ALP detection via resonant regeneration at CAST

A maybe not-so-crazy idea...

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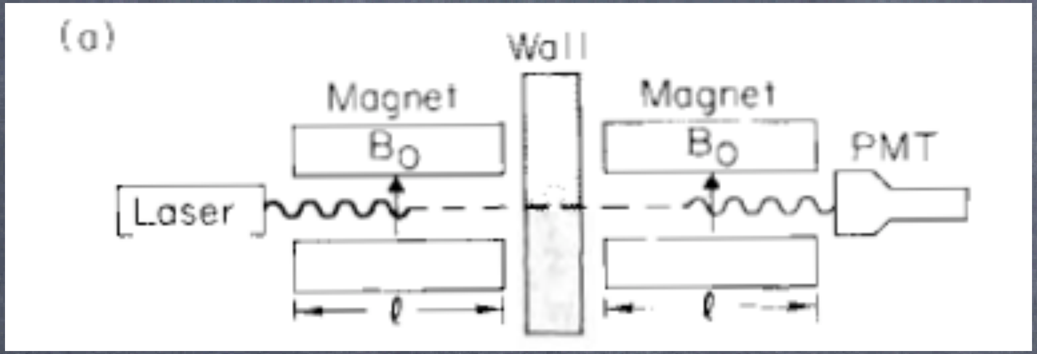
Summary

- The original idea
- The challenge(s)
- Dreams vs. reality
- Outlook

Photon regeneration

- The "experimentum crucis" to prove beyond reasonable doubt that one has seen ALPs is photon regeneration

- Originally proposed by Van Bibber et al., Phys. Rev. Lett. vol. 59, no. 7, (1987), p 759.



$$p_{0,reg} = \left[\frac{2\omega B_0}{M_a m_a^2} sin\left(\frac{m_a^2 L}{4\omega} \right) \right]^4$$

in vacuum and with $m_a \ll \omega$

- It is poetically known as "shining light through a wall". A better descriptive title could be "Axion production and photon regeneration", since strictly speaking also CAST produces regenerated photon from solar axions

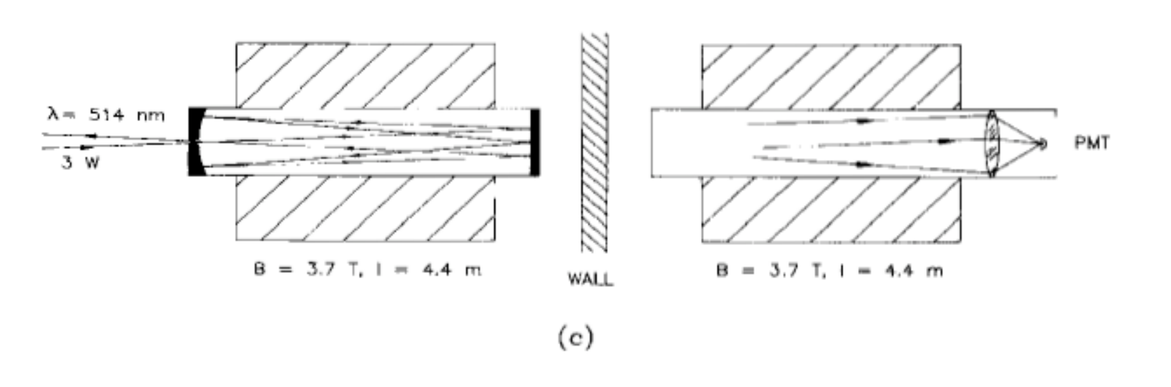
Photon regeneration through the ages...

I. The ancients...

an important improvement is already present: light path in the production region is amplified by means of a multipass cavity

$$p_{reg} = Np_{0,reg} = N\left[\frac{2\omega B_0}{M_a m_a^2} sin\left(\frac{m_a^2 L}{4\omega}\right)\right]^4$$

N is the number of passes in the cavity



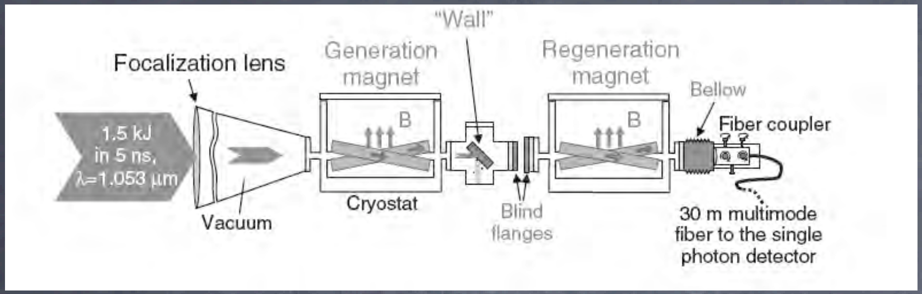
Ruoso et al., Zeitschrift für Physik C Particles and Fields (1992) vol. 56 (4) pp. 505-508

Cameron et al., Phys. Rev. D (1993) vol. 47 (9) pp. 3707-3725

Photon regeneration through the ages... (cont.)

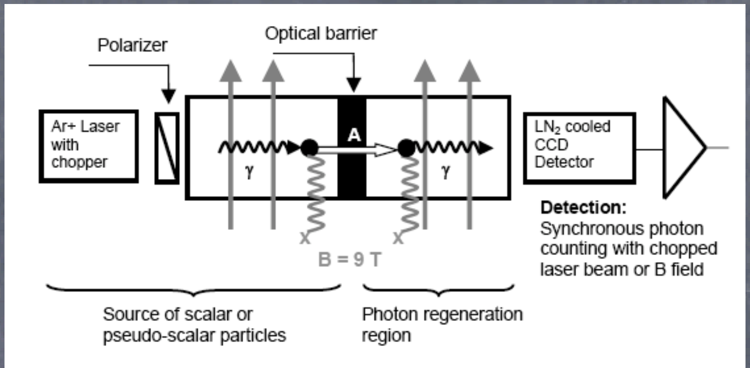
II.The contemporaries...

