dark matter

DESY
Summerstudent Lecture 2021

Axel Lindner, Jose Alejandro Rubiera Gimeno
DESY

https://www.darkmatterday.com/educational-resources-dark-matter-day/

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

New experimental approaches towards finding dark matter

Experiments @ DESY in Hamburg

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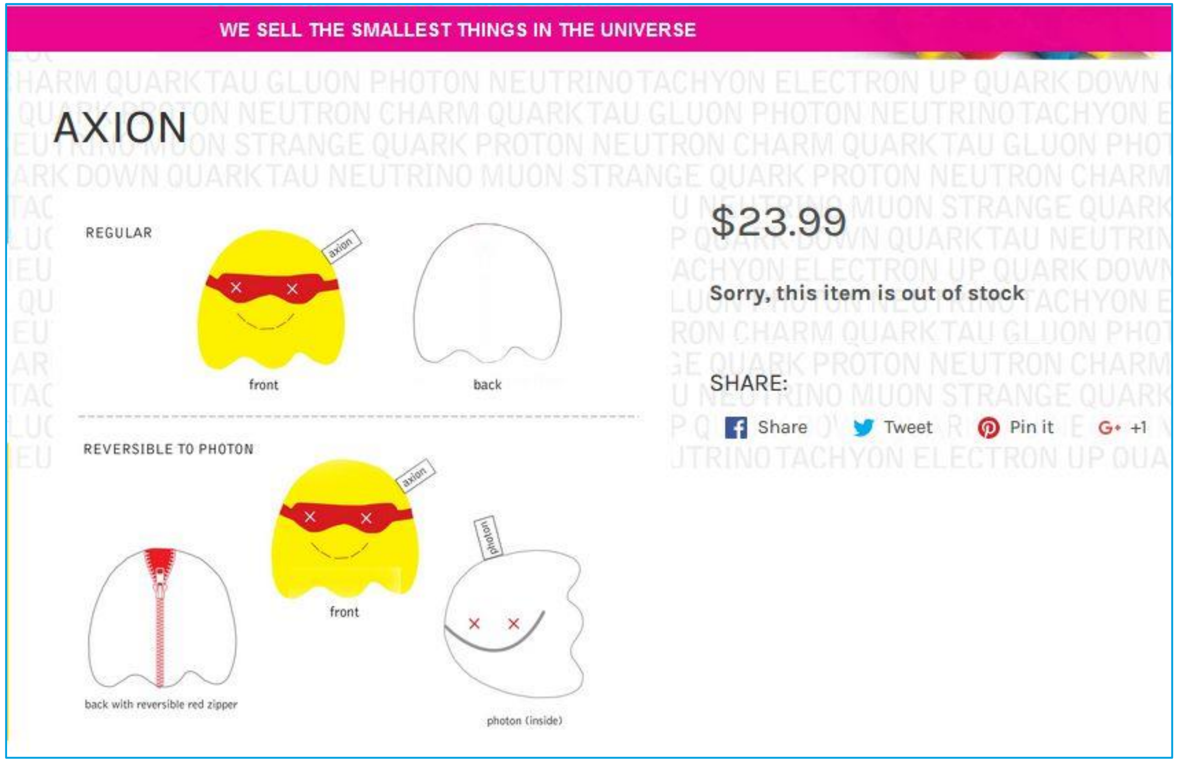


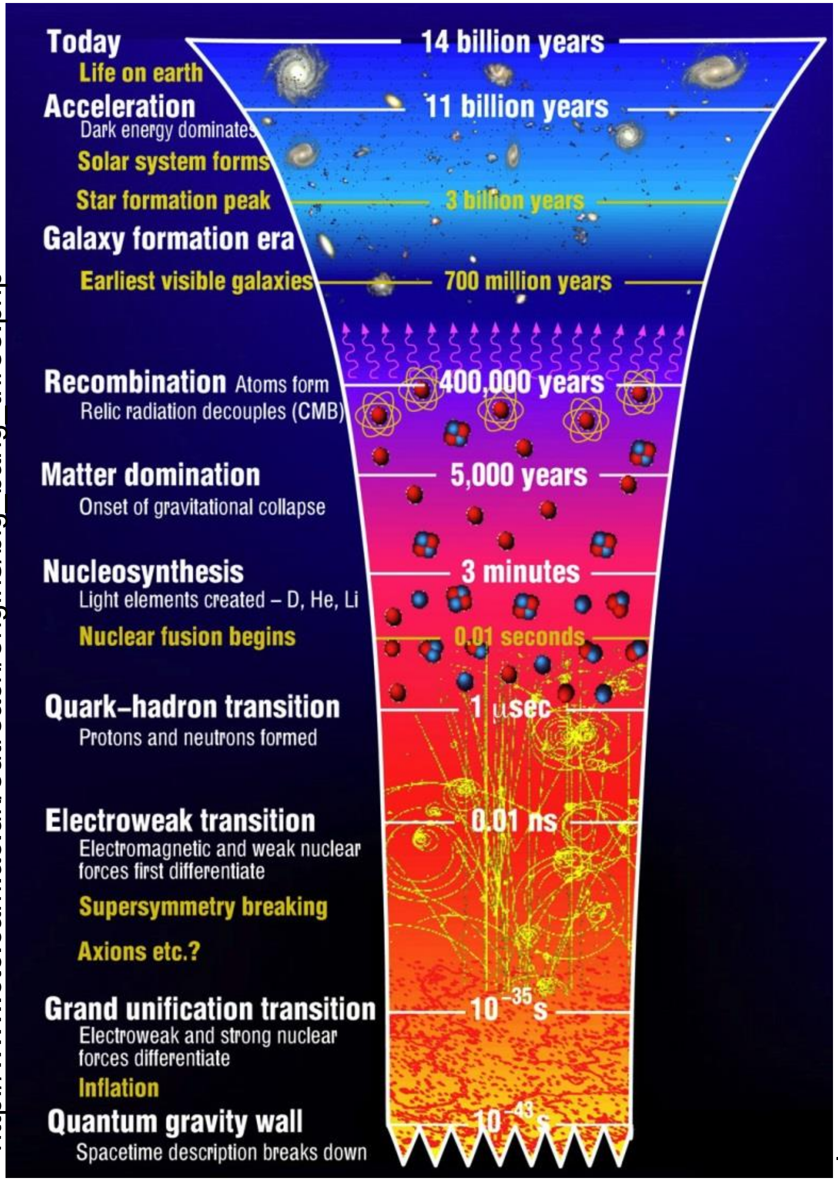
https://www.particlezoo.net

Outline

- Brief motivation for dark matter
- A glimpse on theory
- Weakly Interacting Massive Particles
- Axions and other Weakly Interacting Slim Particles
- Axion experiments at DESY
- Summary

Why?

To understand our universe!



http://www.ctc.cam.ac.uk/outreach/origins/big_bang_three.php

3,000,000,000 years after the Big Bang

400,000 years after BB

3 minutes after BB

0.000001 seconds after BB

0.00000000001 seconds after BB

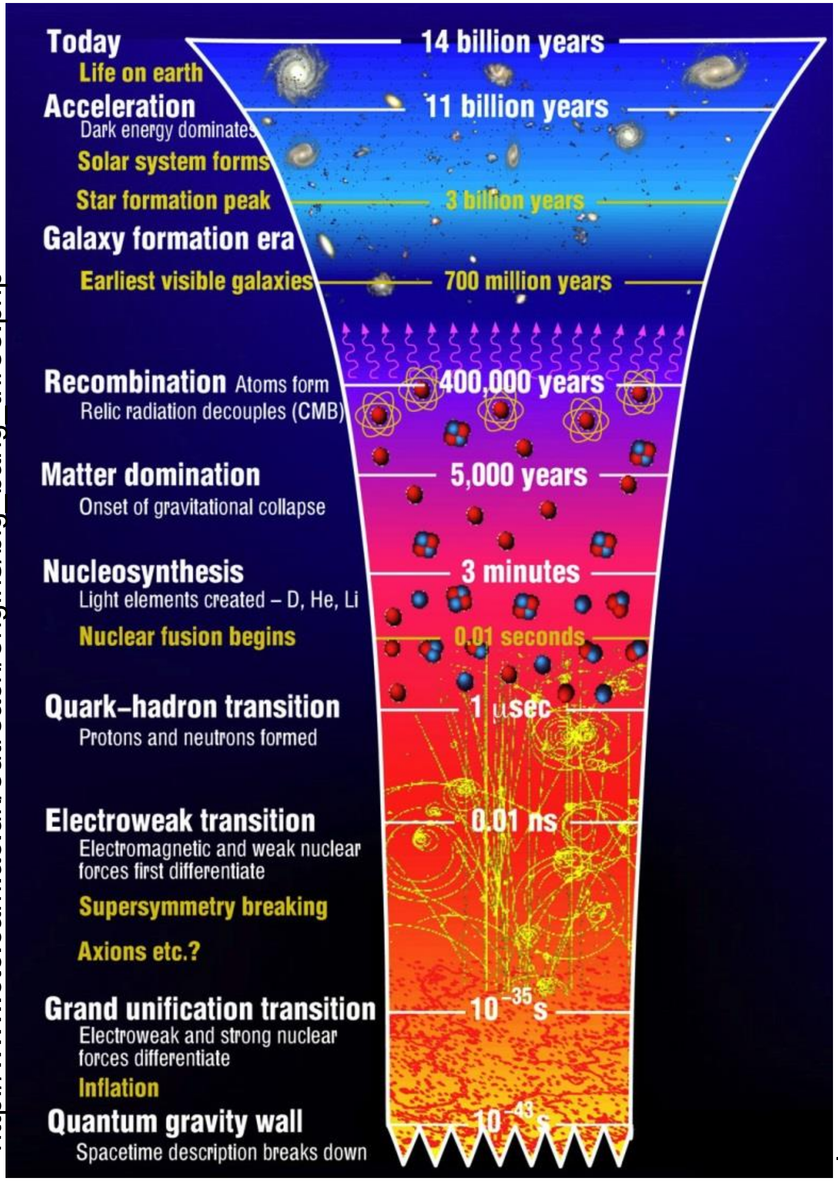
Astronomy

BB in the laboratory:

Elementary particle physics

Why?

To understand our universe!



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3,000,000,000 years after the Big Bang

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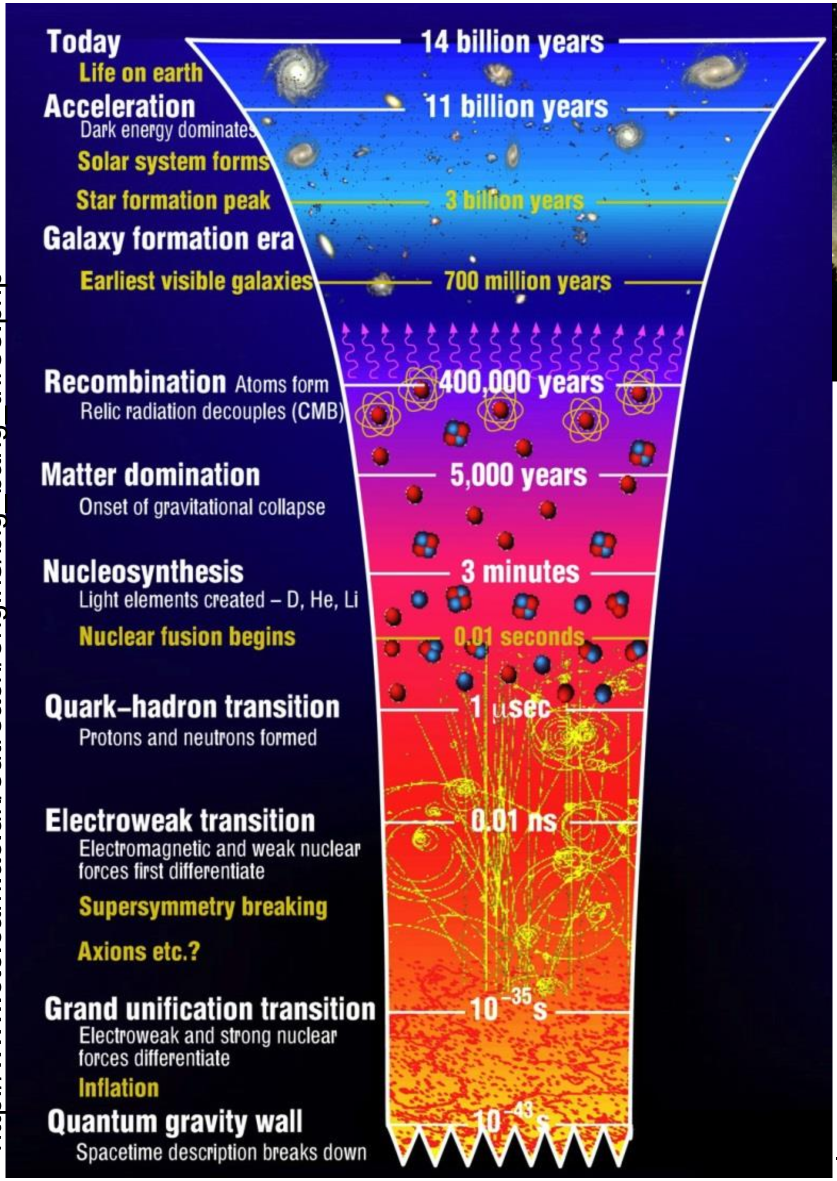
0.00000000001 seconds after BB

Gravitational waves?

What do we know

A very brief status report



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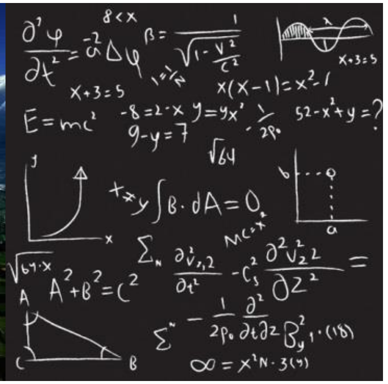


Astronomy, particle physics theory

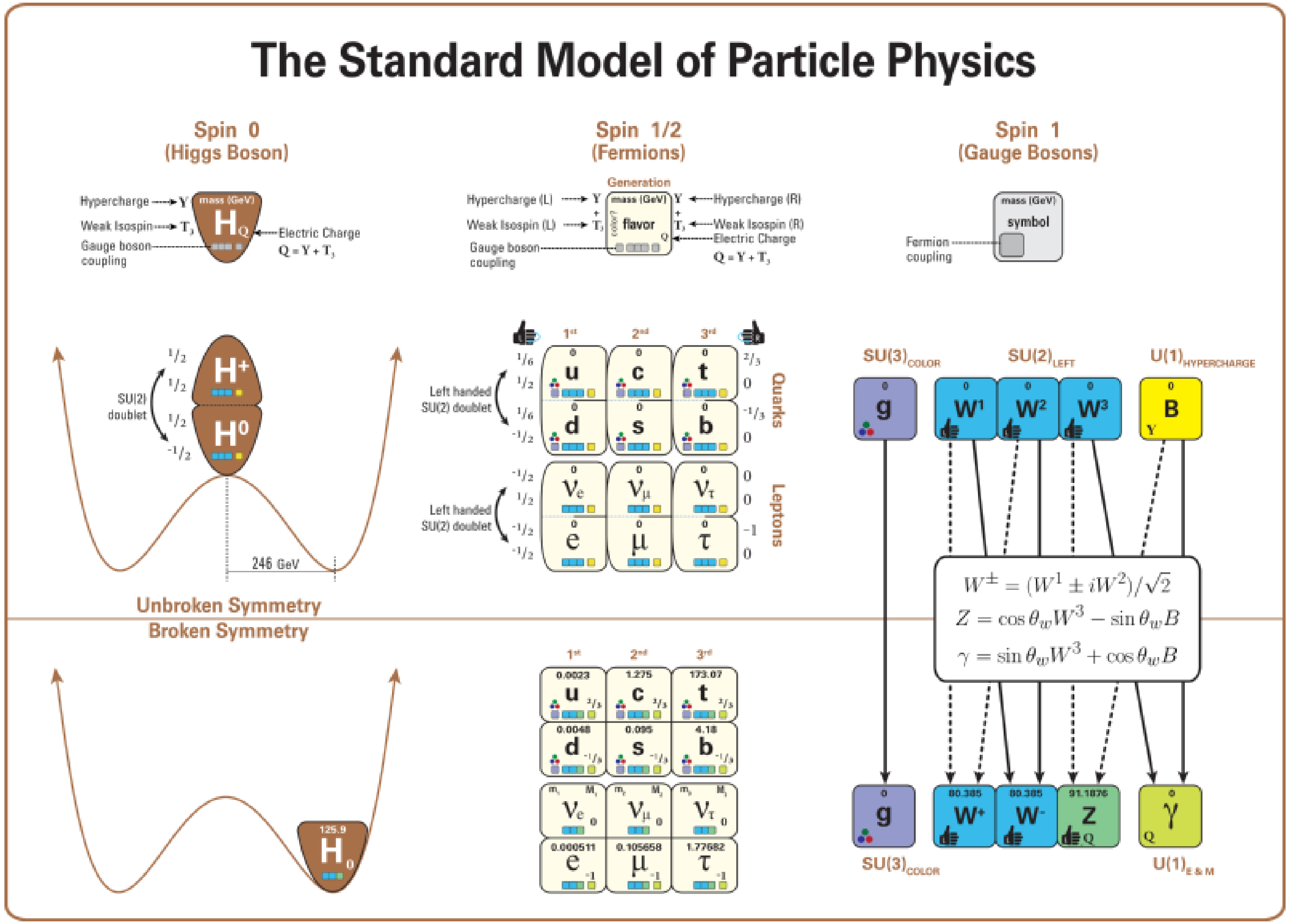
seem to fit perfectly!

We seem to understand how the universe evolved precisely.

Example:
Age of the universe = 13.799 ± 0.021 billion years (0.15% accuracy!)

What do we know

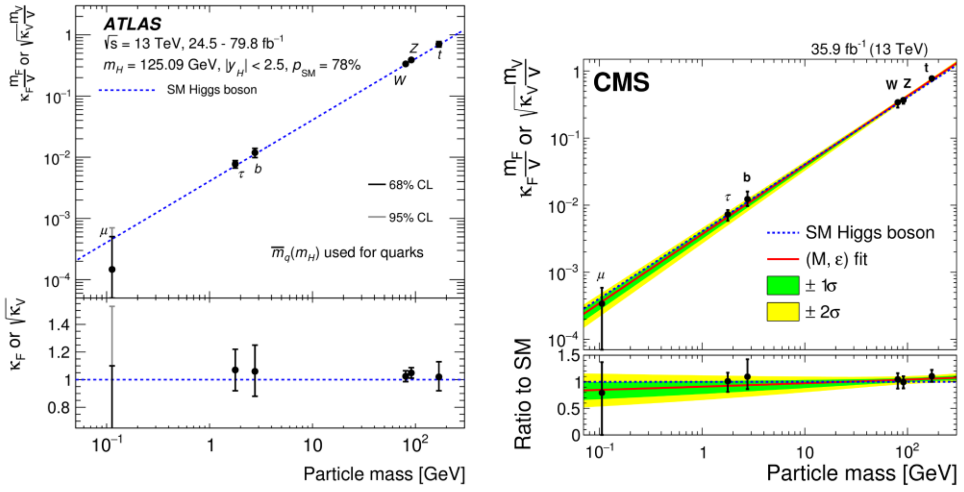
A very brief status report



https://en.wikipedia.org/wiki/Standard_Model

All experiments probing the smallest constituents of matter and its interactions perfectly fit to the standard model,
apart from non-zero neutrino masses.

Example: properties of the Higgs.



Precision Measurements in the Higgs Sector at ATLAS and CMS
A. Sopczak, arXiv:2001.05927 [hep-ex]

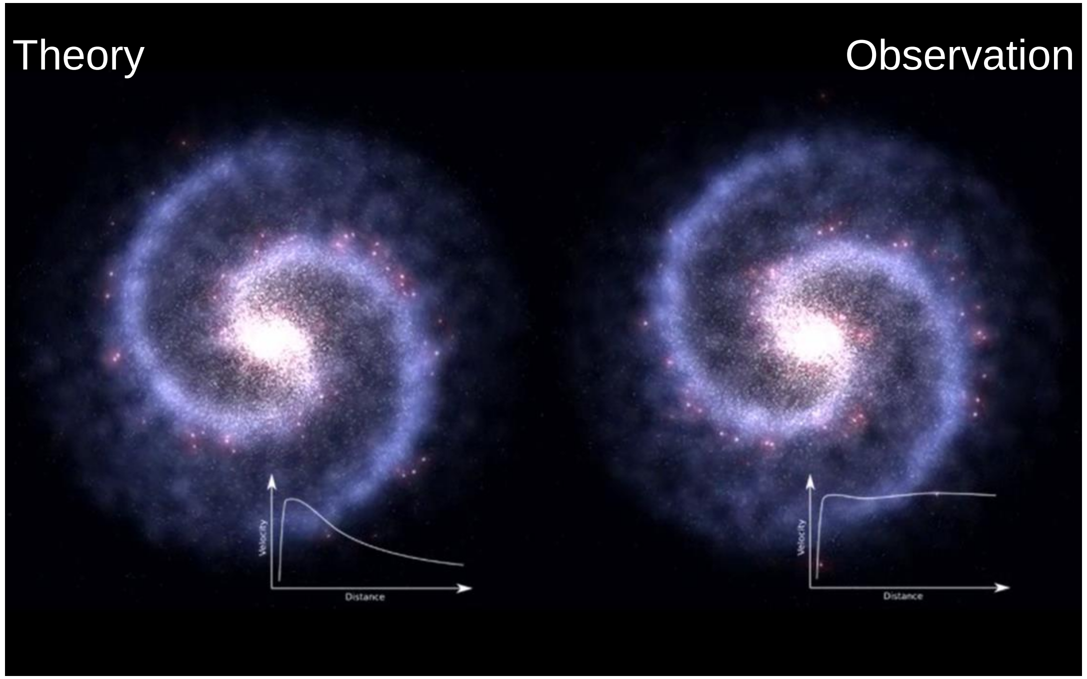
arXiv:

What do we know

Flaw(s) ?

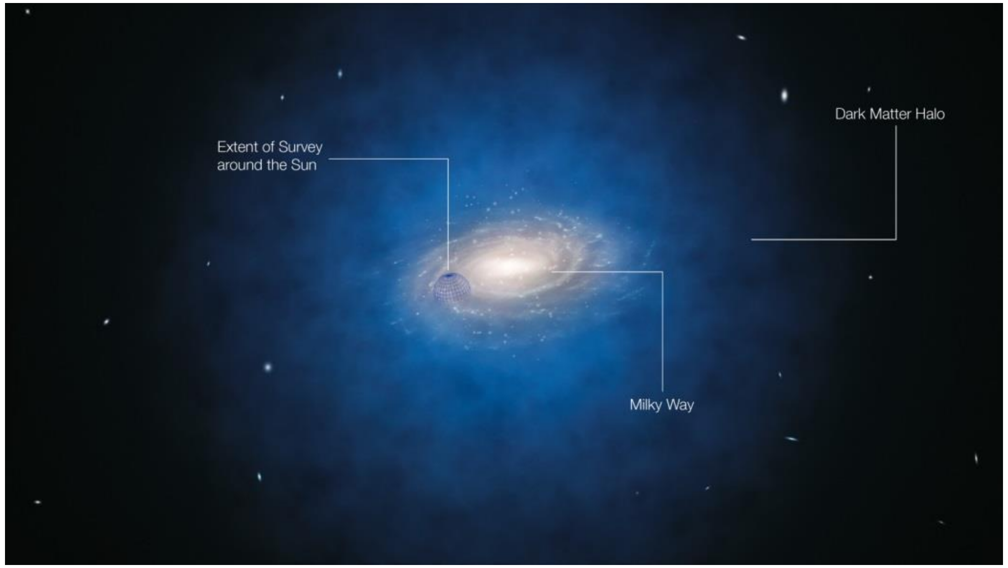
Particle physics and cosmology only fit if a large amount of mass and energy of unknown constituents exist.

