The ALPS Experiment

Dark Matter and
Particle Physics at Lowest Energies

A. Lindner, DESY

DESY Summer Student Lecture, 30 July 2010

HELMHOLTZ ASSOCIATION

DESY

Today's Agenda

> The ALPS Lecture

which is the last one of the common lectures in the past two weeks.

Therefore it might be a good opportunity to ask questions and rise some items.

> Question Time!

- Nagging issues related to the common lectures.
- Curiosity concerning DESY in general.
- Everything you wanted to know about DESY physics but were afraid to ask (answers not guaranteed).
- Other items?

> "Hands on" with Cosmic Rays and a tour to the ALPS?

The ALPS Lecture

> An Introduction to the Axion

> Dark Stuff in the Universe

> From Axions to ALPs and WISPs

> How to search for WISPs

> The ALPS Experiment at DESY

> Outlook on possible future Activities

> Summary

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The Standard Model of Constituents and Forces

Constituents:

> Quarks

> Leptons

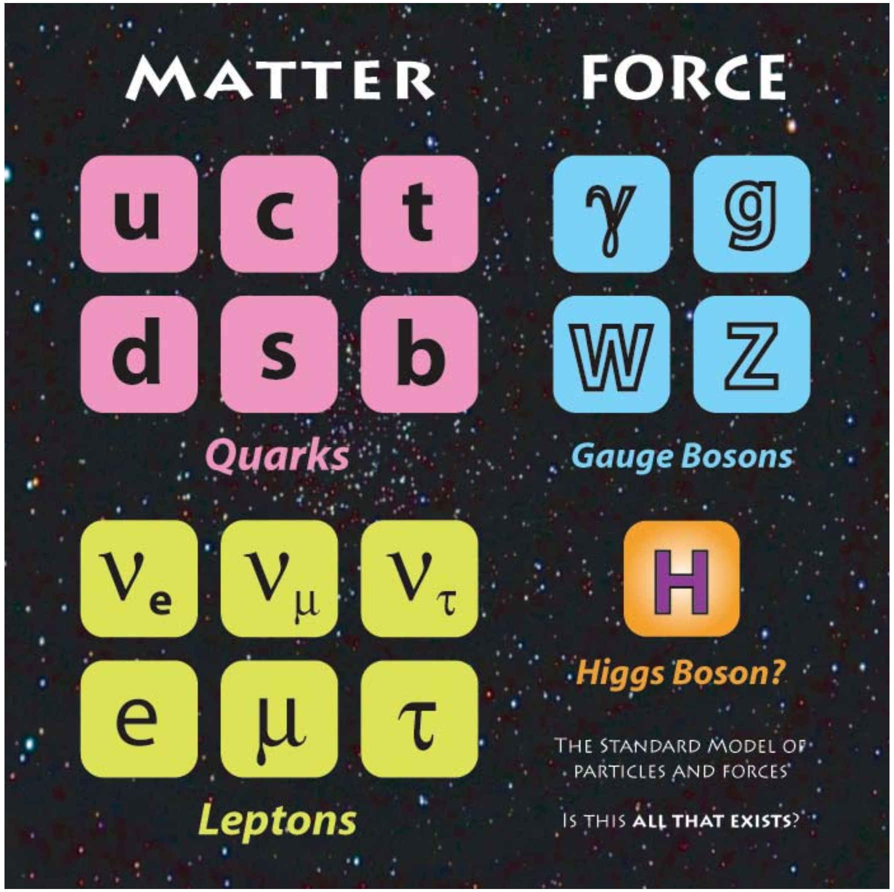
Forces:

> electromagnetic

> strong

> weak

> gravitation



http://www.gridpp.ac.uk/cubes/

Only the Higgs boson is missing!

LHC is on the way to probe its existence.

The Standard Model of Constituents and Forces

Constituents:

> Quarks

> Leptons

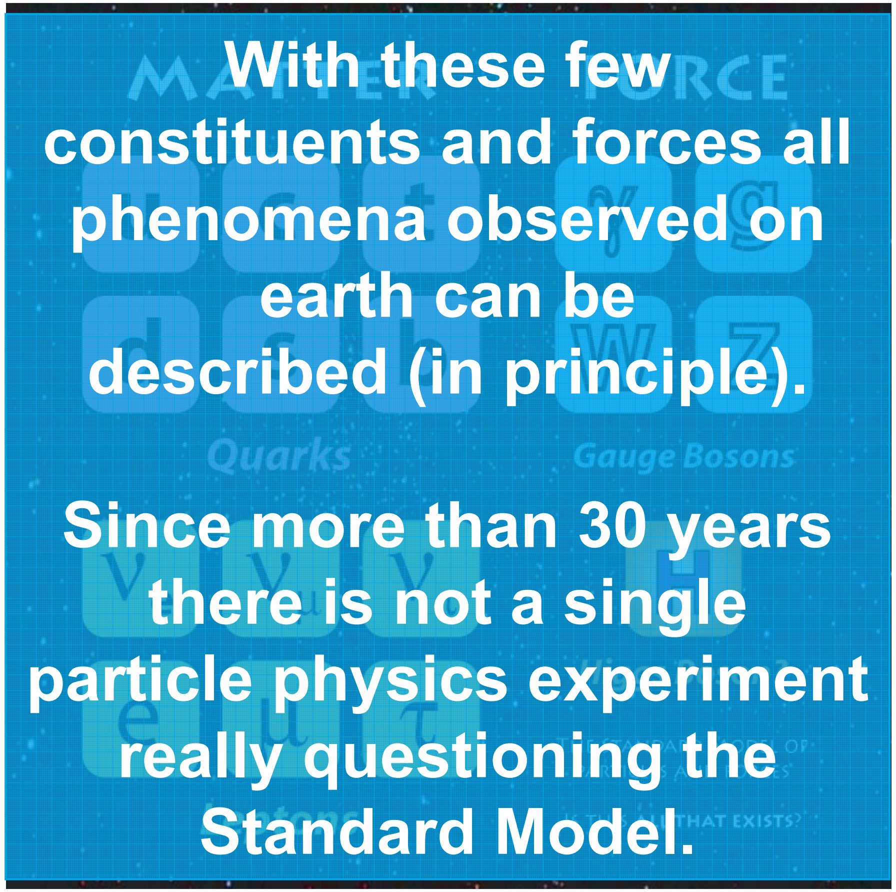
Forces:

> electromagnetic

> strong

> weak

> gravitation



With these few constituents and forces all phenomena observed on earth can be described (in principle).

Since more than 30 years there is not a single particle physics experiment really questioning the Standard Model.

http://www.gridpp.ac.uk/cubes/

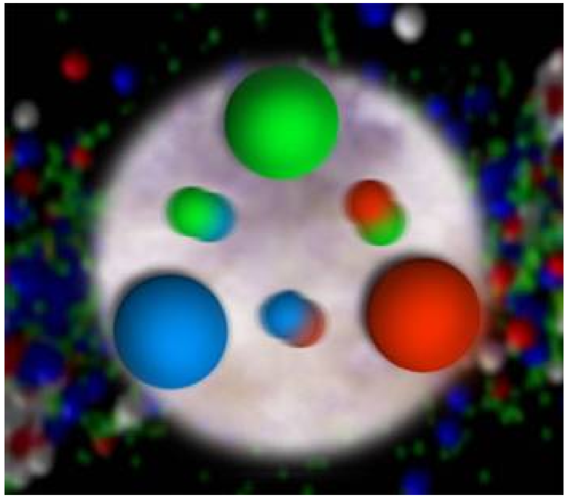
Only the Higgs boson is missing!

LHC is on the way to probe its existence.

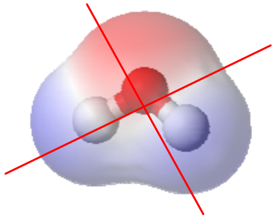
A Flaw in the Standard Model?

The neutron has a strange property:

It consists of three charged quarks, but does not show any static electric dipole moment.



http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Oct/3.html



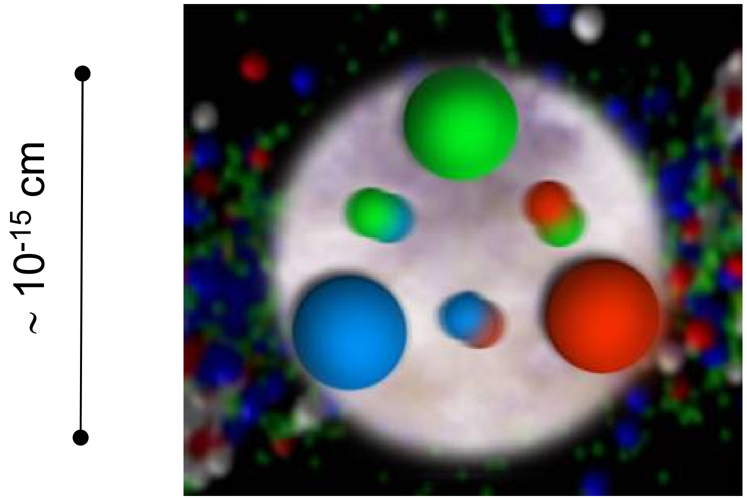
http://en.wikipedia.org

Why do the wave functions of the three quarks *exactly* cancel out any observable static charge distribution in the neutron?

A Flaw in the Standard Model?

Naively one expects for the neutron electric dipole moment:

$d_{n\text{-}QCD} \sim 10^{-15}$ e·cm.



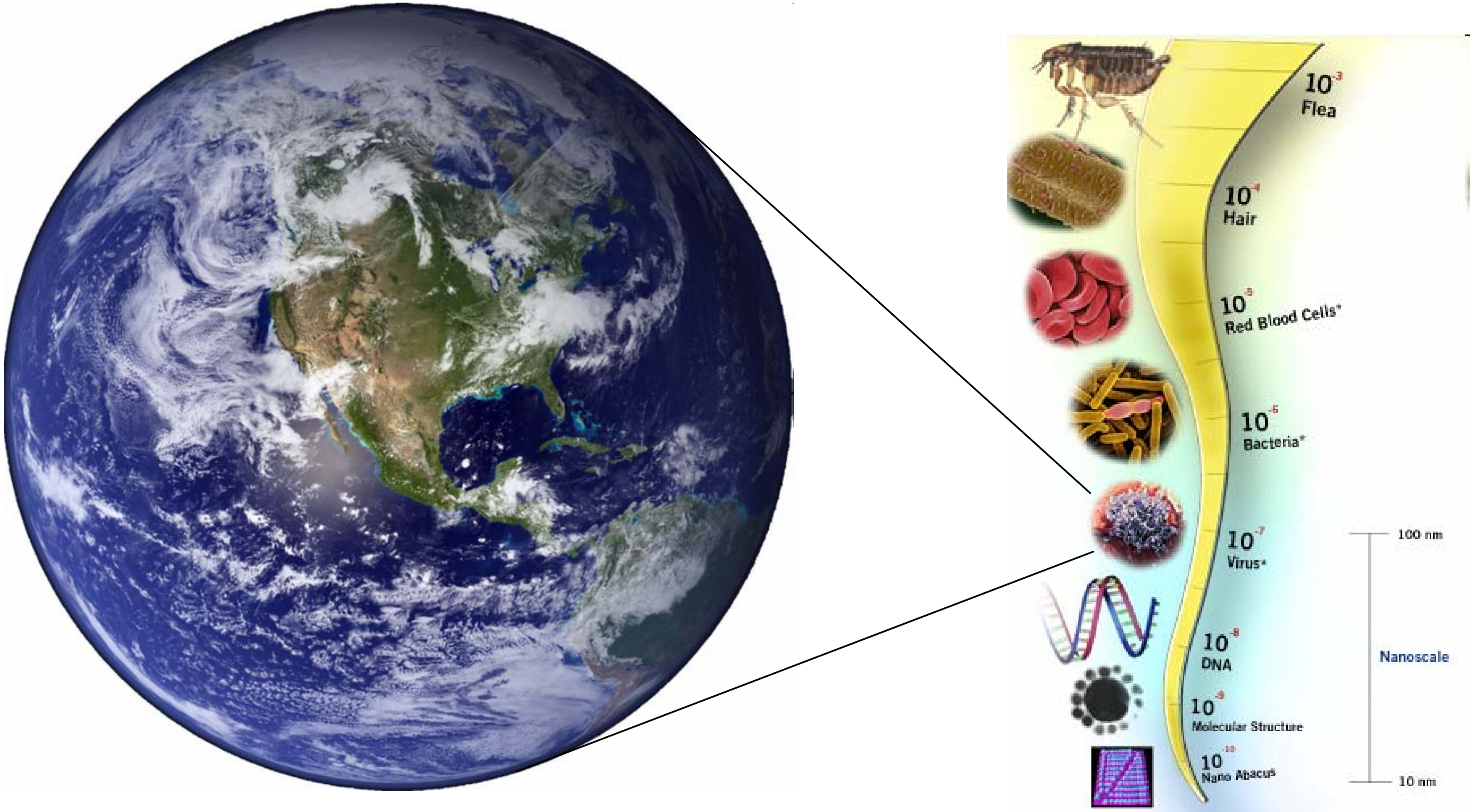
http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Oct/3.html

The data show: $d_{n\text{-}data} < 10^{-26}$ e·cm!

How to explain the difference of at least 11 orders of magnitude?

Eleven Orders of Magnitude

… expecting a planet and finding the nanoscale …



Two Possibilities

> The vanishing electric dipole moment of the neutron is just accidental. The parameters of QCD are “fine-tuned”, nothing remains to be explained.
> A physicist’s nightmare:

“I had the dream about meaningful employment again last night.”

> Can one think of any explanation? If yes, how to confirm this?

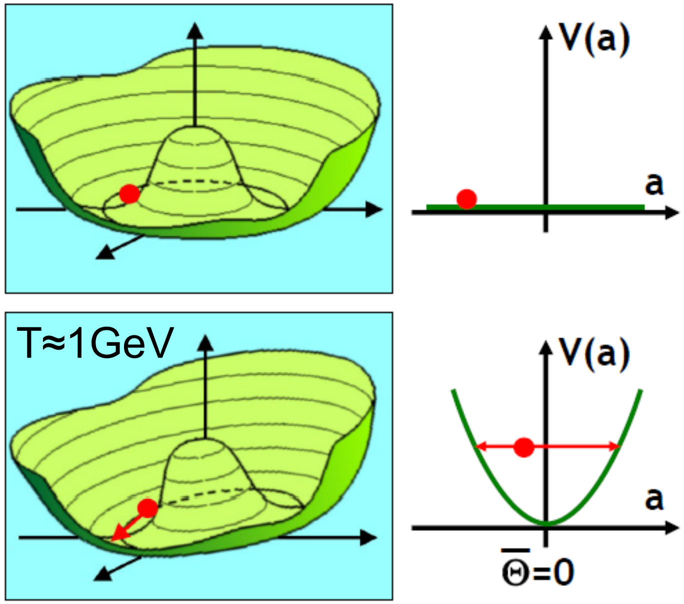
From a Flaw to a new Particle

The size of the neutron electric dipole moment is described by a angle Θ in QCD. There are no theoretical bounds on Θ, but from the missing neutron dipole moment $\Theta < 10^{-9}$ is concluded.

Is this a “just-so”, a “fine-tuning” of QCD? This would be very unsatisfying.

The theoreticians approach:
try to find a dynamic explanation!

<ins>Peccei-Quinn 1977:</ins>
Θ takes an arbitrary value by spontaneous symmetry breaking at a certain high energy scale f_a and roles down by non-perturbative QCD effects to its very small value observed in QCD at low energies.



S. Hannestaad, presentation at 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

From a Flaw to a new Particle: the Axion

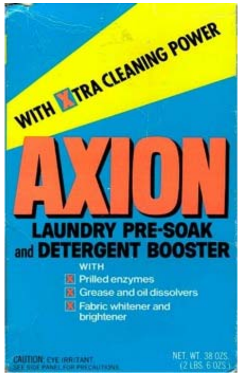
Wilczek and Weinberg independently noticed 1978:

The oscillations of Θ constitute an axion-field (christened by Wilczek).

Summary:

One can explain the vanishing electric dipole moment of the neutron in QCD if a new particle, the axion, exists.

The axion “cleans” QCD.



άξιον = worthy, deserving

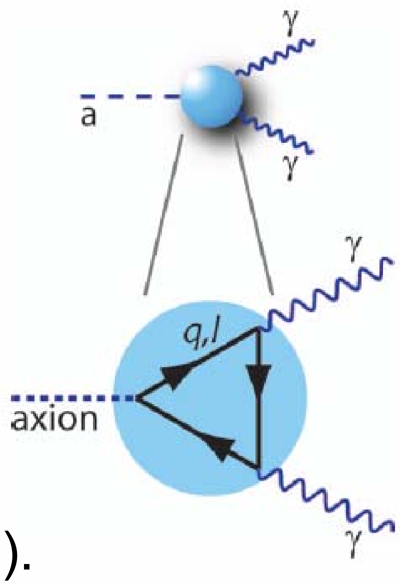
Properties of the QCD Axion

> The axion behaves like a light cousin of the π^0.
  It couples to two photons.

> Mass and the symmetry breaking scale f_a are related:
  $m_a = 0.6\text{eV} \cdot (10^7\text{GeV} / f_a)$

> The coupling strength to photons is
  $g_{a\gamma\gamma} = \alpha \cdot g_\gamma / (\pi \cdot f_a)$, where g_γ is model dependent and O(1).

> The axion abundance in the universe is
  $\Omega_a / \Omega_c \sim (f_a / 10^{12}\text{GeV})^{7/6}$.

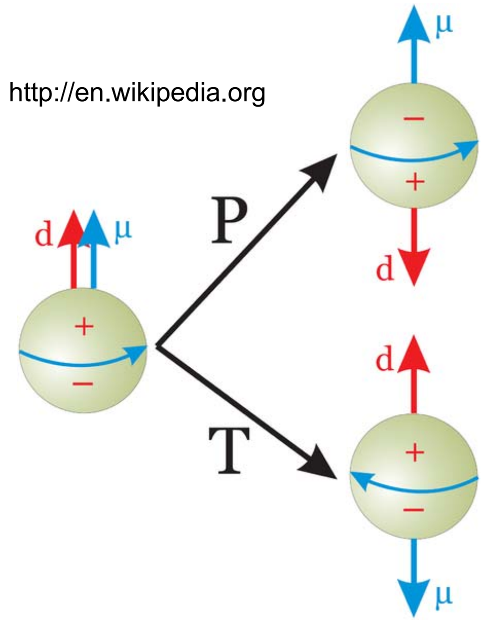


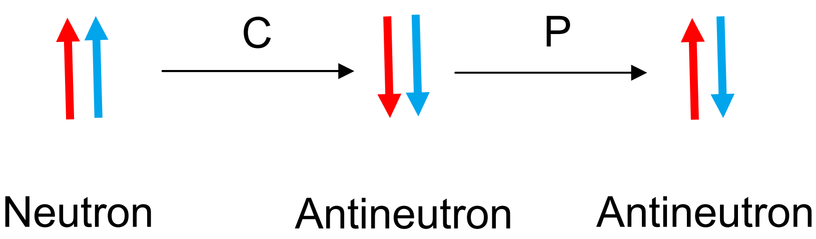
The Search for Axions, Carosi, van Bibber, Pivovaroff, Contemp. Phys. 49, No. 4, 2008

A Flaw and fundamental Properties of Nature

Electric and magnetic dipole moments of the neutron are related to fundamental symmetries:

- P (parity), T (time reversal) and C (charge conjugation) .





If the neutron has an electric dipole moment
in addition to the measured magnetic dipole moment, <u>C·P is not conserved</u>.
Both moments would change from parallelism to anti-parallelism.

The strong interaction conserves CP ↔ no neutron electric dipole moment

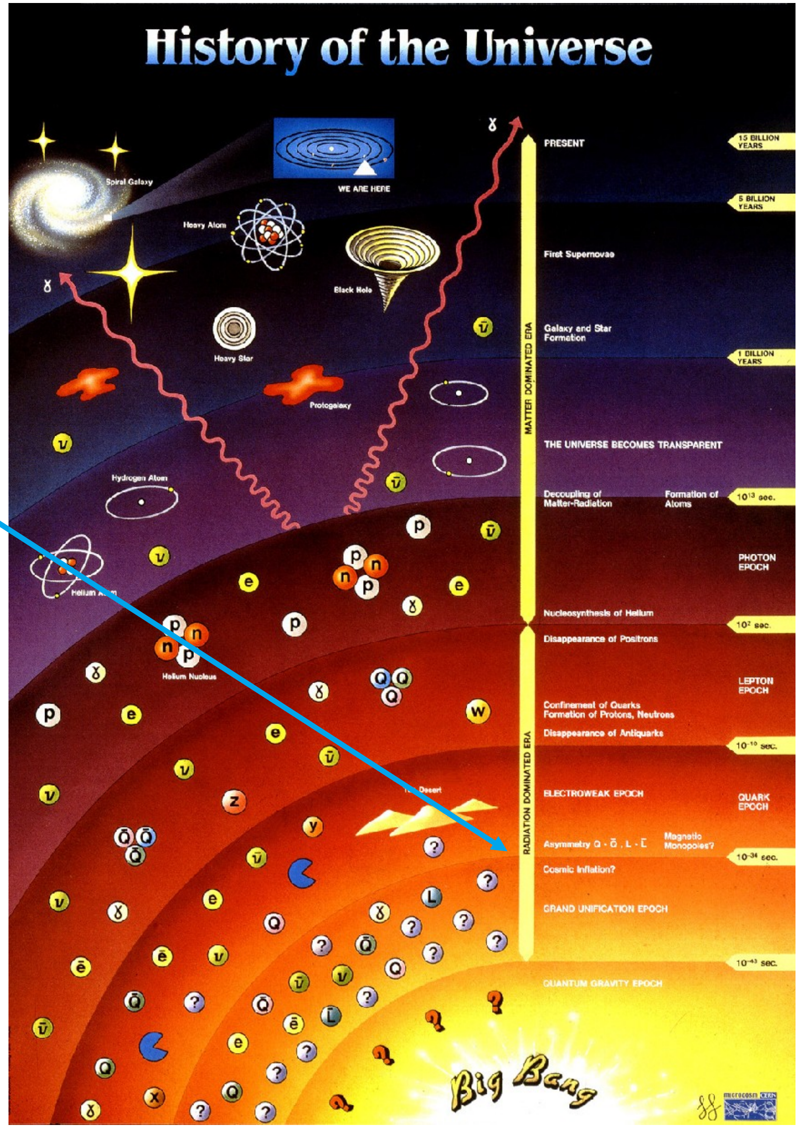
Detour: C·P is not only an academic Question!

C·P violation is essential to explain

why matter and antimatter did not annihilate completely about 10^{-34}s after the Big Bang

and hence essential to explain

our existence!



Unfortunately:

> C·P violation in weak interaction is much too weak for an explanation.

> QCD could do the job, but experiments show that QCD conserves C·P! This is understandable, if the axion exists.

We still don't know, why we are here.

Detour: C·P is not only an academic Question!

C·P violation is essential to explain

why in the very early universe the ratio of matter to antimatter was

Matter/Antimatter = $1+10^{-9}$

one additional grain of sand!

http://www.weltmaschine.de

We and all what we see are made from this 10^{-9} fraction.

