Axion Searches Overview

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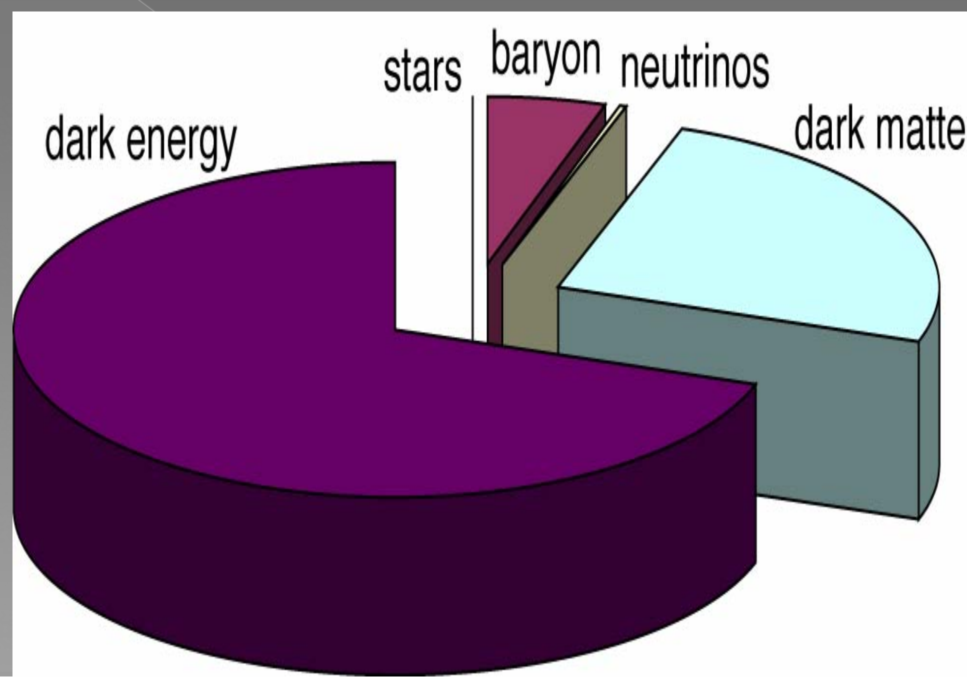
Plan of Talk

- Introduction to a Dark Matter problem
  - Axions as Dark Matter candidates
  - Laboratory searches
  - Solar/cosmic axion searches

Matter/Energy Budget of Universe

- Stars and galaxies are only ~0.5%
- Neutrinos are ~0.3–10%
- Rest of ordinary matter (electrons and protons) are ~5%
- Dark Matter ~30%
- Dark Energy ~65%
- Anti-Matter 0%



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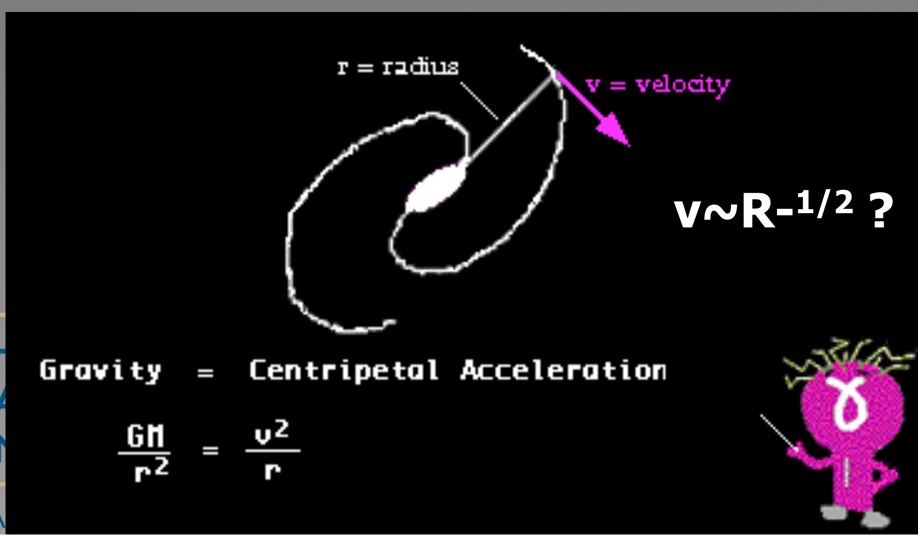
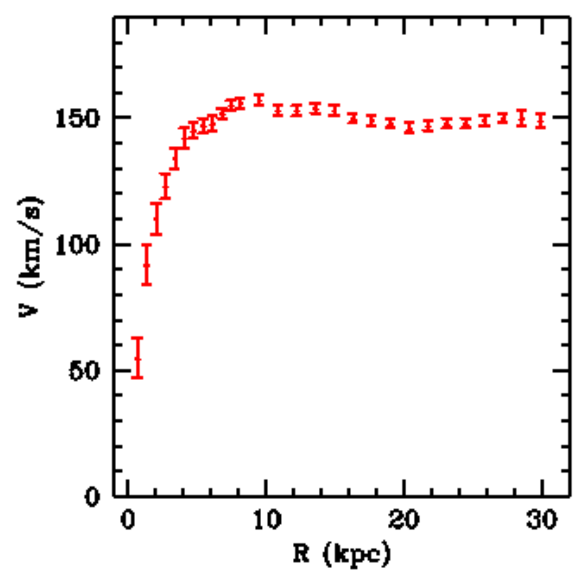
Observational Evidence of Dark Matter

- Fritz Zwicky (1933): Dispersion speed of galaxies in a Coma Cluster too high => `dynamic mass' is ~400 times larger than `luminous mass'
- S. Smith (1936): similar observation in Virgo Cluster; x200 excess in mass, can be explained by presence of additional matter between the galaxies
- Vera Rubin (1970): Measured rotation of spiral galaxies, discovered stars on the periphery revolve too fast around the galaxy center=> an invisible halo carries ~90% of galaxy mass



