FRANZINI fest
Frascati, May 30, 2013

HAPPY BIRTHDAY
PAOLO !!

LHC: WHERE ARE WE ??

Luciano Maiani
CERN and La Sapienza

Figure 2: Paolo and Juliet in 1966, with Charles Baltay, Lawrence Kirsch and the IBM 7090.

Enters Cabibbo

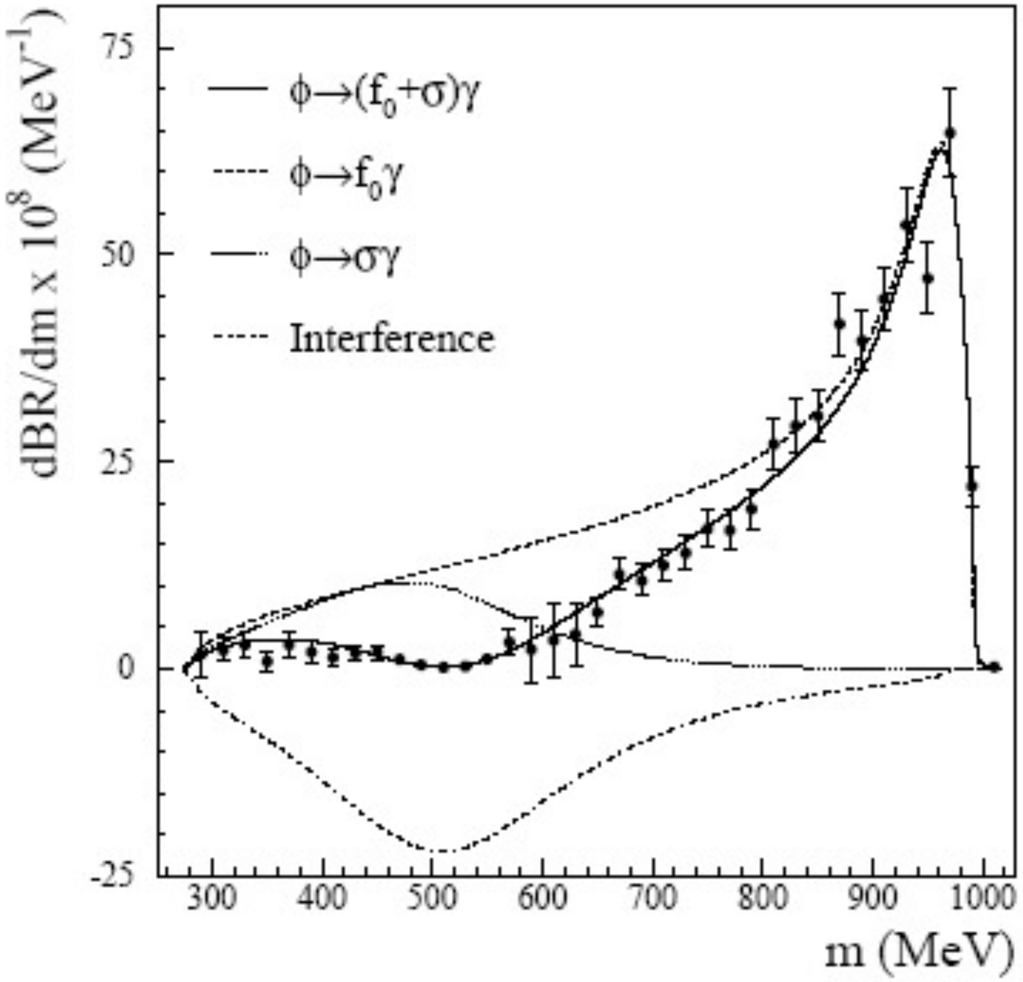
- In his 1963 paper, Nicola made a few decisive steps.
- he decided to ignore the evidence for a $\Delta S = -\Delta Q$ component (the fact that P. Franzini had a larger statistics without any such event was crucial);

a single event: $\Sigma^+ \rightarrow \mu^+ + n + \nu$ had been reported in an emulsion experiment, Barbaro Gualtieri et al. PRL (1962)

- he ignored also the problem of the normalization of non-leptonic processes and of the I=1/2 enhancement;
- he formulated a notion of universality between the *leptonic current* and *one, and only one hadronic current*, a combination of the SU(3) currents with $\Delta S=0$ and $\Delta S=1$: the hadronic current has to be *equally normalized* to the lepton current.
- Axial currents are inserted via the V-A hypothesis.

My collaboration with Paolo in the winter of 1962-63 had an invaluable impact on the development of my own work [7)] on the universality of weak interactions, both for his encouragement "Nicola, why don't you do something fundamental?", and for the many discussions we had on his work that kept me focused on the problem posed by the low rates of the hyperon leptonic decays.

Nicola Cabibbo, *The Physics of Paolo Franzini* , Frascati 2006.



$\phi(1020) \to \pi^0\pi^0\gamma$

Study of the Decay $\phi(1020) \to \pi^0\pi^0\gamma$ with the KLOE Detector
The KLOE Collaboration
arXiv:hep-ex/0204013 Apr 2002

Fit results using f_0 only, Fit (A), and including the σ, Fit (B).

	Fit (A)	Fit (B)
χ^2/ndf	$109.53/34$	$43.15/33$
M_{f_0} (MeV)	962 ± 4	973 ± 1
$g^2_{f_0 K^+K^-}/(4\pi)$ (GeV^2)	1.29 ± 0.14	2.79 ± 0.12
$g^2_{f_0 K^+K^-}/g^2_{f_0 \pi^+\pi^-}$	3.22 ± 0.29	4.00 ± 0.14
$g_{\phi\sigma\gamma}$	—	0.060 ± 0.008

$$M_\sigma = (478^{+24}_{-23} \pm 17)\ \text{MeV}$$

$$\Gamma_\sigma = (324^{+42}_{-40} \pm 21)\ \text{MeV}$$

Heavy flavours

Hidden charm:

$$[cq][\overline{c}\overline{q}] = 8 + 1$$

charmonium octet(??)+singlet . Possible decays:

$$a_c(I=1) \text{®}\ \eta_c + \pi$$

$$f_c(I=0) \text{®}\ (D\overline{D})_{below-threshold?} \text{®}\ \pi\pi, K\overline{K}$$

Open charm:

$$[cq][\overline{q}\overline{q}] = \overline{3} + 6 \text{®}\ D + M$$

Really spectacular signatures.

now seen:
hidden charm, neutral, positive parity, e.g. 1^+ (X)
hidden charm, neutral, negative parity, e.g. 1^- (Y)
hidden charm, charged, positive parity, e.g. 1^+ (Z)
similar states with hidden beauty

Views for the Future of CERN

Symposium to celebrate the discoveries of Neutral Currents (1973) and of W&Z (1983)
CERN, Geneva, September 16, 2003

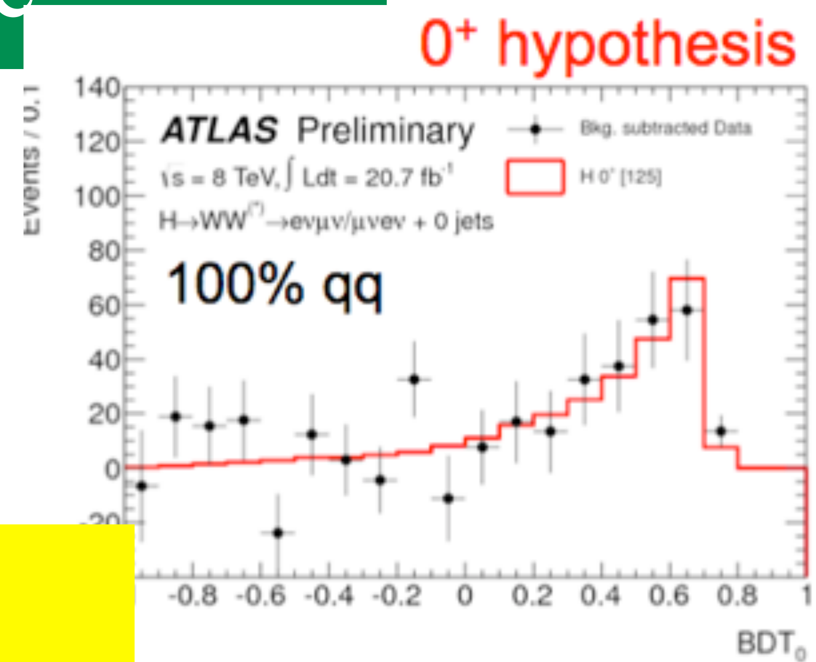
- In a way, it is a trivial question…CERN's future is the LHC:
  - –Commissioning 2007;
  - –Physics: 2007- 2022 (at least);
  - –Consolidation programme
  - –Luminosity upgrade can prolong LHC lifetime and extend its discovery potential by 15-30% in mass;
  - –Energy upgrading rather costly and further in the future, as it requires the development of new high field magnets (Nb3Sn?15 Tesla ?).

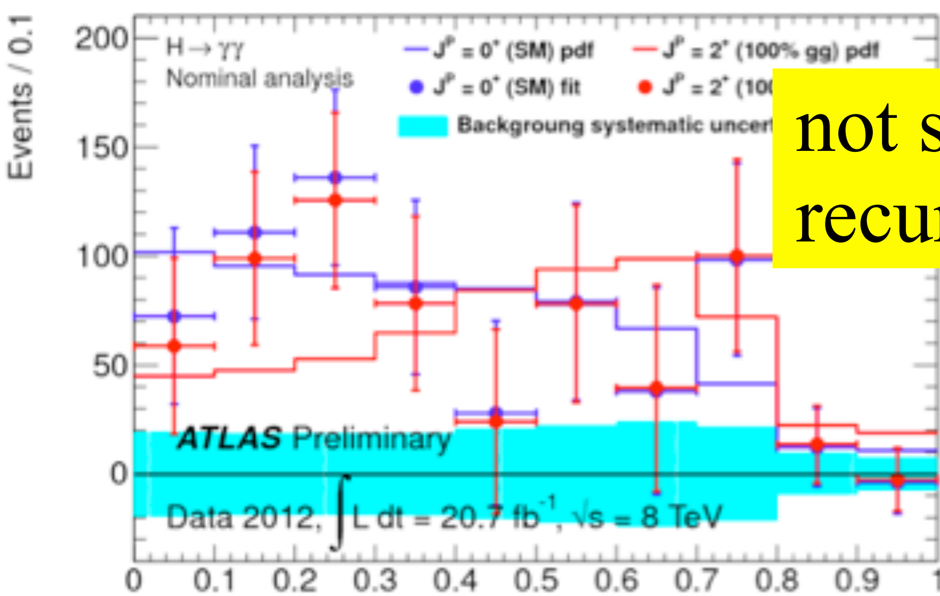
} Some resources available in CERN plan.

