Higgs boson decay in γZ in the NMSSM

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Outline

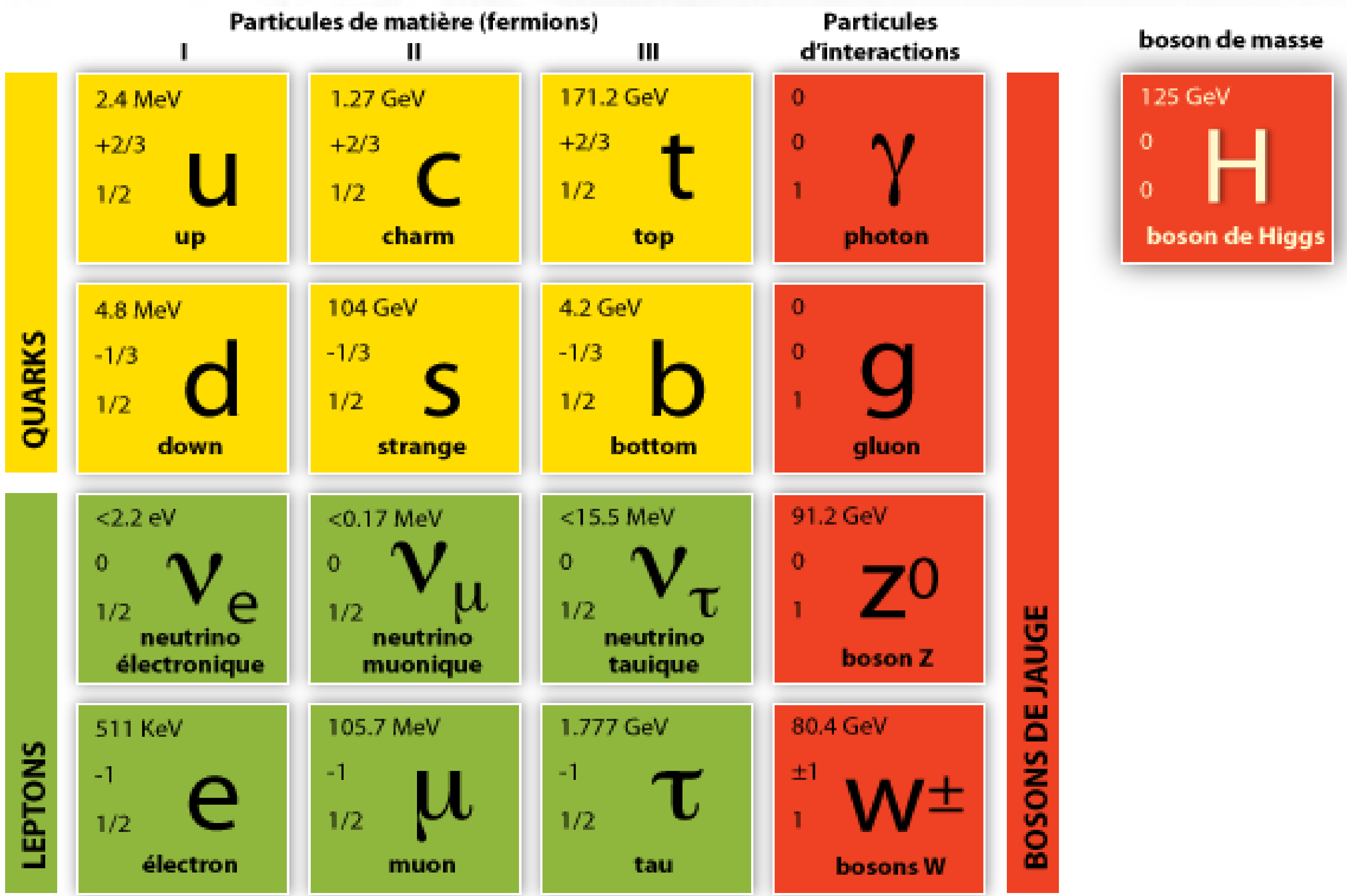
- Introduction
  - Higgs boson discovery
  - Standard Model
  - MSSM,NMSSM
- Higgs boson decay in γZ
  - Effect of charginos
  - Effect of sfermions

Higgs boson discovery

- 4th July 2012 : Announcement of the discovery of a new particle at LHC
- A scalar boson with a mass of 125 GeV, predominantly CP-even
- 8th October 2013 : Nobel Price for Peter Higgs and François Englert

but... which Higgs boson ?

Standard Model

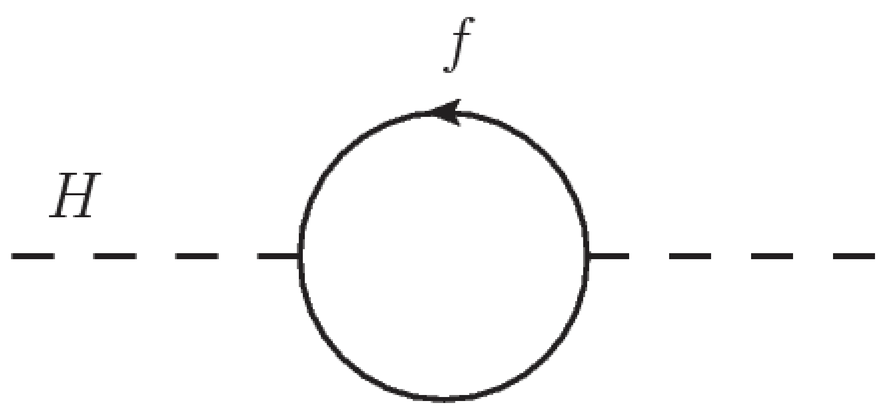


Standard Model

- Higgs boson : last piece of this theory
- Experimentally very well verified
- But do not explain everything :
  - Hierarchy problem
  - Neutrino Masses
  - Quadratic divergence of radiatives corrections to Higgs boson mass
  - Dark matter

