ZHEJIANG UNIVERSITY

Higgs精细测量与味物理

一个超对称模型的例子

王凯

浙江近代物理中心

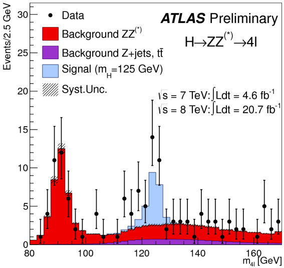
11/5/2013 北京大学

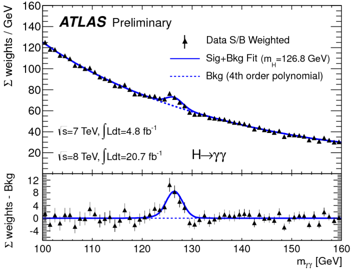
合作者：罗民兴，王浏诚，朱国怀

2013年诺贝尔物理学奖被授予比利时物理学家François Englert与英国物理学家Peter W. Higgs为他们解释基本粒子质量起源机制的贡献及其预言的新粒子Higgs玻色子，该粒子被欧洲核子中心的大型强子对撞机上的ATLAS和CMS两实验组同时探测到。

两个最干净的道支持下的诺贝尔奖

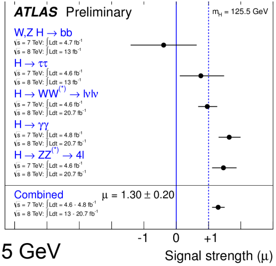
Higgs-like Boson → Higgs Boson





标准模型Higgs? Likely

Signal strength

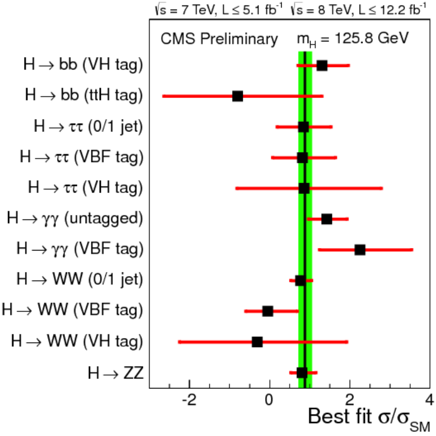


- Combination of
  - W,Z H → bb (4.7 fb^{-1} + 13 fb^{-1})
  - H → ττ (4.6 fb-1 + 13 fb-1)
  - H → WW$^{(*)}$ → $l\nu l\nu$ (4.6 fb-1 + 20.7 fb-1) **Update today!**
  - H → γγ (4.8 fb-1 + 20.7 fb-1) **Update last week!**
  - H → ZZ$^{(*)}$ → 4l (4.6 fb-1 + 20.7 fb-1) **Update last week!**
- Signal strength $\mu = \sigma/\sigma_{SM}$ measured assuming m_H=125.5 GeV
  - Only ±4% change to combined μ for ±1 GeV
- Combined μ = 1.30 ± 0.13 (stat) ± 0.14 (sys)
- Compatibility between measurements and SM (μ=1)
  - Common μ vs SM: 9%
  - with rectangular QCD scale/PDF constraints: 40%
  - All μ_{bb}, $\mu_{\tau\tau}$, μ_{WW}, $\mu_{\gamma\gamma}$, μ_{ZZ} vs μ=1: 8% (5 d.o.f)
  - All μ_{bb}, $\mu_{\tau\tau}$, μ_{WW}, $\mu_{\gamma\gamma}$, μ_{ZZ} vs μ=1.30: 13% (4 d.o.f)
- ATLAS also sets limits (95%CL; not used in combination):
  - H → μμ: μ<9.8 (20.7 fb-1) **New last week!**
  - H → Zγ: μ<18.2 (4.6 fb-1 + 20.7 fb-1) **New last week!**

标准模型Higgs? Likely

Signal Strength

	ggH	VBFH	VH	ttH
H→γγ	✓	✓		
H→ZZ	✓			
H→WW	✓	✓	✓	
H→ττ	✓	✓	✓	
H→bb			✓	✓



$\sigma / \sigma_{SM} = 0.88 +/- 0.21$

Higgs工厂项目启动会(CEPC-SPPC)

利用Higgs耦合的精细测量，特别是Yukawa耦合的测量，以检验超越标准模型的存在性。

Yukawa耦合

$$i\bar{Q}_L^i \not{D} Q_L^i + i\bar{u}_R^i \not{D} u_R^i + i\bar{d}_R^i \not{D} d_R^i + \ldots$$

$$Q_L^i \to U_Q^{ij} Q_L^j, \quad u_R^i \to U_u^{ij} u_R^j, \quad d_R^i \to U_d^{ij} d_R^j$$

三代费米子, $U(3)_Q \times U(3)_u \times U(3)_d \times U(3)_\ell \times U(3)_e$

$$-y_u^{ij} \bar{Q}_L^i \epsilon H^\dagger u_R^j - y_d^{ij} \bar{Q}_L^i H d_R^j + \ldots$$

Yukawa耦合破坏手征对称 $[U(3)]^5 \to U(1)_{\rm B} \times U(1)_{\rm Lep}$

$$Q_L^i \to e^{i\theta/3} Q_L^i, \quad u_R^i \to e^{i\theta/3} u_R^i, \quad d_R^i \to e^{i\theta/3} d_R^i$$
$$\ell_L^i \to e^{i\phi} \ell_L^i, \quad e_R^i \to e^{i\phi} e_R^i$$

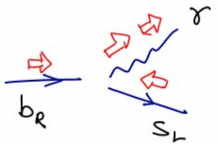
标准模型费米子质量的产生是$[U(3)]^5$手征对称性和弱电对称性同时破缺的结果。

