Detector Design and R&D WG

Tom Shutt and Joern Mahlstedt

30 June 2025

XLZD meeting LNGS

Organisation of WG 3/4

Contact persons:

- Tom Shutt tshutt@slac.stanford.edu
- Joern Mahlstedt joern.mahlstedt@fysik.su.se

Detector design and R&D WG wiki page:

https://wiki.physik.uzh.ch/xlzd/doku.php? id=wg3_4

WG Objectives:

- Design decisions
- Large platform testing
- R&D

Regular meetings (8 meetings since Sept 2024)

Recordings:https://drive.google.com/drive/folders/16j0C0YfcF28i7SBg6r1pq5rGXOLtEur3

Detector design and R&D WG

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WG objectives

- **Design decisions**:
  Work through set of decisions per subsystem, mostly between XnT and LZ designs.
- **Large platform testing:**
  Need to decide on possibly shielded testing.
- **R&D:**
  Provide forum for discussion, presentations.

Meetings

- 2025-05-12 Outer detector part II
- 2025-04-23 Outer detector part I
- 2025-04-10 Photosensor R&D part II
- 2025-03-12 Photosensor R&D part I
- 2024-12-03 Cryostat Serviceability and Layout
- 2024-10-25 Discussion about large shielded testing facilities
- 2024-10-01 Presentation of group interests part II
- 2024-09-03 Presentation of group interests part I

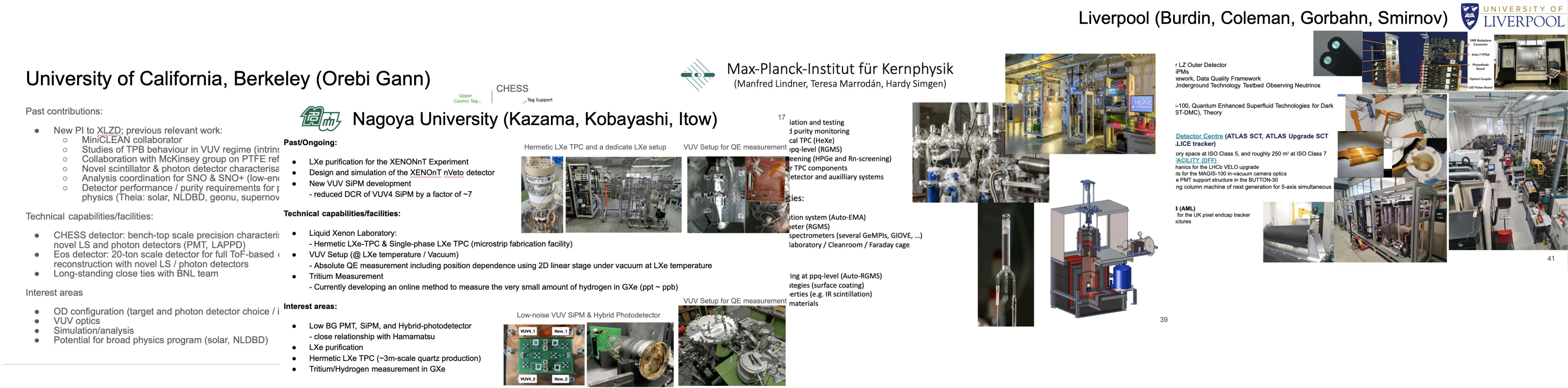
Shared material

- Link to all meeting recordings

Table of (

Topics discussed in our meetings

- Presentation of group interests (Link)
- Discussion about large shielded testing facilities (Link)
- Cryostat, Layout, and Serviceability (Cryostat, Serviceability and Layout)
- Photosensor R&D (Part I, Part II)
- Outer detector (Part I, Part II)



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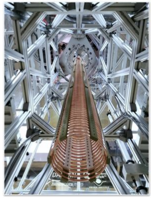
More talks on Tuesday afternoon

Shielded UG testing

- We have significant test facilities, particularly at Freiburg, Zurich and SLAC. We need to coordinate the activity at these, and any UG testing.
- We have several potential sites available to us within broader XLZD. However Gran Sasso / XnT and Kamioka appear most likely to support this work.
- There are many things to decide in terms of scope, goals, and what is needed to make this successful.
- The goal of this presentation is to start planning for this.



