Dark Matter with Liquid Argon

Francesco Di Capua

on behalf of the DarkSide Collaboration

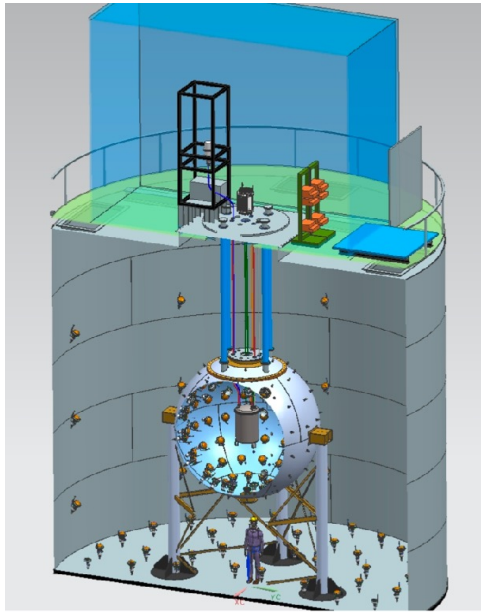
University of Naples Federico II and INFN

Outline

- Dark Matter results with LAr
- Large scaling challenges and infrastructure for future DM searches
- Photodetector R&D and future detection concepts
- DarkSide-20k experiment

Results from LAr experiment

DarkSide50: succesful physics run with underground argon 2013-2018

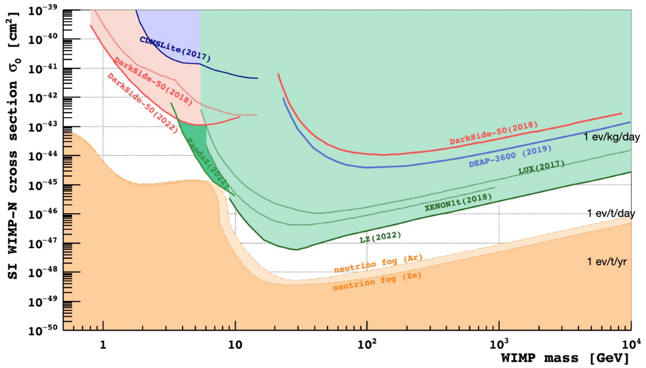


Inner Argon dual phase TPC
- 46 kg LAr target 38 x 3 inches PMTs

Liquid scintillator neutron veto
- 30 t of ^{10}B-loaded liquid scintillator
- active gamma and neutron veto

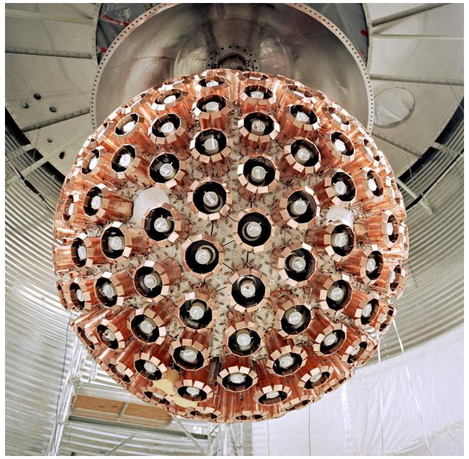
Water Cherenkov muon veto
- 1 kT of ultra-pure water
- passive shield for external radiation
- active veto for muons

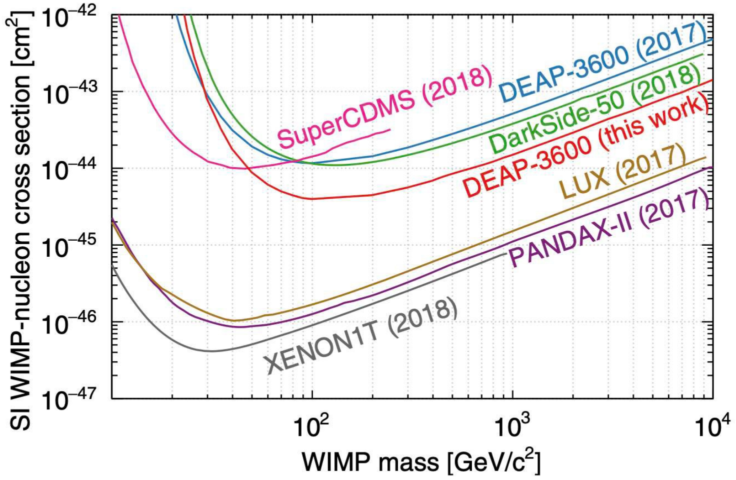
Background free DM search with Uar, Best sensitivity to date for low-mass



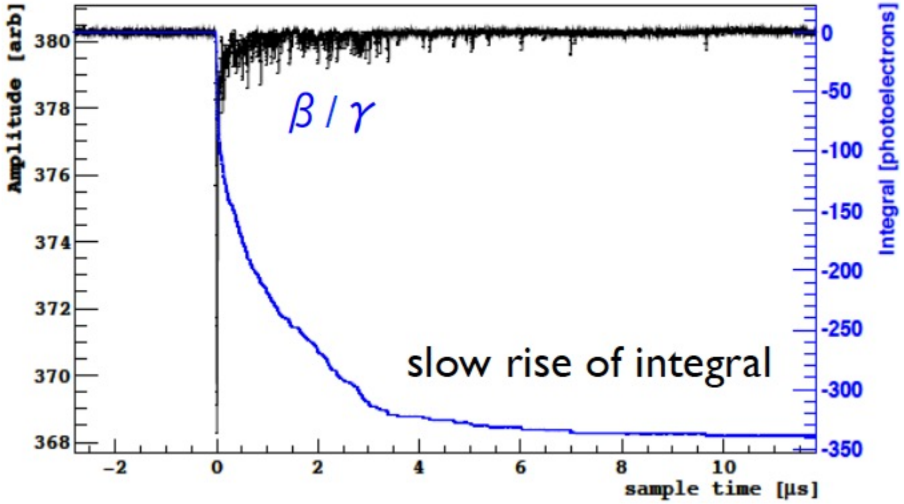
DEAP-3600: largest running LAr detector designed for WIMP search

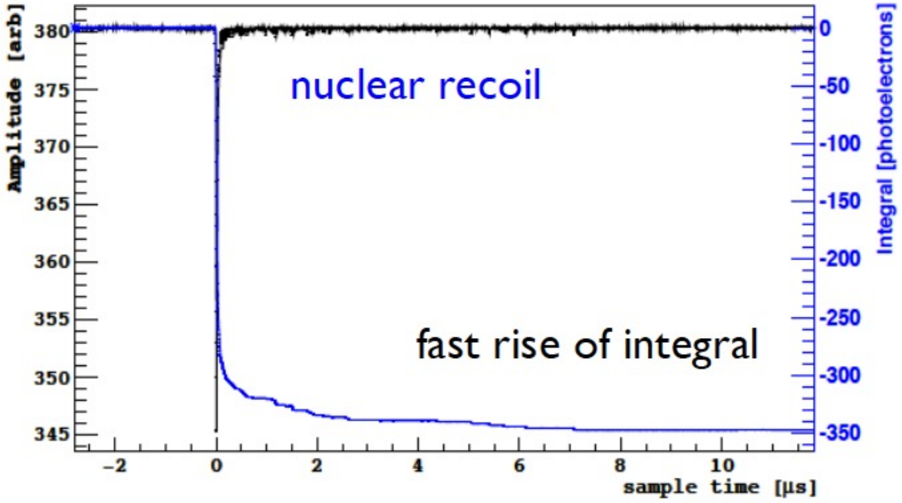
- Ultra-pure acrylic cryostat coated on the inside with TPB wavelenght shifter
- Surrounded by 50 cm plastic for thermal neutron sheilding
- Hamamatsu R5012 PMT view the LAr volume at 71% coverage

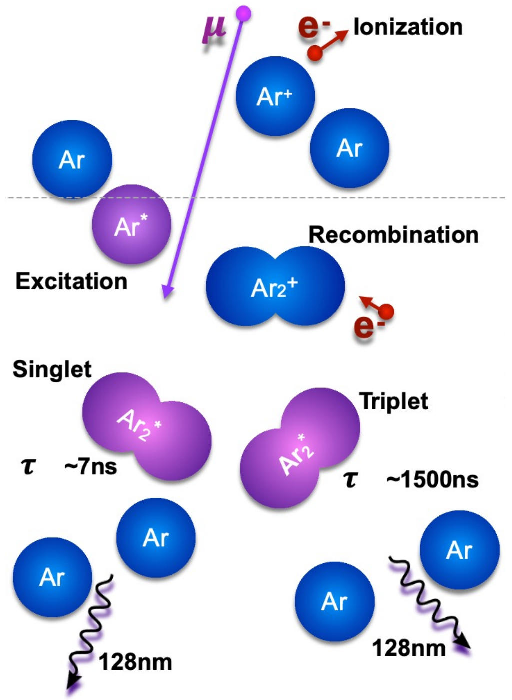


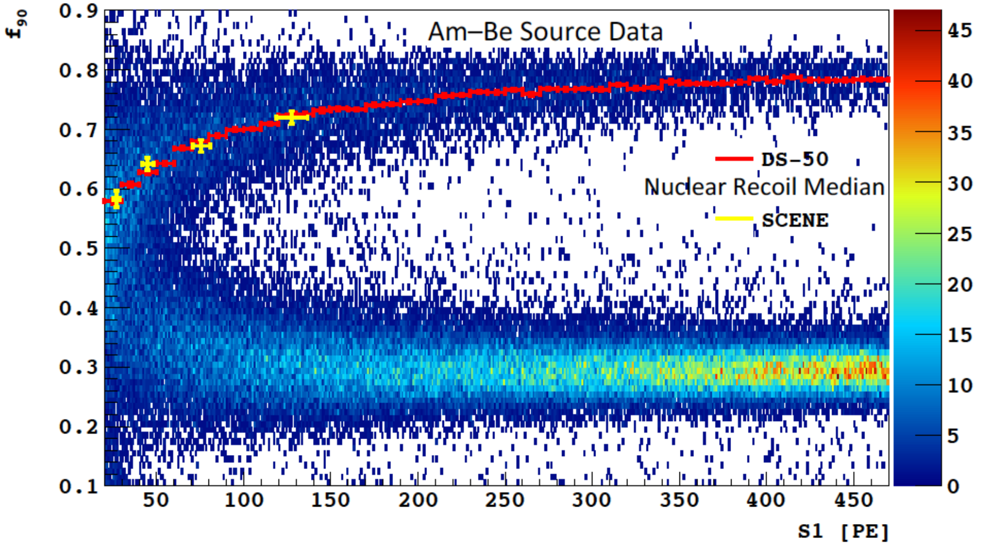


ER rejection in LAr: Pulse Shape Discrimination









$$f_{prompt} = \frac{\textit{Prompt light}}{\textit{Total light}}$$

β , γ rejection

>1.5x10^7 in DS-50

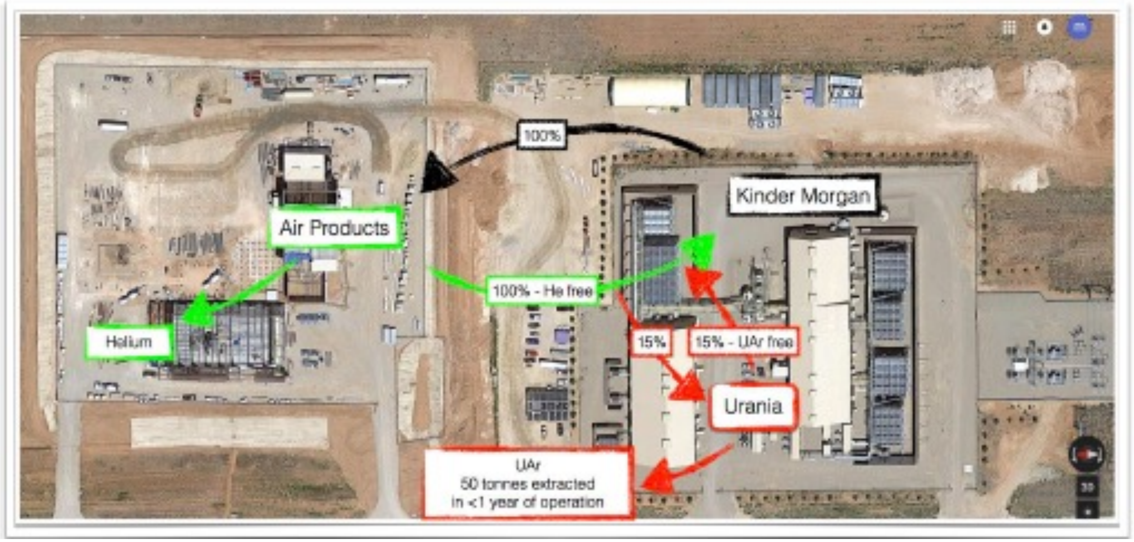
10.1016/j.physletb.2015.03.012

>1x10^8 (DEAP3600)

Eur. Phys. J. C 81,823 (2021)

- Decay constant for triplet state much longer than for singlet
- NRs are characterized by much larger dE/dx than ERs
  - Scintillation light from the triplet states is severely suppressed in case of NRs compared to ERs
- Scintillation light time profile to distinguish:
  - NRs (neutrons + WIMPs) from ERs (background)

Technology challenges for multi-tonne scales: low radioactivity Argon



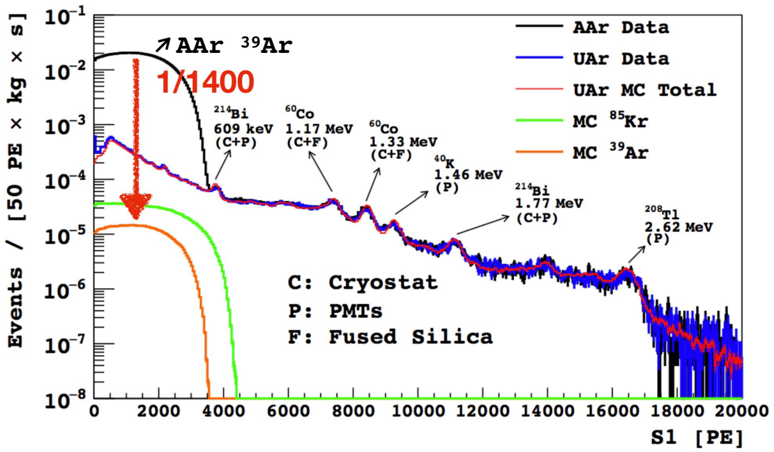
Ar depleted of ^{39}Ar with respect to atmospheric argon to be extracted from underground wells and **Ar purification infrastructures**

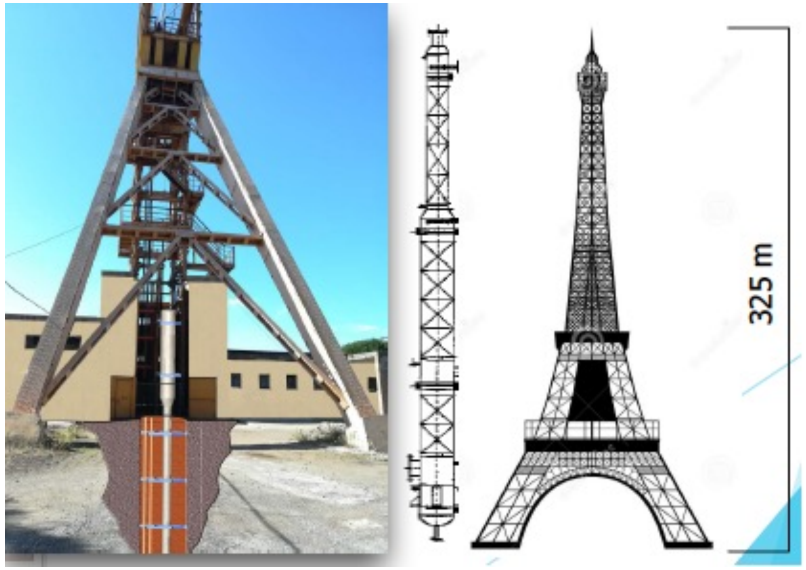
- < 1 yr to process DarkSide UAr
- other rare stable isotopes production for interdisciplinary benefits (^{18}O, ^{13}C, ^{15}N)

URANIA

330 kg/day

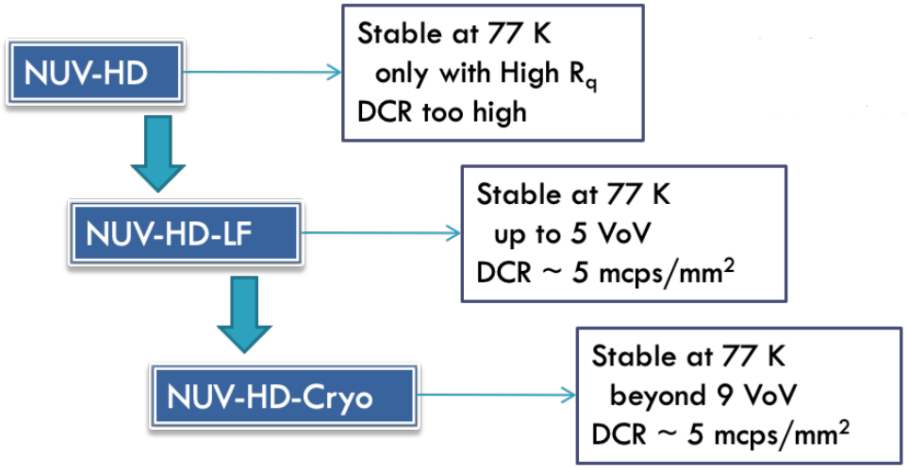
- < 1 yr for 50 tonnes of UAr
- Possible use of UAr for other experiments (LEGEND, COHERENT, …)

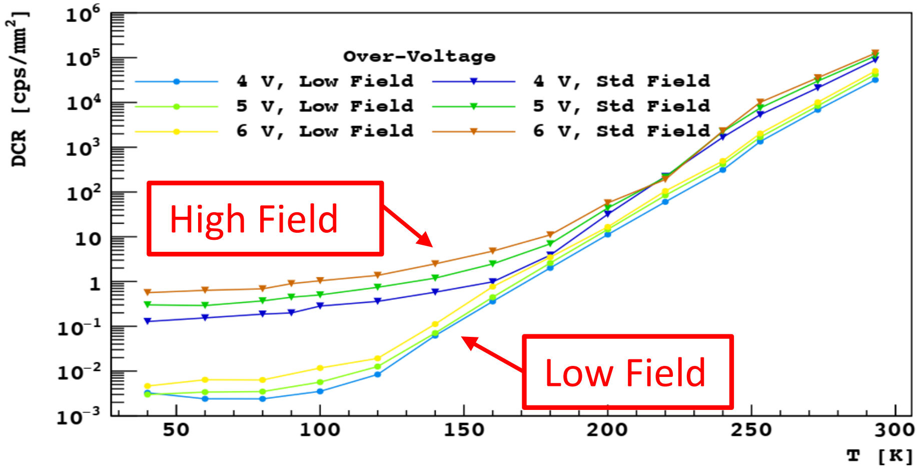




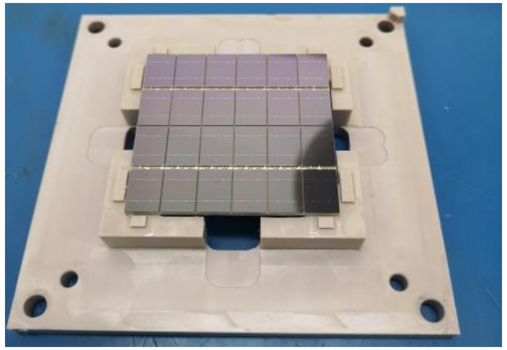
Technology challenges: cryogenic photosensor R&D

Darkside-20k: custom cryogenic SiPMs developed by a collaboration between INFN with Fondazione Bruno Kessler



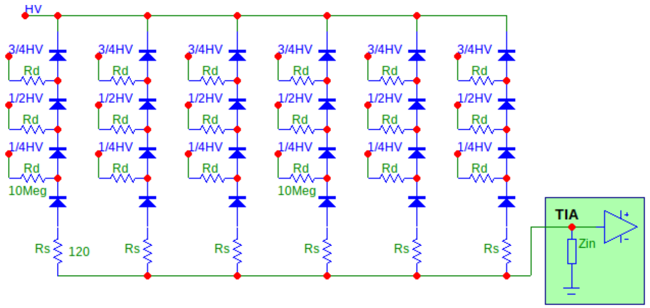


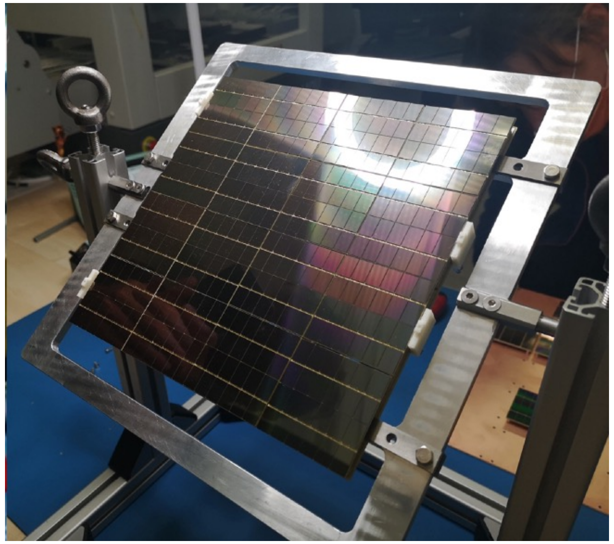
Reduced DCR with a proper optimized E field engineering for cryogenic applications