- However:
  - –Important HEP physics problems and corresponding scientific communities are not addressed by the LHC
  - –Diversification is needed
  - –e+ e - Linear Collider (subTeV): TESLA/NLC/JLC ?
  - –Discussion must start now

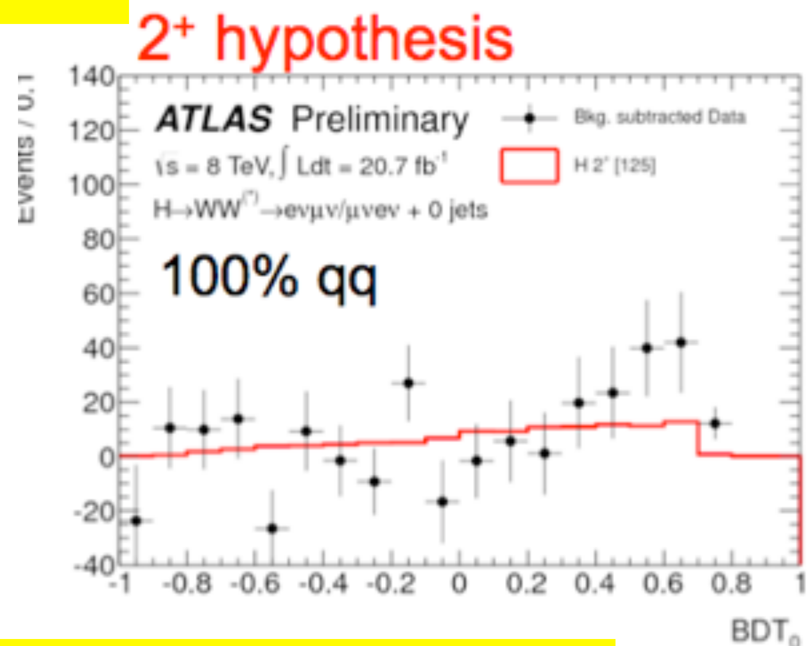
1. The 125 GeV particle

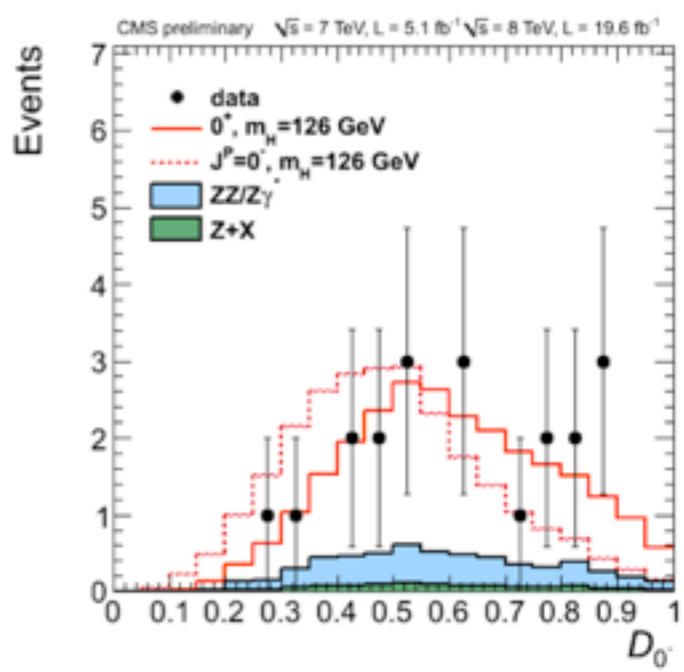
- Not spin 1 (decays into 2γ)
- Most likely 0^+

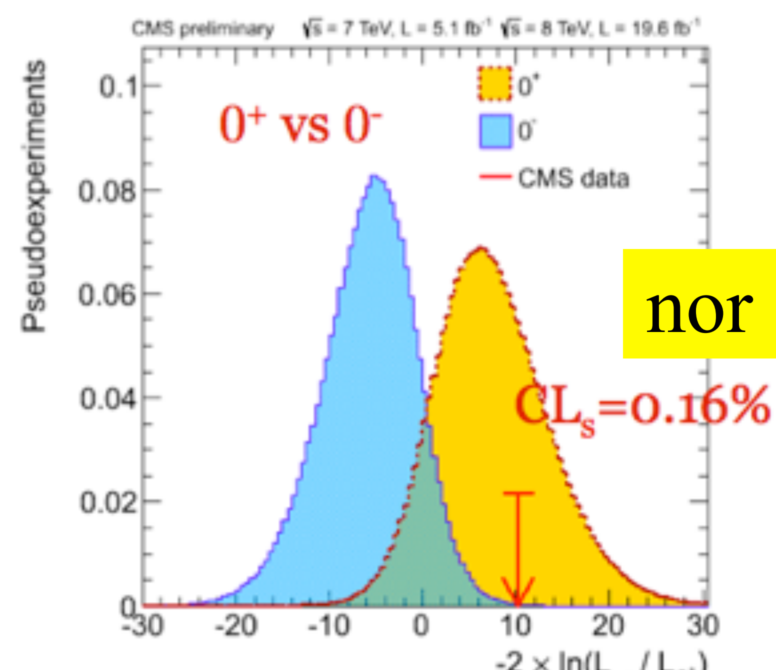




not spin 2+ (Kaluza Klein recurrence of the graviton?)

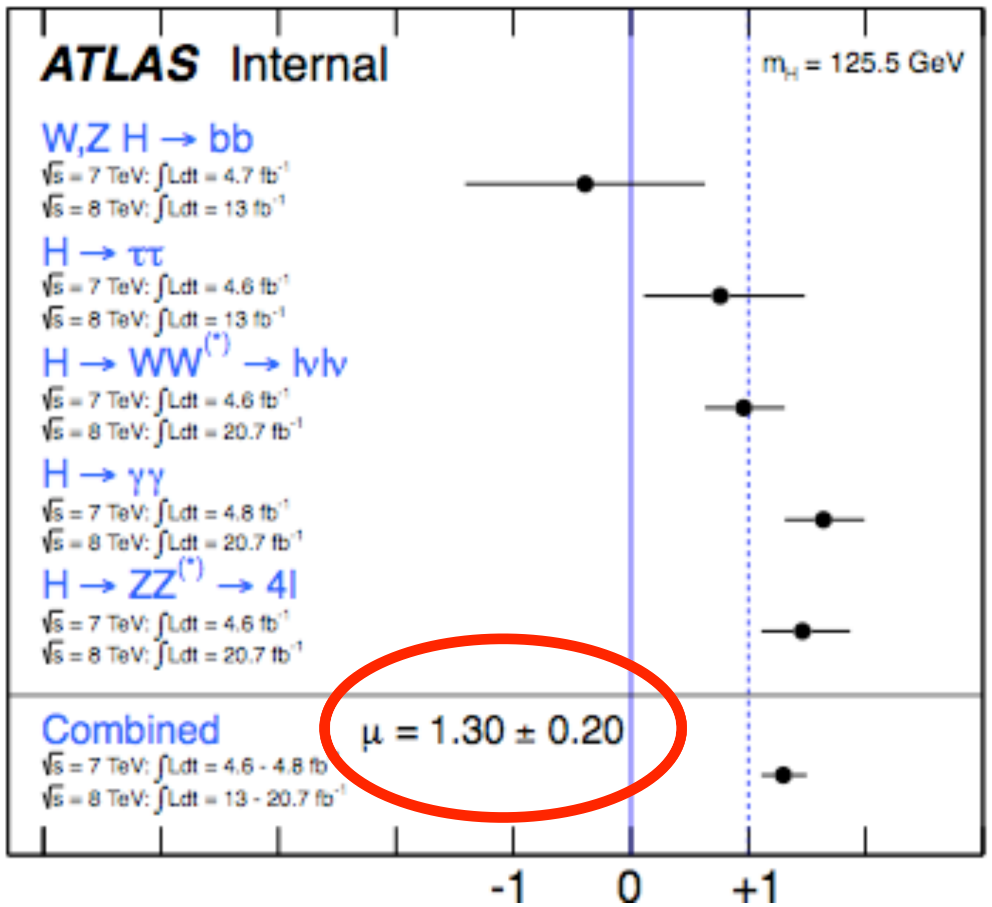




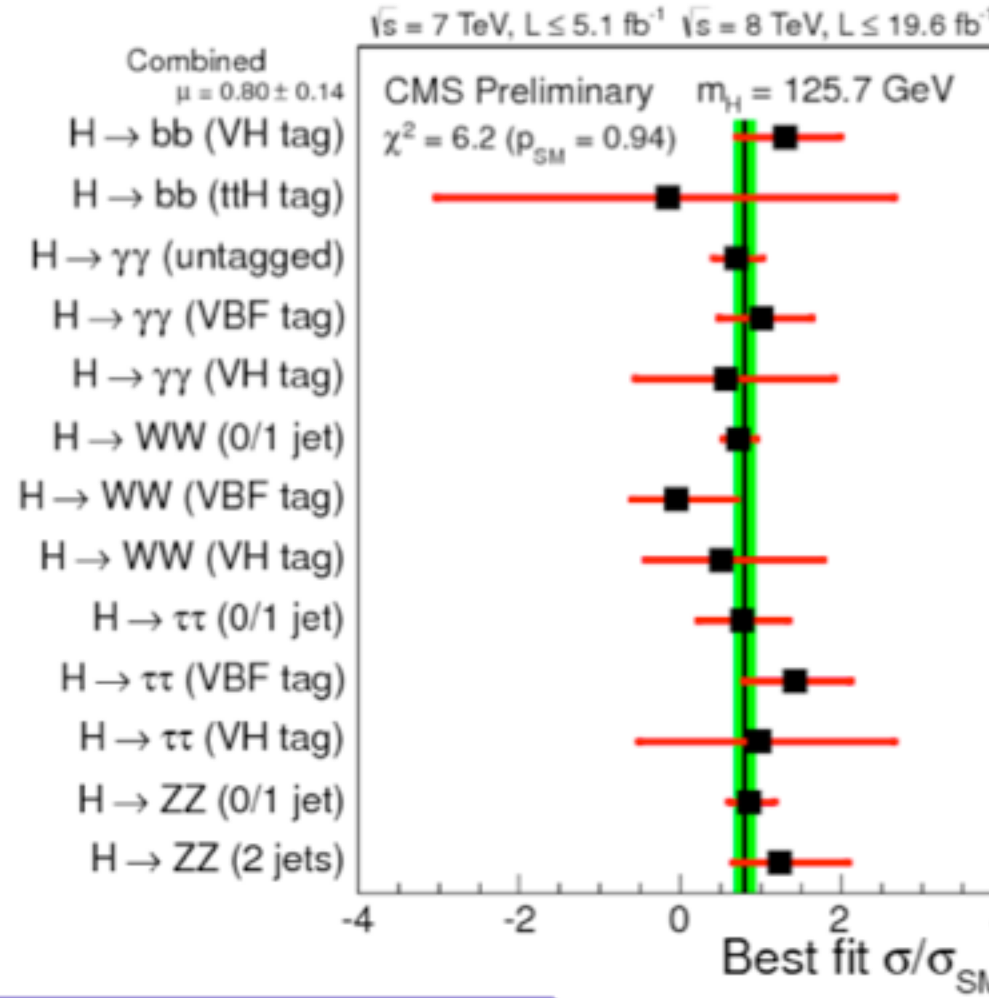


nor spin 0^- (Technipion?)

It smells like the Higgs boson



ATLAS NOTE, March 4, 2013



$\mu = 0.80 \pm 0.14$

CMS PAS HIG-13-005:

Small variations may be there, possible indications of New Physics beyond the ST: SUSY?composite? other ???

SUSY may still be the best contender.

