Development of an Optical Module for LENA

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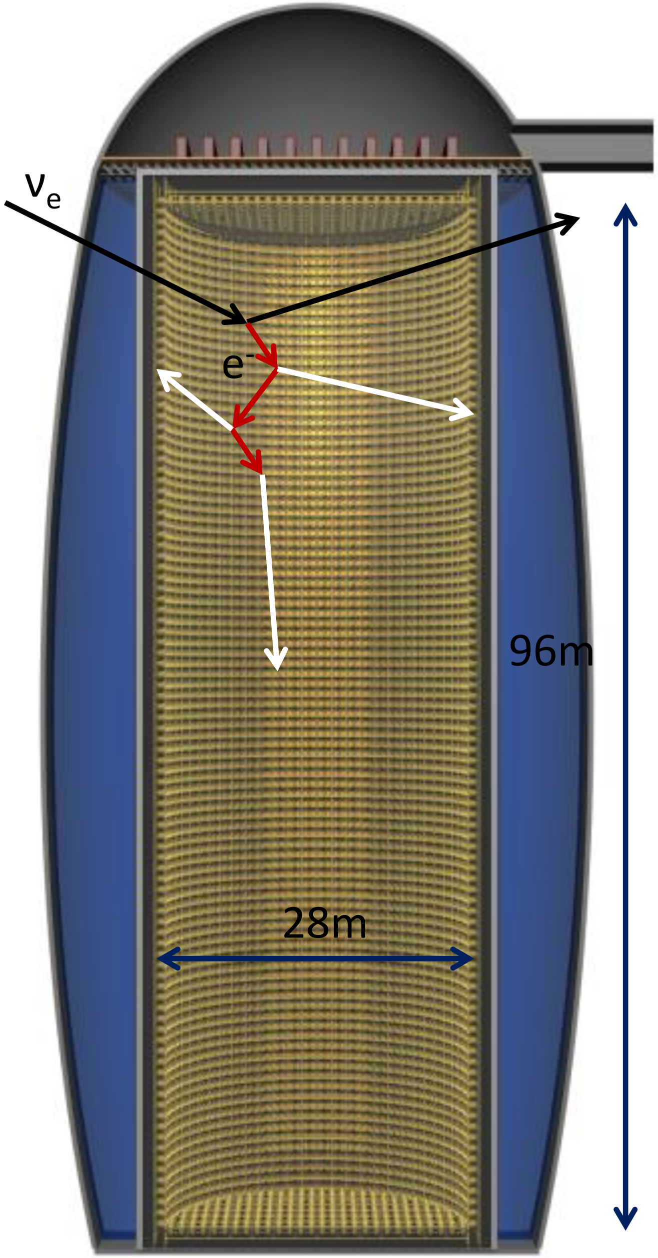
Why do we need photosensors in LENA?
Which demands result from our physics agenda?



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  Neutrino scatters off electron

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  → loses kinetic energy via excitation of scintillator molecules

  → emit light at deexcitation

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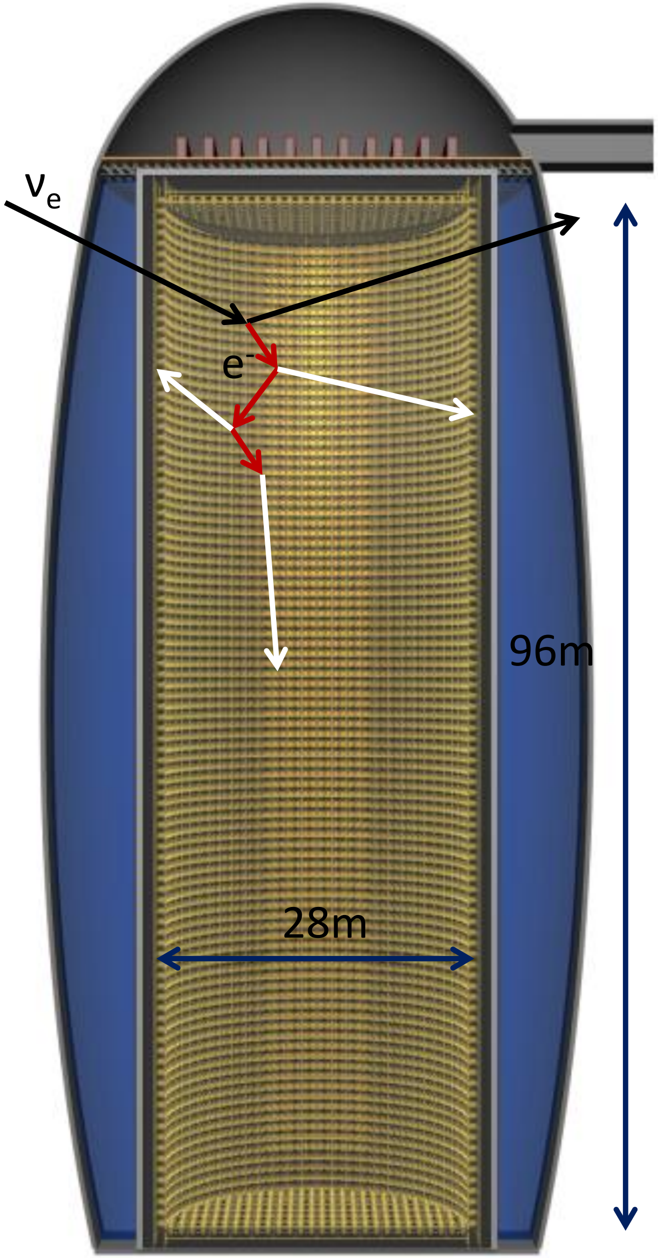

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  → big active volume

  → big surface (9700m²)

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- pressure-withstanding, long-term reliability
- low price/detector area

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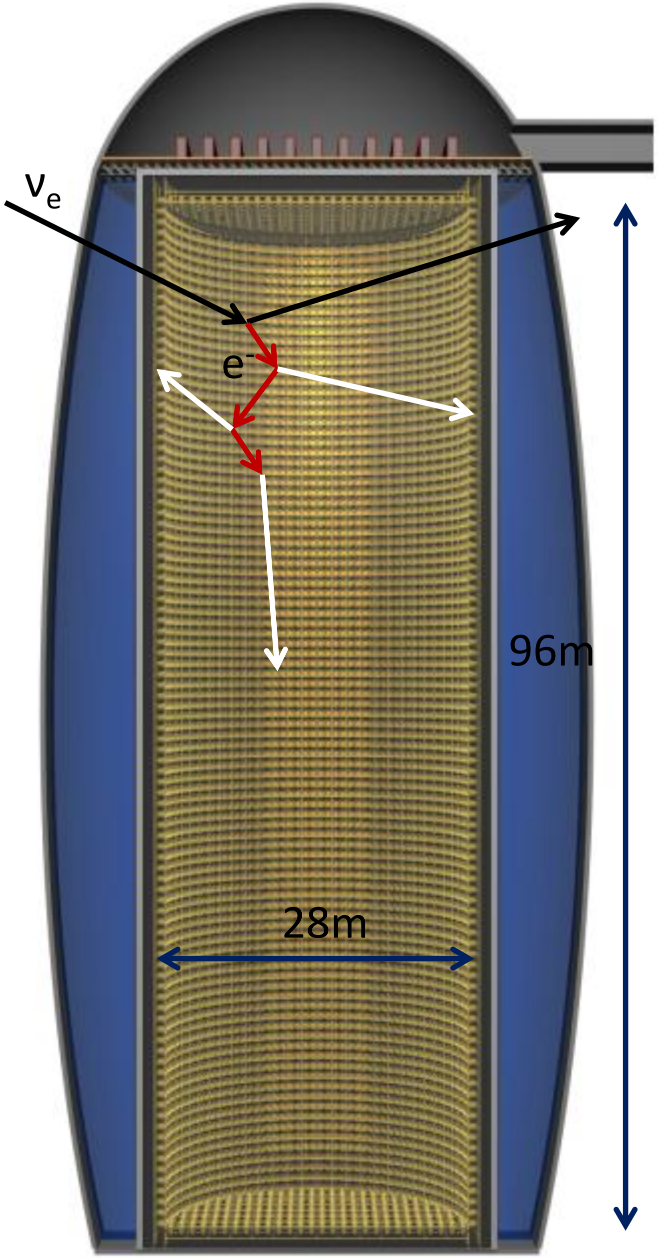

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- Deposited energies: 200keV - ≈5GeV
  → 700 - $15 \cdot 10^6$ photons arriving at photosensor surface