Standard Model : quadratic divergence of m_H^2

- Yukawa potential : $-\lambda_f H \bar{f} f$

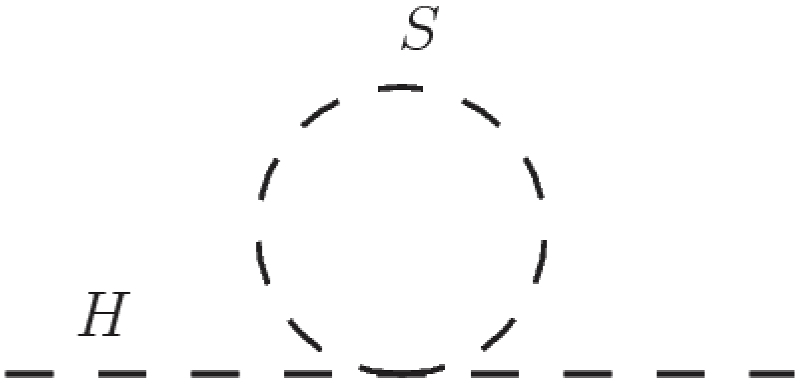


$$\Delta m_H^2 = \frac{-|\lambda_f|^2}{8\pi^2} \Lambda_{UV}^2 + \ldots$$

- But $m_H = 125\mathrm{GeV}$ ...

Idea

- New scalar particle with the following interaction Lagrangian : $-\lambda_S|H|^2|S|^2$



$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}\Lambda_{UV}^2$$

- Compared with : $\Delta m_H^2 = \frac{-|\lambda_f|^2}{8\pi^2}\Lambda_{UV}^2 + \ldots$

Idea

- New symmetry relating bosons and fermions and implying $\lambda_s = |\lambda_f|^2$

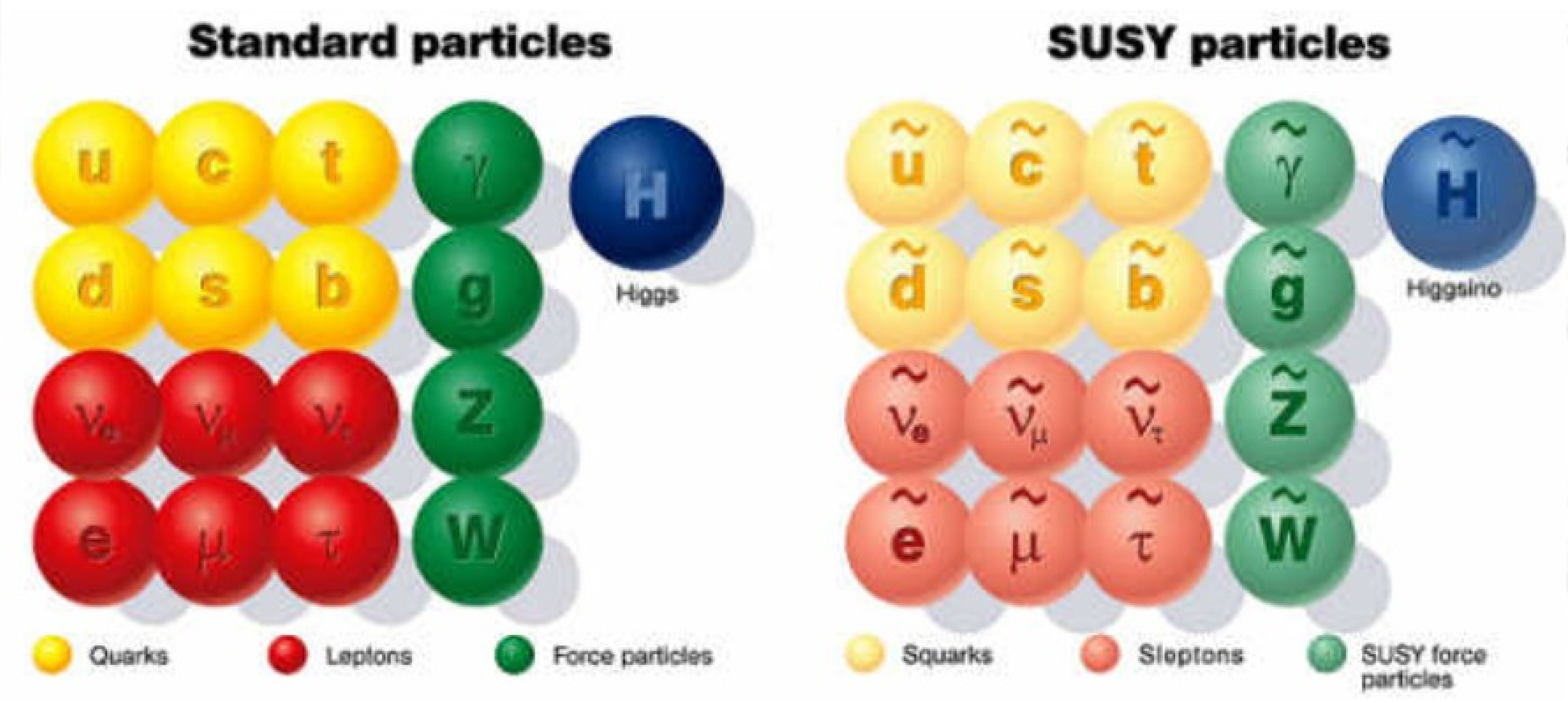
  → Supersymmetry !

- Fermionic degrees of freedom = bosonic degrees of freedom
- Particles and superpartners are degenerate

  → SUSY has to be broken !

