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LZH LASER ZENTRUM HANNOVER e.V.

Lasers for the axion-like particle search

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4th Patras Workshop on Axions, WIMPs and WISPs - 20.06.08

- Introduction
 - Considerations on laser parameters
- Laser systems for ALPS
 - Single- and multi-pass experiments
 - Injection-locked cavity experiments
- eLIGO laser system
 - Nonplanar ring oscillator
 - Amplifier
- Summary and Outlook

Conversion probability

$$P_{\gamma \rightarrow a} = \frac{4B_{ext}^2 \omega^2}{M^2 m_a^4} \sin^2 \left(\frac{m_a^2 l}{2\omega} \right)$$

Regeneration rate

$$R = (P_{\gamma \rightarrow a})^2 \left(\frac{P_l}{\omega} \right) \eta$$

B magnetic field, ω photon energy, M inverse axion coupling, m_a axion mass, l interaction length, P_l laser power, η detector efficiency.

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- Laser power – Photon flux
- Wavelength – Photon energy, detector sensitivity, beam divergence
- Linear polarization – $E \parallel B$ for axion production
- Pulsed or CW operation – Detector noise, injection-locking
- Beam quality – Magnet aperture and detector focus size

Experiments on ALPS:

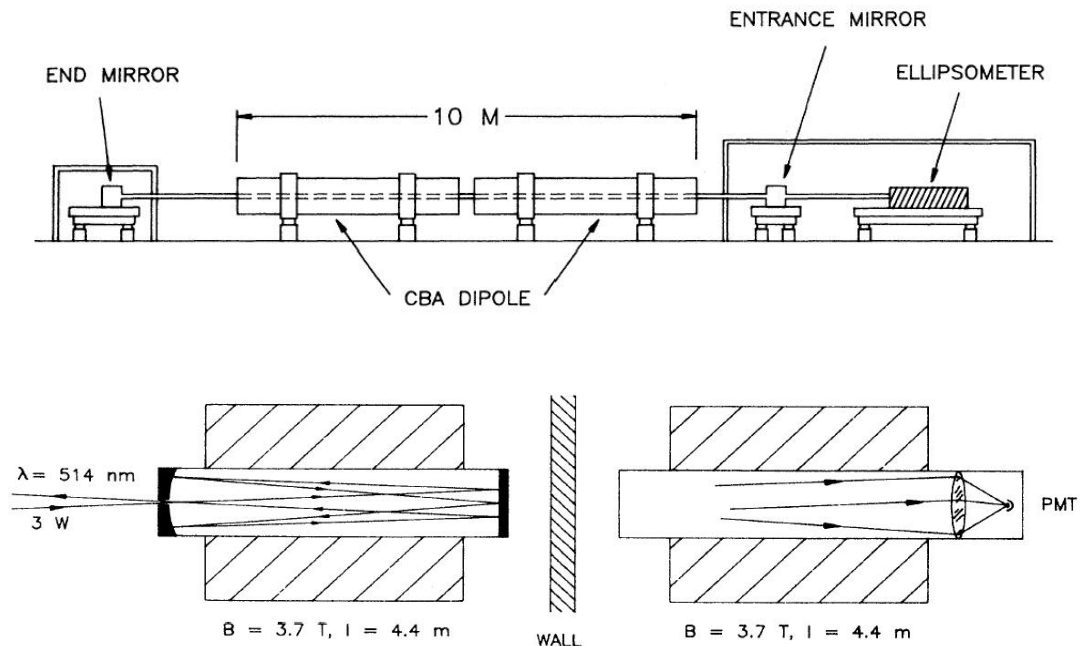
- Single- and multi-pass through magnet
 - BFRT
 - GammeV
 - OSQAR
 - ALPS (DESY) I
- Injection-locked cavity inside magnet
 - PVLAS
 - BMV
 - *ALPS (DESY) II*

BFRT “Brookhaven-Fermilab-Rutherford-Trieste ” - USA, Italy

Coherent Inc.

- Argon-ion laser
- Wavelength 514.5 nm
- Average power 2 W (0.5 W)
- Continuous-wave
- Beam quality $M^2 < 1.1$

- Multi-pass cavity



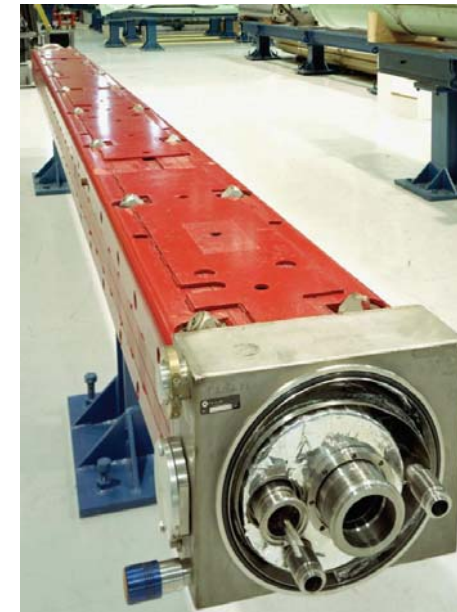
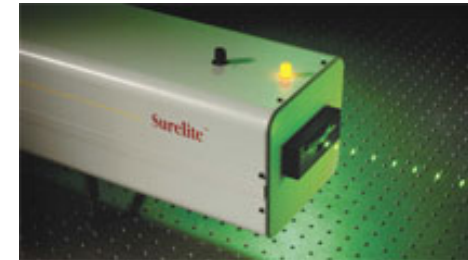
GammeV “gamma to milli-eV particle search” - FNAL, USA