Tile+preampl integrated into a unique PCB

PDM: largest SiPM unit ever: 24 cm²
Series/parallel ganging 4s 6p





PDU : 16 PDM arranged in 4 readout channels 20 cm × 20 cm

Photodetector assembly: Nuova Officina Assergi @ LNGS

Radioclean packaging for cryogenic applications

- 421 m^2 radon-free ISO6 clean room
- Top quality equipments for packaging of silicon devices

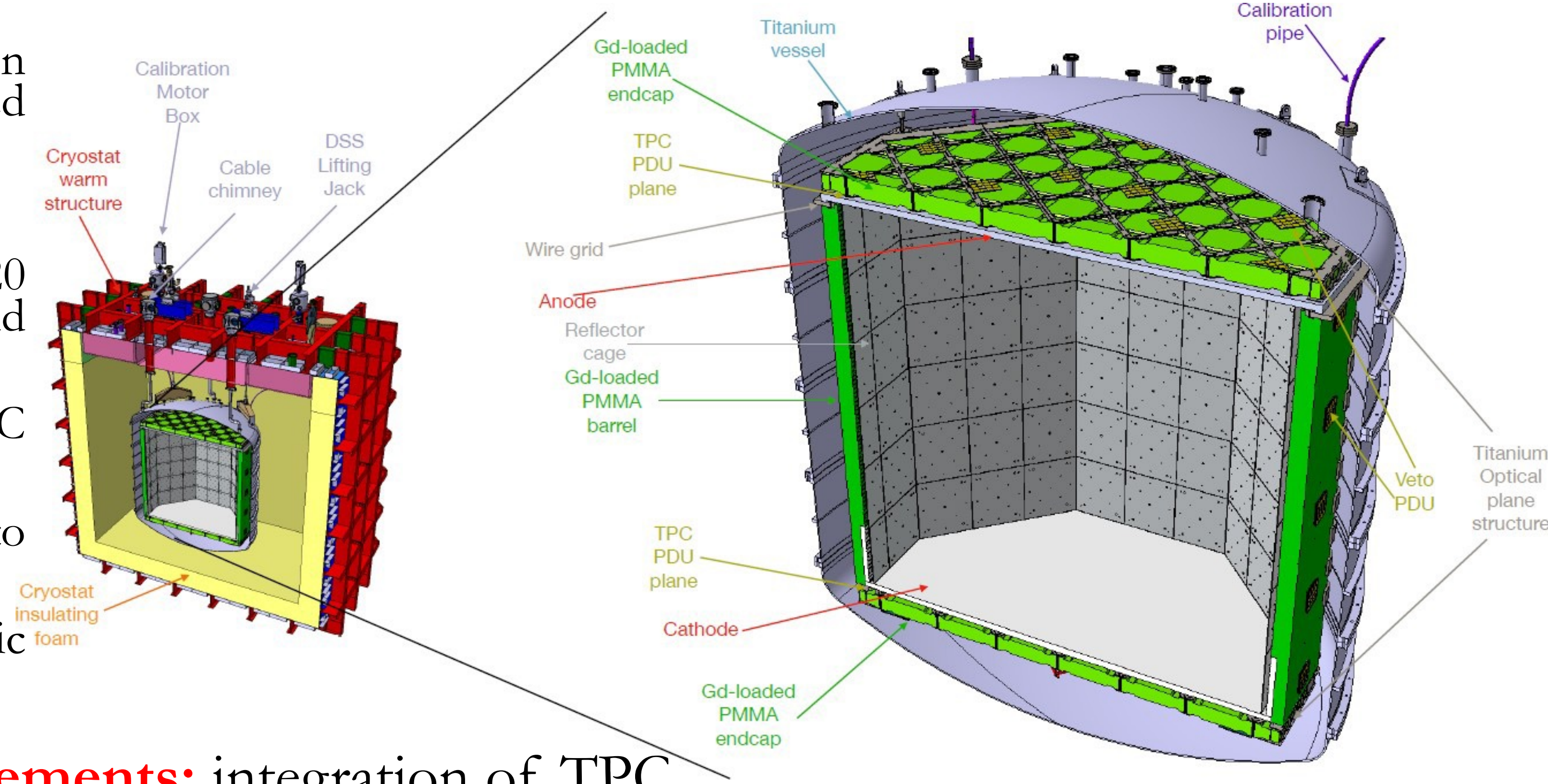
- Cryo silicon prober
- Silicon dicer
- Flip chip bonder
- Wire bonder
- No reflow oven
- Single PDM test line
- PDU assembly

Fully operational by the end of the year

Utility for large scale LAr and LXe detectors

DarkSide-20k overview

- Vessel housed within an atmospheric argon (AAr) volume maintained by a instrumented muon veto membrane cryostate (8x8x8 m^3)
- Ti vessel separating AAr from UAr
- WIMP detector fiducial volume of ≈ 20 tonnes (≈ 50 tonnes total) of underground argon (UAr), depleted in ^{39}Ar
- Active neutron veto integrated into the TPC structure via gadolinium-loaded acrylic
- Silicon photomultilier (SiPM) based photo detection (total area ≈ 26 m^2)
- UAr and AAr will use separate cryogenic systems



Novelty elements: integration of TPC and VETO in a single object

TPC Vessel:

- Lateral walls: Gd-loaded acrylic + reflector + WLS
- Anode, cathode and field cage made with conductive paint (Clevios)
- **TPC readout:** 21 m^2 cryogenic SiPMs

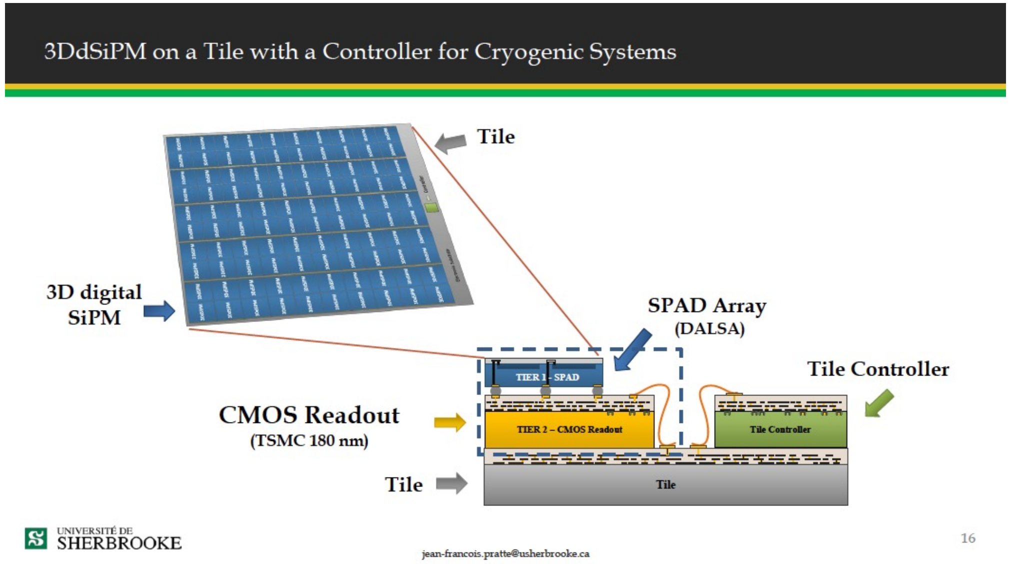
VETO

- TPC surrounded by a single phase (S1 only) detector in Uar
- TPC lateral walls + additional top&bottom planes in Gd loaded acrylic (PMMA)
- **VETO readout: 5** m^2 cryogenic SiPMs

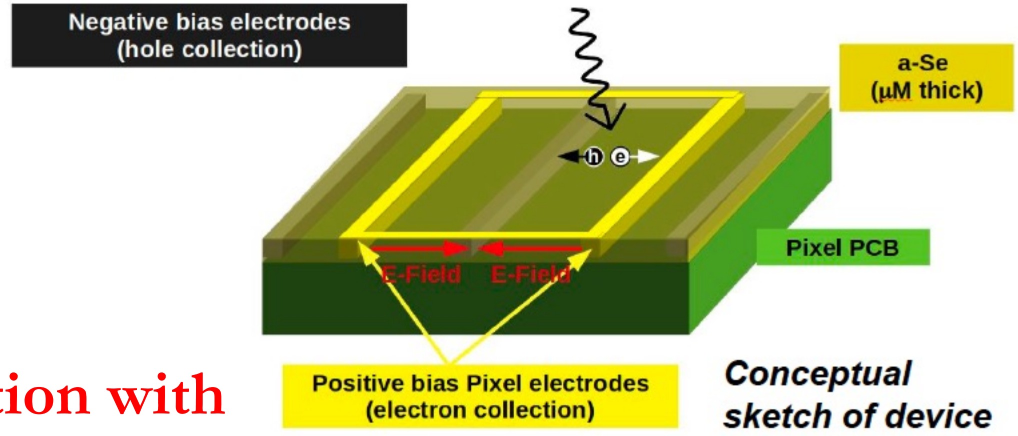
Future photodetection challenges

Digital SiPM

- From analog to digital SiPM
  - Monolithic devices
  - 3D vertical integration (high fill factor)
- Photodetection modules
  - Low power
  - Large area
  - Low background & cryogenics



Charge and light readout



Required cooperation with industrial foundries

- Photosensitive anodic plane
- Pixel readout to collect ionization charge and UV photons D. Nygren, Y. Mei: arXiv:1809.10213
- Thin-film photoconductor coating
- Amorphous Selenium (commonly used in X-Ray digital radiography devices)

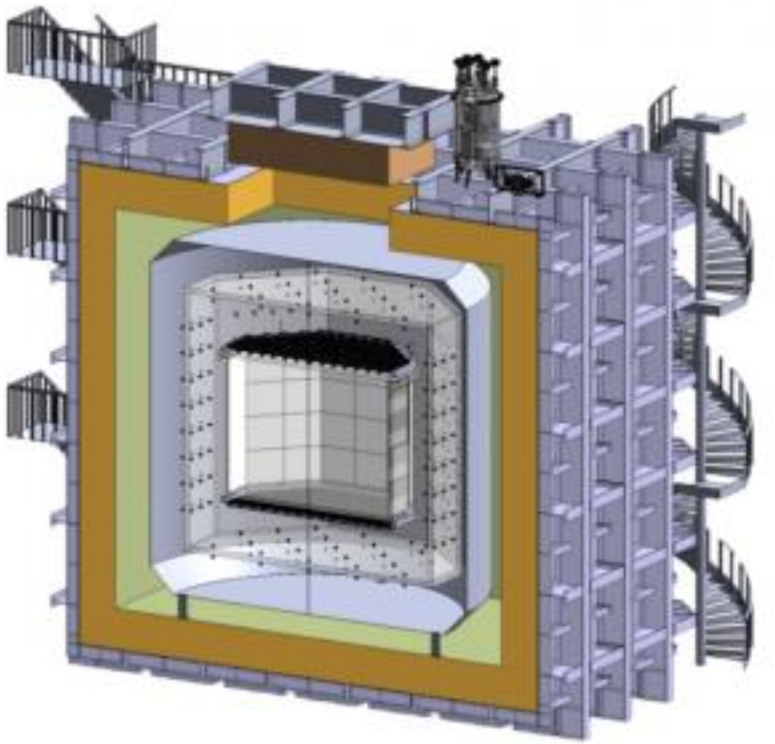
Conclusions

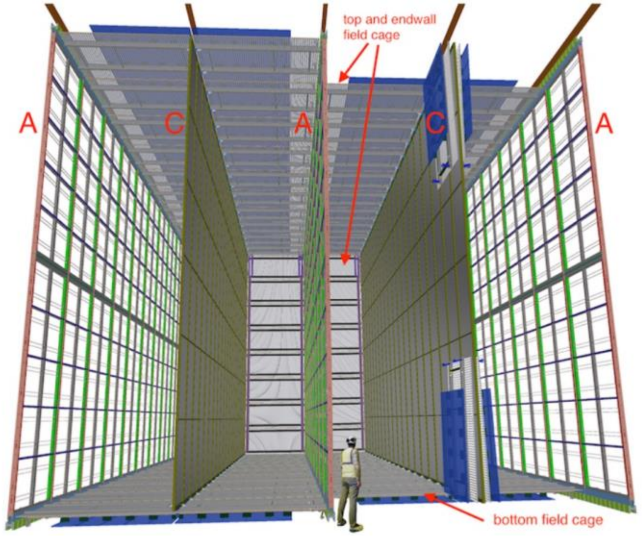
- Achieving background levels below neutrino floor main challenge for next generation Dark Matter experiments
- Technology innovations push forward ultra low background techniques
- Advanced infrastructure required for underground argon extraction (URANIA) and purification (ARIA) and for detector assembly (NOA)
- Strong R&D to develop cryogenic SiPM modules

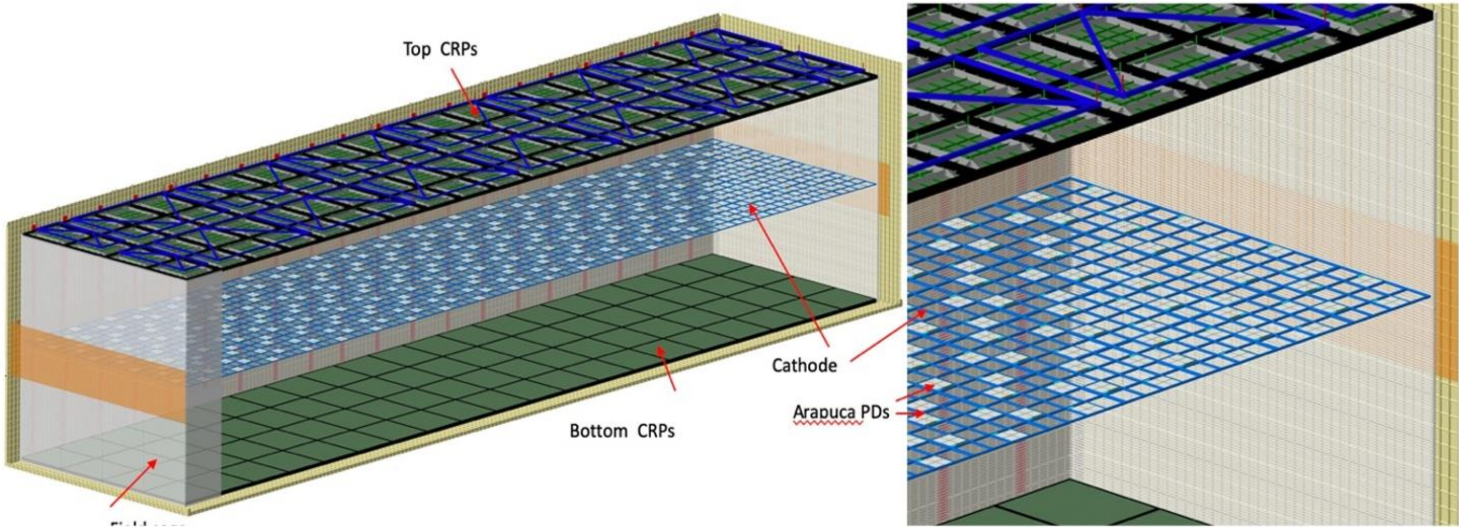
Cryo temperature SiPMs

ANDREA FALCONE – BARI, IFD 2022

- ✓ Neutrino and Dark Matter physics.
- ✓ Advantage: easy photon counting, low DCR, low bias voltage, radio purity.
- ✓ Disadvantage : dimensions.
- ✓ Possible uses in medical phisics and where low DCR is needed.

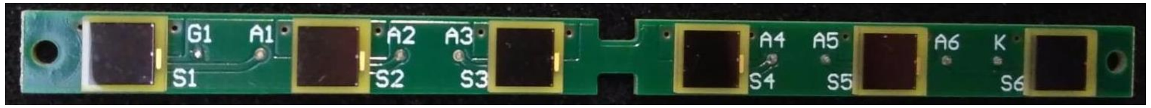




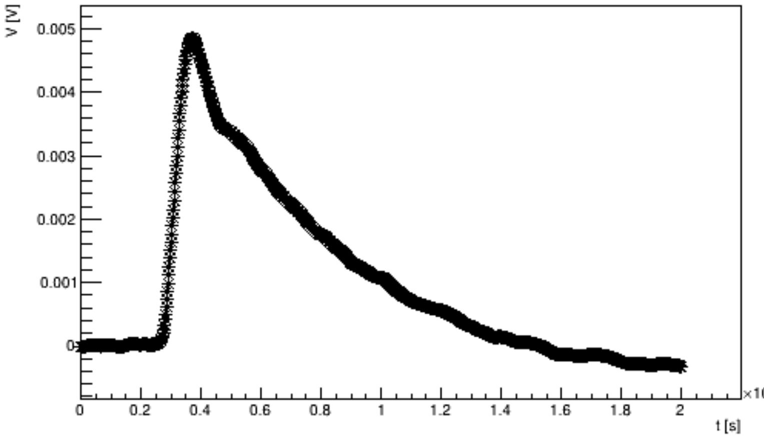


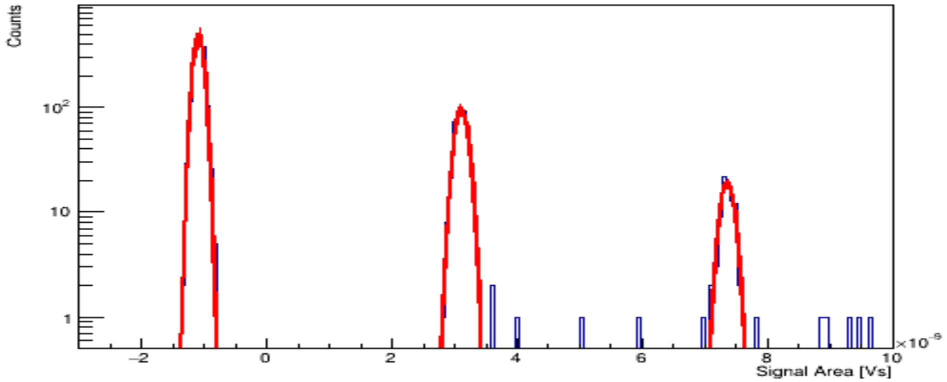
✓ FBK NUV-HD-CRYO – Triple Trench

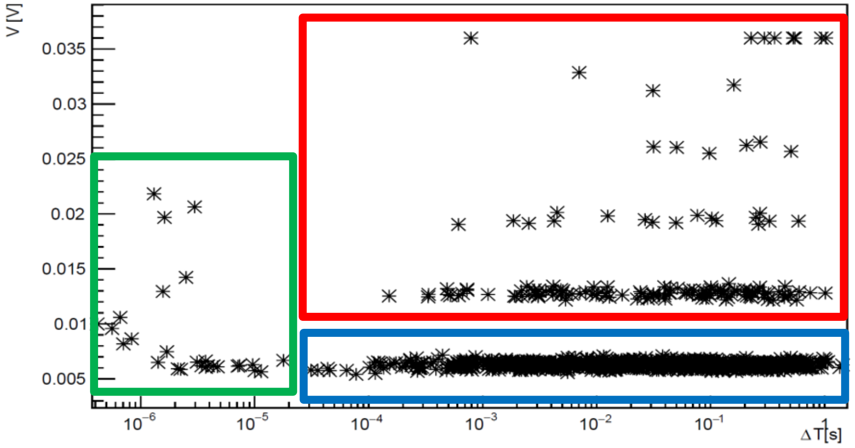
- Epossidic packaging
- Lower CT



SiPM dimension	6x6 mm^2
Gain @ 45% PDE	6 x 10^6
DCR	50 mHz/mm^2
Cross talks	20 %
Afterpulse	2 %