2. The message in the mass

A famous inequality of SUSY:

$$M_h^2 \le M_Z^2 \rightarrow_{(\text{rad. corr.})} M_h^2 \approx \cos^2(2\beta) M_Z^2 + \delta$$

- Can we make δ so as to reproduce 125 GeV?
- A nice formula for δ (M. Carena, S. Gori, N. R. Shah, C. E. M. Wagner, JHEP 1203, (2012), 014, arXiv:1112.3336 [hep-ph]):

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\frac{1}{2}\tilde{X}_t + t + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{v^2} - 32\pi\alpha_3\right)\left(\tilde{X}_t t + t^2\right)\right],$$

where

$$t = \log\frac{M_{\rm SUSY}^2}{m_t^2}.$$

The parameter $\tilde{X}_t$ is given by

$$\tilde{X}_t = \frac{2\tilde{A}_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{\tilde{A}_t^2}{12 M_{\rm SUSY}^2}\right),$$

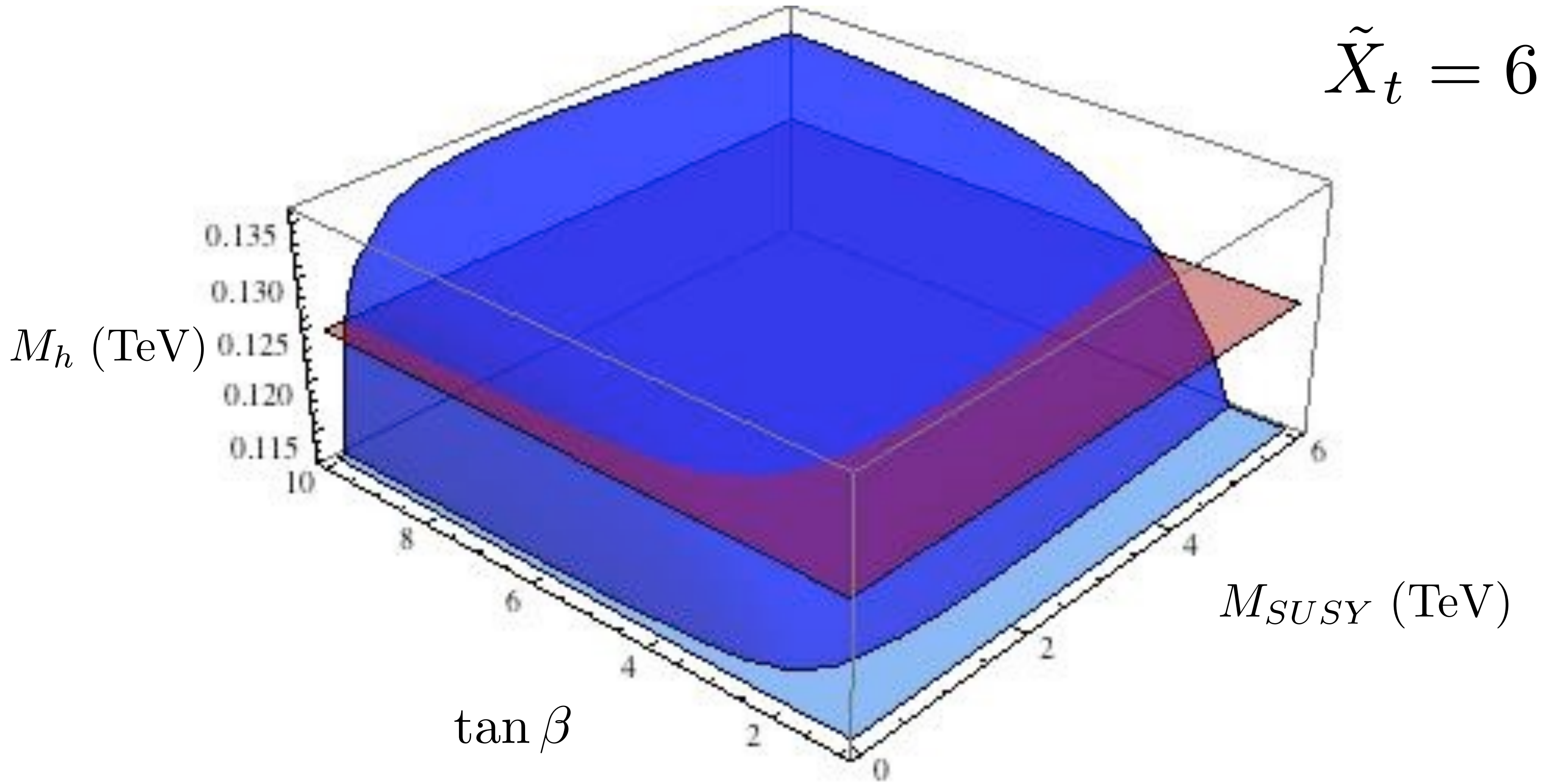
$$\tilde{A}_t = A_t - \mu\cot\beta\,,$$

$$M_{SUSY}^2 = M_{stopL} \times M_{stopR}$$

$$\tilde{X}_t \le 6$$

- leading top/s-top contributions, of $O(y_t^4)$
  - neglected terms $O(g^2\, y_t^2) \approx 20\%$ of the leading ones
  - neglected even smaller s/s-b contr'btns.

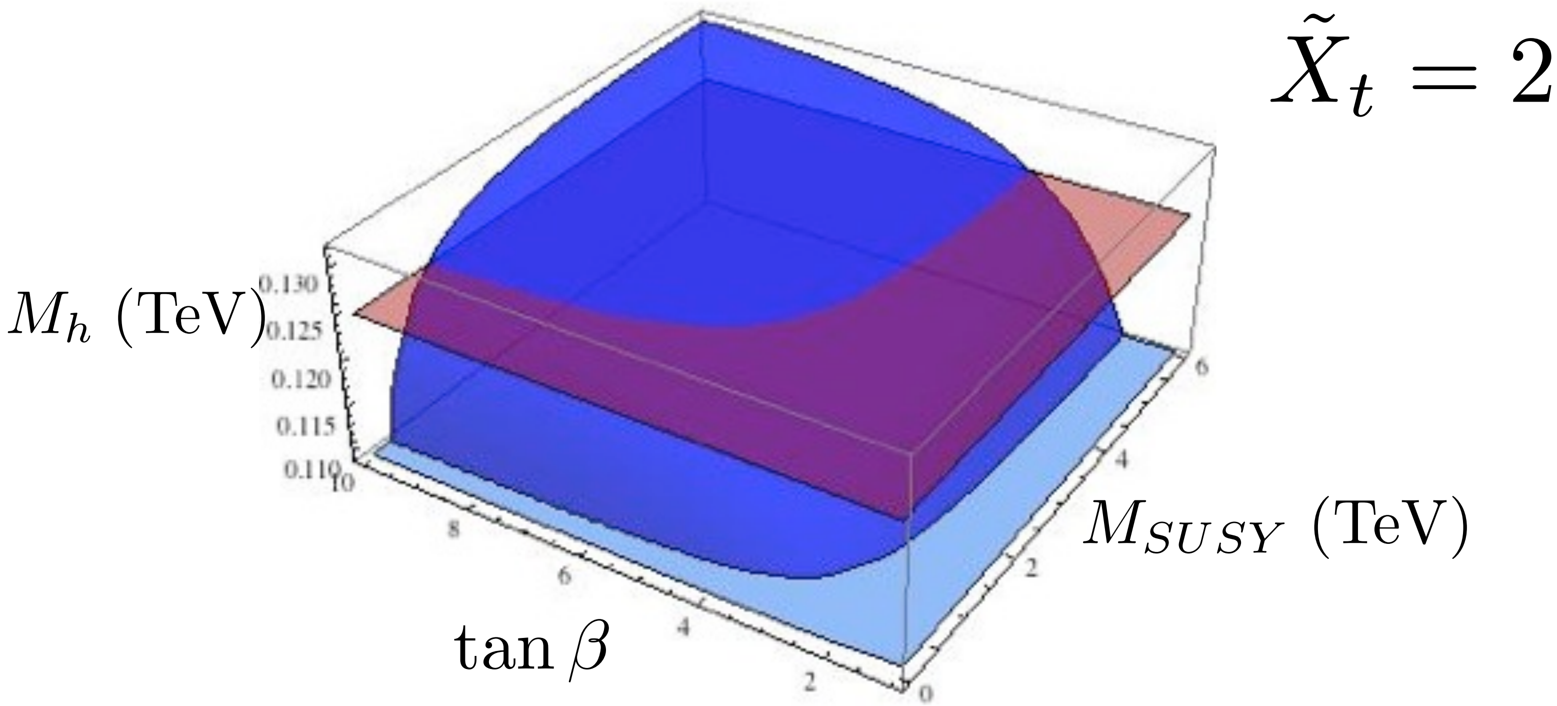
Reproducing 125 in MSSM

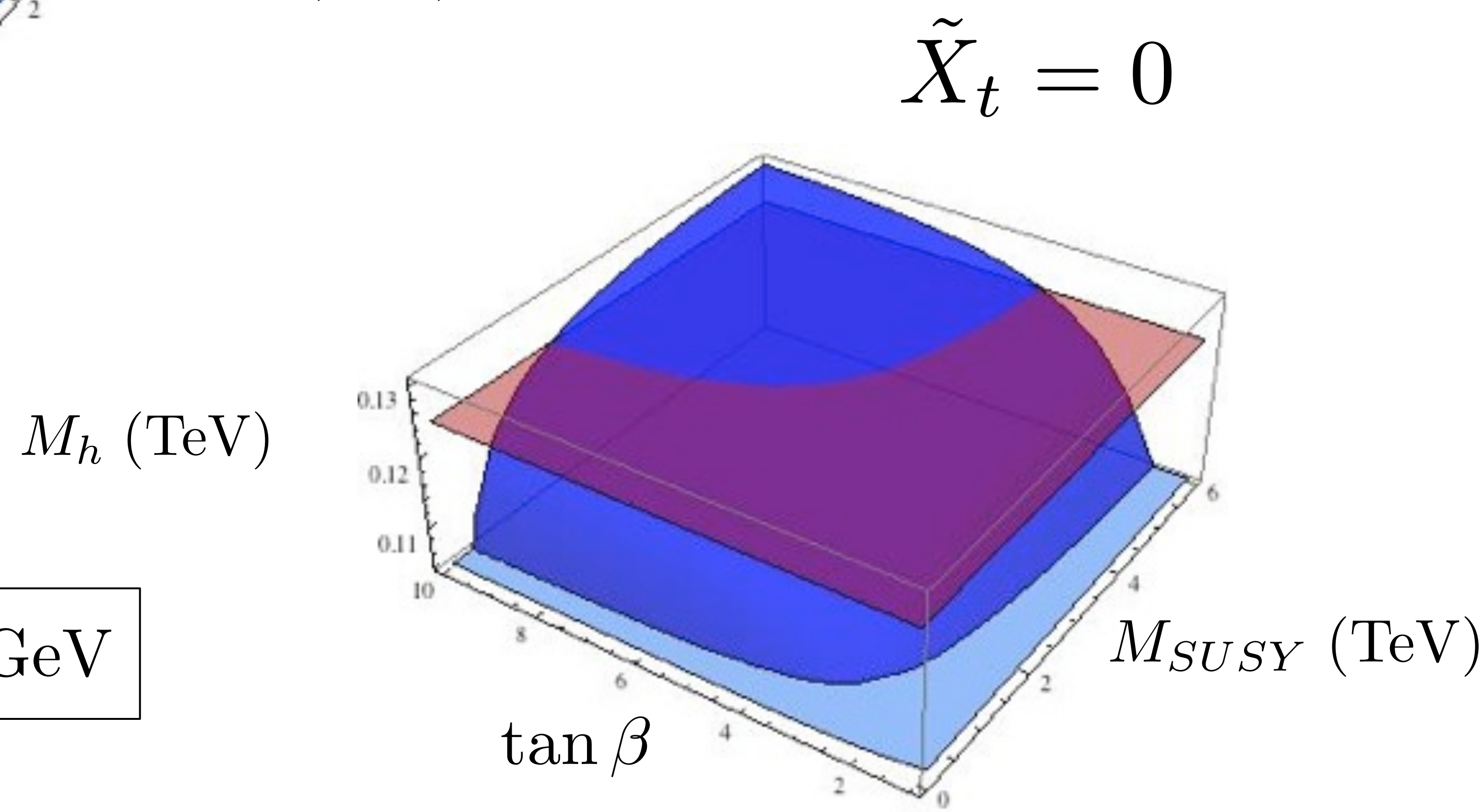


- maximal mixing assumed, X_t=6;
- requires tan β ⩾ 4;
- the branch with high stop mass goes rapidly into the few TeV region
-a relatively light stop, with tan β ≈ 10 considered in:

A. Delgado, G. F. Giudice, G. Isidori, M. Pierini, A. Strumia, arXiv:1212.6847 [hep-ph]

The role of mixing





$$M_h^2 \approx \cos^2(2\beta)M_Z^2 + \delta \leq 135\text{GeV}$$

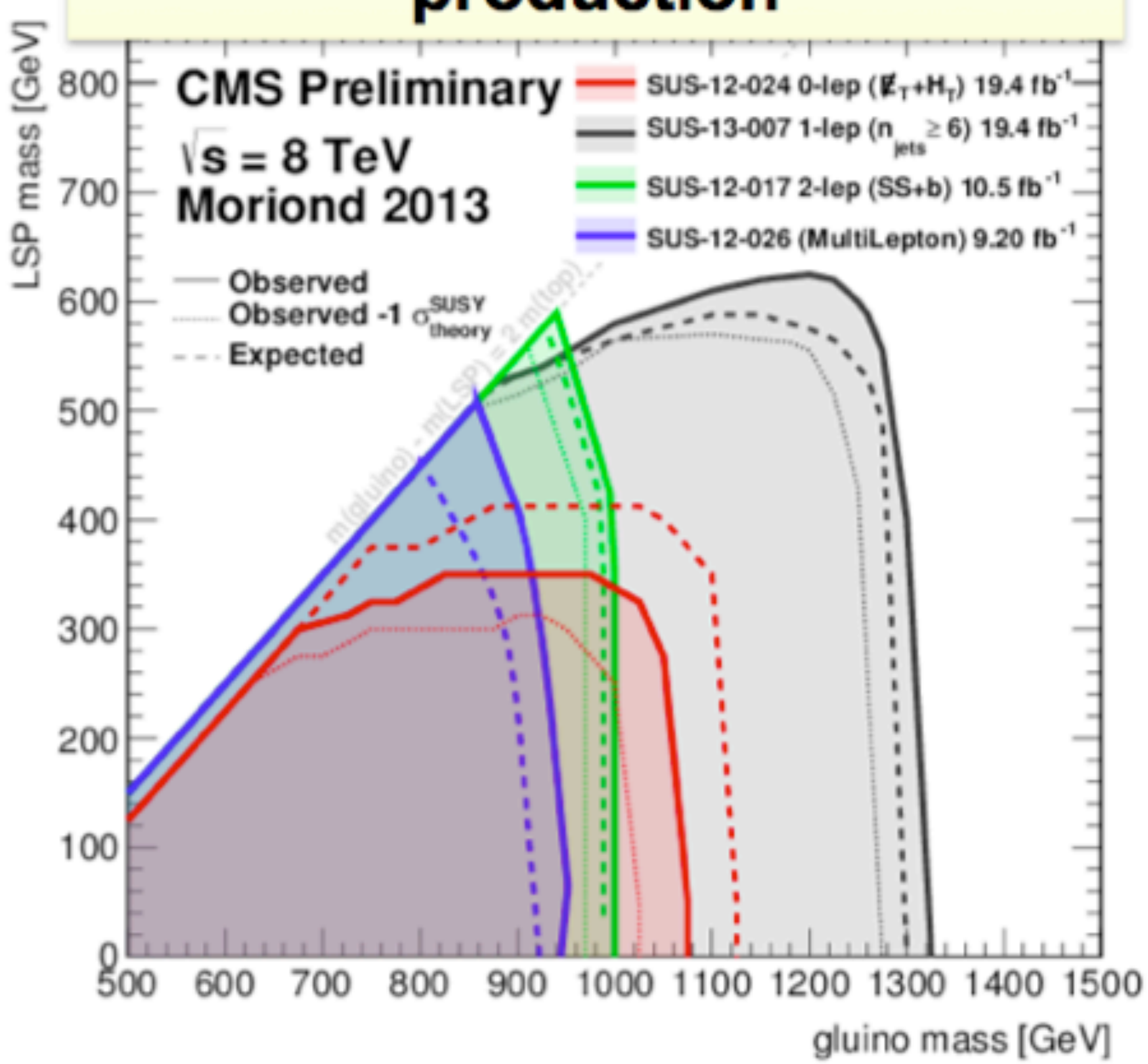
The mass of h speaks for SUSY

Admittedly, No SUSY partners in sight

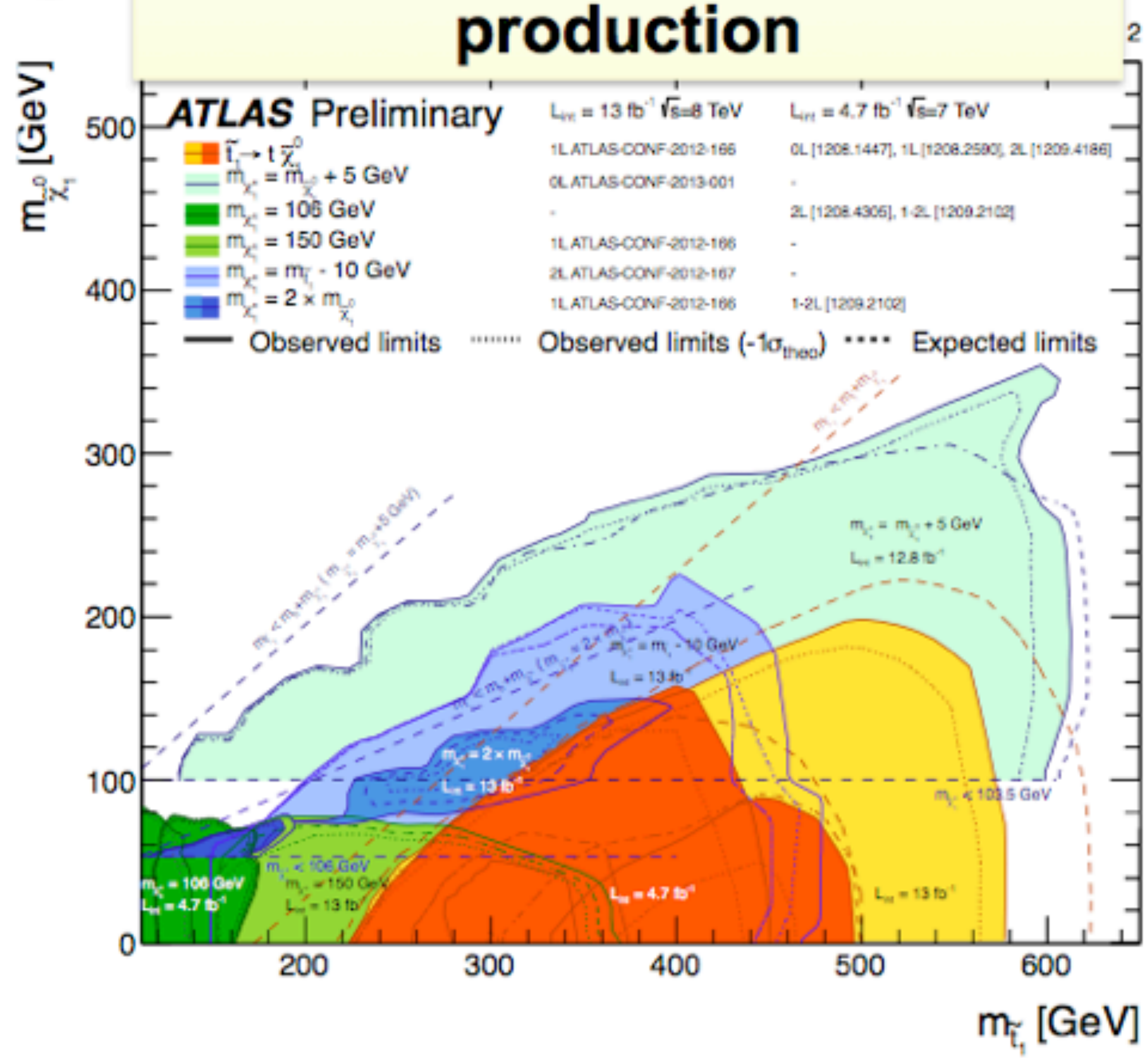
If gluino light enough:
→ gluino induced production

If third-generation squarks light enough:
→ direct production

CMS gluino-induced stop production



ATLAS direct stop production



3. FCNC and new physics at Tev scale

- A light Brout-Englert-Higgs scalar boson in the ST calls for new physics (NP) at TeV scale: SUSY, Composite Higgs, etc.;
- the new particles most likely carry flavor and will potentially add new FCNC effects: this is the so-called *flavor problem*.
- let's write, for example

$$\mathcal{L}_{eff}(d\bar{s} \to \bar{d}s) =$$
$$= -\frac{G_F^2 M_W^2}{16\pi^2} \times \sum_{i,j=c,t} (U_{id}^* U_{is})(U_{jd}^* U_{js}) E(x_i, x_j) \times \left(\bar{d}s\right)_{V-A} \left(\bar{d}s\right)_{V-A} +$$
$$+ \begin{pmatrix} +\frac{1}{\Lambda^2} \\ \\ +\frac{c_S}{\Lambda^2} \end{pmatrix} \left(\bar{d}s\right)_{S,P} \left(\bar{d}s\right)_{S,P}$$

Standard Theory

New Physics at larger scale ?

