Raising WISP production rates by use of optical resonators

Speaker:

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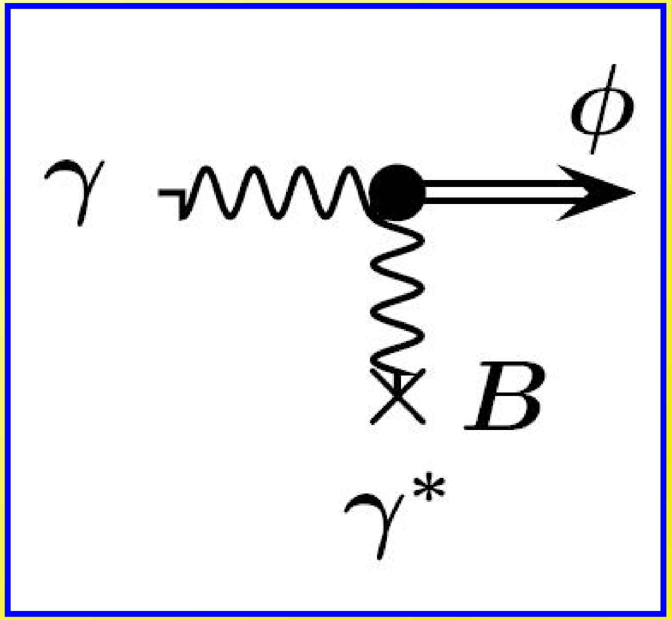
(for the ALPS team)

Raising WISP production rates by use of optical resonators

- **Basics**
  - WISPs/axions
  - Optical resonators / cavities
- **Regeneration experiments with cavities**
  - ALPS and others
  - ALPS status (cavity concerns)
  - Limitations of cavity enhanced production power

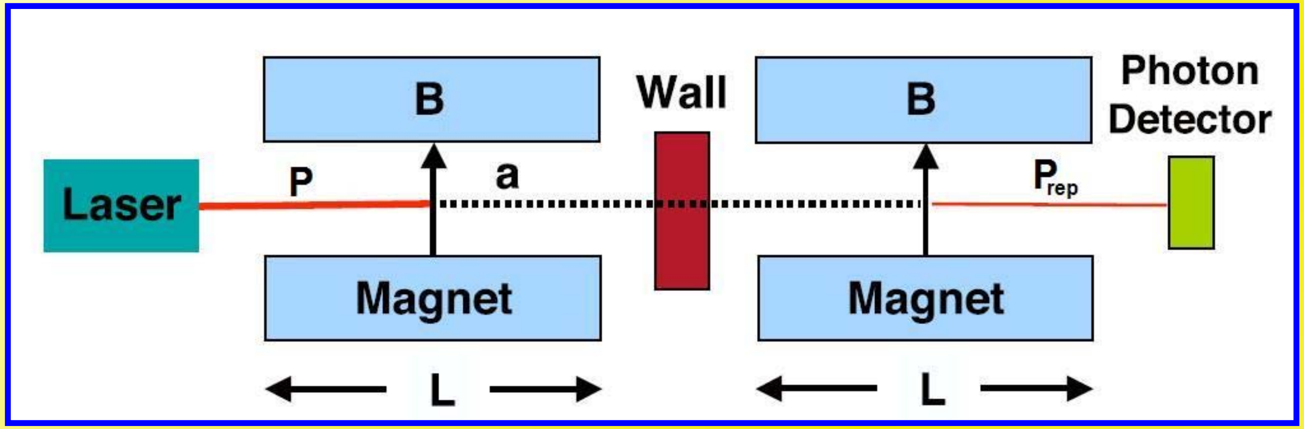
WISP production



[Letter-of-Intent for the ALPS experiment, 2006]

- WISPs = weakly interacting sub-eV particles
  - Nearly no mass interaction
- ALPS and similar: light photons coupling to B-/E-field
  - E.g. axions

Light reproduction experiment

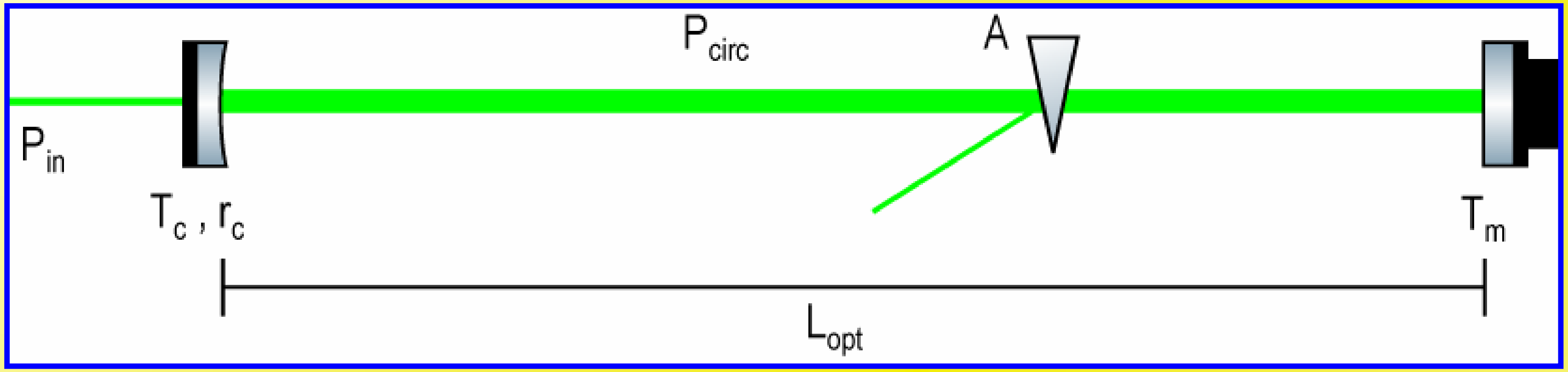


[Letter-of-Intent for the ALPS experiment, 2006]

- Re-/production area seperated by wall
  - No light passing
- Reproduced power proportional to incident power

$$\frac{P_{rep}\,[\mathrm{W}]}{h\,\nu} = \frac{1}{16} \cdot \left(\frac{195.3}{197.3} \cdot g\,[\mathrm{GeV}^{-1}] \cdot L\,[\mathrm{m}] \cdot B\,[\mathrm{T}] \right)^4 \cdot \left(\frac{\sin(\frac{1}{2}\,\Delta k\,L)}{\frac{1}{2}\,\Delta k\,L} \right)^4 \cdot \frac{P\,[\mathrm{W}]}{h\,\nu}$$