味物理

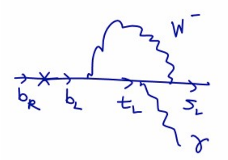
味物理中的稀有衰变过程常见

- Loop压低
- Helicity压低

$$\frac{e}{16\pi^2} m_b (\bar{s}\sigma^{\mu\nu} F_{\mu\nu} P_R b)$$



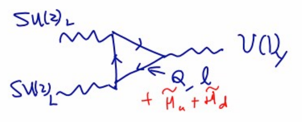
Helicity flip要求手征对称性$U(3)_Q \times U(3)_d$破缺和弱电对称性破缺，在标准模型中意味着m_b。



质量的修正与Higgs扩展：一个超对称的例子

$$m_b = y_b v_d + \Delta m_b$$

超对称标准模型是Type-II 2HDM (Glashaw-Weinberg)



$$A_{[SU(2)_L]^2 U(1)_Y} = \frac{N_f}{2}(3q + \ell) + \frac{1}{2}(h + \bar{h})$$

$$Q u^c H_u + Q d^c H_d + \ell e^c H_d$$

μ-term in 2HDM

$$\mathcal{W} \ni \mu H_u H_d$$

- If $\mu = 0$, $M_{\tilde{H}^{\pm}} = 0$
- If $\mu \to M_{\rm Pl}$, $m_h \to M_{\rm Pl}$
- $\mu \sim \mathcal{O}(\text{TeV})$

假设

$$\mathcal{W} \ni S H_u H_d + \cancel{M_{\rm Pl} H_u H_d}$$

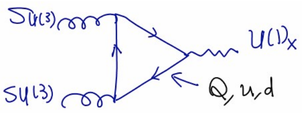
要求存在一个对称性$U(1)_X$来禁止bare的μ-term

$$s \neq 0, \qquad s + h_u + h_d = 0$$

$$\langle S \rangle = \mu \neq 0$$

非零的$\langle S \rangle$破坏了$U(1)_X$对称性

Peccei-Quinn对称性



$$A_{[SU(3)]^2U(1)_X} = \frac{N_f}{2}(2q+u+d)$$

$U(1)_X$对称性下

$$\begin{aligned} Qu^cH_u &: \quad q+u+h_u=0 \\ Qd^cH_d &: \quad q+d+h_d=0 \\ SH_uH_d &: \quad s+h_u+h_d=0 \end{aligned}$$

$$A_{[SU(3)]^2U(1)_X} = \frac{N_f}{2}(2q+u+d) = -\frac{N_f}{2}(h_u+h_d) = \frac{N_f}{2}s$$

$$s \neq 0 \rightarrow A_{[SU(3)]^2U(1)_X} \neq 0$$

Not necessary the same PQ symmetry proposed for Strong CP problem.

Peccei-Quinn对称性破缺

$$W = \mu H_u H_d \qquad \not{\text{PQ}}$$

- Higgsino质量混合 $\mu \tilde{H}_u \tilde{H}_d$
- $y_d \mu^* \tilde{Q} \tilde{d}^c H_u^*$

$$F_{H_d} = \frac{\partial W}{\partial H_d} = y_d Q d^c + y_e \ell e^c + \mu H_u$$

$$V \ni | F_{H_d} |^2 = y_d \mu^* H_u^* \tilde{Q} \tilde{d} + y_e \mu^* H_u^* \tilde{\ell} \tilde{e}$$

- $B\mu$项 $B\mu H_u H_d$

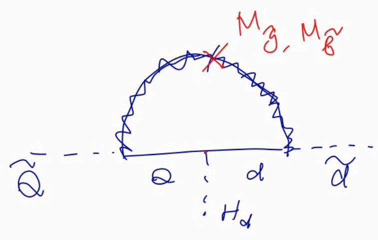
超对称软破缺

$$m_{\tilde{f}}^2 \mid \tilde{f} \mid^2 + \frac{1}{2} M_{\frac{1}{2}} \lambda\lambda + A_u \tilde{Q} \tilde{u} H_u + B\mu H_u H_d$$

- 标量粒子的质量 $m^2 \tilde{Q}^\dagger \tilde{Q}$

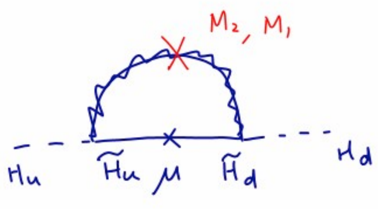
$$\int d^2\bar{\theta} d^2\theta Q^\dagger Q Z^\dagger Z : Q \to UQ$$

- A-term $A\tilde{Q}\tilde{u}^c H_u$



要求手征对称性破缺

- $B\mu$-term $B\mu H_u H_d$



R-对称性

$$R : \theta \to e^{i\alpha}\theta, \bar{\theta} \to e^{-i\alpha}\bar{\theta}$$

$$Q \to e^{-i\alpha}Q, Q^\dagger \to e^{i\alpha}Q^\dagger$$

$$\{Q, R\} = -Q, \{Q^\dagger, R\} = +Q^\dagger$$

Chiral超场

$$\Phi = \phi + \theta\psi + \theta^2 F : \phi \to e^{ir_\Phi \alpha}\phi, \psi \to e^{i(r_\Phi - 1)\alpha}\psi, F \to e^{i(r_\Phi - 2)\alpha}F$$

Vector超场

$$V(x, \theta, \bar{\theta})^* = V : \lambda \to e^{i\alpha}\lambda$$

Suprion场Z ($R_Z = 0$)

$$\int d^2\theta \mathcal{W}_\alpha \mathcal{W}^\alpha \frac{Z}{M_X} \to \int d^2\theta\theta^2 \frac{\langle F_Z \rangle}{M_X}\lambda\lambda$$