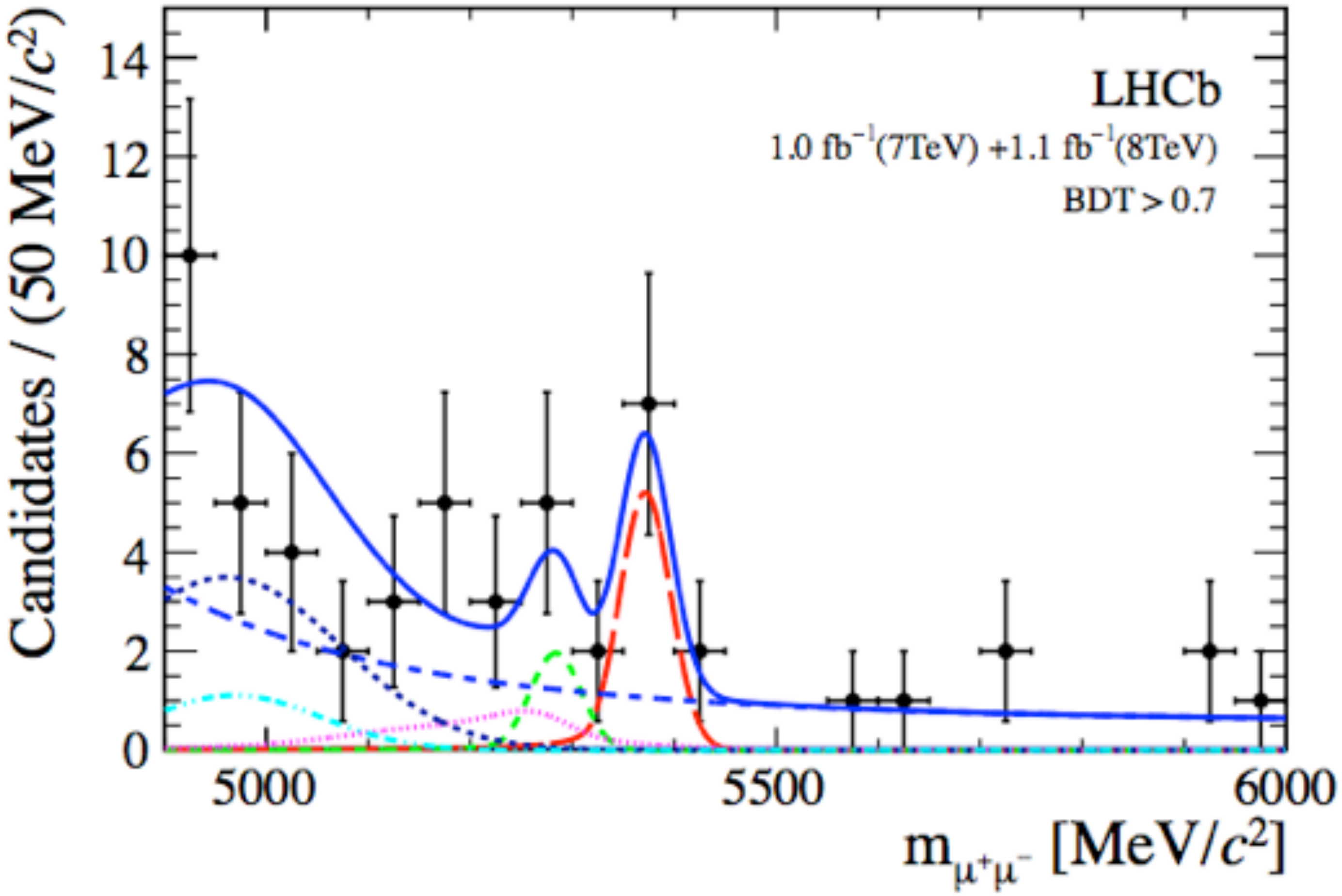
- |NP|<|ST| ➩ very large Λ

Operator	Bounds on Λ in TeV ($c_{\rm NP}=1$) Re	Im	Bounds on $c_{\rm NP}$ ($\Lambda = 1$ TeV) Re	Im	Observables
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{b}_L\gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	2.3×10^{-6}	1.1×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	3.9×10^{-7}	1.9×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L\gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	5.0×10^{-5}	1.7×10^{-5}	Δm_{B_s}; $S_{\psi\phi}$
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	8.8×10^{-6}	2.9×10^{-6}	Δm_{B_s}; $S_{\psi\phi}$

Table 1.1: Bounds on representative dimension-six $\Delta F = 2$ operators, assuming an effective coupling $c_{\rm NP}/\Lambda^2$.

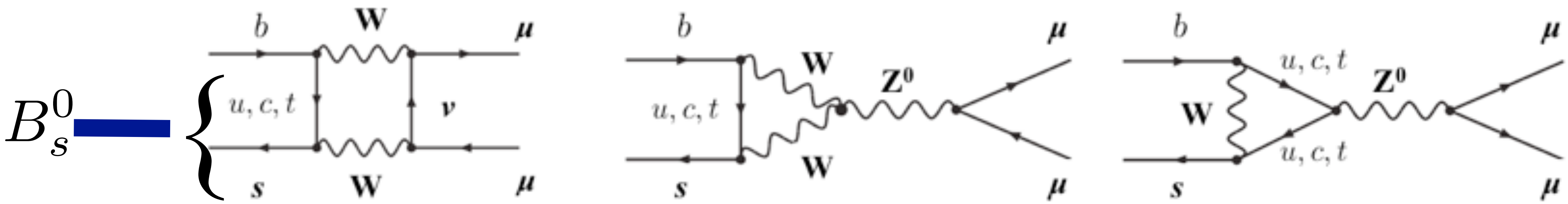
•Isidori, 2012 CERN HEP Summer School, arXiv:1302.0661v1 [hep-ph]

News from $B_s \to \mu^+\mu^-$



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2\,^{+1.4}_{-1.2}(\text{stat})\,^{+0.5}_{-0.3}(\text{syst})) \times 10^{-9}$$

$$\text{ST prediction}: (3.53 \pm 0.38)\ 10^{-9}$$



see e.g. Buchalla, Buras, Lautenbacher, 1995

FCNC (cont'd)

- New Physics cannot be couple to flavor generically; many insights and many interesting papers (see G. Isidori@CERN School 2012)
- Minimal Flavor Violation: *Yukawa couplings are the only source of flavor symmetry violation*
  - Chivukula and Georgi, *Composite Technicolor Standard Model*, PL **B188** (19879
  - D'Ambrosio, Giudice, Isidori and Strumia, Minimal flavor violation: *An Effective field theory approach*, NP **B 645** (2002) 155 [hep-ph/0207036]
  - applies to technicolor (preon masses) and SUSY (SUSY breaking flavor blind)
  - effects of NP at low energy which break flavor will to come mostly with the same CKM suppressions we see in ST, perhaps with small variations to be detected in precision experiments.
- Are Yukawa couplings the VEVs of new fields? If so, Yukawa couplings can be determined by a variational principle, i.e. by the minimum of a new hidden potential
  - an idea pioneered by Froggat & Nielsen, arXiv:hep-ph/9905445;
  - recent applications to neutrino masses and mixing by B. Gavela and coll. (and work in progress by Alonso, Gavela, Isidori, LM)

CMSSM, $B_s \to \mu^+\mu^-$

- The Constrained MSSM (CMSSM) is a SUSY model which satisfies the principles of Minimal Flavour Violation, thus the limits from FCNC are compatible with a relatively low energy scale for New

Supersymmetric constraints from $B_s \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ observables

F. Mahmoudi[1,2,*] S. Neshatpour[2,†] and J. Orloff[2,‡]

arXiv:1205.1845v1 [hep-ph]

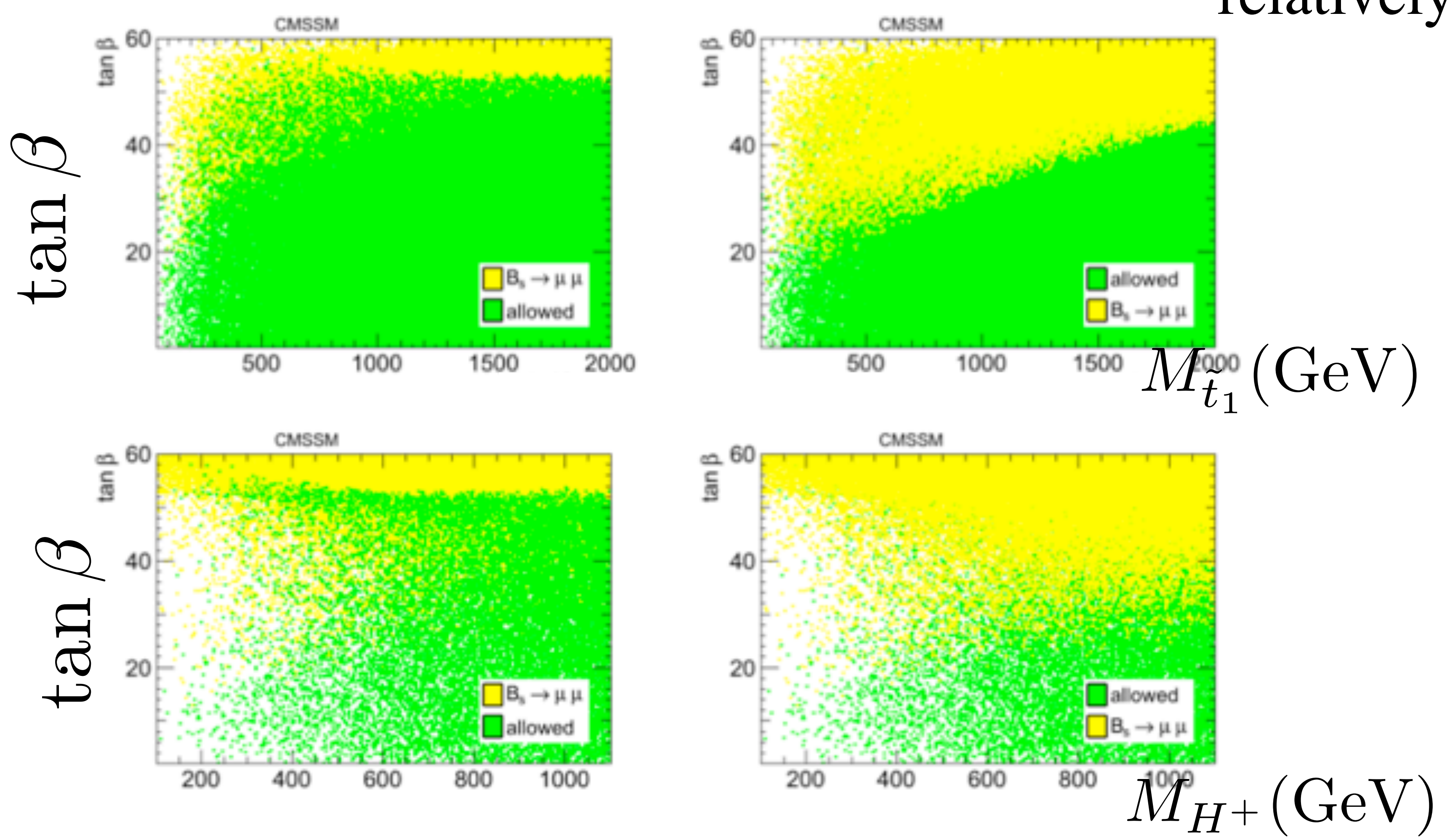


Figure 1: Constraint from BR($B_s \to \mu^+\mu^-$) in the CMSSM plane ($M_{\tilde{t}_1}$, $\tan\beta$) in the upper panel and ($M_{H^\pm}$, $\tan\beta$) in the lower panel, with the allowed points displayed in the foreground in the left and in the background in the right.

4. Probing SUSY in the Higgs sector

L. Maiani, A.D. Polosa , V. Riquer, New J. Phys. **14** (2012) 073029.

•Two Higgs doublets required (Dimopoulos & Giorgi): H_u, H_d

$$\langle 0|H_u^0|0\rangle = v\sin\beta;\quad \langle 0|H_d^0|0\rangle = v\cos\beta;\quad 0 < \tan\beta < +\infty$$

$$v^2 = (2\sqrt{2}G_F)^{-1} = (174\ \mathrm{GeV})^2$$

Physical H bosons: $h:\ 125\ \mathrm{GeV}$

$H,\ A,\ H^{\pm}\ \ ???$

More recent work:
P.Giardino, et al.arXiv:1303.3570 [hep-ph];
A.Djouadi, J.Quevillon,arXiv:1304.1787 [hep-ph];
NMSSM model:
G.~Belanger et al., JHEP **1301**(2013) 069;
R.Barbieri, et al., arXiv:1304.3670 [hep-ph];
Two Higgs Doublets:
B.Grinstein,P.Uttayarat,arXiv:1304.0028 [hep-ph];
O.~Eberhardt et al., arXiv:1305.1649 [hep-ph].

