ALPS-II Lasers and Optics

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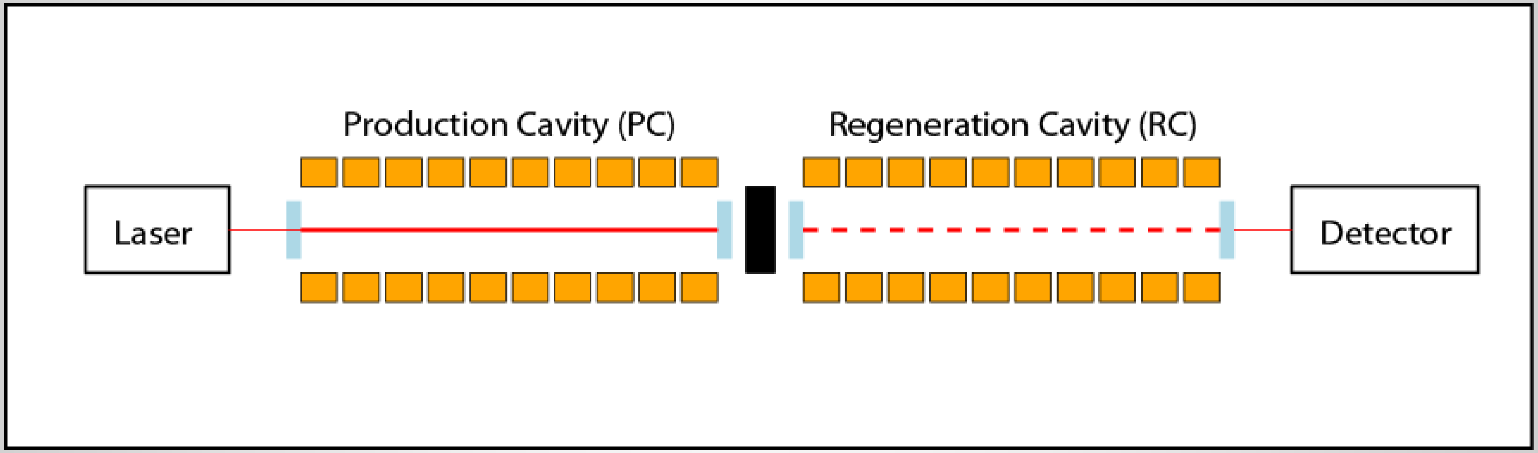
ALPS II TDR review
Zeuthen, 7.-9. November 2012

optical design consideration



photons per second on detector:

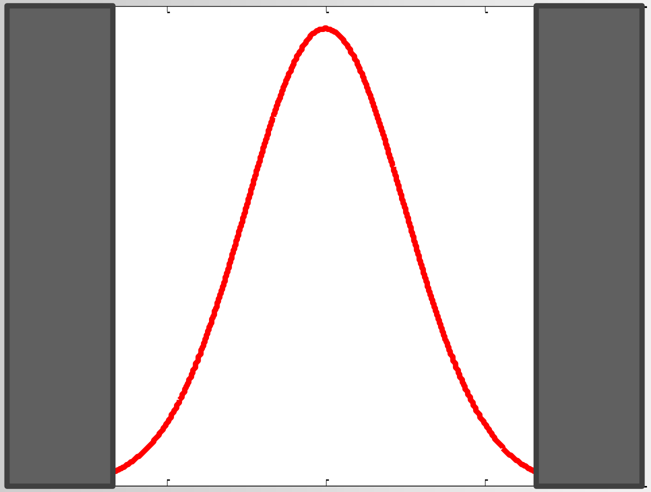
$$n \propto P_{laser} * PB_{PC} * L_{PC}^2 * PB_{RC} * \mathrm{L}_{\mathrm{RC}}^2$$

power buildup (on resonance):

$$PB = \frac{4\,T_{in}}{(T_{in} + T_{out} + A)^2}$$

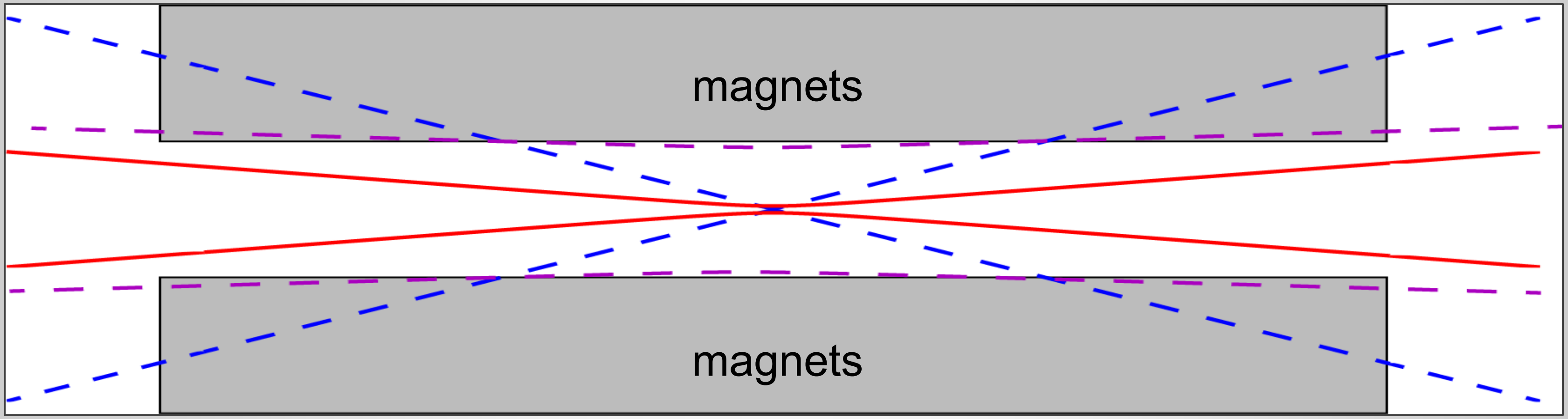
with $A = A_{absorption} + A_{scattering} + A_{aperture}$

