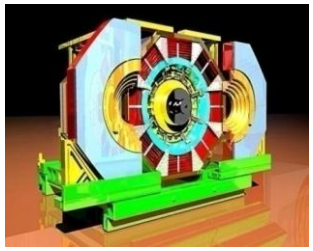
Search for Dark Sector at BESIII

Jinlin Fu

Nanjing University

(For the BESIII Collaboration)

Dark Forces workshop, Oct. 16th-19th, 2012 INFN, LNF



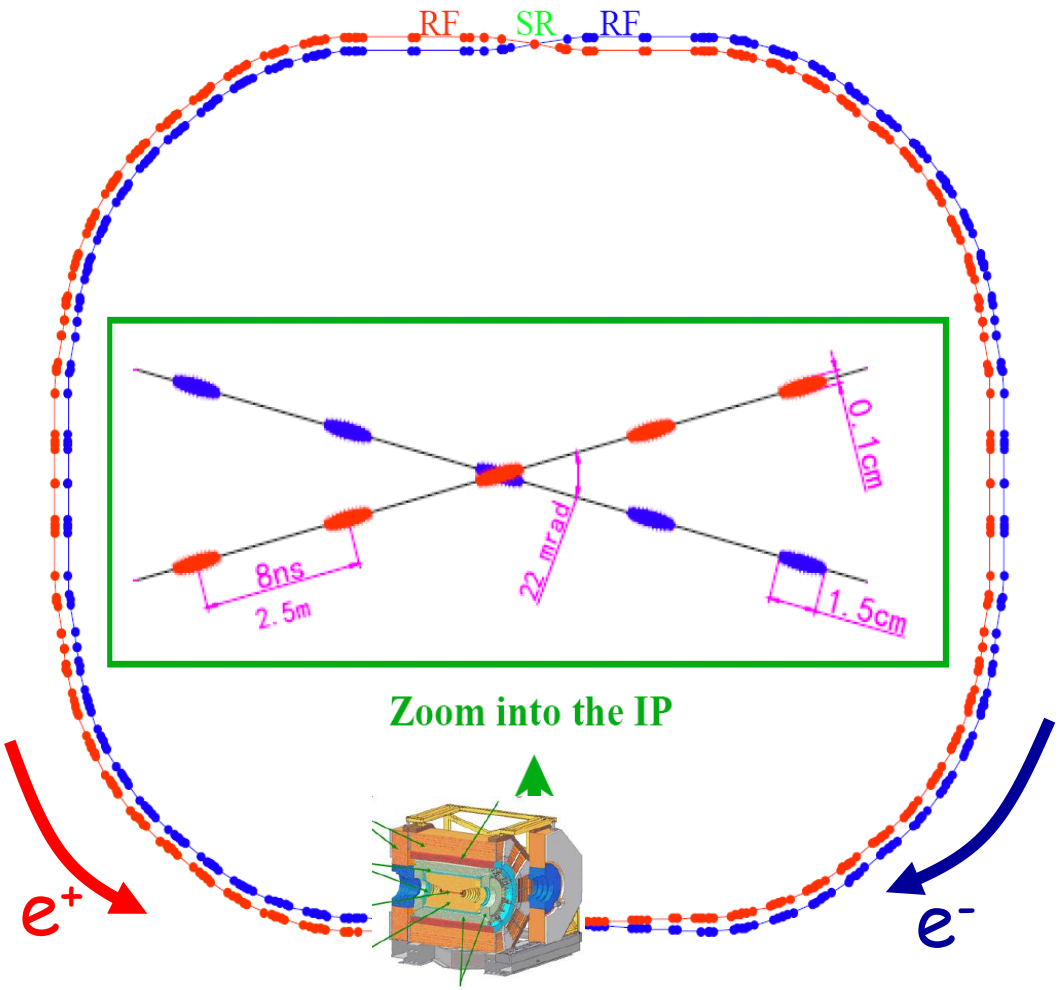
Outline

- BEPCII and BESIII
- Search for a light exotic particle
- Search for $\eta(\eta')$ invisible decays
- Summary

