



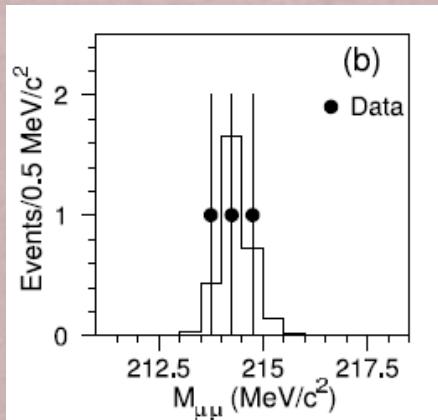
Search for Light Higgs Bosons with $\Upsilon(1S)$ or $\Upsilon(2S)$ decays at Belle



Paoti Chang
National Taiwan University
ICHEP 2012
6 July, Melbourne, Australia

Introduction

- In NMSSM, CP-odd Higgs boson (A^0) may exist with $m_{A^0} < 2 m_b$. \Rightarrow Accessible in $\Upsilon(nS) \rightarrow \gamma A^0$ at B factory
R. Dermisek, J. F. Gunion, B. McElrath PRD 75, 051105 (2007)
- Possible explanations for the three HyperCP events

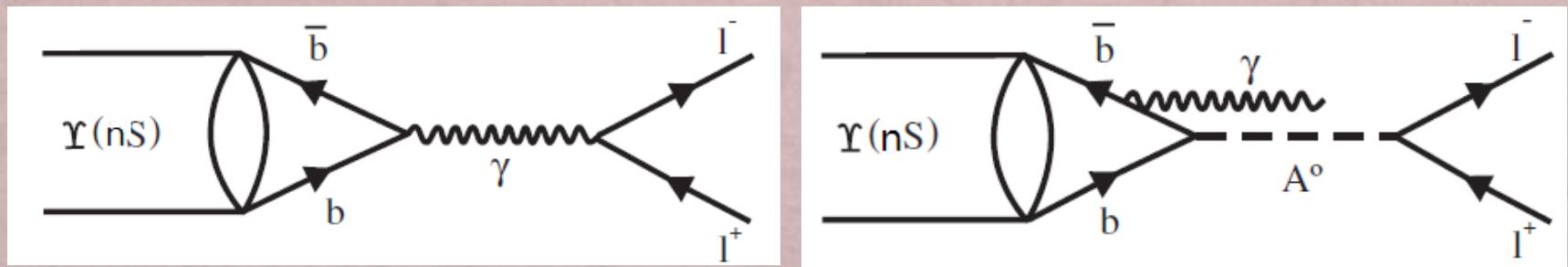


$$\Sigma^+ \rightarrow p \mu^+ \mu^-$$

- H. K. Park et al., PRL94, 021801 (2005)

- Theoretical interpretations
 - \Rightarrow Light scalar Higgs
 - 1. X. G. He et al., PRL 98, 081802 (2007)
 - 2. M. L. Mangano and P. Nason, Mod. Phys. Lett. A 22, 1373 (2007)
 - \Rightarrow Dark photon
 - M. Reece, L.-T. Wang, arXiv: 0904.1743
 - \Rightarrow Axion
 - Y. Nomura et al., PRD 79, 075008 (2009)

Decay Branching Fractions



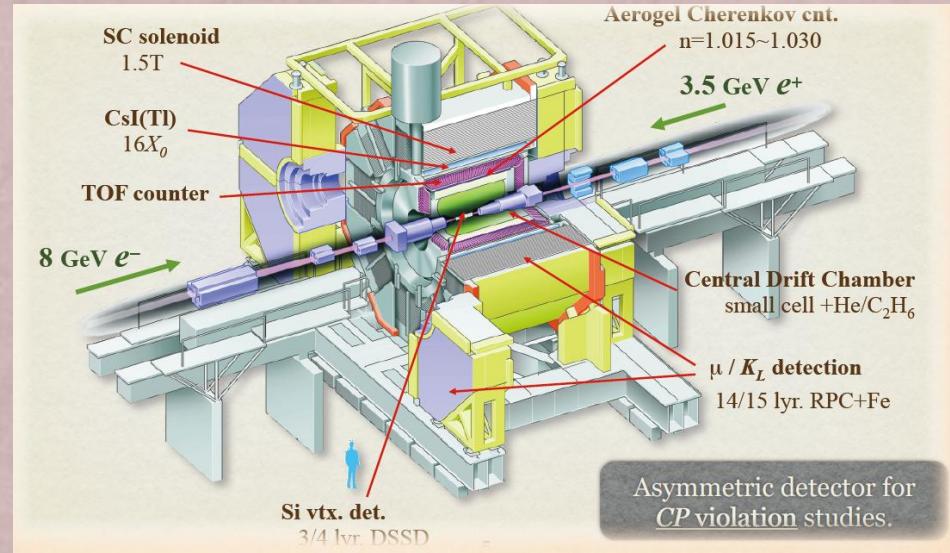
Original figures from M. SANCHIS-LOZANO, JPSJ.76.044101, modified by P. Chang

