Some DARK possibilities at STCF

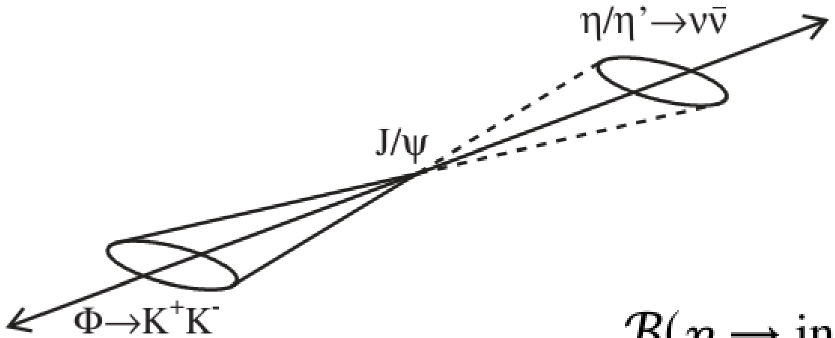
Dayong Wang 王大勇
Peking University 北京大学

2013.6.17

Outline

- What would be limiting factor at STCF?
  - Eta/eta' invisible decays
  - Charge Lepton Flavor Violation(CLFV) process
    - tau->l l l, tau-> e/mu + gamma (Haibo's talk)
    - J/psi->e mu, tau mu, tau e
- Dark photon, dark Higgs and GeV-matter searches:
  - Invisible decays of mesons
    - J/psi, Psi(3686), phi, eta/etap, omega etc
  - Radiative processes
  - Jpsi decays

Case-I:Invisible Decays of eta/eta'



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

	BES2006	BES2013	
$\frac{\mathcal{B}(\eta\to\text{invisible})}{\mathcal{B}(\eta\to\gamma\gamma)}$	1.65×10^{-3}	2.6×10^{-4}	90% C. L.
$\frac{\mathcal{B}(\eta'\to\text{invisible})}{\mathcal{B}(\eta'\to\gamma\gamma)}$	6.69×10^{-2}	2.4×10^{-2}	

BES(2006). *Physical Review Letters*, *97*(20), 1–5.

BESIII(2013). *Physical Review D*, *87*(1), 012009.

efficiencies

Quantity	Value η	η'
n_{UL}^{η} $(n_{UL}^{\eta'})$	3.56	5.72
ϵ_{η} $(\epsilon_{\eta'})$	23.5%	23.2%
$n_{\gamma\gamma}^{\eta}$ $(n_{\gamma\gamma}^{\eta'})$	1760.2 ± 49.3	71.6 ± 13.2
$\epsilon_{\gamma\gamma}^{\eta}$ $(\epsilon_{\gamma\gamma}^{\eta'})$	17.6%	15.2%
σ_{η}^{stat} $(\sigma_{\eta'}^{stat})$	2.8%	18.5%
σ_{η} $(\sigma_{\eta'})$	8.1%	21.6%

BES2006

Thanks to the much improved EMC, but the room for STCF is limited

Quantity	Value η	η'
$N_{\gamma\gamma}^{\eta}(N_{\gamma\gamma}^{\eta'})$	13390 ± 136	400 ± 25
$N_{bkg}^{non-\phi\eta}(N_{bkg}^{non-\phi\eta'})$	2514 ± 64	1482 ± 46
$N_{bkg}^{non-\phi}(N_{bkg}^{non-\phi})$	1132 ± 70	10 ± 15
$N_{bkg}^{non-\eta}(N_{bkg}^{non-\eta'})$	313 ± 54	159 ± 26
$\epsilon_{\gamma\gamma}^{\eta}(\epsilon_{\gamma\gamma}^{\eta'})$	36.3%	31.7%

BES2013

Systematic errors

Source of uncertainties	Sys. error (%) η	Sys. error (%) η'
PDF shapes in the ML fit	3.4	7.3
MC statistics	1.0	1.0
Requirement on N_{BSC}	5.0	5.0
Photon efficiency	4.0	4.0
4C fit for $\eta(\eta') \to \gamma\gamma$	1.0	5.2
Background shape for $\eta(\eta') \to \gamma\gamma$	2.0	1.0
Total	7.7	11.1

Source of uncertainties	Systematic error (% η	Systematic error (% η'
Requirement on N_{shower}	0.3	0.3
ϕ mass window	1.5	1.5
$J/\psi \to \gamma\eta_c$, $\eta_c \to K_L K^\pm \pi^\mp$ background	1.2	$\cdots$
Background shape of $J/\psi \to \phi f_0(980)$	$\cdots$	1.0
Background shape of $J/\psi \to \phi K_L K_L$	$\cdots$	2.9
4C fit for $\eta(\eta') \to \gamma\gamma$	0.4	0.8
Photon detection	2.0	2.0
Signal shapes for $\eta(\eta') \to \gamma\gamma$	0.1	1.0
Background shape for $\eta(\eta') \to \gamma\gamma$	0.1	0.6
Total systematic errors	2.8	4.1
Statistical error of $N^{\eta}_{\gamma\gamma}(N^{\eta'}_{\gamma\gamma})$	1.0	6.0
Total errors	3.0	7.4

BES2006

BES2013

EMC simulation is dominant

cLFV from J/psi decays: BES results

- BESII

$$\mathcal{B}(J/\psi \to \mu e) < 1.1 \times 10^{-6}$$ Phys. Lett. B 561, 49 (2003)

$$\mathcal{B}(J/\psi \to e\tau) < 8.3 \times 10^{-6}$$

$$\mathcal{B}(J/\psi \to \mu\tau) < 2.0 \times 10^{-6}$$

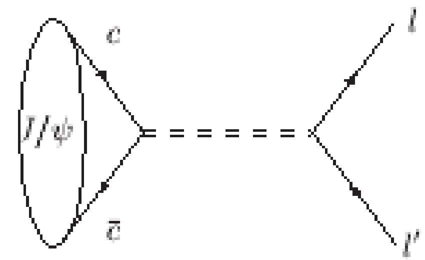
- BESIII results from 225M J/psi

$$\mathcal{B}(J/\psi \to e\mu) < 1.5 \times 10^{-7}$$

arXiv:1304.3205, to appear in PRD

CLFV: predictions

- Laundry list
  - SUSY-based GUT
  - SUSY with a right-handed neutrino
  - gauge-mediated SUSY breaking
  - SUSY with vector-like leptons
  - SUSY with R-parity violation
  - models with a Z
  - models violat-ing Lorentz invariance
- Unparticle physics
  - The European Physical Journal C, 62(3), 593–598. (2009)
  - Phys.Rev.D76:077701,2007



$$BR(J/\psi \to e\mu) = 7 \times 10^{-8}$$

Sources	Error
$e^{\pm}$ tracking	1.00
$\mu^{\pm}$ tracking	1.00
$e^{\pm}$ ID	0.62
$\mu^{\pm}$ ID	0.04
Acollinearity, acoplanarity	2.83
Photon veto	1.19
$N_{J/\psi}$	1.24
Total	3.65

↓

Generator + Detector simulation

NEWS IN FOCUS

US POLICY Effort to protect science from politics hits a bump p.15

SOCIAL SCIENCE Harvard engineers help to police the mean streets p.16

CLIMATE SCIENCE Monitoring the vital signs of Asian glaciers p.19

BRAIN IMAGING fMRI is becoming more than a pretty picture p.24

JEFFERSON LAB

The Jefferson Lab's Free-Electron Laser is a low-cost option in the bid to discover dark-sector forces.

PARTICLE PHYSICS

Physicists hunt for dark forces

Cheap colliders probe debris for hint of 'heavy' photon.

if there are more fundamental forces," says physicist John Jaro[...] HPS experiment.

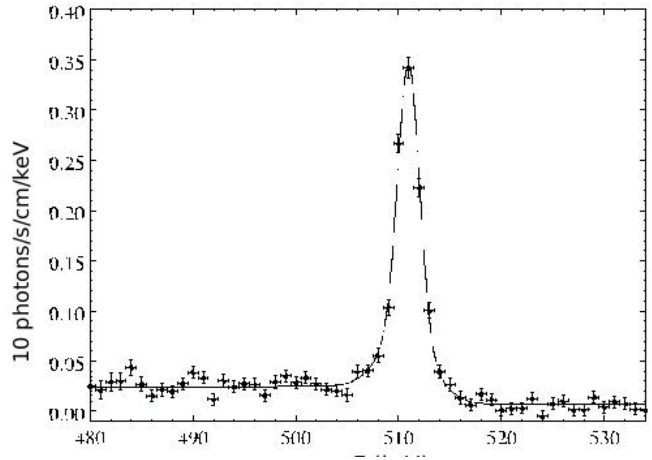
The dark photon, [...] tons, would have m[...] able only indirectly [...] have decayed into electrons and positrons (the antimatter counterparts of electrons). Yet, like the familiar photon, which carries the electromagnetic force, the dark photon would carry a force — a new fundamental force in addition to the four that we already know about. It would be the first sign of a hidden sector, which could include entire zoos of new particles, including dark matter. "It would be like when Galileo saw moons orbiting Jupiter," says Nima Arkani-Hamed, a theorist at the Institute for Advanced Study in Princeton, New Jersey.