Continuum Inc. – Surelite I-20

- Wavelength 532 nm
- Average power 3.2 W
- Repetition rate 20 Hz
- Pulse duration 5 ns
- Pulse energy 160 mJ
- Beam quality $M^2 \sim 2$

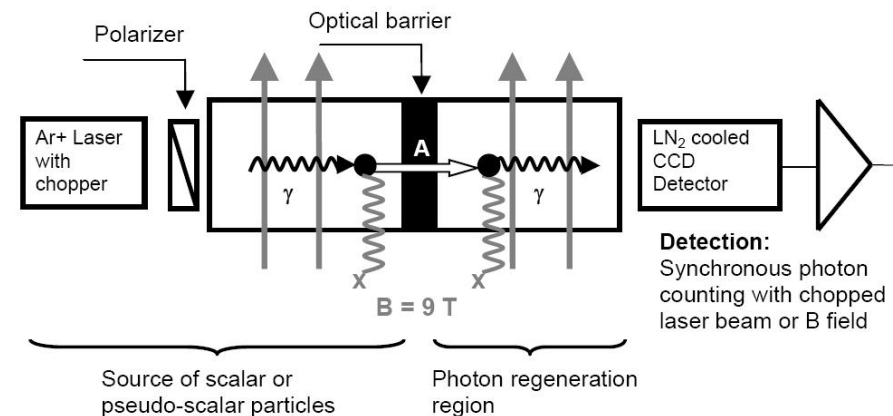
- Search window 10-100 ns

- Single-pass



OSQAR “Optical Search for QED vacuum magnetic birefringence, Axions and photon Regeneration” – CERN, Switzerland

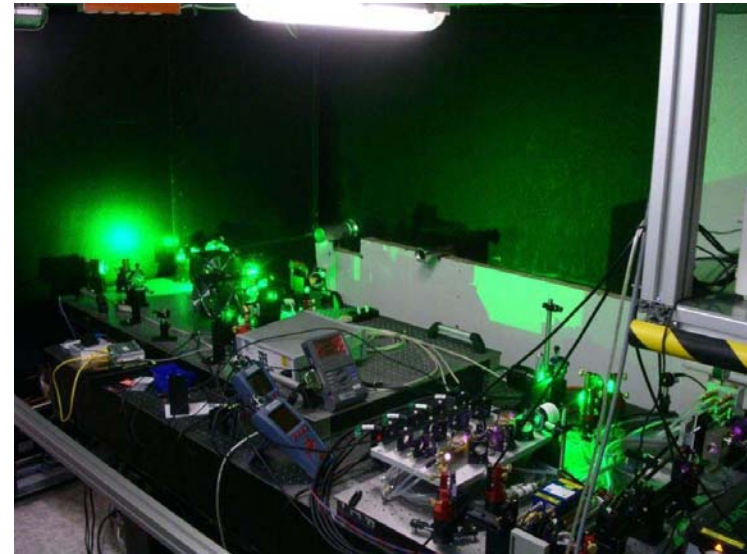
- Argon-ion laser
- Wavelength 488-514 nm
- Average power 18 W
- Continuous-wave
- Single-pass



1) ALPS “Axion-like particle search” - DESY, Germany

LZH laser system

- Nd:YAG laser – Nd:YVO₄ amplifier
 - Wavelength 1064 nm
 - Average power 42 W
 - Repetition rate 20 kHz
 - Pulse duration 15 ns
 - Beam quality $M^2 < 1.1$
-
- Conversion to 532 nm
 - Green average power 15 W
-
- Single-pass (reflected)



PVLAS “Polarizzazione del Vuoto con LASer” - INFN, Italy

Nonplanar ring-oscillator (NPRO)

- Nd:YAG laser
- Wavelength 1064 nm
- Average power 800 mW
- CW - single-frequency
- Beam quality $M^2 < 1.1$

- Conversion to 532 nm
- Green power 80 mW

- Injection-locked cavity

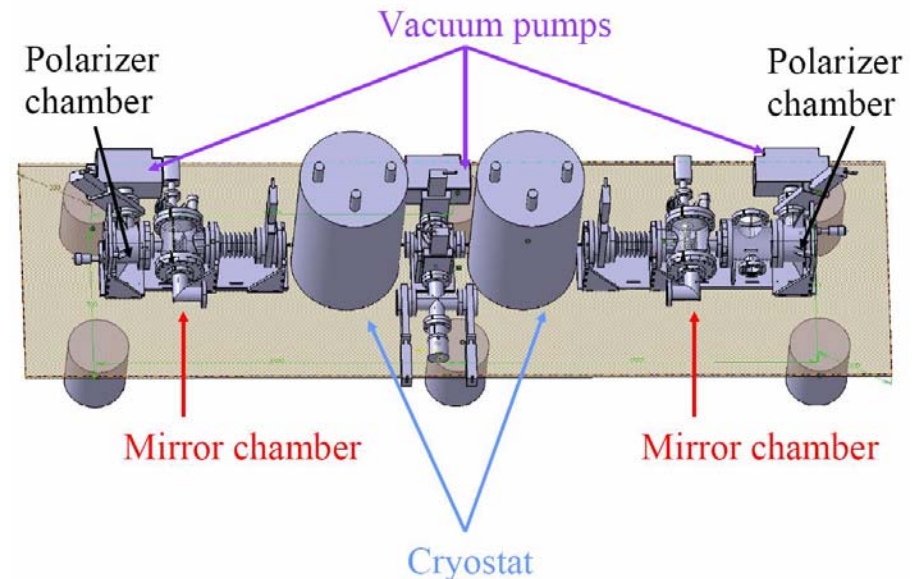


BMV “Biréfringence Magnétique du Vide” - Toulouse, France

Nonplanar ring-oscillator (NPRO)

