A comprehensive optical characterization of the JUNO liquid scintillator

XXXI International Conference on Neutrino Physics and Astrophysics

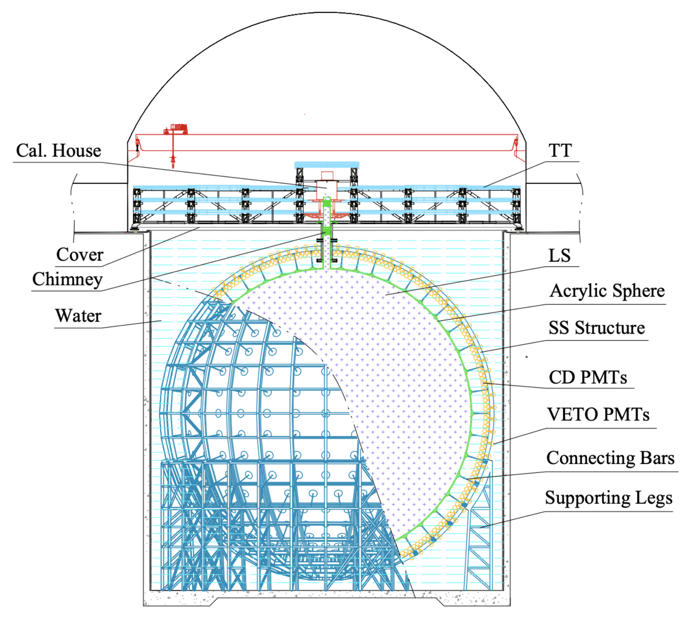
Marco Beretta[1] and Haosen Zhang[2] on behalf of the JUNO collaboration
[1]University of Milan - INFN Sezione di Milano, ***marco.beretta@mi.infn.it***
[2]Institue of High Energy Physics, China

Introduction

JUNO is a huge liquid scintillator detector under construction in China, which will be devoted to neutrino physics. During the preparatory phase of the experiment, an extensive campaign of measurement was performed by the Milano, Perugia (Italy) and IHEP (China) groups to characterize the optical properties of the liquid scintillator in small scale experiments. **This is a fundamental step for the success of JUNO**. In this poster **the most important results are summarized: absorption and emission spectra, refractive index, fluorescence time profile, Cherenkov contribution**.

JUNO detector

The **J**iangmen **U**nderground **N**eutrino **O**bosevatory (JUNO) is a multi-purpose neutrino detector under construction in China, with the main goal of determining the **Neutrino Mass Ordering** (NMO). The detection medium will be **20 000 tons** of **organic liquid scintillator** contained in an acrylic sphere of 17.7 m of radius. The light produced by the liquid scintillator will be seen by 17612 20-inch PMTs[a] and 25600 3-inch PMTs reaching 78 % **of optical coverage**. This will allow JUNO to determine the **NMO in six years** of data-taking **at 3 σ level** [1].



[a]Photo-Multiplier Tubes

Impact on the JUNO physics goal

The capability to accurately reconstruct energy and position on an event-by-event basis will play a pivotal role for the success of JUNO. **The stringent requirements on position and energy reconstruction** ($\sigma_r \sim 7$ cm and $\sigma_E/E \sim 3\,\%$ @ 1 MeV respectively) **could be met only if the optical properties of the liquid scintillator will be known very precisely**.

In particular, **the fluorescence time profile is crucial for position reconstruction** and **particle identification** via pulse-shape discrimination.

On the other hand **refractive index, transparency (absorbance),** and **Cherenkov contribution** are important to determine **the energy response**.

References

[1] Juno physics and detector. *Progress in Particle and Nuclear Physics*, 123:103927, 2022.

[2] M. Beretta H. S. Zhang and et al. Refractive index in the juno liquid scintillator, 2024.

[3] Federico Ferraro and Marco Beretta. Improved measurements of timing and optical properties of the JUNO liquid scintillator with SHELDON. *PoS*, 2022.

