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Recherches du boson de Higgs avec l'expérience DØ

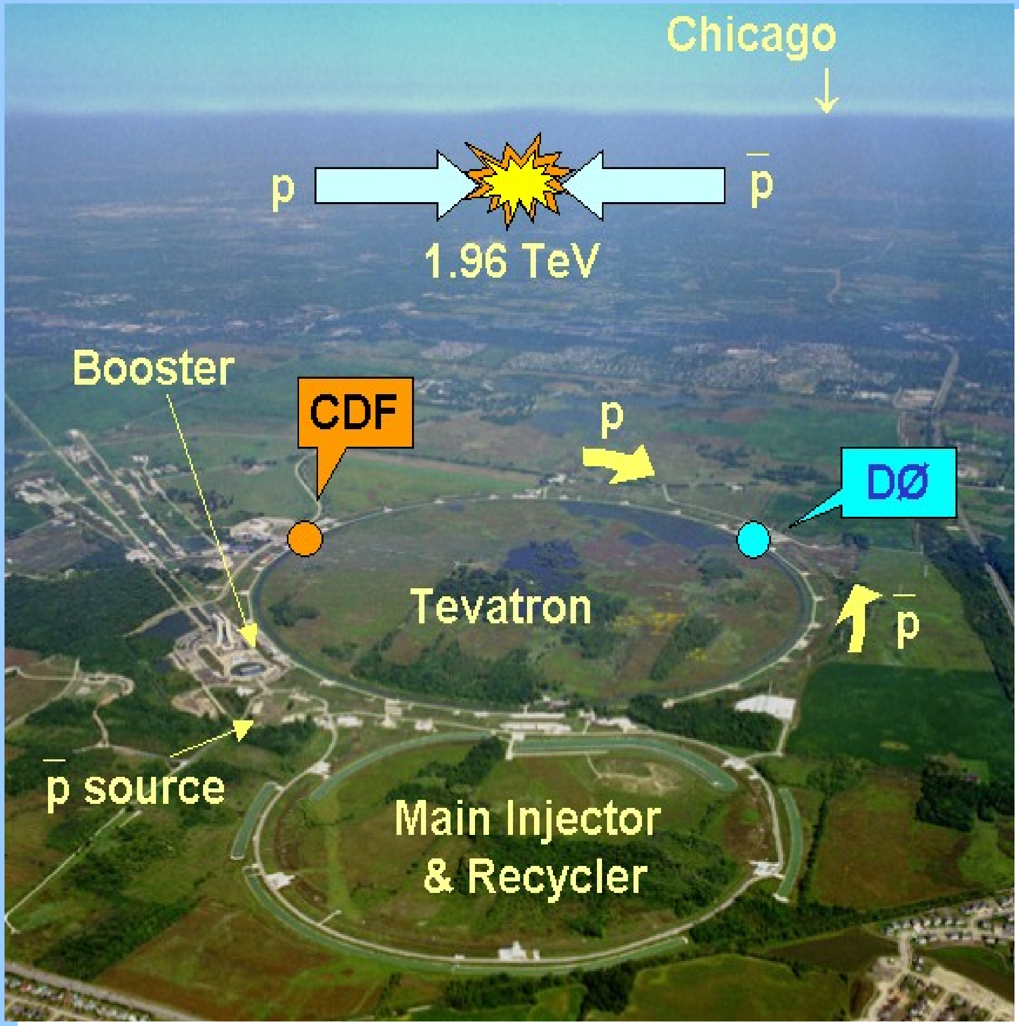
F. Couderc
CEA - Saclay

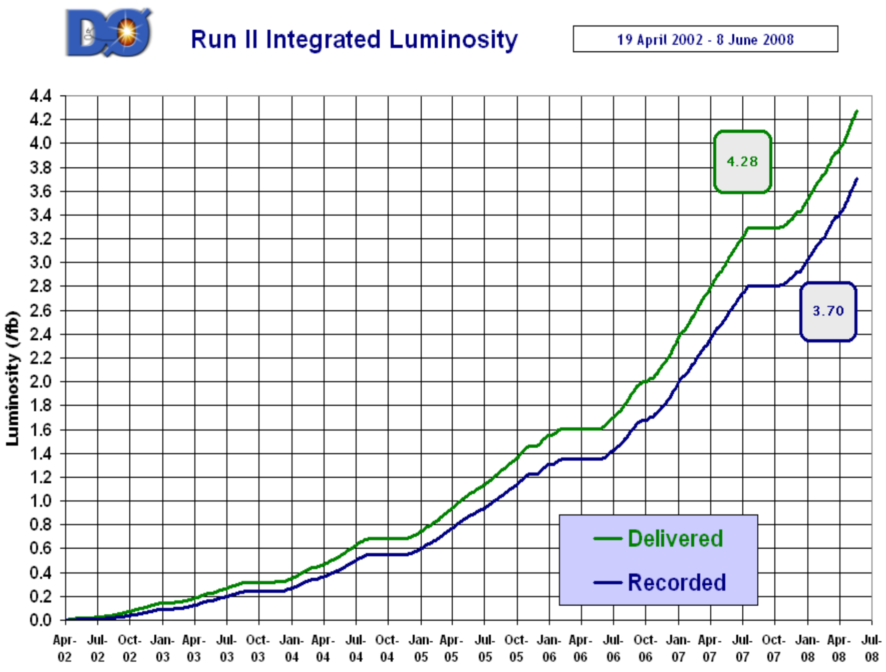
Séminaire LAPP –20 Juin 2008

Overview

- The TeVatron and the D∅ detector
- SM Higgs Boson
  - Low-mass Higgs searches
  - High-mass Higgs searches
  - TeVatron combination
- MSSM Higgs bosons
- Perspectives
- Conclusions

The TeVatron

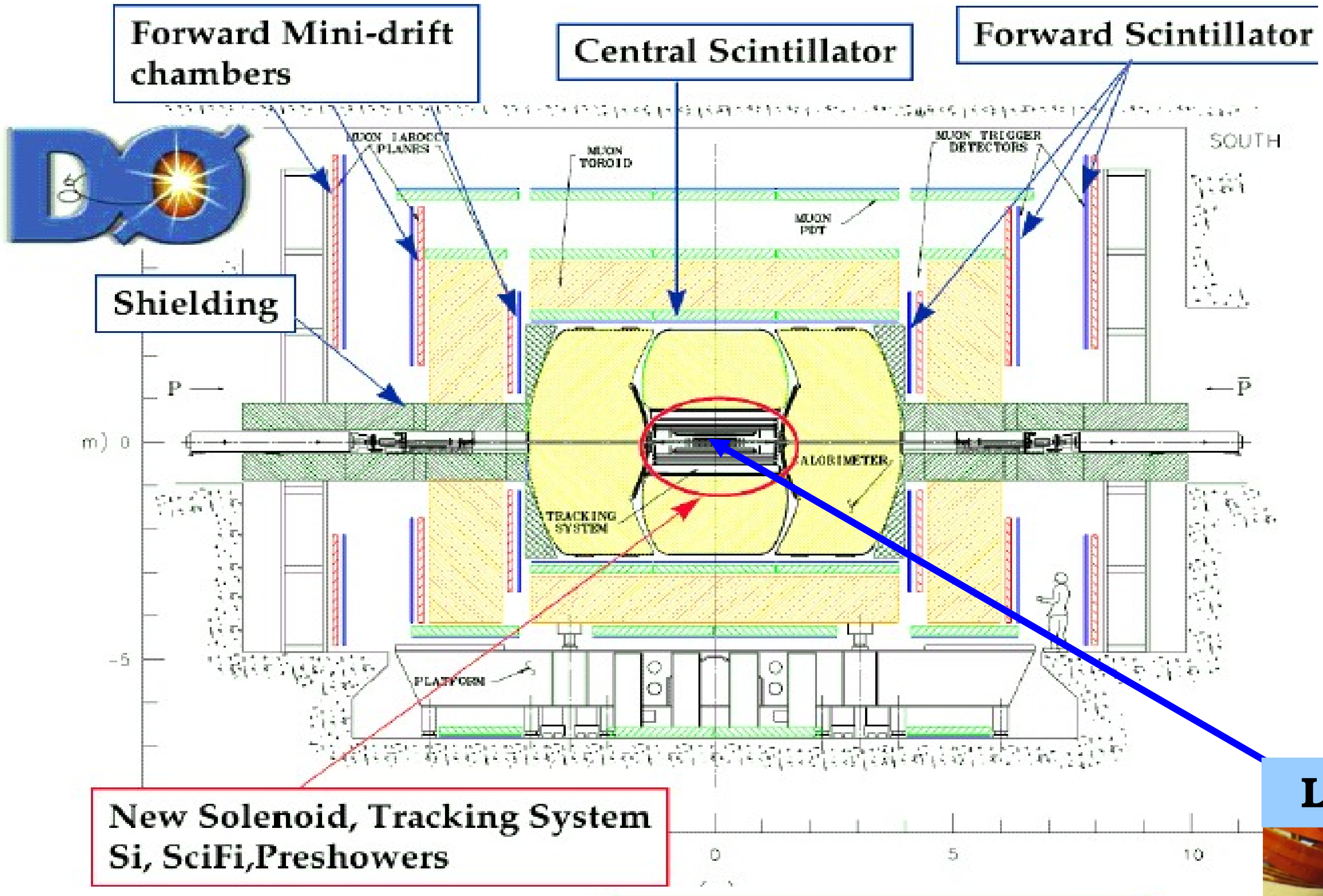




Recorded / Delivered: 4.3 / 3.7 fb^{-1}
Analyzed : 1.0 –2.4 fb^{-1}

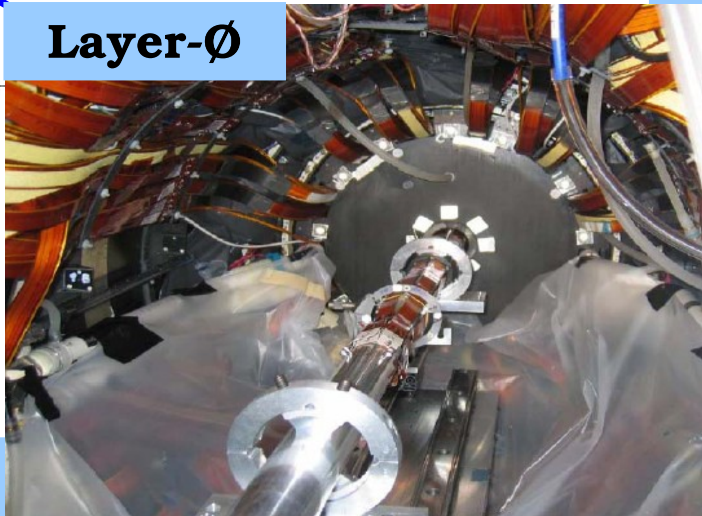
Best peak luminosity: ~ 300E30 cm^{-2}/s^{-1}

DØ detector



+ New Electronics, Trig, DAQ

Multi purpose detector
- silicon vertex detector
- central tracker
- calorimeter (EM/ HAD)
- muon system



Standard Model Higgs boson

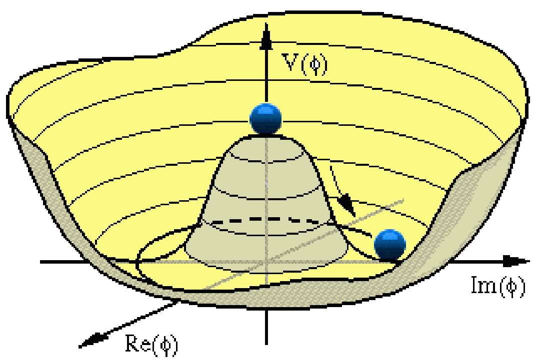
EW symetry breaking: Higgs mechanism

succés de la Théorie électrofaible et de SU(2)xU(1)

MAIS, terme de masse non invariant de jauge

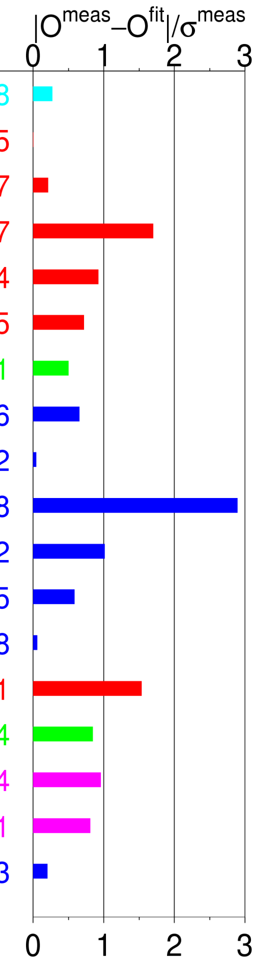
$\Rightarrow$ Particules sans masse!

Mécanisme de Higgs: ajouté un champ scalaire (doublet de SU(2)) avec le bon potentiel



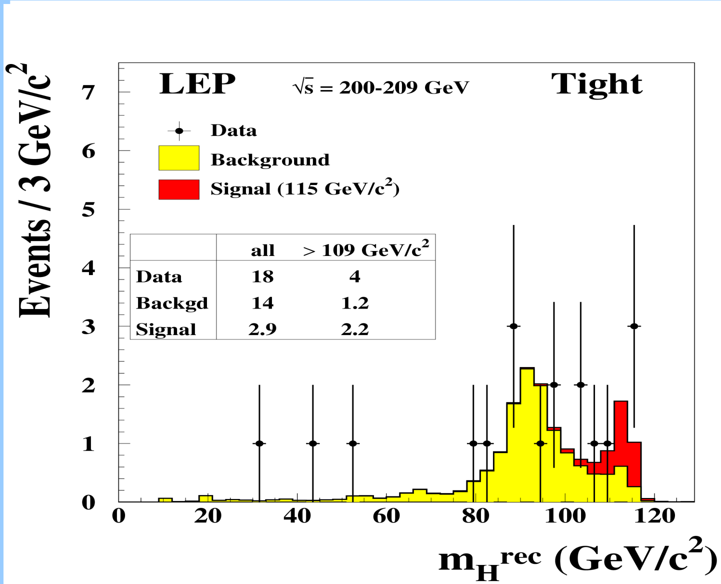
- symétrie de jauge se brise
- bosons de jauges $\rightarrow$ massiques
- couplages de Yukawa
  $\rightarrow$ fermions massiques

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
Γ_W [GeV]	2.140 ± 0.060	2.091
m_t [GeV]	170.9 ± 1.8	171.3

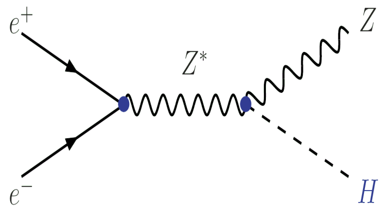


relicat: le boson de Higgs, mais m_H non prédit

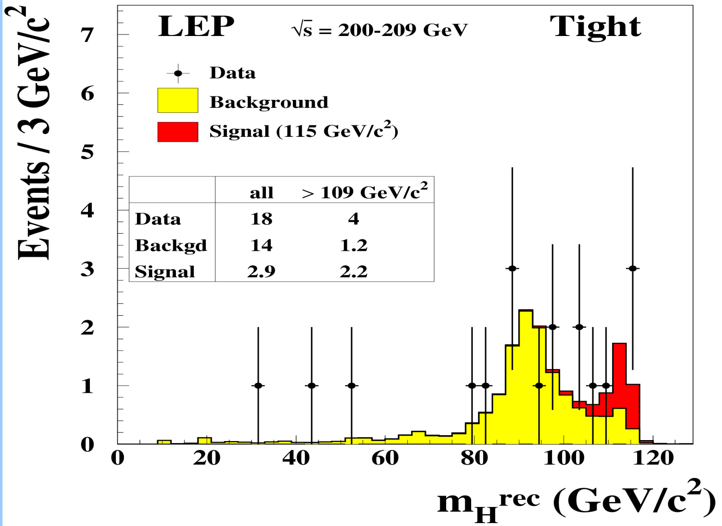
Higgs mass constraints



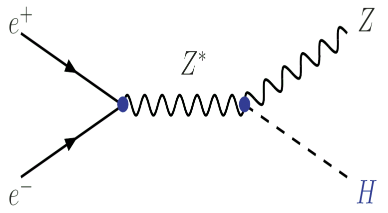
Direct searches at LEP



MH > 114.4 GeV @ 95% CL



Direct searches at LEP

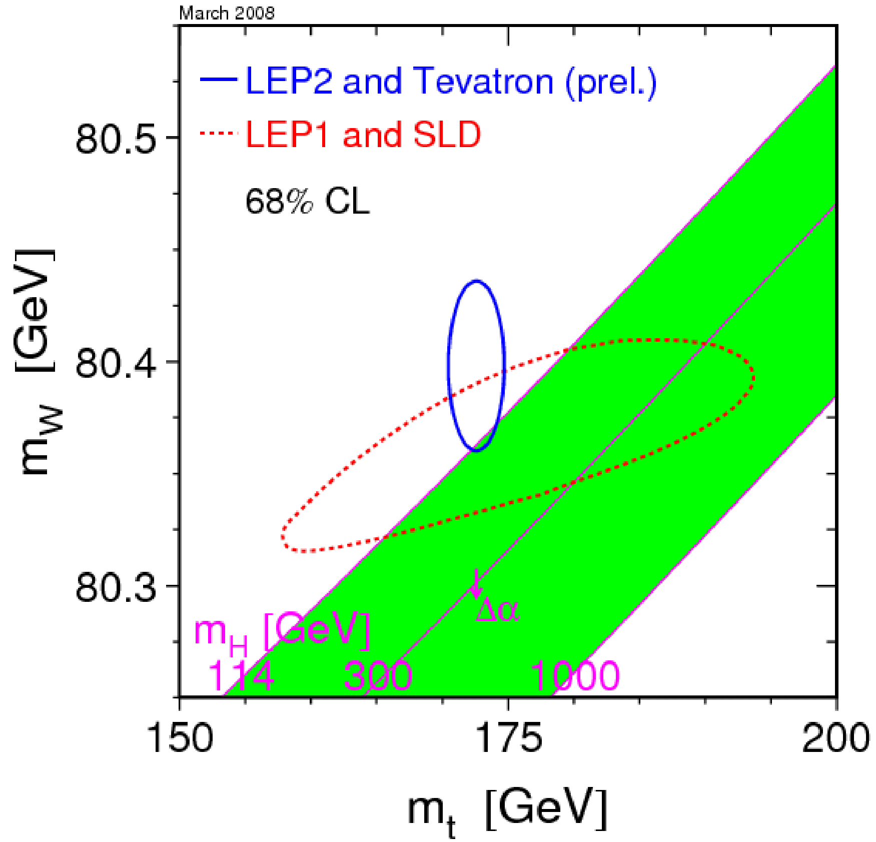


MH > 114.4 GeV @ 95%

Indirect constraints:

m_{top} = **172.6 ± 1.4 GeV/c²** (TeV)

m_W = **80398 ± 25 MeV/c²** (LEP + TeV)



