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Photosensors for LENA

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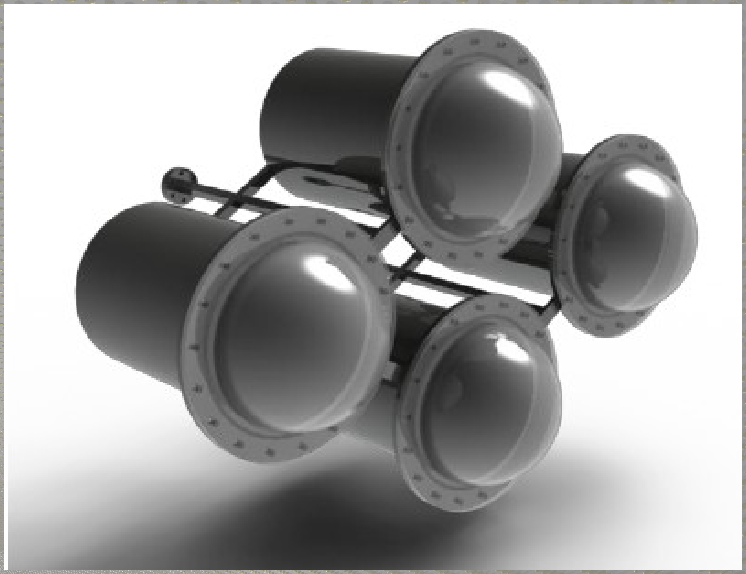
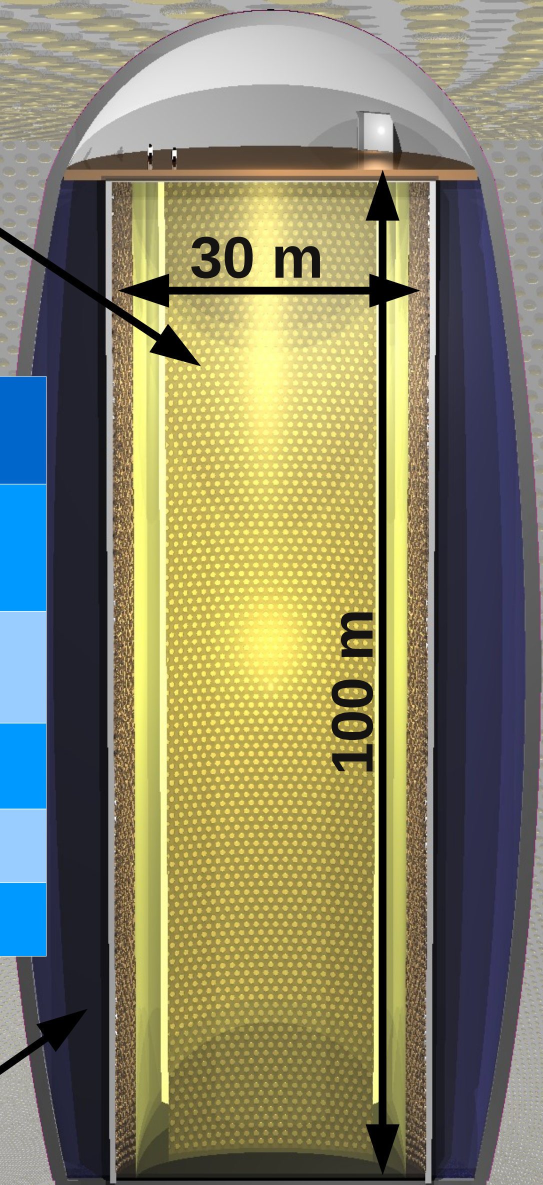
Overview

- LENA photo sensor requirements
- Important PMT characteristics
- PMT characterisation
- Alternative photo sensors
- Summary



LENA Design

Inner Detector (50 kt LSD)
Desired optical coverage: 30%
→ 3,000 m² effective photo-sensitive area



PMT Ø	# PMTs in ID	
	No light concentrators	Light concentrators (1.75)
5''	329,300	188,200
8''	110,400	63,000
10''	82,300	47,000
20''	21,600	12,300

