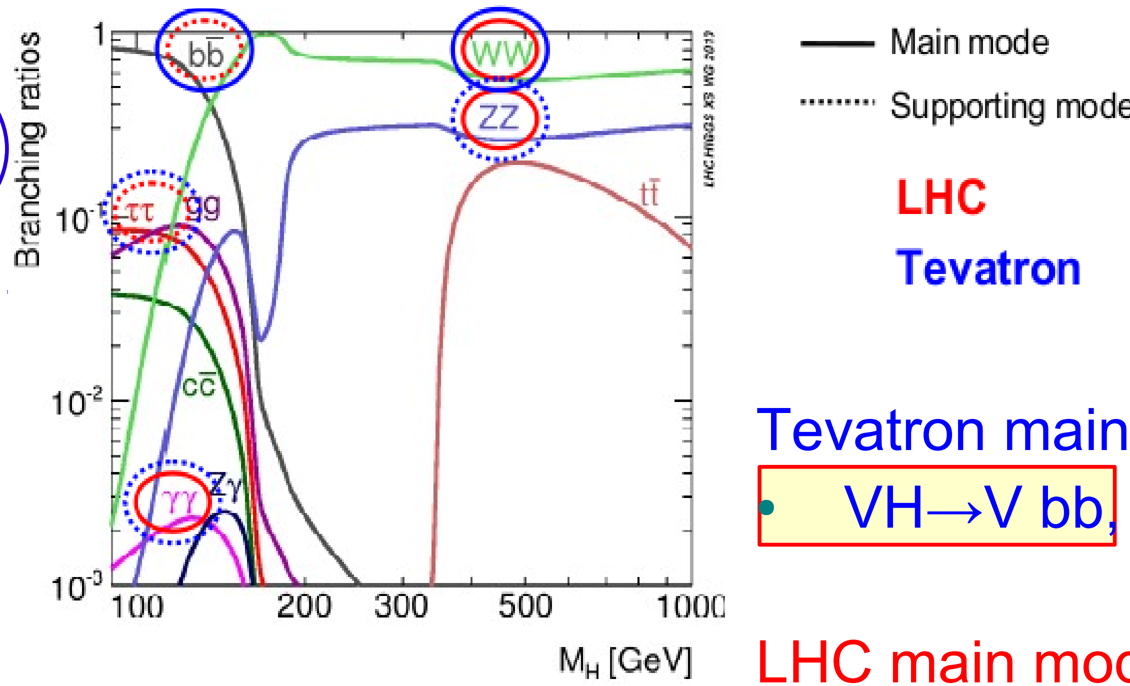
The name of the game now: Probe new particle's couplings

Tev vs LHC: Main sensitivity from different production mechanisms and decay modes




Tevatron main modes:

- VH→V bb, H → WW

LHC main modes:

- H → γγ, qqH → qqττ, H→ZZ, H → WW

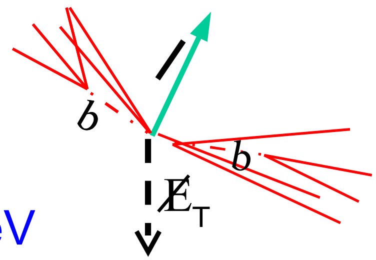
**Tevatron has the possibility to test the Hbb coupling**

# Main channels at the Tevatron

For $M_H$ < 130 GeV

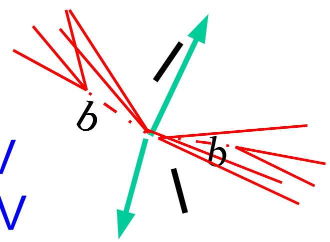
pp → WH → Wbb

- eν bb, μν bb:
  - 2 b-jets ~ 40 GeV
  - 1 lepton ~ 40 GeV
  - $\not{E}_T$ ~40 GeV

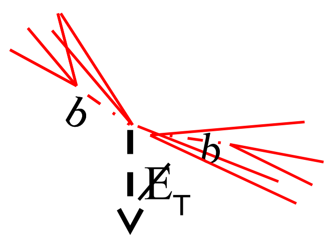



pp→ ZH → Zbb

- ee bb, μμ bb
  - 2 b-jets ~ 50 GeV
  - 2 leptons ~ 40GeV

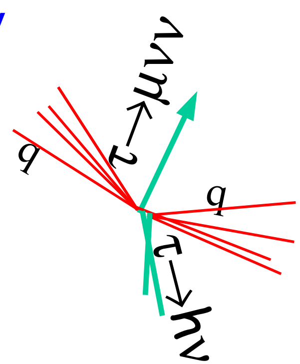



- νν bb:
  - 2 b-jets ~ 50 GeV
  - $\not{E}_T$ ~ 50 GeV




pp →H+ Z/V/X → jj ττ

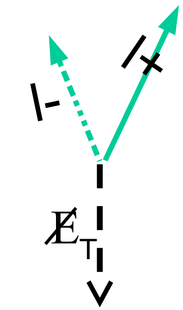
- 2 jets ~ 30 GeV
- 1 leptonic tau
- 1 hadronic tau



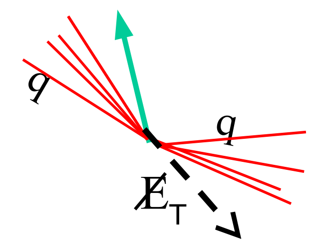

For $M_H$ > 130 GeV

gg→H→WW*

- eνeν, μνμν, eνμν
  - 2 leptons ~ 40 GeV
  - $\not{E}_T$ ~ 60 GeV
  - small Δφ(l+,l-) (H is scalar)




- eν jj, μν jj:
  - 1 leptons ~ 40 GeV
  - $\not{E}_T$ ~ 40 GeV
  - 2 jets ~ 40 GeV
  - $M_{jj}=M_{l,\not{E}T}$=80 GeV

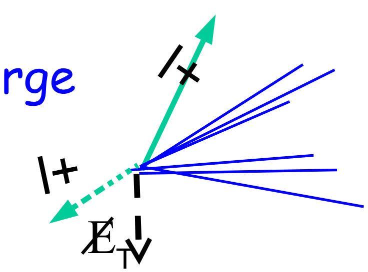



pp → WH→WWW*

ee+jj+νν, eμ+jj+νν, μμ+jj+νν

$\not{E}_T$ ~ 40 GeV

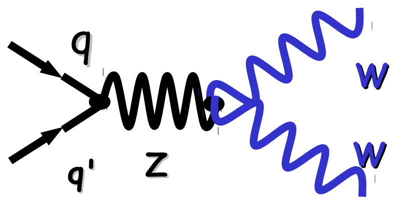
2 leptons of same charge

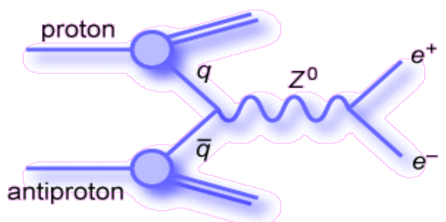


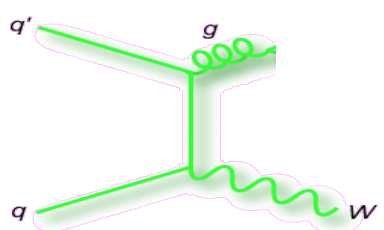

NB: Xsec normalized to NNLO

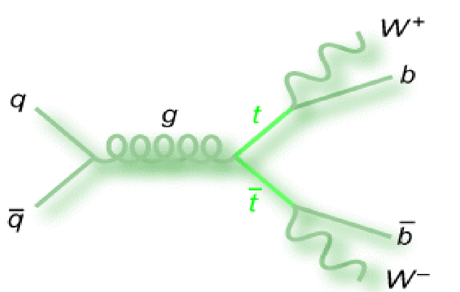
NB: Xsec normalized to NNLO+NNLL

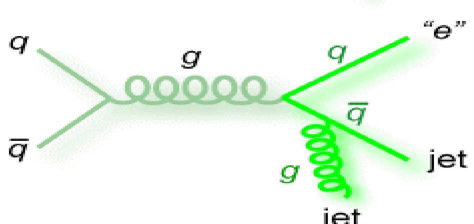
# Backgrounds to Higgs



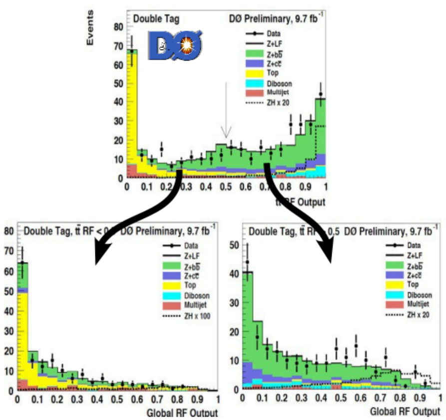




- Di-boson WW, WZ, ZZ
  - Can yield 1, 2, 3 or 4 real leptons
  - NLO calculation for cross-sections
  - WW = irreducible background for H → WW
    - NLO correction for $p_T$ and di-lepton opening angle
- Z+jets, W+jets, W+γν Z+γ
  - Alpgen MC+ pythia showering, NNLO cross-sections, data-based corrections to model $p_T(W)$,$p_T(Z)$
  - background for all channels:
    - For H → WW → leptons, H → ττ
      - jets or photon faking additional lepton
      - mismeasured jets or lepton yielding $\not{E}_T$
    - W+jets background to WW → lν jj signatures
    - W+bb, Z+bb final states mimic ZH, WH
- Top pair
  - Two real W's from top decays + 2b
  - Cross-section normalized at NNLO
- QCD multijet events
  - Jets faking leptons
  - Mismeasured jets creating $\not{E}_T$

# Search Strategy

## Try to maximize acceptance

- Many different lepton reconstruction categories, loose lepton-id using MVA
- Optimized b-tag, use different b-tag categories
- Lower kinematic requirements, Inclusive triggers when possible

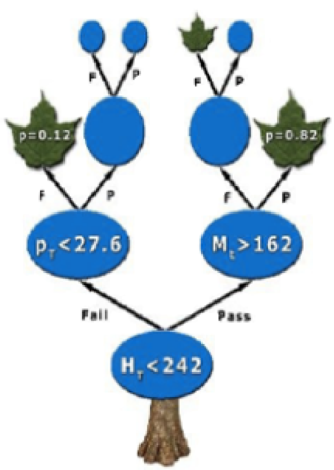



## Split analyses into subchannels

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

## Multivariate techniques to maximize use of available information

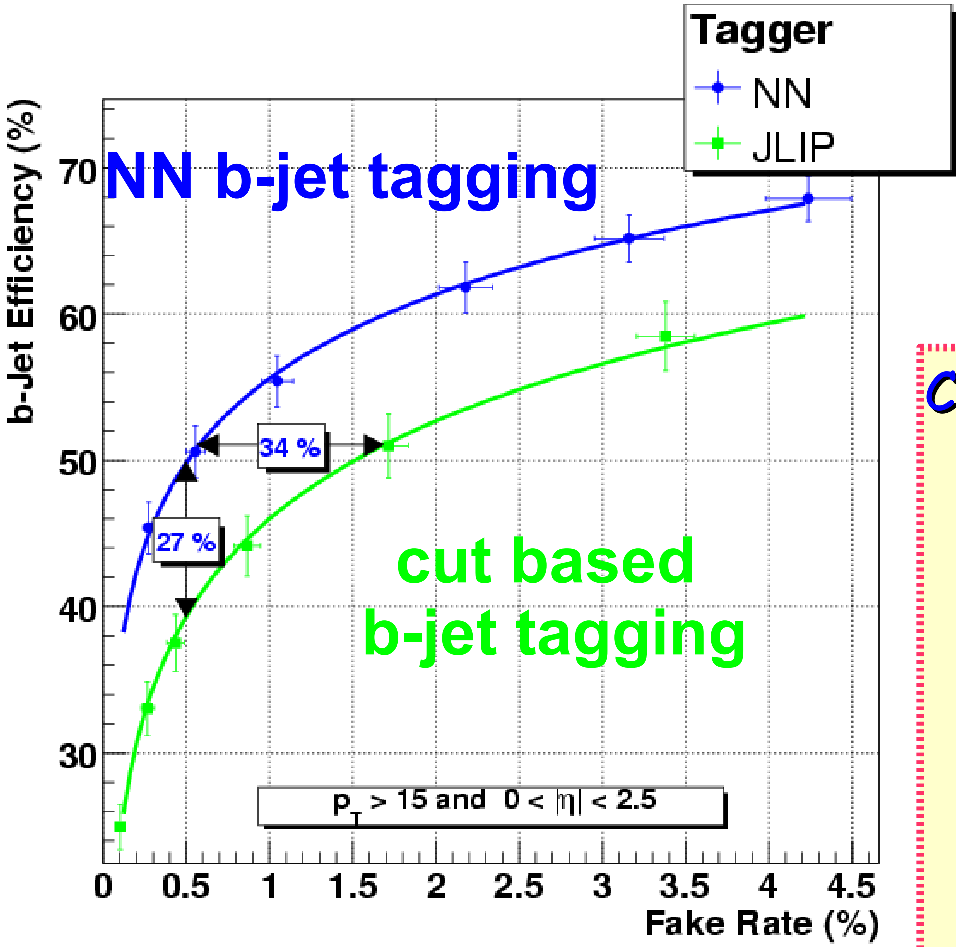
- Decision trees (BDT), Neural Networks (NN), Matrix Element (ME)
- Trained for each subchannel and Higgs mass hypothesis.
- Input variables:
  - event topology, lepton and jet kinematics, quality of leptons, Matrix Element discriminant, relation between lepton and $\not{E}_T$, relation between jets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

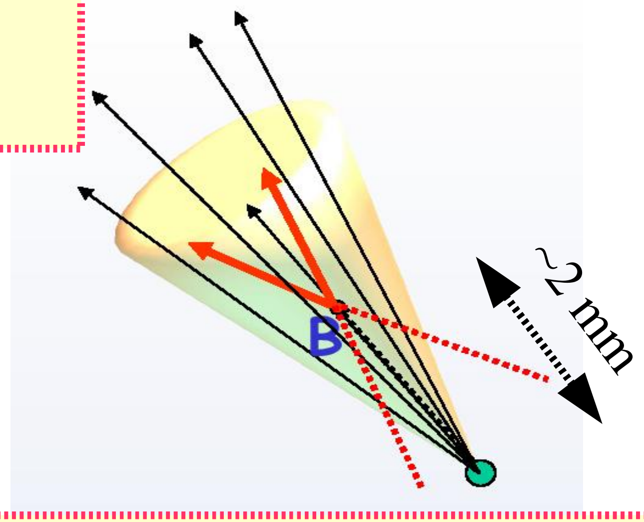



- Use data
  - data control region to model specific bakgrounds
  - Validate technique measuring diboson cross-sections

# b jets tagging: essential for search at low mass

B-hadrons are long lived particles: $c\tau \sim 0.5$ mm.
B-hadrons can decay semi-leptonically: b->μνc



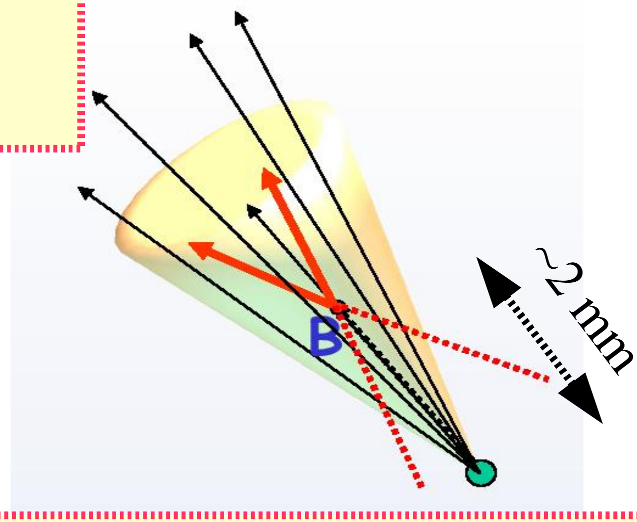

Can make use of:

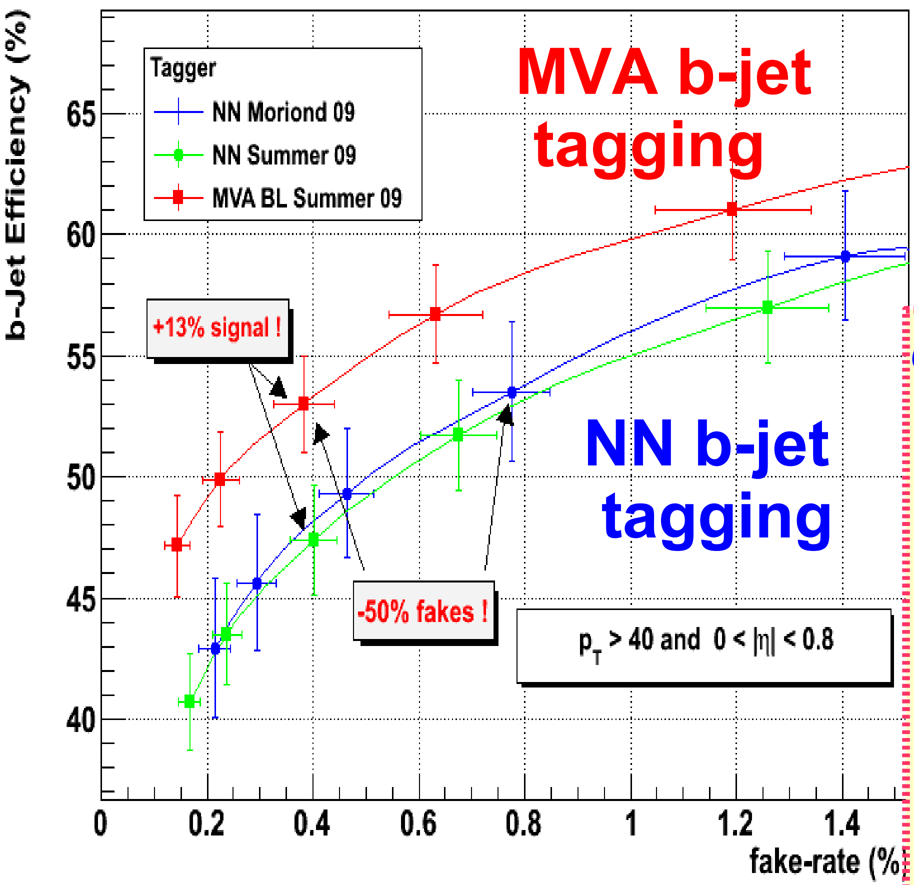
- High impact parameter of tracks
  ==> light quark Jet Probability
- Secondary vertex reconstruction (SVX)
- Lepton tag
- b-jet kinematics (large B-hadron mass)
- Combination of above with multivariate techniques (eg Neural Network)

