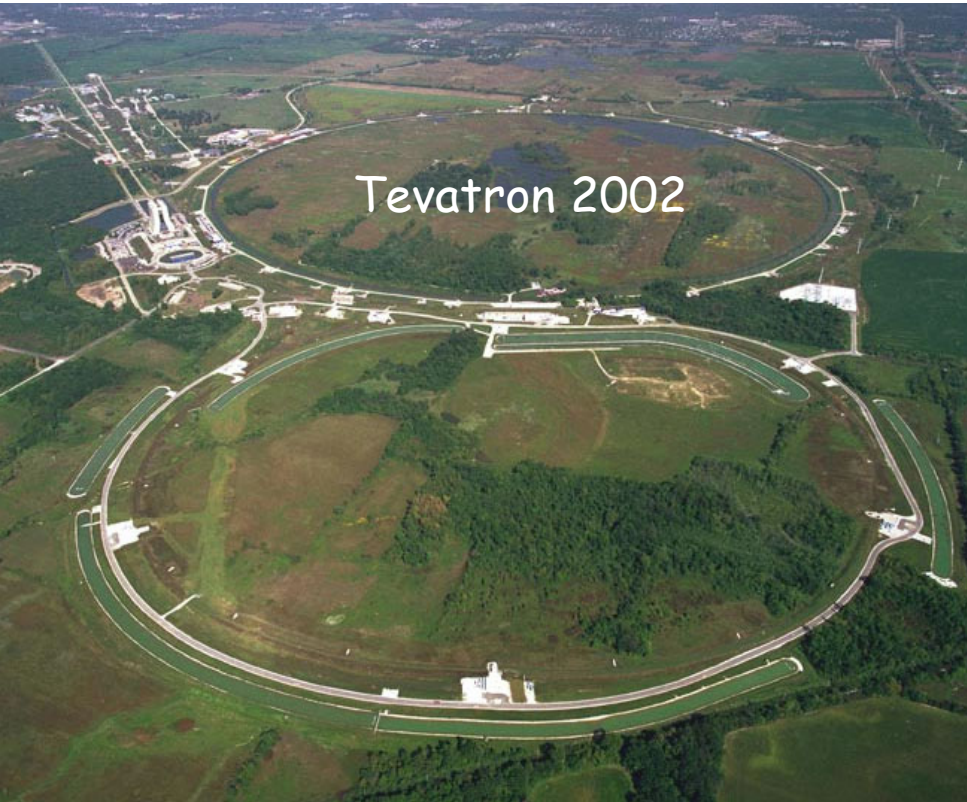
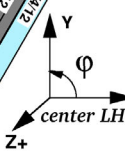
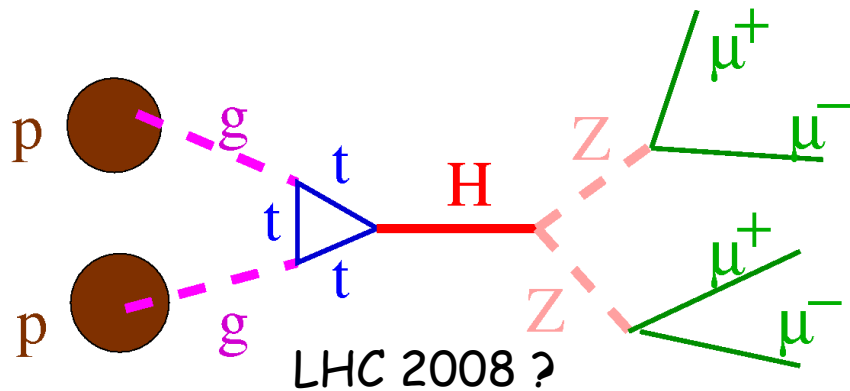
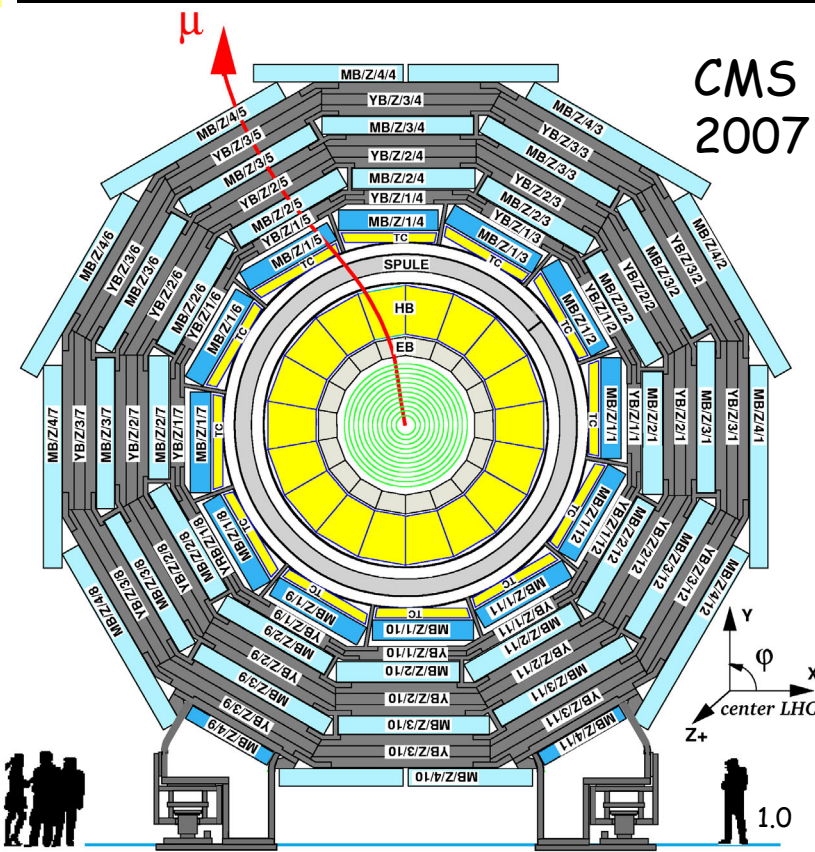
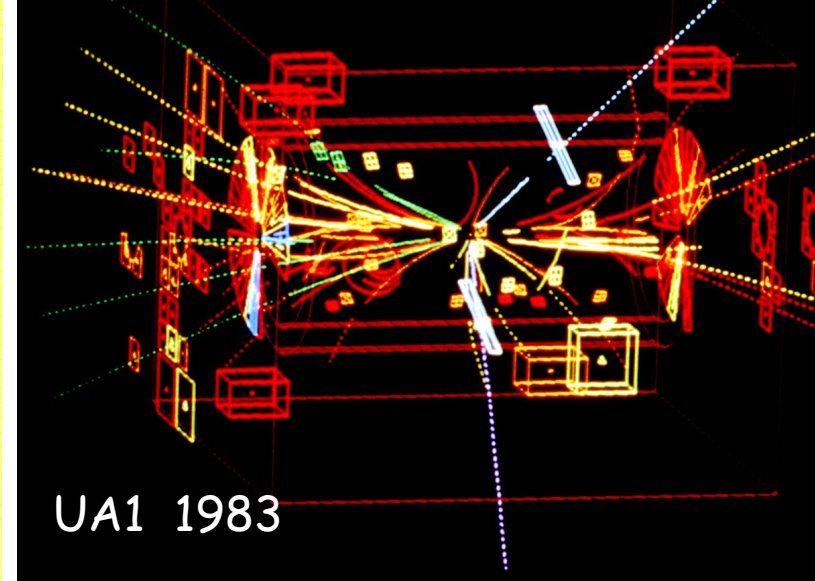


part III



p  
p  
p  
h  
y  
s  
i  
c  
s



Part I Introduction

Part II Standard Model Physics

Part III Higgs

- SM higgs:
  - what do we know ?
  - production and decay
  - detection
- extended higgs models

Part IV New Phenomena

References

# The SM Higgs

## Known (if exists):

- couples to mass (!): bosons and fermions
- scalar, no elm. or strong interactions
- properties calculable as a function of  $m_H$
- LEP:  $114 \text{ GeV} < m_H < 219 \text{ GeV}$  (95%)

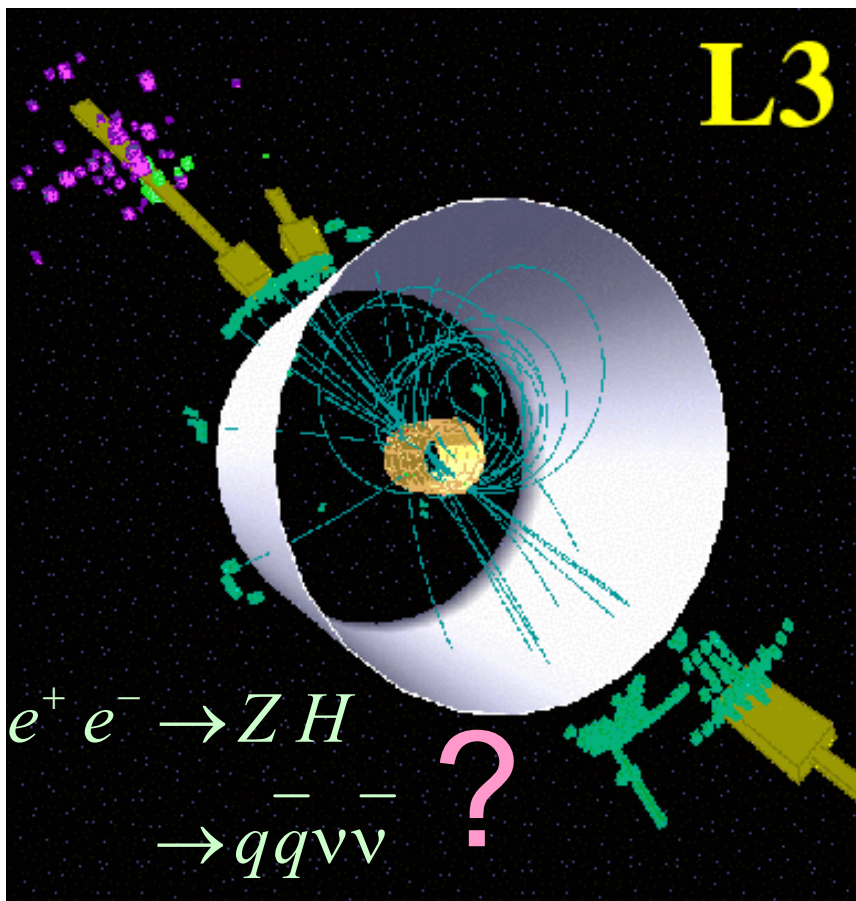
## To be explored:

- existence ? produce and detect !
- properties ? precise measurements  $\rightarrow e^+ e^-$  collider