Example: rotation of galaxies.



http://beltoforion.de/article.php?a=spiral_galaxy_renderer

Dark matter ≈ 10 · visible matter



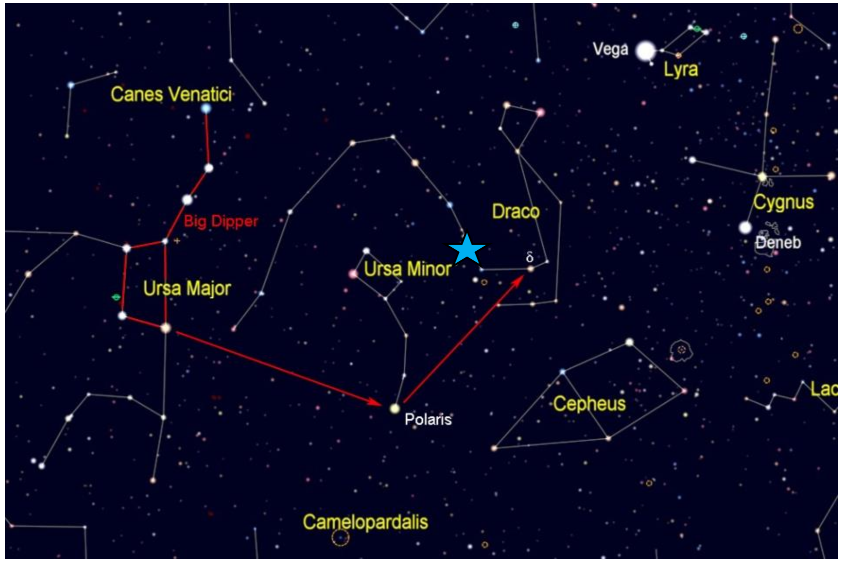
https://www.eso.org/public/news/eso1217/

Rotation of galaxies

A quick look

Galaxy NGC 6503

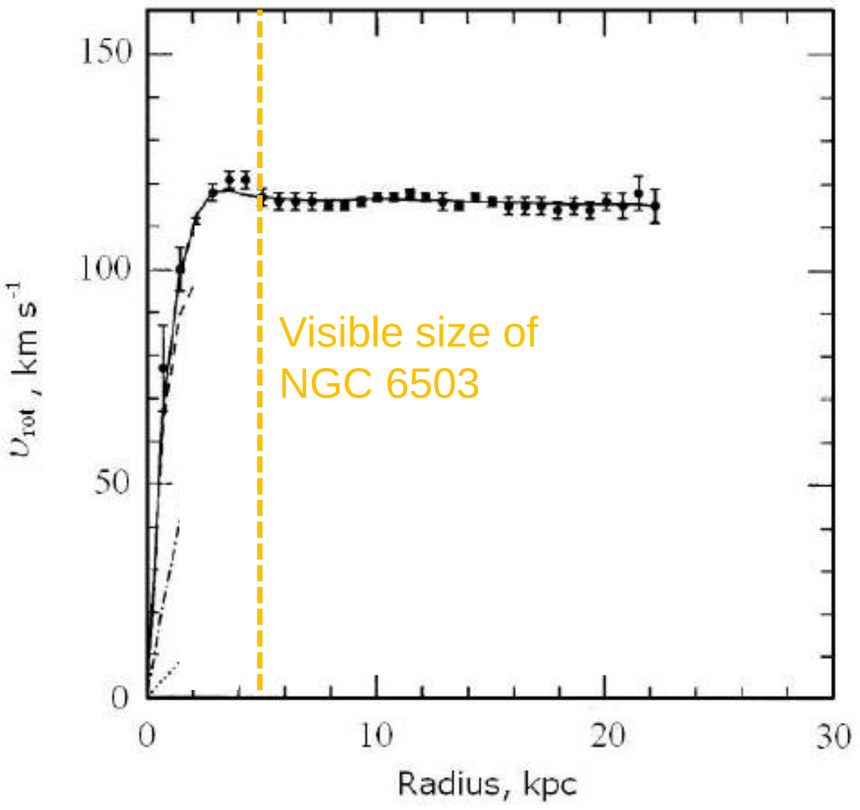
30,000 light-years large dwarf
17 million light-years away



Rotation of galaxies

A quick look

Galaxy NGC 6503

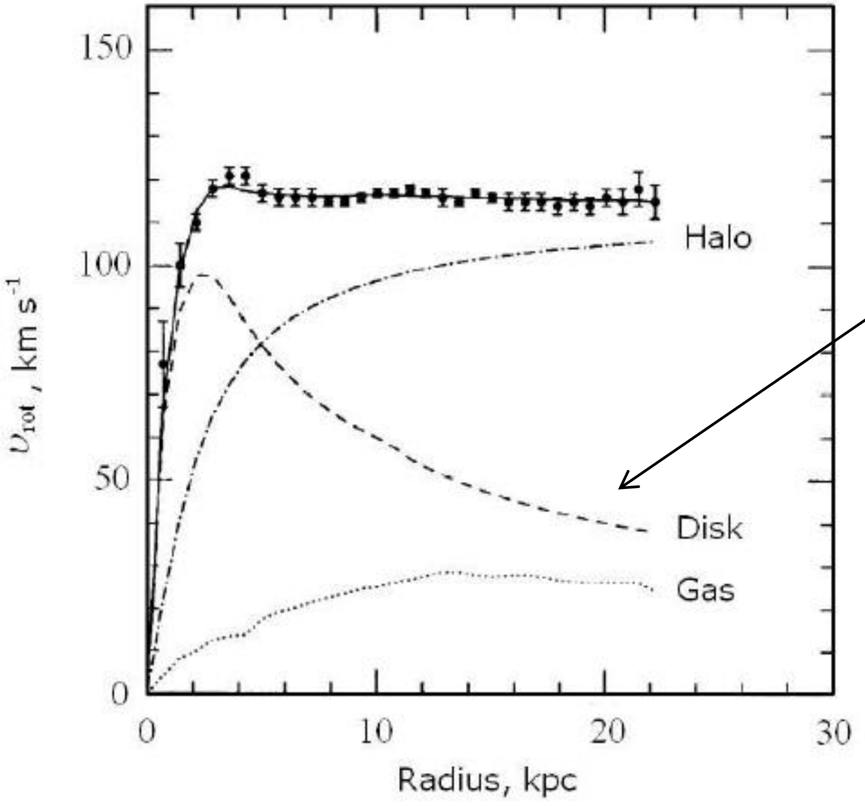


Young, Bing-Lin (2017): A survey of dark matter and related topics in cosmology.

Rotation of galaxies

A quick look

Galaxy NGC 6503



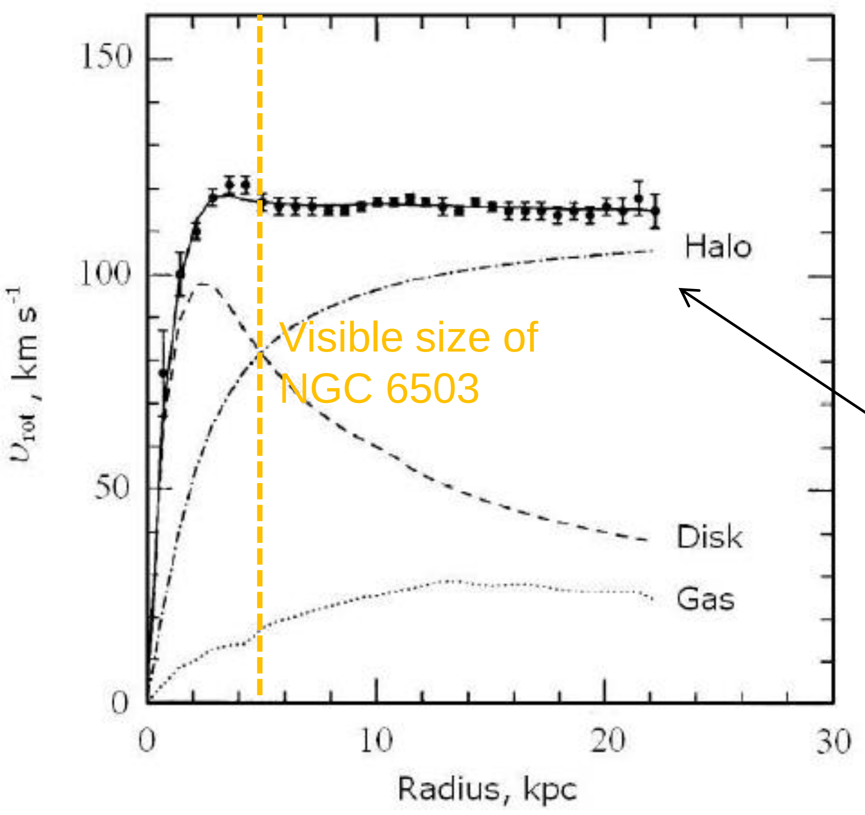
Young, Bing-Lin (2017): A survey of dark matter and related topics in cosmology.

- $v_{rot} = \sqrt{\frac{GM}{r}}$ decreases with $\sim \sqrt{\frac{1}{r}}$

Rotation of galaxies

A quick look

Galaxy NGC 6503



Young, Bing-Lin (2017): A survey of dark matter and related topics in cosmology.

- $v_{rot} = \sqrt{\frac{GM}{r}}$ decreases with $\sim \sqrt{\frac{1}{r}}$
- Observation:

$$v_{\mathrm{obs}} = \sqrt{\frac{GM(r)}{r}} = \mathrm{const}$$

$$\Rightarrow \quad M(r) = \mathrm{const} \cdot r$$

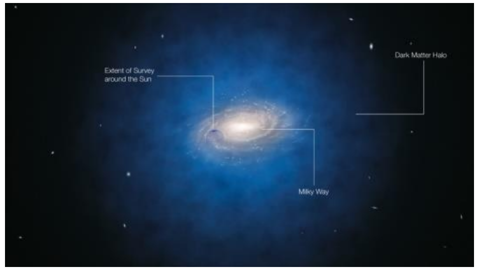
- There must be a halo of invisible mass!

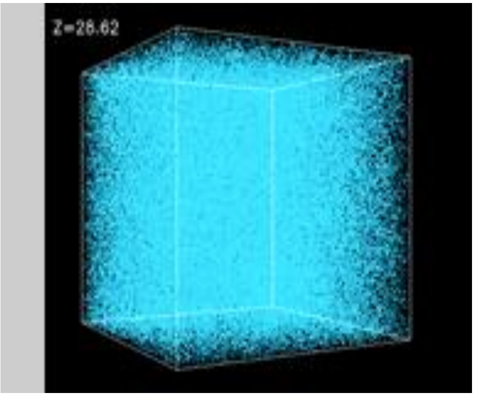
What do we know

Flaw(s) ?

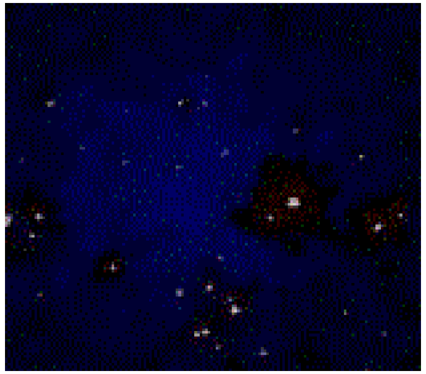
Particle physics and cosmology only fit if a large amount of mass and energy of unknown constituents exist.

Many evidences for dark matter on length scales of galaxies and beyond.

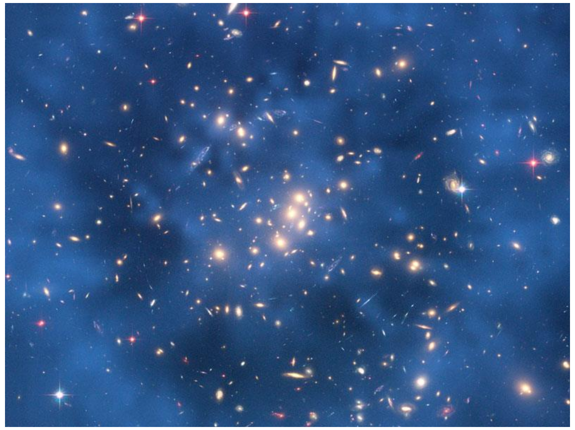




http://cosmicweb.uchicago.edu/filaments.html

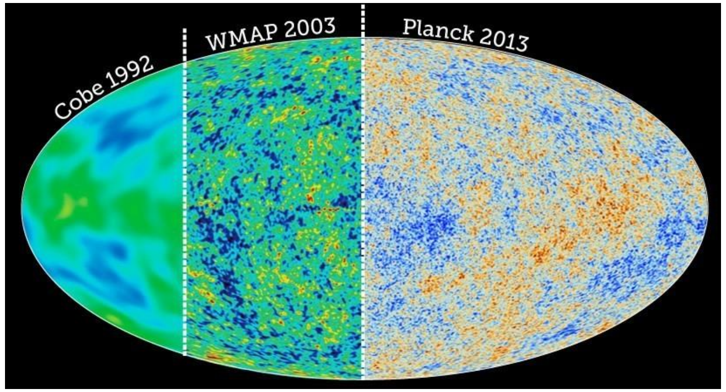


http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/galaxydist.htm



https://www.esa.int/Science_Exploration/Space_Science/Hubble_sees_dark_matter_ring_in_a_galaxy_cluster

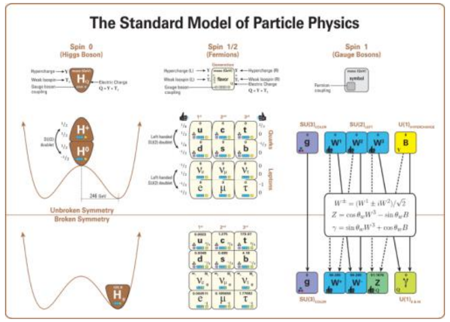
https://www.researchgate.net/figure/Temperature-fluctuations-observed-in-the-CMB-using-COBE-WMAP-Planck-data-Gold-et-al_fig1_328474806



What do we know

Composition of the universe

stars	gas / dust	dark matter	dark energy
0.5%	4.5%	26%	69%



dark matter: additional gravitation (galaxies & beyond)

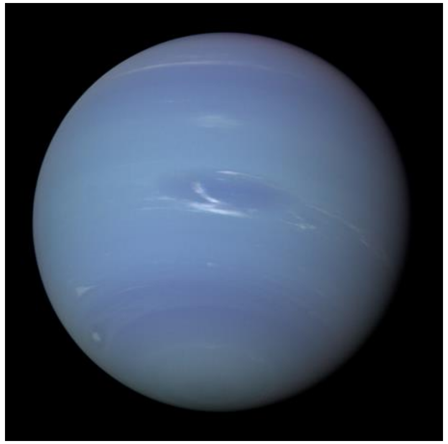
dark energy: anti-gravitation on largest scales

How to find something invisible?

A bit of history

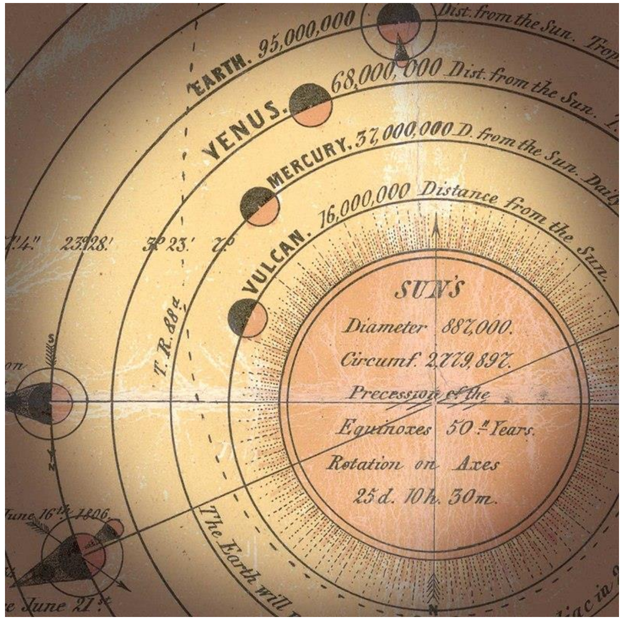
1: Discovery of the planet Neptune:

- The orbit of Uranus did not match calculations (Newtonian forces).
- The differences could be well explained by another gravitating body: Neptune.



2: General relativity:

- The orbit of Mercury did not match calculations (Newtonian forces).
- The differences could not be explained by another gravitating body (Vulcan), but is perfectly explained by general relativity.



You may find either a new form of matter or a new more fundamental theory.

How to find dark matter?

Two approaches

Examples

1: Looking for dark matter (DM) in the cosmos:

- Detect local DM around us. — WIMP searches in underground detectors
- Identify signatures of DM in the universe (beyond gravitation). — Gamma rays from WIMP annihilation

2: Look for DM candidates in the laboratory:

- Experiments at the high energy frontier. — LHC
- Precision experiments. — Shining light through walls
- Understanding extreme conditions in the universe. — Evolution of stars

Theory: dark matter candidates

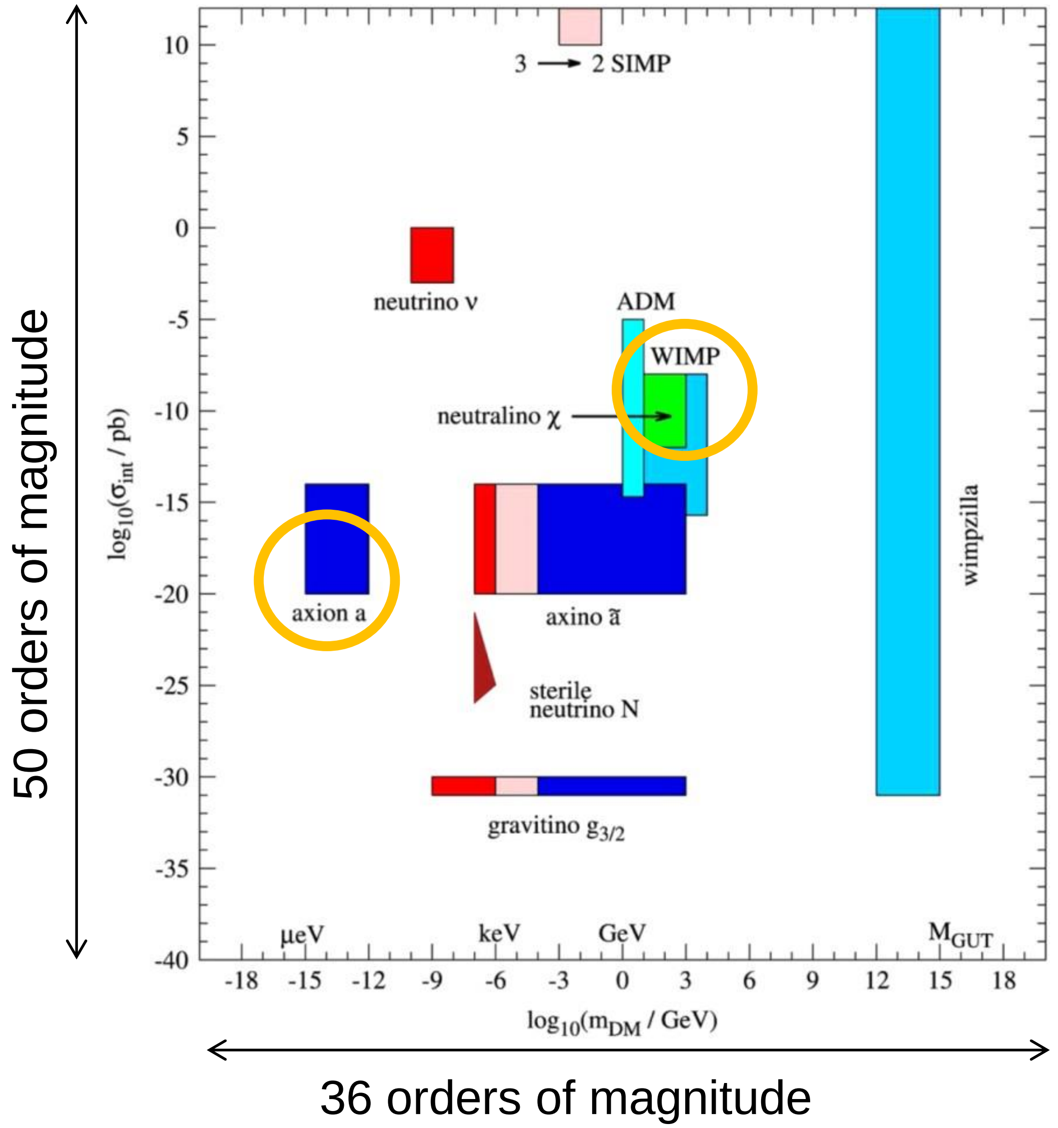
A huge parameter space

There is a plentitude of theories predicting dark matter candidates

covering more than
30 orders of magnitude in mass range

and

predicting interaction strengths with normal matter orders of magnitude below neutrino cross sections.



Dark matter detection (Laura Baudis),
http://iopscience.iop.org/article/10.1088/0954-3899/43/4/044001

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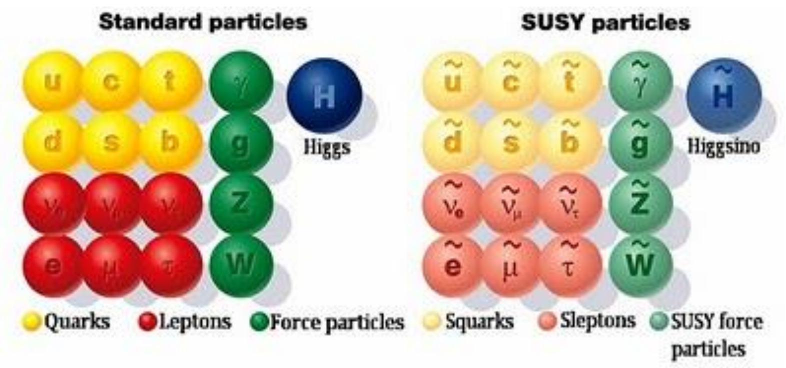
Dark matter candidates: WIMPs

A huge parameter space

- Weakly Interacting Massive Particles (WIMPs)
  - Theory: a SUperSYmmetry between fermions and bosons might exist. The lightest SUSY particle could make up the dark matter.
  - Dark matter: the lightest stable SUSY particle with an self interaction strengths of the order of the weak interaction would “naturally” be produced as dark matter in the early universe.
  - Additional benefit: if SUSY masses are at the TeV scale one could understand details of the standard model (e.g. Higgs mass) and SUSY could show up at the LHC.



- Prediction:
  Dark matter is composed out of elementary particles with masses O(10 to 100 GeV).
  Its number density is about 0.01 1/cm^3.
  It should interact weakly with SM matter.

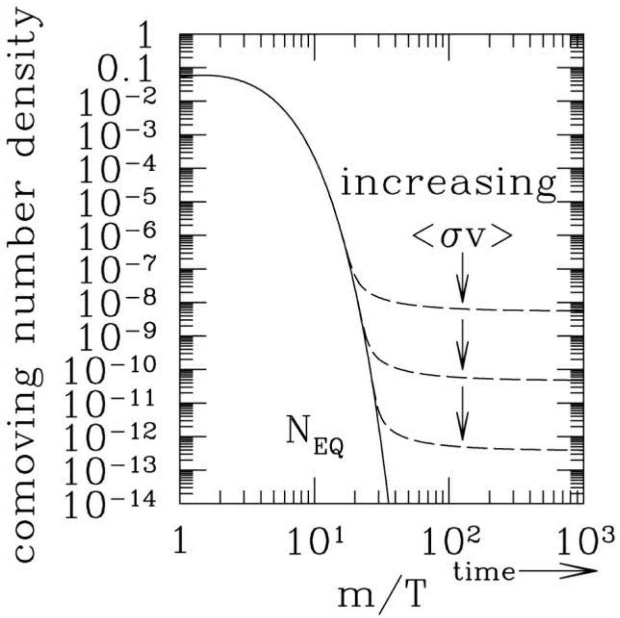
WIMP dark matter in the universe

A brief history

1. When the universe is very hot (hotter than the mass of the WIMP) all particles are in thermal equilibrium: the rates of production and annihilation are the same.

2. The universe expands: the particle energy drops, WIMP production rates drop, but WIMPs can still annihilate.

3. The universe expands further: the WIMP density drops further, WIMPs do not any more meet each other and annihilation stops: WIMPs “freeze out”.



4. Assuming WIMP masses around the electroweak scale (LHC!) and weakly interacting WIMPs gives “automatically” the correct amount of dark matter!