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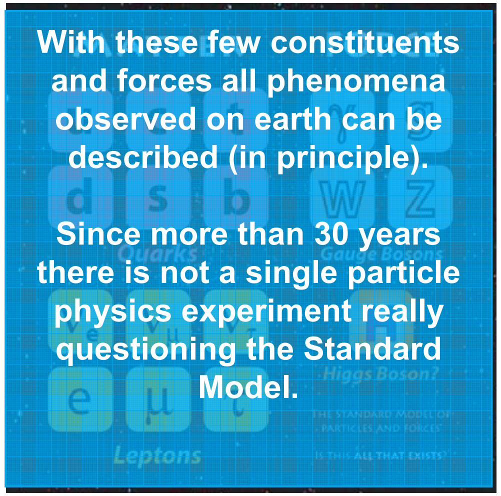
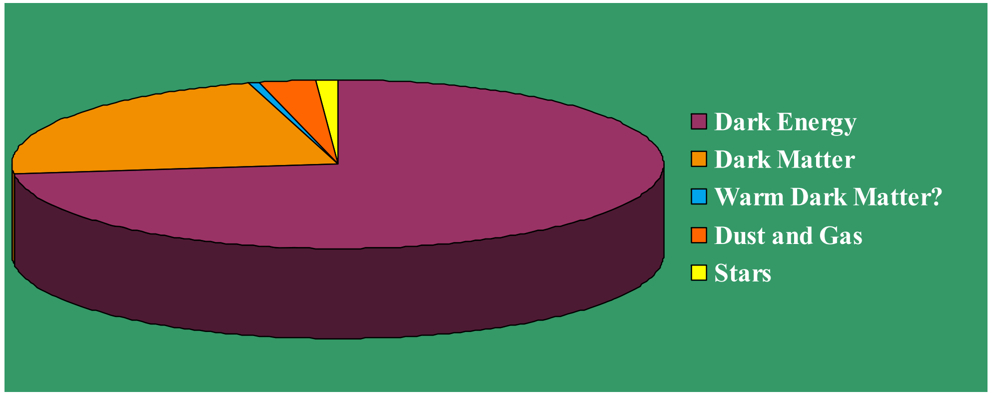
The Standard Model beyond Earth

The great success on earth:



is questioned by astrophysics and cosmology:

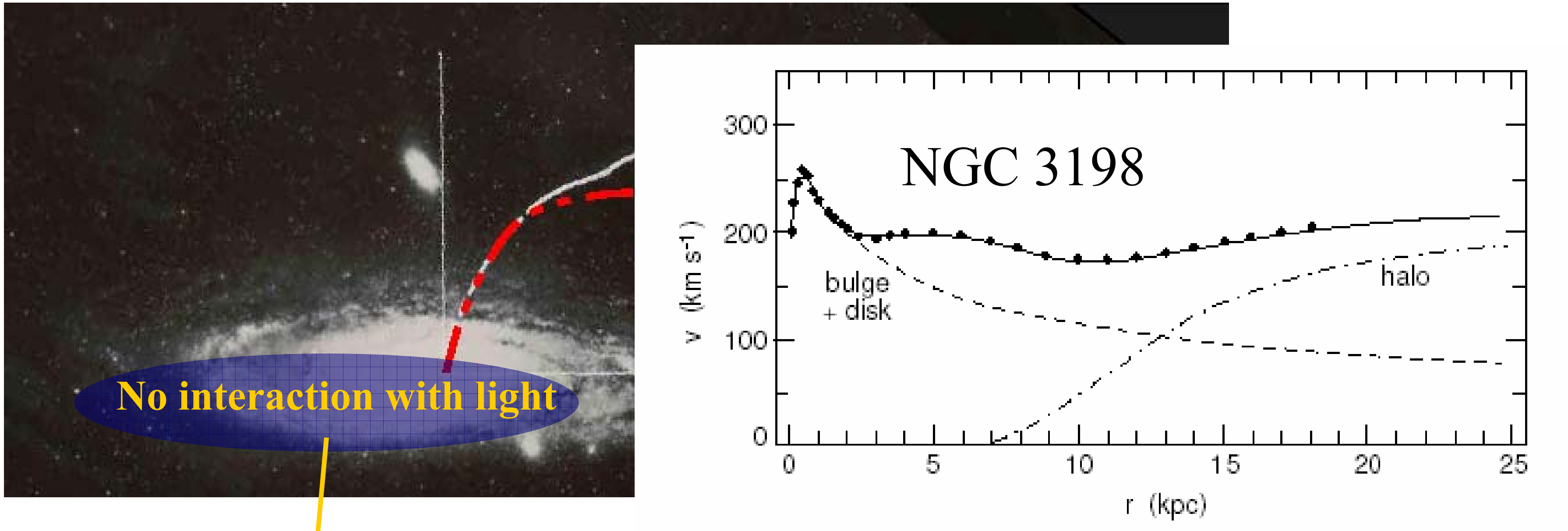


The Standard Model (without axions!) describes only 4% of the matter-energy content of the universe!

Observational Evidence for Dark Matter (1)

Rotation of galactic disks:

Dark Matter and experiments:
http://cdms.berkeley.edu/experiment.html



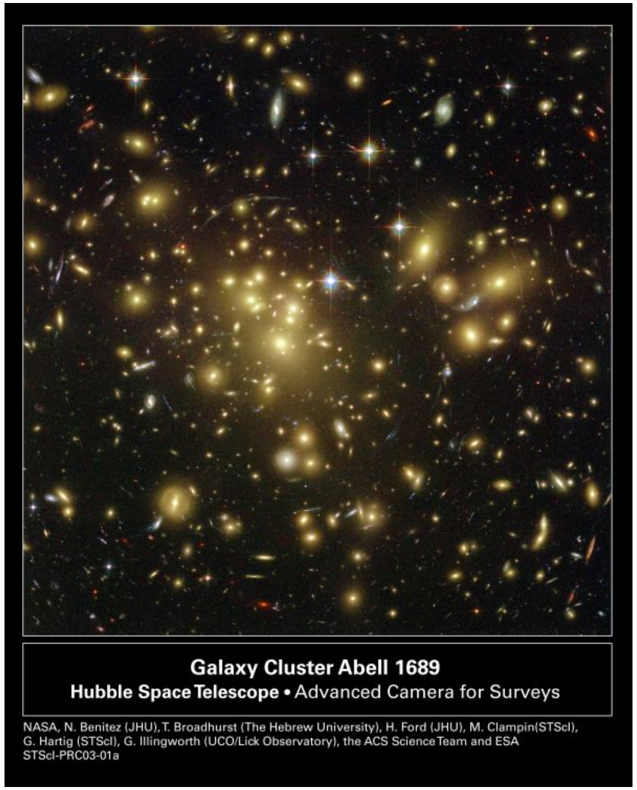
Dark Matter ≈ 10 · Luminous Matter

Observational Evidence for Dark Matter (2)

Motions of galaxies in clusters:

Clusters do not diffuse in spite of high speed of galaxies.

(Dark component first proposed 1933 by F. Zwicky after analysis of the Coma cluster)



$$\text{Dark Matter} \approx 30 \cdot \text{Luminous Matter}$$

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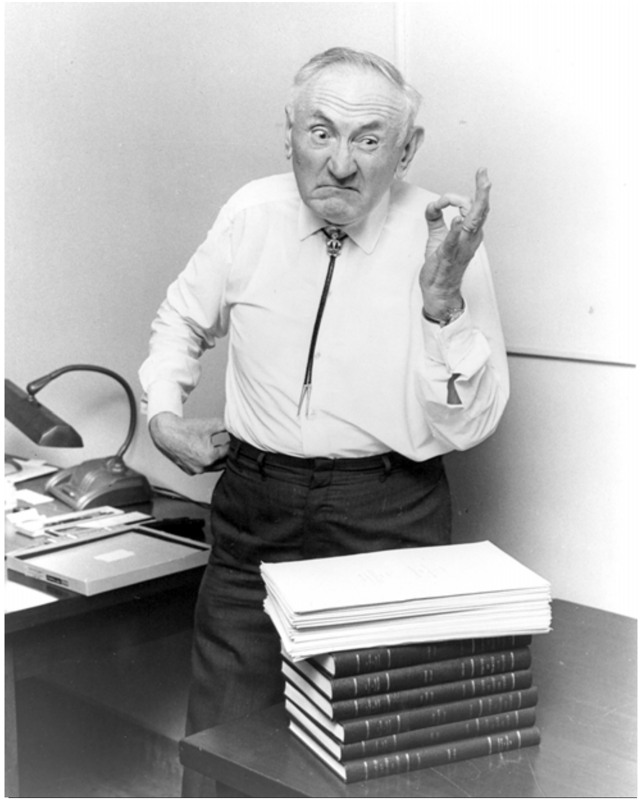

$$\text{Dark Matter} \approx 30 \cdot \text{Luminous Matter}$$

Observational Evidence for Dark Matter (3)

Hot gas in galaxy clusters:

Hot gas (measured by X-ray emission due to e^-- bremsstrahlung) contains too much kinectic energy to be bound by luminous matter in the cluster.

Mass (hot gas) $\approx$
5 · Luminous Matter

Dark Matter $\approx$ 30 · Luminous Matter

How to find Dark Matter in the Universe?

Search for Dark Matter via gravitational effects
(kind of definition of "dark"):

> bound systems
(galaxies, clusters of galaxies, hot gas as shown before)

> distortion of images due to gravitational force on light

"gravitational lensing"

Gravitation distorts Images

http://astronomyonline.org/Cosmology/GravitationalLensing.asp

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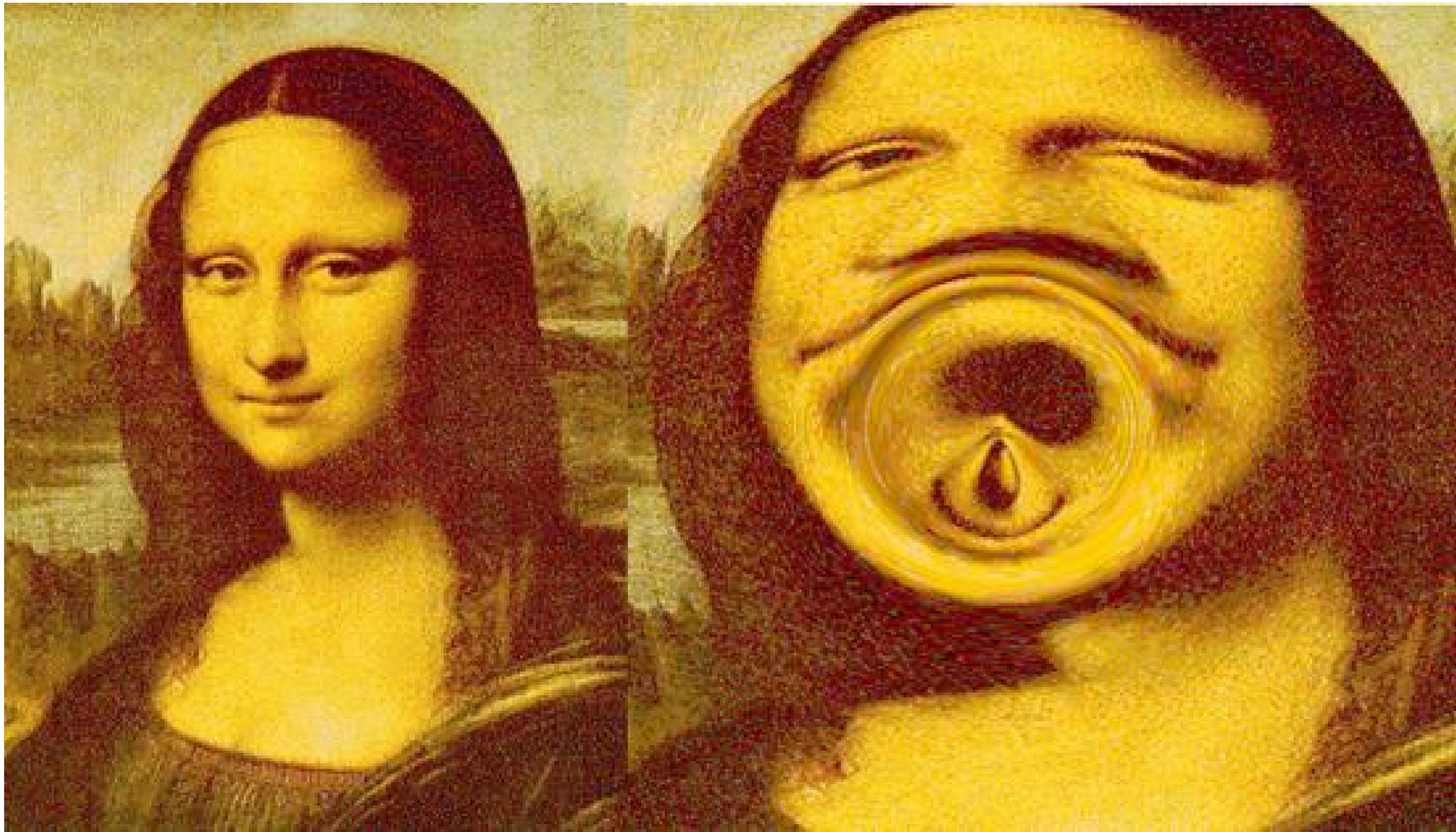
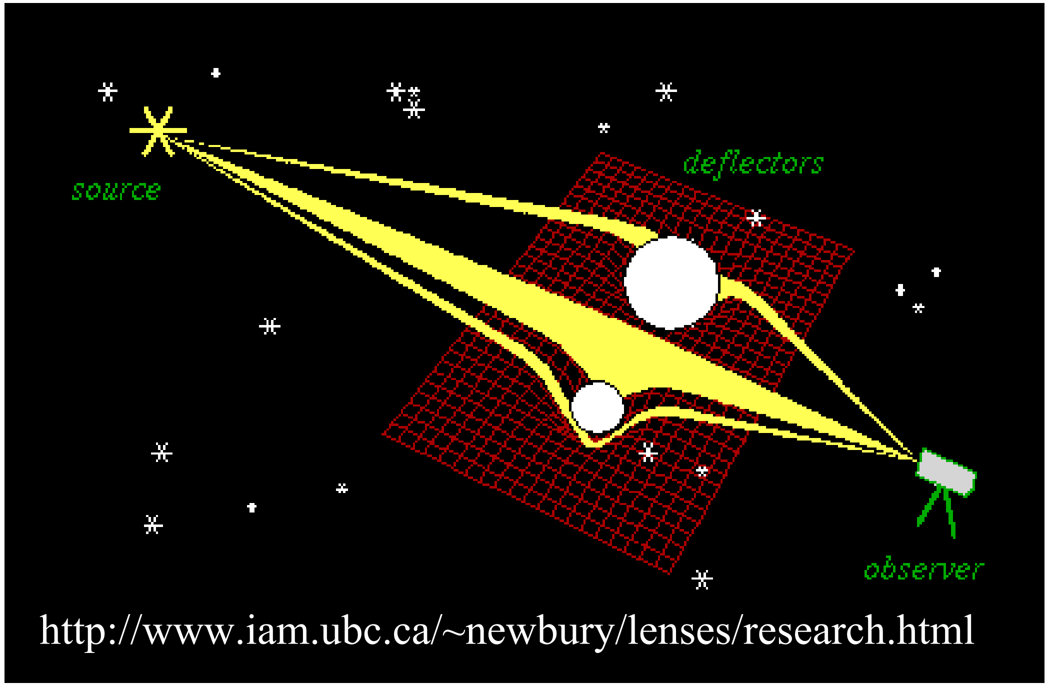
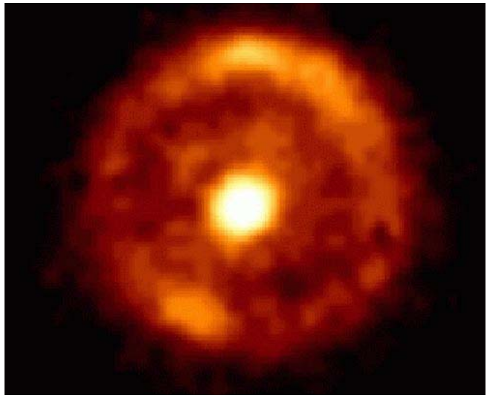
http://astronomyonline.org/Cosmology/GravitationalLensing.asp



Gravitation distorts Images

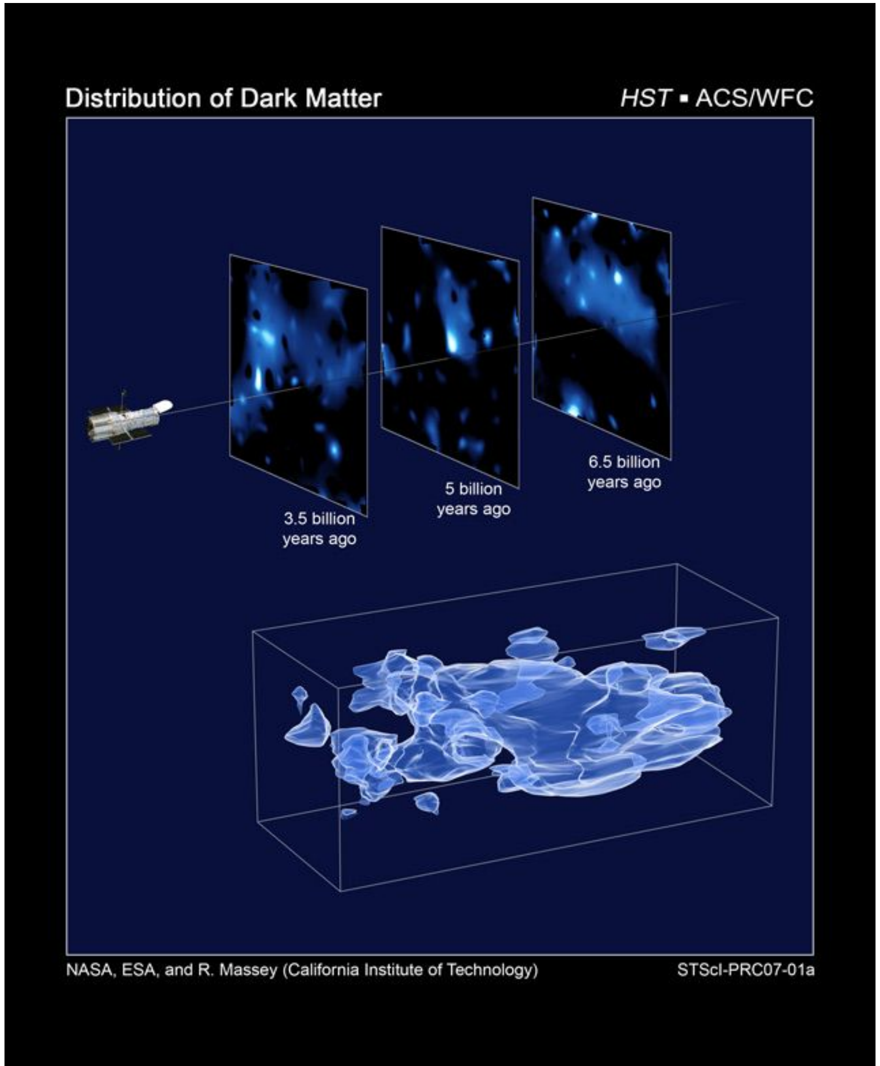




Gravitational lensing:

Derive mass of "lens" from properties of image .

Observational Evidence for Dark Matter (4)

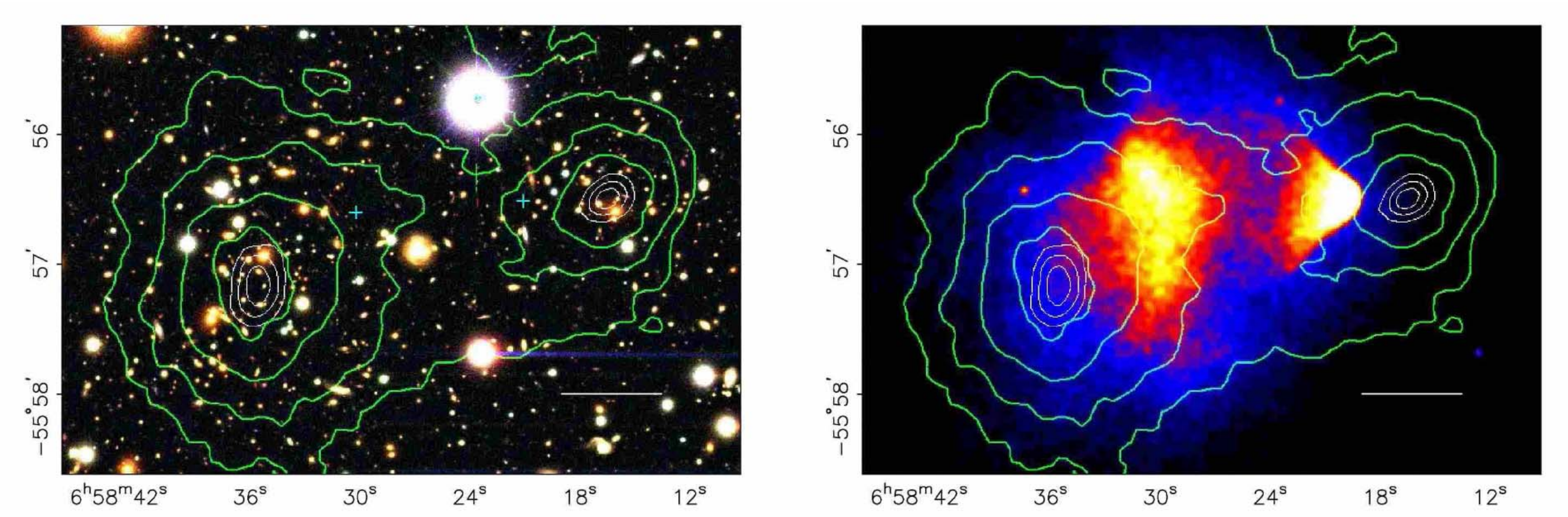


Dark Matter $\approx$ 30 $\cdot$ Luminous Matter

The Smoking Gun Observation (?)

Bullet cluster 1E 0657-56: merging of two galaxy clusters

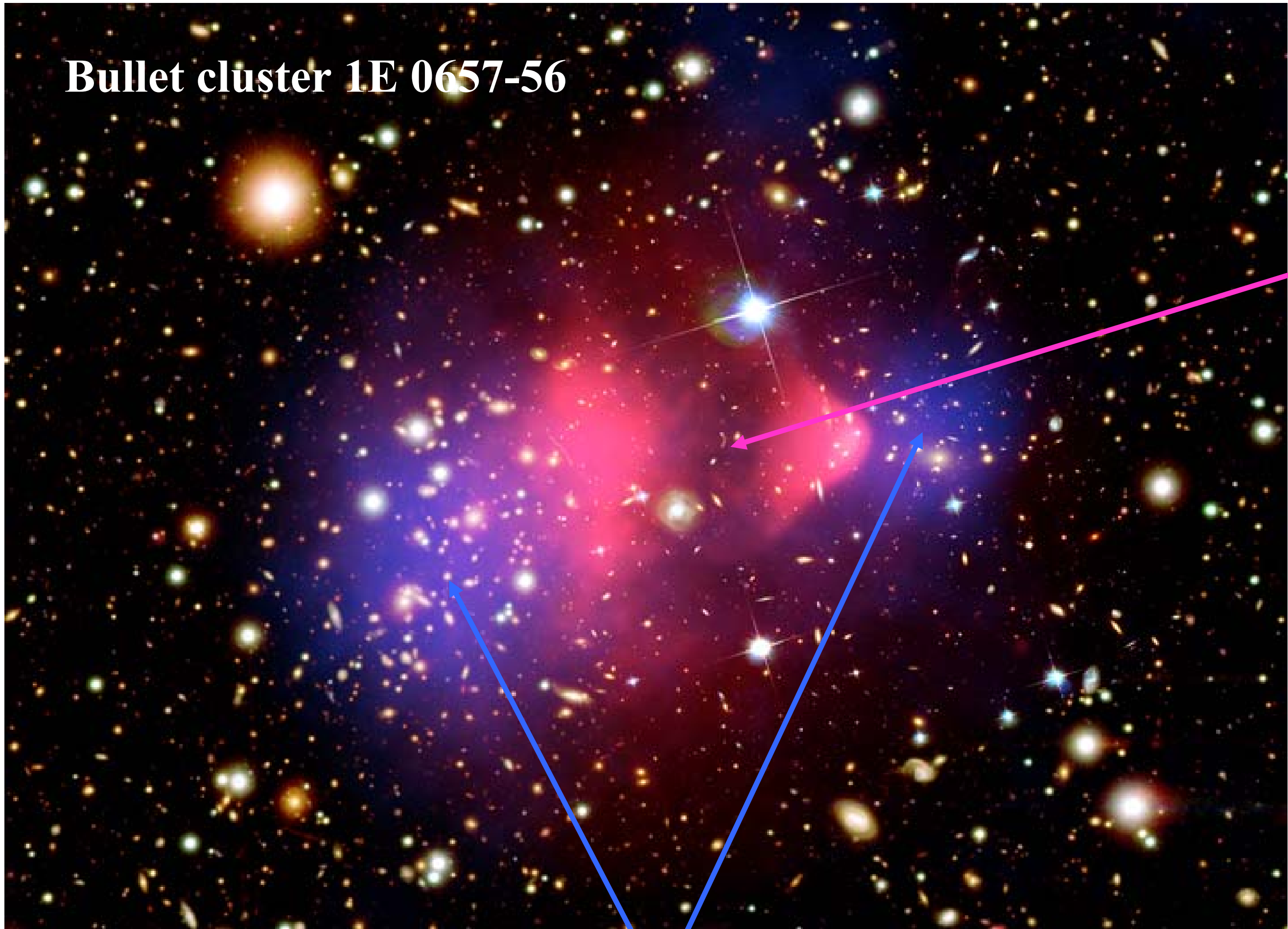
(Clowe et al., astro-ph/0608407v1)