BMV@LULI



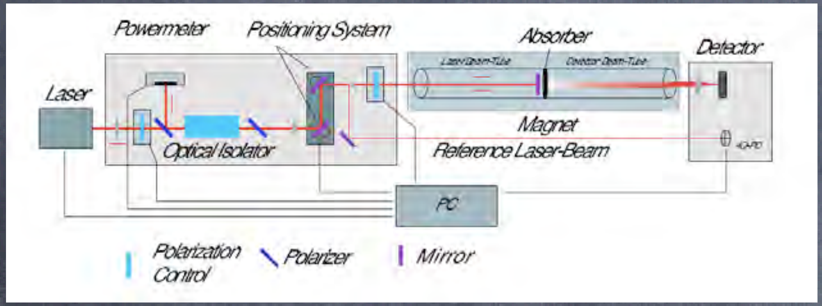
Robilliard et al, Phys. Rev. Lett. (2007) vol. 99 (19) pp. 4

OSQAR



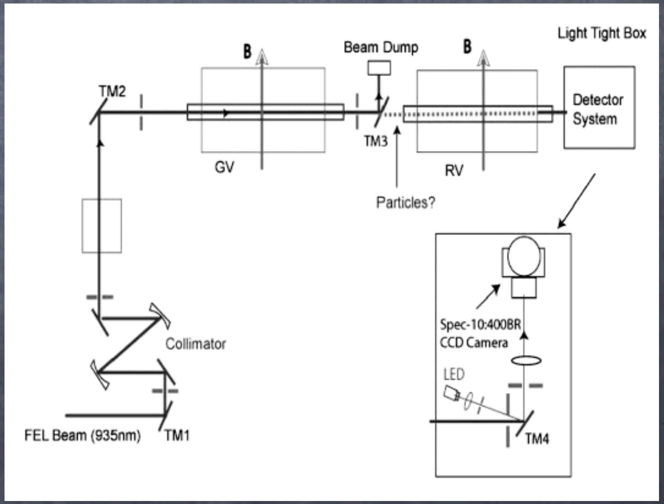
Pugnat et al., arXiv:0712.3362

ALPS



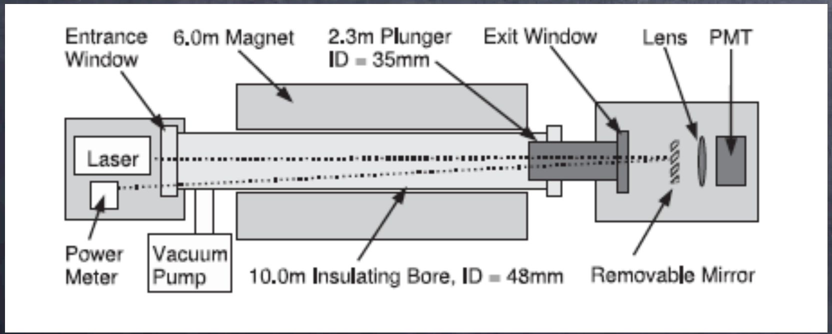
Ehret et al., arXiv (2007) vol. hep-ex

LIPSS



Afanasev et al., Phys. Rev. Lett. (2008) vol. 101 (12)

GammeV

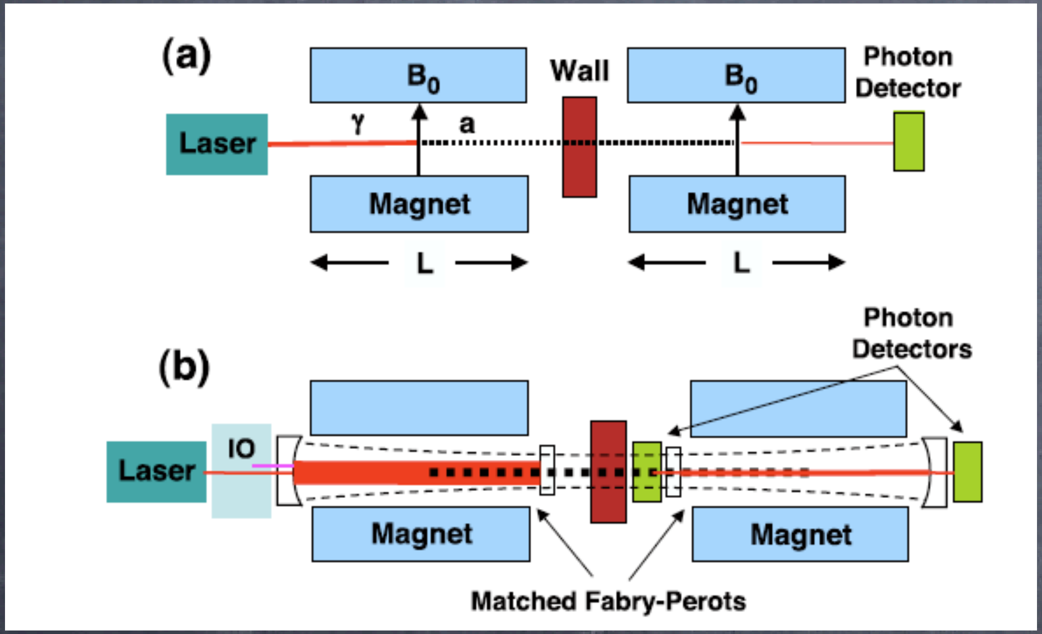


Chou et al., Phys. Rev. Lett. (2009) vol. 102, 030402

The next step: resonant regeneration

i. A Fabry-Perot cavity in the production magnet (left side of (b) in the figure) has the effect of multiplying the production probability by the finesse

ii. A second Fabry-Perot, frequency-matched to the first, placed in the conversion magnet (right side of (b)) multiplies the overall probability by the square of the finesse



