Search for a dark photon

Andrzej Kupść
Uppsala University

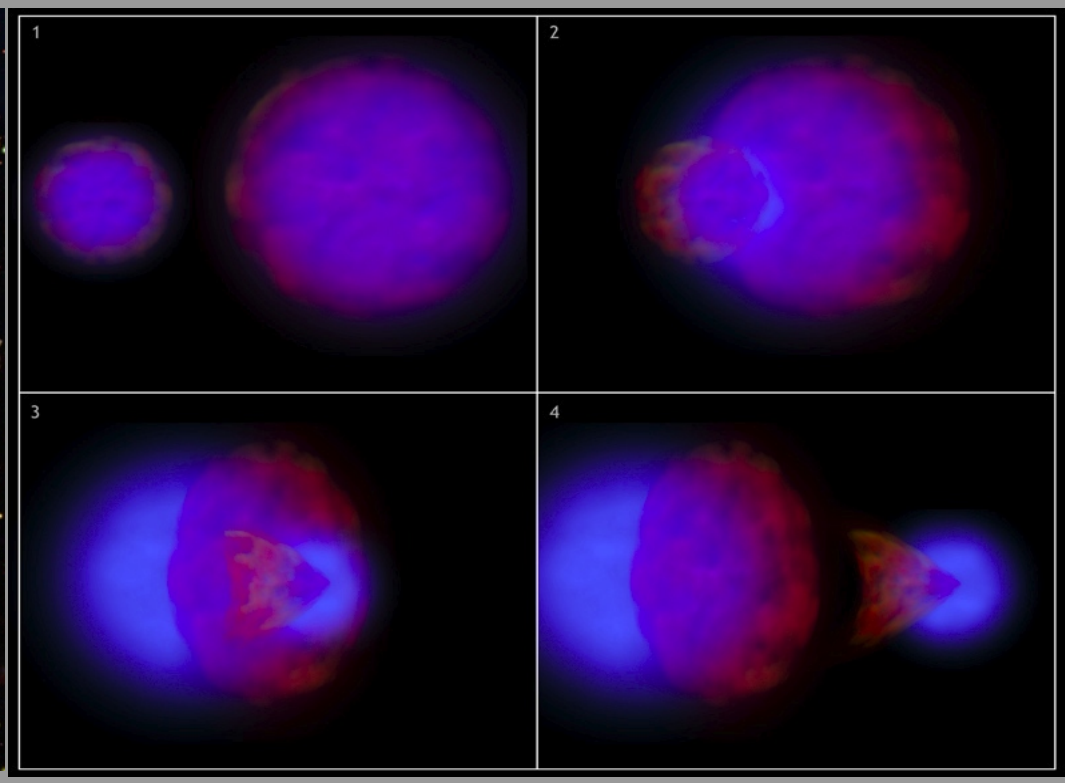
QFPP14, May 8th, 2014

Outline

- Motivation I: Dark Matter → "Dark Force"
- Motivation II: g-2 muon puzzle (status)
- Dark Photon searches (AD 2007-2014)

- Outlook

Origin of Dark Matter

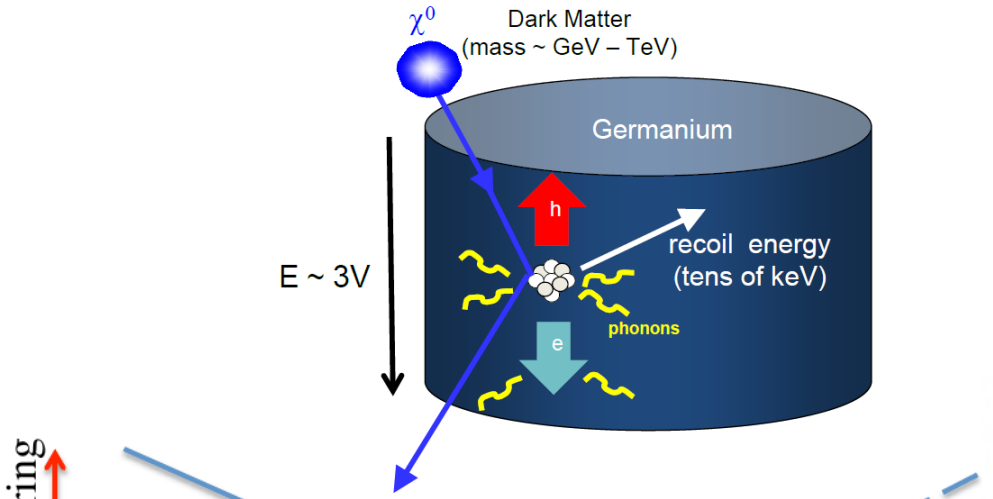


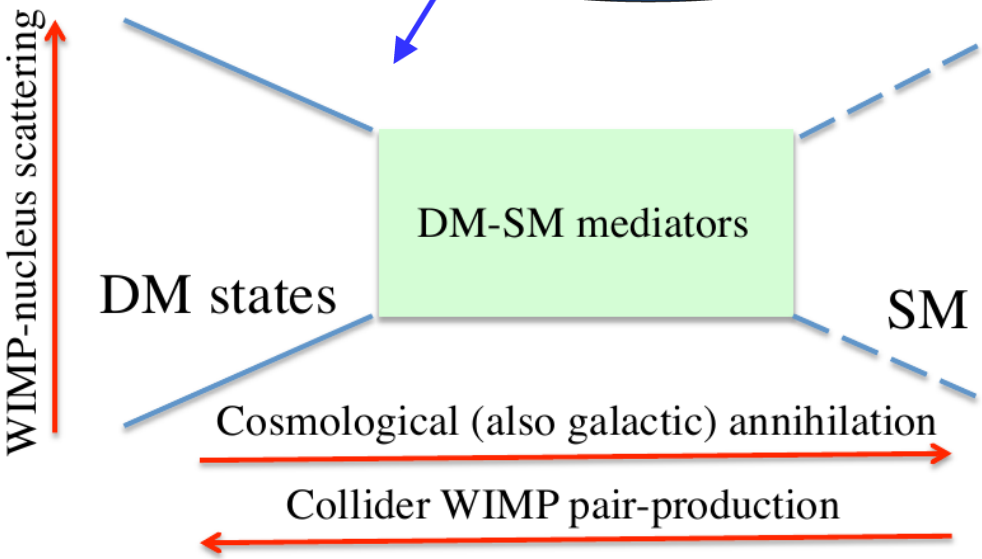
- Massive compact halo objects?
- Weakly Interacting Massive Particles?
- Weakly Interacting Slim Particles?

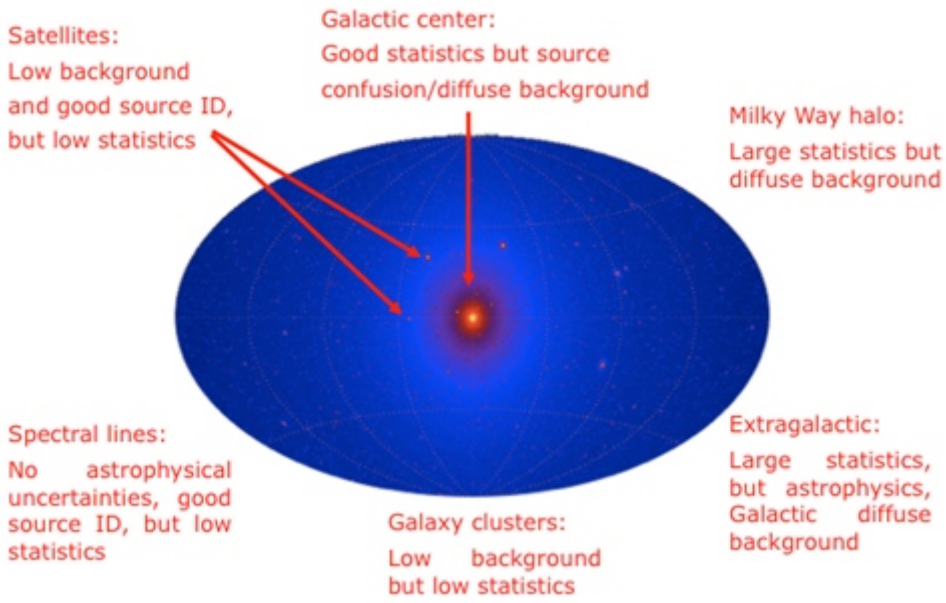
www.symmetrymagazine.org

Picture: NASA/CXC/M.Weiss

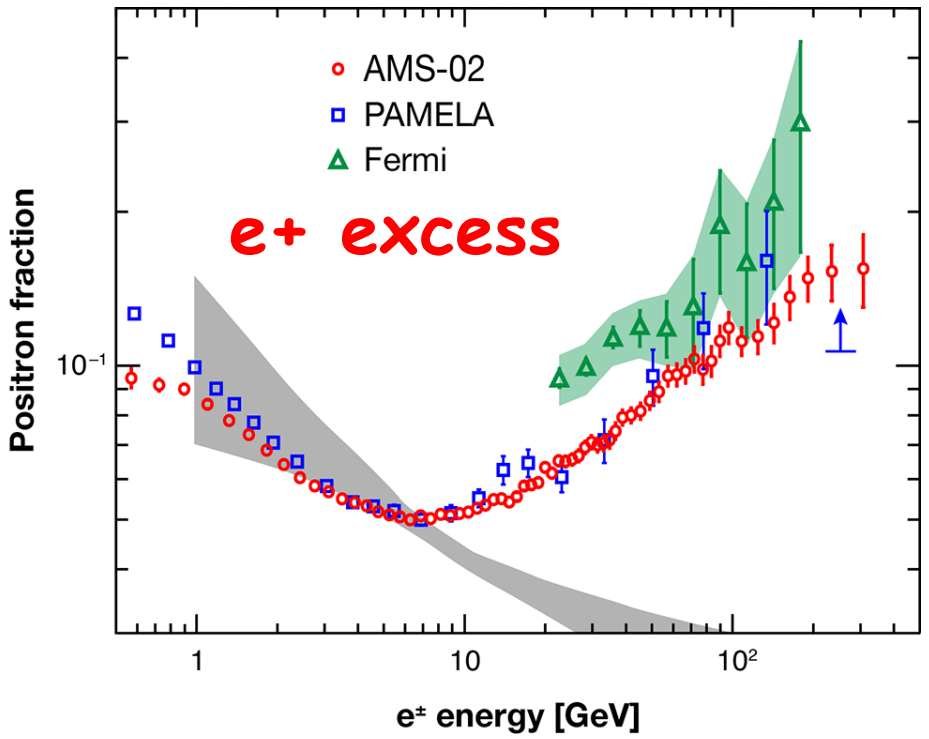
Searches for Dark Matter particles

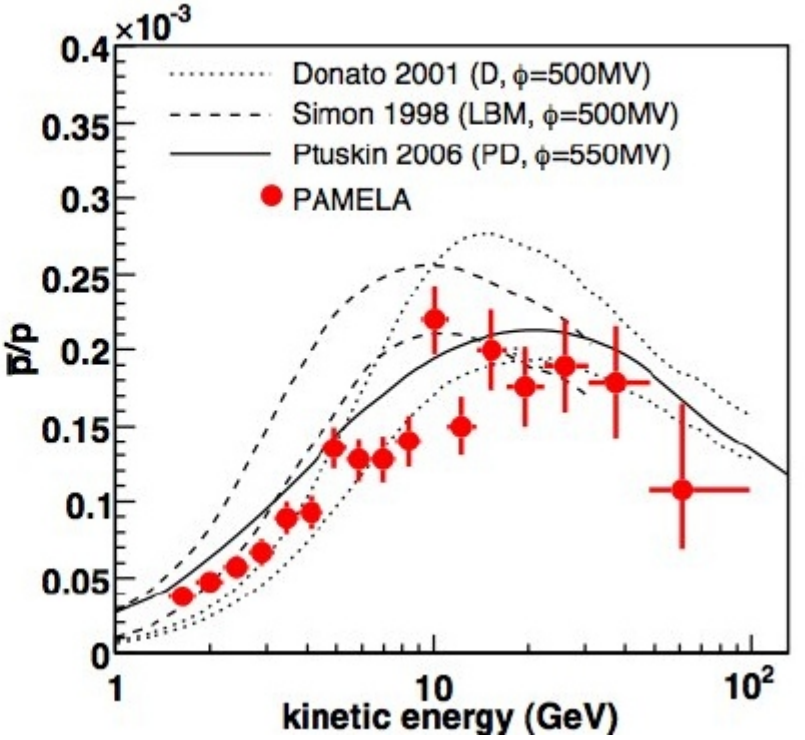






Puzzling astrophysics observations





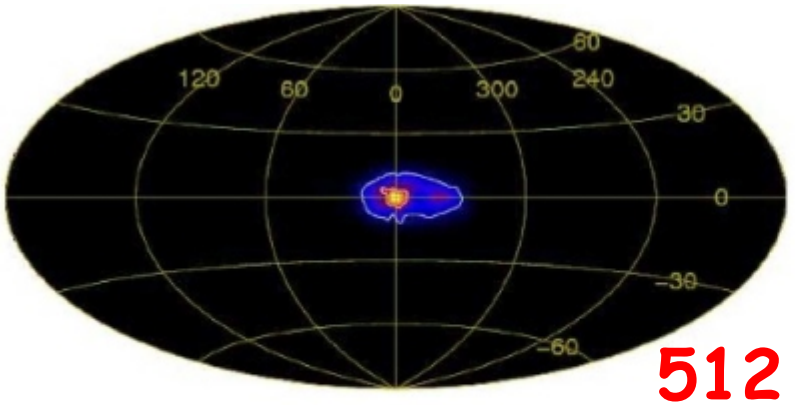


FIG. 4 511 keV line map derived from 5 years of INTEGRAL/SPI data (from Weidenspointner *et al.*, 2008a).