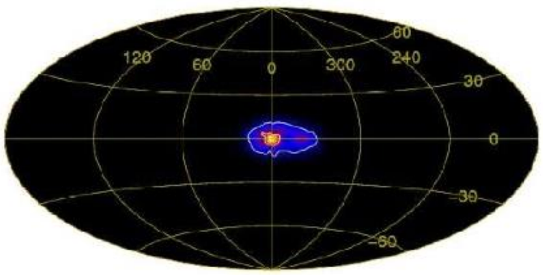
Theorists had hoped that the Large Hadron Collider — the world's highest-energy (and most expensive) particle accelerator at CERN, Europe's high-energy physics lab near Geneva, Switzerland — would open the door to new concepts such as supersymmetry, a set of theories that would resolve some of the problems in the standard model of particle physics. But, so far, it has yielded no clues, such as the dark-matter particles predicted by some supersymmetry models. "The null results are not making people happy," says Philip Schuster, a theorist at Canada's Perimeter Institute for Theoretical Physics in Waterloo, Ontario. "People are wondering what other possibilities are out there."

Instead, some physicists are turning to the 'intensity frontier' — creating many collisions and teasing rare events from the wreckage. The electron beams at the Jefferson Lab are not the most powerful, but they are extremely intense.

NATURE, 2012.4

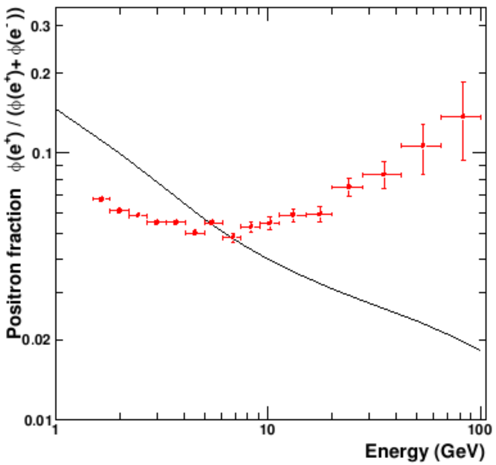
Key observations to be addressed





511 keV line - sky map

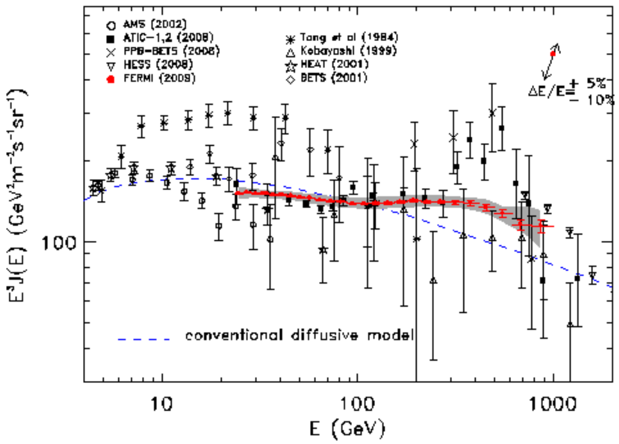
G. Weidenspointner et al., Nature **451** *(2008) 159*



PAMELA: positron fraction

(confirmed by Fermi)

O. Adriani et al., Nature **458** *(2009) 607*

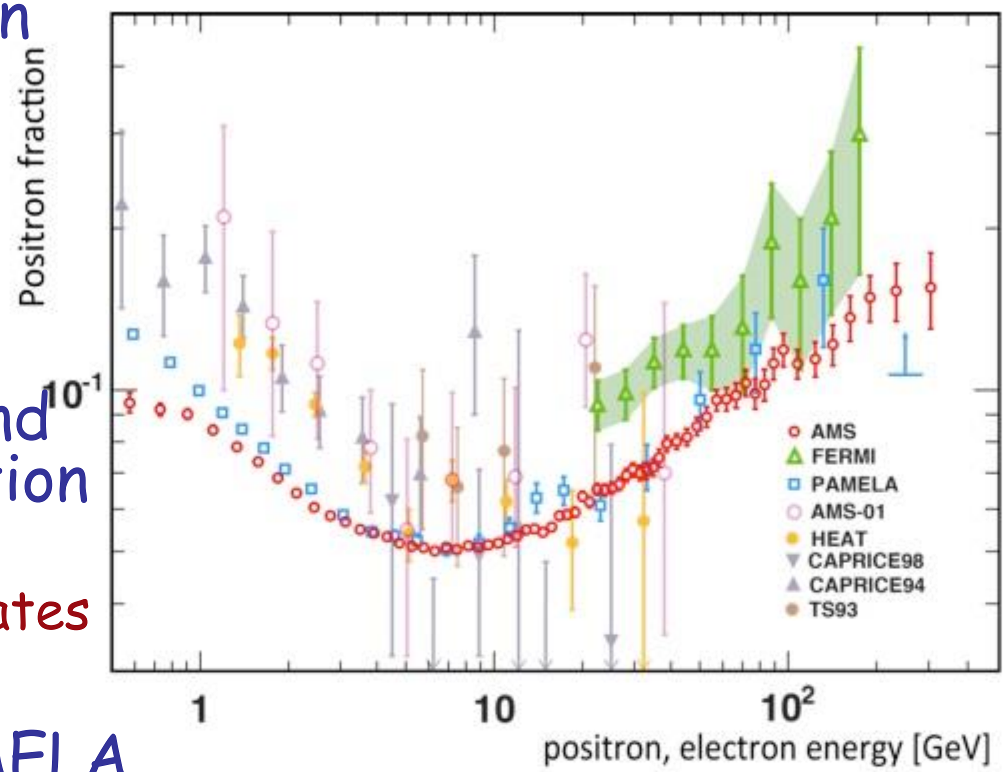


Fermi: $e^+ + e^-$ *spectrum*

A.A. Abdo et al., Phys. Rev. Lett. **102** *(2009) 181101*

motivation of dark forces

- PAMELA/Fermi hard lepton spectrum=> M(DM) ~(100, 1000) GeV
  - New Physics at ~ GeV scale
- PAMELA/Fermi e+ excess without pbar anomalies and large excitation cross section for INTEGRAL
  - DM annihilation into light states
- Large event rates for PAMELA, requiring amplification of DM annihilation
  - Enhanced DM annihilation (by Sommerfeld enhancement)



Other constraints from astro

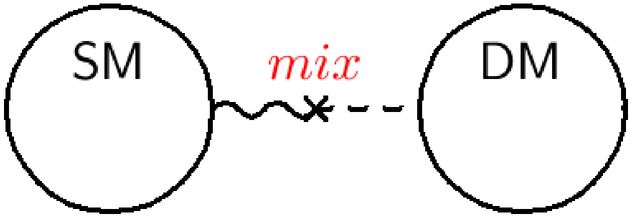
(1) The basic dark matter particle properties [mass, stability, darkness];
(2) The similarity in cosmic abundance between ordinary and non-baryonic dark matter, $\Omega B \sim \Omega dark$;
(3) Large scale structure formation;
(4) Microlensing (MACHO) events;
(5) Asymptotically flat rotation curves in spiral galaxies;
(6) The impressive DAMA/NaI annual modulation signal.

Variety of Models

- General model features
  - New gauge bosons in the secluded hidden sector
  - Dark Matter has self-interactions through the new gauge bosons
  - Mixing between the new bosons and the SM particles
- Specific model choices
  - Secluded sector: abelian or non-abelian gauge group
  - Dark Matter identity (fermion or scalar)
  - Mass generation: Higgs or technicolor
  - Supersymmetric scenarios

