CSN2: Astroparticle Physics
Sezione di Roma

A daily challenge in technological and experimental tasks: unity of purposes in the diversity of ideas

F.Bellini
Sapienza Università di Roma & INFN Roma

Activities in Rome

lucio.ludovici	T2K	Neutrino
claudia.tomei	CUORE	Neutrino
fabio.bellini	CUPID	Neutrino
marco.vignati	CALDER/NUCLEUS	Neutrino
paolo.debernardis	LSPE	CMB
silvia.masi	QUBIC	CMB
gianluca.cavoto	PTOLEMY	CNB
antonio.capone	KM3/ANTARES	UHE neutrinos
fabio.ferrarotto	CTA	HE gammas
alessandro.bartoloni	AMS	Cosmics Rays
antonella.incicchitti	DAMA	Dark Matter
claudia.tomei	SABRE	Dark Matter
marco.rescigno	DarkSide	Dark Matter
massimo.corcione	MOSCAB	DarkMatter
davide.pinci	CYGNO	Dark Matter
giovanni.rosa	NEWS	Dark Matter
roberto.scaramella	EUCLID	Dark Energy
ettore.majorana	VIRGO	Gravitational waves
piero.rapagnani	ET	Gravitational waves
paola.puppo	Archimedes	Quantum

Intro

- Several physics cases:
  - Different experimental challenges and technologies employed
  - Underground, deep sea, ground level, atmosphere, space

- I can’t go too further into details, my choice is:
  - physics in a nutshell, experiments goals,challenges and activities in Rome
  - skip very technical details

- For more details
  - All collected slides from experiments available at link
  - Available Particle Physics thesis at link

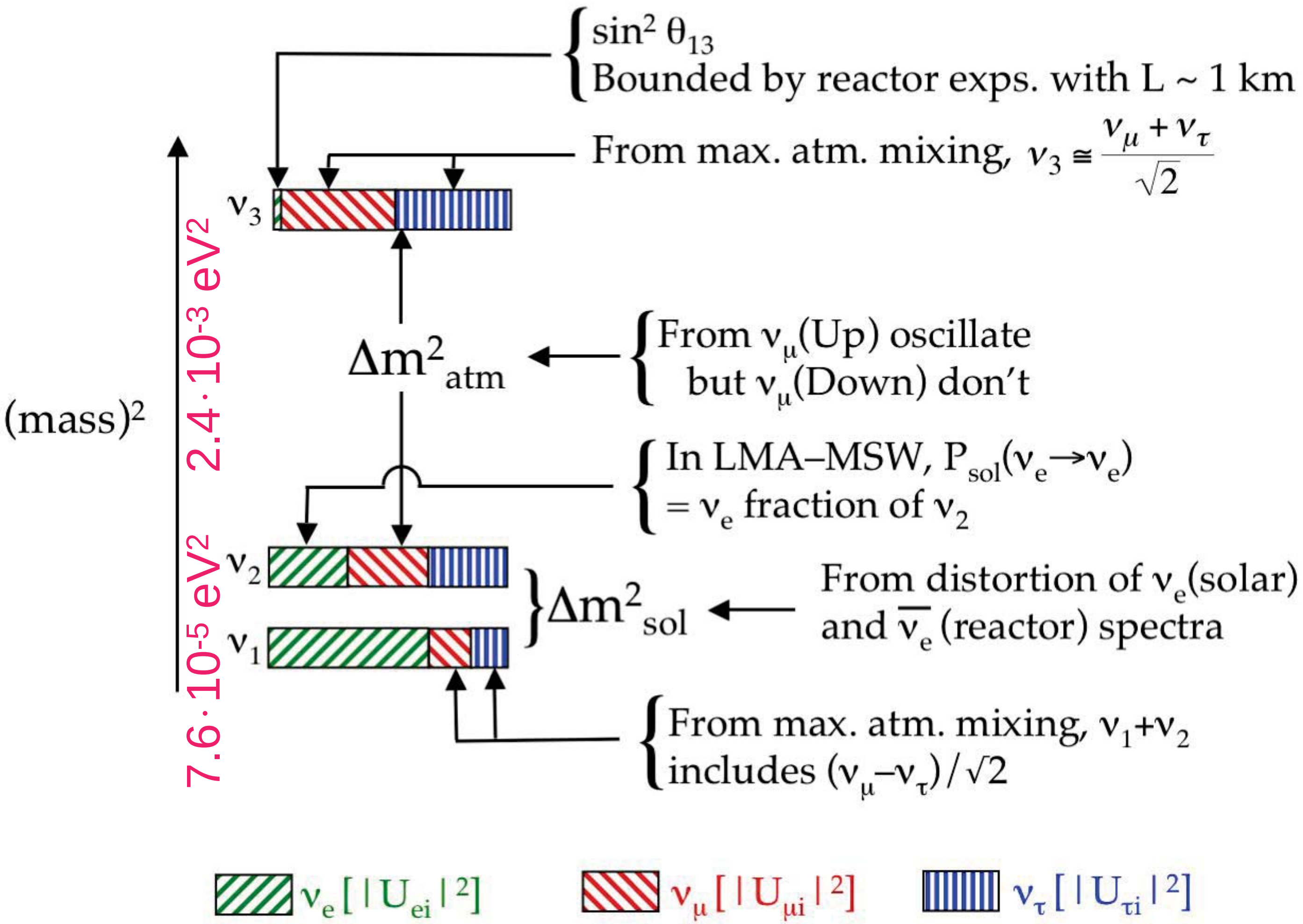
Neutrino Properties

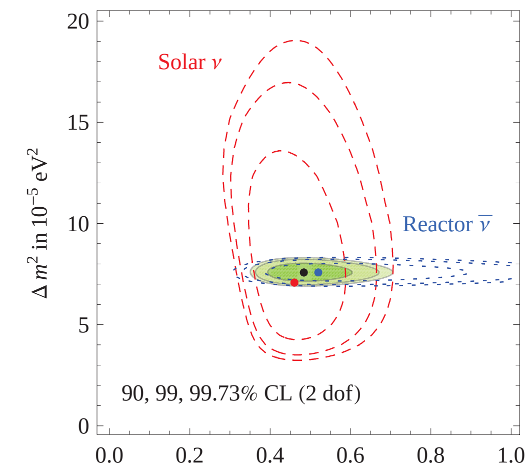
Neutrino oscillations

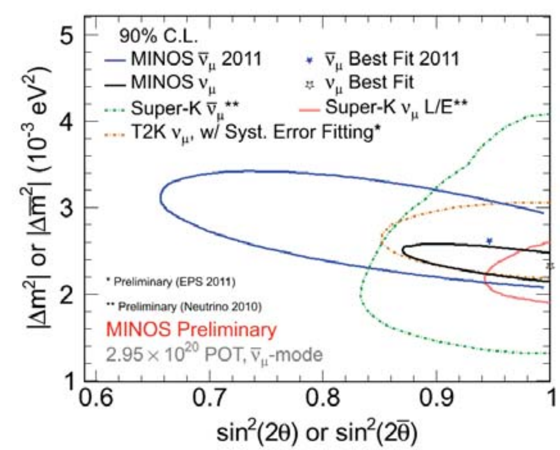
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\theta_{atm} \approx \theta_{23} \approx 47°$ $\theta_{13} \approx 9°$ $\theta_{sun} \approx \theta_{12} \approx 33°$



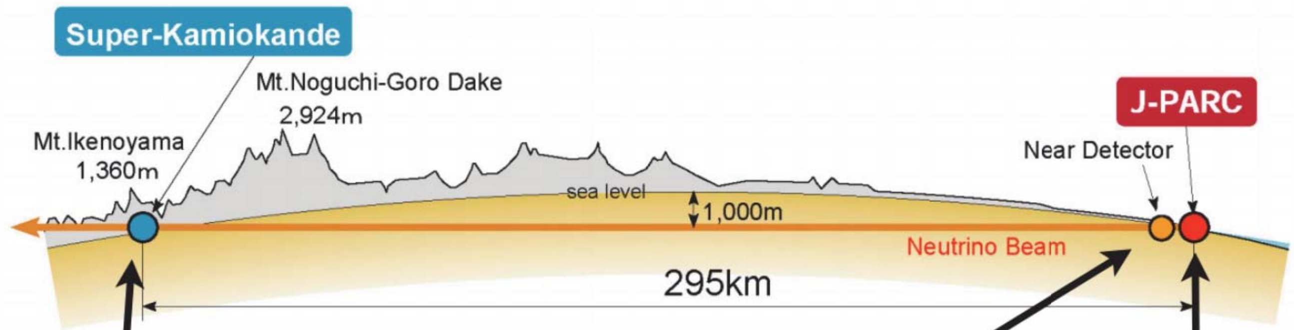




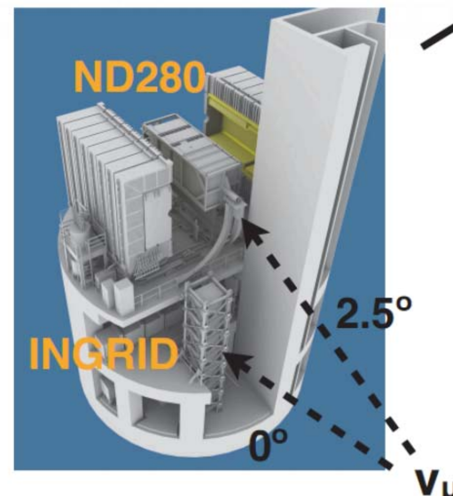
T2K: Tokai (JPARC) to Kiamoka (SK)

- Next Goal
  - CP violation
  - Mass hierarchy

$$A_{CP} = \frac{P[\nu_\mu \to \nu_e] - P[\bar{\nu}_\mu \to \bar{\nu}_e]}{P[\nu_\mu \to \nu_e] + P[\bar{\nu}_\mu \to \bar{\nu}_e]}$$

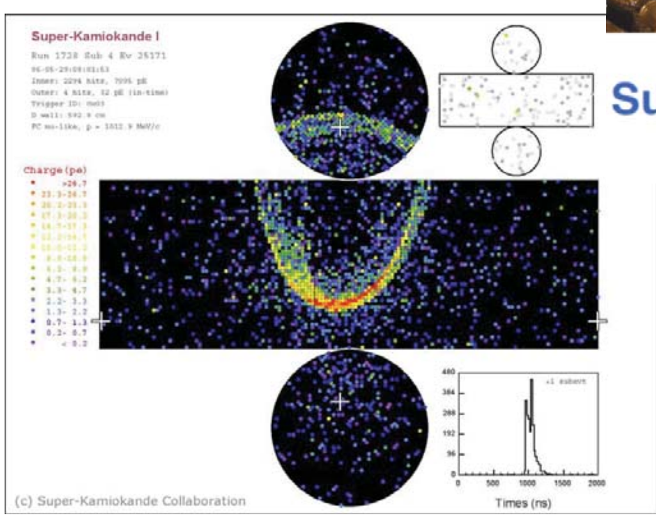


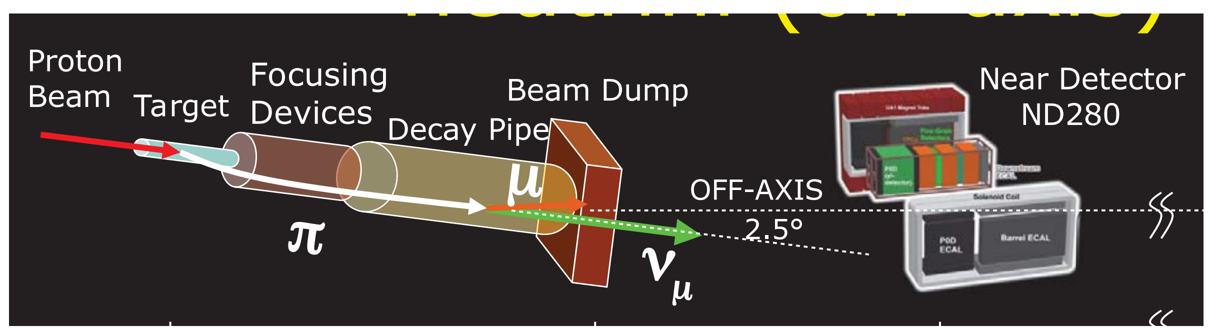
Super-Kamiokande



INGRID (on-axis) and ND280 (off-axis)

Neutrino beam created at J-PARC main ring





Activity in Rome

- Participation in the analysis of SK data
- Development of positive sensitive monitor for the LINAC Beam used for SK calibration
- Montecarlo studies for the future detector HyperKamiokande

- Future program
  - 2020: Add Gd in SK for the neutron tag
  - 2021: Upgrade Beam and Near Detector
  - 2026: Build Hyper Kiamokande = 10 xSK

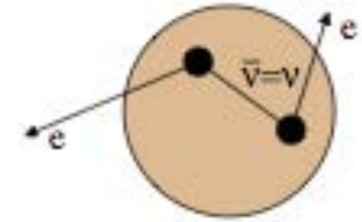
Neutrino: Dirac or Majorana

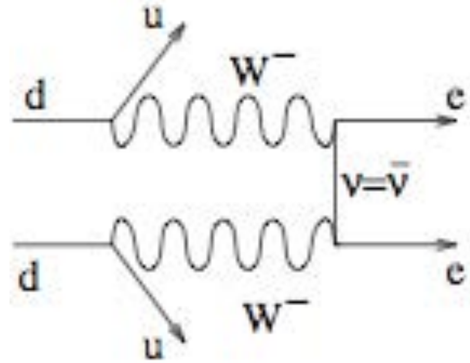
Neutrinoless Double Beta Decay (0ν2β):

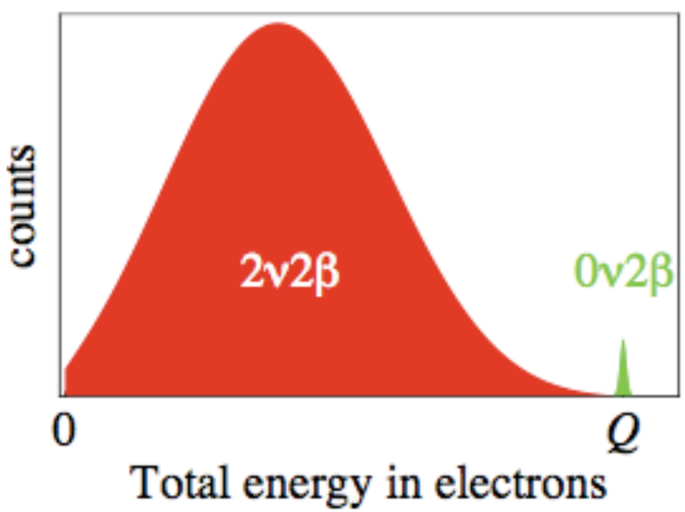
Not allowed in the Standard Model because of lepton number violation

Possible only if neutrino = antineutrino, according to Majorana's hypothesis

Never observed so far. Half life > 10^{25} y (as a comparison, the age of our Universe is 10^{10} y)





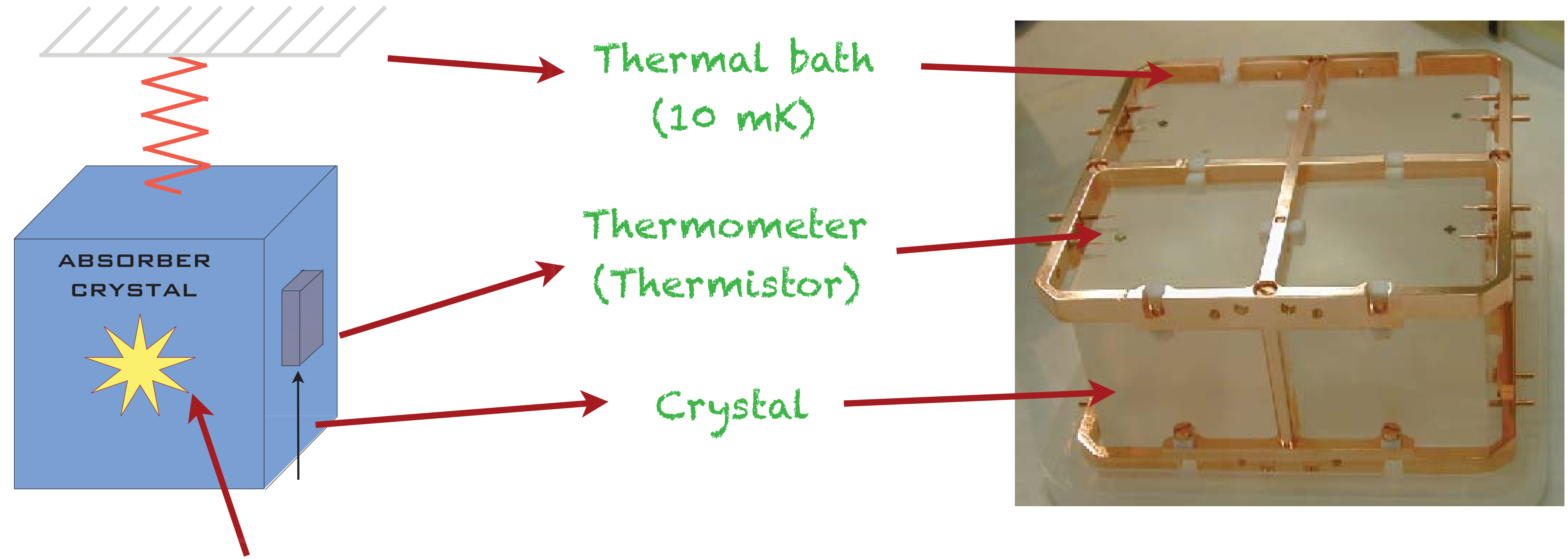


How can we be able to detect such a small signal?

Large mass detectors with excellent energy resolution, to distinguish the 0ν2β signal from the 2ν2β decay (allowed in the SM)

Low rate of spurious events (radioactive decays, muon interactions, neutrons, etc...) at the energy of the Q-value

Cryogenic Calorimeters: bolometers



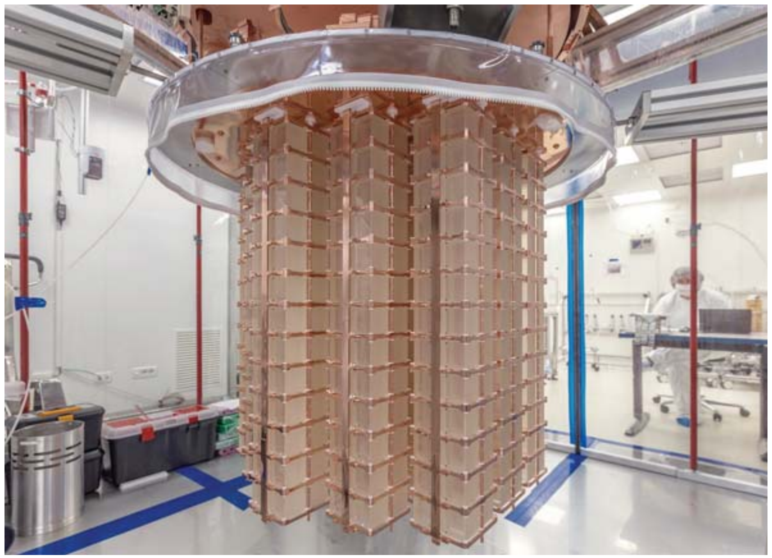
Energy released from particle

The temperature variation induced in the bolometer is proportional to the energy of the particle: $\Delta T = E/C$

Energy resolution ~ 1 μK ~ 2 keV

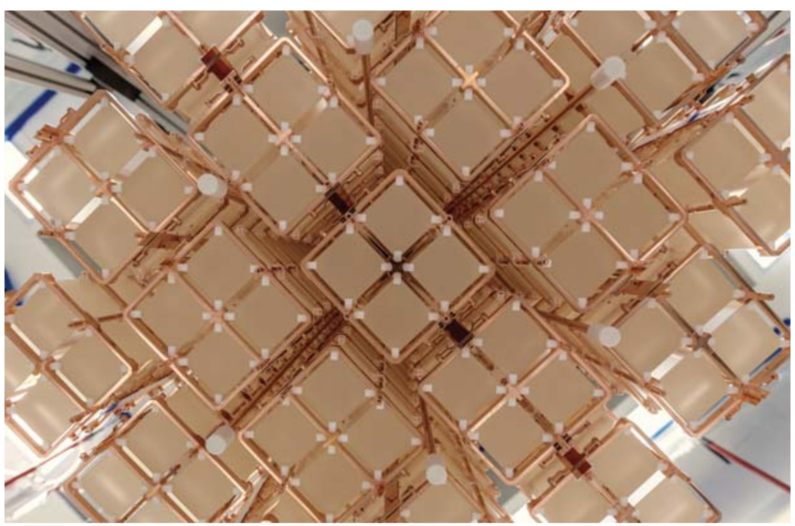
CUORE (Cryogenic Underground Observatory for Rare Events

Taking data @ Laboratori Nazionali del Gran Sasso (LNGS) since 2017



ITA-USA Collaboration (~ 100 people)

1000 TeO_2 bolometers: first ~1 ton $0\nu2\beta$ experiment running



Best limit on the

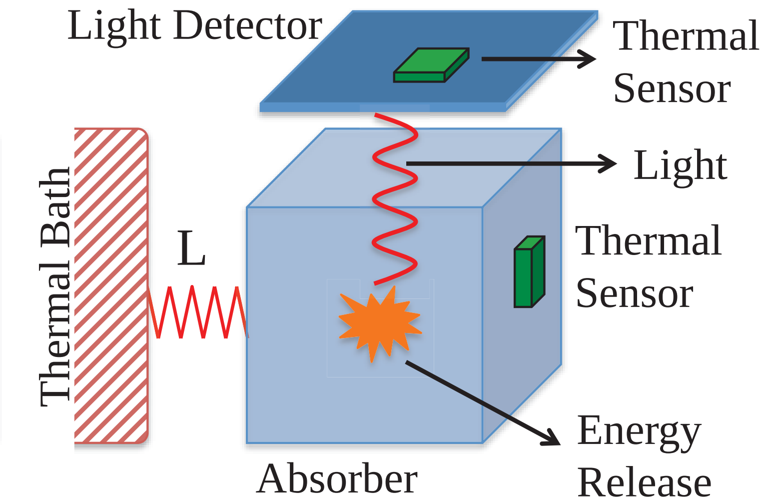
$0\nu2\beta$ ^{130}Te decay half life

$T_{1/2} > 1.5 \times 10^{25}$ y (90% C.L.)

CUORE background goal reached

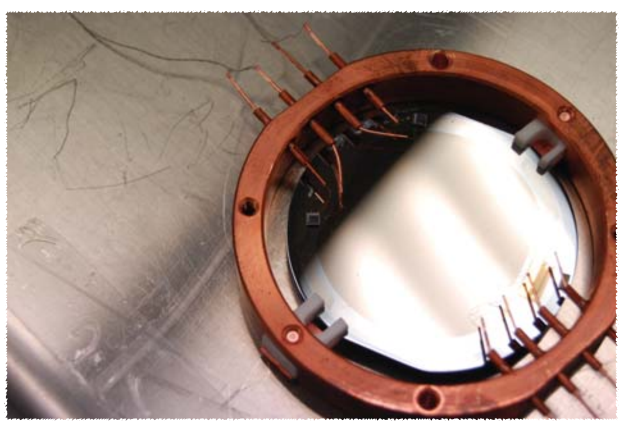
0.01 counts/kg/keV/y @ Q-value

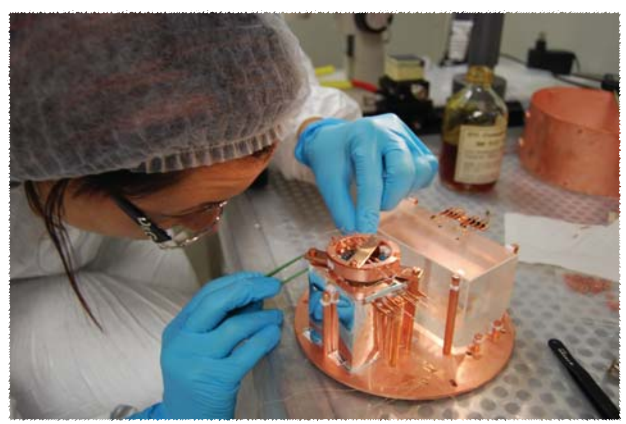
CUPID (CUore with Particle IDentification)

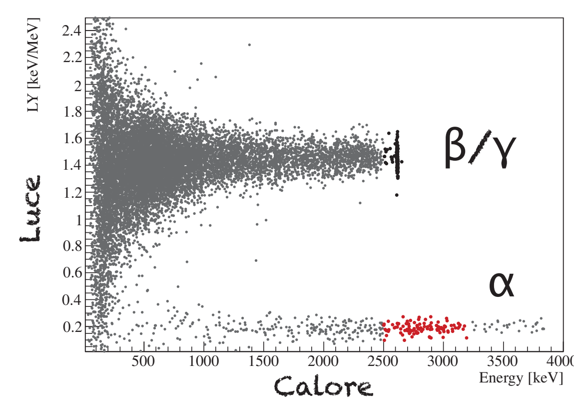


Same CUORE technique but with a light-emitting crystal

The simultaneous readout of heat and light signal (scintillation or Cherenkov) allows to discriminate the 0ν2β decay from the radioactive background







Needs high sensitivity and low-background light detectors

Kinetic Inductance Detectors (KIDs)

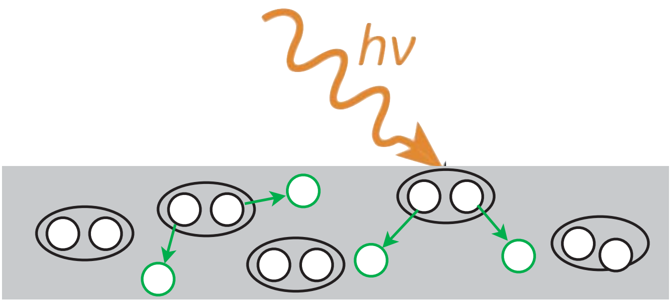
a technology invented at JPL/Caltech

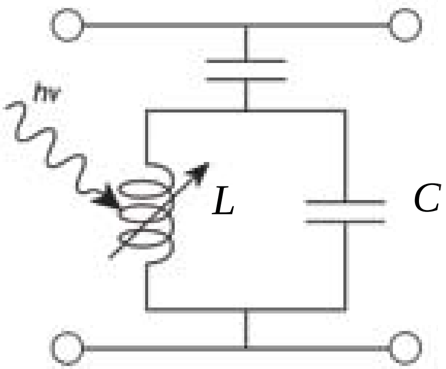
Day et al., Nature 425 (2003) 817

Cooper pairs in a superconductor act as an inductance (*L*).
Absorbed photons or phonons change Cooper pairs density and therefore *L*.

