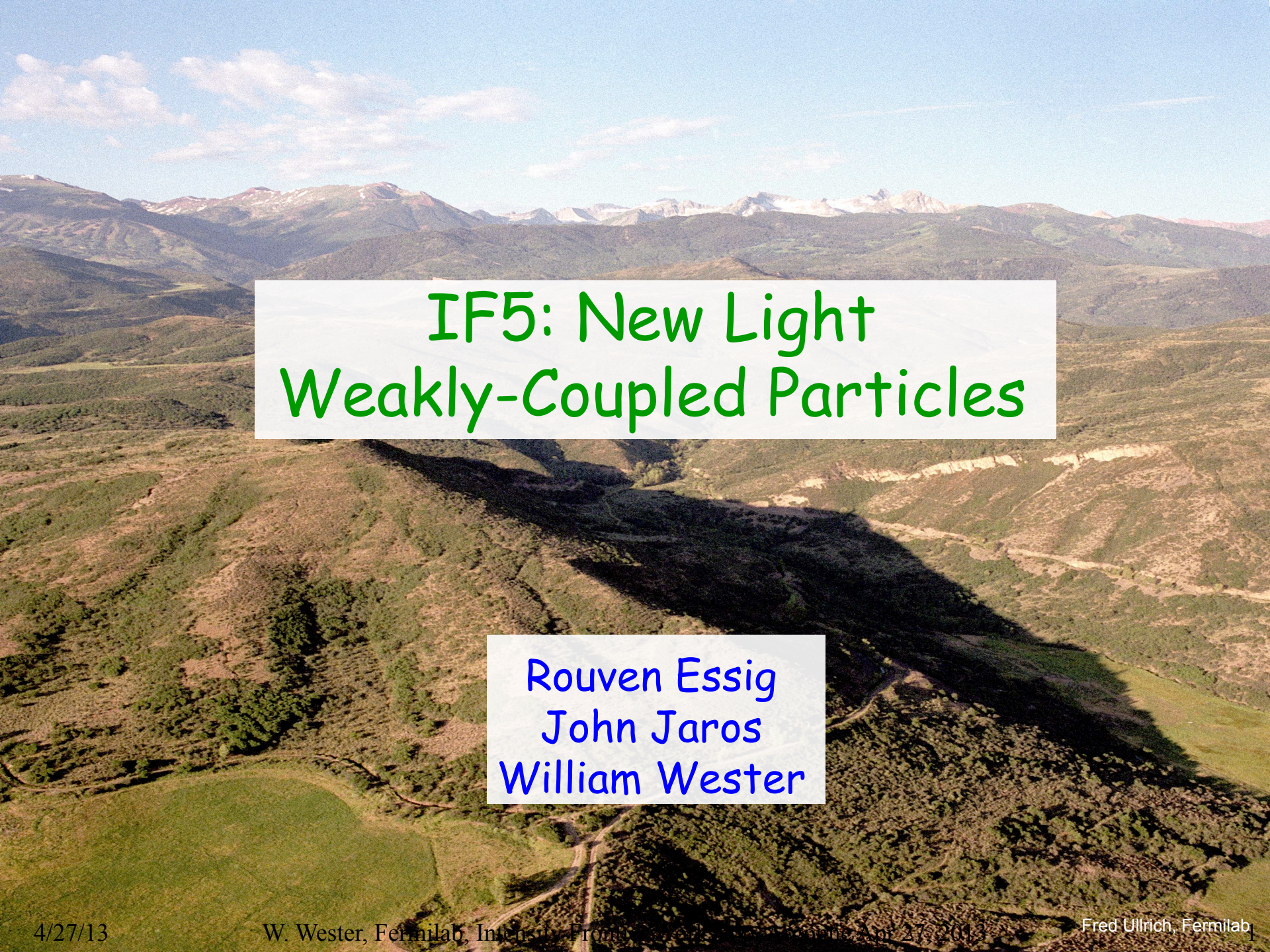


IF5: New Light Weakly-Coupled Particles

Rouven Essig
John Jaros
William Wester

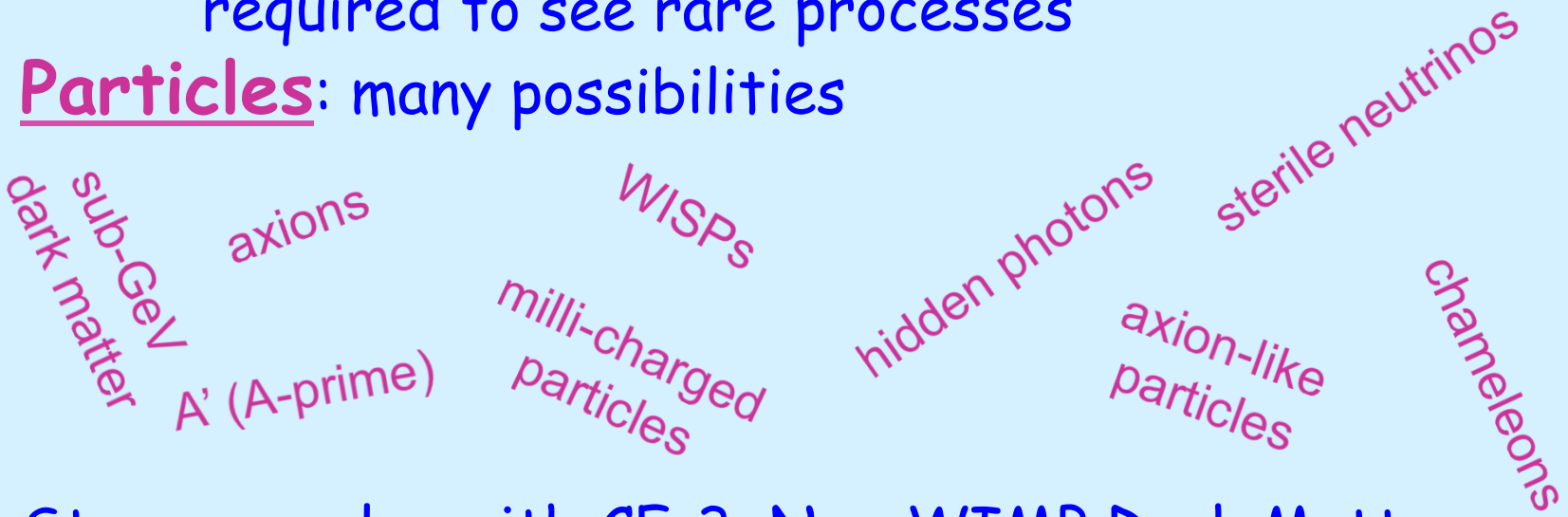
NLWCP

New: New Physics … potentially revolutionary in our understanding of matter, space, and time

Light: low mass possibly related to symmetries and experimentally accessible through direct production

Weakly-Coupled: implies perhaps a very high energy scale is involved and intensity experiments might be required to see rare processes

Particles: many possibilities

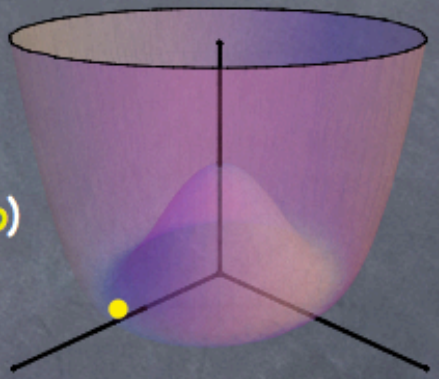


Strong overlap with CF-3: Non-WIMP Dark Matter

Top Down motivation

1- Shift symmetries and Goldstone Bosons

When a global symmetry is spontaneously broken in the vacuum
(i.e. respected by the interactions but not by the vacuum)
there appears a massless particle in the spectrum: a Goldstone boson
(if it is slightly explicitly broken... then it acquires a little mass-> pseudo)



2- Local U(1)s : Hidden Photons

Gauge invariance protects masses of gauge bosons (m=0 for non-abelian group, not for U(1))
Masses can be given by the Stückelberg mechanism
Kinetic mixing with the photon is the stronger of all mediator mechanisms (discussed here)
(Additional U(1)'s are ubiquitous in PBSM)