Optical resonator/Cavity



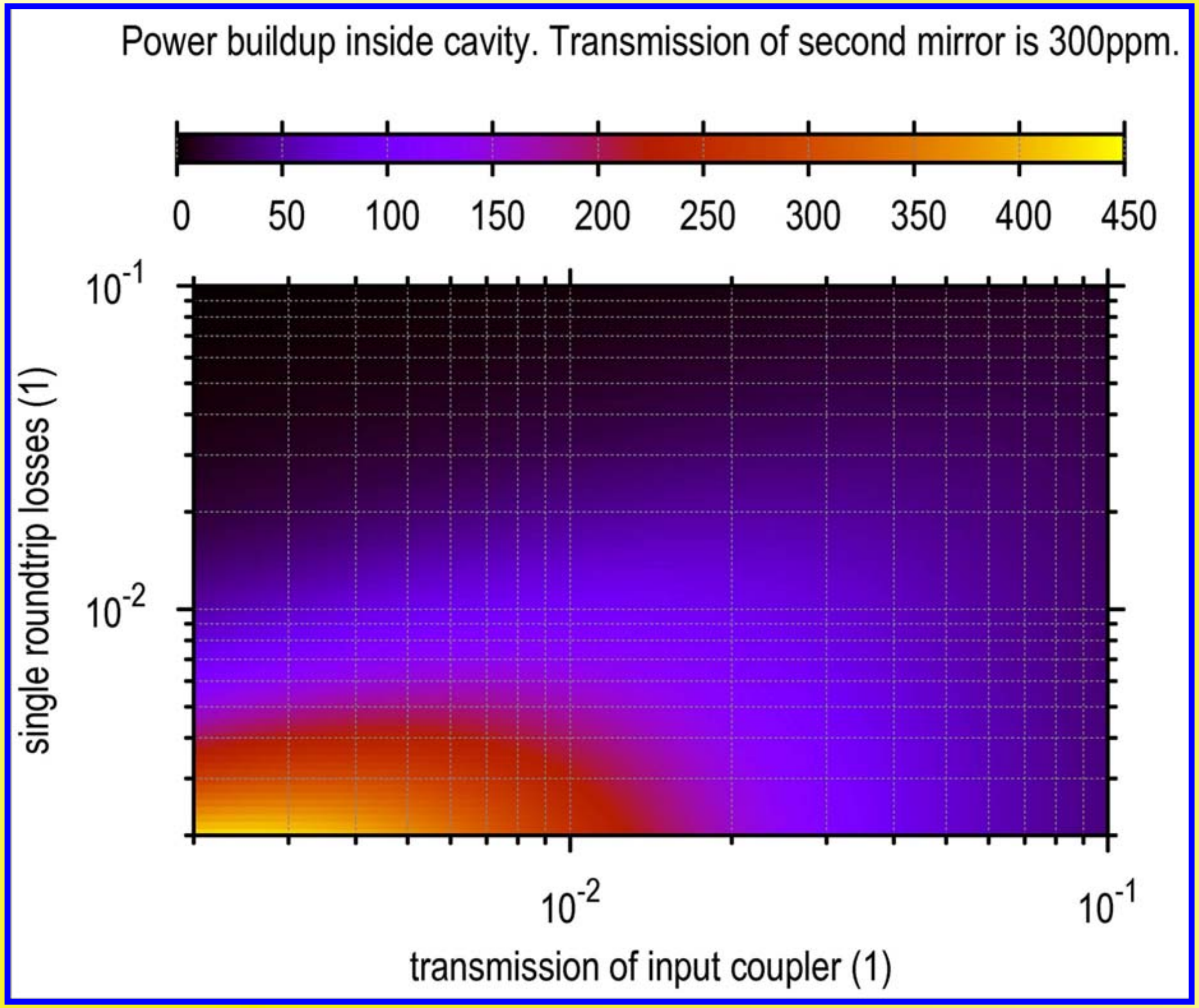
- Coherent superposition enlarges light field between mirrors

    -> Power buildup $PB = P_{circ}/P_{in}$

- Phase of light must reproduce itself after each roundtrip

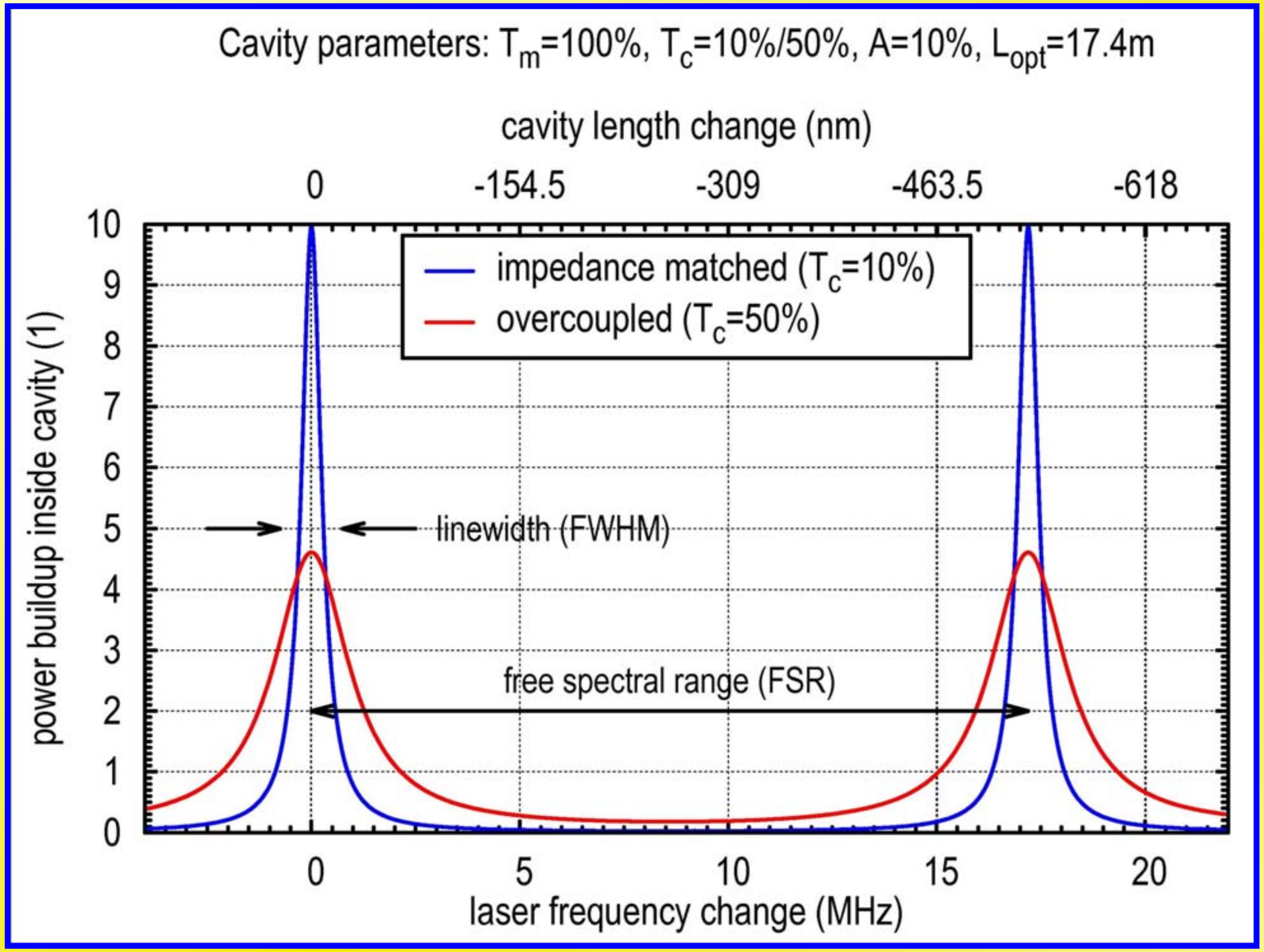
    -> Cavity length must be stable in time

