Experimental Status of Dark Photon Searches

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2013.12.25

Outline

- introduction
  - Major types of exp addressing the problem
  - re-spin of old exp/data
  - collider results
- some recent results/developments
  - new results: some examples
  - projections of near future
- far future exp and new ideas
  - from Krakow and SNOWMASS
- measurements at BESIII
  - ongoing analyses
  - other possible channels

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

NATURE, 2012.4

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 fu… physicist John Jaro… HPS experiment.

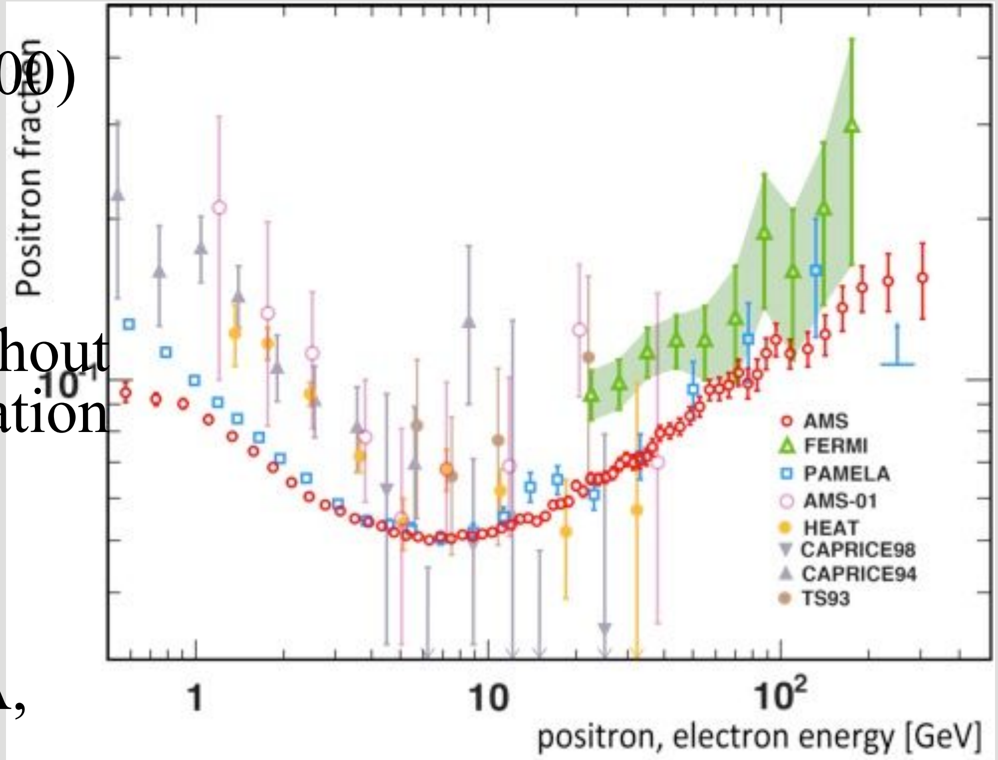
The dark photon, … tons, would have m… able only indirectly — … have decayed into electrons and positrons (the antimatter counterparts of electrons). Yet, like the familiar photon, which carries the electromagnetic force, the dark photon would carry a force — a new fundamental force in addition to the 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."

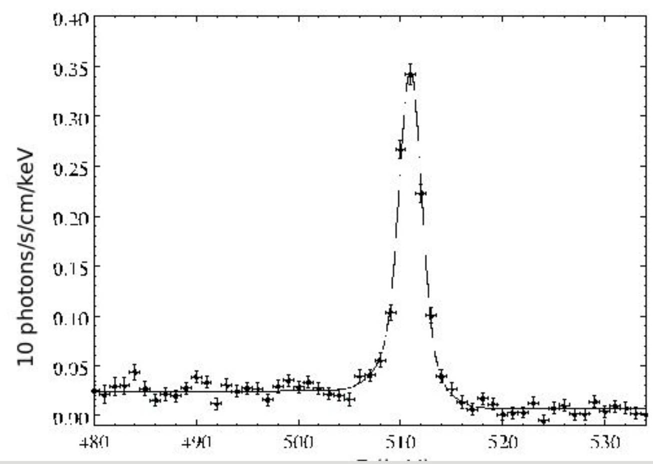
Instead, some physicists are turning to the 'intensity frontier' — creating many collisions and teasing rare events from the wreckage. The electron beams at the Jefferson Lab are not the most powerful, but they are extremely intense

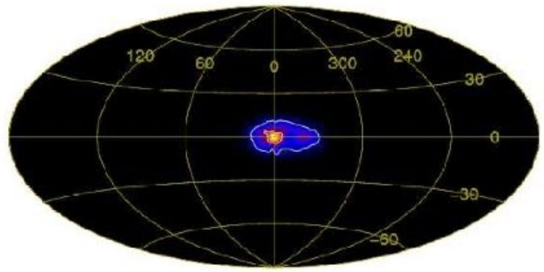
motivation of dark forces

- 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)



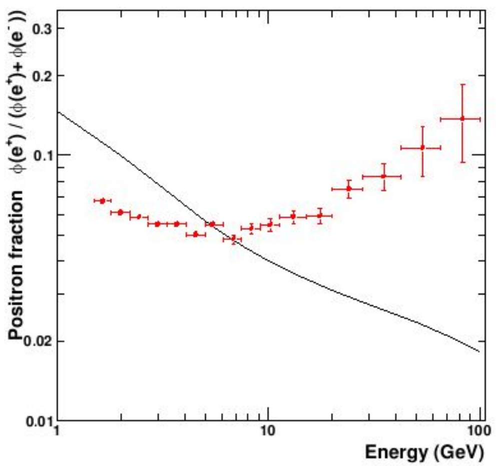
astro observations





511 keV line - sky map

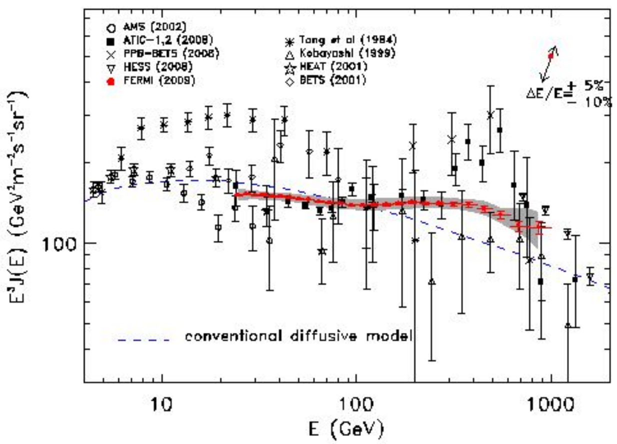
G. Weidenspointner et al., Nature **451** *(2008) 159*



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*

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;

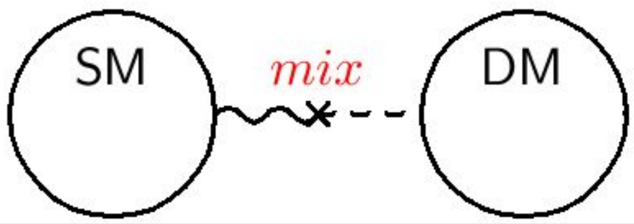
(4) Microlensing (MACHO) events;

(5) Asymptotically flat rotation curves in spiral galaxies;

(6) The impressive DAMA/NaI annual modulation signal.

Messangers from Dark Sector

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



The simplest case: Abelian

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

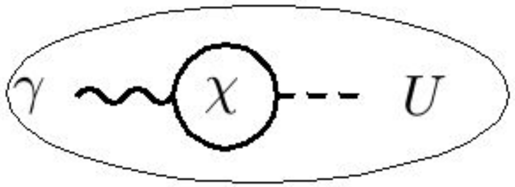
$$\mathcal{L}_{SM} = \mathcal{L}^F_{SM} + \mathcal{L}^B_{SM} + \mathcal{L}^H_{SM}$$

$$\mathcal{L}_{DM} = \mathcal{L}^F_{DM}(\chi) \Rightarrow M_\chi \sim 100 - 1000 \text{ GeV WIMP}$$

$$+ \; \mathcal{L}^B_{DM}(\mathbf{U}) \Rightarrow m_U \sim \text{GeV} \text{ Dark Photon U or } V, A' \ldots$$

$$+ \; \mathcal{L}^B_{DM}(h') \Rightarrow \text{Higgs potential breaking } U(1)_{DM}$$

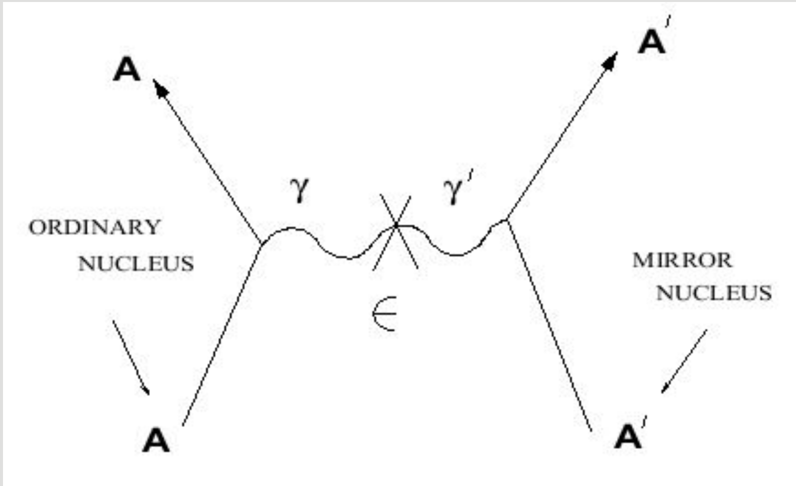
$$\mathcal{L}_{mix} = \epsilon F^{\mu\nu DM} F^{EM}_{\mu\nu}$$



$$+ \; \text{Higgs–Dark Photon int.} + \ldots$$

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

Similar feature from MDM 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.

