Probe Seclude U(1) at BES

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SLAC

Outline

- Introduction
- Invisible decays of mesons @BESII/III

  Limit of invisible decays from BESII data;

  Limit of invisible decays at BESIII (see Yang-Heng Zheng's talk);
- Signature of U boson at BESIII

  Reach of U boson in direct production;

  Reach of U boson decays in charmonium decays;
- Summary

Introduction

- Experimental signature of Super symmetry is focused on heavy particles with 1TeV or above, however,
- A possible U(1) symmetry, which requires a new gauge boson could be light and weakly interacting with SM particles:

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \epsilon_Y F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{,\mu\nu} F'_{\mu\nu} + m^2_{A'} A'^{\mu} A'_{\mu},$$

P. Fayet PLB95, 285(1980)
B. Holdom PLB166, 196(1986)
N.Arkani-Hamed and N.Weiner JHEP 12,104(2008)

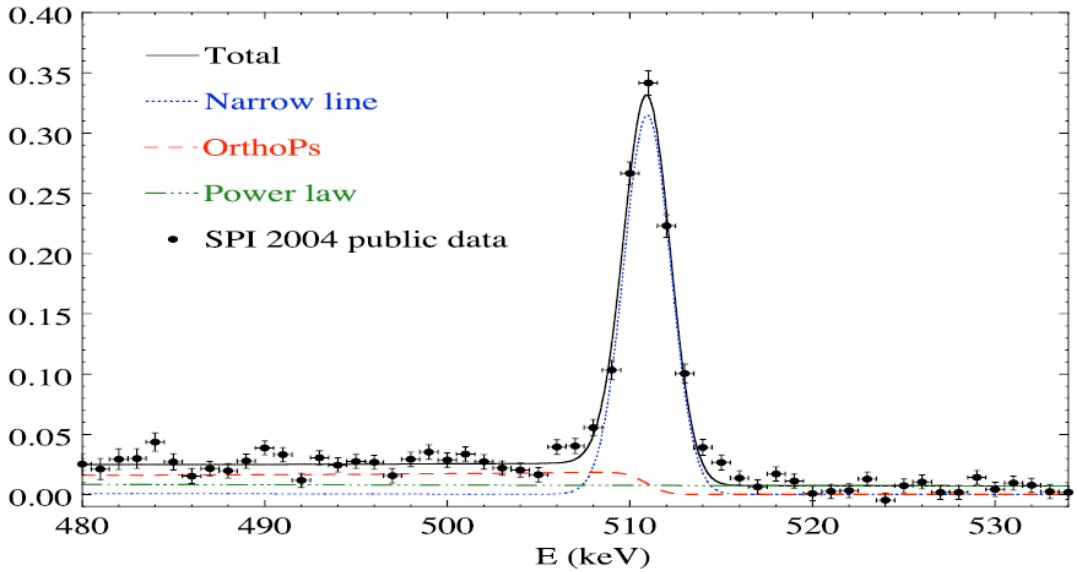
- The possible connection of the U-boson and light DM is interpreted in a view of electron /positron excesses observed by PAMELA, ATIC, FERMI.

Introduction

The SPI Spectrometer aboard the INTEGRAL satellite observed a large flux of photons with energy of 511 keV:

P. Jean et al., Astron. Astrophys. 407, L55(2003)

J. Knodlseder et al., Astron. Astrophys. 411, L457(2003).

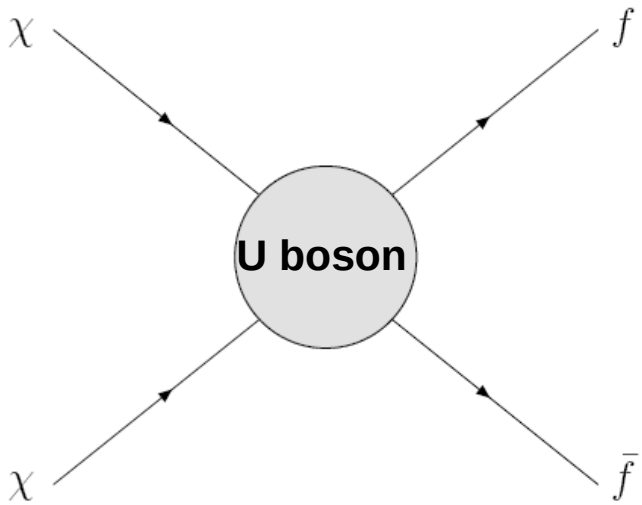


Such sharp line can only come from the annihilation of non-relativistic e^+e^- pairs .
Estimates of e^+ production by astrophysical source fall well short of required flux.
Possible interpretation: annihilation of light DM particles $\chi\chi \rightarrow e^+e^-$:

[C. Boehm, D. Hooper, J. Silk, M. Casse and J. Paul, PRL 92, 101301 (2004]

Light DM candidates and light U boson

Possible massive vector mediates interaction among MeV (scalar or majorana) dark matter and electron-positron:



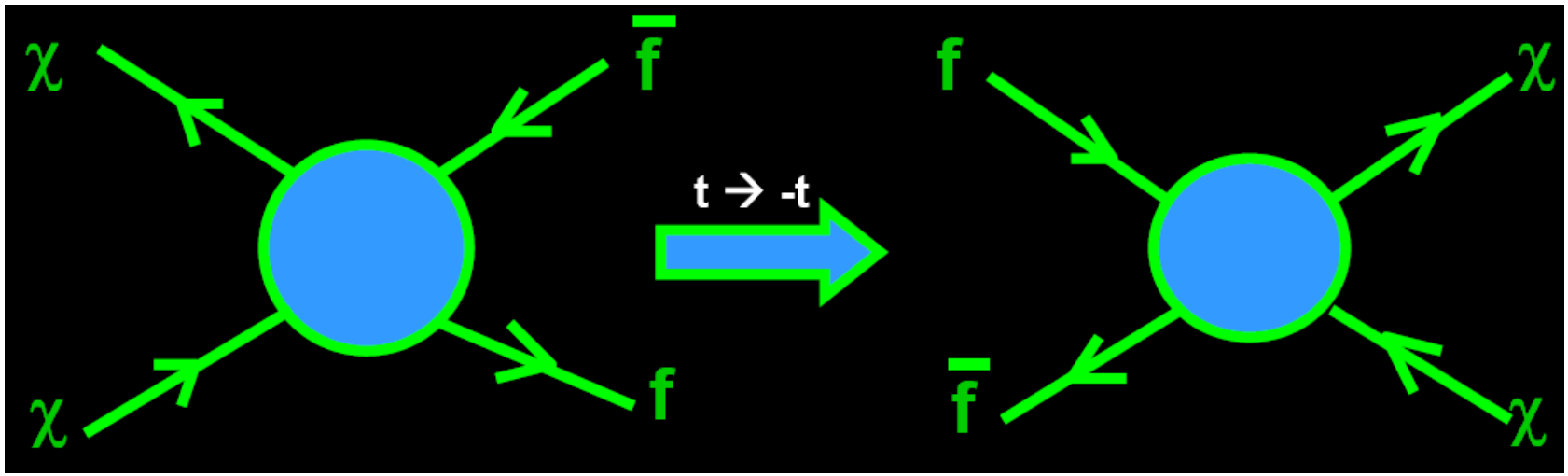
From astrophysical constraints, m_χ >20MeV could be excluded due to over-production of MeV photons through $\chi\chi \to e^+e^-\gamma$