Dependencies of PB



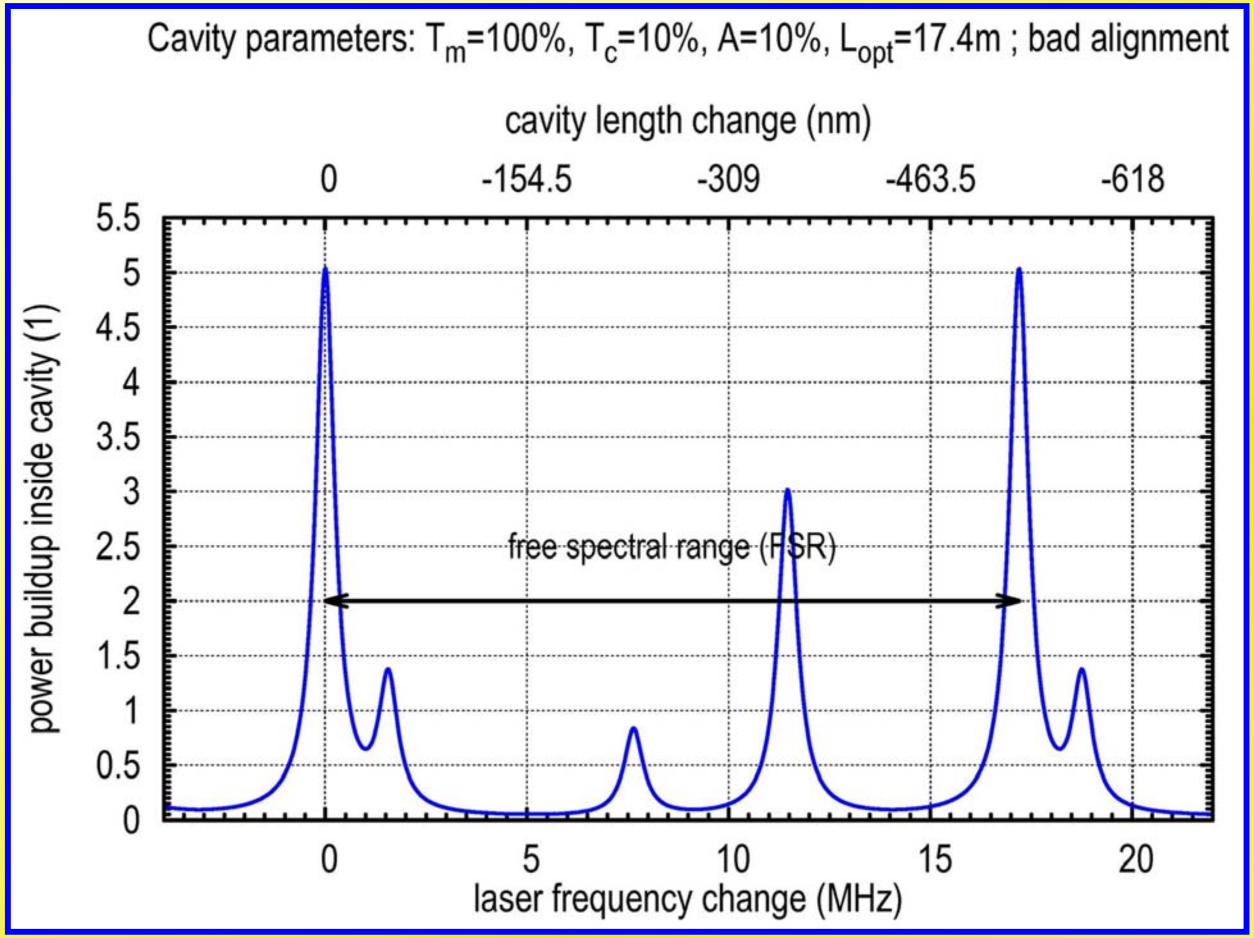
- Power buildup governed by:
  - Internal losses
  - Mirror transmission
- Current ALPS status:
  - Internal losses ca. 4%
  - Mirror transmission ca. 2%

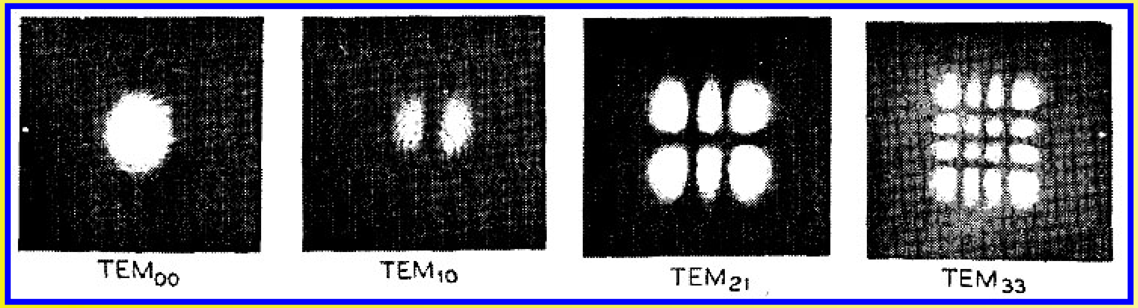
Resonance in frequency space



- Periodic resonances with large power buildup
- BUT:
  - Impedance matching required
  - Only sub-nm(!) length changes allowed