512 keV

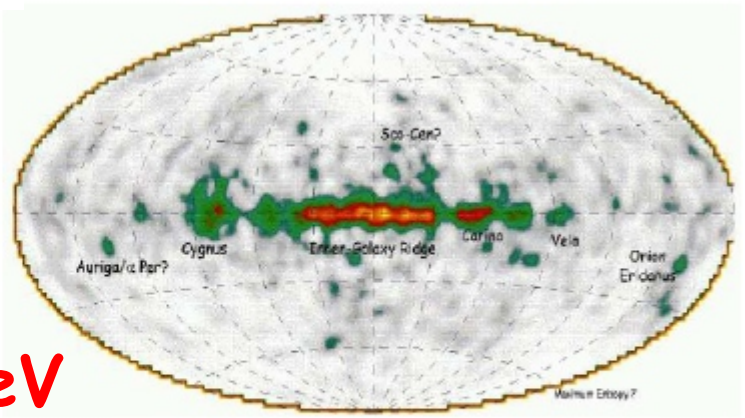


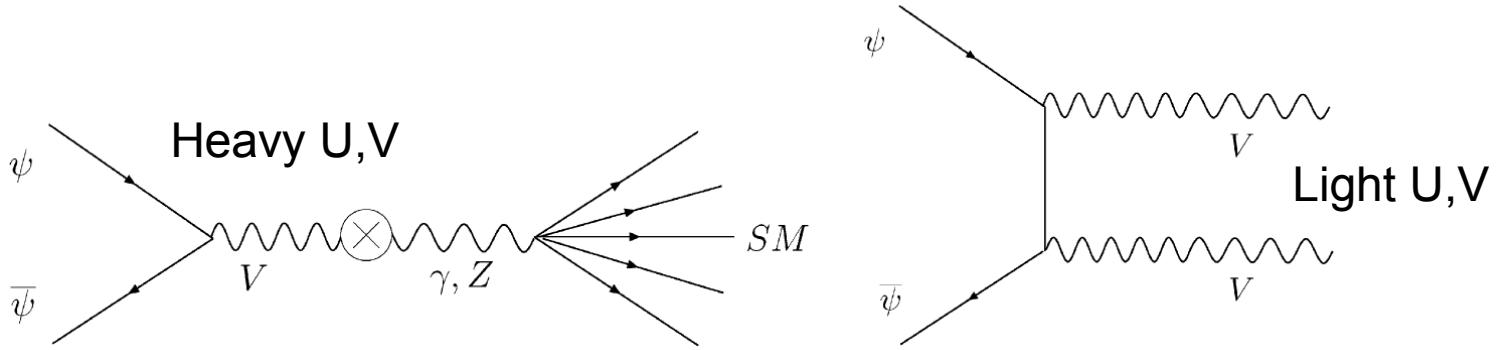
FIG. 7 Map of Galactic ^{26}Al γ-ray emission after 9-year observations with COMPTEL/CGRO (from Plüschke *et al.*, 2001).

note: also astrophys expl

a signal from light Dark Matter?

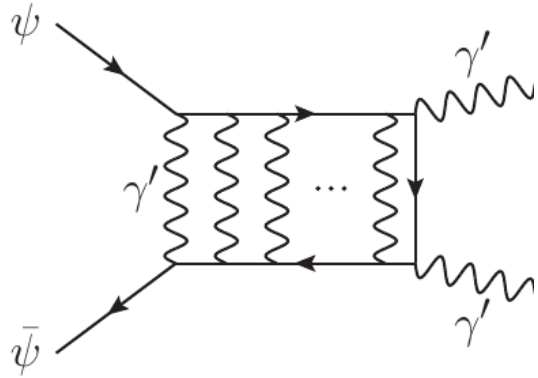
Boehm et al PRL92,101301('04)

Light dark force scenario



Arkani-Hamed et al PRD79 ('09)015014, Pospelov,Ritz PLB671('09)391

A sub-GeV boson provides a "long-range force" between DM particles:



Early Universe: v large, so σv is small

Today: v small, so σv is large

=> correct relic abundance + e+e- data explained

It decays to lepton pairs (e+e−, μ+μ−) but $p\bar{p}$ decays are kinematically forbidden

UPPSALA UNIVERSITET

Dark U(1) group

Hypothesis: Dark matter particles interact via light vector boson 1 MeV – 1 GeV:

which can mix with photon

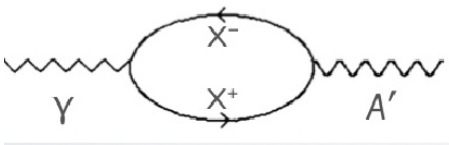
dark/hidden photon, U boson, A'

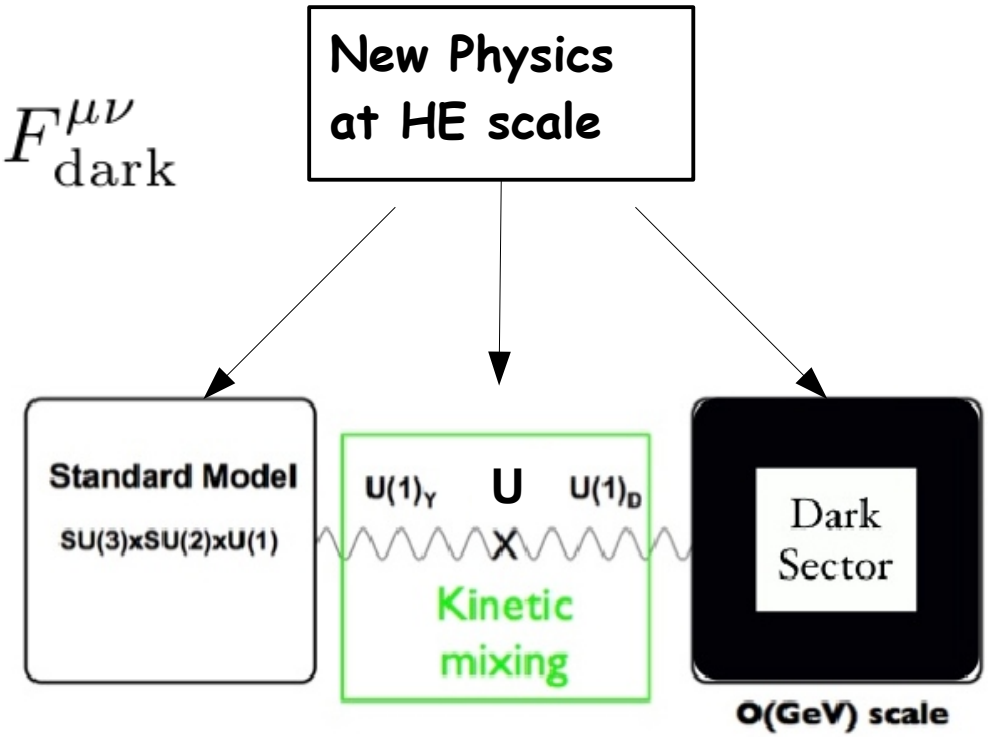
Holdom PLB166 (1986)196

Fayet, PRD75, 115017 ('07)

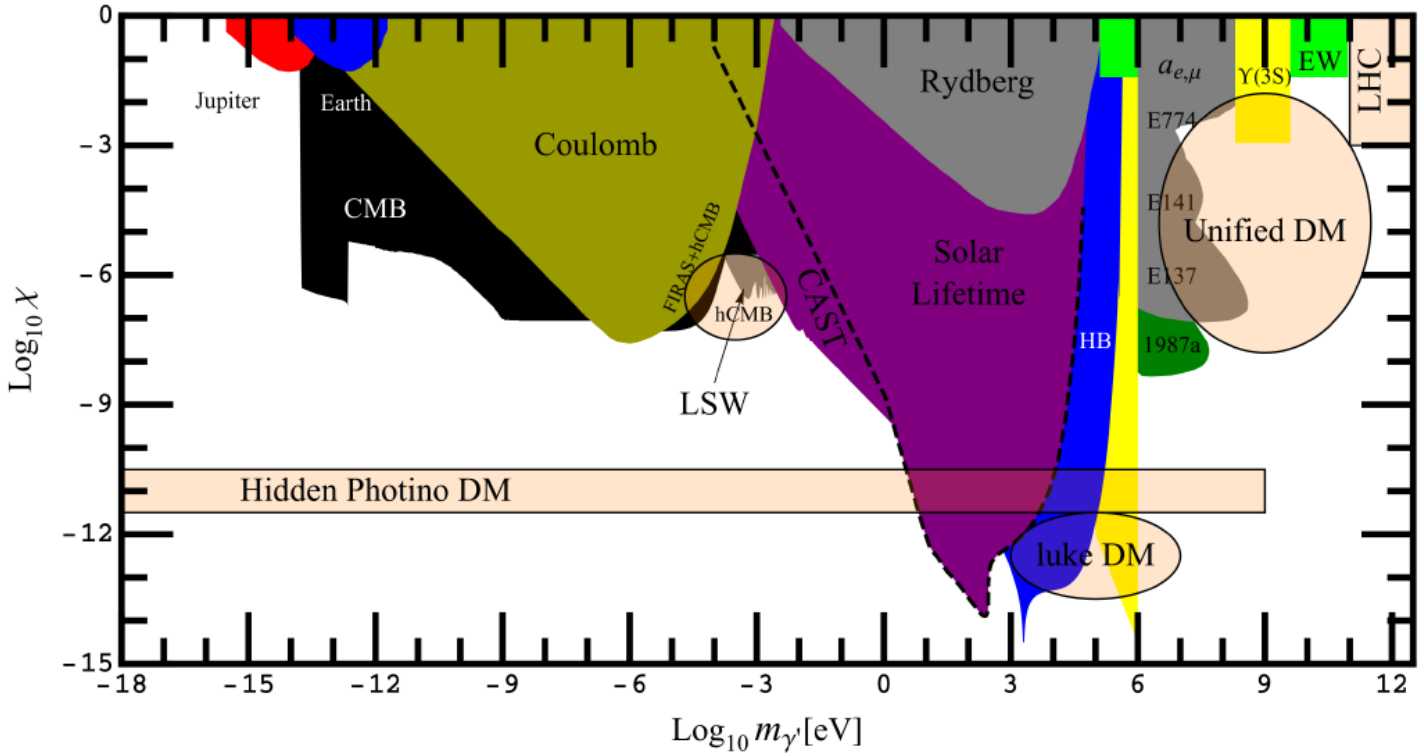
Pospelov et al PLB662 ('08) 53

$$\mathcal{L}_{\rm mix} = -\frac{\epsilon}{2} F^{\rm QED}_{\mu\nu} F^{\mu\nu}_{\rm dark}$$





UPPSALA UNIVERSITET



Ann.Rev.Nucl.Part.Sci. 60 (2010) 405-437

It could explain muon magnetic moment puzzle too!

