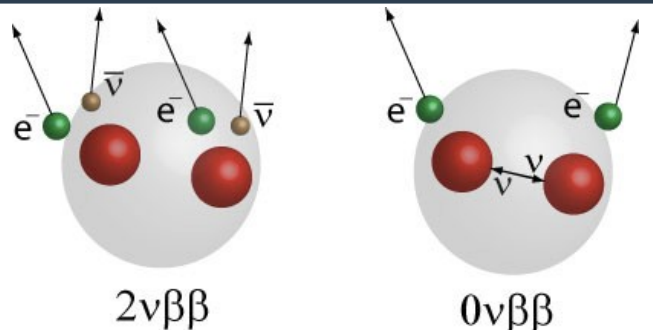
Instrumentation for the future of particle, nuclear and astroparticle physics and medical applications in Spain

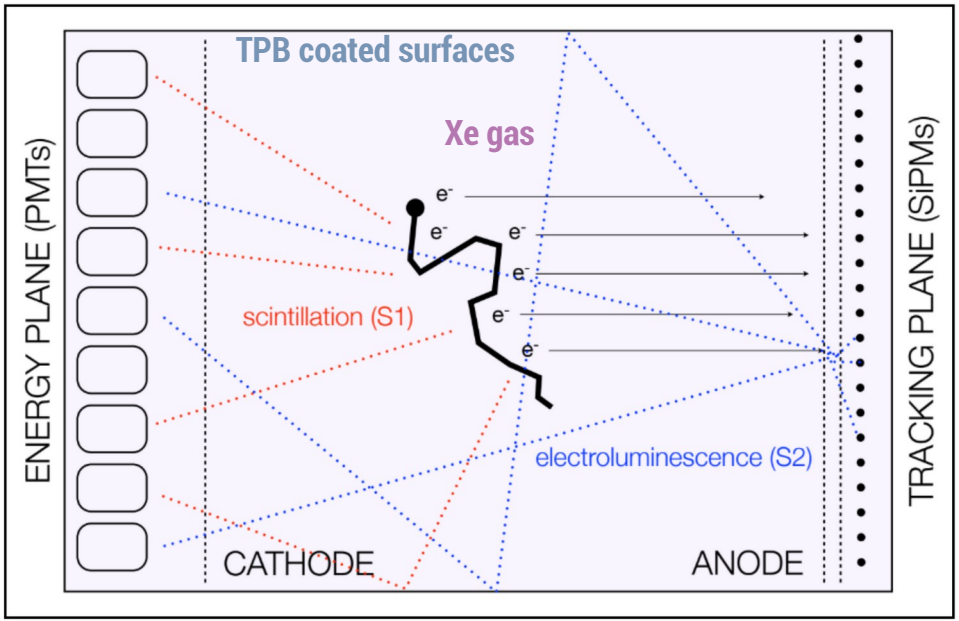
NEXT Detector R&D Activities

A. Simón on behalf of NEXT Spain

Neutrino Experiment with a Xenon TPC

- The NEXT Collaboration is searching for the **neutrinoless double beta decay** (0νββ) in **^{136}Xe**.
- It uses a high pressure TPC with electroluminescent amplification.



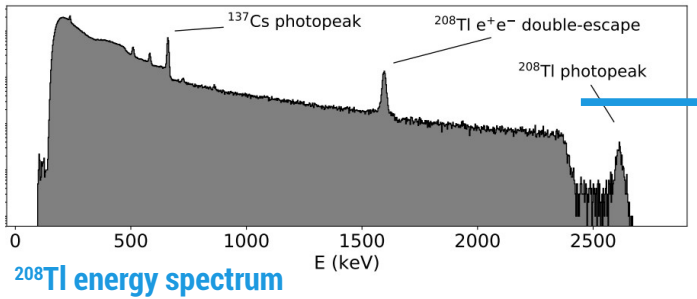


Neutrino Experiment with a Xenon TPC

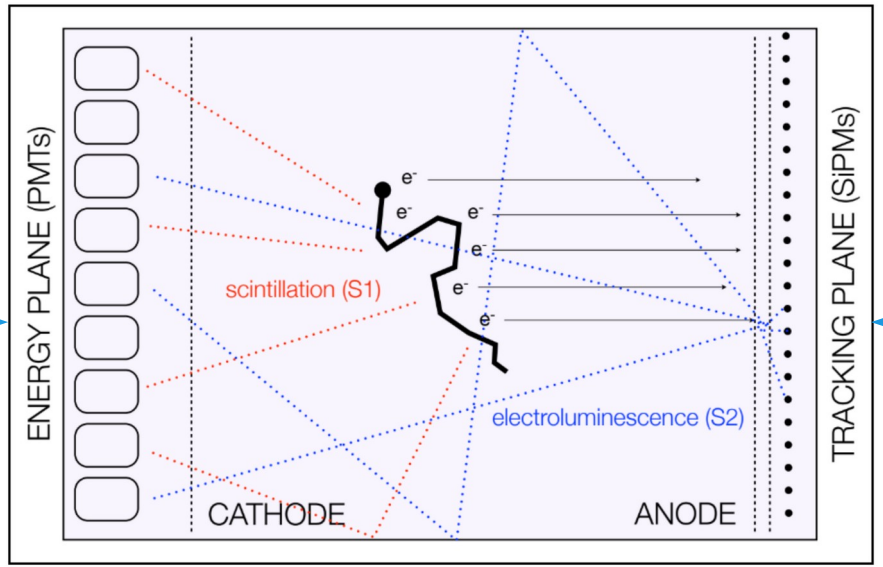
Dedicated sensor planes allow for optimized energy and track reconstruction

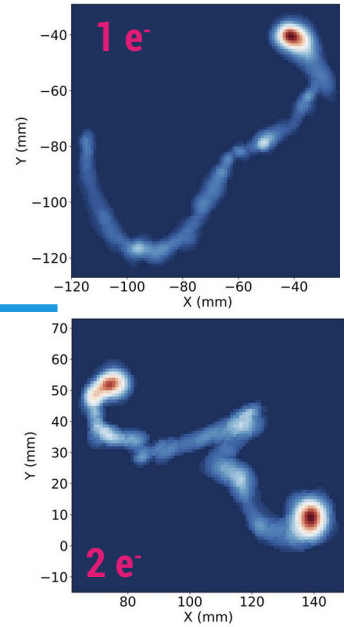
Great energy resolution and topological identification