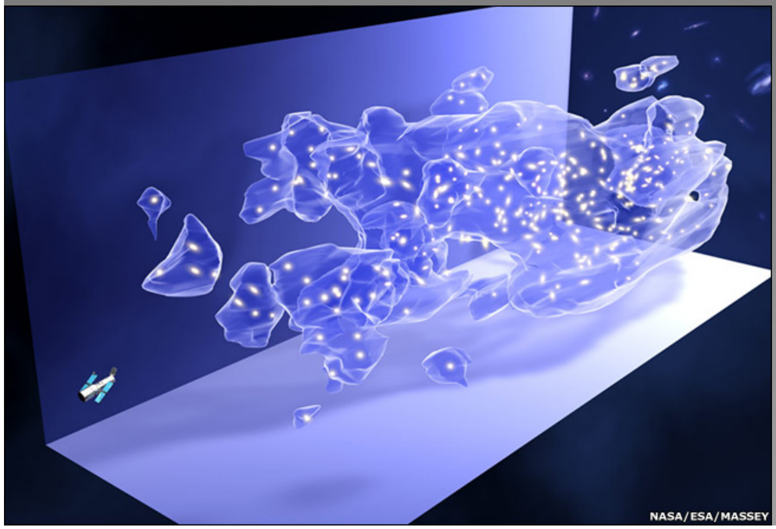
Galaxy NGC3198

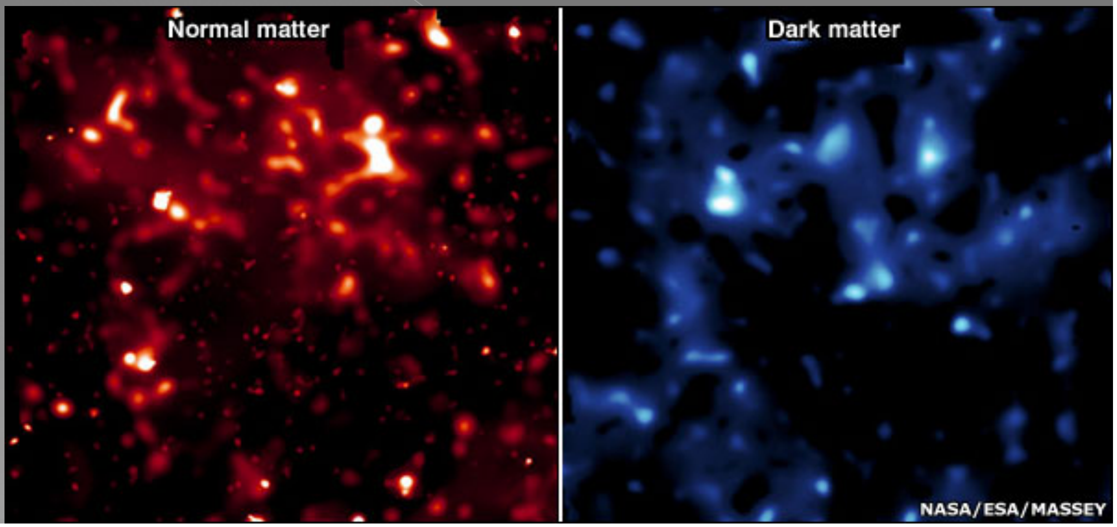


Gravitational lensing: 3D map of observable Universe from Hubble telescope

R. Massey et al, Nature 445, 286 (2007):
Dark Matter Maps Reveal Cosmic Scaffolding

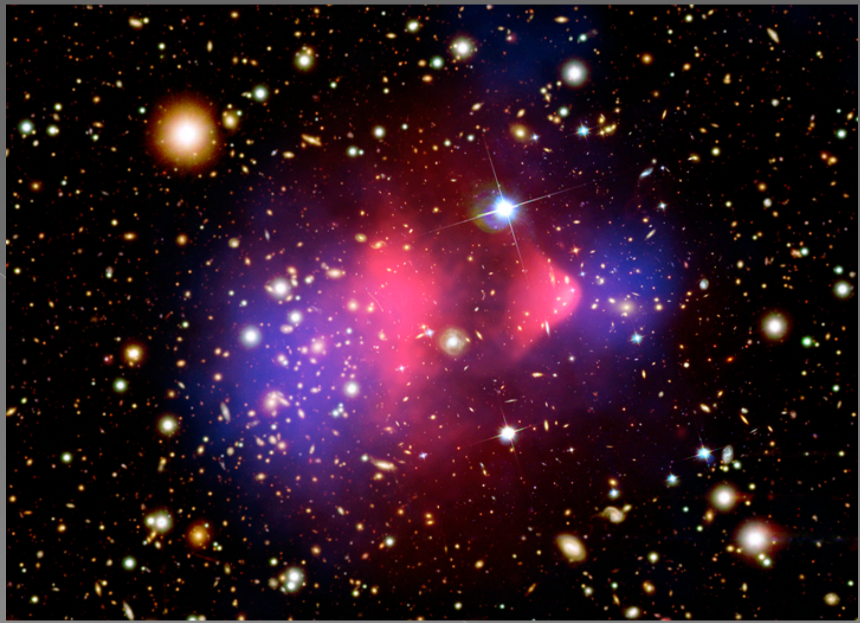
- Area of 1.6 deg^2
- ~1/2 million galaxies





Chandra X-ray observatory data' 06 (see chandra.harward.edu)

- Galaxy cluster 1E 0657-56 (`bullet cluster')
- Dark matter (blue) not slowed by the impact; while hot gas (red) is slowed/ distorted by drag force
- Separation during collision



http://chandra.harvard.edu/photo/2006/1e0657/1e0657_bullett_anim_lg.mov

More dark matter evidence (2007)

- Ring of dark matter formed in collision of two galaxy clusters

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What is Dark Matter?

- An unknown elementary particle that only weakly interacts with ordinary matter
  - May be light (~10^{-3} eV) “axion” (or axion-like particle, ALP)
  - May be heavy (~10^{6} eV) “WIMP”
    - Evidence reported April’ 08 by DAMA Collab., observed semi-annual variations of electromagnetic background in NaI detector
    http://neutrino.pd.infn.it/NO-VE2008/prog-NOVE.htm
    - CDMS (2009): two candidate events

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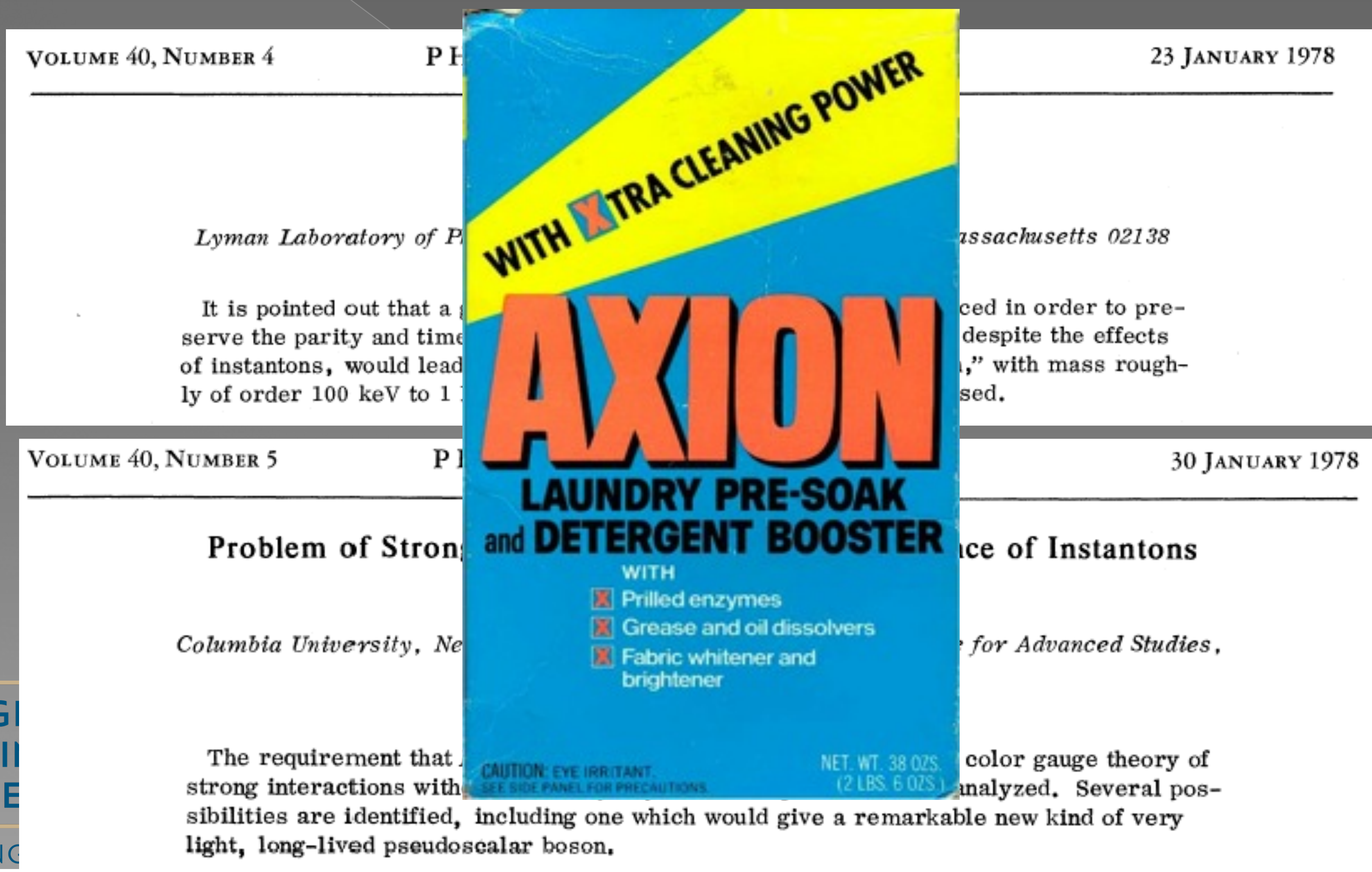
What is Dark Matter? Particle interpretation:
(Still unknown) elementary particles that interact only weakly with `normal' matter

