Status of the ALPS Experiment

Axion Like Particle Search @ DESY

4th Patras Workshop on Axions, WIMPs and WISPs

ALPS @ DESY

using a superconducting HERA Dipole,

primary physics goal:

Axion Like Particle Search

- light shinning through a wall experiment

Any Light Particle Search

- para photons – massive hidden sector γ
- minicharged particles

ALPS Collaboration

- *DESY*
- *Hamburger Sternwarte (Observatory)*
- *Laser Zentrum Hannover*
- *Max Planck Institute for Gravitational Physics (Albert Einstein Institute)*

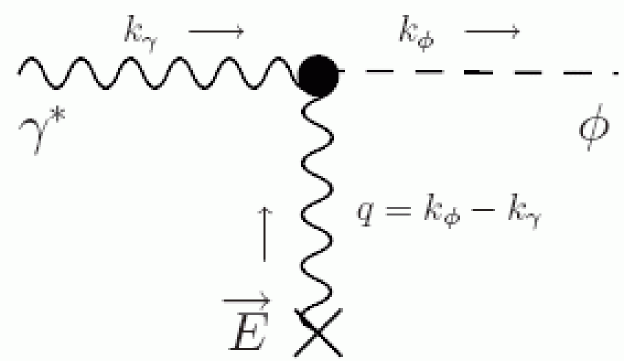
Outline

- Physics
- Experimental Setup
  - Magnet & Beamtube
  - Laser
  - Detector
- Measurements – ALPS Sensitivity
- Improvements: Laser Cavity, Detector
- Status & Plans

New Physics at low Energies

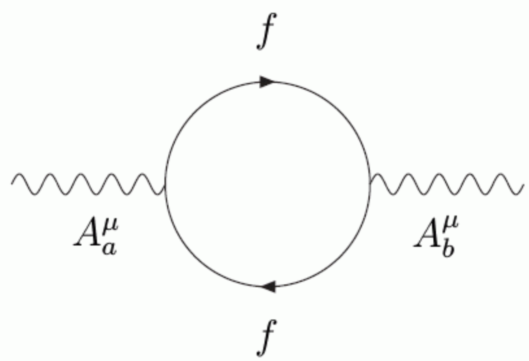
Triggered and inspired by PVLAS observation

- Primakoff effect
  - new neutral particles?



- virtual (or real) production of
  - new charged particles?

  may also involve external fields

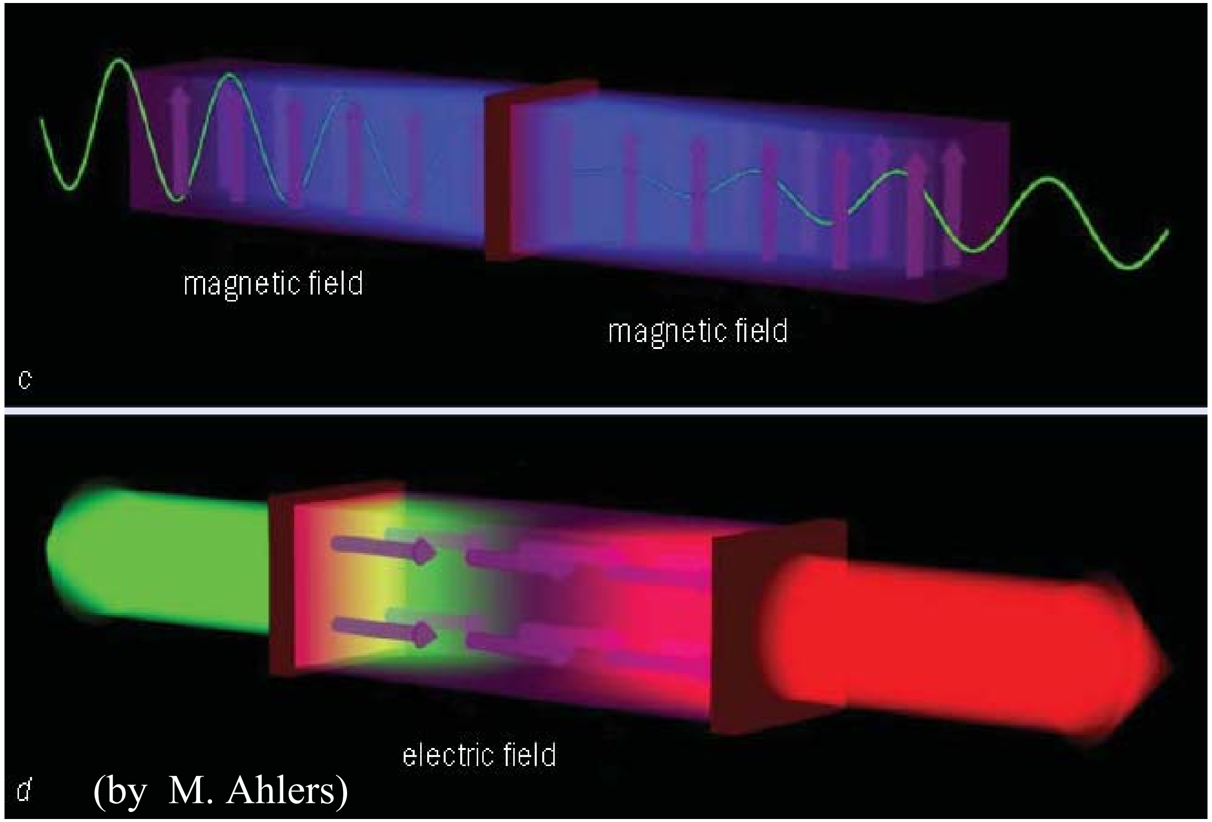


Direct WISP Search

Weakly Interacting Sub-eV Particles

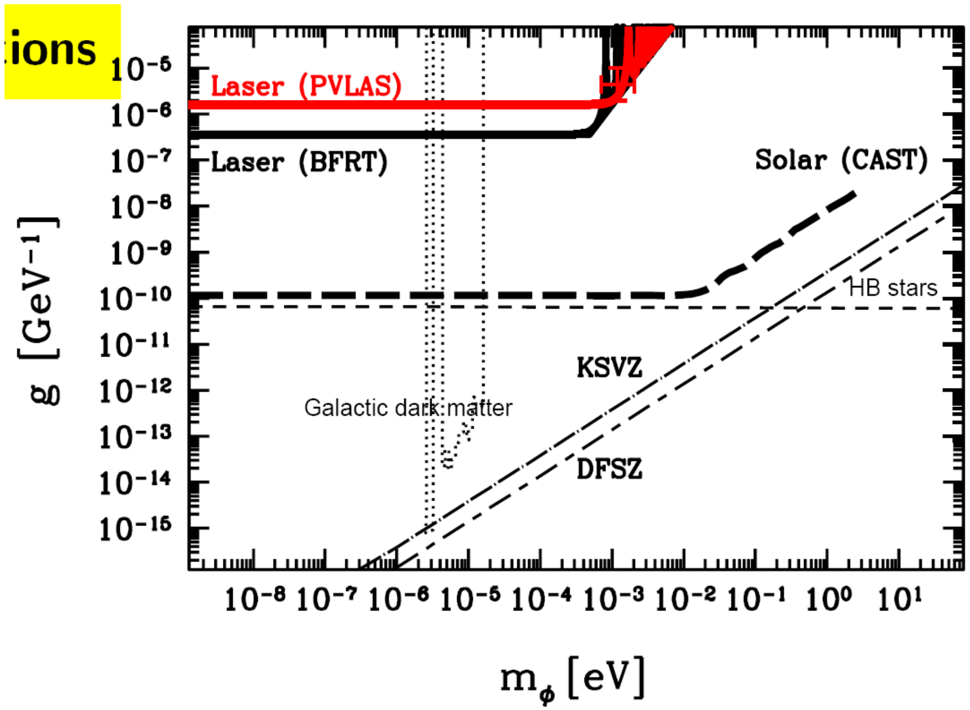
"Light shining through a wall" or "Current through a wall"

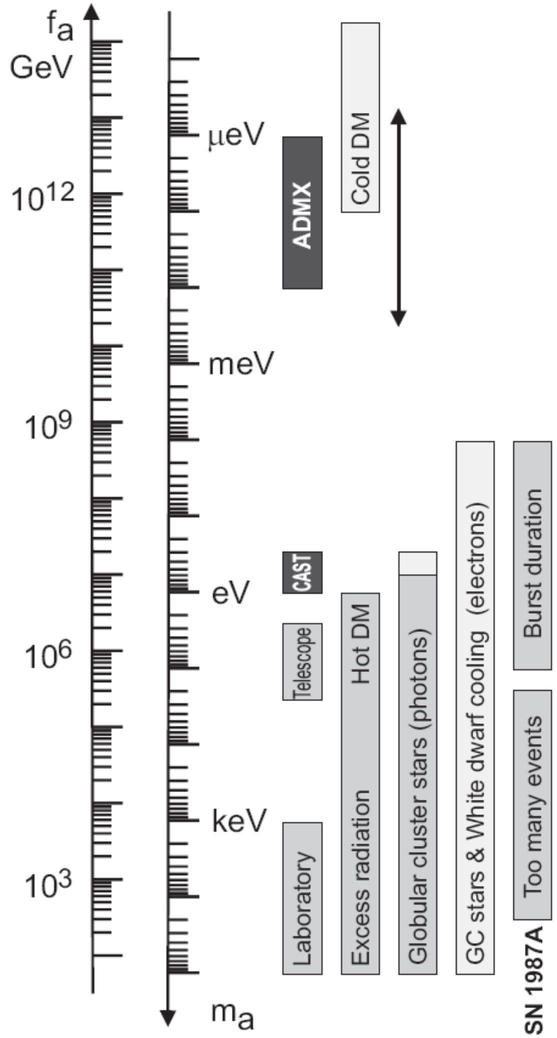
- cross-check of indirect searches,
- determination of properties of new particles,
- access to WISPs not detectable in indirect searches.