Constraints on the Higgs boson mass

Indirect constraints

m_{top} = **172.6 ± 1.4 GeV/c²** (TeV)

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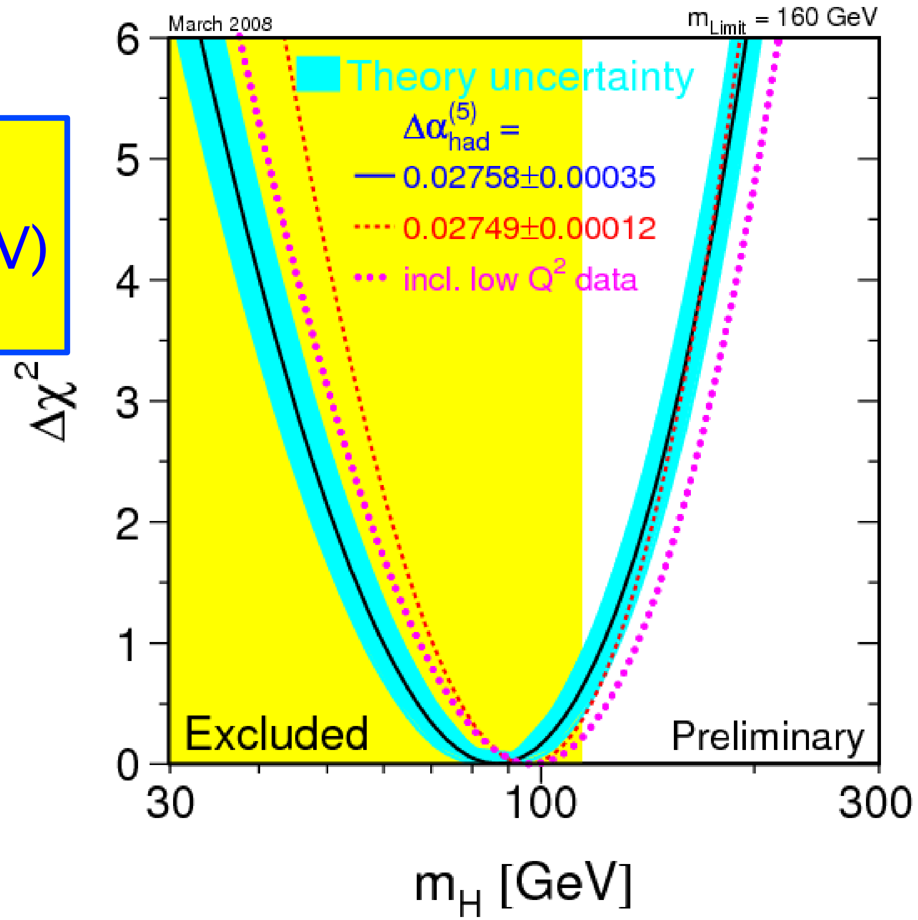
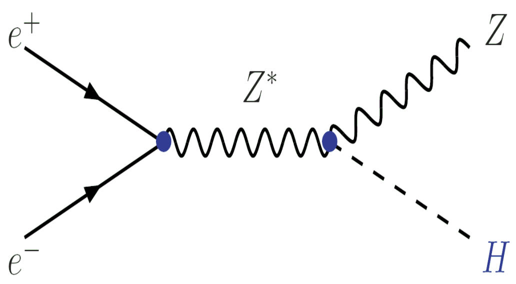


Direct search at LEP:



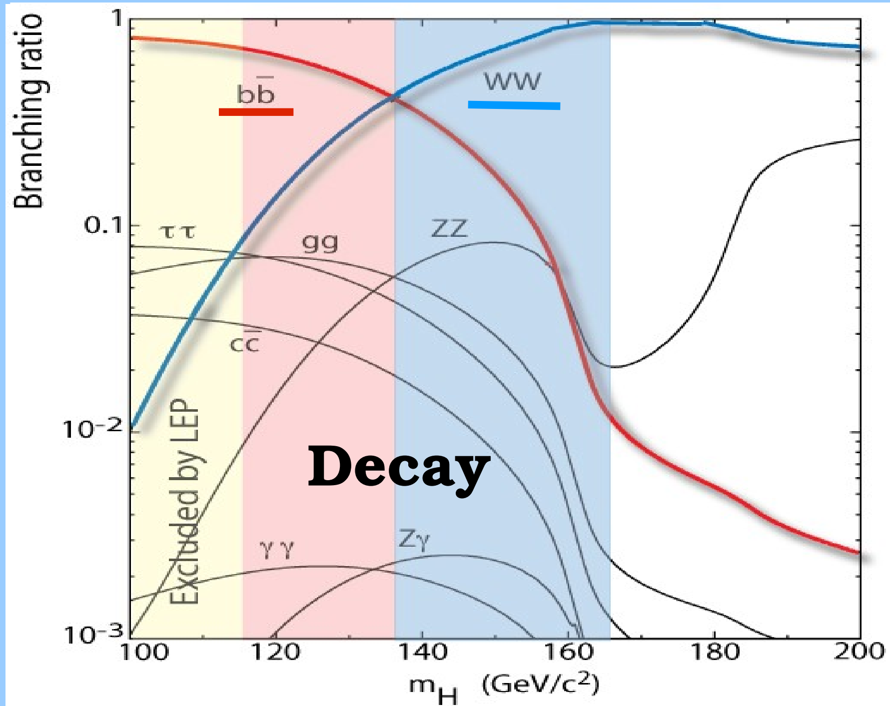
MH > 114.4 GeV @ 95%

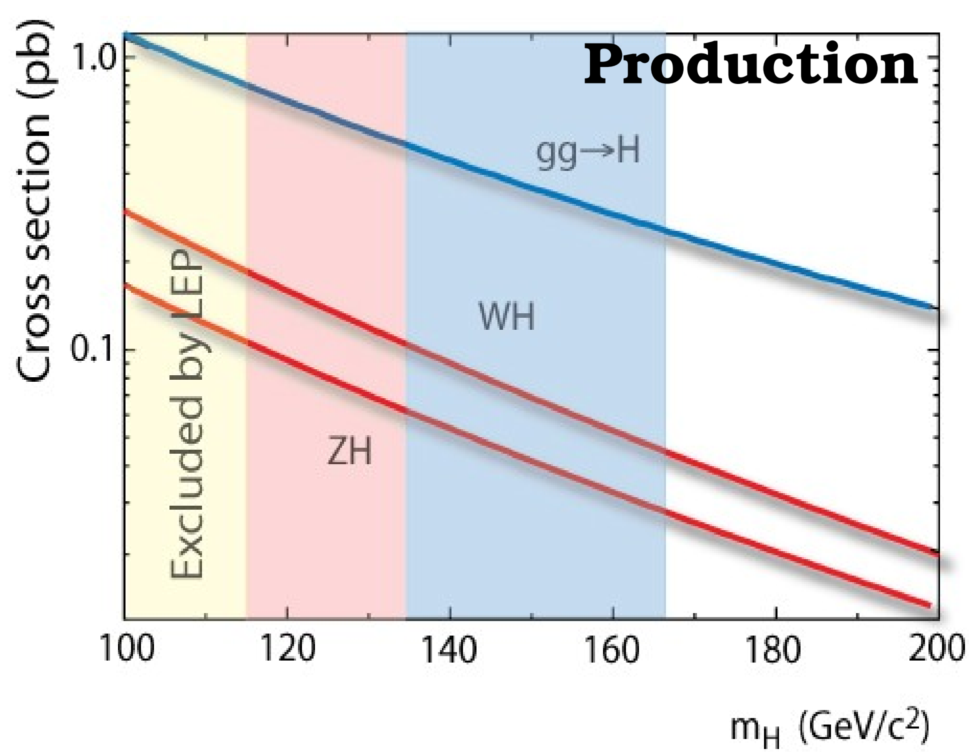
Combination:

MH < 190 GeV/c² @ 95 % CL

MH < 160 GeV/c² (without direct serach)

Search strategy at TeVatron





☛ **Low-mass Higgs** ($m_H < 135$ GeV/c²)

Mainly associated production WH, ZH avec H→bb

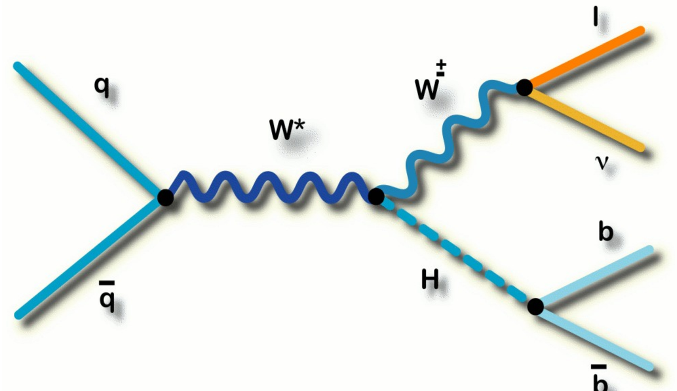
new + inclusive production $H \to \gamma\gamma$

☛ **High-mass Higgs** ($m_H > 135$ GeV/c²)

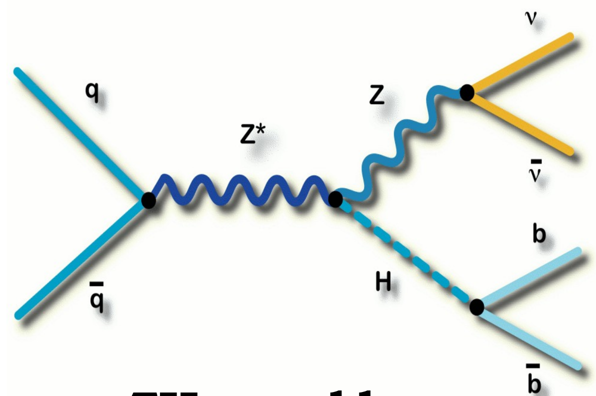
$H \to WW^*$ large branching ratio, "only" electroweak backgrounds (di-boson): search for $gg \to H(X)$

Final states studied

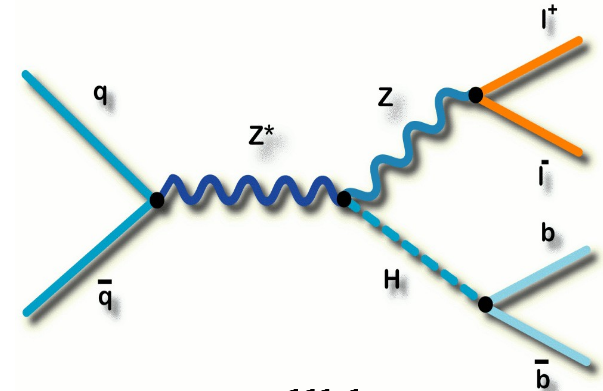
Associated production: low mass, 3 final states



WH→lνbb



ZH→ννbb

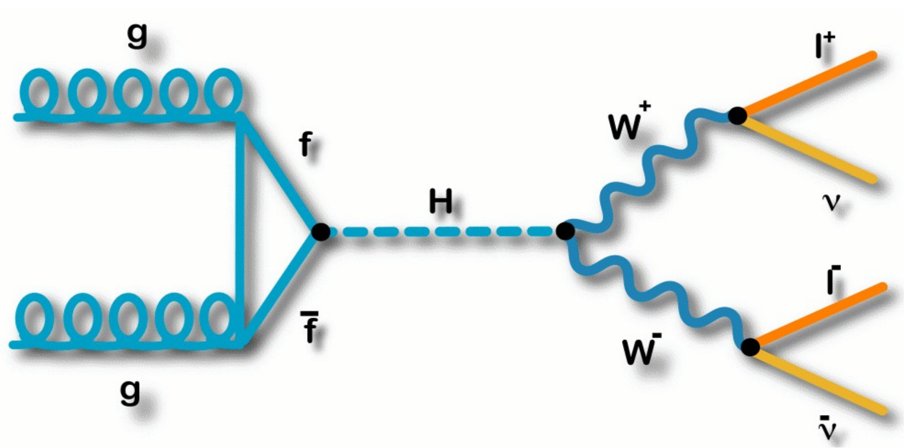


ZH→llbb

Gluon Fusion Production:

Mainly H→WW*→lνlν

high mass,
helpful also at low mass



Signature: high p_T isolated leptons and/or missing transverse energy + high p_T jets for associated production.

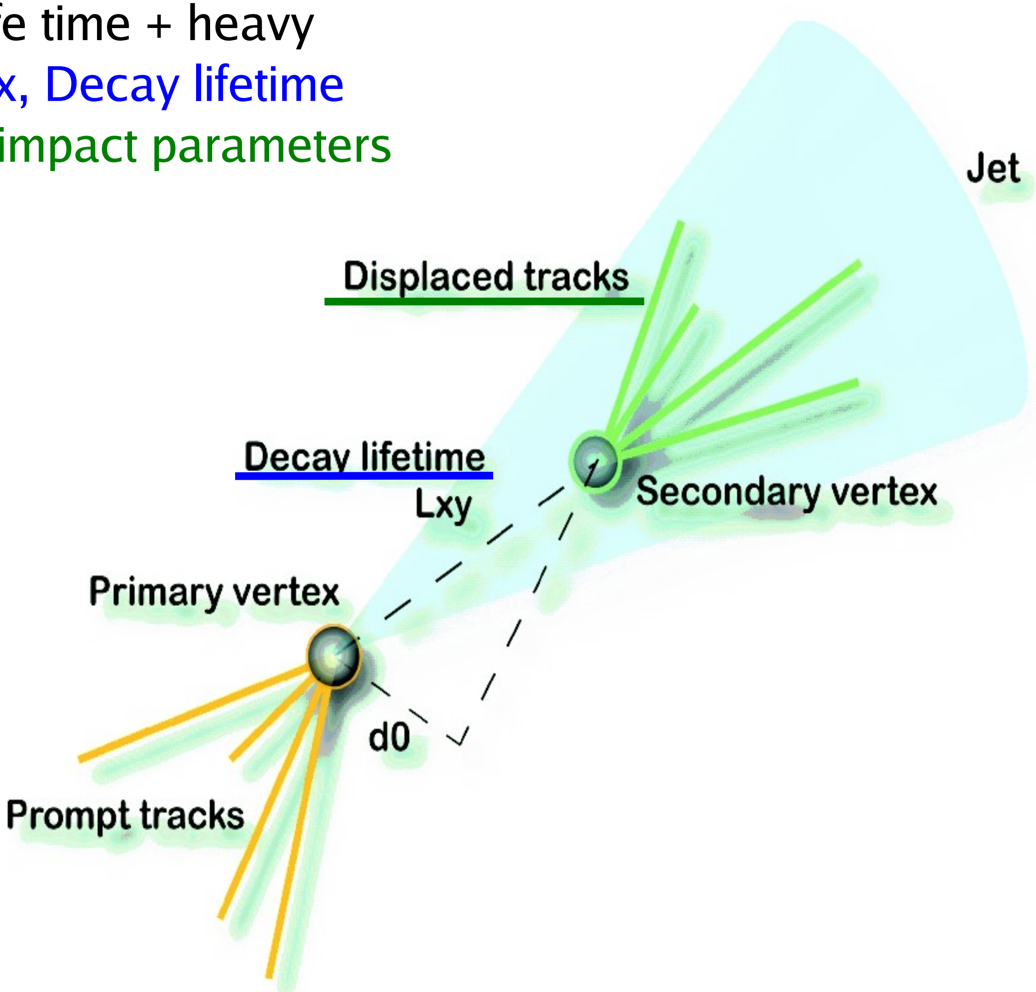
Standard Model: Low-mass Higgs boson searches

The main tool: b-tagging

Search for H → bb, jj background is reducible by

Tagging b-jets

b hadrons: long life time + heavy
- secondary vertex, Decay lifetime
- tracks with high impact parameters
- vertex mass



b-tagging @ D∅:

- kinematics informations combined in a Neural Network

↳ efficiency (b): 50 / 70 %
↳ fake rate (j) : 0.5 / 4.5 %

Electroweak V+jets backgrounds

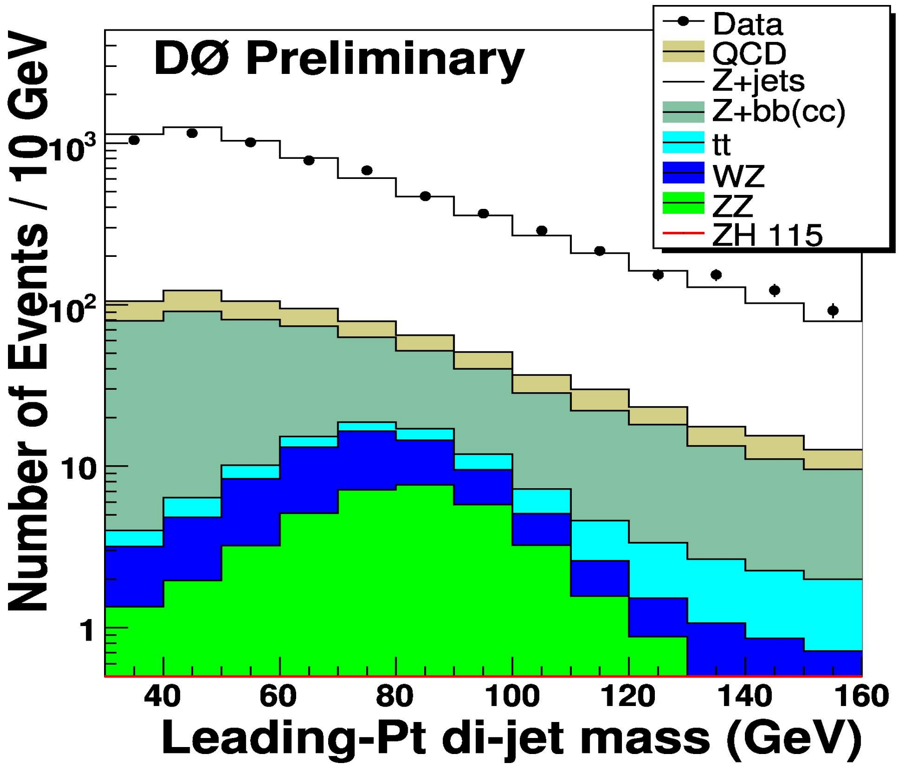
Search for W/Z H with H$\rightarrow$ bb

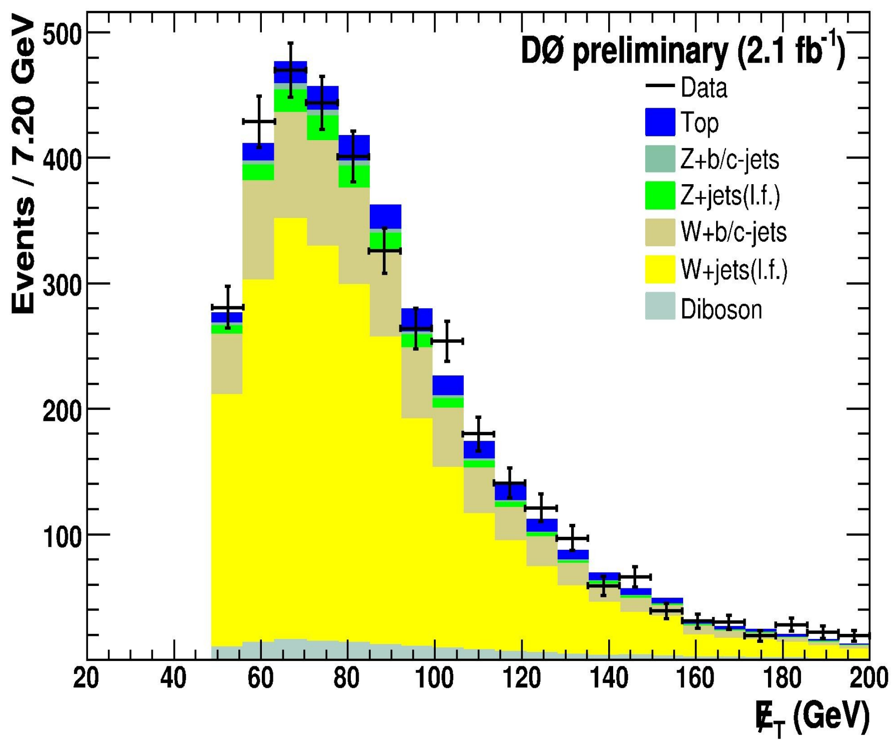
$\Rightarrow$ W/Z + jj/cc/bb are the largest backgrounds

Simulation from MC + data:

* kinematics from LO (Alpgen) simulation
* normalization (cross section) corrected from (N)NLO/LO
* still not enough:
  - create enriched W/Z + jets samples
  - before b-tagging Higgs signal negligible
  - normalize to data in those samples before b-tagging
  - σ[V+bb(cc)] / σ[Vinclusive] kept from simulation (after NLO correction)

Electroweak V+jets backgrounds





Normalize Z+jets before b-tagging:
- select 2 isolated leptons
- cut on mll invariant mass
- estimate other bkgs
- normalize

Normalize W+jets before b-tagging:
- select 1 isolated muon
- cut on $\not{E}_T$
- estimate other bkgs
- normalize

Other backgrounds

- Top production:
  - ttbar + single top use simulation only
  - Discriminate on the total energy of objects in the event
- Di-boson:
  - WW/WZ small backgrounds
  - Can discriminate on di-jet mass (W or Z vs H)
- QCD:
  - Hard to model especially cross sections
  - From data using QCD enriched sample (lepton isolation)
  - Need a good E_T resolution and lepton id.

A first example: ZH → νν bb

Experimental signature:

2.1 fb^{-1}

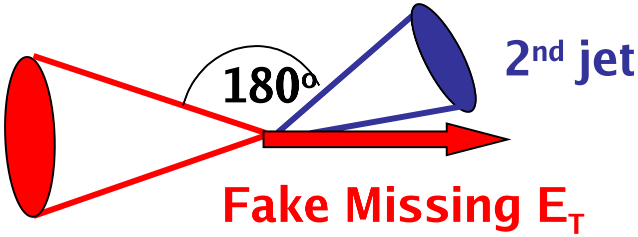
missing E_T (> 50 GeV) + 2 high p_T jets (p_T > 15 GeV/c)

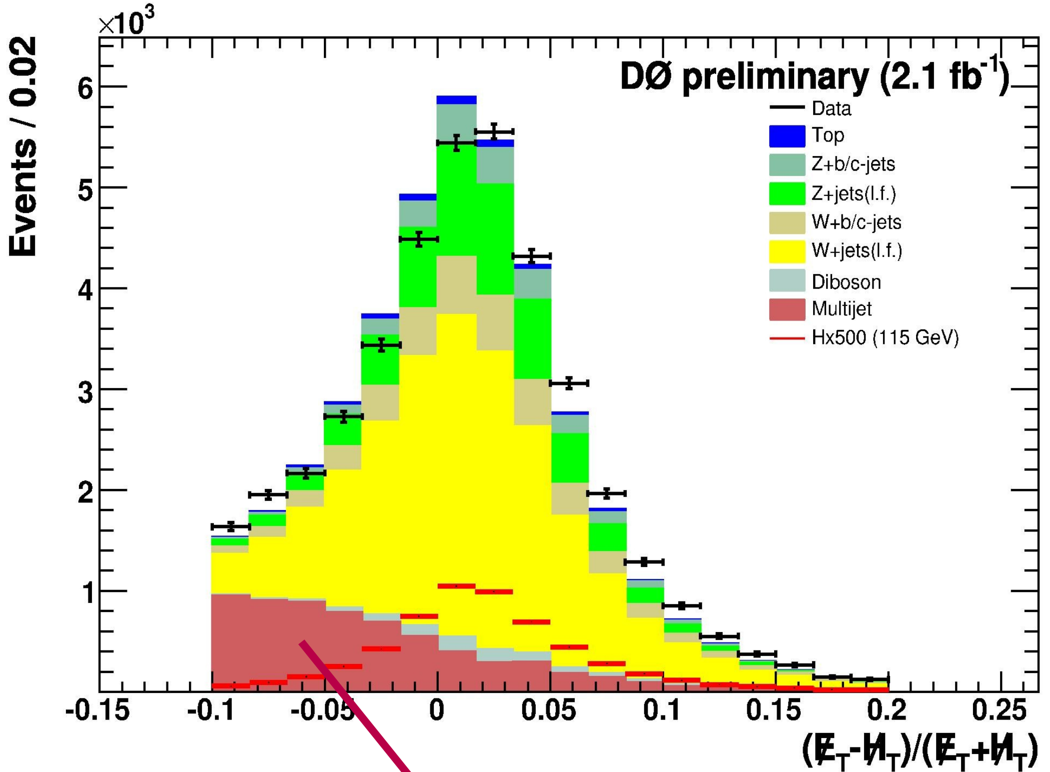
Backgrounds

* Electroweak Vjj, Vcc, Vbb
* QCD jj, bb : data.

Exploits the difference between the missing energy measured:

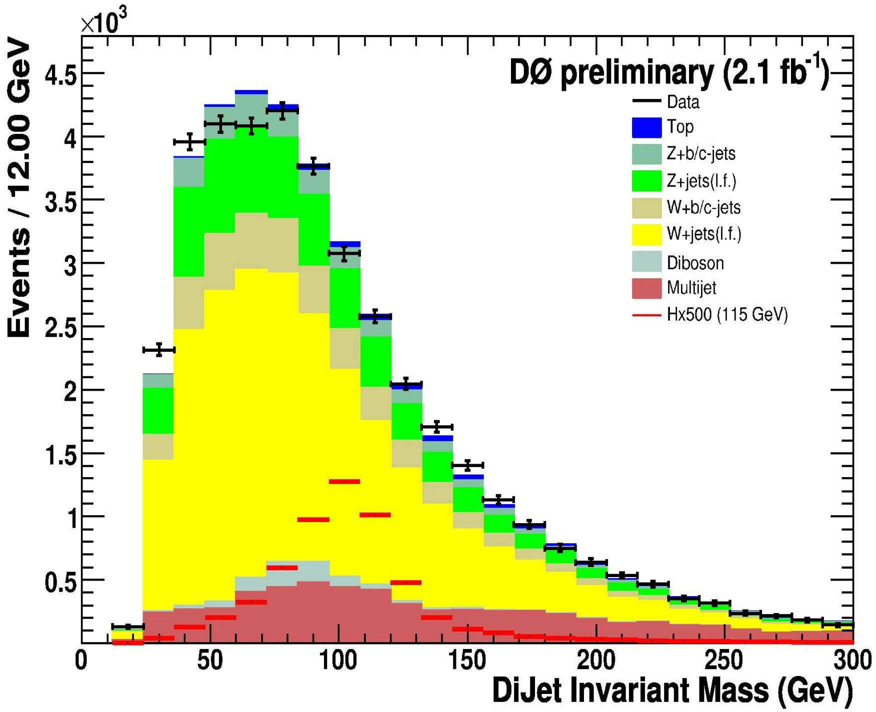
- in the calorimeter ($\not{E}_T$)
- only with jets ($\not{H}_T$)
- in the tracker ($\not{p}_T$)



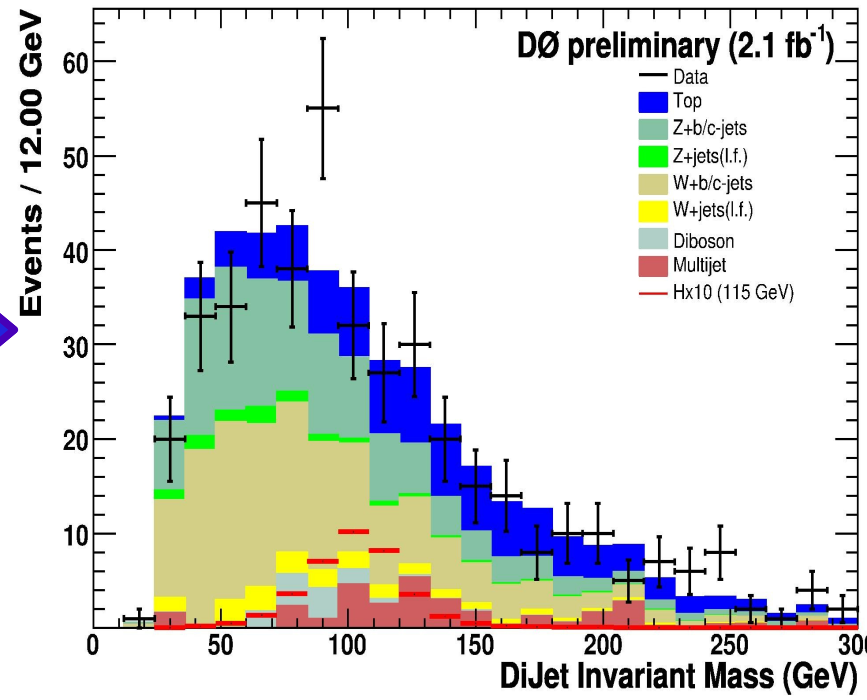


From a QCD background sample requiring: $\not{E}_T$ and $\not{p}_T$ are **not** compatible

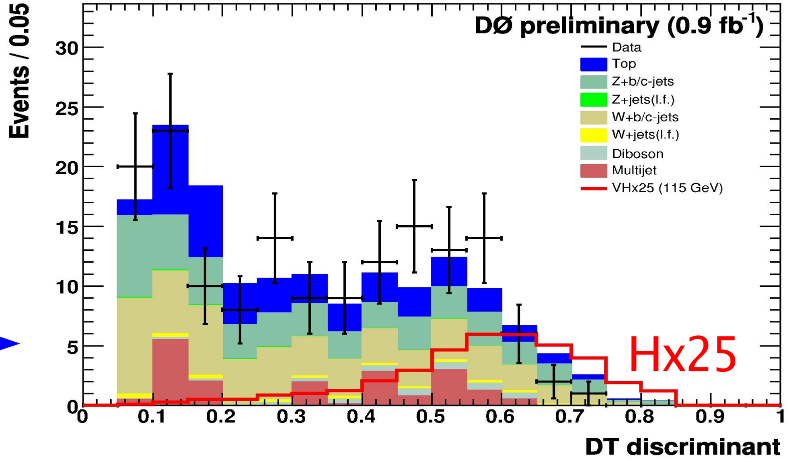
A first example: ZH →νν bb



Require
2 b-tagged
jets



Improving the sensitivity:
- b-tagging: 2 b-tagged jets
- multivariable discriminant:
combine several discri. variables into a Boosted Decision Tree (BDT).



A second example: $WH \to \nu \ell bb$

Experimental signature:

1.7 fb^{-1}

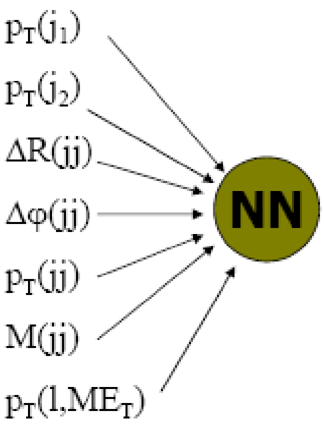
1 isolated lepton (from the W) + missing E_T + 2 high p_T jets

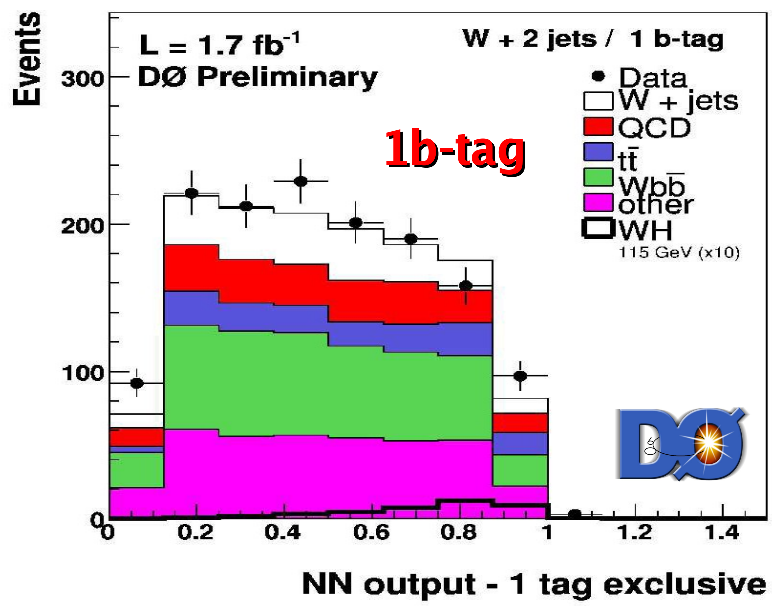
Backgrounds

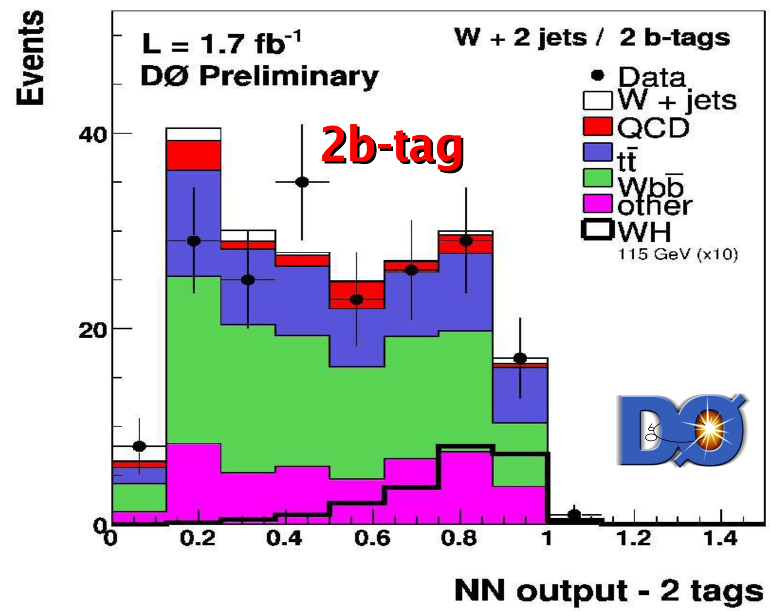
* Electroweak V+jets, di-boson
* Top
* QCD bb: data (invert iso cut)

Improve sensitivity

* 1 and 2 b-tagged jets
* lepton ≡ e or mu
* use a NN







Standard Model: High-mass Higgs boson searches

High mass: $H \to WW^* (l\nu l'\nu)$

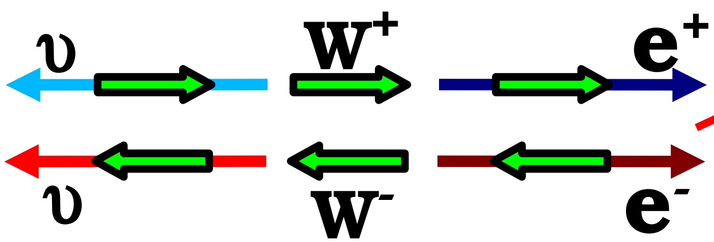
Experimental signature:

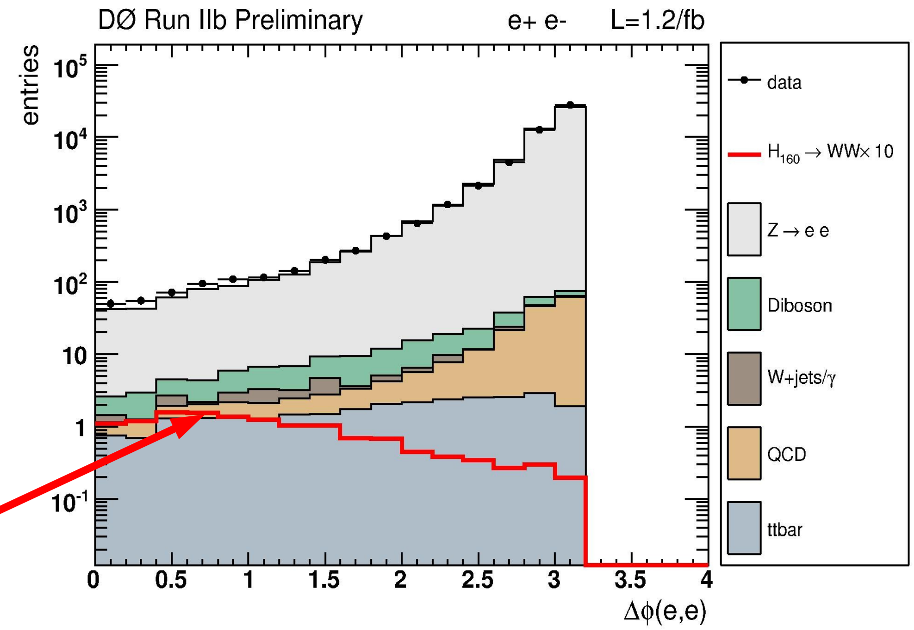
1) 2 high p_T leptons:ee, eμ, μμ

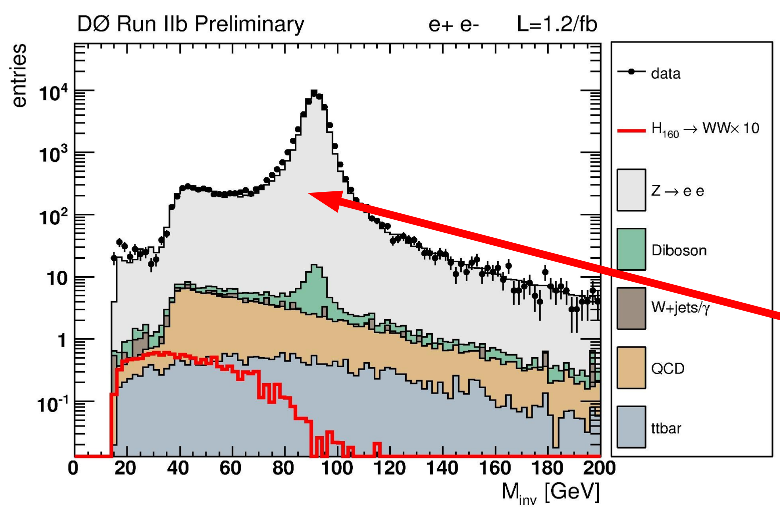
2) large m_{ET} (2 neutrinos)

3) Higgs is a scalar:

~ collinear leptons







Backgrounds

- Dibosons: WW / WZ / Wγ
- Drell yan (2 leptons with opposite charge!)

High mass: H → WW* (lνl'ν)

Probability to observe the kinematic configuration "*obs*" assuming the processus is *m*.

$$P_m(x_{obs}) = \frac{1}{<\sigma_m>} \int \frac{d\sigma_m^{th}(y)}{dy} \epsilon(y) G(x_{obs}, y) dy$$

ME of m + PDFs

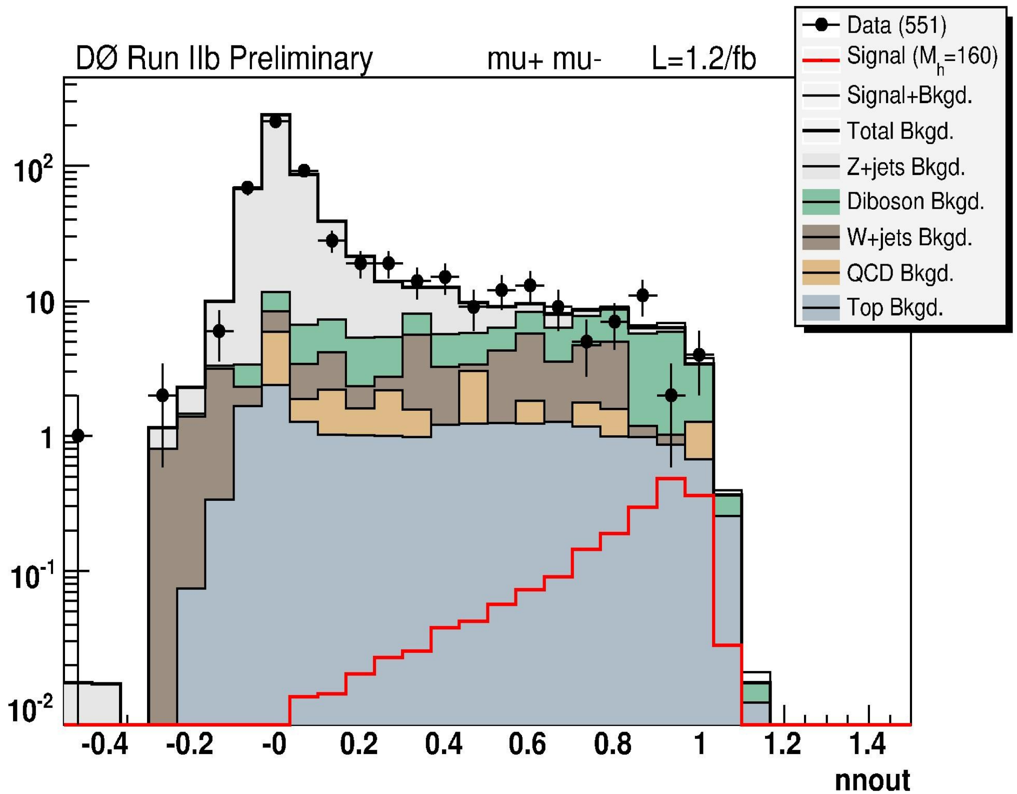
Transfer function

Improve sensitivity with

Neural Network: →

Matrix element discriminant

\+ kinematic variables



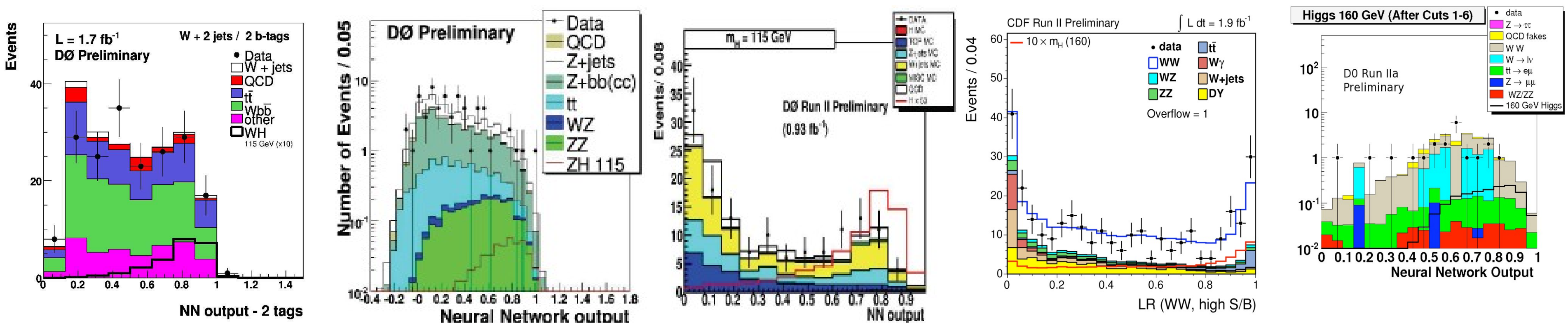
Standard Model searches: Combination before ICHEP 08

TeVatron SM Higgs searches

Channel	CDF Lumi	D0 Lumi	Final State	Exp. (Obs) Upper Limits / SM @ MH (GeV)
WH → lν bb	1.9 fb-1	1.7 fb^{-1}	e/μ, 1b/2b	D0: 8.9 (11) @ 115 GeV CDF: 6.4 (6.4) @115 GeV
ZH→ll bb	1.0 fb-1	1.1 fb^{-1}	e/μ, 1b/2b	CDF: 16 (16) @115 GeV D0:20 (18) @ 115 GeV
ZH → νν bb	2.1 fb^{-1}	1.7 fb^{-1}	Z→ νν/W→ l ν, 2b	D0: 8.4 (7.5) @115 GeV CDF:8.3 (8.0) @115 GeV
H → ττ (gg, VBF,WH,ZH)	2.1 fb^{-1}	---	τ + 2 jets	CDF: 25 (31) @ 115 GeV
H → γγ	---	2.3 fb^{-1}	γγ	D0: 50 (55) @115 GeV
H → WW*	2.3 fb^{-1}	2.4 fb^{-1}	ee, eμ, μμ	D0: 2.4 (2.1) @ 160 GeV CDF:2.5 (1.6) @160 GeV
WH→ WWW*	1.9 fb^{-1}	---	e+e+, e+μ+, μ+μ+	CDF: 35 (33) @ 160 GeV

Combining everything

- A real nightmare
- Combine 28 different channel to get the full sensitivity
- Different techniques at D∅ and CDF, gives compatible results within 10%
- All correlations between systematics are taken into account



...

A word on systematics

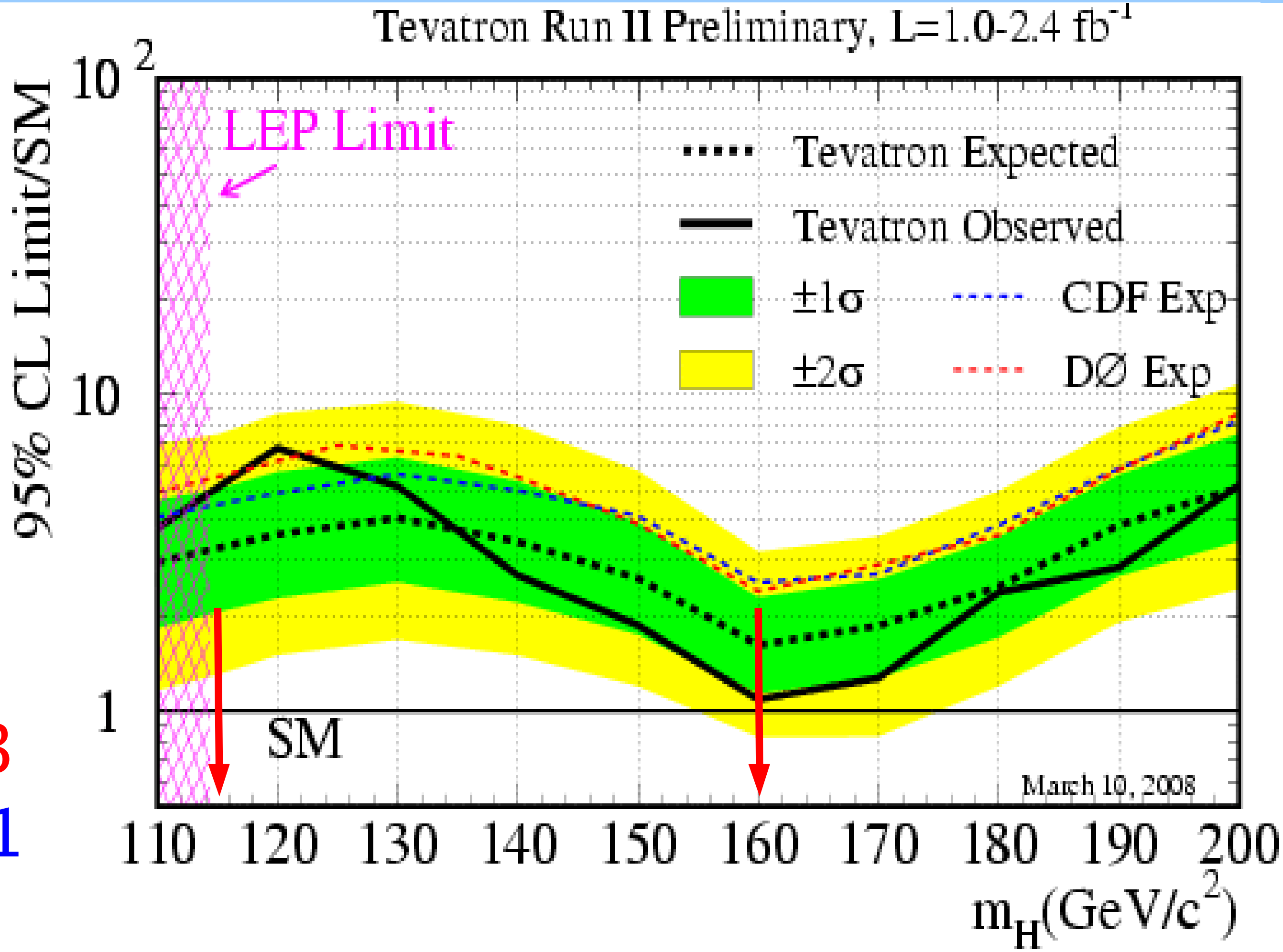
Source	$WH \to e\nu b\bar{b}$ DT(ST)	$WH \to \mu\nu b\bar{b}$ DT(ST)	$WH \to WW^+W^-$	$H \to W^+W^-$
Luminosity (%)	6.1	6.1	-	-
Normalization (%)	-	-	6.1	4-6
Jet Energy Scale (%)	3.0	3.0	0	3.0
Jet ID (%)	3.0	3.0	-	-
Electron ID/Trigger (%)	6.0	-	11	3-10
Muon ID/Trigger (%)	-	11.0	11	7.7-10
b-Jet Tagging (%)	9.2(4.6)	9.2(4.6)	-	-
Background σ (%)	6-20	6-20	6-18	6-18
Signal σ (%)	0	0	0	10.0
QCD multijets (%)	14	14	30-50	15-40

Source	$ZH \to \nu\bar{\nu}b\bar{b}$	$ZH \to e^+e^-b\bar{b}$ DT(ST)	$ZH \to \mu^+\mu^-b\bar{b}$ DT(ST)	$H \to \gamma\gamma$
Luminosity (%)	6.1	6.1	-	6.1
Normalization (%)	-	-	6.1	-
Jet Energy Scale (%)	3.0	2.0	2.0	-
Jet ID (%)	2.0	5.0	5.0	-
Jet Triggers (%)	5.5	-	-	-
Electron ID/Trigger (%)	0	4.0	-	12-17
Muon ID/Trigger (%)	0	-	4.0	-
b-Jet Tagging (%)	6.0	7.5(3.0)	7.5(3.0)	-
Background σ (%)	6-16	10-30	10-30	5-26
Heavy-Flavor Scale (%)	50	-	-	-
QCD multijets (%)	-	41-50	50	20

TeVatron combination

We plot:

$$\frac{\text{Cross section @ limit}}{\text{Cross section for SM}}$$



MH = 115 GeV/c^2
Limit Exp / SM = 3.3
Limit Obs / SM = 5.1

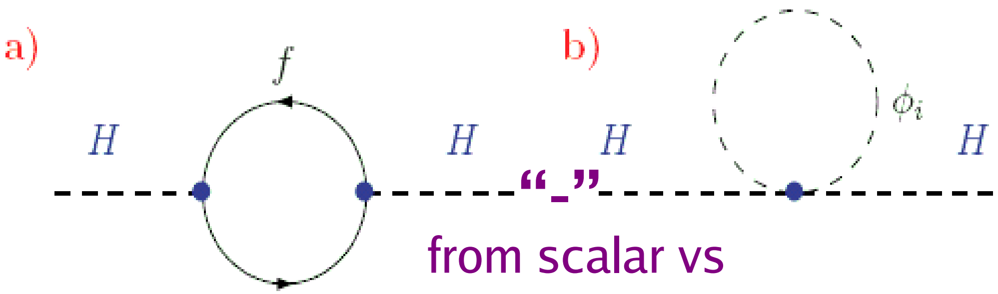
MH = 160 GeV/c^2
Limit Exp / SM = 1.6
Limit Obs / SM = 1.1

Almost there at 160 GeV!

EW symmetry breaking in the Minimal Supersymmetric Standard Model (MSSM)

SUSY in a nutshell

- SUSY relates bosons to fermions. But it requires a complete set of new particles ("s"-particles) : can not "only" relate known bosons to known fermions
- One of the main appeals: it solves naturally the hierarchy problem provided that $m_{Fermion}$ close to m_{Scalar}



"-"

from scalar vs fermions loops

$$= \Delta M_H^2 = \frac{\lambda_f^2 N_f}{4\pi^2}\left[(m_f^2 - m_S^2)\log\left(\frac{\Lambda}{m_S}\right)\right.$$

Quadratic divergences cancel out, only logarithmic ones remain !

⇒ New particles masses should not be much higher than TeV

⇒ Can be produced "on-shell" at the Tevatron/LHC! (direct searches)

The MSSM Higgs sector

- **SUSY requires at least 2 Higgs doublets** (to cancel higgsino contribution to triangle anomalies, structure of superpotential)

MSSM: exactly 2 doublets

⇒ 1 couples to down (up) quarks with vev v_d (v_u): $\tan\beta = v_d/v_u$.

NB: if $\tan\beta \approx 35 \Rightarrow \lambda_{top} \approx \lambda_{bottom}$... large $\tan\beta$ regime appealing

⇒ EW breaking: 5 physical states

- h/H and A
- H^+, H^-

- At tree level, Higgs sector described by M_A and $\tan\beta$

⇒ M_h, M_H and $M_{H\pm}$ related M_A and $\tan\beta$ (tree level only)

⇒ There MUST be a light Higgs boson M_h < 135 (150) GeV/c^2.

The MSSM Higgs sector

- Results at Tevatron are usually interpreted in 2 benchmark scenarii called m_h^{max} and no-mixing.

