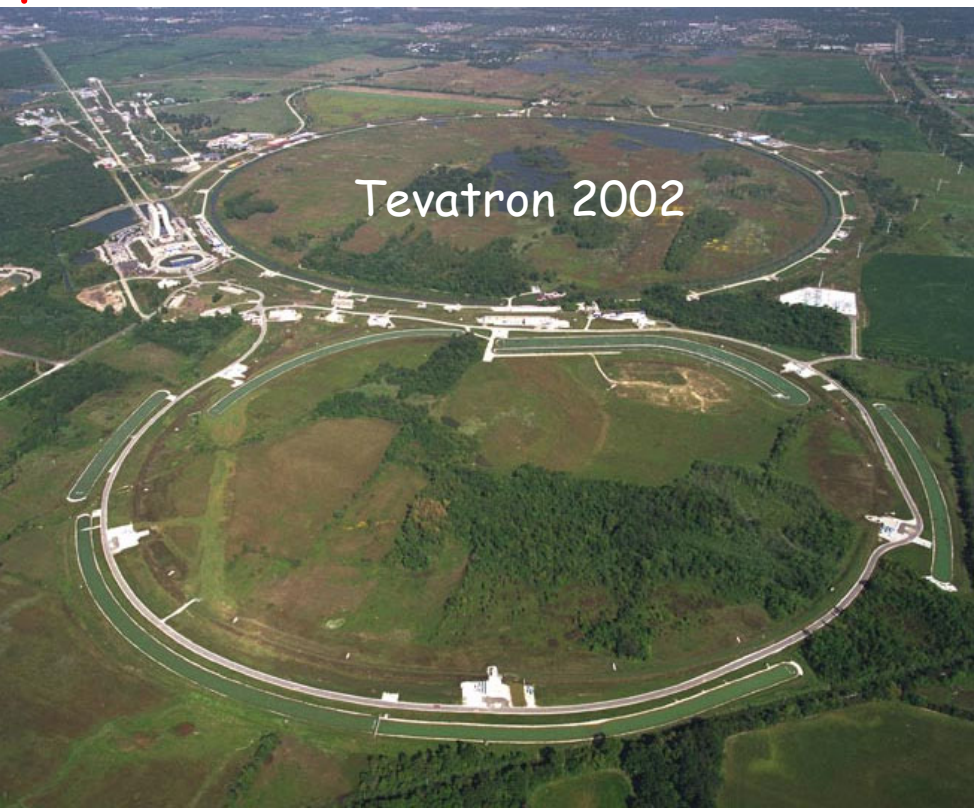
Thomas Hebbeker, RWTH Aachen

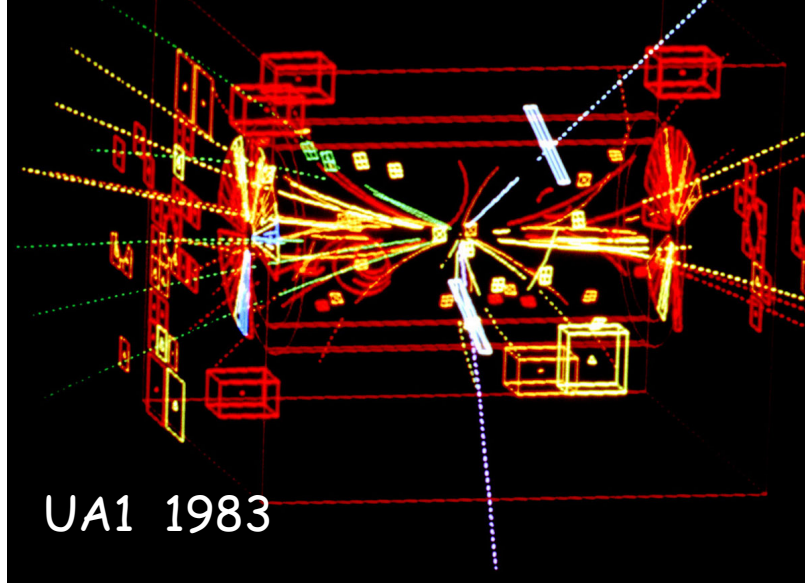
Belgian-Dutch-German school

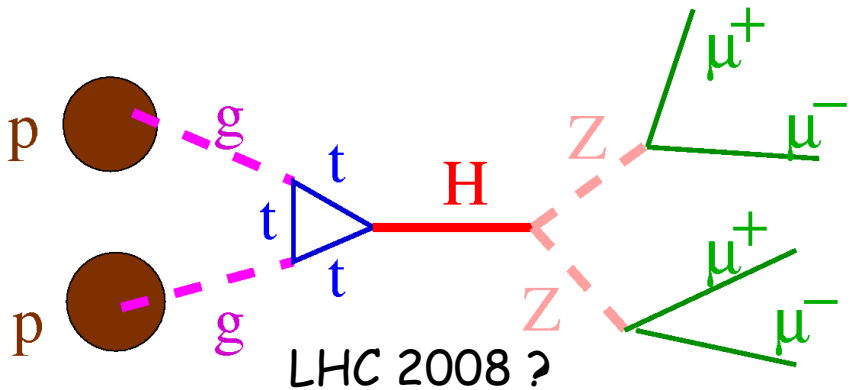
September 2003

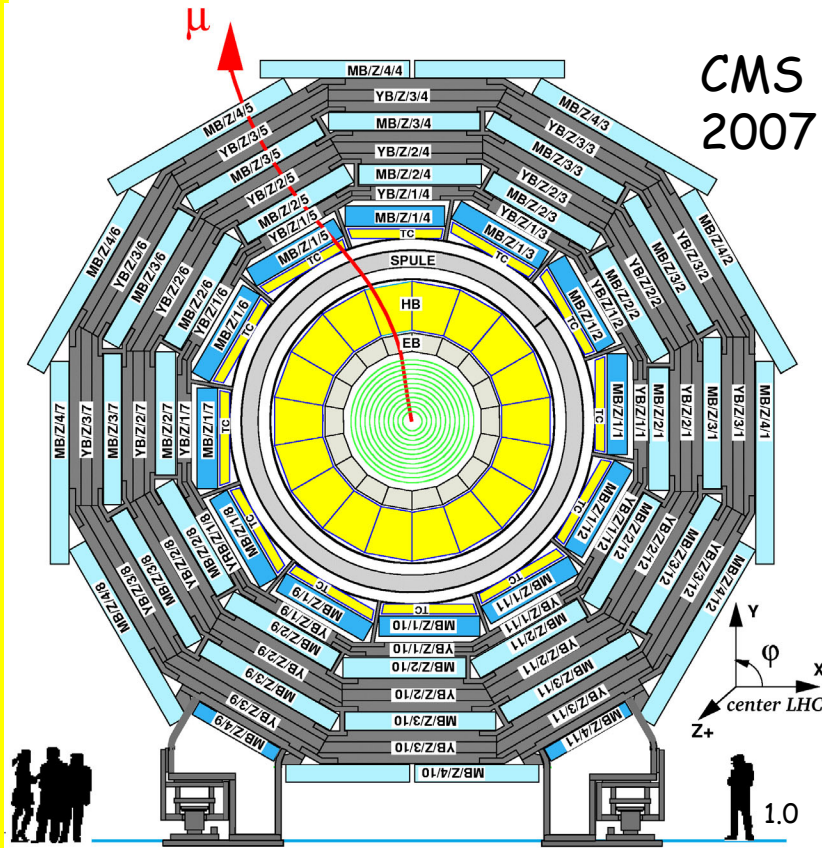
part III

p p physics









pp physics

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):

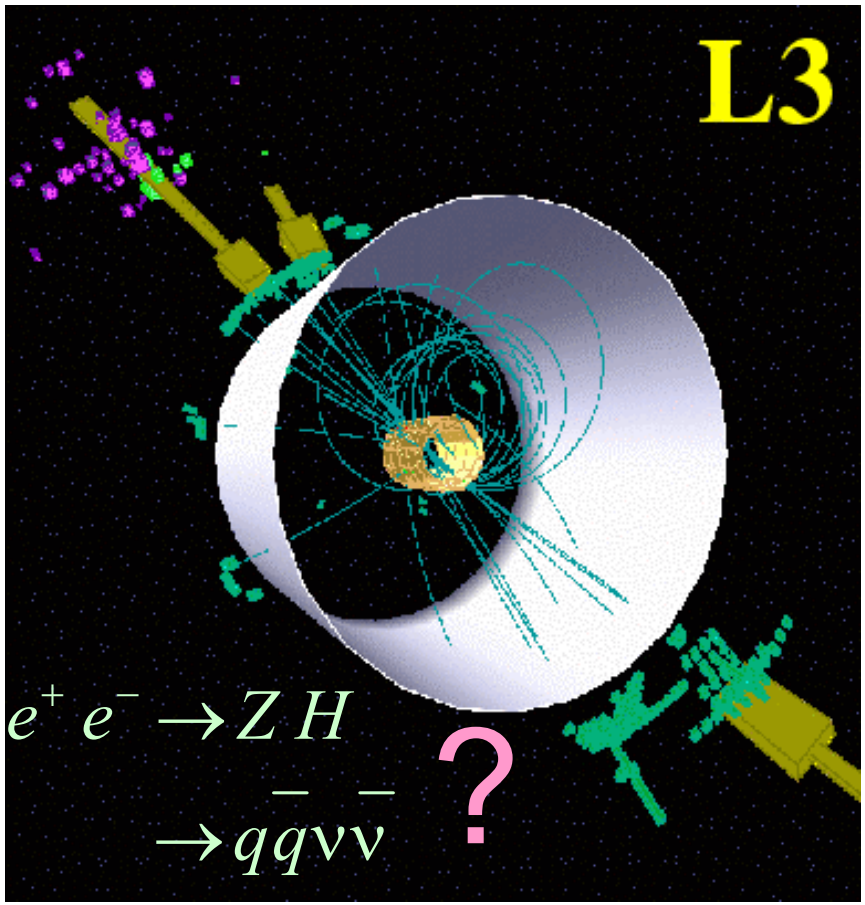
- couples to mass (!): bosons and fermions
- scalar, no elm. or strong interactions
- properties calculable as a function of m_H
- LEP: 114 GeV < m_H < 219 GeV (95%)

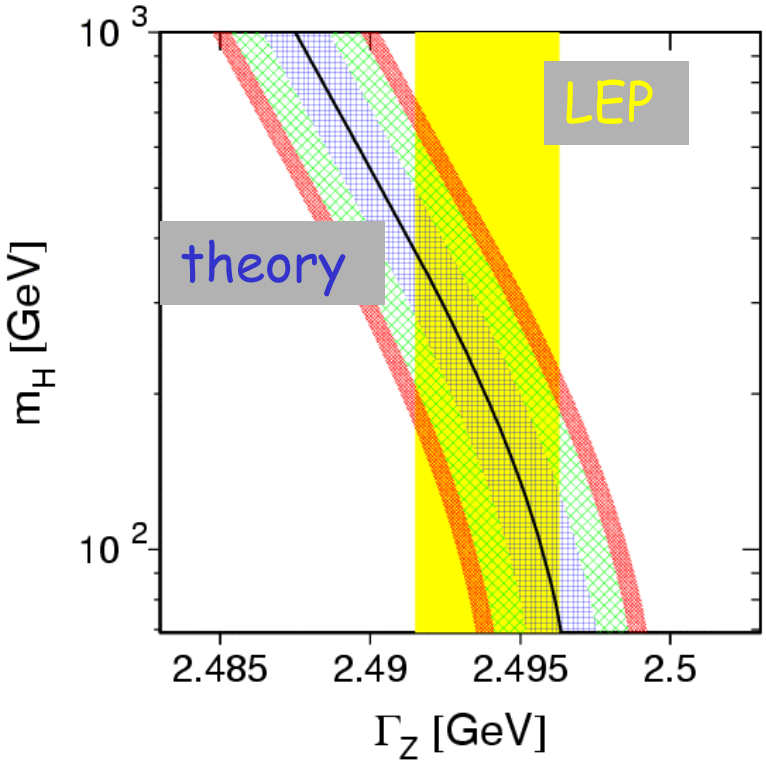
To be explored:

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

Historical reminiscence: LEP and Higgs

direct | indirect





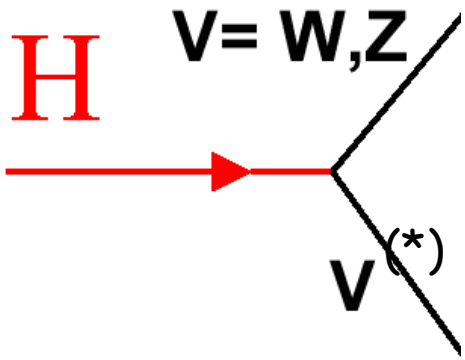
$m_H > 114\,GeV$ (95%)

(LEP)

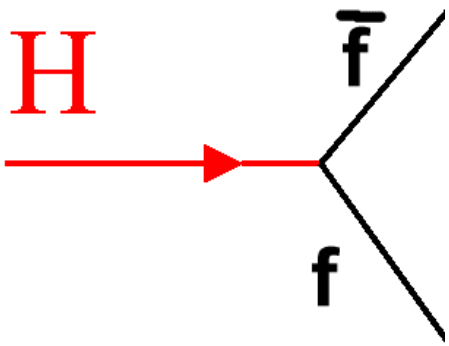
$m_H < 219\,GeV$ (95%)

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

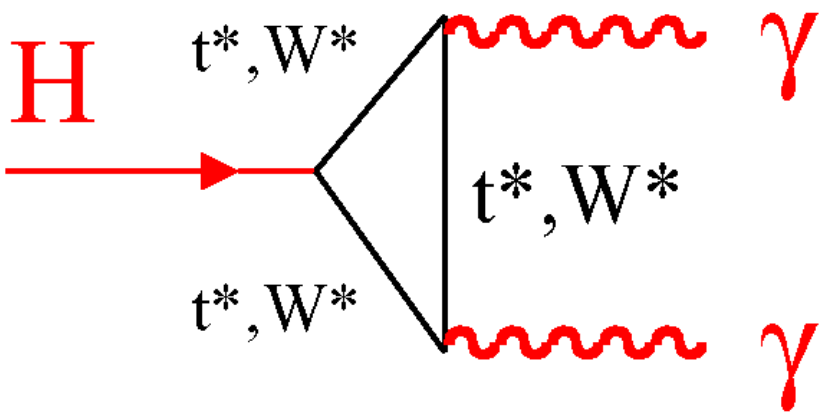
Higgs Decay Modes



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



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



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

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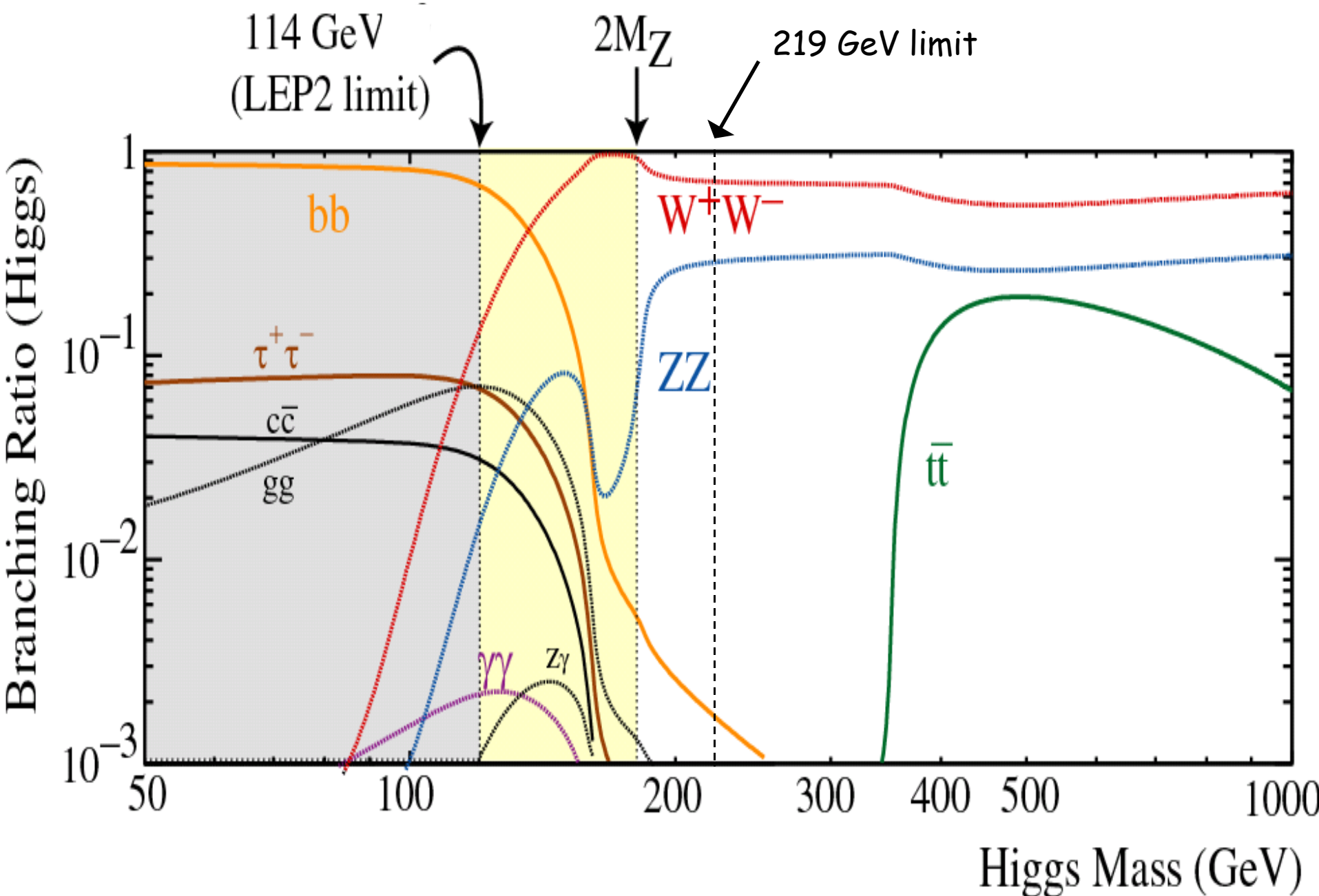
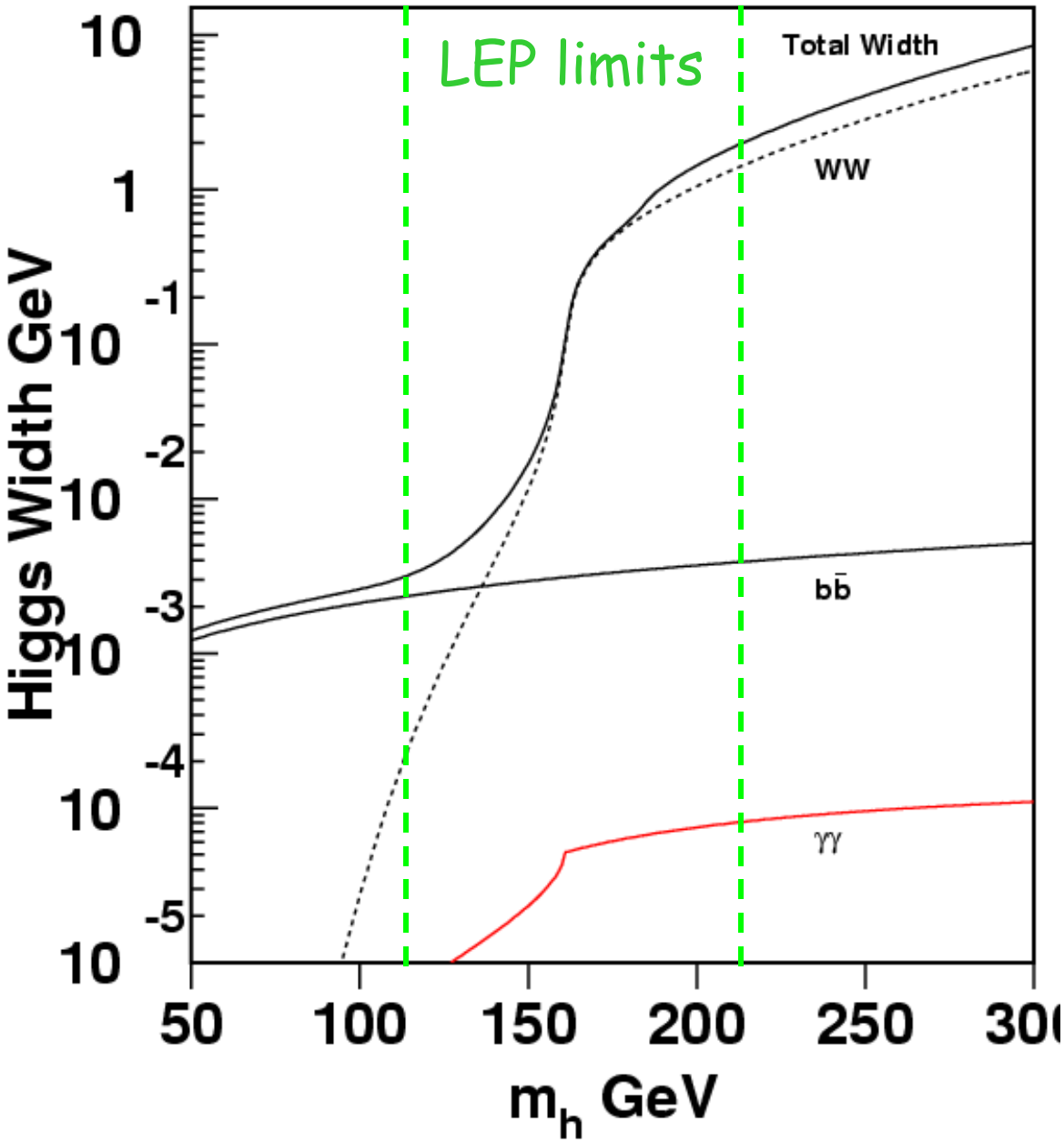
Higgs Branching Fractions



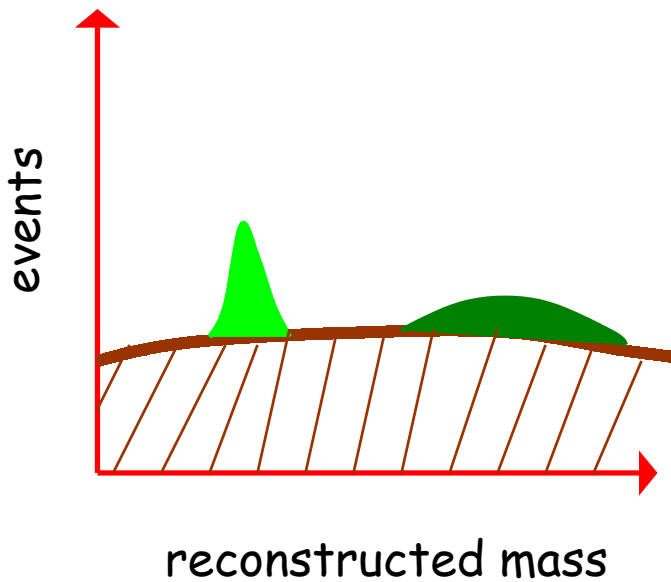
Higgs Decay Width



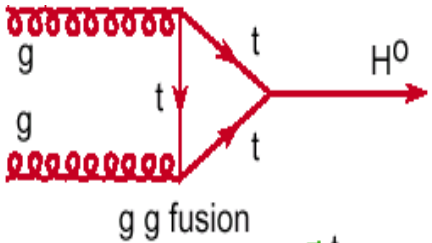
$$\Gamma \sim m_H^3$$

Important for

Signal/background!



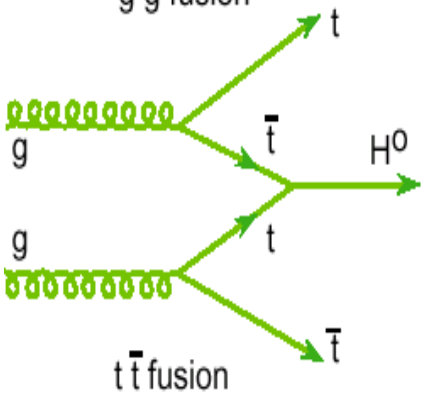
Higgs production in pp



g g fusion

Xsection largest

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

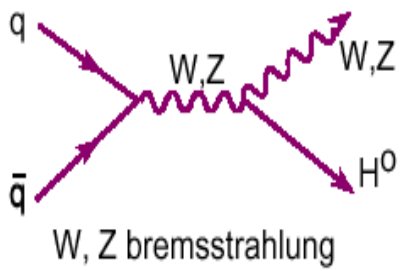


t t̄ fusion

Xsection small

photons, leptons:

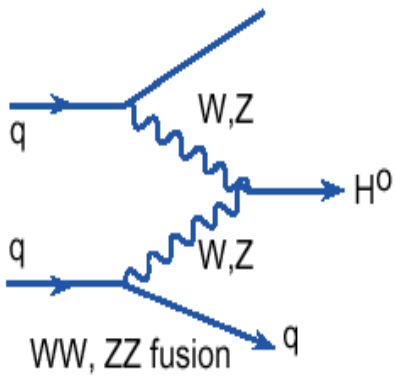
- less background
- mass resolution !