# Historical reminiscence: LEP and Higgs

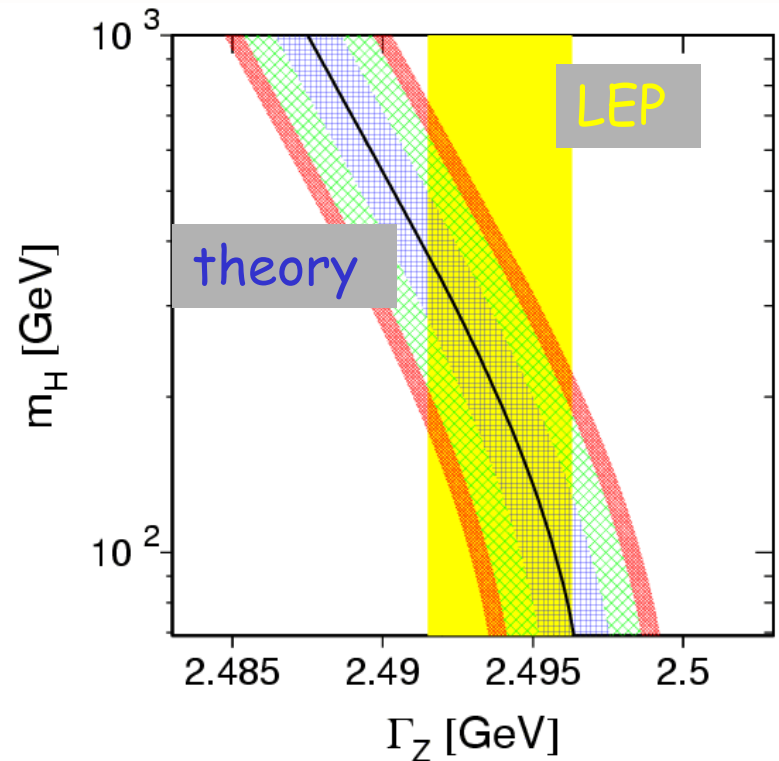
direct

indirect



$$m_H > 114 \text{ GeV} \quad (95\%)$$

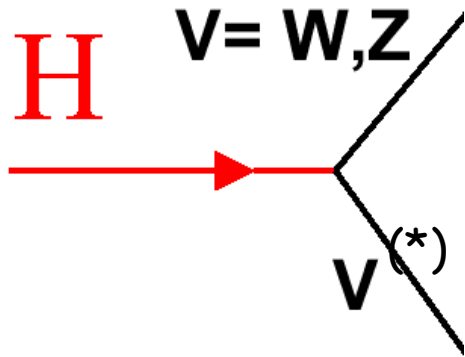
(LEP)



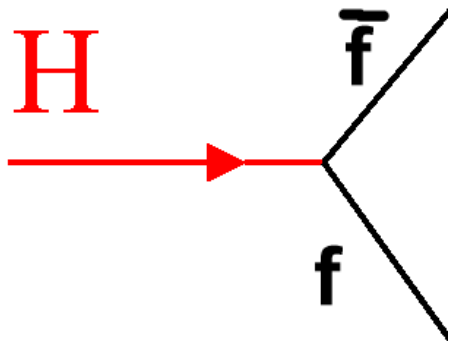
$$m_H < 219 \text{ GeV} \quad (95\%)$$

(LEP, SLD, Tevatron, NuTeV...)

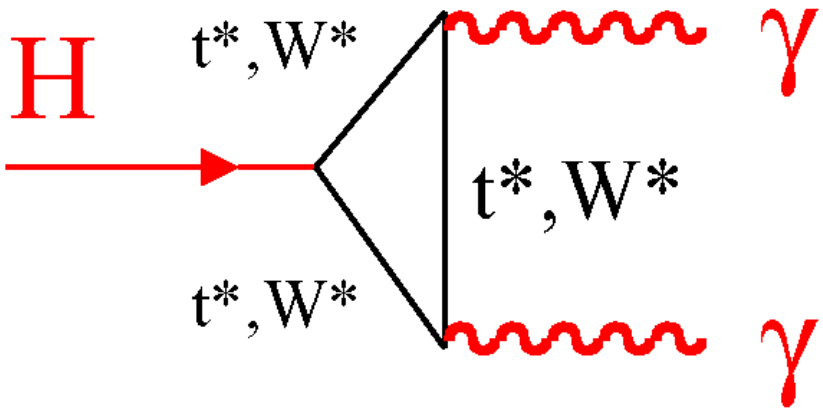
# Higgs Decay Modes



$$\Gamma(H \rightarrow VV) \rightarrow G_F m_H^3$$



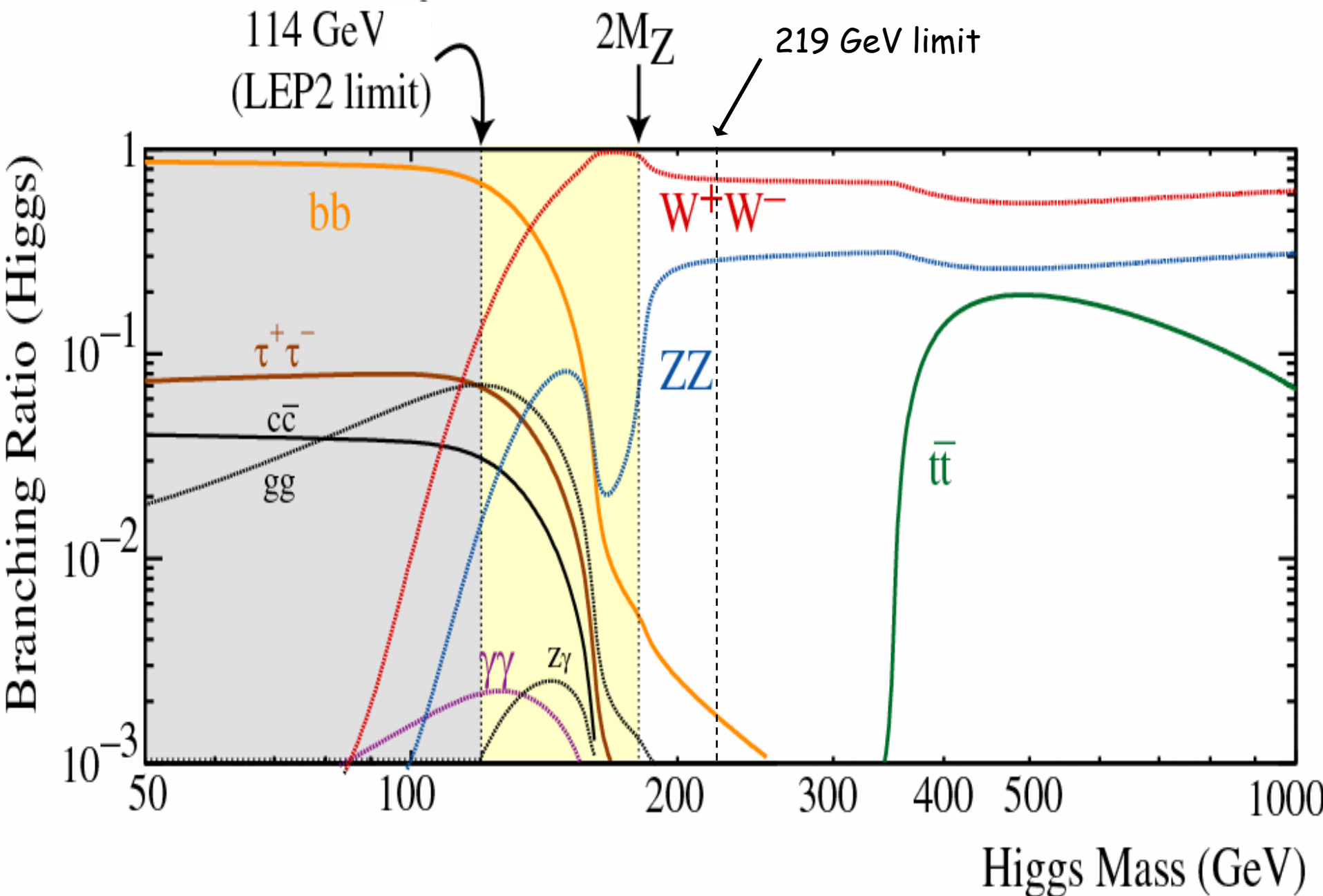
$$\Gamma(H \rightarrow f \bar{f}) \rightarrow G_F m_f^2 m_H$$



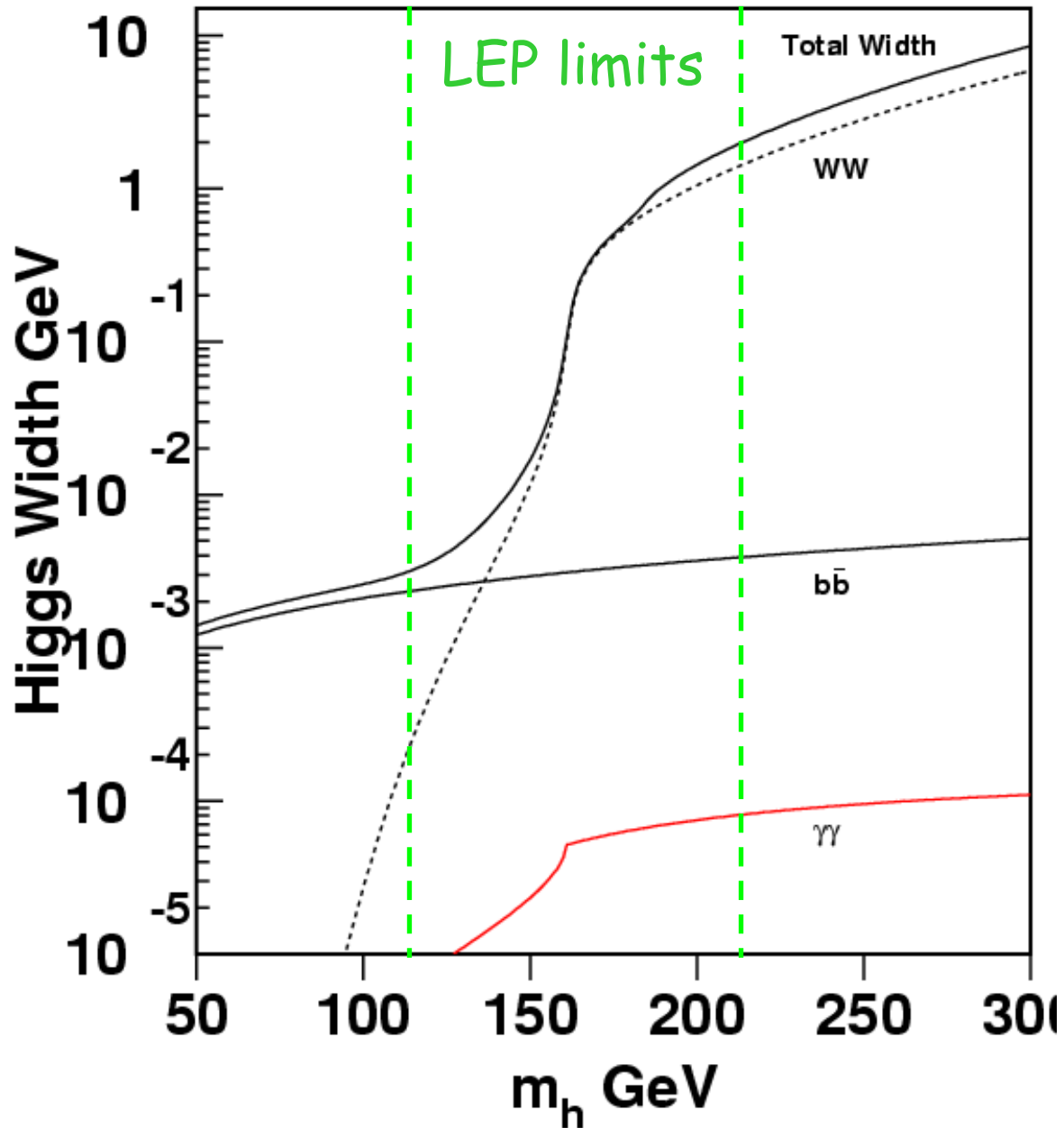
$$\Gamma(H \rightarrow \gamma\gamma) \rightarrow \alpha^2 G_F m_H^3$$



# Higgs Branching Fractions

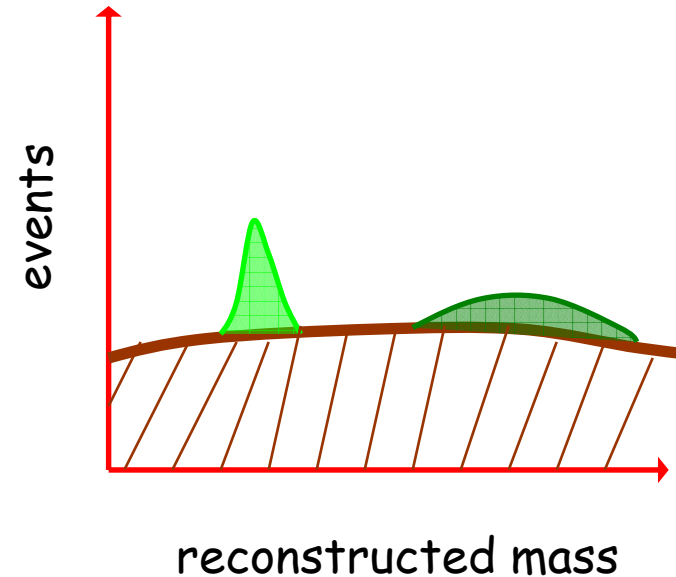


# Higgs Decay Width

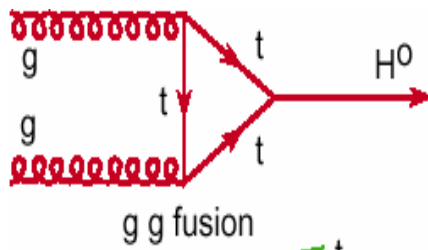


$$\Gamma \sim m_H^3$$

Important for  
Signal/background!