- Low energies:
  only energy of event available to distinguish neutrino sources

- High energies (e.g. neutrino beam):
  also directionality

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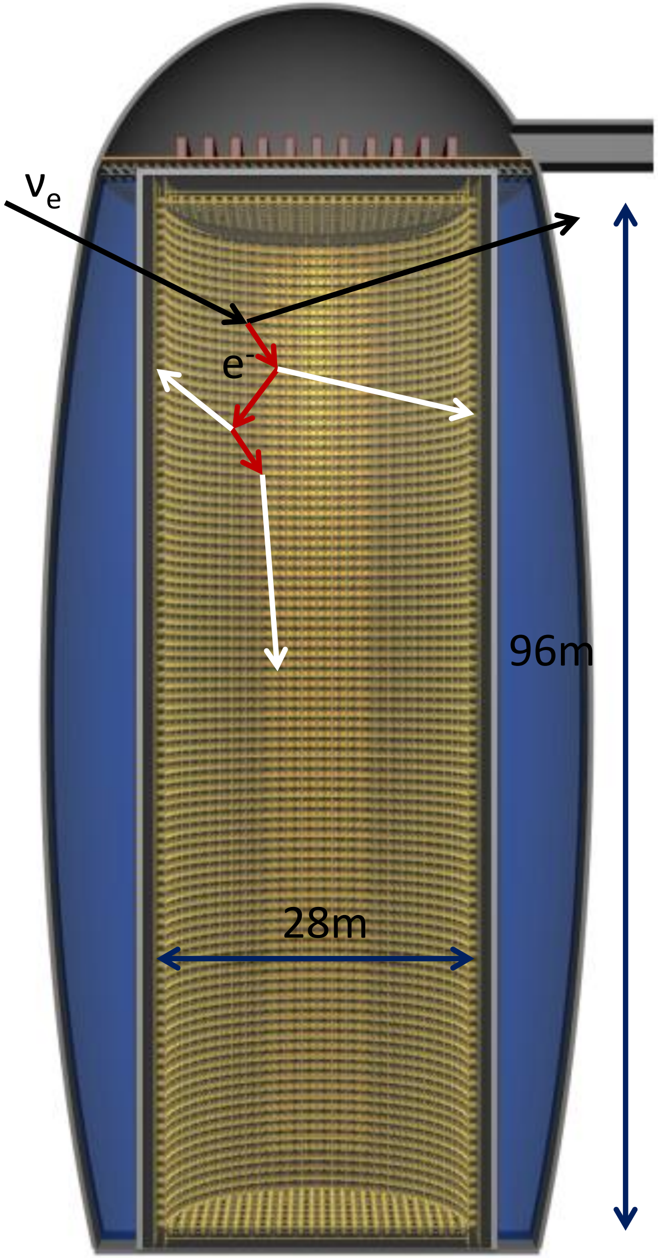

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- High energies (e.g. neutrino beam):
  also directionality
- Background (radioactivity inside + outside of detector, atmospheric muons, …);
  neutrino beam
  → event reconstruction

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- low fake detections: dark count, afterpulsing good time resolution
- low radioactivity

How can we obtain limits for the sensor requirements?

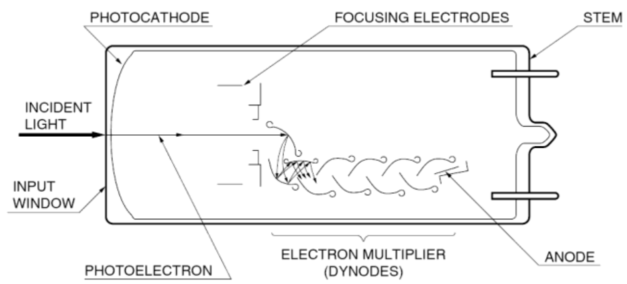
- Determine influence of sensor properties on overall detector behavior
- Detector properties needed to achieve physics goals known → can infer demands on sensor
- Quantify through geant4 Monte Carlo simulations + comparison with previous liquid scintillator experiments (Borexino, KamLAND)
- In progress, first results

Talks:

- Randolph Möllenberg T110.3 (previous talk)
- Dominikus Hellgartner T31.4 (Fr, 10:15)

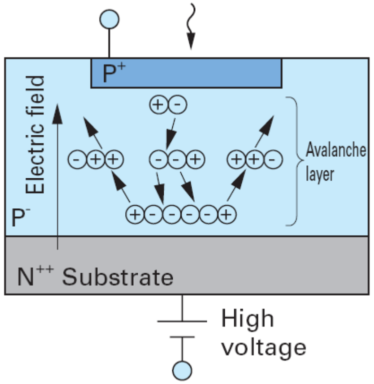
Which photosensors can fulfill the requirements?

- Photomultipliers (PMTs)
  - + Fulfill all requirements
  - → Sensor of choice at the moment



Which sensors could fulfill them?

- Si-Photomultipliers (SiPMs):
  - + Better energy resolution, time resolution, detection efficiency
  - − Dark count possibly too high
  - → Study in detail



- Hybrid detectors
  - Crucial question: Available in high quantities in time for construction?
  - Possibly yes: QUASAR, X-HPD, HAPD, QUPID
  - Probably not: Abalone, LAPPD

Which sensors could fulfill the requirements?

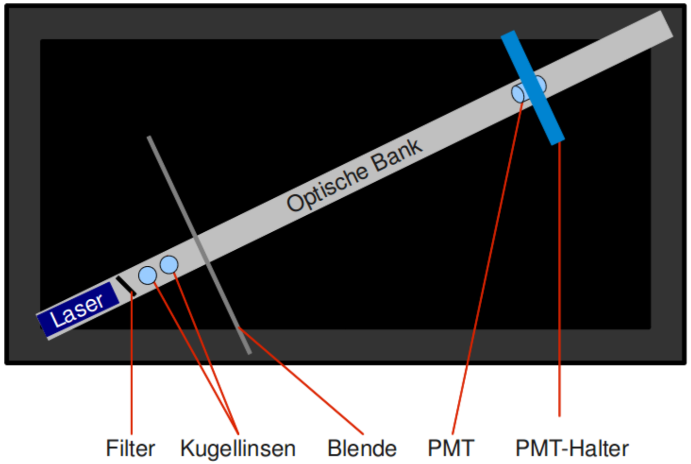
- Featured sensor at the moment: PMTs
  - Most promising models:
    - Hamamatsu R11780 (12“) → ≈ 31000 PMTs
    - Electron Tubes Enterprises D784 (11“) → ≈ 40000 PMTs
- Need to find out missing characteristics for all candidate sensor types
- Also measure properties of candidate PMT series to verify compliance + optimize performance

D784

How can we determine the missing properties?

- Photosensor testing facility is being set up in Munich
  - Was treated in the diploma thesis of Michael Nöbauer

- Measure timing properties, dynamic range, dark count, afterpulsing, energy resolution, …



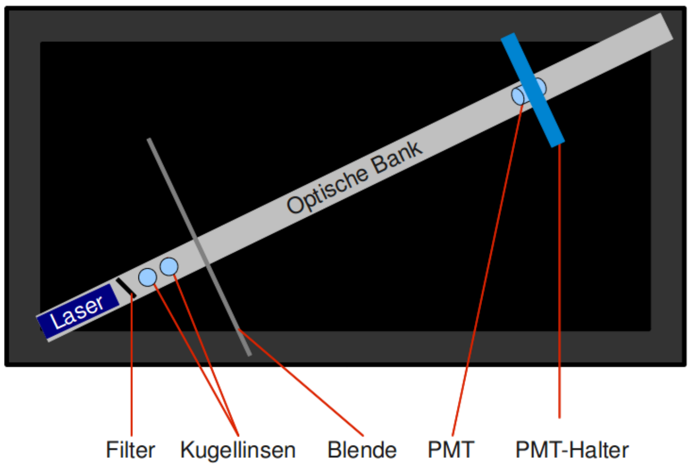
How can we determine the missing properties?

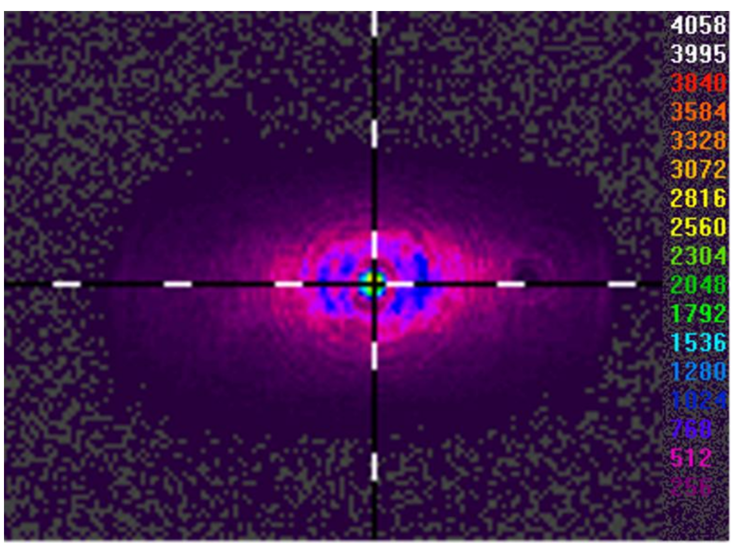
- Need to illuminate sensors…

a) …with photons arriving with very low timing uncertainty
→ ps diode laser (Edinburgh Instruments EPL-405mod)

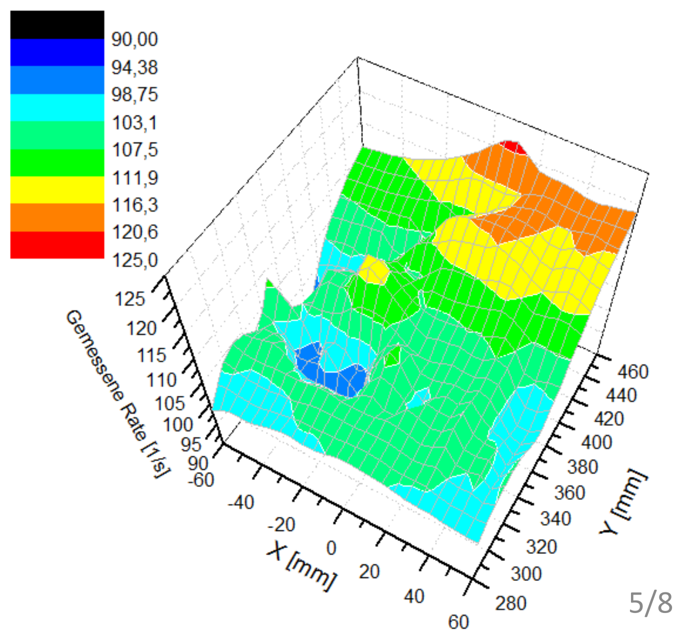
b) …uniformly over the whole area → widen beam radius from 100µm to 20cm
- So far: tried this with lenses with extremely small focal length (ball lenses /GRIN lenses)
  - Works good: in first trial ±20% intensity homogenity in 12×18cm window
  - …but not good enough: goal ≈1%, probably not reachable due to inhomogenities in laser beam profile + optics surfaces

