CSN2: Astroparticle Physics
Sezione di Roma

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

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Experiments in Rome

lucio.ludovici	T2K/HK	Neutrino
antonio.didomenico	DUNE	Neutrino
claudia.tomei/laura.cardani	CUORE/CUPID	Neutrino
marco.vignati	NUCLEUS	Neutrino
paolo.debernardis	LSPE	CMB
silvia.masi	QUBIC	CMB
gianluca.cavoto	PTOLEMY	CNB
irene.dipalma	KM3/ANTARES	UHE neutrinos
fabio.ferrarotto	CTA	HE gammas
alessandro.bartoloni	AMS	Cosmic Rays
fabio.cappella	DAMA	Dark Matter
giulia.dimperio	SABRE	Dark Matter
sandro.dececco	DarkSide	Dark Matter
davide.pinci	CYGNO	Dark Matter
pia.astone	VIRGO	Gravitational waves
piero.rapagnani	ET	Gravitational waves
paola.puppo	Archimedes	Quantum

To contact them name.surname@roma1.infn.it

Disclaimer

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

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

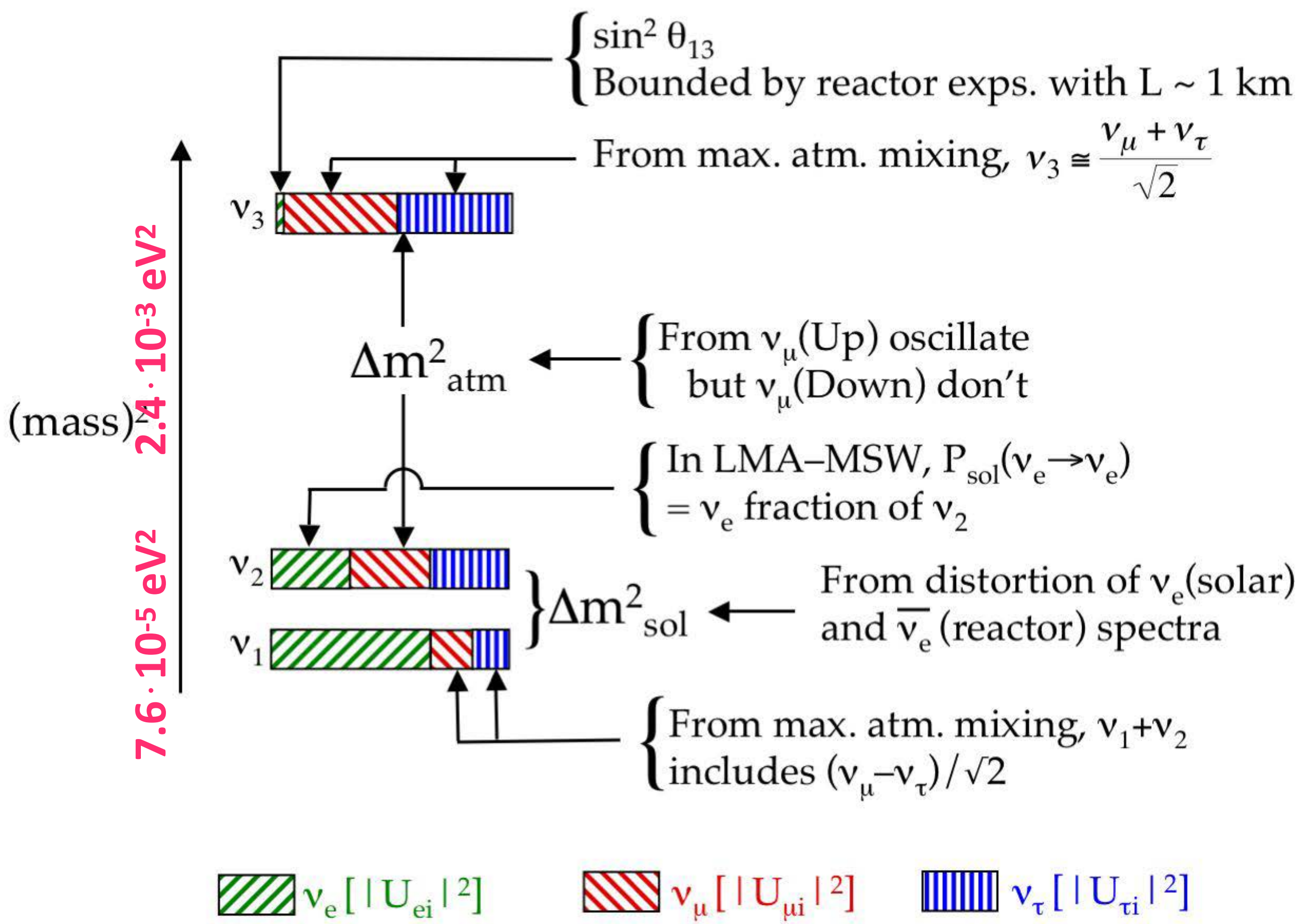
Neutrino Properties

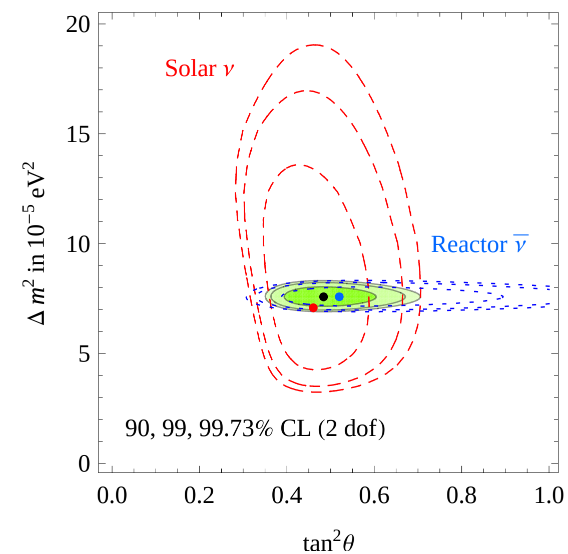
Neutrino oscillations

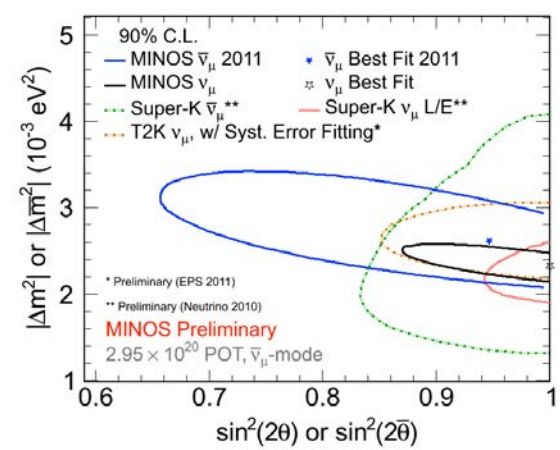
$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3}\\ U_{\mu1} & U_{\mu2} & U_{\mu3}\\ U_{\tau1} & U_{\tau2} & U_{\tau3}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

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

$\theta_{atm} \approx \theta_{23} \approx 45°$ **$\theta_{13} \approx 9°$** **$\theta_{sun} \approx \theta_{12} \approx 34°$**



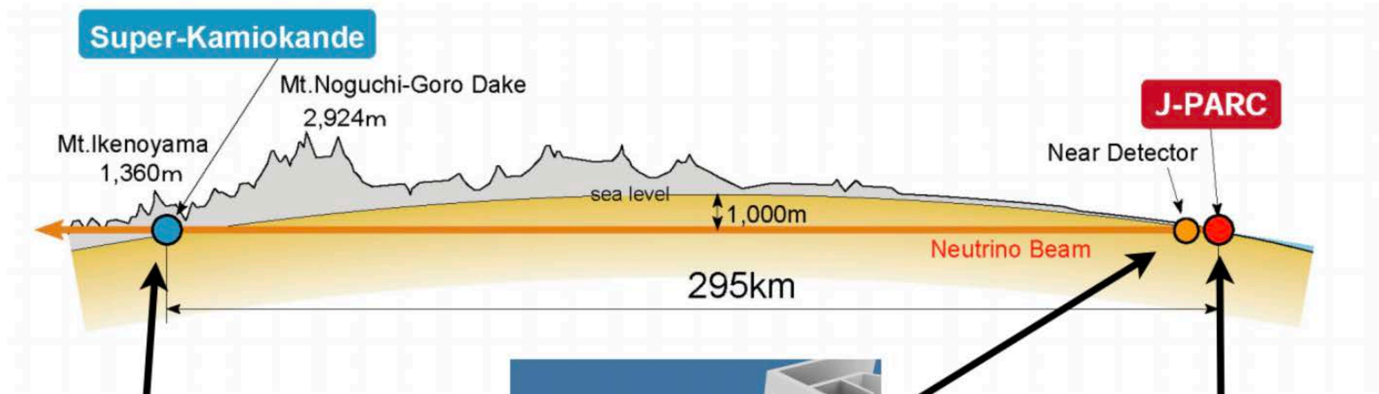




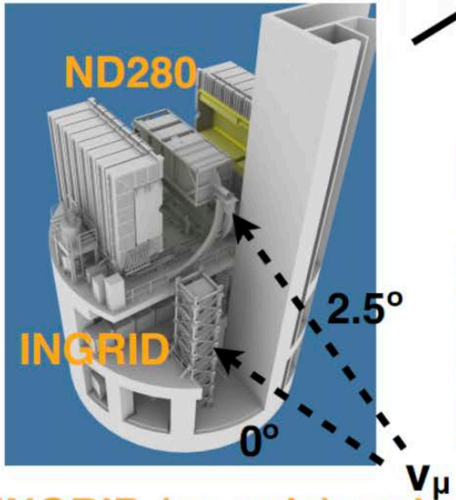
T2K: Tokai (JPARC) to Kiamoka (SK)

- 2013: discovery of ν_μ->ν_e
- Next Goal
  - CP violation
  - Mass hierarchy

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

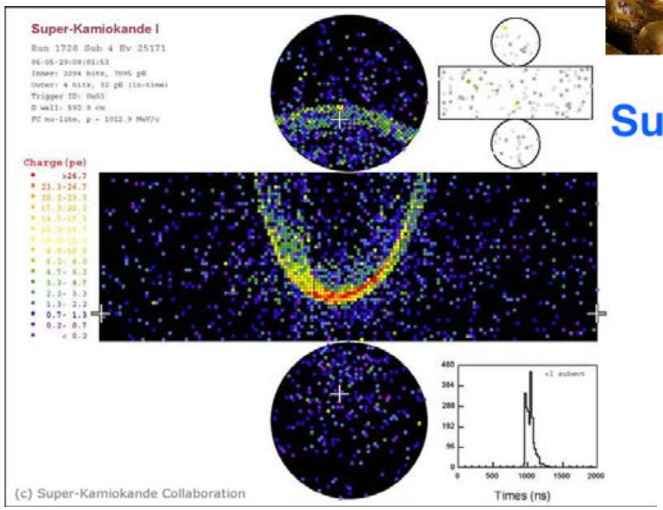


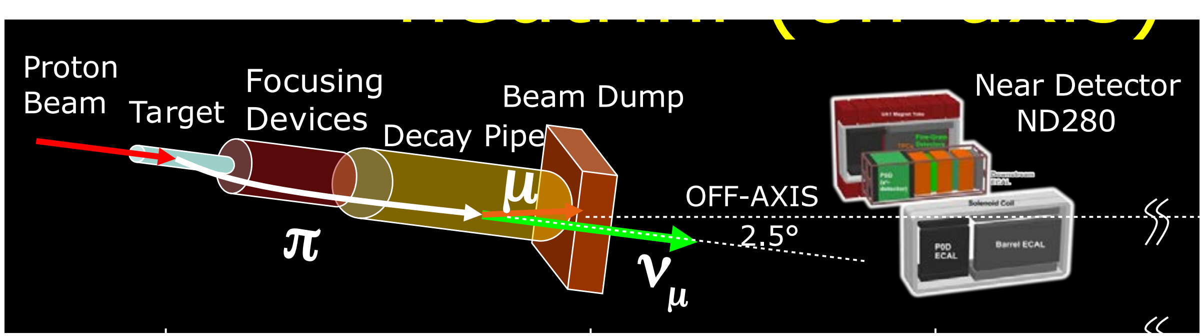
Super-Kamiokande



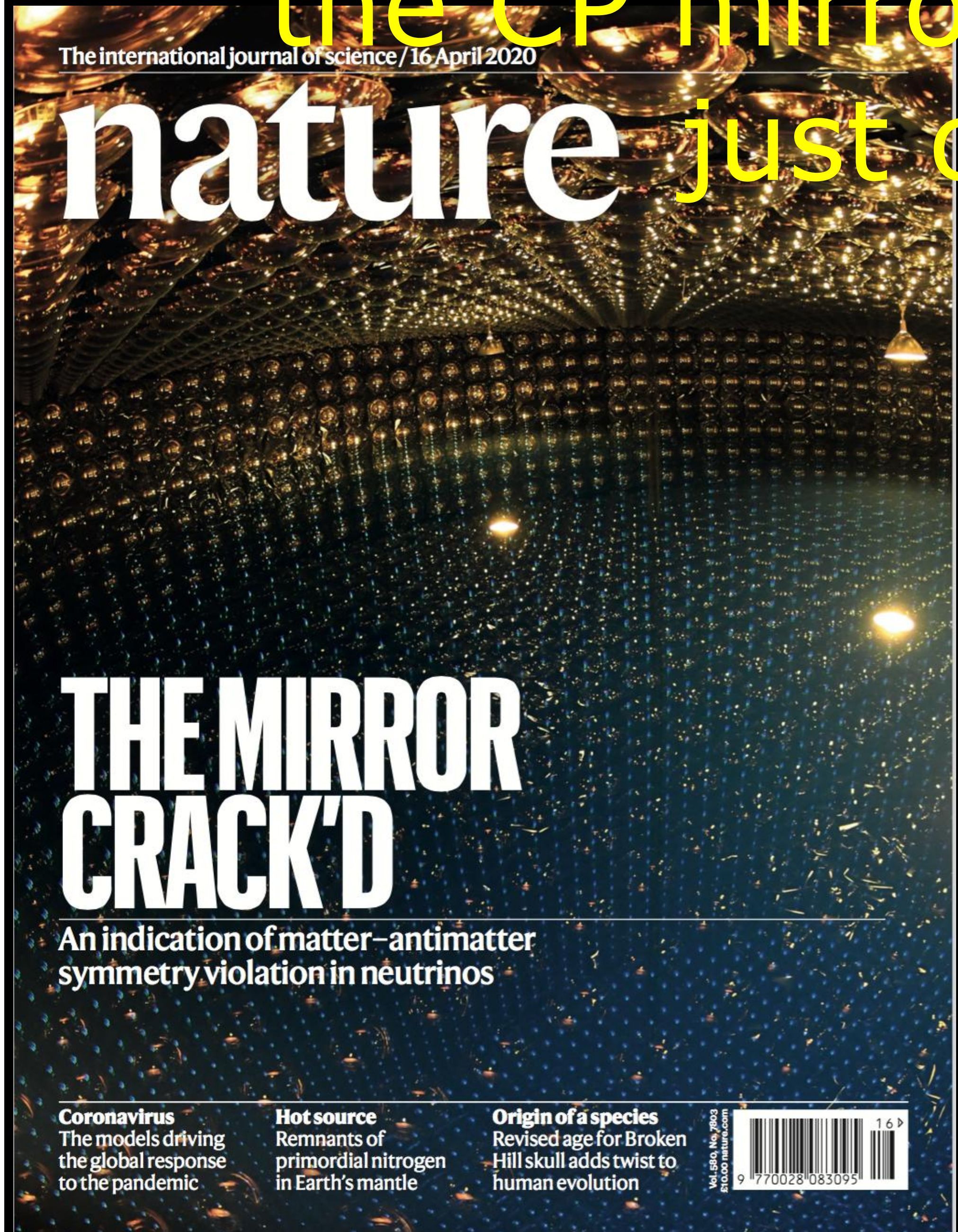
INGRID (on-axis) and ND280 (off-axis)

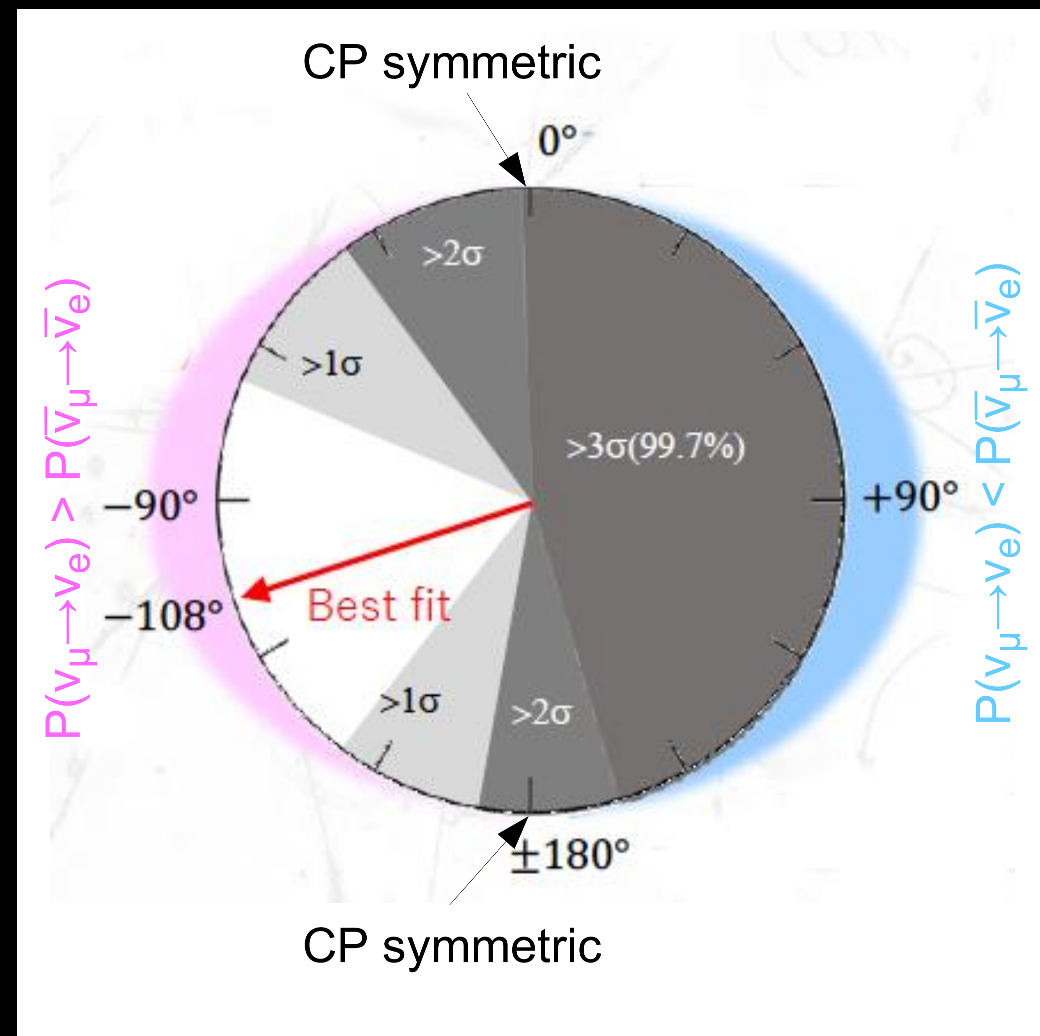
Neutrino beam created at J-PARC main ring





Are neutrinos symmetric in the CP mirror or the mirror is just cracking ?

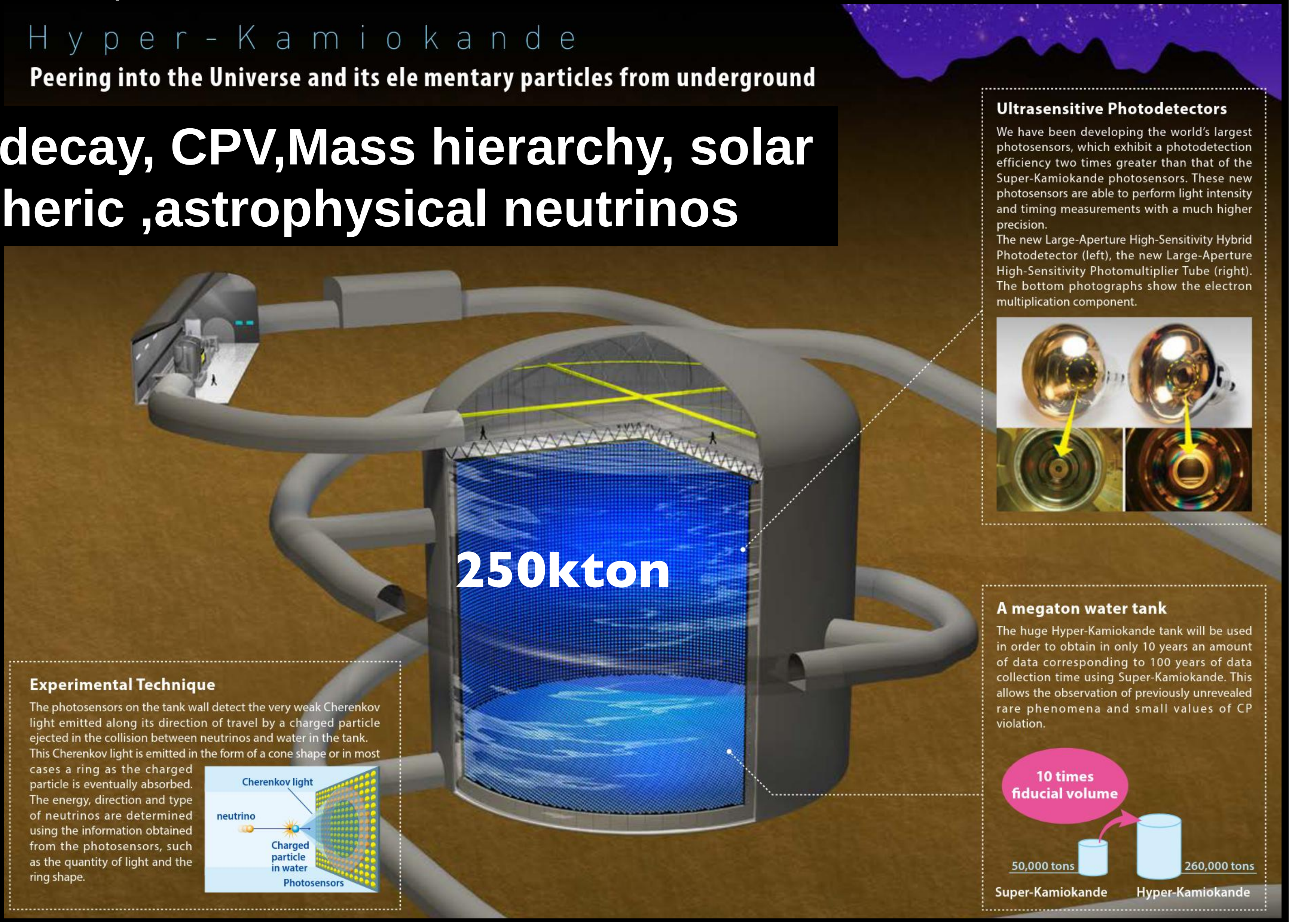




Hyper-Kamiokande: the future

- Largest underground neutrino detector: 10x the SK fiducial volume
- Ultrasensitive photodetectors: 20'' PMTs(new, Hamamatsu)+mPMTs(INFN R&D,KM3NeT-like)
- Upgraded beam 1MW power
- Start in 2027

- **Proton decay, CPV,Mass hierarchy, solar atmospheric ,astrophysical neutrinos**

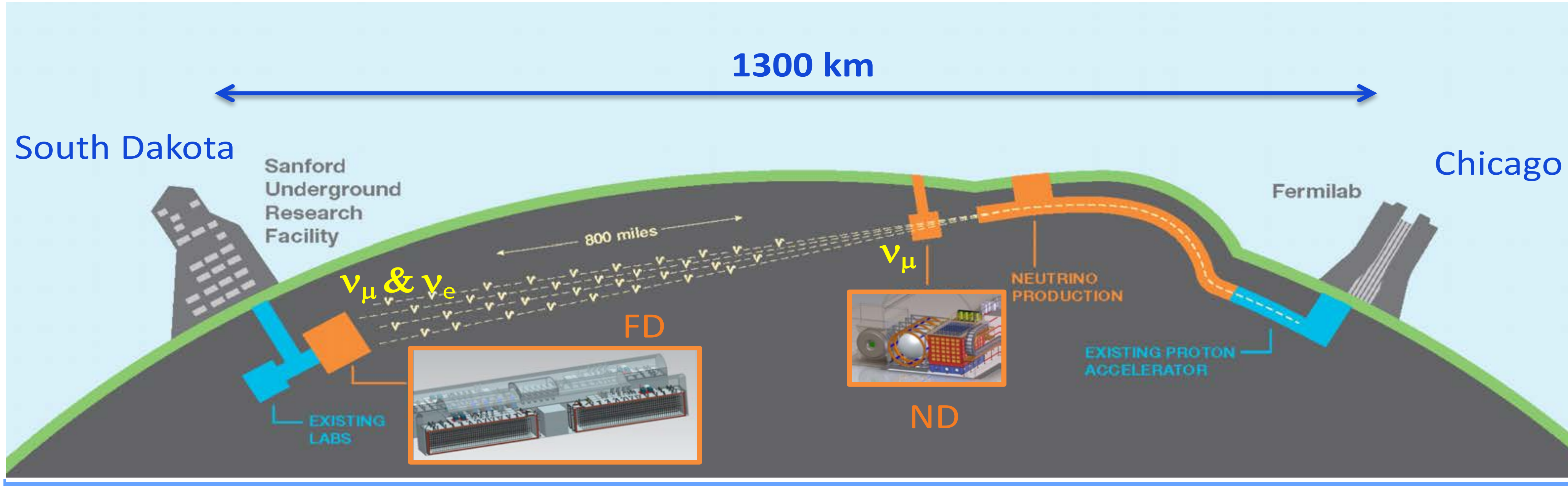


Activity in Rome

- Participation in the analysis of T2K data
- Development of position sensitive monitor for the LINAC Beam used for SK calibration
- HyperK: design and r&d :eletronics (timing, 20” front-end) ,multiPMT
- Future program
  - 2020: Add Gd in SK for the neutron tag
  - 2023: Upgrade Beam (intensity x2) and Near Detector
  - 2027: Build Hyper Klamokande = 10 xSK

  - Info:lucio.ludovici@roma1.infn.it

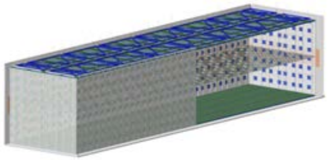
DUNE



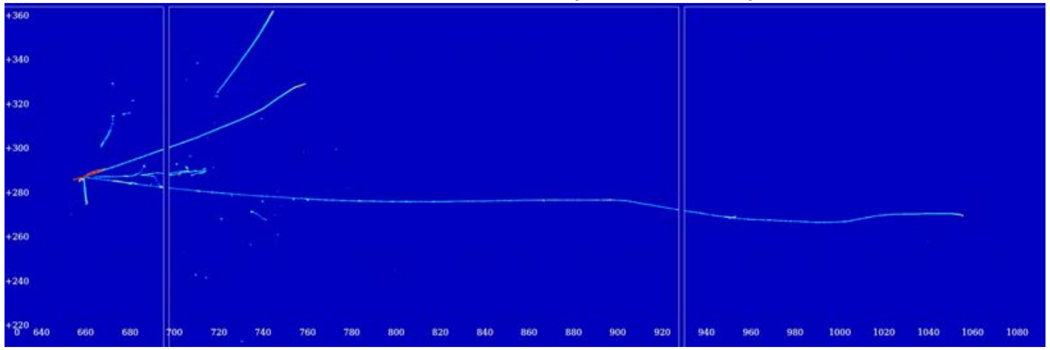
Unambiguous, high precision measurements of Δm^2_{32}, δ_{CP}, $\sin^2\theta_{23}$, $\sin^2 2\theta_{13}$ in a single experiment
Discovery sensitivity to CP violation, mass ordering, θ_{23} octant over a wide range of parameter values
Sensitivity to MeV-scale neutrinos, such as from a galactic supernova burst
Low backgrounds for sensitivity to BSM physics including baryon number violation

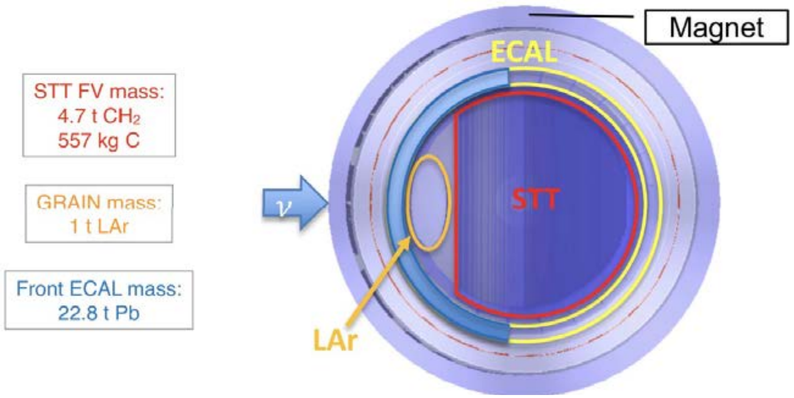
DUNE

Far detector four modules, 17 kt of liquid argon each
dimensions:
19 m (W) x 18 m (H) x 66 m (L)



event reconstruction (LAr TPC)