Eg: CDF 2nd vtx tag, ε=50% for 2% mis-tag at η<1
Eg: D0 NN (2006), ε=60% for 1.5% mis-tag Pt=50 GeV (loose tag)

# Improving acceptance with better b-tagging

B-hadrons are long lived particles: cτ~0.5 mm.
B-hadrons can decay semi-leptonically: b->μνc



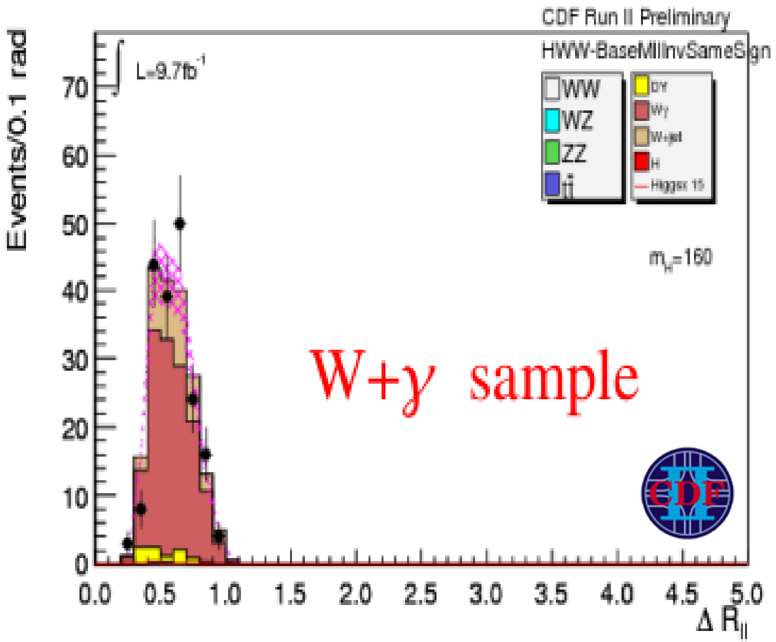

Can make use of:

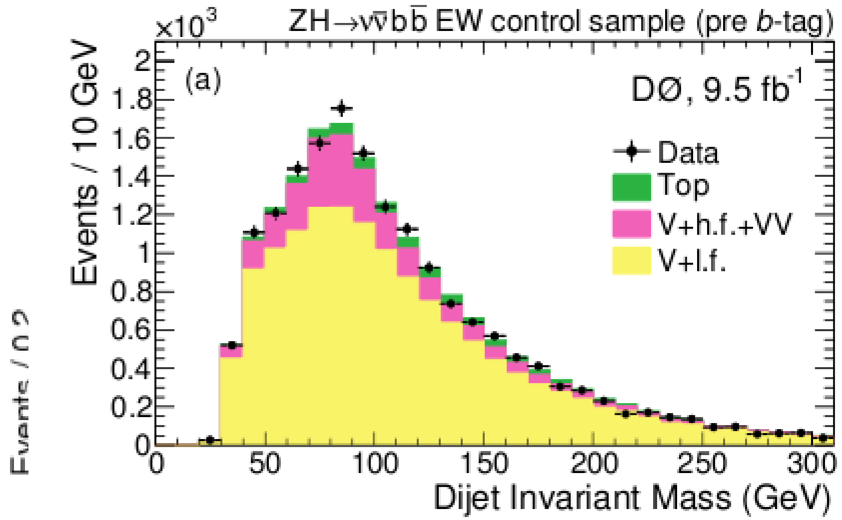
- High impact parameter of tracks
  ==> light quark Jet Probability
- Secondary vertex reconstruction (SVX)
- Lepton tag
- b-jet kinematics (large B-hadron mass)
- Combination of above with multivariate techniques (eg Neural Network)

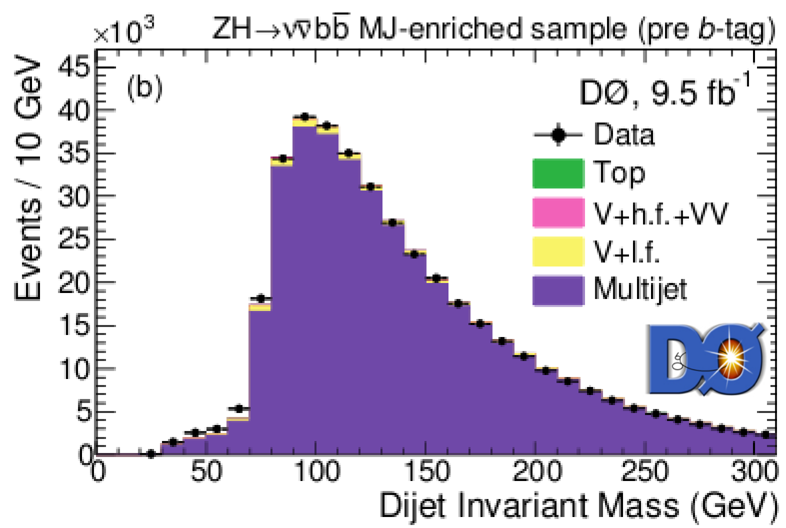
Eg: CDF Hobbit MVA(2012), ε~60% for 2% mis-tag at η<1
Eg: D0 MVA (2009), ε=60% for 1% mis-tag Pt=50 GeV

# Use data as much as possible

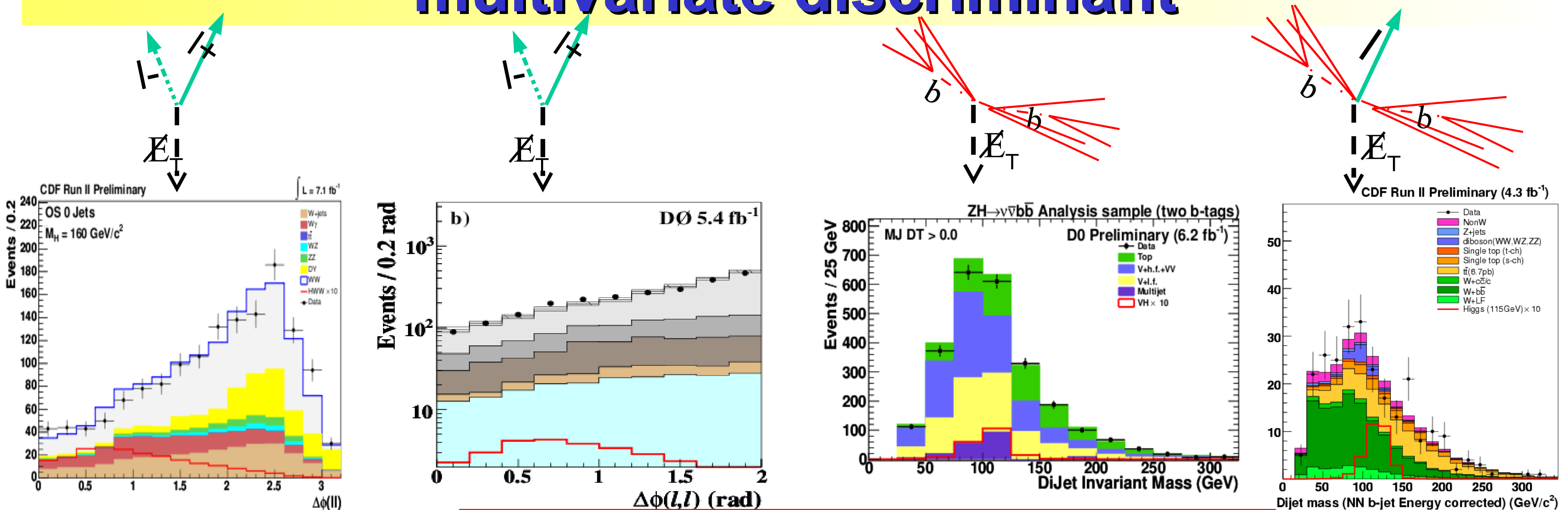
- Instrumental background need to be determined on data
  - jets faking leptons, photon faking electrons, charge mis-measurements, Missing $E_T$
- Background enriched samples to tune or check modeling of specific background processes



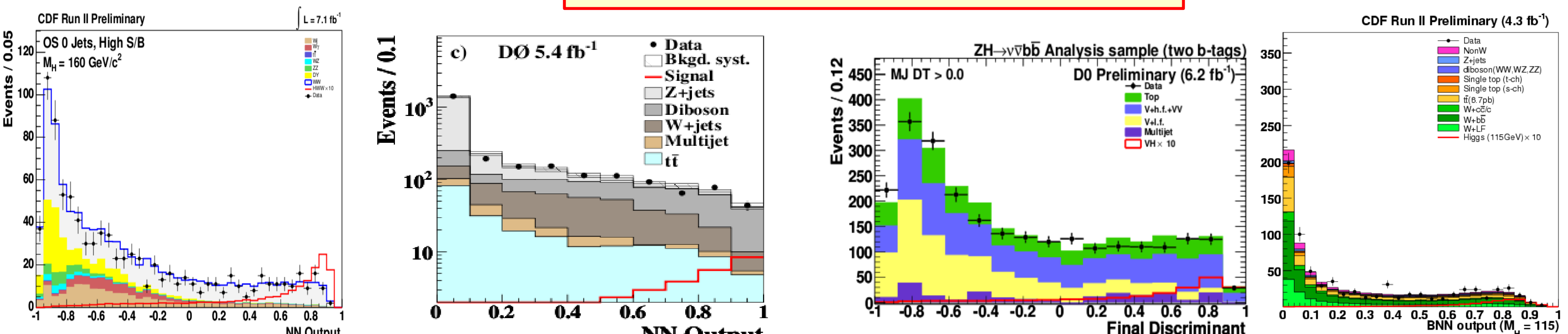



# Each channel uses (at least) one multivariate discriminant




Main discriminating variables as inputs to

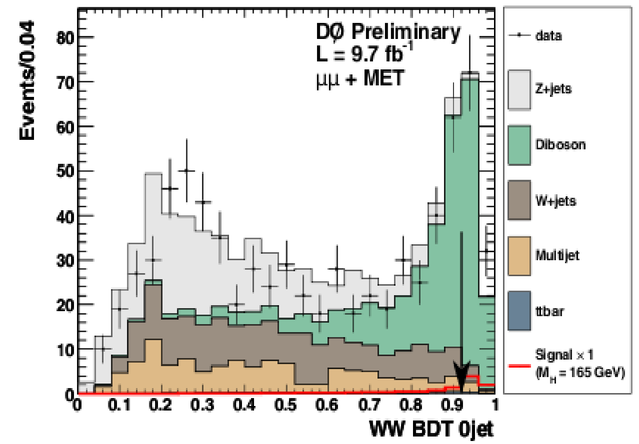
Final multivariate discriminants



# Analysis method: Divide and Rule

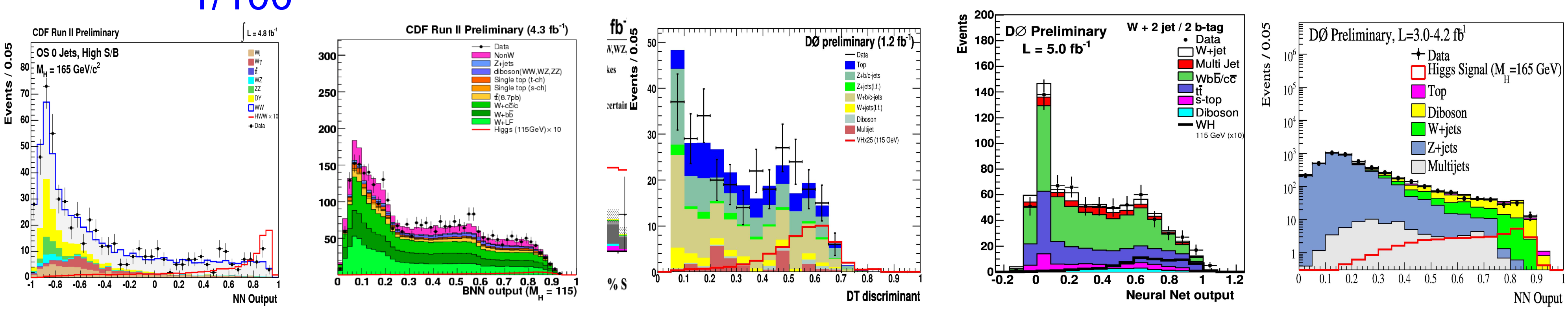
Channels are split into subchannels: O(100) analyses to be combined

- Different bins in jet multiplicity, different b-tagging content, lepton flavour, lepton id criteria
  - llbb at D0 = 8 channels
    - (ee, μμ, e+ICRe , μ+track)x(1 b-tag, 2 b-tag
  - Summer 2012,WW → llνν channel at D0:
    - split into diboson enriched/deplered region




Goal is to maximize sensitiviy : each subchannel has its own S/B

Eg WH, 2jets : 0-btag S/B~1:4000 , 1btag(only) S/B~1/400 2 b-tag S/B ~ 1/100




Build Likelihood based on all multivariate discriminant distributions to test S and S+B hypothesis

# Combine many channels

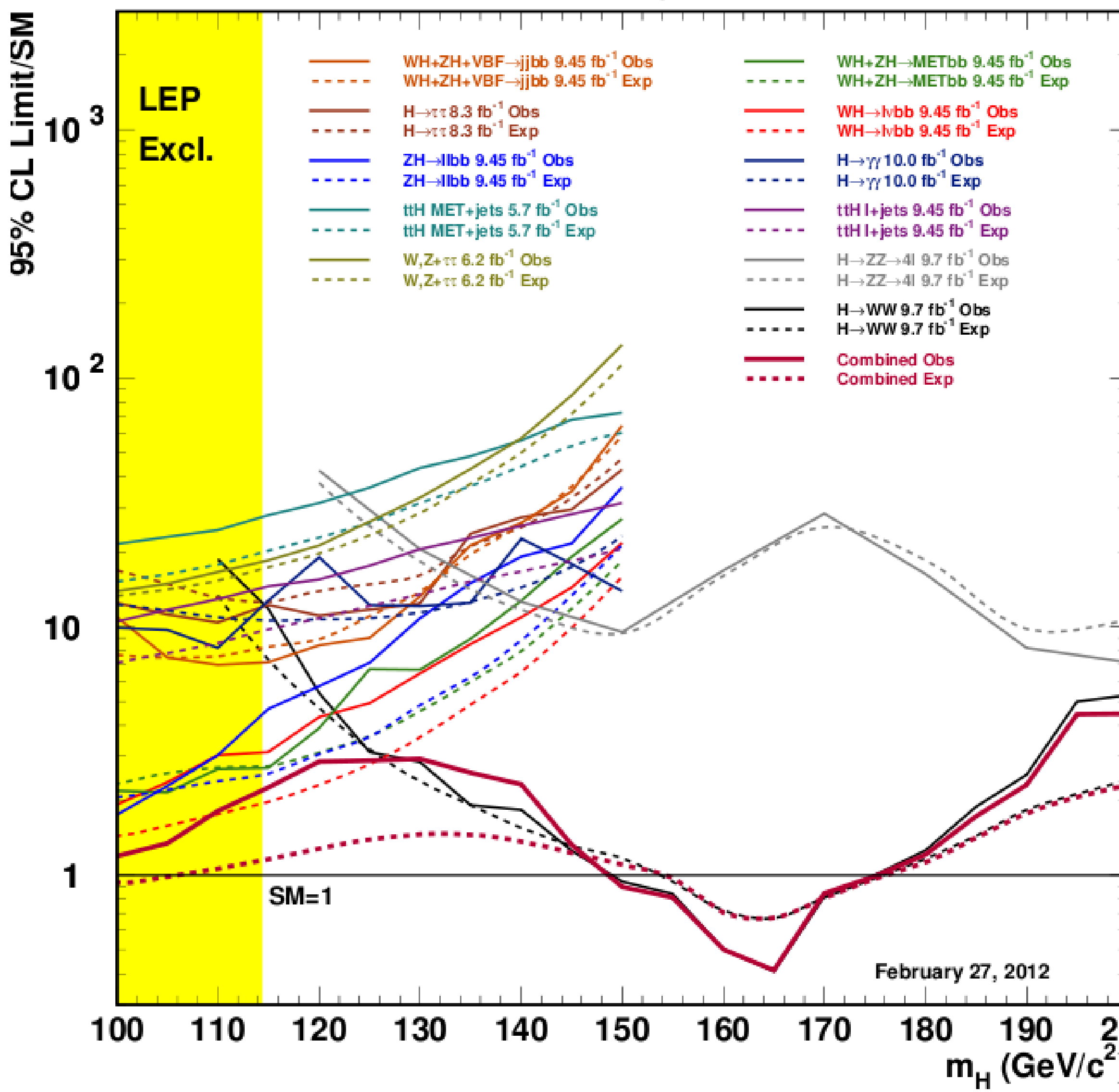
DØ channels

$H+(X) \to \ell\nu + \geq jj$
$ZH \to \nu\bar{\nu}b\bar{b}$
$ZH \to \ell^+\ell^- b\bar{b}$
$VH \to e^{\pm}\mu^{\pm} + X$
$H \to W^+W^- \to \ell^{\pm}\nu\ell^{\mp}\nu$
$H \to W^+W^- \to \mu\nu\tau_{\rm had}\nu$
$H \to W^+W^- \to \ell\bar{\nu}jj$
$VH \to \ell\ell\ell + X$
$VH \to \tau\tau\mu + X$
$H \to \gamma\gamma$