类质量项的SUSY修正

$$\mathcal{W} = -y_u Q u^c H_u - y_d Q d^c H_d - y_e \ell e^c H_d + \mu H_u H_d$$

SUSY修正 $Qd^c\bar{H}_u$

Field	Q	u^c	e^c	d^c	ℓ	H_u	H_d	θ
R-charge	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{7}{5}$	$\frac{7}{5}$	$\frac{8}{5}$	$\frac{2}{5}$	1
PQ	0	0	0	-1	-1	0	1	0

$$R[Qd^c\bar{H}_u]: \quad \frac{1}{5} + \frac{7}{5} - \frac{8}{5} = 0$$
$$\mathrm{PQ}[Qd^c\bar{H}_u]: \quad 0 + (-1) + 0 = -1$$

SUSY修正必须破坏PQ对称性和R-对称性

类质量项的SUSY修正

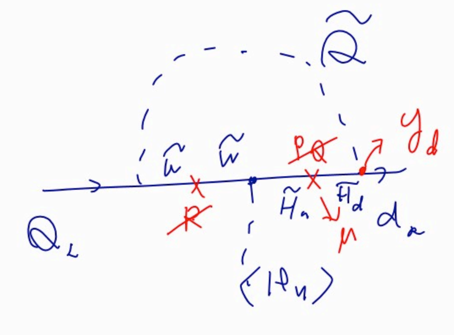
- 手征对称性破缺: y
- 弱电对称性破缺: v_u,v_d
  例如$\tilde{H}-\tilde{W}$混合

$$N=\begin{pmatrix} M_1 & 0 & -g_1 v_d/\sqrt{2} & g_1 v_u/\sqrt{2} \\ 0 & M_2 & g_2 v_d/\sqrt{2} & -g_2 v_u/\sqrt{2} \\ -g_1 v_d/\sqrt{2} & g_2 v_d/\sqrt{2} & 0 & -\mu \\ g_1 v_u/\sqrt{2} & -g_2 v_u/\sqrt{2} & -\mu & 0 \end{pmatrix}$$

- Peccei-Quinn对称性破缺: μ, $B\mu$
- R-对称性破缺: M_1, M_2, M_3, A_i, $B\mu$

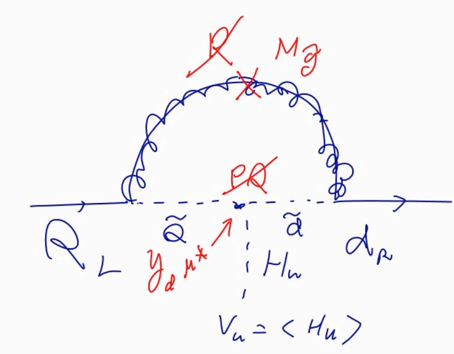
b夸克质量修正 Δm_b

$$m_b = y_b v_d + \Delta m_b$$



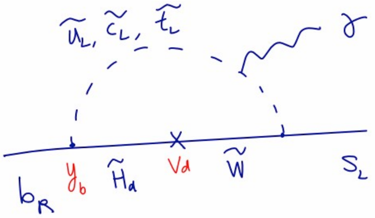
b夸克质量修正 Δm_b

$$m_b = y_b v_d + \Delta m_b$$

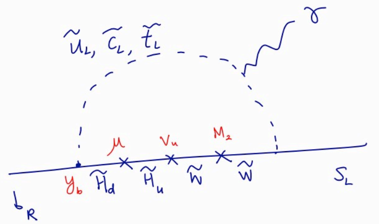


$$|\,F_d\,|^2 \ni y_d \mu^* H_u^* \tilde{Q} \tilde{d}$$

$b \to s\gamma$: v_d 贡献

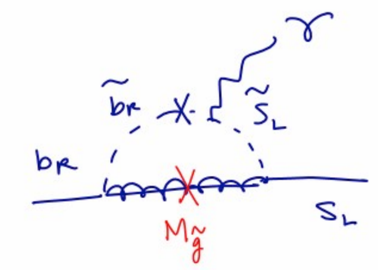


$b \to s\gamma$: v_u 贡献



$$g_2 \tilde{W} \tilde{H}_u \langle H_u^0 \rangle$$

$b \to s\gamma$: v_u贡献



$$| F_{H_d} |^2 \ni y_d \tilde{Q} \tilde{d}^c \mu^* H_u^*$$

$$\delta_{23}^2 : y_d \mu^* v_u^* \tilde{b}_R^* \tilde{s}_L$$

How to interprete the 125 GeV resonance

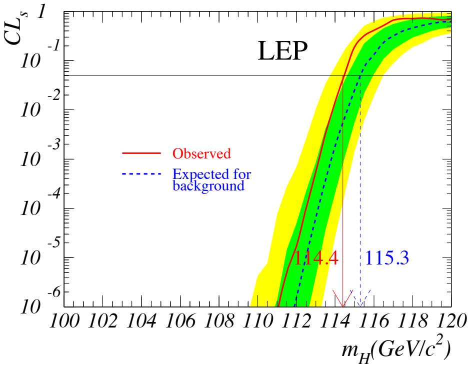
- Standard Model Higgs boson?
- Composite Higgs?
- ....
- Higgs boson in MSSM
  - the light Higgs boson h at 125 GeV? (push the limit)
  - the heavy Higgs boson H at 125 GeV? while h evades all direct searches (or h around 98 GeV?)