MSSM

- New zoo of particles :



2 Higgs bosons here !

MSSM

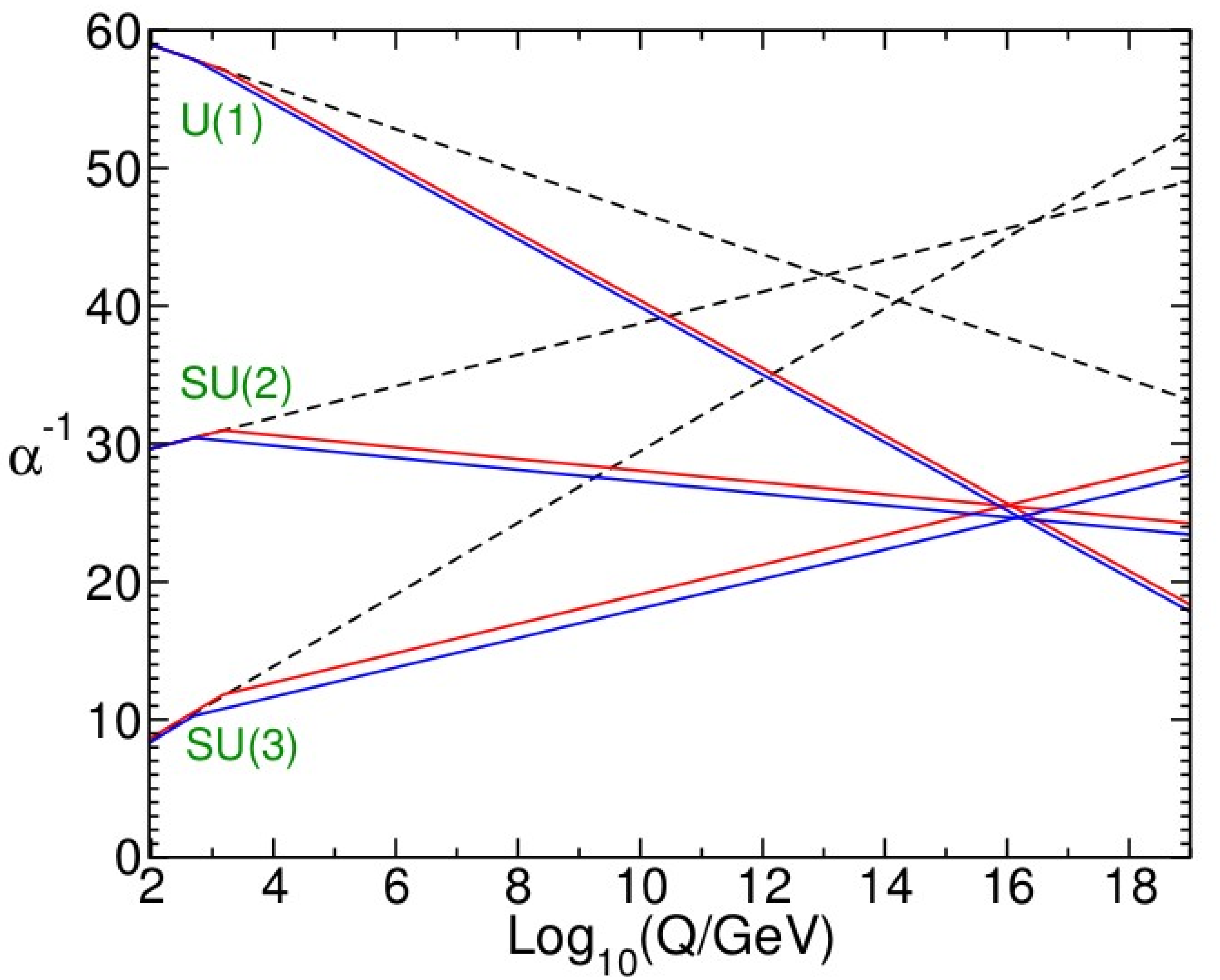
- Neutralinos : mixing of $\tilde{H}_u^0, \tilde{H}_d^0, \tilde{B}^0, \tilde{W}^0$

  Possible solution of dark matter problem

- Charginos : mixing of charged gauginos and higgsinos
- Unification of coupling constants at some very high scale

  Hint for a Grand Unified Theory ?

MSSM



$$\alpha = \frac{g^2}{4\pi}$$

MSSM

- 2 Higgs doublets H_u and H_d

$$W_{Higgs} = \mu H_u H_d$$

- μ is a new undesired scale : so called μ-problem

$$M_Z^2 \simeq -2\mu^2 + 2\frac{m_{H_d}^2 - \tan^2\beta m_{H_u}^2}{\tan^2\beta - 1}$$

- A solution : introduce a new gauge singlet Higgs superfield S ➡ NMSSM

$$W_{Higgs} = (\mu + \lambda\hat{S})\hat{H}_u.\hat{H}_d + \xi_F\hat{S} + \frac{1}{2}\mu'\hat{S}^2 + \frac{\kappa}{3}\hat{S}^3$$

NMSSM

- In the Z_3 invariant NMSSM : $\mu = \mu' = \xi_F = 0$

$$W_{sc.inv} = \lambda \hat{S} \hat{H}_u . \hat{H}_d + \frac{\kappa}{3} \hat{S}^3$$

- Since <S>=s, new effective μ-term :

$$\mu_{eff} = \lambda s$$

... μ-problem solved

NMSSM

- Extended Higgs sector :
  - 3 CP-even Higgs bosons h_1,h_2,h_3
  - 2 Pseudoscalars A_1, A_2
  - 2 charged Higgs bosons $H^{\pm}$
- h_1 or h_2 could be the one observed at LHC

$\longrightarrow$ if h1 is gauge singlet, it avoids all constraints and can be very light