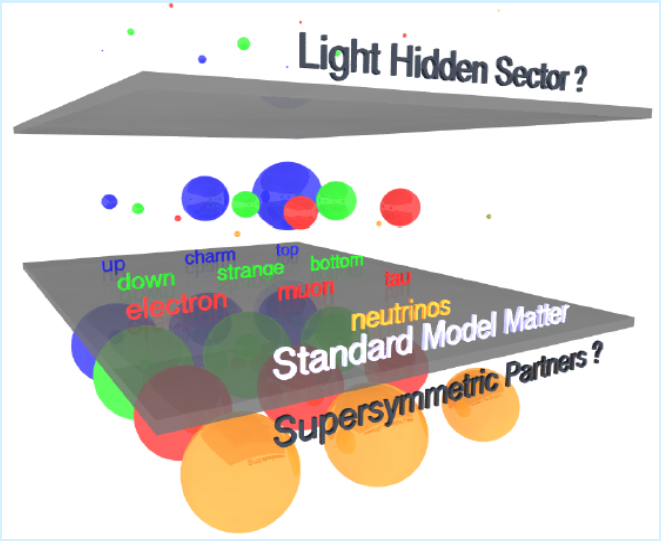
3- Chiral sym : Mini-charged Particles/sterile nu's

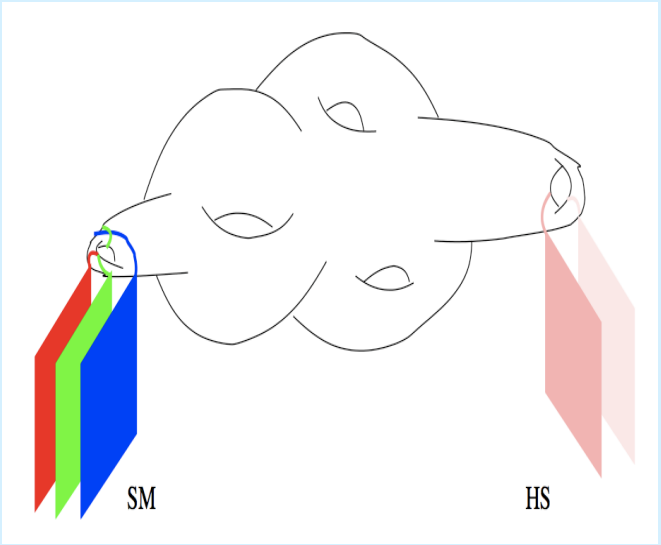
Chiral symmetries may forbid a mass term for fermions; or protect it.
When these particles have interactions with a hidden U(1) that mixes with Photon they appear as mini-charged particles

Javier Redondo

Bottom Up motivation

- Dark Matter
- Dark Energy
- Strong-CP Problem + new U(1)'s possible
- Anomalies or hints such as g-2 and in astrophysical or other lab measurements





Portals connecting to the SM

Hidden particles	Portal
• Dark photons	$-\frac{\kappa}{2}B_{\mu\nu}V^{\mu\nu}$
• Dark scalars	$(\mu S + \lambda S^2)H^\dagger H$
• Sterile Neutrinos	LHN
• PNGBs	$\frac{\partial_\mu a}{f_a}\bar{\psi}\gamma^\mu\gamma^5\psi$
• Dark Matter	$\frac{1}{\Lambda^2}\bar{\chi}\chi\bar{q}q + \ldots,$
	$g_\chi\phi\bar{\chi}\chi + g_q\phi\bar{q}q + \ldots$

Brian Batell

Axions

- Postulated in the late 1970s as a consequence of not observing CP violation in the strong interaction.

$$L_{CP} = -\frac{\alpha_s}{8\pi}(\underbrace{\Theta - \arg\det M_q}_{0 \le \bar{\Theta} \le 2\pi}) \operatorname{Tr} \tilde{G}_{\mu\nu} G^{\mu\nu}$$

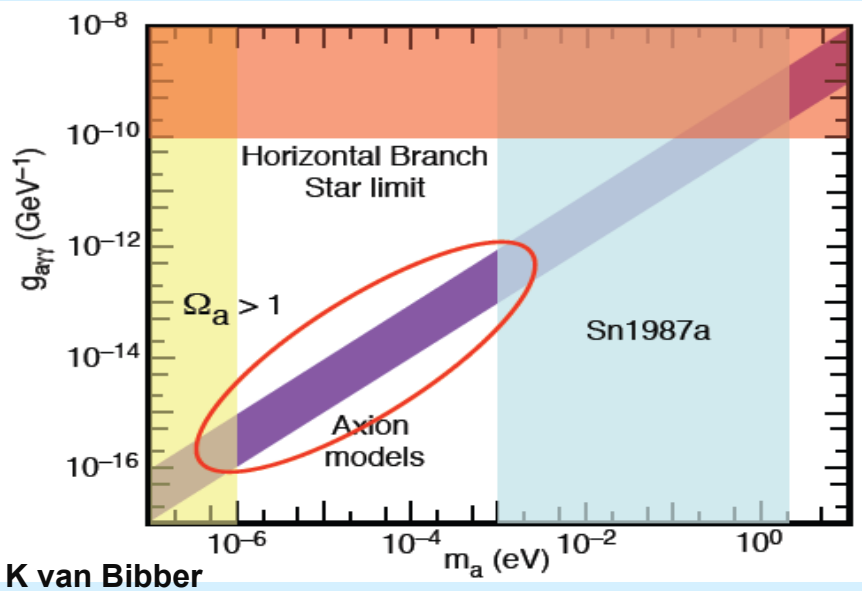
Raffelt

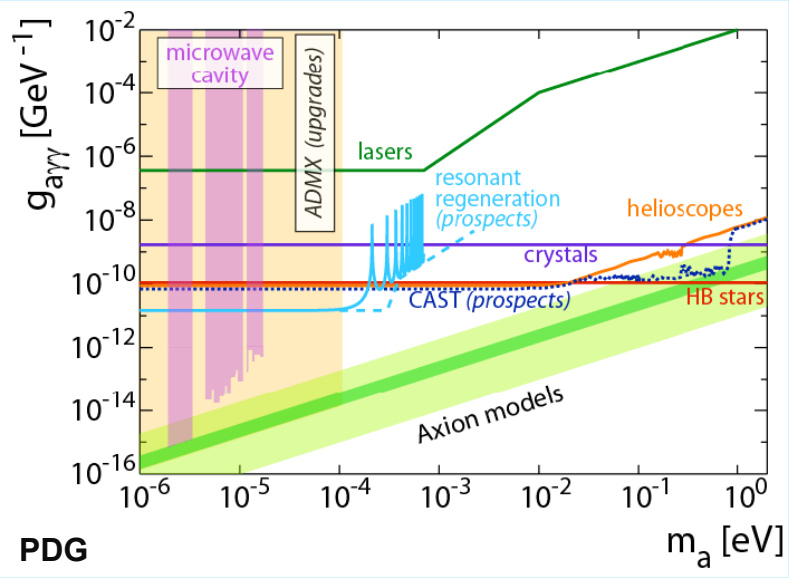
- The measurement of the electric dipole of the neutron implies $\bar{\Theta} < \sim 10^{-10}$. => Strong CP Problem of QCD
  - This is very much on the same order of an issue with the Standard Model as the hierarchy problem that motivates supersymmetry.
  - Axions originate from a new symmetry that explains small $\bar{\Theta}$

Bjorken "Axions are just as viable a candidate for dark matter as sparticles"
Wilczek "If not axions, please tell me how to solve the Strong-CP problem"
Witten "Axions may be intrinsic to the structure of string theory"

Axions and Axion-like Particles

- Parameter space … probed by astrophysics and experiment

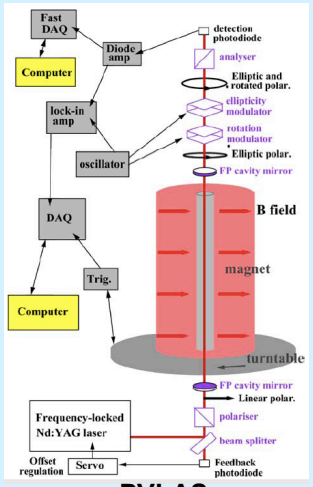




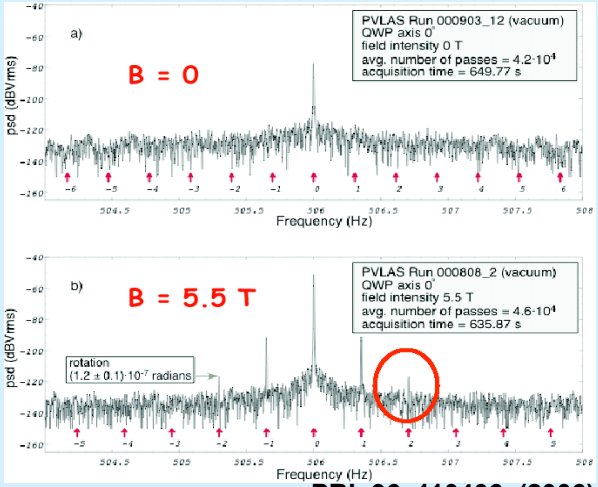
- Naturally motivated dark matter candidate … "axion miracle" simultaneously solve strong CP problem and dark matter problem
- ADMX "Axion Dark Matter Experiment" – microwave cavity search for DM axions