Low background and high 0νββ sensitivities



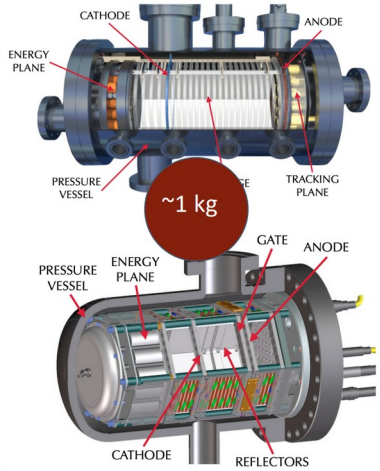
^{208}Tl energy spectrum





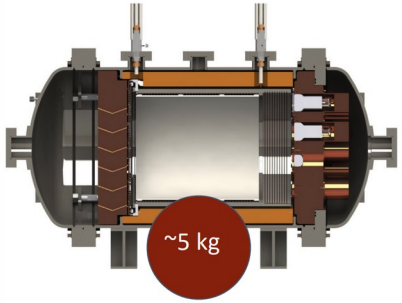
The NEXT program

Prototypes
2008-2014
Demonstration of detector concept



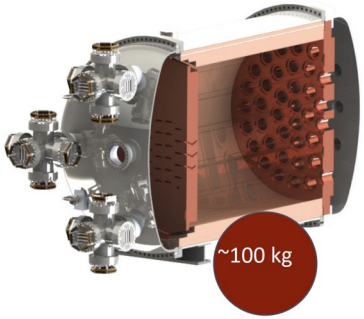
NEXT-White
2015-2021
Background model assessment

$2\nu\beta\beta$ measurement for ^{136}Xe



NEXT-100
2022-2025
Background model assessment

Neutrinoless double beta decay search in ^{136}Xe



NEXT-HD
2026?
Neutrinoless double beta decay search through inverted neutrino mass ordering

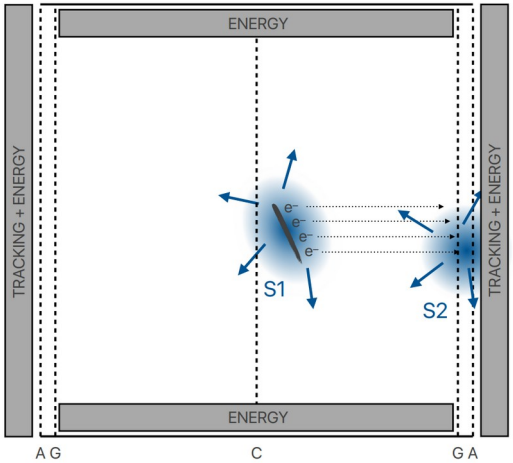
NEXT-BOLD
Barium tagging for background-free experiment

2009 2014 2015 2021 2022 2025 2026

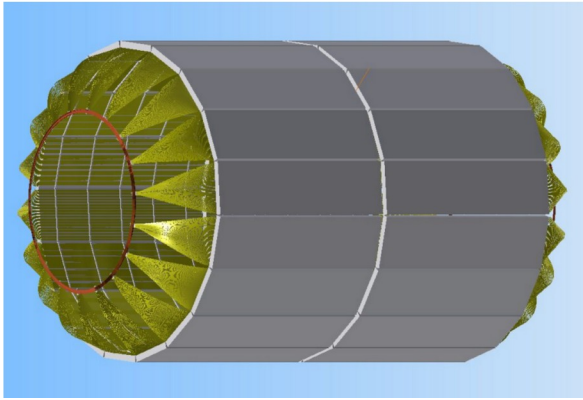
Towards the ton-scale: NEXT-HD

- 'Continuist' improvement of the technique:
  - **Larger TPC** → Increased s/b.
  - **Symmetric TPC** → Reduce e- lifetime, voltage requirements.
  - **Reduced SiPM pitch** → Track reco, extra E measurement.
    (In-vessel electronics)
  - **Optical fiber barrel** → Reduce background, increase light col.
  - **Gas mixtures** → Reduces diffusion smearing.
- **R&D detectors** → DEMO++ (IFIC, Valencia), DEMO-HD (DIPC, Donostia)

Symmetric TPC scheme



Optical fiber barrel mock-up

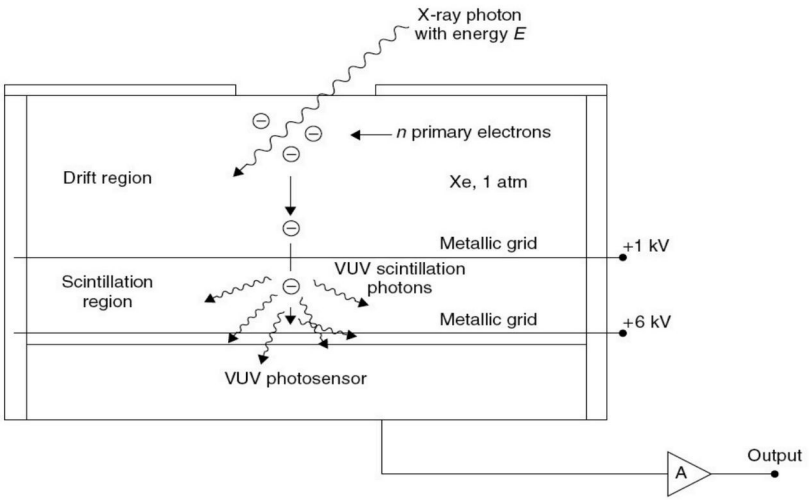


R&D topics

Energy resolution		Track reconstruction
Signal amplification	TPCs for rare event searches	Low diffusion gas mixtures
Light collection systems	Radiopurity	SiPM for large area coverage
Wavelength shifting materials	Cooling systems	ASIC read-out
Calibration techniques	Trigger and data management	digital-SiPMs

R&D topics: Energy resolution

Amplification process based on electroluminescence, fundamental to maintain good energy resolution of xenon gas.