NMSSM

- Advantage of the NMSSM : easier to get a Higgs boson with a mass of 125 GeV

$$\text{MSSM} \quad : \quad m_h^2 = m_Z^2 \cos(2\beta) + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}^2}}\left(1 - \frac{X_t^2}{12 m_Z^2}\right)\right]$$

$$\text{NMSSM} \quad : \quad m_h^2 = m_{h,MSSM}^2 + \lambda^2 v^2 \sin^2(2\beta)$$

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

- Important to investigate the properties of Higgs boson since there could be large deviations from SM expectations

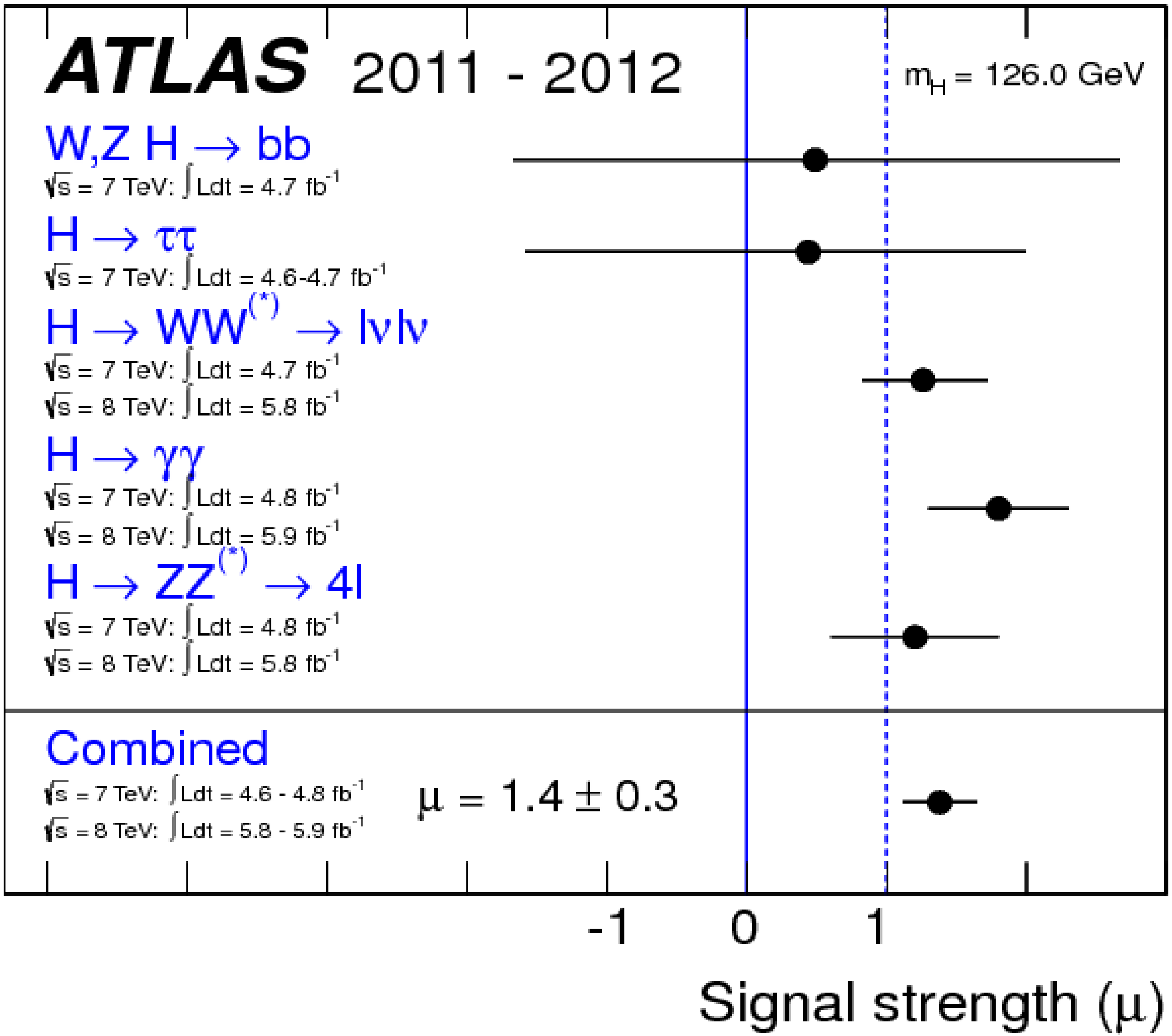
Which signature for γZ channel ?

Higgs boson decays

- Analyses of different decay channels for a given model
- Comparison with Standard Model expectations
- Already measured channels : $H \rightarrow \gamma\gamma$, bb, $\tau\tau$,...
- Future channel : $H \rightarrow \gamma Z$