Contours from gravitational lensing

hot gas from X-rays

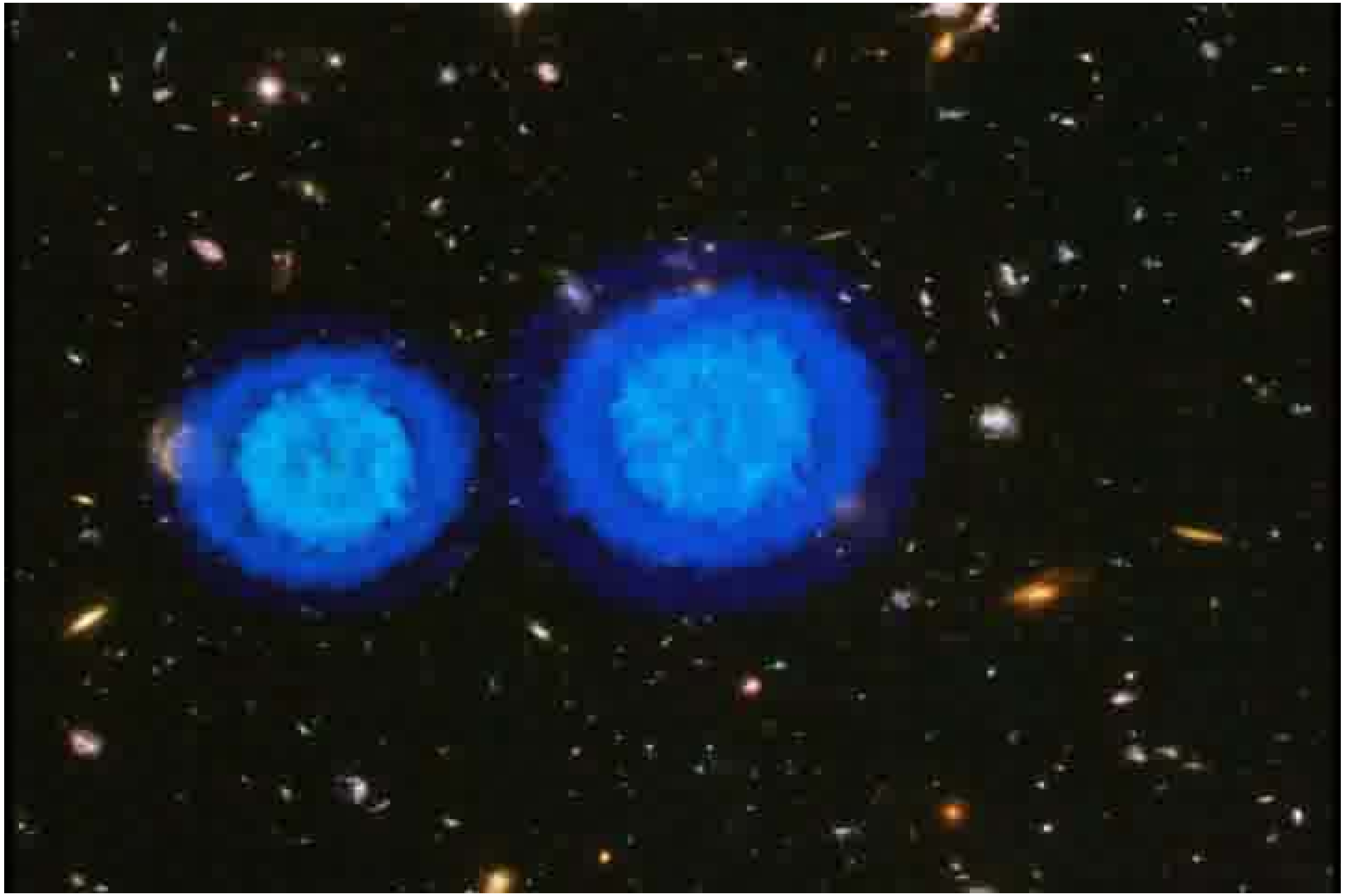
The Smoking Gun Observation (?)



hot gas (X-ray)

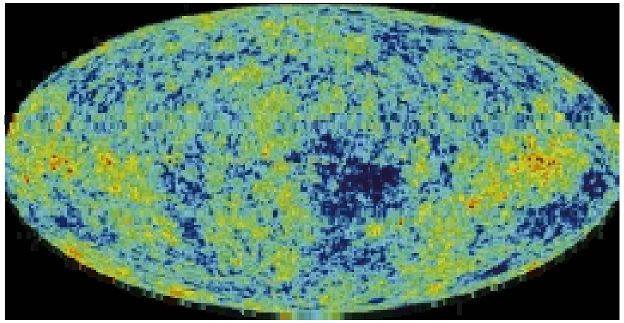
from gravitational lensing

The Smoking Gun Observation (?)

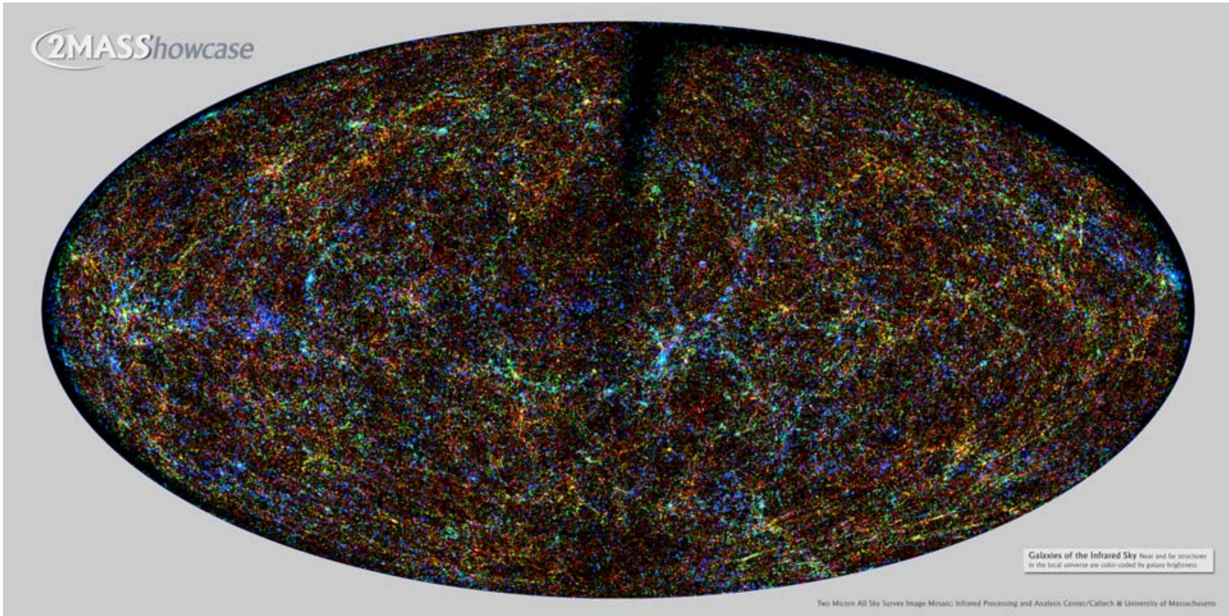


Further Evidences for Dark Matter

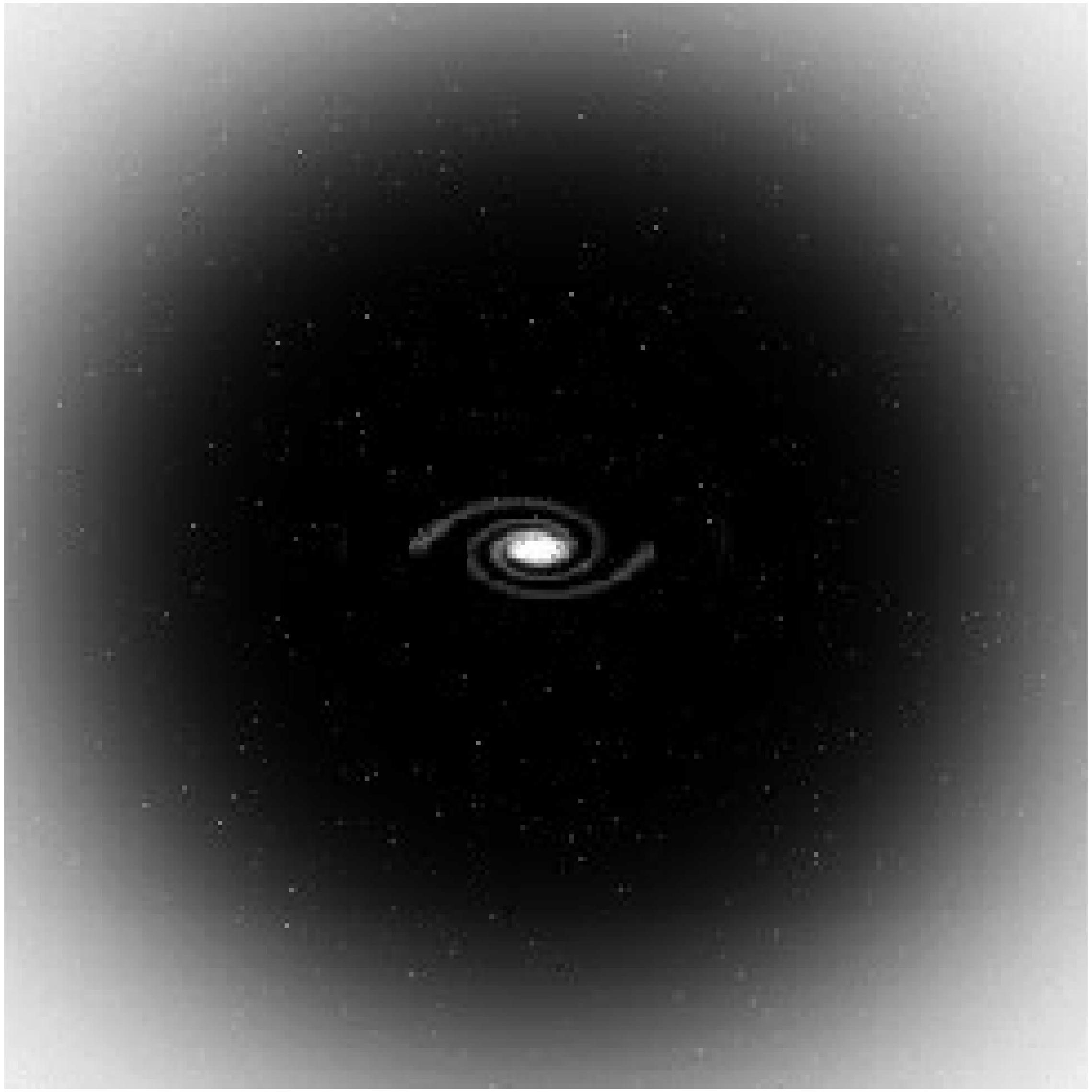
> Cosmic Microwave Background Radiation (CMBR) analyses



> Structure formation in the universe
> ➢ non relativistic "cold" dark matter is required as seeds for galaxies!



Model: Galaxies “swim“ in a Halo of Dark Matter



However, the detailed structure of such a halo is a matter of intense discussion!

More dark Stuff: Dark Energy drives the Universe apart

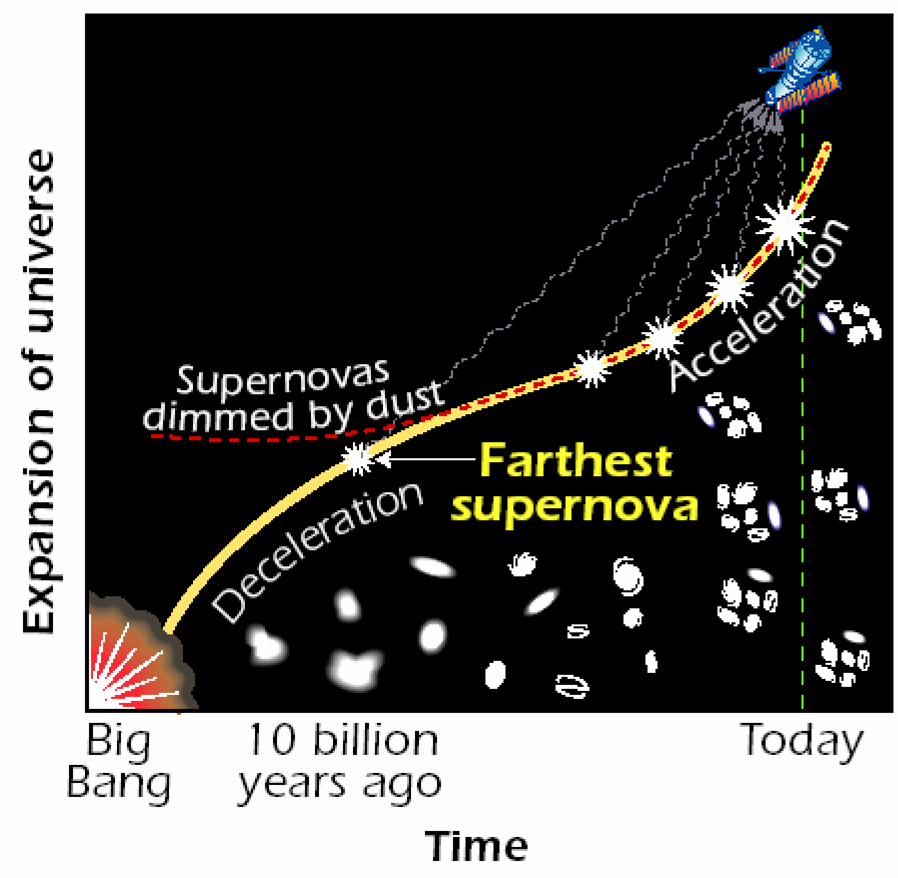
Measurements of Supernovae Ia by the Hubble Space Telescope (and others):

> There is a repulsive force ("anti-gravitation") best explained by "dark energy" (Einstein's Λ)

> Dark energy is an attribute of space. Dark energy per volume is constant. The larger the universe, the larger the fraction of dark energy!

> The universe expands currently with increasing speed!

> This scenario is strongly confirmed by analyses of the Cosmic Microwave Background Radiation and many other data!



Precision Cosmology!

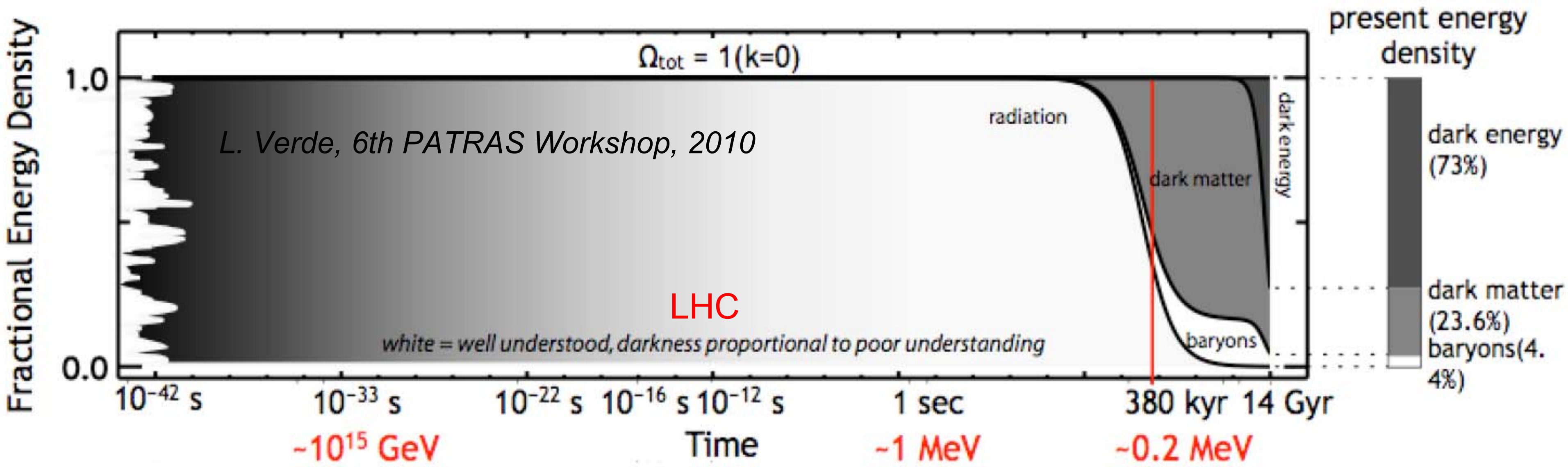
http://lambda.gsfc.nasa.gov/

- Geometry of the Universe: flat
- Age of the Universe: 13.69 ± 0.13 Gyr
- Hubble Constant: 72 ± 3 km s^{-1} Mpc^{-1}
- Fluctuations compatible with inflation

- Ω_b (baryons): 0.044 ± 0.003
- Ω_c (dark matter): 0.214 ± 0.027
- Ω_Λ (dark energy): 0.742 ± 0.030
- Early star light (reionisation): $\Omega_\nu \ll \Omega_{dm}$

In very good agreement to all other data (supernova search with HST, galaxy counting, Big Bang Nucleon-synthesis, ...)

Why LHC alone is insufficient to understand the Cosmos



- LHC probes the very early universe when it was very small, hot and dense.
- Dark energy was totally negligible at those times.
- Surprisingly, we understand the early universe from fractions of a second to minute scales better than today's universe.
- Dedicated "low energy" experiments are required to get a clue on Dark Energy.

Dark Matter and Dark Energy in this Room

Why did physics overlook
Dark Matter and Dark Energy so long?

Densities in this room:

- Matter (earth's crust): 3 g/cm^3
- Dark Matter (DM): 0.000000000000000000000000005 g/cm^3
- Dark Energy (DE): 0.000000000000000000000000000001 g/cm^3

Why dominates matter here and DM und DE in the Universe?

- Matter is "clumpy", interacts strongly: planets are formed.
- Dark Matter interacts only very weakly: halos around galaxies.
- Dark Energy is distributed uniformly all over the universe.

Hitchhiker's Guide to the Galaxy

There is a theory which states that if ever anybody discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable.

There is another theory which states that this has already happened.

Douglas Adams
English humorist & science fiction novelist (1952 – 2001)

Some Caveats on our Picture of a strange Universe

> The Copernican principle is used to interpret the data.

- The Universe in our neighborhood is not special.

  Homogeneity (similarity in all regions of space)
  Isotropy (similarity in all directions).

This principle is

- compatible with observations (if you accept “Dark Energy”!),
- **but fundamentally untested!**

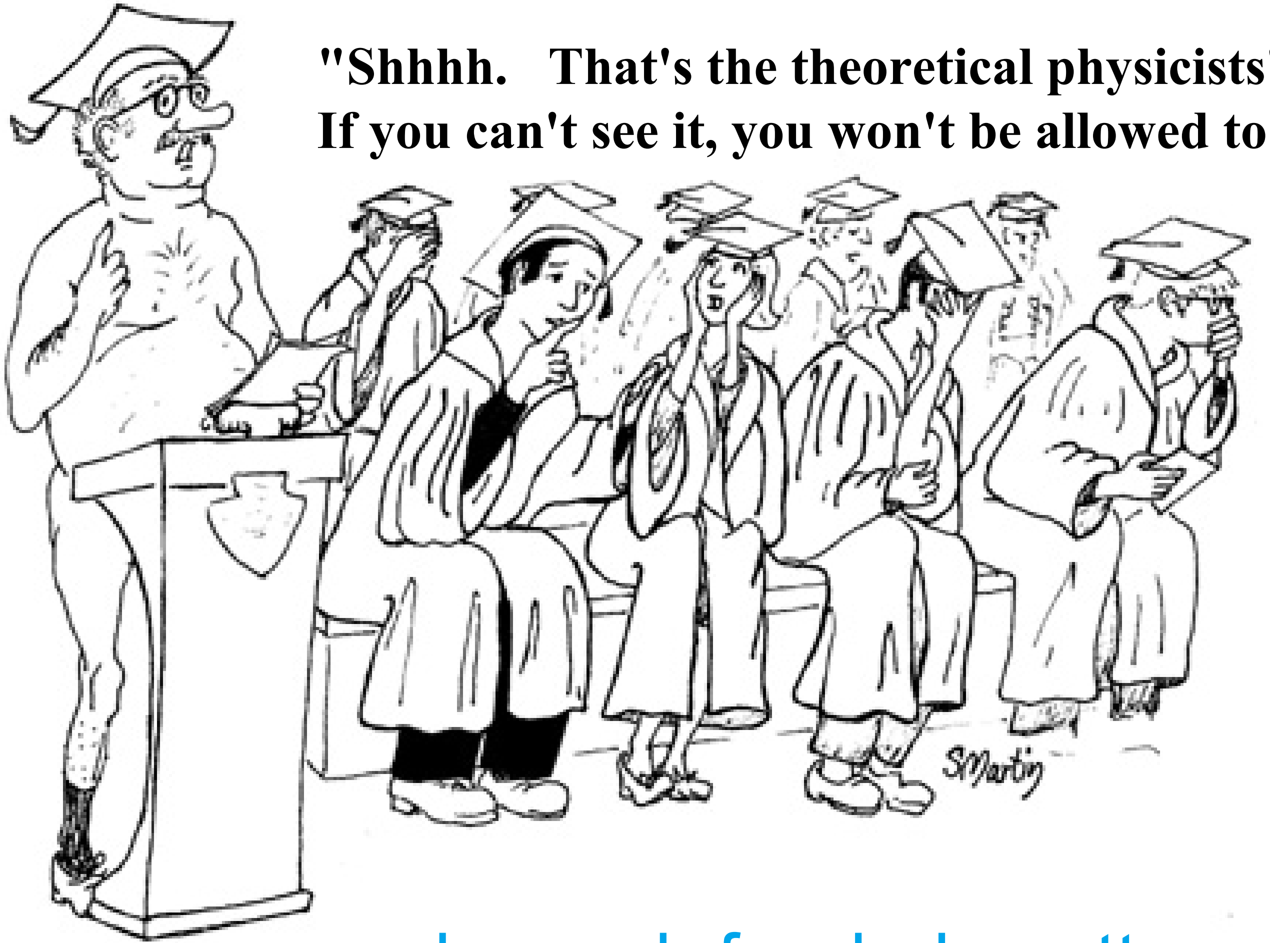
> Which is the relevant scale for homogeneity of the Universe?
Does one have to take into account in-homogeneities when calculating cosmological parameters?

> Do we really understand gravity in the weak acceleration regime?

- Pioneer anomaly: Slava G. Turyshev and Viktor T. Toth, arXiv:1001.3686v1 [gr-qc]
- Swing-by anomaly: J.D. Anderson et al., PRL 100, 091102 (2008)

For the time being …

… let's stick to the general accepted paradigm …



"Shhhh. That's the theoretical physicists' new particle uniform. If you can't see it, you won't be allowed to graduate."

http://www.softcom.net/users/greebo/laugh.htm

… and search for dark matter and dark energy.