superconductor at T<<Tc

$2\Delta \sim 400\,\mu eV\,(\mathrm{Al})$

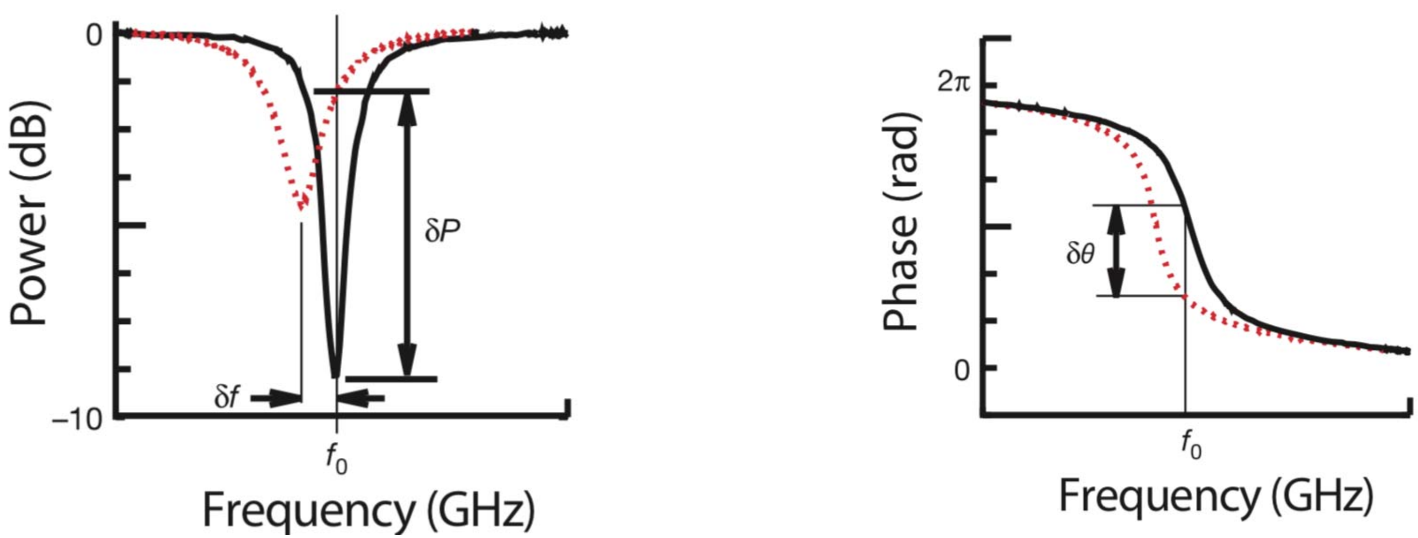




High-Q resonator

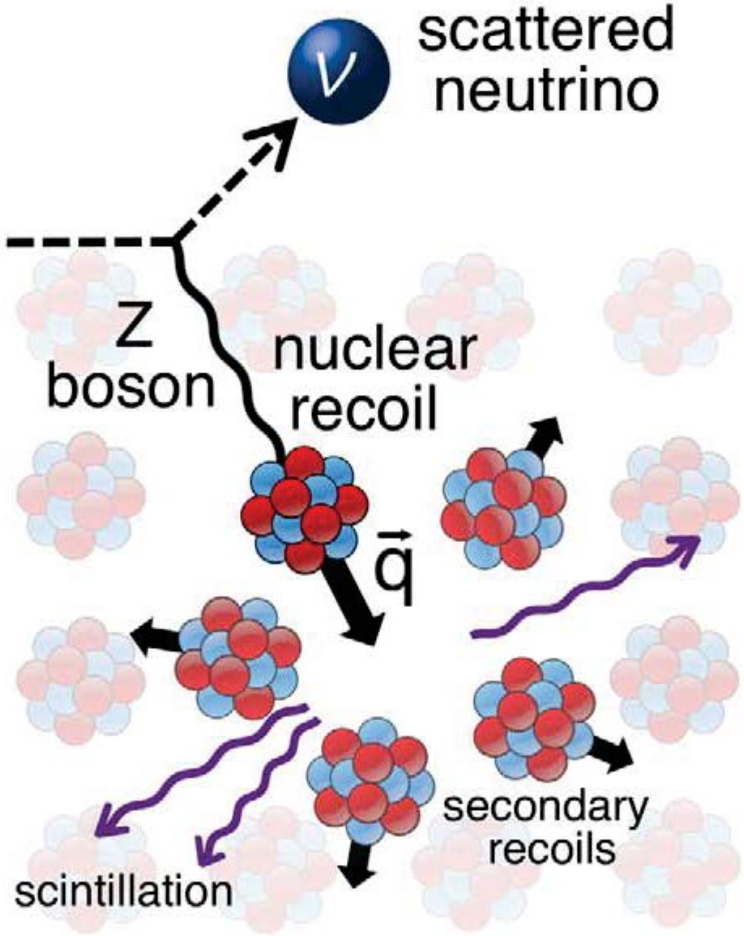
$f_0 = 1/2\pi\sqrt{LC}$

Circuit biased at resonant frequency: signal from amplitude and phase shift.

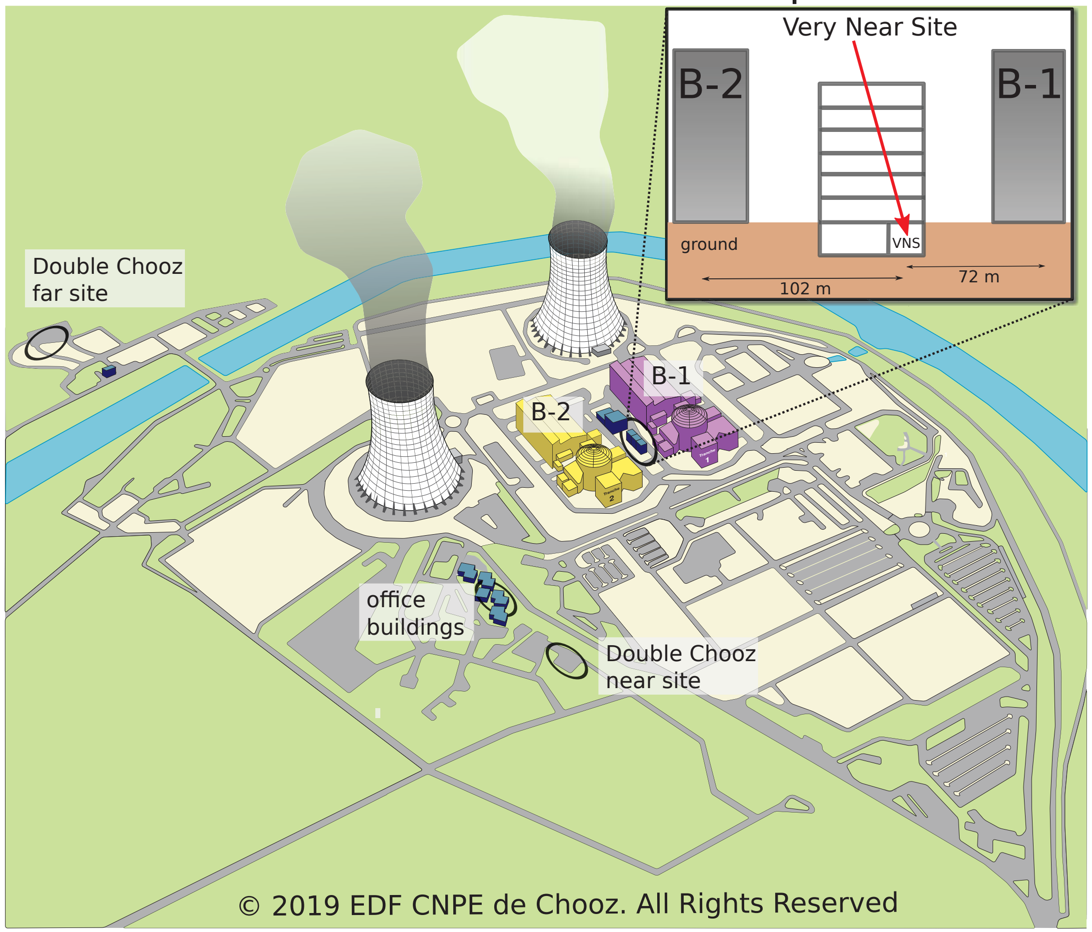


Application to CEνNS

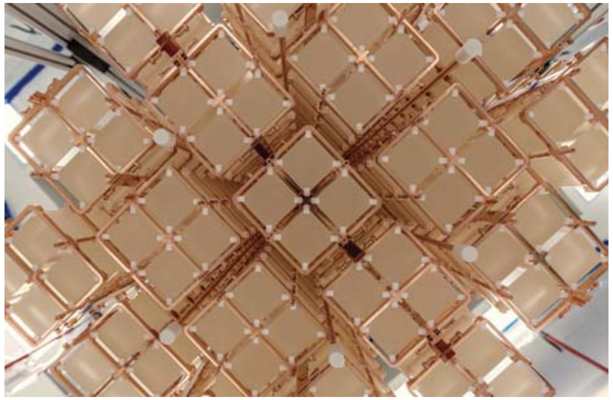
Neutrino coherent scattering on nuclei (CEνNS), recently discovered by COHERENT [Akimov et al, Science 357 (2017) 1123], is a new probe for new physics via precision measurements of the cross-section.



Neutrino measurement at nuclear plants



CUORE

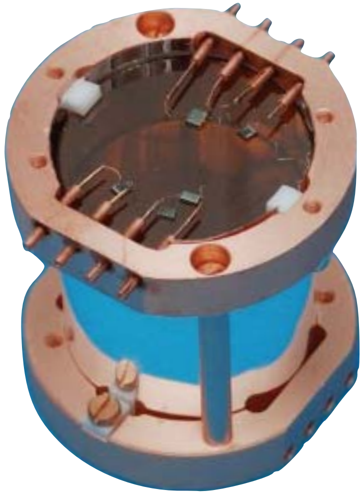


Data analysis:

- search for Majorana neutrino with CUORE
- search for dark matter and other rare events with CUORE

CONTACT:
claudia.tomei@roma1.infn.it

CUPID



Hardware: cryogenic test runs @ LNGS - R&D activity for CUPID

Data analysis: search for Majorana neutrino with CUPID

CONTACT:
fabio.bellini@roma1.infn.it

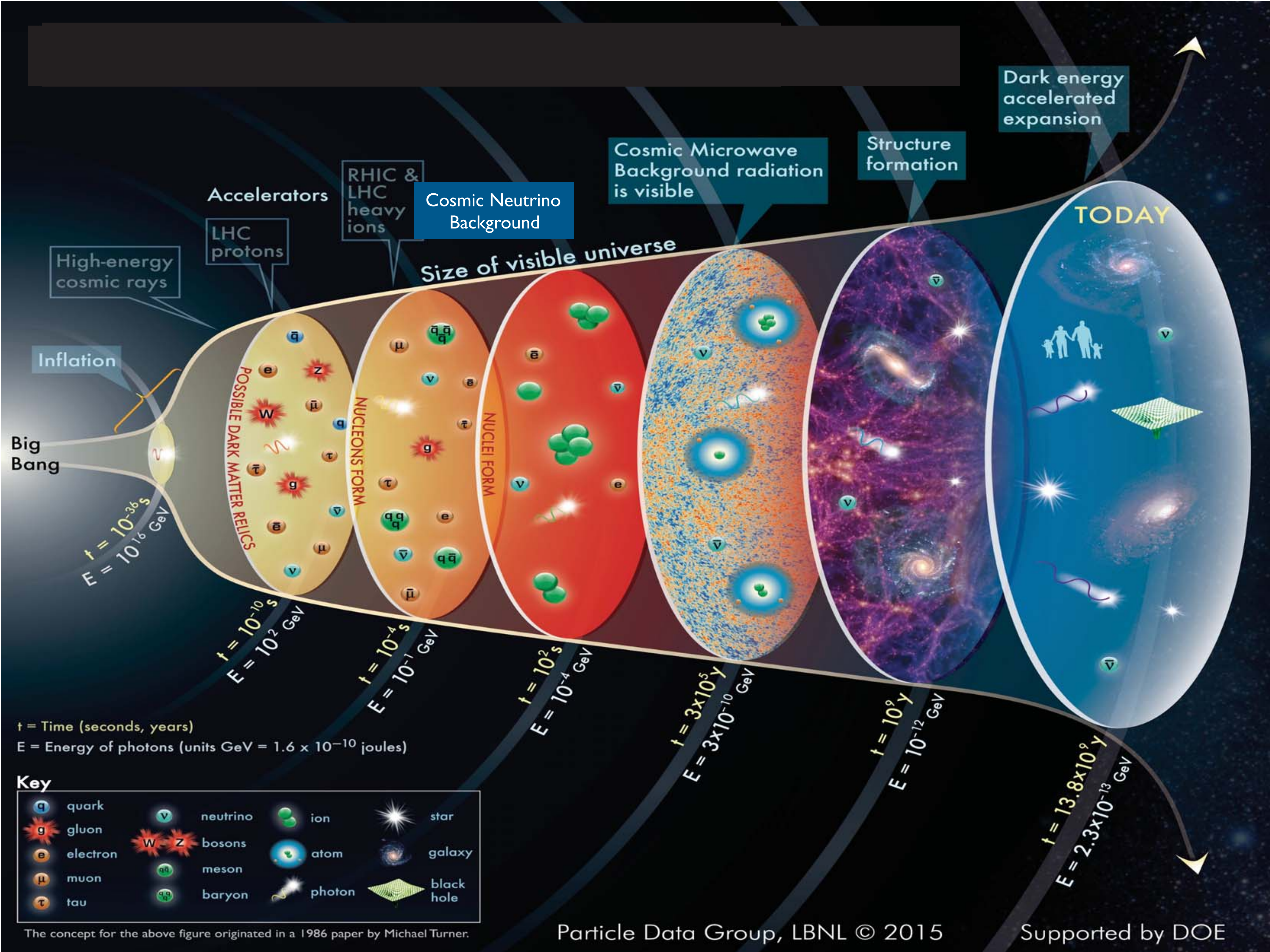
NUCLEUS BULLKID

Cryogenic detectors for neutrino scattering and Dark Matter:
Lab, Data analysis, simulations.

CONTACT:
marco.vignati@roma1.infn.it

Radiation from the Universe

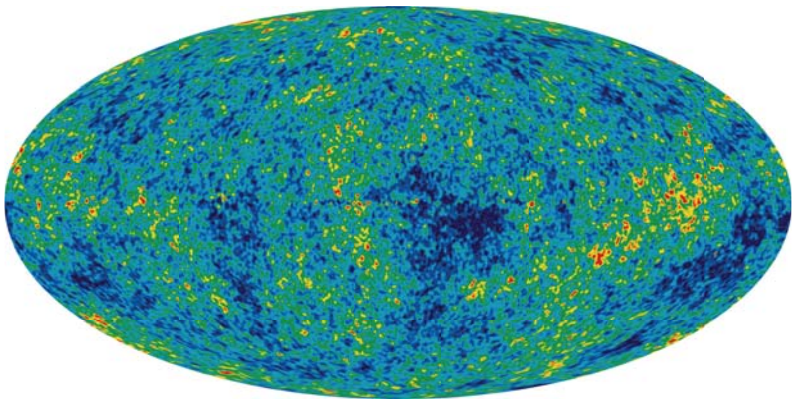
[redacted]

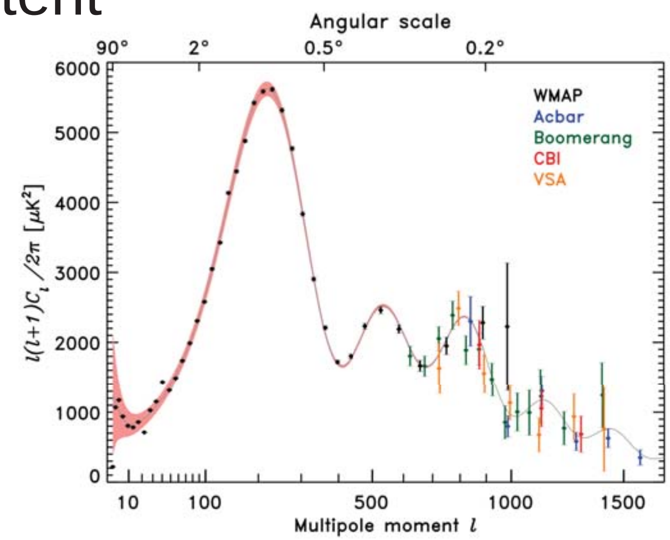

Dark energy accelerated expansion
Structure formation
Cosmic Microwave Background radiation is visible
Cosmic Neutrino Background
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Inflation
Big Bang
Size of visible universe
TODAY
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s
E = 10^16 GeV
t = 10^-10 s
E = 10^2 GeV
t = 10^-4 s
E = 10^-1 GeV
t = 10^2 s
E = 10^-4 GeV
t = 3x10^5 y
E = 3x10^-10 GeV
t = 10^9 y
E = 10^-12 GeV
t = 13.8x10^9 y
E = 2.3x10^-13 GeV
t = Time (seconds, years)
E = Energy of photons (units GeV = 1.6 x 10^-10 joules)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
The concept for the above figure originated in a 1986 paper by Michael Turner.
Particle Data Group, LBNL © 2015
Supported by DOE

Radiation from the Universe: Cosmic Microwave Background

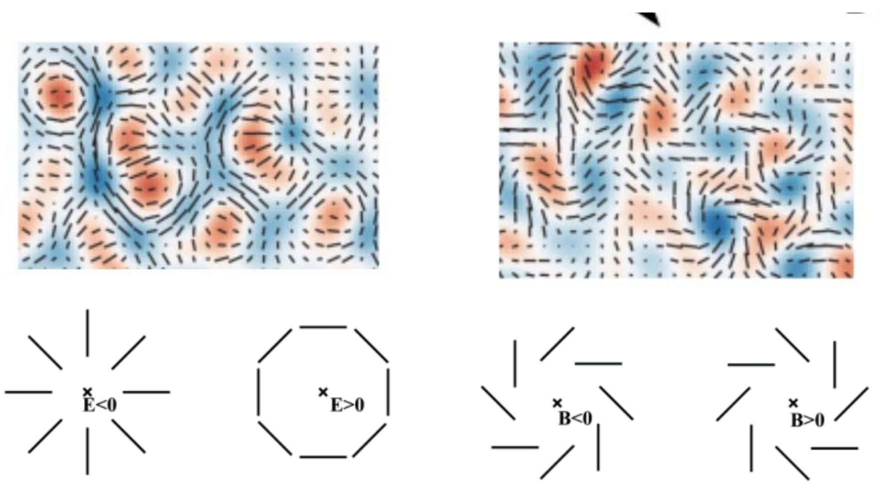
CMB: precision era

- Perfect Black Body radiation at 2.72545 K, anisotropies $O(10^{-5})$ tell us much about universe geometry, energy content





- The CMB polarization O(μK) acts as a GW antenna in the primordial Universe



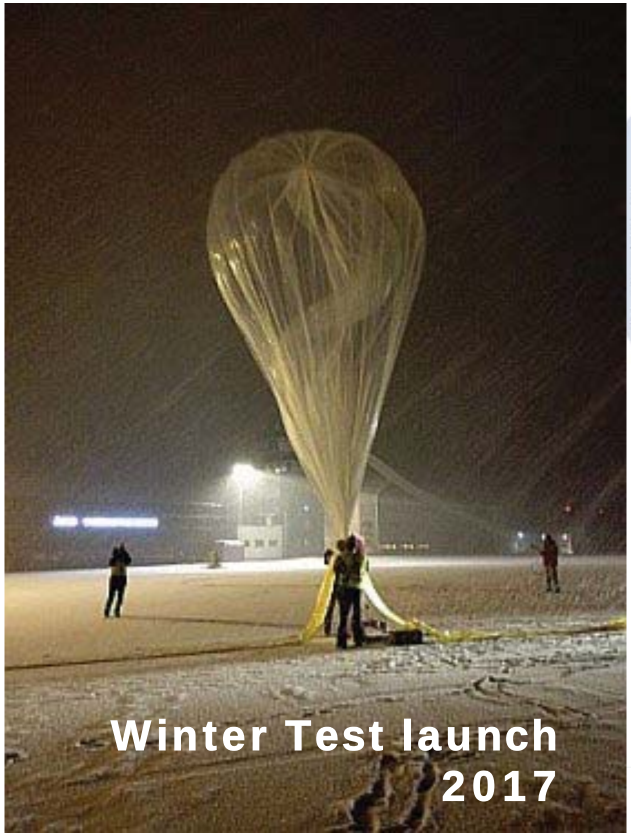
E-modes generated by Thomson scattering in plasma.

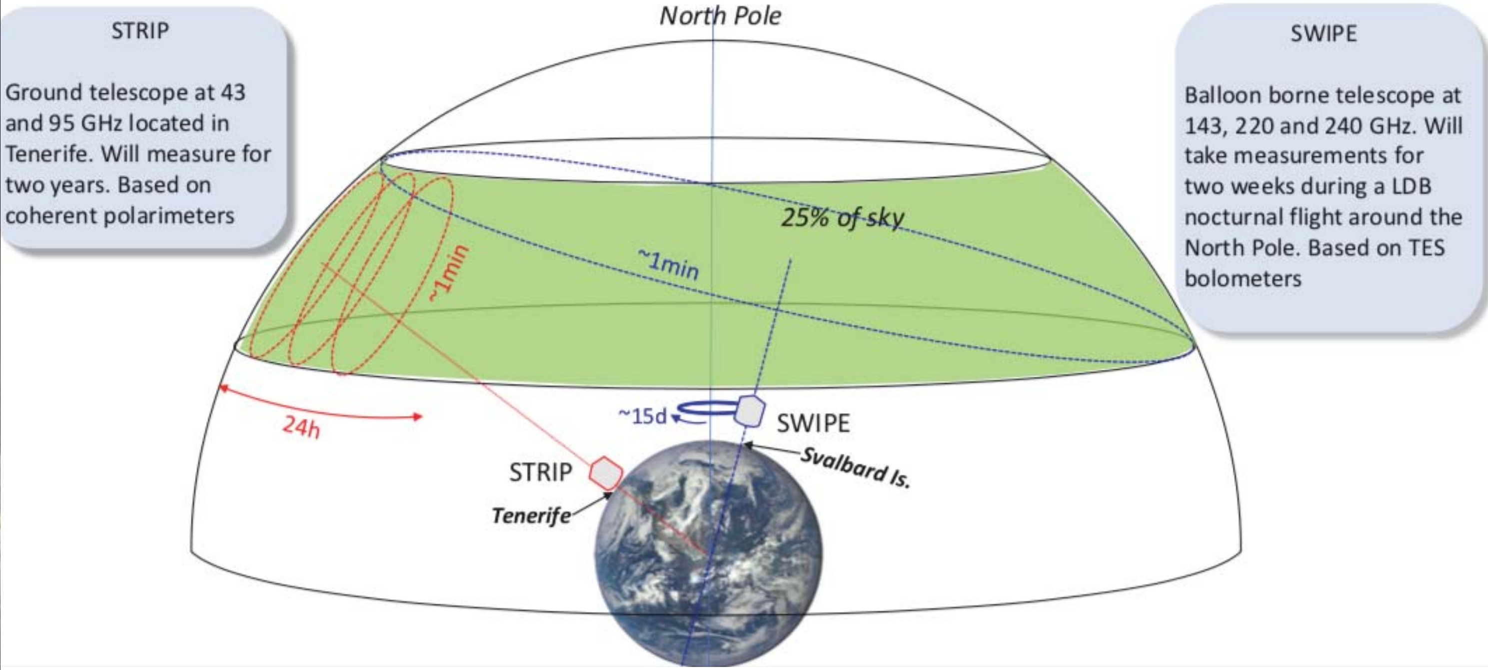
B-modes generated by
-gravitational lensing of E-modes
-gravitational waves during inflation

Need sensitivity, control of polarised background and systematics

LSPE - Large Scale Polarization

- Winter Polar Balloon (SWIPE)
- Ground telescope in Tenerife (STRIP)

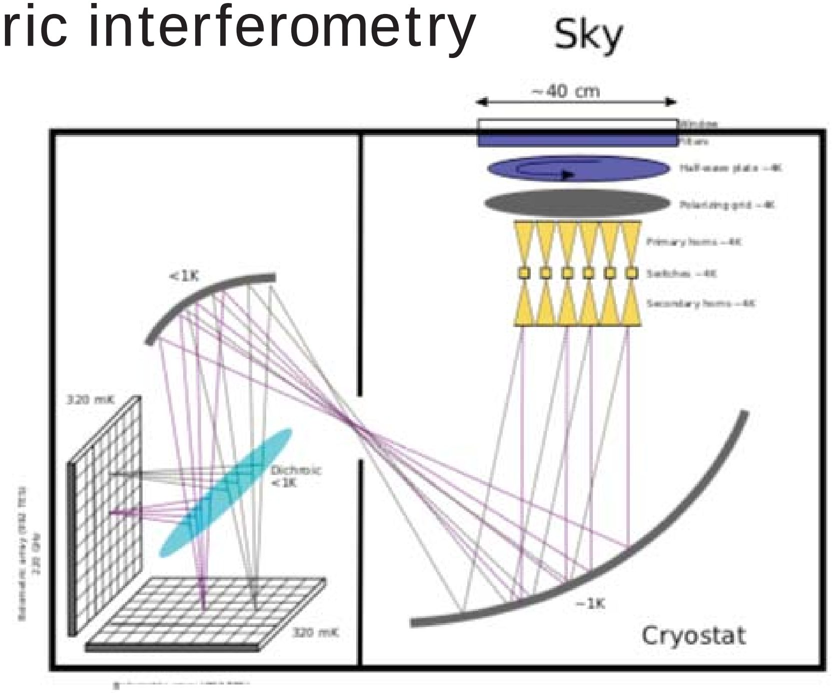


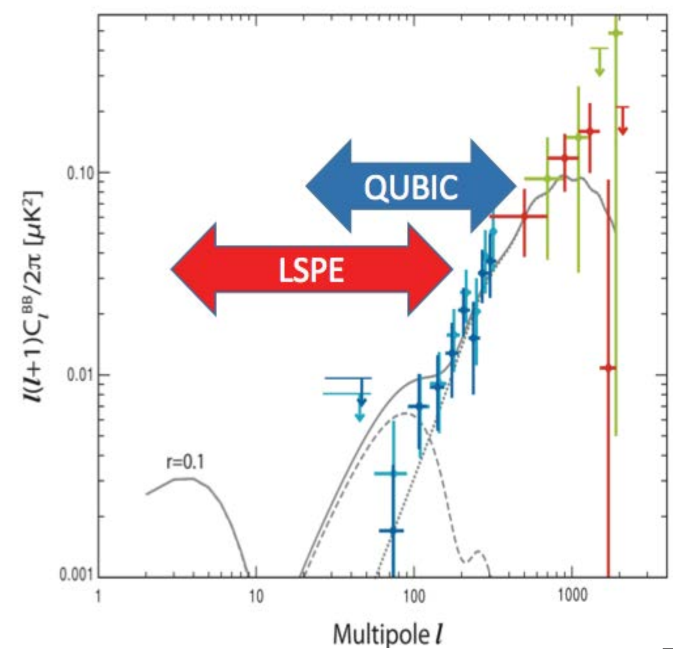


- Rome activity: involved in all the SWIPE activities

QUBIC

- Based on an alternative technology: bolometric interferometry
  - Combines bolometer **sensitivity** + interferometric **control of systematic**
  - The (yellow) internal back-to-back antennas acts as entrance slots of an interferometer
  - Optical system at ~4 K, mirrors at 1K detector at 320 mK
  - Will be installed in Argentinian Andes
- Activities: cryogenics and calibration
-





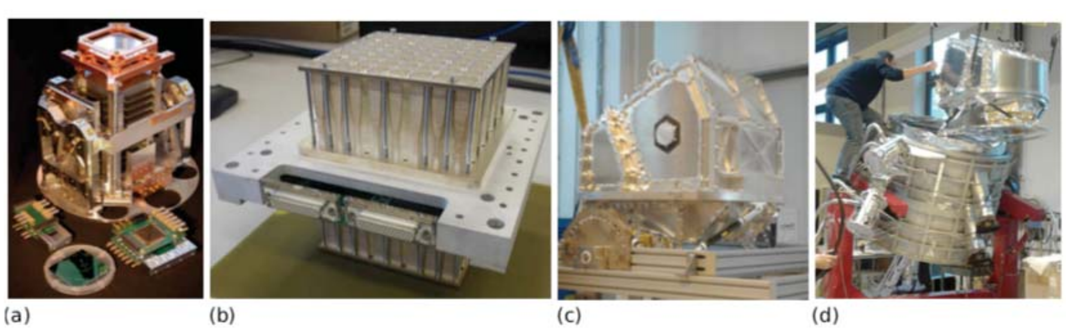
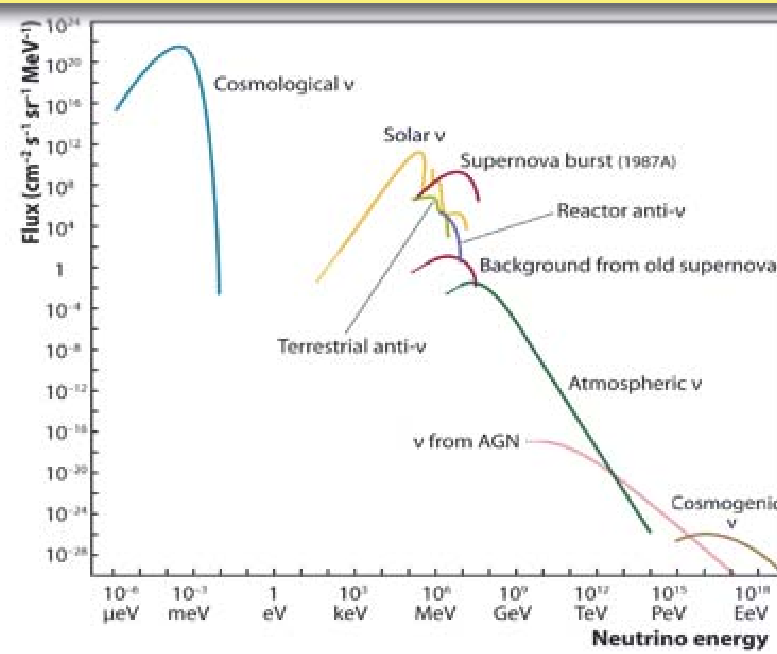


Figure 7. Status of the current QUBIC development. (**a**) The cryogenic section of the QUBIC detection chain; (**b**) the TD array of 64 + 64 back-to-back horns interfaced with their switches; (**c**) the integrated 1 K box; (**d**) integration of the 1 K box in the cryostat shell.