→ Resort to classic solution with diffusor





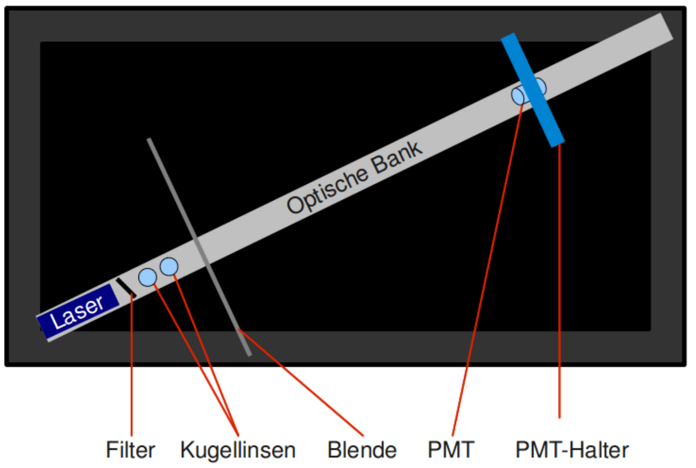
Laser intensity profile

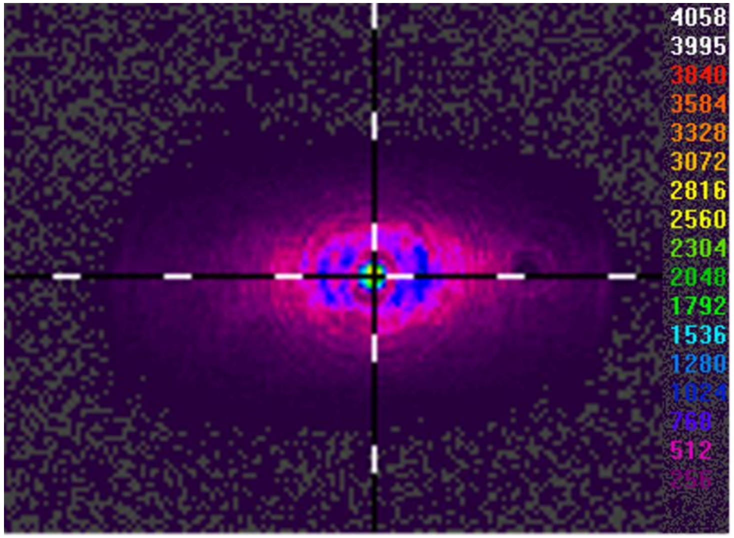


Intensity profile after optics

How can we determine the missing properties?

- Rest of setup is working
  - Can do spot measurements
    - First test measurements in good agreement with measurements done at the LNGS, Gran Sasso
  - Recently improved measurement rate from ≈10Hz to >2kHz by saving 1k pulses / file instead of 1
  - Evaluation software is running (transit time + charge distribution), now implement more features





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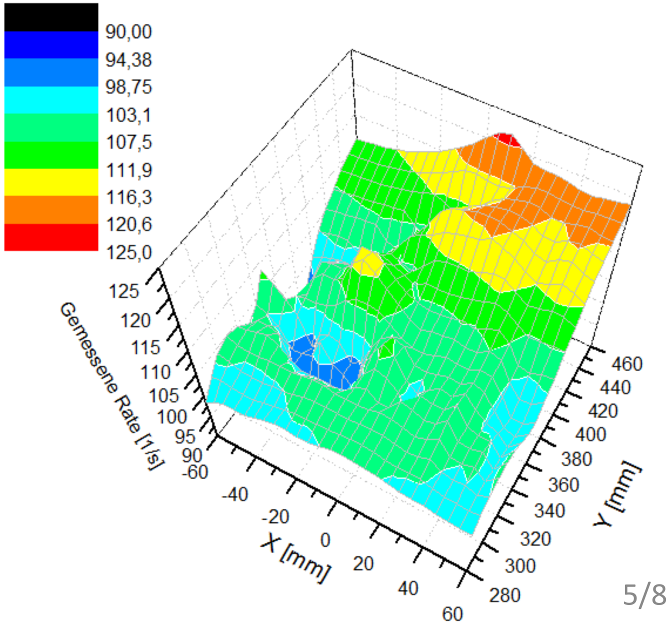
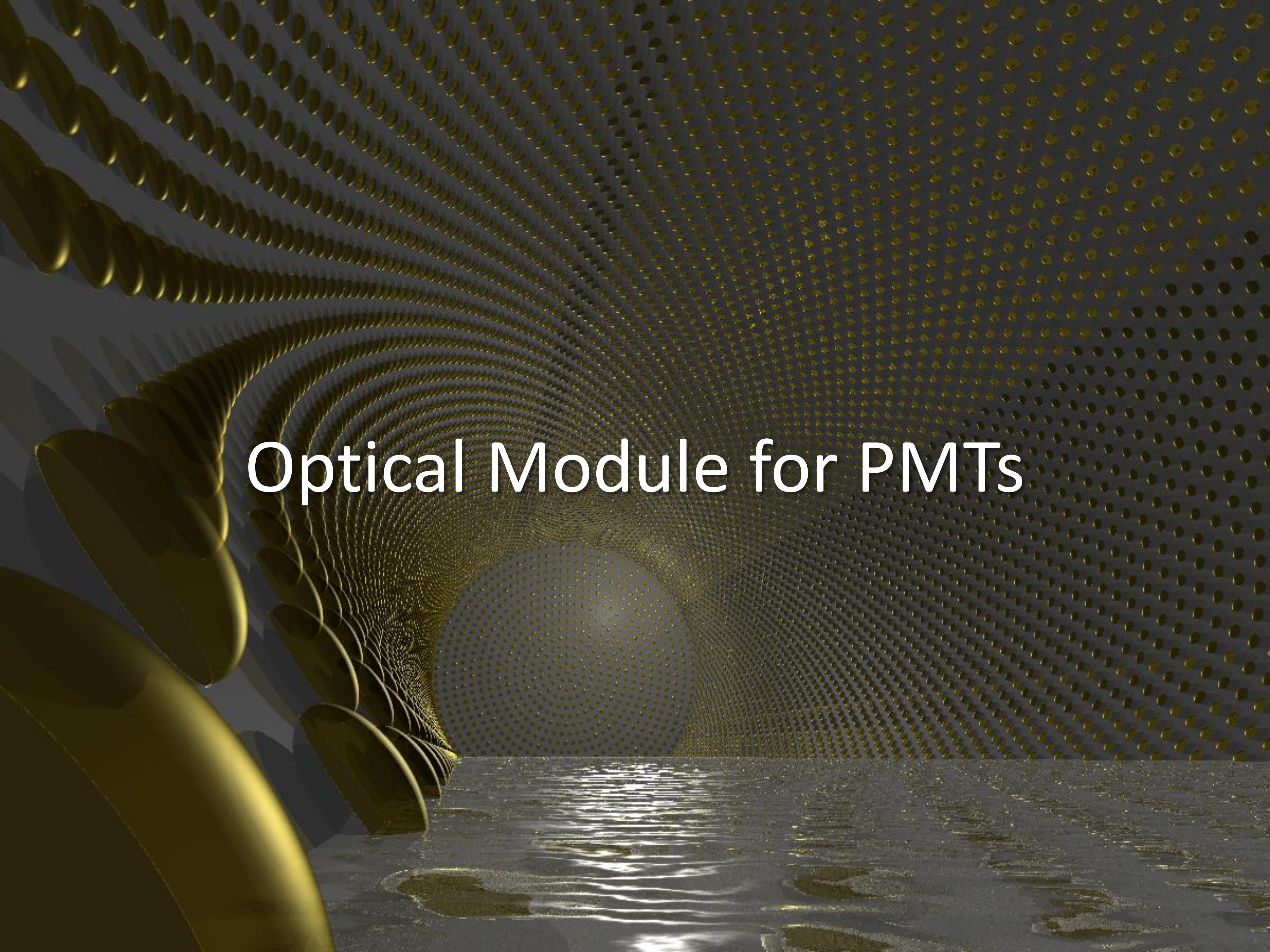


Intensity profile after optics

Optical Module for PMTs

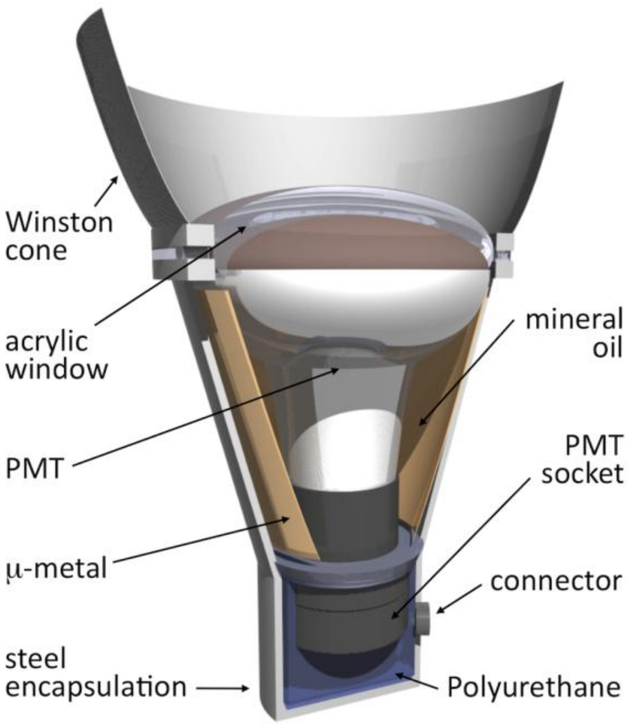


Most probably PMTs will be the photosensor for LENA

→ What components do we need for optimum performance?