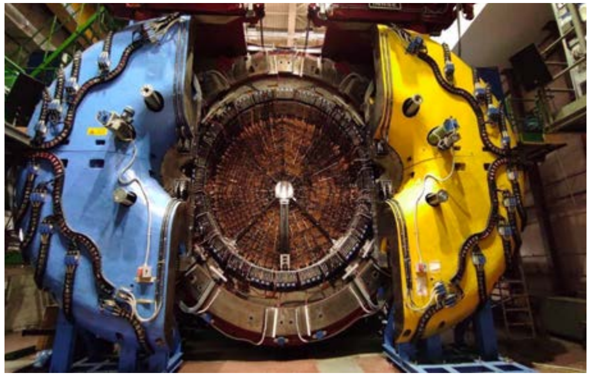




SAND, a multipurpose detector with highly performant ECAL, light-targeted tracker, LAr target, all of them in a magnetic field

From KLOE to SAND

ECAL calorimeter and magnet from the KLOE experiment at Frascati lab.
(thesis available on studies of ECAL/SAND performance and new read-out electronics)



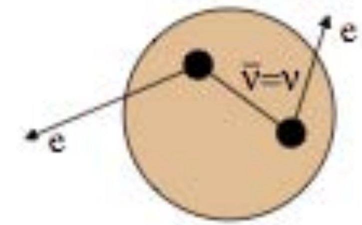
Near Detector Complex

a set of detectors that work in concert with each other to predict the far detector spectrum and monitor the beam stability:

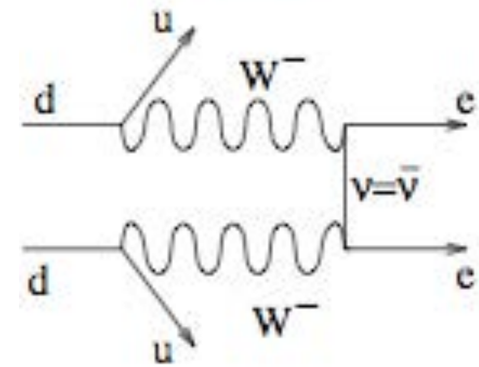
- A liquid argon TPC (ND-LAr) plus a Muon Spectrometer (TMS) ; these can move off-axis
- An on-axis beam monitor (**SAND**) ; SAND will also make precision measurements of multiple channels of neutrino interactions, leading to more control of systematics

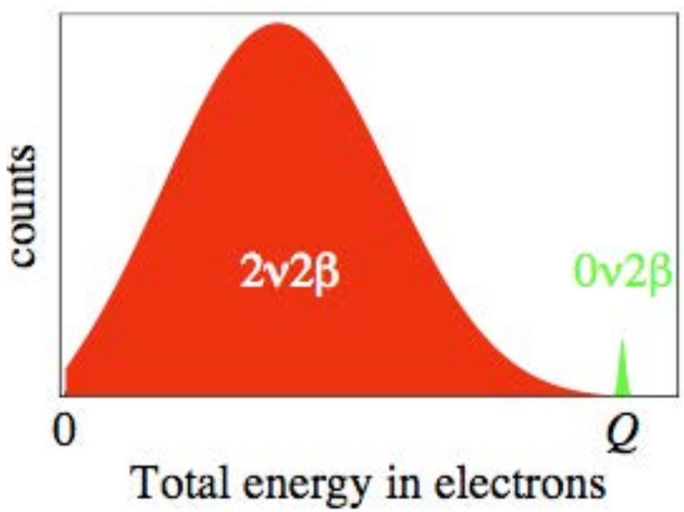
Neutrino: Dirac or Majorana

Neutrinoless Double Beta Decay (0ν2β):



- Not allowed in the Standard Model because it violates L and B-L conservation
- 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)

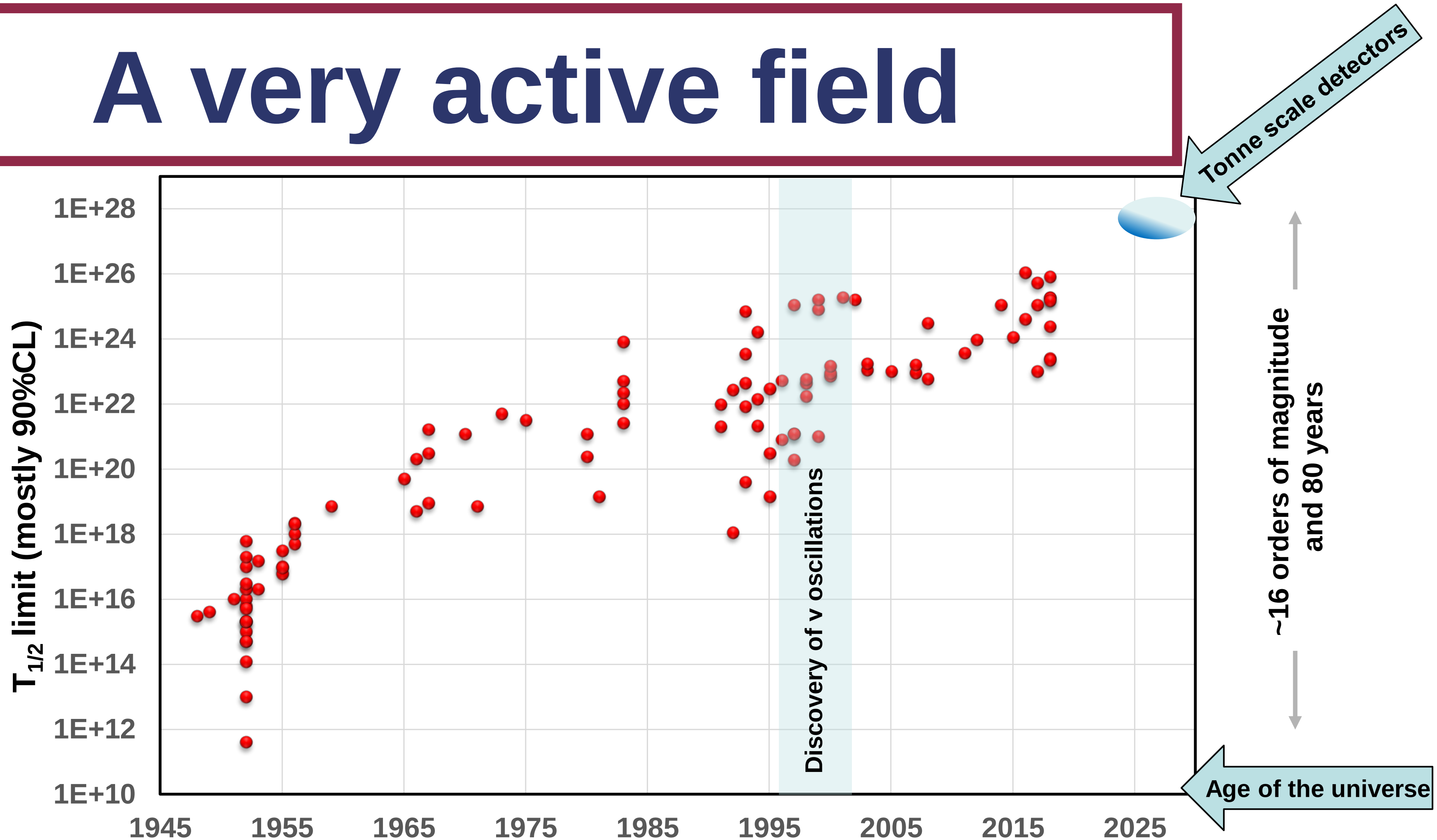


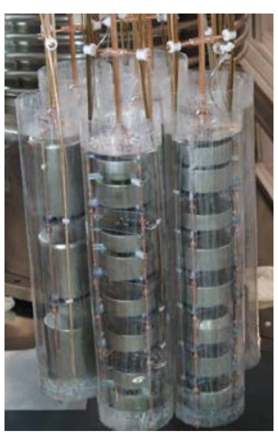


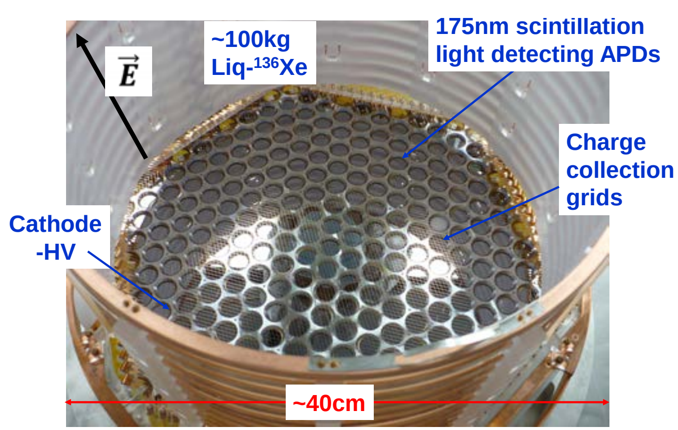
How can we be able to detect such a small signal?

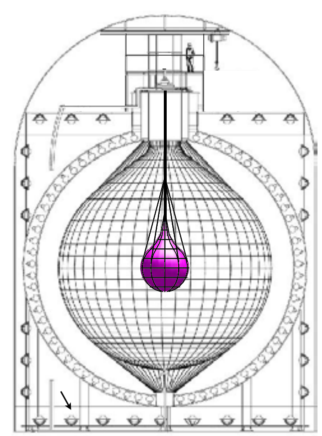
- Large mass detectors with excellent energy resolution, to distinguish the 0ν2β signal from the 2ν2β decay (allowed in the SM)
- Low rate of spurious events (radioactive decays, muon interactions, neutrons, etc...) at the energy of the Q-value

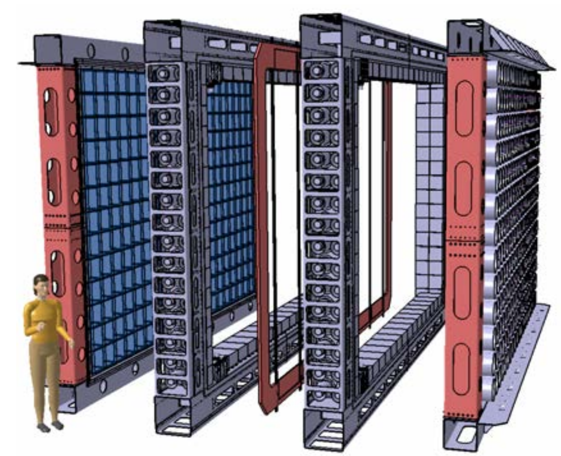
A very active field



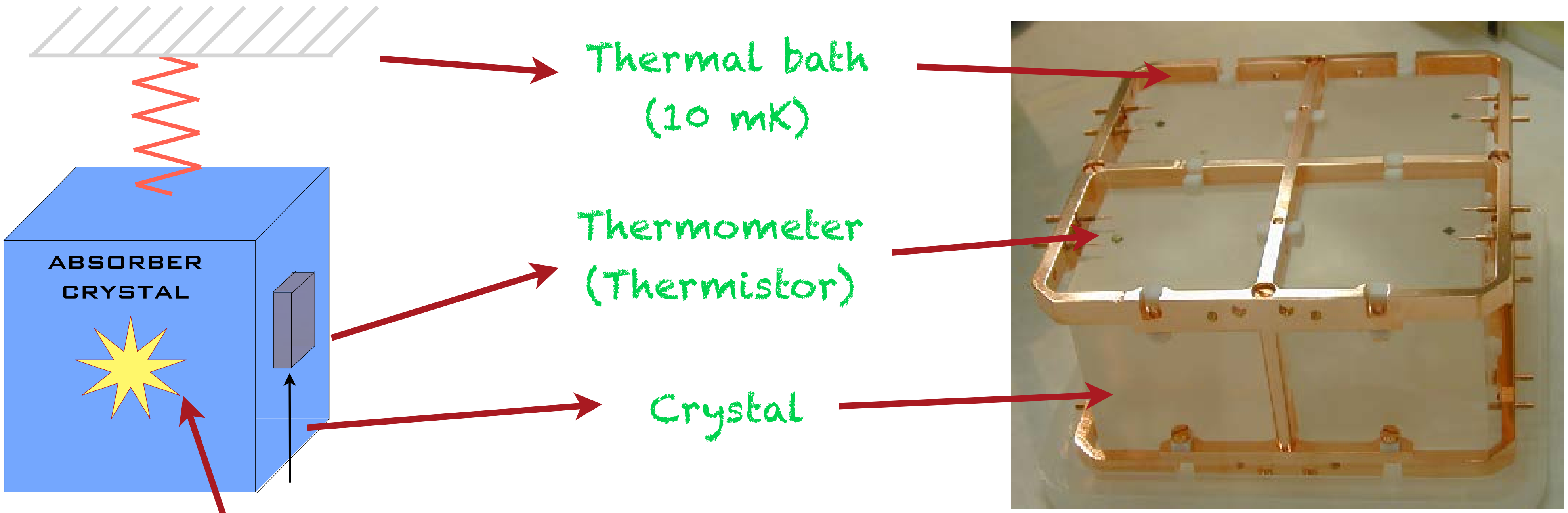








Cryogenic Calorimeters: bolometers



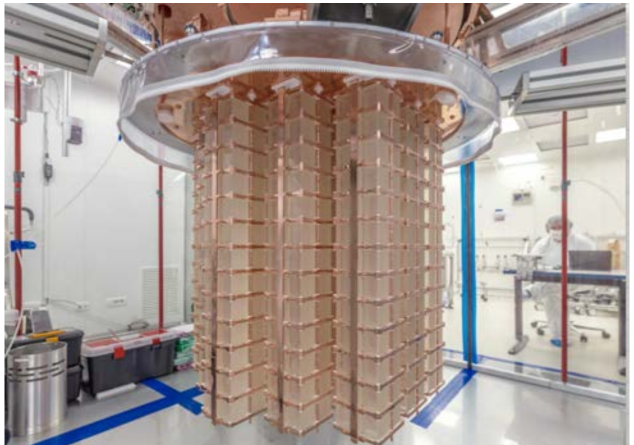
Energy released from particle

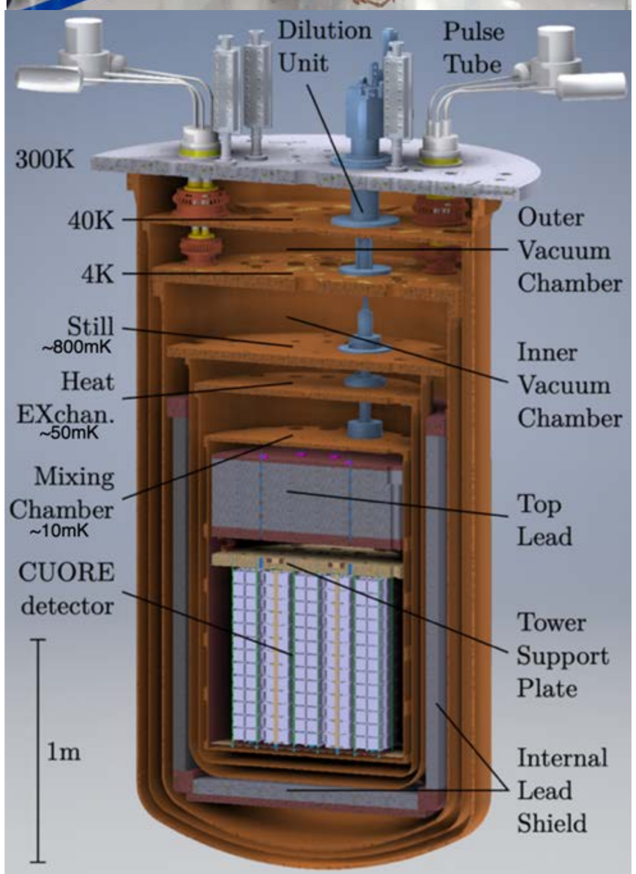
The temperature variation induced in the bolometer is proportional to the energy of the particle: ΔT=E/C

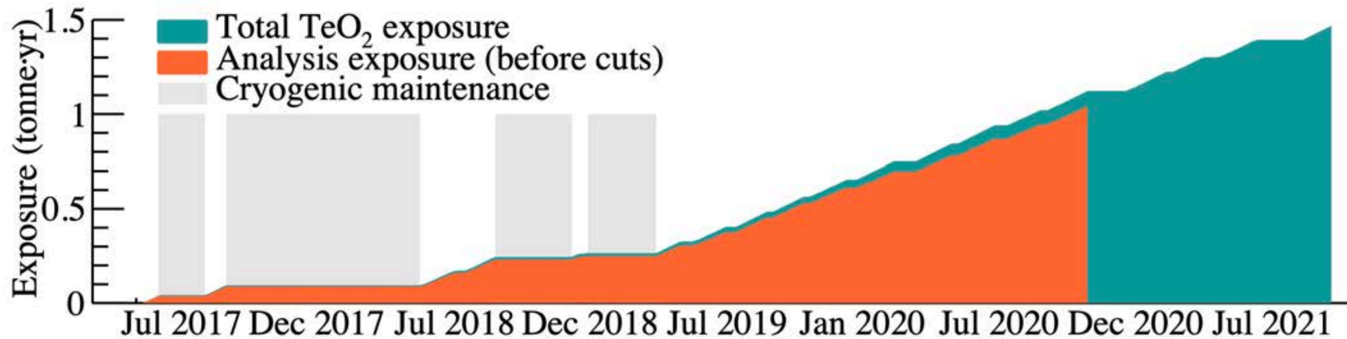
Energy resolution ~ 1 μK ~ 2 keV

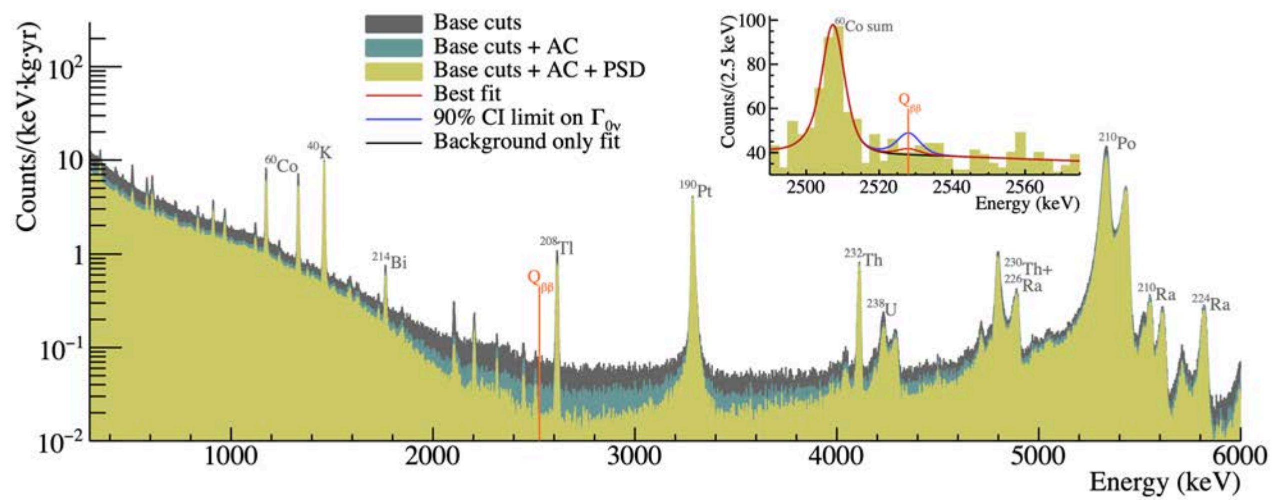
CUORE

Nature 604 (2022) 7904, 53-58



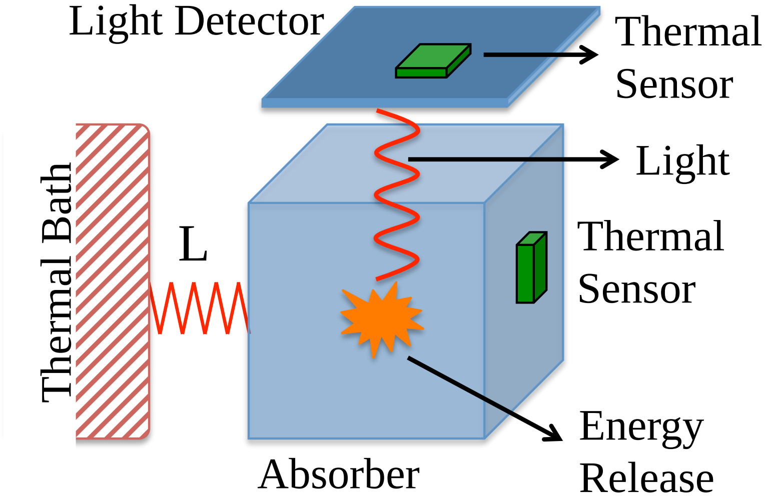




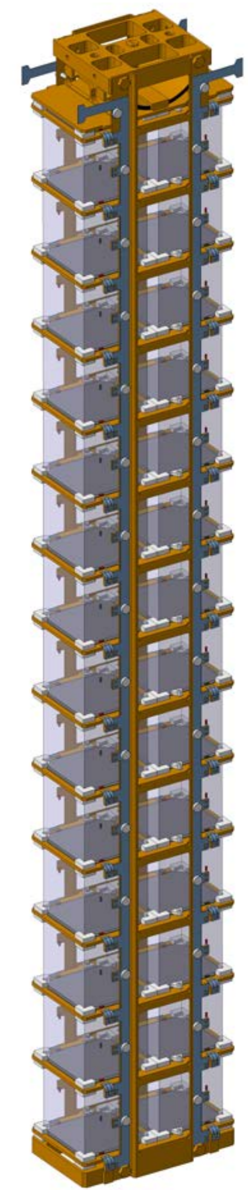


>1 ton*year analyzable exposure
Largest dataset ever collected by a solid-state double-beta decay experiment
Continuous operations at 11mK since March 2019
Demonstrates readiness for a ton-scale bolometric double-beta decay experiment
CUPID proceeding to technical design

CUPID (CUore with Particle IDentification)



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



Activities and theses

- Test of a first CUPID-like tower in the underground Laboratori Nazionali del Gran Sasso
- Study of the internal contamination of final CUPID crystals, to predict the contribution to the final background budget
- Characterisation of new thermal sensors in Roma cryogenic lab
- Study of sensitivity on the search for Physics Beyond the SM (Majorons, Light Exotic Fermions, Lorentz Violations, …)

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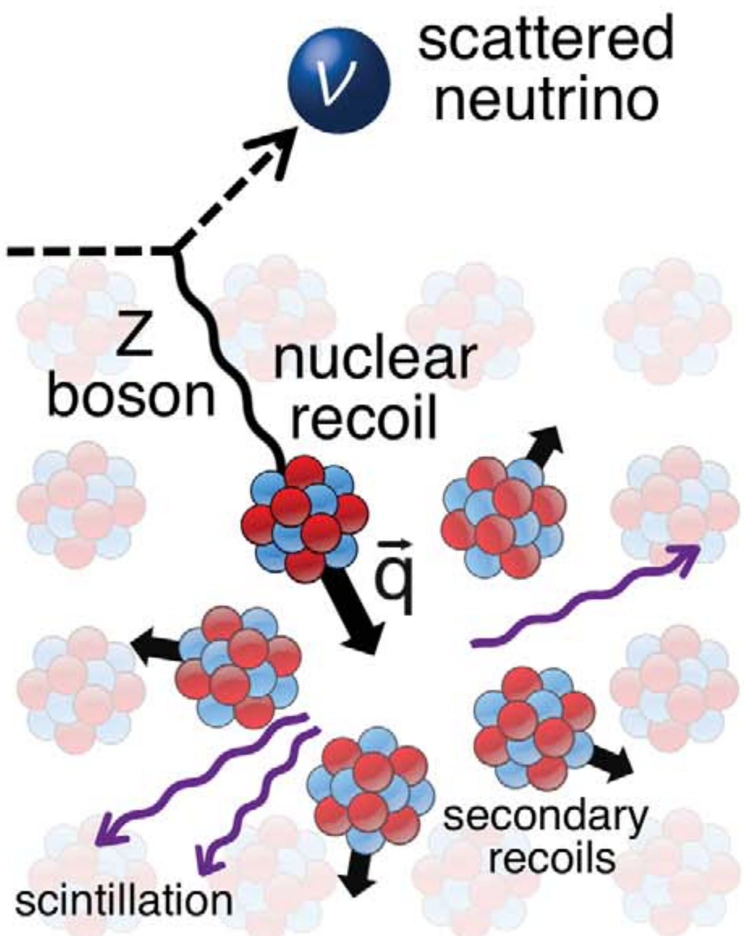
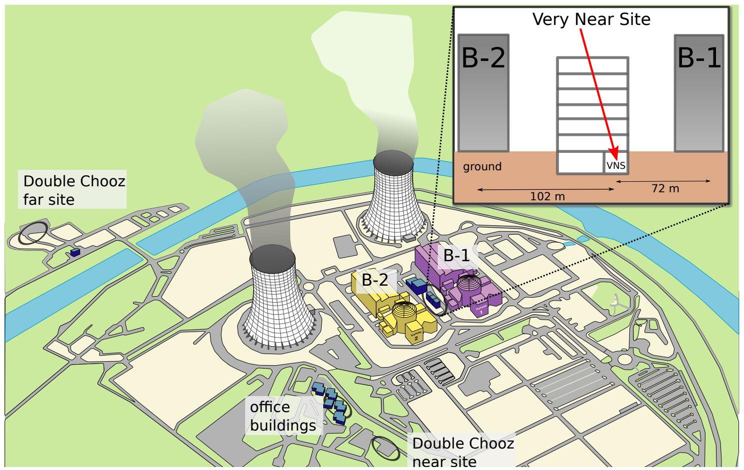
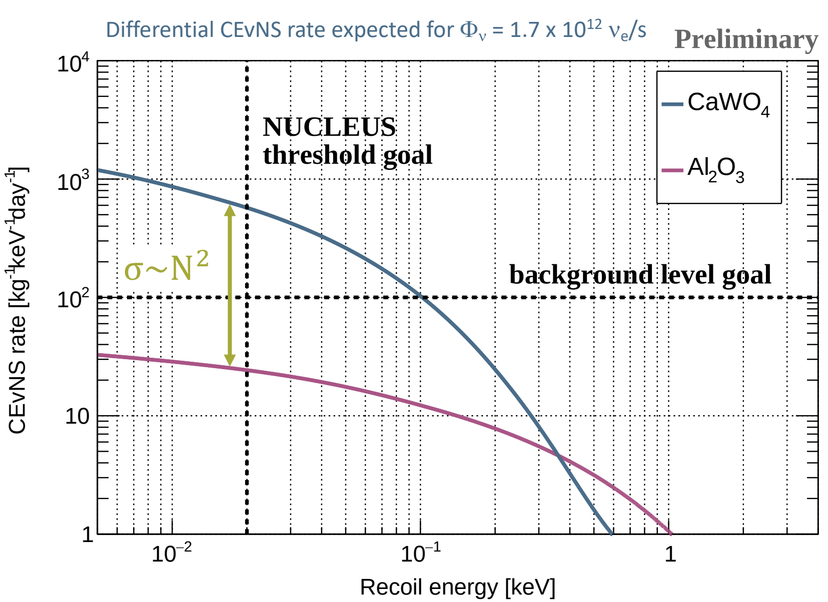
Application of cryogenic detectors

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



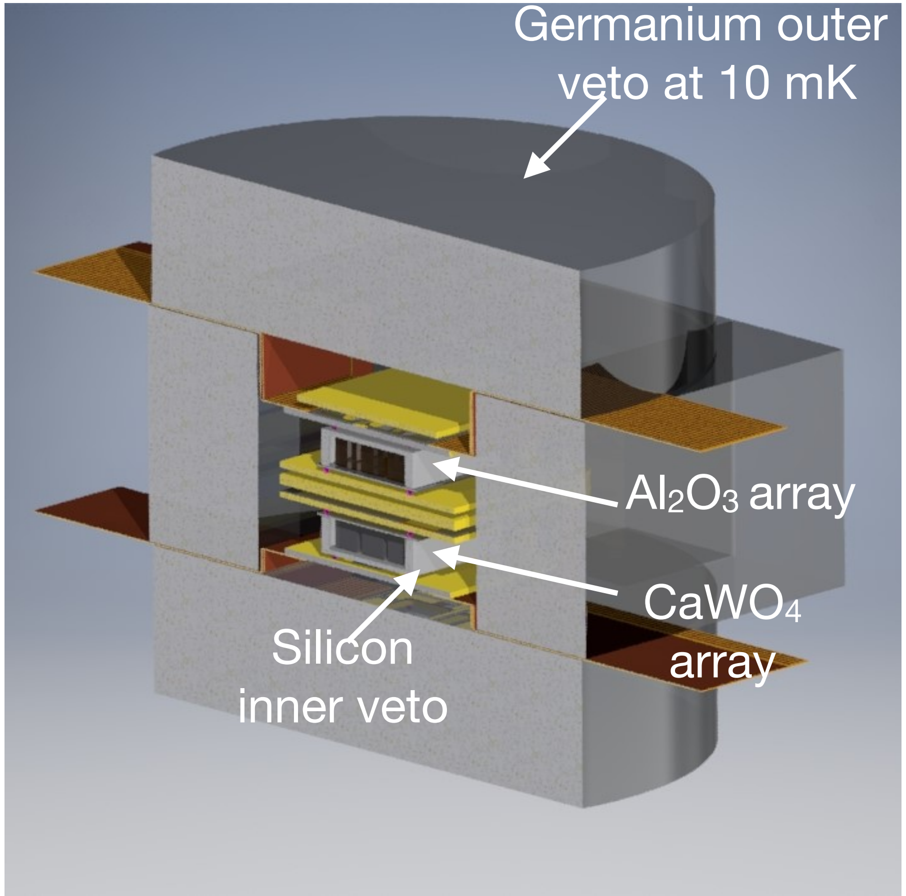


NUCLEUS experiment

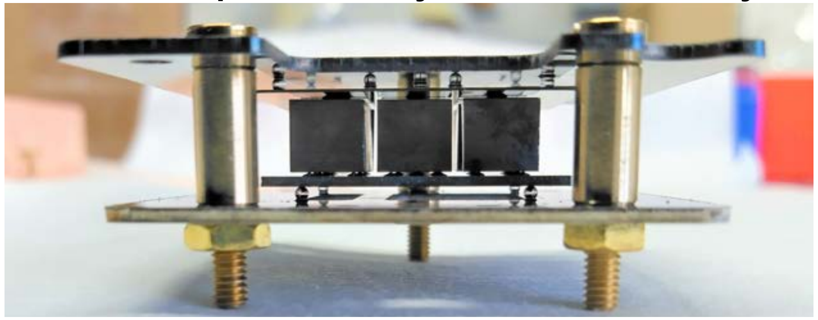
Cryogenic Particle detector at the CHOOZ Nuclear Reactor in France to explore the Coherent and Elastic Neutrino-Nucleus scattering.

