A Calibration System for the nEXO Muon Veto

Samin Majidi
McGill University
samin.majidi@mcgill.ca

WNPPC 2024 - 61st Winter Nuclear Particle Physics Conference (Feb 15 – 18, Mt. Bromont)

MATTER-ANTIMATTER ASYMMETRY

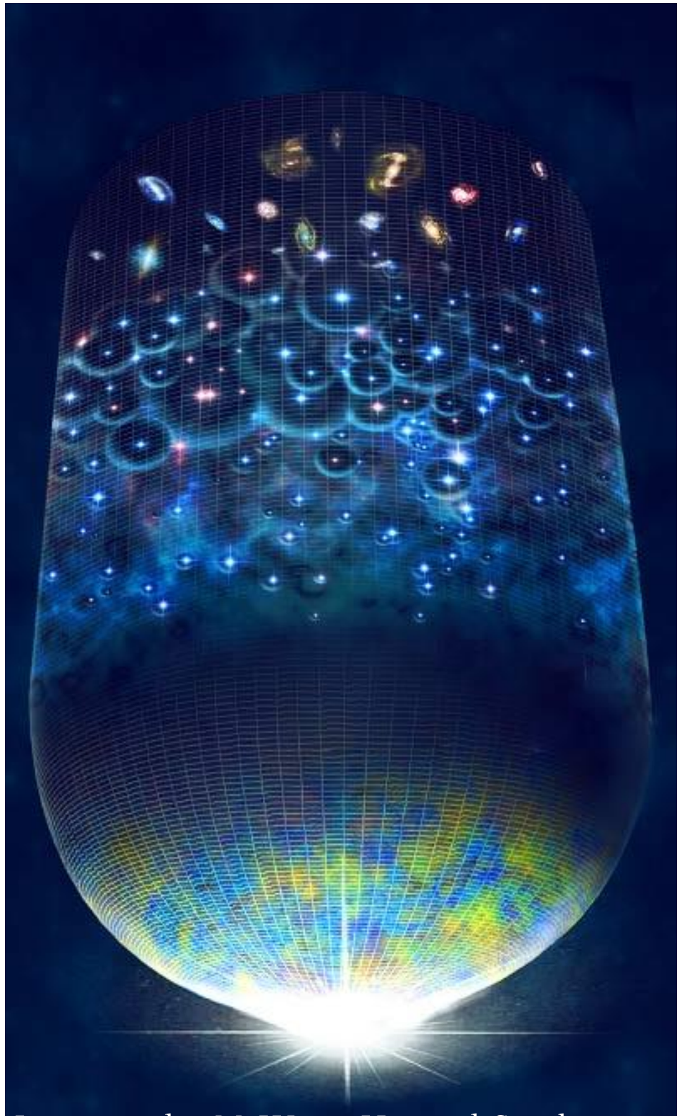


Image credit: M. Weiss, Harvard-Smithsonian Center for Astrophysics

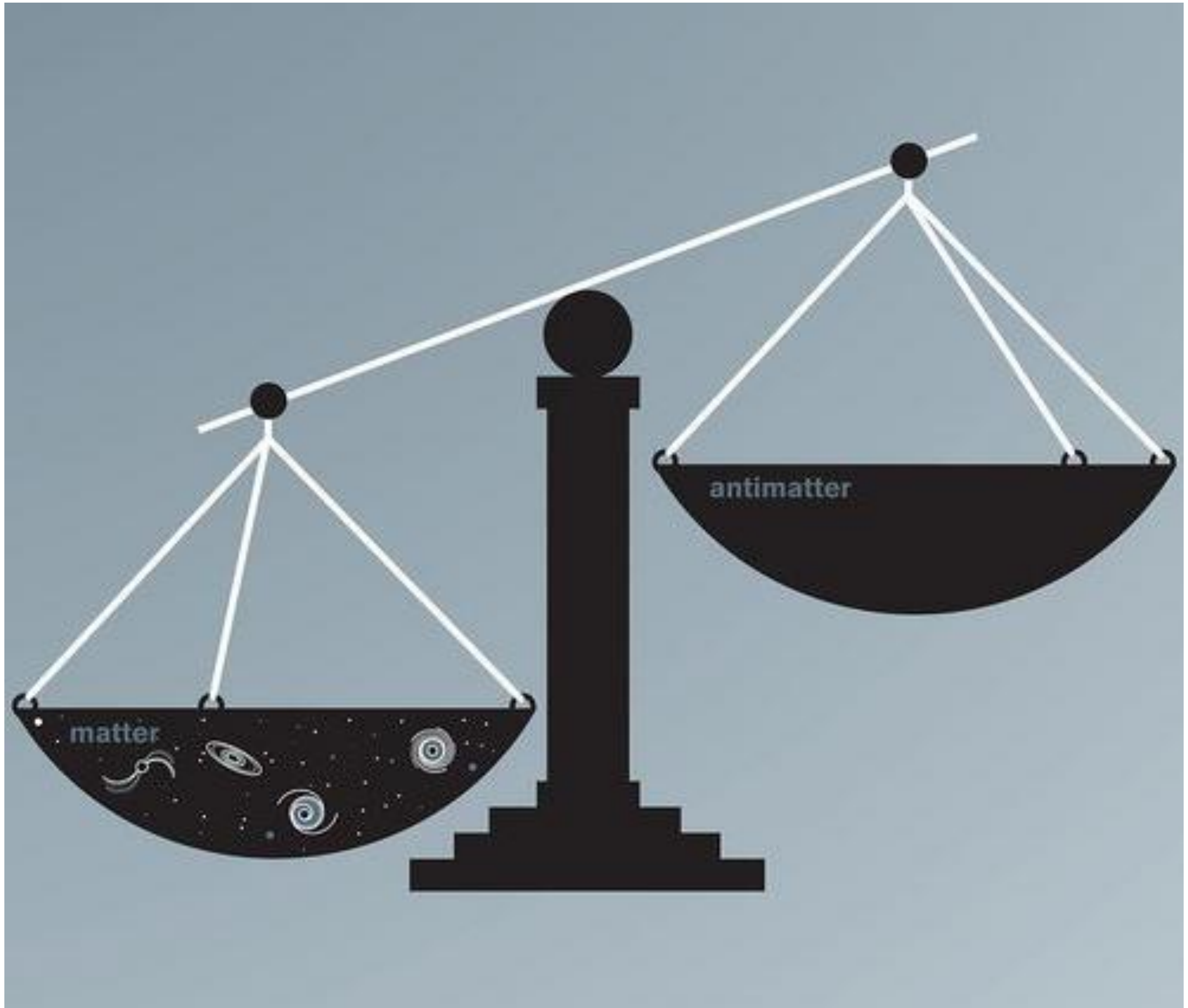
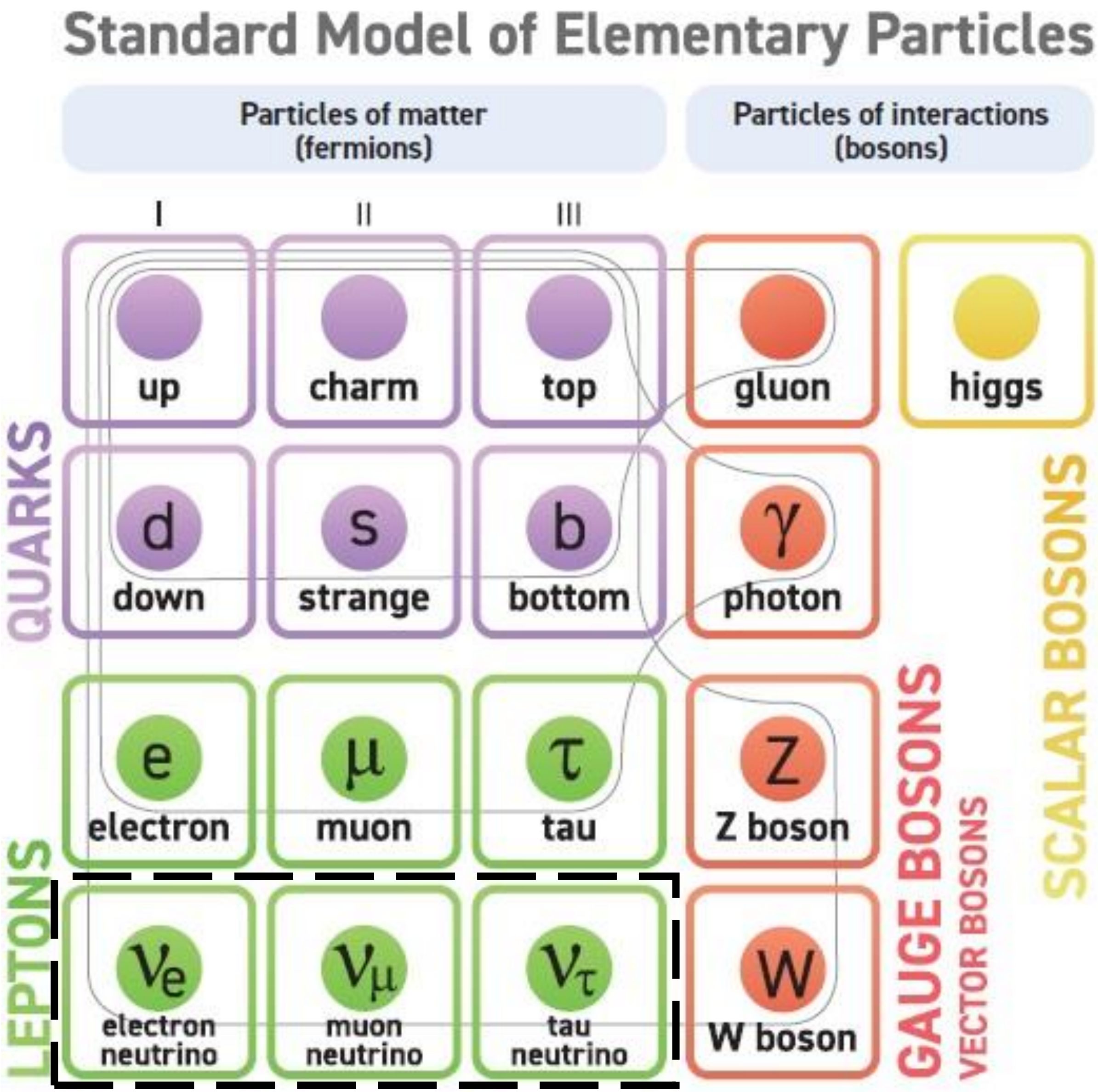
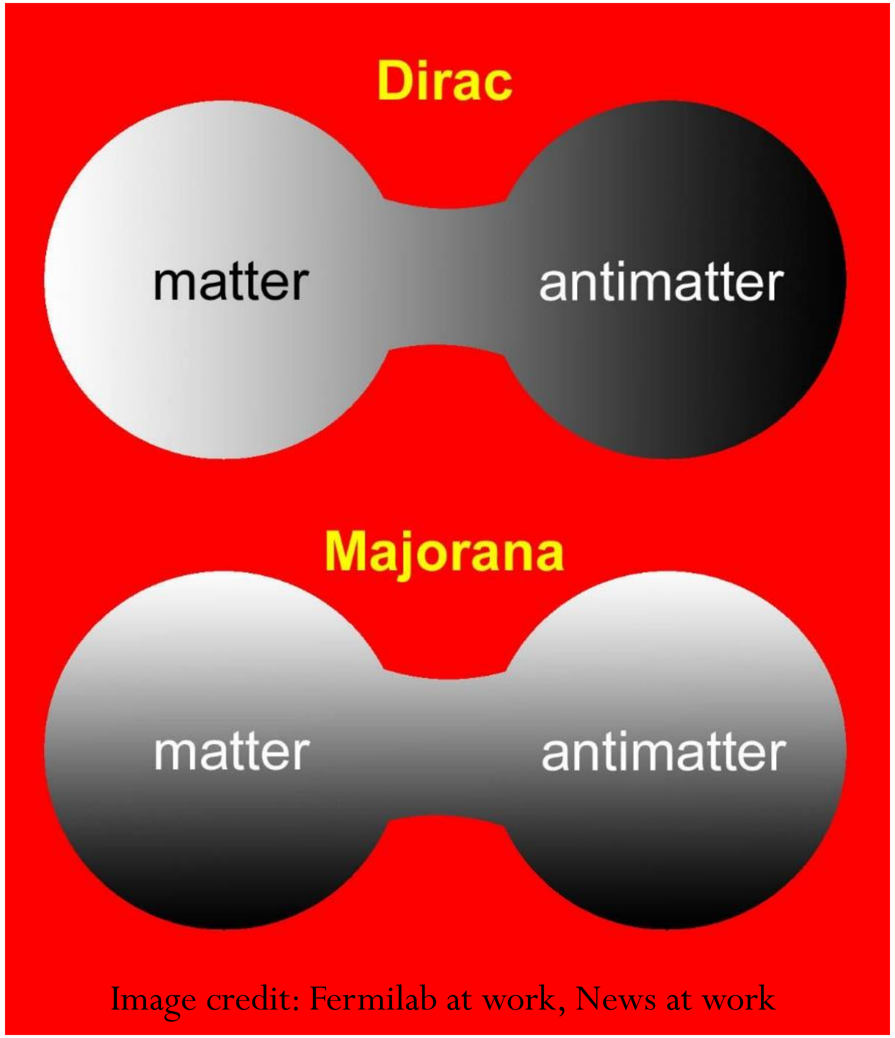


