Combined Higgs Searches @ TeVatron

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For the D0 and CDF collaborations

Outline

Le boson de Higgs et le MS

Recherche du boson de Higgs au TeVatron

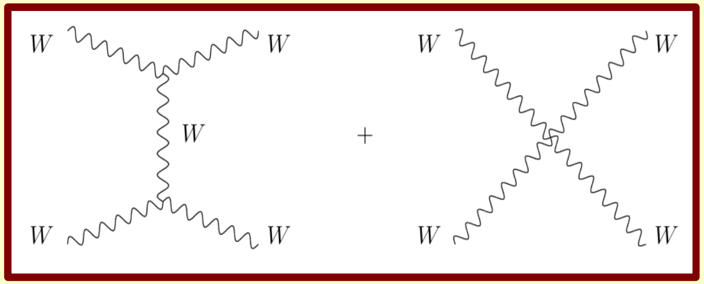
Perspectives et conclusion

Higgs et MS

Interactions faibles

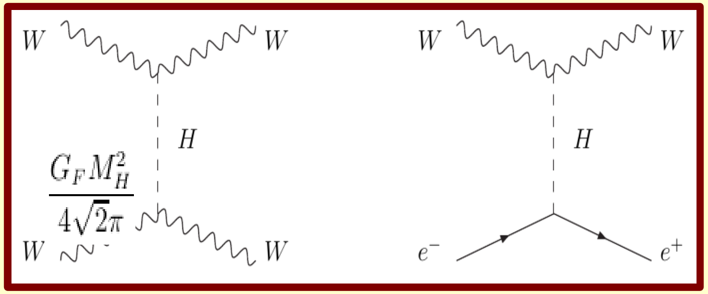
Auto-couplages

- Couplages trilinéaires ⇒ diffusions quasi-élastiques **WW→WW**
- Divergences quartiques
  - Couplage quadri-linéaires !
  - Unitarité pas complètement restaurée



Issues de secours

- Nouvelle(s) *interaction(s) forte(s)* entre les bosons W
- Nouvelle particule, le *boson scalaire de Higgs, **H***
  - Unitarité restaurée si M_H assez *"petite"*
  - Interférences effectives seulement si le couplage de H aux bosons/fermions est ***proportionnel à leur masse***



- Unitarité et processus WW→WWH / HHH permettent de contraindre *l'auto-couplage* de H ⇒ potentiel doit être de forme *quartiques* avec des coefficients prop. à M_H et au couplage WWH

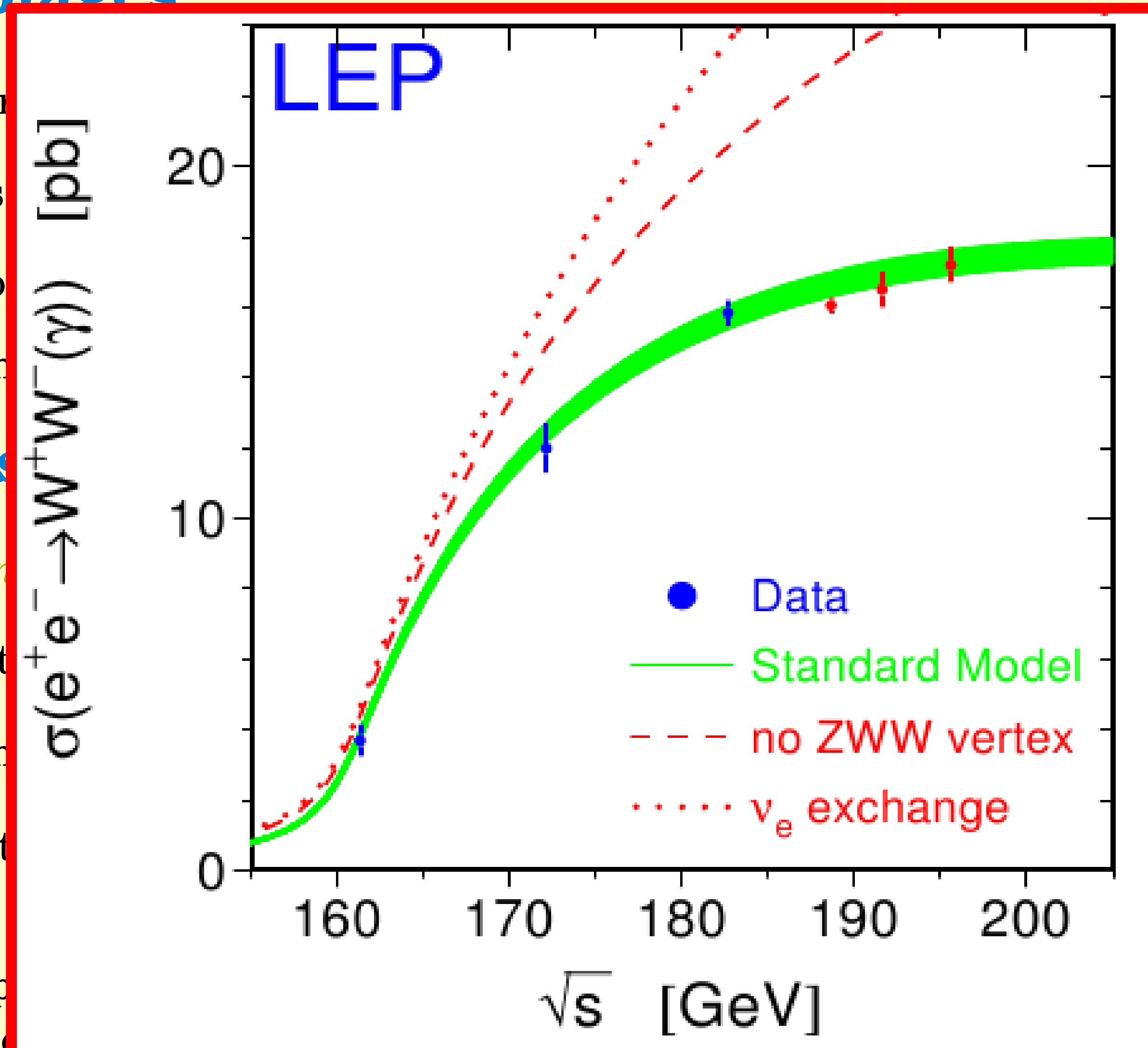
Interactions faibles (II)

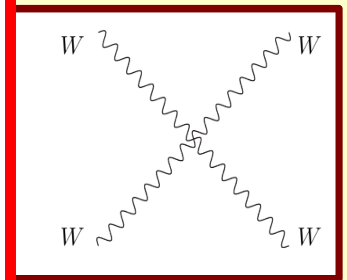
Auto-couplages

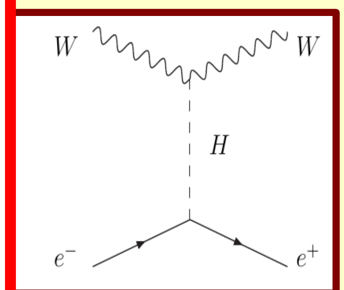
- Couplages tr
- Divergences
  - Co
  - Un

Issues de s

- Nouvelle(s) *in*
- Nouvelle part
  - Un
  - Int





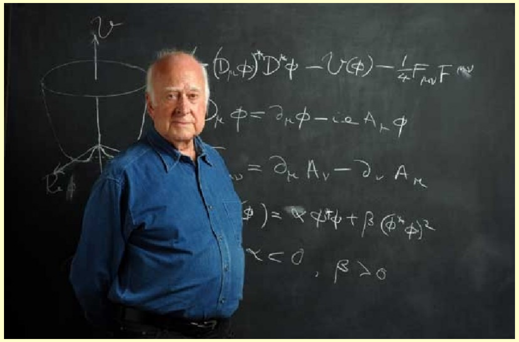


r masse

- Unitarité et p *o-couplage* de H ⇒ potentiel d H t au couplage WWH

Mécanisme de Higgs

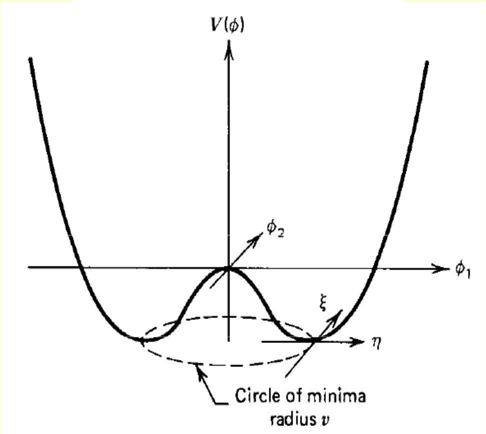
Invariance de jauge



- **Globale :** conservation globale d'un “courant”
- **Locale :** derivée covariante ⇔ **interaction(s) !**
- **'t Hooft :** une théorie est *renormalisable* si de type
  Yang-Mills, *i.e.* invariante par transformation de jauge locale

Brisure “*spontanee*” de symetrie

$$V(\phi) = \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$



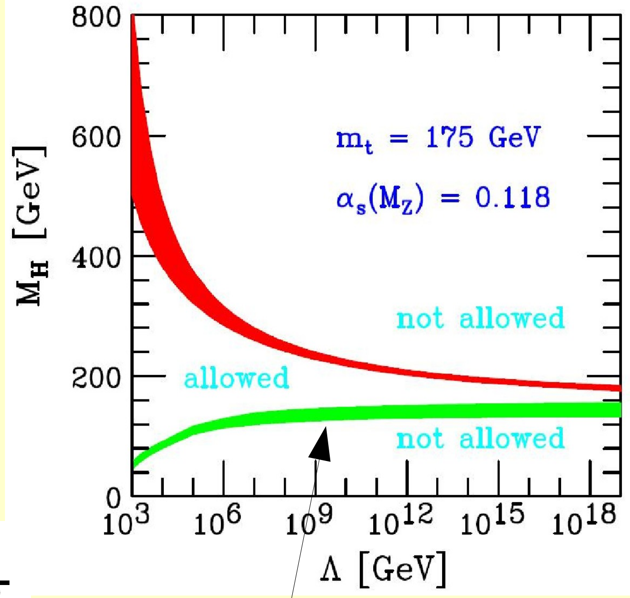
- **Globale :** boson de Goldstone, *non-massif*
- **Locale :** bosons vecteur massifs (*via* derivée covariante) et /
  mais fermions massifs via interactions de Yukawa
  + boson scalaire, le Higgs
- Répond a toutes les conditions nécessaires au respect de
  de l'unitarité *(c.f. transparents précédents)*

Le mécanisme de Higgs permet de construire une théorie renormalisable avec des bosons et des fermions massifs tout en gardant la dynamique invariante de jauge

Contraintes sur la masse du Higgs (I)

M_H: quelles contraintes ?

- Paramètre libre du MS : $\boxed{M_H^2 = \lambda v^2}$
- Unitarité : $M_H = 2\sqrt{2}\pi/G_F < (850\ \text{GeV})^2 \sim$ **(1 TeV)²**

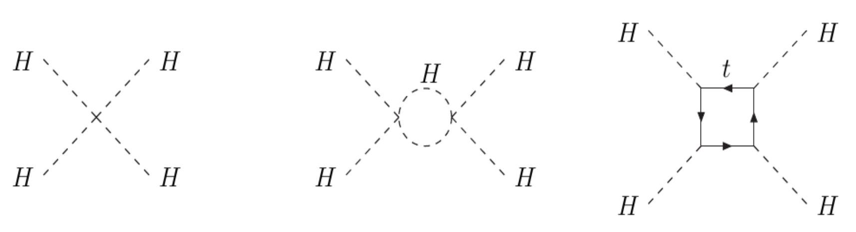


Auto-couplage λ

- Boucles **Higgs**: **λ ↗**, boucles **top**: **λ ↘**
- **Renormalisation:** $\lambda = \lambda(\mu^2)$: $\lambda(\mu^2) = \dfrac{\lambda(v^2)}{1 - \frac{3\lambda(v^2)}{8\pi^2}\log\frac{\mu^2}{v^2}}$

cf. aussi: http://arXiv.org/abs/0802.4423v1

- $\lambda(\Lambda) < \infty \Rightarrow \boxed{M_H^2 \lesssim \dfrac{8\pi^2 v^2}{3\log(\Lambda^2/v^2)}}$
- Si m_{top} est trop grande : $\lambda < 0 \Rightarrow$ **vide est instable ! $M_H > M_{min}(\Lambda)$**



Λ = 1 TeV, 60 < M_H < 700 GeV

Λ = 10^{19} GeV (GUT), 130 < M_H < 190 GeV

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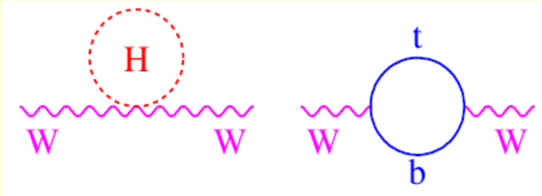
Contrainte sur la masse du Higgs (II)

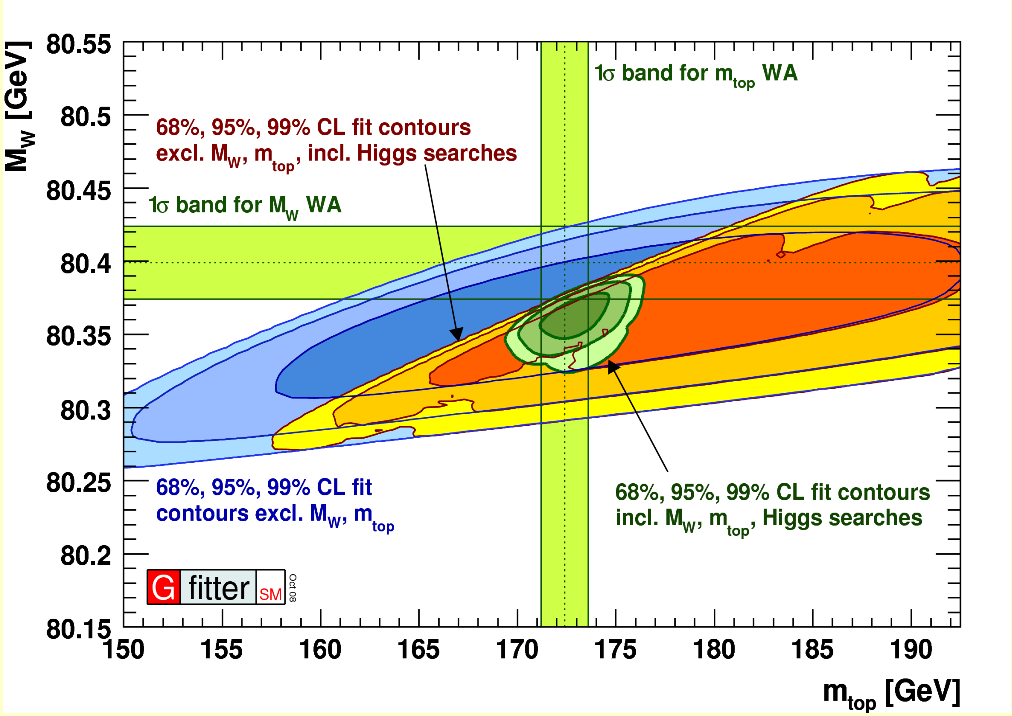
Mesures de precisions



- **Corrections radiatives :**

$$\frac{G_F}{\sqrt{2}} = \frac{2\pi\alpha}{\sin^2 2\theta_W M_Z^2}[1 + \Delta r_\alpha + \Delta r_t + \Delta r_H]$$

- **A l'ordre 0 :** $\Delta r_H = \frac{G_F M_Z^2 (1 + 9\sin^2\theta_W)}{24\sqrt{2}\pi^2} \log\frac{M_H^2}{M_W^2} + \ldots$



Le MS avec un boson de Higgs *(léger)* est compatible avec les mesures de précision électro-faible

Note :

moyenne du Tevatron :

$\Delta M_t = 1.2$ GeV

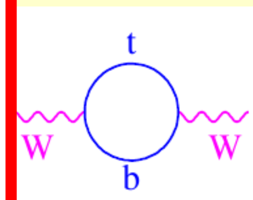
$\Rightarrow$ $\Delta M_W = 7$ MeV necessaire

Contraintes sur la masse du Higgs (II)