Commissioning of the experimental apparatus starting now at TUM University (Germany).

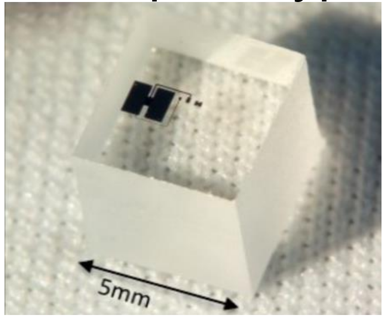
Theses: simulation, data analysis, detector assembly and commissioning.



mockup of 9 crystal assembly



Al_2O_3 prototype



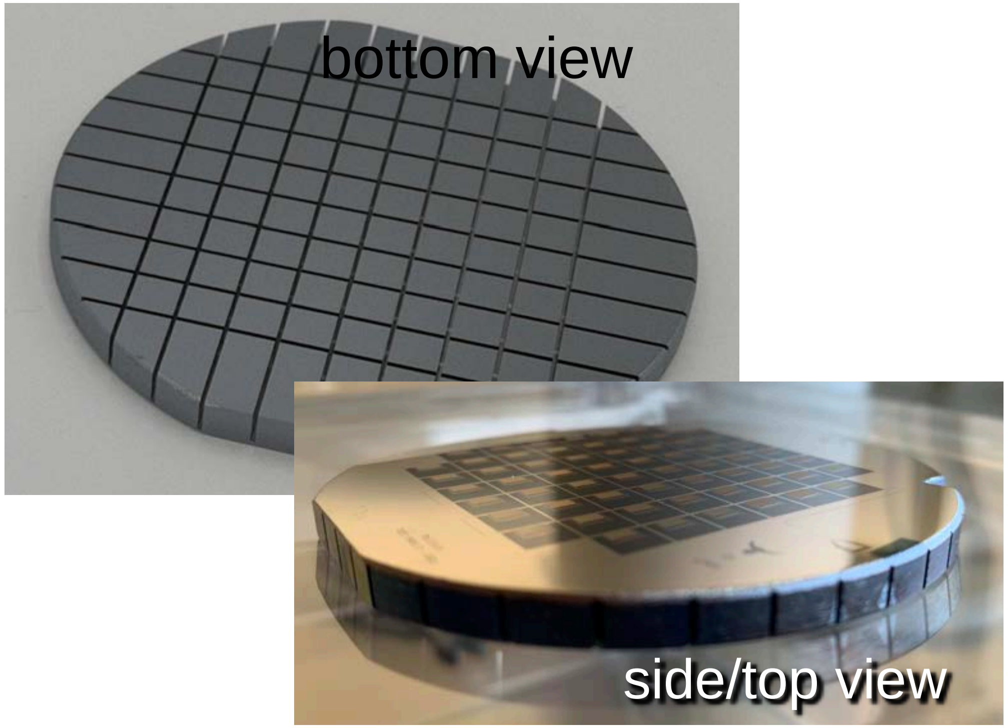
http://nucleus.roma1.infn.it

marco.vignati@roma1.infn.it

Superconducting detectors

Development of low-energy threshold superconducting detectors for next-generation experiments on Neutrino scattering, Majorana neutrinos and Dark Matter.

Theses: Detector design, operation and data analysis in the Sapienza Cryogenic Detectors lab.



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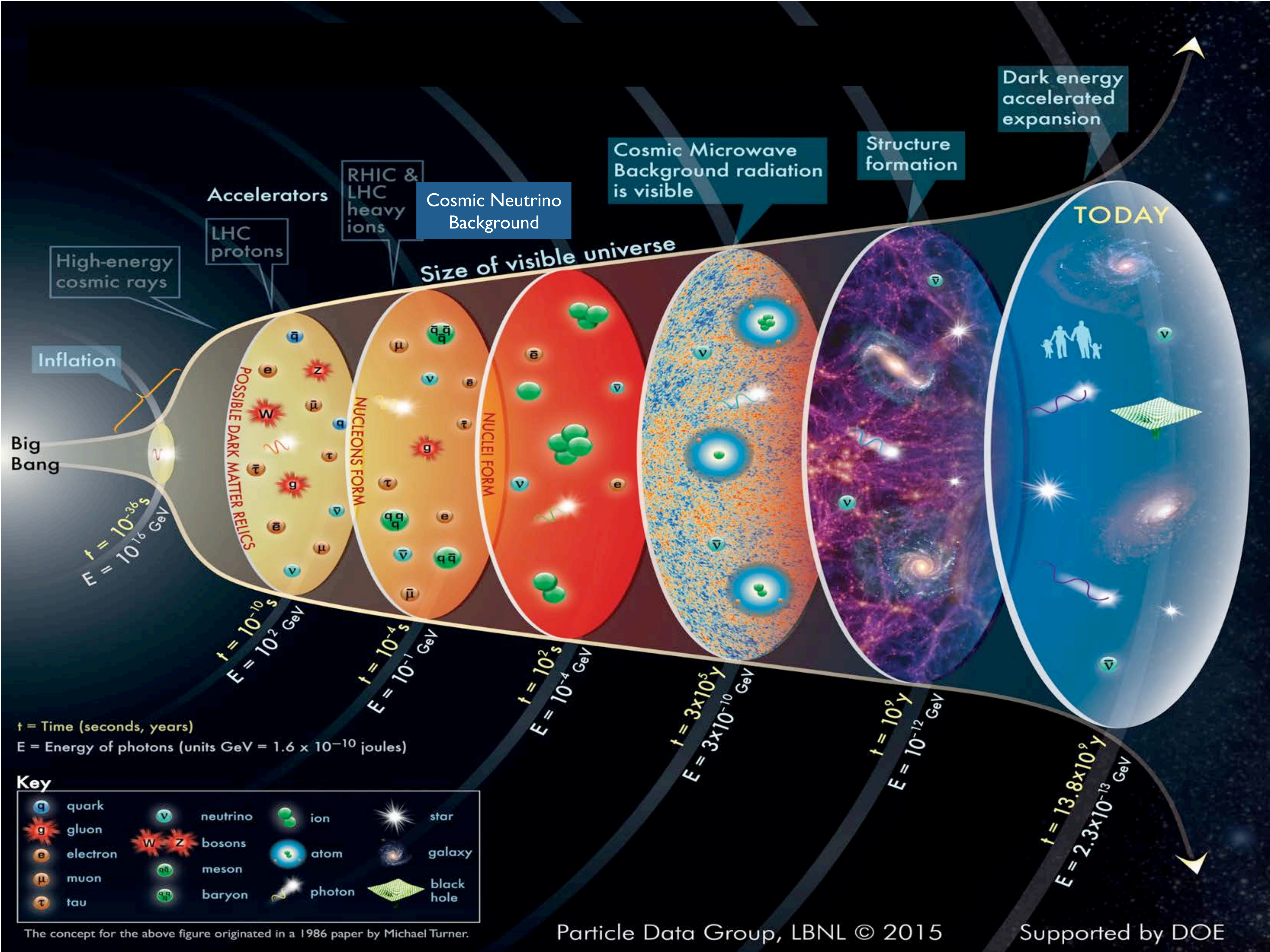
Radiation from the Universe

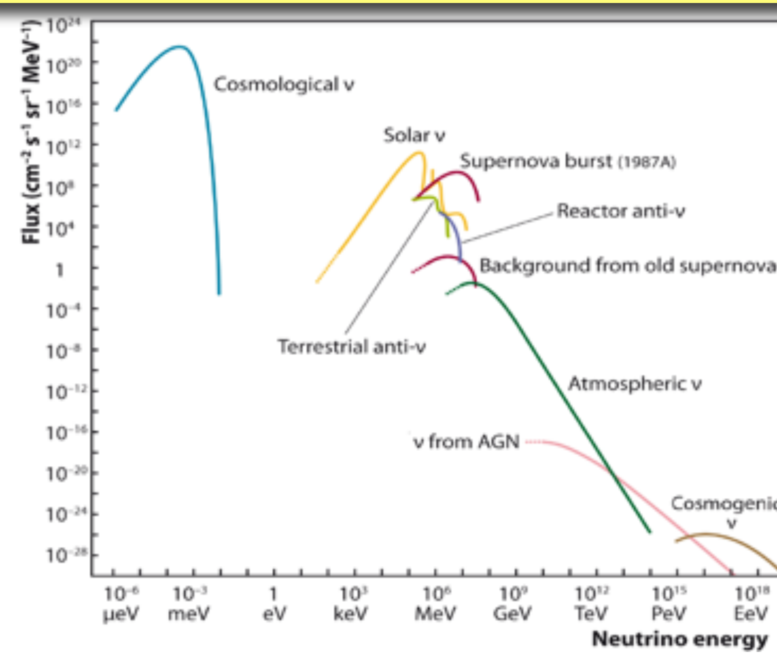


Dark energy accelerated expansion
Structure formation
Cosmic Microwave Background radiation is visible
Cosmic Neutrino Background
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Inflation
Big Bang
Size of visible universe
TODAY
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
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

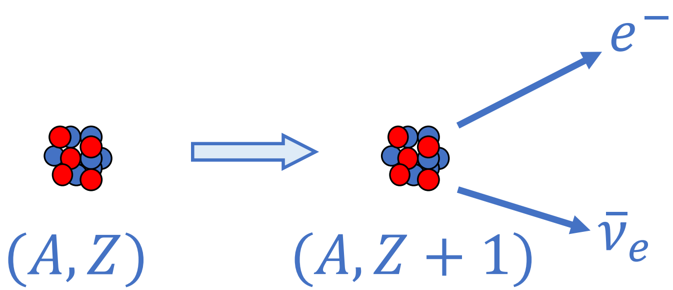
Radiation from the Universe: Cosmic Neutrino Background

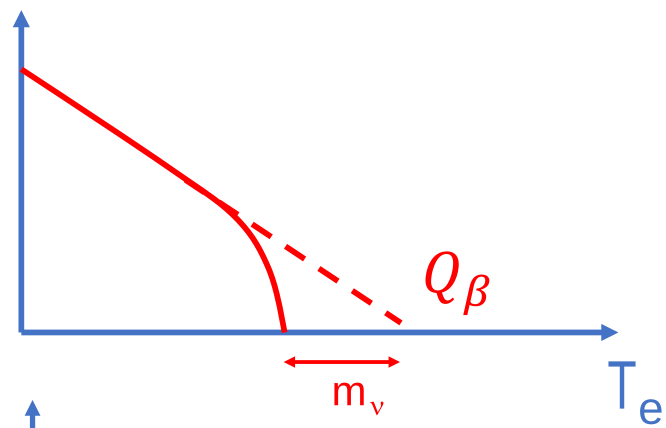
CNB

- ν decoupled from plasma few sec after BB
  - BlackBody at T=1.95 K, $p_\nu = 10^{-3}$ eV
  - Neutrino density: 56 ν_e/cm^3



- How to detect it

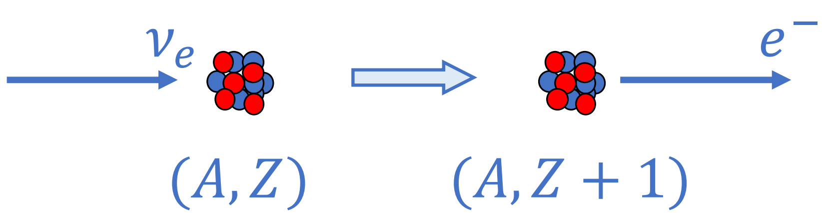


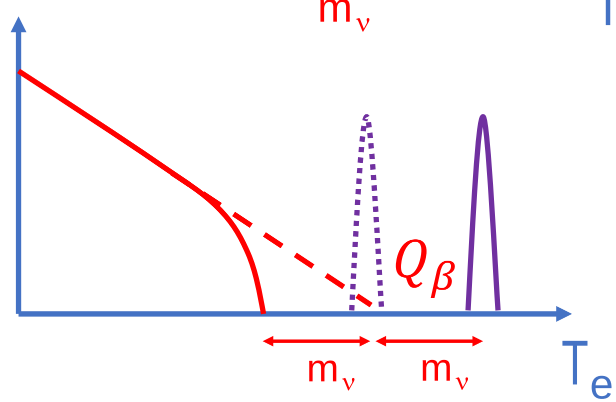


Filter to reduce high rate from target

Low Q + sizeable lifetime

3T decay ~10^{15} Bq/gr





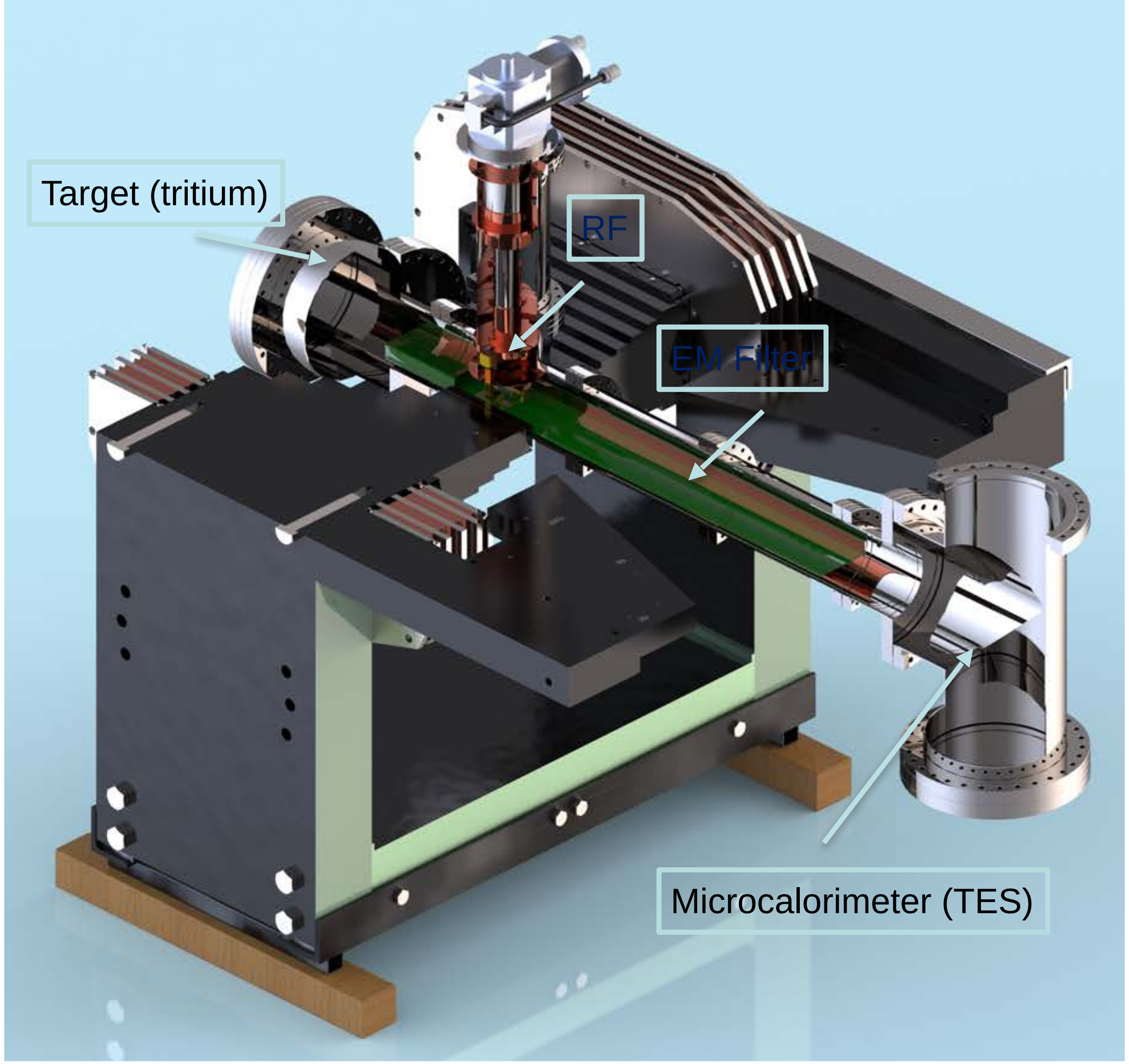
high efficiency

extreme $\sigma_E \sim m_\nu$

PTOLEMY demonstrator

Int.l collaboration see: https://ptolemy.lngs.infn.it/

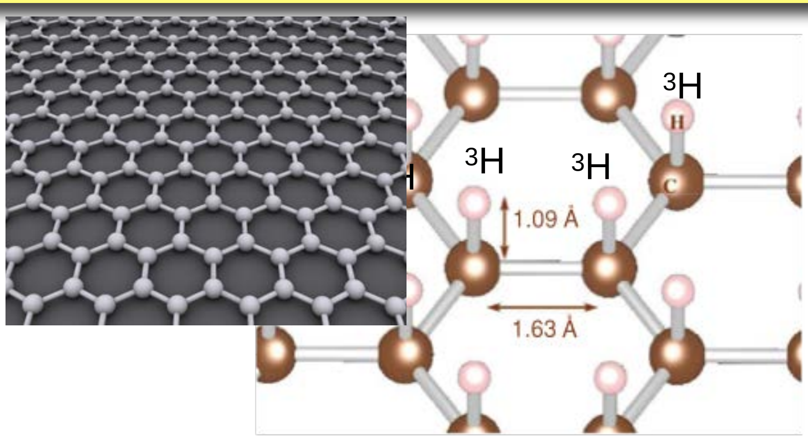
- Tritium on graphene
- 27 GHz cyclotron (RF) radiation detection
- Advanced e.m. Filtering
- Superconducting detectors (TES)



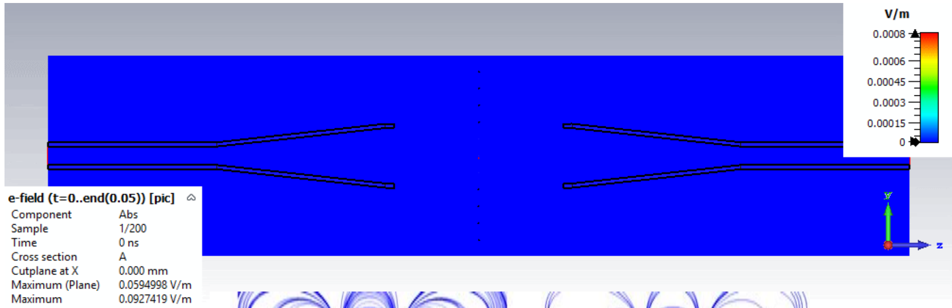
Being built at LNGS

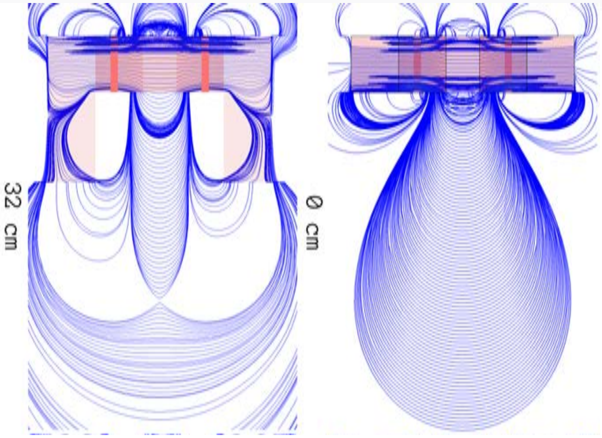
PTOLEMY

- Tritium/hydrogen loading on carbon nanostructure
  - In collaboration with ENEA and with Princeton
  - Hydrogen storage & nuclear fusion applications



- RF radiation detection
  - Simulation and test of electron trap
  - At LNGS
- Graphene transparency
  - In coll with RomaTre
- Innovative filter (at LNGS)



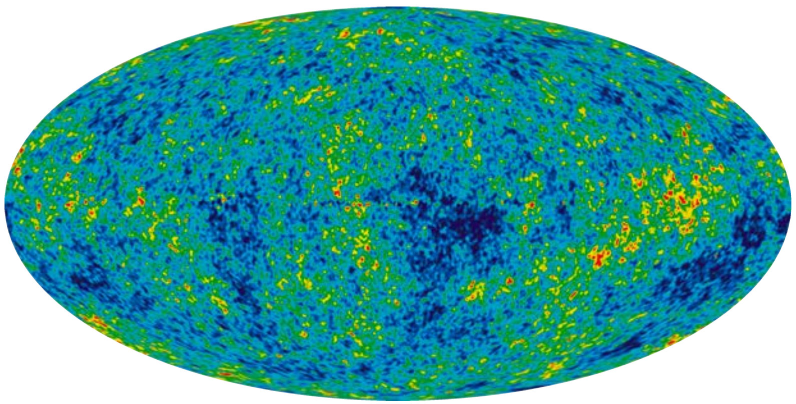


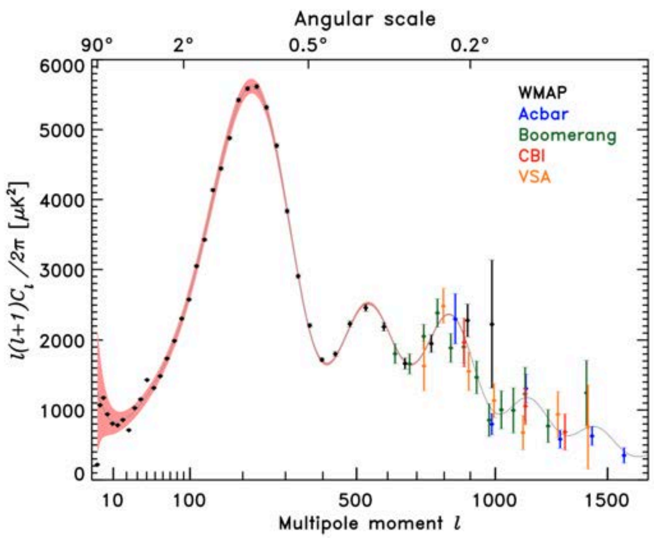
A design for an electromagnetic filter for precision energy measurements at the tritium endpoint M.G. Betti, et al. DOI: 10.1016/j.ppnp.2019.02.004 Prog.Part.Nucl.Phys. 106 (2019), 120-131
Neutrino physics with the PTOLEMY project: active neutrino properties and the light sterile case M.G. Betti et al. 10.1088/1475-7516/2019/07/047 JCAP 07 (2019), 047
Implementation and optimization of the PTOLEMY transverse drift electromagnetic filter Appone et al. : 10.1088/1748-0221/17/05/P05021 JINST 17 (2022) 05, P05021
Heisenberg's uncertainty principle in the PTOLEMY project: a theory update PTOLEMY Collaboration • A. Apponi et al. 2203.11228 [hep-ph]

Radiation from the Universe: Cosmic Microwave Background

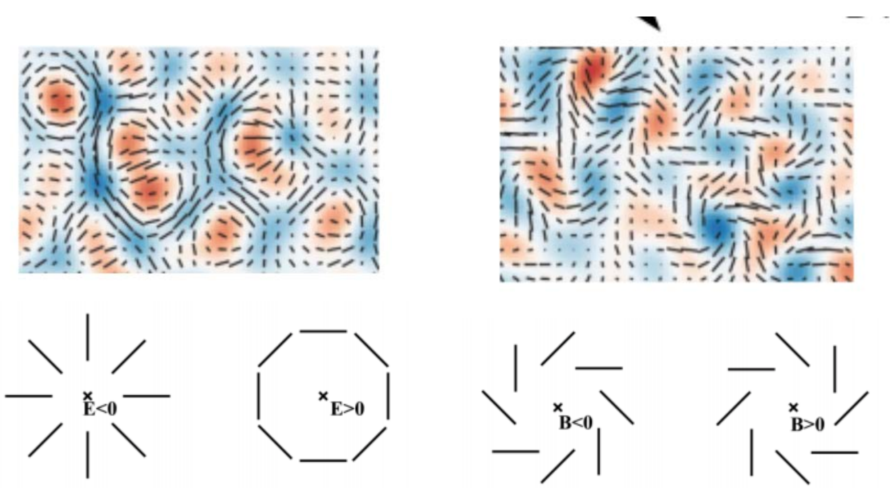
CMB: precision era

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





- The CMB polarization $O(\mu K)$ acts as a GW antenna in the primordial Universe



E-modes generated by Thomson scattering in plasma.

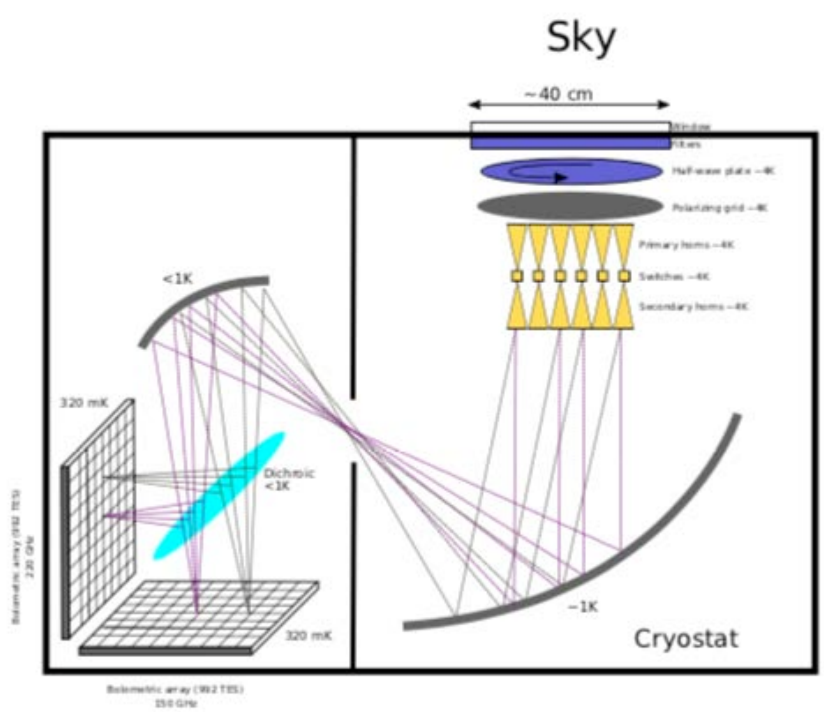
B-modes generated by
-gravitational lensing of E-modes
-<u>gravitational waves during inflation</u>

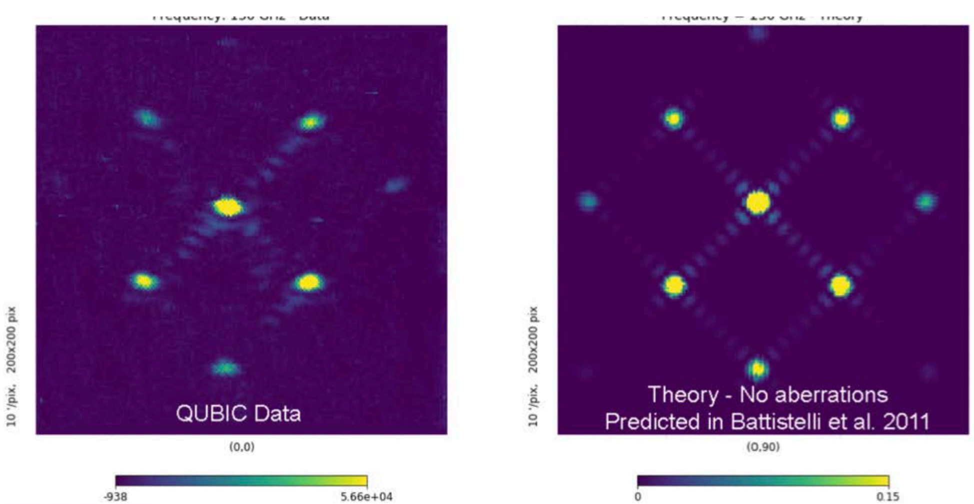
Need sensitivity, control of polarised background and systematics.

