“Search for a light CP-odd Higgs boson in radiative decays of J/ψ”

24/11/2017 JC41

Background (Motivation)

$$\frac{\Gamma(V \to H\gamma)}{\Gamma(V \to \mu\mu)} = \frac{G_F m_q{}^2}{\sqrt{2}\,\pi\alpha}\left(1 - \frac{m_H{}^2}{m_V{}^2}\right)^{1/2}$$

Ref[1] in the paper: F. Wilczek, Phys. Rev. Let. 39. 1304 (1977)

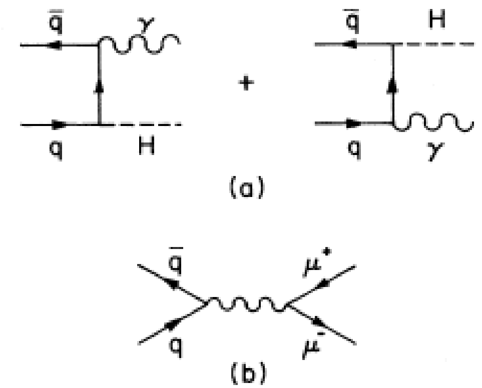


FIG. 1. Comparison of (a) the radiative decay $V \to H\gamma$ and (b) the leptonic decay $V \to \mu^+\mu^-$.

$$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to l^+l^-)} = \frac{G_F m_q^2 g_q^2 C_{QCD}}{\sqrt{2}\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_V^2}\right), \qquad (1)$$

- NMSSM expects very light mass Higgs boson which might be less than twice the mass of the charmed quark.

- Depending on tan(β) and another mixing term $\cos(\theta_A)$ (=between the newly added singlet & the rest)

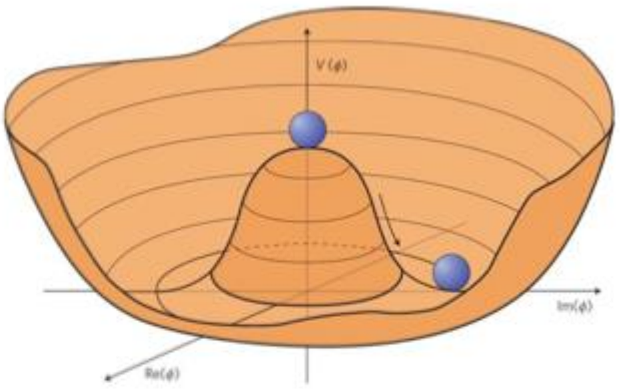
SM Higgs

$$\mathcal{L}_\Phi = (D_\mu \Phi)^\dagger (D^\mu \Phi) - V(\Phi)$$

$$V = -\mu^2 \Phi^\dagger \Phi + \lambda^2 \left(\Phi^\dagger \Phi \right)^2$$

$$\langle \Phi \rangle = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}} \mathrm{v} \end{pmatrix}$$

$$m_H = \sqrt{2\lambda}\,\mathrm{v}$$



Minimal Super Symmetric Model (MSSM)

$$V_{MSSM} = m_1^2 |\Phi_1|^2 + m_2^2 |\Phi_2|^2 - m_3^2 \left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1\right) + \frac{1}{8}\left(g^2 + g'^2\right)\left[|\Phi_1|^2 - |\Phi_2|^2\right]^2 + \frac{1}{2} g^2 \left|\Phi_1^\dagger \Phi_2\right|^2$$

Sometimes written as "μ" , and it is free parameter

$$\Phi_1 = \begin{pmatrix} H_1^+ \\ \frac{1}{\sqrt{2}}\left(v_1 + \eta_1 + i\zeta_1\right) \end{pmatrix} \quad \Phi_2 = \begin{pmatrix} H_2^+ \\ \frac{1}{\sqrt{2}}\left(v_2 + \eta_2 + i\zeta_2\right) \end{pmatrix}$$

$$m_A{}^2 = m_1{}^2 + m_2{}^2$$

$$m_{h,H}{}^2 = \frac{1}{2}\left[m_A{}^2 + m_Z{}^2 \mp \sqrt{\left(m_A{}^2 - m_Z{}^2\right)^2 + 4 m_A{}^2 m_Z{}^2 \sin^2 2\beta}\right]$$