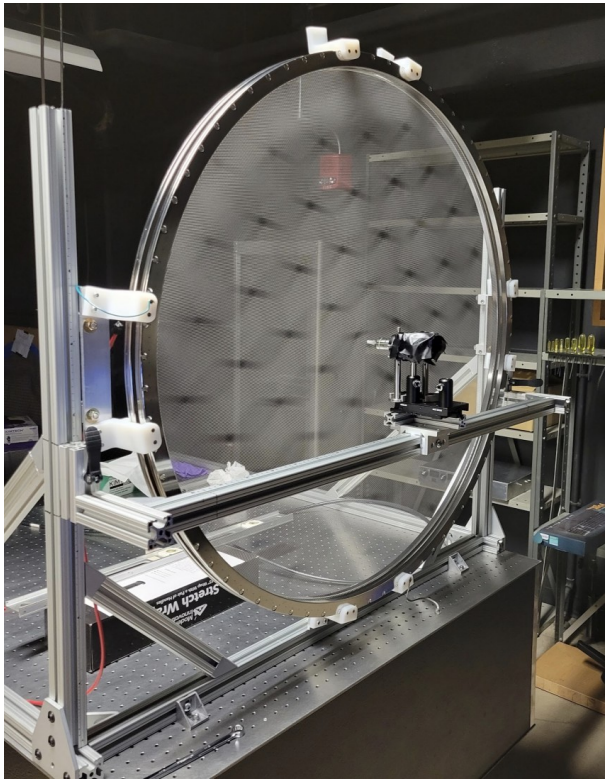


Challenges:

- Structures capable to create intense electric field over large areas.
- Photodetection efficiency at VUV (175 nm).

R&D topics: Energy resolution

Anode (quartz plate) in NEW



NEXT-100 mesh

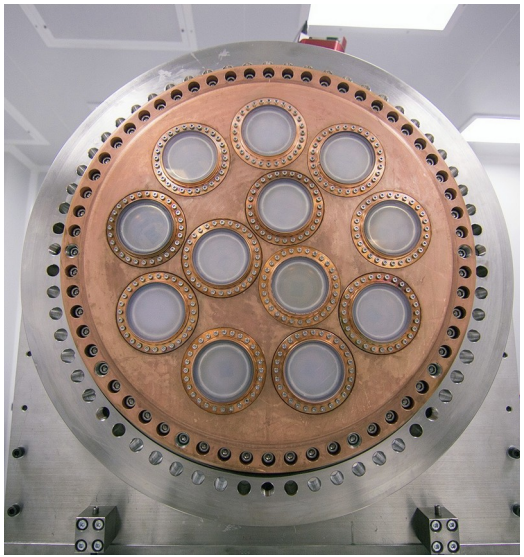
Amplification structures

- Large surfaces → Deformation of meshes due to large electric field.
- New ways of creating these structures, maintaining radioactivity low, are needed.

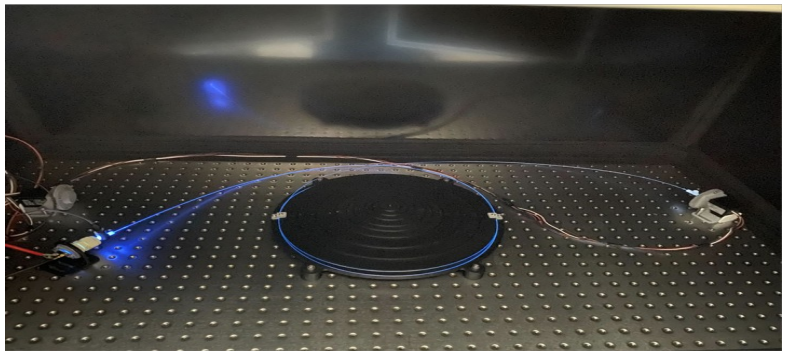
R&D topics: Energy resolution

Photodetection efficiency

- Current solution with PMTs is too radioactive.
- Exploring different approaches:
  - WLS fibers
  - ARAPUCAs
  - SiPMs



