Neutrino Physics Experiments

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Special thanks to: Helena Almazan, Juan Collar, José Crespo, Juan José Gomez Cadenas, Thorsten Lux, Francesc Monrabal, Pau Novella, Joaquim Palacio, Carmen Palomares, Ander Simón

Plan for this talk

- For this talk, the focus will be on **Spanish current contributions and plans** in the area of experimental neutrino physics
  - Objective of this meeting is to discuss and coordinate the Spanish strategy in view of the upcoming APPEC strategic roadmap 2027-2036 for astroparticle physics.

- I will cover:
  - **Neutrino oscillation experiments** → T2K, SK, HK, DUNE, SBND
    - *Won't discuss KM3NeT-ORCA here, see talk by R. Gozzini*
  - **Neutrinoless double beta decay experiments** → NEXT-100, NEXT future
  - **Coherent Elastic Neutrino-Nucleus Scattering Experiments** → Cryogenic undoped CsI crystals, Ge PPC detectors, GanESS, COLINA
  - **LiquidO** detector technology for nuclear reactor monitoring and neutrino physics

Starting point: Spanish Inputs to the European Strategy for Particle Physics - 2026 Update

- ID #58: **Spanish astroparticle community input to the European Strategy Group**, on behalf of RENATA and REDONGRA networks
- ID #147: **Spanish national input to the European Strategy for Particle Physics**, on behalf of the Spanish particle, astroparticle and nuclear physics communities (CPAN)
- Inputs submitted in March, 2025
- For experimental neutrino physics part, most contents to the ECFA-mandated roadmap (inputs above) are common to APPEC roadmap

Spanish astroparticle community input to the European Strategy Group

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On behalf of the RENATA and REDONGRA networks

Spanish national input to the European Strategy for Particle Physics

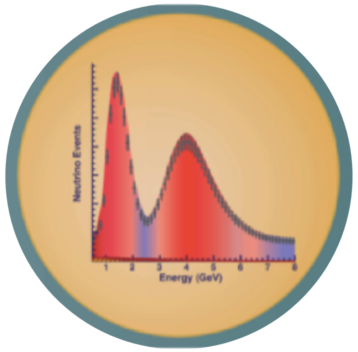
The Spanish particle, astroparticle and nuclear physics community

Editorial team: J. Alcaraz Maestre (CIEMAT), N. Armesto (IGFAE), J. de Blas (UGR), L.M. Fraile (UCM), A. Juste (IFAE), M. Martínez (UZ), G. Merino (CIEMAT), C. Pena (IFT, UAM-CSIC), M. Sorel (IFIC, CSIC-UV), F. Toral (CIEMAT), I. Vila (IFCA, CSIC-UC), M. Vos (IFIC, CSIC-UV)

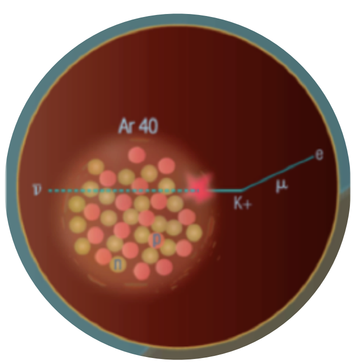
Contacts: N. Colino (CIEMAT), M.J. Costa (IFIC, CSIC-UV), P. Hernández (IFIC, CSIC-UV), C. Martínez (IFCA, CSIC-UC), C. Salgado (IGFAE)

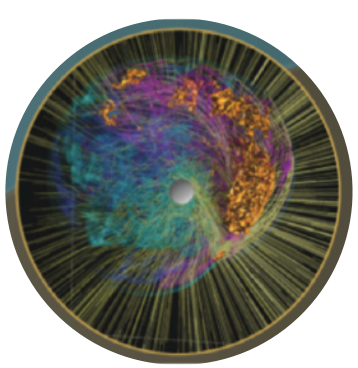
Neutrino Oscillations

Why Neutrino Oscillation Experiments



- Conclusively establish mass ordering and CP violating phase
- Precision measurements of all parameters of three-flavor model
- Search for deviations to three-flavor model: sterile neutrinos, non-standard interactions, PMNS non-unitarity, CPT violation, …
- Beam, atmospheric, solar, and reactor neutrinos
- *See talk by C. Gonzalez-García*



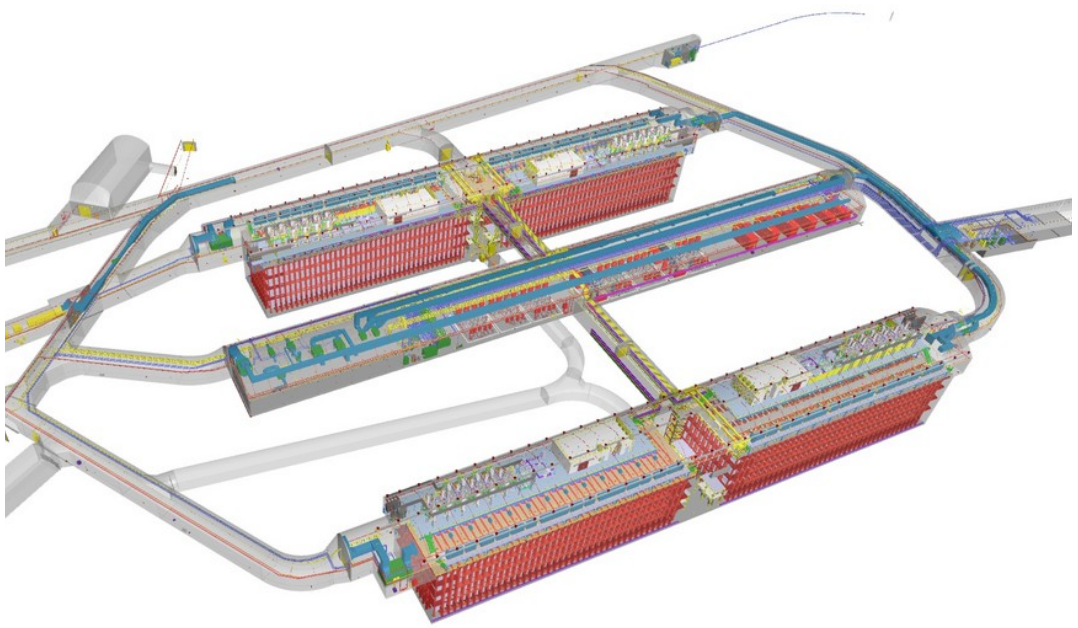


- Massive underground neutrino detectors and high-intensity neutrino beams offer many more physics opportunities:
  - **Astrophysical observatories**: supernova bursts, diffuse supernova neutrino background (DSNB), solar neutrinos, multi-messenger observations,…
  - **BSM rare event searches at the FD**: nucleon decay, n-nbar oscillations, WIMP dark matter indirect searches,…
  - **BSM processes in the beam observed at the ND**: Light Dark Matter (LDM), Heavy Neutral Leptons (HNLs), Axion-Like Particles (ALPs), neutrino trident production,…

DUNE / Hyper-K Complementarity

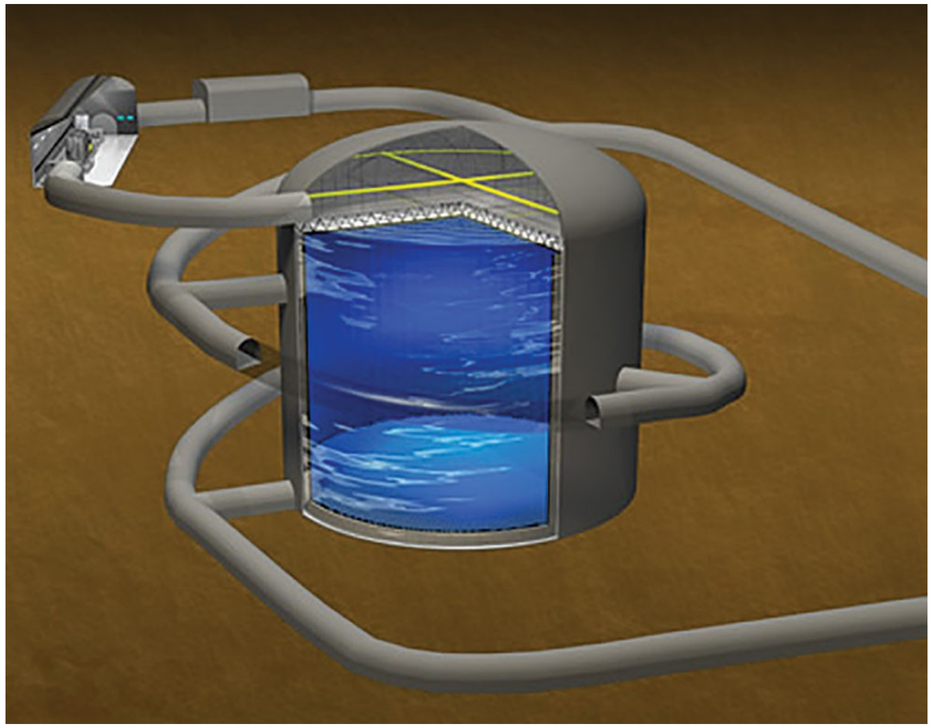
DUNE

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



Hyper-K

- Shorter baseline → small matter effect
- Narrowband neutrino beam
- Lower neutrino energies → very large water Cherenkov FD
- Highly-capable ND to constrain systematic uncertainties



Spanish Participation in DUNE and Hyper-K

DUNE

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

(~50 collaborators)

Hyper-K

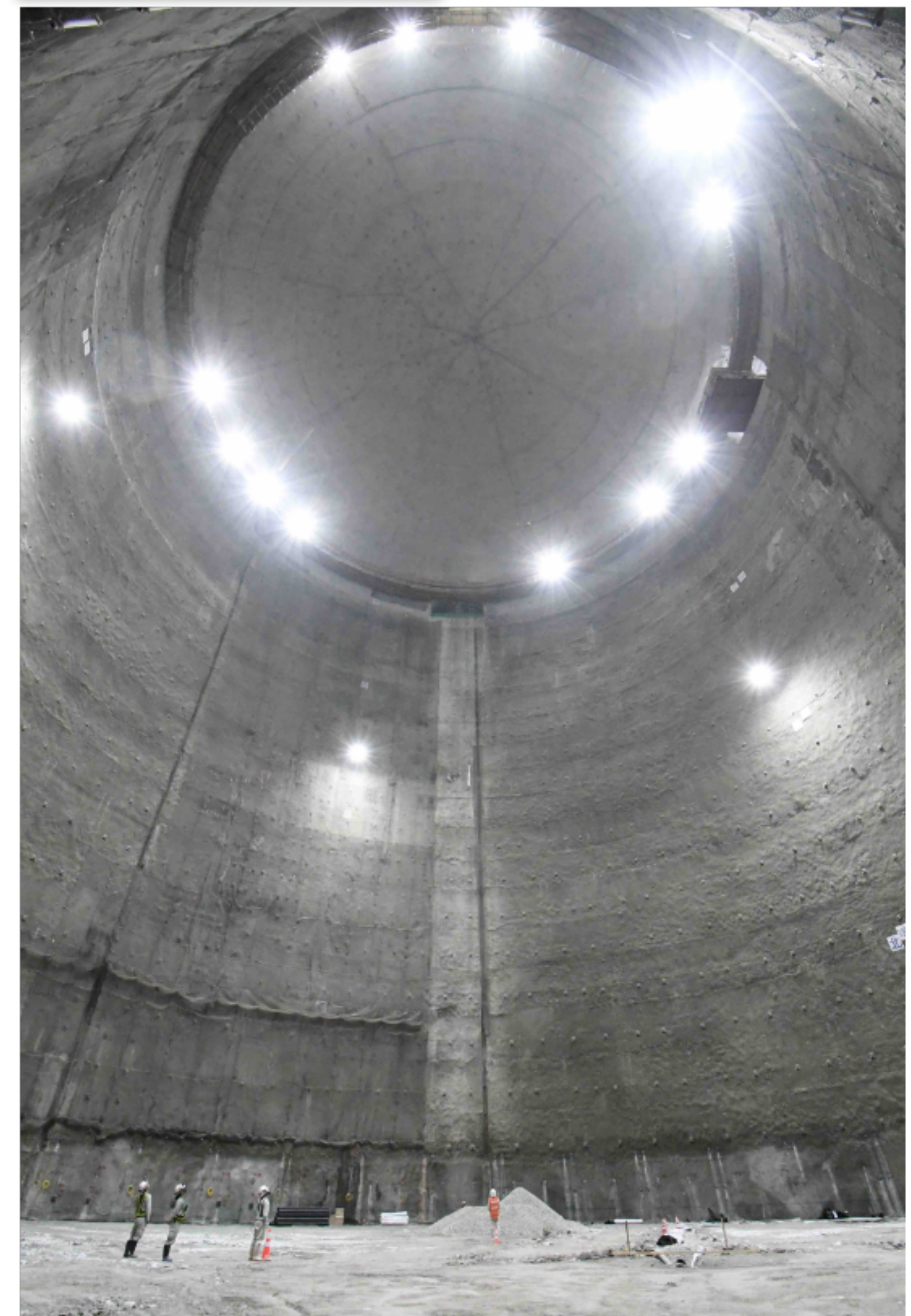
- Shorter baseline → small matter effect
- Narrowband neutrino beam
- Lower neutrino energies → very large water Cherenkov FD
- Highly-capable ND to constrain systematic uncertainties

(~40 collaborators)

DUNE and Hyper-K Caverns Completed!

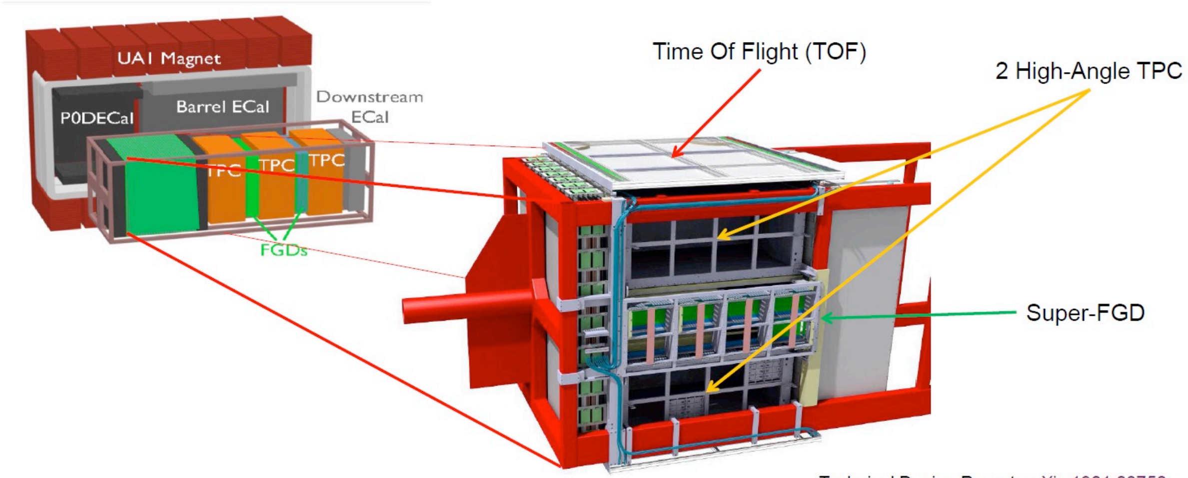
DUNE cavern

Hyper-K cavern

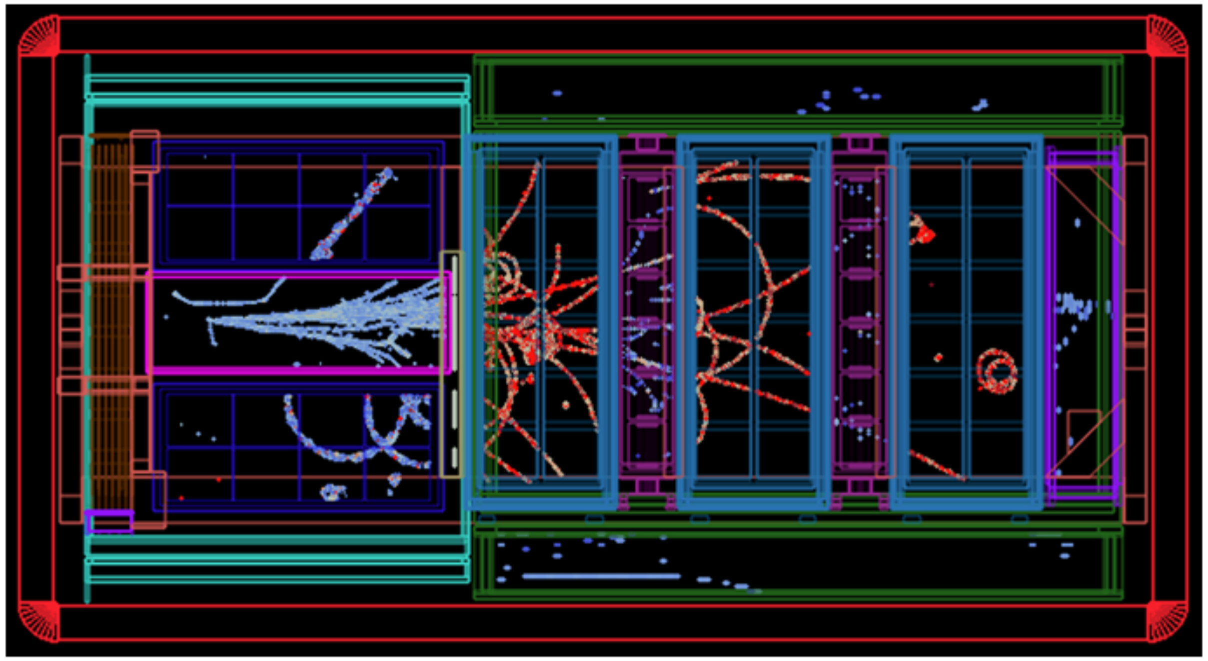


Contributions to T2K/SK, ND280 ND Upgrade

- Research interests in T2K/SK:
  - *Selection development and cross section measurements using ND280 (IFAE)*
  - *Nuclear models for T2K/SK (US)*
  - *PMT calibration and SN vs in SK (UAM)*
- ND280 upgrade completed in 2024:
  - *4π coverage w/ high-angle TPCs, lower detection threshold, n detection capability*
  - *CERN experiment NP07*
  - *T. Lux (IFAE) co-project leader of ND280 upgrade project / NP07*
  - *Finalizing MoU to transfer detectors and ND280 expertise from T2K to Hyper-K*
- Possible additional upgrade, ND280++, under study. To be completed: 2030+



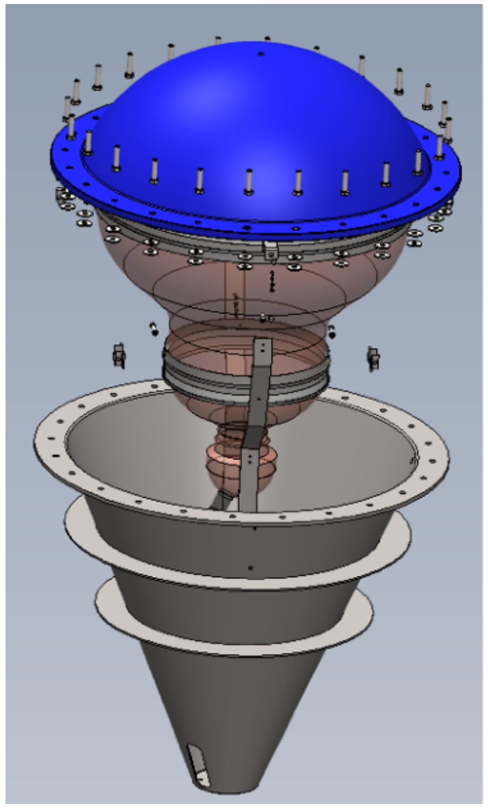
Technical Design Report: arXiv:1901.03750



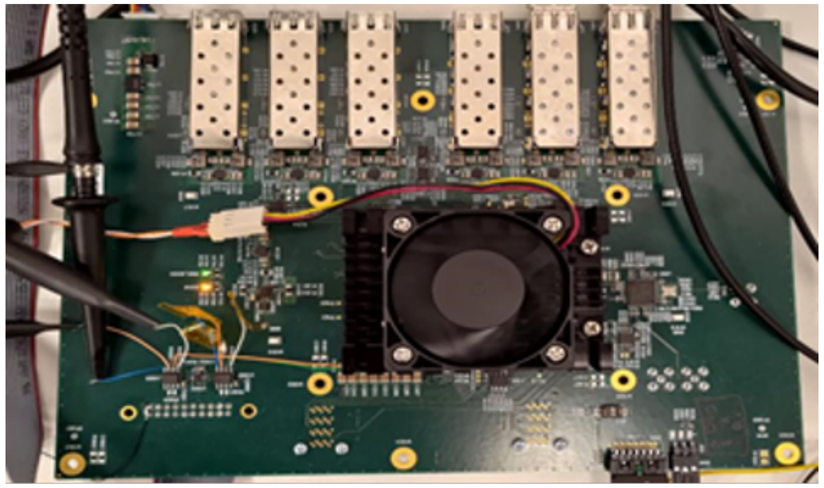
Contributions to Hyper-K FD Construction

- Inner Detector PMT anti-implosion covers - PMMA domes and steel conical bodies - and related assembly elements (DIPC, LSC and UdG)
- Data Processing Module and integration with other electronic modules (UPV)
- Geomagnetic compensation system (UO)
- Radon ventilation system (LSC)

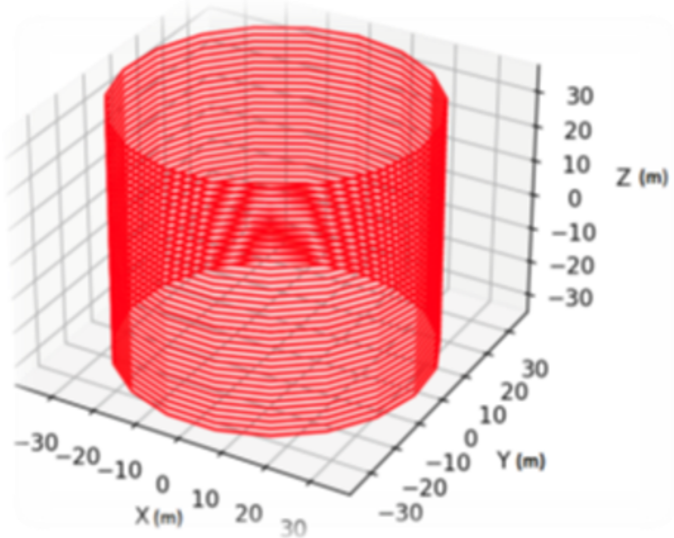
PMT covers



Data Processing Module

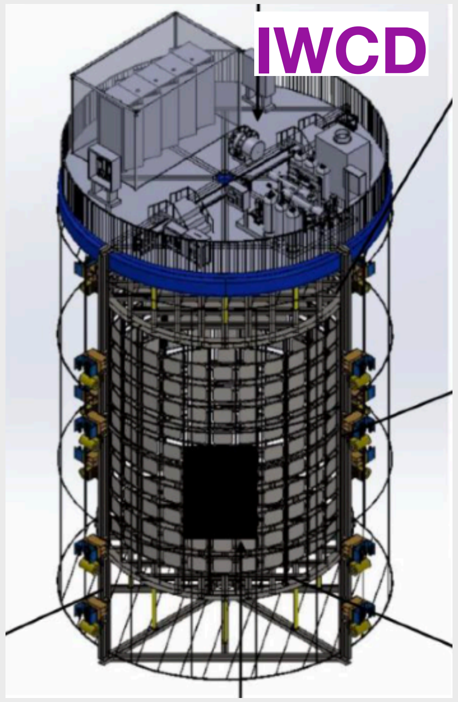


Geomagnetic compensation system

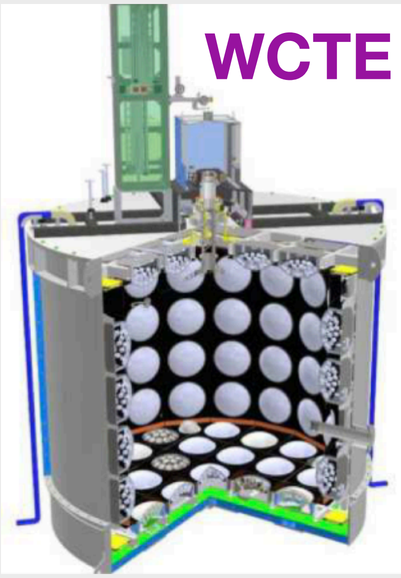


Contributions to WCTE and IWCD

- **Intermediate Water Cherenkov Detector (IWCD)** to be located at ~850m from ν source in J-PARC. Probe different ν energy spectra, measure ν-nucleus cross section ratios.
- Spanish contributions:
  - *Hardware/Analysis: Calibration sources (IGFAE/DIPC)*

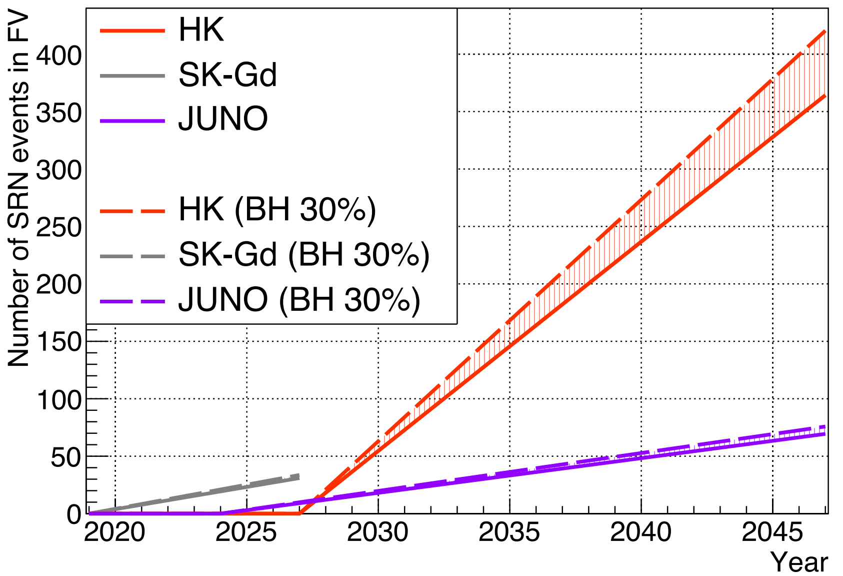


- **Water Cherenkov Test Experiment (WCTE)** located at T9 CERN beam. Control physics samples (for HK) and test mPMT and calibration systems (for IWCD/HK)
- Spanish contributions:
  - *Hardware: Calibration sources (IGFAE/DIPC), mPMT structure (DIPC), Water tank (LSC).*
  - *Analysis: Pion Scattering (IFAE), Calibration Sources (IGFAE/ DIPC), PID with NN (IGFAE), Neutron Captures (DIPC).*