Image credit: Symmetry Magazine

MATTER-ANTIMATTER ASYMMETRY





NEUTRINOLESS DOUBLE BETA DECAY

$2\nu\beta\beta$ decay

$$^{A}_{Z}X \rightarrow \, ^{A}_{Z+2}X + 2e + 2\bar{\nu}$$

$0\nu\beta\beta$ decay

$$^{A}_{Z}X \rightarrow \, ^{A}_{Z+2}X + 2e$$

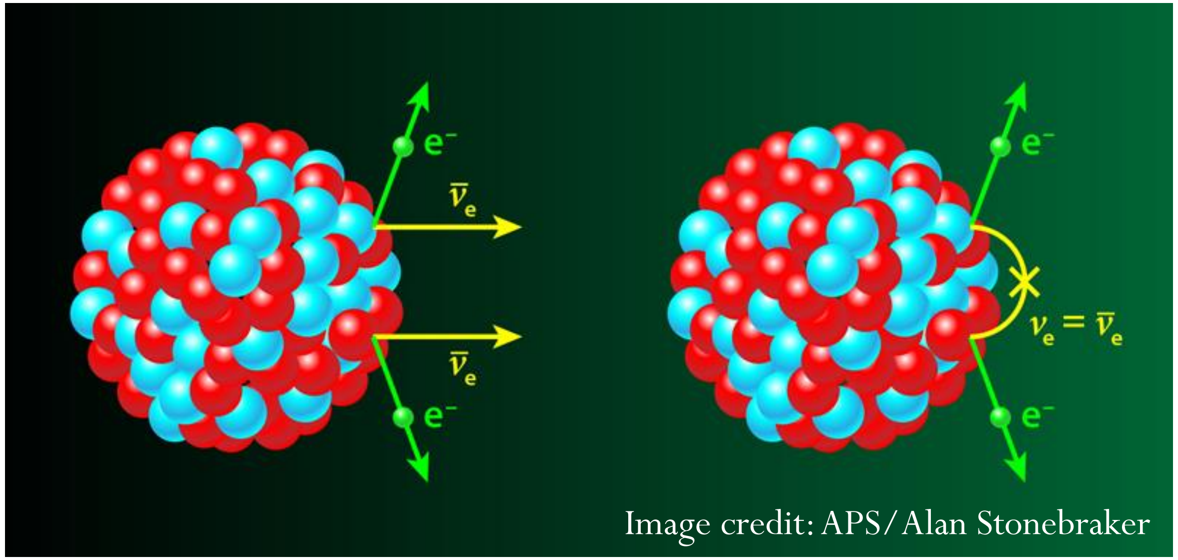


Image credit: APS/Alan Stonebraker

$0\nu\beta\beta$ decay, if observed, would demonstrate the violation of the lepton number conservation and Majorana nature of neutrinos.

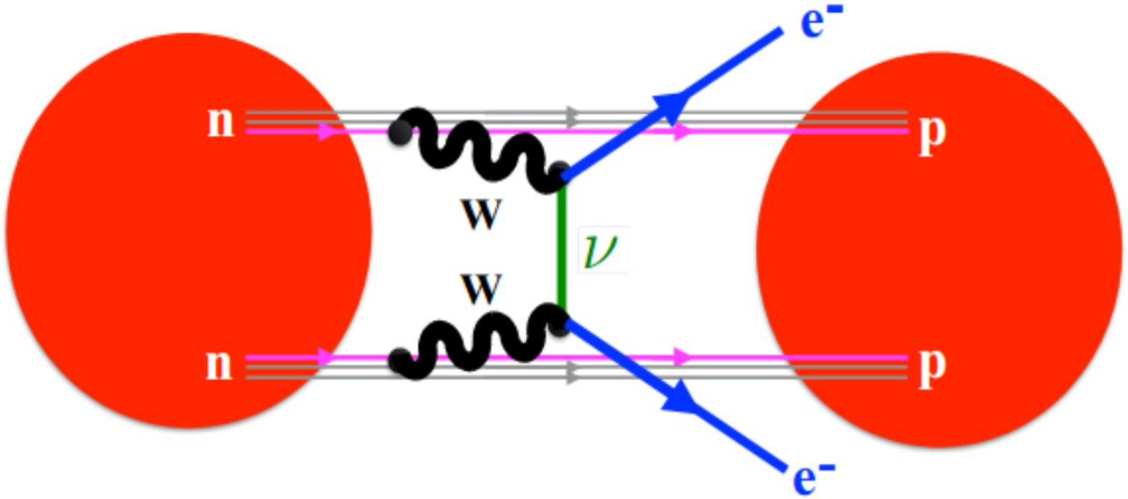


Image credit: ETC, European Center for Theoretical Studies in Nuclear Physics and Related Areas

NEUTRINOLESS DOUBLE BETA DECAY

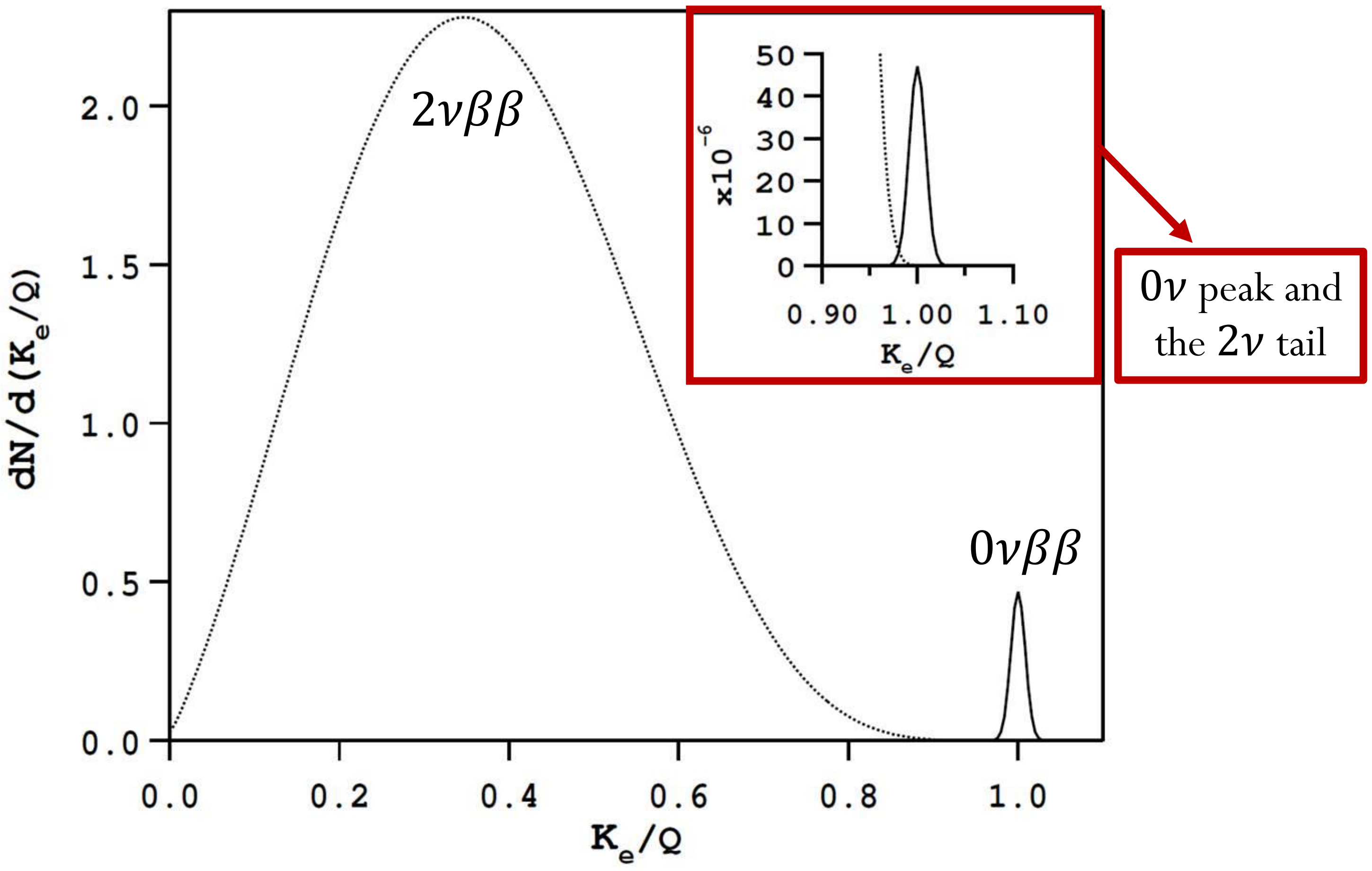


Image credit: Colliders and Neutrinos, The Window into Physics beyond the Standard Model, Neutrinoless Double Beta Decay, P. Vogel

The two-body nature of $0\nu\beta\beta$ decay will cause a peak at the endpoint of the $2\nu\beta\beta$ decay (four-body) spectrum.