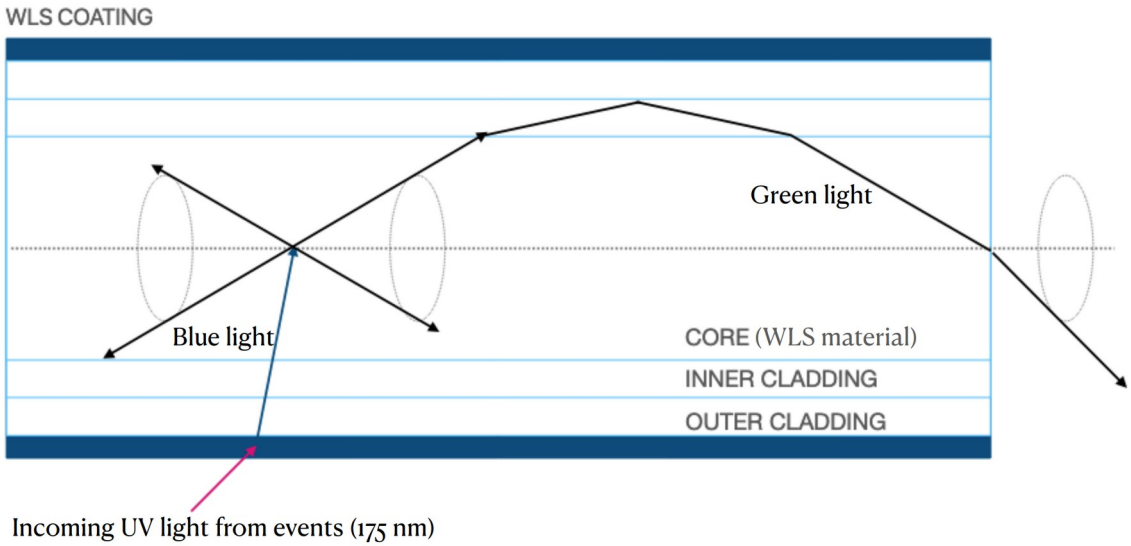
PMTs in NEW



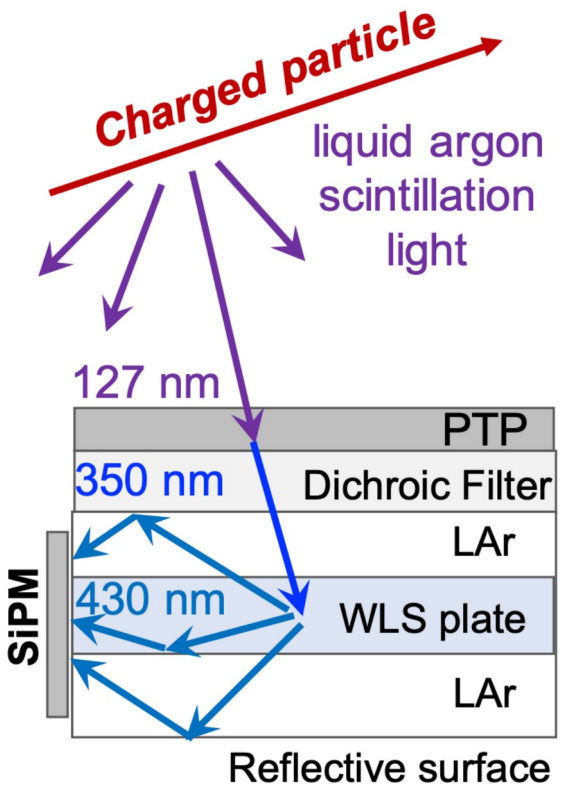
Optic fiber setup

R&D topics: Energy resolution

WLS fibers

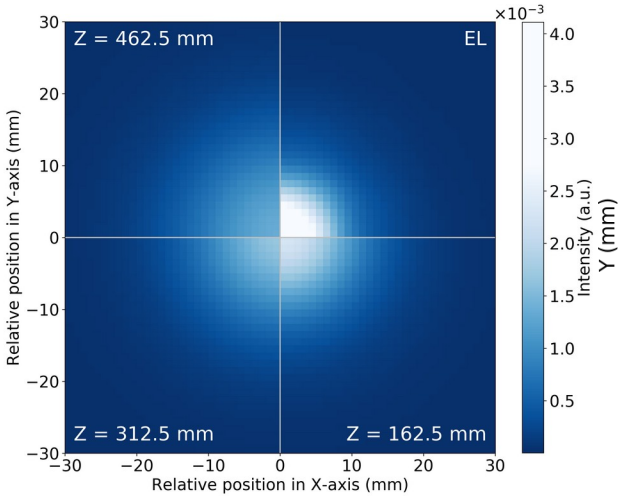


ARAPUCAs

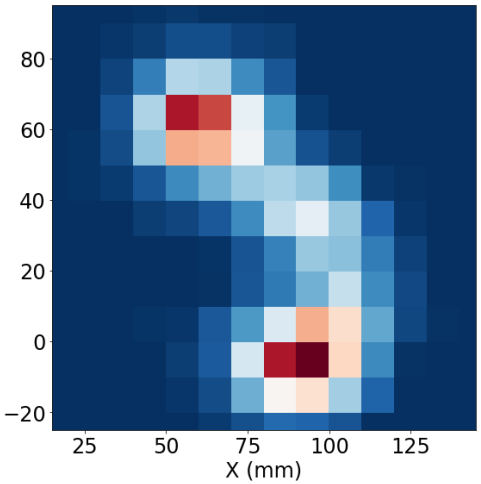


R&D topics: Topological signature

Topological signature allows to reject background, depends on the quality of the track reconstruction



Total light spread



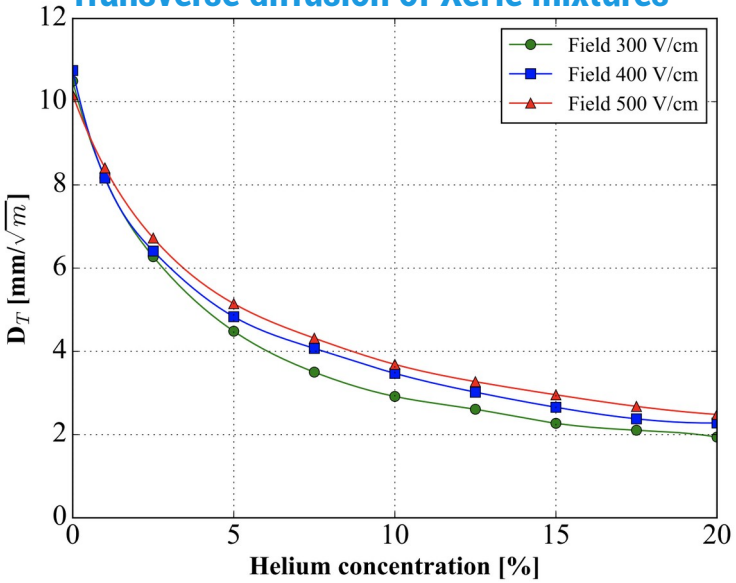
Raw sensor response

Track reconstruction impacted by:

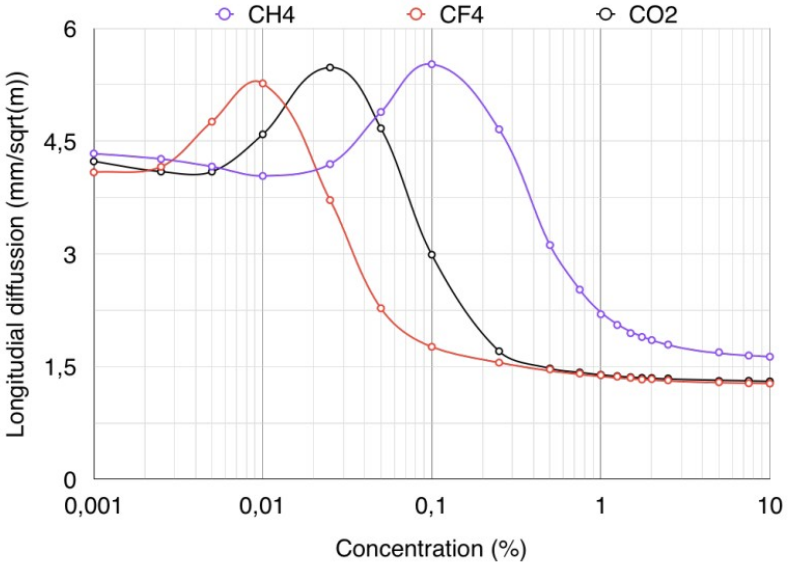
- Light spread → Diffusion from electrons in gas.
- Sensor density in tracking plane.

R&D topics: Topological signature

Transverse diffusion of XeHe mixtures



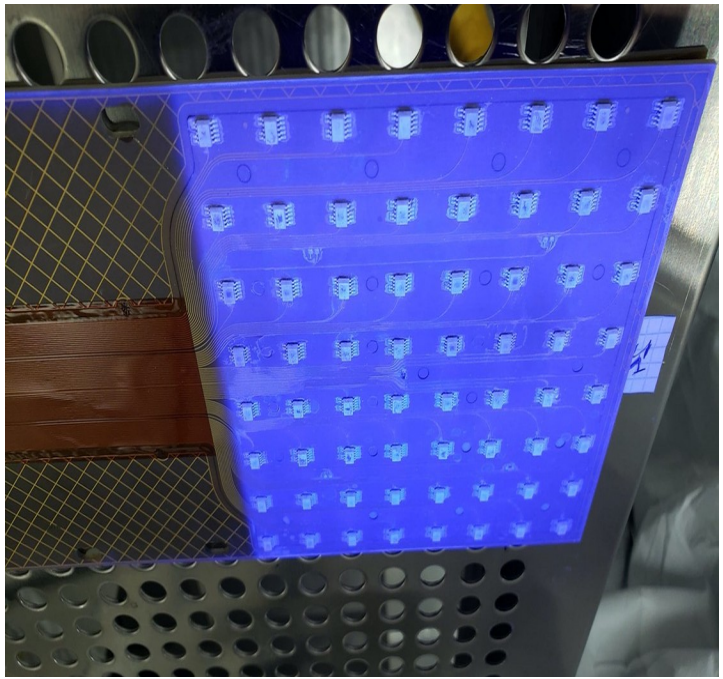
Longitudinal diffusion of different Xe mixtures



e^- diffusion

- Different gas mixtures could reduce significantly the diffusion while maintaining the energy resolution.
  - Gas operation is challenging (recovery, cleaning, etc.)

R&D topics: Topological signature



Sensor density

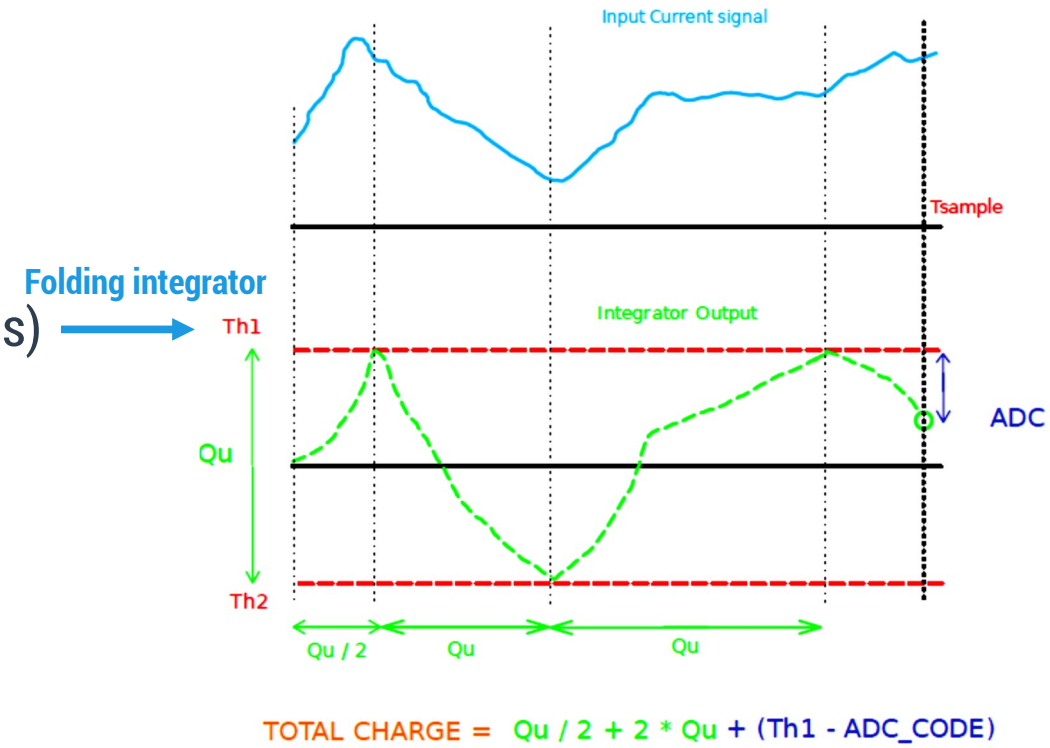
- Reduce SiPM pitch → # channels increase by ^2
  - Challenge: Power consumption, dark noise → cooling, trigger and data management.
- Currently working on a in-vessel solution for the electronics.
- Also working on alternatives like dSiPMs.

