MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AGENCIA ESTATAL DE INVESTIGACIÓN

Noble Detectors for Neutrino Physics

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EXCELENCIA SEVERO OCHOA

Many thanks to: Carlos Benitez, Anselmo Cervera, Raul Esteve, Thorsten Lux, Justo Martin-Albo, Patricia Sanchez, Nadia Yahlali

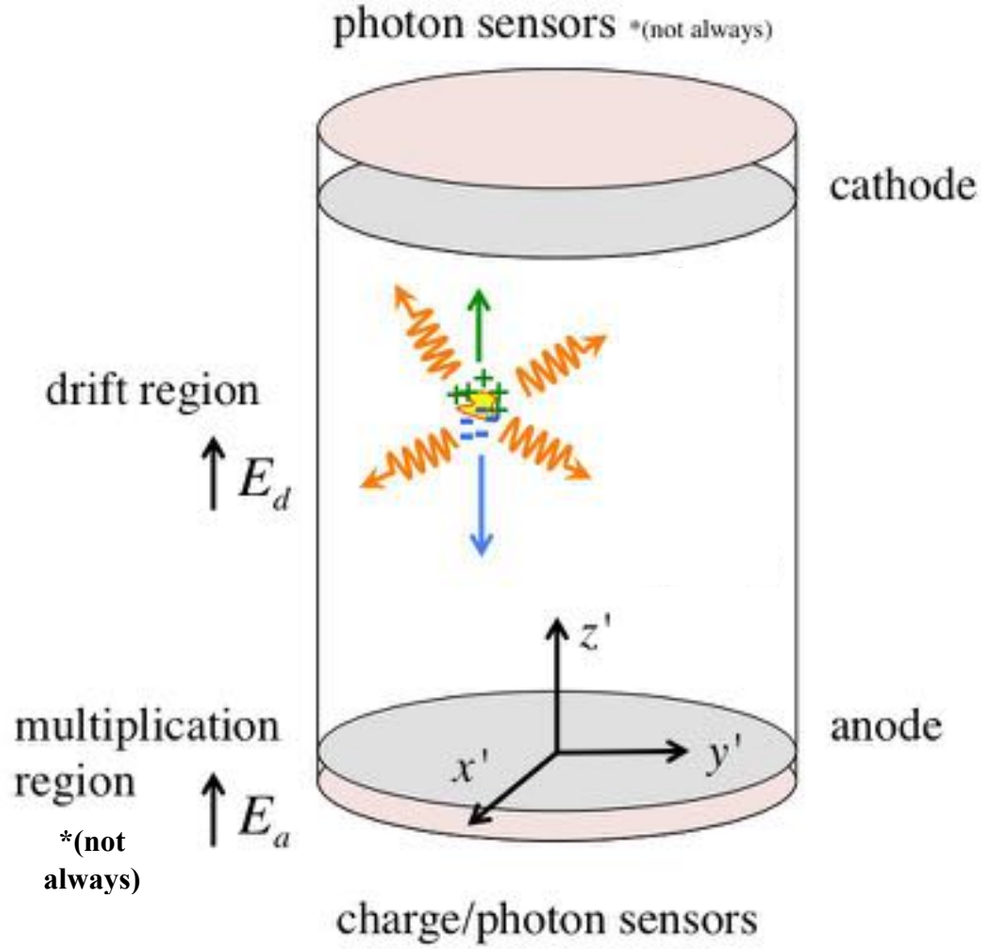
AstroHEP-PPCC24, Zaragoza (Spain), June 2024

PPCC projects covered in this talk

Title	PI (Institution)	Experiment	Amount (kEUR)	Autonomous Community
Instrumentación para experimentos con neutrinos de aceleradores	A. Bueno (UGR)	DUNE	363	Andalucía
Instrumentación para laboratorio de criogenia dedicado a estudios de las propiedades de los neutrinos	P. Sanchez (UGR)	DUNE	363	Andalucía
Desarrollo de nuevos sensores para futuros detectores criogénicos de neutrinos	D. Garcia (UGR)	DUNE	363	Andalucía
The T2K ND280 upgrade	T. Lux (IFAE)	T2K, Hyper-K	130	Catalunya
Electrónica de front-end para fotosensores en el detector NEXT-HD	J. Ballester, R. Esteve (UPV)	NEXT	205	Com. Valenciana
Creation of a multipurpose laboratory at IFIC for the development of cryogenically-cooled gas and liquid noble element detectors	A. Cervera, N. Lopez (IFIC)	DUNE, NEXT	299	Com. Valenciana
Development of state-of-the-art light detection systems for the DUNE and NEXT experiments	N. Yahlali, J. Martin-Albo (IFIC)	DUNE, NEXT	299	Com. Valenciana

Common theme: argon/xenon Time Projection Chambers (TPCs)

- Charged particles deposit energy in Ar/Xe via ionisation and scintillation
- Ionisation electrons collected by establishing drift field
- **TPC**: full 3D imaging from 2D image on readout planes .vs. electron drift time
- **Primary scint. light detection**: timing
- Trigger and calorimetry both with ionisation and scintillation
- **Advantages**: imaging, calorimetry, particle identification, large active mass
- **Disadvantages**: high Ar/Xe purity, very high voltages, cryogenics for LAr



Noble elements

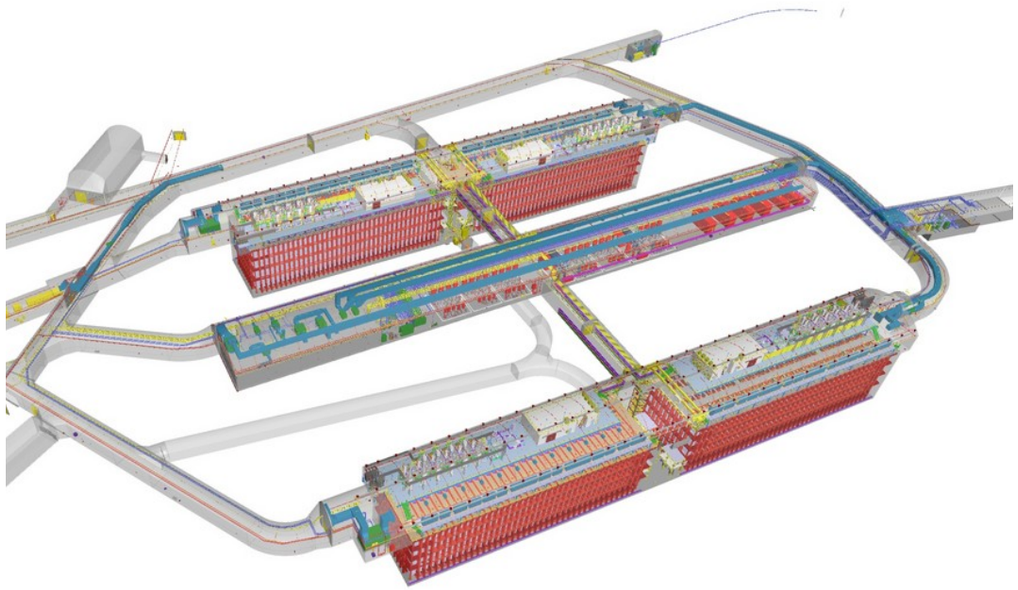
- All noble elements: strong ionisation and scintillation yields.
- Ar: cheapest → best for kton-scale detectors.
- Xe: dense, high-Z and with 9% isotopic abundance of a ββ emitter (^{136}Xe).

Element	He	Ne	**Ar**	Kr	**Xe**
Boiling point at 1 atm [K]	4	27	**87**	120	**165**
Density in liquid [g/cm3]	0.12	1.2	**1.4**	2.4	**3.0**
Ionisation yield [10^4 e/MeV]	3.9	4.6	**4.2**	4.9	**6.4**
Scintillation yield [10^4 γ/MeV]	1.5	0.7	**4.0**	2.5	**4.6**
Scintillation wavelength [nm]	80	78	**128**	150	**175**
ββ isotope	-	-	**-**	-	**^{136}Xe**
Cost [USD/kg]*	24	240	**0.93**	290	**1800**

* https://en.wikipedia.org/wiki/Prices_of_chemical_elements

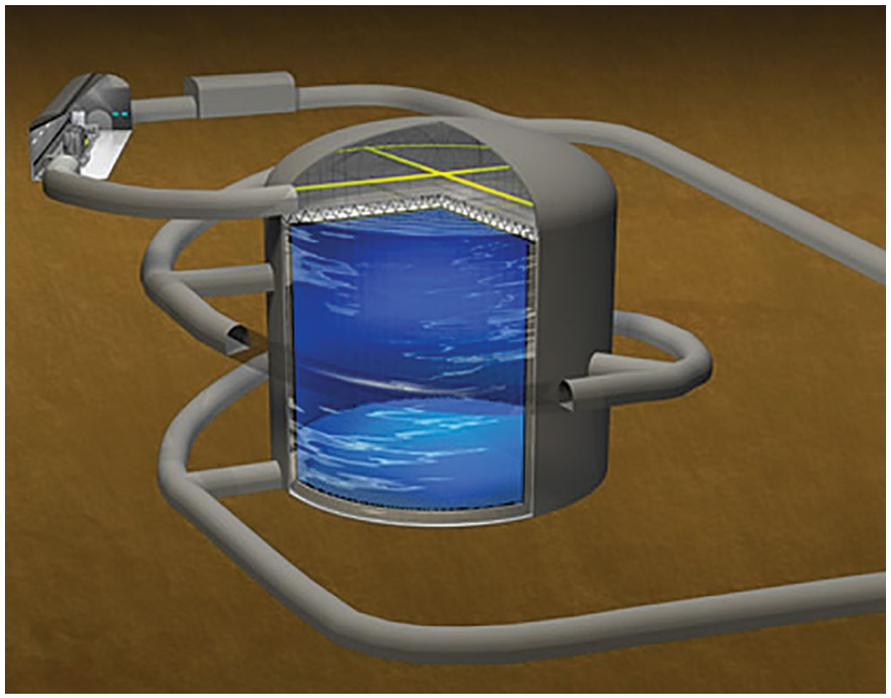
Neutrino oscillations with DUNE and Hyper-K