Alignment



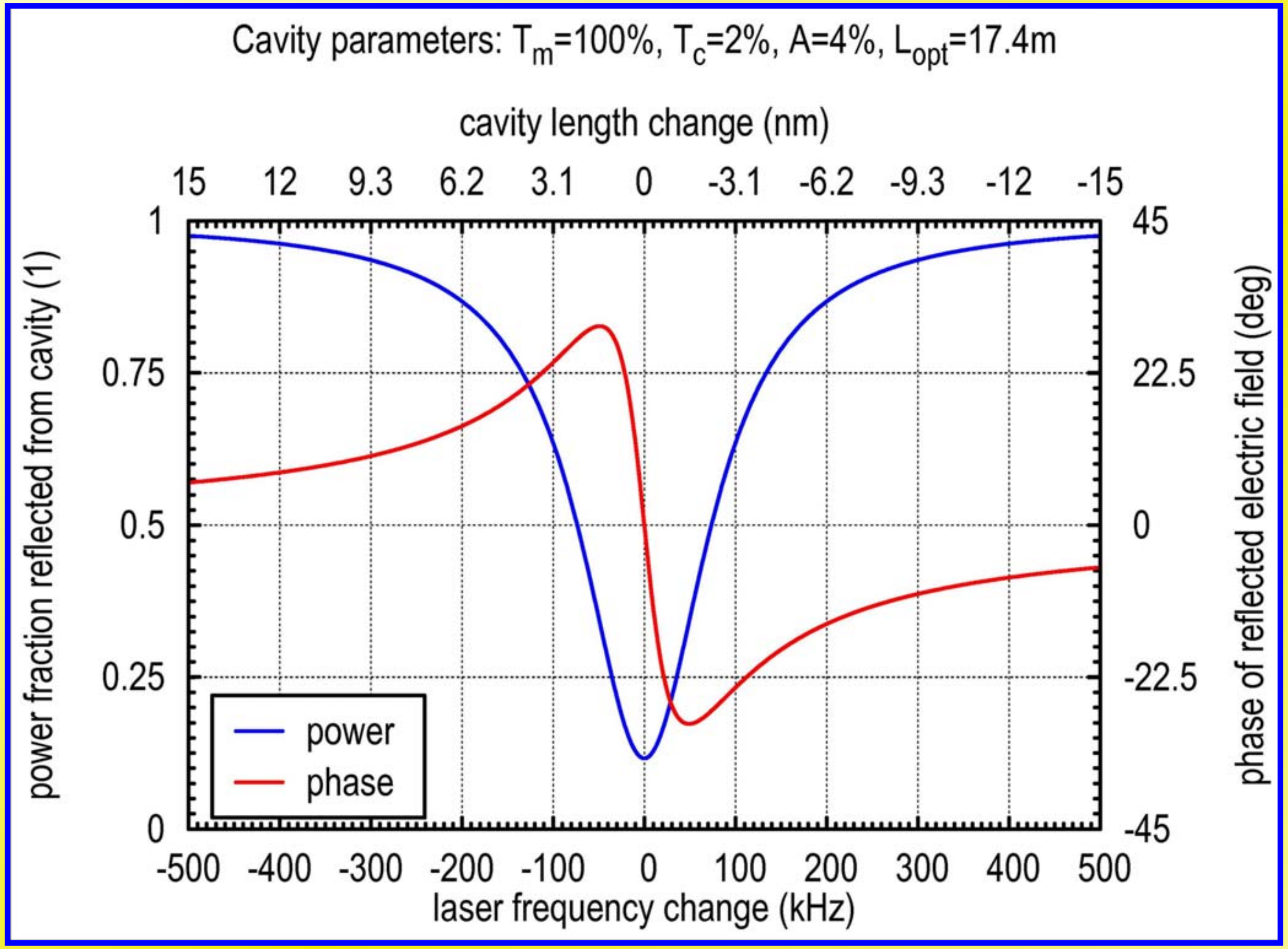


- Non-ideal alignment:
  - power fraction coupled to higher order TE modes

    -> coupling to TEM_{00} mode gets worse

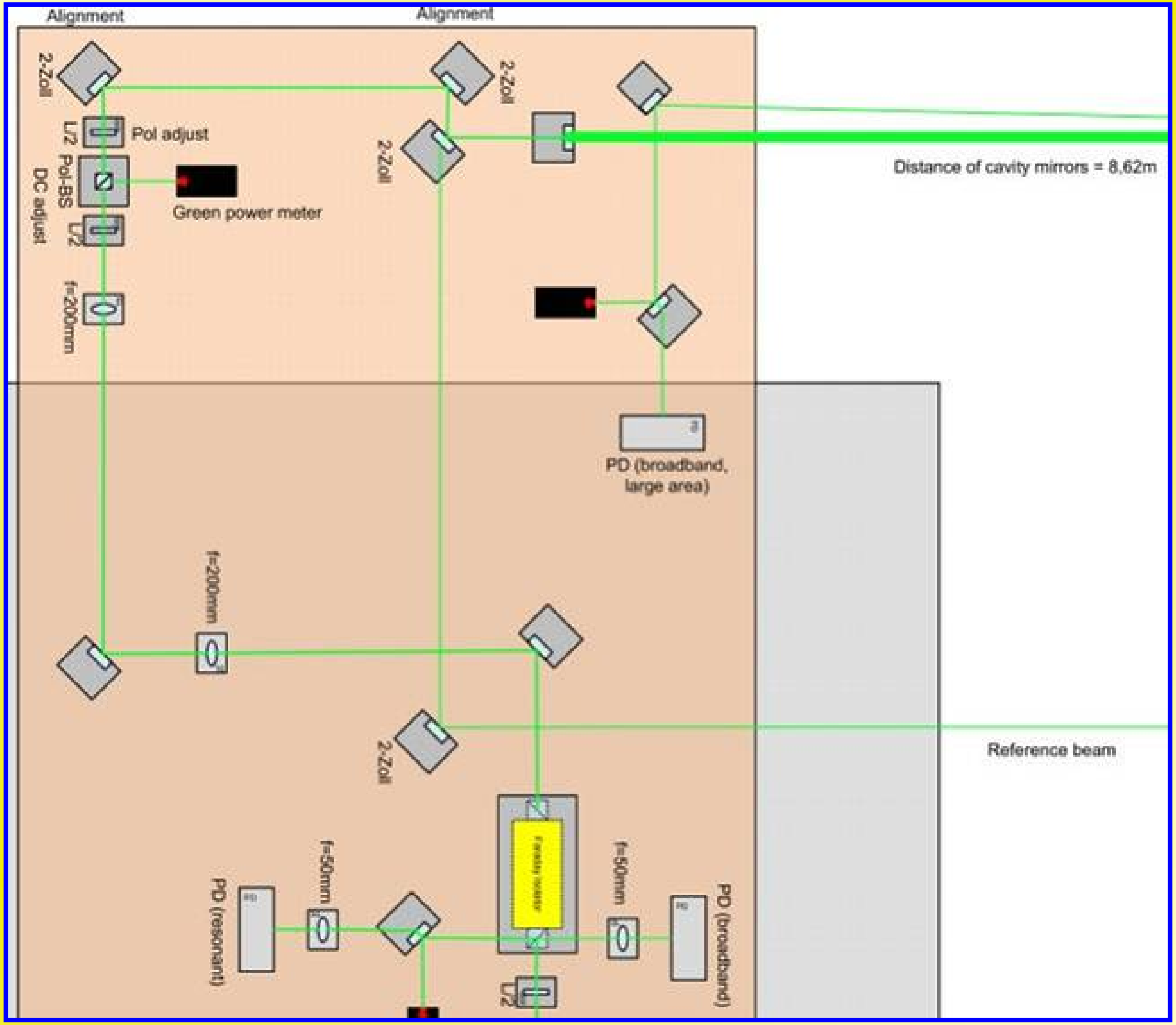
[Applied Optics, Vol. 5, No. 10 (1966)]