Sikivie et al., Resonantly Enhanced Axion-Photon Regeneration, Phys. Rev. Lett. (2007) vol. 98 (17) pp. 4

normal regeneration

$$p_{0,reg} = \left[\frac{2\omega B_0}{M_a m_a^2} sin\left(\frac{m_a^2 L}{4\omega}\right)\right]^4$$

resonant production

$$p_{res.prod.} = (F/\pi)\left[\frac{2\omega B_0}{M_a m_a^2} sin\left(\frac{m_a^2 L}{4\omega}\right)\right]^4$$

resonant regeneration

$$p_{res.reg.} = 2\,(F/\pi)^2\left[\frac{2\omega B_0}{M_a m_a^2} sin\left(\frac{m_a^2 L}{4\omega}\right)\right]^4$$

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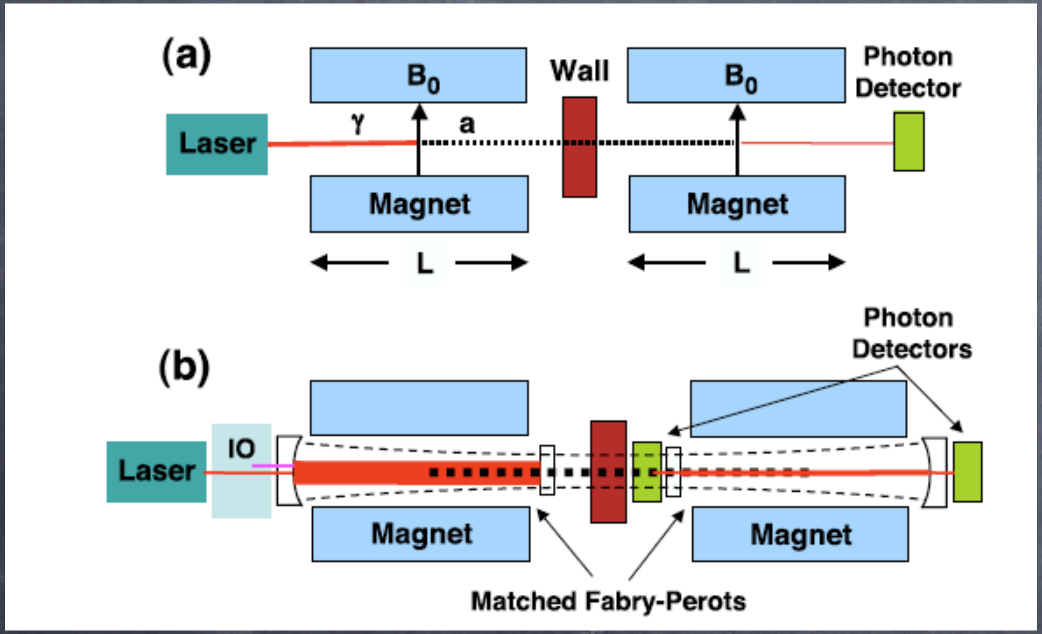

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Bounding the coupling

- Assume one measures for a time T with a detector having a given background DCR.
- If no signal is observed when the laser is on this corresponds to a SNR = 1
- Then inverse coupling M_a can be written as follows as a function of mass m_a

$$M_2 = 2^{\frac{1}{4}} \left(\frac{T\epsilon^2}{2 \cdot DCR} \right)^{\frac{1}{8}} \left(\frac{P_{laser}}{\omega} \right)^{\frac{1}{4}} \sqrt{F/\pi} \left(\frac{2\omega B}{m_a} \right) \sin \left(\frac{m_a^2 L}{4\omega} \right)$$

(production cavity with two detectors)

$$M_1 = \left(\frac{T\epsilon^2}{DCR} \right)^{\frac{1}{8}} \left(\frac{P_{laser}}{\omega} \right)^{\frac{1}{4}} \sqrt{F/\pi} \left(\frac{2\omega B}{m_a} \right) \sin \left(\frac{m_a^2 L}{4\omega} \right)$$

(production cavity with one detector)

The challenge(s)