Different strategies, different detectors



DUNE

- Very long baseline → large matter effect
- Broadband neutrino beam
- Reconstruct neutrino energy over broad range → LArTPC-based far detector
- Highly-capable near detector (incl. Ar TPC) to constrain systematic uncertainties



Hyper-K

- Shorter baseline → small matter effect
- Narrowband neutrino beam
- Lower neutrino energies → very large water Cherenkov far detector
- Highly-capable near detector (incl. Ar TPC) to constrain systematic uncertainties

Upgraded ND280 near detector for T2K-II and Hyper-K

IFAE project → more on T2K ND280 upgrade in T. Lux's talk this afternoon

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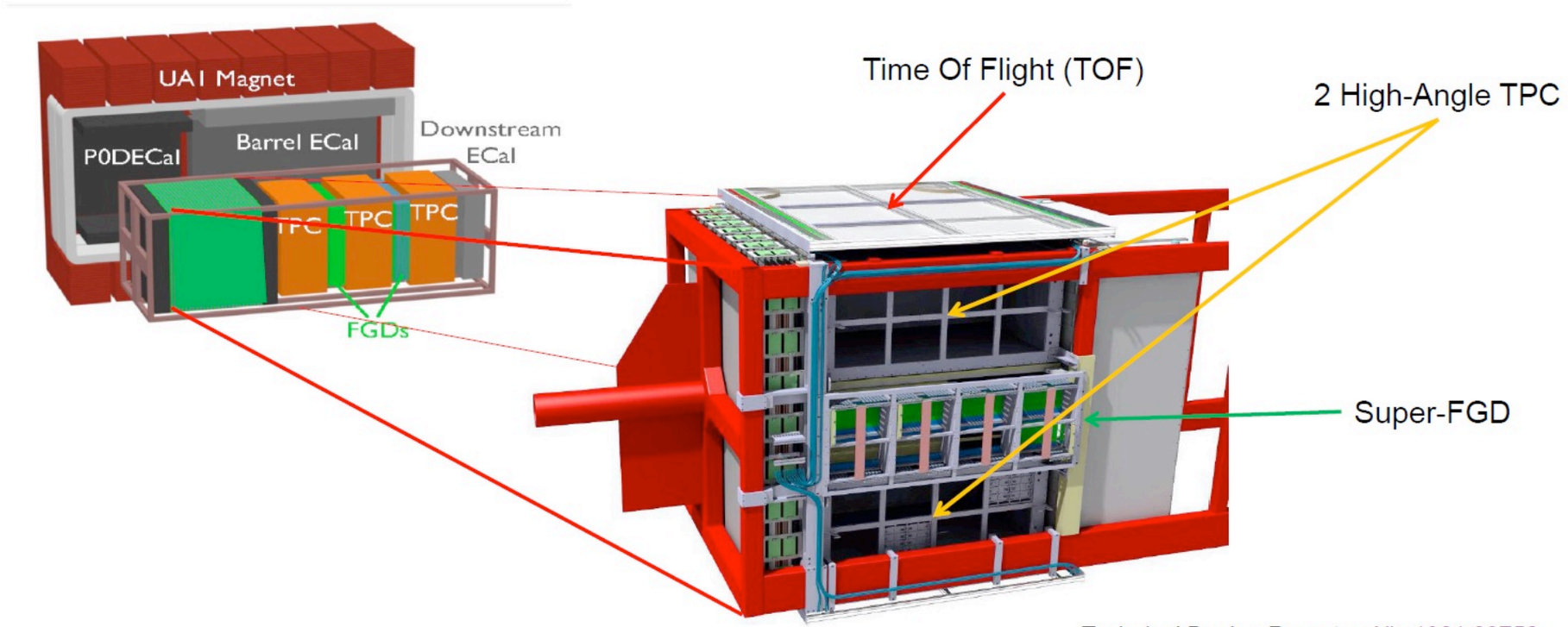
- ND280 upgrade project (started 2016): design, assembly and installation of three new subdetectors
- Will be used for T2K-II phase and afterwards for Hyper-K
- Spanish contributions:
  - *Mainly 2 new (high-angle) TPCs: GAr-TPCs at atmospheric pressure*
  - *Co-project leader: T. Lux (IFAE)*

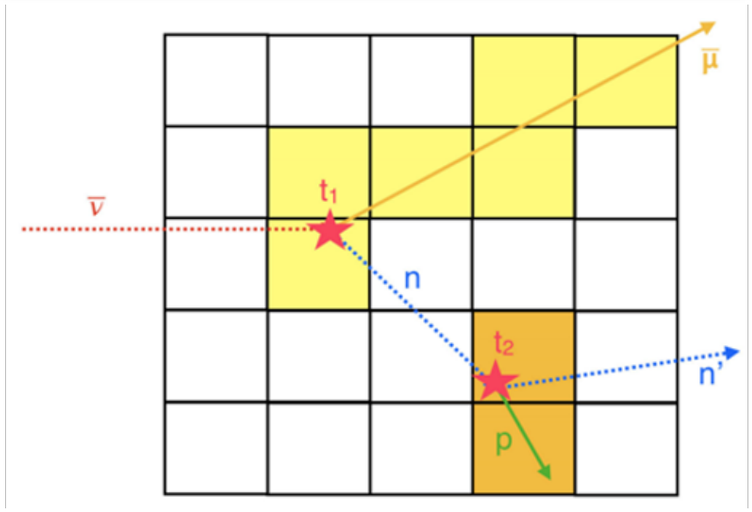


Technical Design Report: arXiv:1901.03750

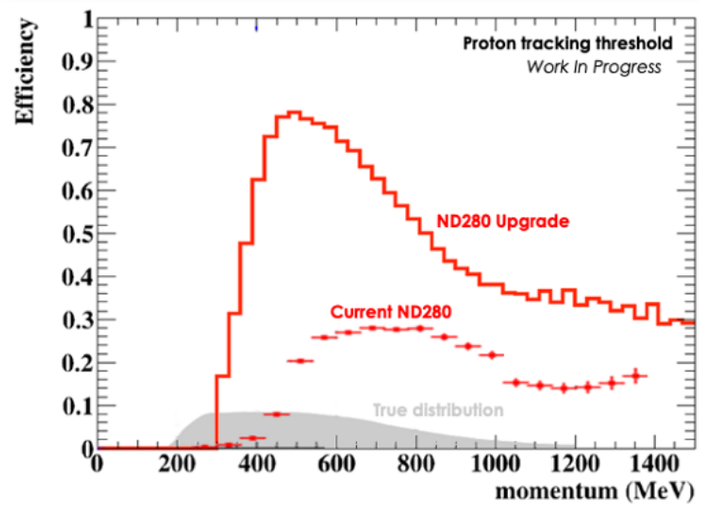
Upgraded ND280 near detector for T2K-II and Hyper-K