[J.F.Beacom, N.F. Bell and G. Bertone, PRL 94, 171301(2005)]

Hence, one has:

$$m_e \leq m_\chi \leq 20 \text{ MeV}$$

Invisible decay of mesons



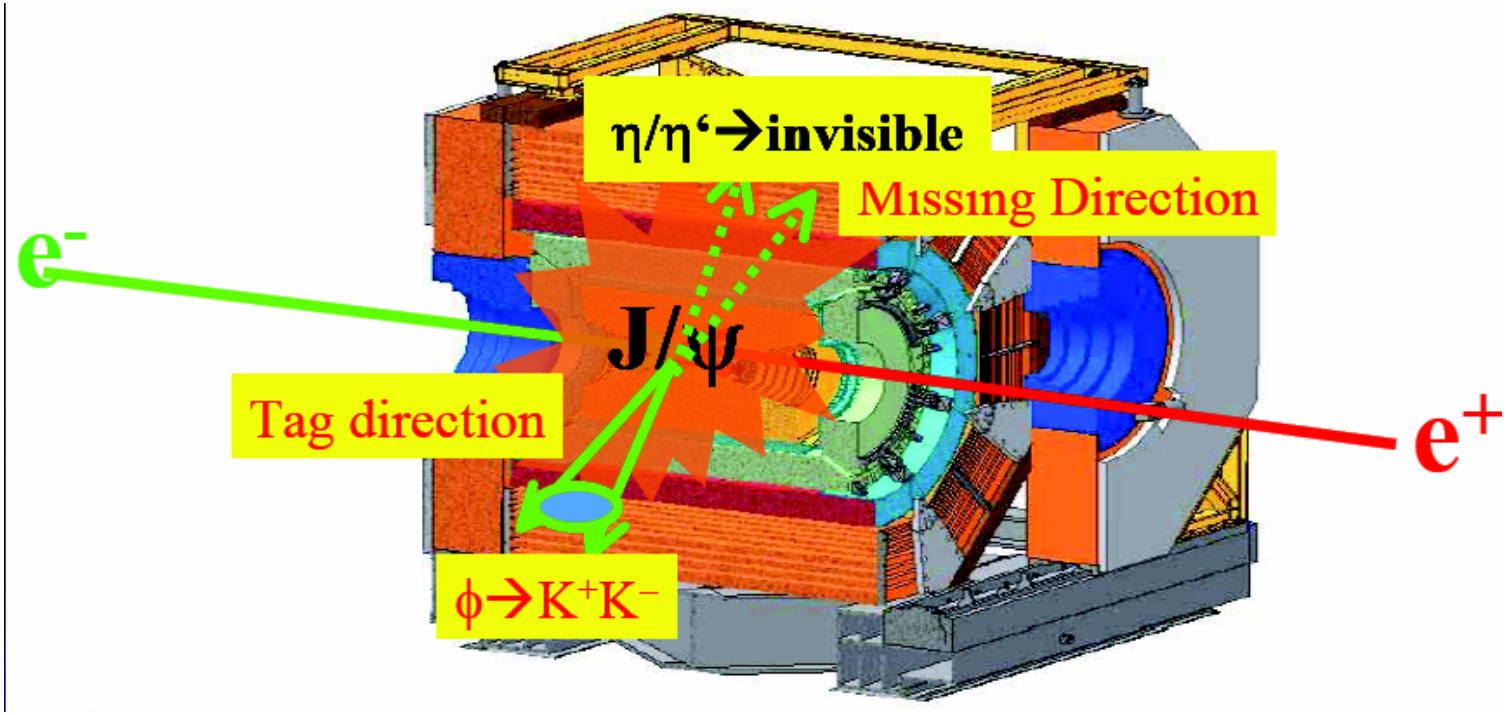
The time reversed annihilation diagram corresponds to invisible decays of quarkonia.

Measuring the invisible decays give direct sensitivity to the J^{PC} of the mediator.

B. McElrath PRD 72, 103508 (2005)

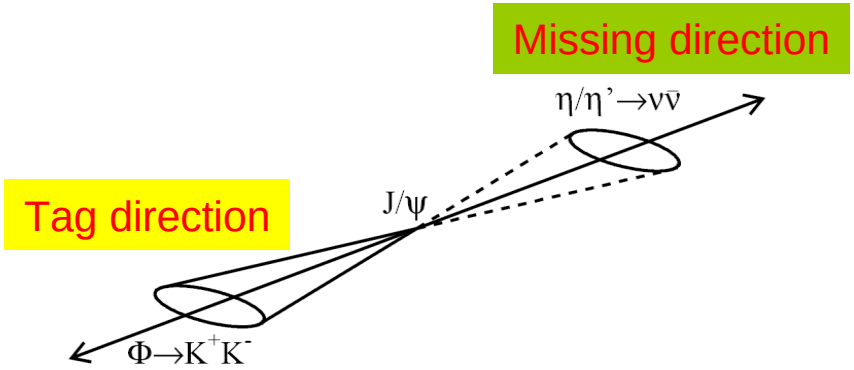
We have many ffbar bound states : π^0, η, ω, ρ, ϕ, η_c,χ_c,ψ(nS),Υ(ns).

Invisible decays of η/η' at BES

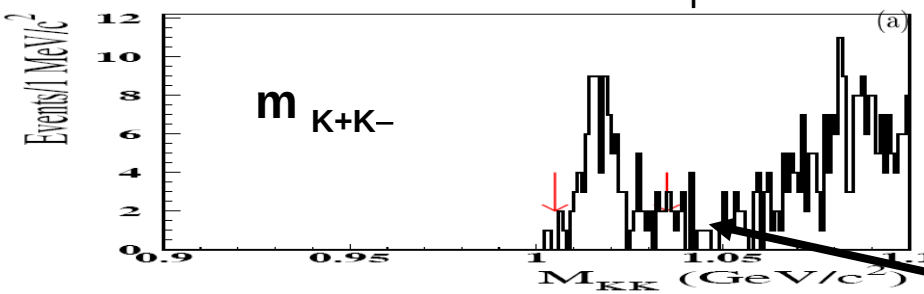


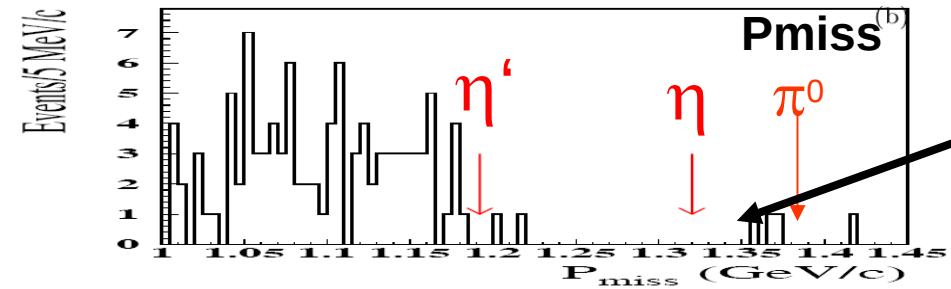
- $J/\psi \rightarrow \phi\eta/\eta(958)$, where $\eta/\eta(958) \rightarrow$ Invisible, both hadrons are boosted.
- Reconstructing $\phi \rightarrow K^+K^-$, looking at missing mass or missing momentum of ϕ .
- No any hit information are required outside of the core of ϕ decays.