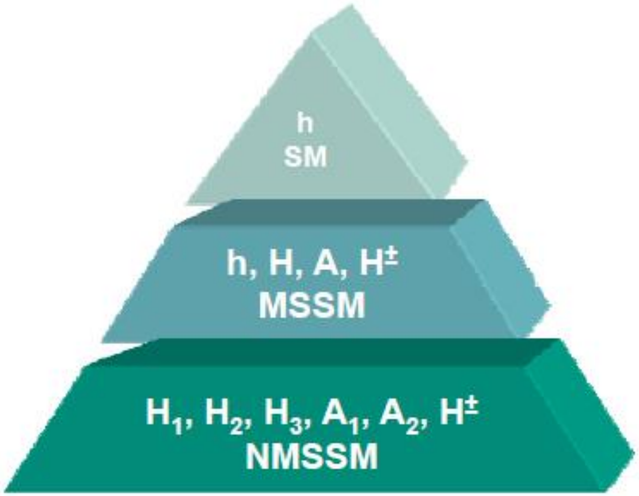
$$m_{H^\pm}{}^2 = m_A{}^2 + m_W{}^2$$

$$m_A \,,\ \tan\beta = v_1 / v_2$$

Next-to-Minimal Super Symmetric Model (NMSSM)

MSSM+SU(2) singlet N

$$V_{NMSSM} = m_1^2 |\Phi_1|^2 + m_2^2 |\Phi_2|^2 + m_N^2 |N|^2$$
$$- \left[\lambda A_\lambda N \Phi_1 \Phi_2 + \frac{k A_k}{3} N^3 + h.c. \right]$$
$$+ \left| \lambda \Phi_1 \Phi_2 - k N^2 \right|^2 + \lambda^2 \left(|\Phi_1|^2 + |\Phi_2|^2 \right) |N|^2$$
$$+ \frac{1}{8} \left(g^2 + g'^2 \right) \left(|\Phi_1|^2 - |\Phi_2|^2 \right)^2$$



expect more “Higgs” than MSSM

Why going to the NMSSM?

- **MSSM**

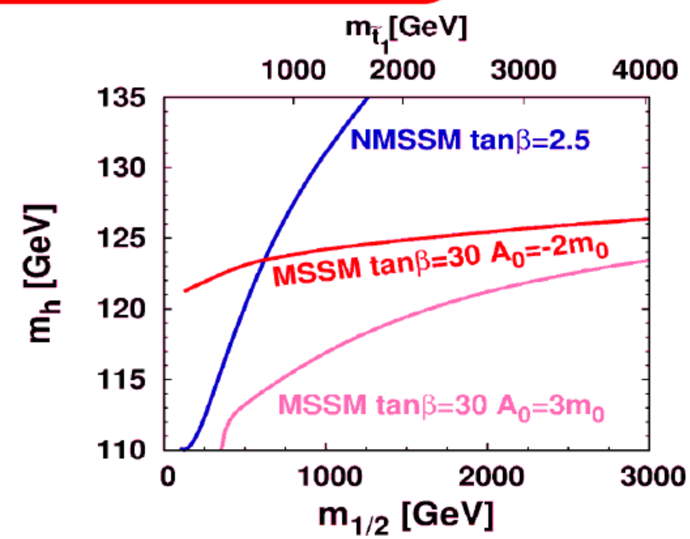
Loop corrections $\quad X_t = m_t(A_t - \mu\cot\beta)$

$$\underbrace{m_h^2}_{<(130\,GeV)^2} \approx \underbrace{m_Z^2\cos^2 2\beta}_{<m_Z^2} + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde t}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde t}^2}\left(1-\frac{X_t^2}{12\,m_{\tilde t}^2}\right)\right]$$

- **NMSSM: Mixing with singlet**

$$m_h^2 \approx \lambda^2 v^2 \sin^2 2\beta + M_Z^2\cos^2 2\beta + \Delta_{rad} + \Delta_{mix}$$