IFAE project → more on T2K ND280 upgrade in T. Lux's talk this afternoon

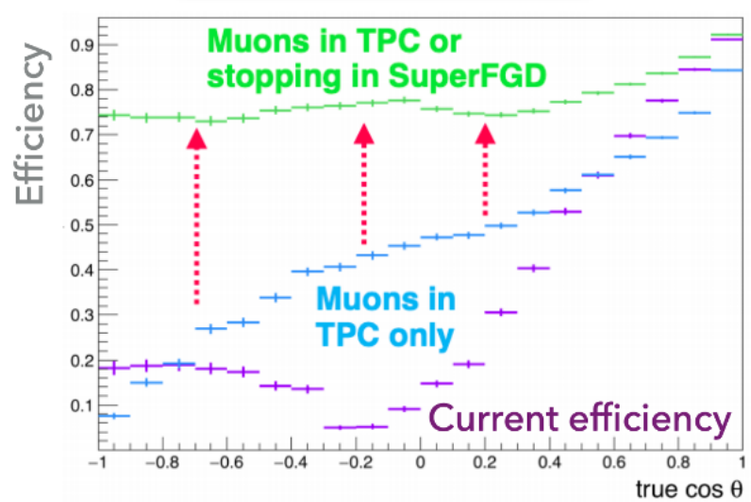
Neutron detection capability



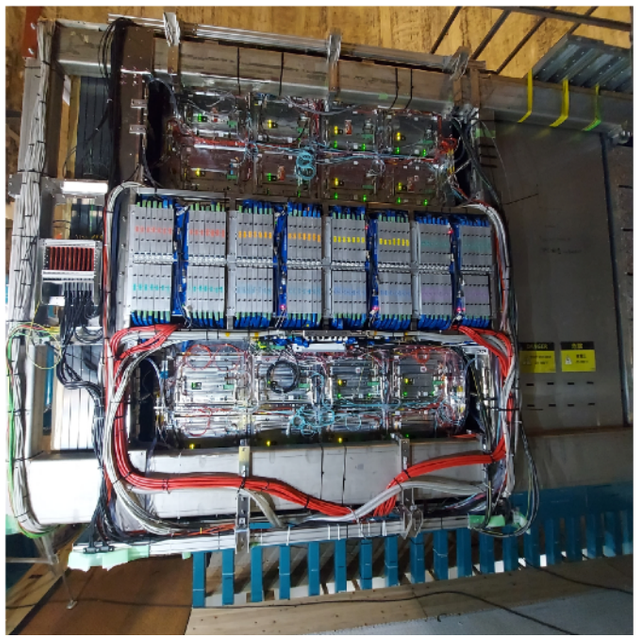
Lower detection threshold

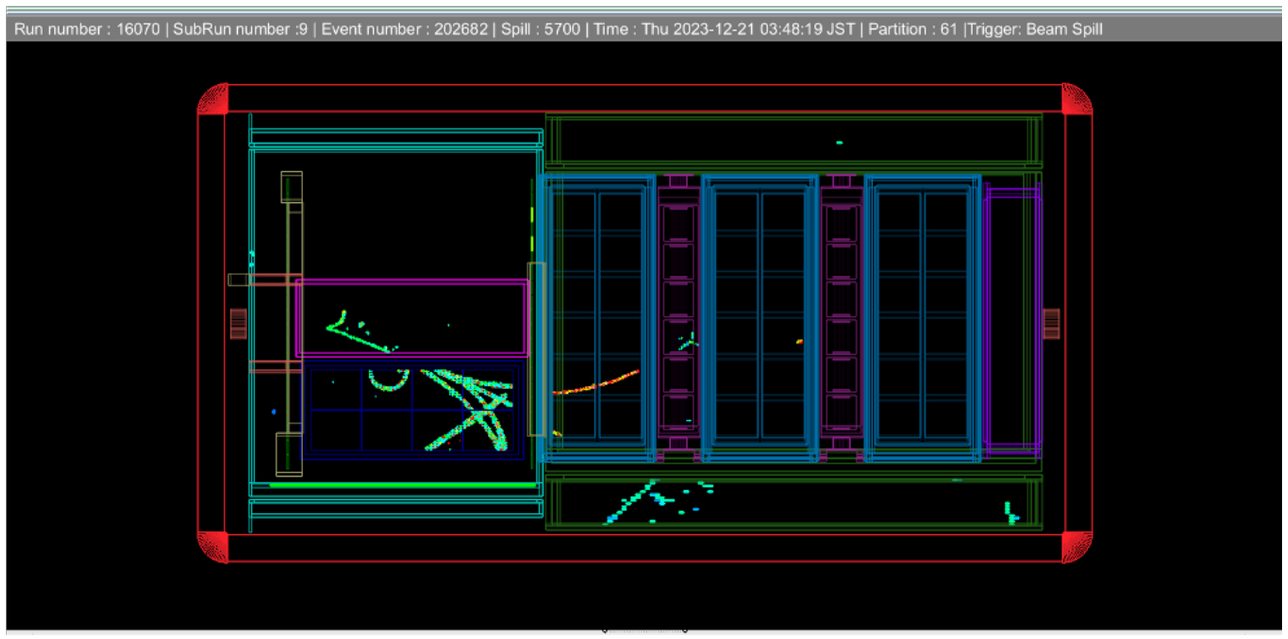


4π acceptance



- Installation completed in May 2024, and first neutrino events recorded!

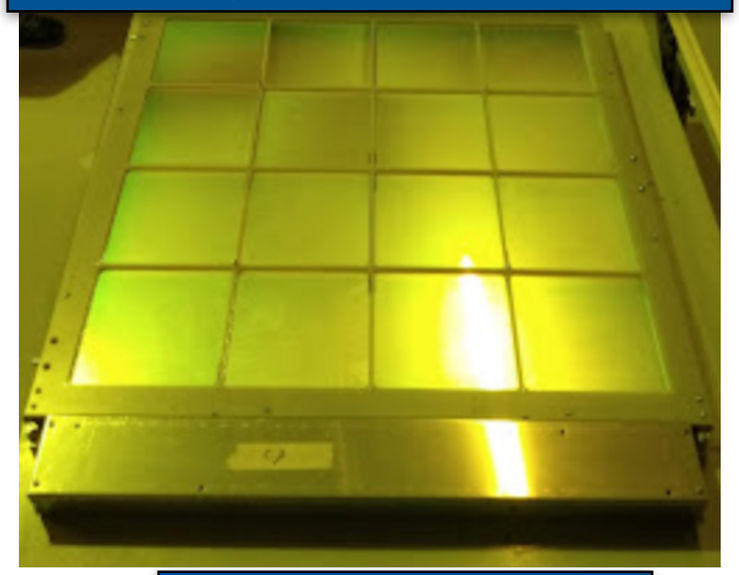




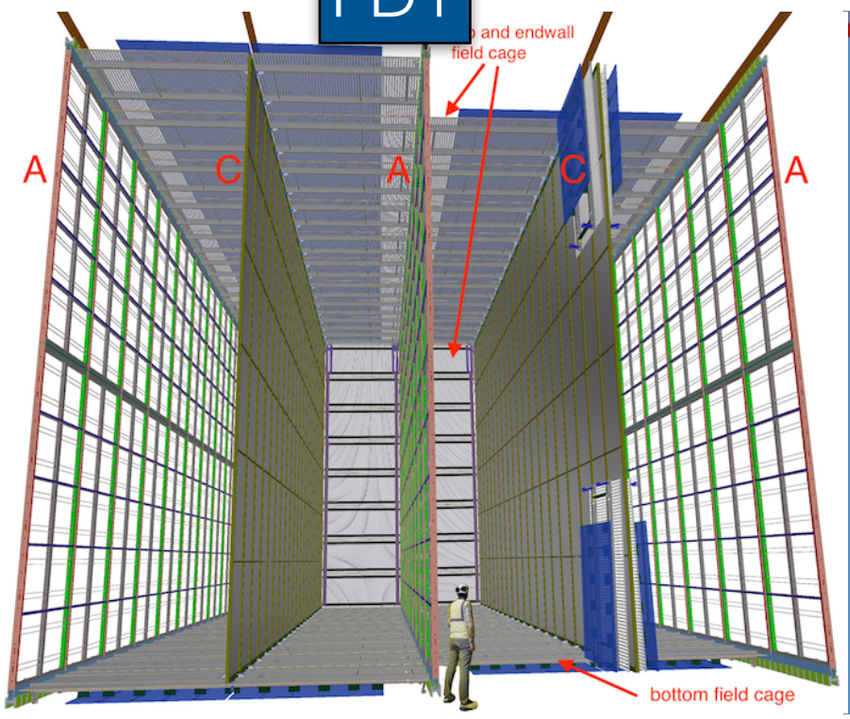
Photon Detector Systems for DUNE Far Detectors

- FD1: PDS in anode planes
- FD2: PDS on cathode and cryostat membrane walls
- Validation in ProtoDUNE detectors at CERN Neutrino Platform since 2018