Reconstruction of $J/\psi \rightarrow \phi(K^+K^-)$+nothing



58 million J/ψ@BESII





- Two good charged Kaons in MDC, $|\cos(\theta)|<0.8$; track from IP; PID as kaons;
- No clusters in BSC in the region of outside cones of 30^0 around the charged kaons.
- For the missing momentum: $|\cos(\theta_{miss})| < 0.7$;
- $1.005 < m(K^+K^-) < 1.035$ GeV (3σ);

Cleanly tagging "nothing"
Background free at BES!

Background estimations in $\eta/\eta' \to$ invisible

- Class I: $J/\psi \to \phi\eta(\eta')$, $\phi \to K^+K^-$, $\eta(\eta') \to$ visible final states, these expected backgrounds are negligible small.
- Class II: $J/\psi \to \phi$ + non-$\eta(\eta')$, or non-$\phi\eta$

  (1) $J/\psi \to \phi\, K_L K_L$, $\phi f_0(980)$ $[f_0(980) \to K_L K_L]$;

  (2) $J/\psi \to K^{*0} K_L$, $K^{*0} \to K\pi$

  The expected backgrounds

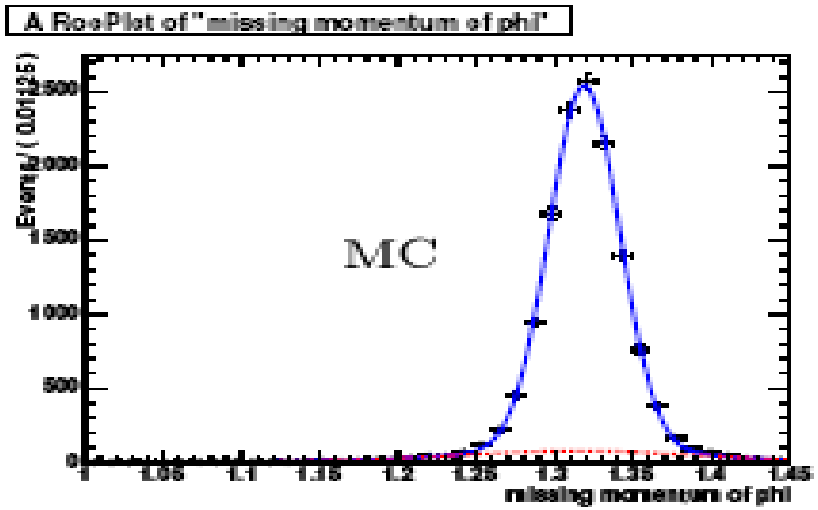
  $N(\eta) = 3.0 \pm 0.2$

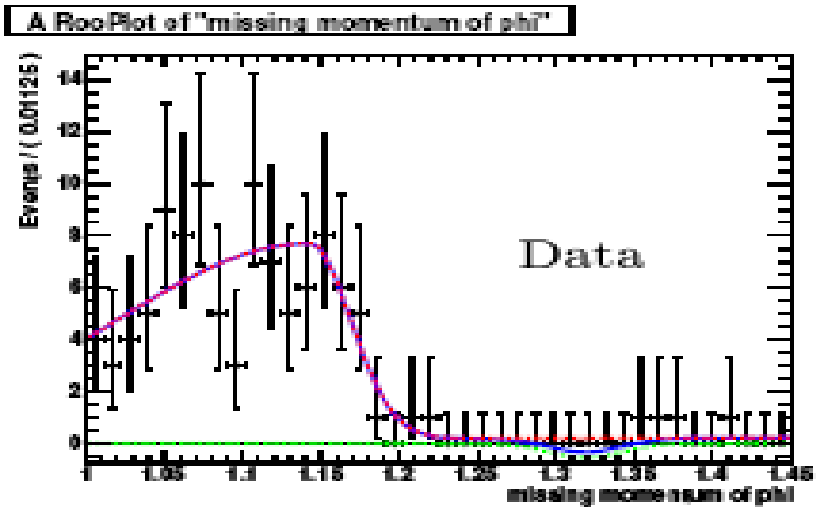
  $N(\eta') = 90 \pm 64$

Looking for η/η' → Invisible decays in $J/\psi \to \phi\eta/\eta'$

An unbinned extended Maximum Likelihood Fit:

$$\mathcal{L}(N^{\eta}_{sig}, N^{\eta'}_{sig}, N_{bkgd}) = \frac{e^{-(N^{\eta}_{sig}+N^{\eta'}_{sig}+N_{bkgd})}}{N!} \times \prod_{i=1}^{N}[N^{\eta}_{sig}\mathcal{F}^{\eta}_{sig}(P^{i}_{miss}) + N^{\eta'}_{sig}\mathcal{F}^{\eta'}_{sig}(P^{i}_{miss}) + N_{bkgd}\mathcal{F}_{bkgd}(P^{i}_{miss})],$$





$N[J/\psi \to \phi\eta\ (\eta \to \text{invisible})] = -2.8 \pm 1.4$

$N[J/\psi \to \phi\eta'\ (\eta' \to \text{invisible})] = 2.2 \pm 3.4$

Looking for η/η' →Invisible Decays in J/ψ→φη/η'

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

n_{UL}^{η} :#observed signal @90%CL

n_{UL}^{γ} :#observed η→γγ

ε_{η} : Efficiency of signal mode

σ_{η} : 1 sigma uncertainty

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

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

Many uncertainty related to tag side and detector noise can cancel in the ratio.