Hyper-K Physics Contributions

Diffuse SN Neutrino Background (DSNB)



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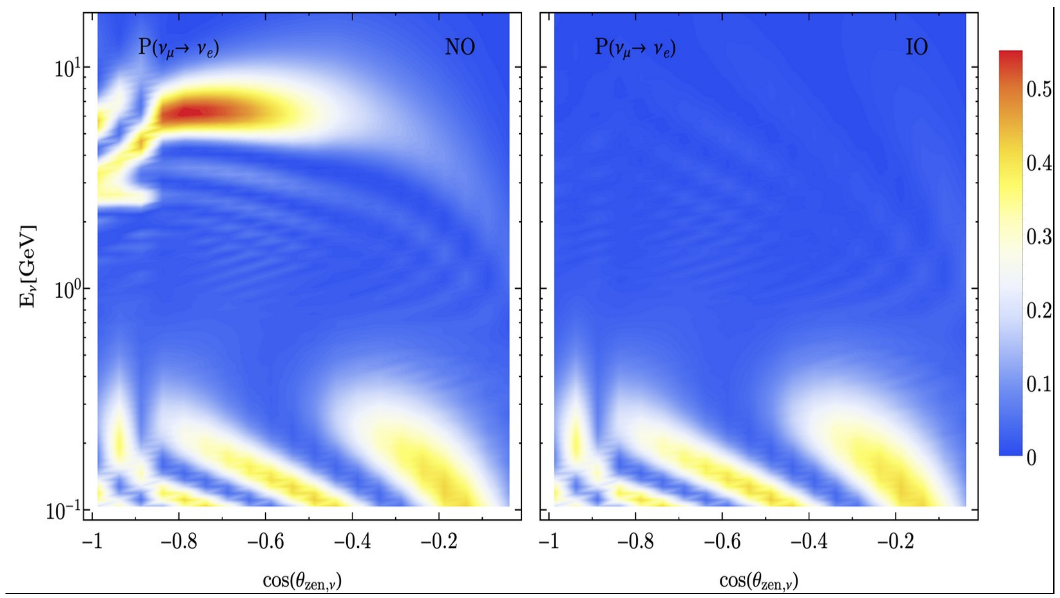
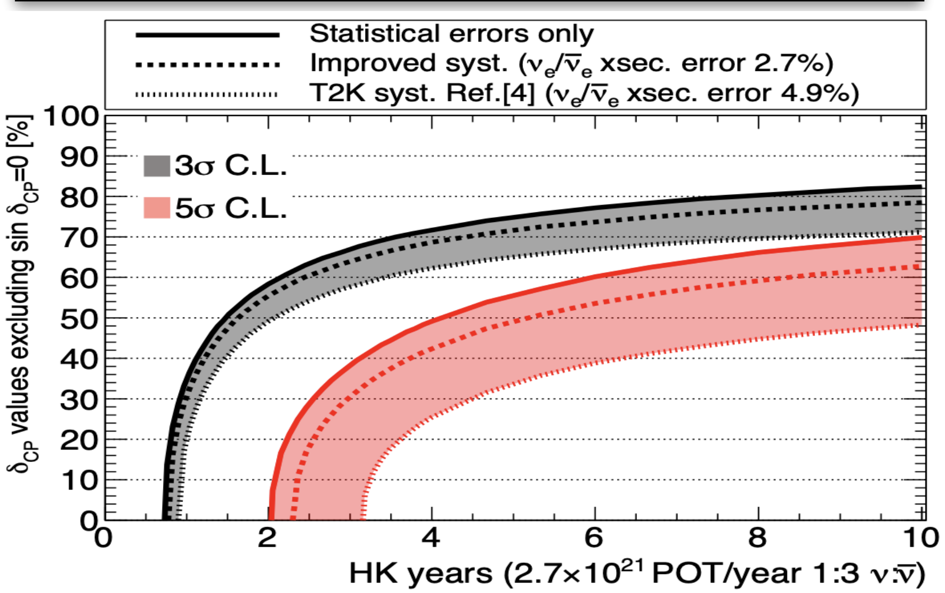
Atmospheric neutrinos (oscillations, flux, tau cross-sections, BSM)



Universidad de Oviedo

Long-baseline neutrinos (oscillations, cross-sections, flux, BSM)



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Calibration sources (WCTE/IWCD/HK-FD)

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Contributions to DUNE FD

Photon Detector System (PDS)

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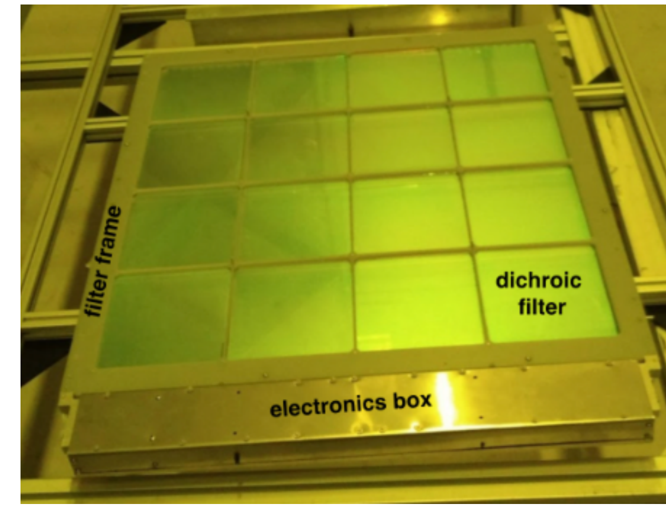
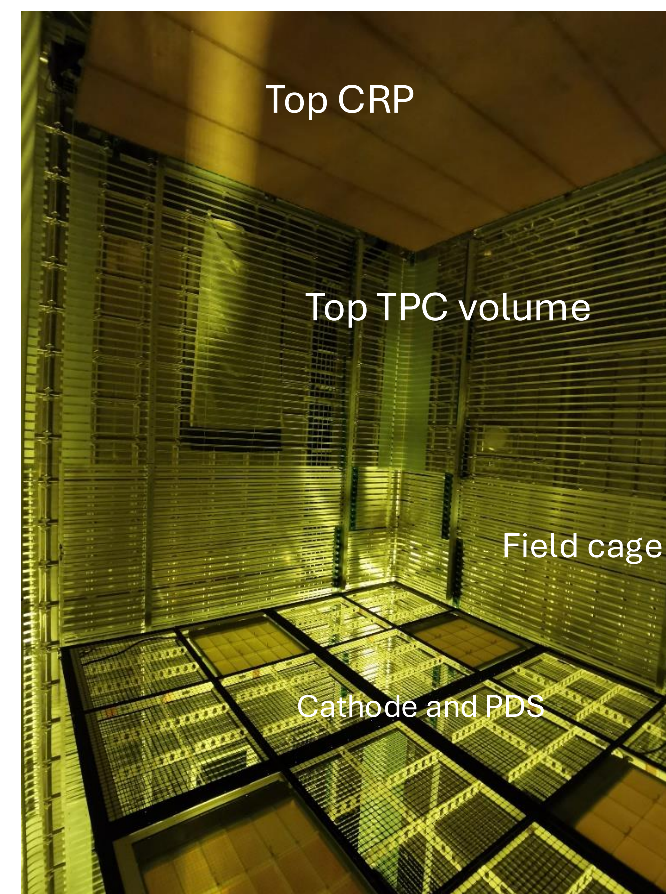
IFIC

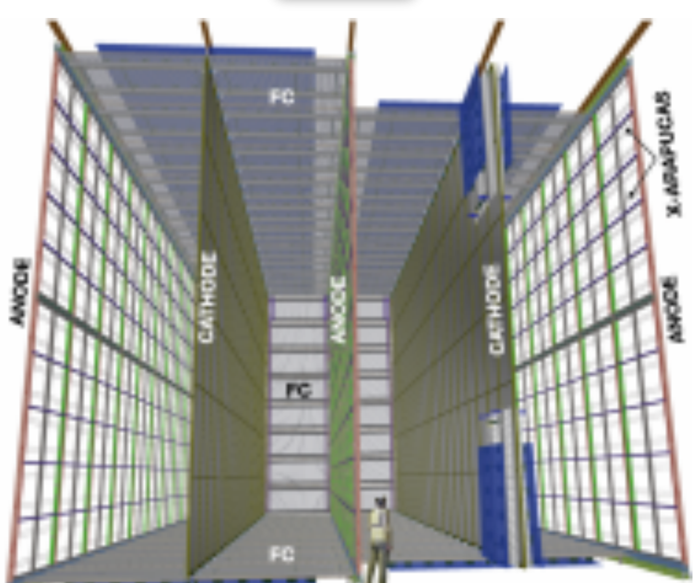
- Detection of Ar/Xe scintillation light (128-175 nm) provides:
  - *Event t0 information (PDS-only)*
  - *Trigger and calorimetry information (TPC and PDS)*
- PDS modules in anode planes (FD1), cathode (FD2) or cryostat walls (FD2)
- Validation in ProtoDUNE detectors at CERN Neutrino Platform since 2018 (NP02 and NP04)
- Also: light and charge readout R&D for Phase II FD modules (FD3 and FD4)



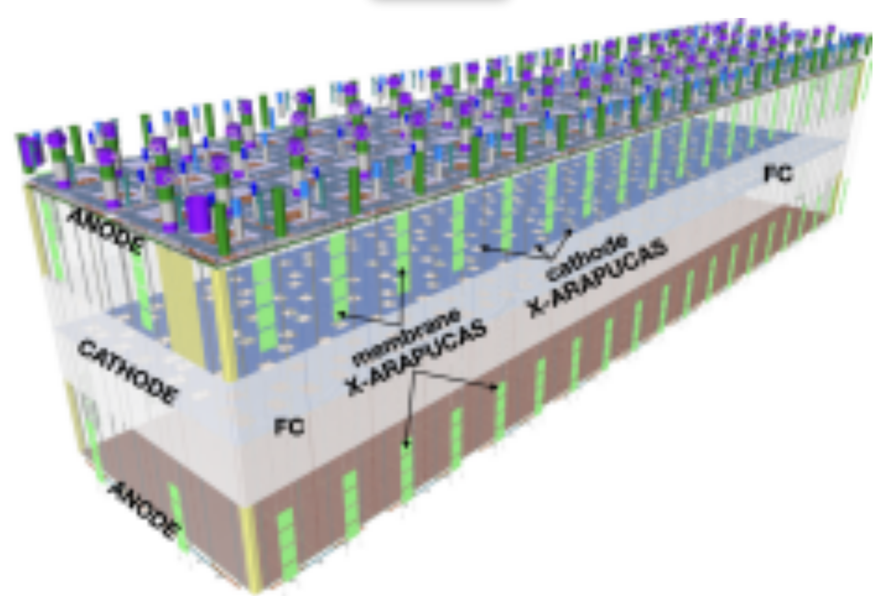
ProtoDUNE-VD / NP02



FD1



FD2

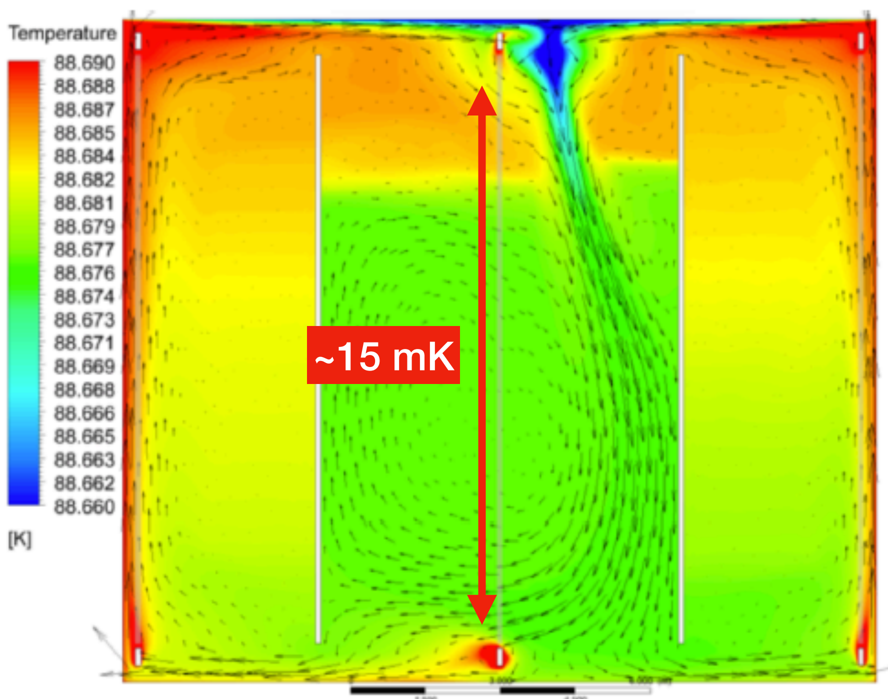


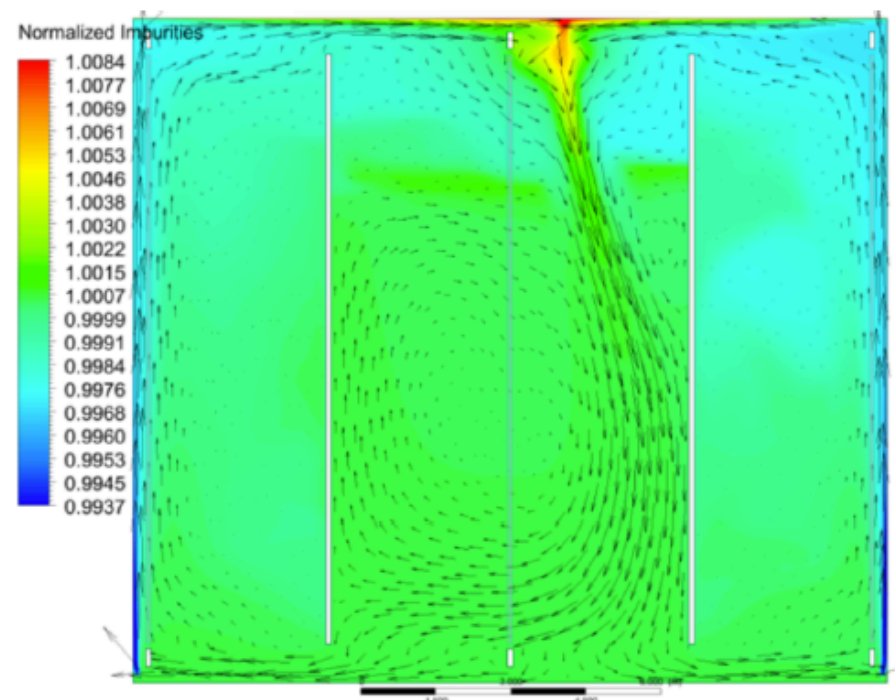
Contributions to DUNE FD

Cryogenic Instrumentation

- Continuous recirculation and purification needed in LAr TPCs
- Precision map of LAr temperature measurements informs LAr flow, LAr impurities and space charge effects

Temperatures





Impurities

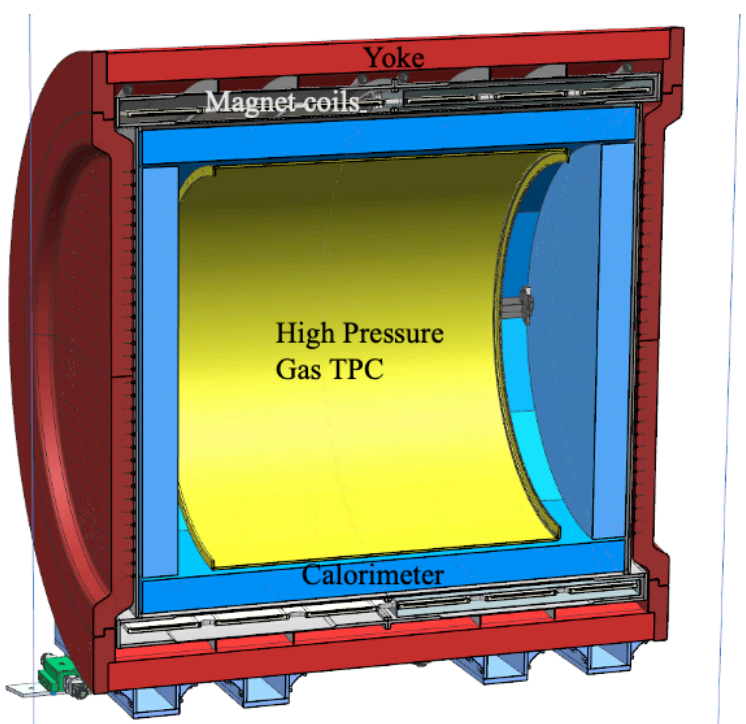
- Two precision temperature sensing technologies developed and deployed:
  - ***RTDs**: Resistance Temperature Detectors. >100 RTDs installed in CERN prototypes, 2 mK resolution. >1000 RTDs to be installed in DUNE far detectors.*
  - ***FBGs**: Fiber-Bragg Gratings. RTDs cannot operate in high E → FBGs. R&D to increase fiber sensitivity and improve calibration.*

Contributions to DUNE ND

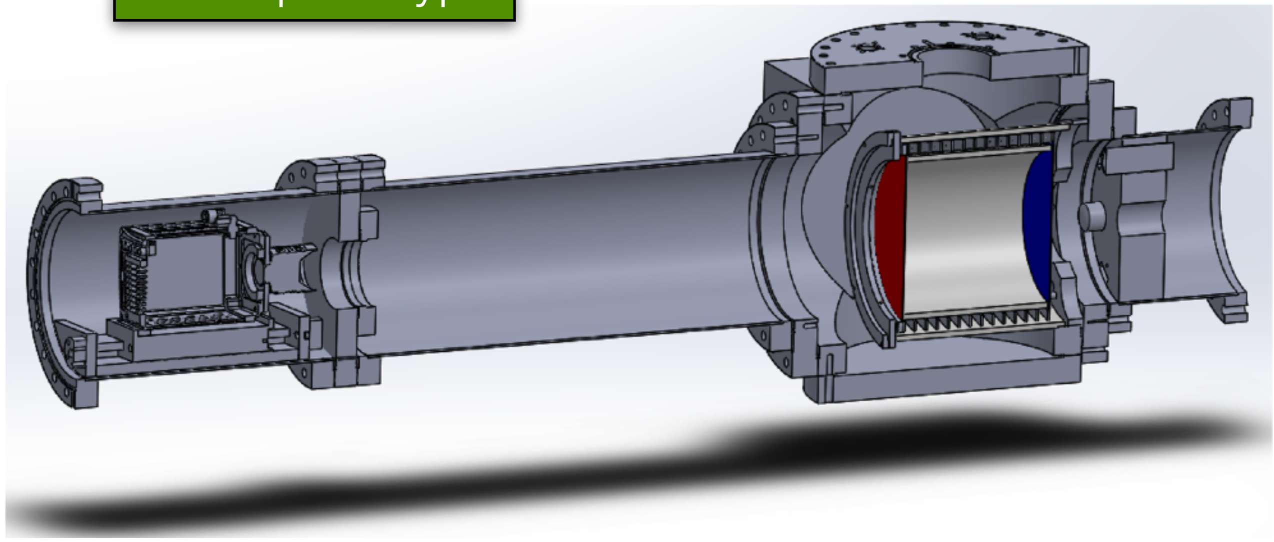
R&D Toward ND-GAr

- As statistics ↗, need lower systematic uncertainties from improved ND constraints
- For DUNE Phase II, replace muon spectrometer with more capable detector: **ND-GAr**
  - *GArTPC, calorimeter, magnet, muon tagging system*
  - *Possibly: primary scintillation light detection system*
- Spanish contributions:
  - *SiPM-based readout system and associated gas mixtures for S1 detection*
  - *Optical TPC readout based on THGEMs and imaging cameras (GAT0)*

ND-GAr

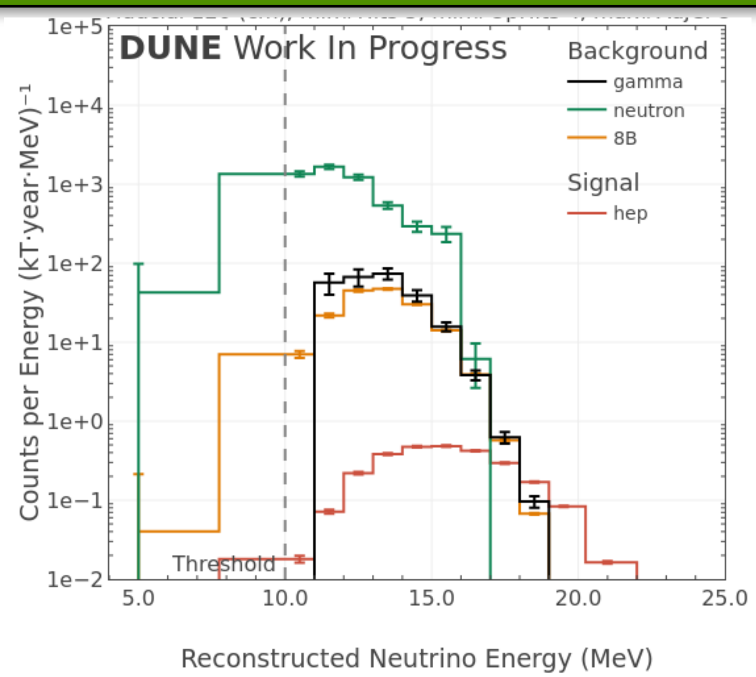


GAT0 prototype



DUNE Physics Contributions

Detection of astrophysical neutrinos at FD



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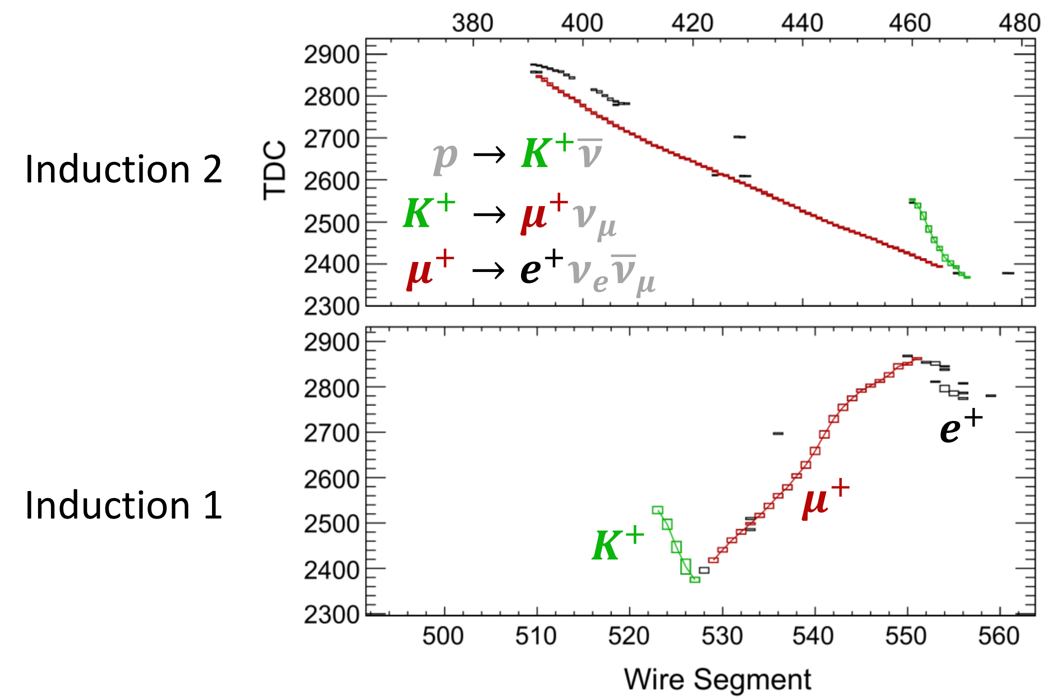
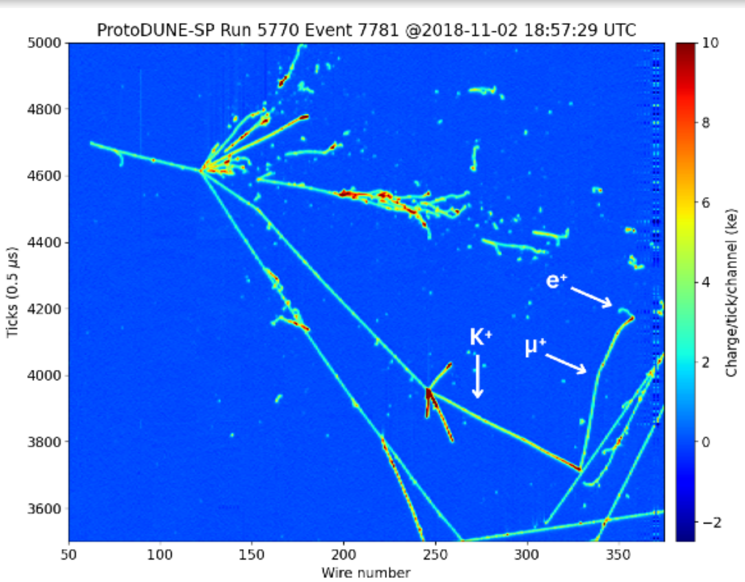
Search for proton decay at FD



ProtoDUNE data analyses (neutrinos, BSM, xsecs, detector performance)