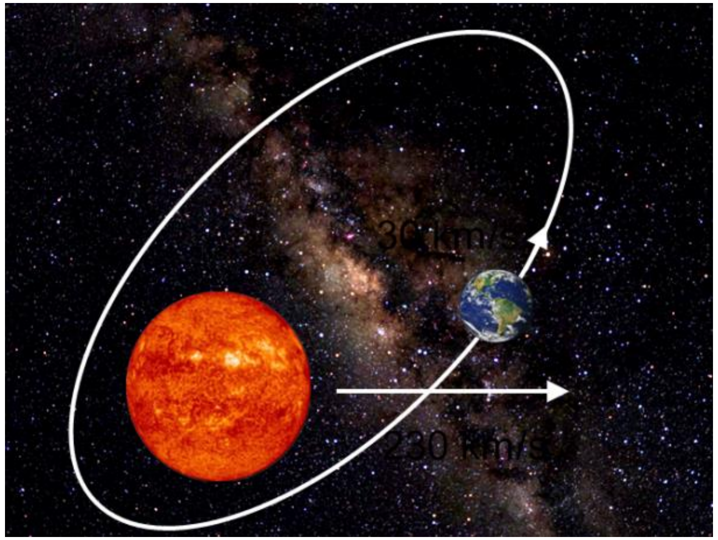
THE WIMP MIRACLE

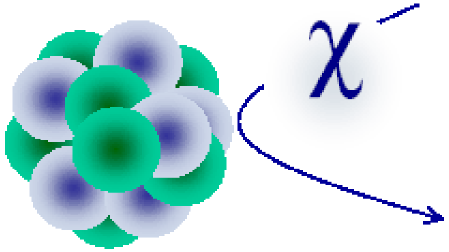
Direct detection of dark matter WIMPs

Basics

The earth moves through the WIMP halo

- WIMPs scatter elastically on nuclei
- Measure nuclear recoils

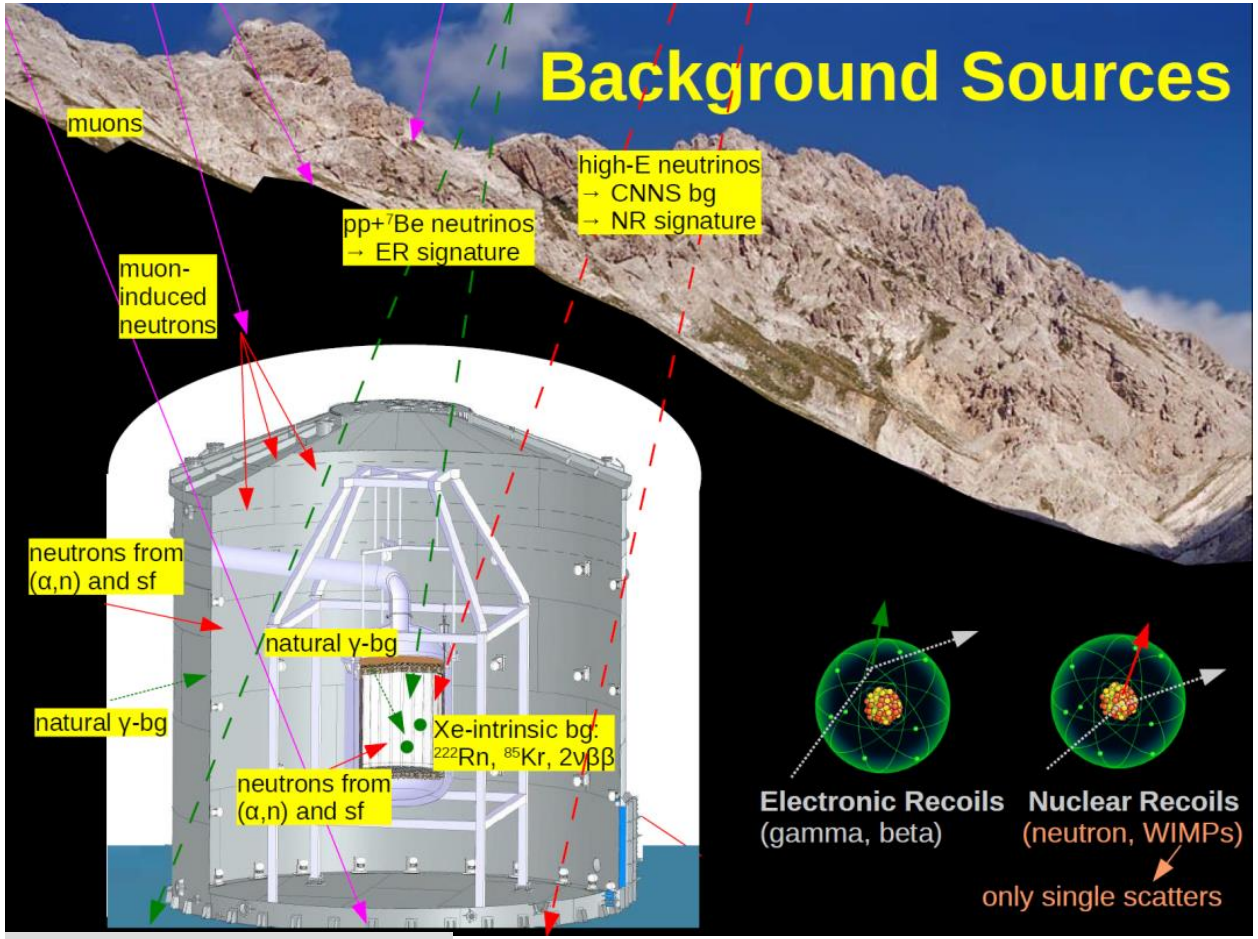




Experimental challenge:

- WIMP mass: 10 GeV to TeV (≈ mass of nuclei)
- Relative speed ~ 220 km/s ⇨ kinetic energy ≈ keV
- Local density: 0.3 GeV/cm^3 ⇨ Event rate 0.1/day/kg
- Very low cross sections: $\sigma_\chi < 10^{-14}\,\sigma_{pp}$

Basic detector considerations



Marc Schumann *U Freiburg*

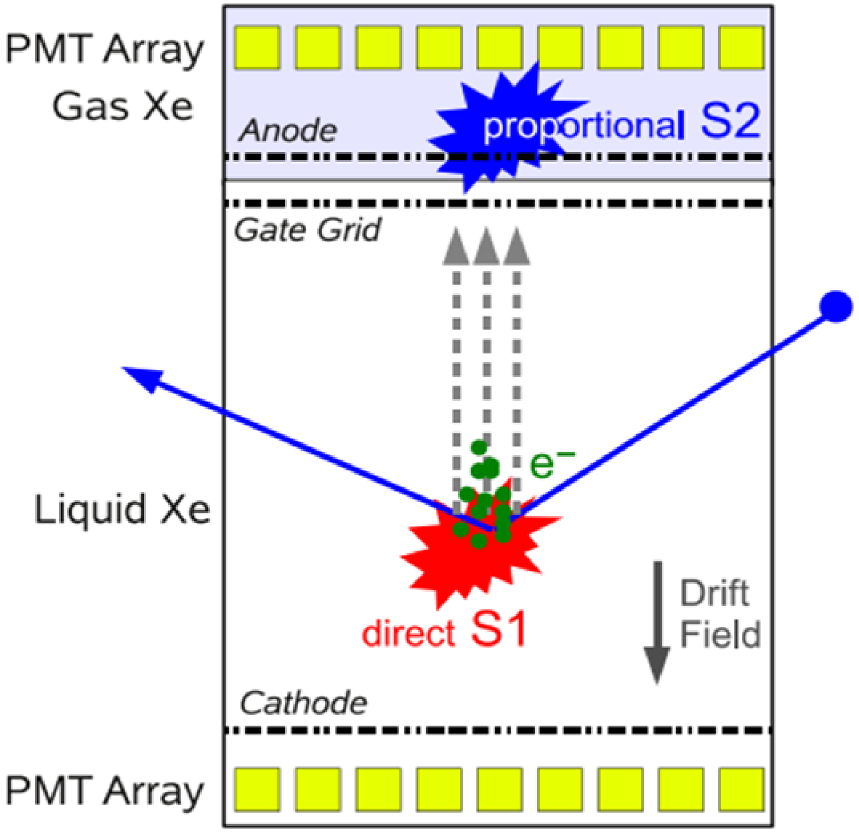
PATRAS 2017
Thessaloniki, May 19, 2017

marc.schumann@physik.uni-freiburg.de
www.app.uni-freiburg.de

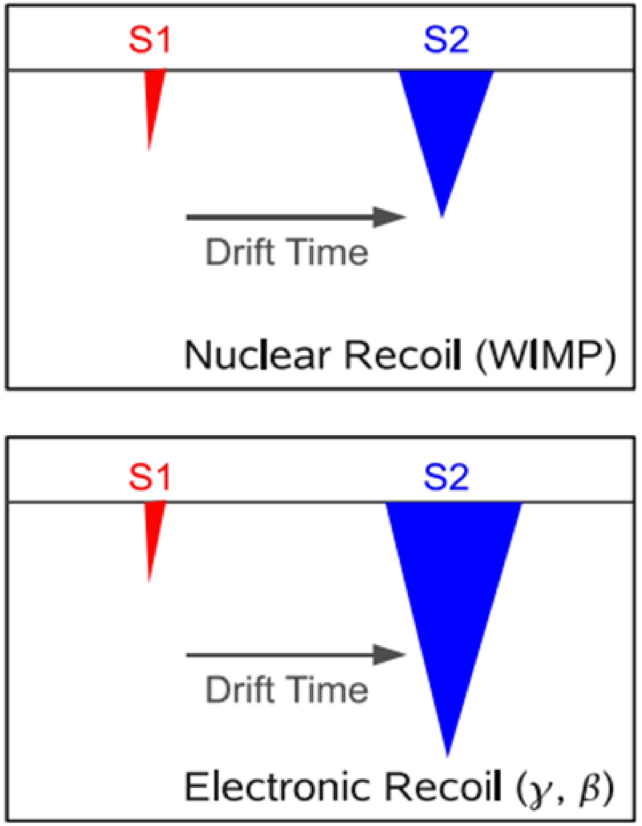
- Large, well shielded detectors to suppress background
- Radio-pure materials
- Discrimination between electronic and nuclear recoils
  → further suppress cosmic ray interactions and radioactivity
- Remaining background: neutron scattering

Example: the XENON experiment

Two-phase Xe Time Projection Chamber



S.E.A. Orrigo, Direct Dark Matter Search with XENON100



- Signal S1:
  Scintillation light from the scattering process in the liquid Xe
- Signal S2:
  Light produced in the gaseous phase by electrons drifted from primary scatter
- Different ionization densities
  → Ratio S2/S1:
  Small for nuclear recoil, larger for electronic recoil

The XENON experiment

Gran Sasso National Laboratory, Italy

https://phys.org/news/2017-05-xenon1t-sensitive-detector-earth-wimp.html

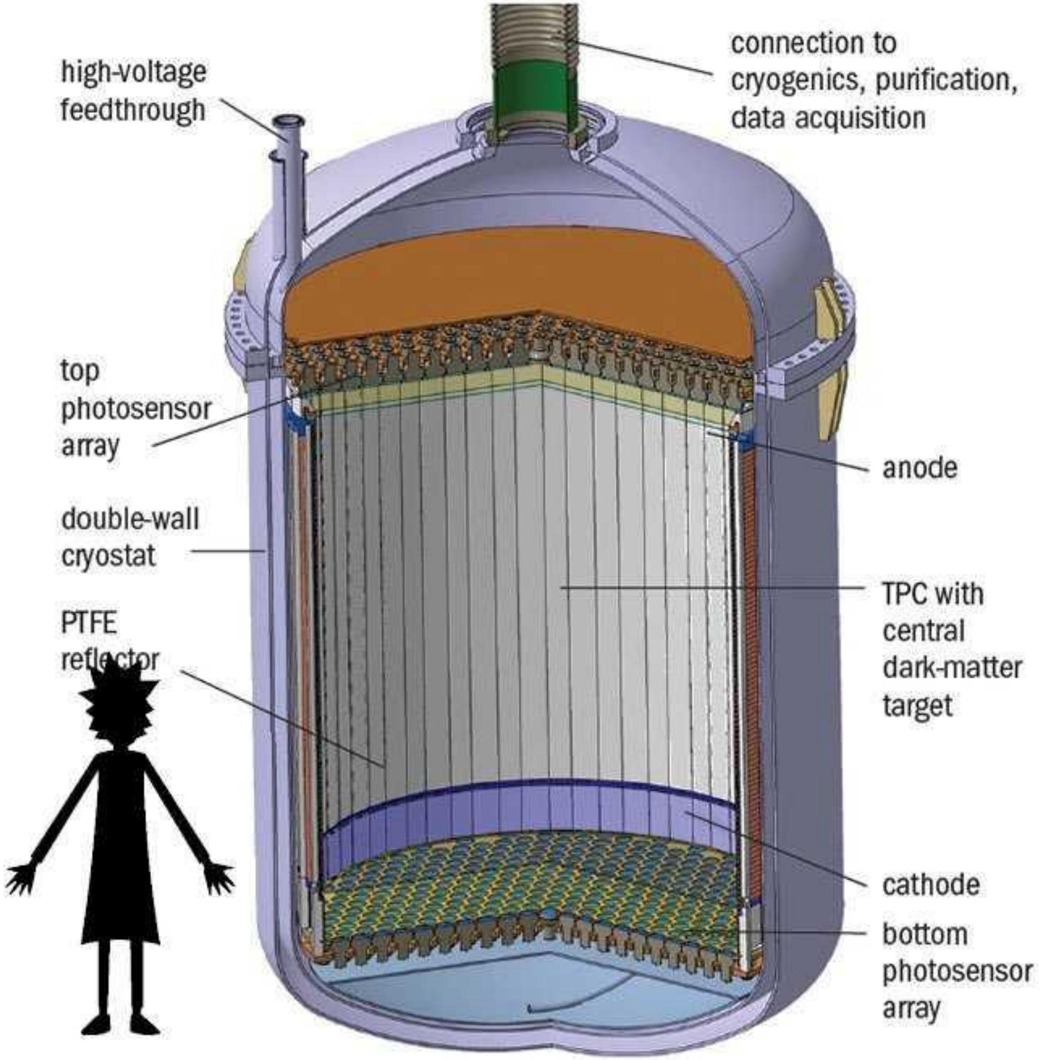
The DARWIN Experiment

An ultimate WIMP search?

Next generation LXe experiment

- DARWIN
  (DARk matter WImp search with liquid xenoN)
- 50 t liquid Xe
  (world-wide annual Xe market: ≈ 100 t)
- Lowest WIMP-nucleon cross-section
  in 50 GeV mass range
- Lots of other rare physics topics.

https://www.media.uzh.ch/en/Press-Releases/2017/Xenon1T-Dark-Matter.html

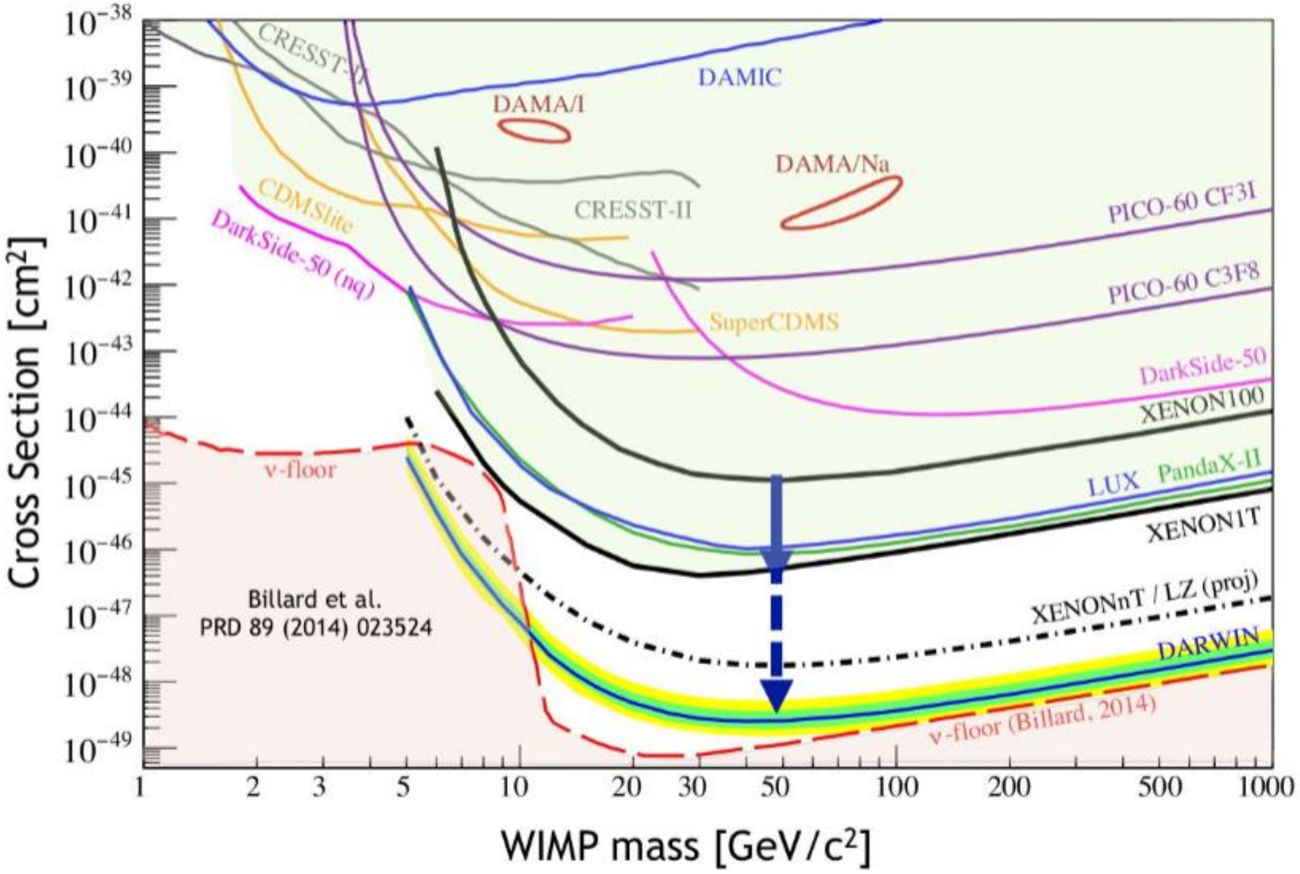


Florian Tönnies, University of Freiburg

Status of direct dark matter WIMP searches

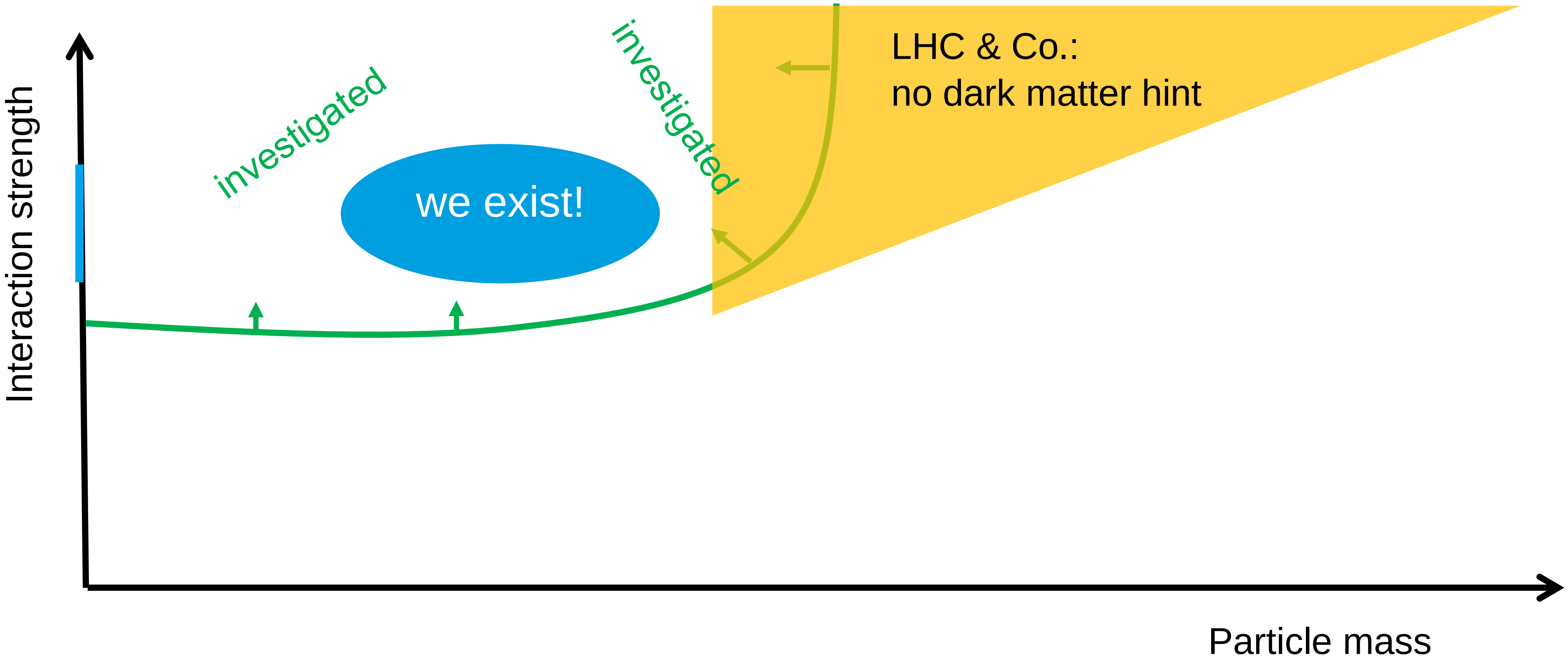
Down to the neutrino floor

- Dark matter WIMP searches have seen fantastic technological improvements in the past decade.
- BUT: No convincing indication for existence of dark matter WIMPs found.
- Next generation of experiments will come close to irreducible background of neutrino interactions.
- **No hint for WIMPy dark matter candidates @ LHC and other colliders.**
- **Are we approaching the final stage of dark matter WIMP searches?**



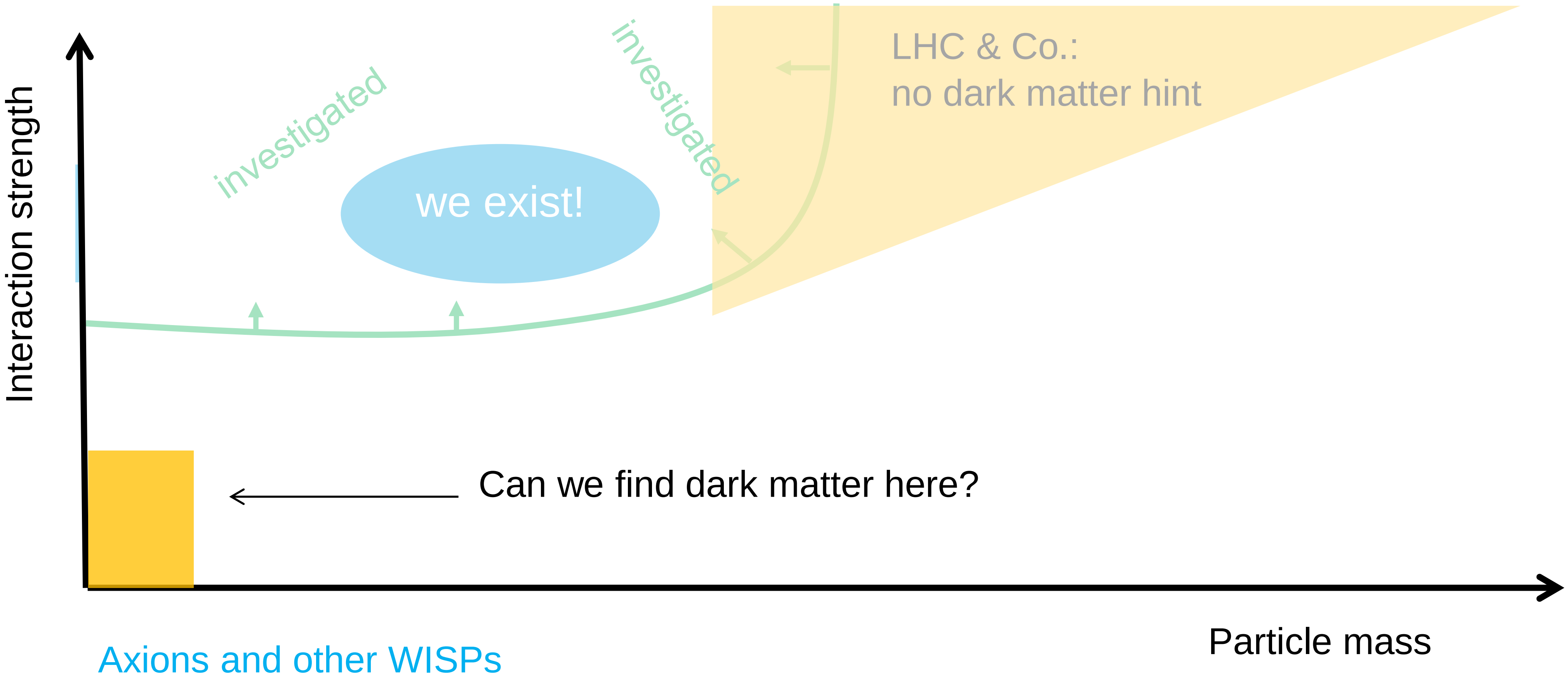
Particle physics at colliders

A very simplified picture



Particle physics beyond colliders

Axions and other Weakly Interacting Slim Particles (WISPs)



Axions and other WISPs
interact much too weakly to be seen at colliders.

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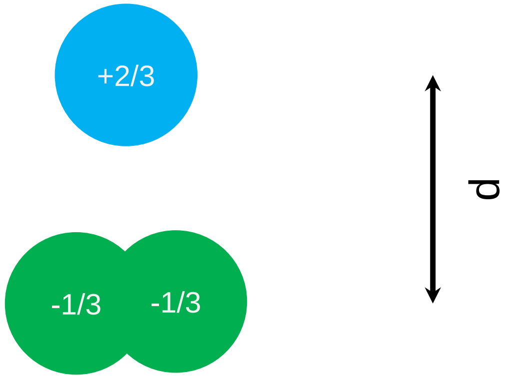
A brief motivation for the axion

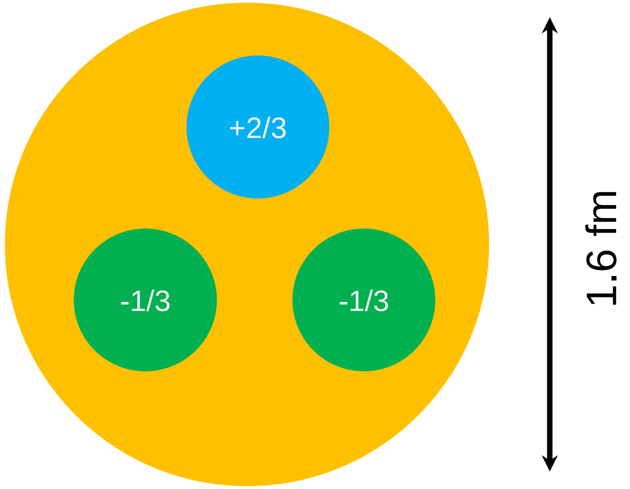
an electric dipole



Electric dipole moment: EDM = 2/3e · d

A brief motivation for the axion

Missing: an electric dipole moment of the neutron and a CP violation of QCD



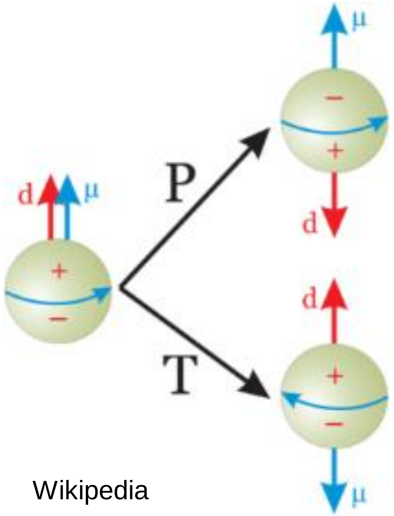
Prediction for the neutron:

EDM = "QCD-factor" · 2/3e · 0.8fm = "QCD-factor" · $5 \cdot 10^{-14}$ e·cm

= $\theta \cdot 2 \cdot 10^{-16}$ e·cm

Measurement:

EDM < $3 \cdot 10^{-26}$ e·cm = prediction / 10^{10}



Wikipedia

This is related to a fundamental symmetry of QCD:
any non-vanishing neutron EDM would result in a CP violation.

Why is CP conserved in QCD?
Why does the neutron not show any EDM?

A brief motivation for the axion

The Peccei-Quinn mechanism, Weinberg and Wilczek

Peccei and Quinn proposed a symmetry breaking mechanism in 1977
to explain the vanishing neutron dipole moment.

In 1978 Weinberg and Wilczek independently noticed that this implies the existence of a new pseudo Goldstone boson.

The axion was named after an detergent as it “cleans up” QCD.

