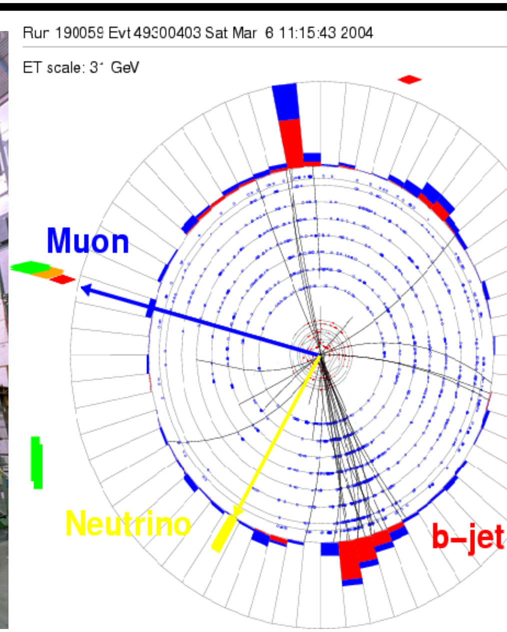
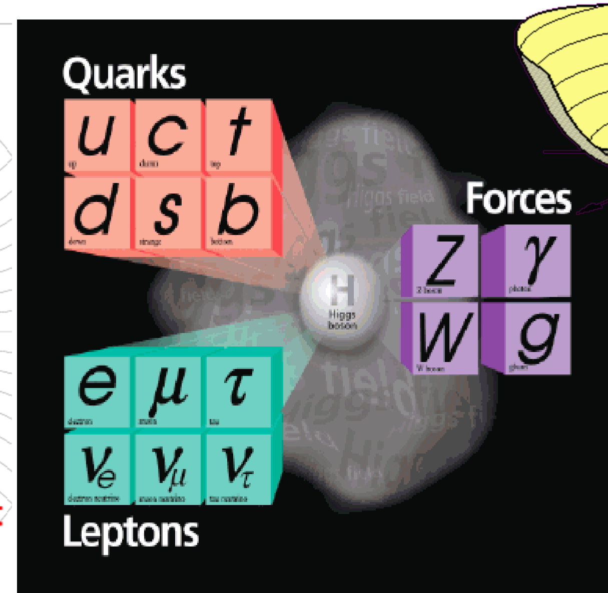
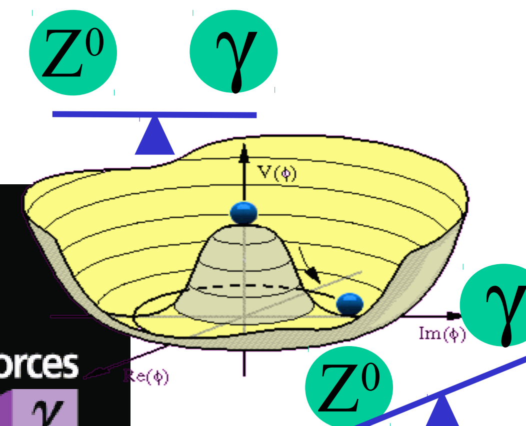
# Search for Higgs bosons at Tevatron

Boris Tuchming – Irfu/Spp CEA Saclay

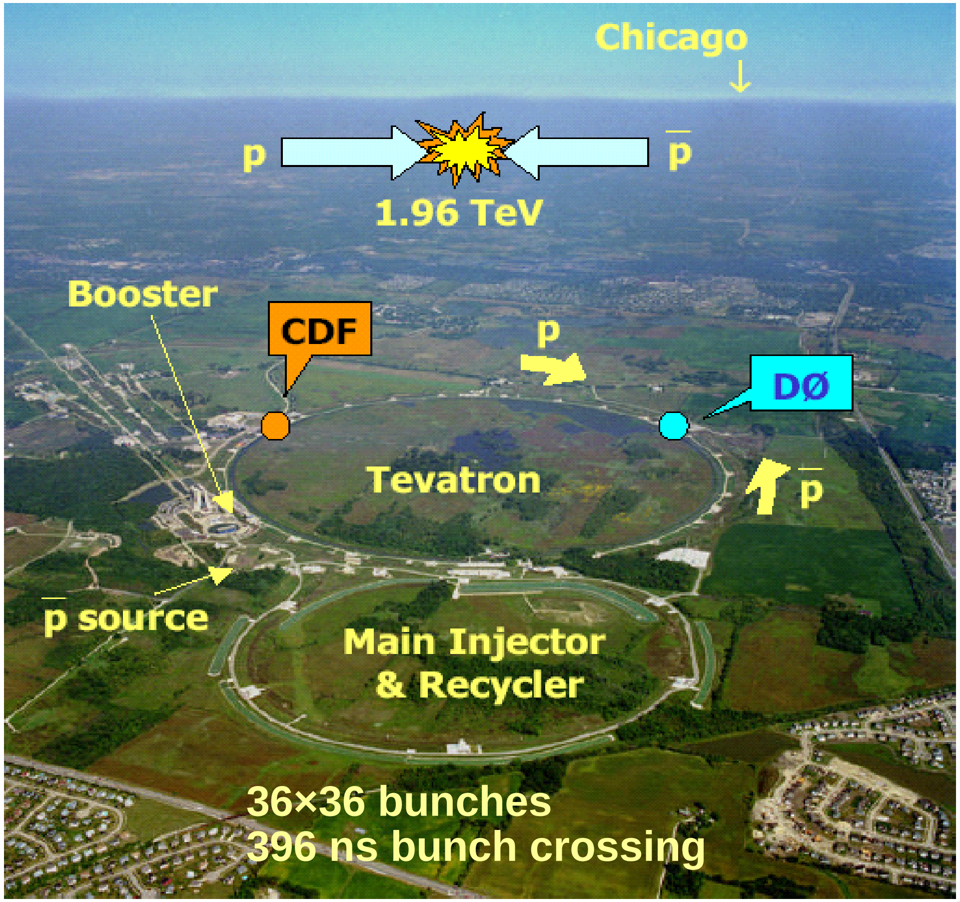
Outline :
- SM Higgs
  - channels
  - techniques
  - results
- selected Beyond SM



# The Tevatron proton-antiproton collider

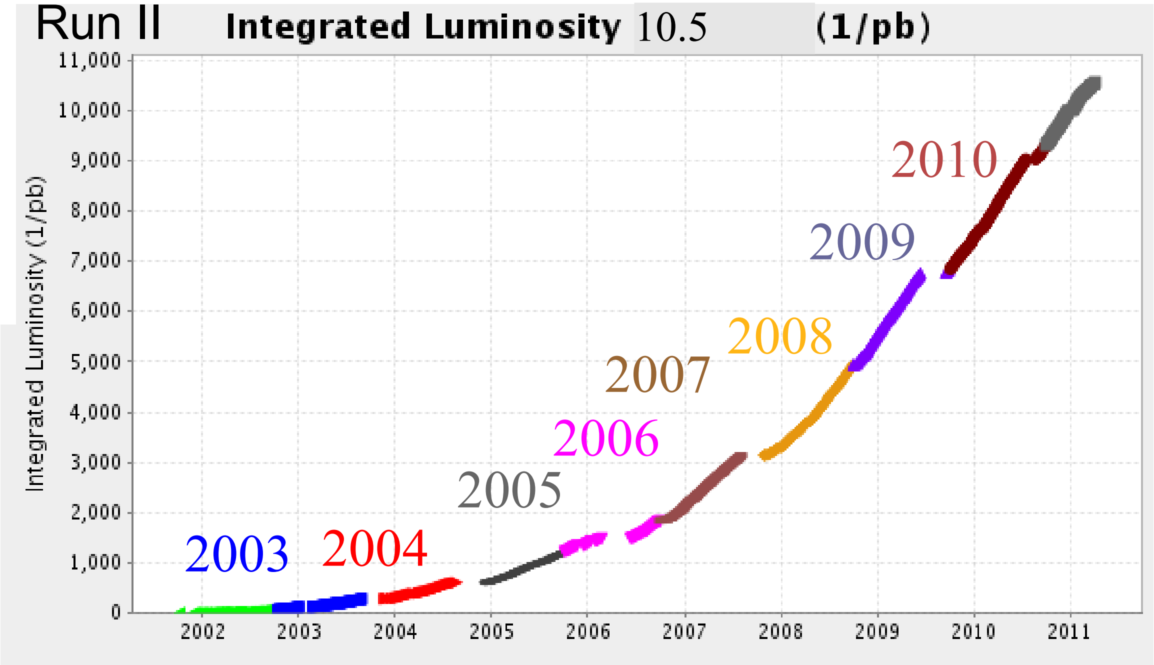



Run I (1993-1996)

~120 $pb^{-1}$ per experiment-top quark discovery

Run II: (2002-2011)

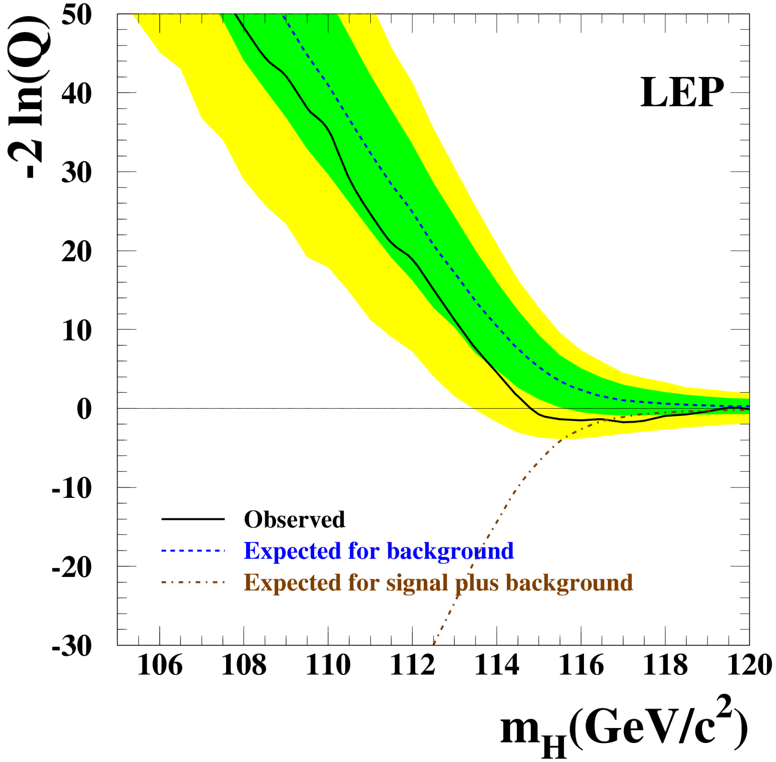
- Tevatron now delivers >2 $fb^{-1}$ per year
- Tevatron shutdown forseen in 2011
- ~10 $fb^{-1}$ delivered per experiment

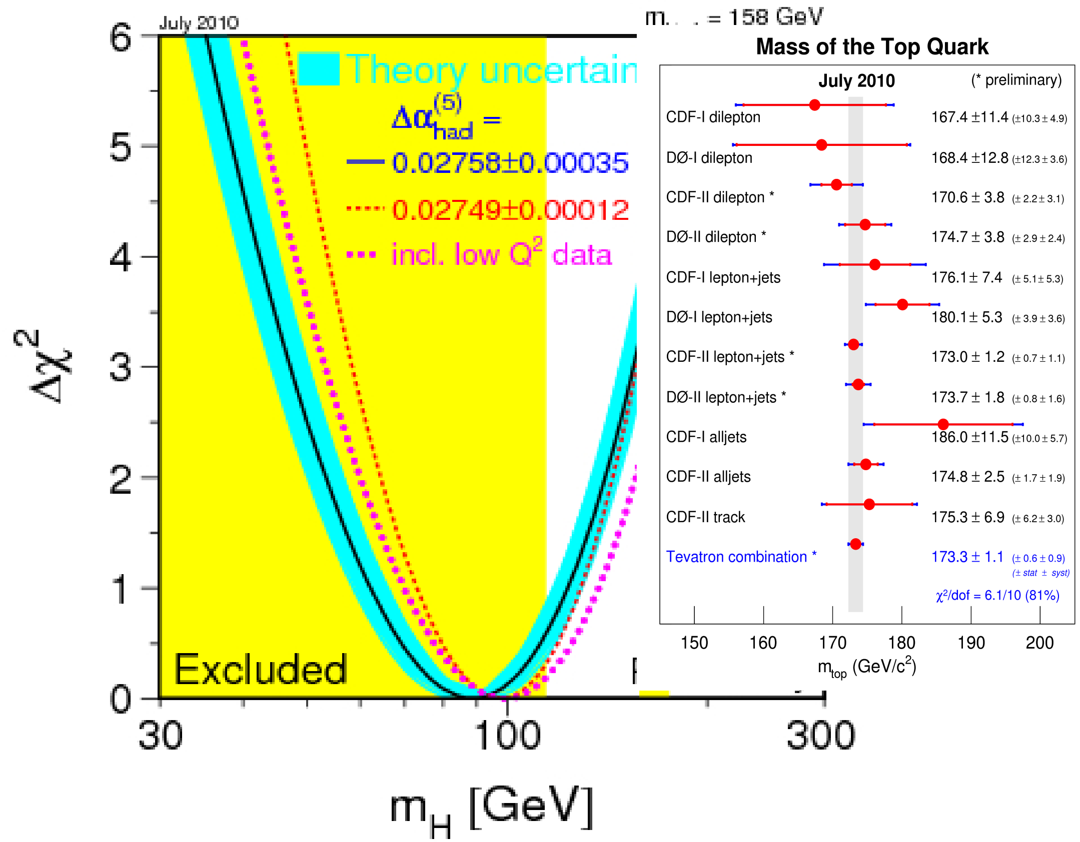



Most of the Higgs results use so far: 5-8 $fb^{-1}$

# Direct and indirect constraints

## Direct constraints from LEP    Indirect (contributions from Tevatron)




$$M_H = 89^{+35}_{-26} GeV$$

$M_H$ > 114.4 GeV @95%

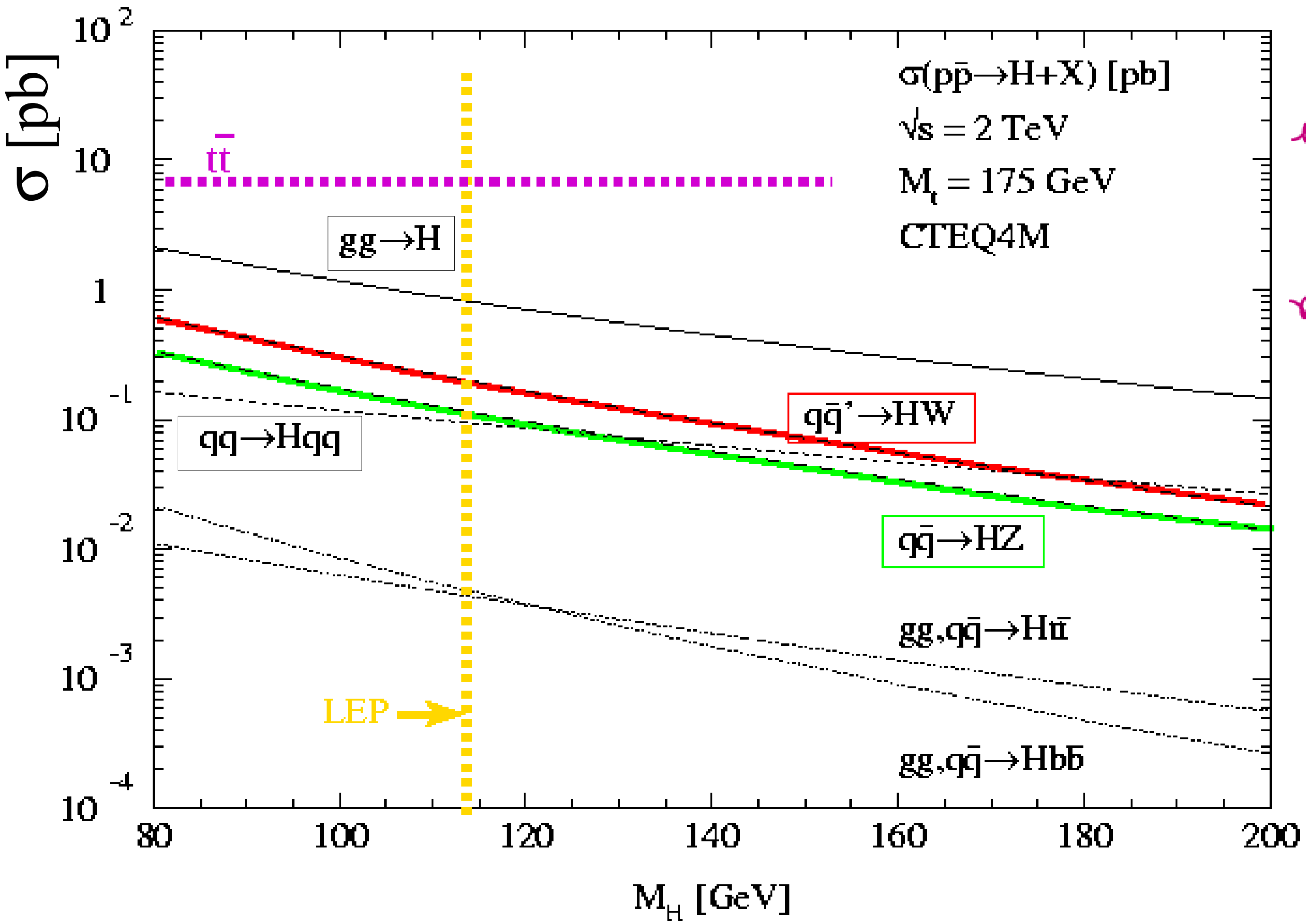
$M_H$ < 185 GeV @95%

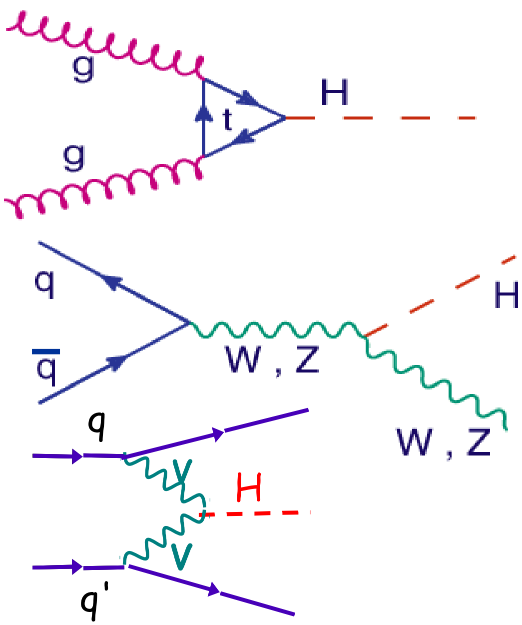
Light mass Higgs is favoured: region accessible to Tevatron

# Higgs production at the Tevatron

## Production cross section (for 115< $m_H$<180 GeV)

- in the 1200-300 fb range for gluon fusion gg → H
- In the 200-30 fb range for WH associated vector boson production
- In the 80-30 fb range for the vector boson fusion qq → Hqq