UPPSALA UNIVERSITET

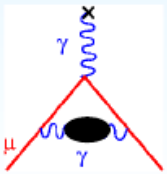
paraphotons L. Okun '82

dark/hidden photon, U boson, γ',A',Z',V

Muon magnetic moment puzzle

$$a_\mu(\text{Expt.}) = 116592089(63) \pm 10^{-11} \qquad (0.54\ \text{ppm})$$

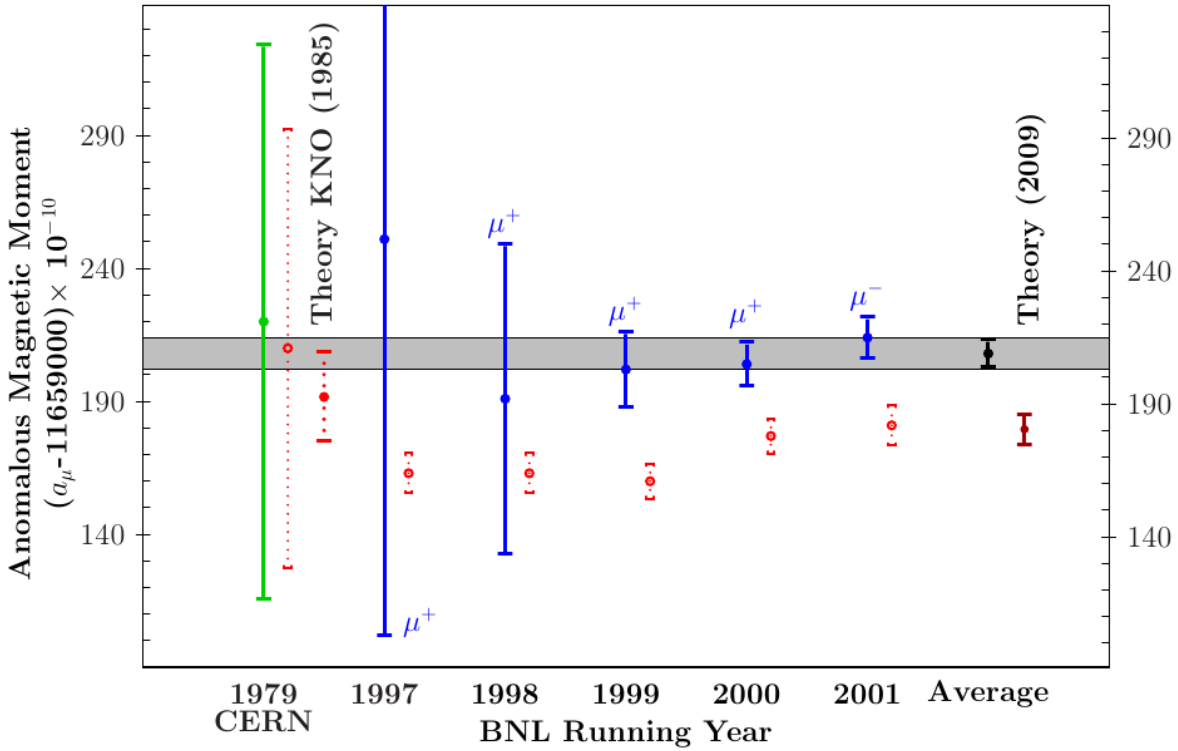
$$\vec{\mu} = g\left(\frac{Qe}{2m}\right) \qquad g = 2(1+a)\,;\; a = \frac{(g-2)}{2}$$

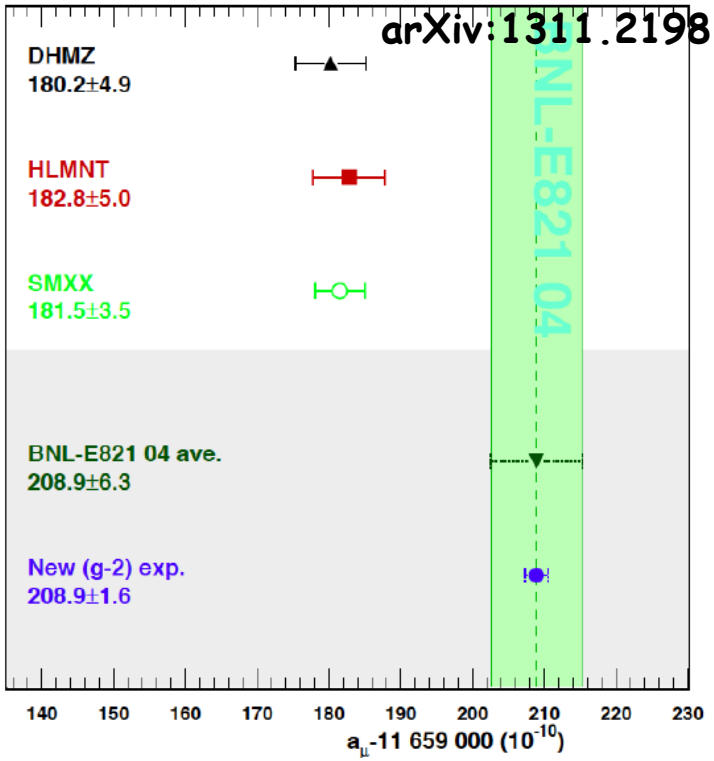


a is the muon anomaly, due to VP effects (g=2, according to Dirac eq.)

$$a_\mu^{SM} = 116\,591\,802 \pm 49 \times 10^{-11}$$ M. Davier et al. 2011

$$a_\mu^{E821} - a_\mu^{SM} = (287 \pm 80) \times 10^{-11}\ (3.6\,\sigma)$$

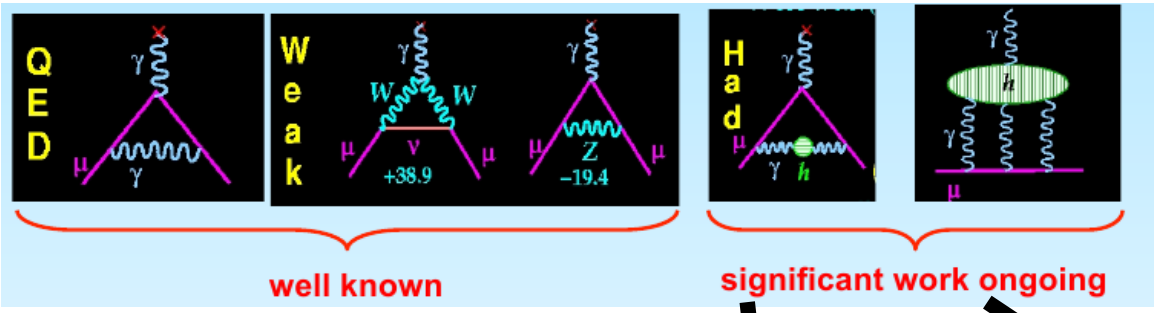




Sources for the discrepancy?

( ) the measurement
( ) uncertainties in hadronic corrections
( ) loop corrections from a particles beyond the SM (EW scale)

a_μ=(g-2)/2 muon



$a_\mu^{E821} = (116\ 592\ 091 \pm 63) \cdot 10^{-11}$

$a_\mu^{EW} = (154 \pm 1) \cdot 10^{-11}$

hadronic vacuum polarization (HVP)

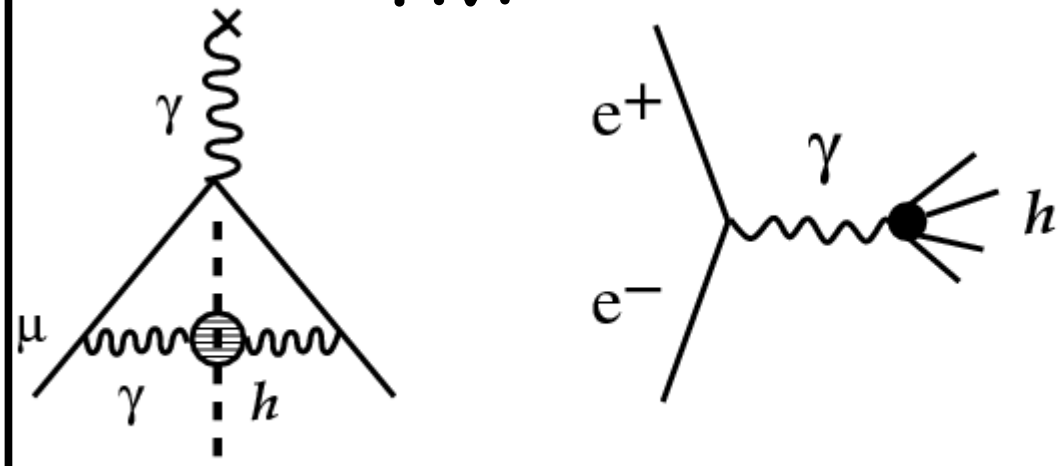
$a_\mu^{HVP} = (6\ 923 \pm 42) \cdot 10^{-11}$

hadronic light-by-light scattering (HLbL)

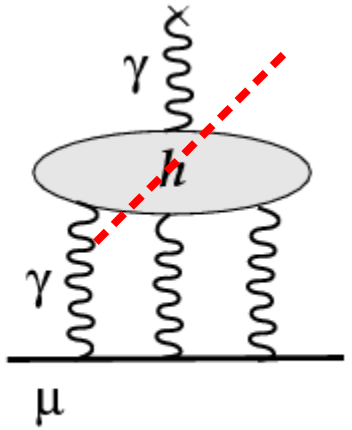
$a_\mu^{HLbL} = (116 \pm 40) \cdot 10^{-11}$

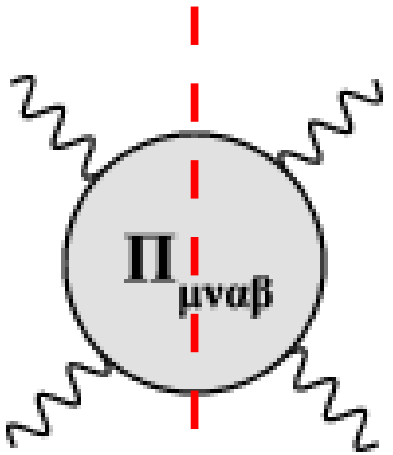
Hadronic contribution to g-2

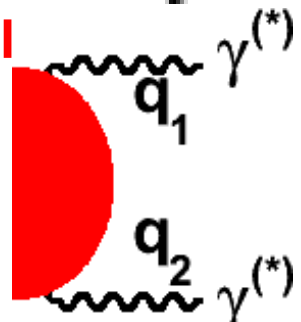
HVP



HLbL







Hadrons

e+e- → γ* → h

KLOE-2

CMD3/SND

BESIII

BelleII

γ(*)γ(*) ↔h

γ(*)→hγ(*), hγ(*)→hγ(*)

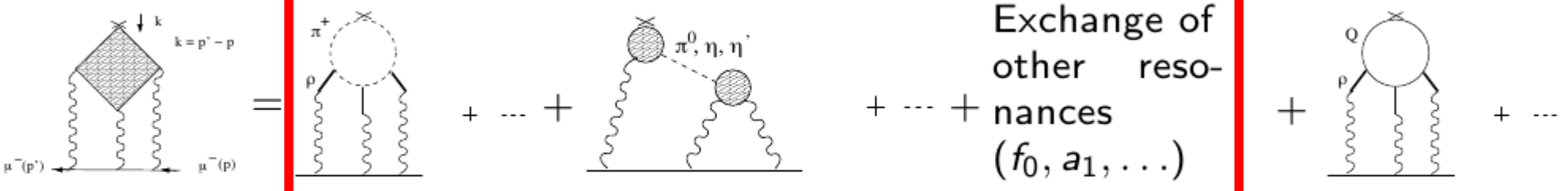
+ hadro- photo-production exp

mh<1-2 GeV

Hadronic Light by Light

Dispersive approach

Pauk,Vanderhaeghen
Colangelo,Hoferichter,Procura,Stoffer



Chiral counting	p^4	p^6	p^8	p^8
N_C-counting:	1	N_C	N_C	N_C
	$\pi^\pm$,K-loop	π^0, η,η' exchange		quark-loop
PdRV PLB322,239	$(-19\pm19)\cdot10^{-10}$	$(114\pm13)\cdot10^{-10}$	$(8\pm11)\cdot10^{-10}$	$2.3\cdot10^{-10}$

Pic:A Nyffeler

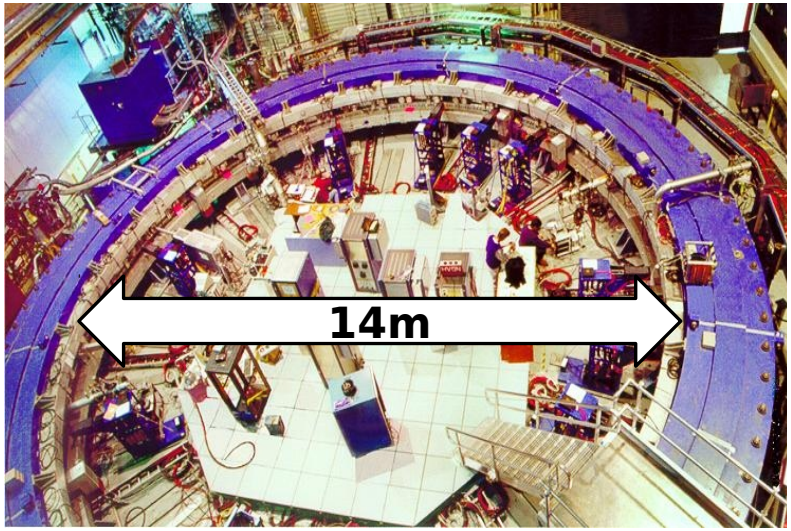
Future a_μ measurements

New FNAL exp. (2016)