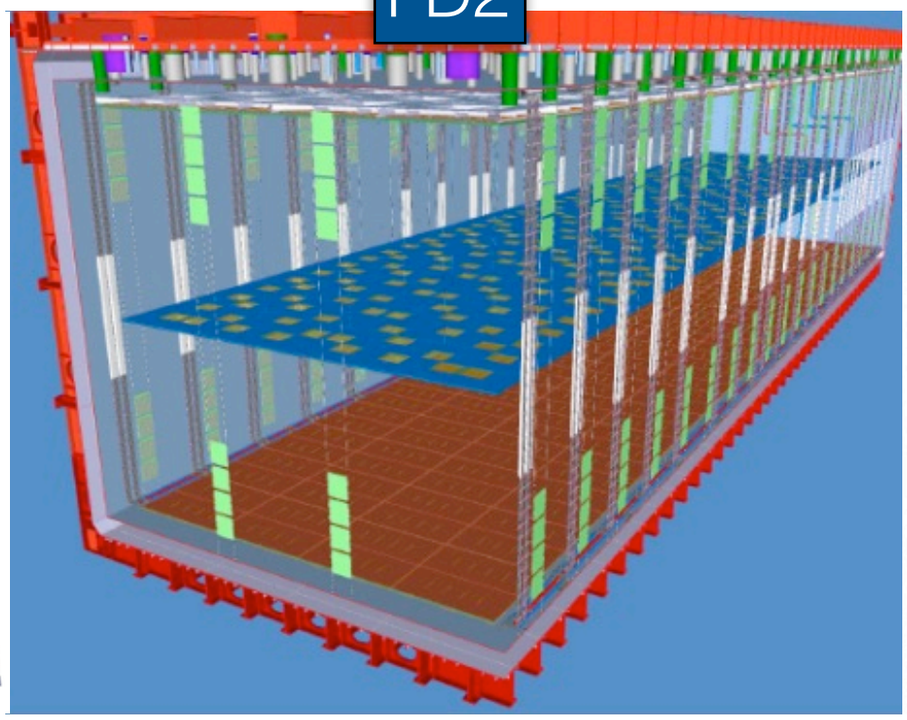
DUNE photon collector



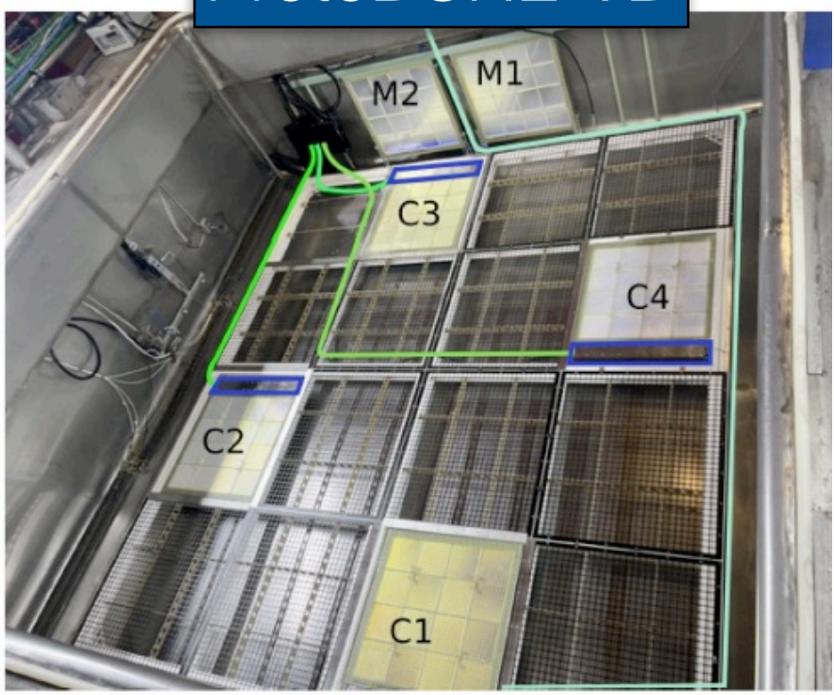
FD1



FD2



ProtoDUNE-VD

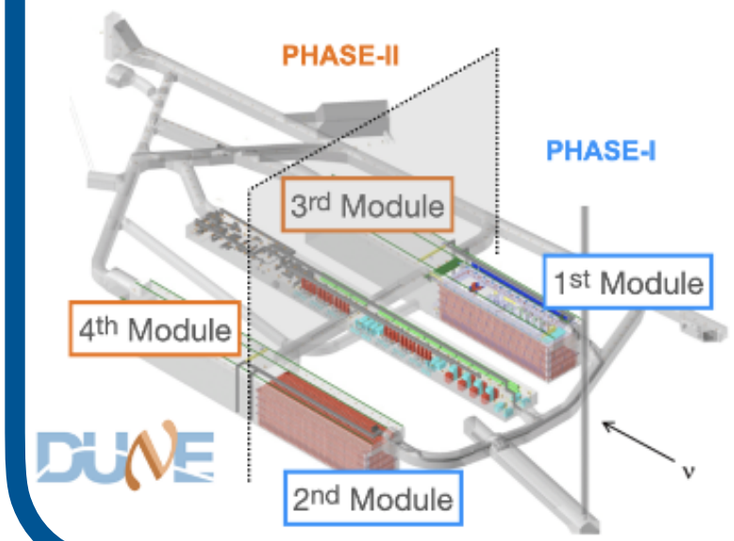


Neutrino physics with cryogenic detectors

Three UGR projects connected with DUNE

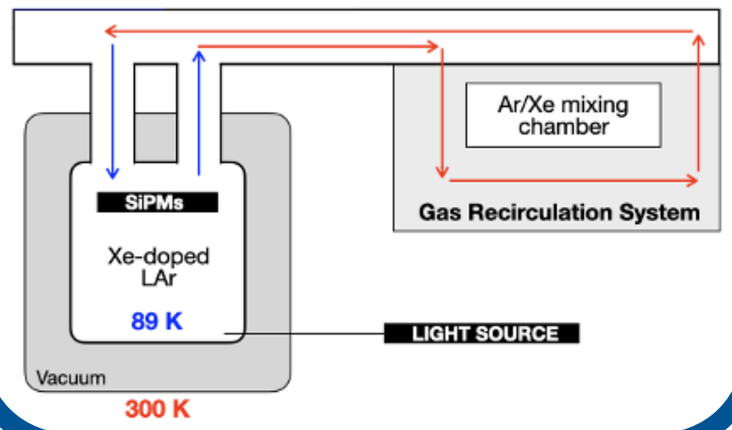
Project 1:
Instrumentation for accelerator-based neutrino experiments

- DUNE Phase-I and Phase-II Far Detector construction (eg, flanges, evaporator)



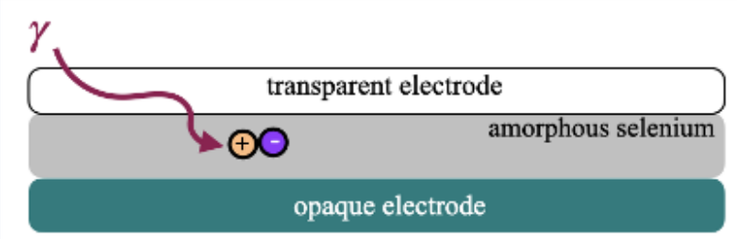
Project 2:
Instrumentation for cryogenics laboratory dedicated to the study of neutrino properties

- Setup to study xenon-doped LAr and LAr operating conditions



Project 3:
Development of new sensors for future cryogenic neutrino detectors

- New sensors based on amorphous selenium technology



Neutrino physics with cryogenic detectors

Three UGR projects connected with DUNE

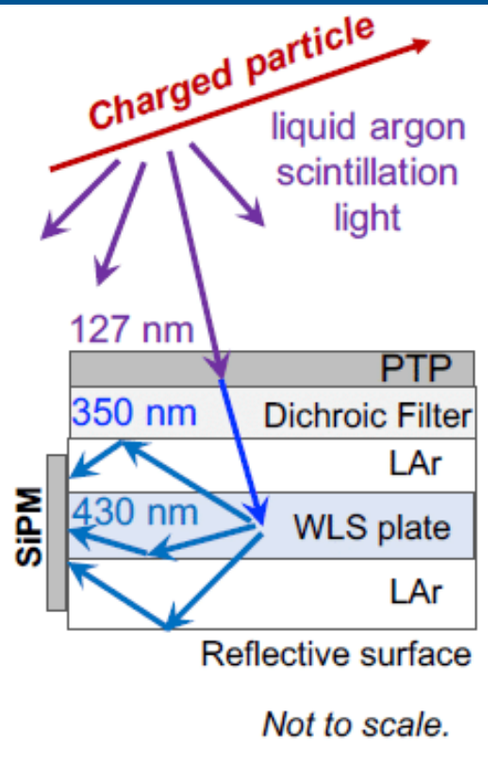
- **Status**:
  - *Concession Agreement with the Junta de Andalucía at the end of December 2023*
  - *The three projects are in an initial phase*
  - *Adjusting objectives to the new execution time of the grants*

R&D on light detection systems for DUNE

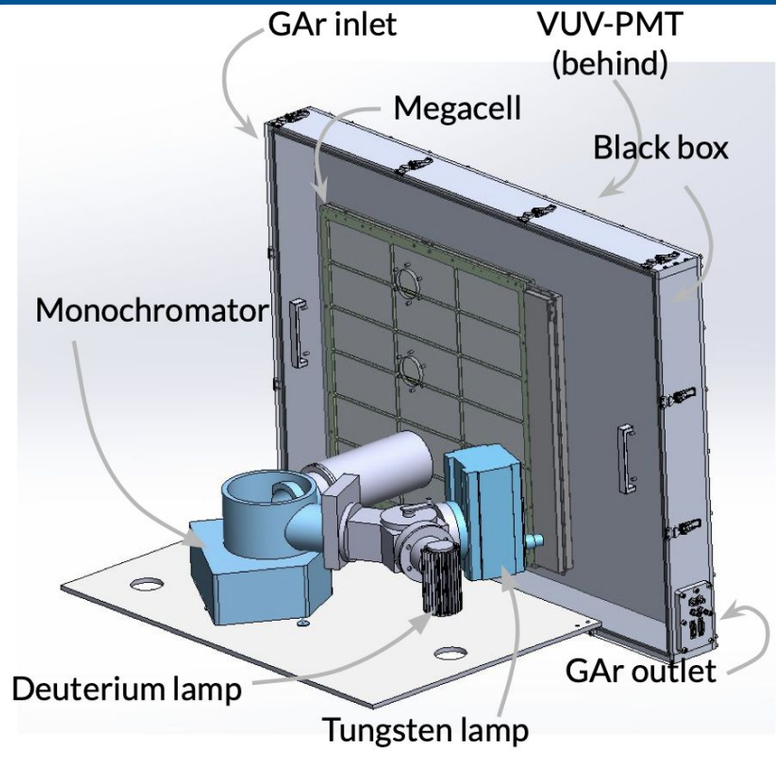
IFIC project ASFAE/2022/029

- Objectives:

    1. *Design optimization of DUNE's X-ARAPUCA photon collectors*



- Optical characterisation of components in vacuum ultraviolet to predict Photon Collection Efficiency (PCE)



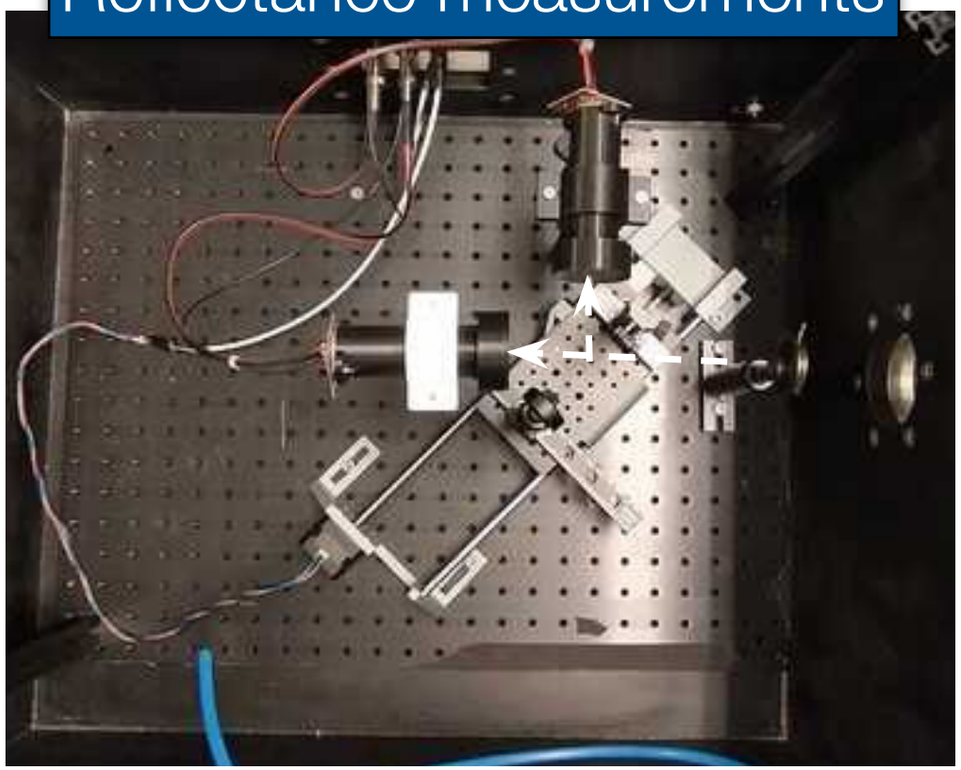
- PCE measurements with monochromator and a cryostat with MgF_2 windows.

