The Filling System Slow Control for the JUNO Experiment

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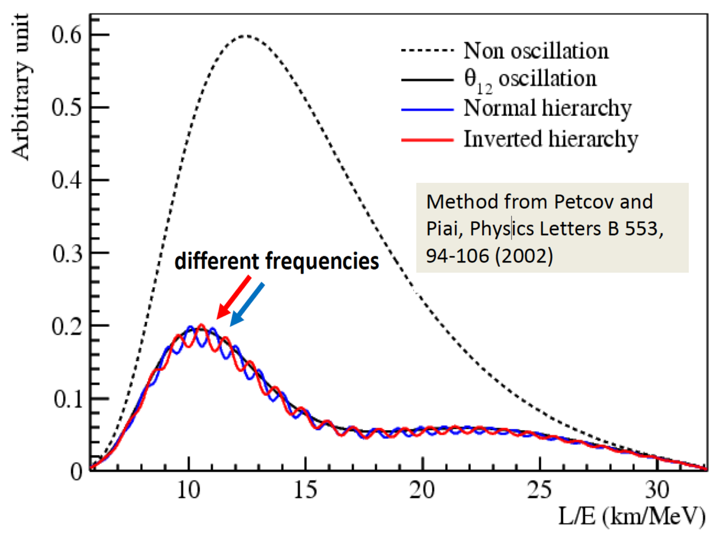
The JUNO Experiment in a Nutshell & Motivation

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?

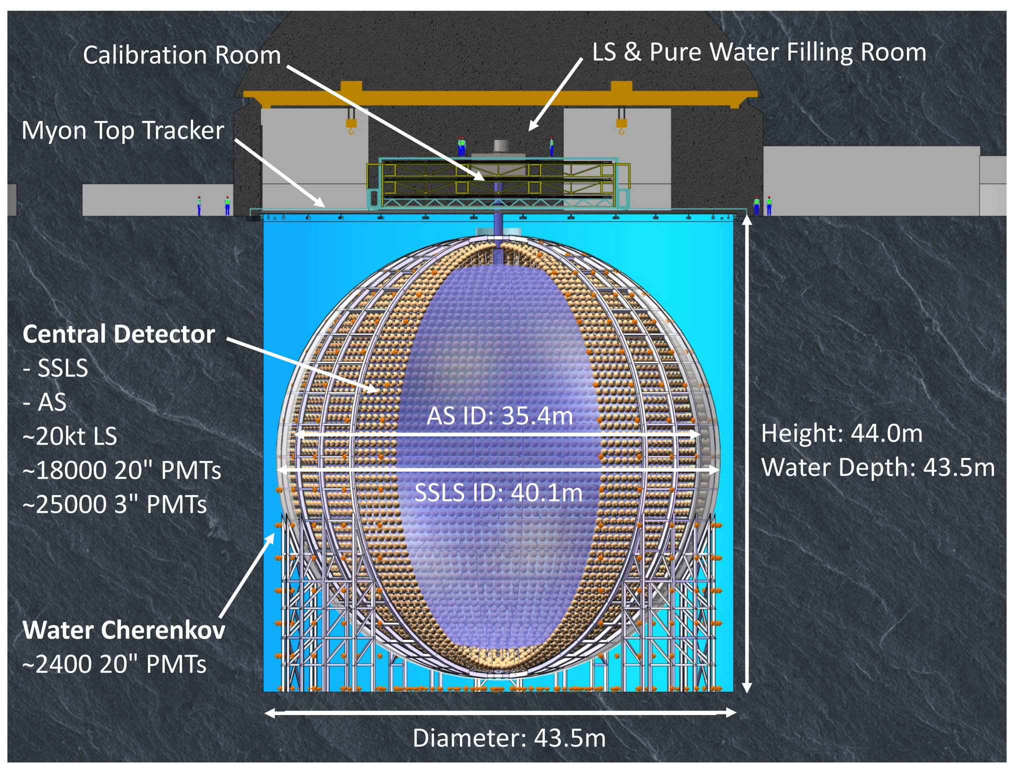
- **JUNO uses interference effects of Δm^2_{31} and Δm^2_{32} in oscillation probabilities**



The measurable $\bar{\nu}$ flux for IH and NH is different due to differences in the corresponding oscillation probability. From the spatial distortion (max. ≈ 53 km) the information on the hierarchy can be gained.