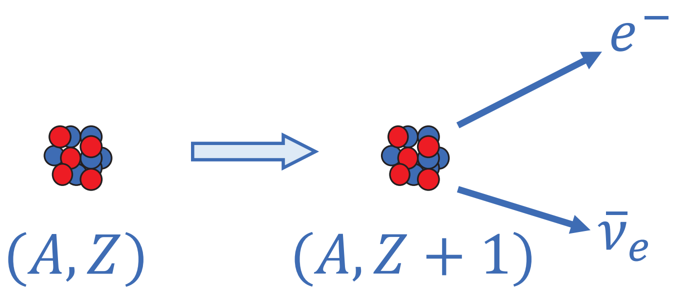
Radiation from the Universe: Cosmic Neutrino Background

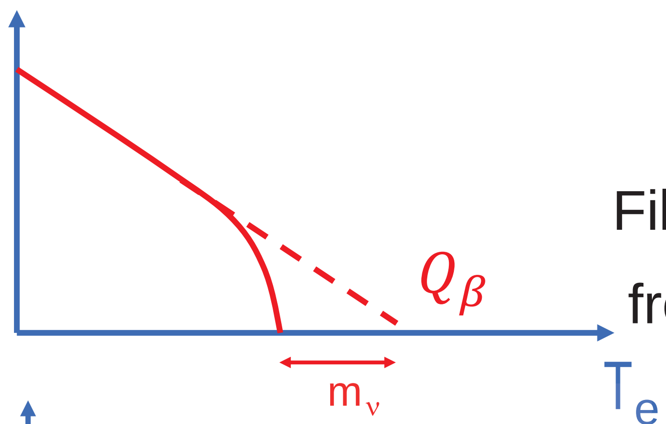
CNB

- ν decoupled from plasma 1s after Big Bang
  - BlackBody at T=1.95 K, p_ν= 10^{-3} eV
  - Neutrino density: 56 ν_e/cm^3



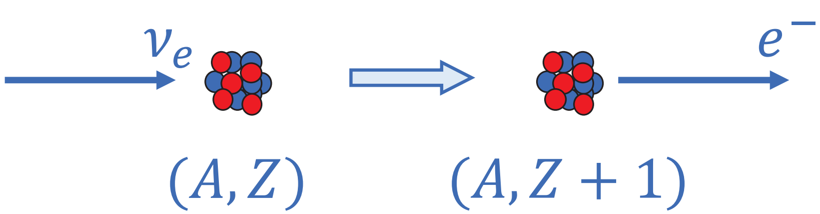
- How to detect it

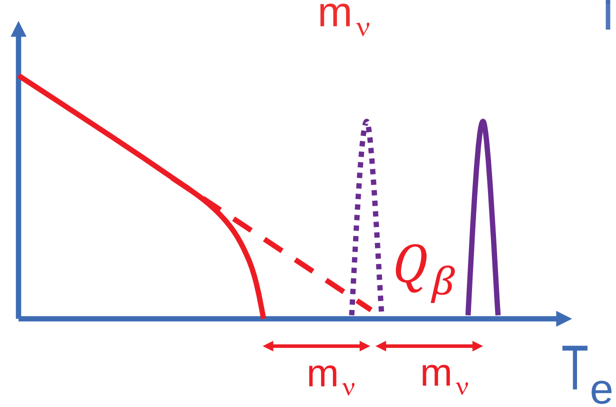




Need

Filter to reduce high rate from target

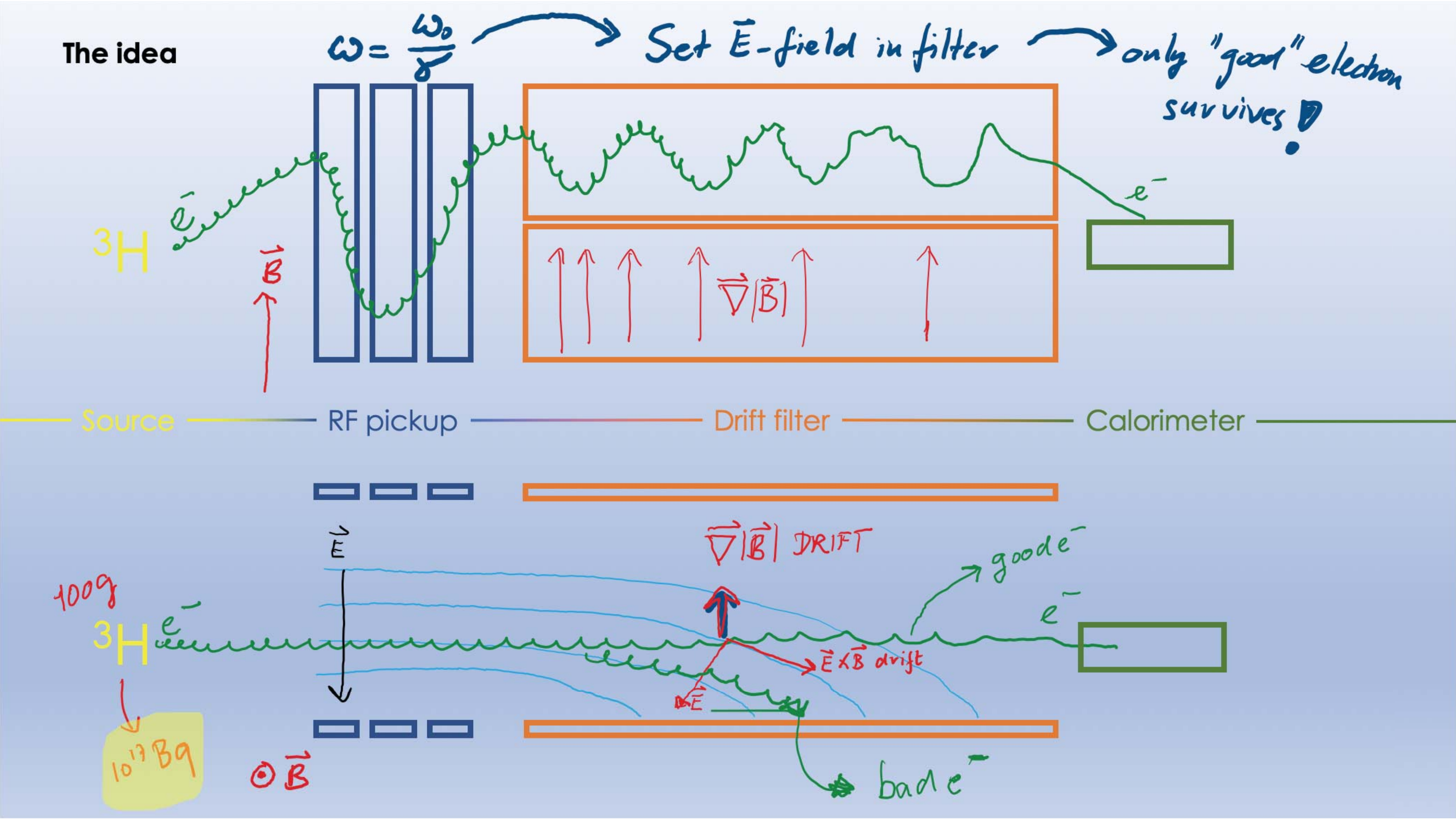




high efficiency

extreme $\sigma_E \sim m_\nu$

Ptolemy



The idea
ω = ω₀/γ
Set E-field in filter
only "good" electron survives!
e⁻
³H
B
∇|B|
e⁻
Source
RF pickup
Drift filter
Calorimeter
E
100g
³H
e⁻
∇|B| DRIFT
good e⁻
e⁻
E×B drift
E
10¹⁷ Bq
⊙ B
bad e⁻

PTOLEMY

- 100 g of Atomic ^3T target: low Q value, sizeable lifetime, β decay rate 10^{15} Bq/g, high cross section for ν capture

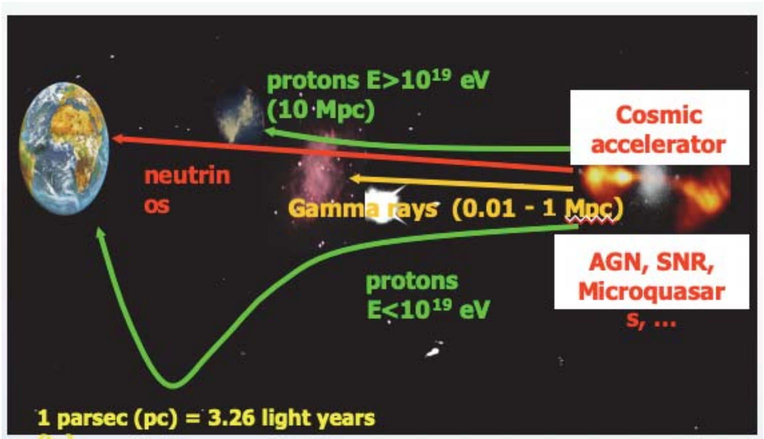
- PTOLEMY is defining the **Conceptual Design** of the experiment
  - In the 3 yr activity related to develop key **R&D**
  - Massive graphene production
  - Graphene loading with tritium (same problem of hydrogen battery)
  - Innovative EM filter (to be tested at LNGS)
  - RF antenna to detect GHz radiation
  - Sensor for 1-100 eV electron (TES calorimeter, electrostatic filter)

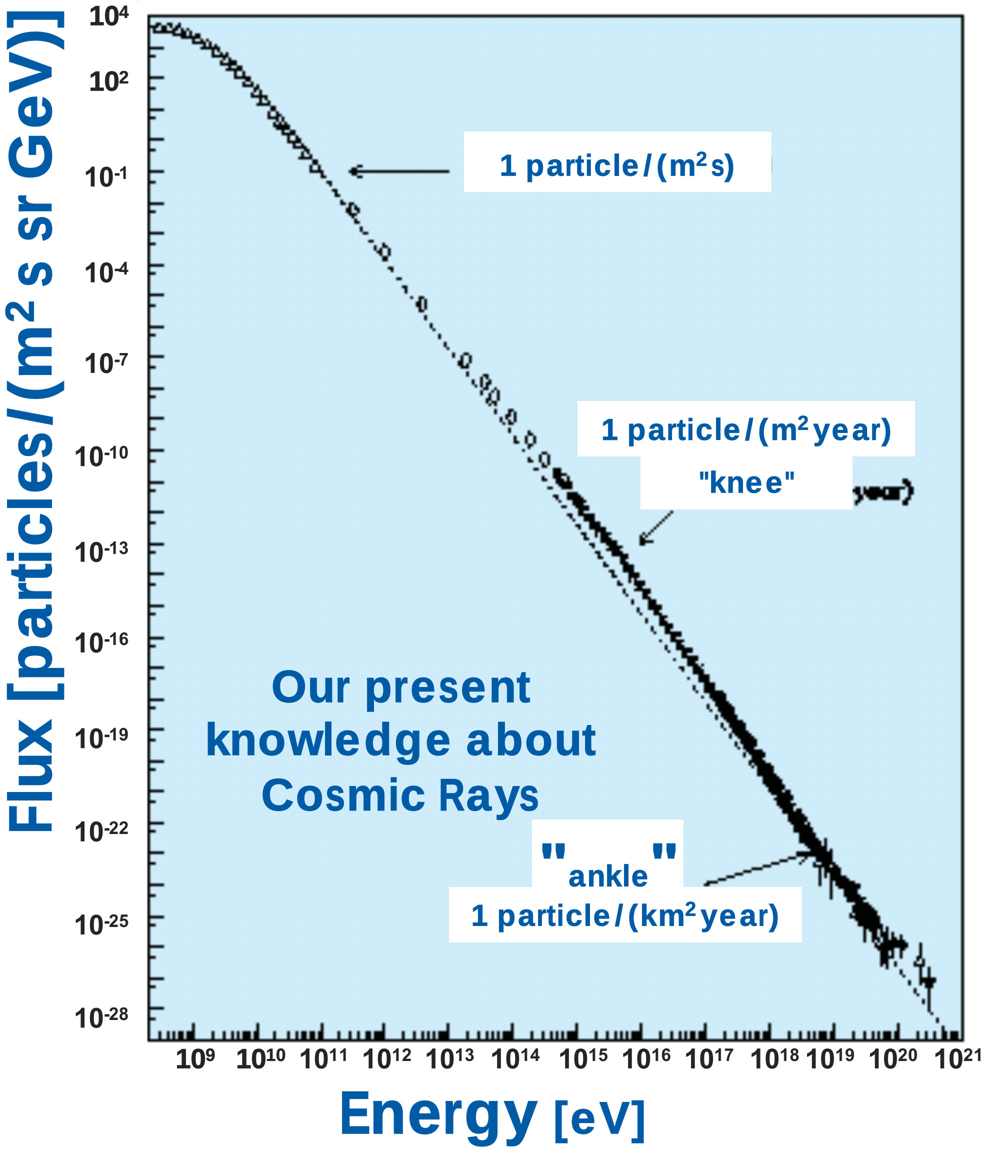
- Particle Physics, material science, nano-structure science

Radiation from the Universe: High Energy Neutrinos & gammas

Motivations

- Observed particle or nuclei up to $E_K=10^{21}$ eV (like a tennis ball at 150 km/h)
- Open questions
  - Where they come from?
  - Which acceleration mechanism





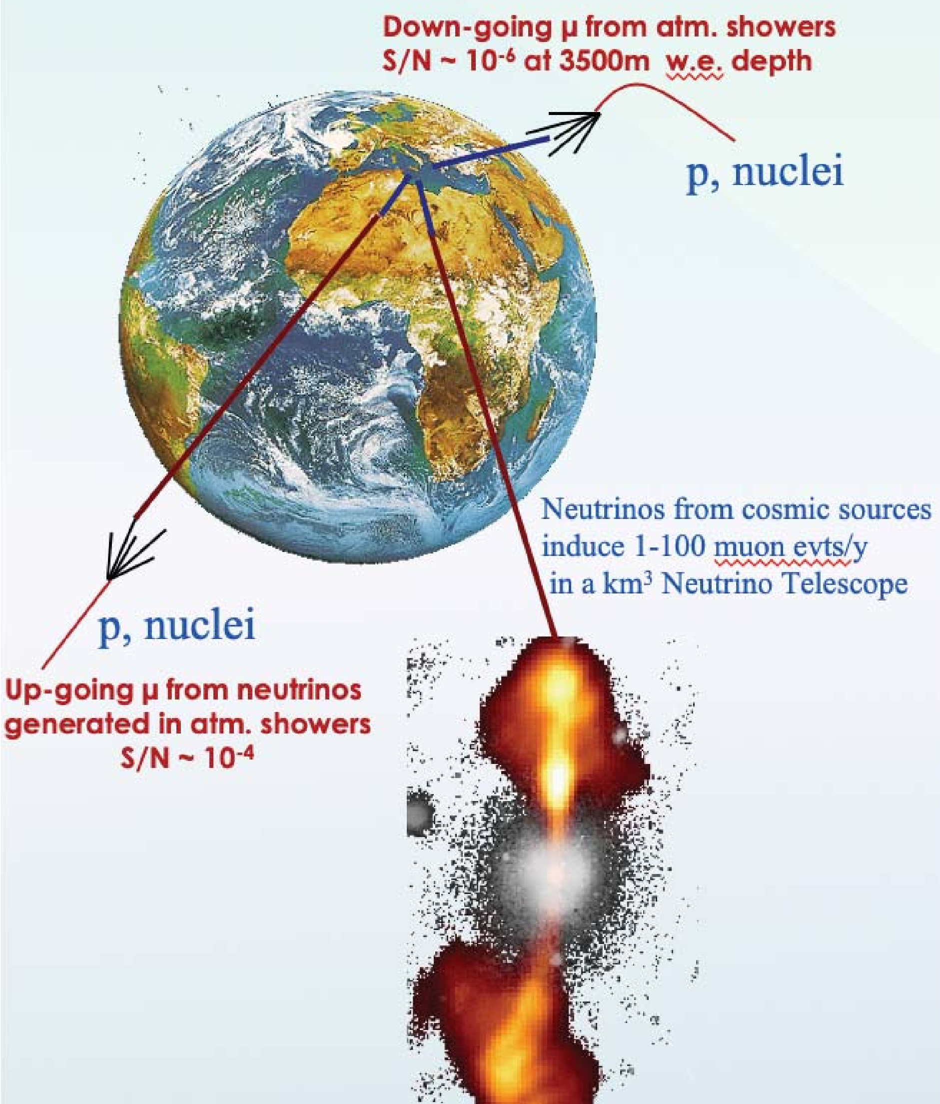
  - UHE astrophysical ν will extend limits of the visibile universe
  - Multi-messenger observations

Neutrinos are a sign of hadronic process since they come from π decays

Antares: Cherenkov ν Telescope

The Largest Neutrino Detector in the Northern Hemisphere

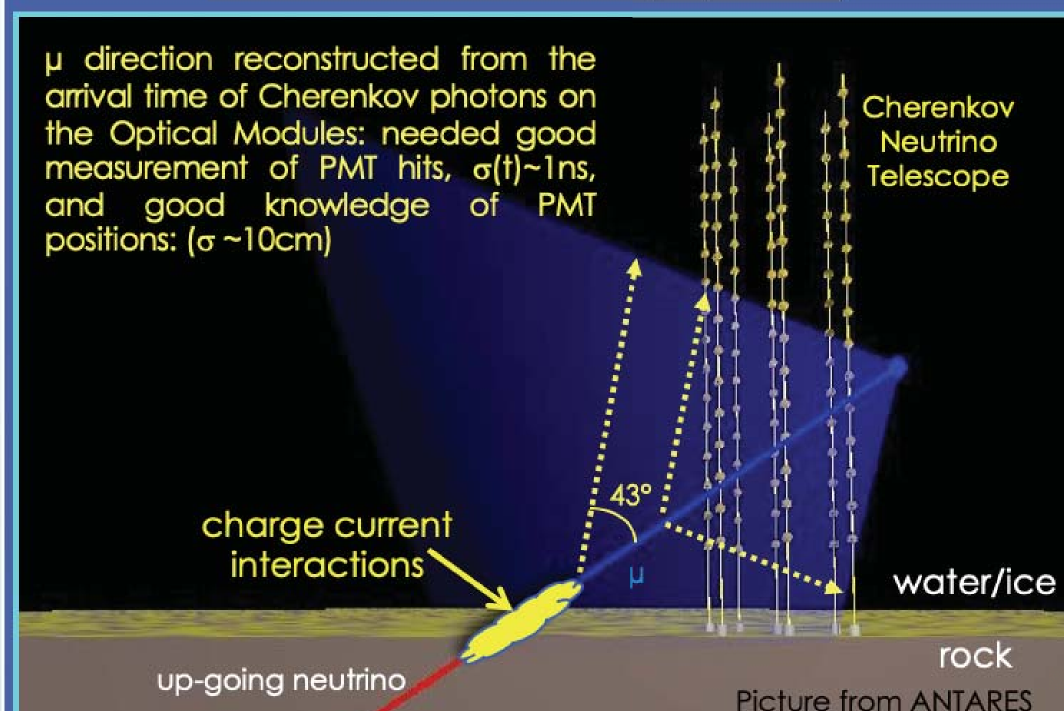
Search for neutrino induced events, mainly $\nu_\mu N \rightarrow \mu X$, deep underwater



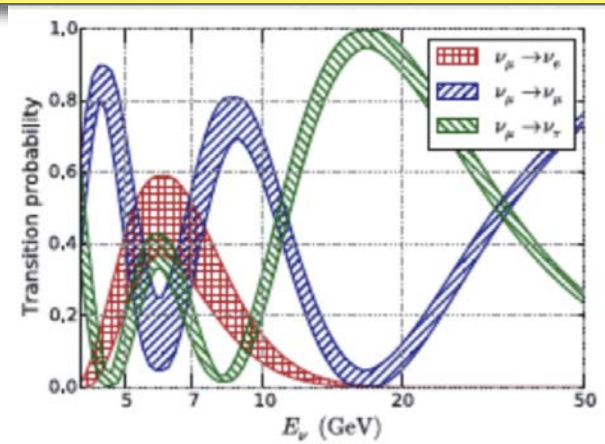
- Atmospheric neutrino flux ~ E_ν^{-3}
- Neutrino flux from cosmic sources ~ E_ν^{-2}
  - Search for neutrinos with E_ν>1÷10 TeV

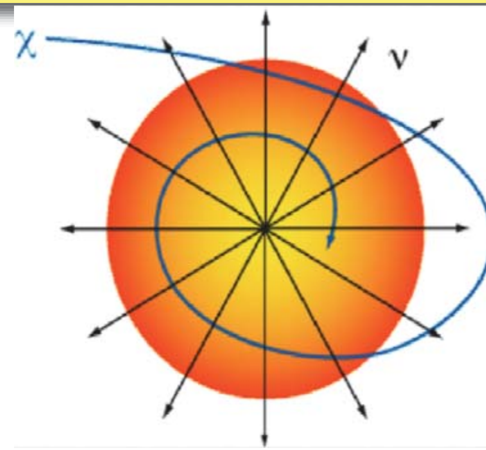
- ~TeV muons propagate in water for several km before being stopped
  - go deep to reduce down-going atmospheric μ backg.
  - long μ tracks allow good angular reconstruction

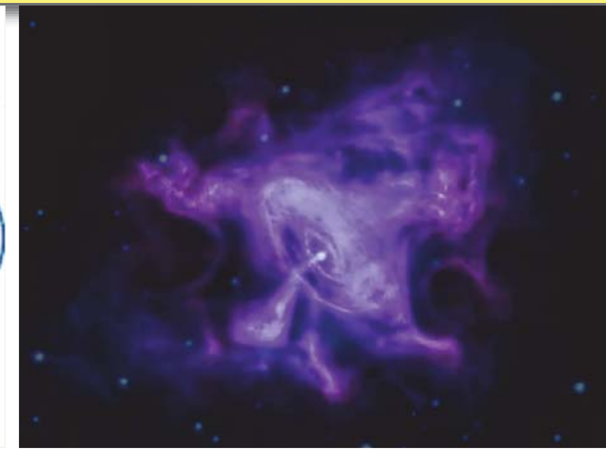
$$For\ E_\nu \geq 1TeV \quad \theta_{\mu\nu} \sim \frac{0.7^\circ}{\sqrt{E_\nu[TeV]}}$$



K3MNet science scopes







Low Energy	Medium Energy	High Energy
MeV < E_ν < 100 GeV	M eV < E_ν < 100 GeV	E_ν > 1 TeV

Low Energy
- Neutrino Oscillations
- Neut. Mass Hierarchy
- Sterile neutrinos
- Neut. From Supernovae

Medium Energy
- Dark Matter search
- Monopoles
- Nuclearites

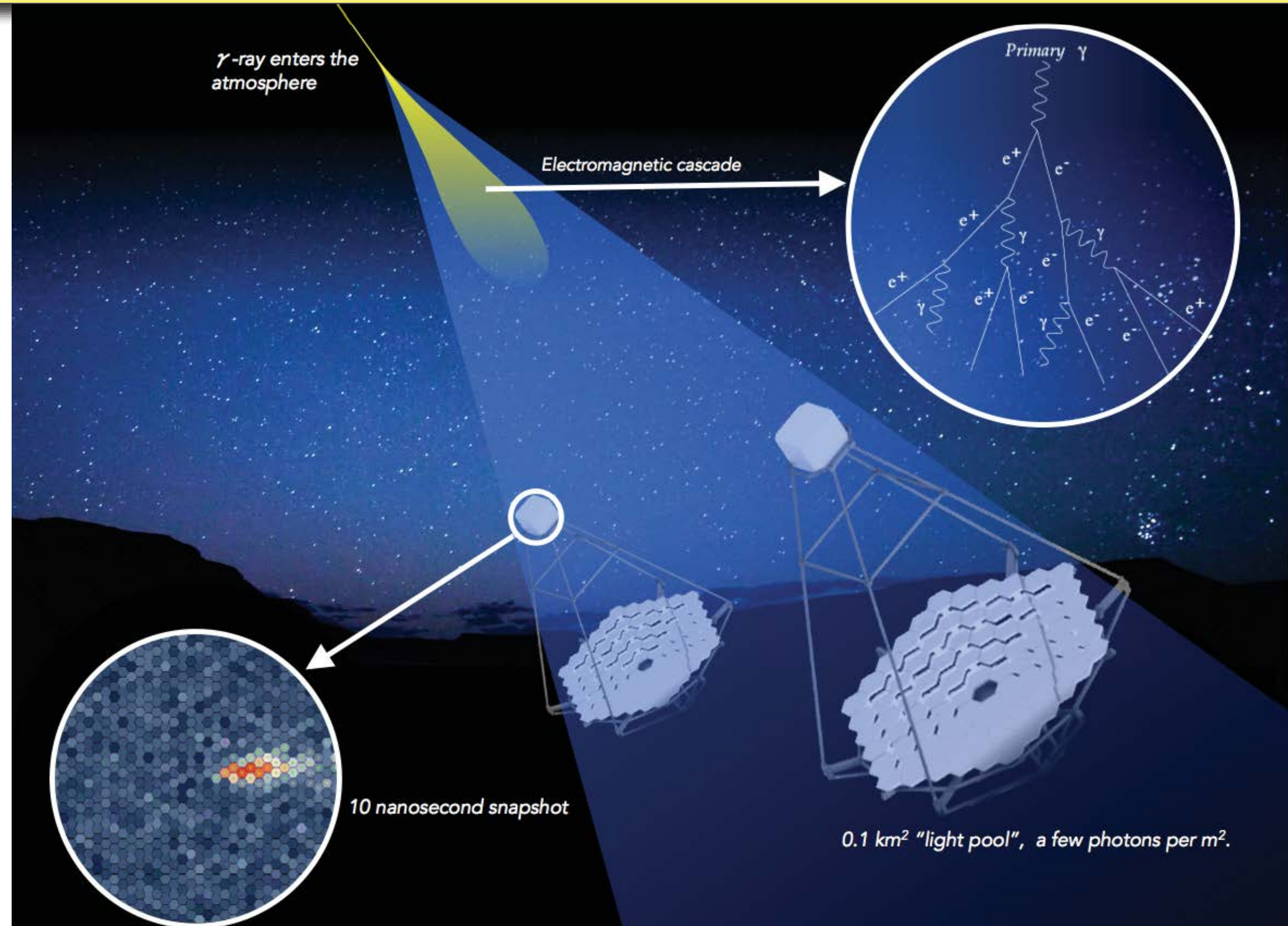
High Energy
- Neutrinos from extra-terrestrial sources
- Origin and production mechanism of HE CR