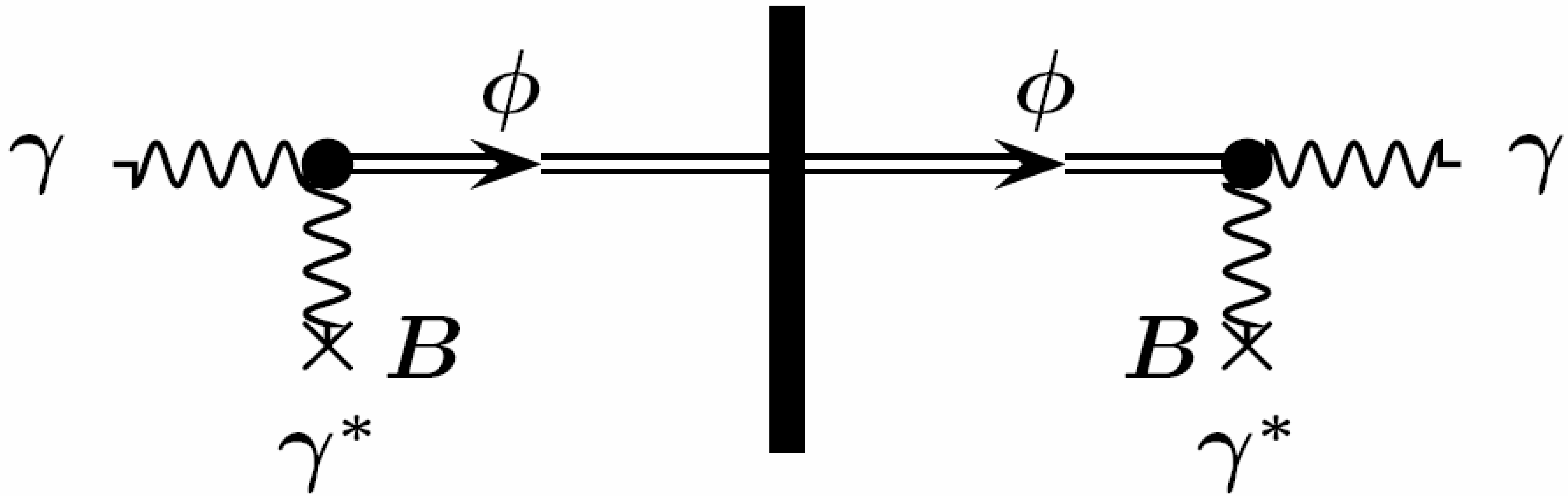
Limits on Axions

- Mainly from Astrophysics, BFRT, GammeV



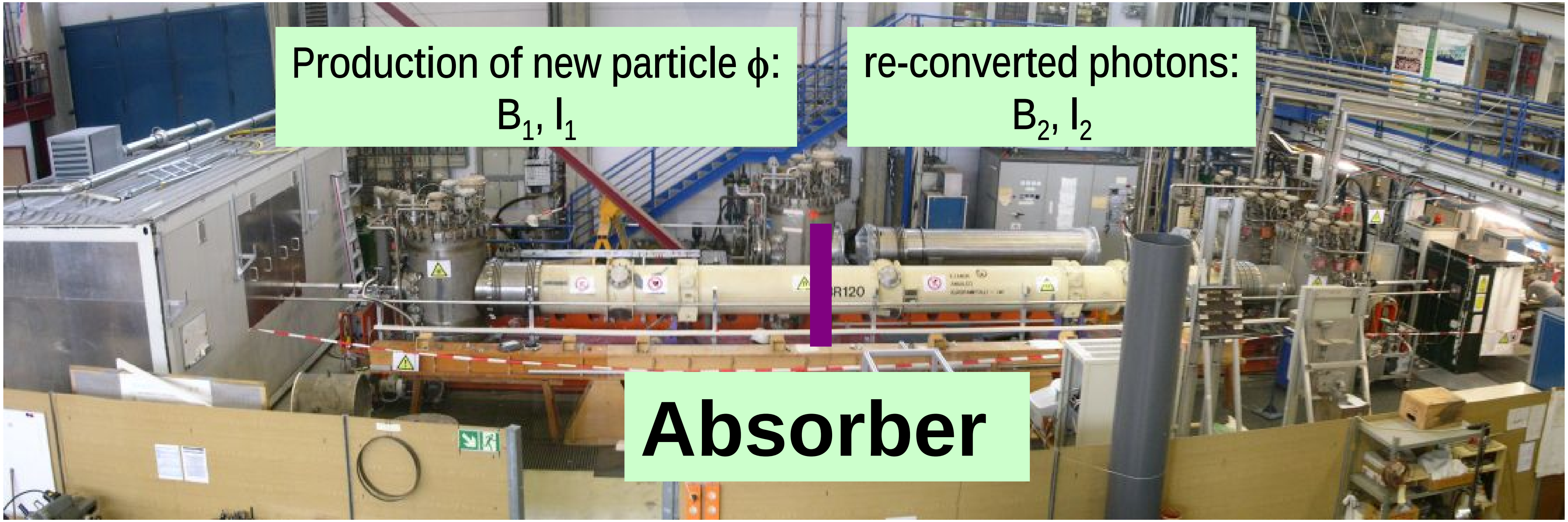


Photon Regeneration Experiments



ALPS Experiment at DESY

Laser **Magnet** **Detector**

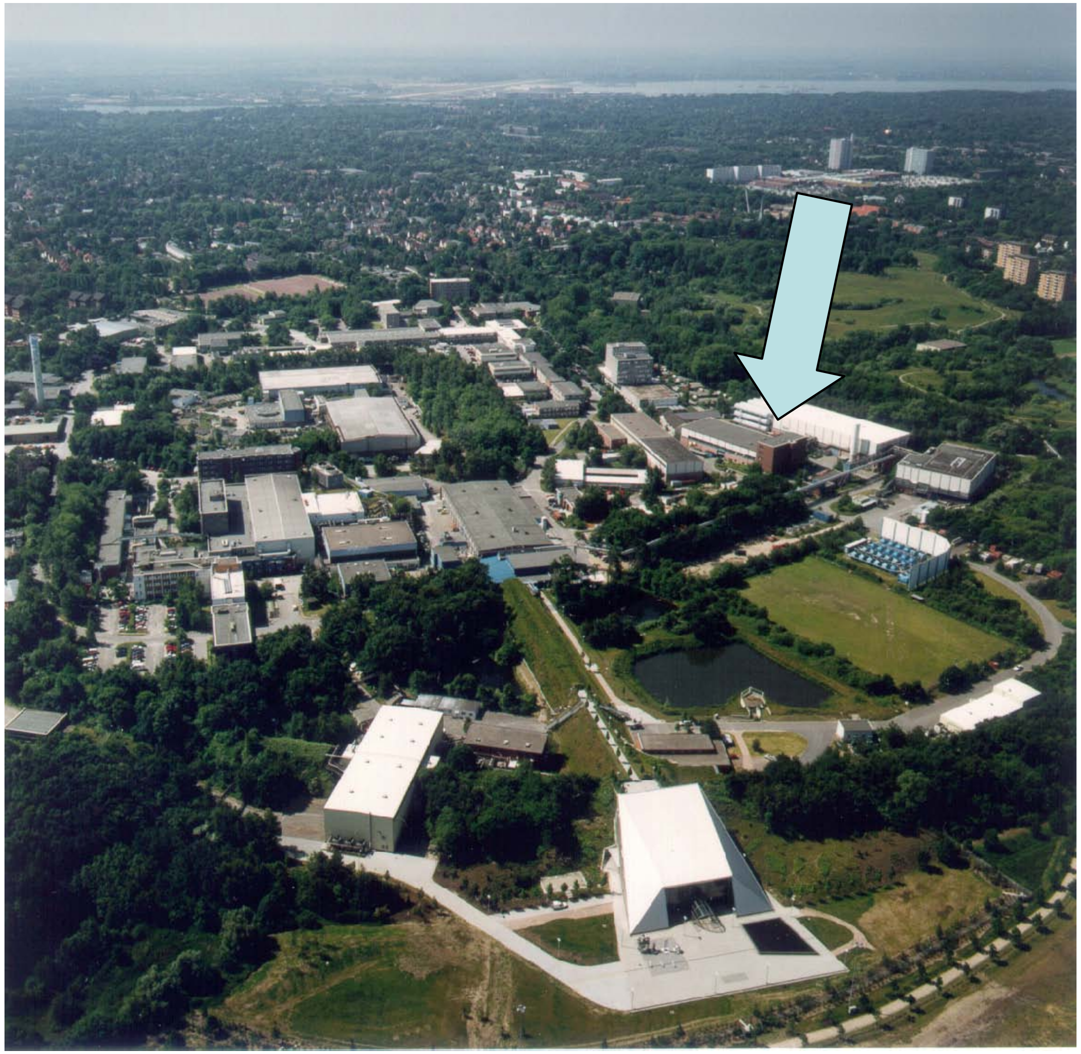


A photon regeneration experiment @ DESY

Location

on the DESY site

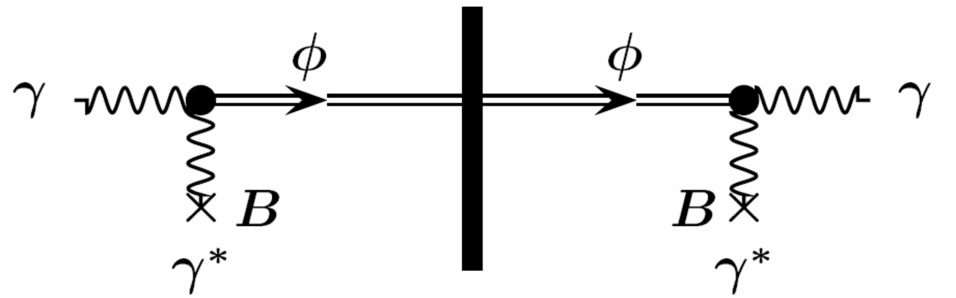
- HERA magnet test hall
- 100 m away



Photon Regeneration in a HERA Dipole Magnet

ALPS@DESY: only one magnet can be used

- Experimental Challenge:
  - mirror and absorber in the middle of the magnet
  - no direct access possible



- Conversion Probability:

$$P_{\gamma\to\phi\to\gamma} = P_{\gamma\to\phi}(B_1, l_1, q_1)\, P_{\phi\to\gamma}(B_2, l_2, q_2)$$

$$P_{\gamma\to\phi}(B, l, q) = \frac{g^2}{4} B^2 L^2 \frac{\sin^2(qL/2)}{(qL/2)^2}$$

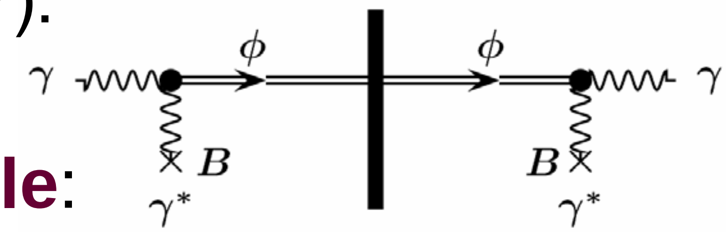
$$q = \frac{m_\phi^2}{2E_\gamma}$$

-> absorber in the middle

ALPS Parameter

- Primary and secondary γ have same properties
- Rate of re-converted photons (for ALP):

  ~ (B·l)^4



- Experimental parameters **HERA-dipole**:
  - Strength of magnetic field: $B_1 = B_2 = 5.16$ T
  - Length of magnets: $l_1 = l_2 = 4.21$ m
- **Laser** - γ parameters:
  - Energy of photons: E_γ (determines ϕ mass reach)
  - Power & time structure: N_γ
  - Polarization: 0+ and 0- ALP
- **Detector**: sensitivity, noise

Brief History of ALPS (1)

- **Summer 2006:**
  PVLAS published indirect hint on new WISPs physics
  Preparations at DESY for the ALPS experiment started.
- **January 2007:**
  Letter of Intent published
  ALPS approved
  Initial plans for an infrared laser
- **May 2007:**
  dedicated funding for ALPS
  ALPS switched from infrared laser to green 532 nm, preparation of phase 0

green (532 nm) vs. red (1064 nm)

In spring 2007:

- camera with high efficiency at 532 nm available
- proper suited (good beam quality) green Laser in hand (3,5 W – Verdi)
- green light is visible – easier operation

-> decision to start with green

more general considerations green vs. red

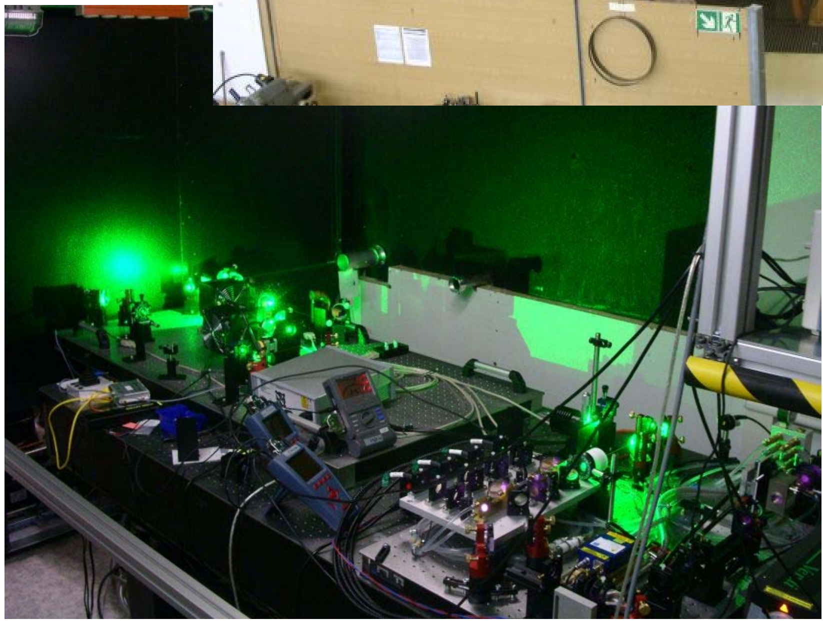
- IR – high power laser available, but good beam quality is not trivial (excludes many industry lasers)
- 532 nm detector systems with high efficiency and low noise available – 1024 nm detectors are a challenging enterprise
- with Laser cavity options also several 100 W green are feasible

-> ALPS sticks to the green Laser option

Brief History of ALPS (2)

- **September 2007:**
  phase 0 data taking with 3 W laser, about 6 h magnet and laser on
- **January to March 2008**:
  commissioning and data taking phase with14 W laser,
  - with magnet and laser
  - study of systematic, stability, alignment and sensitivity
  - end of data taking due to laser induced damage of window of laser tube in the middle of the magnet, improperly coated window by a company
- **March 2008:**
  Albert-Einstein-Institute joined ALPS collaboration to set-up an optical cavity:
  - first step 300 W in magnet (LoI: 200 W infrared),
  - second step up to 10 kW.

ALPS Experimental Setup



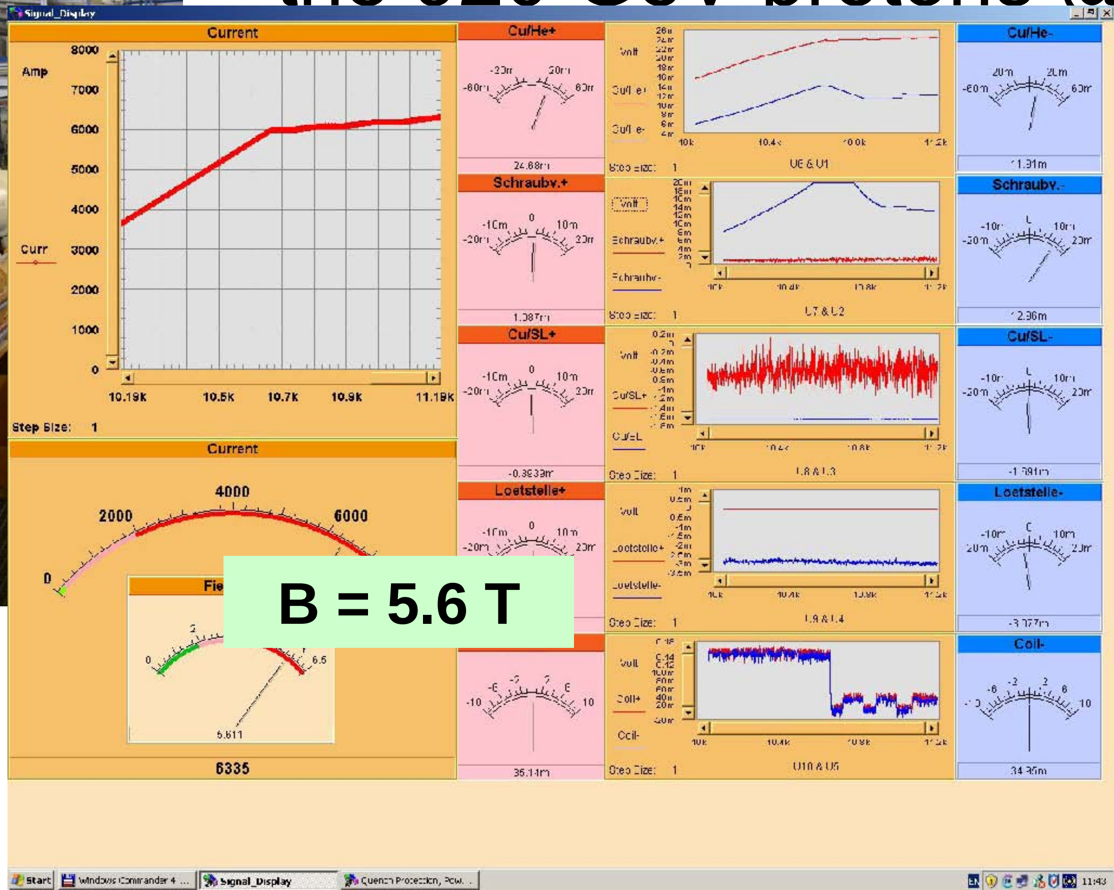
Magnet

Laser

Detector

Magnet: HERA Dipole

- constructed late 80's for the 920 GeV protons @

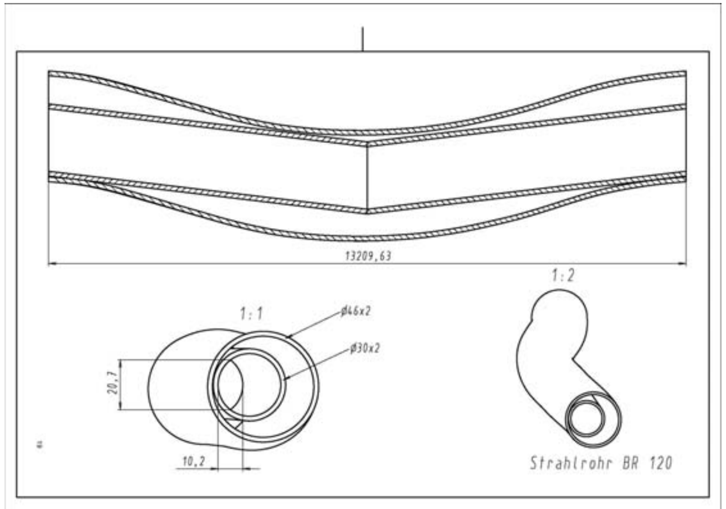


y

HERA-dipole:

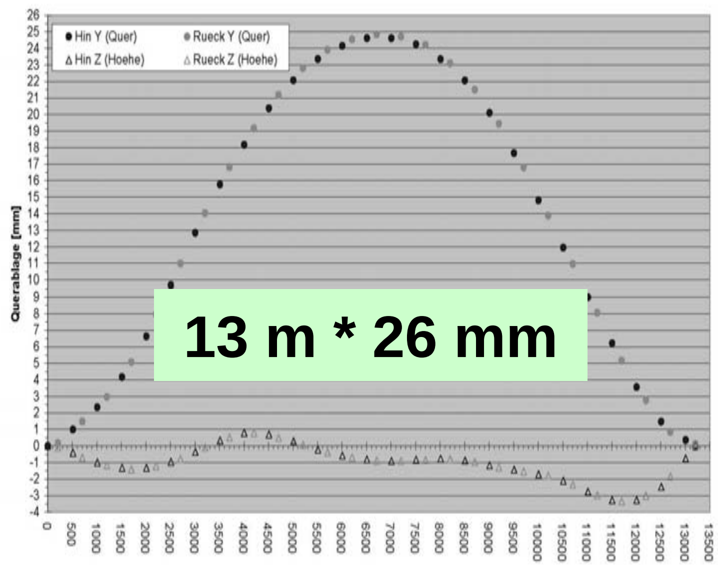
- $B_1 = B_2 = 5.16$ T
- $l_1 = l_2 = 4.21$ m

Magnet: HERA Dipole



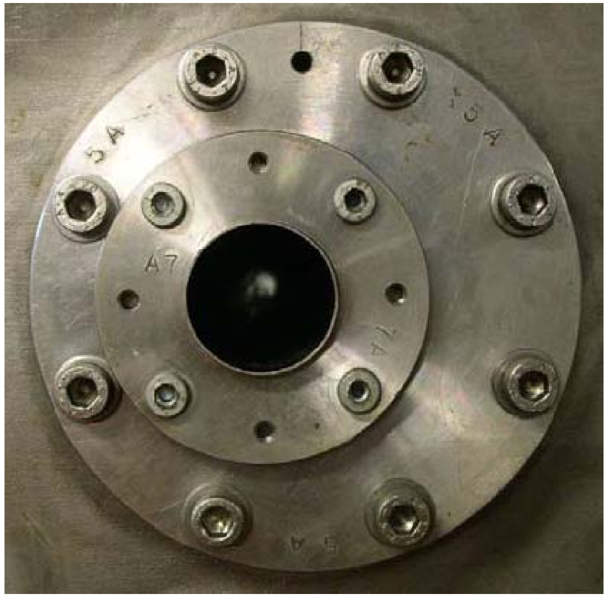
- magnet beam pipe is bent
- clear aperture only 18 mm
- no access to mirror

-> exp. challenge and constrain on beam quality of laser



beam pipe insulated against cold part

can be kept at room temperature



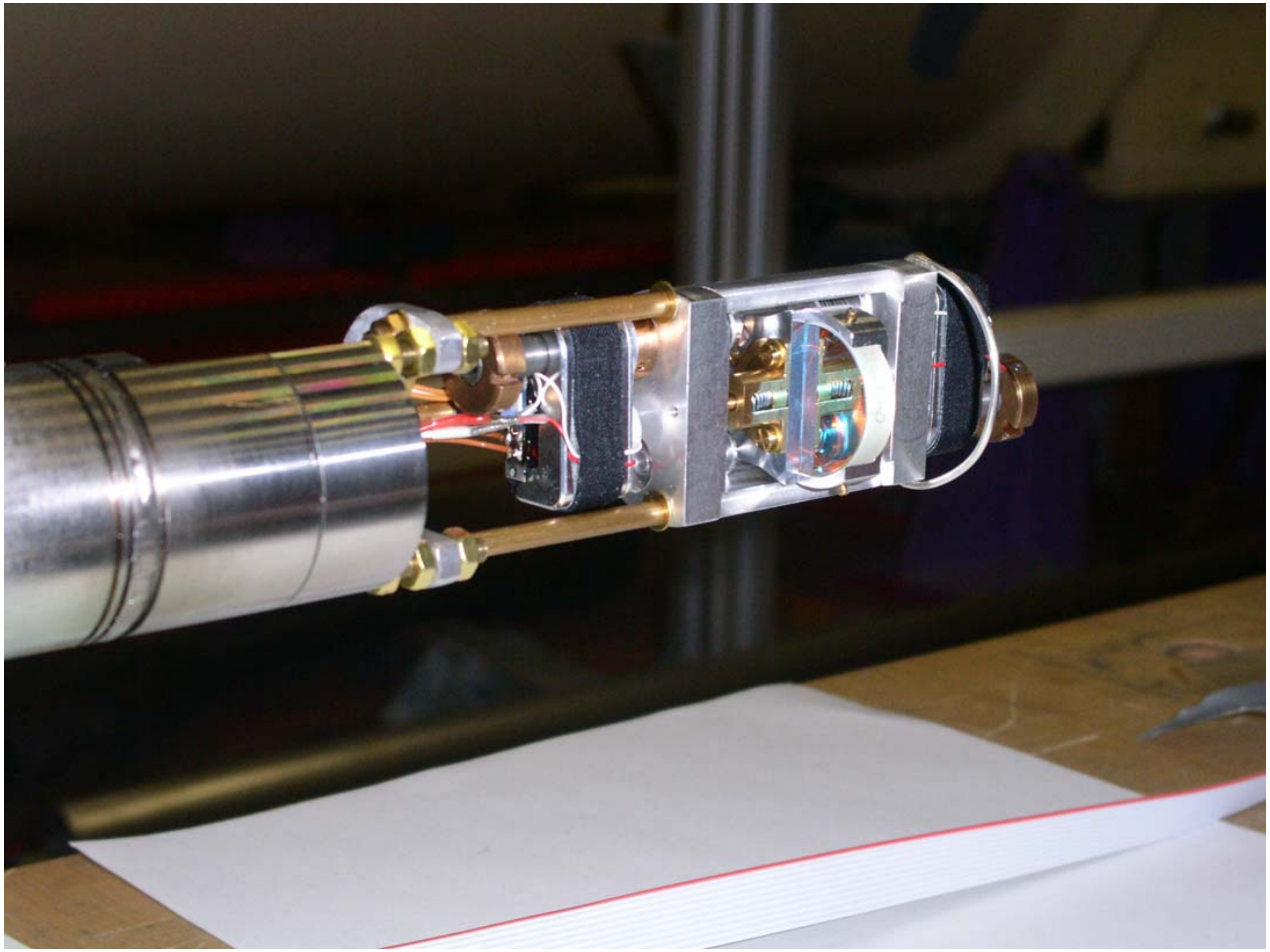
Beam Tubes

two beam tubes – one from each side:

- **"easy" removable**
- **vacuum tight (10^{-7} mbar)**

1. **detector tube:**
   - **removable light tight absorber on inner side (open for alignment purpose)**
   - **window on outer side**
2. **laser tube:**
   - **windows on both sides**
   - **adjustable mirror attached**

Mirror in Beamtube



Autumn 2007

successful installation and operation of mirror steering inside magnet (@ 5 Tesla)

• efficient reflection of high laser power to the outside of the sc magnet essential (avoid quench)

• precise remote control of mirror position (µrad)

-> important precondition for a laser cavity

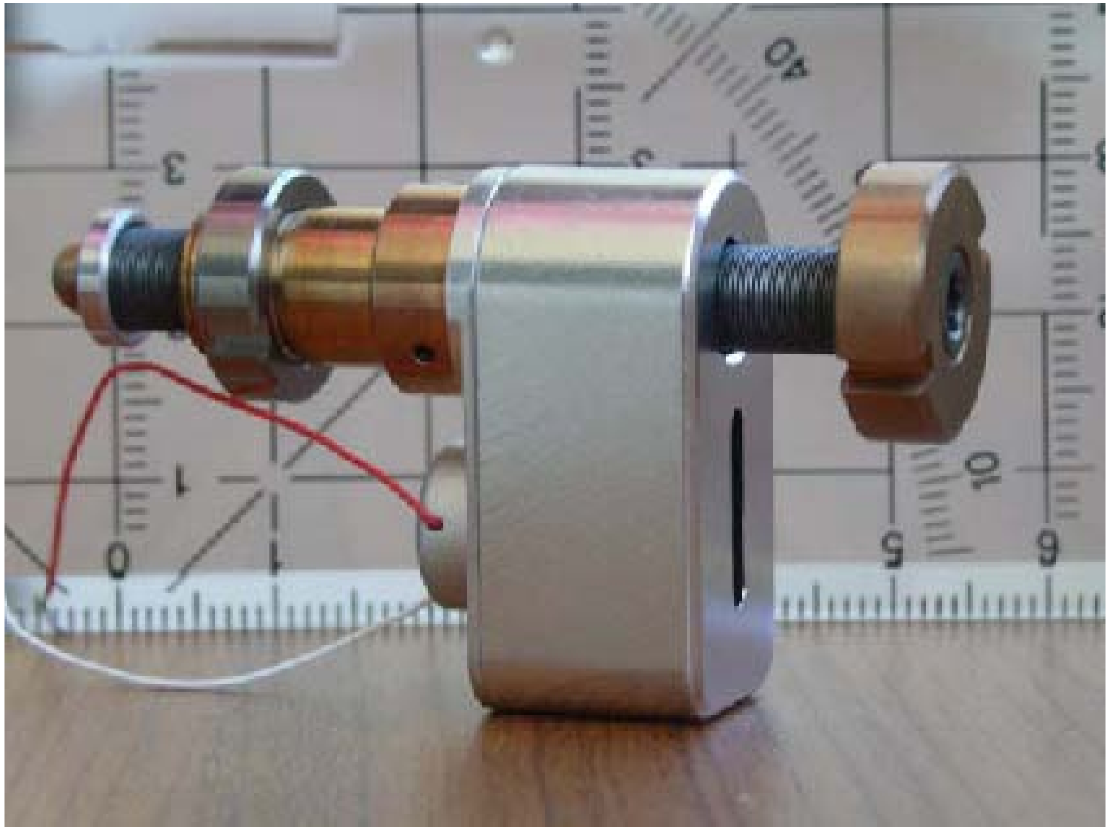
Picomotor

custom made picomotor based on piezo actuators

developed by New Focus (molybdenum, copper)

successful operation in high B field (5 T)

nominal step size around 30 nm



Laser System & Beam Quality

Avoid diffractive losses

- small aperture in beam tube

  => σ < 12 mm

- propagation of be... laser tube

$$\sigma(z) = \sigma_0 \cdot \sqrt{\frac{z \ldots}{\pi \ldots {}_0 / 4}}$$

$$M^2 = \sigma_0 \cdot \Theta \cdot \frac{\pi}{\lambda}$$

Focus Spot Size

- secondary ph... ons focused on s... etector)
- ...s laser
- ...ize comparable ... pixel size of digital cameras

$$\text{focus spot size:} \quad \sigma_{min} = \frac{\lambda \cdot f \cdot M^2}{\pi \cdot \sigma}$$

two talks later this afternoon:

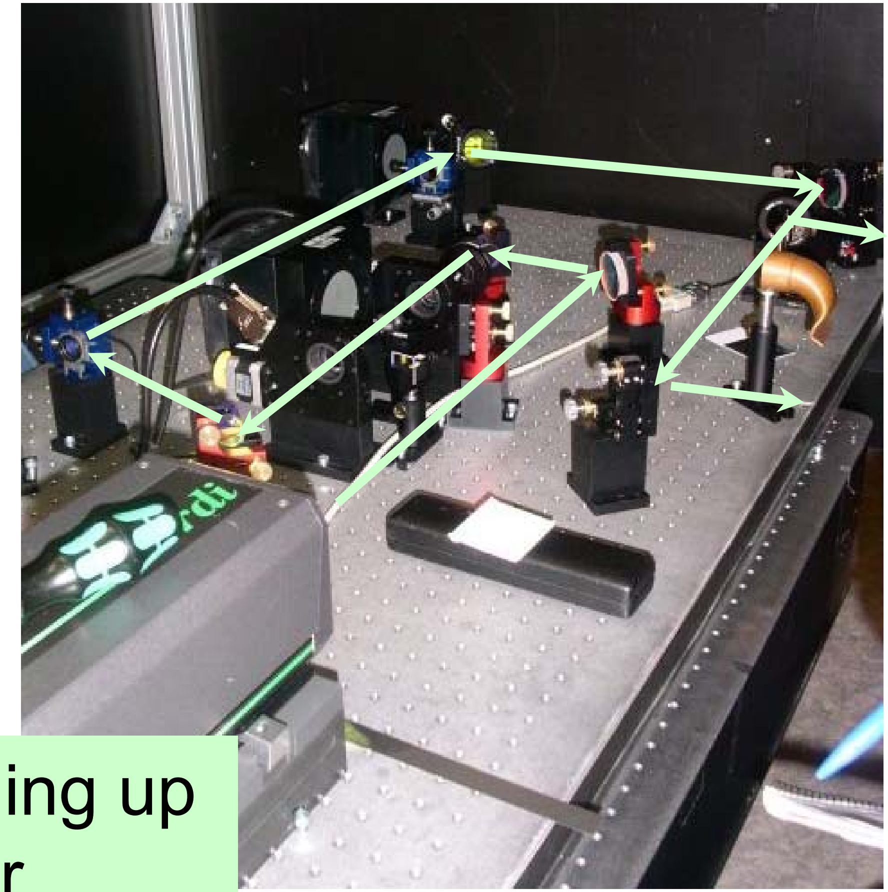
• M. Hildebrand – LZH

• T. Meier - AEI

Laser Setup – 2007

summer / autumn 2007 – phase 0

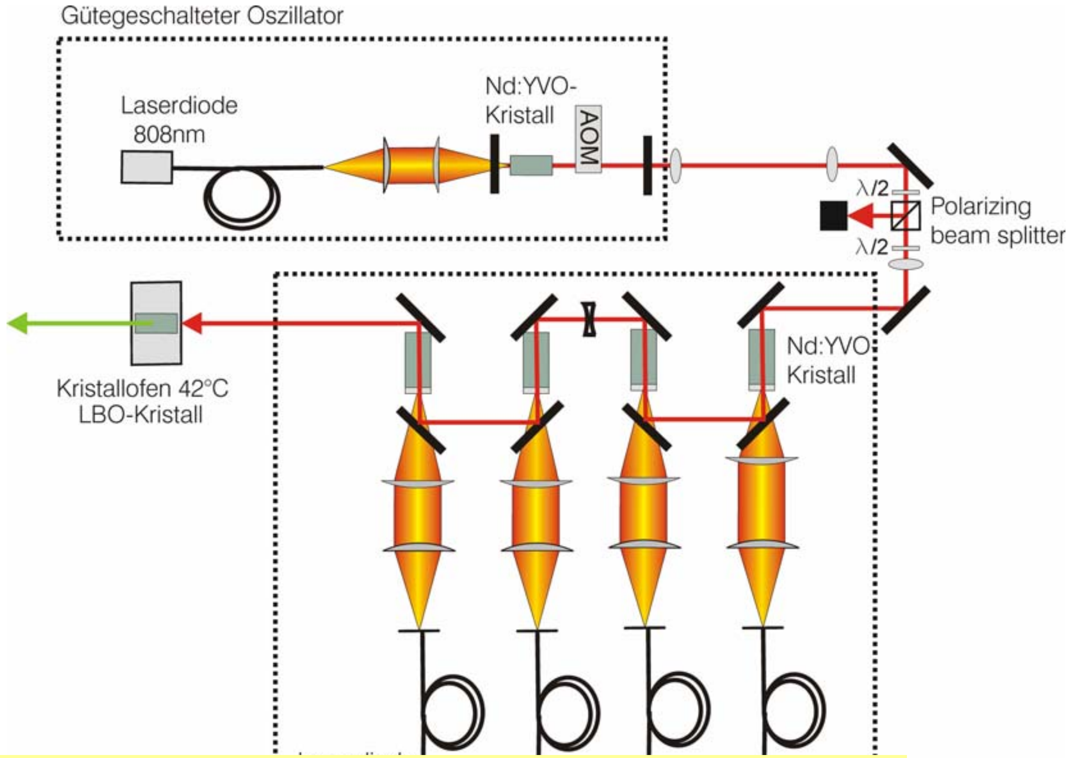
- commercial Laser available (Verdi / Coherent)
- 3,5 W cw Laser @ 532 nm, M^2 <1.1
- adjustable intensity
- polarization rotation
- reference beam



- very valuable experience in bringing up the experiment (handling of Laser, safety issues, alignment, …)
- short data taking period in autumn 2007

ALPS Laser Setup –> March 2008

- **Primary laser: IR 1064 nm, 4 W**
- **Four-stage amplifier (LIGO type): 1064 nm, 45 W**
- **Frequency doubling: 532 nm, 14 W**
- **Photon flux ≈ $4 \cdot 10^{19}$ s^{-1}**
- **Pulslength:15 ns**
- **Repetition rate: 20 kHz**

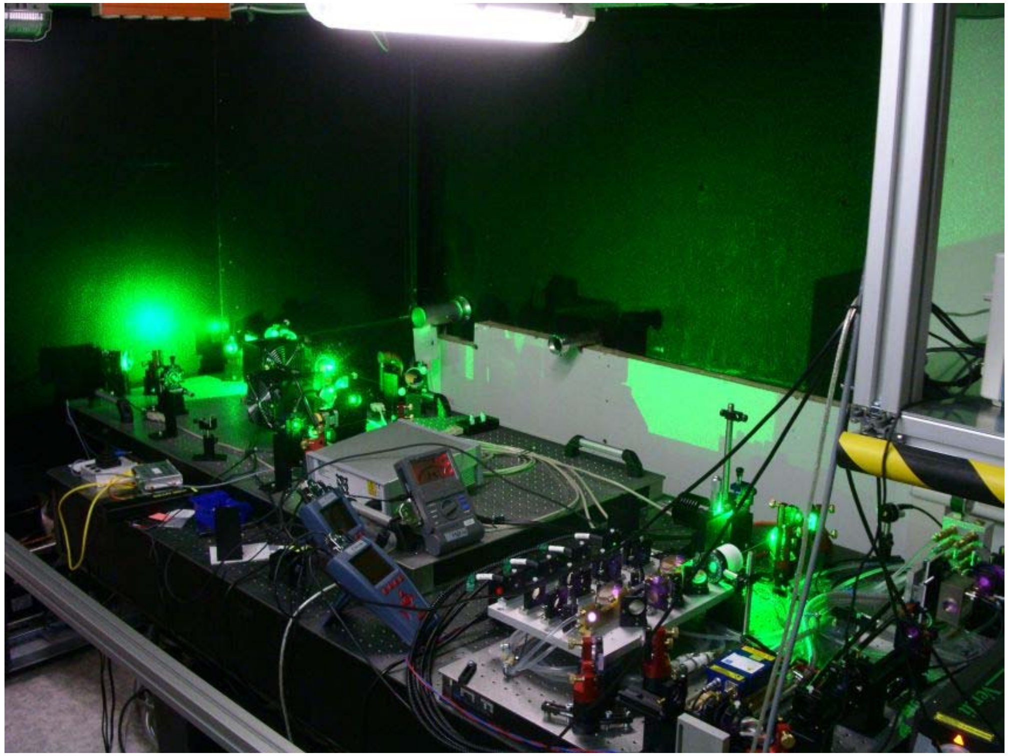


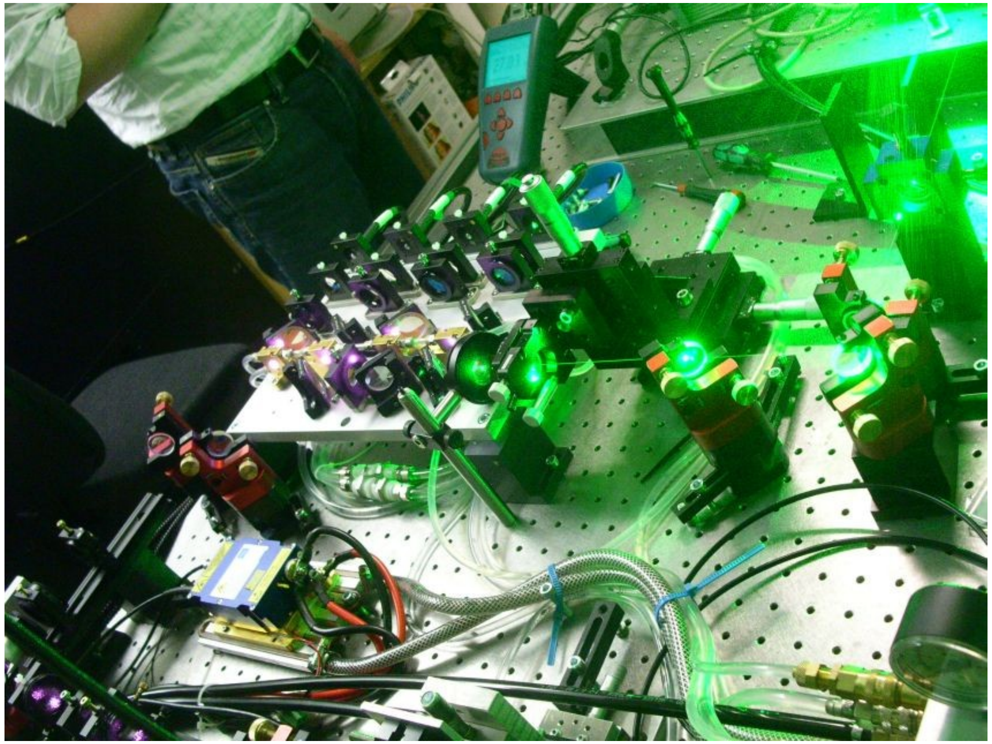
later this afternoon:

- **M. Hildebrand – LZH**

Laser for ALP search

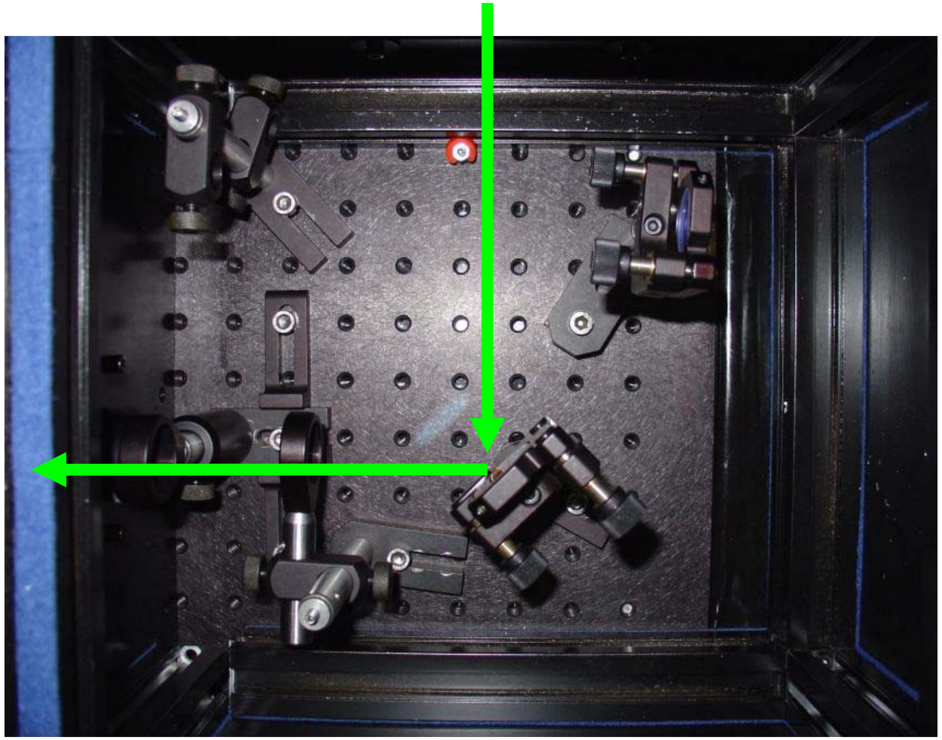
ALPS Laser Setup –> March 2008





- **successful installation and operation early 2008**
- **commissioning and data taking**

Detector - Camera



two beam tubes entering the cabinet / safe:

• reference laser beam

• reconverted “ALP” in detector beam tube

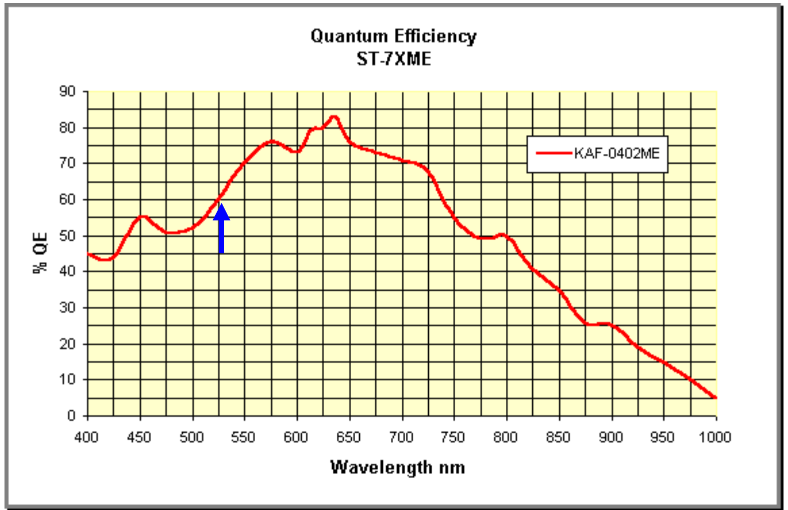
light tight box with optical components installed in safe:

connected to detector beam tube and camera

Camera

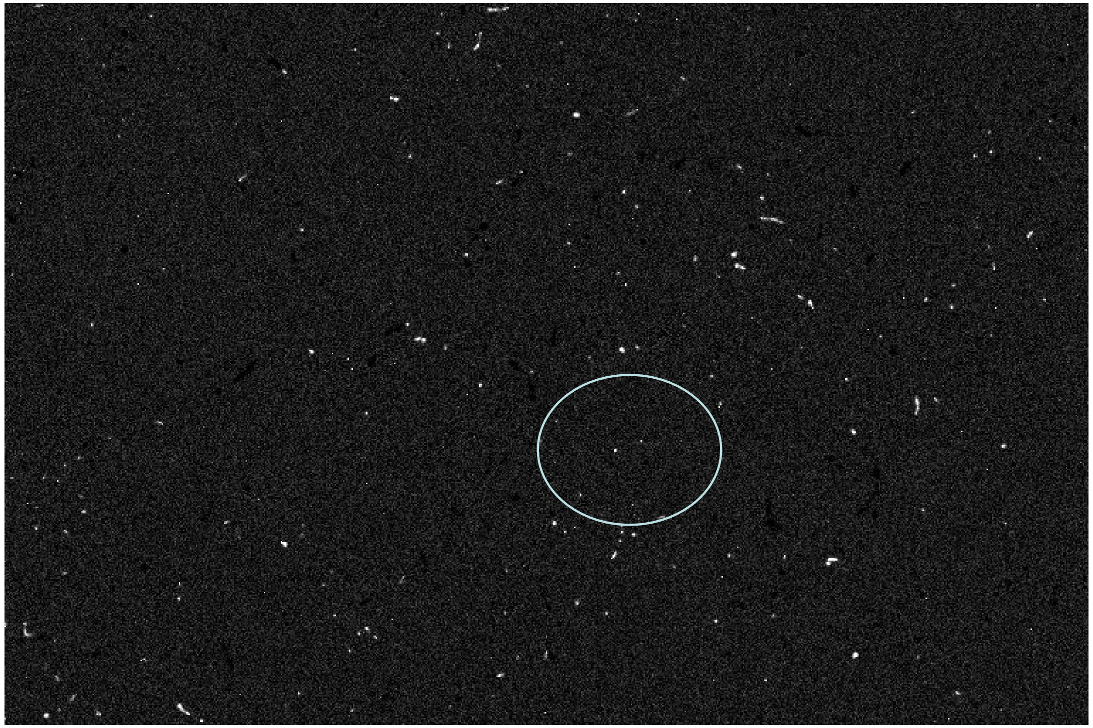
Commercial astro CCD camera
SBIG 402ME

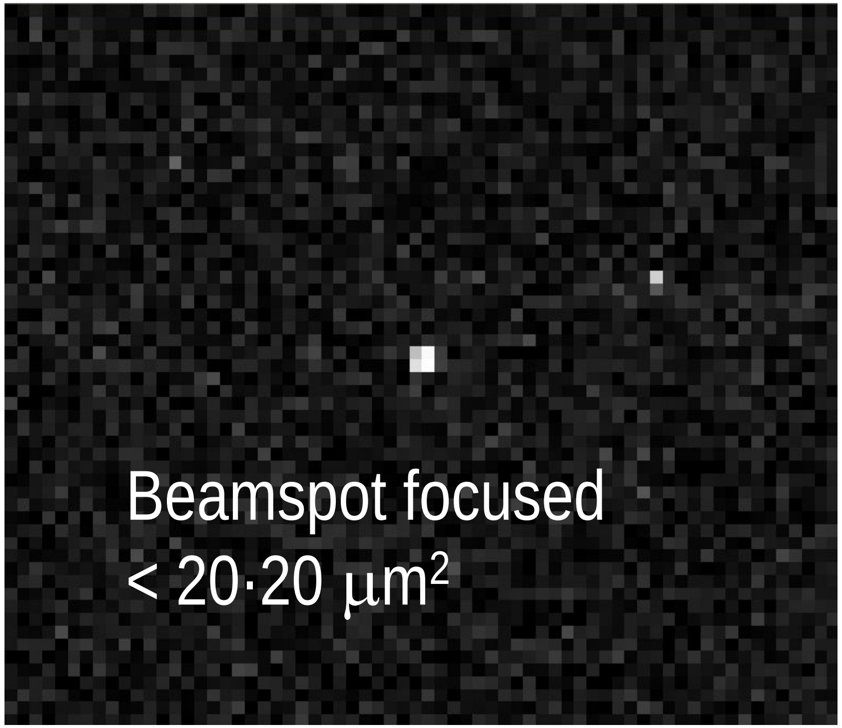
- Operating temperature -5°C
- Quantum efficiency:
  - 85 % at 630 nm
  - 60 % at 532 nm
- Pixel size: 9 µm * 9 µm
- No. of pixels 765 * 510
- Size of chip: 6.9 mm * 4.6 mm
- 1 photon -> 5 electrons
- dark current 0.01e-/pixel/s
- readout noise 17e-
- Focal length of lens 75 mm
- sampling time: 0.04 sec – 1h



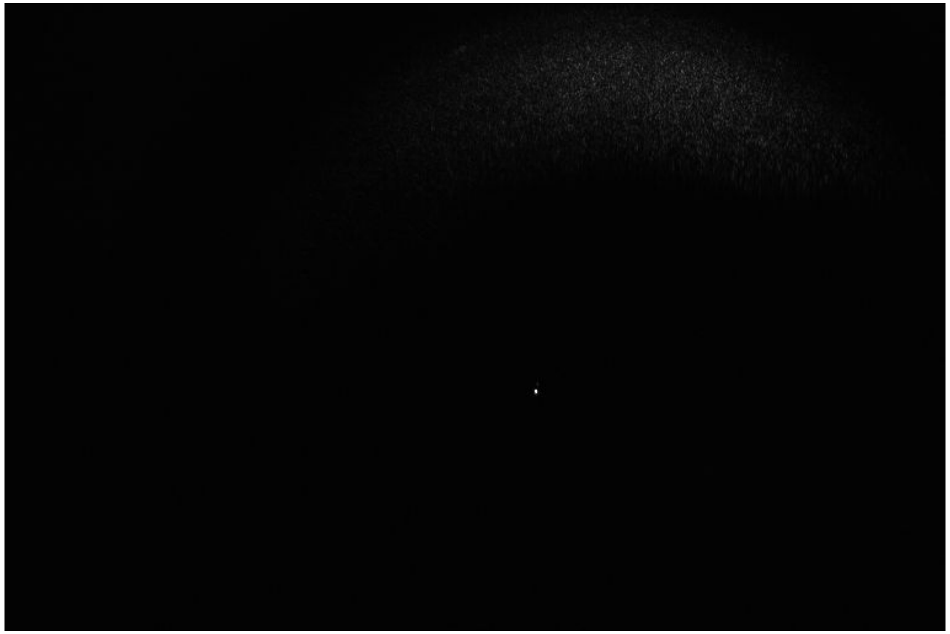
Beam Spot on Camera

- with low photon flux of ≈0.5 Hz
- dark current @ -5°C: 0.04 γ-equivalent / pix /sec
  - **far better than expected**





Alignment Control



- before and after data taking
- difference < 10 µm
- otherwise there was a problem

Commissioning Run in 2008

- **Magnet runs very reliable**
- **Detector works also very reliable & robust**
- **stable long term operation of new 14 W laser after improvements**
- **> 100 h with magnet and laser on**
- **gain experience with handling and stability of setup**
- **identify and improve weak points in the setup:**
  - **mechanical mounting of components**
  - **cooling in Laser hut**

Commissioning Run in 2008

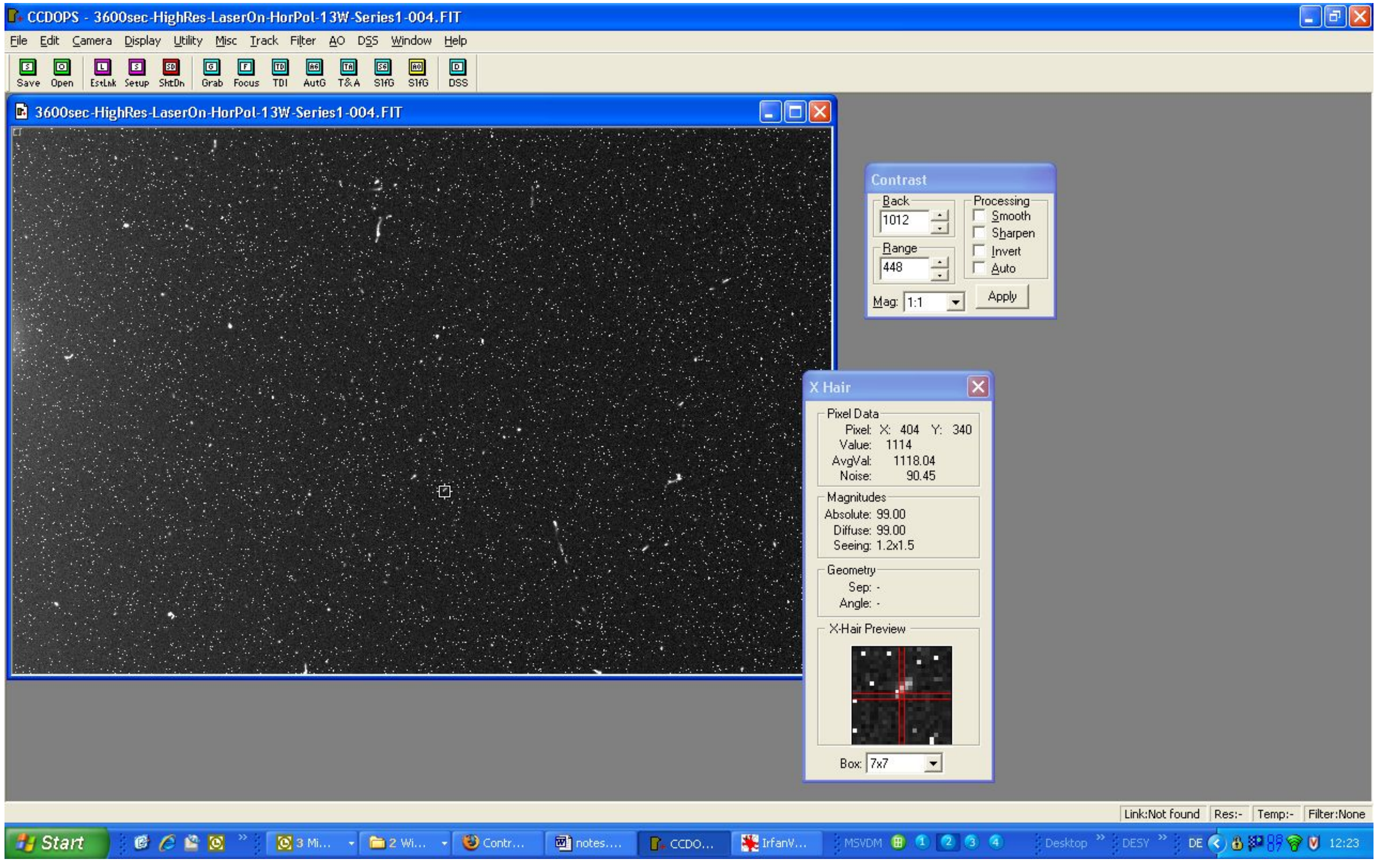
- 20 min or 1h frames: minimizes readout noise while keeping the efficiency due to failures of the setup or cosmics still high
- test and crosscheck of alignment
- data handling & analysis
- explore sensitivity

-> end of this commissioning & data taking period in March due to laser induced damage of improperly coated window of laser tube in the middle of the magnet

-> mirror not as parallel as expected, deflection of light passing the mirror limits knowledge of position of re-converted photons on CCD, no physics

