- The **Astroparticle Physics experiments** at LNS cover a wide range of **physics goals** in a long-range programme of science

- Members of CSN-2 at LNS are constantly **growing** in number and responsibilities

- Role of LNS in international experiments is solid and respected

DarkSide /ReD KM3NeT

DUNE Virgo / ET

Astro Particle Physics at LNS

2020 2025 2030 2035

KM3NeT

Current Phase: Construction, operation, data analysis
Main science cases: neutrino astronomy (multimessenger),neutrino fundamental physics

VIRGO

Current Phase: operation, data analysis, upgrade
Main science cases: Gravitational waves detection (multimessenger)

ET

Current Phase: R&D
Main science cases: Gravitational waves detection (multimessenger)

DarkSide (ReD)

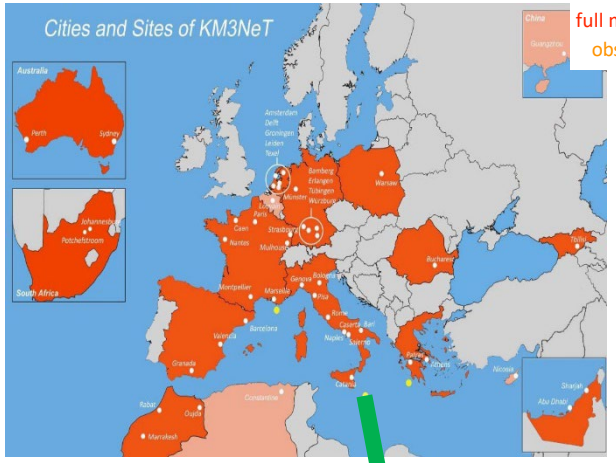
Current Phase: Transition from R&D to Construction
Main science case: Dark Matter detection (multimessenger)

Nu@Fnal (DUNE)

Current Phase: R&D
Main science case: neutrino fundamental physics

38 Persons 24.2 FTE
will increase in 2023 (PNRR, and other projects)

KM3NeT



Network of cabled observatories located in deep waters of the Med Sea

Neutrino astronomy: ARCA @ Capo Passero
3500 m water depth, 100 km offshore
2 building blocks
230 units (700 m Height)

Neutrino oscillations and Mass Hierarchy: ORCA @ Toulon
2500 m water depth, 40 km offshore
1 building block
115 units (250 m Height)

First undersea neutrino detector: ANTARES @ Toulon
2500 m water depth, 40 km offshore
13 units (300 m Height) Decommissioned in 2022!

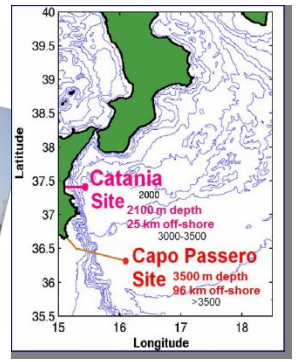
ARCA Capo Passero:
21 DUs in operation

Two electro-optical cable and power/optic distribution system onshore ready for ARCA 230 DUs

KM3NeT cross disciplinary spin-offs

PNRR-ITINERIS

Seafloor data “e-highway”: optical data link and power connection for EMSO-ERIC stations in Capo Passero
Seafloor acoustic data hub at LNS.



ESMO-ERIC: European Seafloor and water column multidisciplinary observatories
Based at Port of Catania Laboratory and at Capo Passero:
Hub for seafloor geophysics and biology observatories and data centre

Marine Hazard
Multidisciplinary seafloor station in Capo Passero

small impact and good reward

test new technologies
multidisciplinary plan
and new personnel

ECCSEL-ERIC: IPANEMA:
Monitoring of CO2 with acoustic antennas and chemical sensors
two stations: in Panarea (20 m depth) and Catania (2100 m depth)

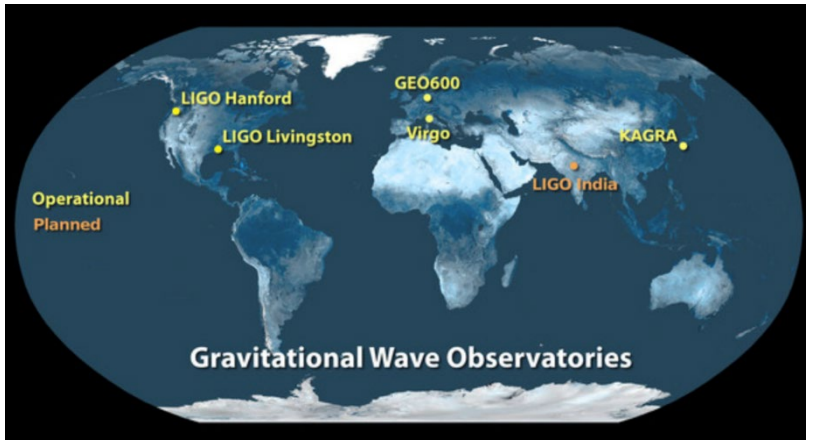
FOCUS-ERC
Monitoring of seismic phenomena with Brillouin Optical time reflectometry using the fibers of the subsea cable of the Port of Catania Test Site

Geo-Inquire EU (K. Fleming PI, GFZ, G. Riccobene PI INFN) – Ends in 2026
Transnational access activity to use optical fibers of the subsea cable at the port of Catania for seismic and volcanic monitoring
56 k€ funded

VIRGO and Einstein Telescope

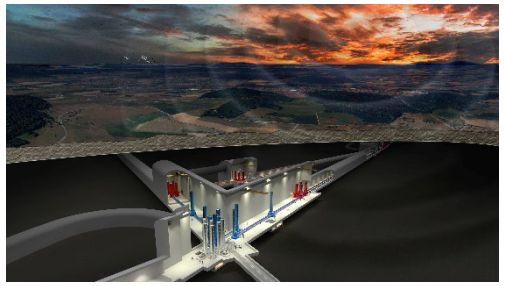
The VIRGO Collaboration

- ~770 members, ~450 authors, 131 institutions from 15 countries
- 34 Groups:
  - 32 full members
  - 2 in the first year (L2I Toulouse, KU Leuven)
- 9 countries represented in the VSC