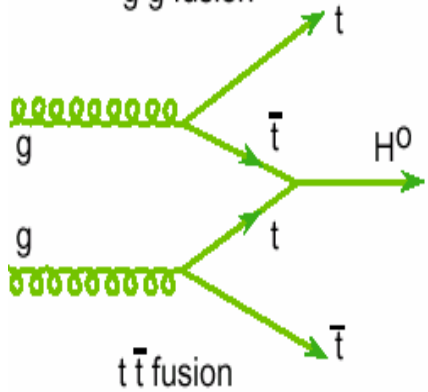


# Higgs production in pp



Xsection largest

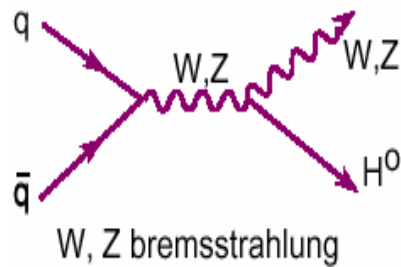
$H \rightarrow \gamma \gamma, (leptons)$



Xsection small

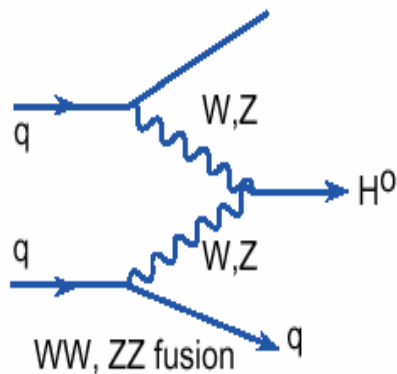
**photons, leptons:**

- less background
- mass resolution !



Xsection „large“ at 2 TeV

$W, Z \rightarrow leptons$

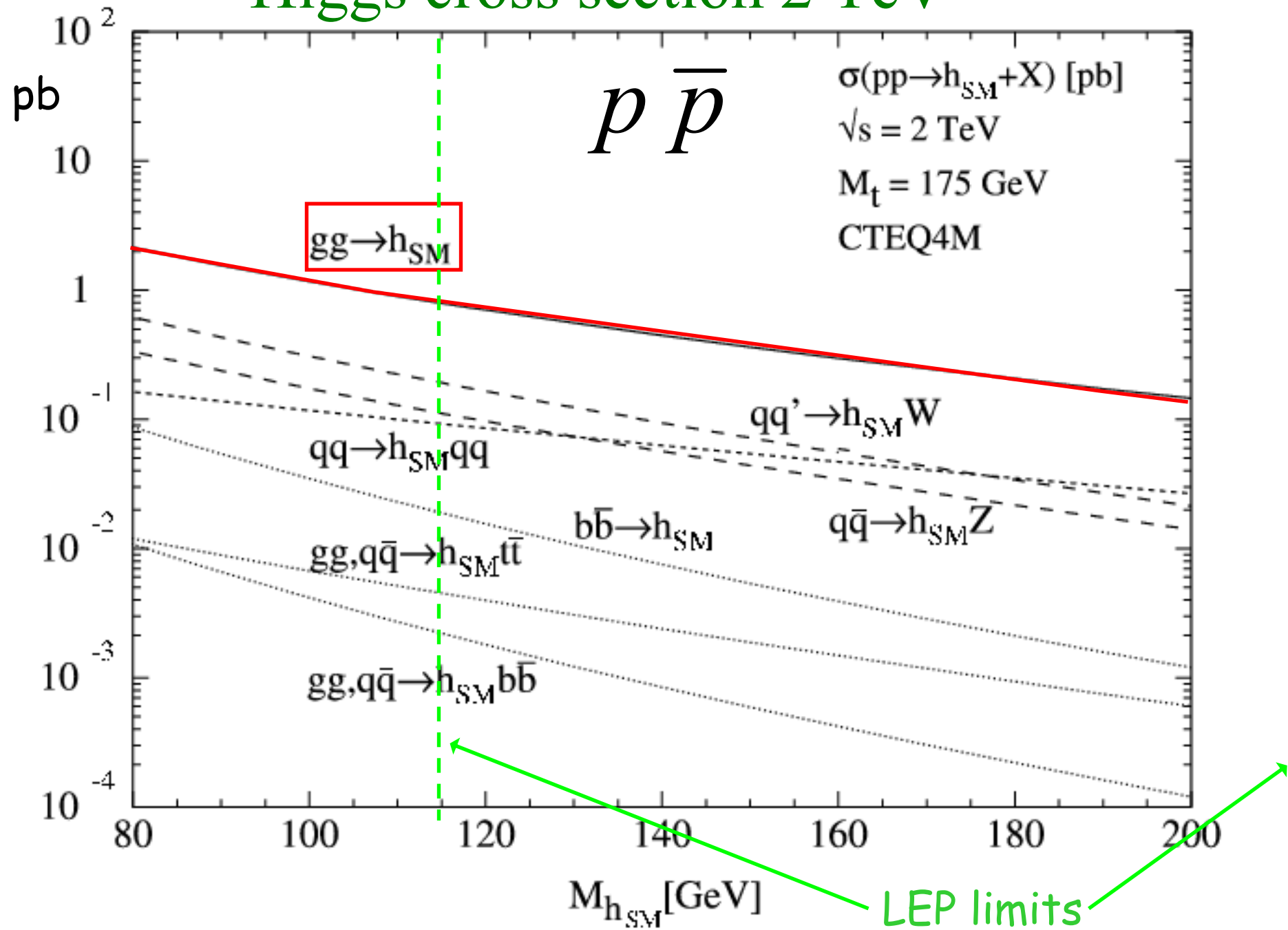


Xsection „large“ at 14 TeV

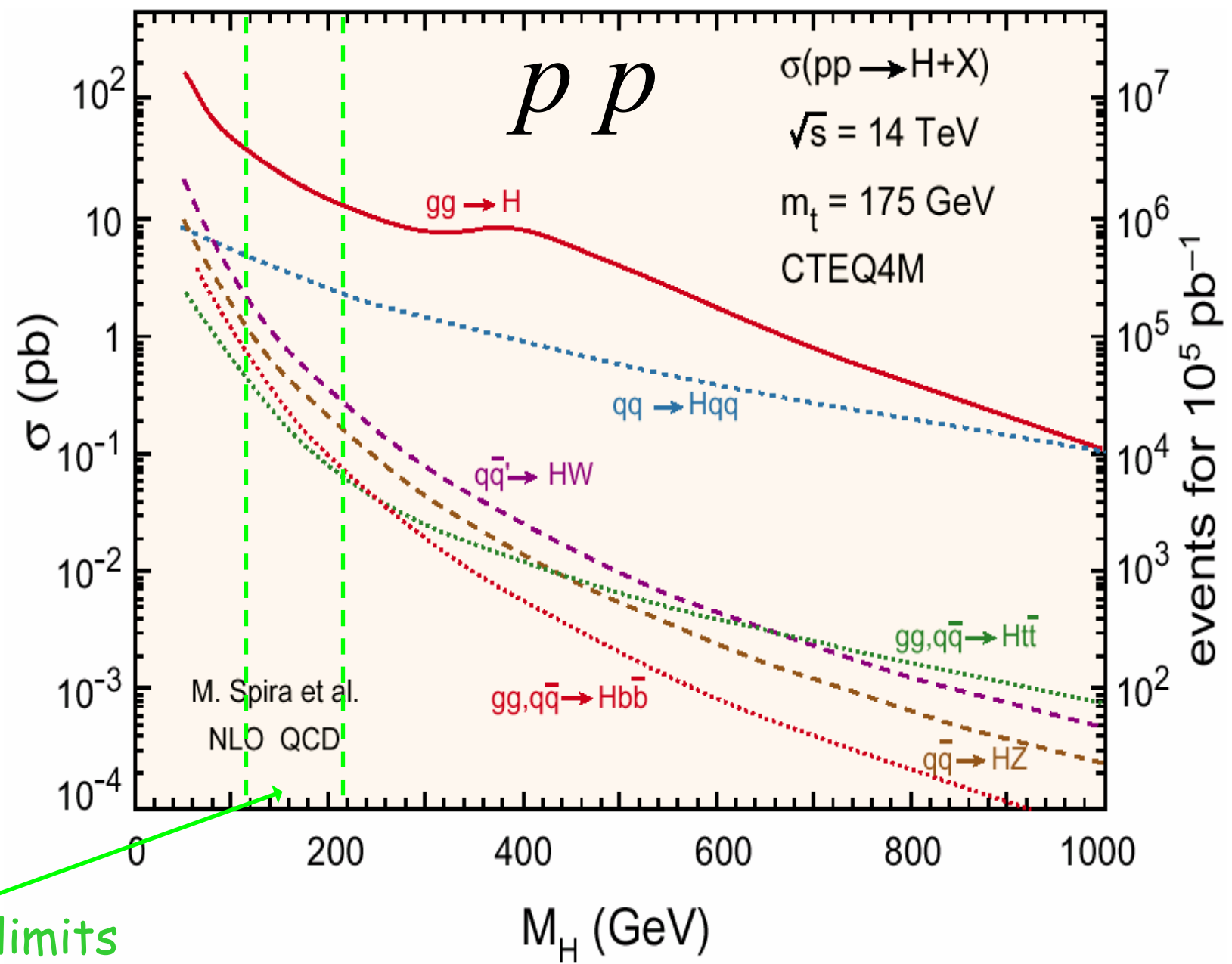
$H \rightarrow \gamma \gamma, (leptons)$