W, Z bremsstrahlung

Xsection „large" at 2 TeV

$$W, Z \rightarrow leptons$$

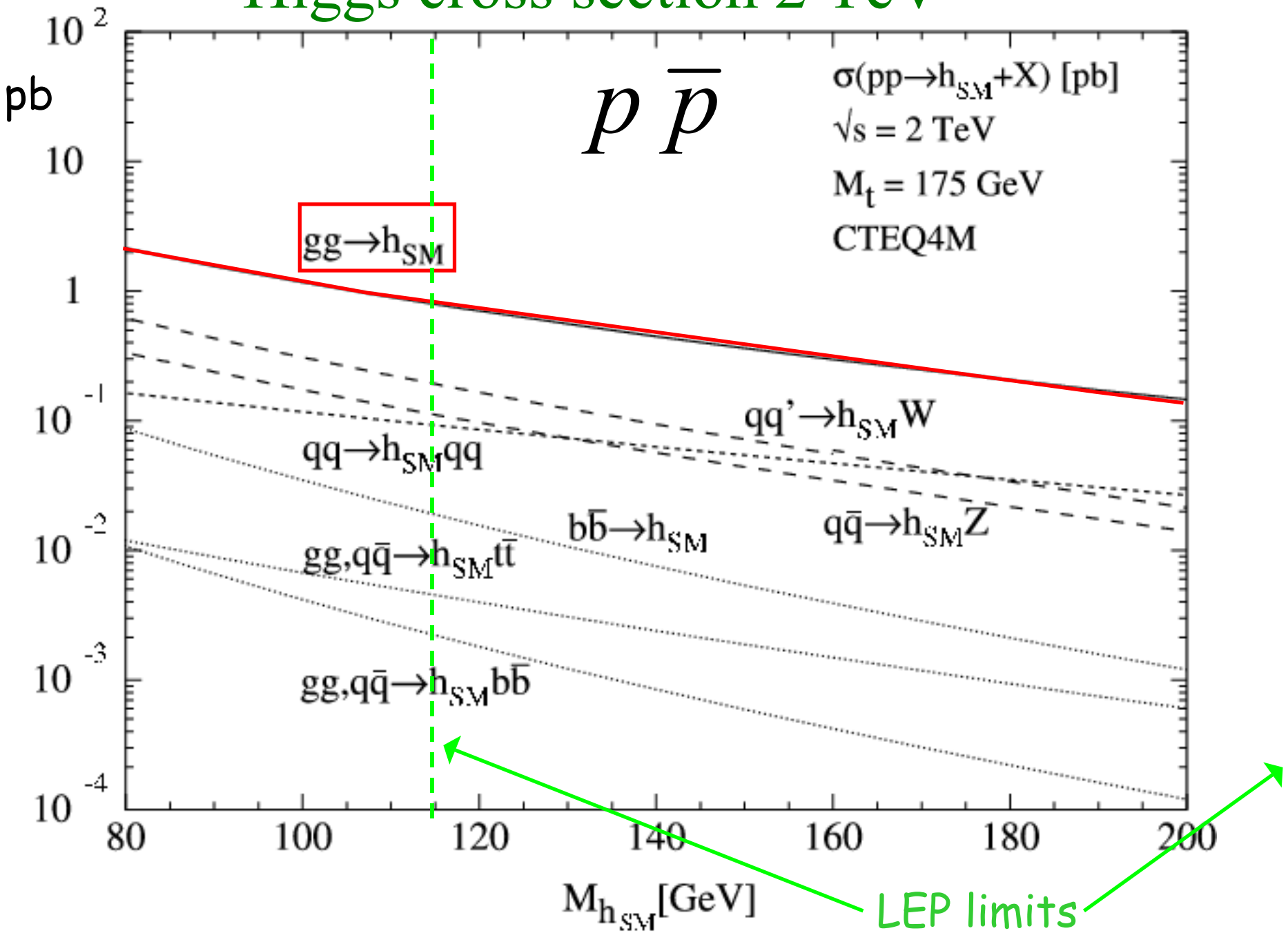


WW, ZZ fusion

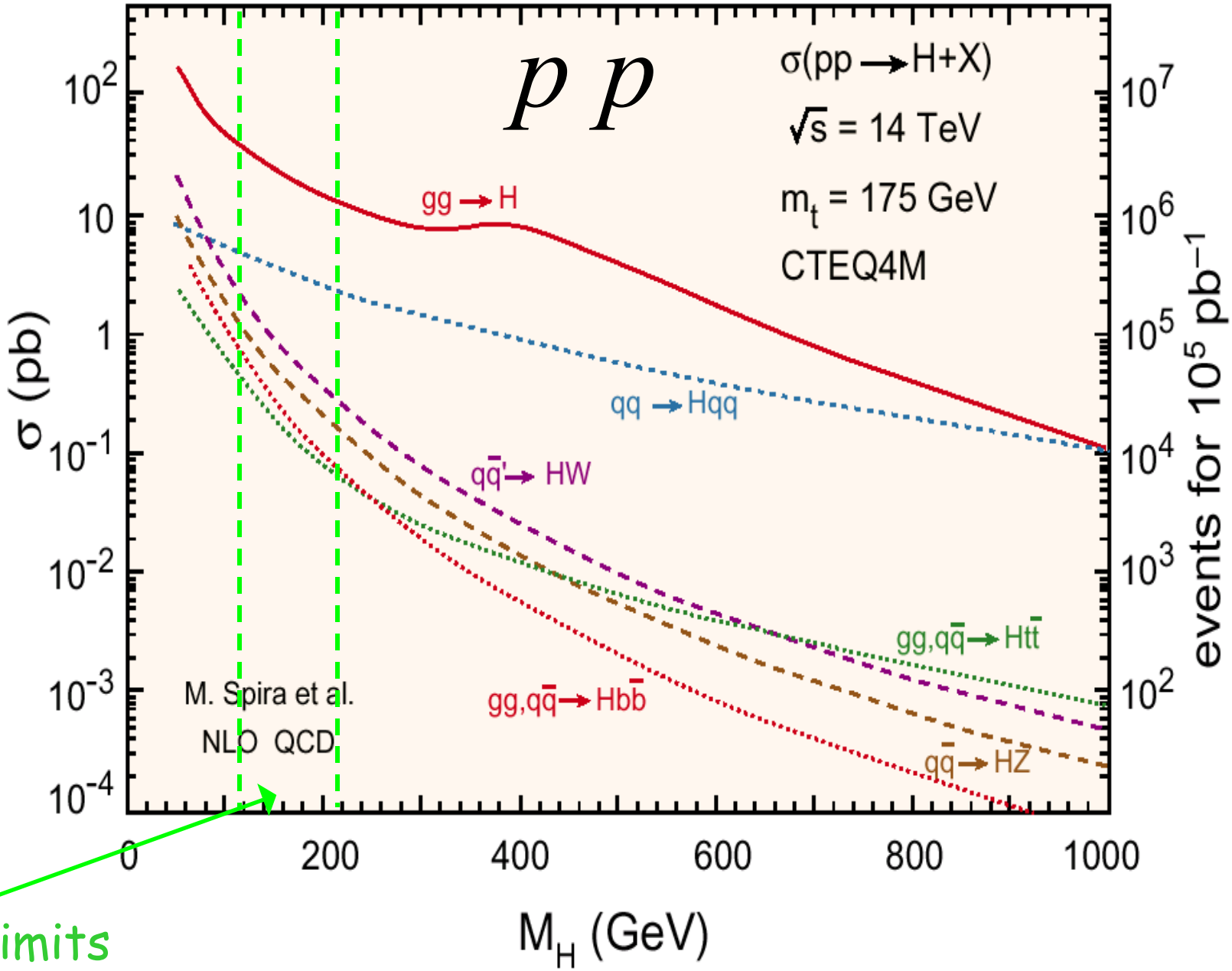
Xsection „large" at 14 TeV

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

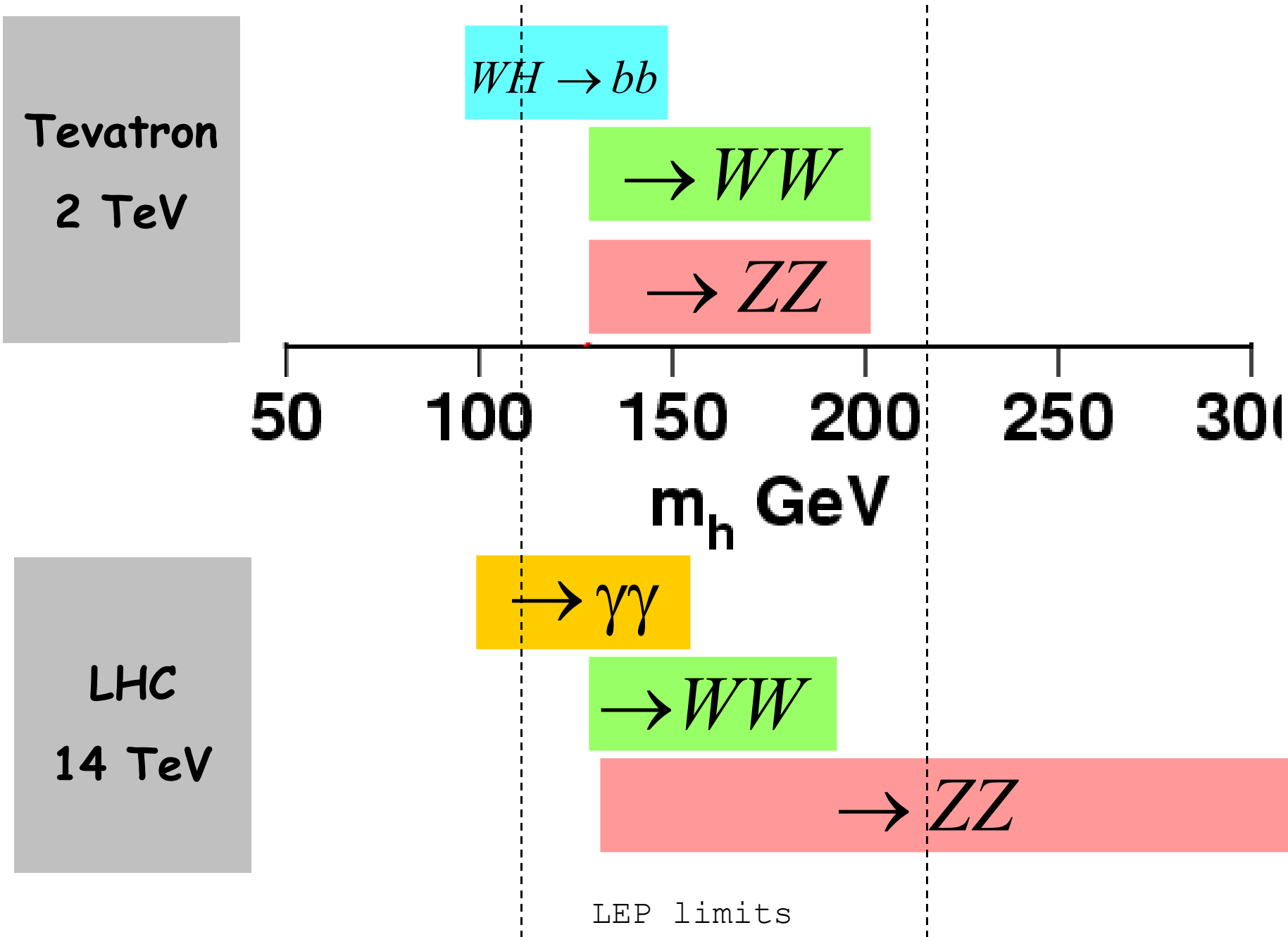
Higgs cross section 2 TeV



Higgs cross section 14 TeV



Higgs search strategies



Higgs (130-190 GeV) → WW [2 TeV]