Properties of the Dark Matter

> Dark Matter $\approx$ 30 · luminous matter (stars)

- Dark baryons (p, n) $\approx$ 5 · luminous matter
  (indirect observations (gas), big bang nucleosynthesis, CMBR)
- Unknown "dark" particles $\approx$ 6 · baryonic matter

  Only gravitational (and weak) interaction
  Should be non-relativistic ("cold")

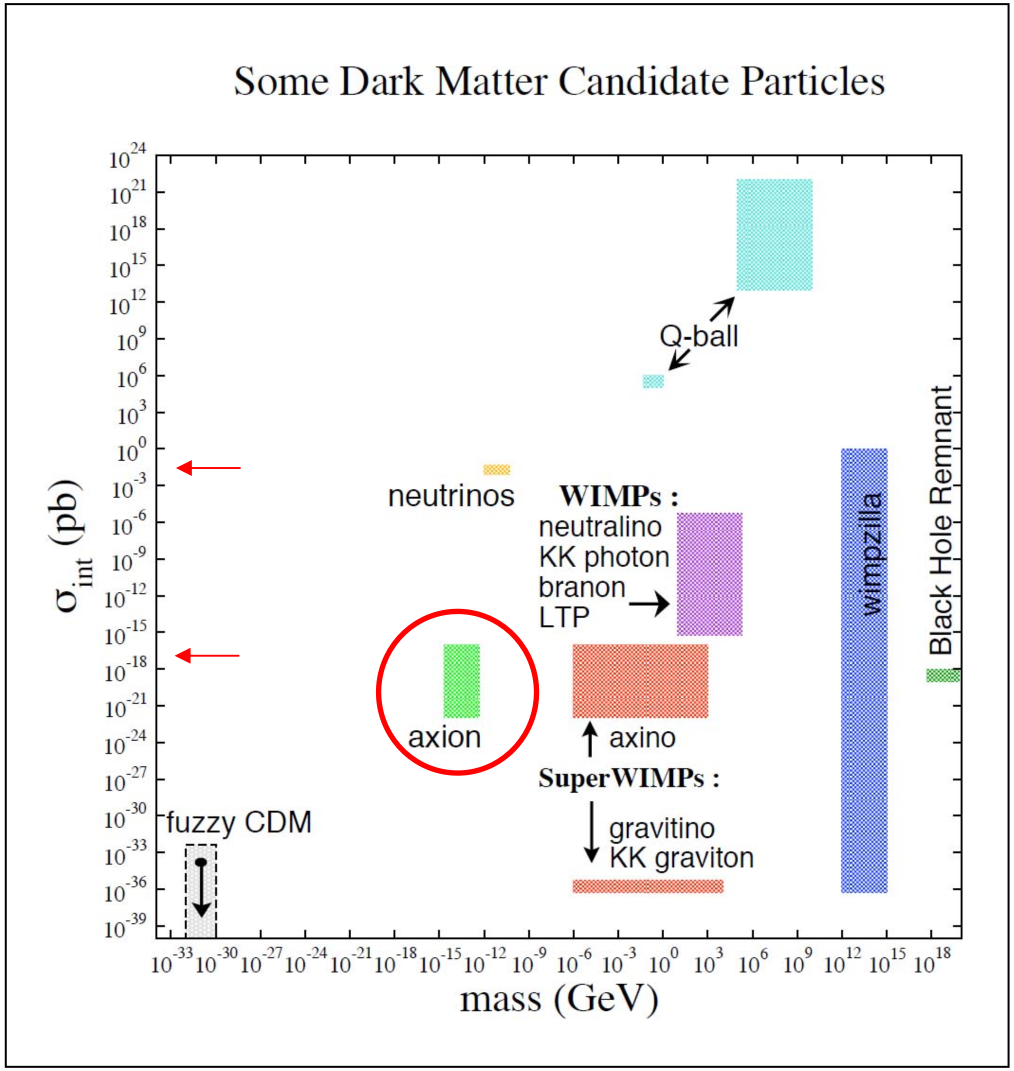
These “dark” particles are not members of the Standard Model!

The prime DM Candidates

1. Weakly Interacting Massive Particles: WIMPs
   Most promising candidate: lightest supersymmetric particle (neutralino, a linear combination of photino, zino and higgsinos, to be found at LHC?),
   very heavy (around 10^{11}eV).

2. Axion or Axion Like Particles: ALPs
   Invented to explain CP conservation in QCD (“why is the electric dipole moment of the neutron zero or extremely small?”).
   Non-thermal production in the early universe,
   very light (around 10^{-5}eV).

Dark Matter could be Axions!



Due to their non-thermal production in the universe light axions would constitute *cold* dark matter.

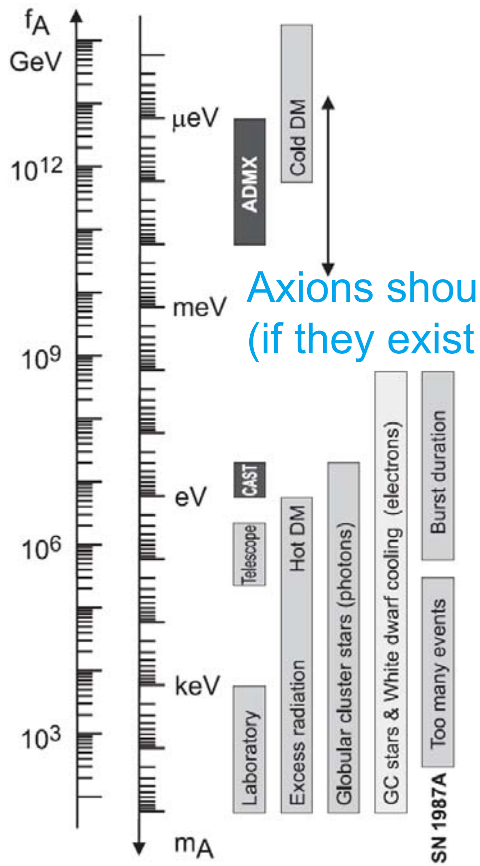
Such axions couple extremely weakly to matter: the “invisible” axion.

The axion was *not* invented to solve the Dark Matter problem!

H. Baer, presentation at 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

… and here we are:

http://pdg.lbl.gov/2009/reviews/rpp2009-rev-axions.pdf



Axions should hide here (if they exist at all)!

Figure 1: Exclusion ranges as described in the text. The dark intervals are the approximate CAST and ADMX search ranges. Limits on coupling strengths are translated into limits on m_A and f_A using $z = 0.56$ and the KSVZ values for the coupling strengths. The "Laboratory" bar is a rough representation of the exclusion range for standard or variant axions. The "GC stars and white-dwarf cooling" range uses the DFSZ model with an axion-electron coupling corresponding to $\cos^2\beta = 1/2$. The Cold Dark Matter exclusion range is particularly uncertain. We show the benchmark case from the misalignment mechanism.

> There could be a new particle, the axion, at the meV scale.

- m_a ≈ 1 meV
- f_a ≈ 10^{10} GeV
- $g_{a\gamma\gamma}$ ≈ 10^{-13} GeV^{-1}

> If found, it might give insight into physics at very large energy scales (f_a).

> However, it would interact extremely weakly with the Standard Model constituents.

> Such an axion could make up most of the mass of the Universe.

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From Axions to ALPs and WISPs

There might be much more than a QCD axion:

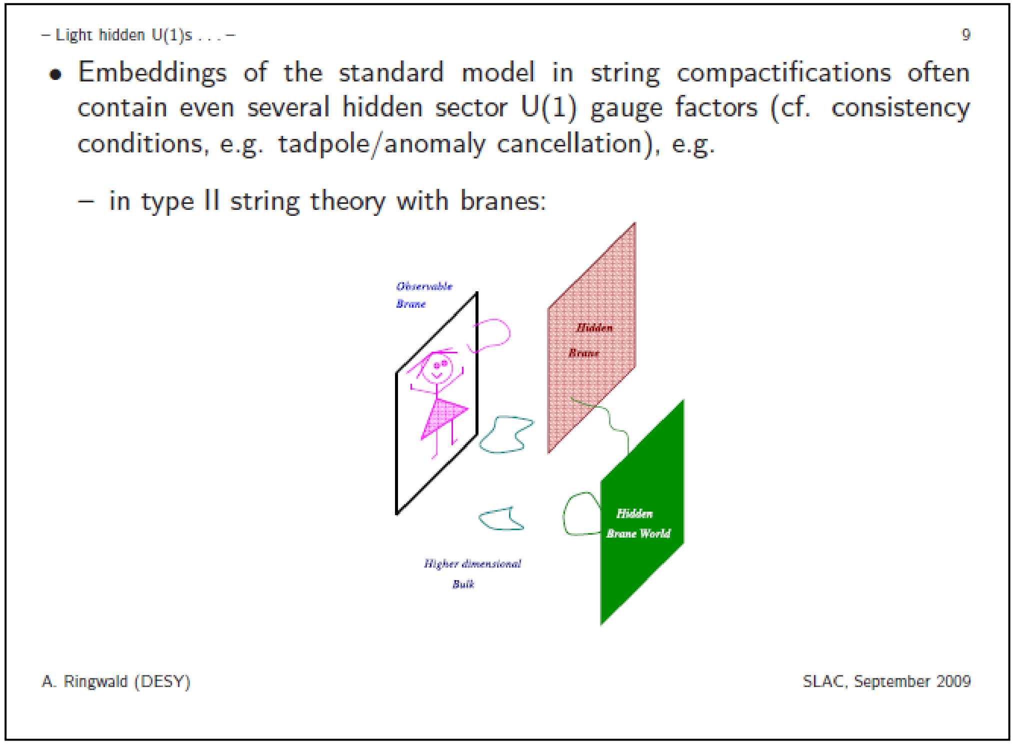
> ALPs: "axion-like particles"

String Axiverse
A. Arvanitaki, S. Dimopoulos, S. Dubovsky, N. Kaloper, and J. March-Russell,
arXiv:0905.4720 [hep-th]
String theory suggests the simultaneous presence of many ultralight axions, possibly populating each decade of mass down to the Hubble scale 10^{-33}eV. Conversely the presence of such a plenitude of axions (an "axiverse") would be evidence for string theory, ...

> WISPs, Weakly Interacting Slim Particles,
(axions and ALPs, hidden sector photons, mini-charged particles) occur naturally in string-theory motivated extensions of the Standard Model

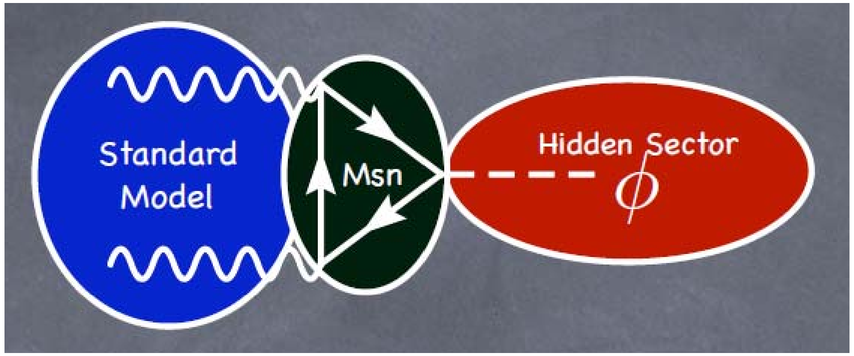
Naturally Light Hidden Photons in LARGE Volume String Compactifications
M. Goodsell, J. Jaeckel, J. Redondo and A. Ringwald,
arXiv:0909.0515 [hep-ph], JHEP 0911:027,2009
Extra "hidden" U(1) gauge factors are a generic feature of string theory that is of particular phenomenological interest. They can kinetically mix with the Standard Model photon and are thereby accessible to a wide variety of astrophysical and cosmological observations and laboratory experiments.

WISPs: Illuminating Hidden Worlds?


– Light hidden U(1)s . . . – 9

- Embeddings of the standard model in string compactifications often contain even several hidden sector U(1) gauge factors (cf. consistency conditions, e.g. tadpole/anomaly cancellation), e.g.
  - in type II string theory with branes:

A. Ringwald (DESY) SLAC, September 2009



> Very massive messengers may communicate between "our" Standard Model world and hidden sectors of a stringy universe.

In this sense WISP searches try to illuminate hidden worlds and probe very high energy scales.

Summary on Motivation

> The axion remains interesting as a
  - solution to the CP conservation of QCD,
  - candidate for Dark Matter.

> The might be a plenitude of Weakly Interacting Slim Particles
  - occurring naturally in string-theory inspired extensions of the Standard Model,
  - opening a window to physics beyond the TeV scale.

> Theory starts to develop detailed scenarios and predictions for WISPs to be probed by experiments.
  - Not only detections, but also upper-limits on WISP productions might become important ingredients for theory.

An Experimentalist's Motivation: Just Coincidences?

> Neutrinos have masses at the meV scale.

> The density of Dark Energy in our Universe is 10^{-29}g/cm^3, being equivalent to $\rho_{DE} \cong (2\ \text{meV})^4$.

The cosmological constant problem, *S. Weinberg*, Rev. Mod. Phys. 61, 1–23 (1989)

ute to the effective cosmological constant. In order to keep $\rho_V < 10^{-48}$ GeV^4, we need the scalar field adjustment to cancel the effect of gravitational and electromagnetic field fluctuations down to frequencies 10^{-12} GeV; for this purpose we must have $m_\phi < 10^{-12}$ GeV. A field this light will have a macroscopic range: $\hbar/m_\phi c \gtrsim 0.01$ cm.

> Today's energy density of the universe is about $(\text{meV})^4$.

Does this hint at new physics at the meV scale?

Presumably, LHC & Co. results will not explain these phenomena.

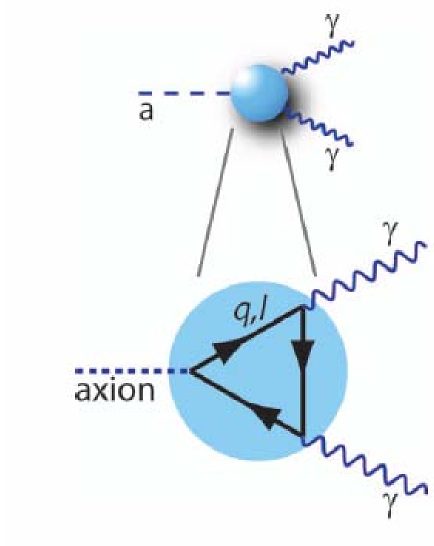
Let's strive for dedicated experiments!

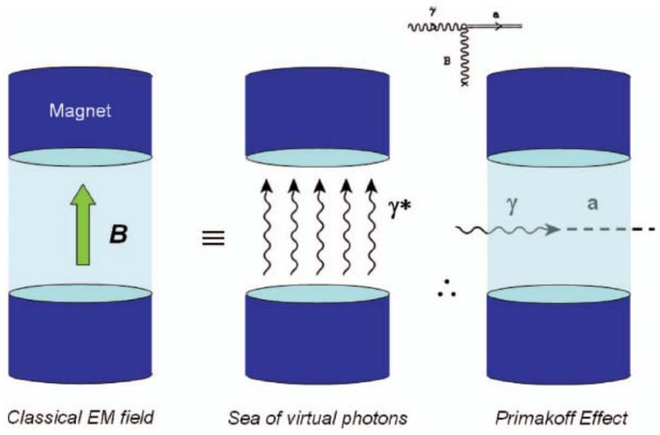
Table of Contents

How to search for “invisible” WISPs

- Axion and axion-like particles: exploit the coupling to photons.
- photon + photon ↔ ALP
  photon + ALP → photon
- photon + (virtual photon) → ALP
  ALP + (virtual photon) → photon

  A virtual photon can be provided by an electromagnetic field.





The Search for Axions,
Carosi, van Bibber, Pivovaroff,
Contemp. Phys. 49, No. 4, 2008

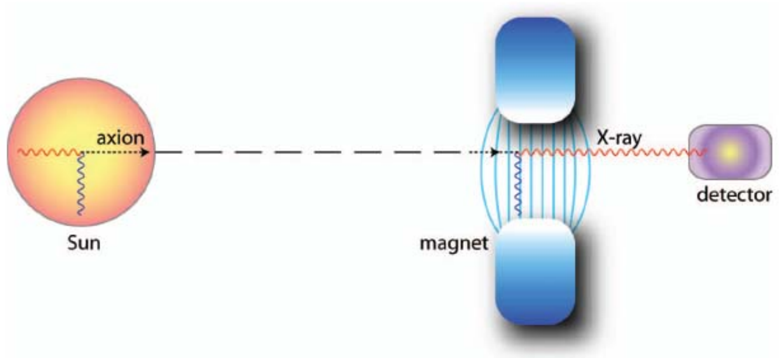
How to search for “invisible” WISPs: Astrophysics

> Indirect:
WISPs would open up new energy loss channels for hot dense plasmas

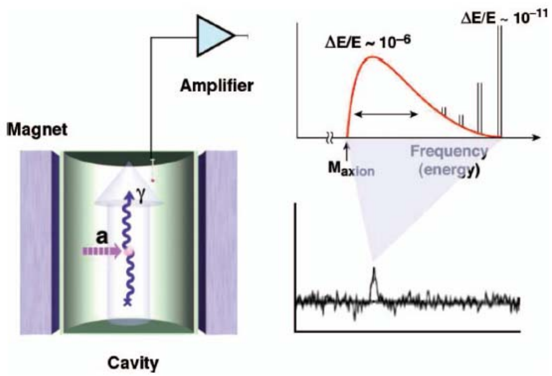
- stringent limits on WISP characteristics from the lifetime of stars, length of neutrino pulse from SN and cosmic microwave background radiation for example.

> Direct:

- Search for axions from the sun (CAST at CERN)



- Search for halo dark matter axions (ADMX at Livermore)



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lhttp://cast.web.cern.ch

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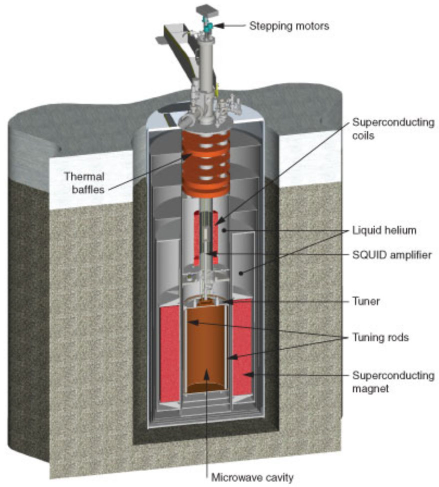
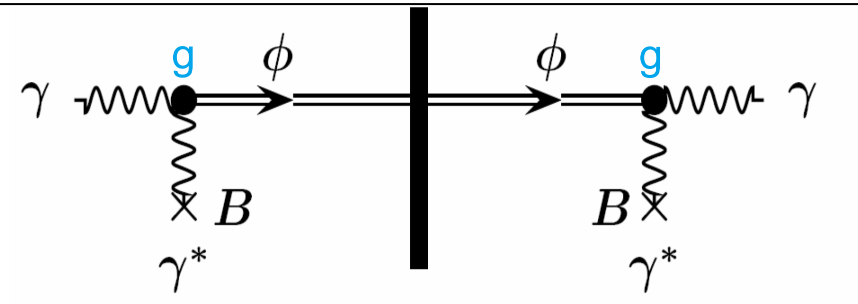


http://www.phys.washington.edu/groups/admx/home.htm

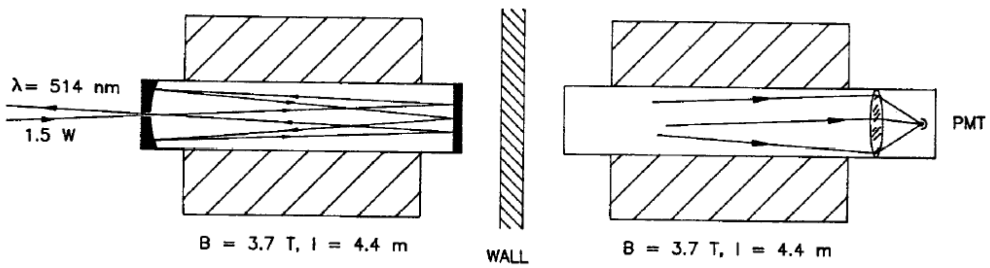
How to search for “invisible” WISPs: Lab Experiments

“Light-shining-through-a-wall” (LSW)



Okun 1982, Skivie 1983, Ansel‘m 1985, Van Bibber et al. 1987

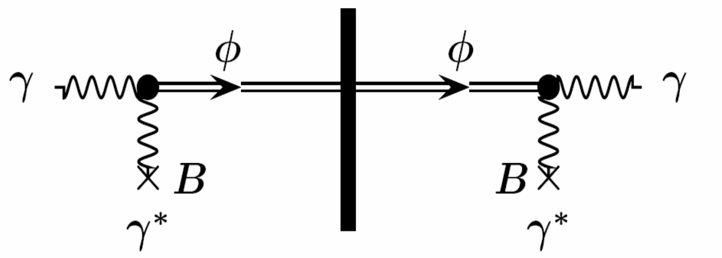
Note:
$P_{\gamma \to \Phi \to \gamma} \sim g^4$



G. Ruoso et al.
(BFRT Experiment),
Z. Phys. C 56 (1992) 505

Axion Production in a magnetic Field

> The production (and re-conversion) of WISPs takes place in a coherent fashion.



For ALPs (Φ):

$$P_{\gamma\to\phi}(B,\ell,q) = \frac{1}{4}\left(g\,B\,\ell\right)^2\,F(q\ell) \qquad F(q\ell) = \left[\frac{\sin\left(\frac{1}{2}q\ell\right)}{\frac{1}{2}q\ell}\right]^2$$

$q = p_\gamma - p_\Phi$
l: length of B field

With $P_{\gamma\to\Phi} = P_{\Phi\to\gamma} = P$: $g = (P)^{1/4} \cdot 2 \cdot / (l \cdot B) / F^{1/2}$

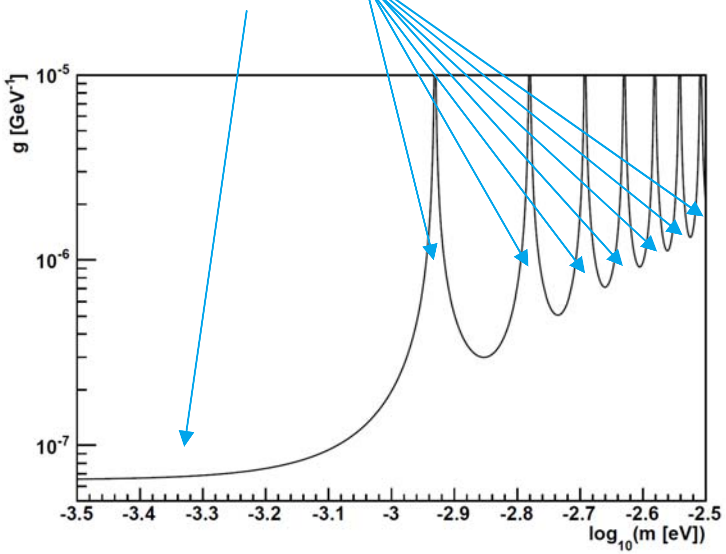


Table of Contents

ALPS @ DESY in Hamburg

ALPS
(the only particle physics experiment on site)

- Approved January 2007
- Final data run Dec. 2009 (end of first phase)

The ALPS Project

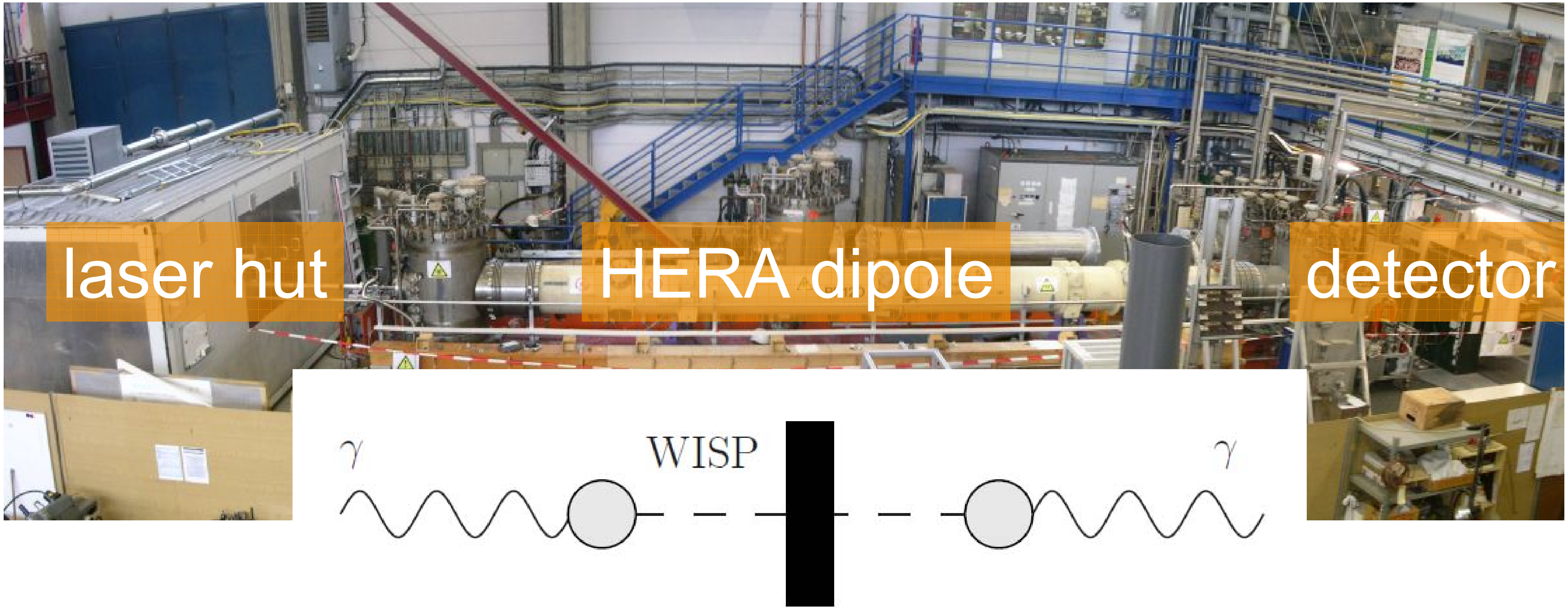
Axion-Like Particle Search @ DESY

The ALPS Project

Any Light Particle Search @ DESY

The ALPS Project

Any Light Particle Search @ DESY



A “light-shining-through-a-wall” experiment

The ALPS Project

Any Light Particle Search @ DESY

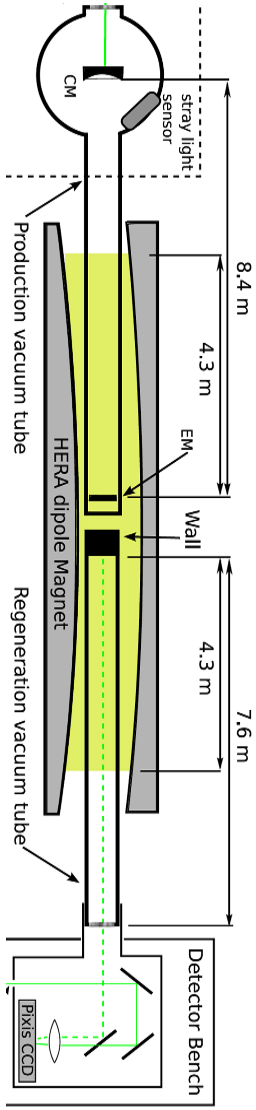
- DESY
- Max Planck Institute for Gravitational Physics (Albert Einstein Institute), and Institute for Gravitational Physics, Leibniz University Hannover
- Laserzentrum Hannover
- Hamburger Sternwarte

Three main ALPS Components

> Powerful laser:
  optical cavity to recycle laser power
  (high quality laser beam)

> Strong magnet:
  HERA dipole: 5 T, superconducting
  (unfortunately just one)

> Sensitive detector:
  CCD
  (determines wavelength of laser light!)