- Nd:YAG laser
- Wavelength 1064 nm
- Average power 200 mW
- CW - single-frequency
- Beam quality $M^2 < 1.1$

- Injection-locked cavity



2) ALPS “Axion-like particle search” - DESY, Germany

eLIGO Laser system

- NPRO – Nd:YVO₄ amplifier
- Wavelength 1064 nm
- Average power 35 W
- CW - Single-frequency
- Beam quality $M^2 < 1.1$

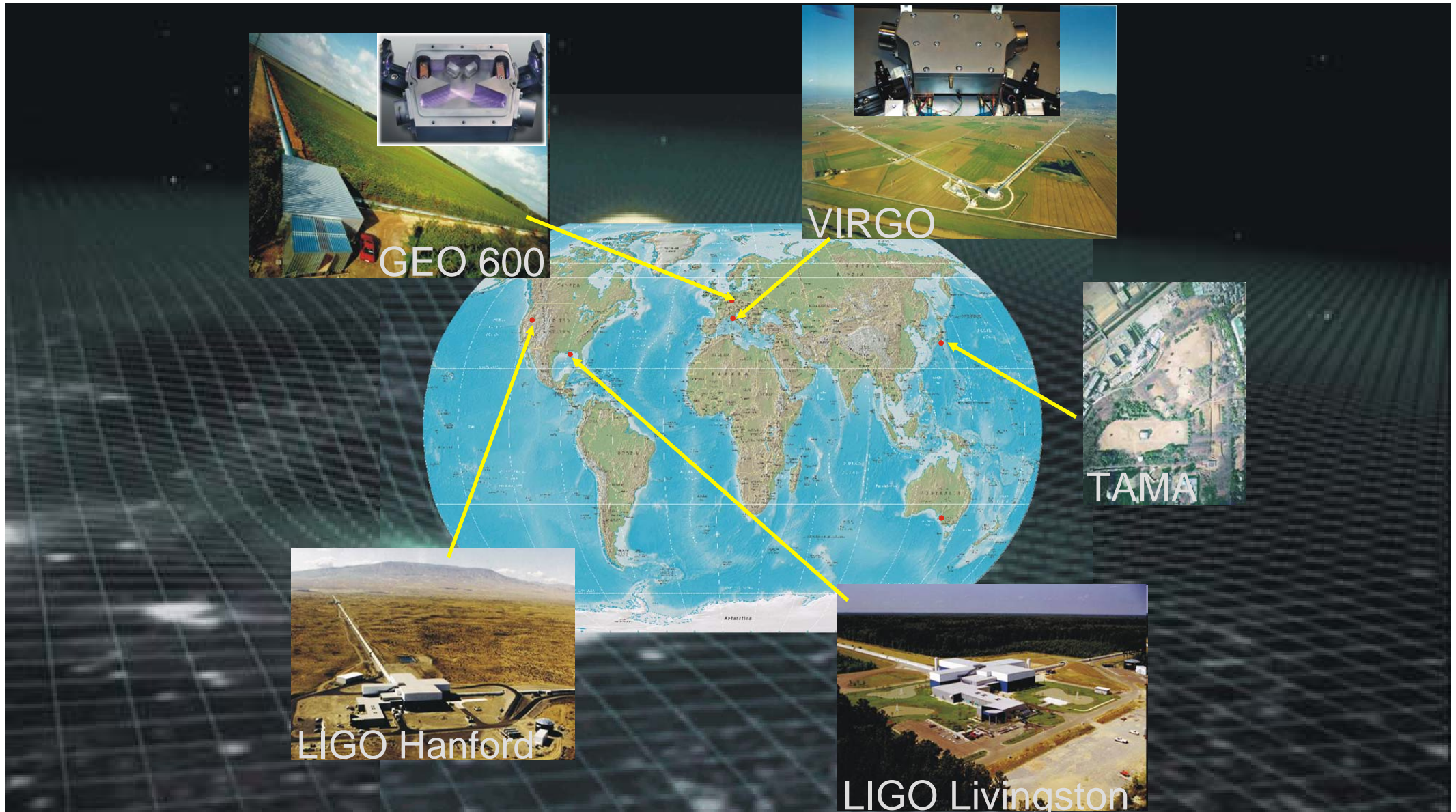
- Conversion to 532 nm
- Green power 20 mW