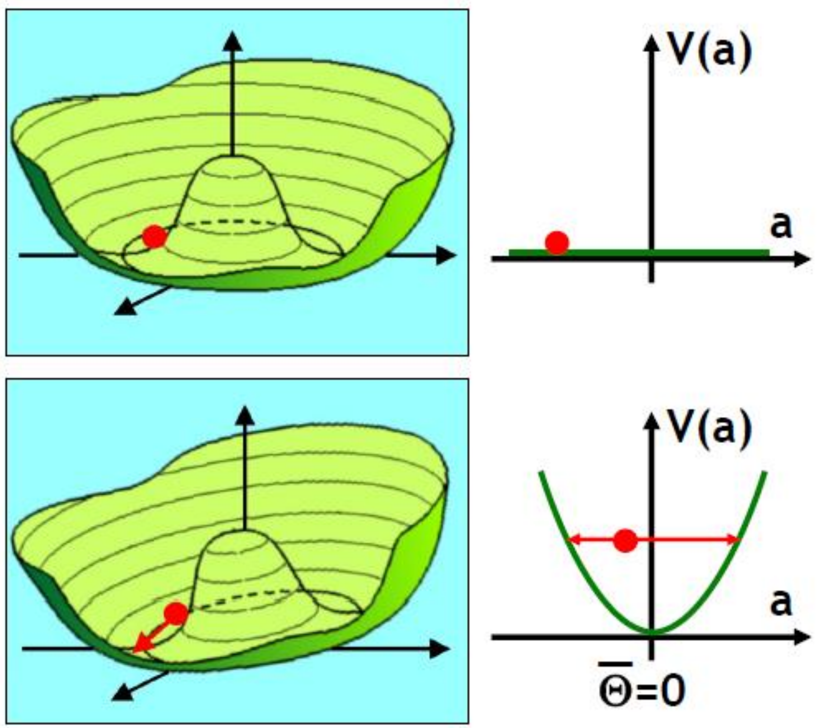
A brief motivation for the axion

The Peccei-Quinn mechanism of 1977

Idea: if θ is not a fixed value, but an evolving field, it relaxes to zero by QCD instanton effects.

Peccei-Quinn symmetry:

- Global U(1), complex scalar field.
- Spontaneously broken at very high energies: a massless Goldestone boson should exist. This is the axion.
- QCD instanton effects explicitly break the axion (a) symmetry, so that it becomes inexact at QCD energies. The axion acquires mass.



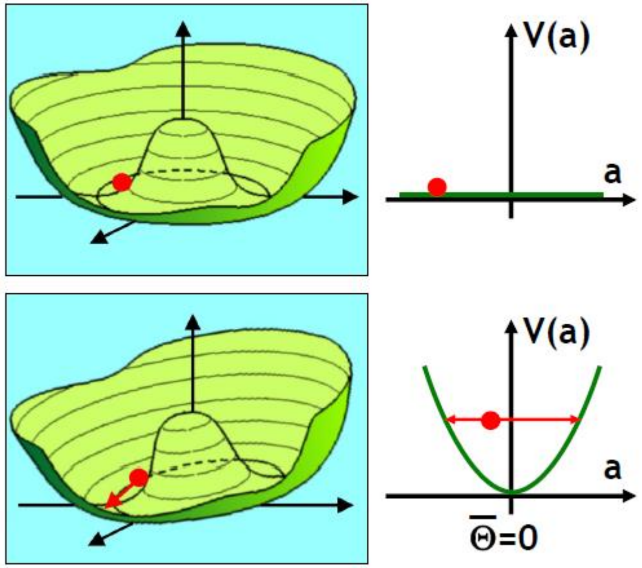
S. Hannestad, presentation at 5th Patras Workshop 2009

If $\theta = 0$ by the Peccei-Quinn mechanism, an axion should exist!

And vice versa.

Axion properties (2)

Feeble interactions and ideal dark matter candidates



- Mass: $m_a = 0.6\ \text{eV} \cdot (10^7\text{GeV} / f_a)$
  Couplings ~ $1/ f_a$ (hence ~ m_a)

  f_a is the energy at which the "Mexican hat" appears.

- The PQ symmetry breaking happened also in the early universe.
  Thus, axions contribute to dark matter (simplified picture):

  $\Omega_a / \Omega_c \sim (f_a / 10^{12}\text{GeV})^{7/6} = (6\ \mu\text{eV} / m_a)^{7/6}$

  For $f_a \approx 10^{12}$GeV ($10^8 \cdot$LHC) and m_a around 10 μeV the axion could make up all of the dark matter!

  Such axions originate from the symmetry breaking and not from any thermal process (like WIMPs).
  Thus they are very cold, although born in a very hot universe!

Weakly Interacting Slim Particles (WISPs)

More than the axion

There may be a complex hidden sector of sub-eV mass particles:

- Pseudoscalars: axion-like particles (ALPs): couplings ~ 1/ f_a, mass independent from f_a.
- Vector bosons: hidden photons
- Scalars: dilaton fields
- Minicharged particles

Such particles are expected in theories of quantum gravity (lot's of global symmetry breakings).

In general WISPs with masses below 1eV are dark matter candidates

- if they are bosonic,
- if they are of non-thermal origin.

Disclaimer:

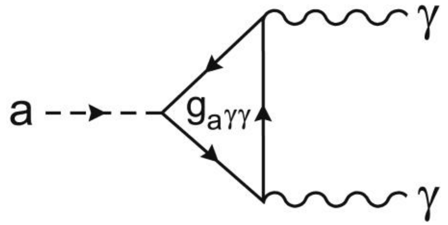
In the following I will not distinguish anymore between the QCD-axion and ALPs, but use both as synonyms.

Unless stated otherwise.

ALP – photon couplings

Exploited by most experiments for lightweight ALPs / axions

Axion decay to two photons



$$\Gamma_{A\to\gamma\gamma} = \frac{G_{A\gamma\gamma}^2 m_A^3}{64\,\pi} = 1.1\times 10^{-24}\ \mathrm{s}^{-1}\left(\frac{m_A}{\mathrm{eV}}\right)^5$$

$$m_A = \frac{z^{1/2}}{1+z}\,\frac{f_\pi m_\pi}{f_A} = \frac{0.60\ \mathrm{meV}}{f_A/10^{10}\,\mathrm{GeV}}$$

http://pdg.lbl.gov/2010/reviews/rpp2010-rev-axions.pdf

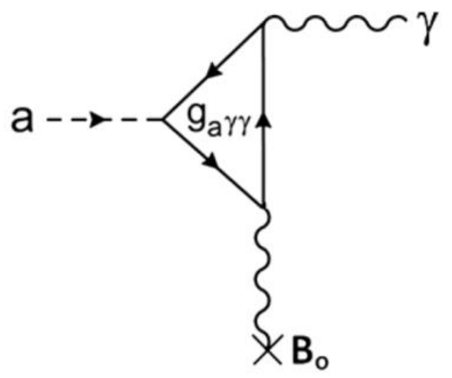
Energy scale to produce axions in measurable quantities at colliders.

m_A [eV]	τ [$T_{universe}$]	f_A [LHC units]
1	10^6	10^2
0.00001	10^{31}	10^8

ALP – photon coupling

Axion photon mixings

… to axion-photon conversion in magnetic fields
(Sikivie conversion)



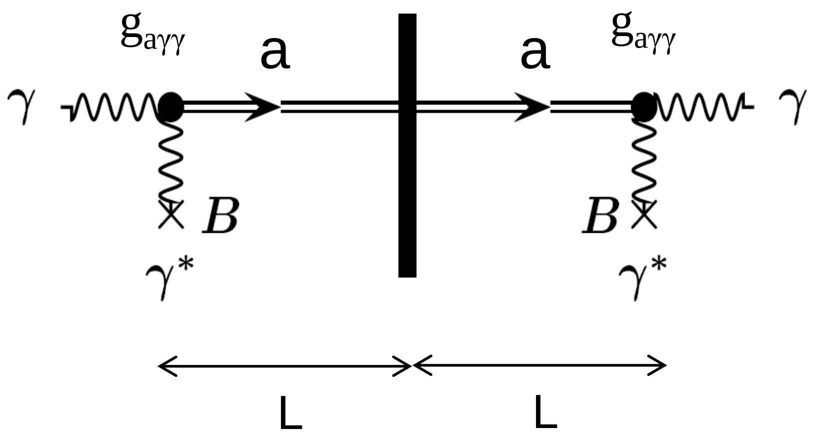
and light-shining-through-walls.

P(γ→a→γ)

$= 6\cdot10^{-38}\cdot (g_{a\gamma\gamma}[10^{-10}GeV^{-1}]\cdot B[1T]\cdot L[10m])^4$

$= 10^{-33}$ (ALPS II at DESY)

increased to 10^{-27} (ALPS II at DESY with some tricks)



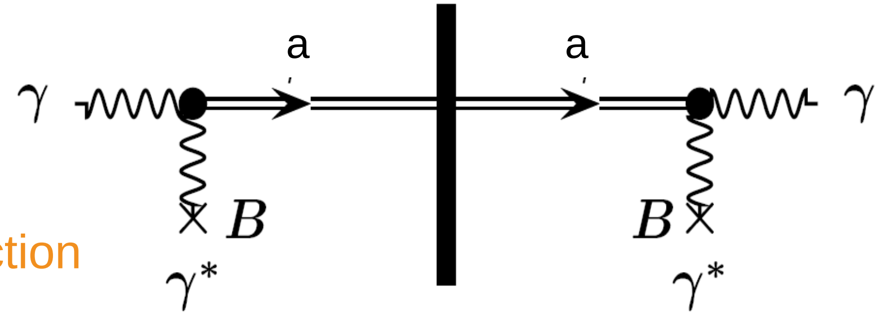
How to look: three kinds of light-shining-through-walls

Axion/ALP photon mixing in magnetic fields

Target sensitivity

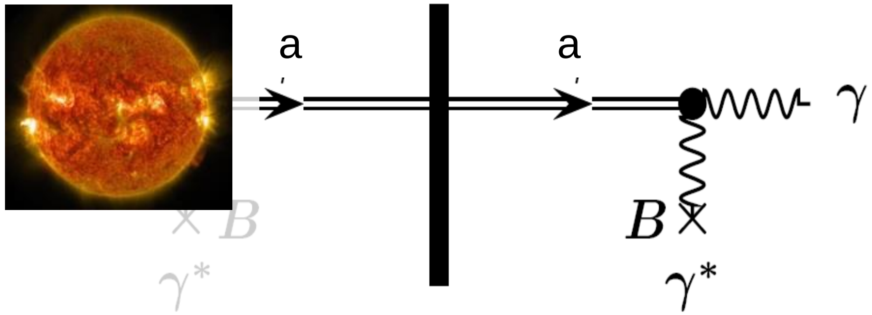
- Purely laboratory experiments
  "light-shining-through-walls",
  microwaves, optical photons

1 photon/day
exploit resonant detection



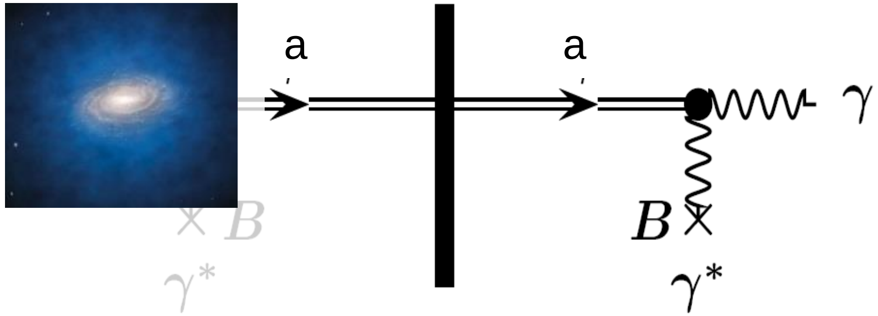
- Helioscopes
  ALPs emitted by the sun,
  X-rays

1 photon/year



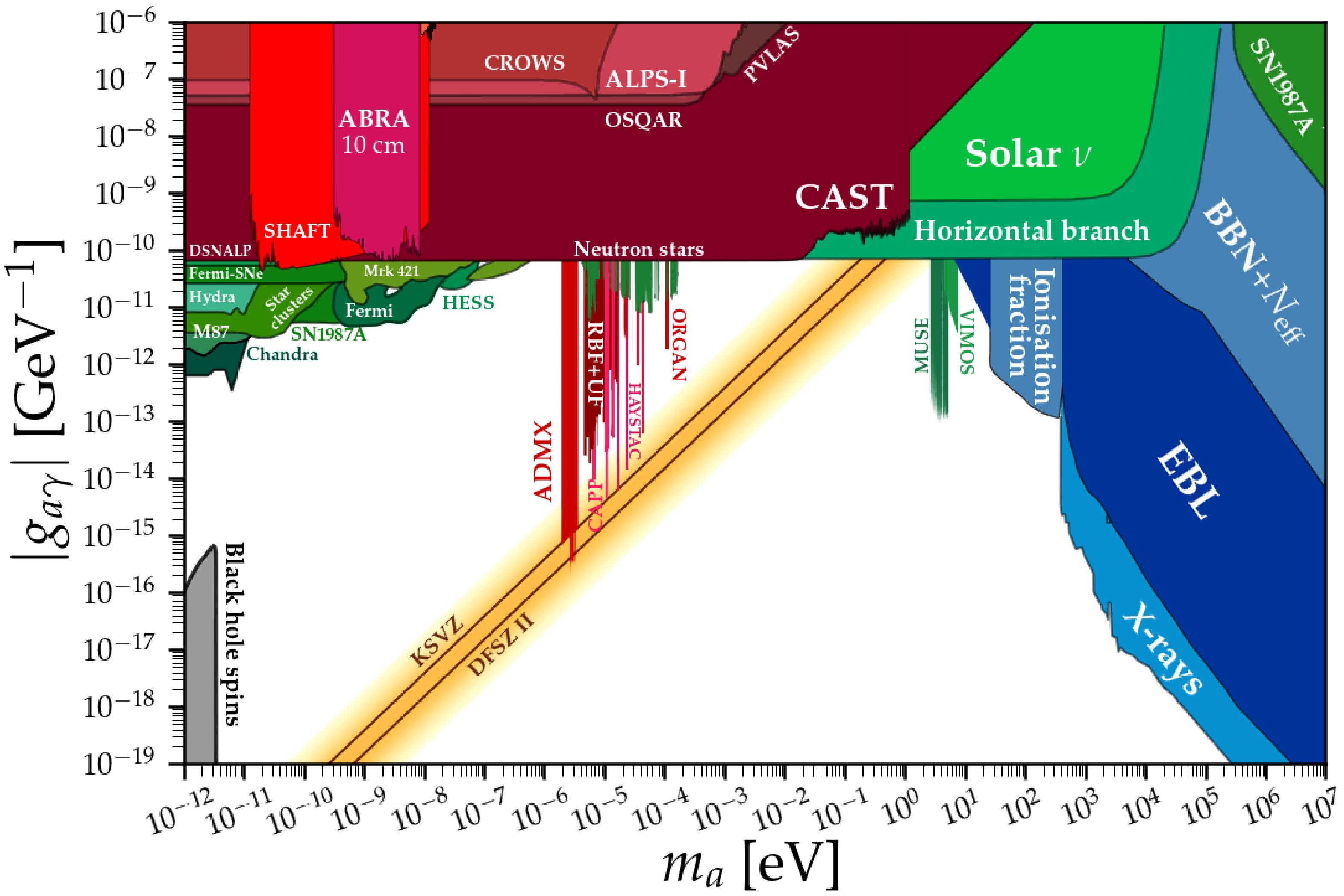
- Haloscopes
  looking for dark matter constituents,
  microwaves.

10^{-23} W
exploit resonant
detection



The axion landscape

Making them visible



Ciaran O'Hare,

https://cajohare.github.io/AxionLimits/

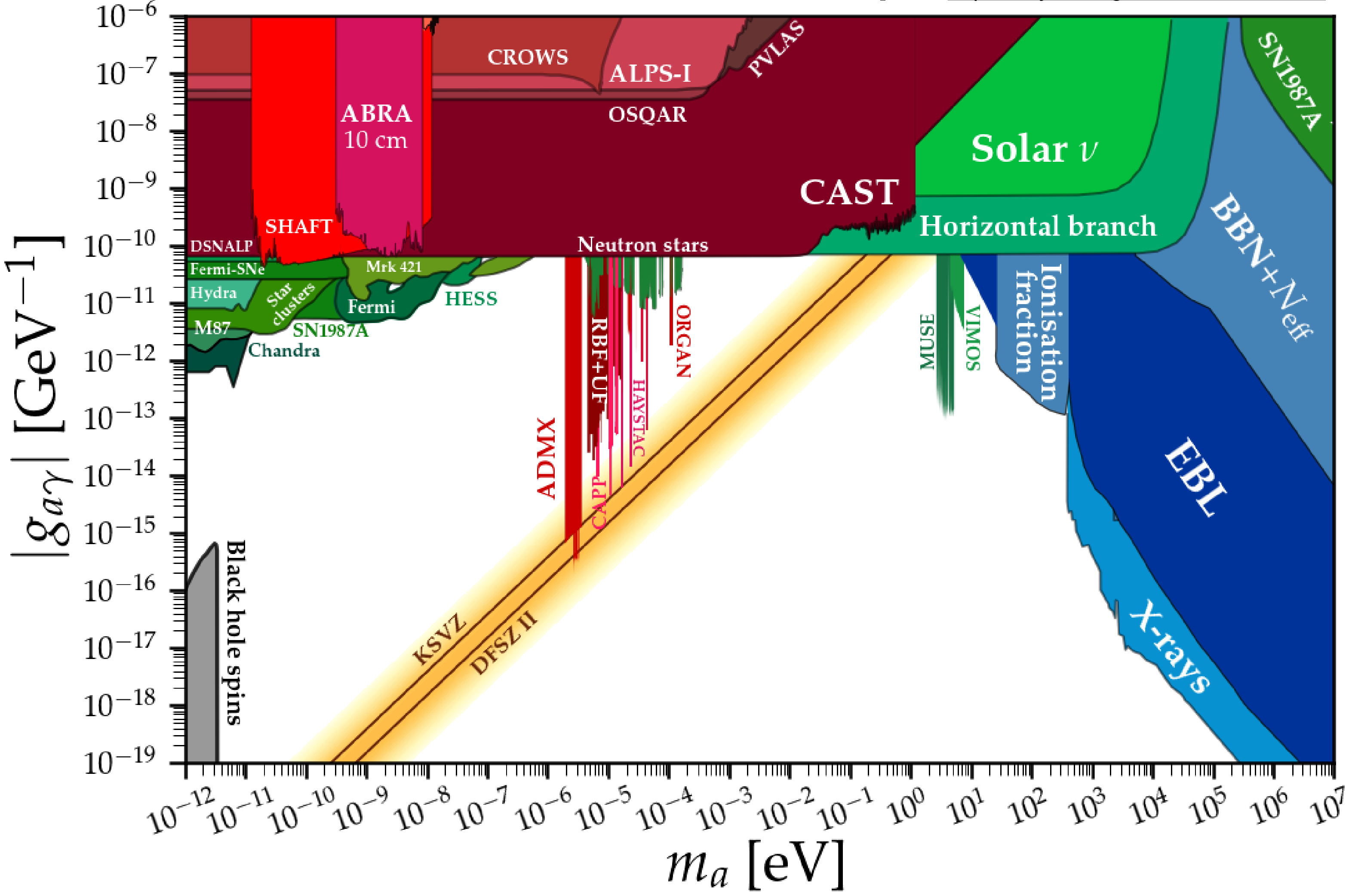
Many orders of magnitude in mass and coupling strength to be probed by different experiments:

- On earth
- Astrophysics
- Cosmology
- Gravitational waves

Axion searches

Making them visible

Ciaran O'Hare, https://cajohare.github.io/AxionLimits/

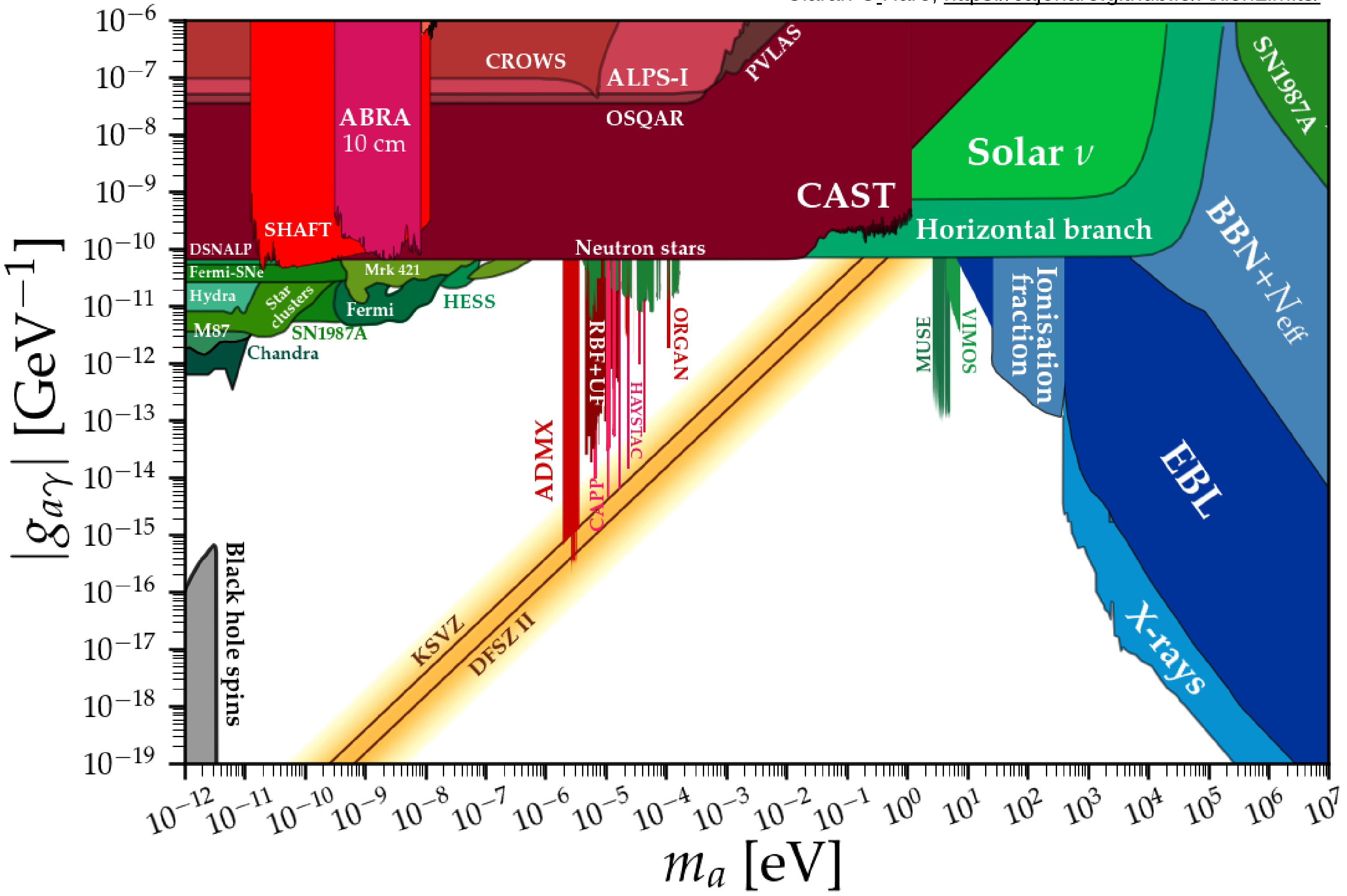


- On earth
- Astrophysics
- Cosmology
  - Looking for signatures of dark matter axions.
- Gravitational waves
  - Superradiance: axions might extract energy from spinning black holes.