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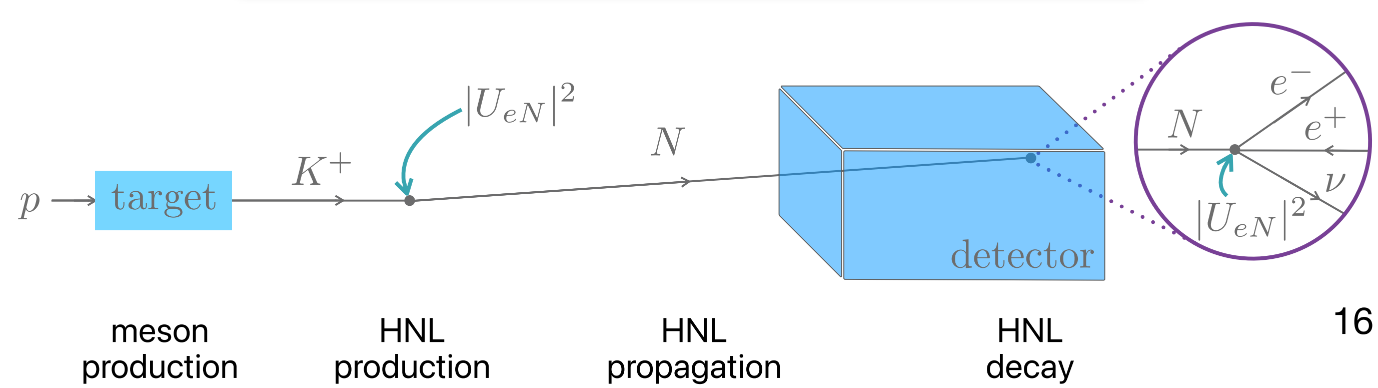
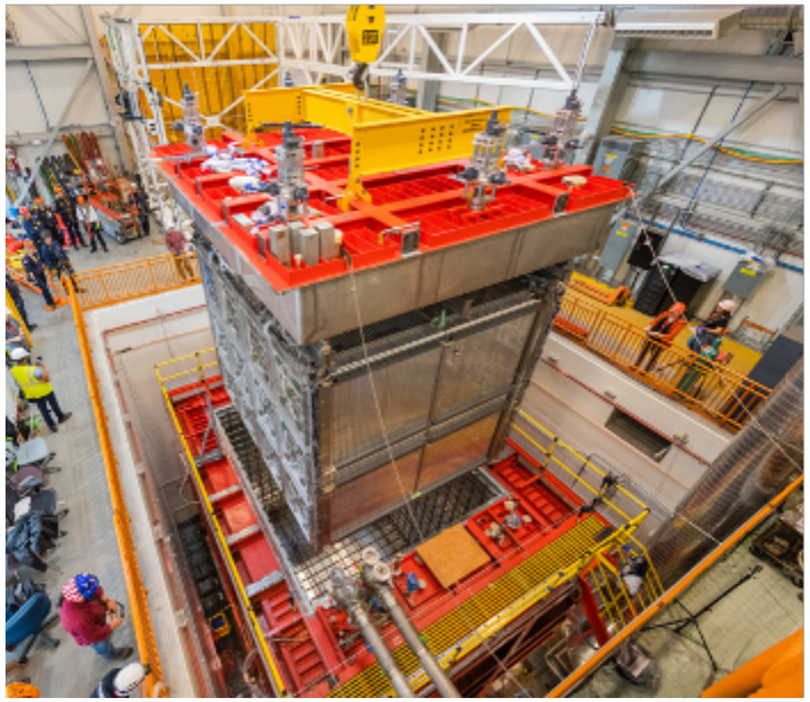
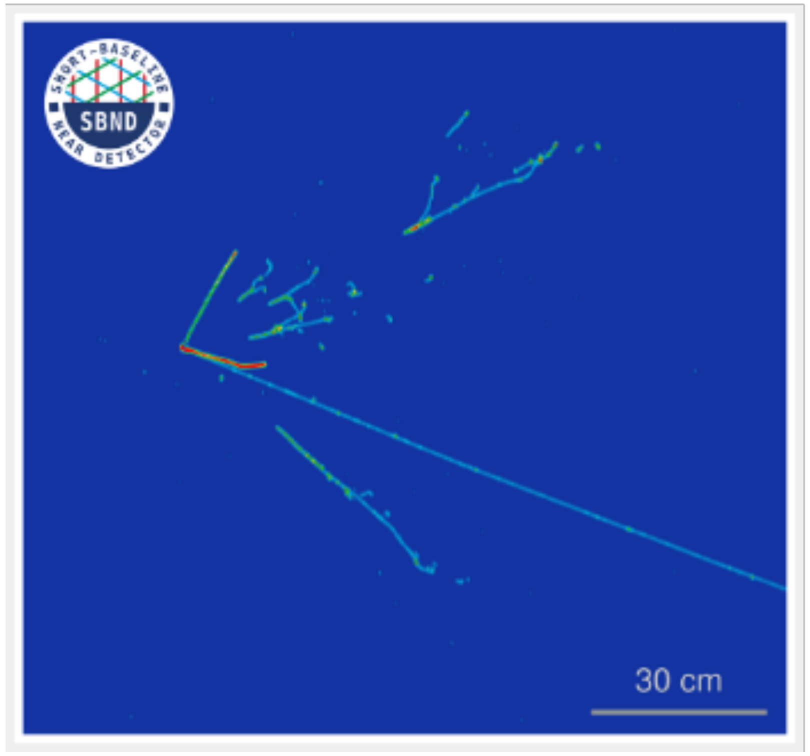
Searches for beam-induced BSM physics at ND



SBND (Short-Baseline Near Detector)

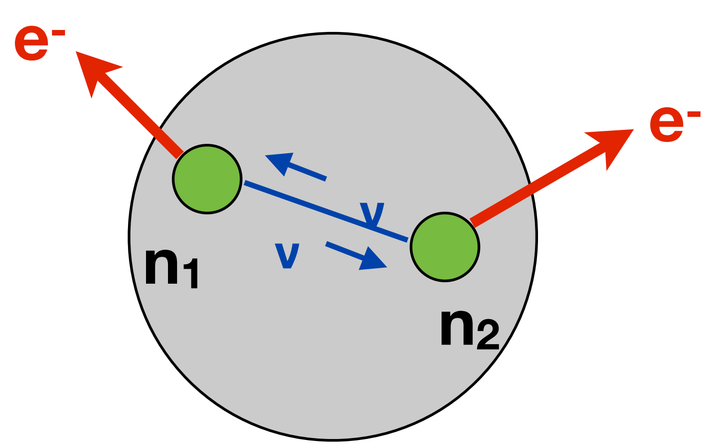
- LAr TPC (112 ton) in Booster Neutrino Beam at FNAL. Near Detector of SBN Program. Similar to ProtoDUNE-HD.
- Physics program:
  - *Address the short-baseline ν oscillation anomalies.*
  - *Measurements of ν_μ and ν_e cross-sections on Ar.*
  - *Search for Beyond Standard Model physics.*
  - *Advance further the LArTPC detector technology.*
- Physics beam data taking since Dec 2024 → Largest ν-Ar interaction dataset in the world. Approved to run until 2028.
- Spanish contributions:
  - *Scintillation light simulation, reconstruction and analysis*
  - *Search for heavy neutral leptons*
  - *Also: contributions to cross-section physics, and X-ARAPUCA readout and DAQ*

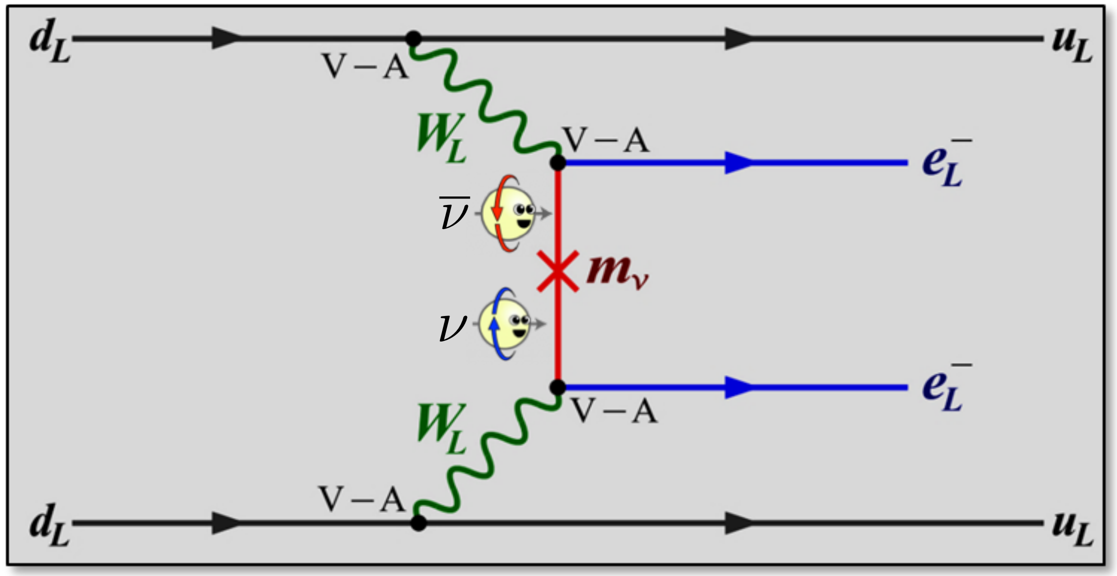




Neutrinoless Double Beta Decay

Why Neutrinoless Double Beta Decay Experiments





An observation of 0νββ would:

- demonstrate that neutrinos are Majorana fermions
  - New mass scale / mass generation mechanism
- imply total lepton number violation
  - Explanation of matter/anti-matter asymmetry (through leptogenesis)?
- provide information on neutrino ordering and mass scale

See talk by C. Gonzalez-García

Laboratorio Subterráneo Canfranc

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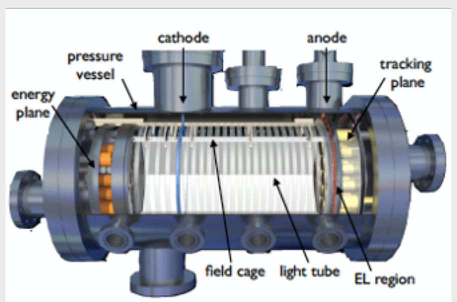
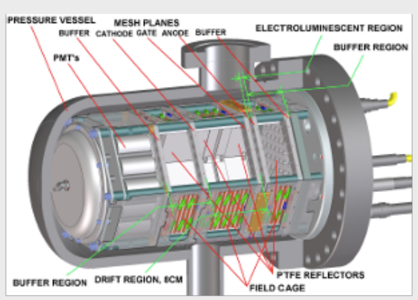
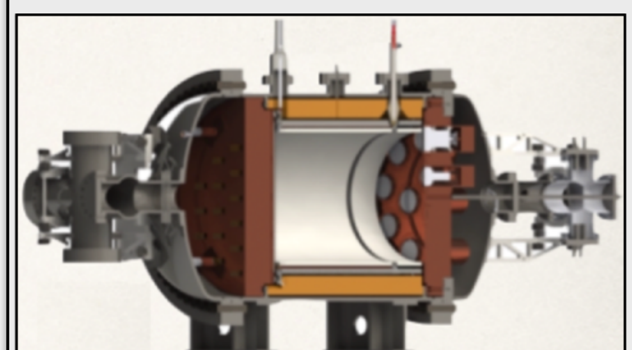
NEXT Experimental Program

Prototypes (~1 kg)
[2009 - 2014]

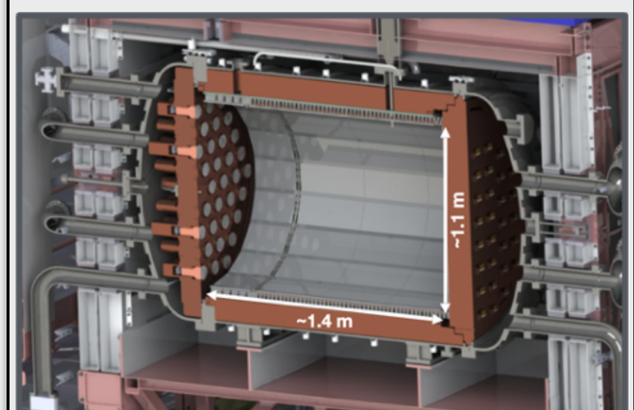




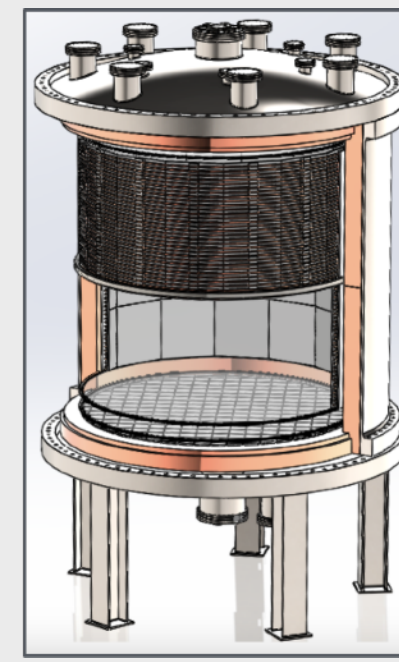
NEXT-White (~5 kg)
[2016 - 2021]



NEXT-100 (~100 kg)
[2024 - 2028]



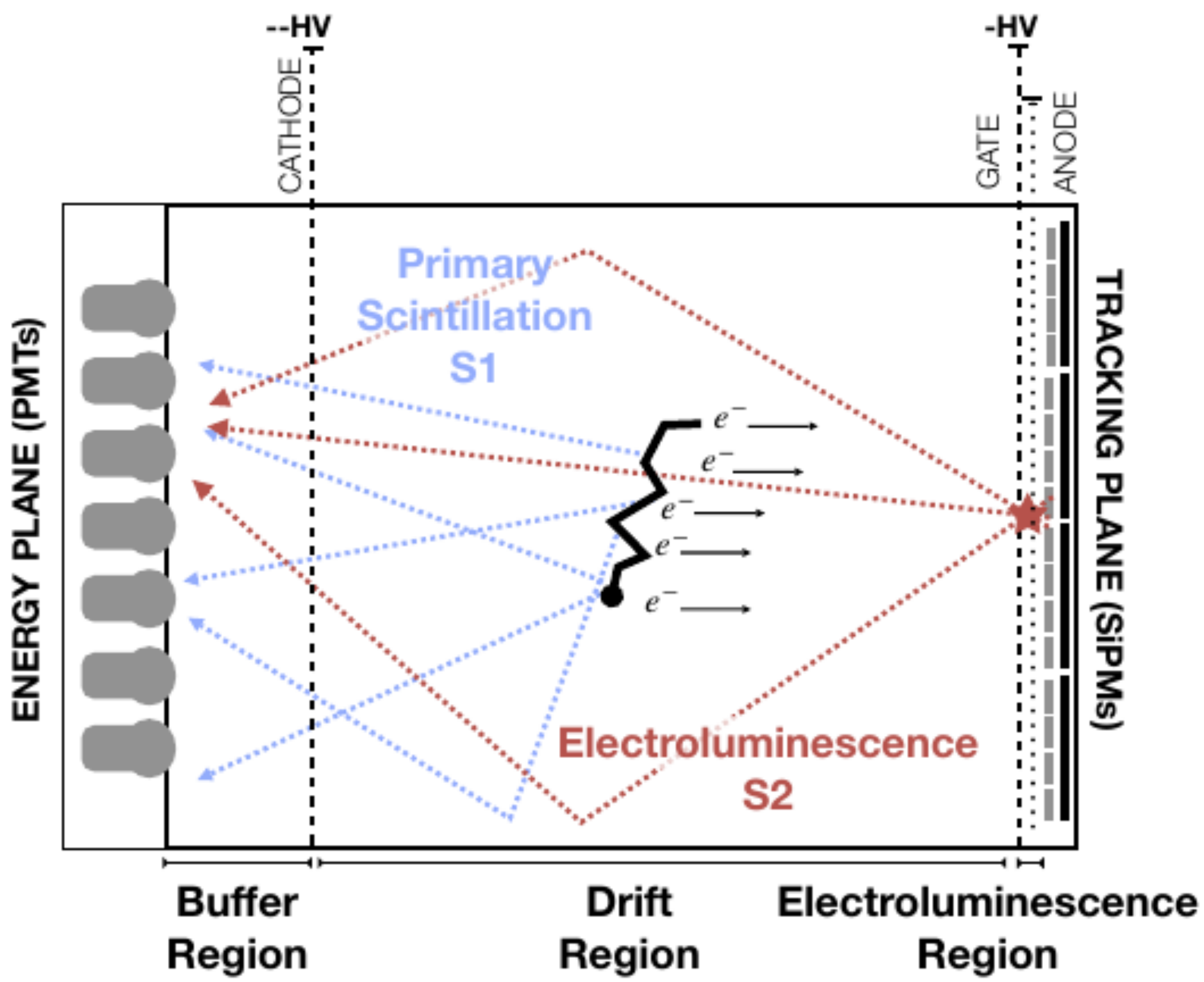
NEXT-HD / NEXT-BOLD (ton-scale)
[future generation]

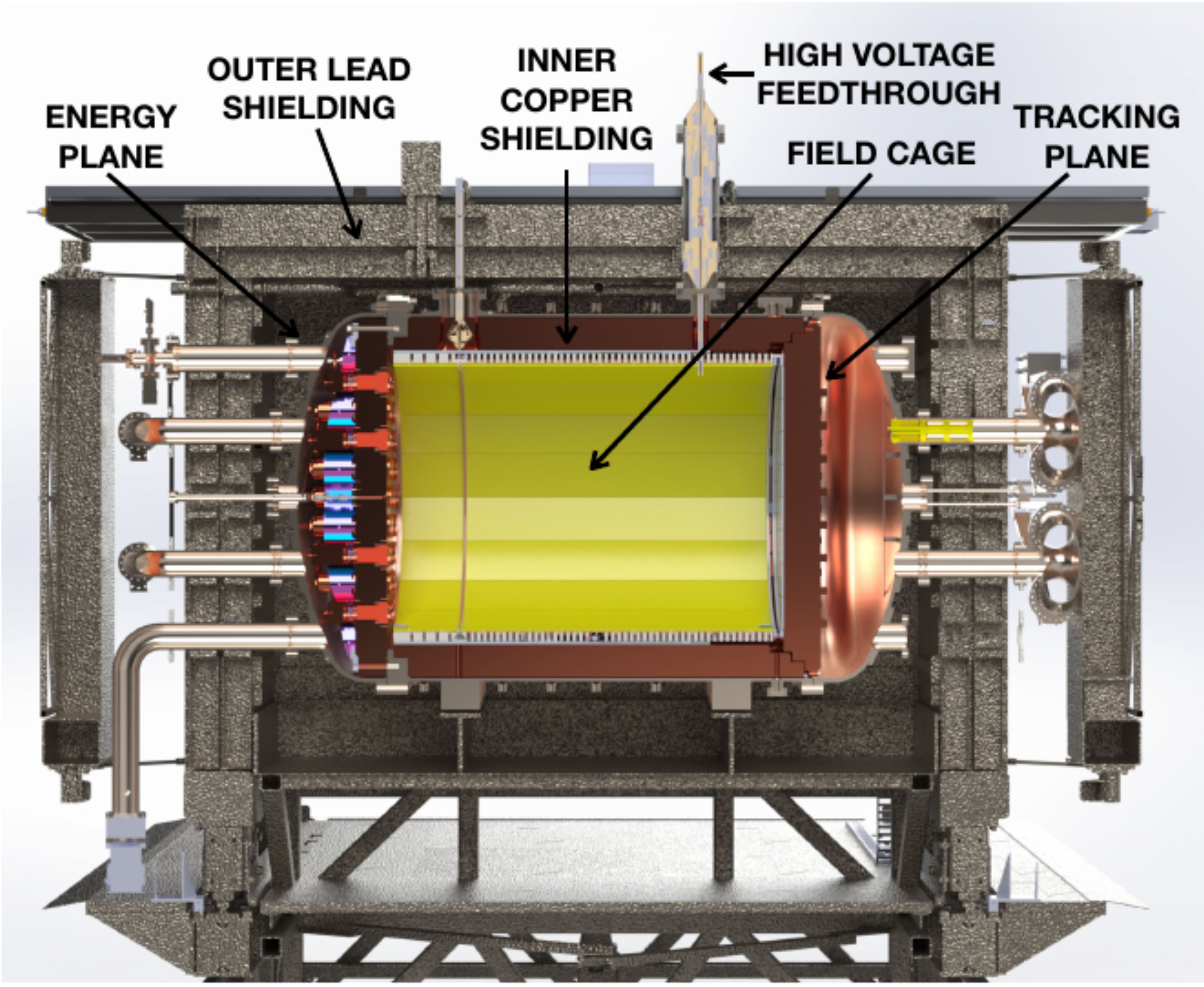


- Spanish institutions (~60 collaborators) lead international collaboration

NEXT-100 at the LSC

- High-Pressure Electroluminescent TPC
- ~100 kg of xenon enriched at 90% in ^{136}Xe at 15 bar
- Search for 0νββ decay in ^{136}Xe (~10^{25} yr) and test-bench for ton-scale technology





NEXT-100 Status

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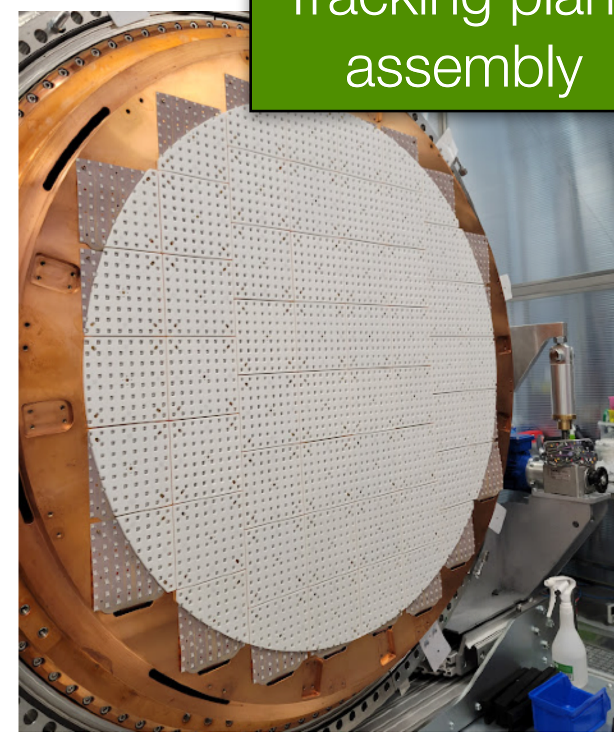
- NEXT-100 operating since mid-2024
- Successful commissioning completed, arXiv:2505.17848

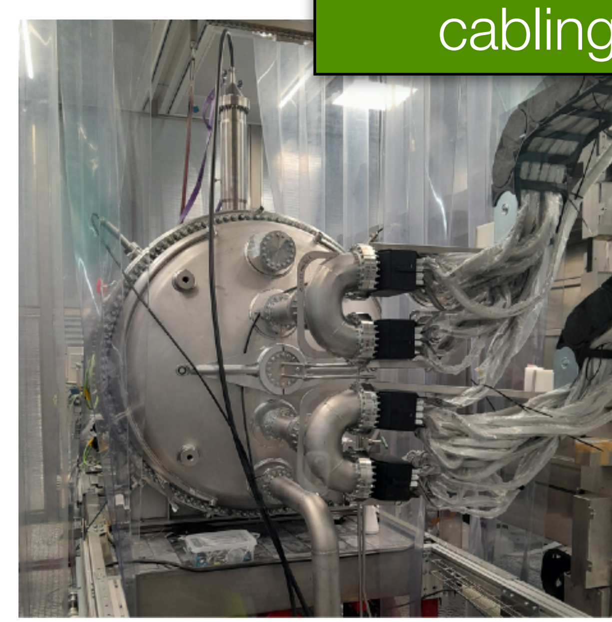


Tracking plane assembly

Pressure vessel

Field cage installation

Energy plane assembly



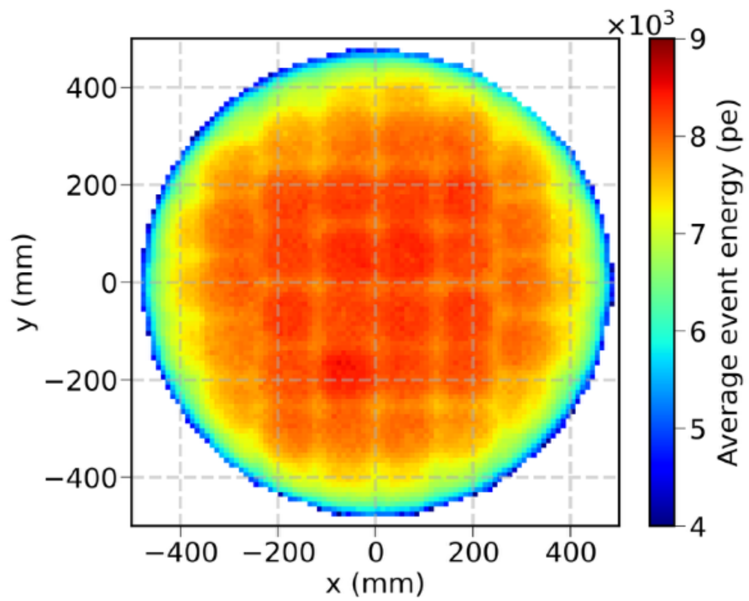
NEXT-100, HV, cabling

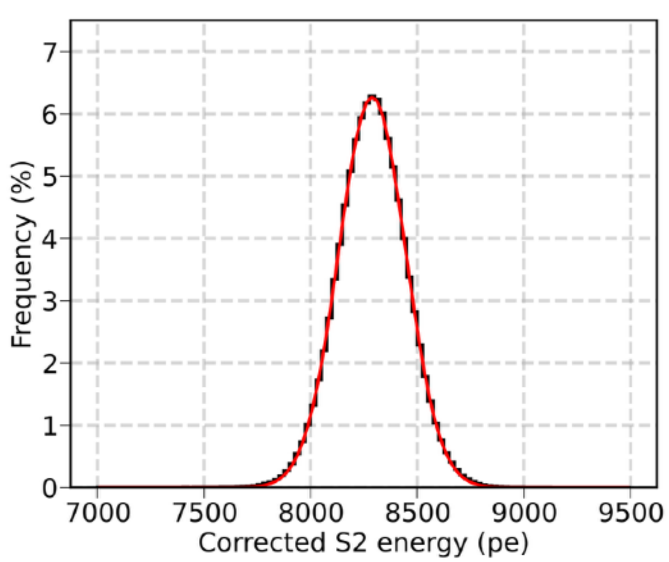
NEXT-100 First Results at 4 bar: Calibration

Low Energy (^{83m}Kr in gas, 41.5 keV)