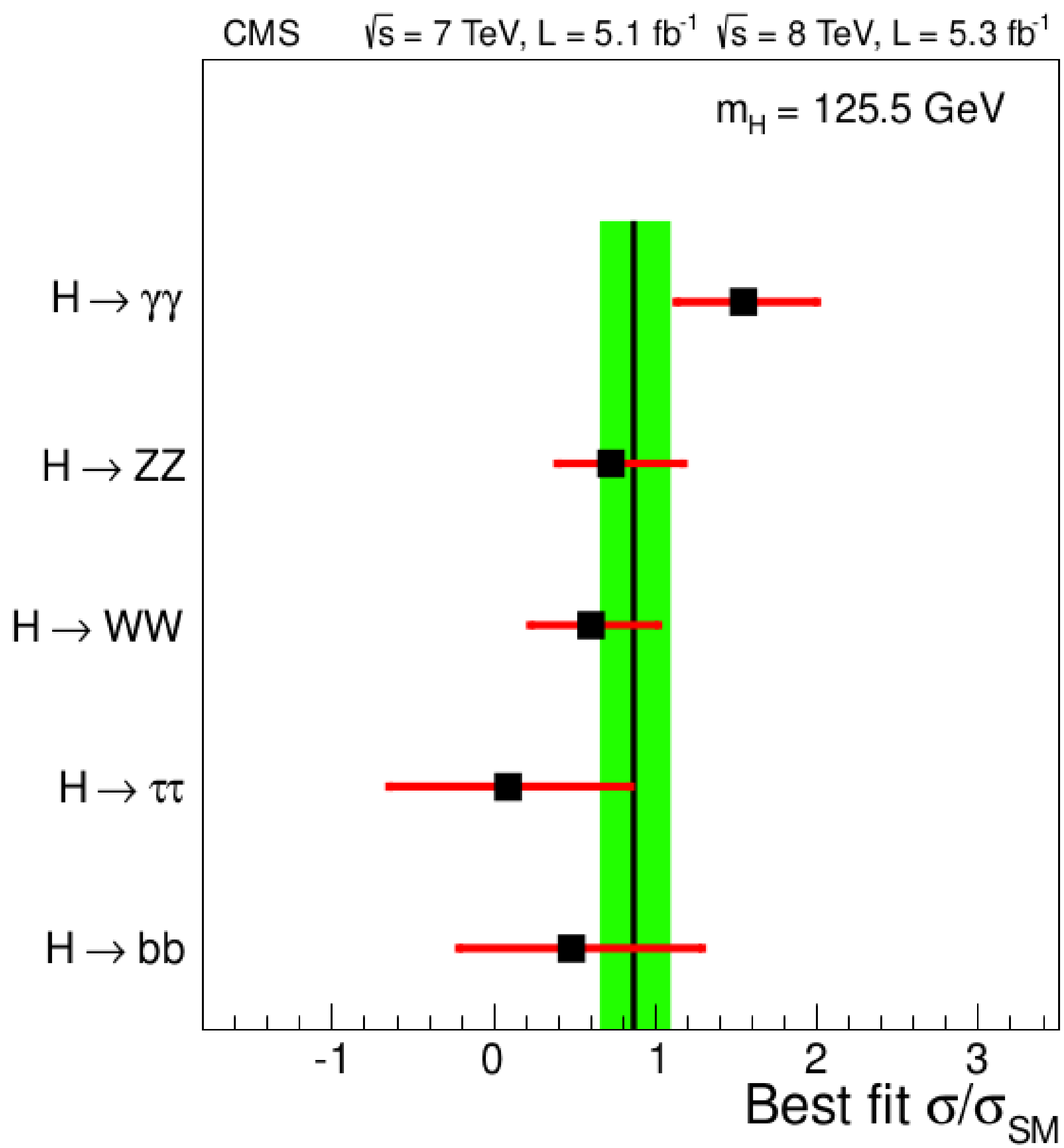
➡ Need of precise calculation of this partial width