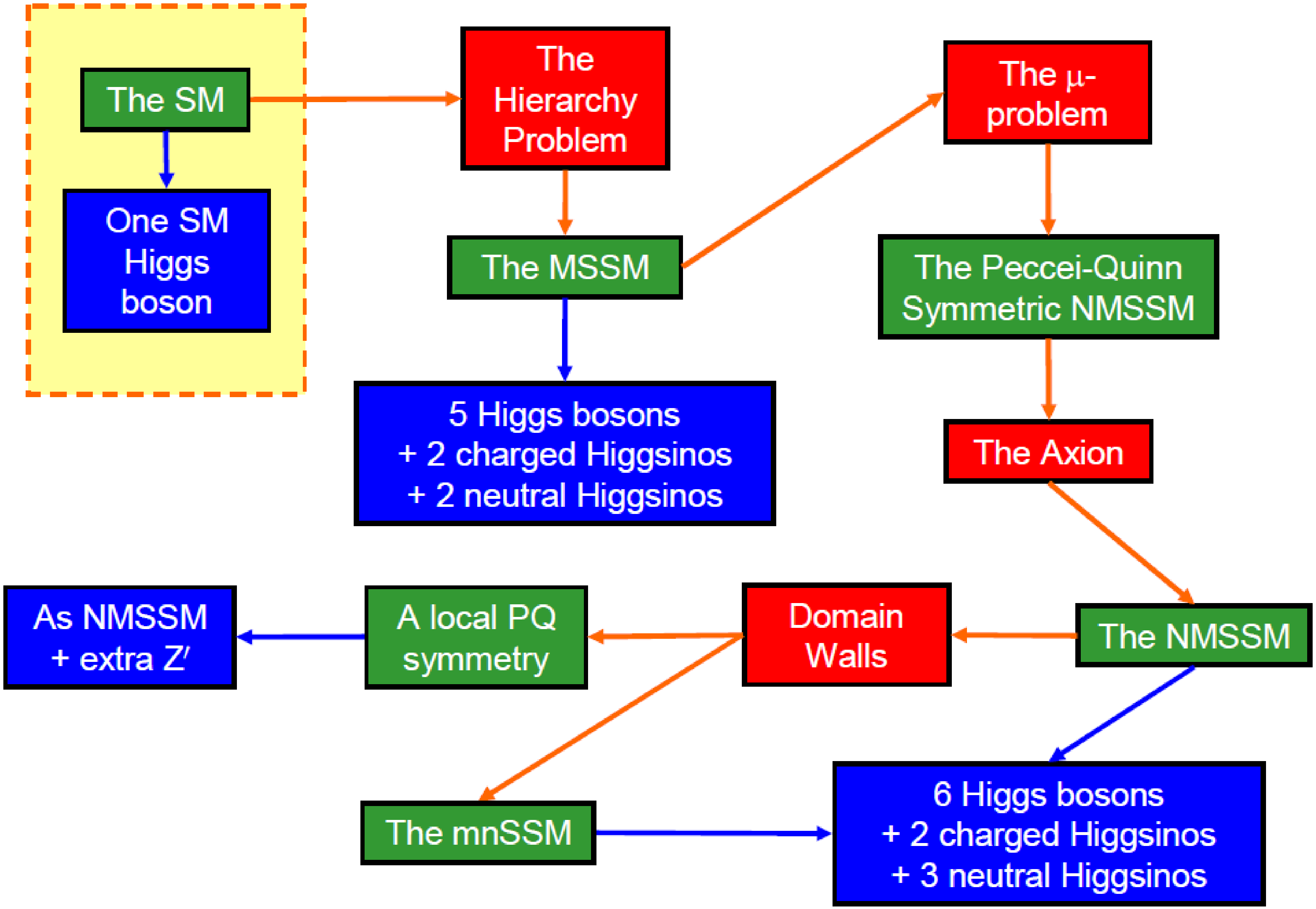
Increases Higgs mass for large values of λ



Ellwanger, arXiv 1108.0157

Getting m_h=126 GeV for TeV instead of multi-TeV stops

1. Introduction: The SM Higgs Sector



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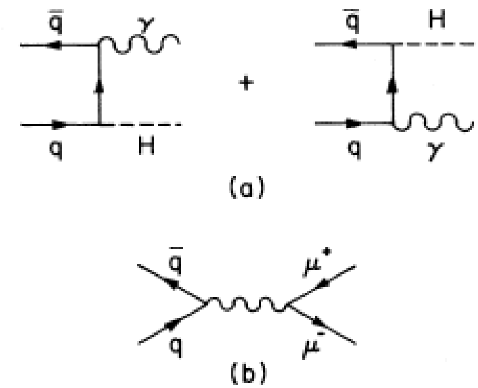

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Data Set & Event Selection

Data : 225M J/ψ, collected in 2009

Channel : $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$ (final state: 1 gamma+di-muon)

Event Selection :

-- charged track ($|Vz| < 10.0$ cm, $|Vxy| < 1.0$ cm, $|\cos(\theta)|<0.93$)

-- gamma candidate (E > 25 MeV (barrel), E > 50 MeV(endcap), 0<t<14)

-- angle separation between tracks&gamma : 20 deg.

