Development of an Optical Module for LENA

Marc Tippmann
for the LENA working group

Technische Universität München
Lehrstuhl für Experimentelle Astroteilchenphysik

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

- Event detection in liquid scintillator detectors:
  Neutrino scatters off electron
  $\rightarrow$ electron freed
  $\rightarrow$ loses kinetic energy via excitation of scintillator molecules
  $\rightarrow$ emit light at deexcitation
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  → big surface (9700m²)

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- pressure-withstanding, long-term reliability
- low price/detector area
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  → 700 - 15·10⁶ 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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- single photon detection, high detection efficiency, large dynamic range
- good energy resolution
- low fake detections: dark count, afterpulsing, good time resolution
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• Background (radioactivity inside + outside of detector, atmospheric muons, ...); neutrino beam → event reconstruction

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- good energy resolution
- 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
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 homogeneity 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
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 \( \approx 10 \text{Hz} \) to \( >2 \text{kHz} \) by saving 1k pulses / file instead of 1
  - Evaluation software is running (transit time + charge distribution), now implement more features
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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  New design: include buffer liquid into pressure encapsulation
  •  Possible due to advanced background rejection algorithms
    →  Bigger active volume!
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• Possibly also HV transformation + signal preprocessing on site
  • Central unit for arrays of PMTs, not part of optical module
  • Studied in PMm² project
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Pressure encapsulations

How to develop an encapsulation?

- *Design, pressure simulations*, build prototype, pressure tests
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  - ...for different designs (spherical, conical, cylindrical, elliptical, rotated spline)
  - ...for 5-10” PMTs of Hamamatsu + Electron Tubes Enterprises
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• Did first Finite Element Analysis simulations with SolidWorks to determine necessary thicknesses + weight
  • Need encapsulations due to pressure, but weight = radioactivity → keep them as thin as safety allows
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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

- \(\alpha/\beta\)-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
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
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“)

• *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 withstanding PMT encapsulations for LENA

Pressure simulation results:
Hamamatsu R7081 (10“)

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

**Spherical encapsulation:**
- Steel: 0.5mm thickness, 4.08kg
- Acrylic glass: 5mm thickness, 1.48kg
- Total surface: 1.01m²
Pressure withstanding PMT encapsulations for LENA

Pressure simulation results:
Hamamatsu R5912 (8“)

<table>
<thead>
<tr>
<th>Encapsulation</th>
<th>Steel</th>
<th>Acrylic glass</th>
<th>Total surface</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conical</strong></td>
<td>1mm thickness, 3.24kg</td>
<td>3mm thickness, 0.50kg</td>
<td>0.53m²</td>
</tr>
<tr>
<td><strong>Spherical</strong></td>
<td>0.5mm thickness, 4.66kg</td>
<td>4mm thickness, 1.10kg</td>
<td>0.83m²</td>
</tr>
</tbody>
</table>
Pressure withstanding PMT encapsulations for LENA

Pressure simulation results:
Hamamatsu R6594 (5”)

Conical encapsulation:
Steel: 1mm thickness, 2.77kg
Acrylic glass: 2mm thickness, 0.22kg
Total surface: 0.37m²

Spherical encapsulation:
Steel: 0.5mm thickness, 2.75kg
Acrylic glass: 4mm thickness, 0.94kg
Total surface: 0.78m²
Pressure withstanding PMT encapsulations for LENA

Pressure simulation results:
Hamamatsu R6594 (5"")

**Elliptical encapsulation:**
- Steel: 2mm thickness, 3.06kg
- Acrylic glass: 2mm thickness, 0.22kg
- Total surface: 0.41m²

**Cylindrical encapsulation:**
- Steel: 0.5mm thickness, 2.61kg
- Acrylic glass: 2mm thickness, 0.22kg
- Total surface: 0.46m²