dark sector searches using photons and Higgs bosons

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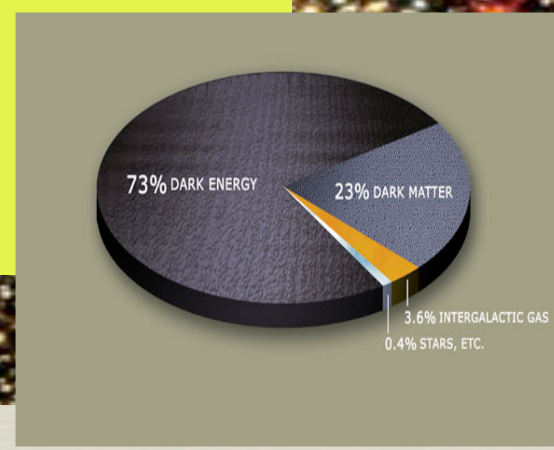
IEB workshop
June 18, 2015

the standard model . . .

36	quarks (6 flavor x 3 color x 2 charges)
8	gluons
6	charged leptons (μ^+, μ^-, e^+, e^-, τ^+, τ^-)
3	neutral leptons (ν_e, ν_μ, ν_τ)
4	gauge bosons (Z^0, W^+, W^-, γ)
1	SM-like Higgs boson (H^0)
58	**known elementary particles in SM**

beyond the standard model . . .

- what is dark matter?
- what is dark energy?
- what happened to the antimatter?
- what about θ term in QCD lagrangian?
- are there dark force mediators?
- . . .




DARK
UNIVERSE
DARK FORCES
DARK
MATTER
darkSector
dark sector physics

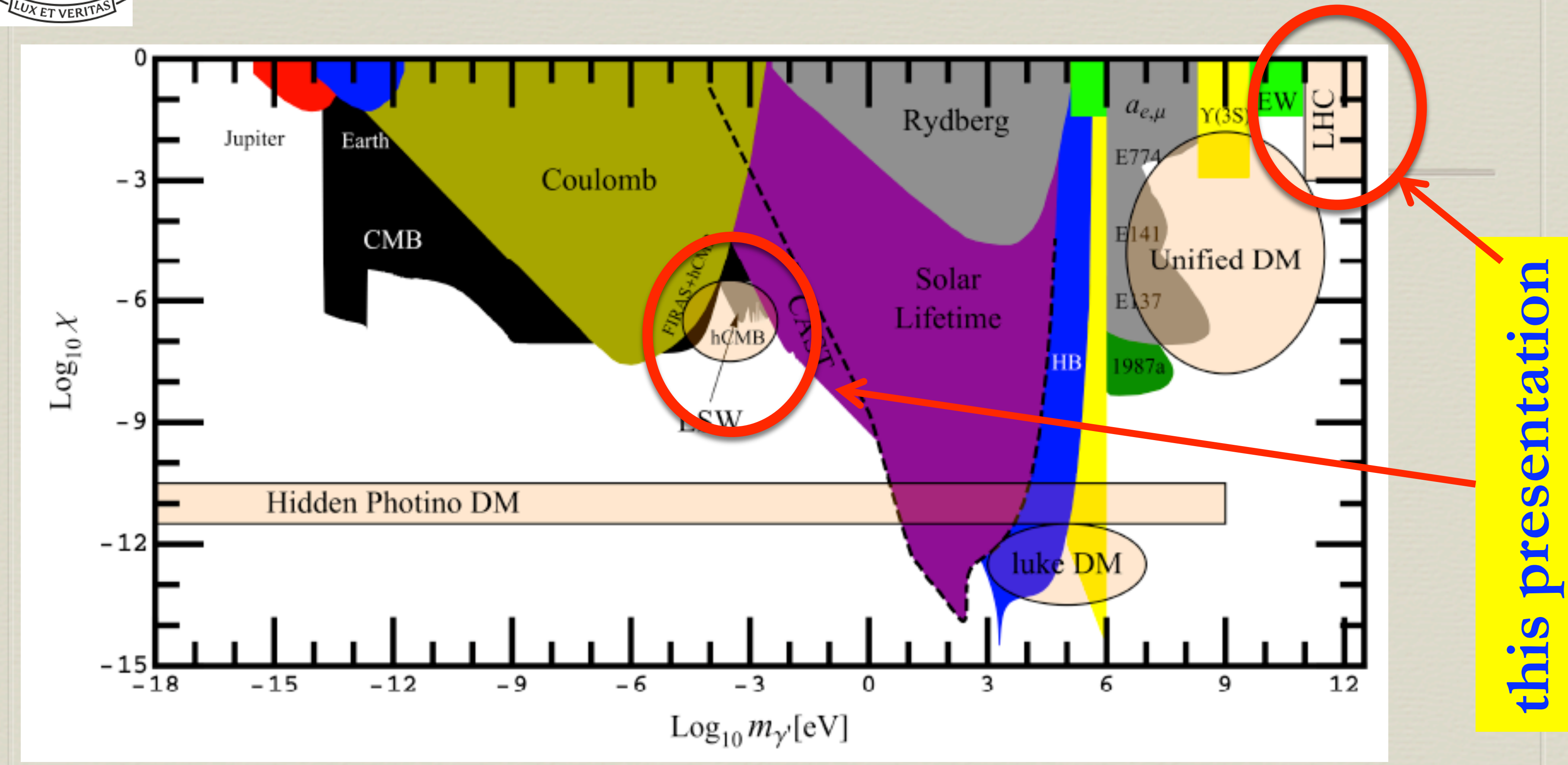
‘dark sector’ particle properties

- non-luminous
- feeble interaction with SM particles and fields
- may be more than one component
- dominates matter budget of the universe
- . . .

dark sector searches using SM particles and fields?

γ-γ_d and Z-Z_d kinetic mixing

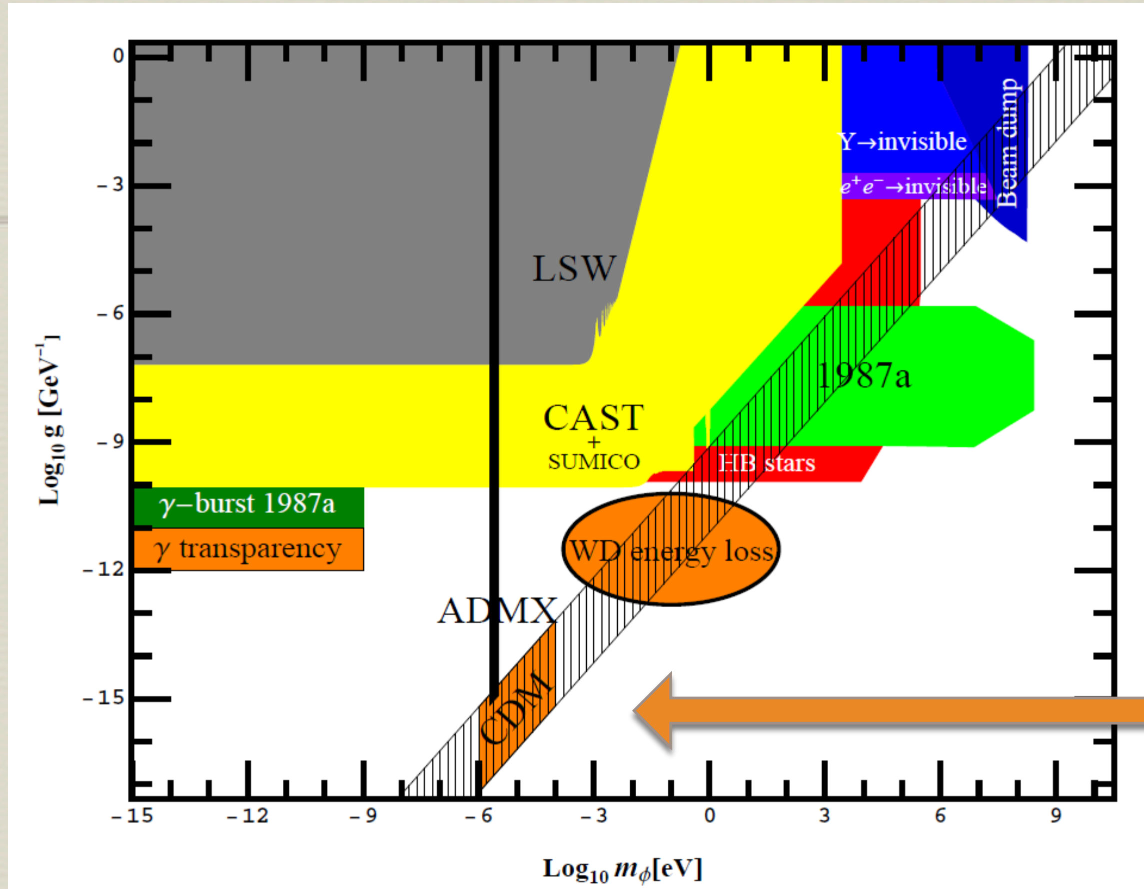
J. Jaeckel, A. Ringwalk arXiv:1002.0329



- large unexplored regions of the landscape
- multiple techniques and strategies
- worldwide search effort