CDF channels

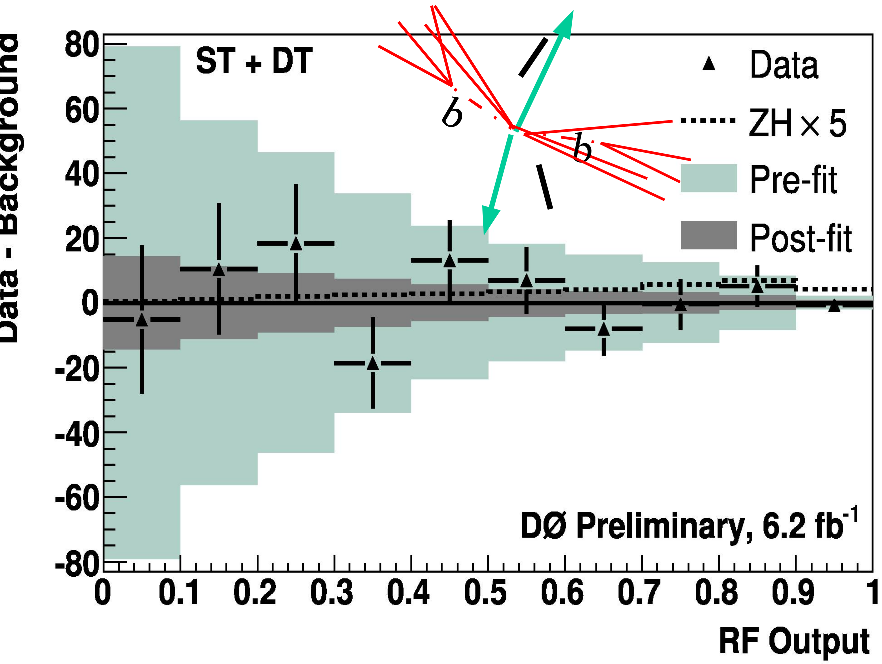
$WH \to \ell\nu b\bar{b}$
$ZH \to \nu\bar{\nu}b\bar{b}$
$ZH \to \ell^+\ell^- b\bar{b}$
$H \to W^+W^-$
$H \to W^+W^-$ $(e\text{-}\tau_{\rm had})+(\mu\text{-}\tau_{\rm had})$
$WH \to WW^+W^- \to \ell^{\pm}\ell^{\pm} + X$
$VH \to VW^+W^- \to \ell\ell\ell + X$
$H \to ZZ \to \ell\ell\ell\ell$
$H + X \to \tau^+\tau^-$
$WH \to \ell\nu\tau^+\tau^- / ZH \to \ell^+\ell^-\tau^+\tau^-$
$WH + ZH \to jjb\bar{b}$
$H \to \gamma\gamma$
$t\bar{t}H \to WWb\bar{b}b\bar{b}$

CDF Run II Preliminary, L ≤ 10.0 fb$^{-1}$




- Use also "low" sensitivity channels:
  - Gain O(10%) sensitivity
  - Can probe SM-ness of Higgs-like particle

# Systematics




Systematics are channel dependent

- Flat systematics: affect overall normalization
- Shape systematics: modify output of final discriminant
- Impact of systematics is reduced thanks to statistical method (~fit procedure in background dominated region)
- Have to account of correlations among channels
- Degrade sensitivity by ~15-25%

Main sources are:

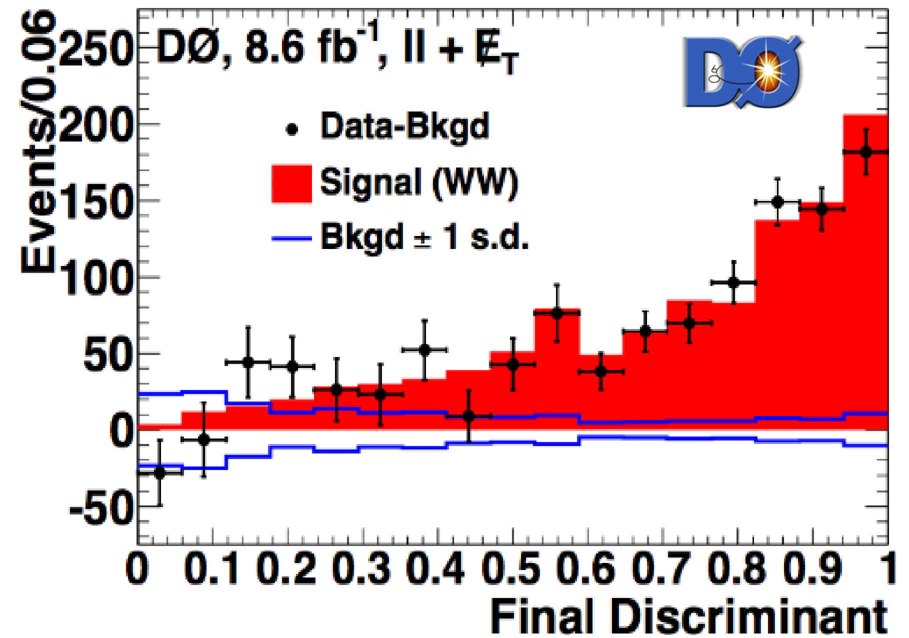
- Luminosity and normalization
- Multijet background estimates
- Background cross-sections, K-factors for W/Z+ Heavy flavor
- Modeling of background differential distributions (shape)
- B-tagging efficiency
- Jet energy calibration
- Lepton identification

# Validate methodology using data

eg at DØ:

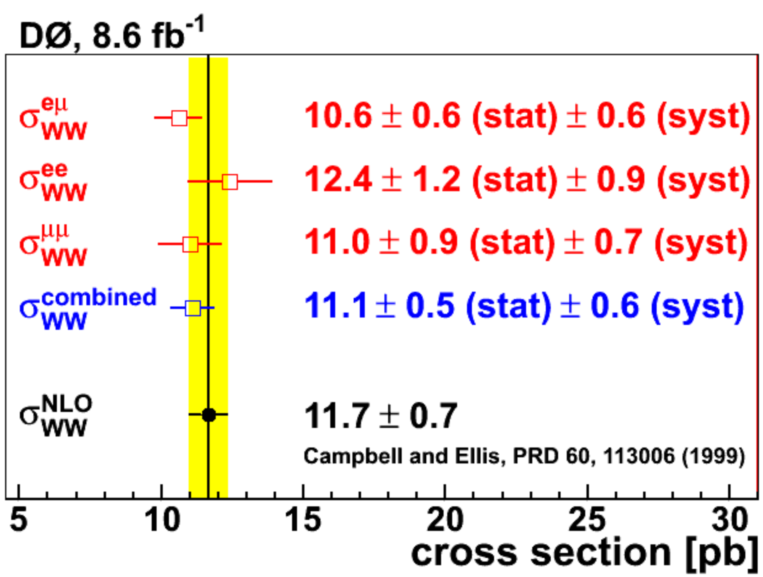
Measure $p\bar{p} \rightarrow WW \rightarrow l\nu\ l\nu$ cross-section

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




$H \rightarrow WW \rightarrow l\nu l\nu$ search with 8.6 fb$^{-1}$

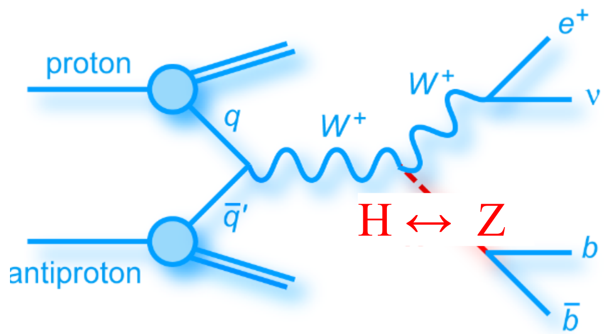
PRD 86, 032010 (2012)[arxiv:1207.1041]




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

# Validate measure WZ/ZZ (Z → bb) cross-section

- Benchmark of H → bb searches with real data
- Employ same MVA techniques
- Also look at dijet invariant Mass




**For $m_H$=115 GeV**

WH→lνbb: σ = 26 fb
ZH→ ννbb:σ = 15 fb
ZH→ llbb: σ = 5 fb

**Total VH: σ = 46 pb**

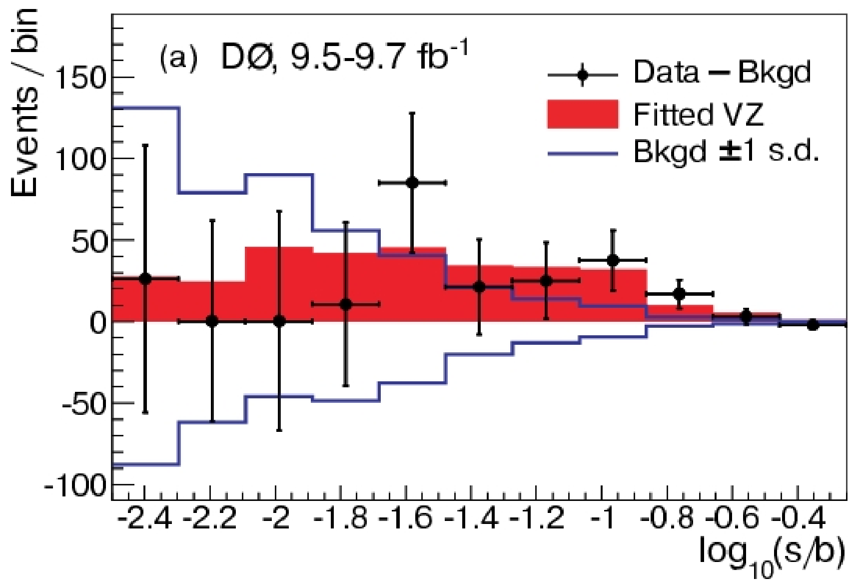
**Replace H with Z**

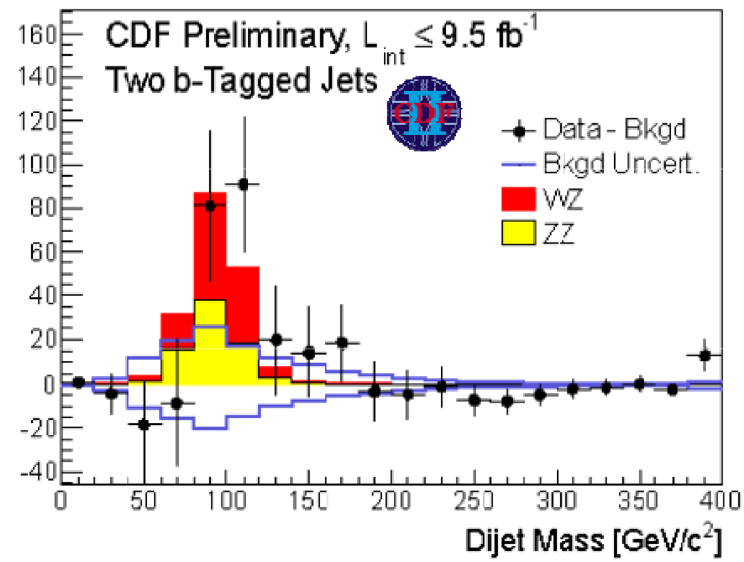
WZ→lνbb: σ = 105 fb
ZZ →ννbb: σ = 81 fb
ZZ → llbb: σ = 27 fb

**Total VZ: σ = 213 fb**

- Higher rate than Higgs,
- But also larger backgrounds and systematics as Pt's are lower

# Validate measure WZ/ZZ (Z → bb) cross-section




- Results (MVA discriminant):
  $\sigma$=3.9±0.6 (stat)±0.7 (syst) pb
- in agreement with SM prediction
  - 4.4±0.3 pb

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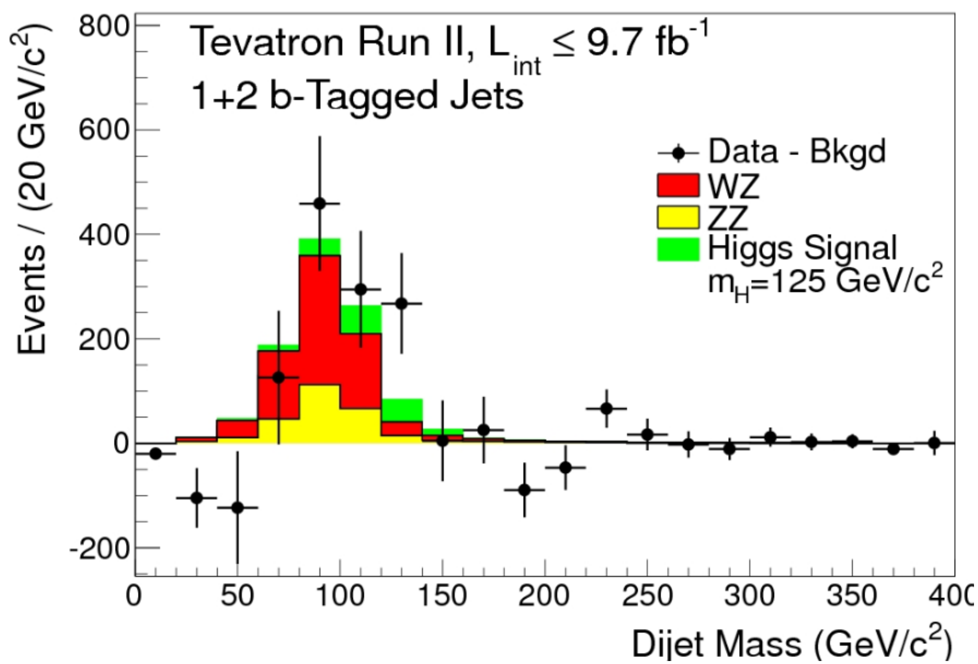
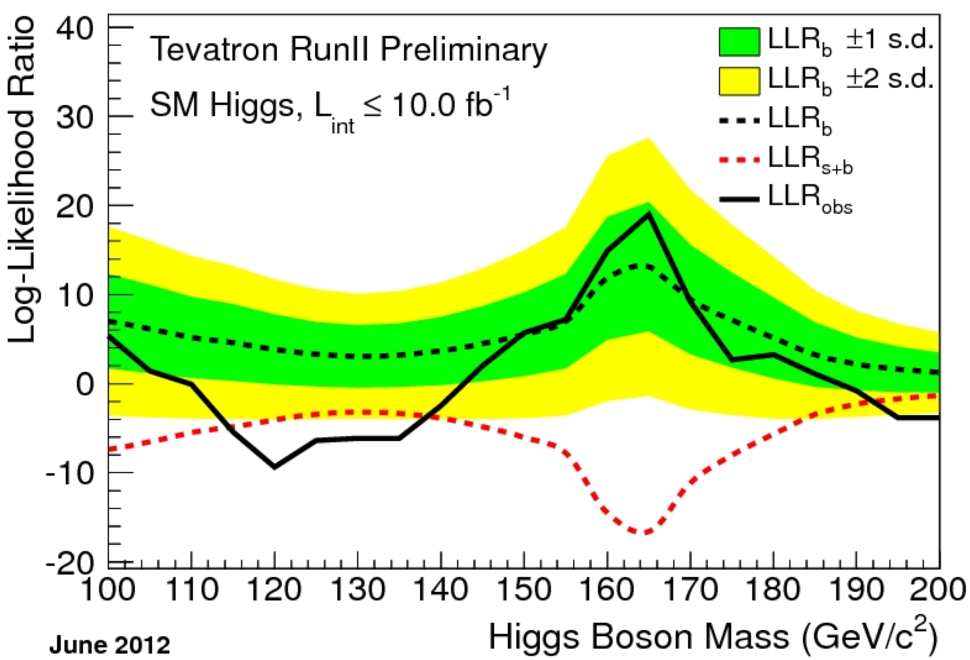
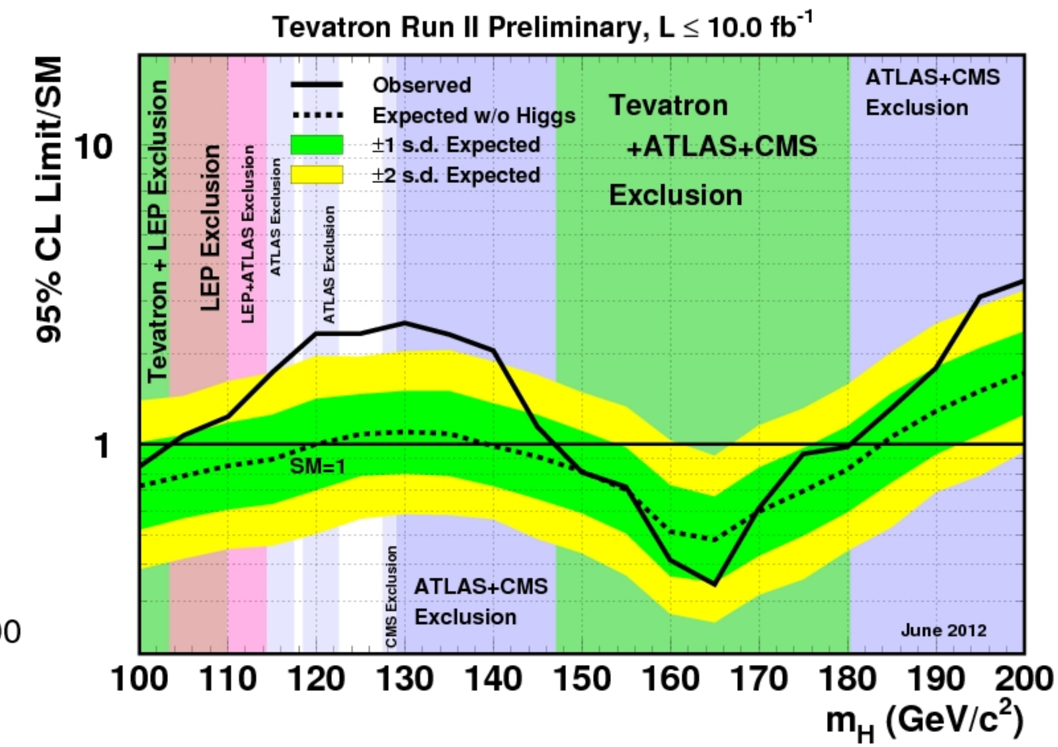