<u>Tubes:</u>
- diameter: 34 mm
- clear aperture: 14 mm

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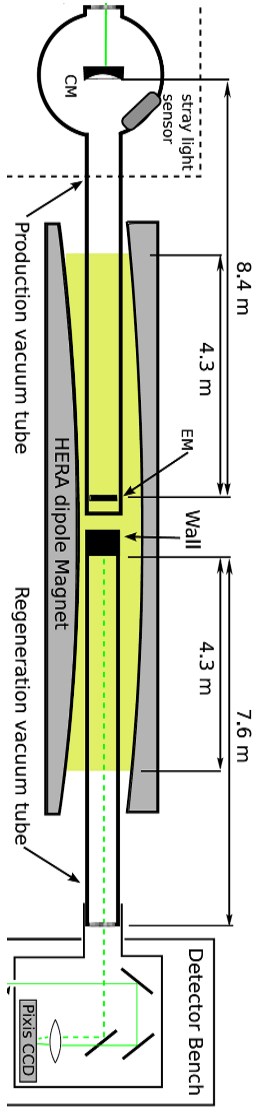
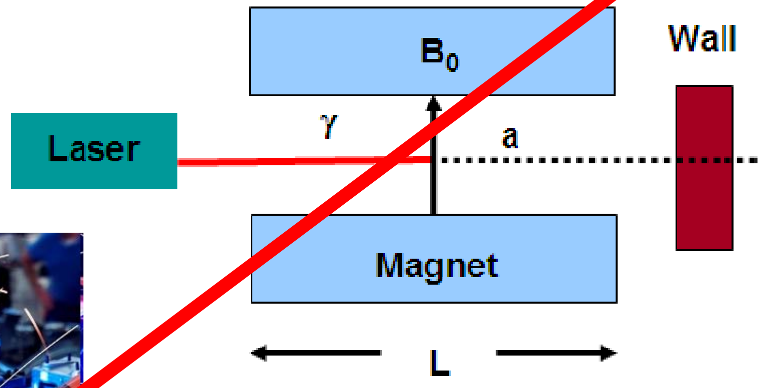


Tubes:
- diameter: 34 mm
- clear aperture: 14 mm

A powerful Laser System for ALPS

> Brute force:
  a very powerful laser



D. Tanner, PATRAS 2009

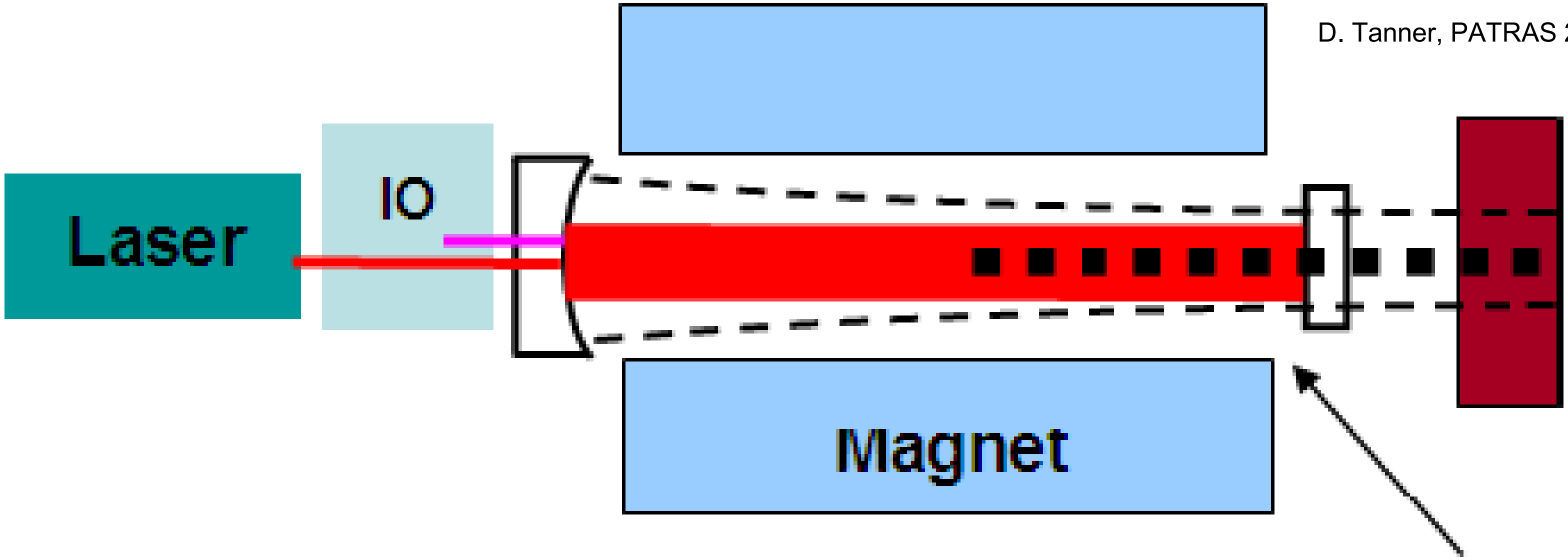
> example:
  laser for welding

> Problems

- significant energy deposition inside the HERA dipole (superconducting) is to be avoided.
- laser properties not suited to guide the beam through the bent tube of the dipole.

A powerful Laser System for ALPS

> Trick:
the light of a relatively low power laser with excellent beam characteristics is reflected back and forth inside the magnet,
the light is stored inside an optical resonator (cavity)
thus enhancing the effective laser power.



D. Tanner, PATRAS 2009

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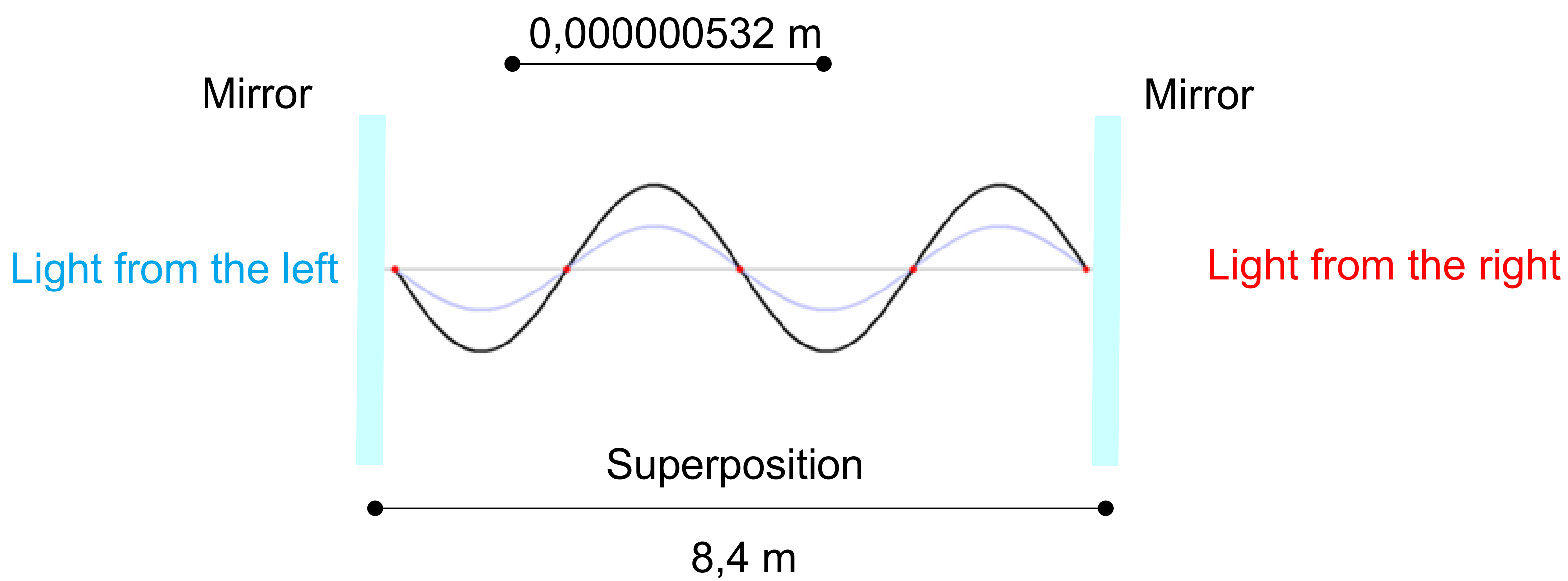
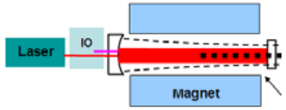


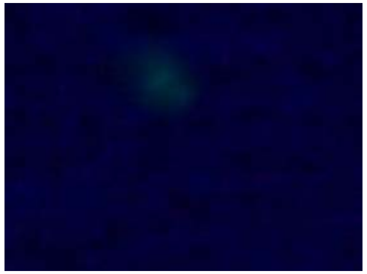
A powerful Laser System for ALPS

> Challenges:

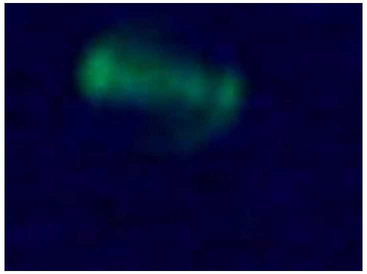
- The distance of the mirrors and the wavelength have to match within ≈ 10 nm in spite of acoustic noise and other fluctuations.
  This is guaranteed by an electronic feedback loop adapting the laser light wavelength to the mirror distance
- The mirrors have to reflect the light back and forth on exactly the same path.
- This is to be done without access to the mirror in the middle of the magnet. There is no way to firmly fix this mirror!

> ALPS succeeded to realize such a set-up for the first time (doi:10.1016/j.nima.2009.10.102)

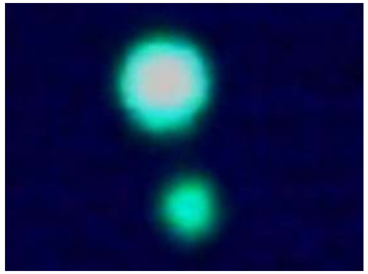




Resonator detuned.



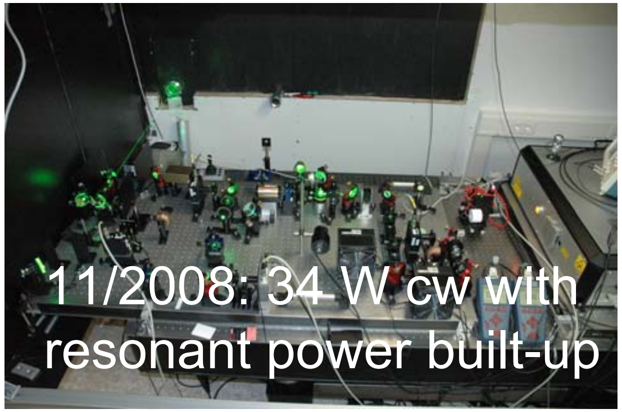
tuned, but not "locked".

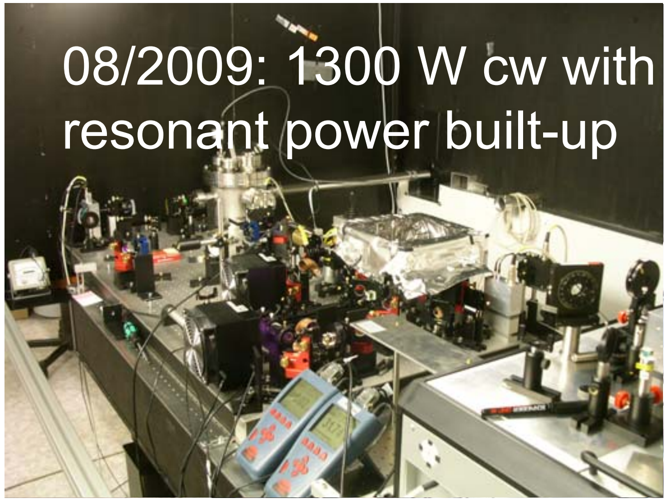


Locked!

The ALPS Lasers

> Result of laser upgrades for data taking August to December 2009:





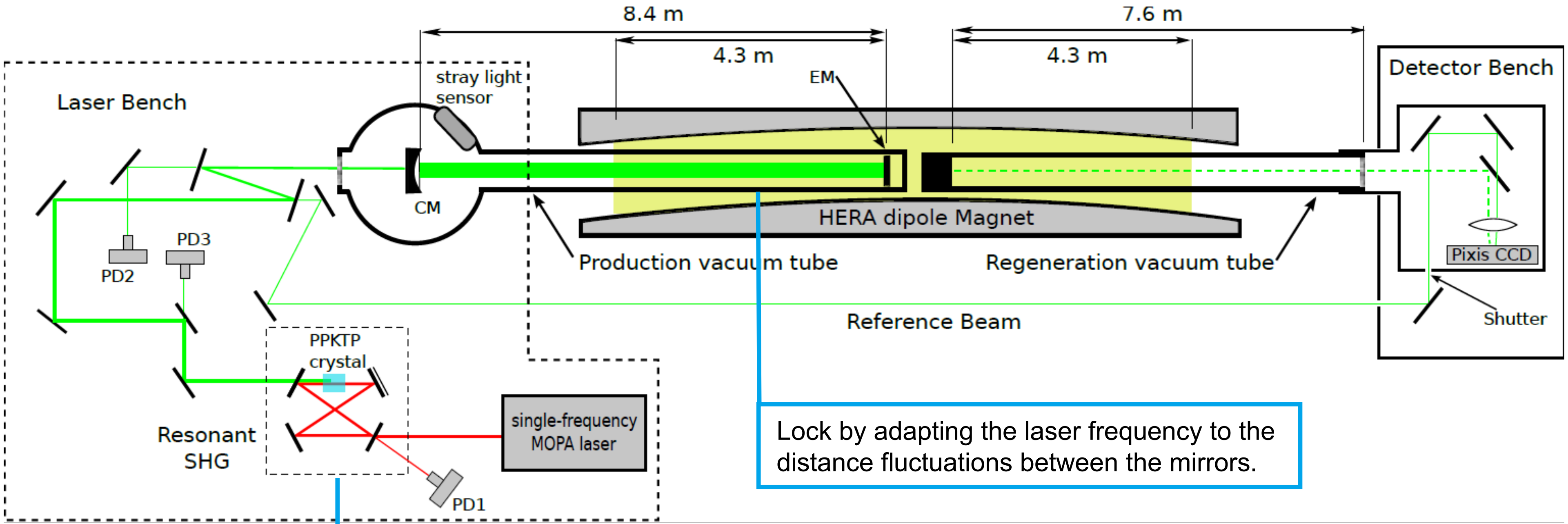
The 1300 W laser power is achieved from 4.4 W built-up in the resonator by a factor of 300.

The power is limited by the lifetime of the mirrors in vacuum (10-30 h) due to heating. However, a significant further improvement would also require investments into beam stabilization and new locking electronics.

1300 W is much more than we ever dreamt of!

The ALPS Laser System

> We are running a quite complex and delicate apparatus!

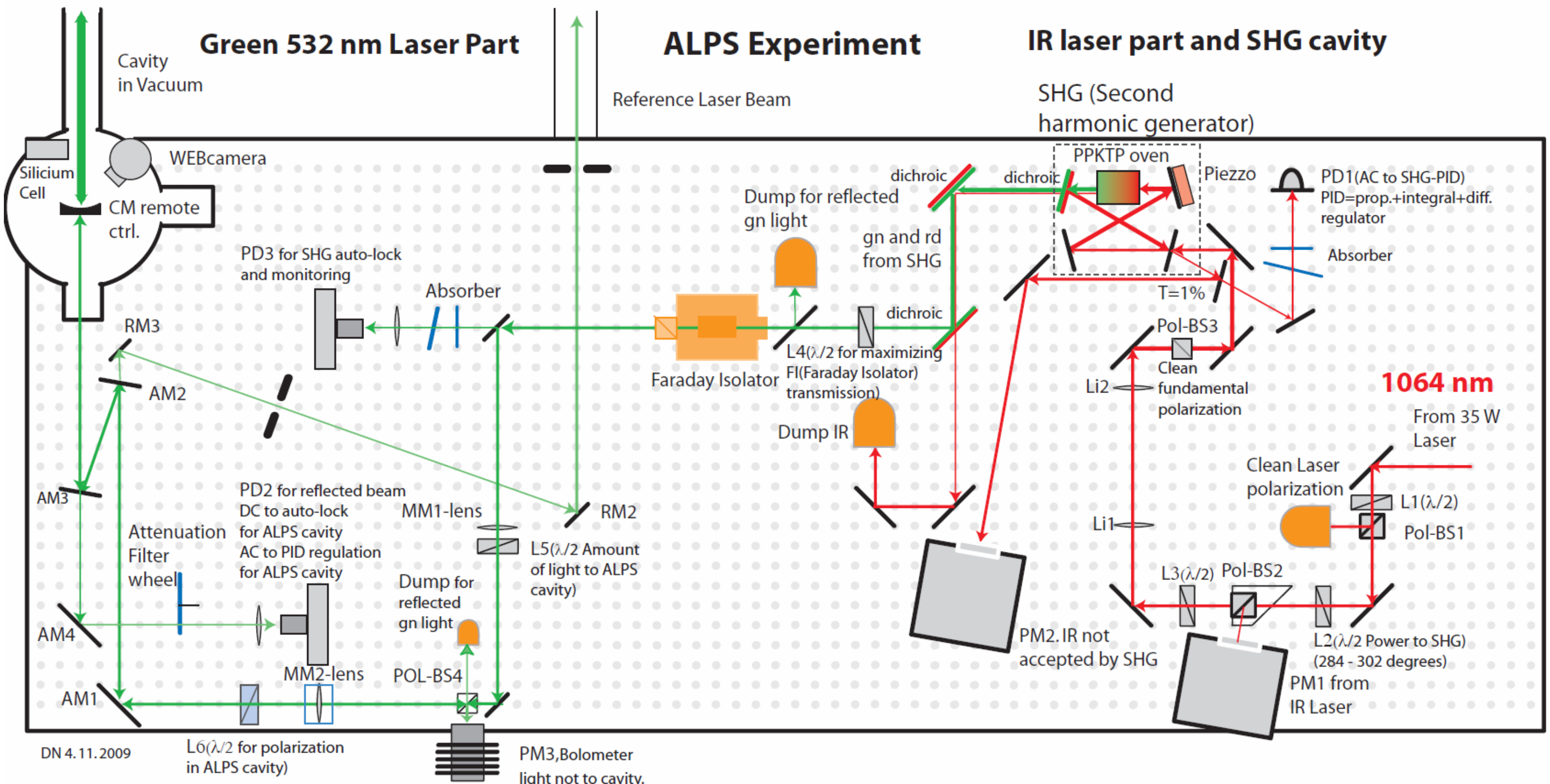


Lock by adapting the laser frequency to the distance fluctuations between the mirrors.

Lock by adapting the distance between the mirrors to the variations of the laser frequency.

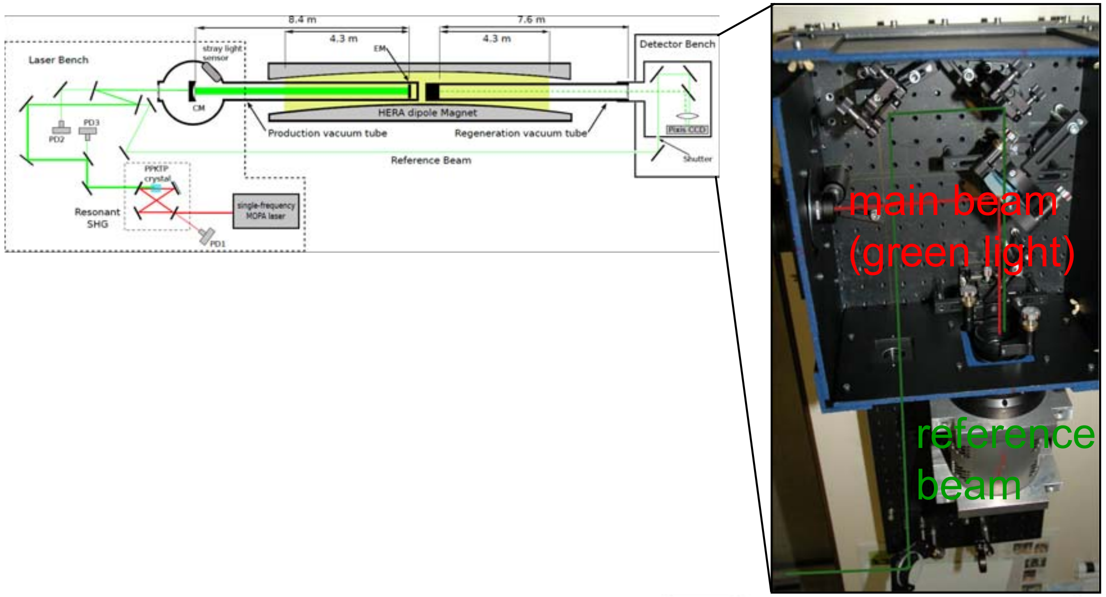
The ALPS Laser System

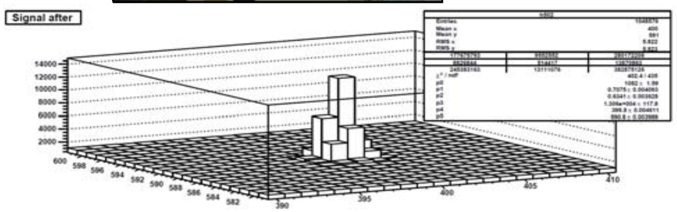
> We are running a quite complex and delicate apparatus!



The ALPS Detector

> Conventional low noise CCD, where the light is focused onto very few pixels to minimize dark current and read-out noise.



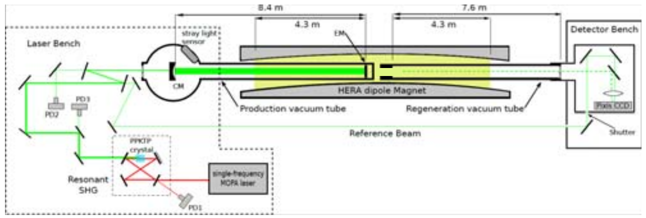


Beam spot on the CCD (pixel size 13 µm).

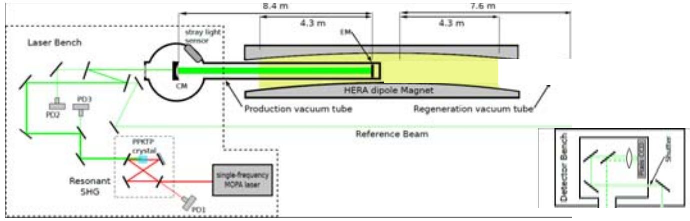
ALPS at Work

Steps of data taking:

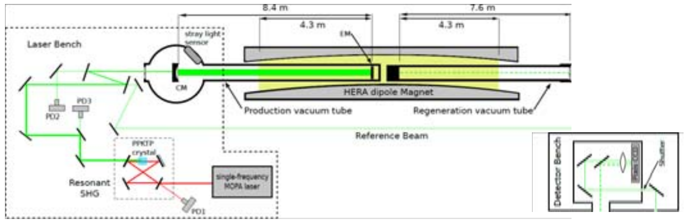
1. Test alignment with open detector tube and fraction of laser light passing the mirror (10^{-4}).