- A. Belyaev, Q. -H. Cao, D. Nomura, K. Tobe and C. -P. Yuan, Phys. Rev. Lett. **100**, 061801 (2008).
- N. D. Christensen, T. Han and S. Su, Phys. Rev. D **85**, 115018 (2012).
- K. Hagiwara, J. S. Lee and J. Nakamura, arXiv:1207.0802 [hep-ph].
- R. Benbrik, M. G. Bock, S. Heinemeyer, O. Stal, G. Weiglein and L. Zeune, arXiv:1207.1096 [hep-ph].
- G. Belanger, U. Ellwanger, J. F. Gunion, Y. Jiang, S. Kraml and J. H. Schwarz, arXiv:1210.1976 [hep-ph].
- M. Drees, arXiv:1210.6507 [hep-ph].
- P. Bechtle, S. Heinemeyer, O. Stal, T. Stefaniak, G. Weiglein and L. Zeune, arXiv:1211.1955 [hep-ph].

LEP exclueds a SM-like Higgs to 114.4 GeV
(in both SM and MSSM)

Higgs Mass Lower Bound

LEP excludes a 114.4 GeV Higgs boson @ 95% CL. (expected 115.3 GeV)



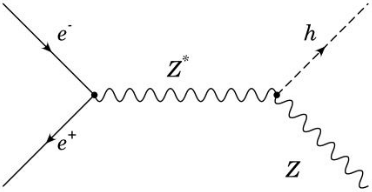
	Exp.	Obs.
ALEPH	113.5	111.4
DELPHI	113.3	114.1
L3	112.4	112.0
OPAL	112.7	112.7

MSSM is a natural 2HDM

- Superpotential is holomorphic and $\bar{H}$ is forbidden in superpotential.
- $\tilde{H}_u$, $\tilde{H}_d$ contributes to anomaly $[SU(2)_L]^2U(1)_Y$,.... and Witten Anomaly

$$W = y_u Q u^c H_u + y_d Q d^c H_d + y_e \ell e^c H_d + \mu H_u H_d$$

To evade the LEP bound: reducing g_{ZZh}



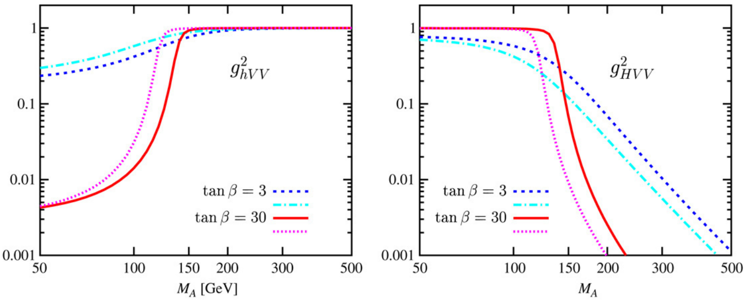
A simple realization: to make h H_d-like and take a small v_d

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

$$\frac{\tan 2\alpha}{\tan 2\beta} = \frac{M_A^2 + m_Z^2}{M_A^2 - m_Z^2}$$

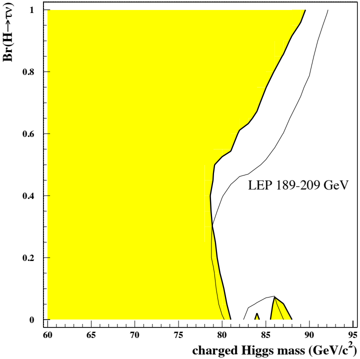
In the limit of small v_d (large $\tan\beta$, $\sin\beta \to 1$)
Taking $M_A \to 0$, $\sin\alpha \to -1$

$$\beta \to \frac{\pi}{2}, \alpha \to -\frac{\pi}{2}, g_{ZZh} \sim \sin(\beta - \alpha) \to 0$$



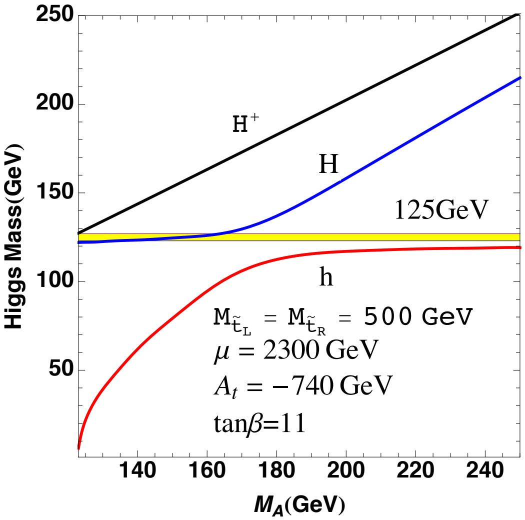
Qualitatively, smaller $M_A \to$ smaller g_{ZZh}

Lower bound of M_A from LEP bound on charged Higgs



non-decoupling limit ($M_A \to m_Z$) may survive the LEP direct search bound (via Zh) and charged Higgs search

At tree level, $M_A \to m_Z$, $M_h \to M_H$: nondecoupling
With radiative corrections:



Large $\tan\beta$ and $\sin\alpha \to -1$ lead to $M_h \simeq \mathcal{M}_{11}, M_H \simeq \mathcal{M}_{22}$

$$
\begin{aligned}
M_H^2 \simeq \mathcal{M}_{22}^2 \quad \simeq \quad & M_A^2 \cos^2\beta + m_Z^2 \sin^2\beta \left(1 - \frac{3}{8\pi^2} y_t^2 t\right) \\
+ \quad & \frac{y_t^4 v^2}{16\pi^2} 12 \sin^2\beta \left\{ t \left[1 + \frac{t}{16\pi^2} \left(1.5 y_t^2 + 0.5 y_b^2 - 8 g_3^2\right) \right] \right. \\
+ \quad & \left. \frac{A_t \tilde{a}}{M_{SUSY}^2} \left(1 - \frac{A_t \tilde{a}}{12 M_{SUSY}^2}\right) \left[1 + \frac{t}{16\pi^2} \left(3 y_t^2 + y_b^2 - 16 g_3^2\right) \right] \right\} \\
- \quad & \frac{v^2 y_b^4}{16\pi^2} \sin^2\beta \frac{\mu^4}{M_{SUSY}^4} \left[1 + \frac{t}{16\pi^2} \left(9 y_b^2 - 5 y_t^2 - 16 g_3^2\right) \right] + \mathcal{O}(y_t^2 m_Z^2)
\end{aligned}
$$