Goal reduce Δa_μ (10^{-11}):

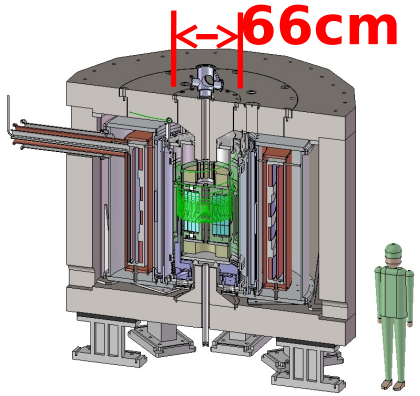
Experiment	63	→	16
HVP	42	→	11
HLbL	39/26	→	10

BNL E821 / FNAL



P= 3.1 GeV/c , B=1.45 T

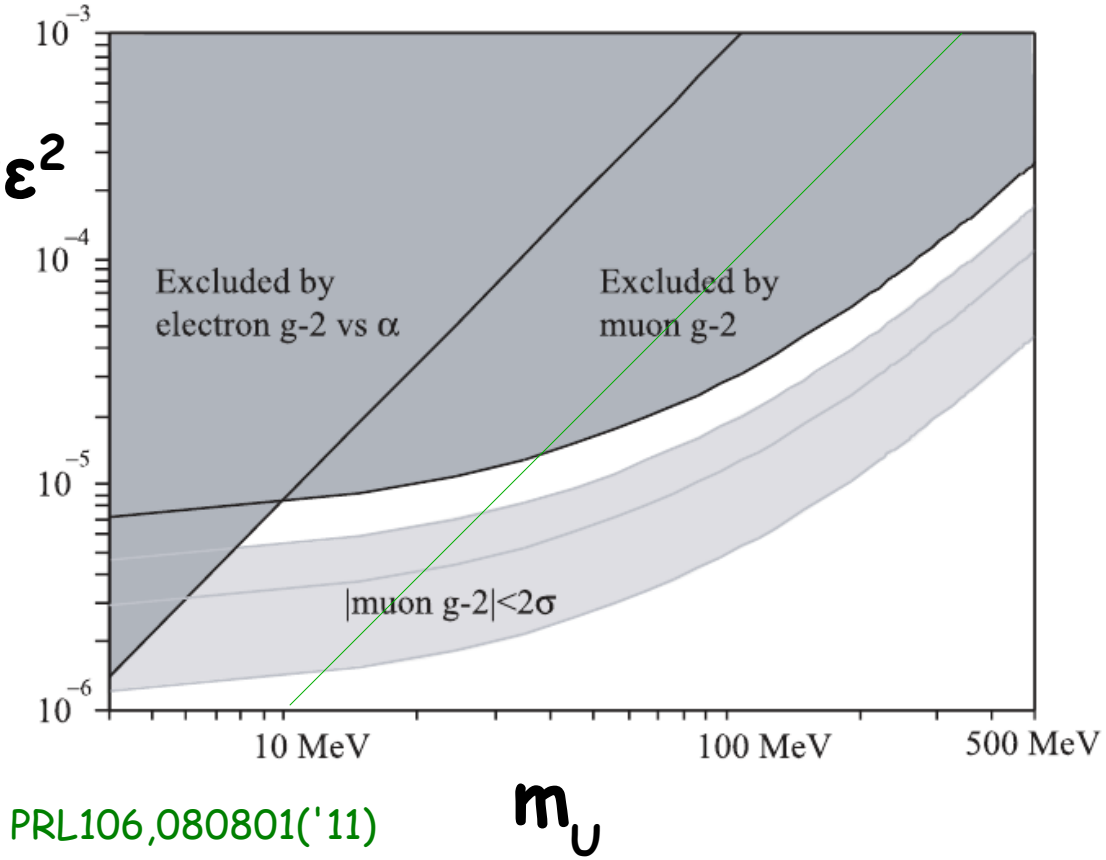
J-PARC



P= 0.3 GeV/c , B=3.0 T

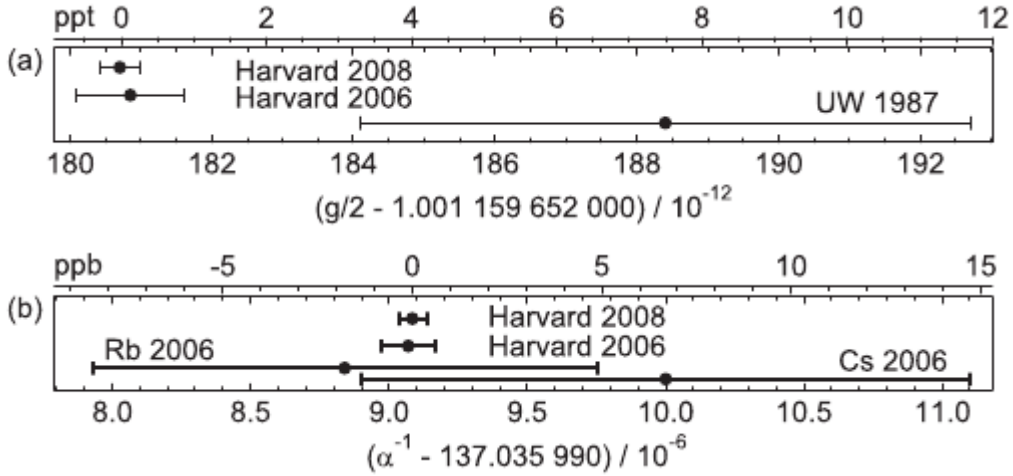
Dark photon constraints from electron/muon g-2

Dark photon constraints from electron/muon g-2:



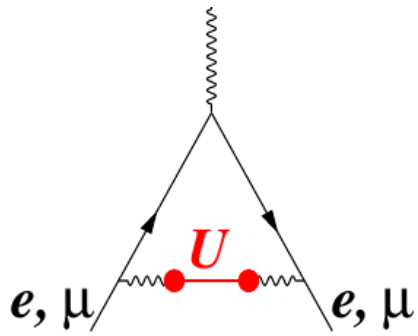
PRL106,080801('11)
PRL109,111807('12)

M. Pospelov, Phys. Rev. **D80** *(2009) 095002*



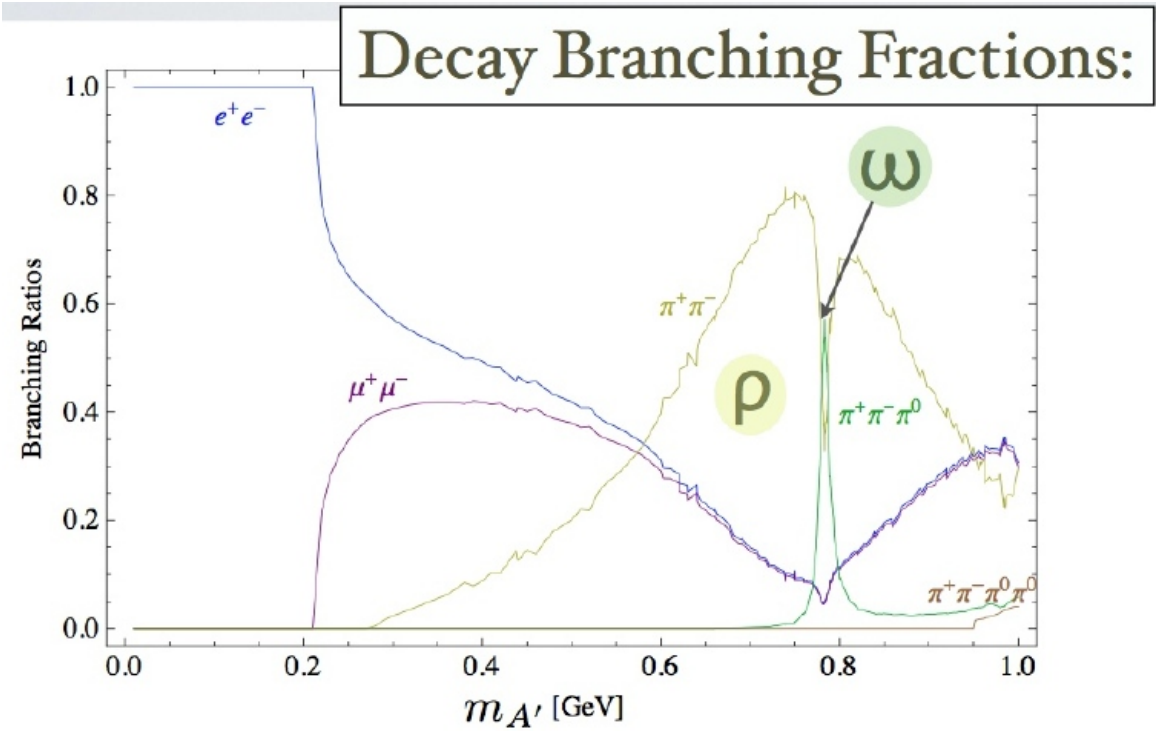
Hanneke,Hogwell,Gabrielse PRL100,120801('08)

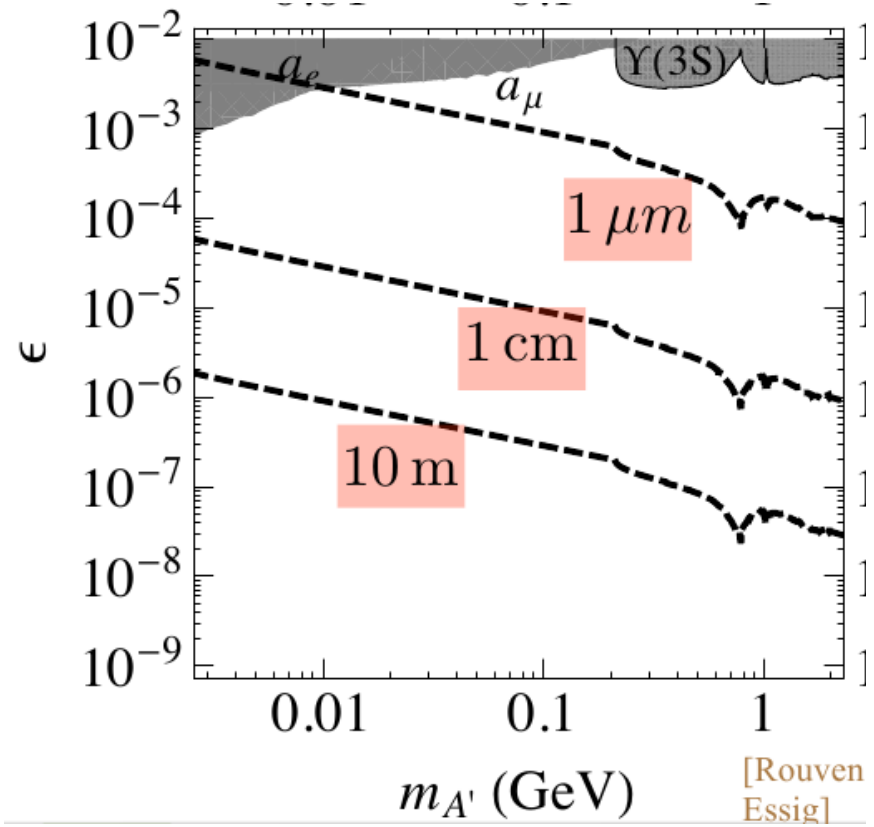
$$\mathcal{L}_{\rm mix} = -\frac{\epsilon}{2} F^{\rm QED}_{\mu\nu} F^{\mu\nu}_{\rm dark}$$



(Krasnikov, Gninenko; Fayet; Pospelov)