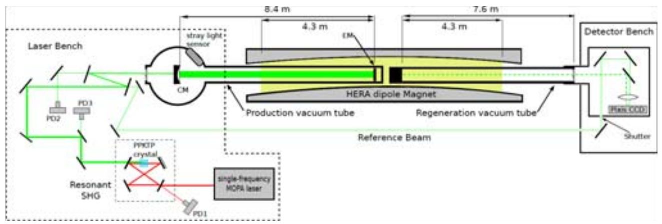
2. Demount detector and detector tube.



3. Close tube and reinstall everything.



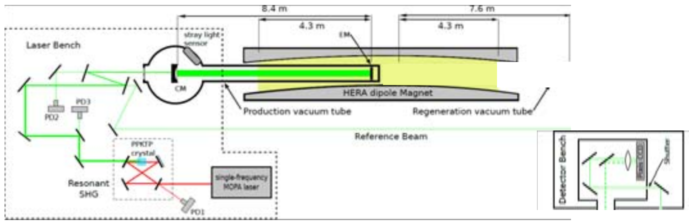
4. Take data (1h CCD exposures).



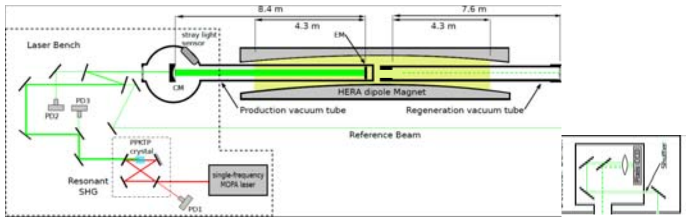
ALPS at Work

Steps of data taking:

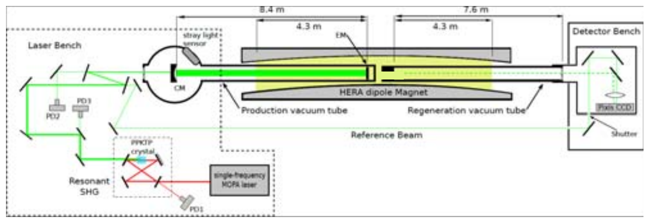
5. Demount detector and detector tube.



6. Open the tube and reinstall everything.



7. Test alignment with open detector tube and fraction of laser light passing the mirror (10^{-4}) to confirm that the alignment has not changed.



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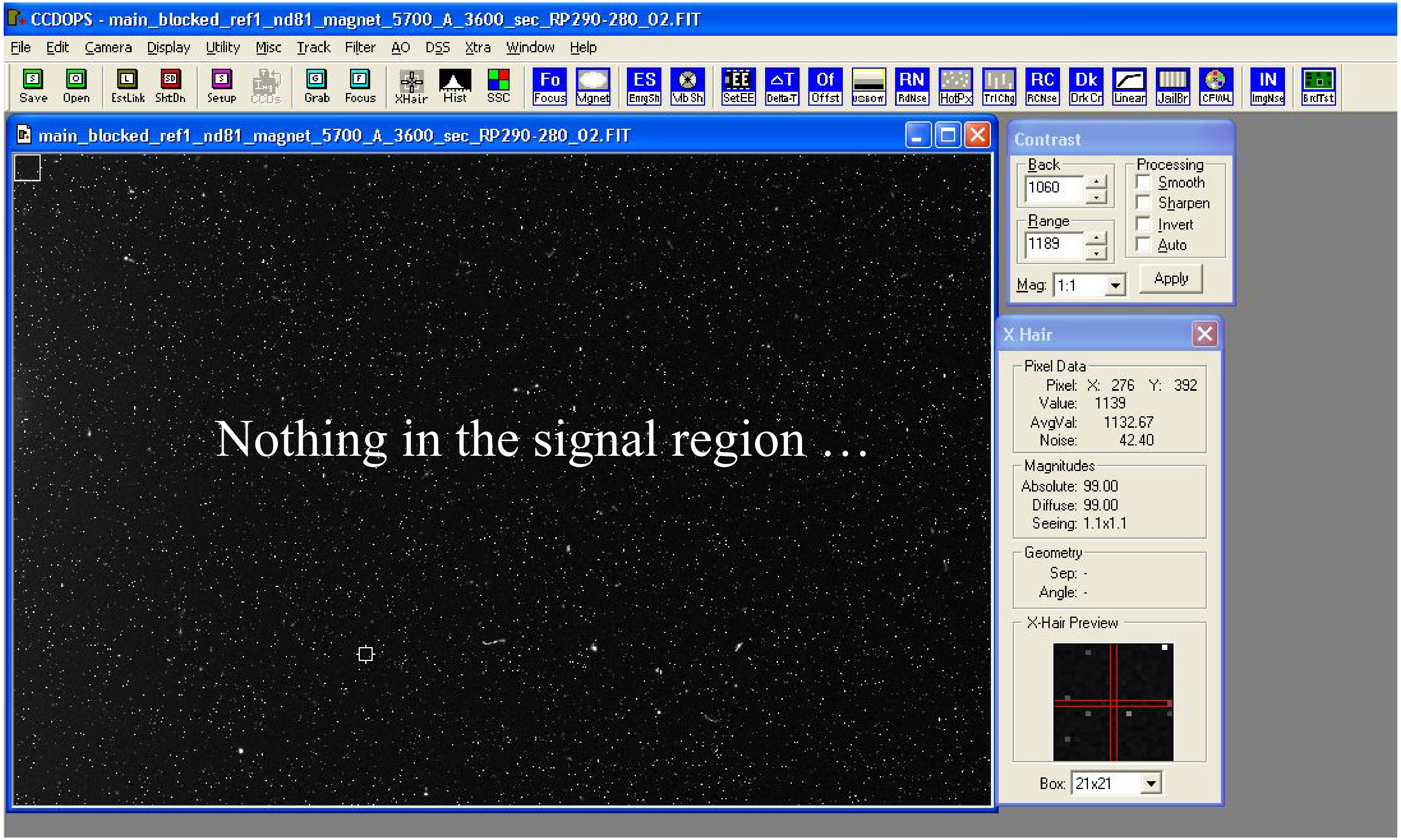
One Data Frame (SBIG ST-402)



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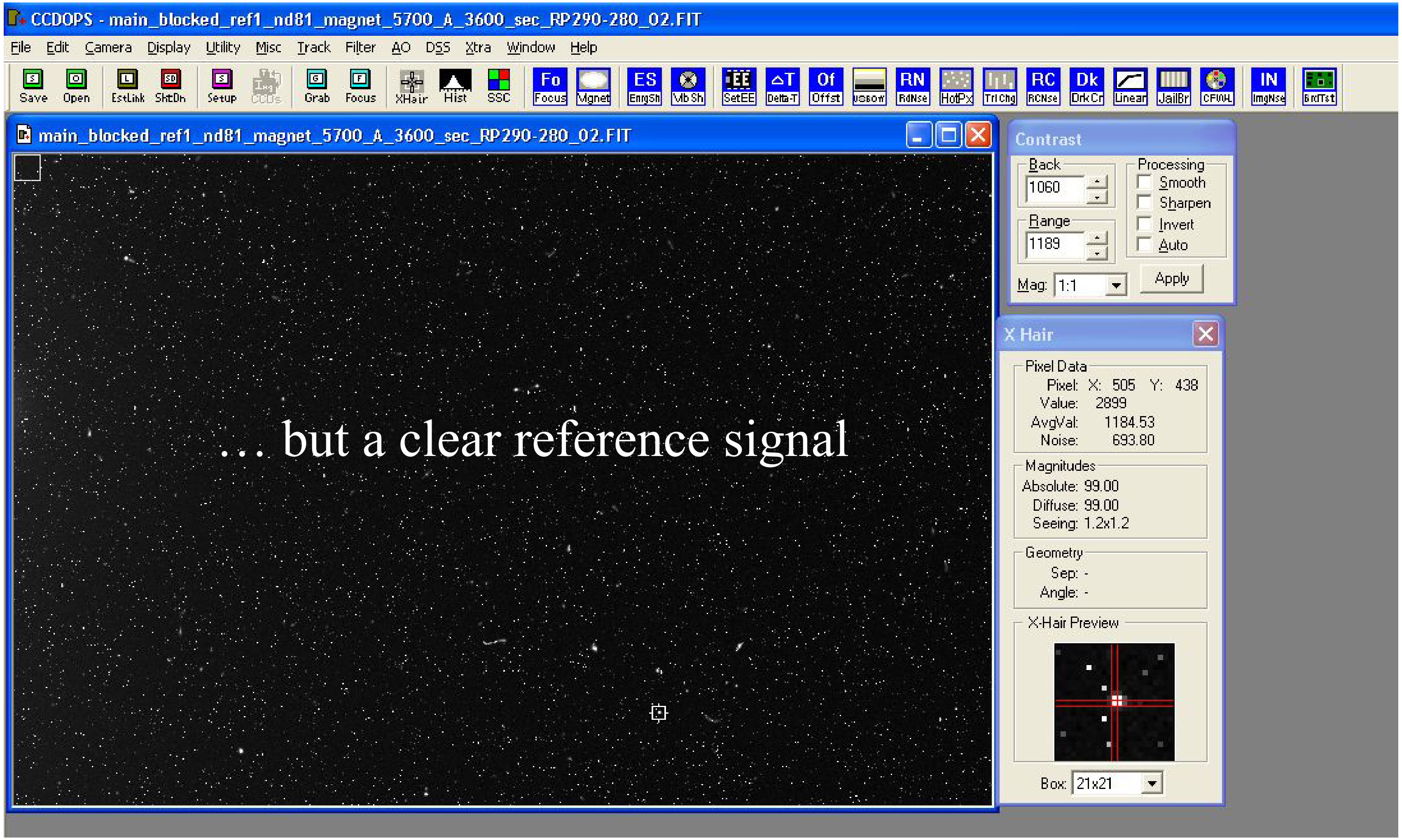
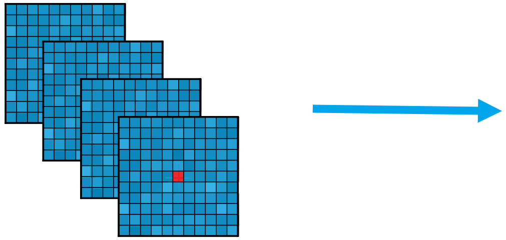
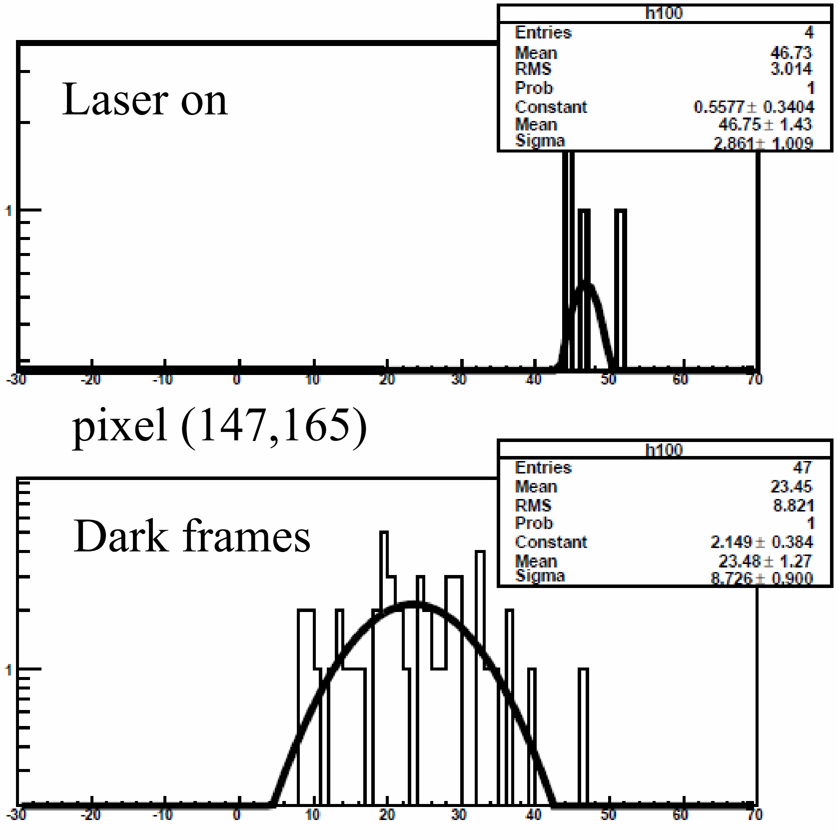
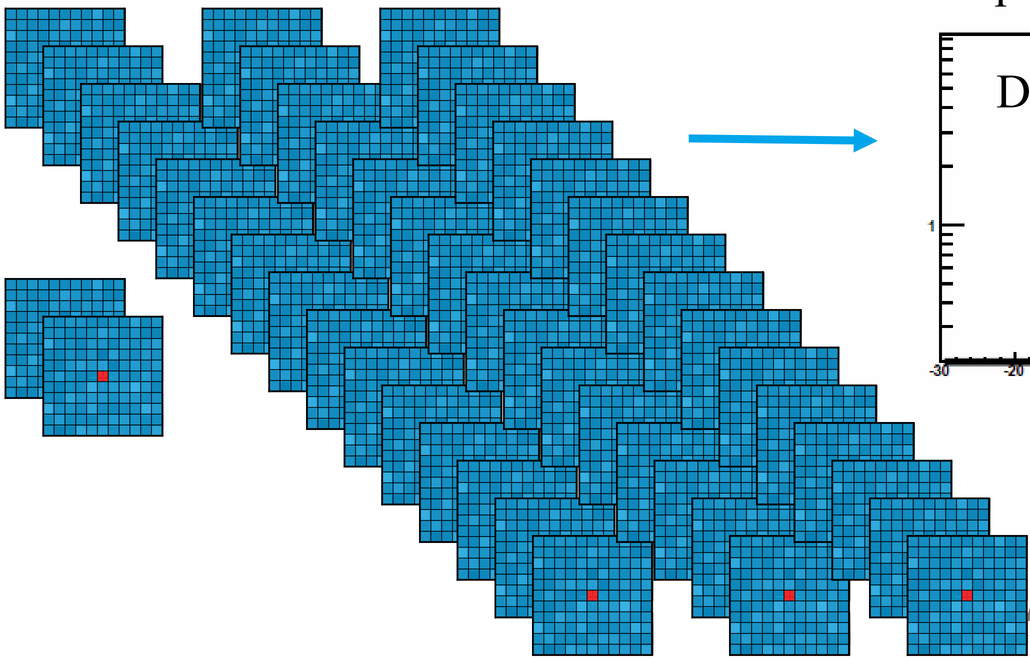


A Glimpse into the Data Analysis

> Each 1 h exposure results in one entry (ADU value of the signal pixel) into the histogram:



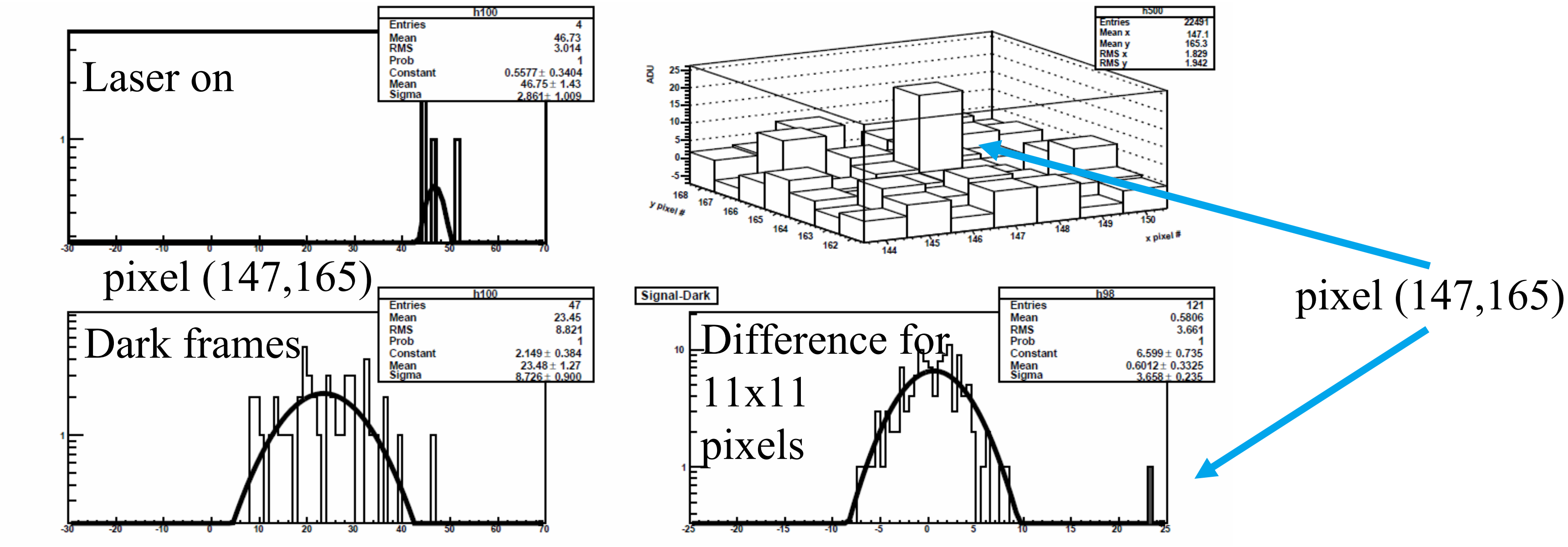




Compare mean ADU for “Laser on” and “Dark frames”.

A Glimpse into the Data Analysis

> Test the CCD and the data analysis with a photon beam of extremely low intensity: between 5 mHz and 50 mHz.



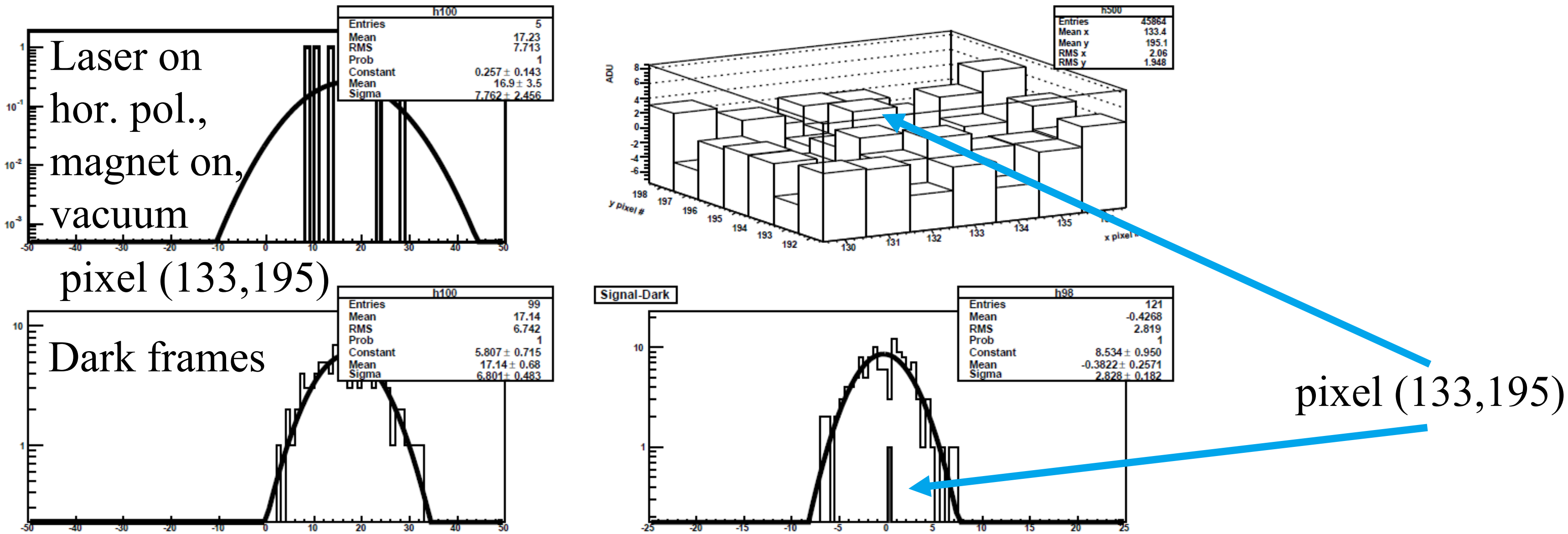
From Gaussians fitted to the data:

Δmean	Δwidth
23.27±3.20	-5.86±3.20

A photon flux of (7.9±1.2) mHz ($3 \cdot 10^{-21}$ W) is detected which agrees nicely to the expectation.

A Glimpse into the Data Analysis

> Example for a data run:



From Gaussians fitted to the data:

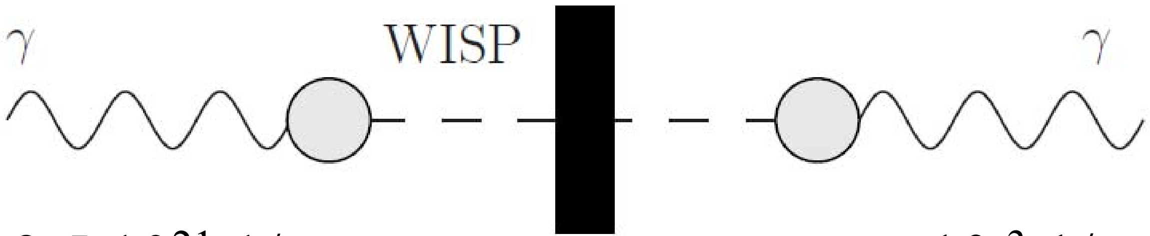
Δmean	Δwidth
-0.24±3.54	0.96±2.50

In none of the preliminary data analyses any evidence for WISP production shows up.

ALPS Results:

(PLB Vol. 689 (2010), 149, or http://arxiv.org/abs/1004.1313)

> Unfortunately, no light is shining through the wall!

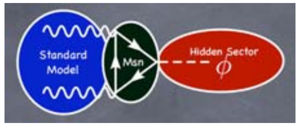


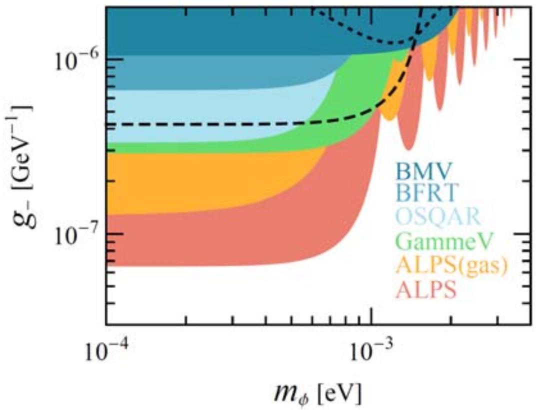
$3.5 \cdot 10^{21}$ 1/s

$< 10^{-3}$ 1/s

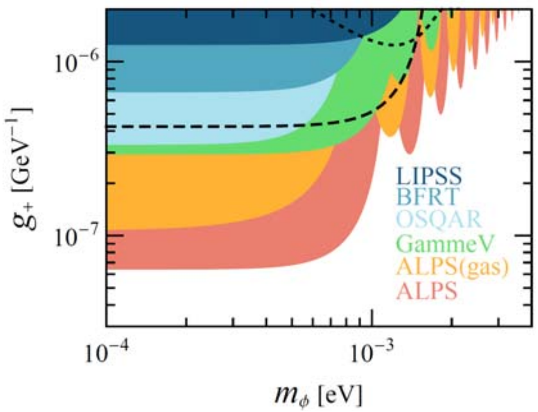
ALPS Results: http://arxiv.org/abs/1004.1313

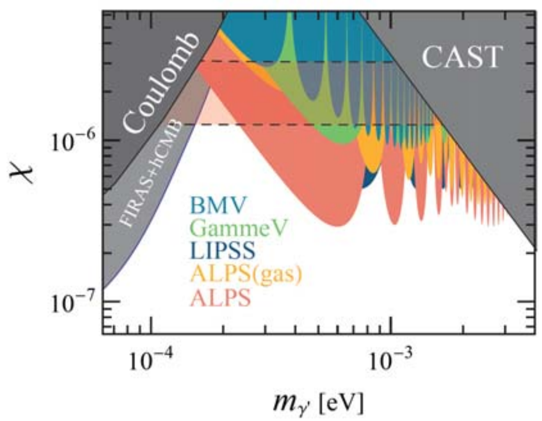
> ALPS is the most sensitive experiment for WISP searches in the laboratory. For axion-like particles, ALPS probes physics at the “multi-10-TeV scale”!