One of the candidates: **Axion** - also addresses a *strong CP problem* in QCD

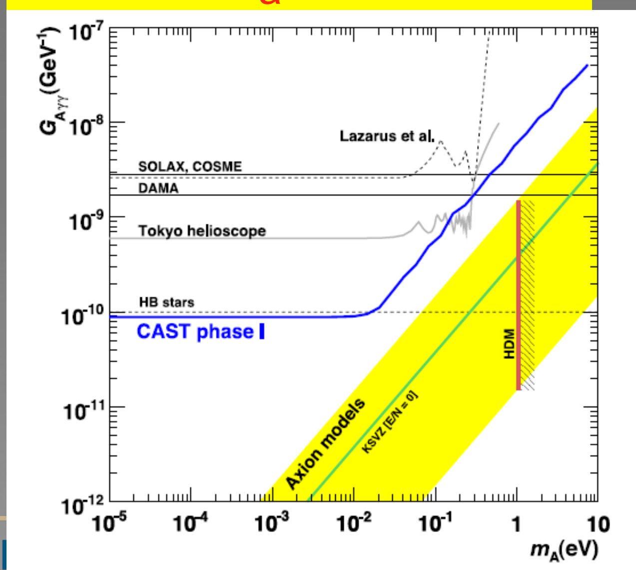


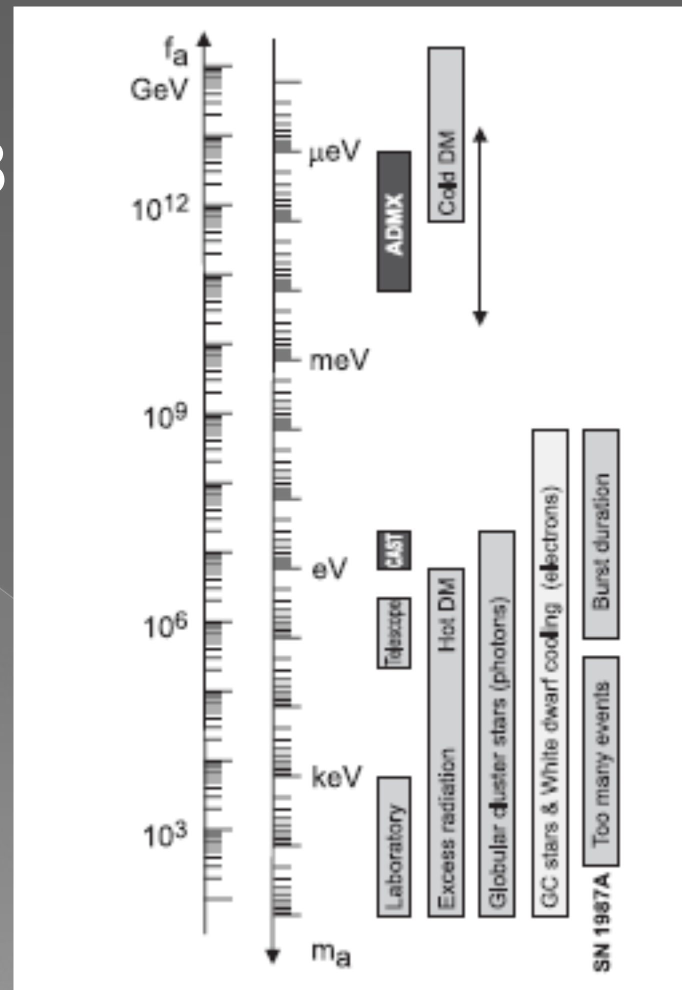
Open mass range for axions

The combination of accelerator searches, astrophysical, and cosmological arguments leaves open a search window

from PDG' 08

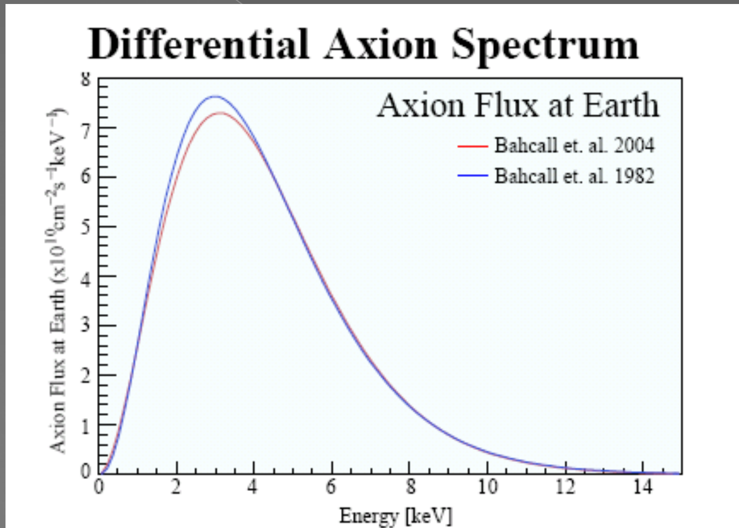
$10^{-6} < m_a < 10^{-3}$ eV





LIPSS at JLAB is a laser-based laboratory experiment that searches for axion-like particles with masses in the range of milli-eV

CAST experiment



Mean energy: $< E >= 4.2\,\mathrm{keV}$

Axion Luminosity:

$$L_a = 1.9 \times 10^{-3} L_\odot$$

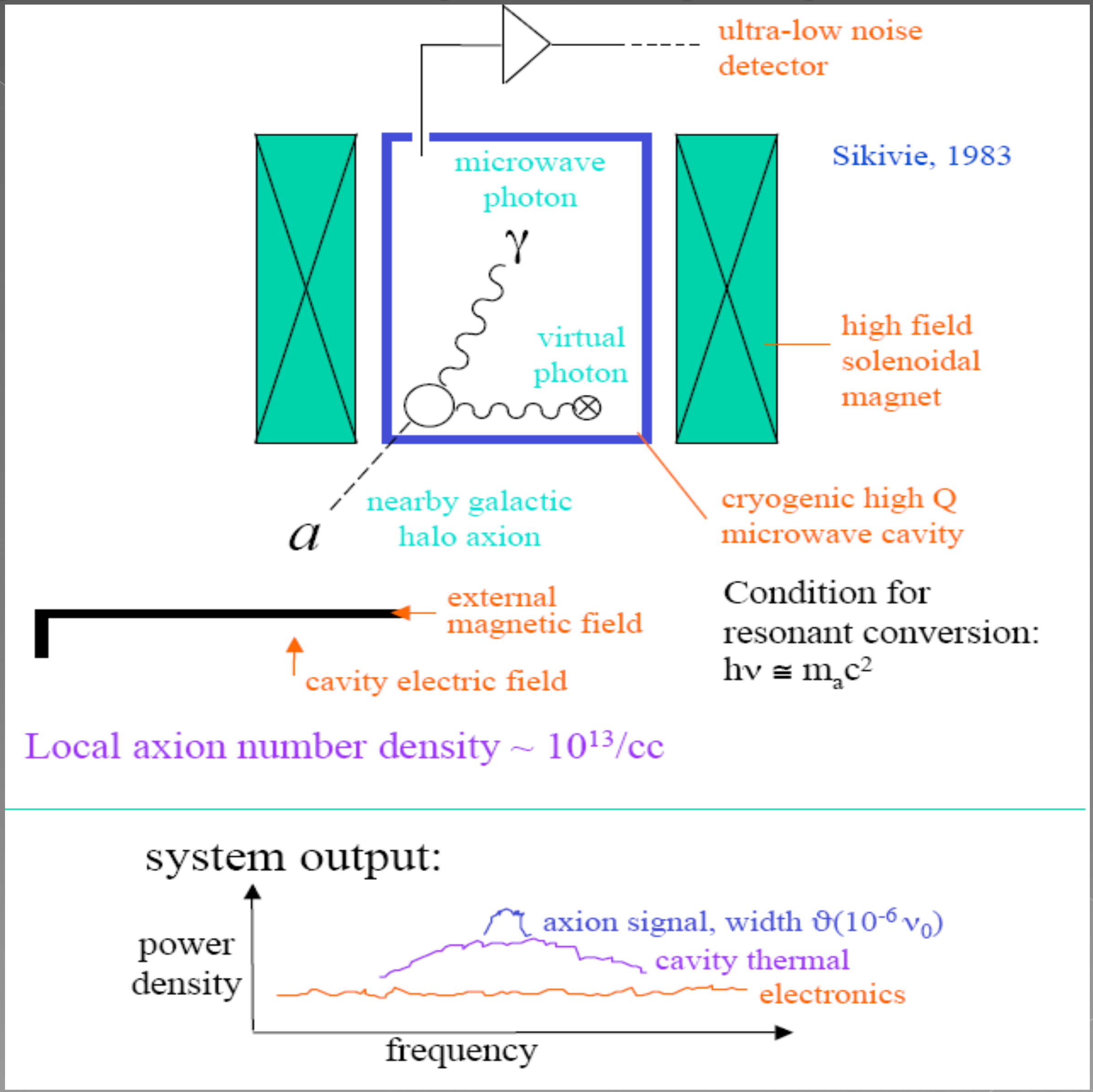
Axion flux: $\Phi_a = 3.8 \times 10^{11}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

Uses LHC prototype dipole, looks for axions from the sun regenerating photons in the x-ray region. K. Zioutas *et al.*, PRL 94, 121301 (2005)

Have seen no effect

microwave cavity technique

R. Bradley et al, Rev. Mod. Phys. 75, 777(2003)



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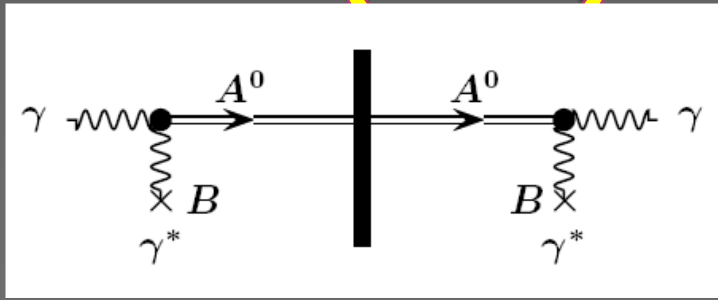
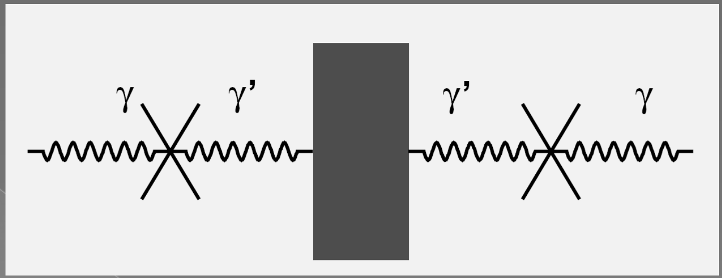
Photon Regeneration in `Light Shining through a Wall' (LSW)

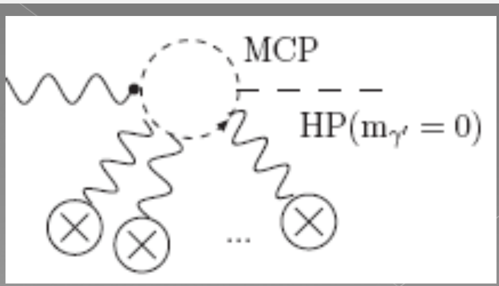
- Photon-axion conversion in presence of magnetic field



- Photon-(massive) paraphoton oscillation (no magnetic field)

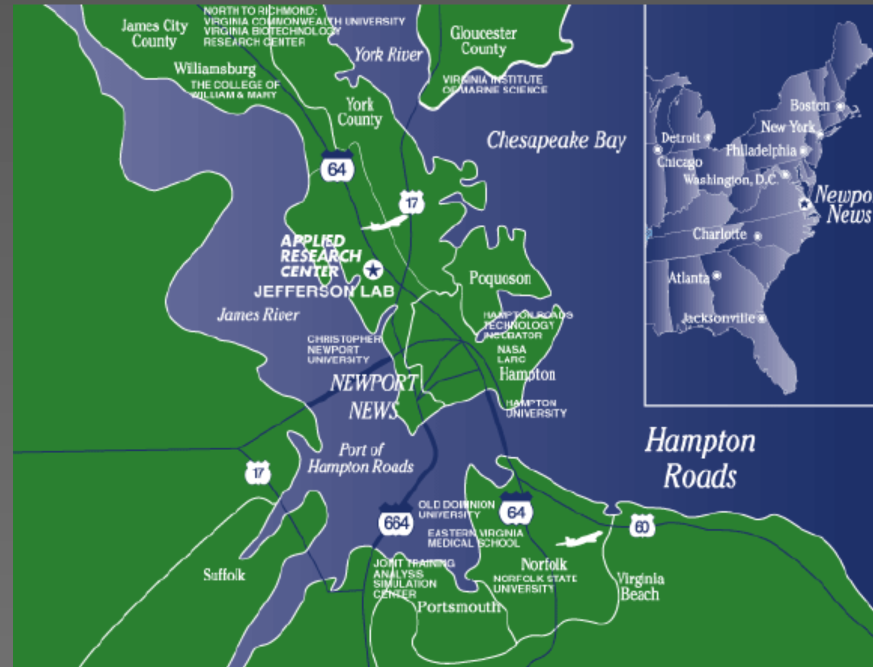


- Photon-(massless) paraphoton conversion in magnetic field via quantum loop of mini-charged particles (MCP)