Higgs boson decays



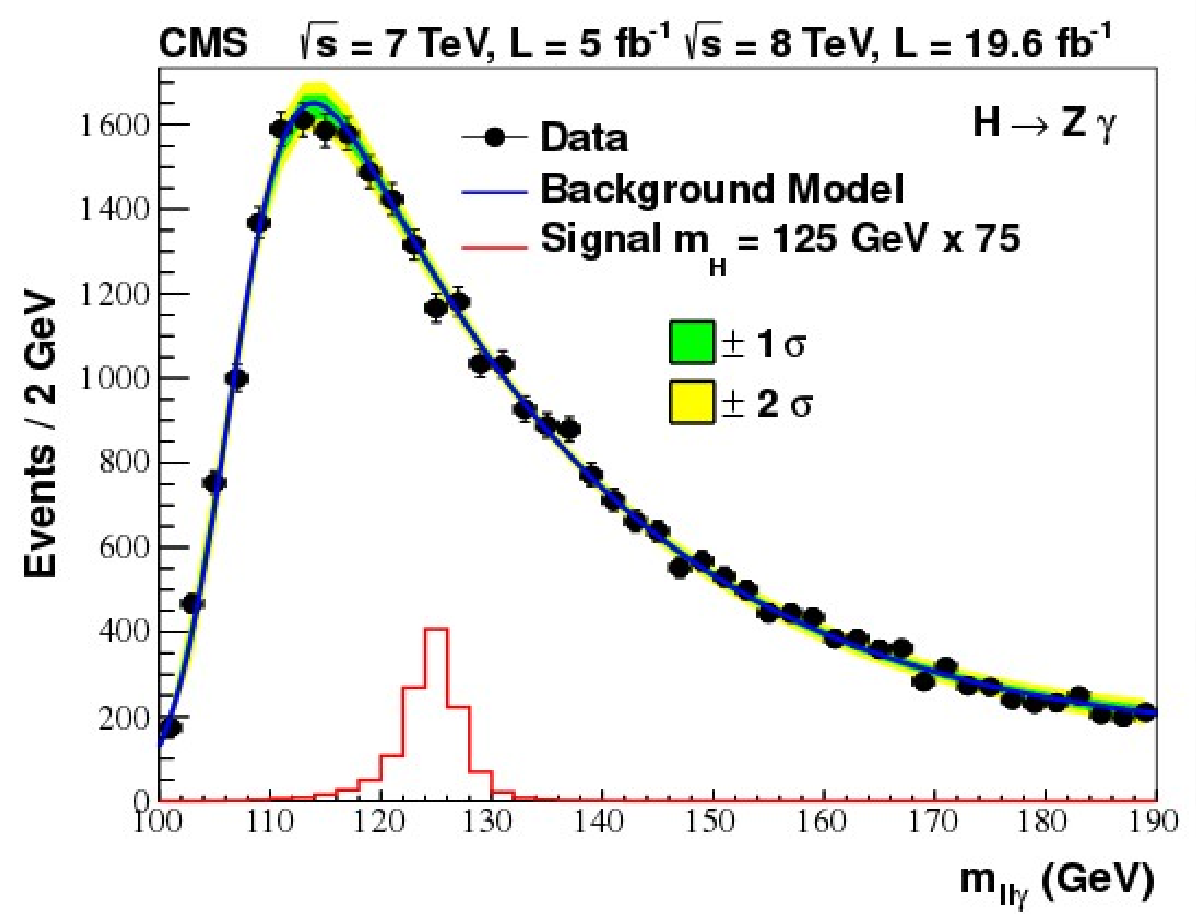
$$\mu = \frac{\sigma}{\sigma_{SM}}$$

Higgs boson decays



Higgs boson decays

- Future channel : H→γZ

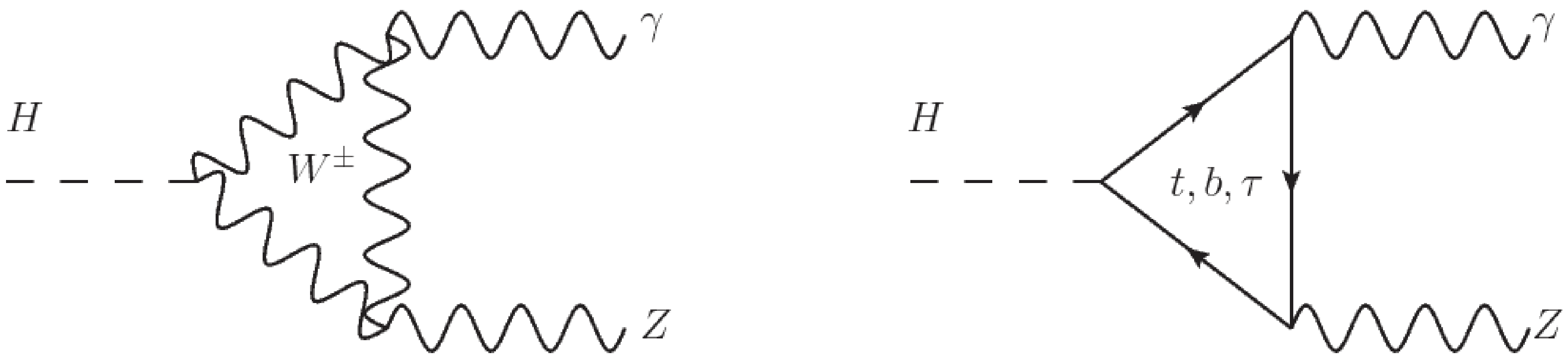


One needs precise theoretical calculation of this partial width

$H \to \gamma Z$: Standard case

$$\Gamma(H \to \gamma Z)_{125GeV} = 6.27 \cdot 10^{-6}\mathrm{GeV}$$

$$BR = 1.54 \cdot 10^{-3}$$



- If there are other new particles in the loop, it will change this value (like for $\gamma\gamma$ channel)

$H \to \gamma Z$

- One loop Feynman diagrams with the following particles in the loop :
  - W, b, t
  - Charged Higgs
  - Charginos
  - Sfermions (stops)
- Only one public code : NMSSMTools (Hugonie, Ellwanger)

...but some of the loop contributions have been omitted in NMSSMTools

$H \to \gamma Z$: with SloopS

- A code for the calculation of loop diagrams in SUSY (Boudjema, Baro, Semenov, Chalons)
- Lanhep : specification of the model and generation of counterterms
- FeynArts : creation of topologies of loops
- FormCalc/LoopTools : computation of loop processes

$H \to \gamma Z$: effect of charginos

- Only diagonal contributions taken into account in NMSSMTools

but the vertex $Z\chi_1\chi_2$ exists

$\to$ negligible contributions ?

- Charginos mass matrix :

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

$$\begin{pmatrix} M_2 & g_2 v_u \\ g_2 v_d & \mu_{eff} \end{pmatrix}$$

- Scan over parameters μ, M_2 and t_β

$H \to \gamma Z$: effect of sfermions

- Contributions of sfermions not taken into account in NMSSMTools
- Stops masses can be sufficiently light to give non negligible contributions

$$\begin{pmatrix} m_{U_3}^2 + h_t^2 v_u^2 - (v_u^2 - v_d^2)\frac{g_1^2}{3} & h_t(A_t v_u - \mu_{eff} v_d) \\ h_t(A_t v_u - \mu_{eff} v_d) & m_{Q_3}^2 + h_t^2 v_u^2 + (v_u^2 - v_d^2)\left(\frac{g_1^2}{12} + \frac{g_2^2}{4}\right) \end{pmatrix}$$