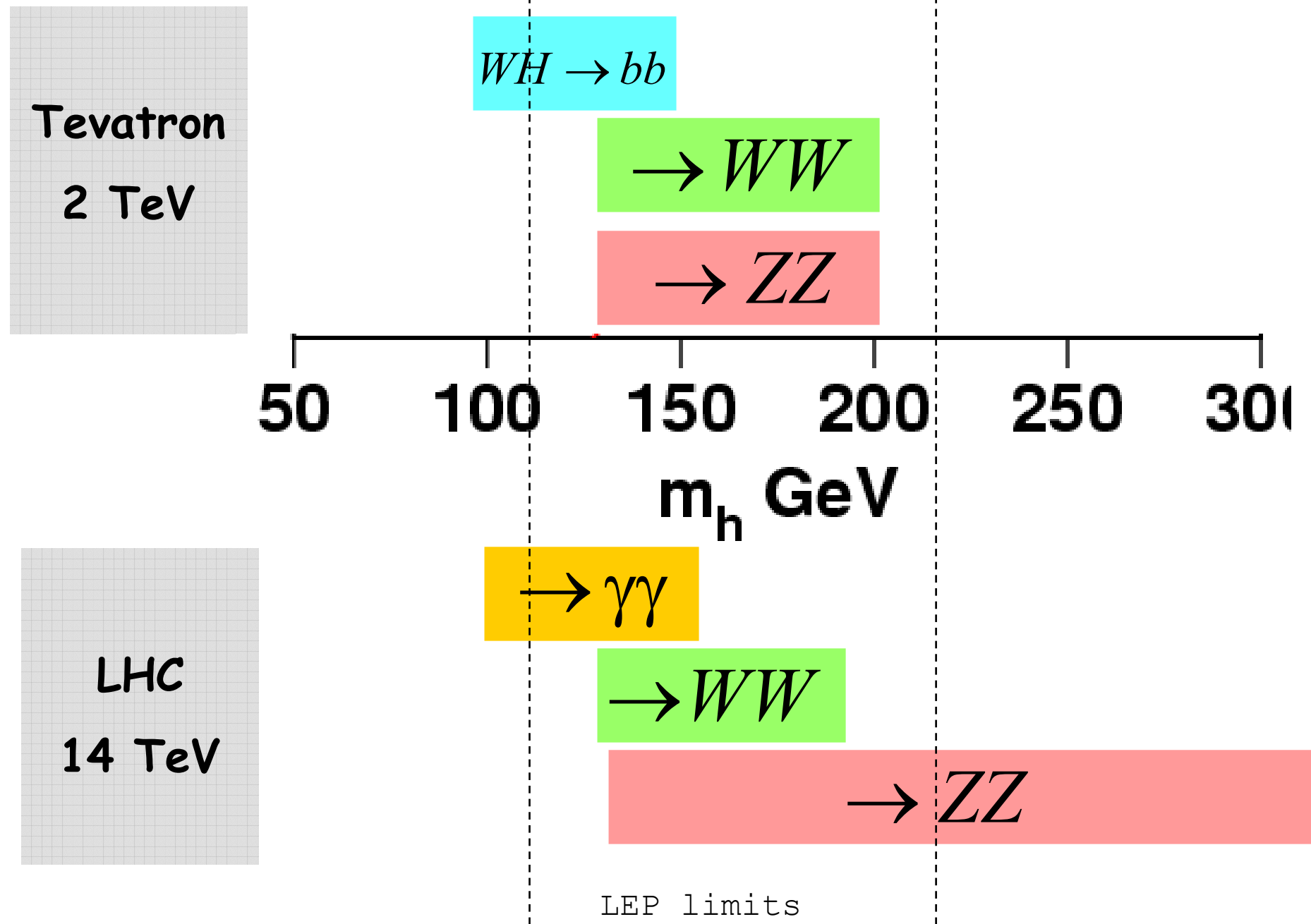
# Higgs cross section 2 TeV



# Higgs cross section 14 TeV



# Higgs search strategies



# Higgs (130-190 GeV) $\rightarrow WW$ [2 TeV]

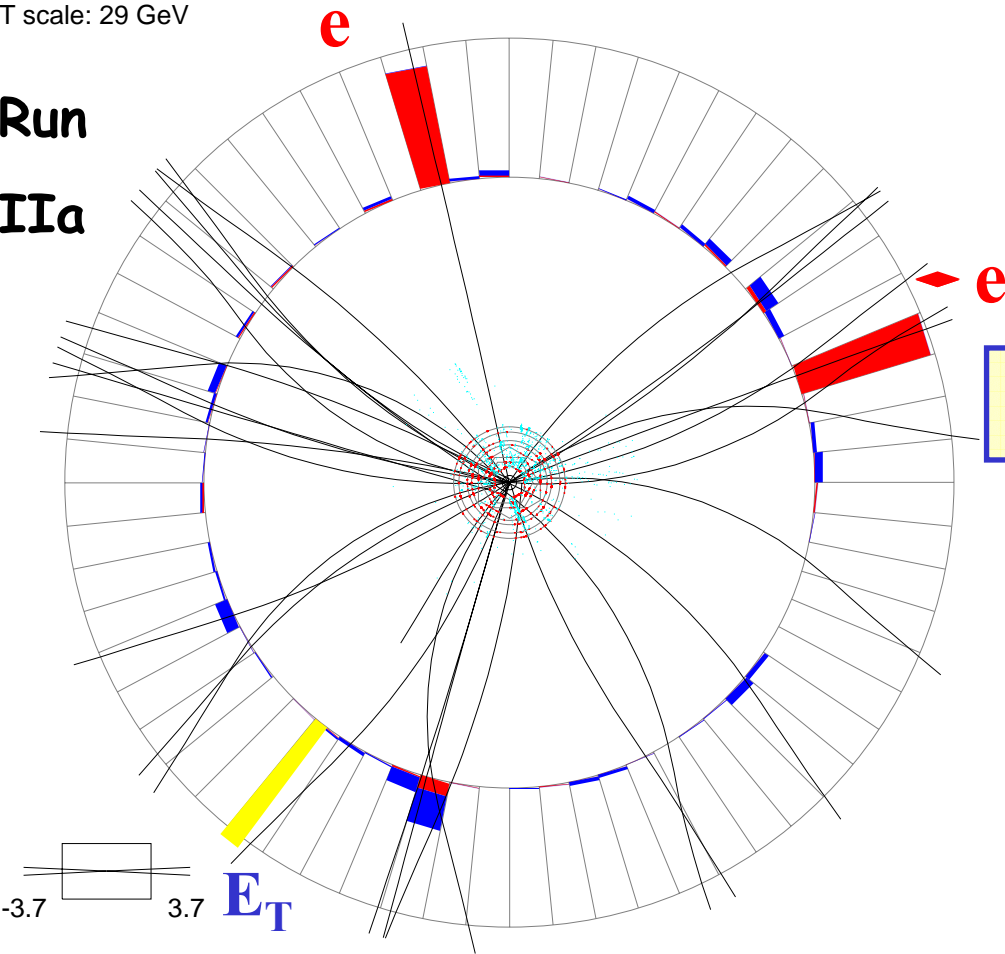
Run 169236 Event 4468684 Thu Feb 13 02:26:58 2003

ET scale: 29 GeV

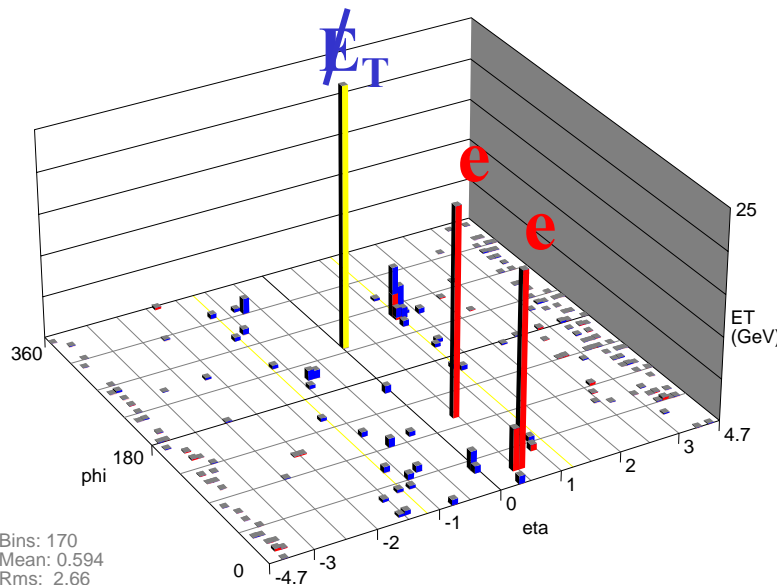
Run

IIa

$$H \rightarrow WW^{(*)} \rightarrow e^+e^- \nu \bar{\nu}$$



Run 169236 Event 4468684 Thu Feb 13 02:26:57 2003



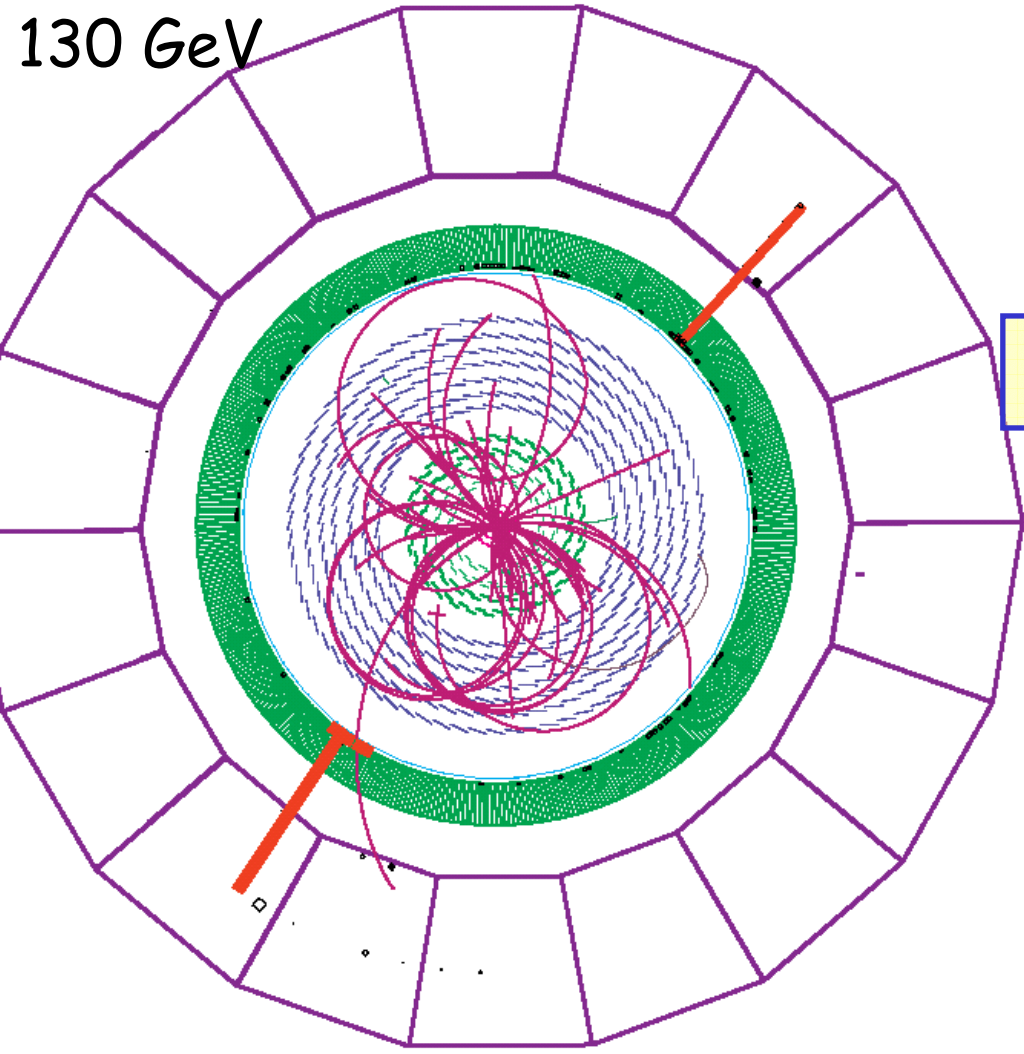
Bins: 170  
 Mean: 0.594  
 Rms: 2.66  
 Min: 0.00933  
 Max: 25