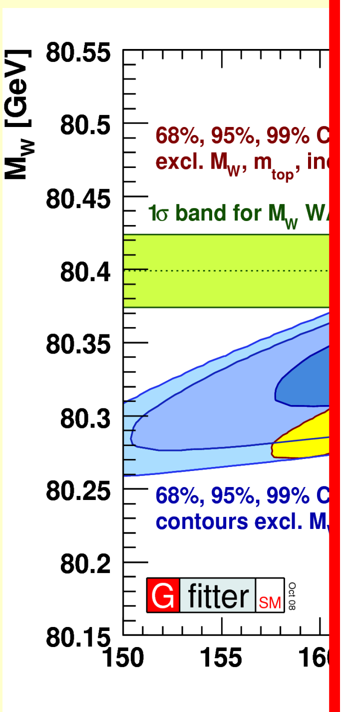
Mesures de

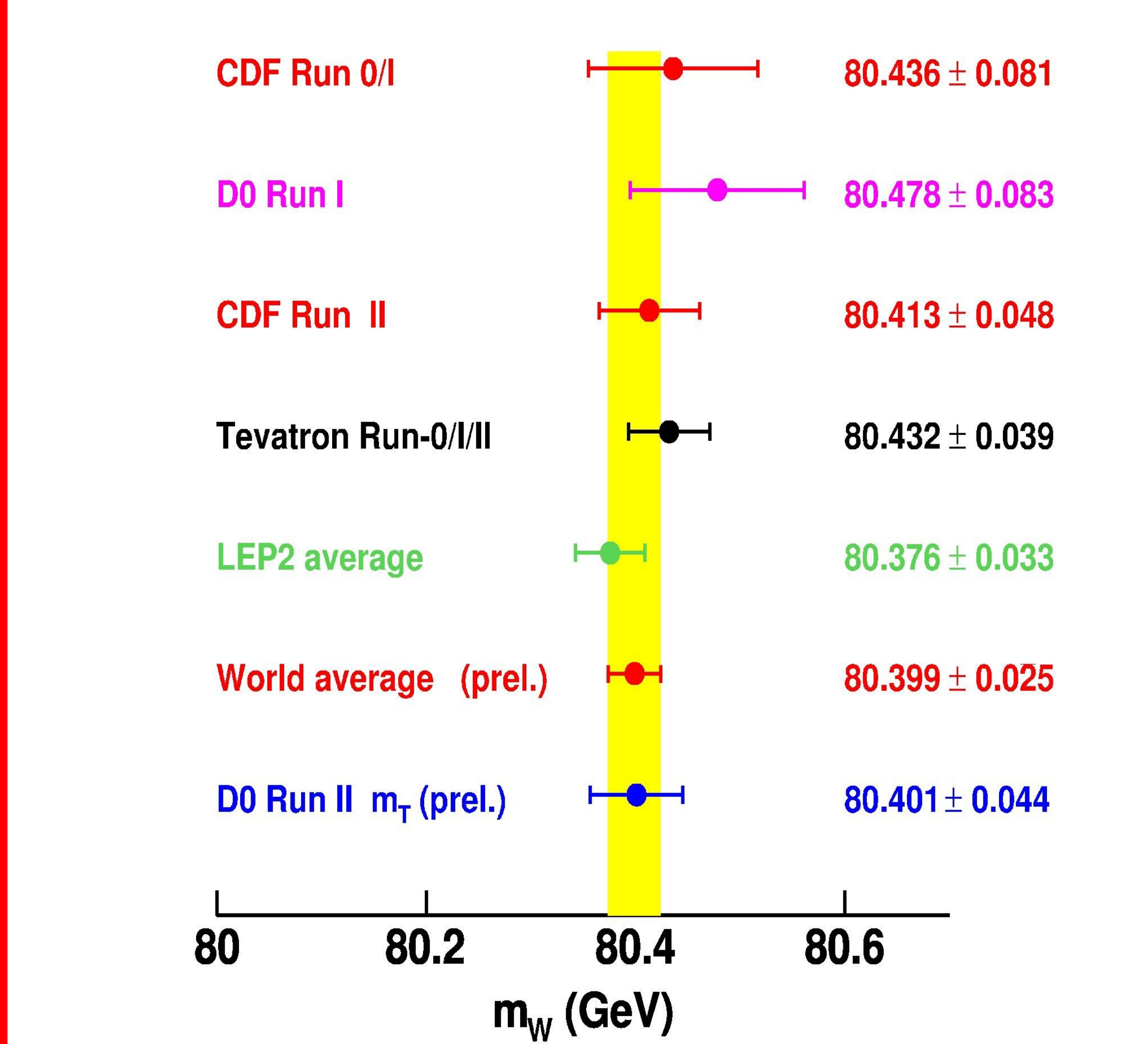
- **correction**

$\frac{G_F}{\sqrt{2}} = \frac{}{\sin^2}$



- **A l'ordre 0**





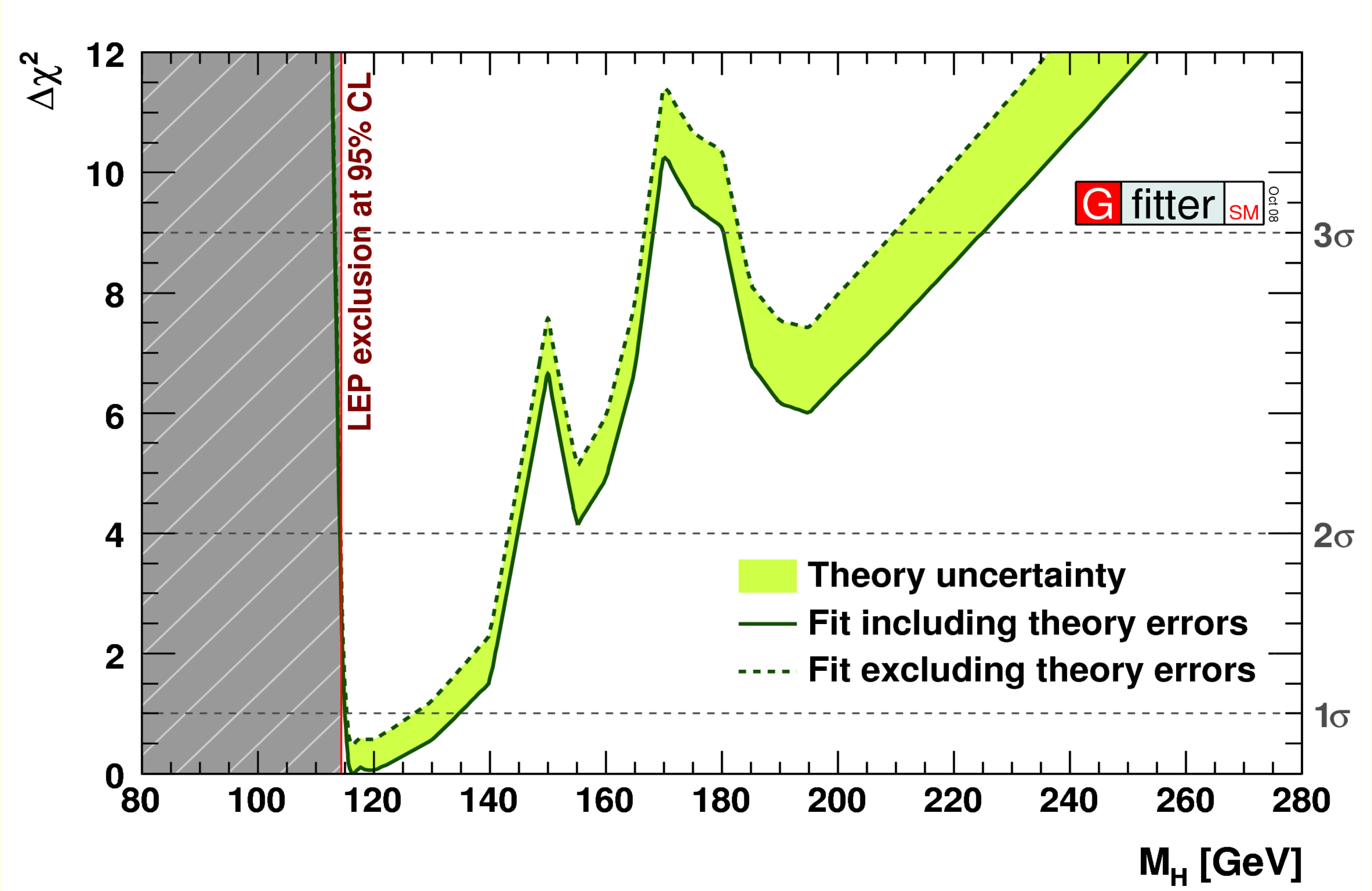
**oson de Higgs
atible avec les
ision electro-**

!! Une erreur combinée (D0,CDF) de *~15 MeV* est envisageable au RunII !!

Contraintes sur la masse du Higgs (III)

Mesures de precisions

- **M_H = 116.4 GeV** *(LEP + TeVatron incl. M_t, recherches directes)*

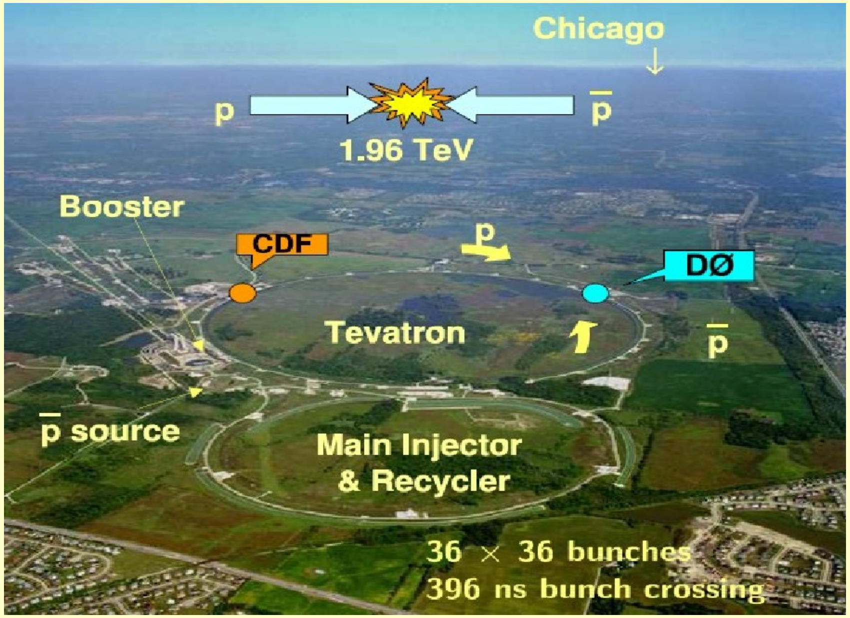


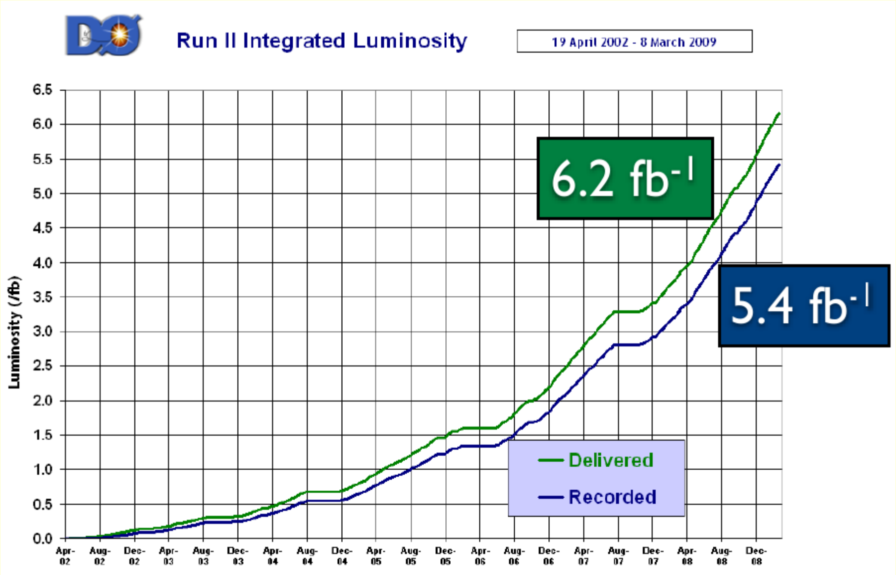
La recherche du boson de Higgs au TeVatron

TeVatron

- Collisions proton-anti-proton @ 1.96 TeV *(Run II, démarrage en 2001)*
- Accélérateur très performant
- Record de luminosité instantanée, Janvier 09 :
  3.5×10^{32} cm^{-2} s^{-1}
- **6 fb^{-1}** delivrées par expérience

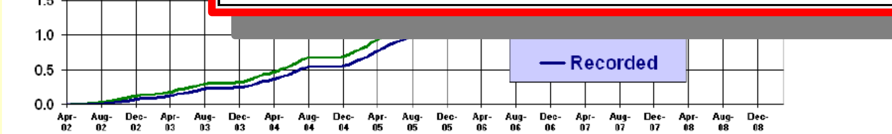
  Rappel: *objectif initial Run II: 4-8 fb^{-1}*
- **CDF** et **DØ** ont **> 5 fb^{-1}** sur bandes