# Tevatron full mass range combined limits

High mass channels able to exclude SM Higgs @ 95% CL

$147 < m_H < 180$ GeV is excluded
expected sensitivity $139 < m_H < 184$ GeV

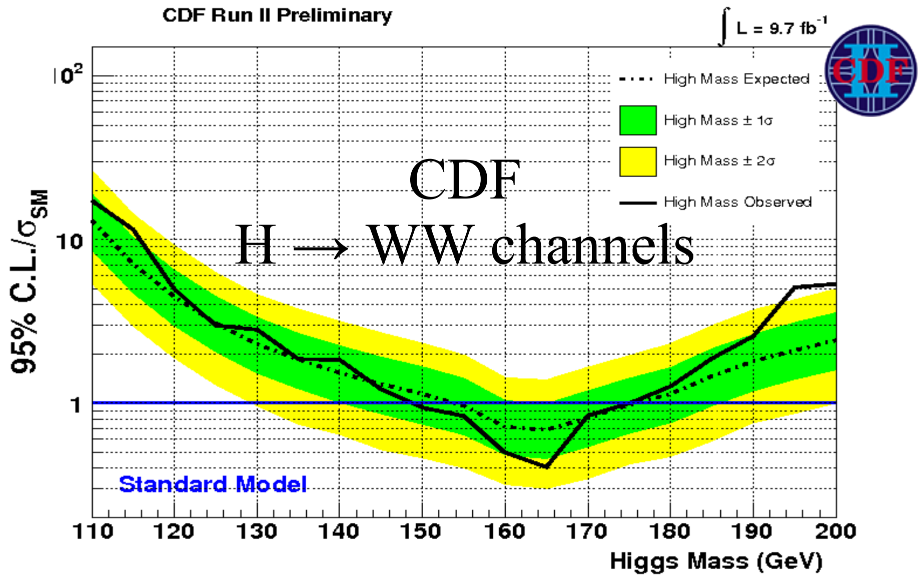


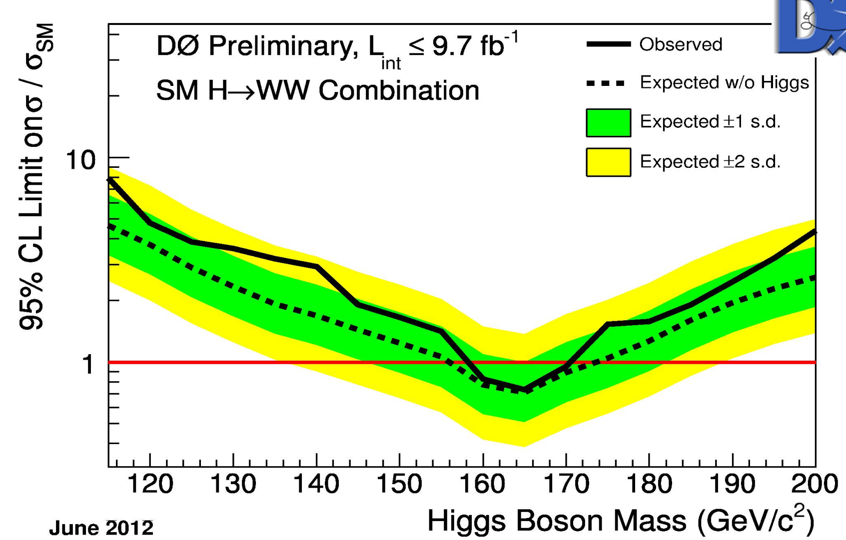




Excess observed in that data at $m_H$=120 GeV
3.0 standard deviation , (2.5 global excess=accounting for LEE)
p-value=1.5E-3
Limits For $m_H$=125 GeV $\sigma_{95}/\sigma(SM)$ =2.35 (1.08 expected)

# High Mass results

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



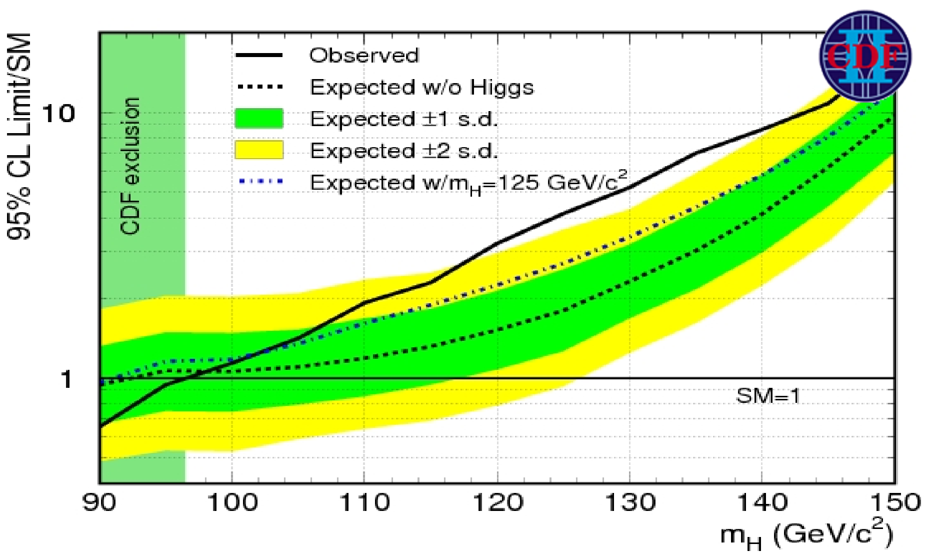



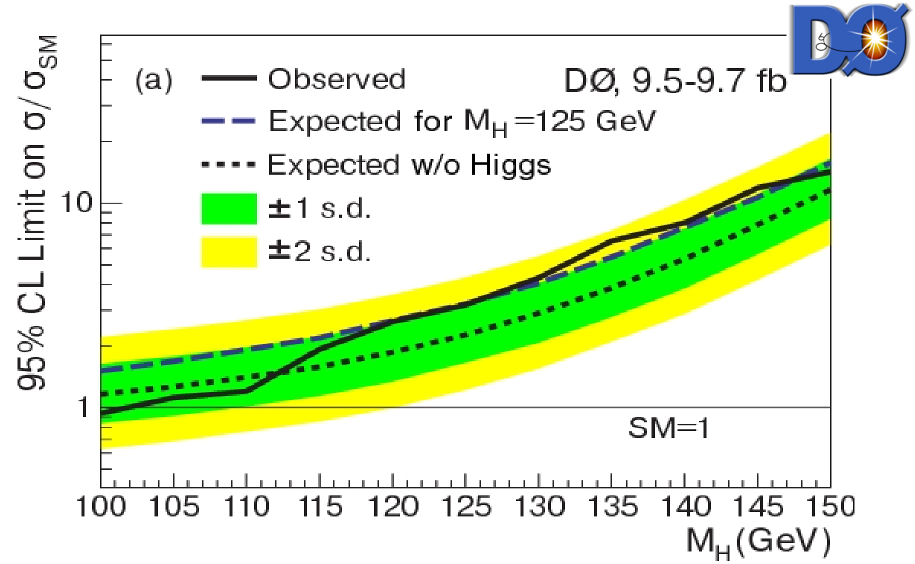

| 95% CL exclusion | | |
|---|---|---|
| | CDF | DØ |
| Expected exclusion | [154,176] GeV | [157,173] GeV |
| Actual exclusion | [149,175] GeV | [158,170] GeV |
| Sensitivy @ 125 GeV | 3.1 x $\sigma_{SM}$ | 3.2 x $\sigma_{SM}$ |

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

# $H \rightarrow bb$ (low mass) results

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



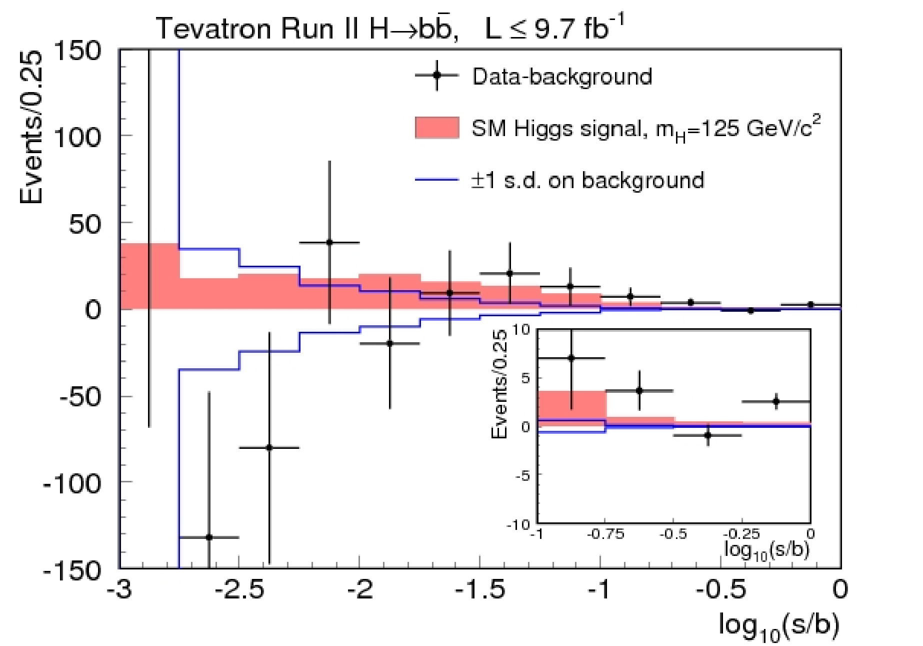



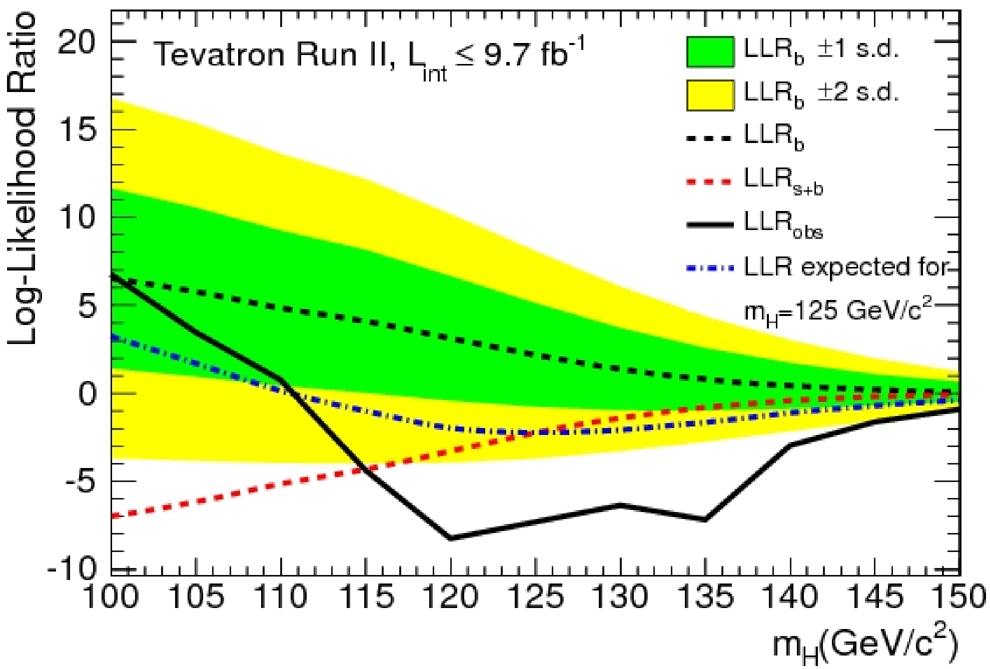

| 95% CL exclusion | | |
|---|---|---|
| | CDF | DØ |
| Exclusion@ 125 GeV | 2.89x $\sigma_{SM}$ | 3.2 x $\sigma_{SM}$ |
| Sensitivy @ 125 GeV | 1.39 x $\sigma_{SM}$ | 2.3x $\sigma_{SM}$ |

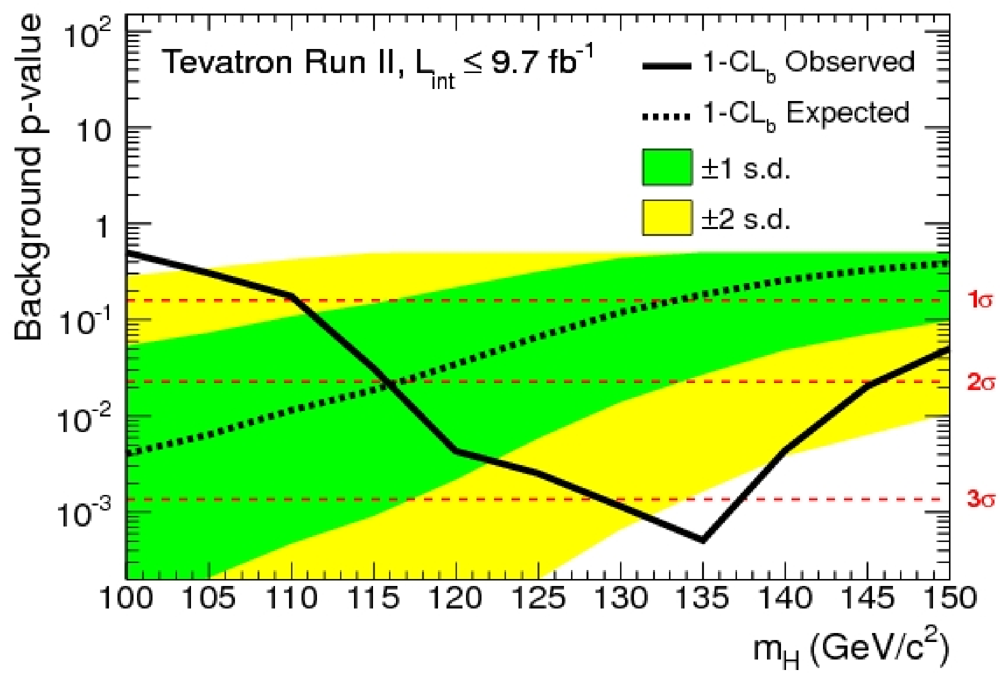
- For low masses [115-145] GeV: excesses in both experiments
  - >2 sigma in CDF
  - >1 sigma in D0

# $H \to bb$ results

- 3.3 sigma @135 GeV
- 3.1 sigma accounting for LEE
- Shape vs Mass is OK but more pronounced than SM Higgs
  - Best fit prefers 2x SM model Yield

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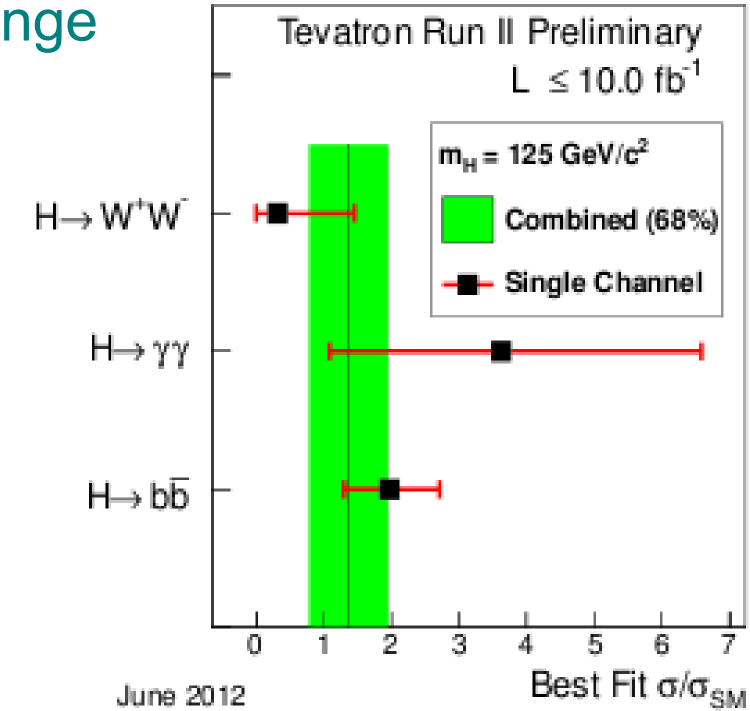
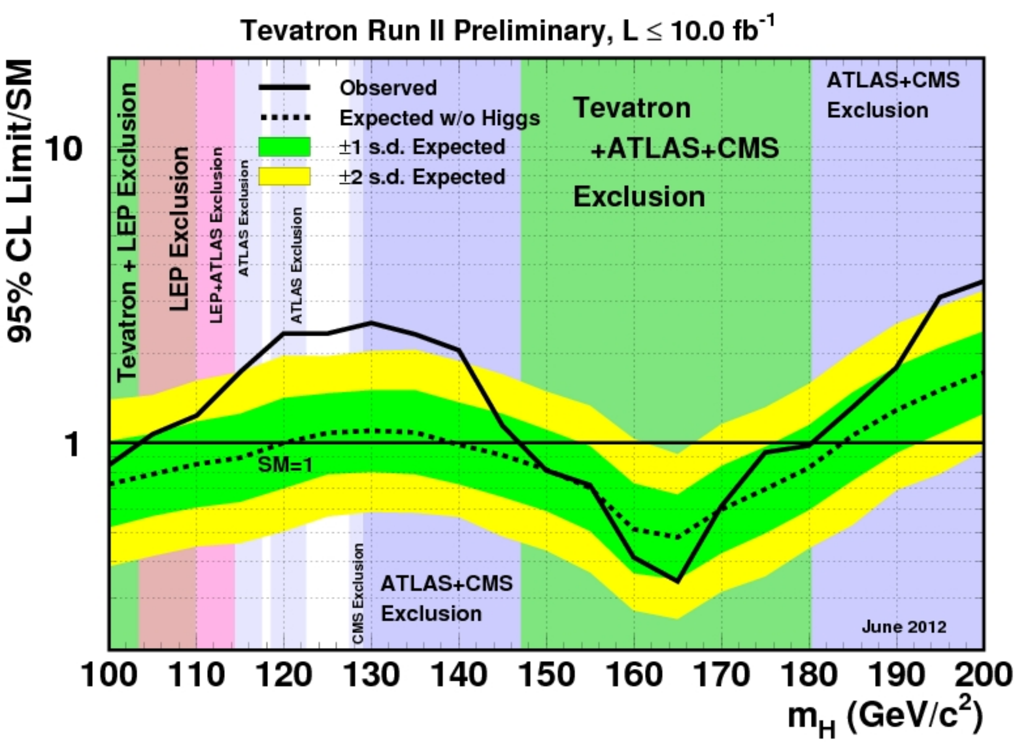
# SM Higgs Summary