axion and axion-like particle coupling to photons

J. Jaeckel and A. Ringwald, Ann. Rev. of Nuc. and Particle Sci., 60, 405, 2010.



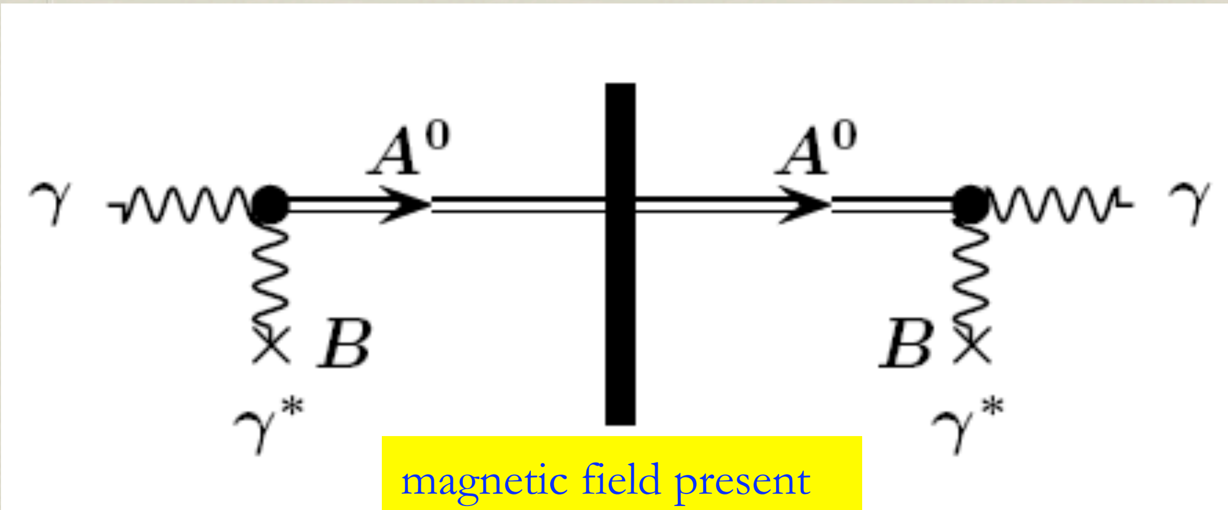
cold dark matter 'sweet spot'

- large unexplored regions of the landscape
- multiple techniques and strategies
- worldwide search effort

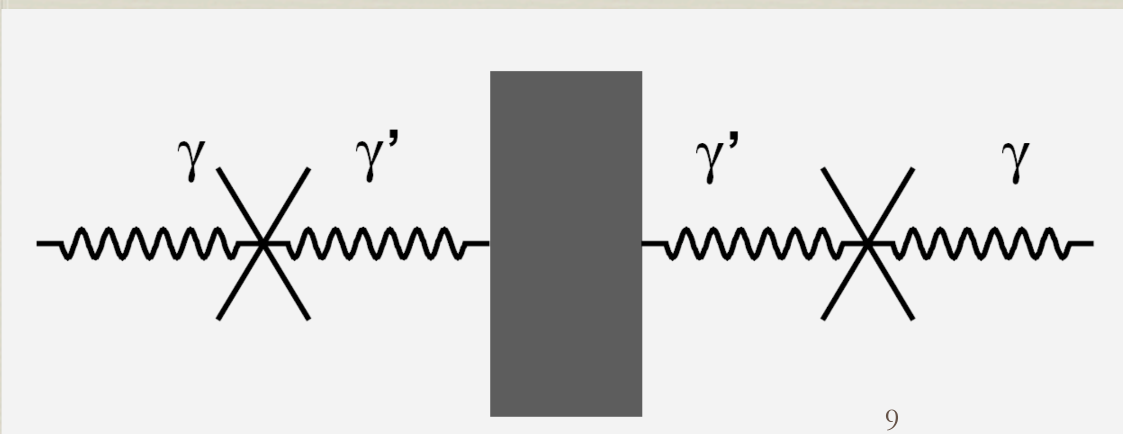
dark sector searches using optical photons

light shining through a wall

can suppress background by over 20 orders of magnitude ! ! !
kW lasers, cavities, ultra low noise detectors, . . .



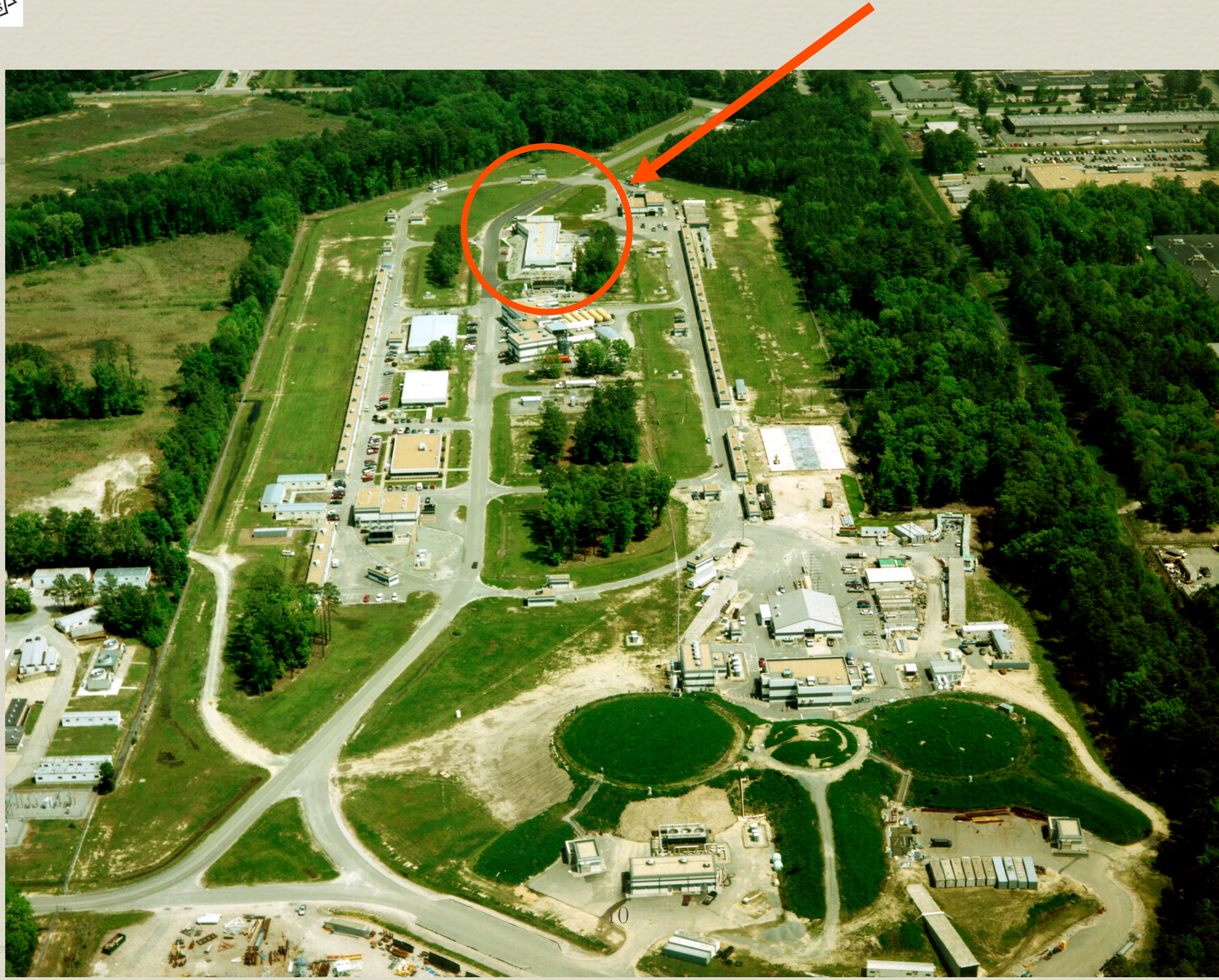
- couple polarized laser light with magnetic field
- Sikivie (1983); Ansel'm (1985); Van Bibber et al (1987)