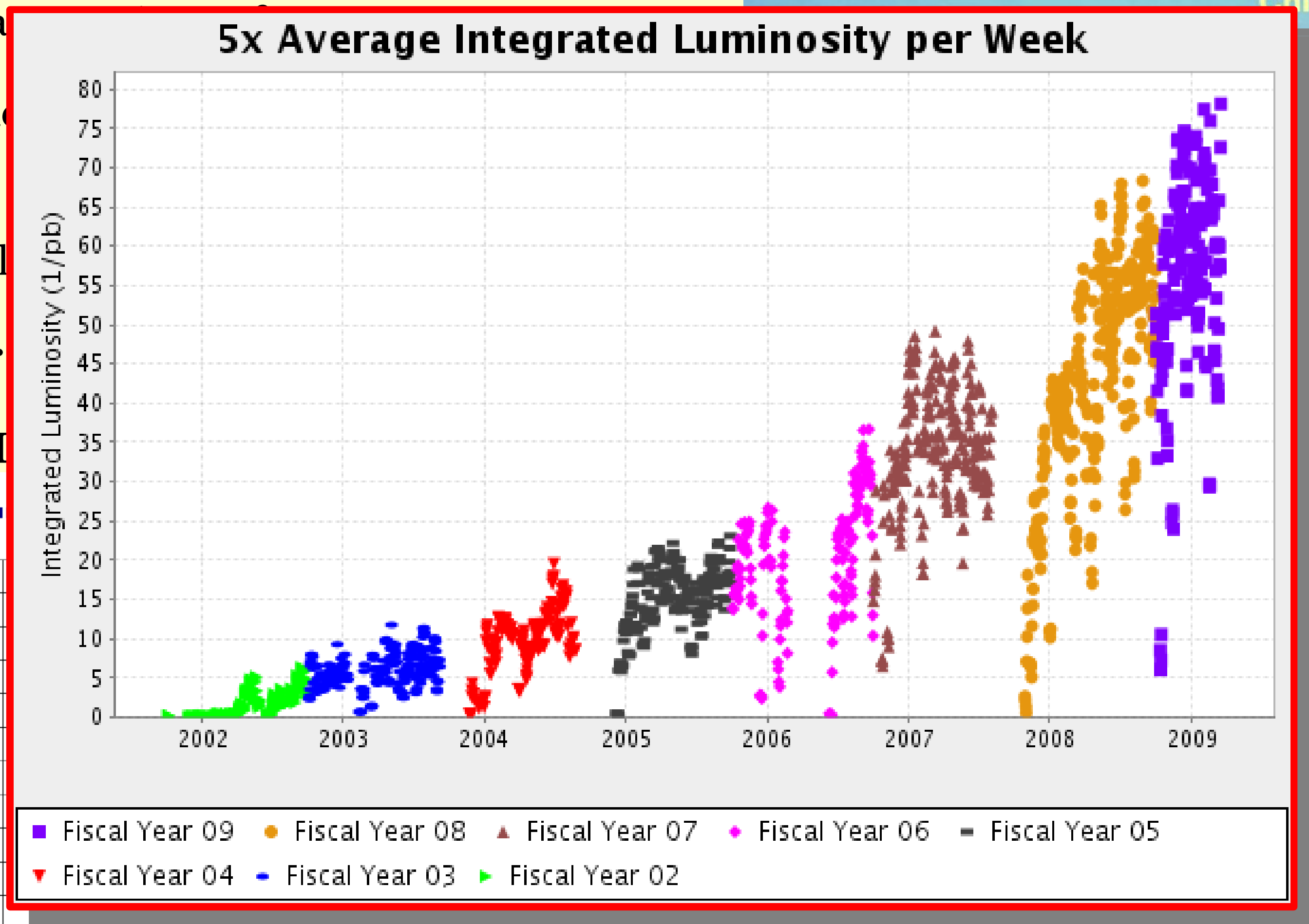




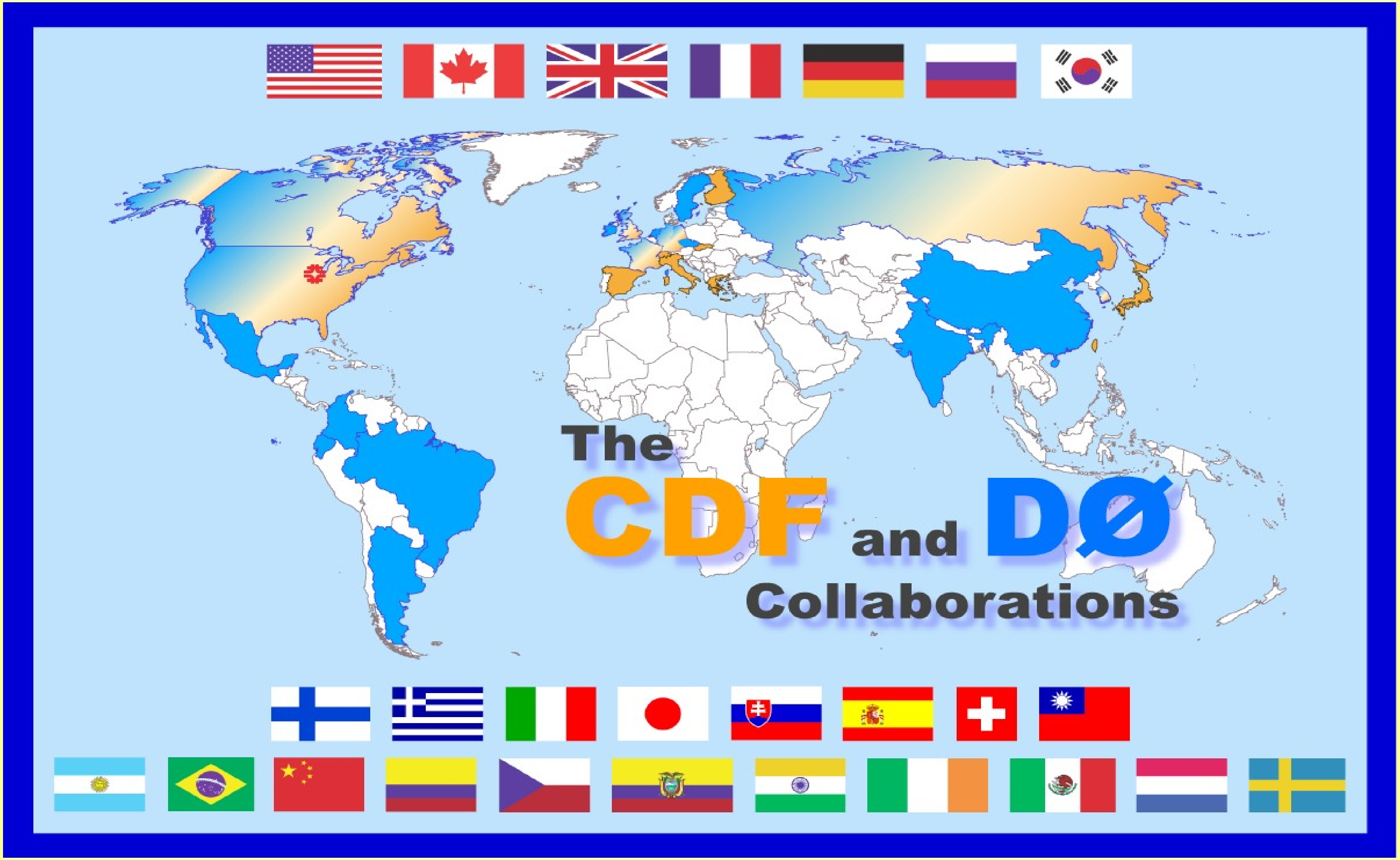
TeVatron

- Collisions proton-anti-proton @ 1.96 TeV *(Run II, démarrage en 2001)*
- Accéléra
- Record de
  3.5 x
- **6 fb^{-1}** del
  Rappel:
- **CDF et I**

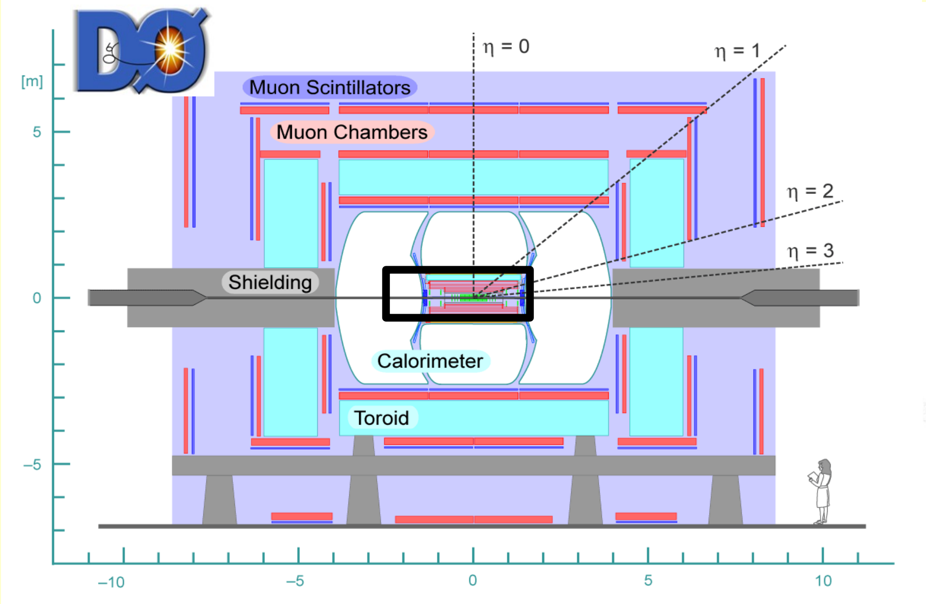


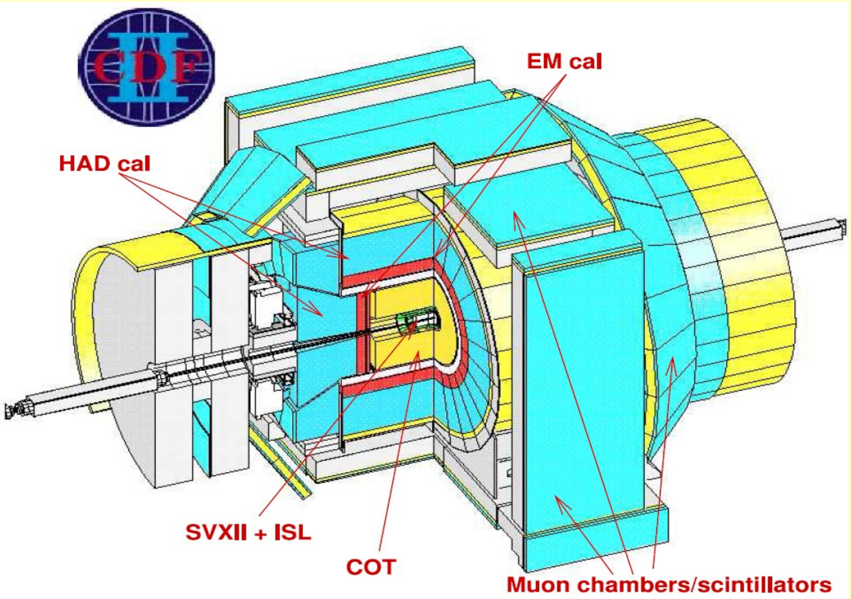


Les collaborations DØ et CDF



Les détecteurs DØ et CDF





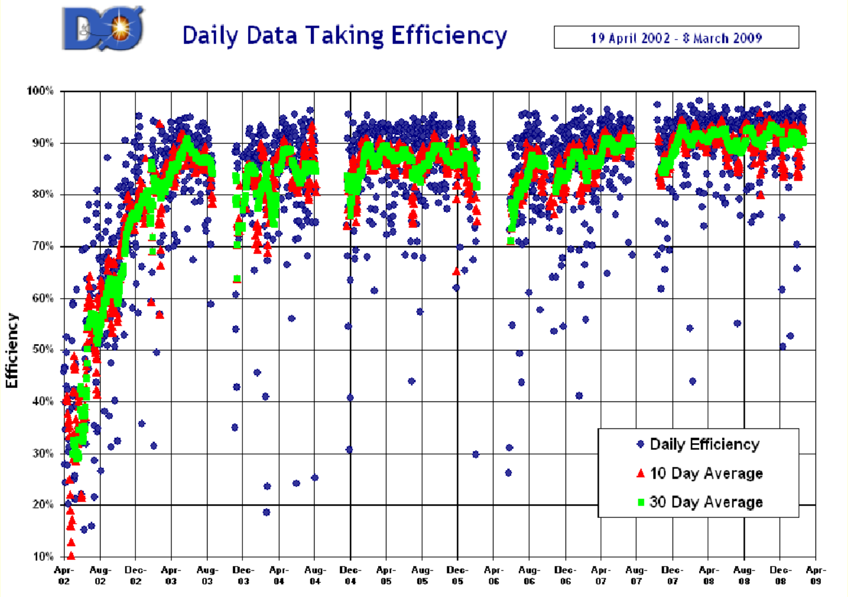
Trajectographe silicium (SMT)

- 6 tonneaux de 4 couches, z ~1 m
- |η|< 2.5 *(CDF: 2)*
- Nouvelle couche 0 @ r =1.6 cm

Détecteur à fibres scintillantes (CFT)

- 8 couches (axial & stereo)
- 20 < r < 51 cm dans 2T

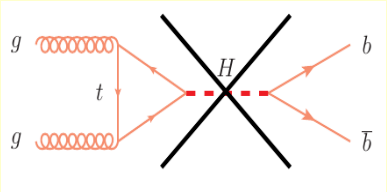
Système muon, |η|<2 *(CDF < 1)*

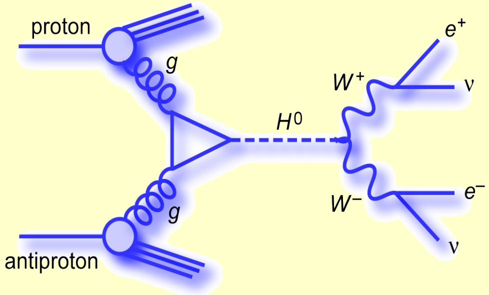


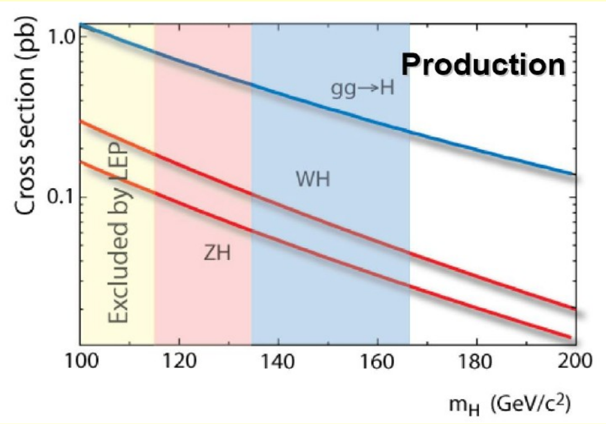
Higgs: productions et désintegrations

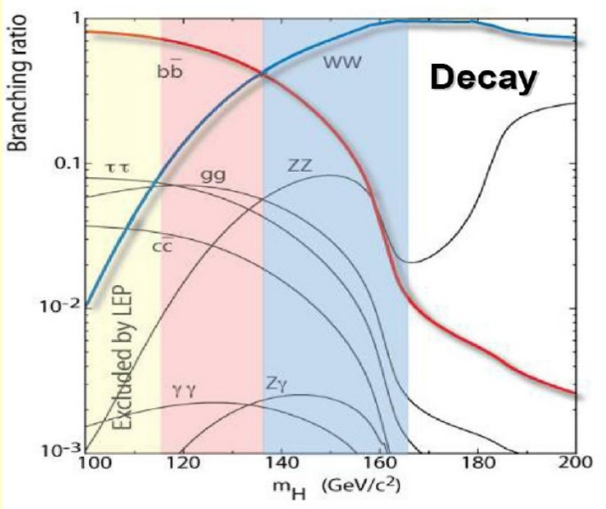
Higgs *"léger"* *(<135 GeV)*, *"lourd"* *(>135 GeV)*

- **Fusion gg :** désintegrations en bb noyée dans fond QCD bb (~$x10^6$); canal H→WW

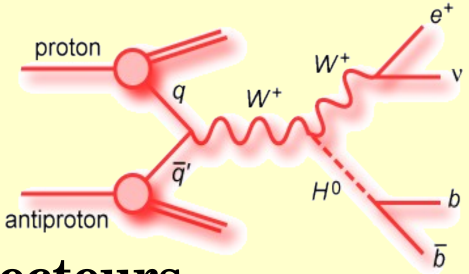




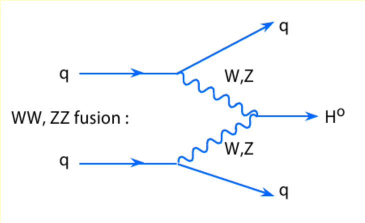




- **Production associée, (W/Z)H**
  - *"golden" mode basse masse !* H→ **bb**, $\tau\tau$



- **Fusion bosons vecteurs**
  - très faible *(mais ok au LHC)*



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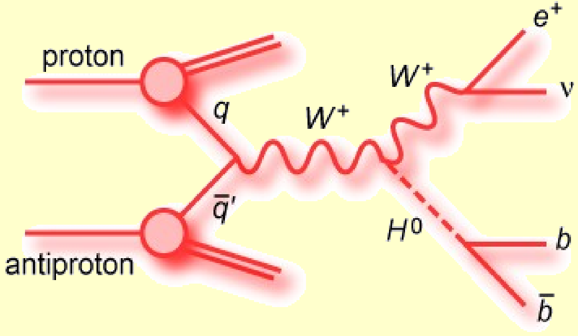
La recherche du boson de Higgs *léger*

Le canal $(W\to l\nu)(H\to bb)$

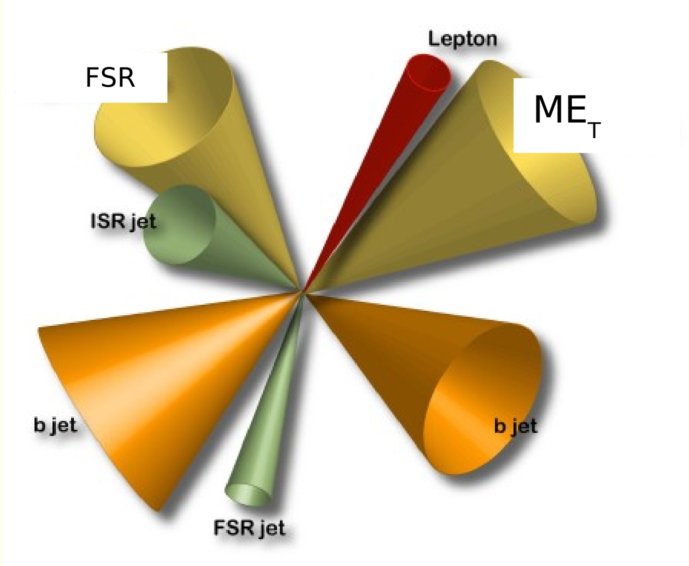
Golden Channel !

- $90 < M_H < 150$ GeV
- Bruits de fond *raisonnables*



Topologie & sélection

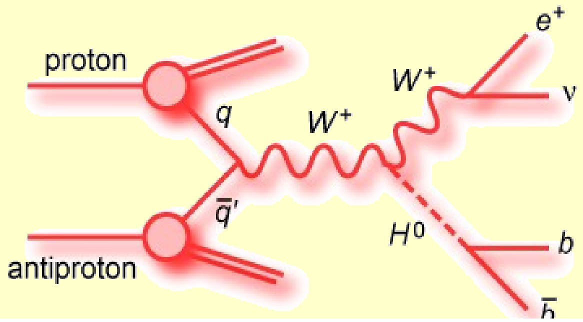
- 1 lepton *isolé* (e,μ), $E_T \geq 20$ GeV
- Energie transverse manquante ≥ 20 GeV (ME_T)
- ≥ 2 jets calorimétriques, $E_T \geq 25(20)$ GeV + $H_T > 60$ GeV



S/B ~ 1:3000

Le canal $(W \to l\nu)(H \to bb)$

Golden Channel !