- $\mathcal{B}(\Upsilon(nS) \rightarrow e^+e^-) \sim \mathcal{B}(\Upsilon(nS) \rightarrow \mu^+\mu^-)$
 $\sim \mathcal{B}(\Upsilon(nS) \rightarrow \tau^+\tau^-)$
- $\Upsilon(nS) \rightarrow \gamma A^0, A^0 \rightarrow l^+ l^-$ is helicity suppressed.
If $m_{A^0} > 2m_\tau$, $A^0 \rightarrow \tau^+\tau^-$ dominates the leptonic decays.

Previous Experimental Results

Experiments	Data Sample	Product of BR	90% upper limits
CLEO	21.5 million $\Upsilon(1S)$ events	$\mathcal{B}(\Upsilon(1S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \mu^+ \mu^-)$	$(1.0 - 20) \times 10^{-6}$
		$\mathcal{B}(\Upsilon(1S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \tau^+ \tau^-)$	$(1.0 - 48) \times 10^{-5}$
BABAR	99 million $\Upsilon(2S)$ events	$\mathcal{B}(\Upsilon(2S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \mu^+ \mu^-)$	$(0.26 - 8.3) \times 10^{-6}$
BABAR	122 million $\Upsilon(3S)$ events	$\mathcal{B}(\Upsilon(3S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \mu^+ \mu^-)$ $\mathcal{B}(\Upsilon(3S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \tau^+ \tau^-)$	$(0.27 - 5.5) \times 10^{-6}$ $(1.5 - 16) \times 10^{-5}$

KEKB and Belle



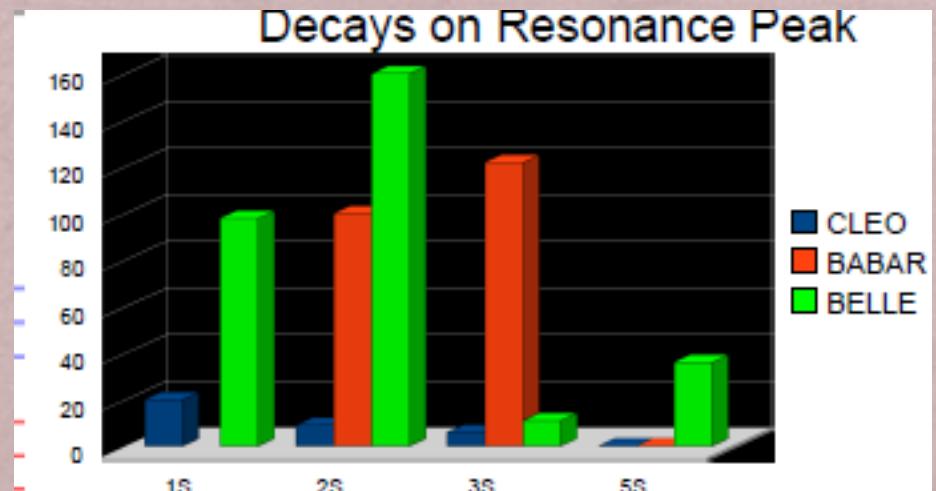
Data samples

$\Upsilon(5S)$: 121 fb^{-1} ; $\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3.0 fb^{-1} ; $\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 5.7 fb^{-1} ; off peak : 87 fb^{-1}

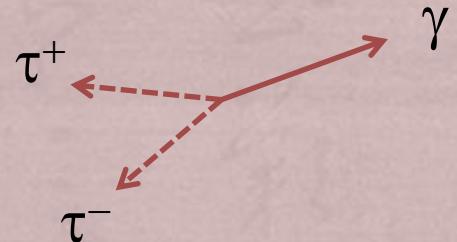
Energy scan: 30 fb^{-1}



Search for Light Higgs at Belle

- Search for decays $\Upsilon(1S, 2S) \rightarrow \gamma A^0$, $A^0 \rightarrow \tau^+ \tau^-$
- Data samples: $1.09 \times 10^8 \Upsilon(1S)$ + 1.08 fb^{-1} off peak
 $1.58 \times 10^8 \Upsilon(2S)$
- m_{A^0} is the recoil mass of γ in the Υ rest frame.

$$m_{A^0}^2 = (m_\Upsilon - E_\gamma)^2 - p_\gamma^2 = m_\Upsilon^2 - 2m_\Upsilon E_\gamma$$