- **Baseline is set to 53km for the JUNO Experiment**

Design of the JUNO Detector



Schematic view of the JUNO (Jiangmen Underground Neutrino Observatory) detector. The water cherenkov Veto has a diameter of 43.5 m and is instrumented with 2400 PMTs (20"). The central detector contains of a Stainless Steel Latticed Shell (SSLS) with an inner diameter (ID) of 40.1m, wherein an acrylic sphere of 35.4 m (ID) stores the liquid scintillator (LS). The photomultipliers (PMTs) high lighted in orange realizing a target coverage of ≈ 77%. In addition, the myon top tracker, the calibration room, the LS and pure water filling room are illustrated as well.

The Detection Principle

- **Measuring the disappearance of reactor electron antineutrinos**
- **Antineutrino detection via the inverse beta decay (IBD):**

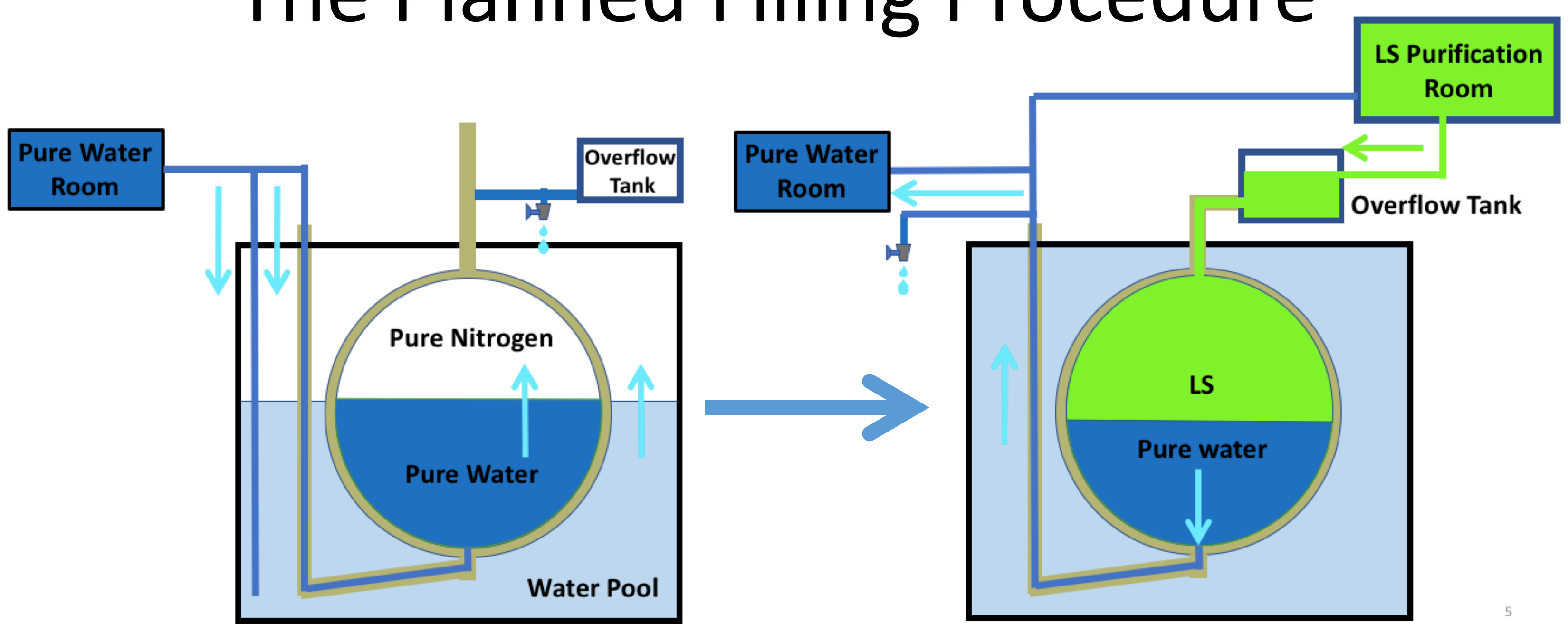
$$\overline{\nu_e} + p \rightarrow n + e^+$$