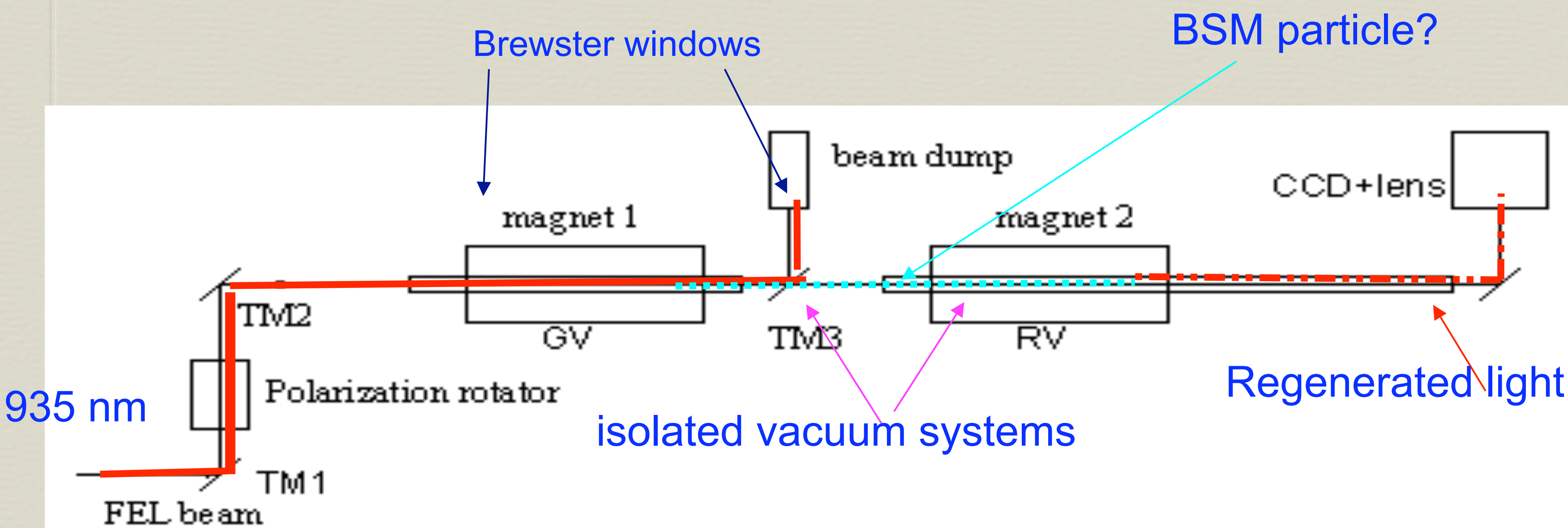
no magnetic field required

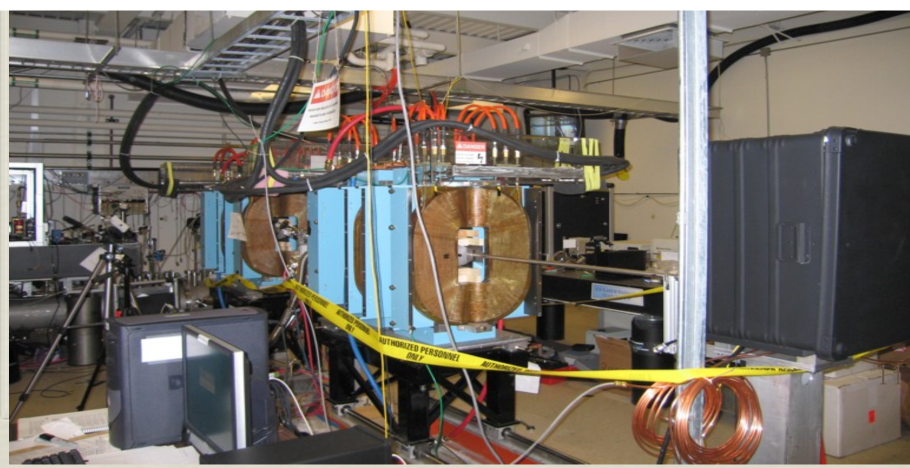
- kinetic mixing
- no magnetic field required
- Afanasev et al (2009)