Common set of parameters

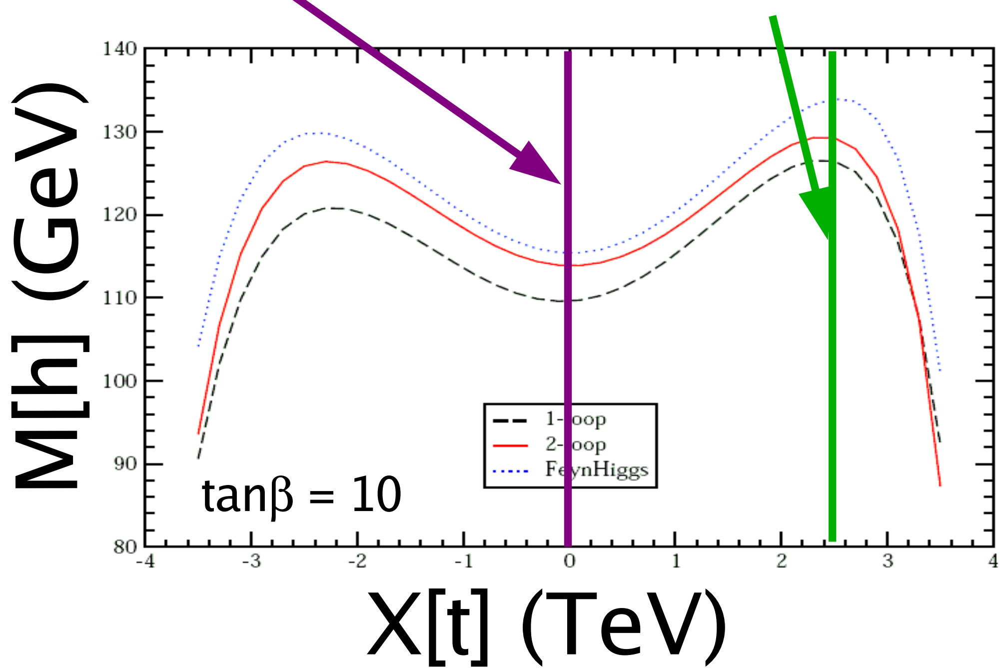
$$
\begin{aligned}
m_t &= 174.3\ \text{GeV},\\
M_{\text{SUSY}} &= 1000\ \text{GeV},\\
\mu &= -200\ \text{GeV},\\
M_2 &= 200\ \text{GeV},\\
A_b &= A_t,\\
m_{\tilde{g}} &= 0.8\, M_{\text{SUSY}}\ .
\end{aligned}
$$

Sign of μ is usually varied

Differences in the stop mixing parameter X_t

No-mixing scenario
$X_t = 0$, ($M_S = 2$ TeV)

Maximal mixing scenario
$X_t = 2.45\times M_{SUSY}$



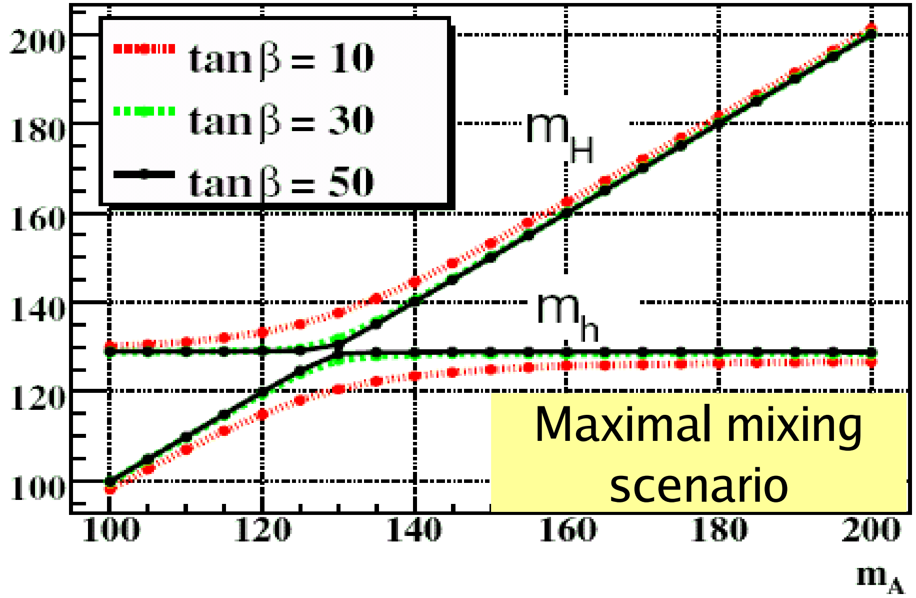
large tanβ regime

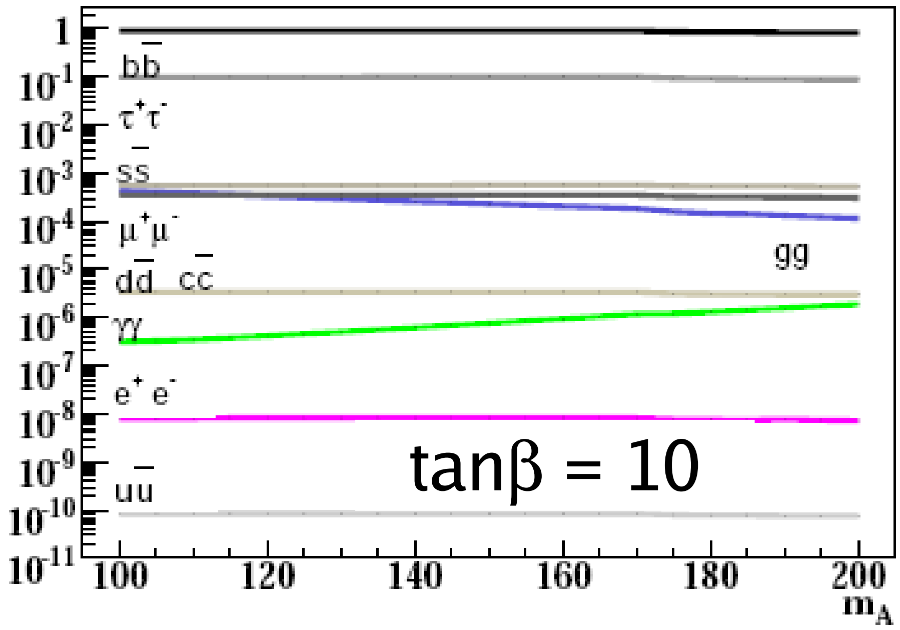
- h/A or H/A or h/H/A are degenerated in mass
- A (+ h or H) coupling to down quark enhanced by tanβ

only 2 decay modes available for neutral higgs !

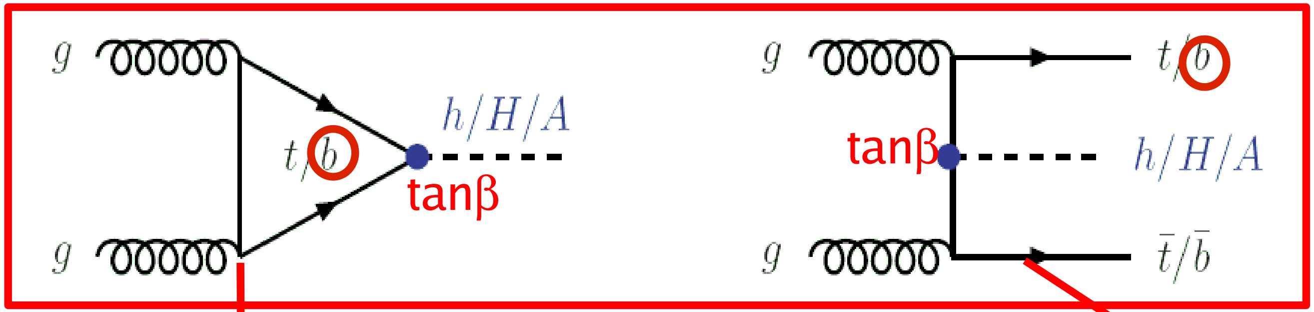
$\Rightarrow \mathcal{B}(\Phi \to bb) \approx 90\%$; $\mathcal{B}(\Phi \to \tau\tau) \approx 10\%$ where $\Phi \equiv$ h/H/A

$\Rightarrow$ If $m_{H+} < m_{top}$, $\mathcal{B}(H^+ \to \tau\upsilon) \approx 1$





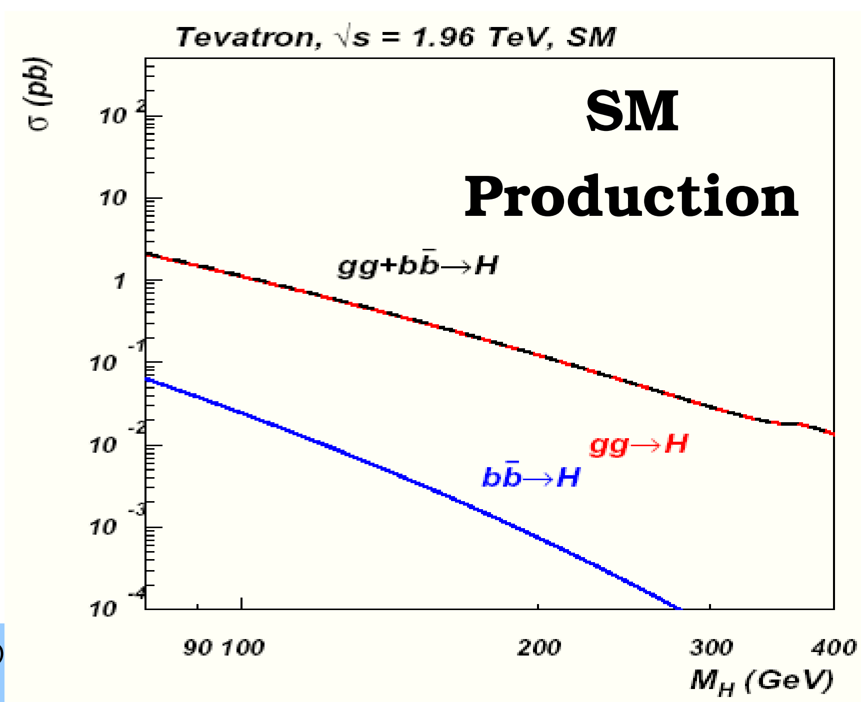
Searches for neutral Higgs bosons

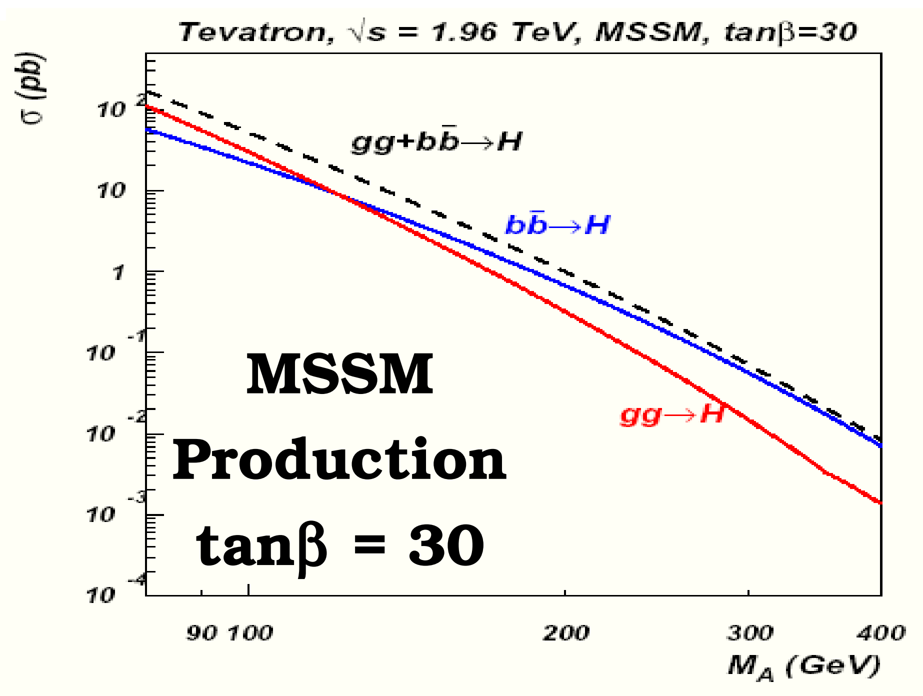


If tanβ >> 1
$\mathcal{B}(\Phi \to bb) \approx 90\%$
$\mathcal{B}(\Phi \to \tau\tau) \approx 10\%$

Susy : h/H/A $\to\tau\tau$
bb out of reach
(QCD background)

Both h/H/A →bb and
h/H/A $\to\tau\tau$ possible
---> 1 additional b-jet





The very first try

First search by CDF RunI data : 100 pb^{-1}

search for bh->bbb: looks like to be the golden channel to discover a susy Higgs at the TeVatron.

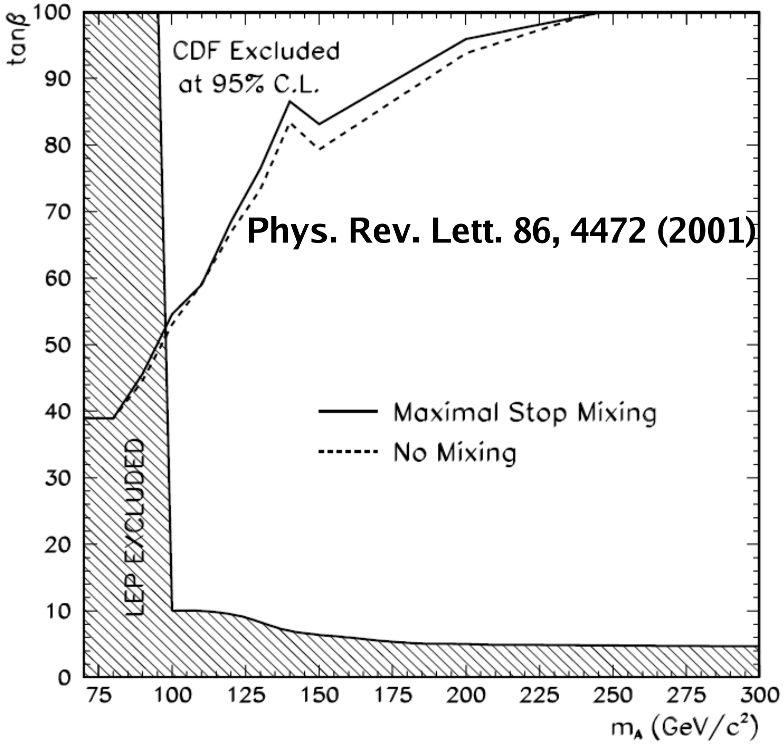
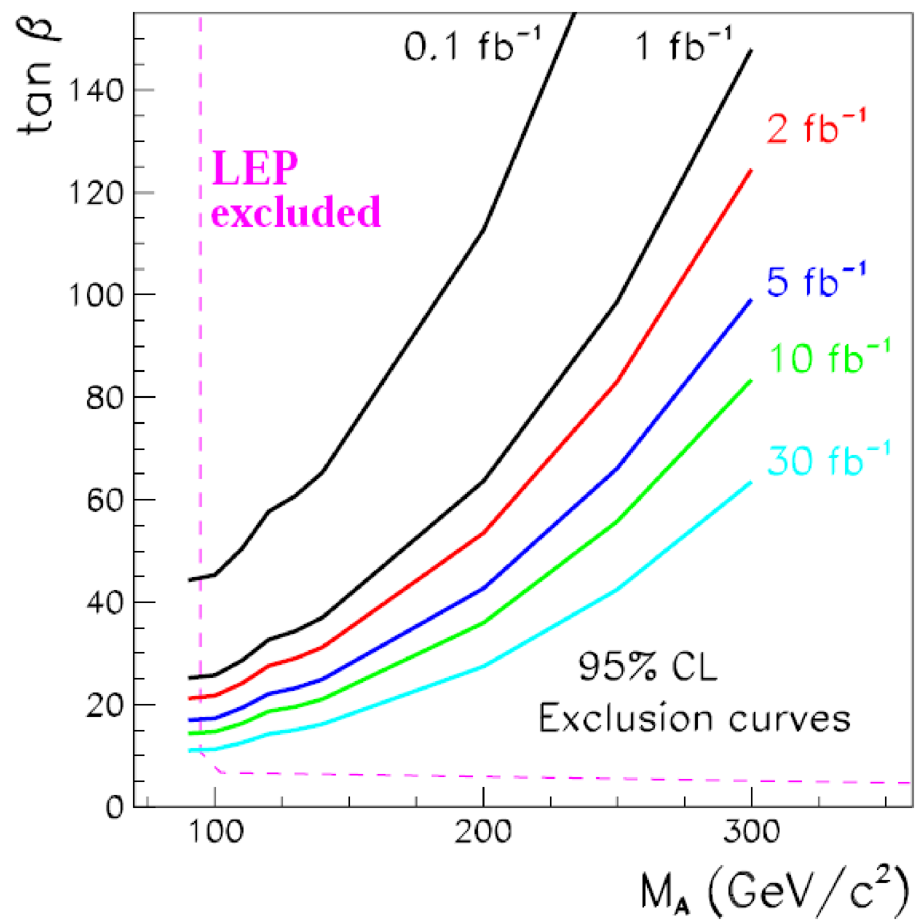


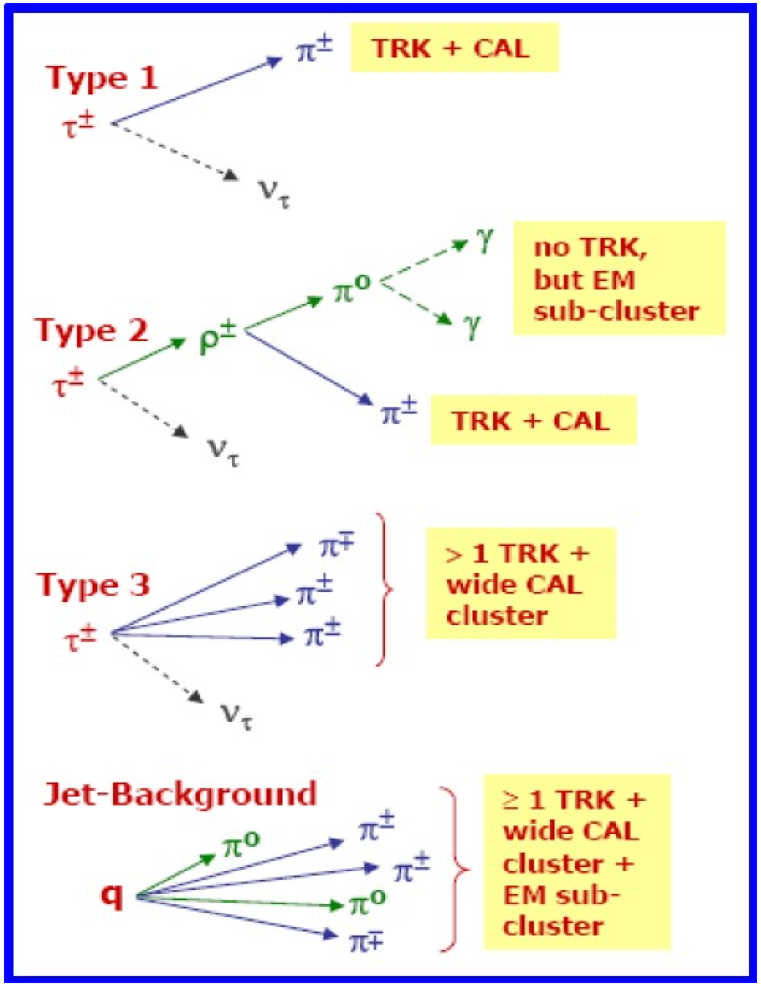
FIG. 3. CDF 95% C.L. excluded region in the parameter space m_A - $\tan\beta$ for the two stop mixing scenarios: *no mixing* (dashed lines) and *maximal mixing* (solid line). In all cases m_S = 1 GeV/c^2 and m_t = 175 GeV/c^2. Also shown is the LEP exclusion region for the *no mixing* scenario [17].