Example Hint

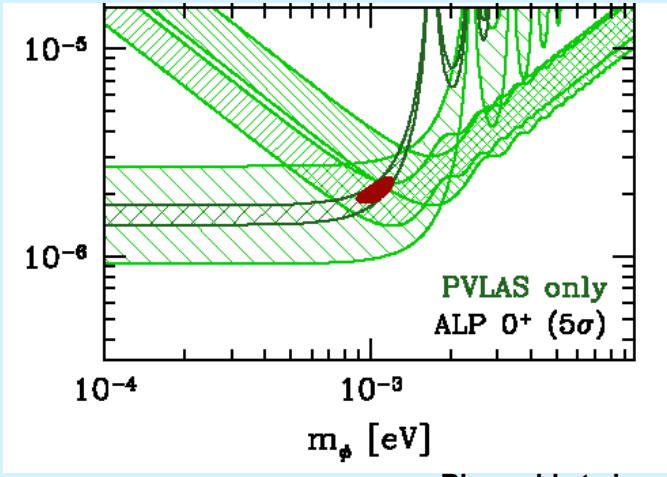
- 2006: spurious signal in an experiment looking to study polarization of the vacuum



PVLAS

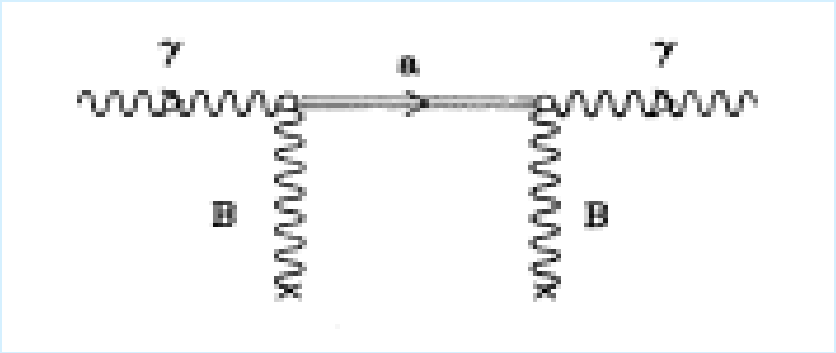


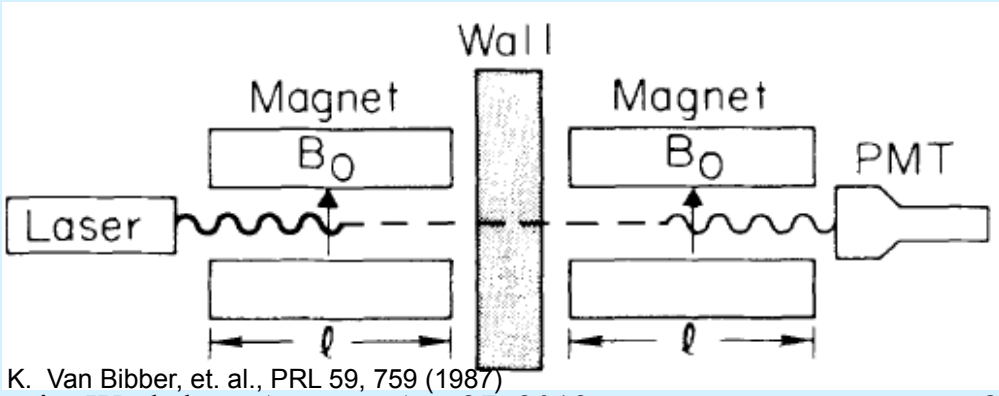
PRL 96, 110406, (2006)



Ringwald et al.

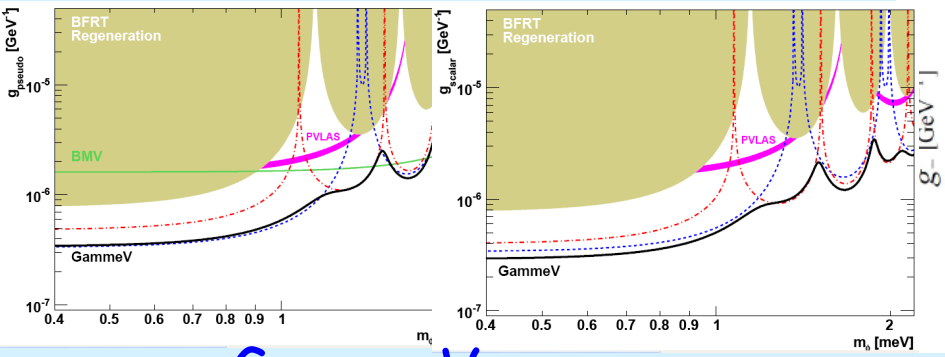
- Redo targeted "Light shining through a wall"





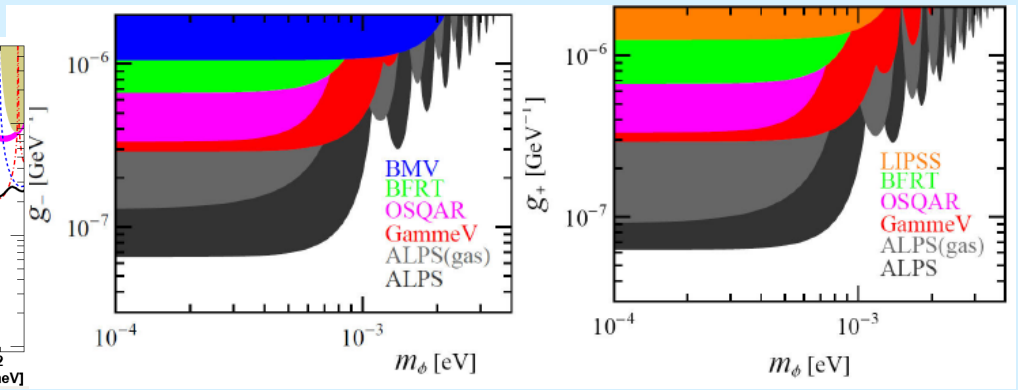
K. Van Bibber, et. al., PRL 59, 759 (1987)

World-wide effort



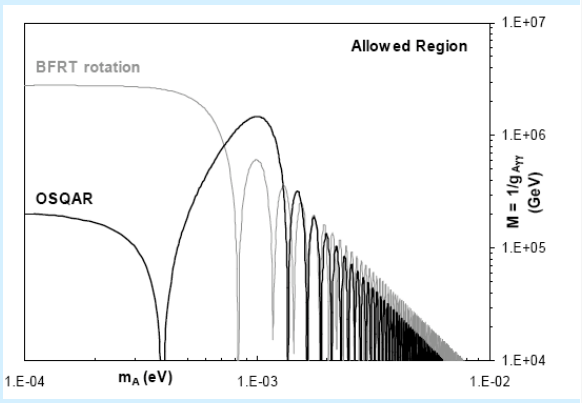
GammeV @FNAL

PRL **100**, 080402 (2008)



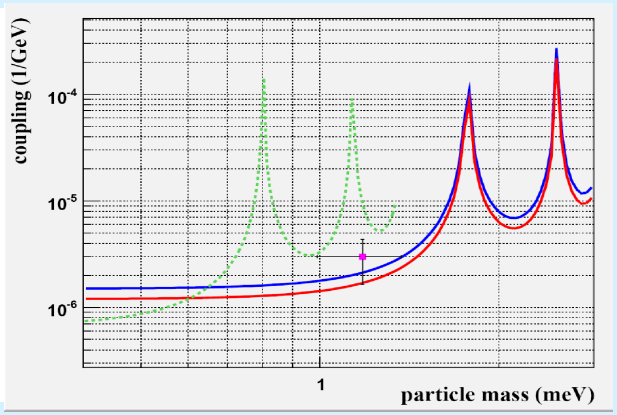
ALPS @DESY

PLB 689, **149** (2010)