THE nEXO EXPERIMENT

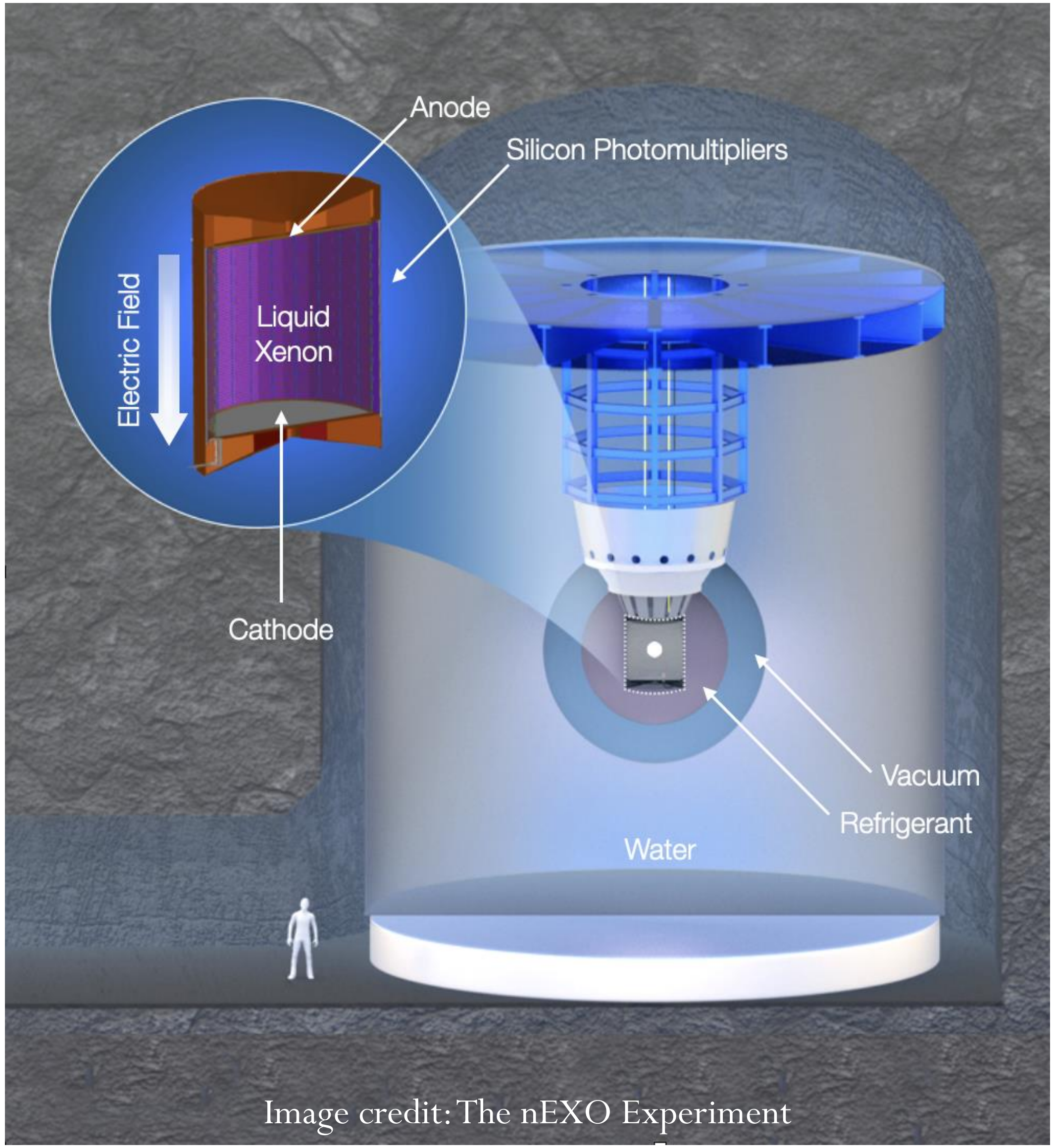
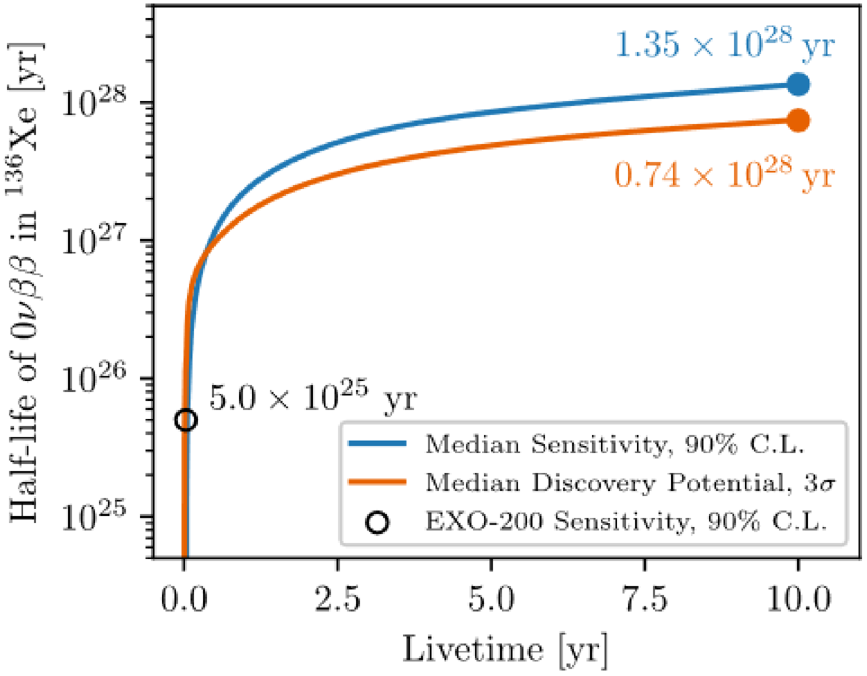


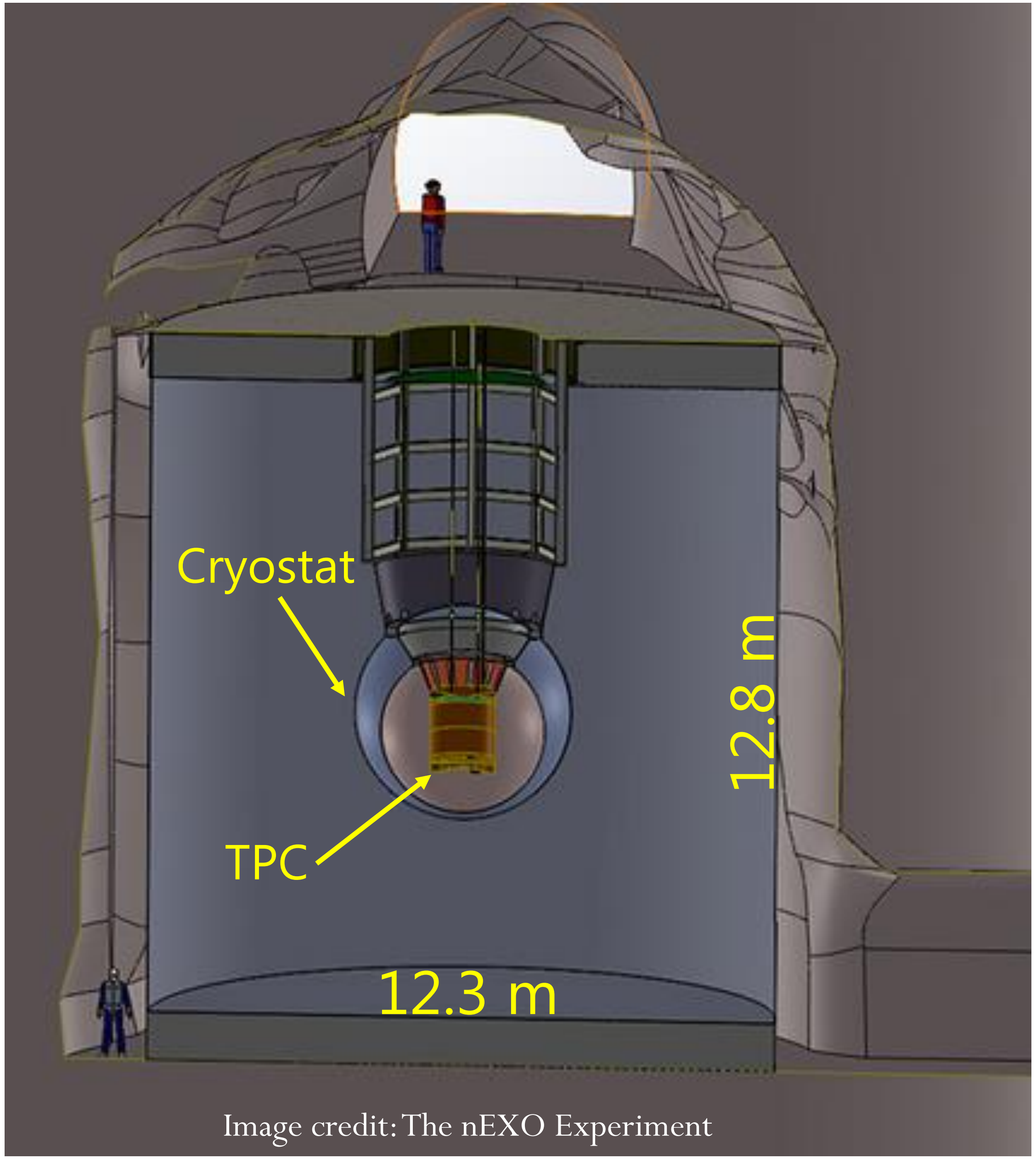
Image credit: The nEXO Experiment

Image credit: nEXO: neutrinoless double beta decay search beyond 10^{28} year half-life sensitivity
Journal of Physics G: Nuclear and Particle Physics, Volume 49, Number 1



The nEXO Experiment will search of $0\nu\beta\beta$ decay to a level of 10^{28} years with 5 tonnes of liquid xenon.