… and synergies with Sea-Sciences: oceanography, biology, seismology, …

- HW activities: electronic system development for data acquisition & transmission
- SW activities: dark matter searches, UHE ν from impulsive sources, high energy cross section studies, development of optical system control

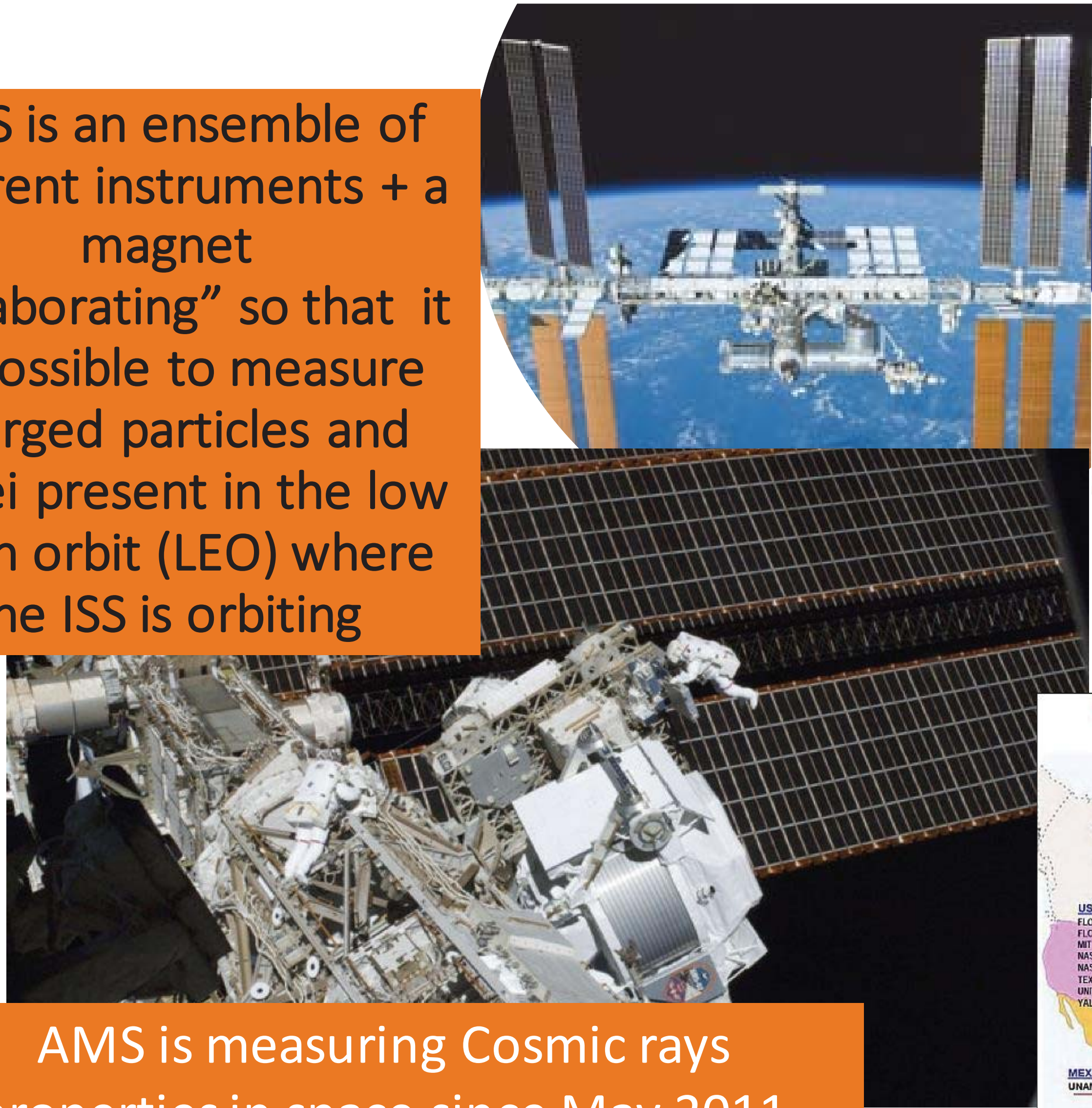
Cherenkov Telescope Array for γs

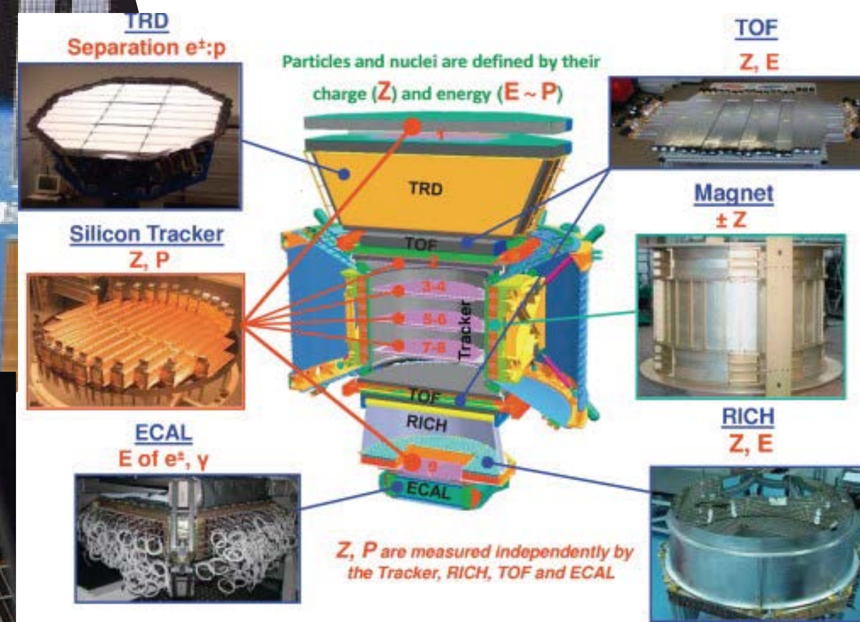
- 100 Telescopes on both hemispheres
  - Energy: 20 GeV-200 TeV
- Large Scale Telescope
  - 23 m diamater, 50 Ton
  - reposition in 20 s
  - PMT camera
- Rome Activity: calibration of the camera and trigger
  - Software and hardware theses



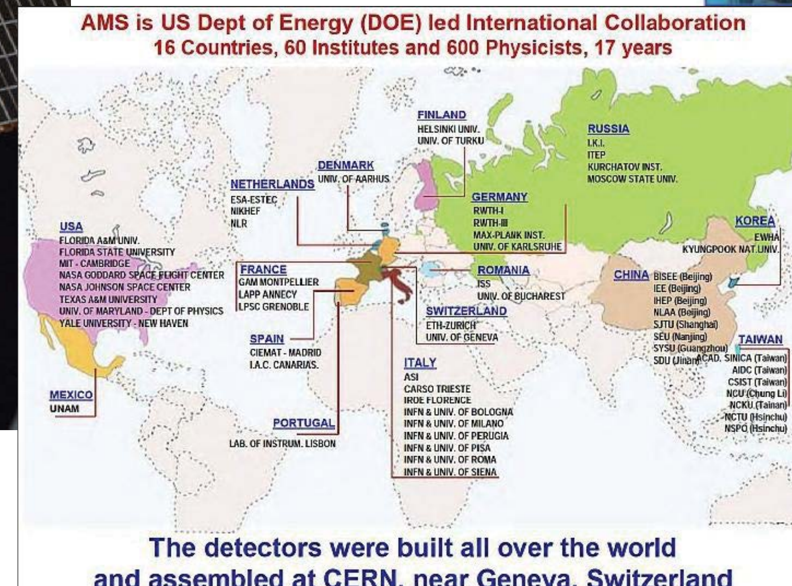
Alpha Magnetic Spectrometer

AMS is an ensemble of different instruments + a magnet "collaborating" so that it is possible to measure charged particles and nuclei present in the low earth orbit (LEO) where the ISS is orbiting





AMS is measuring Cosmic rays properties in space since May 2011 with a precision never reached before



Data Collected by AMS

Particles

- Electrons and positrons
- Protons and antiprotons
- Deuterium and different He isotopes
- Heavy Nuclei

Measured Quantities

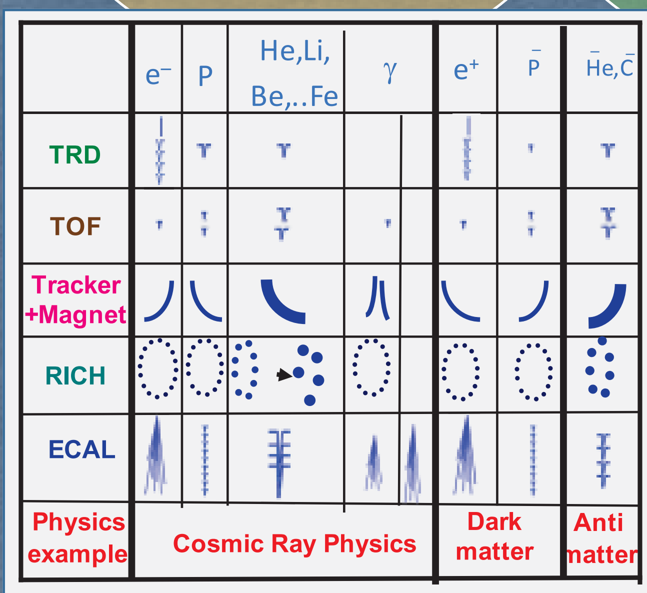
- Kinetic Energy
- Momentum
- Charge
- Rigidity

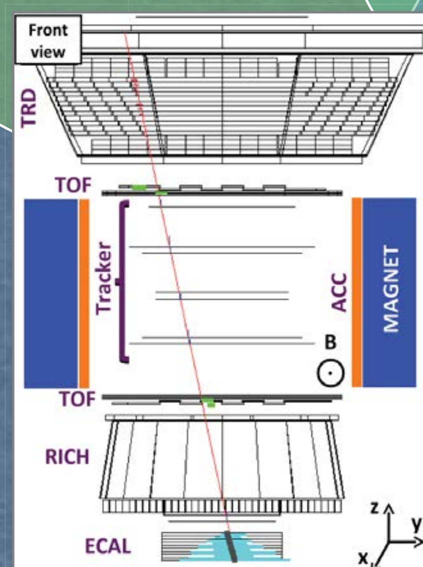
Position

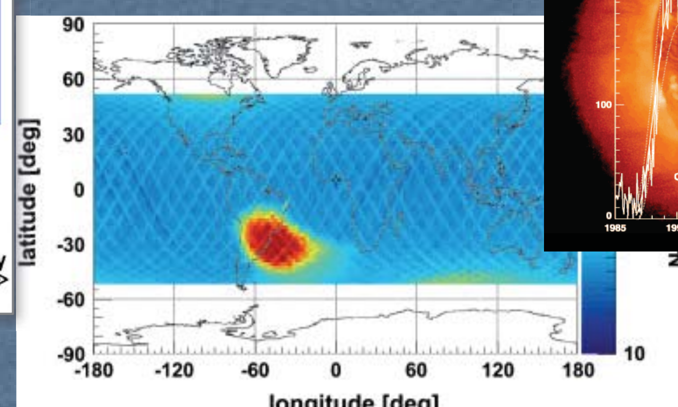
- International Space Station is in the Low Earth Orbit, approx. 400 Km of altitude
- Approx 15 orbit each day (74 minutes)
- AMS measure cosmic ray coming from any direction
- Also measuring in the South Atlantic Anomaly zone (SAA)

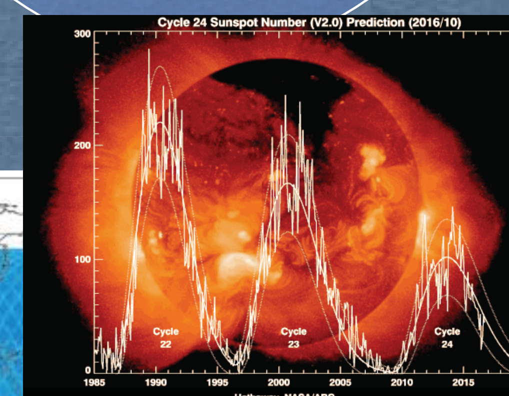
Time

- Operative since May 2011, h24 365day/year
- Possibility to reconstruct the variation in time of CR composition
- Approved to run until 2024
- Possibility to monitor CR for an entire solar magnetic activity cycle (11 years)









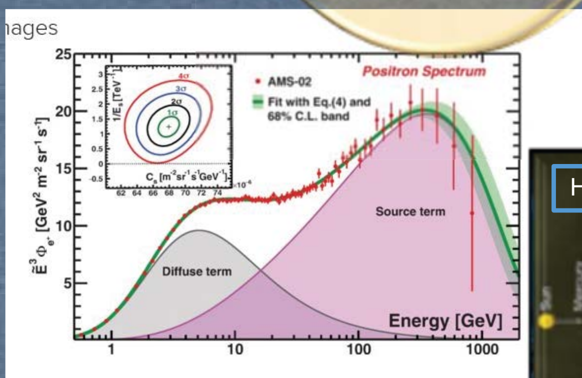
Crucial for research in different fields

Fundamental Physics
- Indirect Dark Matter Search
- Direct Antimatter Search
- Cosmic Ray propagation modelling
- Galactic Sources
- Exotic particles search

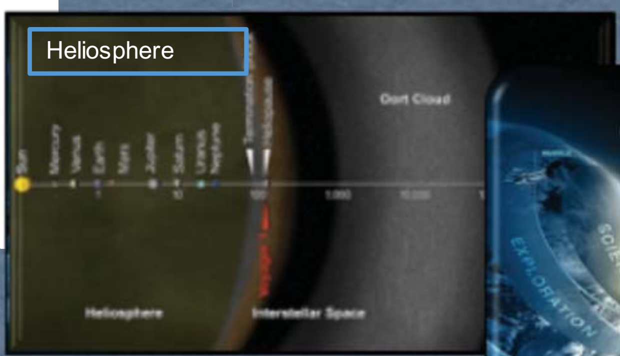
Solar Physics
- Heliosphere properties
- Cosmic Ray solar modulation
- Solar Flares predictions and monitoring

Human Space Exploration
- Earth Magnetosphere
- Missions to Moon and Mars
- Spacecraft shielding design

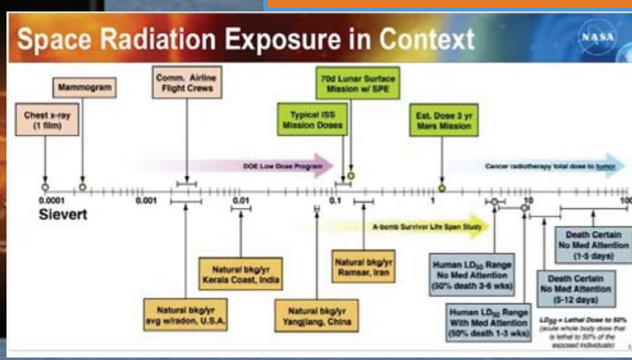
Space Radiation
- Space Radiobiology
- Daily Life applications
  - Biology, Medicine



Since 2013 AMS collaboration reports an excess in the cosmic ray positron spectrum that could derive by annihilation of dark matter particles (latest results in figure - 2019)



There are similarities between the ionizing radiation doses uses in clinical purposes in medicine (i.e radiotherapy, …) and the one absorbed from astronauts in space due to exposure to charged particles

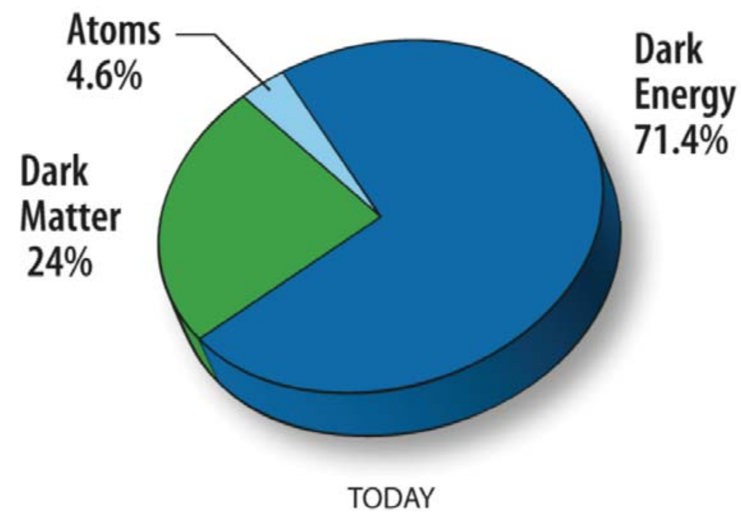


Nowadays Rome activity focused on investigating synergies between the collected AMS data and research in applied physics :
Human Space Exploration, Dose Effect models , space radiobiology

The Dark Universe:
Dark Matter

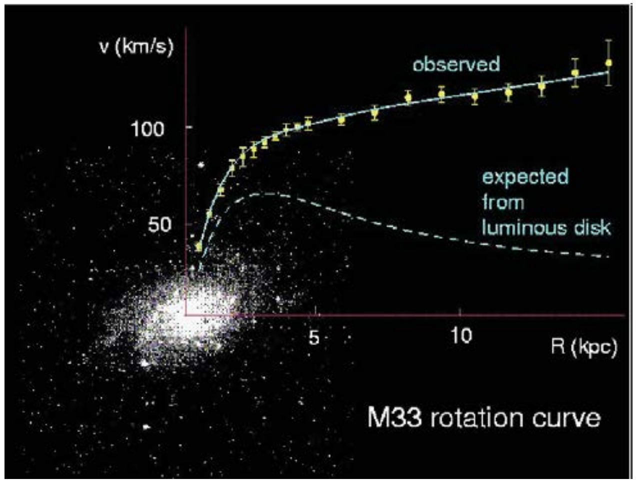
Dark Matter Evidence

- Gravitational evidence at different scale



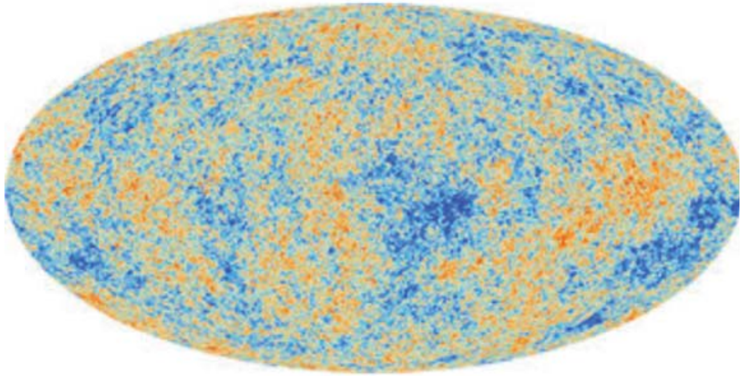
Bullet cluster

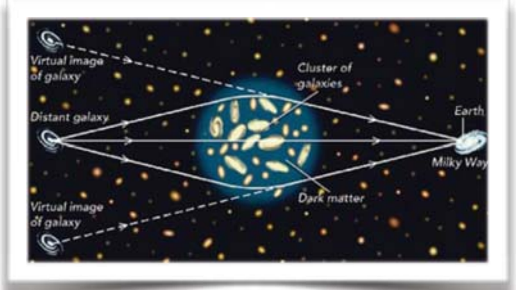
Galaxies



Lensing

Cosmic Microwave Background

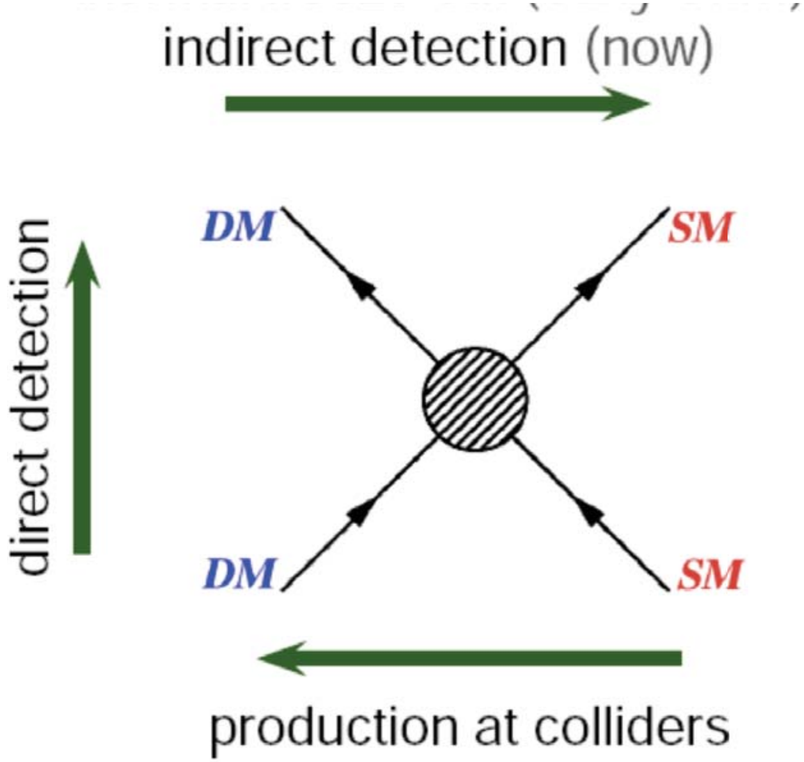


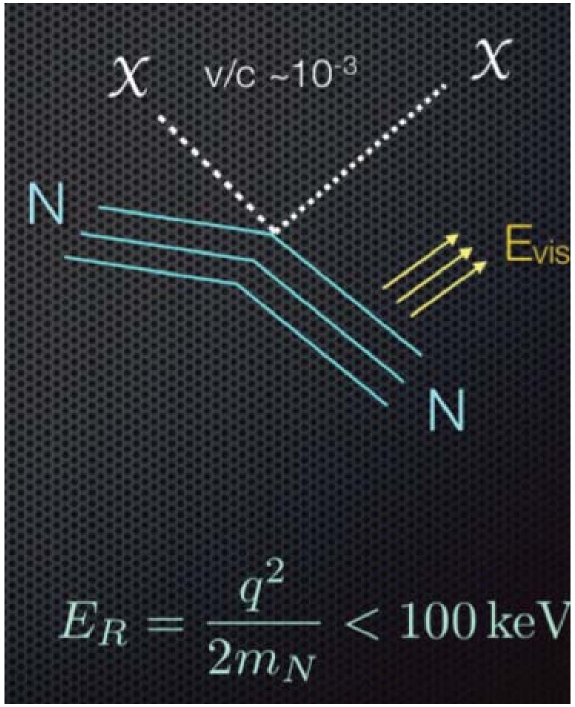


Dark Matter

- Interact weakly with ordinary matter
- Does not emit or adsorb light
- Low density 0.3 GeV/cm^3
- Stable and non relativistic

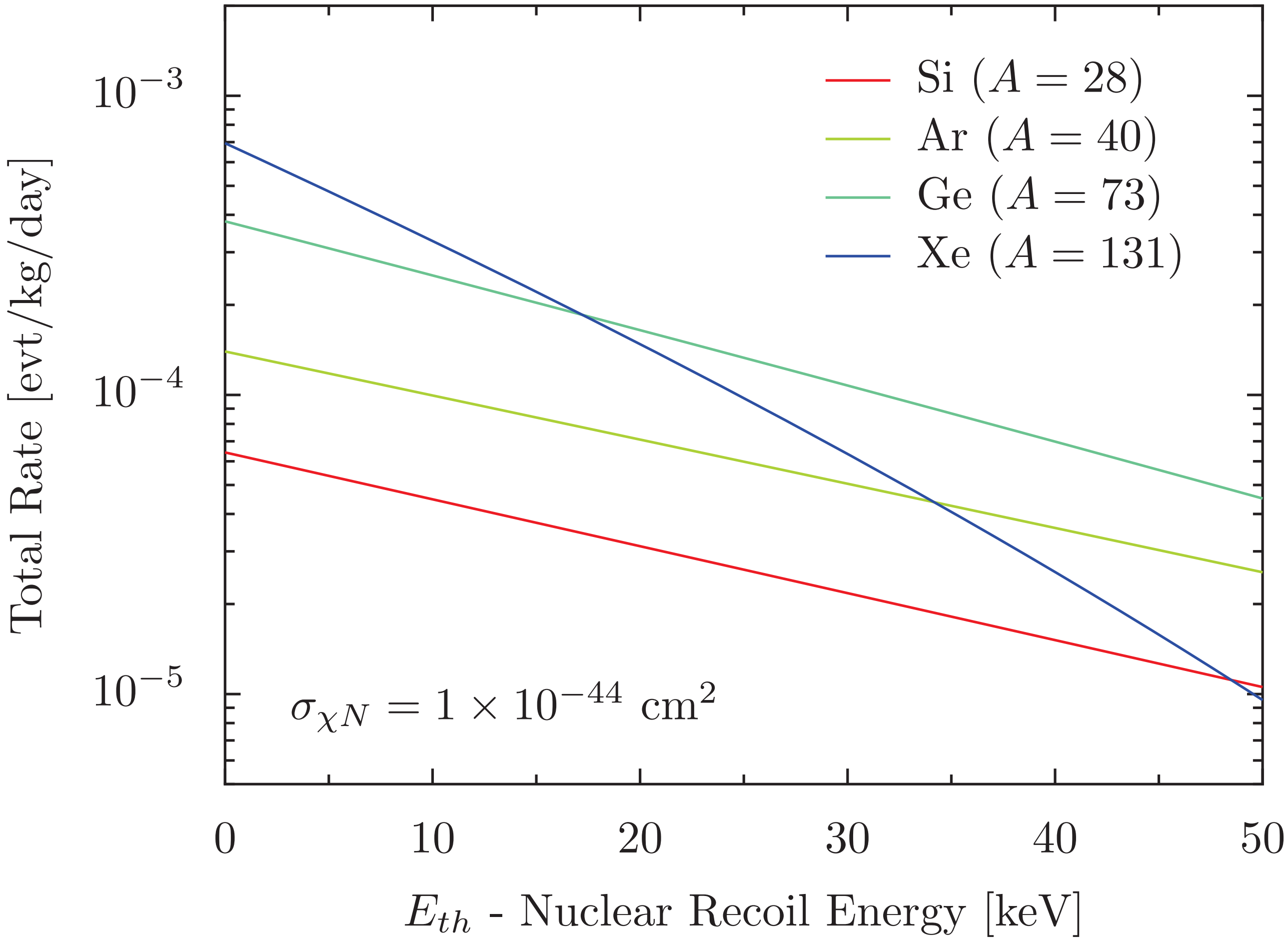
1) Gravitational laws are not exact
2) Weak Interactive Massive Particle or Light Axions Particle





The WIMP signal (SI)

Exponential-like shape, increasing at low E (similar to many bkgds…)



Demands O(keV) thresholds and backgrounds close to zero.