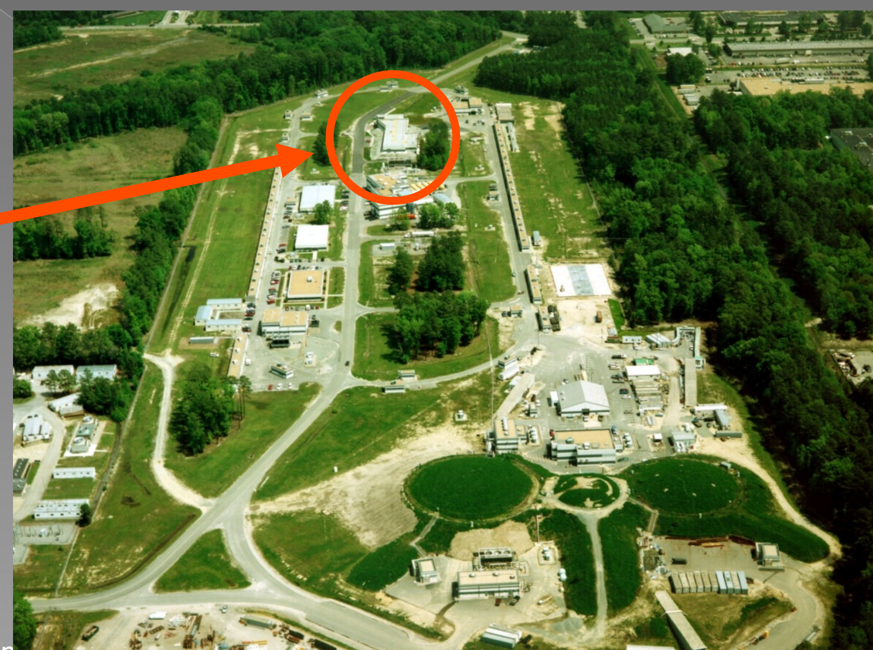
Experimental that use LSW: LIPSS(Jlab, this talk) , BFRT (BNL), BMV(LULI), GammeV (Fermilab), ALPS(DESY), OSCAR (CERN), PVLAS (INFN)

Jefferson Lab is Located in Newport News, Virginia



JLAB's Free Electron Laser

Produced up to 14kW of continuous light at 1.6 micron wavelength



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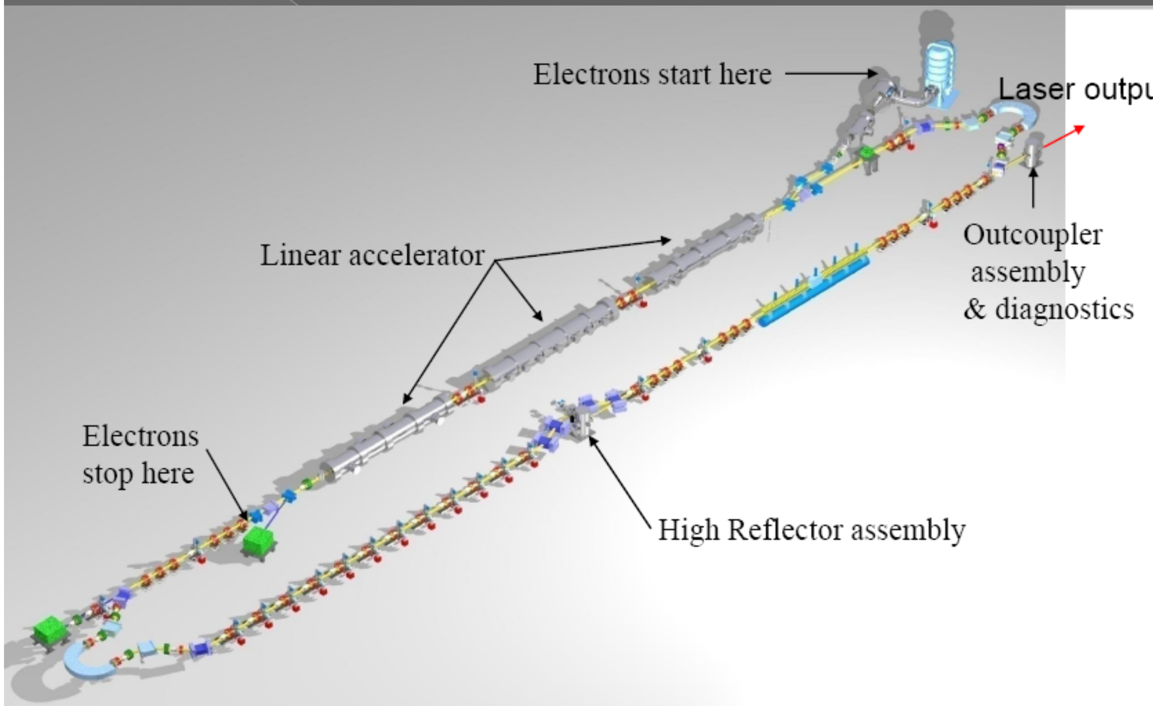
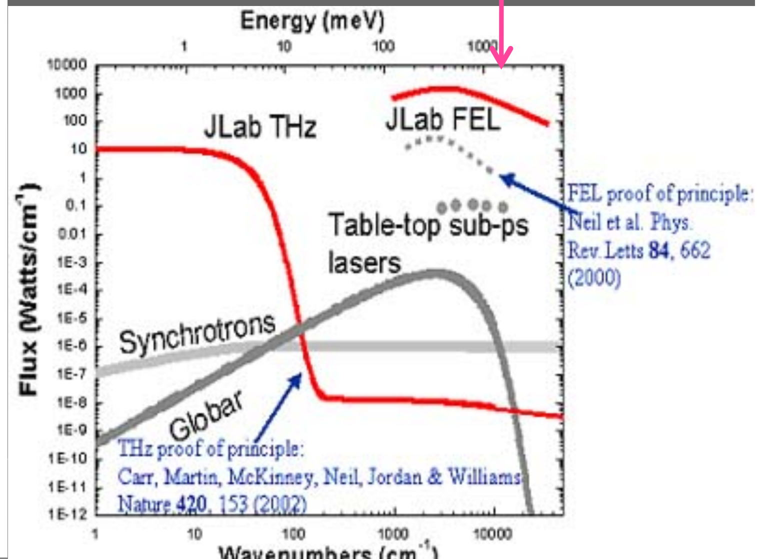
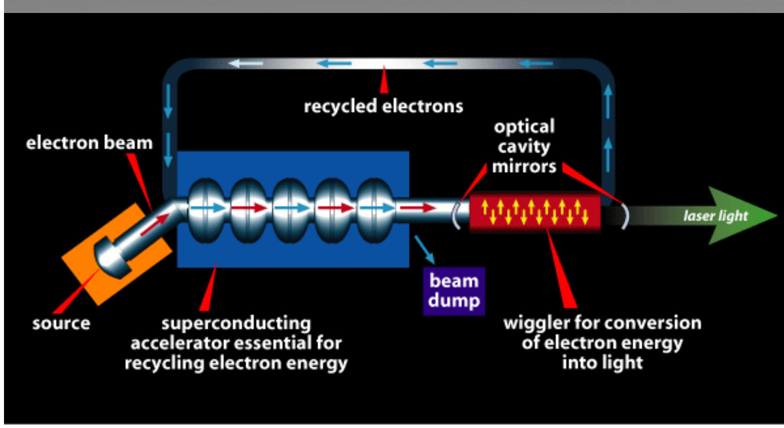
JLAB FEL: Used for LIPSS experiment



Accelerator is over 200 ft long

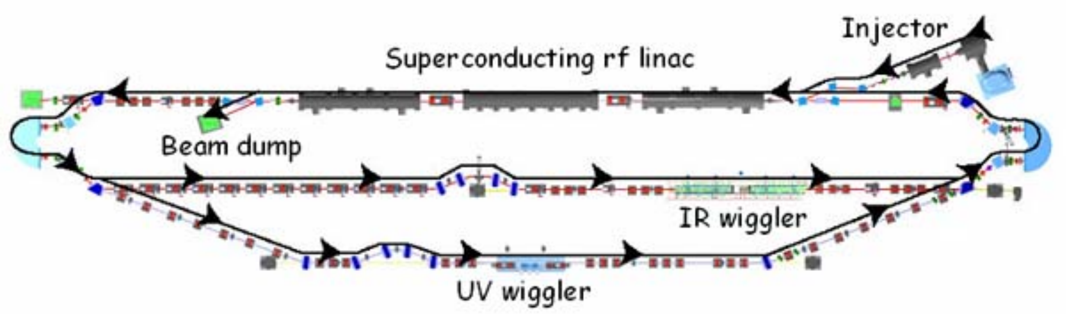
LIPSS IR run at 0.935 micron





- 150 fs wide pulses
- 75 MHz rep rate
- 100 % df
- 935. +/- 005 nm
- 200 watts avg power
- >99% linearly polarized