R&D on light detection systems for DUNE

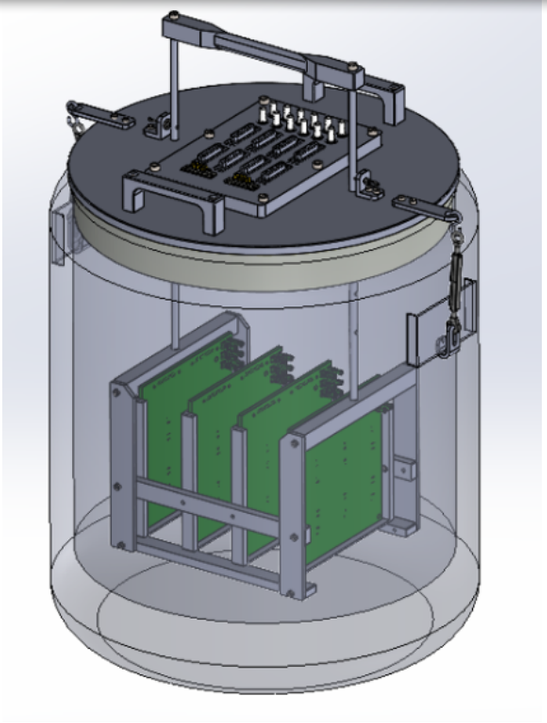
IFIC project ASFAE/2022/029

- Objectives:
  1. *Design optimization of DUNE's X-ARAPUCA photon collectors*
  2. *Reflectance measurements (specular and diffuse) of detector materials to understand total light yields in DUNE far detector*
  3. *Massive SiPM characterization in cryogenic conditions (MASSIBO)*

Reflectance measurements



SiPM characterisation



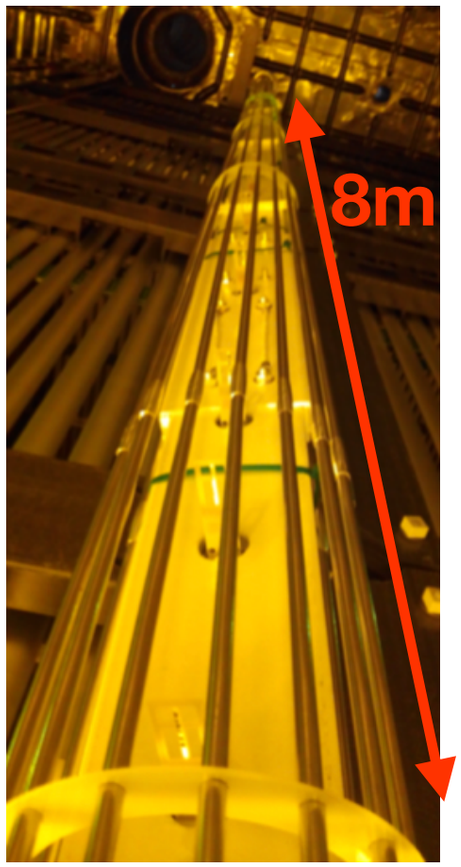
Precision LAr temperature monitoring systems for DUNE

IFIC project ASFAE/2022/028

- IFIC leads cryogenics instrumentation for DUNE far detectors and is in charge of their Temperature Monitoring System (TMS)

RTD-based TMS

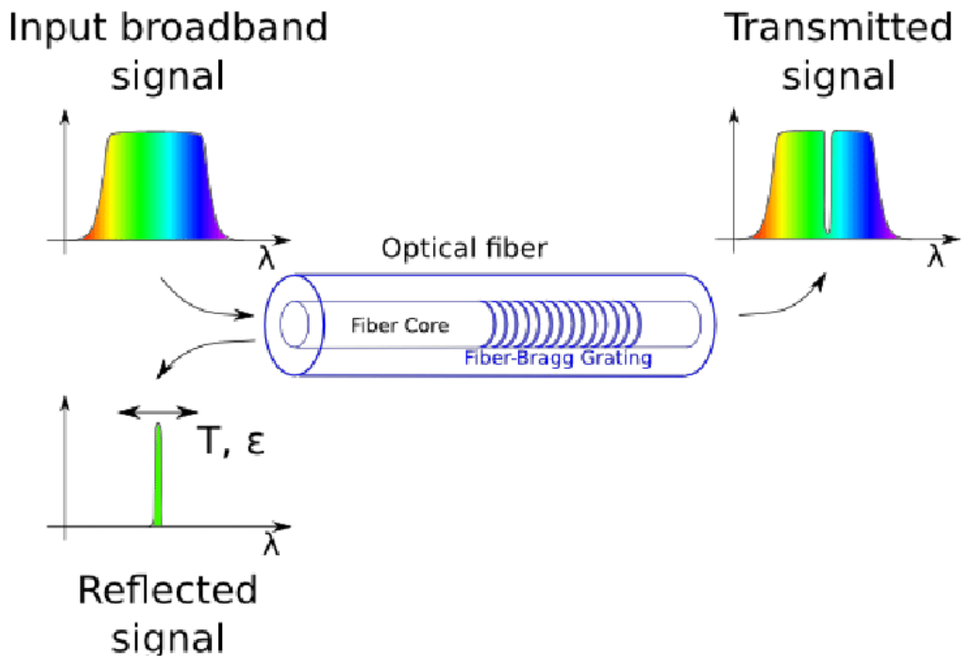
- **RTD**: Resistance Temperature Detector.
- >100 RTDs installed in CERN prototypes, achieving 2 mK resolution.
- >1000 RTDs to be installed in DUNE far detectors.



Vertical array of 48 sensors in ProtoDUNE

FBG-based TMS

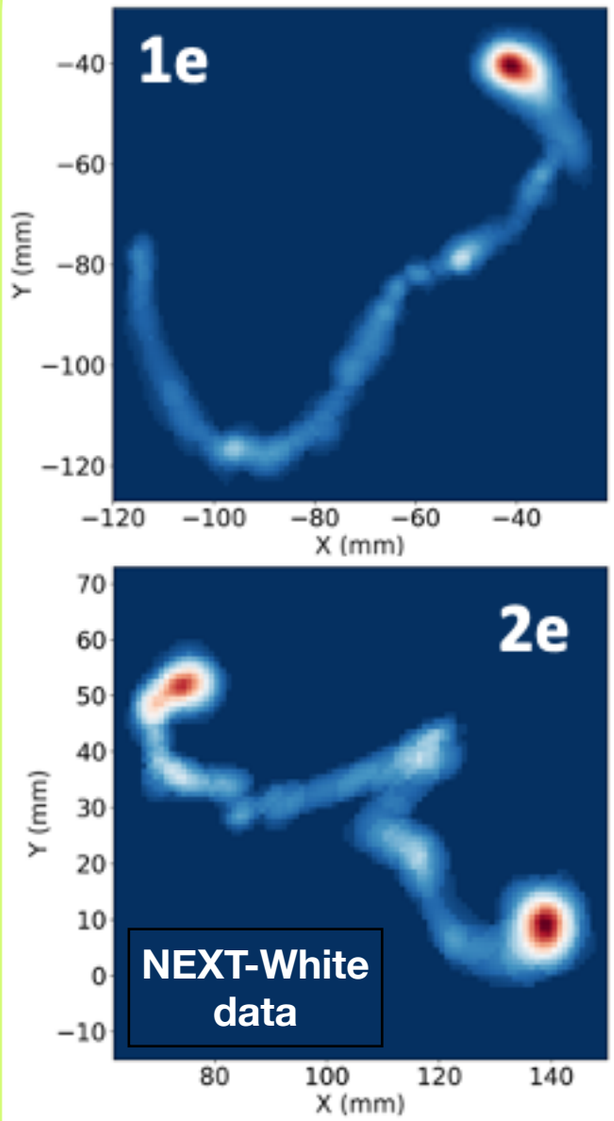
- **FBG**: Fiber-Bragg Grating.
- RTDs cannot operate in high E → FBGs.
- R&D to increase fiber sensitivity and improve calibration.



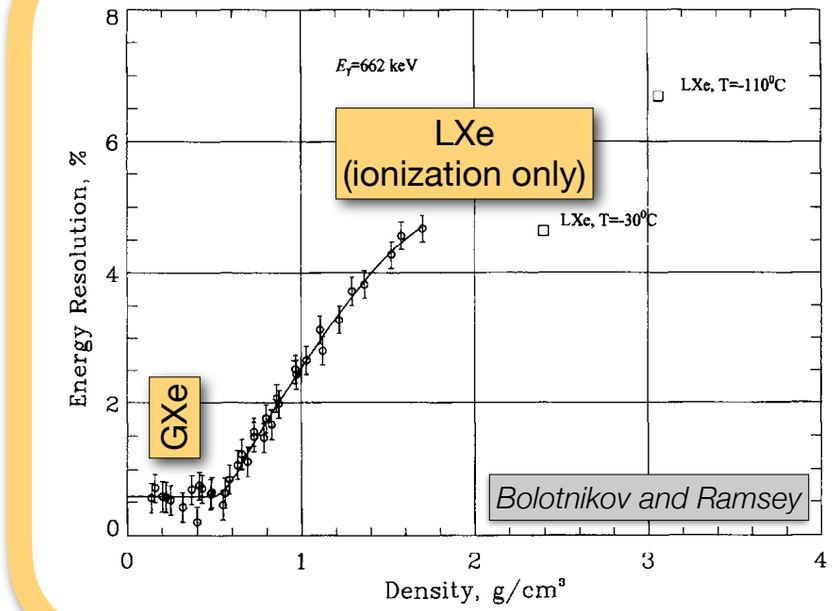
High-pressure xenon gas TPCs for 0νββ in ^{136}Xe

NEXT experiment

Topological event identification distinguishes 2e (signal-like) from 1e (background-like) events



Precise energy resolution of <1% FWHM



Scalability to large masses of isotopically-enriched ^{136}Xe

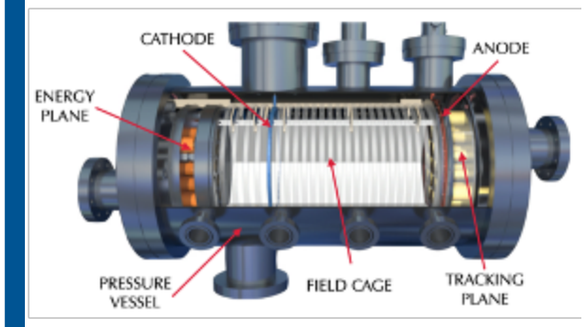
Possibility to detect $^{136}Ba^{++}$ daughter ion in coincidence with decay electrons