BEPCII Storage Rings

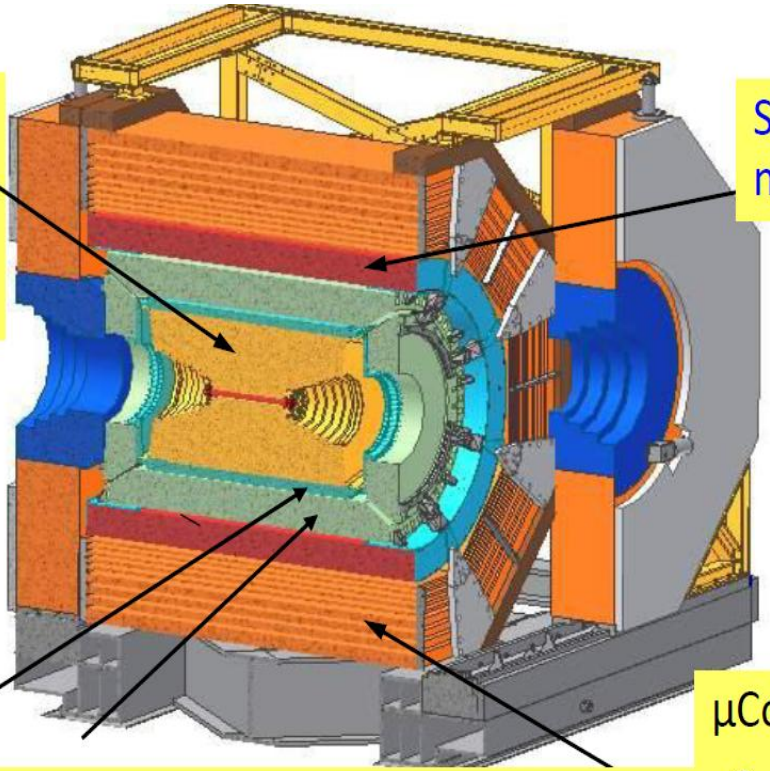
- Beam energy:
  1.0-2.3 GeV
- Design Luminosity:
  1×10^{33} cm^{-2}s^{-1}
- Achieved Luminosity:
  ~0.65×10^{33} cm^{-2}s^{-1}
- Optimum energy:
  1.89 GeV
- Energy spread:
  5.16×10^{-4}
- Number of bunches:
  93
- Bunches length:
  1.5 cm
- Total current:
  0.93 A
- Circumference:
  237 m

Beijing Electron-Positron Collider II



BESIII Detector

NIM A614, 345 (2010)



Drift Chamber (MDC)

$\sigma P/P\ (^0/_0) = 0.5\%(1GeV)$

$\sigma_{dE/dx}\ (^0/_0) = 6\%$

Super-conducting magnet (1.0 tesla)

Time Of Flight (TOF)

σ_T: 90 ps Barrel

110 ps endcap

EMC: $\sigma E/\sqrt{E}(^0/_0) = 2.5\ \%\ (1\ GeV)$

(CsI) $\sigma_{z,\phi}(cm) = 0.5 - 0.7\ cm/\sqrt{E}$

μCounter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

BESIII Data Set

- 2009: 106 M $\psi(2S)$ **4 × CLEOc**
  225 M J/ψ **4 × BESII**
- 2010: ~0.9 fb^{-1} $\psi(3770)$
- 2011: ~2.0 fb^{-1} $\psi(3770)$
  ~0.5 fb^{-1} @ 4.01 GeV

} **3.5 × CLEOc**

- 2012: 0.4 billion $\psi(2S)$
  1 billion J/ψ

World's largest sample of J/ψ, $\psi(2S)$ and $\psi(3770)$.
(and still growing)