-- Muon identification

$E^{\mu}_{cal}/p < 0.9$, $0.1 < E^{\mu}_{cal} < 0.3$

Δt^{TOF} (diff of TOF and expected time)< 0.26 ns

Require MUC depth: (-40.0+70*p/(GeV/c)) cm for 0.5<p<1.1, or 40.0 (p>1.1)

four-constraint (4C) kinematic fitting

$|\cos(\theta)^{hel}_{\mu}| < 0.92$ (angle between direction of muon & direction of J/ψ, in A^0 rest frame)

"Reduced mass" distribution and background components

"non-peaking background"

$e^+e^- \rightarrow \gamma\mu^+\mu^-$

"peaking background"

$J/\psi \rightarrow \gamma f_2(1270);\ f_2(1270) \rightarrow \pi^+\pi^-$

$J/\psi \rightarrow \gamma f_0(1710);\ f_0(1710) \rightarrow \pi^+\pi^-$

$J/\psi \rightarrow \rho^-\pi^+,\ \rho^- \rightarrow \pi^-\pi^0$

$J/\psi \rightarrow \pi^-\rho^+,\ \rho^+ \rightarrow \pi^0\pi^+$

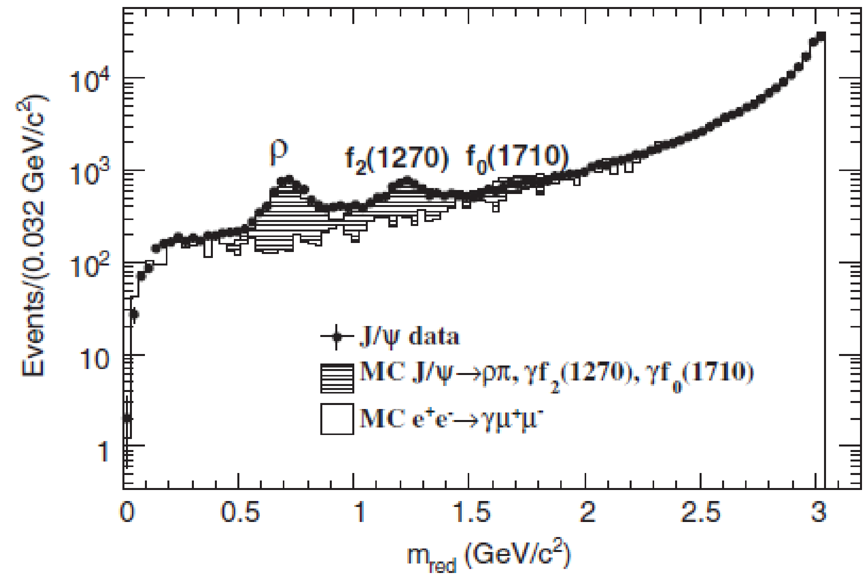


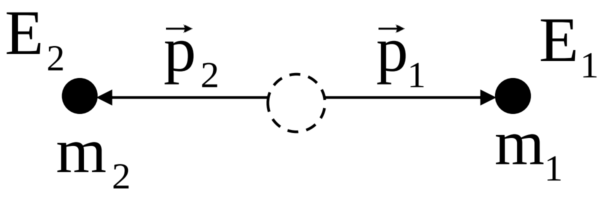
FIG. 1. Distribution of m_{red} for data (black points with error bars), together with the background predictions from the various MC samples, shown by a solid histogram and a histogram with horizontal pattern lines for the nonpeaking and peaking backgrounds, respectively. The MC samples are normalized to the data. Three peaking components, corresponding to the ρ, $f_0(1270)$, and $f_0(1710)$ mesons, are observed in the data.

"m_{red} is equal to twice the muon momentum in the A0 rest frame and is easier to model near threshold than the dimuon invariant mass. " (from the paper)

Ref: Reduced Mass ?