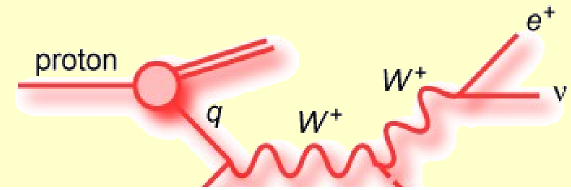
- $90 < M_H < 150$ GeV
- Bruit de fond *raisonnable*,

	Leptons	Missing E_T	Jets
DØ	$P_T > 15$ GeV, $\lvert\eta^{electron}\rvert < 2.5$, $\lvert\eta^{muon}\rvert < 2.0$	$ME_T > 20$ GeV	2 or 3 jets, (sub-)leading jet $P_T > 25(20)$ GeV, $\lvert\eta^{jet}\rvert < 2.5$, $H_T > 60$ GeV
CDF	$P_T > 20$ GeV, $\lvert\eta^{electron}\rvert<2.0$, $\lvert\eta^{muon}\rvert<1.0$	$ME_T > 20$ GeV	2 jets, all jets $P_T > 20$ GeV, $\lvert\eta^{jet}\rvert < 2.0$

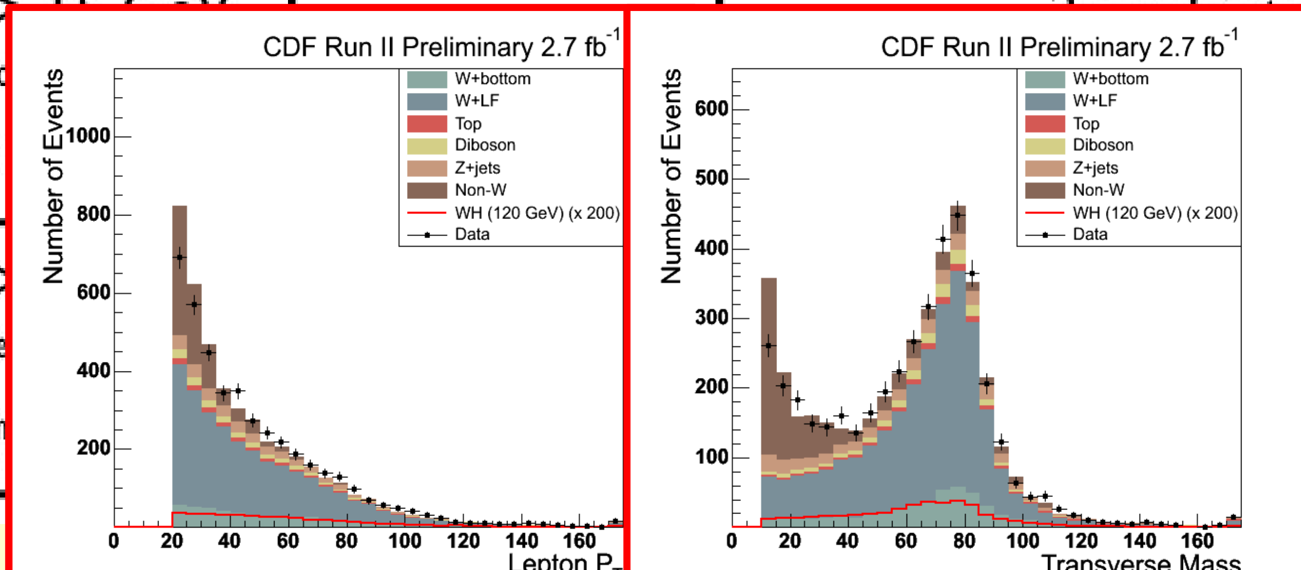
Le canal $(W \to l\nu)(H \to bb)$

Golden Channel !

- $90 < M_H < 150$ GeV



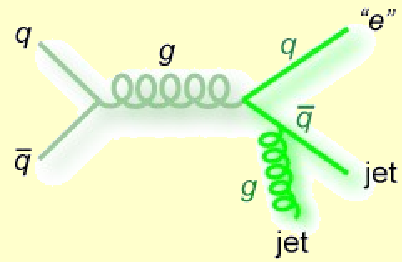
	Leptons	Missing E_T	Jets
DØ	P_T > ... $\|\eta^{elec}$ ... $\|\eta^{m}$ ...		... 25(20) GeV, ... 60 GeV
CDF	P_T > ... $\|\eta^{ele}$ ... $\|\eta^{n}$ ...		... GeV,



Gain d'eff. signal ~ 20% avec trace isolée

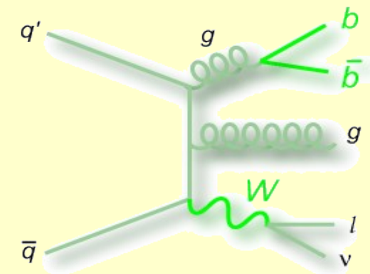
Bruits de fond (I)

Instrumental

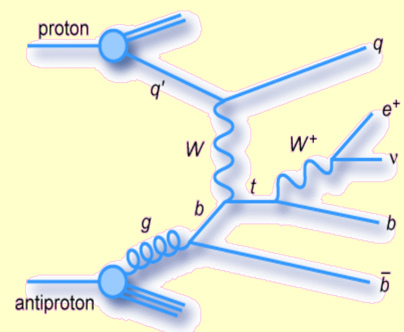


- **Multi-Jets :** *"faux"* leptons
- Données réelles

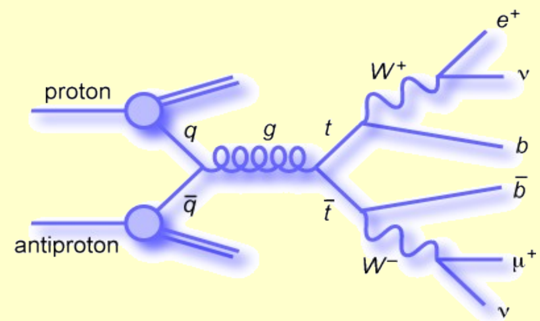
Physiques



- **V+jets :** W/Z+jets *(faux b-jets),* W/Z+b(c)
- Alpgen+Pythia



- **Top :** paires et single-top (CompHEP)
- **Di-bosons:** VV (Pythia)



Bruits de fond (II)

1) QCD

- Evalué dans un lot d'événements avec la *même préselection (lâche) topologique* + critère d'isolation des leptons *inversé*
- Mesure l'efficacité QCD et signal (*i.e.* W) critère isolation *lâche <--> dure* (ex. *vs*. lepton E_T)

2) V*(W/Z)*+jets

- Lots MC normalisés aux *données réelles* (après soustraction tt, st, VV)
    - Scale Factor NLO/LO pour W + saveurs lourdes

3) Identification des jets de b

- Lot de données *"orthogonaux"* :

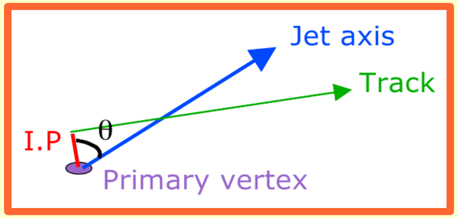
    a) 2 b "lâches"

    b) !a) + 1 b dur + 1 b lâche

    c) !(a&b) + 1 b dur

Identification des saveurs lourdes (I)

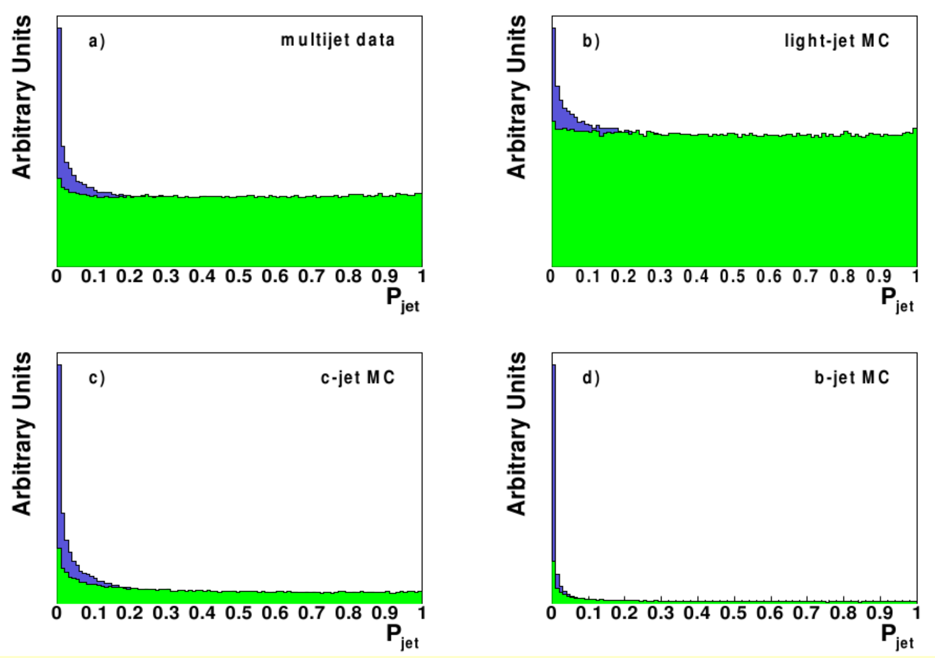
Discriminant à paramètre d'impact

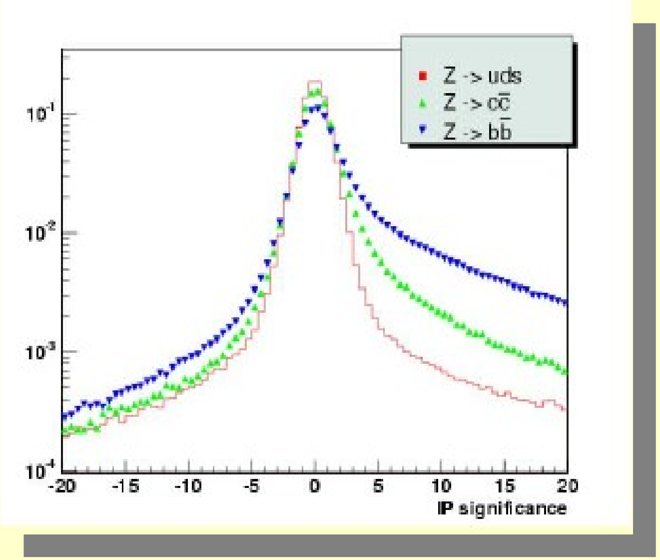


- **Discrêt :** CSIP, compte les traces $S_{IP} > S_0$ ($S_{IP} = IP/\sigma_{IP}$)
- **Continu :** JLIP, construit à partir des fonctions de résolutions, *R(s),* des traces avec $S_{IP} < 0$

$$\mathcal{P}_{trk}(\mathcal{S}_{IP}) = \frac{\int_{-50}^{-|\mathcal{S}_{IP}|} \mathcal{R}(s)ds}{\int_{-50}^{0} \mathcal{R}(s)ds}$$

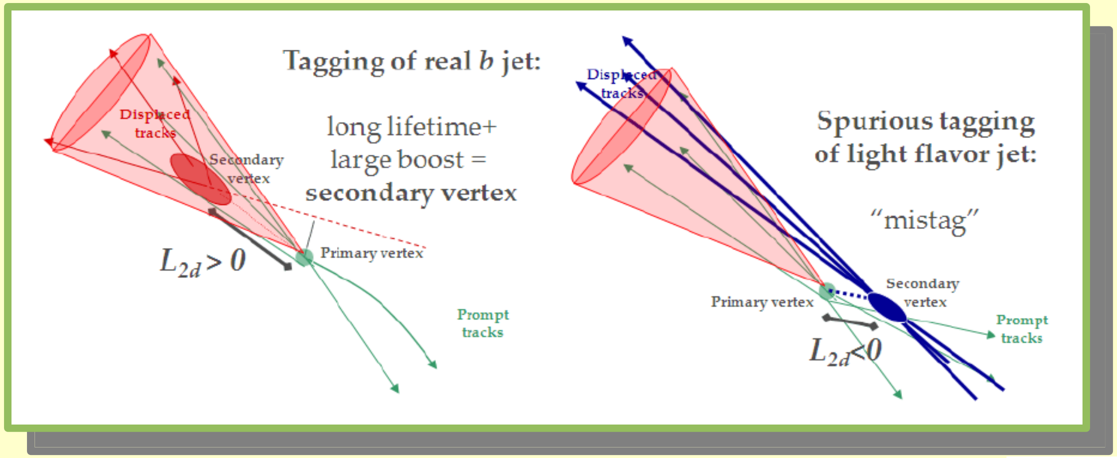
$$\mathcal{P}_{jet}^{\pm} = \Pi^{\pm} \times \sum_{j=0}^{N_{trk}^{\pm}-1} \frac{(-\log \Pi^{\pm})^j}{j!} \quad \text{with} \quad \Pi^{\pm} = \prod_{i=1}^{N_{trk}^{\pm}} \mathcal{P}_{trk}(\mathcal{S}_{IP<0}^{IP>0})$$



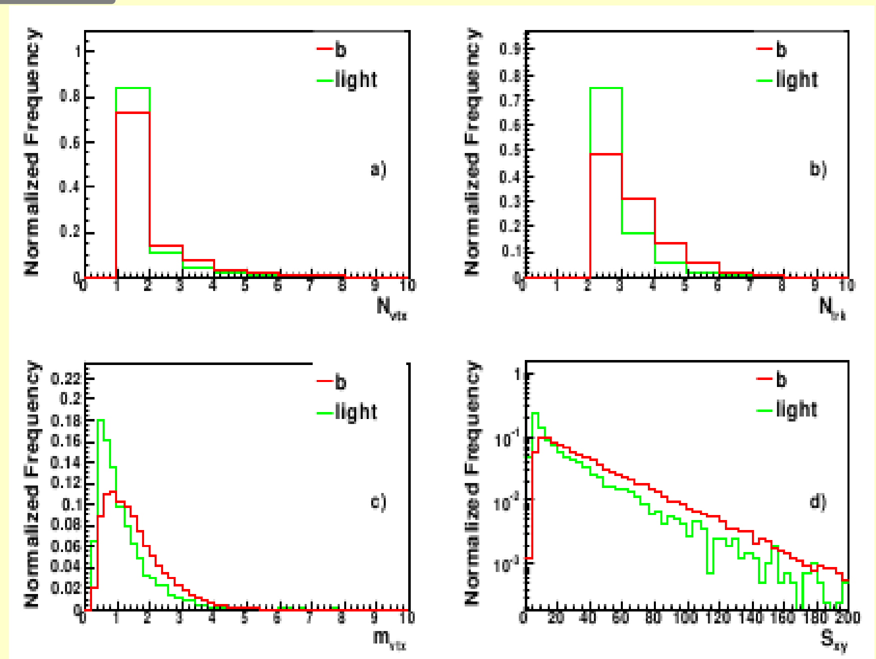


Identification des saveurs lourdes (II)

Vertex secondaire, SVT



- Formation de jets de traces *(type "simple cone")*
- Recherche de vertex deplacé avec un filtre de Kalman
- "Elaguage" des traces à forte contribution au χ^2 du vertex
- **Jet identifié si :** ΔR(vertex,jet) < 0.5 et si la significance de la distance de vol, $S_{Lxy} > S_0$



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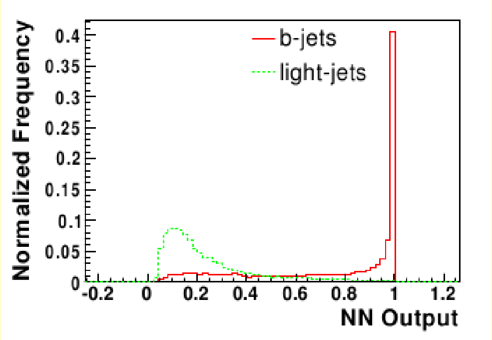
Identification des saveurs lourdes(III)

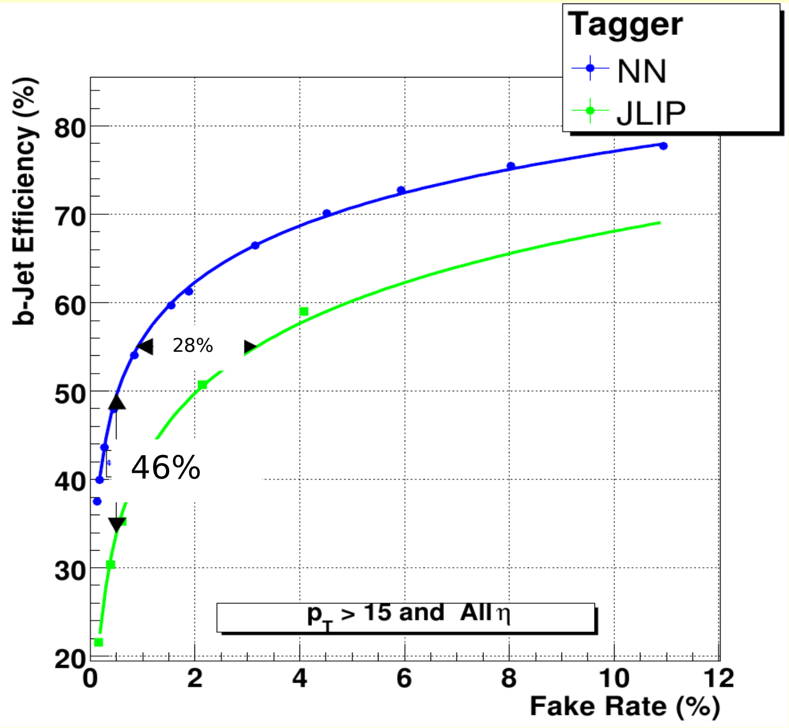
Combinaison / Optimisation

- discriminants de vertex secondaire et de paramètre d'impact sont combinés dans un reseau de neurone (D0)



Performances

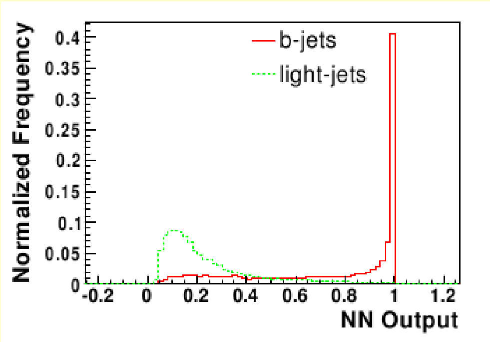
- **D0:** 50-70% signal / 0.3-4.5% b.d.f
- **CDF:** 40-50% signal / 0.5-1.5% b.d.f



Identification des saveurs lourdes(III)