Axion searches

Making them visible

Ciaran O'Hare, https://cajohare.github.io/AxionLimits/

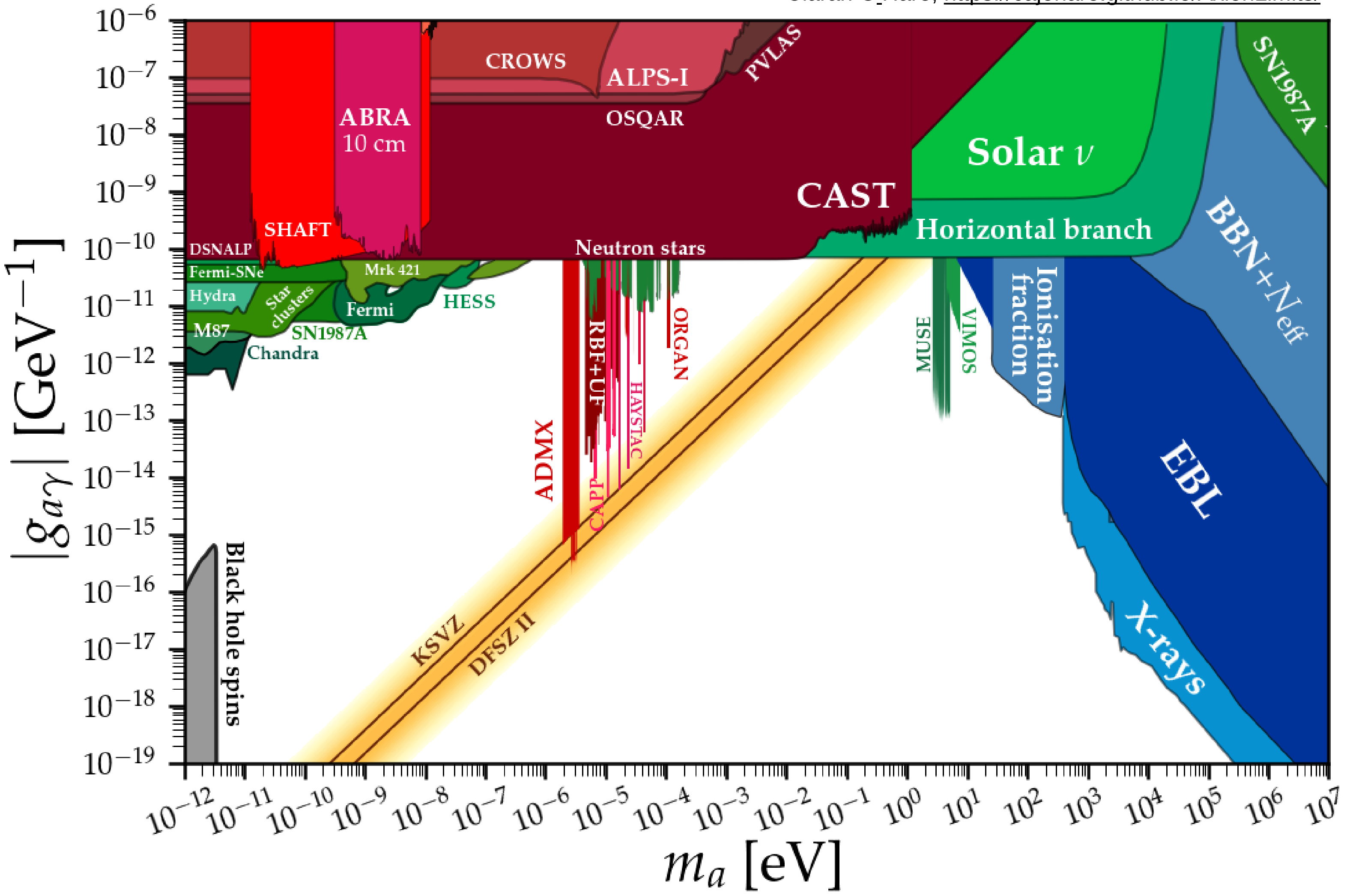


- On earth
- Astrophysics
  - General: Axions as very light particles might be generated in today's universe.
- Cosmology
- Gravitational waves

Axion searches

Making them visible

Ciaran O'Hare, https://cajohare.github.io/AxionLimits/

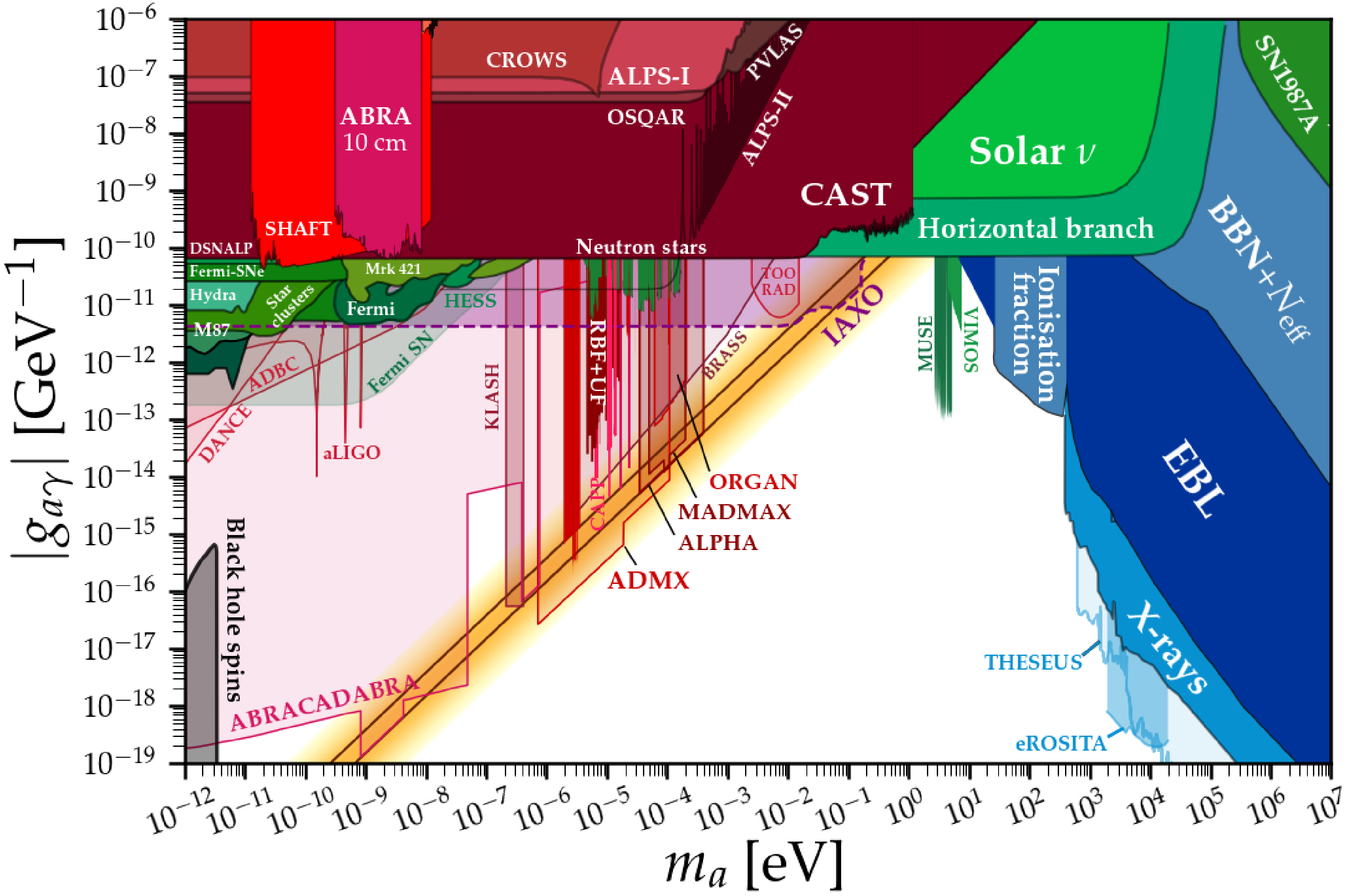


- On earth
  - Direct detection of dark matter axions.
  - Direct detection of solar axions.
  - Purely laboratory-based experiments.
- Astrophysics
- Cosmology
- Gravitational waves

Axion searches

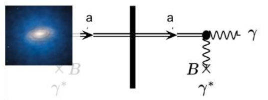
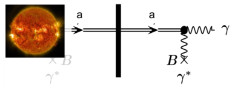
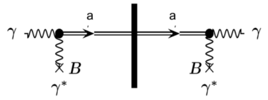
Making them visible at future experiments

Ciaran O'Hare, https://cajohare.github.io/AxionLimits/



- On earth
- Astrophysics
- Cosmology
- Gravitational waves

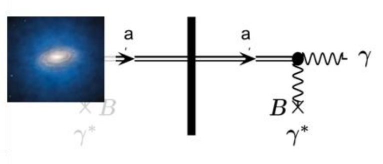
Experiments at DESY:

- MADMAX 
- IAXO 
- ALPS II 

Search strategies

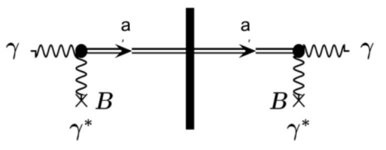
For axions and other WISPs

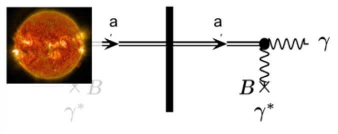
1. Look for axions as the constituents of the local dark matter.



Dark matter converts to light!
MADMAX @ DESY, skipped here

2. Look for axions independent of the dark matter paradigm.



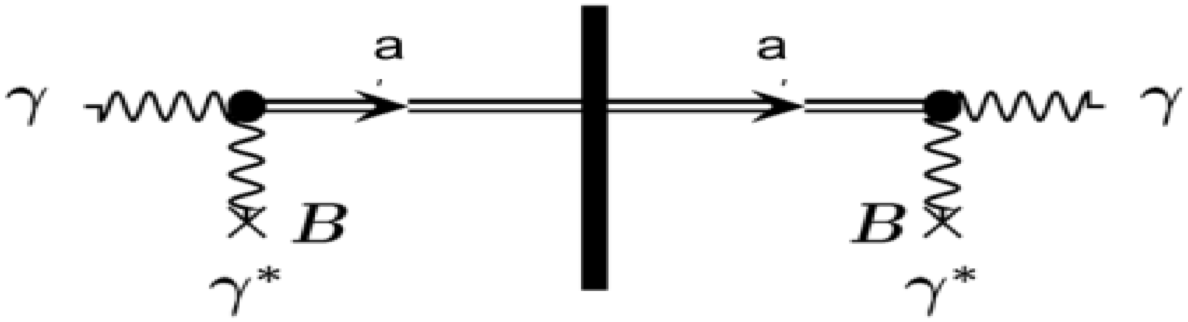


Dark matter particles traverse every shielding!
ALPS II @ DESY,
BabyIAXO @ DESY, skipped here.

3. Look for an axion-mediated 5th force (not covered here).

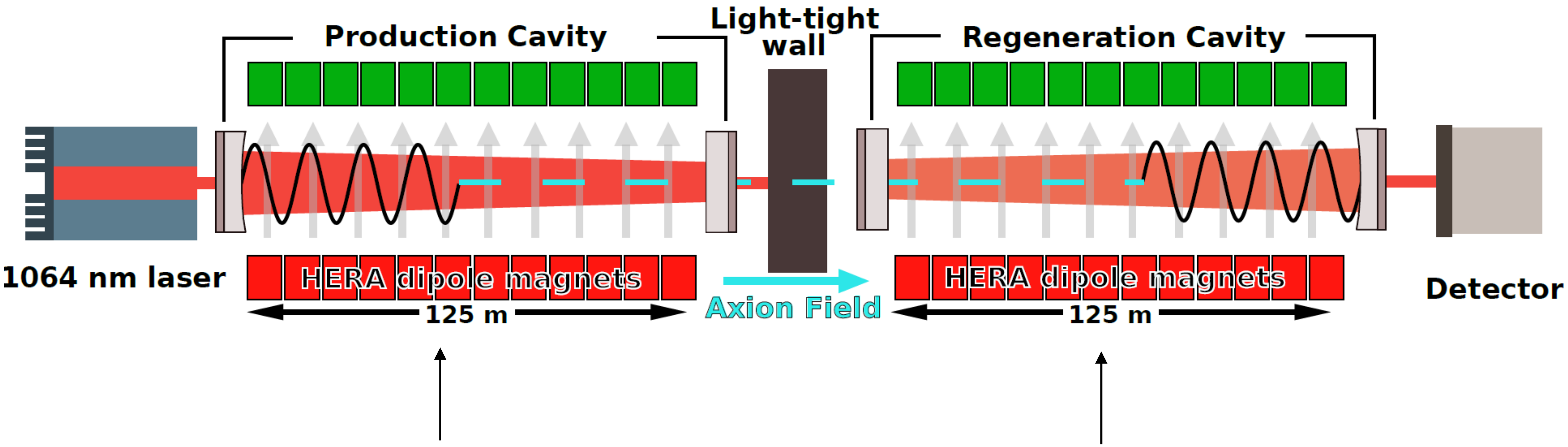
Any Light Particle Search ALPS II

Model independent search: light-shining-through-walls



Any Light Particle Search ALPS II

Model independent search: light-shining-through-walls

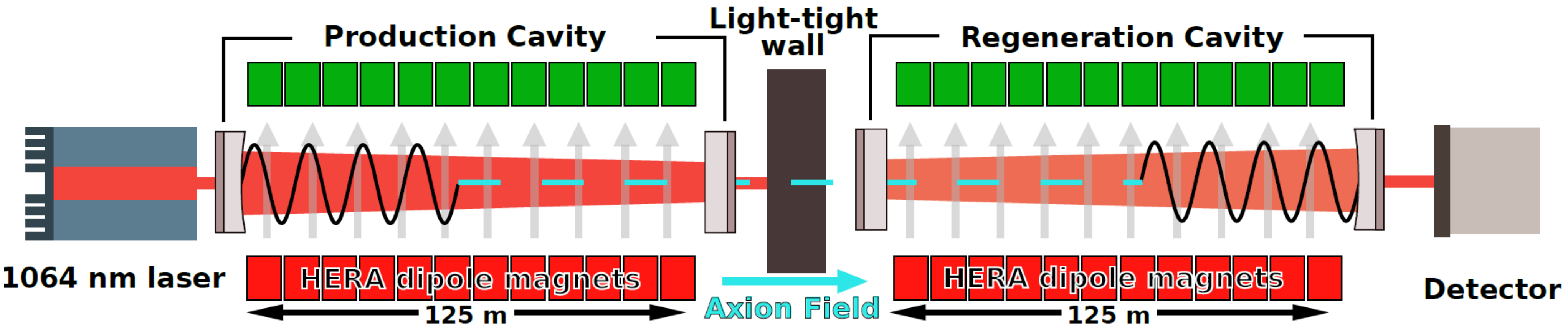


Optical resonator:
re-cycle injected photons

Optical resonator:
increase conversion to photons

Any Light Particle Search ALPS II

Model independent search: light-shining-through-walls



$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot(g_{a\gamma\gamma}Bl)^4 = 6\cdot 10^{-38}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\frac{B}{1\,T}\frac{l}{10m}\right)^4$$

$= 8\cdot 10^{-26}$

5,000 16,000 0.2 5.3 10.56

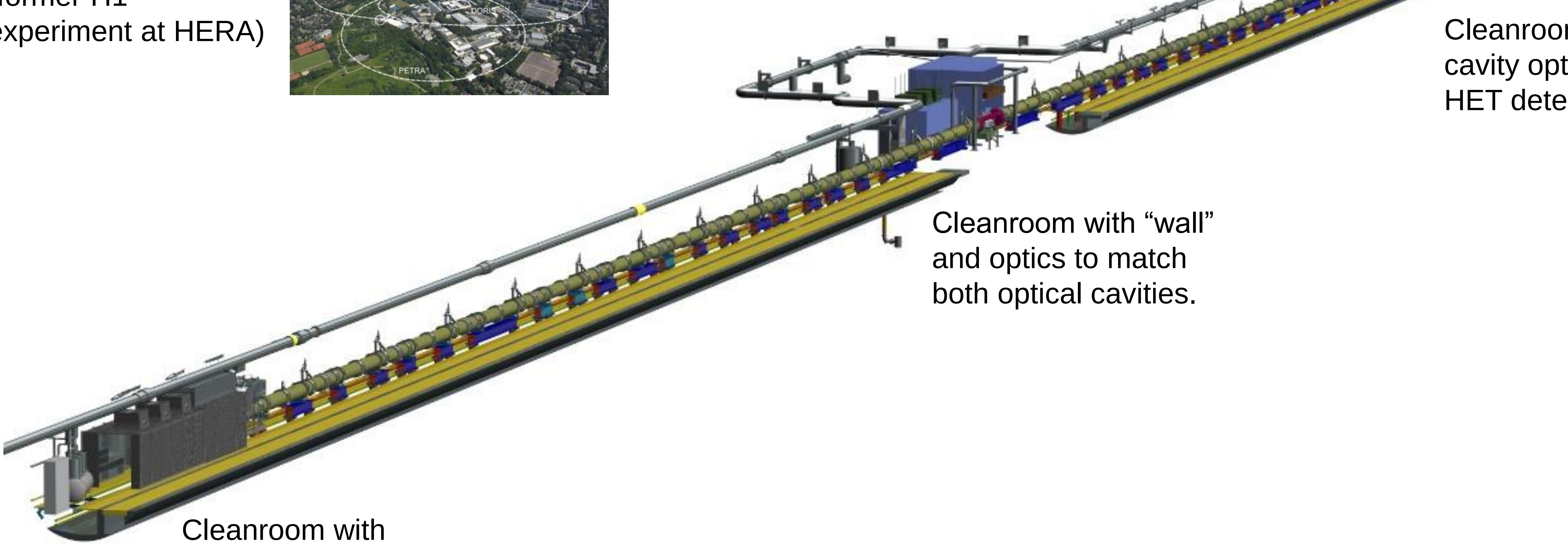
0.2 ↕ astrophysics ALP motivation

30 W cw laser at 1064 nm: $1.2\cdot 10^{-5}$ photon/s ($2\cdot 10^{-24}$ W).

ALPS II in the HERA tunnel

250m installation in a straight HERA section

HERA hall North (former H1 experiment at HERA)



Cleanroom with cavity optics and HET detection.

Cleanroom with “wall” and optics to match both optical cavities.

Cleanroom with high power laser.

Any Light Particle Search ALPS II

Collaboration

DESY
Albert Einstein Institute Hannover
UF UNIVERSITY of FLORIDA
JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

ALPS II main contributions				
Partner	Magnets	Optics	Detectors	Infrastructure
DESY	X	X	X	X
AEI Hannover		X		
U. Cardiff		X		
U. Florida		X	X	X
U. Mainz			X	

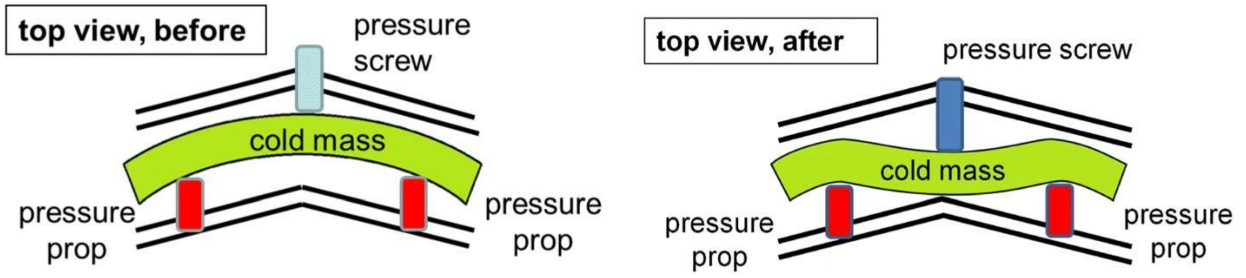
Significant funding from HEISING-SIMONS FOUNDATION

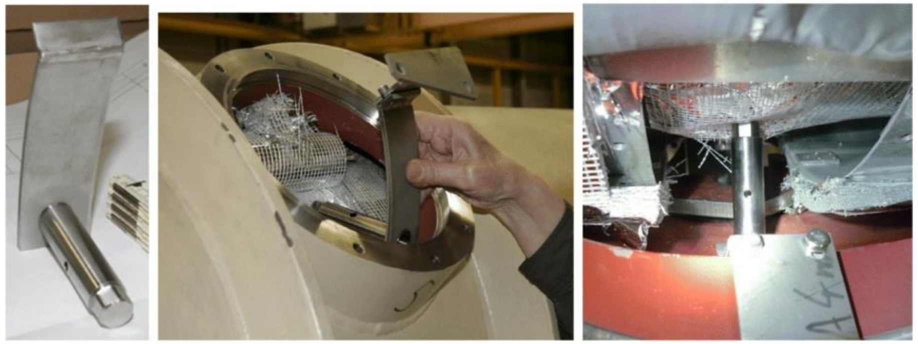
Strong support by PTB, TU Berlin, Magnicon, NIST for detector development.

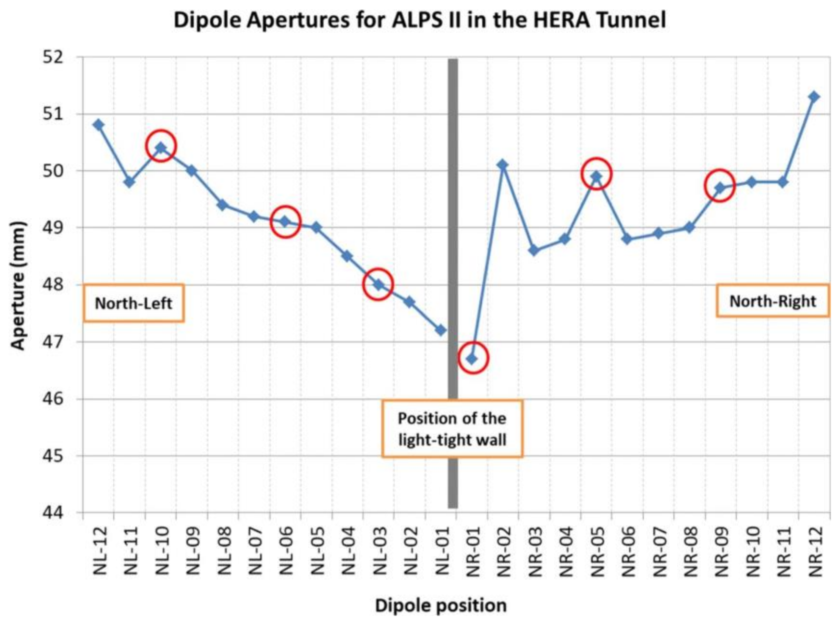
ALPS II: dipole magnets

Re-using superconducting HERA dipoles

- 12+12 superconducting dipoles from HERA, each 5.3 T on 8.8 m.
- Straightened to achieve ≈ 50 mm aperture from 35 mm (600 m bending radius).
- 26 magnets modified and tested successfully (out of 27).
- All magnets are installed and aligned.



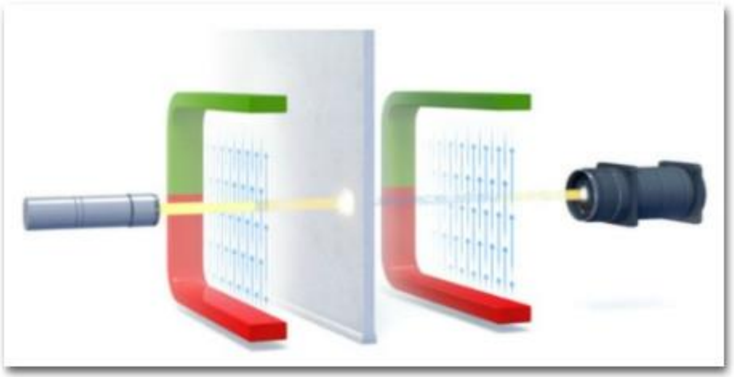


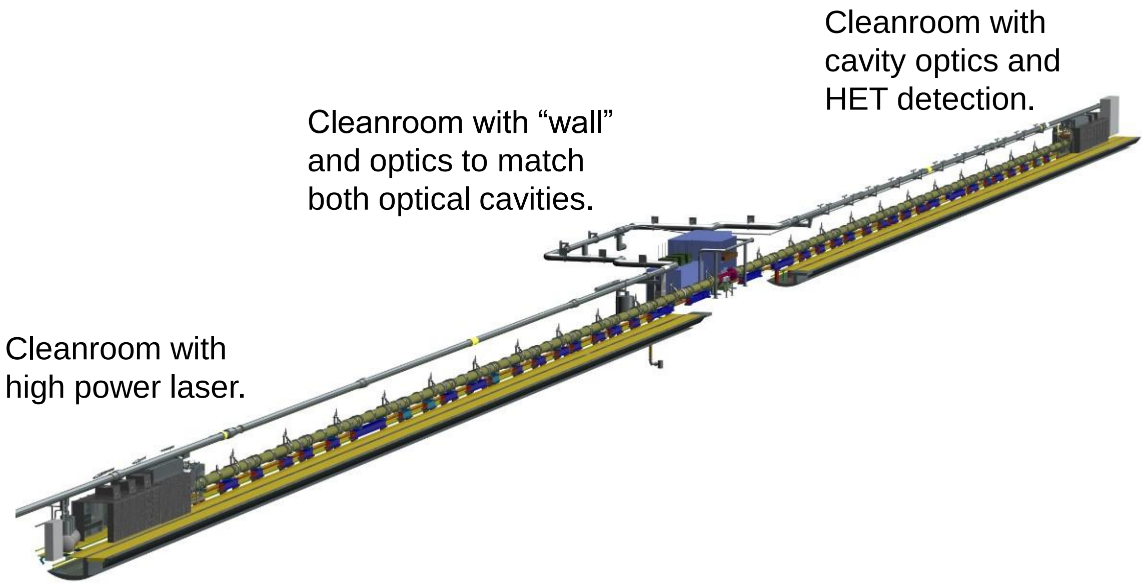


”Straightening of superconducting HERA dipoles for the any-light-particle-search experiment ALPS II“,
C. Albrecht *et al., EPJ Techn Instrum* 8, 5 (2021).

ALPS II in the HERA North area

Installation nearly completed





Ambition:

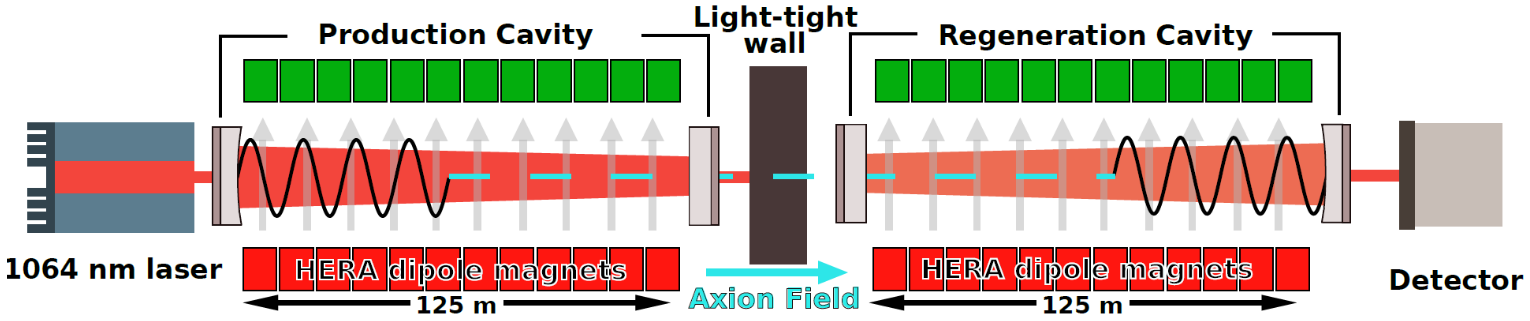
Improve the ration signal/noise compared to previous experiments by a factor 10^{12}.
The largest sensitivity jump ever?

And, of course: find the axion.