Charmonium Physics
D-Physics
Light Hadron Spectroscopy
τ-Physics
... **New Phyics**

Tentative future running plans:

- 2013: E_{CM}=4260 and 4360 MeV for "XYZ" studies(0.5 fb^{-1} each point)
- 2014: E_{CM}=4170 MeV for D_s (~2.4 fb^{-1})
- 2015: TBD Additional $\psi(3770)$

Search for a light exotic particle in $J/\psi \to \gamma\mu^+\mu^-$

PRD 85, 092012 (2012)

Motivation

- NMSSM: solvoes hierarchy problem by extending Higgs sector, leads to a CP-odd Higgs and adds a light neutralino(χ^0)
- Light CP-odd Higgs A^0 can be directly produced in decay of heavy quarkonium, and dominantly decays to $\mu^+\mu^-$.

  J. Gunion et al., PRD 73, 015011 (2006),Nomura et al., PRD 79, 075008 (2009)

- HyperCP: observation of 3 anomalous $\Sigma^+ \to p\mu^+\mu^-$ events with $M(\mu^+\mu^-) \sim 214.3$ MeV/c^2 H.K.Park et al., PRL 94, 021801 (2005)
- No evidence of new physics by searching for light di-lepton resonance: BABAR, BELLE…
- But still important to search for $J/\psi \to \gamma A^0$:
  possible couples to c-quark and leptons.
  $Br(J/\psi \to \gamma A^0)$ $10^{-9} \sim 10^{-7}$ level; R.Dermisck et al., PRD 77, 015013 (2008)
  Only one search from charmonium: Crystall Ball experiment
  $Br(J/\psi \to \gamma A^0) < 1.4 \times 10^{-5}$ (90% C.L.) for $M(A^0)<1.0$ GeV/c^2

  C. Edwards et al., PRL 48, 903 (1982)

Event Selection

- $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma\mu^+\mu^-$
- Four good charged tracks and at least one good photon
- π^0 veto: multi-γ with $E\gamma > 25$MeV
  $|M(\gamma\gamma)-0.135| >= 0.04$GeV/$c^2$
- $E\gamma$ highest
- π: Pair of oppositely charged tracks with recoil mass closest to M(J/ψ)
  μ: the other two tracks, at least one of them PID as muon.
- $3.092 < M(\text{recoil } \pi^+\pi^-) < 3.102$ GeV/c^2
- Kinematically fit using energy-momentum constraints
- $M(\mu^+\mu^-) < 3.02$ GeV/c^2

Data Set:
106 million ψ' collected in 2009

Upper limits for different masses

Unbinned ML fit to each interval in $2M_{\mu} < M(\mu^+\mu^-) < 3GeV$

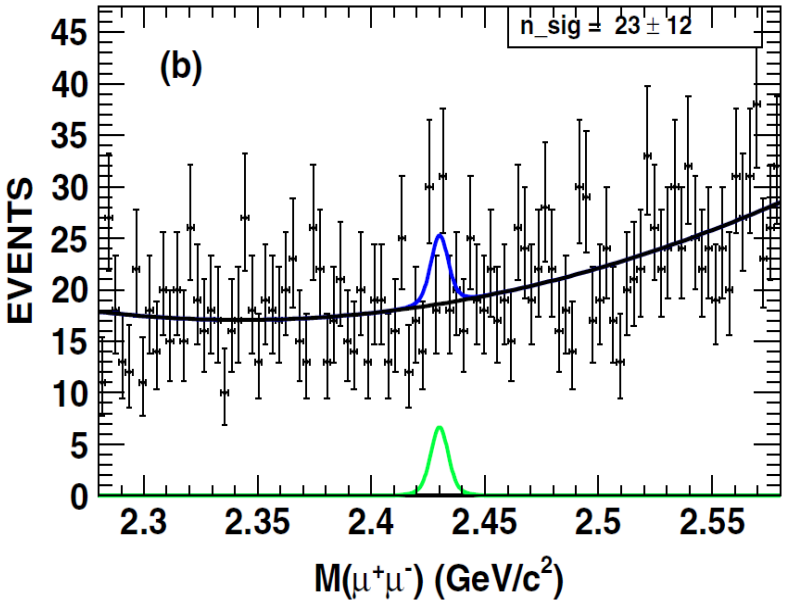
For each fit:

A^0 signal: MC-determined shape,

A^0 peak mass restricted to 5MeV/c^2-wide interval

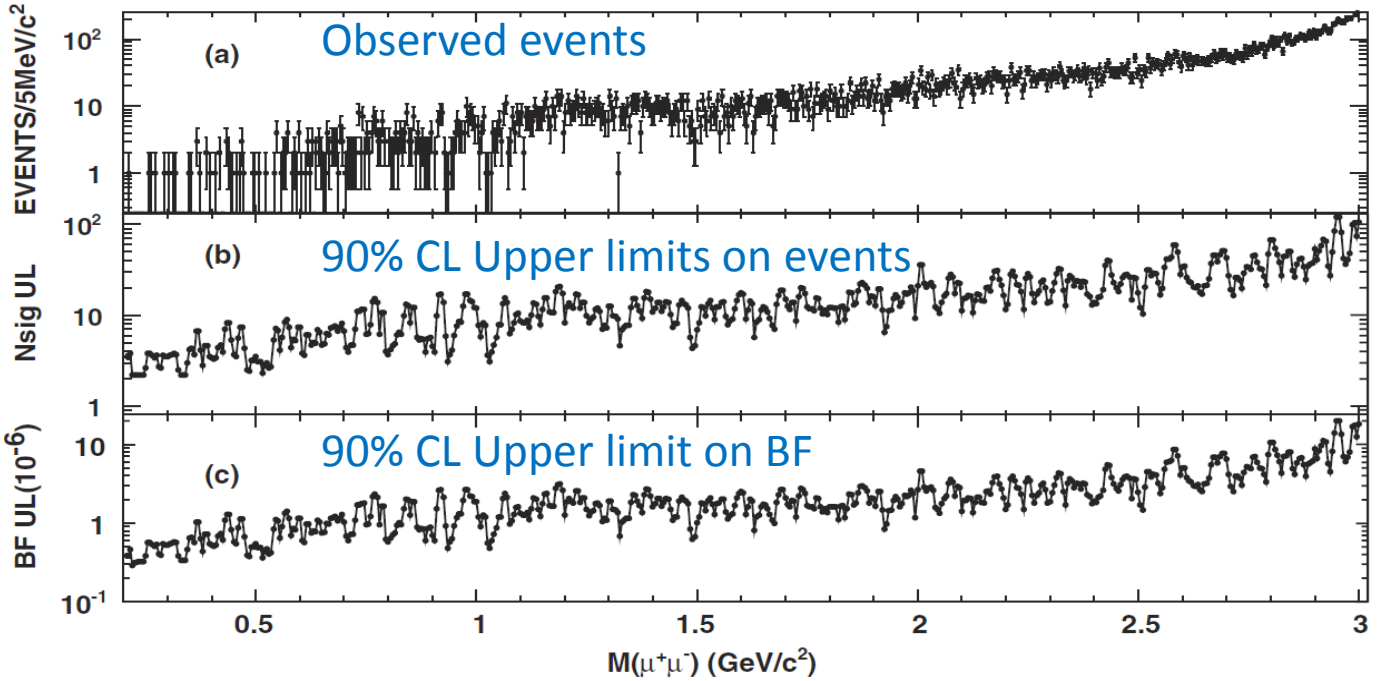
Background: polynomial;