I. Match two high finesse Fabry-Perots

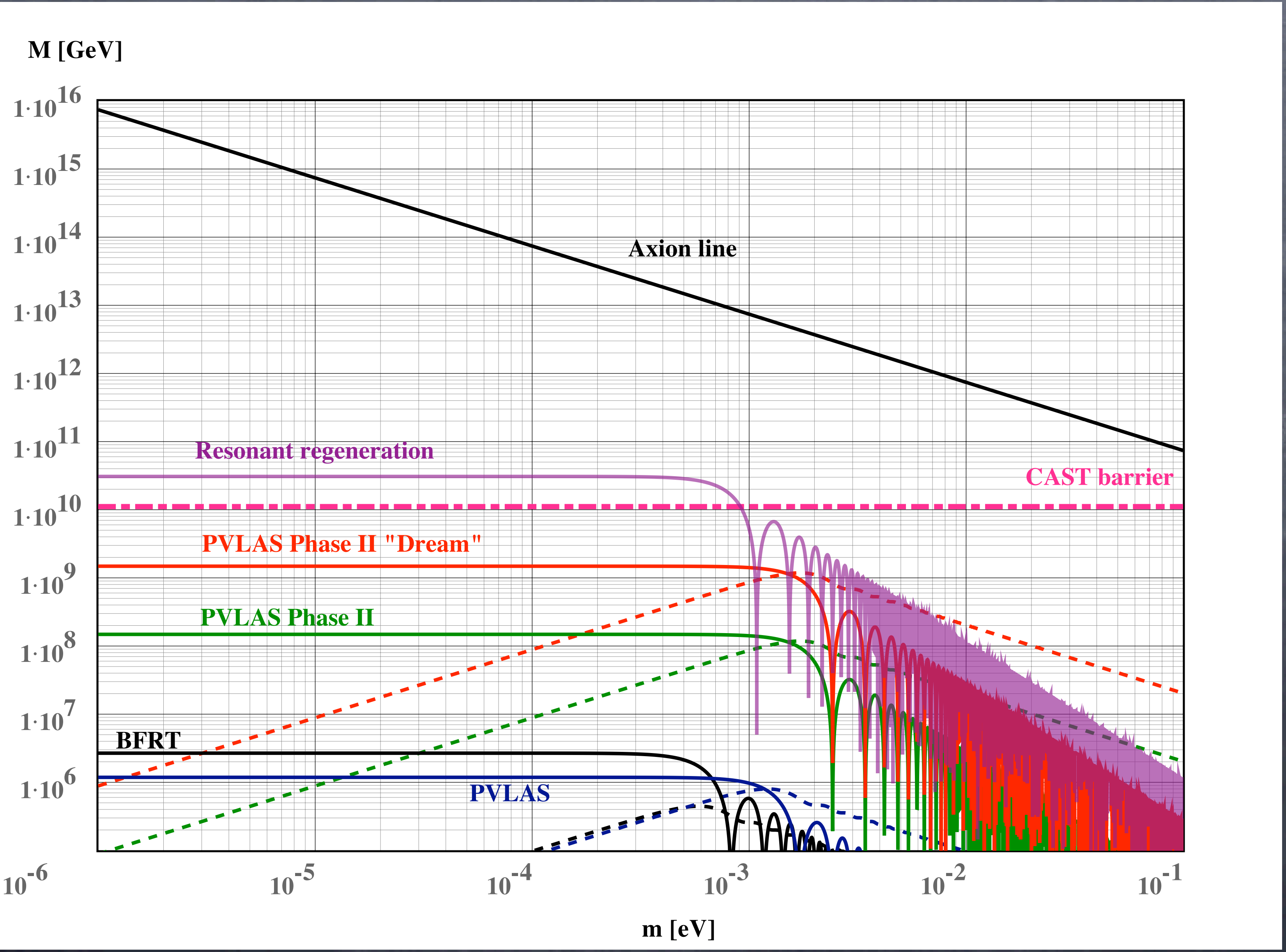
II. Low background detectors

III. High-power laser

IV. Accumulate statistics

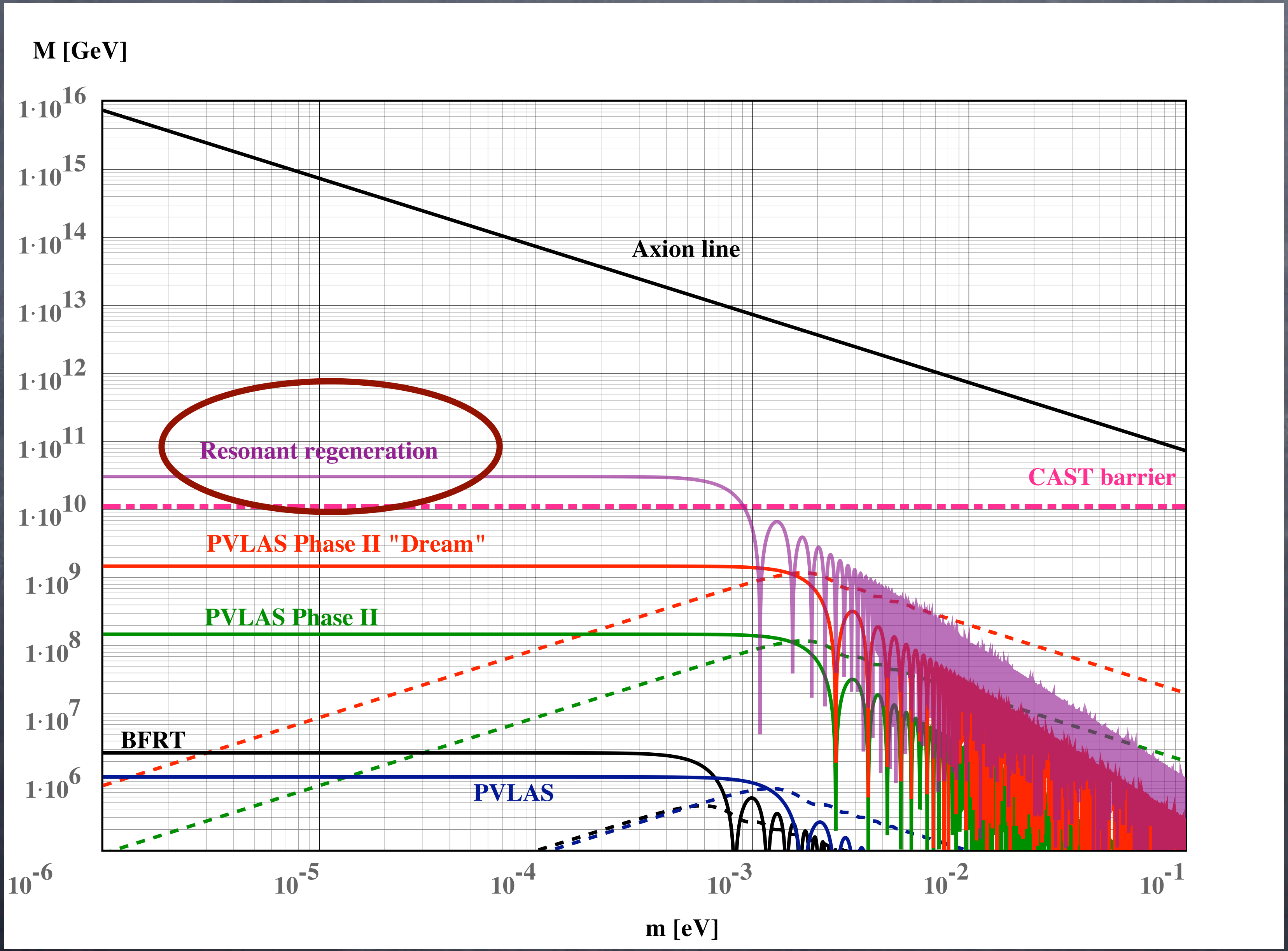
The reward

