

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

Contact persons:

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

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 C

- ♦ Detector
- ♦ WG ob
- ♦ Meetin
- ♦ Shared

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](#))

University of California, Berkeley (Orebi Gann)

Past contributions:

- New PI to XLZD; previous relevant work:
 - MiniCLEAN collaborator
 - Studies of TPB behaviour in VUV regime (intrinsic)
 - Collaboration with McKinsey group on PTFE ref
 - Novel scintillator & photon detector characterisation
 - Analysis coordination for SNO & SNO+ (low-en physics) (Theia: solar, NLDBD, geonu, supernov)

Technical capabilities/facilities:

- CHES detector: bench-top scale precision characterisation of novel LS and photon detectors (PMT, LAPPD)
- Eos detector: 20-ton scale detector for full ToF-based reconstruction with novel LS / photon detectors
- Long-standing close ties with BNL team

Interest areas

- OD configuration (target and photon detector choice / i)
- VUV optics
- Simulation/analysis
- Potential for broad physics program (solar, NLDBD)

Nagoya University (Kazama, Kobayashi, Itow)

Past/Ongoing:

- LXe purification for the XENONnT Experiment
- Design and simulation of the XENONnT nVeto detector
- New VUV SIPM development
- reduced DCR of VUV4 SIPM by a factor of ~7

Technical capabilities/facilities:

- Liquid Xenon Laboratory:
 - Hermetic LXe-TPC & Single-phase LXe TPC (microstrip fabrication facility)
- VUV Setup (@ LXe temperature / Vacuum)
 - Absolute QE measurement including position dependence using 2D linear stage under vacuum at LXe temperature
- Tritium Measurement
 - Currently developing an online method to measure the very small amount of hydrogen in GXe (ppt ~ ppb)

Interest areas:

- Low BG PMT, SIPM, and Hybrid-photodetector
- close relationship with Hamamatsu
- LXe purification
- Hermetic LXe TPC (~3m-scale quartz production)
- Tritium/Hydrogen measurement in GXe



CHES

See Support

Hermetic LXe TPC and a dedicated LXe setup



VUV Setup for QE measurement



Low-noise VUV SIPM & Hybrid Photodetector



VUV Setup for QE measurement



Max-Planck-Institut für Kernphysik
(Manfred Lindner, Teresa Marrodán, Hardy Simgen)

17

ation and testing
i purity monitoring
at TPC (in-keV)

sq-level (RGMS)

ening (HPGe and Rn-screening)

TPC components

detector and auxiliary systems

ies:

tion system (Auto-EMA)

eter (RGMS)

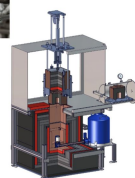
spectrometers (several GeMPis, GIOVE, ...)

laboratory / Cleanroom / Faraday cage

ing at ppg-level (Auto-RGMS)

eries (e.g. IR scintillation)

materials



Liverpool (Burdin, Coleman, Gorbahn, Smirnov)



LZ Outer Detector
PMA
Network, Data Quality Framework
Indigenous Technology Tested Observing Neutrinos

-100. Quantum Enhanced Superfluid Technologies for Dark
ST(GMC). Theory

Detector: Centre (ATLAS SCT, ATLAS Upgrade SCT
LICE tracker)
ory space at ISO Class 5, and roughly 250 m² at ISO Class 7
AGILITY (SPT)
tion for the LUXE VETO upgrade
is for the MAGIS-100 in-vacuum camera optics
PMT support structure in the BOTTOM-20
ing column machine of next generation for 5-axis simultaneous

(AML)
for the UK post endstop tracker
cures



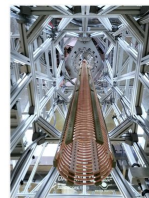
Topics discussed in our meetings

- 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](#))

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.