Upper limit determined with Bayesian Method



A typical fit at 2.43 GeV/c^2

Results



$$\mathcal{B} < \frac{\mathrm{Nsig(UL)}/\varepsilon}{N(\psi') \times \mathcal{B}(\psi' \to \pi^+\pi^- J/\psi) \times (1-\sigma)}$$

σ: total error

1-σ: conservative result

Limits for $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$, $4 \times 10^{-7} \sim 2.1 \times 10^{-5}$ searched

No conformation of HyperCP around 214.3 MeV/c^2,

Observes one $\mu^+\mu^-$ event below 255MeV/c^2, limit set at 5×10^{-7}

Search for $\eta(\eta')$ invisible decays

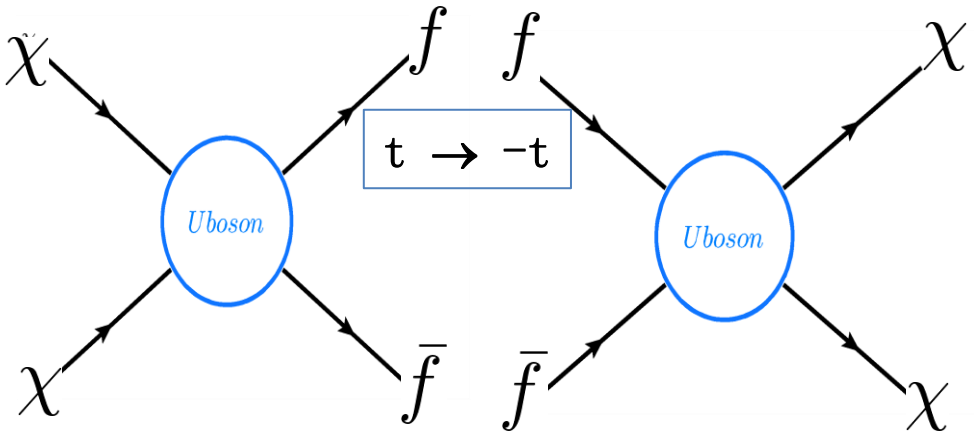
BESII: PRL 97, 202006 (2006)
BESIII: arXiv1209.2469, submitted to PRD

Motivation

- INTEGRAL satellite observed a large flux of 511 keV gamma from galactic center: non-relativistic $e^+e^- \to \gamma\gamma$
  Possible interpretation: from LDM annihilation: $\chi\chi \to e^+e^-$

  C. Boehm et al., PRL 92, 101301(2004)

- A new possible massive vector (U boson) mediates interaction between LDM and e^+e^- pair.

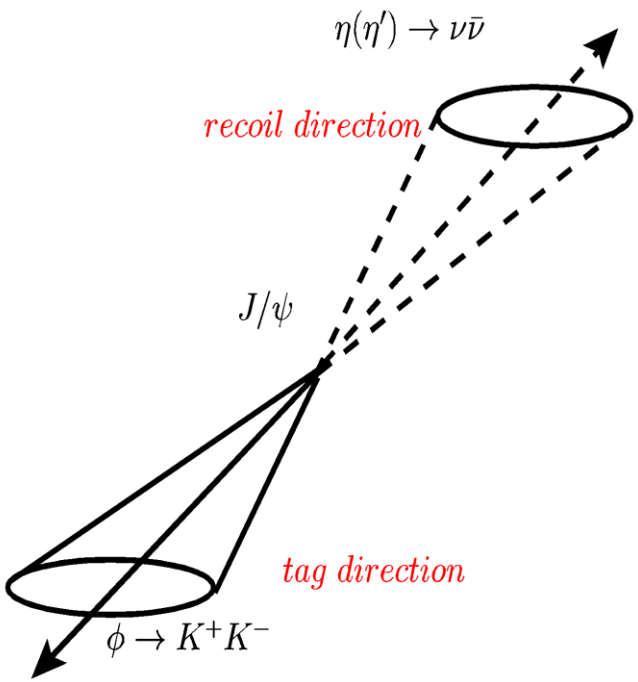


- Time reversed annihilation corresponds to **invisible decays** of quarkonia,
  measuring these decays give direct sensitivity to the $\mathbf{J^{PC}}$ of U boson.