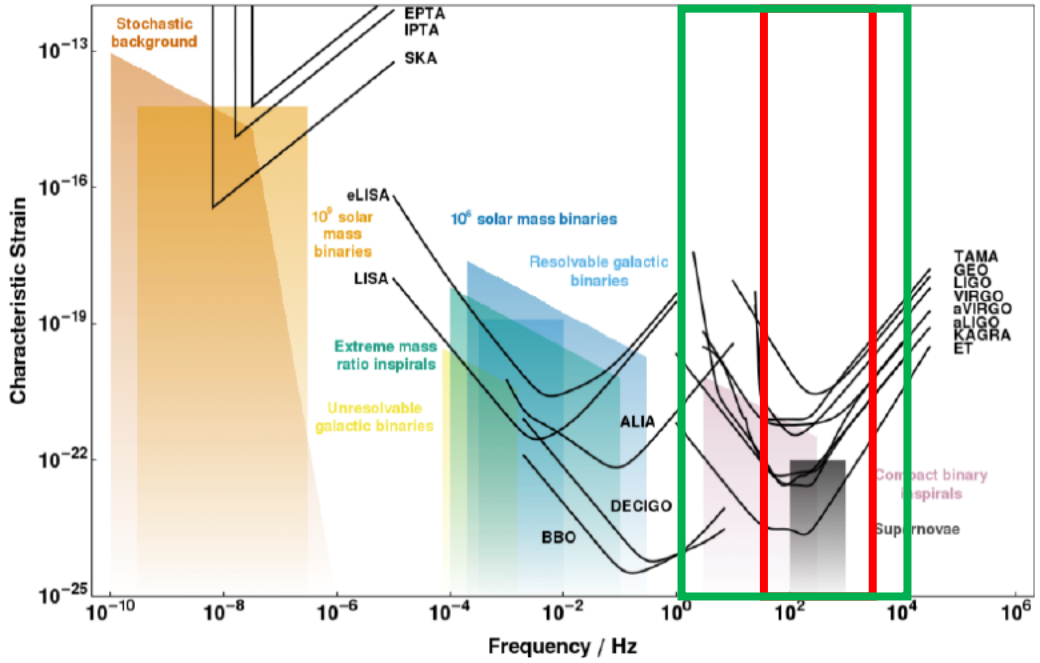
Based in **Cascina (Pisa) at the European Gravitational Observatory**
new director Massimo Carpinelli (Uni Sassari - on leave to Milano Bicocca- and LNS)