Jefferson Lab and the Free Electron Laser



LIPSS at JLab experiment schematic





150 fs wide pulses

<75 MHz rep rate

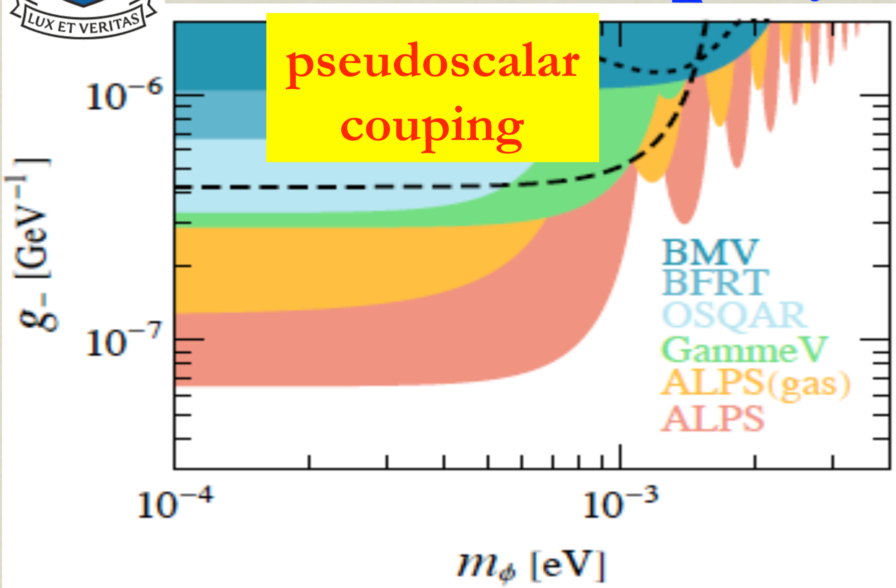
100 % df

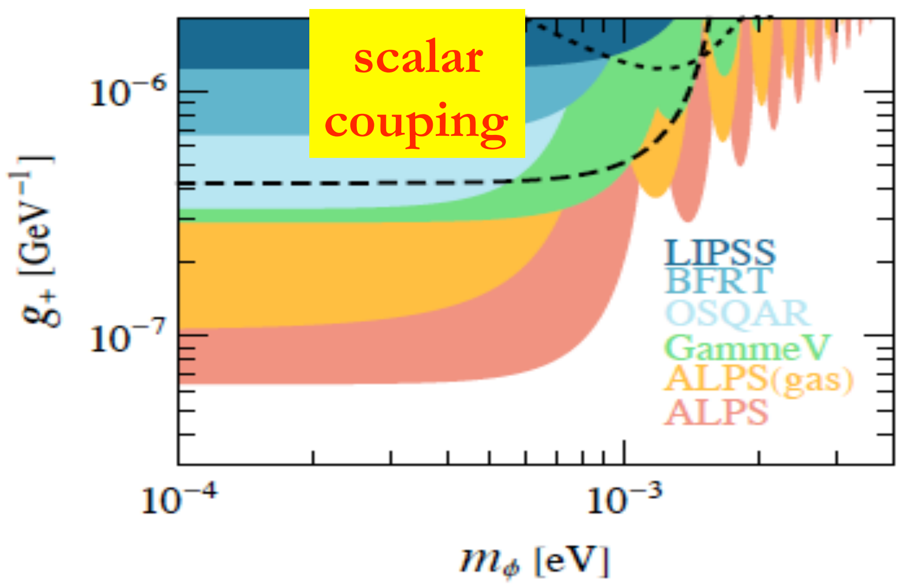
935. +/- 15 nm

200 (→400) watts avg power

>99% linearly polarized

lsw physics results



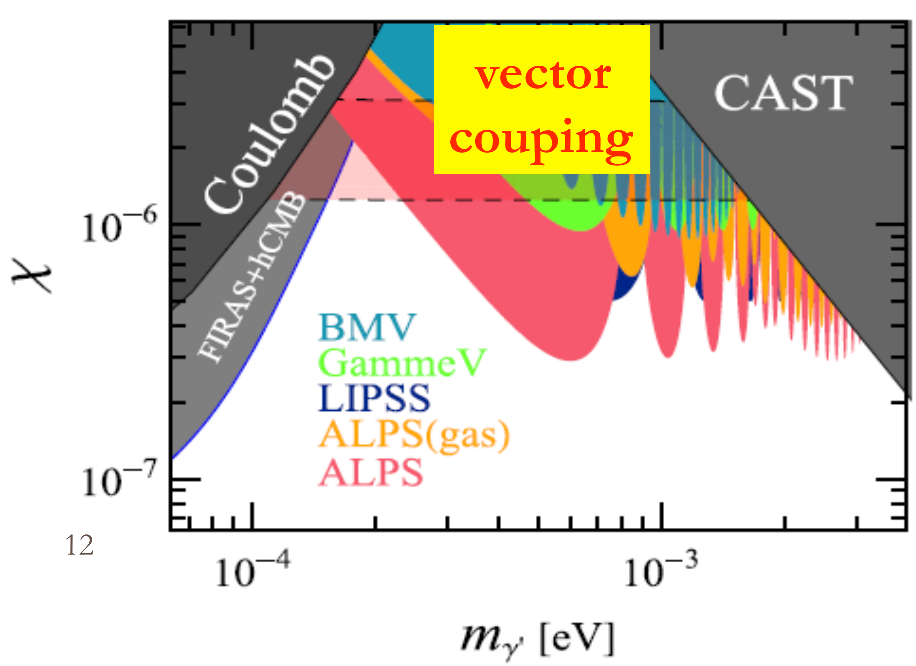


M. Ahlers et.al., Phys.Rev.D77:095001,2008

J. Jaeckel, J. Redondo, A. Ringwald,

astro-ph:0804.4157

ALPS: DESY
BMV: France
GammeV: FNAL
LIPSS: Jlab
OSQAR: CERN



LIPSS at JLab collaboration

A. Afanasev, R. Ramdon

Hampton University

G. Biallas, J. Boyce, M. Shinn

Jefferson Lab

K. Beard

Muons, Inc

M. Minarni

Universitas Riau

O.K. Baker, P. Slocum

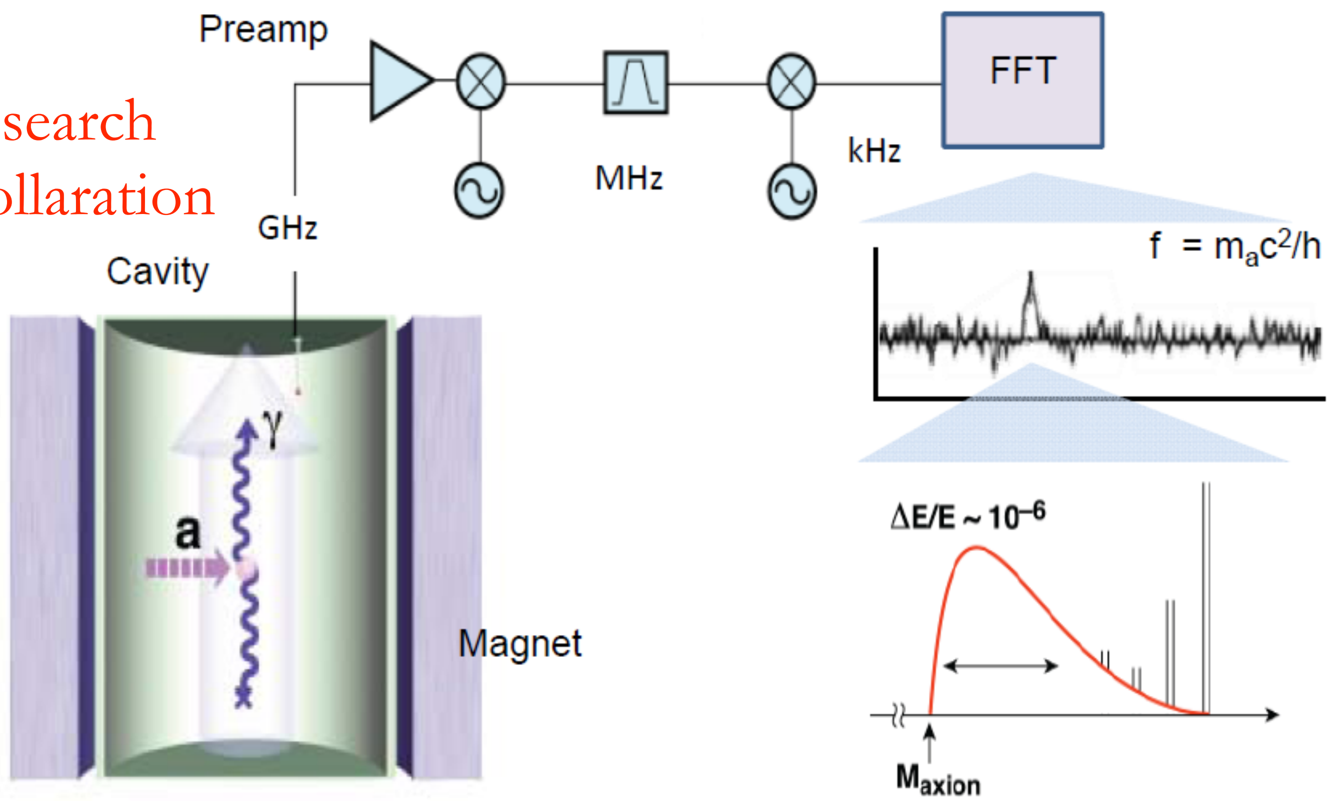
Yale University

dark sector searches using microwave photons

dark matter axion and ALP search using microwaves

The Microwave Cavity Search for DM Axions (Pierre Sikivie, 1983)

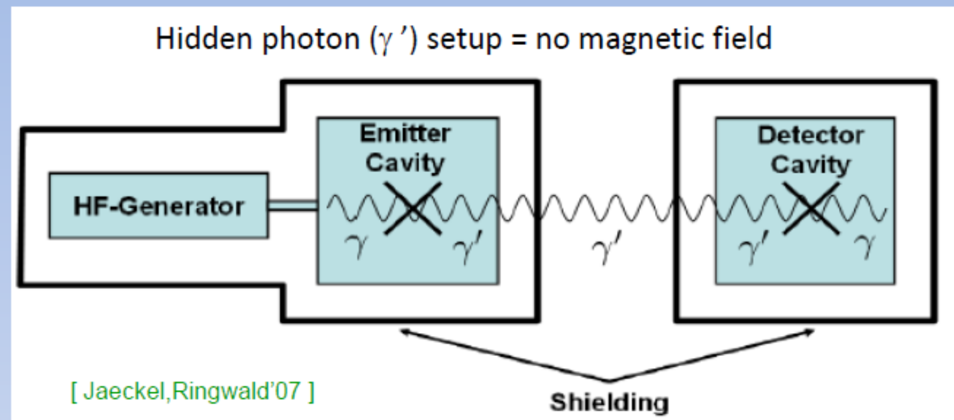
pioneering research by ADMX collaration

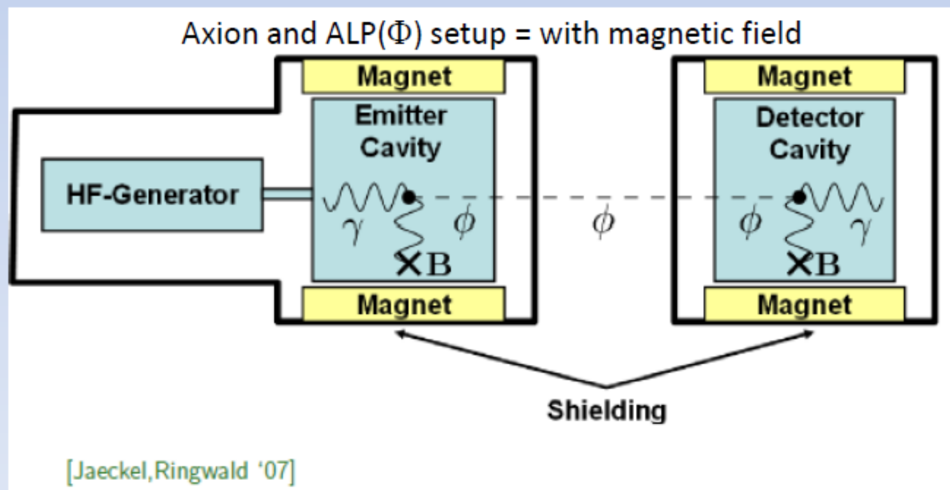


$$P_{sig} \propto (B^2 V Q_{cav})(g^2 m_a \rho_a) \sim 10^{-23}\,W \qquad s/n = \frac{P_{sig}}{kT_{sys}}\sqrt{\frac{t}{\Delta\nu}}$$