  B. McElrath PRD 72, 103508(2005)

- Many ffbar states have been searched for, experimentally:
  π^0, η, η', J/ψ, Υ(1S)…

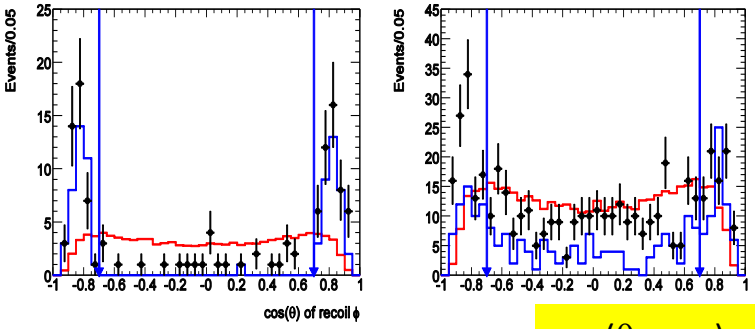
Event selection



- **$J/\psi \to \phi\eta(\eta')$, simple event topology.**
- **Only two charged tracks in event, identified as Kaons**
- **$1.01 < m(K^+K^-) < 1.03$ GeV/c^2**
- **Photon veto inside 1 rad cone around recoil ϕ**

$$P^{\mu}_{recoil} = P^{\mu}_{e+} + P^{\mu}_{e-} - P^{\mu}_{K+} - P^{\mu}_{K-}$$

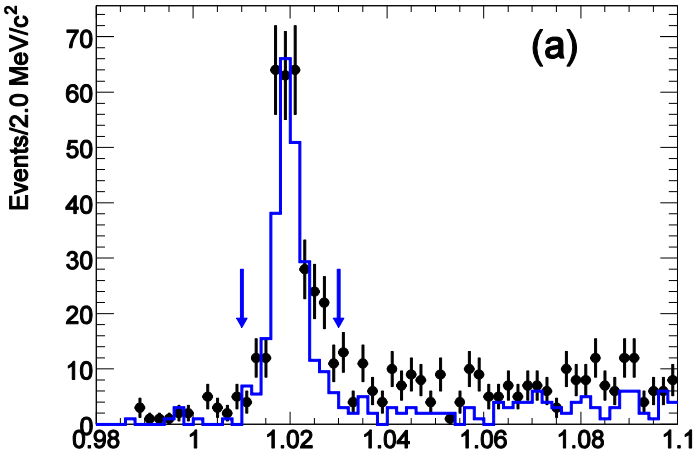
- **$|\cos\theta_{recoil}| < 0.7$**

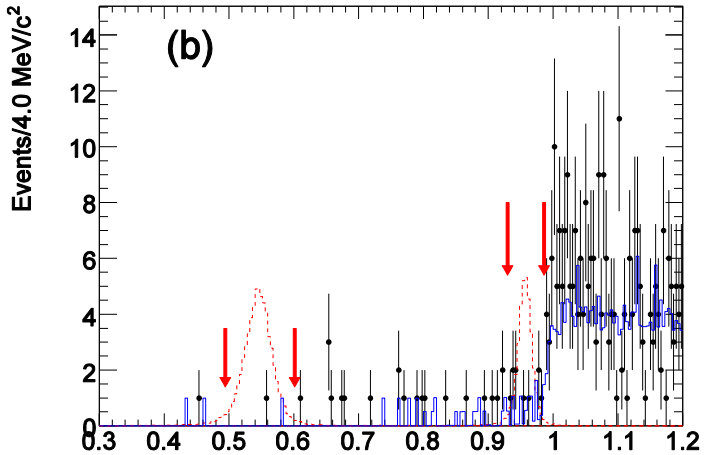


$\cos(\theta_{recoil\ \phi})$

Data Set:
225 million J/ψ collected in 2009

Backgrounds





Class I: $J/\psi\to\phi\eta(\eta'),\phi\to K^+K^-$, $\eta(\eta')\to$**visible final states:**