- Breaking the CAST barrier



The reward

- Breaking the CAST barrier



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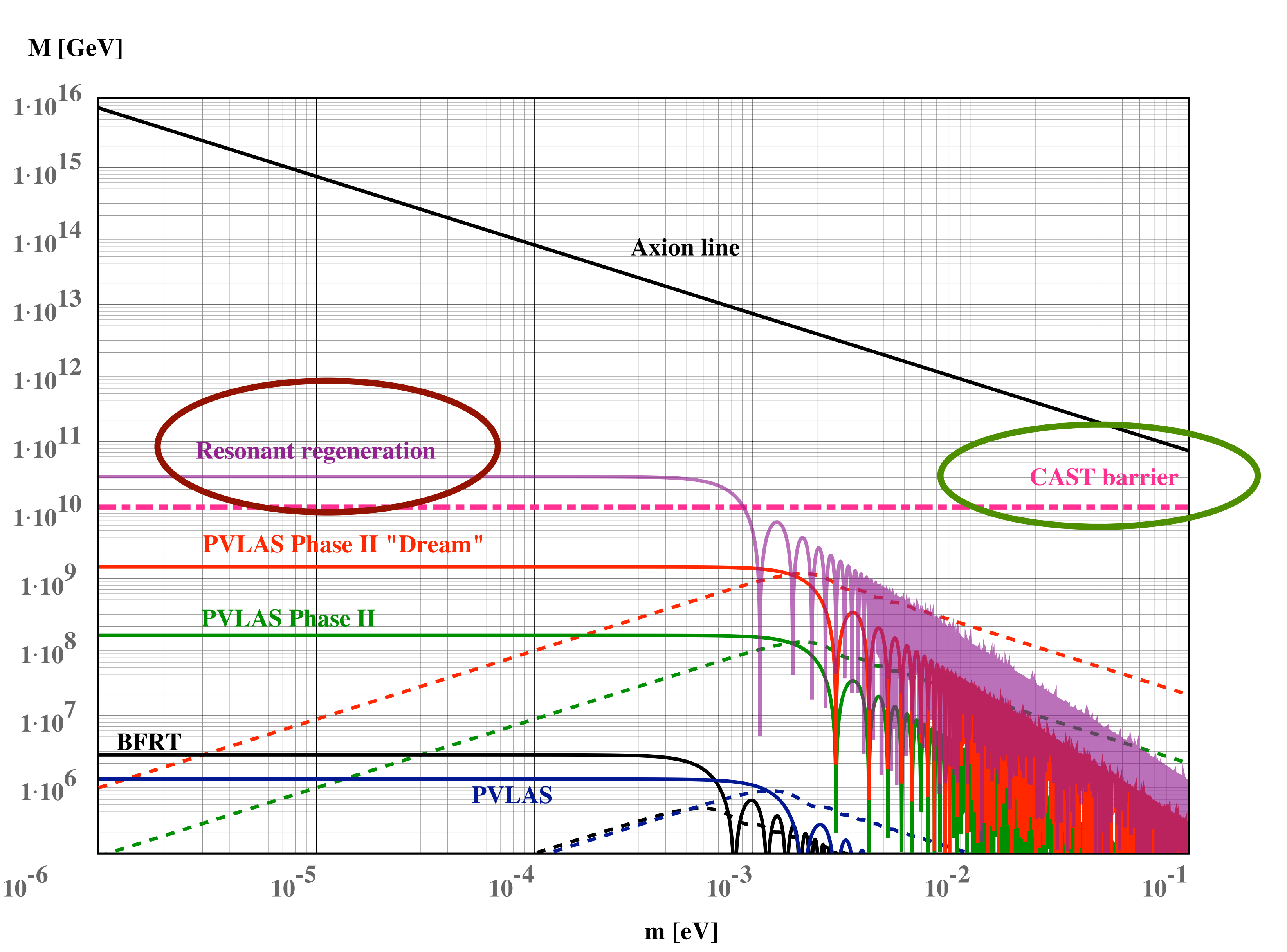
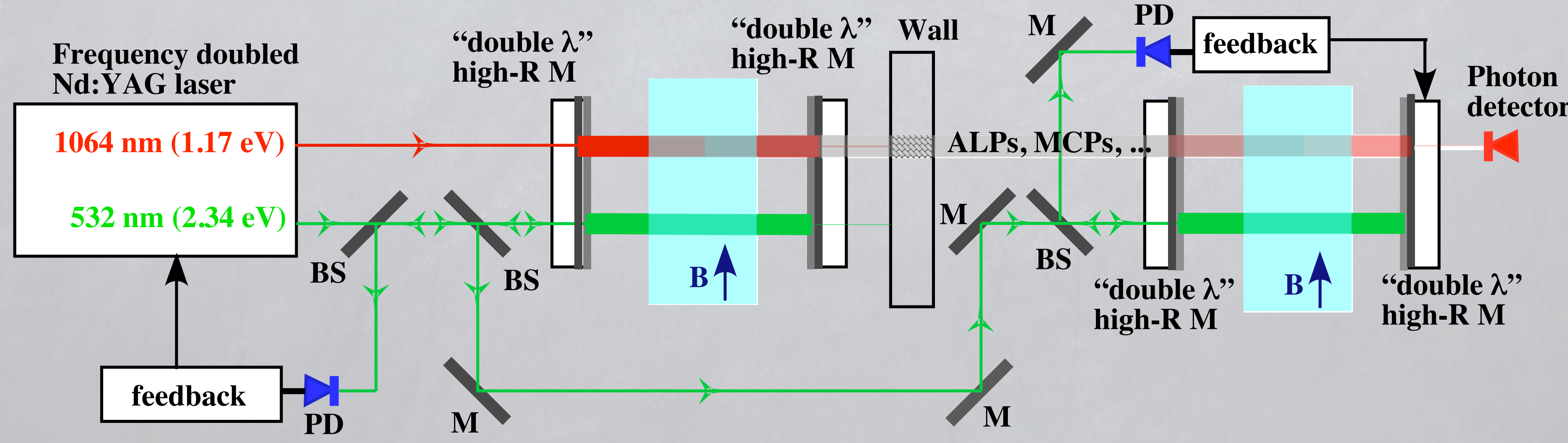