- **The coincidence of the prompt positron and the delayed neutron signal (τ≈200µs) allows efficient background reduction.**
- **Positron carries the energy of the neutrino: $E_{e^+} = E_{\bar{\nu}}$ - 0.78MeV**
- **Neutron is captured by proton emitting a photon: E_γ = 2.2MeV**

Requirements to resolve the MH?

- **High statistics of IBD events (100k in 6 years data taking)**
- **An energy resolution of at least $3\%/\sqrt{E(MeV)}$ is needed to resolve differences between NH and IH**
- **Energy resolution depends mainly on the light yield (1200 p.e. per MeV energy deposit) and transparency of the liquid scintillator (attenuation length > 20 m at 430 nm wavelength) as well as on the coverage (≈ 77%) of the target by PMTs with sufficient performance.**
- **Radiopurity for the MH Measurement:**
  C(^{238}U) < 10^{-15} g/g , C(^{232}Th) < 10^{-15} g/g C(^{40}K) < 10^{-16} g/g
- **Radiopurity for Solar Neutrino Spectroscopy:**
  C(^{238}U) < 10^{-17} g/g , C(^{232}Th) < 10^{-17} g/g C(^{40}K) < 10^{-18} g/g

The Planned Filling Procedure



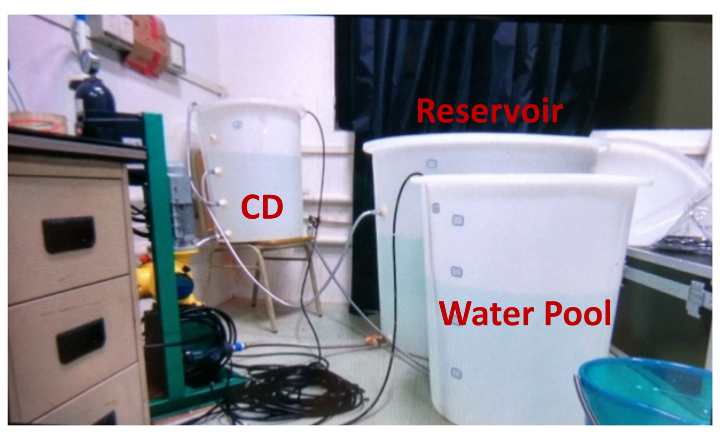
Nitrogen / Pure Water Exchange

- **The CD will be filled with ultrapure nitrogen or artificial air to reduce the radon content before the liquid filling**
- **The water pool and the CD will be filled with approx. 6 m³/h with pure water**
- **The liquid levels in the CD and the pool have to be controlled with a precision of approx. ± 20 cm to avoid fatal damage on the acrylic structure.**