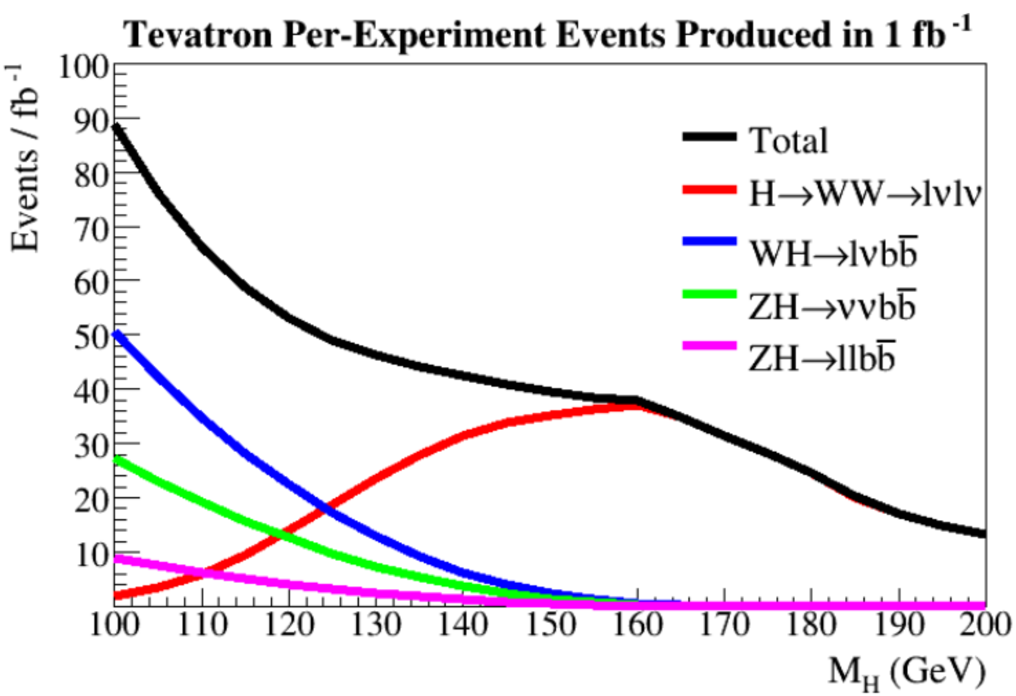


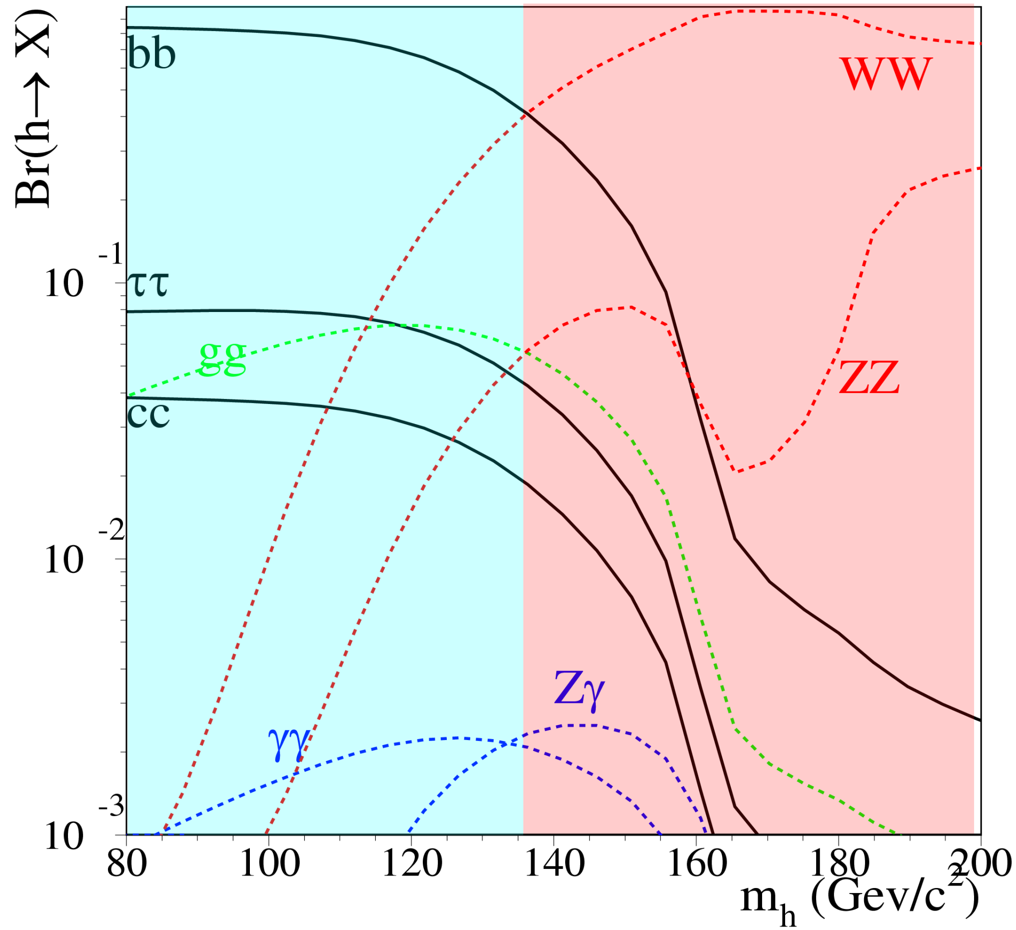



# Low Mass vs High Mass

- Decay modes depend on the Standard Model Higgs mass

- At high mass :
  - Look for W decay products
  - Peak sensitivity just above threshold $M_H$~165 GeV.




$m_H$<135 GeV

H → bb

H → ττ

$m_H$>135 GeV

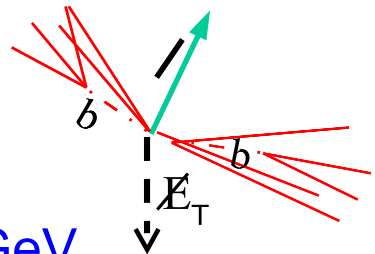
H → WW*

# Main channels at the Tevatron

For $M_H$ < 130 GeV

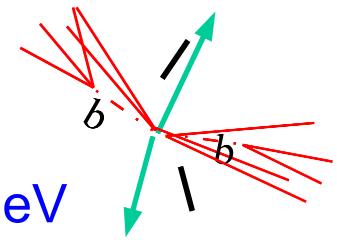
pp → WH → Wbb

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

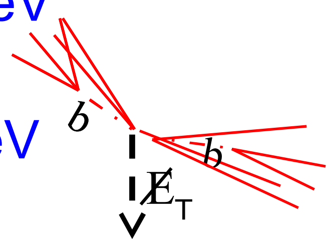



pp→ ZH → Zbb

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

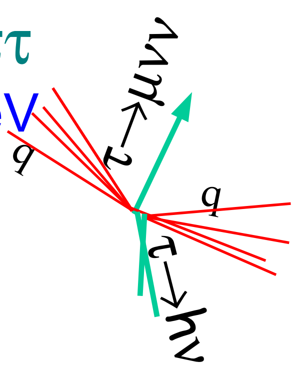



- νν bb:
  - 2 b-jets ~ 50 GeV
  - $\not{E}_T$ ~ 50 GeV




pp →H+ Z/V/X → jj ττ

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

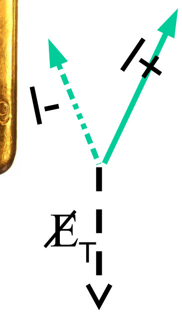



NB: Xsec normalized to NNLO

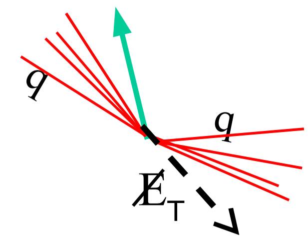
For $M_H$ > 130 GeV


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

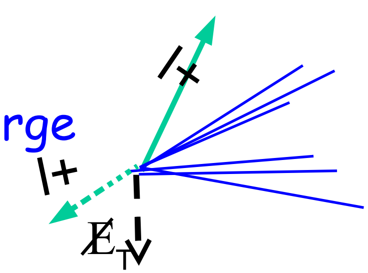



pp → WH→WWW*

ee+jj+νν, eμ+jj+νν, μμ+jj+νν

$\not{E}_T$ ~ 40 GeV

2 leptons of same charge

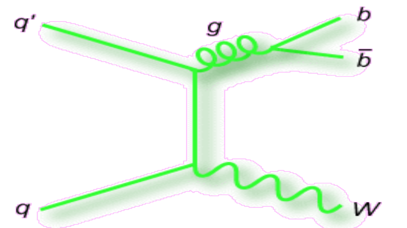



NB: Xsec normalized to NNLO+NNLL

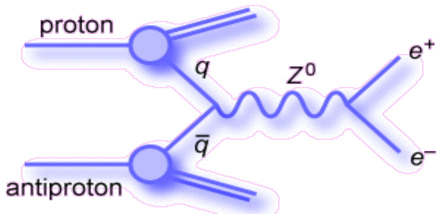
# Backgrounds to Higgs Searches



- W+jets

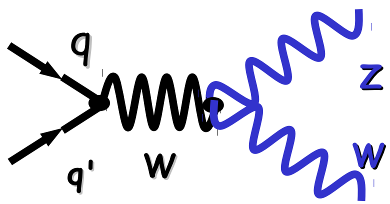



- Z/γ

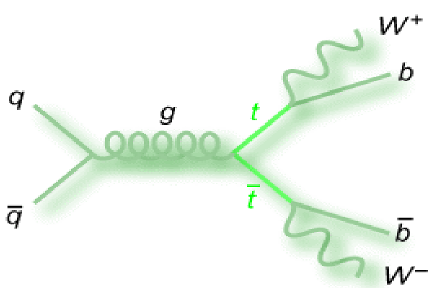



- WW

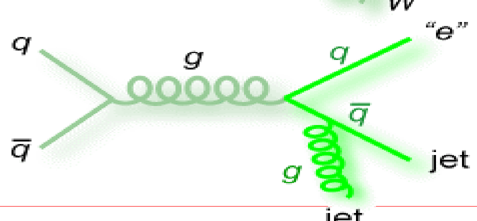

- WZ




- Top



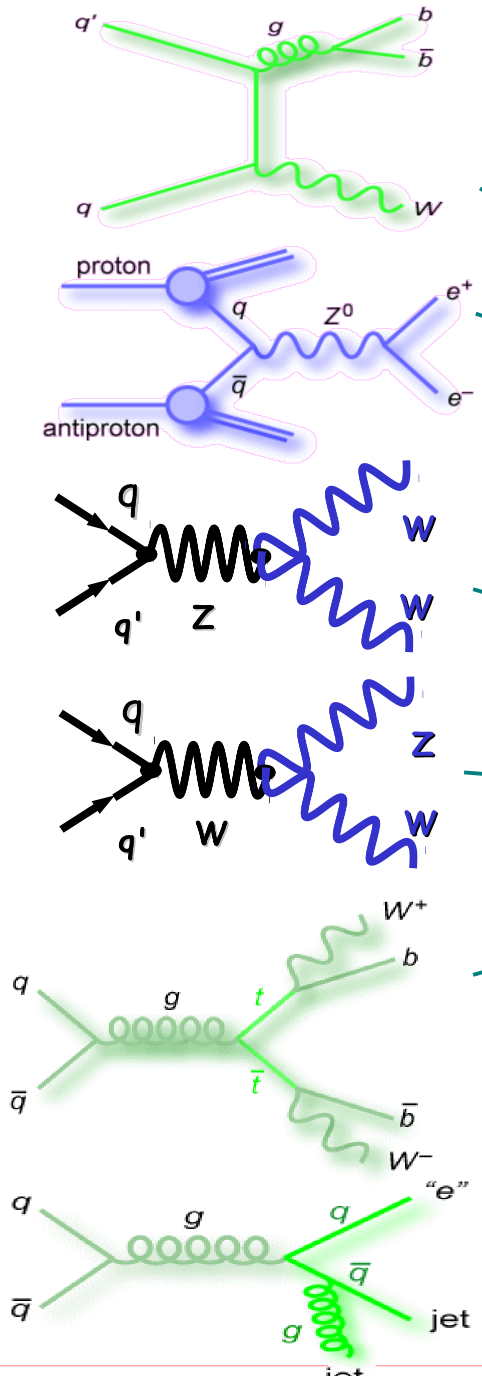

- multijet

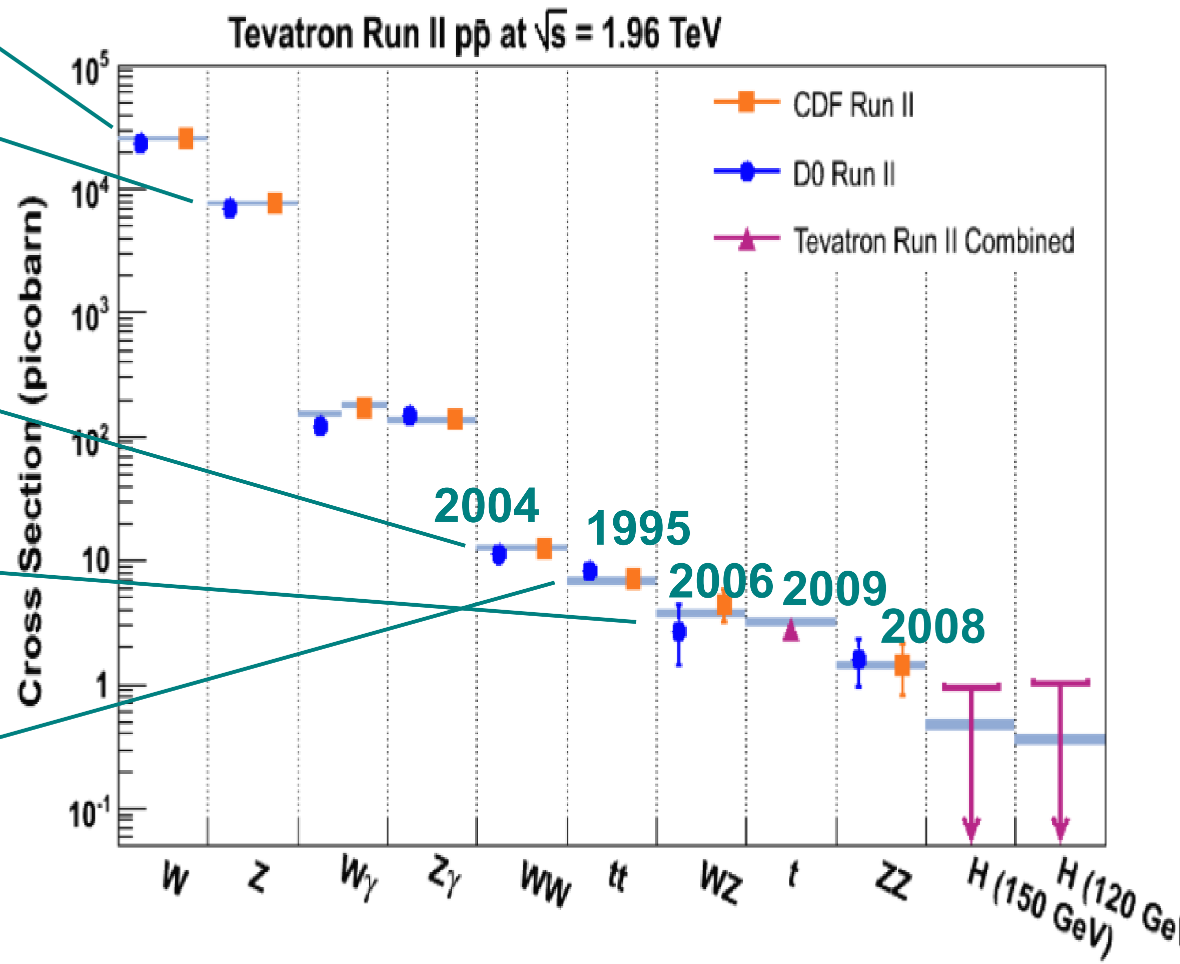



- W+jets, Z/γ +jets
  - Alpgen MC+ pythia showering, NNLO cross-sections, data-based corrections to model $p_T(W)$,$p_T(Z)$
  - background for all channels:
    - jets faking lepton
    - mismeasured jets or leptons MET
    - W+bb, Z+bb final states (mimic ZH, WH)
- Di-boson WW, WZ, ZZ
  - NLO calculation for cross-sections
  - for WW: NLO correction for $p_T$ and di-lepton opening angle
- Top pair and single top
  - cross-section normalized at NNLO
- QCD multijet events
  - jets faking leptons
  - mismeasured jets creating MET

# Backgrounds to Higgs Searches

- W+jets
- Z/γ
- WW
- WZ
- Top
- multijet

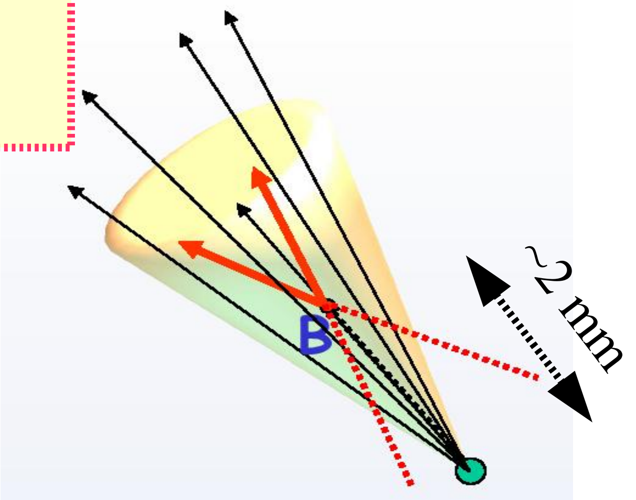


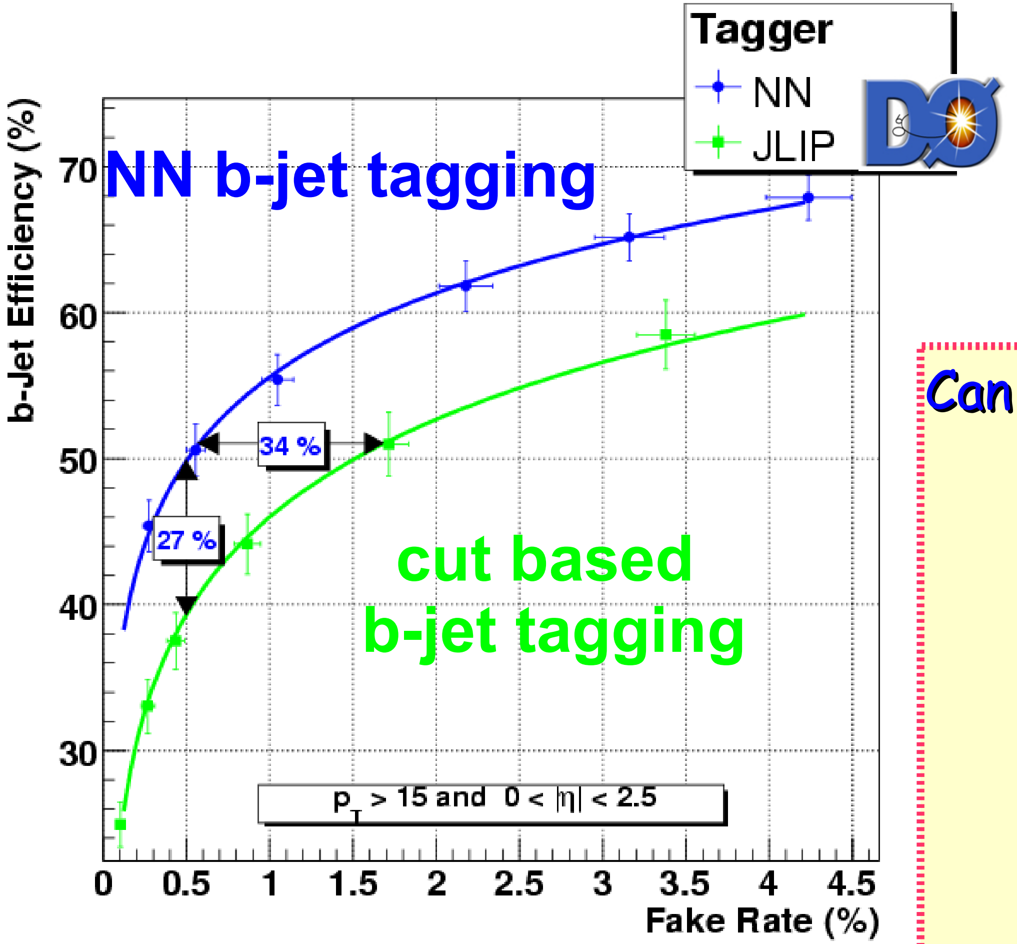




The Higgs signal is several order of magnitude below backgrounds

# 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:

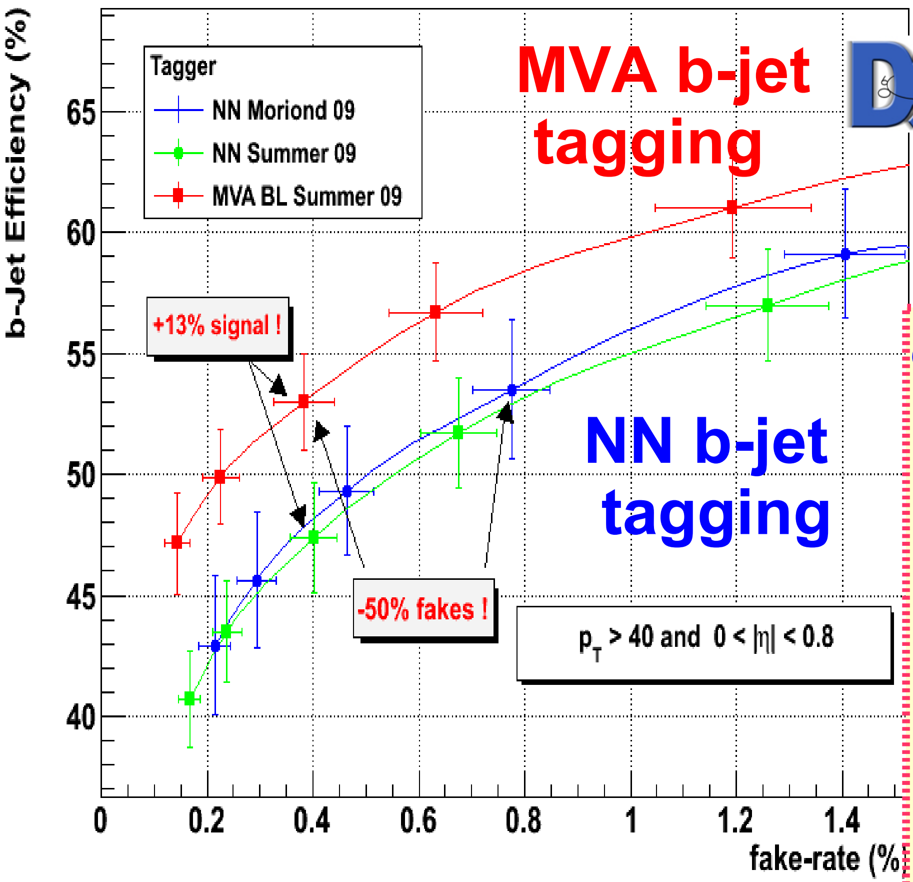
- High impact parameter of tracks
  ==> light quark Jet Probability
- Secondary vertex reconstruction (SVX)
- Lepton tag
- b-jet kinematics (large B-hadron mass)
- Combination of above with multivariate techniques (eg Neural Network)