Challenge I - matching two cavities

- Frequency doubled Nd:YAG laser emitting two mutually coherent beams at different wavelengths, 1064 nm and 532 nm
- Two "identical" Fabry-Perot cavities made with "double λ" mirrors coated for high reflectivity at the two laser wavelengths
- Use "green" low-power beam to lock and match cavities
- Use "IR" high-power beam to produce and detect ALPs



Challenge II - low background detector

- Common problem of ALP search experiments
- In CAST -> coverage of the visible part of the spectrum
  - started with a PMT and an APD
  - will move to LN2-cooled APD
- Resonant regeneration measurements can begin with a cooled APD (DCR?, maybe 10^{-2} Hz, BaRBE will find out)
- Dream detector: a TES (no background!)

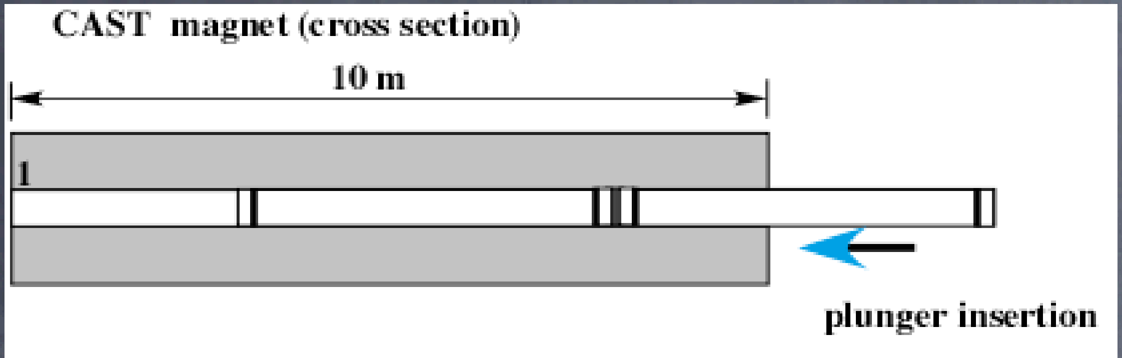
Challenges III-IV : laser power and statistics

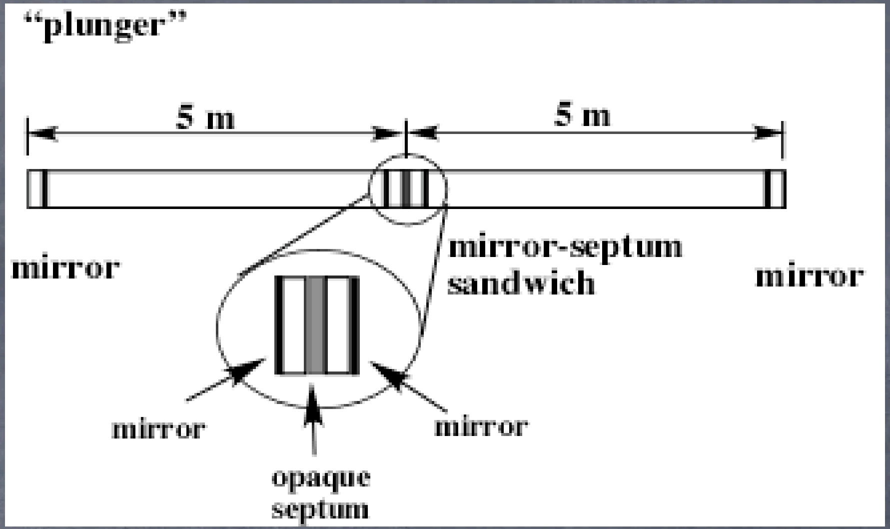
- Lasers up to 10 W CW in the IR -> commercially available (e.g. Innolight - Hannover)
- 100 W IR and above -> look at the VIRGO and LIGO experience
  - 100 W should be within reach and will not thermally stress the optics
  - above 100 W things get harder, but feasible
- Statistics: remotely controllable apparatus with large duty cycle

