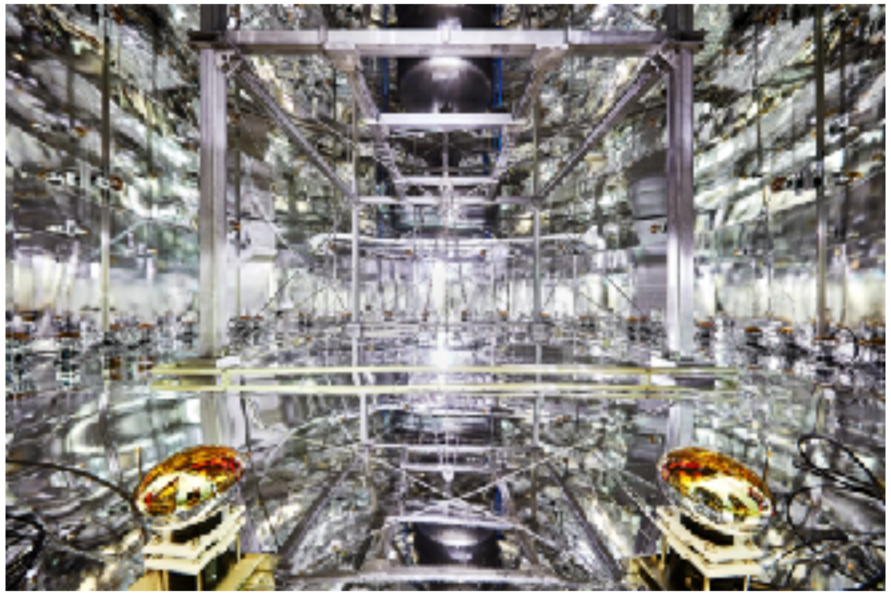
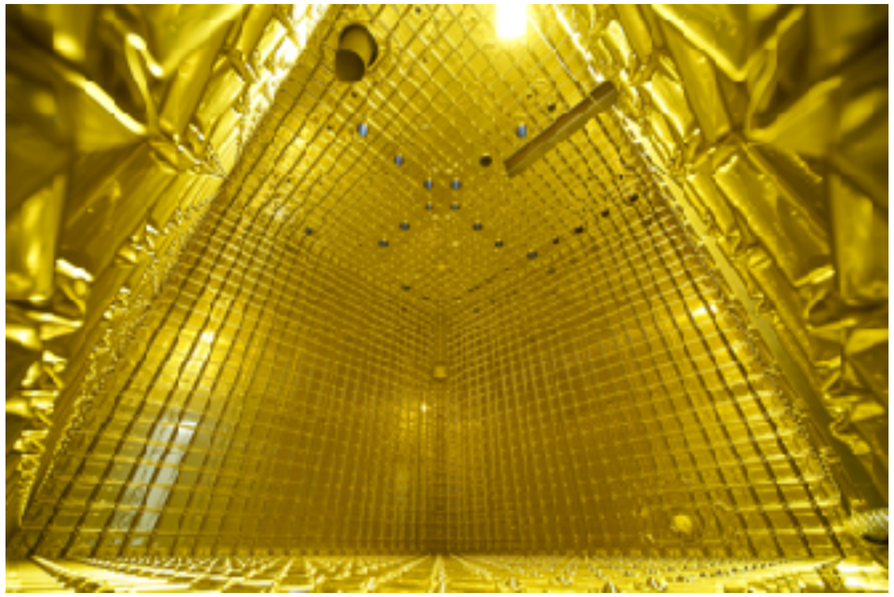
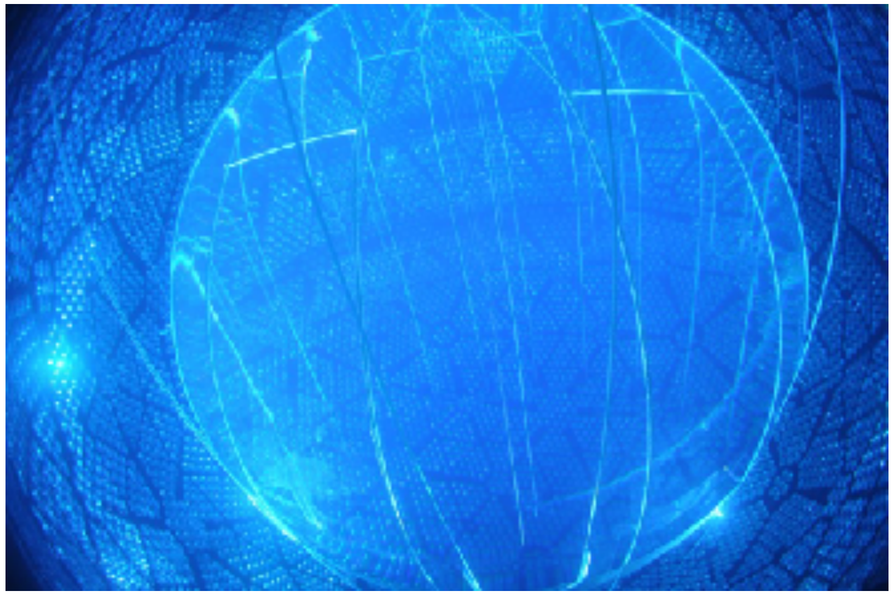
  