gaussian beams – aperture effects



intensity: $I(r) = \frac{2P}{\pi\omega^2}\, e^{-\frac{2r^2}{\omega^2}}$

beam radius: $\omega(z) = \omega_0 \sqrt{1 + \frac{z^2}{z_r^2}}$

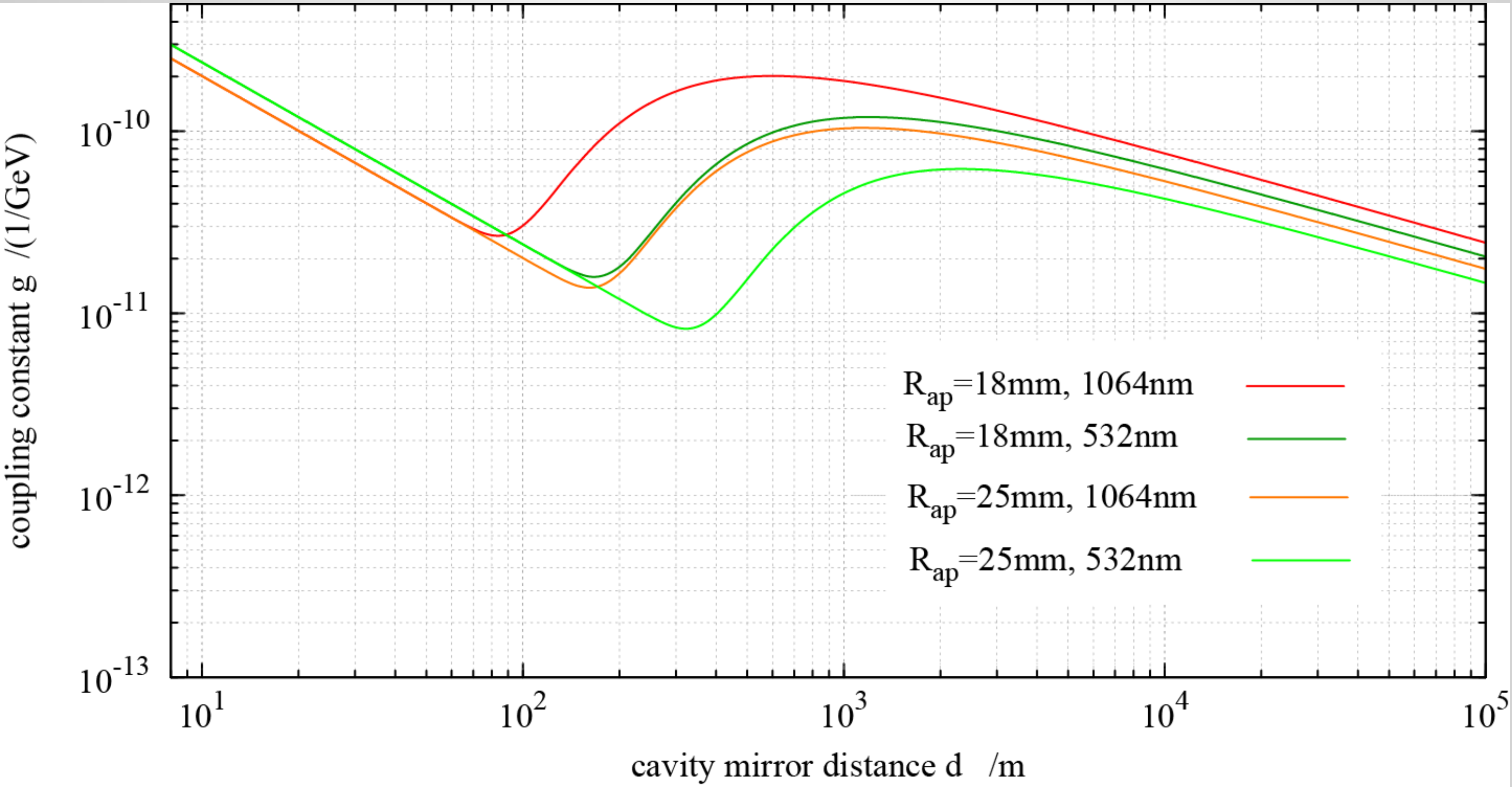


design cavity Eigenmode for smallest aperture loss ⇒ $z_r \overset{!}{=} L$

optical design – optimize length

- make aperture as large as possible ⇒ straighten magnets
- for a given aperture the power buildup depends on the length

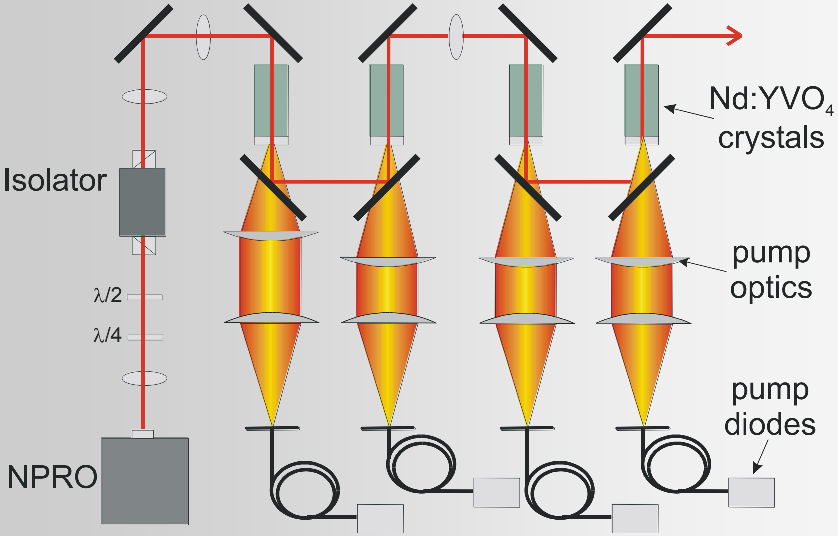
$$\Rightarrow \text{maximize} \quad PB * L^2$$