- Exclude@95% CL 147<$M_H$<180 GeV
- Observe broad 2.5σ excess in low mass range
  - Compatible with SM Higgs of 125 GeV
  - Compatible with experimental resolution
  - Shared between D0 and CDF
  - excess mainly from H → bb (3.1 σ)
    - Yield ~ 2x SM for $m_H$=125 GeV

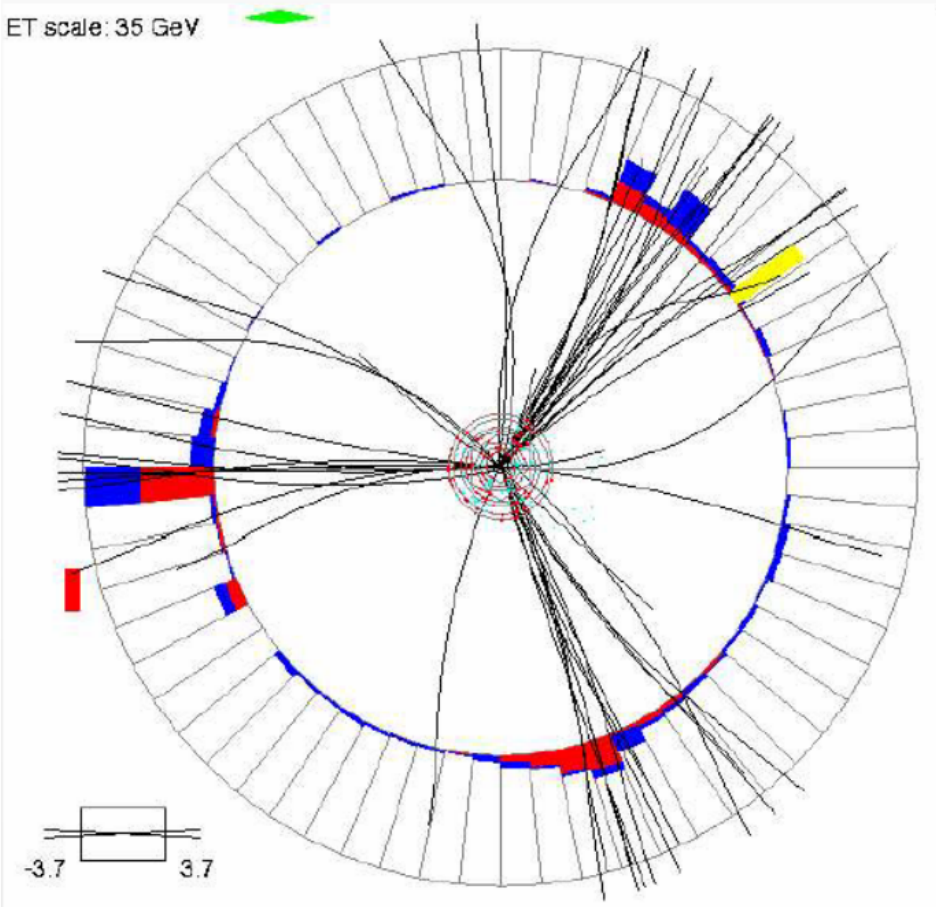



Local and global excesses at Tevatron:

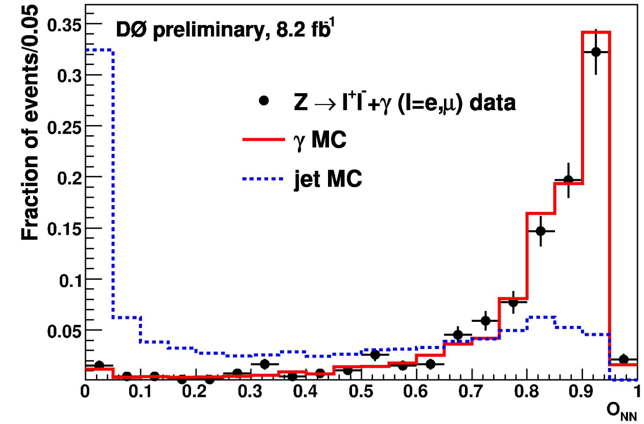
| Channels | Local | Global |
|---|---|---|
| All Tevatron | 3.0 σ | 2.5 σ |
| H→bb | 3.3 σ | 3.1 σ |

# (selected) results for Higgs beyond SM

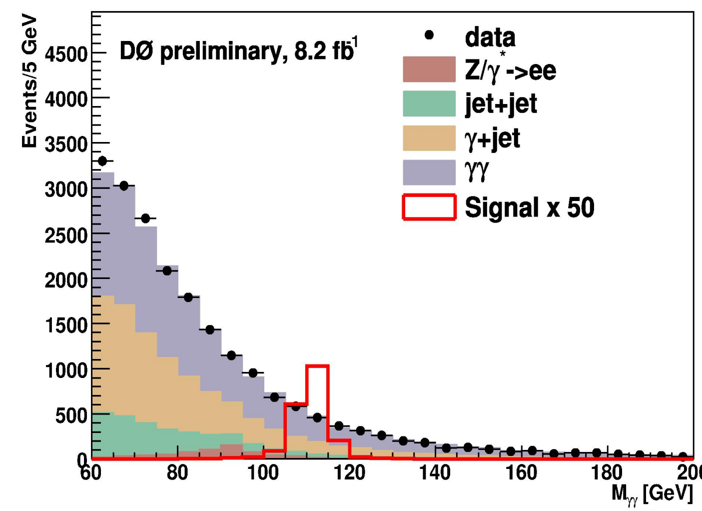


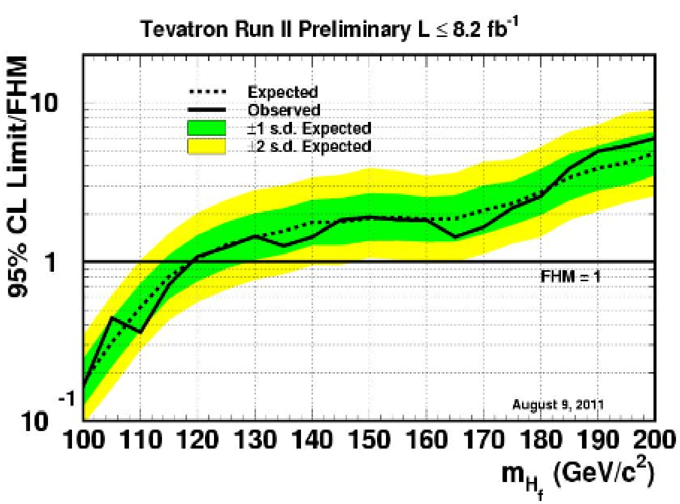
# Fermiophobic Higgs search

- Recycle SM analysis but gg $\rightarrow$ H is suppressed
  - Look for H $\rightarrow \gamma\gamma$ decay
  - Look for H $\rightarrow$ WW decay
- Benefits from SM search improvements
  - eg NN based photon Identification at D0
  - MVA for final discrimination




| Channel | Luminosity ($fb^{-1}$) |
|---|---|
| CDF $H_f \rightarrow \gamma\gamma$ | 7.0 |
| CDF $H \rightarrow W^+W^-$ 2×(0 jets,1 jet)+(2 or more jets)+(low-$m_{\ell\ell}$)+($e$-$\tau_{had}$)+($\mu$-$\tau_{had}$) | 8.2 |
| CDF $WH \rightarrow WW^+W^-$ (same-sign leptons)+(tri-leptons) | 8.2 |
| CDF $ZH \rightarrow ZW^+W^-$ (tri-leptons with 1 jet)+(tri-leptons with 2 or more jets) | 8.2 |
| D0 $H_f \rightarrow \gamma\gamma$ | 8.2 |
| D0 $VH \rightarrow \ell^\pm\ell^\pm + X$ | 5.3 |

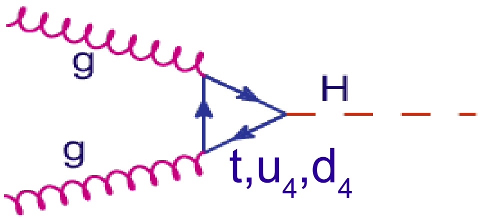


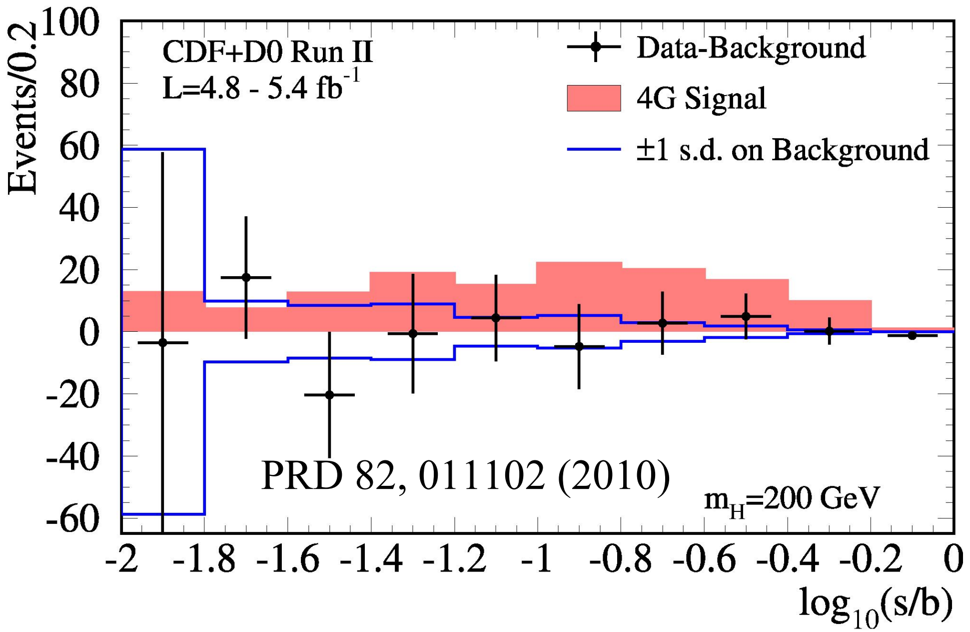



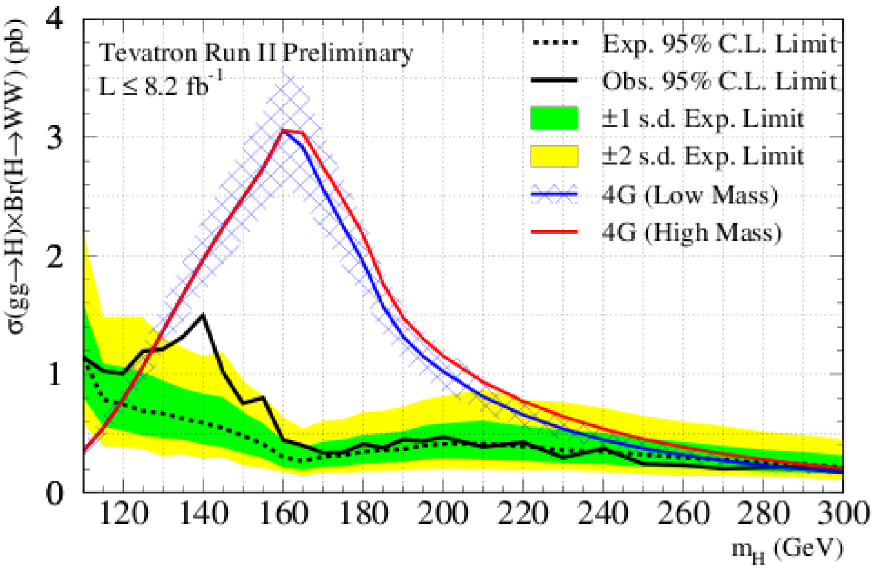

**exclude: $m_H$<119 GeV @95%CL**

# Higgs search within $4^{th}$ generation model

- New heavy generation of quarks
  - ggH coupling is multiplied by 3 compared to SM
  - Production is enhanced by 9
- Search in di-lepton +MET channel can be recycled



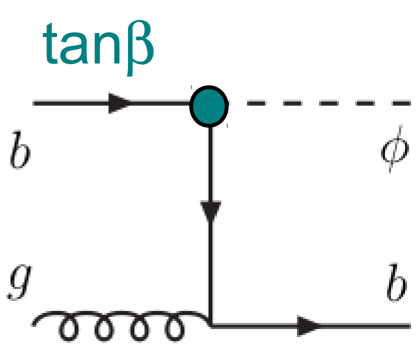




**CDF+D0 combined exclusion: $124<m_H<286$ GeV @95%CL**

# SUSY Higgs at large tan β

In MSSM 2 Higgs doublets (type II)

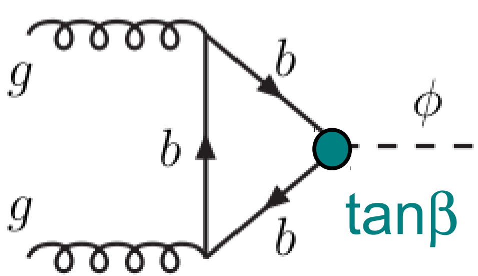
- tanβ= v2/v1 ratio of vev's
- 5 Higgs : 3 neutral (h,H,A) and 2 charged (H+,H-)
- 2 parameters at tree level : ($M_A$, tan(β))
- At large tanβ : 2 neutral ~degenerated in mass with bbϕ coupling ~tanβ
  - Decays $\phi \rightarrow bb$ (90%), $\phi \rightarrow \tau\tau$ (10%)
- cross-section enhanced by ~ 2 x $\tan^2\beta$ (at leading order) relative to SM
- Region of interest : when tanβ < $M_t/M_b$ ~30




Search channels at Tevatron

$b\bar{b}b(\bar{b})$

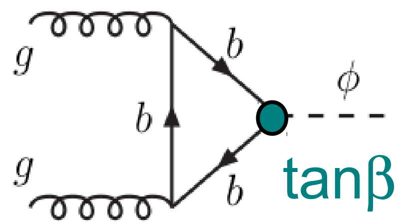
$b\tau^+\tau^-(\bar{b})$



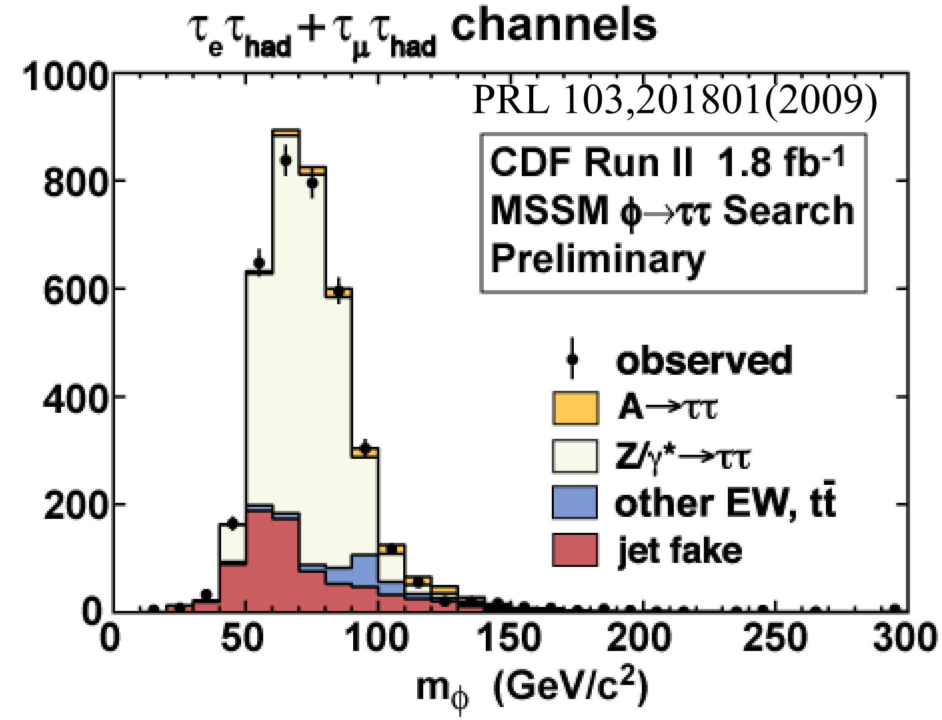

Search channels at Tevatron :