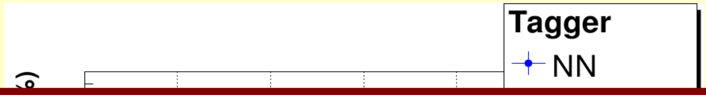
Combinaison / Optimisation

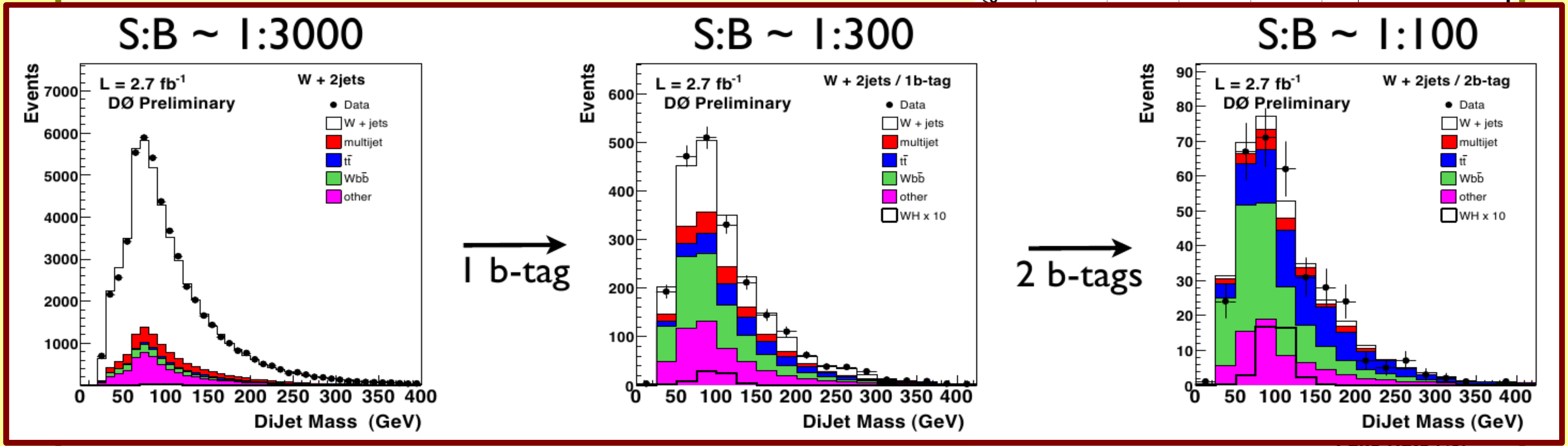
- discriminants de vertex secondaire et de parametres d'impact sont combines dans un reseau de neurone (D0)



Performances

- **D0:** 50-70% signal / 0.3-4.5% b.d.f
- **CDF:** 40-50% signal / 0.5-1.5% b.d.f



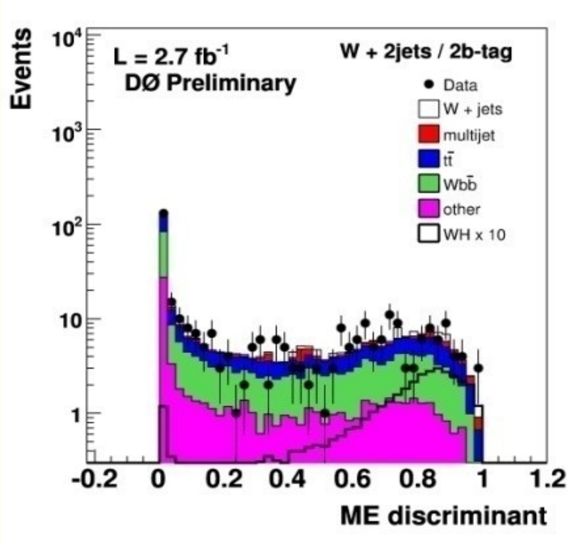


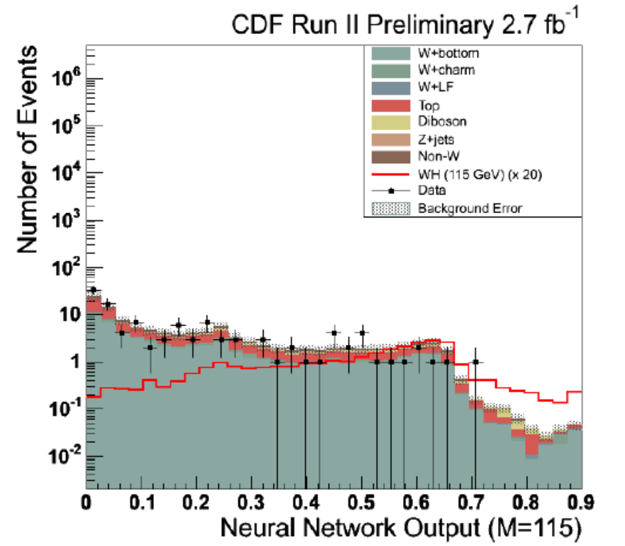
Optimisation

Techniques multivariées

- **D0** et **CDF** entrainent des réseaux de neurones *(NN)* pour chaque hypothèse de masse
  - ↳ gain de **15-20%** en sensibilité par rapport à la variable de masse du systeme di-jet seule
- *Méthode des éléments de matrice* dans le NN
  - ↳ Définit une probabilité d'événement en utilisant les éléments de matrices à l'ordre 0

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



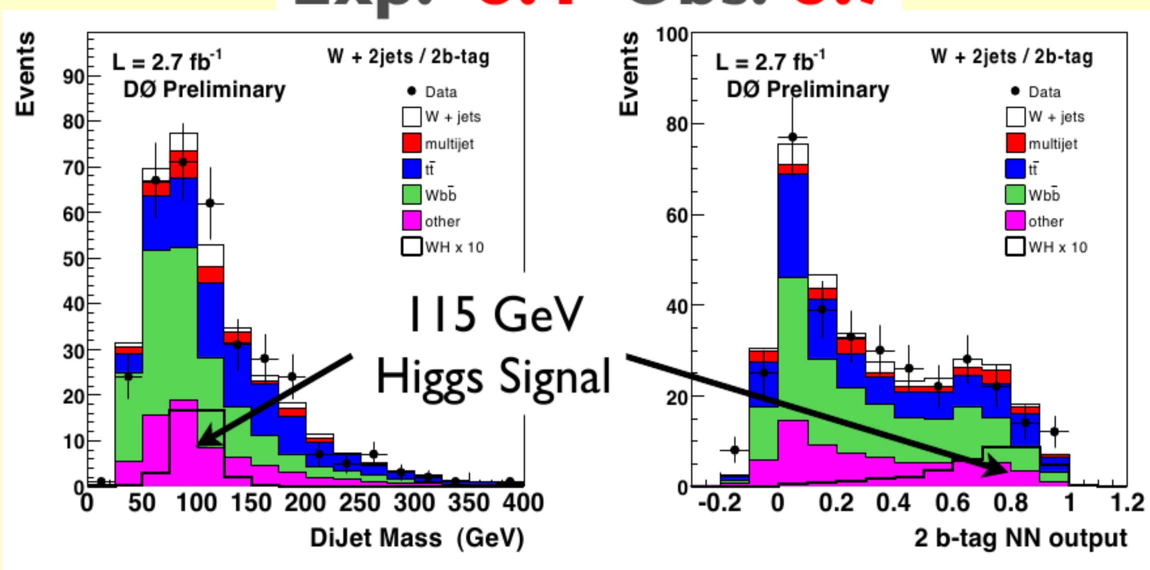


Résultats

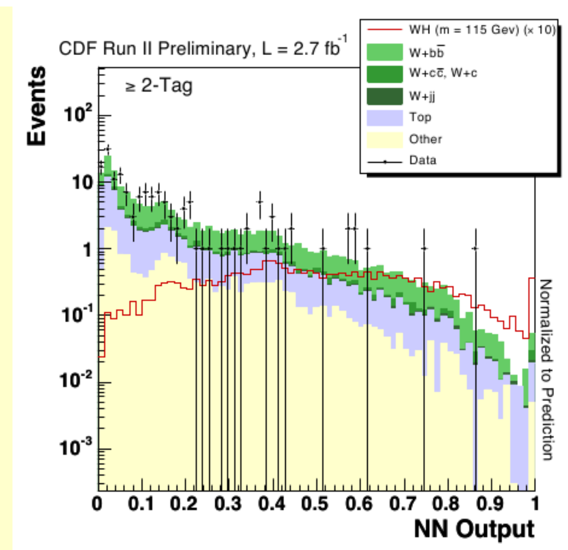
Resultats

- Aucun excès n'est observé dans les données
- La sortie des réseaux de neurones sont utilisées pour l'extraction de limites
- Avec une luminosité de 2.7 pb:

M_H = 115 GeV
Exp: 6.4 Obs: 6.7



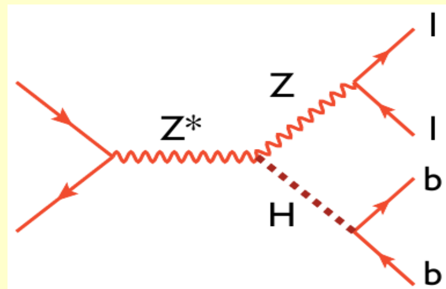
M_H = 115 GeV
Exp: 4.8 Obs: 5.6

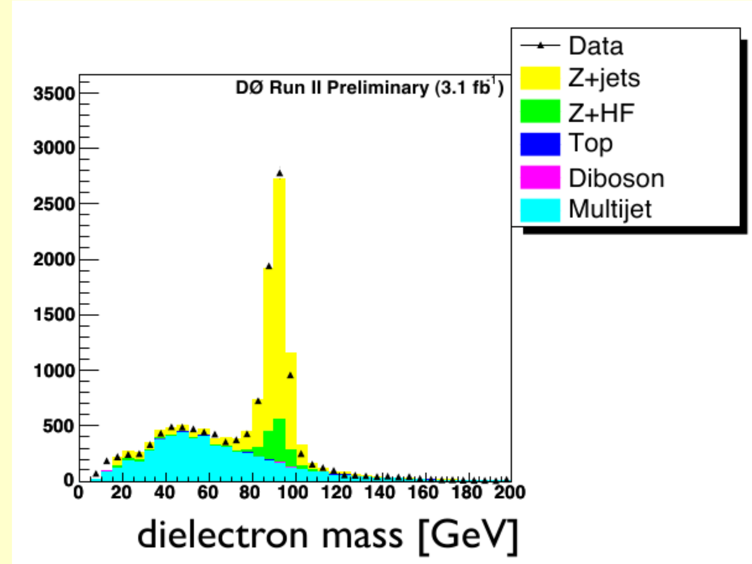


ZH→llbb

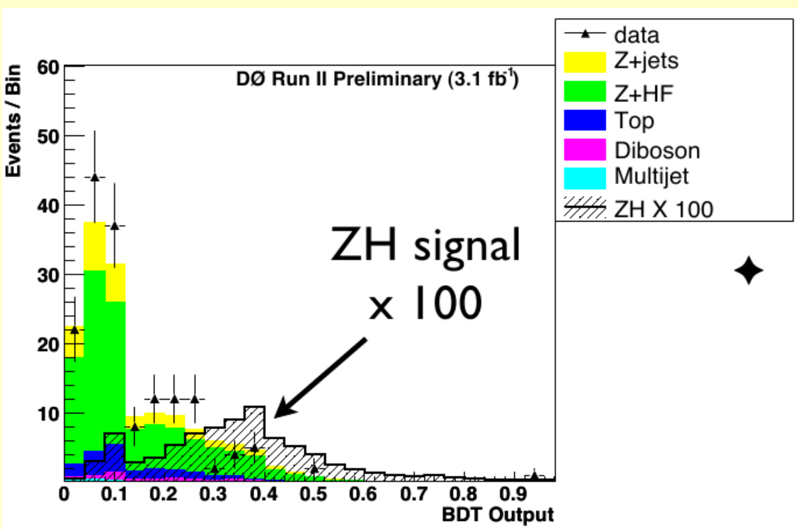
Topologie

- **Bruits de fond:** Z+jets, multijet, top
- **CDF:** 2.7fb^{-1}, **D0:** 3.1-4.2fb^{-1}

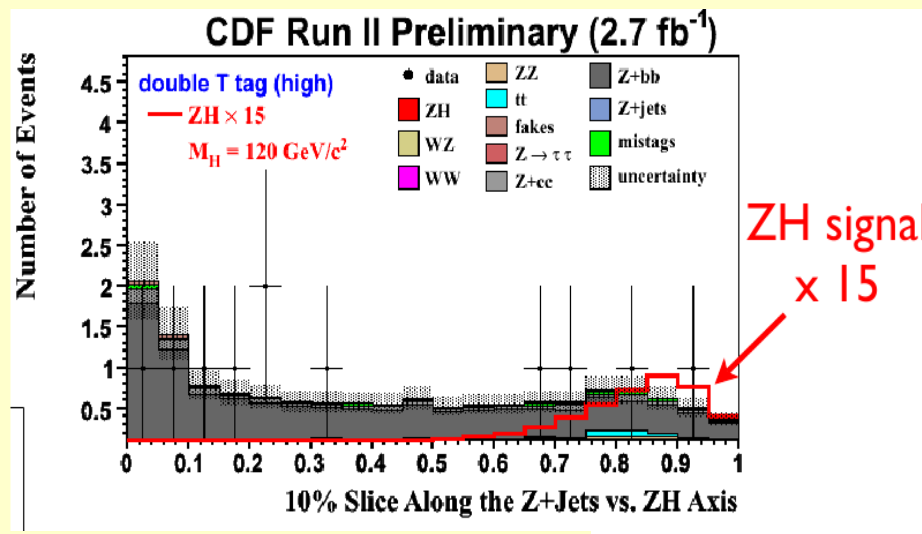




D0: arbre de decision / canal



CDF: NN 2D (Zbb/tt)



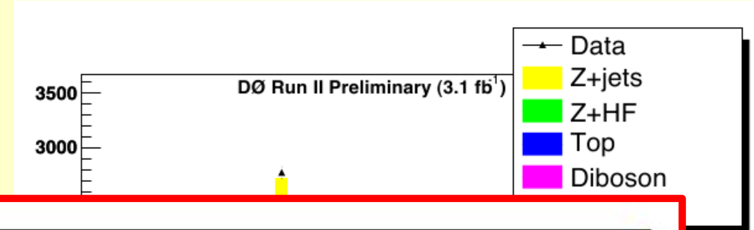
M_H = 115 GeV
Exp: 8.0 Obs: 9.1

M_H = 115 GeV
Exp: 9.9 Obs: 7.1

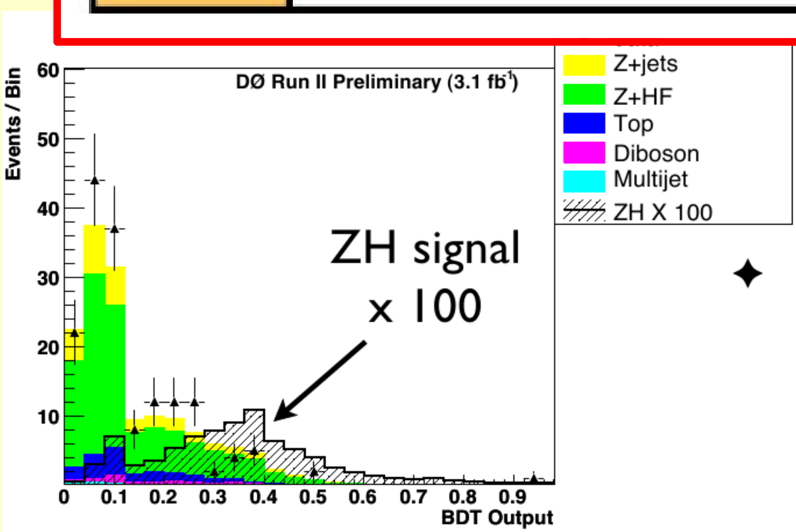
ZH→llbb

Topologie

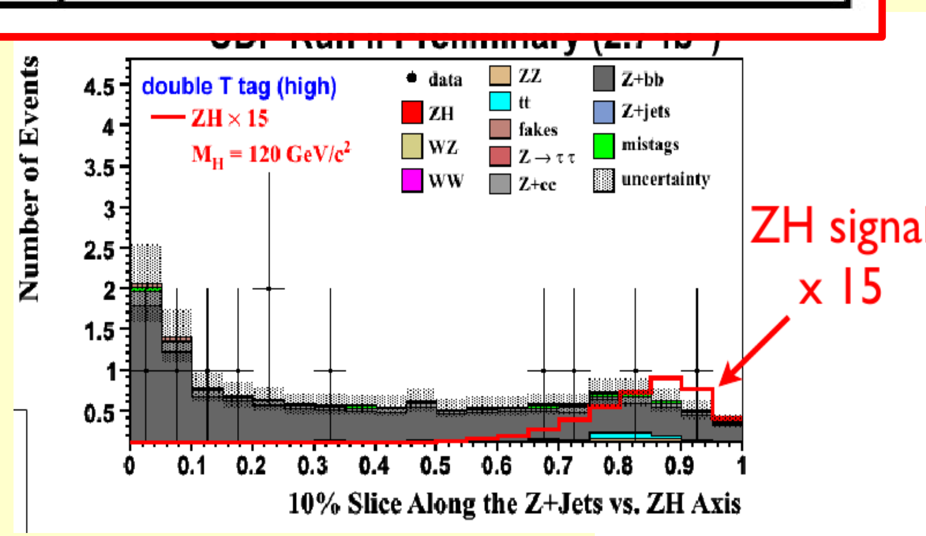
- **Bruits de fond:** Z+jets, multijet, top
-