Dark photon decays





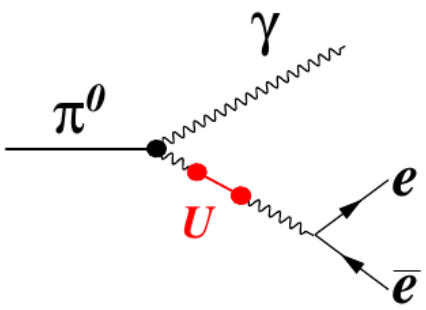
UPPSALA UNIVERSITET

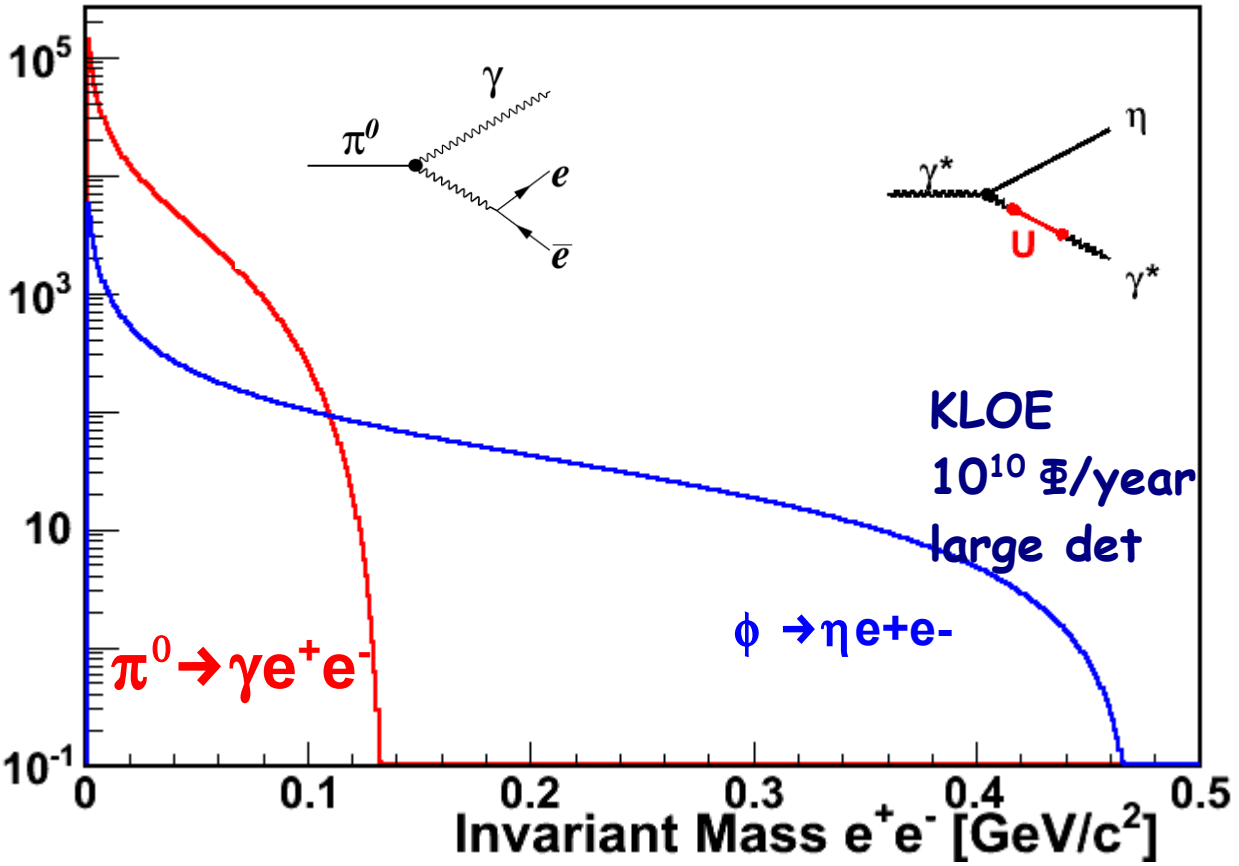
$$\Gamma_{U\to e^+e^-} = \frac{1}{3}\alpha\epsilon^2 M_U \sqrt{1-\frac{4m_e^2}{M_U^2}}\left(1+\frac{2m_e^2}{M_U^2}\right)$$

Dalitz decays

$\pi^0 \rightarrow \gamma e^+e^-$

$2m_e < m_U < m_\pi$





WASA-at-COSY

$pp \rightarrow pp\pi^0$

10^4 π^0/s

small detector

UPPSALA UNIVERSITET

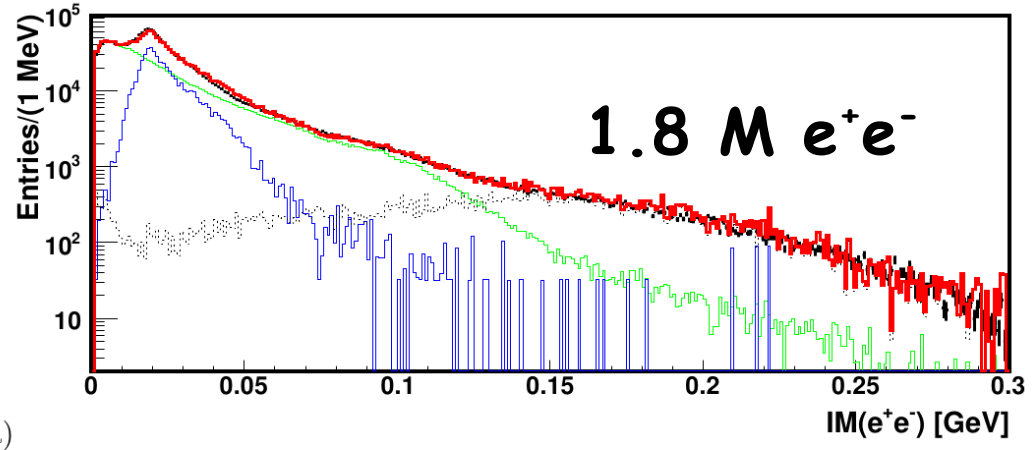
C-O Gullstrom UU

J. Zdebik JU

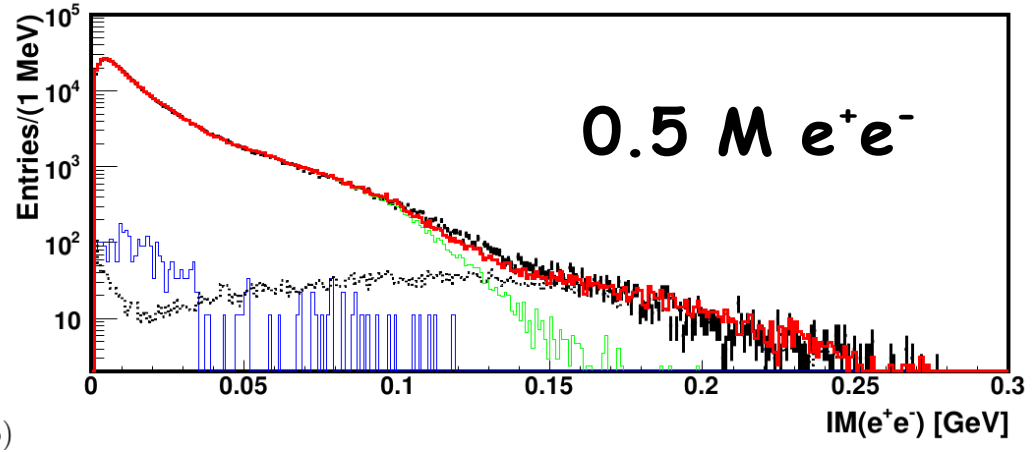
I Sarra, Roma ...

UPPSALA UNIVERSITET

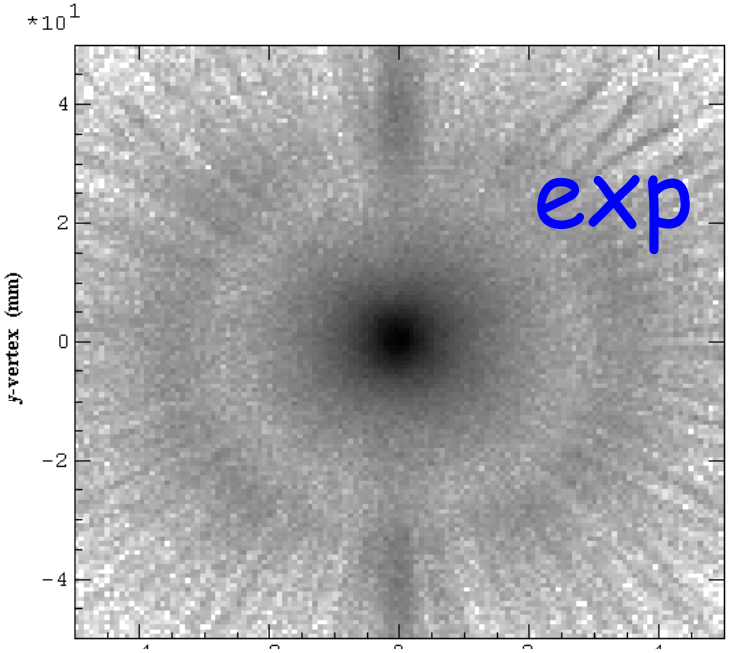
Data analysis: $\pi^0 \rightarrow \gamma e^+ e^-$

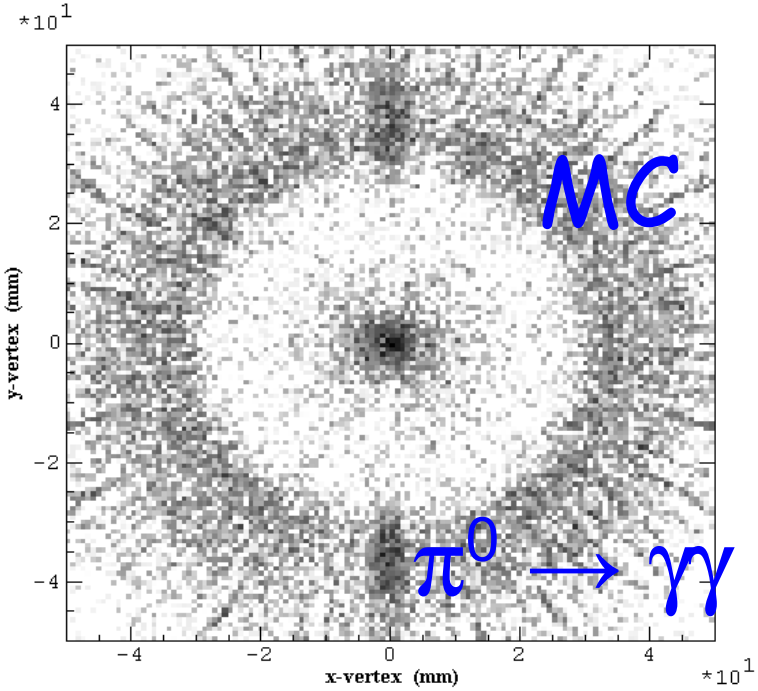


a)



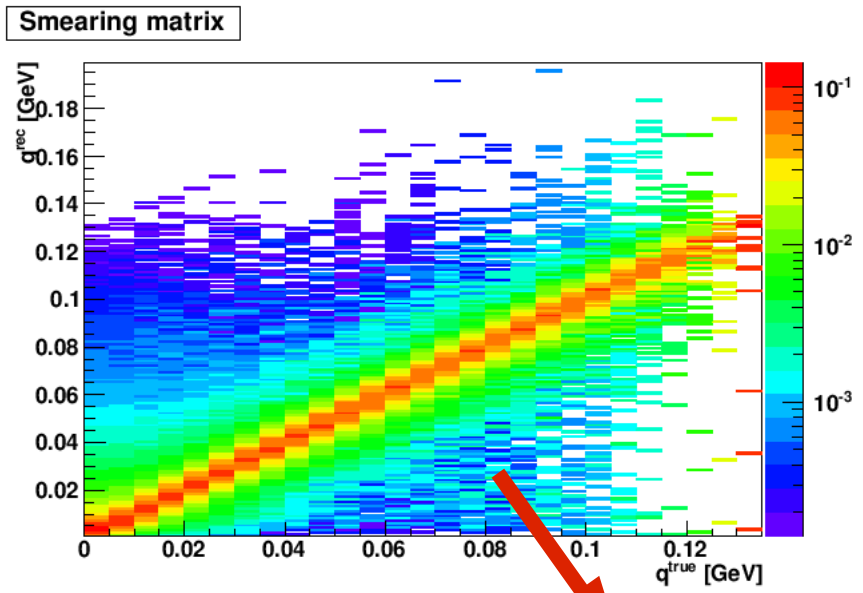
b)