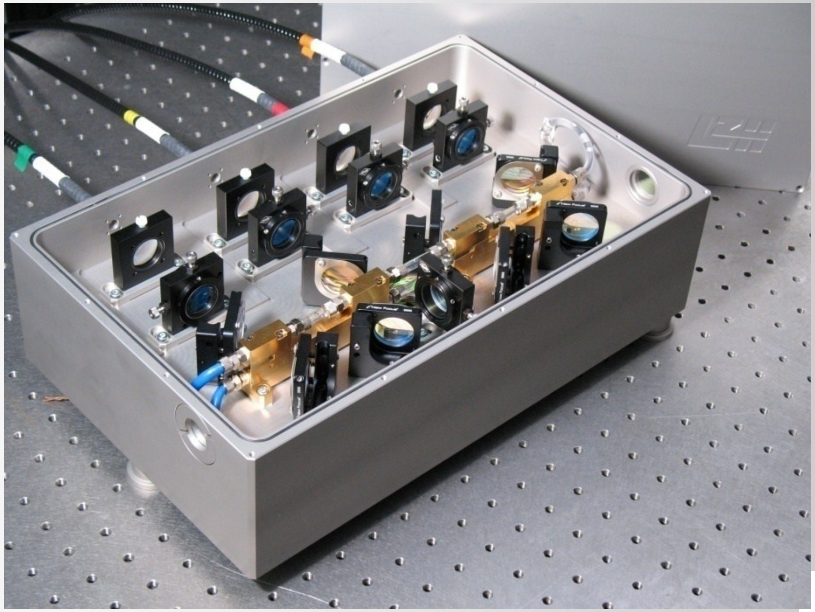


optical design – laser power and PB_{PC}

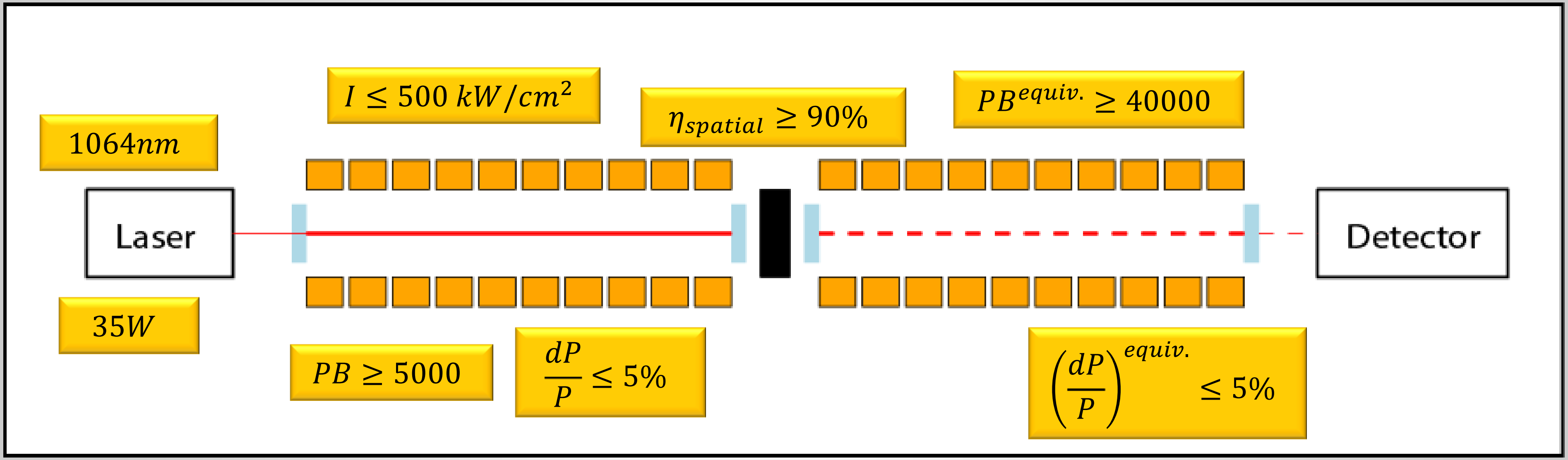
$$n \propto P_{laser} * PB_{PC} * L_{PC}^2 * PB_{RC} * \mathrm{L}_{\mathrm{RC}}^2$$

- to reduce risk of mirror damage we limit $I_{max} \overset{!}{\leq} 500\ \mathrm{kW/cm^2}$ and use 1064nm light
- reliable 35W laser is available
- reduce power buildup in production cavity to $PB_{PC} = 5000$