DRD2: Liquid Detectors Collaboration and proposal

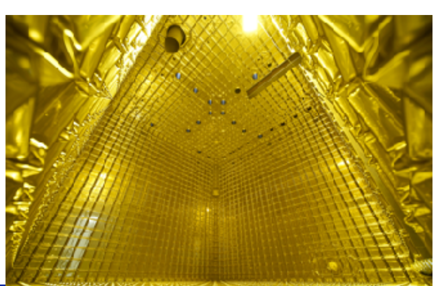
Roxanne Guenette

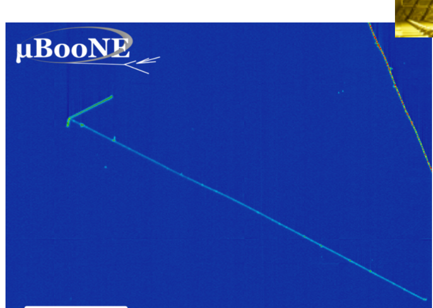
DUNE Phase II meeting
18 September 2023

The Science covered

Neutrinos

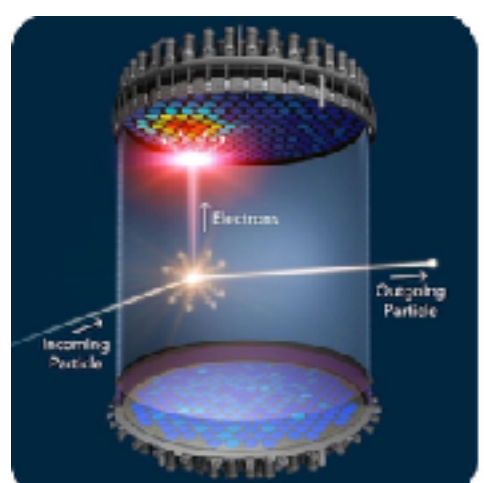
- Oscillation precision measurements (δ_{CP}, mass ordering, θ_{23} octant, sterile νs)
- Neutrino interactions (from CEvNS to DIS)
- Astro neutrinos





Dark Matter

- Direct detection (WIMPs, …)



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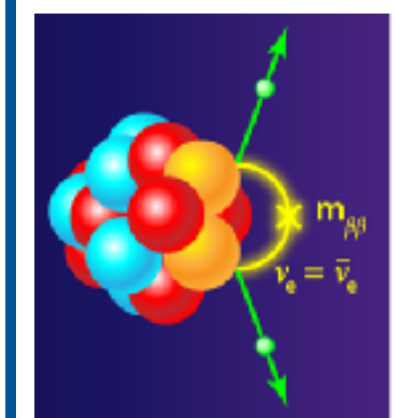
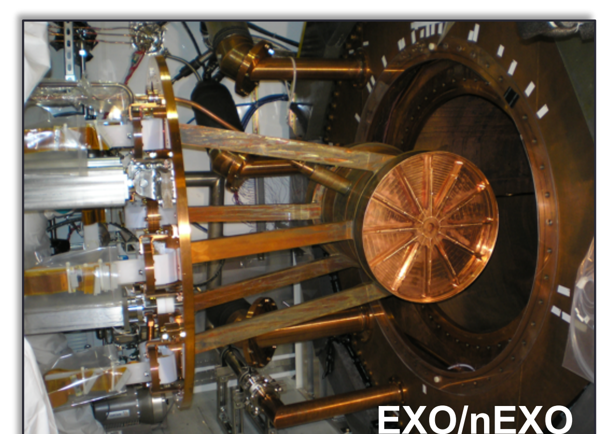
- Search for Majorana neutrinos





The Experiments (not exhaustive)

Neutrinos

- Current generation:
  - ✓ MicroBooNE & SBN
  - ✓ LArIAT
  - ✓ protoDUNEs
  - ✓ CAPTAIN
  - ✓ COHERENT
  - ✓ Borexino
  - ✓ SK
  - ✓ Antares
  - ✓ KM3Net
- Future generation:
  - ✓ DUNE modules 1 & 2
  - ✓ DUNE near detectors
  - ✓ DUNE modules 3 & 4
  - ✓ HK
  - ✓ Future neutrino telescopes

Dark Matter

- Current generation:
  - ✓ LUX / LZ
  - ✓ XENON 10/100/1T/nT
  - ✓ Dark Side 50/20k
  - ✓ DEAP-3600
  - ✓ Panda-X
- Future generation:
  - ✓ XLZD
  - ✓ GADMC/Argo
  - ✓ HeRALD
  - ✓ SBC

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- Current generation:
  - ✓ EXO-200
  - ✓ KamLand-Zen
  - ✓ SNO+
- Future generation:
  - ✓ nEXO
  - ✓ KL-Z+
  - ✓ Upgrades to SNO+

The Physics Needs (high level overview)

Neutrinos

- **Push Energy thresholds down** to ~1MeV to enhance oscillation physics, supernovae νs study, to enable solar νs …
- **Unambiguous readout**
- **Scalability**

Dark Matter

- **Push Energy thresholds down** to 1 meV/10 eV/1 keV to enable low mass DM/1 GeV DM/ WIMPs.
- **Reduce background rates**
- **Scalability**

0νββ

- **Improve Energy Resolution** to sub-% FWHM
- **Reduce background rates**
- **Scalability**

ECFA Roadmap (2021)

2022-2025

		DRDT	PIP-II/LBNF/DUNE (module 1&2)	JParc/HK	Neutrino near detectors	Neutrino telescopes (km^3)	Light dark matter detectors	Multi-ton scale DM detectors	Ton-scale 0nbb	Low-E scintillator neutrino detectors
Readout development	Higher energy resolution	2.1	Green	Green	Orange	Orange	Red	Orange	Orange	Orange
	Lower energy threshold	2.1	Yellow	Yellow	Yellow	Yellow	Red	Orange	Green	Orange
	Expand wavelength sensitivity	2.1	Orange	Green	Orange	Green	Orange	Orange	Orange	Orange
Measurement strategy	Fine granularity	2.2	Green	Green	Orange	Yellow	Orange	Orange	Orange	Red
	dE/dx (combine modalities: charge, light, heat, acoustics)	2.2	Green	Green	Orange	Green	Orange	Orange	Orange	Green
Target properties	Liquid doping and purification (87 - 290K)	2.3	Green	Yellow	Orange		Red	Red	Orange	Orange
	High pressure	2.3	Green	Green	Orange	Green	Orange	Green	Orange	Green
Scaling up challenges	Detector services (e.g. cryogenics) and integration	2.4	Green	Orange	Yellow	Green	Orange	Orange	Orange	Orange
	Large arrays (sensors)	2.4	Green	Orange	Orange	Orange	Yellow	Orange	Yellow	Yellow
	Low power	2.4	Yellow	Green	Green	Green	Red	Red	Red	Green
	Detector components radiopurity and background mitigation	2.4	Green	Green	Green	Green	Red	Red	Orange	Orange