THE OUTER DETECTOR

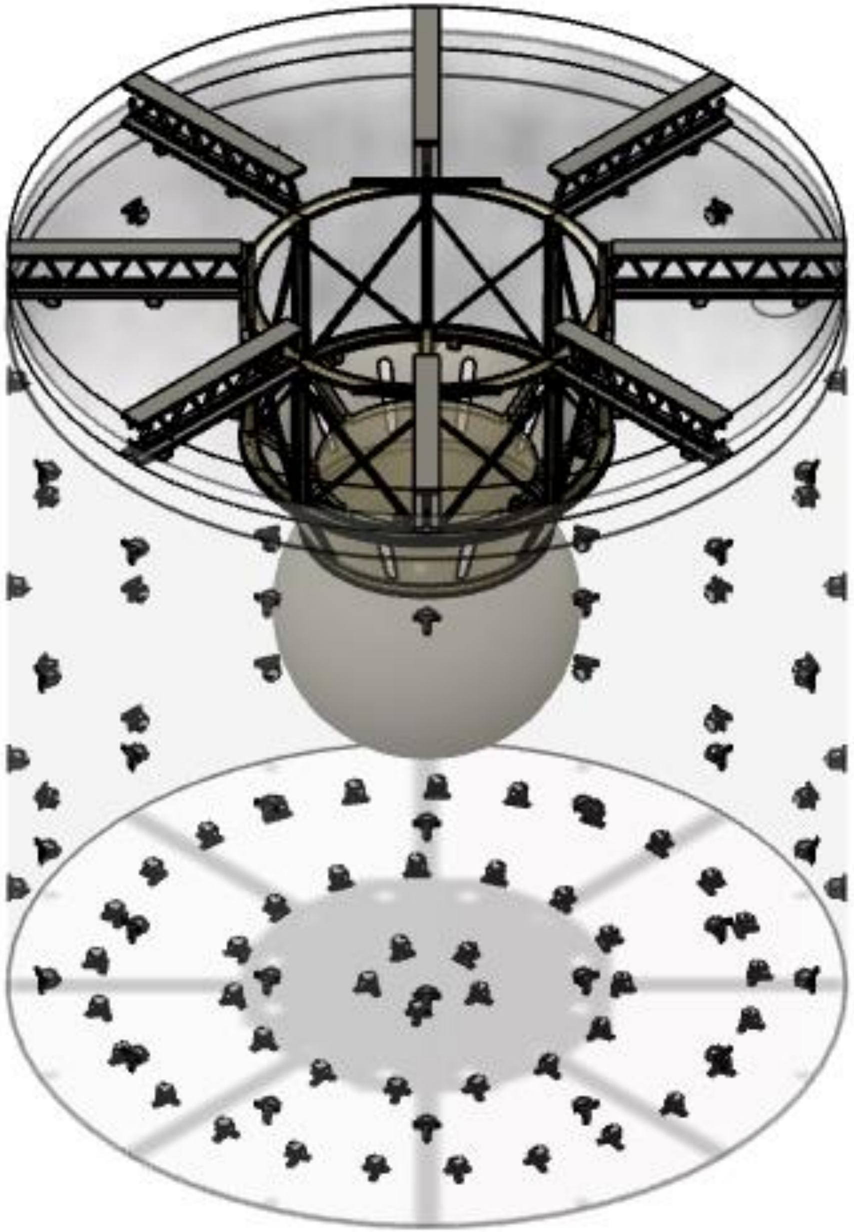


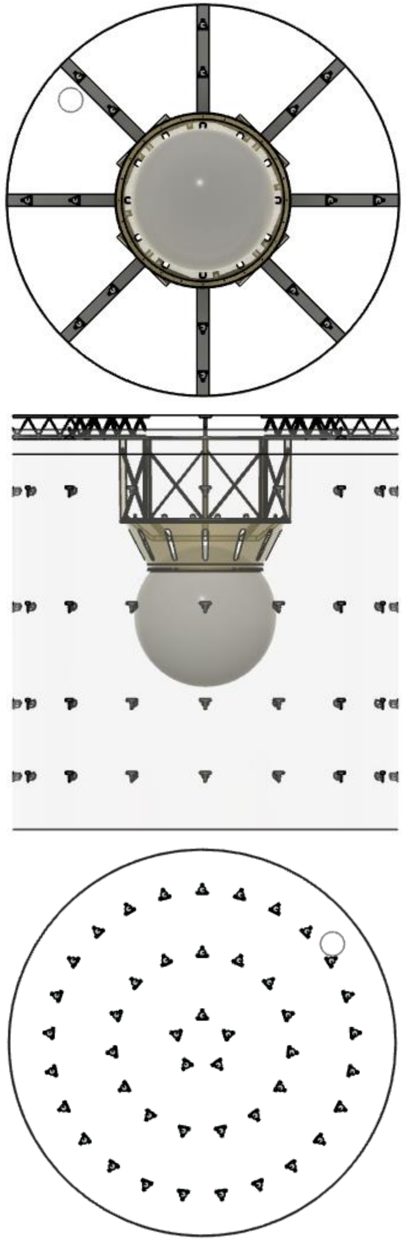
The nEXO Outer Detector (OD) is a shield that fully submerges the Time Projection Chamber (TPC) and the Cryostat.

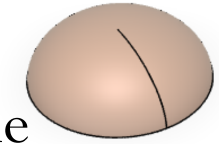
It provides shielding from radioactive backgrounds.

It functions as a water Cherenkov muon veto system.