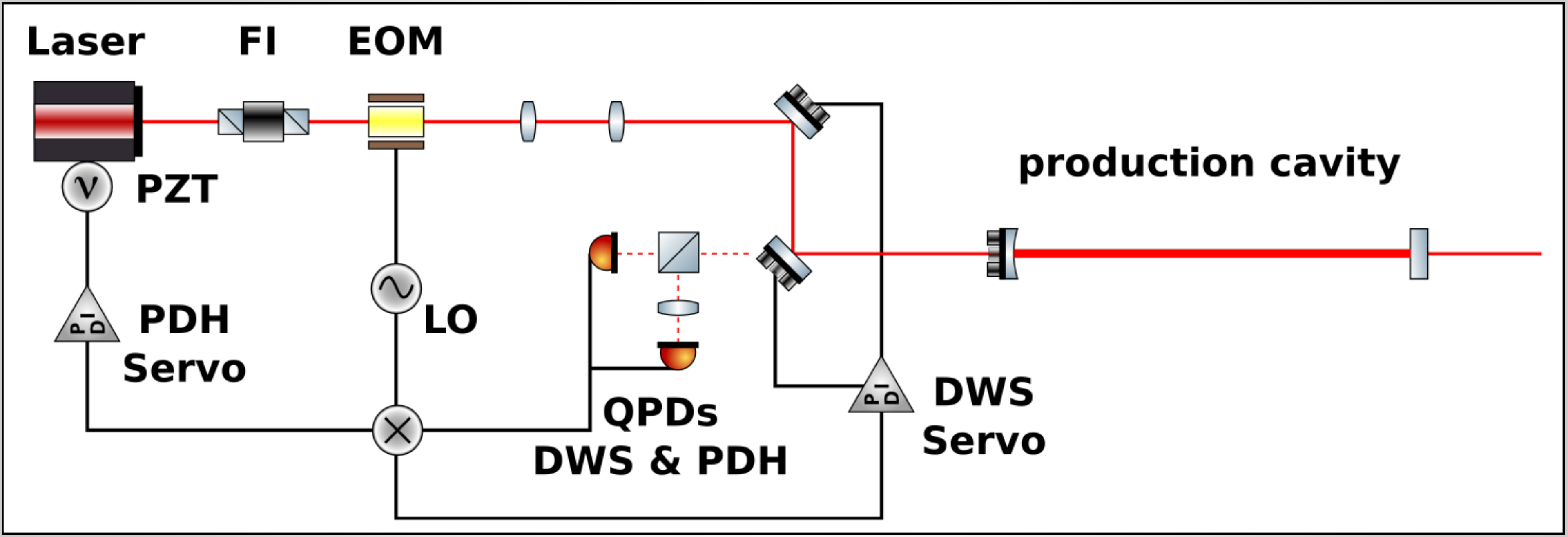
ALPS II – optical parameters and control tasks



main tasks:

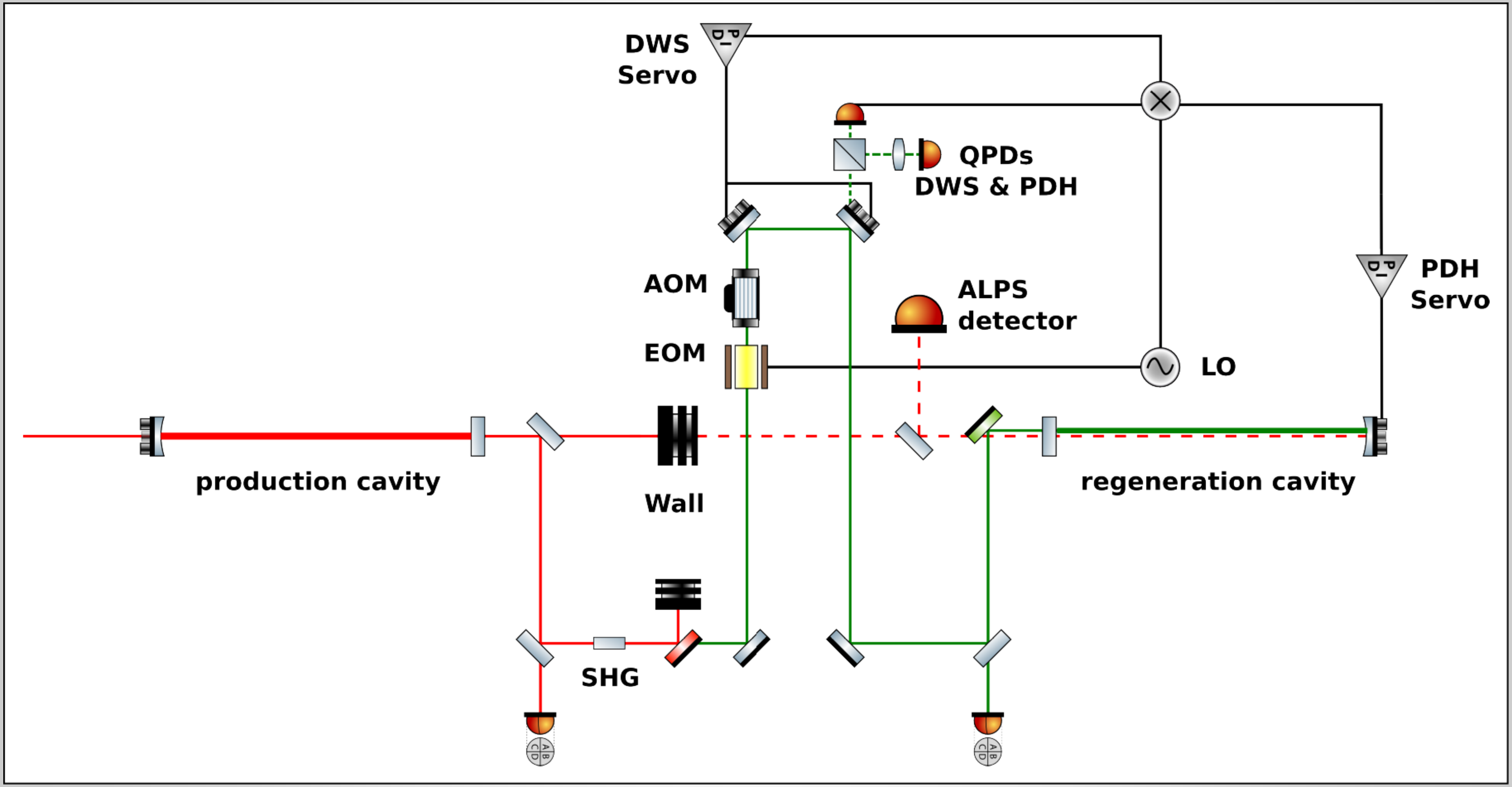
- control mirrors to achieve and maintain power build-up
- align mirrors such that regenerated field has large overlap with Eigenmode of regeneration cavity
- keep control beam photons away from detector

control of laser and production cavity



- Pound-Drever-Hall (PDH) sensing and feedback to laser frequency
- differential-wave-front sensing (DWS) on quadrant-photodiodes (QPD) and feedback to piezo-electrically controllable mirrors

control of regeneration cavity



- use green control beam (which is phase-stable wrt. main laser) for length and alignment control of regeneration cavity
- AOM to compensate for dispersion of RC mirrors