ALPS II: optics

Adapting technologies from aLIGO, GEO 600

“Design of the ALPS II Optical System”, arXiv:2009.14294 [physics.optics]



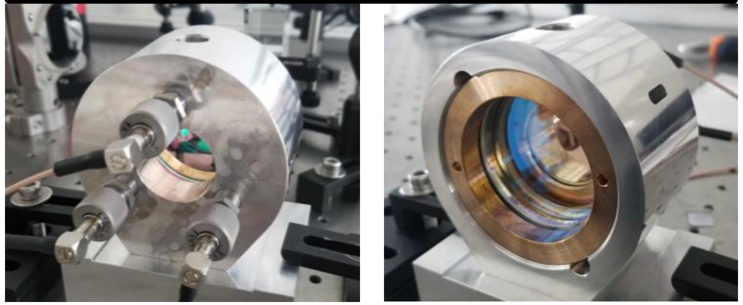
- Mode-matched optical resonators before (“PC”) and behind (“RC”) the wall.
- Relative angle between PC and RC less than 0.5 μrad.
- Each 124 m long, need to compensate seismic noise.
- Circulating power PC: 150 kW.
- Power built-up RC: 16,000 (aim for 40,000 later).
- PC and RC relative length stabilized to pm accuracy.
- Light-tightness PC to RC: less than 10^{-30}.

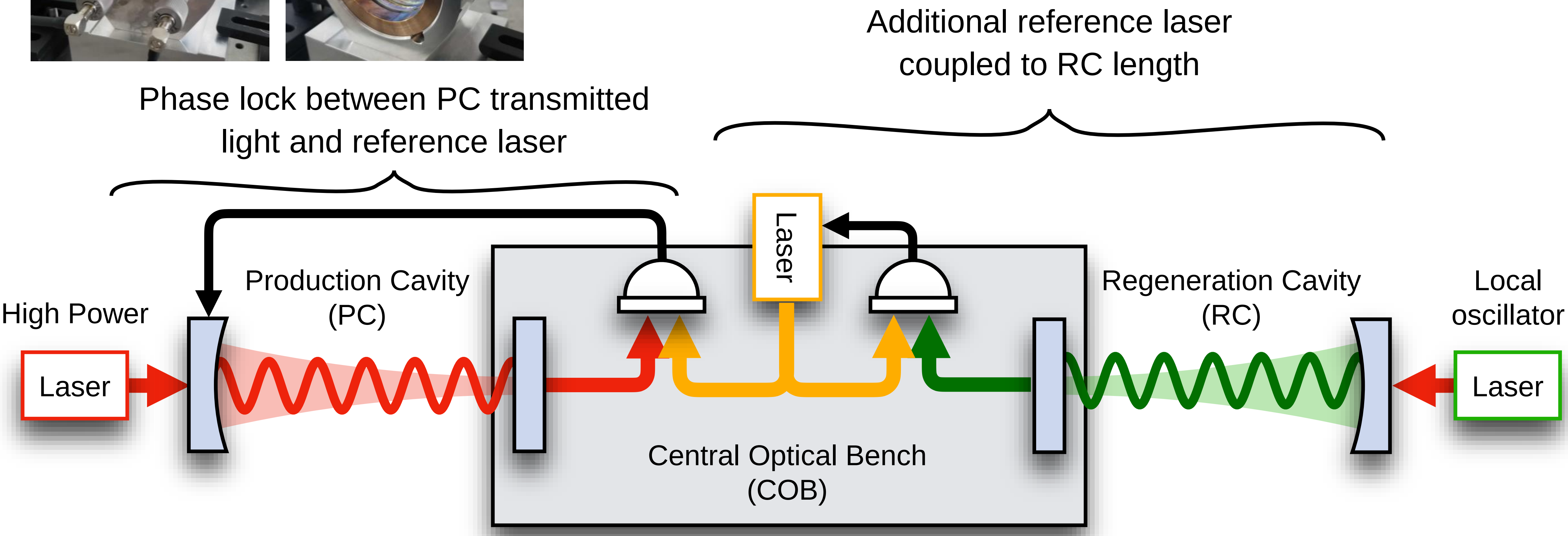
Light storage time: 5.4 ms
(2 x world-record;
aLIGO 1.0 ms)

Optics challenges

Example: dual resonance; field in PC resonant in RC

Actuators: *picometer* position accuracy required



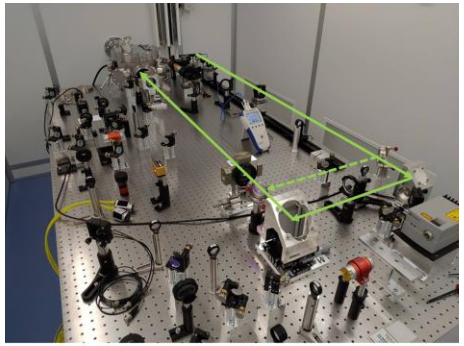


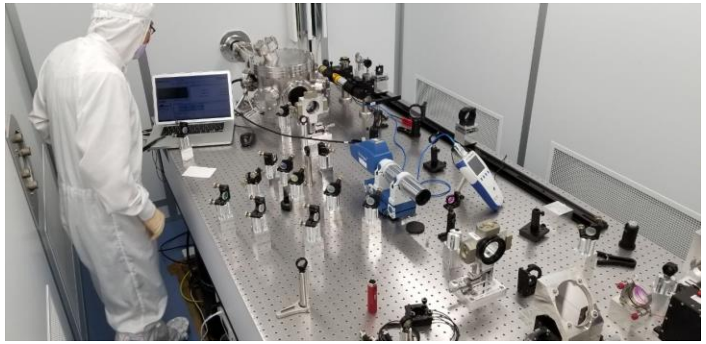
Optics status

From R&D to installation

- R&D started 2012 in a dedicated laserlab at DESY as well as at AEI Hanover and (a bit later) at University of Florida.

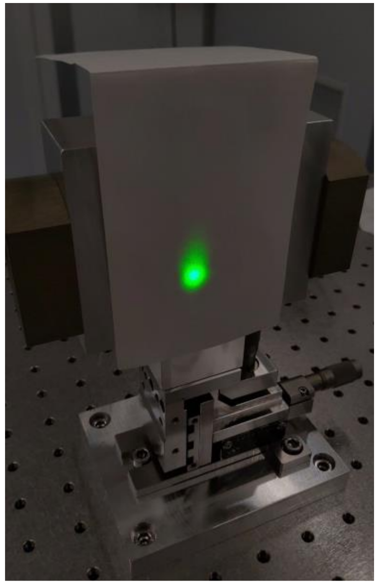
- March 2021:
  installation of optics at ALPS II started.





- April 2021:
  Initial alignment laser through the magnet string.

- May 2021:
  infrared laser through the magnet string.

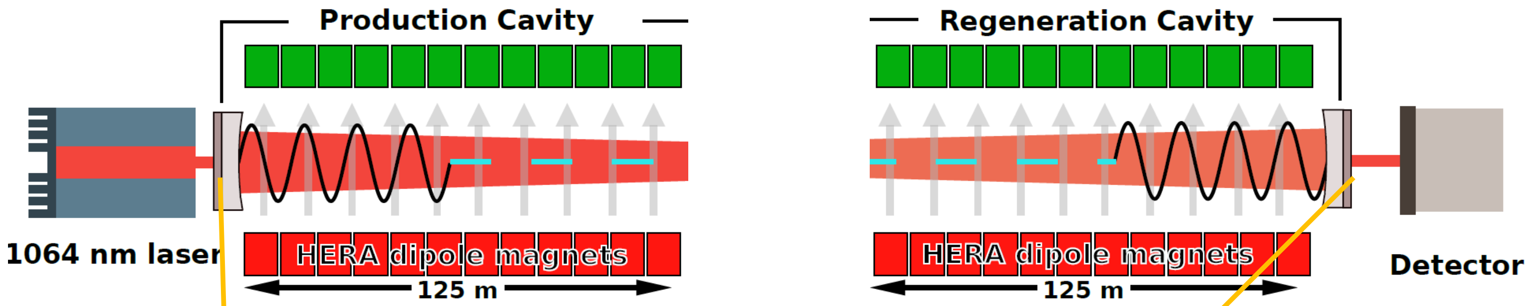


50 mm aperture on 250 m lenght!

Optics status

First cavity lock!

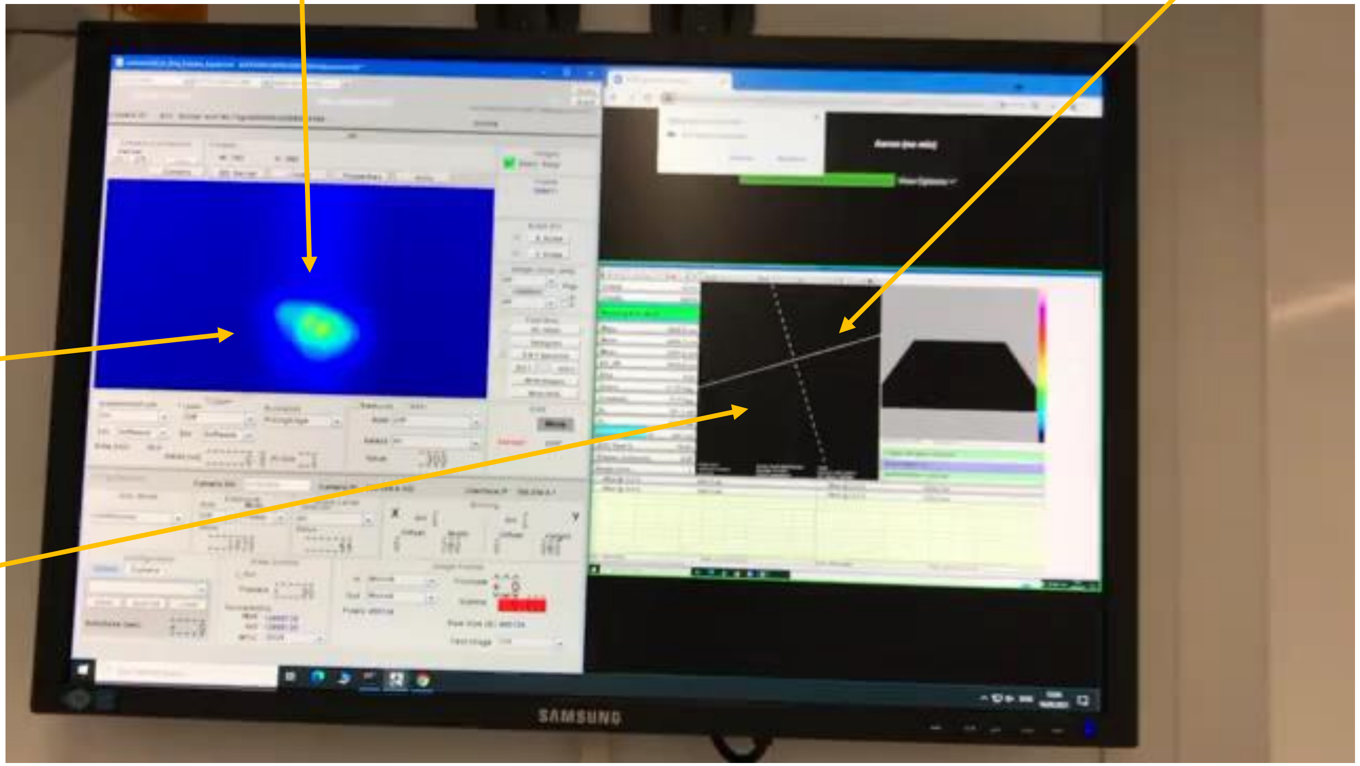
- Start with 250 m cavity to understand seismic noise and check aperture constrains.



- 21 June 2021:
  Robust cavity "lock"!

Reflection of in-coupling mirror.

Transmission of cavity end mirror



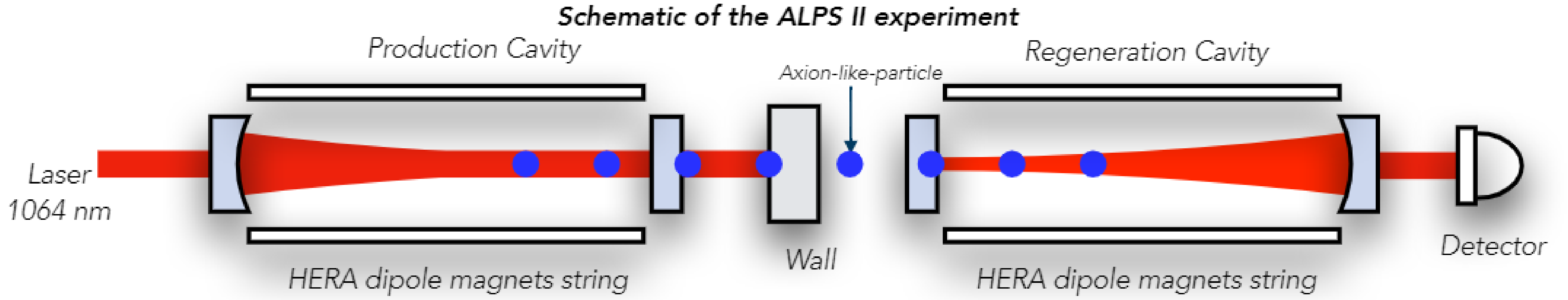
A glimps into a PhD thesis at ALPS II

Detecting one infrared photon per day

Optimizing a Transition Edge Sensor detector system for low flux infrared photon measurements at the ALPS II experiment

José Alejandro Rubiera Gimeno

ALPS II



$$P_{\gamma\to\phi\to\gamma} = \frac{1}{16}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot(g_{a\gamma\gamma}Bl)^4 = 6\cdot10^{-38}\cdot\mathcal{F}_{PC}\mathcal{F}_{RC}\cdot\left(\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}\frac{B}{1\,T}\frac{l}{10m}\right)^4$$

$\mathcal{F}_{PC}$: 5000 $\quad$ $\mathcal{F}_{RC}$: 16000 $\quad$ $\frac{g_{a\gamma\gamma}}{10^{-10}GeV^{-1}}$: 0.2 $\quad$ $\frac{B}{1\,T}$: 5.3 $\quad$ $\frac{l}{10m}$: 105.6

$$P_{\gamma\to\phi\to\gamma} = 8 * 10^{-26}$$

PC: $30\ W$ → $RC\text{: } 2 * 10^{-24}\ W$

$\sim 2 * 10^{-5} Hz \approx 2\ photons\ per\ day$

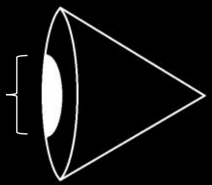
Schematic adapted from Rikhav Shav

$800\ lm$

23% of power converted to light

$2.3\ W \rightarrow 6.24 * 10^{18}\ \gamma/s$

Narrow pupil
$2\ mm$ diameter



$4.8 * 10^{12}\ \gamma/s$

$1\ m$

$800\ lm$

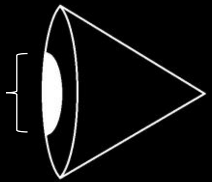
23% of power converted to light

$2.3\ W \rightarrow 6.24 * 10^{18}\ \gamma/s$

Narrow pupil

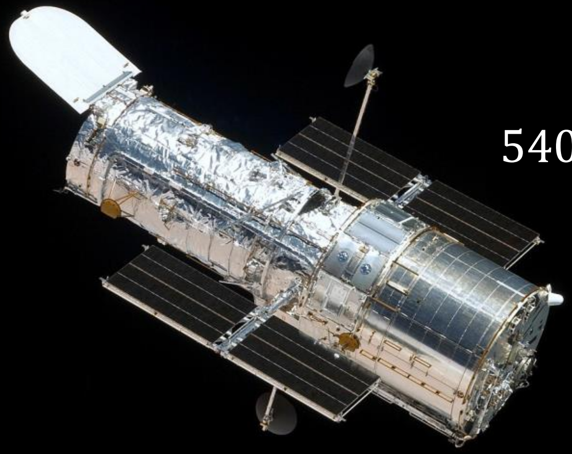
$2\ mm$ diameter

$4.8 * 10^{12}\ \gamma/s$



$1\ m$

$1\ \gamma/s \longrightarrow 2.19 * 10^{3}\ km$



$540\ km$

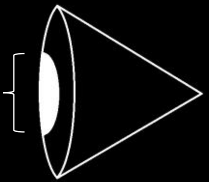
https://en.wikipedia.org/wiki/File:HST-SM4.jpeg

$800\ lm$

23% of power converted to light

$2.3\ W \rightarrow 6.24 * 10^{18}\ \gamma/s$

Narrow pupil
$2\ mm$ diameter



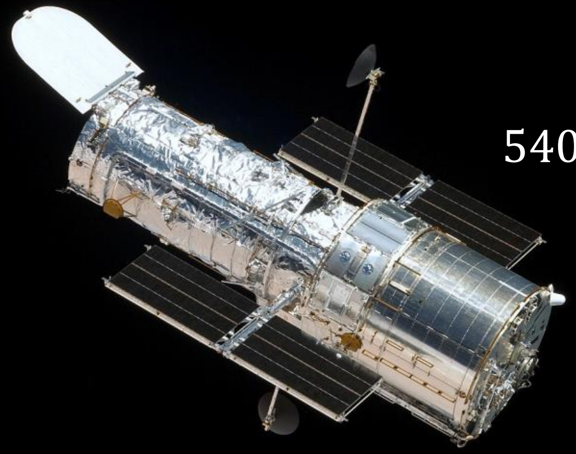
$4.8 * 10^{12}\ \gamma/s$

$\longleftrightarrow$

$1\ m$

$1\ \gamma/s \longrightarrow 2.19 * 10^{3}\ km$

$10^{-5}\ \gamma/s \longrightarrow 6.92 * 10^{5}\ km$



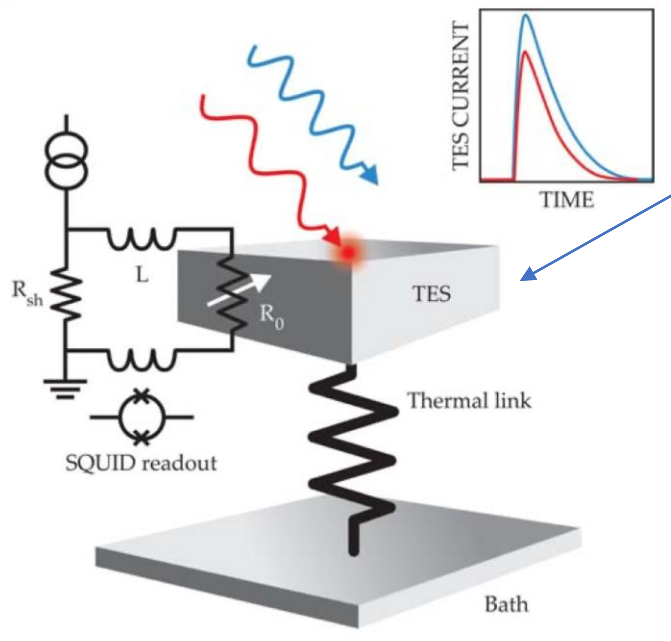
$540\ km$

$3.84 * 10^{5}\ km$

https://en.wikipedia.org/wiki/File:HST-SM4.jpeg

https://en.wikipedia.org/wiki/Moon#/media/File:FullMoon2010.jpg

Transition Edge Sensor (TES)

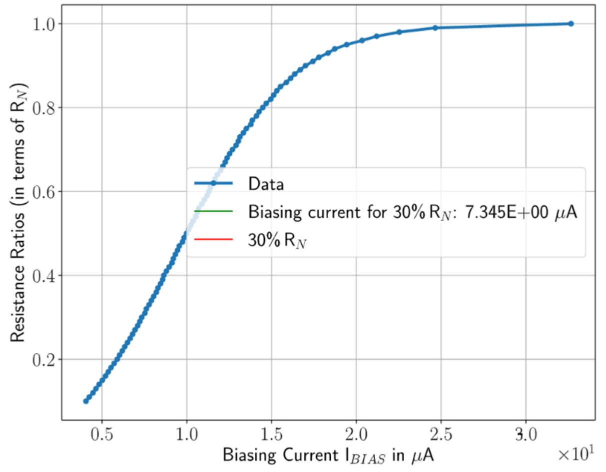


Tungsten microchip at critical transition region ($\sim 140\ mK$)

Temperature increase: Single photon ($1064nm \approx 1.16eV$) heats TES by $\sim 100\ \mu K$

$\sim 6.6\ \Omega$ resistance increase: from superconducting to normal conducting

Plot made by Rikhav Shaw

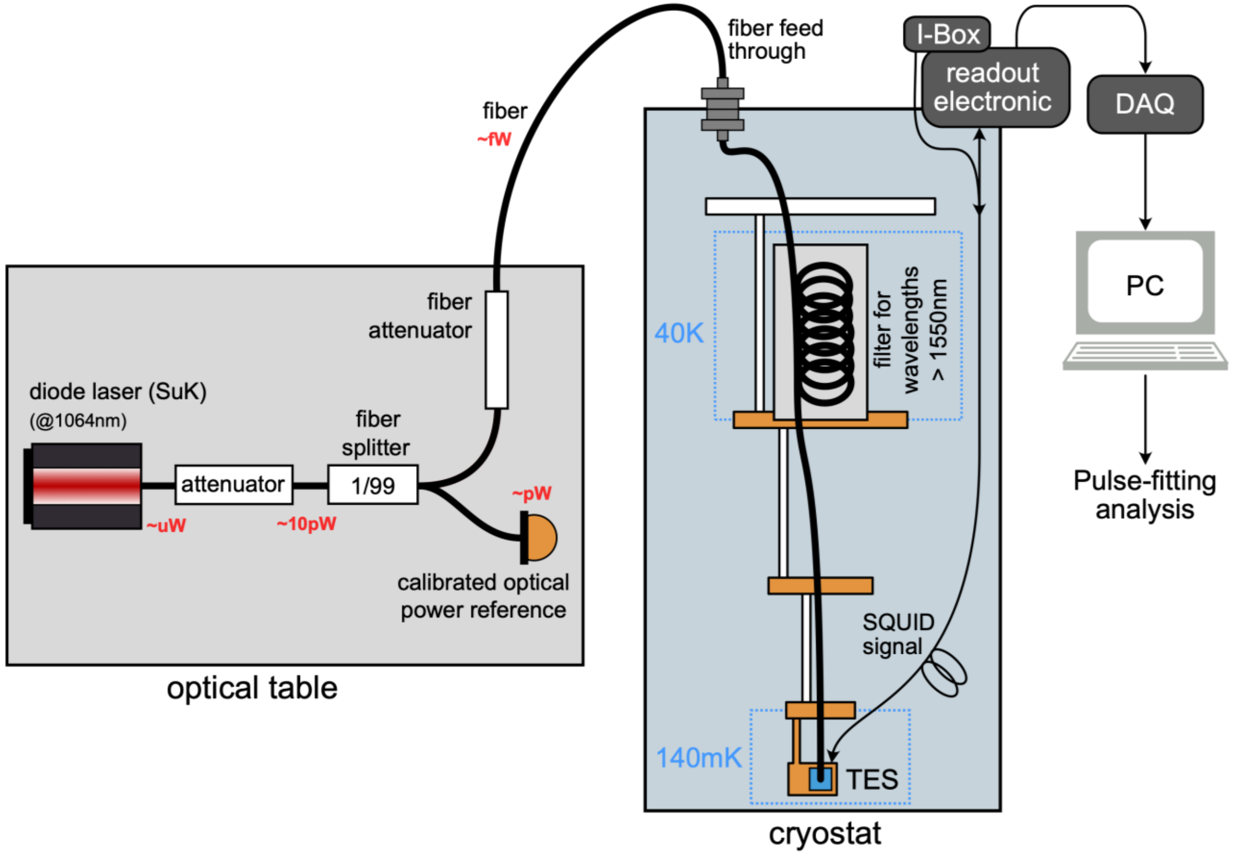


Current change (voltage-biased circuit): TES current measured by SQUID (superconducting quantum interference device)

Readout electronics in the lab at room temperature

Schematic adapted from Katharina-Sophie Isleif.

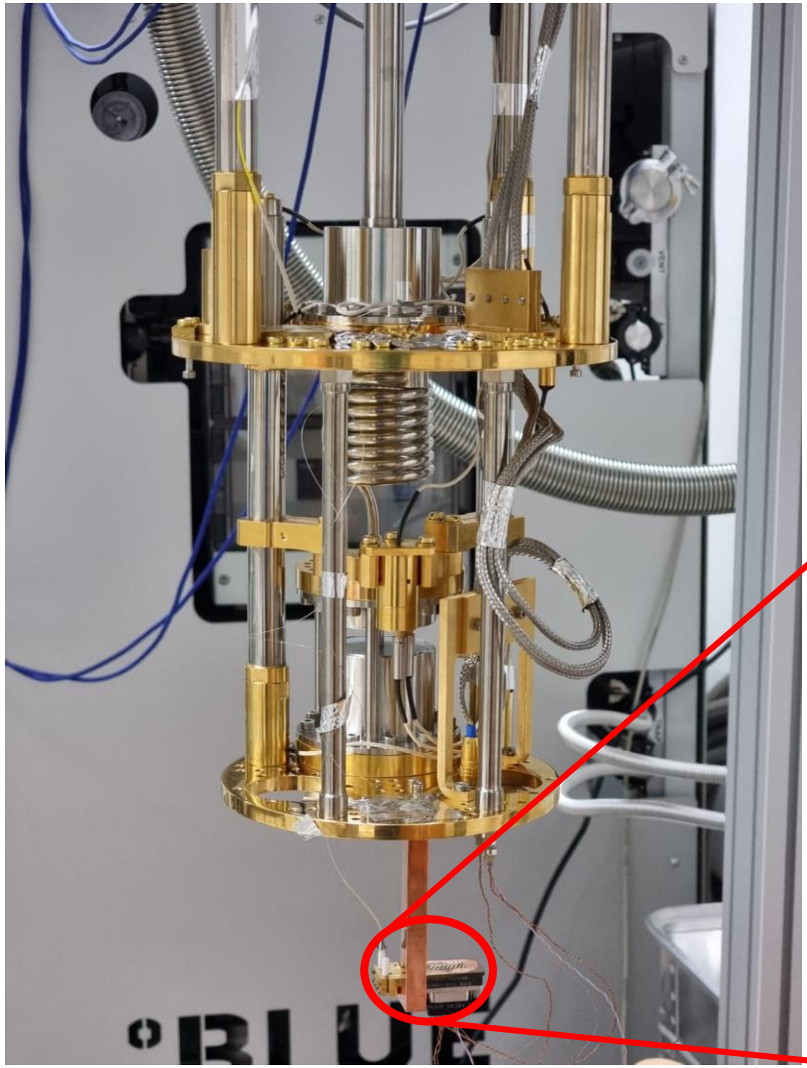
Transition Edge Sensor (TES)

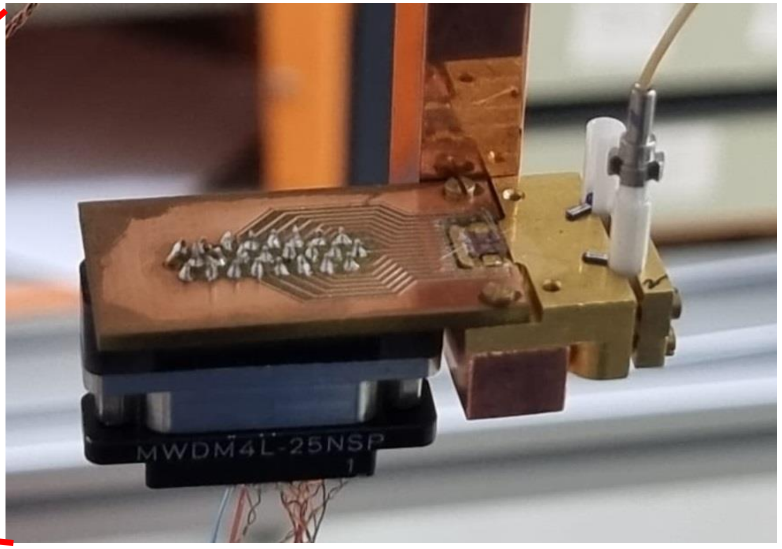


$\sim 1\,m$

Schematic adapted from Katharina-Sophie Isleif.