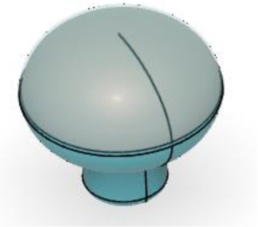
THE OUTER DETECTOR



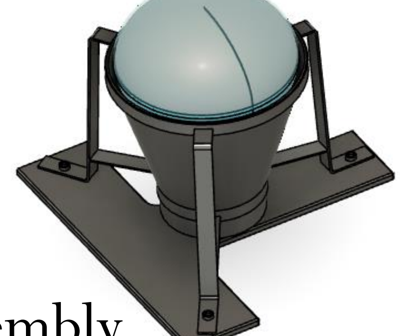




Photocathode

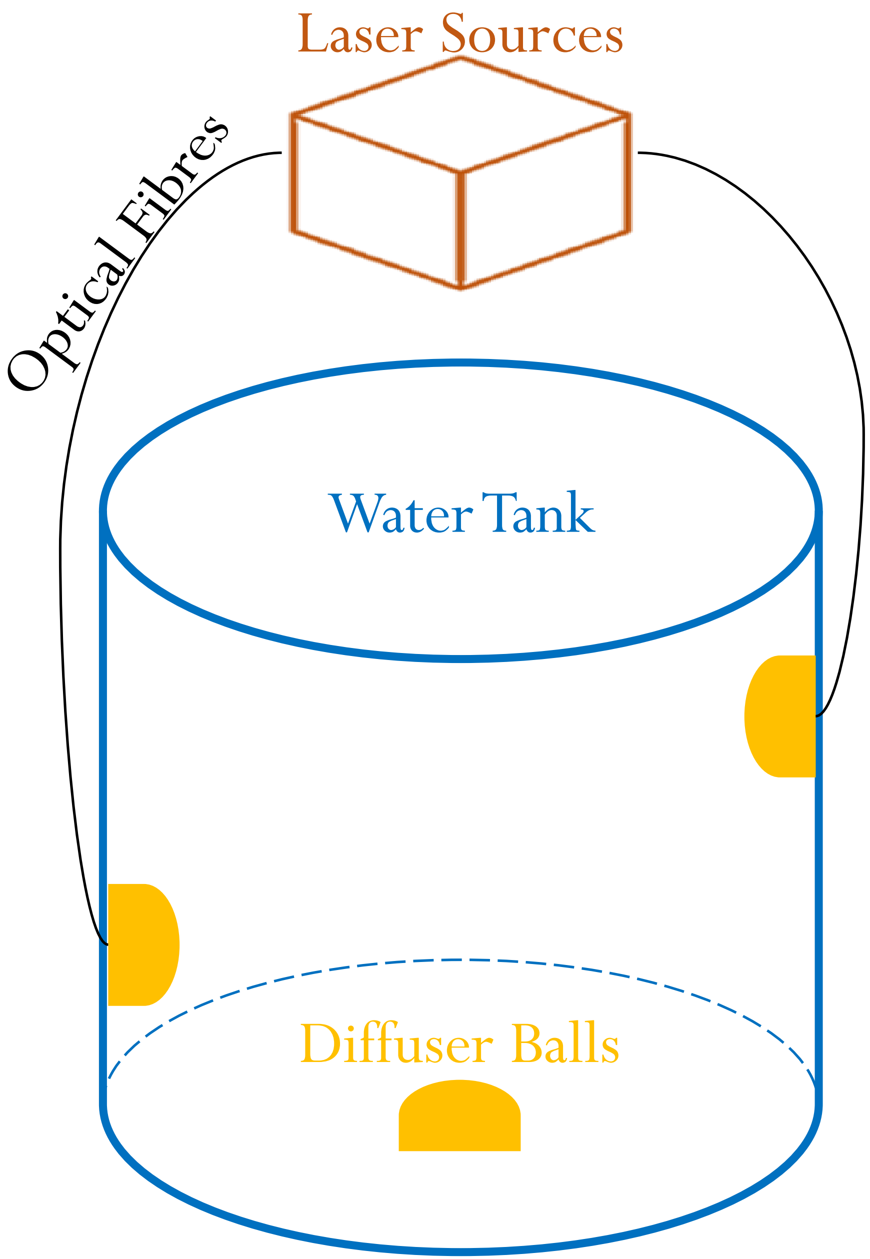


Glass



PMT assembly

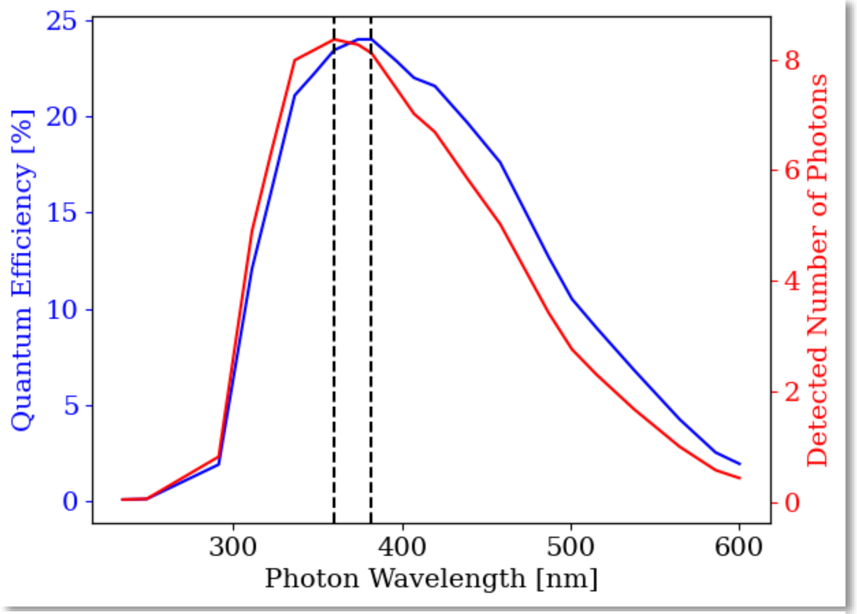
THE CALIBRATION SYSTEM

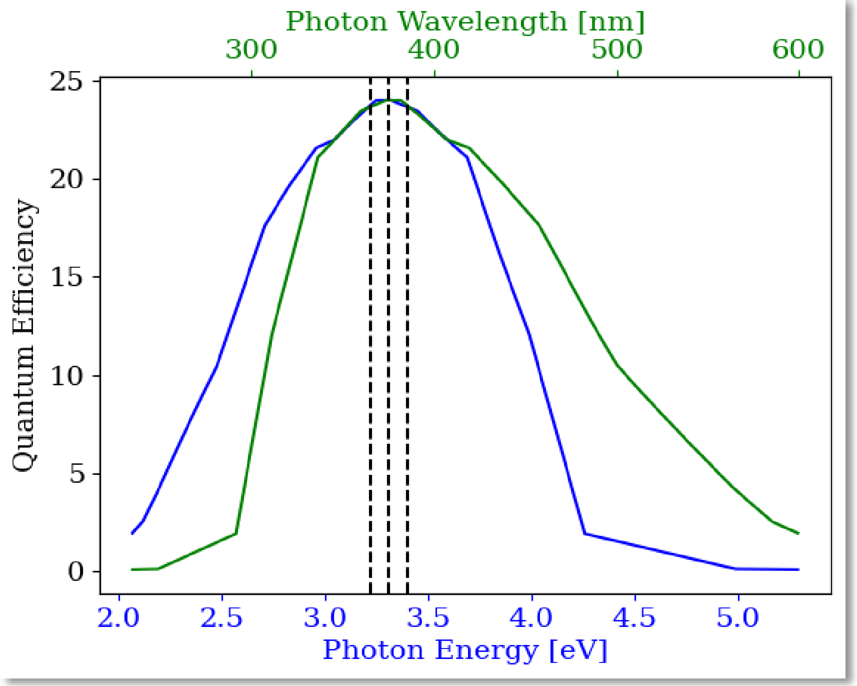


Calibration system objectives:
- Assess PMTs performance
- Calibrate timing properties
- Monitor water optical properties

Calibration system components:
- Laser sources
- Optical fibers
- Diffuser balls

LASER SOURCES – WAVELENGTH & INTENSITY





Wavelength selection: considering the quantum efficiency of the PMTs and the Frank- Tamm formula.

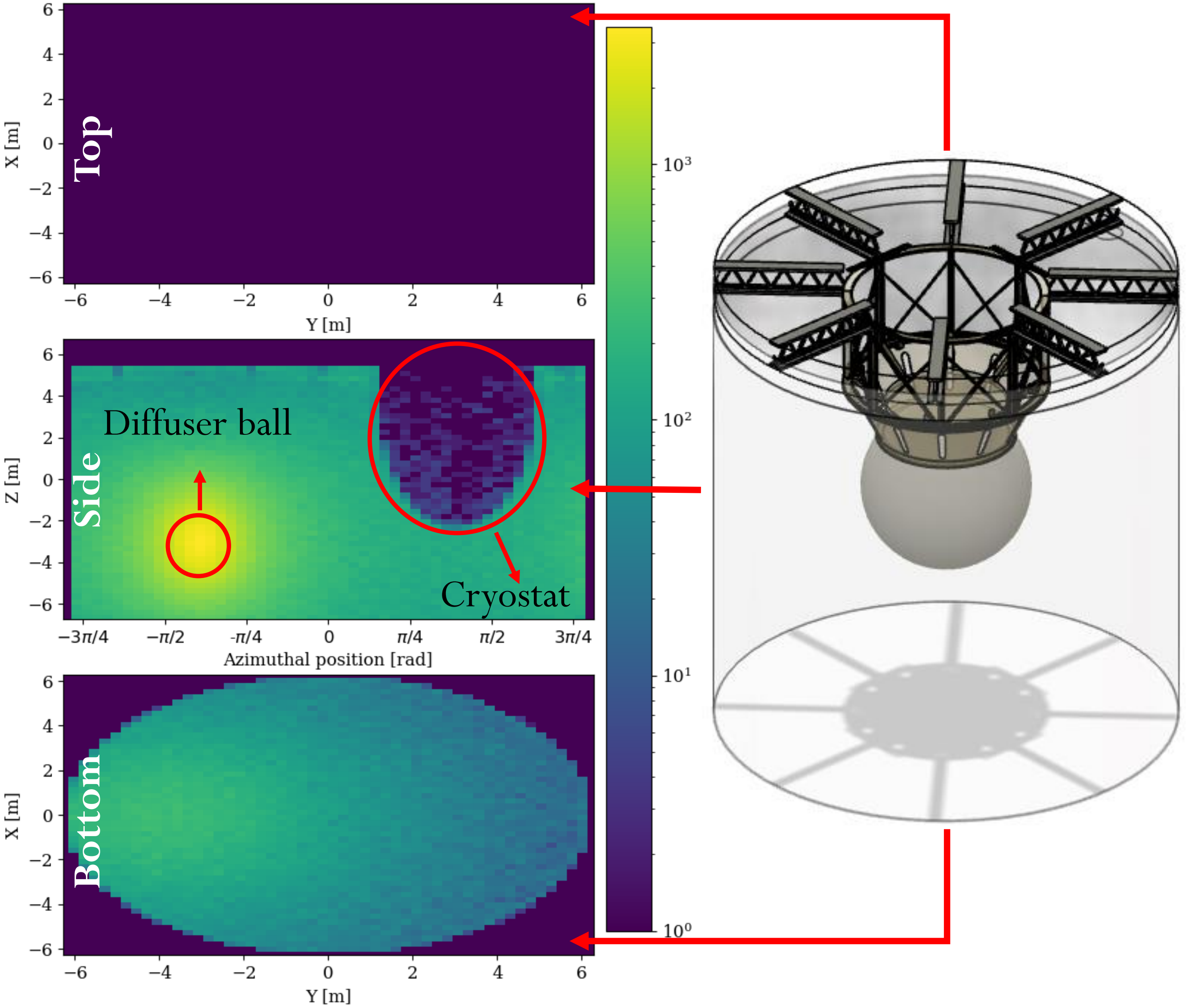
Requirements of the laser sources:

- Wavelength: between 360 to 390 nm.
- Light intensity: on the order of 1million photons.
- Range of the number of photons at each PMT location: between the minimum number required for calibration, which is 10, and avoiding saturation, which is 10^7 photons per second.

CHROMA SIMULATIONS

Utilizing a CUDA-enabled GPU, Chroma achieves remarkable performance, allowing it to propagate a rate of 2.5 million photons per second within a detector featuring 29,000 photomultiplier tubes.