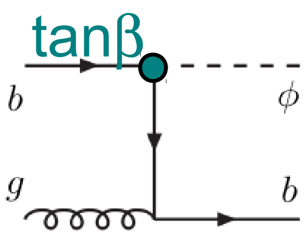
$\tau^+\tau^-$

# Tau channels at large tan(β)

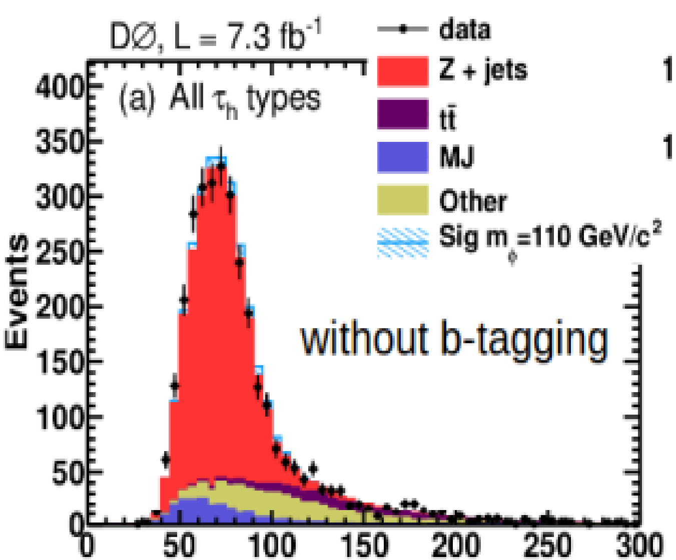



$\phi^0 \rightarrow \tau\tau$

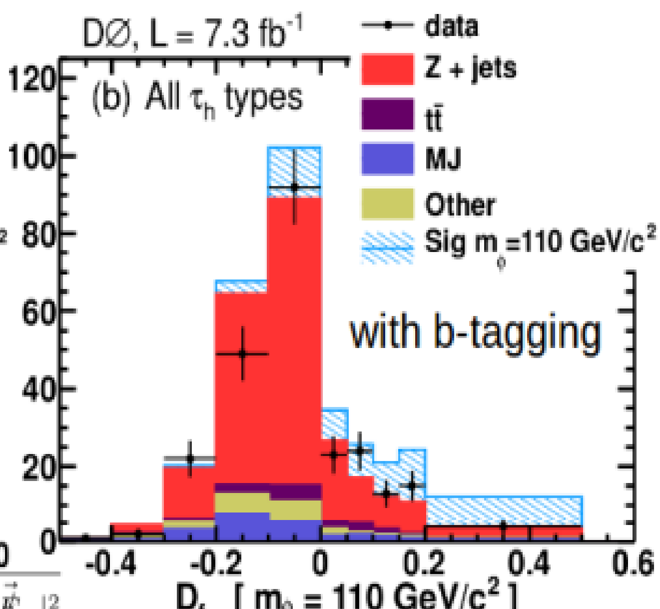


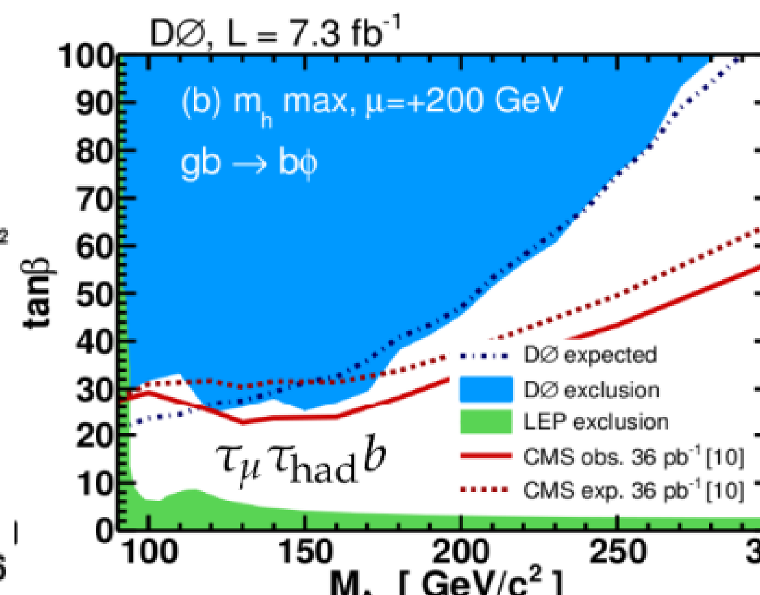




$\phi^0 b \rightarrow \tau\tau b$




$$M_{\rm hat} \equiv \sqrt{\left(E^{\mu\tau_h} - p_z^{\mu\tau_h} + \not{E}_T\right)^2 - |\vec{p}_T^{\,\tau_h} + \vec{p}_T^{\,\mu} + \vec{\not{E}}_T|^2}.$$



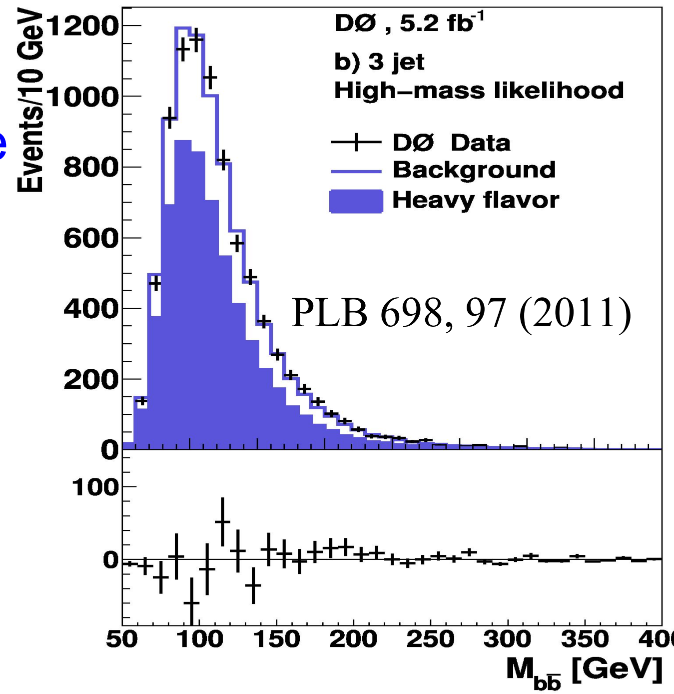

PRL 107,121801(2011)

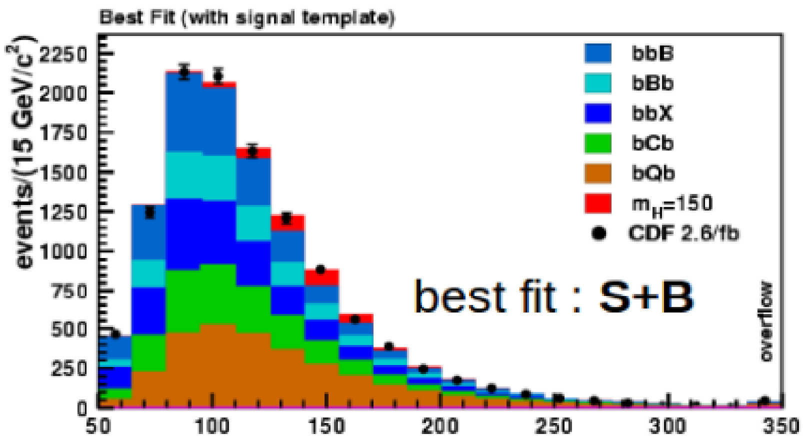
# Searching for a bbb signal

Difficulty : model multi-jet background

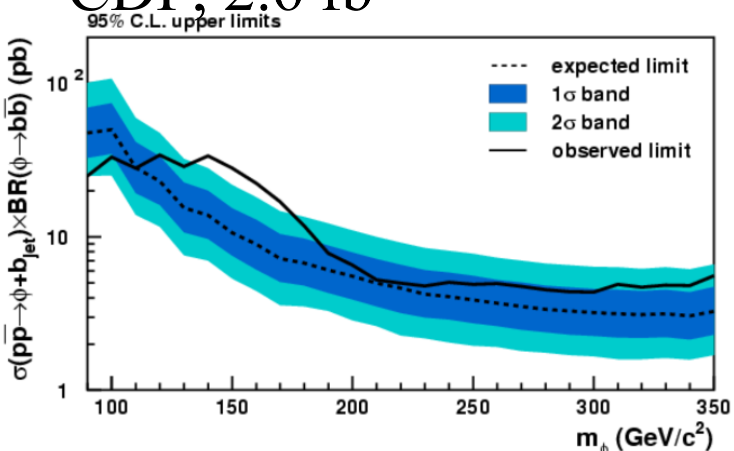
- Even more challenging at LHC
- DØ and CDF find similar flavour admixture
- But large systematic uncertainties

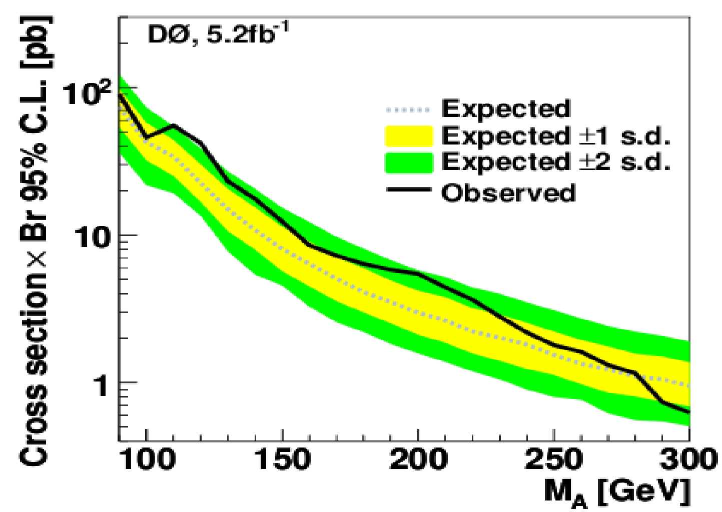
Look for excess in di-jet mass spectrum



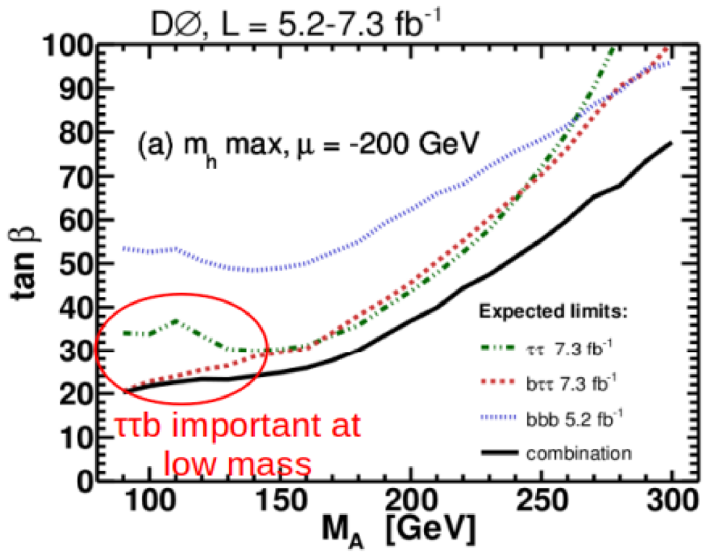

CDF, 2.6 fb$^{-1}$

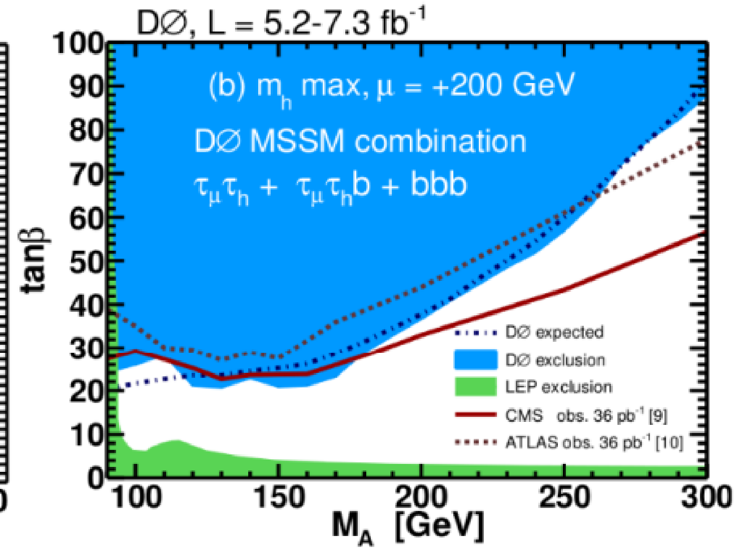


# Tev constraints on MSSM parameters

- Most stringent limit arise from D0 tau+b combination: probing tan β~20

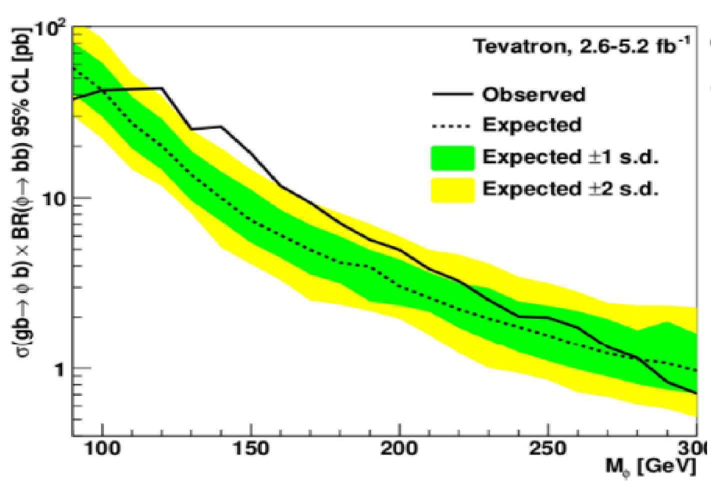


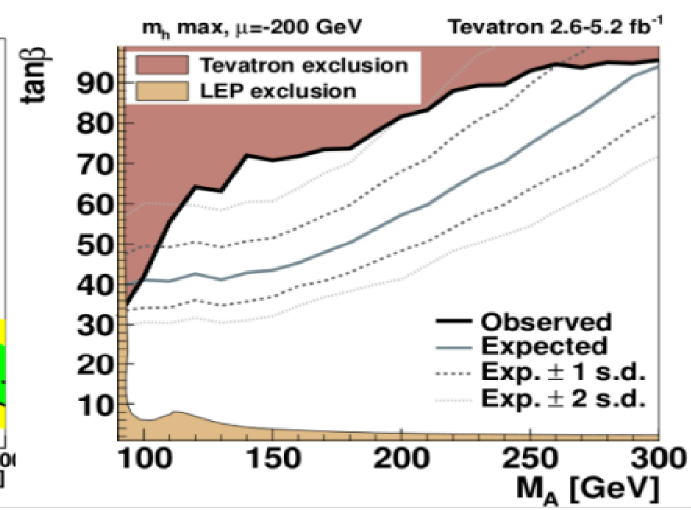




PLB 710, 569 (2012)

- Tevatron combination for bbb channel (accepted by PRD RC)

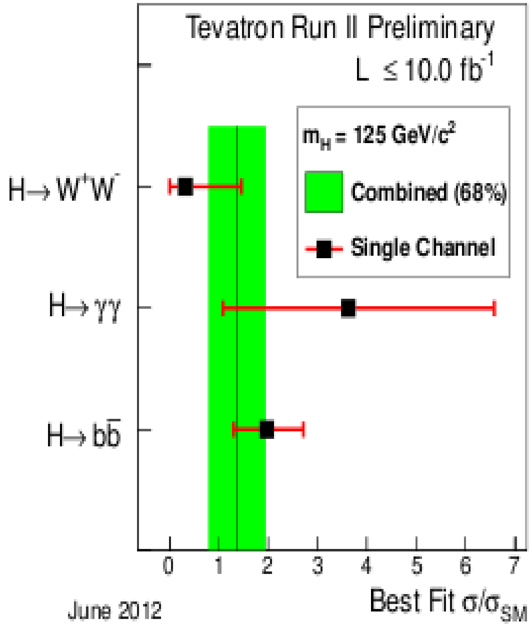
Intriguing excess @140 GeV (2.5σ local, 2σ with LEE)



# Conclusion

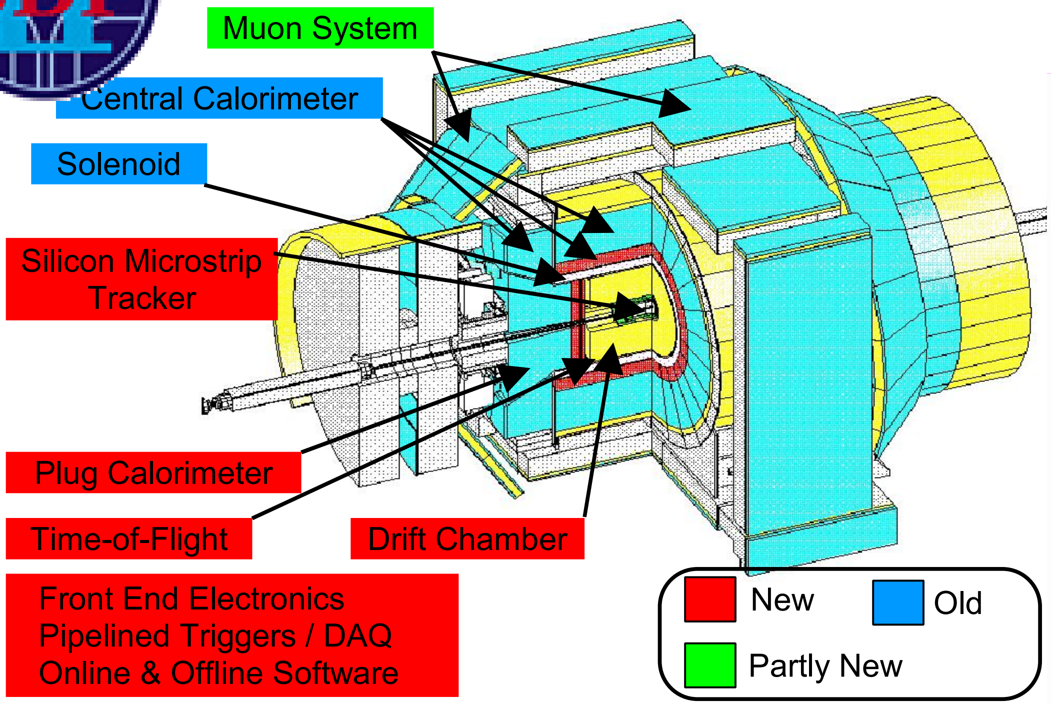
- Evidence for SM Higgs-like particle @125 GeV
  - Probing the bb coupling
  - We expect finalized publication of present results quite soon, with more sensitivity( O(5%) )
  - Further sensitivity O(20%) could be achieved with improvements
    - jet resolution, b-tagging, kinematical contraint to 125 GeV
    - But Tevatron man-power is leaking toward Switzerland