An additional tool: tau-tagging

Neural network ID

3 types distincts de Taus

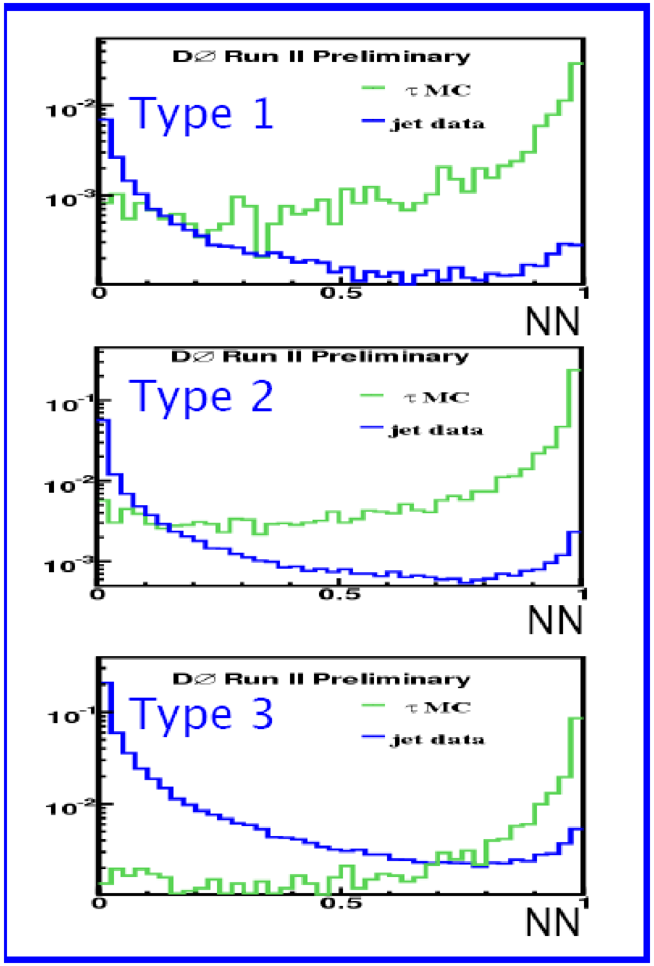


Performance for p_T [τ]>15 GeV :

jet rejectection rate ~40

for a τ efficiency of 70%

Tau Type	1	2	3
Reconstruction			
Jets	1.5	10	38
Taus	9.1	50	20
NN > 0.9			
Jets	0.04	0.2	0.8
Taus	5.8	37	13



Searches for h/H/A→ττ

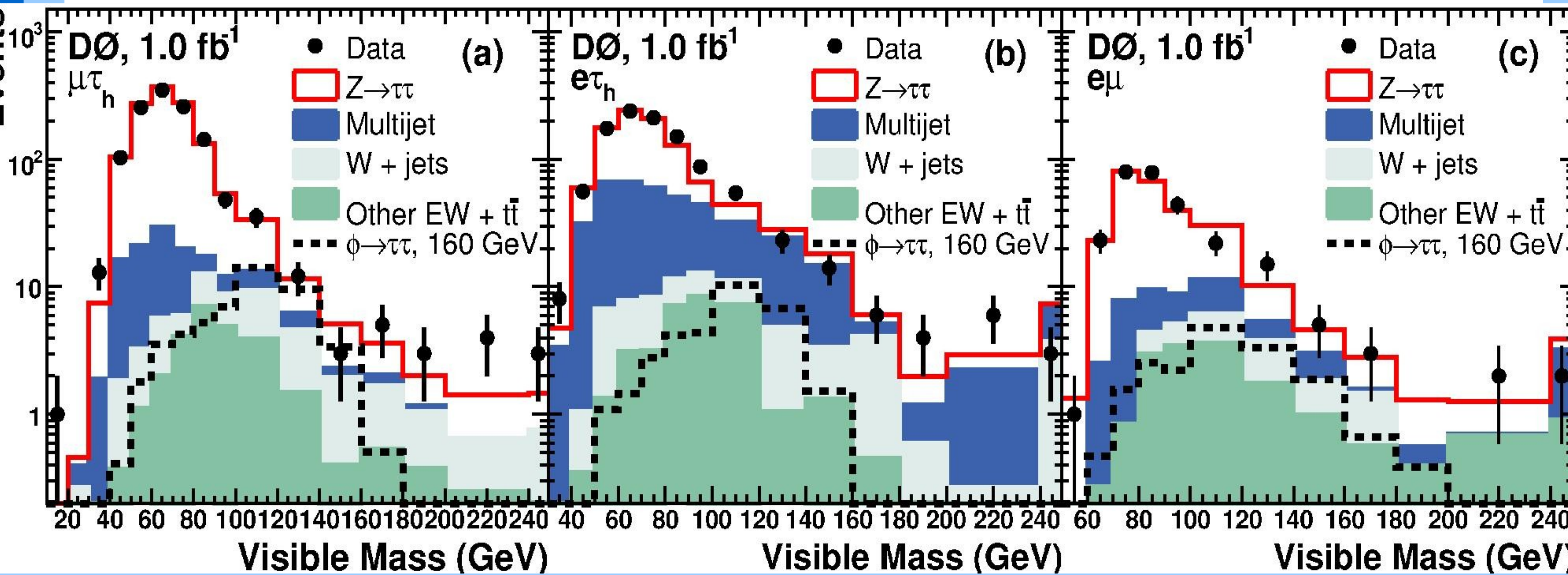
Experimental signature

- 2 iso high p_T leptons
- opposite charge
- small missing E_T
- 3 channels: μ-had, e-had, e-μ

1 fb^{-1}

Backgrounds

main Z→τ ,
QCD,
Z→ee, Z→μμ,
di boson



Searches for h/H/A b(b)→ bbb(b)

Experimental signature

1 fb^{-1}

$3 \leq N_{jets} \leq 5$ high p_T jets

at least 3 b-tagged jets

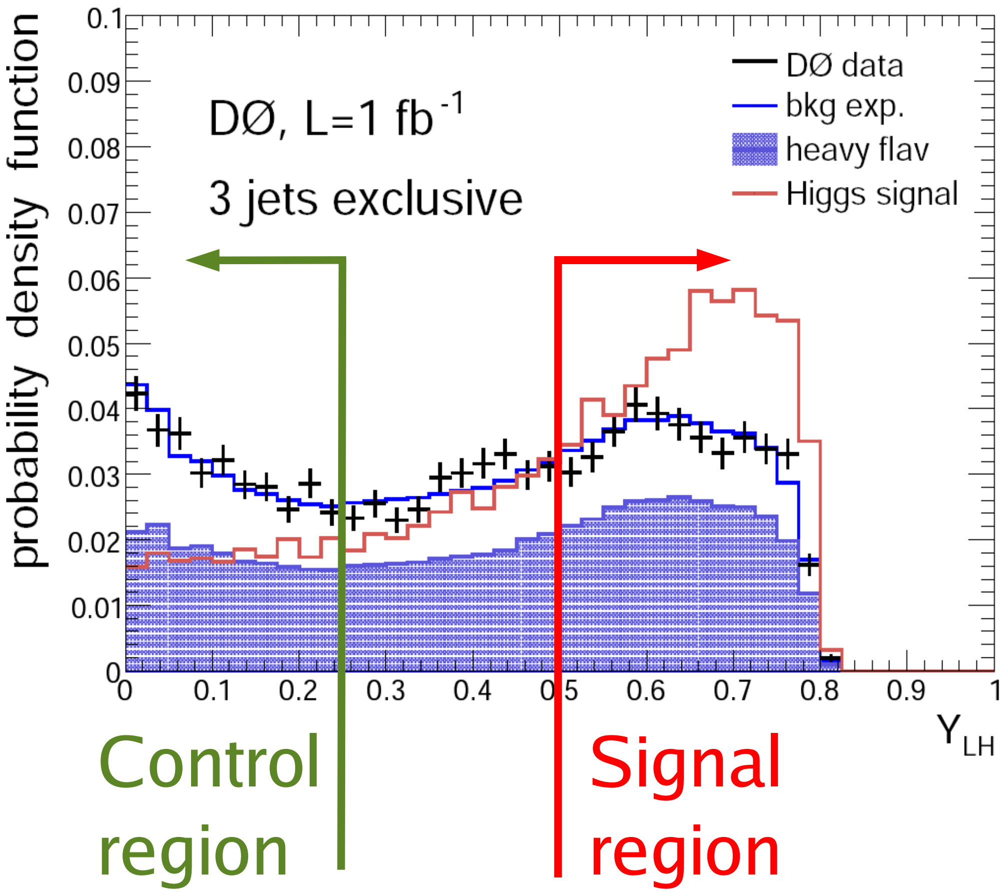
Backgrounds

QCD multijet

ccj, bbj, bcc, bbc, bbb (+ nj)

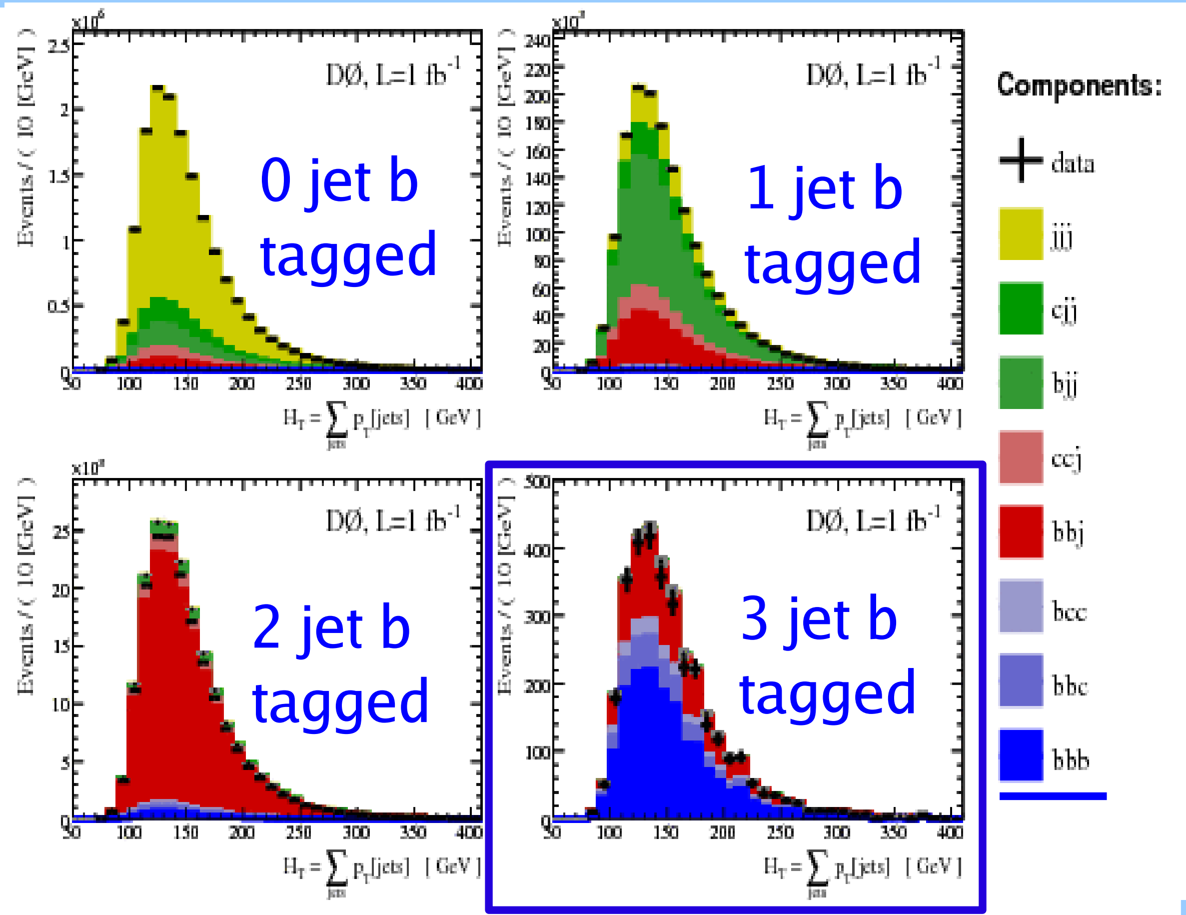
Improving sensitivity

- split sample into 3 sub-channels:
    * 3 jets (most sensitive)
    * 4 jets
    * 5 jets
- keep several jet pairings
- combine several kinematic variables in a Likelihood to:
    * increase s/b
    * define a control region



bbb(b) background modeling

- **Normalization:**
  - Theoretical σ have large errors… useless.
  - only sensitive to shapes
- **Composition:** →
  - From data: using several b-tagging operating points
- **Shapes:**
  - Data + MC



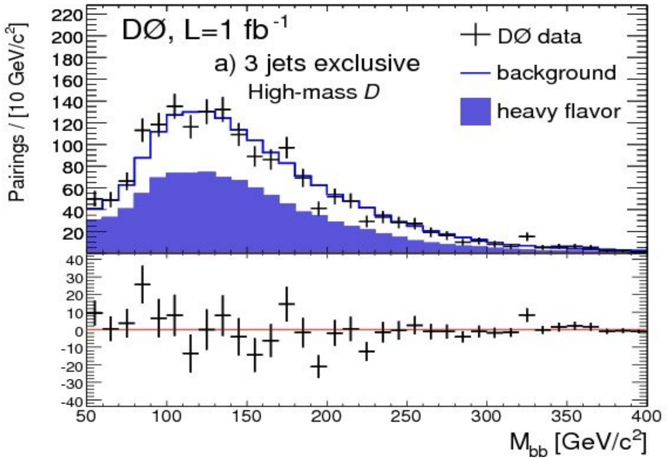
$$Shape^{exp}_{3Tag}(M, Y_{LH}) = \frac{Shape^{MC}_{3Tag}(M, Y_{LH})}{Shape^{MC}_{2Tag}(M, Y_{LH})} \times Shape^{data}_{2Tag}(M, Y_{LH})$$

Expected shape in 3-tag data

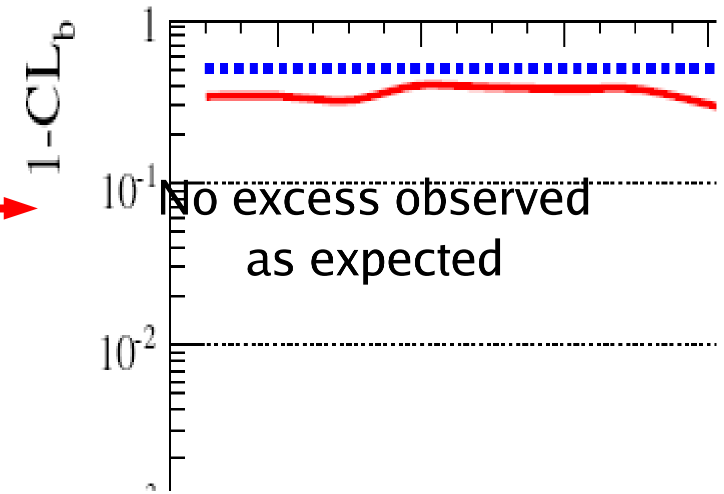
correction from MC

Main shape from 2-tag data (signal neglibible)

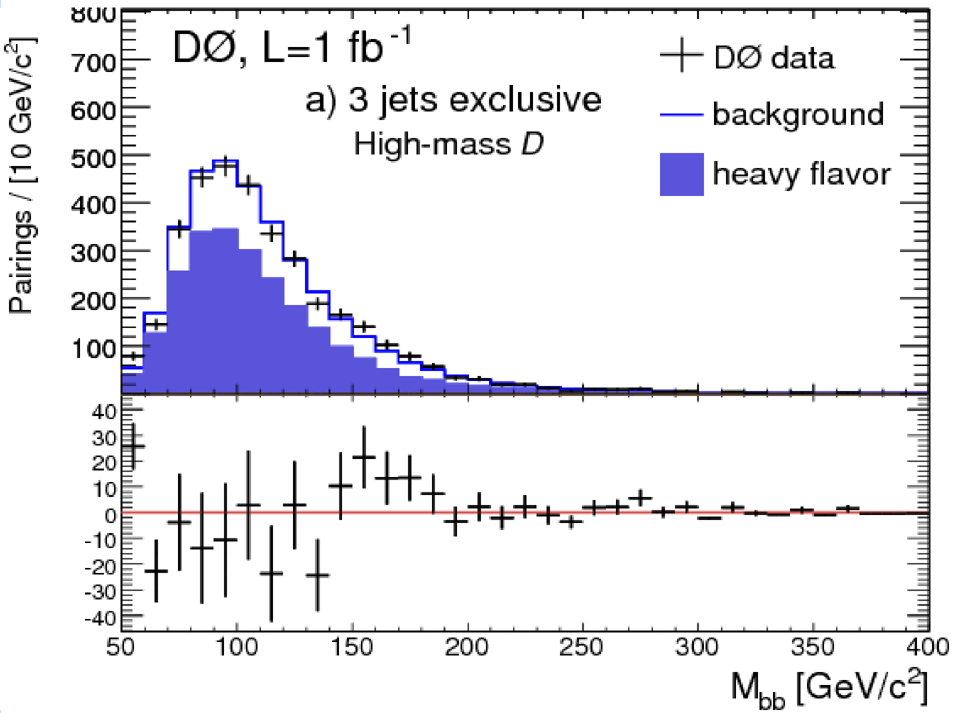
Searches for h/H/A b(b)→ bbb(b)