- Since ht is big, important mixings between stops

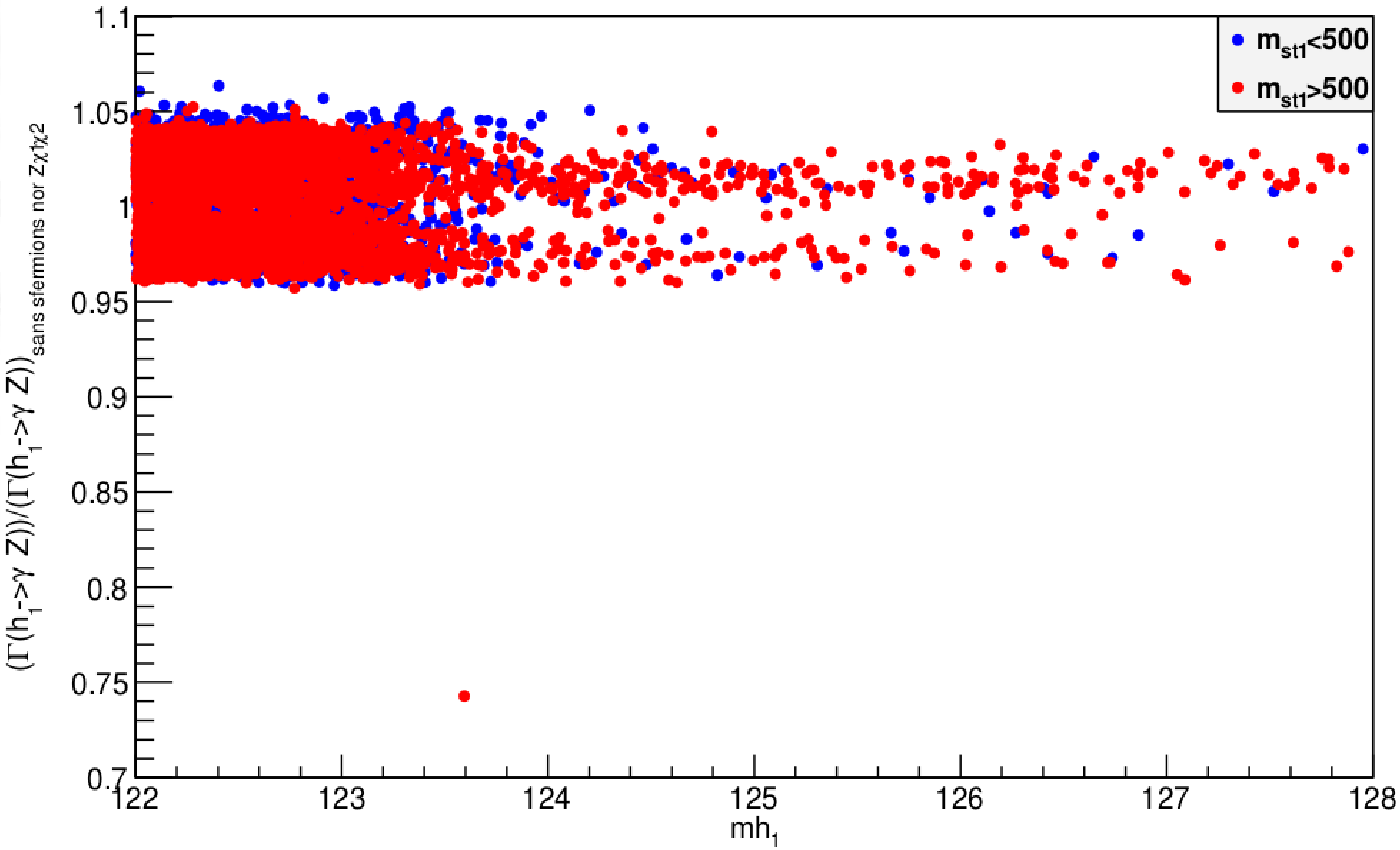
→ Scan also over A_t ,m^2_{U3}, m^2_{Q3}

$H \rightarrow \gamma Z$: Sfermions and charginos

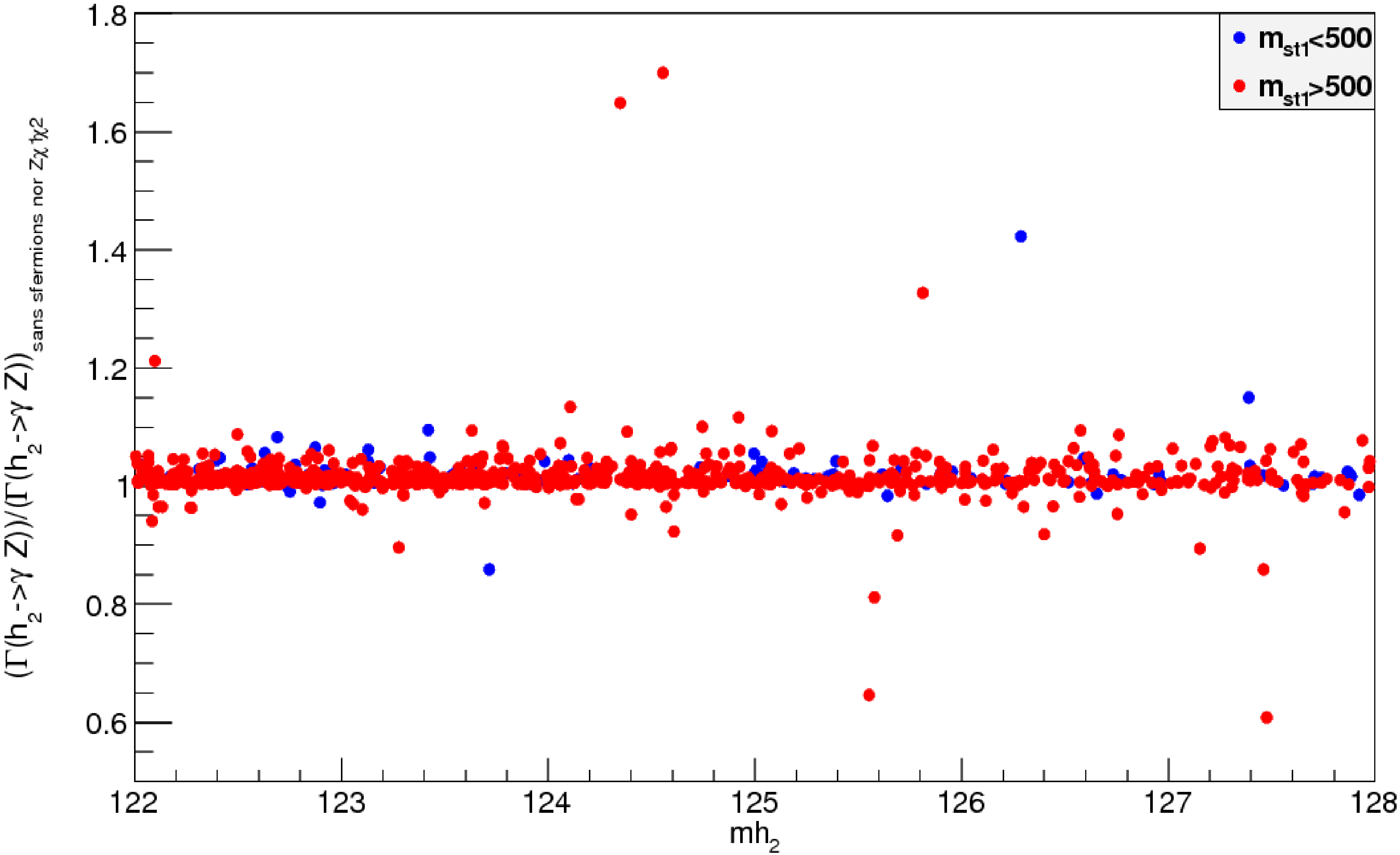
- What happens if we take both effects into account ?
- Is there a compensation, since charginos are fermions and sfermions are scalars ?