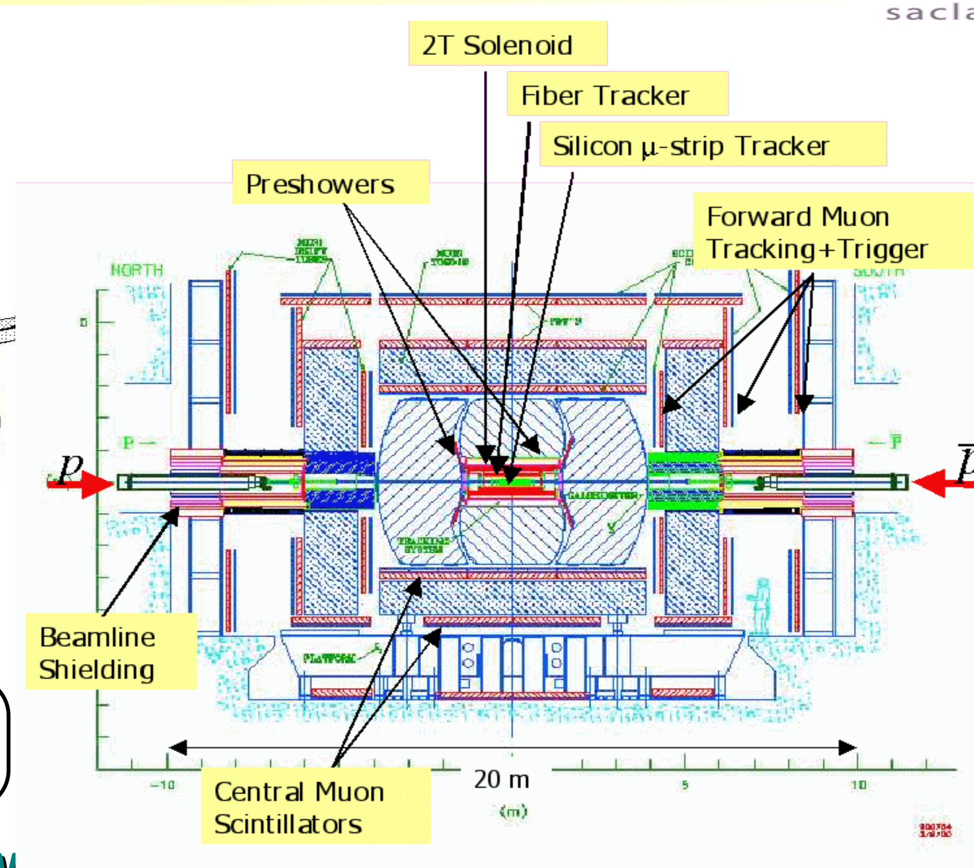



- MSSM at large tanβ
  - Explore down to tanβ~20
  - Could gain by combining D0+CDF bbb+tautau
  - Intriguing excess in bbb : will be worth to analyze full dataset
- Some other more exotic final states have been looked for
  - Fermiophobic, $4^{th}$ Generation
  - Not mentioned here
    - h → aa → μμμμ, μμττ
    - $H^+ \rightarrow W^+A$
    - $H^{++} \rightarrow$ ττ, μτ, μμ
- New ideas to probe signatures unique at ppbar colliders are also welcome

# Support slides

# Tevatron Experiments at RunII




## New
- silicon detector
- Drift chamber
- TOF PID system

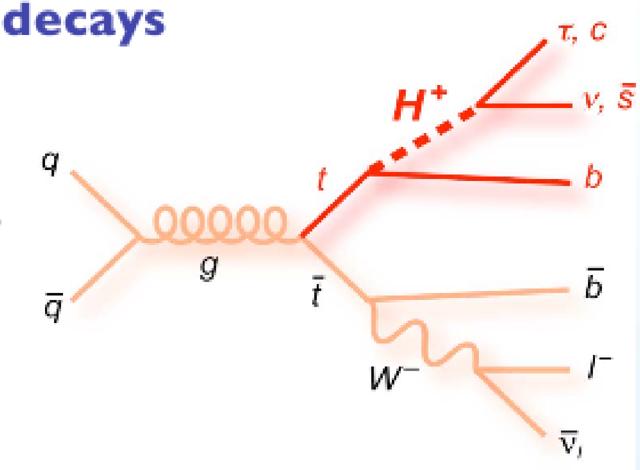
## Upgraded
- Calorimeter
- DAQ/trigger
- displaced-vertex trigger

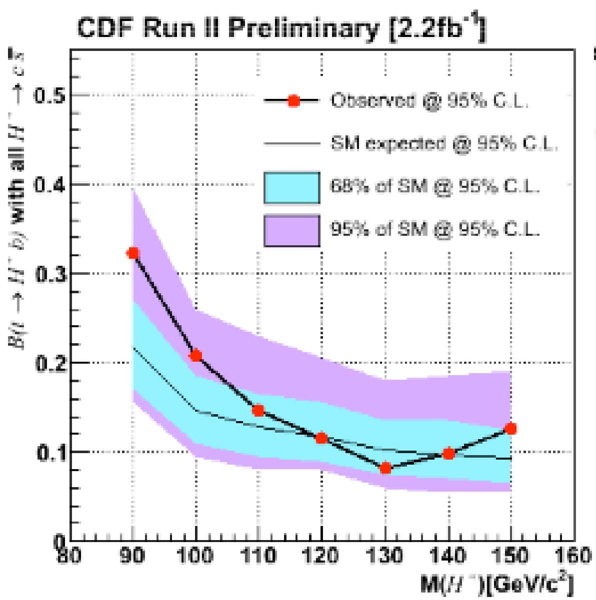
## New
- Tracking in B-field
- Silicon detector
- fiber tracker

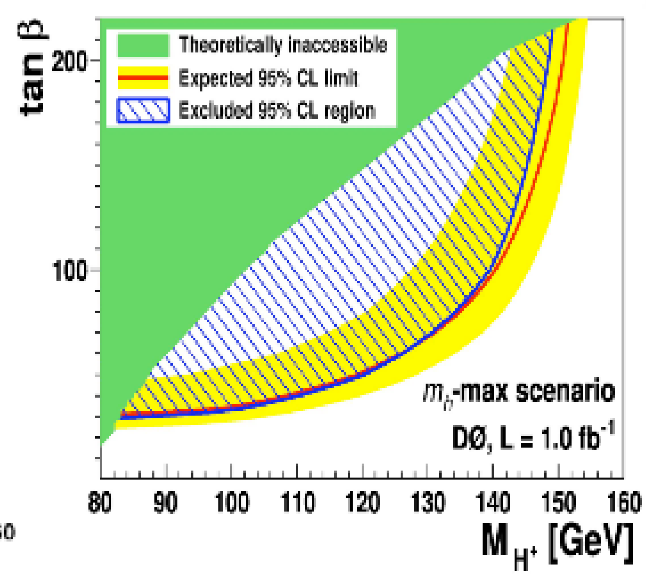
## Upgraded
- Calorimeter, muon system
- DAQ/trigger
- RunIIb: Silicon layer 0, Cal Trigger

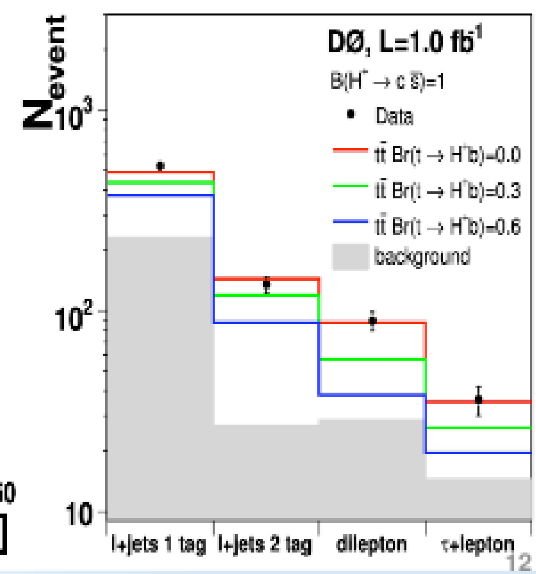
# Charged Higgs

- If $m_{H^\pm} < m_{top}$: search in top pair sample for decay to $H^\pm$
- Consider two search modes based on $H^\pm$ decays
  - Tauonic model: $H^\pm \to \tau\nu$ (high $\tan\beta$)
  - Leptophobic model: $H^\pm \to c\bar{s}$ (low $\tan\beta$)
- Search dilepton, $\ell$+jets, $\ell+\tau$ top channels
- Select high-$p_T$ leptons, $\not{E}_T$, and b-tag
- 95% CL limits on $BR(t \to H^+ b)$
  - DØ 1.0 fb$^{-1}$: PLB 682, 278 (2009)
  - CDF 2.2 fb$^{-1}$: PRL 103, 101803 (2009)



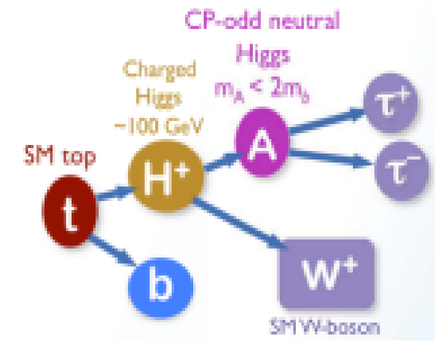



# Search for $H^+ \to W^+A(\to \tau\tau)$ @ CDF

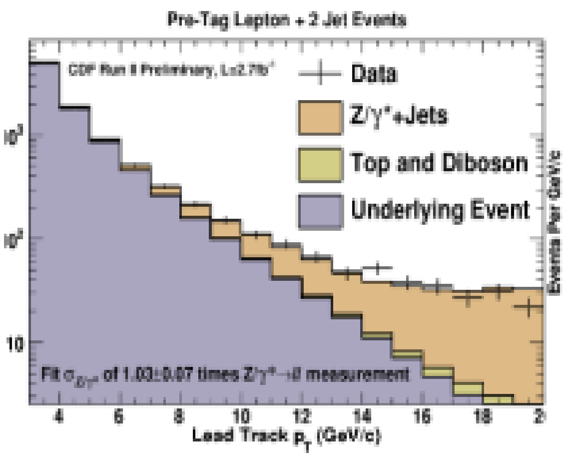
**Data sample :** 2.7 $\text{fb}^{-1}$ of analyzed data in the $\ell$+jets+low $p_T$ track final state

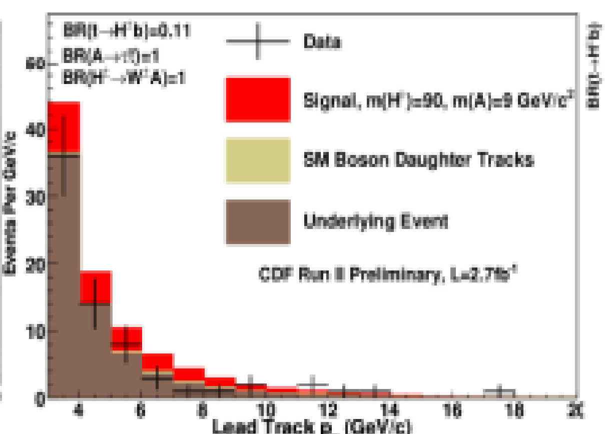
**Analysis overview :**

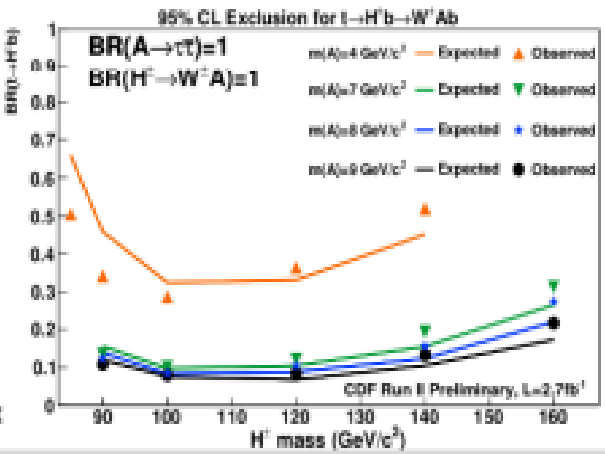
- Look at SM deviation in $t\bar{t}$ events
- $\tau$'s very softs : easily lost in usual $t\bar{t}$ decay
- look at highest low $p_T$ track ($p_T < 20$ GeV)
- Challenging : modeling of MJ with heavy flavour and MB ("Underlying Event")
- Bkg modeling validation : $\sigma_{Z\to\ell\ell}$ measurement




First look at this phase space region !



# Search for $H^{++}$ @ DØ

**New : published in PRL !**

*Phys. Rev. Lett. 108, 021801 (2012)*

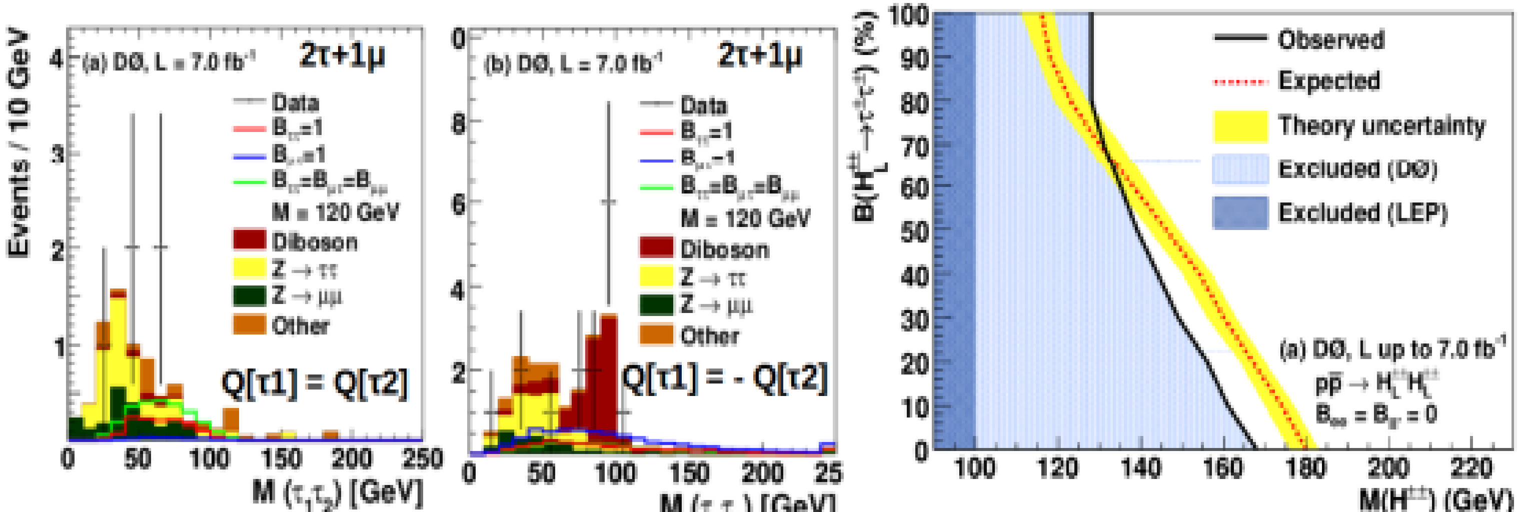
**Motivations :** doubly charged Higgs are predicted by :

- models with larger gauge symmetry, like $SU(3)_c \otimes SU(3)_L \otimes U(1)_Y$.
- Seesaw mechanism giving mass to neutrinos (with Higgs triplets).