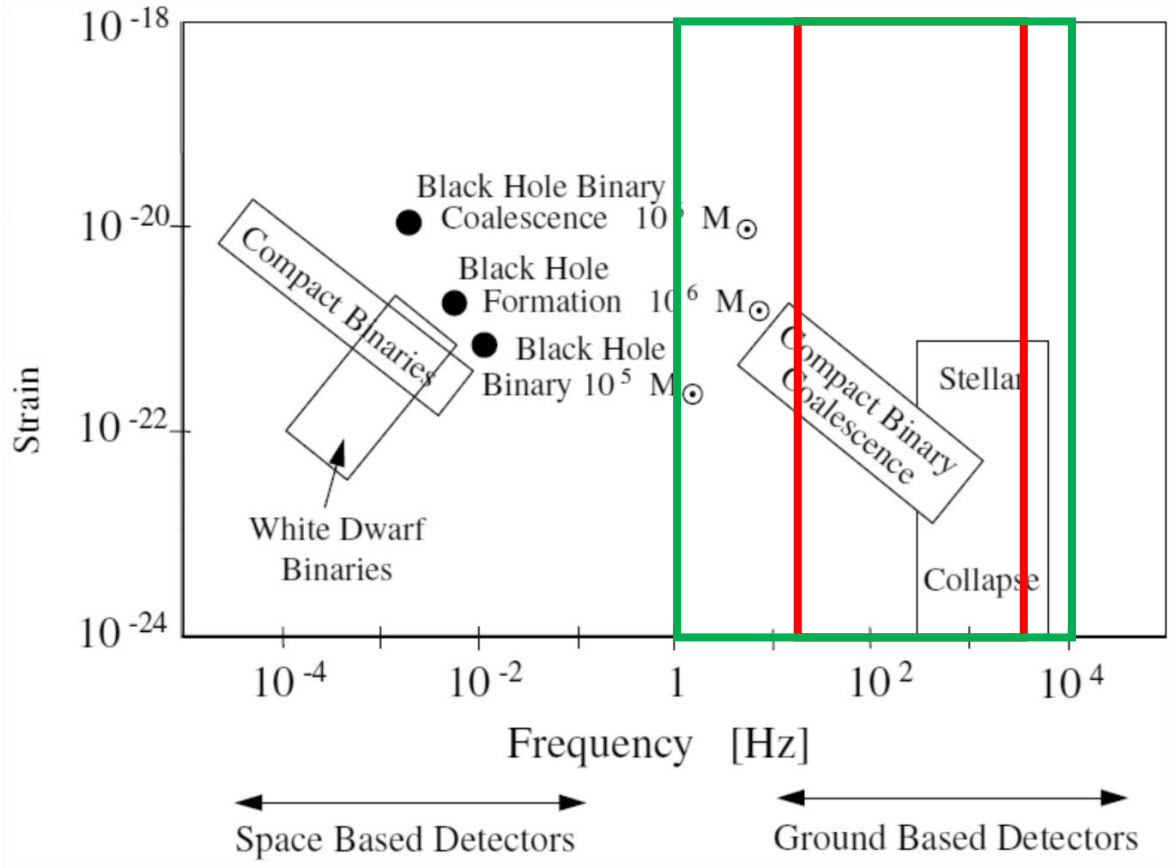
VIRGO and Einstein Telescope



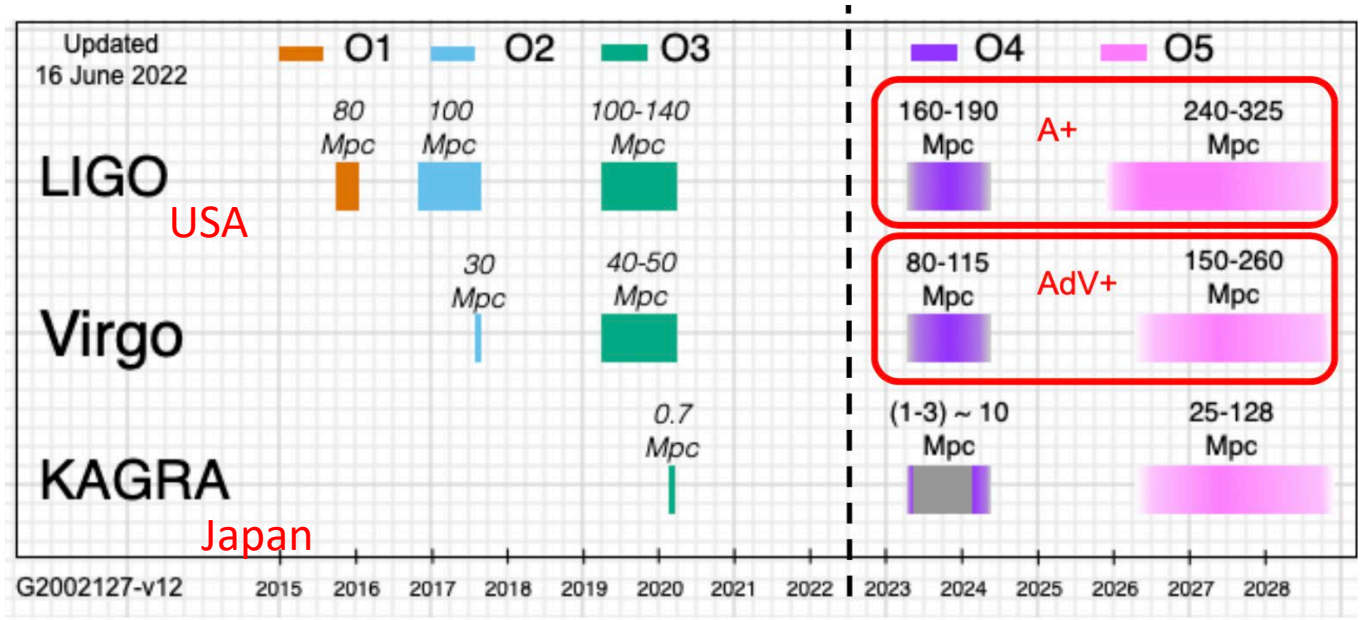
Virgo: 20-2000 Hz
compact binary inspirals (BBH, BNS and BH-NS), supernovae and bursts.

Einstein Telescope: 1-10000 Hz
Precision measurements **AND** new discoveries

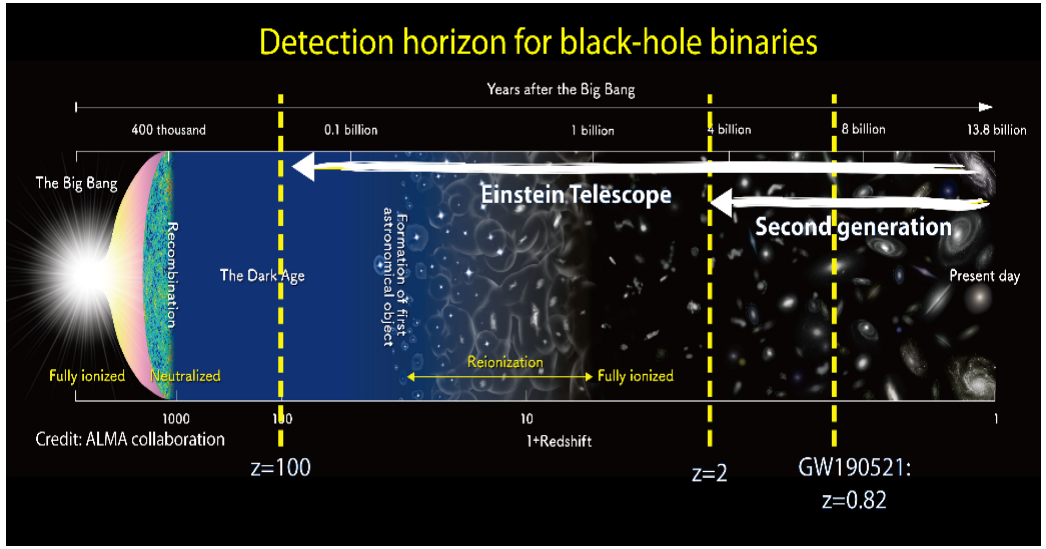




From VIRGO to Einstein Telescope



constant increase of observation horizon



ET EINSTEIN TELESCOPE

Collaboration birth in 2022: 1200 scientists from USA, Europe and Japan

ET will be a new discovery machine:

will explore *almost the entire Universe* listening the gravitational waves emitted by black hole

ET will be a precision measurement observatory:

will detect, with high SNR, *hundreds of thousands* coalescences of binary systems of Neutron Stars per year

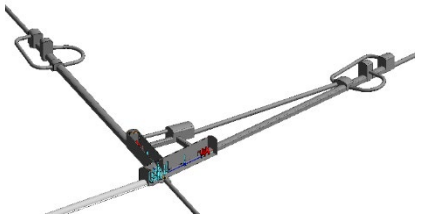
Einstein Telescope: key design

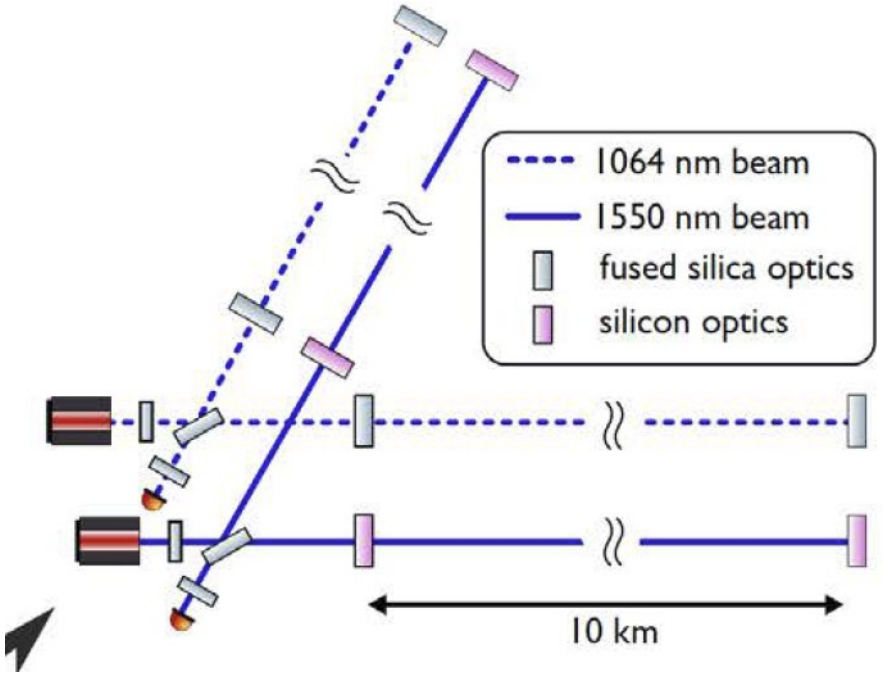
Requirements

- Wide frequency range
- Massive black holes (LF focus)
- Localisation capability
- (more) Uniform sky coverage
- Polarisation disentanglement
- High Reliability (high duty cycle)
- High SNR