DIFFUSER BALLS - QUANTITY

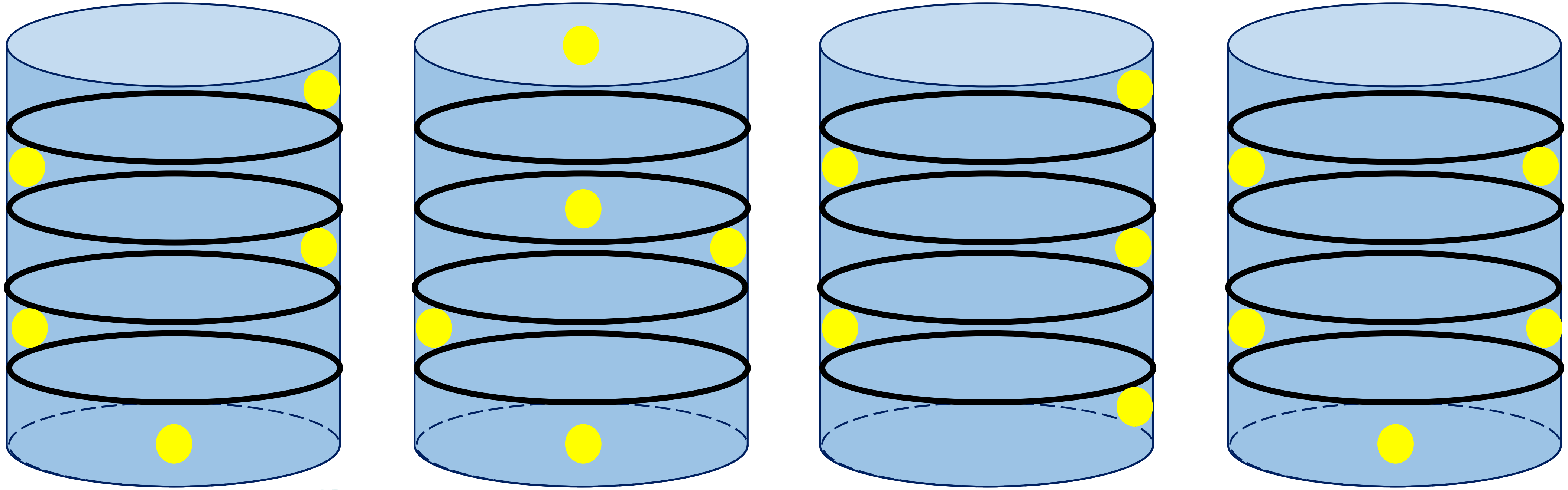


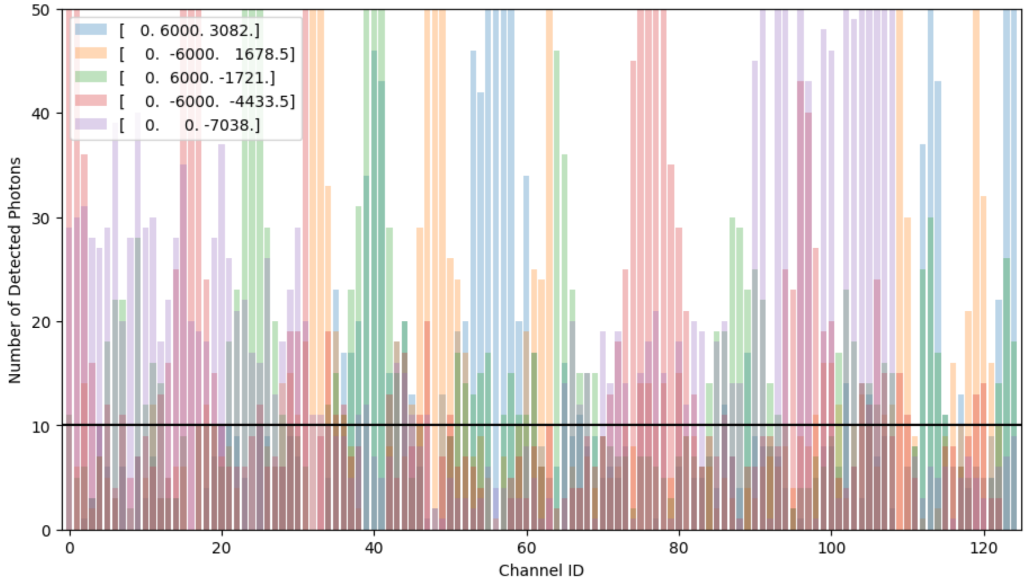
Light map of the Outer Detector

- Diffuser ball location: [0, -3, -4] m
- Wavelength: 390 nm
- Number of photons: 1,000,000

Using five diffuser balls is an optimal choice for our system.

DIFFUSER BALLS - CONFIGURATION

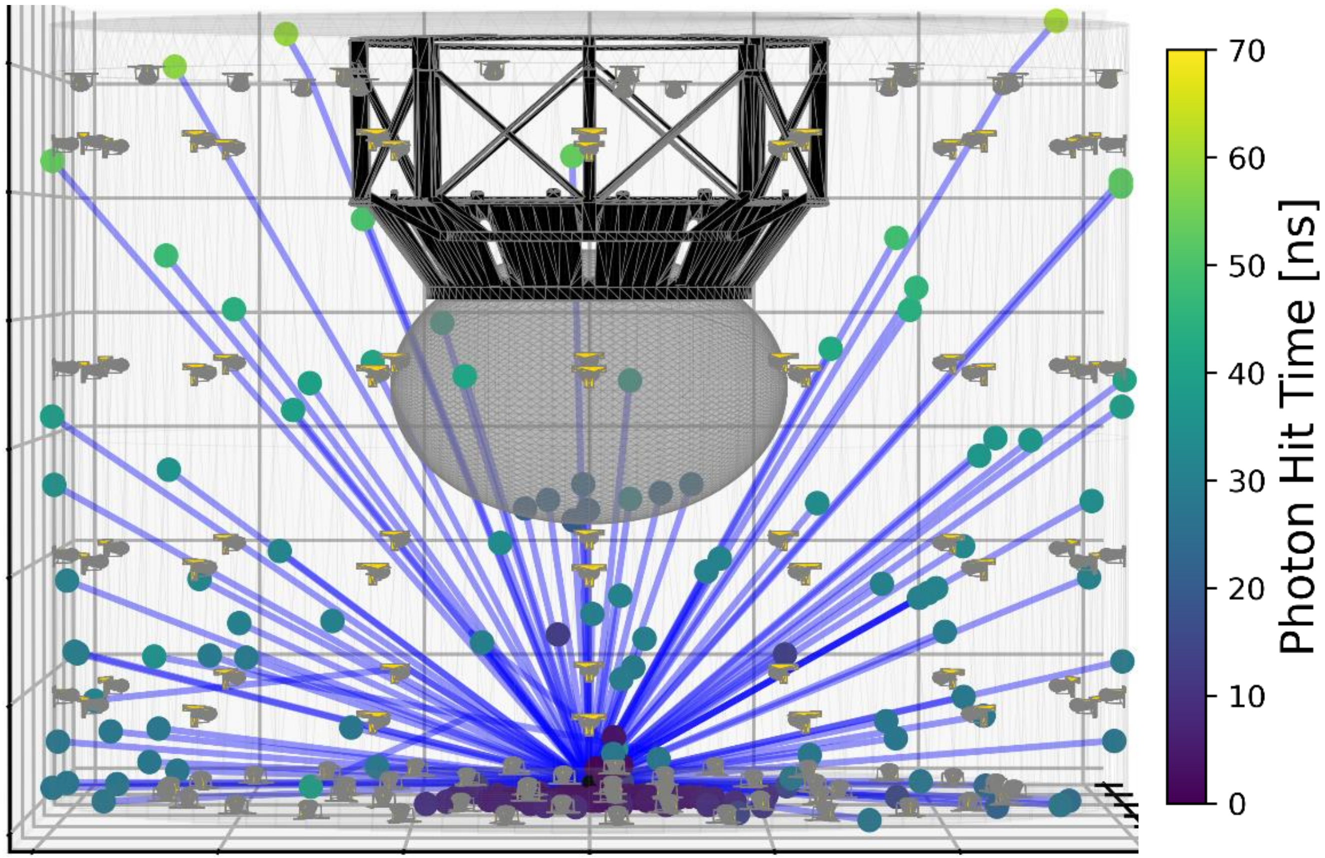




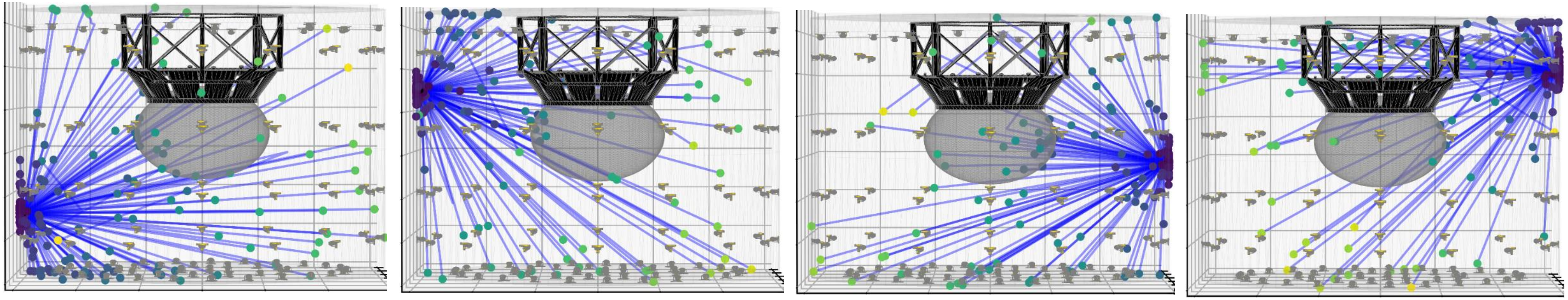
The configuration of the diffuser balls does not significantly affect the functionality of the calibration system.

Cite: Irina Nitu

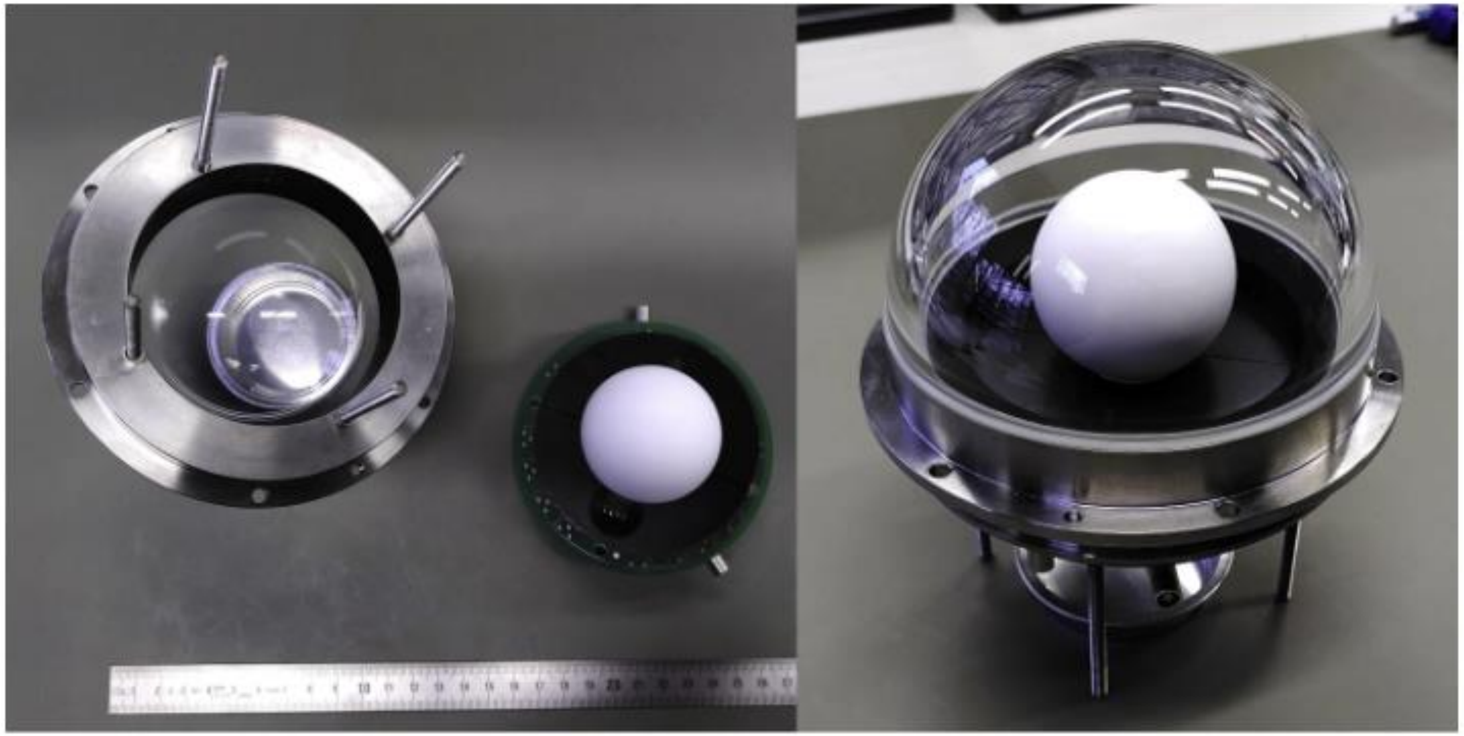
DIFFUSER BALLS - CONFIGURATION



Photon path plots resulting from running Chroma simulations show the initial and final locations of produced photons.
The colors indicate the photon hit time in nanoseconds.