Experiments at different frequencies (different backgrounds and signal)

QUBIC

- bolometric interferometry
  - Combines bolometer sensitivity + interferometric control of systematics
  - 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





QUBIC

LATEST updates QUBIC press release and useful links:

https://home.infn.it/en/media-outreach/infn-newsletter/newsletter-focus/4905-qubic-a-new-way-of-studying-the-primordial-universe

- http://qubic.in2p3.fr/wordpress/
- JCAP (Journal of Cosmology and Astroparticle Physics) special issue : https://iopscience.iop.org/journal/1475-7516/page/Special%20Issues

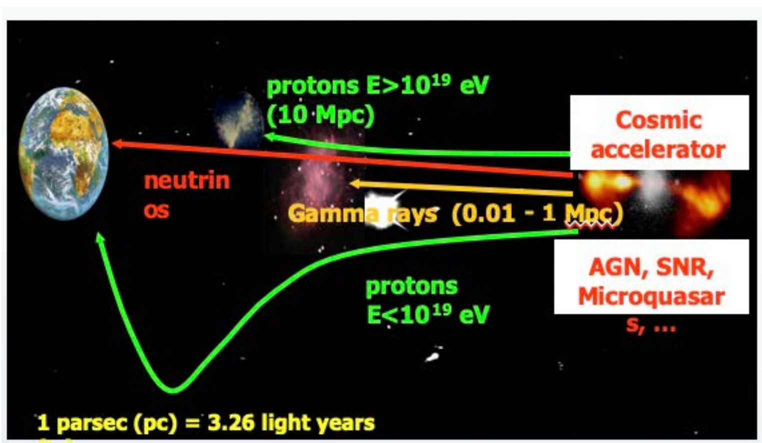
The cryogenic polarization modulation system is shown here: it does operate in a step and integrate configuration at a temperature of about 10 K. The white surface in the picture is the Half Wave Plate. The rotation system allows the measurement of the polarized emission of the CMB. It has been designed, built and optimized in Rome 1.

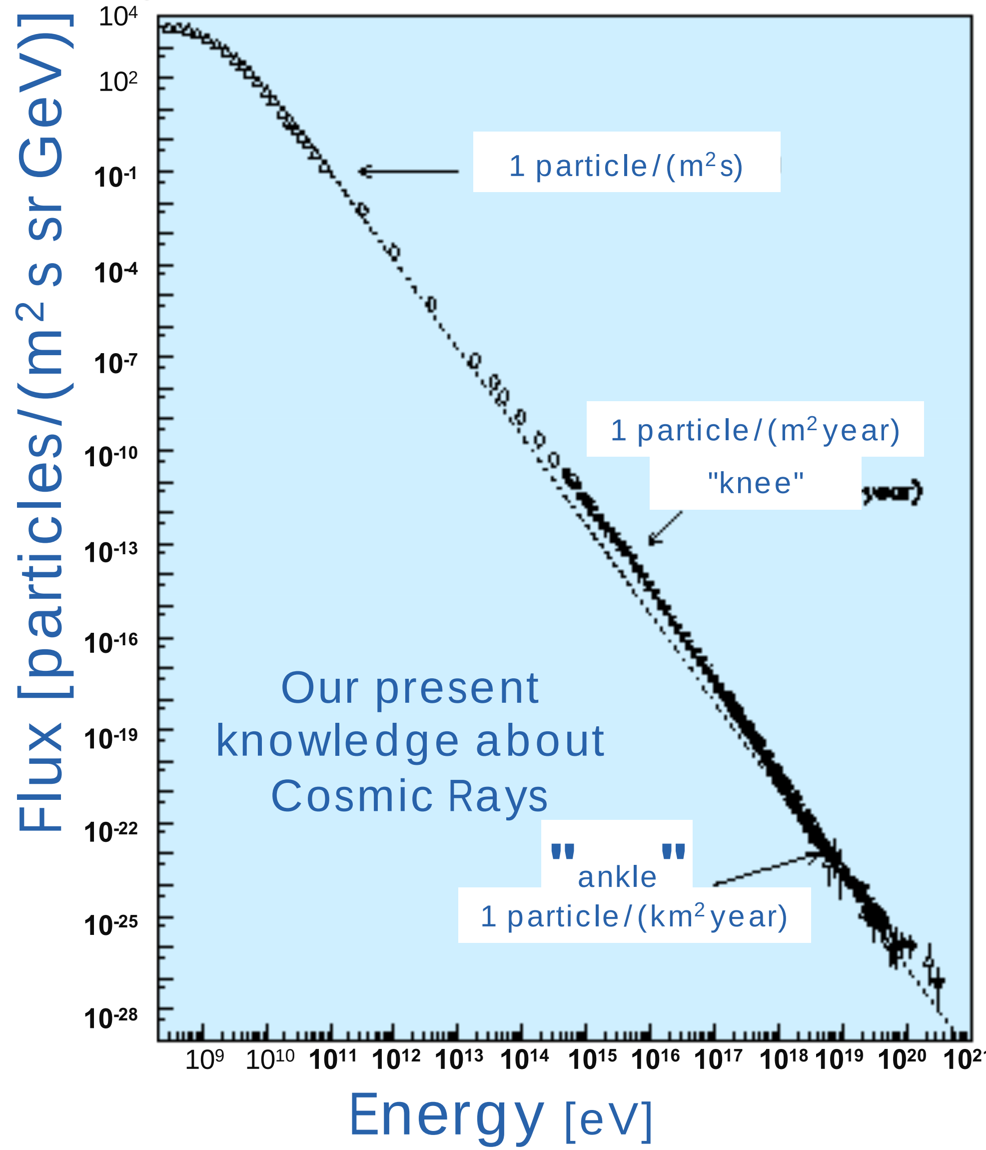
- Video https://f.io/G-WVKNbU - credits: Comisión Nacional de Energía Atómica (CNEA)

Radiation from the Universe: High Energy Neutrinos & gammas

Motivations

- Observed particle or nuclei up to $E_K=10^{21}$ eV
- Open questions
  - Where they come from?
  - Which acceleration mechanism





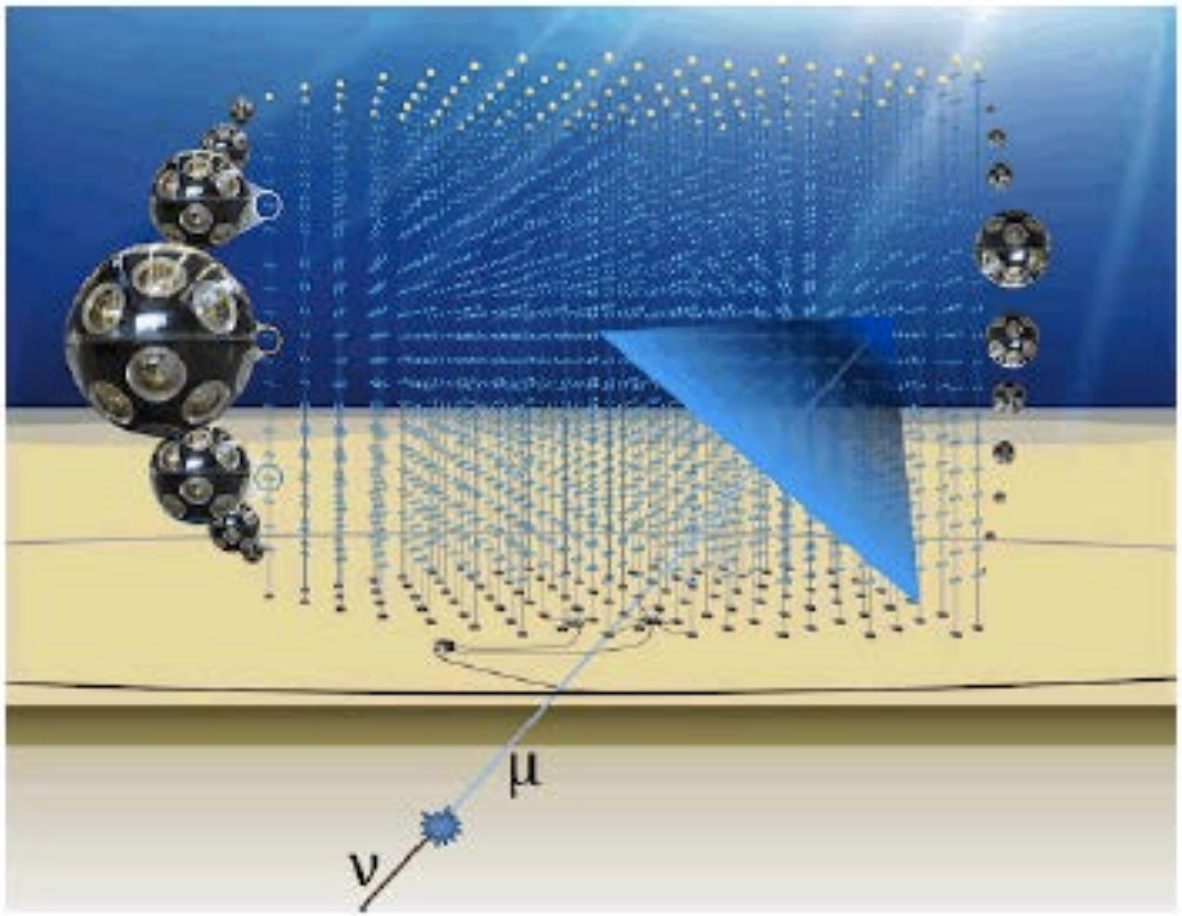
- UHE astrophysical ν will extend limits of the visibile universe
- Multi-messenger observations

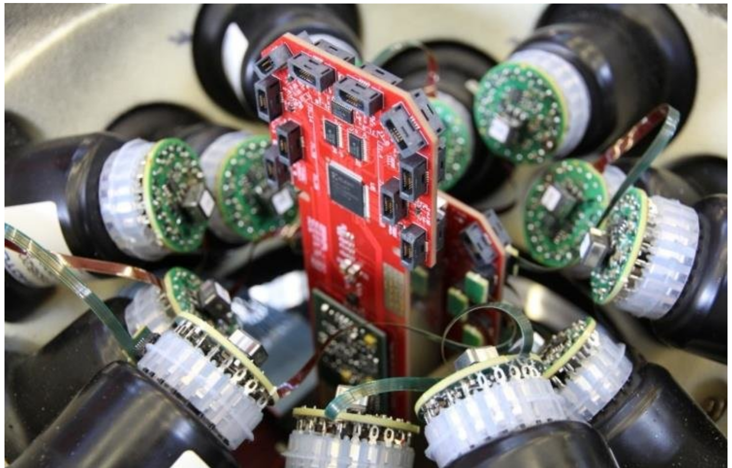
Neutrinos are a sign of hadronic process since they come from π decays

Astroparticle KM3NeT

Staff: Celli, Di Palma; INFN: Ameli, Nicolau, 2 Postdocs, 1 PhD student + master students

- ✓ ANTARES members and KM3NeT members.
- ✓ Key responsibilities: 1) **Development of electronics; 2) Calibration of digital optical modules;** 3) Real-time alerts framework for multimessenger studies; 4) ν in coincidence with γ-ray sources (GRBs, PeVatron); 5) Multimessenger search of Core–Collapse Supernovae through neutrinos and gravitational waves.





On the left: KM3NeT and neutrino detection principle. On the right: Digital Optical Module, view of the PMT bases (green) and the Octopus boards (red).

Astroparticle KM3NeT

Staff: Celli, Di Palma; INFN: Ameli, Nicolau, 2 Postdocs, 1 PhD student + master students

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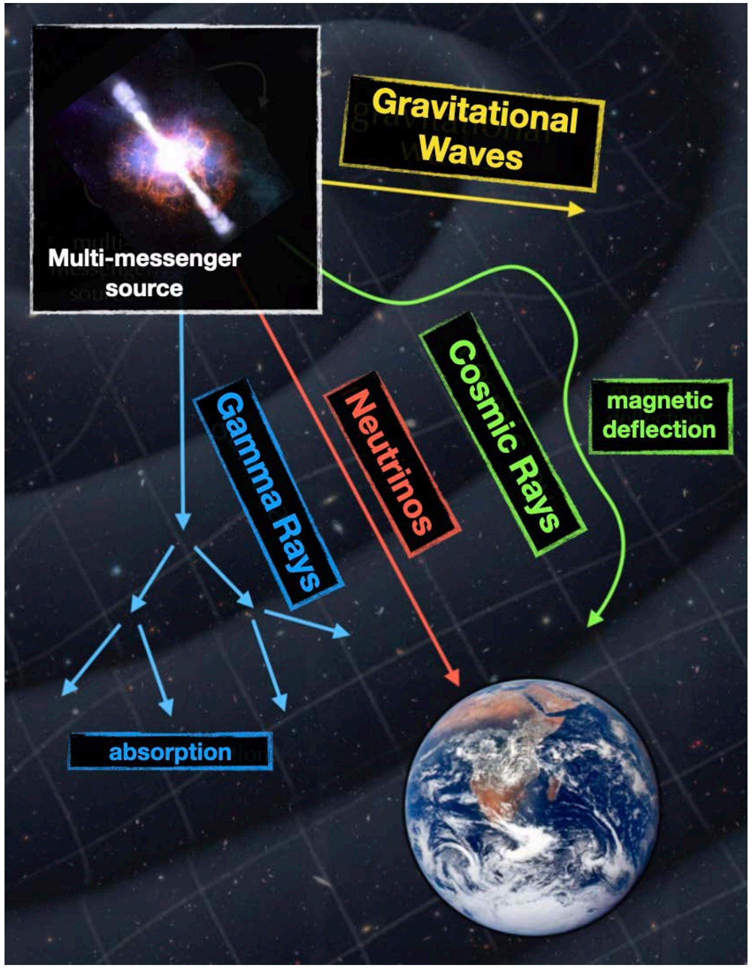
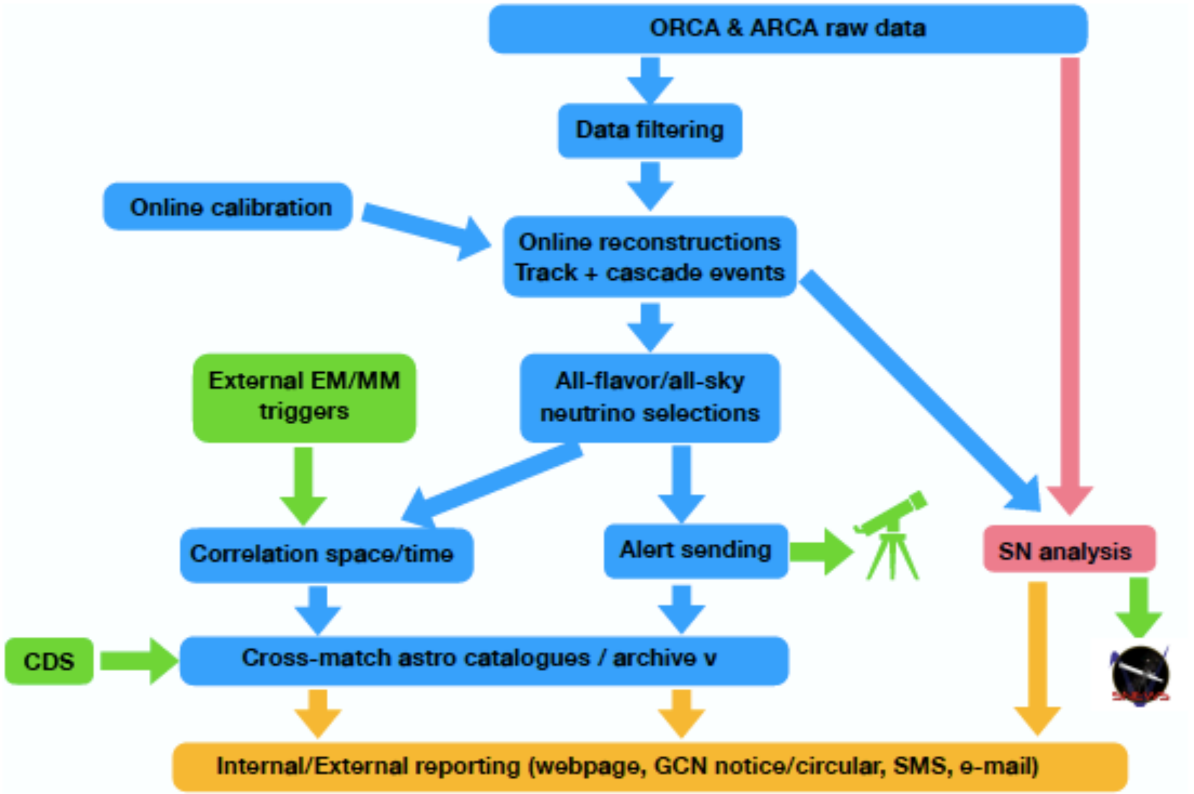


Multimessenger Astronomy

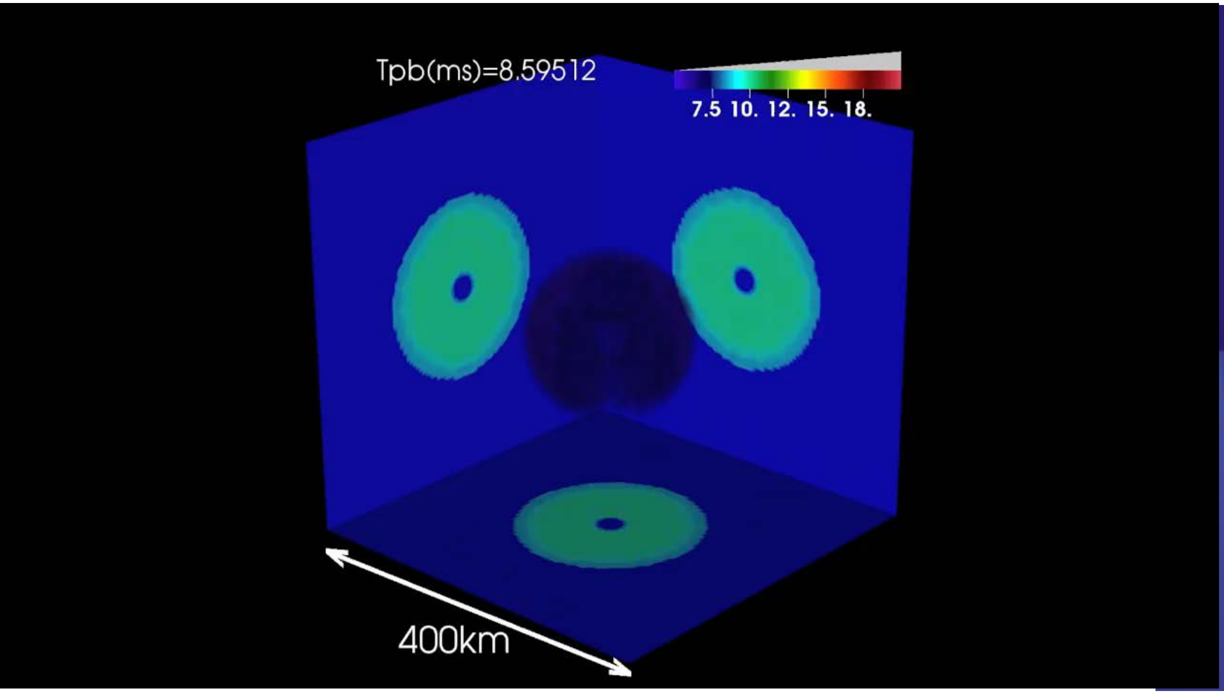


KM3NeT real-time alert system

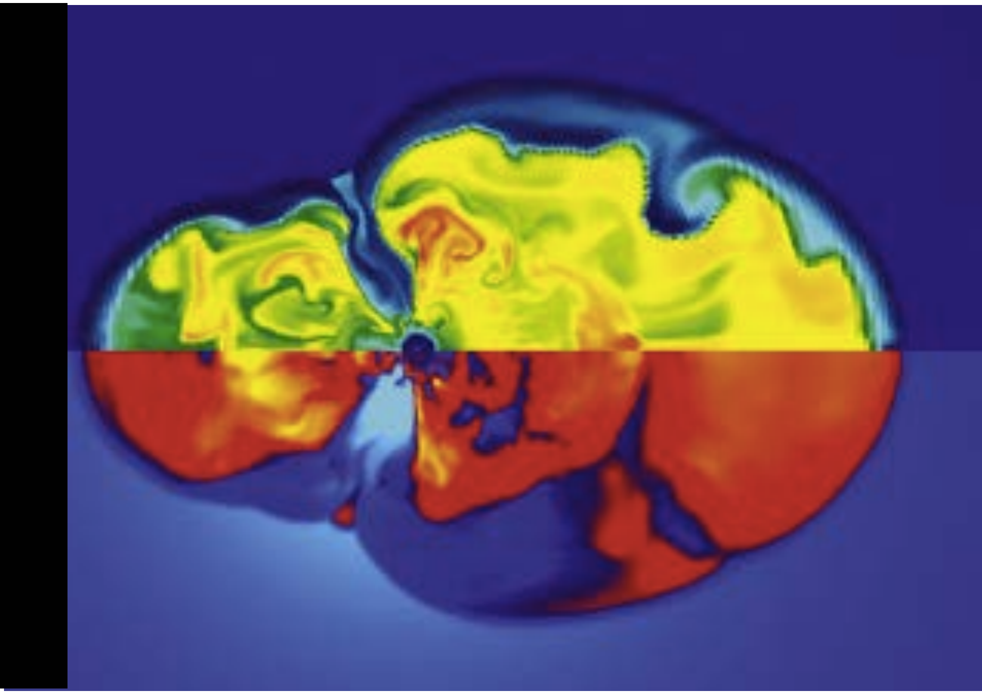
Astroparticle KM3NeT

Staff: Celli, Di Palma; INFN: Ameli, Nicolau, 2 Postdocs, 1 PhD student + master students

- ✓ ANTARES members and KM3NeT members.
- ✓ Key responsibilities: 1) Development of electronics; 2) Calibration of digital optical modules; 3) Real-time alerts framework for multimessenger studies; 4) ν in coincidence with γ-ray sources (GRBs, PeVatron); **5) Multimessenger search of Core–Collapse Supernovae through neutrinos and gravitational waves.**



Simulation of the evolution of a Proto-Neutron–Star before the explotion of the Core-Collapse Supernovae.

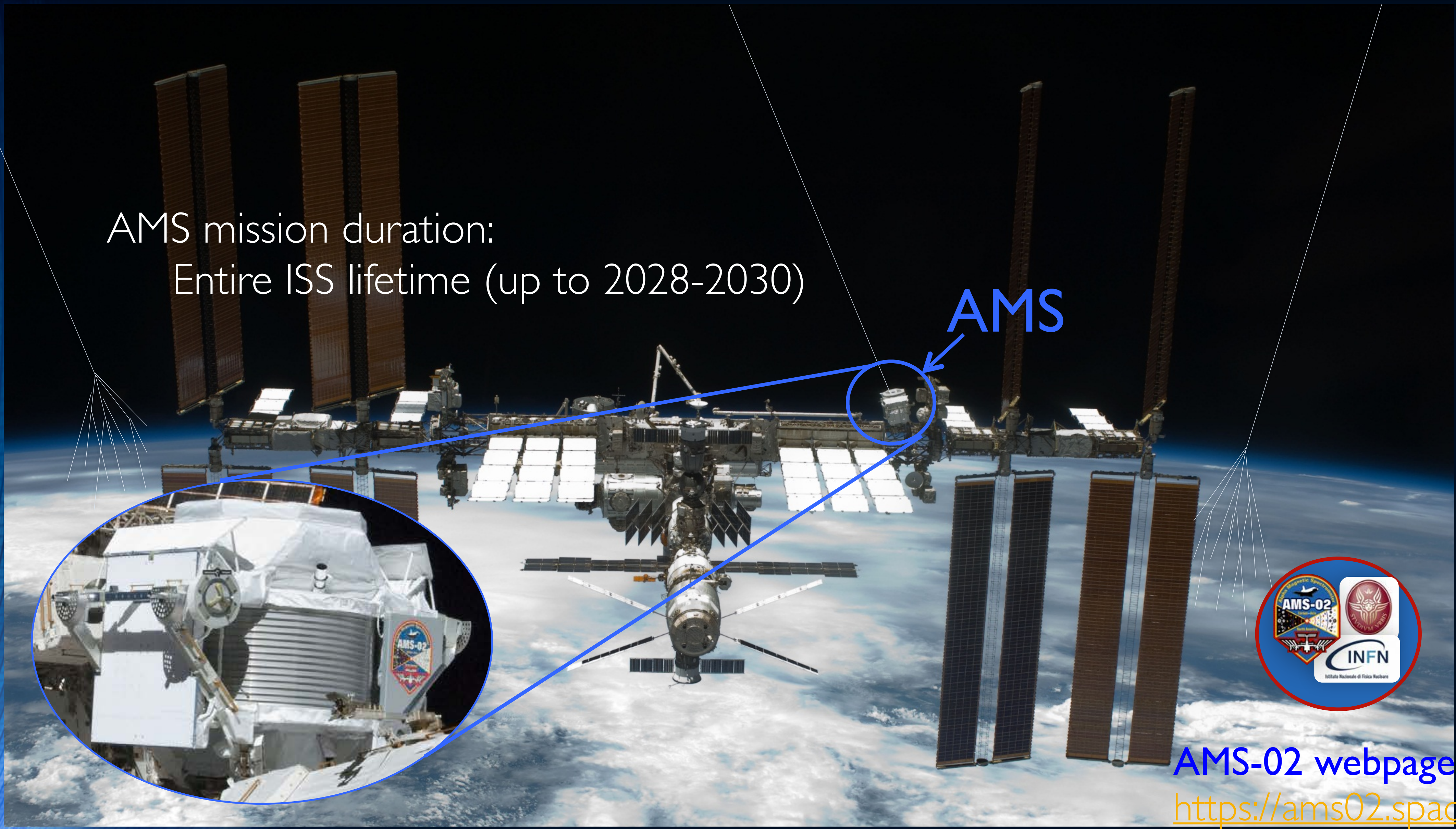


Axial slice of the Proton-Neutron-Star evolution.

AMS

AMS mission duration:

Entire ISS lifetime (up to 2028-2030)

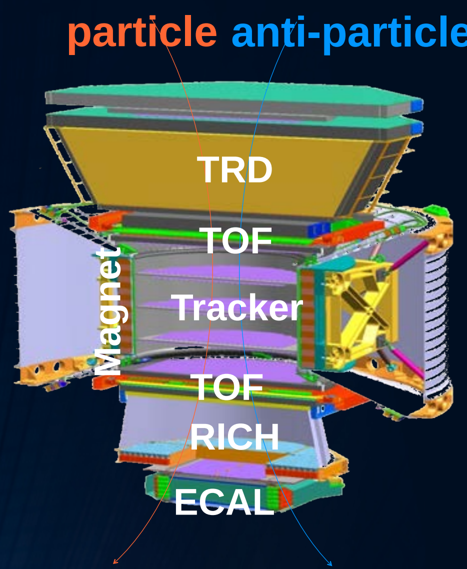


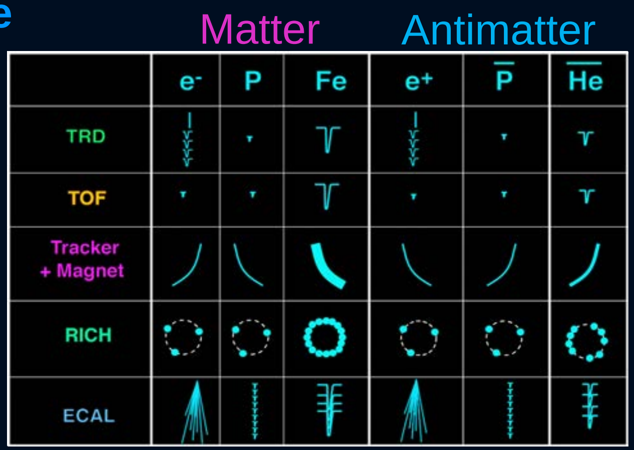
AMS-02 webpage

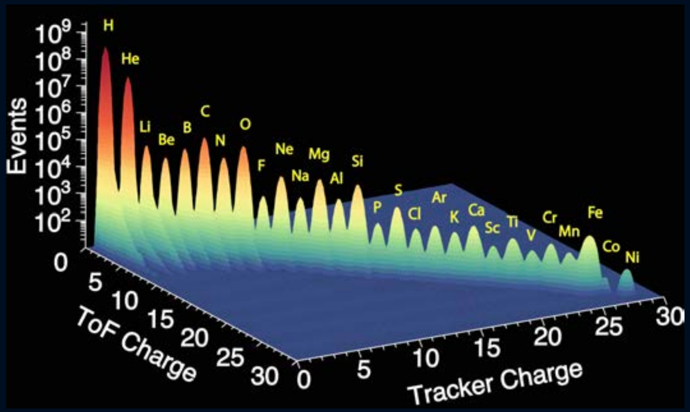
https://ams02.spac

AMS

AMS is a space version of a precision detector used at accelerators





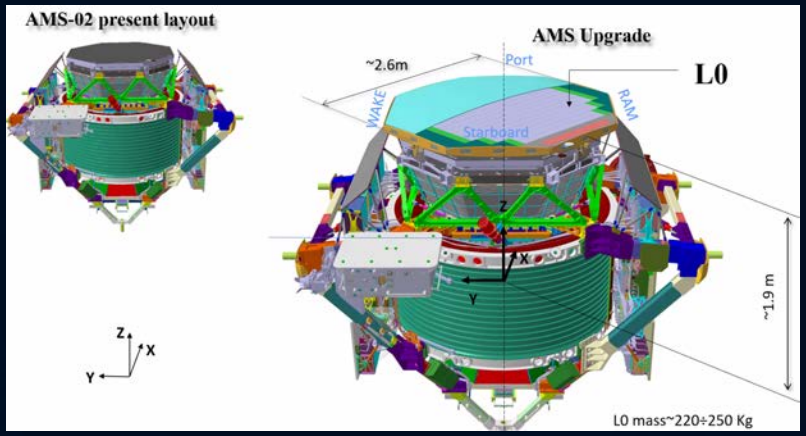


Cosmic-ray properties

Dark Matter searches

Primordial antimatter searches

In 2023 an upgrade of the Tracker , a new silicon detection layer, will improve the AMS02 detectors capability



AMS

Space Radiation Environment

Human Space activities must cope with the high radiation environment of outer space.