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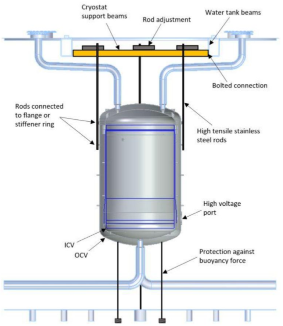
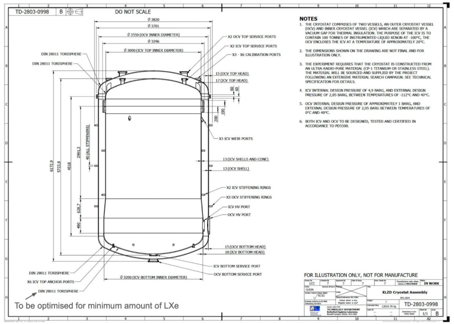
More talks this afternoon

Ongoing design work



Dimensions ⇩ Specification ⇩



Total LXe mass : 100 tonnes

Serviceability and Experimental Layout

- Cryostat slides from Pawel Majewski
- There is a strong argument to make the detector as serviceable as possible
  - Allow fix of problems. Risk order: grids, field cage resistor, cathode HV, PMT arrays.
  - Allow final test of subsystems - grids, PMT arrays
  - Necessary for two-stage operations. i.e., half-height, then full height.
- This affects many aspects of the design of the TPC, vessel, outer detector and other infrastructure

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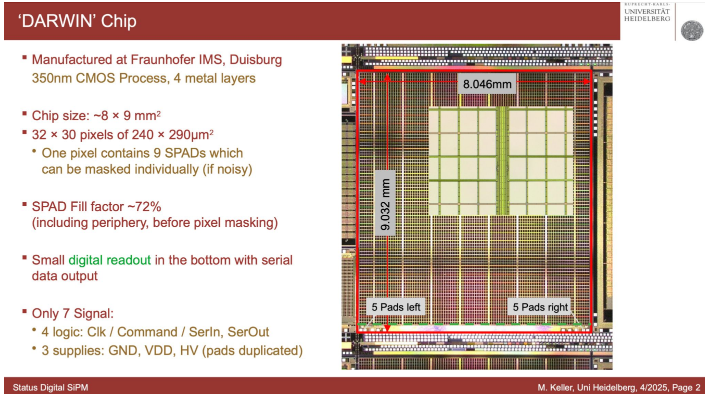
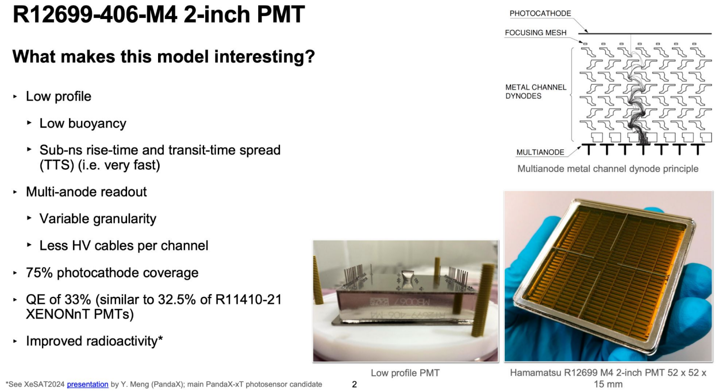
More talks on Wednesday morning





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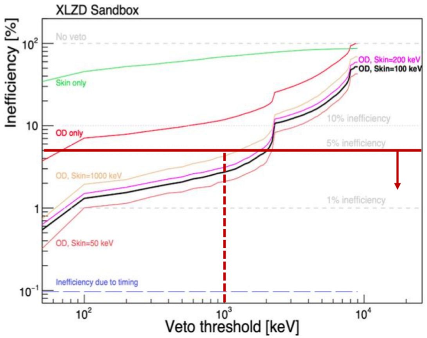
More discussion in breakout session