More info on JLAB FEL



Jefferson Lab FEL Output Light Parameters

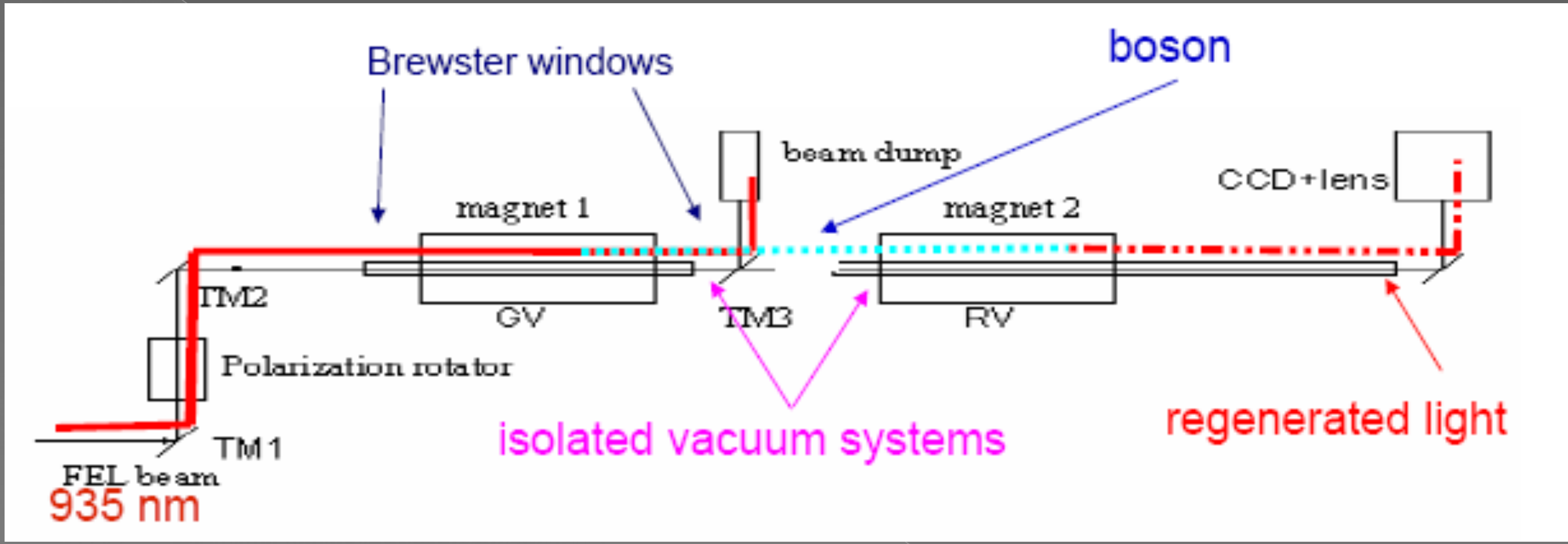
	IR Branch	UV Branch
Wavelength range (microns)	1.5 - 14	0.25 - 1
Bunch Length (FWHM psec)	0.2 - 2	0.2 - 2
Laser energy / pulse (microJoulesJ)	100 - 300	25
Laser power (kW)	> 10	> 1
Repetition Rate (cw operation, MHz)	4.7 - 75	4.7 - 75

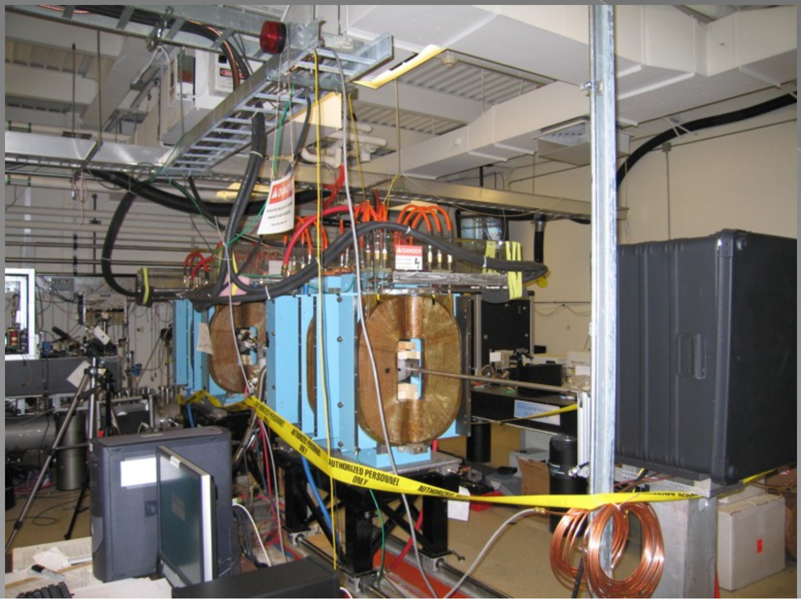
Jefferson Lab FEL Electron Beam Parameters

Energy (MeV)	80-200	200
Charge per bunch (pC)	135	135
Average current (mA)	10	5
Peak Current (A)	270	270
Beam Power (kW)	2000	1000
Energy Spread (%)	0.50%	0.13%
Normalized emittance (mm-mrad)	<30	<11
Induced energy spread (full)	10%	5%

See G. Neil et al., NIM A 557, 9 (2006); www.jlab.org/FEL

LIPSS experiment schematic





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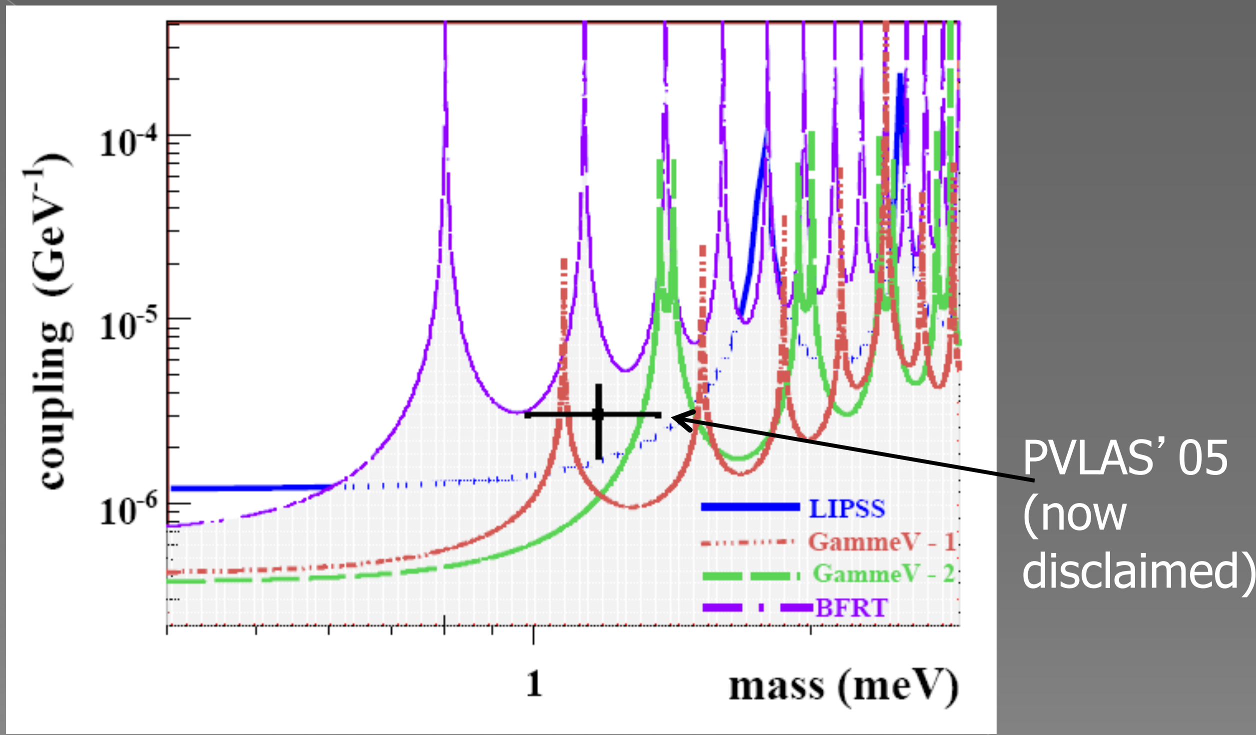
LIPSS Result on Axion-Like Particle