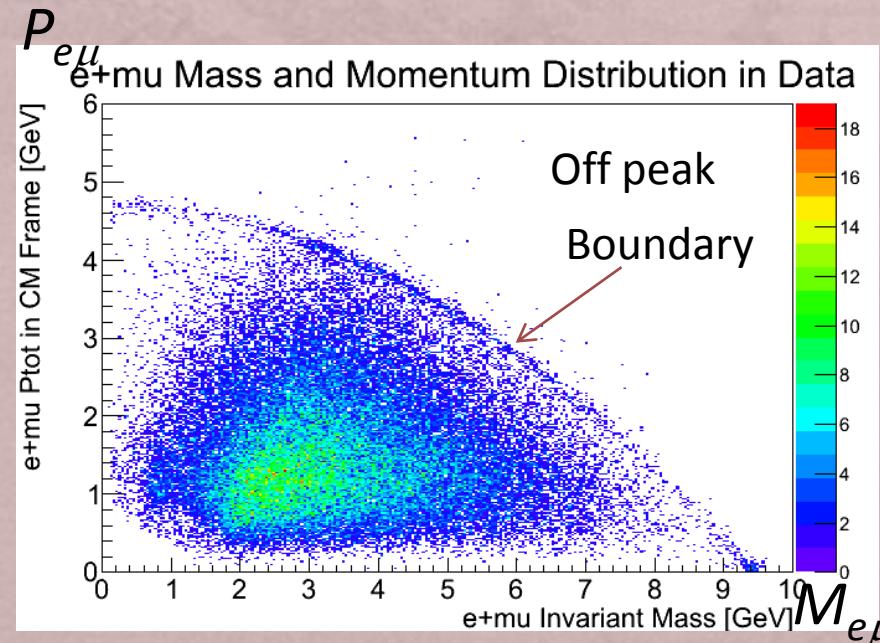
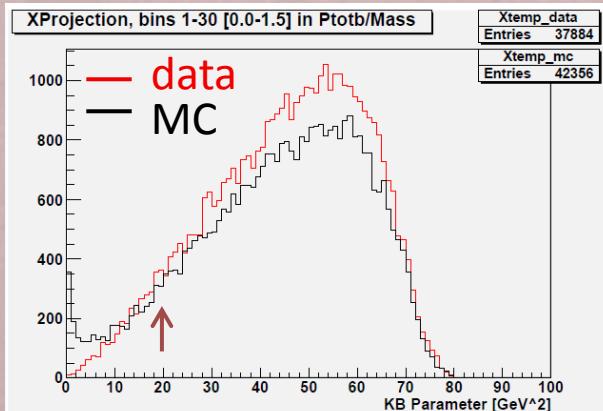
- Identify $\tau^+ \tau^-$ with their leptonic decays.
Search for bumps in photon energy spectrum.

$\Upsilon(1S)$ Analysis

+ Event selections:

1. Identify $\tau^+\tau^- \rightarrow e^\pm\mu^\mp\nu_\tau\nu_e\bar{\nu}_\tau\nu_\mu$; No additional tracks.
2. π^0 veto for γ ; $\Delta R(e, \gamma) > 0.2$ to avoid Bremsstrahlung
3. $1.5 < E_{\text{miss}} < 7.5$ GeV; $-0.9 < \cos(\theta_{\text{miss}}) < 0.96$
5. kinematic boundary

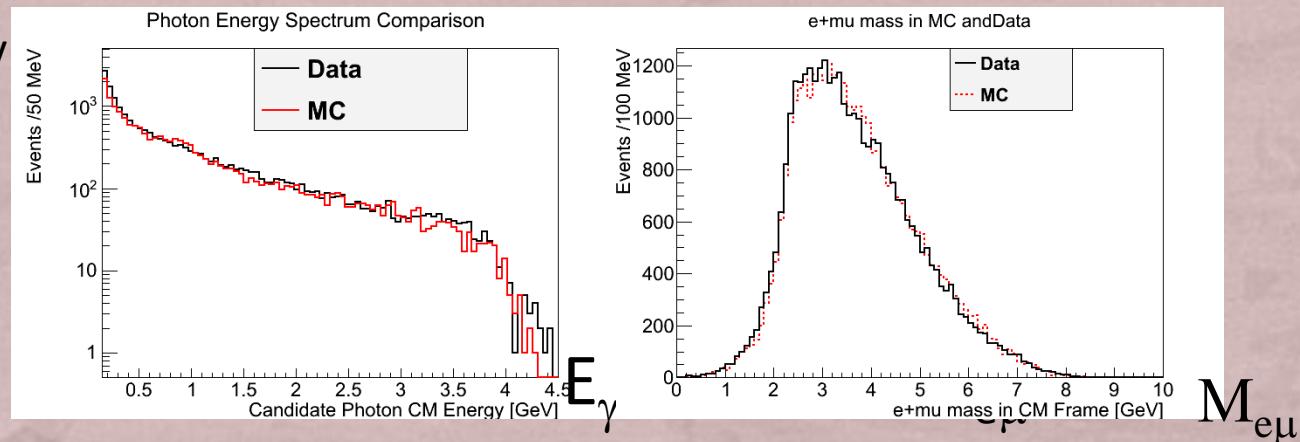
$$KB = s - M_{e\mu}^2 - 2E_{e\mu}P_{e\mu}$$