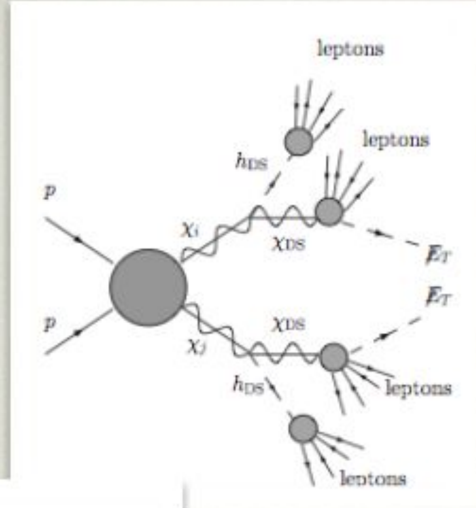
Hidden Sectors: General

- WISPs and the alike on market
  - hidden U(1) gauge bosons,
  - CP-odd Higgs of the NMSSM,
  - axion-like particles (ALPs)
  - Hidden Valeys
  - asymmetric dark matter arXiv:0911.4463
  - Mirror DM
  - Supersymmetric model with an extra singlet chiral superfield: photinos, gravitinos
- Will put more emphasis on searches for MeV-GeV dark particls

MeV-GeV Dark photon: Variety of Models

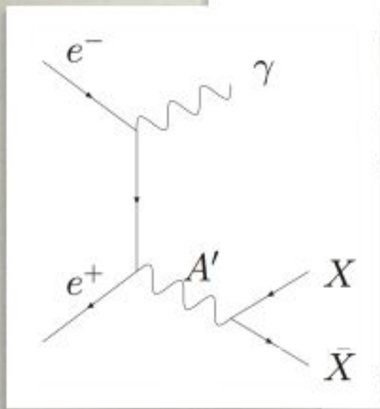
- General model features
  - New gauge bosons in the secluded hidden sector
  - Dark Matter has self-interactions through the new gauge bosons
  - Mixing between the new bosons and the SM particles
- Specific model choices
  - Secluded sector: abelian or non–abelian gauge group
  - Dark Matter identity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

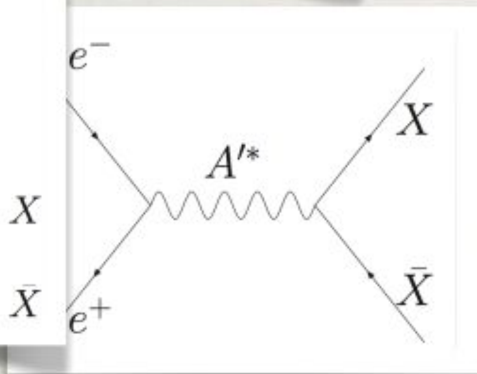
MeV-GeV DP:broad array of searches



High Energy Hadron Colliders: New heavy particles decaying into dark sector (lepton jets)

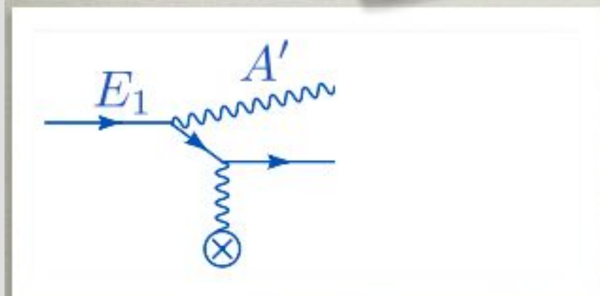
(ATLAS, CMS, CDF & D0)





Colliding e+e-: On- or Off- shell A′, X=dark sector or leptons & pions

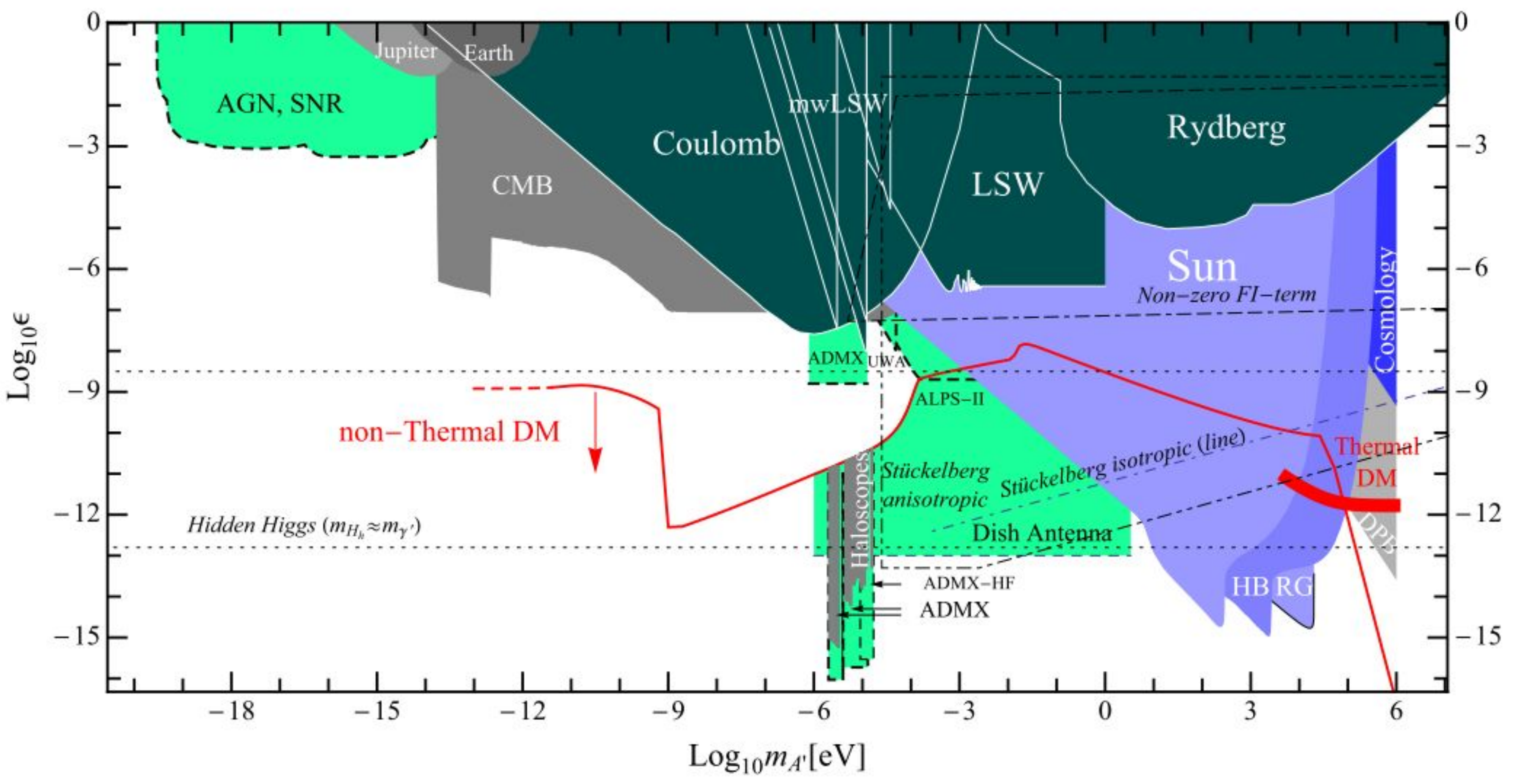
(BaBar, BELLE, BES-III, CLEO, KLOE)



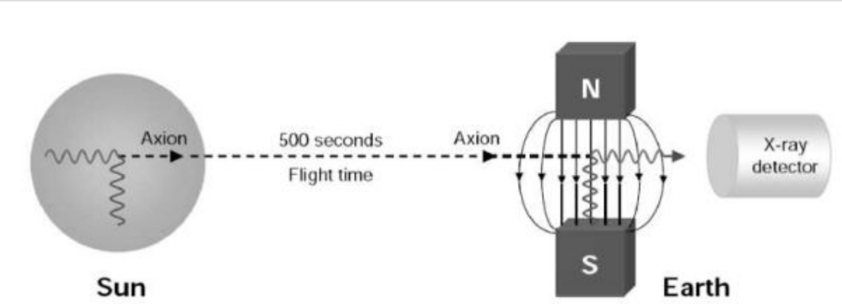
Fixed-Target: Electron or Proton collisions, A′ decays to di-lepton, pions, multiple channels

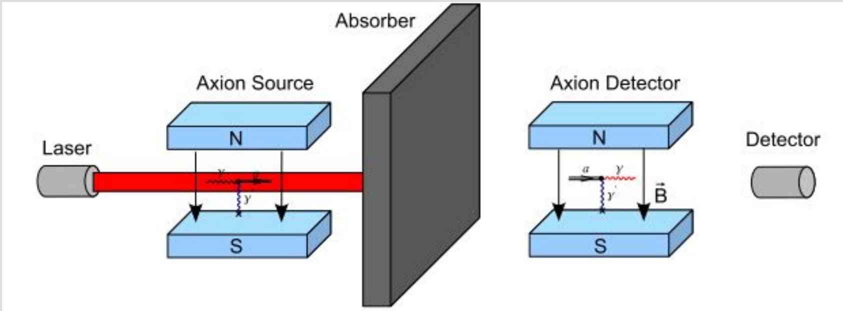
(FNAL, JLAB (Hall A & B & FEL), MAMI (Mainz), WASA@COSY ...)

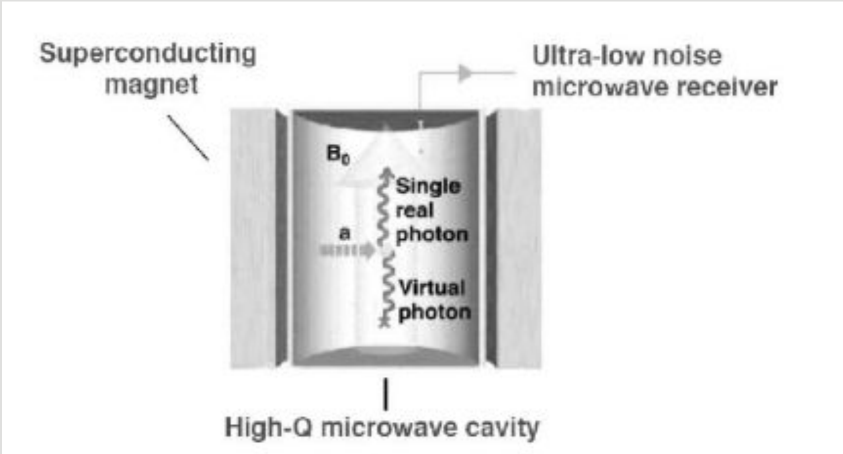
low mass region: a lot of coupling with ALP searches



ALP searches







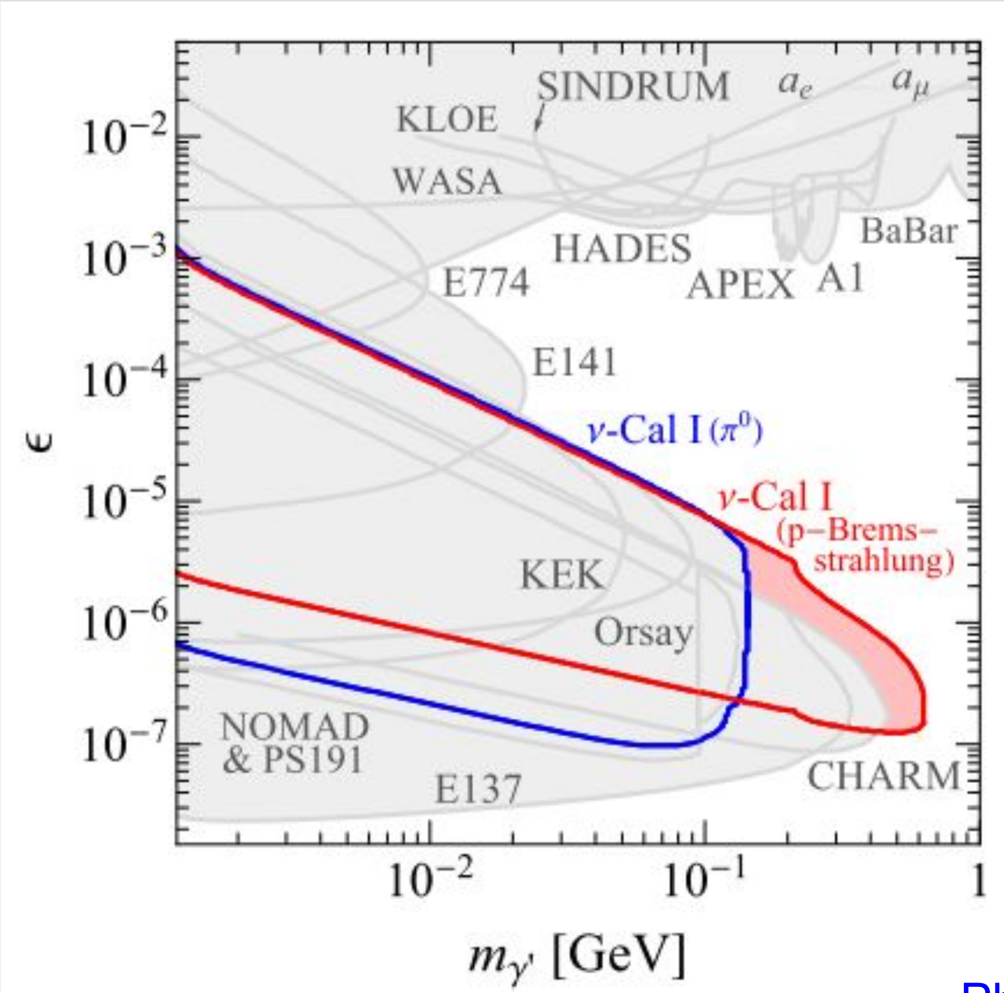
major types of exp

- low energy e-p collision
  - Freytsis M, Ovanesyan G, Thaler J. J. High Energy Phys. 2010(1): (2010)
- high lumi collider
- shinning through a wall
- cavity
- meson decays
- reactor exp
- beam dump
  - electron beam
  - proton beam
- electron scattering fixed target experiments
- rare K decays

respin of old data

- electron-dump:
  - KEK(1986)
  - SLAC: E141(1987), E137(1988)
  - FNAL: E774(1989)
  - Orsay(1989)
- proton-dump:
  - PS191(1986)
  - CHARM(1986)
  - ν-CAL I(1991)
  - LSND(1998)
  - NOMAD(2001)
- Other types
  - SN1987
  - mQ@SLAC(1998)