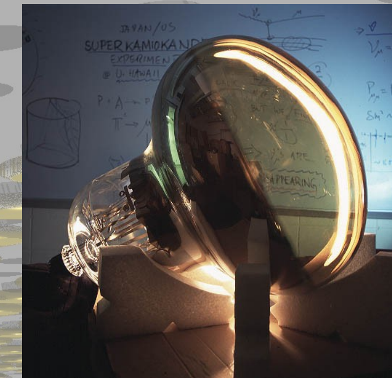
Muon Veto (100 kt WCD)
with 5,000 8'' PMTs

Photo sensor requirements

- Sensor performance
- Environmental properties
- Availability
- Cost-performance ratio

PMTs are probably the only photo sensor type which can fulfill all requirements

PMT requirements



- **Sensor performance**
  - Photo detection efficiency and spectral response
  - Time jitter
  - Afterpulses
  - Dynamic Range
  - ...
- **Environmental properties**
  - Radiopurity
  - Pressure resistance
- **Design**
  - Optical coverage
  - Granularity

→

Detector performance

- Spatial resolution
- Tracking
- Energy resolution
- Time resolution
- Energy threshold
- Particle discrimination
- Event topologies

↓

Physics Programme

PMT properties

- Photo detection efficiency
  - Quantum efficiency of photocathode
  - Photo electron collection efficiency
  - Backscattering losses

- Spectral response
  - Should match spectrum of scintillation light
  - Bialkali photocathode best choice
  - Peak senitivity at 430 nm

LENA benchmark value: 20 % at 420 nm

PMT properties

- Optical coverage
  - Light concentrator to increase area
    → influence on energy+time+spatial resolution

    LENA benchmark value: 30 %
- Granularity
  - Number of photosensors
    → increasing spatial resolution for increasing granularity

    high granularity vs cost optimization

PMT properties

- Time jitter

  → time and position resolution

  LENA: ~ few ns

- Pulse shape
  - Rise and fall times of the spe voltage pulses

    → tracking and position reconstruction

- Dynamic Range
  - Low-E : 1 p.e. per sensor
  - High-E: 100s of p.e. per sensor

  LENA: spe – 0.3 pe/cm²

- Afterpulses (<5%)
  - Might fake double peak coincidences (e.g. proton decay)

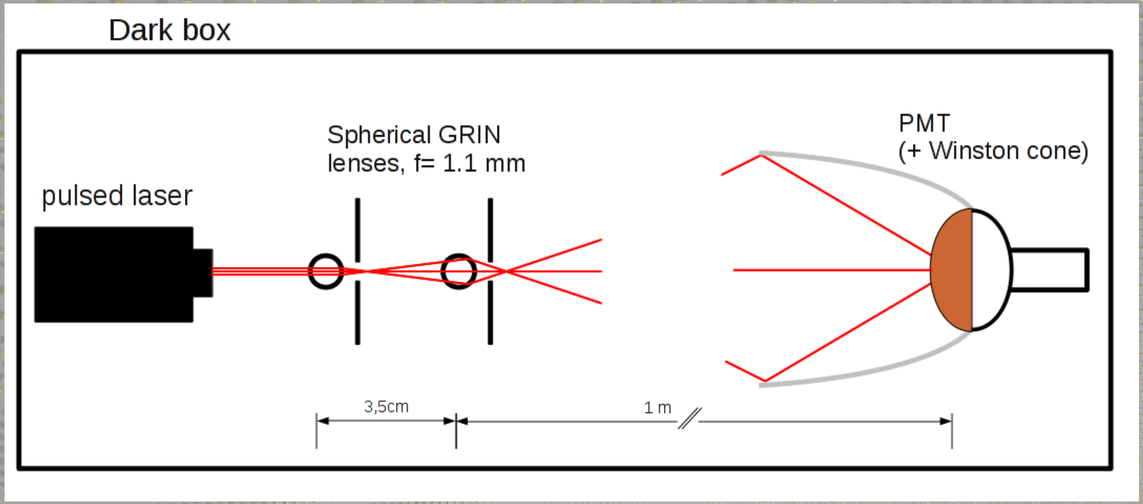
PMT properties

- Gain, single electron resolution
  - Large peak-to-valley ratio
    → LENA: peak-to-valley >2
- Dark count (<15 Hz qm)
  - Might cause random coincidences
    → position and energy resolution, energy threshold
- Environmental properties
  - Radioactive purity
  - Pressure resistance: up to 13 bar
  - Long-term reliability: 30 yrs