Stabilization onto resonance



- Change of sign needed for stabilization
- Use dispersion of cavity

ALPS experiment (Phase 1)



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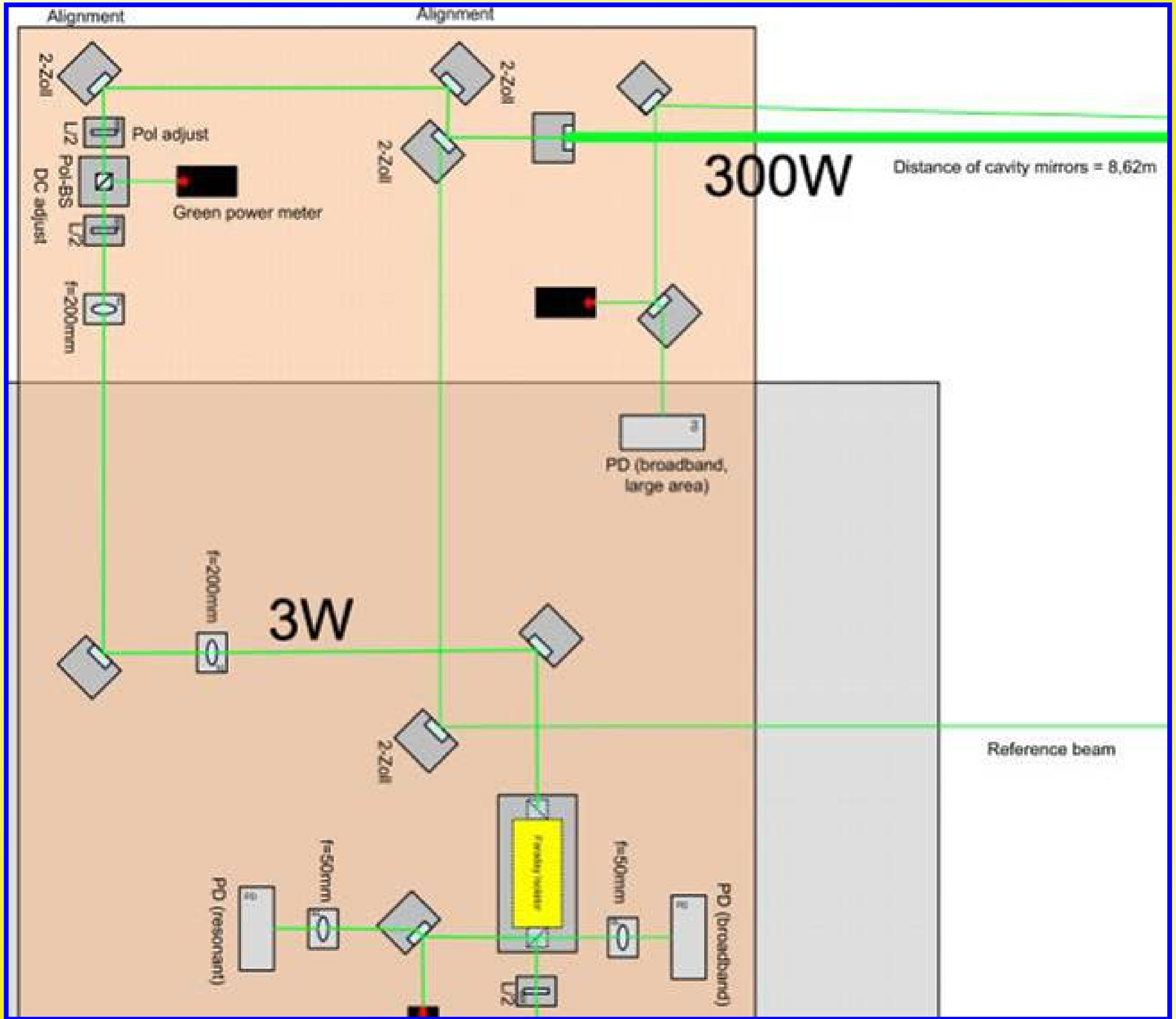
Planned power levels at ALPS



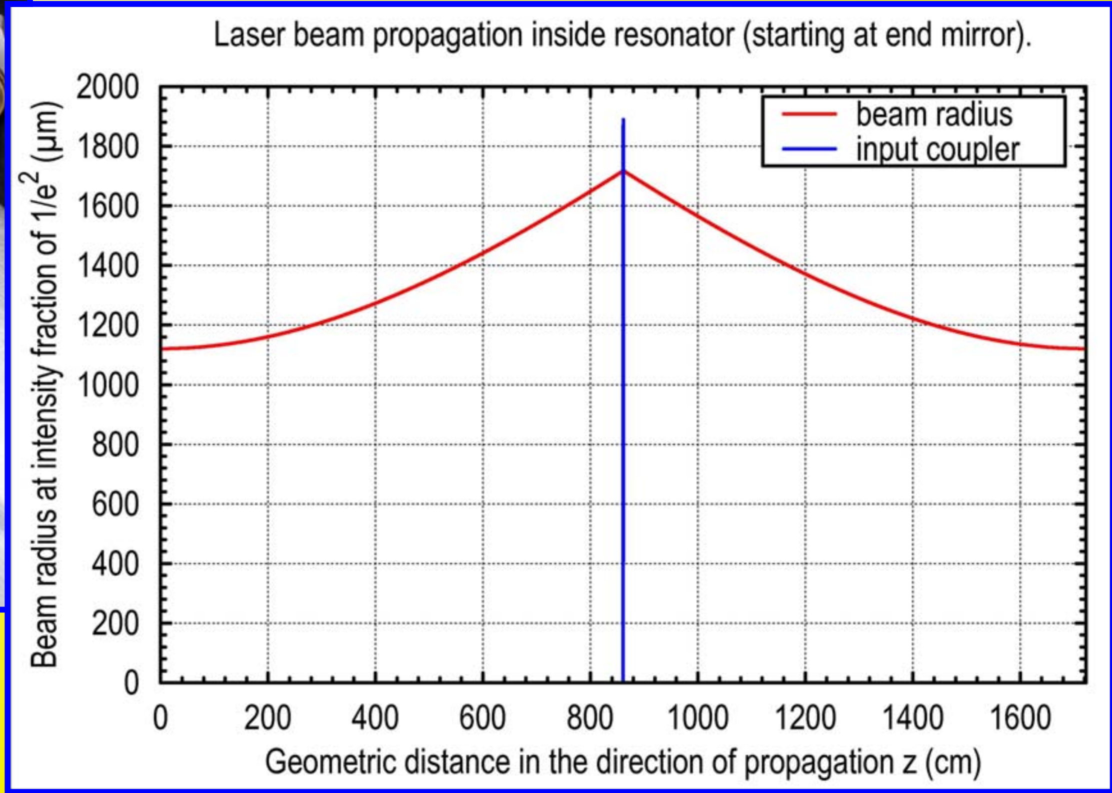
- Planned PB approx. 100
- Limited by 8 AR-coated facettes per pass