Messangers from Dark Sector

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{DM} + \mathcal{L}_{mix}$$



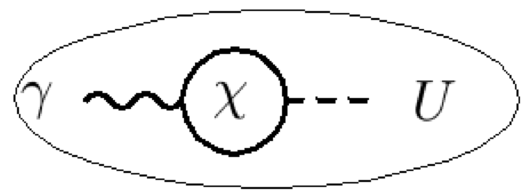
The simplest case: Abelian Symmetry

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{DM} \otimes \dots$$

$$\mathcal{L}_{SM} = \mathcal{L}^F_{SM} + \mathcal{L}^B_{SM} + \mathcal{L}^H_{SM}$$

$$\begin{aligned} \mathcal{L}_{DM} &= \mathcal{L}^F_{DM}(\chi) && \Rightarrow \quad M_\chi \sim 100 - 1000 \text{ GeV WIMP} \\ &+ \mathcal{L}^B_{DM}(\mathbf{U}) && \Rightarrow \quad m_U \sim \text{GeV Dark Photon U or } V, A' \dots \\ &+ \mathcal{L}^B_{DM}(h') && \Rightarrow \quad \text{Higgs potential breaking } U(1)_{DM} \end{aligned}$$

$$\mathcal{L}_{mix} = \epsilon F^{\mu\nu DM} F^{EM}_{\mu\nu}$$

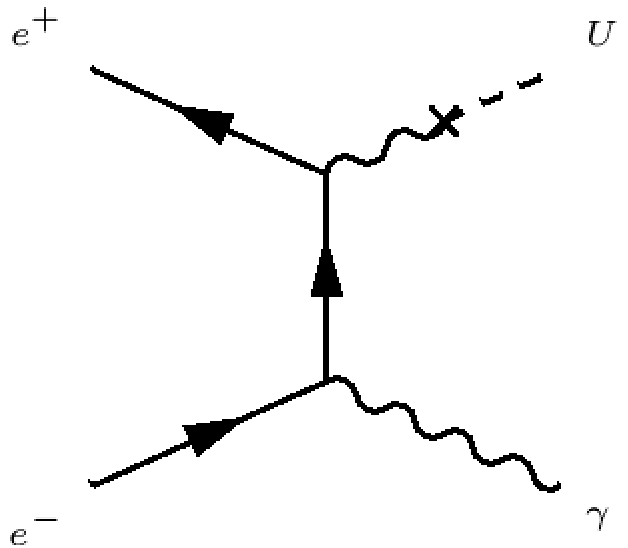


$$+ \quad \text{Higgs–Dark Photon int.} + \dots$$

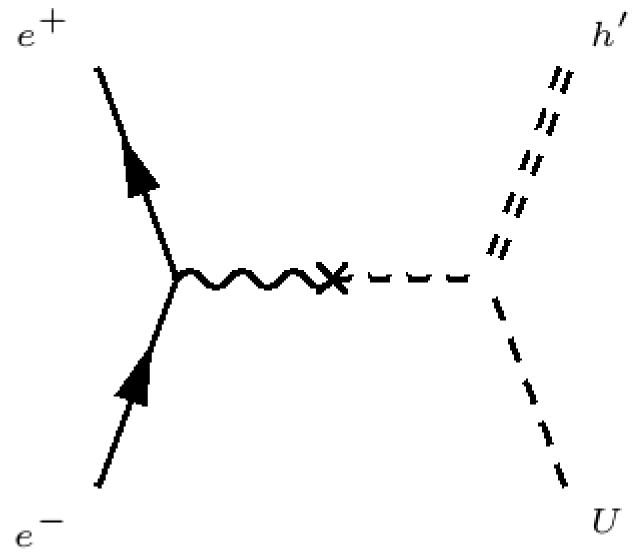
ϵ (or κ): **kinetic mixing parameter** $\epsilon \sim 10^{-3} \longrightarrow$ milli–charged SM fermions with coupling $\epsilon\, e$ to the dark photon (neglecting mixing with the Z)

Least suppressed processes

- Most promising scenarios:
- 1) e+e-->gamma U
- 2) Higgsstralung:
- e+e-->AU, h'->UU

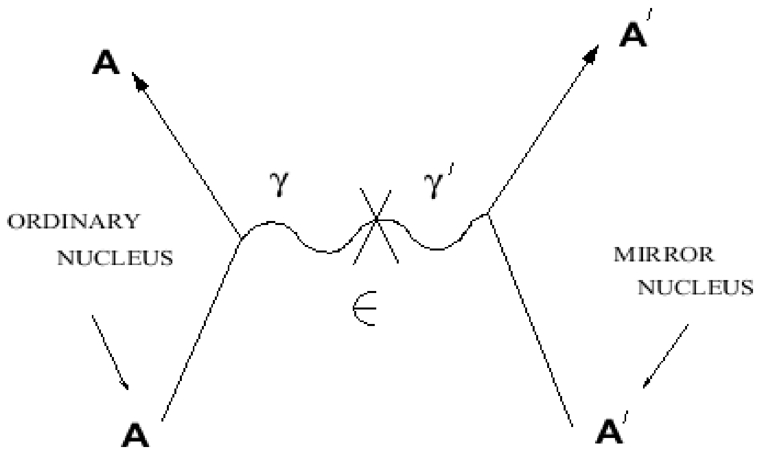


Radiative process



Dark higgs-strahlung

Similar features from Mirror DM Model

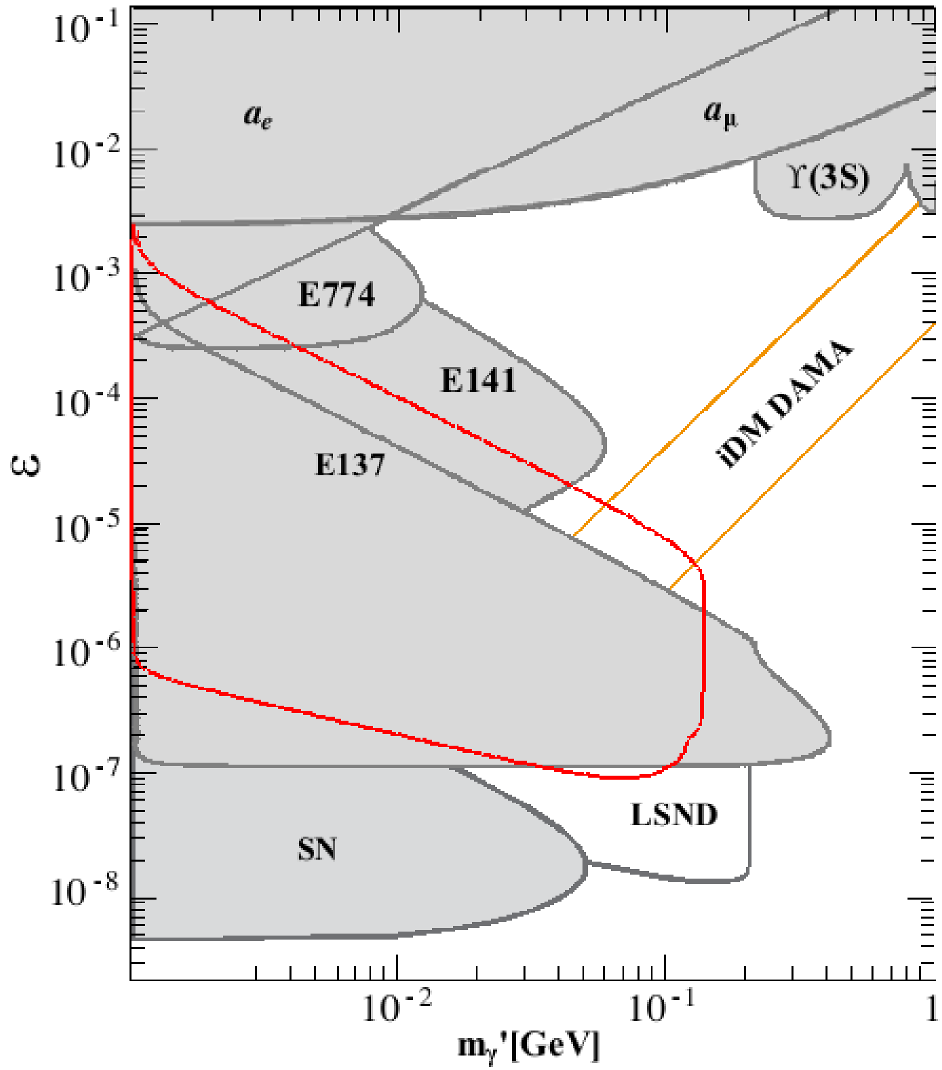


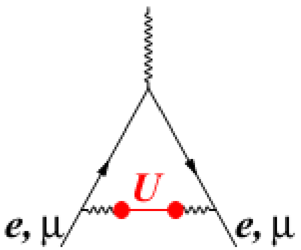
photon-mirror photon kinetic mixing:

$$\mathcal{L}_{int} = \frac{\epsilon}{2} F^{\mu\nu} F'_{\mu\nu},$$

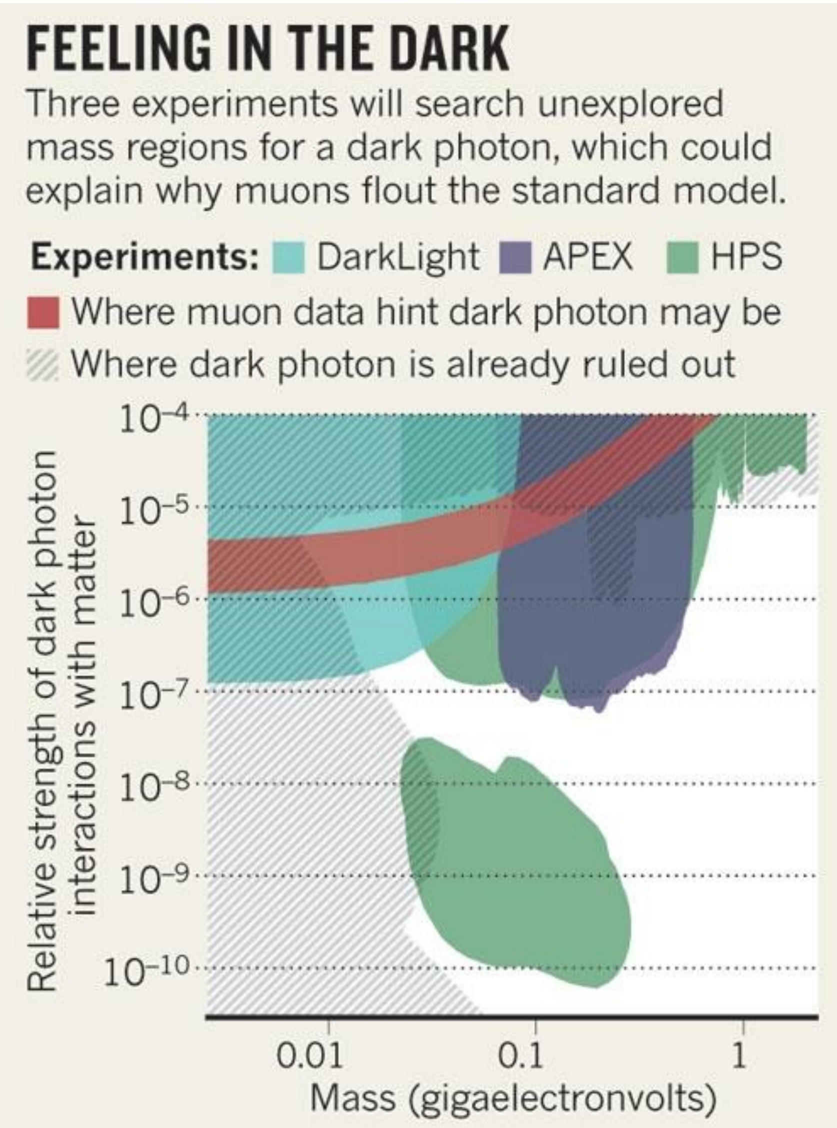
FOOT, R. (2004). International Journal of Modern Physics D, 13(10), 2161–2192.

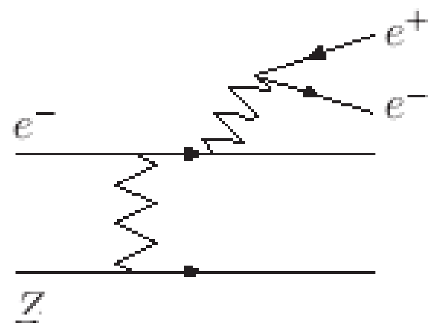
Present limits from astro/g-2/beam-dump/neutrino etc