Background Modeling

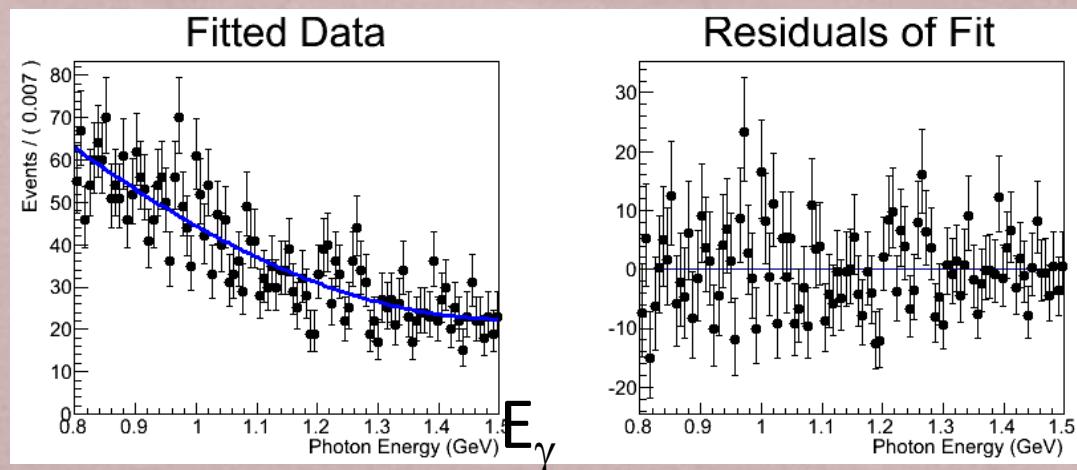
- Compare data and MC using off-peak data

1. Small discrepancy at low energy.
2. Dominant by $e^+e^- \rightarrow (\gamma)\tau^+\tau^-$
3. $E_\gamma > 0.8$ GeV



- Obtain background PDF using MC, including Υ decays

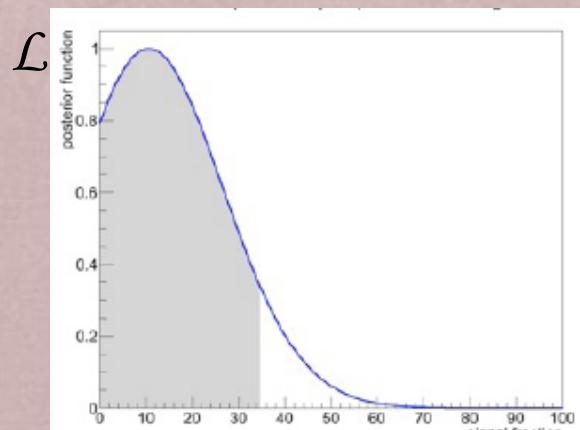
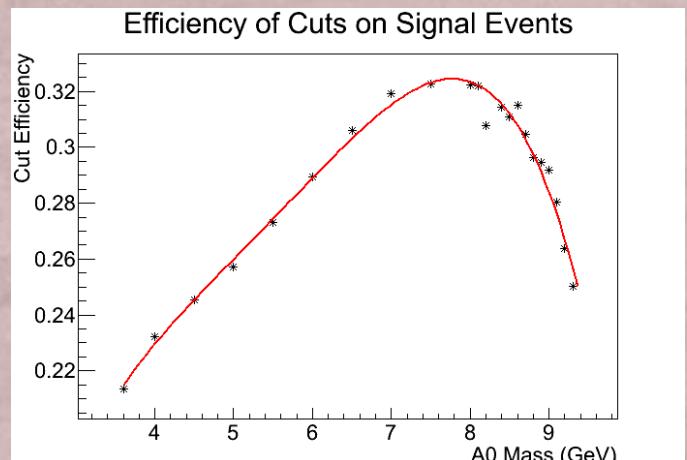
Two E_γ regions:
0.8 – 1.5, 1.5–4.3.
Each fit with 3rd order polynomial