- PMT
- Increase active area + limit field of view
  → Light concentrator (Winston Cone)
- Shield PMT from earth magnetic field
  → metal
- Power supply
  → Voltage divider
- Pressure
  → Encapsulation, acrylics glass window + stainless steel housing
- During filling, tank is filled with water → conductive
  → Cast voltage divider into insulator compatible with ultrapure water + liquid scintillator: polyurethane

- Need to shield scintillator from radioactive contamination contained in the PMT‘s glass → layer of inactive buffer liquid between scintillator and PMTs



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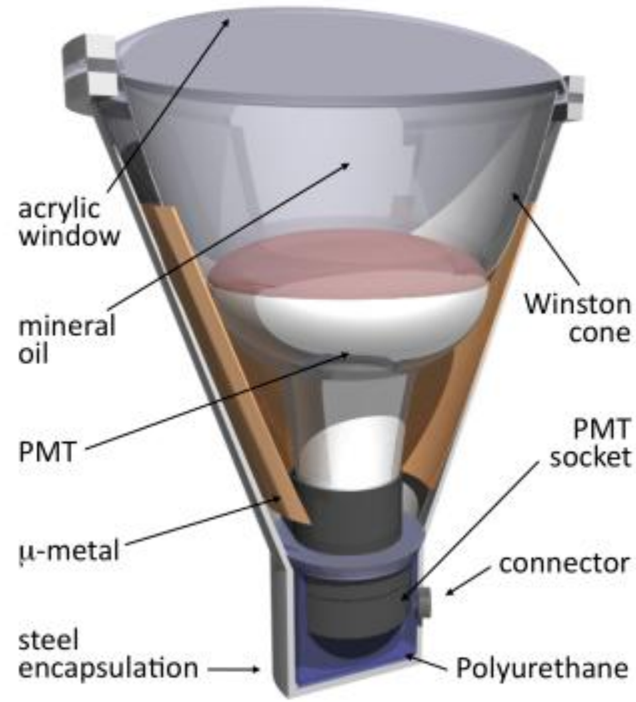
  - Possible due to advanced background rejection algorithms

  → Bigger active volume!



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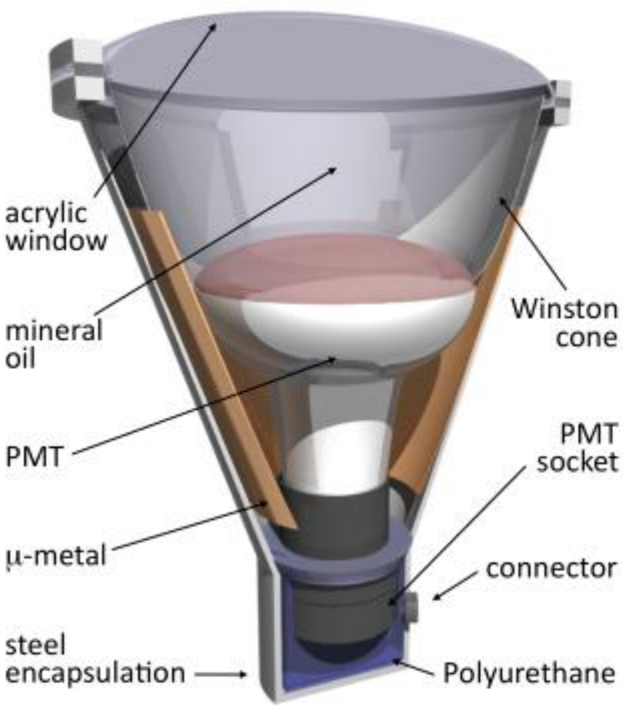

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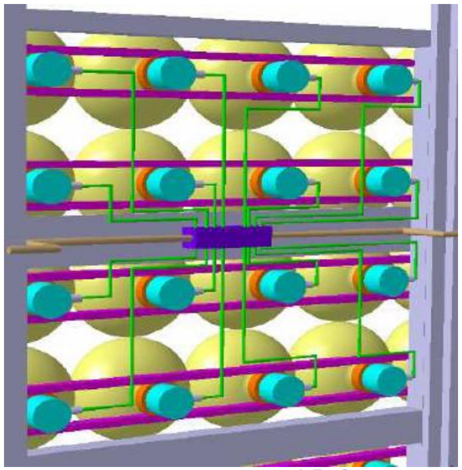
  - Central unit for arrays of PMTs, not part of optical module
  - Studied in PMm² project



J.E. Campagne

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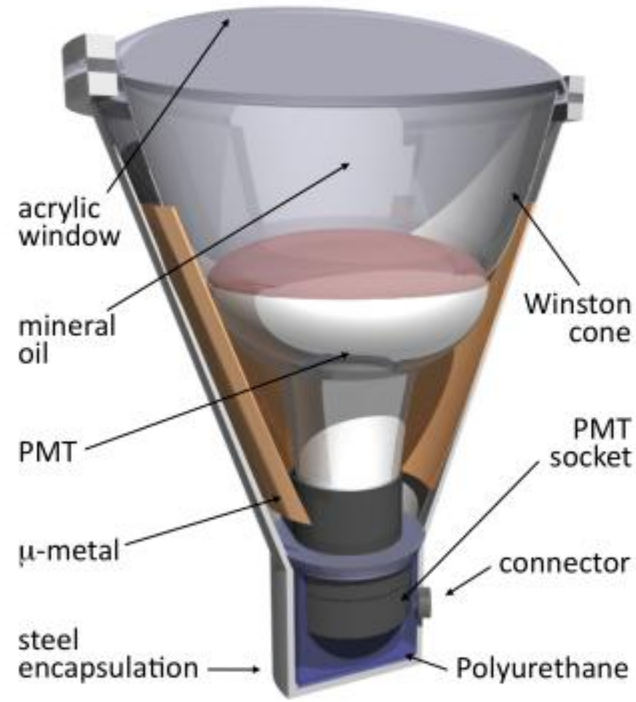
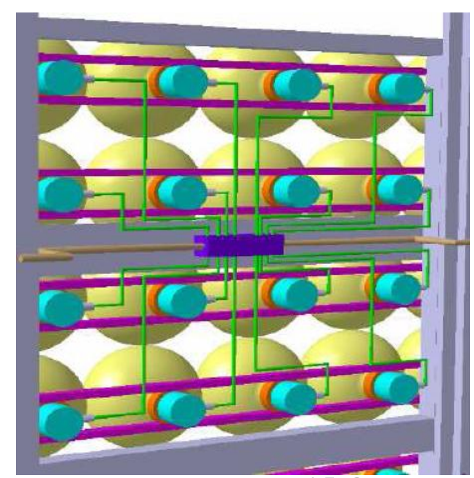


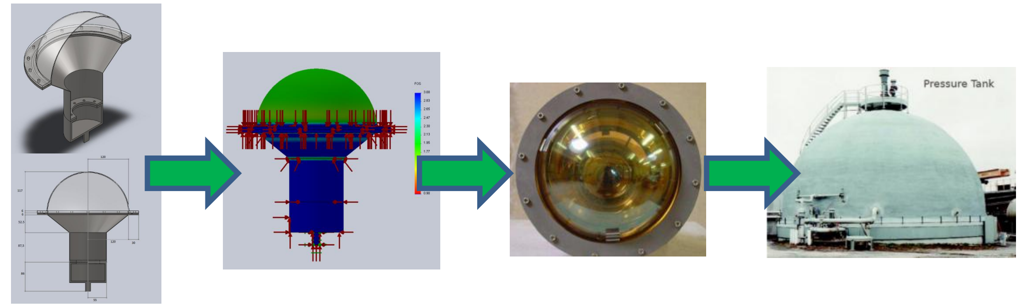


J.E. Campagne

Pressure encapsulations

How to develop an encapsulation?

- *Design, pressure simulations*, build prototype, pressure tests



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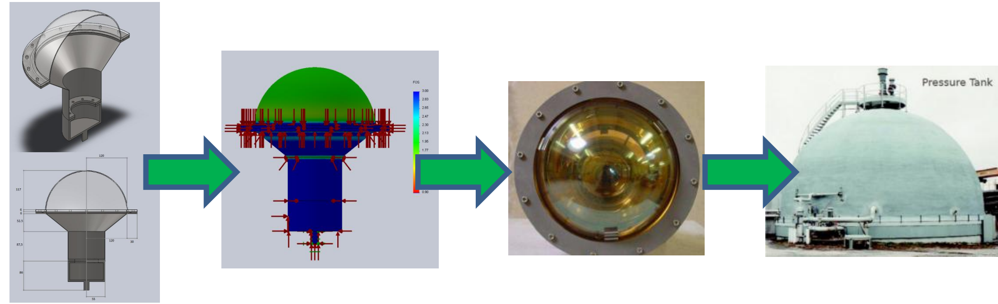

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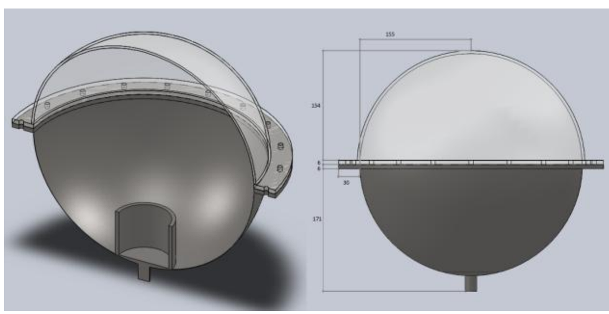