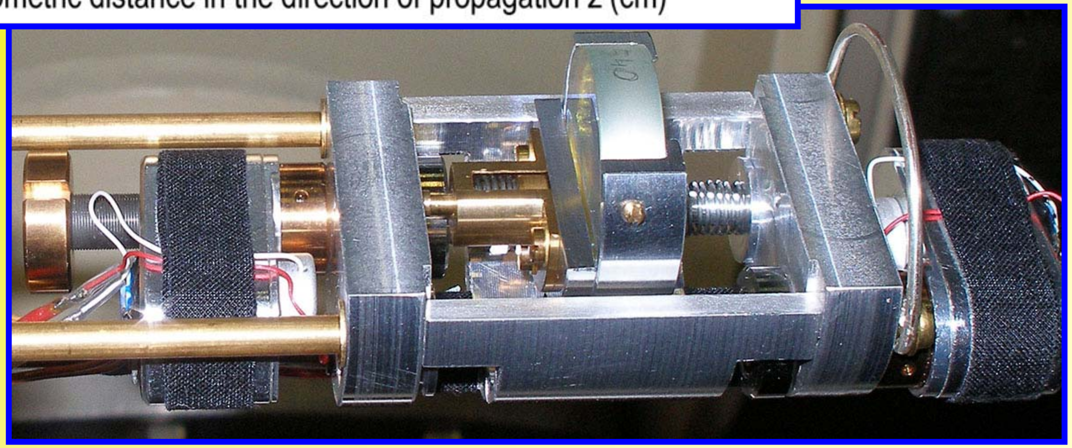
Comparison of regeneration experiments with cavities

Experiment	Incident Power	Finesse	Power buildup	$(B * L_{cav})^2$	Start
OSQAR	1kW, 1064nm	10000	3MW	$(9.5T*14m)^2$	2009 ?
PVLAS	0.8W, 1064nm	120000	32kW	$(5.5T*1m)^2$	2009 ?
ALPS	3W, 532nm	300	300W	$(5T*4m)^2$	This summer !
BFRT (delay line)	3W, 514nm	200 reflections	eff. 300W	$(3.7T*4.4m)^2$	Finished 1993
BMV/ GammeV	No cavity enhanced regeneration experiments proposed!				

The ALPS cavity (Phase 1)

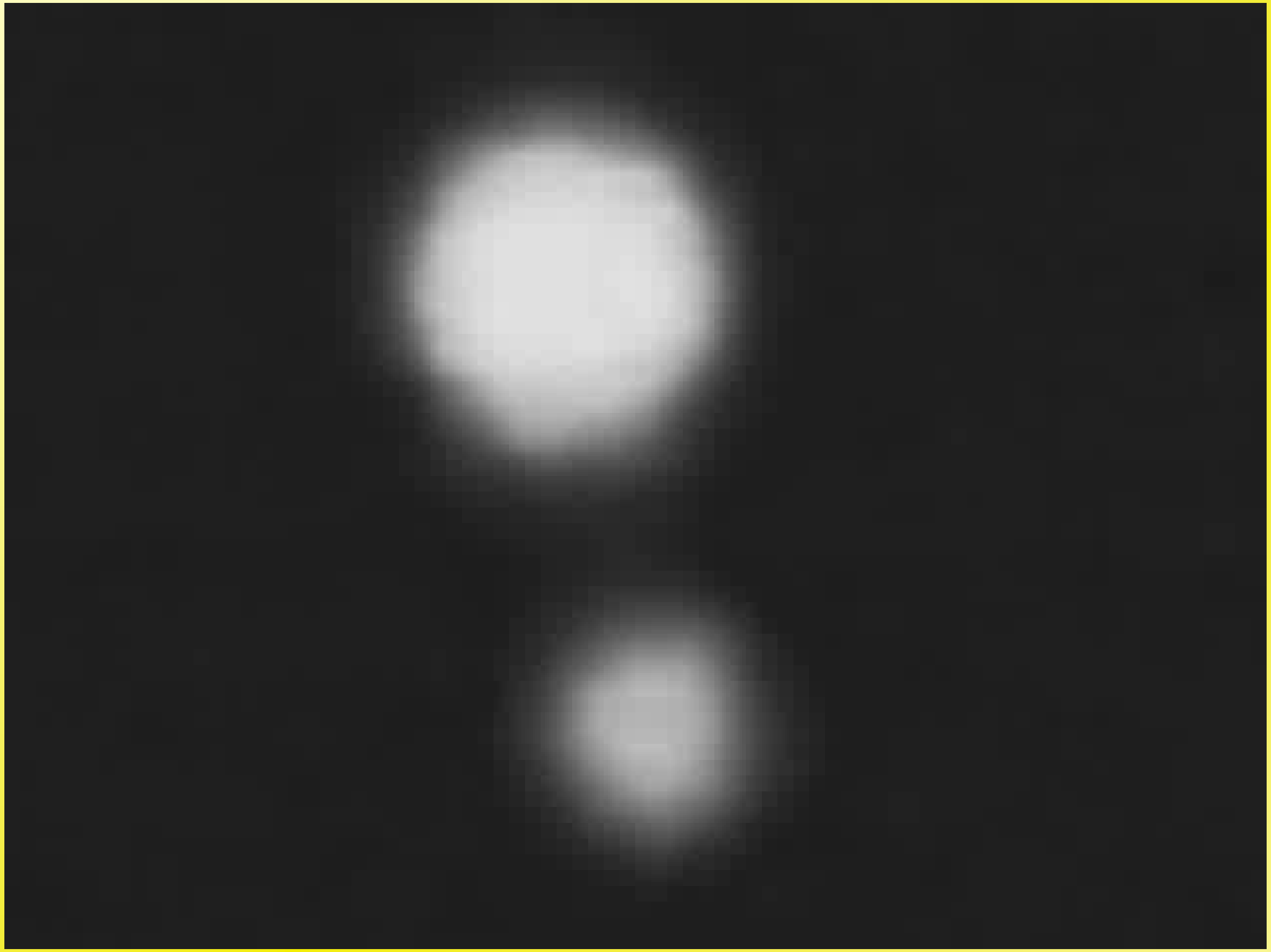
Stable manual mirror
mount on optical table