	Leptons	Jets
DØ	P_T > 10 GeV, $\lvert\eta^{electron}\rvert$ < 2.5, $\lvert\eta^{muon}\rvert$ < 2.0	≥2 jets, jets P_T > 20(15) GeV, $\lvert\eta^{jet}\rvert$ < 2.5
CDF	P_T > 18(10) GeV, $\lvert\eta^{electron}\rvert$<2.8, $\lvert\eta^{muon}\rvert$<2.0	≥2 jets, jets P_T > (25)15 GeV, $\lvert\eta^{jet}\rvert$ < 2.0



M_H = 115 GeV
Exp: 8.0 Obs: 9.1

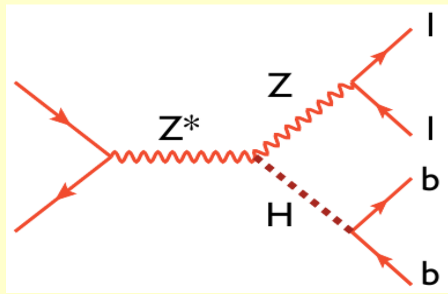


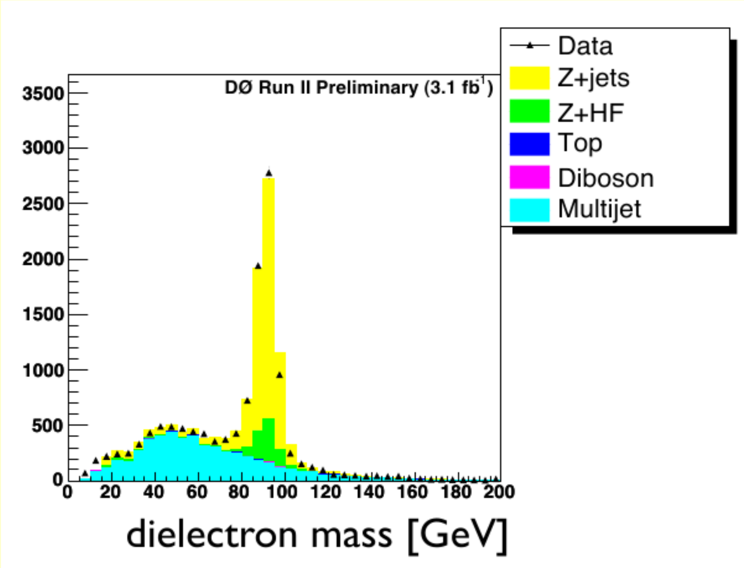
M_H = 115 GeV
Exp: 9.9 Obs: 7.1

ZH→llbb

Topologie

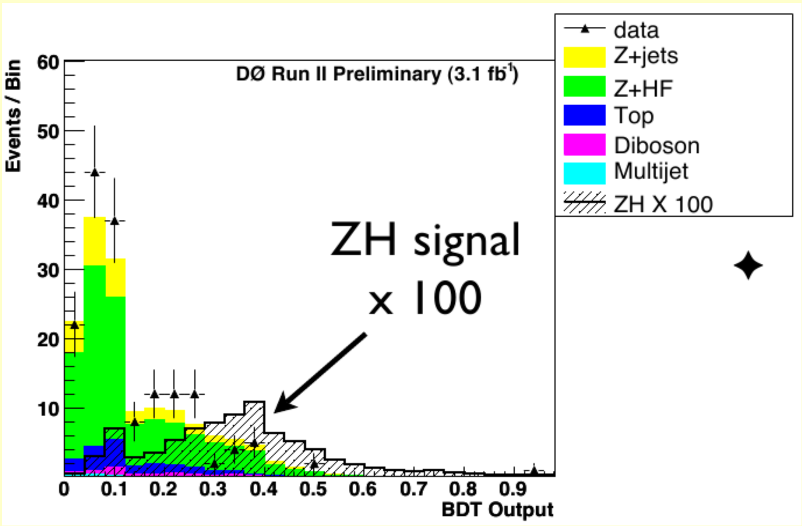
- **Bruits de fond:** Z+jets, multijet, top
- **CDF:** 2.7fb^{-1}, **D0:** 3.1-4.2fb^{-1}

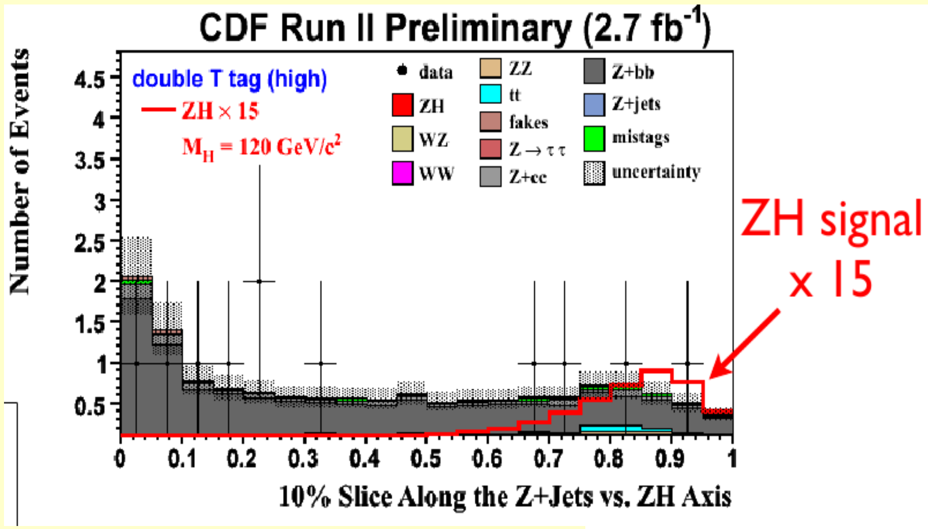




D0: arbre de decision / canal

CDF: NN 2D (Zbb/tt)





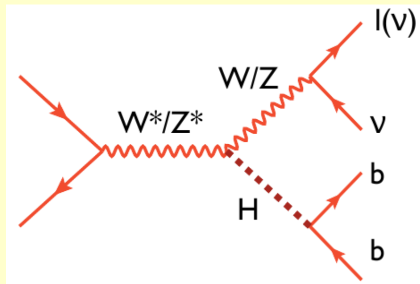
M_H = 115 GeV
Exp: 8.0 Obs: 9.1

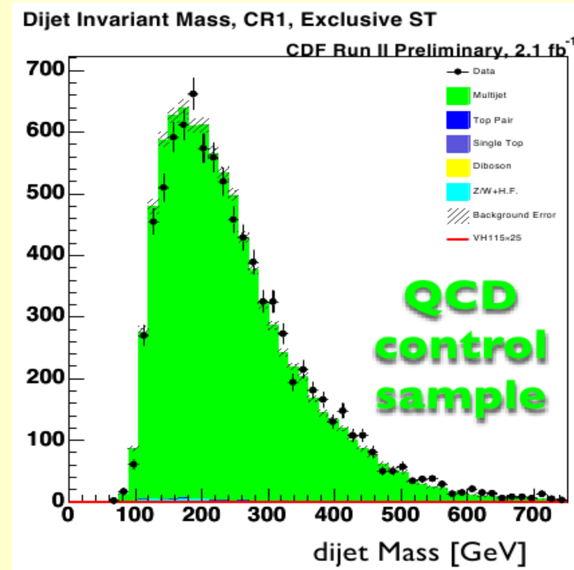
M_H = 115 GeV
Exp: 9.9 Obs: 7.1

ZH→ννbb

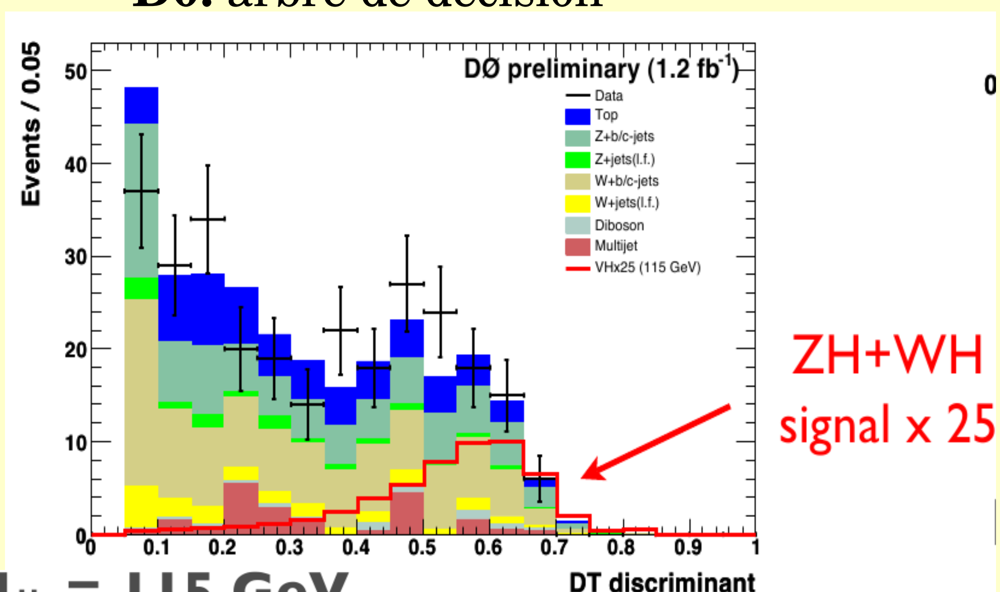
Topologie

- **Bruits de fond:** QCD multijets *(*10⁹ !)*, top, V+jets
- **CDF & D0:** 2.1fb^{-1}



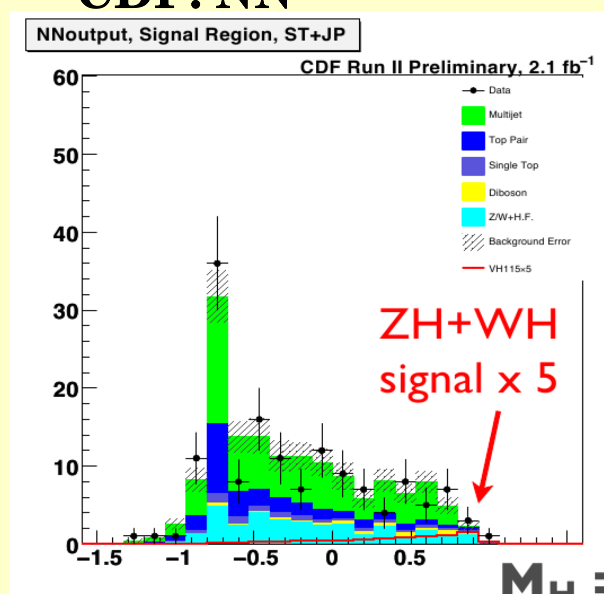


D0: arbre de décision



M$_H$ = 115 GeV
Exp: 8.4 Obs: 7.5

CDF: NN

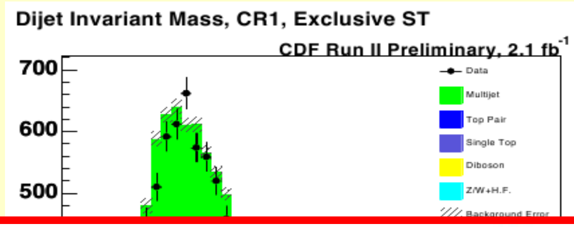


M$_H$ = 115 GeV
Exp: 5.6 Obs: 6.9

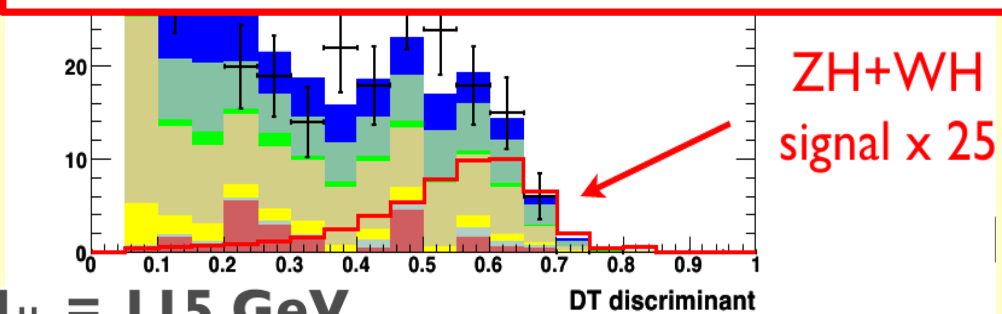
ZH→$\nu\nu$bb

Topologie

- **Bruits de fond:** QCD multijets *(*10^9 !)*, top, V+jets

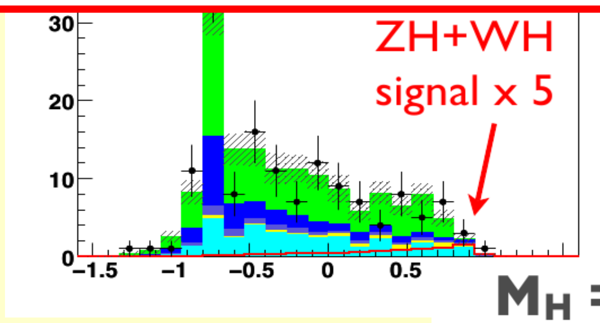


	Missing E_T	Jets
DØ	ME_T > 50 GeV	≥2 jets, ($\Delta\Phi$(jet1, jet2) < 165° jets P_T > 20 GeV, $\|\eta^{jet}\|$ < 2.5
CDF	ME_T > 50 GeV	≥2 jets, jet P_T > (35)20 GeV, $\|\eta^{jet}\|$ < 2.0



M_H = 115 GeV

Exp: 8.4 Obs: 7.5



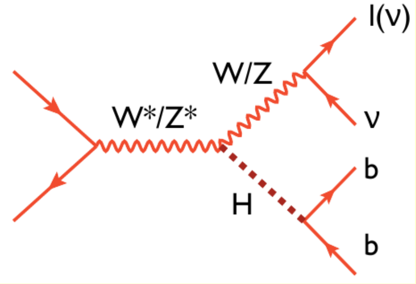
M_H = 115 GeV

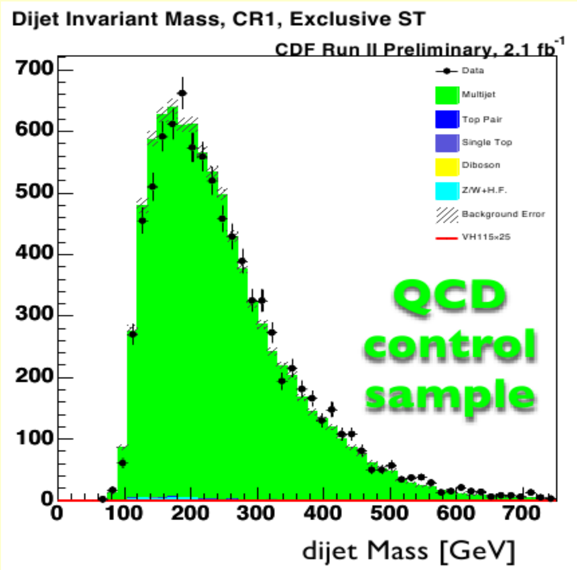
Exp: 5.6 Obs: 6.9

ZH→$\nu\nu$bb

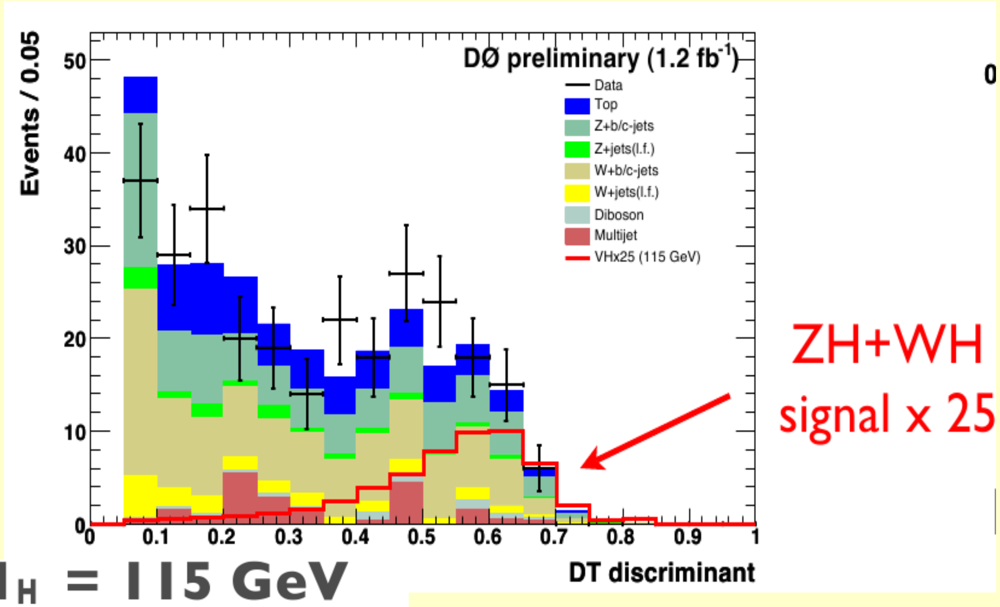
Topologie

- **Bruits de fond:** QCD multijets *(*10^9 !)*, top, V+jets
- **CDF & D0:** 2.1fb^{-1}