optics control tasks

Goal	Plan	Check
$\Delta\nu_{PC,laser} \leq 0.1\ FWHM_{PC}$	Active control of laser frequency with automatic lock acquisition (ALA), PDH sensing	Monitor $P_{circ,PC}$
$\epsilon^2_{laser,PC} = \left(\frac{\delta x}{\omega}\right)^2 + \left(\frac{\delta\phi}{\phi_D}\right)^2 \leq 0.2$	Active beam steering with PZT mirrors and differential wave-front sensing (DWS)	Monitor $P_{circ,PC}$
$overlap\ PC \leftrightarrow RC > 0.9$ (angular deviations)	Mount planar mirror on CB parallel	Monitor$P^{1064nm}_{circ,RC}$ with open shutter
$overlap\ PC \leftrightarrow RC > 0.9$ (lateral deviations)	Active steering control of curved cavity mirrors	Monitor $P^{1064nm}_{circ,RC}$ with open shutter
$\Delta\nu_{RC,532nm} \leq 0.1\ FWHM_{RC}$	Active control of length of RC and AOM with ALA, PDH sensing	Montitor $P^{532nm}_{circ,RC}$
$\epsilon^2_{532nm,RC} \leq 0.2$	Active beam steering with PZT mirrors DWS	Monitor $P^{532nm}_{circ,RC}$

(techniquies used in GWD interferometers, checks in ALPS-IIa phase)

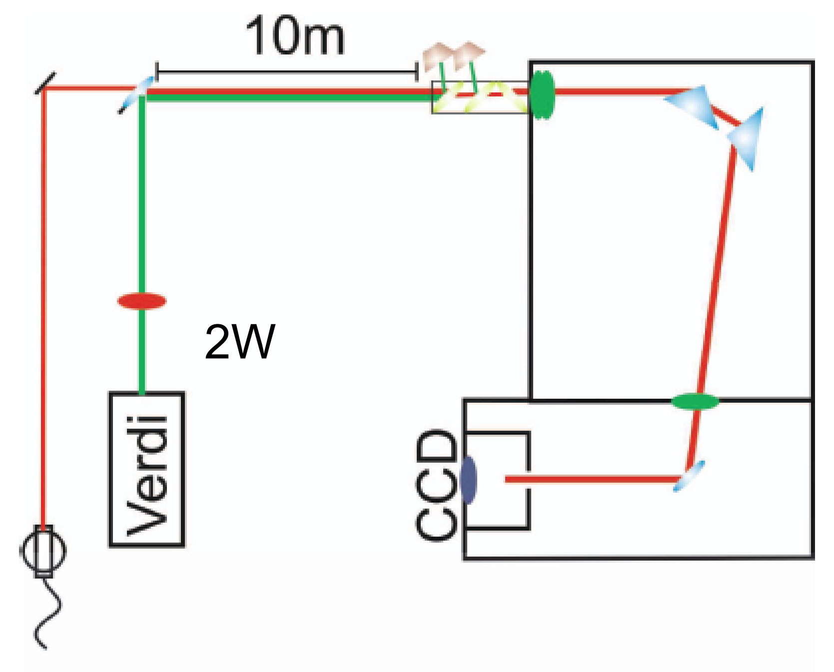
optics – control tasks II

Goal	Plan	Check
simultaneous resonance of 1064nm and 532nm in RC	shift 532nm control beam with AOM, static, no active control	monitor $P_{circ,RC}^{1064nm}$ with open shutter
Overlap RC ↔ WISP	avoid beam shift or tilt during central bread board fabrication	post-fabrication test
avoid primary 1064nm photons or control light on detector	appropriate wall design, dichroitic attenuation of control beam	shift control beam to make RC not resonant @ 1064nm

(techniquies used in GWD interferometers, checks in ALPS-IIa phase)

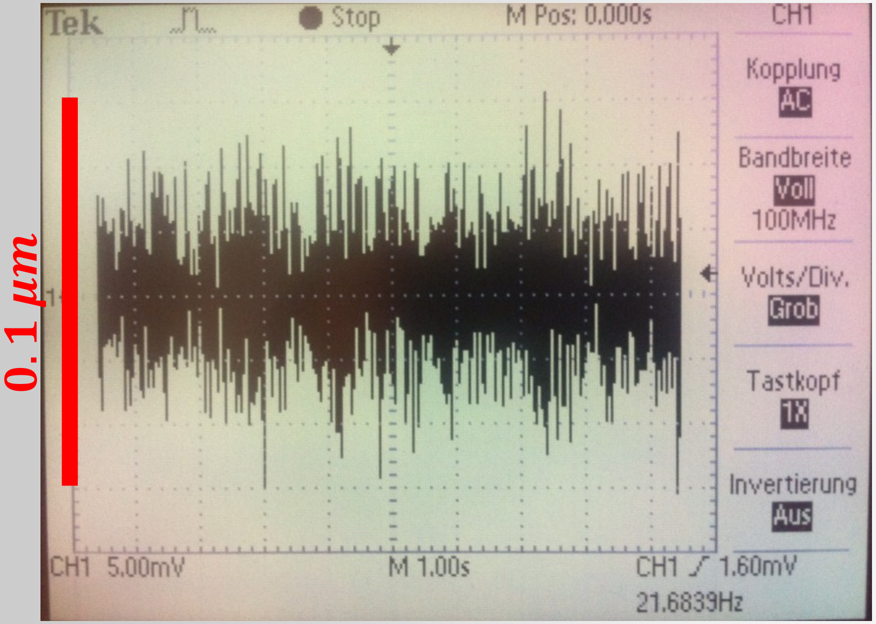
first results of control beam attenuation