- Continuous calibration and monitoring

Geometrical corrections



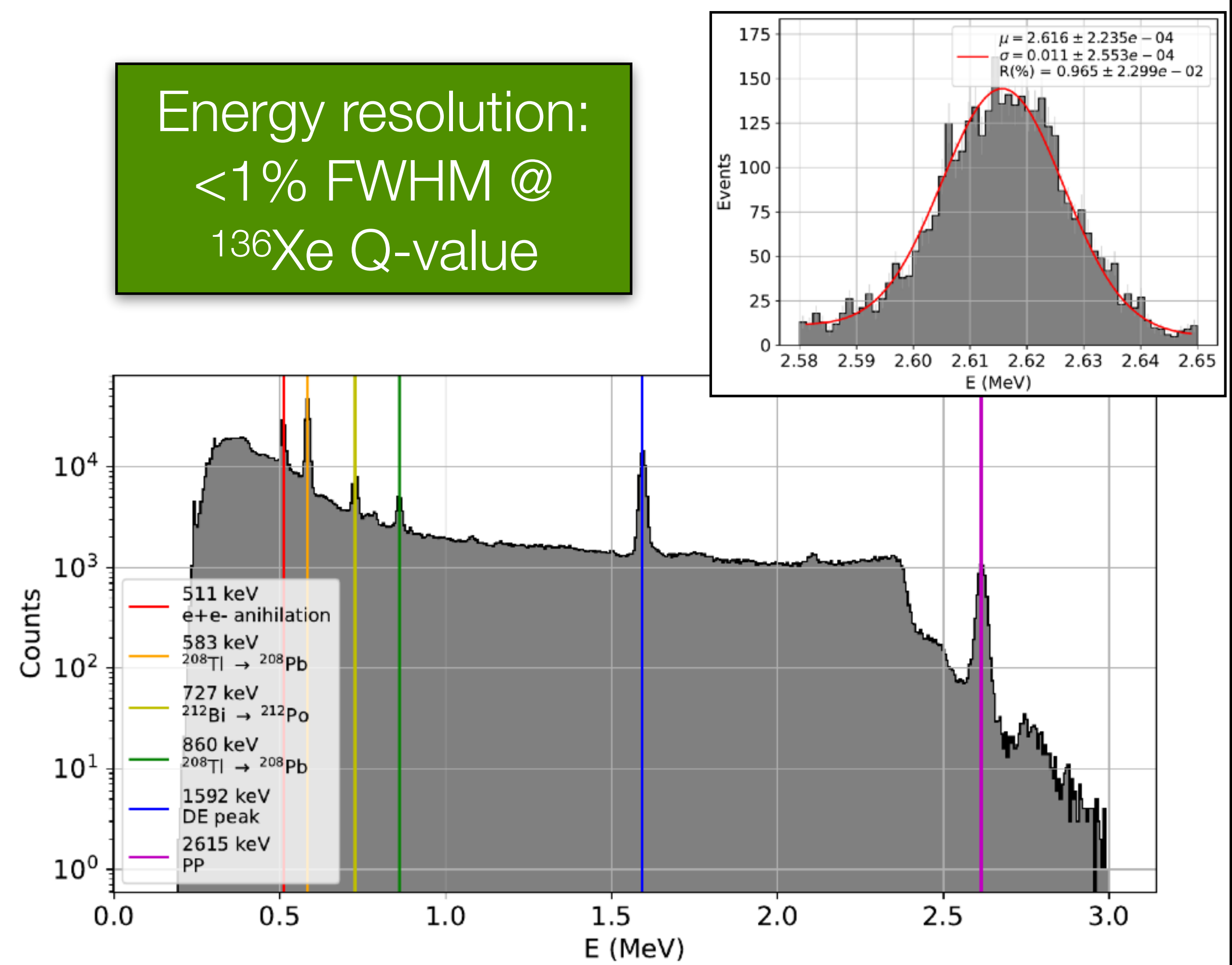


Energy resolution: 4.45% FWHM @ 41.5 keV

High Energy (^{228}Th in external port, 511 - 2615 keV)

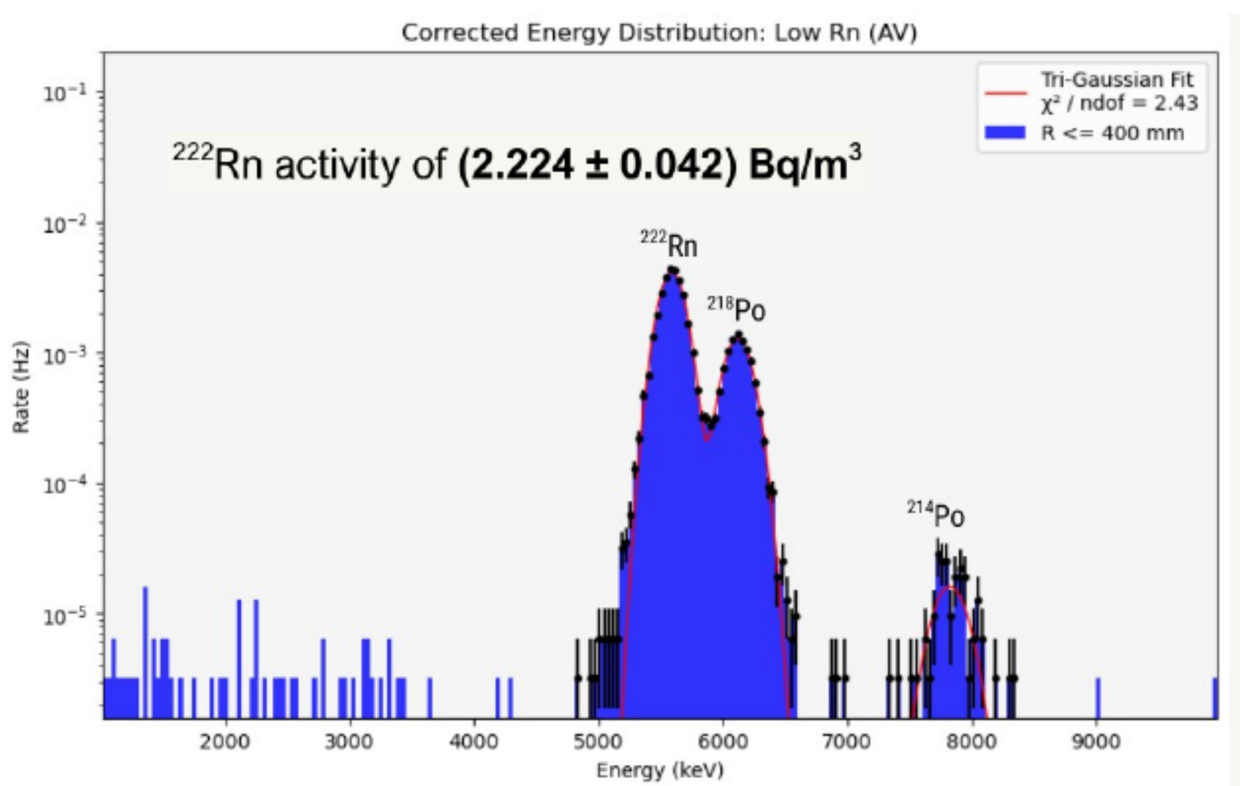
- Measurement of the energy scale and resolution versus energy

Energy resolution: <1% FWHM @ ^{136}Xe Q-value

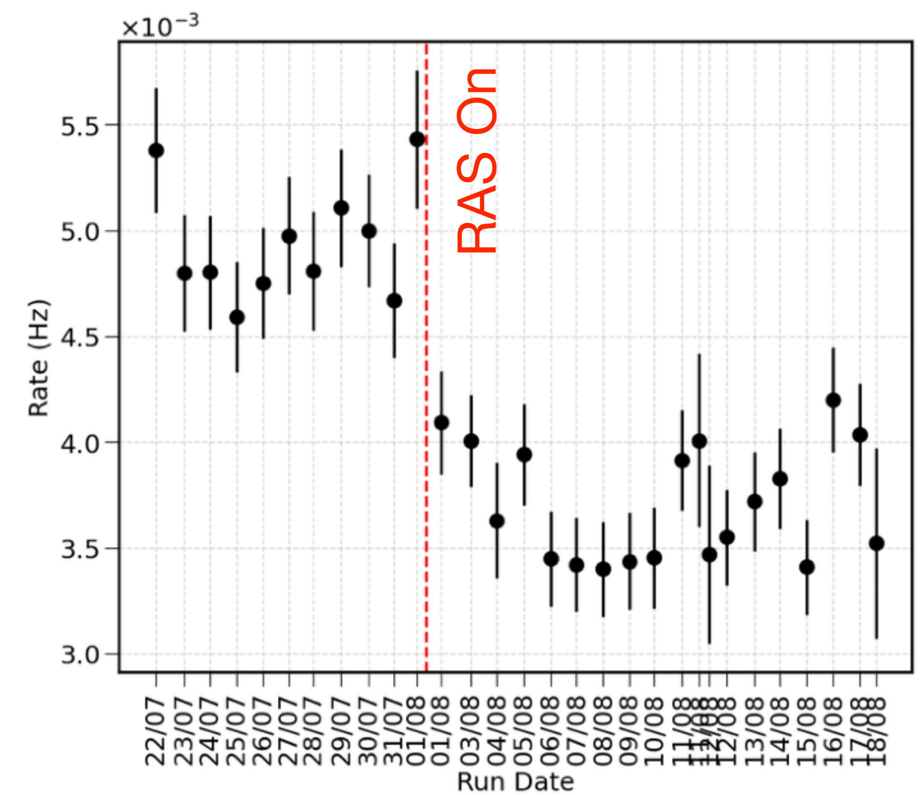


NEXT-100: Backgrounds and Plans

- Internal and airborne Rn-induced background:



- First low-background run (lead castle closed + Rn Abatement System):



Plans:

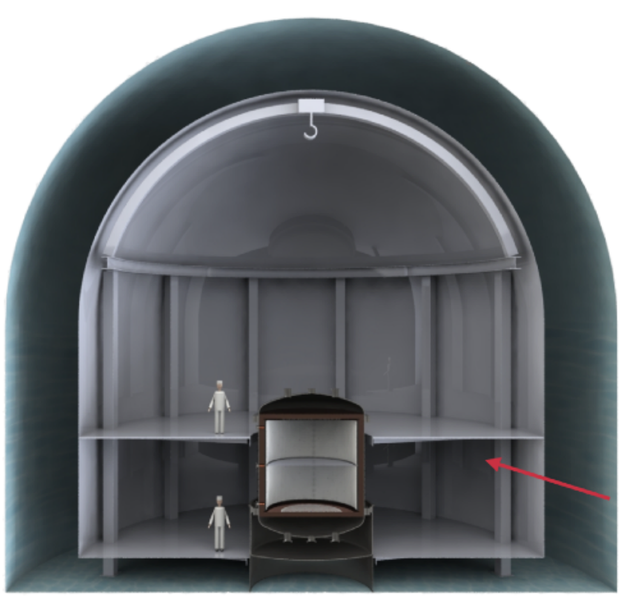
- *Short-term: validation of the expected background budget at 4 bar*
- *Mid-term: 0νββ search with extended (~3 yr) run at 10 bar with both ^{136}Xe-enriched and depleted Xe*
- *Long-term: NEXT-100 upgrade to validate NEXT-ton technologies*

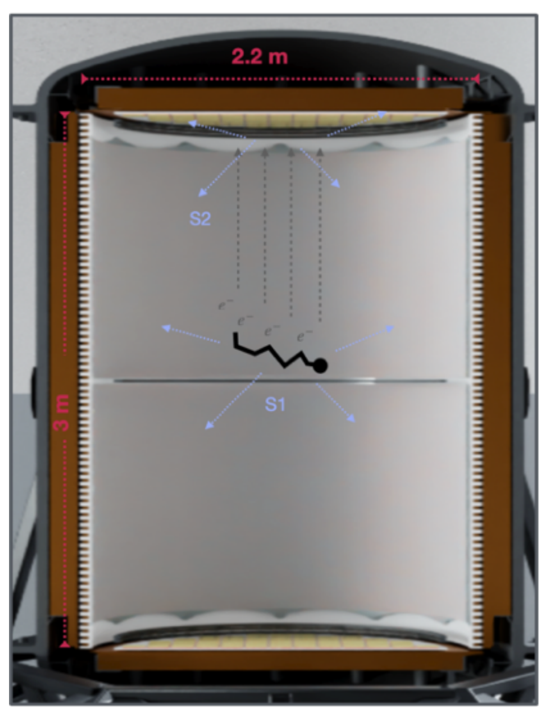
NEXT Future: NEXT-HD and NEXT-BOLD

- Two parallel lines of development for ton-scale detectors
  - *Exact detector mass TBD*
  - *Baseline host lab: LSC*

NEXT-HD

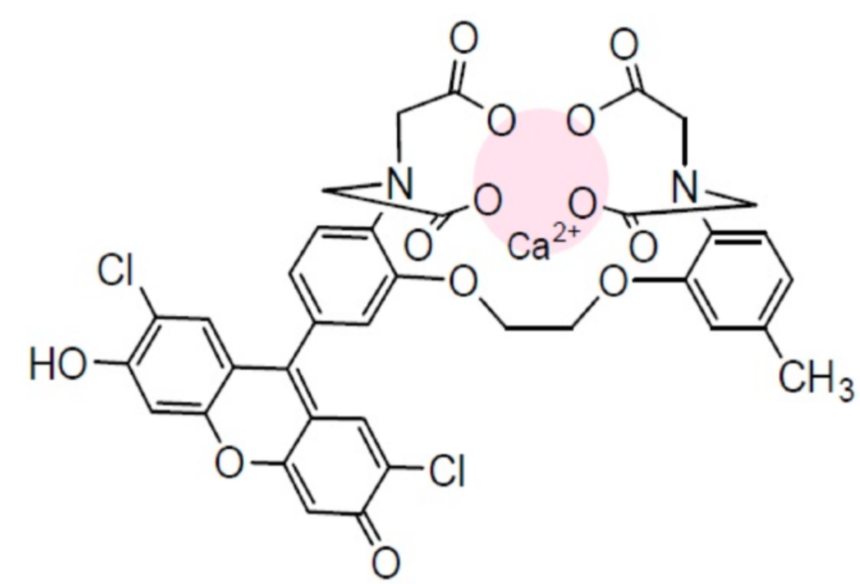
- High-definition reconstruction of e^- tracks with improved conventional technologies
- Sensitivity ~10^{27} yr after 10 yr





NEXT-BOLD

- Addition of single barium (Ba^{++}) tagging for a background-free experiment
- $^{136}Xe \rightarrow {}^{136}\mathbf{Ba^{++}} + 2e^-$
- Sensitivity ~10^{28} yr after 10 yr



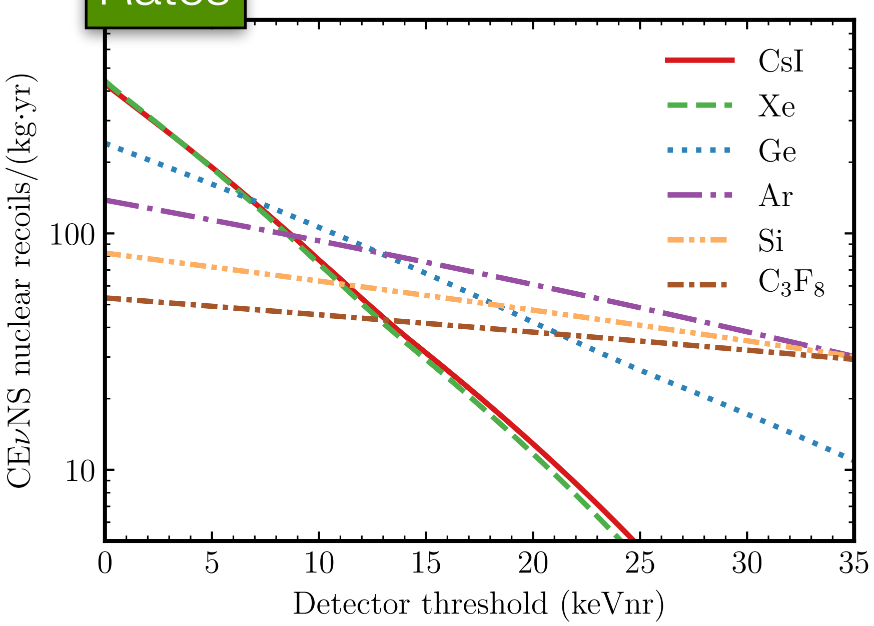
European Research Council
Established by the European Commission

Coherent Elastic Neutrino-Nucleus Scattering

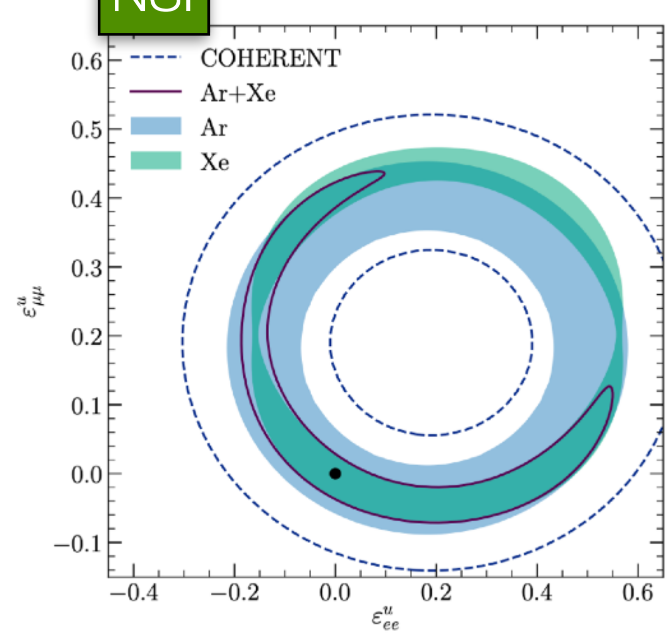
Why CEvNS Experiments

- **CEvNS**: scattering between low-energy neutrinos and atomic nuclei as a whole, via the weak neutral current. Only observable: recoiling nucleus
- Precision measurement of CEvNS provides a direct probe to:
    - **SM** physics: weak mixing angle, nuclear structure,…
    - **BSM** physics: NC non-standard neutrino interactions (NSI), ν magnetic moment,…
- New physics typically at low energies. Different nuclei and ν sources break degeneracies
- *See talk by C. Gonzalez-García*

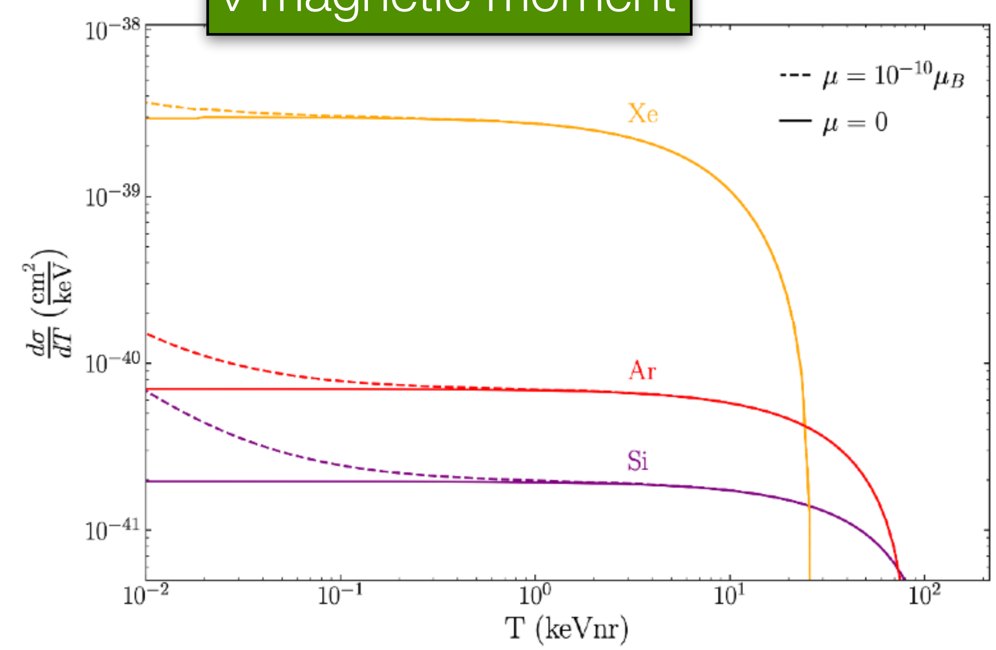
Rates



NSI



ν magnetic moment



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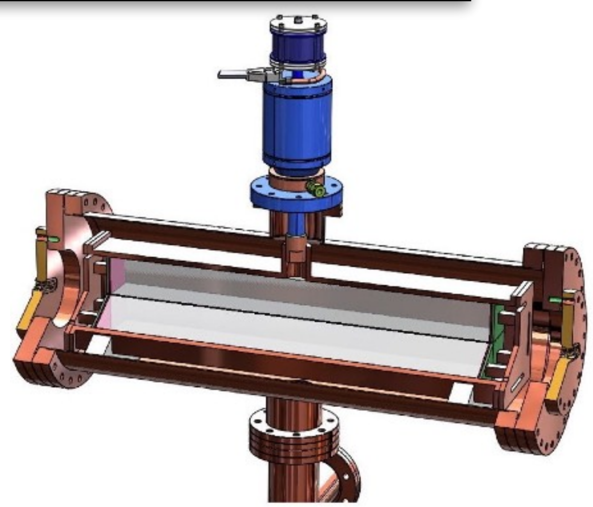
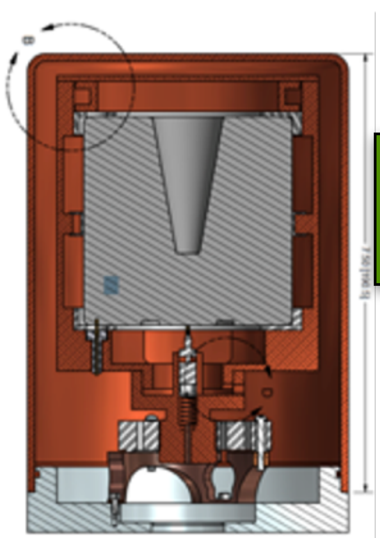
European Research Council
Established by the European Commission

CEνNS Experiments in Spain

- Four experiments in development, supported by 3 ERC grants
- Innovative technologies to detect νs from spallation sources and nuclear reactors

CºSI: Cryogenic undoped CsI

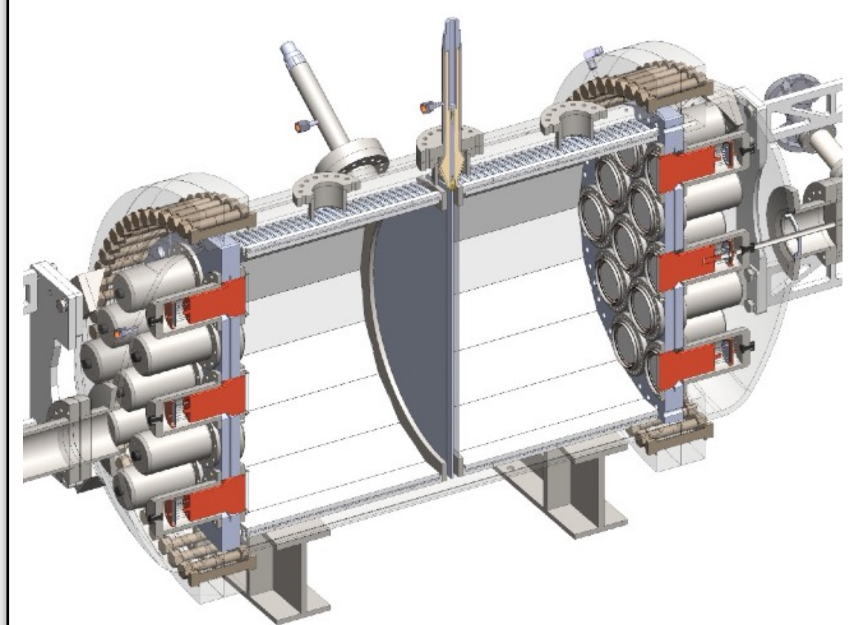




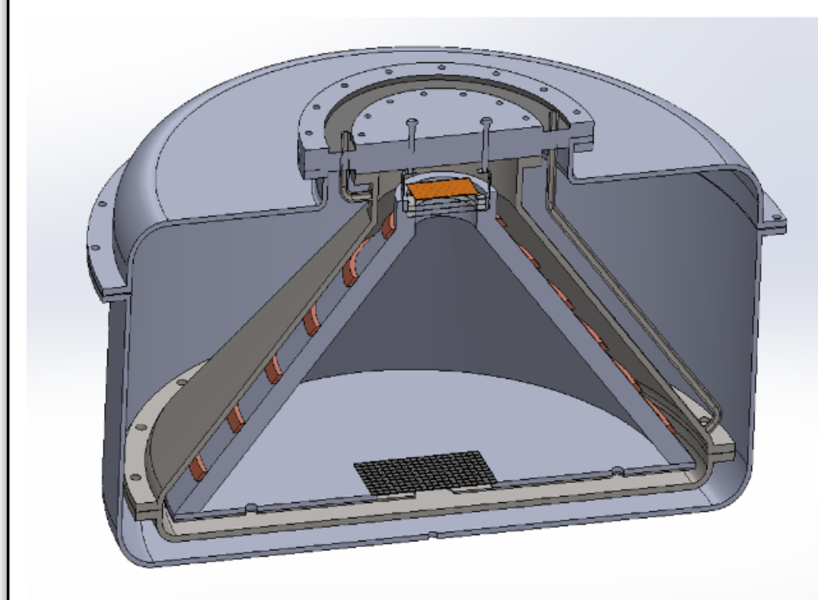
PPC: p-type point contact Ge

@

GanESS: High Pressure Gas TPC



COLINA: Conical liquid noble gas TPC



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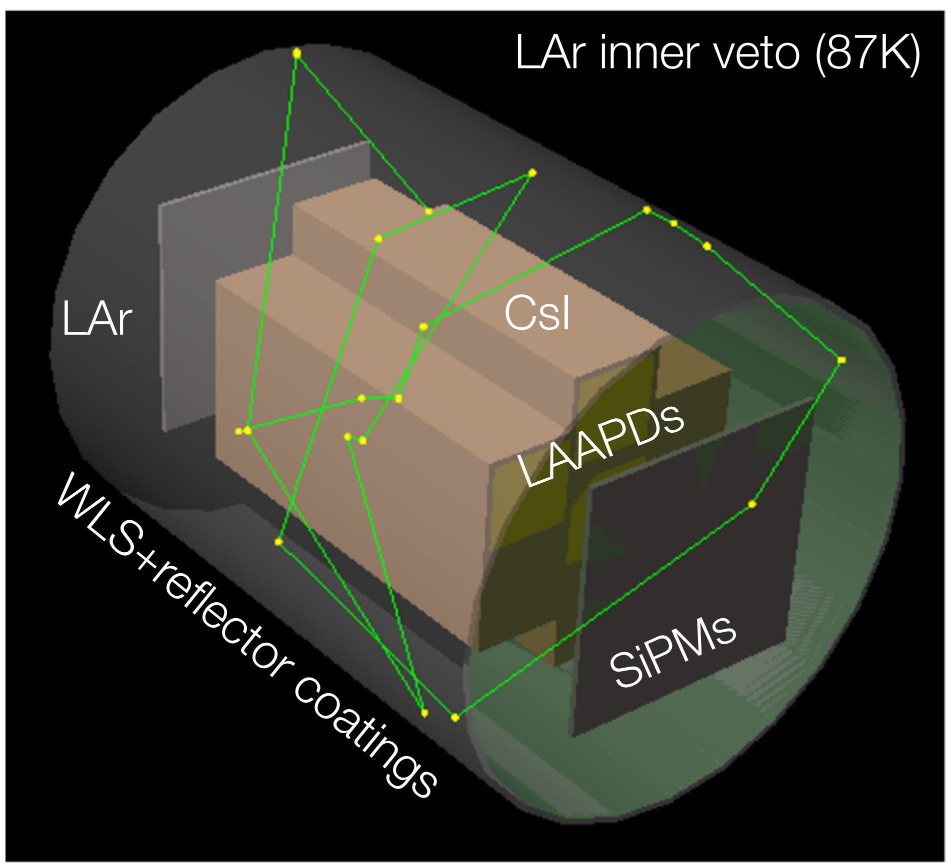
CEvNS Solid Detectors: C^{o}SI and PPC

Cryogenic undoped CsI crystals at spallation sources

- Developing a LAr inner active veto
- Much improved radiopurity wrt SNS



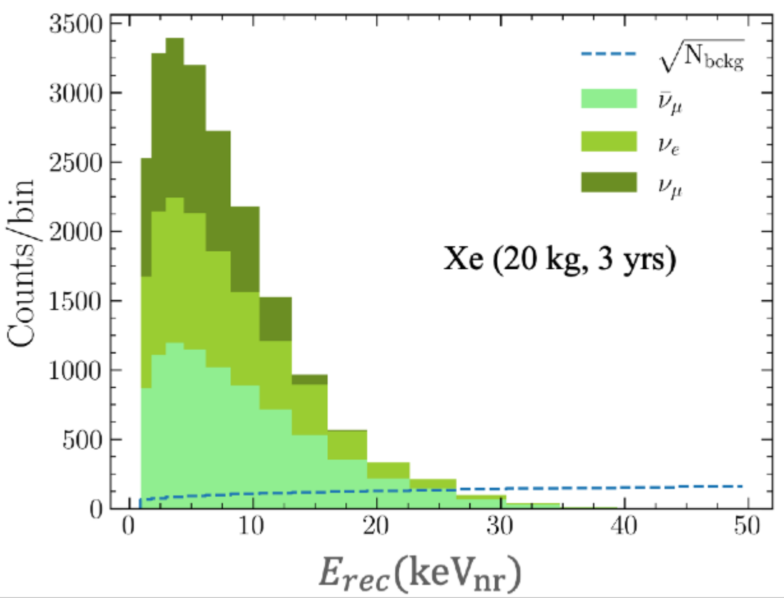
Ge PPC deployment at Vandellòs-II power plant

- Upgraded 3 kg Ge PPC, 20.1 m from 2.94 GW_{th} core.
- 160 eV_{ee} threshold, background x20 lower than latest CONUS result
- Stable data-taking since Dec 2024. Results expected for early 2026.