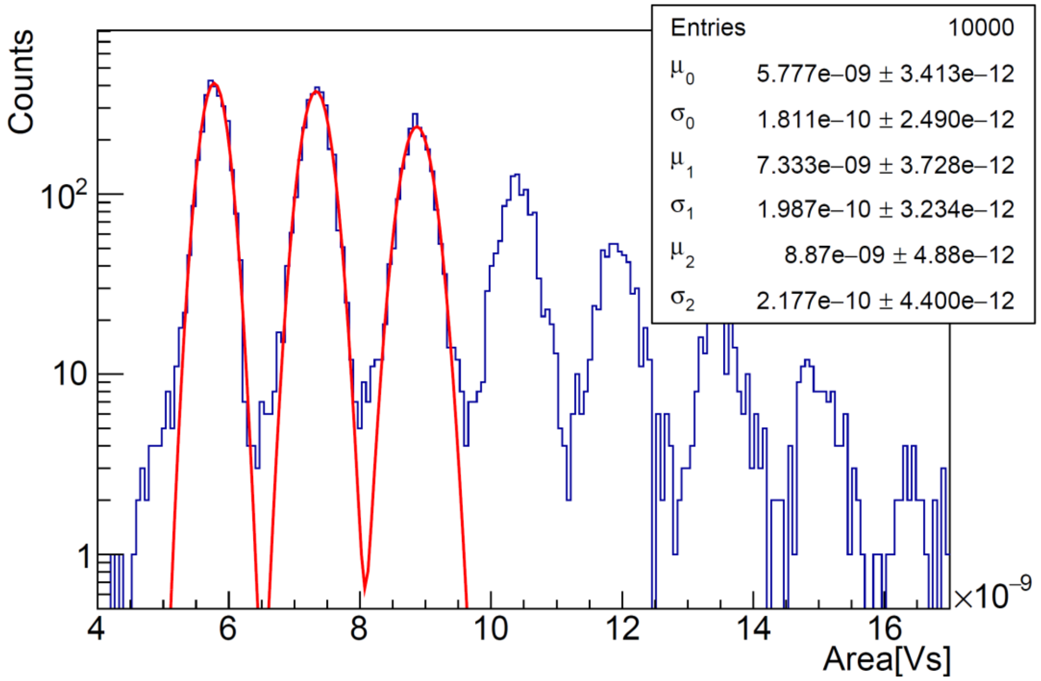






✓ Very good S/N in ganging mode

Num SiPM	S/N @ 45% PDE
24	10.6
48	9.7
72	8.4
96	7.9



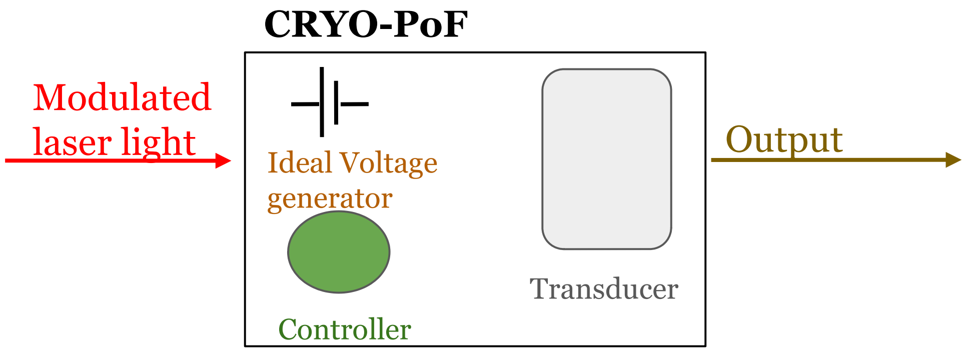
https://arxiv.org/abs/2207.13616

Cryogenic Power-over-Fiber for fundamental and applied physics

Marta Torti
INFN- Sezione di Milano Bicocca

Concept overview

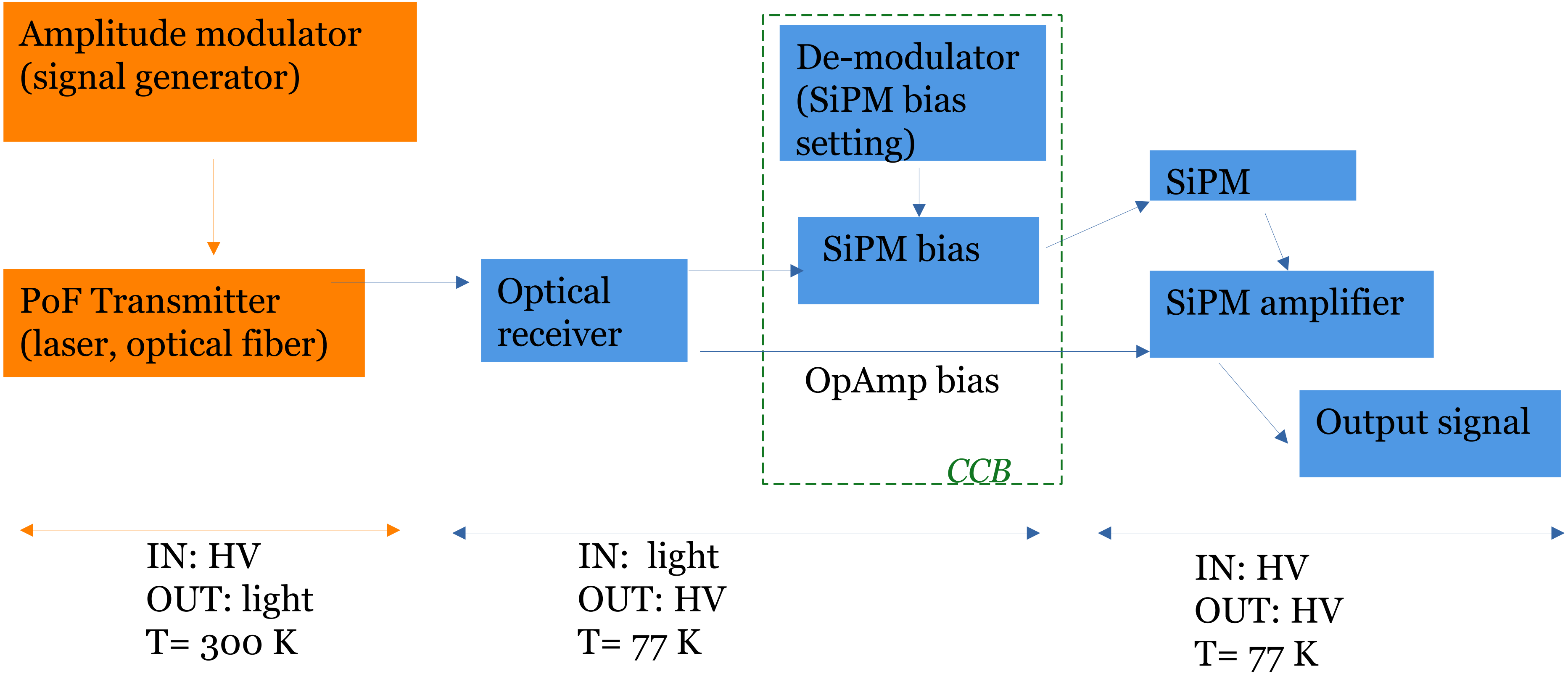
- CRYO-PoF is aimed at designing a cryogenic system based on optoelectronic devices to power analog and digital electronics.
- Using the same laser line, we want to:
  - give bias to the SiPM,
  - give HV to SiPM amplifier,
  - regulate the SiPM bias, with amplitude modulation.
- This solution provides noise immunity, voltage isolation, and spark-free operation.



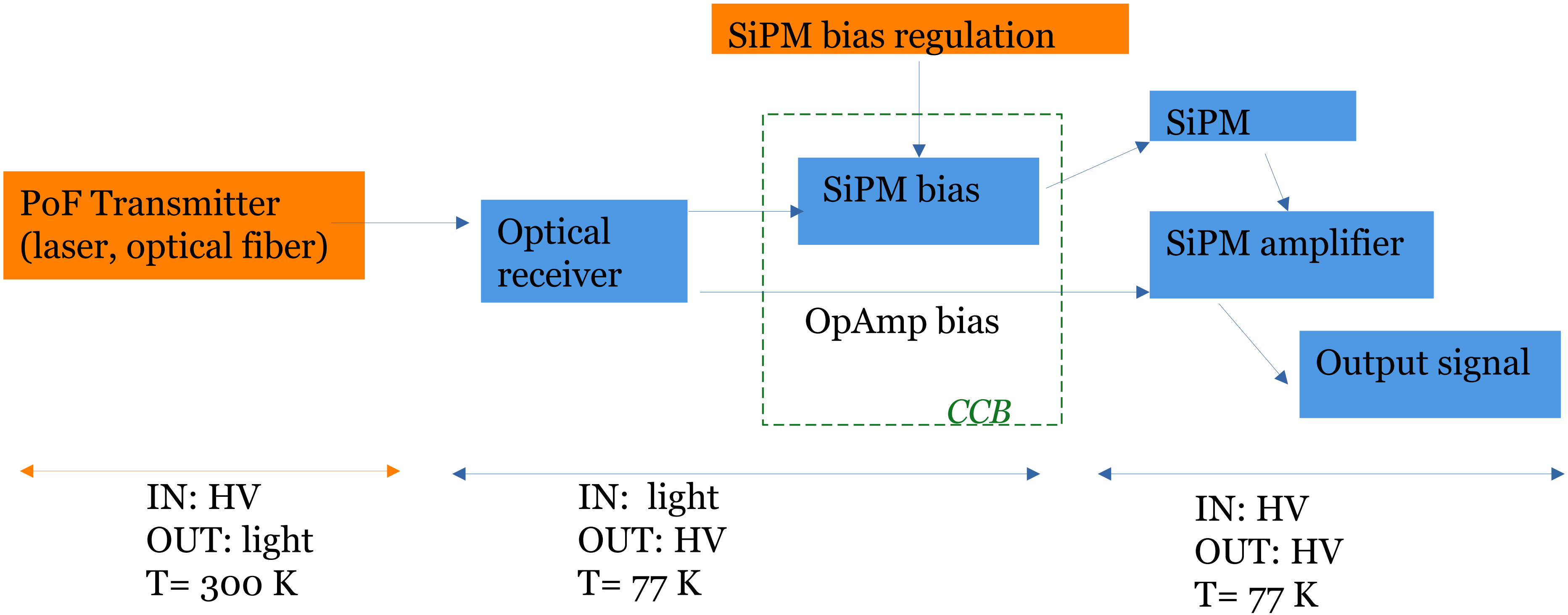
This solution is inspired by the needs of the DUNE Vertical Drift detector.

All systems that operate in harsh environments (low temperature and prohibitive for a copper-based power line) can benifit.

A schematic view



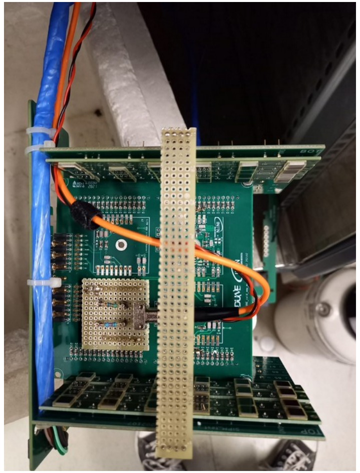
A schematic view – first step



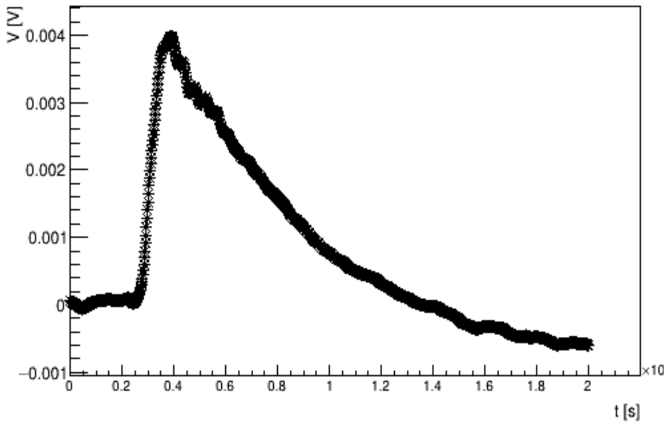
PoF transmitter

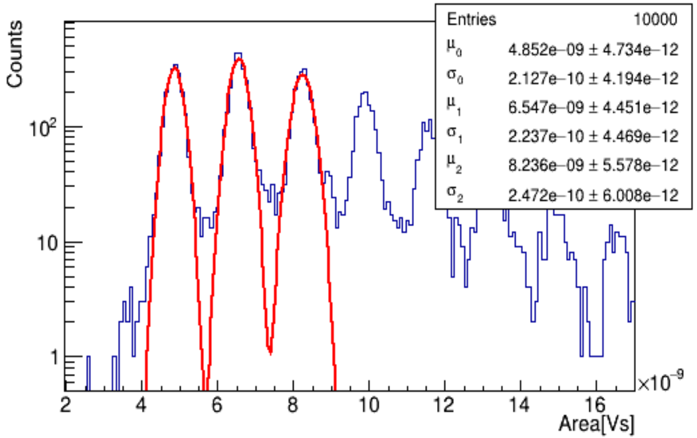
Laser: GaAs 808 nm

Laser connected to the optical receiver by an optical fiber.
The receiver is directly connected to the SiPM amplifier (3.3 V).



Firs results – 77 K

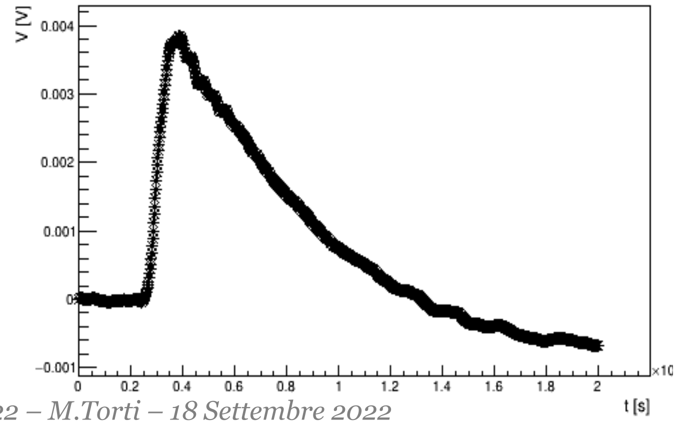


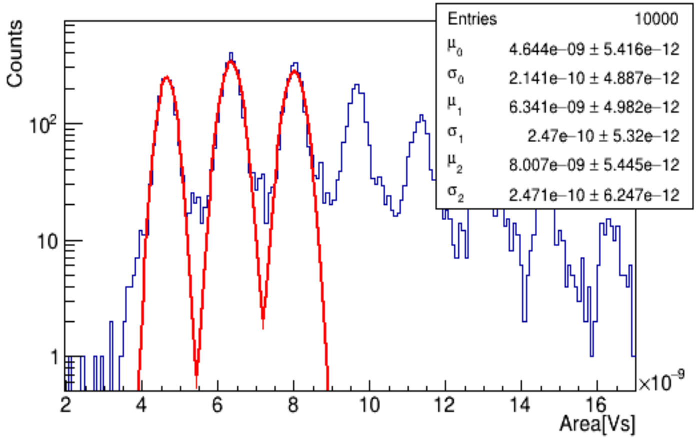


Output signal from SiPM (no PoF):

- standard biased SiPMs
- standard biased amplificator

S/N = 7.97





Output signal from SiPM (PoF):

- standard biased SiPMs
- PoF biased amplificator

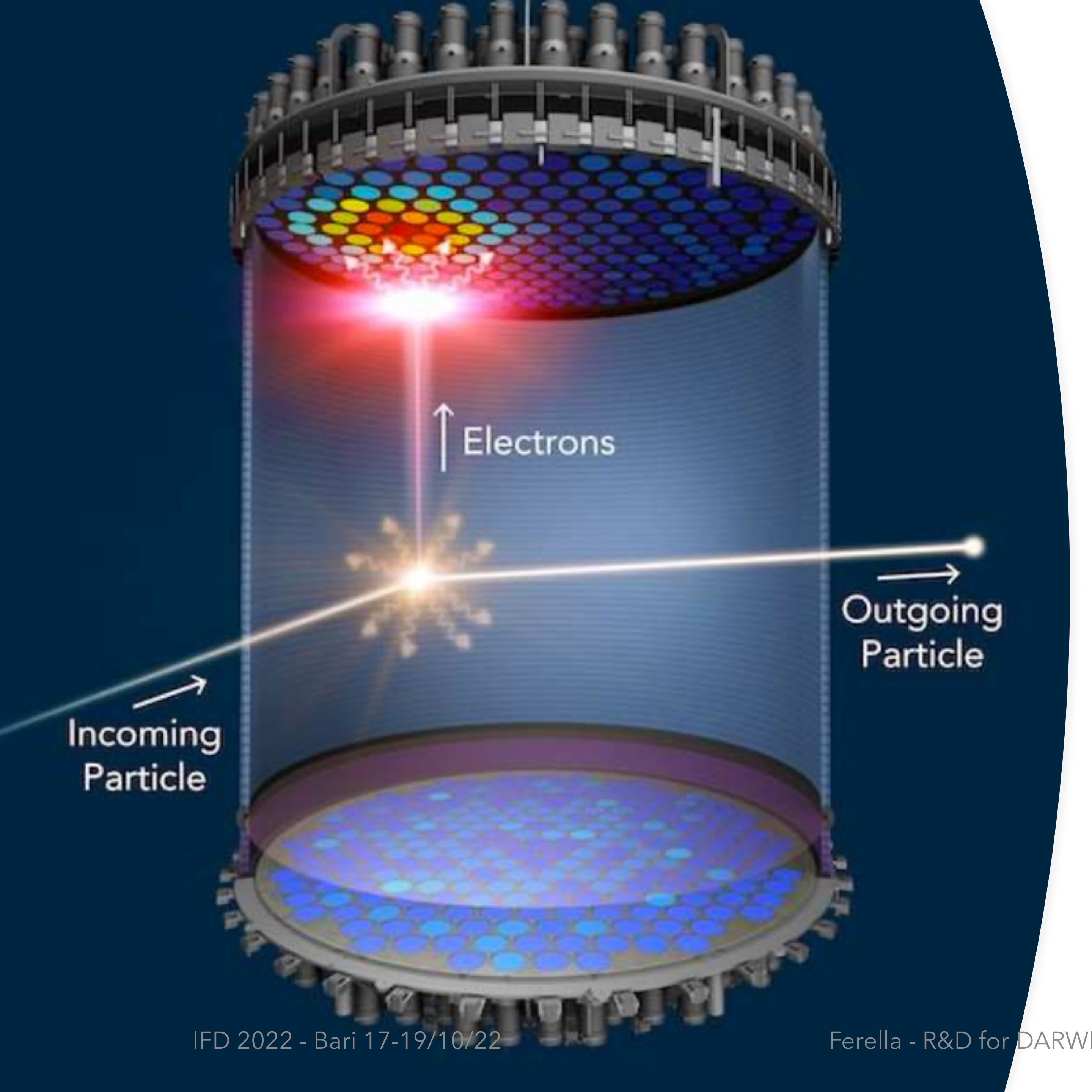
S/N = 7.92

New ideas on Photosensors & Electrodes for DARWIN, the Next-Gen LXe TPC

Alfredo Davide Ferella

on behalf of the XENON INFN groups (LNGS-UnivAq)

DARWIN



TPC main challenges

- What is special we all know!
- Main challenging parts:
  - PMTs:
    - radioactivity
    - Spurious events (after-pulses, dark counts)
  - Electrodes:
    - Warping
    - Wires may break
    - Both grids and meshes generate micro-discharge
  - UV light (178 nm @ LXe)

Our solutions

ABALONE

SiPM

Transparent Conductive Electrodes (TCEs)

Wavelength shifter suitable for LXe

Tested in a new facility @LNGS dedicated to DARWIN

Photosensors

ABALONE

Glass-glass sealing

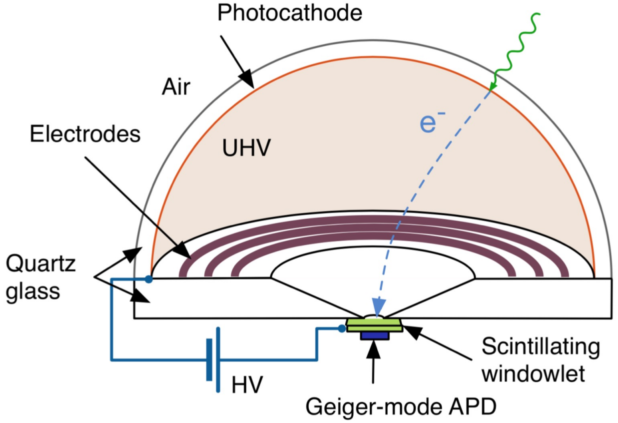
- Indium-based evaporated seal

  arXiv:1703.04546

  arXiv:1810.00280, NIM A 954 (2020)

  JINST 17 C01038 (2022)