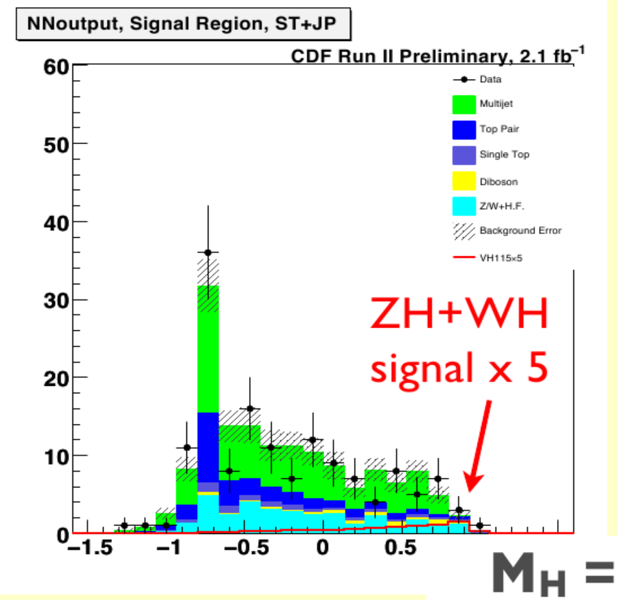




D0: arbre de décision



CDF: NN



M_H = 115 GeV

Exp: 8.4 Obs: 7.5

/15/09

M_H = 115 GeV

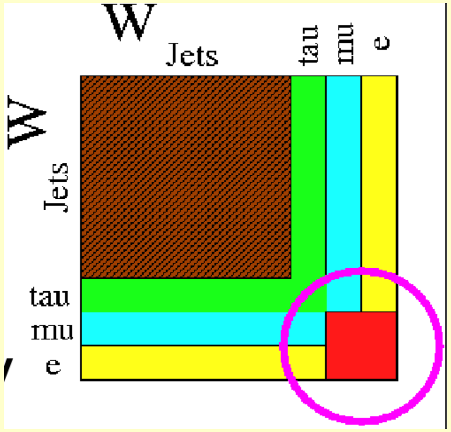
Exp: 5.6 Obs: 6.9

La recherche du boson de Higgs *lourd*

gg→H→WW

Topologie

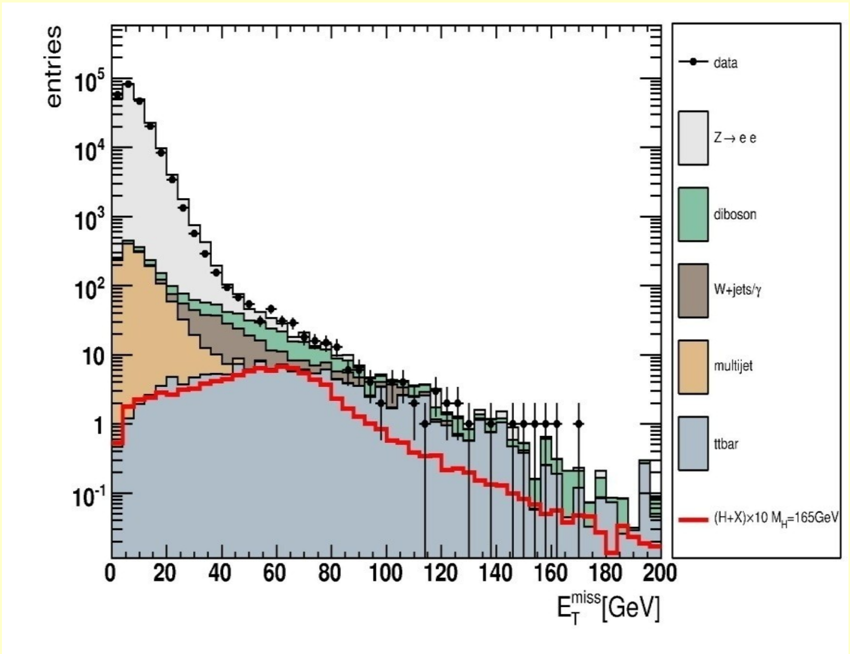
- $H \to W^+W^- \to l^+ \nu l^- \nu$



- Déclenchement sur un lepton de grand p_T (10-15 GeV/c)

Bruits de fonds:

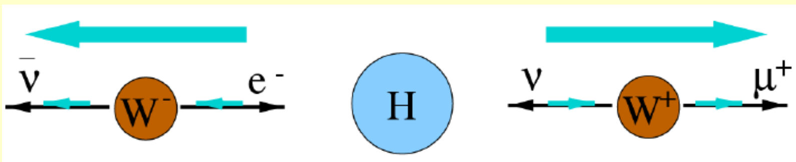
- Z/g DY --> l^+l^- mais *faible MET*
- Diboson (VV)
- Top, V+jets (mauvaise identification du lepton)

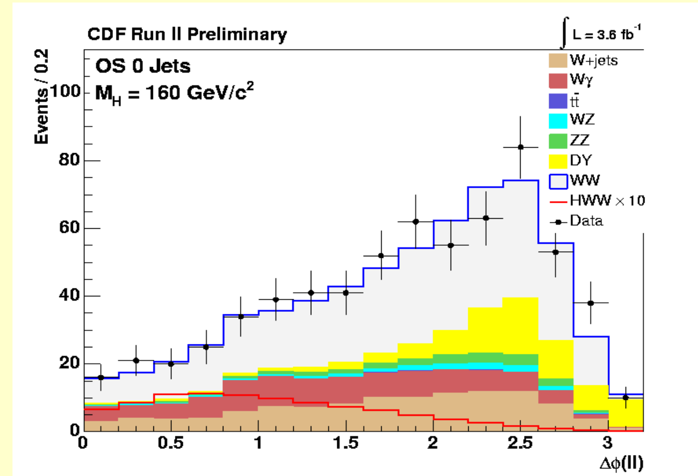


gg→H→WW

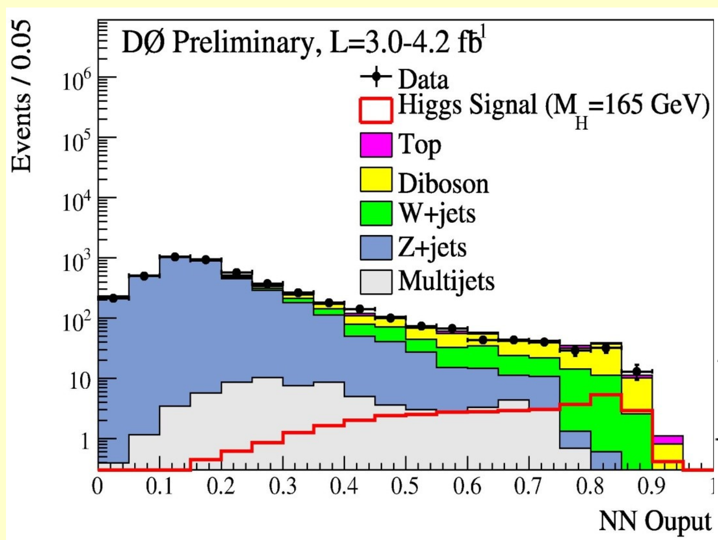
Correlation de spins

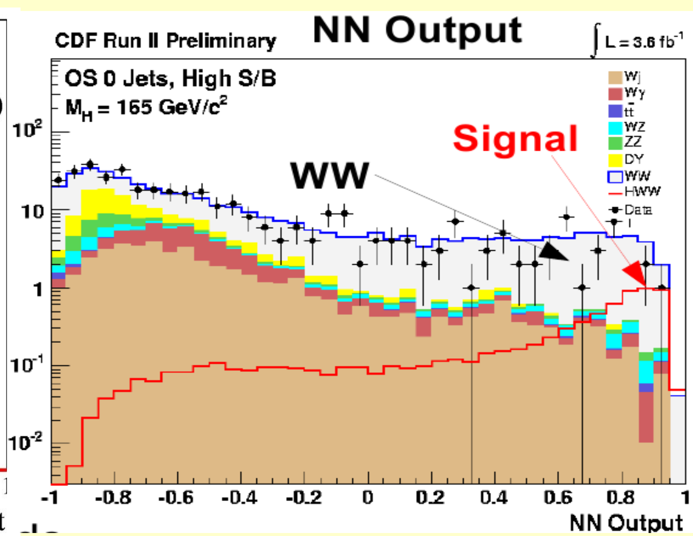
- Boson vecteur / scalaire



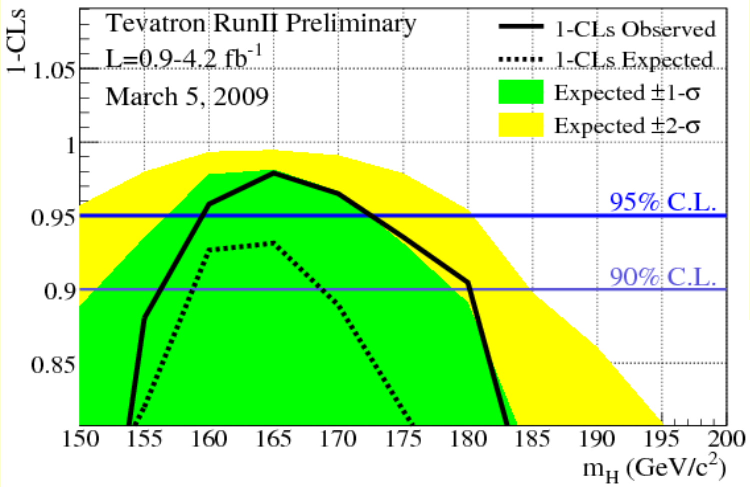


- 23 / 4994 événements signal / b.d.f
- Sensibilité maximisée avec un réseau de neurone
- CDF sépare 0,1,2 jets





Résultats combinés DØ et CDF

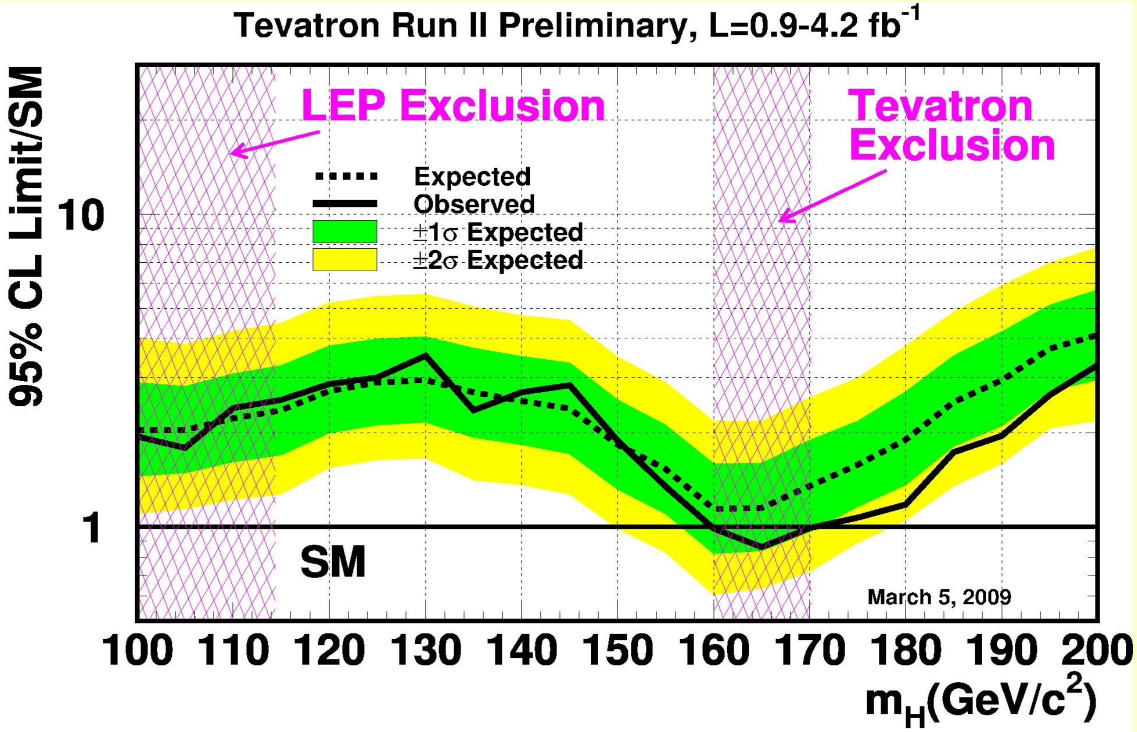


Erreurs systématiques :

- Normalisations (ex: sections efficaces theoriques)
- Formes (ex: JES, lepton-id, ...)

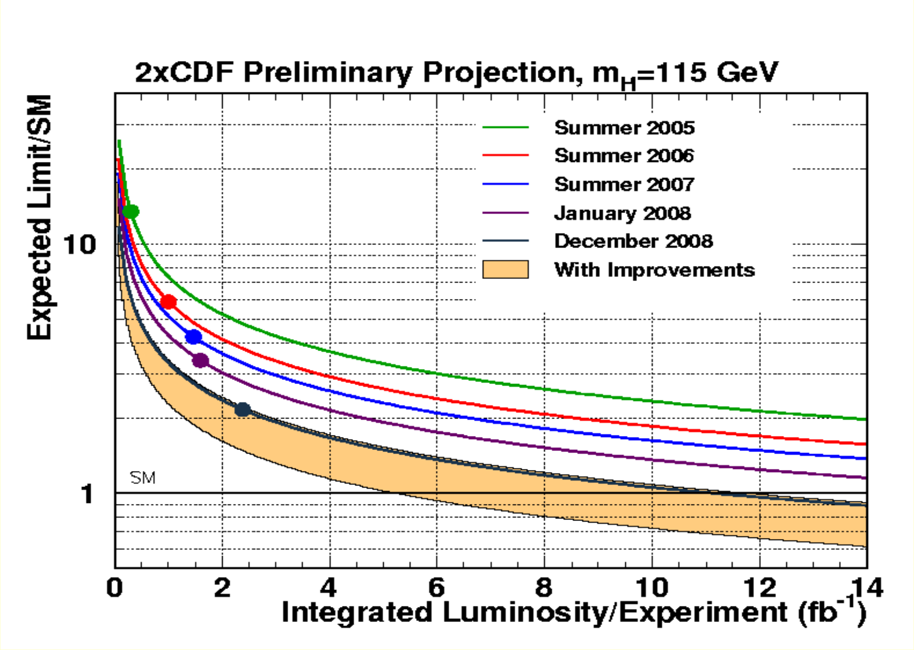
Latest Tevatron Exclusion @ M_H = 115

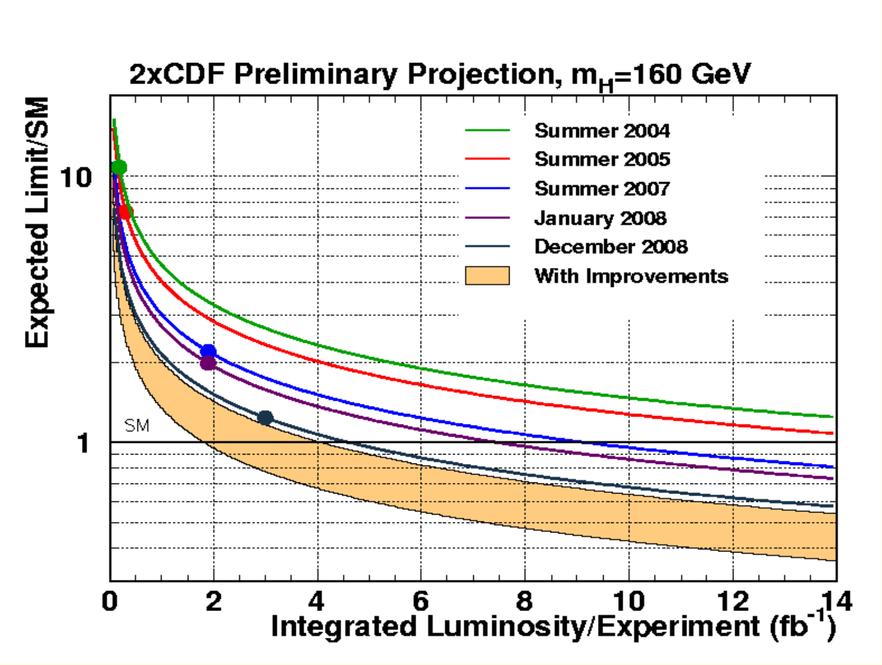
Exp: 2.4 x SM
Obs: 2.6 x SM



Perspectives

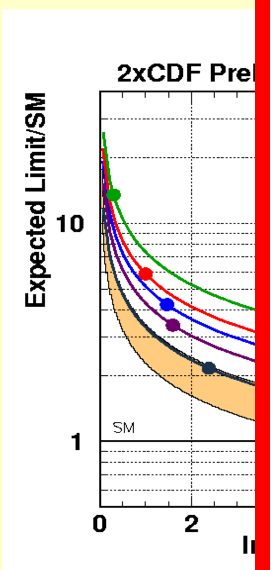
Perspectives (***1/√(Luminosité)***) en fonction de la luminosité integrée pour des hypothese de masses de 115 et 160 GeV *(La borne haute (basse) de la bande orange représente une amélioration de x1.5 (2.25) des résultats "Summer 2007")*