AA et al (LIPSS Collab), Phys Rev Lett 101, 120401 (2008)



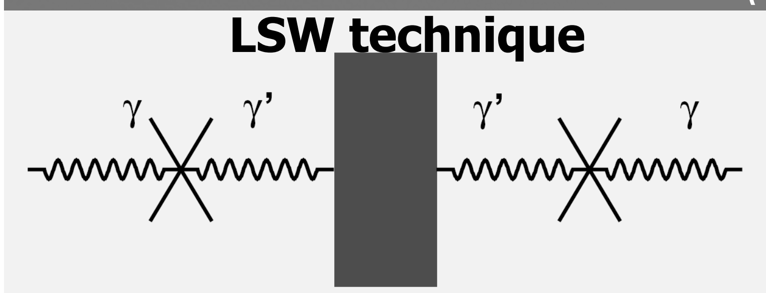
- No signal observed, regions above the curves are excluded by the experiment(s) at 95%CL
- Scalar coupling probed (`B^2' interaction)

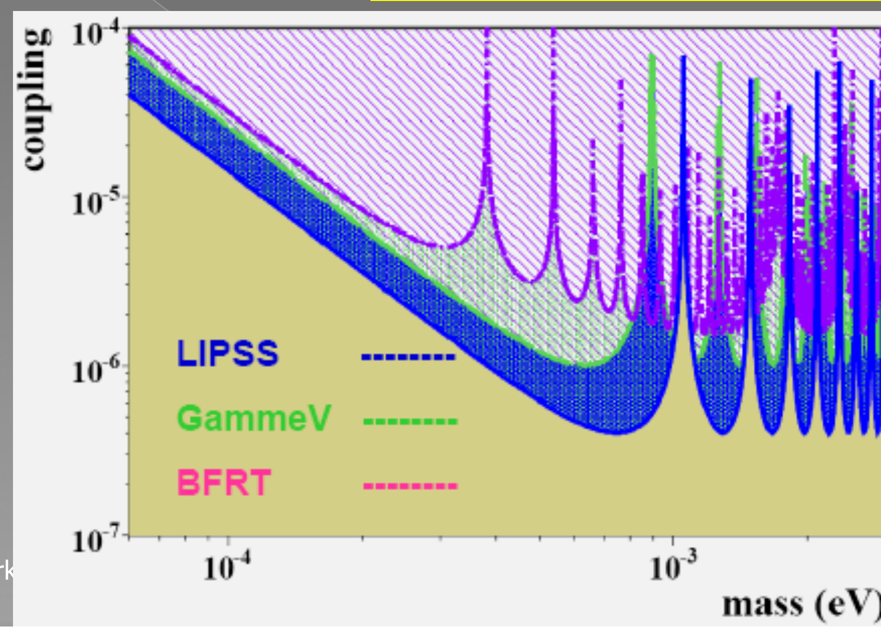
New Constraint on Photon Paraphoton Mixing

- Hidden-sector $U(1)_H$ symmetry: Paraphotons
  L.B. Okun, Sov Phys JETP 56, 502 (1982); B. Holdom, Phys Lett B 166, 196 (1986) "**Ho**ldom's **Bo**son" or HoBo
  - For the latest, see Ahlers et al, PRD 78, 075005 (2008) ; Abel et al, JHEP07, 124 (2008)

$$L_{mix} = -\frac{1}{2}\chi F^{\mu\nu} B_{\mu\nu}$$

$$P = 16\chi^4\left[\sin(\frac{\Delta k L_1}{2})\sin(\frac{\Delta k L_2}{2})\right]^2$$





- AA et al, Phys.Lett.B 679, 317 (2009) LIPSS observed no oscillations
- Best LSW constraints due to high initial photon flux
- Region above the curves excluded at 95% CL

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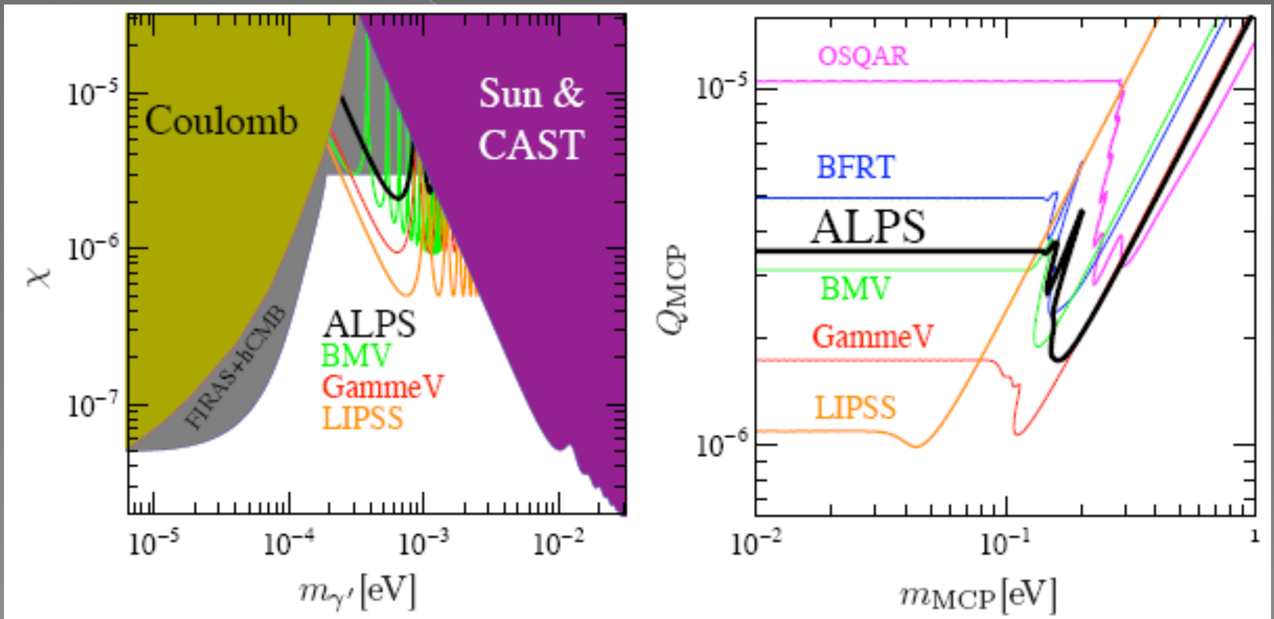
Photon-Paraphoton Mixing

- LIPSS results Phys.Lett. B679, 317(2009) vs other constraints:
  - Achieved the highest sensitivity in milli-eV mass range (plot compiled in arXiv:0905.4159)



- Also results in a new constraint on mini-charged particle (MCP) mass and charge, see formalism in Ahlers et al, PRD 78, 075005 (2008)