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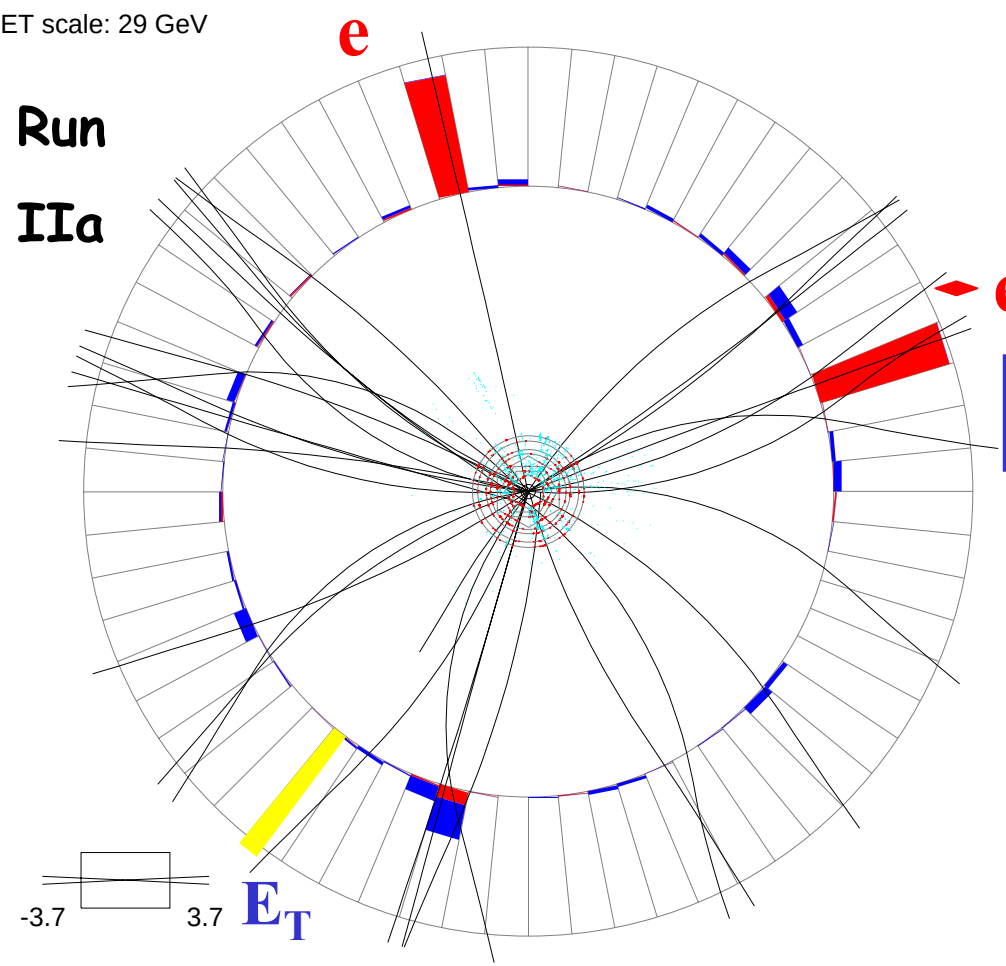
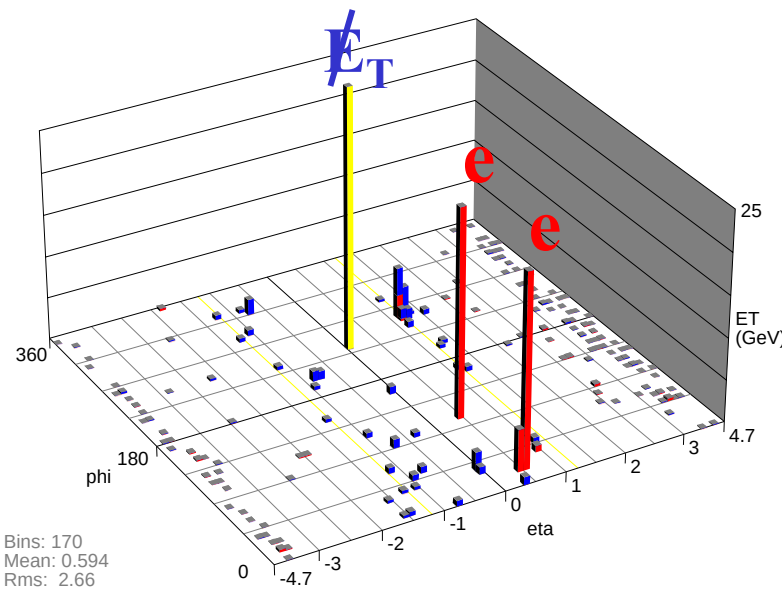
Run 169236 Event 4468684 Thu Feb 13 02:26:58 2003

ET scale: 29 GeV



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

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



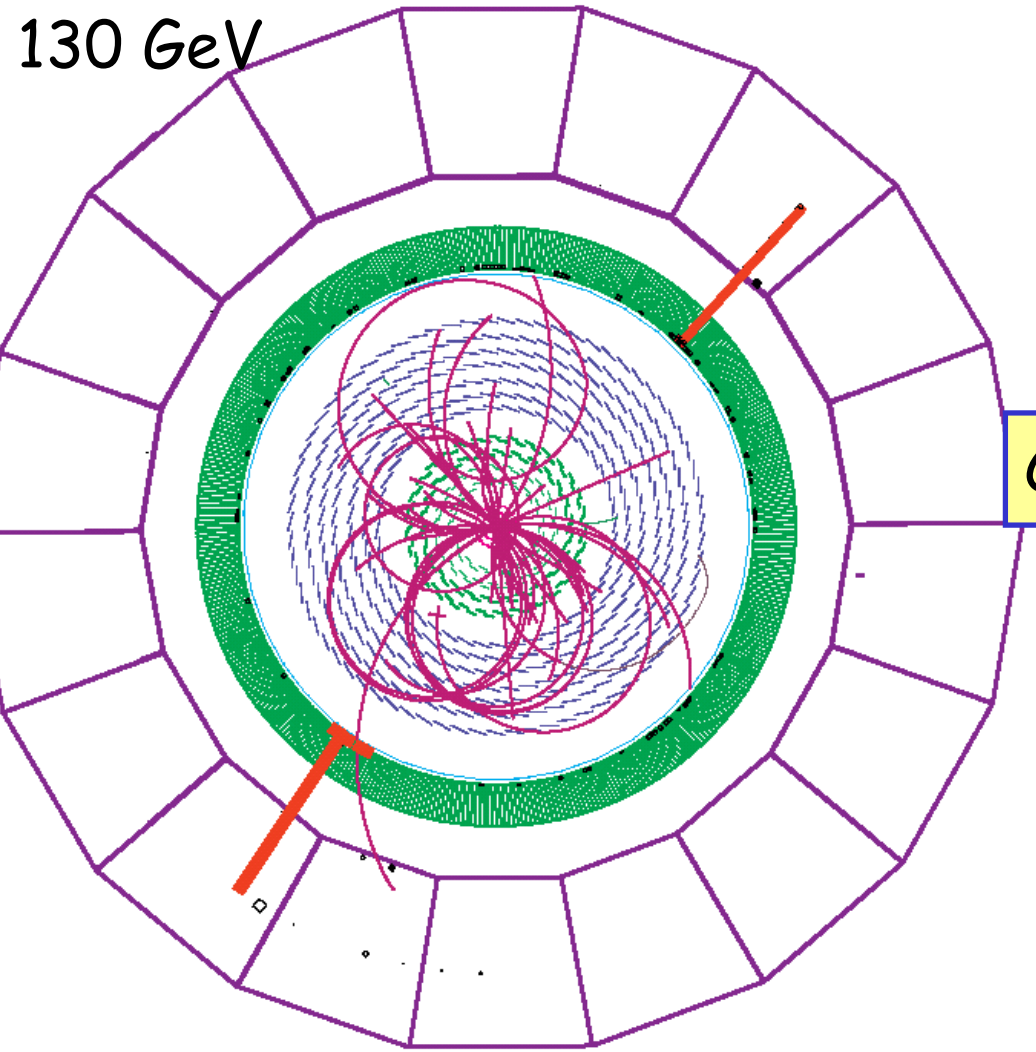
Bins: 170
Mean: 0.594
Rms: 2.66
Min: 0.00933
Max: 25

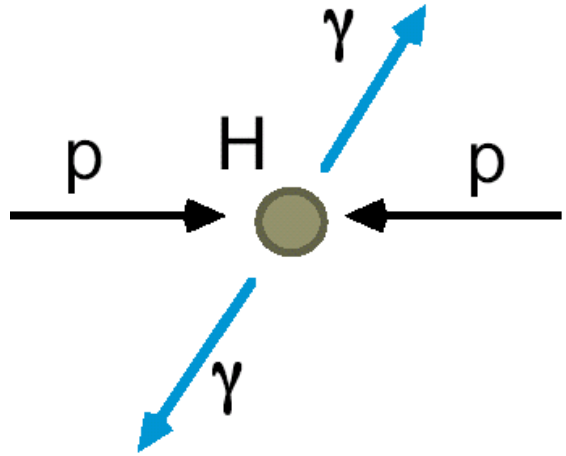
mE_t: 31.2
phi_t: 232 deg

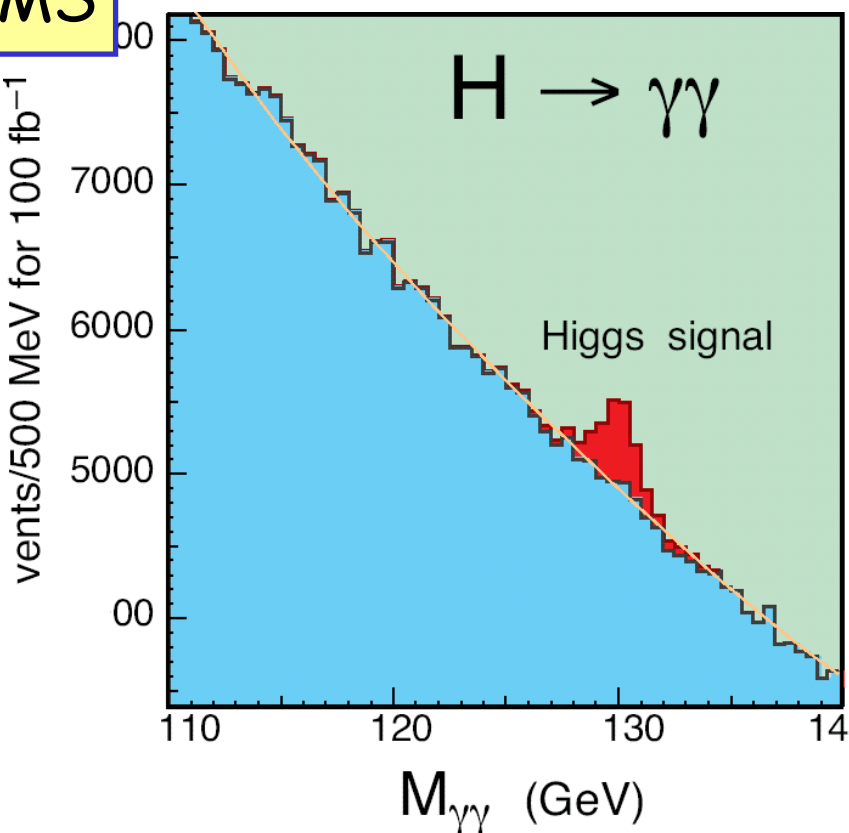
Background: $WW^{(*)}, Z\gamma^{(*)}, tt$