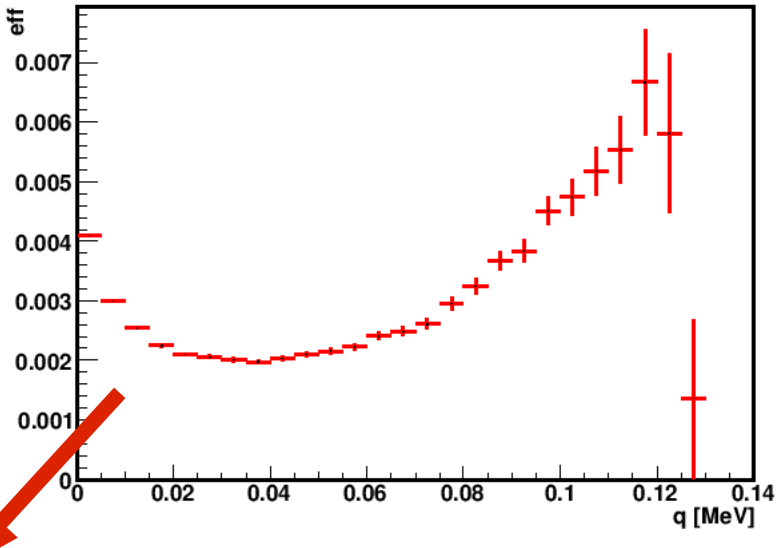




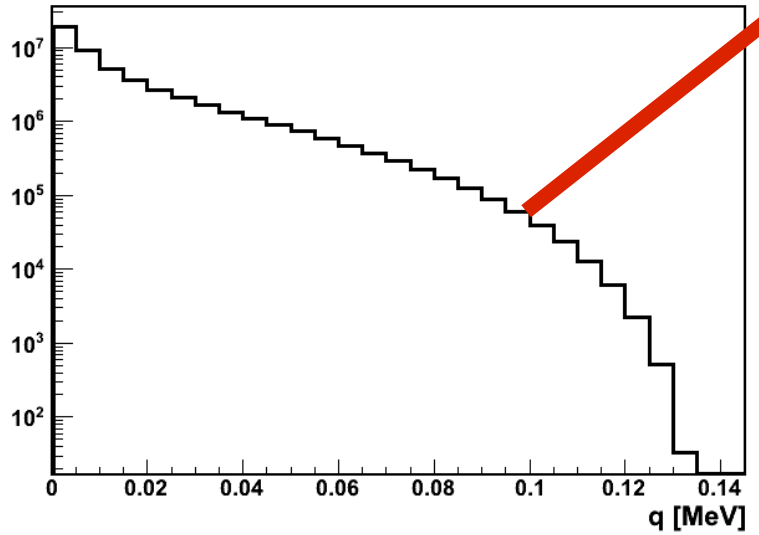
UPPSALA UNIVERSITET

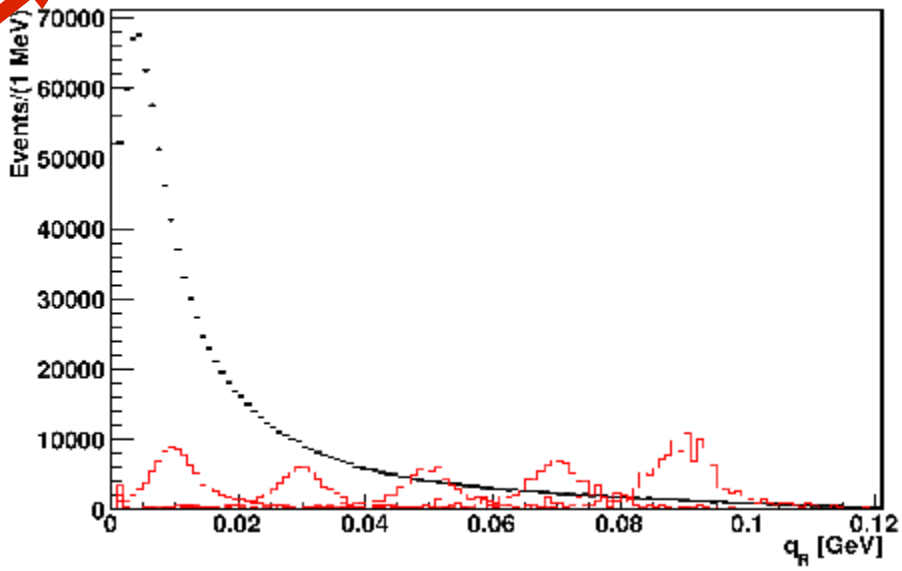
Search for: $\pi^0 \rightarrow \gamma U \rightarrow \gamma e^+ e^-$





$$N_i^d / N_{Tot} = \sum_j S_{ij} \varepsilon_j \nu_j (\pi^0 \rightarrow e^+ e^- \gamma) + S_{ik} \varepsilon_k \beta_k$$