- h, H mass matrix contains M_Z, M_A, $\tan\beta$, δ

$$\mathcal{M}_S^2 = M_Z^2\begin{pmatrix}\cos^2\beta & -\cos\beta\sin\beta\\ -\cos\beta\sin\beta & \sin^2\beta\end{pmatrix} + M_A^2\begin{pmatrix}\sin^2\beta & -\cos\beta\sin\beta\\ -\cos\beta\sin\beta & \cos^2\beta\end{pmatrix} + \begin{pmatrix}0 & 0\\ 0 & \frac{\delta}{\sin^2\beta}\end{pmatrix}$$

- EW interactions control the quartic potential, hence M_Z
- δ embodies the leading radiative corrections related to the top-sector and summarizes all details and variations of the MSSM (see Sect.2);
- absence of the b-sector contribution: a very mild assumption for tan β<10 (see later);
- ***with M_h=125 GeV, we can obtain $\delta = \delta(M_A, \tan\beta)$ and determine all quantities in the Higgs sector as function of M_A, tan β, or M_H, tan β.***

Mixing coefficients and couplings

Mixing coefficients depends upon: (M_A, tan β), or (M_H, tan β)

$$|h>=\sum_i S_{hi}|H_i>, \quad |H>=\sum_i S_{Hi}|H_i> \quad (i=d,u)$$

	$WW=ZZ$	$t\bar{t}=c\bar{c}$	$b\bar{b}=\tau^+\tau^-$
i=h, H	$\cos\beta\ S_{id}+\sin\beta\ S_{iu}$	$(\sin\beta)^{-1}S_{iu}$	$(\cos\beta)^{-1}S_{id}$

	hZ	$t\bar{t}=c\bar{c}$	$b\bar{b}=\tau^+\tau^-$
A	$\sin\beta\ S_{id}-\cos\beta\ S_{iu}$	$\cos\beta$	$\sin\beta$

SUSY suggests a fit to h data with three couplings, in alternative to the usual c_V, c_F fit:

L. Maiani, A.D. Polosa , V. Riquer, Phys.Lett. **B**718 (2012) 465.

$$c_t(\tan\beta,m_H)=\frac{\sqrt{1+\tan^2\beta}}{\tan\beta}\,S_{hu}(\tan\beta,m_H)$$ (up quarks)

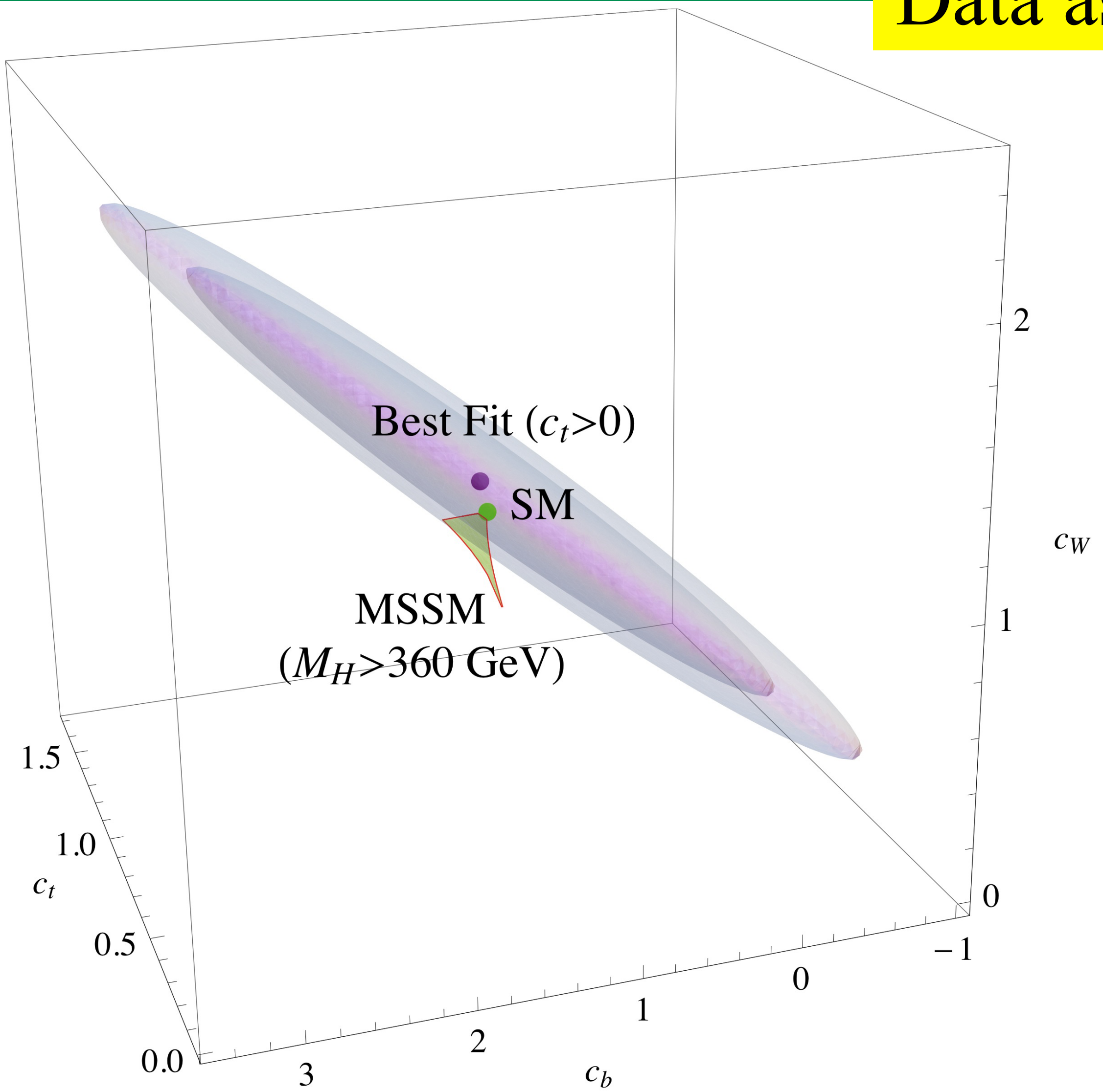
$$c_b(\tan\beta,m_H)=\sqrt{1+\tan^2\beta}\,S_{hd}(\tan\beta,m_H)$$ (down quarks and leptons)

$$c_W(\tan\beta,m_H)=\frac{1}{\sqrt{1+\tan^2\beta}}\,S_{hd}(\tan\beta,m_H)+\frac{\tan\beta}{\sqrt{1+\tan^2\beta}}\,S_{hu}(\tan\beta,m_H)$$ (vector bosons)

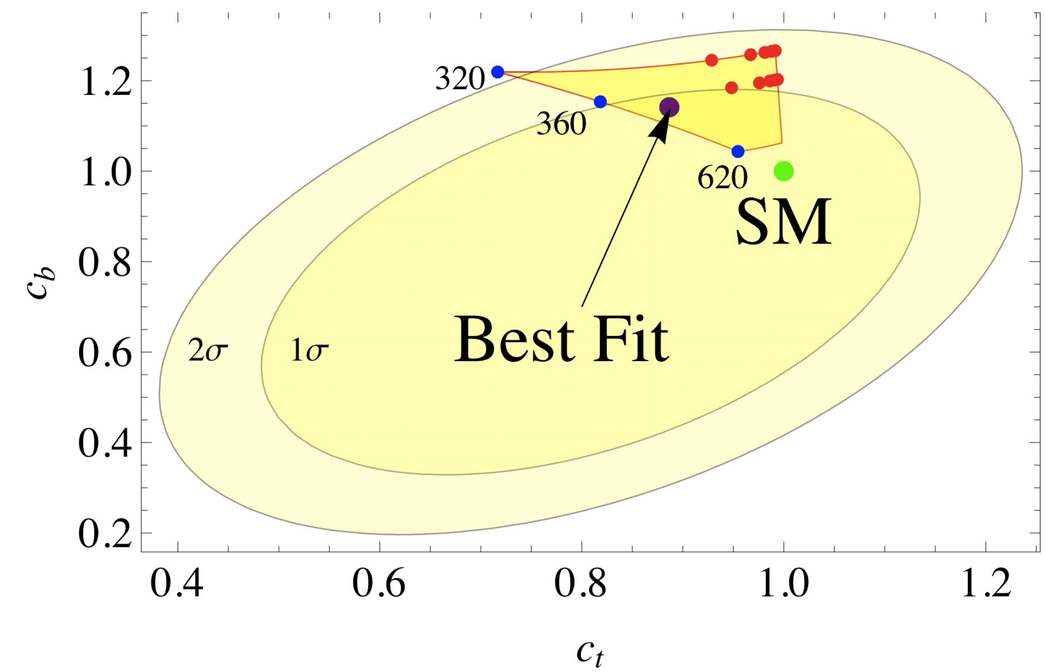
5. Fit to ATLAS & CMS data

Data as of July 4th, 2013

MPR, Phys.Lett. **B**718 (2012) 465.



Intersection of the surface S in the (c_t, c_b, c_W) space, with the 1σ and 2σ regions around the best fit point to ATLAS and CMS data (July 2012)



The surface S in the (c_t, c_b) space at $c_W = 1$. The 1σ and 2σ regions are the intersections of the ellipsoids at $c_t > 0$, with the plane $c_W = 1$. The intersection with the 1σ border corresponds to $M_H = 360$ GeV. Red points mark values of $\tan\beta$ from 1 (lefthand side) to 6 (righthand side)

L. Maiani, A.D. Polosa , V. Riquer, arXiv: 1305.2172 [hep-ph]

- combined fit to the full set of ATLAS and CMS data published in 2013;
- same cuts we had used for the previous data;
- a very encouraging fit:

$$\bar{c}_t = 0.99;\ \bar{c}_b = 1.22,\ \bar{c}_V = 1.11$$

while :

$$c_t = 0.998;\ c_b = 1.20,\ c_V = 1.00 \ @ \tan\beta = 10, M_H = 360\ GeV$$

- the 1-2 sigma regions shrink w.r.t. 2012 data, new limits on H, A and H +/- :