Neutron Tagging Efficiency Requirement



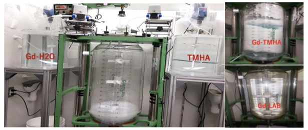
- Simulation based on backgrounds scaled from LZ predicts 1.13 SS NR in FV per year (Cuts are not optimized)
  - 10 years of operation ➔ 11.3 SS NR
  - Expecting ~20 CνNS events
    - 30% uncertainty?
    - Neutron background should be subdominant ➔ 1 SS NR after veto
  - ~1 SS NR after veto requires 91% veto efficiency: $11.3 \cdot 0.09 = 1$
- LZ experience: 4% discrepancy between simulation and measurements ➔ should aim for **95% neutron tagging efficiency**
- Without skin the OD threshold should be unrealistic (for long window) ~70 keV
- With skin the OD threshold could be up to ~1 MeV
  - 0.1% Gd is assumed
- Proton recoil signal is used in LZ in prompt (very short) window
  - ~100 keV

GdLS Production & Filling

- Procurement, purification of raw material, and production of GdLS all at BNL under Minfang Yeh
- Purified $GdCl_3$ mixed w/ TMHA as "chelating agent")... makes $Gd(TMHA)_3$ which readily dissolves in organic LAB
- Shipped to SURF in ~120 drums (cheap option)
- Filling system comprised of acrylic, teflon tubing, and SS fittings… effort to keep surfaces purged with N2
- Co-filled acrylic tanks with water fill to keep pressure differential across acrylic low
- Now… continuous monitoring of GdLS levels in tanks, stable operations

Table 2.1: Chemical components in 1 liter of GdLS.

Acronym	Molecular Formula	Molecular Weight (g/mol)	Mass (g)
LAB	$C_{17.14}H_{28.28}$	234.40	853.55
PPO	$C_{15}H_{11}NO$	221.25	3.00
Bis-MSB	$C_{24}H_{22}$	310.43	0.015
$TMHA^-$	$C_9H_{17}O_2^-$	157.23	2.58
Gd	Gd	157.25	0.86
GdLS	$C_{17.072}H_{28.128}O_{0.0126}N_{0.0037}Gd_{0.0015}$	233.89	860.0



Planned next meetings

- Outer detector (Part III - Gd-Water option)
- Measurements of photoluminescence (PTFE contamination, solder flux and a PMT) by Tina

- We have a list of topics we want to cover in the future
- Should you have a topic you would like to discuss / present, contact us

Backup

Detector Design Decisions I - Slides from 2024

- Field cage
  - sealed TPC for Rn
  - PTFE thickness, ring configuration
- Weirs vs bell jar
  - If weirs: How many, movable?
- Kr removal. Method. Online?
- Extraction region design - S2 size/shape, optimization for S2 only, reduction of e-trains
- HV feedthrough, side vs top entrance
- Grids - crossed wires, single wires, electroformed?
- PMT shield grids - different method? Top PMT grid?
- Instrumented skin? HV standoff if not instrumented
- Cabling, bases
- Cold readout electronics?
- Instrumentation - level sensors, thermometers, anything else?
- Possible design mods for backgrounds
  - Accidentals. S1 only and S2 only regions, extraction region design, other?
  - Materials that drive backgrounds - PTFE, Ti, SS, other … Need MC.
  - Skin vs no skin, if skin, how is dome handled?
  - Outer detector

Detector Design Decisions II - Slides from 2024

- Rn removal, Kr removal
- Internal fluid, gas flows design
- Electronegative purification, cryogenics
    - Liquid phase
    - What are goals? e-train suppression? Fast tritium removal?
    - What to do with gas phase
    - Materials changes to reduce outgassing?
    - Fluid movement, temperature control
    - Purity sampling
- Calibrations - any internal sources, e.g., deposited on cathode? photocathode? Neutrons: conduits, very low energy
- Outer detector - scintillator? What type of tank(s)?
- SiPM vs PMTs vs hybrid
-
- Extra grids for BB decay SS vs MS?
- Optimization for other physics channels - SN neutrinos?
-
- …

Large platform testing - Slides from 2024

Which subsystems?