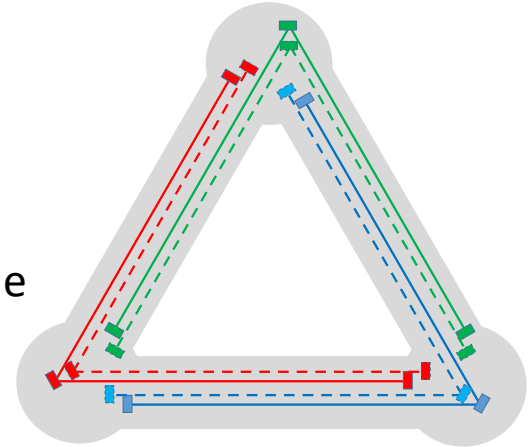
Design Specifications

- Xylophone (multi-interferometer) Design
- **Underground**
- **Cryogenic**
- **Triangular shape**
- Multi-detector design
- Longer arms





6 arms: 1 LF and 1 HF arm in each side



Einstein Telescope: role of UniSS/LNS

Coordination of the **Sardinian Site Characterization** Activity:

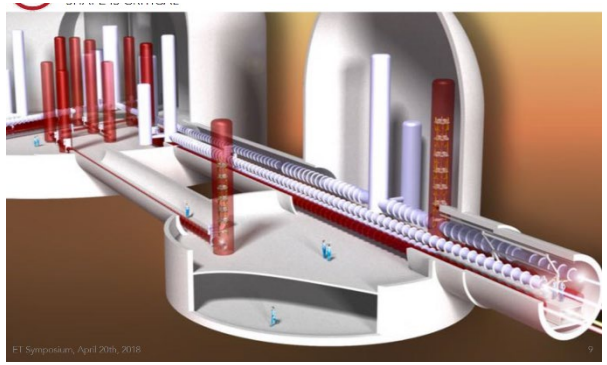
Data analysis and ET sensitivity estimation

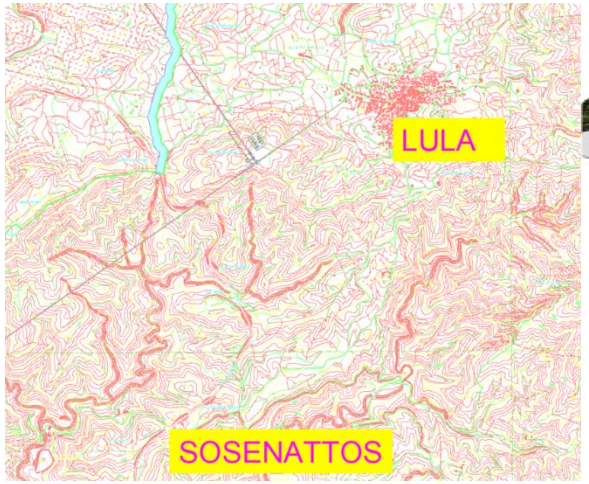
Infrastructure design and feasibility study

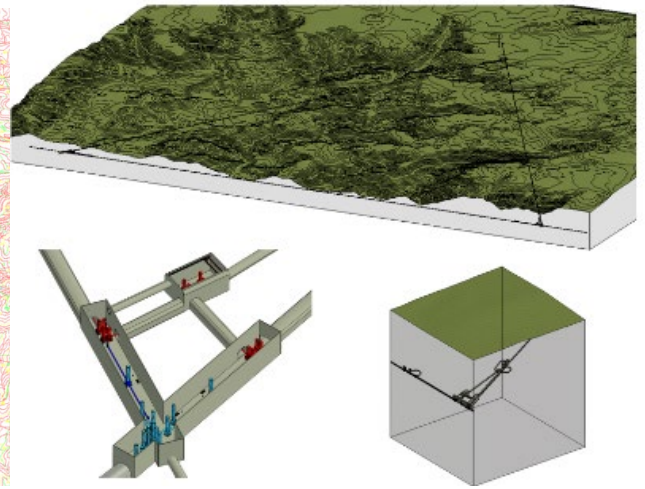
- Sensor Instrumentation and maintenance
- Acquisition system and mechanics of the novel “Archimedes” tiltmeter
- Sardinian site shows extremely low seismic noise in worldwide data

Role of LNS empowered within PNRR ETIC

- Site characterization and infrastructure design
- 17.6 M€ at LNS over 50 M€ funding



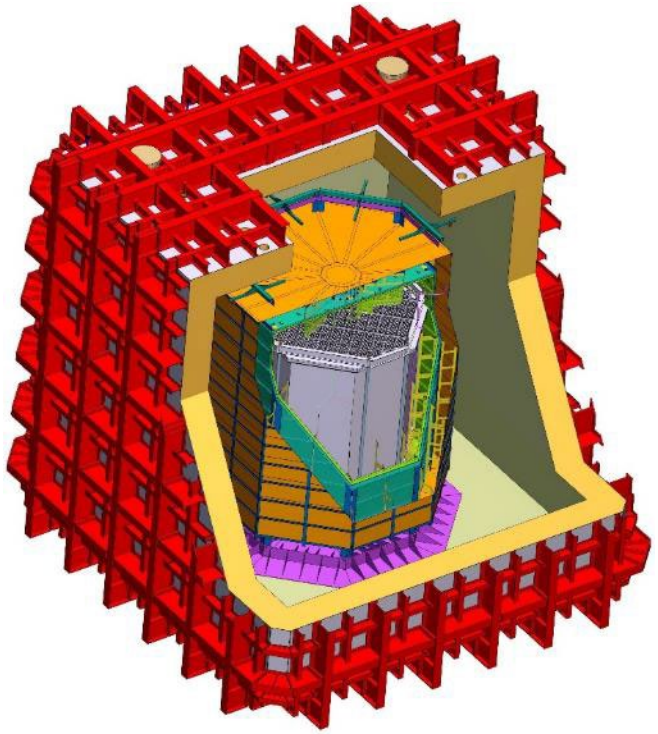




Darkside and ReD

- Search for **dark matter** in the form of Weakly Interacting Massive Particles (WIMPs)
- Signature: low energy (< 100 keV) nuclear recoil produced by WIMP elastic scattering