Motorized non-magnetic
mirror mount inside magnet

Current status of ALPS



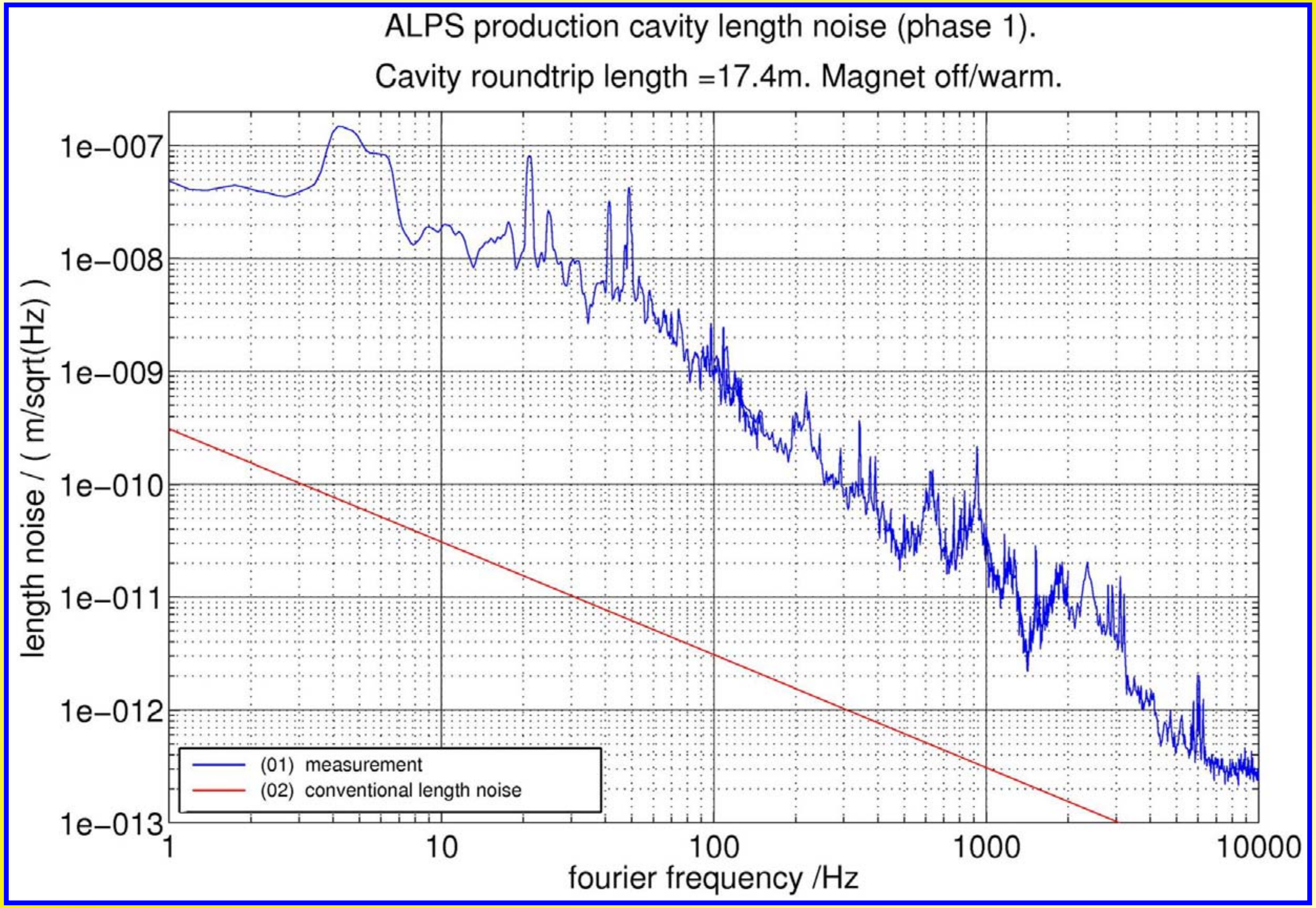
- Cavity can be locked!
- Approx. 100mW inside cavity
- PB of ca. 10

Lock limitations/noise sources

- **Lock unstable due to limited bandwidth**
  - Low frequency regime: temperature actuation of laser frequency not working at the moment
  - High frequency regime: bandwidth of high voltage amplifier (PZT actuation) too small

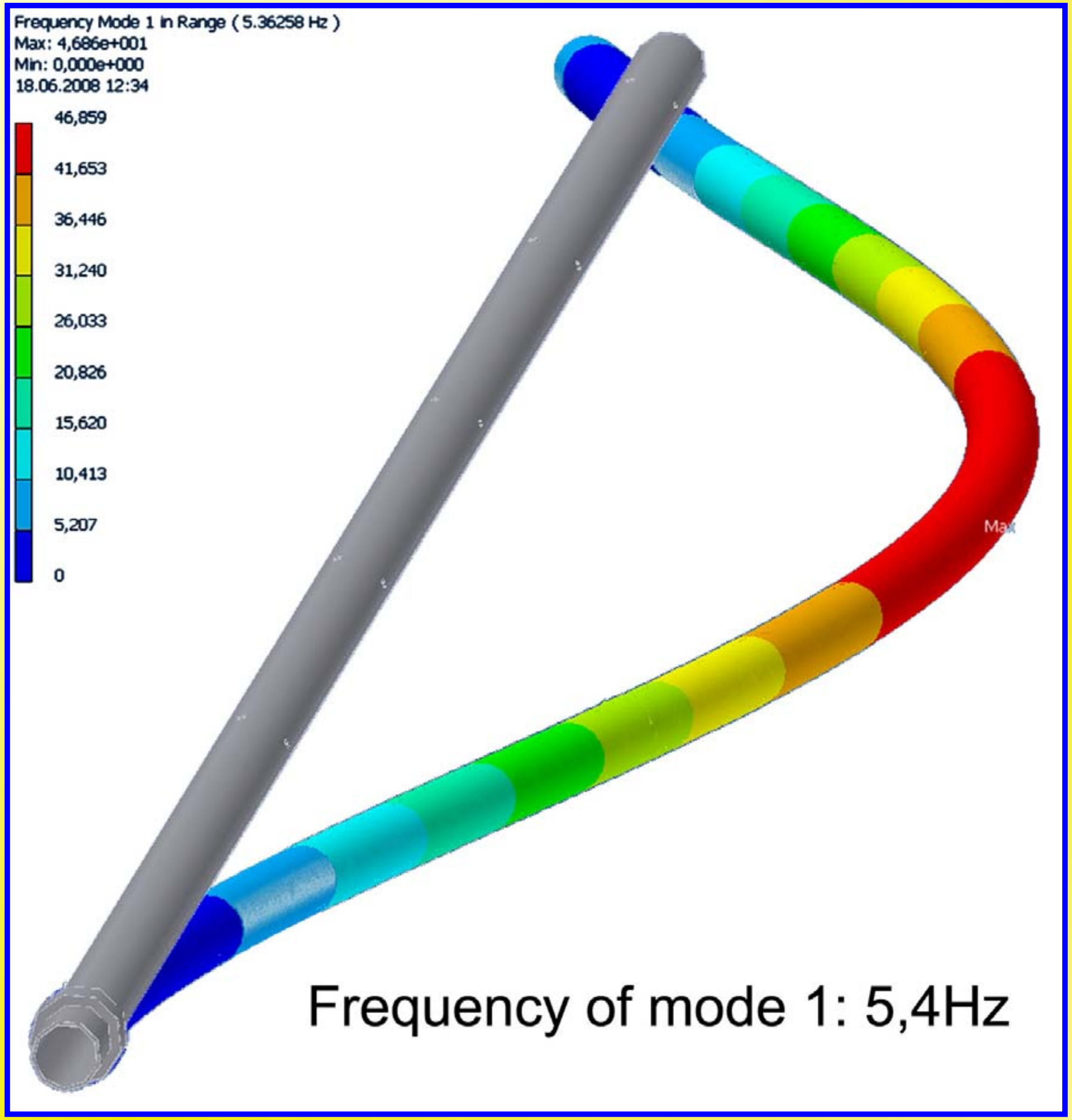
- **Strongest noise sources:**
  - Transversal vibrations due to turbo pump
  - Longitudinal vibrations below 100Hz (possibly tube eigenmodes)