- Grids
- Field cage
- HV delivery
- PMTs

What are the goals?

- Breakdown
- SE emission
- Photon emission
- Long term stability
- Isolated S1/S2
- Liquid vs gas
- Surface charging?
- Fluid flow, purification?

Which requirements?

- Shielding, backgrounds
- SE sensitivity
- LCE
- HV

Which instrumentation?

- PMTs
- Reflectors
- Cameras
- Fluid measurement

Which timelines?

- Fabrication, commissioning
- Prototype testing
- Final parts testing

Large surface facilities

- Pancake
- Xenoscope
- SLAC LNTF
- Mainz

Future shielded facilities

- Kamioka
- LNGS
- SURF?
- Boulby?

PMT testing facilities

Research & Development - Slides from 2024

- **PMTs**
  - Low background capacitors
  - Low background, and HV stable TPC resistors
  - Cabling - backgrounds, Rn.
  - Cold electronics?
  - Bases
  - Cold testing
- **Alternative PMTs**
- **SiPMs**
  - Dark current
  - CMOS readout - digital SiPMs and related
- **Hybrid photosensors**
  - ABALONE
  - PMR+SiPM
- **Grids - hot spots, diffuse emission**
  - why / how does passivation work. Diffuse vs hot spots
  - how can hot spots be variable?
  - what is ratio of light/charge
  - is there diffuse multi-electron emission?
  - large scale mechanics
  - Reflectivity
  - Grid style, fabrication method - welded vs woven vs stretched
  - alternative metals, coatings
  - anode - fine grained, high uniformity
- **S2 signal design**
  - optimization for accidentals, S2 only. Extraction efficiency, S2 size and shape of S2, uniformity of anode (and gate?)
  - optimization for wall events
- **Fluids in detector - stability of liquid surface, stability of fluid, sealing for Rn**

- **Accidentals - isolated S1s**
  - fluorescence in ptfe - https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=14217 claims due to impurities. Can we reduce?
  - could we block fluorescence with filter?
  - PMT flashers as origin of > ~4 pe S1s? Effect of field?
- **Accidentals / S2 only - reducing SEs**
  - what are the sources of the several types of SEs?
  - what are the relevant impurities, and how low can we reduce them?
  - any other detector optimization for S2 only?
  - Speculative - could we ionize negative ions with light?
- **HV resistors - long terms stability, radioactivity**
- **HV feedthrough**
  - Field grading at cathode
  - Feedthrough
- **Radon**
  - Emanation, screening, coatings
  - Removal
  - Hermetic TPC - Nagoya, Freiburg designs
  - Ti - plating, source
- **Kr - emanation? other removal?**
- **Various radioactivity screening development**
  - Cold Rn emanation
- **Material radioactivity**
  - Ti
  - Resistors
  - Grid material
  - PMTs
  - PTFE

- **Purification**
  - better pump
  - liquid flow meter
  - low Rn getter / filter.
  - use of gas phase, driving impurities into gas
  - characterizing and minimizing outgassing
  - improved sampling
- **Cryogenics - anything?**
- **NR calibration**
- **Other calibrations, measurements:**
  - neutrinos vs betas
  - Migdal
  - low energy NR
  - Signals in 2-10 e- range - S2 only
  - Xe microphysics: W value, extraction efficiency, band shapes, P, T, field dependencies
  - Pulsed photocathode?
  - New sources?
- **Outer detector**
- **SS vs Ti vs Cu cryostat**
- **Neutron background suppression: skin veto, outer detector**
- **Instrumentation**
  - improved liquid surface monitoring
  - liquid flow meter?
  - cold camera?
- **Cold readout and optical output (and low bkgd)**
  - Front end amplifier? Front end DAQ? Fiber out?
- **BB decay reach**
  - Induction wires for multi-site detection
  - Alternate materials - capacitors, resistors, cabling. Grid rings. Field cage rings.
- **Charge, light gain in liquid, single phase TPC**
- **No PTFE tpc - SiPMS on walls**
- **HydroX, Crystallize**