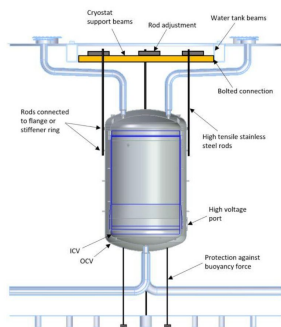


Topics discussed in our meetings

- 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](#))

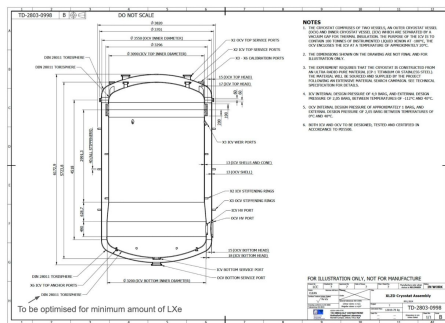
More talks this afternoon

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

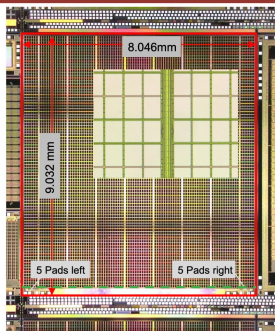
Topics discussed in our meetings

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

More talks on
Wednesday morning

'DARWIN' Chip

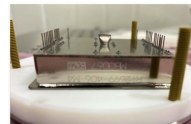
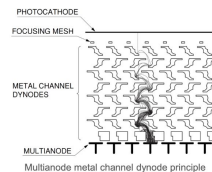
- Manufactured at Fraunhofer IMS, Duisburg
350nm CMOS Process, 4 metal layers
- Chip size: $\sim 8 \times 9 \text{ mm}^2$
- 32×30 pixels of $240 \times 290 \mu\text{m}^2$
 - One pixel contains 9 SPADs which can be masked individually (if noisy)
- SPAD Fill factor $\sim 72\%$
(including periphery, before pixel masking)
- Small **digital readout** in the bottom with serial data output
- Only 7 Signal:
 - 4 logic: Clk / Command / SerIn, SerOut
 - 3 supplies: GND, VDD, HV (pads duplicated)



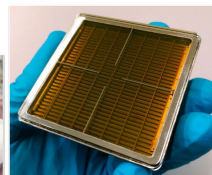
R12699-406-M4 2-inch PMT

What makes this model interesting?

- Low profile
 - Low buoyancy
 - Sub-ns rise-time and transit-time spread (TTS) (i.e. very fast)
- Multi-anode readout
 - Variable granularity
 - Less HV cables per channel
- 75% photocathode coverage
- QE of 33% (similar to 32.5% of R11410-21 XENONnT PMTs)
- Improved radioactivity*



Low profile PMT



Hamamatsu R12699 M4 2-inch PMT 52 x 52 x 15 mm

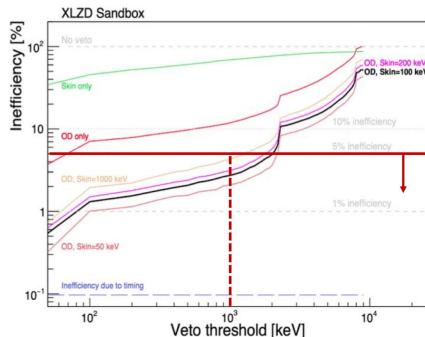
*See XsSAT2024 [presentation](#) by Y. Meng (PandaX); main PandaX-xT photosensor candidate

Topics discussed in our meetings

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

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 $\text{Gd}(\text{TMHA})_3$ 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 N_2
- 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	$\text{C}_{17.14}\text{H}_{28.28}$	234.40	853.55
PPO	$\text{C}_{15}\text{H}_{11}\text{NO}$	221.25	3.00
Bis-MSB	$\text{C}_{24}\text{H}_{22}\text{O}_2$	310.43	0.015
TMHA	$\text{C}_8\text{H}_{15}\text{O}_2$	157.23	2.58
Gd	Gd	157.25	0.86
GdLS	$\text{C}_{17.072}\text{H}_{28.128}\text{O}_{0.0126}\text{N}_{0.0037}\text{Gd}_{0.0015}$	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

Which requirements?

- Shielding, backgrounds
- SE sensitivity
- LCE
- HV

Large surface facilities

- Pancake
- Xenoscope
- SLAC LNTF
- Mainz

What are the goals?

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

Which instrumentation?

- PMTs
- Reflectors
- Cameras
- Fluid measurement

Future shielded facilities

- Kamioka
- LNGS
- SURF?
- Boulby?

Which timelines?

- Fabrication, commissioning
- Prototype testing
- Final parts testing

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**