BES, Phys.Rev.Lett.97:202002,2006

Br(η → χχ) < 6.4×10⁻⁴ @90%

Br(η' → χχ) < 1.4×10⁻³ @90%

Theory:

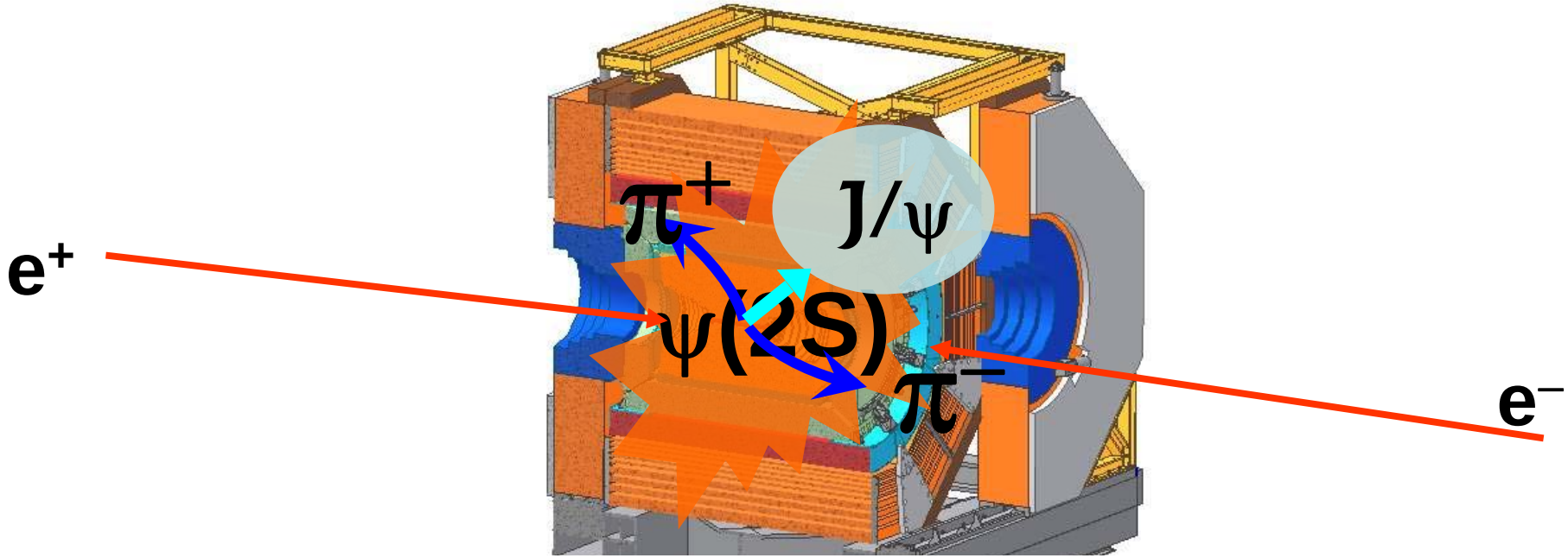
B. McElrath PRD 72, 103508 (2005)

Br(η → χχ) ~ 7.4×10⁻⁵

Br(η' → χχ) ~ 8.1×10⁻⁷

$\psi(2S) \rightarrow \pi^+\pi^- J/\psi^{\text{invisible}}$

Invisible means nothing besides two charged pions are seen in tracking and calorimetry systems at BESII.



The charged-track trigger@BESII:

(1) at least one hit in the 48 barrel TOF counter array

(2) at least one track in the tracking system

(3) at least 100 MeV of energy deposit in the BSC

The trigger is sensitive to two soft pions in this decays

$\psi(2S) \rightarrow \pi^+\pi^- J/\psi^{invisible}$

- **Two good charged pions:**
  from IP; $|\cos(\theta)|<0.8$; each pion: $p_\pi<0.4$GeV/c; $m(\pi\pi)>0.35$GeV
- **Requirement in Vertex Chamber(VC):**
  Events with additional tracks from IP penetrate at least 6 layers in inner vertex chamber, should be rejected.
- **Requirement in Barrel Shower Counter:**
  The number of SC cluster, with E>10 MeV, and no matched with either charged tracks in MDC, is required to be zero.

The $\psi \rightarrow \pi^+\pi^-$ J/ψ ($\rightarrow\mu\mu$) are also reconstructed to make the ratio, so that many systematic errors related to the soft pions cancel:

$$\frac{\mathcal{B}(J/\psi \rightarrow \text{invisible})}{\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)}$$

$\psi(2S)\rightarrow\pi^+\pi^-\psi(1S)^{invisible}$ backgrounds

- **Two-photon**
  - 2 prong $\pi\pi$, ee, $\mu\mu$ …
  - 3 body $\pi^+\pi^-\pi^0$ …
- $J/\psi\rightarrow$ $\mu\mu$, **ee … (outside of acceptance)**
  - **Same distribution as signal (peaking bkg)**
  - **Huge contribution as signal for BESII**

TABLE I. Expected number of events (N_{bg}) and efficiencies for peaking backgrounds.

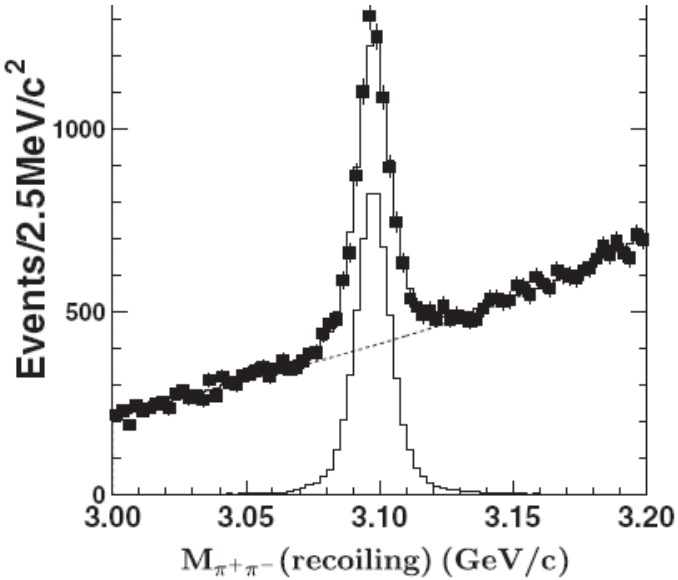
Background channel $[\psi(2S) \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow]$	Efficiency (%)	Expected N_{bg}
$\mu^+\mu^-$	0.964	2543 ± 254
e^+e^-	0.907	2393 ± 240
$n\bar{n}$	10.46	1011 ± 85
$p\bar{p}$	0.434	42 ± 13
$n\bar{n}\pi^0$	0.486	29 ± 10
Total		6018 ± 514

$\psi(2S) \to \pi^+\pi^- J/\psi^{\text{invisible}}$

Huge standard model backgrounds as expected:

By using 14 million $\psi(2S)$ decays, 90% upper limit:

$$\frac{\mathcal{B}(J/\psi \to \text{invisible})}{\mathcal{B}(J/\psi \to \mu^+\mu^-)} < \frac{N_{UL}^{J/\psi}/\epsilon_{\text{invisible}}}{N_{\mu^+\mu^-}^{J/\psi}/\epsilon_{\mu^+\mu^-}^{J/\psi}} = 1.2 \times 10^{-2}$$



BES, Phys. Rev. Lett. 100: 192001 (2008)