M. S. Carena, J. R. Espinosa, M. Quiros and C. E. M. Wagner, Phys. Lett. B **355**, 209 (1995) [hep-ph/9504316].

Consequences of Non-decoupling

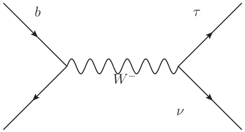
Non-decoupling scenario may evade all constraints from direct search experiments but ....

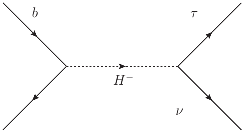
- $H^{\pm}$ are around ($M^2_{H^{\pm}} = M^2_A + m^2_W$ at tree level)
  Is the scenario flavor safe?

- Light Higgs bosons can enhance spin-independent neutralino-nuclei scattering
  If DM consists of only neutralino, how about bounds from direct detection?

Tree level $H^{\pm}$: $B_u \to \tau\nu$ in 2HDM and SUSY

Farvah Mahmoudi and Oscar Stal

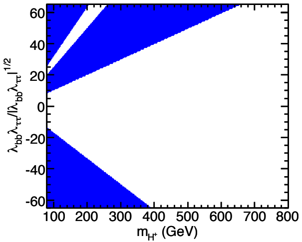




- $$\frac{BR(B^+\to\tau^+\nu)_{\rm MSSM}}{BR(B^+\to\tau^+\nu)_{\rm SM}} = \left|1 - \frac{m_B^2}{M_{H^+}^2}\frac{\tan^2\beta}{(1+\epsilon_0^*\tan\beta)(1+\epsilon_l\tan\beta)}\right|^2$$
- $\tan\beta$ ~10: ϵ_0^* and ϵ_l below 1%
  MSSM corrections to d-type quarks and lepton mass matrix have been neglected
- nondecoupling: $M_{H^+} \sim$ 130 GeV
  MSSM prediction: 20% – 30% smaller than the SM value

Tree level $H^{\pm}$: $B_u \to \tau\nu$ in 2HDM and SUSY

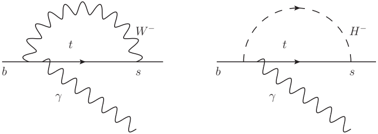
Farvah Mahmoudi and Oscar Stal

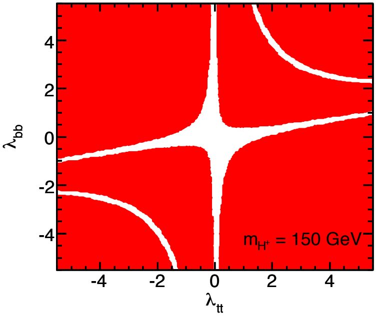


- $$\frac{BR(B^+\to\tau^+\nu)_{\rm MSSM}}{BR(B^+\to\tau^+\nu)_{\rm SM}} = \left|1 - \frac{m_B^2}{M_{H^+}^2}\frac{\tan^2\beta}{(1+\epsilon_0^*\tan\beta)(1+\epsilon_l\tan\beta)}\right|^2$$
- nondecoupling: $M_{H^+} \sim$ 130 GeV， $\tan\beta \sim 10$
  MSSM prediction: 20% – 30% smaller than the SM, consistent with the new Belle data
  SM prediction: $(0.95 \pm 0.27) \times 10^{-4}$
  world average before 2012: $(1.65 \pm 0.34) \times 10^{-4}$
  Belle: $0.72^{+0.29}_{-0.27} \times 10^{-4}$ (new)

$B \to X_s\gamma$ in general 2HDM

Farvah Mahmoudi and Oscar Stal





- light H^+ enhances $B \to X_s\gamma$
- type-II 2HDM: M_{H^+} > 300 GeV
- nondecoupling: $M_{H^+} \sim$ 130 GeV
  non-trival SUSY setup to cancel H^+ contribution

$B \to X_s\gamma$ in MSSM

Helicity must be flipped in the involved quark states: m_b insertion in SM

- $U(3)_Q \times U(3)_d$ chiral symmetry breaking
- Electroweak symmetry breaking

$$W = Qu^cH_u + Qd^cH_d + \ell e^cH_d + \mu H_uH_d$$

SUSY correction $Qd^c\bar{H}_u$

Field	Q	u^c	e^c	d^c	ℓ	H_u	H_d	θ
R-charge	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{7}{5}$	$\frac{7}{5}$	$\frac{8}{5}$	$\frac{2}{5}$	1
PQ	0	0	0	-1	-1	0	1	0

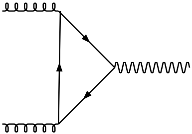
$$R[Qd^c\bar{H}_u]: \quad \frac{1}{5} + \frac{7}{5} - \frac{8}{5} = 0$$

$$\mathrm{PQ}[Qd^c\bar{H}_u]: \quad 0 + (-1) + 0 = -1$$

SUSY correction must break PQ and R-symmetry

2HDM has Peccei-Quinn symmetry

(DFSZ axion, 1981).