Patent Numbers: U.S. 9,064,678, US-2017-0123084



Principle:

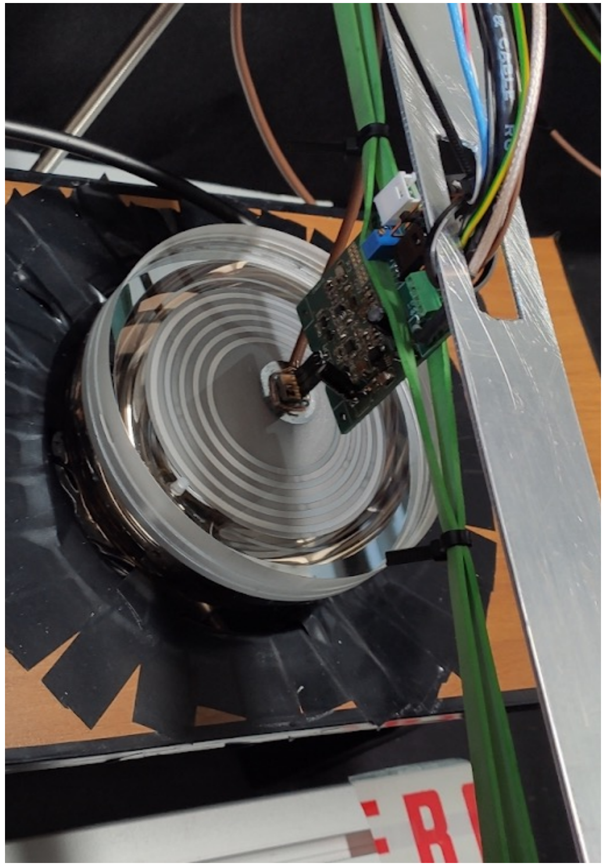
- p.e. accelerated towards scintillator windowlet (LYSO)
  - L_0=32 γ/keV →
  - Readout using SiPM (G = ~ 10^6)
  - @ 25 kV, assuming (pessimistic) collection efficiency η = 10% → ~ 80 PE
- Total gain: ~10^8

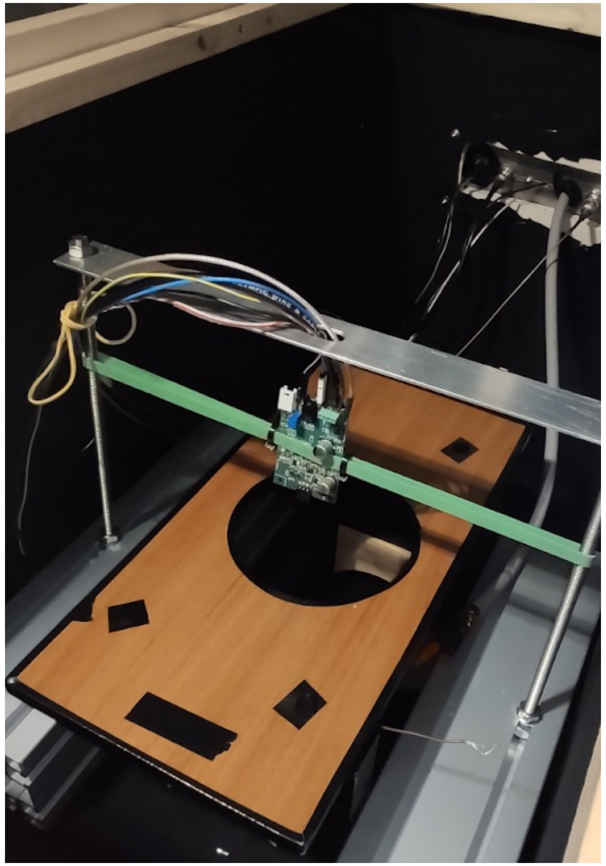
Major advantages:

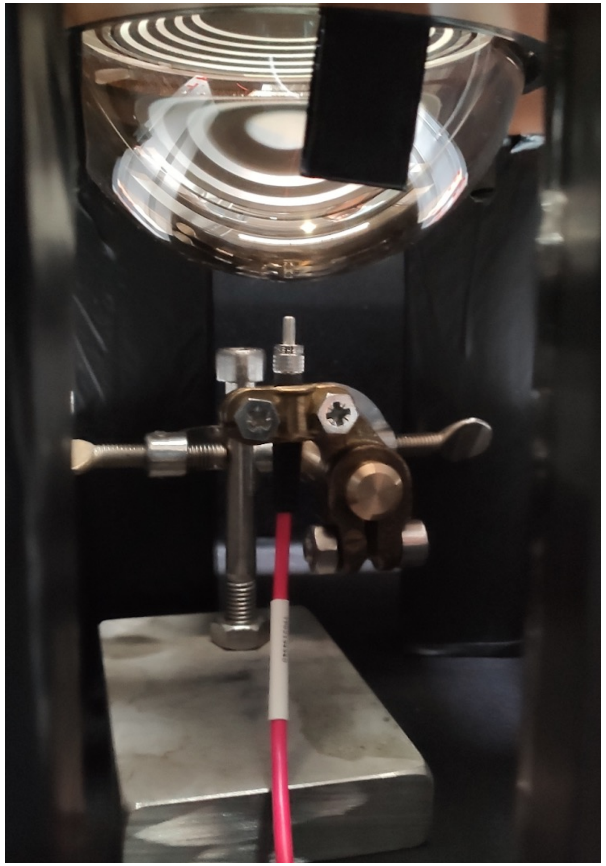
- all UHV-components are evaporated
  - production can be fully automated
- field-shaping electrodes work as getter
- good timing
- good pulse height separation

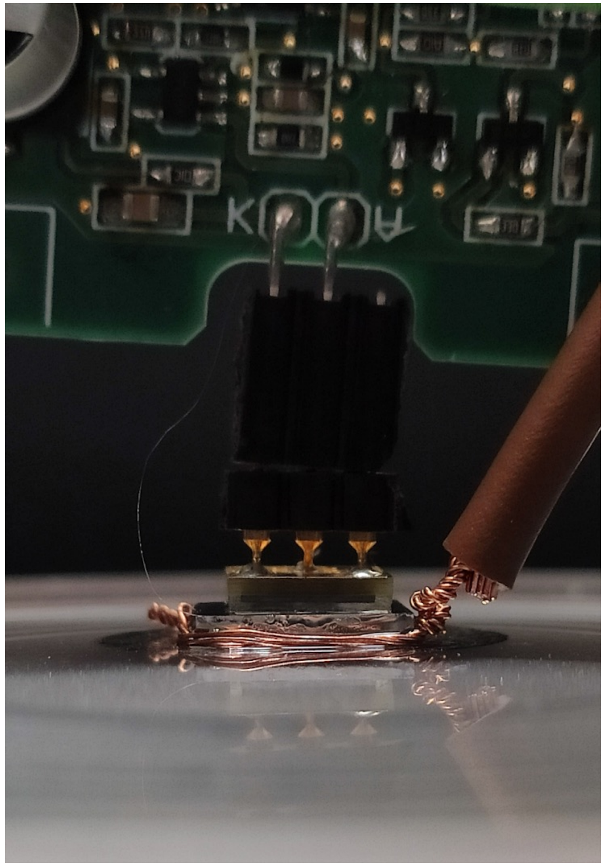
ABALONE tests at LNGS

The setup at LNGS



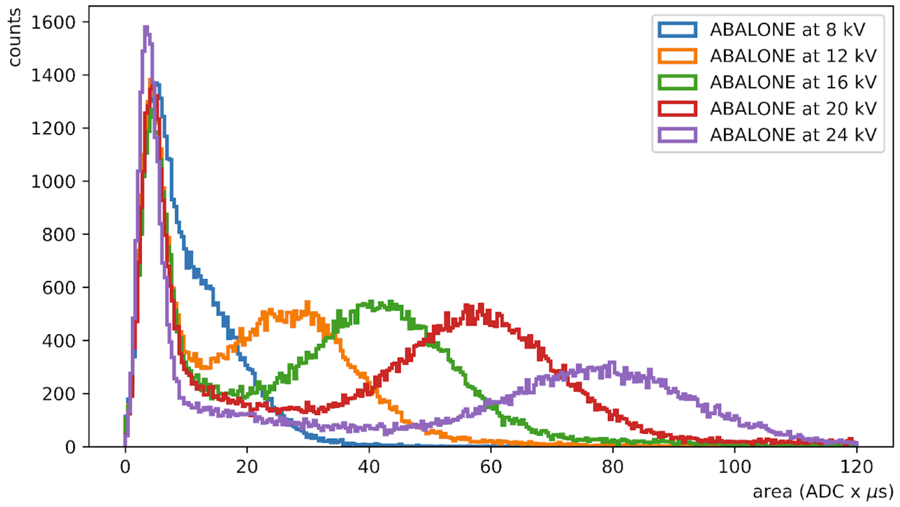


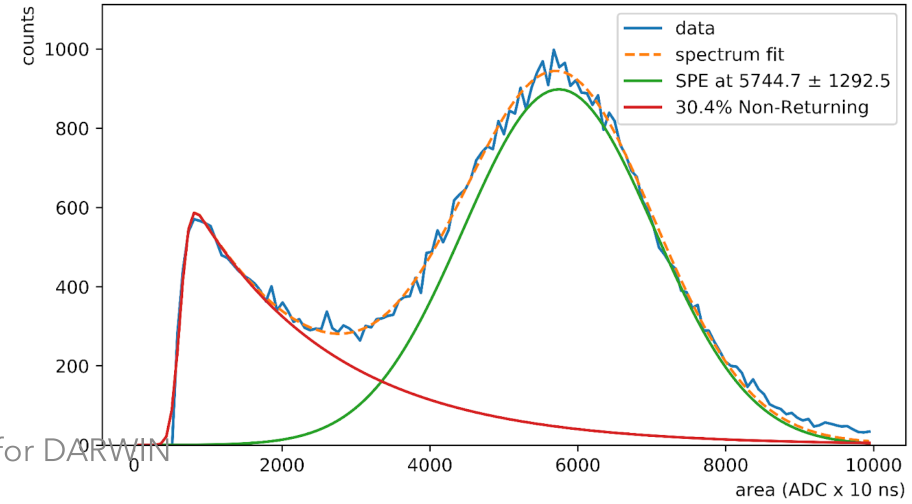




ABALONE tests at LNGS

- Percentage of Non-Returning measured: around 30%
  - As expected from simulation
- We increased the voltage up to 24 kV
- Spectrum with 2 peaks:
- SiPM dark counts, not changing with V
- ABALONE Single PE, increasing with V

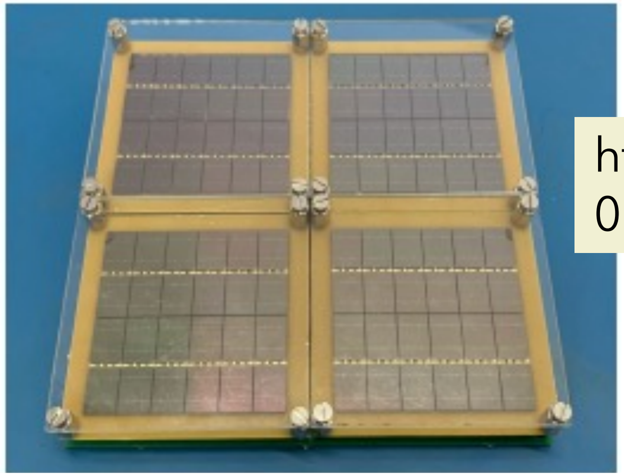




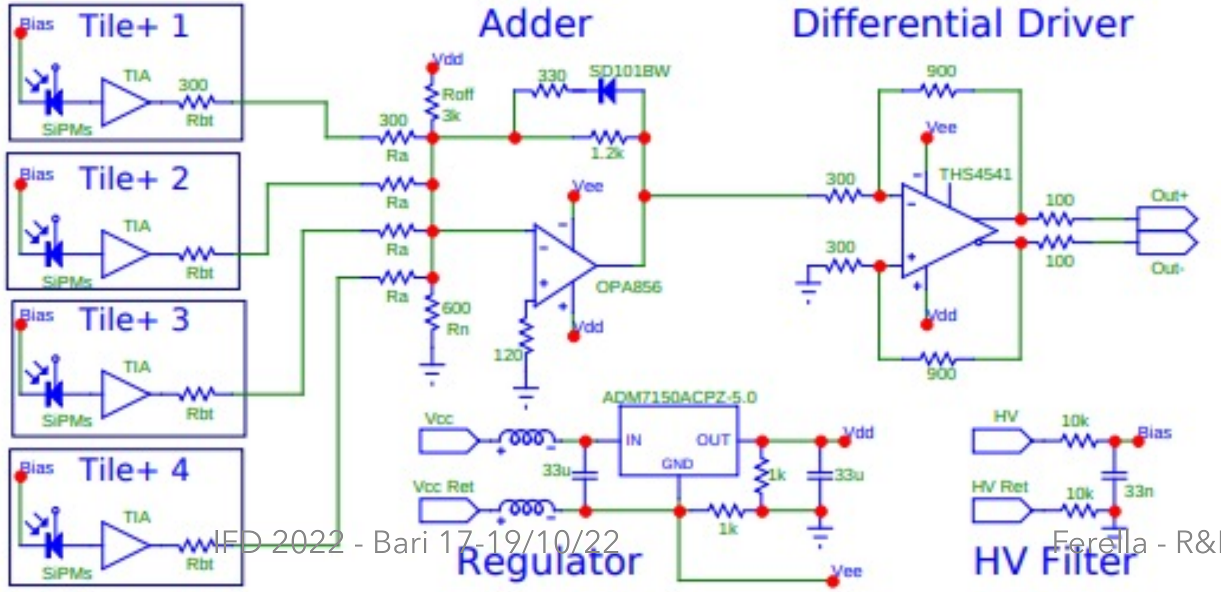
Next step:

- measure in LXe

SiPM Photo-detectors



https://arxiv.org/pdf/2201.01632v2.pdf



Radiopure SiPM-based photo-detectors are a reality

- Design and realization at LNGS
- 10 x10 cm^2 with aggregated output

This technology now has to be ported to xenon

- Selecting the right SiPMs
- The electronics is already designed and working
  - Including radiopure components, packaging techniques, …

SiPM tests and plan

We need to measure NUV-HD-Cryo SiPMs in xenon with PEN (and others WLS)

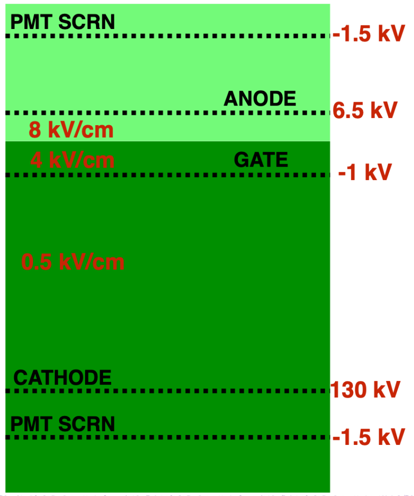
- To estimate the LY and the correlated noises
- We will need to test newest SiPM with metal trenches

We need to measure newest VUV-HD-Cryo SiPM to verify the DCR & correlated noises

- An R&D for BSI VUV SiPM is ongoing with NEXO:
  - PDE may increase to 30-40%
  - iCT can decrease to 5% & AP is already very low for newest NUV devices
  - DCR may still be an issue (need to go to 0.01 cps/mm^2 not sure it is possible)
- We need to stay tuned to the R&D testing samples

Electrodes

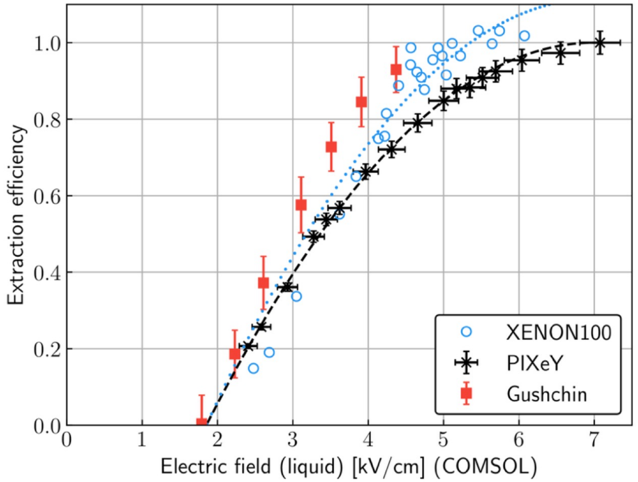
Constraints for DARWIN electrodes



DARWIN electrodes dimensions:
~**2.6 m diameter** and ~**30 mm thick**

High voltage constraints for DARWIN

- Need sufficient drift field for particles to go towards the gas
- Need sufficient extraction efficiency in gas
- High HV values for cathode in liquid and anode in gas
- Tension for wires or meshes is high



From these constraints:

- maximum HV for the cathode
- maximum field between anode and gate
- local maximum allowed S2 variation

So far XENON detectors employed:

- Wire mesh
- Parallel wires grid

Transparent conductive electrodes (TCEs)

Idea:

- Use TCEs with deposited on transparent substrate

GOAL of the R&D:

- Explore different solutions for the TPCs in terms of:
    - Transparency (at both 175 nm and 440 nm)
    - Electrical conductivity
    - Mechanical stability
    - Thermal stability
    - Electrical stability

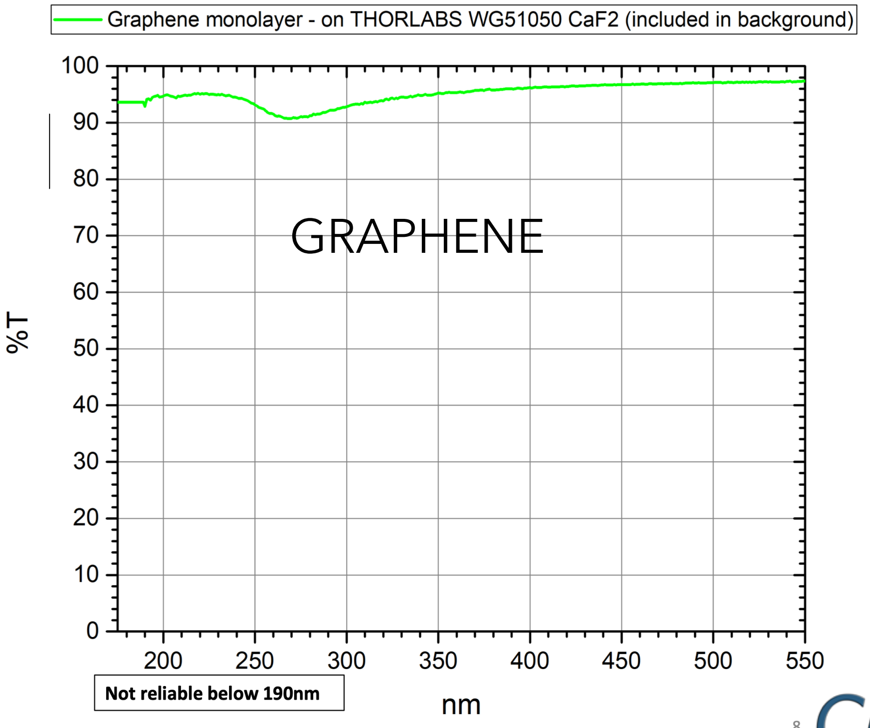
Next steps:

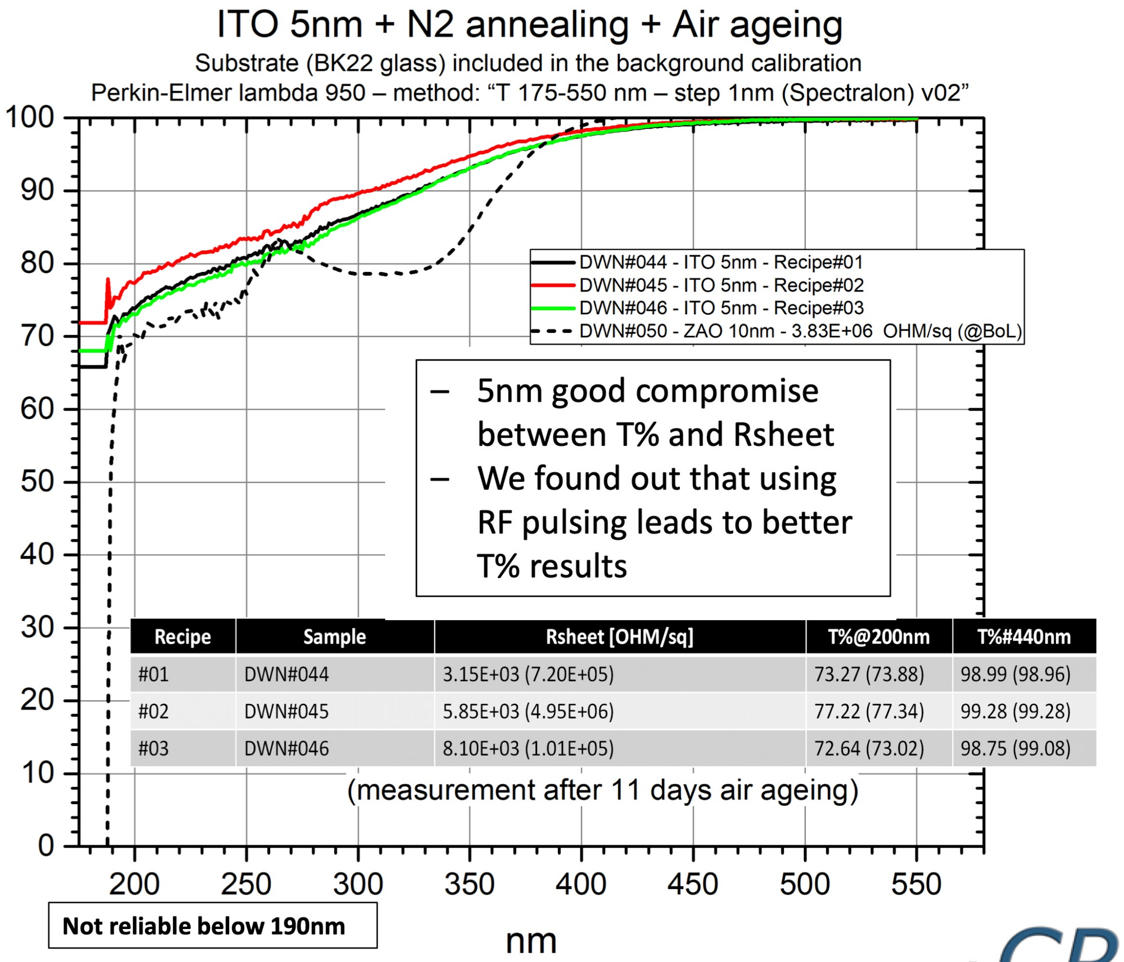
- 4 additional larger prototypes (~20 cm diameter) made of:
- AlN/ITO
- Silver nanowires
- Copper nanowires
- Graphene

Current status

Study in collaboration with the CREO, www.consorziocreo.com , Centro di Ricerche Elettro-Ottiche

- Very good transparency for graphene
- No effect to air exposition or other





Recipe	Sample	Rsheet [OHM/sq]	T%@200nm	T%#440nm
#01	DWN#044	3.15E+03 (7.20E+05)	73.27 (73.88)	98.99 (98.96)
#02	DWN#045	5.85E+03 (4.95E+06)	77.22 (77.34)	99.28 (99.28)
#03	DWN#046	8.10E+03 (1.01E+05)	72.64 (73.02)	98.75 (99.08)

Wavelength shifter

Why not using a wavelenght shifter?