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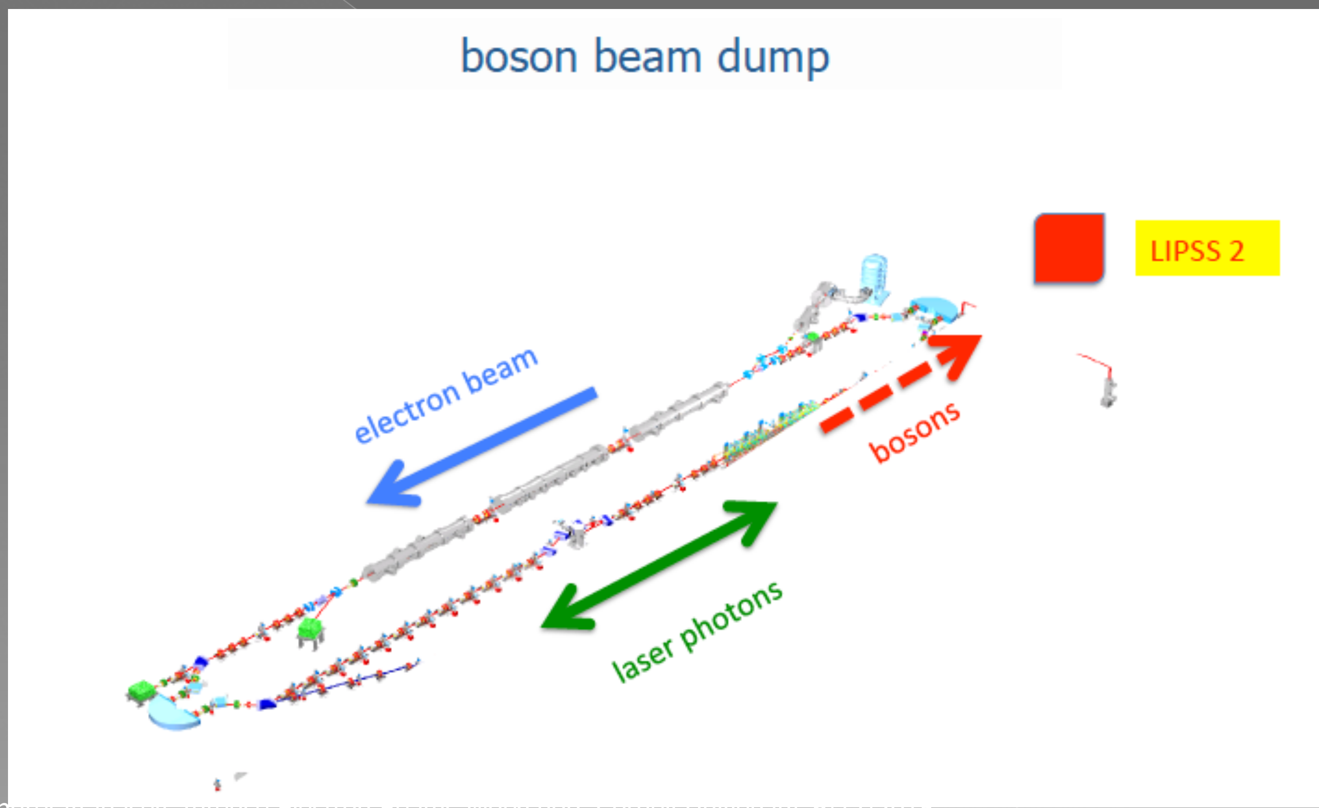
Low-mass Paraphoton Search

- Evaluated for JLAB FEL, see Baker's talk at Searching for a New Gauge Boson at Jlab, September 20-21, 2010

(mass < 25 keV)



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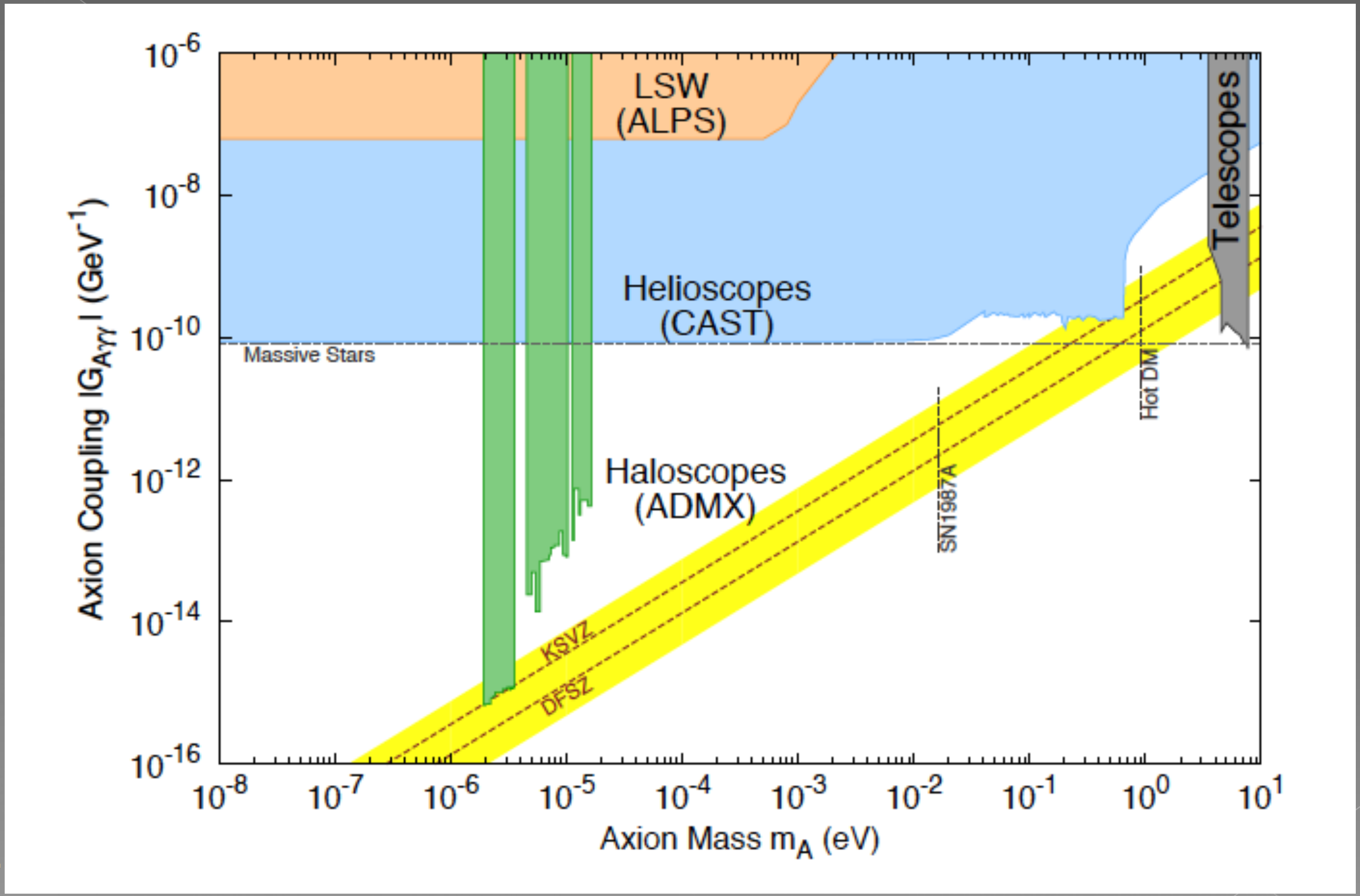
Axion Parameters (PDG14)



Combined Exclusion Ranges (PDG14)