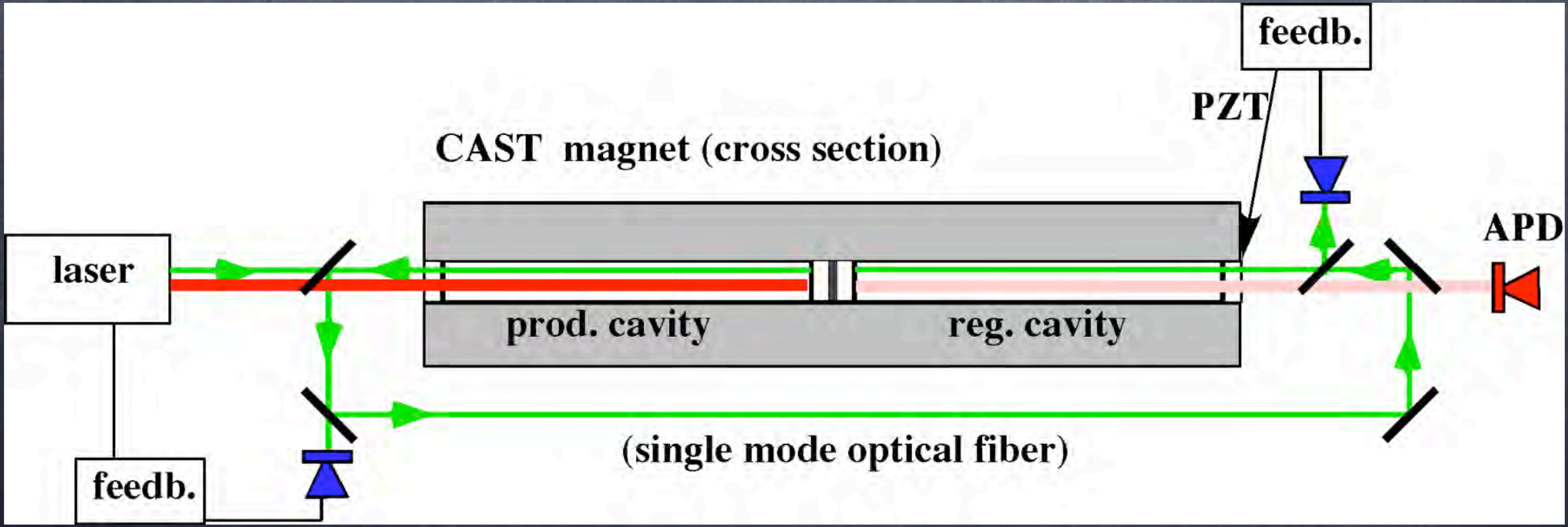
Dreams

- Can CAST offer a solution, at least in our dreams?
- YES!
  - 10 T, 10 m long magnet
  - potentially large duty cycle
  - good laboratory environment and support
  - detector experience