Data Selection

search for cosmic rays in the signal area

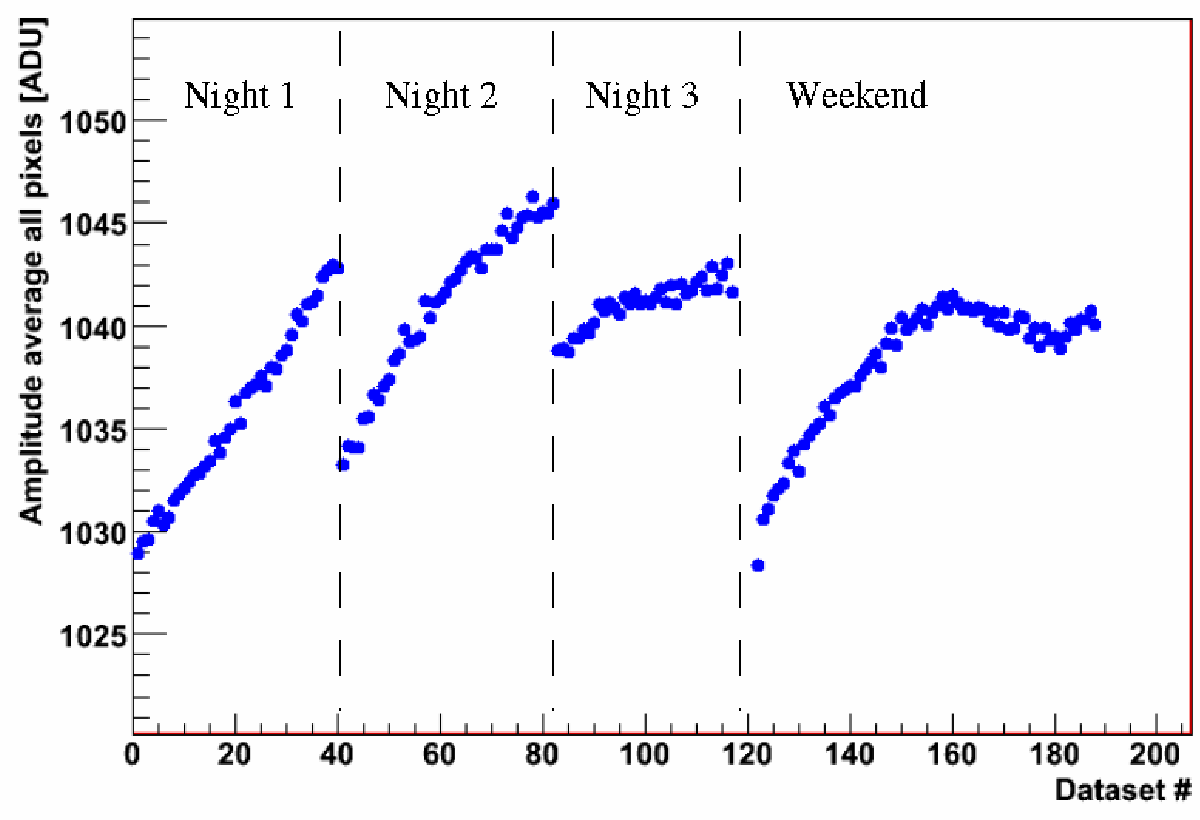


➢ **reject these frames (< 10%)**

Data Analysis

Use dark frames to correct for drift of CCD

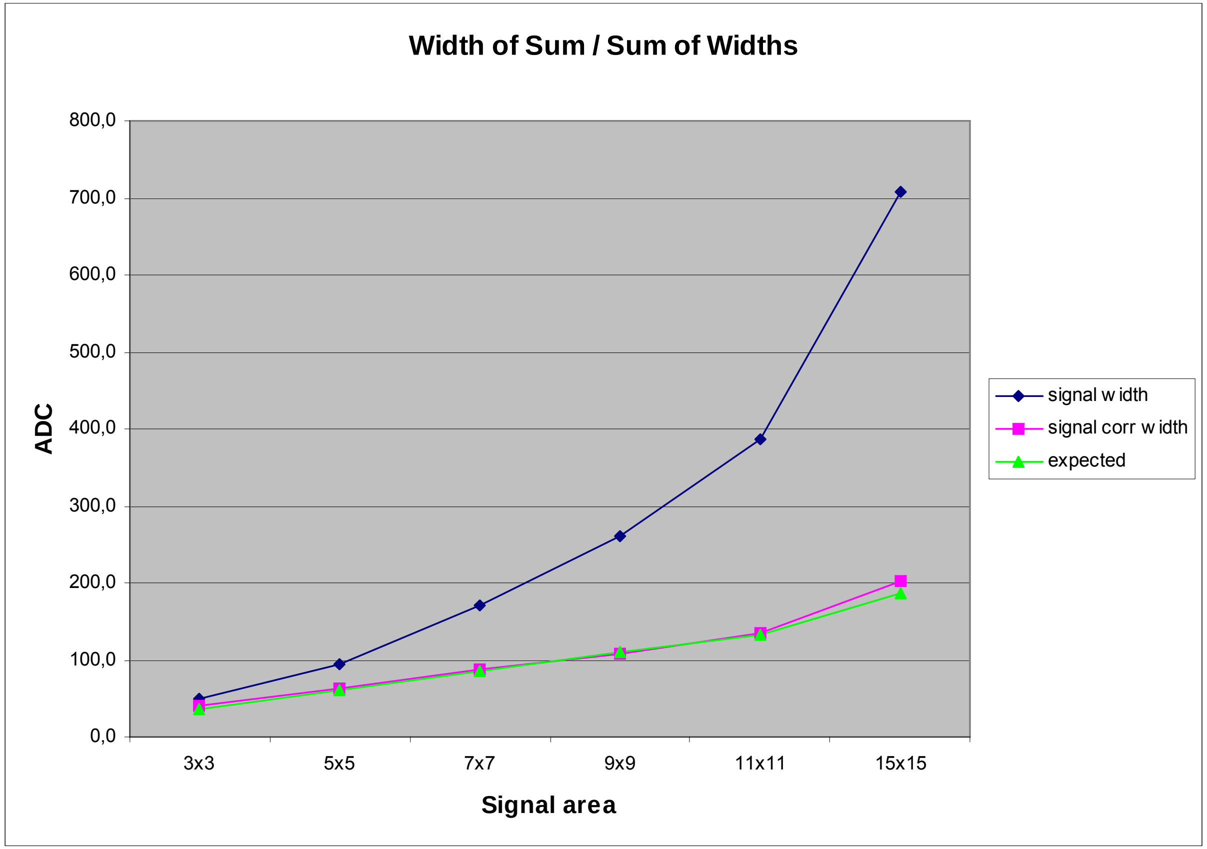
Shift mean pixel amplitude to the same arbitrary value for each frame.



Data Analysis

Remaining fluctuations are due to uncorrelated dark currents and read-out noises of individual pixels.

Width of distribution of sum
of pixels corresponds to quadratic sum of width of amplitude distribution of individual pixels.



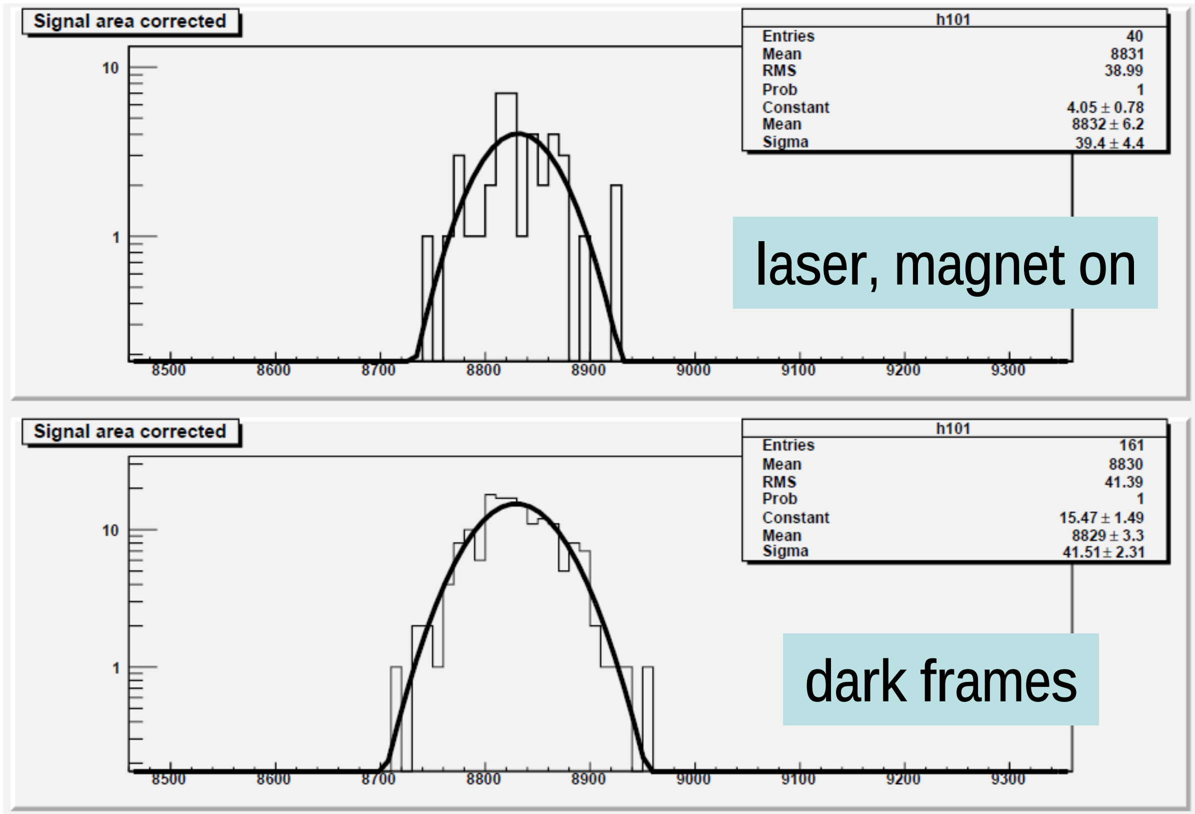
Data Analysis

Compare signal (sum of 3·3 pixels) of data and dark frames

Observable: difference in mean of many 'signal' to mean 'background'

Widths and means of "signal" distributions agree always within statistics for all data

- Data – camera frames (20 min / 1h)
- Signal region – defined by beam spot pictures



Classification of Data

Categories, Signals and Backgrounds

<table>
<tr><th></th><th>ALP-</th><th>ALP+</th><th>MCP</th><th>HidPh</th></tr>
<tr><td>G0 (no laser)</td><td rowspan="2">B_-</td><td rowspan="3">B_+</td><td rowspan="2">B_{MCP}</td><td>B_{HP}</td></tr>
<tr><td>G1 (no magnet)</td><td rowspan="3">S_{HP}</td></tr>
<tr><td>G2-v (LaserV,MagnetOn)</td><td>S_-</td><td rowspan="2">S_{MCP}</td></tr>
<tr><td>G2-h (LaserH,MagnetOn)</td><td>B_-</td><td>S_+</td></tr>
</table>

8 groups of frames to analyze, 4 Signals, 4 Backgr.

conversion from ADU to photons:

- gain [ADU / p.e.]
- quantum efficiency [p.e. / γ]
- beam spot eff. / stability
- laser power, optical losses

Data Analysis

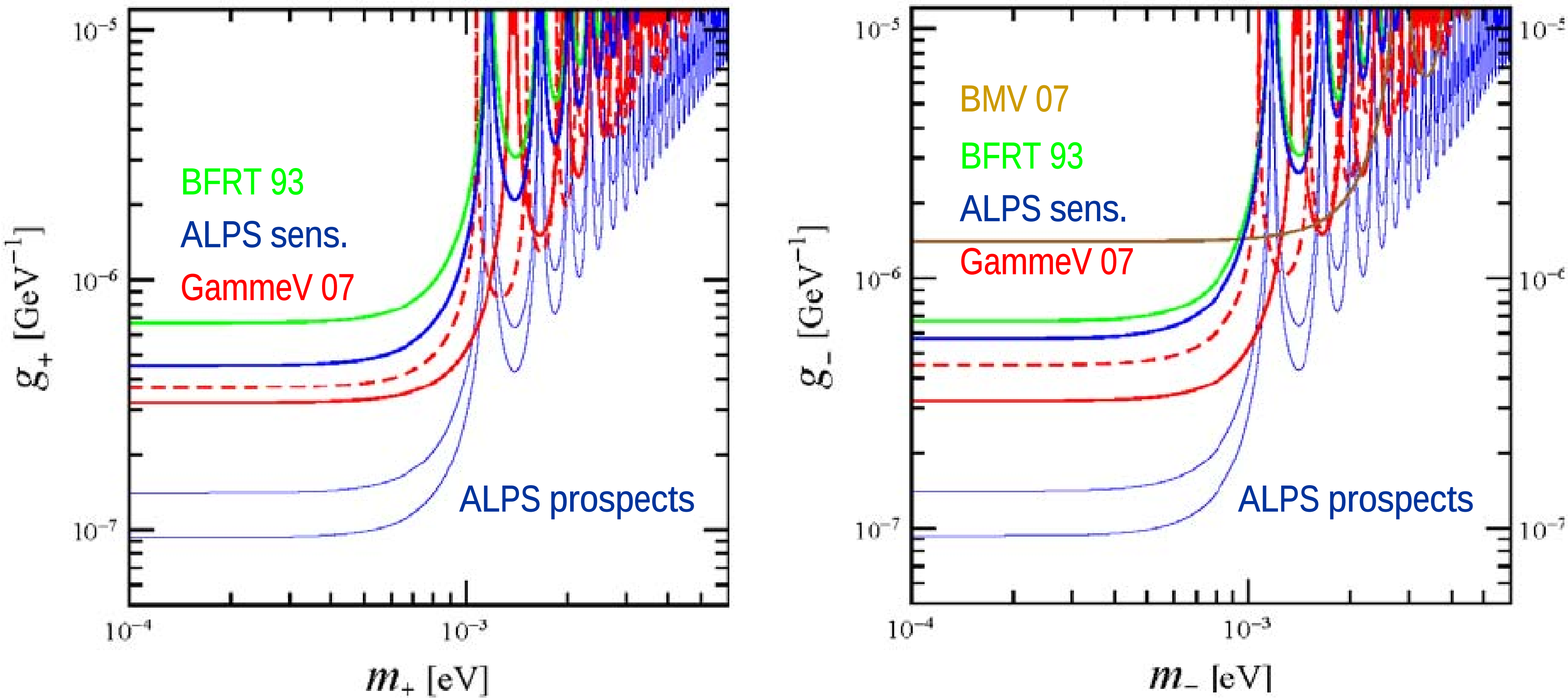
1. Remove frames spoiled by cosmic rays in the signal area.
2. Correct for drift of CCD.
3. Compare signal (sum of 3·3 pixels) of data, dark frames.
4. Calculate upper limit for flux of re-converted photons from difference of mean values of “signal” and background amplitudes.
   - conservative estimates for efficiencies and systematic
   - no attempts yet to partly recover from misalignments
   - sensitivity study (not a physics analysis)

-> Sensitivity to re-converted photon flux ~ 40 mHz

-> with actual Laser: $4 \cdot 10^{19}$ γ/s^{-1}

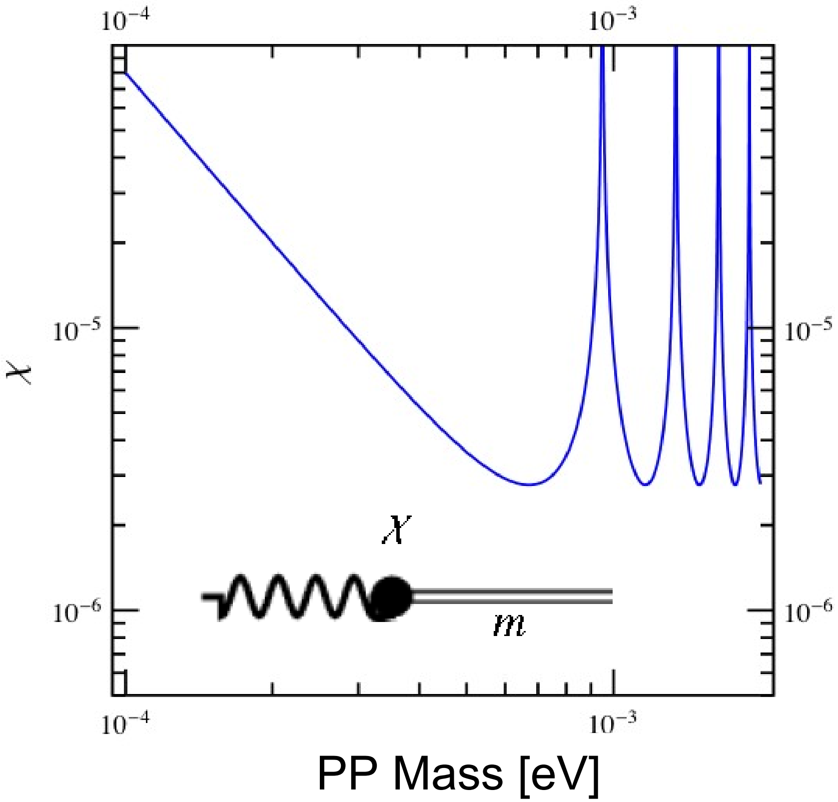
=> detection probability $P_{\gamma \to \phi \to \gamma} \approx 10^{-21}$