Space Radiation composition

- Galactic Cosmic Rays **(GCR)**
- Particle emitted by the Sun **(SEP)** during isolated events
- Particle trapped in Earth's magnetic field **(Radiation Belt)**

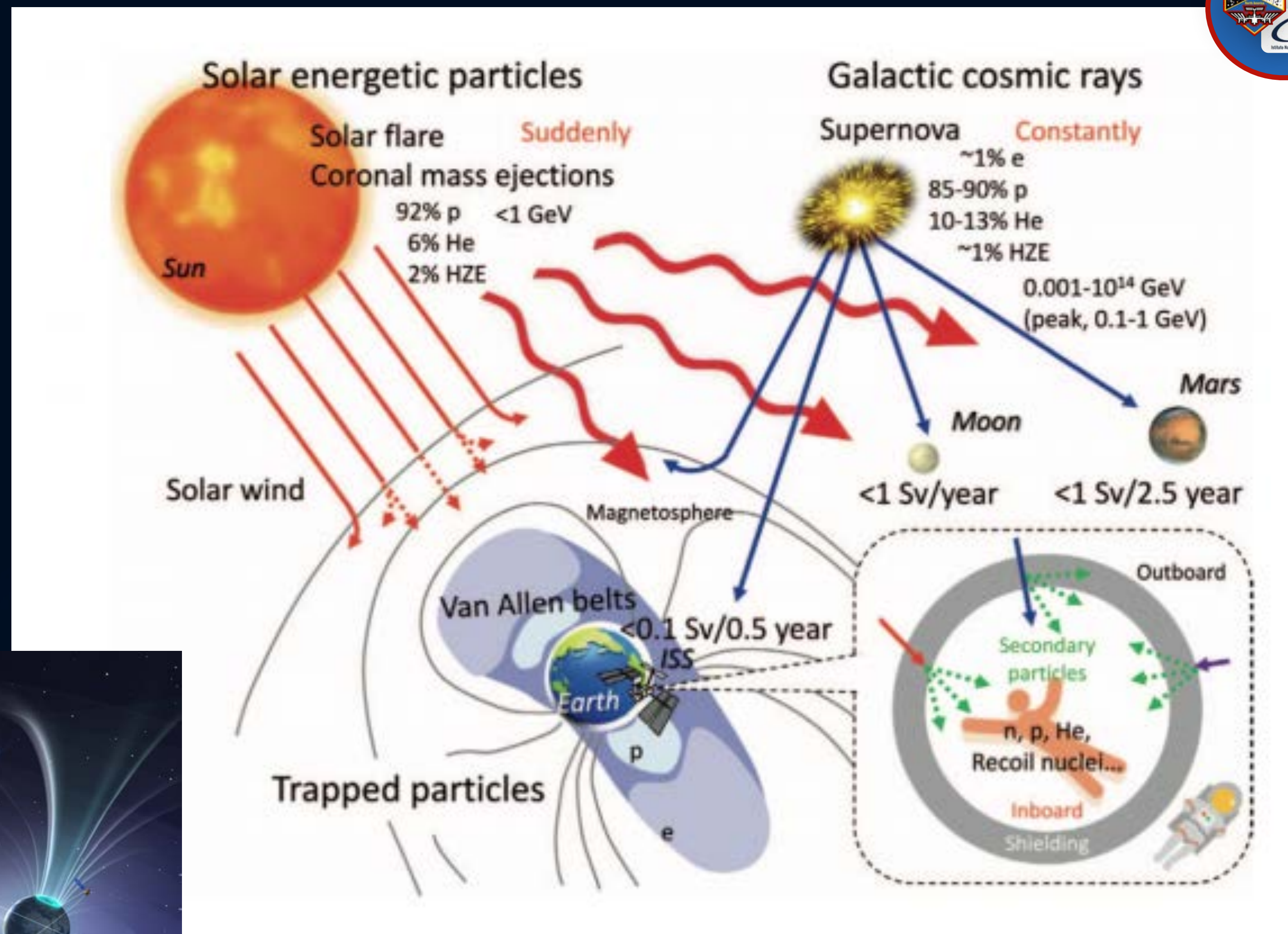


Image courtesy of European Space Agency (ESA)

None of the 3 components is constant in time, mainly due to the solar activity

AMS

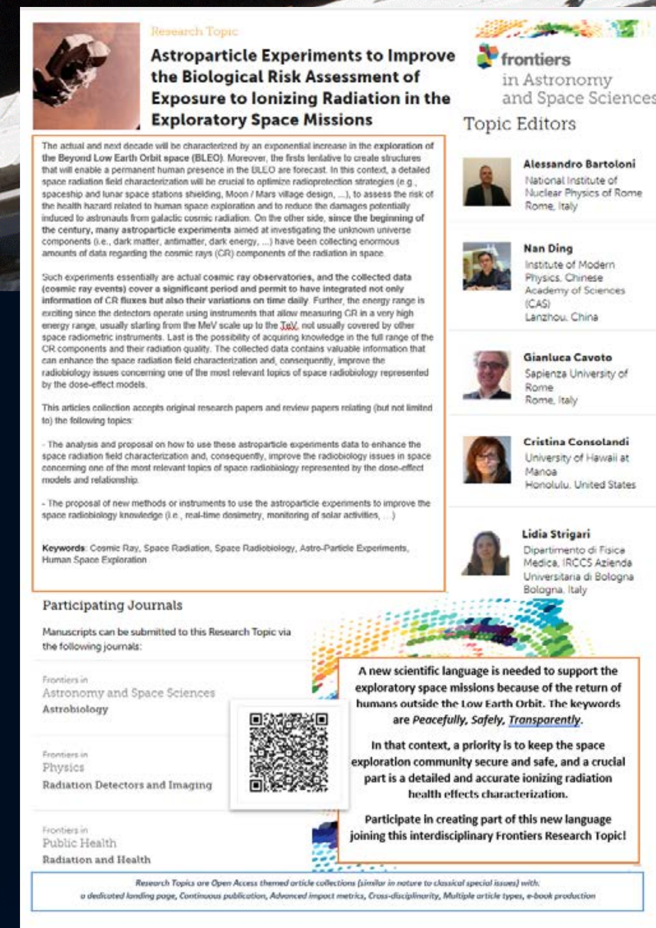
Available Thesis

Strategies for preventing radiobiological effects in space
Galactic Cosmic Rays induced Target and Non Target Effects in space
AMS02 Charged Particle characterization for Space Radiobiology investigations

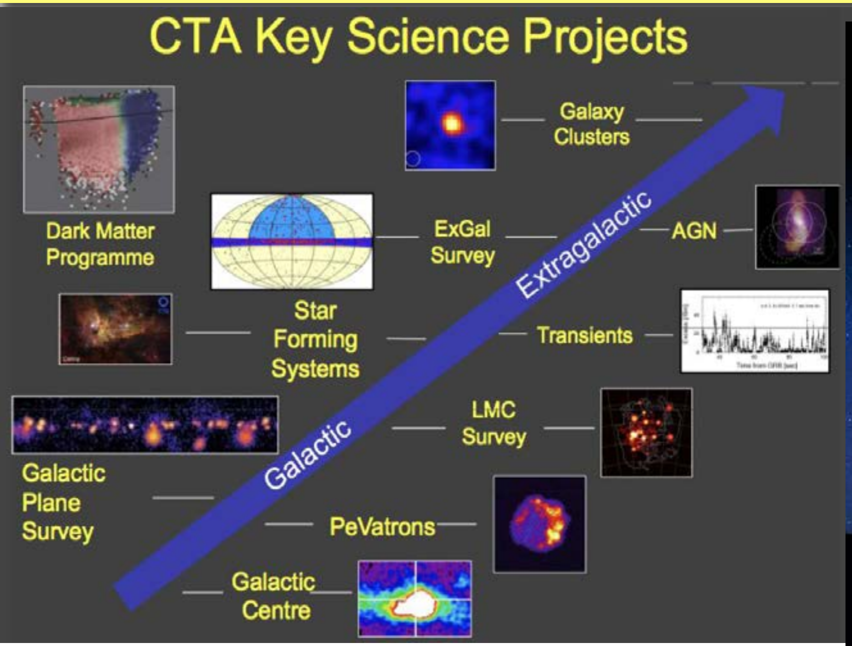
INFN Roma AMS-02 wiki:
https://wiki.infn.it/strutture/roma1/experiments/ams2/home

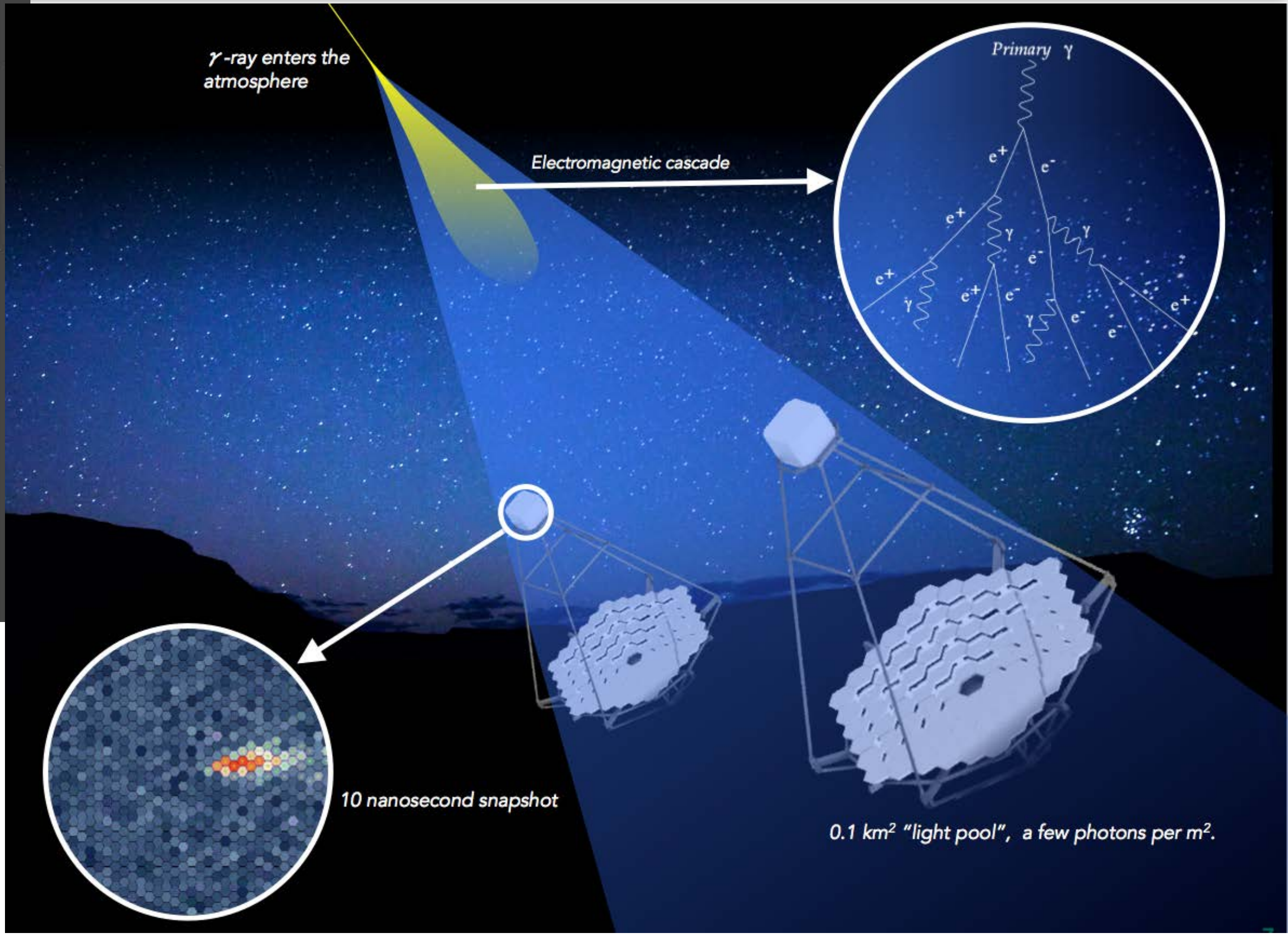
At INFN Roma AMS group, led by **Alessandro Bartoloni,** the primary activity is the use of the AMS measurements of cosmic rays to improve the space radiobiology knowledge with a primary emphasis on ***the space radiation relevance and risk for human space exploration***.

In this topic, there is a strong collaboration and



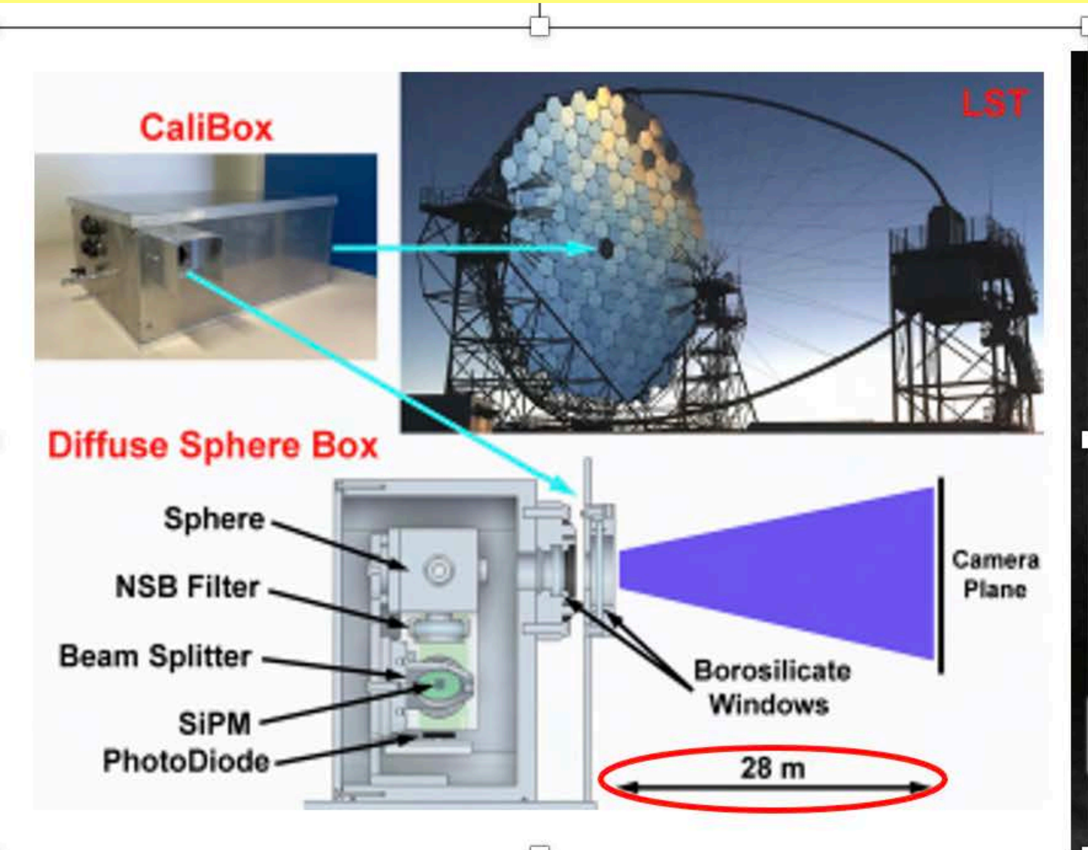
Cherenkov Telescope Array for γs

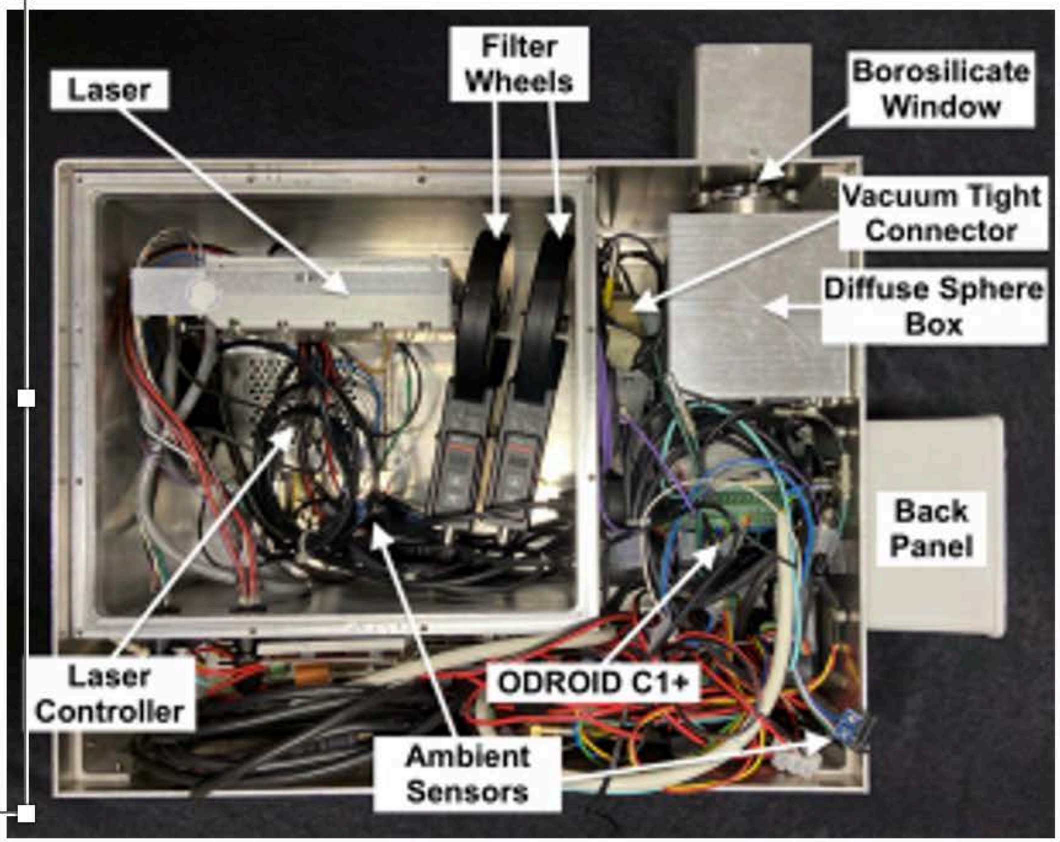




- 100 telescopes on both hemispheres: energy: 20 GeV-200 TeV
- Large Scale Telescope
  - 23 m diamater, 50 Ton
  - reposition in 20 s
  - PMT/siPM camera
- Rome Activity: calibration of the camera and trigger

CTA @ Rome





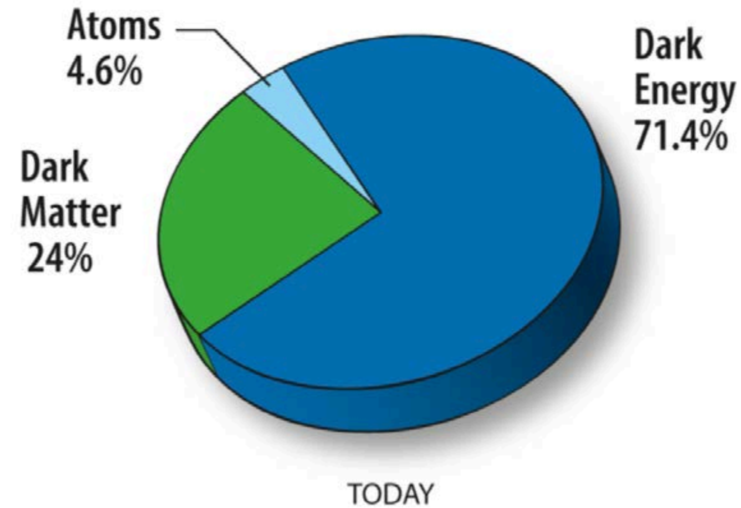
Calibox design and frame developed by INFN-RM1.
Tests performed with success in RM1 and Ud.
Working continuously without major problems since 2019 at LST1.
Other 2 caliboxes prepared and ready to be installed in LST2/LST3 in 2022-2023.

The calibox is controlled by an OPC server installed on Odroid (Linux).
The full remote client control of relays, laser, wheels, weatherboards is tested and operational.

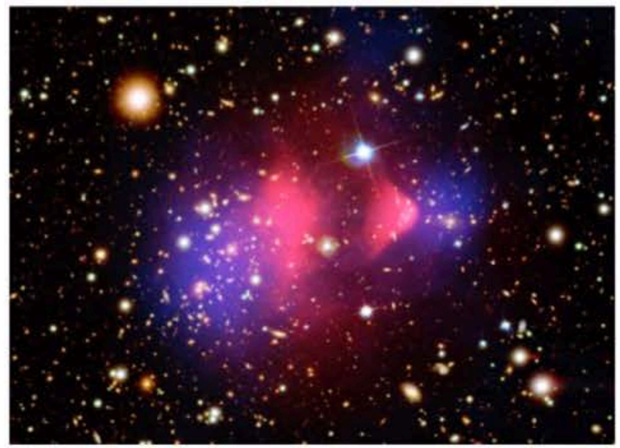
The Dark Universe: Dark Matter

Dark Matter Evidence

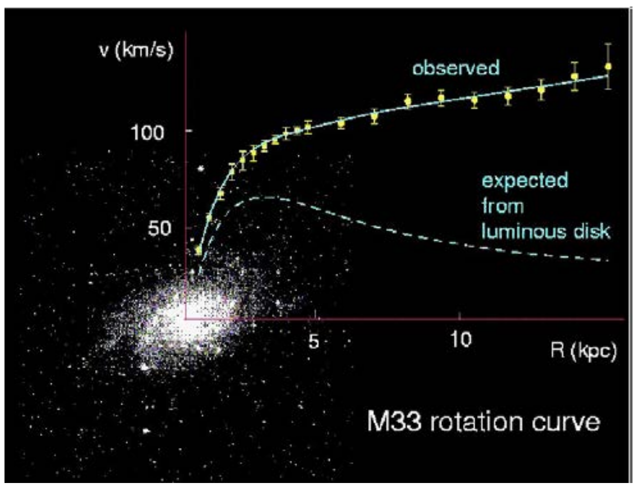
- Gravitational evidence at different scale



Bullet cluster

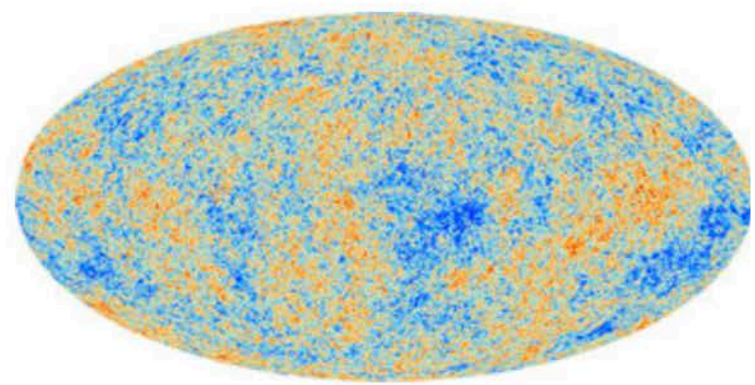


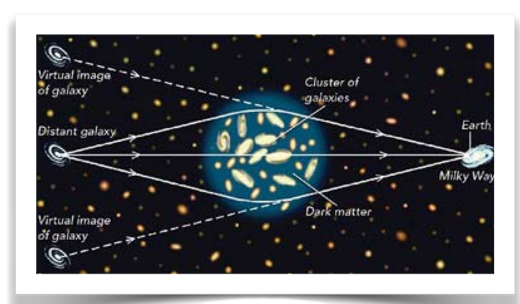
Galaxies



Lensing

Cosmic Microwave Background

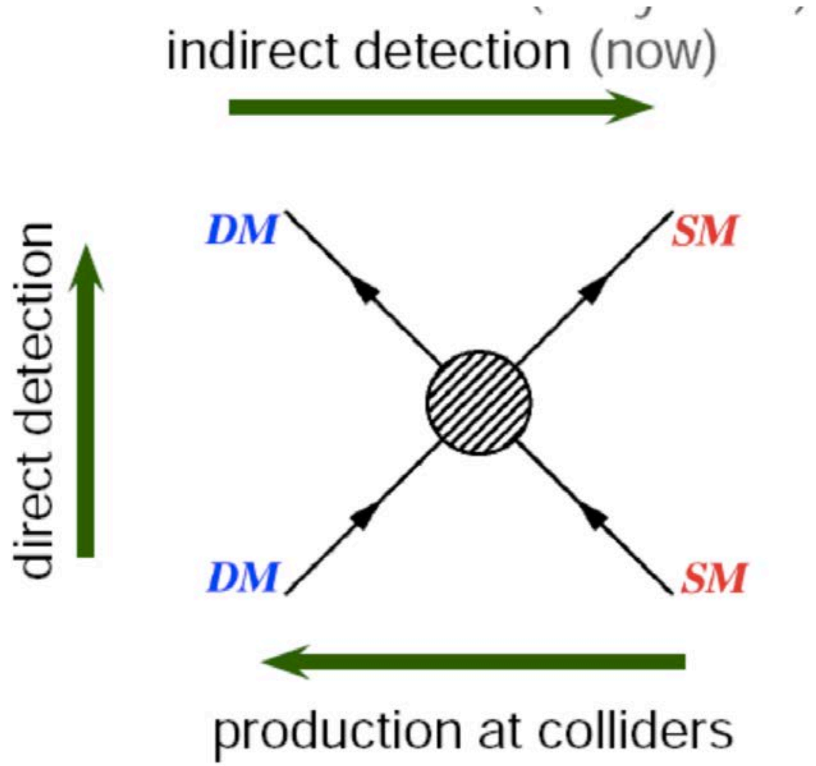


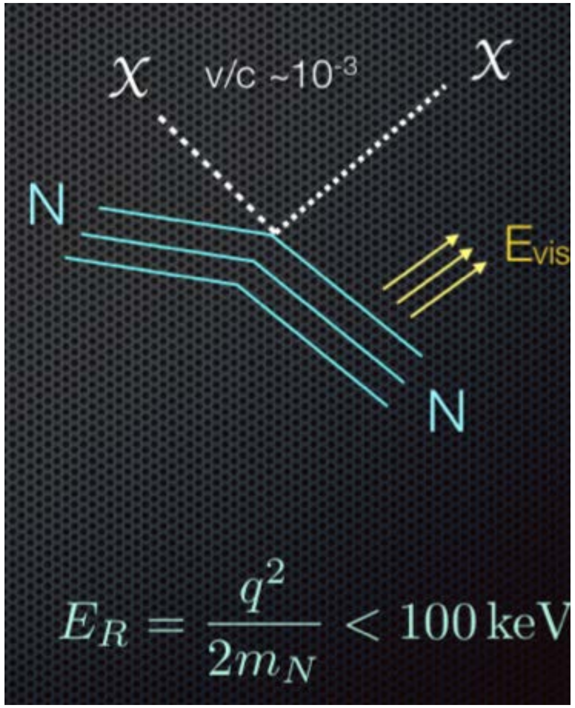


Dark Matter

- 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





Exponential-like shape, increasing at low as many bkgds

Demands O(keV) thresholds and backgrounds close to zero

Counting rate annual modulation

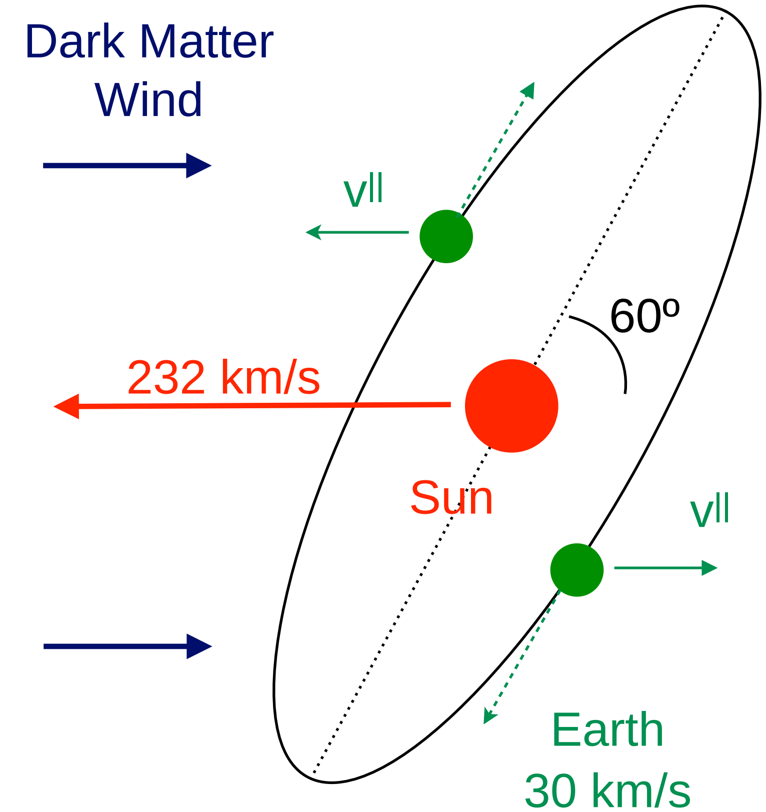
Earth velocity combines to solar system velocity in the galaxy.

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 $\qquad$ t_0 = 2nd June

Pro: model independent

Con: requires detector stability and bkg control.