2025-2030

		DRDT	PIP-II/LBNF/DUNE (module 3)	JParc/HK	Neutrino near detectors	Neutrino telescopes (km^3)	Light dark matter detectors	Hundred-ton scale DM detectors	Ton-scale 0nbb	Low-E scintillator neutrino detectors
Readout development	Higher energy resolution	2.1	Yellow	Green	Orange	Yellow	Red	Orange	Red	Orange
	Lower energy threshold	2.1	Orange	Yellow	Yellow	Yellow	Red	Orange	Green	Orange
	Expand wavelength sensitivity	2.1	Orange	Green	Orange	Green	Orange	Orange	Orange	Orange
Measurement strategy	Fine granularity	2.2	Yellow	Green	Yellow	Yellow	Red	Orange	Red	Red
	dE/dx (combine modalities: charge, light, heat, acoustics)	2.2	Orange	Green	Orange	Green	Red	Orange	Orange	Green
Target properties	Liquid doping and purification (87 - 290K)	2.3	Yellow	Orange	Yellow		Red	Red	Red	Orange
	High pressure	2.3	Green	Green	Orange	Green	Orange	Green	Orange	Green
Scaling up challenges	Detector services (e.g. cryogenics) and integration	2.4	Orange	Orange	Yellow	Yellow	Red	Red	Red	Orange
	Large arrays (sensors)	2.4	Orange	Orange	Red	Orange	Yellow	Red	Yellow	Orange
	Low power	2.4	Orange	Green	Green	Yellow	Red	Red	Red	Green
	Detector components radiopurity and background mitigation	2.4	Orange	Green	Green	Green	Red	Red	Red	Orange