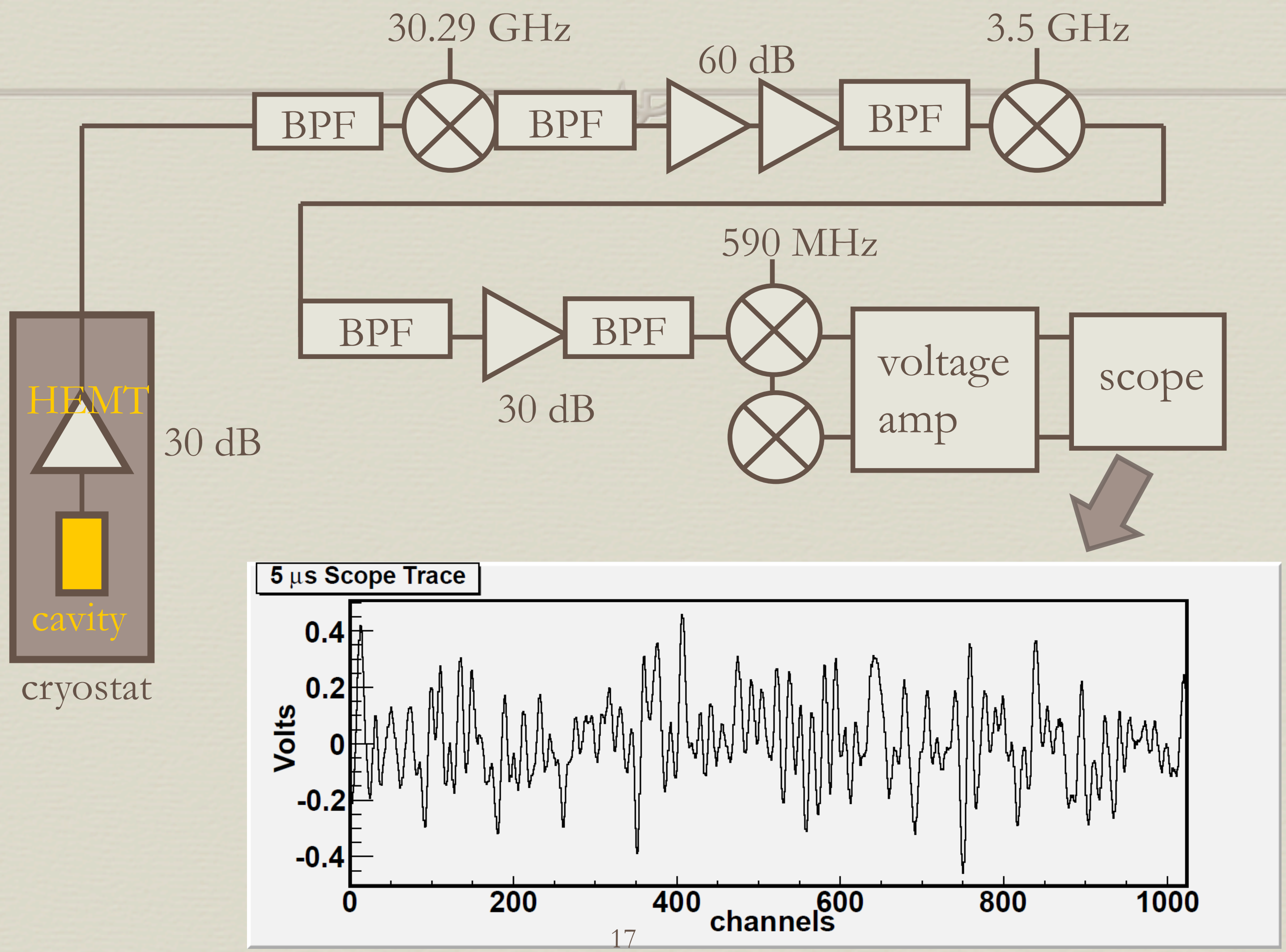
lsw resonant cavity searches

- Idea: exploit microwave cavities instead of optical resonators [Hoogeveen '92; Jaeckel,Ringwald'07; Caspers,Jaeckel,Ringwald '09]
- With current technology, expect increased sensitivity in certain mass range
- First test experiments have already been done (Livermore; Perth), or are set-up (Daresbury; Yale)