DAMA

an observatory for rare processes @ LNGS

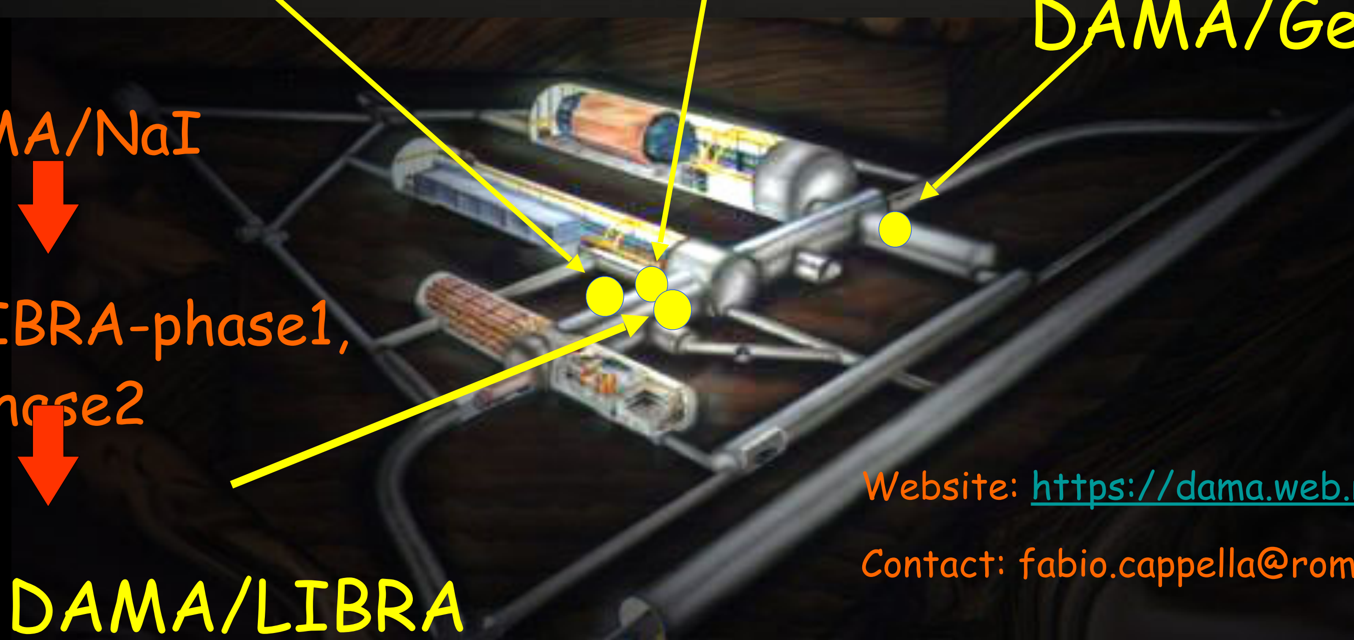
Roma2,Roma1,LNGS,IHEP/Beijing

+ by-products and small scale expts.: INR-Kiev and others (as NIIC+ITEP-Moscow+ JSC NeoChem)
+ some studies on ββ decays(DST-MAE, inter-univ. agreem.): IIT Kharagpur/Ropar, India

DAMA/CRYS

DAMA/R&D

DAMA/Ge



DAMA/NaI

DAMA/LIBRA-phase1, phase2

Empowered DAMA/LIBRA

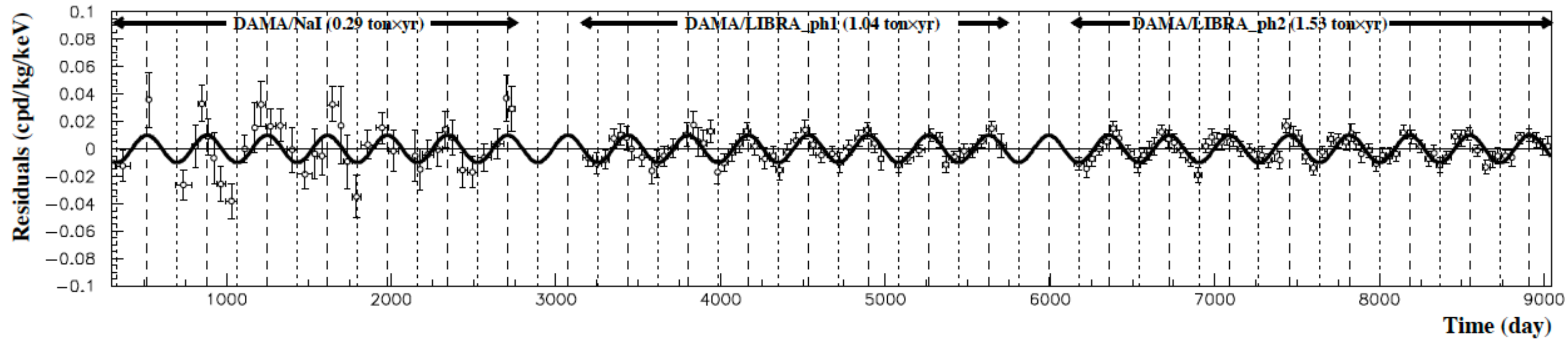
Website: https://dama.web.roma2.infn.it

Contact: fabio.cappella@roma1.infn.it

Model Independent Annual Modulation Result

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

DAMA/NaI+DAMA/LIBRA-phase1+DAMA/LIBRA-phase2 (2.86 ton × yr)



$A\cos[\omega(t-t_0)]$

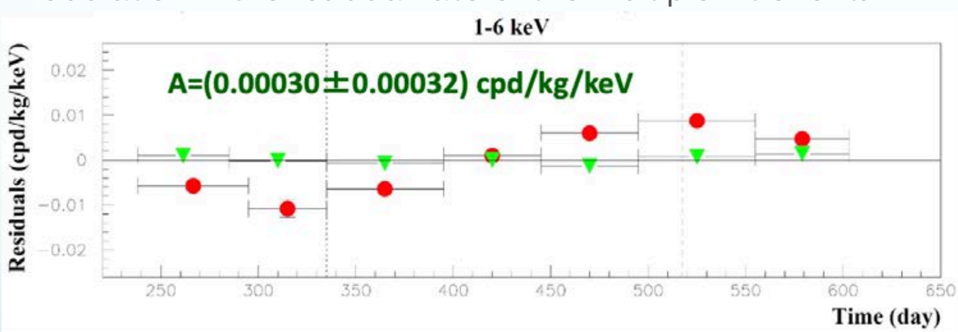
Fit with all the parameters free:

A = (0.01014 ± 0.00074) cpd/kg/keV

T = (0.99834±0.00067) yr

t_0 = (142.4±4.2) d

Comparison between single hit residual rate (red points) and multiple hit residual rate (green points); Clear modulation in the single hit events; No modulation in the residual rate of the multiple hit events



Multiple hits events = Dark Matter particle "switched off"

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

NEW Empowered DAMA/LIBRA

After the recent upgrade (fall 2021) DAMA/LIBRA is now running with a lower software energy threshold, i.e. increased sensitivity to DM

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

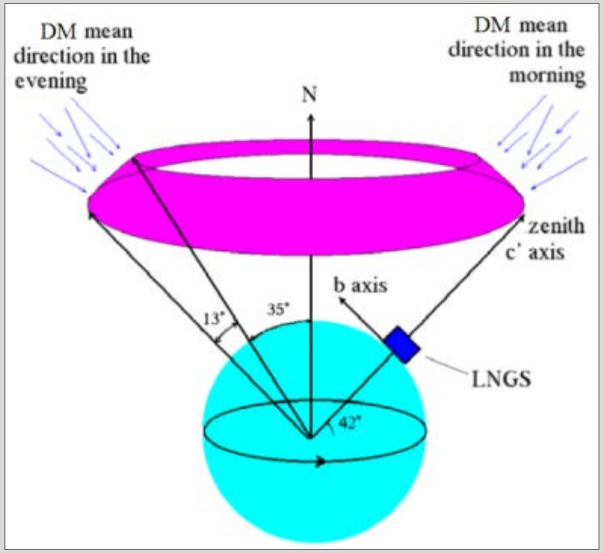
Study of the directionality of Dark Matter using detectors with anisotropic response

Directionality: Study of the correlation between the arrival direction of Dark Matter particles and the Earth motion in the galactic frame

Nuclear recoils are expected to be strongly correlated with the DM impinging direction

This effect can be pointed out through the study of the variation in the response of anisotropic scintillation detectors during sidereal day:

- for heavy particles the light output and the pulse shape depends on the particle impinging direction with respect to the crystal axes
- for γ/e the light output and the pulse shape are isotropic

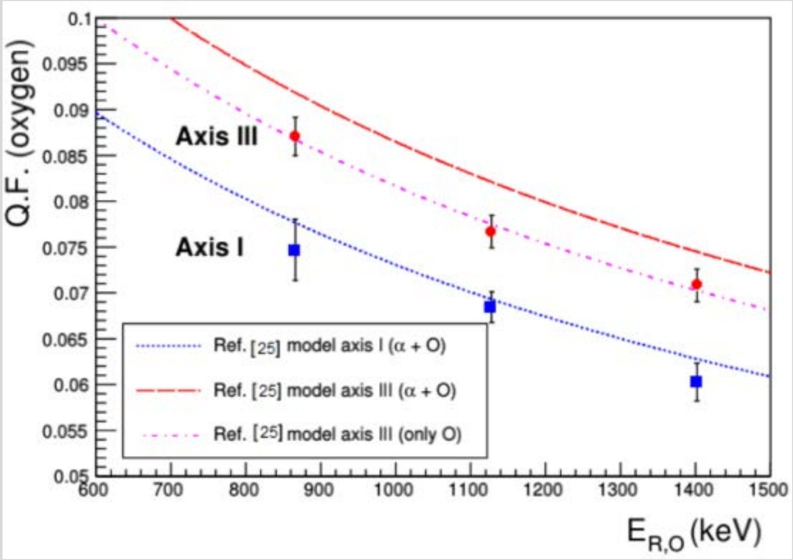


Eur. Phys. J. C 73 (2013) 2276
Eur. Phys. J. A 56 (2020) 83

ADAMO project: Study of the directionality approach with $ZnWO_4$ anisotropic detectors

- ✓ The light output and pulse shape of $ZnWO_4$ detectors have anisotropic behaviour
- ✓ Very high reachable radiopurity
- ✓ Threshold at keV level feasible
- ✓ Sensitivity to small and large mass DM (Zn,W,O)

Anisotropic response to nuclear recoils recently confirmed by DAMA at 5.4σ! [Eur. Phys. J. A 56 (2020) 83]

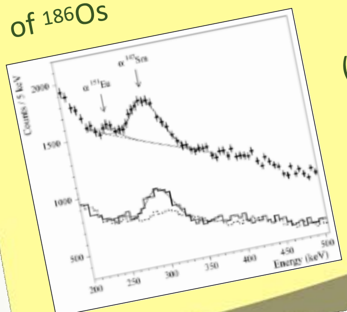


Main DAMA results in the search for rare processes

- Search for 2β decays of ~30 candidate isotopes: ^{40}Ca, ^{46}Ca, ^{48}Ca, ^{64}Zn, ^{70}Zn, ^{100}Mo, ^{96}Ru, ^{104}Ru, ^{106}Cd, ^{108}Cd, ^{114}Cd, ^{116}Cd, ^{112}Sn, ^{124}Sn, ^{134}Xe, ^{136}Xe, ^{130}Ba, ^{136}Ce, ^{138}Ce, ^{142}Ce, ^{144}Sm, ^{154}Sm, ^{156}Dy, ^{158}Dy, ^{180}W, ^{186}W, ^{184}Os, ^{192}Os, ^{190}Pt and ^{198}Pt (obtained the best experimental sensitivities for many of them)

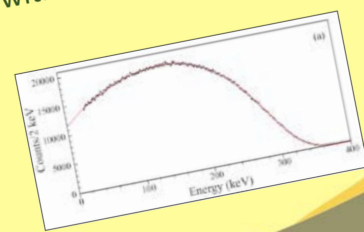
- DAMA has also observed the 2ν2β decay in ^{100}Mo, ^{116}Cd, ^{150}Nd

First observation of α decays of ^{151}Eu with a CaF_2(Eu) scintillator and of ^{190}Pt to the first excited level (E_{exc}=137.2 keV) of ^{186}Os



($T_{1/2}=5\times10^{18}$yr)

Investigations of rare β decays of ^{113}Cd ($T_{1/2}=8\times10^{15}$yr), ^{113m}Cd with $CdWO_4$ scintillator and ^{48}Ca with a CaF_2(Eu) detector



Investigations of rare α decays in Hf and Os isotopes

Observation of correlated e^+e^- pairs emission in α decay of ^{241}Am ($A_{e+e-}/A_\alpha \approx 5\times10^{-9}$)

Search for cluster decays of ^{127}I, ^{138}La and ^{139}La

CNC processes, e.g. in ^{127}I, ^{136}Xe, ^{100}Mo and ^{139}La

Search for spontaneous transition of ^{23}Na and ^{127}I nuclei to superdense state

Search for PEP violating processes in Sodium and in Iodine

Search for N, NN, NNN decay into invisible channels in ^{129}Xe and ^{136}Xe

Search for ^{7}Li solar axions using resonant absorption in LiF crystal

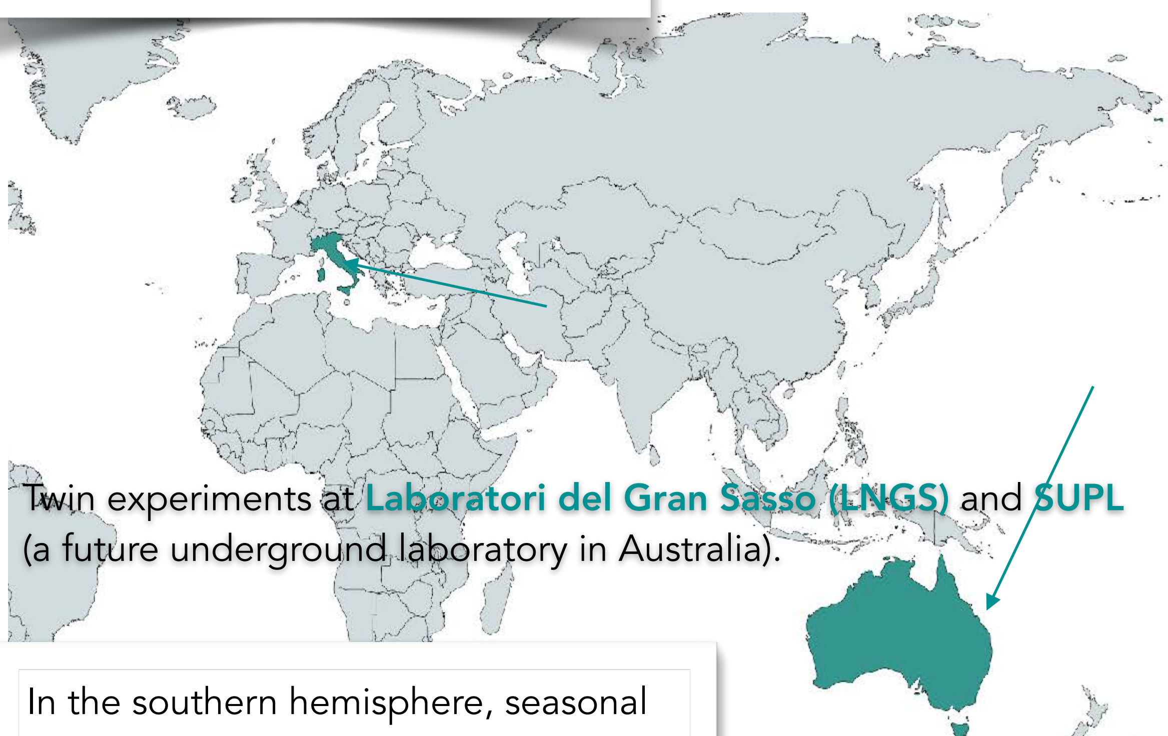
Dark Matter investigation

… many others are in progress

SABRE:Sodium Iodide with Active Background Rejection

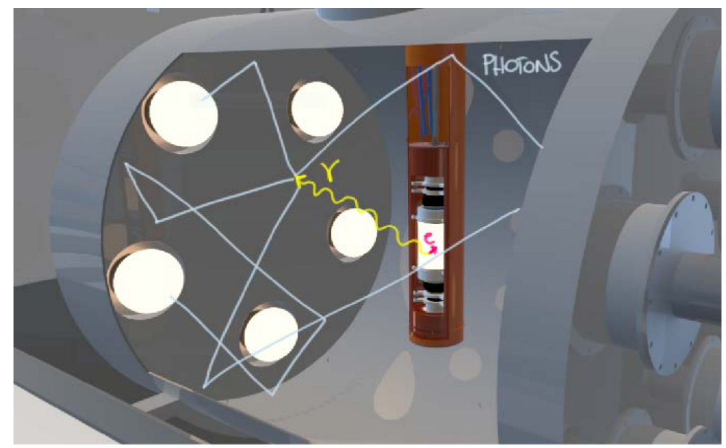
Search for DM particles in the galactic halo through the annual modulation effect = signal from DM expected to modulate yearly with maximum in June.

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

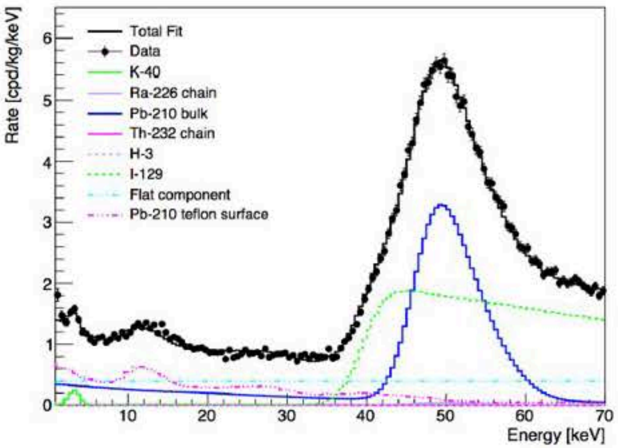
SABRE: Proof of Principle PoP

A Proof of Principle (1 crystal+ active veto) recently concluded @LNGS

Results:
- Breakthrough background level: ~1 count/day/kg/keV in the 1-6 keV ROI
- Active veto no longer required, need radiopure reflector

Goals for near future:
- Test the same crystal (NaI-33) with a new clean reflector
- Test reproducibility of crystal radiopurity → 1 new crystal already at LNGS + 1 in production at RMD (USA)
- Assembly of detector modules at LNGS with a new custom glovebox (previously done in Princeton)

→ Demonstrate feasibility of a full-scale experiment without active veto and finalize the design of crystal array + shieldings



THESIS ACTIVITIES:

Detector assembly and data taking @LNGS
NaI crystal tests @ INFN Roma and LNGS
Montecarlo simulations for SABRE-North full scale

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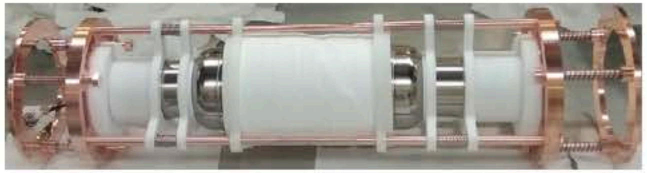
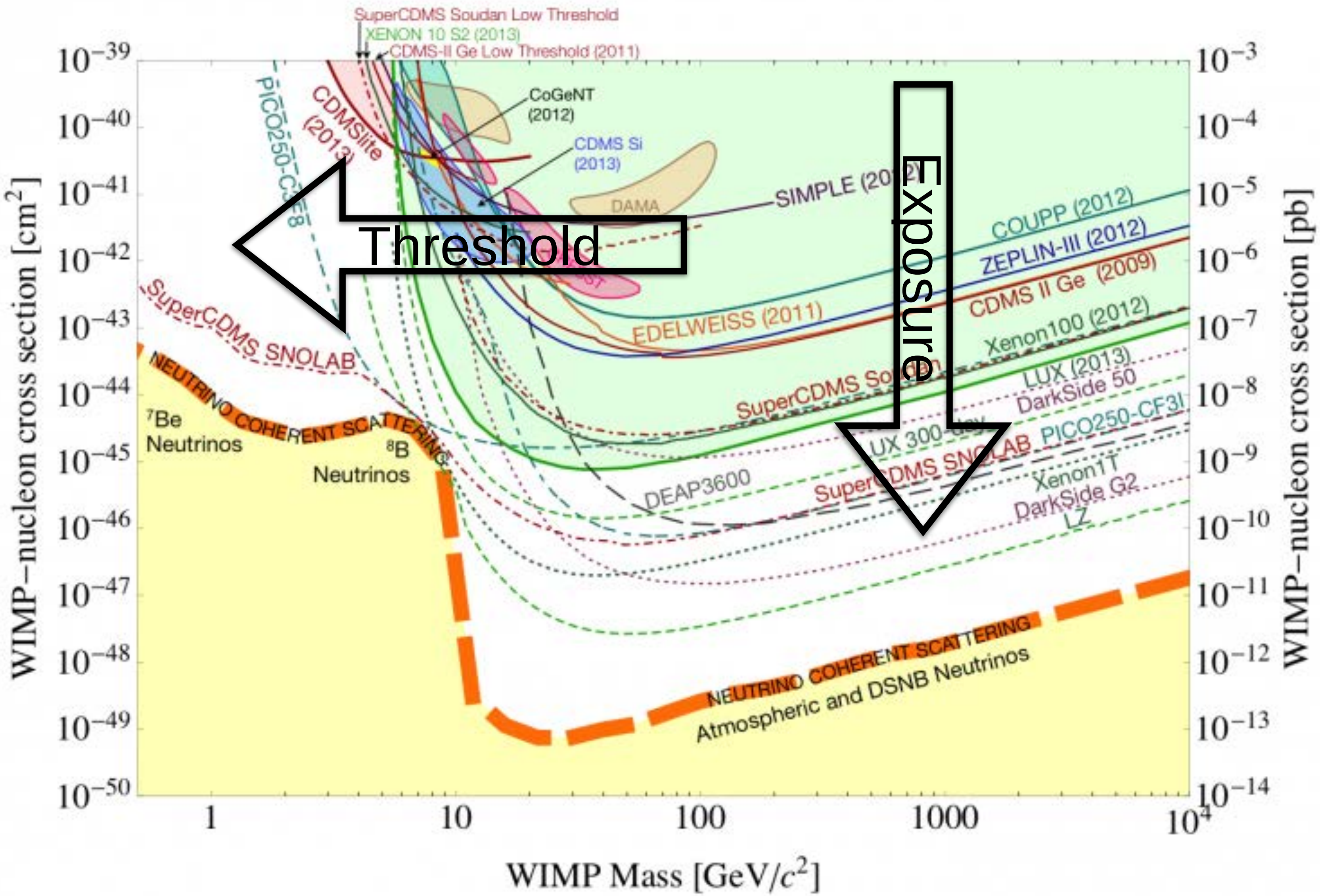


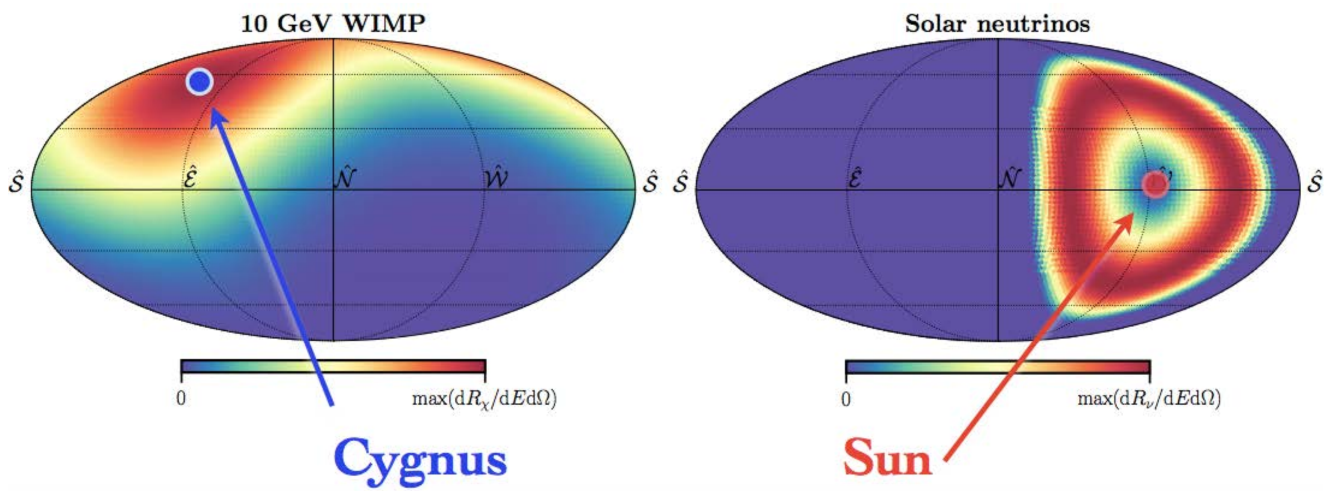
Where are we going?

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



DIRECTIONAL DARK MATTER SEARCHES

- **Nuclear recoils** induced by solar neutrinos are the ultimate irreducible background for WIMP dark matter (DM) searches, unless we are sensitive to the direction of the incoming particle

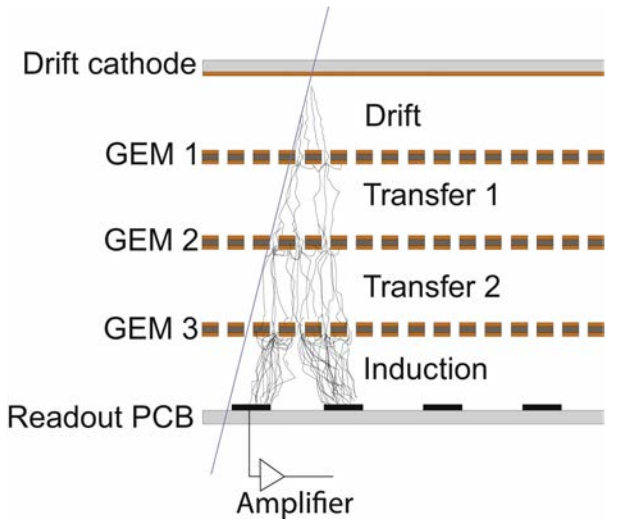


- Discrimination of DM-induced vs. neutrino-induced recoils is possible if the detector can reconstruct the direction of the ionization track –> **requires an extremely high detector granularity to determine the orientation of micrometric tracks**

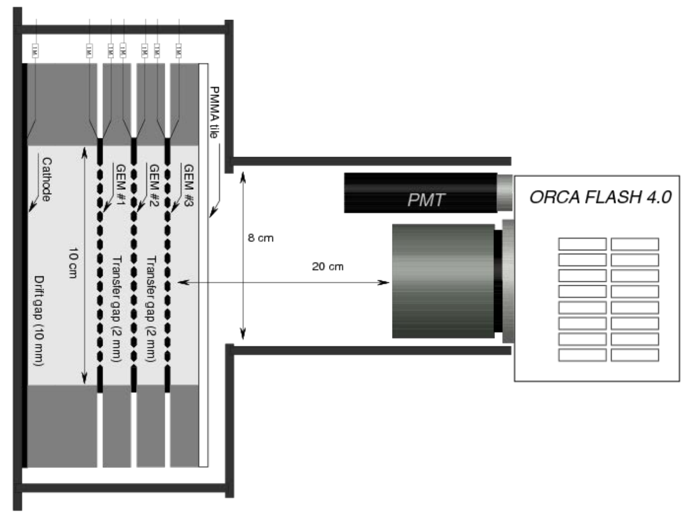
CYGNO:1m^3 TPC

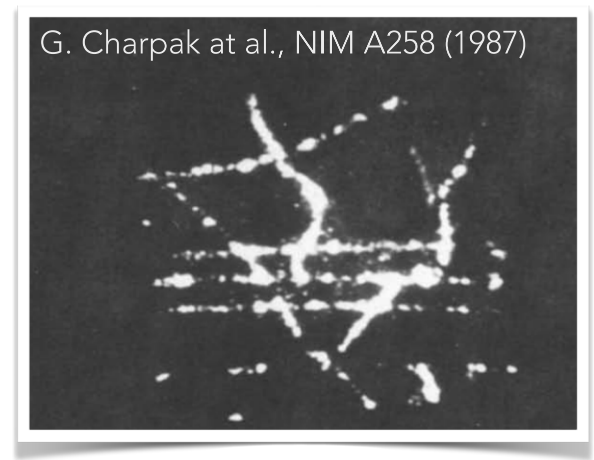
OPTICAL READOUT OF A TRIPLE GEM DETECTOR

CONVENTIONAL READOUT



OPTICAL READOUT



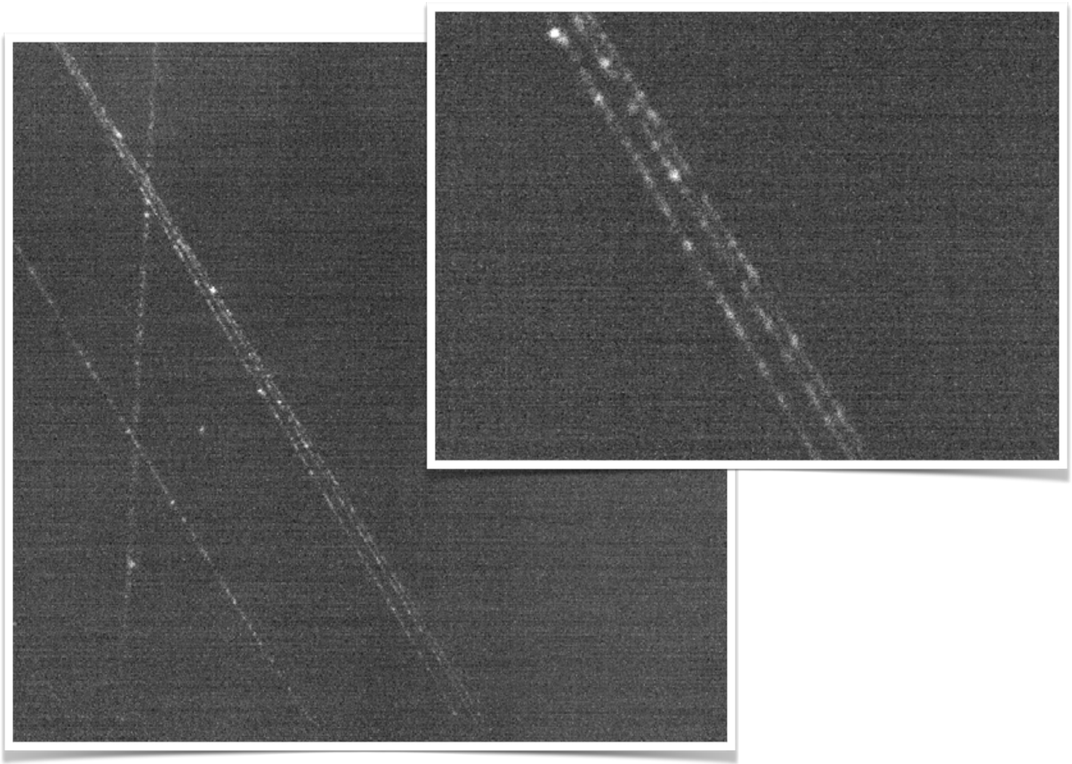


G. Charpak at al., NIM A258 (1987)

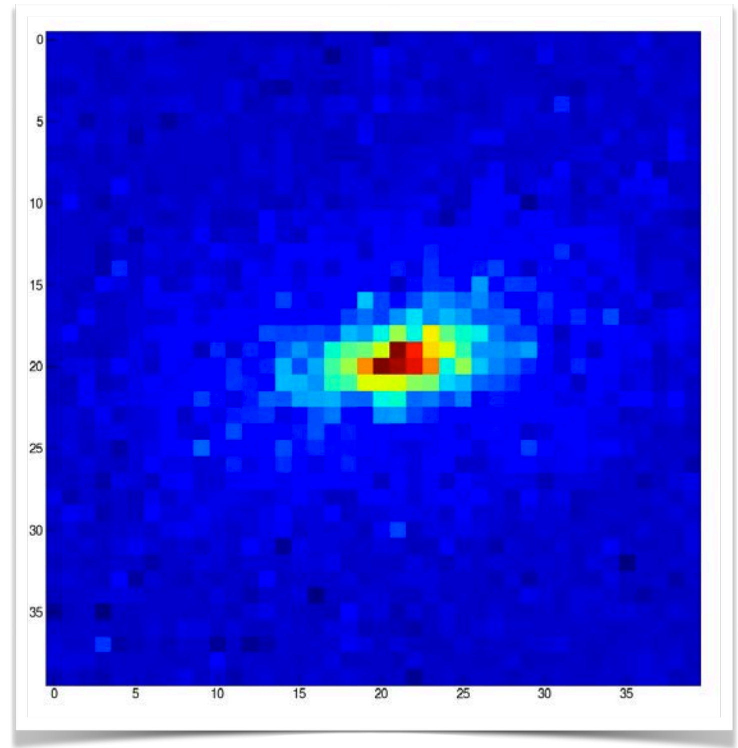
During the multiplication process, optical photons are also produced along with electrons by the gas through atomic and molecular de-excitation