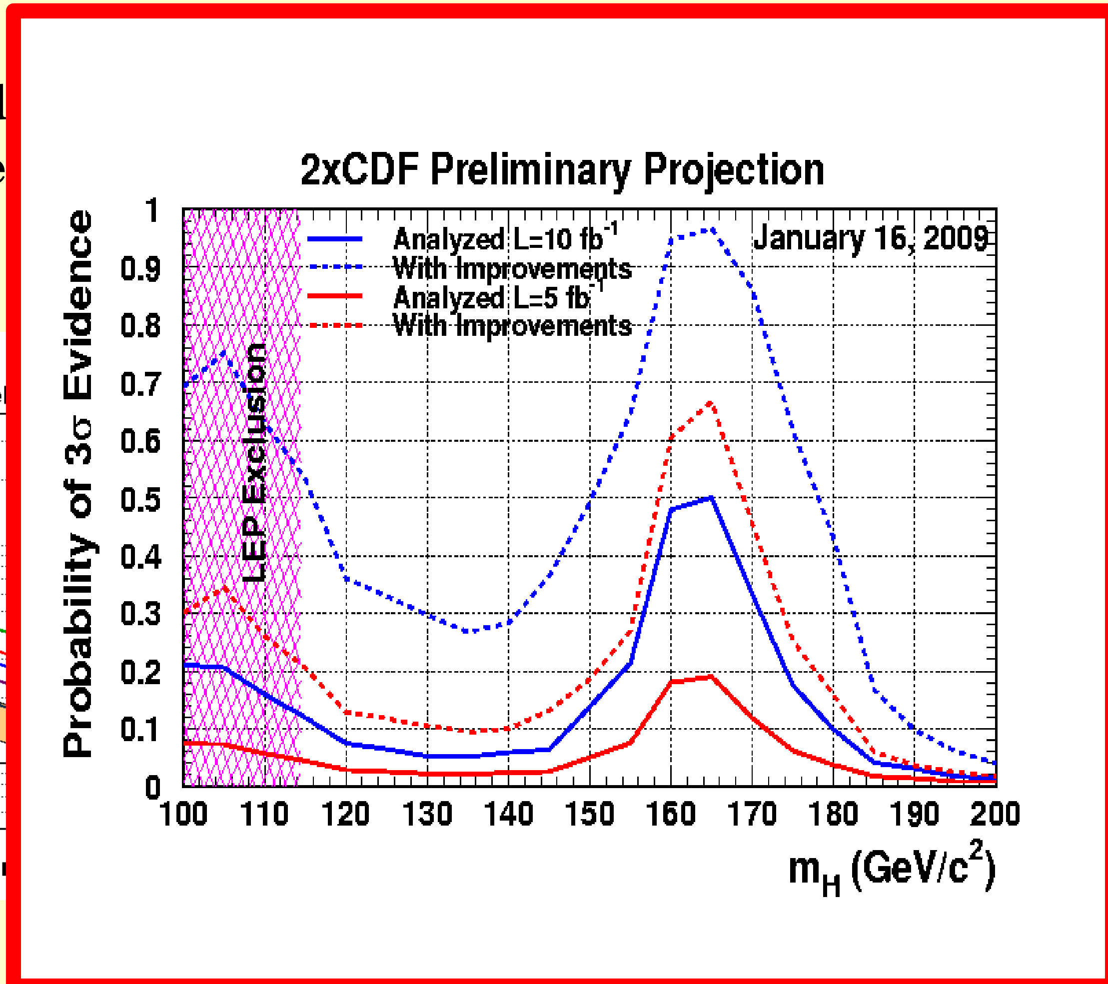


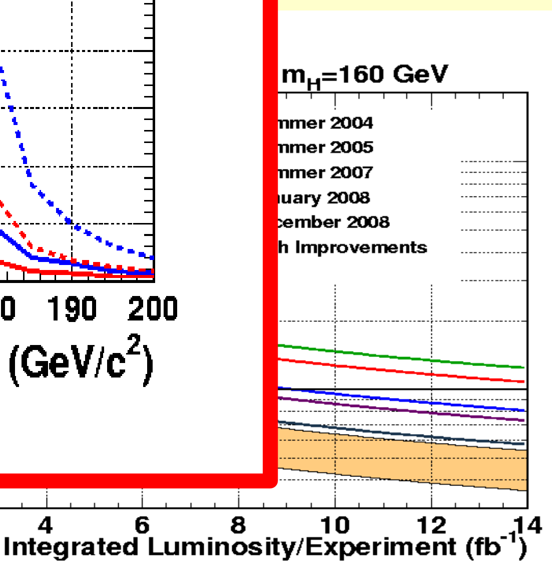


Perspectives

Perspectives d ergree pour des
hypothese de *la bande orange*
represente une)

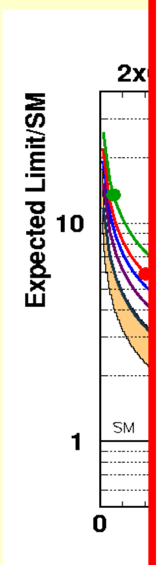


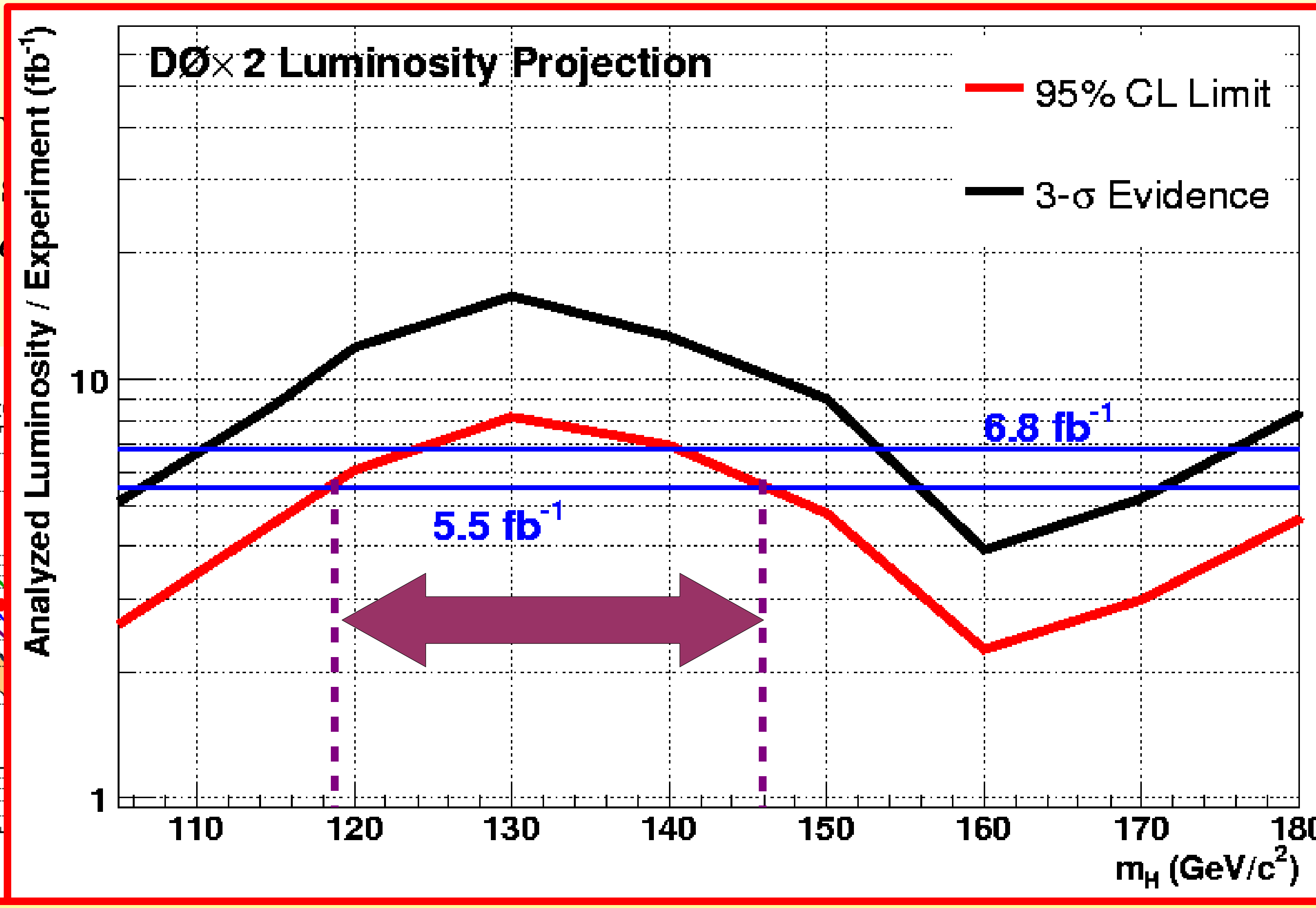


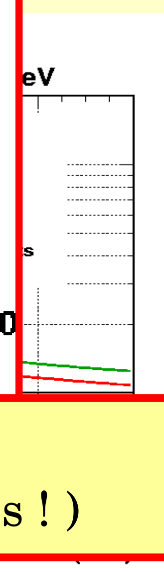


Perspectives

Perspecti… pour des
hypothe… *…ade orange*
represente…



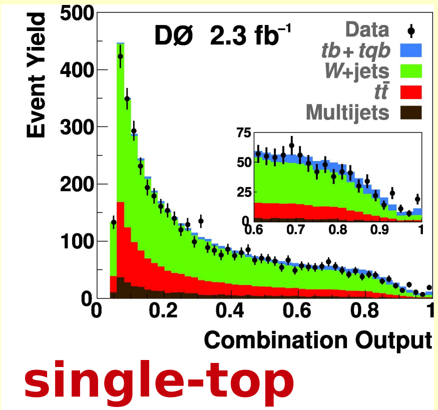


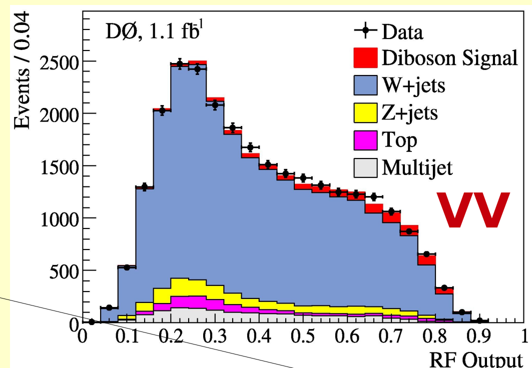


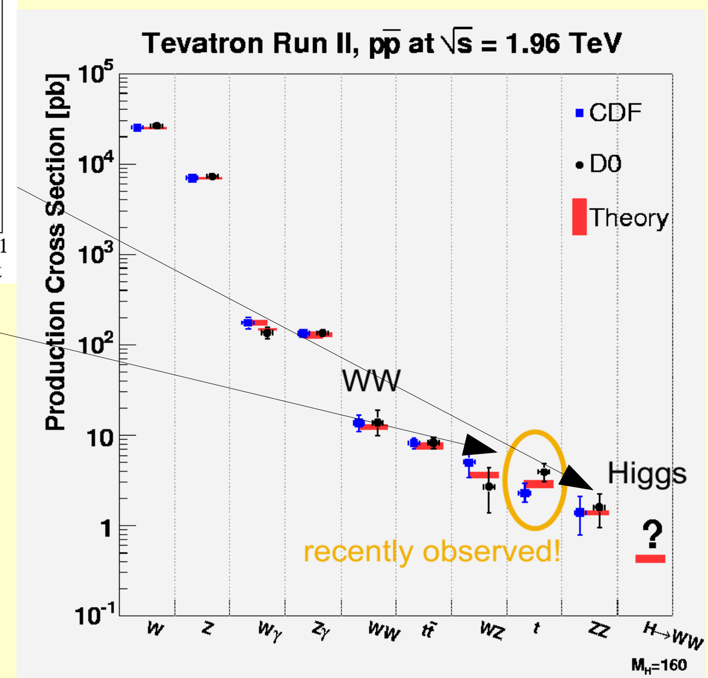
~2010: seul 115 < MH < 145 GeV @ 95 C.L
Domaine **difficile** pour le LHC (nécéssitera ~5fb-1 = plusieurs années !)

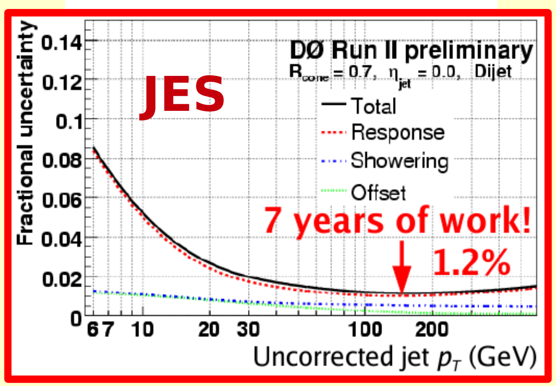
Conclusion

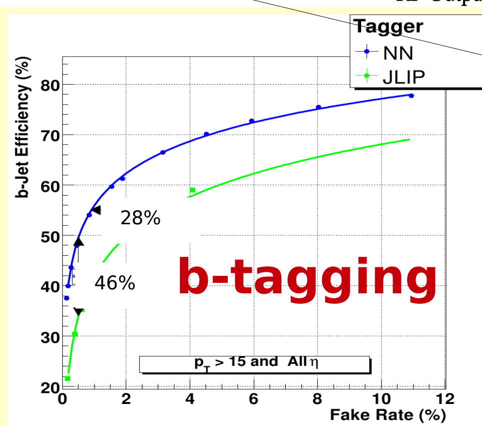
- Les performances du TeVatron et des détecteurs D0,CDF sont **excellentes**
- La ***maturité*** des analyses croît plus vite que l'accumulation des données
- **Perspectives impressionantes :** exclusion $120 < M_H < 200$ GeV d'ici 2011 !









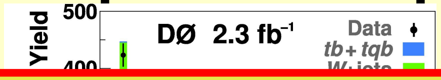


Conclusion

Les performances du TeVatron et des détecteurs D0,CDF sont **excellentes**

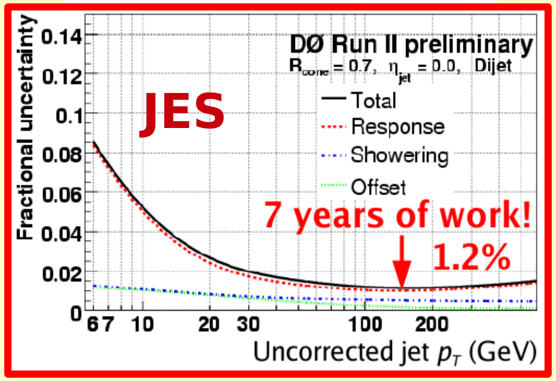
La ***maturité*** des analyses croît plus vite que l'accumulation des données !

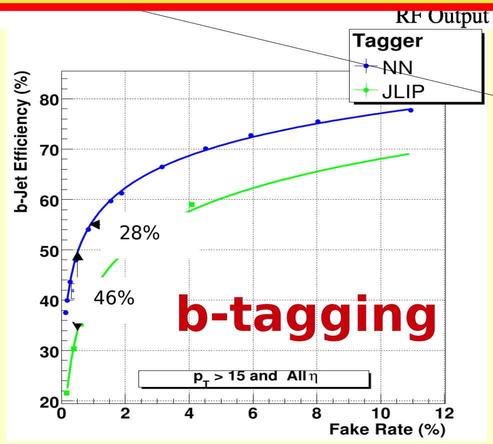
Perspectives impressionantes : exclusion $120 < M_H < 200$ GeV d'ici 2011 !

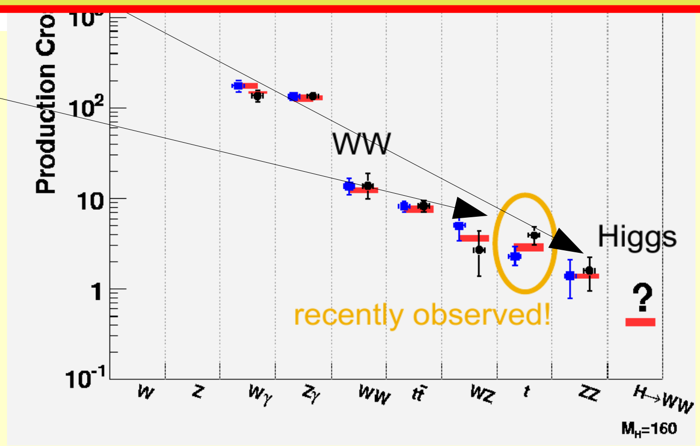


http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_09/

single-top







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Greder Sébastien, 5/15/09