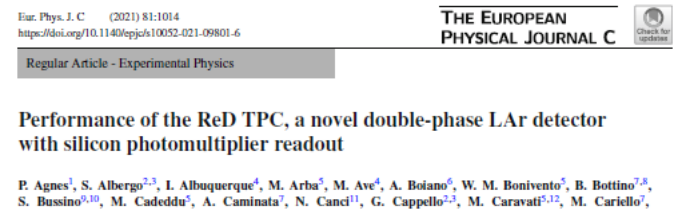
- **DarkSide** at Gran Sasso Laboratory, WIMPs search using a dual-phase TPC with low-radioactivity LAr
  - Operated a **50 kg TPC** (DarkSide-50) with **UAr**
  - Next step: 30 ton LAr **TPC** (DarkSide-20k)
    - Novel light readout with SiPM
    - Getting ready for data in **2026**, exposure O(100) ton yr
    - Expected sensitivity 10^{-47} cm^2 @ M_W =1 TeV/c^2
  - Next-next step: global worldwide effort (ARGO, 300 ton LAr)
    → **Global Argon Dark Matter Collaboration** (GADMC)



darkside

Darkside and ReD

- **ReD** is a project within the GADMC, three-fold goal:
  - check if a dual phase LAr TPC has sensitivity to the direction of Ar recoil
  - characterize the response of the LAr TPC to very low-energy recoils (< few keV) → **hot topic (S2-only)**
  - act as a test bench of the technical solutions for DarkSide-20k TPC
- Major involvement of LNS
- Phase 1 (Napoli) – **Characterization** of the TPC
  - Stability over time scale of months
  - Check that performance OK for phase 2
- Phase 2 (LNS) – **Directionality run**
  - TANDEM beam LNS (February 2020)
  - No indication for directionality
- Phase 3 (Sez. Catania) – **Low-energy run** with ^{252}Cf
  - In preparation (up to 2-5 keV)
  - Complemented with low-energy ERs


Eur. Phys. J. C (2021) 81:1014
https://doi.org/10.1140/epjc/s10052-021-09801-6

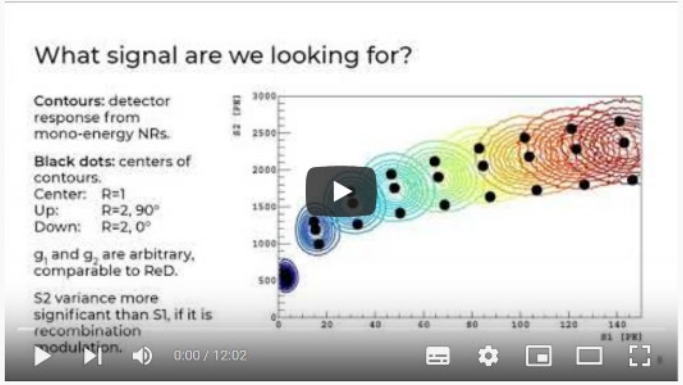
THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Performance of the ReD TPC, a novel double-phase LAr detector with silicon photomultiplier readout

P. Agnes[1], S. Albergo[2,3], I. Albuquerque[4], M. Arba[5], M. Ave[4], A. Boiano[6], W. M. Bonivento[5], B. Bottino[7,8], S. Bussino[9,10], M. Cadeddu[5], A. Caminata[7], N. Canci[11], G. Cappello[2,3], M. Caravati[5,12], M. Cariello[7],

EPJ C 81 (2021) 1014



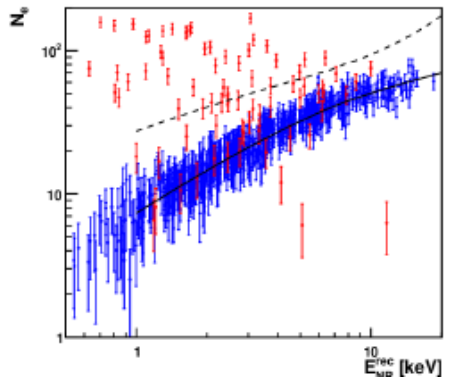
Directionality for nuclear recoils in a liquid argon Time Projection Chamber | Xinran Li | TAUP2021

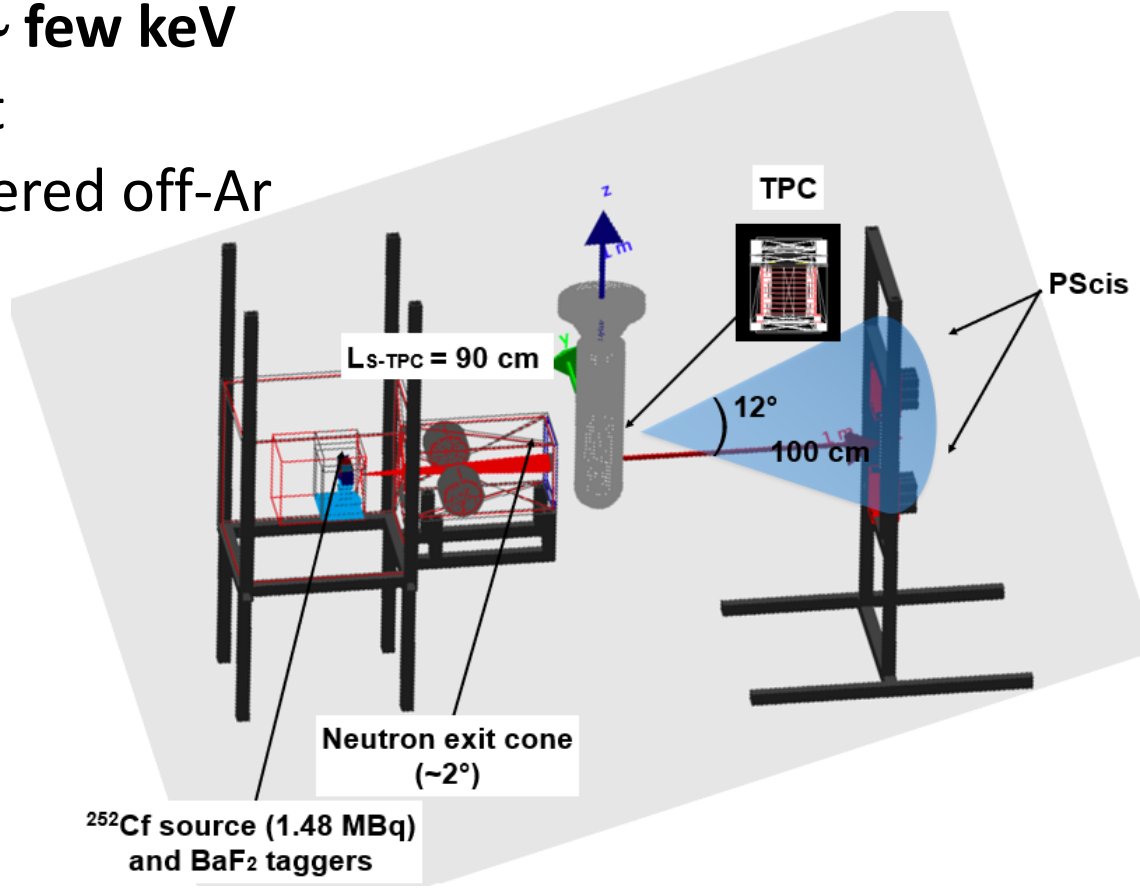
Talk at TAUP 2021

Darkside and ReD

- Low-energy recoil measurements (< few keV) by using neutrons from a **^{252}Cf fission source**
  - Neutrons **O(2 MeV)**, more appropriate for **E_{rec} ~ few keV**
  - Use close fission tagger (BaF_2) and time of flight
  - Neutron spectrometer to detect neutrons scattered off-Ar
    - Use 1-inch plastic scintillators
- Sensitivity down to