Pure Water / Liquid Scintillator Exchange

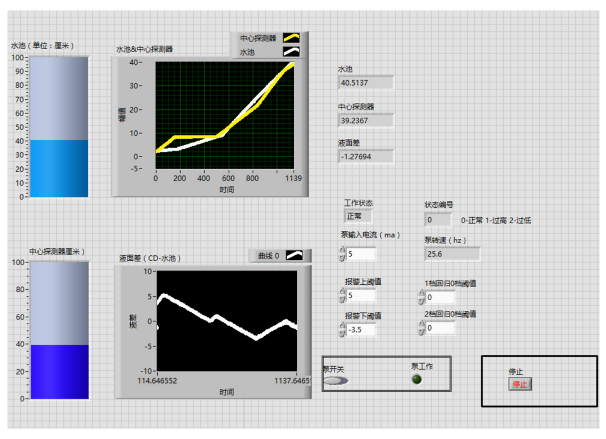
- **The water in the CD is replaced from above by LS**
- **The temperatures in the water pool and the CD have to be stabilized since, 1 °C of temperature change in the CD completely filled with LS will lead to 23 m³ of volume change!**
- **Due to the different densities of water and LS, the increasing buoyance of the CD in the pool has to be controlled.**

Filling Test Setup at the Sun Yat-Sen University (SYSU, PR China)



The test setup for the filling procedure of JUNO. CD, reservoir and water pool are represented by plastic vessels equipped with hydrostatic pressure sensors.

The electric pump used for circulating the water from vessel to vessel.



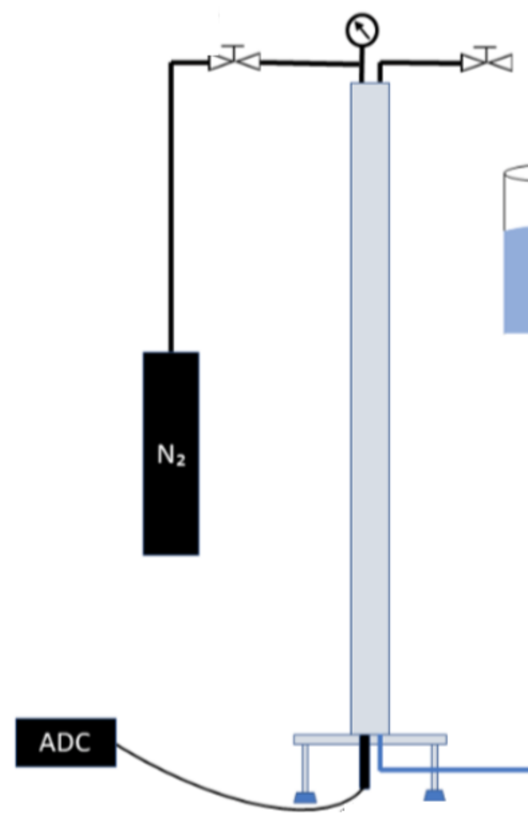
Graphic user interface of the LAB View based pump controlling software developed at SYSU. The liquid levels and sensor values are visualized.

- **The CD, liquid reservoir and water pool are represented by plastic vessels.**
- **Water serves as a liquid for pump tests.**
- **All vessels are equipped with hydrostatic pressure sensors from SISEN Automation (precision ± 10 mbar).**
- **The sensors are read out via a National Instruments solution.**
- **For data processing and pump controlling a dedicated LabView based software was programmed at SYSU.**
- **The electric pump, allows water pumping with sufficient precision and variable speed (< 50 l / min) for the laboratory setup.**