All experiments operated in low radioactivity environments and deep underground.

Counting rate annual modulation

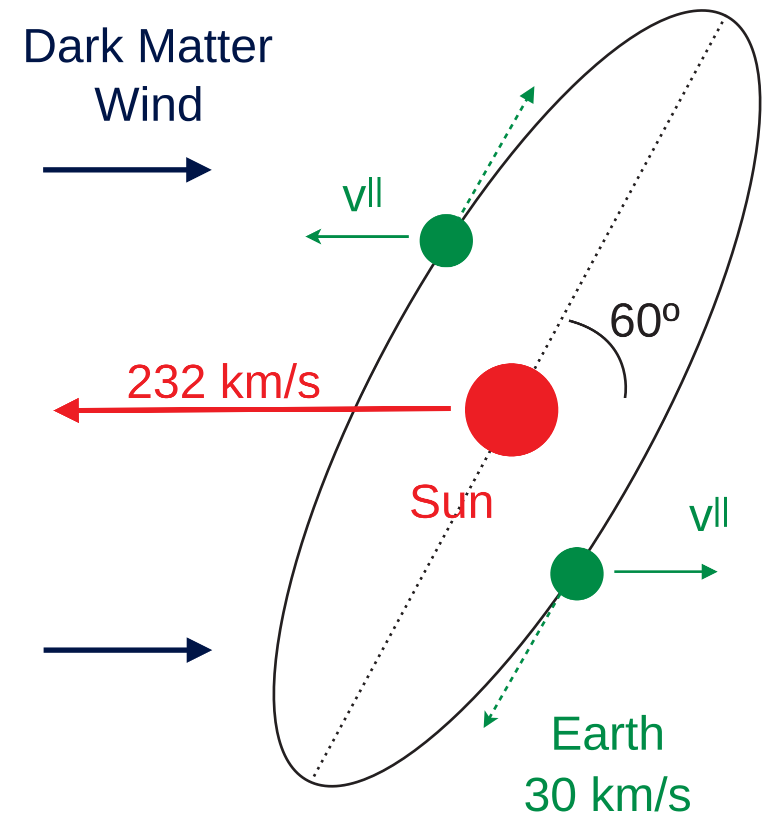
Earth velocity combines to solar system velocity in the galaxy.

Dark matter “wind” in the earth rest frame is modulated:

$$v(t) = v_{\rm sun} + v_{\rm orb}^{||} \cos[\omega(t - t_0)]$$

and affects the counting rate:

$$S(E,t) = S_0(E) + S_m(E) \cos[\omega(t - t_0)]$$



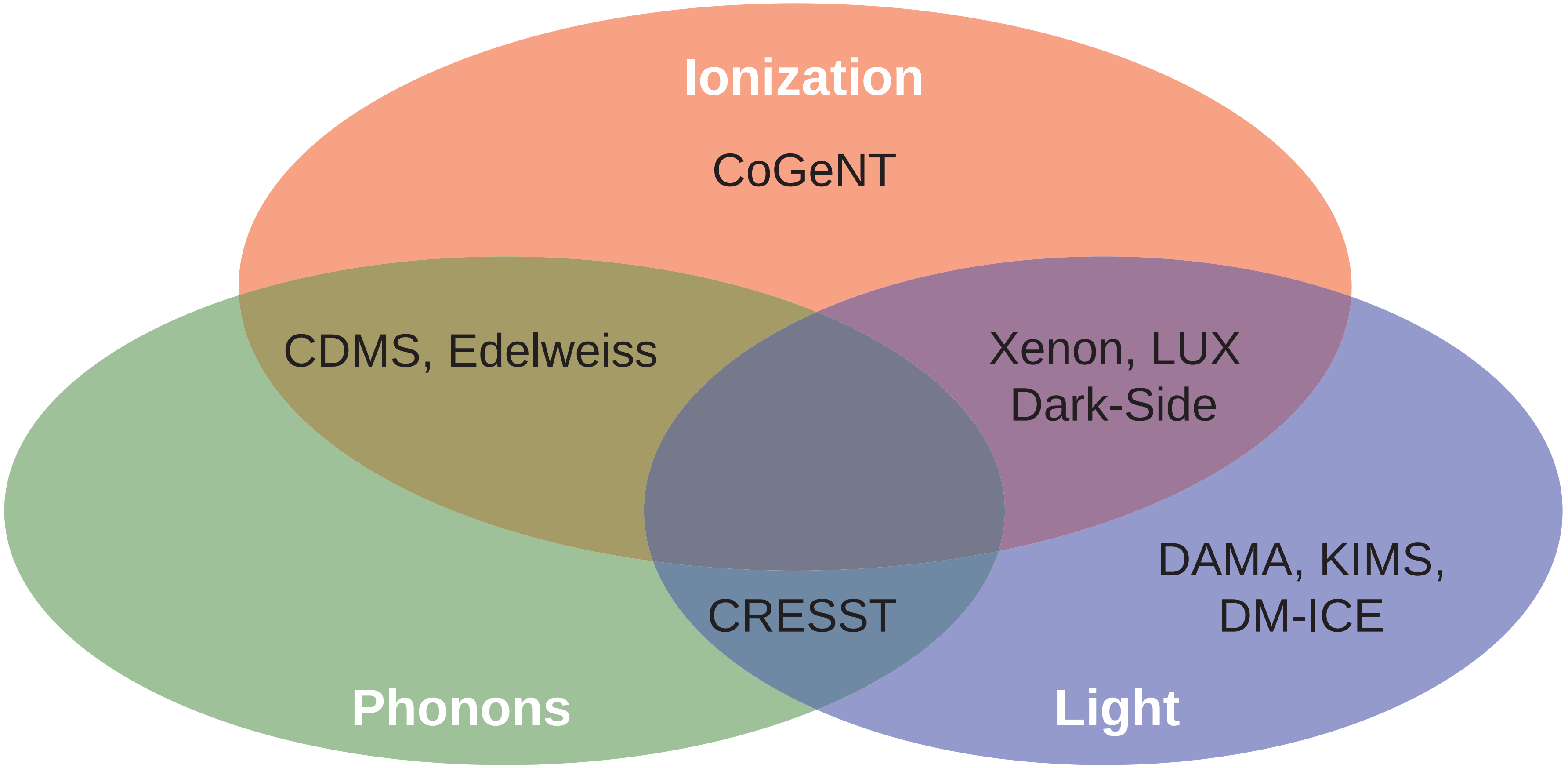
Distinctive modulation signal features:

T = 1 year t_0 = 2nd June

Pro: model independent   **Con:** requires detector stability and bkg control.

Detection channels

The combination of different techniques allows one to discriminate between electron and nuclear recoils, and thus to reduce the β/γ background.



Energy calibrations are done with γ sources (electron recoils).

The relative calibration of nuclear recoils (keV_{ee} ➡ keV_{nr}), the quenching factor (QF), must be known with accuracy

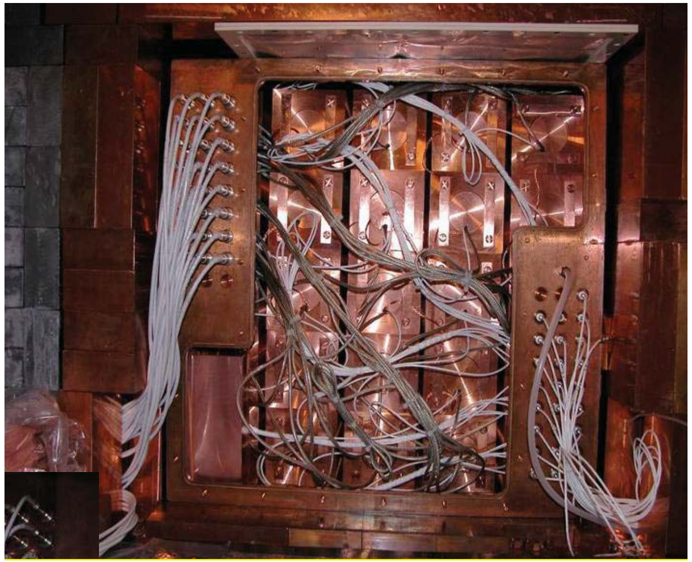
DAMA/LIBRA

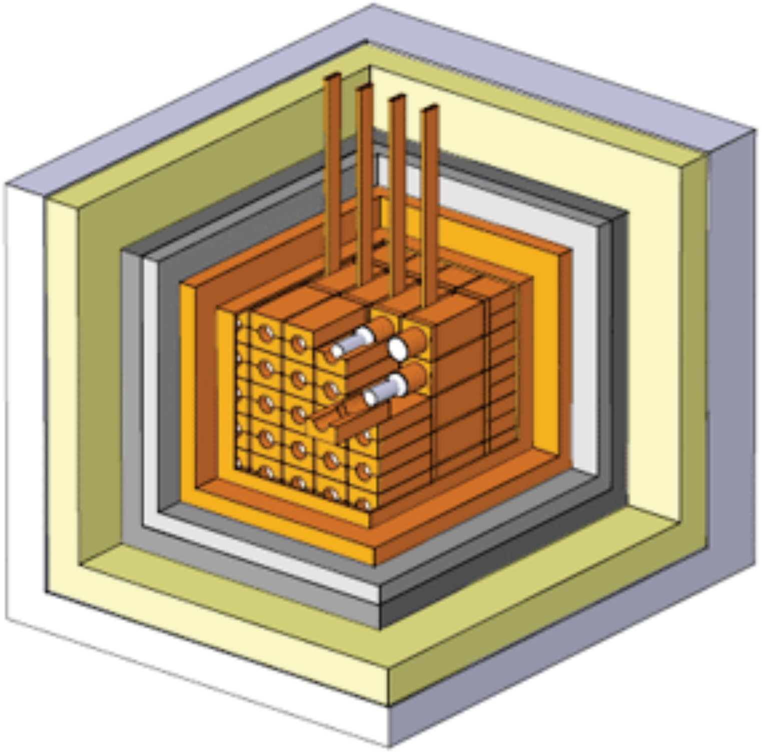
25 NaI crystals, 9.70 kg each

- QF: Na (30%), I (10%)
- High radiopurity: ^{232}Th and ^{238}U (ppt), ^{40}K (<20 ppb)

Dual read-out of each crystal via PMTs (noise reduction via coincidence), 5.5-7.5 photoelectrons/keVee

- Energy threshold: 2 keVee
- Granularity: select single crystal events

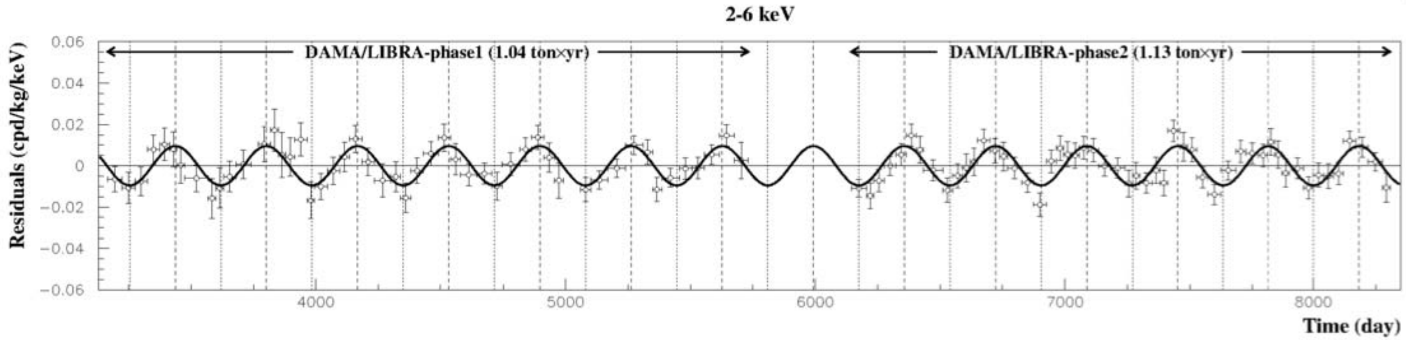




Model Independent Annual Modulation Result

DAMA/LIBRA-phase1 + DAMA/LIBRA-phase2 (2.17 ton×yr) https://arxiv.org/abs/1805.10486

Single-hit residuals rate vs time in 2-6 keV



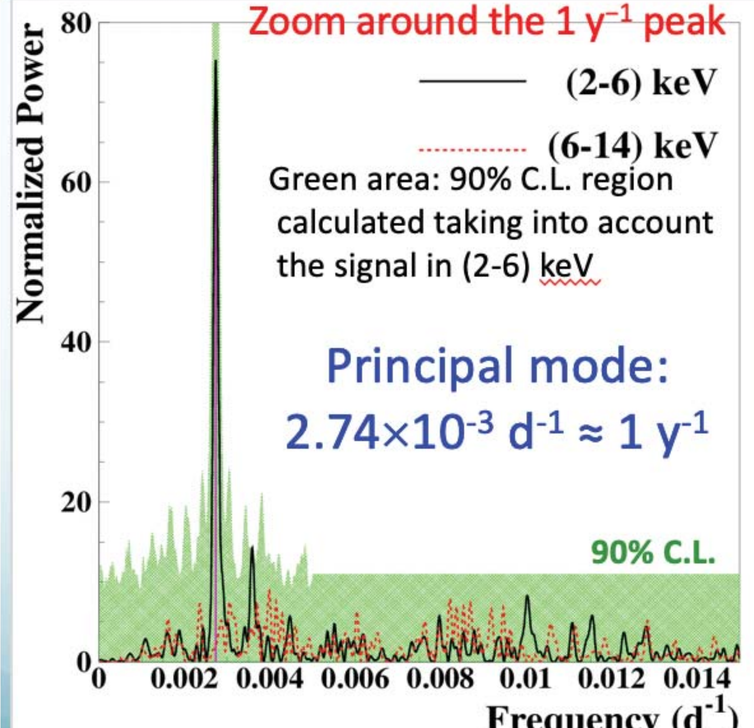
2-6 keV

continuous line: t_0 = 152.5 d, T = 1.0 y

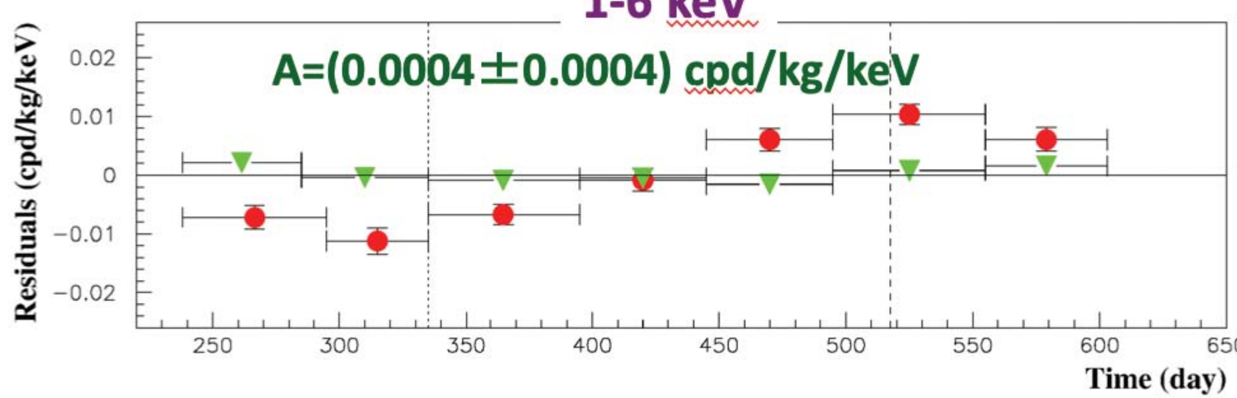
A=(0.0095±0.0008) cpd/kg/keV
χ^2/dof = 71.8/101 11.9 σ C.L.

Absence of modulation? No
χ^2/dof=199.3/102 P(A=0) = 2.9×10^{-8}

Fit with all the parameters free:
A = (0.0096 ± 0.0008) cpd/kg/keV
t_0 = (145±5) d - T = (0.9987±0.0008) yr



Comparison between **single hit residual rate (red points)** and **multiple hit residual rate (green points)**; Clear modulation in the single hit events;

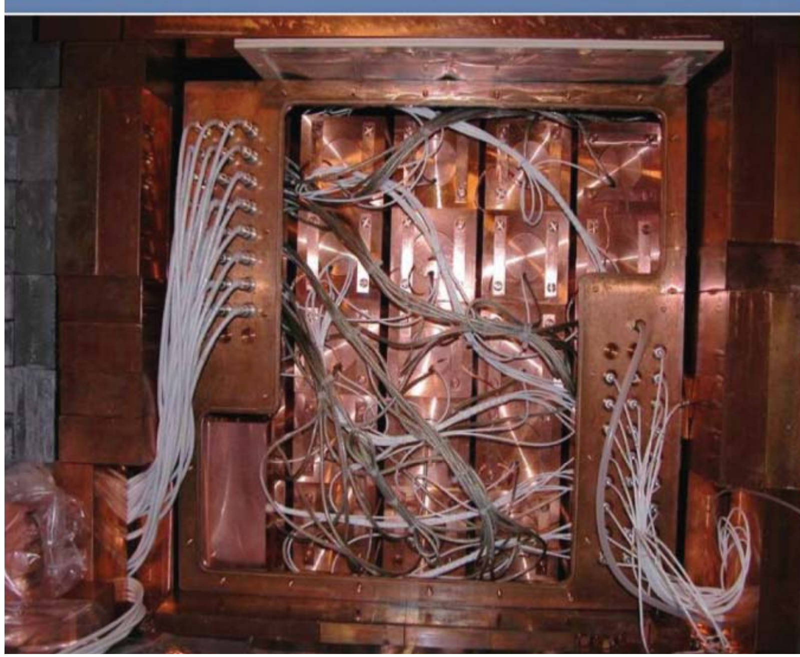


This result offers an additional strong support for the presence of DM particles in the galactic halo further excluding any side effect either from hardware or from software procedures or from background

The data favour the presence of a modulated behaviour with all the proper features for DM particles in the galactic halo at high C.L.

DAMA/LIBRA activities

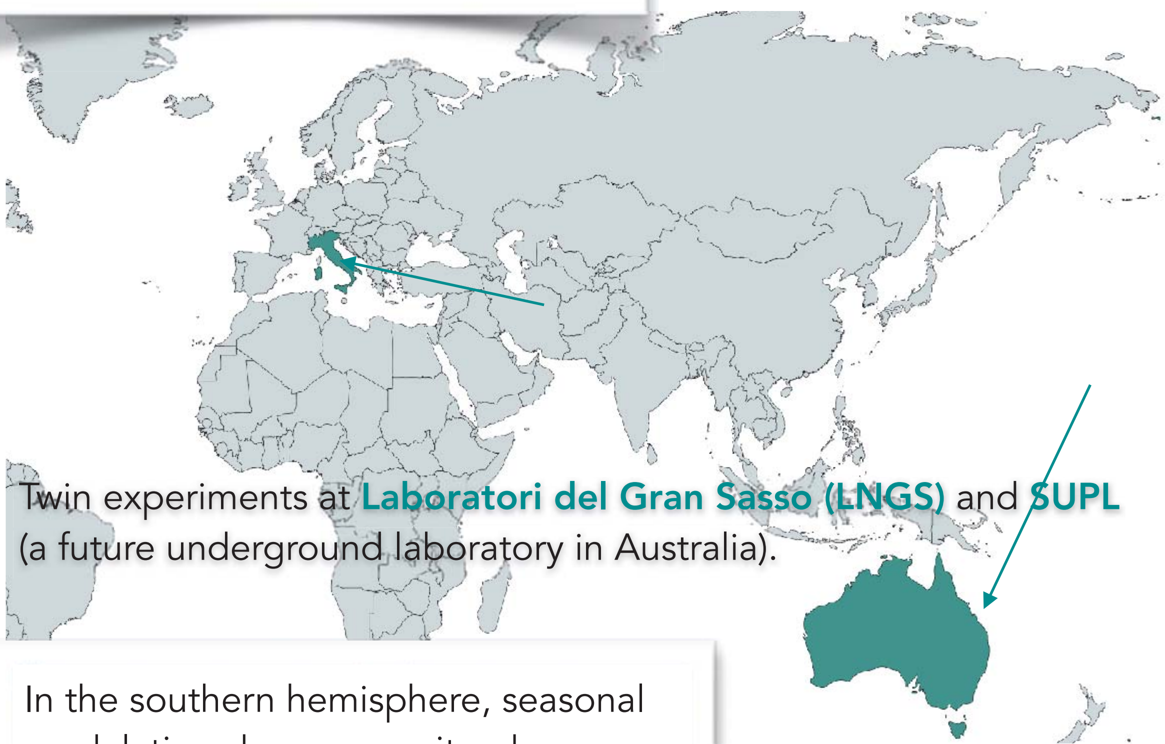
- Presence of DM particles in the galactic halo supported at 12.9σ C.L. (cumulative exposure 2.46 ton × yr – 20 annual cycles with three different set-ups).
- Modulation parameters determined with increasing precision.
- New investigations on different peculiarities on the DM signal exploited in progress.
- DAMA/LIBRA-phase2 running.
- DAMA/LIBRA-phase3 R&D in progress.
- Continuing investigation of rare processes other DM.



SABRE:Sodium Iodide with Active Background Rejection

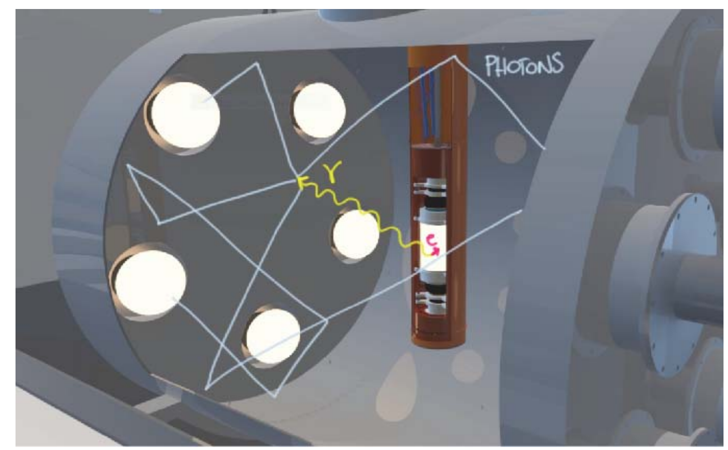
Search for DM particles in the galactic halo through the annual modulation effect = signal from DM expected to modulate yearly with maximum in June.

SABRE is a new experiment using NaI(Tl) scintillating crystals. Its goal is to reach an extremely low background.



Twin experiments at **Laboratori del Gran Sasso (LNGS)** and **SUPL** (a future underground laboratory in Australia).

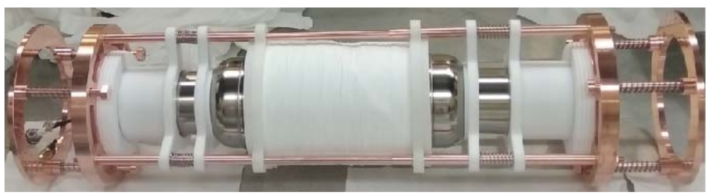
In the southern hemisphere, seasonal modulations have opposite phase while DM induced modulation maintains the same phase.

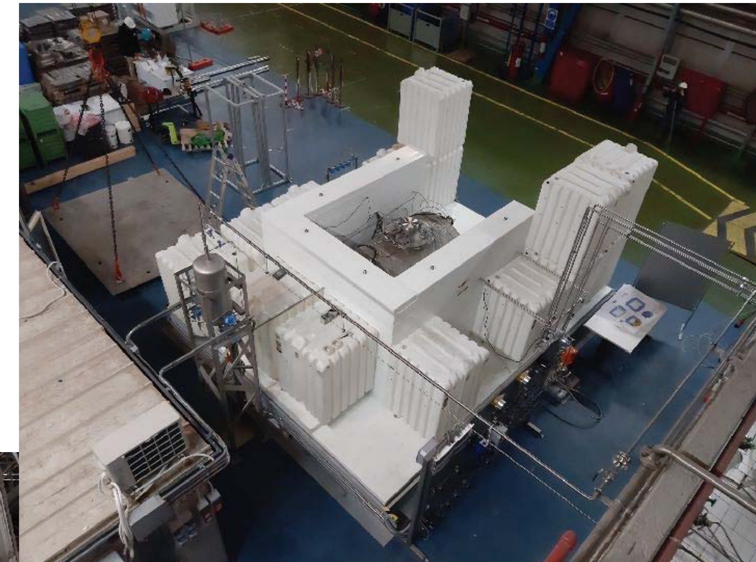


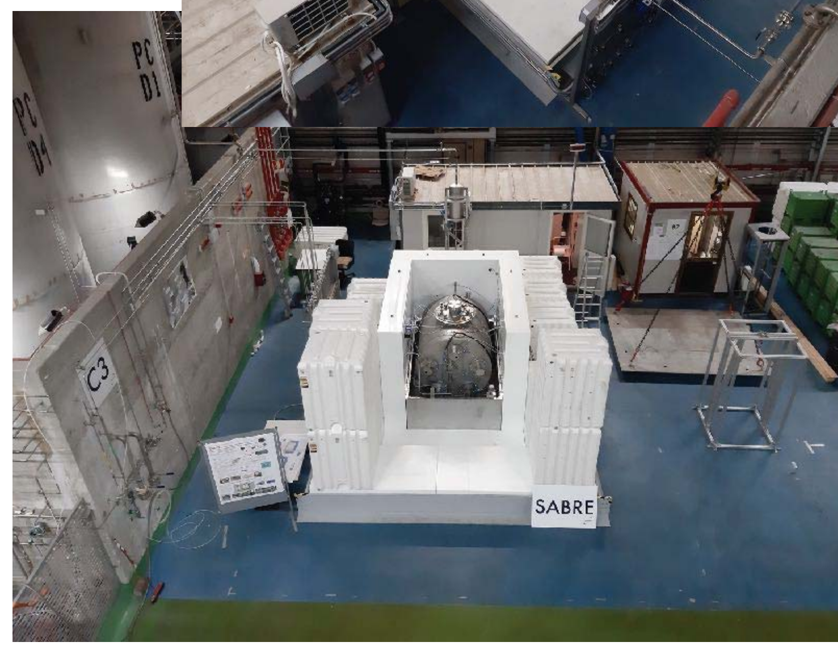
- NaI(Tl) scintillating crystal of ultra high radiopurity
- A **liquid scintillator veto,** surrounding the NaI detector at 4π, strongly reduce:
    - external backgrounds
    - internal backgrounds that release energy also in the liquid scintillator

SABRE: Proof of Principle PoP

A Proof of Principle stage for SABRE is planned at LNGS
Goals:
Test active veto performance
Fully characterise the intrinsic and cosmogenic backgrounds of the SABRE crystals





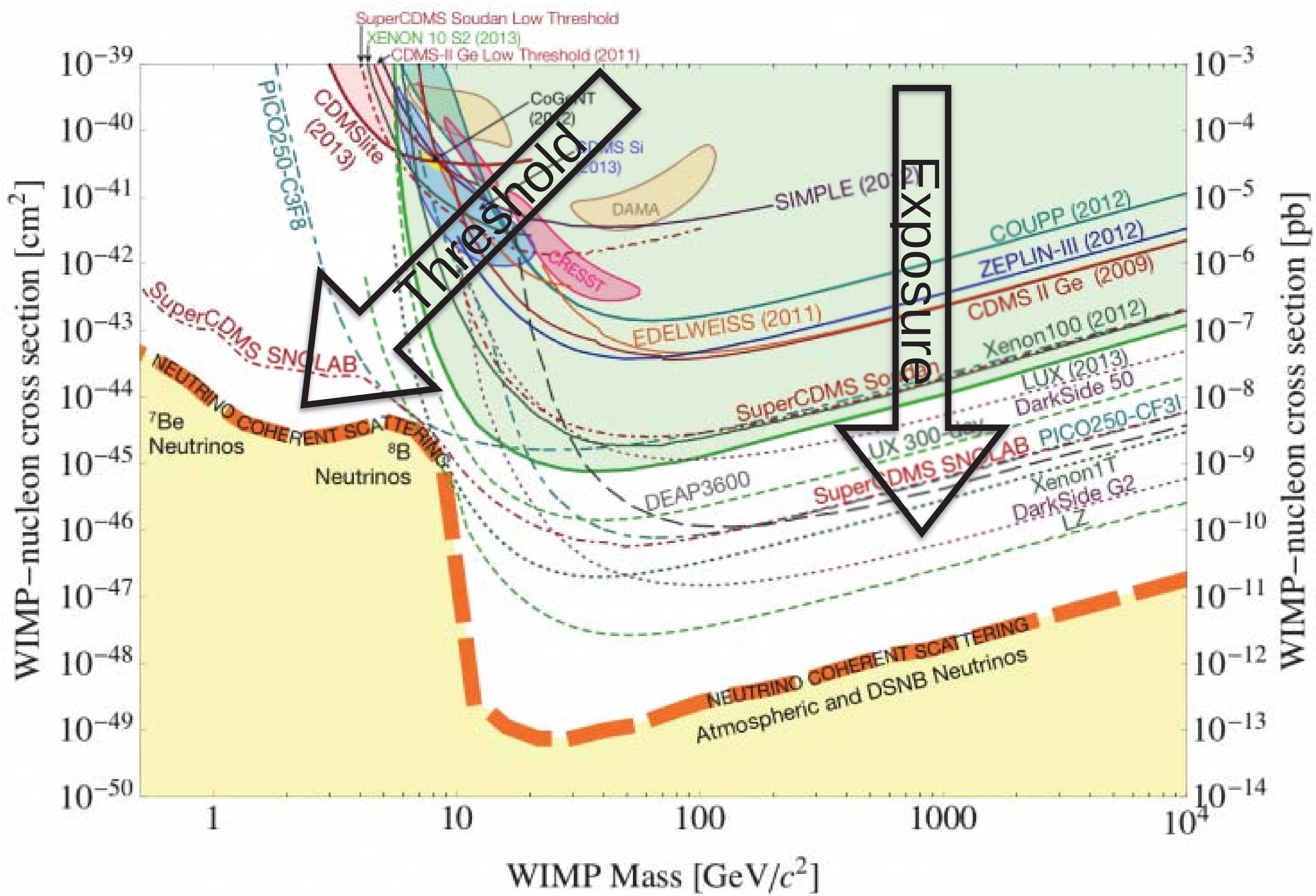


The SABRE PoP setup in Hall C @ LNGS is READY!