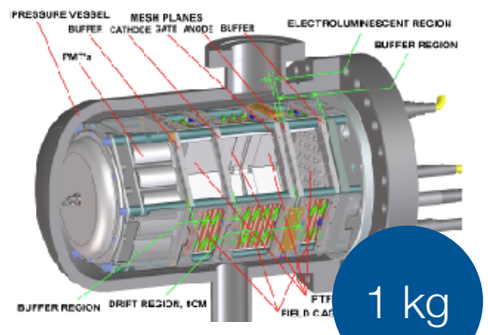
NEXT experimental program

Prototypes

2008-2015

- Demonstration of detector concept



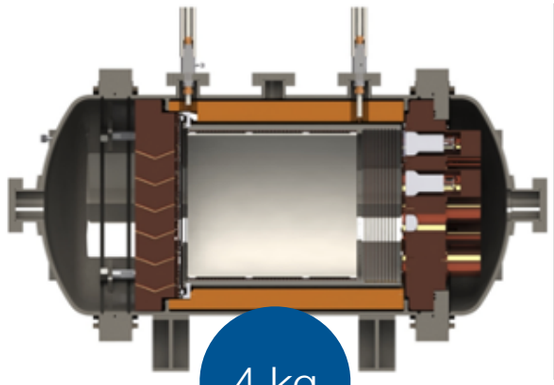


1 kg

NEXT-White

2016-2021

- Performance at $Q_{\beta\beta}$
- Background meas.
- 2νββ measurement

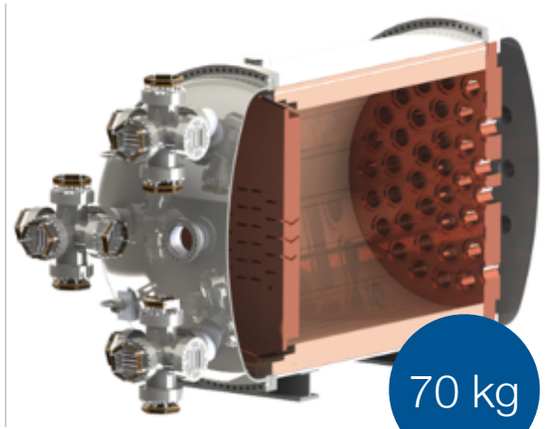


4 kg

NEXT-100

2022-2028

- Background meas.
- 0νββ search



70 kg

NEXT-HD / NEXT-BOLD

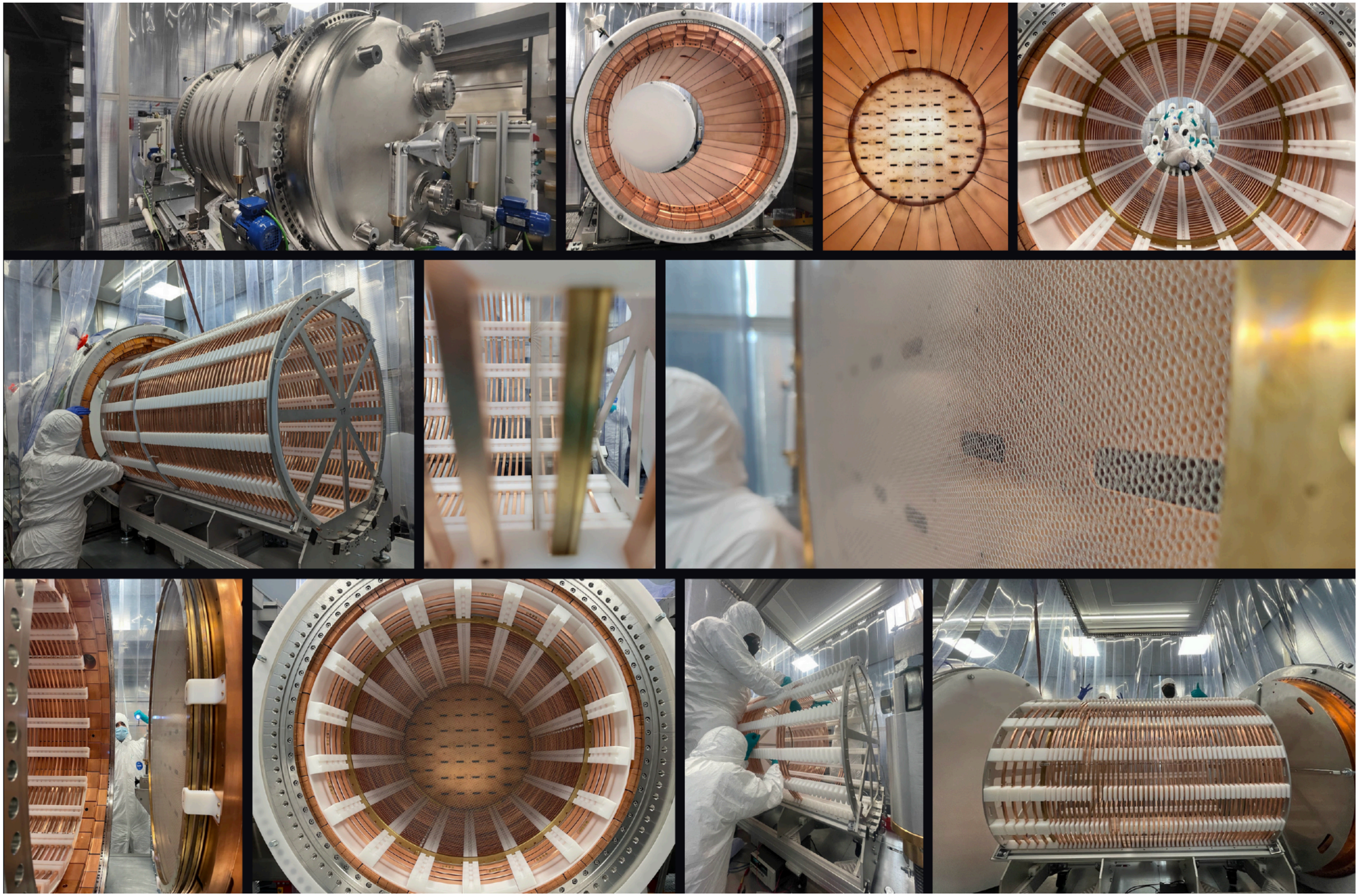
Late 2020s

- 0νββ at inverted ν mass ordering
- Ba^{++} tagging

1 ton

NEXT-100 status

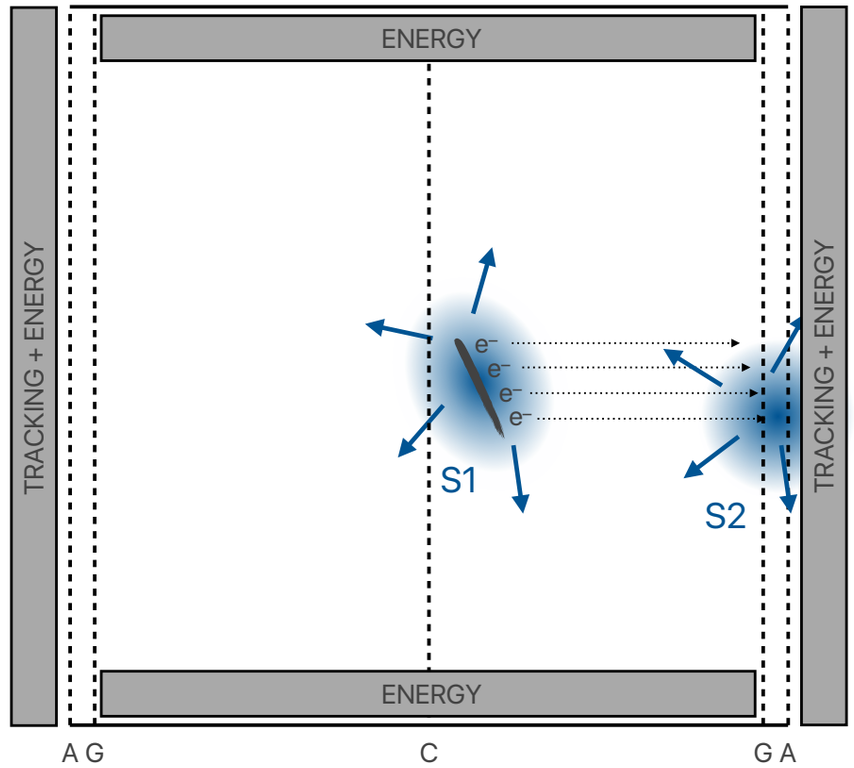
Detector installed and under commissioning at the LSC!

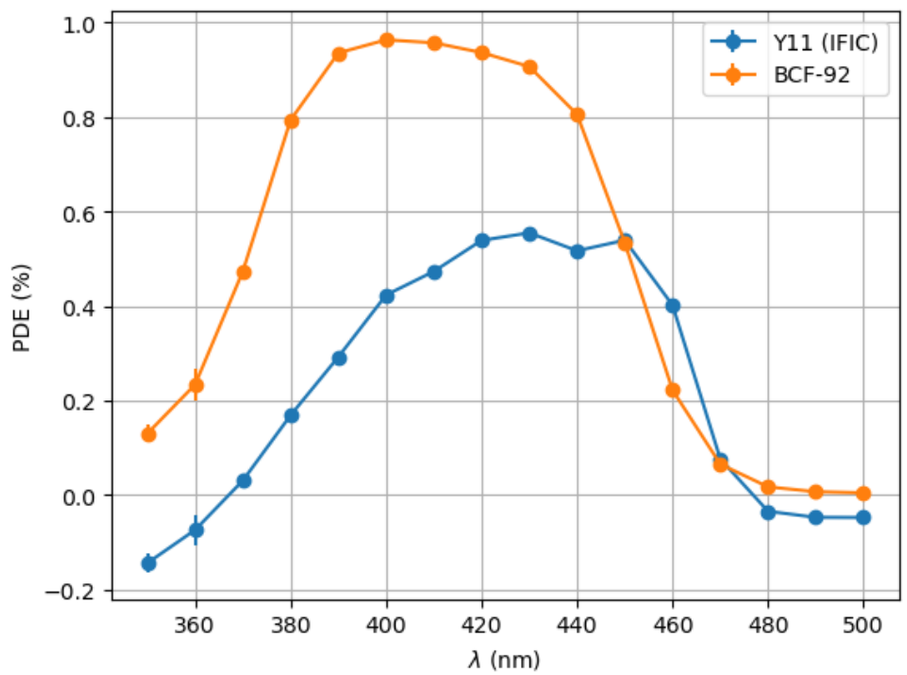


Towards NEXT-HD: photon detector system R&D

IFIC projects ASFAE/2022/028 and ASFAE/2022/029

- Photon detection system will replace PMTs (a leading background source) with a new system.
- **Baseline concept**: symmetric TPC with dense SiPM arrays at the anodes (tracking and calorimetry) and a barrel photon detector made of scintillating optical fibers (calorimetry).
- **IFIC**: detailed characterization of the photon detection efficiency of the new barrel photon detectors.





