A Liquid Scintillator Transparency Monitoring Laser System for JUNO

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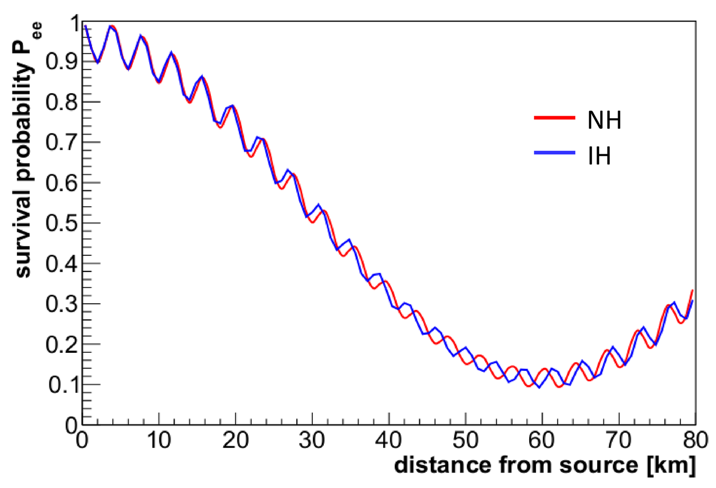
The JUNO Experiment & Motivation

Main Goals of the JUNO Experiment

- **Determination** of the neutrino **mass hierarchy** (sign of $|\Delta m^2_{32}|$)
- **Precision measurement** of **solar oscillation parameters** θ_{12}, Δm^2_{21} and **atmospheric oscillation parameter** $|\Delta m^2_{32}|$ to better than 1%

How to measure the Mass Hierarchy?

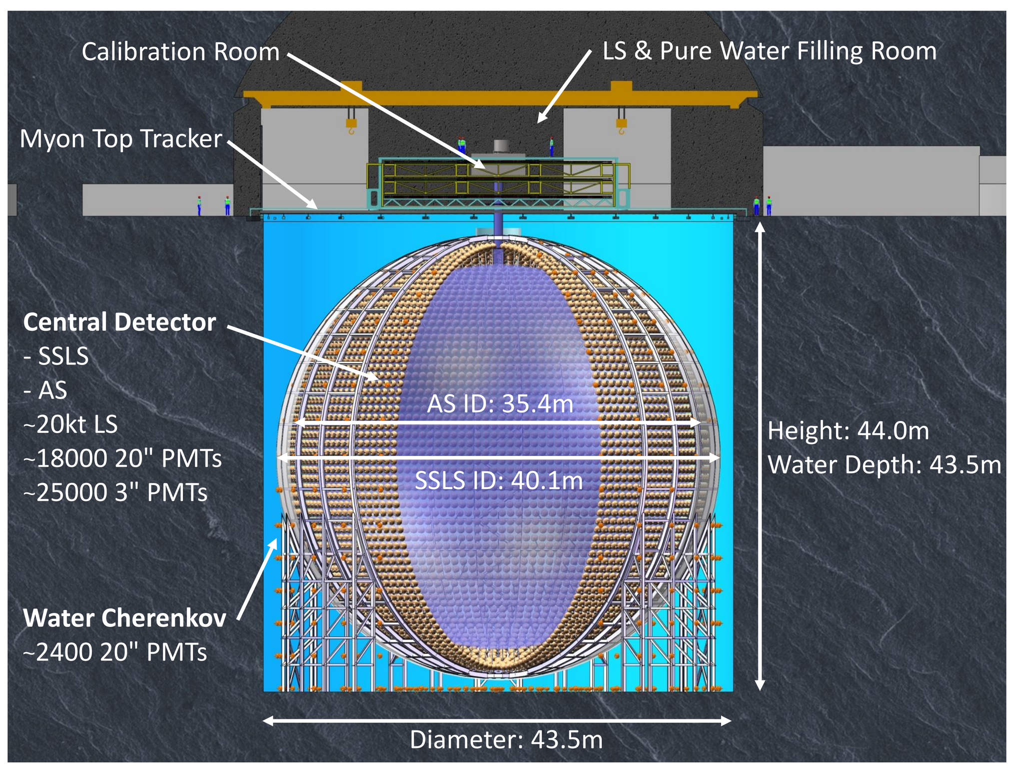
- JUNO uses **interference effects** of Δm^2_{31} and Δm^2_{32} in **oscillation probabilities** of $\bar{\nu}_e$ emitted by nuclear reactors



Due to differences in the oscillation probability, the measured ν flux for the NH will be different compared to the IH. The fine structure tells us which hierarchy order is correct. Maximal distortion at around 53km.