ν-Cal I@U70 Serpukhov



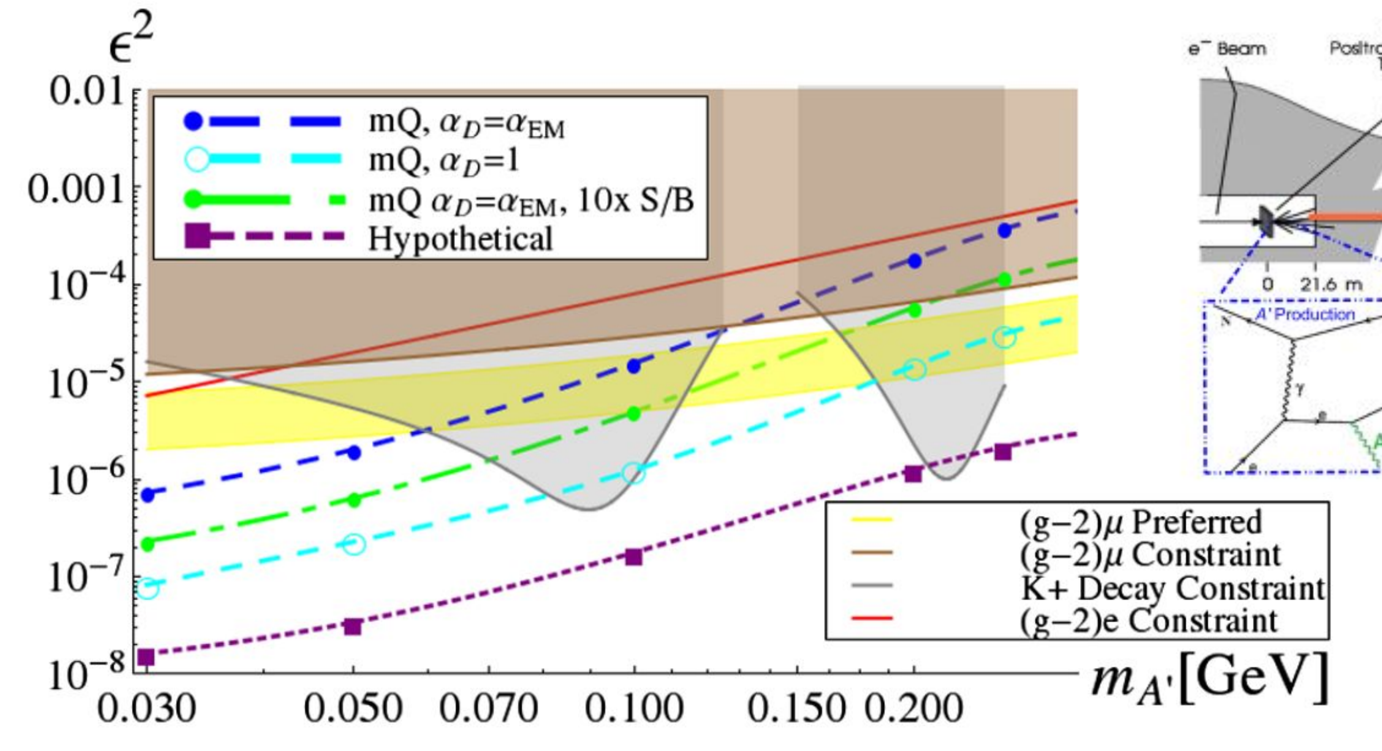
- data from 1989
- latest results extend to larger masses [mð 0 , 0 . 63 GeV] for values in the mixing parameter $\sim 10^{-6}$

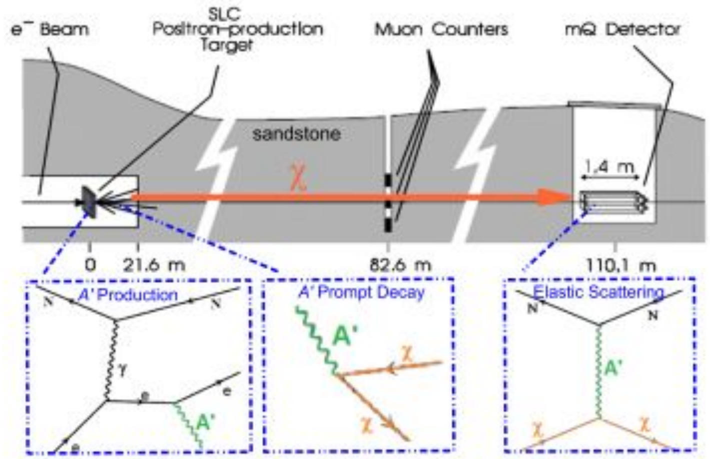
Phys.Lett.B701:155-159,2011

arXiv:1311.3870

MilliCharge(mQ) @ SLC

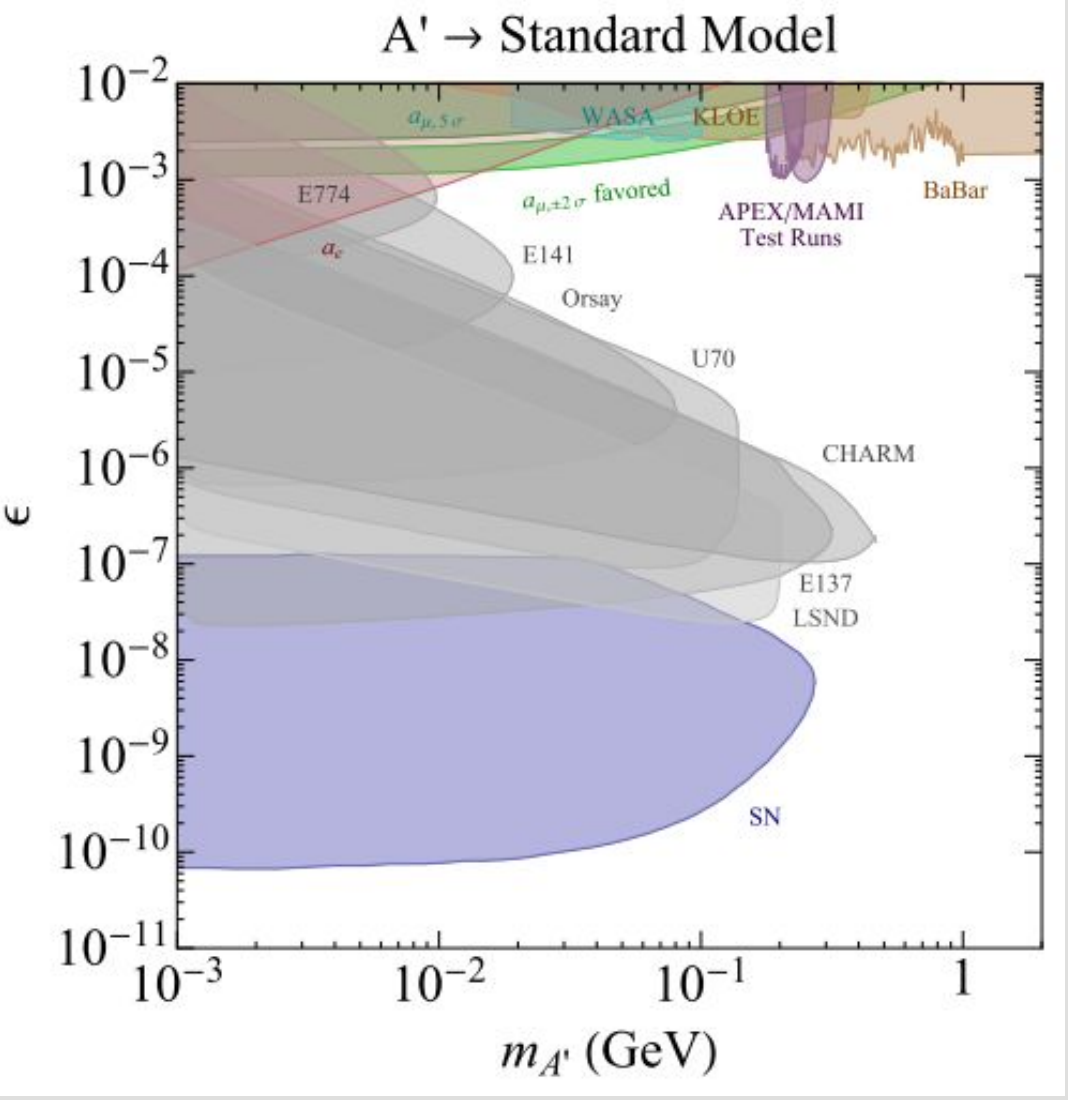
- data from around 1998

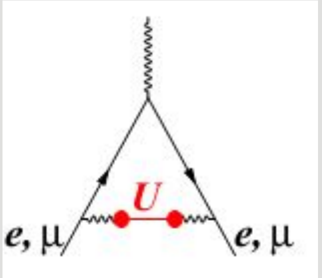




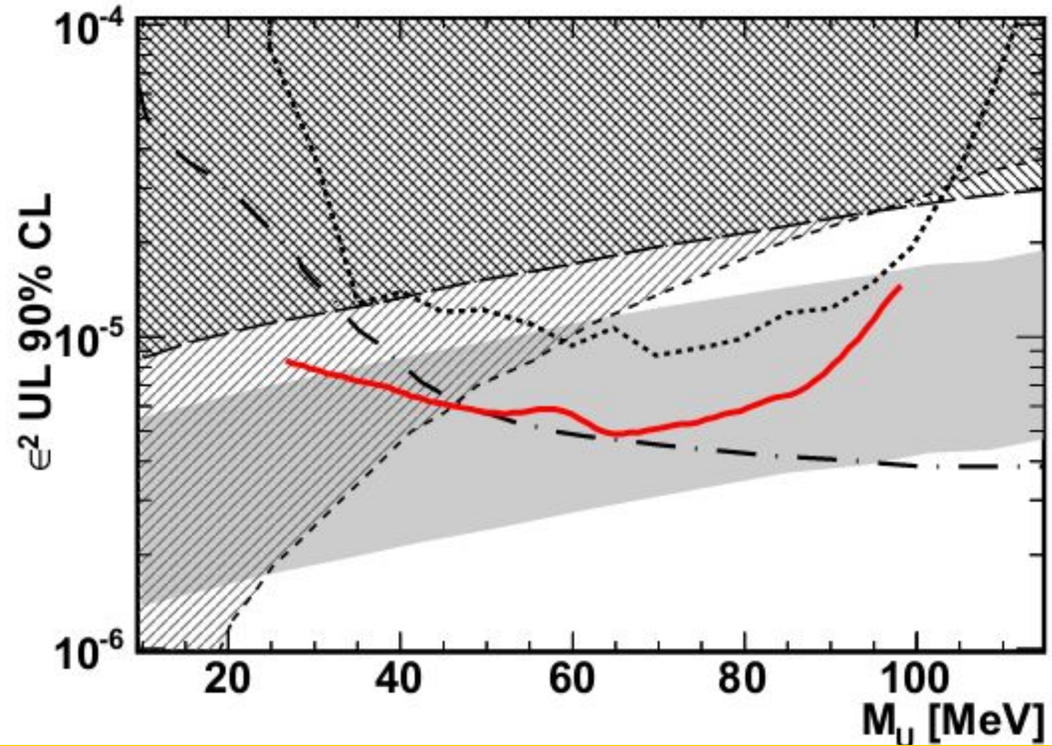
Phys. Rev. Lett. 111, 221803 (2013).