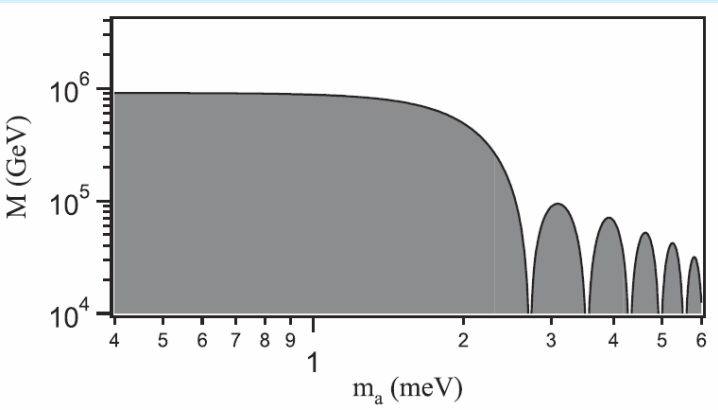
OSQAR @CERN

PRD **78**, 092003 (2008)
Note: with N_2 gas



LIPSS @JLab

scalar only
PRL **101**, 120401(2008)



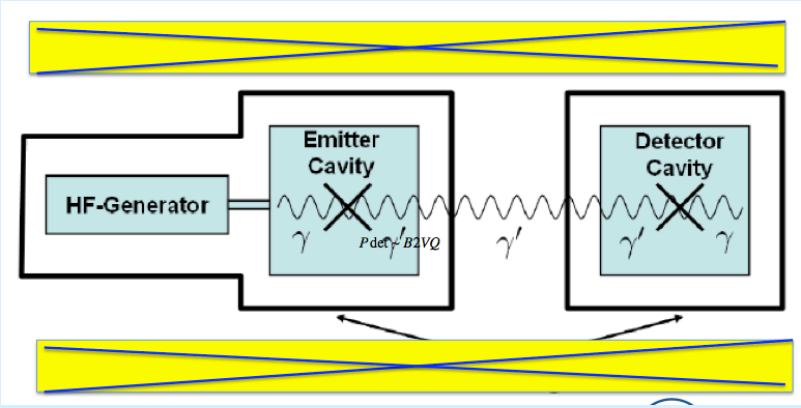
BMV @France

pseudoscalar only
1st results: PRL **99**, 190403 (2007)
Final results: PRD **78**, 032013 (2008)

4/27/13

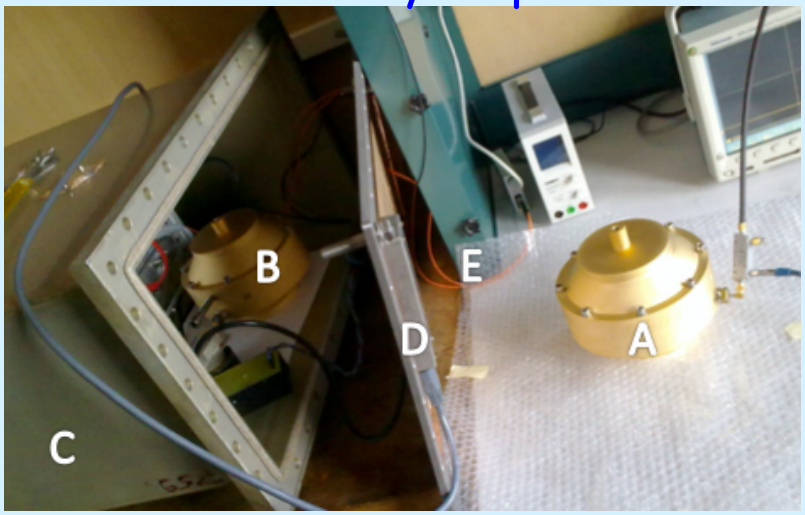
Cavities

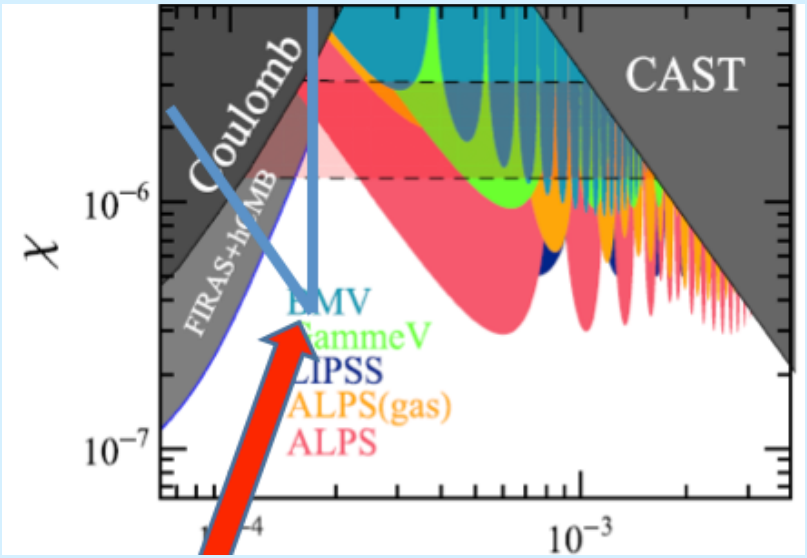
Yale Microwave Cavity Experiment



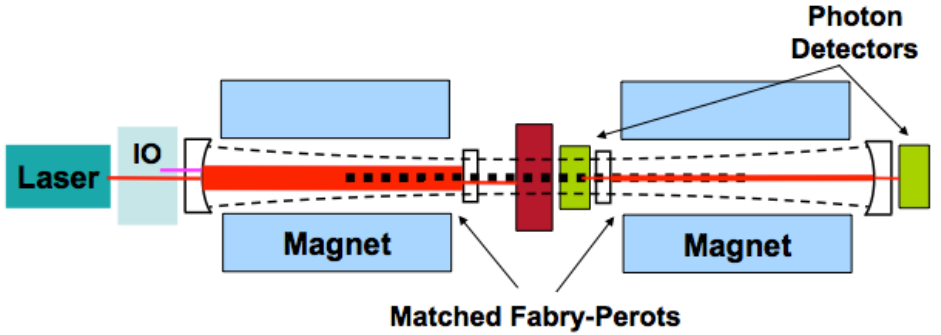
Keith Baker

Microwave Cavity Exp't @ CERN





Next generation light shining through walls



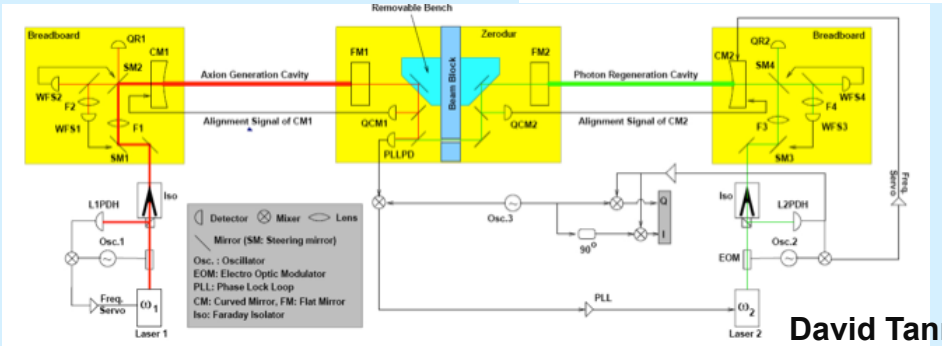
Matched optical cavities on both sides of the wall give an enhancement of $\mathcal{FF}$ (finesse)

F. Hoogeveen and T. Ziegenhagen, Nucl. Phys. B **358**, 3 (1991)
Mueller, Sikivie, Tanner, van Bibber, Phys. Rev. D **80**, 072004 (2009)
Phys. Rev. Lett. **98**, 172002 (2007)

ALPS-II DESY approved first stage hidden γ measurements

Axel Linder

Parameter	Scaling	ALPS-I	ALPS-IIc	Sens. gain
Effective laser power P_{laser}	$g_{a\gamma} \propto P_{\text{laser}}^{-1/4}$	1 kW	150 kW	3.5
Rel. photon number flux n_γ	$g_{a\gamma} \propto n_\gamma^{-1/4}$	1 (532 nm)	2 (1064 nm)	1.2
Power built up in RC P_{RC}	$g_{a\gamma} \propto P_{reg}^{-1/4}$	1	40,000	14
BL (before& after the wall)	$g_{a\gamma} \propto (BL)^{-1}$	22 Tm	468 Tm	21
Detector efficiency QE	$g_{a\gamma} \propto QE^{-1/4}$	0.9	0.75	0.96
Detector noise DC	$g_{a\gamma} \propto DC^{1/8}$	$0.0018\,\text{s}^{-1}$	$0.000001\,\text{s}^{-1}$	2.6
Combined improvements				3082