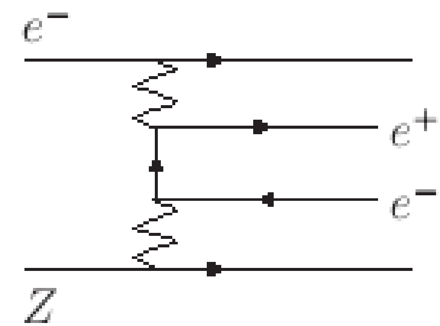


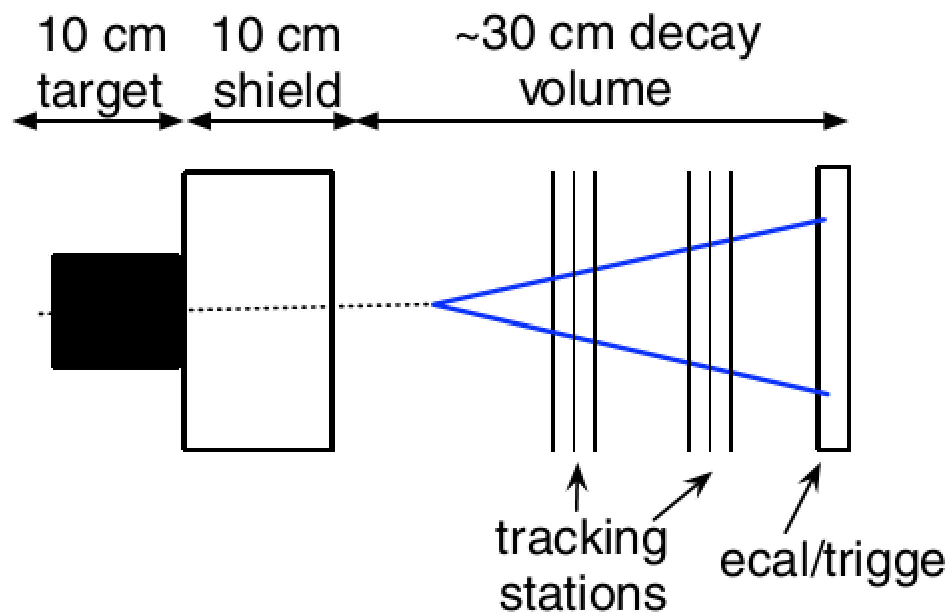


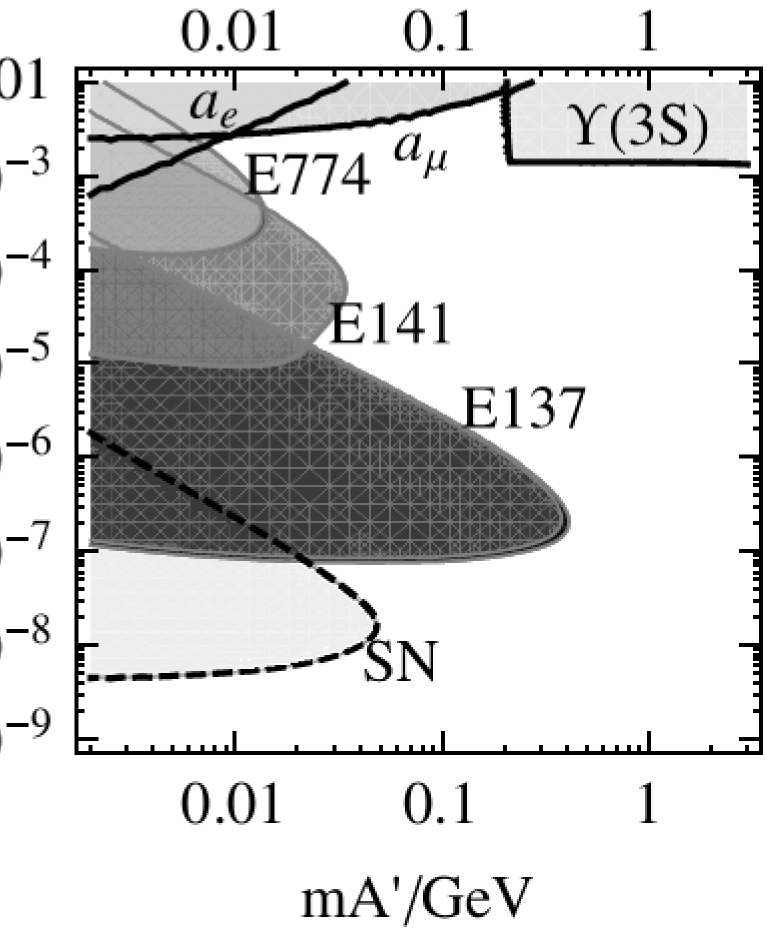
beam dump experiements

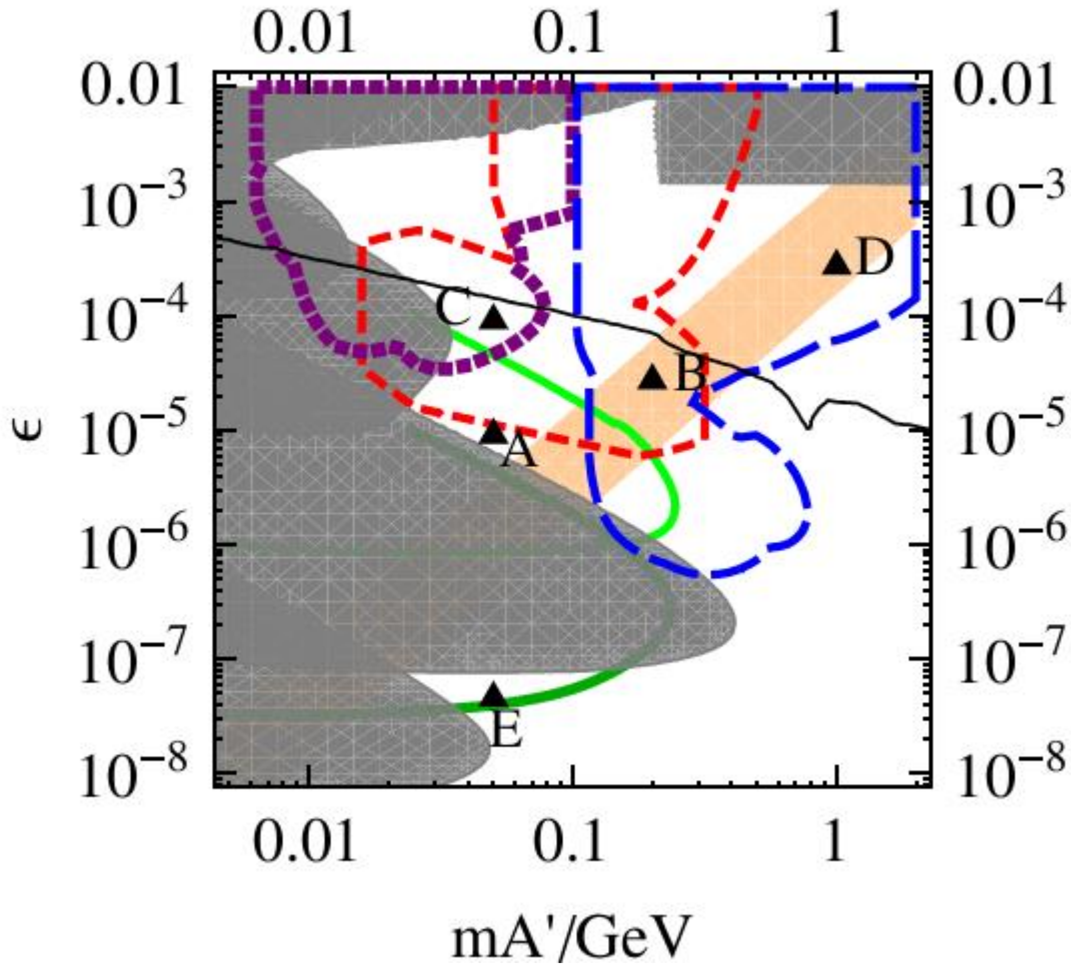






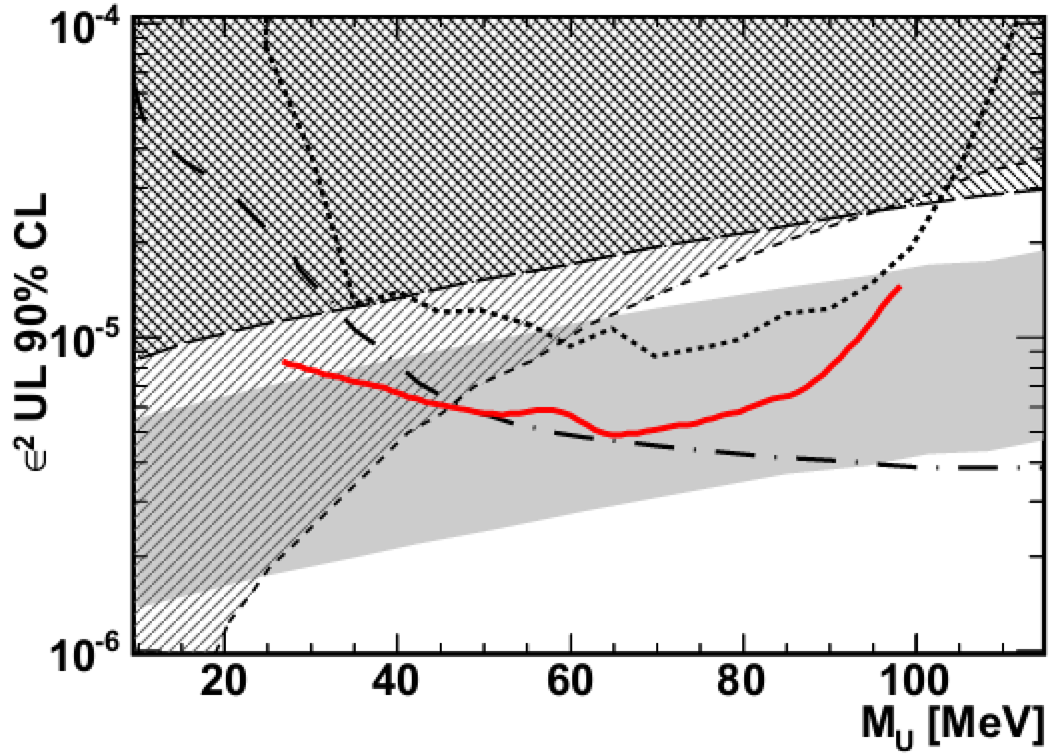






J.D. Bjorken et al., PRD 80 (2009) 075018

Latest Pi0 Dalitz decay results



Arxiv:1304.0671

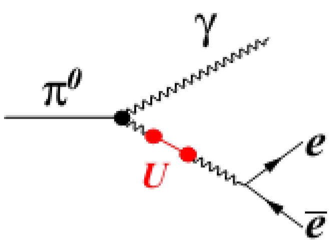


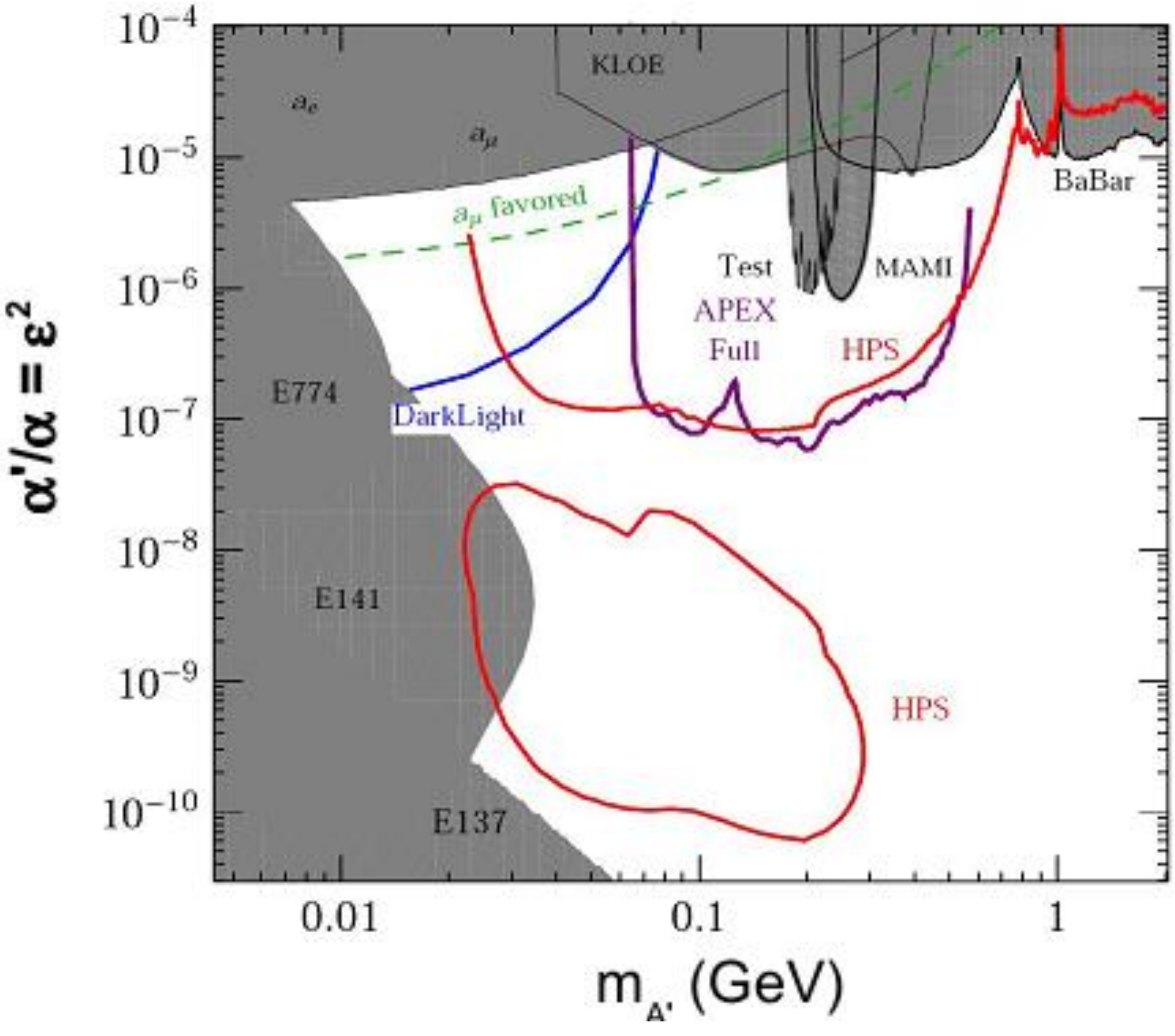
Figure 8: Summary of the 90% CL upper limits for the mixing parameter ϵ^2 from WASA-at-COSY (red solid line) compared to SINDRUM $\pi^0 \to e^+e^-\gamma$ [34] (dotted line) and recent combined KLOE $\phi \to \eta e^+e^-$ [43] (dashed dotted) upper limits. The long respectively short dashed lines (and the corresponding hatched areas) are the upper limits derived from the muon and the electron $g-2$ [29]. In addition the gray area represents the $\pm 2\sigma$ preferred band around the present value of the muon $g-2$.