Tracks can be imaged looking at the last GEM with a low-noise digital photo camera –> **an extremely high granularity on large surfaces at low cost**

Cosmic rays & nuclear recoils



Resolution of single ionization clusters from MIP

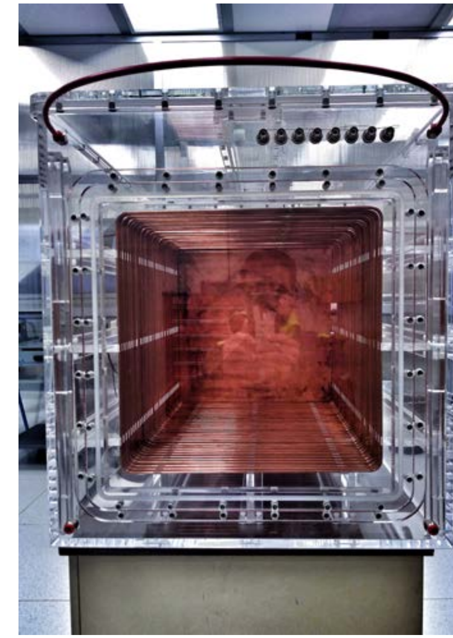


Detection of low energy nuclear recoils with directional capabilities

From demonstrators to experiments

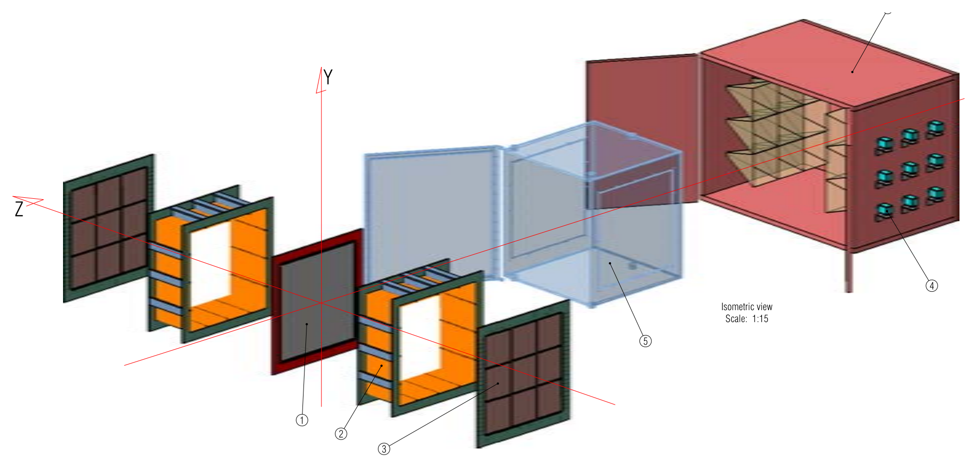
LIME (Large Imaging ModulE)

- Time Projection Chamber (TPC) with **50 litres** sensitive volume
- **33 x 33 ~ 1000 cm²** GEM surface
- **50 cm** drift path
- Commissioning ongoing at Laboratori Nazionali del Gran Sasso



THE CYGNO EXPERIMENT

- 1 m^3 of He/CF_4 60/40 (1.6 kg) at atmospheric pressure
- 100 x 100 cm2 GEM surface readout by multiple cameras
- gamma-ray and neutron shield



Thesis

- Commissioning and characterization of the LIME detector as a demonstrator for the directional search of Dark Matter with gaseous detectors (both hardware-oriented and analysis-oriented theses)
- The CYGNO experiment: simulation of backgrounds and sensitivity estimates

FOR MORE INFORMATION, PLEASE CONTACT THE CYGNO GROUP IN SAPIENZA

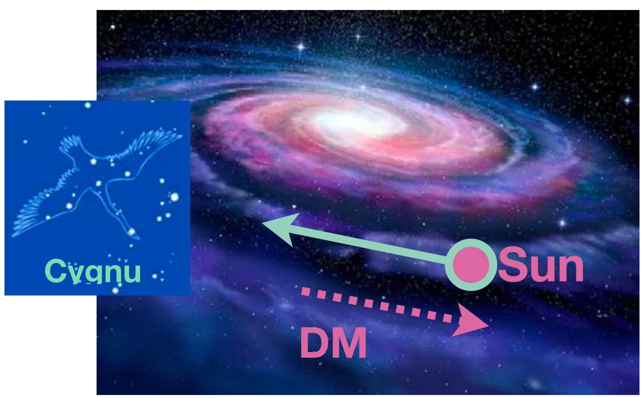
Gianluca Cavoto, Emanuele Di Marco, Giulia D'Imperio, Francesco Iacoangeli, Andrea Messina, Stefano Piacentini, Davide Pinci, Francesco Renga (local reference person)

Andromeda

ANDROMeDa
Aligned Nanotube Detector for Research On MeV Darkmatter

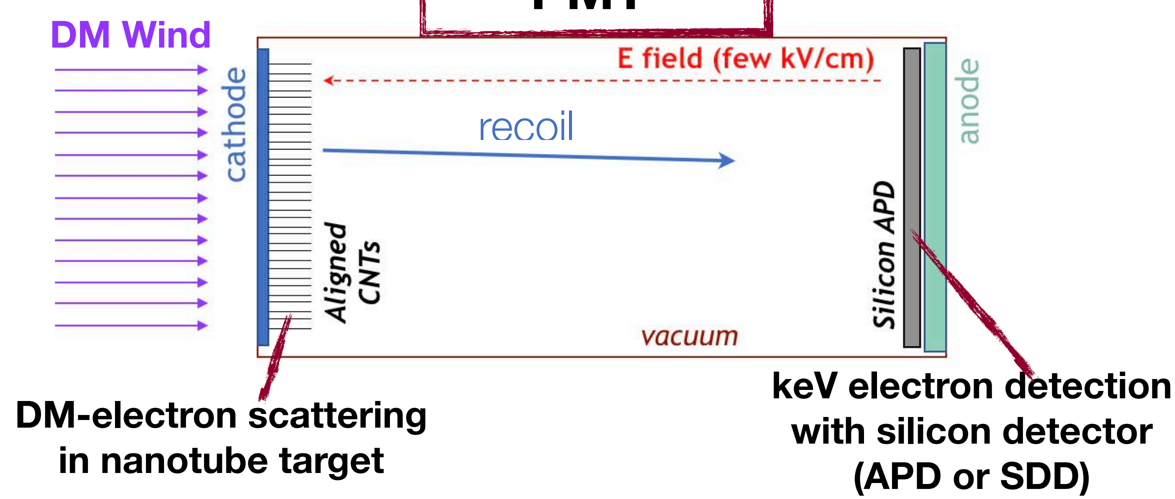
ANDROMeDa: Searching for

- Developing the **Dark-PMT**: a novel dark matter (DM) detector based on carbon nanotubes
  - Sensitive to **DM-electron scattering** inside a **nanotube** target



Searching for light DM
1 MeV < mass < 1 GeV
(eg SIMP model)

The 'Dark-PMT'



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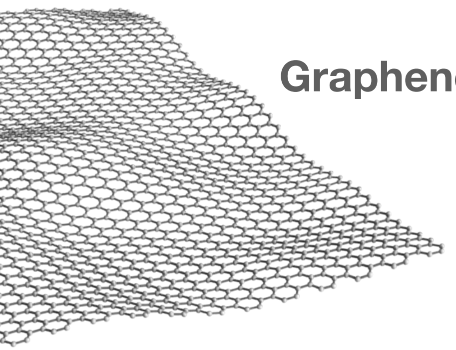
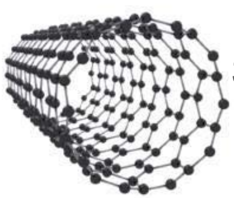
Aligned Carbon Nanotubes

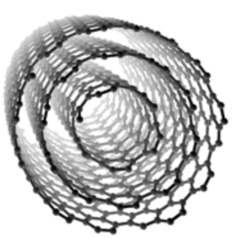
An Ideal Target for Dark Matter



Graphene

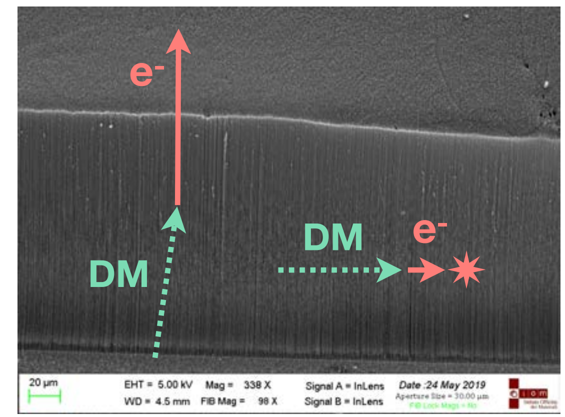


Single-wall nanotube



Multi-wall nanotube

- **Nanotubes:** ‘straws’ of graphene
    - Ø = 5-10 nm, length up to 300 μm
- Vertically-aligned nanotubes: **hollow** in direction of the

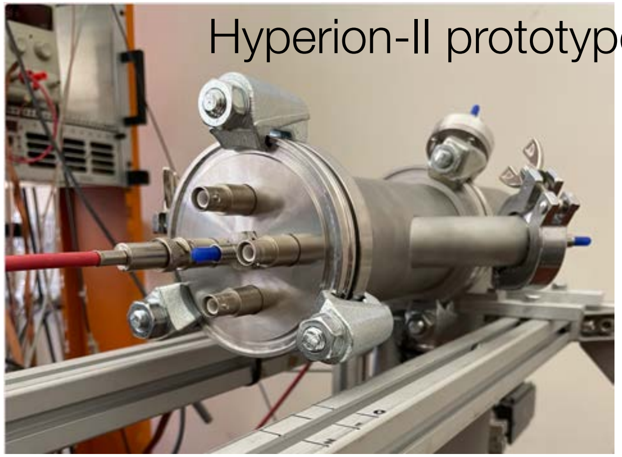


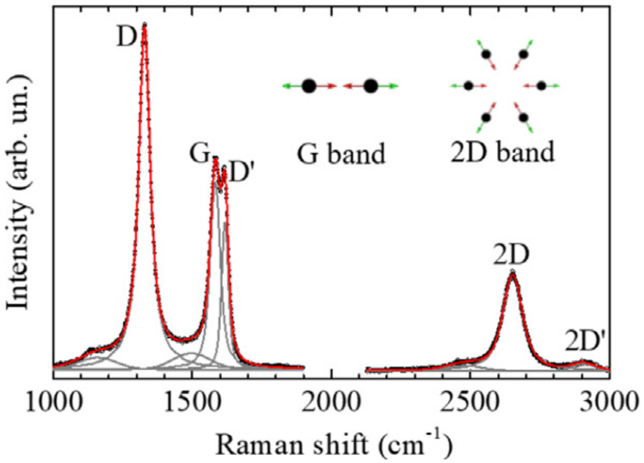
Our state-of-the-art nanotube growing facility in Sapienza

ANDROMeDa: Activities and Thesis

DETECTORS & DATA ANALYSIS

- Measurements with **Dark-PMT prototype** ‘Hyperion-II’
  - Operation of **silicon detectors** (APD, SDD),
    reconstruction of keV electrons and UV photons,
    data analysis with C++/ROOT
- Design of the **next-gen** Dark-PMT prototype

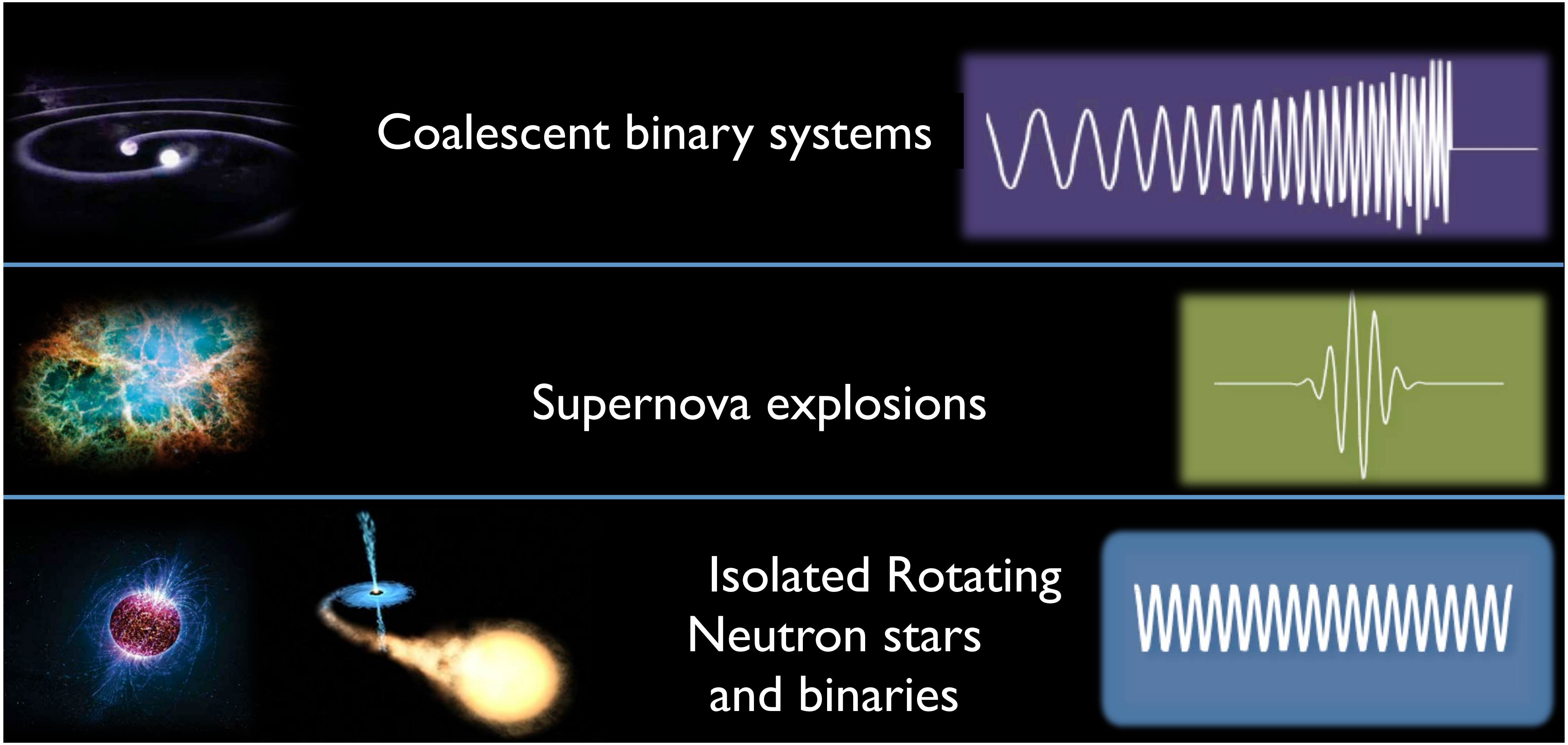




Gravity and Quantum: Gravitational Waves

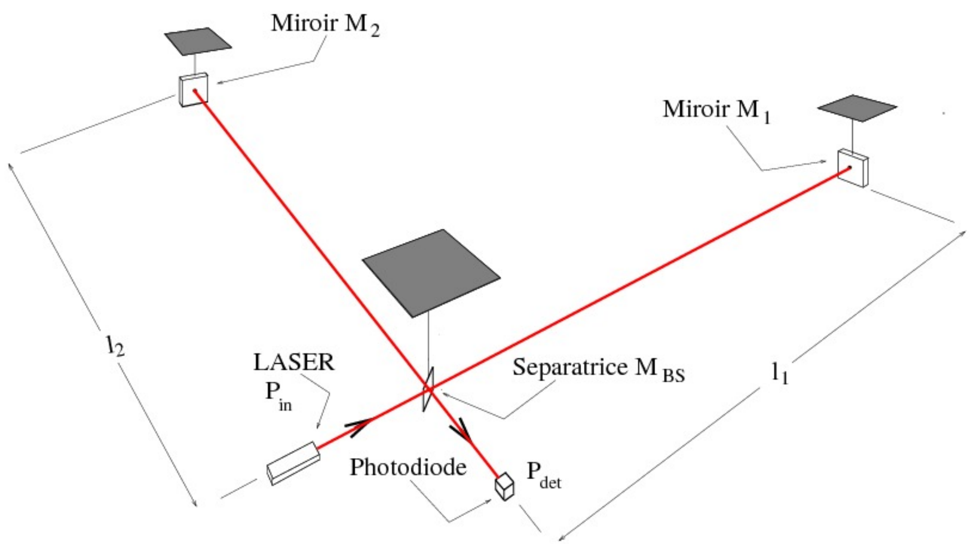
Gravitational waves

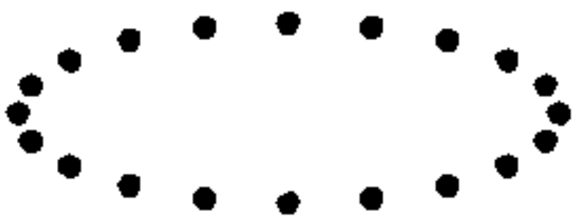
- General Relativity foresees emission of gravitational wave