Towards NEXT-HD: front-end electronics for photo-sensors

UPV project ASFAE/2022/012

- **Objective 1:** DAQ concentration inside the vessel for a dense tracking plane.
  - *Development of solutions, at the power and thermal management levels.*
  - *Development of solutions for the concentration of data from several ASICs in a small number of fiber optic links.*

- **Objective 2:** Develop front-end electronics for an energy measurement based on a fiber barrel detector (FBD).

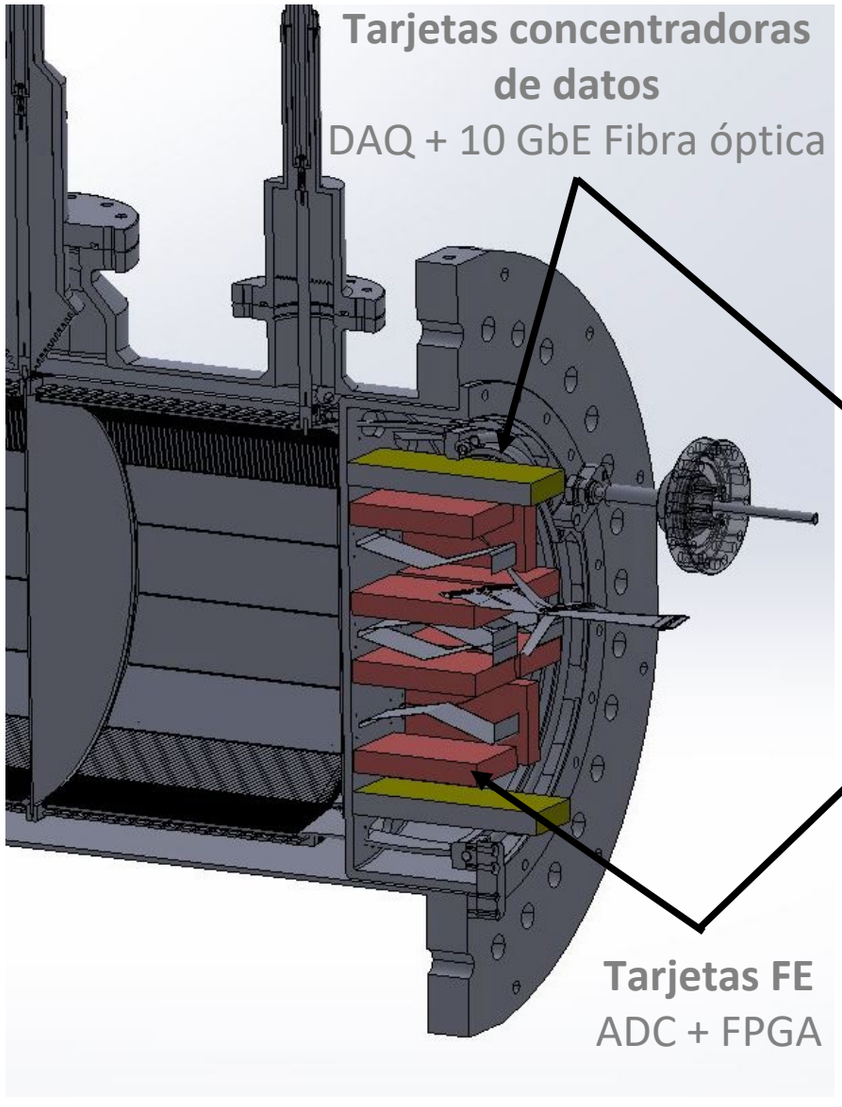
- **Objective 3:** The above objectives must be compatible with the low level of radioactivity necessary in low background experiments such as NEXT.

Towards NEXT-HD: front-end electronics for photo-sensors

UPV project ASFAE/2022/012

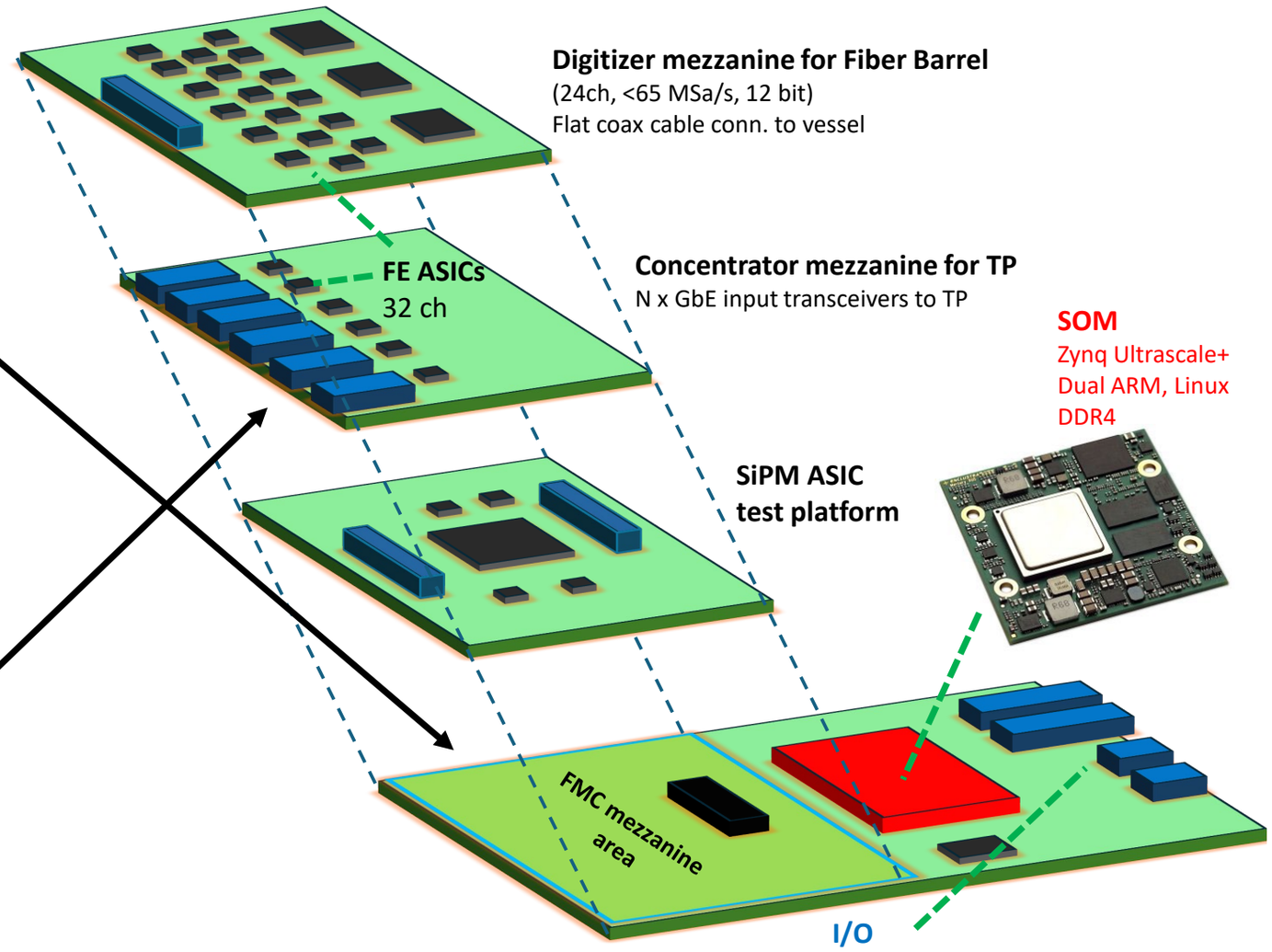
- Concept of modular electronics for objectives 1 and 2:

DEMO-HD



Plataforma Modular para FE y DAQ FLEX module

Basado en procesador System-on-Module más mezzanines con conexión por cable o FMC



Summary

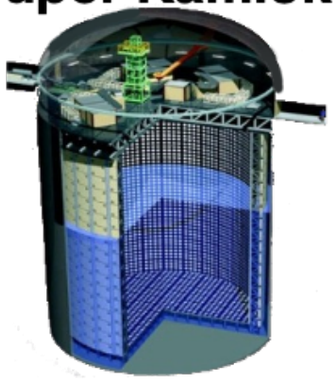
- LIA6 on Neutrino Physics includes advanced instrumentation for:
  - *Neutrino telescopes (**KM3NeT**, F. Salesa's talk)*
  - *Accelerator-based neutrino oscillation experiments (**T2K-II**, **Hyper-K** and **DUNE**, this talk)*
  - *Neutrinoless double beta decay experiments (**NEXT**, this talk)*
- Three autonomous communities involved: Andalucía, Catalunya and Comunidad Valenciana
- Important fraction of the PPCC funds targeted to improve our in-house laboratories, to deliver on current experimental commitments and to prepare for the future