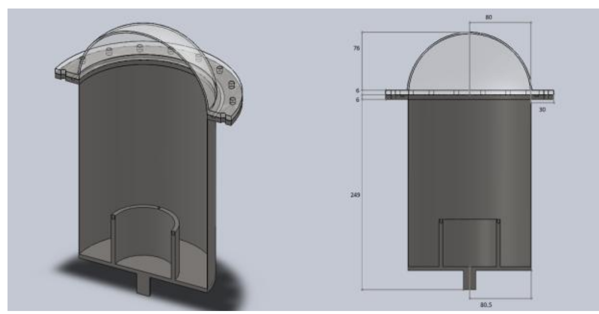

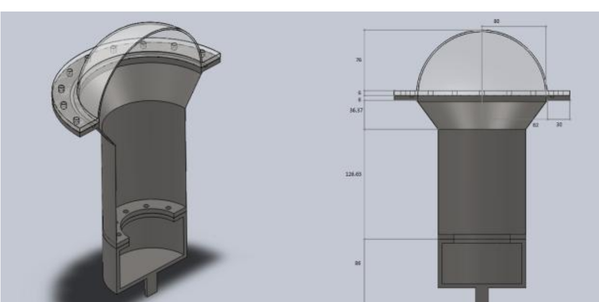

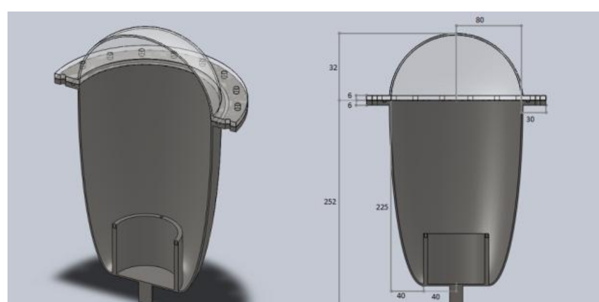

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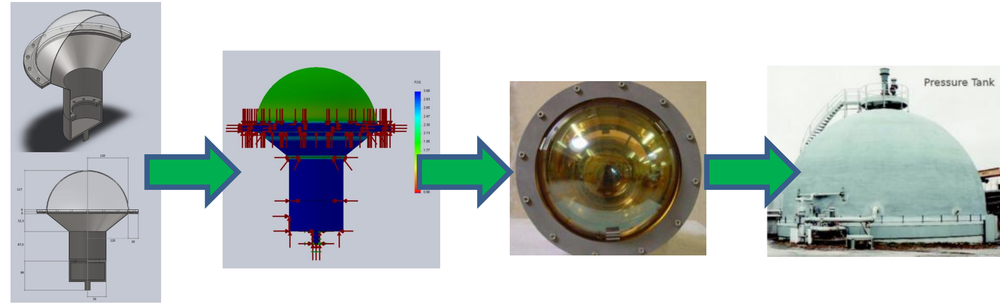

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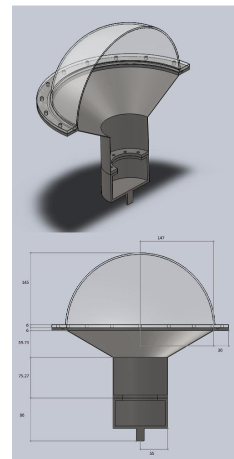

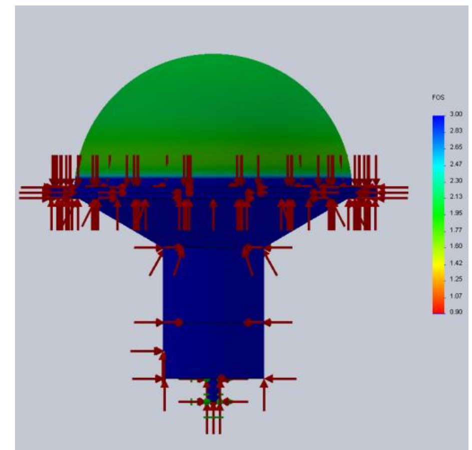

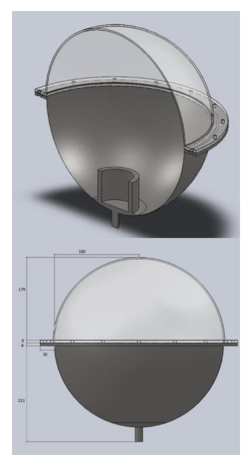

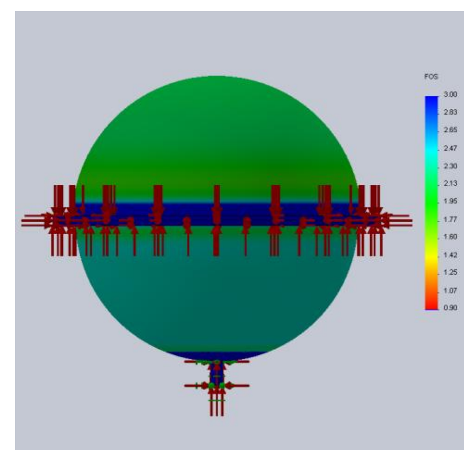

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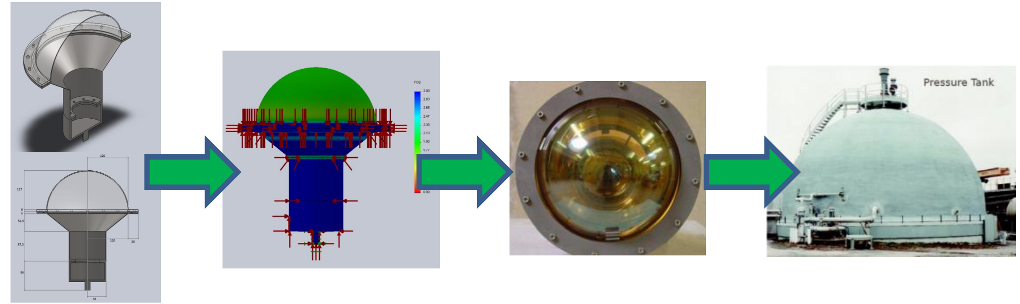

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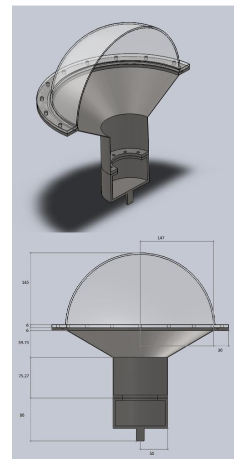
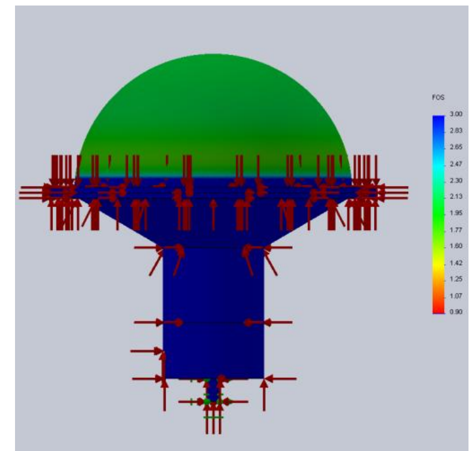
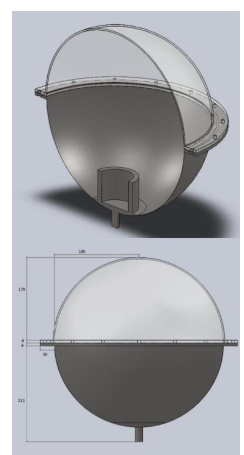
- Simulations so far were still for the old optical module without the buffer liquid ⟶ have to adapt design
- Currently cross-checking results + dependence on simulation parameters and improving simulations

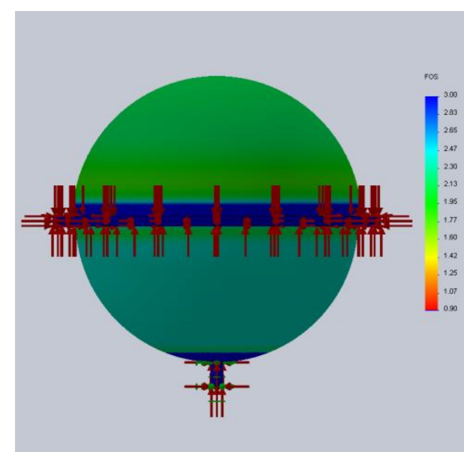
⟶ lots of basic questions to be cleared

⟶ *If somebody has experience with FEA simulations, any advice or help is most welcome!*