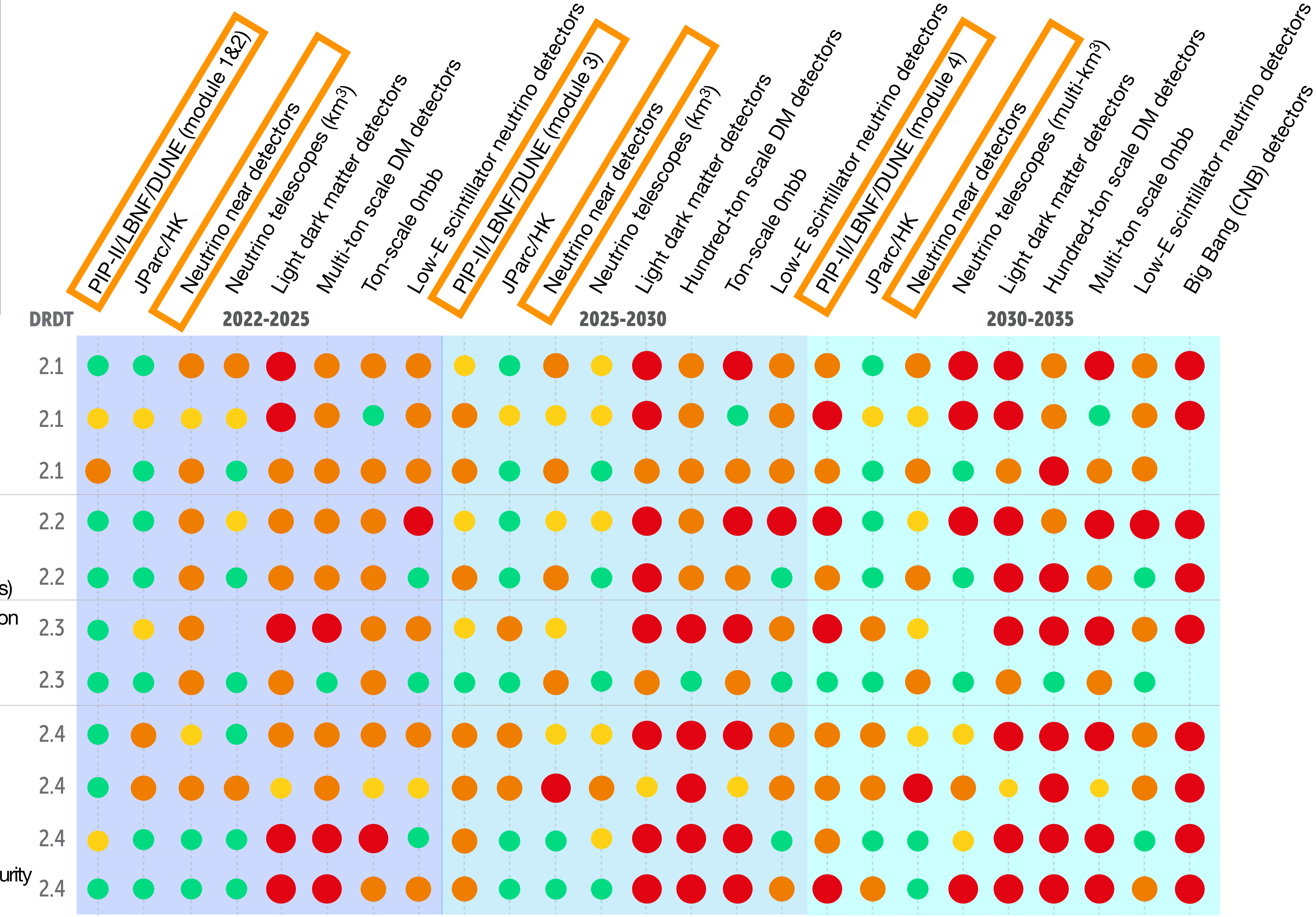
2030-2035

		DRDT	PIP-II/LBNF/DUNE (module 4)	JParc/HK	Neutrino near detectors	Neutrino telescopes (multi-km^3)	Light dark matter detectors	Hundred-ton scale DM detectors	Multi-ton scale 0nbb	Low-E scintillator neutrino detectors	Big Bang (CNB) detectors
Readout development	Higher energy resolution	2.1	Orange	Green	Orange	Red	Red	Orange	Red	Orange	Red
	Lower energy threshold	2.1	Red	Yellow	Yellow	Red	Red	Orange	Green	Orange	Red
	Expand wavelength sensitivity	2.1	Orange	Green	Orange	Green	Orange	Red	Orange	Orange	
Measurement strategy	Fine granularity	2.2	Red	Green	Yellow	Red	Red	Orange	Red	Red	Red
	dE/dx (combine modalities: charge, light, heat, acoustics)	2.2	Orange	Green	Orange	Green	Red	Red	Orange	Green	Red
Target properties	Liquid doping and purification (87 - 290K)	2.3	Red	Orange	Yellow		Red	Red	Red	Orange	Red
	High pressure	2.3	Green	Green	Orange	Green	Orange	Green	Orange	Green	
Scaling up challenges	Detector services (e.g. cryogenics) and integration	2.4	Orange	Orange	Yellow	Yellow	Red	Red	Red	Orange	Red
	Large arrays (sensors)	2.4	Orange	Orange	Red	Orange	Yellow	Red	Yellow	Orange	Red
	Low power	2.4	Orange	Green	Green	Yellow	Red	Red	Red	Green	Red
	Detector components radiopurity and background mitigation	2.4	Red	Orange	Green	Red	Red	Red	Red	Orange	Red

Red: Must happen or main physics goals cannot be met
Orange: Important to meet several physics goals
Yellow: Desirable to enhance physics reach
Green: R&D needs being met

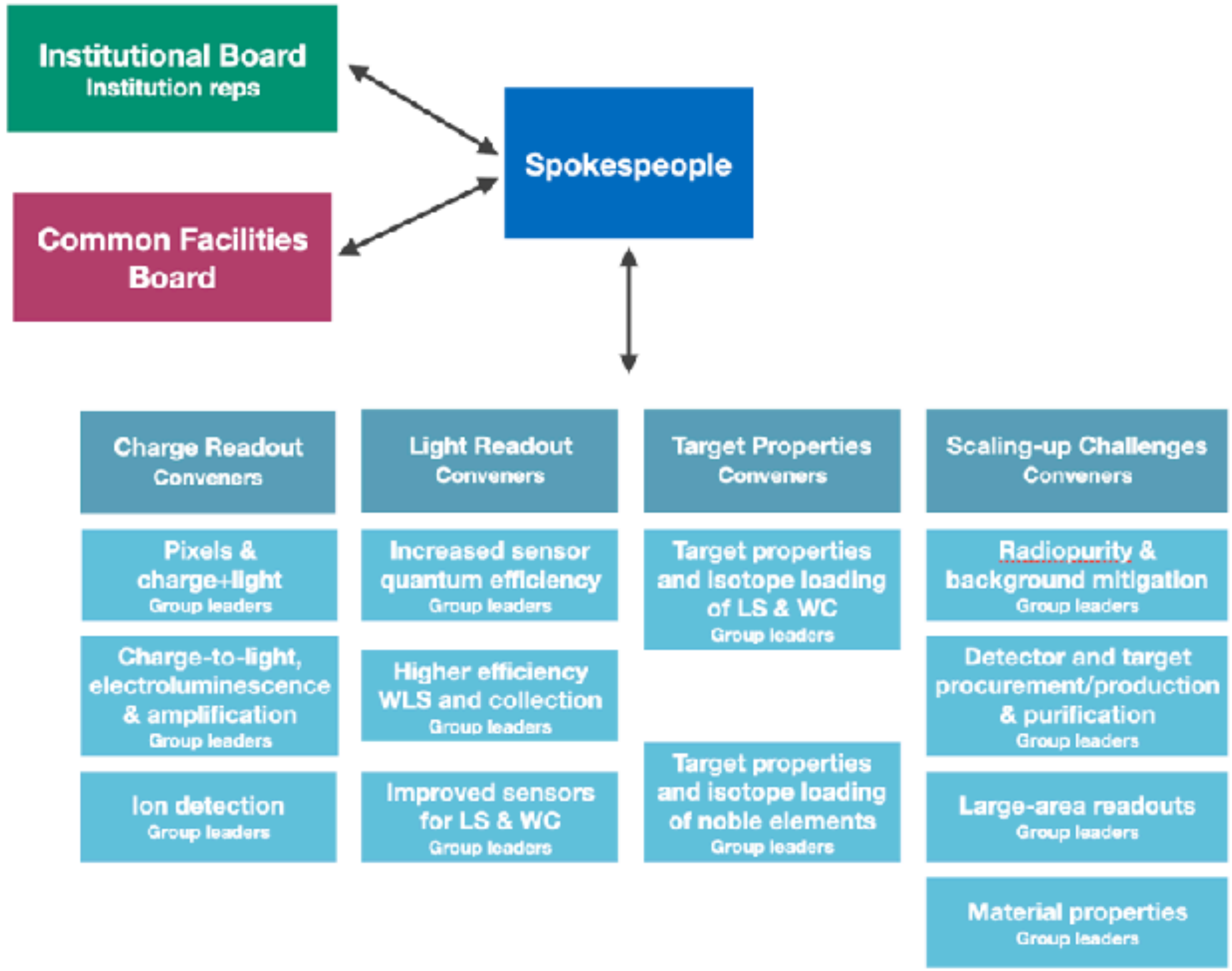
ECFA Roadmap (2021)

Related to DUNE...