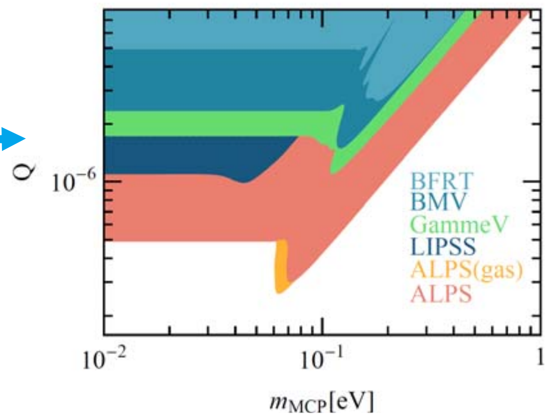
pseudoscalar
and
scalar
axion-like particles





hidden sector photons
and
minicharged particles

Filling a gap remaining from astrophysics and other experiments!



PLB 689 (2010), 149

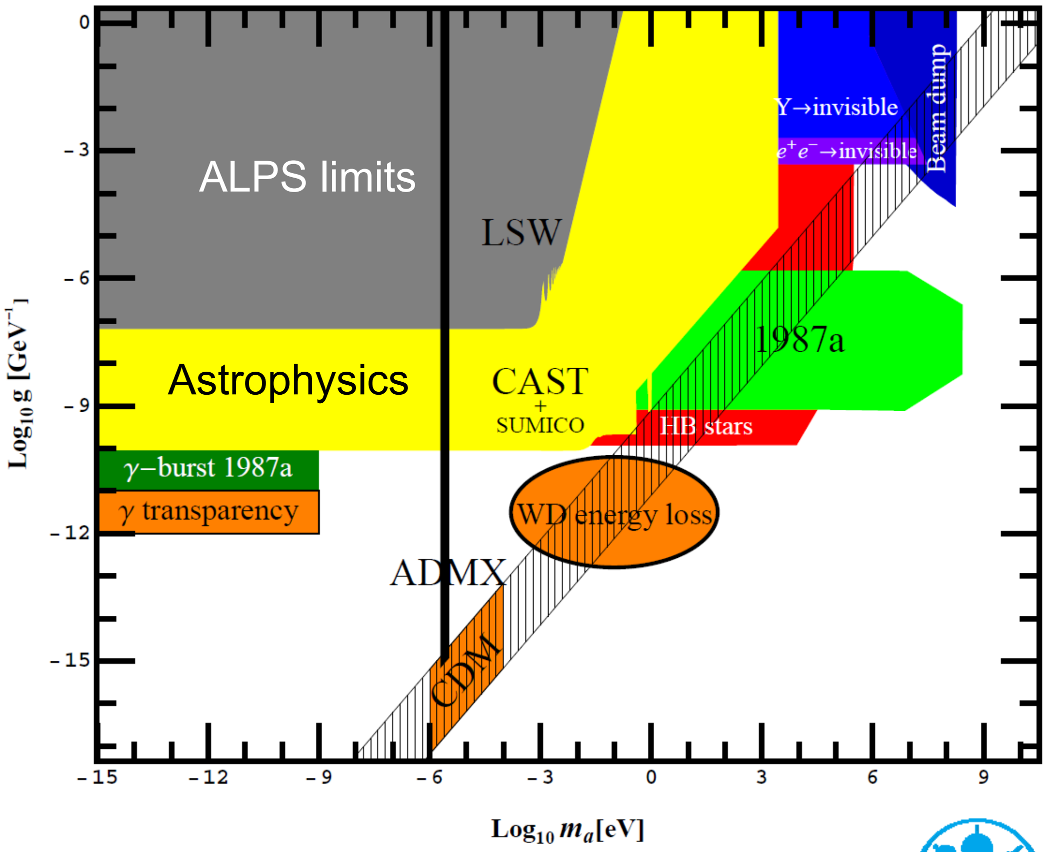
ALPS Summary

> Experience gathered with ALPS is a firm foundation for continuing to probe the hints for WISPs, now on larger scales.

> The essential strength of ALPS is the collaboration of particle physicists (theory and experiment) and laser physicists from the gravitational wave detector community.

> Infrastructure and large magnets provided by a lab like DESY are essential to accomplish experiments like ALPS.

> Significant efforts required to compete with astrophysics!



compiled by J. Jäckel and A. Ringwald

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Outlook

> The world-wide activities in this research field are strengthening.

Laser Experiments: History & Presence

Experiment	Reference	$\Delta\theta$	ψ	LSW
ALPS (DESY/D) "**A**xion-**L**ike **P**article **S**earch"	arXiv:0905.4159	✘	✘	✔
BFRT (**B**NL-**F**ermilab-**R**ochester-**T**rieste)	Phys.Rev.**D47**(1993)	✔	✔	✔
BMV (LULI/F) "**B**iréfringence **M**agnétique du **V**ide"	Phys.Rev.Lett.**99** (2007) Phys.Rev.D**78** (2009)	✘	✘	✔
GammeV (Fermilab/USA) "**Gamm**a to m**eV** particle search"	Phys.Rev.Lett.**100** (2008) Phys.Rev.Lett.**102** (2009)	✘	✘	✔
LIPSS (Jefferson Lab/USA) "**LI**ght **P**seudoscalar or **S**calar particle **S**earch"	Phys.Rev.Lett.**101** (2008) arXiv:0810.4189	✘	✘	✔
OSQAR (CERN/CH) "**O**ptical **S**earch for **Q**ED vacuum magnetic birefringence, **A**xions and photon **R**egeneration"	Phys.Rev.D**78** (2008)	✘	✘	✔
PVLAS (INFN/I) "**P**olarizzazione del **V**uoto con **LAS**er"	Phys.Rev.Lett.**96** (2006) Erratum-ibid.**99** (2007) Phys.Rev.D**77** (2008)	✔	✔	(✔)
Q&A (Hsinchu/Taiwan) "**Q**ED & **A**xion"	Mod.Phys.**A22** (2007)	✔	✘	✘

Markus Ahlers July 13, 2009 | Introduction | Axions | ALPs | WISPs | Summary

M. Ahlers, presentation at the 5th Patras Workshop on Axions, WIMPs and WISPs, 2009

Outlook

However, is this worthwhile to continue?

YES, indeed!

Hints for WISP Physics?

Theory:

> A QCD axion in the mass region of 10^{-5} to 10^{-4} eV would be a “perfect” cold Dark Matter candidate.

> A zoo of WISPs is expected from string theory inspired extensions of the Standard Model
A. Arvanitaki, S. Dimopoulos, S. Dubovsky, N. Kaloper, and J. March-Russell, arXiv:0905.4720 [hep-th]
M. Goodsell, J. Jaeckel, J. Redondo and A. Ringwald, arXiv:0909.0515 [hep-ph], JHEP 0911:027,2009

Astrophysics:

> *Axions and the cooling of white dwarf stars.*
J. Isern et al., arXiv:0806.2807v2 [astro-ph], Astrophys.J.L. 682 (2008) L109

> *Evidence for a New Light Boson from Cosmological Gamma-Ray Propagation?*
M. Roncadelli et al., arXiv:0902.0895v1 [astro-ph.CO]

> Does the X-ray spectrum of the sun points at a 10 meV axion?
K. Zioutas et al., arXiv:0903.1807v4 [astro-ph.SR]

> Large-Scale Alignments of Quasar Polarization Vectors: Evidence at Cosmological Scales for Very Light Pseudoscalar Particles Mixing with Photons?
D. Hutsemekers et al., arXiv:0809.3088v1 [astro-ph]

> Signatures of a hidden cosmic microwave background
J.Jaeckel, J. Redondo, A. Ringwald, Phys.Rev.Lett.101:131801,2008

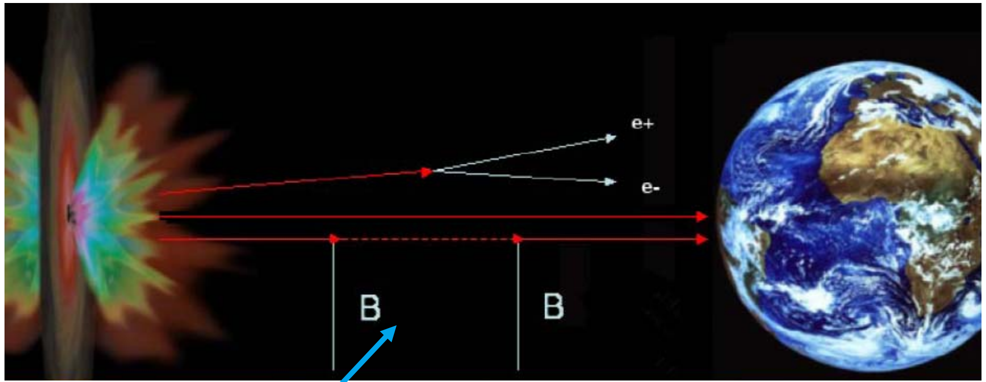
Hints for ALP Physics: Cosmological TeV γ Propagation

TeV photons should be absorbed by e^+e^- pair production due to interaction with the extragalactic background light (EBL):

$\gamma_{TeV} + \gamma_{eV} \rightarrow e^+ + e^-$

However, the TeV spectra of distant galaxies do hardly show any absorption.

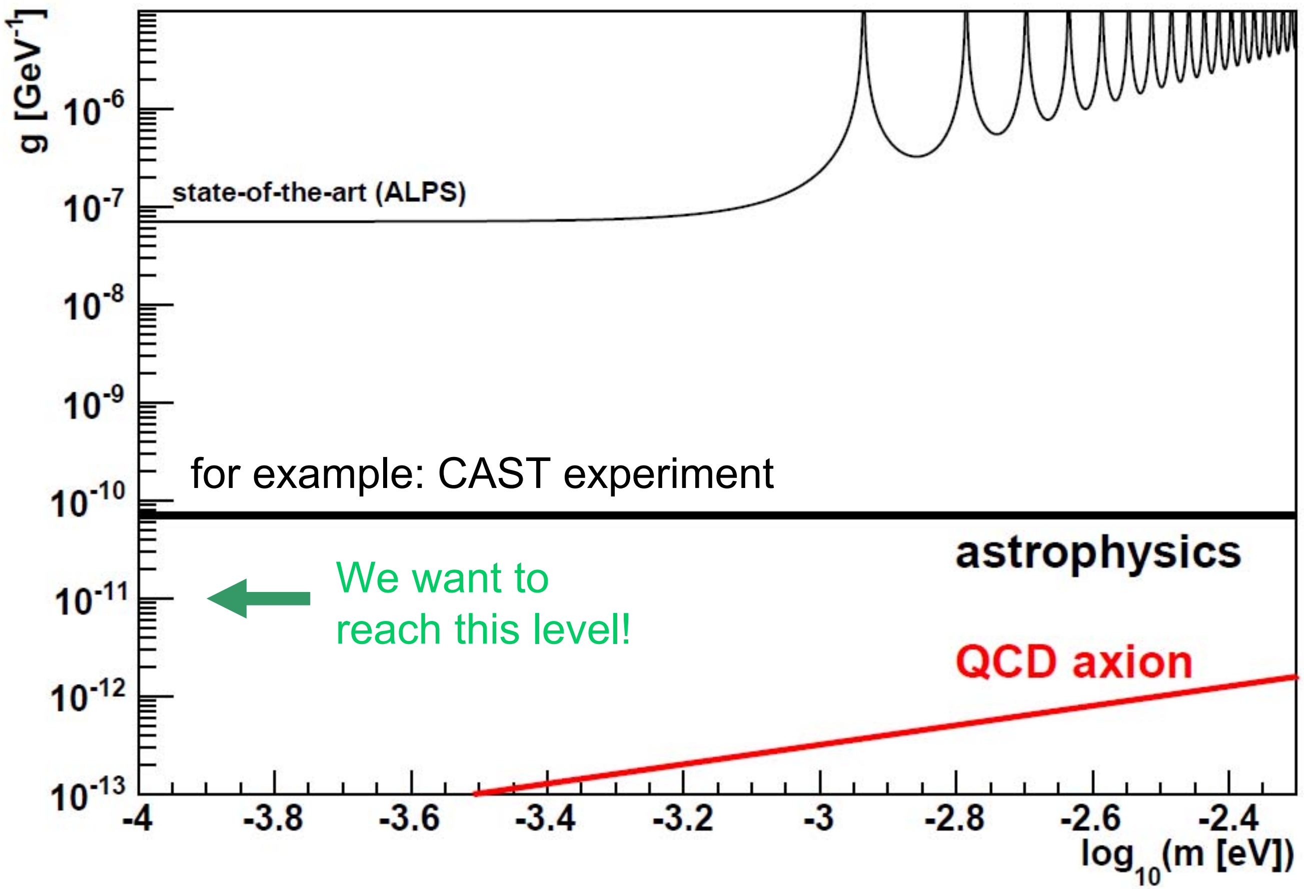
M. Roncadelli, presentation at the 4th Patras Workshop on Axions, WIMPs and WISPs, 2008

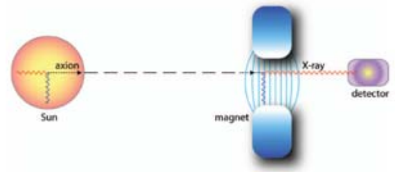


TeV photons may "hide" as ALPs!

A possible Scenario for ALPS II

> Still a way to go!



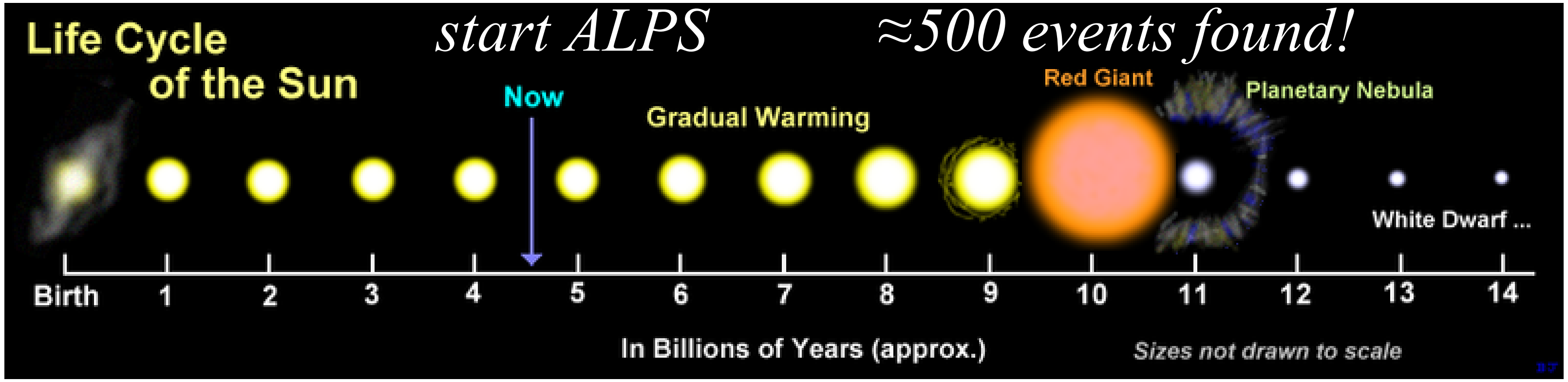


More Beam Time for Lab Experiments?

CAST: expected ALPs flux from the sun for $g=10^{-10}$ GeV^{-1}:
$\Phi_a = g^2_{10} \cdot 3.75 \cdot 10^{11}$ $1/cm^2/s$ = $1.5 \cdot 10^{12}$ s^{-1}

ALPS: expected ALPs flux for $g=10^{-10}$ GeV^{-1}: $\Phi_a = 3 \cdot 10^3$ s^{-1}

Nine orders of magnitude are difficult to beat just by beam time:
(the ALPs have to convert into photons for detection: $\sim g^4$)



Need a more clever approach!

Prospects for ALPS-II Components

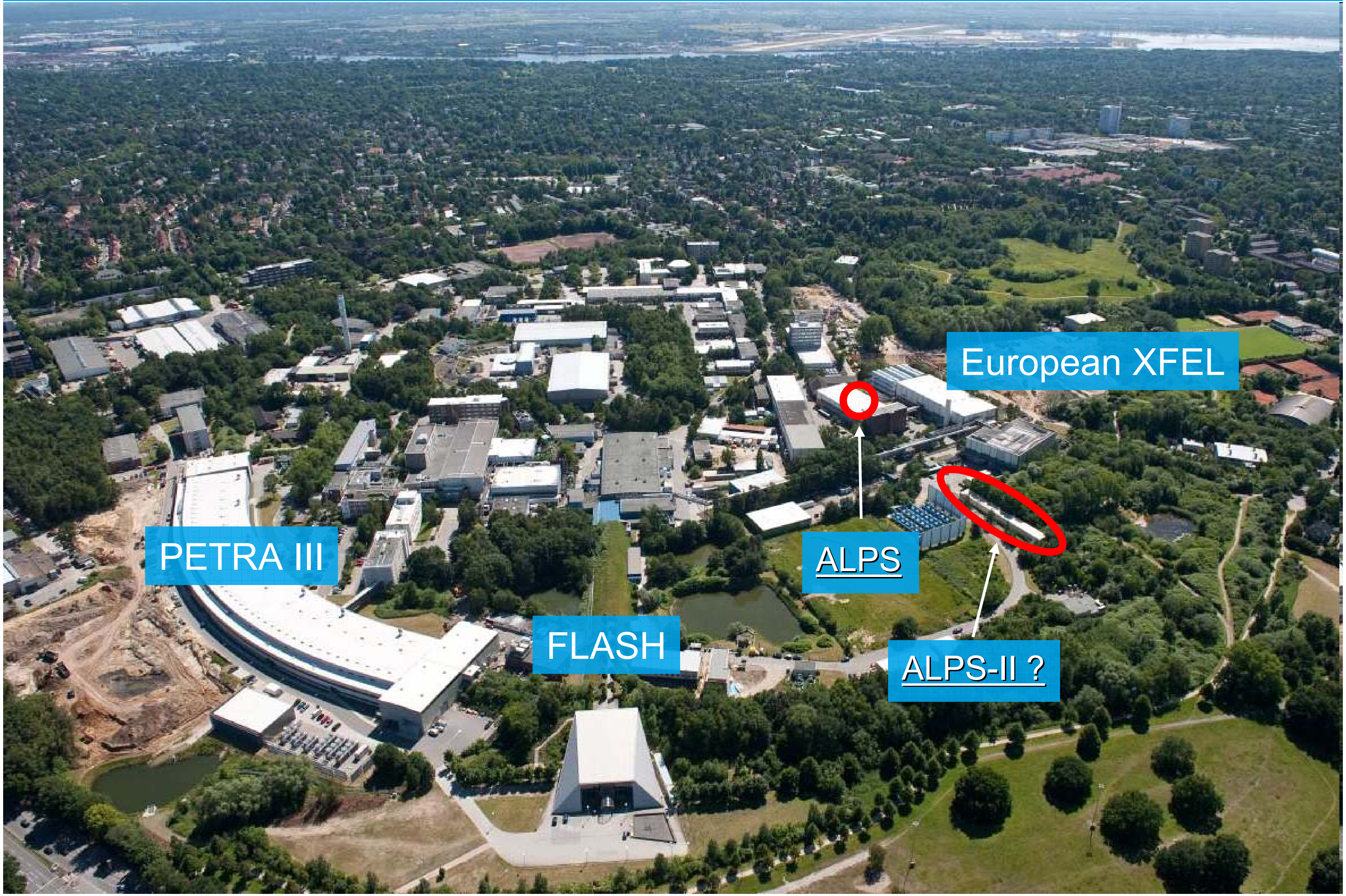
> Laser with optical cavity to recycle laser power, switch from 532 nm to 1064 nm.

> Magnet:
> upgrade to 2+2 or even 6+6 (?) HERA dipoles instead of ½+½
> (260 Tm on each side equivalent to 2 LHC dipoles).

> Regeneration Cavity and
> single photon counter (transition edge sensor?).

All set up in a clean environment!

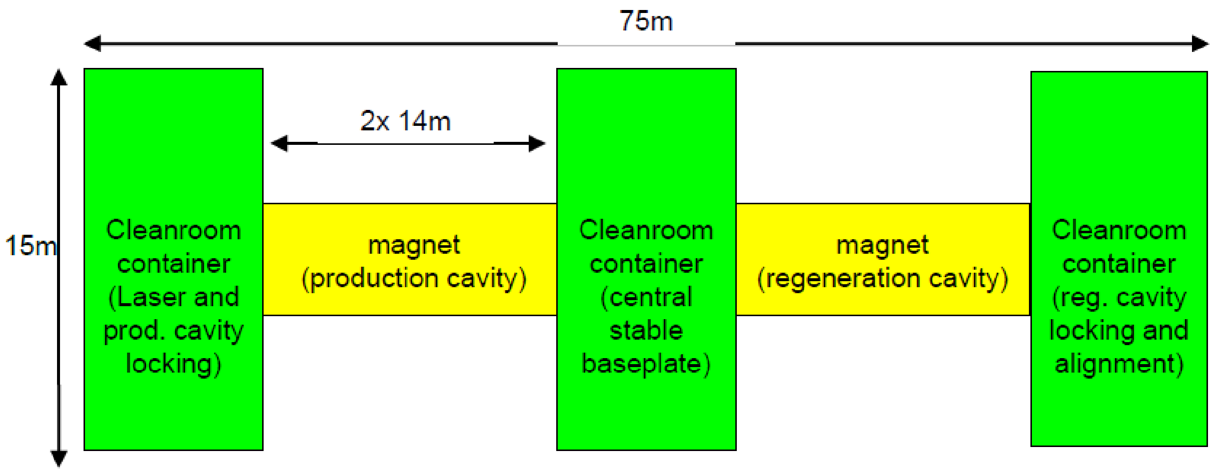
ALPS @ DESY in Hamburg



A possible Scenario for ALPS II

Basics:

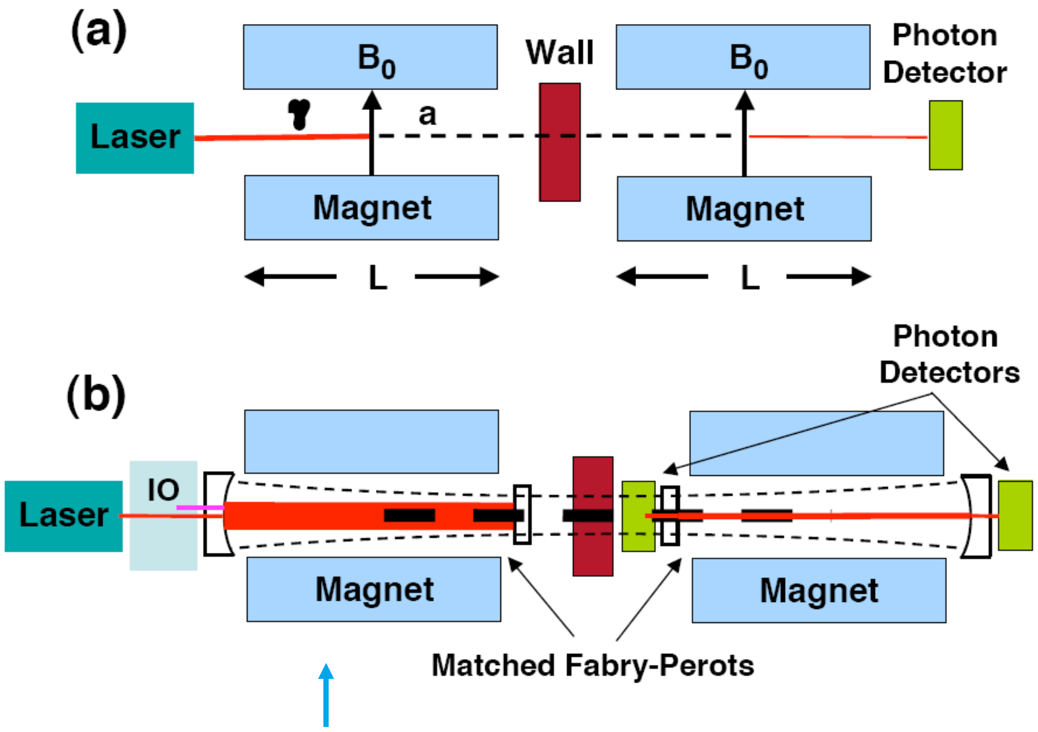
- Need to switch to a scenario with at least two magnets in order to have a handle on both mirrors defining the resonator.
  At ALPS there is no access and no firm support of the mirror in the middle of the HERA dipole.
- Ensure clean room conditions from the beginning.
  At ALPS this was introduced at a late stage.