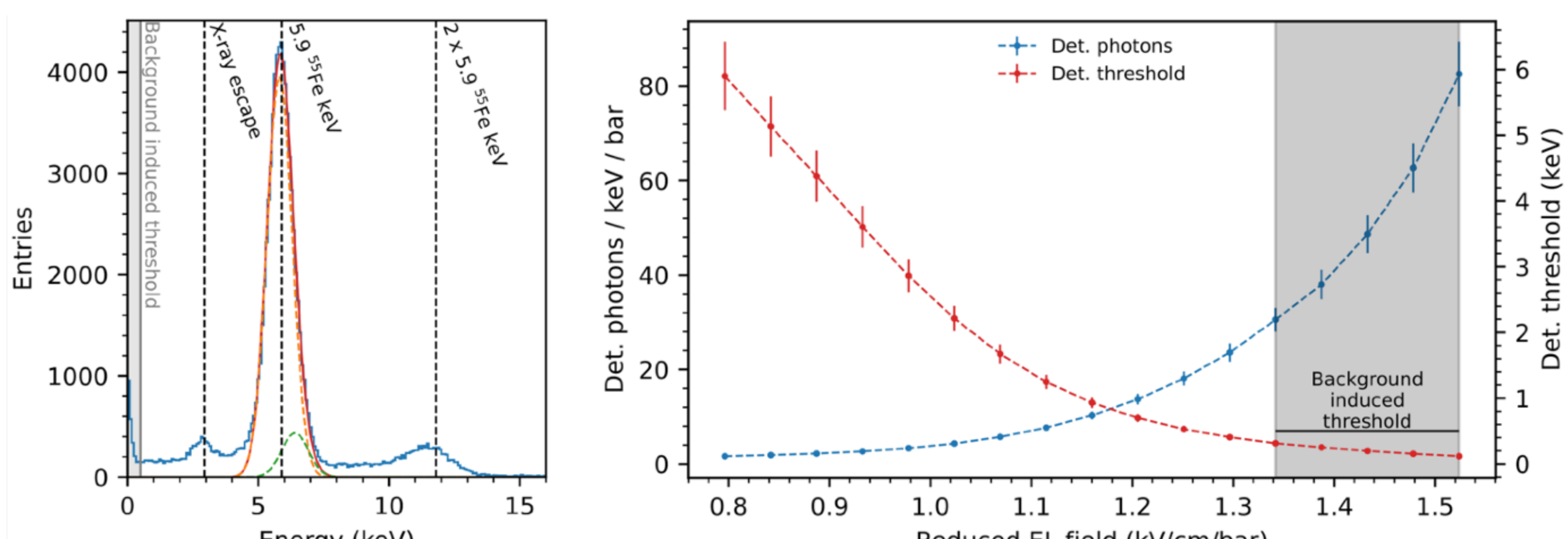
CEvNS Gaseous Detectors: GanESS

- High Pressure Gaseous TPC technology developed by NEXT collaboration for 0νββ searches, pushed towards higher pressures.
- Electroluminescent amplification of ionization signals allow for lower thresholds
- Operation with different nuclei (Xe, Ar, Kr) to break degeneracies
- GanESS demonstrator operated with Ar at 8.62 bar

Events after 3 years running a 20 kg Xe detector at 20 m from ESS target



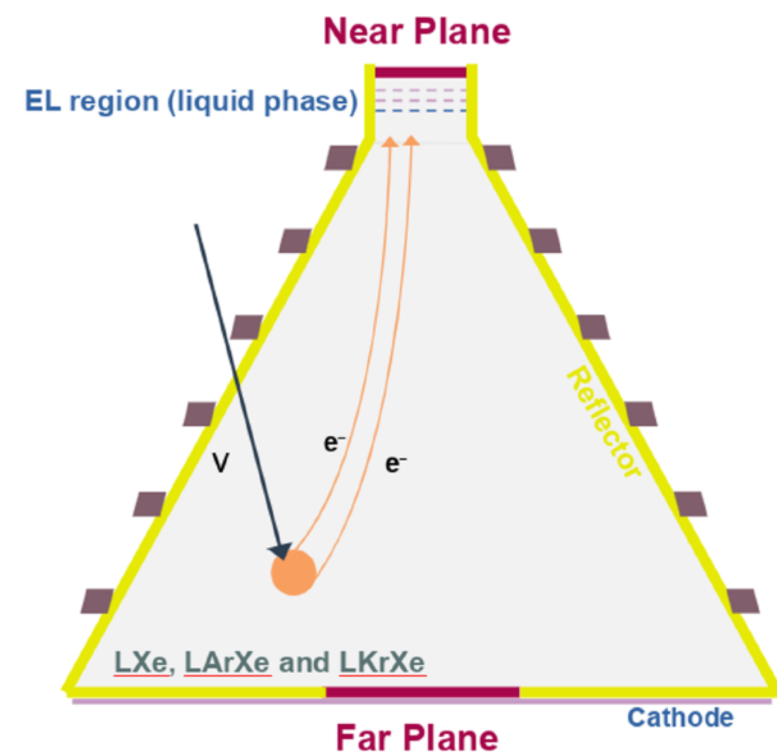
Energy spectrum and detection threshold evaluated with ^{55}Fe source → threshold of 0.42±0.04 keV$_{ee}$ (~16 ionization electrons)

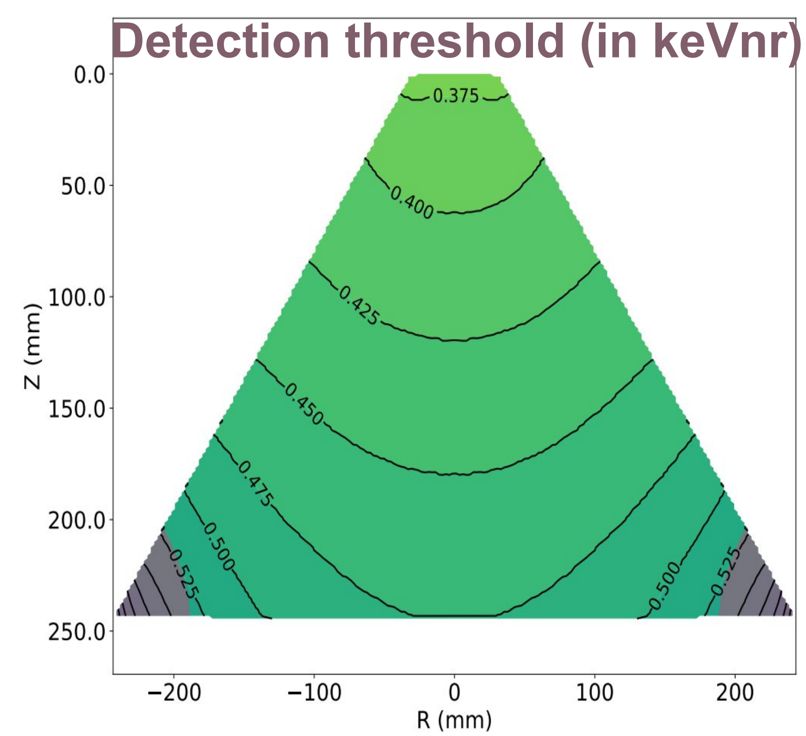


CEvNS Liquid Detectors: COLINA

- Conical shape TPC to focus charges into small region
  - EL amplification in liquid with thin wires
  - Good S2 light collection efficiency (~13%) with few sensors
    - *100 VUV SiPMs at Near Plane*
    - *400 VUV SiPMs at Far Plane*
  - 17 dm^3 internal volume → ~50 kg of LXe, ~25 kg of LAr with ~80% fiducial volume
  - Potential S2 threshold of 0.525 keV_{nr} (S2-only searches, 4-5 keV_{nr} with S1)

2026	2027	2028	2029	2030 and beyond
p-COLINA (prototype COLINA) construction and operation		COLINA construction		COLINA operation

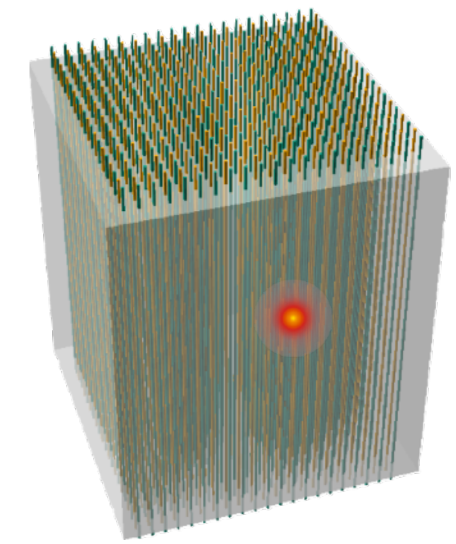




LiquidO

LiquidO

- Liquid scintillator detection using an opaque medium and an array of WLS fibers for light detection
- Main purpose: stochastically confine light near its creation point to preserve the topological information of particle interactions



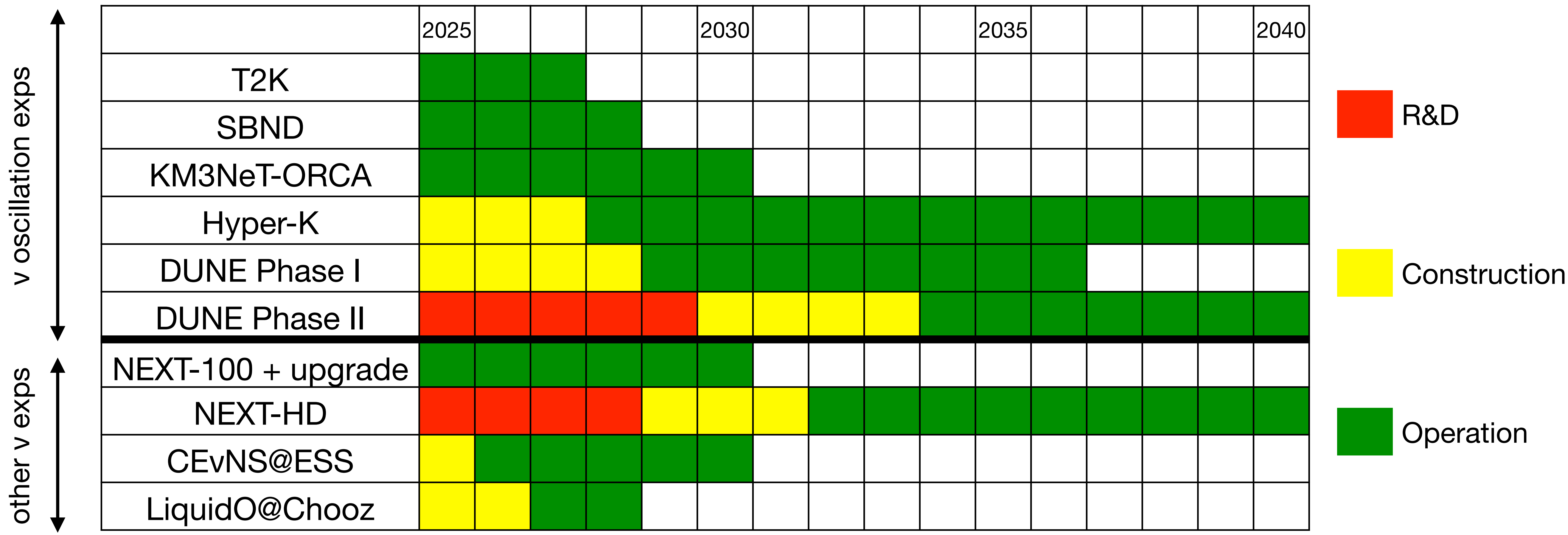
Spanish participation:

- AntiMatter-OTech (HORIZON-EIC-2021-PATHFINDEROPEN-01) (2023 – 2027) CIEMAT
  - *Innovation project: development of ton-scale prototype to use anti-neutrinos as a direct probe of the functioning of industrial nuclear reactors*
  - *Scientific program from the exploitation of the reactor neutrino data (after innovation)*
  - *Ton-scale detector for testing the doping capability (after innovation)*
- Also: Axion search & $0\nu\beta\beta$ (U. Zaragoza), Sterile neutrino at ESS (DIPC), Compton Camera for gamma-ray detection (DIPC), Near Detector for long-baseline oscillation neutrino experiments (IFAE)

Summary

Neutrino Physics Experiments

Spanish contributions and plans



Three possible recommendations (to be discussed):

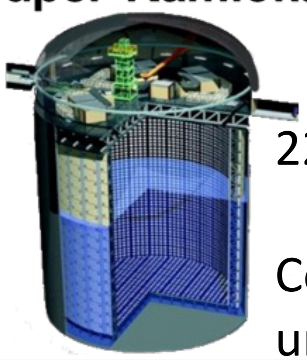
- *Large-scale ν experiments: complete construction and exploitation of DUNE and Hyper-K as a top priority*
- *Smaller-scale ν experiments (some tabletop!): maintain current level of diversity*
- *Keep supporting unique infrastructures such as CERN Neutrino Platform and LSC, for science and R&D*

Backups

From T2K to Hyper-K

Far detector

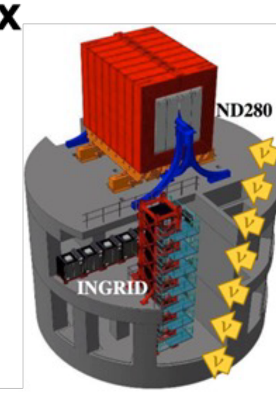
Super Kamiokande



22.5 kton

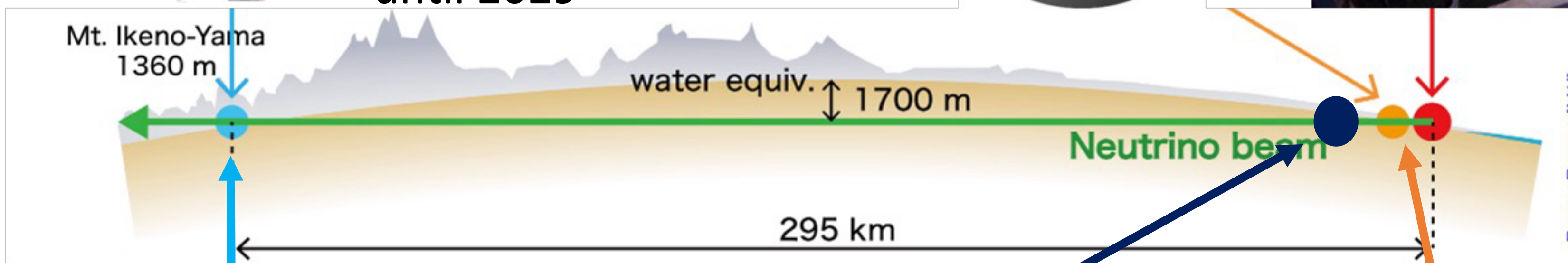
Continues until 2029

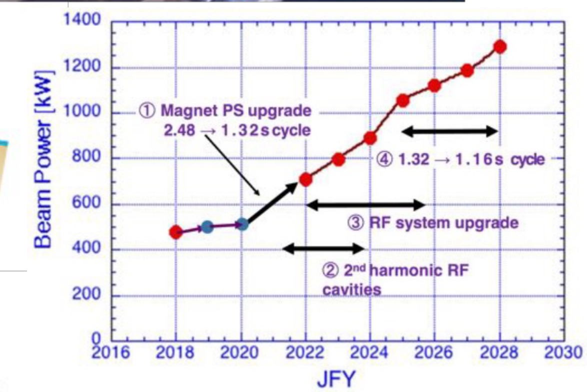
Near detector complex

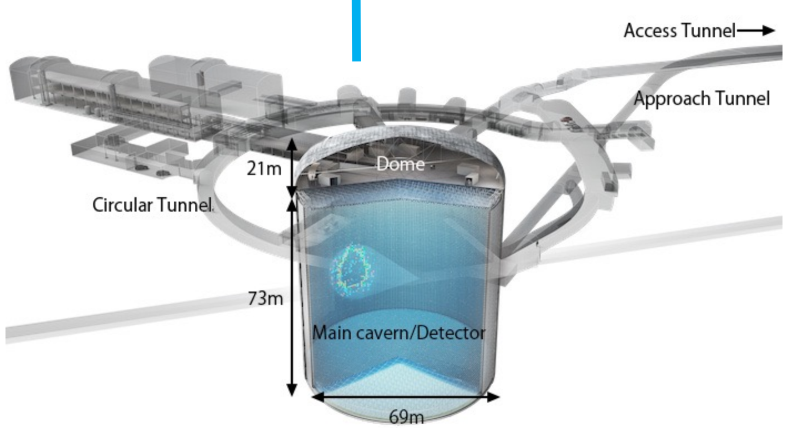


J-Parc

Neutrino Beam

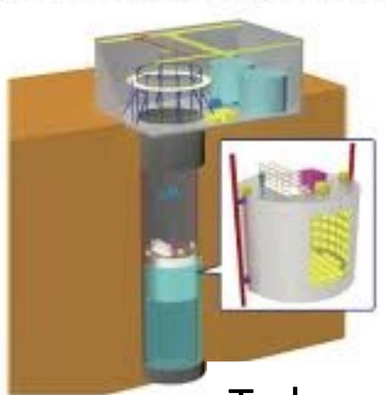






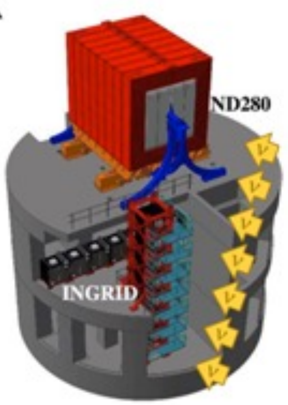
190 kton (fiducial mass)

Off-axis spanning intermediate water Cherenkov detector (IWCD)



To be constructed

Near detector complex

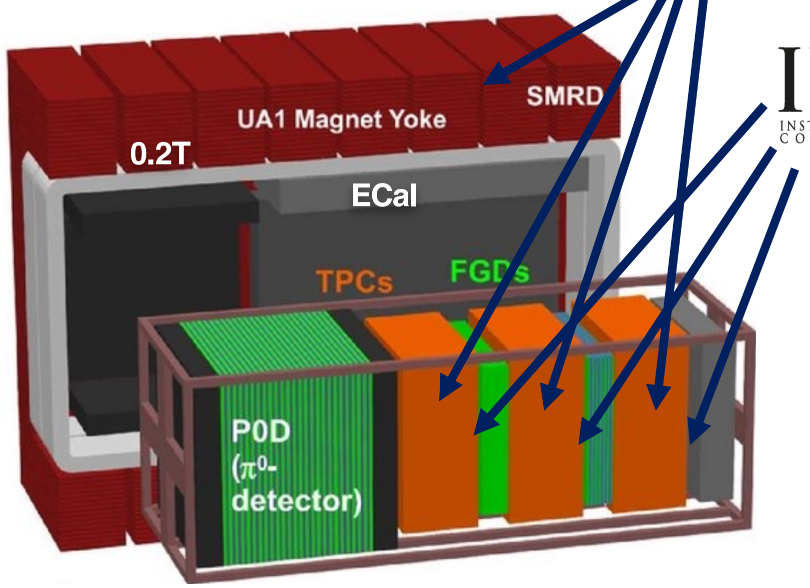


T2K-HK ND280 MOU being finalized soon

INGRID/ND280 crucial for HK

Spanish contributions to T2K/SK

Original ND280 (2009-2022)



Current Spanish institutes:

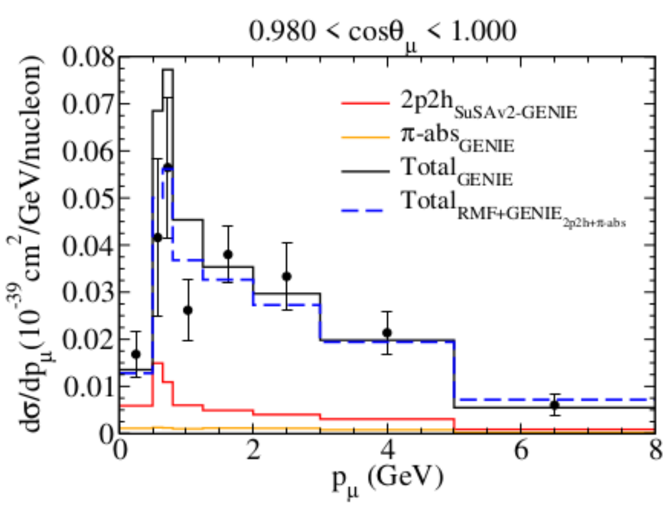
Spanish EC members:

- **T. Lux (IFAE): 2022 –**
- **F. Sanchez (IFAE)**

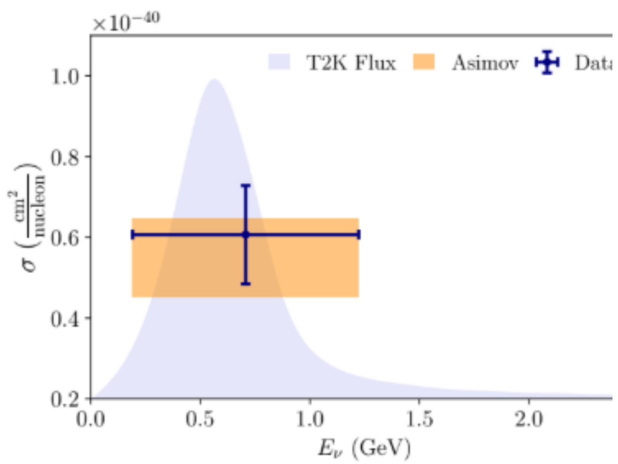
Research interests:

- **Selection development and cross section measurements e.g. CC1pi and NC1pi using ND280 (IFAE)**
- **Implementation of nuclear models in NEUT/GENIE, low energy effects, C to O extrapolation for T2K/SK (US)**
- **SK PMT calibration, low energy neutrino physics e.g. SN neutrinos (UAM)**

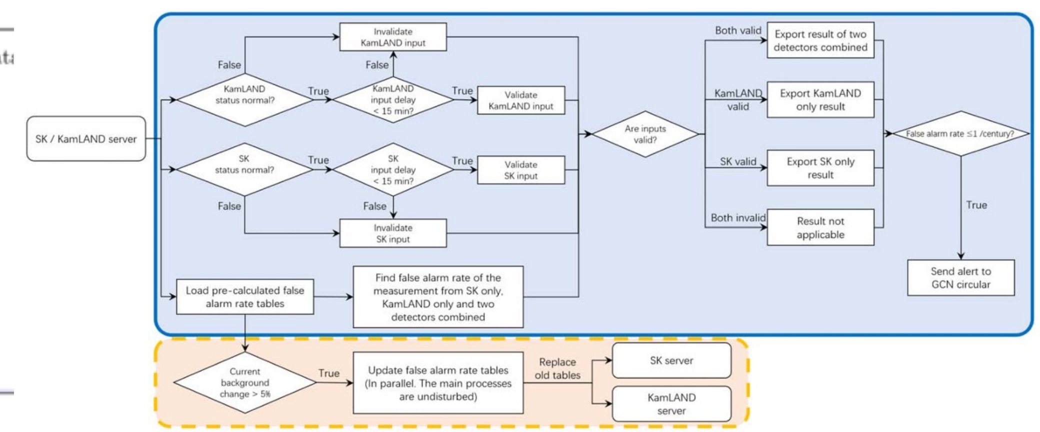
Low-energy effects at T2K CC0π data on ^{12}C (US)



NC1pi+ cross-section (IFAE)