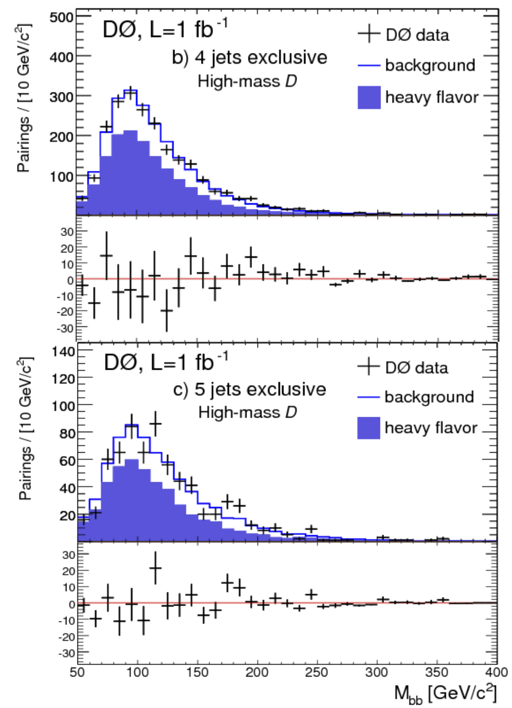


Control region

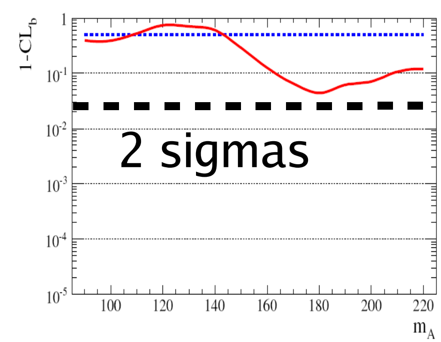


No excess observed as expected





Signal region

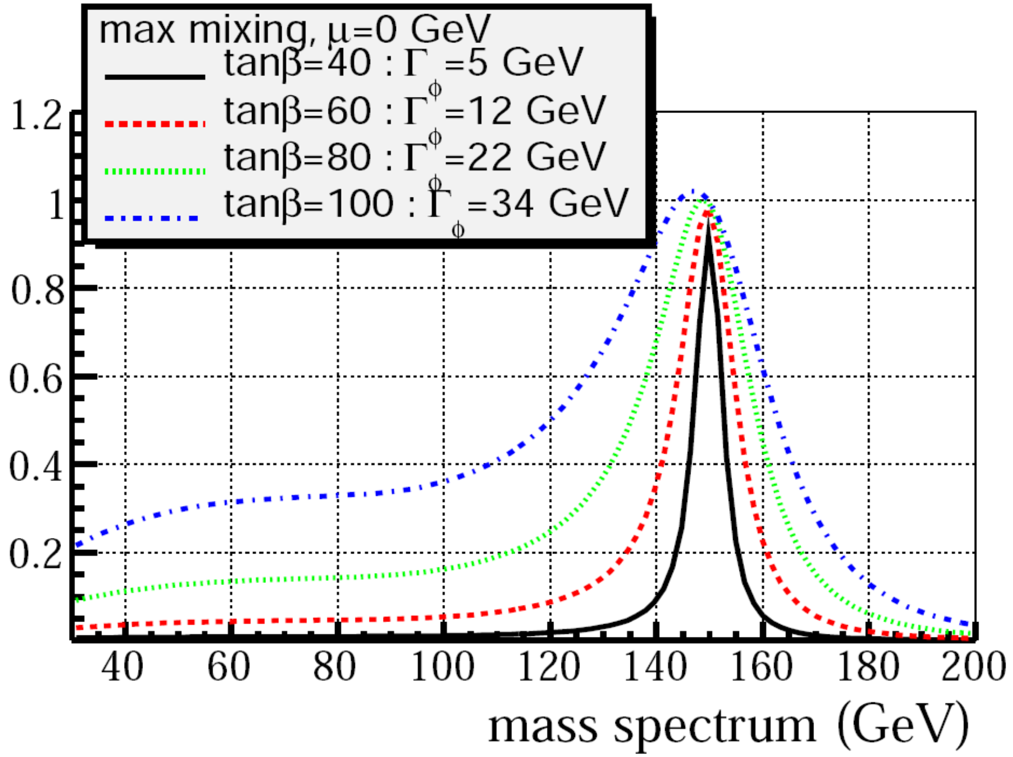


2 sigmas

MSSM translation for both analysis

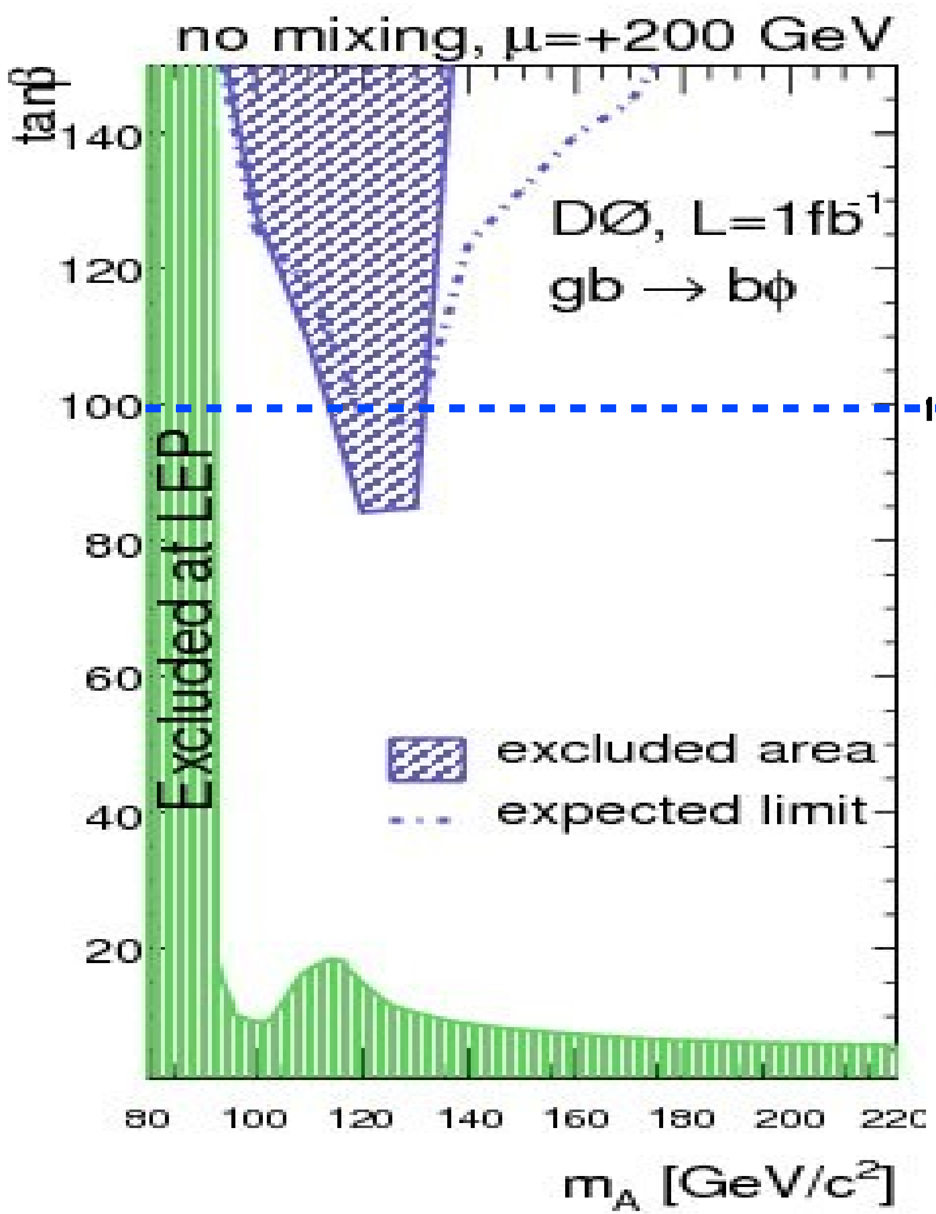
Two effects must be accounted for:

1. The production **cross section enhancement depends on the details of the MSSM scenario beyond LO.** MSSM/SM enhancement factors are computed with the help of FeynHiggs (model dependent)
2. With increasing coupling to b (ie tanβ), **Γ_H is not negligible** anymore

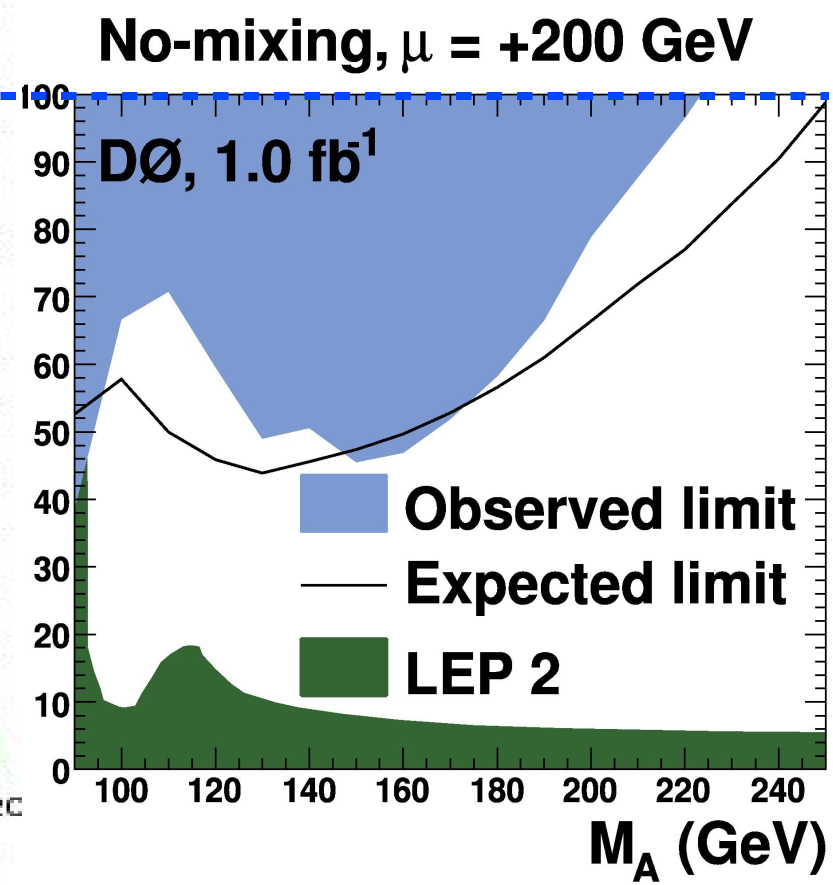


Analysis level: the width is simulated by using a weighted combination of all the different Higgs mass MC.

Dzero results: bbb vs $\tau^+\tau^-$



Both Dzero results with 1 fb^{-1}
No Comparison



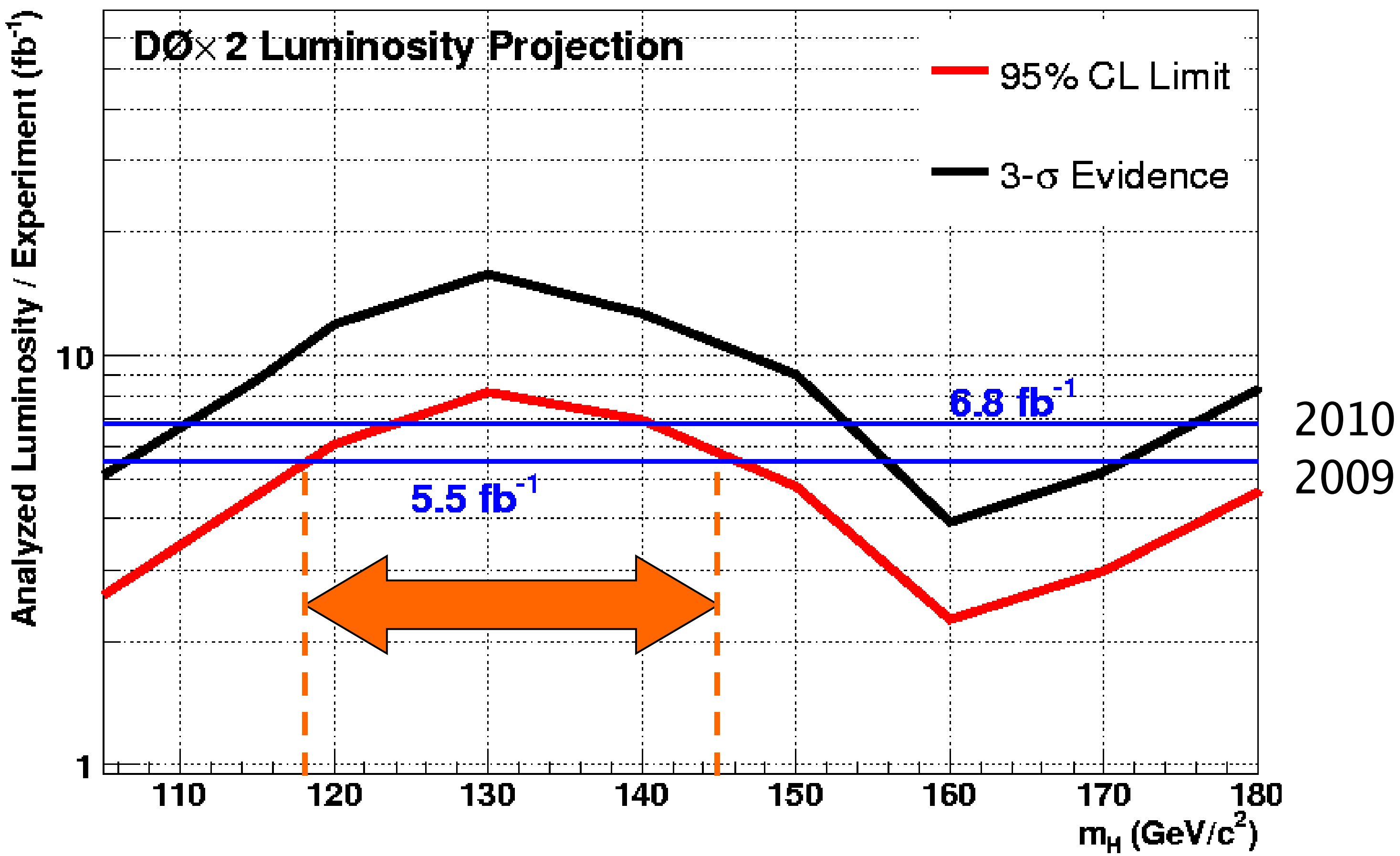
Perspectives

Expected exclusion sensitivity

Assumes two experiments

+

additional improvements



By the end of 2009 (Physics at LHC?), Tevatron might allow only

SM Higgs between 118 and 145 GeV

If the Higgs boson (exists? and) is light, will be hard for LHC as well!

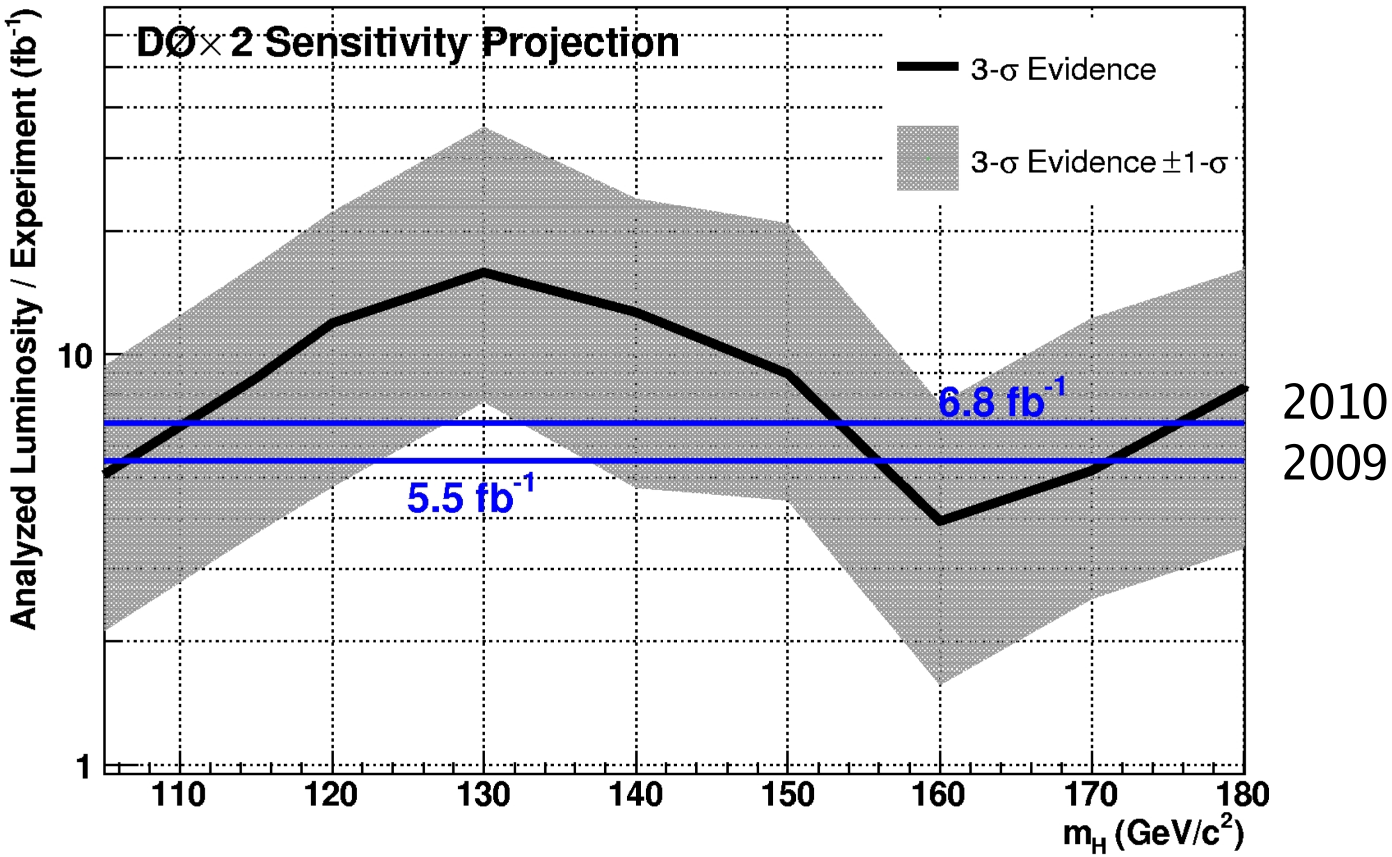
➔ LHC/Tevatron complementarity H➔ γγ vs H➔ bb