mE\_t: 31.2  
 phi\_t: 232 deg

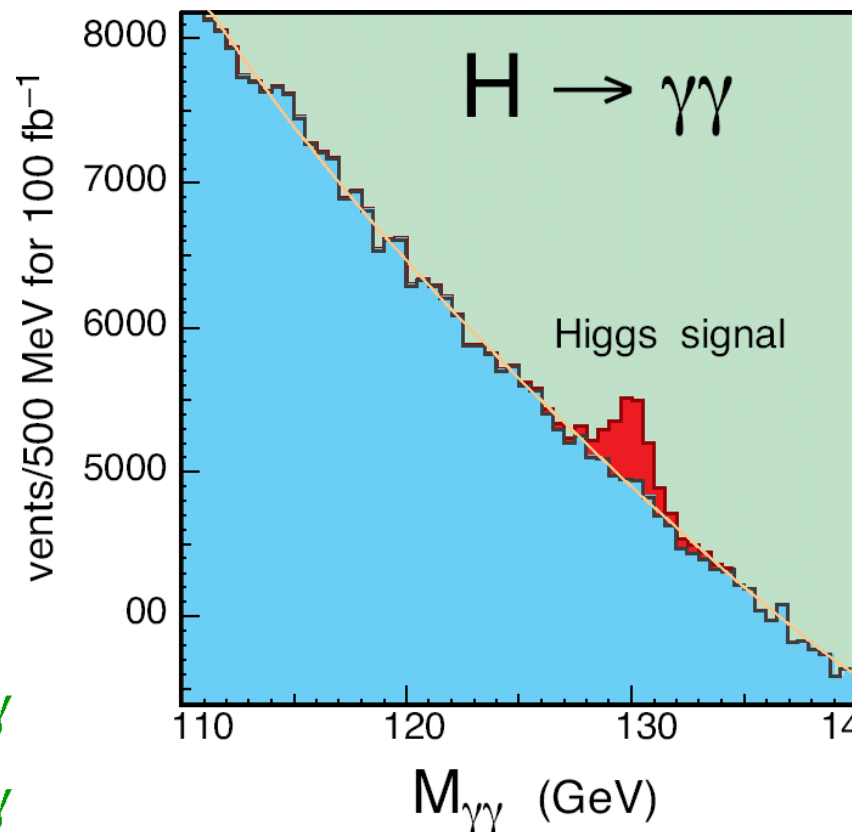
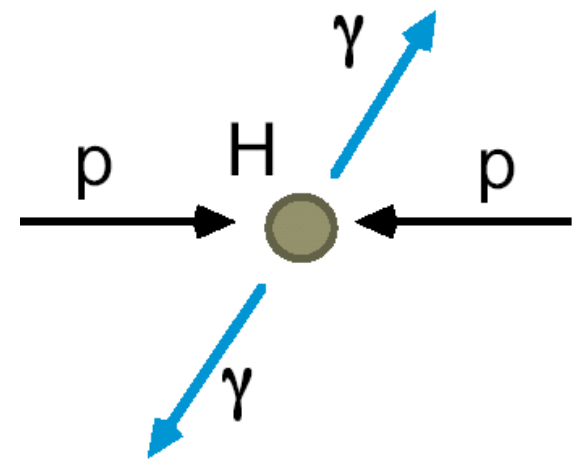
Background:  $WW^{(*)}, Z\gamma^{(*)}, tt$

# Higgs (110-150 GeV) $\rightarrow \gamma\gamma$ [14 TeV]

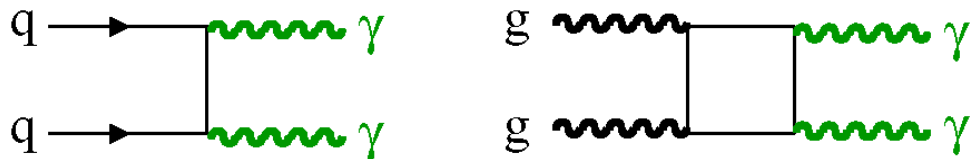
130 GeV



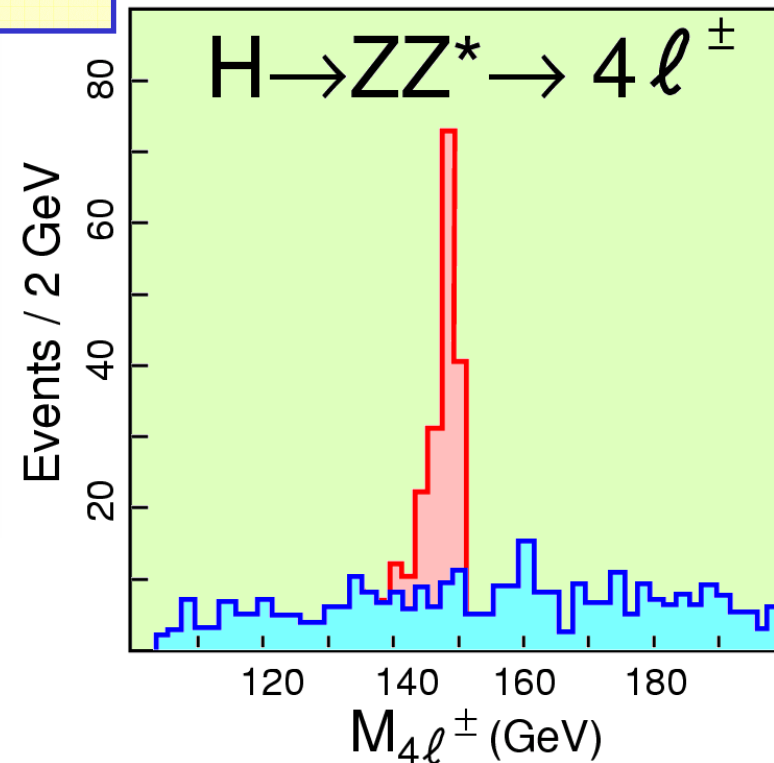
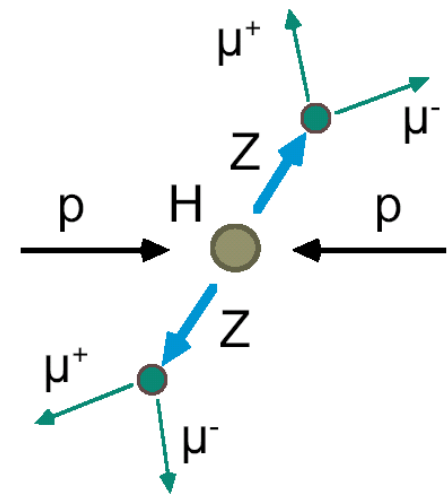
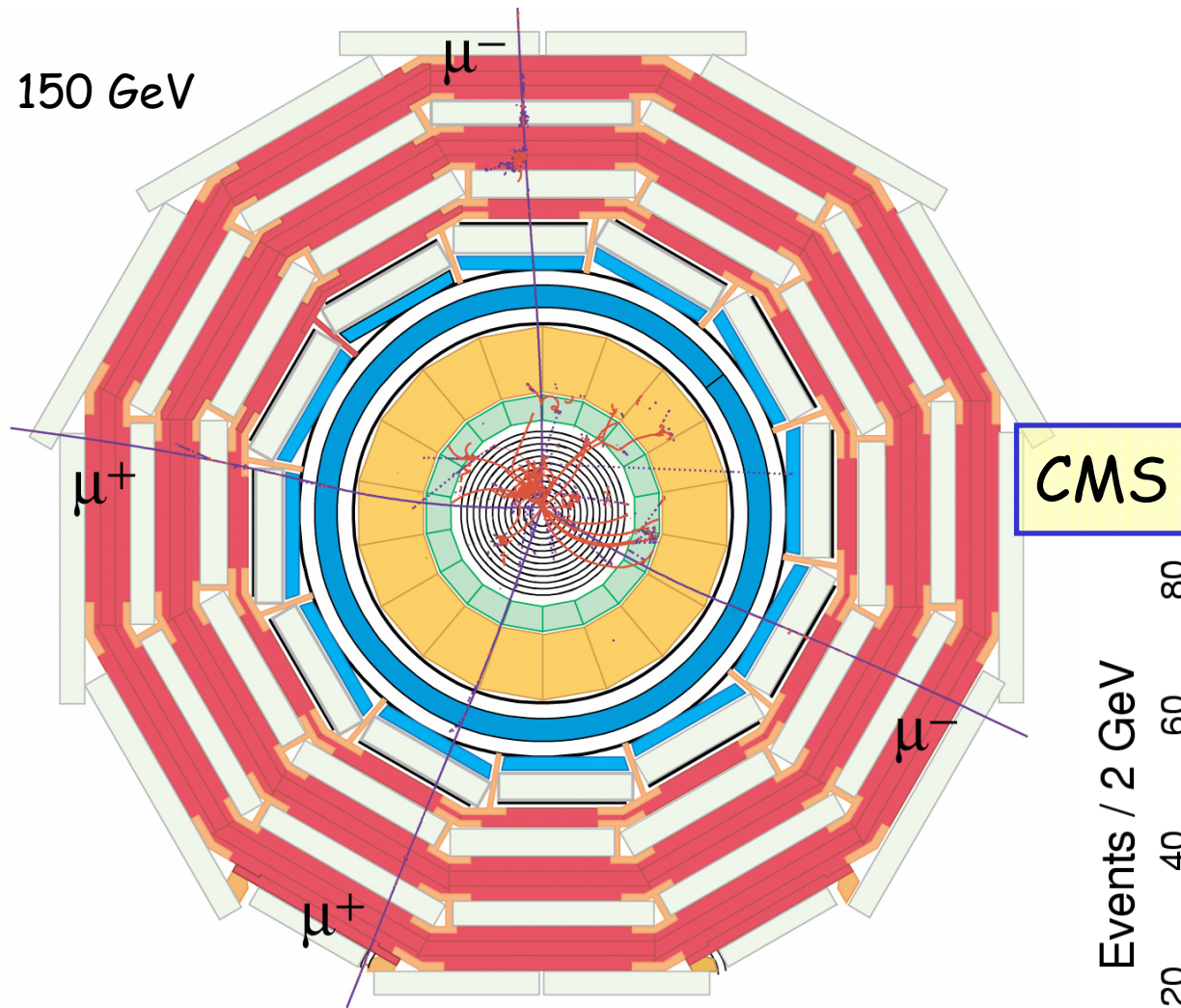
CMS



Background:



# Higgs (130-700 GeV) $\rightarrow$ Z Z<sup>(\*)</sup> [14 TeV]

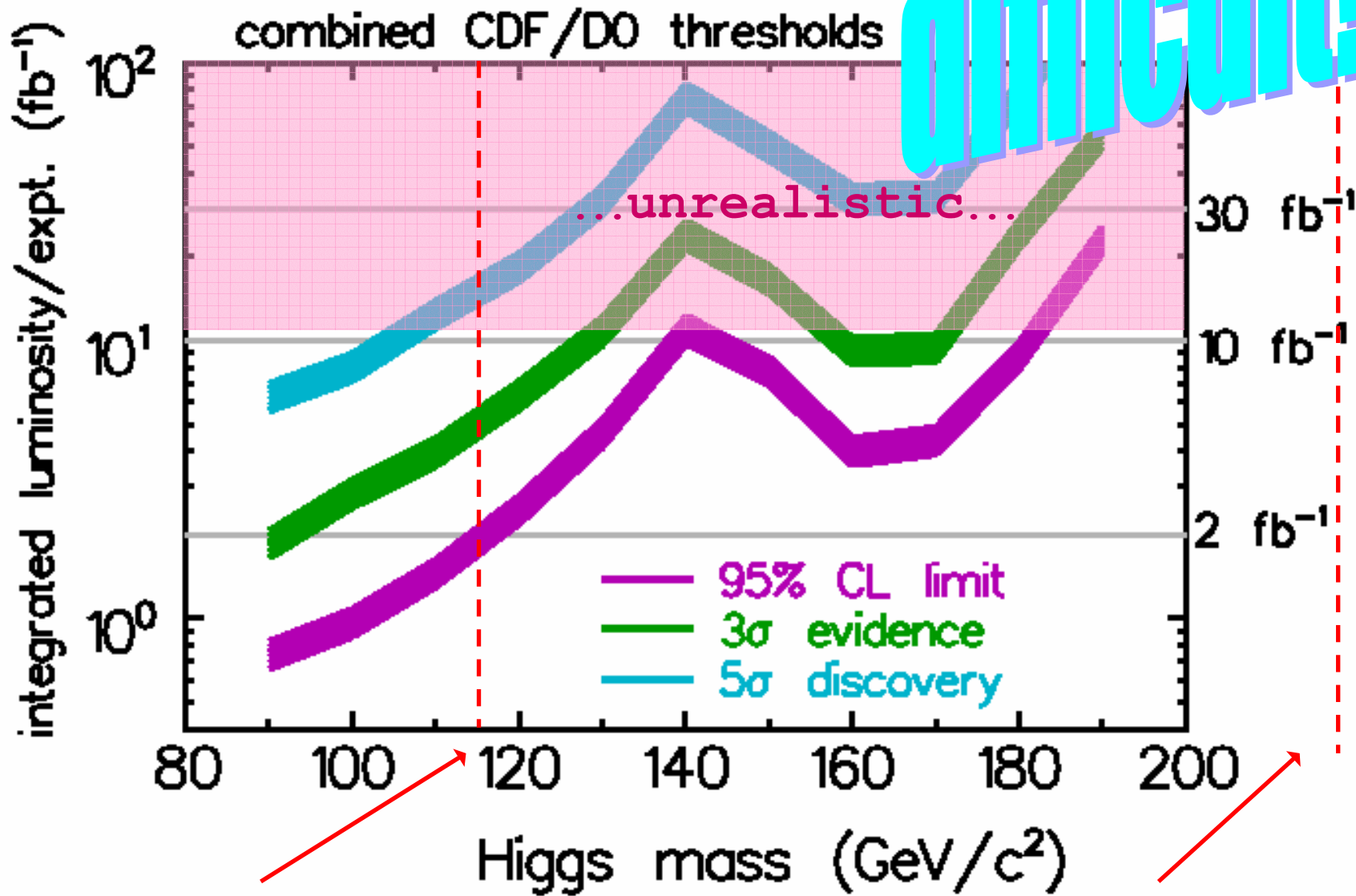


Background:  $ZZ^{(*)}, Z\gamma^{(*)}$



# Higgs discovery prospects at Tevatron

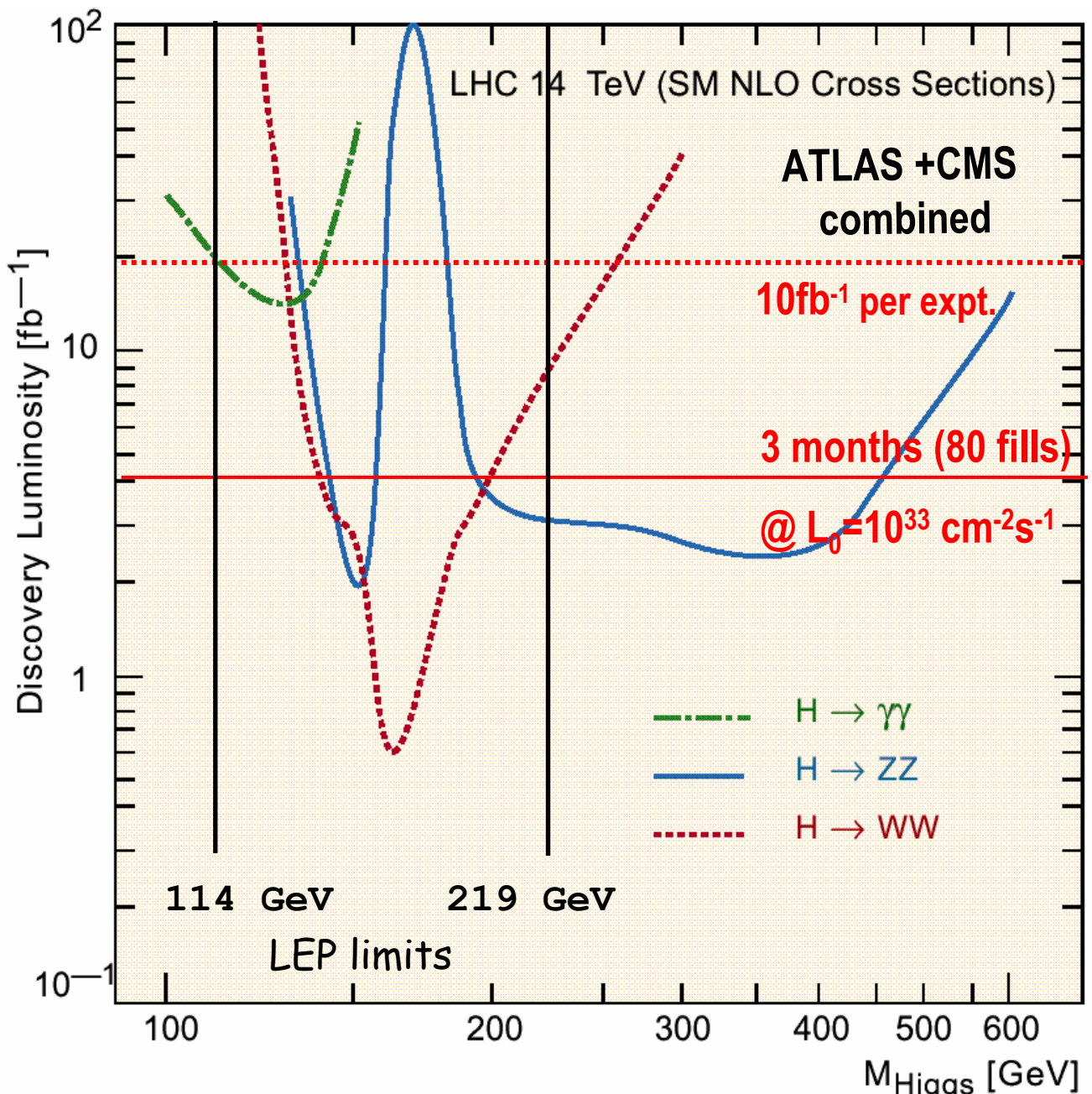
difficult!



LEP limit 114 GeV

limit 219 GeV

# Higgs discovery prospects at LHC



# yes!

**experimentum  
crucis:**

if SM Higgs exists  
↔  
it can/will be seen

# Extended Higgs Models - Supersymmetry

Minimal SuSy = MSSM:

$$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$$

couples to  
up-fermions

$$\begin{pmatrix} H_d^+ \\ H_d^0 \end{pmatrix}$$

couples to  
down-fermions

$$\tan \beta = v_u / v_d$$

8 real fields - 3 ( $W^+$   $W^-$   $Z$ ) = 5 higgs bosons:

$h$

$H$

$A$

$H^+$   $H^-$

CP odd

mass relations (lowest order):

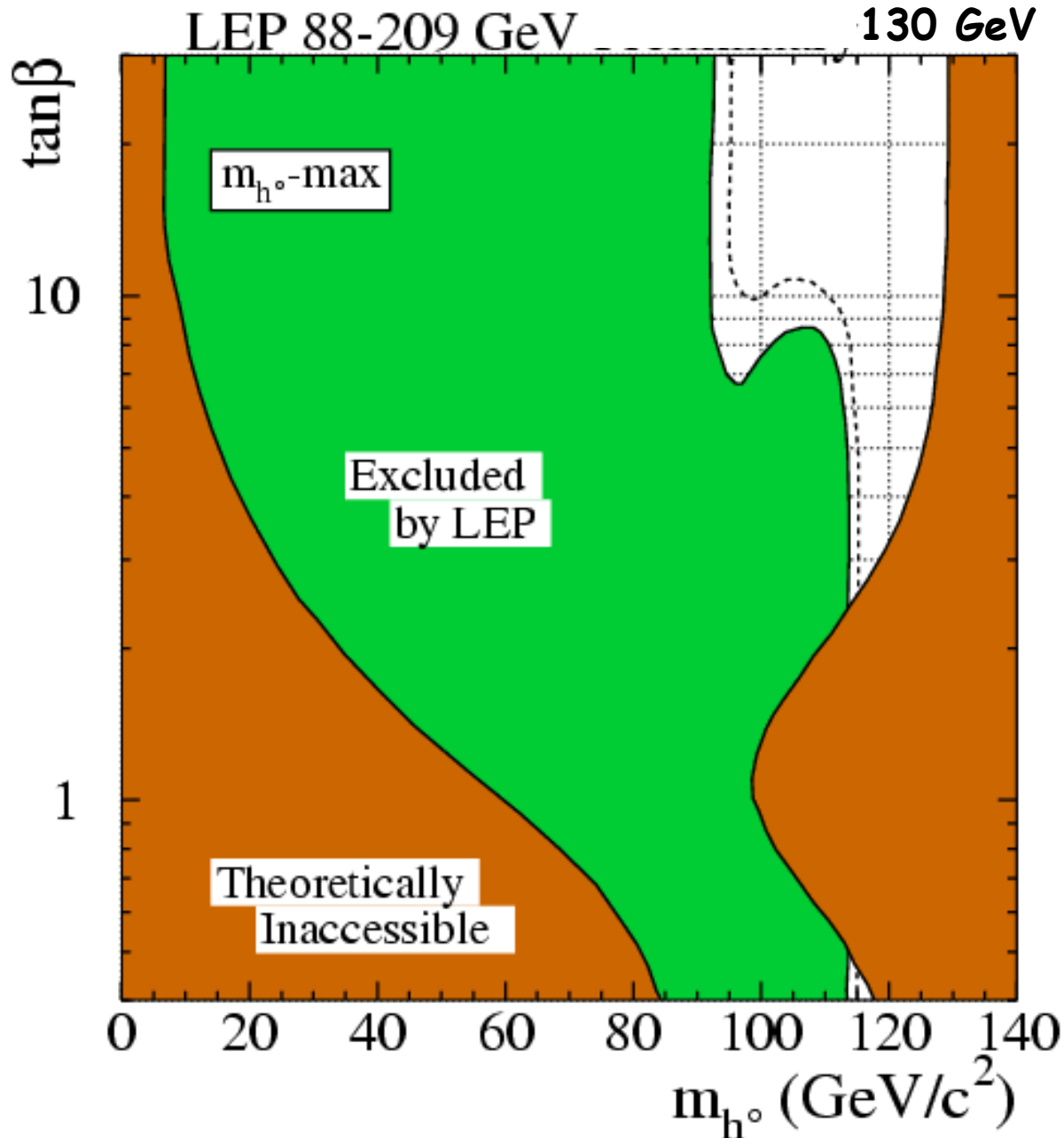
$$m_h < m_Z < m_H$$

$$m_h < m_A$$

$$m_W < m_{H^\pm}$$

$$m_h < 130 \text{ GeV} \quad \text{incl. radiative corrections}$$

# MSSM Higgs Limits LEP



In addition:  
limits on  
charged  
higgses...