  2-5 keV_{NR}





DarkSide: URANIA Facility

- The URANIA plant will extract and purify the underground Ar (low in ^{39}Ar) from the CO_2 wells at the Kinder Morgan Doe Canyon Facility, Colorado
  - Plant **built** & **commissioned** at the Company site
  - Ready for shipment to Colorado
- Expected production: 50 tons
  - To be purified and further depleted by distillation in the ARIA facility
- LNS actively involved in the design and construction of the plant

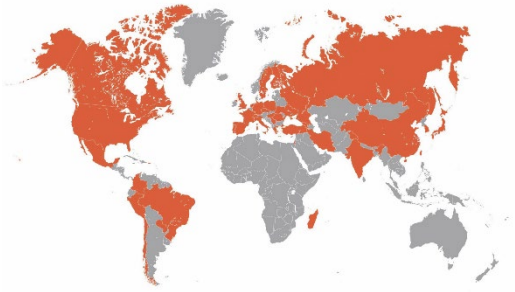
Nu at FNAL: DUNE

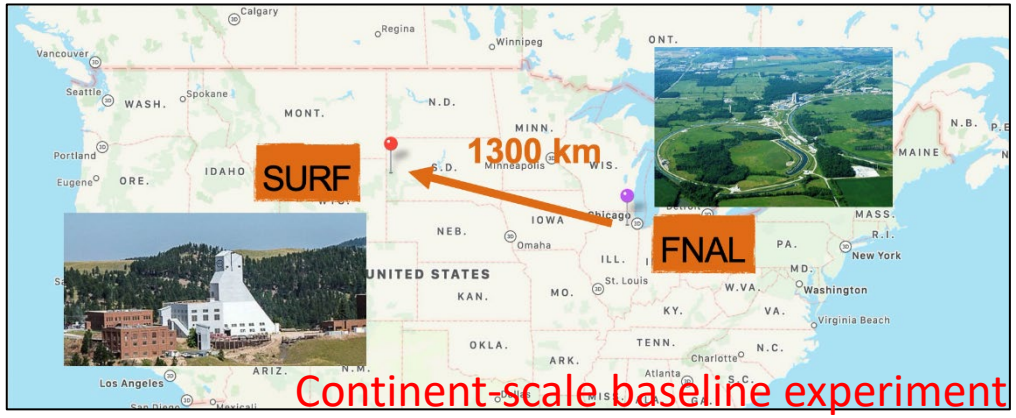
The Deep Underground Neutrino Experiment

1300 scientists and engineers

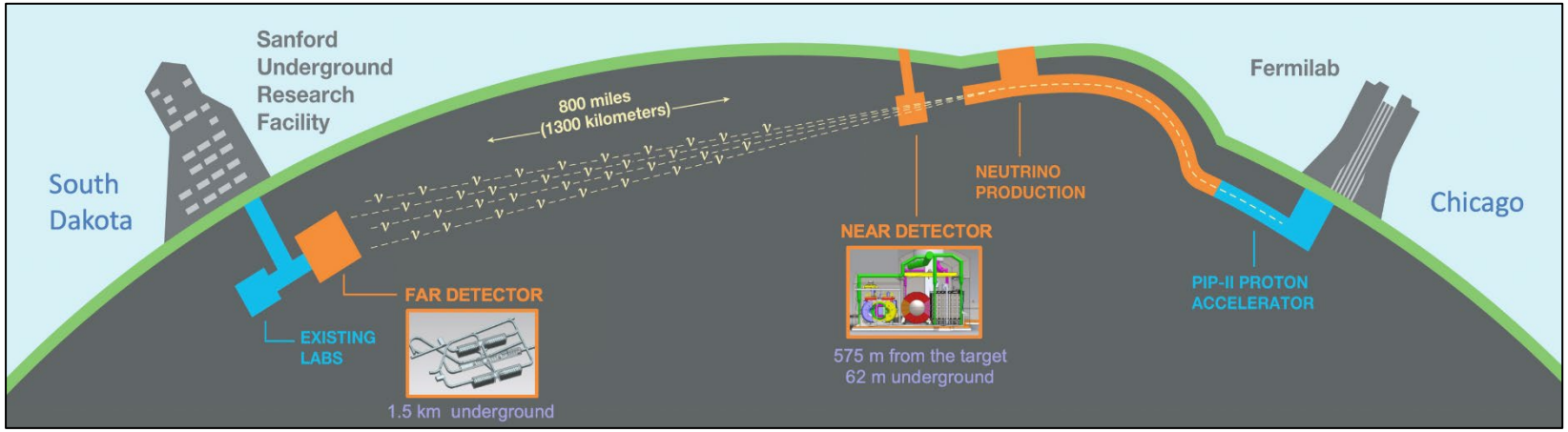
190 institutes

37 countries + CERN





LNS has responsibilities in **hardware construction and testing** (Far and near detector) and **software** (Geasigen for DUNE)