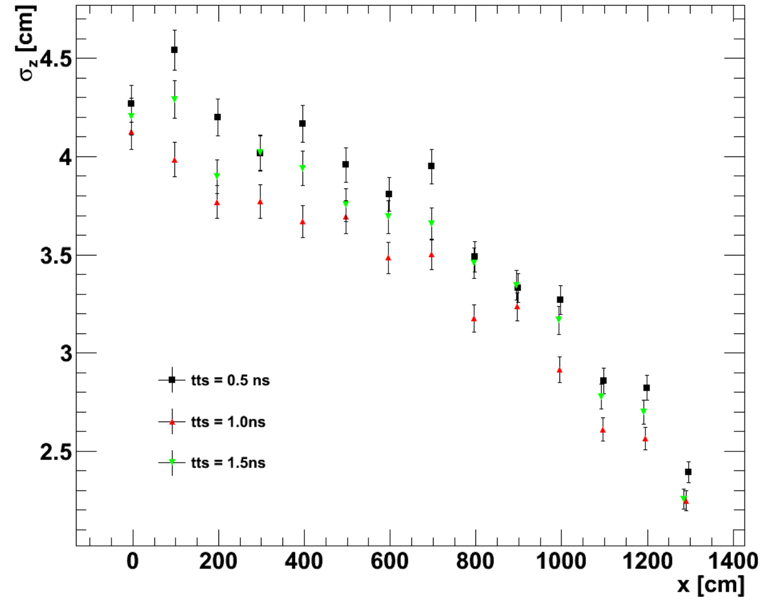
Conclusions

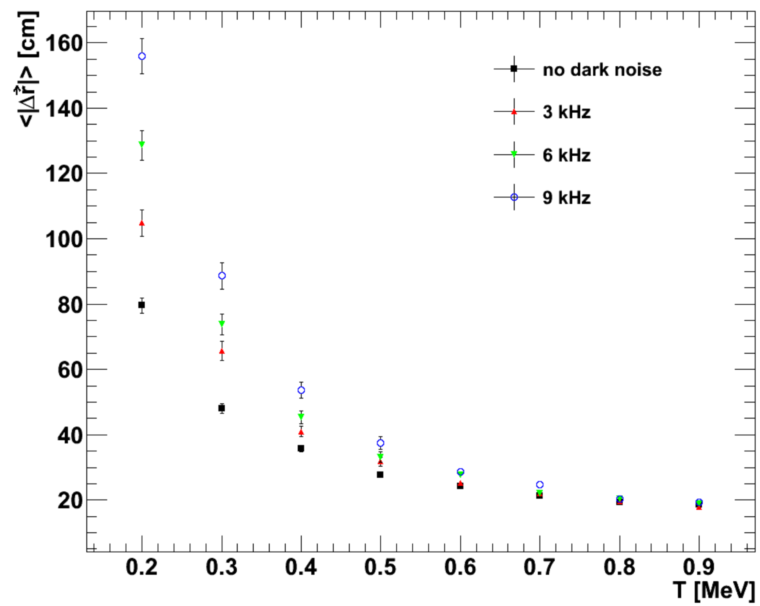
- Physics goals of LENA set hard requirements for photosensors
- Have started to determine influence of photosensor properties on detector performance with Geant4 Monte Carlo
- Have constructed photosensor test facility in Munich to measure missing sensor properties
- So far PMTs favoured option
  - Some other promising alternative sensors have to be tested
- Designed an optical module for PMTs consisting of Winston Cone, buffer liquid, mu metal, voltage divider, pressure encapsulation
- Have completed first designs + FEA simulations of pressure encapsulations → optimize designs, cross-check simulation results

Backup slides

Influence of sensor properties on detector behavior

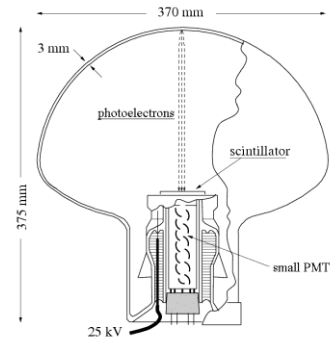
- Determine influence through Geant4 based Monte Carlo simulations
- Position and energy resolution (Dominikus Hellgartner)
  - Timing uncertainty:
    - First simulations, still fighting some problems with small timing uncertainties
    - First impression: no big influence
  - Dark Noise:
    - No big influence for energies around 1MeV or bigger
    - For 200keV position + energy resolution ≈30% worse
- α/β-discrimination (Randolph Möllenberg)
  - Dark Noise:
    - Strong influence on efficiency
  - Late Pulses + Fast Afterpulses
    - Negligible effect
  - Winston Cones (50°opening angle)
    - Improve separation by factor two



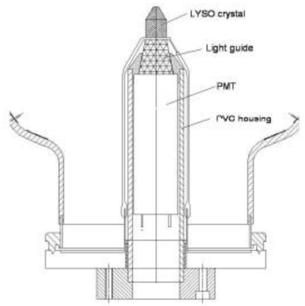


Alternative photosensor types

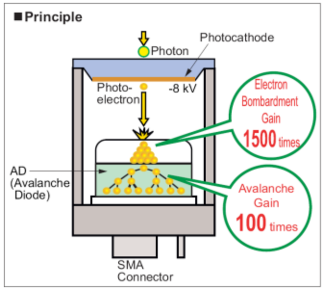
- Crucial question: Available in high quantities in time for construction?
- Possibly available for first detector:
  - QUASAR (14.6“):
    - Layout: Photocathode → HV → scintillator crystal → small PMT;
    - Very promising sensor in most regards (tts, DN, AP, …), are even working to further improve design with faster scintillator + fast small HQE PMT;
    - Drawbacks: currently no manufacturer, dynamic range=?
  - X-HPD (8“):
    - Layout: basically as QUASAR
    - Drawbacks: high dark rate, 100-10Hz/cm², dyn. range=?
  - HAPD (13“):
    - Layout: Photocathode → HV → APD
    - Expect commercial availability in spring 2012 (status Jan. 2011)
    - Drawbacks: dyn. range?
  - QUPID (3“):
    - Layout: same as HAPD
    - Drawbacks: small size, designed for LAr/LXe, dark count @RT =?, QE=?, dyn. range?
- Need to test samples to determine all properties

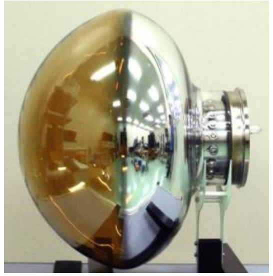


QUASAR-370

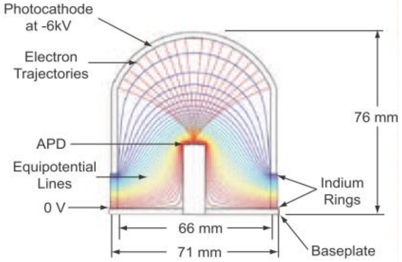


X-HPD





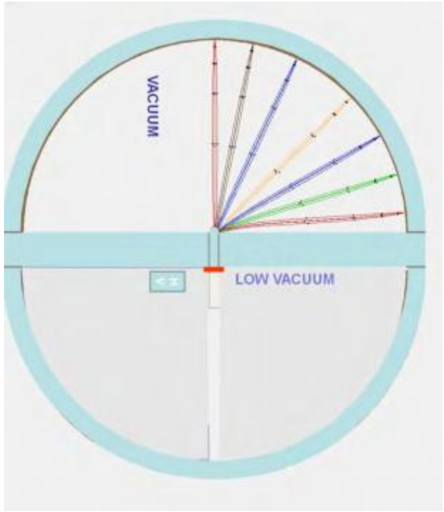
HAPD



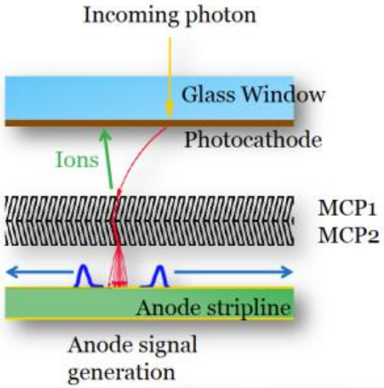
QUPID

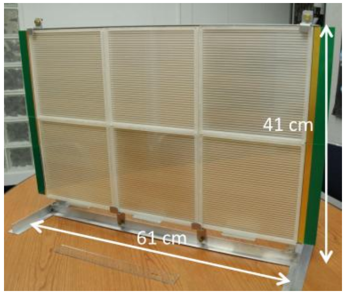
Alternative photosensor types

- Probably not available in time:
  - Abalone (≈13“):
    - Layout: Photocathode ⟶ HV ⟶ scintillator crystal ⟶ G-APD
    - Advantages: simple, robust + cheap design
    - Status: Prototypes not yet stable under atmospheric pressure
  - LAPPD (scalable):
    - Layout: Photocathode ⟶ 2 microchannel plates ⟶ anode striplines read out at both ends
    - Advantages: ps time resolution, large area, position sensitive, cheap(?)
    - Status: working prototypes of MCP sheets + electronics, QE still low, no complete prototype yet



Abalone





LAPPD

Pressure withstanding PMT encapsulations for LENA:
Pressure simulations

- Simulate behaviour under pressure with a Finite Elements Analysis (FEA) simulation software
  - Engineering drawings and FEA pressure simulations were done with same software

- Software: SolidWorks Educational Edition Academic Year 2010-2011 SP4.0, *Simulation Premium package*

- Settings: Linear static study, 12bar pressure, node distance 3mm ± 0.15mm

- Materials: High impact resistant acrylic glass, 1,4404 stainless steel X2CrNiMo17-12-2

- Computer: Intel i7-2600, 8GB DDR3-RAM, AMD Radeon HD 6450 1GB GDDR3, Win7 Prof. 64bit

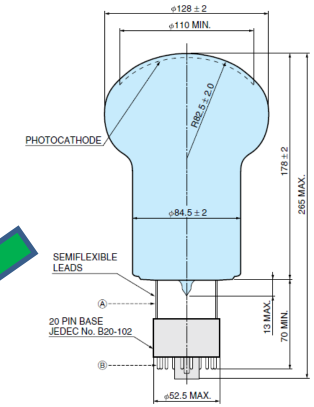
- So far designs + simulations for 5 candidate PMTs:
  - Hamamatsu: R7081 (10“), R5912 (8“), R6594 (5“)
  - Electron Tubes Enterprises Ltd.: 9354 (8“), 9823 (5“)