**Data sample :** 7.3 $\text{fb}^{-1}$ of analyzed data with at least 1 muon and at least 2 $\tau$

**Analysis overview :**

- Production of doubly charged Higgs : $q\bar{q} \rightarrow H^{++}H^{--}$
- Decay : $H^{++} \rightarrow \tau\tau, \mu\tau, \mu\mu$ (given by $m_\nu$ hierarchy),
- Splitting events according $\tau$ and $\mu$ multiplicity,



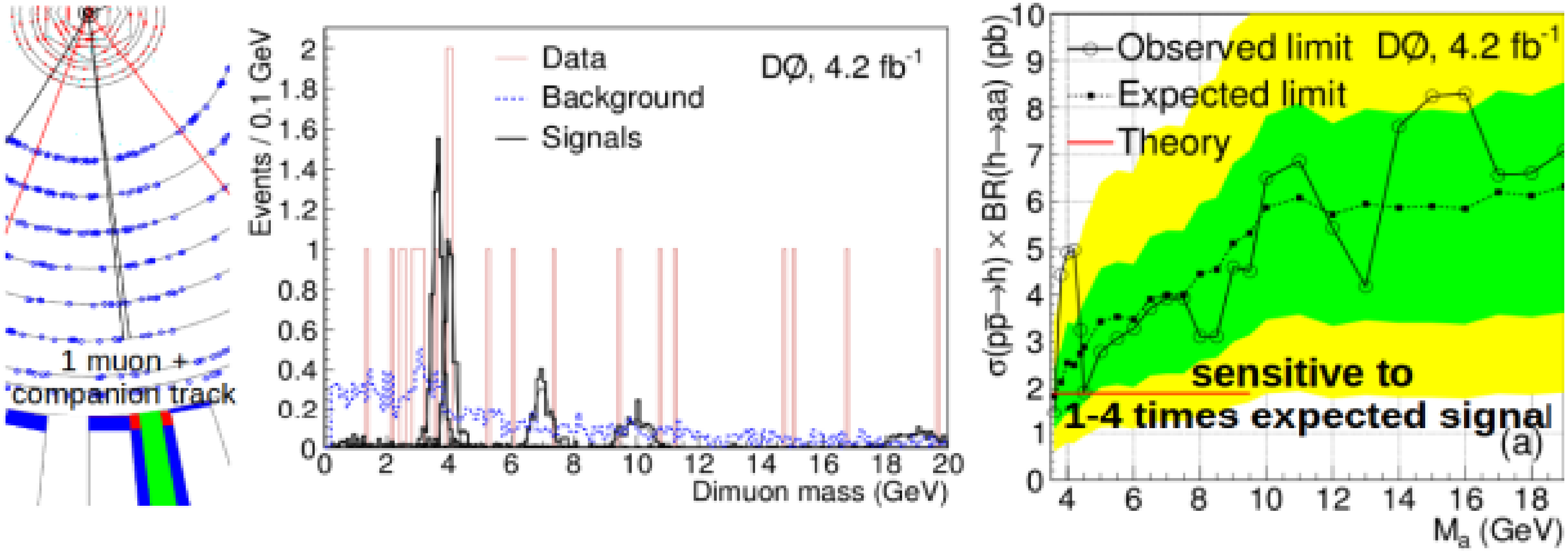
# Search for $h \to aa$ @ DØ

*Phys. Rev. Lett. 103, 061801*

**Data sample :** $4.2\ \mathrm{fb}^{-1}$ of data analyzed in the $\mu\mu\mu\mu$ and $\mu\mu + \not{E}_T$ final state.

**Analysis overview :**

- $aa \to \mu\mu\mu\mu$ : select 2 extreamly colinear muon pairs,
- $aa \to \mu\mu\tau\tau$ : select 1 colinear muon pair + $\not{E}_T$ (from colinear $\tau$'s),
- For one pair : reconstruct only one muon and associate a "companion track" (due to the muon chamber granularity)
- Main background : MJ with heavy hadrons decaying into muon.




Romain Madar (Freiburg Universität) Higgs Hunting 2012

# MSSM Benchmark

- 2 parameters, ($M_A$, tan(β)) to describe SUSY Higgs sector at Leading Order
- hbb vertex receive large corrections from sbottom-gluino and stop-higgsino loop

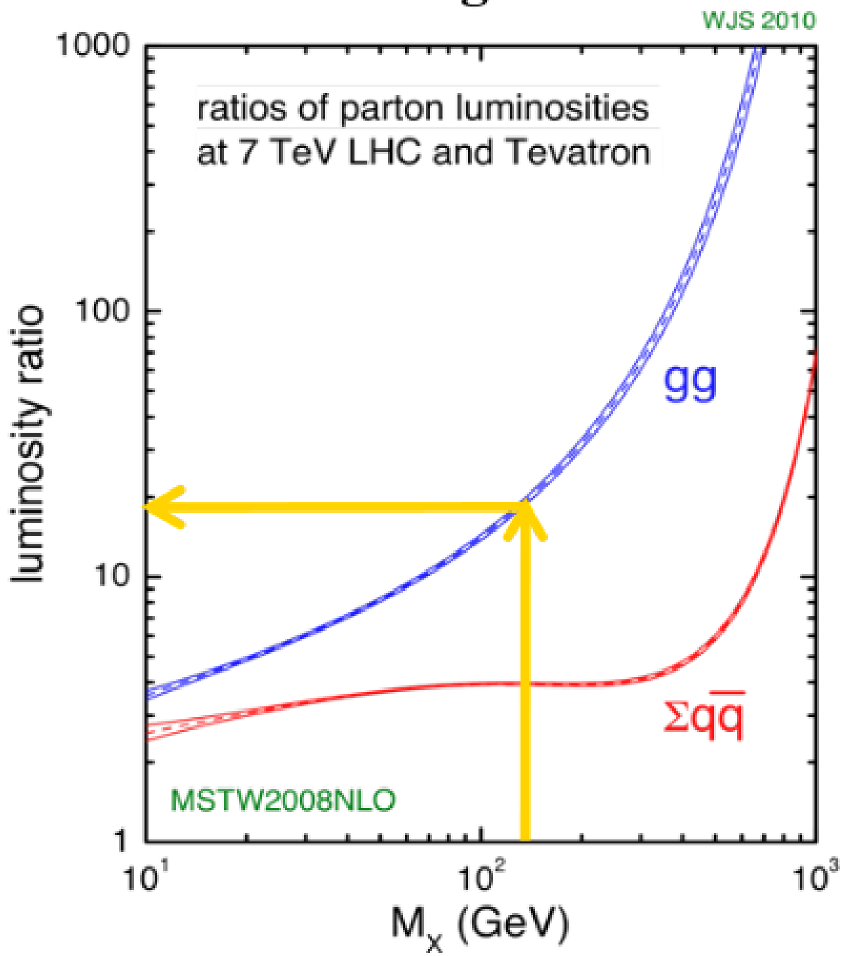
- Five additional parameters due to radiative correction
  - $M_{SUSY}$ (parameterizes squark, gaugino masses)
  - $X_t$ (related to the trilinear coupling $A_t \rightarrow$ stop mixing)
  - $M_2$ (gaugino mass term)
  - $\mu$ (Higgs mass parameter)
  - $M_{gluino}$ (comes in via loops)

- Two common benchmarks
  - Max-mixing - **Higgs boson mass $m_h$ close to max possible value for a given tanβ**
  - No-mixing - **vanishing mixing in stop sector → small mass for h**

| | $m_h$-max | no-mixing |
|---|---|---|
| $M_{SUSY}$ | 1 TeV | 2 TeV |
| $X_t$ | 2 TeV | 0 |
| $M_2$ | 200 GeV | 200 GeV |
| $\mu$ | ±200 GeV | ±200 GeV |
| $m_g$ | 800 GeV | 1600 GeV |

# LHC & Tevatron Compared (I)

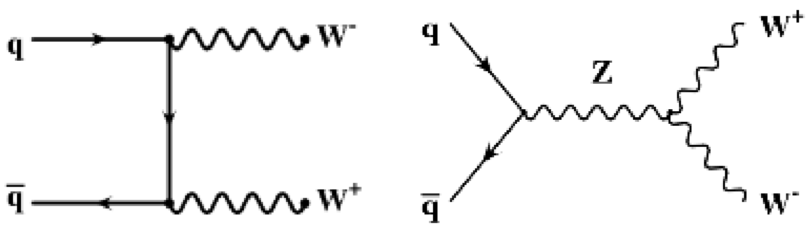
Stirling *et al*




**For $M_X$ > 140 GeV**

gg → H cross section at 7 TeV is >15 times that at 2 TeV

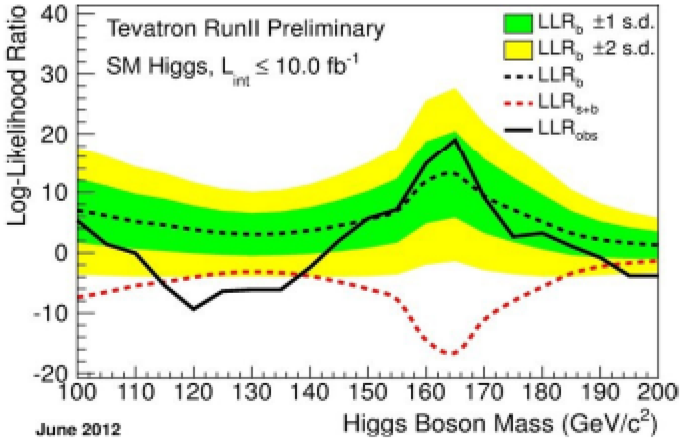
Irreducible backgrounds (WW,ZZ) originate from $q\bar{q}$ process which rises relative slowly ( $pp$ vs $p\bar{p}$ )



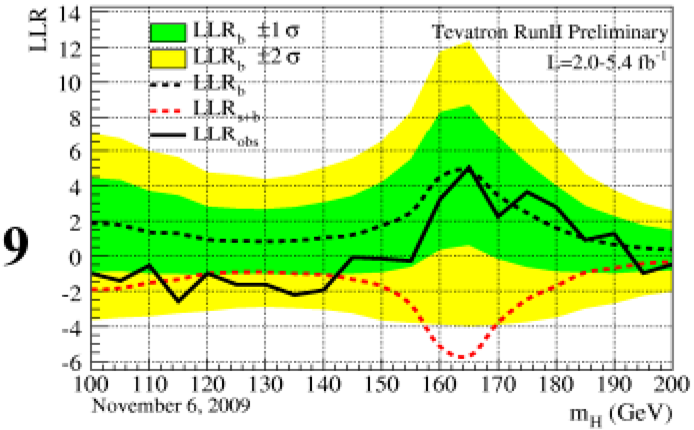

⇒ Larger signal, better S/N

3

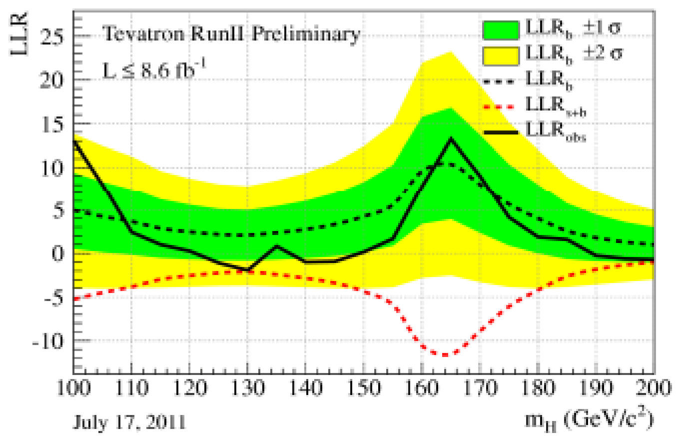
# Historical Look at Tevatron Higgs Combination



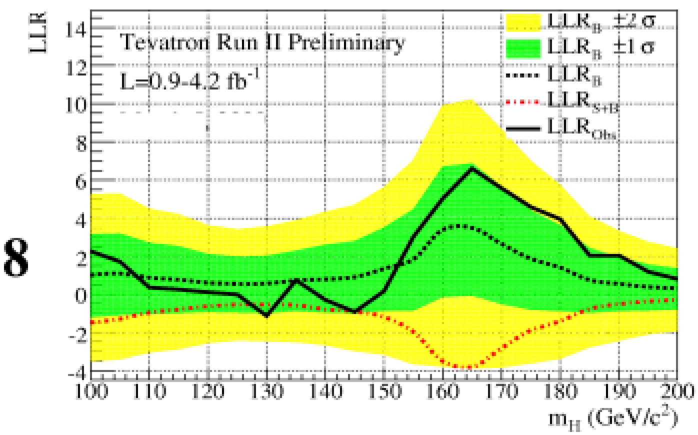

2012



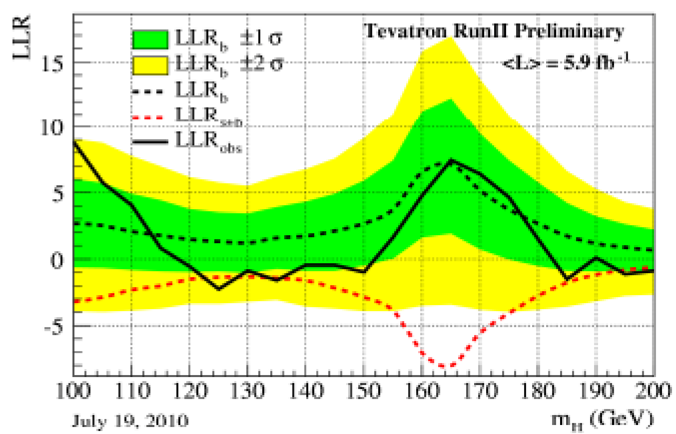

2009



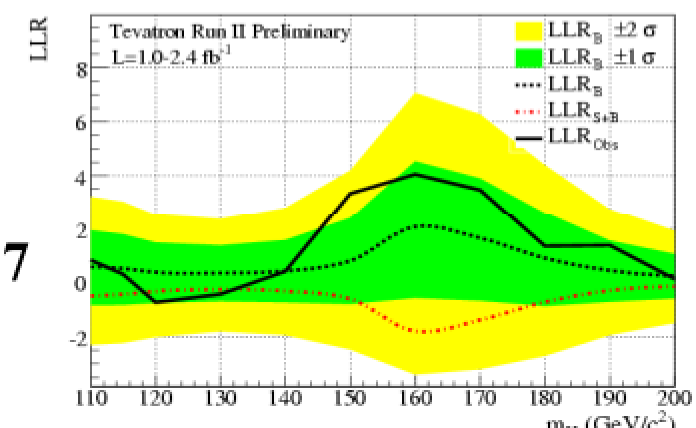

2011



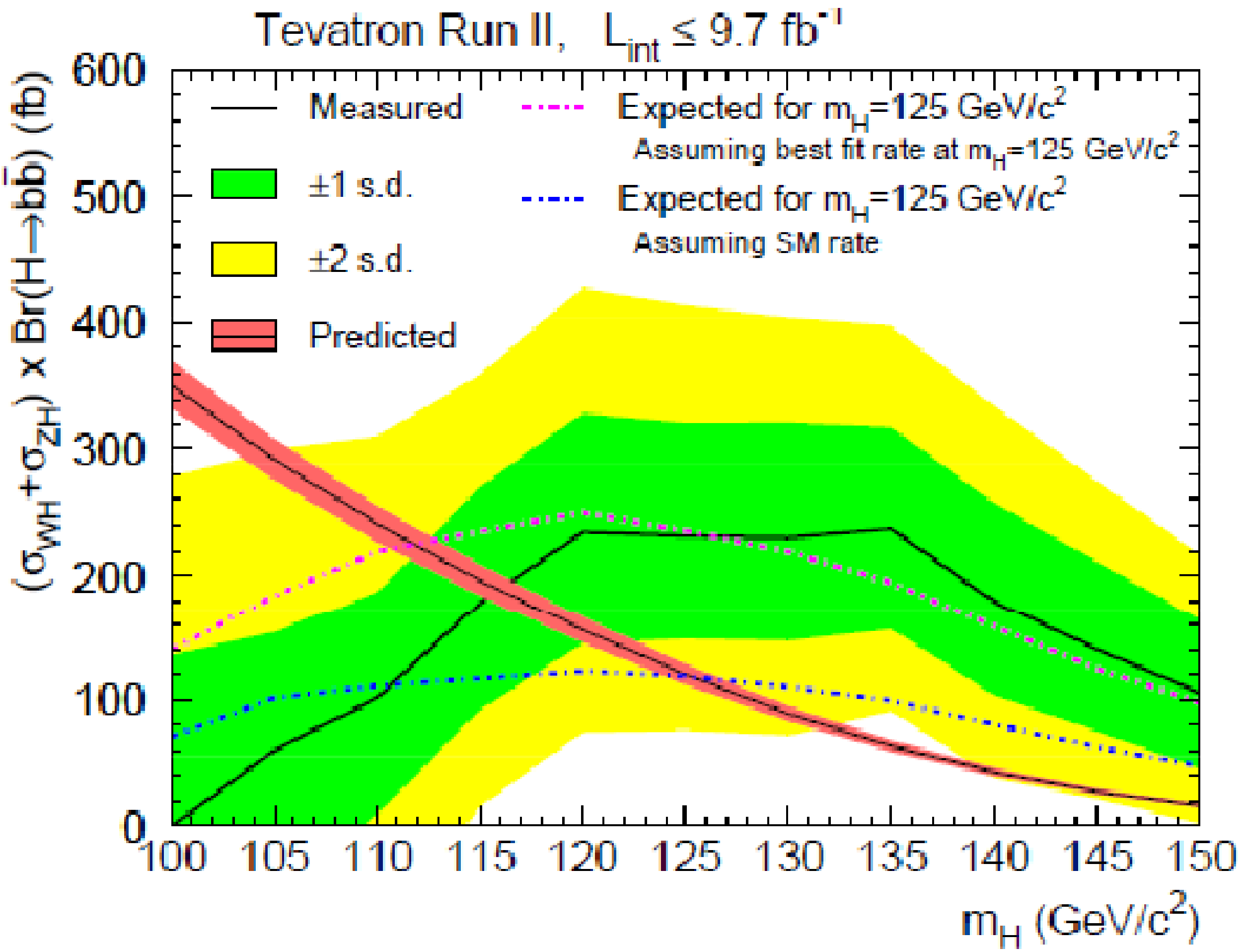

2008




2010




2007




$$(\sigma_{WH} + \sigma_{ZH}) \times \mathcal{B}(H \rightarrow b\bar{b}) = 0.23^{+0.09}_{-0.08}\ (\mathrm{stat} + \mathrm{syst})\ \mathrm{pb}$$

SM Higgs @ 125 GeV: $0.12 \pm 0.01$ pb

# $H \rightarrow \gamma\gamma$

- Modeling improvements
  - Rapidity dependent photon energy sca
  - $O_{NN}$ epoch dependent correction
- Sensitivity improvements
  - Revertexing with CPS pointing
  - Split into categories
    - (NN<0.75, NN>0.75)x (in mass window, out mass window)
- Gain at the level of ~25%@125 GeV