- **Baseline** is set to **53km**

General Design of the JUNO Detector



*Schematic of the Jiangmen Underground Neutrino Observatory (JUNO). Highlighted are the **Acrylic Sphere** (AS) in violet with an inner diameter (ID) of 35.4m, the **Stainless Steel Latticed Shell** (SSLS) in gray with an ID of 40.1m, the **PMTs** in orange and the **Water Cherenkov Detector** in blue. In addition, the **Myon Top Tracker**, the **Calibration Room**, the **Liquid Scintillator** (LS) & **Pure Water Filling Room** are illustrated as well.*

What is the Detection Principle?

- Measuring the **disappearance** of reactor **electron antineutrinos**
- They can be detected via the **inverse beta decay** (IBD):
- $\bar{\nu}_e + p \rightarrow n + e^+$
- Coincidence of **prompt positron** and **delayed neutron signal** (τ≈200µs) is easier to distinguish from background.
- Positron carries the energy of the neutrino: $E_{e^+} = E_{\bar{\nu}} - 0.78MeV$
- Neutron is captured by proton emitting a photon: $E_\gamma = 2.2MeV$

Requirements to resolve the MH?

- **High statistics** of 100k IBD events (**3σ significance**)
- An **energy resolution** of at least $3\%/\sqrt{E(MeV)}$ is needed to resolve differences between NH and IH
- Energy resolution depends predominantly on the **PMT coverage**, the **light yield** and **transparency** of the liquid scintillator

Why do we need the Laser System?

- In the run-up to JUNO the **LS transparency is mainly measured in small scaled set-ups** (value might **change at larger distances**)
- **Transparency might also change** over time **due to aging effects**
- **Monitoring** of the liquid scintillator transparency **is mandatory**
- **Measuring the attenuation of laser beams** inside JUNO **to determine the liquid scintillator transparency**

The Liquid Scintillator & Transparency

Transparency of the Liquid Scintillator

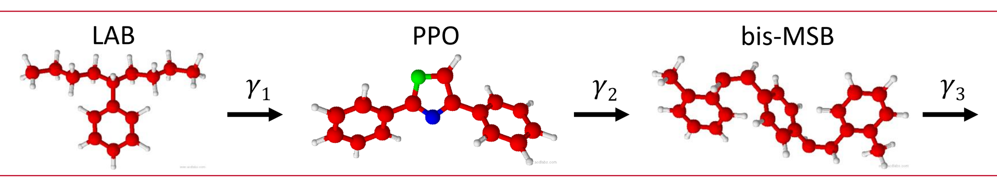
- Transparency is related to the absorption of light during its propagation through the medium
- Can be described by the **Beer-Lambert law** (1)
- Parameter **L** stands for the **attenuation length**
- L is a combination of the **absorption length** L_a and **scattering length** L_s (2)
- In order to enhance the transparency **wavelength shifters** are added to the scintillator

$$I(x) = I_0 e^{-x/L} \quad (1)$$

$$\frac{1}{L} = \frac{1}{L_a} + \frac{1}{L_s} \quad (2)$$

Scintillation Mechanism

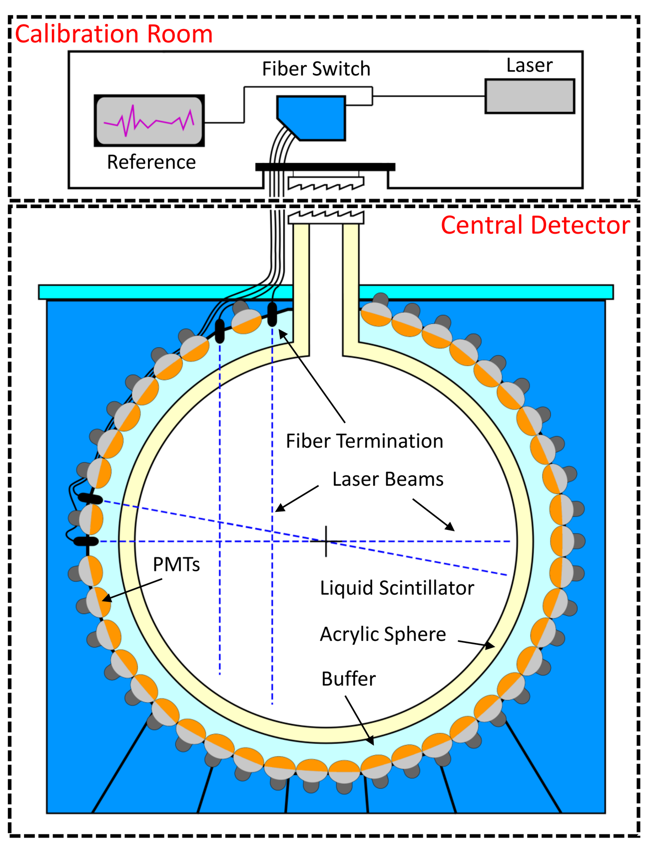
- π-electrons in benzene rings get excited by passing charged particles
- fluorescent/phosphorescent light is emitted during de-excitation