Invariant Mass

$$M^2 = (E^1 + E^2)^2 - |\vec{p}_1 + \vec{p}_2|^2$$
$$= m_1^2 + m_2^2 + 2(E_1 E_2 - \vec{p}_1 \cdot \vec{p}_2)$$



if both particles are muons,

$$M_{\mu\mu}^2 = 2m_\mu^2 + 2(E_\mu^2 - \vec{p}_\mu \cdot (-1)\vec{p}_\mu) = 4m_\mu^2 + 4|\vec{p}_\mu|^2$$

Reduced Mass

$$m_{red} = \sqrt{M_{\mu\mu}^2 - 4m_\mu^2} = 2|\vec{p}_\mu|$$

PDF & Fitting

I(RK) am not familiar with those functions . . .

Signal PDF : sum of two Crystal Ball functions

Background PDF (non-peaking) :
polynomial functions

Background PDF (peaking) ρ :
"Cruijff" function

$$f_{L,R}(m_{\text{red}}) = \exp[-(m_{\text{red}}-\mu)^2/(2\sigma^2_{L,R} + \alpha_{L,R}(m_{\text{red}}-\mu)^2)]. \quad (2)$$

Background PDF (peaking) $f_2(1270)/f_0(1710)$:
sum of two Crystal Ball functions

$$f(x|\mu,\sigma,\alpha,n) = C. \begin{cases} exp(\frac{-(x-\mu)^2}{2\sigma^2}), & \frac{x-\mu}{\sigma} > -\alpha \\ (\frac{n}{|\alpha|})^n exp(-\frac{\alpha^2}{2}) \cdot (\frac{n}{|\alpha|} - |\alpha| + \frac{x-\mu}{\sigma})^{-n}, & \frac{x-\mu}{\sigma} \le -\alpha \end{cases}$$