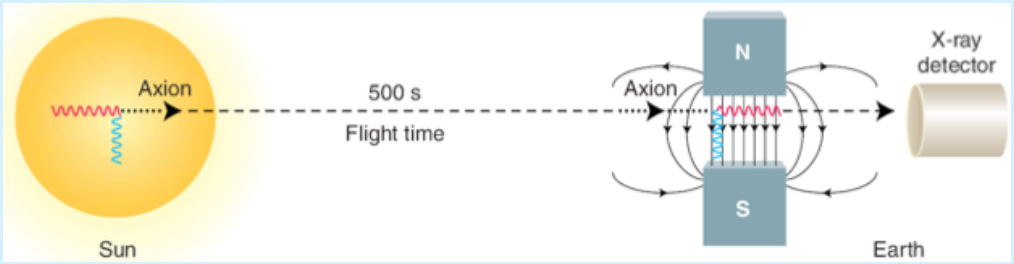


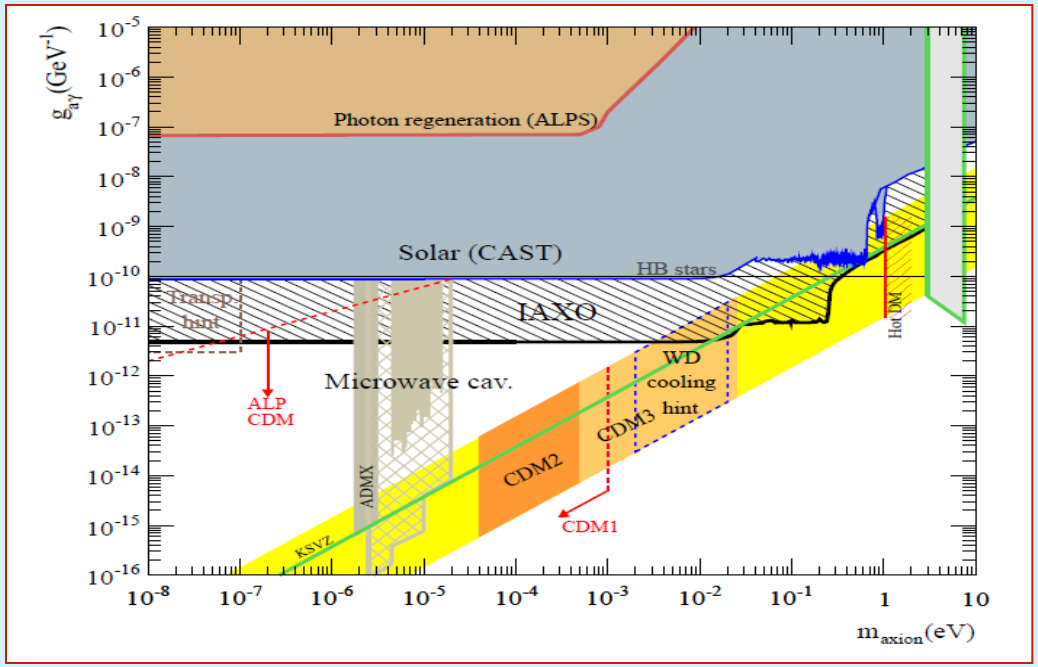
David Tanner

REAPR – US effort (Univ of Florida and Fermilab, etc.) submitting R&D proposals. Related laser expt's at FNAL.

Solar Helioscopes

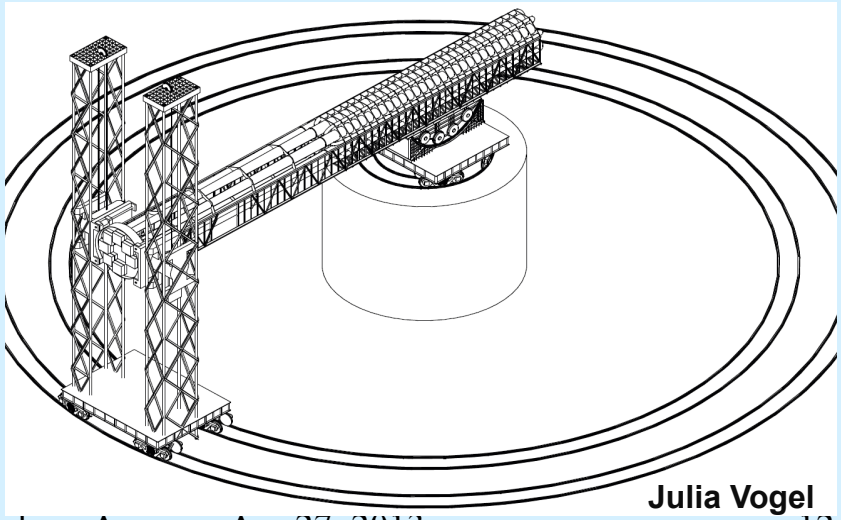
Conversion from γ to a in B_{SUN}
Reconversion back into x-ray w/magnet





CAST Experiment

IAXO concept



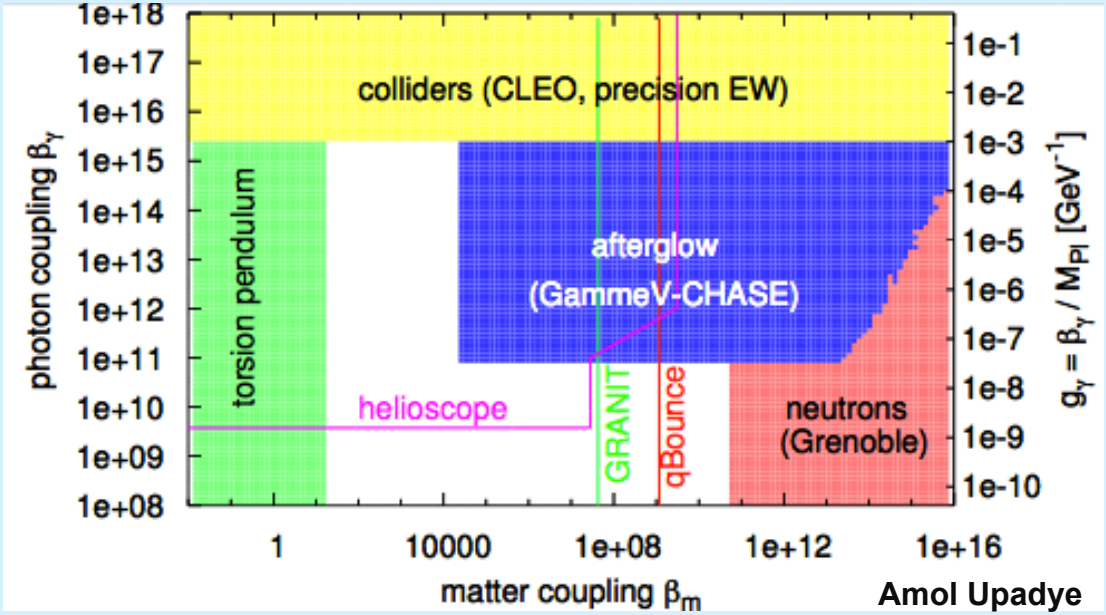
Chameleons

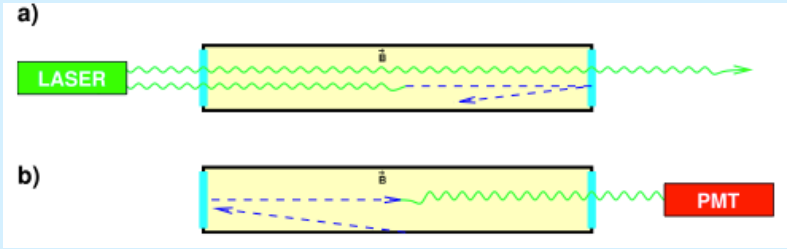
A Chameleon is a particle whose properties depend on it's environment. At low mass density the chameleon is light, and acquires a large effective mass in high mass density.