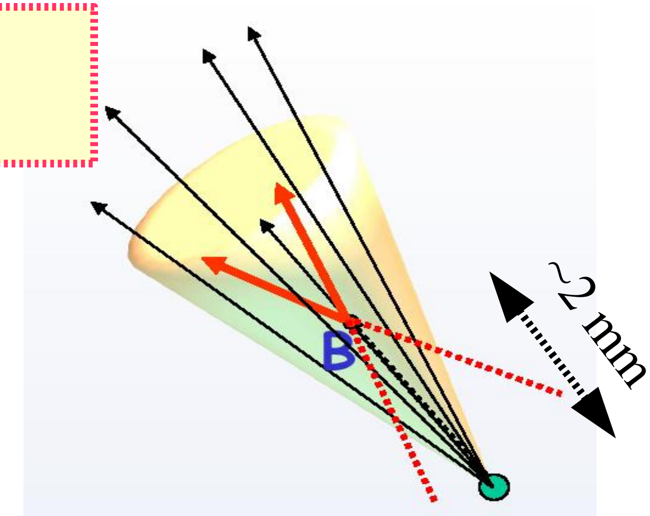
Eg: CDF 2nd vtx tag ε=50% for 2% mis-tag at η<1
Eg: D0 NN (2006) ε=60% for 1.5% mis-tag Pt=50 GeV (loose tag)

# Improving acceptance with better b-tagging

B-hadrons are long lived particles: $c\tau \sim 0.5$ mm.

B-hadrons can decay semi-leptonically: $b \to \mu\nu c$




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 $\varepsilon=50\%$ for 2% mis-tag at $\eta<1$

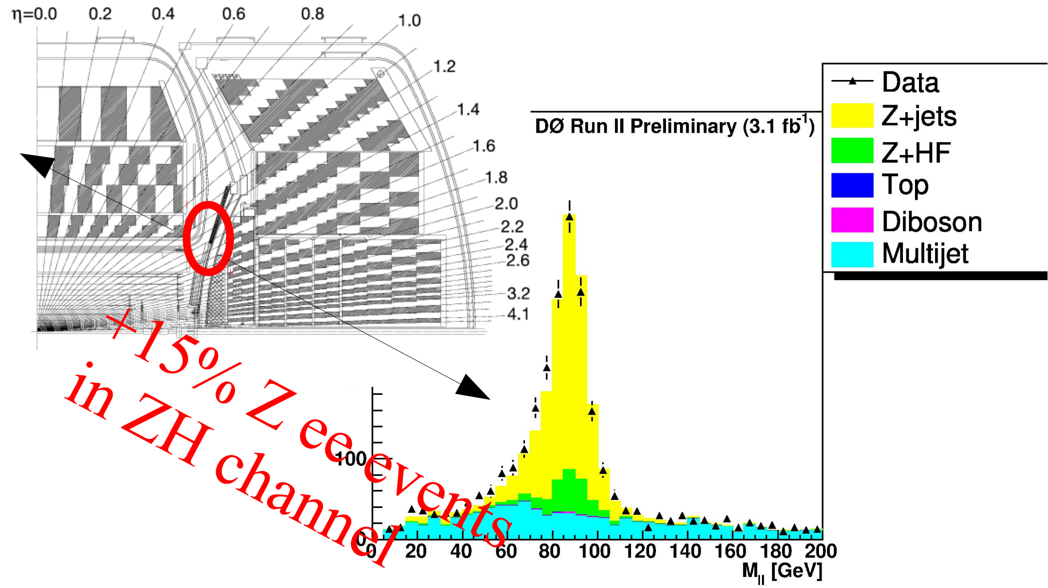
Eg: D0 NN (2006) $\varepsilon=60\%$ for 1.5% mis-tag Pt=50 GeV (loose tag)

D0 MVA (2009) $\varepsilon=60\%$ for 1% mis-tag Pt=50 GeV

# Increasing number of Higgs candidate events

Increase in lepton acceptance

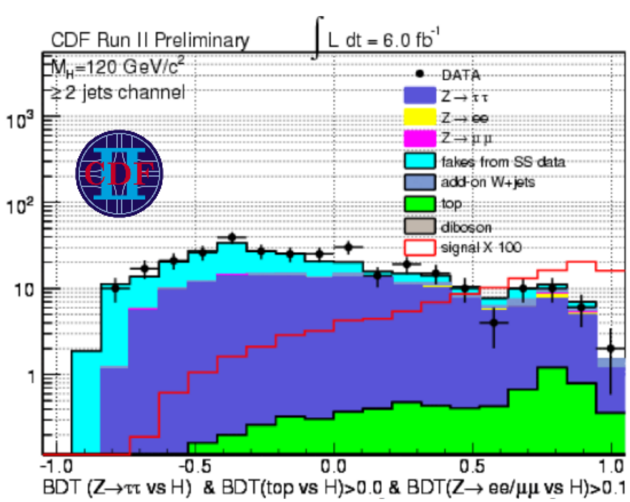
- D0
  - electrons in intercriostat region
  - isolated tracks without muon identification
- CDF
  - plug (forward) electrons
  - muon chamber extensions
  - Inclusive triggering

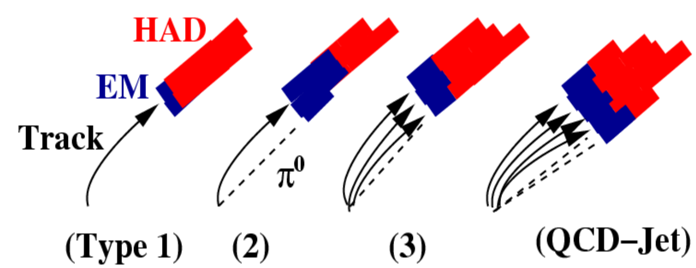



Add low sensitivity channels

- Channels with τ, ttH, H → γγ,

ττ+jets



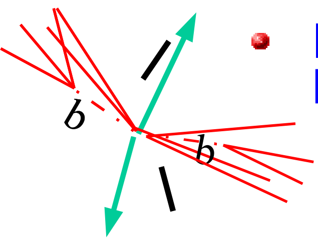



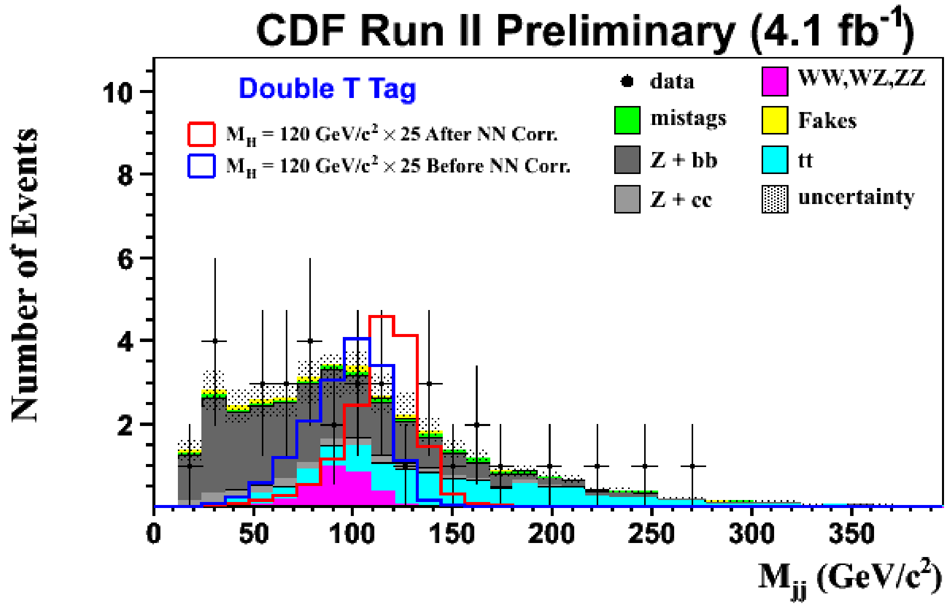

hadronic taus perfomances:

| NN cut effi | Th 1 | Th 2 | Th 3 |
|---|---|---|---|
| jets | 3 % | 2.5 % | 2.5 % |
| τ | 60 % | 75 % | 65 % |

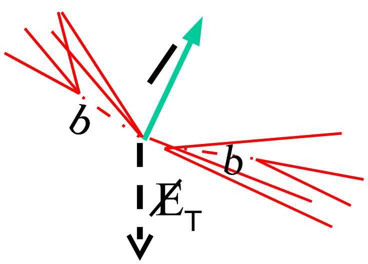
# Jet energy resolution

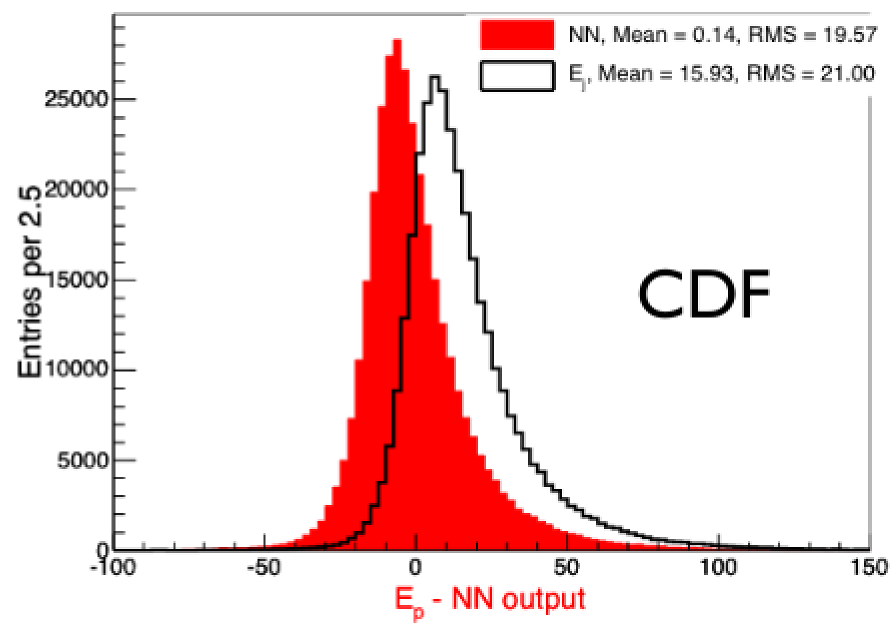
- ZH $\rightarrow$ ll bb :
  - $\not{E}_T$ ~0 as kinematical constraint
  - Improve dijet mass resolution at D0 and CDF



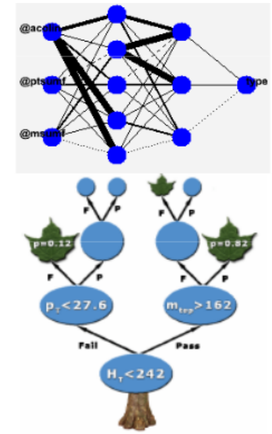

- WH $\rightarrow$ lν bb
  - Kinematics variable of (b) jets to bring energy closer to the initial parton energy
  - Gain of ~ 20-25% in relative resolution



# Multivariate techniques

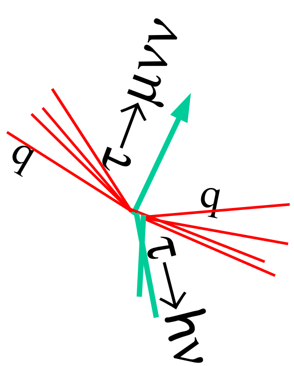
- Extended use of :
  - Artificial Neural Network (NN)
  - Boosted Decision Tree (BDT)
    - Easier and faster to train
  - Matrix Element (ME)
    - computer intensive



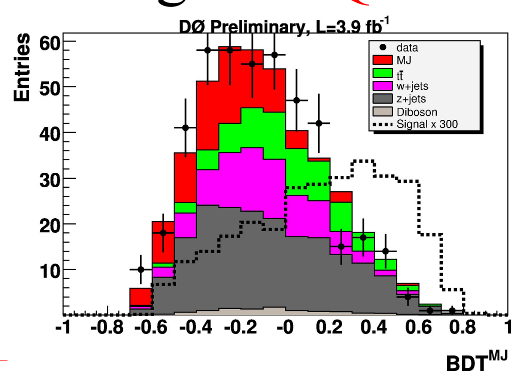
**Major Inputs at low mass:**
- Dijet mass
- $p_T$ of dijet
- W $p_T$ Z $p_T$
- Sphericity
- $\Delta R_{jj}$ , $\Delta\phi_{jj}$, $\Delta\eta_{jj}$

$$P_{WH}(x) = \frac{1}{\sigma}\underbrace{\sum_{i,j}}_{\text{Flavor}}\int_y \underbrace{f_i(q_1)f_j(q_2)}_{\text{PDF}} \times \underbrace{\frac{d\sigma_{WH}}{dy}}_{\text{ME}} \times \underbrace{W(x,y)}_{\text{Detector Responce}}$$

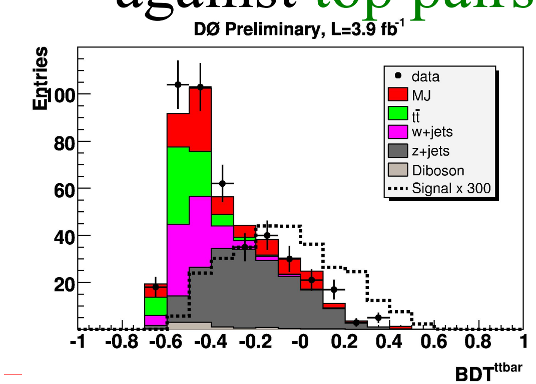
- Can be used several times per analysis:
  - Eg signal ME as inputs to BDT
  - Eg 3 BDT trained specifically against 3 kind of background