- Must happen or main physics goals cannot be met
- Important to meet several physics goals
- Desirable to enhance physics reach
- R&D needs being met

DRD2 Collaboration



Charge Readout:
1.1 Jonathan Asaadi & Elena Gramellini
1.2 : Alexander Deisting & Kostas Mavrokoridis

Light readout:
2.1 Jocelyn Monroe
2.2 Marcin Kuzniak, Justo Martin-Albo, Clara Cuesta
2.3 Mathieu Bongrand & Tobias Lachenmaier

Target Properties:
3.2: Davide Franco , Marie-Cecile Piro, Andrea Zani, Andrzej Szelc
3.1: Hans Steiger, Micheal Wurm, Stefan Schoppmann

Scaling-up Challenges:
4.1 Roberto Santorelli & Jim Dobson
4.2 Walter Bonivento & Minfan Yeh
4.3 Ines Gil-Botella , Jose Crespo , Giuliana Fiorillo

DRD2 Proposal

- Year-long process to prepare the proposal
- Community workshops held on 20 April 2023
- Proposal draft circulated in June
- Submitted to ECFA beginning of August

Contents

Deliverables (charge readout)

		Timeline of milestones and major deliverables				
Deliverables	**Milestone**	**2024**	**2025**	**2026**	**2027-2030**	>2030
TA1: Charge Readout						
TA1.1: Pixels and Charge + Light Readouts						
TA1.1.D1: Design a fC charge sensing pixel readout optimized for low energy detection and minimizing power consumption.	D1.1.M1.1 Lower pixel thresholds to the limit of CMOS capabilities.	$\mathcal{O}(1000\,\mathrm{ENC})$	$\mathcal{O}(500\,\mathrm{ENC})$		$\mathcal{O}(<200\,\mathrm{ENC})$	$\mathcal{O}(<100\,\mathrm{ENC})$
	TA1.1.M1.2 Lower power consumption	$\sim 100\,\mu\mathrm{W/ch}$	50-100 $\mu\mathrm{W/ch}$		$<50\,\mu\mathrm{W/ch}$	
TA1.1.D2: Scaling pixel readout to O(100 million) channels		$\mathcal{O}(10^5)$	$\mathcal{O}(10^6)$		$\mathcal{O}(10^7)$	
TA1.1.D3: Design of an architecture capable of capturing multimodal signals	TA1.1.M3.1 Maximize photocathode coverage and QE in an integrated fC charge and VUV light sensing scheme for pixel TPCs	- Complete simulation of embedded photodetector technology - Measurement low γ flux in ASe horizontal geometry - ASe vertical geometry viability - Integrated Pixel/SiPM demonstrations (SoLAr) - Organics viability - ZnO explorations	- Small scale prototyping for embedded photodetector technology - Simulation package for multiple modality pixels	- Joint readout scheme for ASe horizontal geo - Measurement Low γ flux in ASe vertical geo - Other material explorations (Perovskites, Nanoplatelets, etc)	- Performance assessment for embedded photodetector technology - Small scale prototyping ASe horizontal geo - Joint readout scheme & small scale prototyping for ASe vertical geo - Measurement Low γ flux in perovskites & nanoplatelets	- Mid-scale prototype for pixel embedded photodetectors (data taking and validation) - Mid-scale prototype for multiple modality (data taking and validation) Scalability
	TA1.1.M3.2 Novel fast (O(GHz)) clock/timing architectures for charge & Q+L readout	50 MHz	100 MHz	500 MHz	1 GHz	
TA1.2: Amplification structures, charge to Light conversion, and granular light readout of dual phase detectors						
TA1.2.D1: Granular S2 light	TA1.2.M1.1: Camera-based particle tracking	first testing of photosensitive TPX4	testing TPX4 camera on prototype TPC; Design of VUV optics	testing integrate VUV image intensifier and TPX4 camera	test tracking, physics capability long TPX4 camera TPC runs	scalability implementation R&D
	TA1.2M1.2: SiPM-based particle tracking				demonstrate mm tracking resolution and sub-percent energy resolution	
	TA1.2.M1.3: Camera-based S1 detection				demonstrate S1 detection with TPX4cam using WLS-coated GEMs or S2 induced by S1 via photoelectric effect	
TA1.2.D2: Optimisation and characterisation of charge amplification structures	TA1.2.M2.1: dual phase		demonstrate single electron sensitivity using novel amplification structures	optimisation of large-area cryogenic glass thick GEMs, demonstrate ER/NR discrimination; demonstrate feasibility of new techniques to generate intense proportional scintillation		
	TA1.2.M2.2a: single phase LXe			demonstrate single electron sensitivity using novel electroluminescence structures	demonstrate ER/NR discrimination, developments for m^2-scale testing device and integration techniques	
	TA1.2.M2.2b: single-phase LAr		demonstrate stable charge amplification	demonstrate sub-keV detection threshold		
	TA1.2.M2.3: novel amplification strategies for single and mixed-phase detectors		report on the feasibility of LAr/LXe 10 l scale detector with bubble-assisted amplification/electroluminescence			
TA1.2.D3: Demonstration of scalability of D1 an D2	TA1.2.M3.1: LAr / dual phase Ar large scale tests			imaging large-area with TPX camera readout in protoDUNE	Evaluate tracking and physics capabilities in protoDUNE rune	
	TA1.2.M3.2: Single phase LXe / dual phase Xe large scale tests		m^2-sized demonstrator of a dual-phase LXe electroluminescence stage	m^2-sized demonstrator of a single-phase LXe electroluminescence stage	demonstrate scalabiilty to m^2 scale	experimental implementation

Table 1: Deliverables and milestones of TA1: Charge Readout.