THESIS ACTIVITIES:
SABRE PoP assembly and data taking @ LNGS
NaI crystal tests @ INFN Roma
Montecarlo simulations for SABRE PoP and SABRE

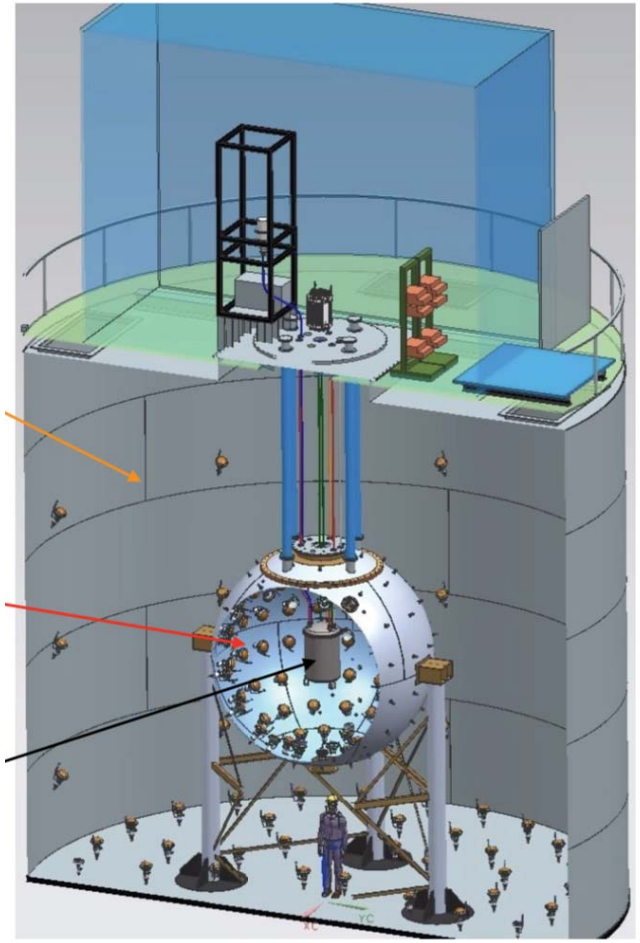
Where are we going?

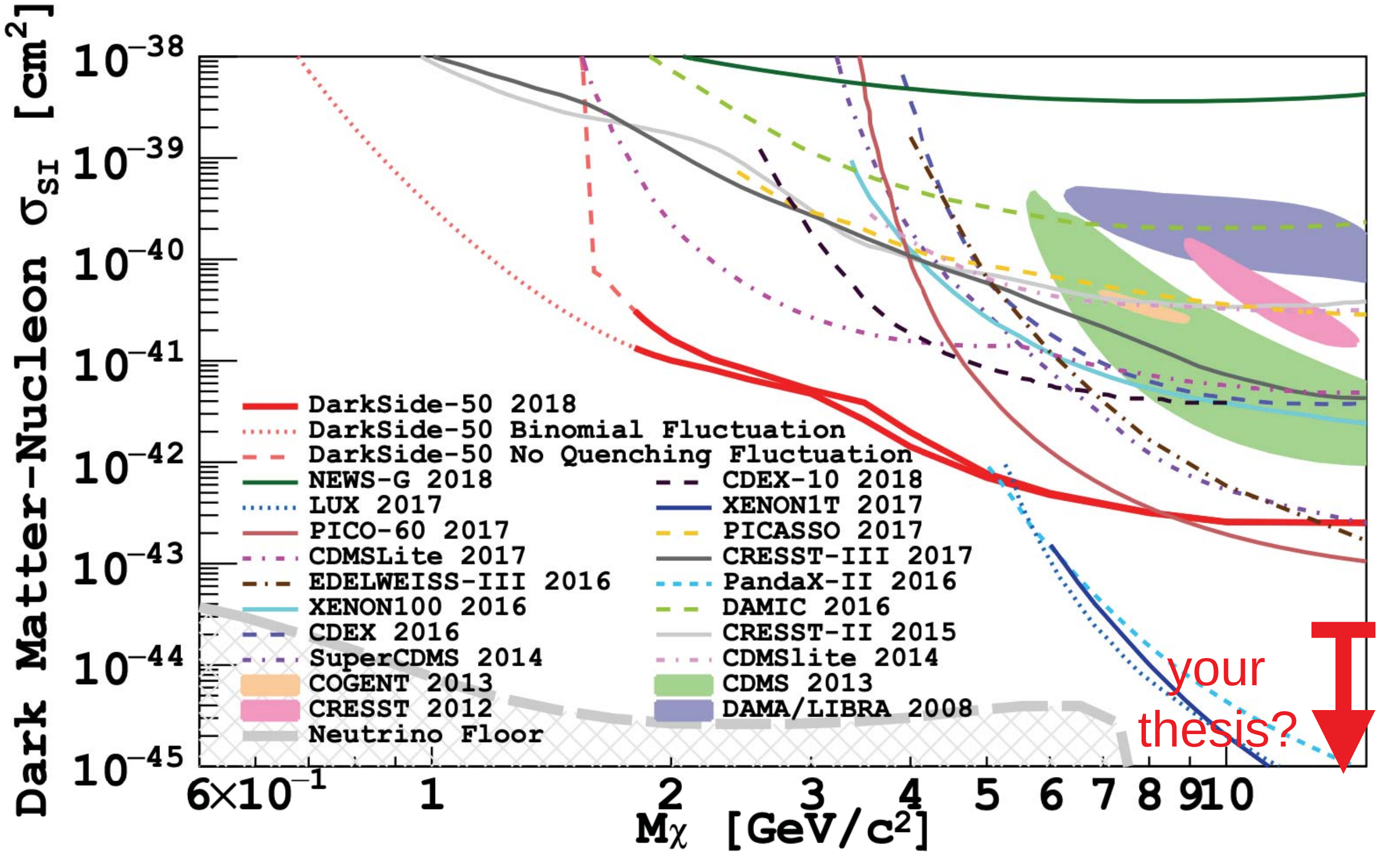
- Experiments with mass larger than 20 tons are expected in the '20s.



Take a walk on the dark side

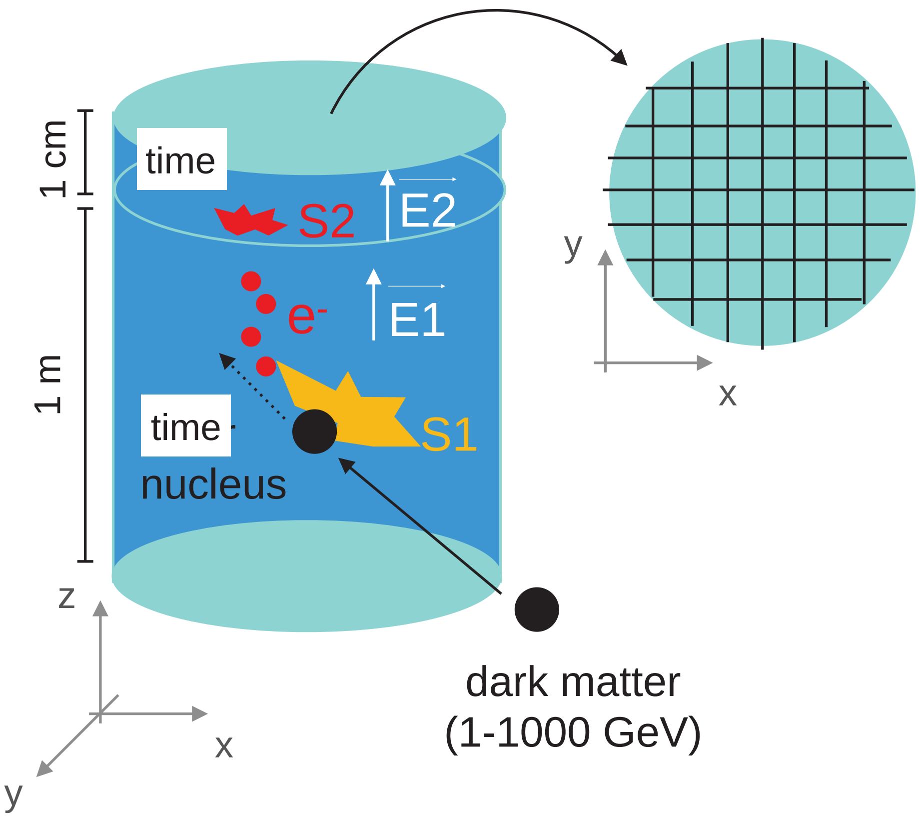
- 2018: highest discovery potential for low-mass Dark Matter (DM) using 50 kg LAr active volume
- 2019-2021: scaling up to 20 ton to touch neutrino floor!

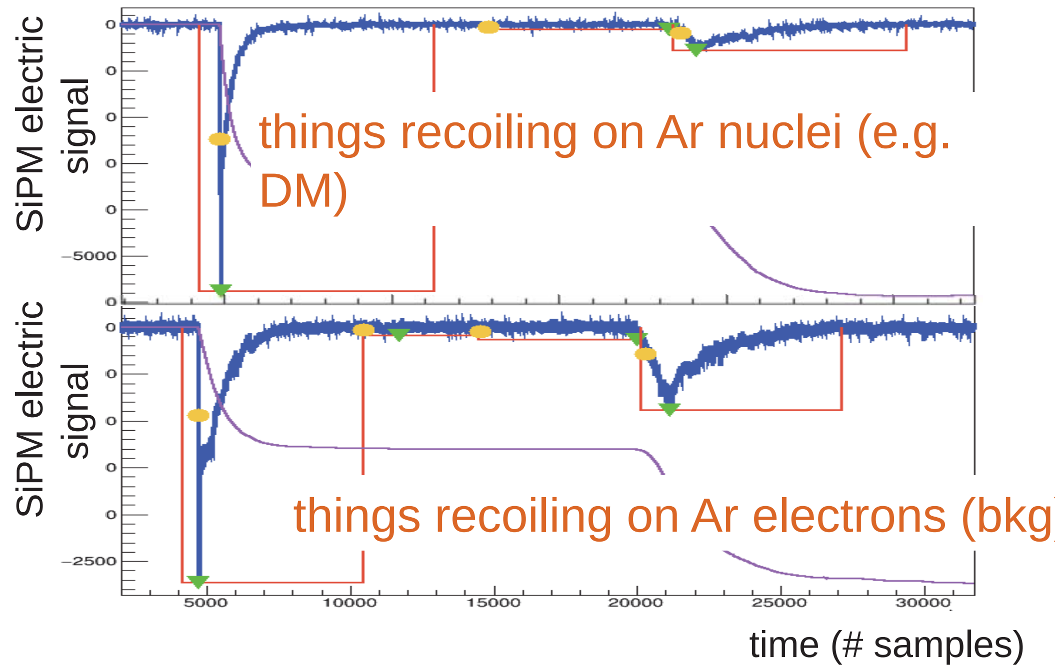




DARKSIDE 20K

- 20-ton LAr detector: double-phase TPC with 8000 light detectors (SiPM)
- strategy: study #photons vs time to separate DM from bkg

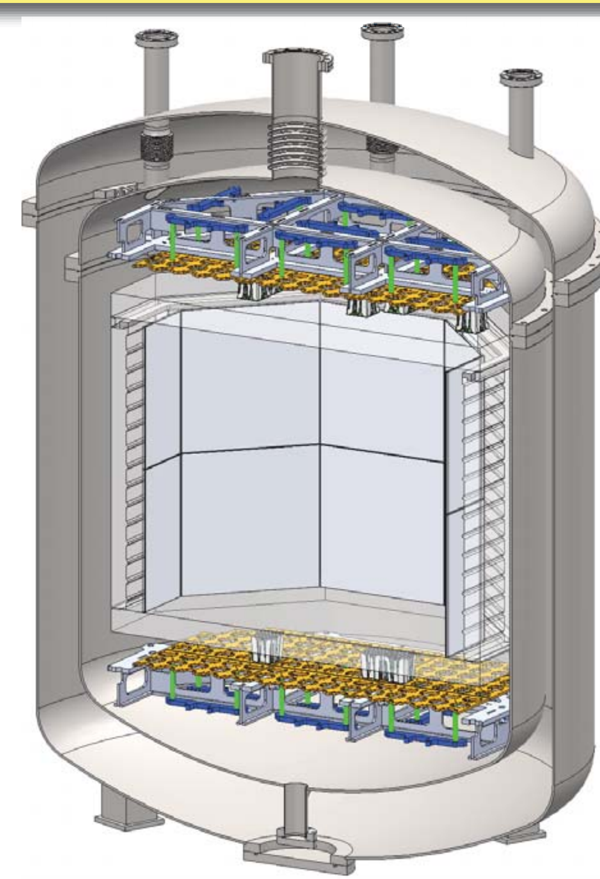


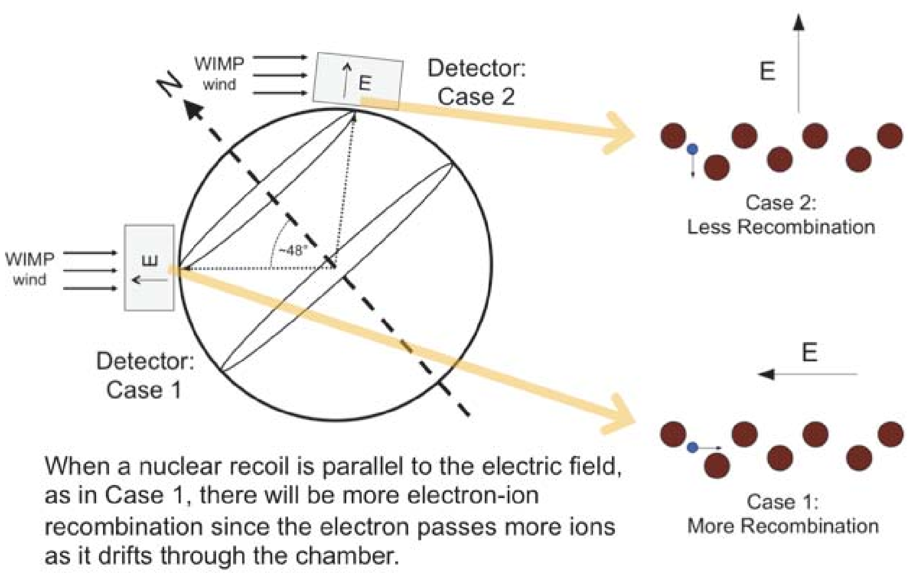


- Roma Activity: similar rate as LHC ⇒ develop trigger & reconstruction

1 ton prototype and ReD

- 1-ton prototype of 20-ton detector is now being built at CERN
  - you can take part to all aspects of the design of an experiment: Monte Carlo simulation, building, commissioning,
  - unique possibility to take and analyse data to characterise SiPM and LAr response





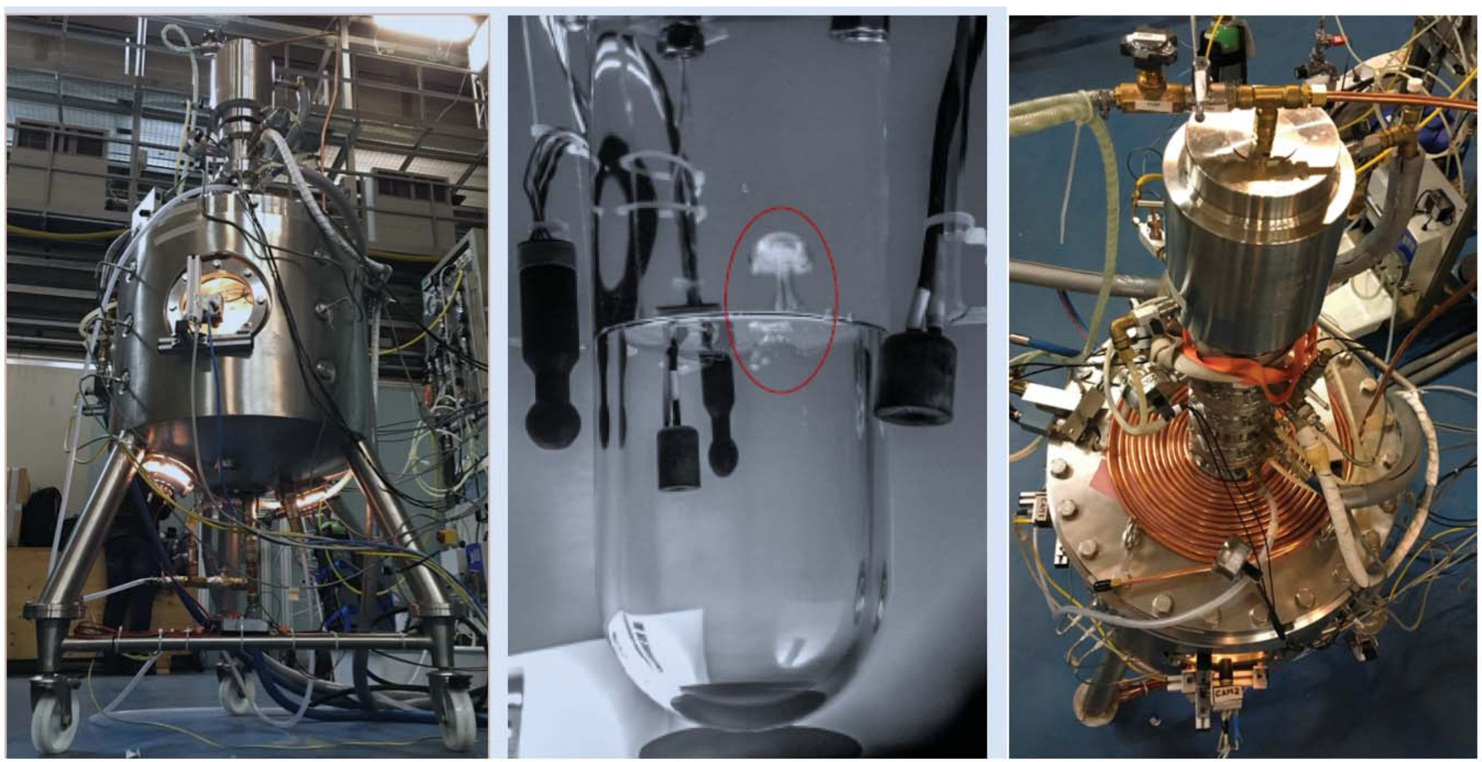
- Dark Matter signal would arrive from Cygnus
  - electron-ion recombination in LAr may give a way to confirm so
  - ReD: dedicated R&D experiment to quantify this effect

MOSCAB

MOSCAB is a geyser-concept bubble chamber used to explore the spin-dependent WIMP-proton coupling in which the achievement/retention of the superheated state of the sensitive liquid (C_3F_8) is obtained thermally rather than mechanically. The detector is presently operated in Hall C at LNGS.

In the MOSCAB bubble chamber the metastability is gained by filling the chamber with the target liquid in equilibrium with its vapour at a given temperature, and subsequently cooling the top portion of the chamber to produce a partial condensation of the vapour and a decrease of the operating pressure to the saturation value at the cooling temperature, while the liquid is still kept at the original temperature. A buffer layer of propylene glycol is inserted between the target liquid and its vapour. Once a vapour bubble nucleates due to a nuclear recoil, it rises through the superheated liquid generating a small geyser when crossing the interface with the overlying buffer layer. After the condensation of the excess vapour occurs in the top portion of the detector, the drops of condensate fall back into the target liquid, which recovers its original superheated state.

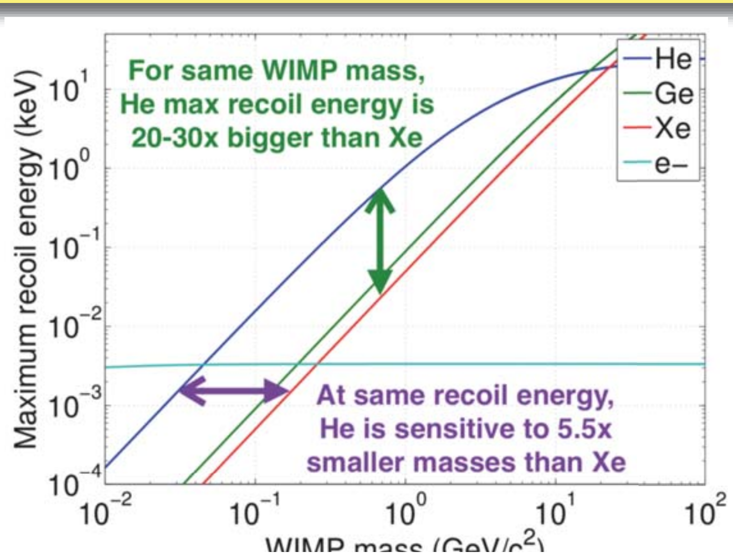
Details are available in MOSCAB: a geyser-concept bubble chamber to be used in a dark matter search, Eur. Phys. J C 77 (2017) 752



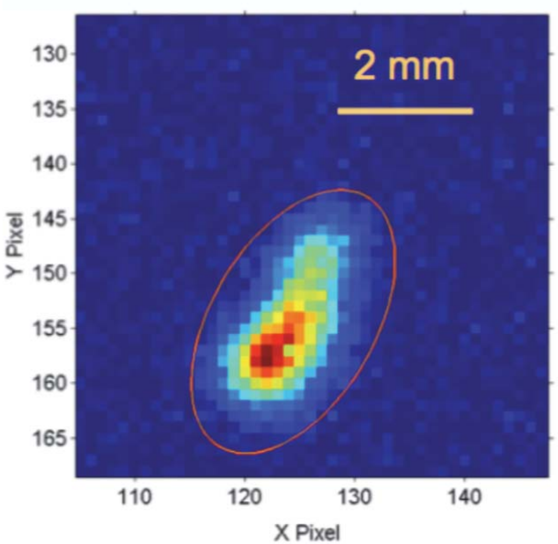
Overcome
the neutrino floor

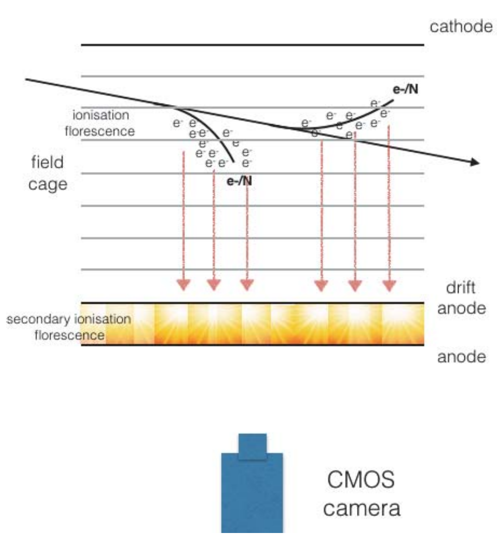
CYGNO:1m³ TPC + Optical Readout

- 3D tracking (position and direction);
- total released energy measurement;
- dE/dx profile (PID, head-tail);
- Nuclei free path can be long enough to be reconstructed;
- Low A gases allow an efficient momentum transfer from light DM
- Avalanche mechanism allows sensitivity to primary electrons (30-40 eV of energy released