Backups

T2K and the ND280 role

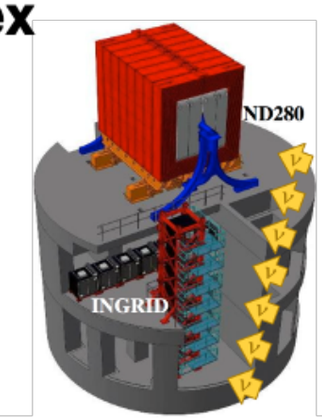
Far detector

Super Kamiokande



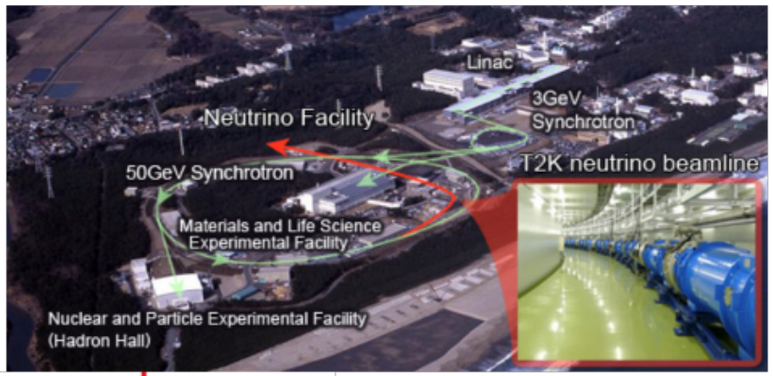
Near detector

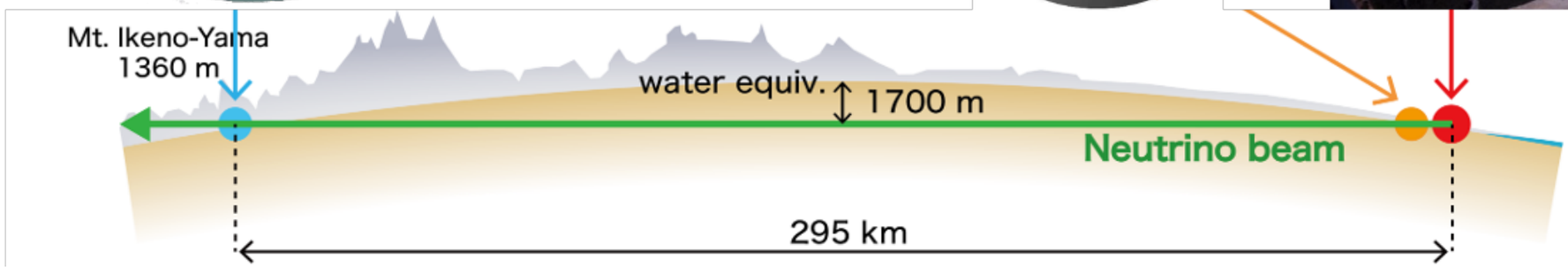
complex



J-Parc

Neutrino Beam

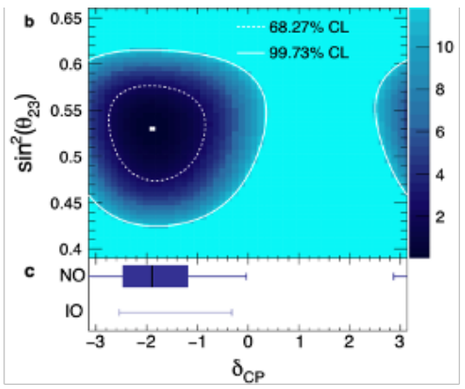


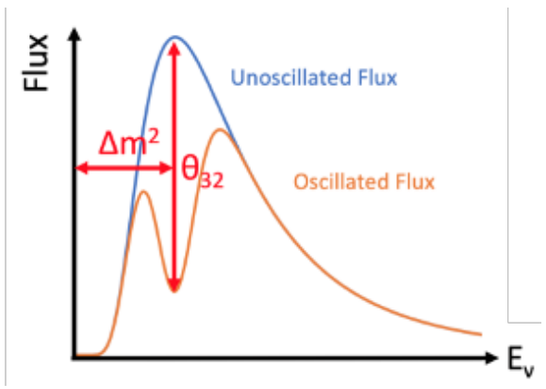


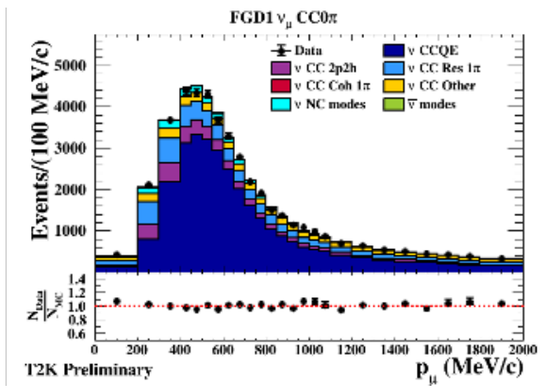
@SK:
measure oscillated beam

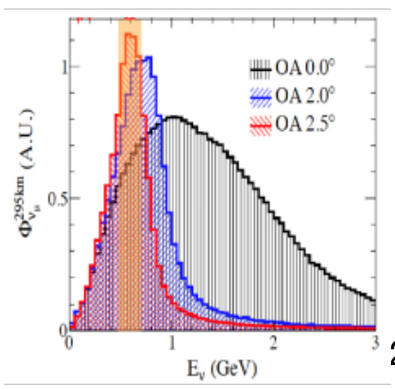
@ND280:
characterise beam and ν int.

@J-PARC:
create ν off-axis beam



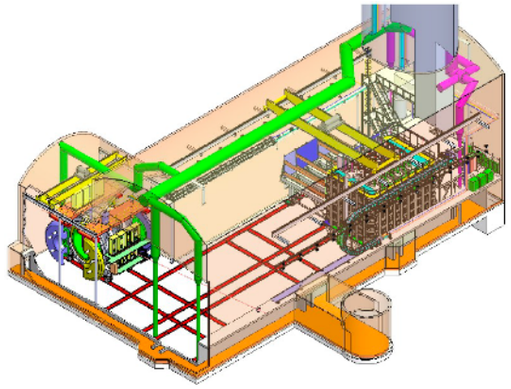


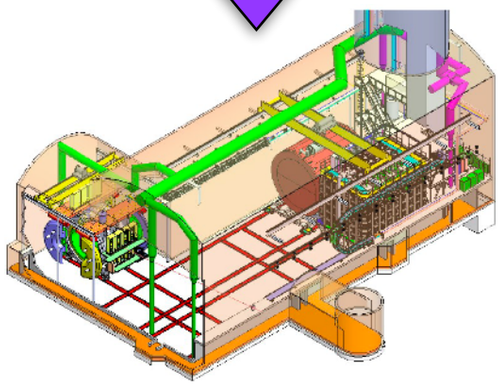




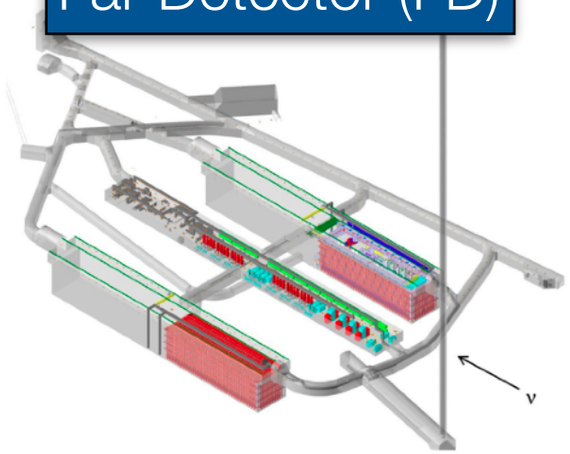
DUNE will be built in two phases

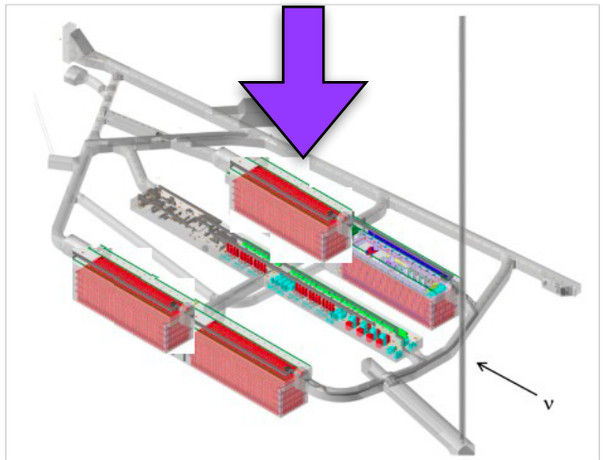
Near Detector (ND)



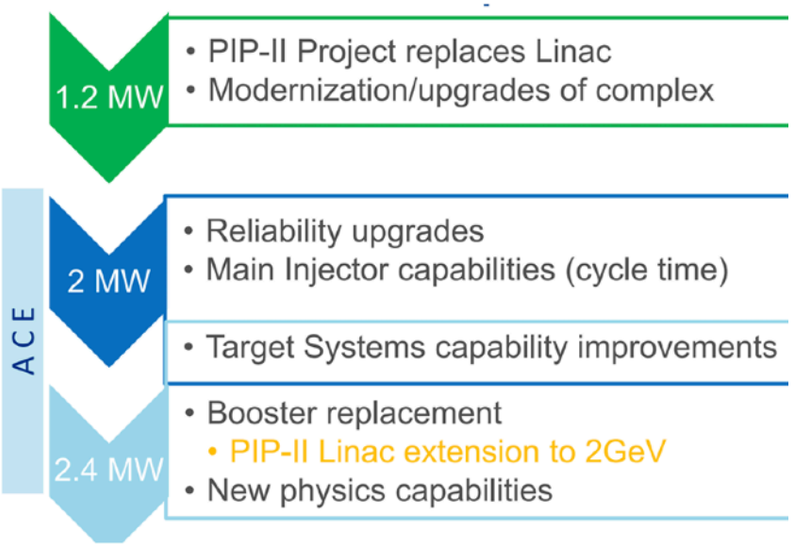


Far Detector (FD)





Beam



Phase I

- **FD:** 2 x 17 kt LArTPC modules
- **ND:** ND-LAr+TMS (with PRISM) + SAND
- **Beam:** 1.2 MW beam line (PIP-II)

Phase II

- **FD:** 2 additional modules (total: 4 x 17 kt LAr-equivalent)
- **MCND:** ND-LAr+ND-GAr (with PRISM) + SAND
- **Beam:** > 2 MW beam line (ACE Upgrades)

Optics laboratory at IFIC

Projects ASFAE/2022/028 and ASFAE/2022/029

- Optics laboratory at IFIC is being expanded with ASFAE funding.