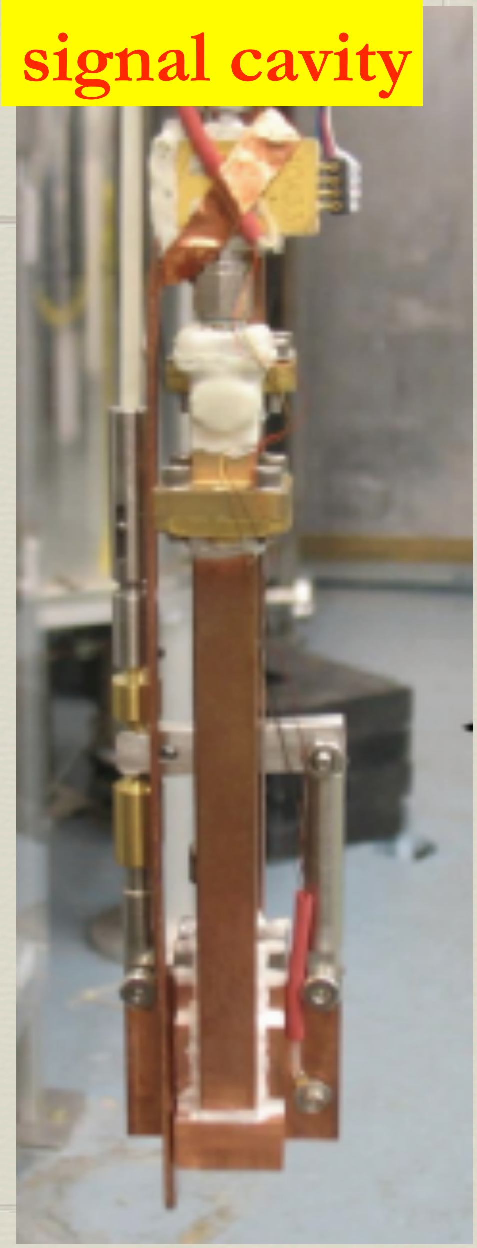




ymce microwave receiver
triple heterodyne



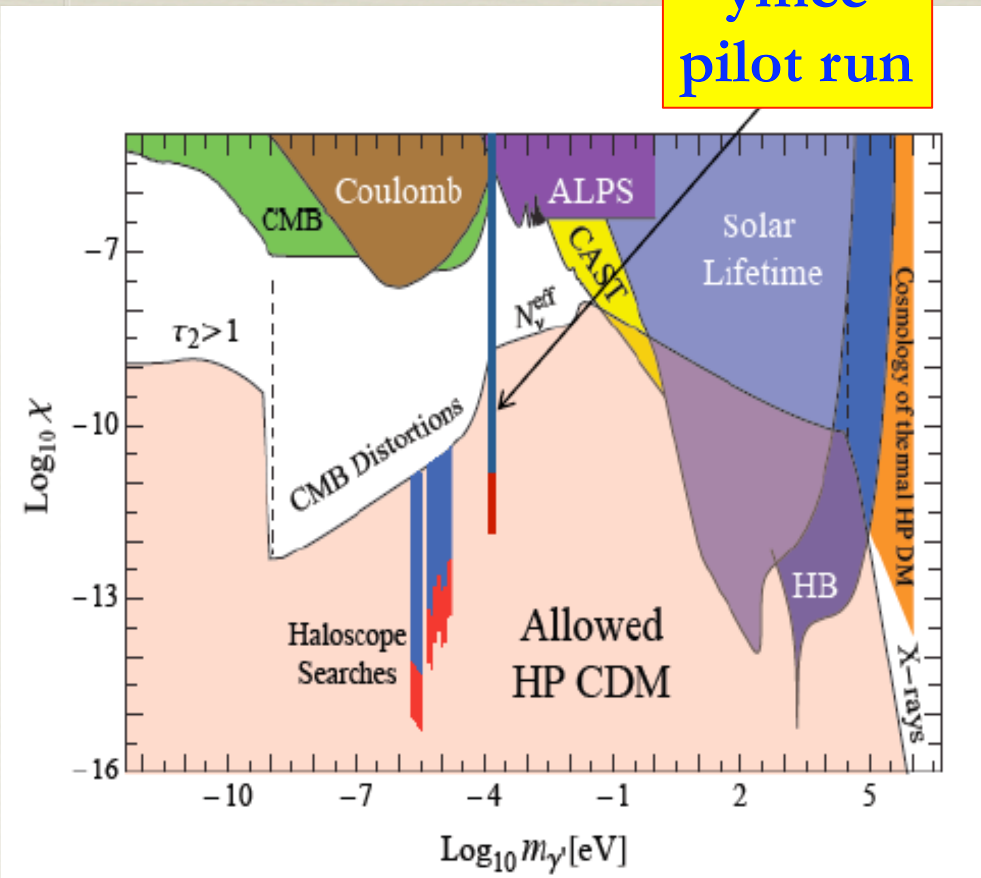
ymce cavities



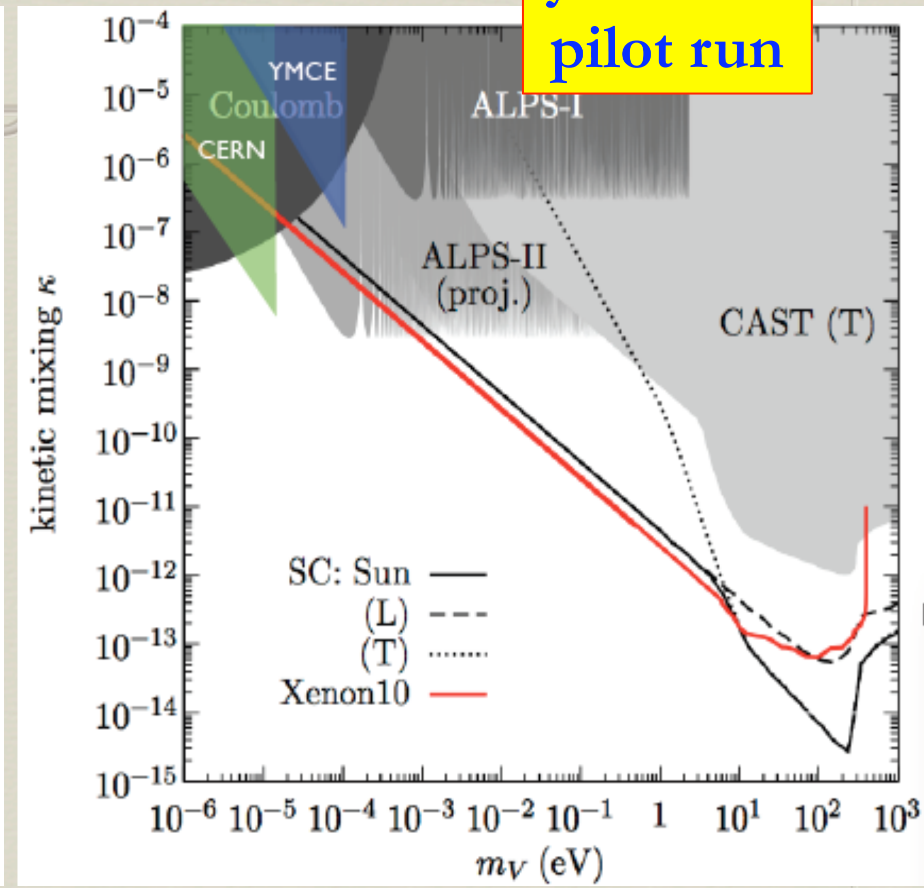
ymce

dark vector searches

ymce pilot run



ymce lsw pilot run

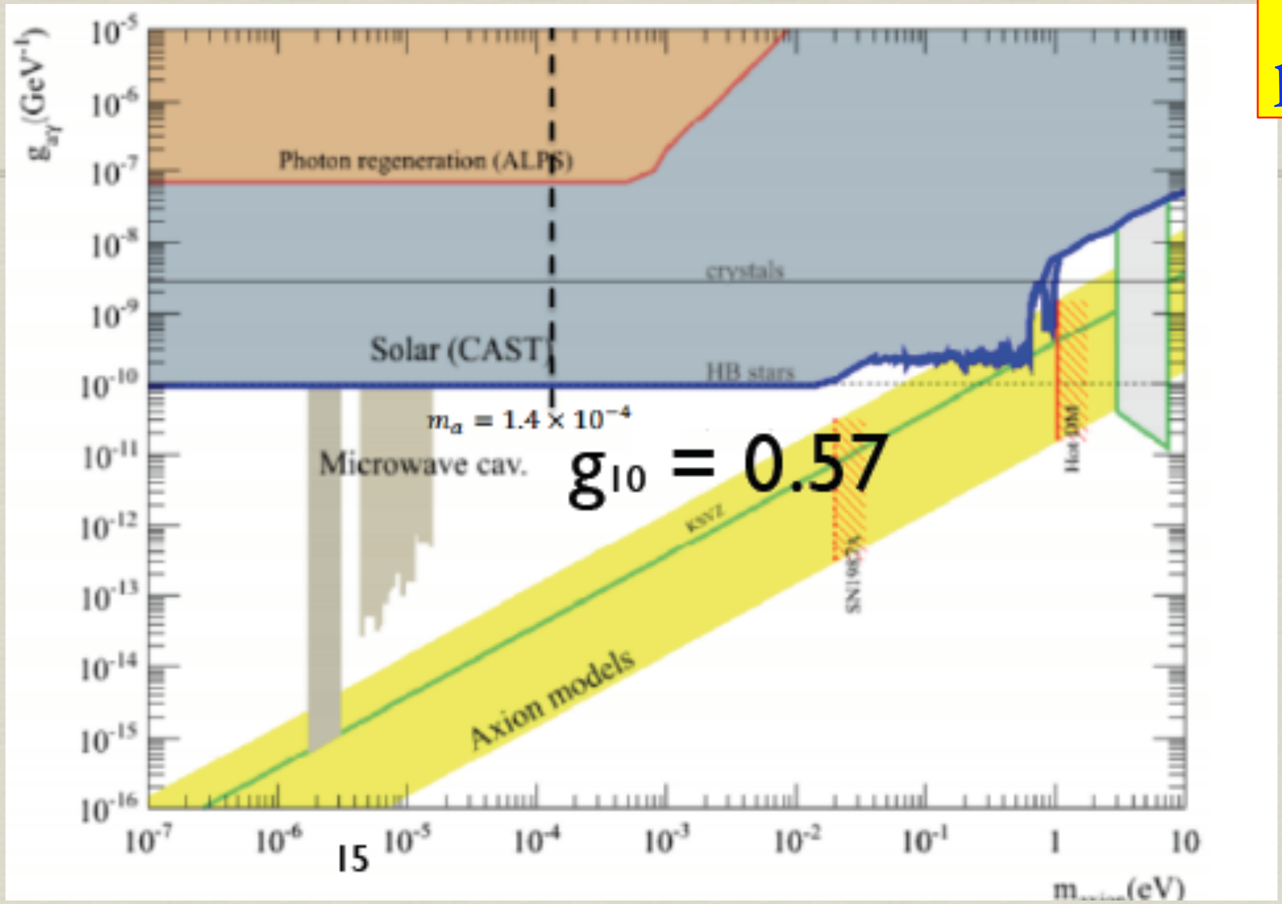


dark matter could hidden photons (HP)!

Ana Malagon, doctoral dissertation, Yale (2014)

ALP dark matter

ymce
pilot run



dark matter could be axion-like particles

Ana Malagon, doctoral dissertation, Yale (2014)

Yale microwave cavity experiment collaboration

J. Hirshfield, M. LaPointe, G. Kazakevitch, S. Kazakov, S. Shchelkunov, Y. Jiang

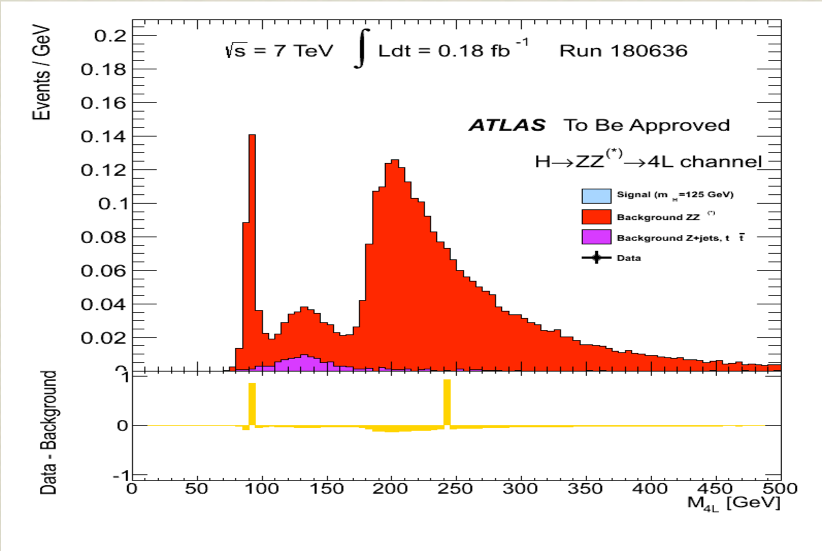
Omega-P and Yale University

O.K. Baker, A. Malagon*, A. Martin, P. Slocum, A. Szymkowiak

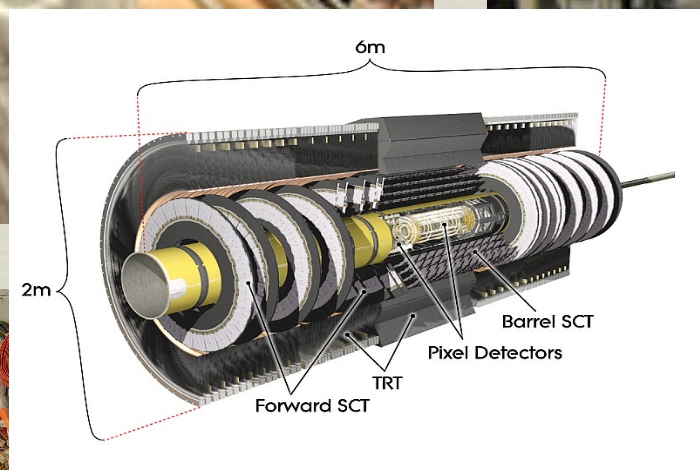
Yale University

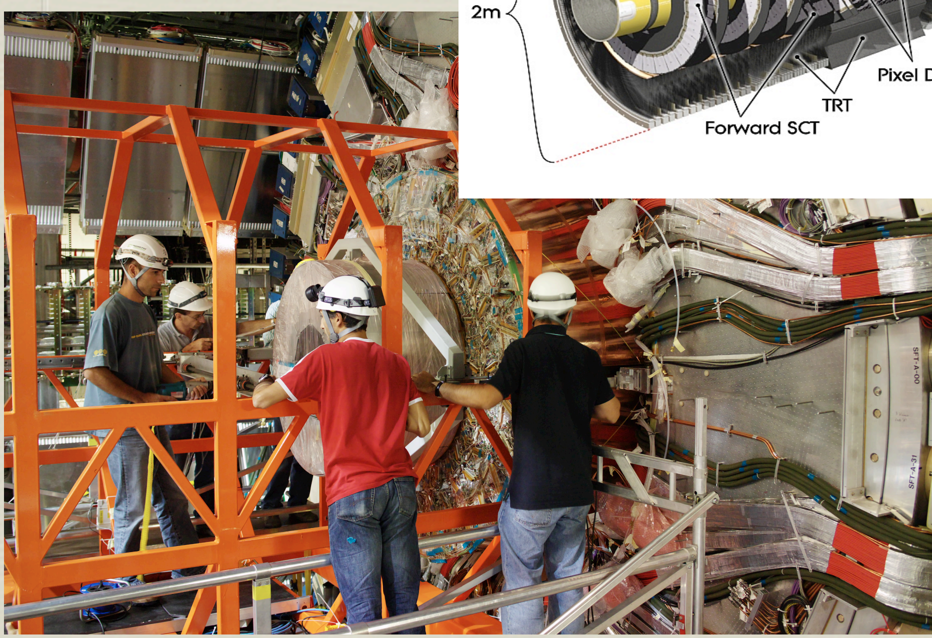
* now at the University of Washington/ADMX