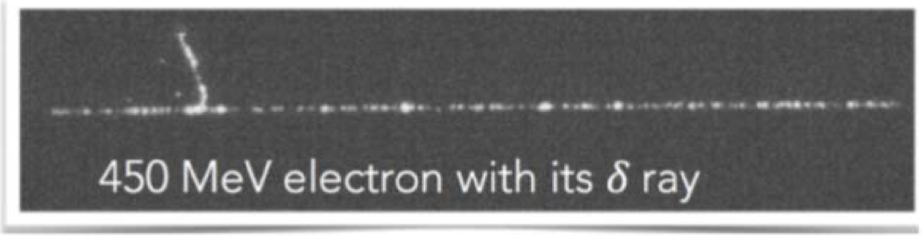
Nuclear recoil in gas

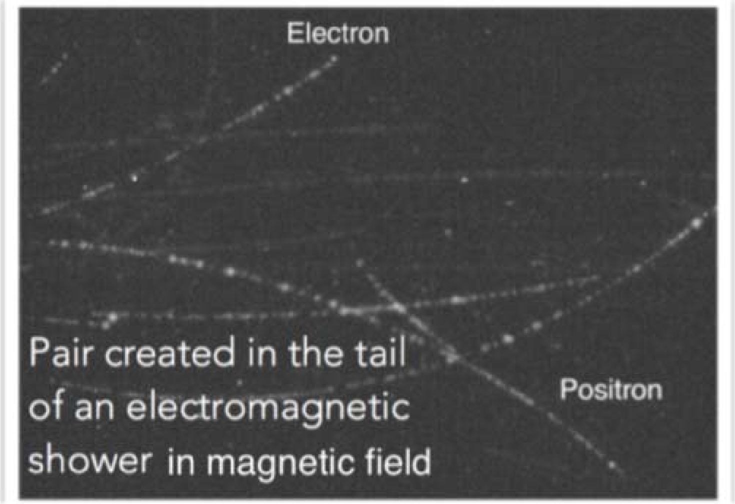


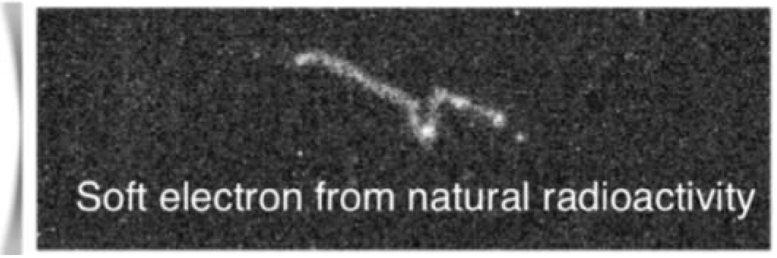


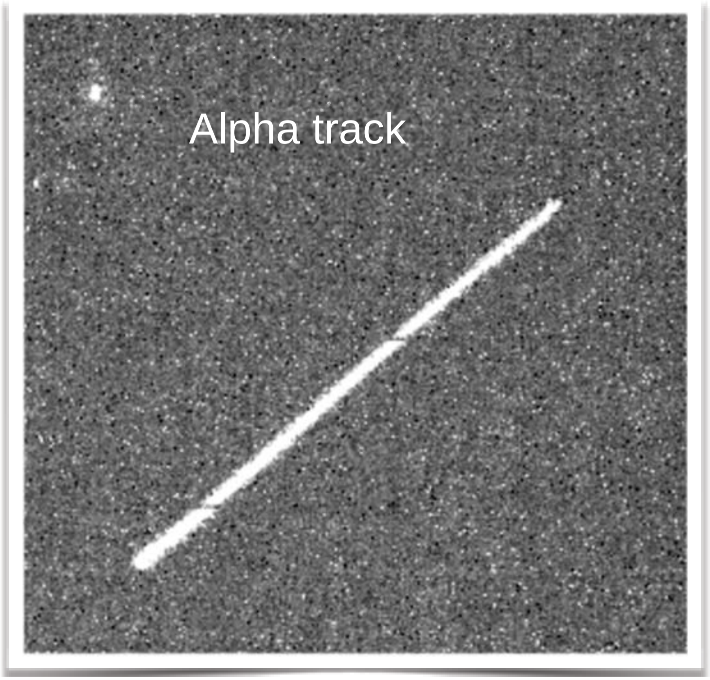
- CMOS camera
  - Available on the market
  - Single photon sensitivity
  - Large areas with proper optics
  - Not coupled with active volume

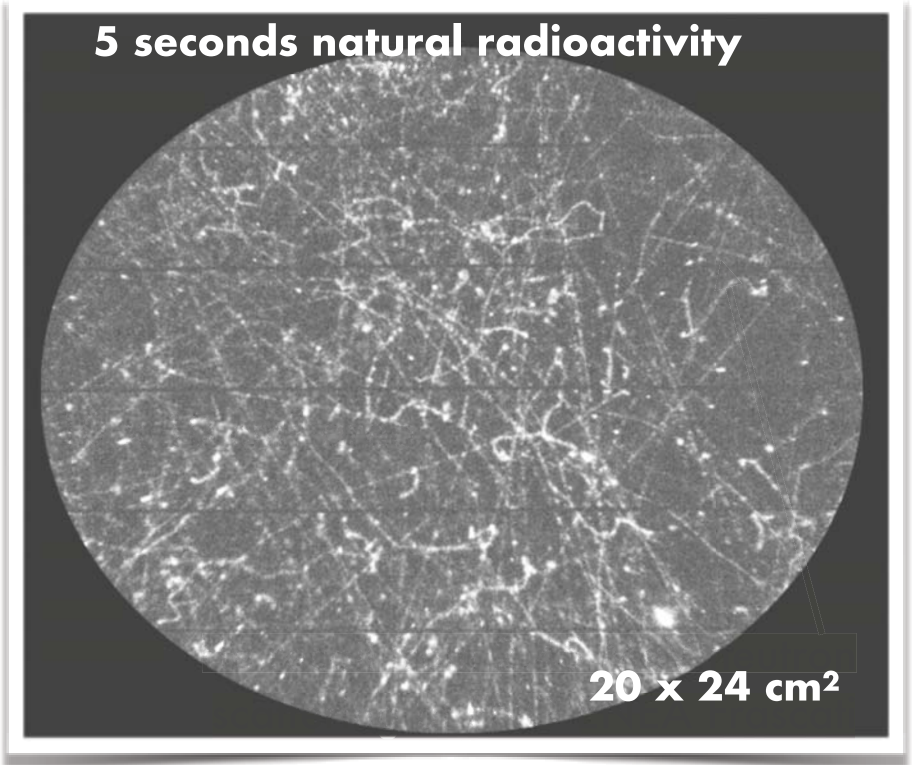
Particle tracks



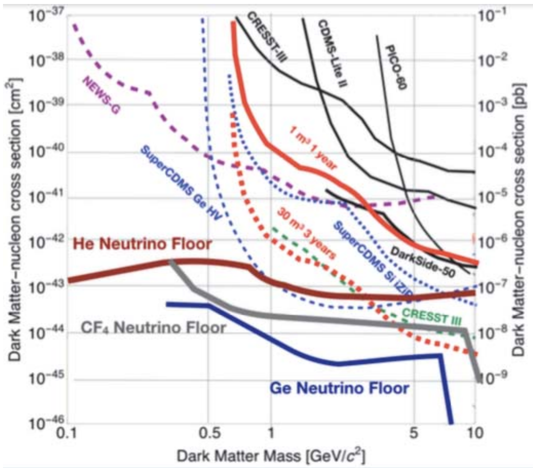


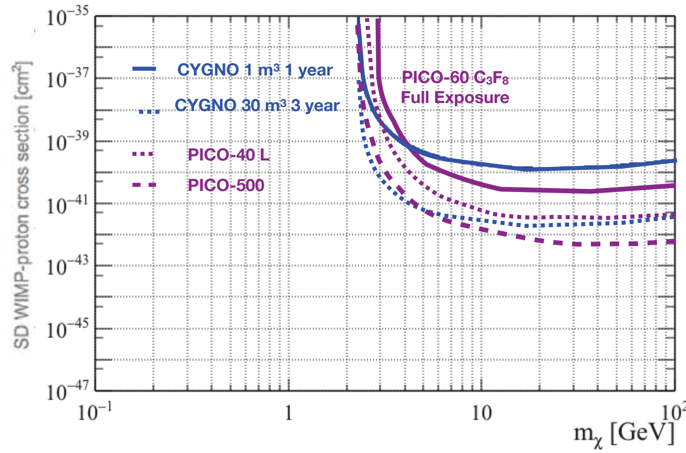


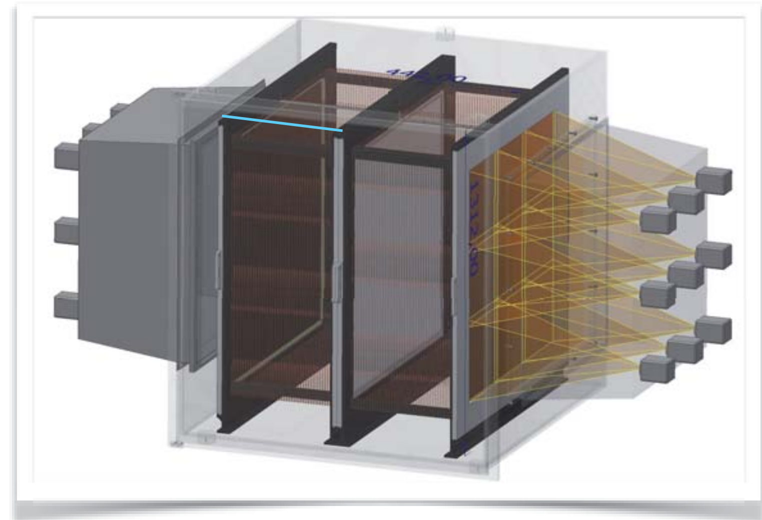




The CYGNO apparatus

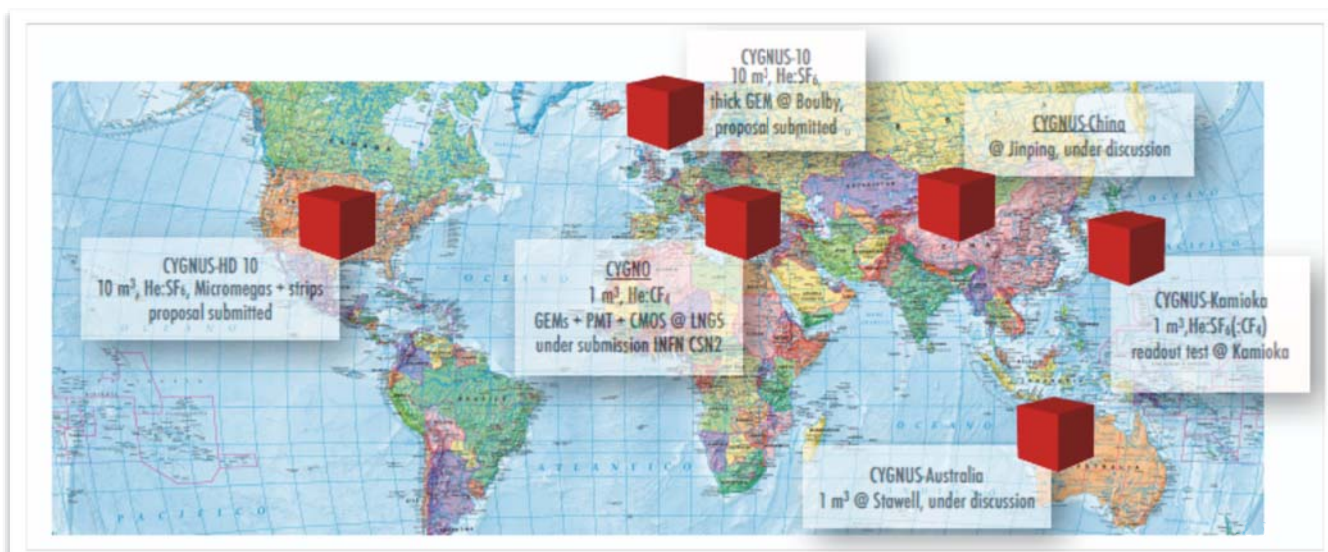






- Working on the Technical Design Report for 1 m^3 of He/CF_4 60/40 (1.6 kg) at atmospheric pressure as a demonstrator of the technology performance in order to prepare a proposal for a **30-100 m^3 experiment**

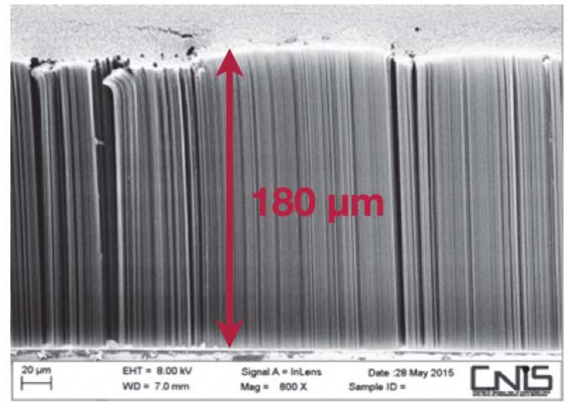
- Directional Dark Matter search in the low mass region that can represent the **first module of a World Wide Network** of underground observatories

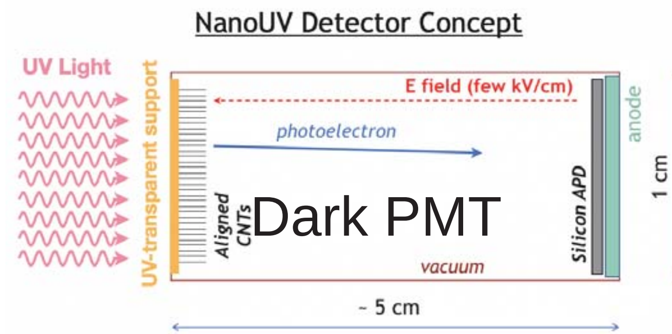


CNT, ADAMO, News

CNT

Aligned Carbon NanoTubes
As anisotropic target for DM
Unexplored range of mass ~MeV
Need grams not tons





ADAMO

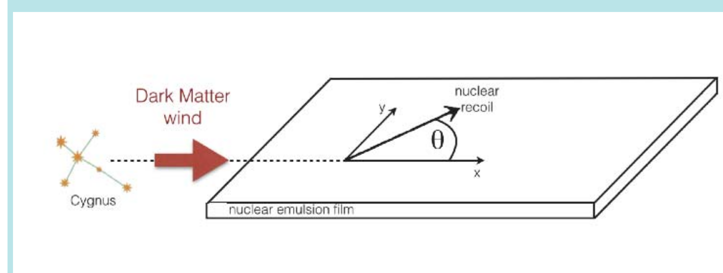
Development of $ZnWO_4$ scintillators

- ✓ Both light output and pulse shape have anisotropic behavior and can provide two independent ways to study directionality
- ✓ Very high reachable radio-purity;
- ✓ Threshold at keV feasible;

Presently running at ENEA-Casaccia with neutron generator to measure anisotropy in keV range

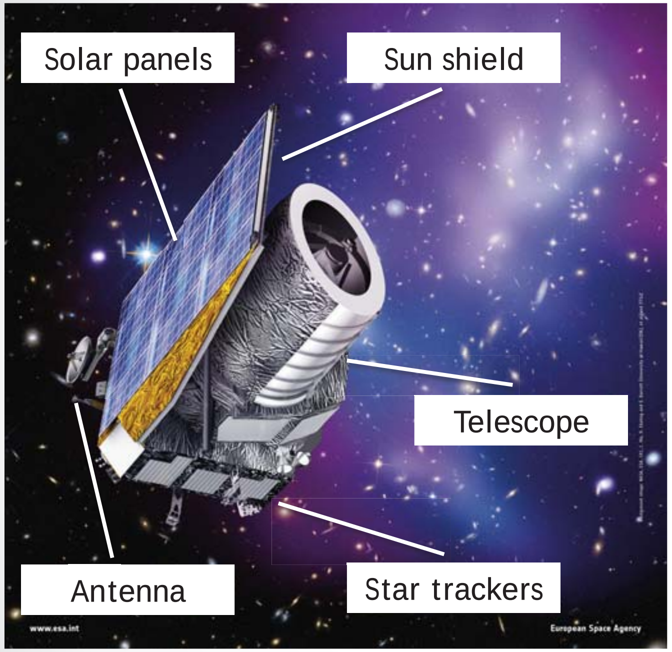
NEWS

A directional experiment, for DM candidates inducing nuclear recoils, based on the use of a solid target made of newly developed nuclear emulsions and of optical read-out systems reaching unprecedented nanometric resolution.



the angular distribution of recoiled nuclei is centered around the direction of the Cygnus constellation, while the background distribution is expected to be isotropic. The nuclear emulsions act both as target and nanometric tracking device.

Euclid: next ESA space mission for Cosmology. 2022-2028.
Focus on Dark Energy/Modified Gravity & Dark Matter



- ESA medium class mission (6yr)
- 1.2 m aperture telescope
- Optical imaging in RIZ up to 24.5
- NIR imaging in Y, J, H
- Slitless spectroscopy
- Launch in June 2022 to L2 orbit
- Cosmology
  - weak lensing
  - galaxy clustering
  - clusters
  - CMB cross – correlation
- Legacy science

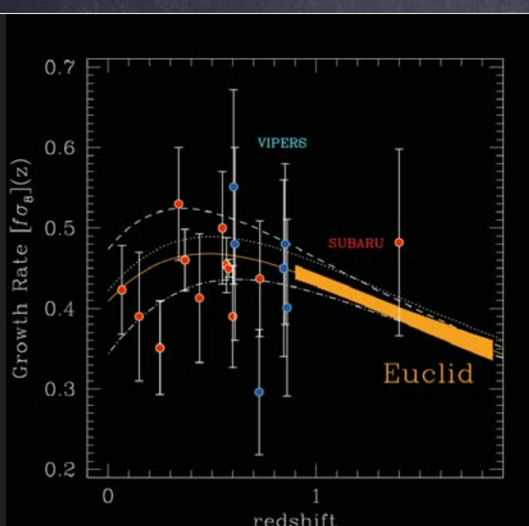
Largest project (so far) in Astronomy:
~ 1330 members ~130 Labs
13 EU countries NASA Canada ~ 1G€

Italy is the second largest contributor after France, with many key roles and responsibilities in instruments, science ground segment, sconce groups and technical groups

Euclid is a cosmological factory:
primary probes are Galaxy clustering and Gravitational Lensing to which add galaxy clusters, cross correlations with Cosmic Microwave background and strong lensing

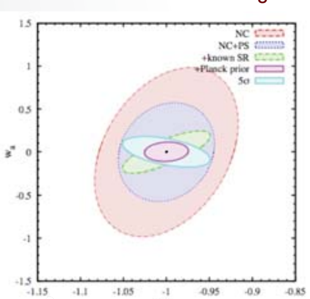
Euclid consortium

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
20 ANNI DI RICERCA SCIENTIFICA DI ECCELLENZA



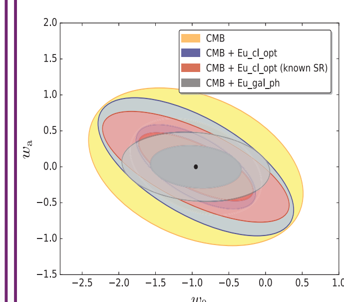
Galaxy Clusters

- 20K clusters at $0.2 < z < 2.0$
- 80% at $M_{200} = 8 \times 10^{13}\ M_{sun}$
- Different degeneracies
- Different systematics
- Relatively easy to model
- Two approaches
  - cluster abundance
  - cluster clustering



CMB Cross Correlation

- CMB x Euclid data
- Integrated Sachs - Wolfe
- Systematics control
- CMBX estimators
- CMB lensing ray tracing
- Forecasts and likelihood
- GR and Modified Gravity
- PPN parameters



Strong Lensing Systems

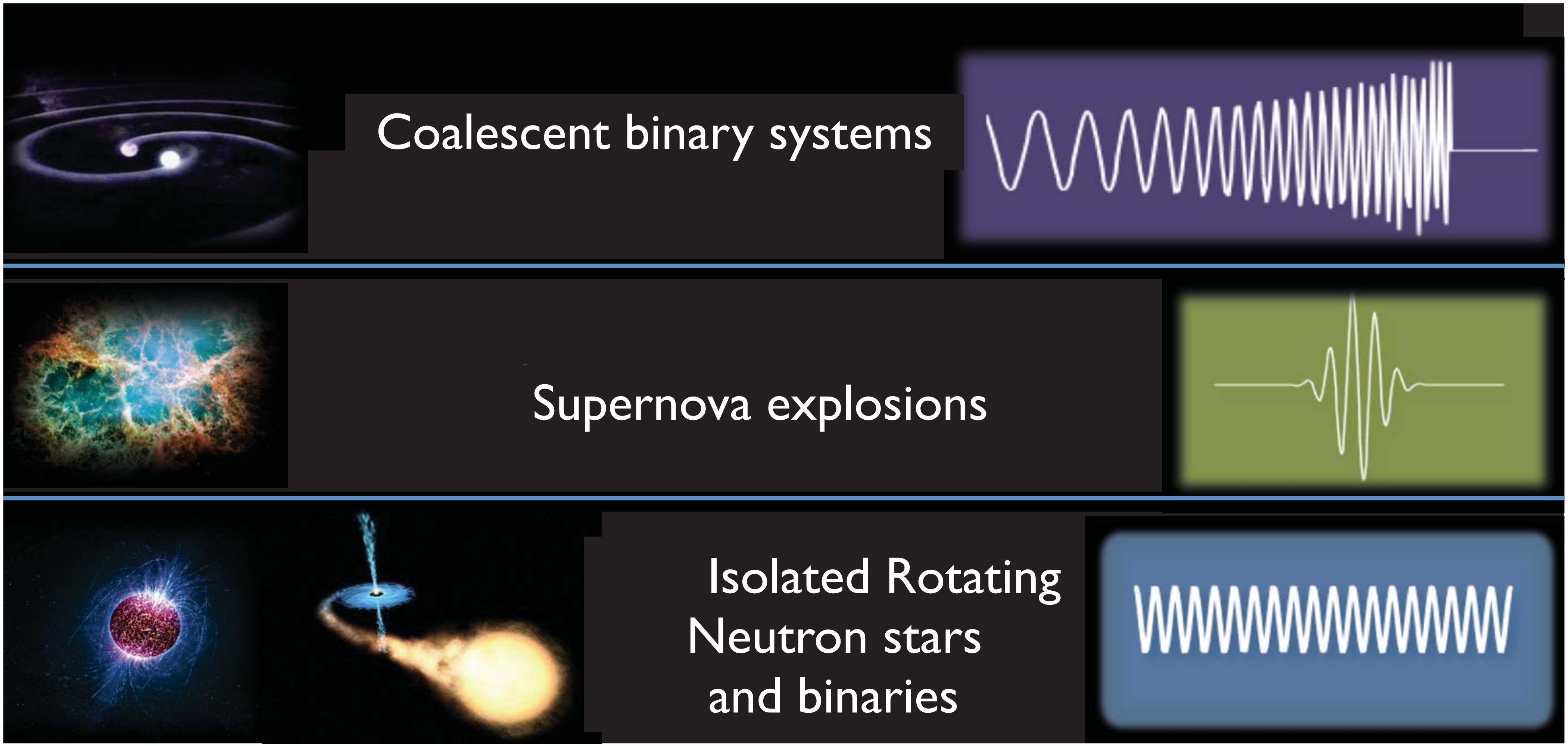
- 1 – 2 x 10^5 gal – gal lenses
- 10^3 QSO – gal lenses
- 8 x 10^3 giant arcs clusters
- 10^2 multiple images clusters
- Lens statistics
- Cosmography
- Time delay distances
- Dark haloes modeling

euclid

Gravity and Quantum: Gravitational Waves

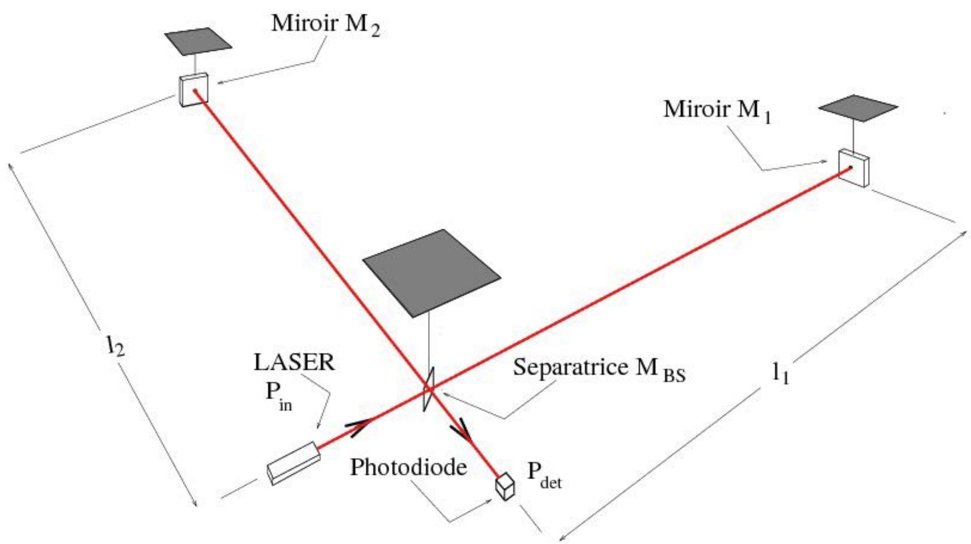
Gravitational waves

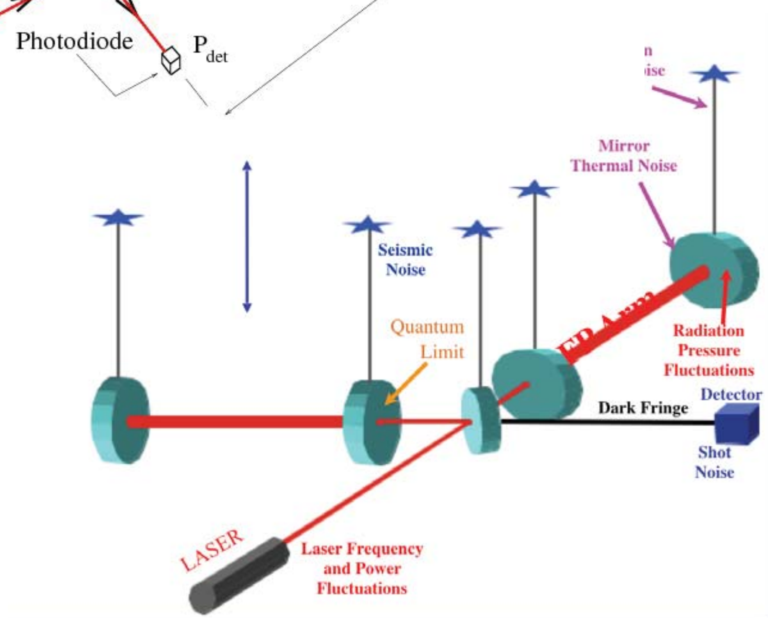
- General Relativity foresees emission of gravitational wave