Present limits

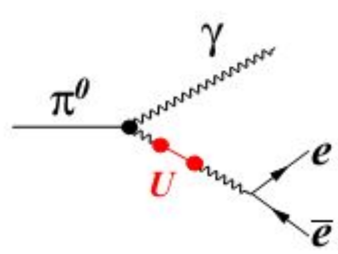




WASA-at-COSY: Pi0 Dalitz decay



Arxiv:1304.0671

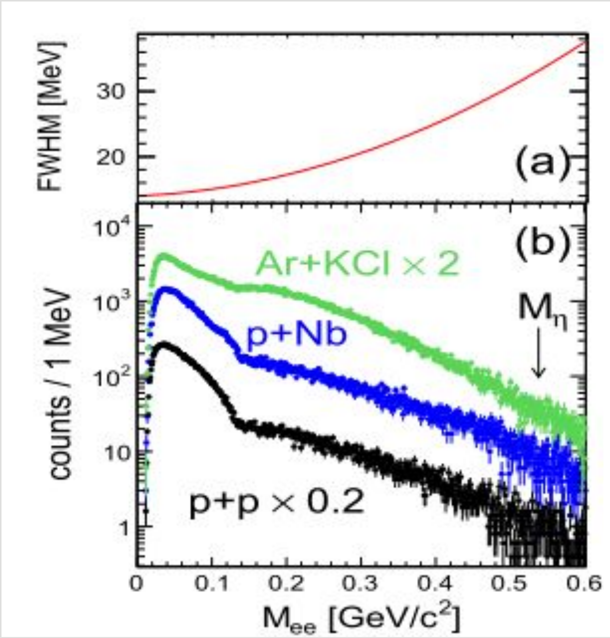


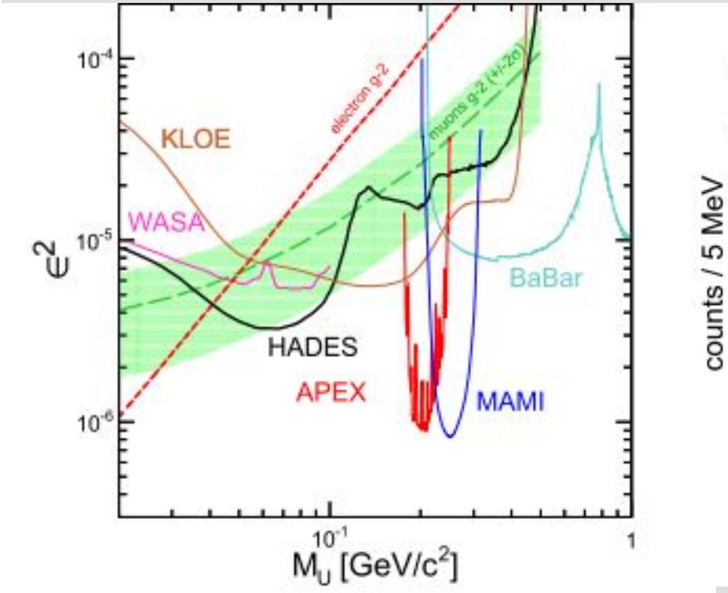
ð 0 ũ ã U ũ ã e+e− decay from the pp ũ ppð 0 reaction

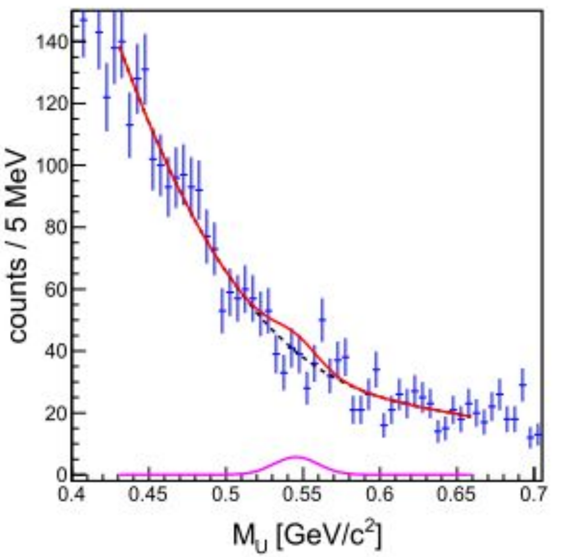
Figure 8: Summary of the 90% CL upper limits for the mixing parameter ϵ^2 from WASA-at-COSY (red solid line) compared to SINDRUM $\pi^0 \to e^+e^-\gamma$ [34] (dotted line) and recent combined KLOE $\phi \to \eta e^+e^-$ [43] (dashed dotted) upper limits. The long respectively short dashed lines (and 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 $g-2$.