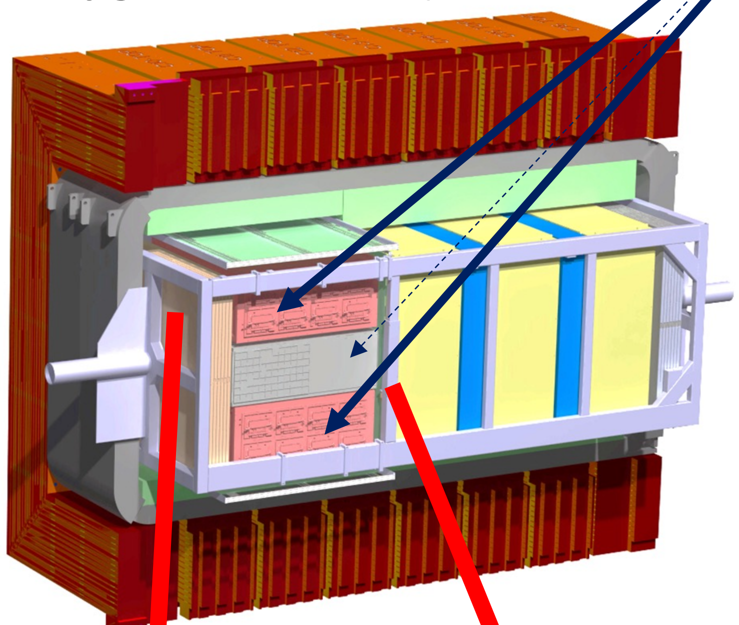


Contribution to SN trigger (UAM)

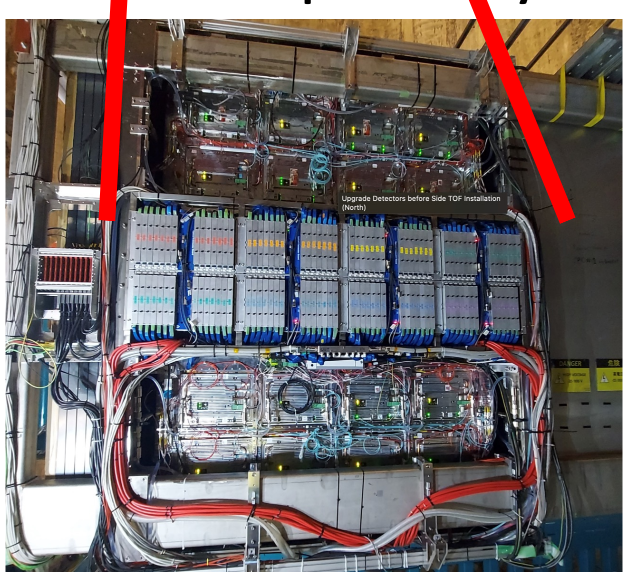


ND280 upgrade

Upgraded ND280 (2017-2024)

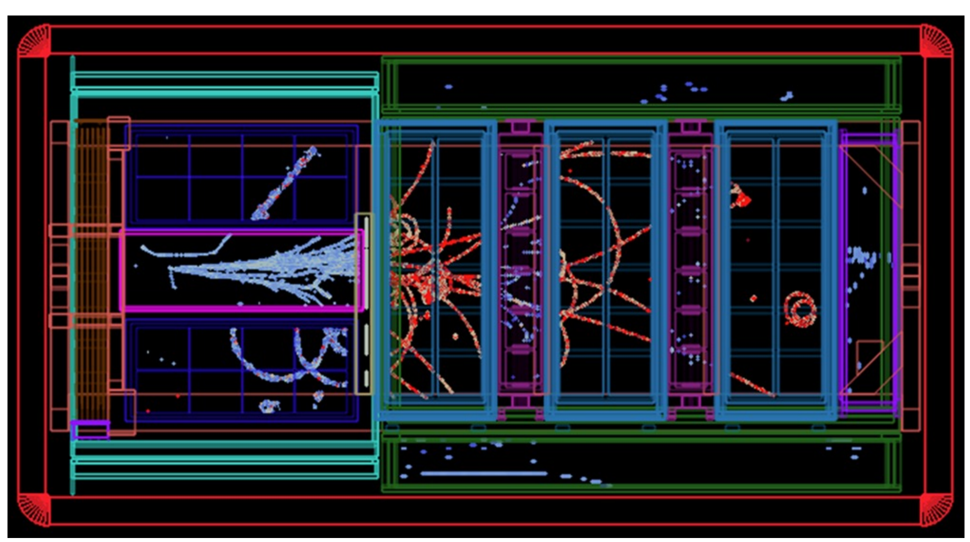


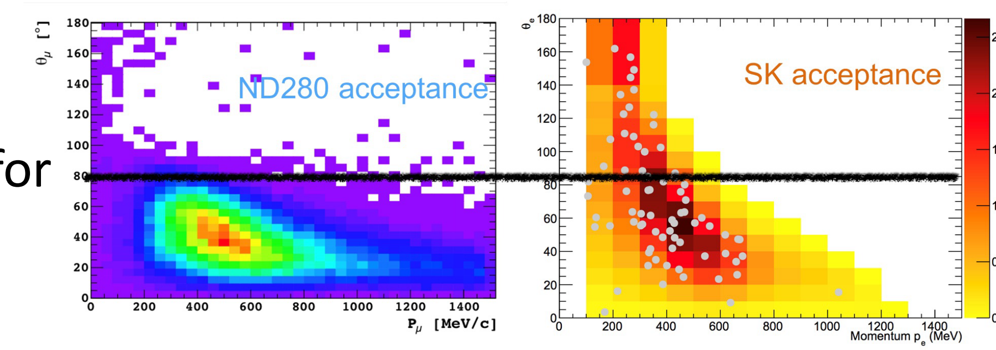
Installation completed May 2024

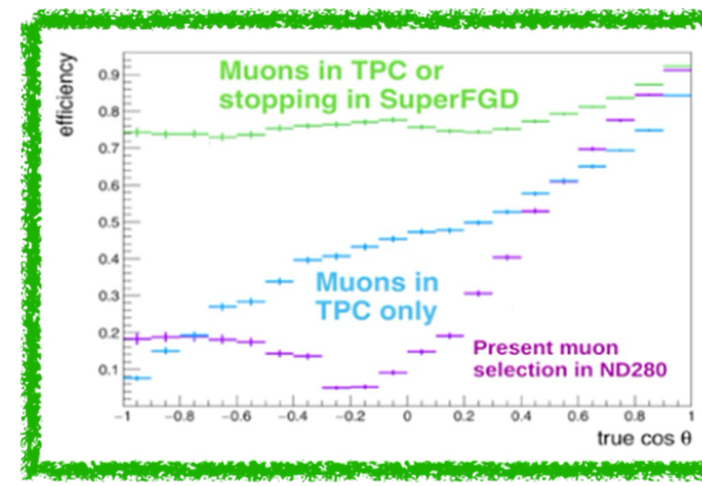


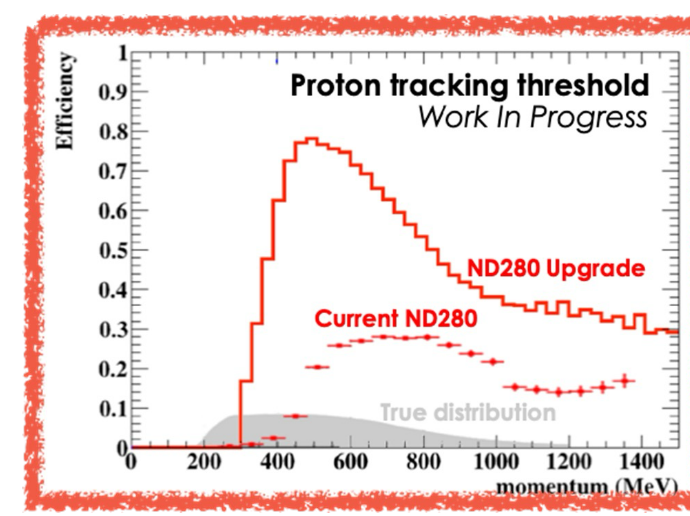
ND280 Upgrade:

- Original ND280 was optimized for forward direction
- Upgrade of ND280 to have 4pi coverage as FD
- Lower detection threshold
- Neutron detection capability
- CERN experiment NP07
- Partly built by Spanish companies
- **T. Lux (IFAE) Co-project leader of ND280 Upgrade project / NP07 spokesperson.**









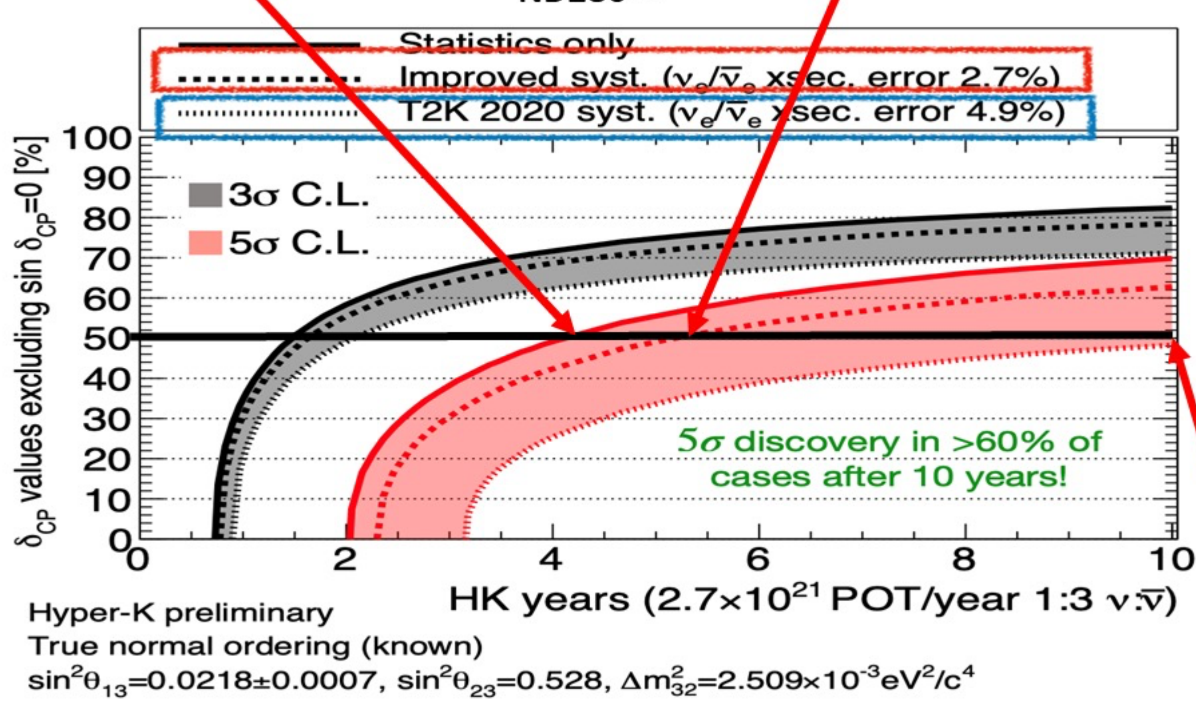
ND280 for HK

- Finalizing MOU to transfer detectors and ND280 expertise from T2K to HK
- Reduced manpower due to T2K colleagues leaving to DUNE
- **T. Lux (IFAE) co-coordinator to ensure operation and data analysis of ND280 for HK**
- Upgraded ND280 crucial for HK

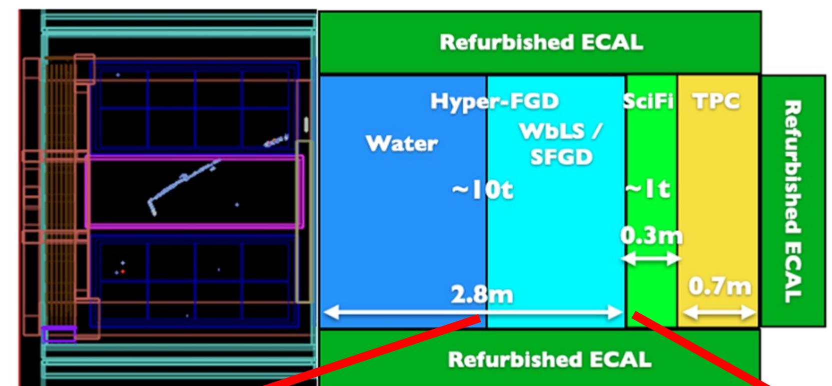
- Possible additional upgrade of ND280, ND280++, under study
- To be completed: 2030+
- IFAE group exploring feasibility to use LiquidO-like scintillator tracker

~4 years statistics only

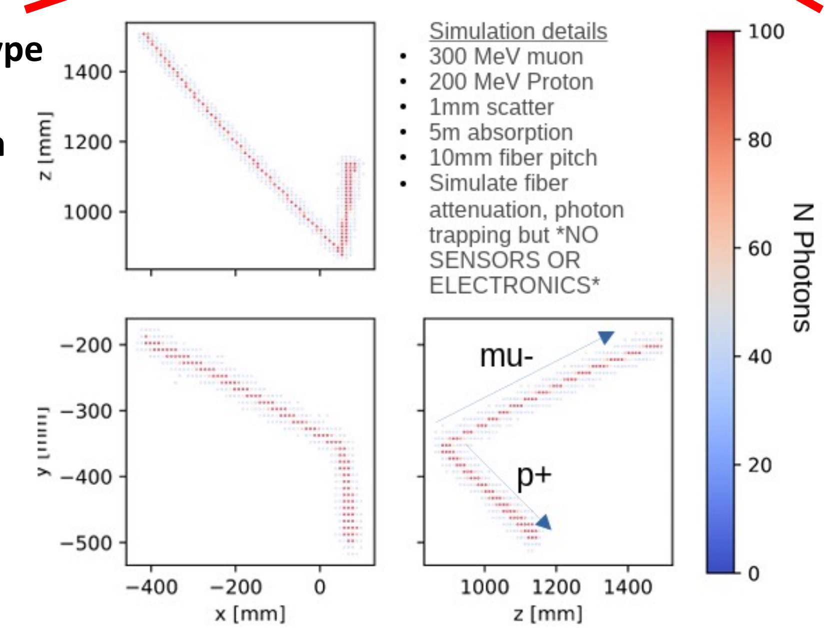
~5 years upgraded ND280 + IWCD + ND280++



10+ years with original ND280 systematics

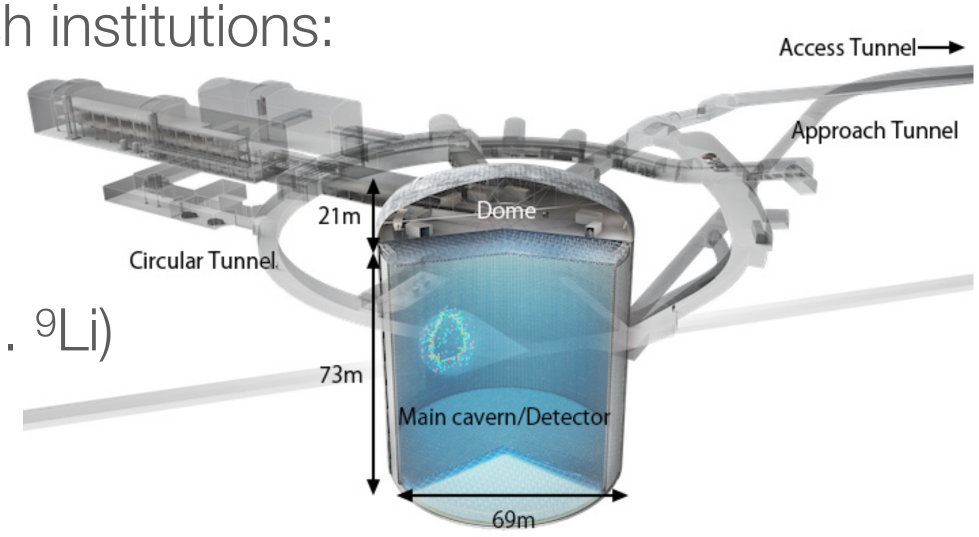


LiquidO-type detector simulation (E. Miller, IFAE)



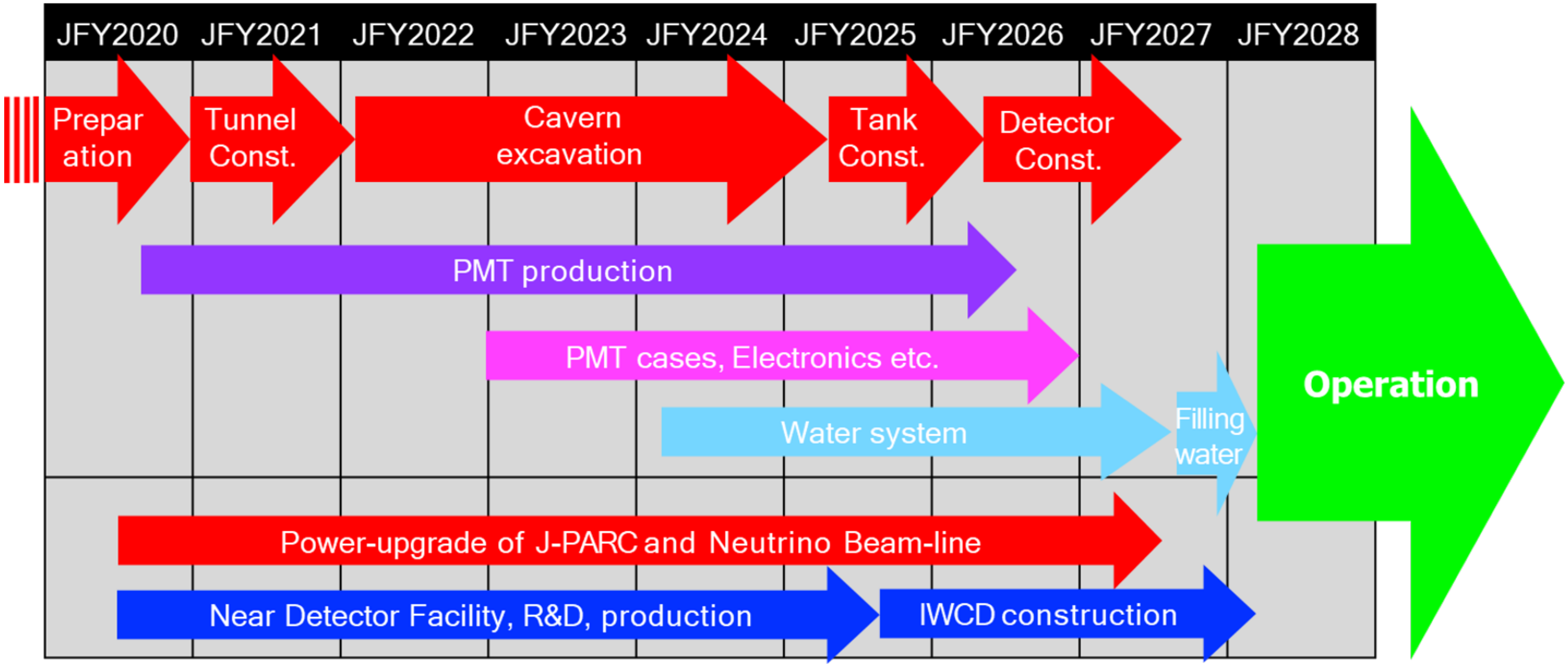
HK Physics Contributions

Very large physics program with strong contribution from Spanish institutions:



- Solar neutrinos (oscillations, flux, BSM)
- Reactor neutrinos (oscillations)
- Cosmic rays (spallation studies, unstable nuclei production e.g. ^{9}Li)
- Pre-supernova neutrinos (w/ neutron tagging)
- Supernova bursts
- **Diffuse SN Neutrino Background (DSNB)**
- **Atmospheric neutrinos (oscillations, flux, tau cross section, BSM)**
- **Long-baseline neutrinos (oscillations, cross-section, flux, BSM)**
- **Calibration sources (WCTE/IWCD/HK-FD)**
- Proton decays
- Exotic decays (BSM e.g. neutron-antineutron oscillations)
- High Energy neutrino astrophysics (GRB, GW coincidence, astrophysical diffuse flux)

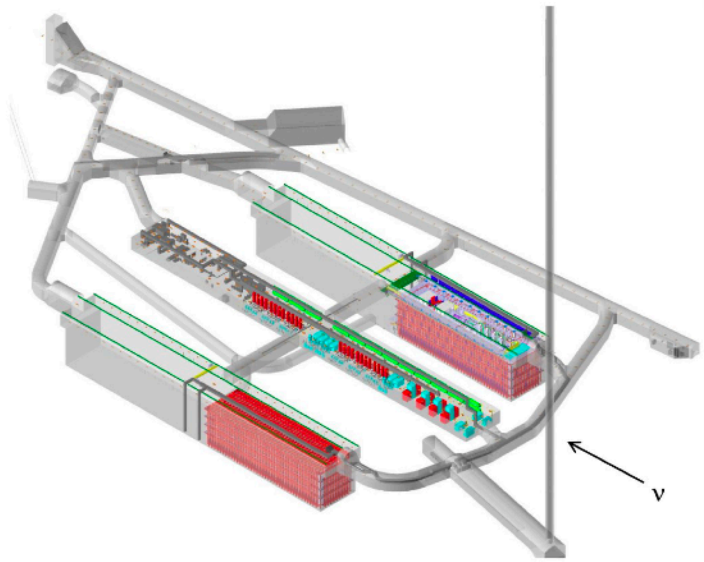
HK Schedule

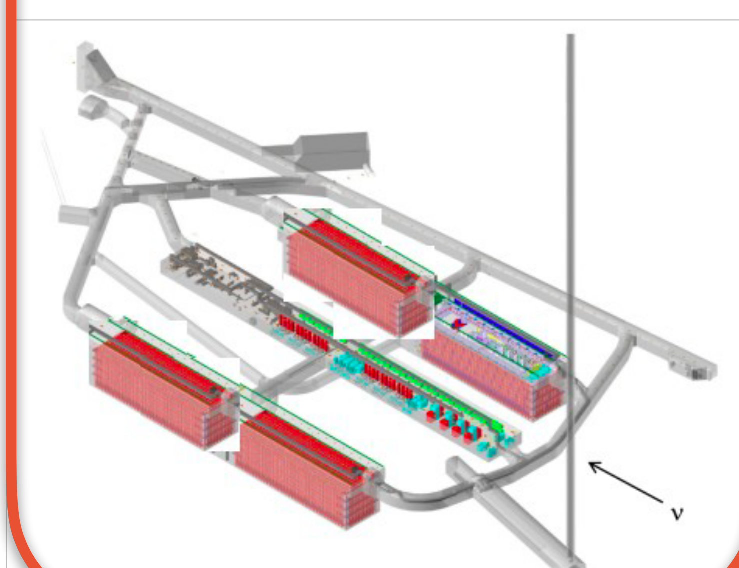


JFY2020 JFY2021 JFY2022 JFY2023 JFY2024 JFY2025 JFY2026 JFY2027 JFY2028
Prepar ation
Tunnel Const.
Cavern excavation
Tank Const.
Detector Const.
PMT production
PMT cases, Electronics etc.
Water system
Filling water
Operation
Power-upgrade of J-PARC and Neutrino Beam-line
Near Detector Facility, R&D, production
IWCD construction