$$A_{[SU(3)_C]^2U(1)} = 3\alpha + \frac{3}{2}(2(q-\alpha)+(u-\alpha)+(d-\alpha))$$
$$= 3\alpha - \frac{3}{2}(h_u + h_d)$$

$$q + u + h_u = 2\alpha, q + d + h_d = 2\alpha$$

$$h_u + h_d \neq 2\alpha \to A_3 \neq 0$$

$M_{\rm PQ} \sim M_{\rm Intermediate}$, Kim-Nilles

Peccei-Quinn symmetry breaking in MSSM

$$W = \mu H_u H_d \qquad \cancel{\mathrm{PQ}}$$

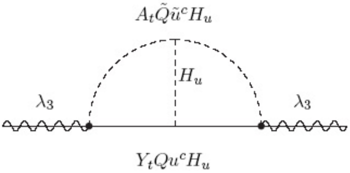
Another $\cancel{\mathrm{PQ}}$ source, (proportional to μ)

$$F_{H_d} = \frac{\partial W}{\partial H_d} = y_d Q d^c + y_e \ell e^c + \mu H_u$$

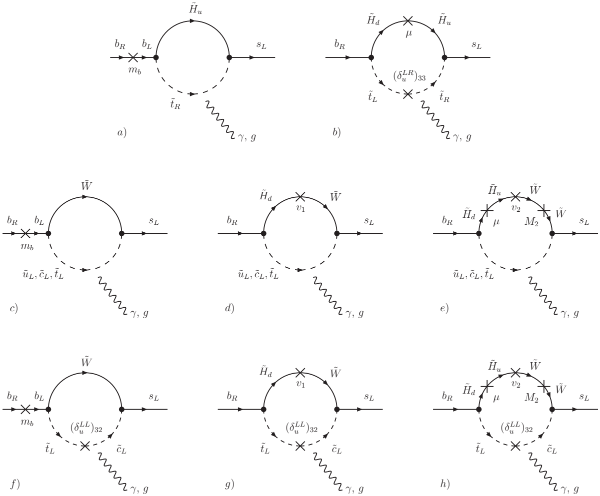
$$V \ni \mid F_{H_d} \mid^2 = y_d \mu^* H_u^* \tilde{Q} \tilde{d} + y_e \mu^* H_u^* \tilde{\ell} \tilde{e}$$

Chiral R-symmetry in SUSY

$$
\begin{aligned}
\mathcal{L}_{\text{soft}} \ &\ni \ m_{\tilde{f}}^2 \mid \tilde{f} \mid^2 && R-\text{invariant} \\
&+ \ M_{\frac{1}{2}}\lambda\lambda + A_u \tilde{Q}\tilde{u}H_u + \ldots && \not{R} \\
&+ \ B\mu H_u H_d && \not{R}, \not{\text{PQ}}
\end{aligned}
$$

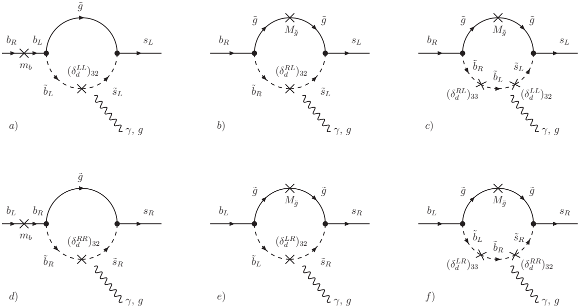


$B \to X_s\gamma$ in MSSM



Light stop helps to cancel the $H^{\pm}$ contribution [Top right figure]

$B \to X_s\gamma$ in MSSM



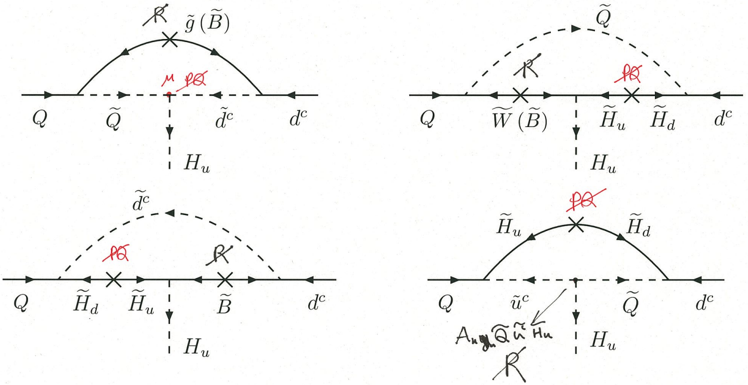
Light stop helps to cancel the $H^{\pm}$ contribution [Top right figure]

$B \to X_s\gamma$ in MSSM

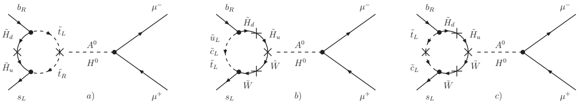
Helicity must be flipped in involved quark states
Breaking $U(3)_Q \times U(3)_d$ chiral and electroweak symmetries

- m_b insertion
  wino-stop contribution suppressed by Super-GIM if degenerate squark masses.
- v_d insertion (not important due to large $\tan\beta$)
- v_u insertion (effectively $\mathbf{10} \cdot \mathbf{5}^c \cdot H_u^*$-like coupling)
- chargino penguins from v_u insertion destructively interfere with the SM and charged Higgs if $\mu A_t < 0$
- light stop helps the cancellation as $\frac{\mu A_t}{M_{\tilde{t}}^2}$
- gluino penguins important: enhanced by $\mu \tan\beta$, $M_{\tilde{g}}/m_b$

Contribute to m_b at the same time!