➔ A possible dark energy particle

➔ Afterglow experiment is one test

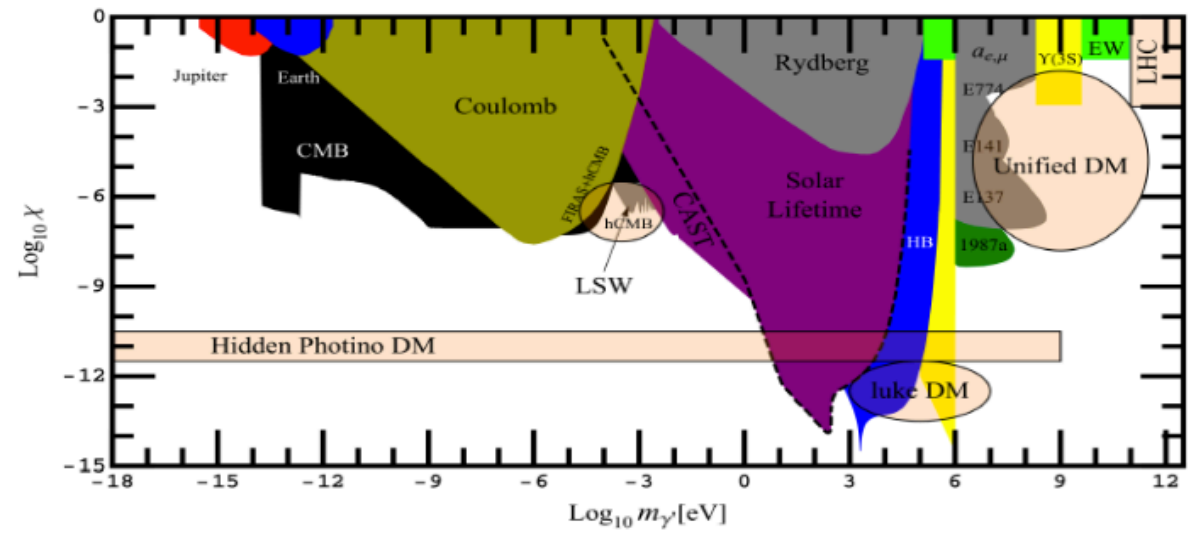
$$\mathcal{L}_{\rm int} = -V(\phi) + \exp\left(\frac{\phi}{M_D}\right) g_{\mu\nu} T^{\mu\nu} - \frac{1}{4}\frac{\phi}{M} F_{\mu\nu} F^{\mu\nu}$$





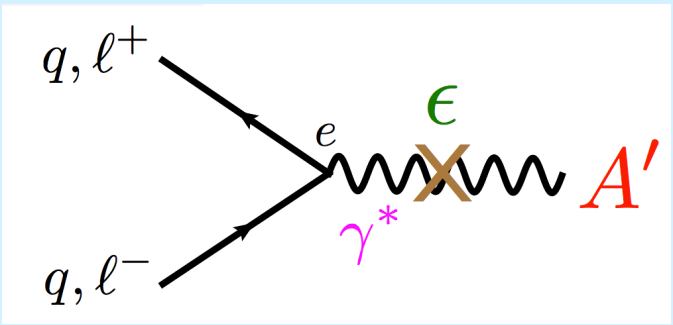
Hidden Sector Photons

- Hidden/Heavy Photon, A′ (A-prime), γ′,U, Z_D, …
- Theoretically discussed since at least 1980s
- Strong motivation is the extension of the Standard Model to have new U(1) gauge groups
- Vector portal to a hidden sector is particularly accessible



30 orders of magnitude in mass
15 orders of magnitude in coupling

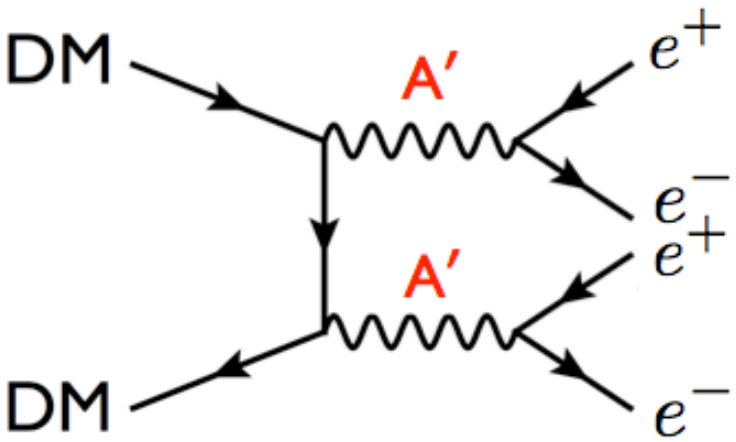
Kinetic Mixing between A' and photon

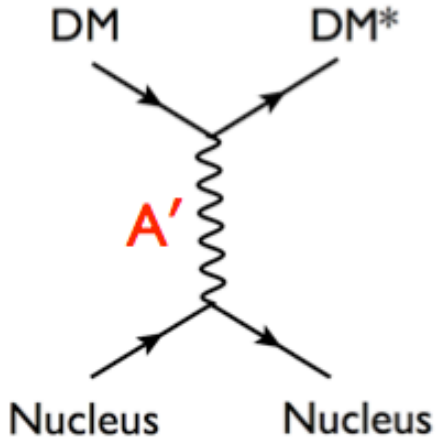


Hints for A'

New dark matter interactions?

Arkani-Hamed et.al.; Cholis et.al.; Pospelov & Ritz





cosmic-ray e^+, e^- excesses?

PAMELA, Fermi, AMS

direct detection hints?

DAMA, CoGeNT, CRESST

Speculative but amazing if true - clear connection to Cosmic Frontier

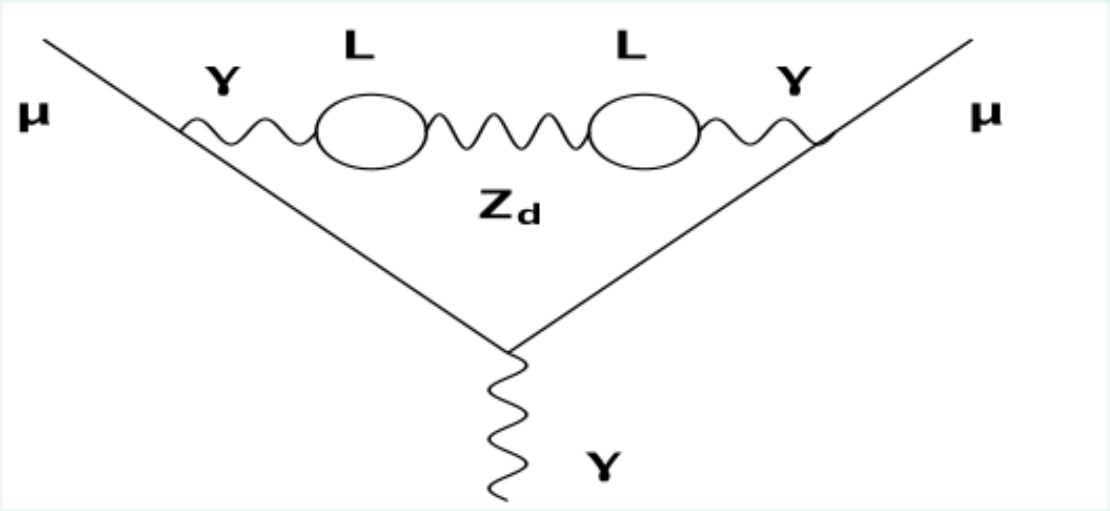
Rouven Essig

Tracy Slater

Hints for A'

Effective 3 loop g_μ-2 Diagram

$a_\mu^{Zd}=\alpha/2\pi\varepsilon^2F(m_{Zd}/m_\mu)$, F(0)=1 solves g_μ-2 discrepancy
for $\varepsilon^2\approx3\text{-}5\times10^{-6}$ & $m_{Zd}\approx20\text{-}50$MeV (see figure)



Bill Marciano

Collider searches

- B factories, ϕ factories, hadron machines

Uγ Events: $e^+e^- \rightarrow U\gamma \rightarrow \mu^+\mu^-\gamma$

Φ Dalitz decay: $e^+e^- \rightarrow \Phi \rightarrow U\eta \rightarrow e^+e^-\eta$

Higgs Strahlung: $e^+e^- \rightarrow h'U \rightarrow h'\mu^+\mu^-$

Search for dark photon

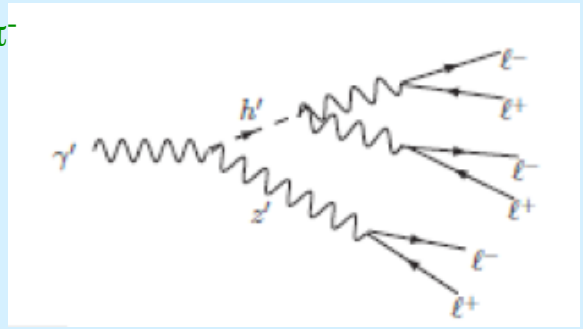
$e^+e^- \rightarrow \gamma A'$, $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$