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

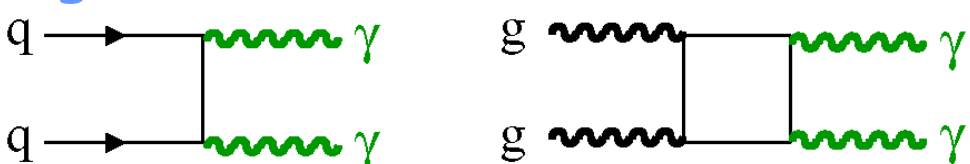
T.Hebbeker



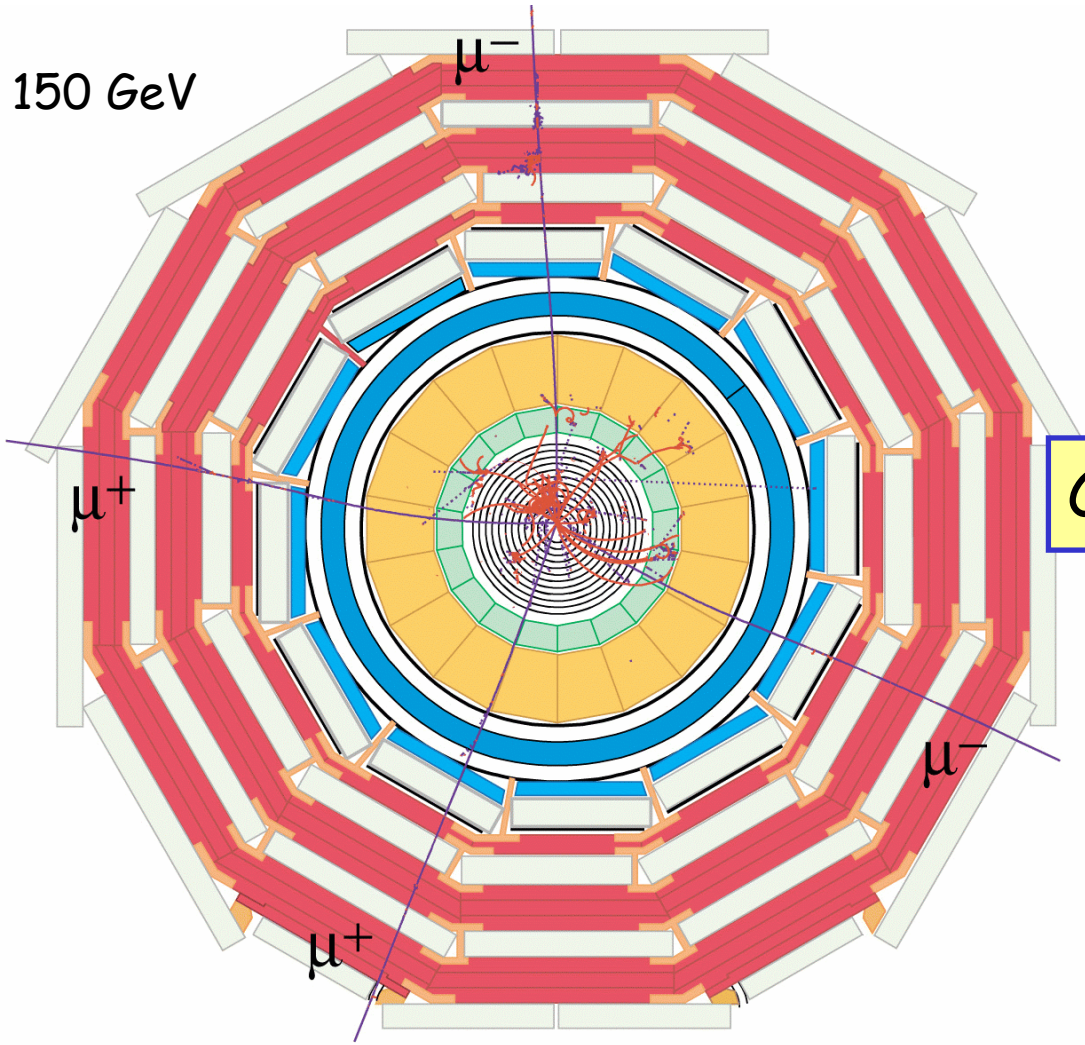


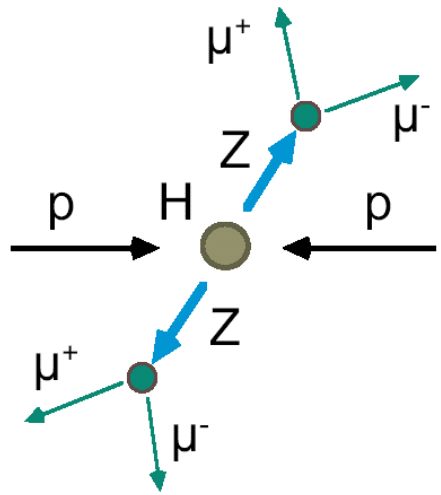


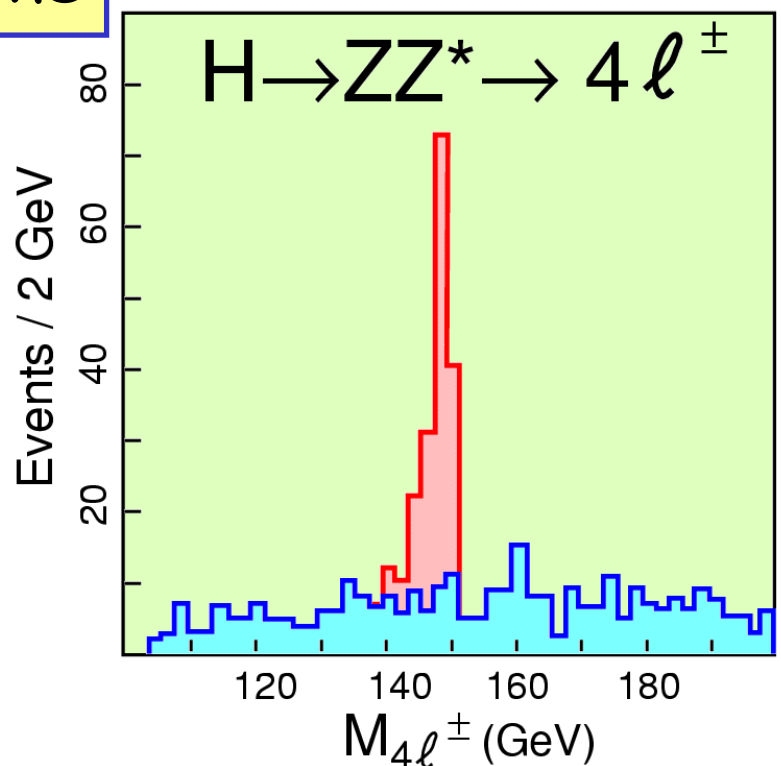
Background:



Higgs (130-700 GeV) $\rightarrow Z\,Z^{(*)}$ [14 TeV]







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

Higgs discovery prospects at Tevatron

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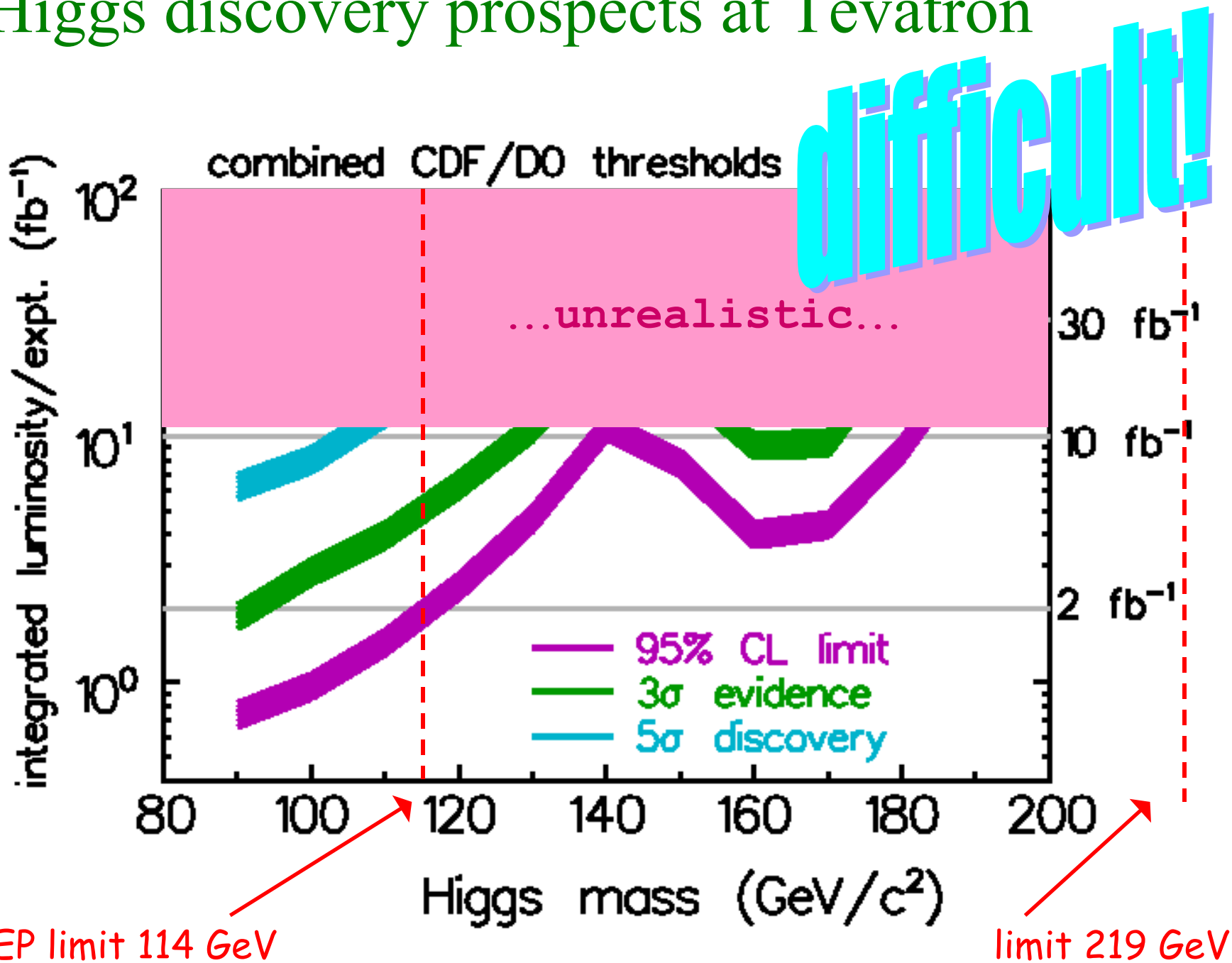

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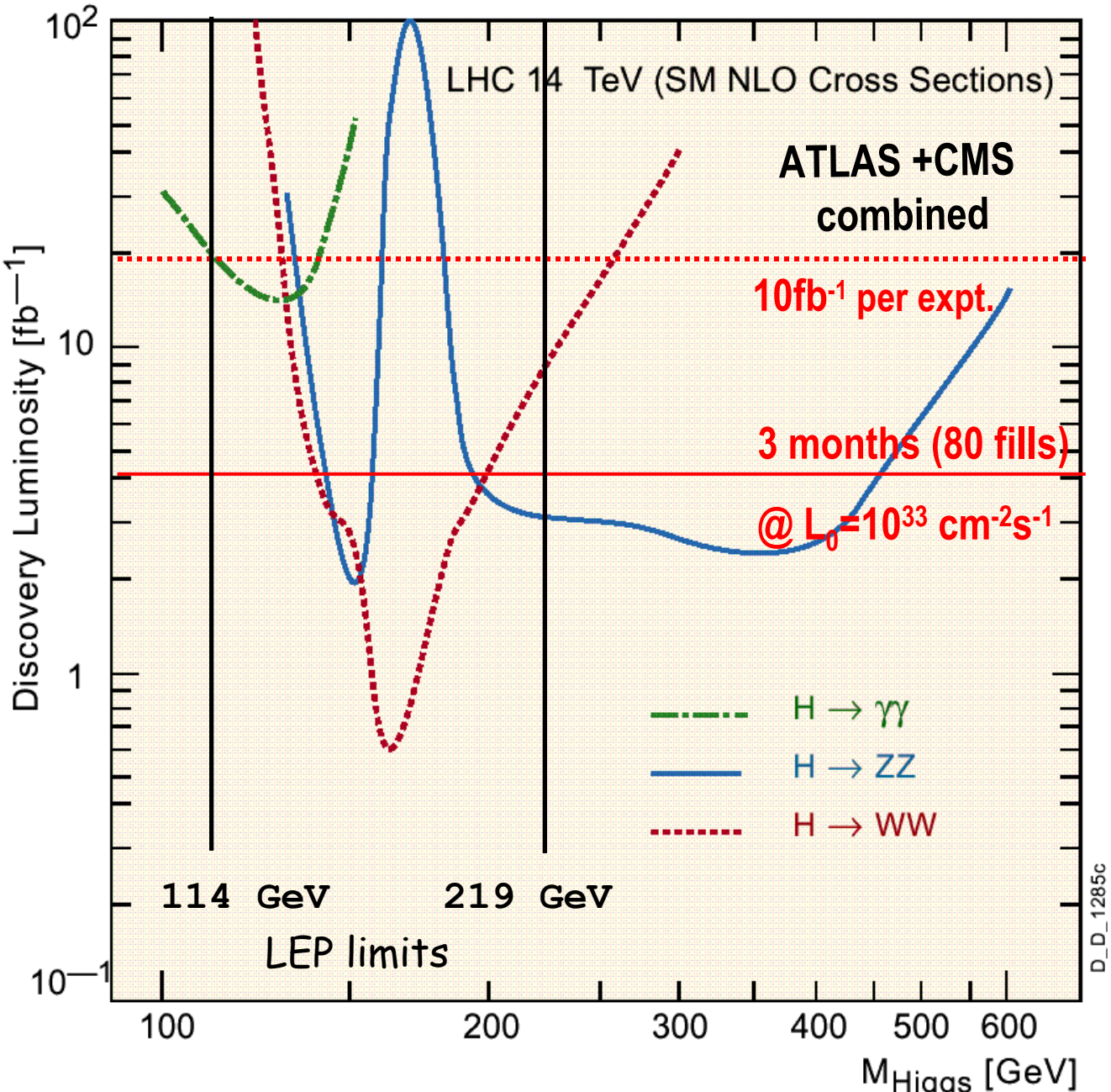
Higgs discovery prospects at LHC



yes!