Development of Sensors and Monitoring Systems for the Filling of JUNO at TUM

Hydrostatic Pressure Sensors Test Facility

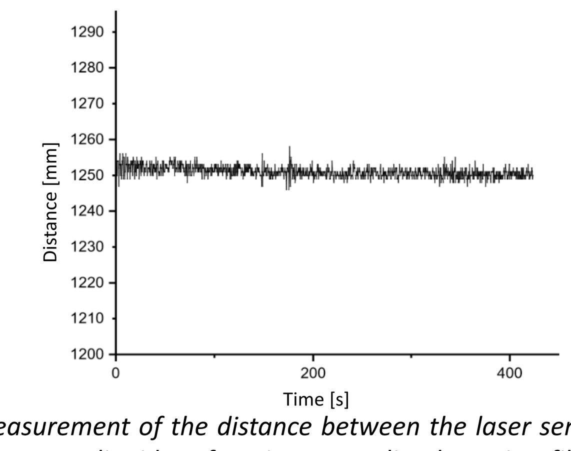
- **Different hydrostatic pressure sensors are tested with respect to precision, time stability, material compatibility with ultra pure water and LS as well as there radioactivity is measured in a low background gamma screening facility**
- **A dedicated testing pipe can be continuously filled with liquids by the principle of communicating vessels via a movable tank.**
- **By pressurized nitrogen higher liquid levels in the pipe can be simulated. Sensors can be tested up to 40 m water depth.**
- **An ADC connected to a micro computer (Raspberry Pi 3B) digitizes the industrial standard 4 mA – 20 mA sensor signal which is converted to a voltage signal beforehand.**
- **Sensors with different range and precision provided by SISEN Automation have been tested so far and a precision of ± 5 cm and linearity over the sensor range were demonstrated.**



IR Laser Level Measurement System

- **For the precision measurement of liquid levels an IR Laser Sensor System is developed at TUM.**
- **The sensor uses a 905 nm laser diode.**
- **The amplitude is modulated with high frequencies.**
- **This frequency is also modulated to allow absolute distance measurements.**
- **By the usage of diffusor lenses the influence of vibrations on the liquid's surface could be eliminated.**
- **The laser system is controlled via a custom made software solution with GUI, which allows also data storage and live plotting of the sensor output.**
- **The laser system demonstrated fill height measurements of water and LS in acrylic glass vessels with a precision of ± 4 mm.**

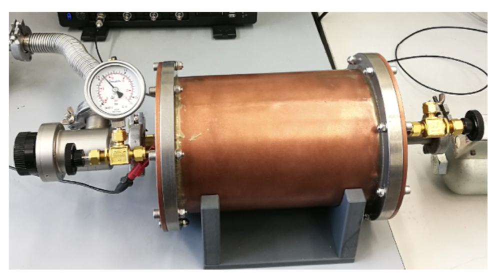
IR Laser Sensor TruSense S310 provided by Laser Technology Inc. for the measurement of distances with millimeter precision on ranges of a few hundred meters.



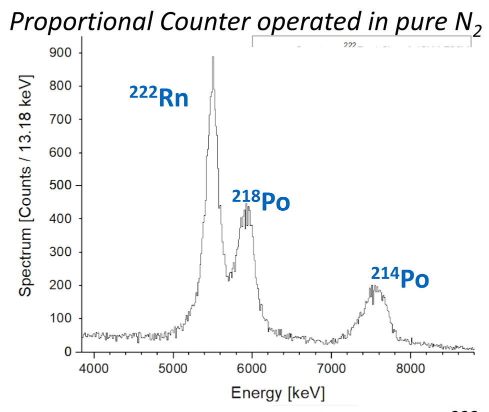
Measurement of the distance between the laser sensor and the upper liquid surface in an acrylic glass pipe filled with water.

Monitoring of the Radon Content in Nitrogen Gas

- **A proportional counter (225mm length, 155 mm diameter) for the operation in pure nitrogen gas was designed.**
- **Due to the small counting wire diameter (20 µm) sufficient gas amplification in nitrogen can be achieved.**
- **Since also the α-decays of the ^{222}Rn daughters are detected, a total Rn detection efficiency above 200% can be realized.**
- **The detector demonstrated a resolution below 300 keV at 5.5 MeV in calibration measurements.**
- **Currently sensitivities of 50 mBq / m³ within 7.5 h of measuring time are demonstrated.**
- **In a future upgrade the detector is aiming for a sensitivity in the order of 1 mBq / m³.**



Proportional Counter operated in pure N_2



Measured α-spectrum of a gaseous ^{222}Rn source with the proportional counter