- Injection-locked cavity in progress



Gravitational-wave observatories

Enhanced LIGO due 2008 – Advanced LIGO due 2013



eLIGO Laser system



Laser head



Diode box



Control box

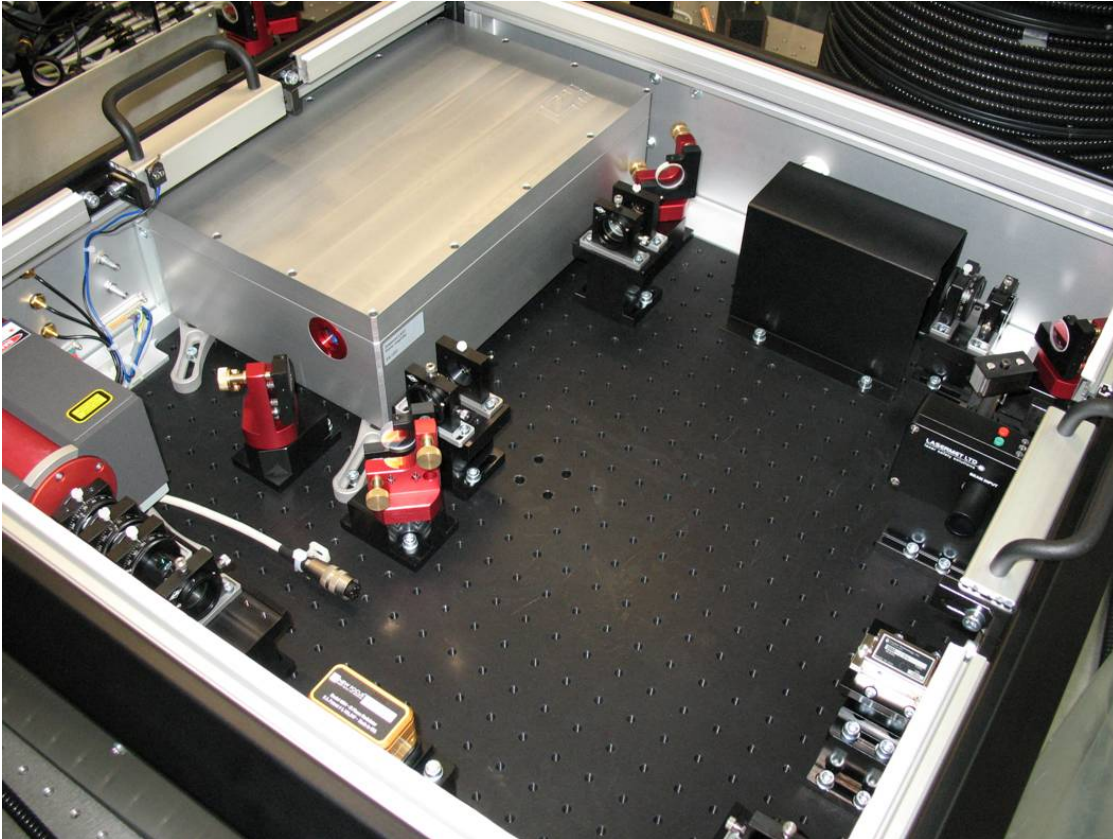


Chiller



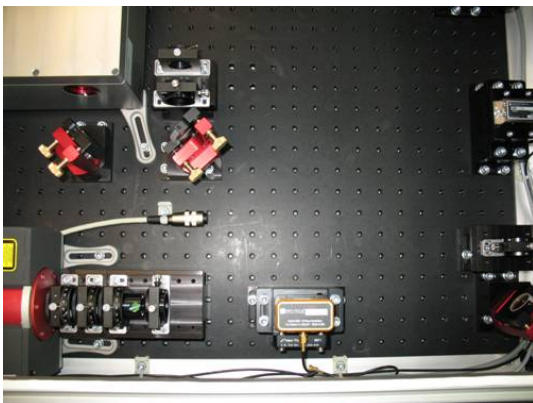
NPRO driver

eLIGO Laser system

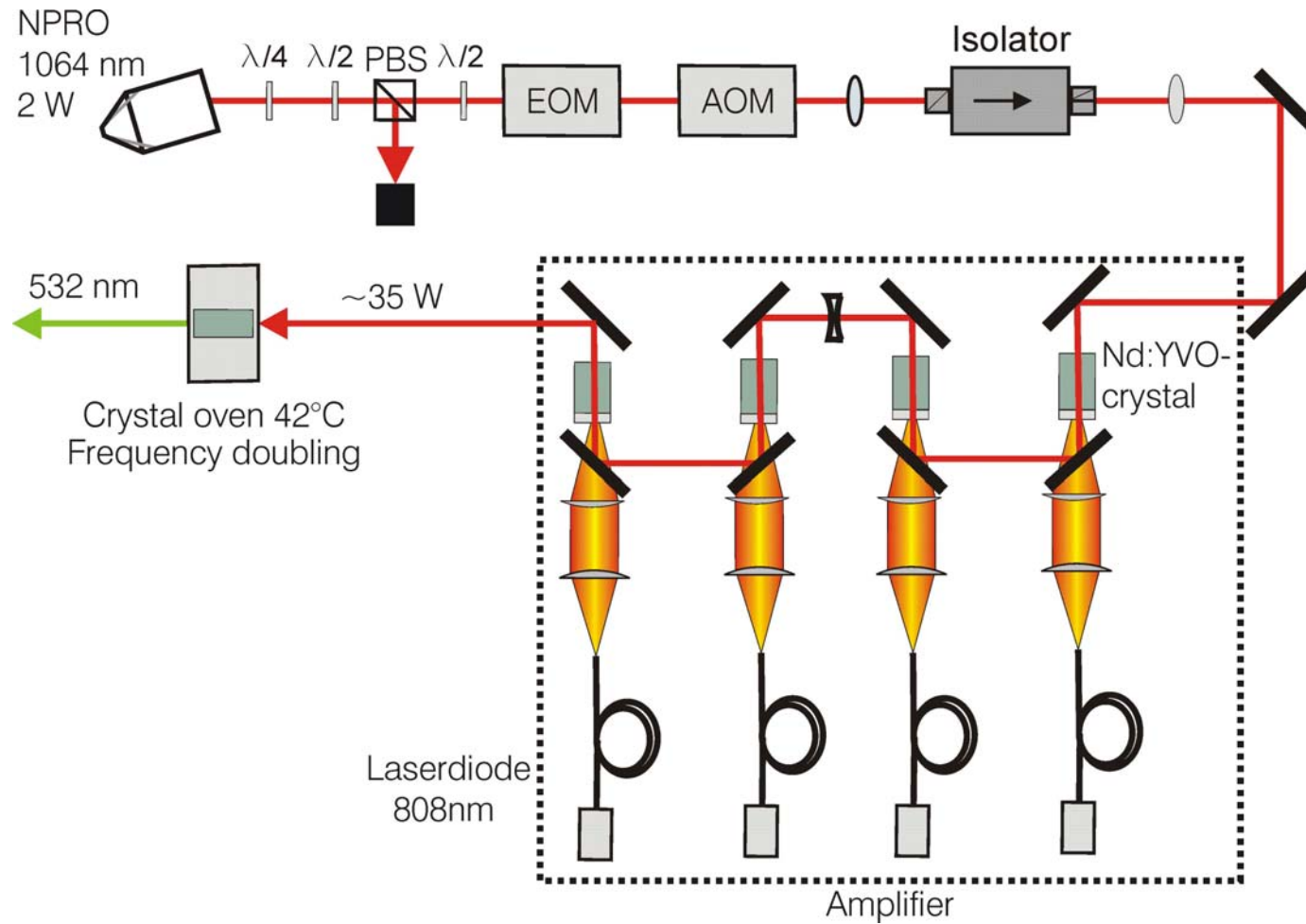


Laser Head

- NPRO
- EOM
 - sideband modulation
- AOM
 - amplitude stabilization
- Shutter
 - remote controlled
- Faraday Isolator
- 4-stage Nd:YVO₄ amplifier

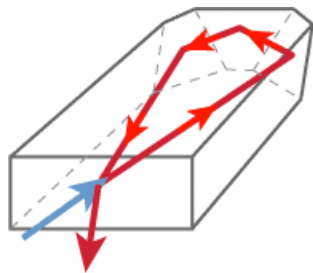


eLIGO Laser system





Mephisto 2000NE



Nonplanar ring resonator

Innolight GmbH – Mephisto 2000NE