A possible Scenario for ALPS II

Essential:

> Implementation of a second cavity in the regeneration part of the experiment to enhance the conversion probability WISP→ photon.



Realized at ALPS

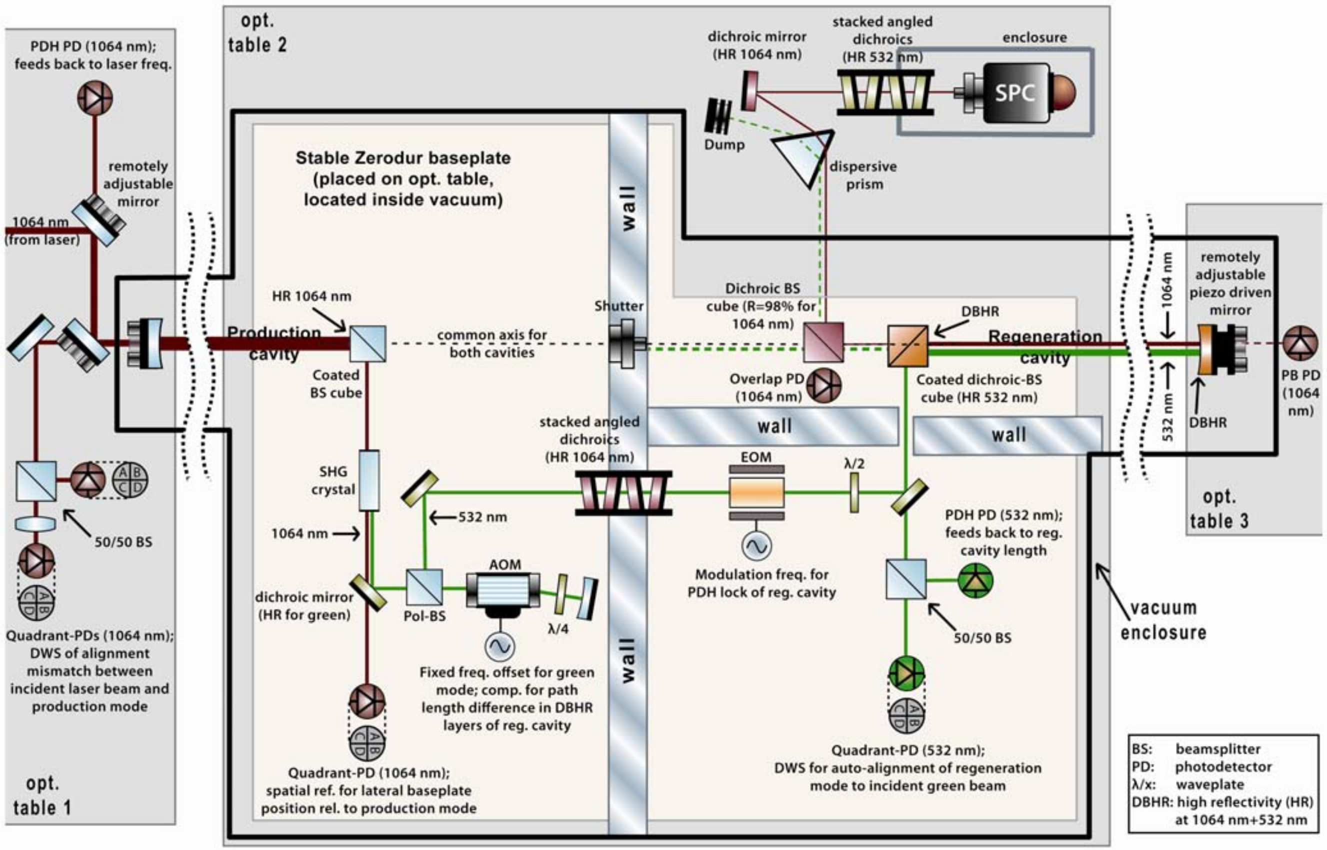
"Resonantly enhanced Axion-Photon Regeneration"
P. Sikivie, D.B. Tanner , Karl van Bibber. Phys.Rev.Lett.98:172002,2007.

(also F. Hoogeveen, T. Ziegenhagen, DESY-90-165, Nucl.Phys.B358)

A possible Scenario for ALPS II

Laser and resonators:

150 kW effective laser power, second cavity with a finesse of more than 10^5.



T. Meier (AEI Hannover):

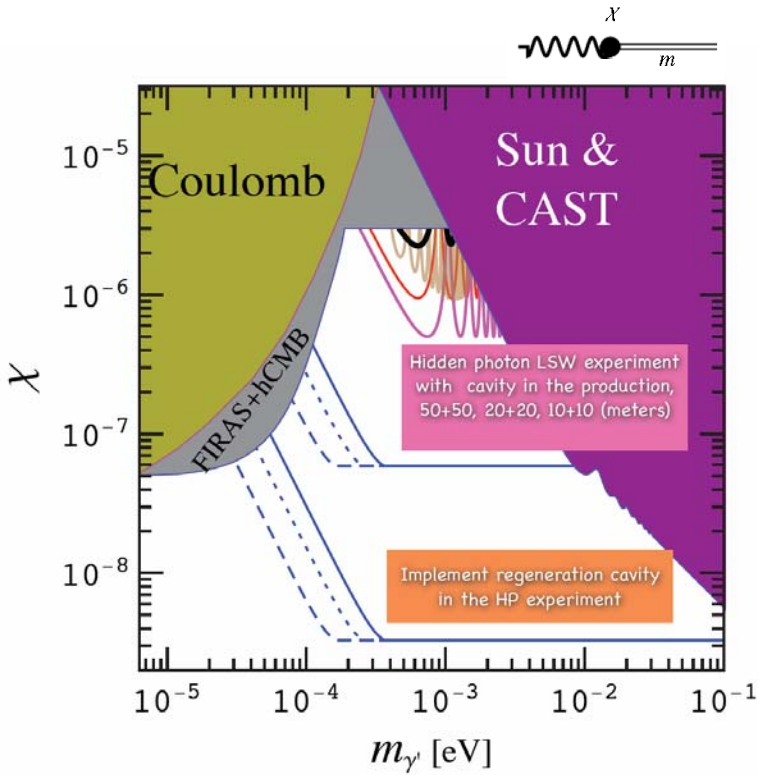
Challenging, but not a daydream.

Based on existing technologies for LIGO and LISA.

<u>Alternative in the US:</u>
G. Mueller, P. Sikivie, D. B. Tanner, K. v.Bibber
10.1103/PhysRevD.80.072004

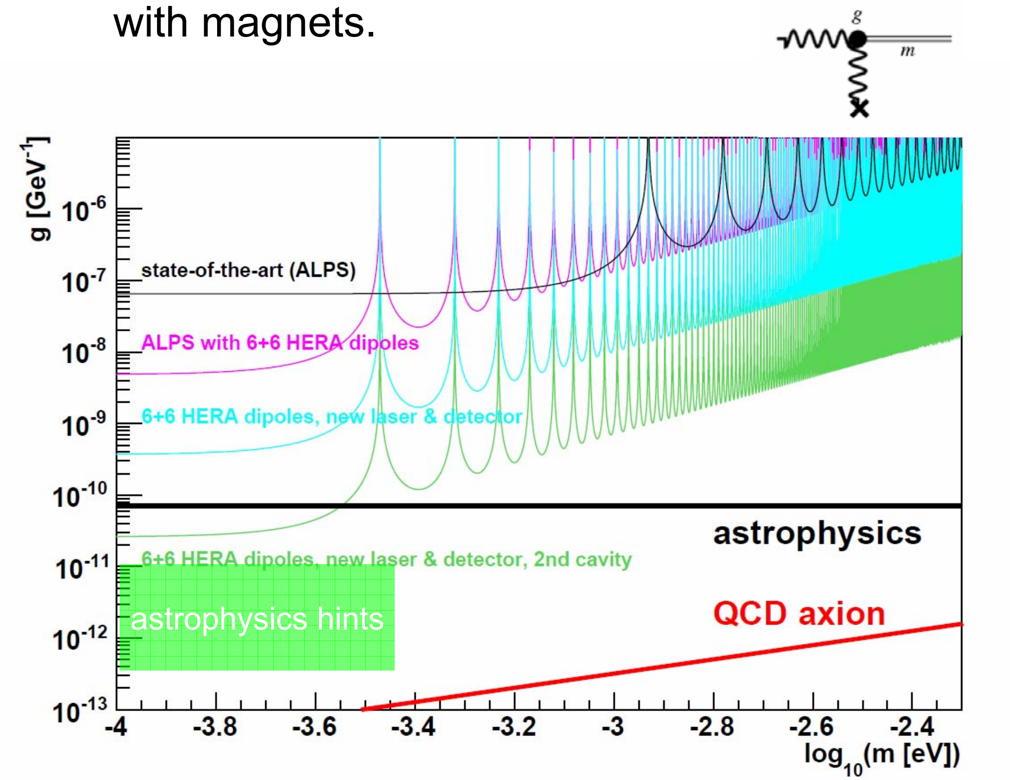
Physics Prospects of ALPS II

First phase:
Hidden sector photon search,
no magnets required.



(compiled by J. Redondo)

Second phase:
Any Light Particle Search
with magnets.



Another rediscovered Area: GeV Dark Forces

Dark Forces Workshop

SEARCHES FOR NEW FORCES AT THE GeV

- Home
- Registration
- Program
- Organizers
- Participant List
- Accommodations
- General Information
- Travel and Directions
- Visa Information
- Contact

Dark Fo

Credit: source images u

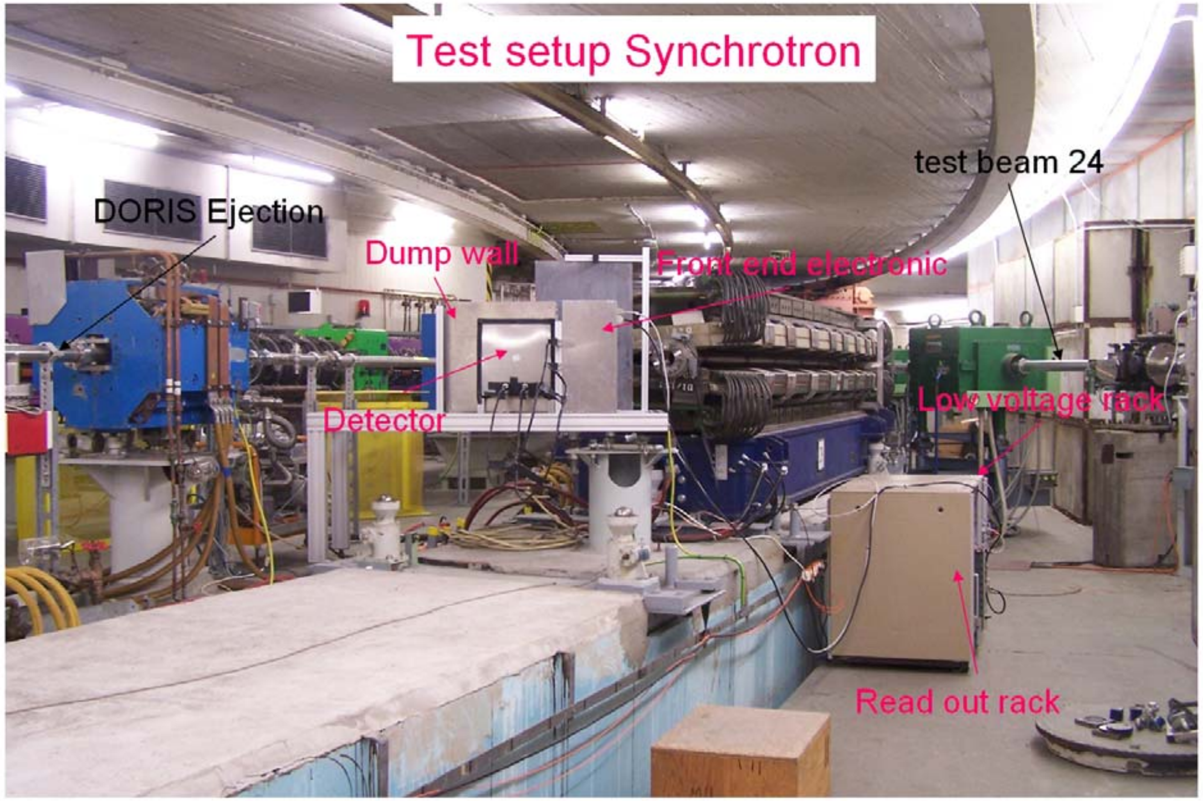
Searches for

Date/Time: Septer
- Thu : from 8:30am
- Fri : from 9:00am
- Sat : from 9:00am

Location
Building: 48 ROB A
SLAC National Acc
Menlo Park, Califor

Theoretical models
forces mediated by
weak coupling to or
these new gauge bo
and experimentalist
arenas:

1. new fixed-tar
   SLAC, and F
2. searches at
   CLEO-c, KL
3. searches at the Tevatron experiments.

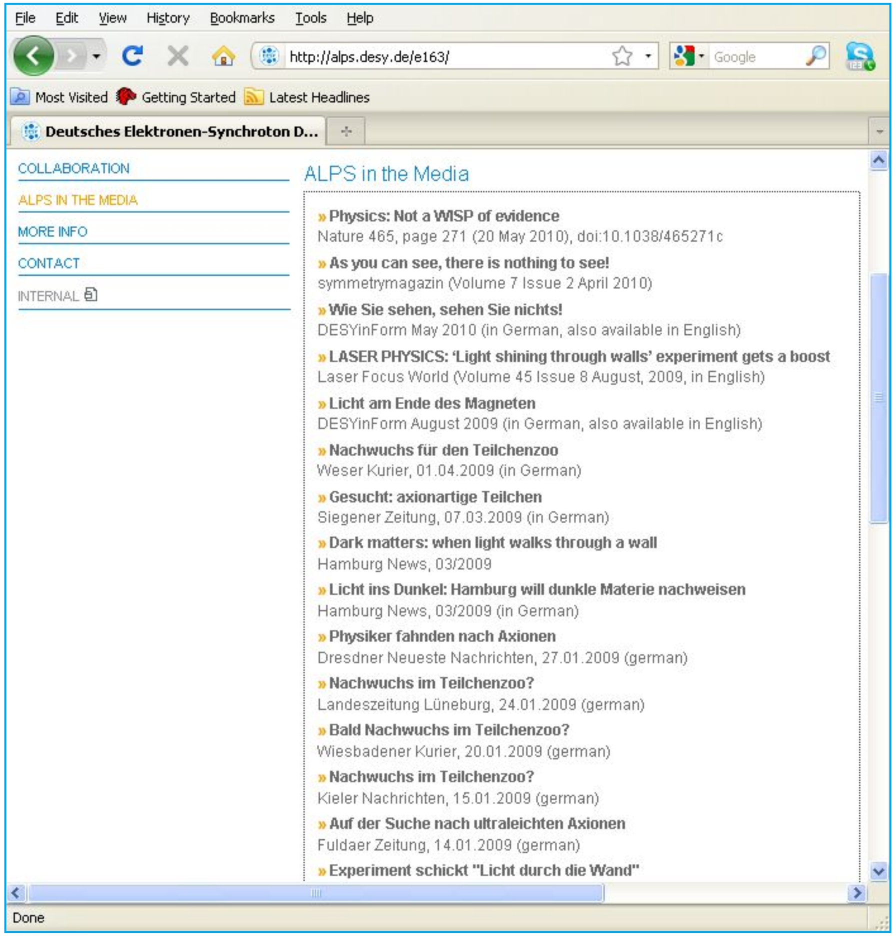


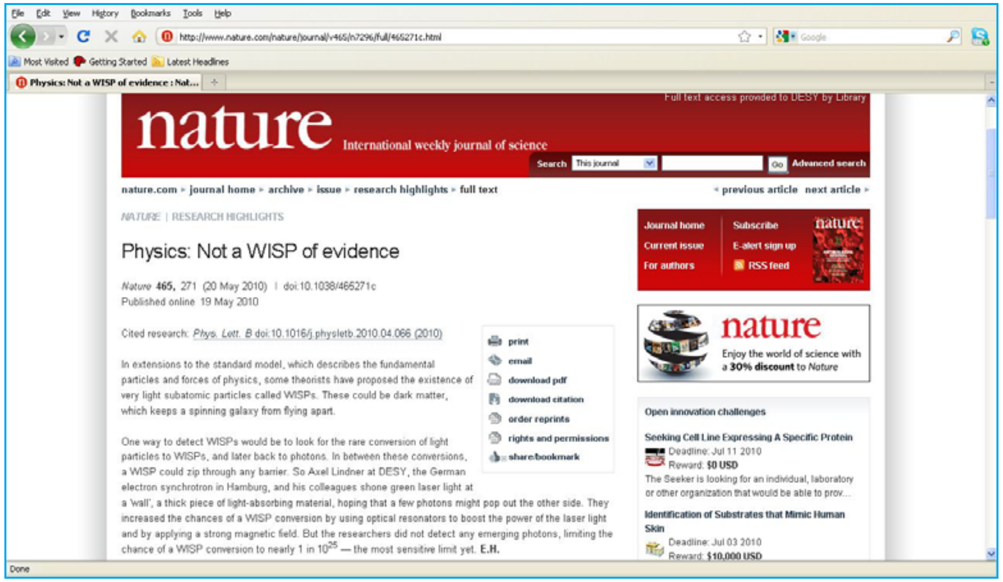
SLAC National Accelerator Laboratory, Menlo Park, CA
Operated by Stanford University for the U.S. Dept. of Energy
Office of Science

http://www-conf.slac.stanford.edu/darkforces2009/

Outreach (see also http://alps.desy.de)

Large interest in media:



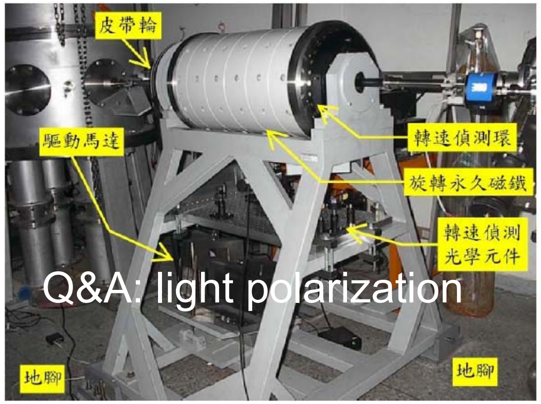


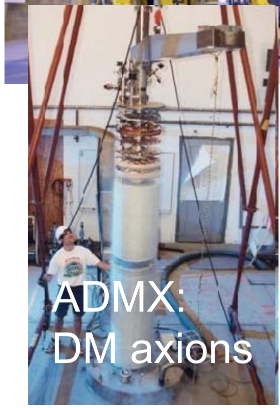
Summary

> There are some fascinating leftovers from main stream particle physics
  - WISP physics, GeV dark forces

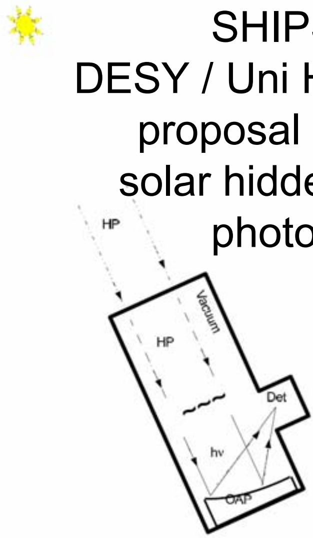
which may hide solutions to long-standing and fundamental physics question
  - CP conservation in QCD, dark matter, (dark energy), astrophysics miracles

> Efforts to explore the leftovers are very moderate.





SHIPS:
DESY / Uni HH
proposal for
solar hidden
photons



> We should close these gaps of knowledge!

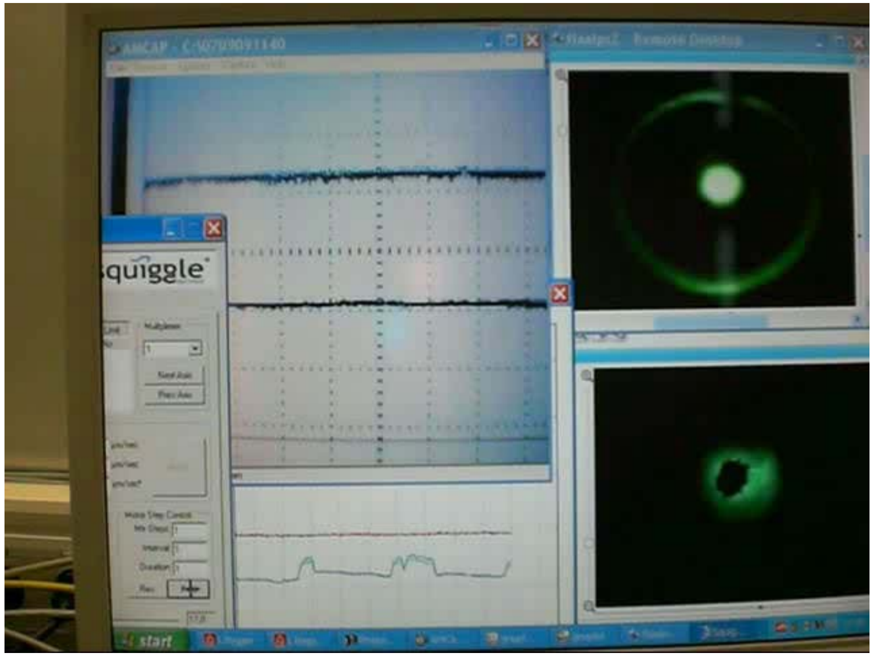
Thanks to the ALPS Collaboration!

Klaus Ehret[a], Maik Frede[b], Samvel Ghazaryan[a], Matthias Hildebrandt[b], Ernst-Axel Knabbe[a], Dietmar Kracht[b], Axel Lindner[a], Jenny List[a], Tobias Meier[c], Niels Meyer[a], Dieter Notz[a], Javier Redondo[a], Andreas Ringwald[a], Günter Wiedemann[d], Benno Willke[c]

[a] *Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22607 Hamburg, Germany*
[b] *Laser Zentrum Hannover e.V., Hollerithallee 8, D-30419 Hannover, Germany*
[c] *Max-Planck-Institute for Gravitational Physics, Albert-Einstein-Institute, and Institut für Gravitationsphysik, Leibniz Universität, Hannover, Callinstraße 38, D-30167 Hannover, Germany*
[d] *Hamburger Sternwarte, Gojenbergsweg 112, D-21029 Hamburg, Germany*

Intensity of light inside the ALPS magnet

Intensity of light in the frequency doubling resonator



Scattered light from coupling mirror (resonator lock))

Reference beam (pointing stability)

Today's Agenda

> The ALPS Lecture

which is the last one of the common lectures in the past two weeks.

Therefore it might be a good opportunity to ask questions and rise some items.

> Question Time!

- Nagging issues related to the common lectures.
- Curiosity concerning DESY in general.
- Everything you wanted to know about DESY physics but were afraid to ask (answers not guaranteed).
- Other items?

> "Hands on" with Cosmic Rays and a tour to the ALPS?

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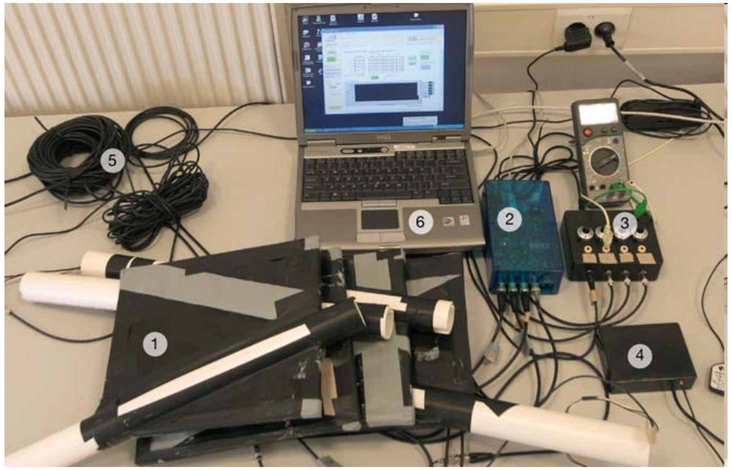
“Hands on” with Cosmic Rays and a Tour to the ALPS?

Proposal for Tuesday next week (3 August), 14:00 to 16:00 h:



> A few “fundamental” studies with cosmic rays:
- detector issues (calibration, coincidence)
- muon flux measurements

> A visit to the ALPS experiment

If you are interested, for organizational matter please

> send an email to axel.lindner@desy.de

> latest Monday noon!