Deliverables (light readout)

Deliverables	Milestone	Timeline of milestones and major deliverables 2024	2025	2026	2027-2030	>2030
TA2: Light Readout						
TA2.1: Increased Sensor Quantum Efficiency						
TA2.1.D1: Sensor optimisation	TA2.1.M1.1 design optimisation for low-noise, high fill-factor	digital SPAD design	digital SiPM design	SIGHT and SiPMs for full wavelength range coverage development	organic photosensors prototypes available	
	TA2.1.M1.2 purpose-optimised coatings for LAr/LXe wavelengths	reflectivity reduction strategies exploring graphene	narrowband coatings optimised for VUV	VUV characterisation measurements of prototypes	novel coatings materials development and characterisation	
	TA2.1.M1.3 optimised surface passivation for VUV		apply BSI-CCD passivation strategies	device integration of samples	PDE characterisation measurements	
TA2.1.D2: detector integration optimisation	TA2.1.M2.1: demonstrated 2D/3D integration processes	for FSI-SPADs	cryogenic PDE characterisation	for BSI-SPADS achieving low noise	optimisation for ultra-low radioactivity	
	TA2.1.M2.2: development of cryogenic SiPMs with enhanced PDE, reduced noise and connectivity for 3D integration	Development of FSI SiPMs with medium-to-fine pitch TSVs; Start of development of BSI SiPM. Study/improvement of correlated noise in FSI/BSI SiPMs at cryogenic temperatures.	Optimize for cryogenic compatibility of FSI SiPMs with TSVs; Development of BSI SiPM. Study/improvement of correlated noise in FSI/BSI SiPMs at cryogenic temperatures.	Study/improvement of correlated noise in BSI SiPMs at cryogenic temperatures.	addition of VUV surface passivation to BSI and characterization	
	TA2.1.M2.3: development of cryogenic SPAD and readout electronics technology on a commercial CMOS foundry	Sensor design of a prototype mini-SiPM pseudo-matrices and front-end readout electronics using LFoundry LF11is technology	Tapeout preparation of CMOS test structures; design of PCB carriers for characterisation	Characterisation activities	Design of a full-scale sensor matrix and readout electronics tier; hybrid 3D stacking of sensor and electronics	
	TA2.1.M2.4: segmentation optimised for measurement strategy	PIONEER facility development	measurements in LXe/LAr	characterise optical segmentation impact on energy resolution	simulations benchmarking using LoLX; comparing Optiks and Chroma performance; run at high energies (70 MeV).	
TA2.1.D3: characterisation facilities for VUV	TA2.1.M3.1 PDE vs. λ,T measurement capability		Liverpool & Napoli cryogenic PDE measurement facilities construction CIEMAT cryogenic characterisation facility development	measurements at access facilities programme operational		
	TA2.1.M3.2: sensor noise characterisation	Microscope for Injection and Emission of Light (MIEL) operation at TRIUMF	study of noise burst / rare events (potentially attributed to package and / cosmic rays)	RAL PPD SiPMs/fibres & Oxford & Zurich LAr/LXe characterisation operational	measurements at access facilities programme operational	
	TA2.1.M3.3: rare-event search qualification	BUTTON underground sensor test facility in water/scintillation construction	Nikhef SiPM and materials characterisation facility development	SoLAIRE underground sensor test facility m in LAr/LXe development	underground measurements access facility programme operational	
TA2.2: Wavelength shifters and increasing light collection						
TA2.2.D1: Better scalable wavelength shifters and reflectors	TA2.2.M1.1: Optimal WLS for application in water;	Polymeric synthesis optimized; Broader WLS survey completed (Ar and Xe)	WLS characterization facility commissioned; Determined solubility/long term stability of TPB in LAr	Polymeric production scaled-up; Stable WLS solution for LXe demonstrated;	WLS and WLS-reflector production and installation scaled up	
	TA2.2.M1.2: 4π evaporation source prototype commissioned	Test 4π TPB coatings characterized; Understood performance of large-scale WLS	Final 4π evaporator design ready	4π evaporation crucible constructed and tested	WLS and WLS-reflector production and installation scaled up	
TA2.2.D2: Optimized light collectors and concentrators	TA2.2.M2.1: Facility design and construction for light collector optimization from VUV to visible light in cryogenic temperatures	Commissioning of the facility			Proposal for X-ARAPUCA optimization	
	TA2.2.M2.2: Facility design and construction for light collection through WLS fibers in liquid scintillators		Commissioning of the facility		Proposal for light collection optimization	
	TA2.2.M2.3: Metalens and flat light concentrator + SiPM for the VUV and development: proof of concept	Adhesion/durability of WLS coatings in water; Directional WLS metasurface: proof of concept	Development of flat light concentrators: proof of concept	Large-scale light concentrator based on metasurfaces or flat light concentrators		

Table 3: Deliverables and milestones of TA2: Light Readout.