All higgs masses  
fixed by two  
parameters

$$\tan\beta > 2.4$$

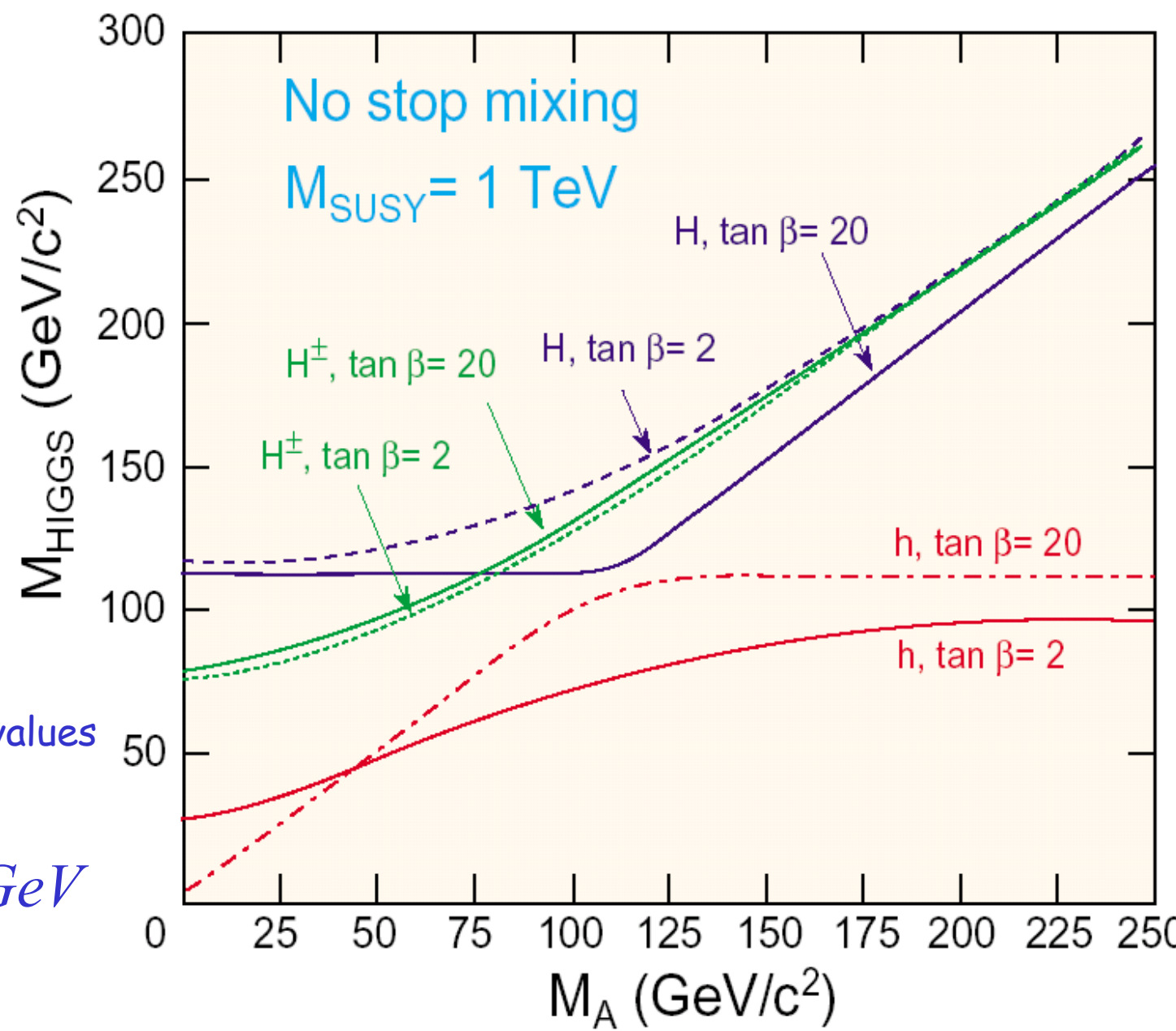
# MSSM Higgs Masses

All higgs masses fixed by two parameters:

$$\tan \beta = \frac{v_u}{v_d}$$

= vacuum expect. values

$m_A = 90 \dots 500 \text{ GeV}$   
 $\tan \beta = 1 \dots 50$

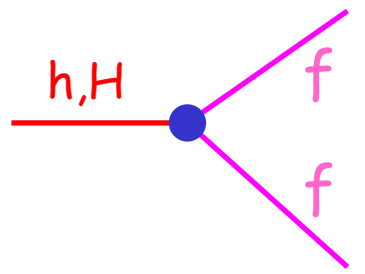


# MSSM Higgs Couplings

also fixed by  $m_A, \tan \beta$  !

in particular  $h, H$ :

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{pmatrix} \begin{pmatrix} H_u^0 \\ H_d^0 \end{pmatrix}$$

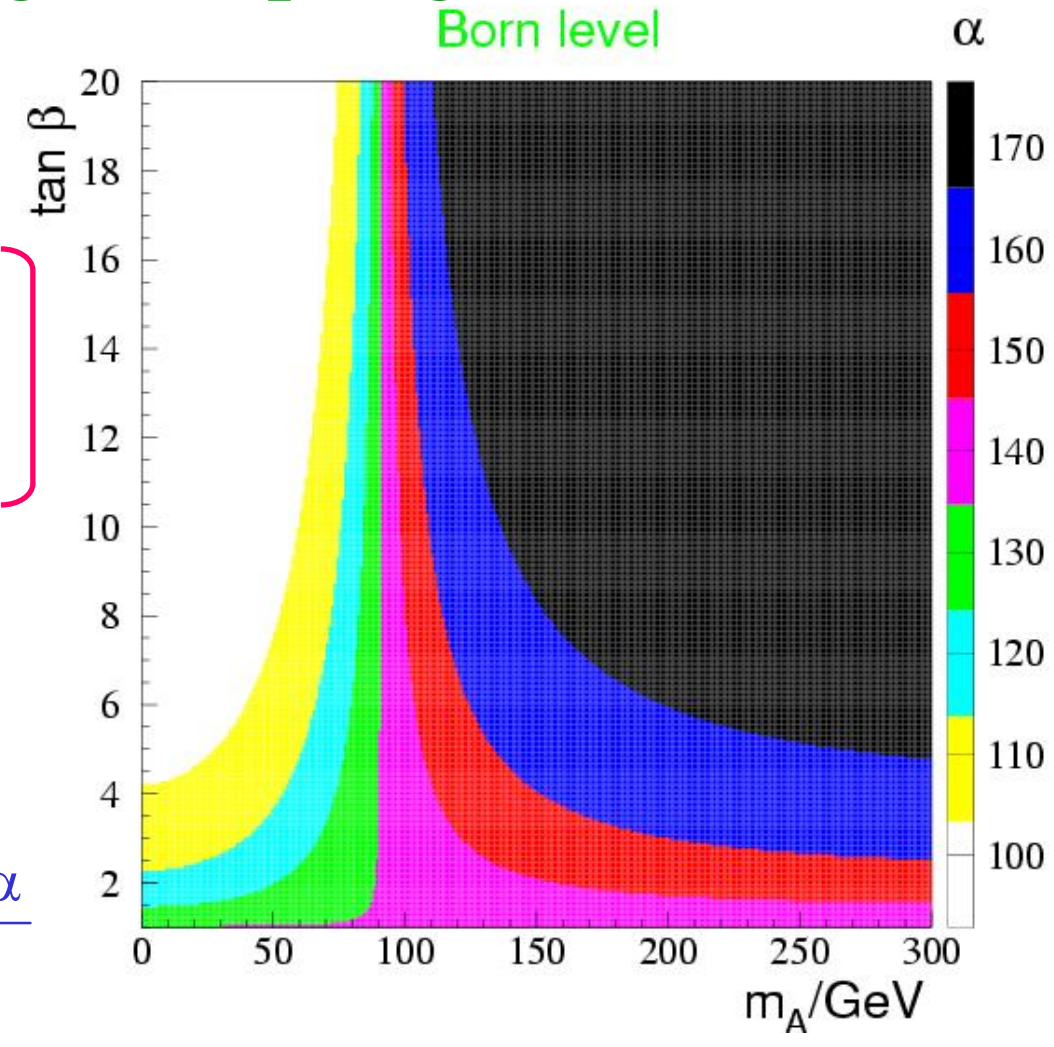


$$uu h \sim \frac{m_u \cos \alpha}{\sin \beta}$$

$$dd h \sim \frac{m_d \sin \alpha}{\cos \beta}$$

$$uu H \sim \frac{m_u \sin \alpha}{\sin \beta}$$

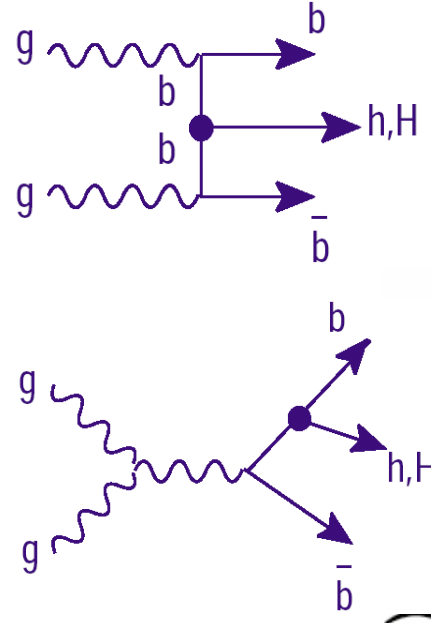
$$dd H \sim \frac{m_d \cos \alpha}{\cos \beta}$$



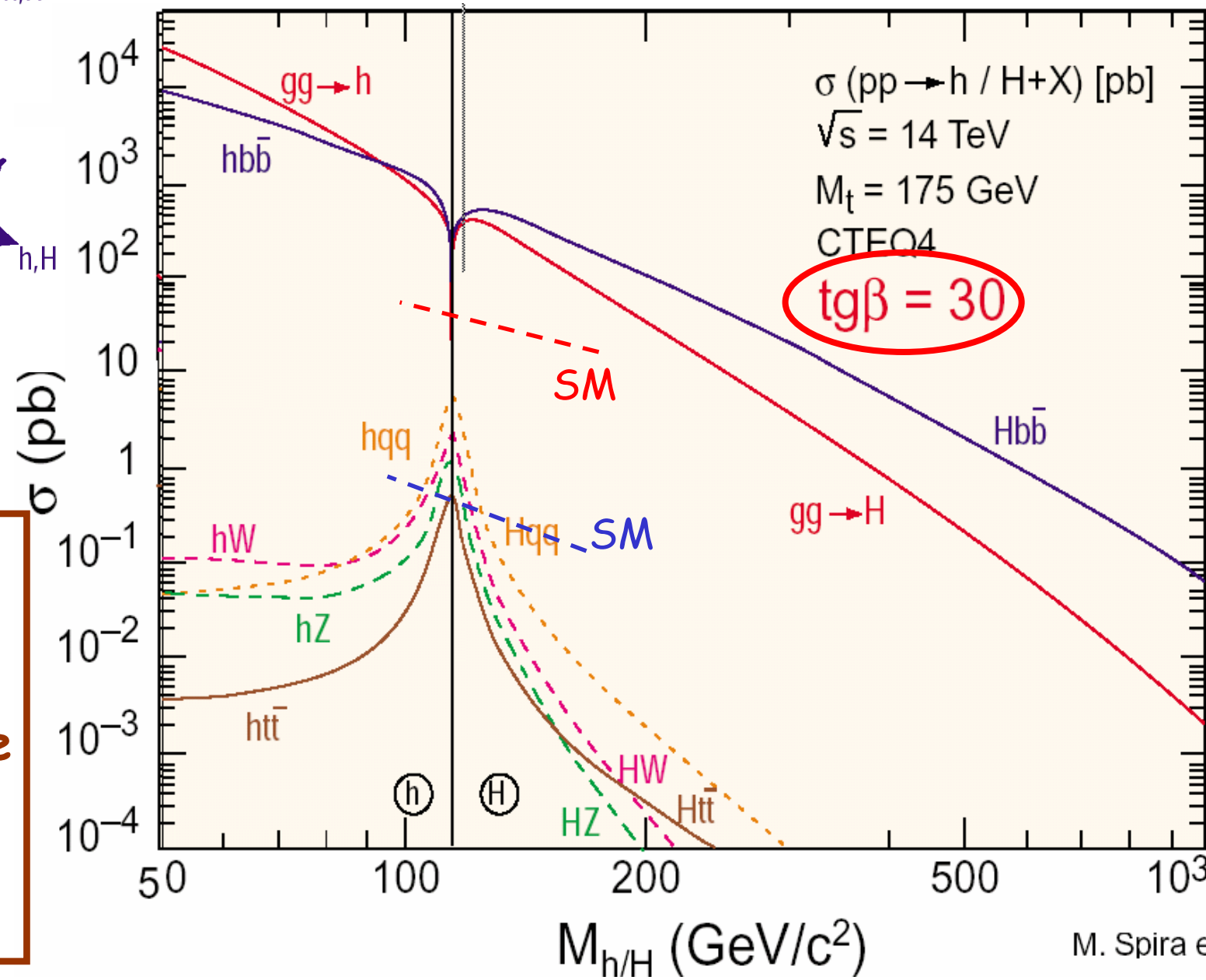
For large  $\tan \beta$  coupling  $h, H \leftrightarrow bb$  very large ! (similar for  $A$ )