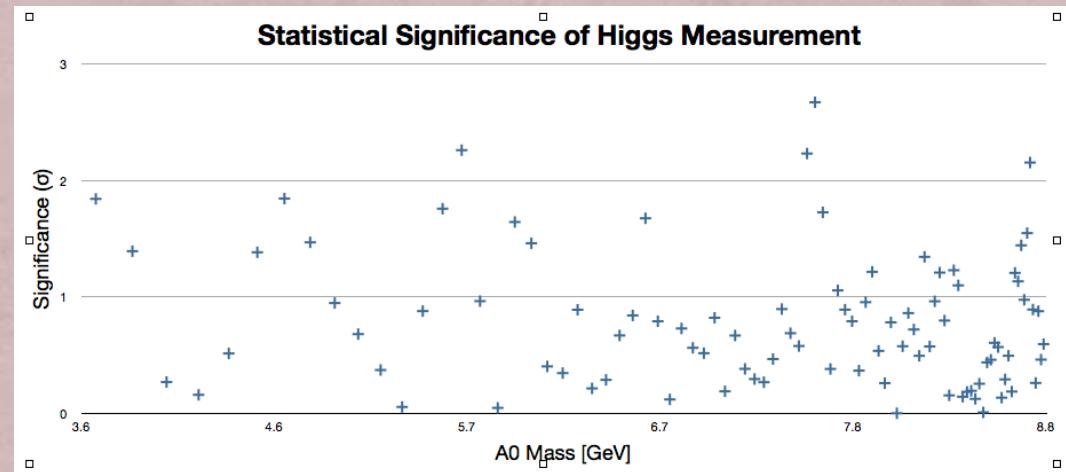
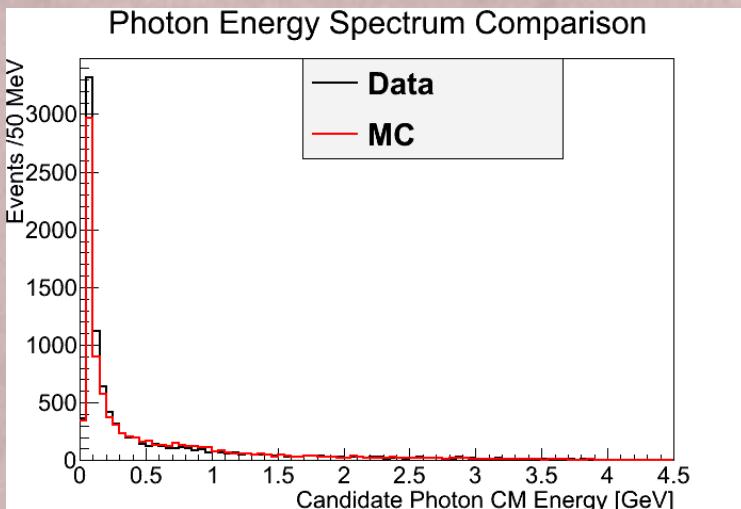
Signal Extraction

- Model signal PDFs by a Gaussian function.
Obtain efficiencies and Gaussian width as a function of A^0 and E_γ from MC.
- Scan E_γ with a fit within $\pm 10\sigma$ for each assumed E_γ peak.
- If no significant signal is found, provide 90% C.L. limit.

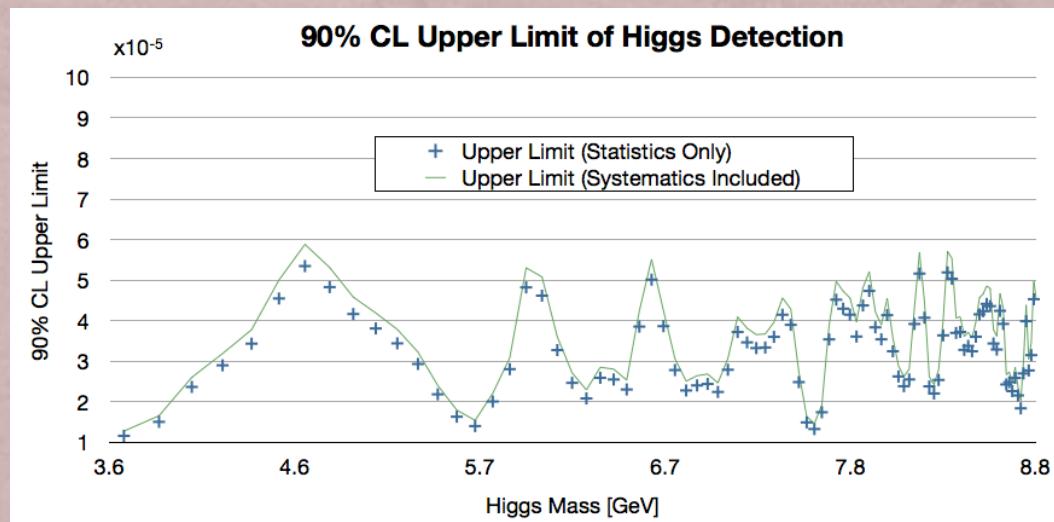
$$\int_0^N \mathcal{L}(n)dn = 0.9 \int_0^\infty \mathcal{L}(n)dn$$