CELSIUS in Uppsala => COSY (COoler SYnchrotron) J¨ ulich

HADES

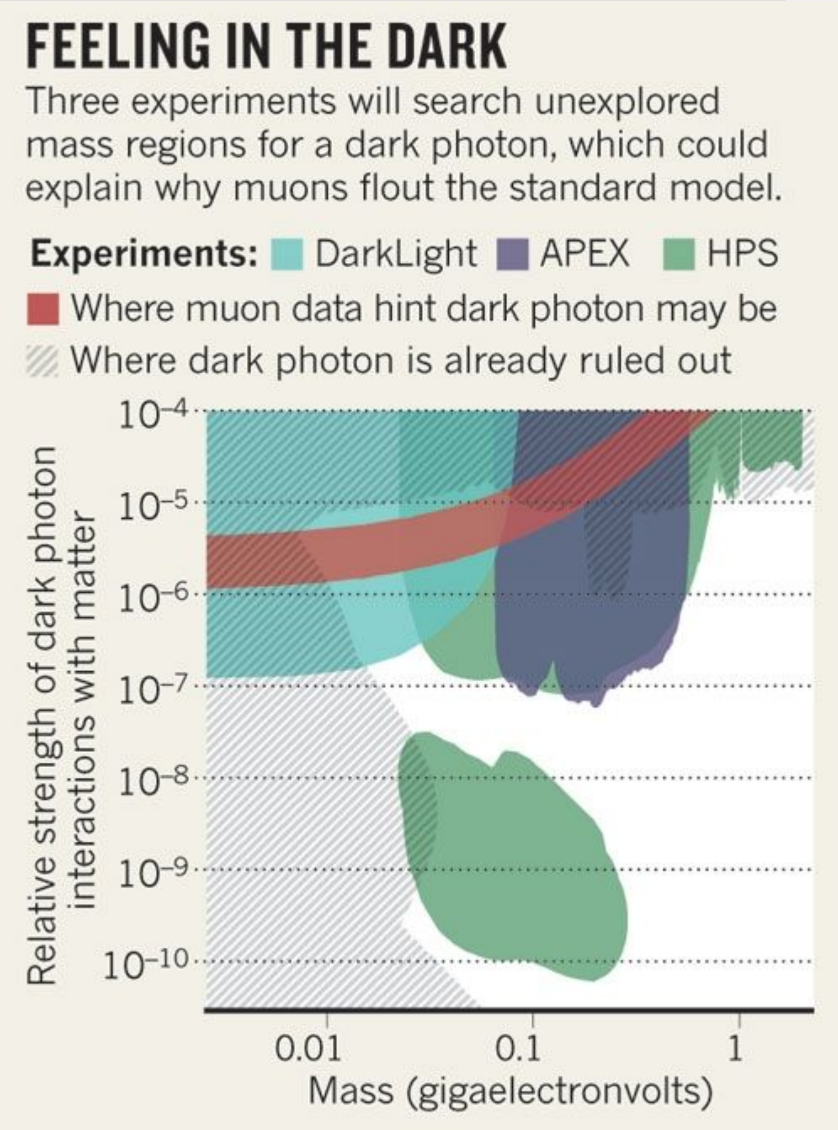


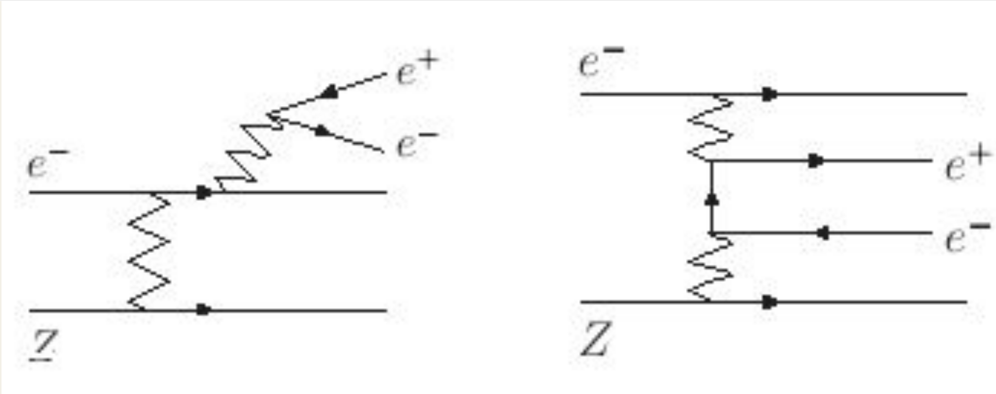


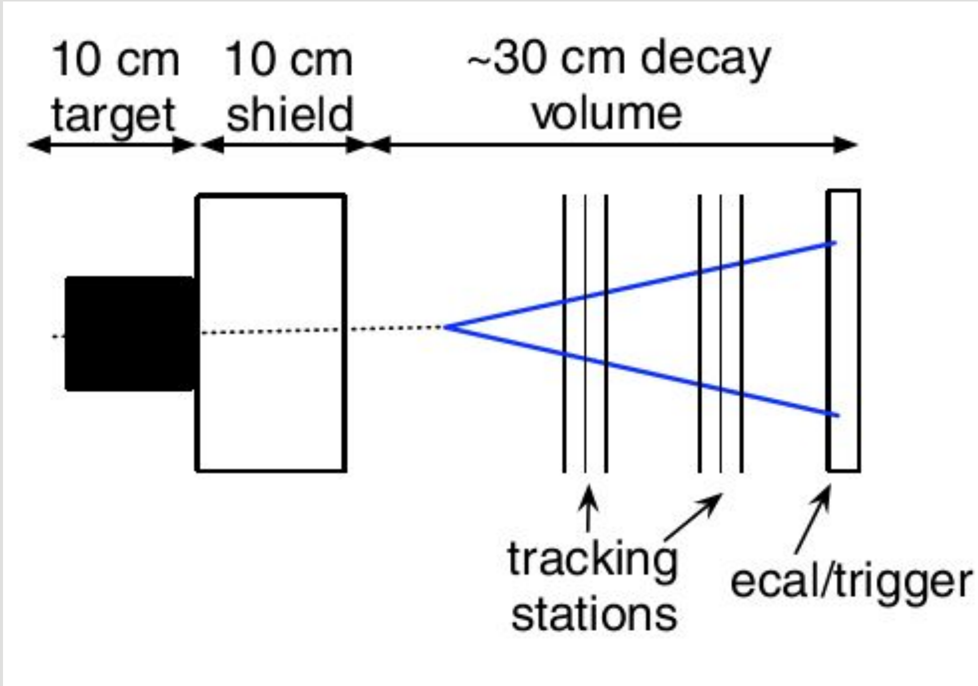


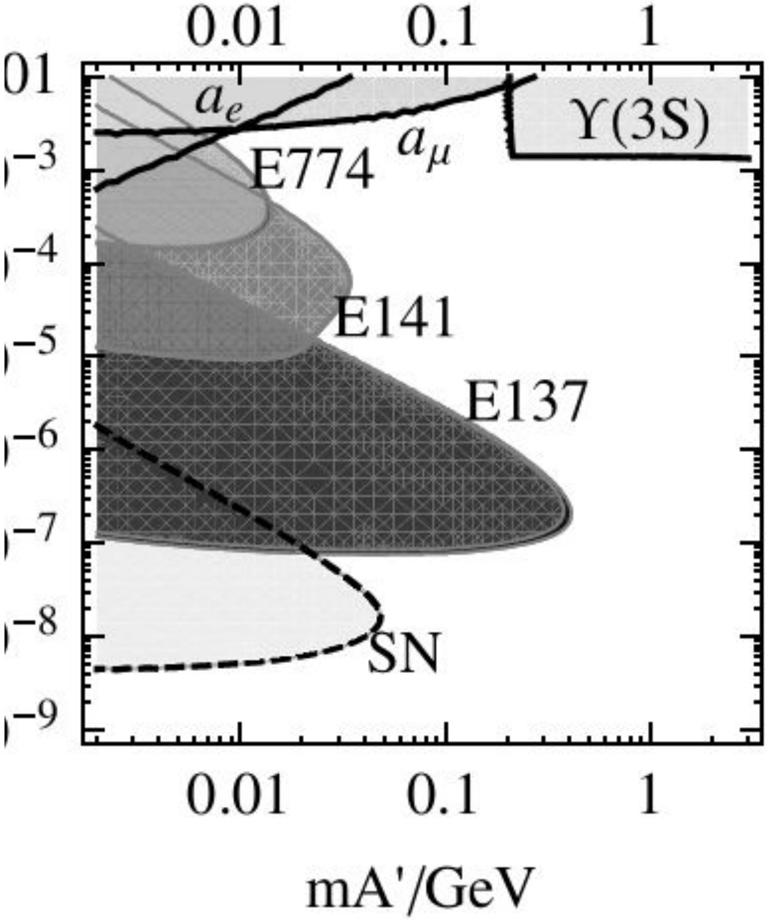
HADES Collaboration 1311.0216
will continue at FAIR

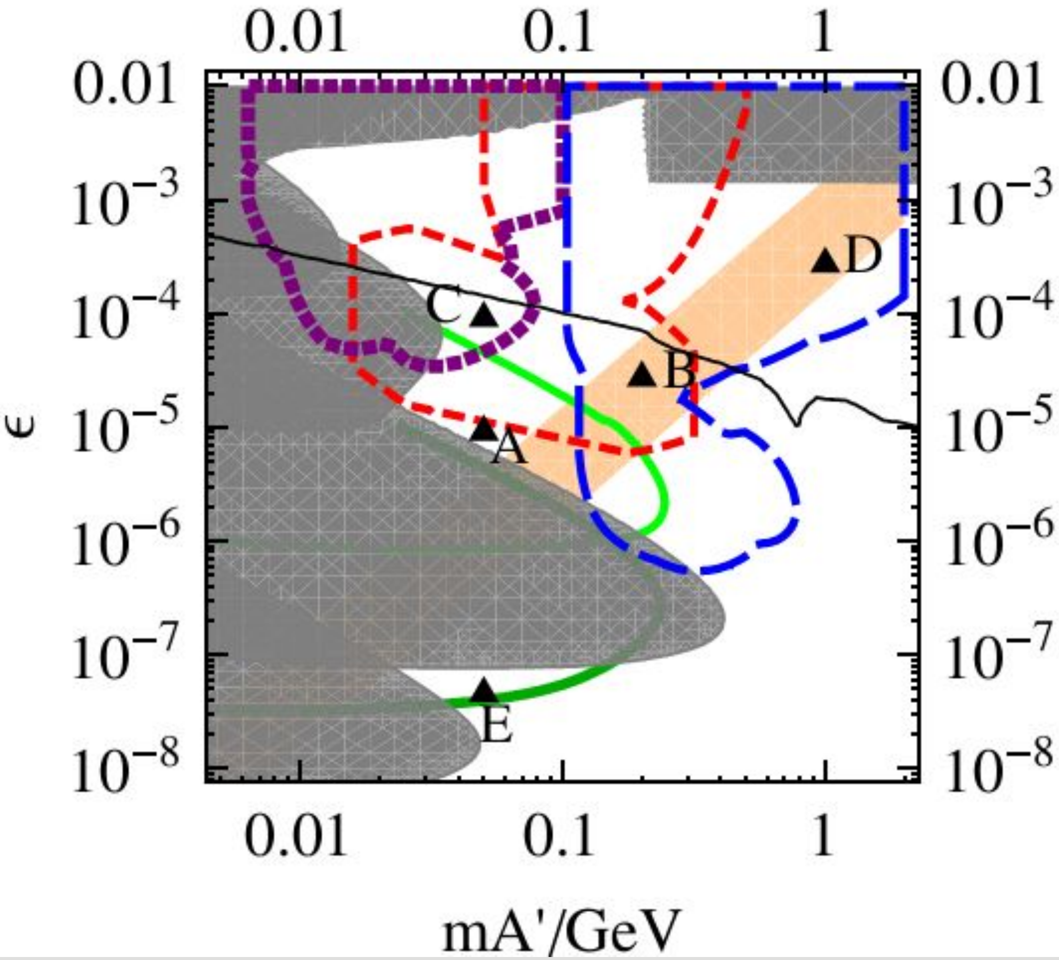
fix target experiements









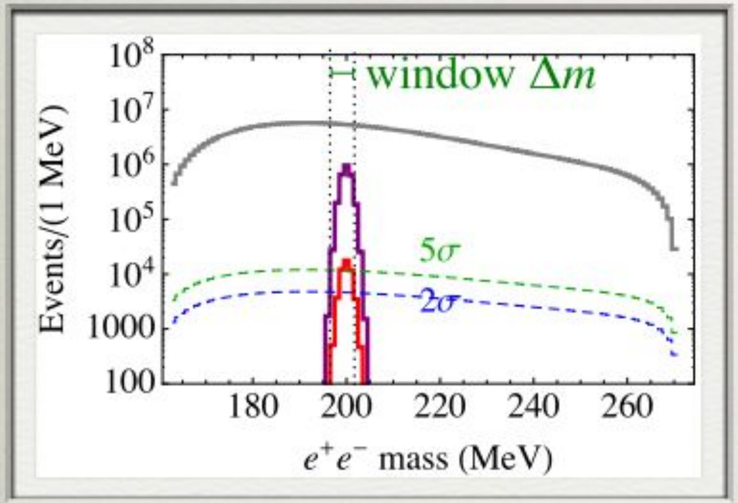


J.D. Bjorken et al., PRD 80 (2009) 075018

new experiments in near future

High-Statistics
Resonance Search

(MAMI, APEX, HPS, DarkLight)



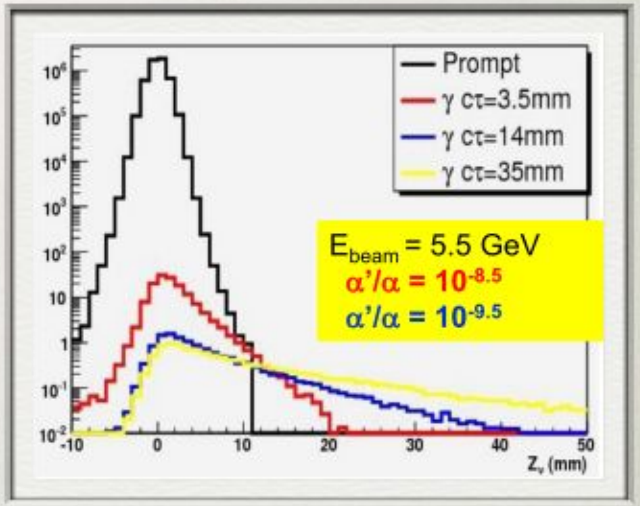
Demands high data-taking rate, background suppression and excellent mass resolution

Demonstrated in test runs: Mainz (1101.4091) and APEX (1108.2750)

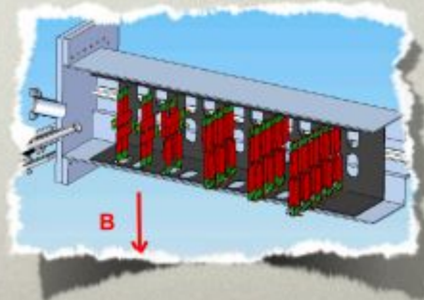
DarkLight: full reconstruction of recoil → sensitive to invisible A′ decays

Displaced
Resonance search

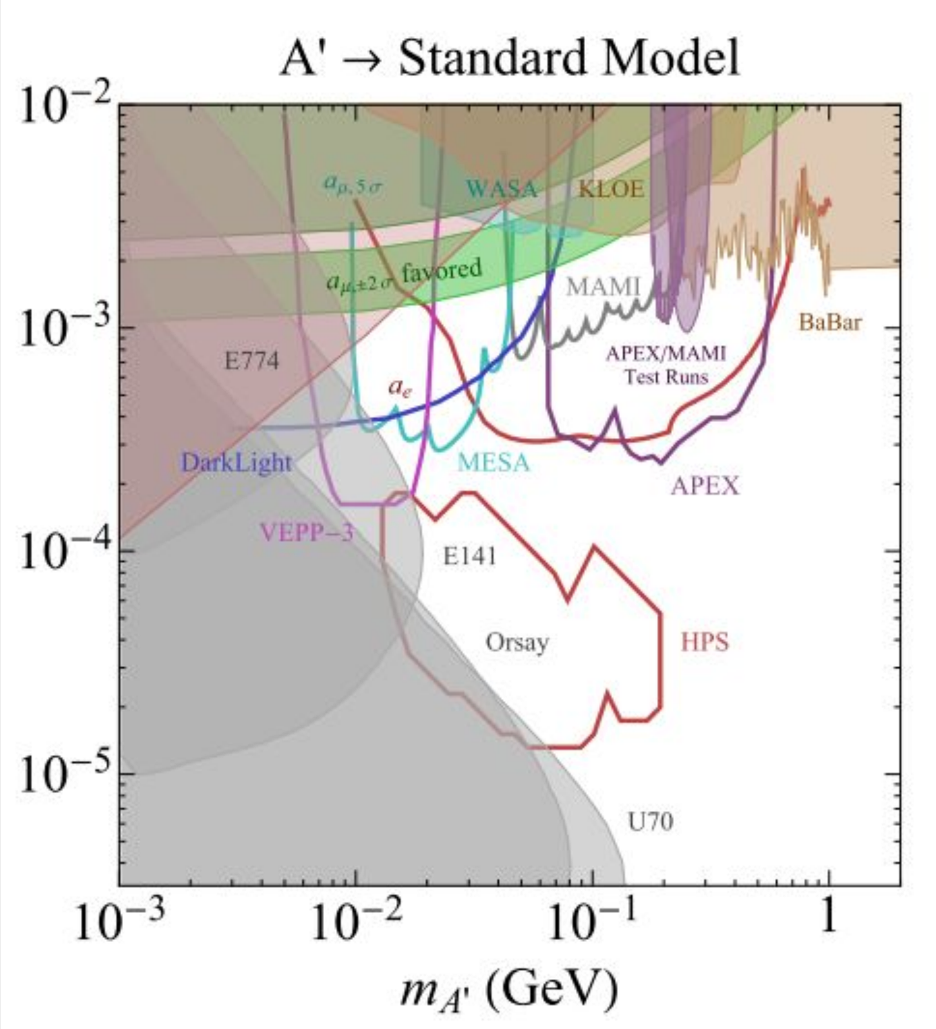
(HPS)