Signal region(3σ)

$N(\eta) = 0.18 \pm 0.02$

$N(\eta') = 1.0 \pm 0.2$

Class II: $J/\psi\to\phi$ **+non-**$\eta(\eta')$**, or non-**$\phi\eta(\eta')$**:**

Signal region(3σ)

$N(\eta) = 0.8 \pm 0.2$

$J/\psi\to\gamma\eta_c$, $\eta_c\to K\pi K_L$

$N(\eta') = 9.4 \pm 1.7$

$J/\psi\to\phi f_0(980), f_0(980)\to K_L K_L$

$J/\psi\to\phi K_L K_L$

$N(\eta)_{total} = 1.0 \pm 0.2$

$N(\eta')_{total} = 10.4 \pm 1.9$

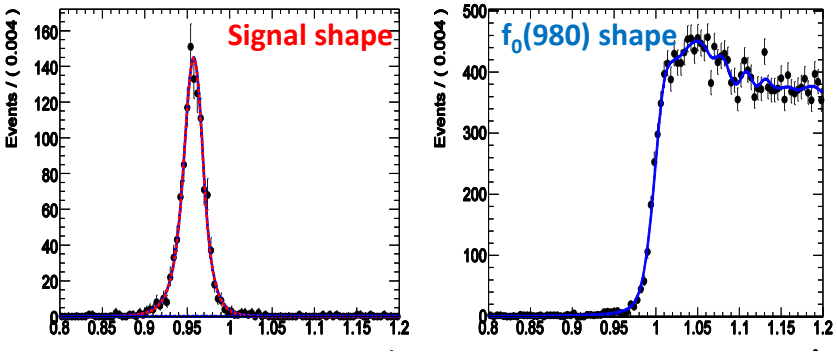
Upper Limit Calculation

BESIII Preliminary

- **For $\eta \to$ invisible:**
  observed event: 1,
  expected background: 1.0 ± 0.2,
  $N^{\eta}_{UL} = 3.34$ 90% C.L. (Feldman-Cousins)

POLE^{++} http://polepp.googlecode.com/svn/tags/POLEPP-1.1.0/

Flatté form



- **For $\eta' \to$ invisible:**
  An Unbinned extended Maximum Likelihood fit

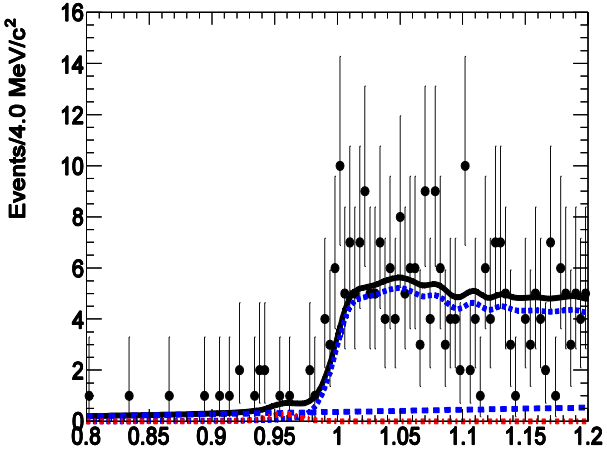
$$PDF = N_{sig} \times PDF_{sig} + N^{bkg}_{f0} \times PDF^{bkg}_{f0} + N^{bkg}_{non\text{-}f0} \times PDF^{bkg}_{non\text{-}f0}$$