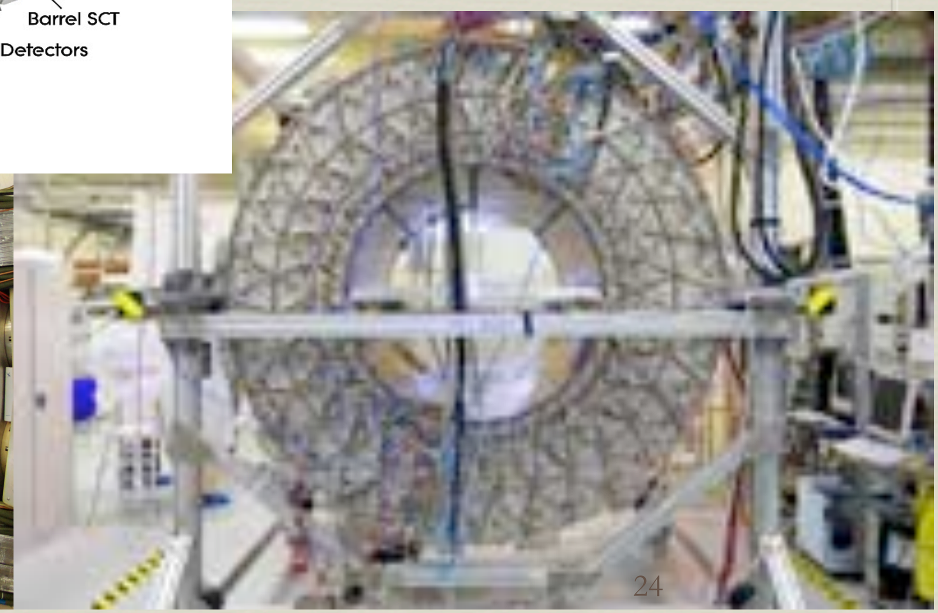
dark sector searches using the Higgs boson



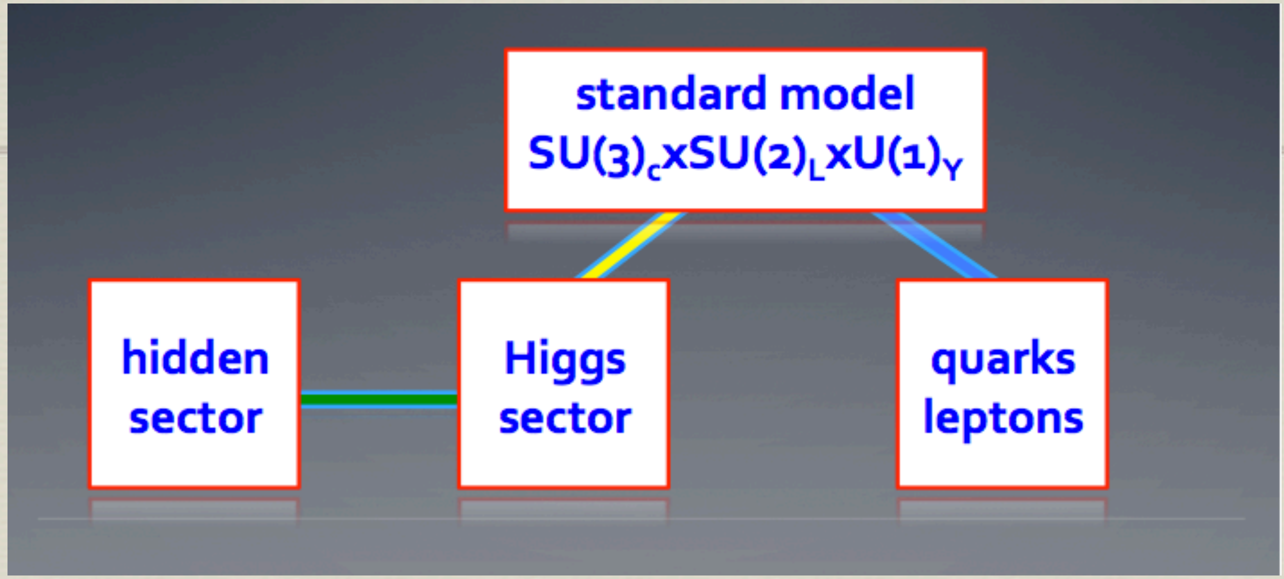
https://espace.cern.ch/atlas-phys-higgs-htogamgam/Lists/Hgg Moriond 2013/Attachments/46/mass_animation_ZZ4L.gif - mass-animation


6m
2m
Barrel SCT
Pixel Detectors
TRT
Forward SCT





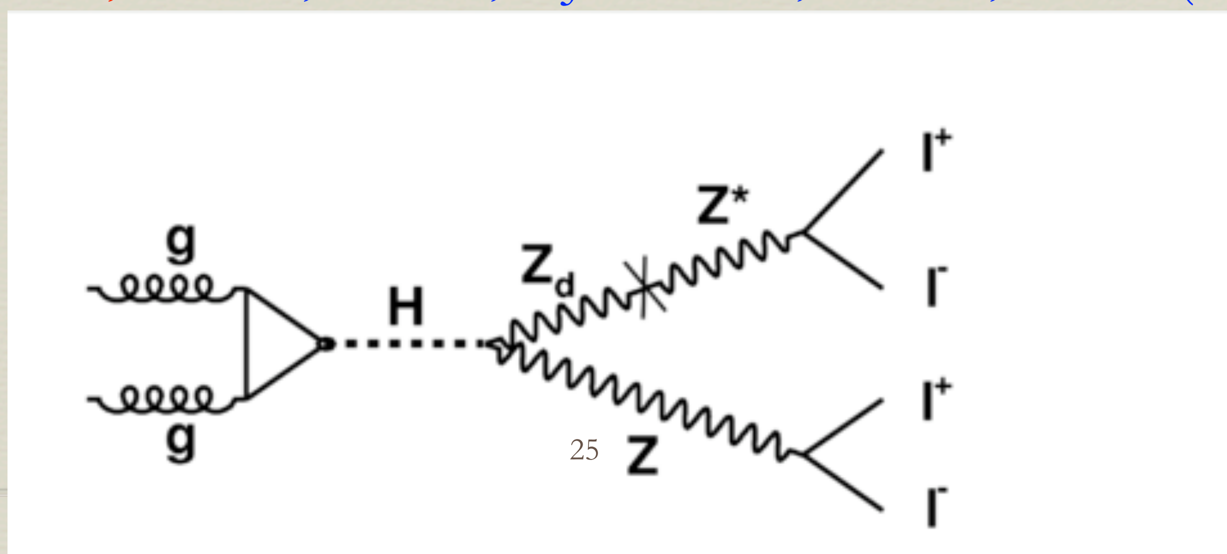
physics motivation



H. Davoudiasl, H-S Lee, I. Lewis, W.J. Marciano, PRD 88, 015022 (2013)

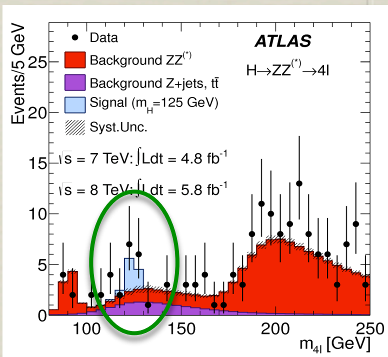
Higgs a portal to the hidden or "dark" sector

one possibility,
as an example



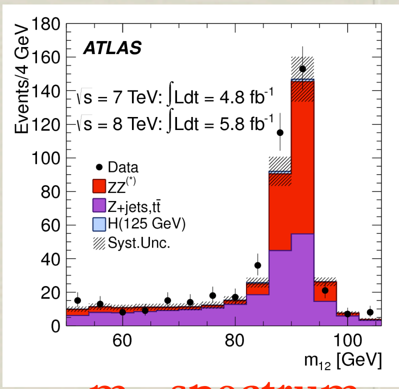
analysis strategy

- 1. use Higgs decays: H → ZZ* →4l events from HSG2 cut-based 'Moriond' analysis (Phys. Lett. B 726 (2013) 88)
  - Higgs decays to 4e, 4μ, 2μ2e, and 2e2μ
  - 115 GeV < M_{4l} < 130 GeV