$B_s \to \mu^+\mu^-$ in MSSM



- SM: (3.27±0.23)$\times 10^{-9}$ due to small muon mass $m_\mu^2/m_{B_S}^2$
- LHCb: $3.2^{+1.5}_{-1.2} \times 10^{-9}$ (Nov. 12, 2012)
- MSSM: leading Higgs penguin diagrams $\propto \tan^6\beta$
- if $\tan\beta$ ~10, all 1-loop diagrams have to be considered: e.g., charged Higgs diagrams $\propto \tan^4\beta$
- nondecoupling $\to$ light M_A
  $B_s \to \mu^+\mu^-$ is even more sensitive as the neutral Higgs bosons are all light: $\tan^6\beta/M_A^4$ (Chao-Shang Huang, Wei Liao, Qi-Shu Yan, Shou-Hua Zhu, 2000)

General Constraints

- M_H : 125 ± 2 GeV
- $R_{\gamma\gamma} = \sigma^{\gamma\gamma}_{\rm obs}/\sigma^{\gamma\gamma}_{\rm SM} : 1 \sim 2$
- LEPII+Tevatron+LHC Higgs search bounds
- BR$(B \to X_s \gamma) < 5.5 \times 10^{-4}$
  Experimental: $(3.43 \pm 0.22) \times 10^{-4}$
  SM NNLO: $(3.15 \pm 0.23) \times 10^{-4}$
  FeynHiggs SM NLO predicton: $(3.8) \times 10^{-4}$
- BR$(B_s \to \mu^+ \mu^-) < 6 \times 10^{-9}$
  Experimental upper limit: 4.2×10^{-9}
  SM prediction $(3.27 \pm 0.23) \times 10^{-9}$
  SUSYFlavor SM predicton 4.8×10^{-9} (Hadronic parameters ?)
- SUSYFlavor2.01, FeynHiggs2.9.2, HiggsBound3.8.0

Input

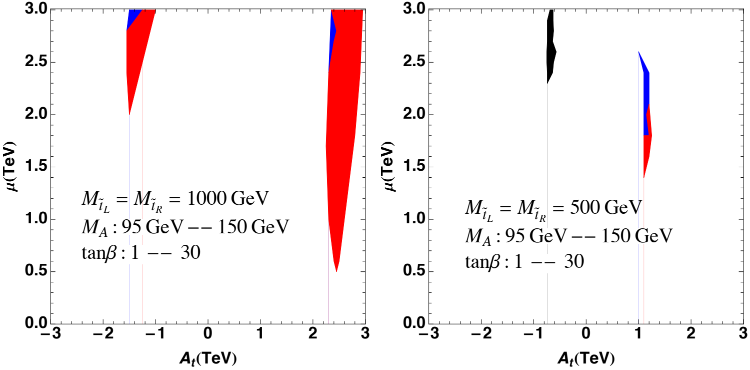
$$M_{\tilde{Q}_{1,2}} = M_{\tilde{u}_{1,2}} = M_{\tilde{d}_{1,2,3}} = M_{\tilde{L}_{1,2,3}} = M_{\tilde{e}_{1,2,3}} = 1 \text{ TeV} ,$$

$$M_1 = 200 \text{ GeV}, M_2 = 400 \text{ GeV}, M_3 = 1200 \text{ GeV} .$$

$$M_{\tilde{Q}_3} = M_{\tilde{t}} = 200 \text{ GeV}, \ 300 \text{ GeV} , 500 \text{ GeV and } 1\text{TeV}.$$

$$\begin{aligned} M_A &: \quad 95 \sim 150 \text{ GeV} \\ \tan\beta &: \quad 1 \sim 30 \\ \mu &: \quad 200 \text{ GeV} \sim 3 \text{ TeV} \\ A_u = A_d = A_\ell &: \quad -3 \sim 3 \text{ TeV} \end{aligned}$$

Light stau enhances the diphoton but irrelevant to $b \to s$ transition

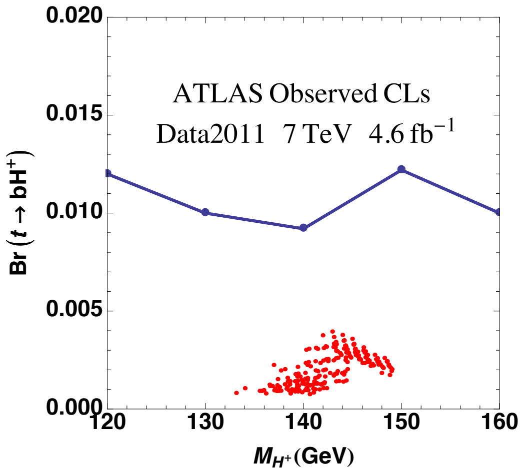


- no survivors when assuming 200GeV and 300GeV stop, reduced $gg \to H$ (cancels top-quark loop)
- red: $M_H : 125 \pm 2$ GeV, $R_{\gamma\gamma} : 1 - 2$, and combined direct search bounds
- blue: $B \to X_s \gamma$
- black: $B_s \to \mu^+ \mu^-$

Typical survival points are $M_A \sim 140 \sim 150$ GeV, $\tan\beta \sim 10$

$t \to bH^+$ at the LHC

Assuming BR$(H^+ \to \tau^+\nu_\tau) = 100\%$



Way below the ATLAS bounds

H is most H_u and $v_u \gg v_d$ which dominates v

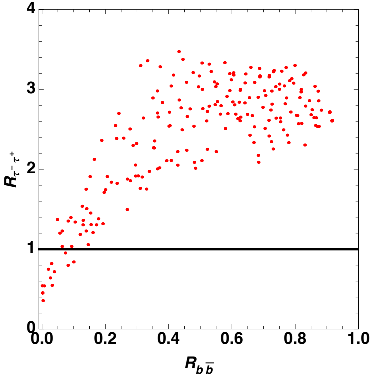
- Htt is close to 1: $gg \to H$ similar to SM rate
- HWW is similar to SM: $\Gamma(H \to \gamma\gamma)$ similar to SM values (W-loop dominates)
- $\Gamma(H \to WW^* \to 2\ell 2\nu)$ and $\Gamma(H \to ZZ^* \to 4\ell)$ similar to SM values

Decay BRs may be similar to SM.
Light stau can enhance the diphoton partial width.
Reduced Hbb can also enhance the $R_{\gamma\gamma}$

$$H \to \tau^+\tau^-$$

Large PQ and R-symmetry breaking to suppress the flavor violation would lead to large correction in Δm_b but not to m_τ which is only bino contribution.