Acknowledgements

We would like to thanks the JUNO collaboration for this opportunity and all our institution for founding this research:

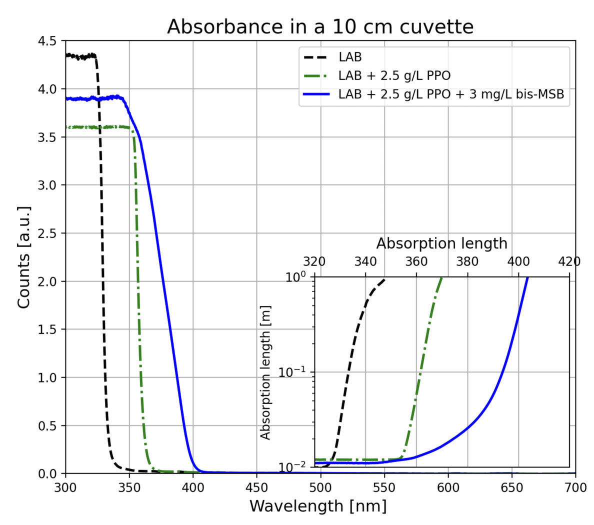
Absorption and emission of the fluorescence light

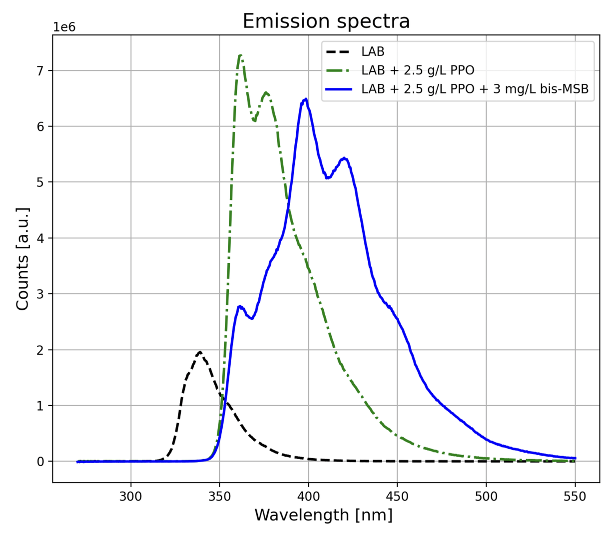
The JUNO liquid scintillator is a mixture of different organics compounds in different concentrations:

- **Linear Alkyl Benzene (LAB)**, solvent, 20 000 ton;
- **2,5-Diphenyloxazole (PPO)**, primary flour, 2.5 g/L;
- **1,4-bis-(o-methylstyryl)-benzene (bis-MSB)**, wavelength shifter, 3 mg/L.

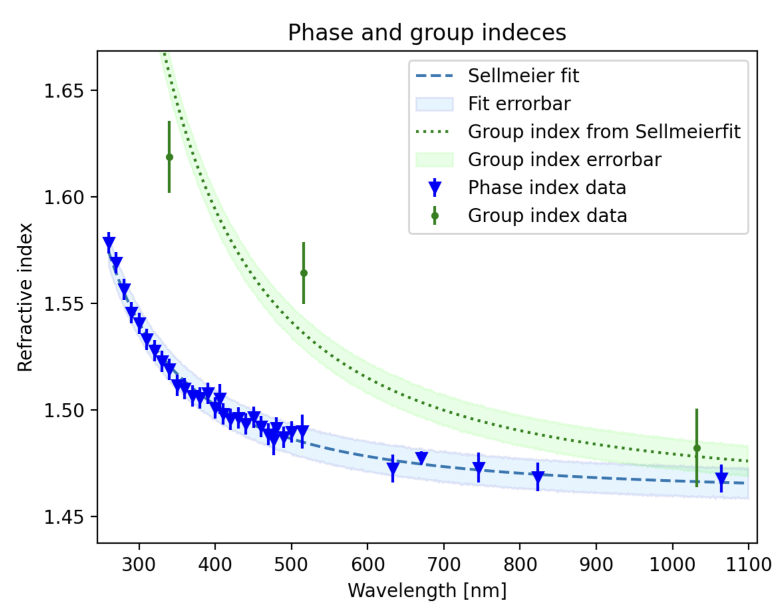
The recipe of the scintillator was **developed to maximize the coupling of the emission with the quantum efficiency of the photomultiplier tubes** and to reduce the self absorption of the fluorescence light in order to increase the collected light as much as possible.