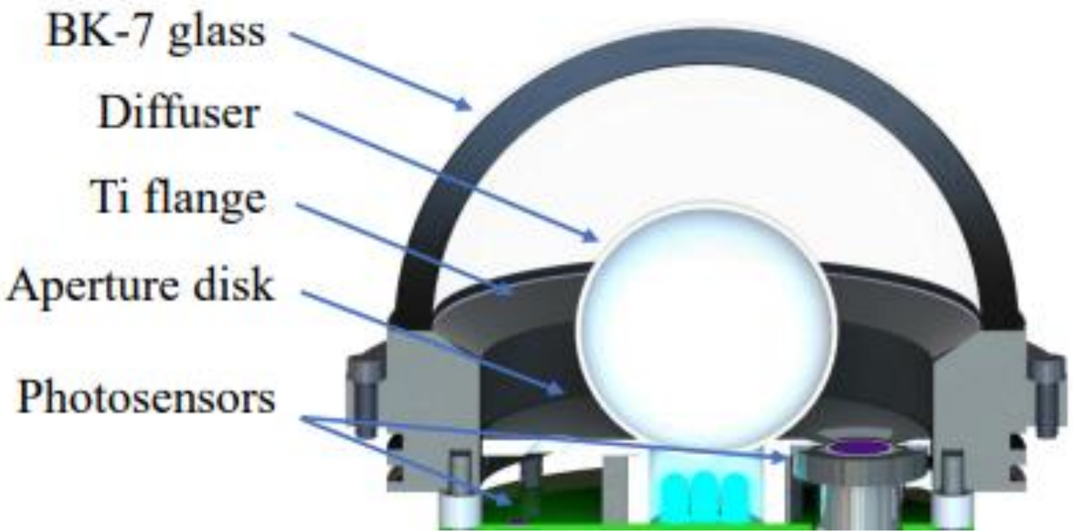
DIFFUSER BALLS - DESIGN



Precision Optical Calibration Module (POCAM) hemisphere

[A self-monitoring precision calibration light source for large-volume neutrino telescopes]
Journal of Instrumentation, Volume 15, July 2020

F. Henningsen, M. Böhmer, A. Gärtner, L. Geilen, R. Gernhäuser, H. Heggen, K. Holzapfel, C. Fruck, L. Papp, I.C. Rea, E. Resconi, F. Schmuckermaier, C. Spannfellnera and M. Traxler



nEXO MUON VETO CALIBRATION SYSTEM

Laser Sources:

A wavelength of 360-390 nm.

An intensity of 2 million photons per pulse for optimal precision.

Diffuser Balls:

Five diffuser balls for enhanced dispersion.

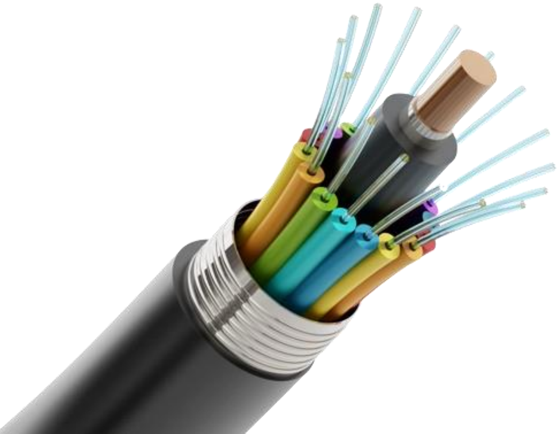
Flexibility in the configuration of diffuser balls inside the water tank.

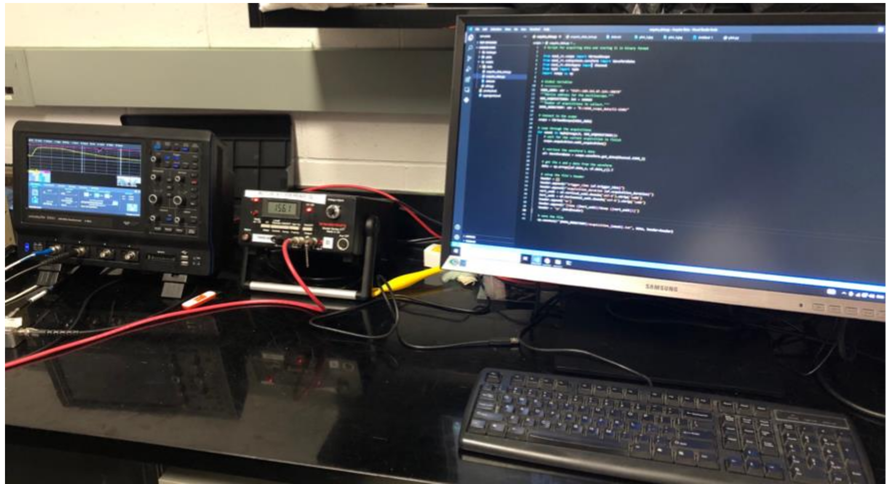
Future plans:

Building the prototype of diffuser ball.

Testing diffuser ball properties such as homogeneity.

Testing the behavior of different parts inside the ultra-pure water.





nEXO

SNOLAB

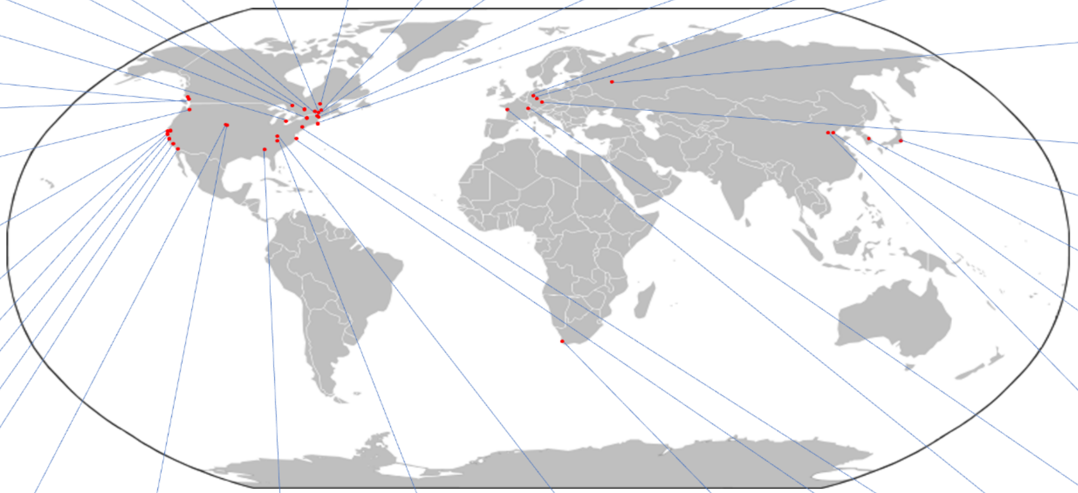
BNL

McGill

The nEXO Collaboration

Carleton University
SNOLAB
Queen's University
Université de Sherbrooke
McGill
University of Massachusetts Amherst
Yale University
Brookhaven National Laboratory
WWU Münster

Laurentian University Université Laurentienne
Rensselaer
University of Windsor
The University of British Columbia
TRIUMF
Pacific Northwest National Laboratory
Skyline College Achieve.
Lawrence Livermore National Laboratory
SLAC National Accelerator Laboratory
Stanford University
Caltech
UC San Diego



FAU Friedrich-Alexander Universität Erlangen-Nürnberg
ИТЭФ
Technical University of Munich TUM
KEK
IBS Institute for Basic Science
IHEP
IMECAS
u^b Universität Bern
Subatech

Colorado School of Mines
Colorado State University
The University of Alabama 1831
Oak Ridge National Laboratory
University of Kentucky
University of the Western Cape
UNCW University of North Carolina Wilmington
Drexel University

INTENSITY ANALYSIS

The initial intensity (I_0) needed for each PMT to detect 10 photons (I) as a function of the distance between a diffuser ball and the PMTs.

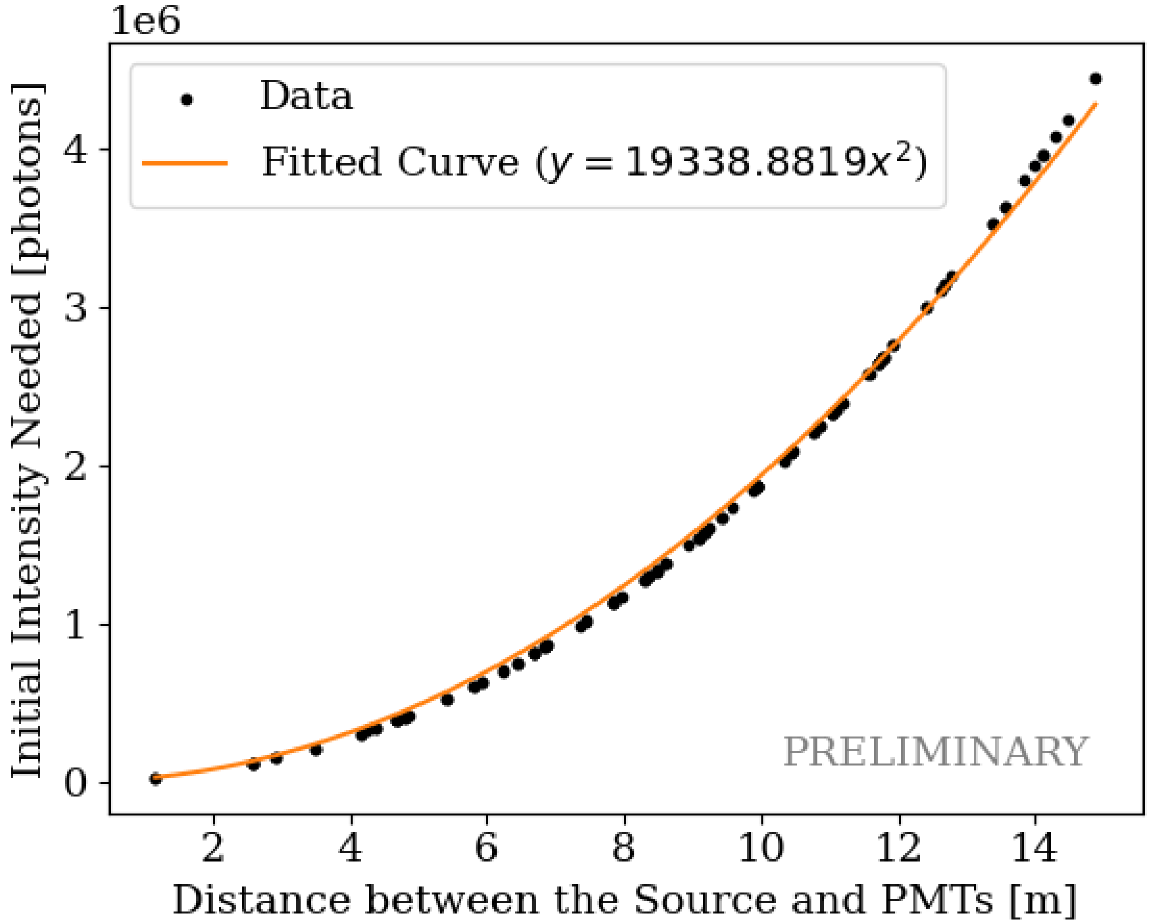
$$I_0 = \frac{I\, e^{\mu D}}{\varepsilon\, (r^2/4D^2)}$$