Within SM, the invisible quarkonium decays are predicted by:

hep-ph/9806487, L.N Chang, O.Lebedlev and J. N. Ng

$$\frac{\Gamma(\Upsilon \to \nu\bar{\nu})}{\Gamma(\Upsilon \to e^+e^-)} = \frac{27G^2M_\Upsilon^4}{64\pi^2\alpha^2}(-1+\frac{4}{3}\sin^2\theta_W)^2 = 4.14 \times 10^{-4},$$

$$\frac{\Gamma(J/\Psi \to \nu\bar{\nu}))}{\Gamma(J/\Psi \to e^+e^-)} = \frac{27G^2M_{J/\Psi}^4}{256\pi^2\alpha^2}(1-\frac{8}{3}\sin^2\theta_W)^2, = 4.54 \times 10^{-7},$$

BESIII milestones

Peak Lumi. @ Nov. 2008:
$1.2 \times 10^{32} cm^{-2} s^{-1}$
Peak Lumi. @ May 2009:
$3.2 \times 10^{32} cm^{-2} s^{-1}$

July 18, 2008: First e+e- collision event in BESIII

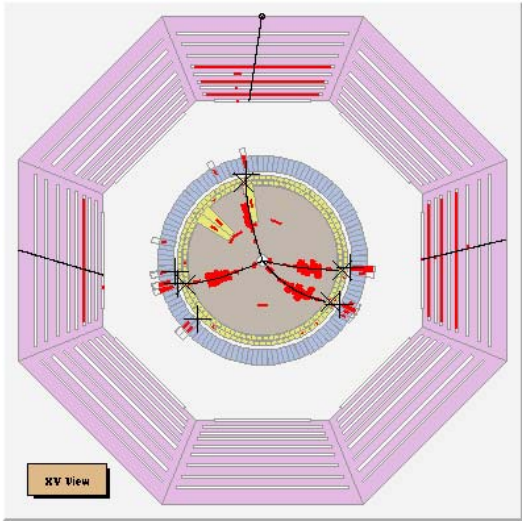
Nov. 2008: ~ 14M $\psi(2S)$ events collected

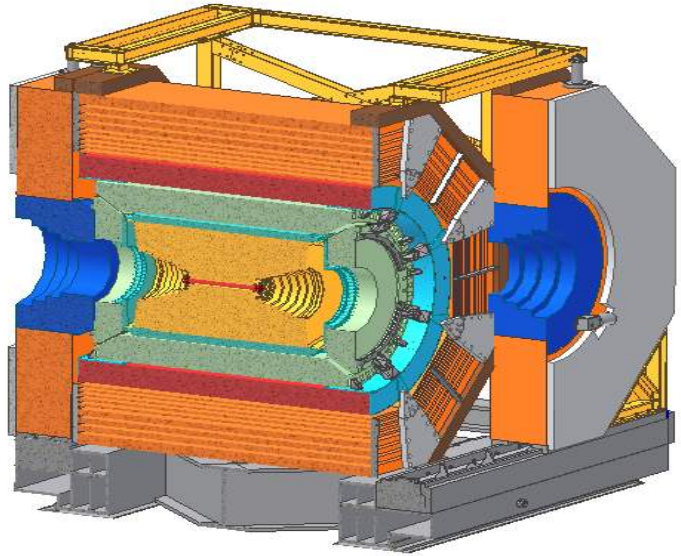
April 14, 2009 ~100M $\psi(2S)$ events collected

May 30, 2009 42 pb^{-1} at continuum collected

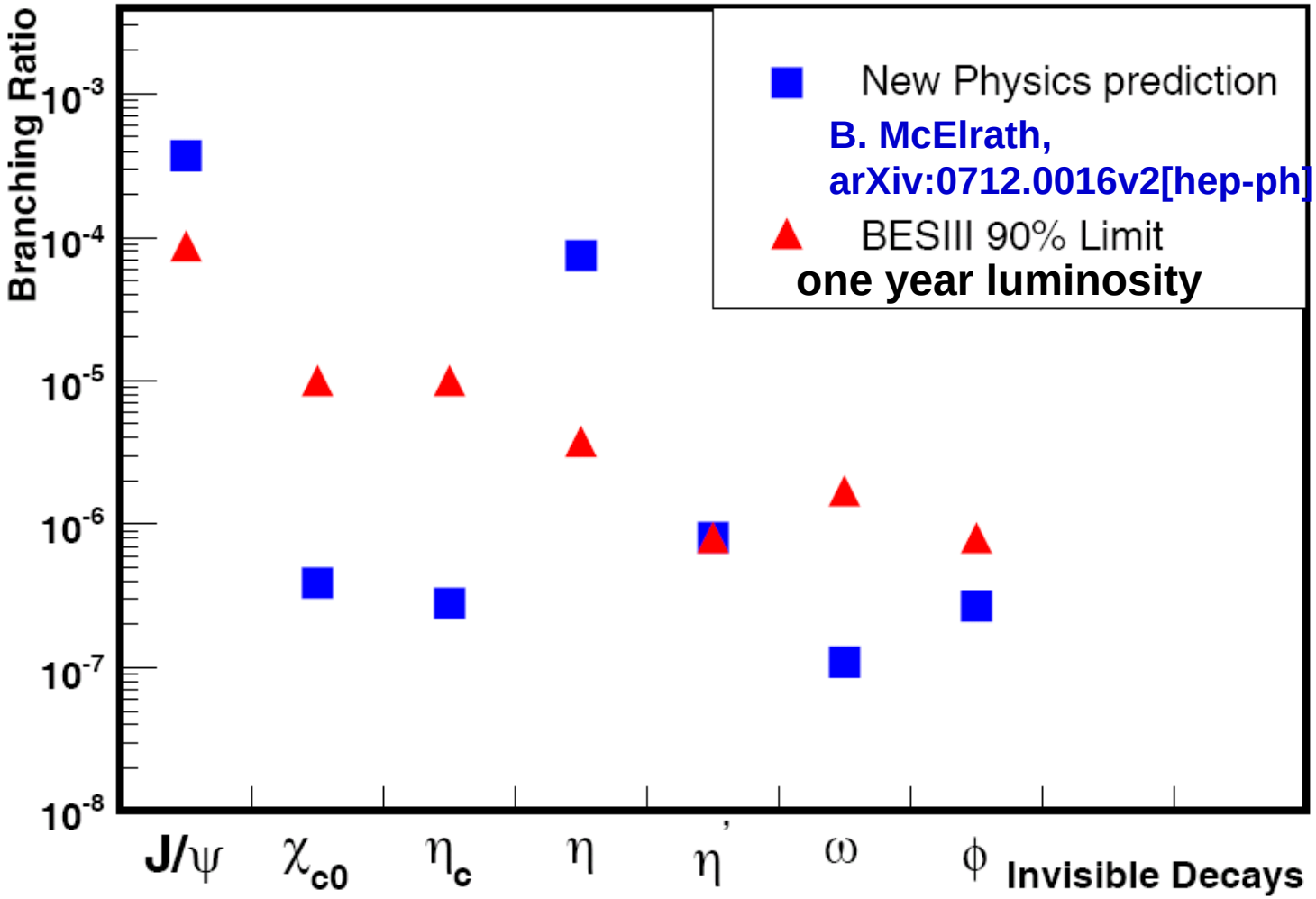
July 28, 2009 ~230M J/ψ events collected