The top right plot, show the absorbance measured by the Milano and Perugia groups: it is possible to see how absorbace changes adding the different components in the right concentrations. In the bottom plot the measured emission spectrum of the JUNO mixture is shown. The effect of the bis-MSB is to absorb the light emitted by the PPO and shift it to 400 nm, which is the spectral position where the PMTs have the maximum quantum efficiency.





Refractive index of the JUNO liquid scintillator



Knowing the exact refractive index of the JUNO liquid scintillator is crucial for both **energy and the position reconstruction**.

These measurements were made both in Milan and in Beijing using both the **refractometric and ellipsometric** techniques respectively. The measurements were performed in two different wavelenght regions and then combined to obtain an accuracy of 0.5% on the refractive (phase) index [2].

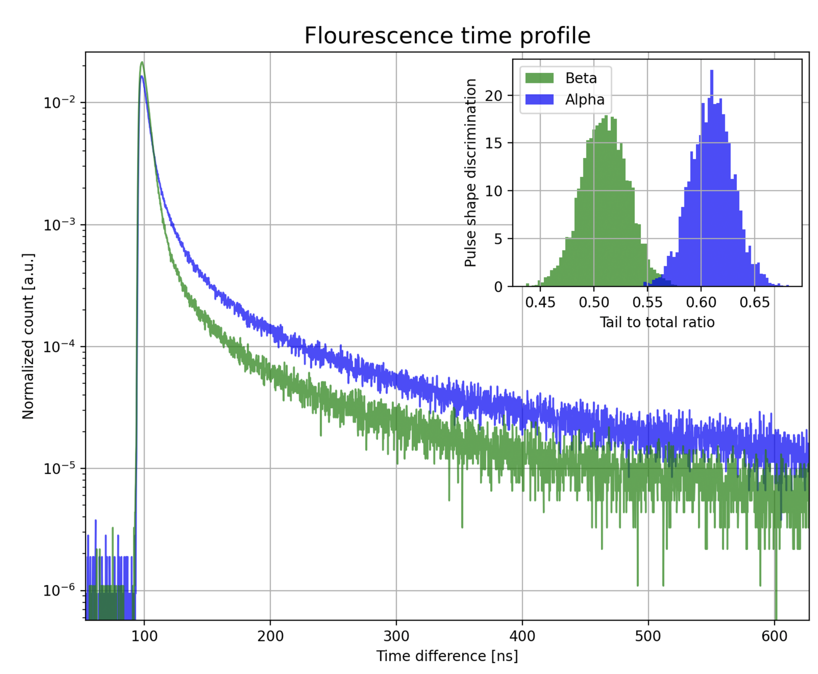
In Milan, we also used an interferometer to direct measure the group velocity in order to cross-check the group velocity curve derived from the refractive index measurements (green points).

Time profile measurements

The fluorescence time profiles of an organic liquid scintillator are fundamental for position and time reconstruction, as well as for particle identification..

In the figure we show the accurate measurement of the fluorescence time profile both for β (^{60}**Co**) and α (^{244}**Cm**) radiation performed in a small scale setup in Milano. The measurement is performed using the **Time Correlated Single Photo-Counting technique** with two PMTs and a optical glass cuvette of 3 cm. These measurements performed in Milan allow to determine the **fluorescence parameter with an accuracy grater then** 1% [3].

In the top right part of the plot the capability of the particle identification of the JUNO LS is shown based on the tail to total ratio method assuming the JUNO DAQ integration window.



Cherenkov spectrum measurements

The Cherenkov light has a significant impact on the energy reconstruction in JUNO due to its absorption in the UV region, and re-emission as fluorescence.

In Milan, using the same experimental setup of the fluorescence time profile and performing a spectral separation, we are able **to directly measure the Cherenkov to scintillation ratio** thanks to the different emission time of the two radiations.

A measurement for the JUNO liquid scintillator in a selected wavelength region is shown. The **Cherenkov light is visible as a Gaussian peak** in the first part of the time profile, since it is emitted instantaneously, while **scintillation light is emitted following the time profile** shown above.