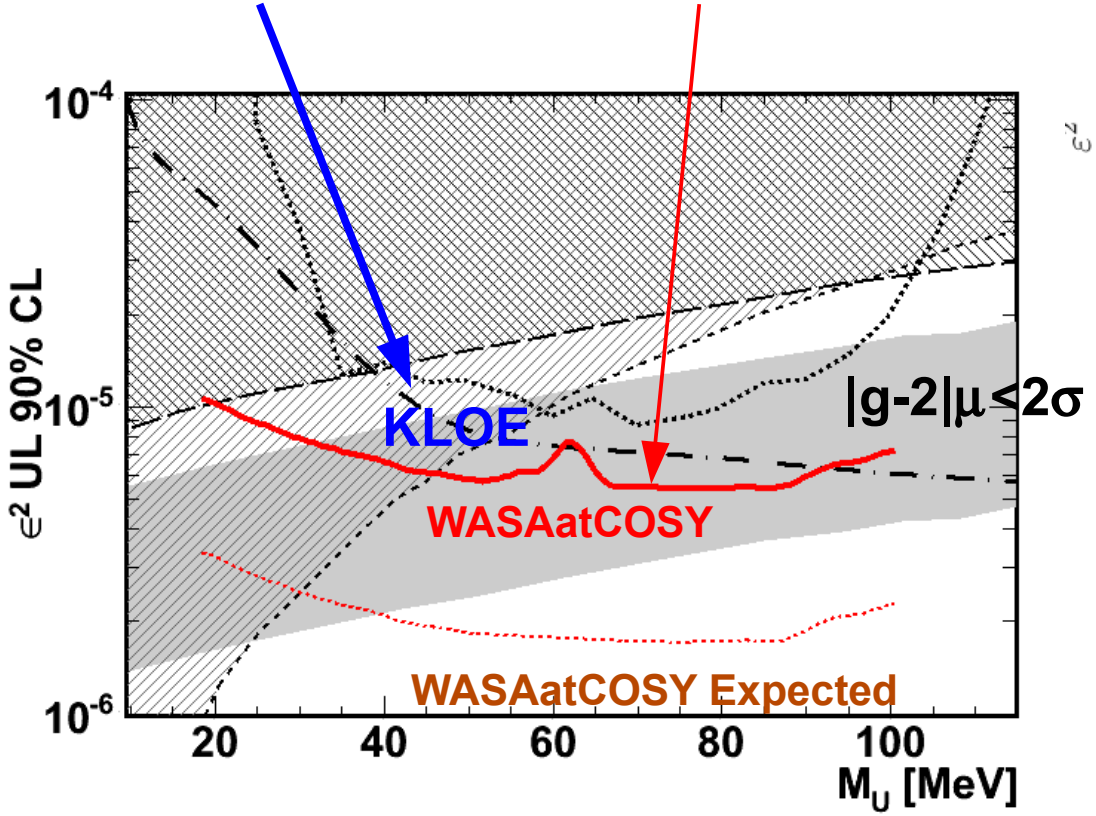


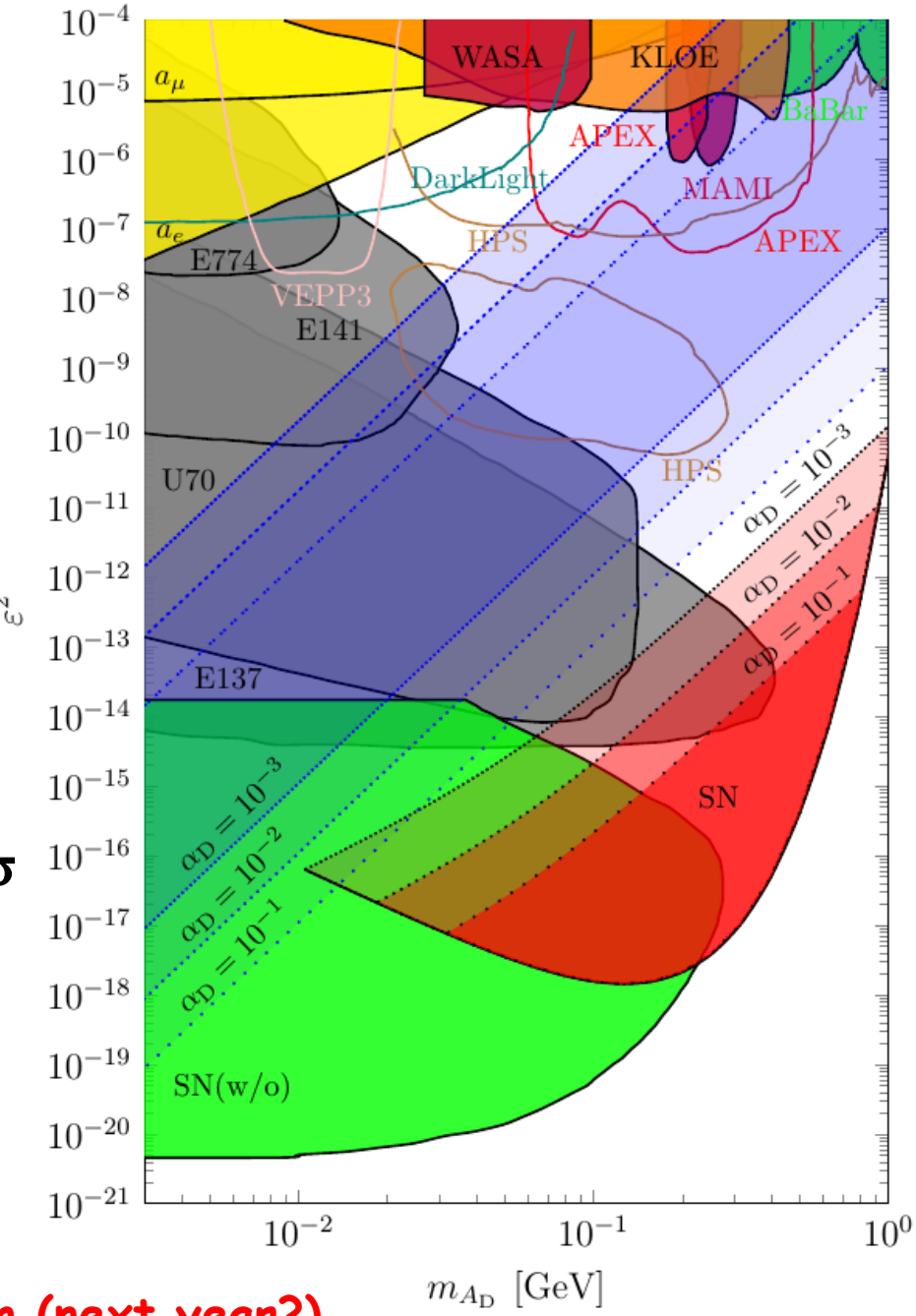


Dark photon searches status 2013

KLOE
$\phi \rightarrow \eta e^+e^-$
PLB706 (2012) 251
PLB720 (2013) 111

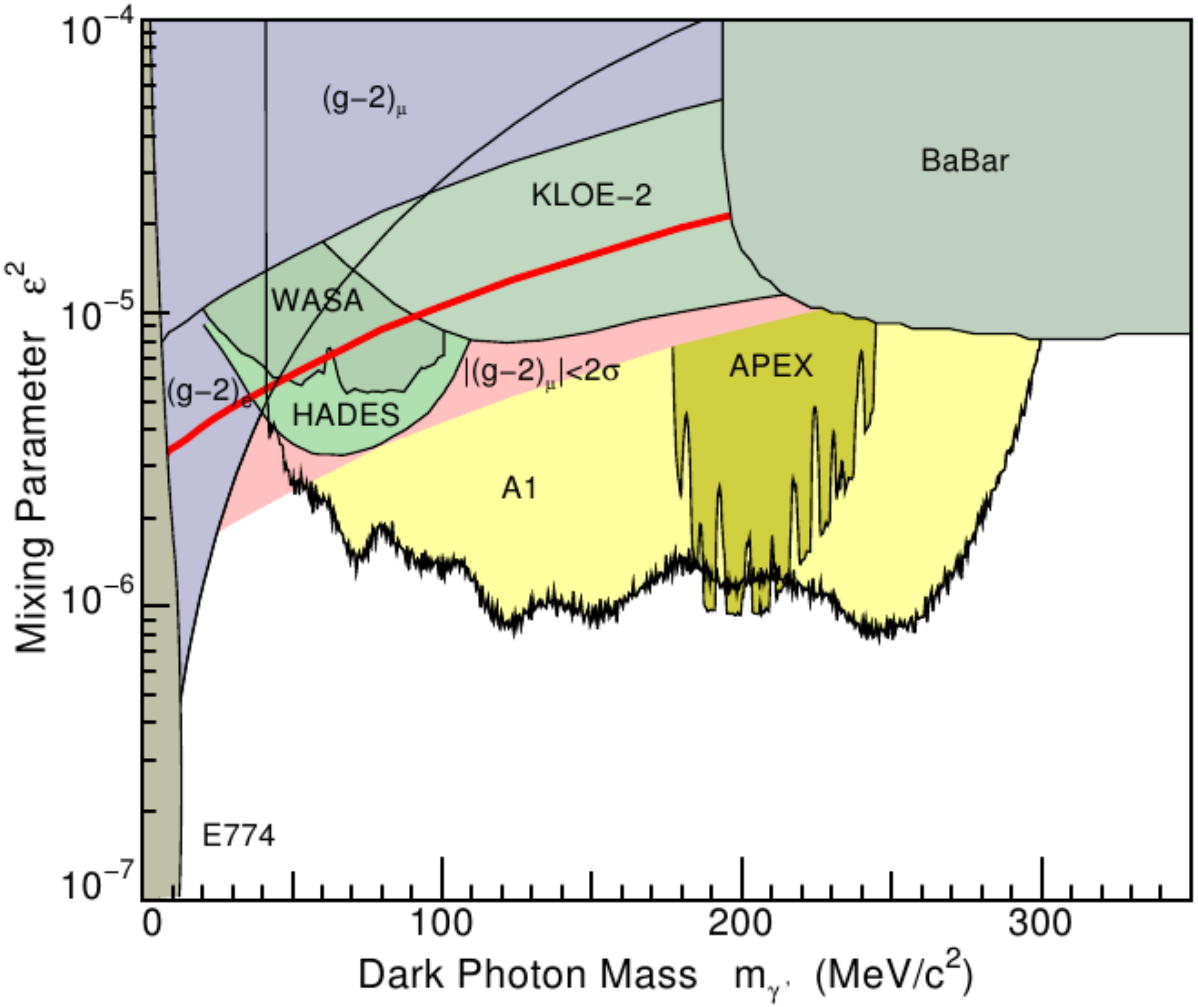
WASA-at-COSY
$\pi^0 \rightarrow \gamma e^+e^-$
PLB726 (2013) 187

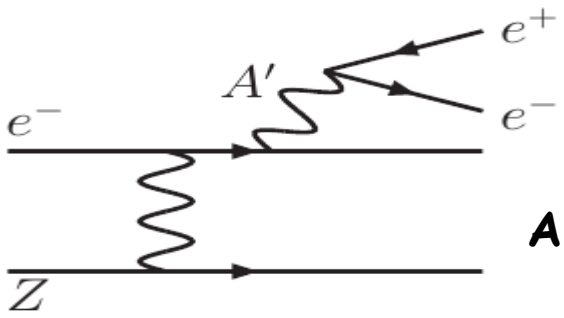




g-2 preferred region will be covered soon (next year?)

Dark photon searches: April 2014



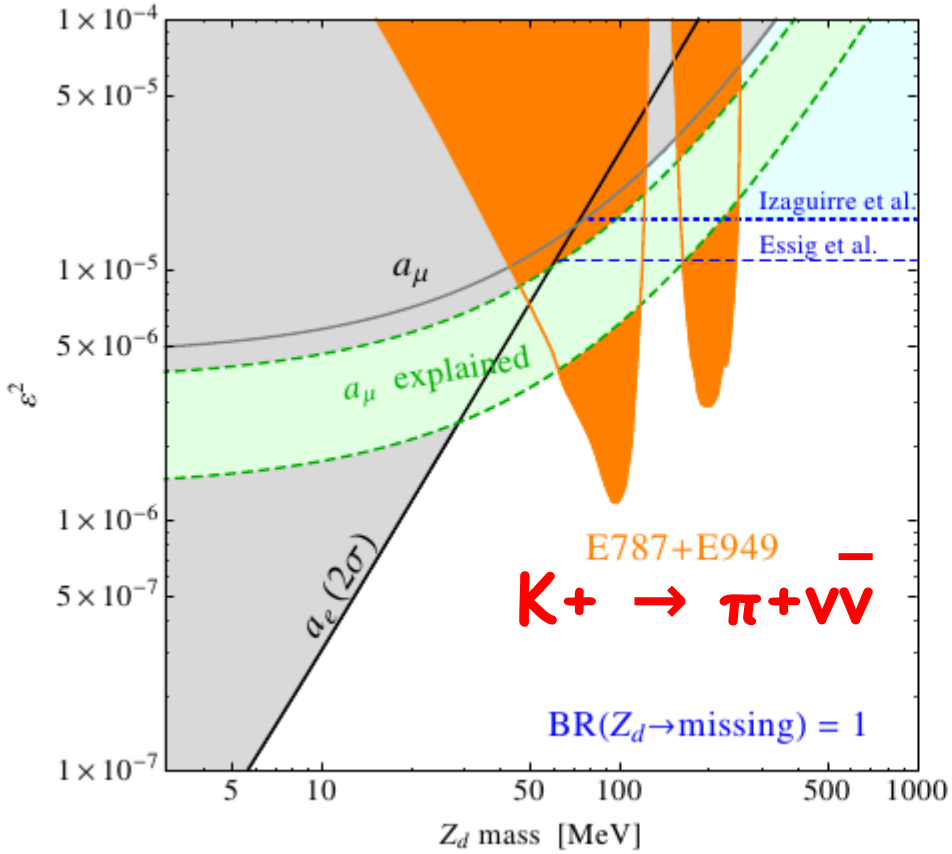


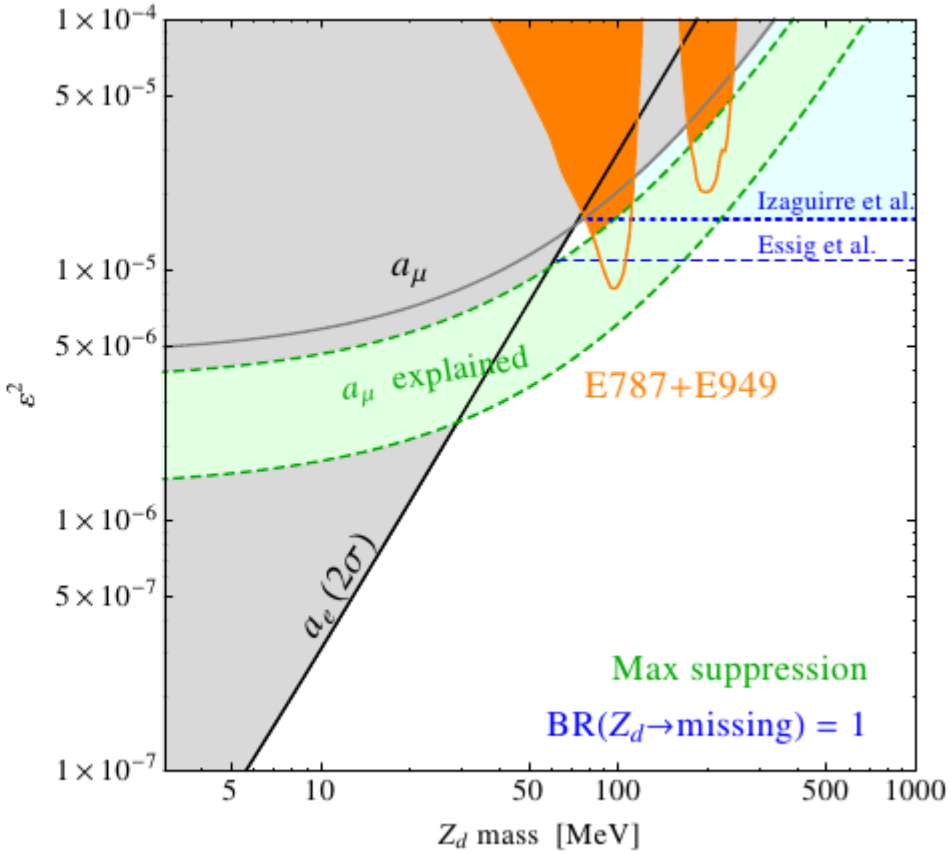
A1 arXiv:1404.5502

BaBar,PRL103,081803 ('09).
APEX PRL107, 191804 ('11)
KLOE-2,PLB720,111('13)
WASA-at-COSY. PLB726,187('13)
HADES, PLB731,265('14)

+ PHENIX prel

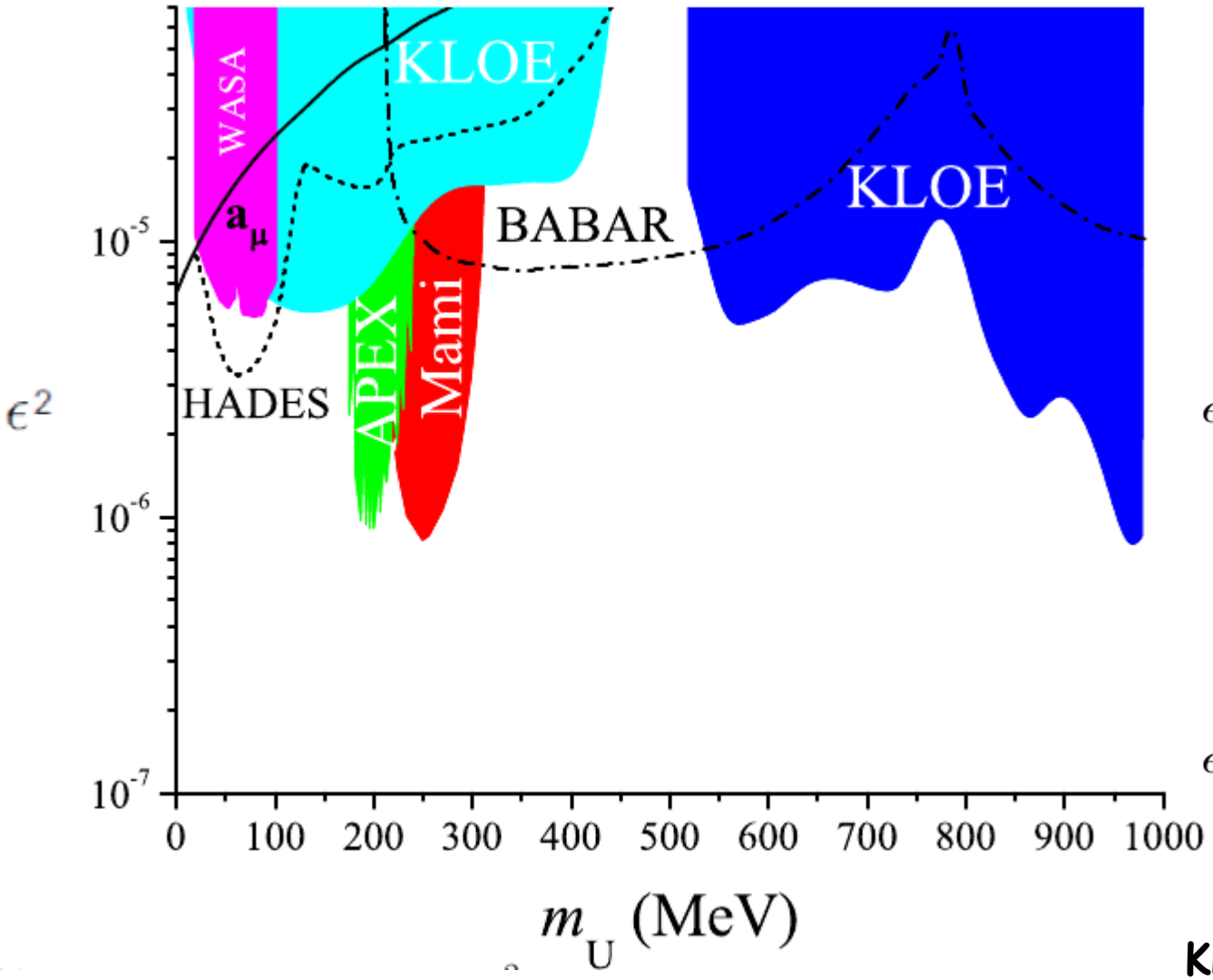
Outlook I: Invisible U decays

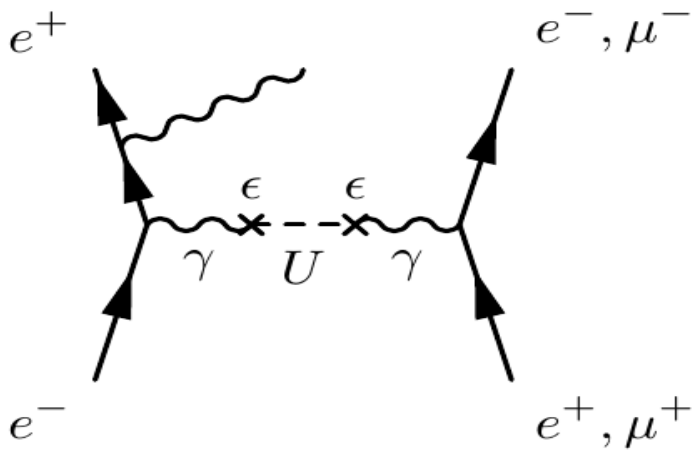




H. Davoudiasl, H-S Lee, W. J. Marciano arXiv:1402.3620

Outlook II: Explore other regions





KLOE-2 arXiv:1404.7772

UPPSALA
UNIVERSITET

Outlook III: Leptophobic U / B

Dark photon limits are for a specific model where *A'* couples to electrons. But there may be new forces that **do not couple to leptons**. How do we search for these types of new forces?