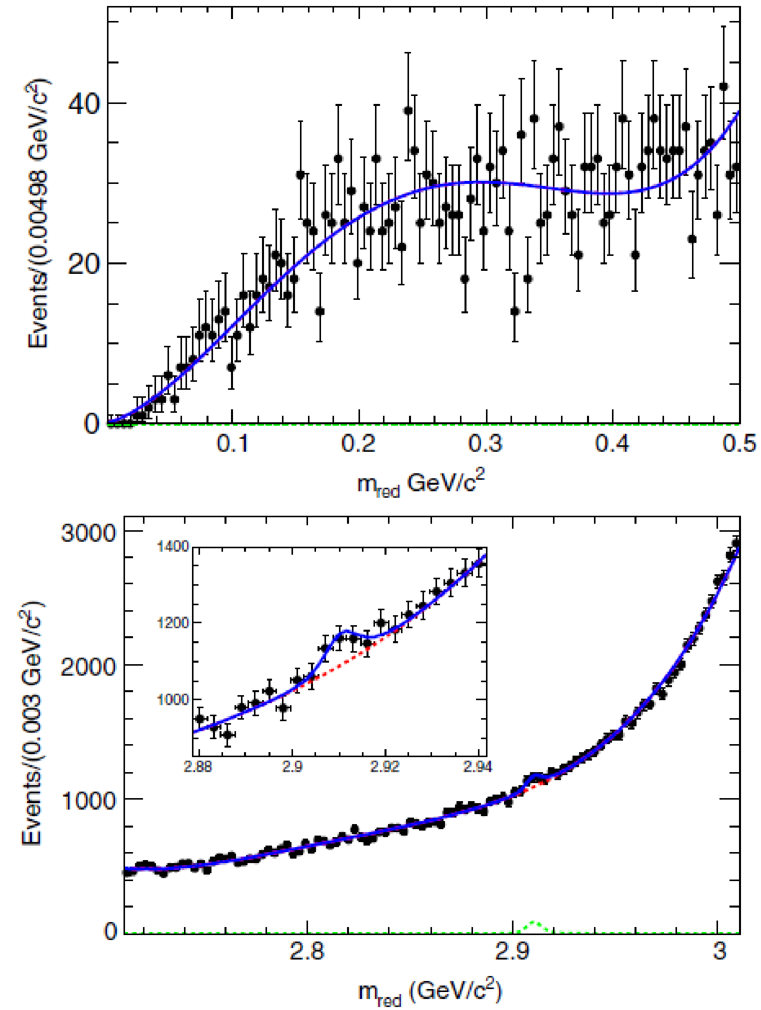


Fig2. Plot of the fit to the m_{red} distribution

Obtained Significance

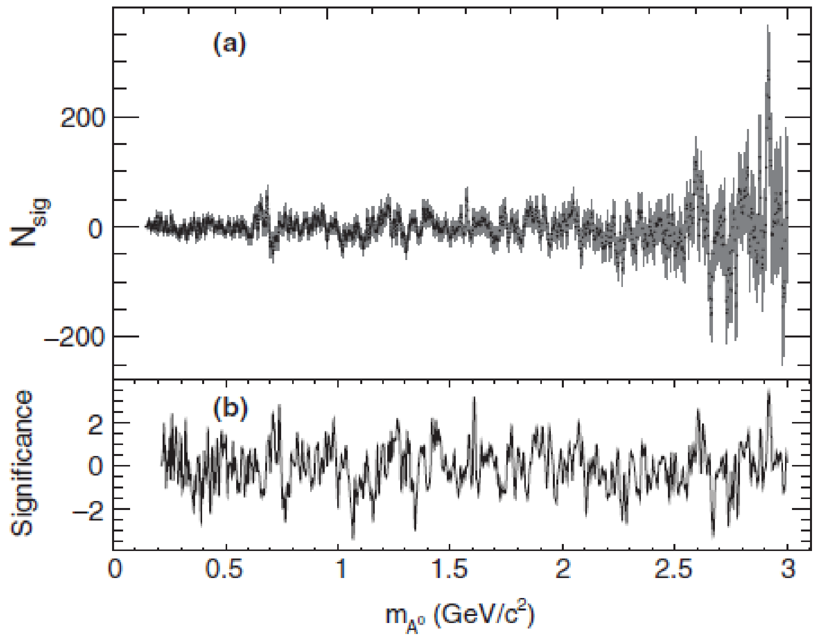


FIG. 3. (a) Number of signal events (N_{sig}) and (b) signal significance ($\mathcal{S}$) obtained from the fit as a function of m_{A^0}.

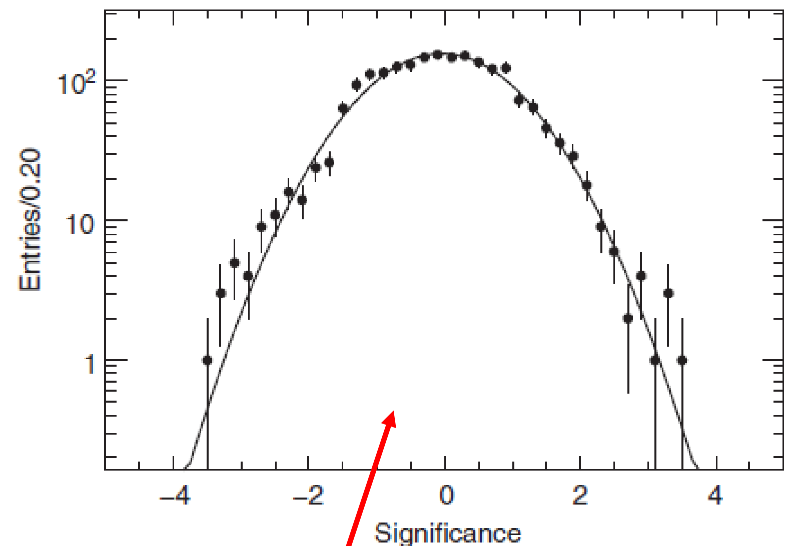


FIG. 4. Histogram of the statistical significance $\mathcal{S}$ obtained from the fit at 2,035 m_{A^0} points, together with the expected $\mathcal{S}$ distribution in the absence of signal, which is shown by the solid curve.

" The distribution of S (significant) is expected to follow the normal distribution under the null hypothesis, consistent with the distribution in Fig.4 " (from the paper)