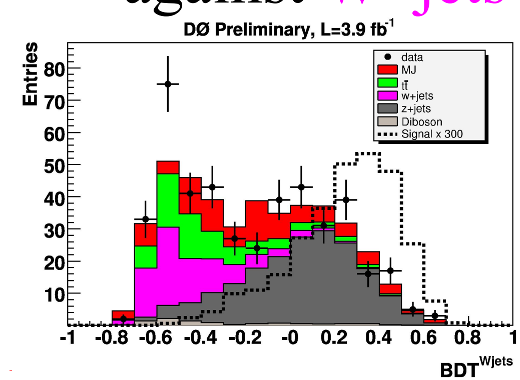

against QCD



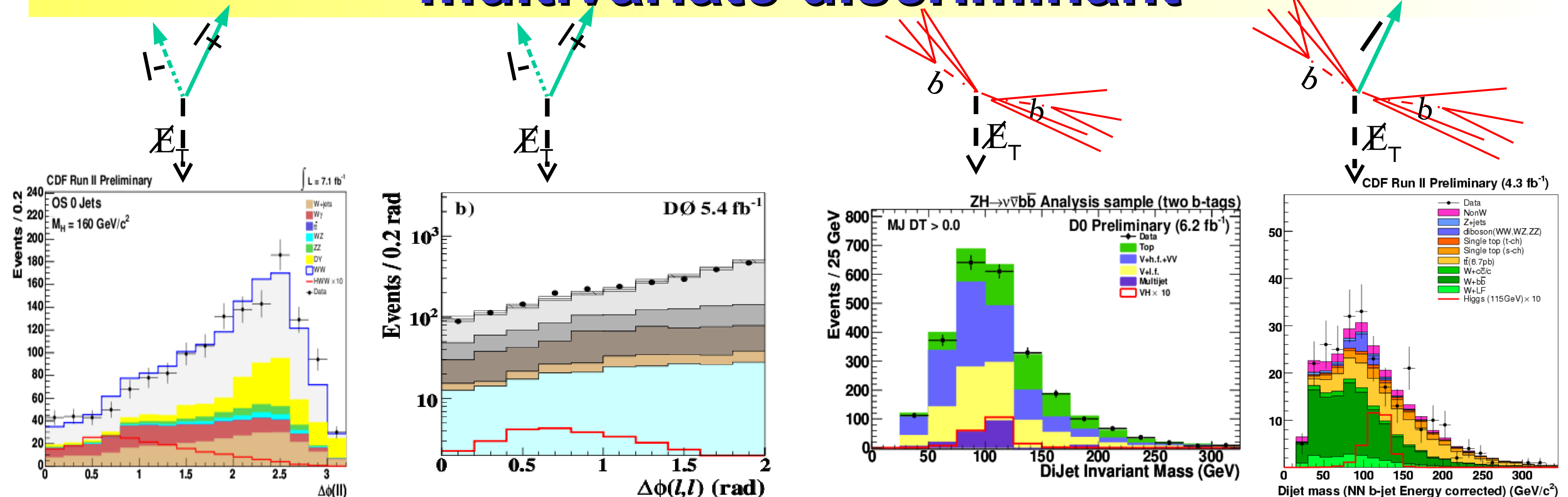

against top pairs




against W+jets

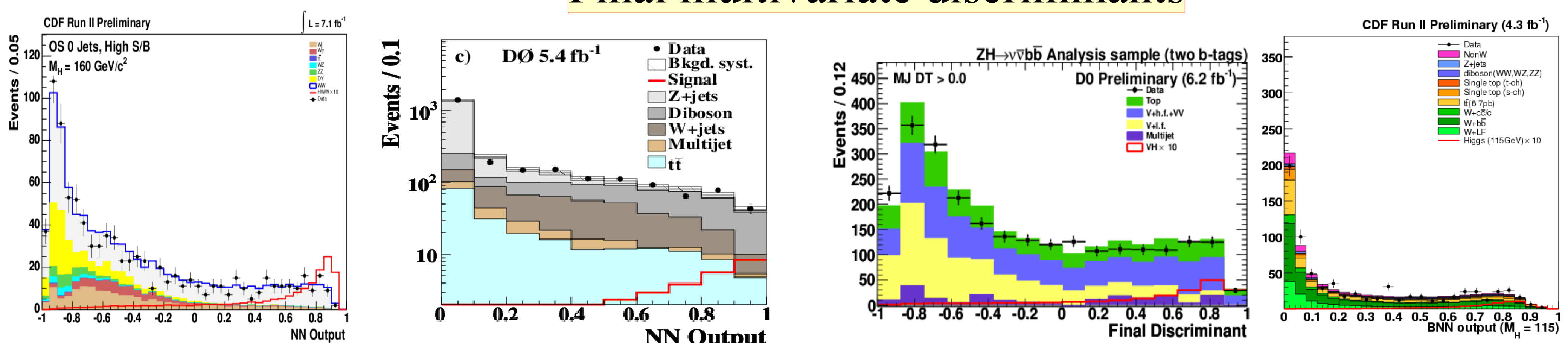


# Each channel now uses (at least) one multivariate discriminant

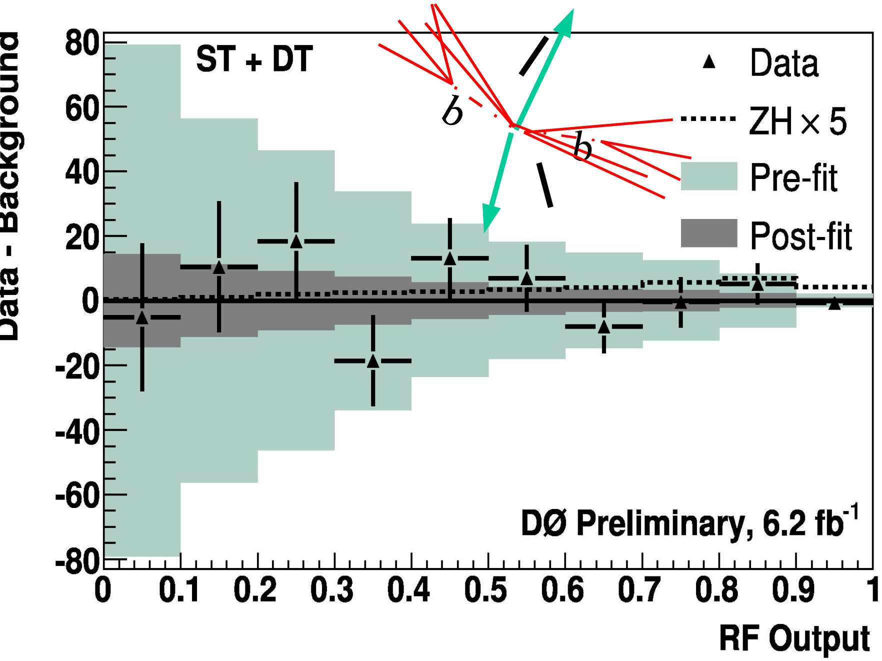



Main discriminating variables as inputs to

Final multivariate discriminants



# Systematics




Systematics are channel dependent

- Flat systematics: affect overall normalization
- Shape systematics: modifiy 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

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

Improved sensitivity in the future if we reduce our systematics

# Some systematics from Tevatron combination (July 2010)

D0: double tag (TLDT) $ZH \rightarrow \nu\nu b\bar{b}$ channel relative uncertainties (%)

| Contribution | WZ/ZZ | Z+jets | W+jets | $t\bar{t}$ | ZH,WH |
|---|---|---|---|---|---|
| Jet Energy Scale pos/neg (S) | $\pm$ 5.1 | $\pm$ 7.1 | $\pm$6.6 | $\mp$0.5 | $\pm$1.6 |
| Jet ID (S) | 1.1 | $\pm$1.2 | 0.8 | 0.1 | 1.1 |
| Jet Resolution pos/neg (S) | $\mp$1.6 | $\pm$2.0 | $\pm$1.9 | $\mp$2.0 | $\mp$ 1.6 |
| MC Heavy flavor $b$-tagging pos/neg (S) | $\pm$ 8.0 | $\pm$0.6 | $\pm$8.5 | $\pm$10.2 | $\pm$9.9 |
| MC light flavor $b$-tagging pos/neg (S) | 1.5 | $\pm$12.6 | $\pm$1.2 | $\pm$0.1 | 0.0 |
| Direct taggability & Vertex Confirmation(S) | 7.4/1.5 | $\pm$9.0 | $\pm$6.8 | 5.2/0.1 | 8.3/0.0 |
| Trigger efficiency (S) | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| Parton Distribution Function (S) | $\pm$0.1 | 0.0 | $\pm$0.4 | 0.6/-0.5 | 0.6/0.9 |
| EM ID | 0.3 | - | 0.6 | 0.8 | 0.3 |
| Muon ID | 1.1 | 0.5 | 1.0 | 1.8 | 1.0 |
| Cross Section | 7.0 | 6.0 | 6.0 | 10 | 6.0 |
| Heavy Flavor Ratio | - | 20 | 20 | - | - |
| Luminosity | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 |

CDF: loose double-tag (LDT) $WH, ZH \rightarrow \not{E}_T b\bar{b}$ channel relative uncertainties (%)

| Contribution | ZH | WH | Multijet | Top Pair | S. Top | Di-boson | W + h.f. | Z + h.f. |
|---|---|---|---|---|---|---|---|---|
| Luminosity | 3.8 | 3.8 | | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 |
| Lumi Monitor | 4.4 | 4.4 | | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 |
| Tagging SF | 11.6 | 11.6 | | 11.6 | 11.6 | 11.6 | 11.6 | 11.6 |
| Trigger Eff. (shape) | 1.2 | 1.3 | 1.1 | 0.7 | 1.2 | 1.2 | 1.8 | 1.3 |
| Lepton Veto | 2.0 | 2.0 | | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| PDF Acceptance | 2.0 | 2.0 | | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| JES (shape) | $^{+3.7}_{-3.7}$ | $^{+4.0}_{-4.0}$ | $^{-5.4}_{+5.2}$ | $^{+1.1}_{-0.7}$ | $^{+4.2}_{-4.2}$ | $^{+7.0}_{-7.0}$ | $^{+1.3}_{-7.6}$ | $^{+6.2}_{-7.1}$ |
| ISR | $^{+1.4}_{-2.9}$ | | | | | | | |
| FSR | $^{+5.3}_{+2.5}$ | | | | | | | |
| Cross-Section | 5.0 | 5.0 | | 10 | 10 | 6 | 30 | 30 |
| Multijet Norm. (shape) | | | 11 | | | | | |

| Contribution | Diboson | $Z/\gamma^* \rightarrow \ell\ell$ | $W + jet/\gamma$ | $t\bar{t}$ | Multijet | $H$ |
|---|---|---|---|---|---|---|
| Trigger | 2 | 2 | 2 | 2 | – | 2 |
| Lepton ID | 3 | 3 | 3 | 3 | – | 3 |
| Momentum resolution (s) | 0 | 3 | 1 | 0 | – | 0 |
| Jet Energy Scale (s) | 1 | 5 | 1 | 1 | – | 1 |
| Jet identification (s) | 1 | 3 | 1 | 1 | – | 1 |
| Cross Section | 7 | 7 | 7 | 10 | 10 | 11 |
| Luminosity | 6 | 6 | 6 | 6 | – | 6 |
| Modeling (s) | 1 | 1 | 3 | 0 | 0 | 1 |

# Analysis method: Divide and Rule

Channels are split into subchannels: ~50 analysis to be combined

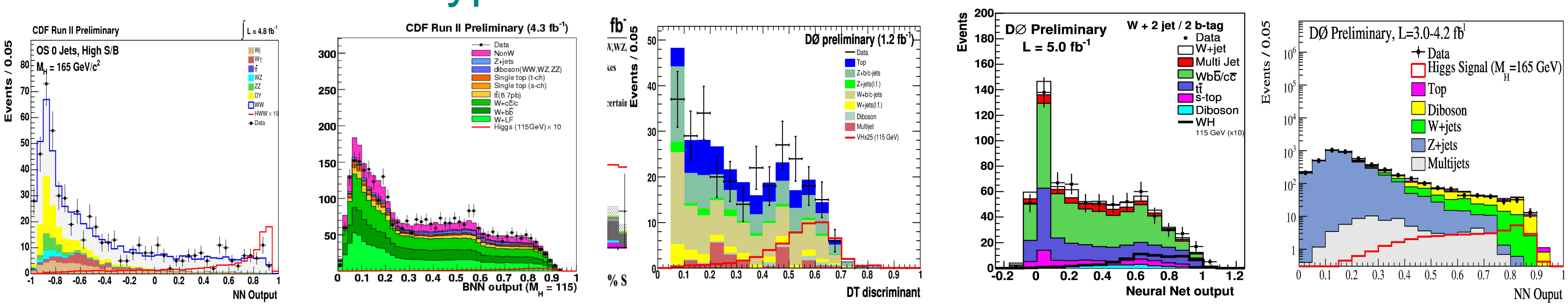
- Different bins in jet multiplicity
- Different b-tagging content
- Lepton flavour, lepton id criteria

Eg: llbb at D0 = 8 channels (ee, μμ, e+ICRe , μ+track)x(1 b-tag, 2 b-tag)

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 multivariate discriminant distribution to test S and S+B hypothesis




• • •

# Analysis method: Divide and Rule

Channels are split into subchannels: ~50 analysis to be combined

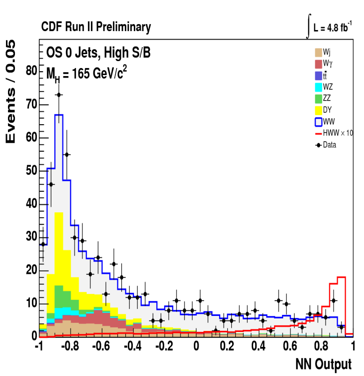
- Different bins in jet multiplicity
- Different b-tagging content
- Lepton flavour, lepton id criteria

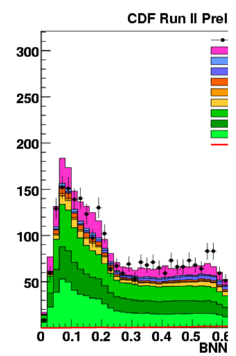
Eg: llbb at D0 = 8 channels (ee, μμ, e+ICRe , μ+track)x(1 b-tag, 2 b-tag)

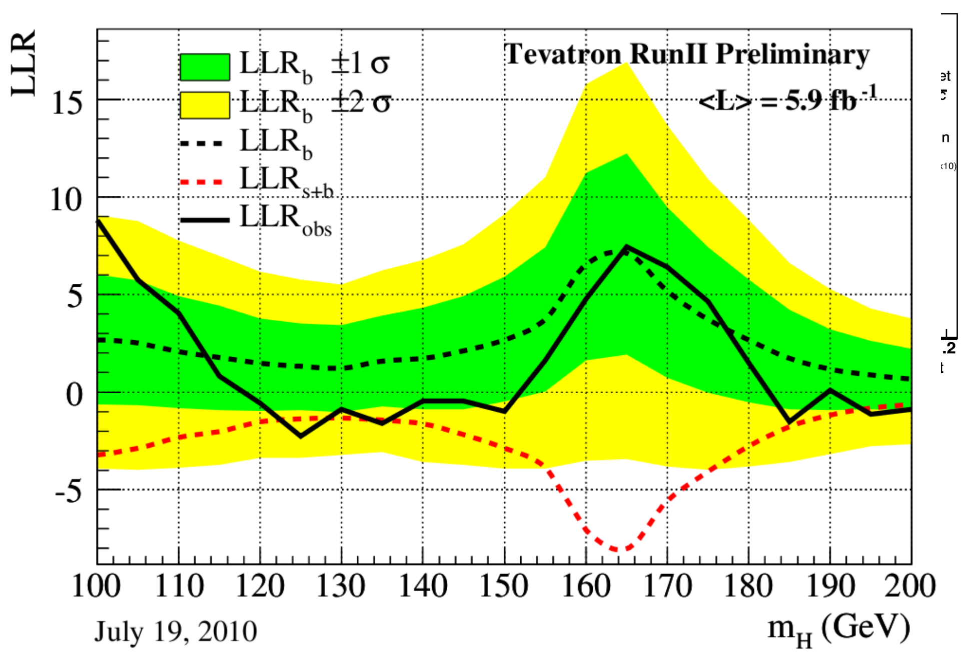
Goal is to maximize sensitiviy : each subchannel has its own S/B

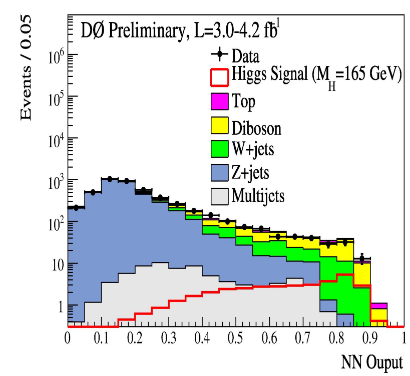
Eg WH, 2jets : 0-btag S/B~1:4000 , 1btag(only) S/B~1/400 2 b-tag S/B ~ 1/100

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



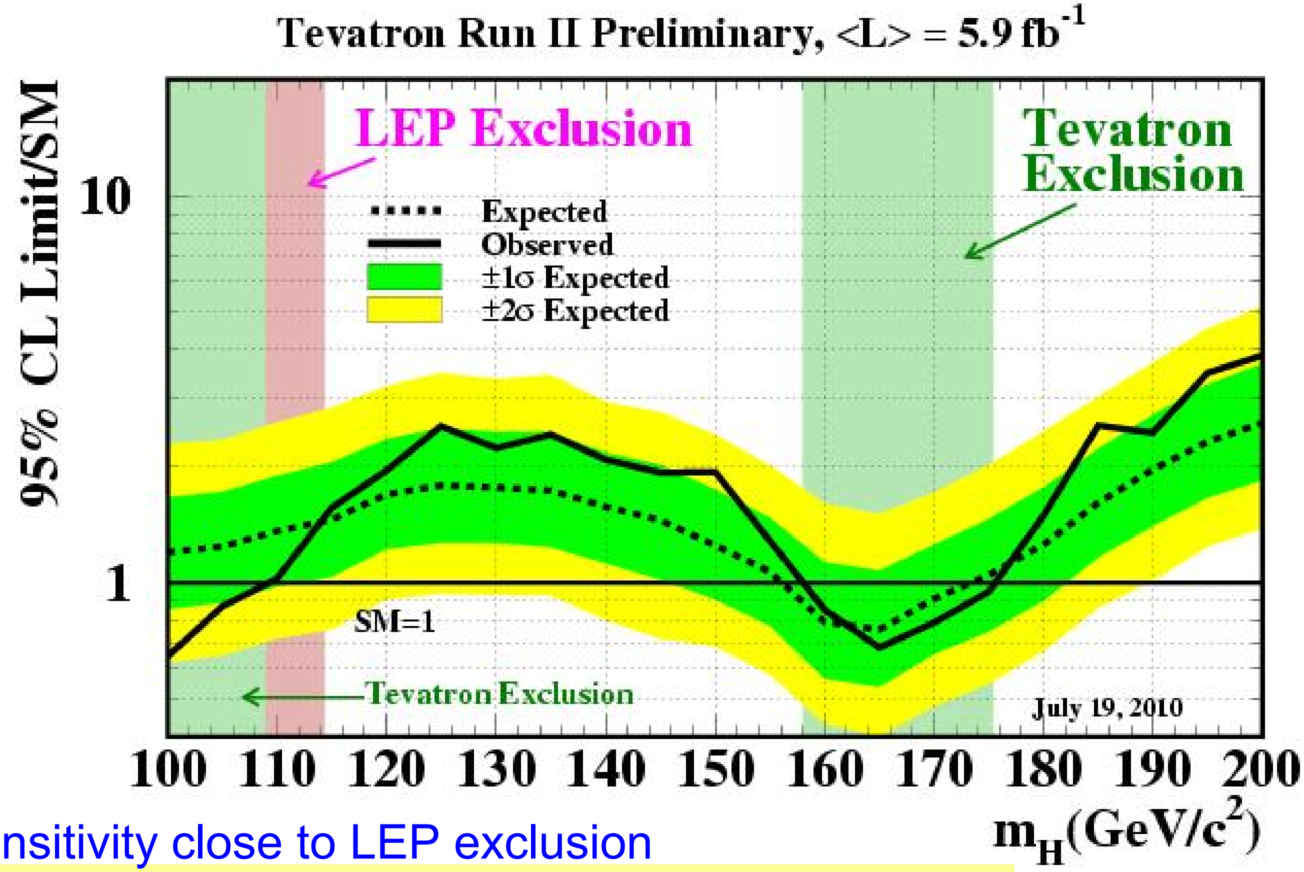




• • •

# Tevatron full mass range combined limits (Last update July 2010 )

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

158<$m_H$<175 GeV is excluded
expected sensitivity 156<$m_H$<175 GeV




Low mass sensitivity close to LEP exclusion

Limits For $m_H$=115 GeV $\sigma_{95}/\sigma(SM)$ =1.56 (1.45 expected)

Limits For $m_H$=130 GeV $\sigma_{95}/\sigma(SM)$ =2.23 (1.76 expected)

# Break down in july 2010

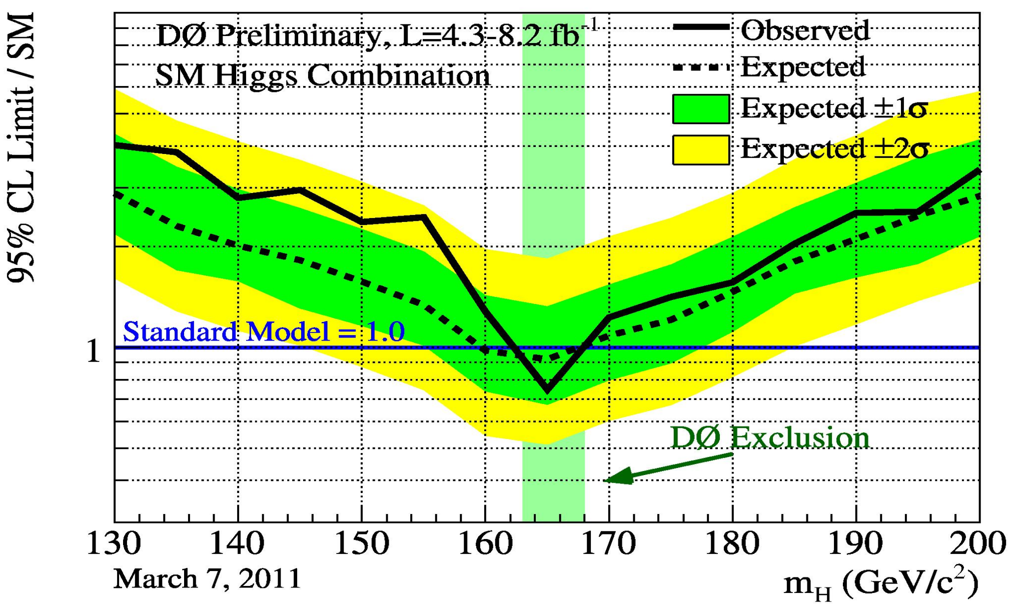
| Channel | Expt | Dataset now | Increase since Nov. 2009 combination |
|---|---|---|---|
| $H \to WW$ | D0 | 6.7 | 24% |
| $H \to WW$ | CDF | 5.9 | 23% |
| $WH \to l\nu bb$ | CDF | 5.7 | 30% |
| $WH \to l\nu bb$ | D0 | 5.3 | 6% |
| $ZH/WH \to METbb$ | CDF | 5.7 | 60% |
| $ZH/WH \to METbb$ | D0 | 6.4 | 23% |
| $ZH \to llbb$ | CDF | 5.7 | 40% |
| $ZH \to llbb$ | D0 | 6.2 | 45% |
| $H \to \gamma\gamma$ | CDF | 5.4 | New! |
| $H \to \gamma\gamma$ | D0 | 4.2 | 0% |
| $H \to \tau\tau$ | CDF | 2.3 | 15% |
| $H \to \tau\tau$ | D0 | 4.9 | 0% |
| $ZH/WH \to qqbb$ | CDF | 4 | 100% |
| $t\bar{t}H$ | D0 | 2.1 | 0% |