...and forward vertex resolution (well-controlled tails)



projected sensitity in near future



general comments

- hidden/dark photons are less contrained
- the remaining parameter space will be best explored by fixed-target experiments

EU:

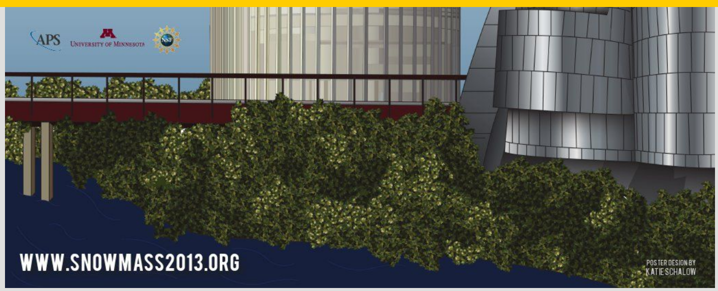
- ApPEC associated with the Eranet ASPERA, coordinates research in Astroparticle Physics. These bodies have published a roadmap which contains the list of topics under consideration.
- From this roadmap, the topics directly related to particle physics discussed in the session on Astroparticle Physics:
  - Direct and indirect WIMP dark matter searches
  - Axion searches
  - Neutrino properties extracted from experiments searching for neutrino-less double beta decay and from cosmological data.
  - Large underground detectors for the study of proton decay, low energy neutrino astrophysics and geo-neutrinos.

US: Snowmass2013

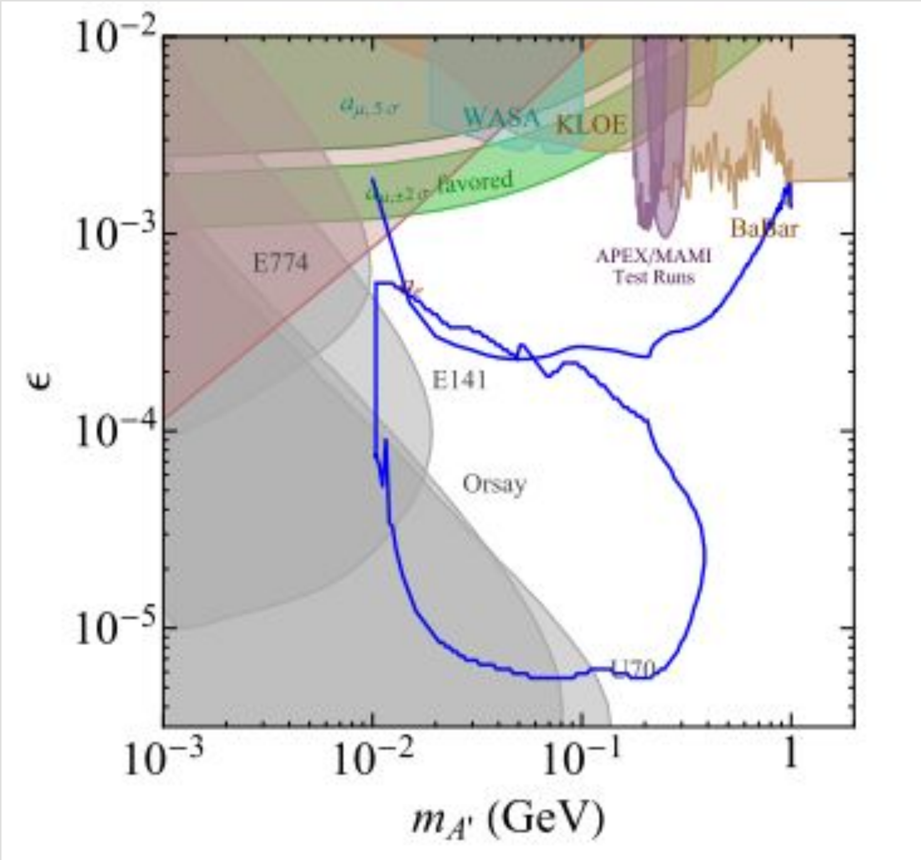
Major IF science opportunities identified:

A. CP violation, rare decays, K's, Charm, B's
B. LFV with μ,τ & (g-2)
C. Neutrino oscillations & mass, CP violation, $0\nu\beta\beta$
D. Baryon number violation (proton decay & neutron oscillations)
E. EDMs, Parity Violation
F. New Light, Weakly Coupled Particles

Existing facilities and technologies and modest experiments enable the exploration of dark sectors. A rich, diverse, and low-cost experimental program is already underway that has the potential for one or more game-changing discoveries. Current ideas for extending the searches to smaller couplings and higher masses increase this potential markedly.



far future



a future HPS-style fixed target experiment. The projected reach here assumes a factor of two improvement in the vertex resolution, a factor of four improvement in mass resolution, a factor of 30 times more luminosity, and higher-energy running with improved particle ID.

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
- Barzè, L., Balossini, G.et al The European Physical Journal C, 71(6). (2011).

Dark Searches at B-factories: topics

Search for dark photon

$e^+e^- \rightarrow \gamma A'$, $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$
$e^+e^- \rightarrow \gamma A'$, $A' \rightarrow$ invisible

Search for dark boson(s)

$e^+e^- \rightarrow A'^* \rightarrow W' W'$
$e^+e^- \rightarrow \gamma A' \rightarrow W' W''$

Search for dark Higgs boson

$e^+e^- \rightarrow h' A'$, $h' \rightarrow A' A'$

Search for dark hadrons

$e^+e^- \rightarrow \pi_D + X$, $\pi_D \rightarrow e^+e^-, \mu^+\mu^-$

Search for dark photon in meson decay

$\pi^0 \rightarrow \gamma l^+l^-$, $\eta \rightarrow \gamma l^+l^-$, $\phi \rightarrow \eta l^+l^-$,...

Search for dark scalar (s) / pseudoscalar (a)

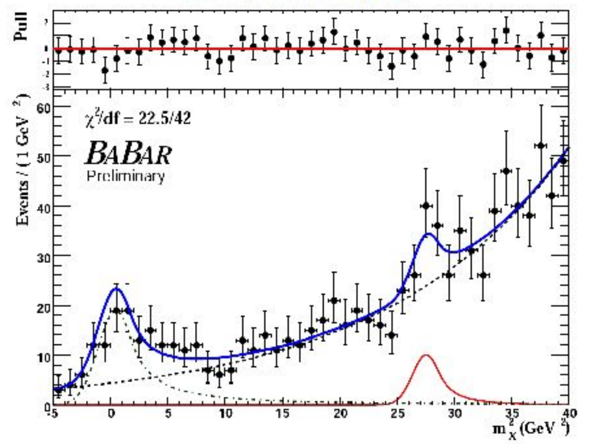
$B \rightarrow K^{(*)}s \rightarrow K^{(*)} l^+l^-$
$B \rightarrow K^{(*)}a \rightarrow K^{(*)} l^+l^-$
$B \rightarrow ss \rightarrow 2(l^+l^-)$
$B \rightarrow K\ 2(l^+l^-)$
$B \rightarrow 4(l^+l^-)$

+ related searches (hidden warped extra dimensions,...)

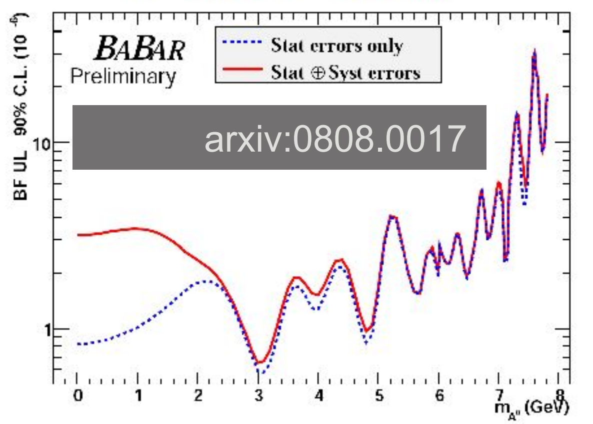
B-factories: results &projection

Υ(3S) → γ A⁰, A⁰→ invisible,
new analysis in progress +
extension to A’

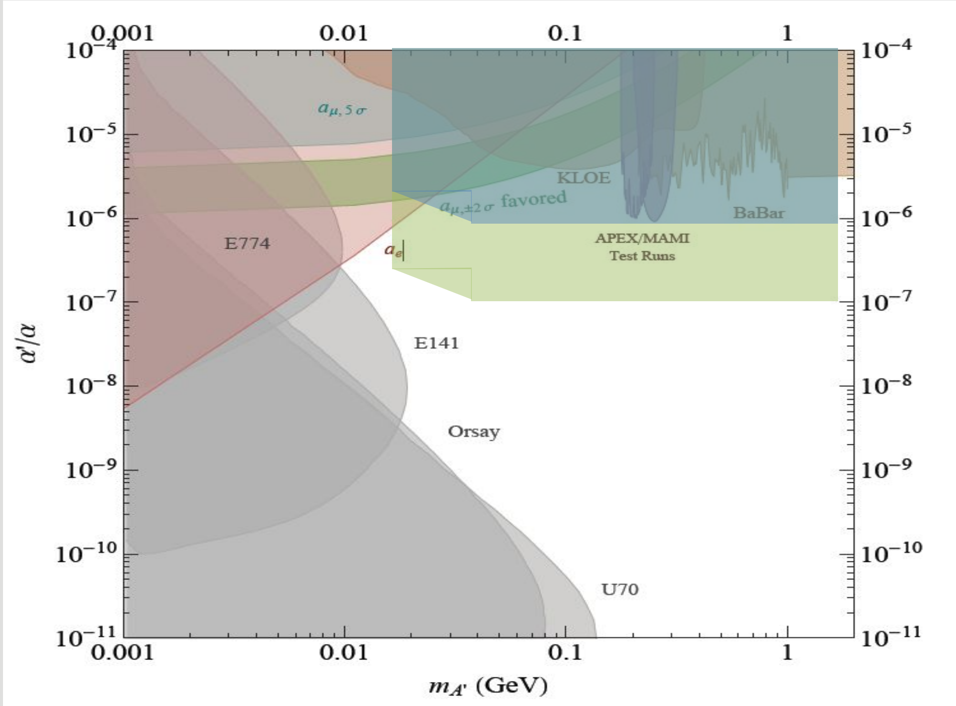
Sample fit Υ(3S)