See Yang-Heng Zheng's slides





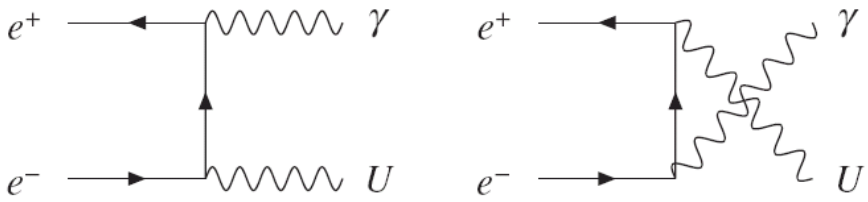
Sensitivities of invisible decays of mesons@BESIII



See Yang-Heng's talk for detail

Signature of light U boson at BEPCII/BESIII

Direct production of spin-1 boson:



P. Fayet, PRD75, 115017(2007);
R. Essig, P.Schuster and N. Toro 0903.3941[he-ph];
S.H.Zhu 0904.4644[hep-ph].

$$\frac{d\sigma_{\gamma A'}}{d\cos\theta} = \frac{2\pi\epsilon^2\alpha^2}{E_{\rm cm}^2}\left(1-\frac{m_{A'}^2}{E_{\rm cm}^2}\right)\frac{1+\cos^2\theta+\frac{4m_{A'}^2/E_{\rm cm}^2}{(1-m_{A'}^2/E_{\rm cm}^2)^2}}{(1+\cos\theta)(1-\cos\theta)},$$

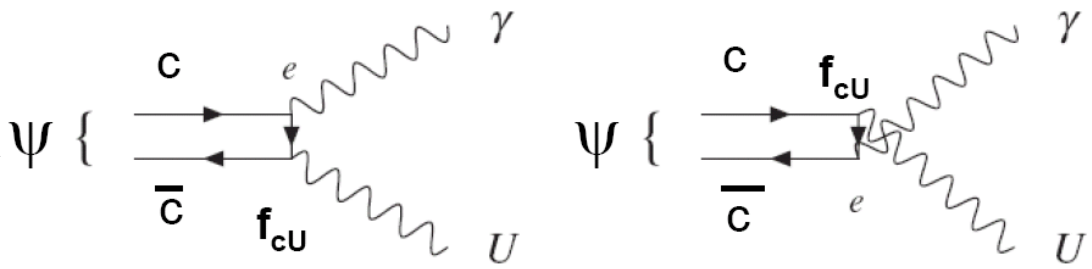
Low energy colliders better!

Spin-1 boson in ψ decay:

S. H. Zhu PRD75, 115004(2007)

(1) $\psi\to e^+e^-U(U\to e^+e^-,\mu^+\mu^-)$

(2) $\psi\to\gamma U(U\to e^+e^-,\mu^+\mu^-)$



The mass of U-boson : $U\to e^+e^-$, $\mu^+\mu^-$, $\pi^+\pi^-$, $\nu\nu$, $\chi\chi$

U-boson in direct production $e^+e^- \to U\gamma \to l^+l^-\gamma$

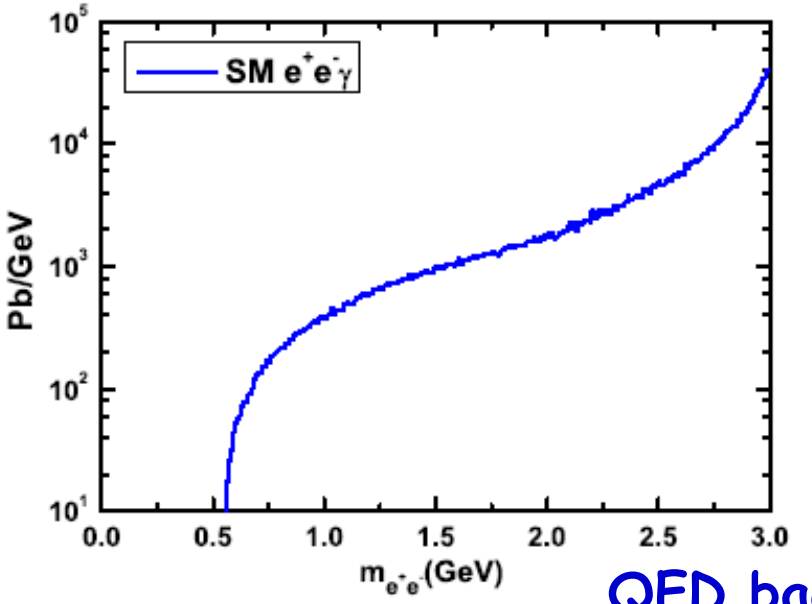
The major standard model processes: $e^+e^- \to \gamma e^+e^-$ $e^+e^- \to \gamma\mu^+\mu^-$