Expected discovery sensitivity

Assumes two experiments

+

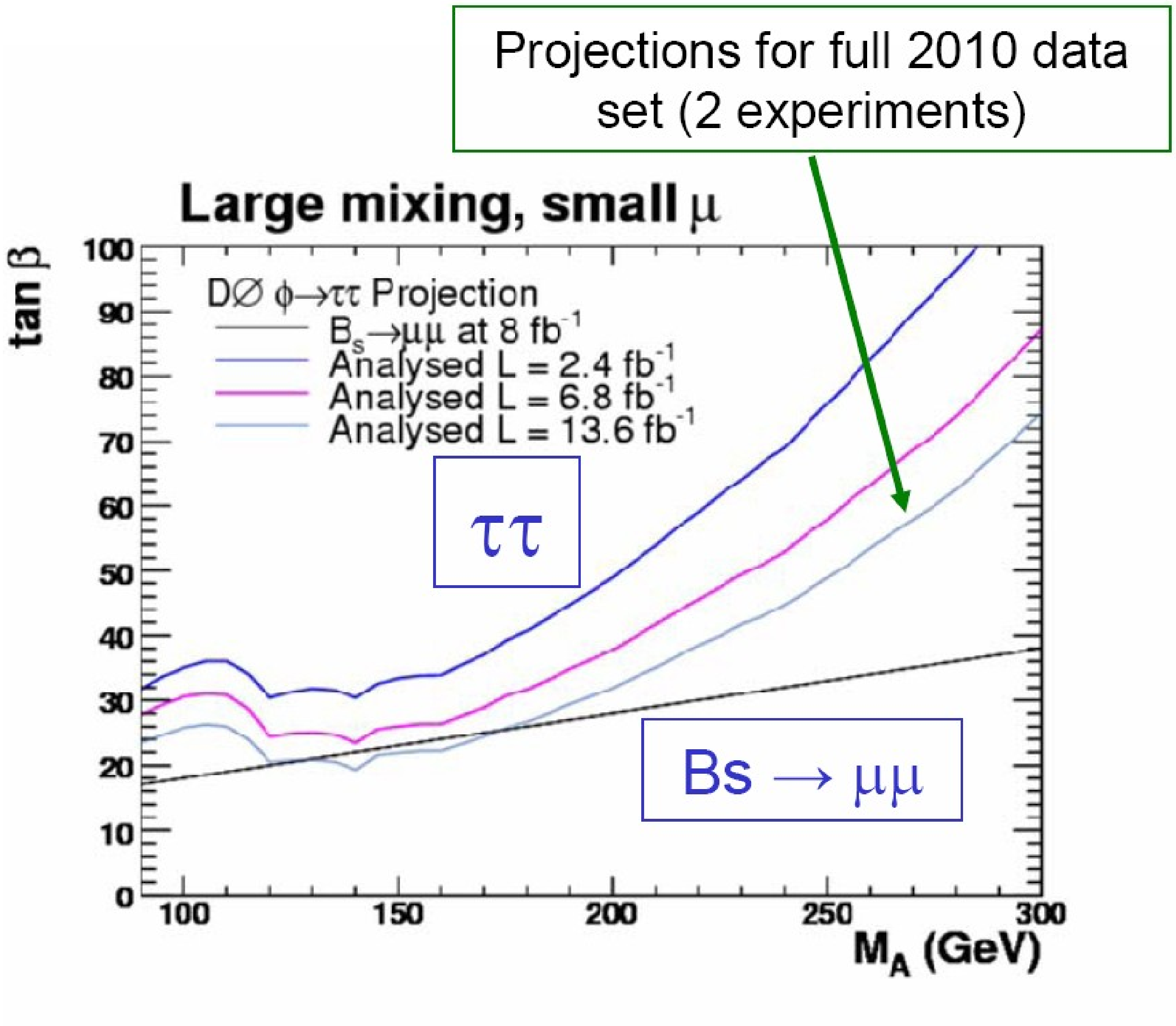
additional improvements



A little bit of propaganda:

With luck 3-sigma evidence is possible over the whole range!

MSSM Higgs



* bbb search interesting but not very sensitive compared to τ

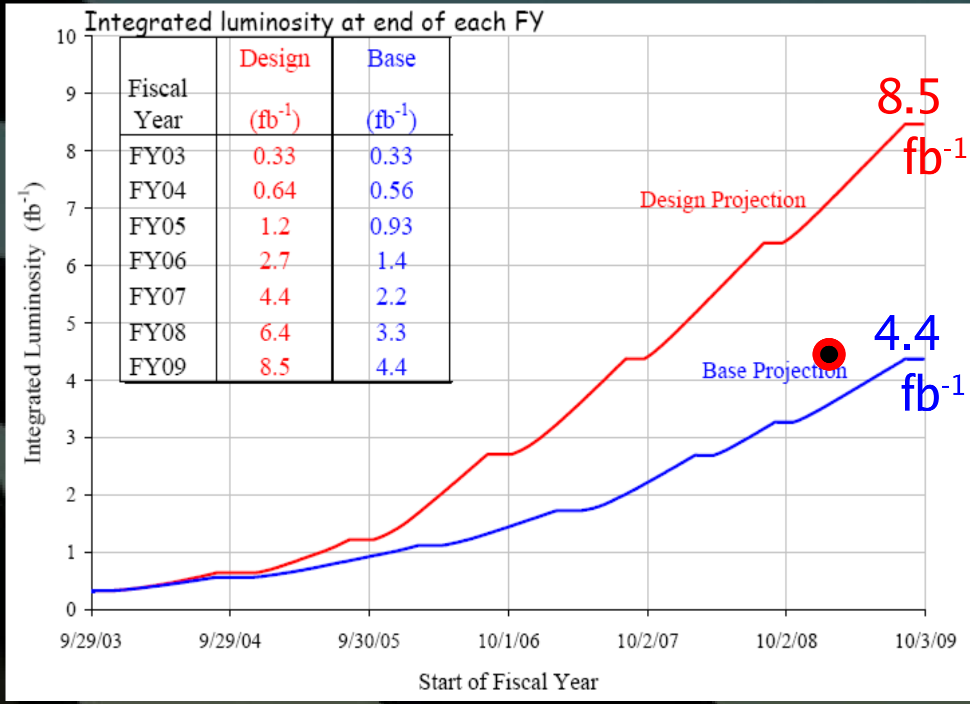
* τ b (hb) in preparation

* no combination has been done for now, neither internally nor with CDF

Conclusion

Le TeVatron et son premier 1fb^{-1}:
- 2006 : B_s mixing à CDF (et Dzero)
- 2007 : single top à Dzero

et avec un 7/8 fb^{-1} ?



La quête du boson de Higgs commence seulement au TeVatron:

- tous les canaux sont analysés
- les outils de combinaisons sont en place
- des améliorations encore possible:
  addition des τ, b-Tagging (Layer ∅ à D∅), améliorations des analyses (ME, NN), amélioration de l'identification des leptons....

Higgs beyond SM :

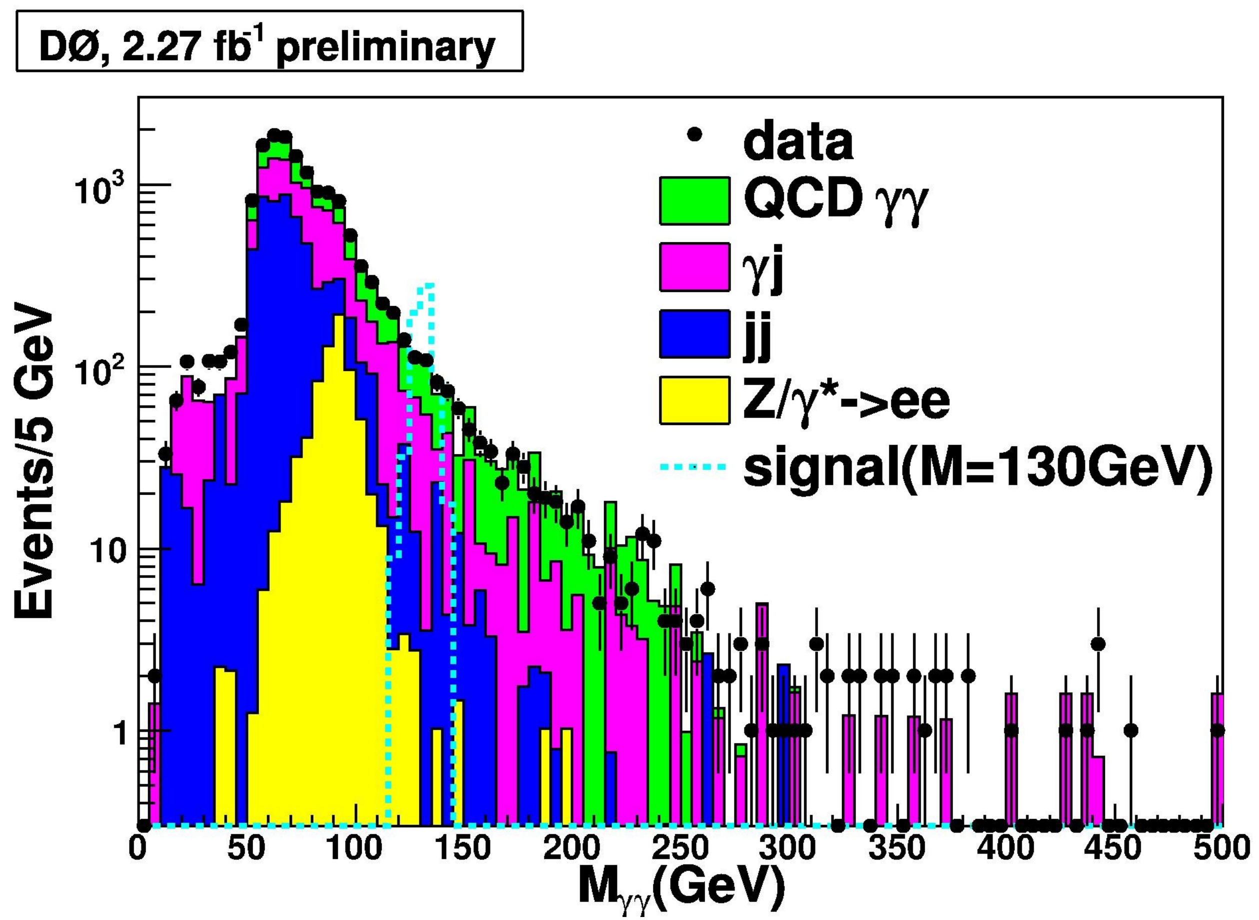
D'ores et déjà atteint le domaine “intéressant” $\tan\beta \sim 40$ (MSSM)

Une surprise est toujours possible !

“Difficile de trouver un chat noir dans une pièce sombre... surtout s'il est ailleurs.”

backup

H->gamgam

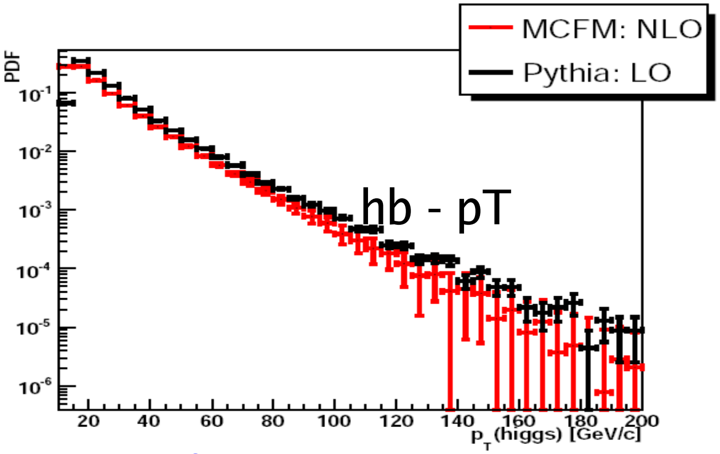


DØ, 2.27 fb-1 preliminary
data
QCD γγ
γj
jj
Z/γ*->ee
signal(M=130GeV)
Events/5 GeV
Mγγ(GeV)

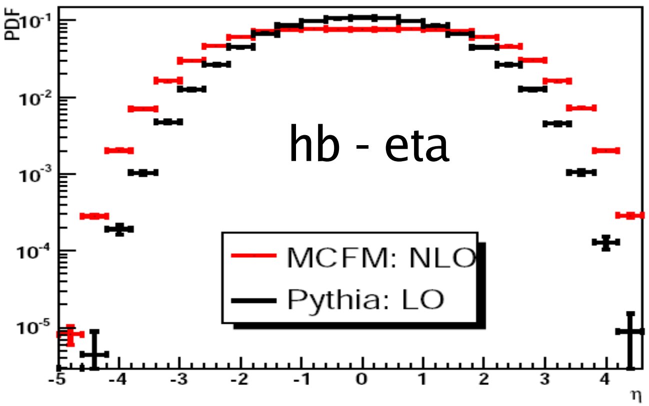
Higgs signal simulation

Higgs signal: SM signal generated with pythia

- Use NLO SM cross sections from MCFM
- Reweight pythia evt using MCFM kinematics
- SM --> MSSM enhancement computed with Feynhiggs



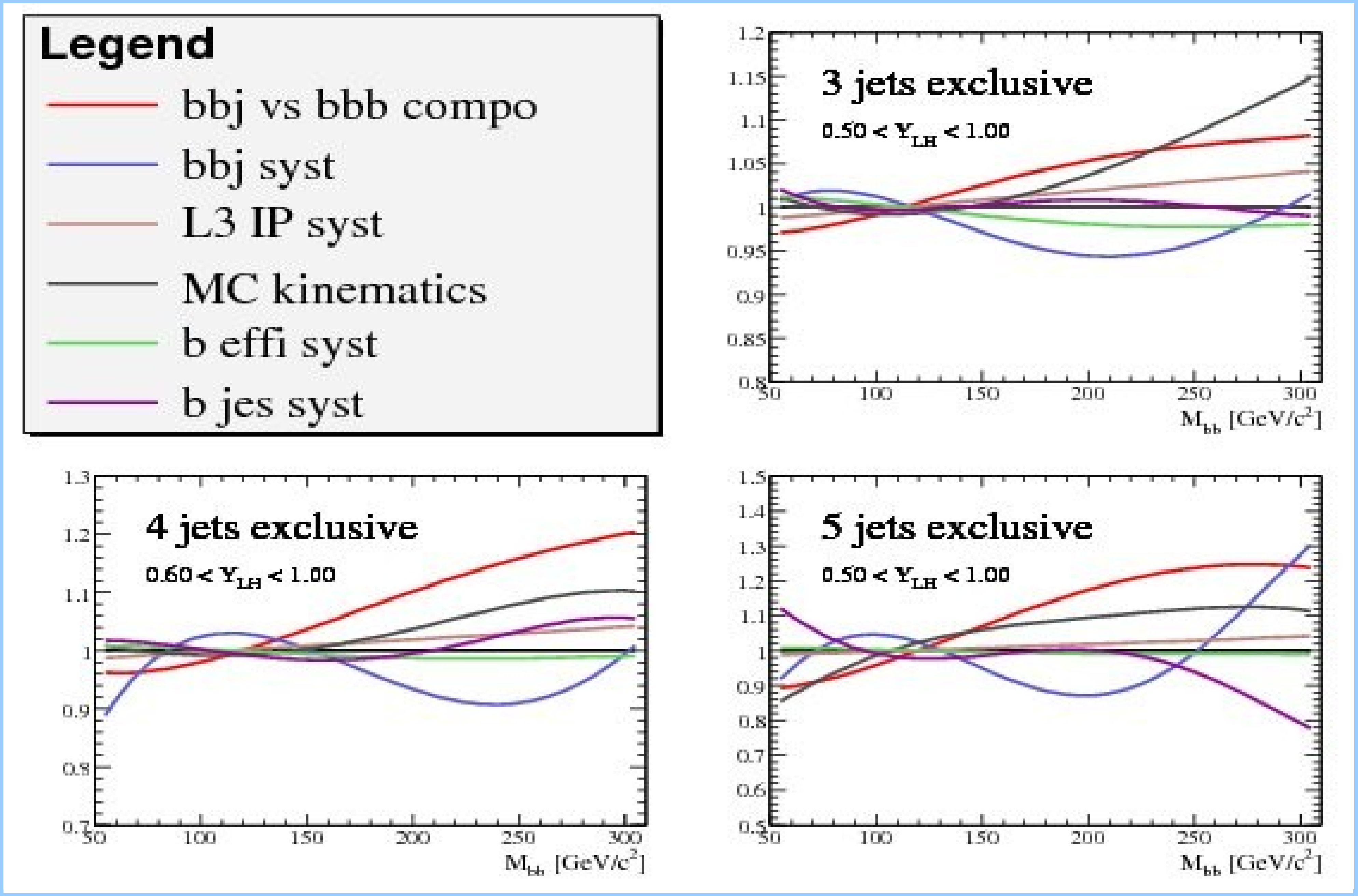
MH= 100 Gev/c^2



1. reweight vs η[b]
2. reweight vs pT[b]

Separate hb and hbb channels

Ratio Syst to Nominal shape



Results in the m_H max scenario

* CDF released a result for summer 07

* Much better sensitivity at Dzero with same lumi