^{238}U content	$<3\cdot10^{-8}$ g/g
^{232}Th content	$<1\cdot10^{-8}$ g/g
^{nat}K content	$<2\cdot10^{-5}$ g/g

PMT characterisation at TUM

- Setup to determine PMT properties
  - Pulse shape: TTS, LP, BP, PreP
  - Afterpulsing: fast, ionic
  - Dynamic range



Collaborations with

- MEMPHYS (PMm2), KM3Net
- INFN Milano, LNGS, Tübingen
- ETEL, Hamamatsu

PMT characterisation at TUM

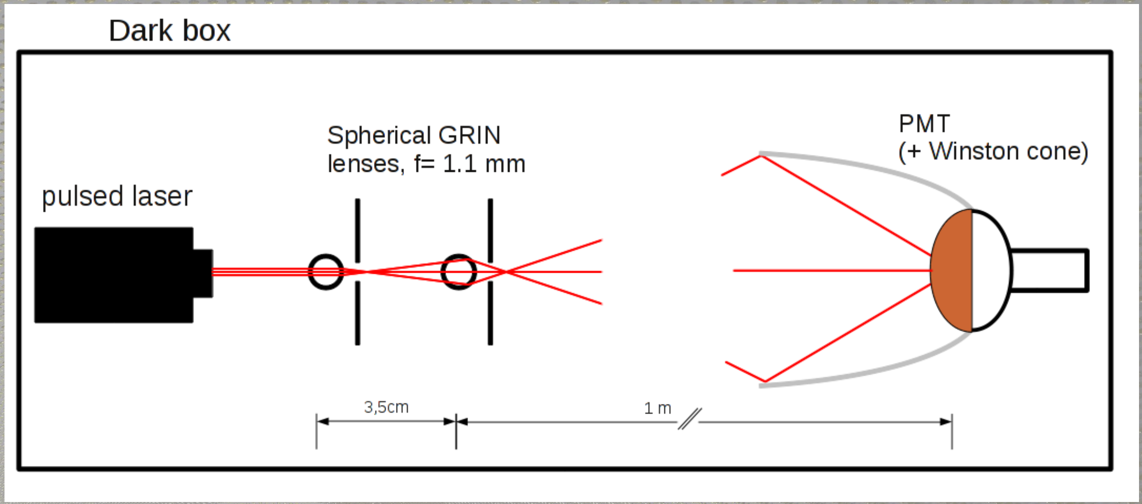
- Light sources:
  - Pulsed ps diode **laser**: Edinburgh Instruments EPL-405-mod, 403nm, pulse width 48ps, 2 kHz-2 MHz
  - Fast **LED** driven by avalanche diode: 430nm, time jitter (FWHM) <≈1ns
- PMTs from Hamamatsu and ETEL
- FADC readout
- Planned
  - Wiston cones
  - Fiber to scan photcathode
  - SiPMs

- At the moment no conclusive decision possible:
  - ~10 PMTs/series needed
  - Simulation to determine limits + implications better

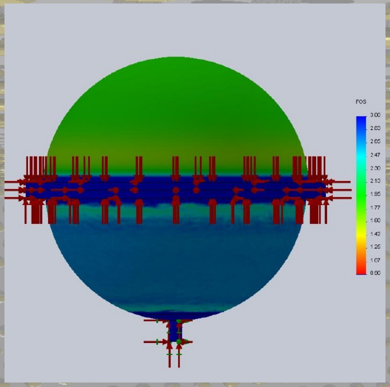
Light collectors

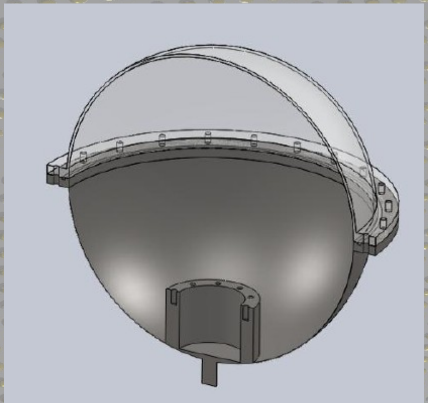
- MC simulations of light concentrators with Geant4
- Incorporate results into optical model of detector (Geant4 MC) → determine optimum light concentrator
- Build prototype
- Use new setup to scan over aperture and incident angles of winston cones