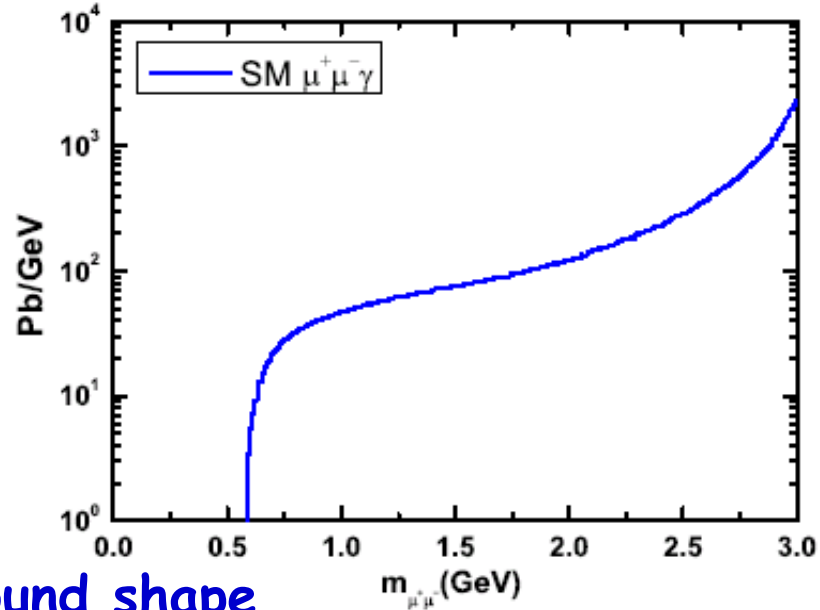
$$\cos(\theta_i) < 0.9,$$

θ_i : **polar angle of final states**

$$\cos(\theta_{l\gamma}) < 0.94,$$

$\theta_{l\gamma}$: **angle between lepton and photon**

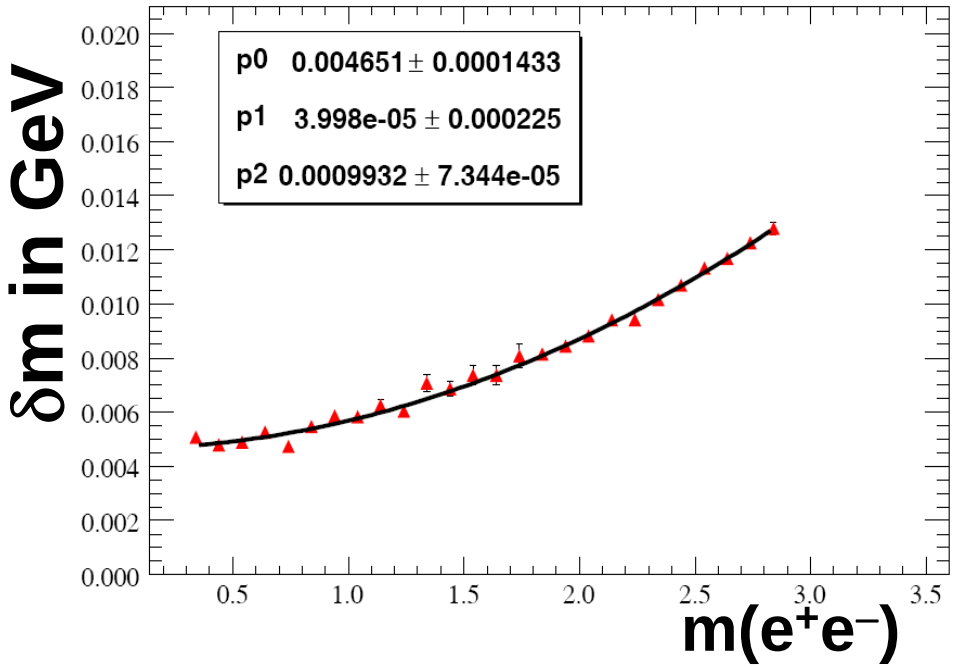


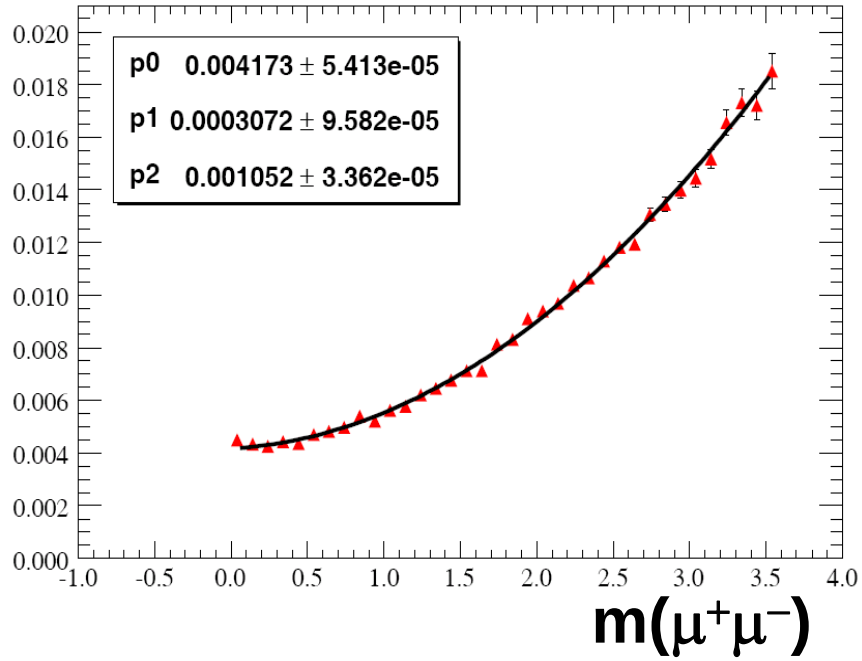


QED background shape

P.F.Yin, J.Liu and S.H.Zhu arXiv:0904.4644v2[hep-ph]

Resolution function of $U \to l^+l^-$





Resolution as a function of U boson mass:

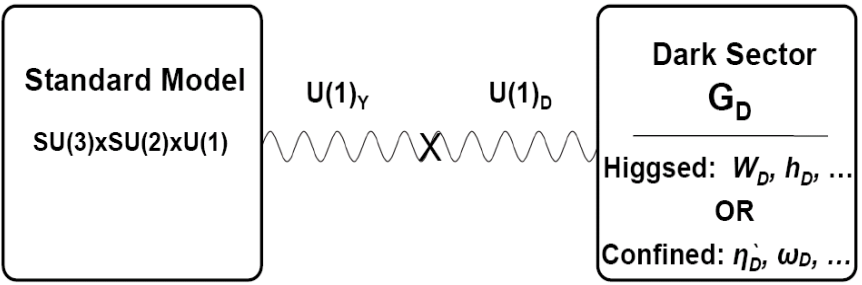
$$\delta m(\mu^+\mu^-) = \left(4.6 + 0.04\left(\frac{m_U}{1.0GeV}\right) + 1.0\left(\frac{m_U}{1.0GeV}\right)^2\right) MeV$$

$$\delta m(e^+e^-) = \left(4.1 + 0.3\left(\frac{m_U}{1.0GeV}\right) + 1.0\left(\frac{m_U}{1.0GeV}\right)^2\right) MeV$$

Reach of U boson decay in visible channel at BESIII

Following the study of M. Reece and L.T.Wang 0904.1743v2hep-ph]
The reach of U boson search at BESIII is estimated.

The model: (R.Essig et al, 0903.3941)