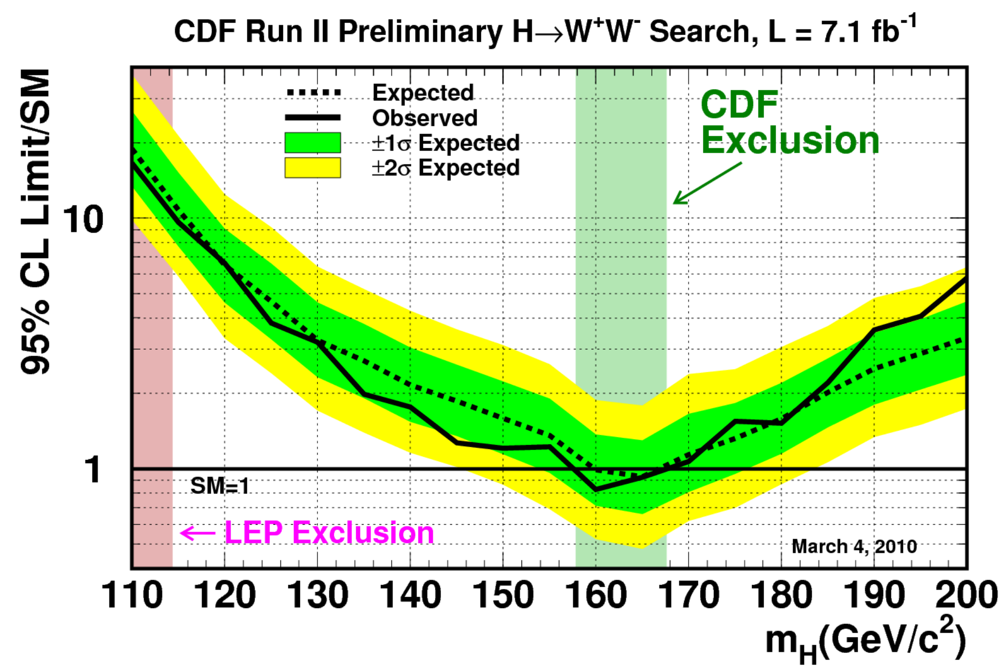
- Final Tevatron results should be based on 10 $fb^{-1}$
  - will scale statistics by ~1.8 on average

# Last update for high mass only (Moriond 2011)

Increase statistics and improved analysis :

Each experiment has reached SM Higgs sensitivity



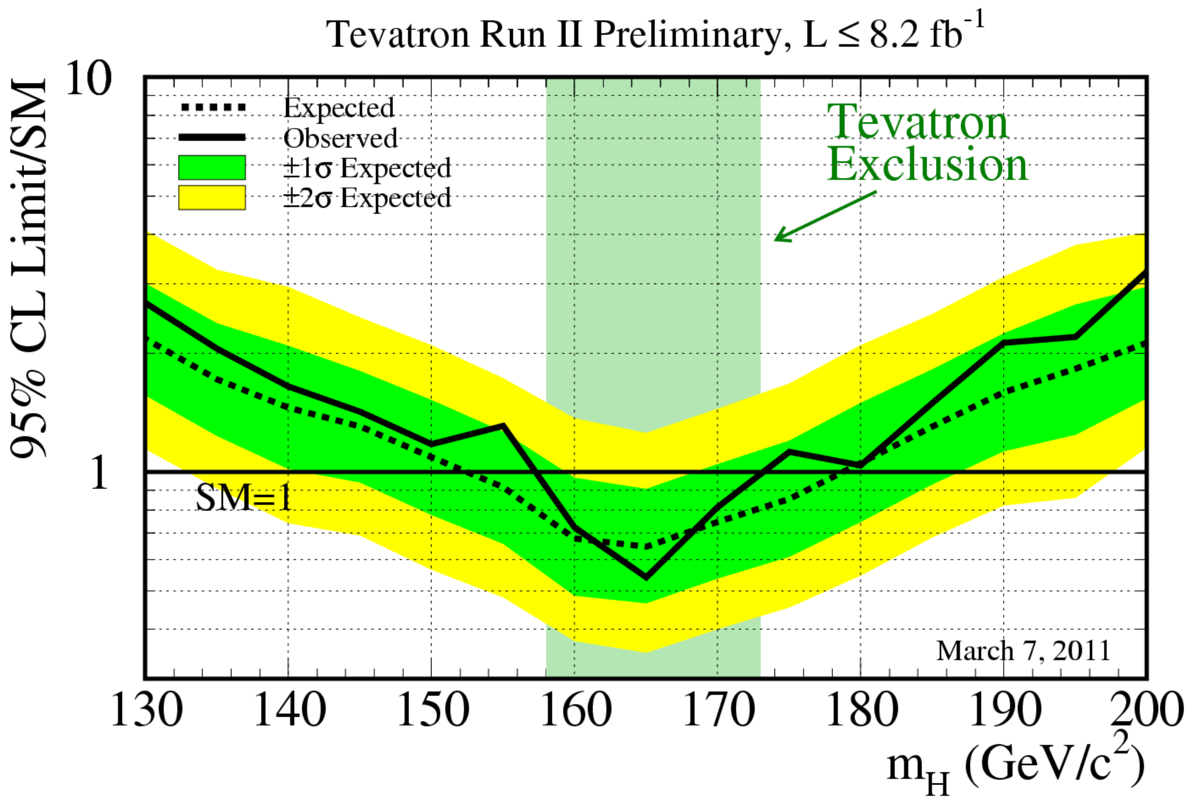

$163 < m_H < 168$ GeV is excluded
expected sensitivity $160 < m_H < 168$ GeV

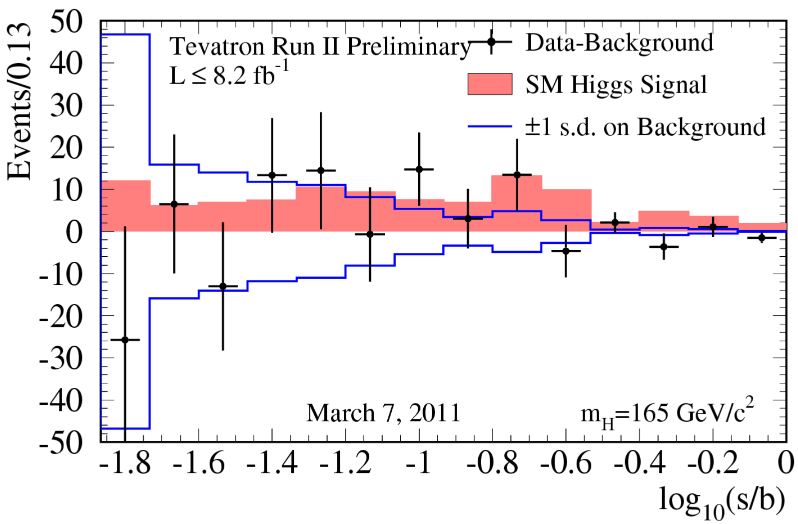
$159 < m_H < 168$ GeV is excluded
expected sensitivity $158 < m_H < 168$ GeV

# Combined update for high mass (Moriond 2011)

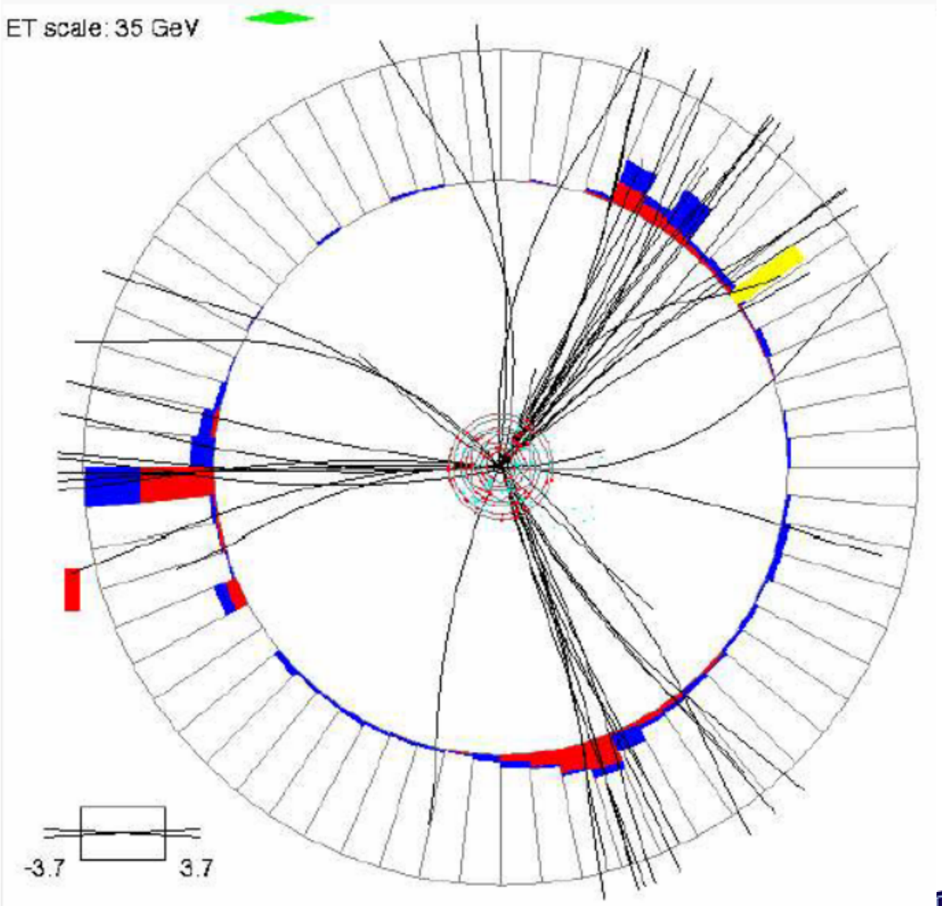
High mass channels able to exclude SM Higgs @ 95% CL

$158<m_H<173$ GeV is excluded
expected sensitivity $153<m_H<179$ GeV



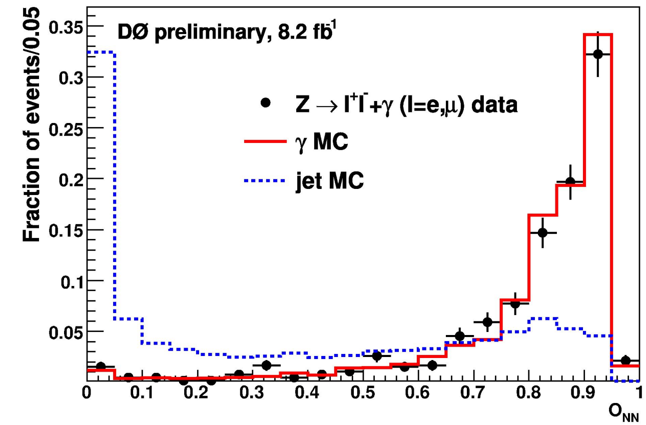



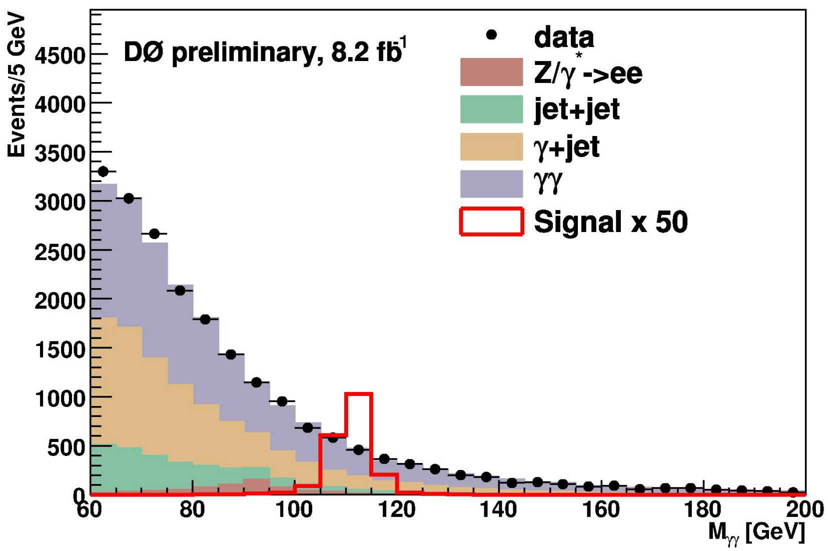
# (selected) results for Higgs beyond SM

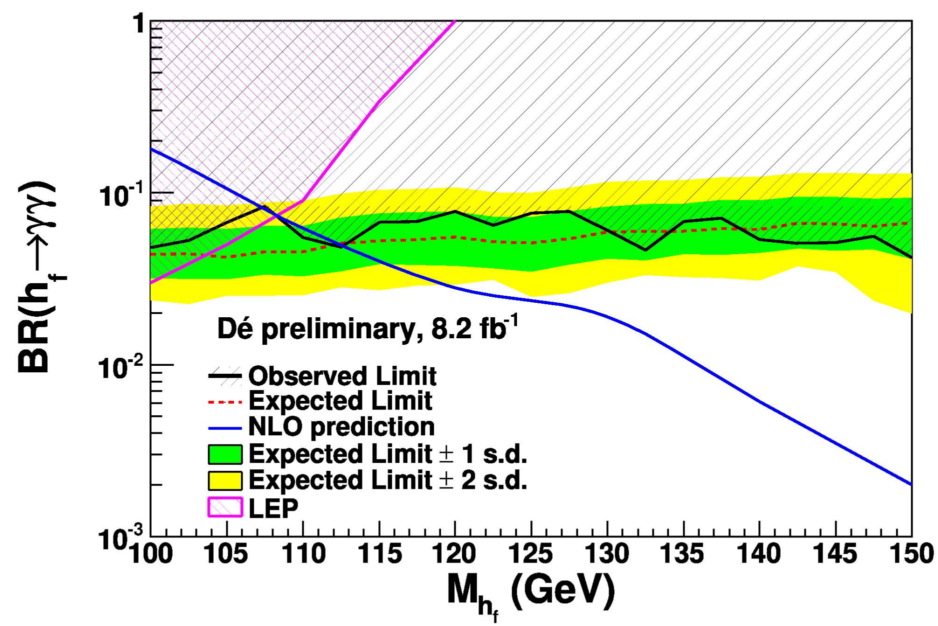


# D0 new fermiophobic Higgs search

- Look for H → γγ decay
- Employ NN based photon Identification
- MVA for final discrimination



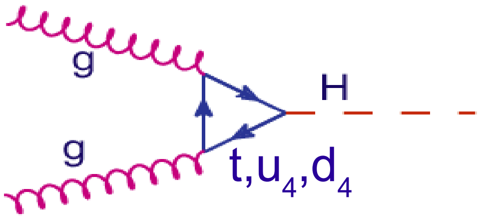



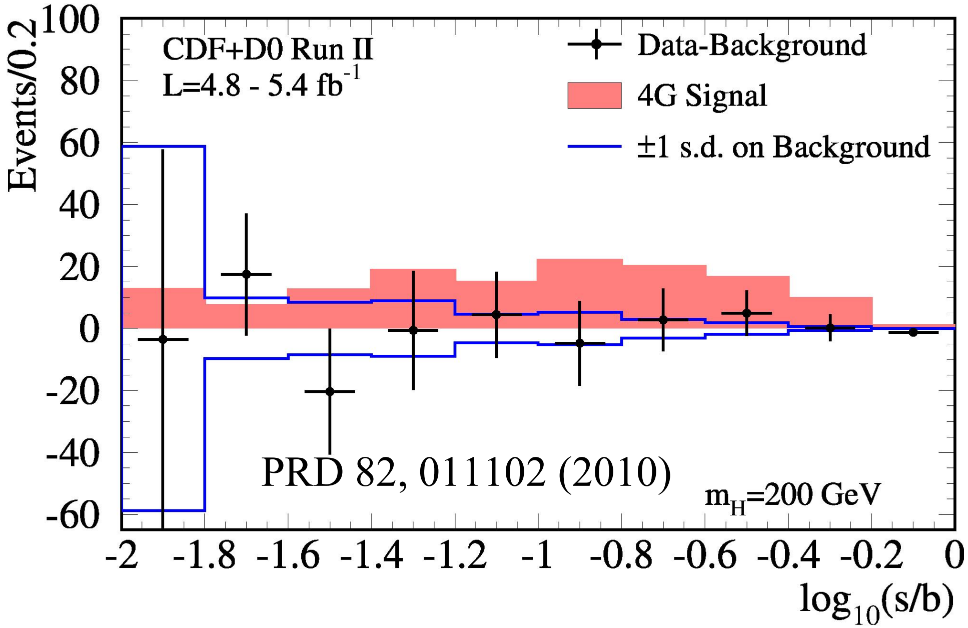

**D0 exclude: $m_H$<112 GeV @95%CL**

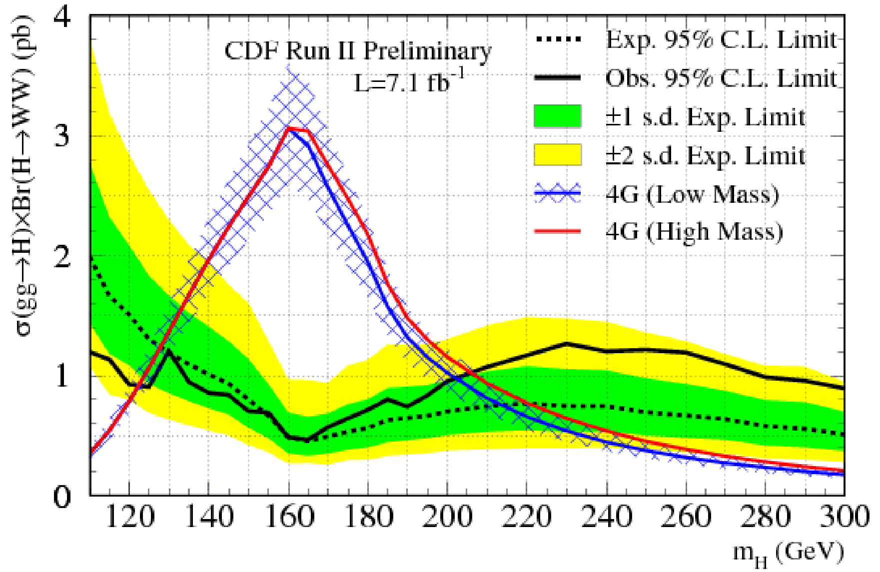
Improve over LEP limit (109.7 GeV ) and CDF (106 GeV, 2.6 fb$^{-1}$)

# 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
  - Some analysis tuning required because of extended mass reach (eg $\Delta\phi(l,l)$ cut not applicable when W's are boosted)



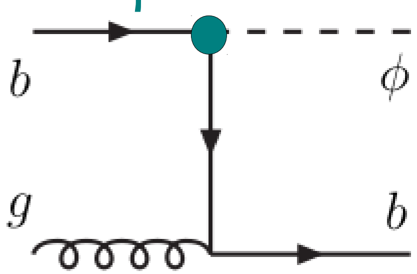

**CDF+D0 combined exclusion: $130<m_H<210$ GeV @95%CL**
**$4.8\text{-}5.4\ fb^{-1}$**
**CDF only $7.1\ fb^{-1}$ (spring 11) $123<m_H<202$ GeV @95%CL**