Transition Edge Sensor (TES)

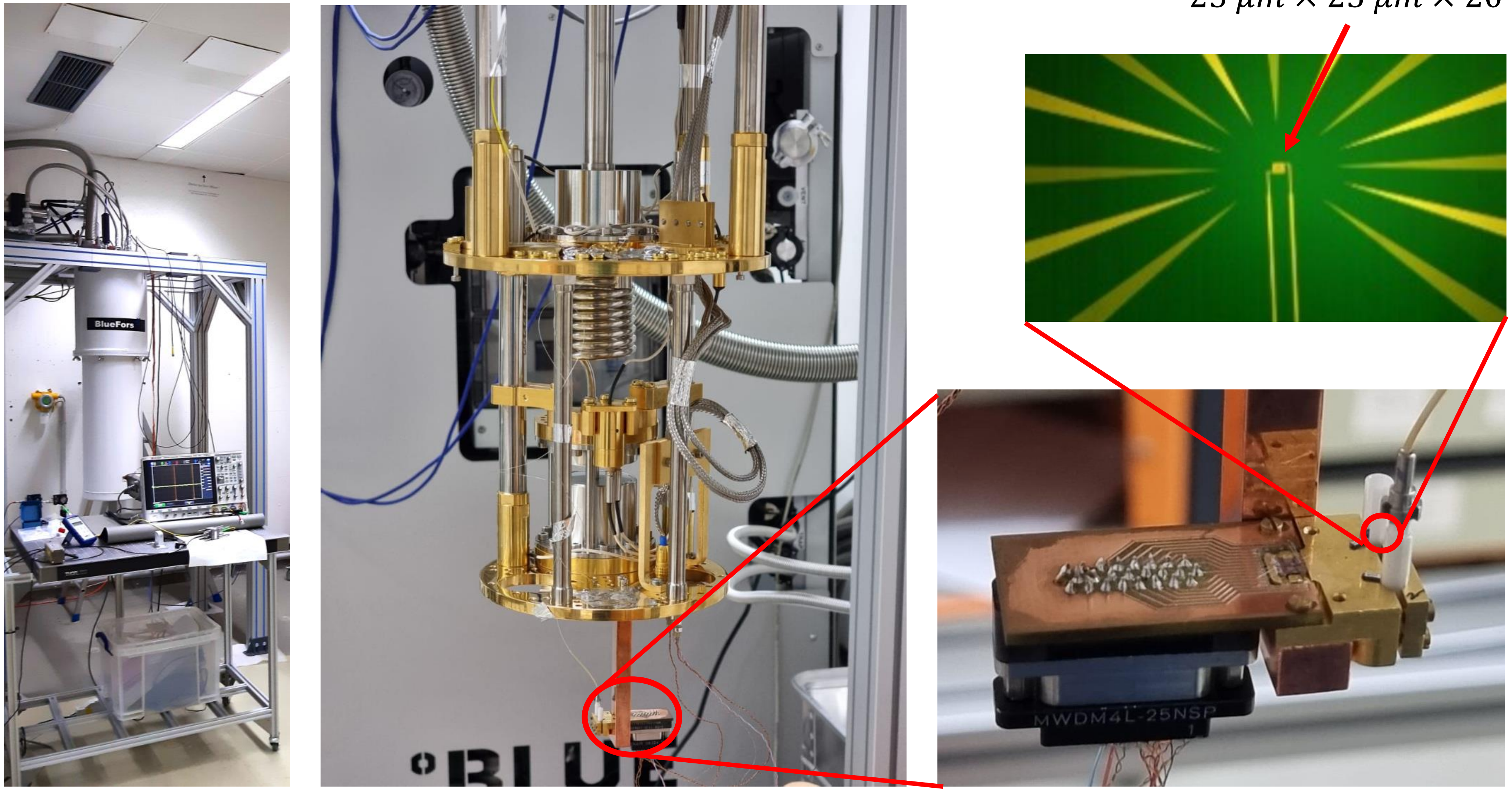




Schematic adapted from Katharina-Sophie Isleif.

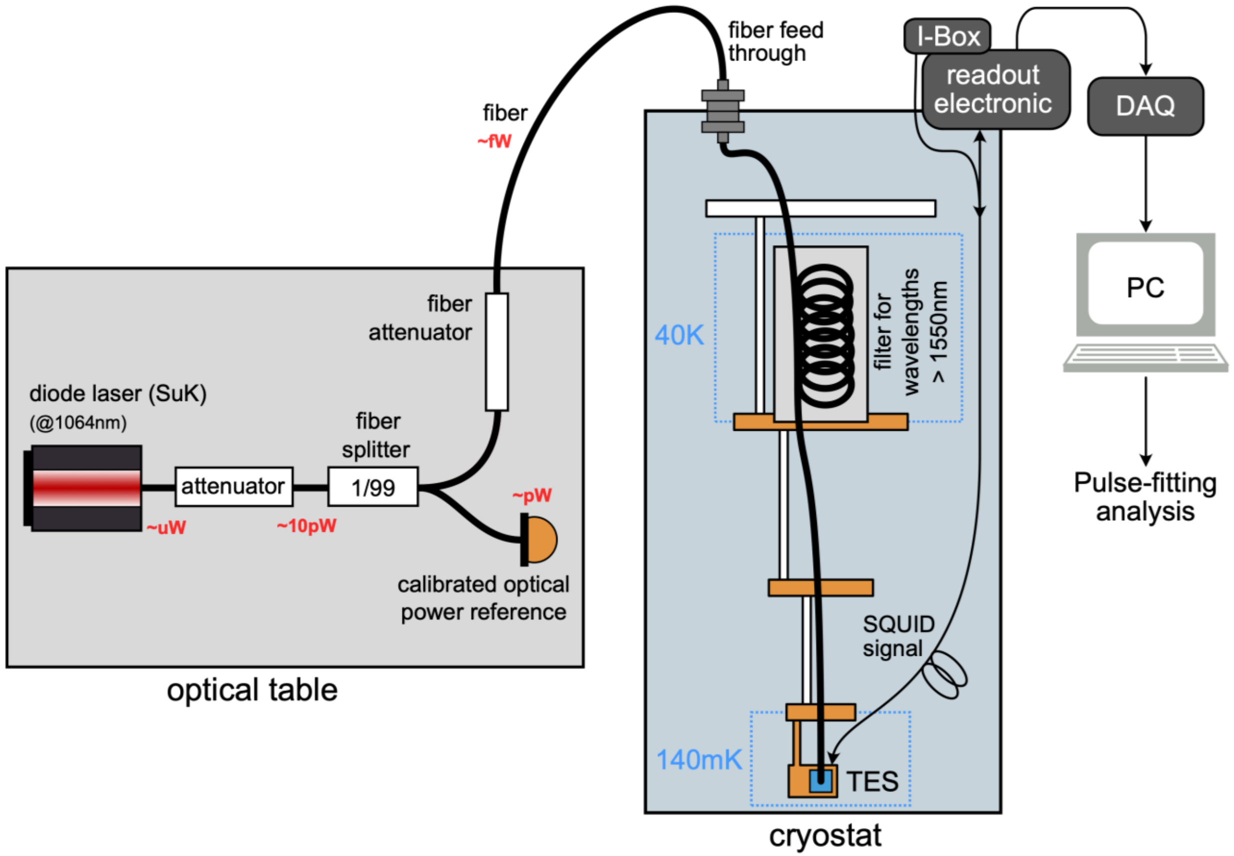
Transition Edge Sensor (TES)

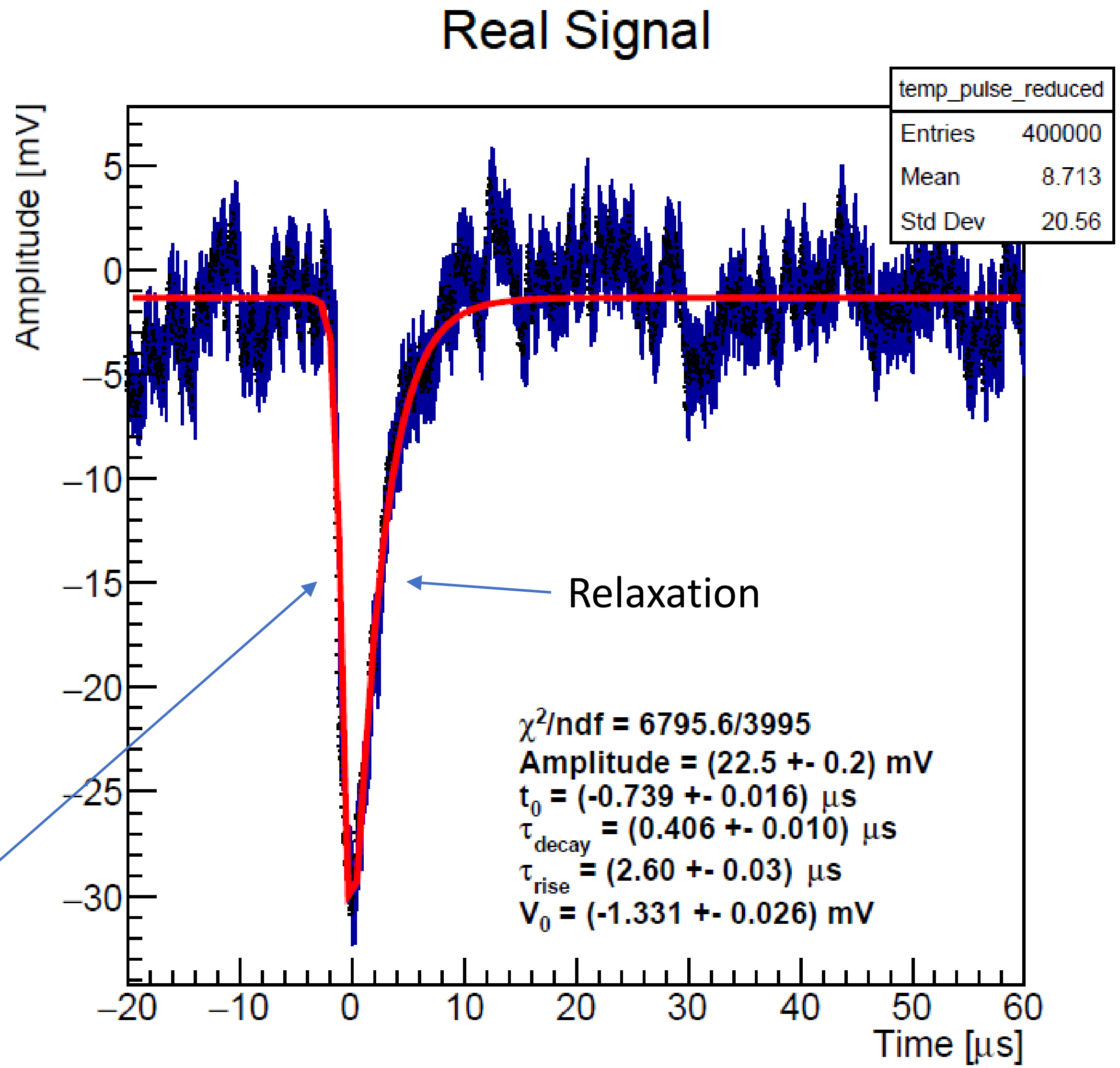
$25\ \mu m \times 25\ \mu m \times 20\ nm$



Schematic adapted from Katharina-Sophie Isleif.

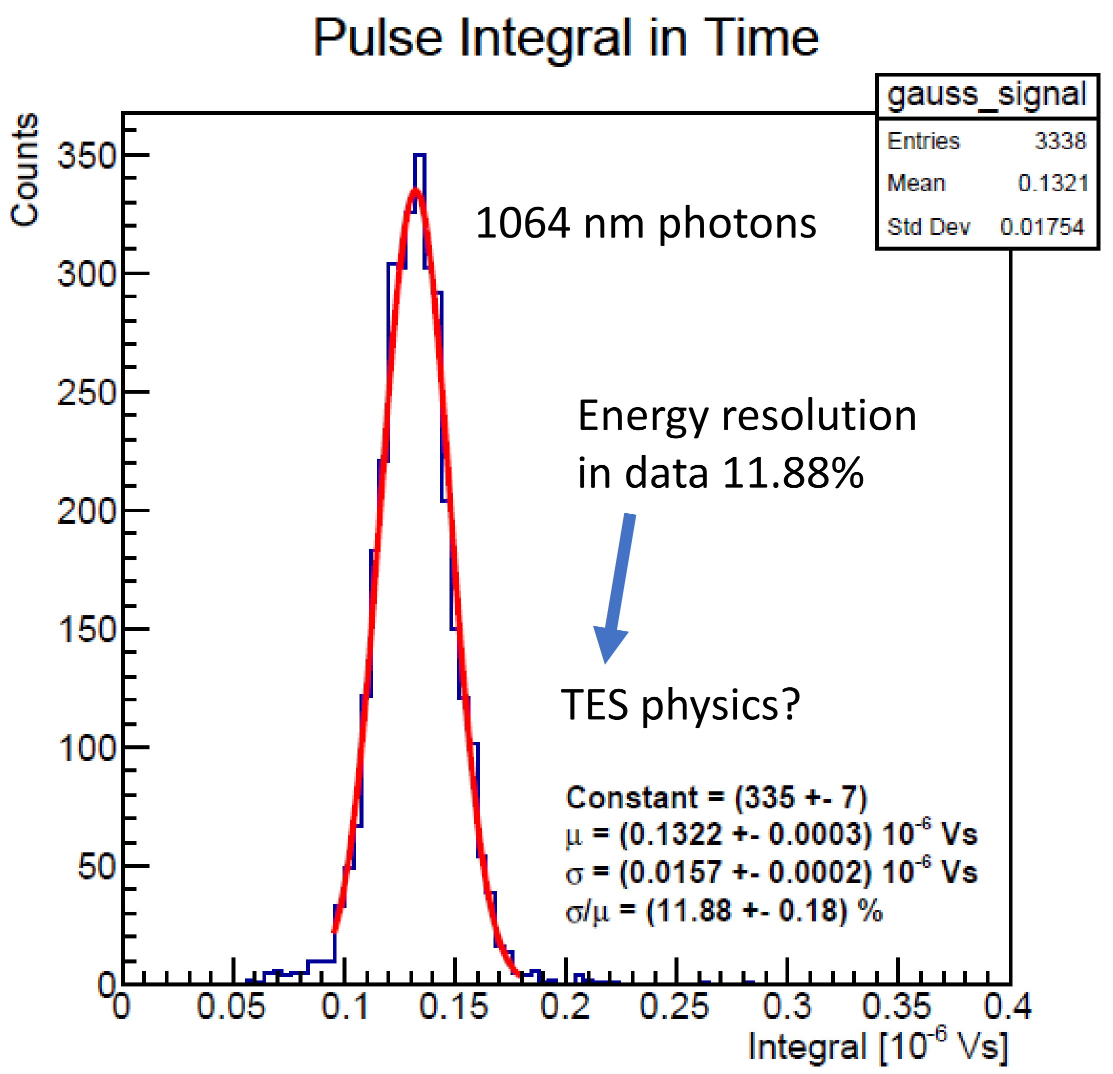
Transition Edge Sensor (TES)

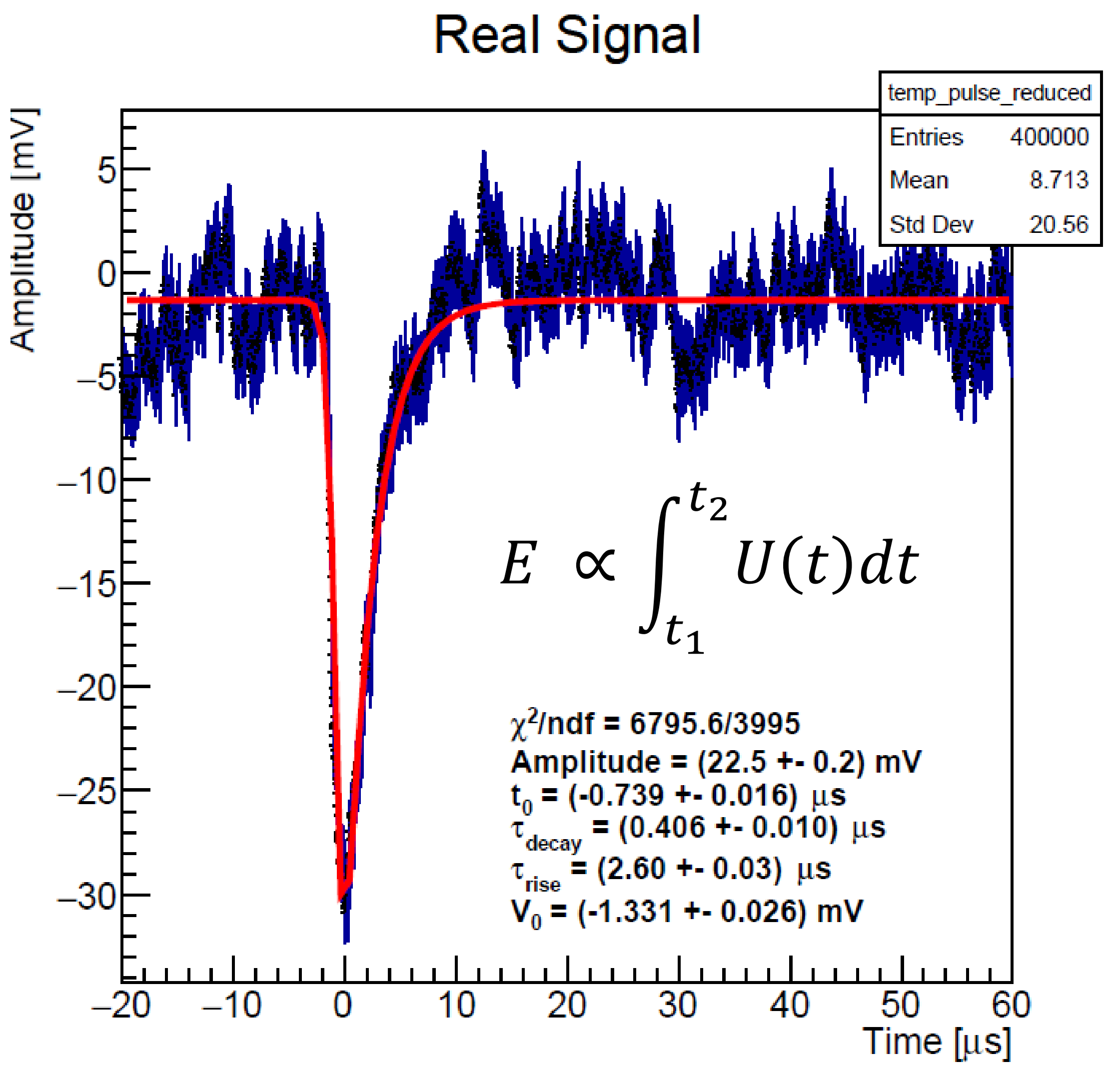




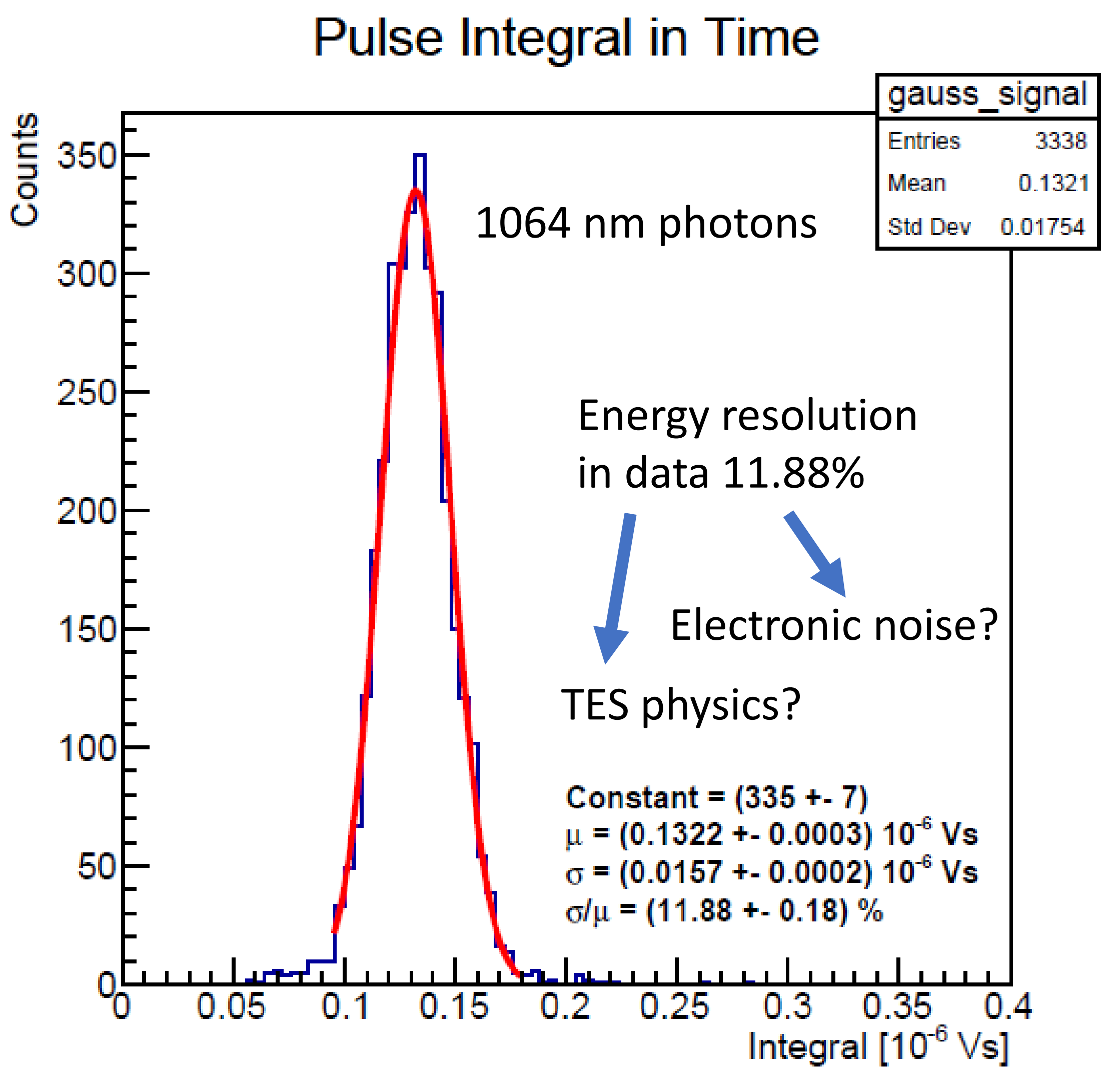
Schematic adapted from Katharina-Sophie Isleif.