R&D topics: Topological signature

ASICs

Requirements

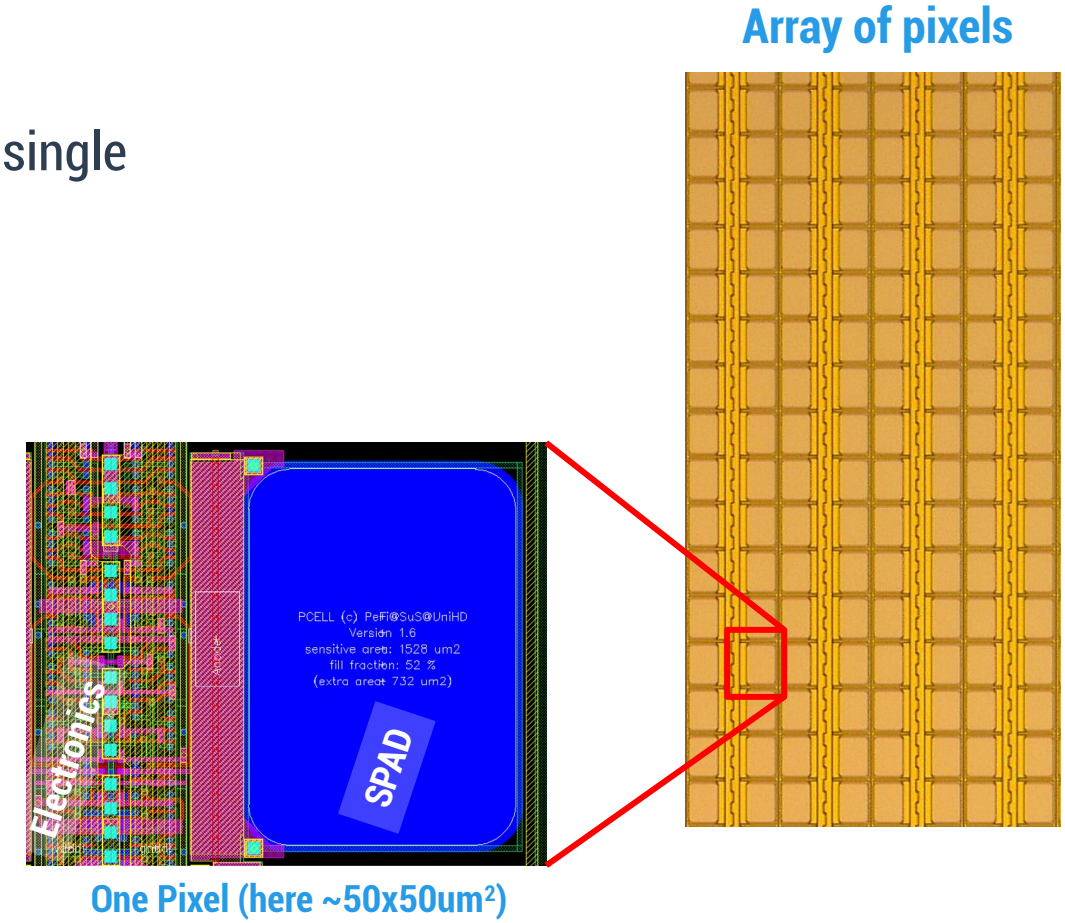
- High channel density
- Wide dynamic range (Target: 1 pe to 400 pe/us)
- Synchronized periodic trigger.
- Large area SiPM → High capacitance
- Radiopurity.



R&D topics: Topological signature

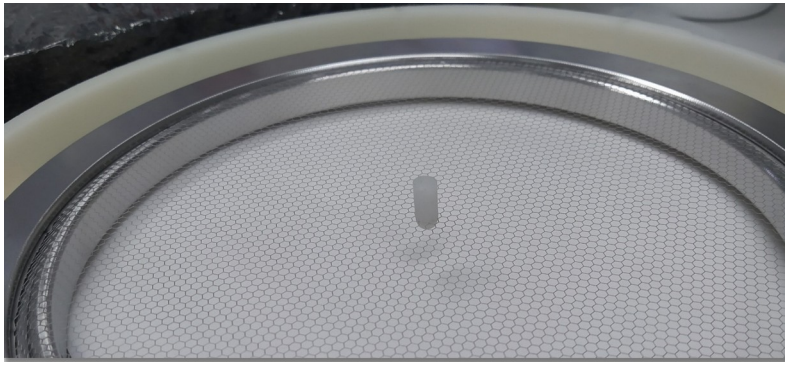
digital - SiPM

- dSiPMs = SPADs + readout electronics on a single silicon die (CMOS SPAD)
- Arbitrary geometries can be designed
- Hits can be processed immediately
- Readout of the chips can be fully digital

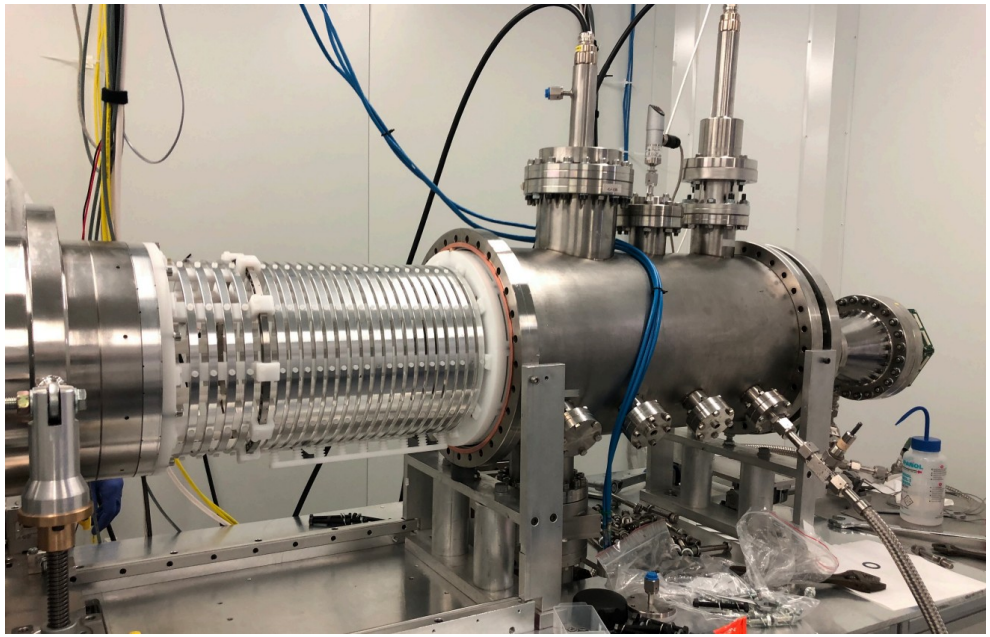


R&D: DEMO++

- Upgraded NEXT-DEMO original detector, used as a test-bench for future detector iterations.
- Operating at IFIC.
- Focus on gas mixtures, EL structures tests and ARAPUCA based read-out.