Upper Limit

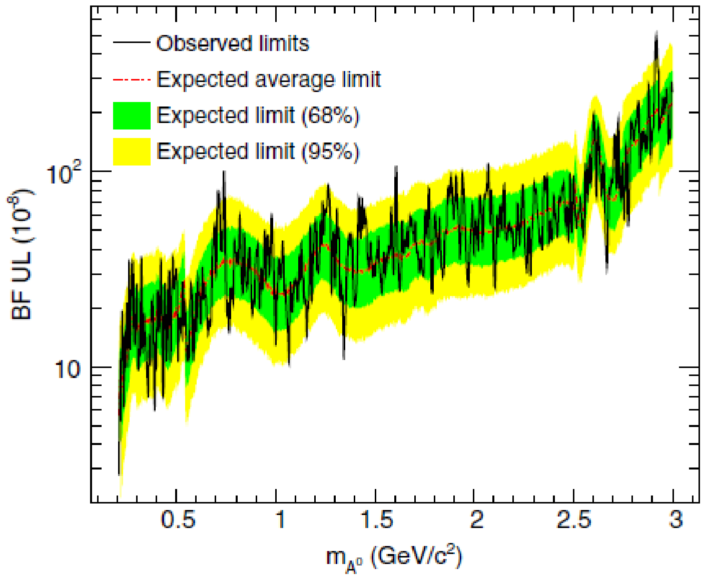


FIG. 5. The 90% C.L. upper limits (UL) on the product branching fractions $\mathcal{B}(J/\psi \to \gamma A^0) \times \mathcal{B}(A^0 \to \mu^+\mu^-)$ as a function of m_{A^0} including all the uncertainties (solid line), together with expected limits computed using a large number of pseudoexperiments. The inner and outer bands include statistical uncertainties only and contain 68% and 95% of the expected limit values. The average dashed line in the center of the inner band is the expected average upper limit of 1600 pseudoexperiments. A better sensitivity in the mass region of $0.212 \leq m_{A^0} \leq 0.22$ GeV/c^2 is achieved due to almost negligible backgrounds as seen in Fig. 2 (top).

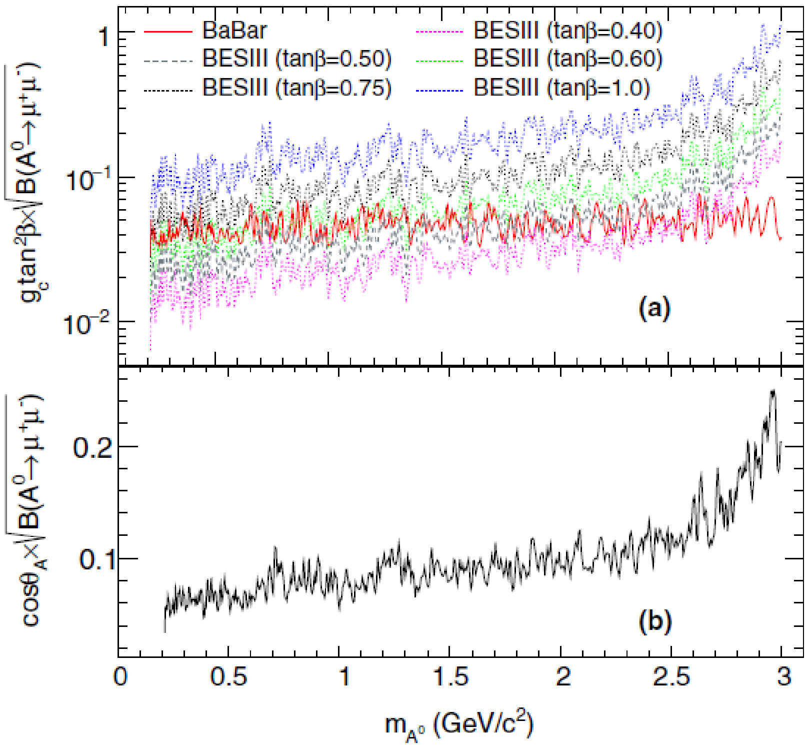


FIG. 6. (a) The 90% C.L. upper limits on $g_b (= g_c \tan^2\beta) \times \sqrt{\mathcal{B}(A^0 \to \mu^+\mu^-)}$ for the *BABAR* [16] and BESIII measurements and (b) $\cos\theta_A (= |\sqrt{g_b g_c}|) \times \sqrt{\mathcal{B}(A^0 \to \mu^+\mu^-)}$ as a function of m_{A^0}. We compute $g_c \tan^2\beta \times \sqrt{\mathcal{B}(A^0 \to \mu^+\mu^-)}$ for different values of $\tan\beta$ to compare our results with the *BABAR* measurement [16].

Summary

- Search was conducted for a light Higgs boson in the radiative decays of J/ψ , using large data sample taken in 2009.

- No significant signal and set 90% C.L. upper limit on $B(J/\psi\text{->}\gamma A^0)\text{x}B(A^0\text{->}\mu^+\mu^-)$ for $0.212 < M_{A0} < 3.0$ GeV/c^2

- The combined limits on $\cos(\theta_A)$*sqrt($B(A^0\text{->}\mu^+\mu^-)$) for BESIII & BABAR favor that the A^0 is to be mostly singlet.