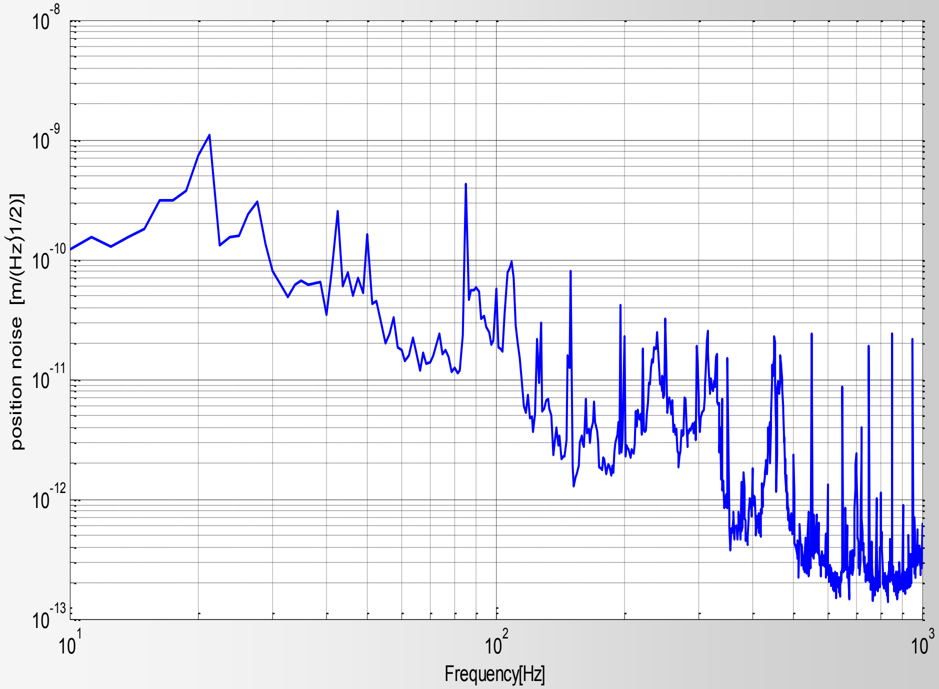
- we were able to demonstrate an attenuation of the green beam by $\alpha = 3 * 10^{-17}$
- limited by dark rate of CCD and available light power @532nm
- required sensitivity will be available during ALPS-IIa phase



ALPS-IIa - first lock of 10m cavity

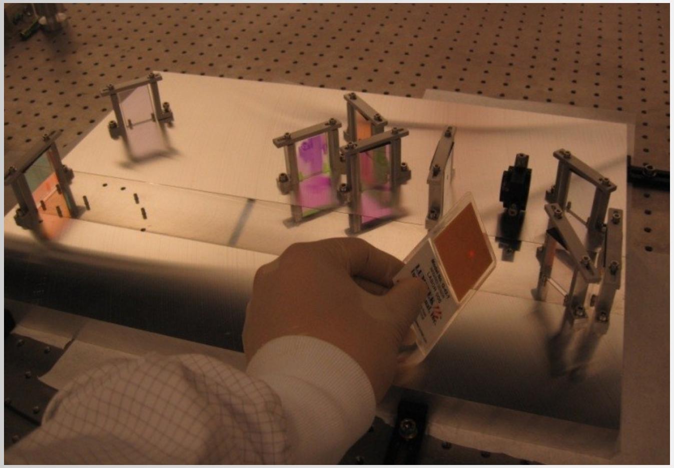
- 10m long cavity between laser and central table could be stabilized
- actuator range sufficient to compensate for relative table motion

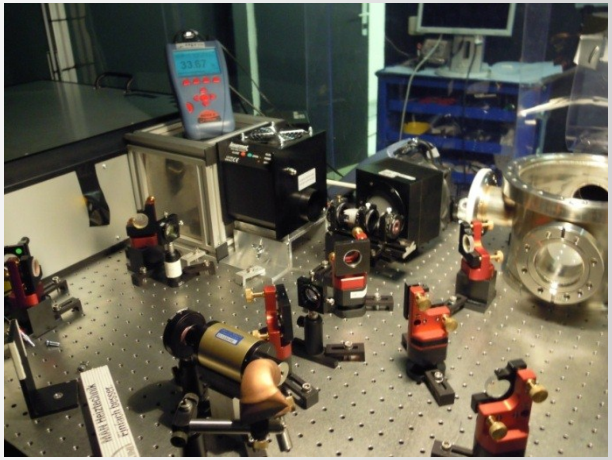




summary

- conservative optical design
- optical control based on well established techniques used in field of GWD detection
- several prototype stages to test / demonstrate new challenges and mitigate risk before large investments
- encouraging first results
- next steps: demonstrate control concept at AEI 1m table top experiment / lock ALPS-IIa PC with high PB





committee questions raised prior to review

- justify the stability requirements
- justify level of acceptable ground motion (spectrum) for the system to lock reliably
- justify the level of temperature control required
- identify critical descision points