experimentum crucis:

if SM Higgs exists

<->

it can/will be seen

Extended Higgs Models - Supersymmetry

Minimal SuSy = MSSM:

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

couples to up-fermions

couples to down-fermions

8 real fields – 3 (W^+ W^- Z) = <u>5 higgs bosons:</u>

h H A H^+ H^-

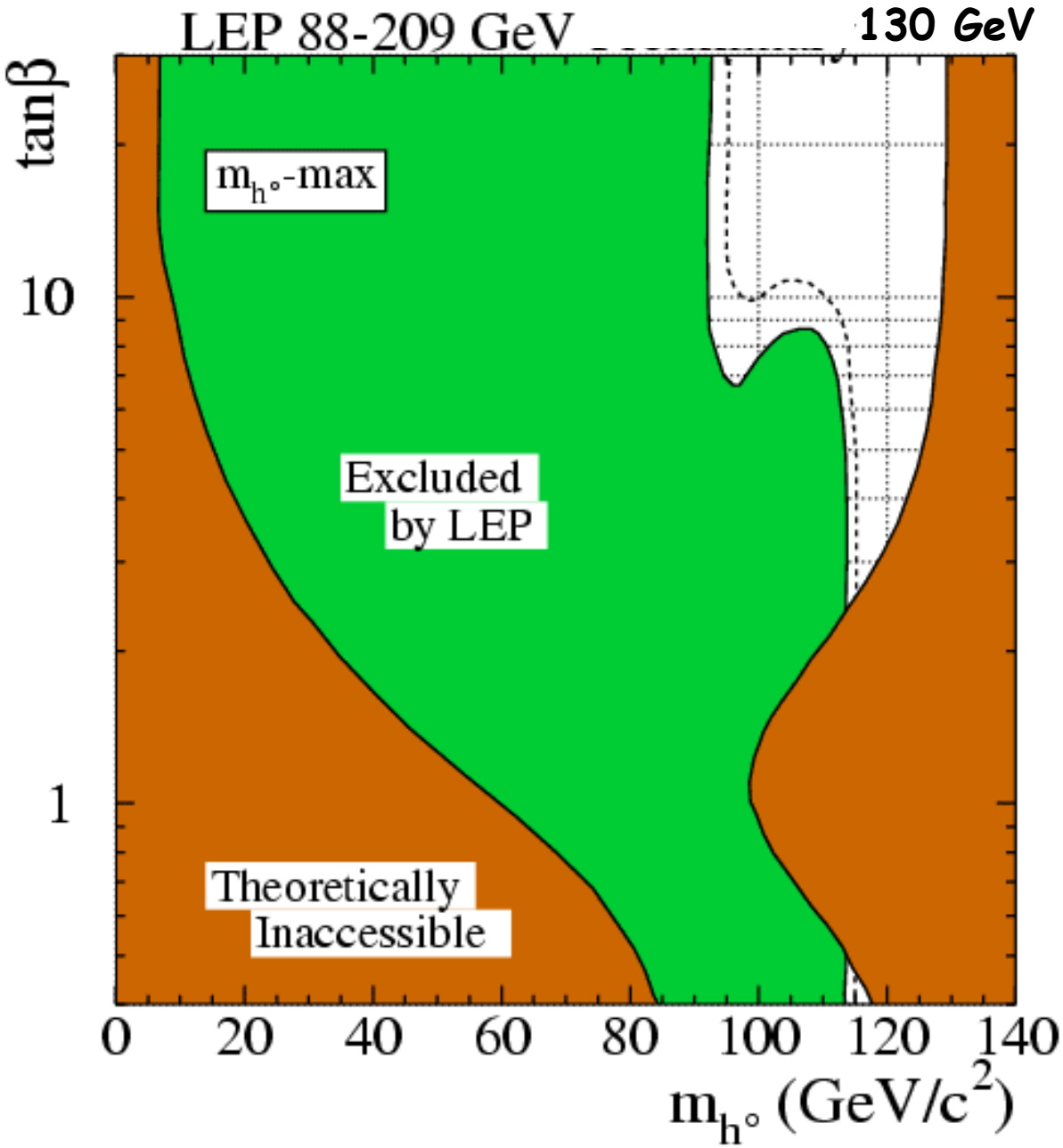
CP odd

<u>mass relations (lowest order):</u>

$$m_h < m_Z < m_H \qquad m_h < m_A \qquad m_W < m_{H^\pm}$$

$m_h < 130\,GeV$ incl. radiative corrections

MSSM Higgs Limits LEP



In addition:

limits on charged higgses...

$\tan\beta > 2.4$

MSSM Higgs Masses

All higgs masses fixed by two parameters:

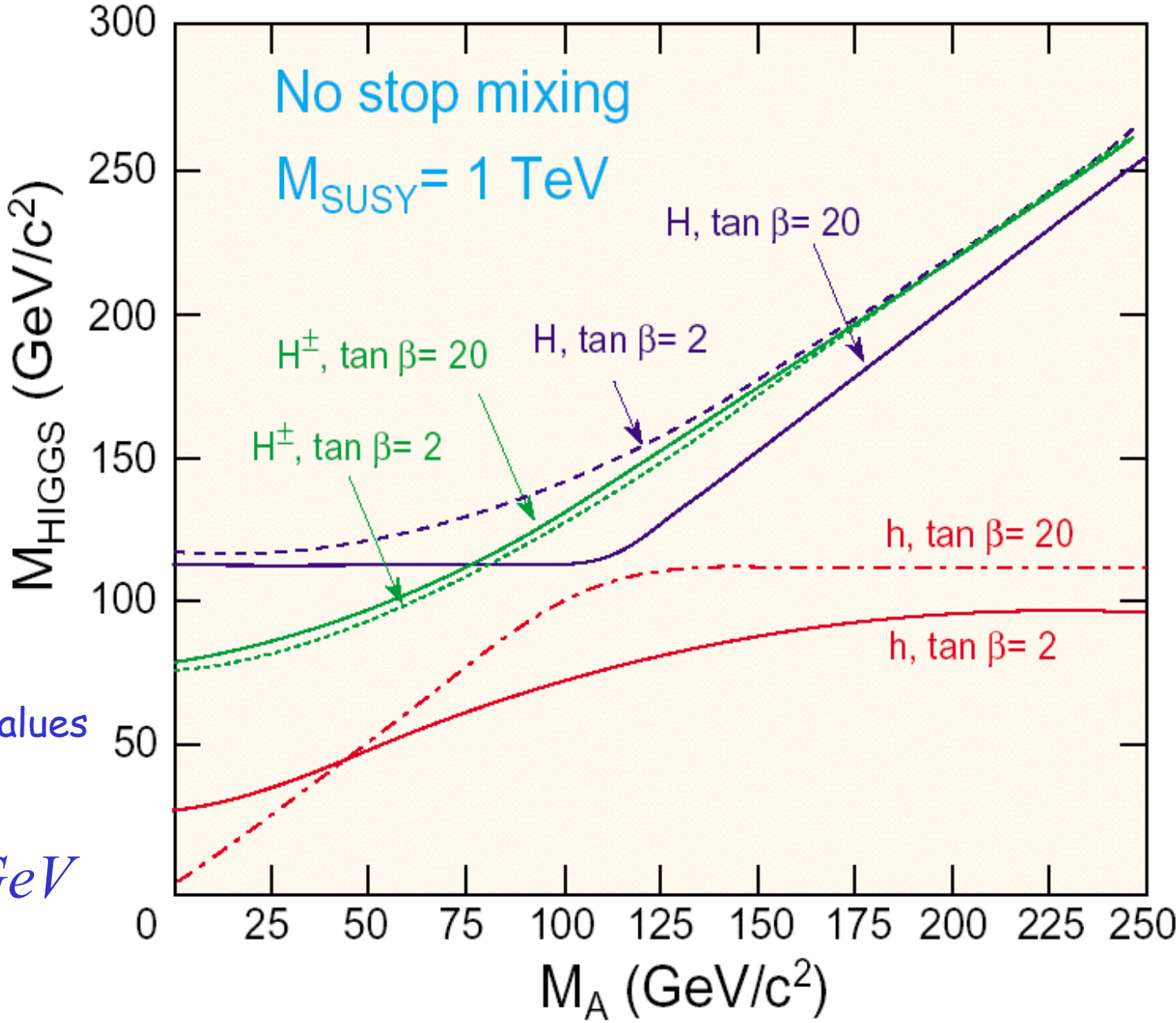
$$m_A$$

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

= vacuum expect. values

$$m_A = 90...500\,GeV$$

$$\tan\beta = 1...50$$

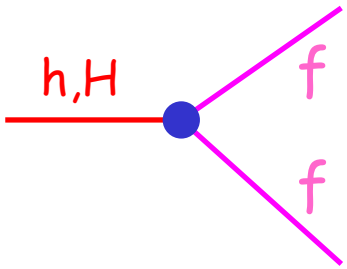


MSSM Higgs Couplings

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

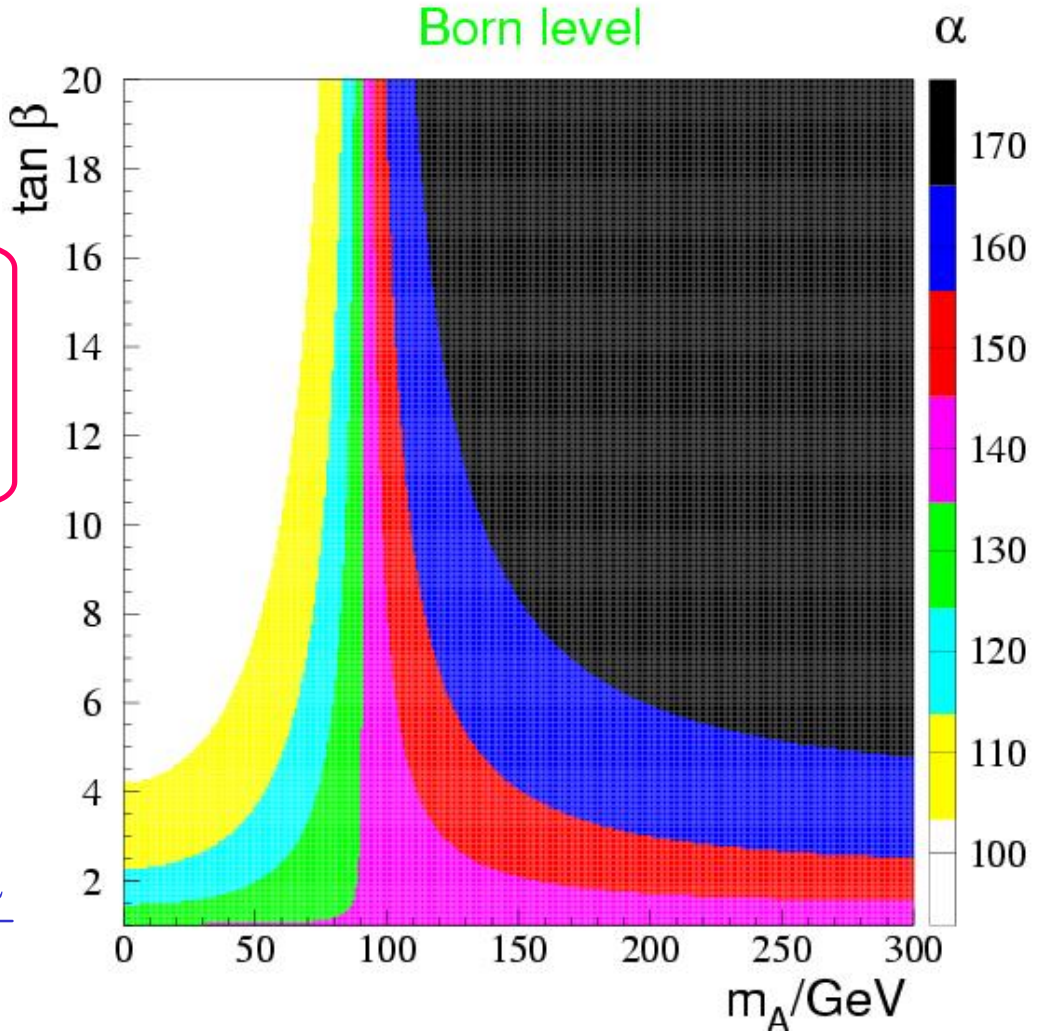
in particular h, H:

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



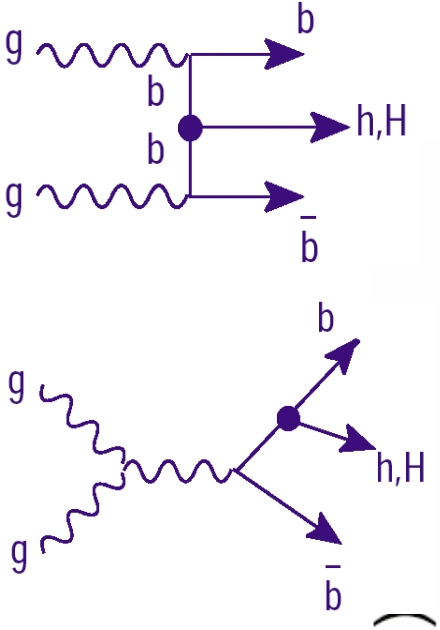
$$uu\,h \sim \frac{m_u \cos\alpha}{\sin\beta} \qquad dd\,h \sim \frac{m_d \sin\alpha}{\cos\beta}$$

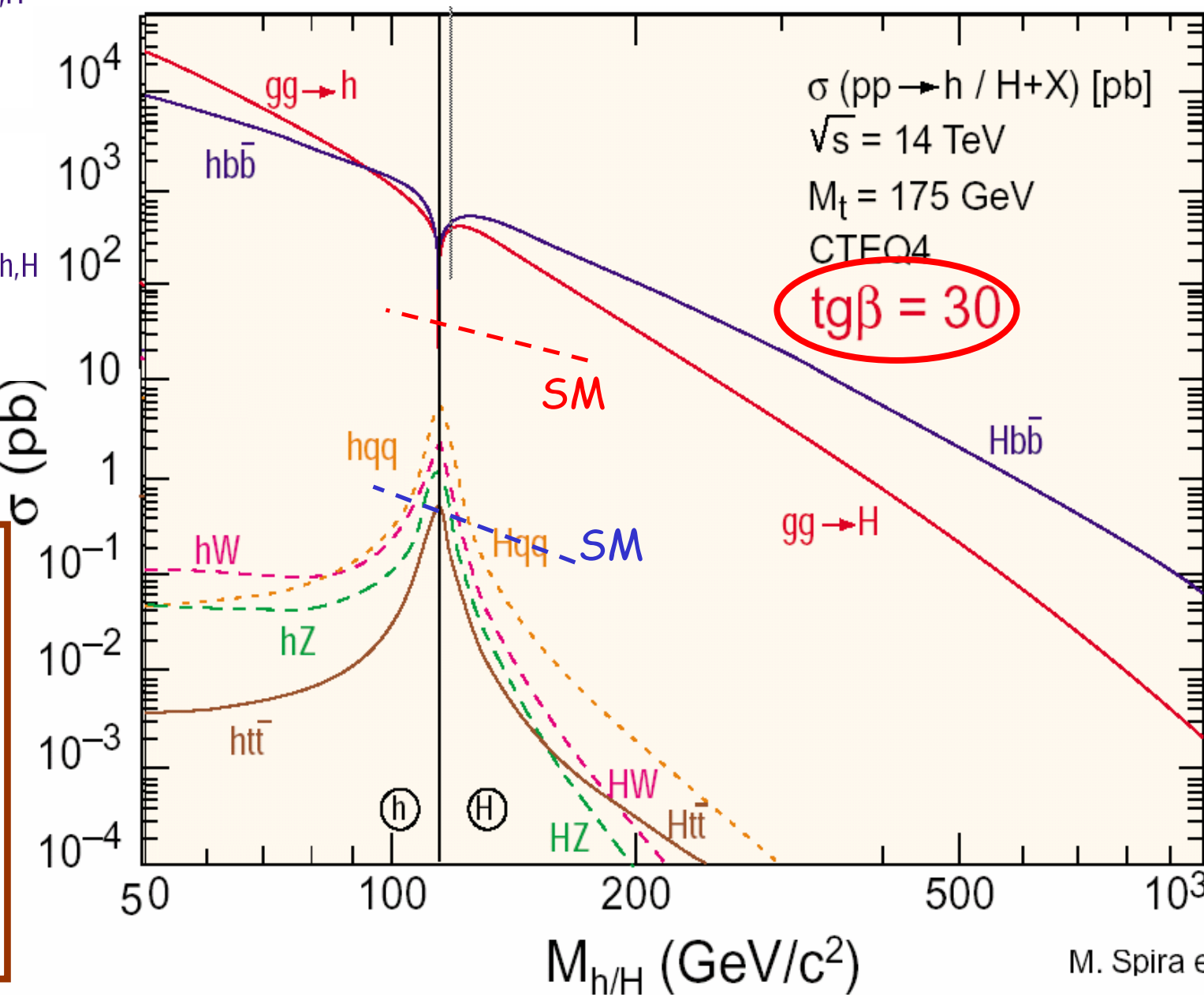
$$uu\,H \sim \frac{m_u \sin\alpha}{\sin\beta} \qquad dd\,H \sim \frac{m_d \cos\alpha}{\cos\beta}$$



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

MSSM Higgs Xsections





some xsections very large compared to SM !

M. Spira e

MSSM Higgs Search LHC

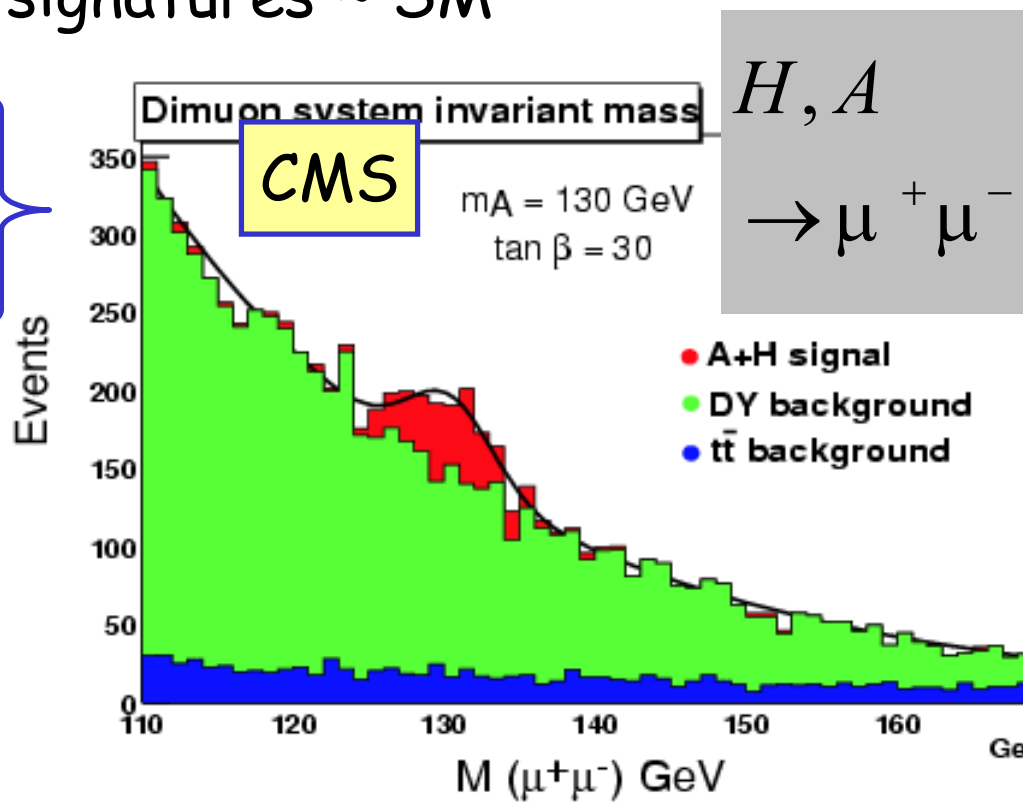
Many channels:

- charged Higgs H^+, H^-
- if $\tan\beta$ small, h decay signatures ~ SM
- if $\tan\beta$ large, „down" fermions preferred
- `cascade decays'

  eg $A \to Zh$
- if sparticles light:

  eg $H \to \chi^0\chi^0$

  $H^+ \to \chi^+\chi^0$



Charged Higgses

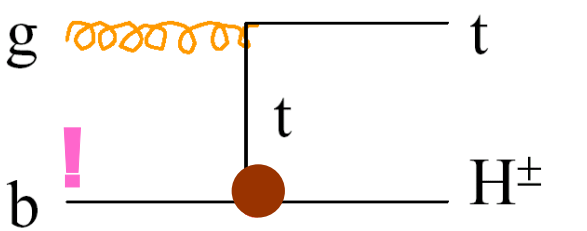
a) $m_{H^\pm} < m_t$

$gg \to tt$

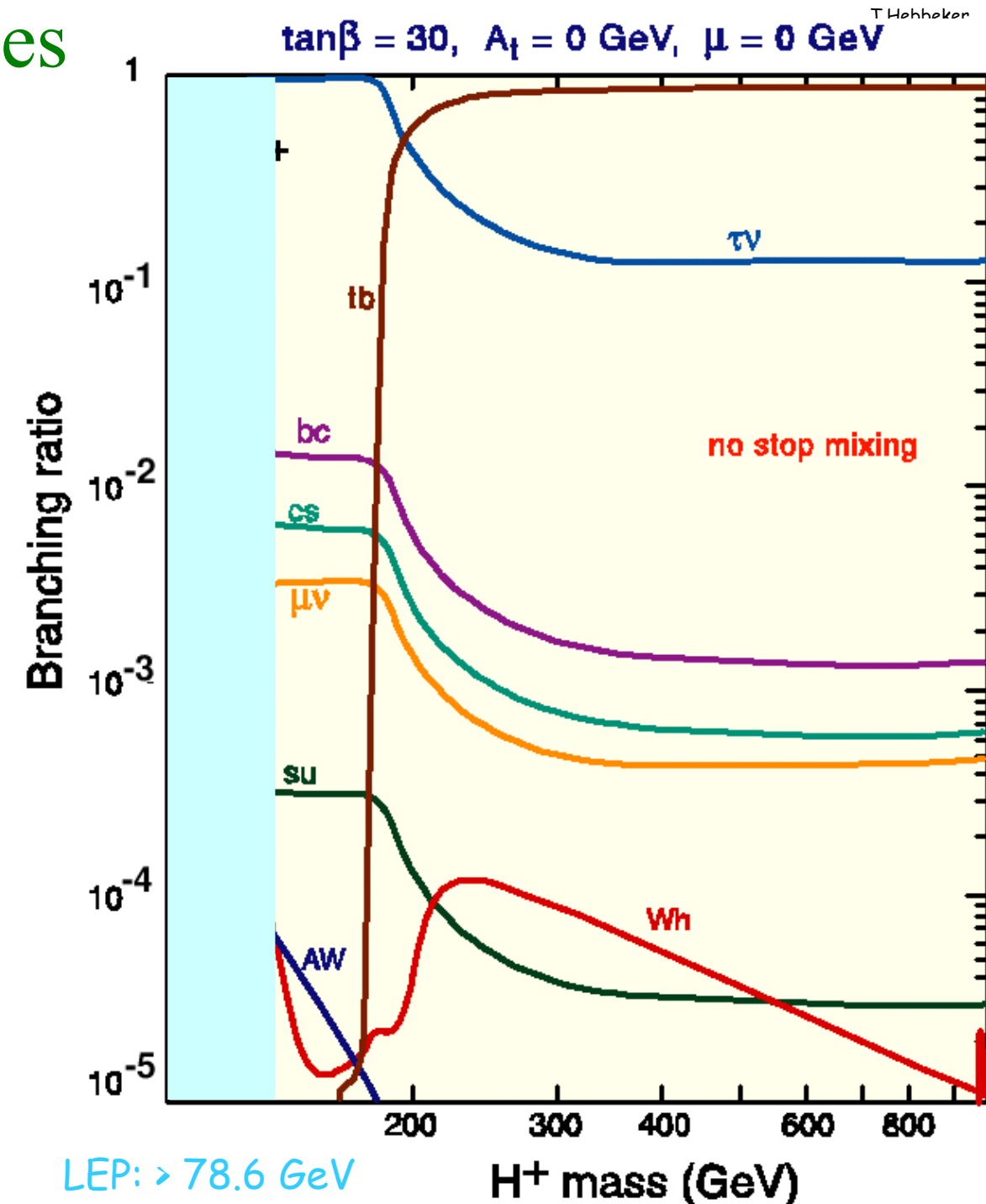
$t \to bH$

$H \to \tau\nu$

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

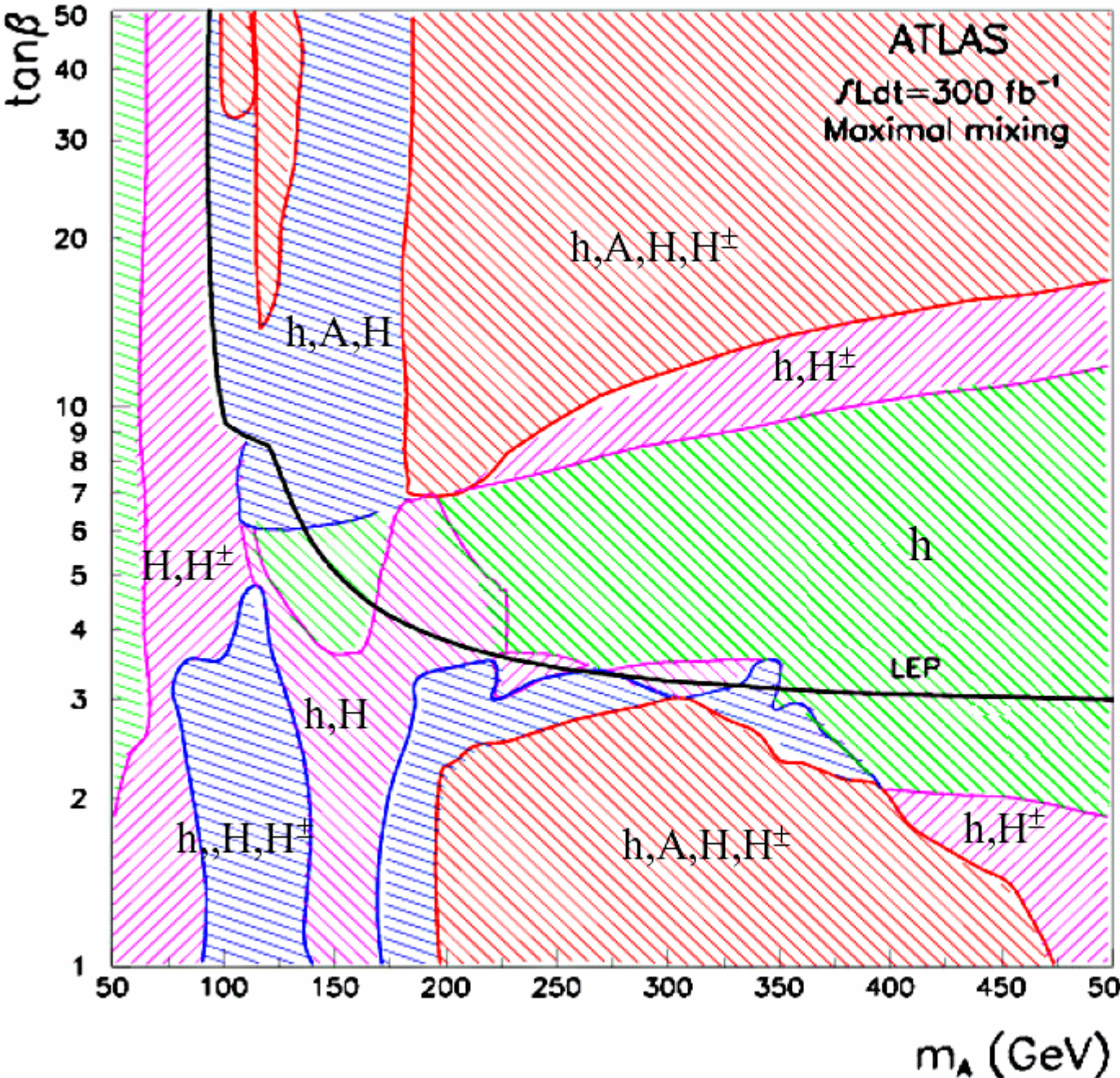


$H \to t\,b$



LEP: > 78.6 GeV

MSSM Higgs Discovery at LHC ?



whole region covered!

Higgses cant escape !

pp physics

Part I Introduction

Part II Standard Model Physics

Part III Higgs

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

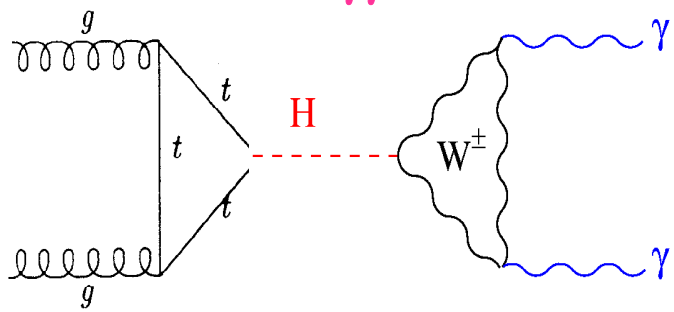
Part IV New Phenomena

References

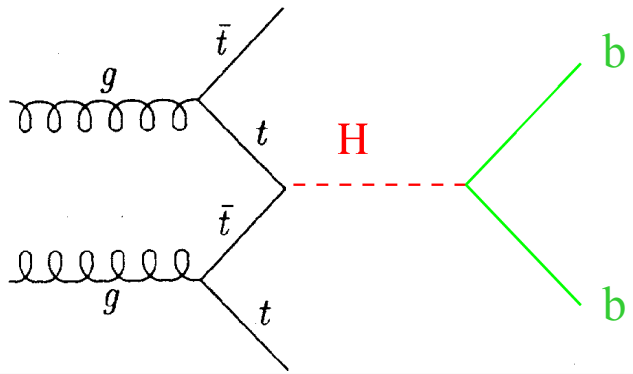
Appendices

Higgs production

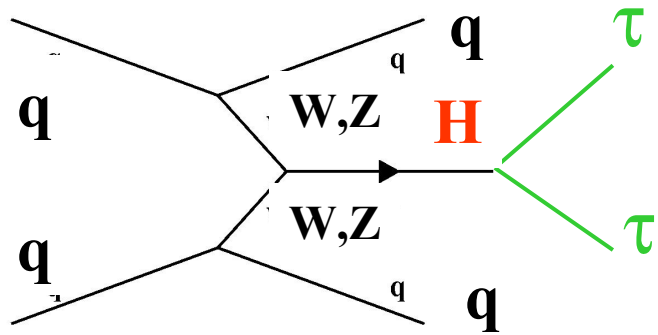
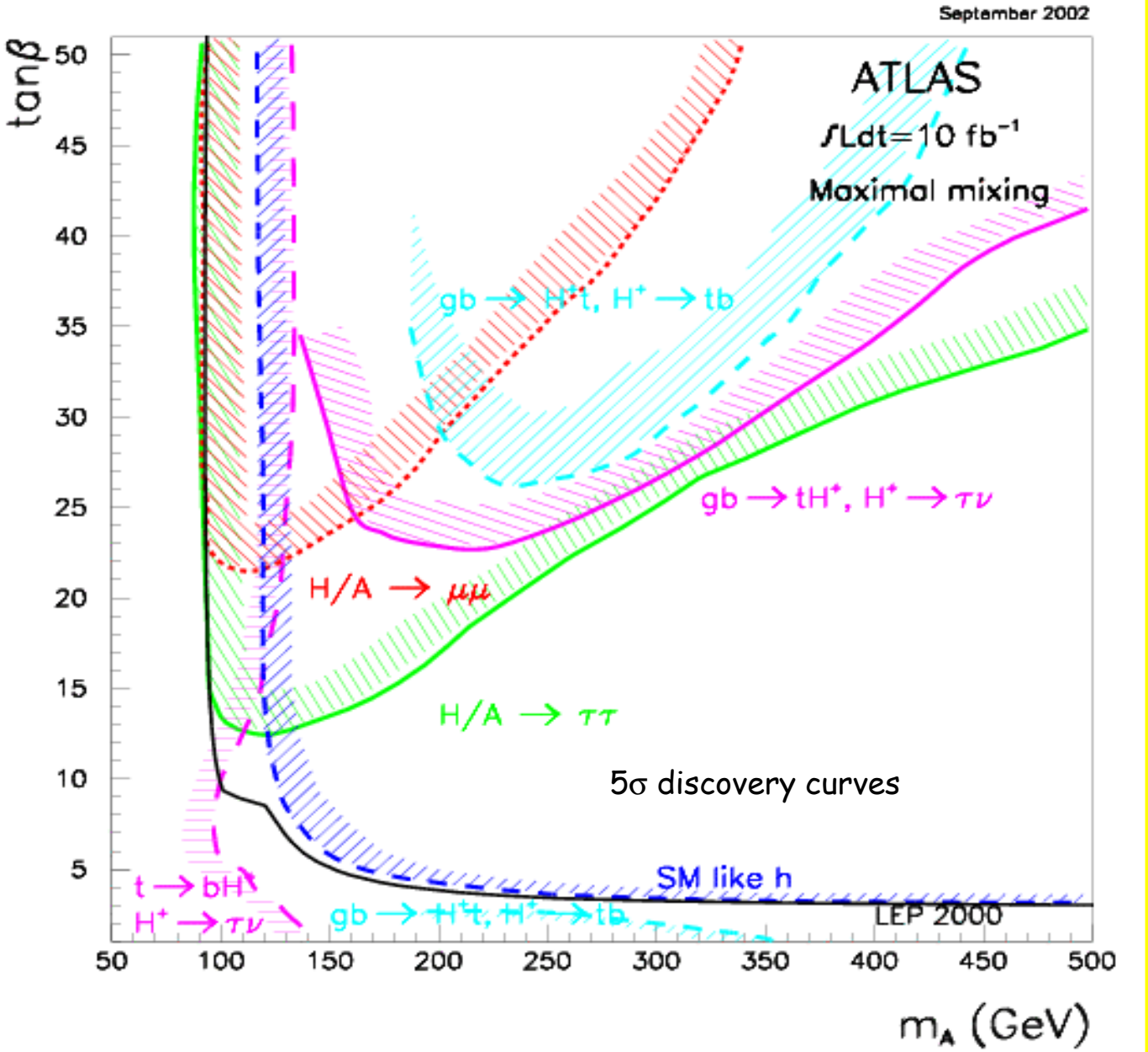
$H \rightarrow \gamma\gamma$



$ttH \rightarrow tt\ bb \rightarrow b\ell\nu\ bjj\ bb$



$qqH \rightarrow qq\tau\tau$



MSSM Higgs Limits LHC