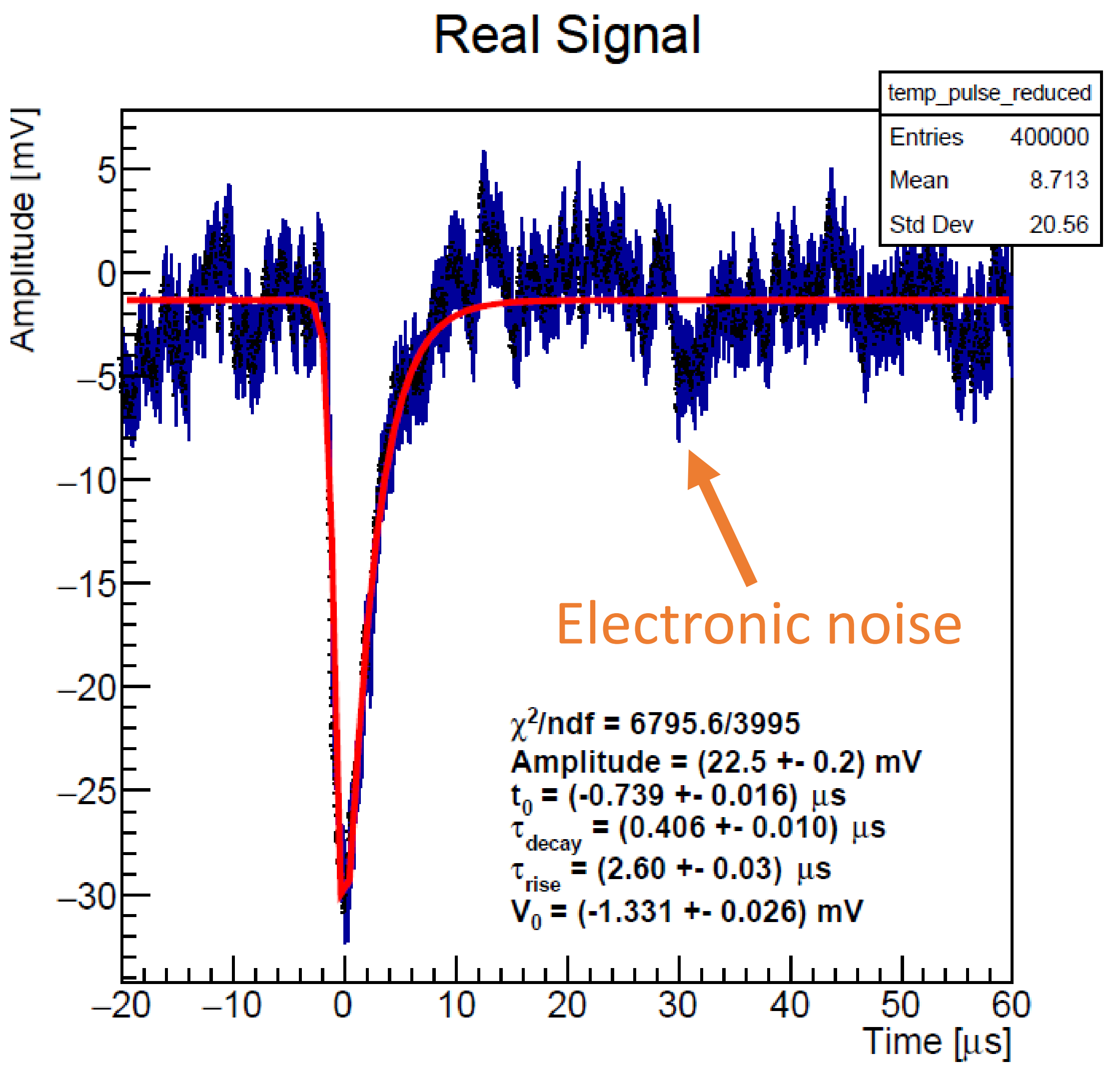
Understanding the signal



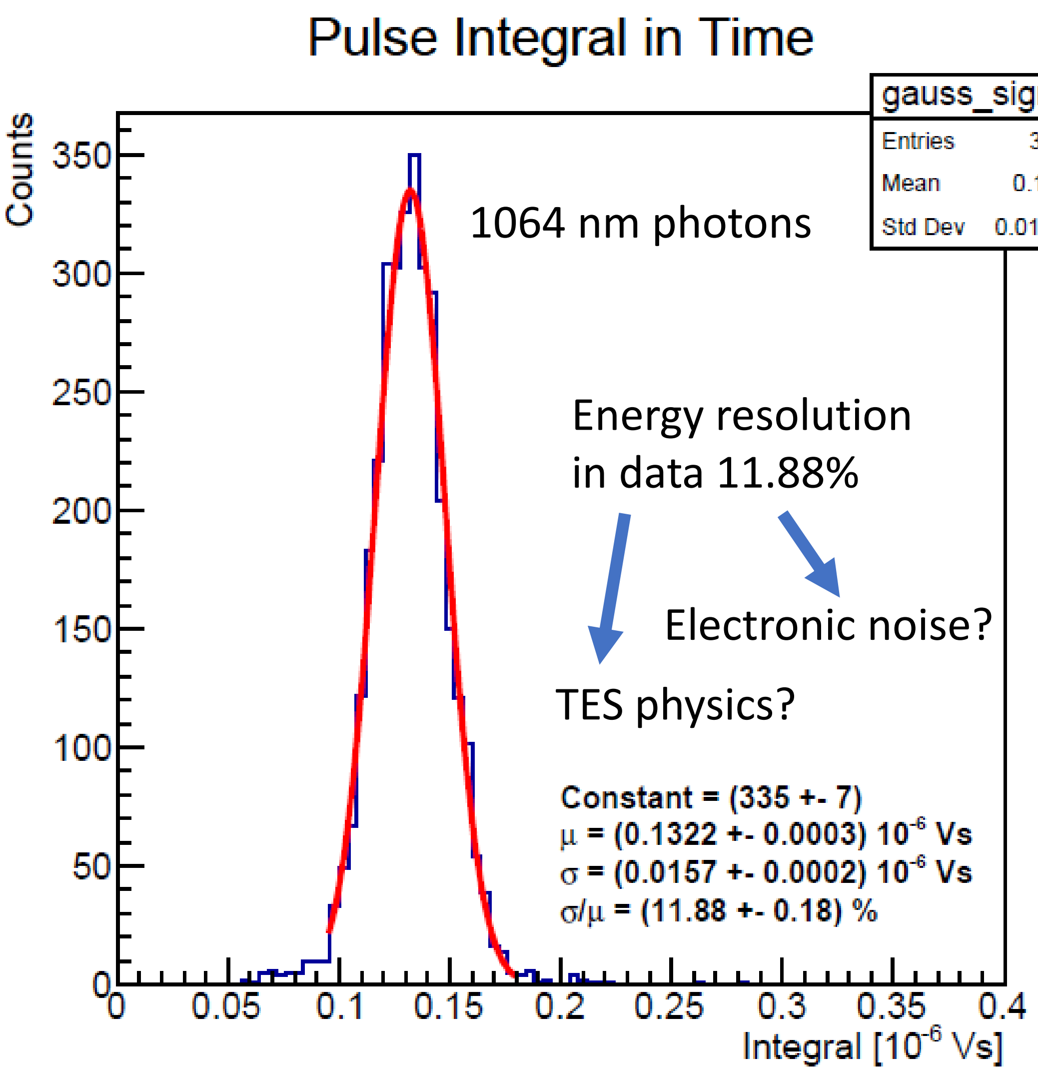


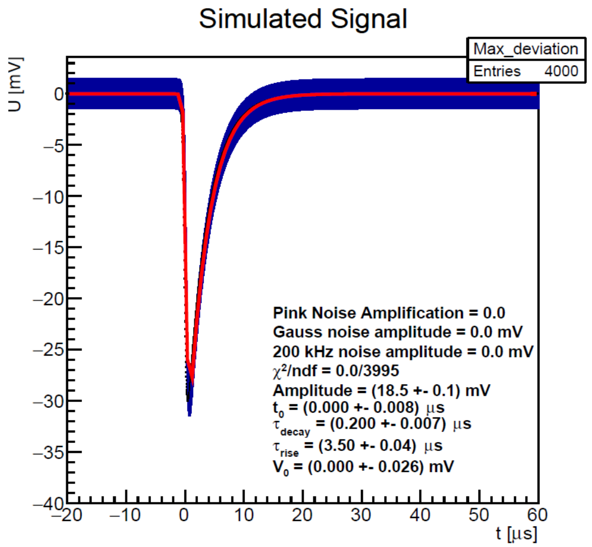
Understanding the signal





Understanding the signal





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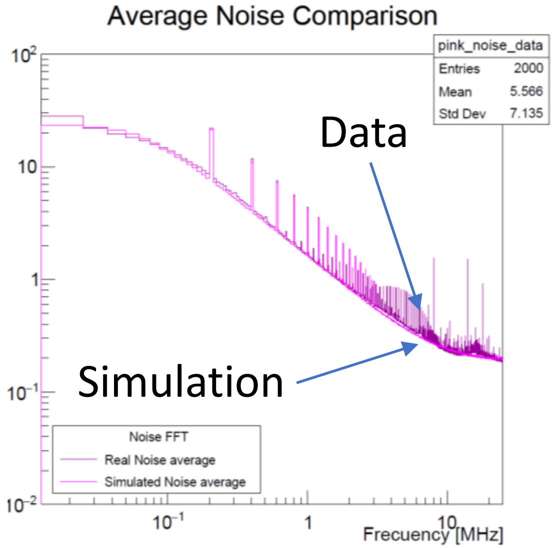
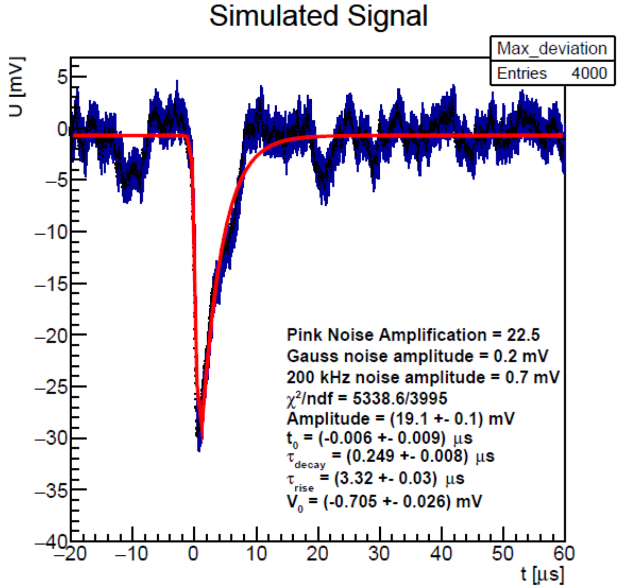
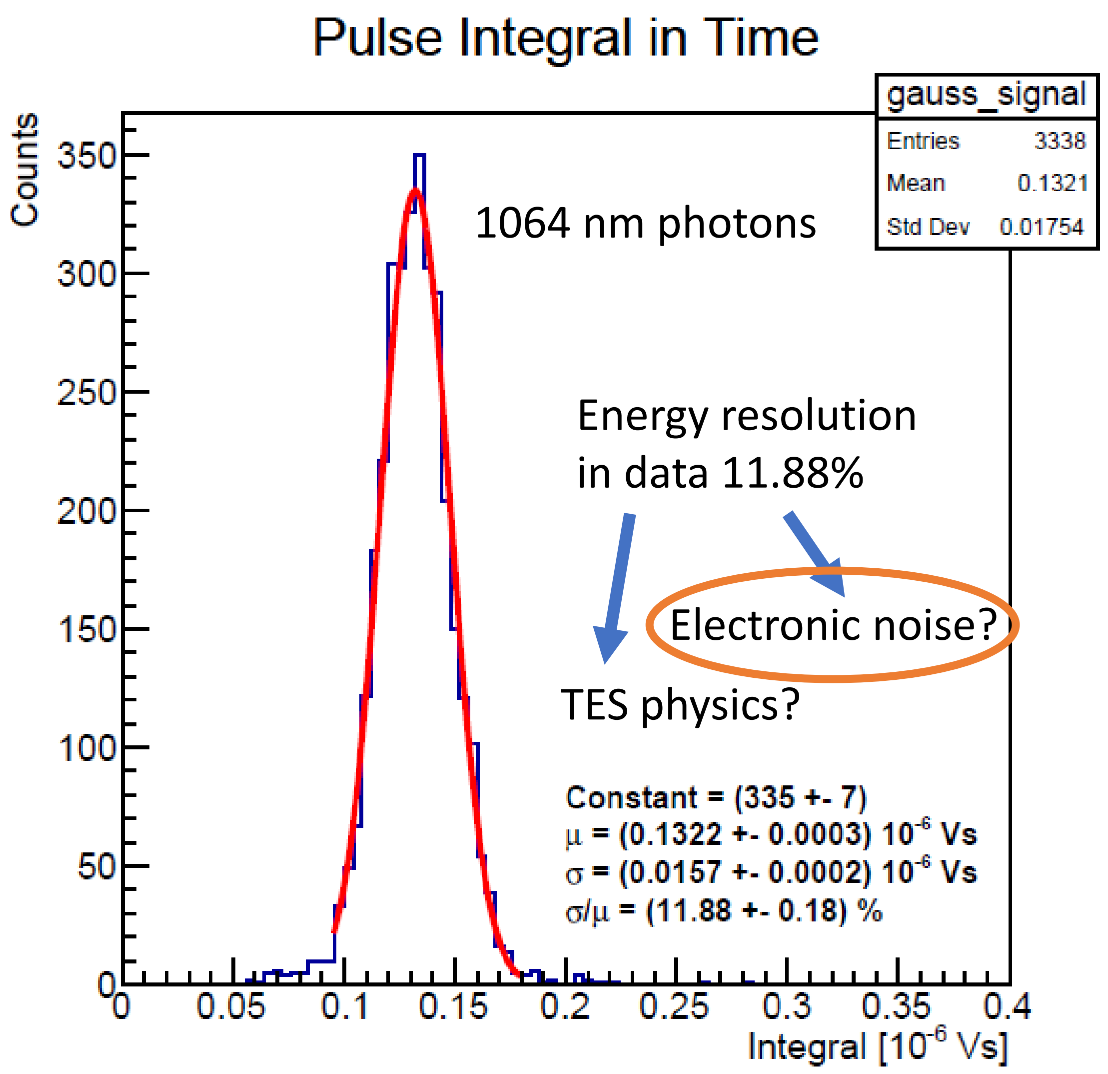
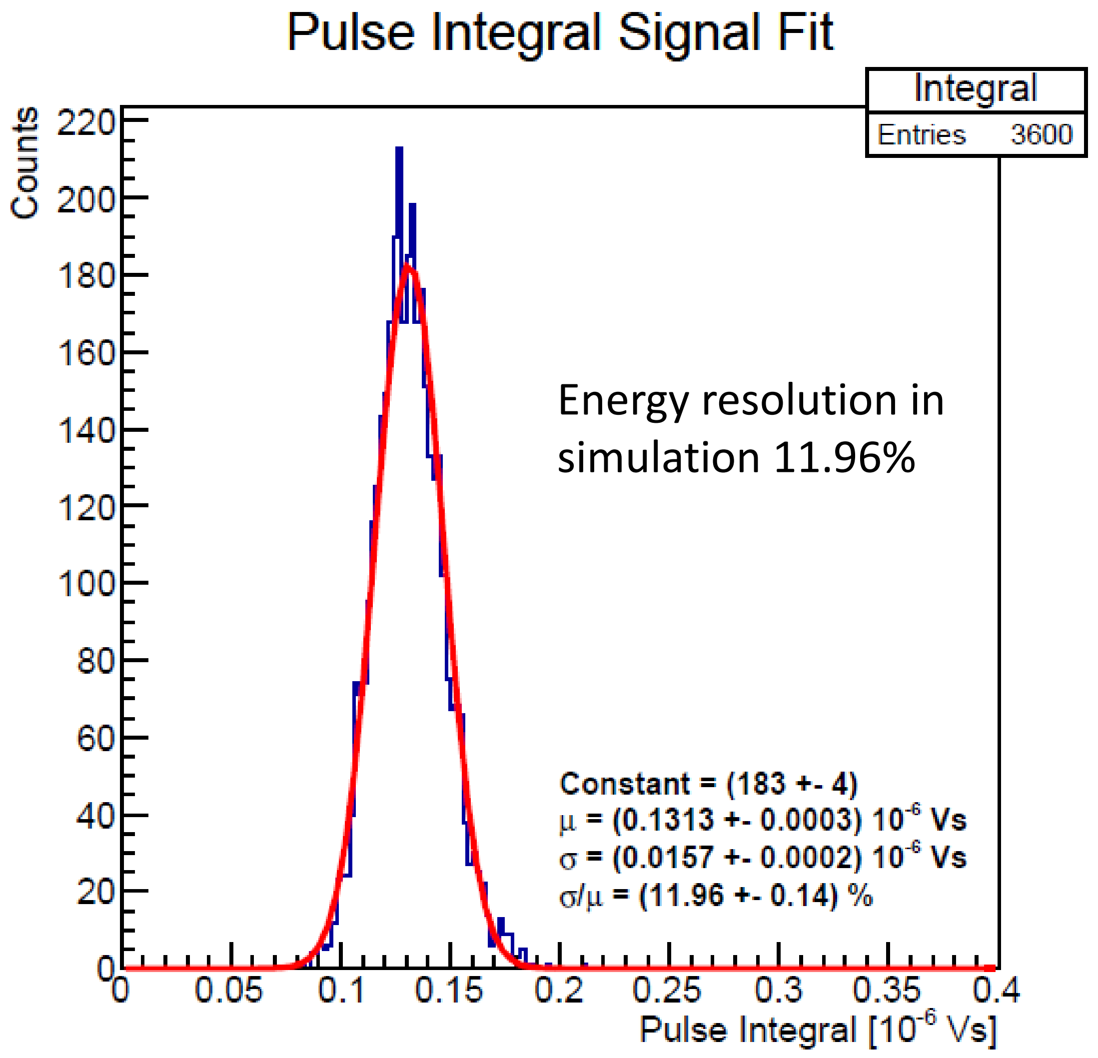
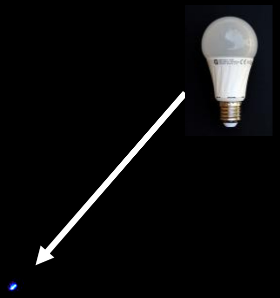




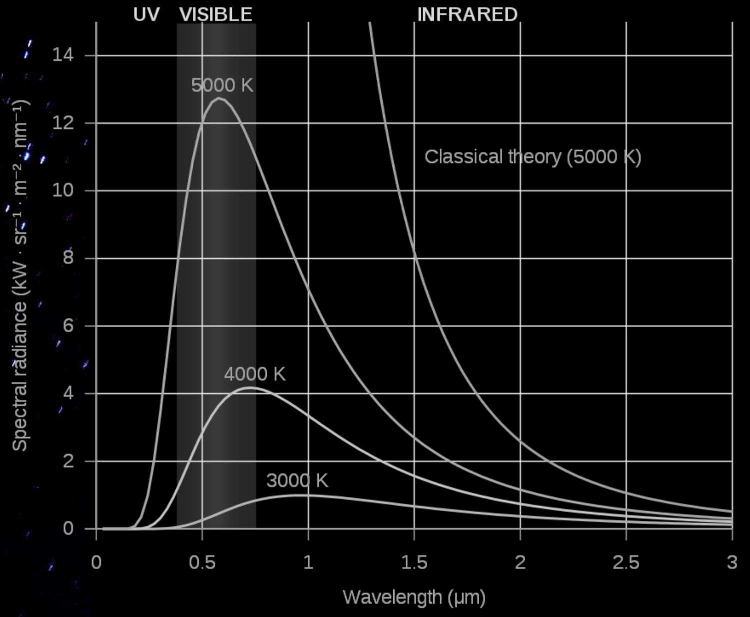
Understanding the signal

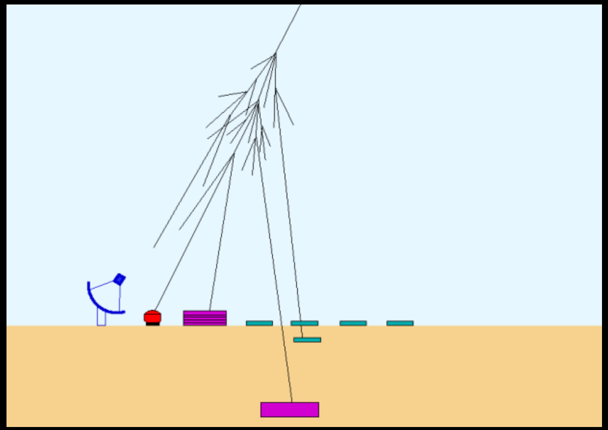






https://upload.wikimedia.org/wikipedia/commons/a/ae/Auvergne%2C_d%C3%A9cembre_2018_%E2%80%94_29.jpg



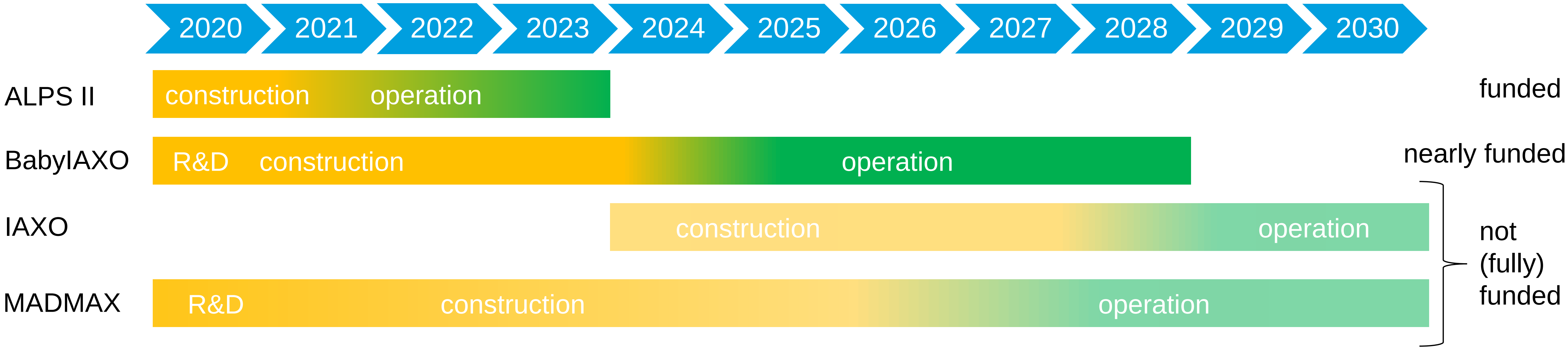


https://upload.wikimedia.org/wikipedia/commons/a/ae/Auvergne%2C_d%C3%A9cembre_2018_%E2%80%94_29.jpg

Timelines

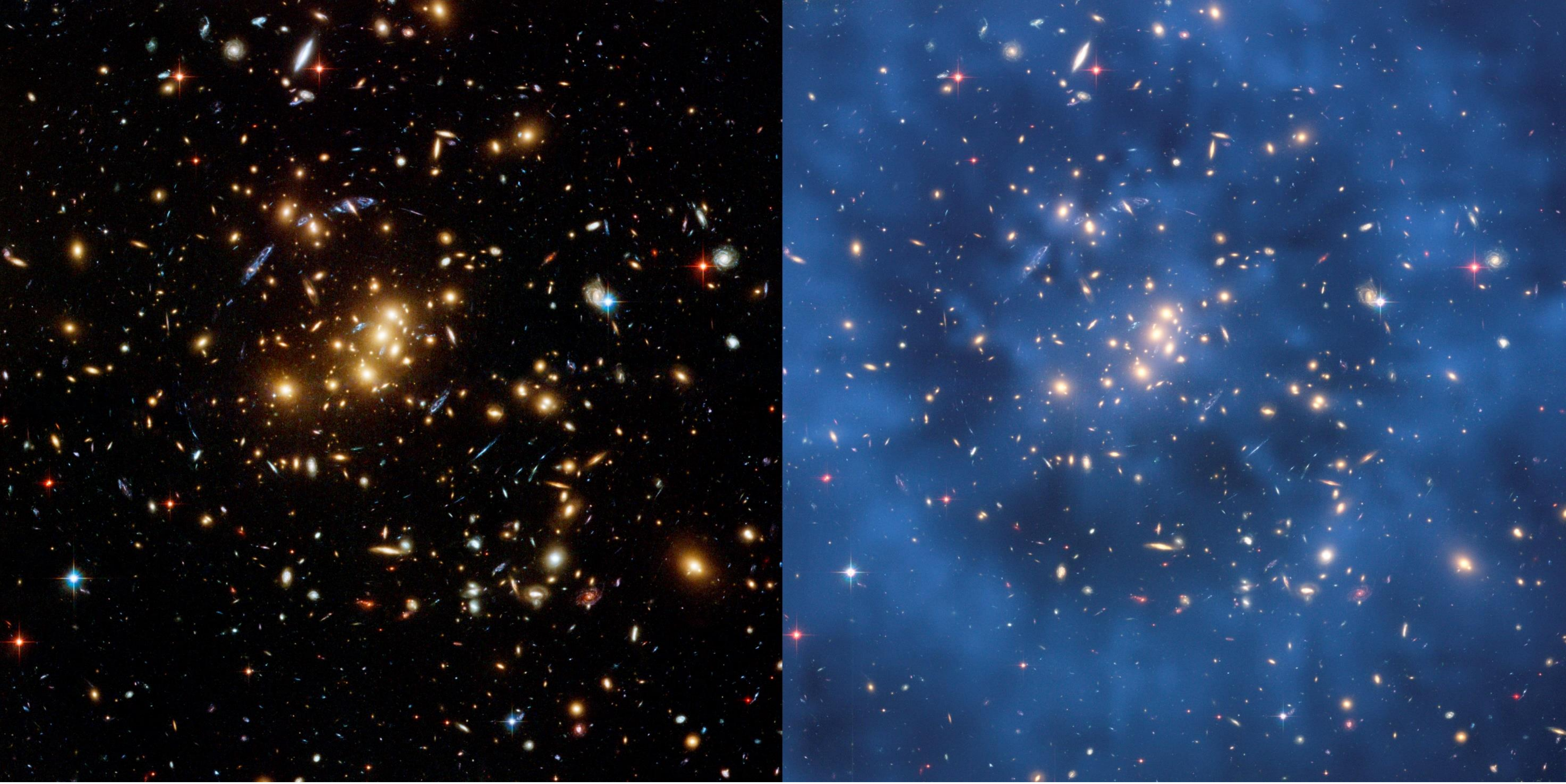
ALPS II, BabyIAXO, IAXO, MADMAX

Some optimistic view (funding), assuming no surprises (axion discovery).



DESY: also a center for experimental axion physics in this decade?

Program well aligned with other international axion searches.



https://www.nasa.gov/sites/default/files/thumbnails/image/galaxy-cluster-cl-0024-17-zwcl-0024-1652.jpg

Summary

Dark matter in the universe

- is very likely to exist (we do not have good alternatives),
- is expected to exist by theories beyond the standard model of particle physics.

Experiments seaching for WIMPs

- have demonstrated a fantastic technological development,
- might approach a final phase in the next decade (“neutrino floor”, no signal at LHC).

Experiments searching for axions and ALPs

- are coming up world-wide with DESY potentially becoming a world-leading center,
- probe particle physics at energies far above the reach of any colliders.

Dark matter is one of the most pressing and thrilling physics questions.
It could be detected at any time!   Or never.

https://www.nasa.gov/sites/default/files/thumbnails/image/galaxy-cluster-cl-0024-17-zwcl-0024-1652.jpg

Thank you!

Contact

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www.desy.de

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