Deliverables (Target properties)

TA3.2: Target properties of liquid nobles						
TA3.2.D1: Understanding Microphysics of noble liquid (NL) response	TA3.2.M1.1: Measuring the NL response to low energy recoils in the sub-keV	1. Monte-carlo campaign for the optimization of the system completed. 2. New optimized TPC constructed and equipped with photosensors. 3. Redesign and procurement of the new neutron spectrometer.	1. TPC commissioned and characterized. 2. Procurement of the neutron source/gun. 3. Integration and mounting of the global system at LNS.	1. Commissioning of the integrated system. 2. Data taking for low-energy recoils.	1. Data taking for single-electron background. 2. Ancillary calibrations, data analysis and finalization.	
	TA3.2.M1.2: Establishing directionality from bubble formation in superheated noble mixture	1. Commissioning of the detector and R&D technology for new cameras	1. R&D technology for new cameras and Data taking to establish techniques to measure directionality	1. Measurement with the optimized detector design.		
	TA3.2.M1.3: Developing techniques for low-energy calibrations	1. Validation of ^{37}Ar source. 2. novel TOF detectors for O(10-100 keV) neutrons	1. Test new calibration sources (photoneutron) 2. Test of new neutron beams	1. Commissioning of low energy calibration detectors.		1. Commissioning for actual dark matter search detectors.
	TA3.1.M1.4: Modelling microphysics	1. Nucleation efficiency revisited and MD modeling.	1. Validation of the nucleation model with calibration data. 2. MD simulations with NEST.	1. Extension of the NEST model from low to high energy regime.		
TA3.2.D2: Characterizing and Modelling NL light emission and transport	TA3.2.M2.1: Measuring NL Scintillation pulse shape as a function of dopants and or contaminants		1. Pulse Shape characterization of the scintillation response from the far to the near UV		1. Pulse Shape characterization of the scintillation response in the near IR	
	TA3.2.M2.2: Characterizing Near IR emitted from Xe-LAr.	1. Tests and construct charge-only readout.	1. Charge and light readout (IR+VUV)	1. Test in large scale TPC.		
	TA3.2.M2.3: Precise measurement of scattering and absorption lengths as a function of contaminant concentrations	1. Setup for Xe-doping assembled. Xe-loading established 2. Measure group velocity in LXe using existing, commissioned DPXe setup and muon detectors. 3. Study scattering and propagation in LXe	1. First measurements of Rayleigh scattering length (RSL) and refractive index in Xe-Ar mixture. 2. Optical time domain reflectometry (OTDR) measurements with ps laser pulses to determine refractive index and RSL.	1. RSL and refractive index measurements as a function of Xe-doping.	1. Consolidating findings from previous measurements and R&D studies. Refine measurement techniques for group velocity and Rayleigh Scattering length measurements. 2. Contribute to advancements in particle detection at the Xenoscope facility.	
	TA3.2.M2.4: Develop new strategies for fast optical simulations	1. Establish mathematical model to minimize training of numerical approximated simulation models.	1. Identify and validate best performing paradigm to use GPUs for NL transport simulation.	1 Implement solutions in experiment code and standalone software.		
TA3.2.D3: Characterizing Properties of Xe-Ar mixture	TA3.2.M3.1: Characterize thermodynamics of Xe-doped LAr	1. Phase diagram and solubility measurement				
	TA3.2.M3.2: Verify stability in time and uniformity in volume.	1. Stability test with low concentrations (¡ppm) of Xe		1. Stability test with high concentrations (a few %-level) of Xe		
	TA3.2.M3.3: Measuring Scintillation and ionization of Xe-LAr as a function of Xe concentration		1. Characterization of electronic recoil scintillation and ionization in LAr doped with ¡1% Xe 2. Characterize light response of different Xe doping levels in LAr using X-ARAPUCAs operating at CERN	1. Characterization of nuclear recoil scintillation and ionization in LAr doped with $\leq$1% Xe. 2. Bubble chamber Characterization of Xe-doped LAr concentration 3. Pulse Shape characterization of the scintillation response from the Far to the near UV for controlled amounts of Xe doping up to 100 ppm 4. Characterization of electronic recoil scintillation and ionization in LAr doped up to the maximum Xe solubility 5. Characterize light response of different Xe doping levels in LAr using X-ARAPUCAs operating at CERN	1. Pulse Shape characterization of the scintillation response in near IR or controlled amounts of Xe doping up to 100 ppm	

Deliverables (Scaling-up challenges)