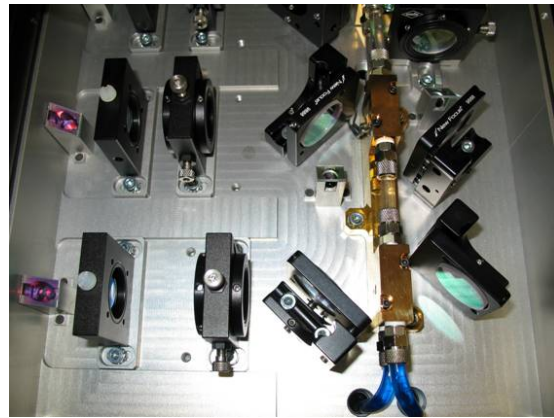
- Nd:YAG laser
- Nonplanar ring oscillator
- Wavelength 1064 nm
- Average power 2 W
- Linewidth ~1 kHz (100 ms)
- Frequency stability ~1 MHz/min
- RIN < -140 dB/Hz (>10 kHz)
- Beam quality $M^2 < 1.1$

eLIGO Laser system



Amplifier

- 4 stage Nd:YVO₄
- Water cooled
- Fiber coupled pump diodes
- Pump power 4 x 32 W
- Seed power 1.7 W
- Output power 35 W
- Pump light pickups
- Laser pickups
- Temperature monitoring



eLIGO Laser system



Diode Box

- 4 pump diodes
- Water cooled heat sink
- Temperature interlocks
- Diode power supplies
- Peltier driver boards with power supply
- Beckhoff interface