Preliminary Results



- All fit significances are less than 3.0 σ .
- $\mathcal{B}(\Upsilon(1S) \rightarrow \gamma A^0) X$
- $\mathcal{B}(A^0 \rightarrow \tau^+ \tau^-)$
- $< (1.2 - 5.9) \times 10^{-5}$



$\Upsilon(2S)$ Analysis

- Strategy:

1. $\Upsilon(2S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+ \tau^-$
2. $\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^-, \Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+ \tau^-$
ISR background is substantially reduced.
3. Identify $\tau^+ \tau^-$ in $e^\pm \mu^\mp$ plus missing energy.

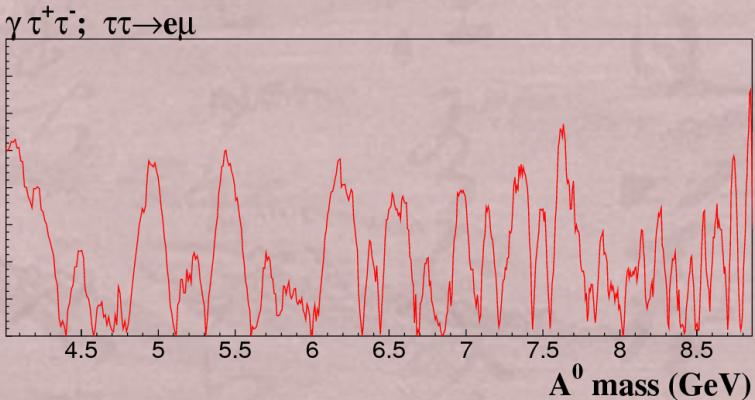
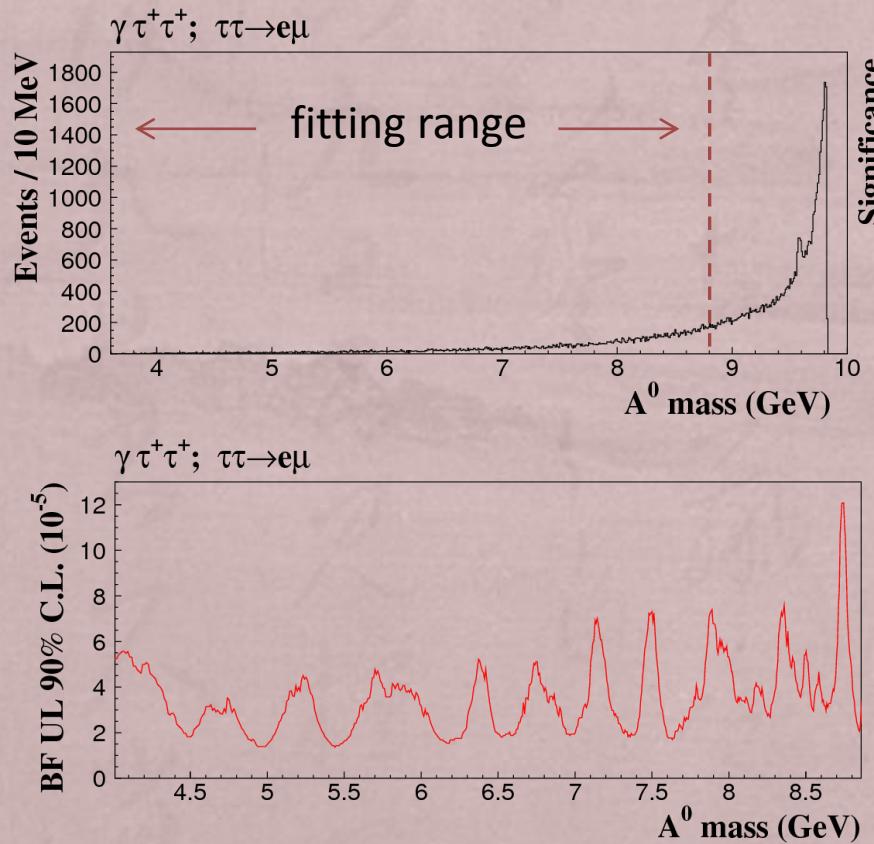
- Event selections:

1. Require only two charged tracks for $\Upsilon(2S) \rightarrow \gamma A^0$
2. $E_\gamma > 0.2 \text{ GeV}, E_{\text{miss}} > 2 \text{ GeV}, 30^\circ < \cos\theta_{\text{miss}} < 150^\circ$
3. For $\pi\pi$ tagged $\Upsilon(1S) \rightarrow \gamma A^0$ analysis,
require the recoil mass of $\pi^+ \pi^-$ lies in $\Upsilon(1S)$.