		Timeline of milestones and major deliverables				
Deliverables	**Milestone**	**2024**	**2025**	**2026**	**2027-2030**	>2030
TA4: Scaling-up Challenges						
TA4.1: Radiopurity and background mitigation						
TA4.1.D1: Radioassay techniques at required sensitivity for next generation of rare-event search experiments	TA4.1.M1.1 Achieve <5 µBq sensitivity for warm/cold Rn emanation	Design and material selection for warm/cold Rn emanation at <5 µBq sensitivity;	Portable gas Rn monitor constructed and tested;	Rn emanation warm/cold sensitivity demonstrated at <5 µBq;	Throughput scale up for all techniques; Characterisation of stock materials and barrier methods for next-generation experiments.	
	TA4.1.M1.2 Achieve <20 ppq U/Th sensitivity with ICP-MS and HPGe to <2 µBq/kg	ICP-MS sample preparation protocols for key materials at <20 ppq U/Th	HPGe detector built and characterised;	Demonstration rapid pre-screening using laser ablation ICP-MS to 10 ppt U/Th.	Throughput scale up for all techniques; Characterisation of stock materials and barrier methods for next-generation experiments.	
TA4.1.D2: Mitigation through material selection/treatment and clean manufacture	TA4.1.M2.1 Reach few ng/cm^2 surface cleanliness levels	Demonstration of ML-enabled optical and fluresence surface dust contamination to few ng/cm^2; Evaluation of barrier materials and methods (electroplating, conventional); Design and material selection for surface alpha-screening system (with industrial partners) with 10 µBq/m^2 sensitivity; Synthesis of new microporous adsorbents for Rn capture in gas phase (Ar, Xe, N2).	Demonstration of dust removal using atmospheric plasma surface treatment; New generation of microporous radon adsorbents characterised in Ar, Xe gas a function to T, P.	Protocols for dust removal surface treatments (chemical/electrochemical) demonstrated (few ng/cm^2); Facility for tests of surface contamination of large electrodes O(m^2); Barrier surface treatment of large scale detector components operational; Surface alpha-screening system operational with 100 µBq/m^2 sensitivity; Vacuum Swing Absorption prototype developed using optimised absorbent.	Demonstration of dust removal using vacuum plasma surface treatment.	
TA4.1.D3: Development of novel materials for background suppression	TA4.1.M3.1 Demonstrate low-radioactivity Gd-PMMA at scale	Development of low-background polymerization processes for passive shields and light guides; Design optimisation for Gd-PMMA system (maximum Gd-fraction, veto thickness).	Scale-up passive shield production; Evaluation of microporous adsorbent materials for Rn capture; Materials screening/selection for high-radiopurity Gd-PMMA active shielding.	Design and prototype Rn removal system based on microporous absorbants; Gd-PMMA scale-up via industrial transfer.		
TA4.1.D4: Tools for the evaluation of backgrounds	TA4.1.M4.1 Public release of simulation and accounting tools;	Implementation of generic highly shielded detector in GEANT4; Development of GPU-accelerated statistical inference tools; Improvement in accuracy of neutron yield calculations with uncertainties of 10% for most materials; Comparison between codes, models and datasets for cosmogenic and beam activation products; Development of material background accounting tool and data formats.	Development of techniques for high-stats simulations of highly shielded detectors (event biasing, bootstrapping, GPU/TPU accelerated); Release updated neutron yield library (SOURCE4) and paper; Toolkit for accurate simulation of cosmogenic production and activation of detector components and target materials	Improved (α-n) production cross-section measurements for key materials (e.g., argon); Report on design studies optimising active veto strategies vs fiducial trade off for 0vBB, DM.		
TA4.2: Detector & Target Procurement/Production and Purification						
TA4.2.D1: Scale-up mass production	TA4.2.M1.1: massive purification/production facilities for (Md & Wb) LS/Wc	tonne-scale facility to exercise scale-up technology and requirement for metal-doped & water-based LS/Wc manufacture	facility capable of producing metal-doped & water-based LS/Wc to support 10s tons of prototype and deployment (i.e. 30TBNL, Eos, ANNIE, LiquidO, BUTTON100X)	Facility capable of >100-ton scale metal-doped & water-based LS/Wc manufacture for experimental deployment		
	TA4.2.M1.2: Massive (ktonne) xenon production		R&D to extract xenon from air, Construct pilot plant and production plant.	Complete R&D for pilot plant	Construct pilot plant	
	TA4.2.M1.3: Massive UAr Production and sampling	Measurements of residual contamination Setup and test a detector for 39Ar	Run the detector for 39Ar	Setup a detector for 42Ar	Run a detector for 42Ar	
	TA4.2.M1.4: Purification from contaminants	Urania and Aria construction	Urania and Aria run	Scale up production for Argo, DUNE MoO	Find new UAr sources, scale up plants	
TA4.2.D2: Purification technologies	TA4.2.M2.1: In-situ purification and production scheme *for (Md & Wb) LS/Wc detector*	QA/QC procedures to guide manufacture process		Demonstrate the feasibility of nanofiltration for WbLS detector and inline purification technology for metal-doped LS/Wc at 10s of tons	A scale-up nanofiltration system for WbLS and an inline purification system for LS detectors at 100s-1000s of tons	Tech-transfer and communicate with the commercial vendors to improve starting materials
	TA4.2.M2.2: xenon purification	85Kr and Rn suppression by online distillation		Kr and Rn removal technology for DARWIN/XLZD	Online Kr and Rn diagnostics for DARWIN/XLZD	
	TA4.2.M2.3: Ar extreme purification	Measure electron lifetime/liquid argon purity in-situ using a system of l aser beams; Residual isolated electron study	Construction and installation of laser-based, programmable, calibration systems for the ProtoDUNE detectors at CERN Understand sources of single electrons developing and verification of countermeasures;	Characterization of ionization charge dependence with track length, and stability	Measurement of electron lifetime in ProtoDUNE-HD or VD with laser; Tuning of simulation model for ionisation charge with real calibration data in PD	
TA4.3: Large-area Readouts						
TA4.3.D1: Development of mid-scale facilities for large-area readout assembly and characterization at cryogenic temperature	TA4.3.M1.1 Operation of the photodetector facility	Design of the photodetector facility	Construction and commissioning of the photodetector facility	First operation of the photodetector facility		
	TA4.3.M1.2 Operation of the TPC-testing facility	Upgrade of the TPC-testing facility	Commissioning and TPC construction for the TPC facility	First operation of the TPC-testing facility		
TA4.3.D2: Large-scale digitization technologies	TA4.3.M2.1 PMT readout demonstration	Test of multi-PMTs readout at WC Test experiment at CERN				
	TA4.3.M2.2 SiPM readout demonstration		Design of cold ADC and FPGA boards for scintillation light signal processing	Production of prototypes of cold ADC and FPGA boards for scintillation light signal processing	Testing of cold electronics for scintillation light signal processing	
TA4.3.D3: Large-scale joint integration tests	TA4.3.M3.1 Demonstration of large scale photodetection in a field cage			Demonstration of large scale photodetection in a field cage at ProtoDUNE with charged particle beams		
	TA4.3.M3.2 First O(10 million) pixel readout				Scaling pixel readout to O(10 million) channels	
	TA4.3.M3.3 Operation of large fill-factor UV sensors.	Operation of 192 $6 \times 6\,\mathrm{mm}^2$ MPPCs in Xenoscope				

Table 7: Deliverables and milestones of TA4: Scaling-Up Challenges.

What's next

- Proposals are currently under review by ECFA (timescale December 2023)
- Approved collaborations should be formed early 2024
- There will always be possibilities to join these collaborations
- In discussion with the US-side (RDCs) to ensure efficient collaboration and procedures
- If you have not done yet, consider joining DRD2!
  - ➡ "Register" to the indico: https://indico.cern.ch/event/1214404