Sensitivity to ALPs

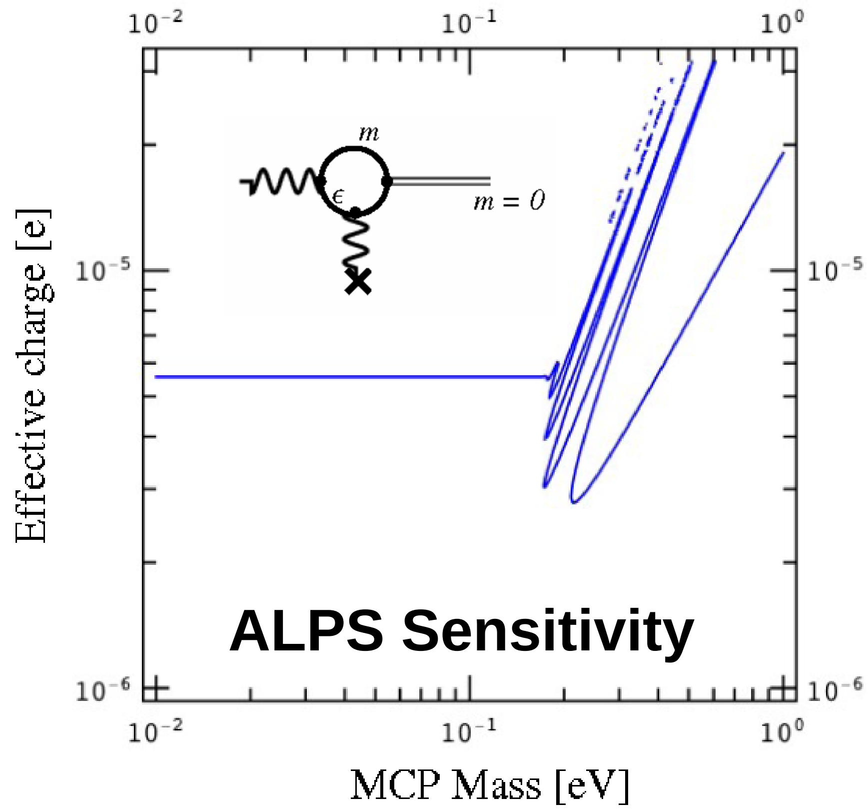


Sensitivity: Para-Photons + MCP

massive para-photons
- mass
- mixing parameter with γ



95% CL limits for minicharged particles in a scenario with m=0 hidden sector γ



ALPS Status early 2008

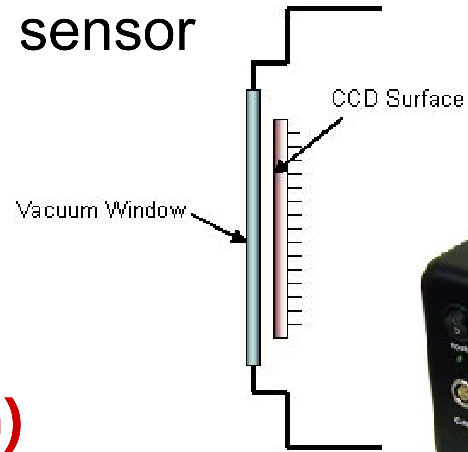
- successful commissioning, detected and cured many weak points
- setup which exceeds the initial anticipated sensitivity – PVLAS crosscheck
- more than photon regeneration – MCP & PP:
  Any Light Particle Search
- competition esp. GammeV – one order of magnitude better
- problems with window & alignment: stop data taking

➢ **substantial improvement of setup**:
  - Laser: FP Cavity, provides a cw signal
  - Detector: large sensitivity, low noise, ~~trigger able~~

A New Camera for ALPS

PRINCETON INSTRUMENTS PIXIS:1024BL

- Permanent vacuum with all-metal seals
- liquid cooling circulator
  -70°, avoid vibration
- customized interfaces and supports
- CCD47-10 AIMO Back Illuminated CCD sensor
  – 13 µm square pixel, 1024 * 1024
  – eff 95 % at 532 nm
  – dark current 0.001 e-/sec/bin (-70°C)
  – low readout noise: 2 e-

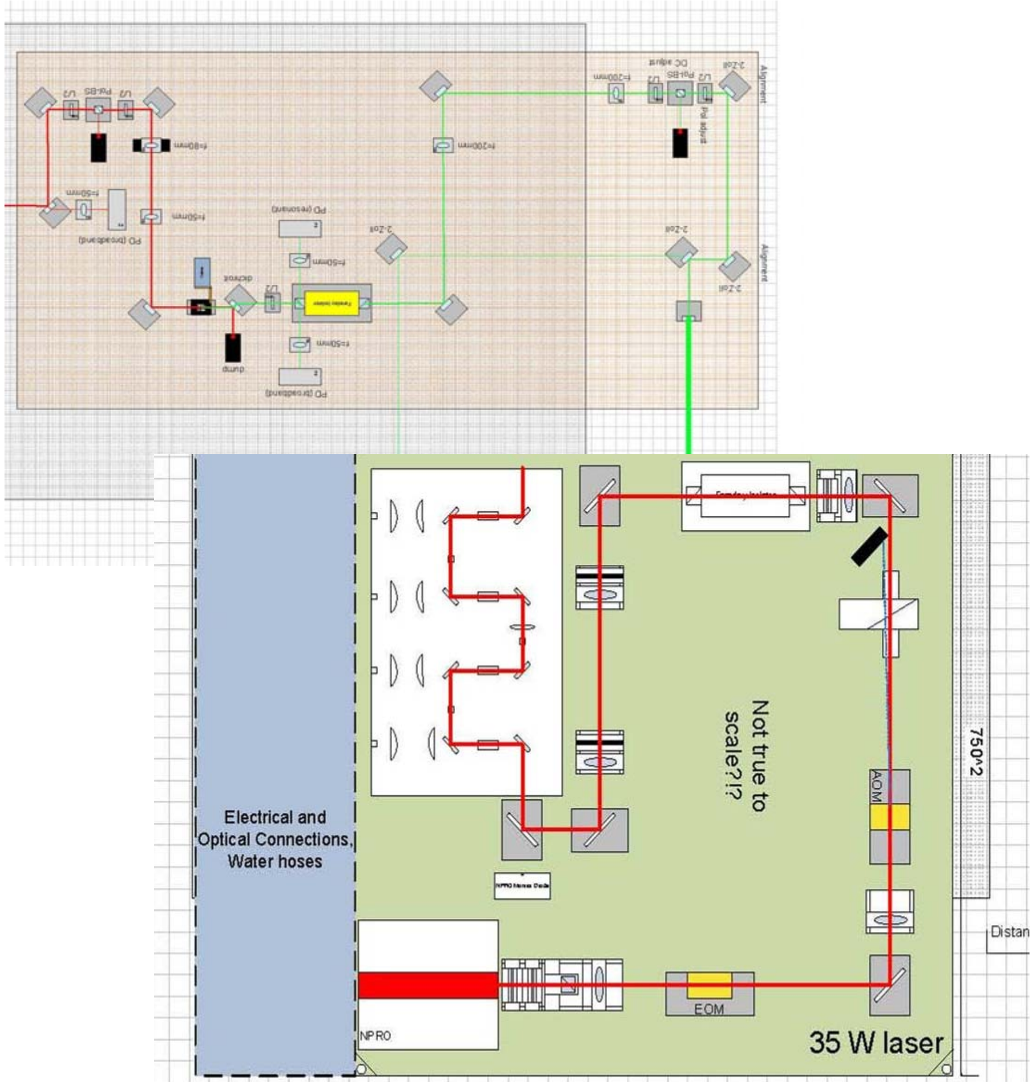


➢ **factor of 5-10 improvement (wrt SBIG)**

➢ **delivery early July**

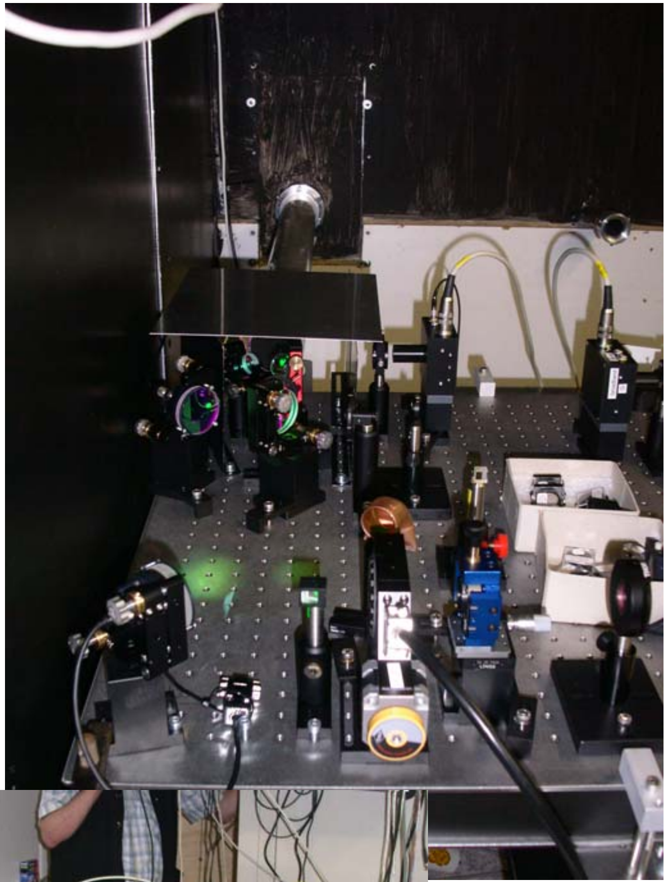
Laser Cavity

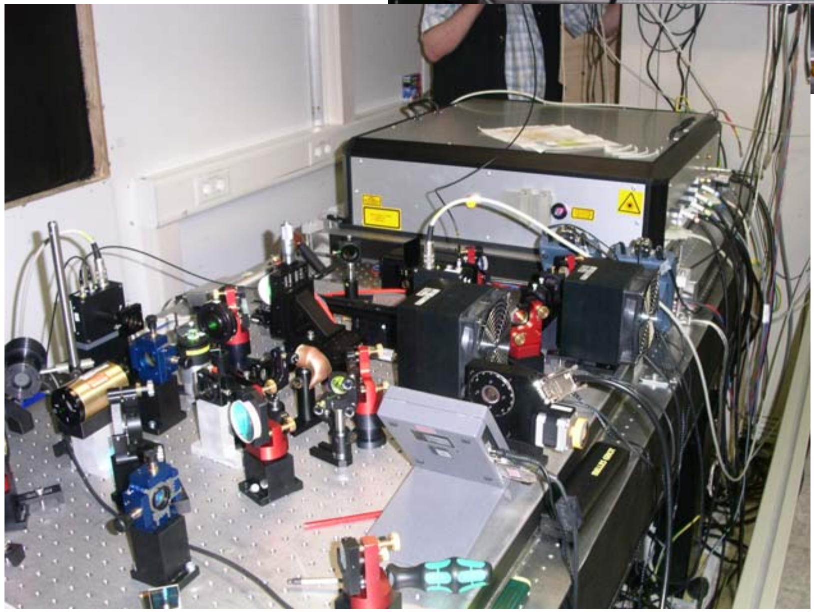
- AEI & LRZ setting up a laser cavity for ALPS
- cf. Talk - T. Meier
- LiGo IR Laser 35 W
- 4 W green
- Power build up by factor 90
- Step 1 goal: 300 W
- Step 2 goal: 10 kW



Laser Cavity - Status

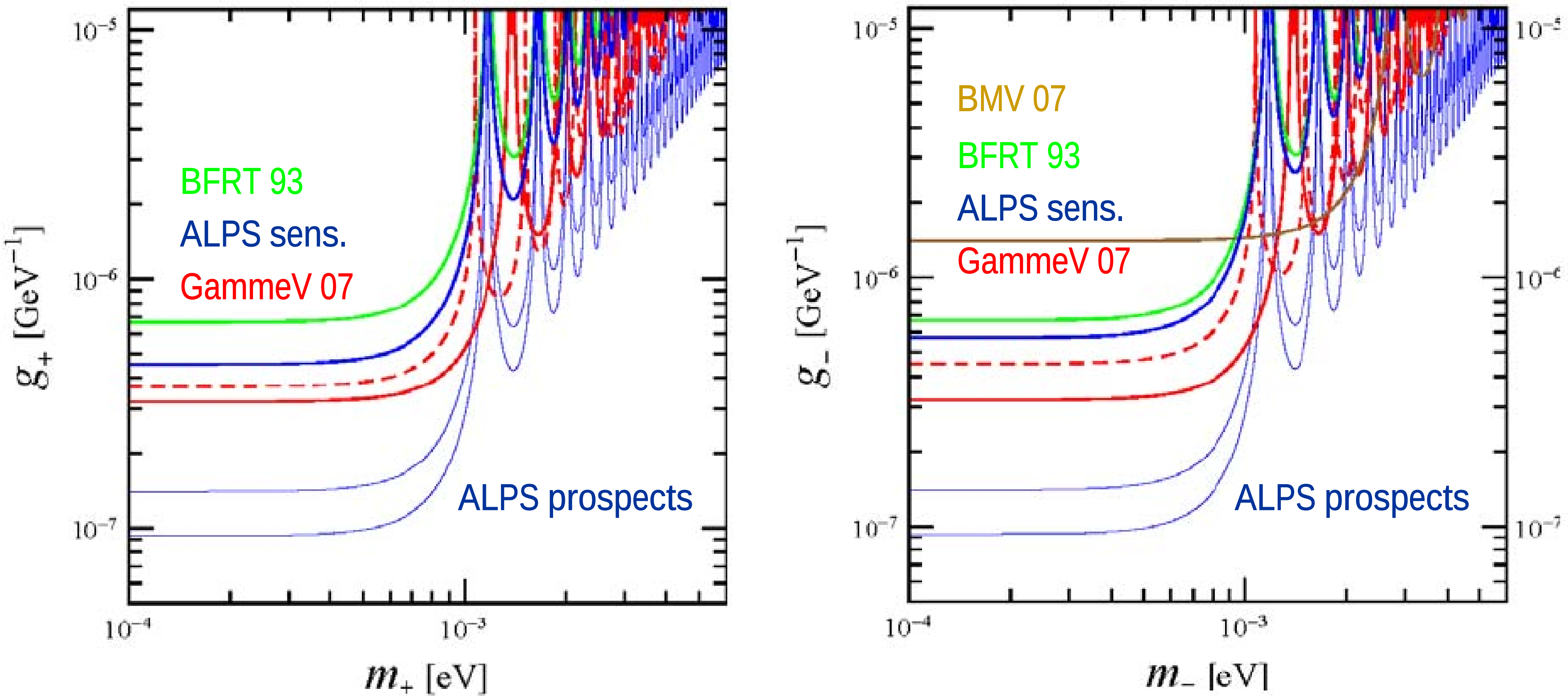
- Laser and optics installed and operated in May
- test of cavity with low power 20 mW green (problem: temperature control for crystal oven)
- June 4th – first locking
- last week successful and stable operation with TEM00 mode, cold magnet powered
- approx factor of 40 gain