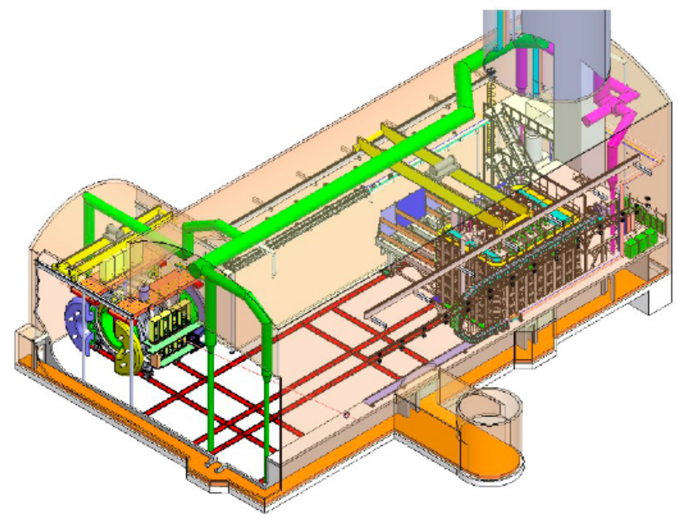
DUNE Phase I and Phase II

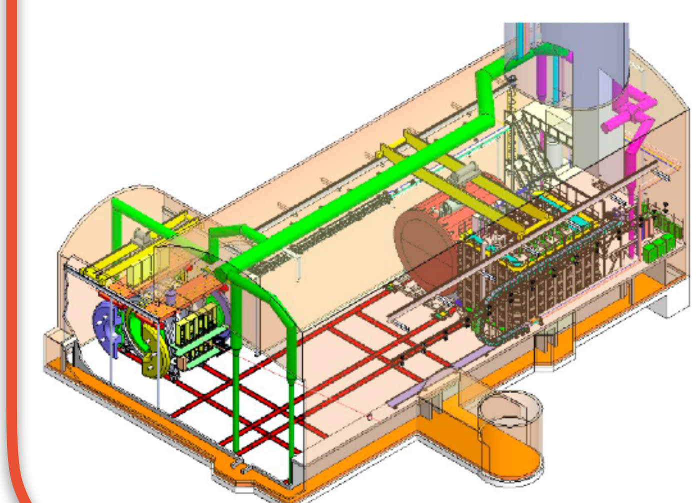
FD



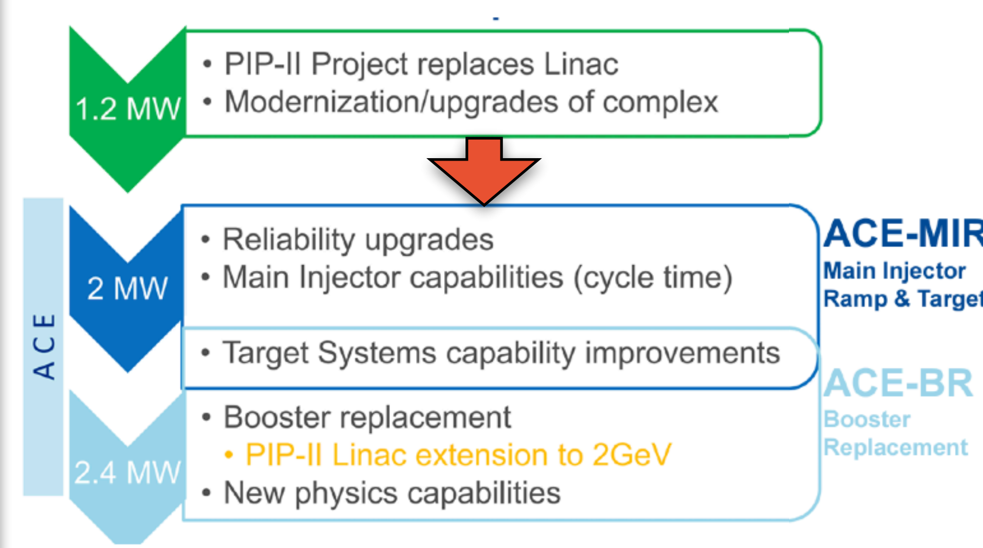


ND



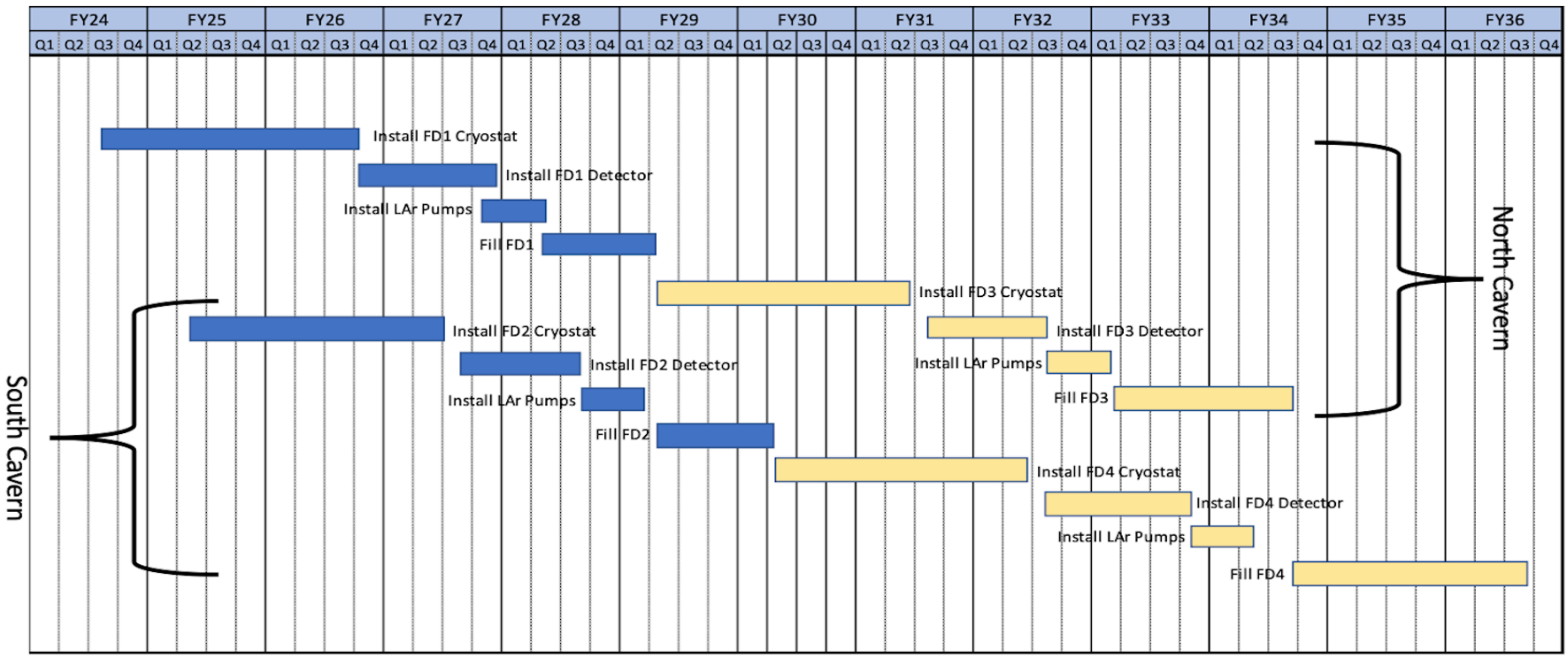


Beam



DUNE Schedule

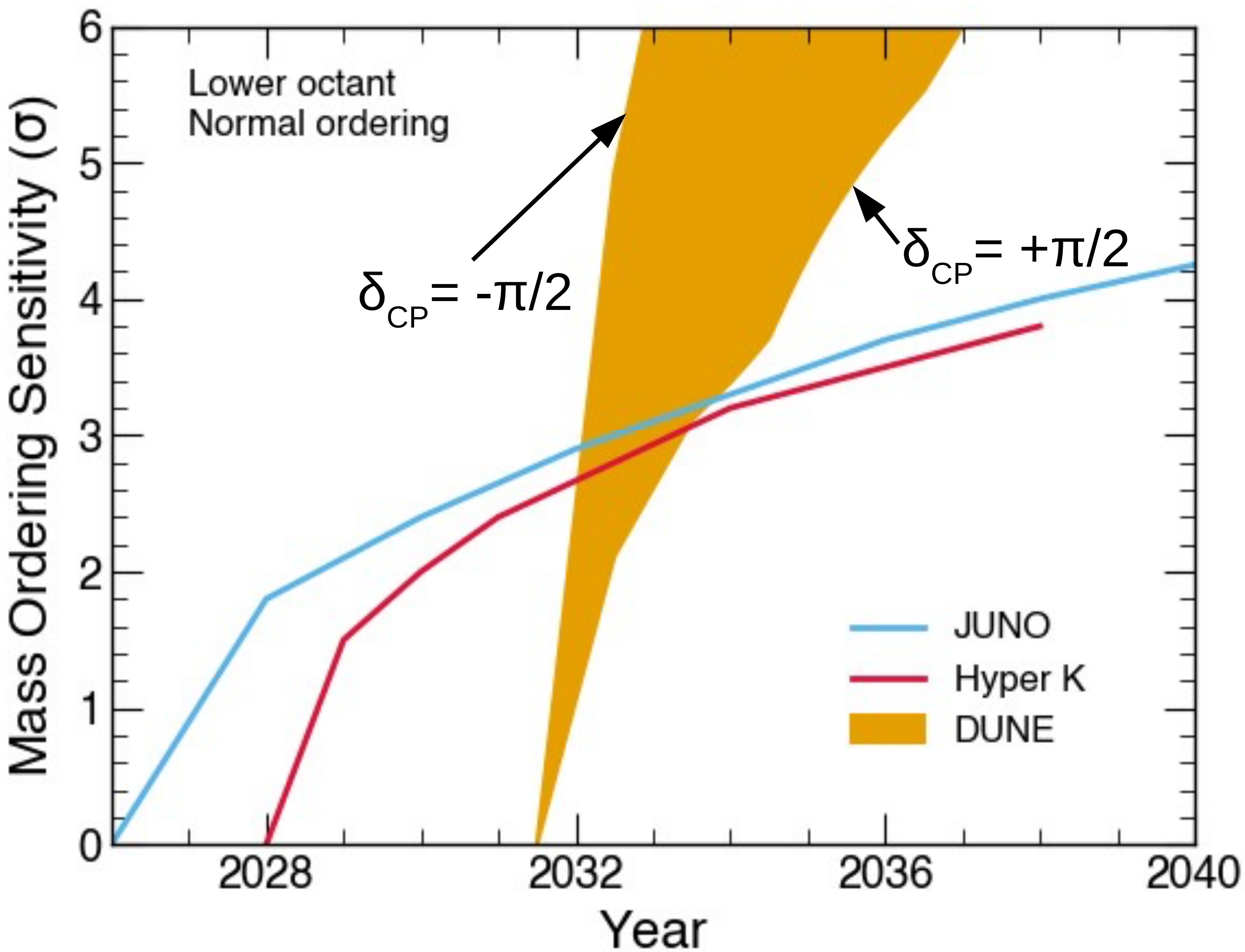
- FD (technically-limited schedule for Phase II):



- ND: Phase I ND complete in 2032, Phase II ND in mid-2030s

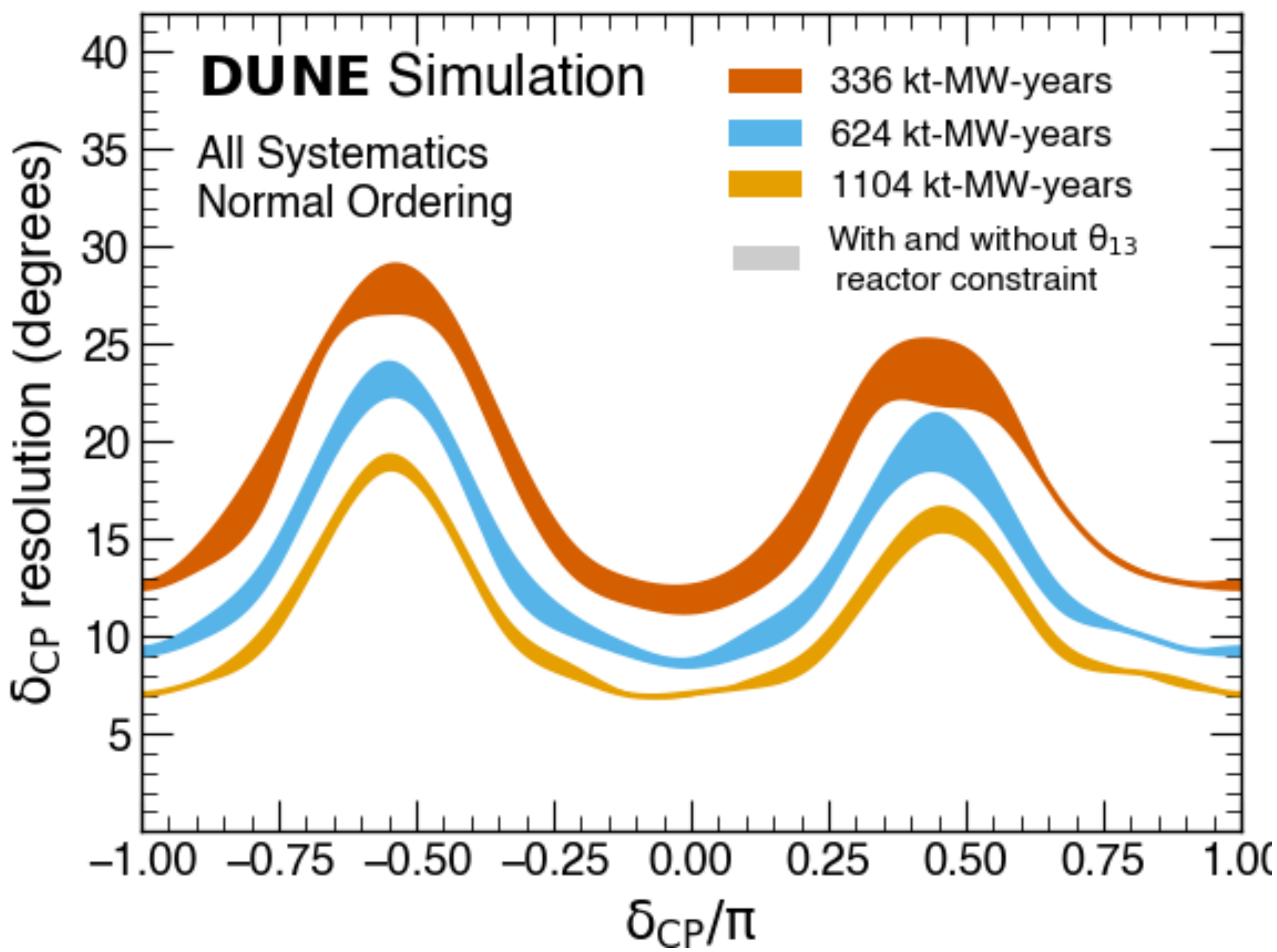
DUNE Mass Ordering Reach

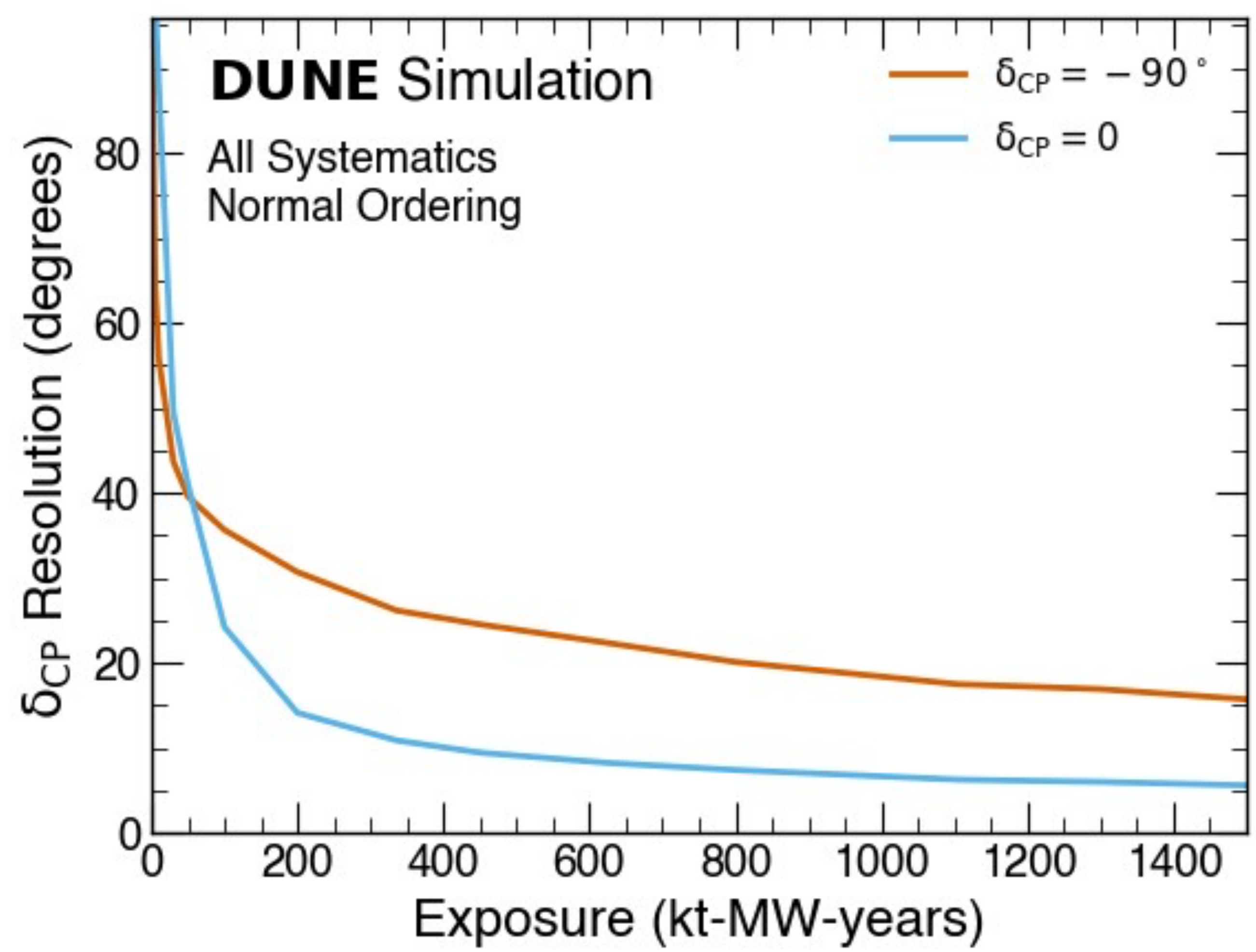
Pessimistic Scenario



- Existing Super-K atmospheric data (weakly) prefers normal ordering and lower octant
- In this scenario, atmospheric experiments do not reach 5σ for mass ordering discovery
- Despite starting later, DUNE is the only experiment to 5σ

DUNE Precision to CP Violating Phase

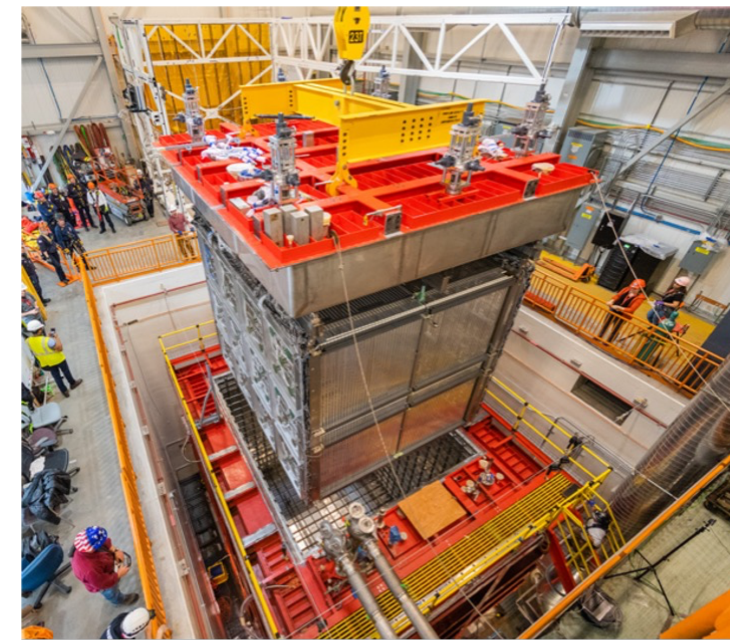




- DUNE has the best ultimate δ_{CP} resolution, especially if CP is violated
- DUNE can resolve degeneracies between different values of δ_{CP} with broad L/E spectrum

SBND

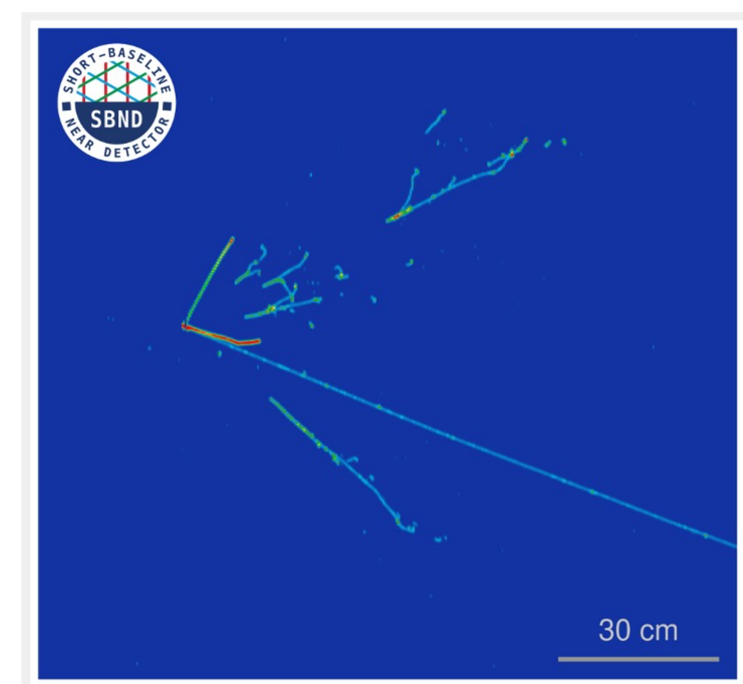
Liquid argon TPC (112 ton) located 110 m from Booster Neutrino Beam at Fermilab. Near Detector of the Short-Baseline Neutrino Program. Similar design as ProtoDUNE-HD.



Physics program:

- Conclusively address the short-baseline neutrino oscillation anomalies.
- Perform high-precision measurements of cross-sections of ν_μ and ν_e on Ar.
- Search for Beyond Standard Model physics.
- Advance further the LArTPC detector technology.

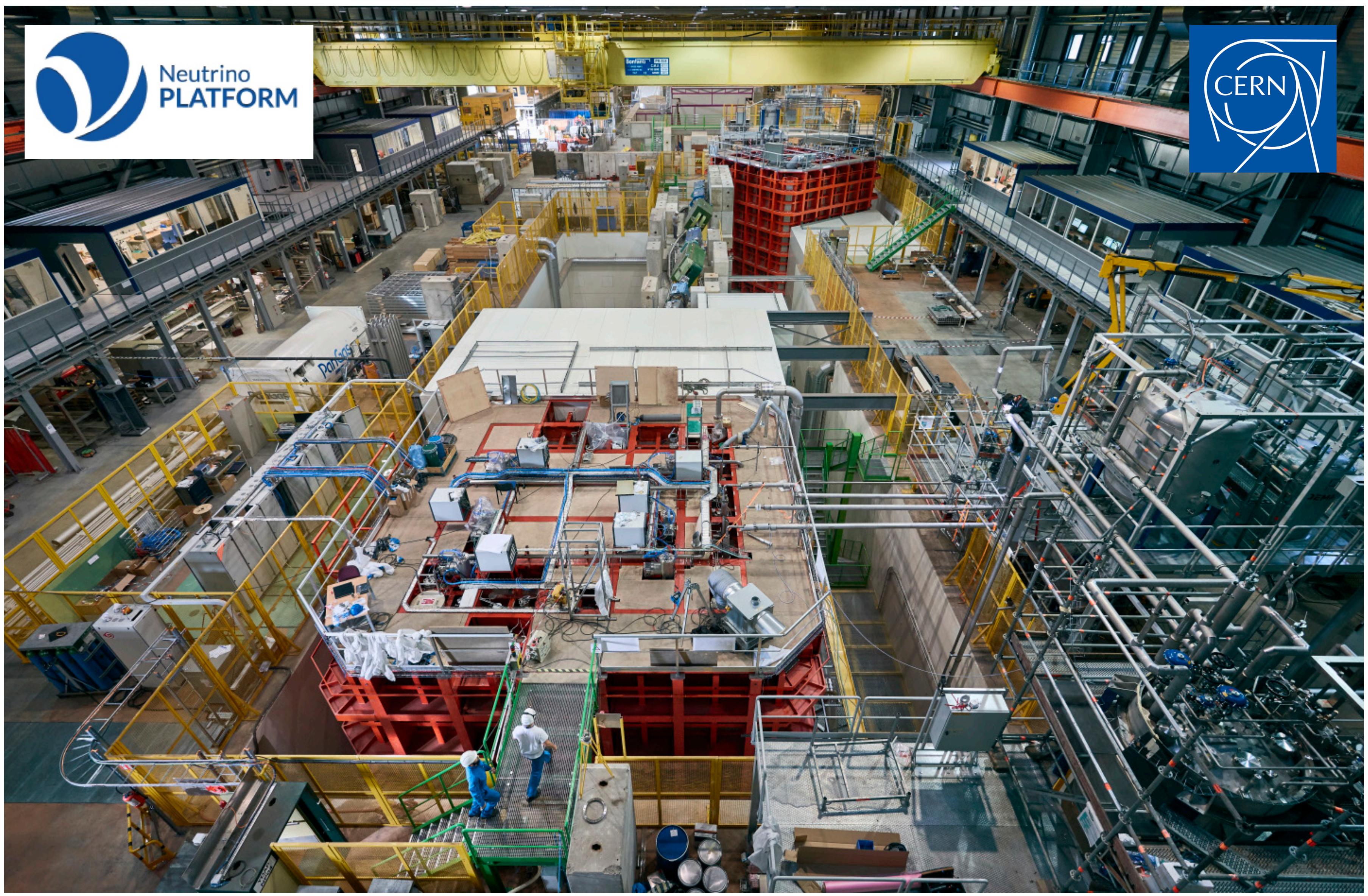
Physics beam data taking since December 2024 → **Largest neutrino-argon interaction dataset available in the world.** Approved to run until Fermilab long-accelerator shutdown (end of 2027/early 2028).



2 Spanish (**CIEMAT and UGR**) out of 40 institutions. 12 out of 202 collaborators (6%).

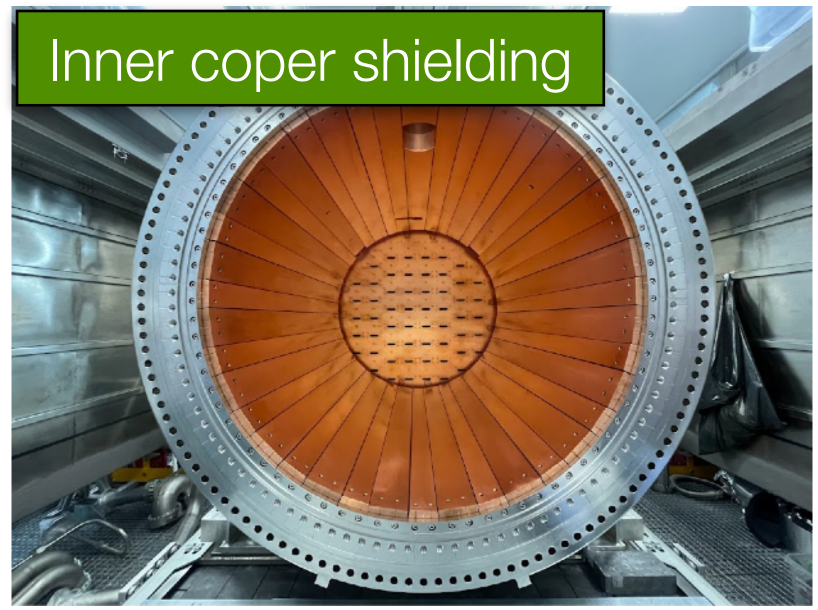
- High visibility roles (Executive Board, BSM Convener, Reconstruction Convener, Publication Committee, Shift Coordinator).
- Leaders of scintillation light simulation, reconstruction and analysis (PMTs and X-ARAPUCAs –like DUNE), and the heavy neutral lepton search. Significant contributions to cross-section physics (transference to DUNE), and X-ARAPUCA readout and DAQ.
- First Spanish SBND PhD theses in 2024 and 2025. Spanish-led works:
    - *Scintillation Light in SBND: Simulation, Reconstruction, and Expected Performance of the Photon Detection System* **published in Eur. Phys. J. C 84, 1046 (2024)**
    - *The Short-Baseline Near Detector at Fermilab – Input to the European Strategy for Particle Physics 2026 Update*, arXiv:2504.00245

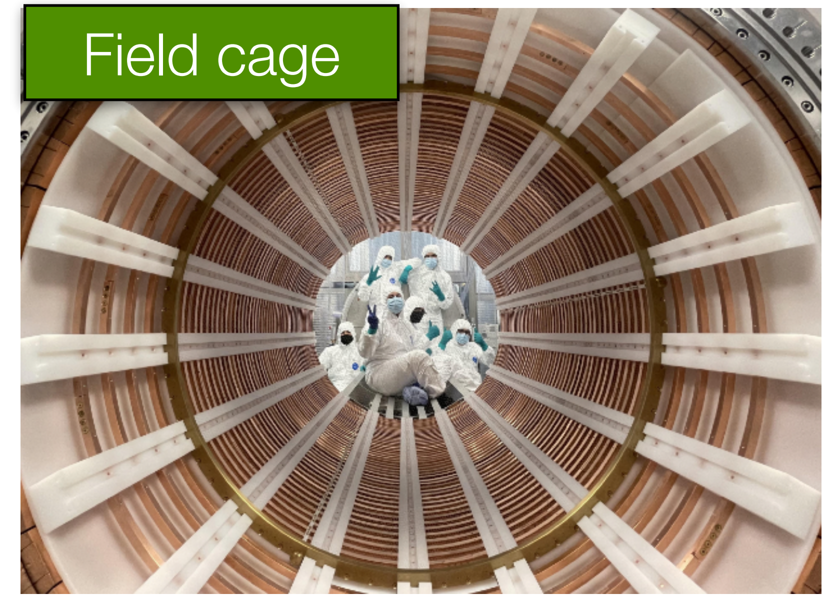
CERN Neutrino Platform: Unique Infrastructure!