$$\frac{\Gamma(h_i \rightarrow \gamma Z)_{\text{with } Z\chi_1\chi_2 \text{ and sfermions}}}{\Gamma(h_i \rightarrow \gamma Z)_{\text{without } Z\chi_1\chi_2 \text{ nor sfermions}}}$$

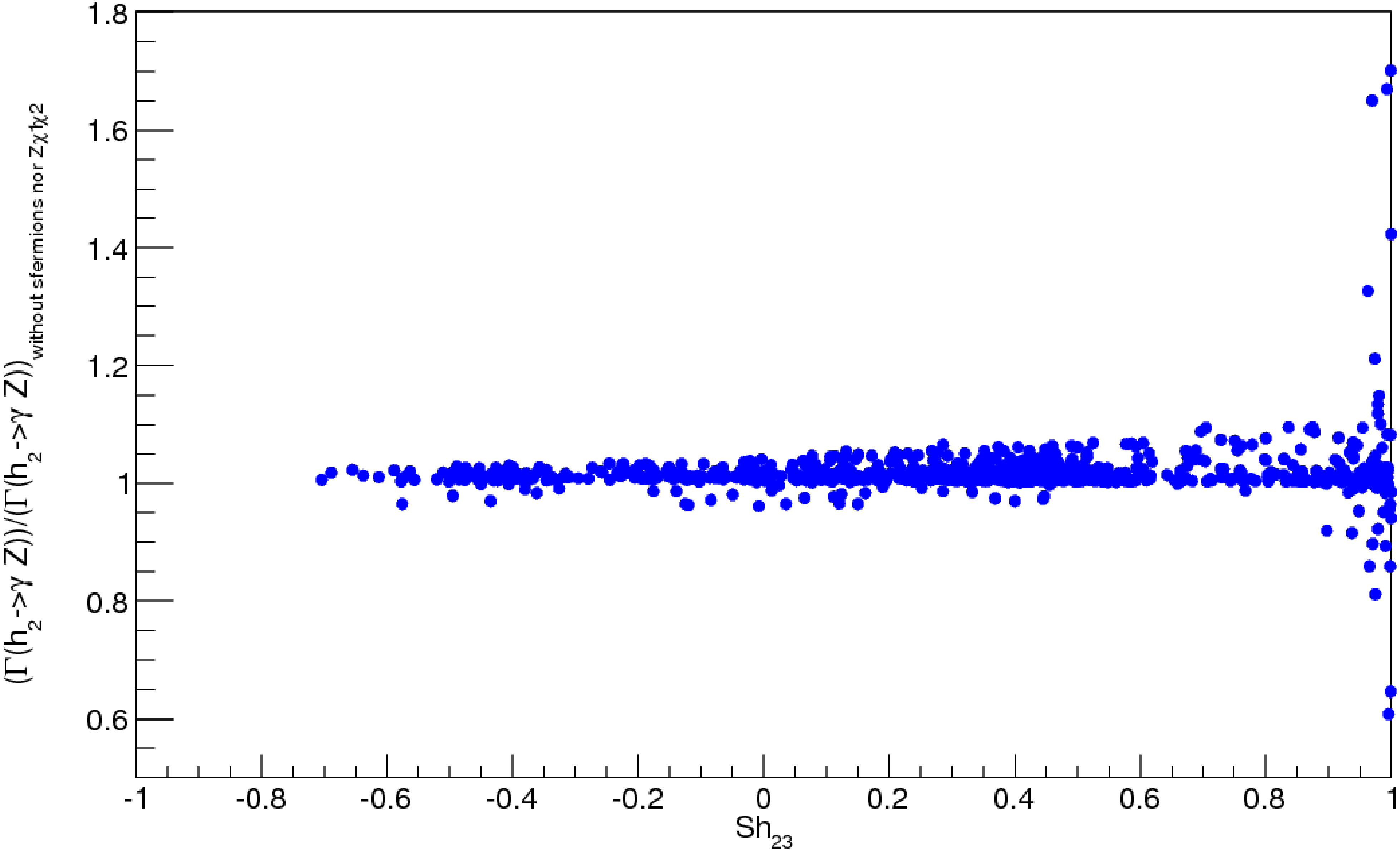
$H \to \gamma Z$: Sfermions and charginos



$H \rightarrow \gamma Z$: Sfermions and charginos



H→γZ : Sfermions and charginos



Conclusion

- The effect is quite small (<10%), except when the Higgs boson is predominantly singlet
  - → In this case the partial width is suppressed.
- Theoretical imprecision lower than experimental one (at least for LHC)
  - → we don't really need to take these effects into account... for the moment !

Questions ?