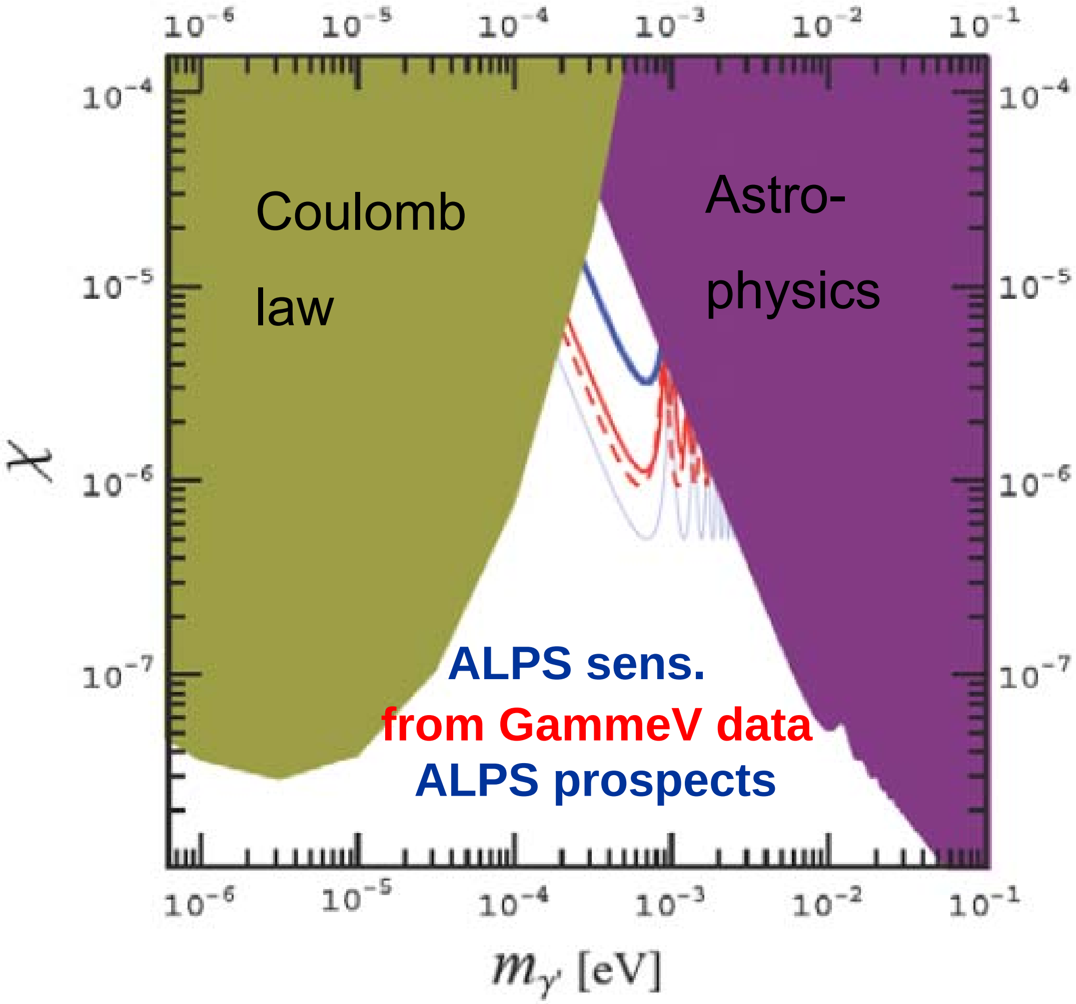
ALP Sensitivity

ALPS with 300 W laser light and with an improved detector



Paraphoton Prospects

Only laboratory experiments searching for massive hidden sector γ might close the gap in the meV mass region!

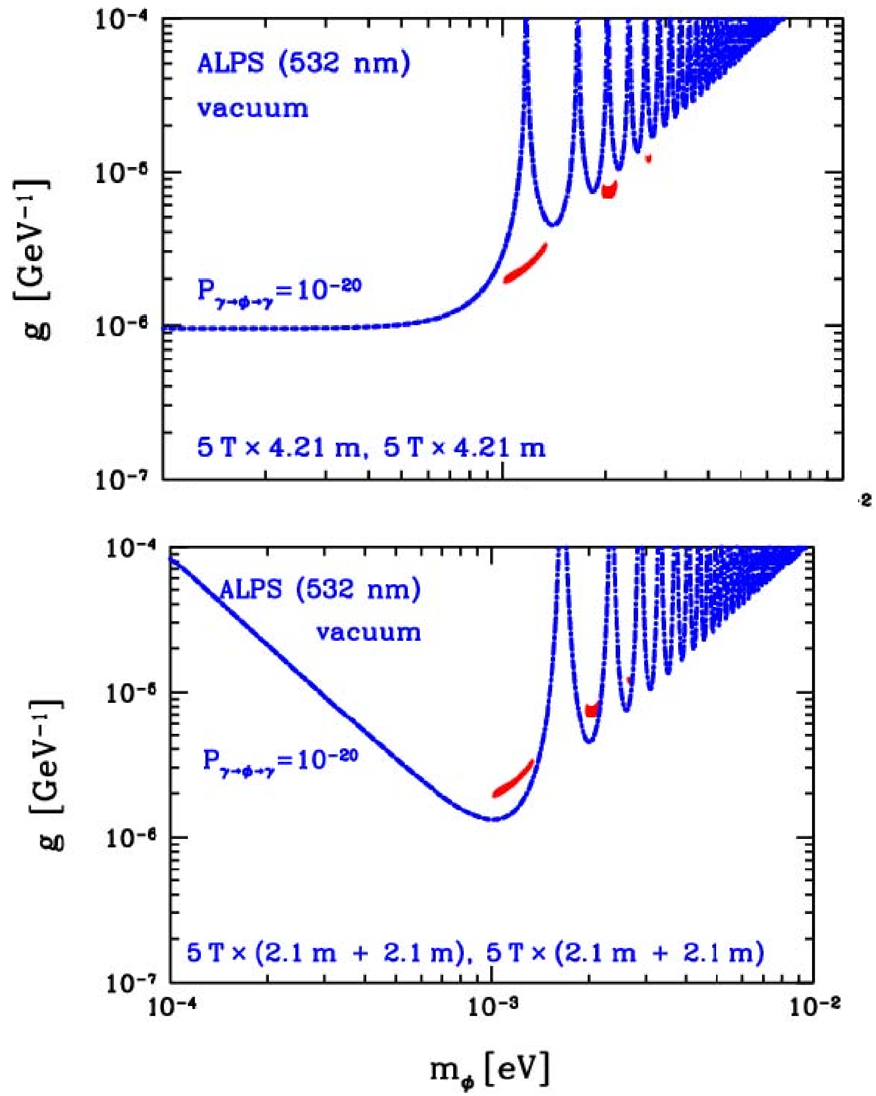


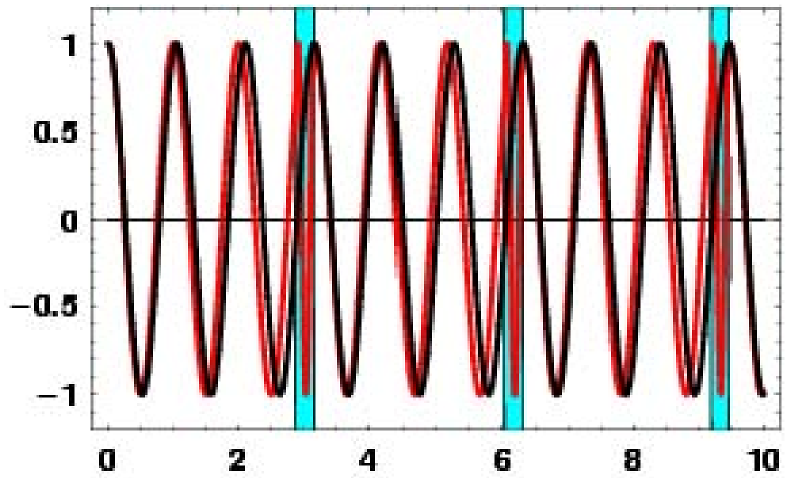
Summary & Outlook

- ALPS has started – bright experimental prospects
- June/July 2008:
  Set-up 300 W cavity at DESY.
  Delivery and commissioning of new Camera
- Summer 2008:
  Data taking - surpass original specifications and existing and planned experiments in sensitivity
- Late 2008:
  Set-up of 10 kW cavity at DESY,
  extension of mass reach with phase shift plates
- Plans for future DESY activities in “low energy particle physics”.

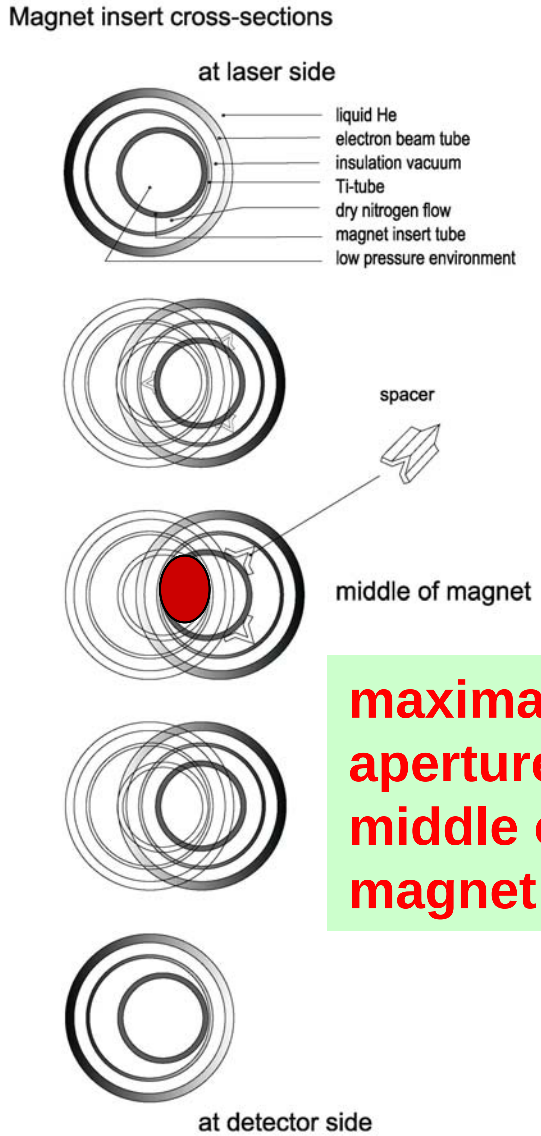
Phase Shift Plates

- extending the mass reach towards larger masses by "correcting" incoherence of ALP and γ waves
- prototype of mechanics and set of $\lambda/2$ plates in hand

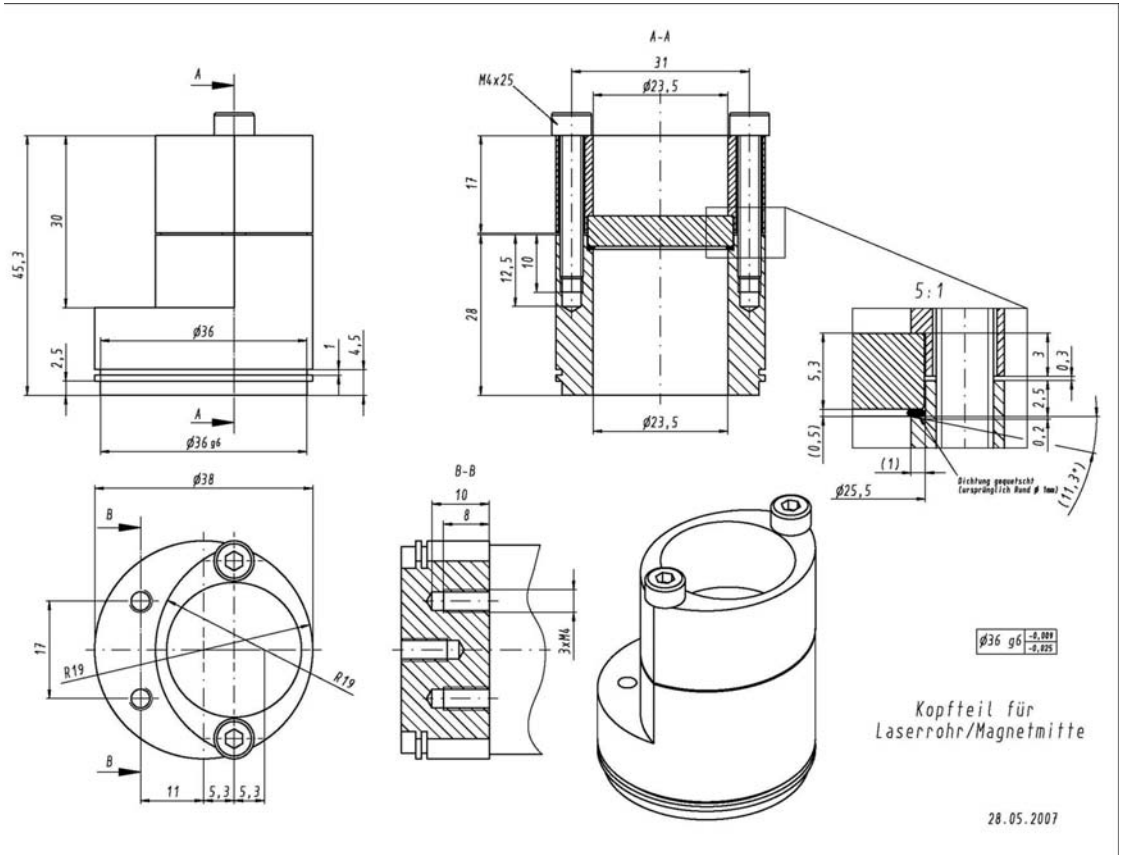




Magnet Insert



maximal free aperture in middle of the magnet



fix window to the tube (vacuum tight) and apply mirror support (centre of the magnet)