178 nm is still a challenging wavelength:

- Quartz transmissivity ~ 80 – 85 % with 2.5 mm thickness
- Photocathode sensitivity is maximal at 420 nm
- Most TCEs are developed for optical light applications

Back of the envelope calculation:

- Total collection efficiency with NUV-SiPM ~30%
  - PEN: ~60% efficiency
  - SiPM: ~50% PDE
- To be compared with PMT ~ 30%:
  - QE ~ 40%
  - Fill factor ~ 70%

The end

IFD2022 - INFN WORKSHOP ON FUTURE DETECTORS

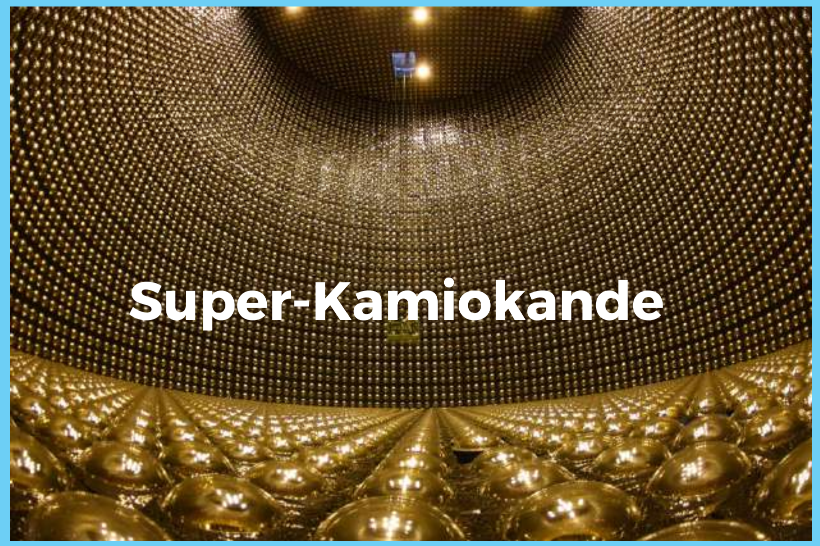
Gd-loaded Water Cherenkov Detectors

XENON

DARWIN

Andrea Mancuso - INFN & Università di Bologna

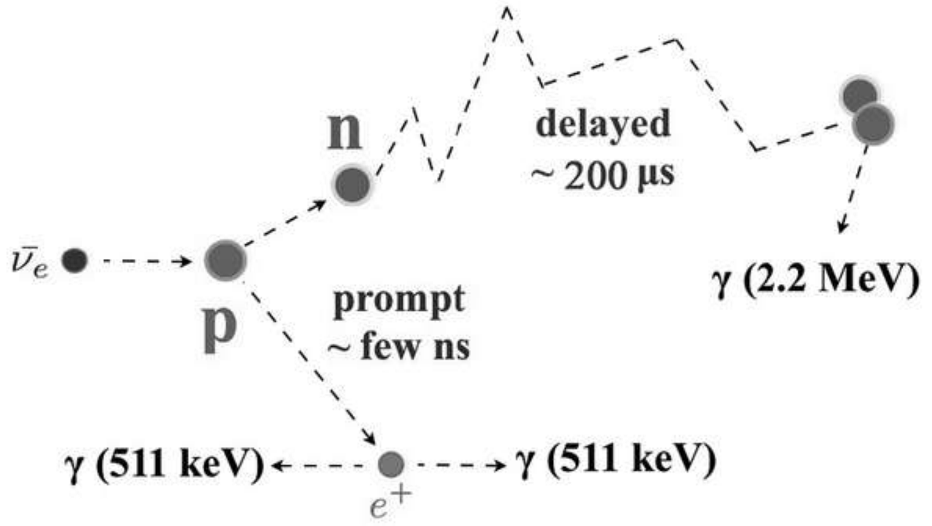
Water Cherenkov Detectors

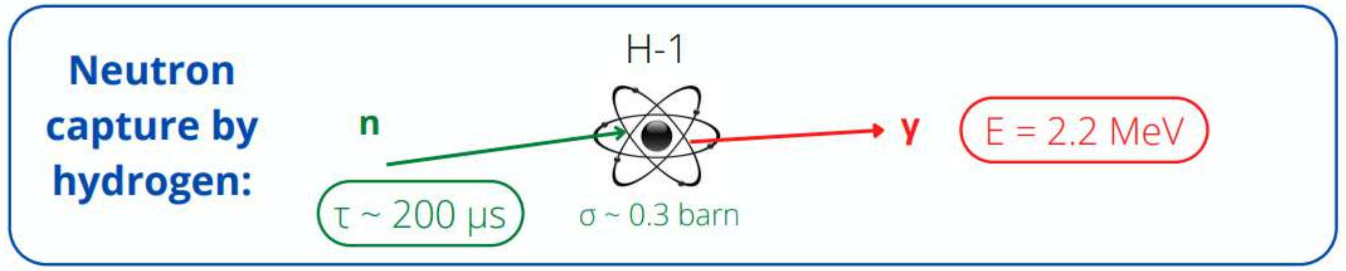


- **Large number of protons** (p decay, target for neutrino interactions)

Neutrons

- **Low energy for capture on p** (close to Cherenkov th.)
- **Low capture cross section** (~0.3 barns)





+ Gadolinium (Gd)

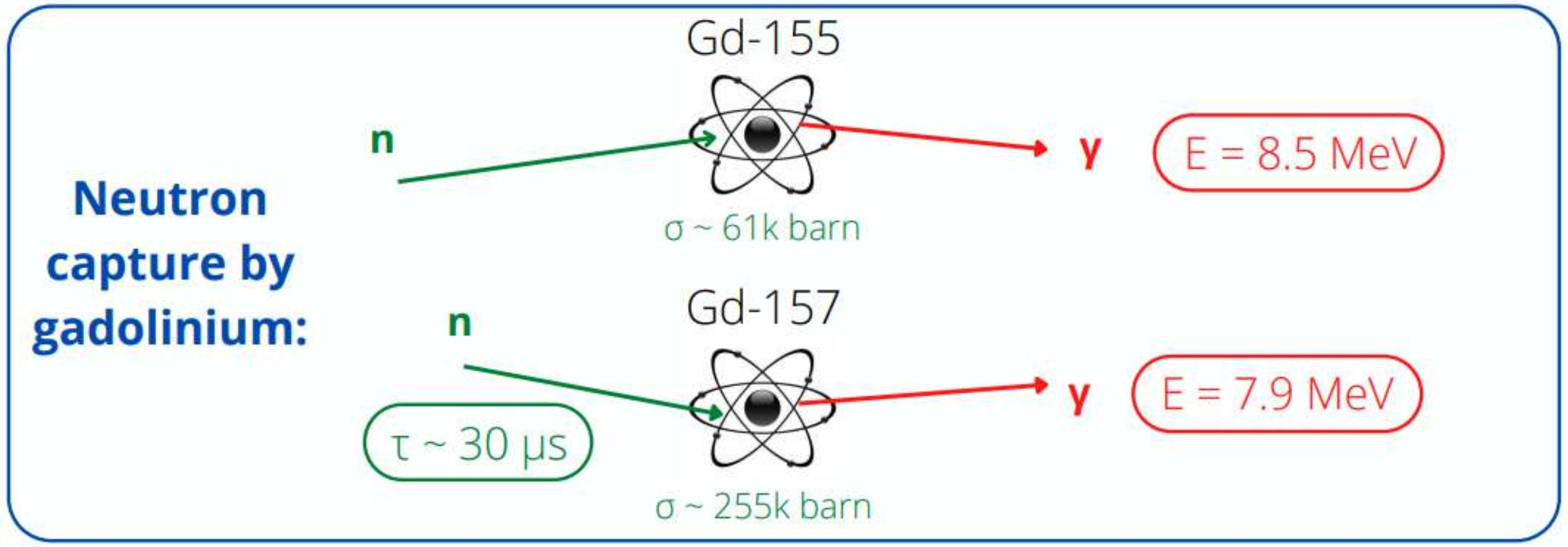
- **EGADS & Super-K**
- **XENONnT**

Gd has the largest cross section for the capture of thermal neutrons

Idea: enrich WC detectors with a water soluble gadolinium (Gd) salt.

$Gd(NO_3)_3$ $GdCl_3$ $Gd_2(SO_4)_3$

- easily soluble
- good Cherenkov light transparency
- suitable to be used in a detector (no reactive)

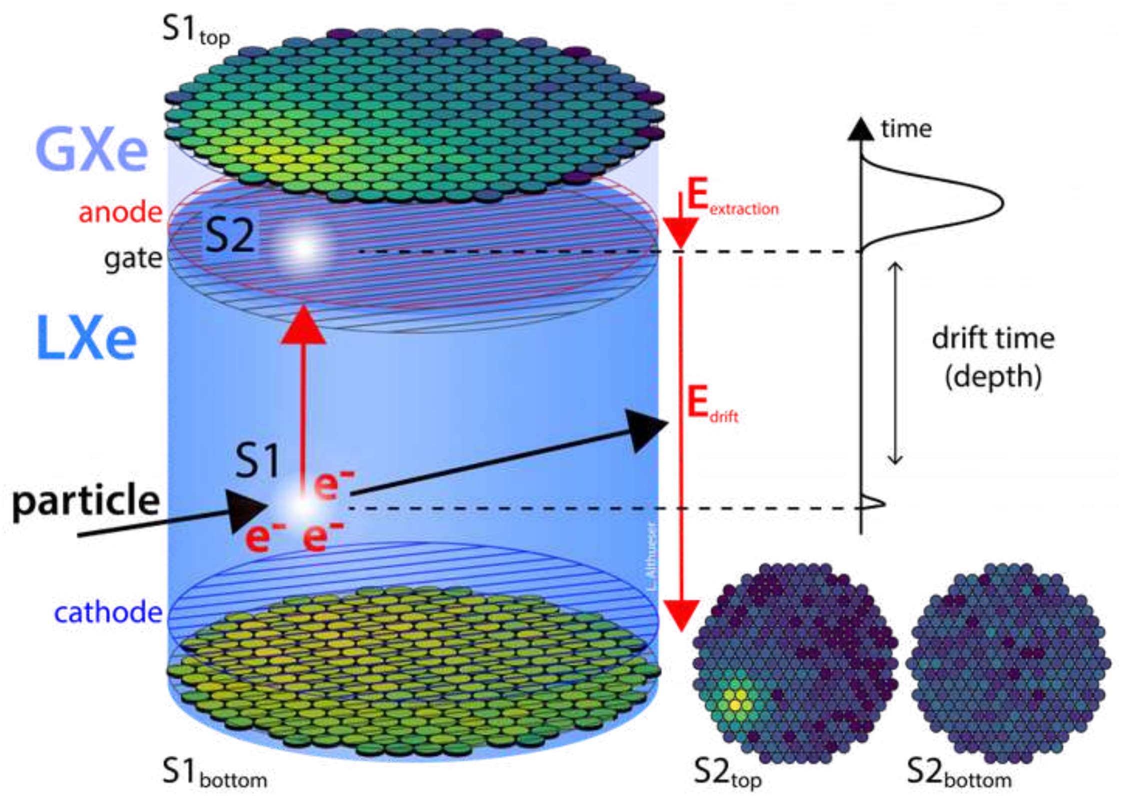


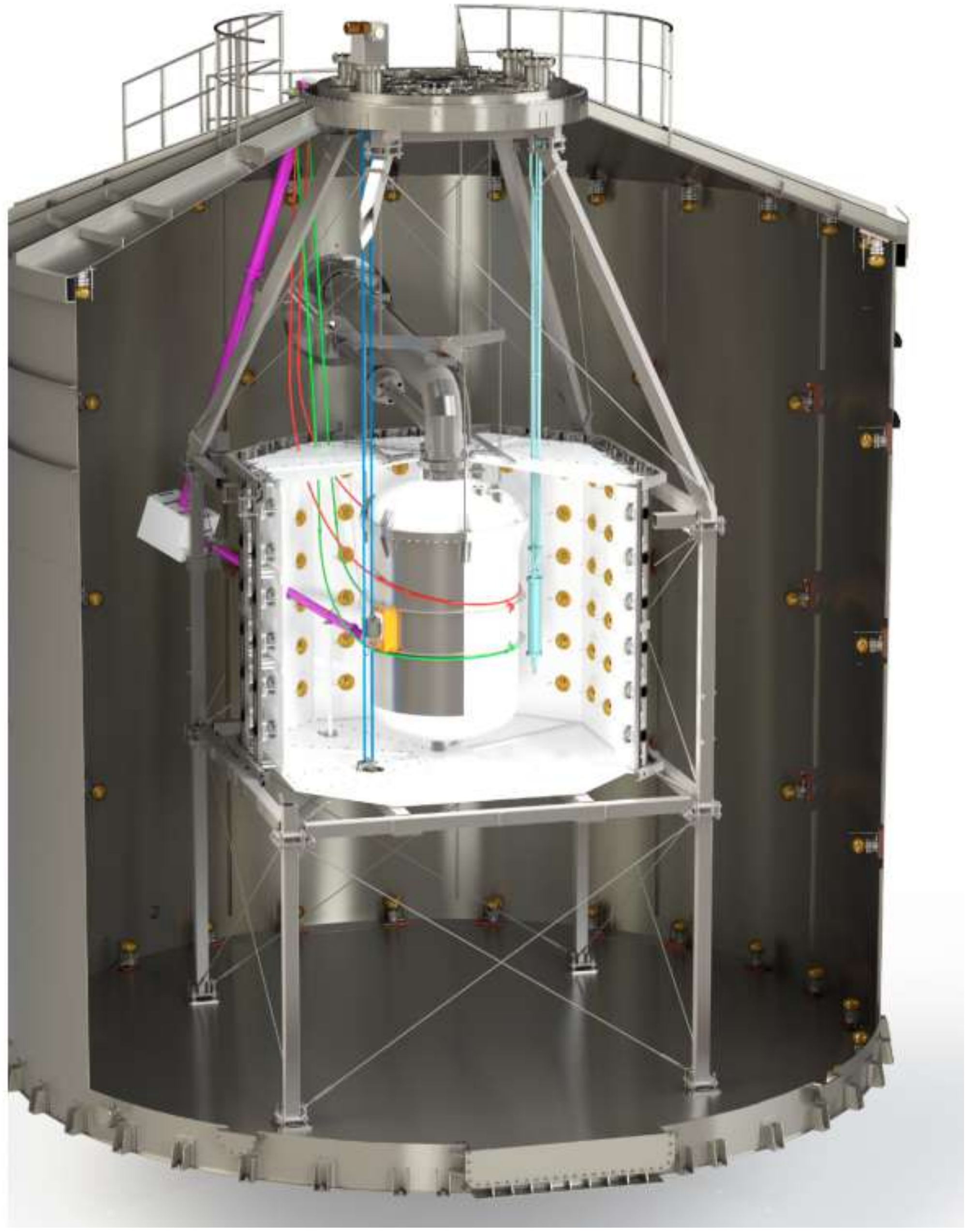
Neutron Veto of XENONnT

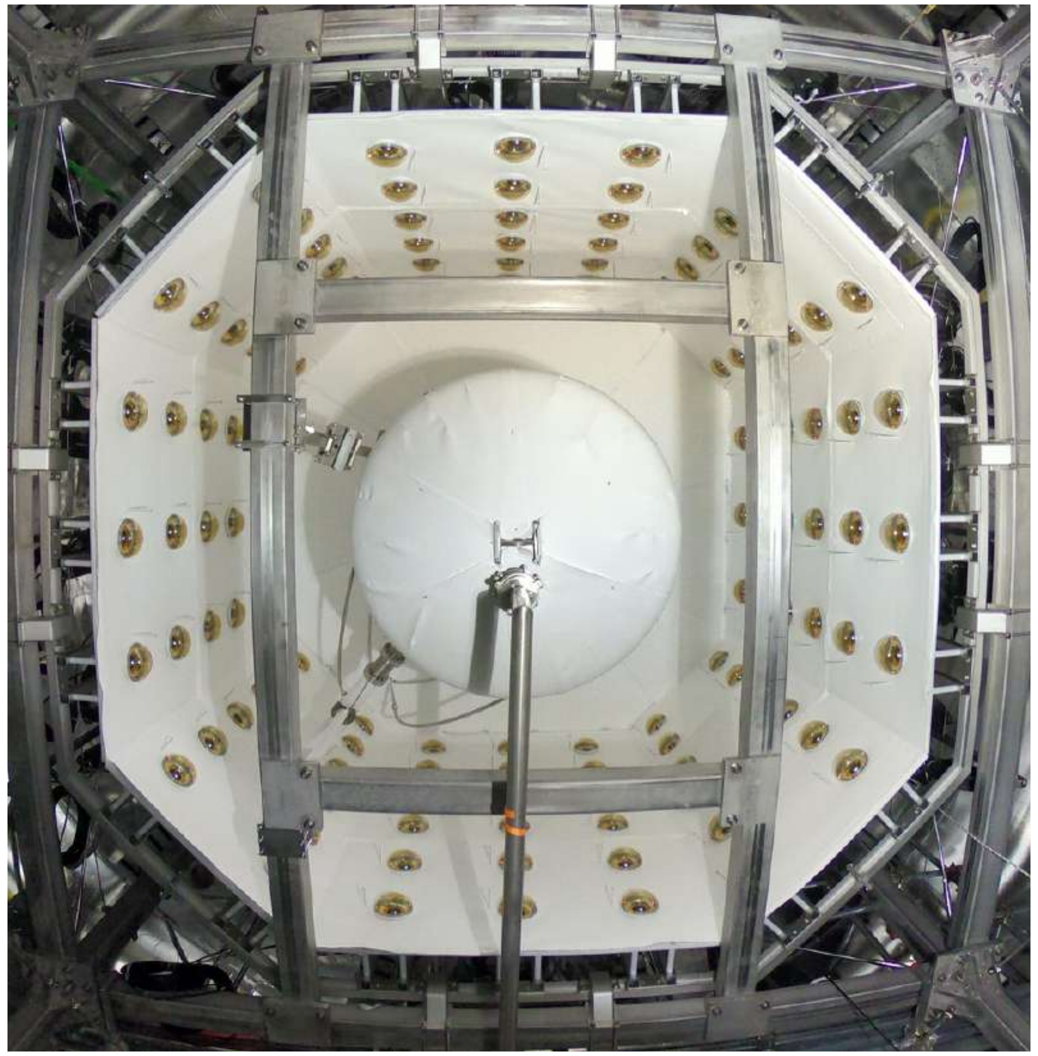
XENONnT - Dark Matter Direct Detection Experiment (WIMP)
Three nested detectors:

- Muon Veto
- Neutron Veto
- Dual Phase (LXe+GXe) Time Projection Chamber (TPC)

Radiogenic Neutrons are one of the main background !