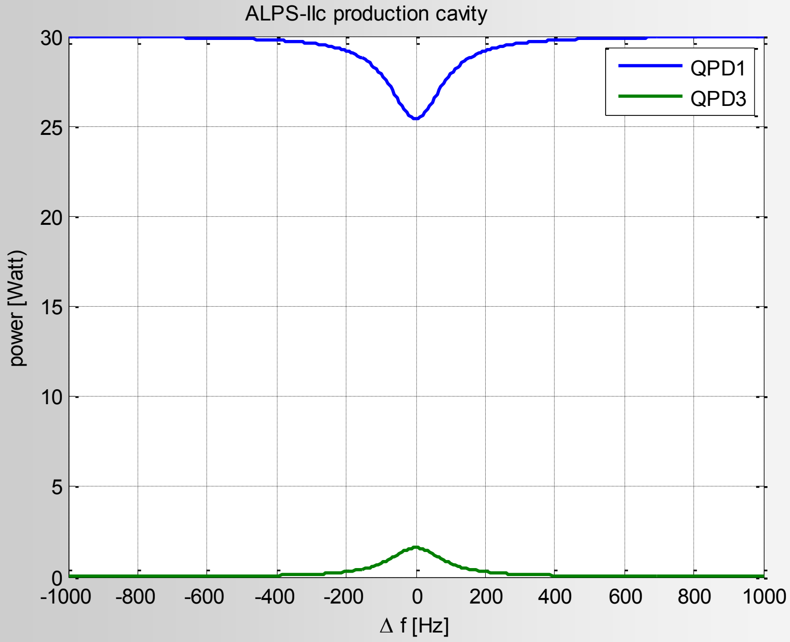
pointing requirements

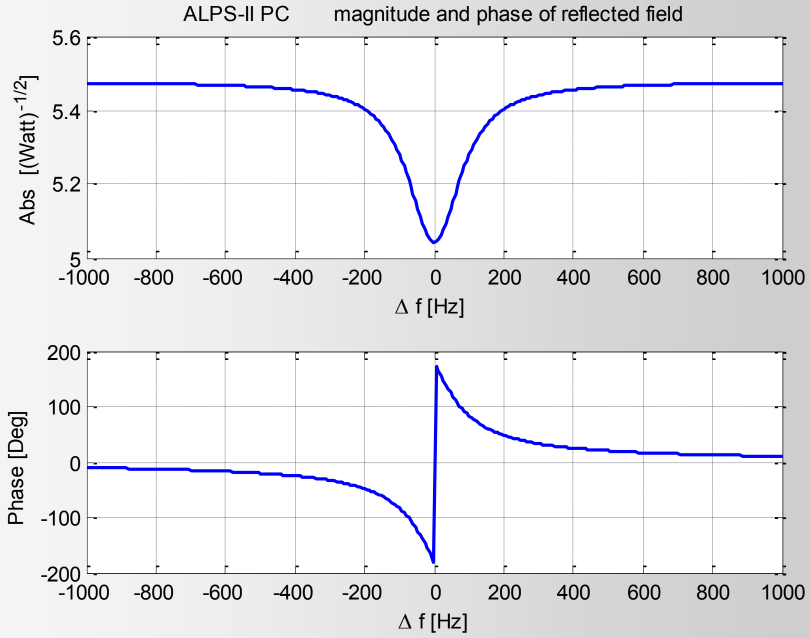
$$U(\delta x, \delta \theta) = \phi_{0,0} + \epsilon_x \phi_{1,0} \qquad with\ \epsilon = \frac{\delta x}{\omega_0} + \frac{\delta \theta}{\Theta_D}$$

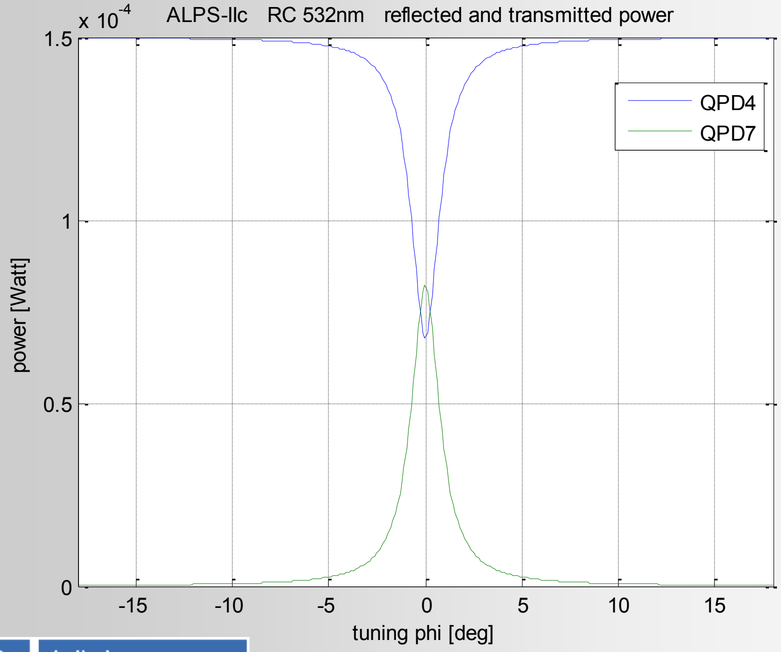
time average overlap: $P(t) = 1 - \epsilon(t)^2 \overset{!}{\geq} 0.95$

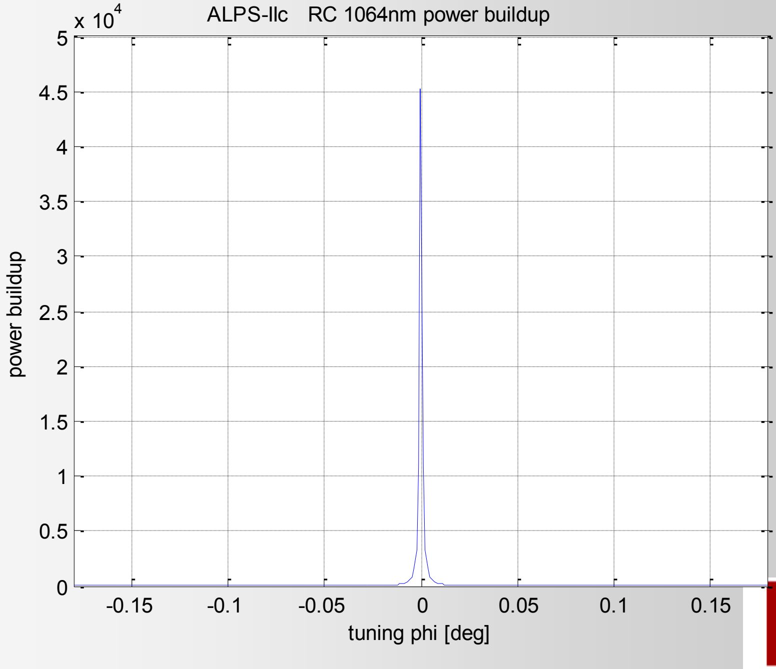
$$\Rightarrow \epsilon \overset{!}{\leq} 0.22$$

z_R [m]	w_0 [mm]	Θ_D [µrad]	$d\theta_{max}$ [µrad]	dx_{max} [mm]
1	0.5	582	128	0.128
10	1.8	184	40	0.4
100	5.8	58	13	1.3