eLIGO Laser system



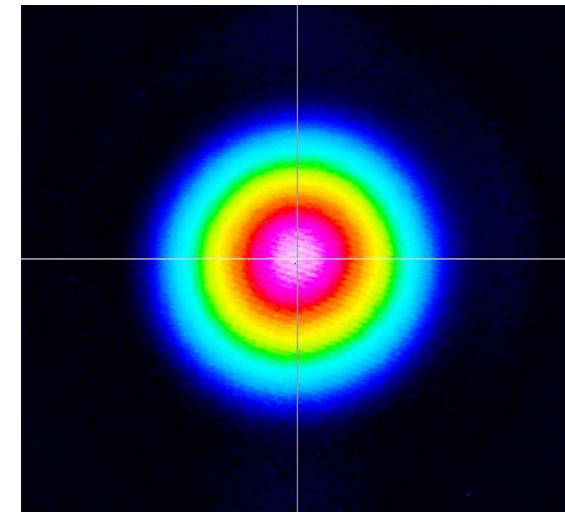
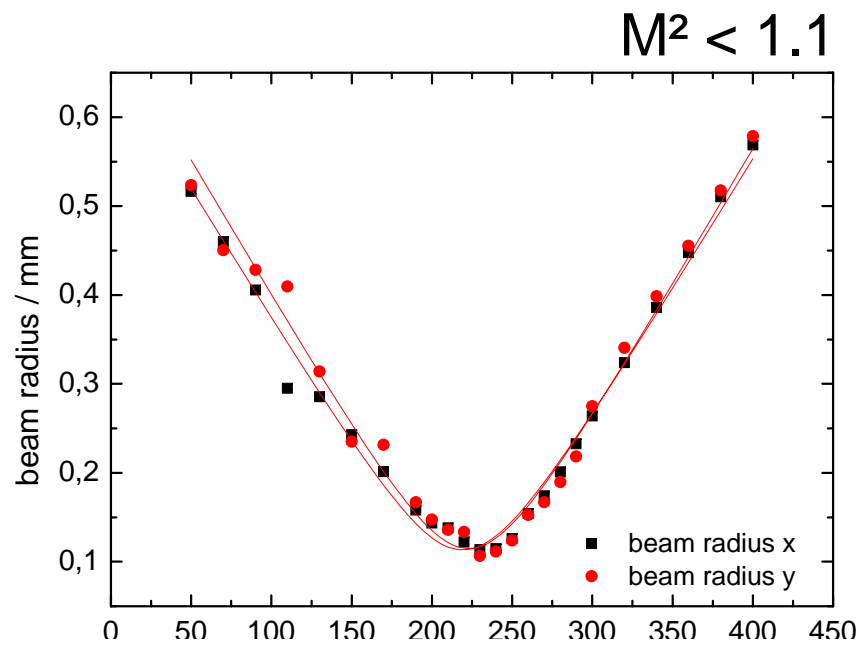
Pickoff calibration	Diode Temps
Current mod	1: 25.0 °C
Power Watchdog	2: 25.0 °C
	3: 26.0 °C
	4: 28.5 °C
	Diode Current
	1/2: 46.0 A
	3/4: 46.0 A
	Mod. depth: 1.0 %
	System Status
Back	Shutter open - system running

Set	Diode Temps	Diode Power
Diag	1: 25.00 °C	1: 33.7 W
Manual mode	2: 25.00 °C	2: 32.4 W
Close shutter	3: 26.00 °C	3: 31.9 W
Reset	4: 28.52 °C	4: 30.9 W
System ON	Diode Current	Laser Power
System OFF	1/2: 46.0 A	1: 10.1 W
	3/4: 45.9 A	2: 13.2 W
	System Status	3: 23.6 W
	Shutter open - system running	

v5 build080219

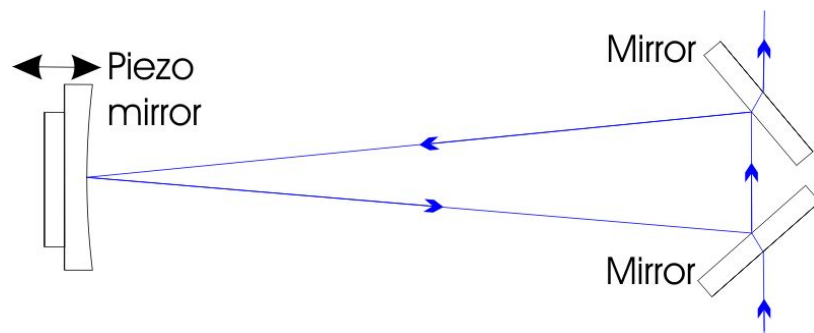
System Operating Hours	NPRO Diag
0d 14h 12m 23s	D1 set temp: 22.0 °C
Misc Diag	D1 act temp: 22.0 °C
Xtal heatsink temp: 23.04 °C	D1 temp error: 0.00 K
DB heatsink temp: 22.60 °C	D1 act power: 2.74 W
	D2 set temp: 23.9 °C
	D2 act temp: 24.0 °C
	D2 temp error: -0.00 K
	D2 act power: 2.80 W
	Xtal set temp: 24.2 °C
	Xtal act temp: 24.2 °C
	Xtal temp error: 0.00 K
	NE monitor: 15.43 mA
	Diode set current: 1.99 A
	Diode act current: 2.00 A
	System Status
Back	Shutter open - system running