Simplest example: Gauge boson *(B)* coupled to baryon number

Assume *B* couples to quarks only but not leptons (leptophobic *Z'*).

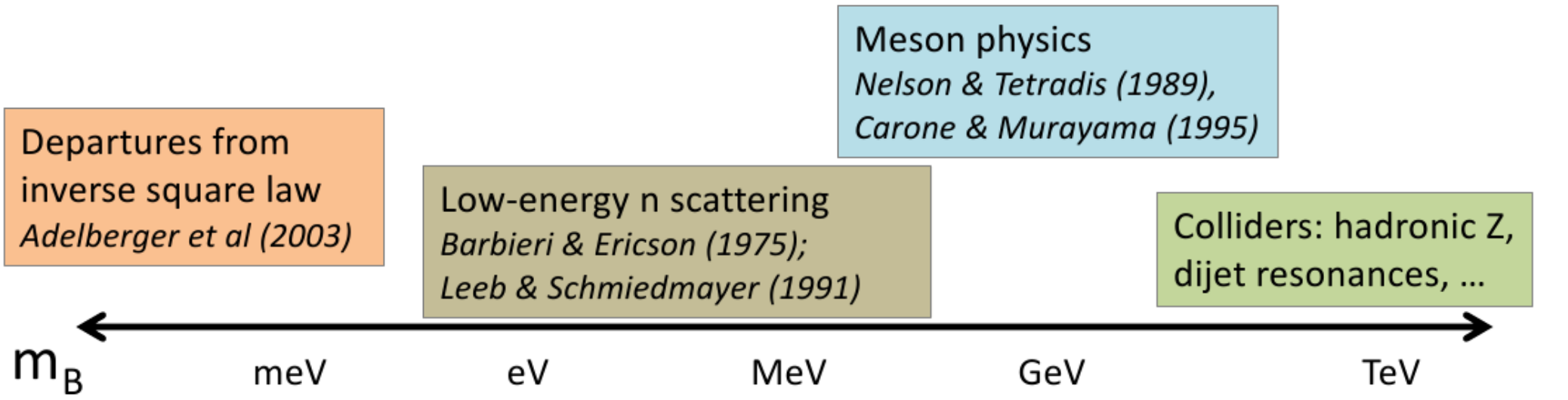
$$\mathscr{L} = \frac{g_B}{3}\,\bar{q}\gamma^\mu q B_\mu$$

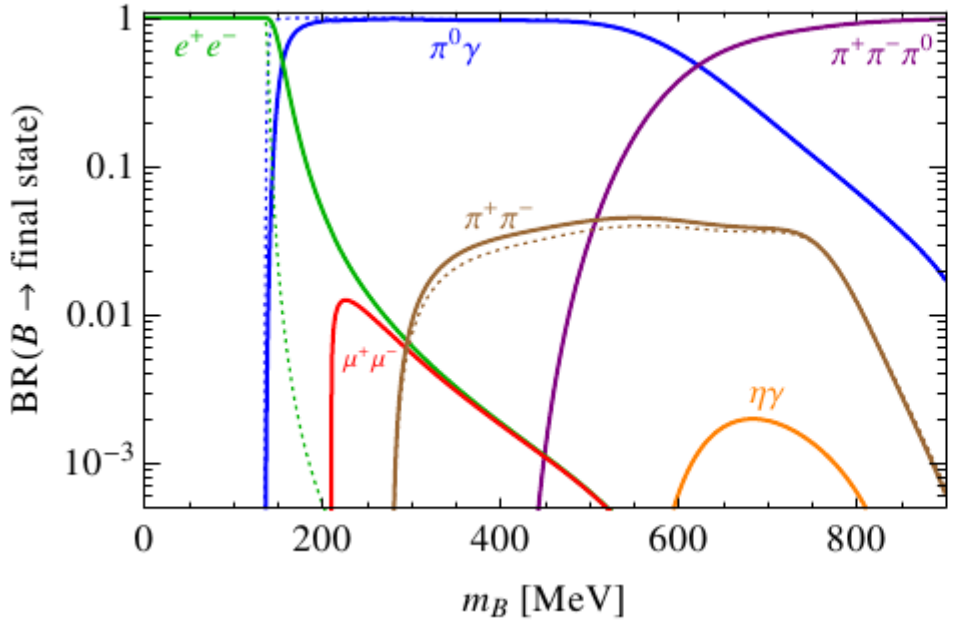
Flavor-universal vector coupling g_B to all quarks

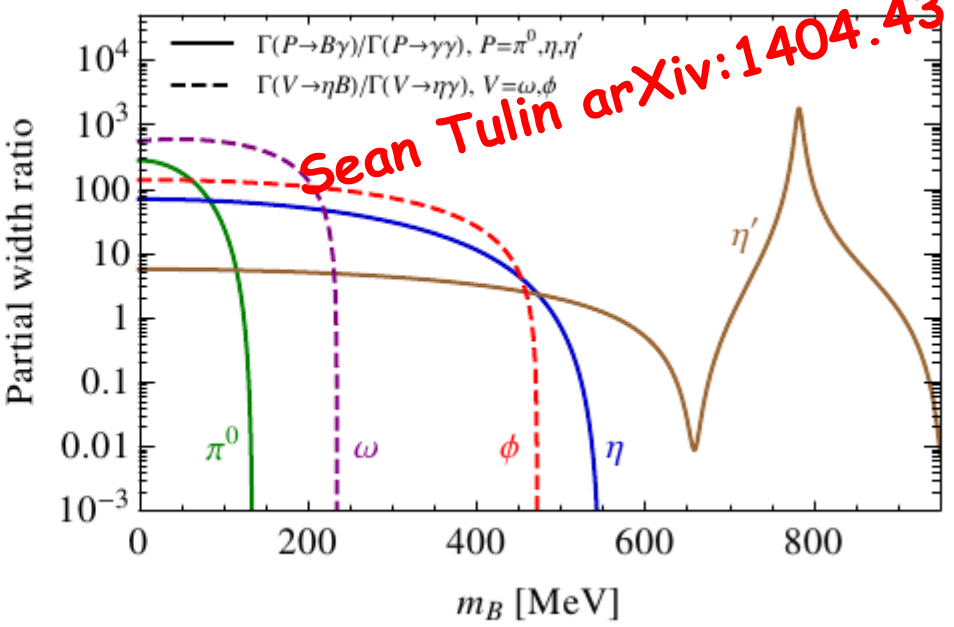
Literature: *Radjoot (1989), Foot, et al (1989), He & Rajpoot (1990), Carone & Murayama (1995), Bailey & Davidson (1995), Aranda & Carone (1998), Fileviez Perez & Wise (2010), Graesser et al (2011), …*

Sean Tulin arXiv:1404.4370

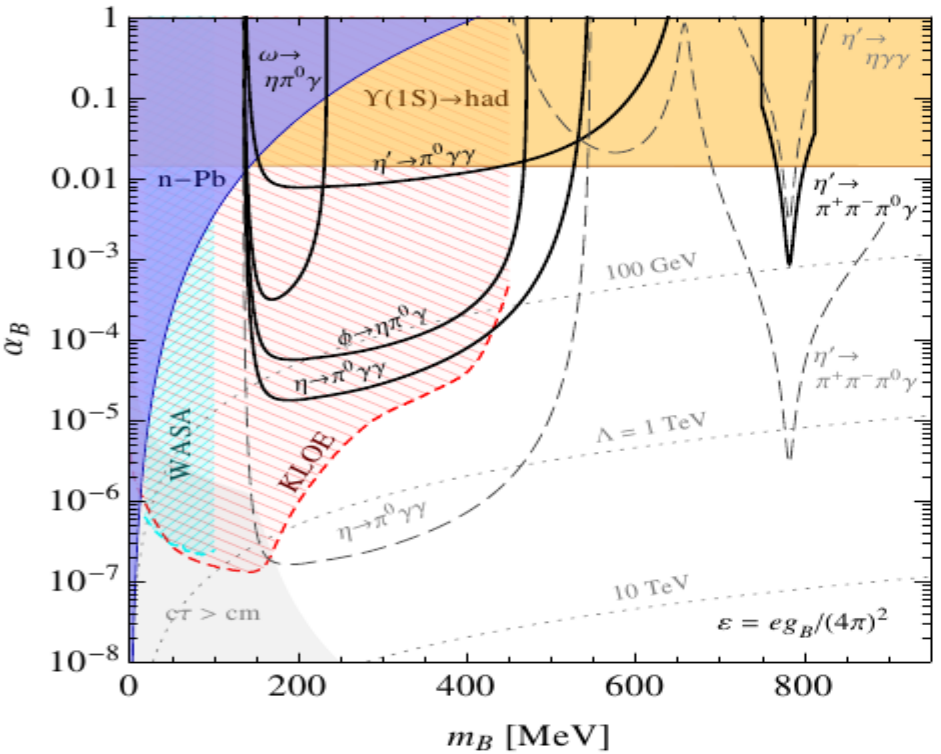
Discovery signals depend on the *B* mass

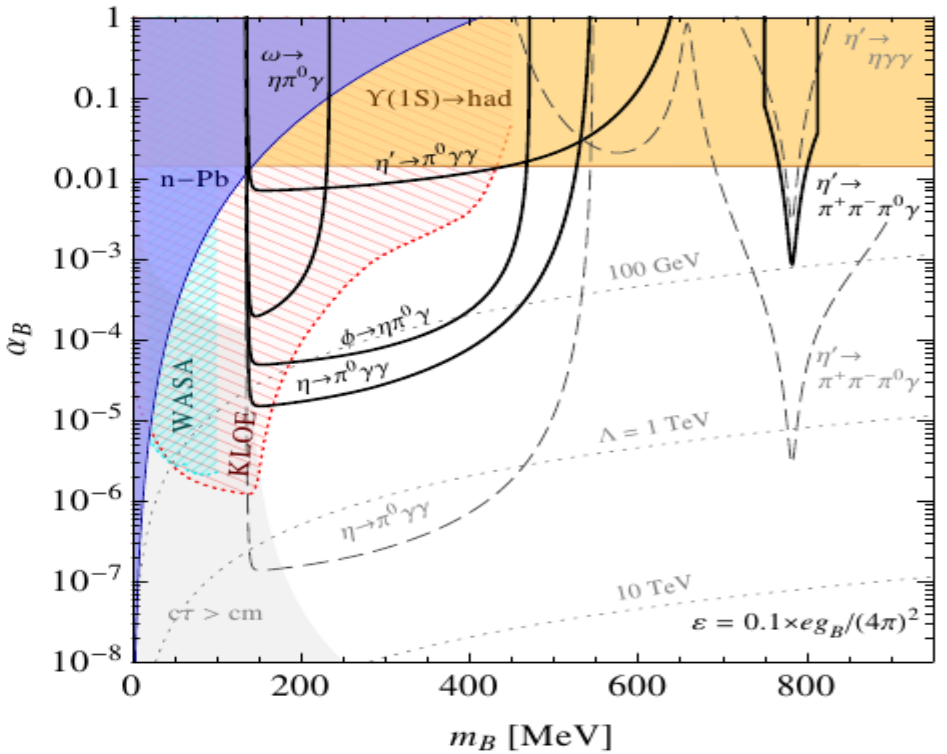






Sean Tulin arXiv:1404.4370





Summary

- Dark Photon searches at many experiments: MAMI, JLAB, CERN, GSI, RHIC, COSY, DAFNE, BEPCII, DESY …

  g-2 preferred region has been covered? (U → e+e-)

  Avoid e+e- constraints, Parity Violating U/Z' ,…

- Muon g-2 puzzle should be solved in few years (exp + coordinated effort for precise hadron contribution)

UPPSALA
UNIVERSITET

HadronPhysics
HORIZON