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

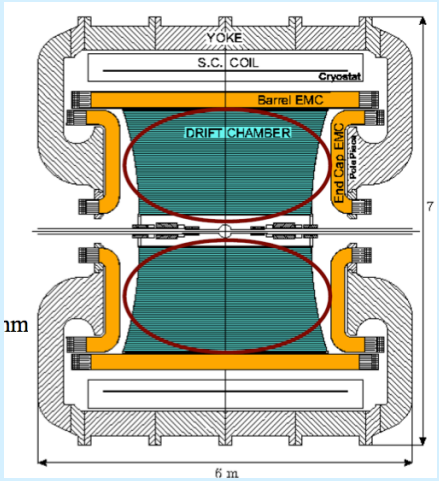
Search for dark Higgs boson

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

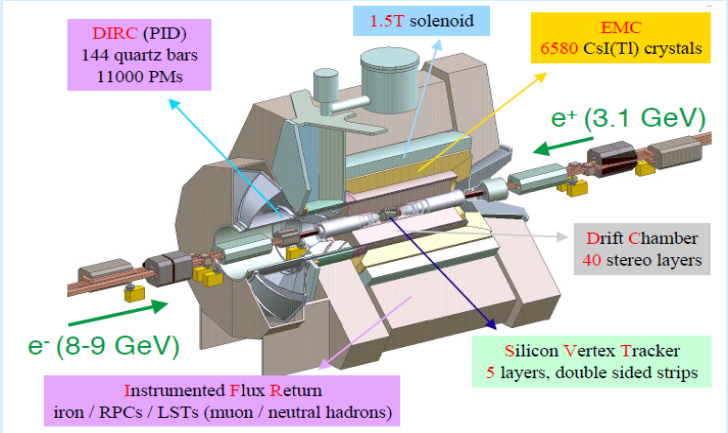
Lepton Jets



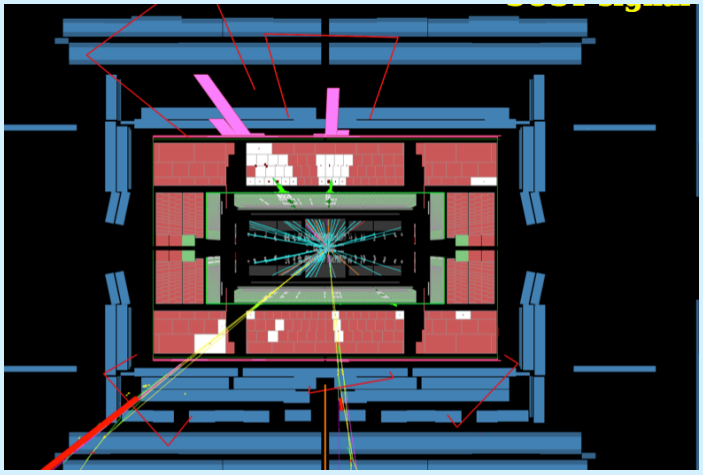
KLOE



Francesca Curciarello



Bertrand Echenard

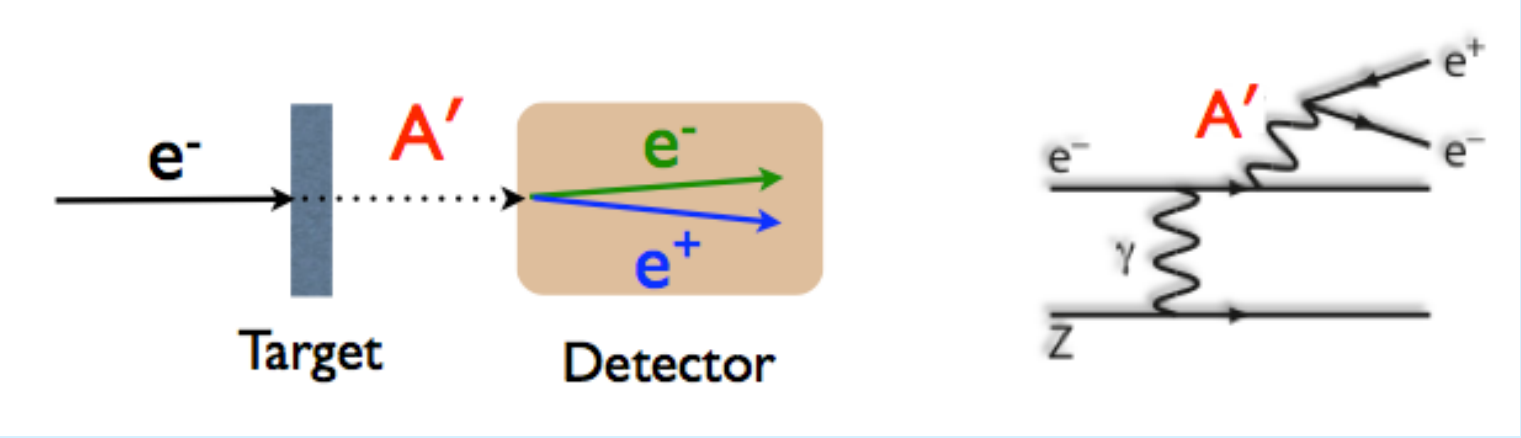


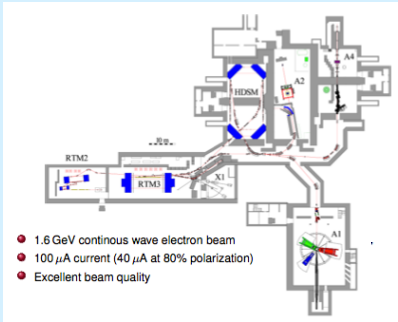
Andy Hass

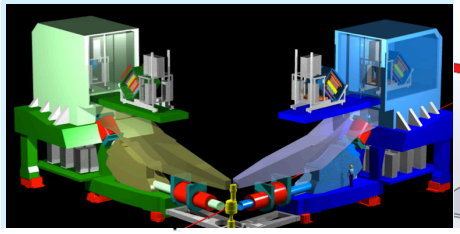
e- fixed targets

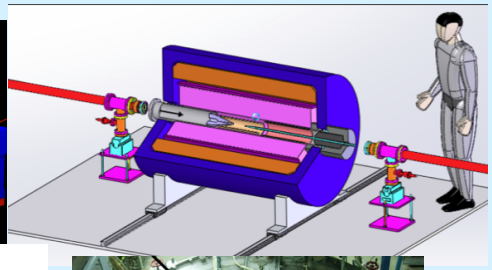
- Jefferson Lab, Mainz, VEPP-3, e- beam dump