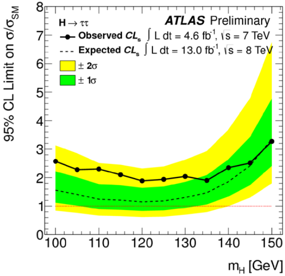
$$\frac{\Gamma(H \to \tau^+\tau^-)}{\Gamma(H \to bb) + \Gamma(H \to WW^*) + \Gamma(H \to ZZ^*) + \ldots}$$

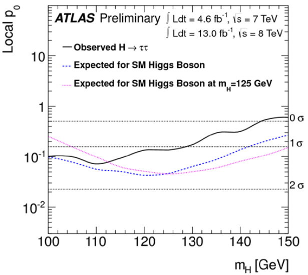


$\tau^+\tau^-$ Channel

Kevin Einsweiler for HCP 2012

The results are consistent with either the background hypothesis, or the SM Higgs hypothesis. The best-fit μ value at 125 GeV is μ = 0.7 ± 0.7

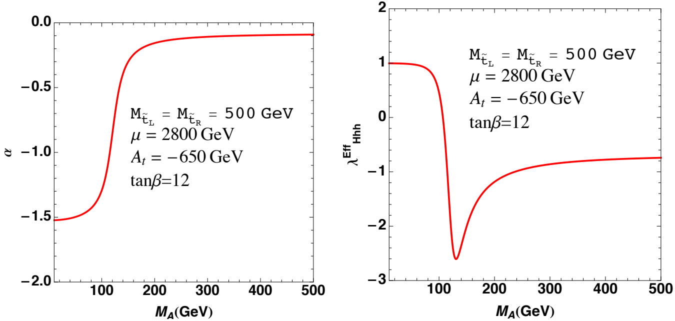




No Enhanced $\tau^+\tau^-$ observed!

New $H \to hh$ Channel

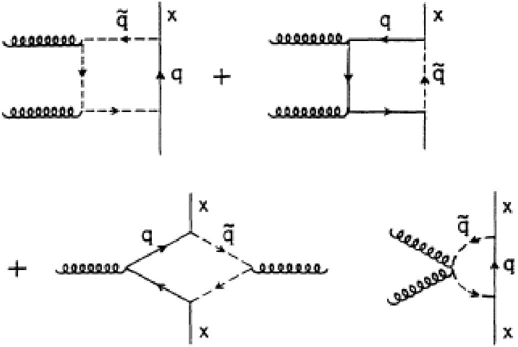
Highly fine-tuned though



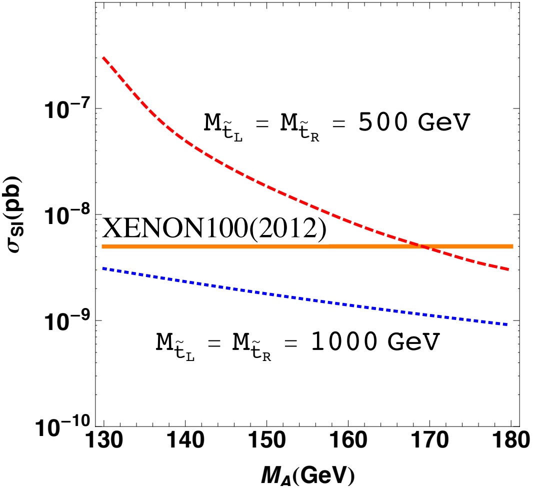
- $e^+e^- \to Ah$ with $A \to b\bar{b}$, $A \to hZ$ for $M_h \sim 20$ GeV, bs are soft. Evade the LEPII search of $4b + 2b2\tau$
- WH/ZH with $H \to hh \to 2b2\tau + 4b + 4\tau$ combined requires 100 fb^{-1} at 14 TeV LHC. (gluon fusion requires 300 fb^{-1})

DM Direct Detection

- Light higgs h and H may significantly enhance the spin-independent neutralino-nuclei cross section through Higgs exchange.
- Light Stop may further enhance this cross section due to loop contribution to neutralino-gluon scattering.



DM Direct Detection



For 500 GeV stop and $M_A < 170$ GeV, XENON100 put strong constraint over this scenario.
Irrelevant if neutralino dark matter is not the only DM

Conclusions

- MSSM: $m_h > 120\text{GeV}$ is nontrival $\Rightarrow$ nondecoupling
- LEP bounds: $\begin{cases} g_{ZZh} \downarrow & \Rightarrow \text{small } M_A \\ m_{H^+} & \Rightarrow M_A > 80\text{GeV} \end{cases}$
- Is the scenario flavor safe as $m_{H^+} \sim m_A$? The strong constraint comes from $b \to s$ transition:
  (I) large PQ and R symmetry breaking with μA_t < 0
  (II) a light stop $M_{\tilde{t}} \sim 500$ GeV
- Consequence:

$$\begin{cases} (I) & \Rightarrow \text{large } \Delta m_b \Rightarrow R_{\tau\tau} \uparrow \Rightarrow \;\; H \to hh \text{to make} R_{\tau\tau} < 1 \\ (II) & \Rightarrow \text{strongly constrained by XENON100} \end{cases}$$

Thank you!