10 MeV -10 GeV nu physics:

- Neutrino Physics

CPV in the leptonic sector

Mass Hierarchy and Oscillation Physics

- Nucleon Decay
- Supernova physics & astrophysics

→ **multi-messenger**

Galactic core collapse supernova

- Other topics

Atmospheric neutrinos

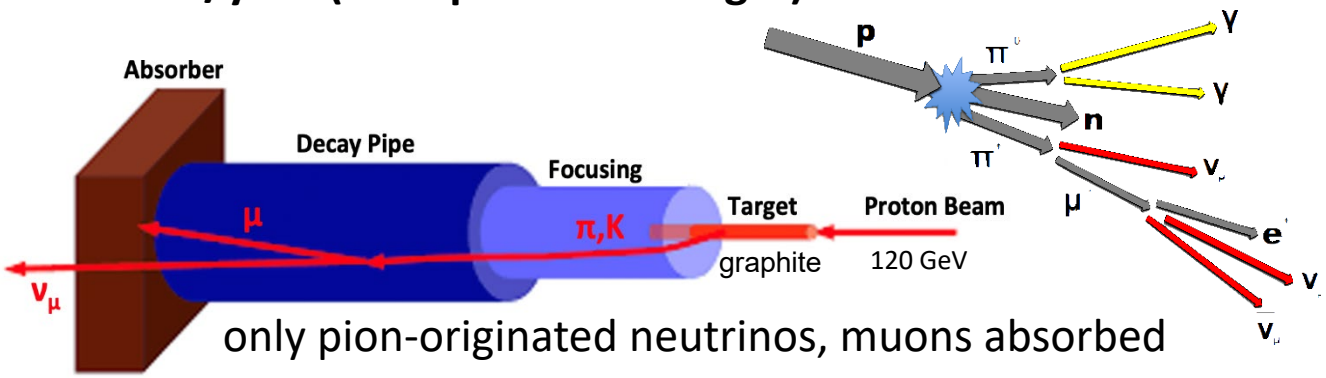
Neutrino interaction physics

DUNE Setup

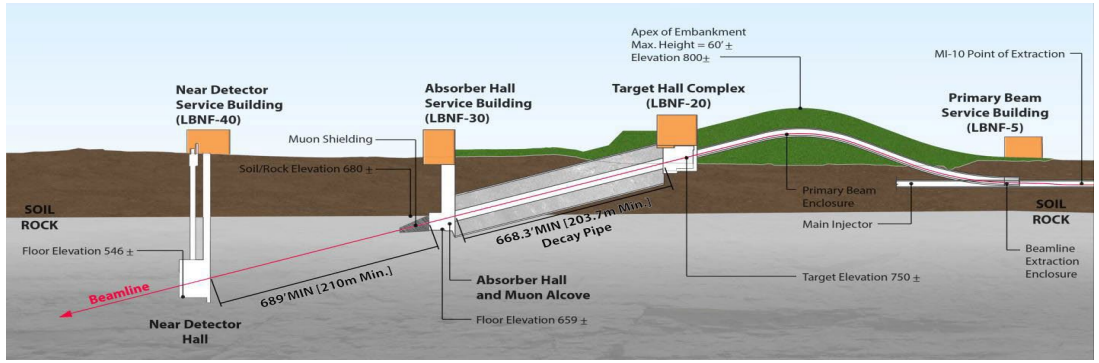
PIP-II accelerator: proton beam 1.2 MW (2028)

(PIP-III upgrade to 2.4 MW)

10^{21} POT/year (POT: proton on target)



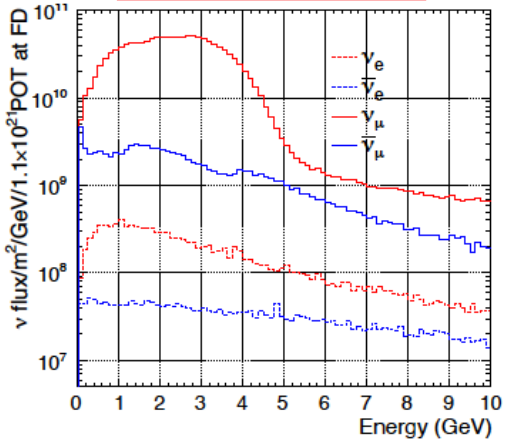
only pion-originated neutrinos, muons absorbed



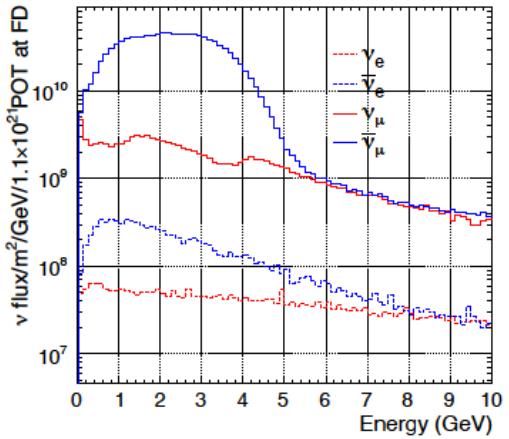
5.8° inclined beam (specially created 18 m artificial hill)

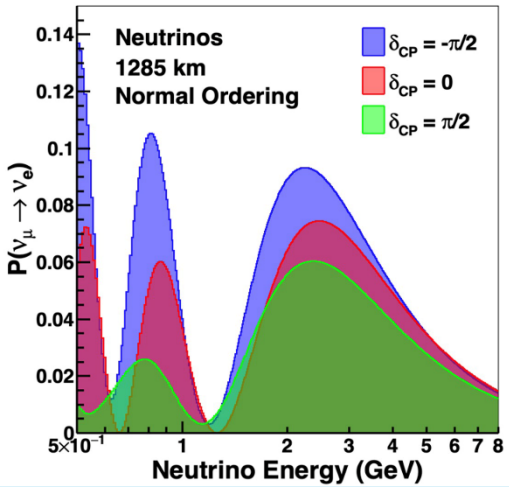
Feature: select the **polarity** of the current of the "magnetic horn" (focusing system)