Cavity length noise (ALPS)



- Length noise 500 times stronger than usual!

FE analysis of tube



- Strong vibrational eigenmodes at few hz could explain low f noise peaks

Limits for power buildup

- **Keep cavity empty/get extraordinarily good AR-coatings**

- **Tradeoff for cavities finesse:**
  - High finesse complicates lock acquisition/stability
    -> Favour input power instead of finesse
  - Dissipation inside cooled magnet
    -> Favour finesse instead of input power

- **Internal dissipation (problematic above ca. 20kW):**
  - Mirror destruction
    -> Enlarge beam spot on mirror/use good mirrors
  - Mirror deformation/Thermal lensing
    -> Use compensation plate/good mirrors

AdvLIGO limits

- **Realistic aims with maximum effort: 800kW @1064nm**
  - **Low finesse:**
    - Input power of 125W@1064nm in TEM_{00}
  - **Thermal distortion/destruction:**
    - EMPTY (!) cavity
    - Very good mirrors
    - Ring heater around cavity mirrors
    - Compensation plate in front of cavity
    - Large beam spot RADIUS of ca. 6cm (!)

Summary

- Cavities can scale light power for WISP production by decades (in principle)

- **At ALPS we succeeded in locking a test cavity with a weak buildup of 10 to test feasibility**
  - Compensation for strong length noise seems most demanding

- **Resonators should be empty for large power buildup**
- Scaling PB above ca. 20kW gets increasingly difficult
  - Different compensation strategies for thermal destruction/distortion must be traced

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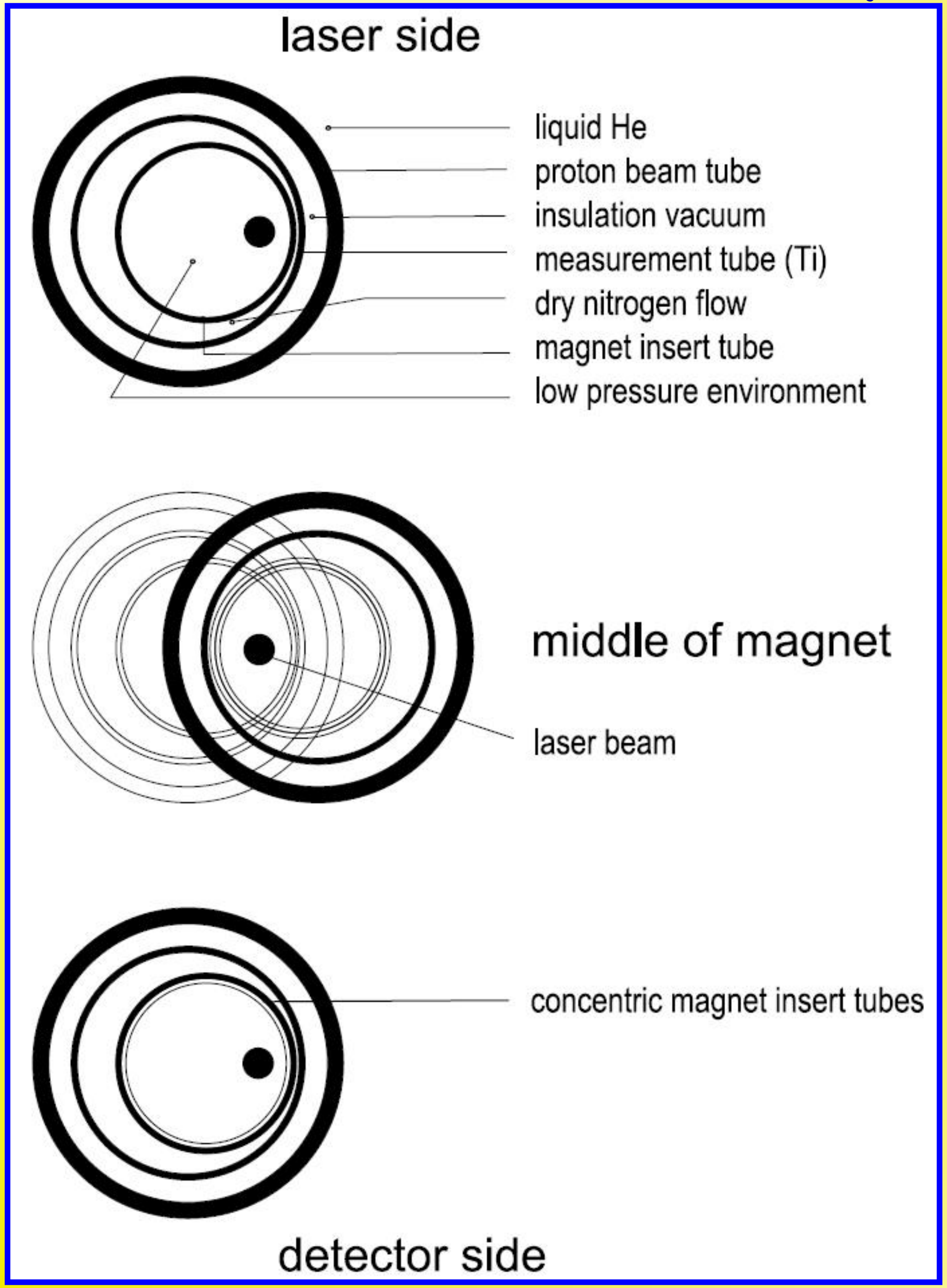
Thank you for your attention!

Cavity aperture



- Magnet cooled with liquid helium
- Strong thermal isolation needed
- Additional bending leads to small aperture