PDF_{sig}: shape of $J/\psi \to \phi\eta'(\pi^-\pi^+\eta)$ from data

PDF^{bkg}_{f0}: shape of $J/\psi \to \phi f_0(980)(K_L K_L)$ from MC

M.Ablikim et al. (BES Collaboration) PLB 607, 243(2005)

$PDF^{bkg}_{non\text{-}f0}$: 1st chebychev polynomial



M(recoil ϕ)(GeV)

$N^{\eta'}_{UL} = 10.1$ 90% C.L. (Bayesian)

Results

BESIII Preliminary

$$\frac{\mathcal{B}(\eta \to \text{invisible})}{\mathcal{B}(\eta \to \gamma\gamma)} < \frac{N^{\eta}_{UL}/\epsilon_{\eta}}{N^{\eta}_{\gamma\gamma}/\epsilon^{\eta}_{\gamma\gamma}} \frac{1}{1-\sigma_{\eta}}$$

Many uncertainties cancelled:
J/ψ event, tracking efficiency, PID…

N^{η}_{UL}: # observed signal @ 90%CL

$N^{\eta}_{\gamma\gamma}$: # observed $\eta \to \gamma\gamma$

ε_{η}: efficiency of signal channel

$\varepsilon^{\eta}_{\gamma\gamma}$: efficiency of $\eta \to \gamma\gamma$

σ_{η}: total uncertainty

$B(\eta \to \text{invisible})/B(\eta \to \gamma\gamma) < 2.58 \times 10^{-4}$ @ 90% C.L.

$B(\eta' \to \text{invisible})/B(\eta' \to \gamma\gamma) < 2.39 \times 10^{-2}$ @ 90% C.L.

$B(\eta \to \text{invisible}) < 1.0 \times 10^{-4}$ @ 90% C.L.

$B(\eta' \to \text{invisible}) < 5.3 \times 10^{-4}$ @ 90% C.L.

disfavor

$B(\eta \to \chi\chi) \approx 1.4 \times 10^{-4}$
$B(\eta' \to \chi\chi) \approx 1.5 \times 10^{-6}$

Theoretically:
B. McElrath, arXiv:0712.0016

6 and 3 times

$B(\eta \to \text{invisible}) < 6.5 \times 10^{-4}$ @ 90% C.L.

$B(\eta' \to \text{invisible}) < 1.5 \times 10^{-3}$ @ 90% C.L.

2 times

CLEO-c result: PRL 102, 061801 (2009)

$B(\eta' \to \text{invisible}) < 9.5 \times 10^{-4}$ @ 90% C.L.

$B(\eta \to \text{invisible})/B(\eta \to \gamma\gamma) < 1.65 \times 10^{-3}$ @ 90% C.L.

$B(\eta' \to \text{invisible})/B(\eta' \to \gamma\gamma) < 6.69 \times 10^{-2}$ @ 90% C.L.

BESII result:
PRL 97, 202002 (2006)

Summary

- No observed signal of light CP-odd Higgs in radiative J/ψ decay in $\mu^+\mu^-$ final state.
  - Set upper limit on Br(J/$\psi\rightarrow\gamma A^0$, $A^0\rightarrow\mu^+\mu^-$): $10^{-7} \sim 10^{-5}$
  - Only one event observed below 225 MeV/c^{-2},
    Including 214.3 MeV/c^{-2} mass value of HyperCP, limit set at 5×10^{-7}.

- No observed signal of light DM in invisible decays of $\eta(\eta')$
  - Set upper limit on ratio of Branching Fraction, also Br($\eta(\eta')\rightarrow$invisible) improved by a factor of 6(3) to result from BESII,
    almost 2 times better than CLEO-c experiment for $\eta'\rightarrow$invisible.
  - $\eta\rightarrow$invisible disfavor a theory: $\eta\rightarrow\chi\chi$ B. McElrath, arXiv:0712.0016

THANK YOU!

BACKUP