Wavelength Shifting Chain

- Wavelength shift takes place on the first meters
- After that Rayleigh scattering is the dominant process
- Transparency should be measured in the same wavelength region
- Measurement should be above the absorption spectrum of bis-MSB (λ ≥ 410 nm)
- Laser should operate at λ = 430 nm

Determination Method



Set-up of the laser system AURORA

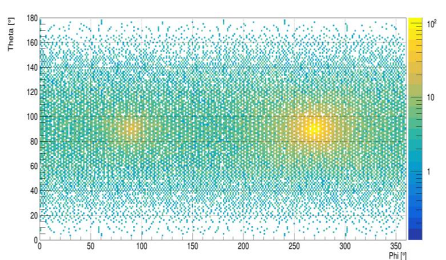
Monitoring of LSc Transparency via Laser System

Purpose:

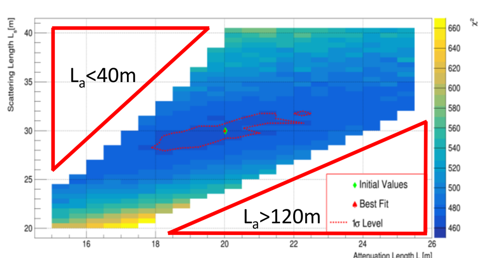
- monitoring of L, L_a & L_s (**O**ptical **P**arameters)
  - are there changes over time due to aging effects?

Approach:

- total amount & photon distribution depends on OP
- construction of LookUpTable (**LUT**) via MC simulation
  - collecting photon distribution for different OP combinations
- laser beams @ 430nm traverse the central detector
  - get scatter profile for current OP
- comparison between measurement and LUT
  - using likelihood method to determine OP



photon distribution for one laser beam



sensitivity plot for OP determination

Design of the Laser System & Characterization of single Components

A Unit for **R**esearching **O**nline the LSc t**RA**nsparency

The Laser Diode

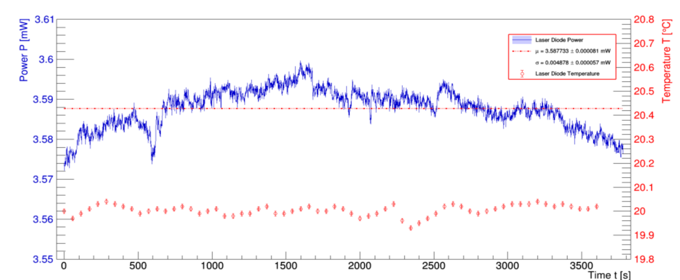
We will use the light of **a laser diode** to illuminate the detector in order to determine the optical parameters of the scintillator.

Requirements:

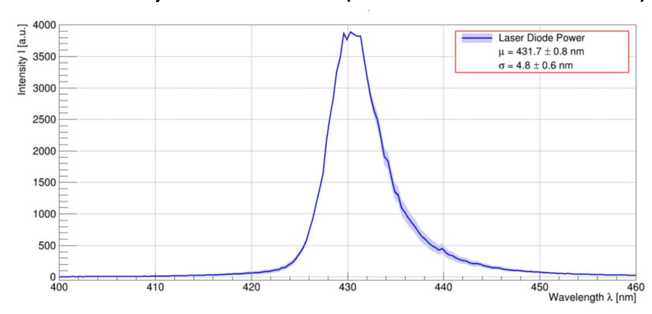
- Stability
- Linearity
- Fitting spectrum

Specifications:

- Roithner Lasertechnik
- λ_{max} @ 430 nm
- P_{max} is around 50 mW
- Lifetime of 5000 h
- Continuous wave mode

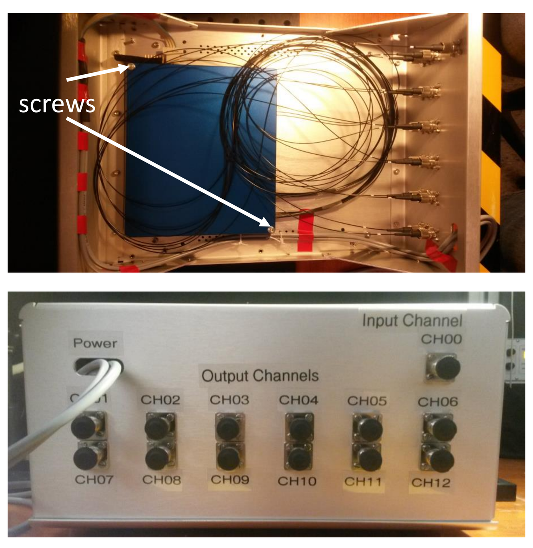


- Stability is sufficient (fluctuations < 0.14%)



- Spectrum is well shaped ($\lambda_{max} \approx 430\ nm$)

The Fiber Switch Module



The **Fiber Switch module** has twelve different outlets through which the laser can be guided via optical fibers into the detector. Only one outlet is open at a time.

Requirements:

- Stable intensity ratio between outlets
- No channel-channel-communication

Specifications:

- Performance stability ≤ 0.01 dB

The Fiber Termination

Here, the laser couples out of the fiber being collimated by a **GRIN lens**. The beam direction is adjustable by a **piezo-electric device** – the **Fiber Termination Holder** (FTH).

Fiber Termination Holder:

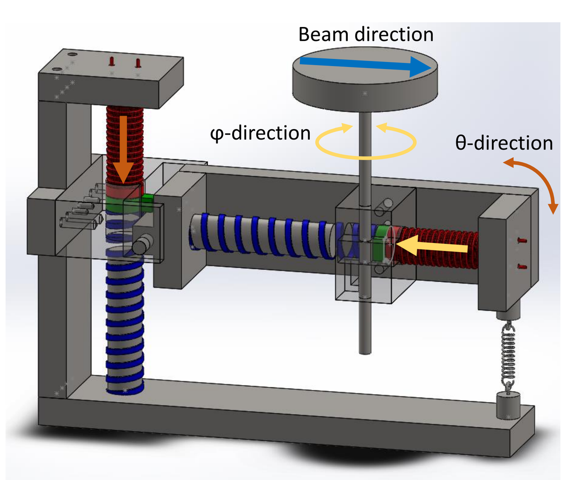
- Beam tiltable in φ- and θ-direction
- Ensures that no PMT is hit directly
- Beam is tunable even after filling

FTH – working principle:

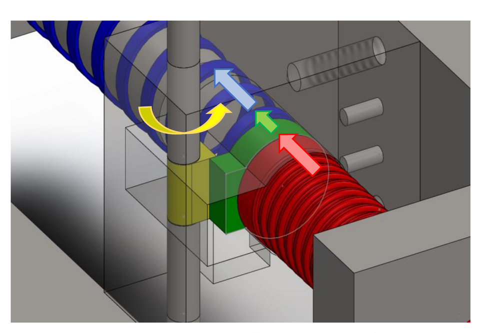
- **Piezo crystal** (red) expands
- **lever plate** (green) is pushed against extension of rotation axis (yellow)
- Expansion of 48 µm
  - Rotation of 1°

GRIN lens for collimation:

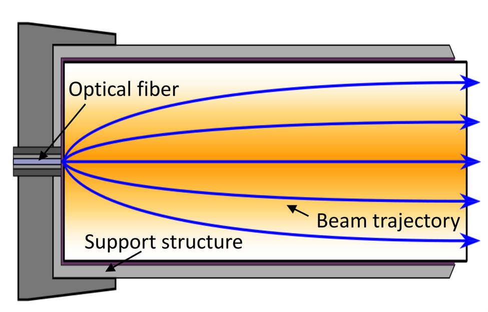
- Mounted on fiber termination
- Gradient in the refractive index
  - decreasing from inside to the outside
- Collimation inside the lens
  - ensures collimation even under water



Fiber Termination Holder



FTH – working principle



GRIN lens– working principle