# MSSM Higgs Xsections



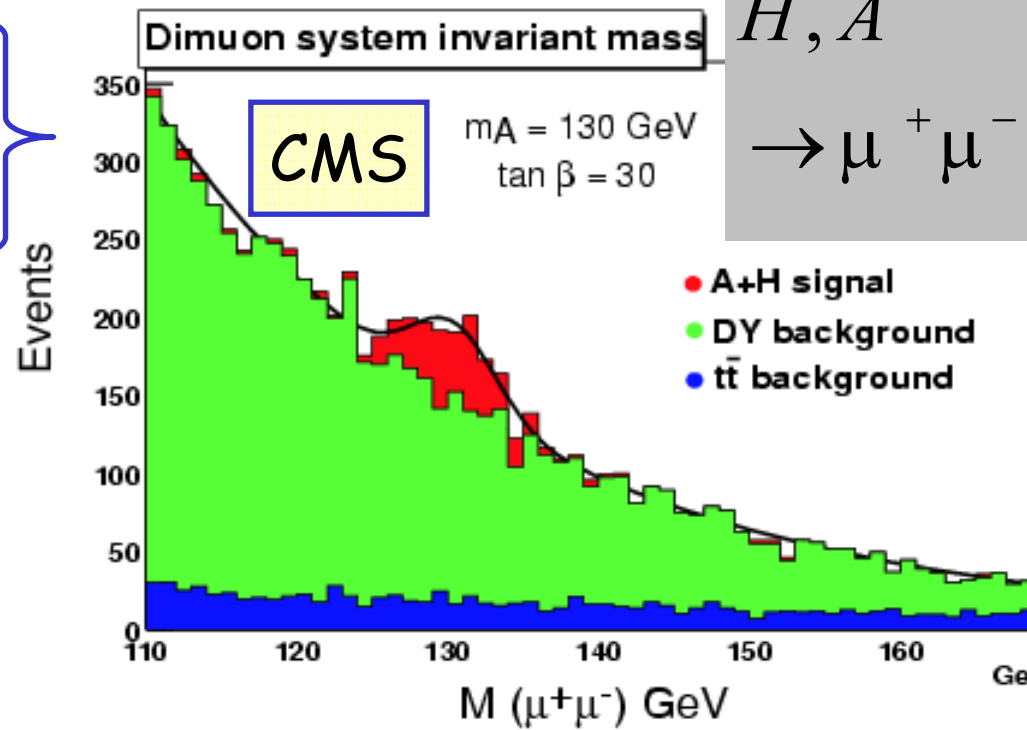
**some  
xsections  
very large  
compared  
to SM !**



# MSSM Higgs Search LHC

## Many channels:

- charged Higgs  $H^+, H^-$
- if  $\tan \beta$  small, h decay signatures  $\sim$  SM
- if  $\tan \beta$  large, „down“ fermions preferred
- `cascade decays`  
eg  $A \rightarrow Zh$
- if sparticles light:  
eg  $H \rightarrow \chi^0 \chi^0$   
 $H^+ \rightarrow \chi^+ \chi^0$



# Charged Higgses

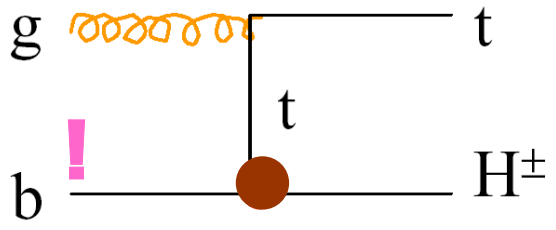
a)  $m_{H^\pm} < m_t$

$gg \rightarrow tt$

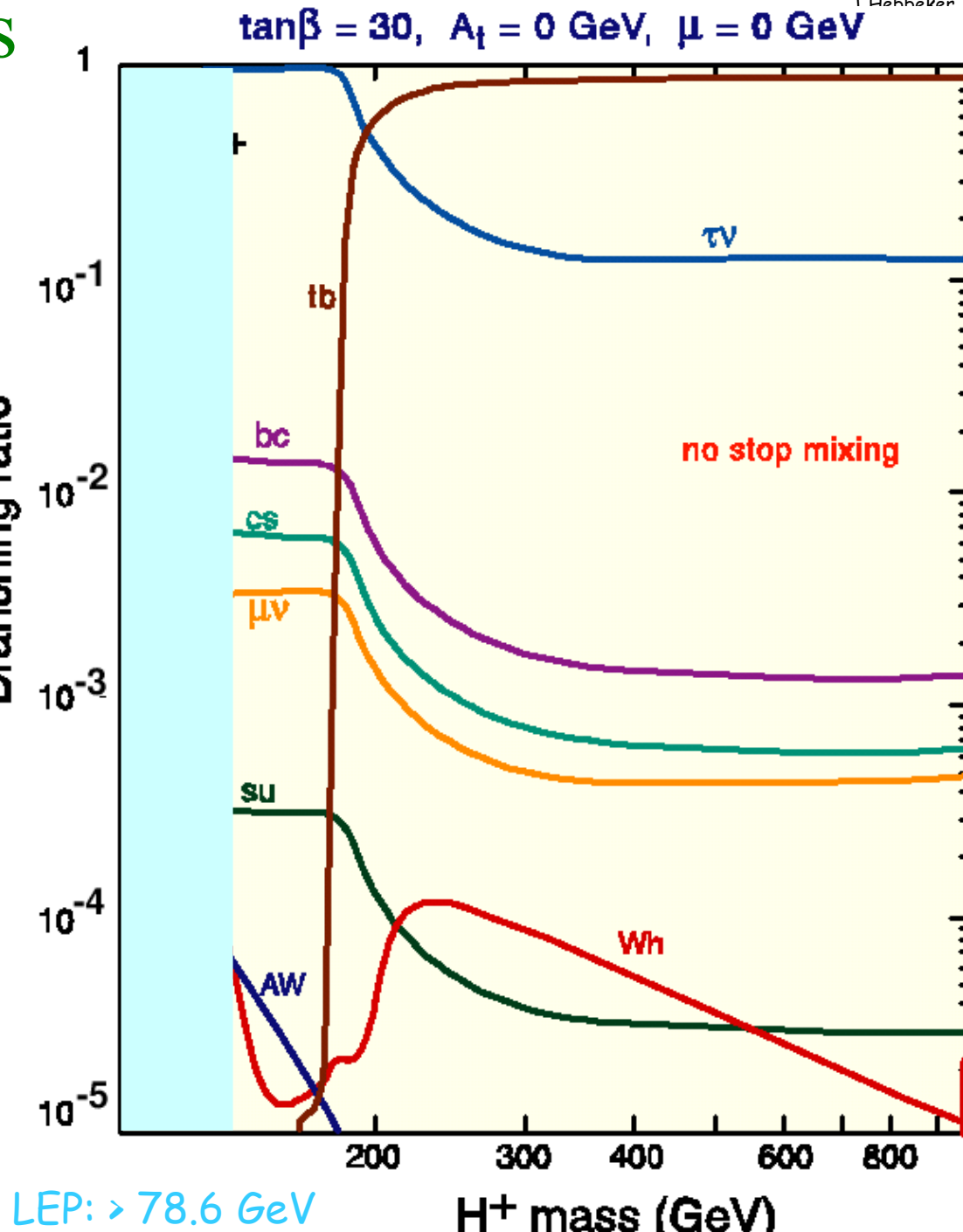
$t \rightarrow bH$

$H \rightarrow \tau\nu$

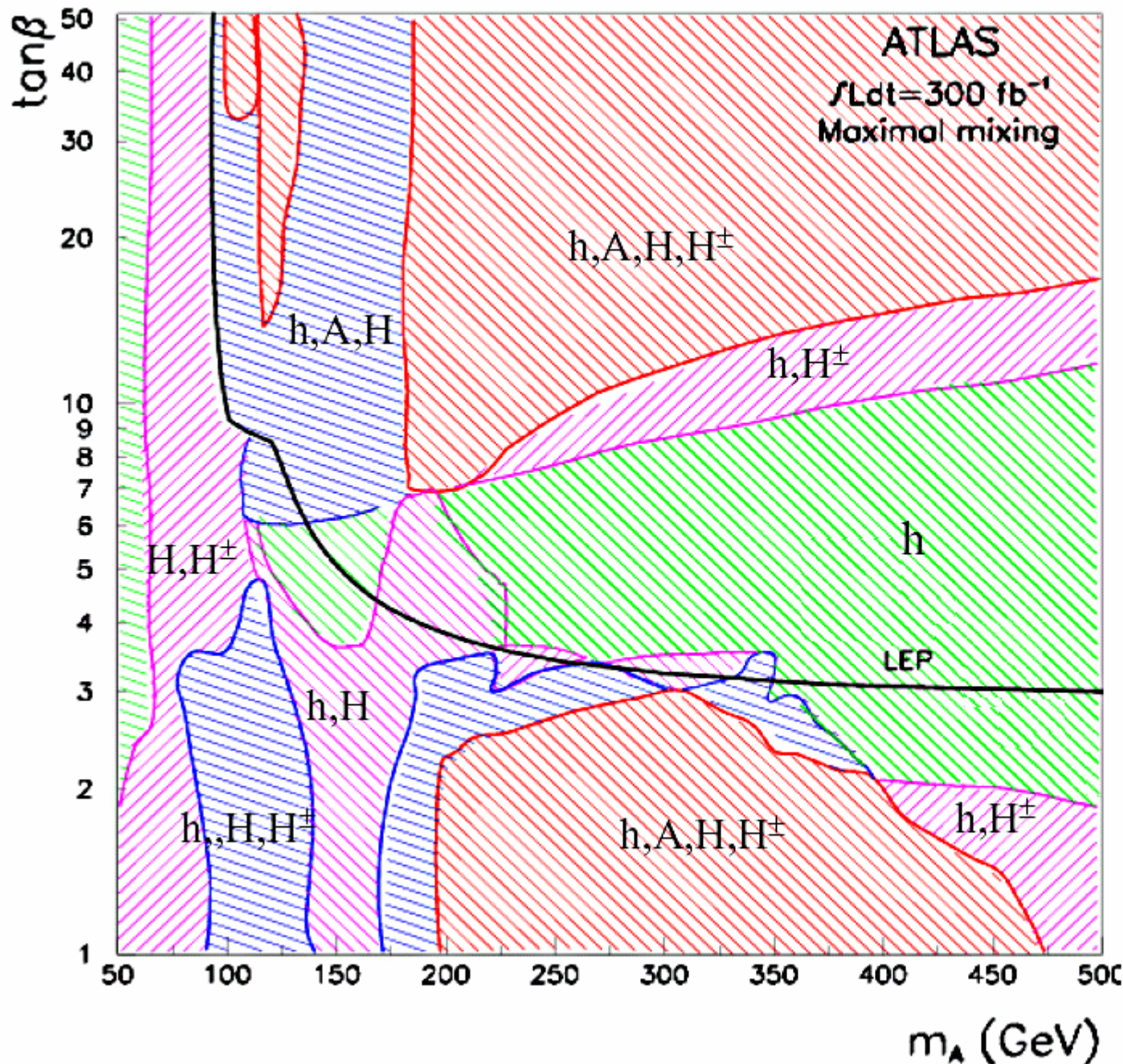
b)  $m_{H^\pm} > m_t$



$H \rightarrow tb$



# MSSM Higgs Discovery at LHC ?



- 4 Higgs observable
  - 3 Higgs observable
  - 2 Higgs observable
  - 1 Higgs observable
- $5\sigma$  contours

**whole region covered!**

**Higgses cant escape !**

Part I Introduction

Part II Standard Model Physics

Part III Higgs

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  - detection
- extended higgs models

Part IV New Phenomena

References