Υ(3S)→γA⁰, A⁰ → invisible

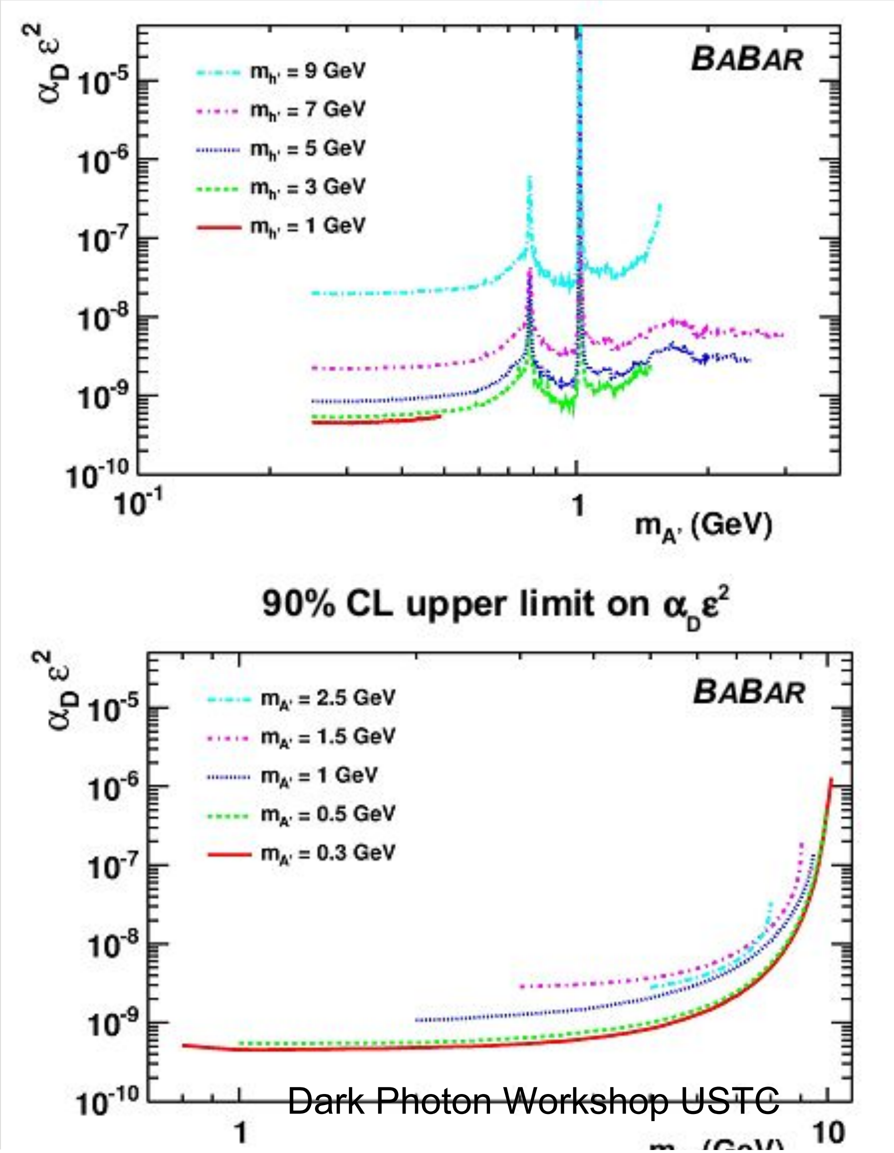


Projected limits with full *BABAR* dataset
for $e^+e^- \rightarrow \gamma A'$, $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$



BABAR 40 fb^{-1}
BABAR 500 fb^{-1}
Belle II 50 ab^{-1}

Babar


BABAR
$m_{h'}$ = 9 GeV
$m_{h'}$ = 7 GeV
$m_{h'}$ = 5 GeV
$m_{h'}$ = 3 GeV
$m_{h'}$ = 1 GeV
$\alpha_D \varepsilon^2$
$m_{A'}$ (GeV)
90% CL upper limit on $\alpha_D \varepsilon^2$
BABAR
$m_{A'}$ = 2.5 GeV
$m_{A'}$ = 1.5 GeV
$m_{A'}$ = 1 GeV
$m_{A'}$ = 0.5 GeV
$m_{A'}$ = 0.3 GeV
$\alpha_D \varepsilon^2$

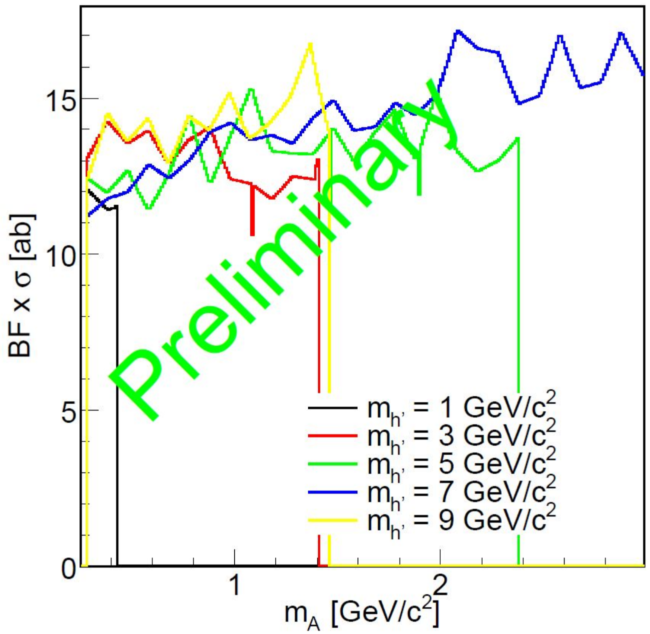
Search for the “Dark Photon” and “Dark Higgs” at Belle

$e^+e^- \to Ah' \to AAA$ with $A \to l^+l^-$ (l=e or μ) or hadrons

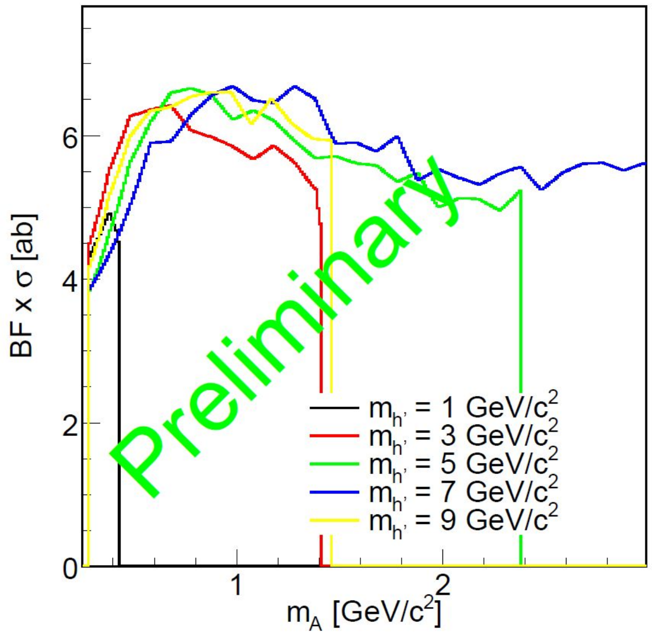
Preliminary predicted sensitivity

- assume number of events observed = number of background
- upper limit (90 % CL) determined by Feldman-Cousins method.

- $e^+e^- \to 3e^+3e^-$

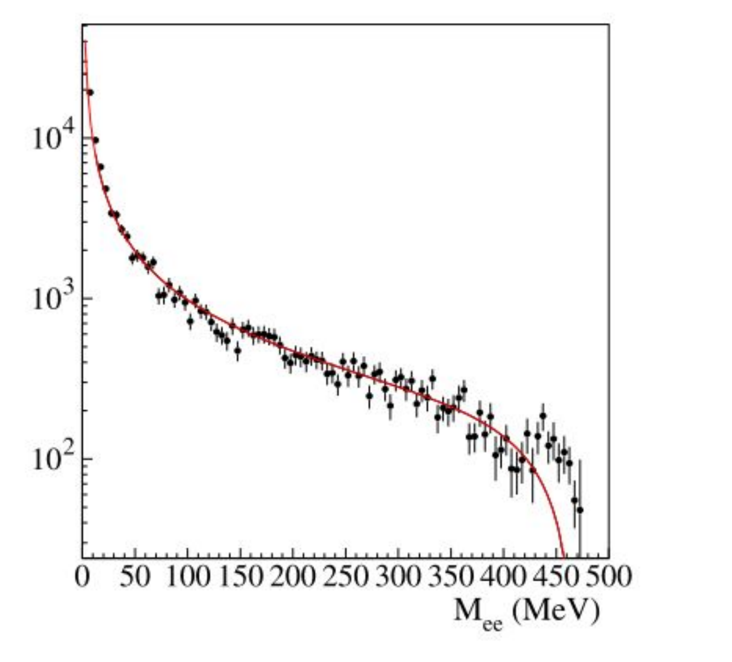


- $e^+e^- \to 3\mu^+3\mu^-$

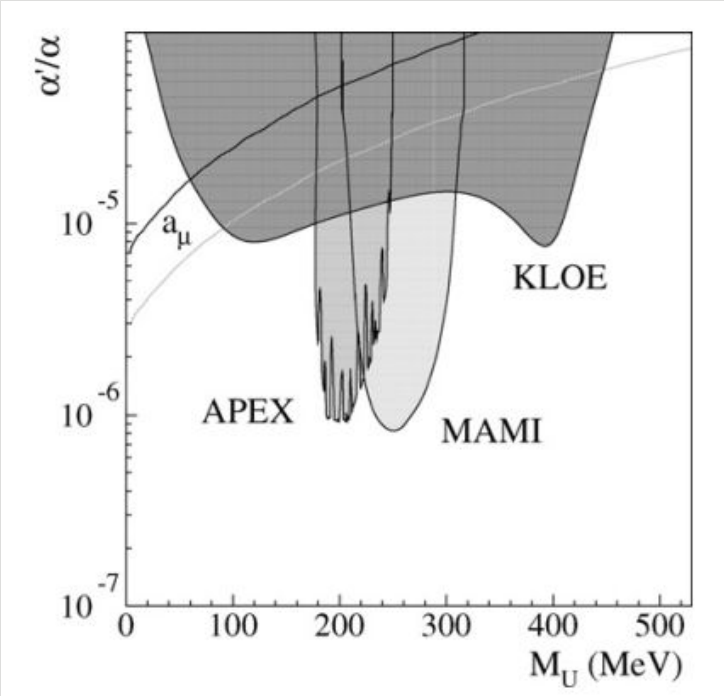


=> sensitivity scales nearly linearly with integrated luminosity

KLOE



Fit to the corrected M_{ee} spectrum for the Dalitz decays $\phi \to \eta e^+ e^-$



1. The KLOE-2 Collaboration. Phys. Lett. B. 706(4-5):251. (2012)

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;
$J/\psi \to U l^+l^- \to 4l$;
$\psi(2S) \to U\chi_{c1,2} \to e^+e^-\chi_{c1,2}$;
$J/\psi \to Uh' \to l^+l^-$ + 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

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

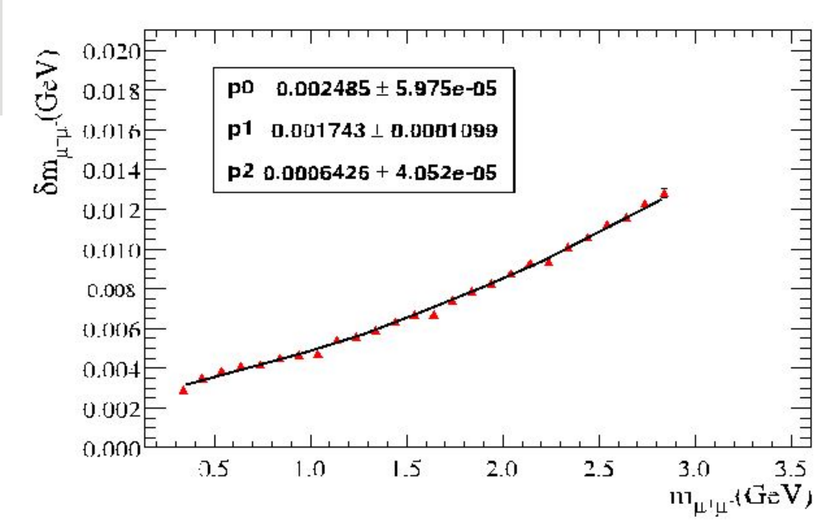
- Babayaga@NLO
  - 0.1% precision
  - U boson process with ISR, FSR and interf
- Cut following BESIII
- Figure of Merit