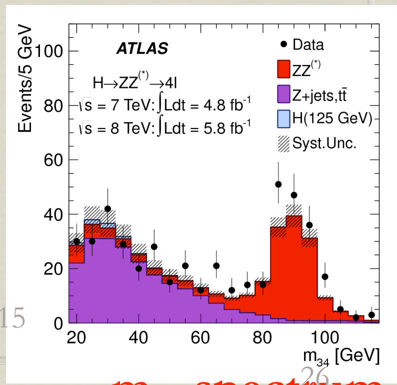
m_{4l} spectrum

- 2. use Z^0 (Z1) and Z* (Z2) mass distributions
  - leading dileptons: invariant mass (m_{12}) closest to Z^0 PDG value
  - subleading dileptons: highest invariant mass (m_{34})



m_{12} spectrum

- 3. search for narrow peak or excess above background in m_{34} mass distribution; signals V_D
  - ZZ*,ttbar, Z+jets, H→ZZ*→4l are backgrounds
  - use Roostats and BumpHunter statistical tools



m_{34} spectrum

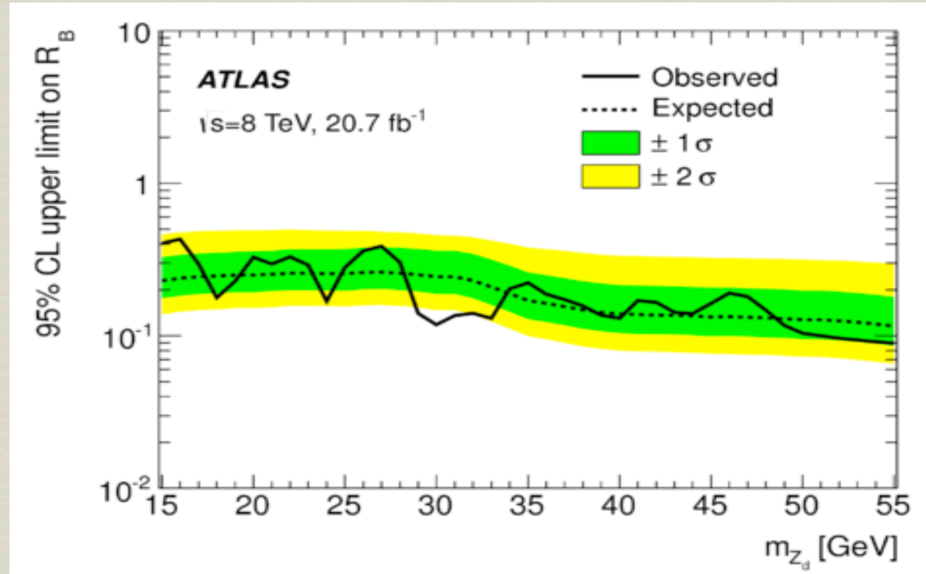
- 4. in the absence of a signal, set upper limits on the relative branching ratio

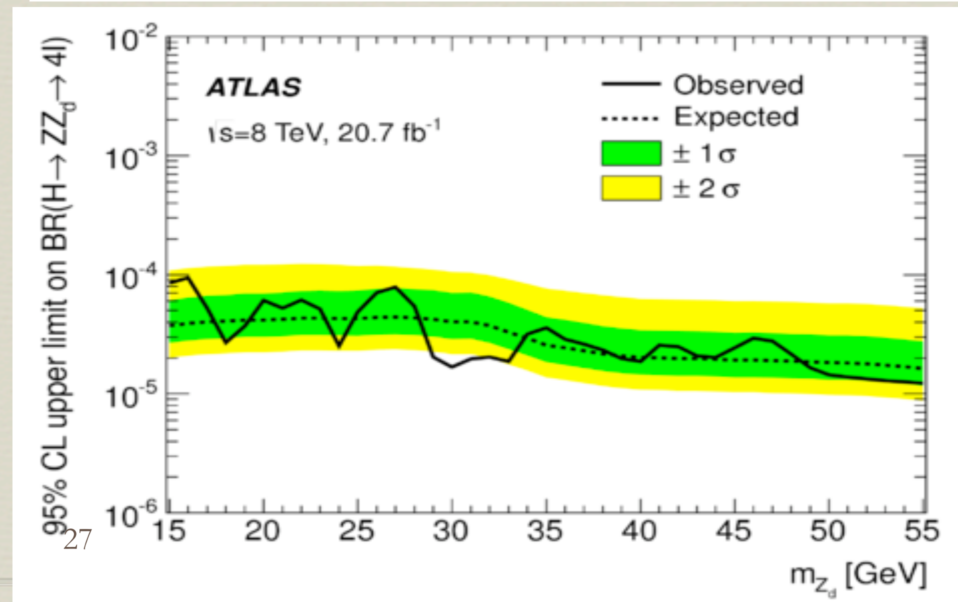
$$\frac{bf(H \to ZZ_d \to 4l)}{bf(H \to 4l)}$$

95% CL exclusion limits

$$R_{\rm vis} = \frac{n(H \to ZZ_d \to 4\ell)}{n(H \to 4\ell)}$$

$$RelBR = \frac{R_{\rm vis}}{R_{\rm vis} + C(1 - R_{\rm vis})}$$



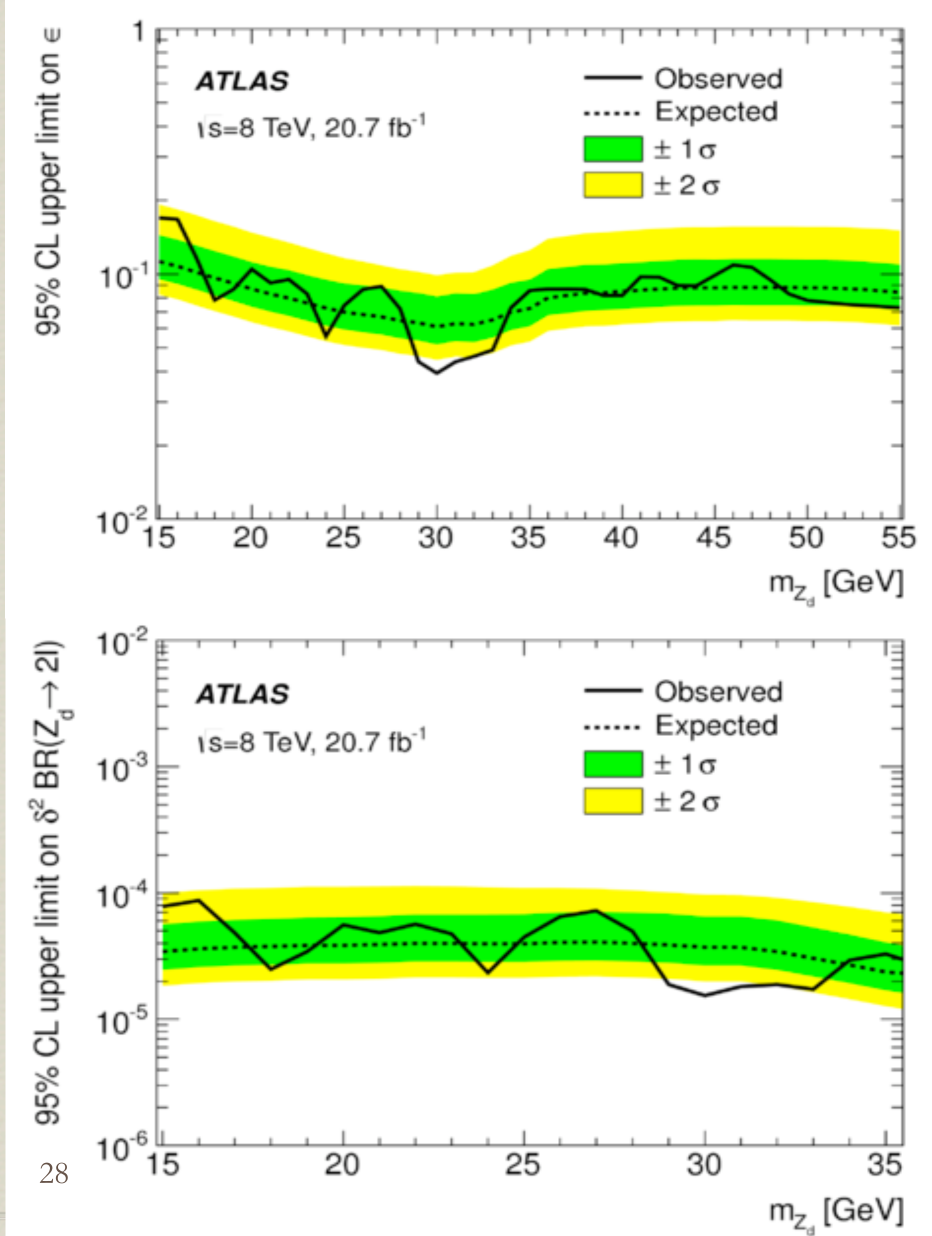


submitted to PRD (2015)

95% CL exclusion limits

kinetic mixing parameter

mass mixing parameter



submitted to PRD (2015)

summary

- dark sector physics important part of BSM searches
  - dark sector particles, dark forces, …
- many different probes (two presented today)
  - optical and x-ray photons
  - microwave photons
  - beam dumps
  - particle decays
  - medium energy searches
  - energy frontier search using Higgs boson
- opportunities for new ideas/strategies
  - great for students interested in this physics