Flavor Factory is a good place to probe these

- Low energy;
- high luminosity
- clean signatures

- N. Borodatchenkova, D. Choudhury, M. Drees, Phys. Rev. Lett. 96 (2006) 141802
- R. Essig, P. Schuster, N. Toro, Phys. Rev. D80 (2009) 015003
- Peng-fei Yin, Jia Liu, Shou-hua Zhu, Phys. Lett. B679 (2009) 362
- Hai-Bo Li, Tao Luo, Phys. Lett. B686 (2010) 249
- B. Batell, M. Pospelov, A. Ritz, Phys. Rev. D79 (2009) 115008
- M. Reece, Lian-Tao Wang, JHEP 07 (2009) 051
- Barz è, L., Balossini, G.et al The European Physical Journal C, 71(6). (2011).

Global With Babar/KLOE etc



BESIII specific references

$e^+e^- \to U\gamma$ $J/\psi \to e^+e^-U$ $U \to \chi\chi^*$ $U \to e^+e^-$

ZHU S-H, PHYSICAL REVIEW D75,115004 (2007)

$e^+e^- \to U\gamma$, followed by $U \to e^+e^-$, $U \to \mu^+\mu^-$ and $U \to \nu\bar{\nu}$.

Yin Liu & Zhu. (2009). *Physics Letters B*, *679*(4), 362–368

$e^+e^- \to \gamma + U \to \gamma l^+l^-$, where $U \to l^+l^-$, l could be electron or muon;
$J/\psi \to Ul^+l^- \to 4l$;
$\psi(2S) \to U\chi_{c1,2} \to e^+e^-\chi_{c1,2}$;
$J/\psi \to Uh' \to l^+l^- +$ missing energy; or $J/\psi \to Uh' \to 3U \to 6l$.

- Hai-Bo Li, Tao Luo,
- Phys. Lett. B686 (2010) 249

$J/\psi \to PU$ $(U \to l^+l^-)$

Fu, J., Li, H.-B., Qin, X., & Yang, M.-Z. (*Mod. Phys. Lett. A* **27**, 1250223 (2012)

relevant BESIII results

$\eta(\eta') \to UU$ BESIII(2013). *Physical Review D*, *87*(1), 012009.

Search for a light exotic particle in Jpsi radiative decays
BESIII, PHYSICAL REVIEW D85,092012 (2012)

invisible decays prediction

mode	s-wave	p-wave
$\mathrm{BR}(\Upsilon(1S) \to \chi\chi)$	4.2×10^{-4}	1.8×10^{-3}
$\mathrm{BR}(\Upsilon(1S) \to \nu\bar{\nu})$	9.9×10^{-6}	
$\mathrm{BR}(J/\Psi \to \chi\chi)$	2.5×10^{-5}	1.0×10^{-4}
$\mathrm{BR}(J/\Psi \to \nu\bar{\nu})$	2.7×10^{-8}	
$\mathrm{BR}(\eta \to \chi\chi)$	3.4×10^{-5}	1.4×10^{-4}
$\mathrm{BR}(\eta' \to \chi\chi)$	3.7×10^{-7}	1.5×10^{-6}
$\mathrm{BR}(\eta_c \to \chi\chi)$	1.3×10^{-7}	5.3×10^{-7}
$\mathrm{BR}(\chi_{c0}(1P) \to \chi\chi)$	2.7×10^{-8}	1.2×10^{-7}
$\mathrm{BR}(\phi \to \chi\chi)$	1.9×10^{-8}	7.8×10^{-8}
$\mathrm{BR}(\omega \to \chi\chi)$	7.2×10^{-8}	3.0×10^{-8}

arxiv: 0702.0016

Dataset per 10B Jpsi at BES

J/ψ decay mode	Number of events /10 billion J/ψ decays
$J/\psi \to \phi\eta$	$(31.4 \pm 3.4) \times 10^5$
	$(25.7 \pm 2.8) \times 10^5$
$J/\psi \to \phi\eta'$	$(16.2 \pm 1.9) \times 10^5$
	$(9.6 \pm 1.2) \times 10^5$
$J/\psi \to \omega\eta$	$(13.9 \pm 1.4) \times 10^6$
	$(6.2 \pm 0.6) \times 10^6$
$J/\psi \to \omega\eta'$	$(1.5 \pm 0.2) \times 10^6$
	$(0.7 \pm 0.1) \times 10^6$
$J/\psi \to \rho^0\eta$	$(1.9 \pm 0.2) \times 10^6$
	$(0.8 \pm 0.09) \times 10^6$
$J/\psi \to \rho^0\pi^0$	$(55.3 \pm 5.8) \times 10^6$

$\psi(2S)$ decay mode	Number of events expected
$\psi(2S) \to \pi^+\pi^- J/\psi$	9.3×10^8
$\psi(2S) \to \pi^0\pi^0 J/\psi$	5.6×10^8
$\psi(2S) \to \eta J/\psi$	9.3×10^7
$\psi(2S) \to \pi^0 J/\psi$	3.7×10^6
$\psi(2S) \to \gamma\chi_{c0}$	2.7×10^8
$\psi(2S) \to \gamma\chi_{c1}$	2.6×10^8
$\psi(2S) \to \gamma\chi_{c2}$	2.5×10^8
$\psi(2S) \to \gamma\eta_c(1S)$	7.8×10^6
$J/\psi \to \gamma\eta_c(1S)$	1.3×10^8

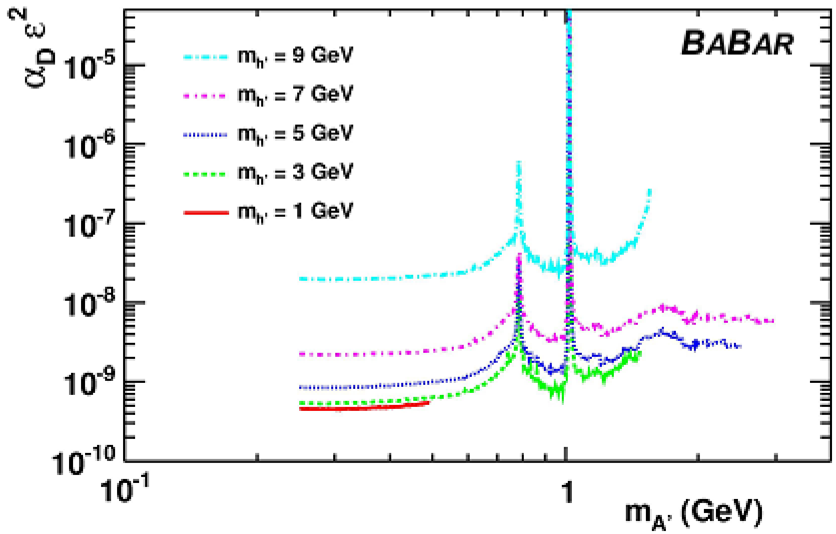
Li, H.-B., & Zhu, Sh.-H. (2012). *Chinese Physics C*, *33*(10), 932–940.