# 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 bbf coupling ~tanβ
  - Decays $\phi \to bb$ (90%), $\phi \to \tau\tau$ (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

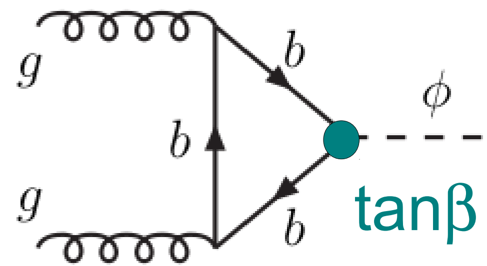
tanβ




Search channels at Tevatron

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

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



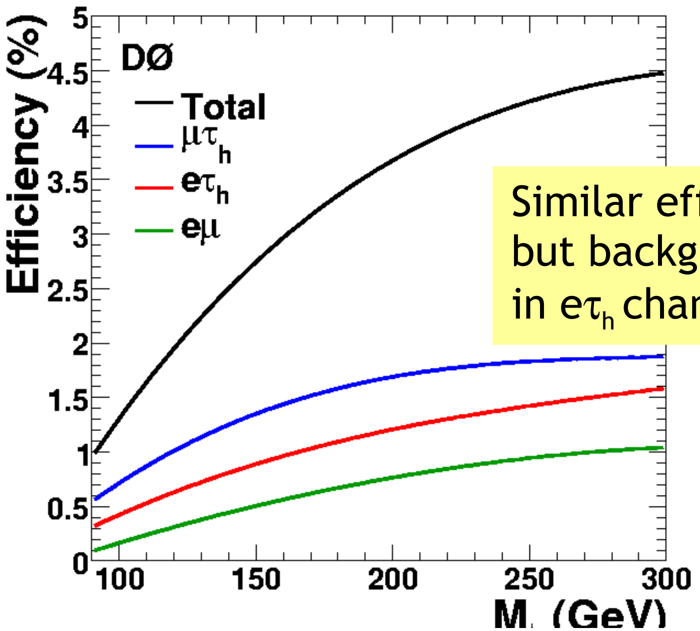

tanβ

Search channels at Tevatron :

$\tau^+\tau^-$

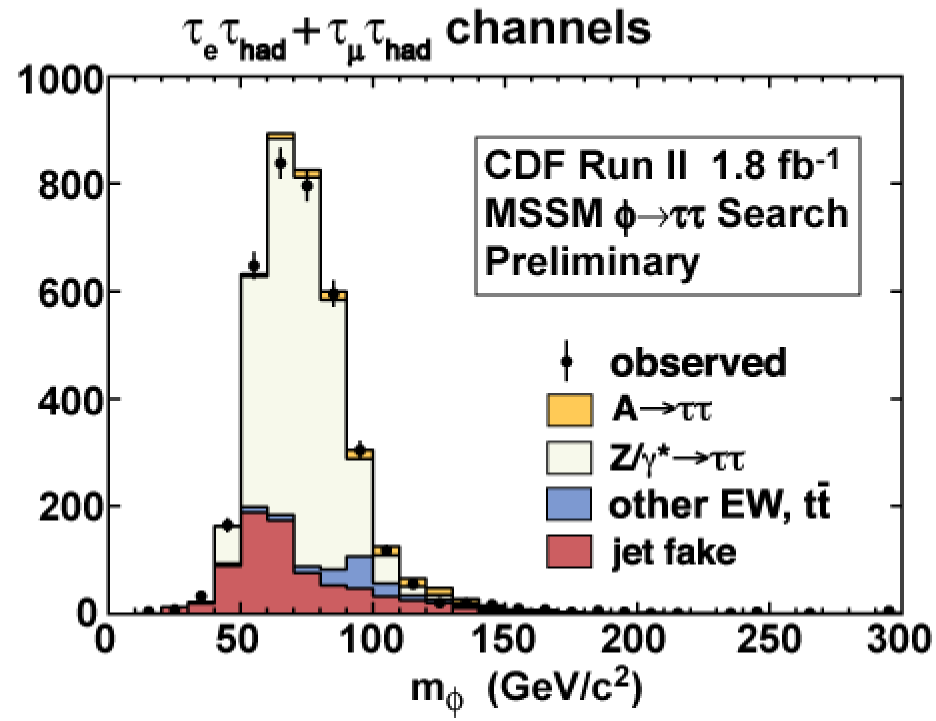
# Tau channels at large tan(β)

## Small efficiencies

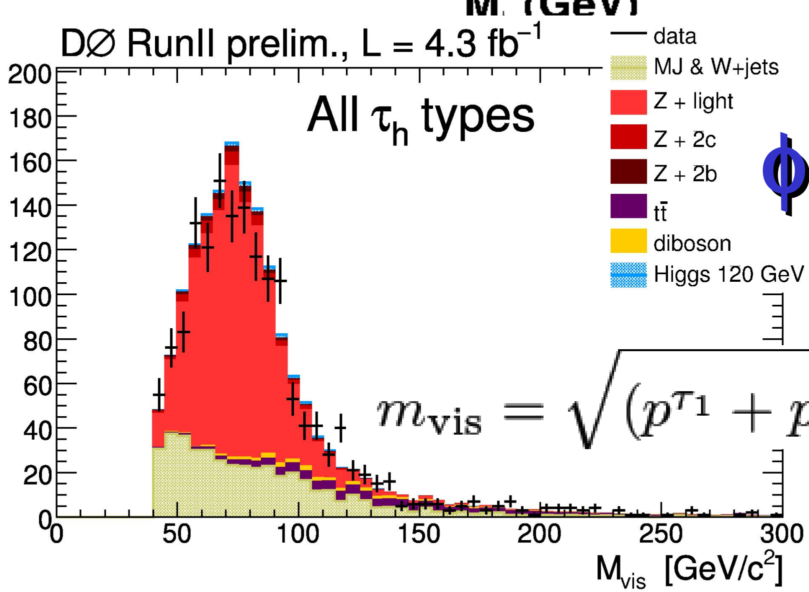



Similar efficiencis
but background worse
in $e\tau_h$ channel

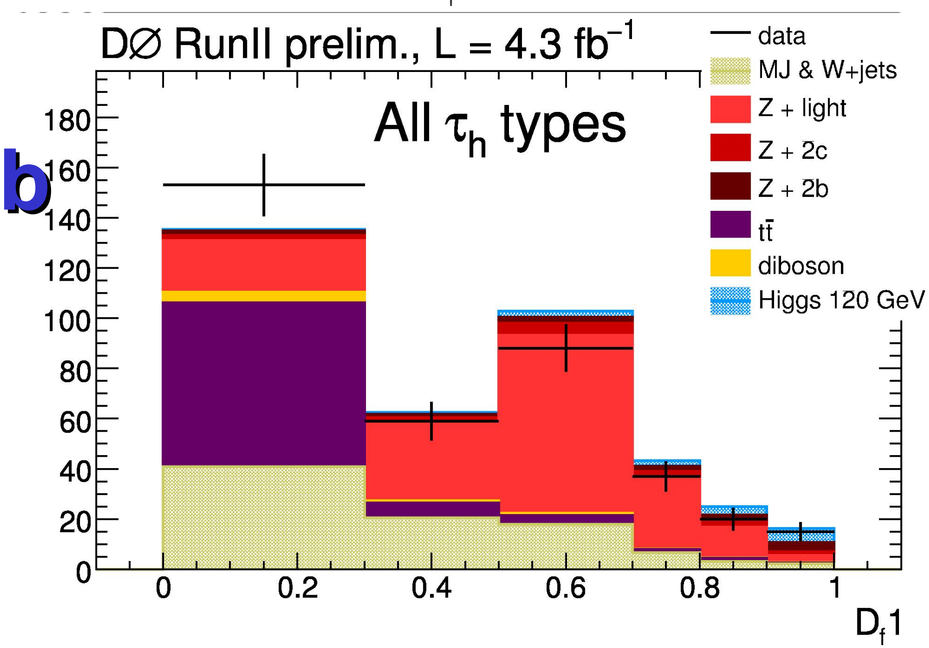
$\phi^0 \rightarrow \tau\tau$




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




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

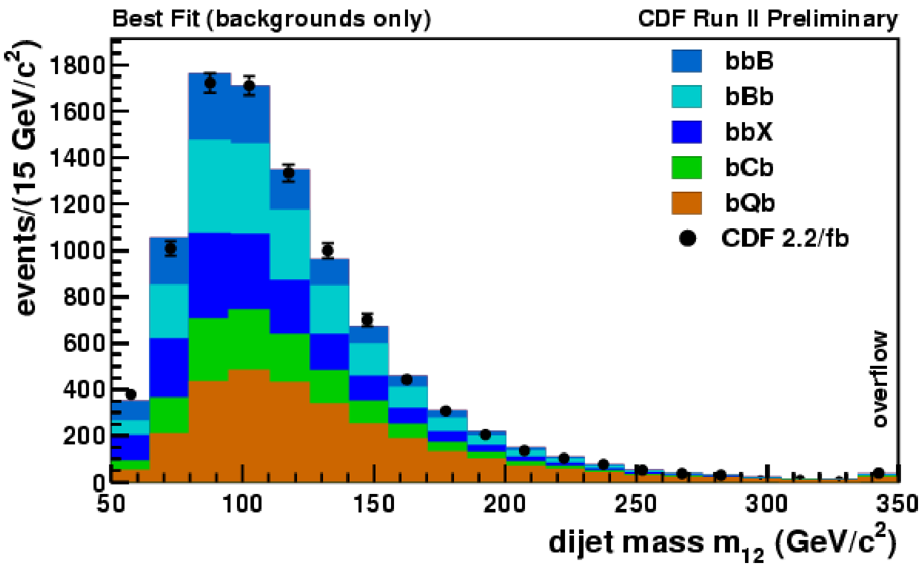


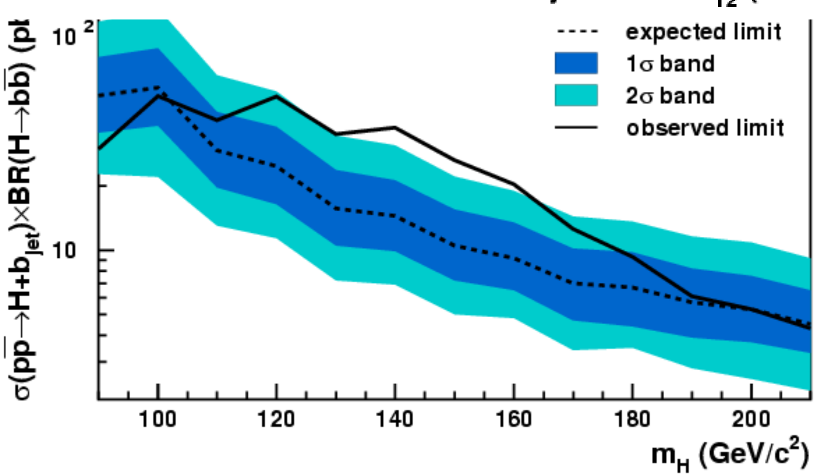
# Searching for a bbb signal

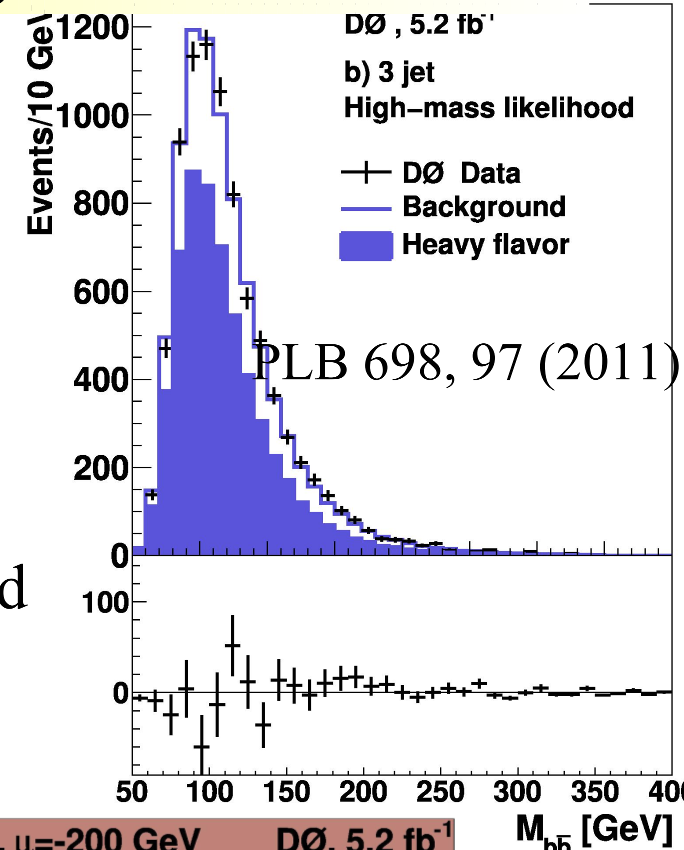
Difficulty : model multi-jet background

- DØ and CDF find similar flavour admixture
- But large systematic uncertainties

Look for excess in di-jet mass spectrum

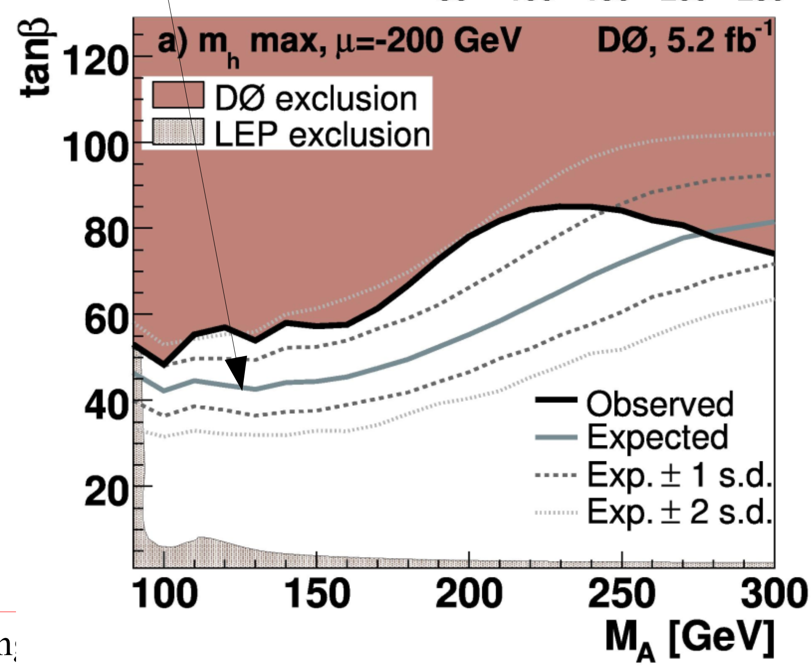


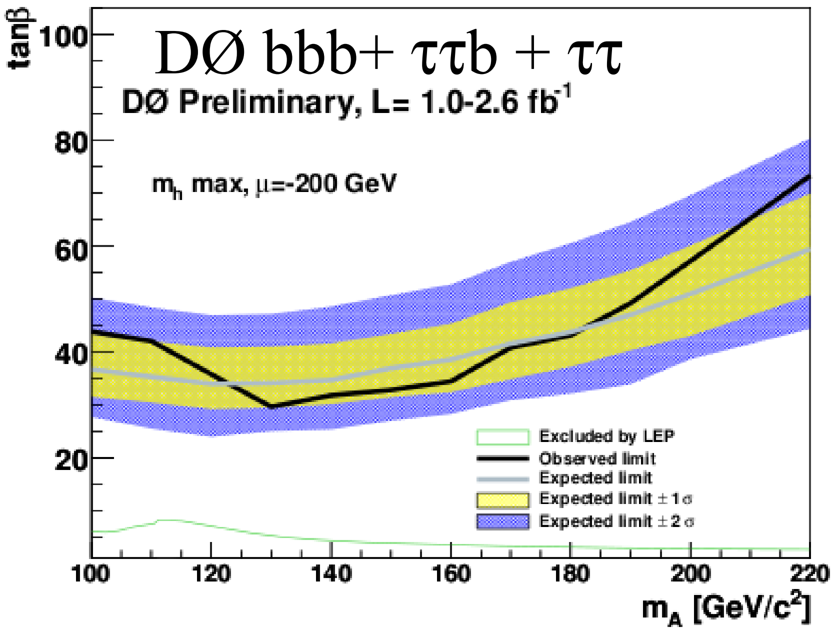



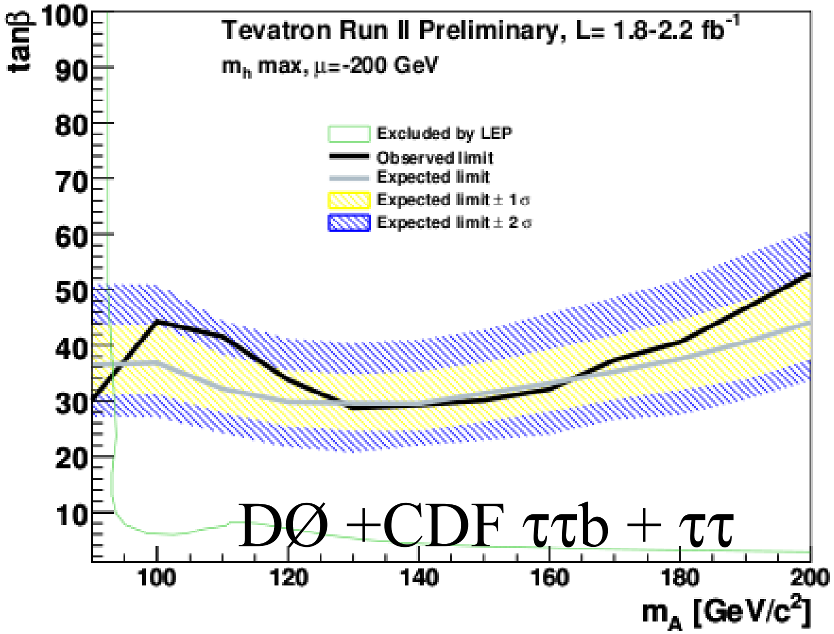

PLB 698, 97 (2011)

sensitivity around
tan β ~50



# Constraints on MSSM parameters



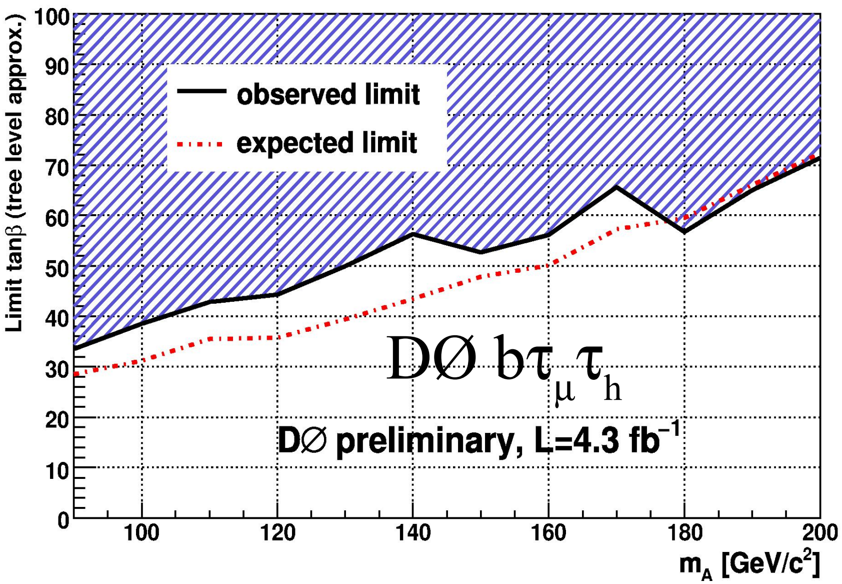

The Combinations probe value tanβ~30

- DØ combination: 2 yrs old, L<2.6 fb-1
- CDF/DØ combination L<2.2 fb-1

Need to update with recent analysis from D0 :