Schematic of resonant regeneration at CAST







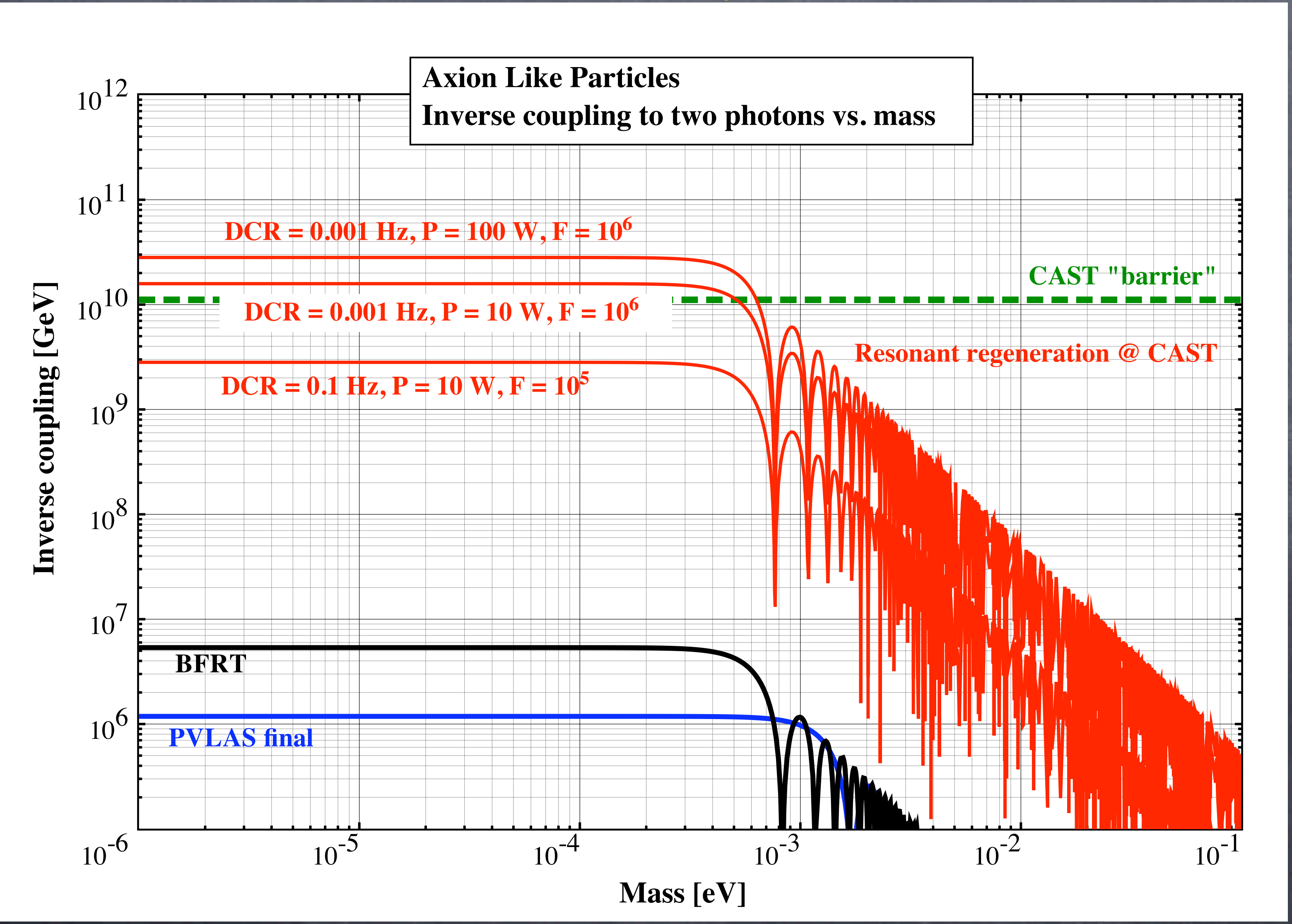
Reality check

- Experimental parameters (@CAST): from reality to dream

	Available	Desirable	Dream
Det. efficiency	0.5	0.5	0.5
Meas. time [s]	$8.64 \cdot 10^6$	$8.64 \cdot 10^6$	$8.64 \cdot 10^6$
DCR [Hz]	0.1	0.001	0.001
Lase power [W]	10	10	100
Photon energy [eV]	1.17	1.17	1.17
Cavity Finesse	100000	1000000	1000000
Field intensity [T]	10	10	10
Cavity length [m]	5	5	5

Dreams vs. reality

- Reach in the M-m plane



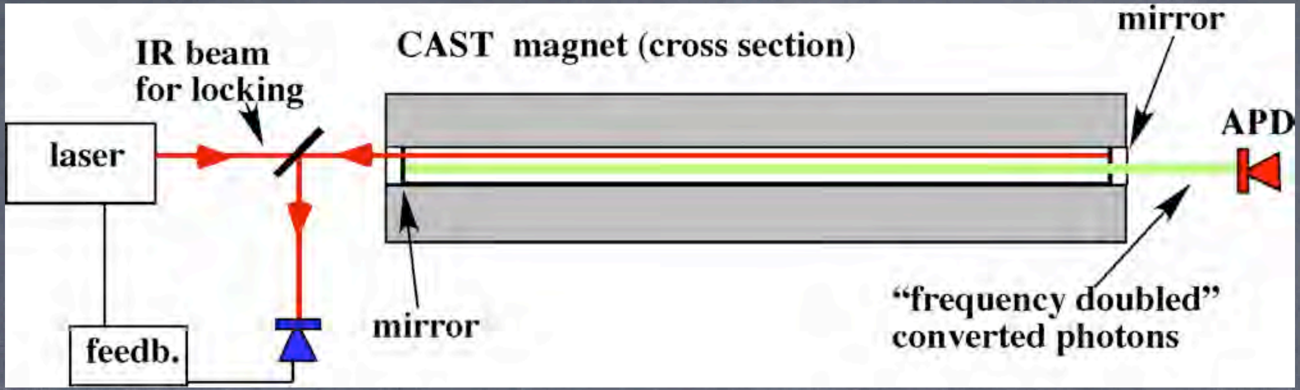
Outlook

- Is it worthwhile?
  - It is the only way to make purely laboratory bounds competitive with astrophysics-based bounds
  - Better coverage of the parameter space means larger discovery potential
- What is needed to start
  - a dedicated CAST magnet bore
  - 10 W laser
  - careful design
  - detector and optics work
  - interested researchers
- Possible timing
  - the Trieste group is applying for Italian Ministry funds to build a table-top pilot resonant regeneration set-up -> timeline: 2 years
  - the Trieste group will test a cooled APD detector system for "visible CAST" -> timeline: 6 months-1 year

Cavity enhanced ALP-photon reconversion in the visible

- The principle of resonant conversion can be applied to the current CAST search for solar axion
- Advantages
  - conversion rate in the magnet is multiplied by the finesse
- Drawbacks
  - search bandwidth limited by the cavity linewidth (decreases with increasing finesse)
  - needs a dedicated CAST magnet bore

Schematic



- Cavity mirrors placed in chambers at opposite sides of the magnet to form a cavity
  - each mirror in vacuum and equipped with 4-axis remote motion control
- Primary IR beam is used to lock the laser to the cavity with the Pound-Drever-Hall technique -> the laser frequency will follow the cavity frequency
- Photons from ALPs having an energy double the energy of the locking beam will resonate, and the conversion probability will increase by F/π