Attenuation Coefficient (μ)

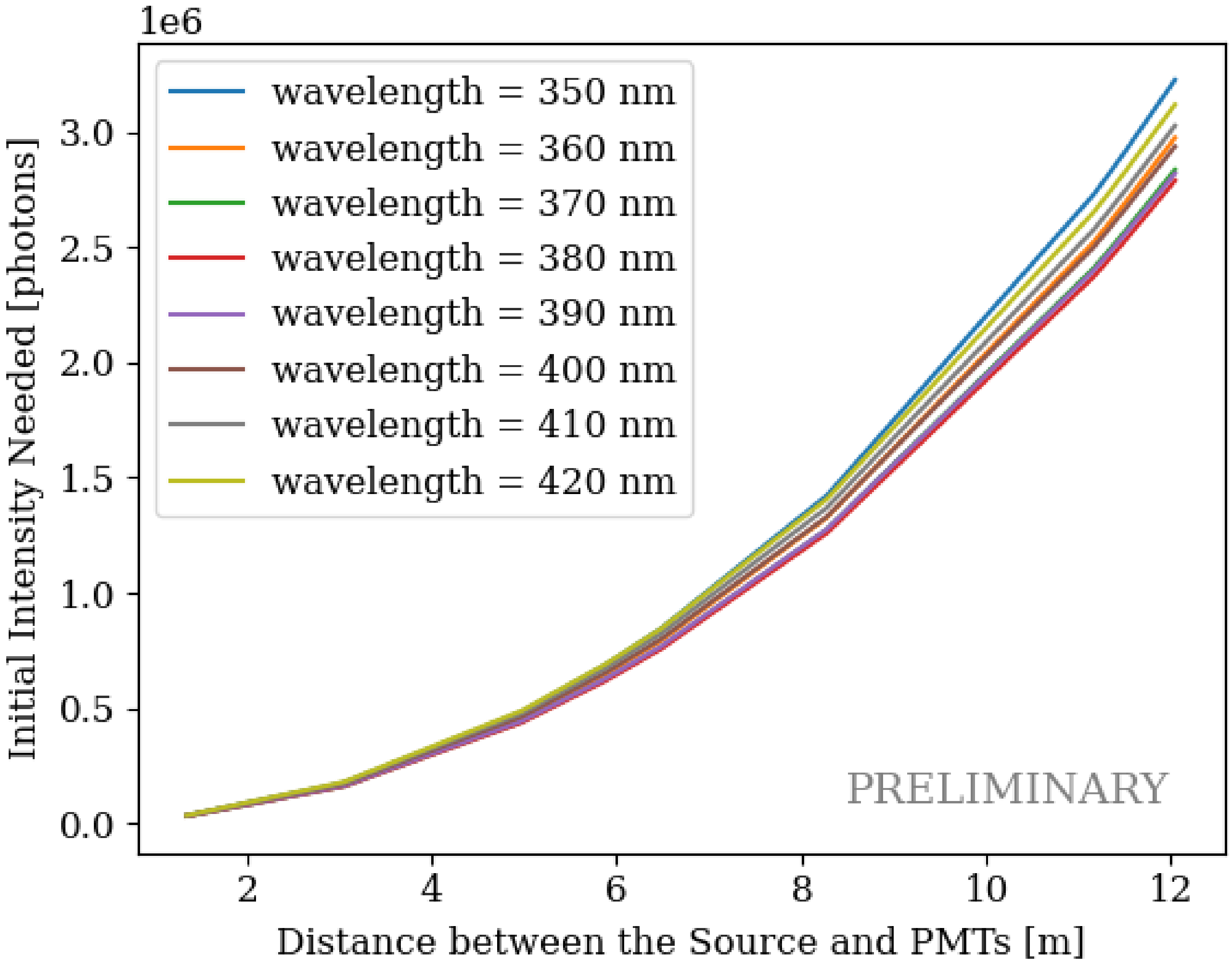
Distance (D)

Quantum Efficiency (ε)

PMT Radius (r)



WAVELENGTH ANALYSIS



PMT SATURATION

When photons continuously enter PMTs at intervals matching its pulse-pair resolution, it is theoretically possible to measure photons up to the reciprocal of this resolution. However, beyond a certain light intensity threshold, the count value no longer correlates proportionally with the light level.

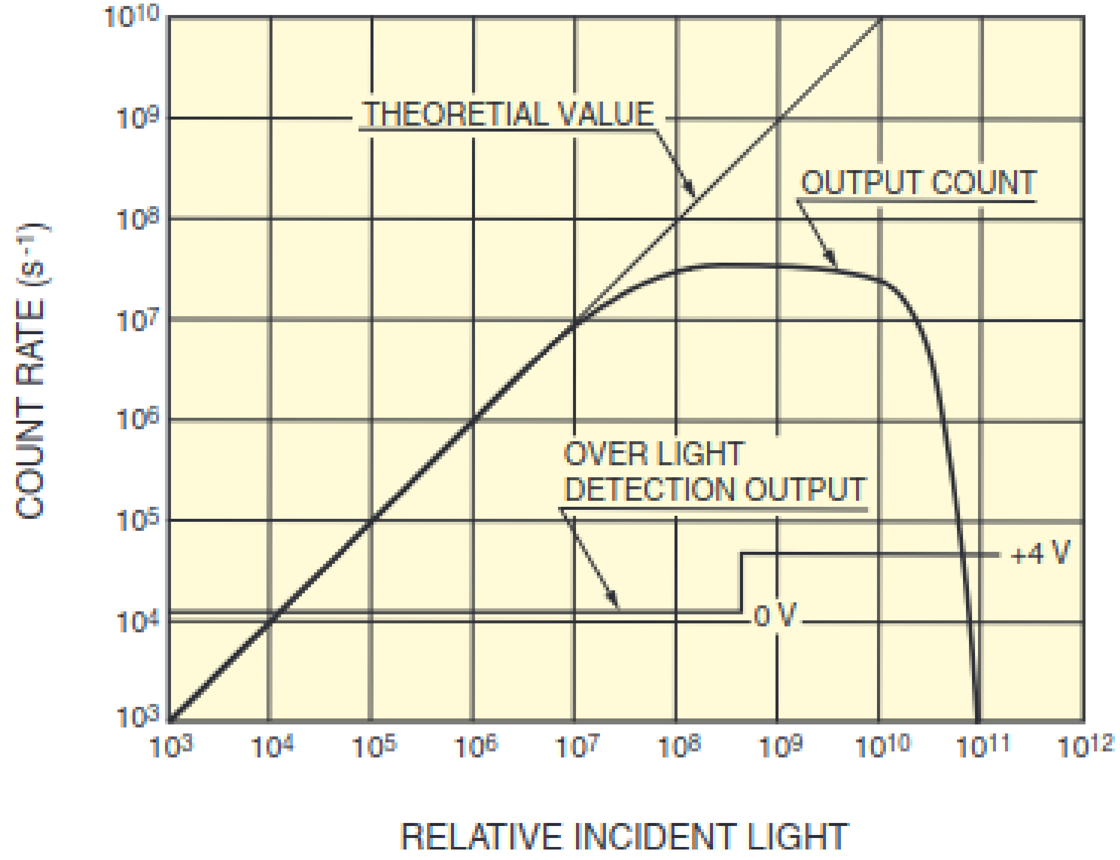


Image credit: [PHOTOMULTIPLIER TUBES, Basics and Applications, 4th edition]

WNPPC 2024
Samin Majidi

FRANK-TAMM FORMULA

$$\frac{dE}{dx} = \frac{q^2}{4\pi} \int \mu(\omega)\, \omega \left(1 - \frac{c^2}{v^2 n^2(\omega)}\right) d\omega$$

$$\frac{dE}{dx} = \frac{q^2}{4\pi} \mu(\omega) \left(1 - \frac{c^2}{v^2 n^2(\omega)}\right) \left(\frac{\omega^2}{2}\right)$$

```
[22.32576903 22.51756212 22.80998164 23.6526877  24.80611367 25.79510278
 26.49648878 27.19523543 28.79736091 29.99648443 31.29671874 32.2048756
 32.98691989 34.12278837 34.77839818 36.01571027 37.14707255 38.2305452
 39.66346214 40.93865875 43.2960859  48.75707443 50.72012338]
Total number of photons per mm:  29.427497575684598
```

Calculation of the Cherenkov light yield from low energetic secondary particles accompanying high-energy muons in ice and water with Geant4 simulations

Leif Rädel[a], Christopher Wiebusch[a,*]

[a] *III. Physikalisches Institut, RWTH Aachen University, Otto Blumenthalstrasse, 52074 Aachen, Germany*

25 photons/mm for 300 – 500 nm

WolframAlpha computational intelligence.

(2*pi*(1/137)*(1/300- 1/500)*(1-1/((0.9999*1.34)**2)))*1e6

NATURAL LANGUAGE | MATH INPUT | EXTENDED KEYBOARD | EXAMPLES | UPLOAD | RANDOM

Input interpretation

$$\left(2\pi \times \frac{1}{137}\left(\frac{1}{300} - \frac{1}{500}\right)\left(1 - \frac{1}{(0.9999 \times 1.34)^2}\right)\right) \times 1 \times 10^6$$

Result | More digits

27.0878...

27 photons/mm for 300 – 500 nm