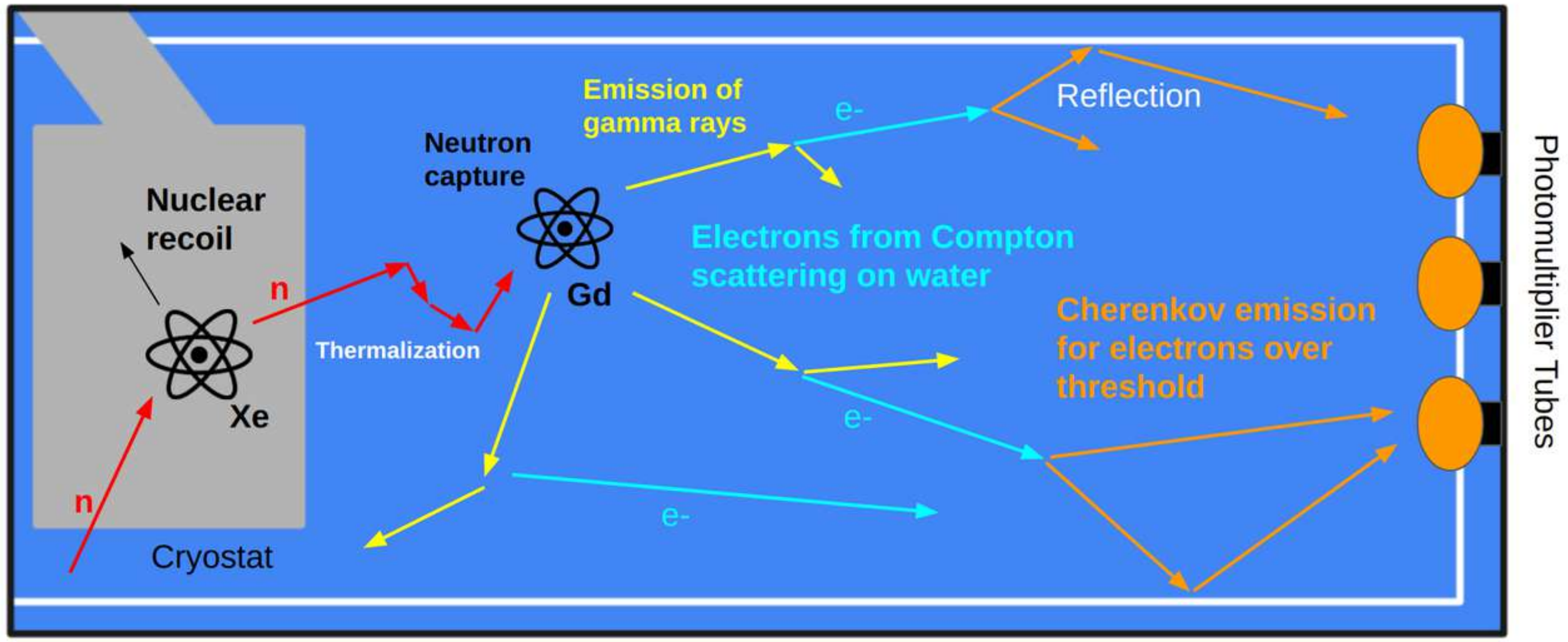
Neutron Veto:

High Reflectivity Volume + **Large PMT coverage**

- Inner region optically separated from the Muon Veto through high reflectivity ePTFE panels
- Instrumented with 120 low-radioactivity, high-QE PMTs

Currently operating with demi-water only

Neutron Veto of XENONnT



Neutron detection:

Radiogenic neutrons scatter in TPC : WIMP-like signal

- Thermalization of n in water
- Neutrons captured by Gd (~ 90%) and H (~ 10%)

τ ~ 30 μs

- Cascade of γ-rays with total energy of 8 MeV
- Cherenkov emission from Compton electrons detected by the PMTs

Performances

Measured in pure water

dedicated calibration (AmBe source)

$$\text{Tagging Eff.} = (0.682 \pm 0.026)$$

$$\tau_{\text{n-capture}} = (177 \pm 8)\ \mu s$$

TPC dead time due to the veto (5%)

+ Gd

Expected with Gd

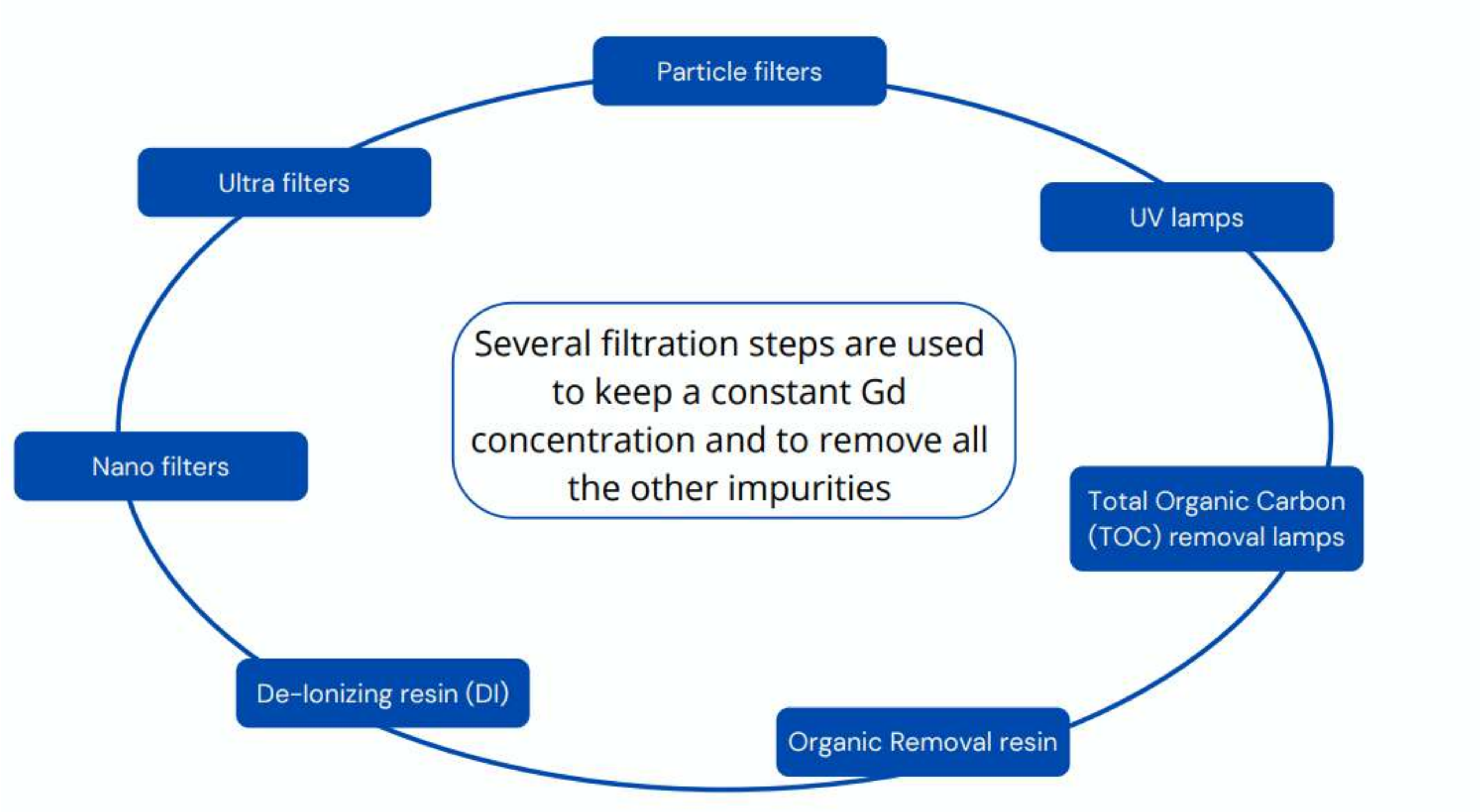
(MC)

Tagging Eff. ~ 0.87

τ ~ 30 μs

Lower TPC dead time due to the veto (< 1%)

Gd - Water purification plant



- Used to dissolve the Gd-Sulphate inside the Neutron Veto water
- Separate the Gd-rich fraction, purify the Gd-depleted water and unify back the two parts
- Maintain good quality of the water transparency, which affect the light collection efficiency of the Neutron Veto

Conclusions

- Gd-loaded Water Cherenkov detectors have been employed to detect neutrons both to enhance some physics channels (SK) and to suppress the background (XENON);

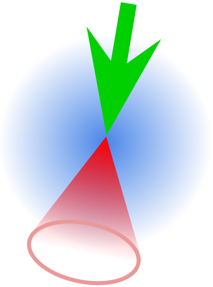
- The Neutron Veto of the XENONnT experiment exploits this technology to reduce the radiogenic neutrons background, which is one of the main backgrounds for the WIMP search.

- Overall the system showed very good performances with demi-water - **best n-tagging efficiency ever achieved with a pure water Cherenkov detector** - and the tagging efficiency will be enhanced after the deployment of the Gd salt

- The same technology can be employed for larger-scale detectors : **DARWIN**

- Several R&D to increase the Gd concentration without losing water transparency and with an efficient recovery of the salt.

IFD 2022
17–19 Oct 2022
Bari, Villa Romanazzi Carducci



Detection of Cherenkov light in liquid scintillators

<u>Federico Ferraro</u>, Davide Basilico, Marco Beretta, Augusto Brigatti, Barbara Caccianiga, Simone Cialdi, Cecilia Landini, Paolo Lombardi, Marco Malabarba, Gioacchino Ranucci, Alessandra Re, Gioele Reina

Università degli Studi di Milano
INFN-Sezione di Milano

What am I talking about?

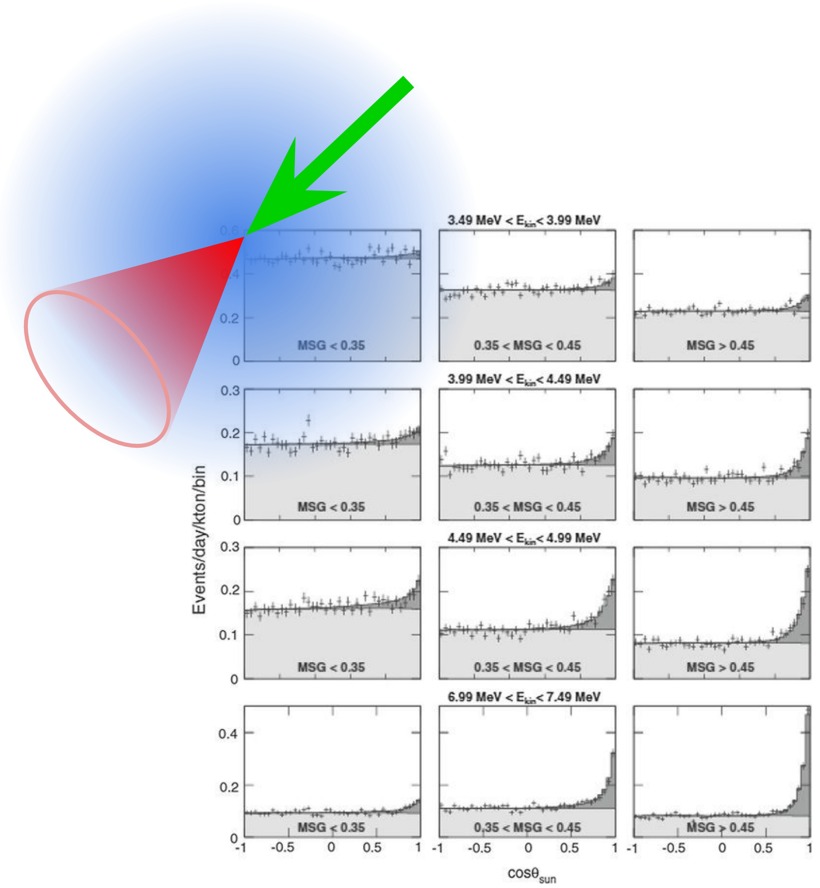
Since **scintillation light** is isotropic, any directional information is lost

However, a few **Cherenkov light** is emitted and provides information on the **neutrino direction**

The separate detection of scintillation light and Cherenkov light in a liquid scintillator:

- would open up new possibilities for present experiments (e.g.: JUNO)
- would pave the way to a new generation of experiments exploiting both detection techniques (e.g.: THEIA)

The separation can be realized thanks to timing and/or spectral features



Suzuki, Y. The Super-Kamiokande experiment. *Eur. Phys. J. C* 79, 298 (2019).
https://doi.org/10.1140/epjc/s10052-019-6796-2

Timing, spectral and optical features of liquid scintillators

1. measurement of **fluorescence time**
   a. measurements with α/β/p radioactive sources
   b. measurements with muons
   c. fit and investigation on systematics
2. detection of **Cherenkov light**
   a. LS emission and absorption spectrum
   b. spectral features of Cherenkov light
   c. timing features of Cherenkov light
3. measurement of **refractive index**
   a. compact refractometer with LS cuvette
   b. CW lasers (208 nm to 1035 nm)
   c. beam displacement on CCD
4. measurement of **group velocity**
   a. compact interferometer with LS cuvette
   b. short coherence-length lasers (208 nm to 1035 nm)
   c. fringe displacement on CCD or SiPD

- ➔ **improved event reconstruction**
- ➔ **particle identification via PSD**
- ➔ **improved description of fluorescence parameters in the JUNO MC**

- ➔ **improved understanding of the energy response**
- ➔ **reconstruction of the direction of incident neutrino**
- ➔ **Improved reconstruction of interaction vertex**

SHELDON (Separation of CHErenkov Light for Directionality Of Neutrinos)

A quasi-tabletop experiment to improve the reconstruction performances in JUNO

1. measurement of **fluorescence time**
   a. measurements with α/β/p radioactive sources
   b. measurements with muons
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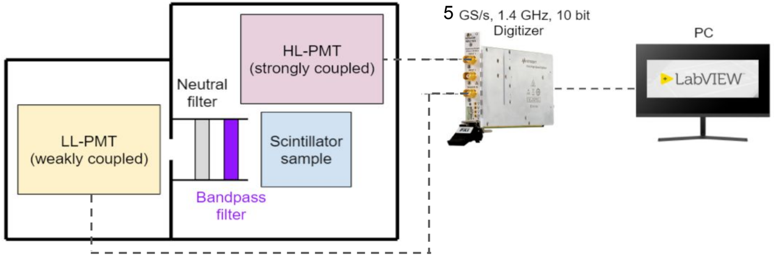

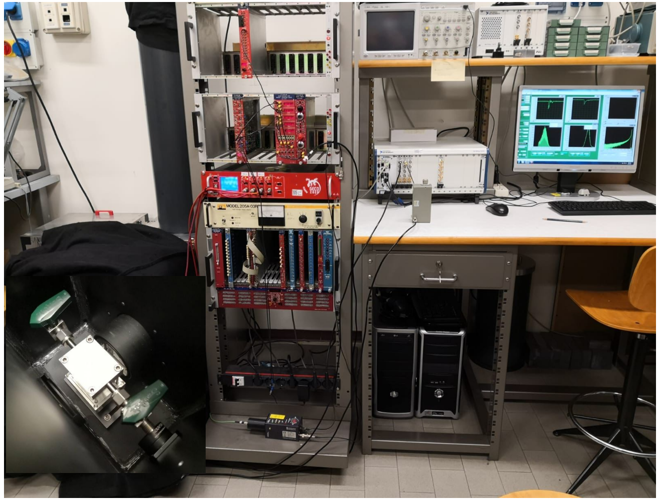

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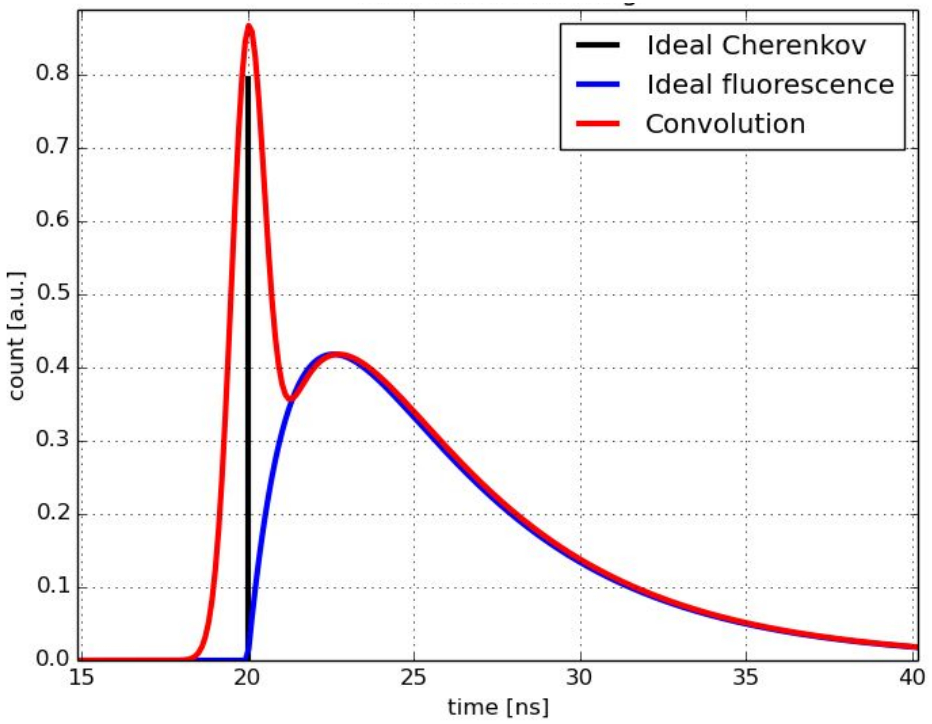
Fluorescence + Cherenkov light emission model



The **Cherenkov** contribution is modeled as a delta function

The **fluorescence** contribution is distributed as a superposition of exponential distributions

The **sum** is convolved with the detector Impulse Response Function

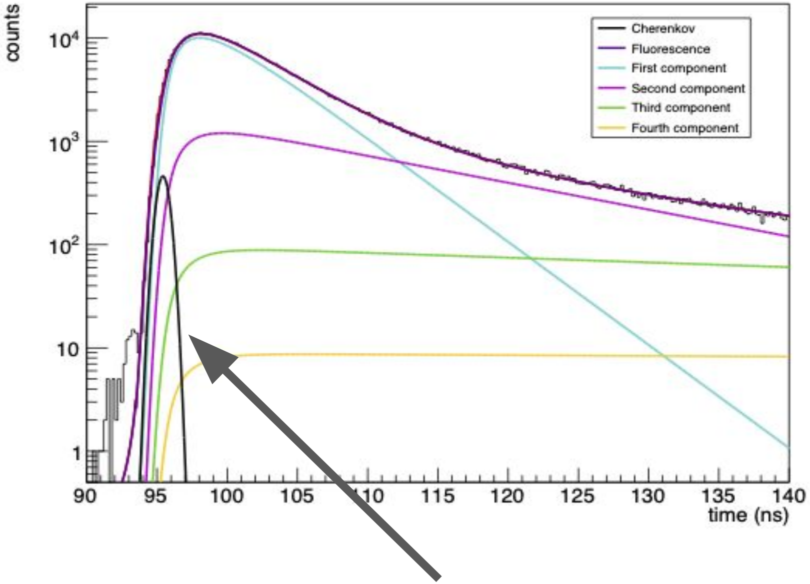
$$\mathrm{IRF}(t) = \sum_{j=1}^{7} N_j \, G_j(t; \mu_j, \sigma_j)$$

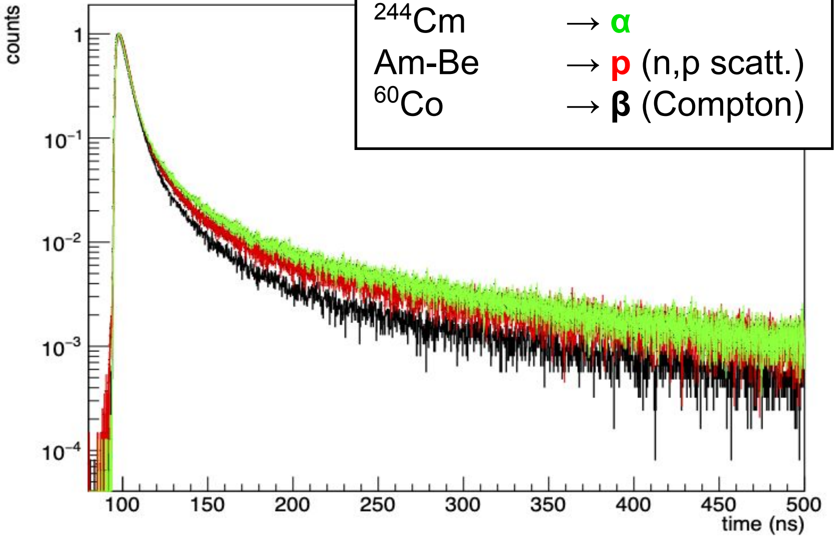
$$F_{Total}(t) = [N_{Ch} \, \delta(t, t_0) + (1 - N_{Ch}) \, F_{Fluo}(t)] * \mathrm{IRF}(t)$$

Inclusion of Cherenkov light ⇒ improved PSD parameters

useful tool for **radioactive background rejection**

Data obtained with ^{60}Co source on top of the LS cuvette





^{244}Cm → α
Am-Be → p (n,p scatt.)
^{60}Co → β (Compton)

Cherenkov light contributes approximately 1% of total light but impacts the measurement of fluorescence times significantly!