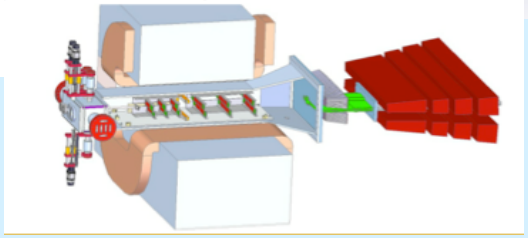
  APEX, HPS, DarkLight

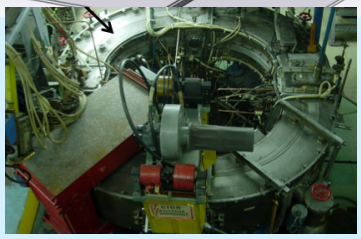




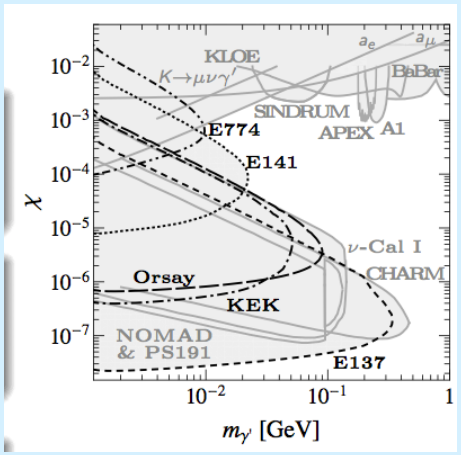








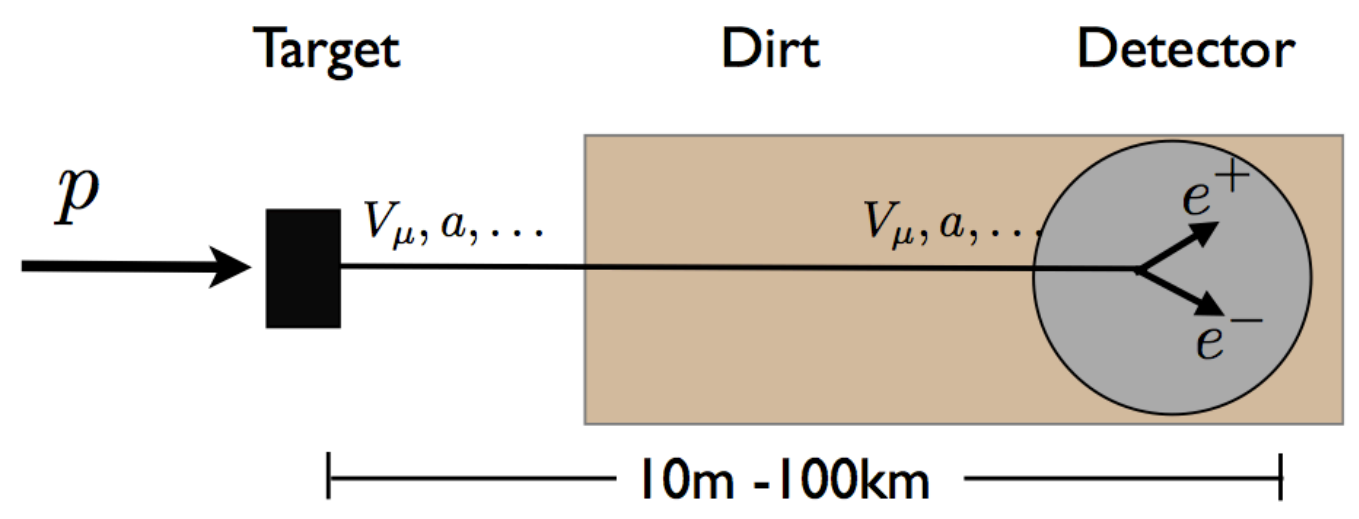
Tobias Beranek
Philip Schuster
Ross Corliss
Stepan Stepanyan



Sarah Andreas

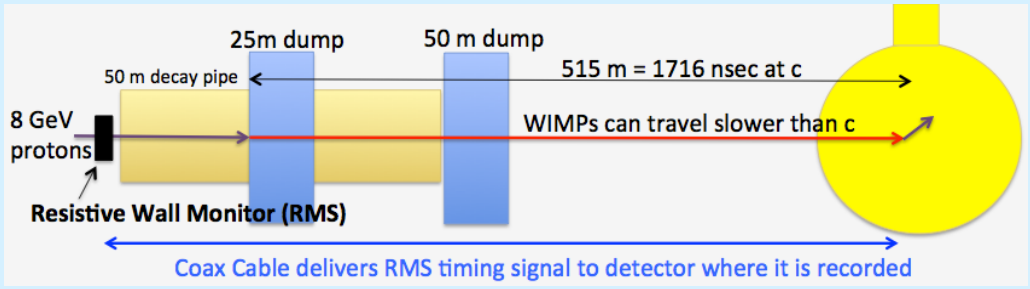
p fixed targets

- Neutrino beamlines, Project X, beam dump

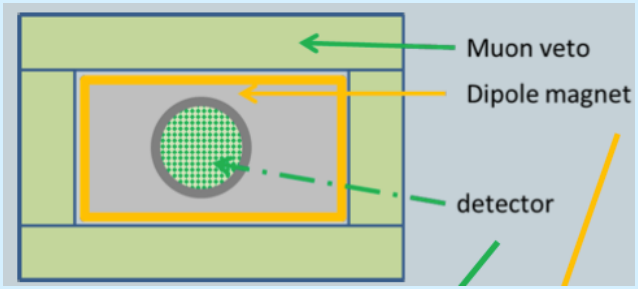


Brian Batell

MiniBooNE

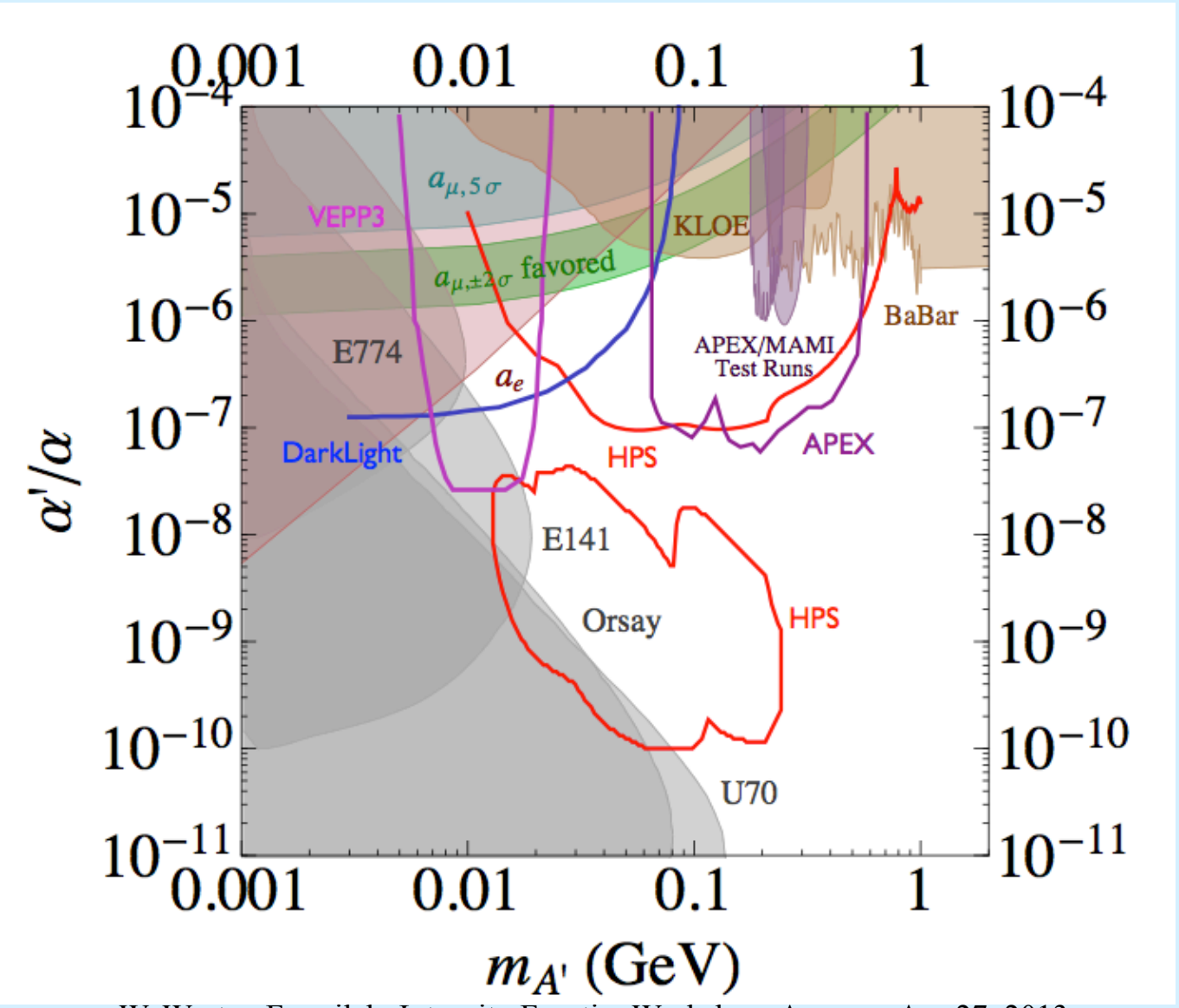


Richard Van de Water



Athanasios Hatzikoutelis

Current and future status



A point

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- In the beginning, fishing is simple, does not take much hardware, and is a lot of fun – and you might catch a fish.

Points for HEP Community

- New light weakly-coupled particles
  - Strongly motivated theoretically
  - Hints from laboratory experiments as well as astrophysical observations
  - The Intensity Frontier approach provides a means to directly produce new particles
  - Relatively new, energetic subfield of particle physics with world-wide interest
  - Opportunities are quite extensive, sometimes limited by imagination, and represent a low cost means towards high impact discovery physics!