Sensitivity studies with Babayaga@NLO for radiative process

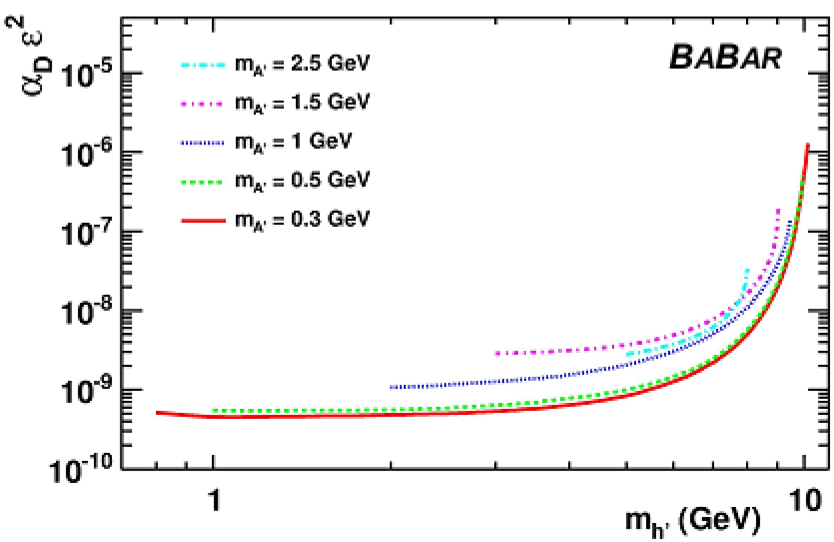
- Babayaga@NLO
  - 0.1% precision
  - U boson process with ISR, FSR and interf
- Cut following BESIII
- Figure of Merit

$$\frac{\mathscr{L}(\sigma_{SM+U} - \sigma_{SM})}{\sqrt{\mathscr{L}\sigma_{SM}}} \equiv \sqrt{\mathscr{L}}\frac{\sigma_S}{\sqrt{\sigma_{SM}}}$$

B/super B factory



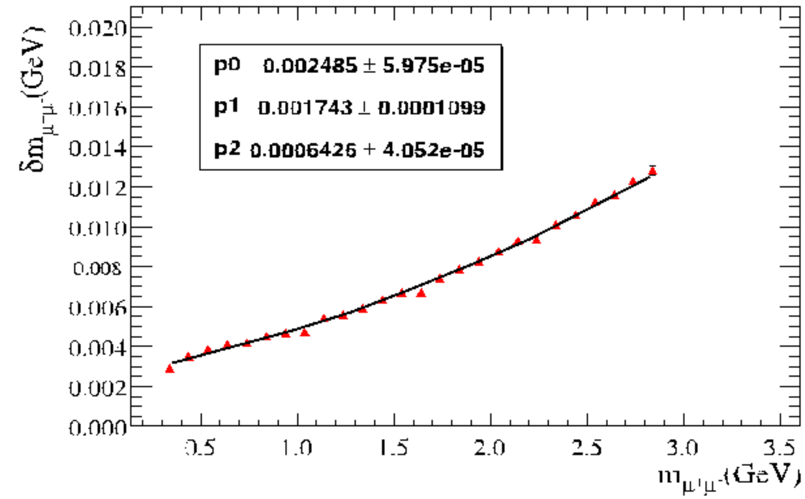
90% CL upper limit on $\alpha_D \varepsilon^2$

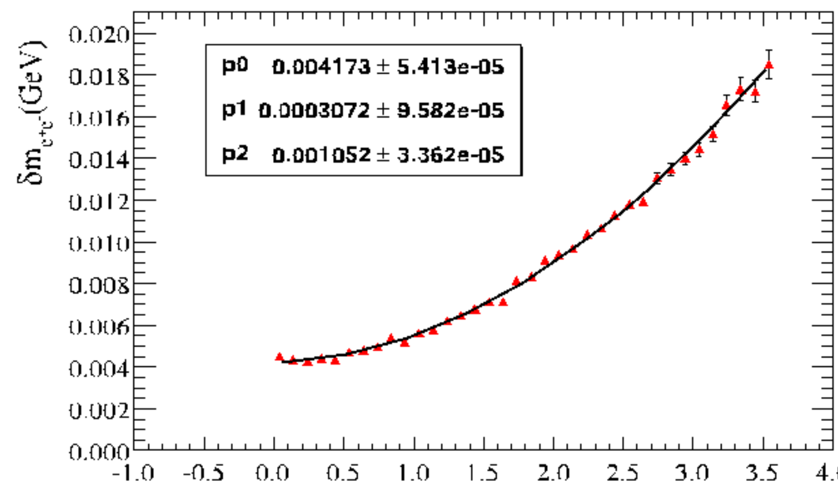


resolutions at BESIII

$$\delta m(\mu^+\mu^-) = \left(2.5 + 1.7\left(\frac{m_U}{1.0\ \text{GeV}}\right) + 0.6\left(\frac{m_U}{1.0\ \text{GeV}}\right)^2\right)\ (\text{MeV}),$$

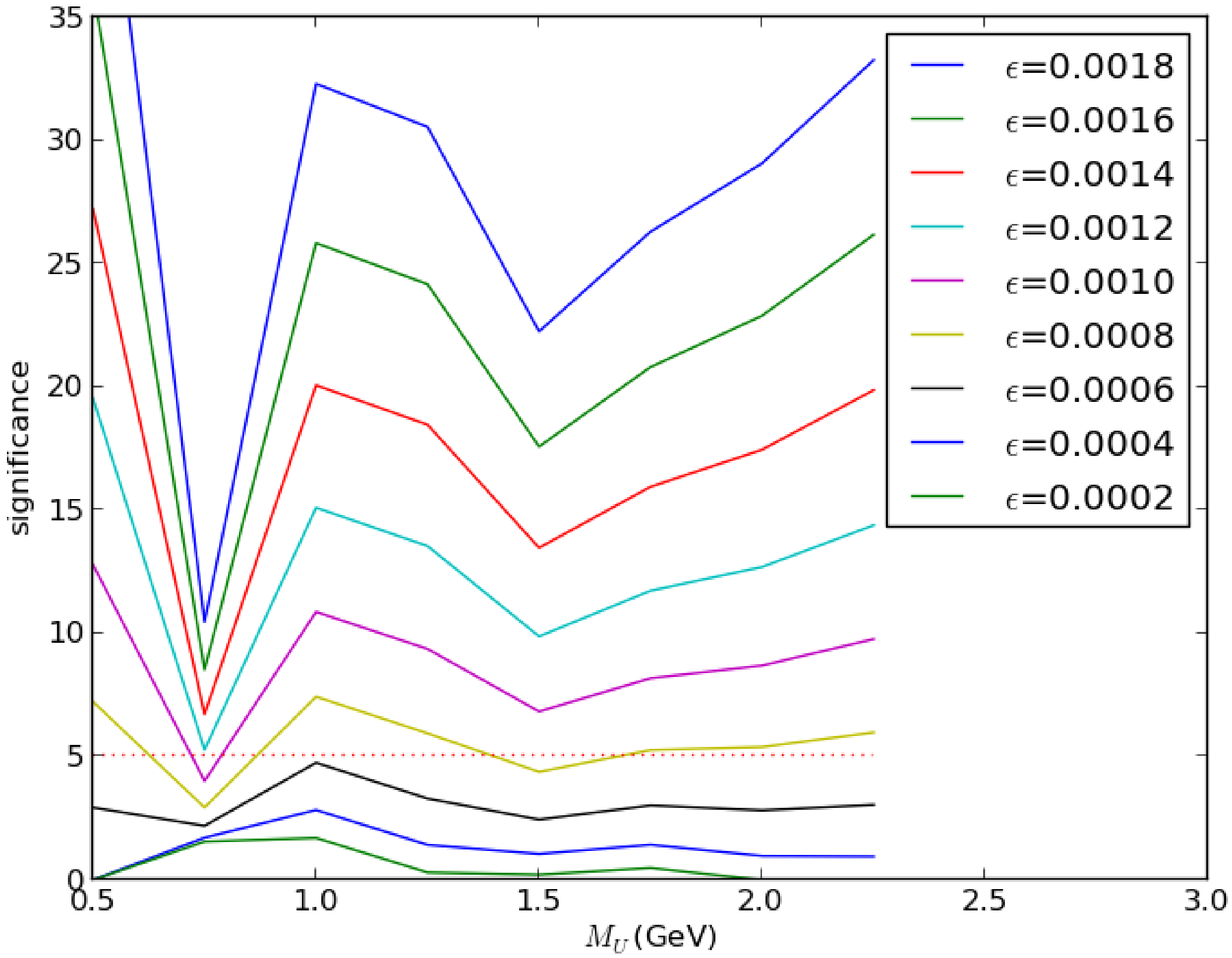
$$\delta m(e^+e^-) = \left(4.1 + 0.3\left(\frac{m_U}{1.0\ \text{GeV}}\right) + 1.1\left(\frac{m_U}{1.0\ \text{GeV}}\right)^2\right)\ (\text{MeV}).$$