SHELDON (**S**eparation of **CHE**renkov **L**ight for **D**irectionality **O**f **N**eutrinos)

A quasi-tabletop experiment to improve the reconstruction performances in JUNO

Same goal, different measurements:

1. measurement of **fluorescence time**
   a. measurements with α/β/p radioactive sources
   b. measurements with muons
   c. fit and investigation on systematics
2. detection of **Cherenkov light**
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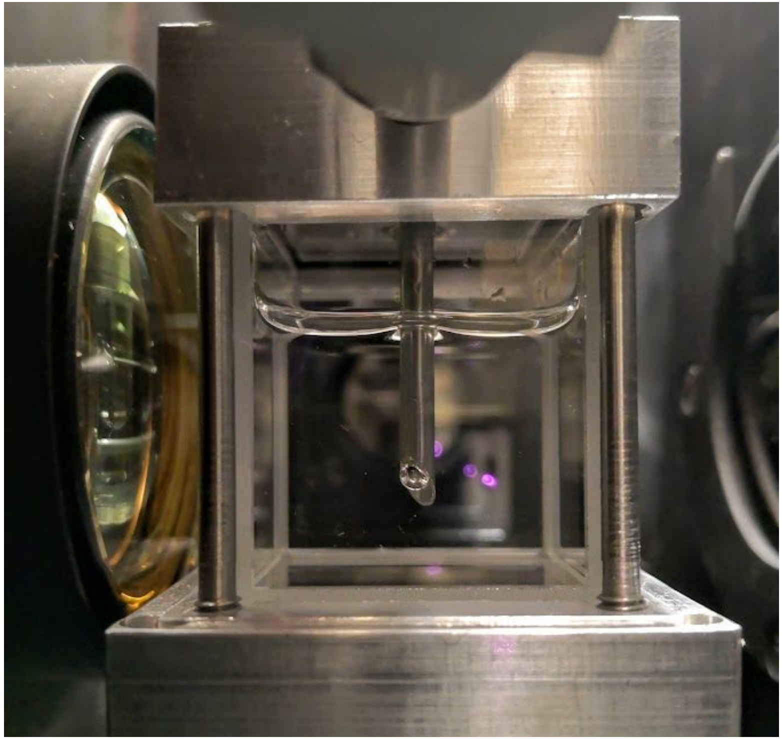
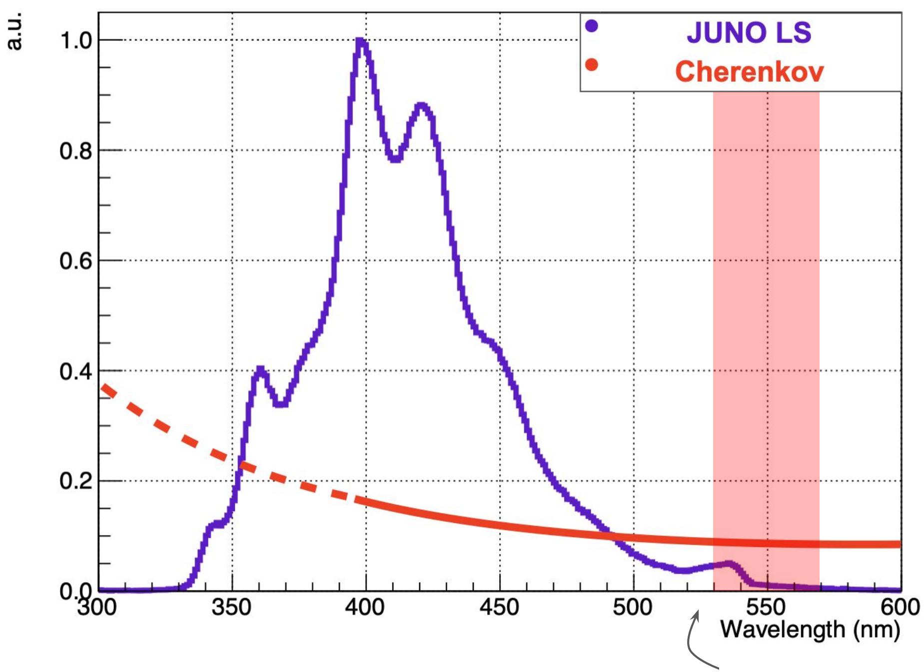
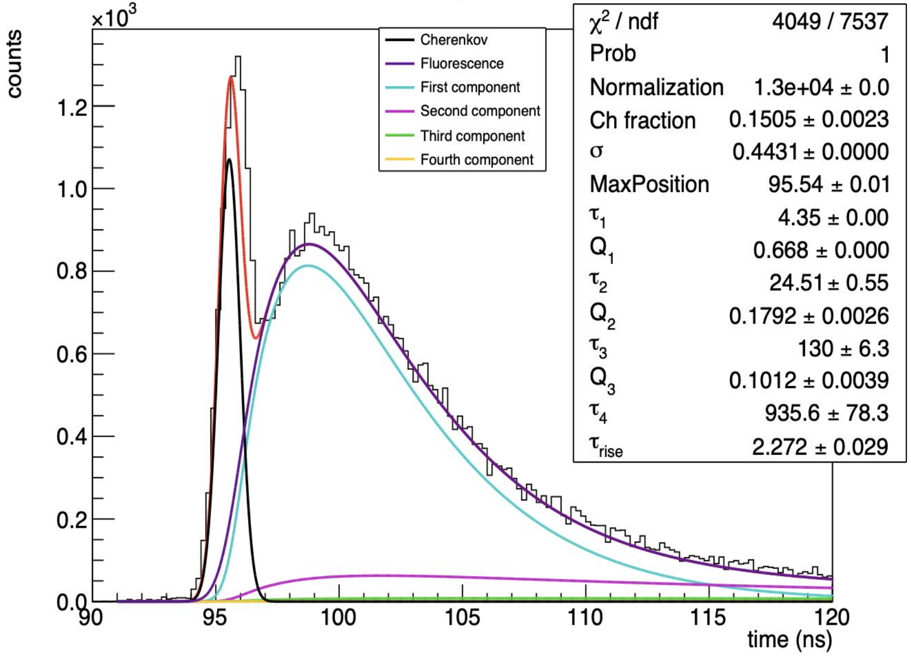


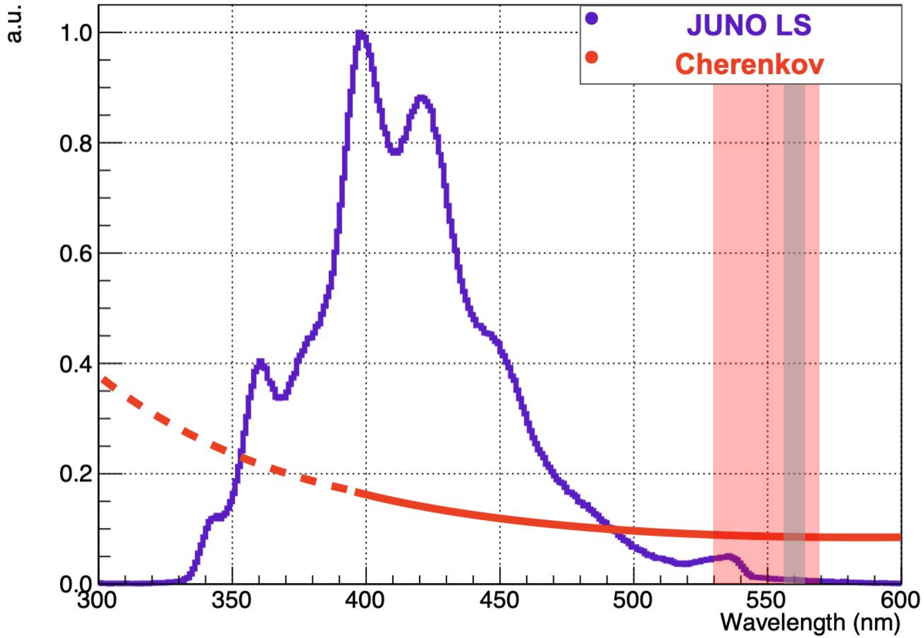
Spectral separation of Cherenkov light

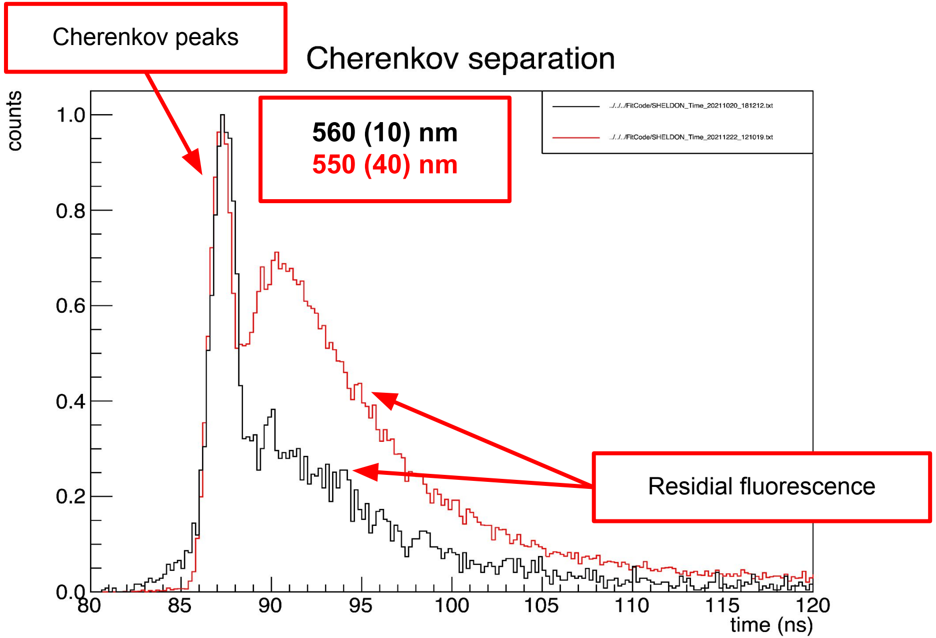


530-570 nm



Spectral separation of Cherenkov light





SHELDON/REWIND (**R**efractive ind**E**x **W**ith **IN**terferometric **D**evices)

Yet another quasi-tabletop experiment to improve the reconstruction performances in JUNO

Same goal, different measurements:

1. measurement of **fluorescence time**
   a. measurements with α/β/p radioactive sources
   b. measurements with muons
   c. fit and investigation on systematics
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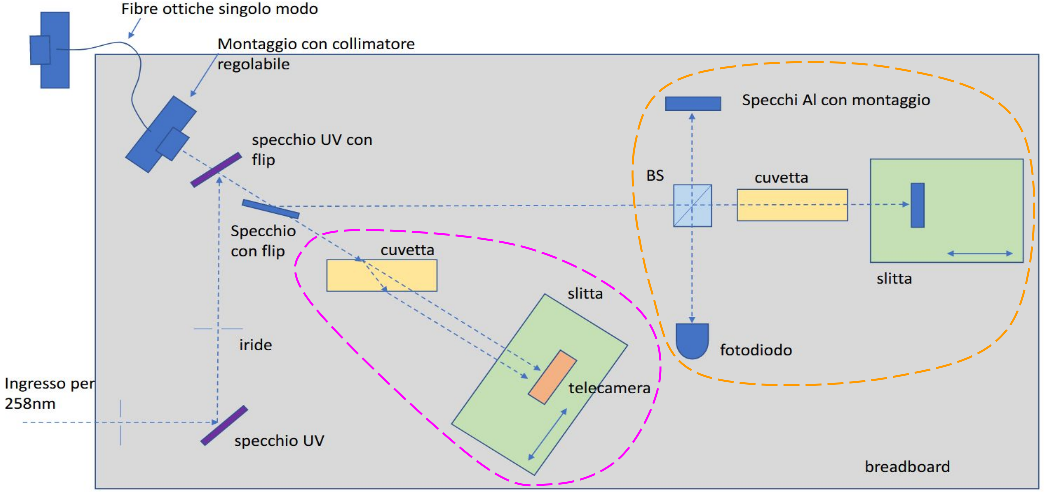
   c. fringe displacement on CCD or SiPD

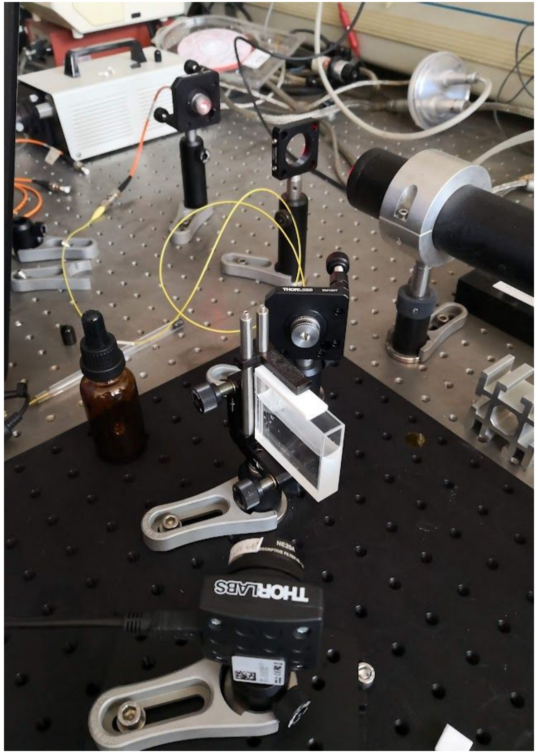
Both SHELDON and SHELDON/REWIND are very-small-scale R&D activities whose realization relies on **prompt micro-financing**

The same applies to LArRI (**L**iquid **Ar**gon **R**efractive **I**ndex), that I will mention later

UNIMI: Piano Sostegno alla Ricerca - linea 2A
INFN: in-kind

Measurement of refractive index and group velocity





Refractive index

- refractometer
- CCD sensor

Group velocity

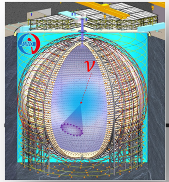
- Interferometer
- Photodiode

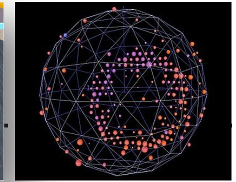
Relative sensitivity: $\sim 10^{-4}$

Community and ongoing R&D (disclaimer: this list is not complete)

Organic Liquid Scintillators

LAB-based (JUNO, SNO+, [...])........

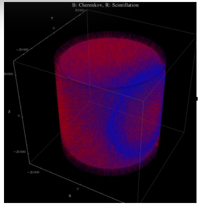




...**SHELDON** (looking forward to JUNO)
CHESS (looking forward to THEIA)

Water-Based Liquid Scintillators

THEIA...



.............CHESS, SHELDON (future)

Noble Liquid Scintillators

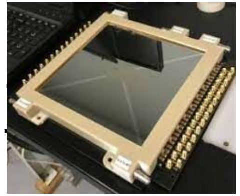
Xenon, nEXO, […]............................ too many to display here ....**LoLX** (looking forward to nEXO)
DarkSide, SBN, DUNE, […]................ ....**LArRI** (looking forward to DUNE)

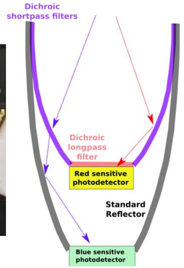
these ones need extra effort because of cryogenics and short wavelength

Innovative photon detectors

LAPPD..................................

Dichroicons..............................





….on-the-shelf
….CHESS

ANDIAMO, an innovative acoustic neutrino telescope proposal

Andrea Simonelli, *Antonio Marinelli, Pasquale Migliozzi*
INFN sezione di Napoli

Motivations

- The availability of a large number of inactive oil platforms permits to realise a detector of unprecedented size: 10000 Km^2 and a volume ~ 500 Km^3 with low costs
- Most of the acoustic array setup installed up to now where linked to Cherenkov telescopes or already existing military arrays, A dedicated large volume undersea/ice acoustic neutrino telescope would be preferred
- Giant steps in signal processing, computing, data storage since the last attempts were made
- We have nowadays dedicated digital hydrophones with ARM processors for onboard trigger/preprocessing for signal discrimination
- Multidisciplinar application (geophysics, marine biology)
- The experience with KM3NeT underwater technologies is a plus