Fitting strategy

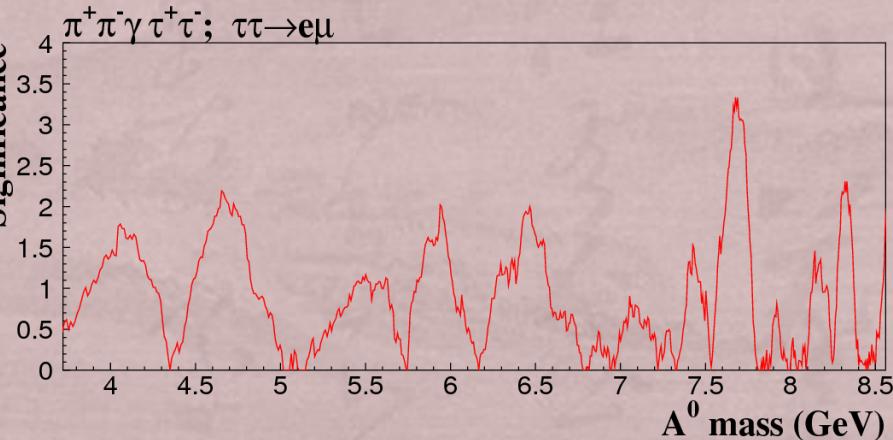
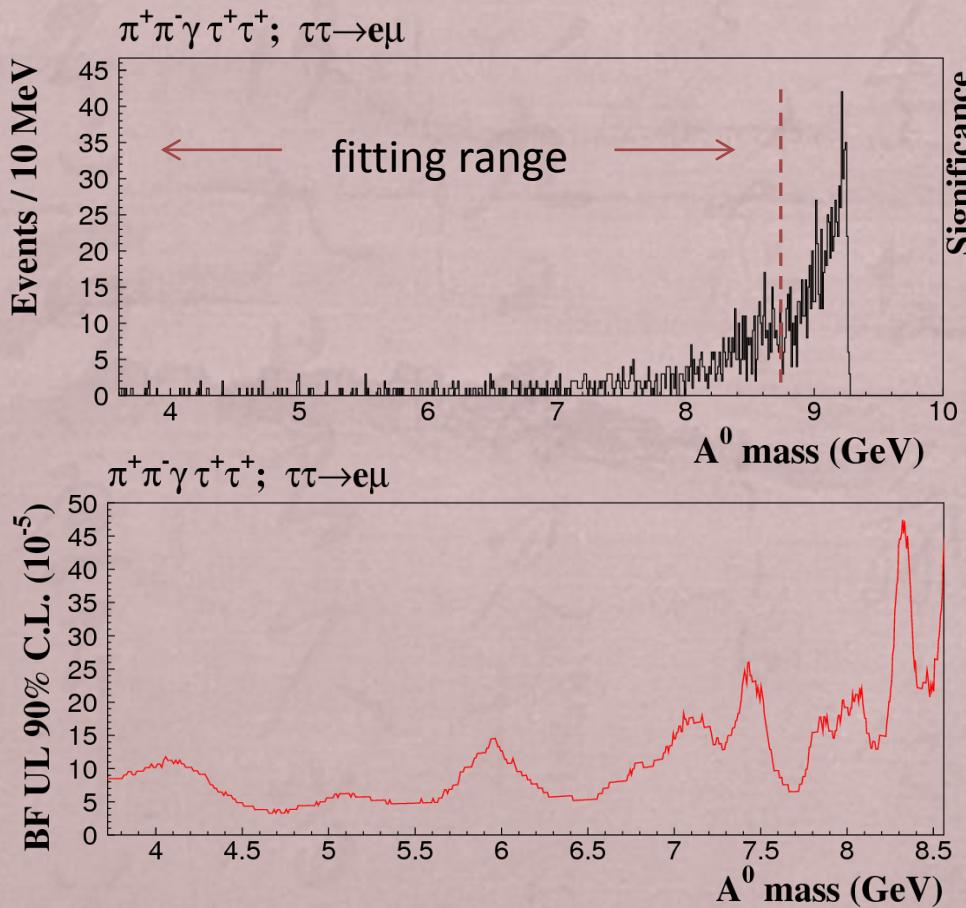
- Obtain signal efficiency and PDF parameters for various A^0 masses using MC. \Rightarrow Look-up tables
- Use interpolation to provide the efficiency and PDF parameters for any A^0 mass.
- Each fitting range is about $\pm 5\sigma$ (obtained from signal MC) for an assumed A^0 mass, ranging from 700 to 1200 MeV.
- Model background shape by a first order Chebyshev.
- Perform E_γ scan in 5 MeV step up to $M_{A^0} = 8.8$ GeV.