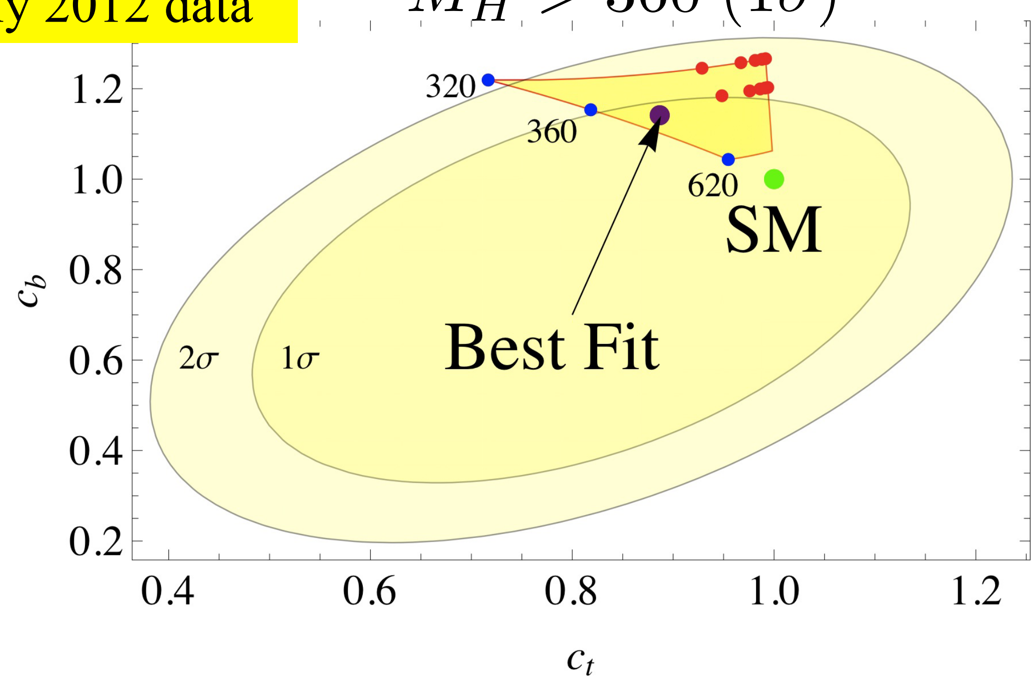
$M_H > 320\ (2\sigma)$

$M_H > 360\ (1\sigma)$

$M_H > 340\ (2\sigma)$

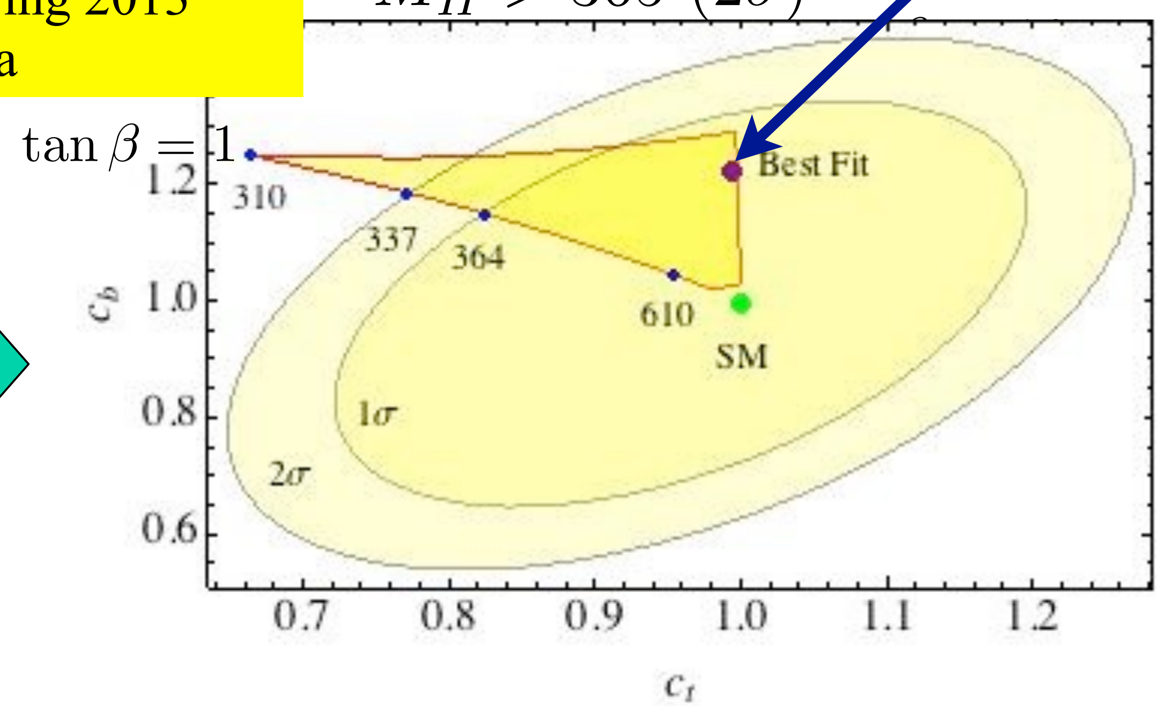
$M_H > 365\ (2\sigma)$

July 2012 data

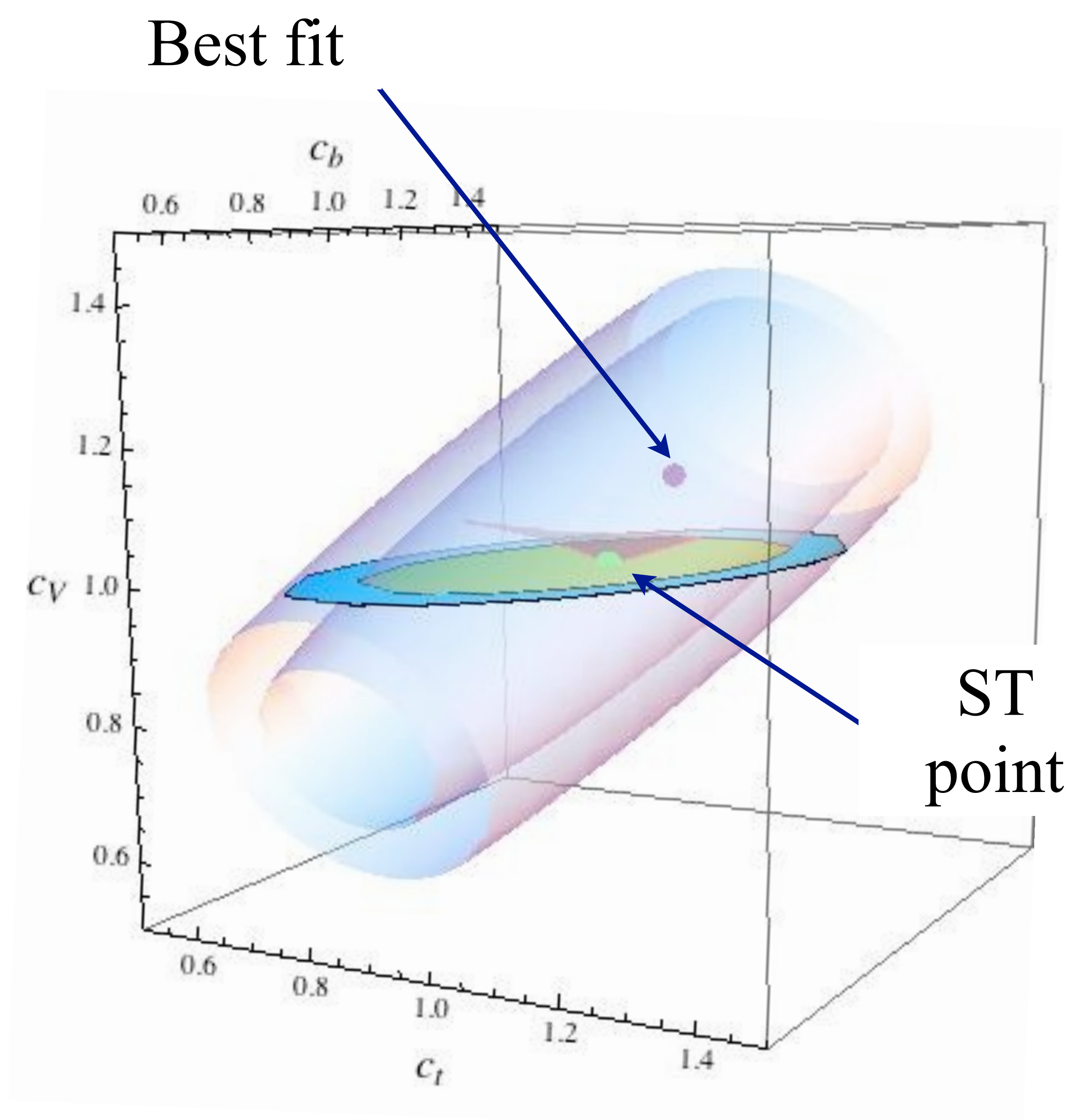


Spring 2013 data

Best Fit



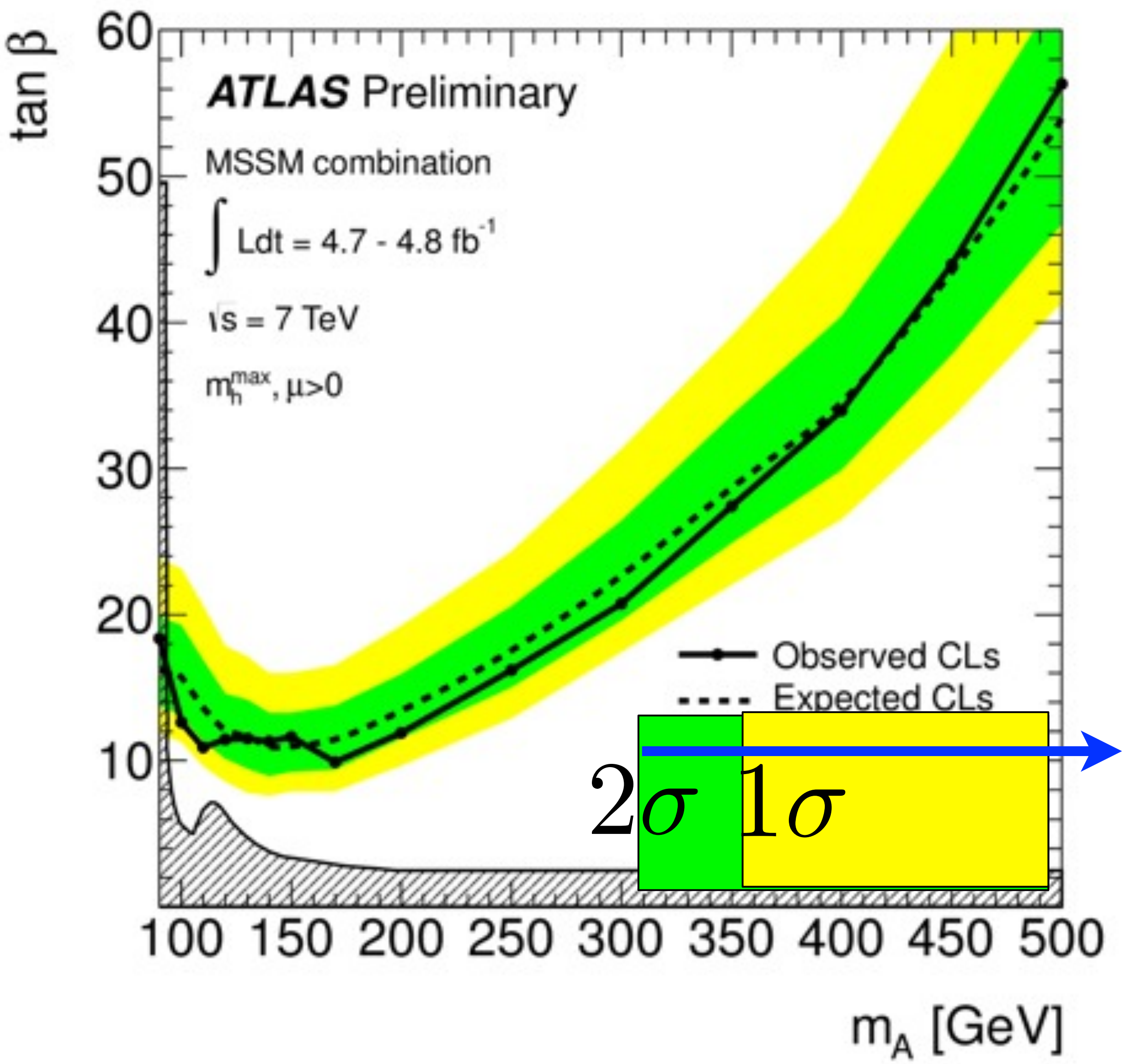
A view in 3D

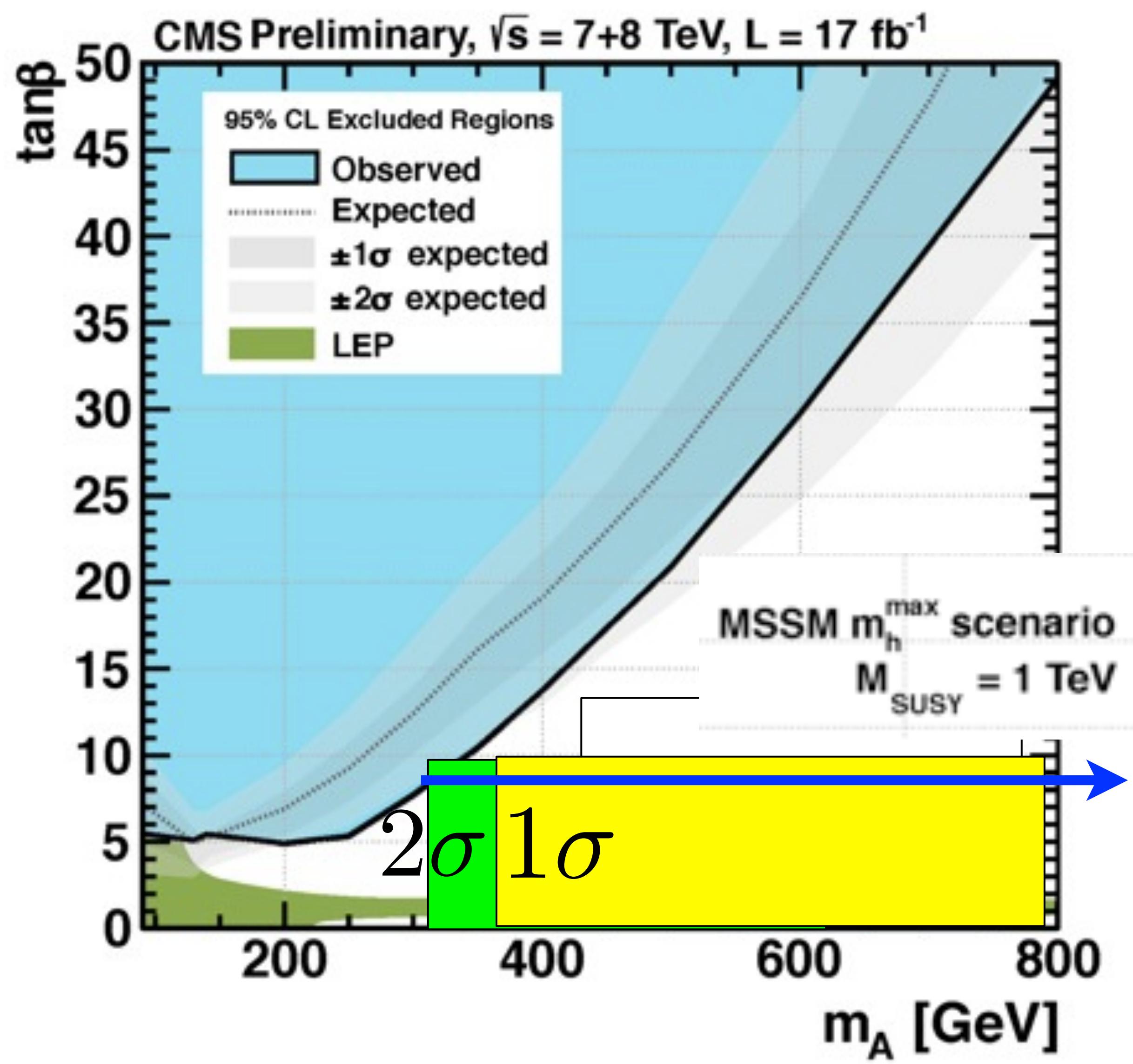


Best fit
c_b
0.6 0.8 1.0 1.2 1.4
c_V
1.4
1.2
1.0
0.8
0.6
0.6 0.8 1.0 1.2 1.4
c_t
ST point

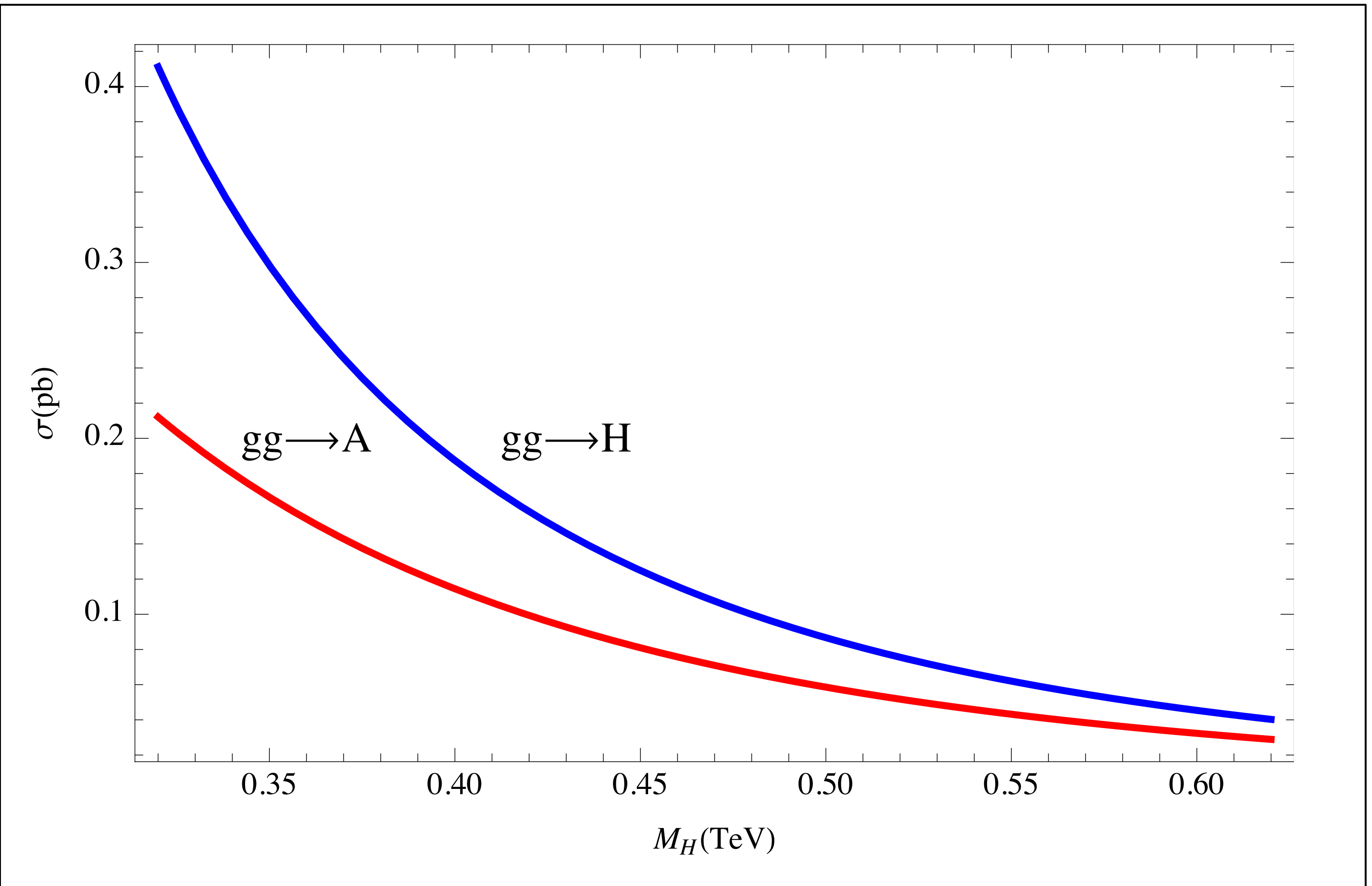
Present Experimental limits

Exclusion region of H in the plane: $\tan\beta,\ M_A$



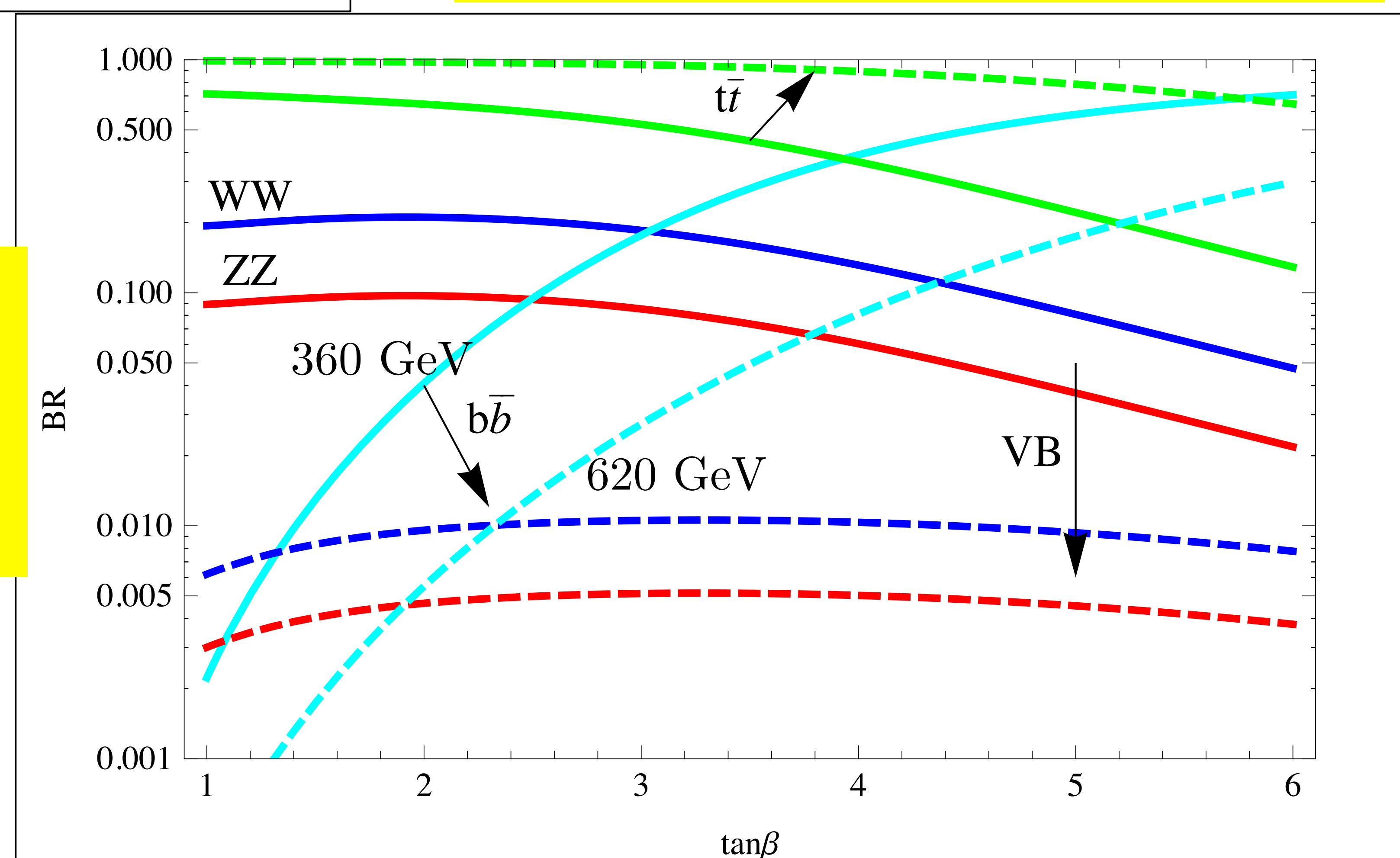


cross sections and BR of A



H- branching ratios for M_H= 360 and 320 GeV

H-bb coupling increases with tanβ (unlike h-bb) control decay channels with b and t is essential



6. Conclusions

- An "intermediate decoupling" region:

– $\tan\beta$=1-10,

– M_H in few 100 GeVs,

– scalar top below 1 GeV
  is not excluded by present data on h(125) and by limits from Flavor Changing Neutral Currents;
- it entails 10-20% deviations of down fermions from ST: a better determination of h couplings, in particular to b and τ is crucial;
- three coupling fit to data very effective in mapping the allowed region;
- the fit is sensitive to the esperimental cuts: a fit made directly by tthe LHC collaborations would be very useful;
- the search for SUSY signal to continue in the next experimental round.

New Physics in TeV range may still be there,
Look everywhere,
No time to give up