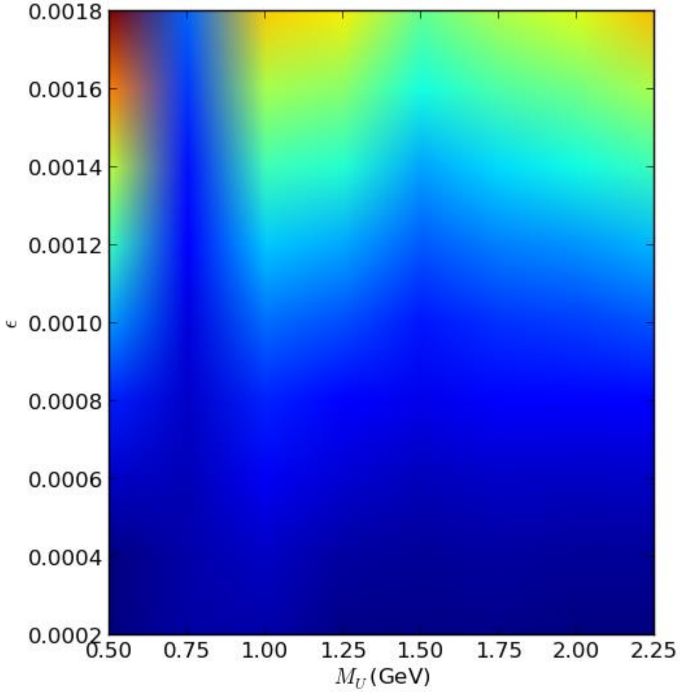


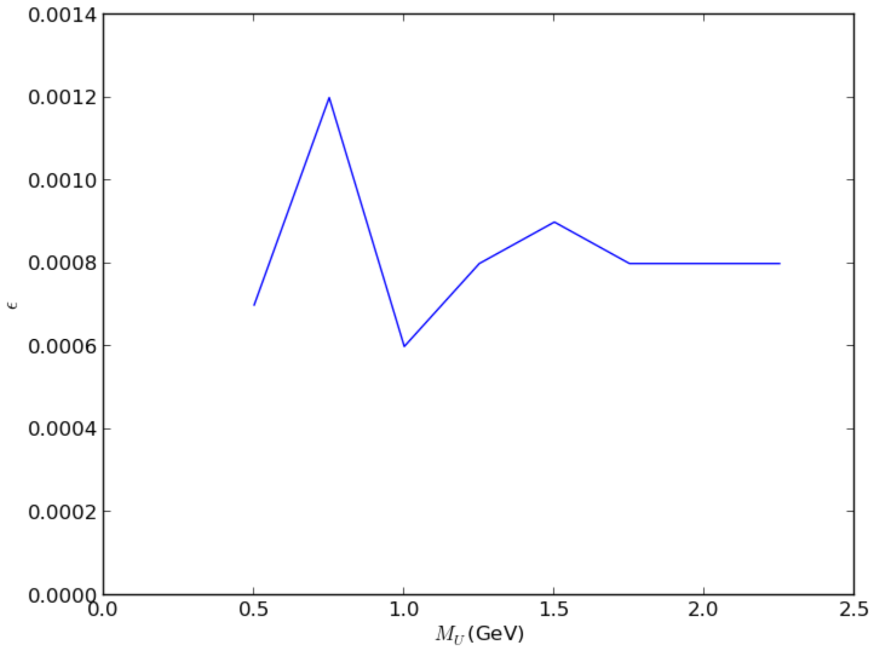
H.-B. Li, T. Luo / Physics Letters B 686 (2010) 249–253

BESIII, 10fb-1

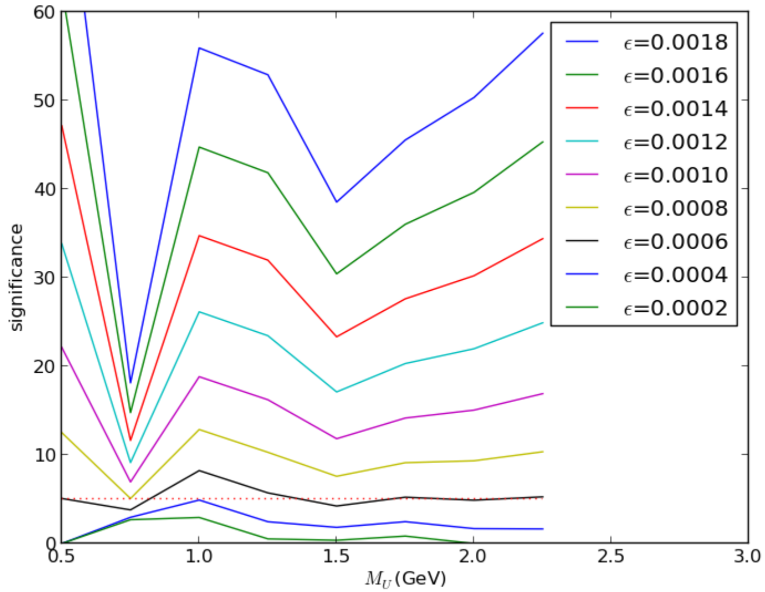


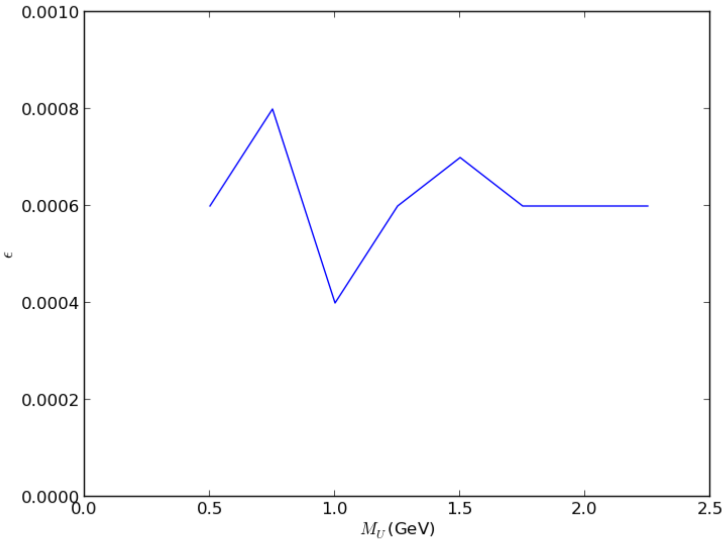
10fb-1, limit plots



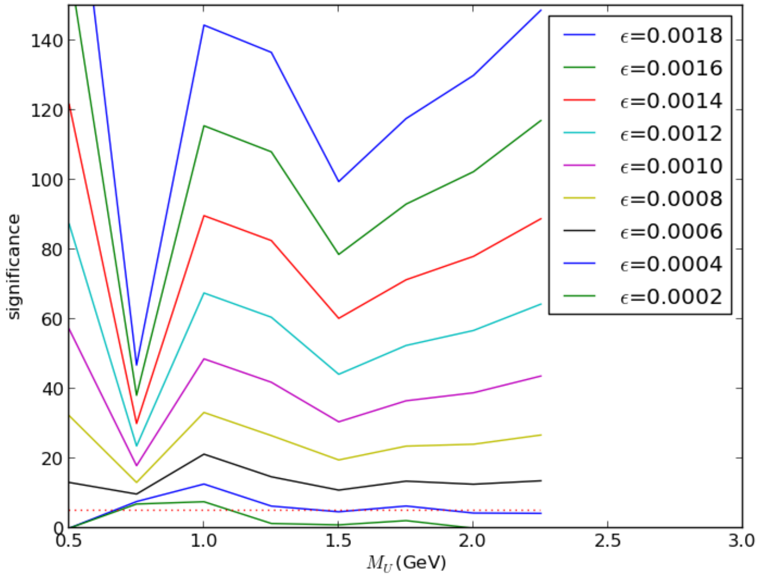


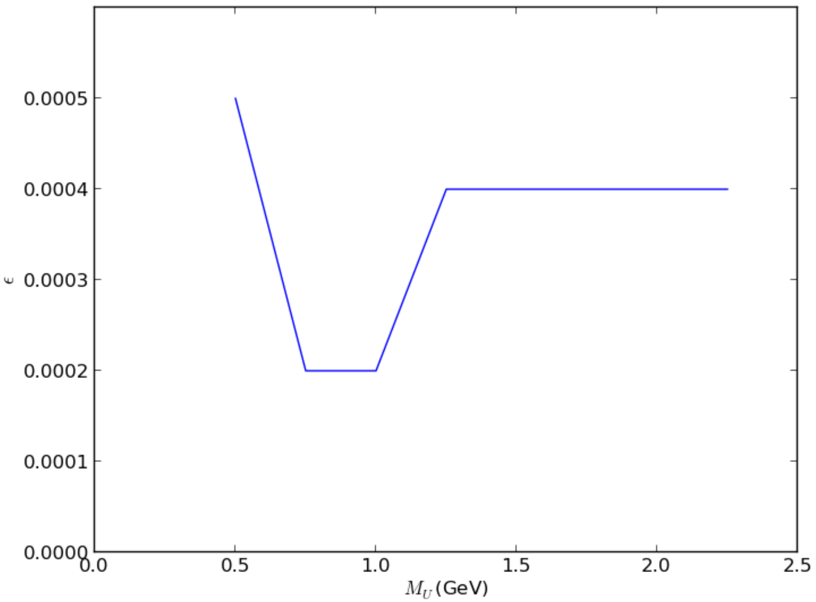
BESIII, 30fb-1





STCF=0.5*BES3 resolution, 200fb-1





Summary

- STCF will provide good opportunities for exotic physics topics, such as Dark photon/dark higgs.
- And let us keep open minds for unexpected
- Detector simulation (esp EMC) will be challenging to meet increased Lumi and improved resolution