Preliminary results on $\Upsilon(2S) \rightarrow \gamma A^0$



$\mathcal{B}(\Upsilon(2S) \rightarrow \gamma A^0) \times$
 $\mathcal{B}(A^0 \rightarrow \tau^+ \tau^-)$
 $< (1.4\text{--}12) \times 10^{-5}$

Preliminary results on $\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^+ \pi^-$, $\Upsilon(1S) \rightarrow \gamma A^0$



$\mathcal{B}(\Upsilon(1S) \rightarrow \gamma A^0) \times$
 $\mathcal{B}(A^0 \rightarrow \tau^+ \tau^-)$
 $< (3.3 - 53) \times 10^{-5}$

Summary

- We perform CP-odd light Higgs searches using $\Upsilon(1S)$ and $\Upsilon(2S)$ data samples. No significant signals were seen. We set upper limits for the product of branching fractions.
- Our limits are compatible with the CLEO and BABAR results.
- Search for $\Upsilon(nS) \rightarrow \gamma A^0$, $A^0 \rightarrow \mu^+ \mu^-$ is ongoing.

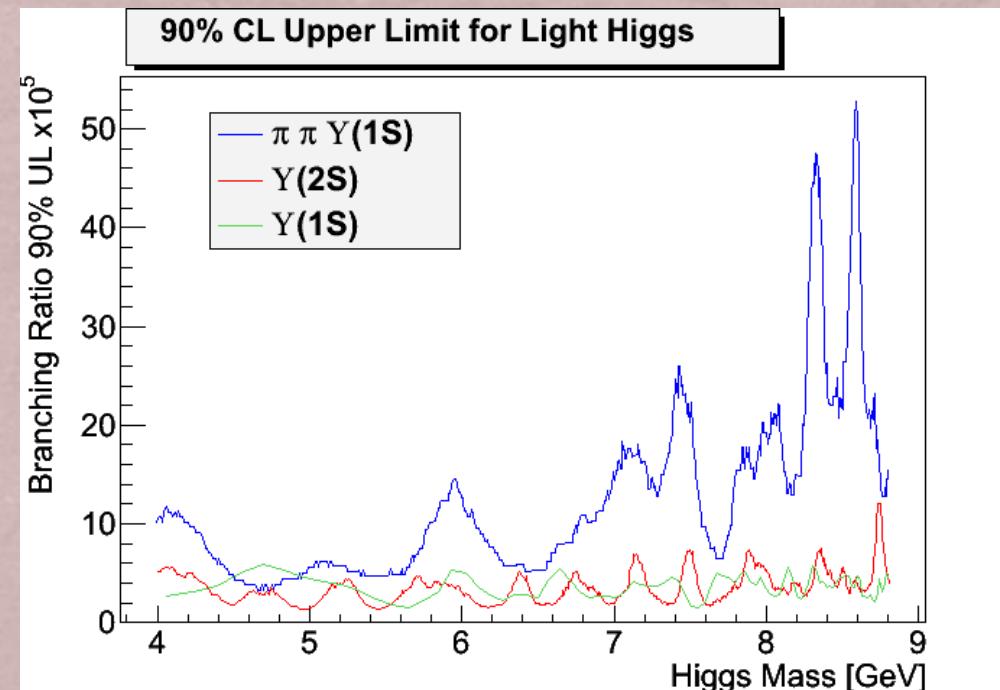
CLEO $\Upsilon(1S)$: $<(1.0-48)\times 10^{-5}$

BABAR $\Upsilon(3S)$: $<(1.5-16)\times 10^{-5}$

Belle $\Upsilon(1S)$: $<(1.2-5.9)\times 10^{-5}$

$\Upsilon(2S)$: $<(1.4-16)\times 10^{-5}$

$\pi\pi\Upsilon(1S)$: $<(3.3-52)\times 10^{-5}$



BACK UP

$\Upsilon(1S)$ Background MC and Kinematic Bound

- Off resonance background MC: $e^+e^- \rightarrow \tau^+\tau^- \Rightarrow \text{KKMC}$
- On resonance background MC: $e^+e^- \rightarrow \tau^+\tau^- + \dots$ (KKMC)
$$\Upsilon(1S) \rightarrow \tau^+\tau^- \quad (\text{Evtgen})$$
- Kinematic background