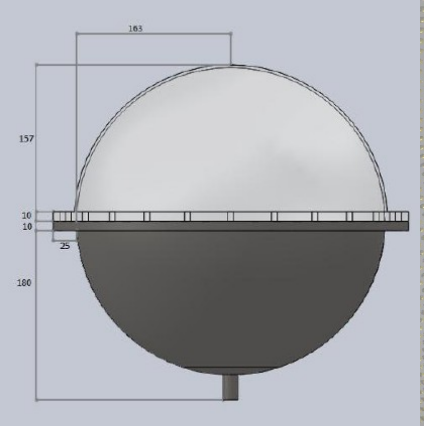
Borexino WC



Pressure encapsulation



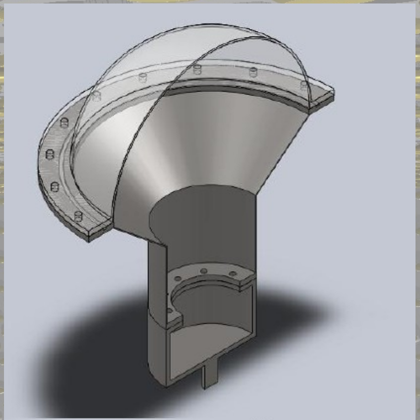


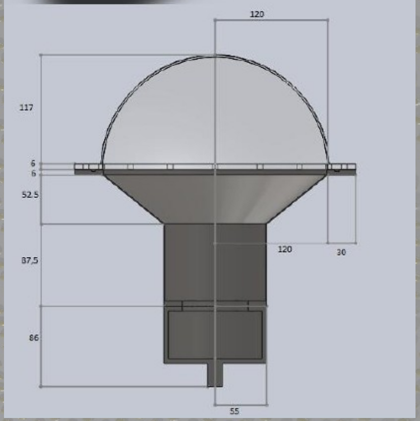


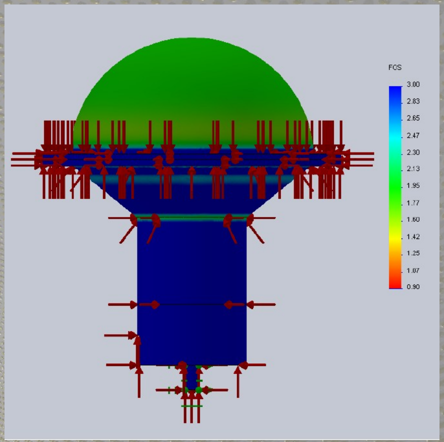
- PMTs have to withstand up to 11 bar (+ shock wave)
  → encapsulation

- Calculations with SolidWorks:
  - Finite elements calculation
  - different encapsulation shapes for different PMT types

→ Steel thickness >0.5 mm
→ Acrylic glass: >3-4 mm







Other photosensors

- Quasar (Baikal): *solid scintillator block + PMT*
  + small jitter even for large photocathodes, excellent energy resolution
  - price
- Hybrid-Gas Photomultiplier: *photocathode in vacuum + THGEM*
- SiPM: *array of small APDs*
  + excellent TTS (FWHM< 0.5ns), excellent energy resolution
  - immense cost/area; huge dark count (100kHz- Mhz), cooling needed
- Qupid/ Hybrid Photo-Detector: *Photocathode + APD*
- Microchannel Plate (MCP): *Photocathode + thin etched channels*

In all cases
- further investigation and characterisation needed
- price reduction
- reliabilty

→ PMTs still favoured solution

Conclusions

- PMT considered most feasible candidate at the moment
- Approximate limits on photosensor properties known → do simulations to refine values
- tested promising PMT (test SiPMs and Hybrid Phototubes in future)
- development of pressure-withstanding optical modules for PMTs
- Development of Winston cones