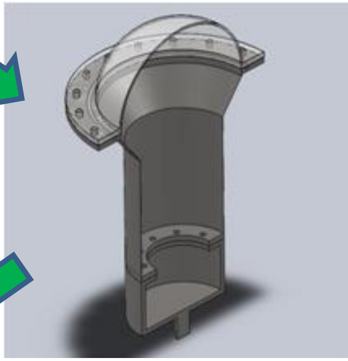
German Beischler

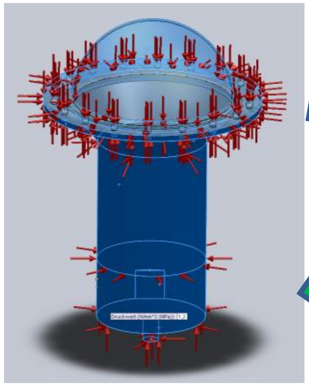
- *Was treated in a bachelor thesis by **German Beischler***
  - *In consultance with Harald Hess (head of workshop + SolidWorks expert of our chair)*
  - *Continues these studies!*

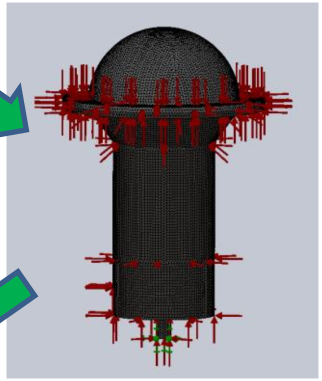
Pressure withstanding PMT encapsulations for LENA:

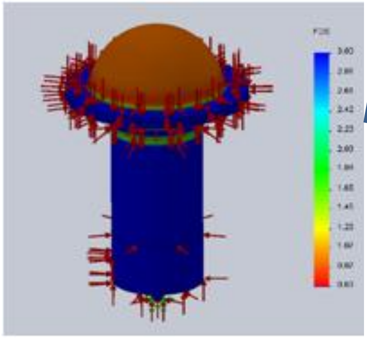
Pressure simulations







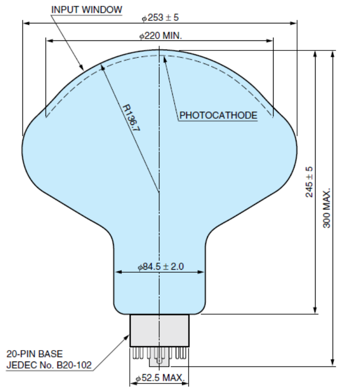


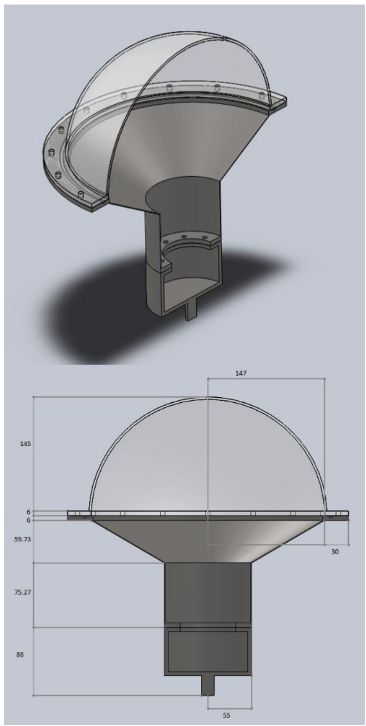


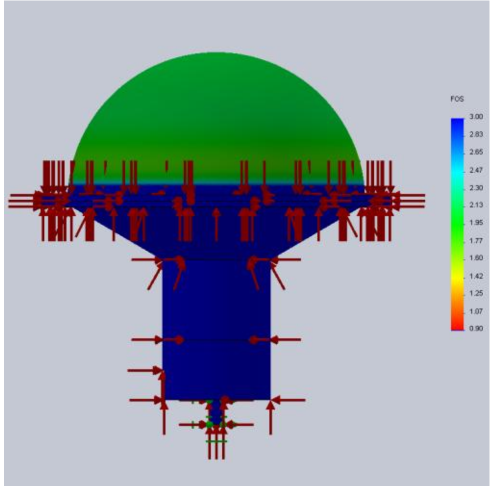
Procedure:

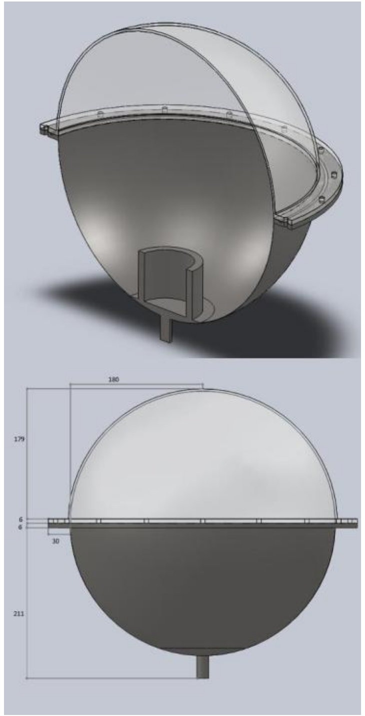
- Import PMT contour from engineering drawing in datasheet
- Rotate to obtain model of PMT
- Construct encapsulation based on PMT dimensions and experience from design of the Borexino + Double Chooz encapsulation
- Simulate encapsulation with 12bar pressure applied
    - Apply forces → meshing → simulate to determine factor of safety
    - Vary thicknesses of acrylic glass + stainless steel to find minimum values
- Compare results for different designs regarding weight (U, Th, K impurities in materials), surface (adsorbed Rn) and construction costs

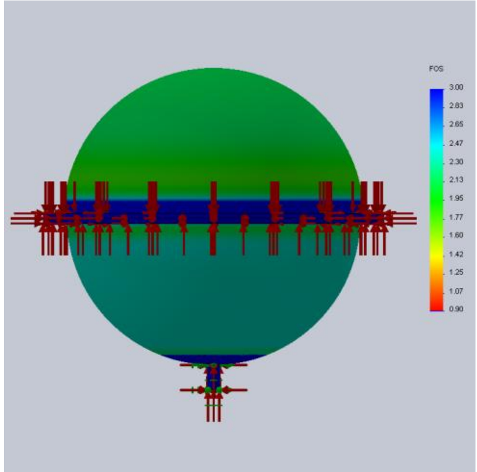
Pressure simulation results: Hamamatsu R7081 (10“)











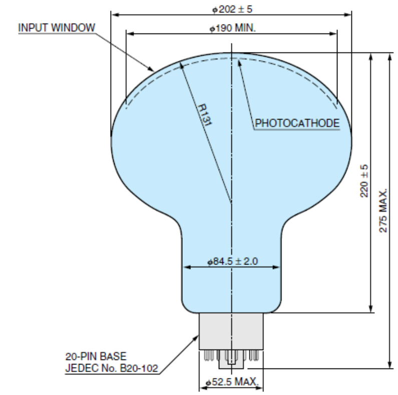
<u>Conical encapsulation:</u>

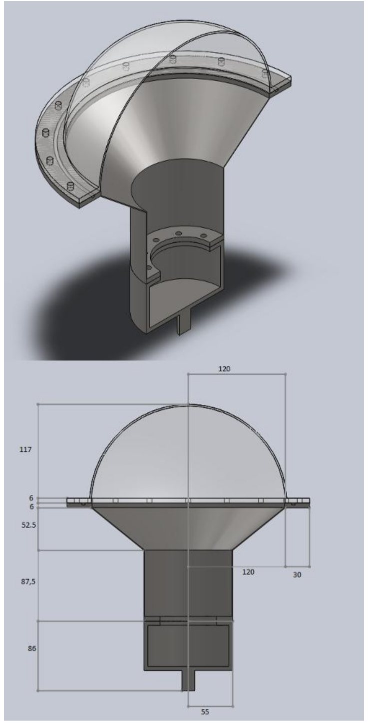
Steel: 2mm thickness, 4.38kg
Acrylic glass: 4mm thickness, 0.86kg
Total surface: 0.69m²

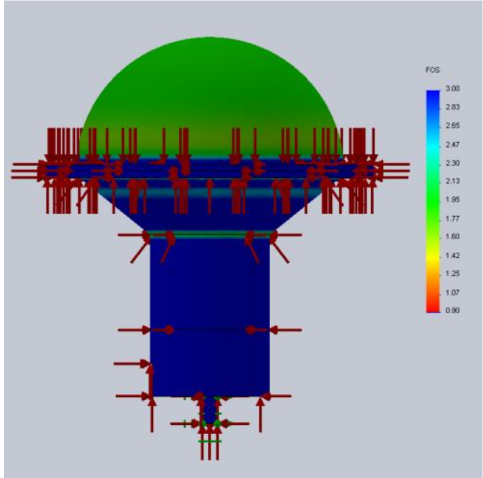
<u>Spherical encapsulation:</u>

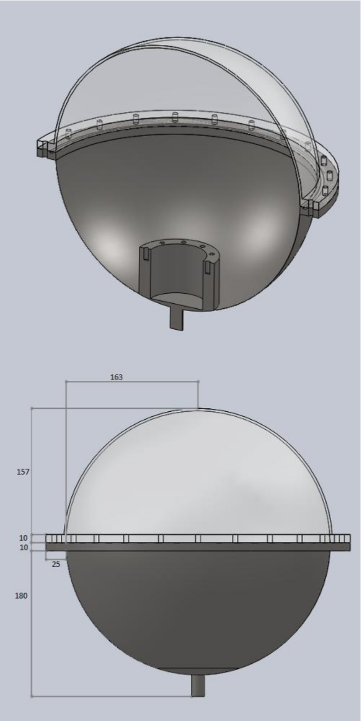
Steel: 0.5mm thickness, 4.08kg
Acrylic glass: 5mm thickness, 1.48kg
Total surface: 1.01m²