Characterization – Laser head

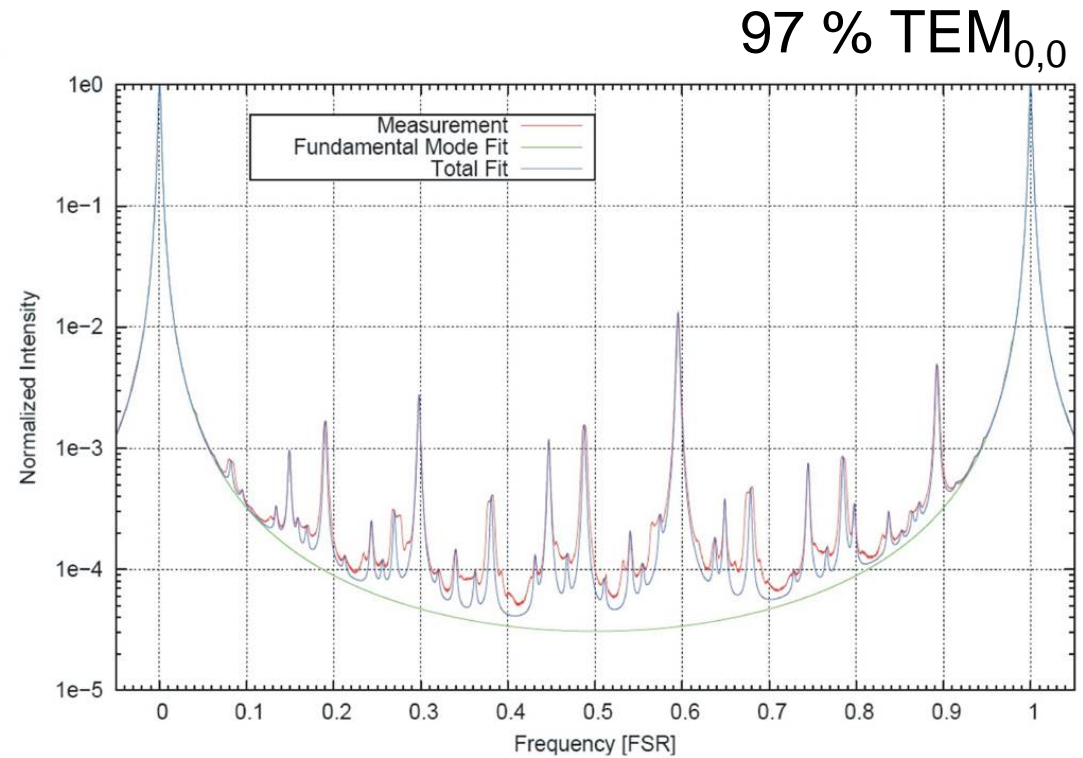


CCD-camera profile

Characterization – Laser head

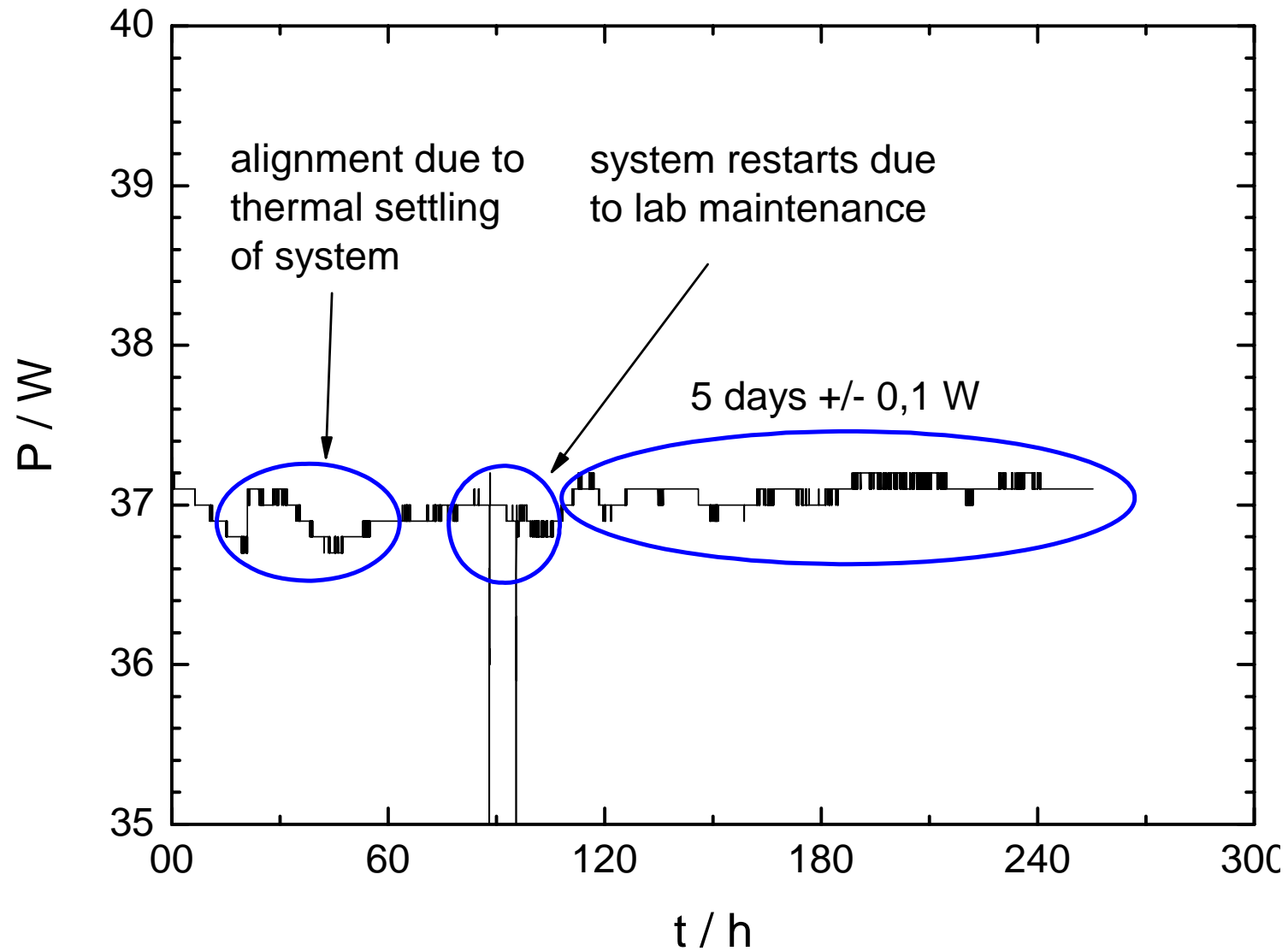


Fabry-Perot ring cavity



Cavity scan (FSR 714 MHz)

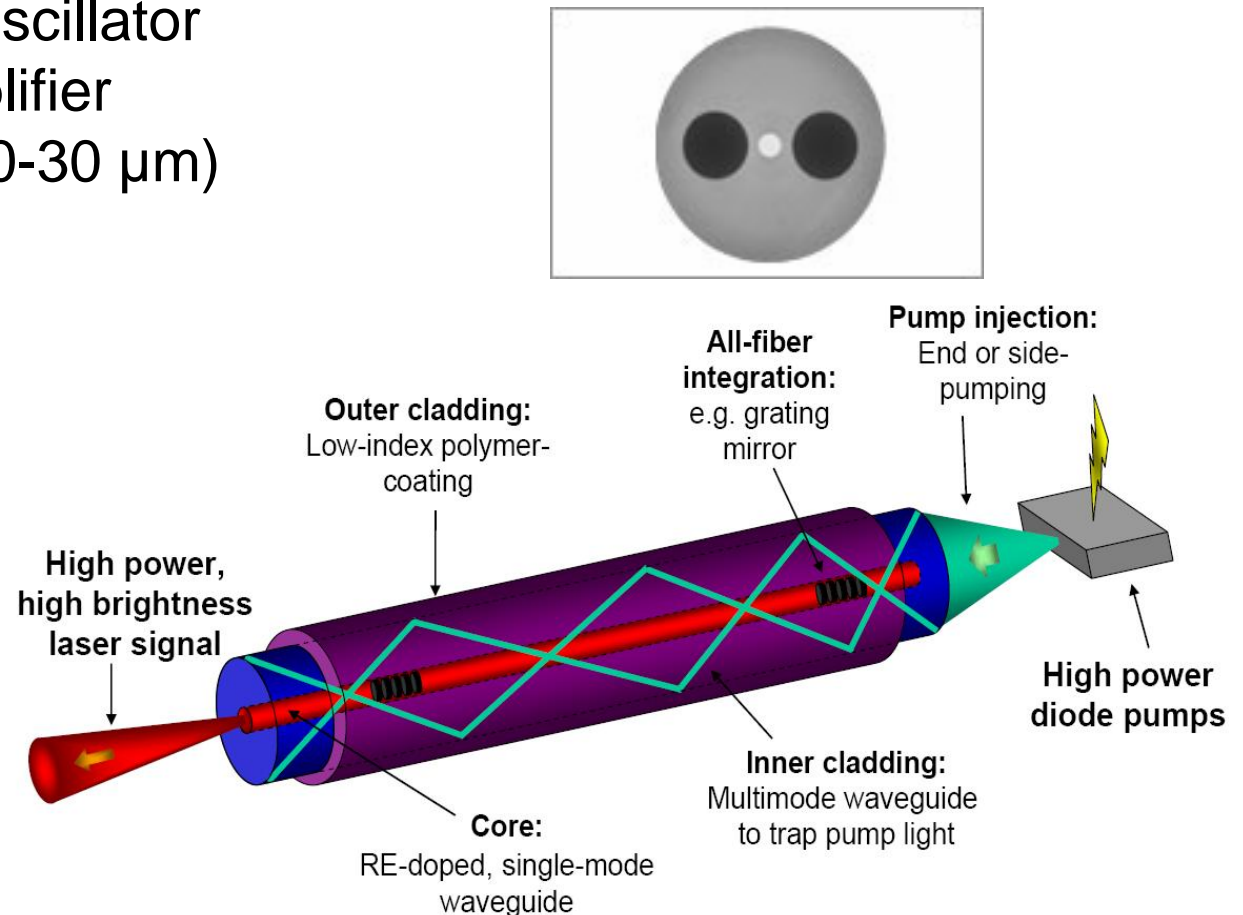
Characterization – Laser head



- Considerations on laser parameters
- Laser systems for ALPS experiments
 - Pulsed and CW operation for single- or multi-pass experiments
 - CW single-frequency operation for injection-locking
- eLIGO laser system
 - 35 W single-frequency at 1064 nm
 - TEM₀₀ content >95%
- Advanced LIGO laser due 2011
 - 180 W single-frequency
 - TEM₀₀ content >90%

Master-oscillator fiber amplifier systems

- Single-frequency master-oscillator
- Ytterbium doped fiber amplifier
- Large mode-area (LMA, 20-30 μm)
- Wavelength 1064 nm
- Average power 402 W
- Polarization <16 dB
- Beam quality $M^2 < 1.1$



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Thank you for your attention!