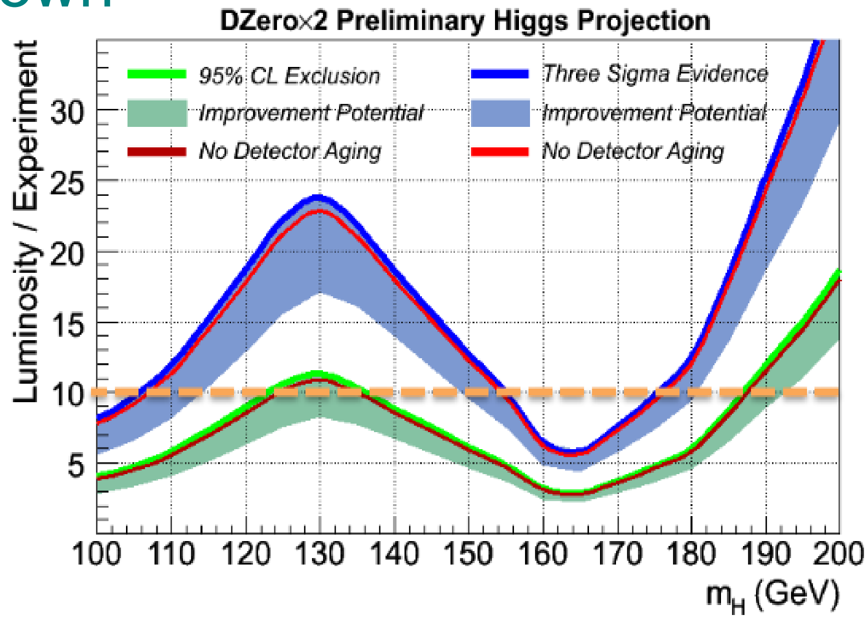
- $\tau_\mu\tau_h$: 1+4.3 fb$^{-1}$, $\tau_e\tau_h$ 3.7 fb$^{-1}$, bbb 1+4.2 fb$^{-1}$

Should be able to probe tanβ~20-25



# Conclusion

- Already a lot of results from Tevatron for SM and BSM Higgs
- More data expected before 2011 shutdown
  - Full data set : + 25% to 70% statistics for most of the analysis
- Analysis improvement still foreseen
  - The demonstrated improved acceptances and resolutions are not yet propagated to all channels.
  - Some further improvements still expected




Standard Model Higgs

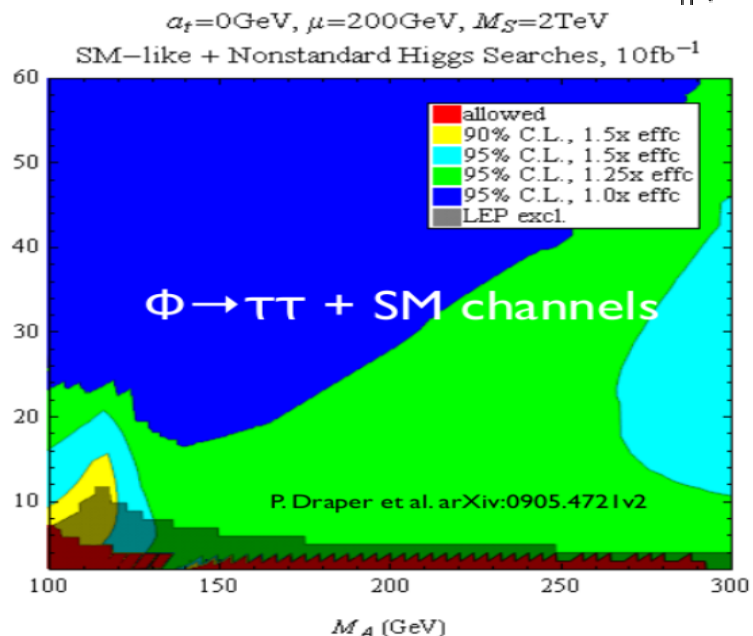
- Should explore mass range [100-190] GeV with final datase

MSSM at large tanβ

- Combining existing results is foreseen to explore down to tanβ~20

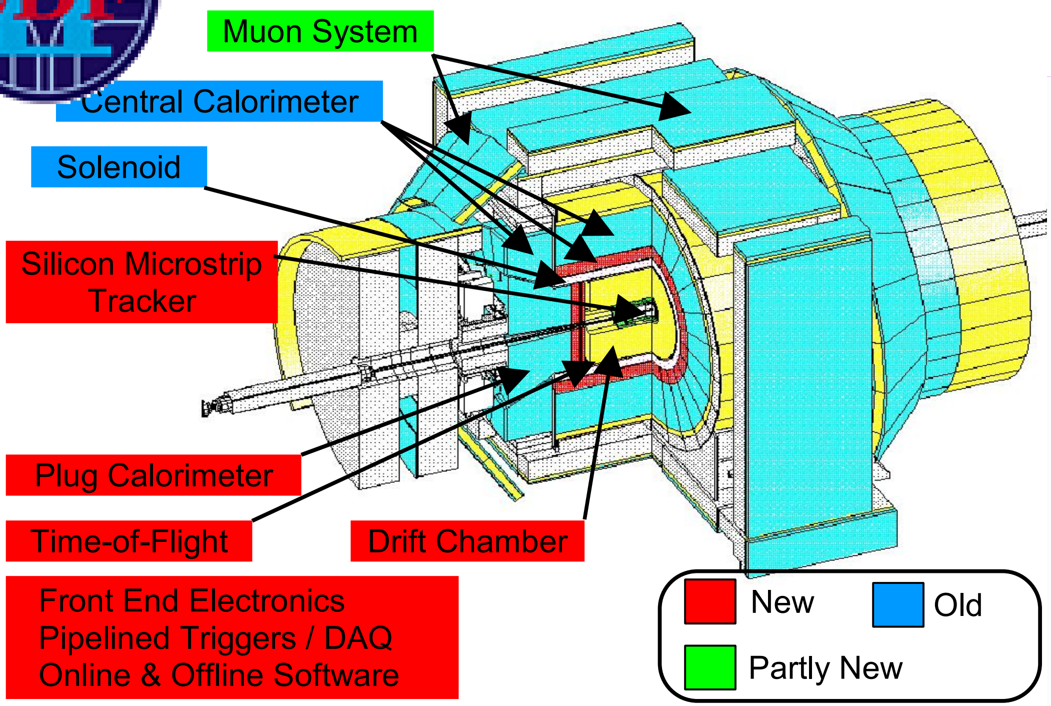
full MSSM combination

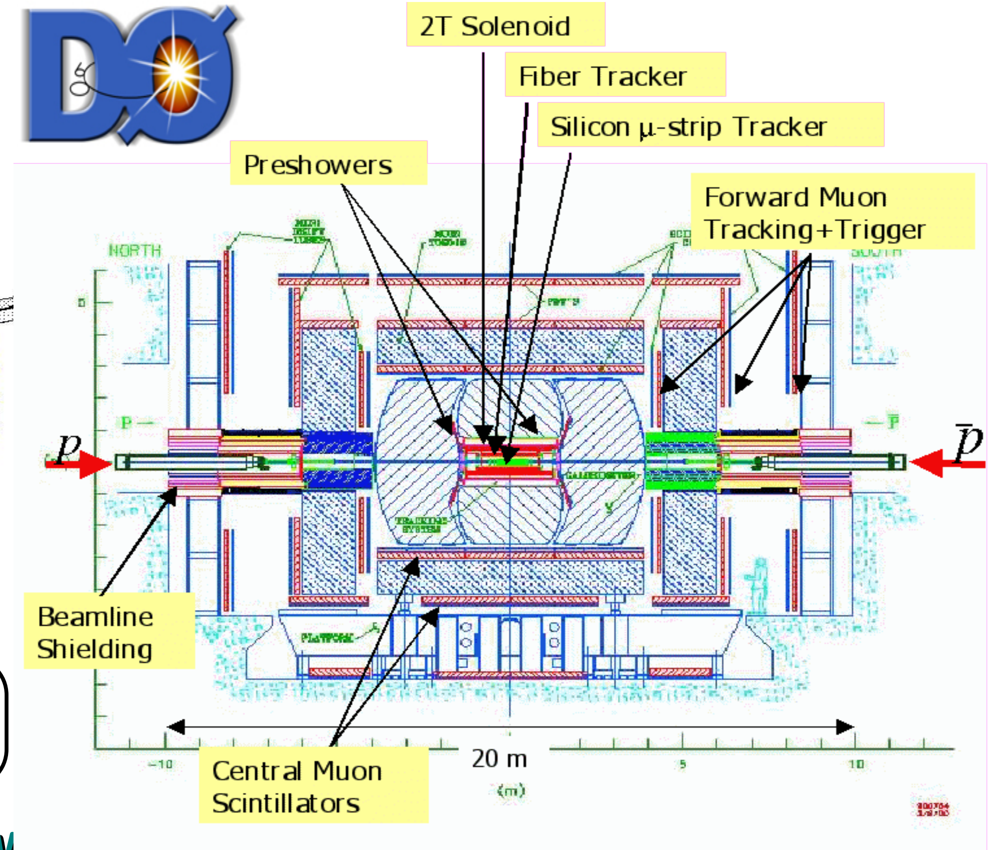
- Tevatron as the potential to cover a large part of the $(m_A, \tan\beta)$ plane



# Support slides

# Tevatron Experiments at RunII




## New

- silicon detector
- Drift chamber
- TOF PID system

## Upgraded

- Calorimeter
- DAQ/trigger
- displaced-vertex trigger

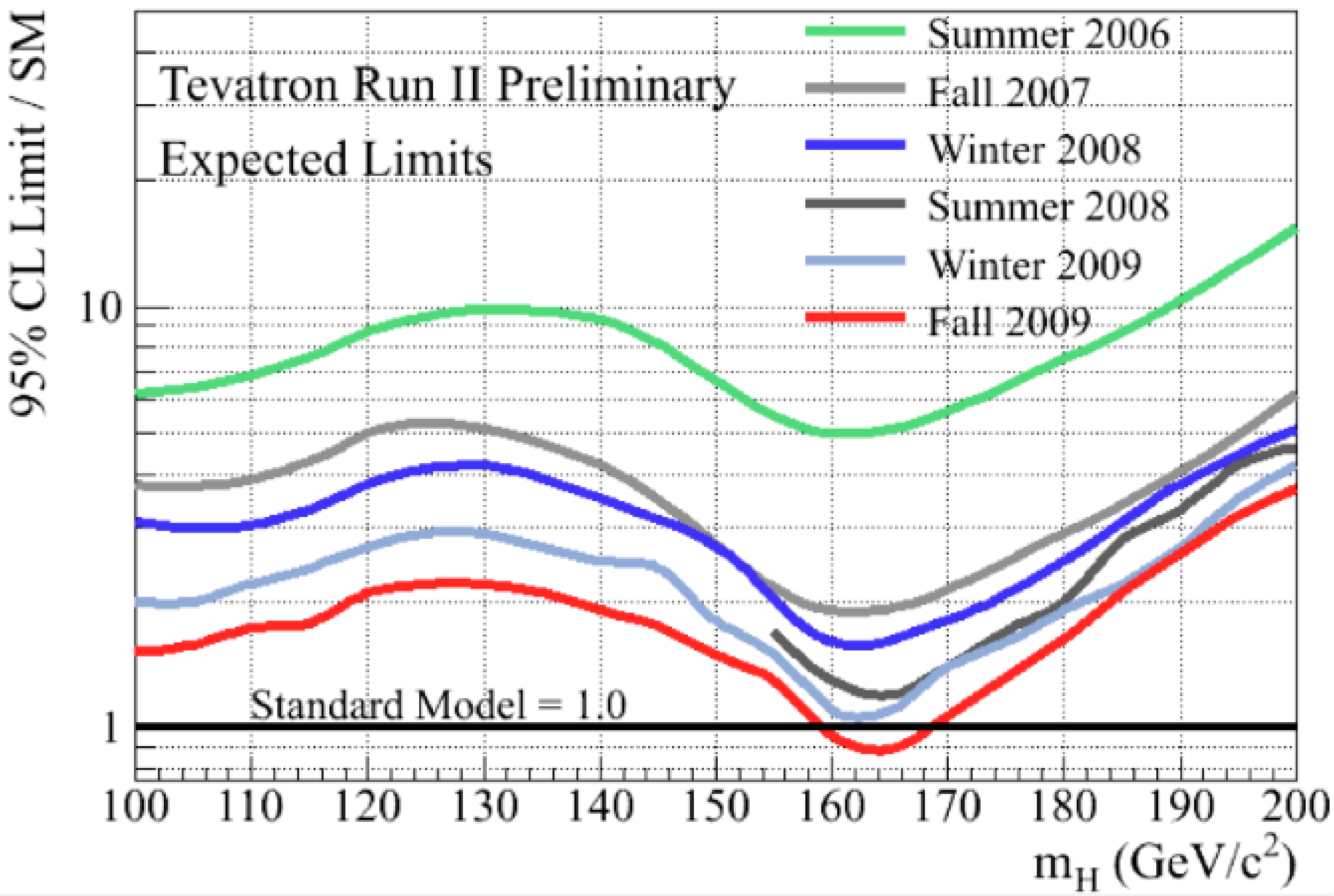
## New

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

## Upgraded

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

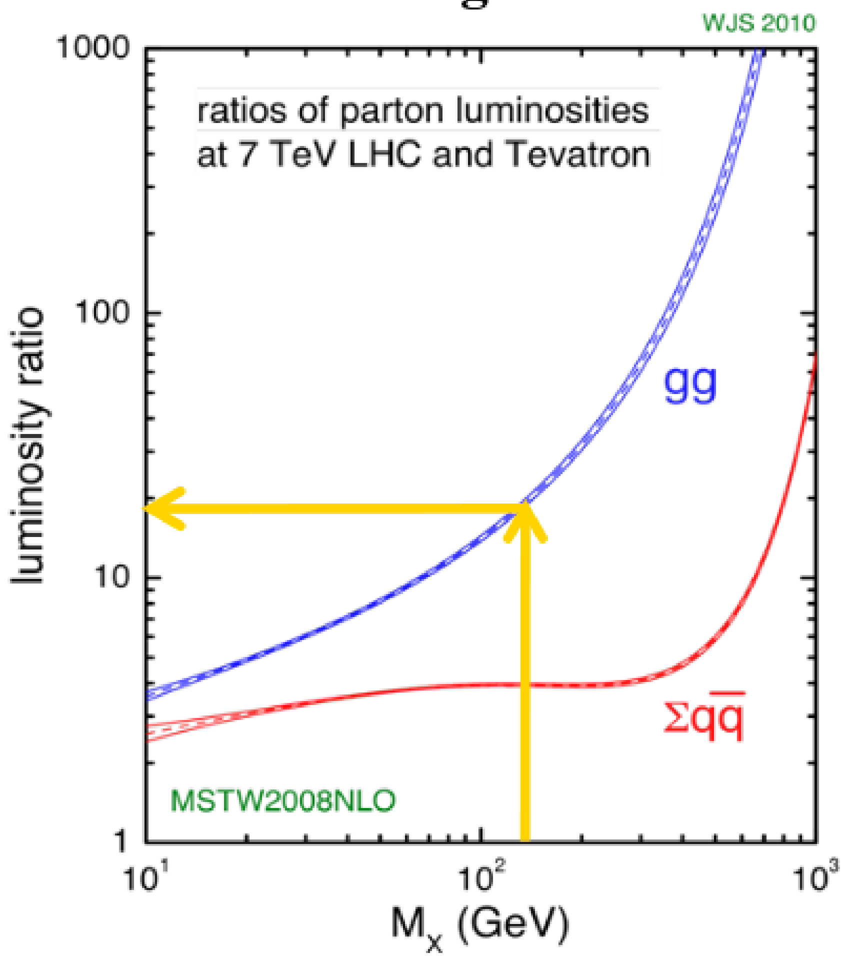
# Evolution of sensitivity




- How to go further ?
  - more data
  - but also more clever analysis techniques

# LHC & Tevatron Compared (I)

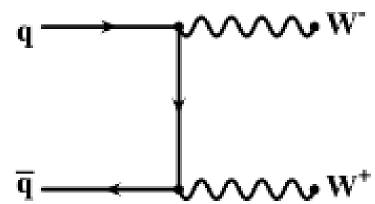
**Stirling *et al***

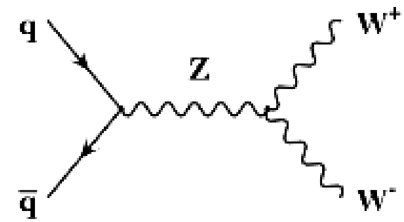



**For $M_X$ > 140 GeV**

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 $p\bar{p}$ )



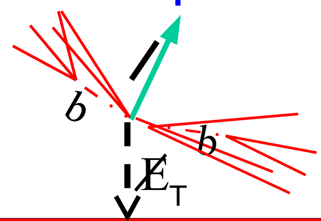

⇒ Larger signal, better S/N

# Controlling background

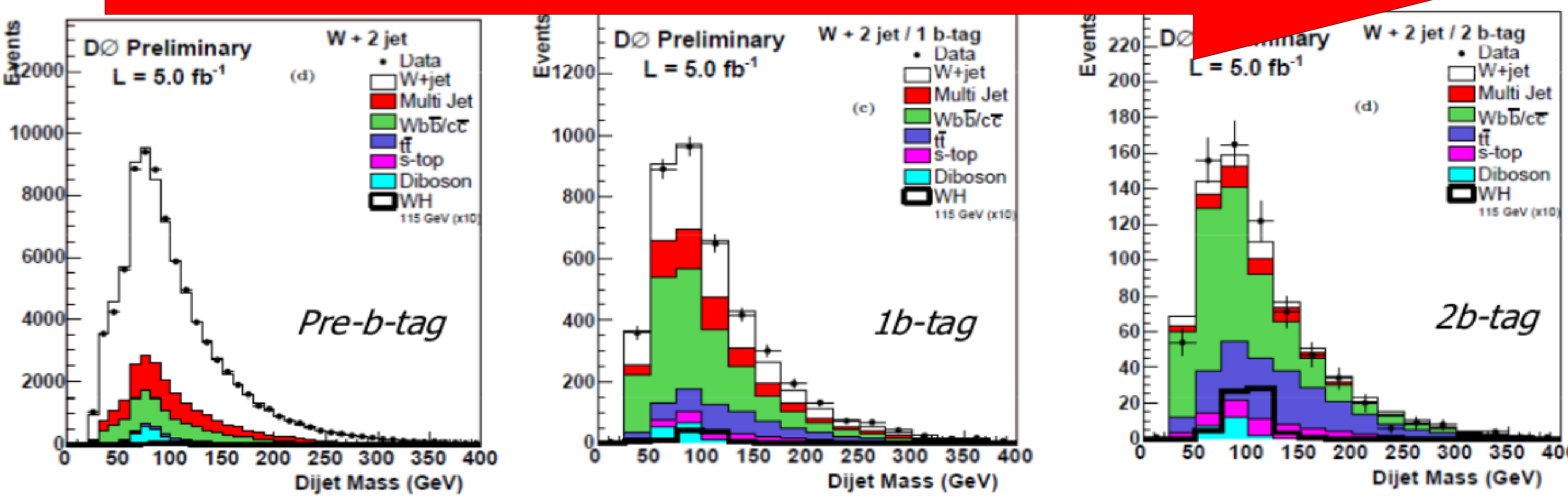
Example of method that  define data « control region »

- B-tagging selection is varied to
  - Study  background composition
  - Study background shape

Eg WH channels :