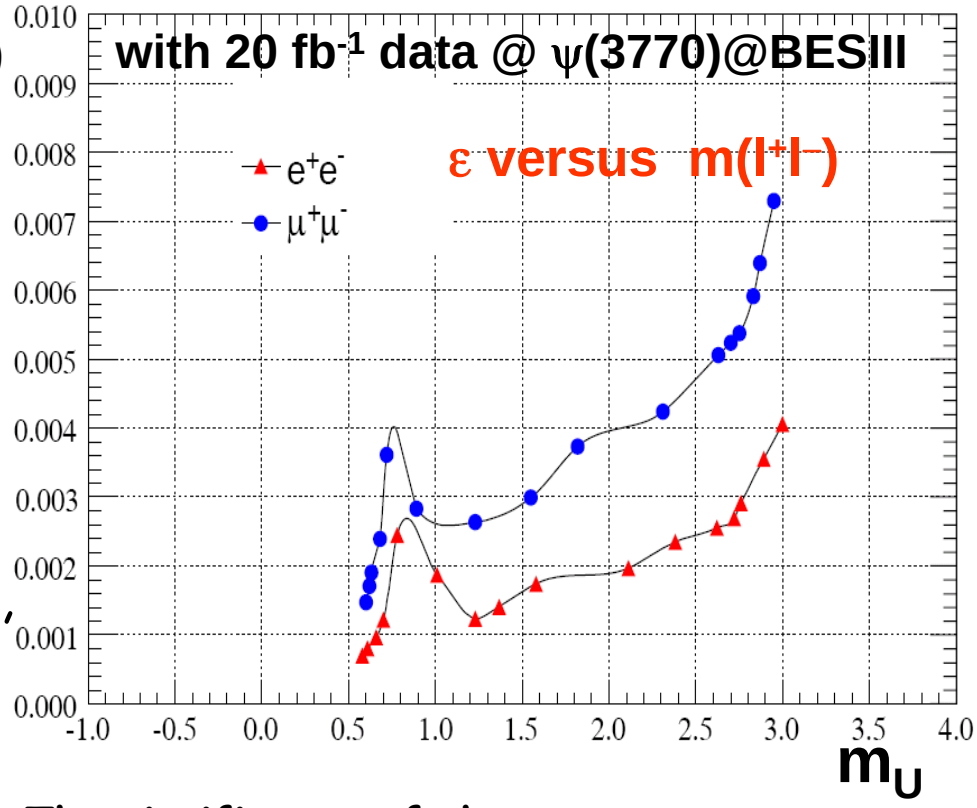
$$\mathcal{L}_{\rm kin-mix} = -2\epsilon F_d^{\mu\nu} F_{\mu\nu}$$

We consider the case $\varepsilon \sim 10^{-3}$ --10^{-4},

$$\epsilon \sim 10^{-4}\left(\frac{m_U}{1\ \mathrm{GeV}}\right)^2$$

The signal cross section:

$$\sigma_s(e^+e^- \to U\gamma) \propto \varepsilon^2 \times \sigma_0(e^+e^- \to \gamma\gamma)$$



The significance of the measurement:

$$\frac{\mathrm{S}}{\sqrt{\mathrm{B}}} \sim \sqrt{\sigma_0 \mathcal{L}}\frac{\epsilon^2}{\sqrt{\alpha/\pi}}\sqrt{\frac{m_U}{\delta m}} \times \mathrm{BR}(U \to \ell^+\ell^-)$$

Spin-1 boson in J/ψ decays

Br(J/ψ→ee) ~ 5%
Br(J/ψ→ee γ) ~0.9% with E(γ)>100 MeV

We measure the ratio of J/ψ decays:

$$R = \frac{Br(\psi \to e^+e^- U(\to e^+e^- or \mu^+\mu^-))}{Br(\psi \to e^+e^-)}$$

With 10^{10} J/ψ decays, one can obtain ε

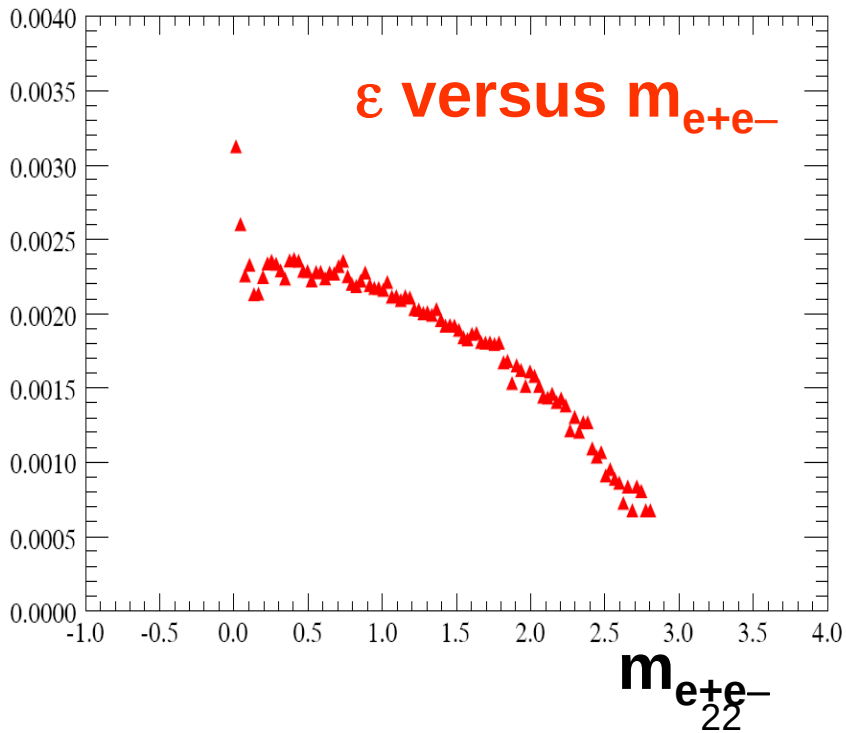
$R < 5.0\times10^{-6}$ **for U→ee**

$R < 3.0\times10^{-6}$ **for U→μμ**

ε ~ (0.5–2.5)×10^{-3}

2.3×10^8 J/ψ collected in one and half month:

ε ~ (01.5–7.5)×10^{-3}



Spin-1 boson in ψ(2S) radiative decays

We can look for U boson with mass less than 170 MeV in

$$R = \frac{Br(\psi(2S) \to U\chi_{c1,2}, U \to anything)}{Br(\psi(2S) \to \gamma\chi_{c1,2})}, \chi_{c1,2} \to \gamma J/\psi(\to l^+l^-)$$

$Br(\chi_{c1,2} \to \gamma J/\psi, J/\psi \to l^+l^-)$ **is large (about 0.36*0.12=4% for χ_{c1}.)**

Here: anything: ee, νν or χχ since below μμ threshold.
Advantage: many systematic uncertainties due to reconstruction of χc1,2 cancel in the ratio R.

Technique: only reconstruct $\chi_{c1,2} \to \gamma J/\psi(\to$ee or μμ), by looking at the missing-mass distribution, to search for narrow U boson decaying to anything.

With 3×10^9 ψ(2S) per year, the R can be measured to 1×10^{-5} for 10 MeV<m_U<170 MeV, and the Br(ψ(2S)→Uχ_{c1}) ~1×10^{-6} , hence, ε can be reached at level of 10^{-3}.
1×10^8 ψ(2S) decays in tape, the ε < 2.5×10^{-3} for U boson 10-170MeV

Summary

- Invisible decays of mesons give opportunity for probing new physics beyond SM,
- The rates of invisible decay can reach 10^{-4} –10^{-6} for light mesons at BESIII (see Yang-Heng Zheng's talk).
- The reach of searching for U boson at BESIII has been estimated in direct production and ψ decays:
  The reach of mixing parameter ε is less than 10^{-3} (20 fb^{-1}@$\psi(3770)$).

Thank you!