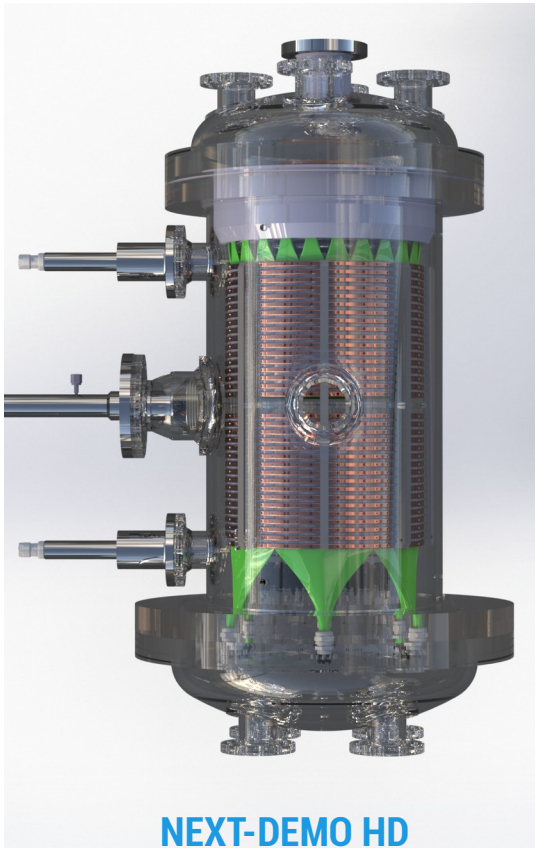


Grids being tested at DEMO++, plastic holder to stop deflection



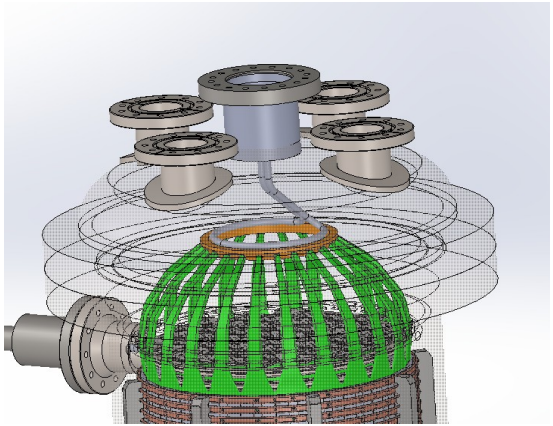
NEXT-DEMO++ detector at IFIC

R&D: DEMO-HD

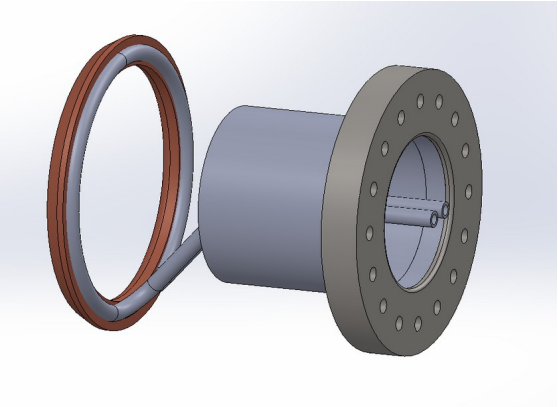


NEXT-DEMO HD

- A new prototype aiming to test the different solutions to be implemented in the tonne scale
- Being design and will be built at DIPC.
- Focus on fiber read-out and dense SiPM tracking planes.



Fiber coupling to SiPM



Cooling system for SiPMs on fibers

R&D: Workforce

Institution	Researchers	Students	Engineers	Technicians
DIPC	8	5	3	2
IFIC Institut de Física Corpuscular	5	4	3	1
Universitat Politècnica de València	5	-	-	-
USC Universidade de Santiago de Compostela	2	2	-	-
LSC Laboratorio Subterráneo Canfranc	2	-	1	1