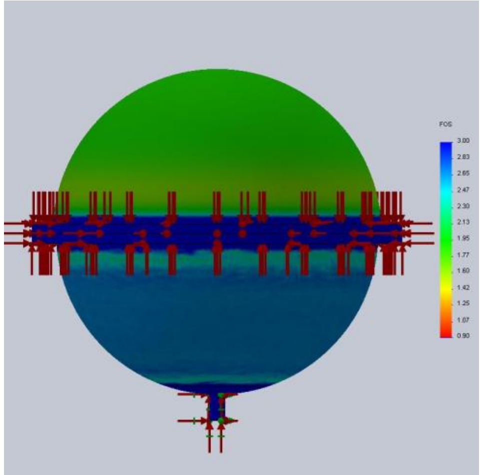
Pressure simulation results: Hamamatsu R5912 (8“)











<u>Conical encapsulation:</u>

Steel: 1mm thickness, 3.24kg

Acrylic glass: 3mm thickness, 0.50kg

Total surface: 0.53m²

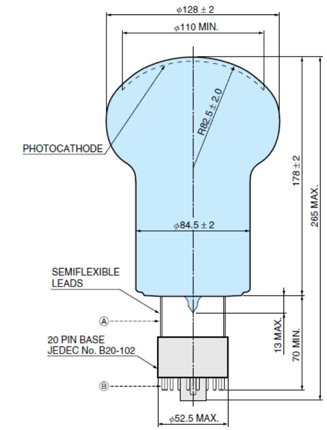
<u>Spherical encapsulation:</u>

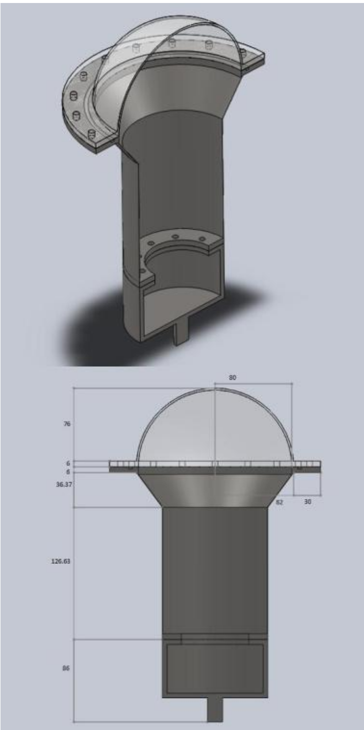
Steel: 0.5mm thickness, 4.66kg

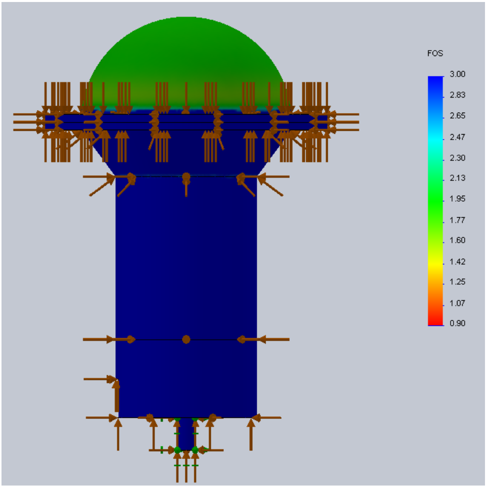
Acrylic glass: 4mm thickness, 1.10kg

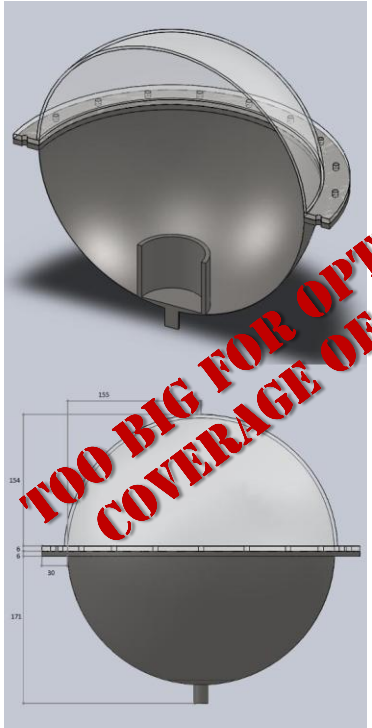
Total surface: 0.83m²

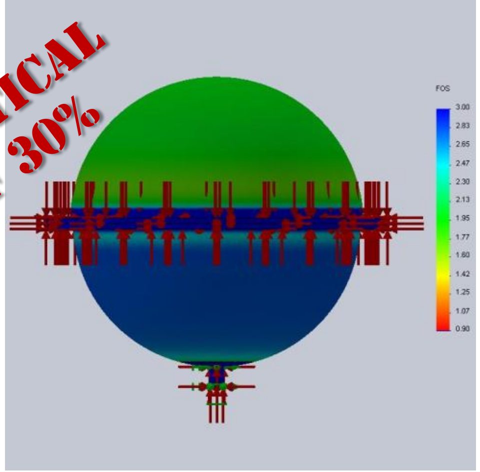
Pressure simulation results: Hamamatsu R6594 (5“)











TOO BIG FOR OPTICAL COVERAGE OF 30%

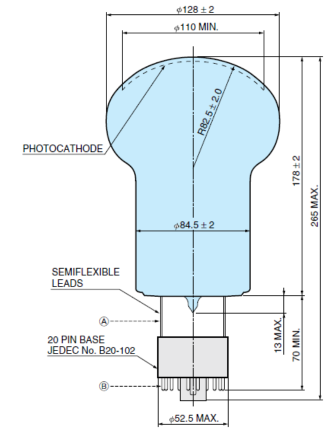
<u>Conical encapsulation:</u>

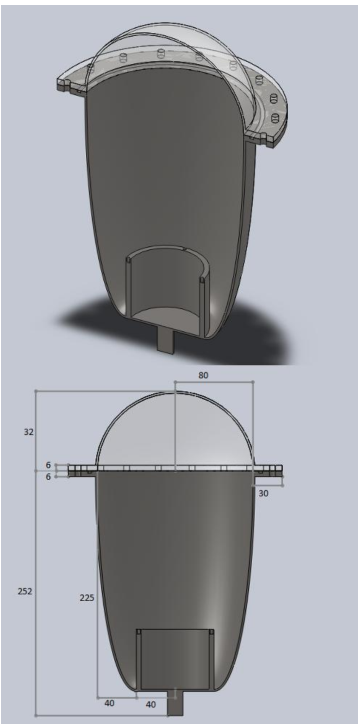
Steel:	1mm thickness,	2.77kg
Acrylic glass:	2mm thickness,	0.22kg
Total surface:	$0.37m^2$	

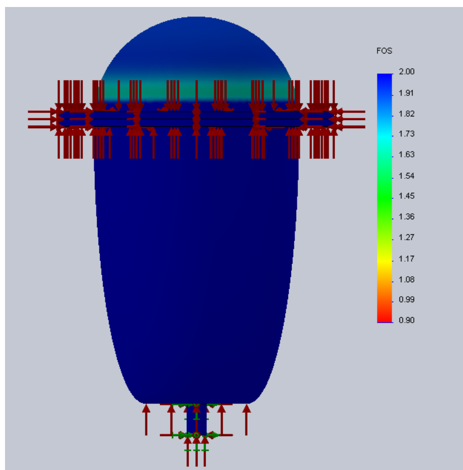
<u>Spherical encapsulation:</u>

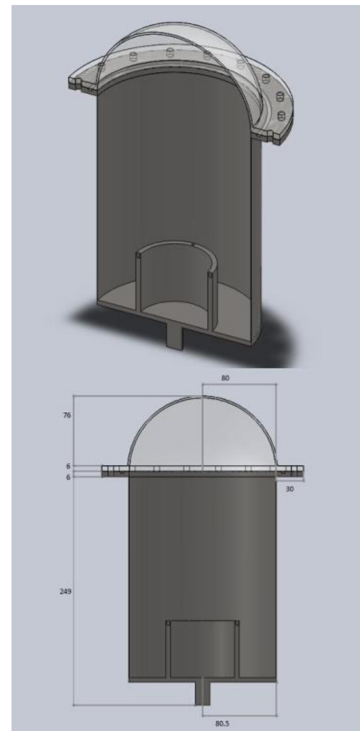
Steel:	0.5mm thickness,	2.75kg
Acrylic glass:	4mm thickness,	0.94kg
Total surface:	$0.78m^2$	

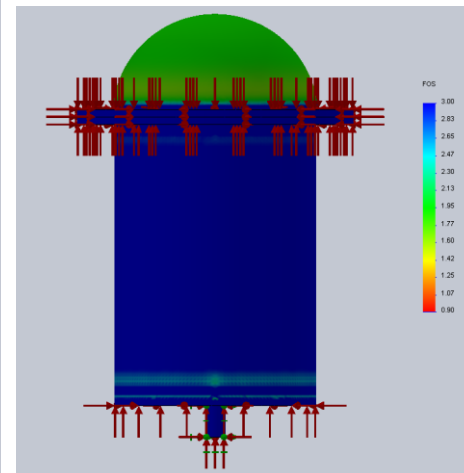
Pressure simulation results: Hamamatsu R6594 (5“)











<u>Elliptical encapsulation:</u>

Steel:	2mm thickness,	3.06kg
Acrylic glass:	2mm thickness,	0.22kg
Total surface:	$0.41m^2$	

<u>Cylindrical encapsulation:</u>

Steel:	0.5mm thickness,	2.61kg
Acrylic glass:	2mm thickness,	0.22kg
Total surface:	$0.46m^2$	