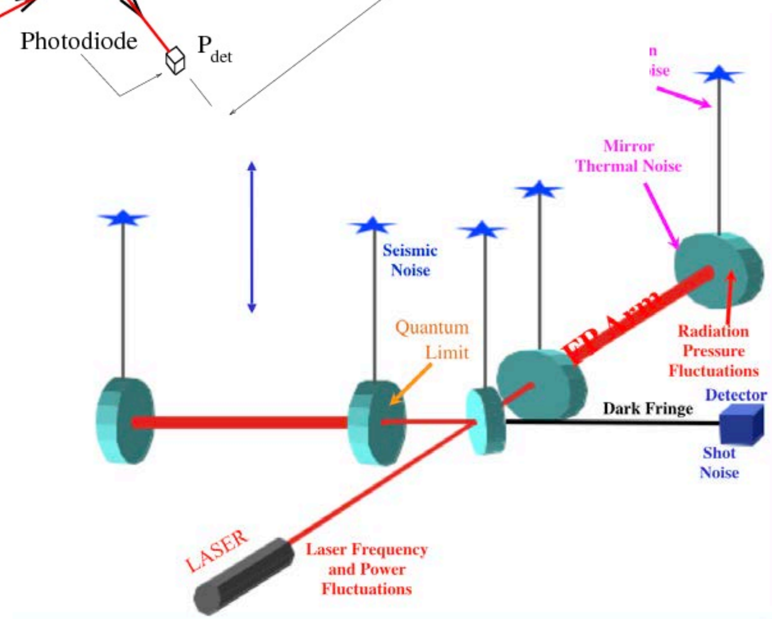


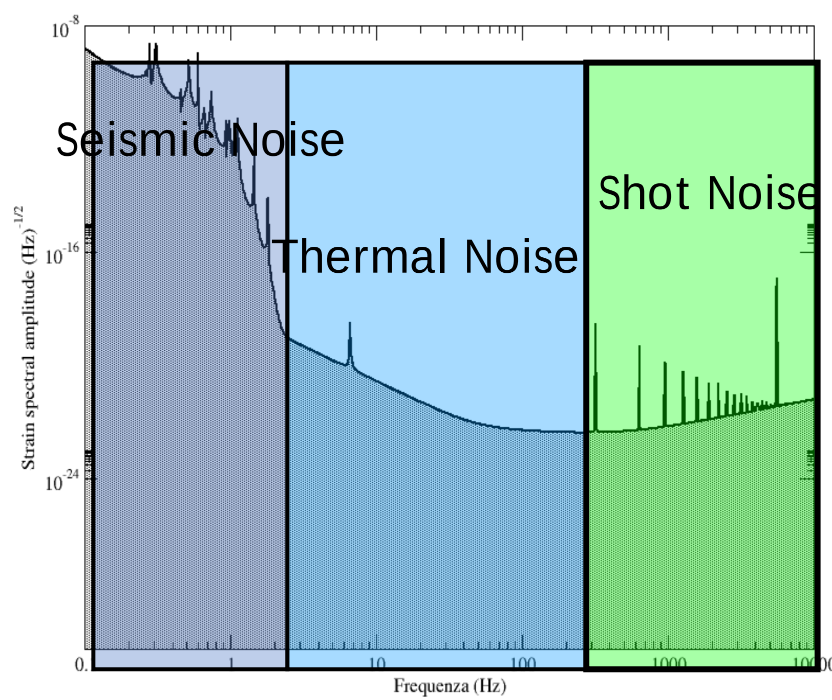
How to detect gravitational waves

- 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

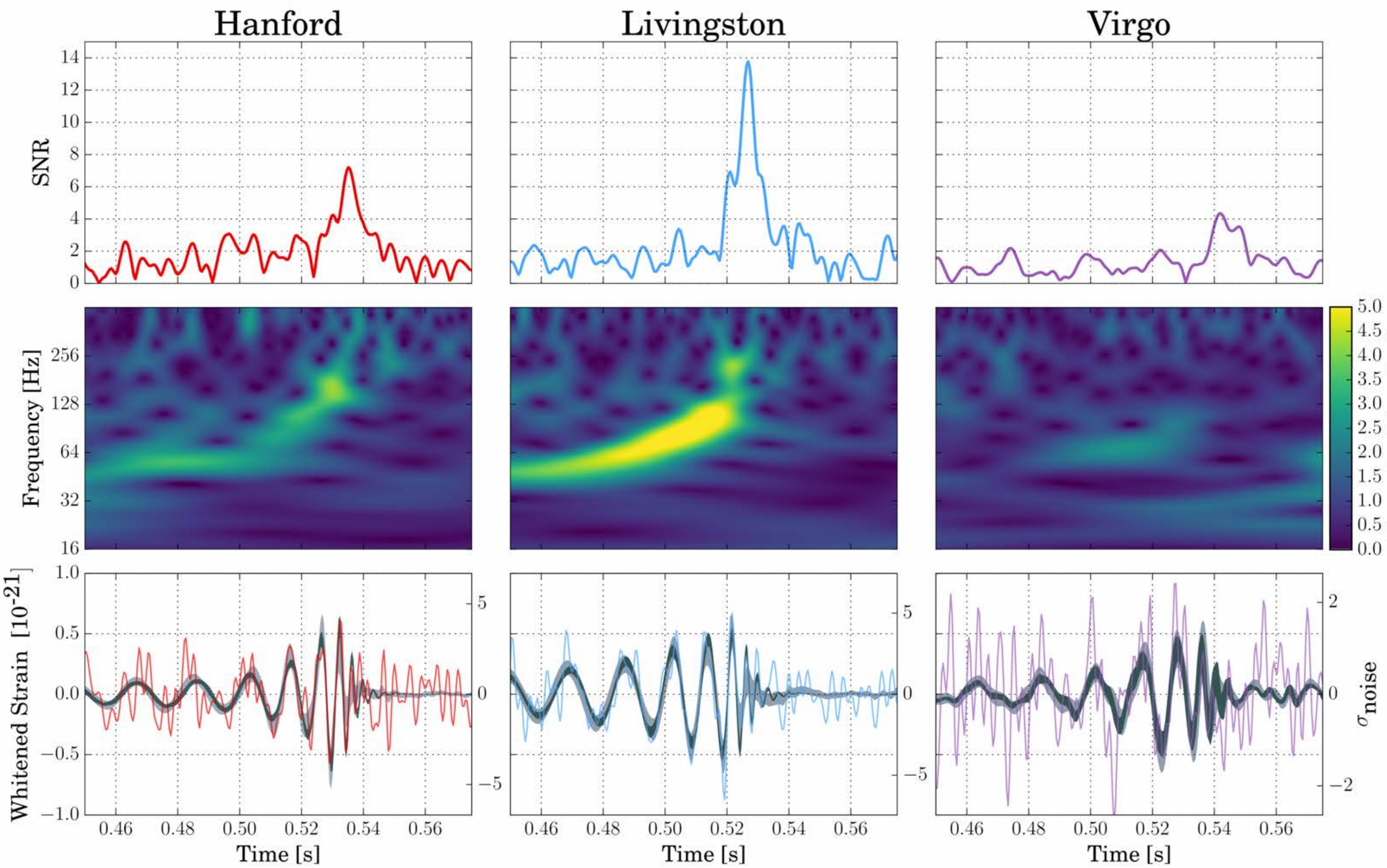




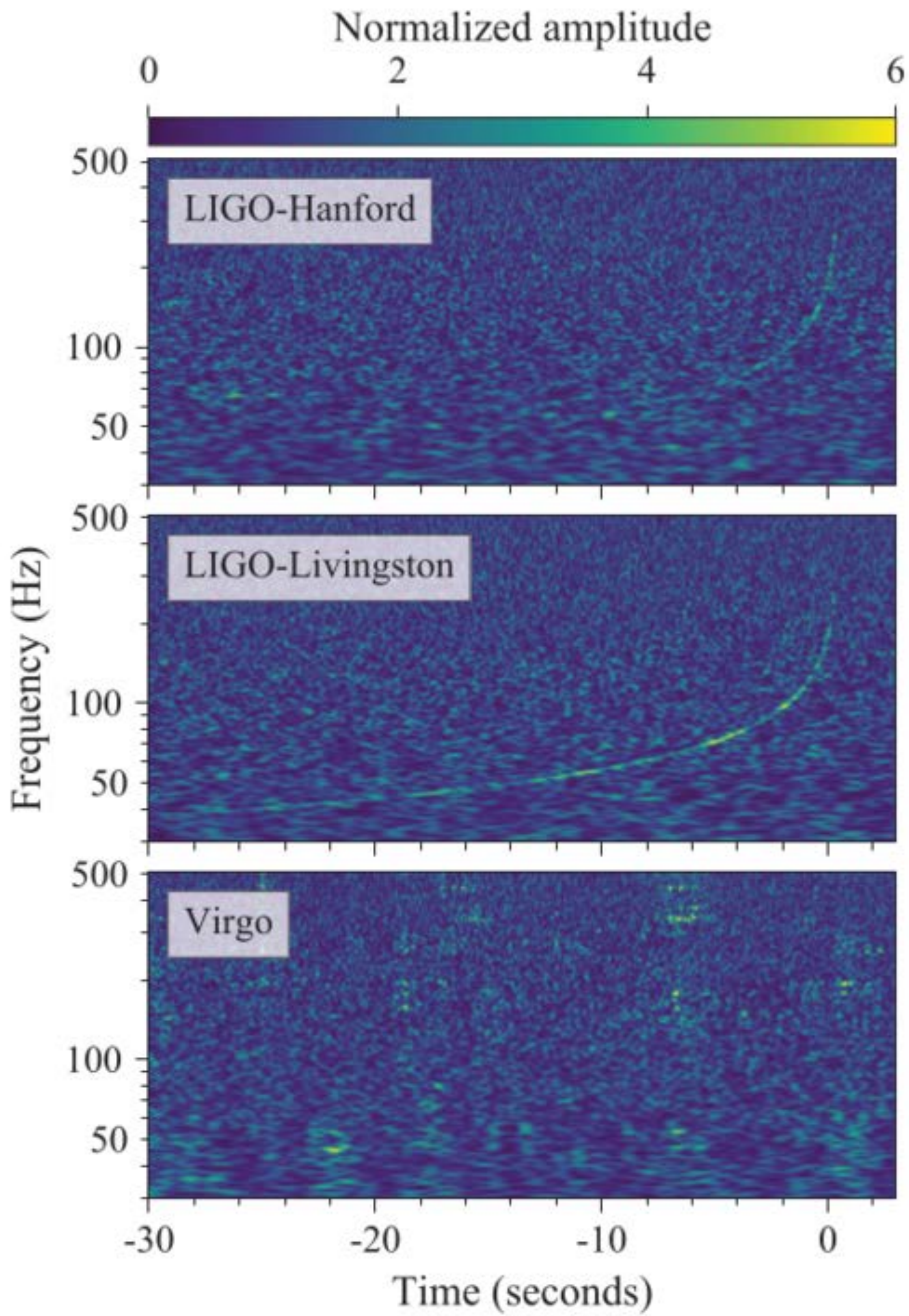


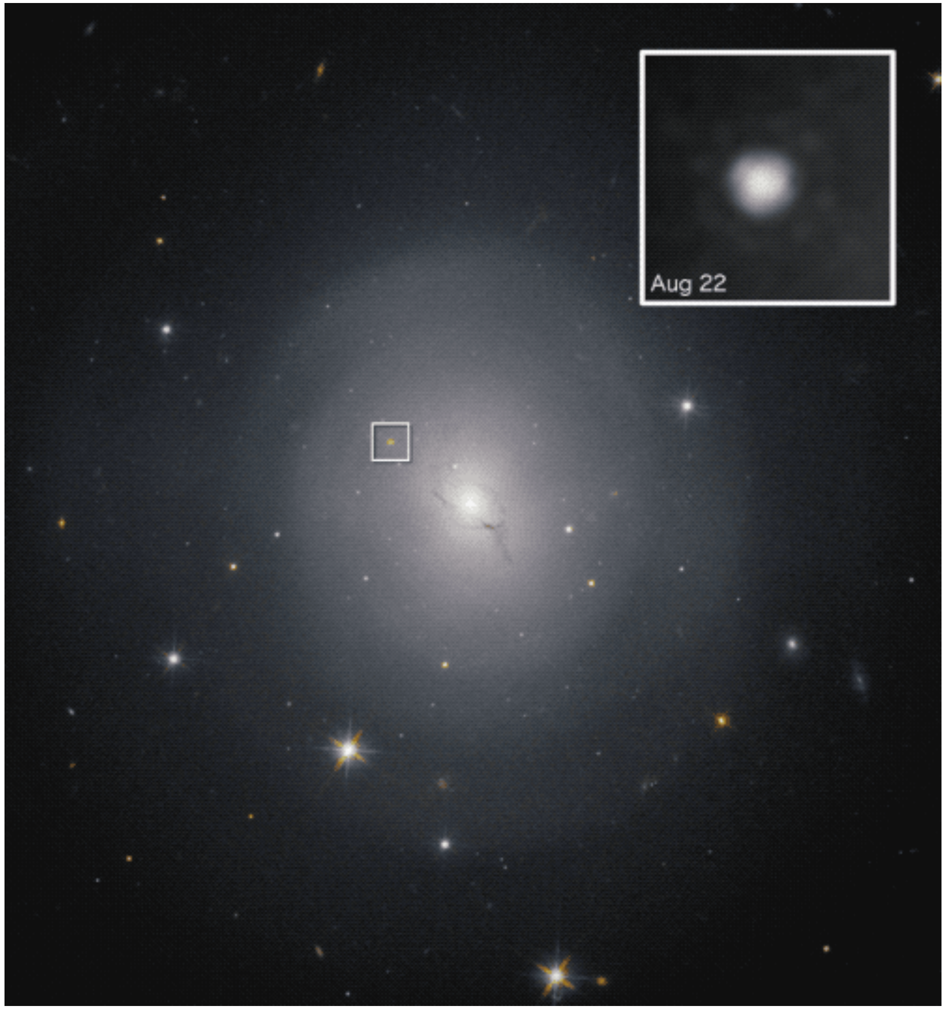


Birth of GW era: 14/09/2015

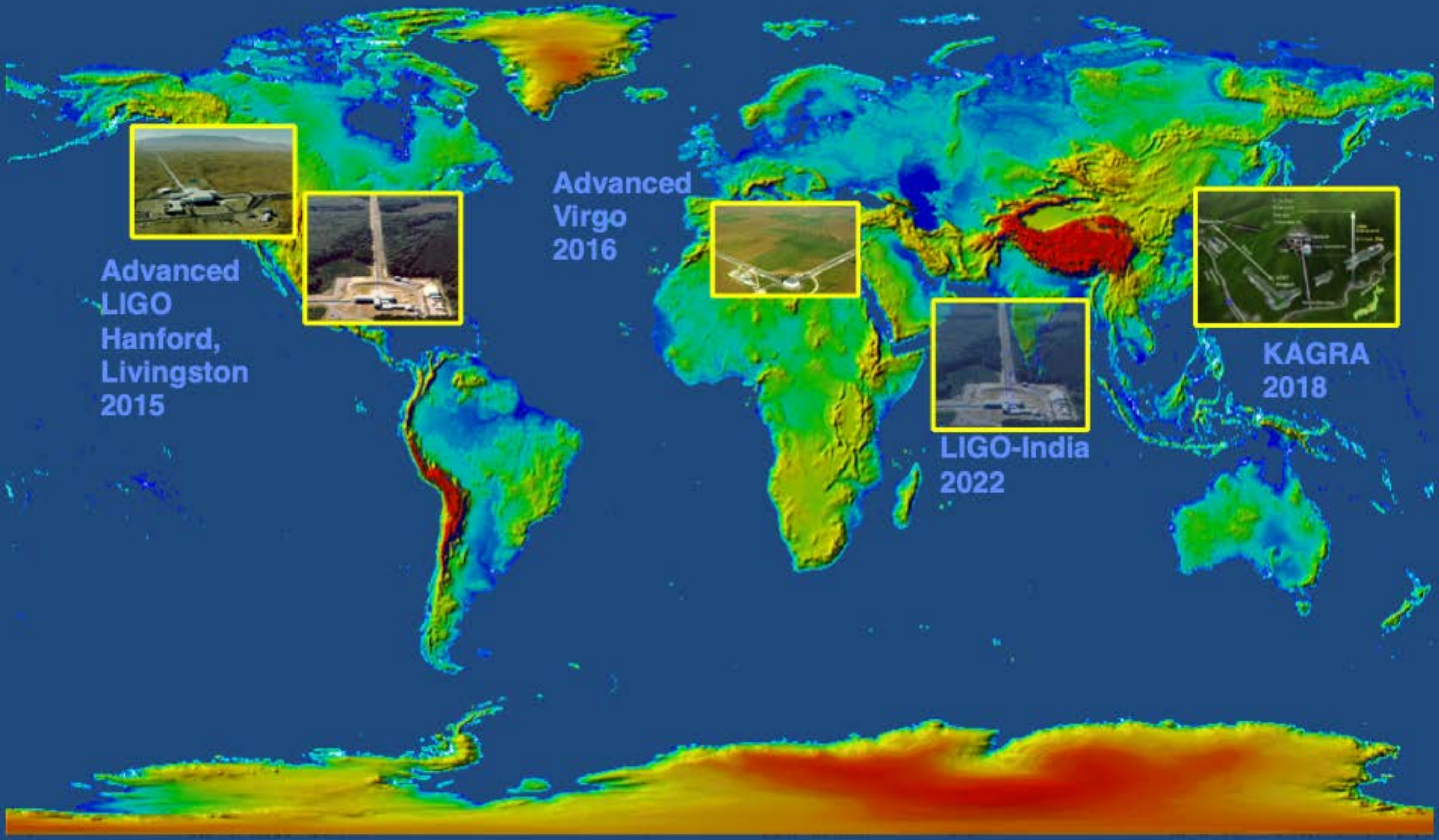


Birth of multimessanger: 16/10/2017



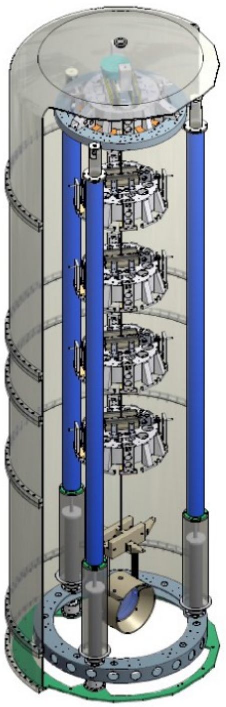


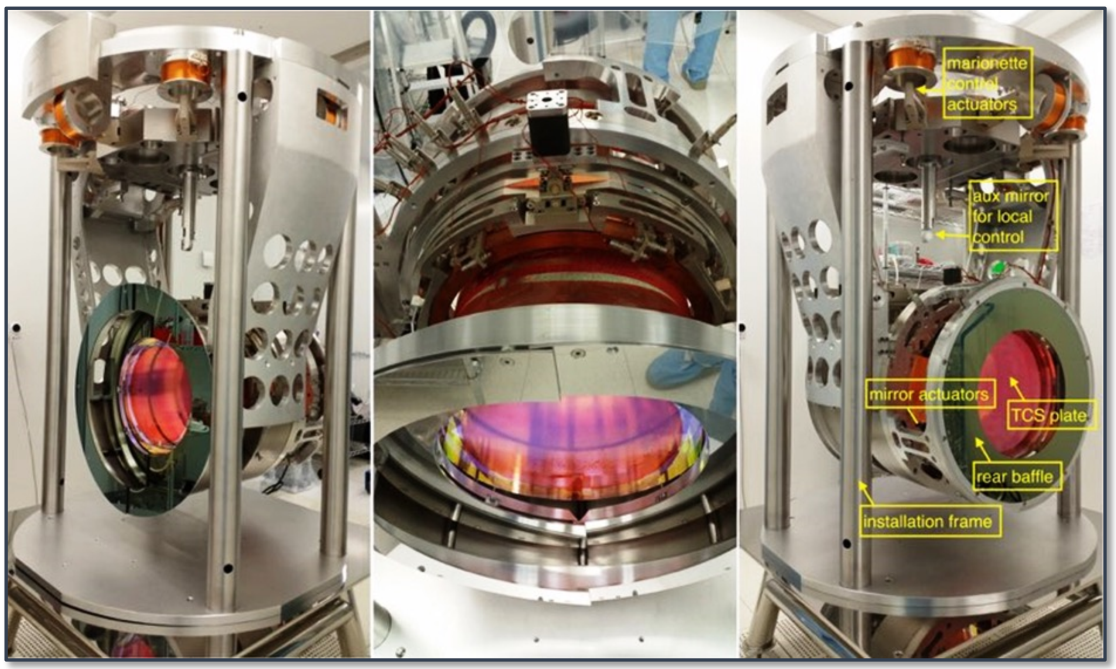
Worldwide GW detector network

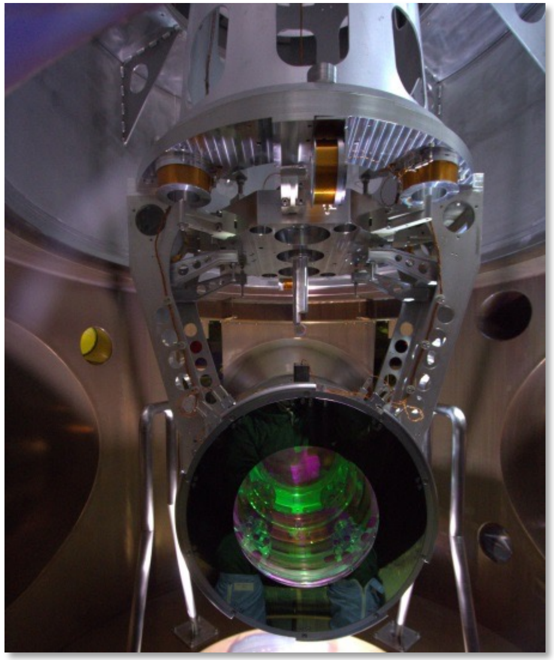


Virgo

The **PAYLOADS** are the last stage of suspension of the gravitational test masses (i.e. the heavy FP cavity mirrors) and main optics (beamsplitter, recycling mirrors).
The VIRGO ROMA group is in charge of the payload design, development, production and integration in the detector, as well as of the mirror suspension characterisation.



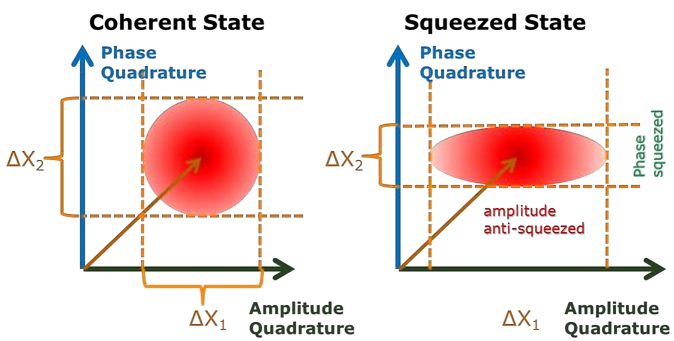


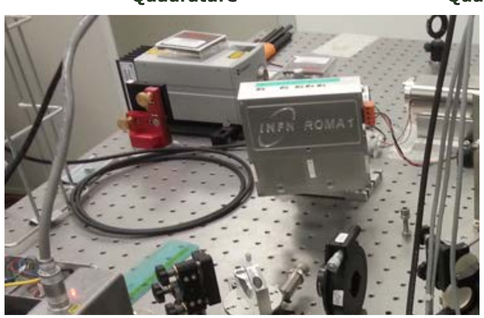


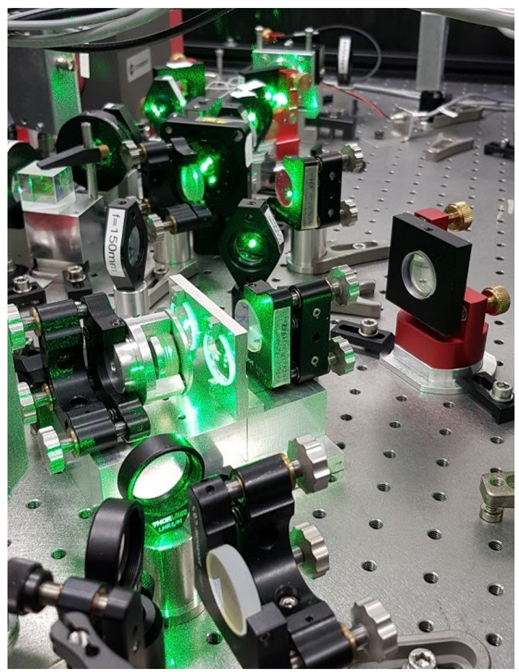
Virgo

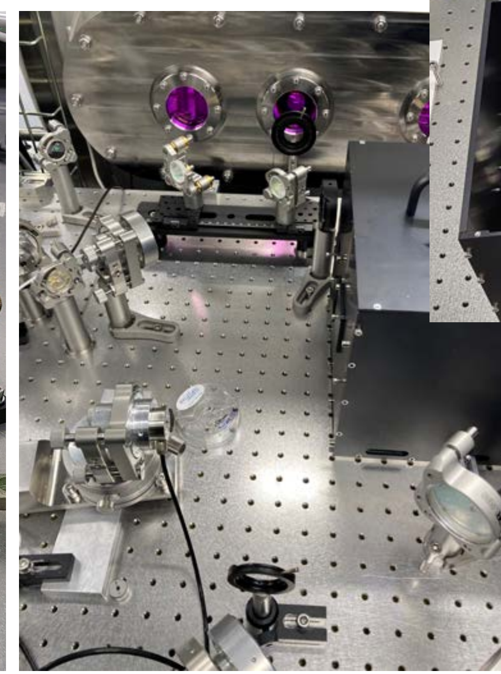
The **QUANTUM NOISE** (radiation pressure & shot noise) is one of the main limit to the detector sensitivity.

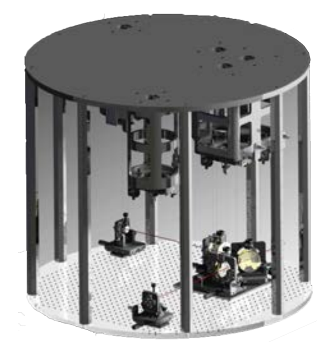
The VIRGO ROMA group is engaged in the application of SQUEEZED LIGHT in the detector laser injection as well as in the R&D on new techniques (e.g. Einstein-Podolsky-Rosen entanglement squeezing, ponderomotive squeezing).











Virgo

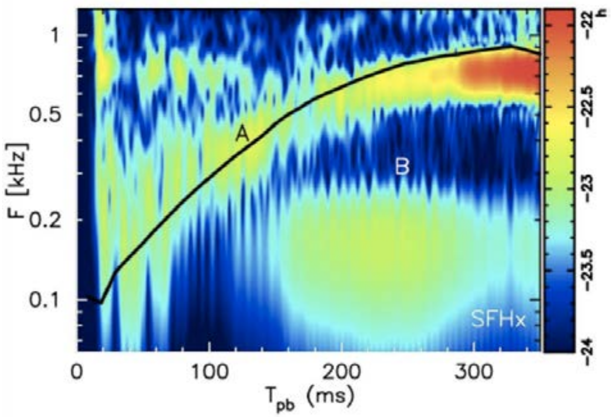
Analysis and code optimizations for a wide class of transient signals

LIGO/Virgo low-latency searches

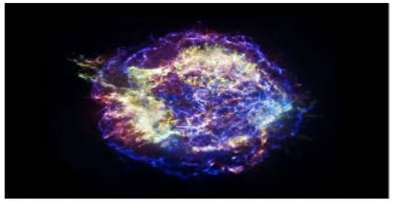
Waveform parameter estimation for unmodeled signals

Analysis procedures for the science case of MMA with neutrinos and GWs for Supernova searches

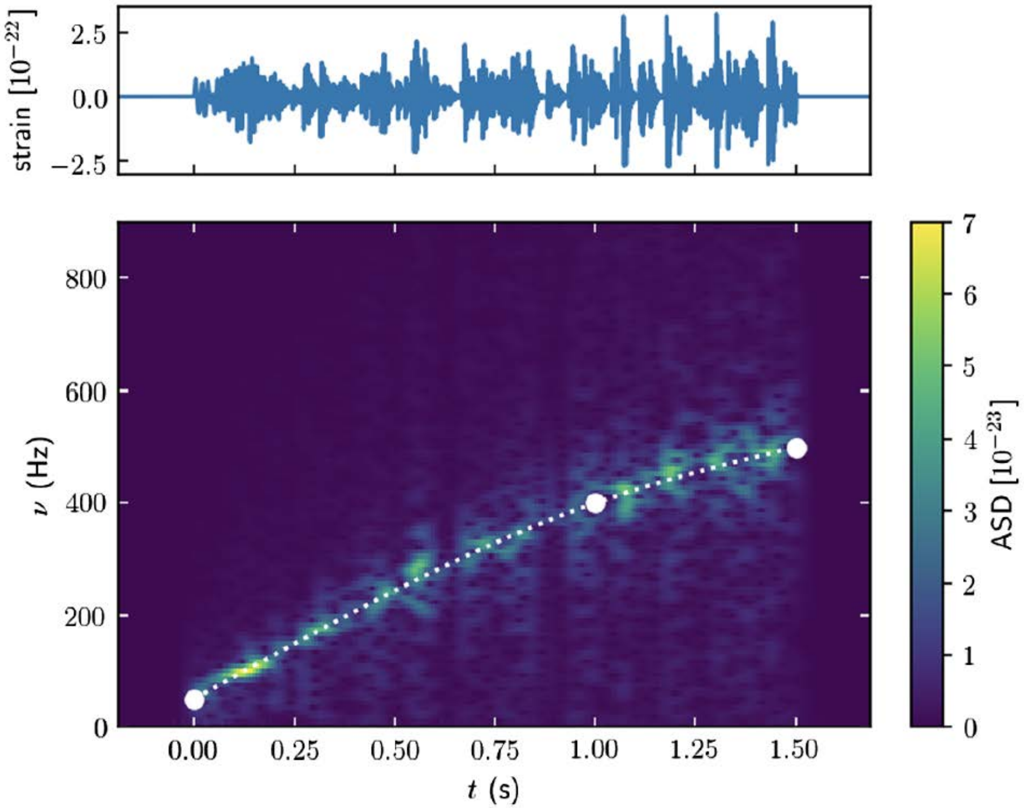
Machine learning algorithms for Core Collapse Supernovae



Burst (unmodeled signals) Searches



(Dimensionless) strain of the signal



Deep learning for multi-messenger core-collapse supernova detection

Virgo

Group Coordinator: Pia Astone pia.astone@roma1.infn.it

Experimental work

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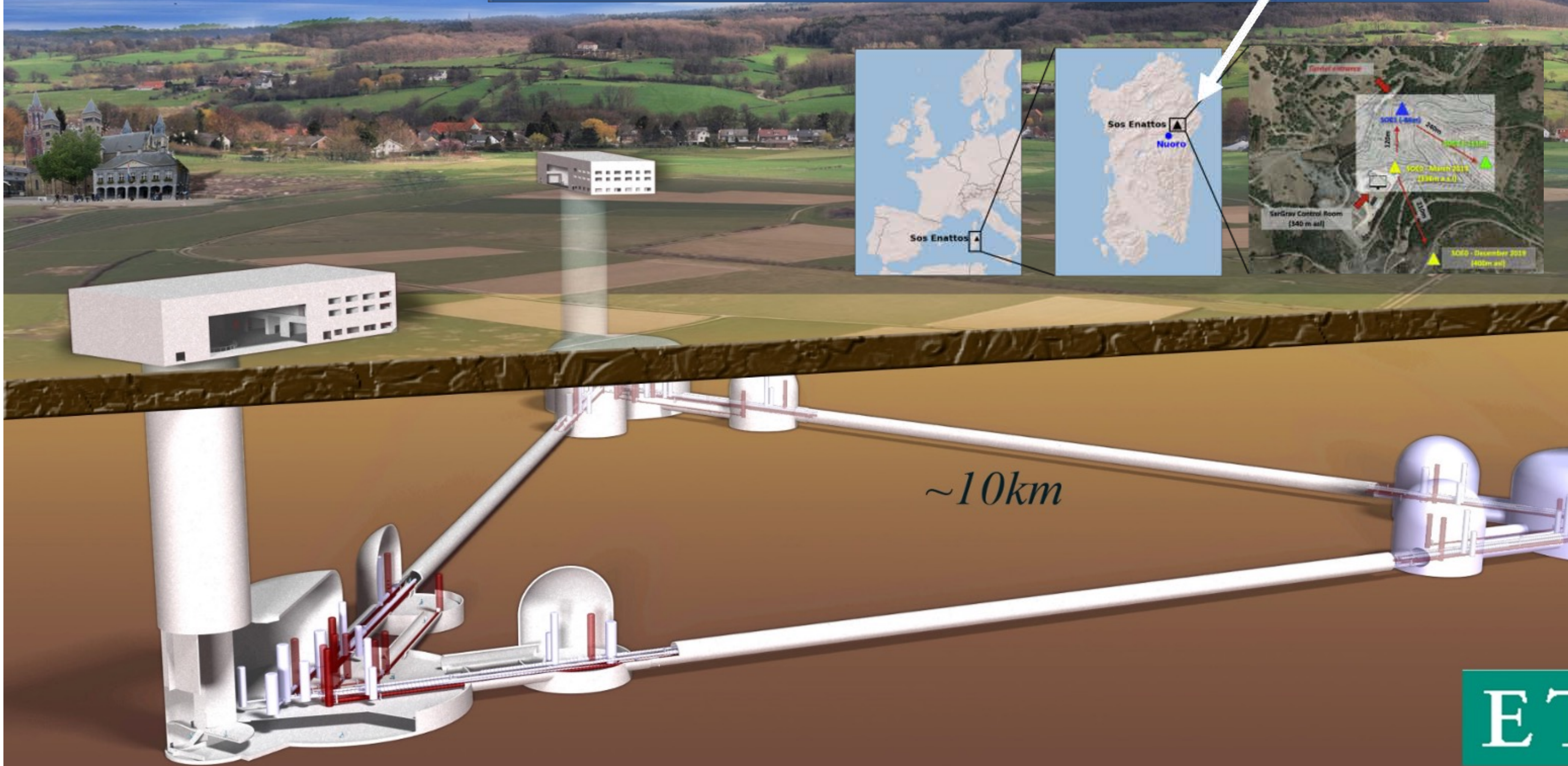
Simone Dall' Osso Simone.Dall-Osso@roma1.infn.it. **CWs**
Marco Serra marco.serra@roma1.infn.it. **CWs**

Experimental and data analysis thesis are available in our group

Future: Einstein Telescope

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

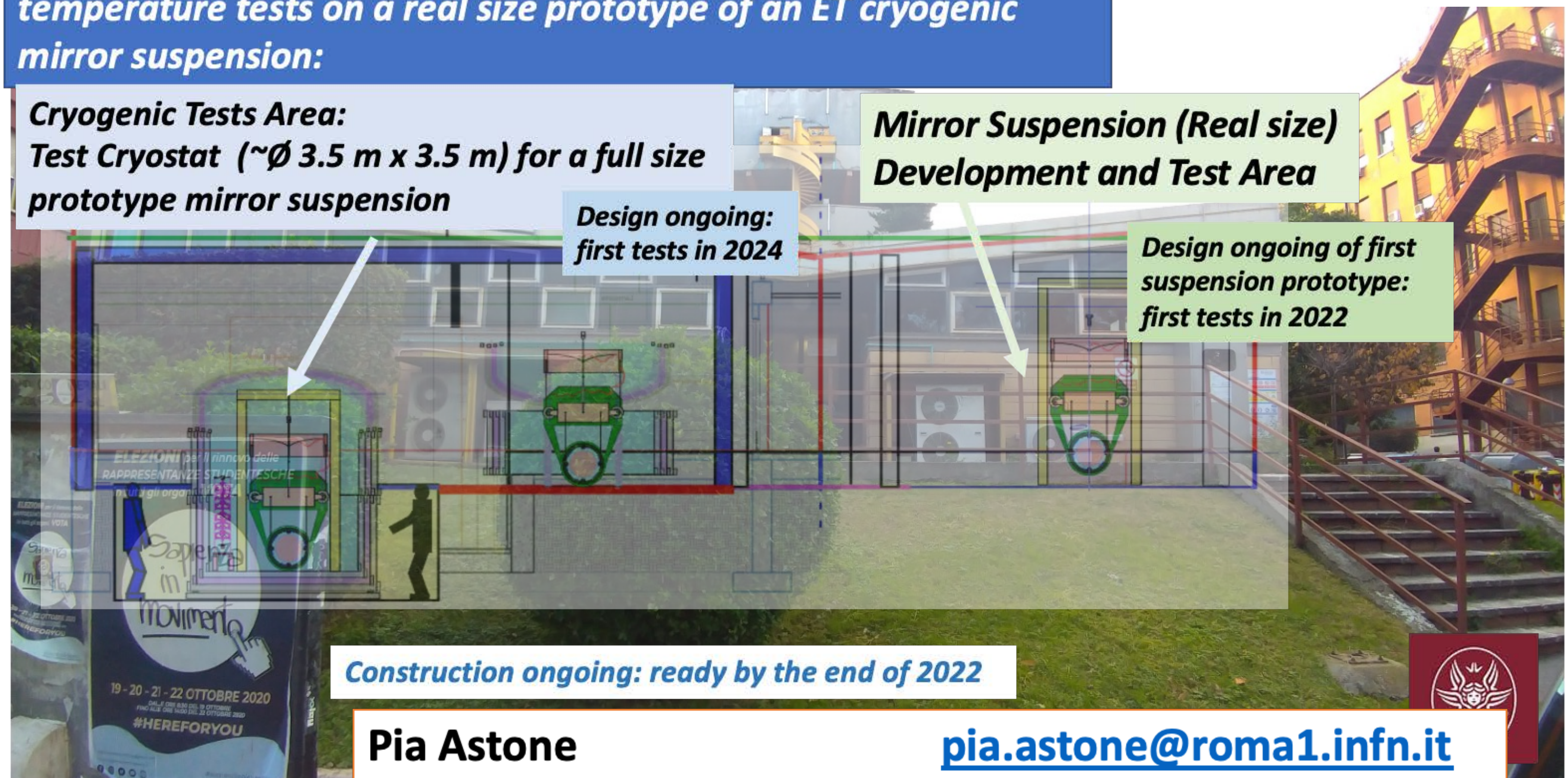
The future is Einstein Telescope, a gravitational wave interferometers with a sensitivity 10 times better than Virgo and LIGO, to be built somewhere in Europe (we hope in Sardinia).



Future: Einstein Telescope

In Rome, we shall contribute to ET on <u>site characterization, data analysis and mirror suspension</u>. We are preparing a lab for low temperature tests on a real size prototype of an ET cryogenic mirror suspension:

Amaldi Research Center
ET Cryogenic Tests Lab



Cryogenic Tests Area:
Test Cryostat (~Ø 3.5 m x 3.5 m) for a full size prototype mirror suspension

Design ongoing: first tests in 2024

Mirror Suspension (Real size) Development and Test Area

Design ongoing of first suspension prototype: first tests in 2022

Construction ongoing: ready by the end of 2022

If interested, please contact:

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