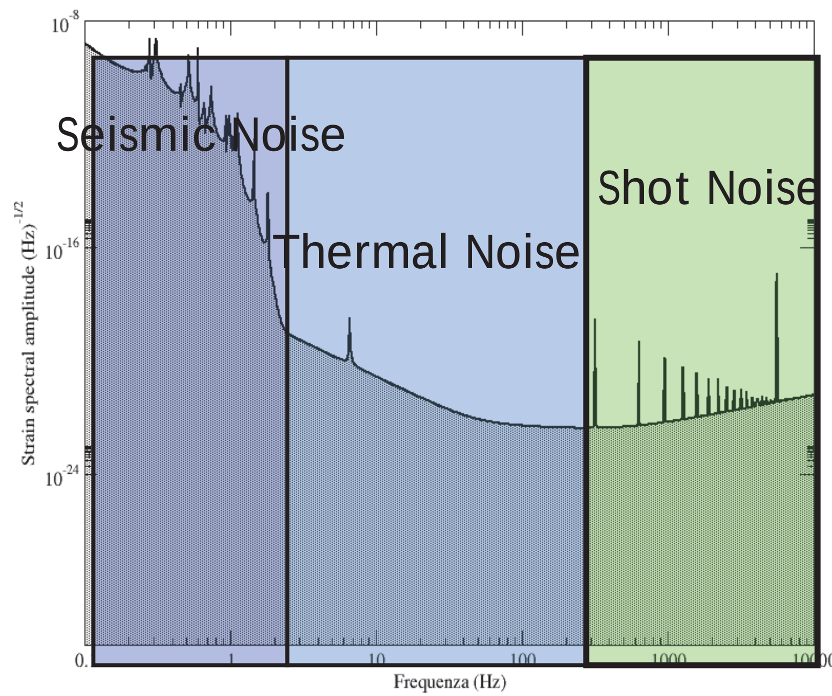


How to detect gravitational waves

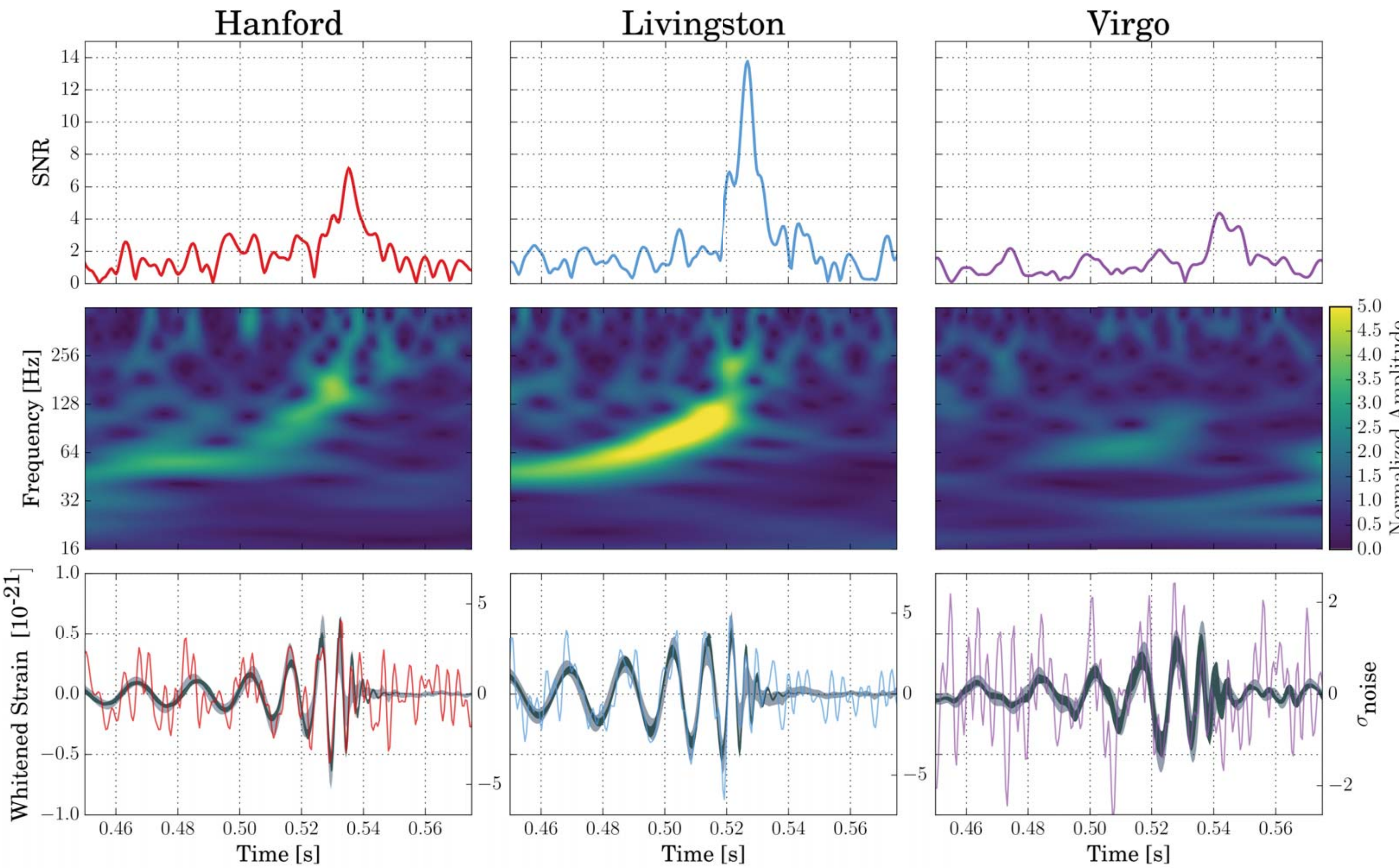
- GW amplitude is a strain h: fractional change in length or equivalently light travel time, across the detector
  - $h=10^{-21}$, on a 3 km arm difference in length of $\sim 10^{-3}$ fm



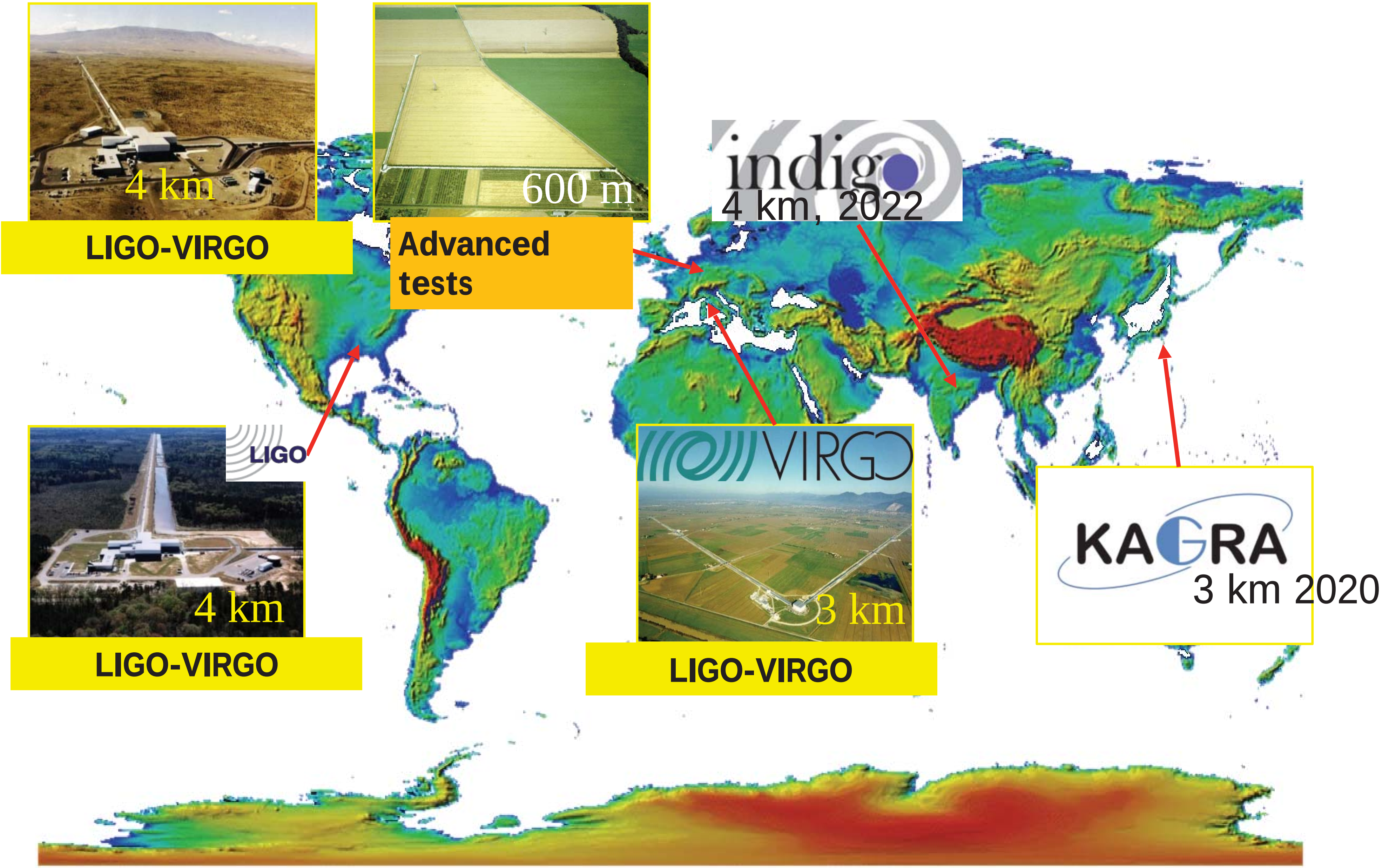




Birth of GW era: 14/09/2015



Worldwide GW detector network

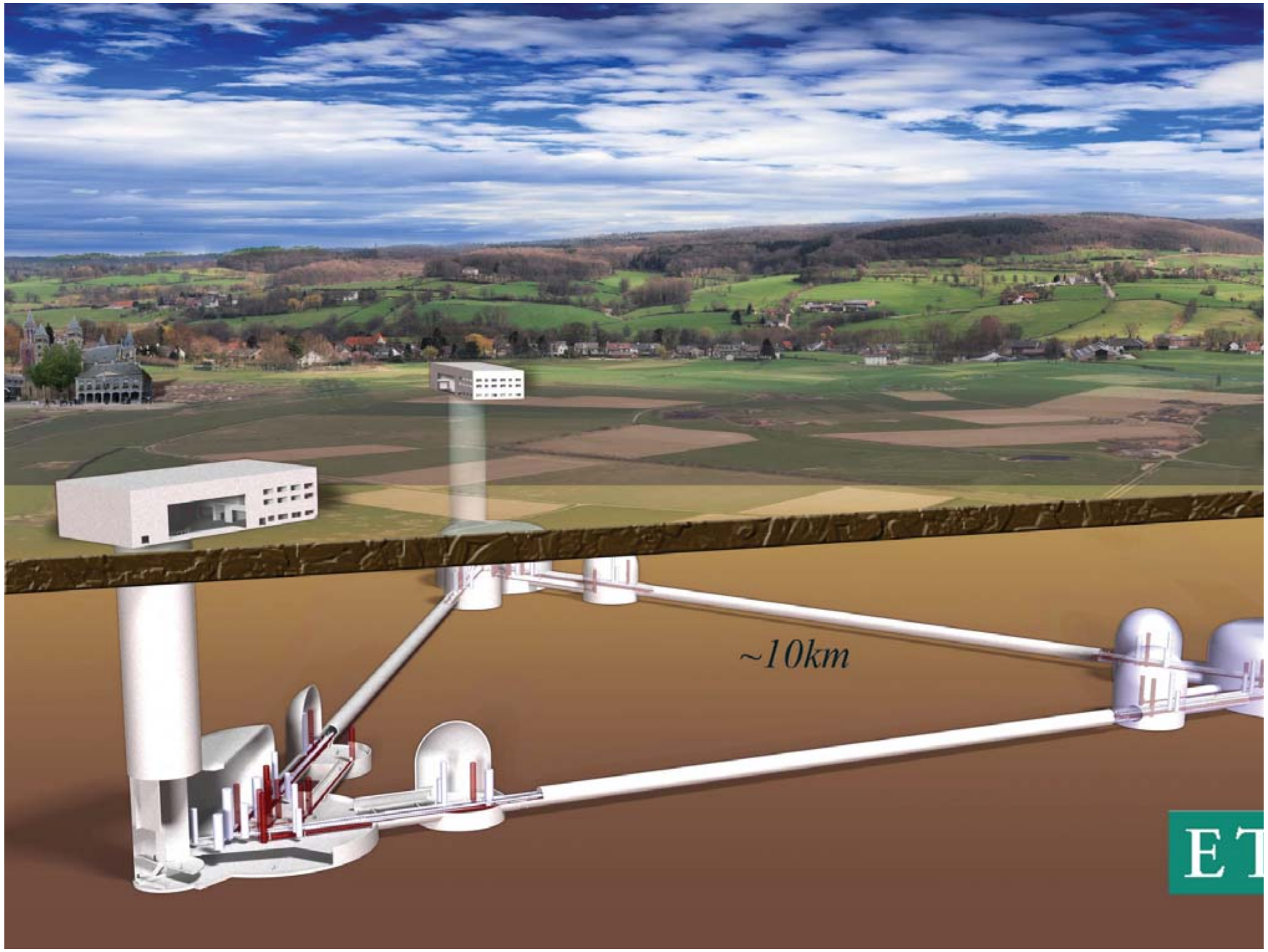


Virgo run III recently started 19/04

- It will last 1 year
- Hardware activities
  - Thermal noise in Test-Mass suspension for Virgo, quasi-monolithic suspension and enhanced steering stage
  - Squeezing techniques developments
- Software analysis
  - Development of advanced data analysis techniques for the search of periodic gravitational waves emitted by spinning neutron stars and their application to the data of Virgo and LIGO detectors.
  - A narrowband Continuous-Wave search from Neutron Stars in binary systems

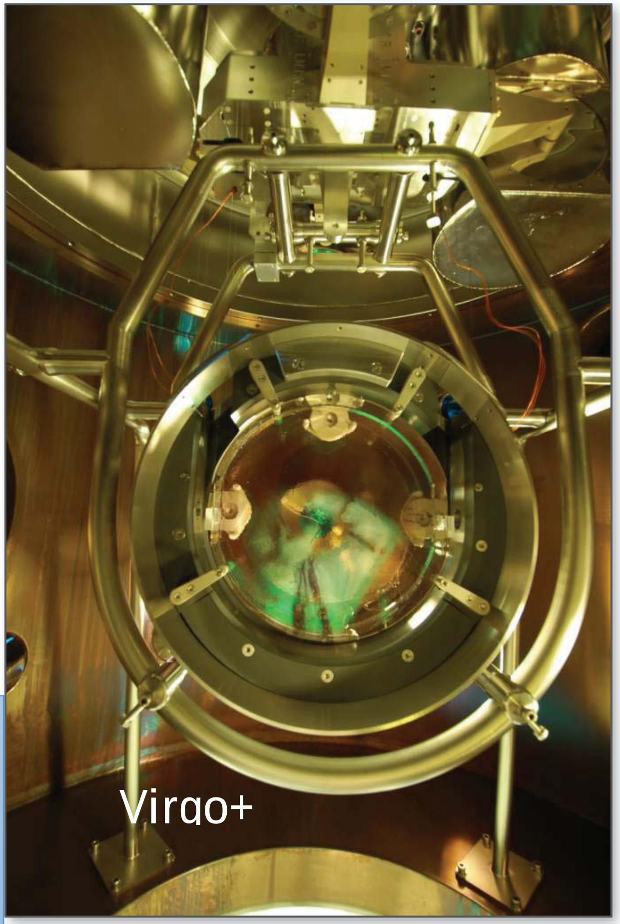
Future: Einstein Telescope

- Sensitivity 10 times better than advanced interferometers
- From GW detection to GW astronomy



Rome expertise

- In Virgo: **last stage suspension of the mirrors** *(payloads)* which are at the bottom of a high efficiency **seismic isolation system**



So far, we have built and integrated all the test mass mirror suspensions in Virgo.

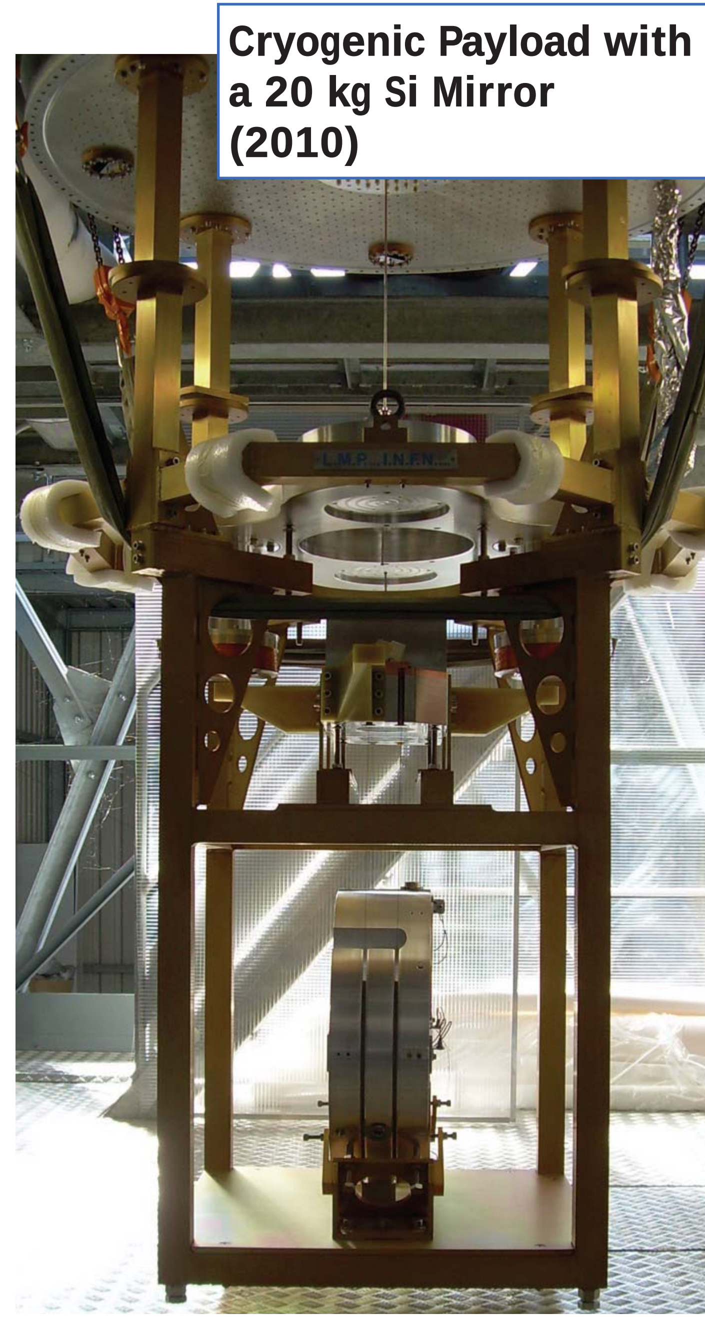
Cooling test mass mirror

While building Virgo, we have started to study how to cool down a test mass mirror in a GW Interferometer

Active System for Pulse Tube Vibrations Attenuation

RSI 77(9):095102 - 095102-7 · 2006

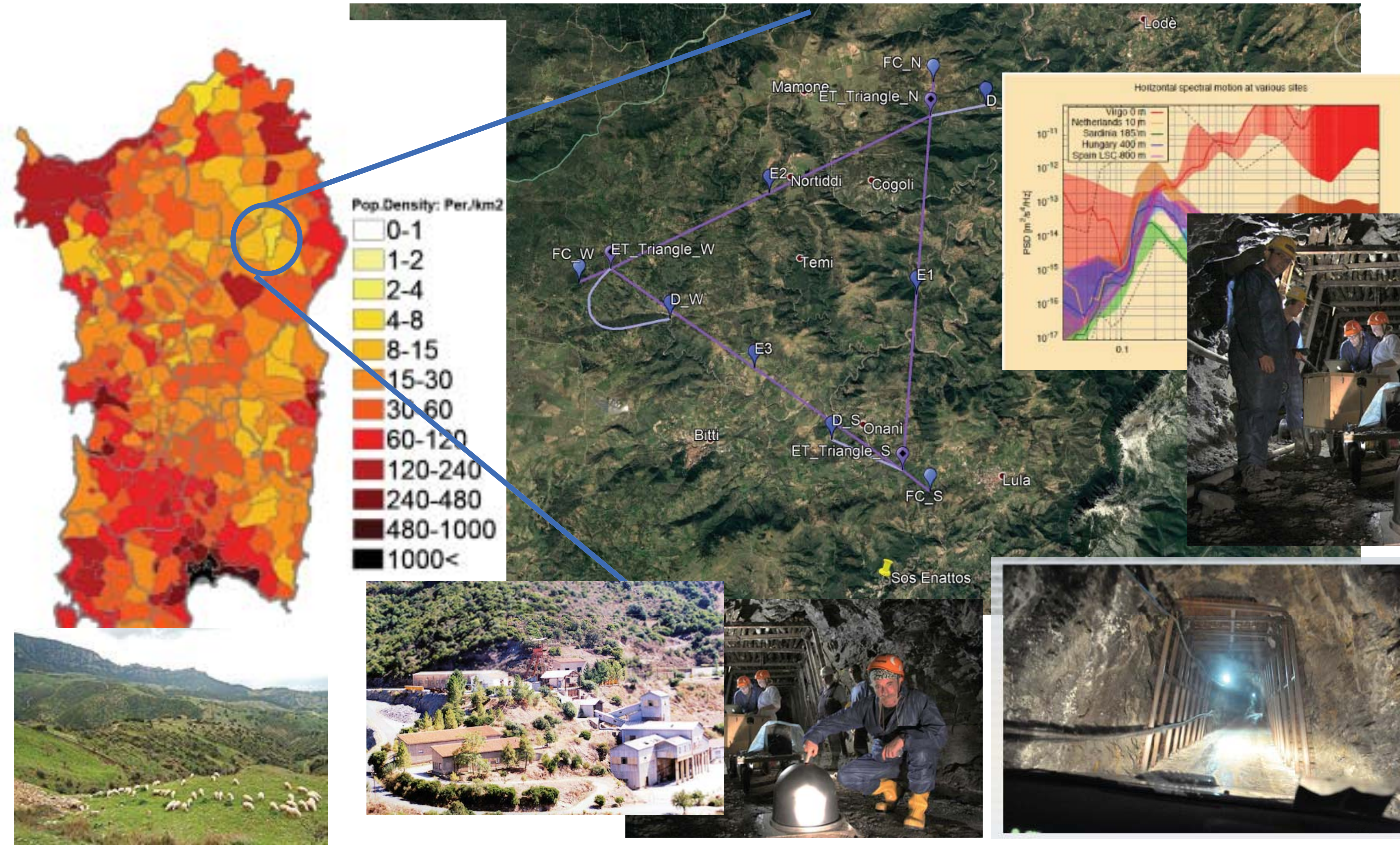
Cryogenic Payload with a 20 kg Si Mirror (2010)



R&D on a cryogenic detector started since 2008 with the Einstein Telescope (ET) Design Study

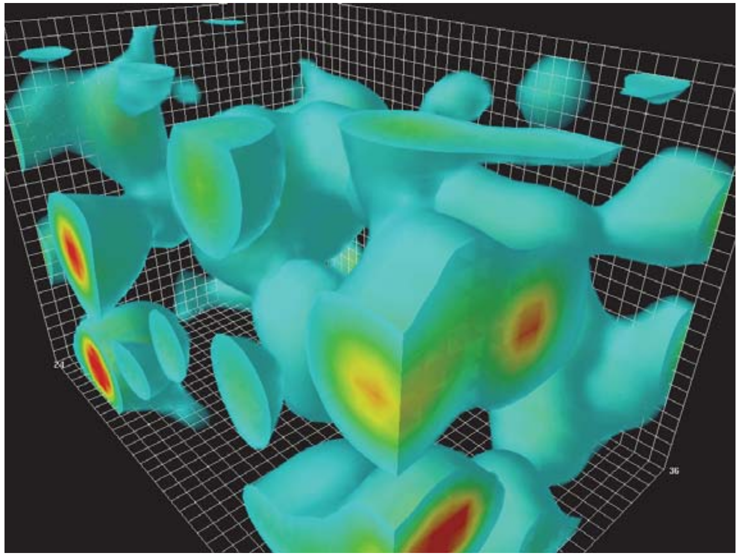
Site characterisation

- Sos Anattos (Orosei)

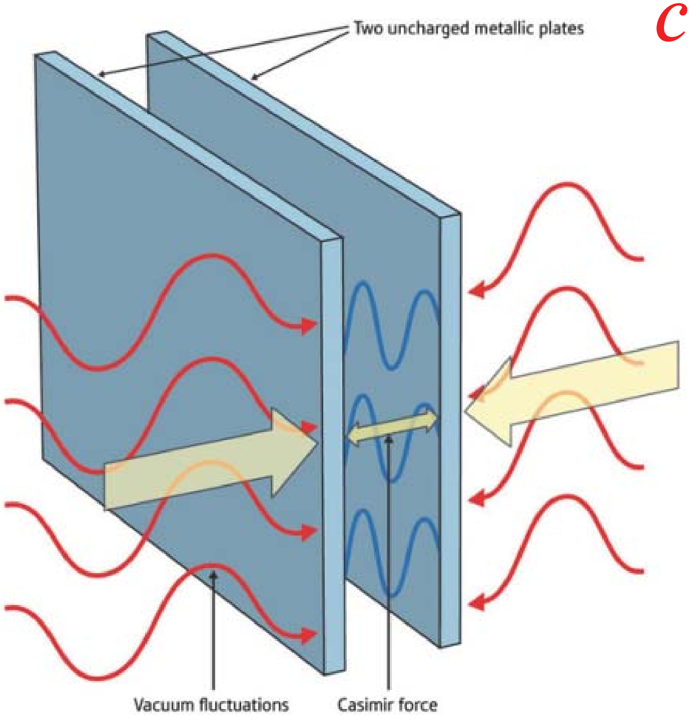


Archimedes

- Do vacuum fluctuations interact with gravity?
- Does the vacuum stress gravitates?
- Does vacuum weighs?



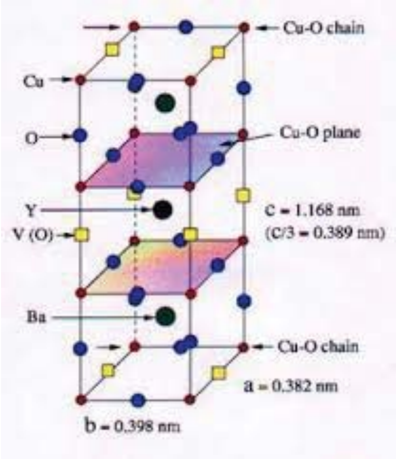
$$\vec{F}_{tot} = -\frac{|E_C|}{c^2}\vec{g}$$



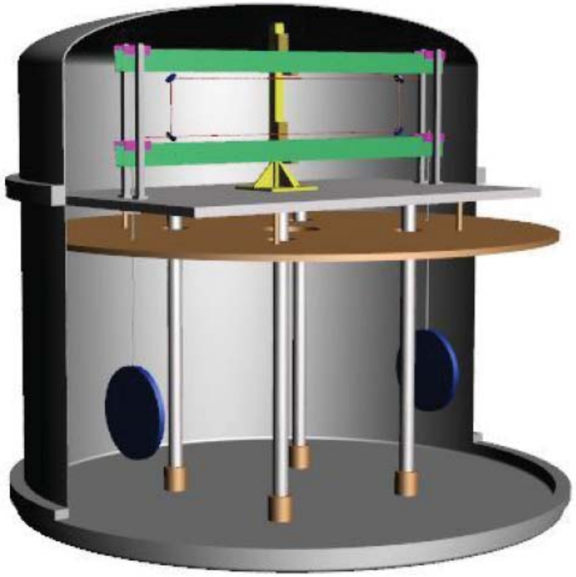
- Casimir effect: If the vacuum «weighs» then there is a force, directed upward, equal to the weight of the modes expelled from the cavity. In analogy with the Archimedes force.

How to measure it

- Modulate vacuum energy of rigid Casimir cavity changing plate reflectivity with time
  - Use **high Tc layered superconductors** (like YBCO) as natural multi Casimir-cavities.
  - in normal state the superconducting plane is a very conductor.



Expected upward force 10^{-16} N



- High Sensitivity Balance:
  - arm center of mass & suspension point positioned within 4μm
- Temperature modulation around Tc
- Interfermoetric Readout

- Rome activities: thermal modulation tests and cryostat construction