ALPS-IIc production cavity


ALPS-II PC magnitude and phase of reflected field


ALPS-IIc RC 532nm reflected and transmitted power


ALPS-IIc RC 1064nm power buildup

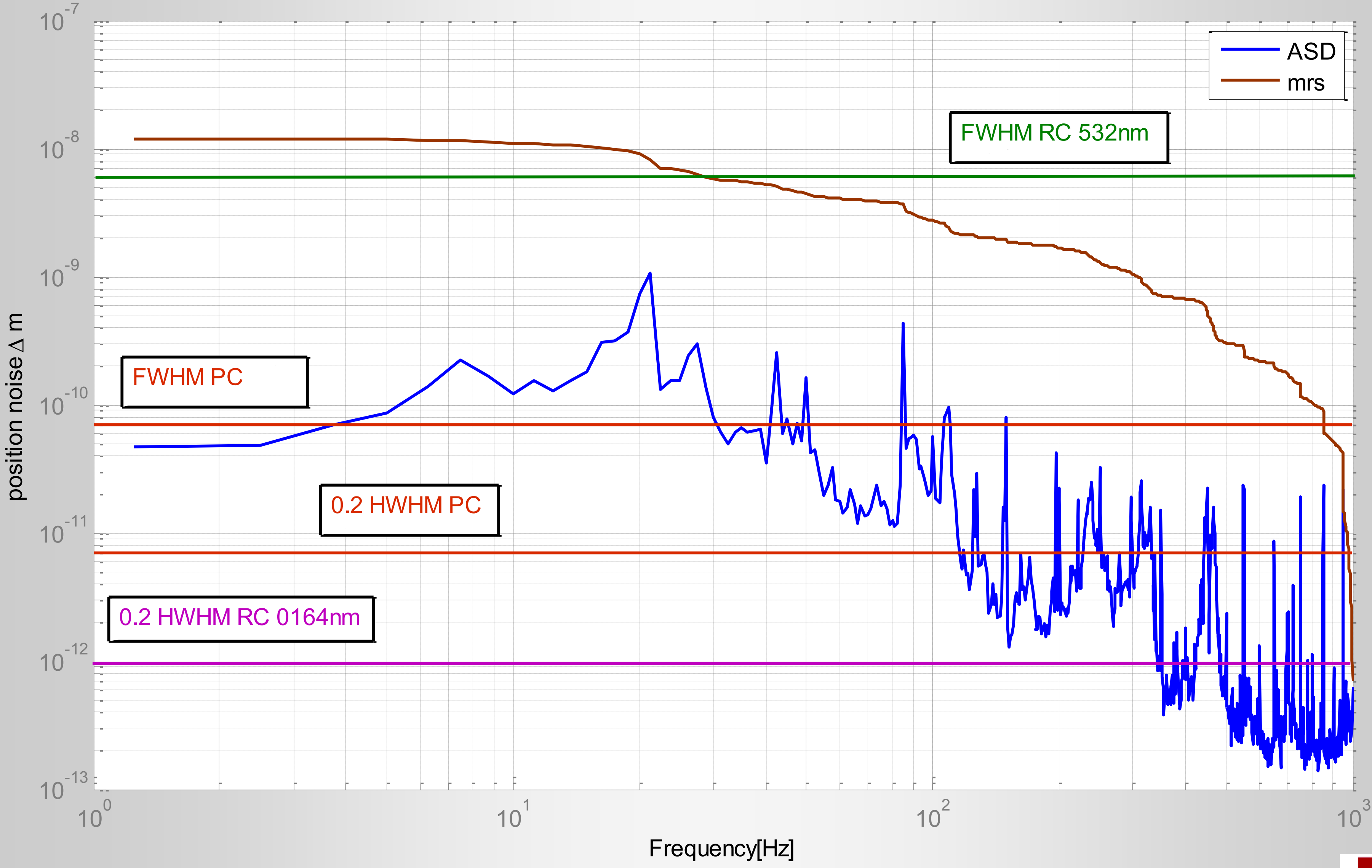
requirement for length / frequency stability

$$PB \approx PB_{max} \frac{1}{1+\left(\frac{\delta\nu}{HWHM}\right)^2} \quad with \quad PB_{max} = \frac{4\,T_{in}}{(T_{in}+T_{out}+A)^2}$$

$$\frac{\delta\nu}{HWHM} \overset{!}{\leq} \sqrt{\frac{PB_{max}}{PB}-1} \quad for\ \mathrm{PB} \geq 0.95\,PB_{max} \quad \Rightarrow \quad \delta\nu \leq 0.23\,HWHM$$

$\boldsymbol{phase}$	$\boldsymbol{FSR}$	$\boldsymbol{FWHM_{PC,100}}$	$\boldsymbol{FWHM_{PC,5.000}}$	$\boldsymbol{FWHM_{RC,40.000}}$	$\boldsymbol{FWHM_{RC,55}}$
AEI test	150 MHz	477 kHz			
ALPSII-a	15 MHz	47 kHz	950 Hz	119 Hz	87 kHz
ALPSII-b/c	1,5 MHz	4,8 kHz	95 Hz	12 Hz	8.6 kHz
Δx_{FWHM} [pm]		3387	68	8	6158

lock acquisition and disturbance reduction



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schedule and milestones

- Q4 2012 – demonstrate control concept at AEI 1m table top experiment
  - ⇨ design and build ALS-IIa electronics
- Q4 2012 – first ALPS-IIa cavity (info on length and alignment fluctuations ⇒ build electronics
  - ⇨ design and build ALS-IIa electronics
- Q2 2013 – ALPS-IIa production cavity with PB=5.000
- Q4 2013 – ALPS-IIa regeneration cavity with PB=40.000
  - ⇨ purchase ALPS-IIb components,
  - ⇨ design clean environments for ALPS-IIb
- Q4 2015 – ALPS-IIb cavities ready
- Q1 2017 – ALPS-IIc cavities ready