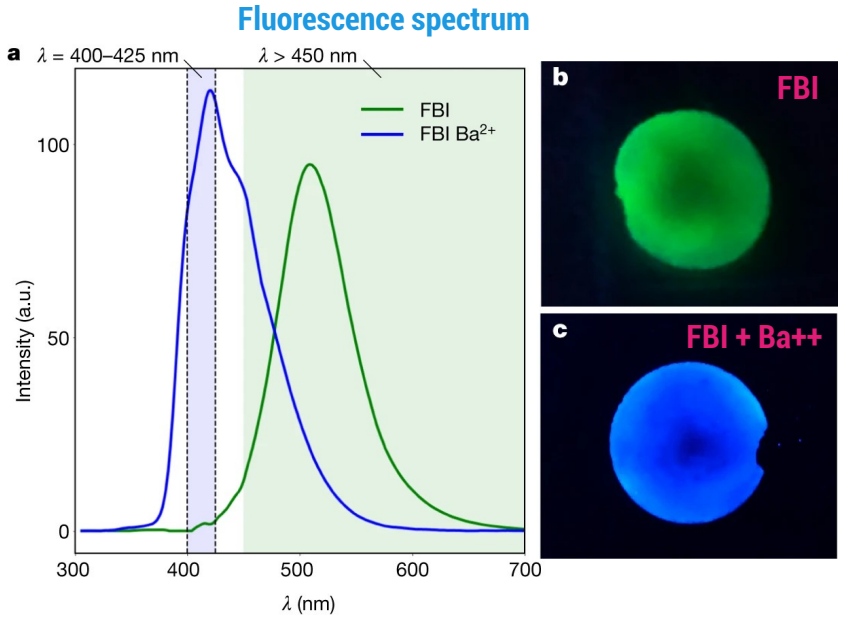
Summary

- NEXT has developed over the last decade the technology of high pressure xenon gas TPCs with electroluminescent amplification.
- +40 persons (~20 FTE), 5 groups involved: Donostia International Physics Center, Instituto de Física Corpuscular, Universidad Politécnica de Valencia, Universidad de Santiago de Compostela and Laboratorio Subterráneo de Canfranc.
- The list of R&D topics where the collaboration is currently involved is:
  - TPCs for rare event searches
  - Radiopurity
  - Signal amplification in gas for large detectors.
  - Light collection systems
  - Wavelength shifting materials
  - Low diffusion gas mixtures.
  - Calibration sources and techniques
  - SiPM technology for large area coverage.
  - ASICs to read-out large number of SiPM channels.
  - Development of digital-SiPMs.
  - Cooling systems for large number of channels.
  - FPGA programming, trigger and adquisition systems.

Backup

R&D: BOLD

- **0νββ: $^{136}Xe \rightarrow Ba^{++} + 2e^{-}$**
  - Detecting Ba++ → essentially **background free experiment**.
- Detection using **single molecule fluorescent imaging (SFMI)**.
  - Fluorescent bicolour indicator.
- **Strongly multidisciplinar R&D:**
  - Chemistry → Develop the indicator for gXe
  - Optics → Detect the fluorescence



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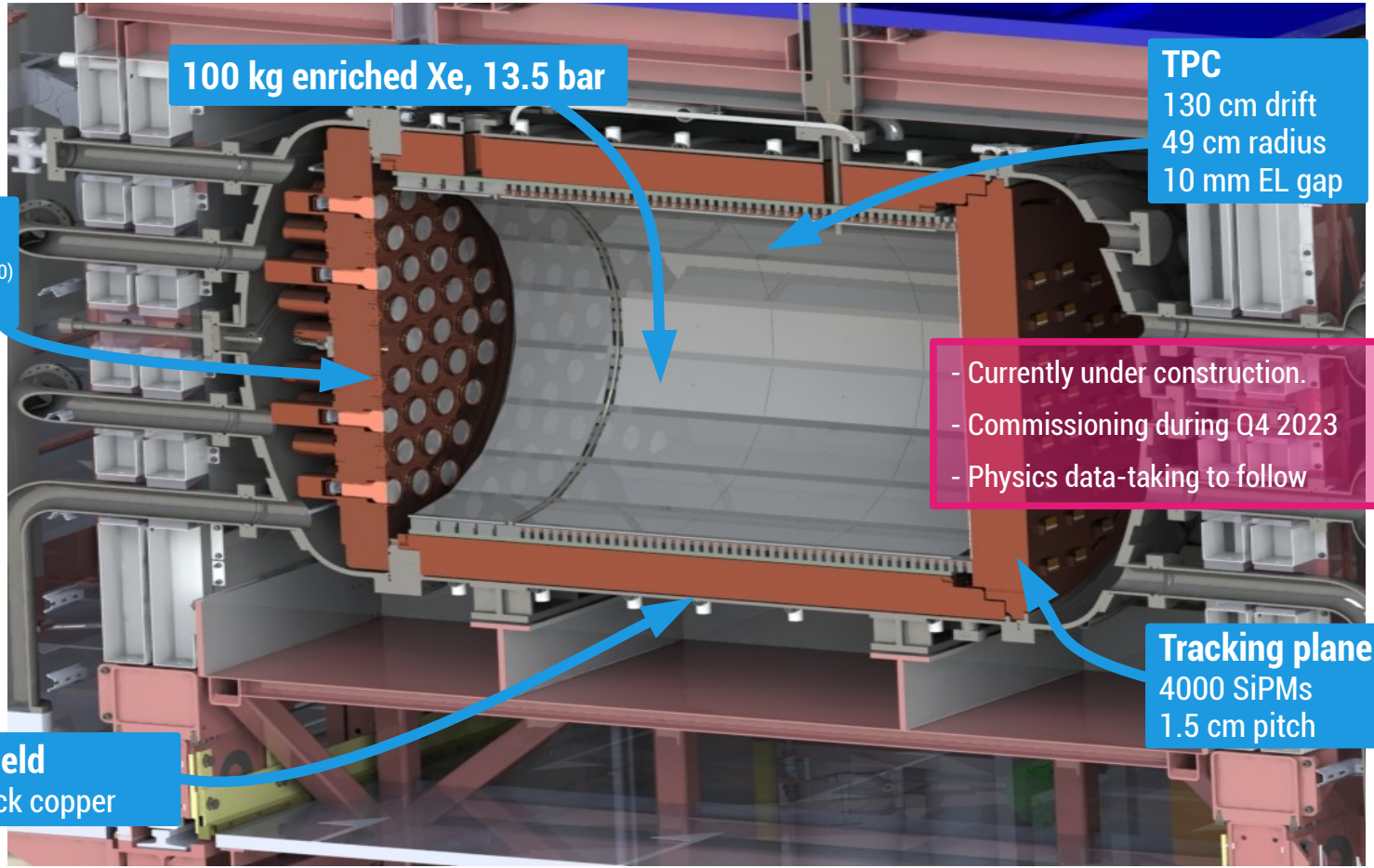
100 kg enriched Xe, 13.5 bar
TPC
130 cm drift
49 cm radius
10 mm EL gap
Energy plane
58 PMTs (Ham. R11410-10)
30% coverage
- Currently under construction.
- Commissioning during Q4 2023
- Physics data-taking to follow
Tracking plane
4000 SiPMs
1.5 cm pitch
Inner shield
12 cm thick copper

NEXT-100