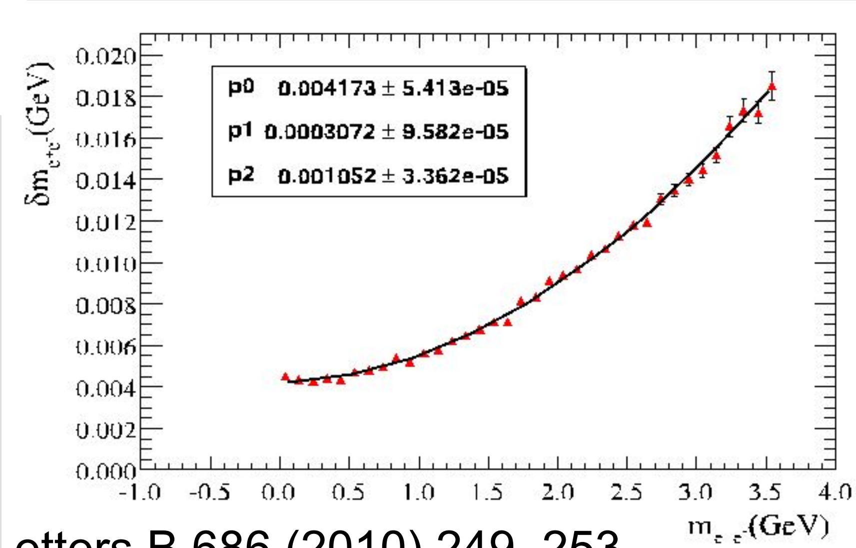
$$\frac{\mathscr{L}(\sigma_{SM+U} - \sigma_{SM})}{\sqrt{\mathscr{L}\sigma_{SM}}} \equiv \sqrt{\mathscr{L}}\frac{\sigma_S}{\sqrt{\sigma_{SM}}}$$

resolutions at BESIII

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

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

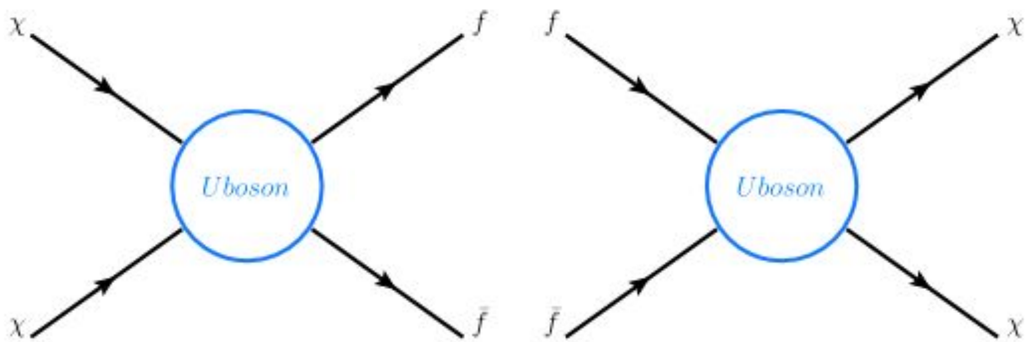




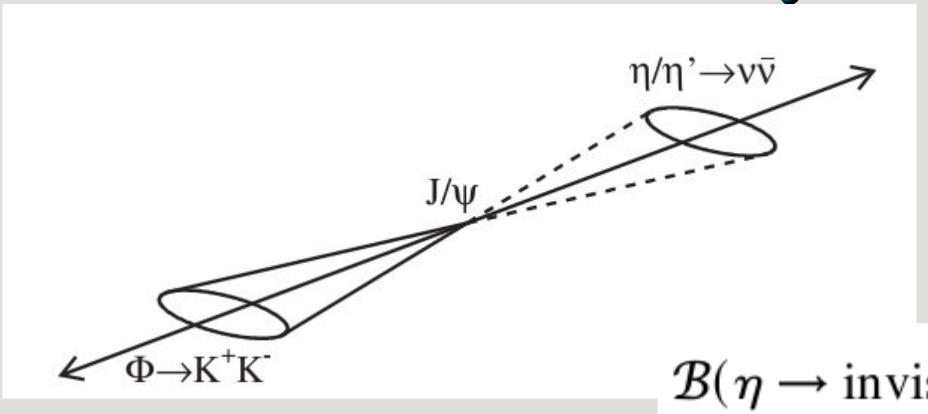
H.-B. Li, T. Luo / Physics Letters B 686 (2010) 249–253

Status of invisible meson analysis:

- **Light DM candidates**
- **U_d(1) and U Boson**
  - **Dark matter interaction**
  - **511 keV line observed in INTEGRAL**
  - **PEMELA/ATIC/Fermi results**
  - **DAMA/LIBRA**
- **Rare decays to νν: BR are very low in SM**



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

BES2006

Quantity	Value: η	Value: η'
$n_{\rm UL}^{\eta}$ ($n_{\rm UL}^{\eta'}$)	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%
$\sigma_{\eta}^{\rm stat}$ ($\sigma_{\eta'}^{\rm stat}$)	2.8%	18.5%
σ_{η} ($\sigma_{\eta'}$)	8.1%	21.6%

Thanks to the much improved EMC

BES2013

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

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

BES2006

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

BES2013

EMC simulation is dominant

Invisible decays in psi

- **Possible psi decays:**
  - **Vector coupling**
  - **Axial coupling**

$$\psi \text{ (or } \Upsilon) \to \text{invisible } \chi\chi, \ldots$$

$$\begin{cases} \psi \text{ (or } \Upsilon) & \to \gamma U, \\ \psi \text{ (or } \Upsilon) & \to \gamma\chi\chi, \ldots \end{cases}$$

- **J/psi-> gam + inv: No analysis in referee stage**
  - **Geng Cong(USTC)'s talk on Collaboration Meeting 2011/12/2**
  - **Some MC studies, no numbers**

J/psi->invisible

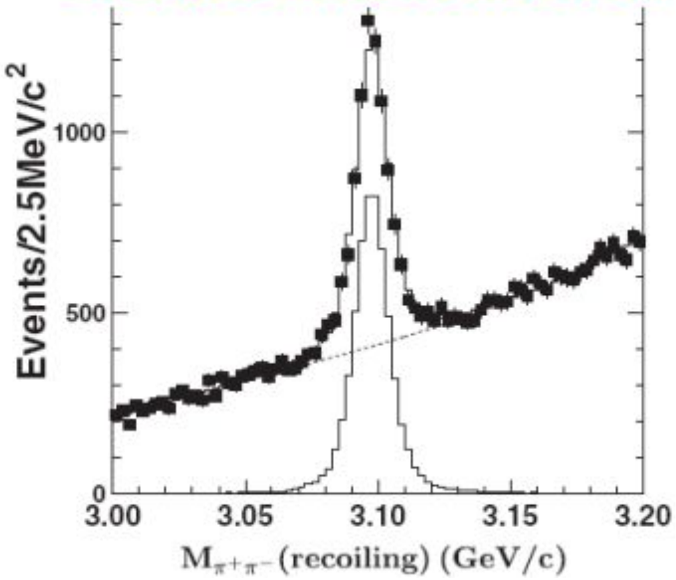
- **through psi'->pipiJ/psi**
  - **No BESIII results yet**
  - **There was BESII results on PRL**

By using 14 million ψ(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)

backgrounds as expected:



- **No analysis at BESIII yet**
  - **HUGE backgrounds**

psi" data

Idea: Search for the ISR process $e^+e^- \to \gamma_{ISR}\gamma' \to \gamma_{ISR}\mu^+\mu^-$

B. Kloss
Nov 2013

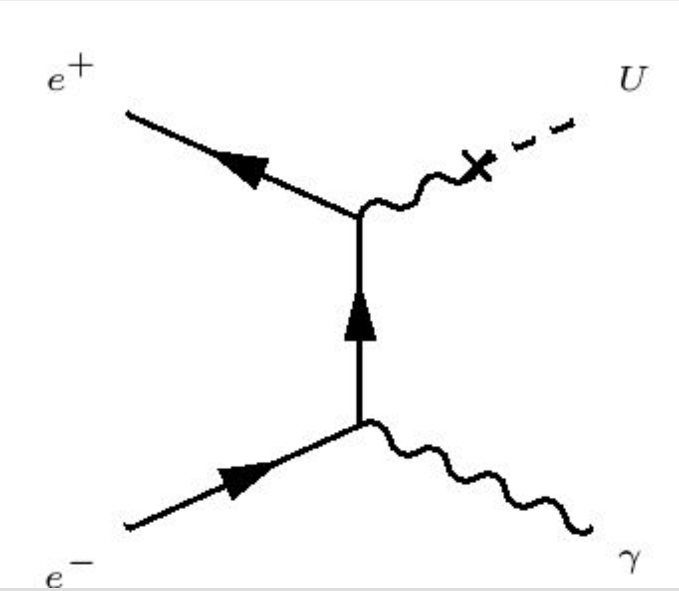
Dominating background: $e^+e^- \to \gamma_{ISR}\gamma^* \to \gamma_{ISR}\mu^+\mu^-$

Use untagged ISR events of the ψ(3770) data sample and BOSS 6.6.2.

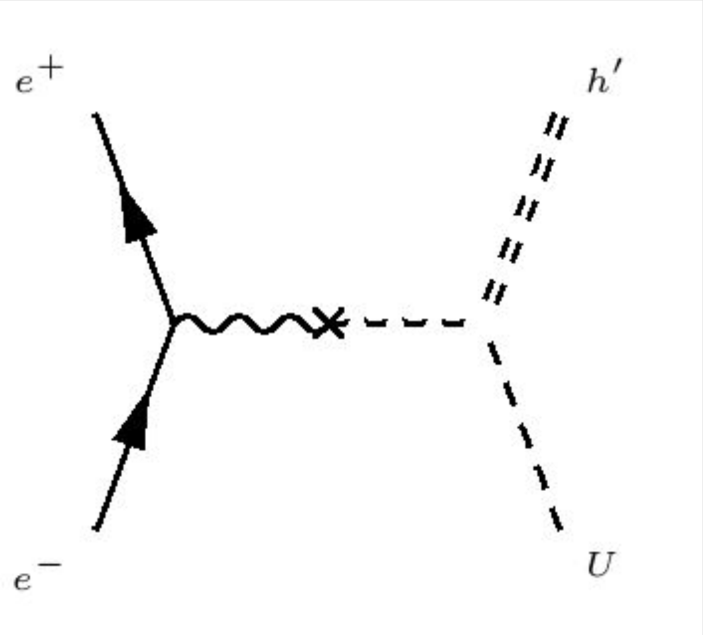
This is a spin off of the pi+pi-gamma analysis.

Least suppressed processes

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



Radiative process



Dark higgs-strahlung

Uncovered channels: priorities

- **Psi' data**
  - **Psi'->pi pi J/psi, Jpsi->gamma + U, U->inv**
  - **Psi'->pi pi J/psi, Jpsi->gamma + U, U->e+ e-**
  - **Psi'->U+chic1, chic1->gamma+J/psi, J/psi-> lepton pairs**
- **J/psi data**
  - **J/psi->phi eta/eta'**
  - **J/psi->eta ll**