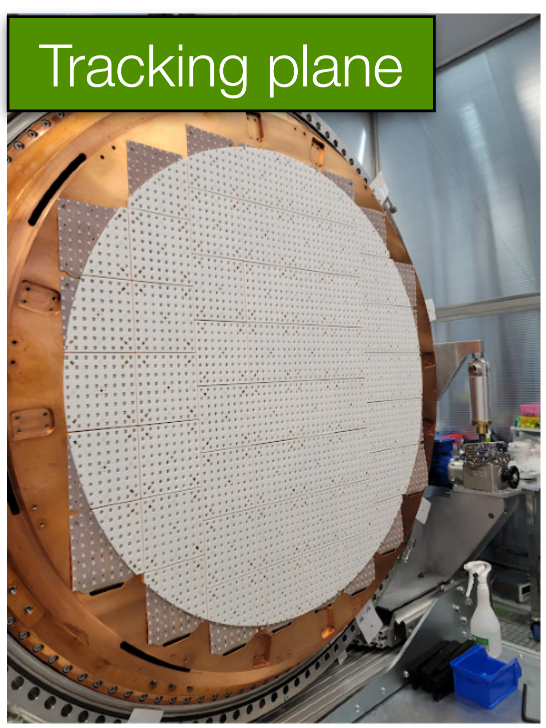


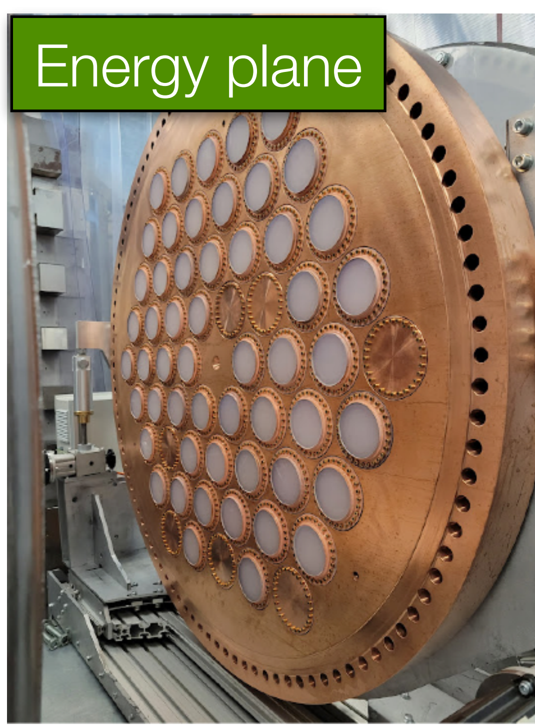
- It has been instrumental in enabling European participation in LBL neutrino experiments worldwide
- Crucial to advancing new technologies and planned R&D for neutrino detection and rare event searches
- Cryogenics system successfully developed and operated for years
- Hosting two 770-ton LAr TPCs in addition to large-size cold boxes and medium-size TPCs
- Test-beams available
- Strong technical team of experts
- Acting as a reference center for coordinated R&D activities and large-scale prototyping

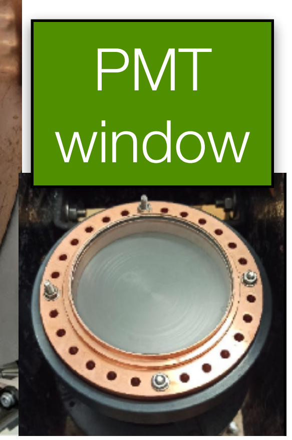
NEXT-100 Building Blocks

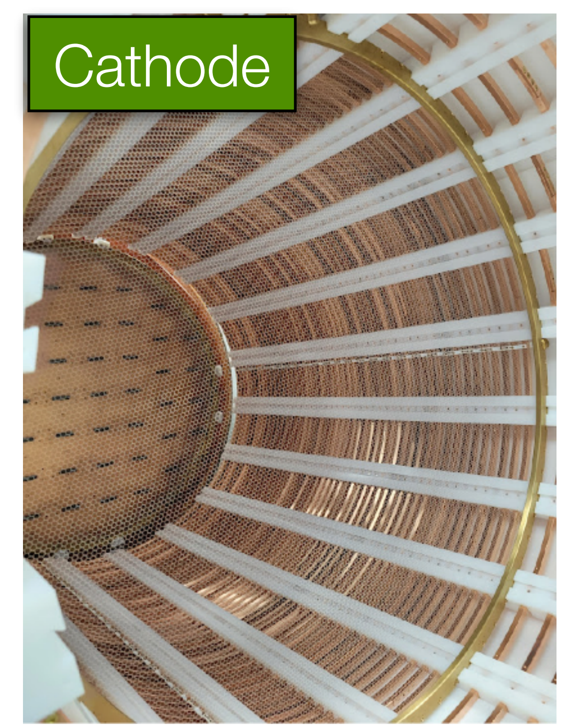








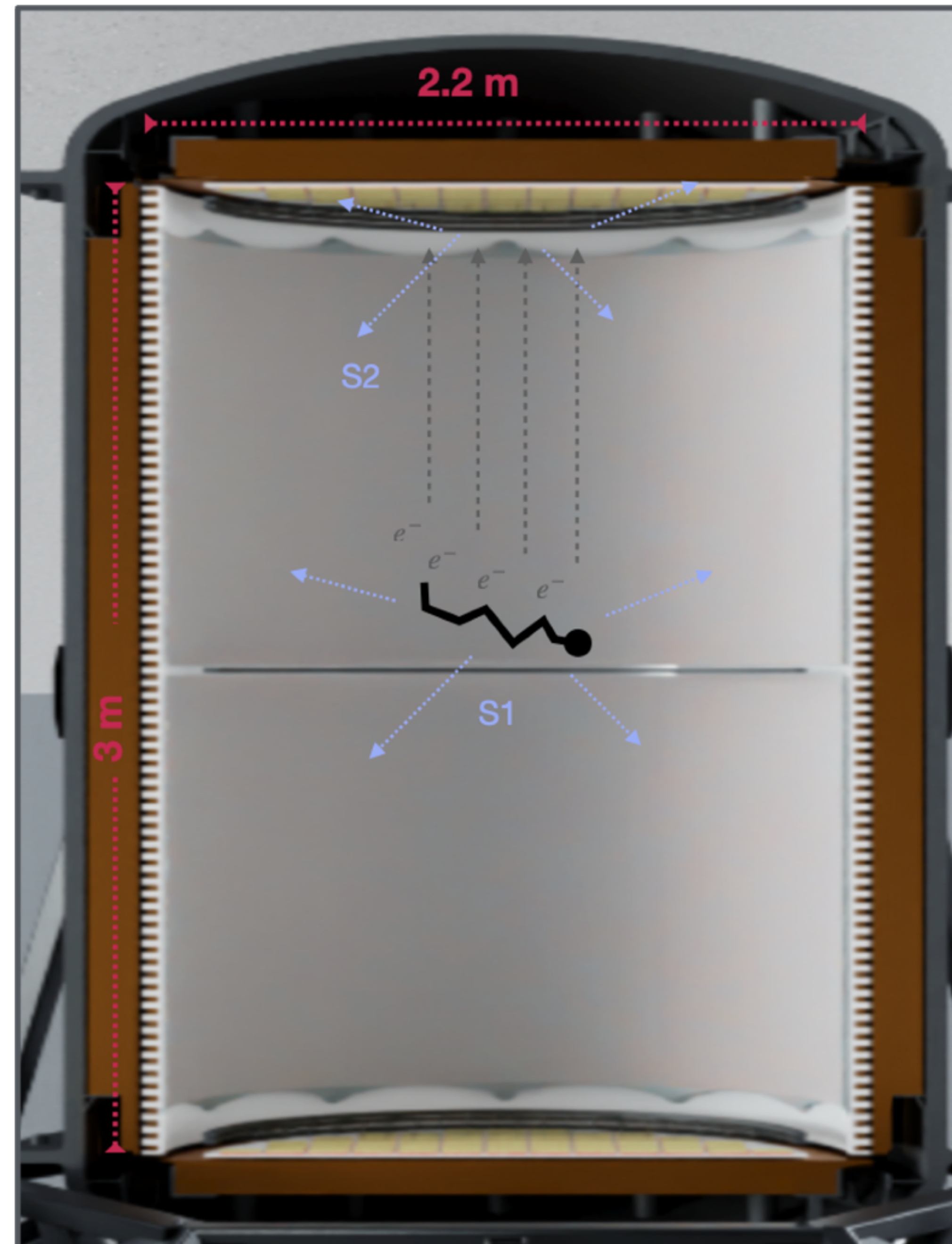




NEXT-HD

Concept

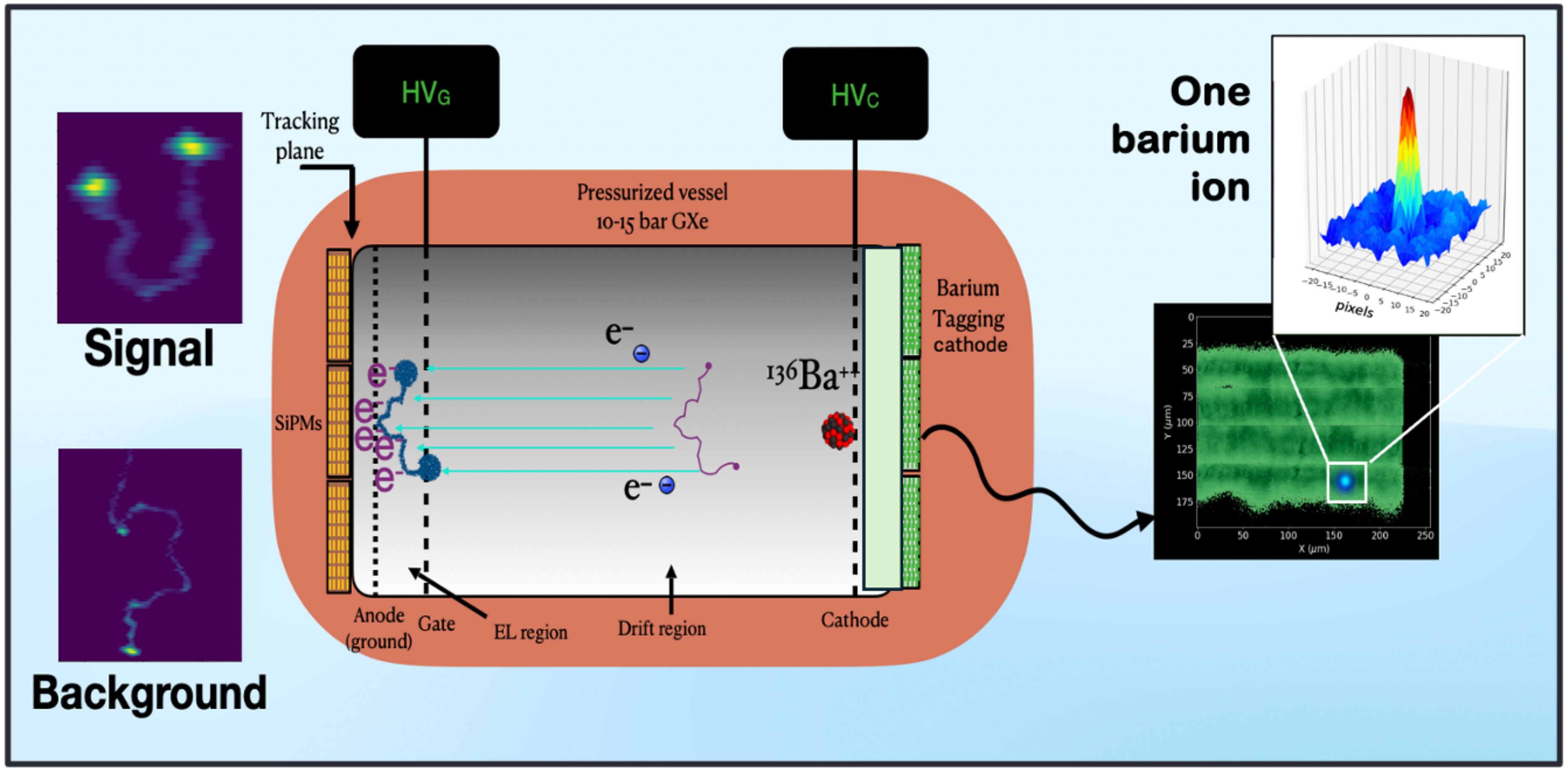
- Symmetric TPC: two anodes and a single central cathode
- Capacity (15 bar): ~1 ton Xe
- Two planes of SiPMs for tracking
- Optical fibers installed in field cage barrel for detection of S1/S2
- External water shielding



Projections (JHEP 2021 (2021) 08):

- Sensitivity (5 ton-yr): 1.4 x 1027 yr
- Background: < 0.01 ct / (keV·ton·yr)

NEXT-BOLD

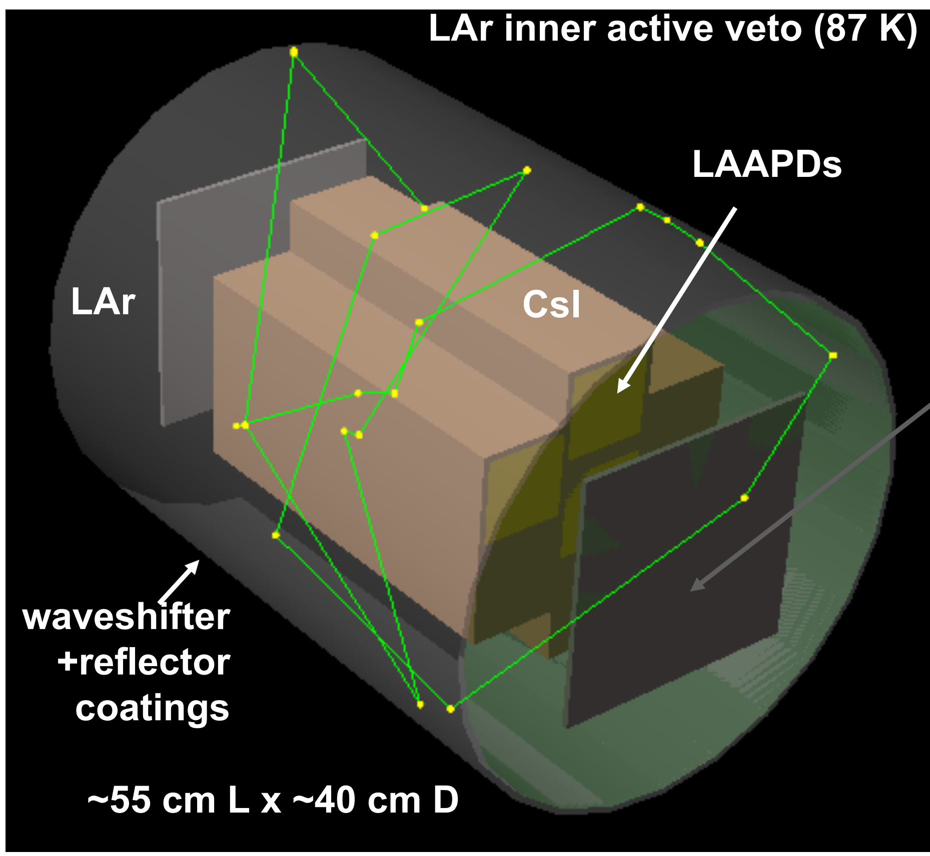


Ingredients:

- *Molecular sensors: selectively respond to trapped Ba^{2+} ions*
- *Molecular targets: capture Ba^{2+} ions with high efficiency on detector surfaces*
- *Precision microscopy: image individual Ba^{2+} ions in high pressure xenon gas environments*
- *Levitating ions: RF carpets are being studied to concentrate ions in scanning regions*

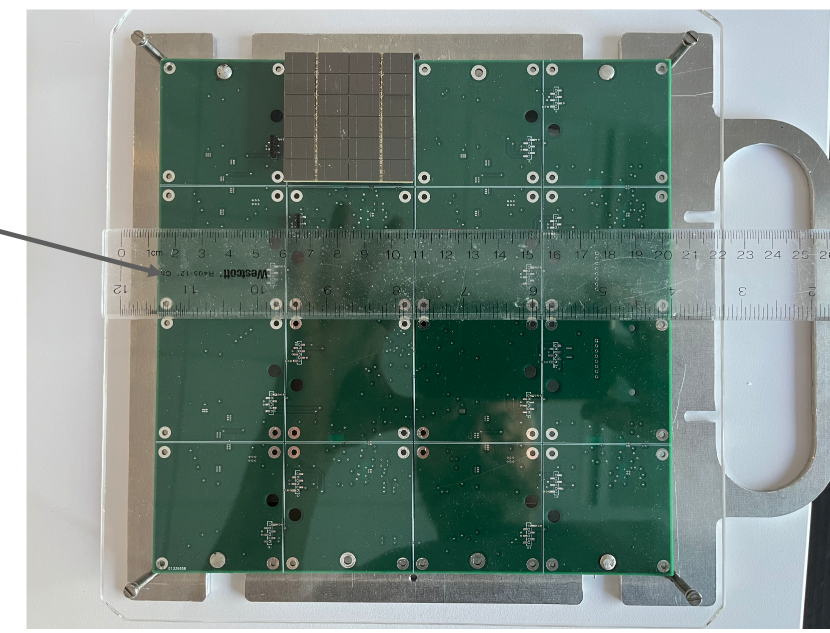
Cryogenic undoped CsI crystals

- Developing an internal liquid argon veto

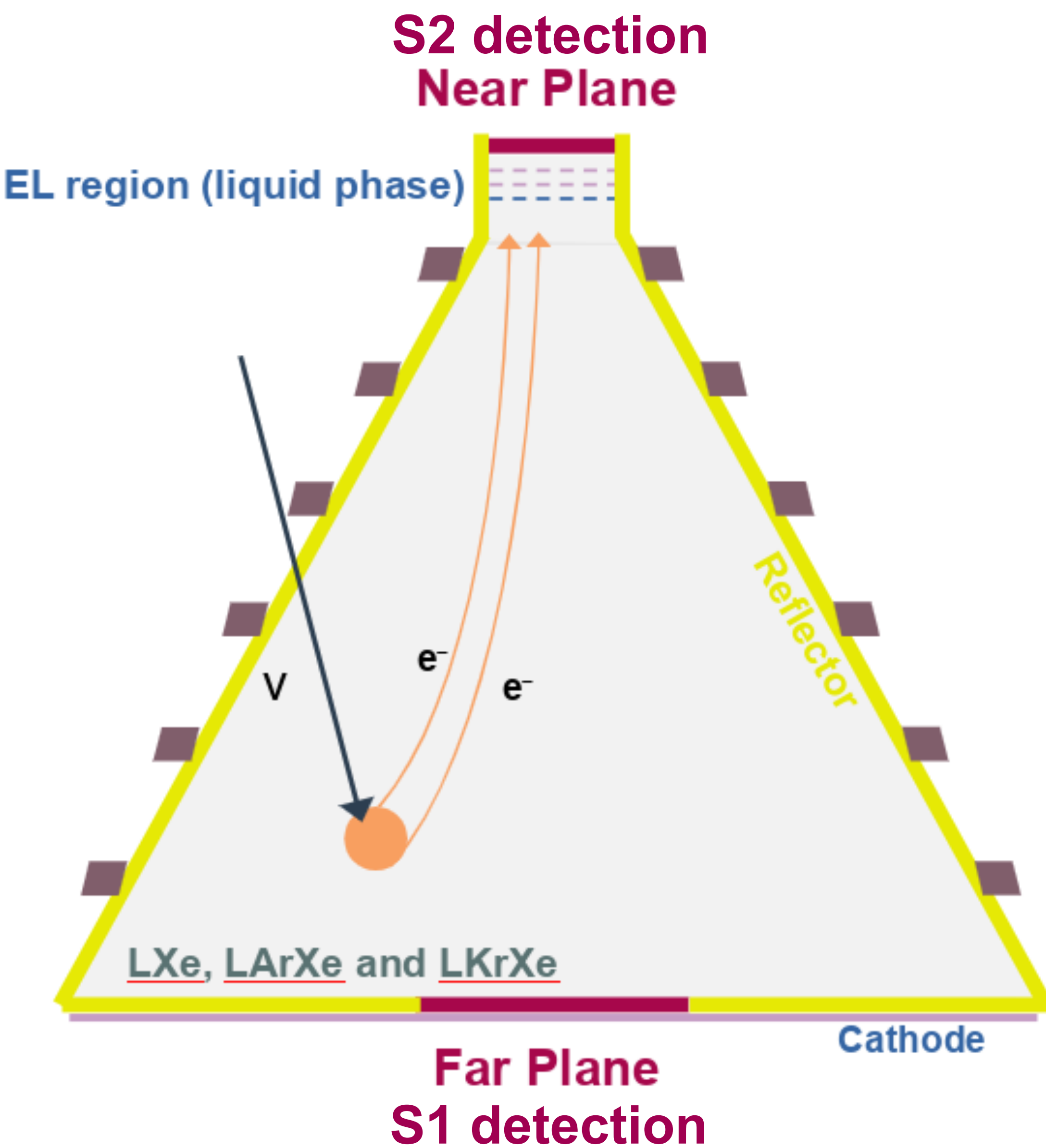


DarkSide-20k SiPM

20x20 cm low-field modules
~80 Hz dark rate @ 87 K
(single photon operation)
16 channel output



COLINA concept



Conical shape TPC

↓

Focus charges into small region

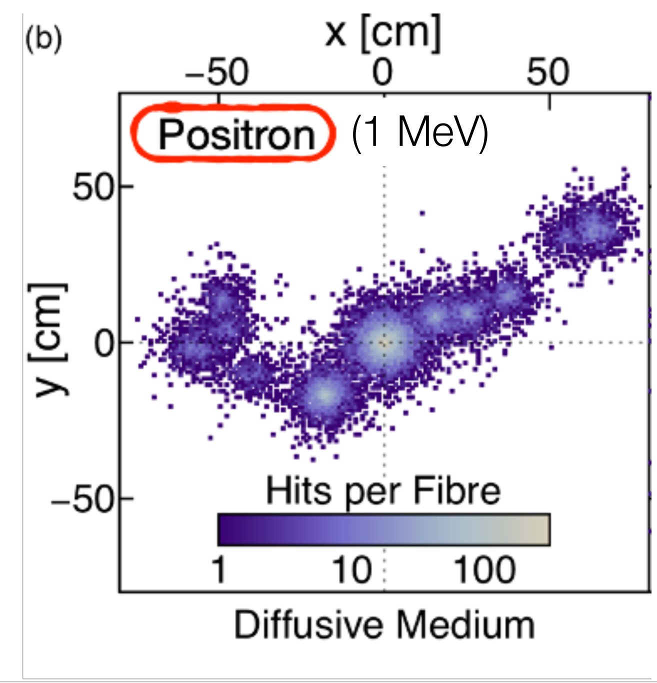
↓ **EL amplification in liquid with thin wires**

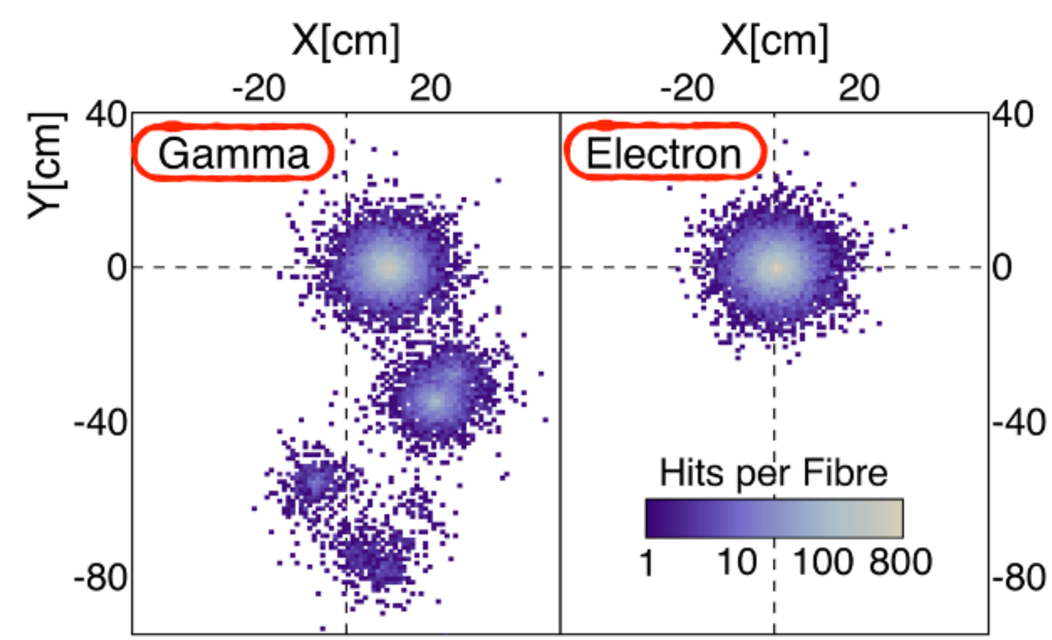
↓ **Good S2 light collection efficiency with few sensors**

- The nice things:
  - Benefits of TPCs (EL amplification, different nuclei)
  - Operation in denser medium
  - Reduction of low-energy background (no charge trapping, possibility of removing reflectors if fluorescence is an issue)
- The ugly things:
  - Cryogenic operation
  - Non-uniform electric field (hard to calibrate, possible charge losses, etc.)

LiquidO

- Liquid scintillator detection using an opaque medium and an array of WLS fibers for light detection
- Main purpose: stochastically confine light near its creation point to preserve the topological information of particle interactions
- The result:
  - *Autosegmentation*
  - *Powerful background rejection capability*
  - *Possibility of doping at high concentrations*
- Detector concept with the potential to break ground in various frontiers of neutrino physics





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