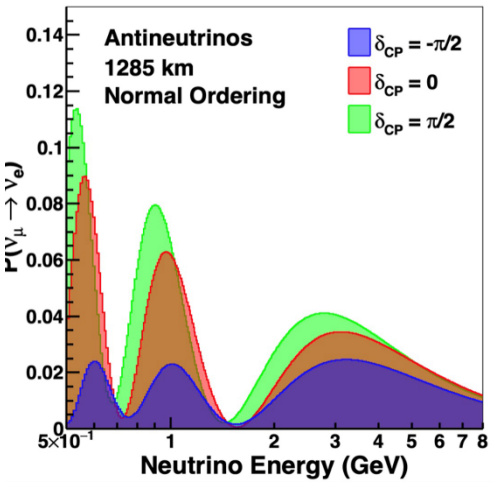
Neutrino mode



Antineutrino mode







DUNE: the far detector

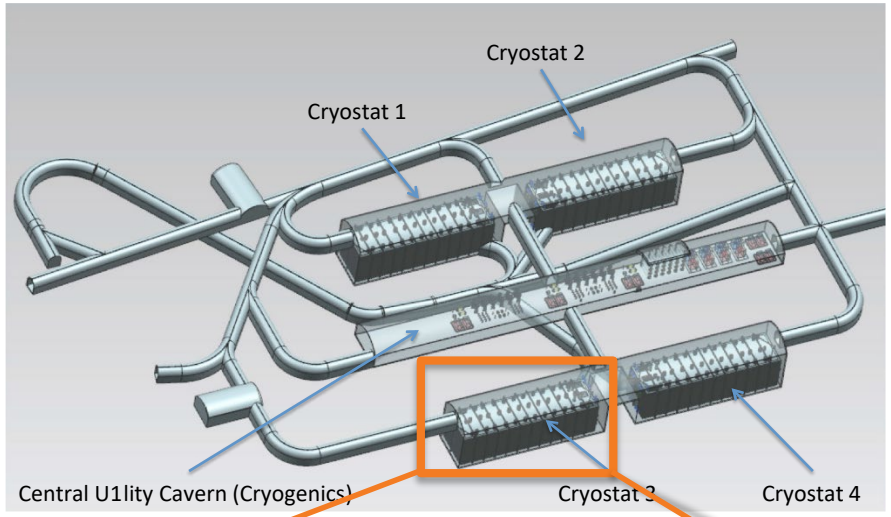
The site consists of 5 main caves at a depth of 1.5 km:

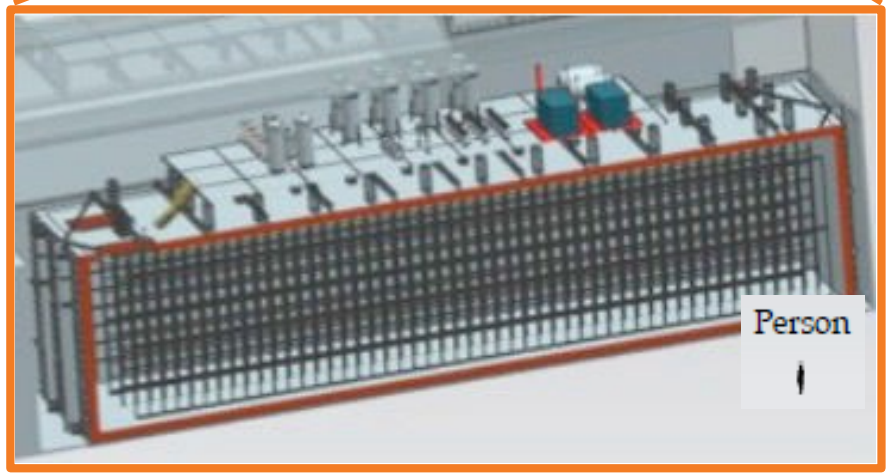
- 4 detection modules
- 1 support module (cryogenics and DAQ)

Detection modules:

- Detectors based on LArTPC technologies
  - LAr is both the target and the detection medium
- Same cryostat (62 m x 19 m x 18 m)
  - 17 kt of LAr in the whole volume (70 kt total)
  - 10 kt di LAr in the fiducial volume (40 kt total)
  - possibility of hosting detectors of different designs

LNS responsible for the qualification of electronic components at cryogenic temperatures

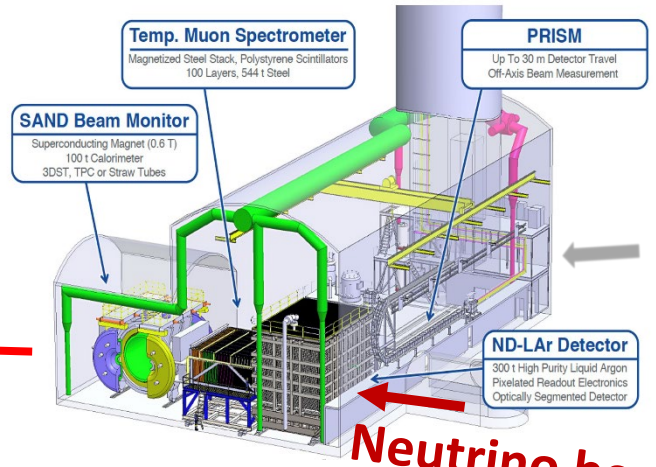




DUNE: the near detector

Complex of detectors based on different technologies and focused on:

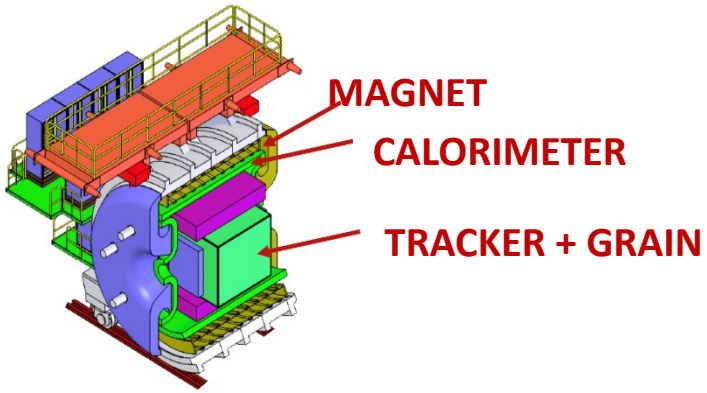
- precise characterization of the neutrino beam
- reduction of uncertainties in the cross sections



SAND

will monitor the intensity, spectrum and profile of the neutrino beam:

→ real-time variations in beam operating conditions



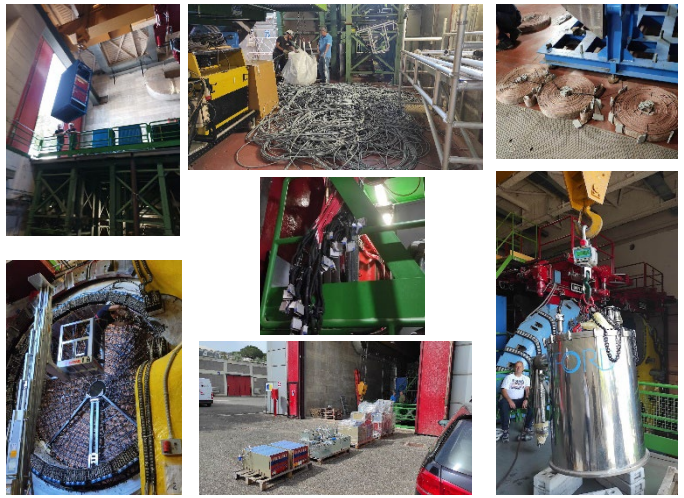
re-use/upgrade KLOE (LNF):

- 0.6 T superconduction solenoid magnet
- 4pi electromagnetic calorimeter

new design:

- internal straw tube tracker
- GRAIN LAr Meniscus (1 T)

LNS involved in both activities



SAND must be operational at first beam (2028)

Thanks for your attention!