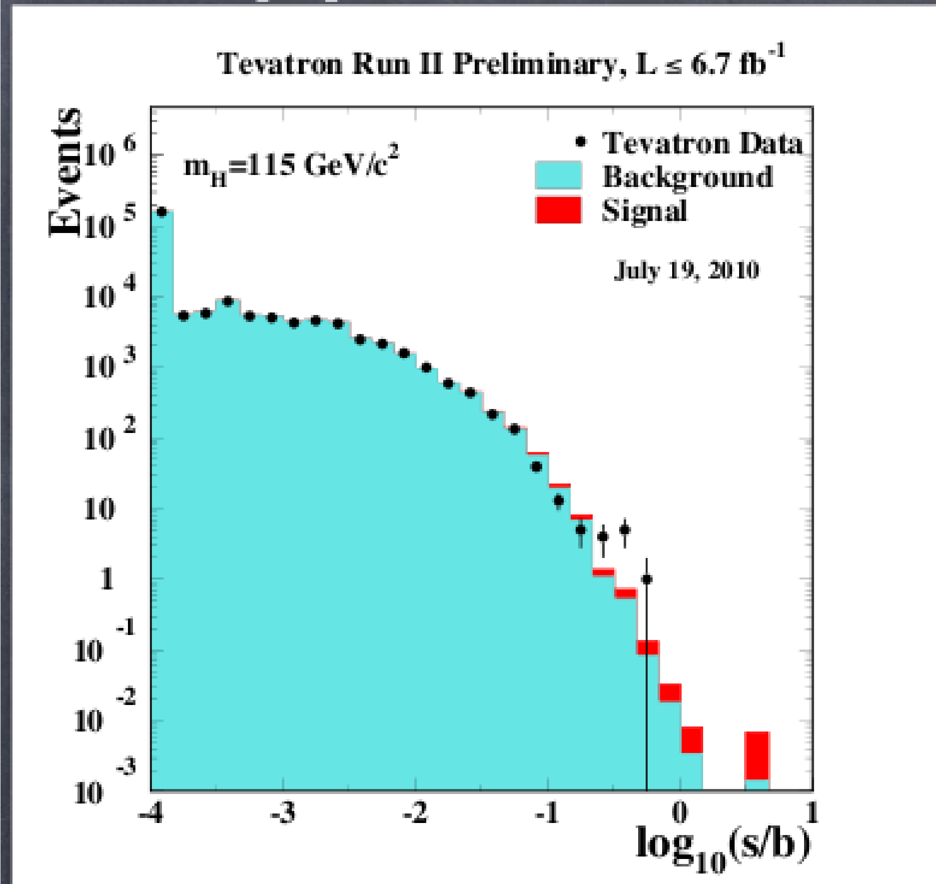



Dominated by W+jj QCD     Dominated by W+bb

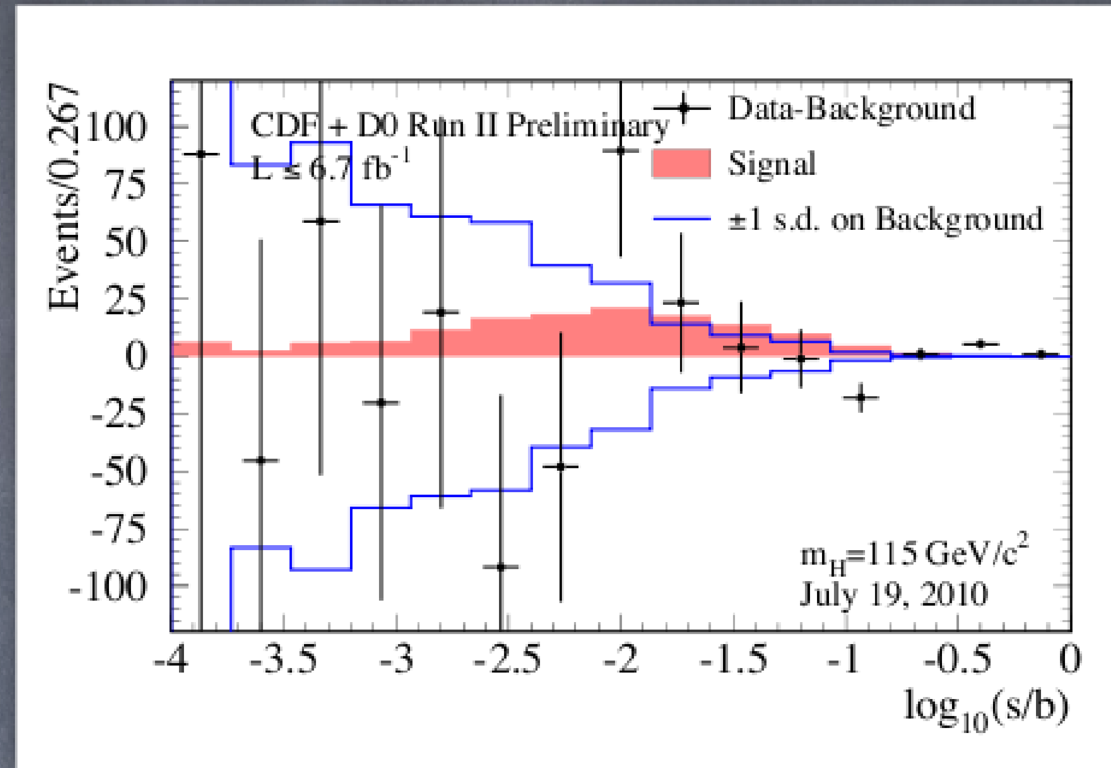



Note that S/B remains small, need to be increased........

# Hypothesis : $m_H$ = 115 GeV




All bins of all sub-channels of all channels




Data - Background shown compared to signal in red

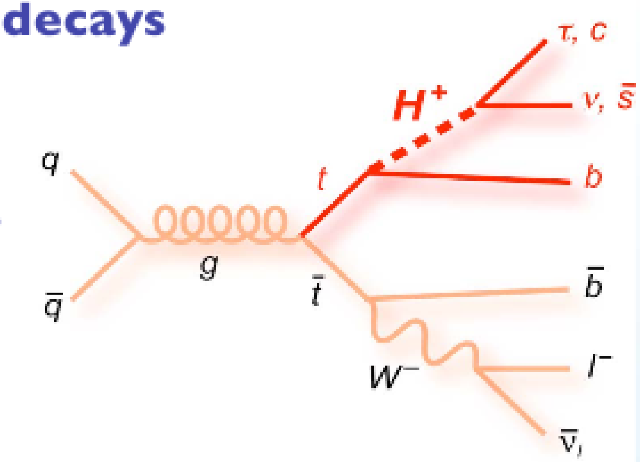
Fluctuations: Excess and deficit average out :

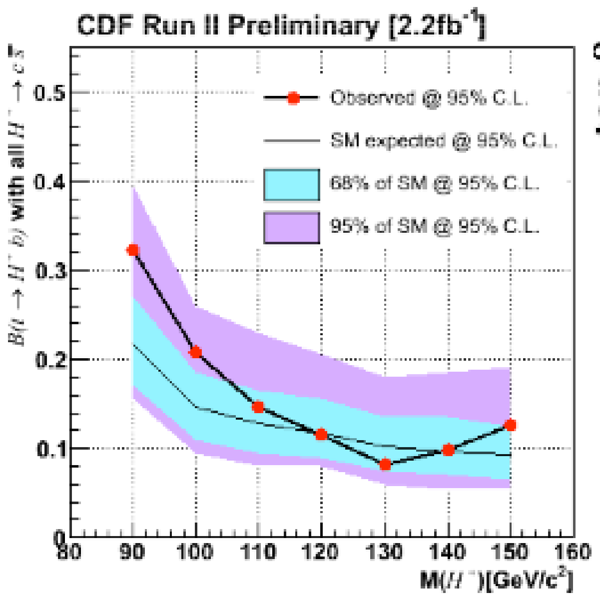
Expected limit 1.45*SM

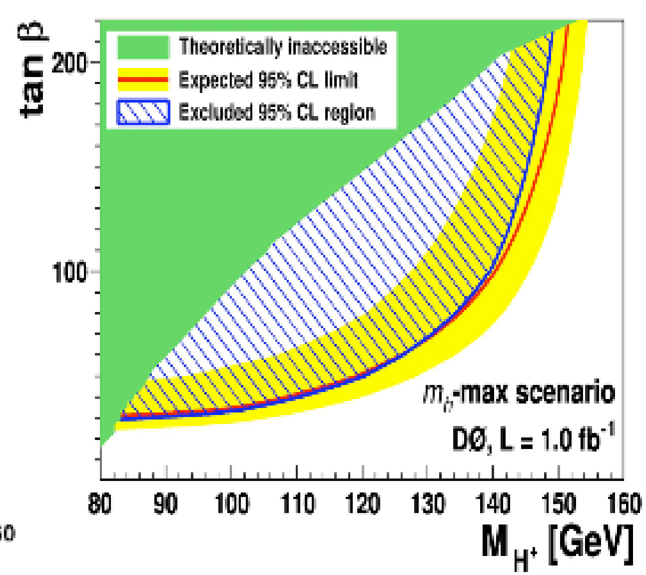
Observed limit 1.56*SM

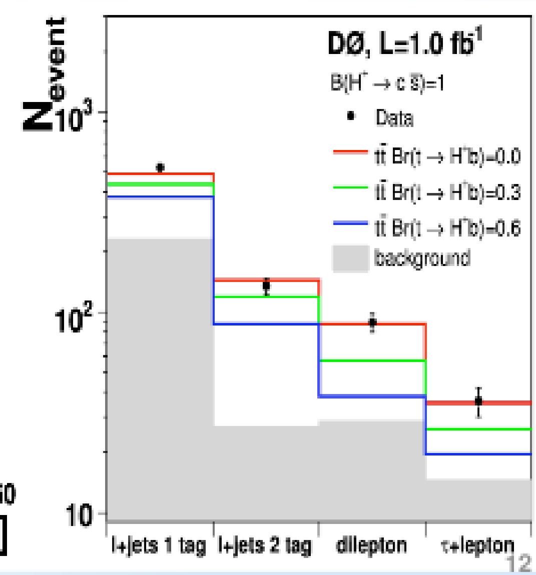
# Charged Higgs

- 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)



# 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

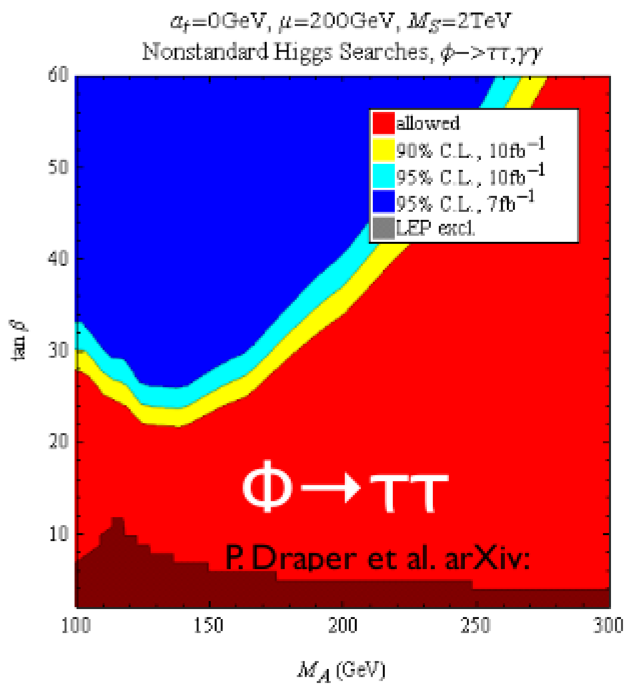
- Five additional parameters due to radiative correction
  - $M_{SUSY}$ (parameterizes squark, gaugino masses)
  - $X_t$ (related to the trilinear coupling $A_t$ → stop mixing)
  - $M_2$ (gaugino mass term)
  - μ (Higgs mass parameter)
  - $M_{gluino}$ (comes in via loops)

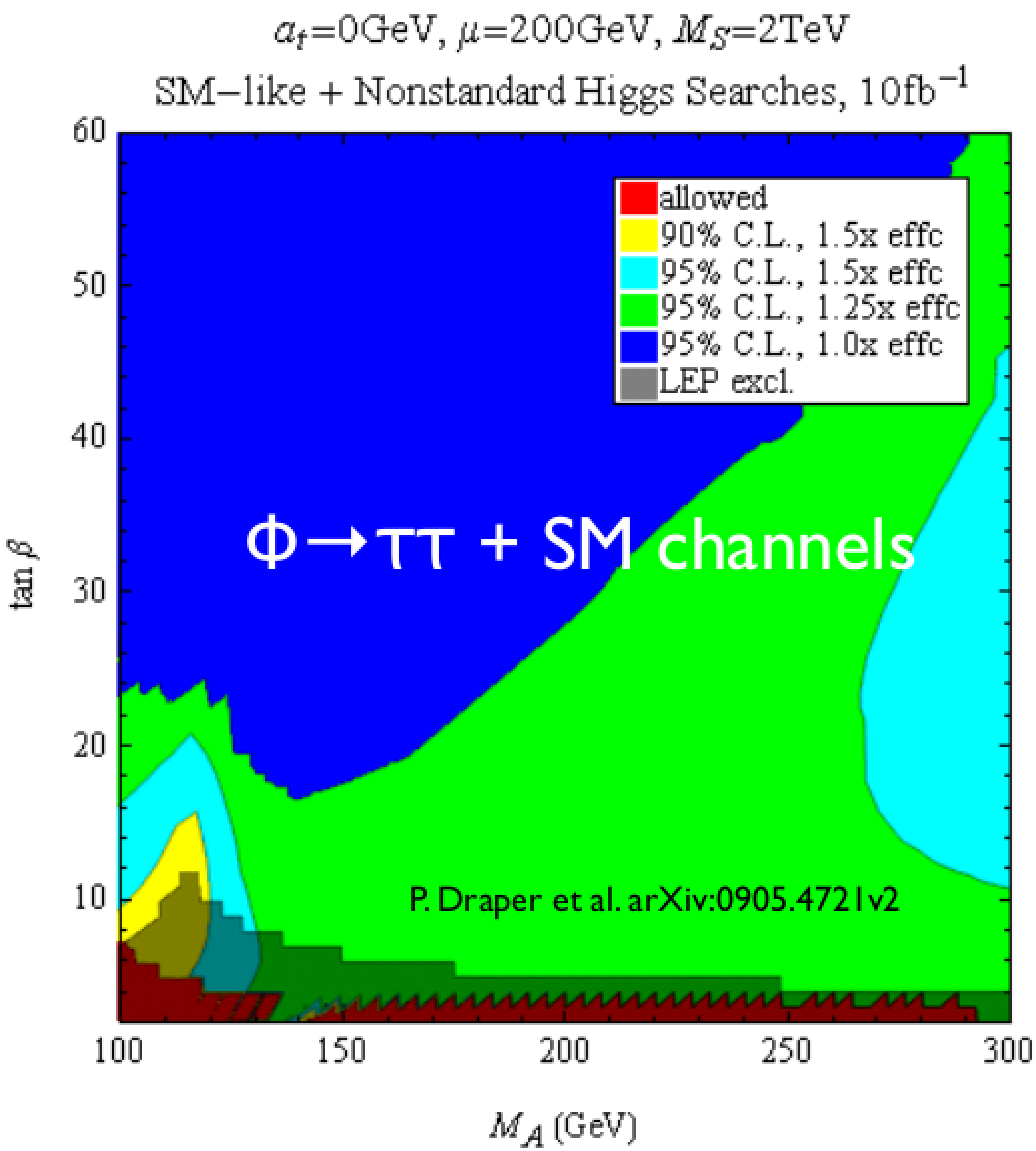
- Two common benchmarks
  - Max-mixing - **Higgs boson mass $m_h$ close to max possible value for a given tanβ**
  - No-mixing - **vanishing mixing in stop sector → small mass for h**

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

# MSSM prospects

## Including SM searches



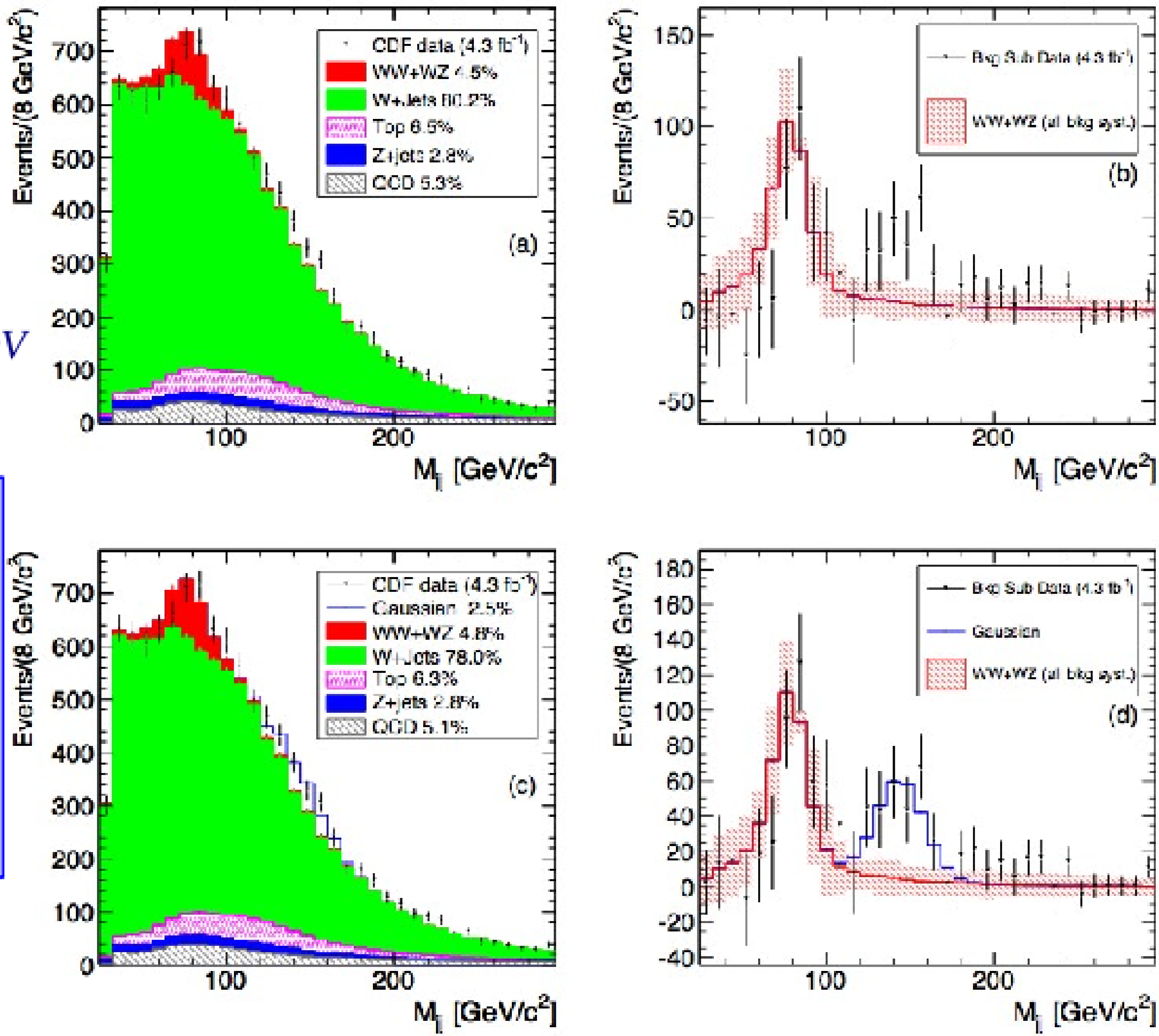



# Di jet invariant mass in association with a W boson

fit with SM template

and SM+gaussian template

$$\sigma_{resolution} = \sigma_W \sqrt{\frac{M_{jj}}{M_W}} = 14.3\,GeV$$




| excess events | |
|---|---|
| electrons | muons |
| **156 ± 42** | **97 ± 38** |
| **excess/expected diboson** | |
| electrons | muons |
| **0.60±0.18** | **0.44±0.18** |

**3.2 sigma excess in the 120-160 GeV mass range**

arXiv: 1104.0699