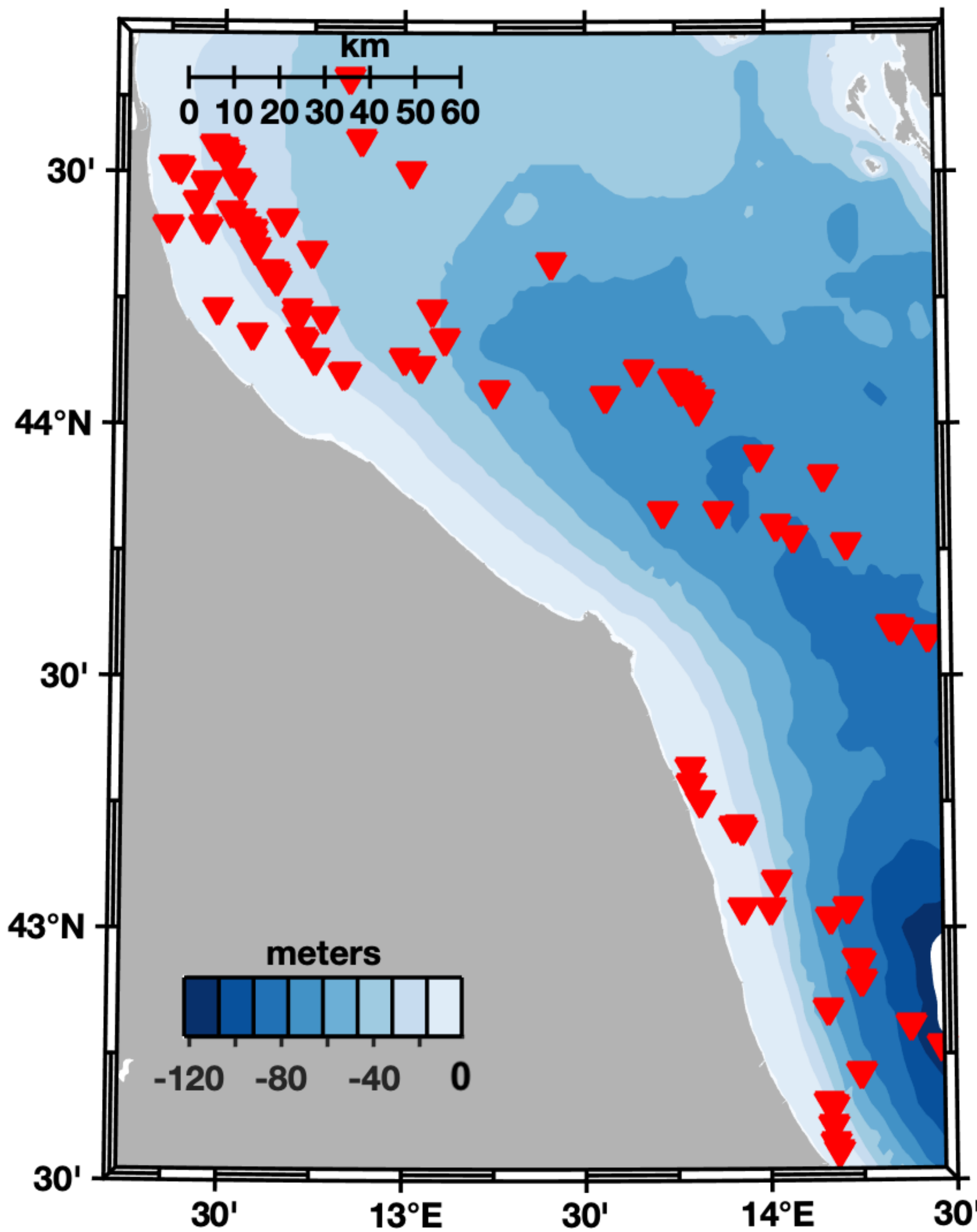
former acoustic experiments

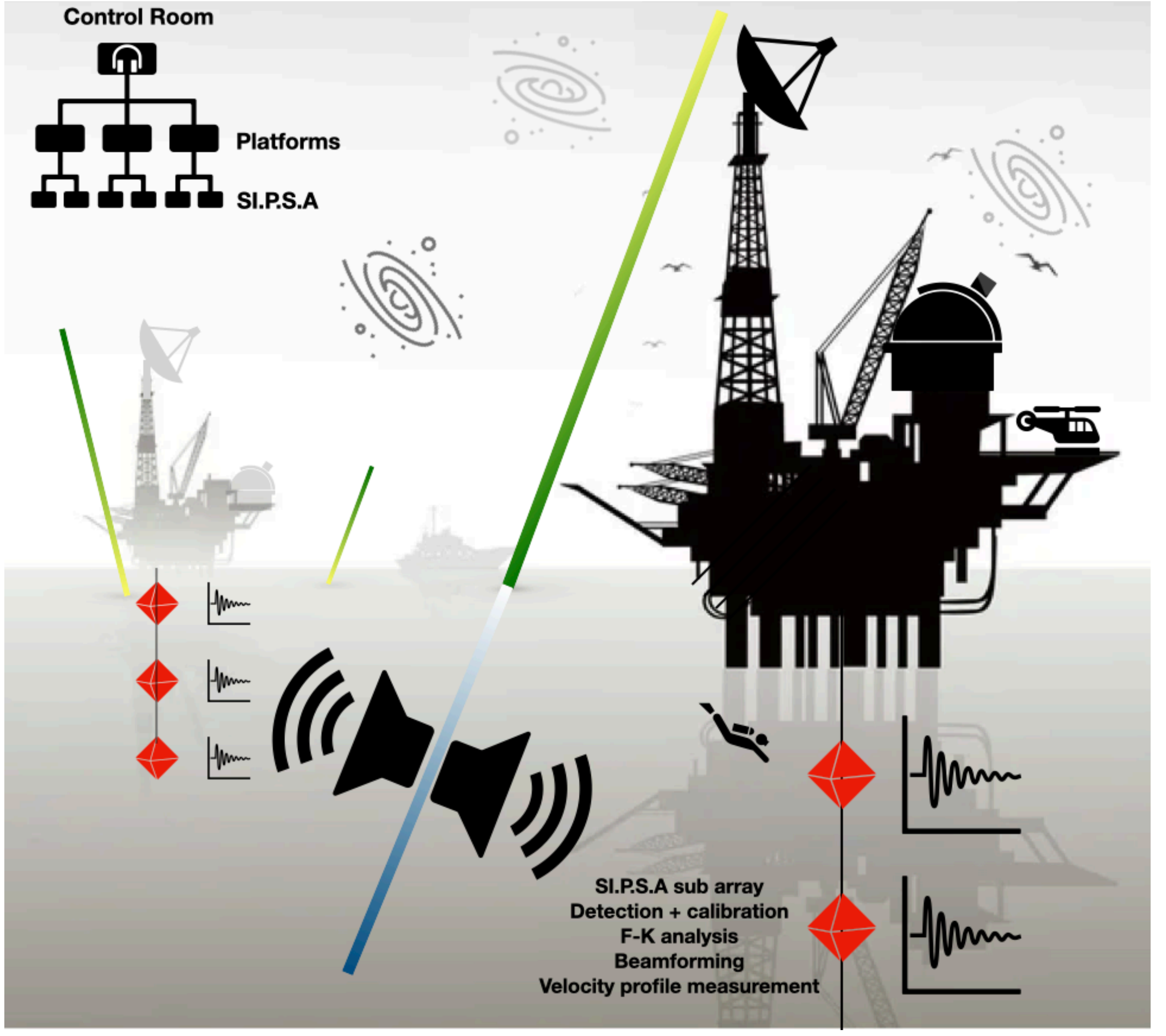
Experiment	Location	Medium	Sensor Channels	Host Experiment
SPATS [19, 20]	South Pole	Ice	80	IceCube
Lake Baikal [7]	Lake Baikal	Fresh Water	4	Baikal Neutrino Telescope
OνDE [21]	Mediterranean Sea (Sicily)	Sea Water	4	NEMO
AMADEUS [22]	Mediterranean Sea (Toulon)	Sea Water	36	ANTARES
ACoRNE [23]	North Sea (Scotland)	Sea Water	8	Rona military array
SAUND [24]	Tongue of the Ocean (Bahamas)	Sea Water	7/49(⋆)	AUTEC military array

(⋆) The number of hydrophones was increased from 7 in SAUND-I to 49 in SAUND-II

ANDIAMO: the concept

AstropartPh Volume 143, October 2022, 102760 A.M.,P.Migliozzi, A.Simonelli.

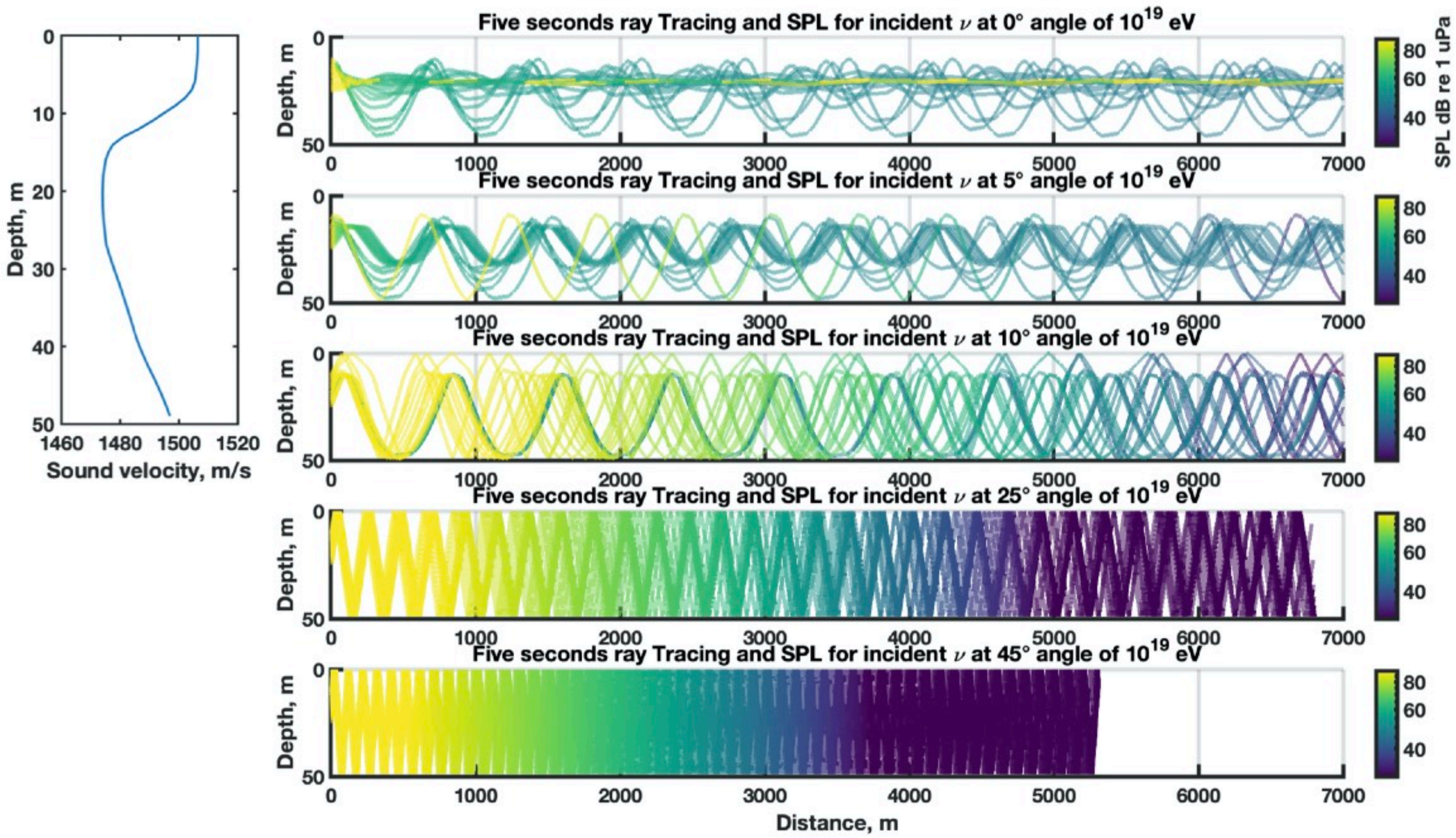


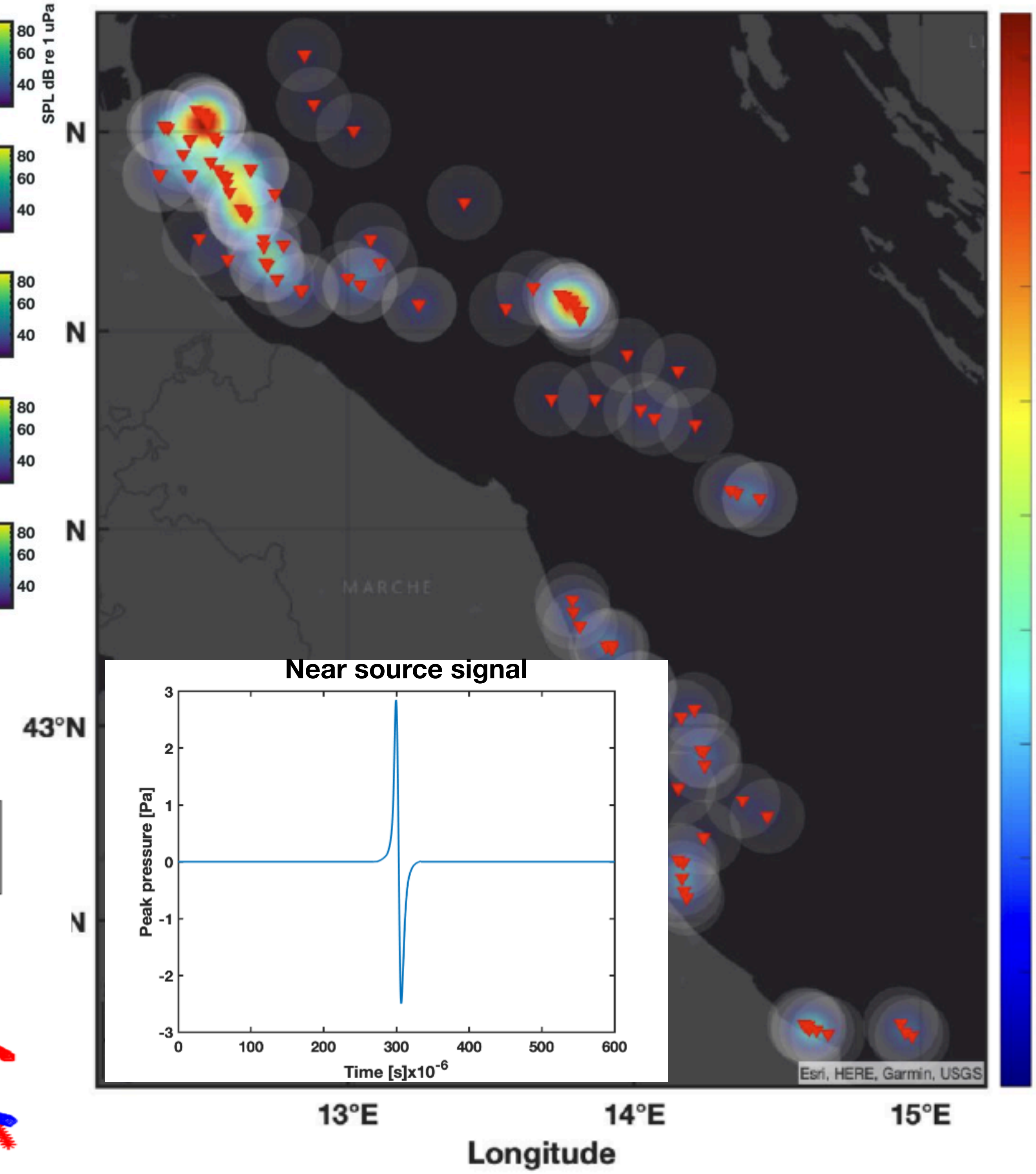


- Reuse the powered ENI oil rigs
- Take advantage of the Adriatic favourable conditions
- Use the ray tracing techniques in a shallow water environment and the advances in computing (from last attempts of 30+y ago)
- Possibility to reach an unprecedented instrumented surface ~ 10000 Km^2 and a volume ~ 500 Km^3 with low costs

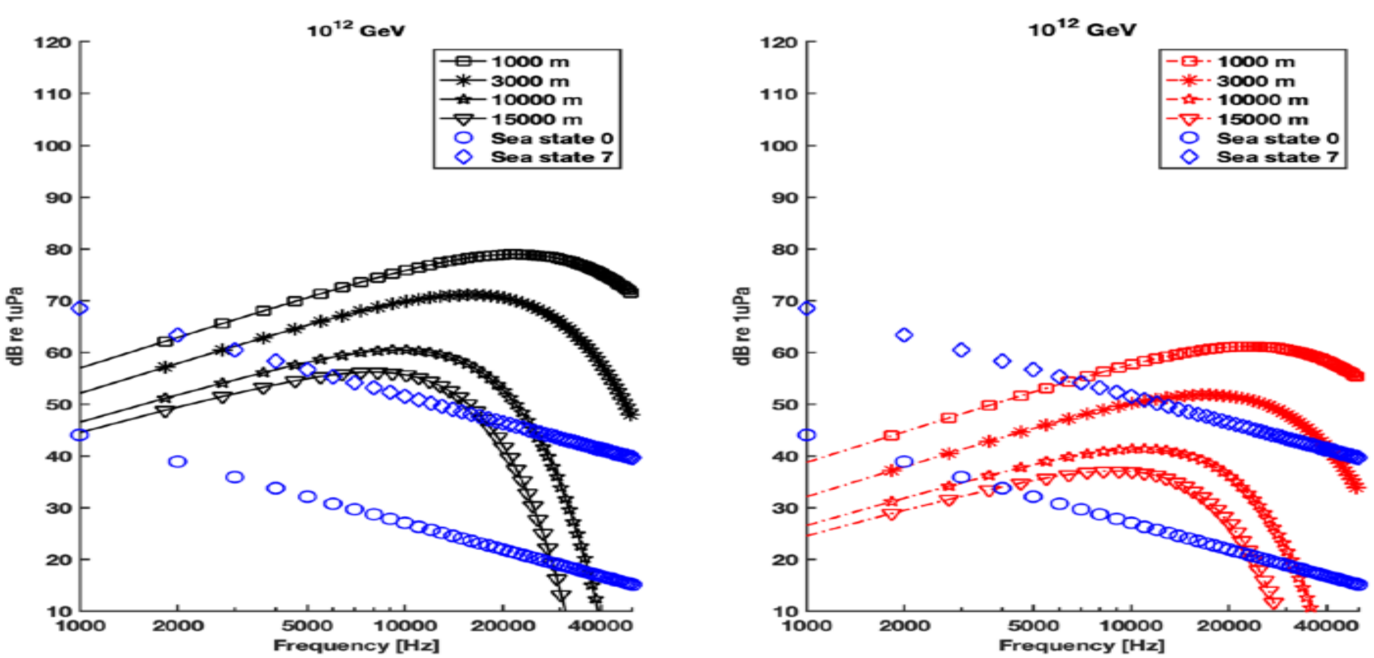
Ray tracing and surface covered

exploiting advances in processing techniques and computational power





Shallow waters advantage



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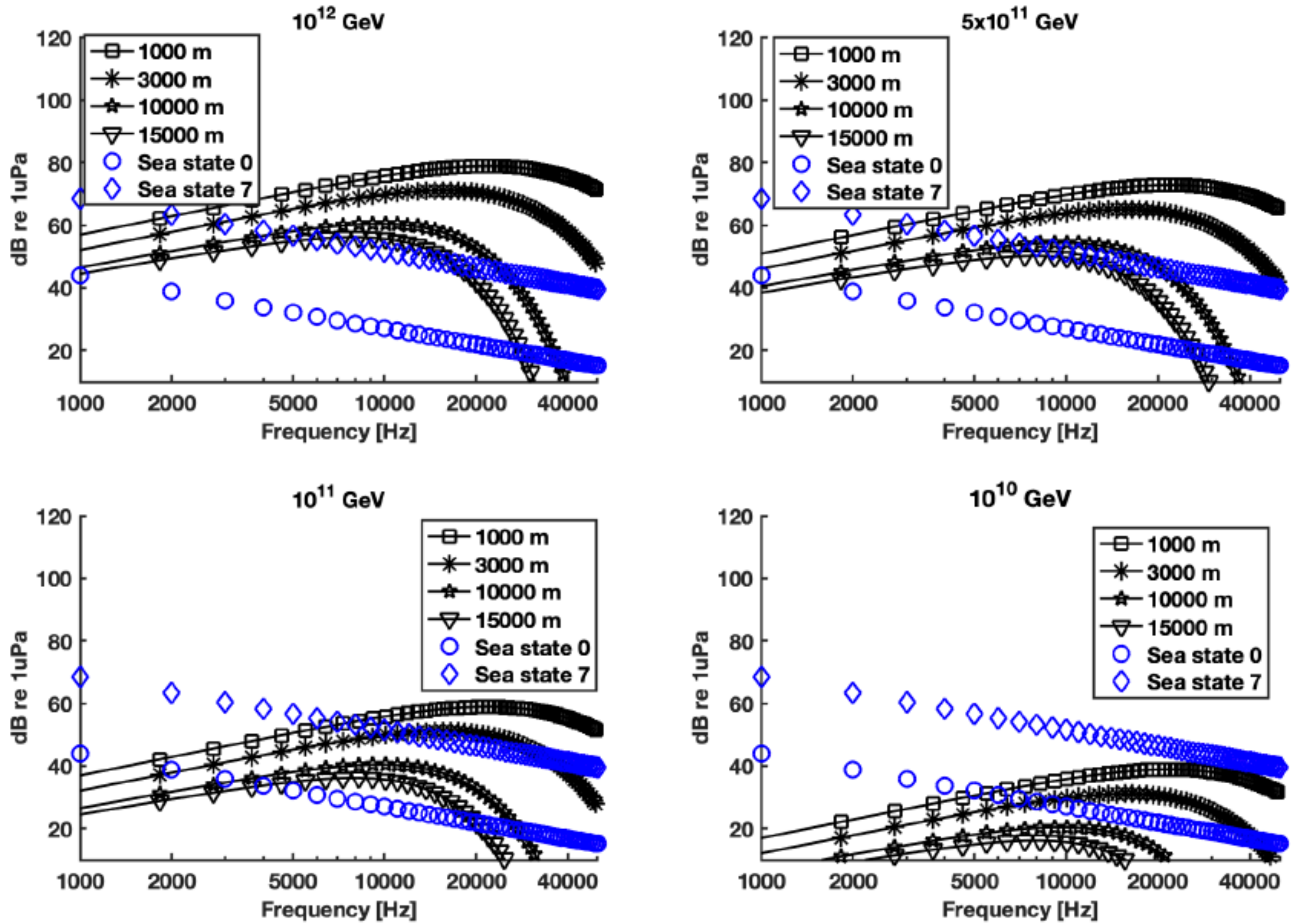
Istituto Nazionale di Fisica Nucleare

Simulated spectra for different distances and cascade energies



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Some facts

Astroparticle Physics 143 (2022) 102760

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journal homepage: www.elsevier.com/locate/astropartphys

ELSEVIER

Acoustic neutrino detection in a Adriatic multidisciplinary observatory (ANDIAMO)

Antonio Marinelli *, Pasquale Migliozzi, Andreino Simonelli *

INFN - Sezione di Napoli, Complesso Univ. Monte S. Angelo, I-80126 Napoli, Italy

- **A paper showing the feasibility of the idea is published**
- **ENTRANCE, a CSN5 progetto giovani proposed passed the first selection phase and eventually will grant the funding for the first noise studies and measurements**
- **Contacts with ENI are ongoing**