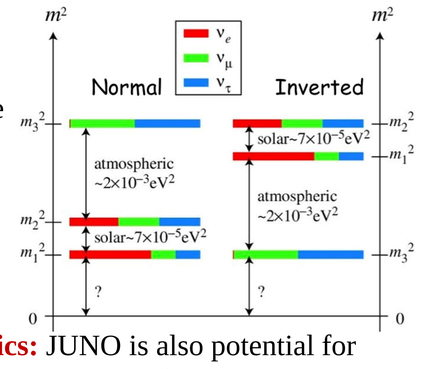
JUNO Central Detector and its Calibration System

Qingmin Zhang (On behalf of JUNO Collaboration)

Department of Nuclear Science and Technology, School of Energy and Power Engineering,
Xi'an Jiaotong University, Xi'an 710049, China

1. JUNO Introduction

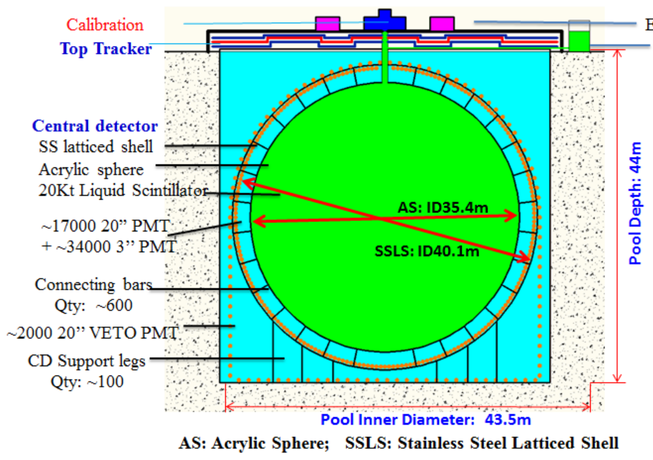
The Jiangmen Underground Neutrino Observatory (JUNO) , which will be constructed at Kaiping, Jiangmen in South China, is designed to primarily determine the neutrino **Mass Hierarchy** by detecting reactor anti-neutrinos via inversed beta decay.



Rich Physics: JUNO is also potential for precisely measurement of oscillation parameters, search of dark matter, nucleon decay, Supernova, Solar, Geo- and Sterile neutrinos ……

2. JUNO Central Detector

JUNO Central Detector, the main part of JUNO, is a 20 kton multi-purpose underground liquid scintillator (LS) detector, which has best resolution $3\%/\sqrt{E}$.



Main Requirements for JUNO central detector

- ✓ 20 kt high purity LS with high light yield and long attenuation length
- ✓ 17000 20" PMTs wih high Q.E.+ 34000 3" PMTs
- ✓ High light yield: >= 1200 p.e. /MeV
- ✓ Background: minimization
- ✓ Structure: reliable no leakage
- ✓ Material: Long-term Compatibility with LS and pure water
- ✓ Long lifetime: >= 20 years

2.1 Liquid Scintillator

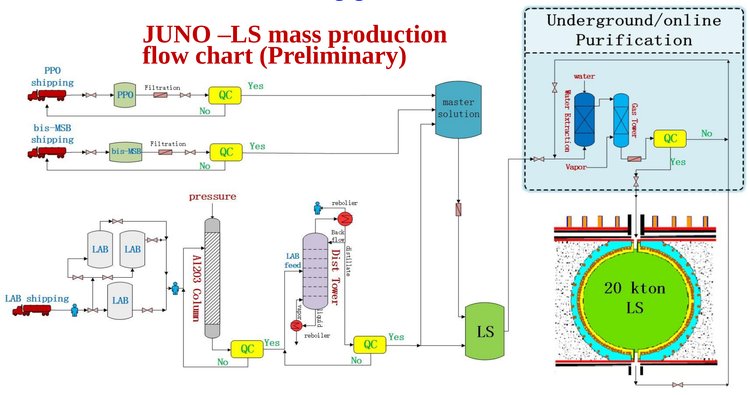
Requirements for LS:

- ✓ **Long Attenuation Length:** >20m@430nm
- ✓ **Low background:** $^{238}U < 10^{-15}$g/g
  $^{232}Th < 10^{-15}$g/g
  $^{40}K < 10^{-17}$g/g

LS Recipe (based on Dayabay)

- ✓ Solvent: Linear Alkyl Benzene
- ✓ 3g/L PPO (purity>=99.5%)
- ✓ 15mg/L bis-MSB

JUNO –LS mass production flow chart (Preliminary)



Purification for 20 kton LS

- ✓ LS A.L. is increased by Al_2O_3 column
- ✓ Distillation, water extraction and steam stripping will be used to reduce the radiation background.

2.2 PMTs

20" PMTs with High QE

- ✓ **15k NNVT MCP-PMT:** newly developed by North Night Vision Technology (NNVT), use for central detector and veto detector.
- ✓ **5k Hamamatsu R12860:** use for central detector

NNVT MCP-PMT

Hamamatsu R12860

Mixture of 20" and 3" PMTs

Characteristics	MCP-PMT (NNVT)	R12860 (Hamamatsu)
Detection Eff. (QE×CE*area) (%)	27%, >24%	27%, >24%
P/V of SPE	3.5, >2.8	3,>2.5
TTS on the top point (ns)	~12,<15	2.7,<3.5
Rise time/Fall time(ns)	R~5; F~12	R~5,<7; F~9,<12
Anode Dark count(Hz)	20k,<30k	10k,<50k
After Pulse Percentage(%)	1,<2	10,<15
Glass Radioactivity(ppb)	^{238}U:50 ^{232}Th:50 ^{40}K:20	^{238}U:400 ^{232}Th:400 ^{40}K:40

34,000 3" PMTs: an vital "aider" to 20" PMTs

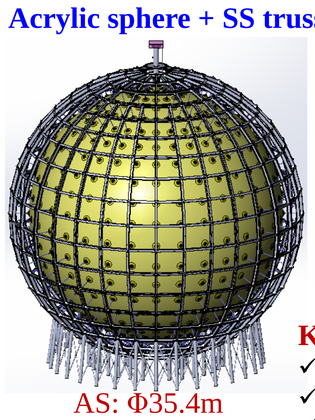
- ✓ **Can serve as a standalone calorimetry because of no saturation and better linearity in JUNO situation**

Challenges

- ✓ Water-proof potting
- ✓ PMT protection to avoid chained explosion
- ✓ Reliability of Integrated PMT: 20~30years under 40-meter-deep water
- ✓ Geomagnetism shielding

2.3 Structure

Acrylic sphere + SS truss



AS: Φ35.4m
SSLS: Φ 40.1m

Key features

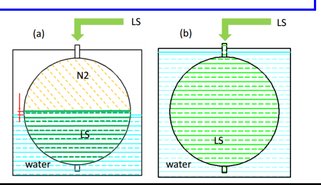
- ✓ Thickness of Acrylic: 120mm
- ✓ Acrylic panels(21/23 layers + top chimney+ bottom flange): ~260 pieces
- ✓ Connecting node: ~590
- ✓ Total Weight: 600 tons of acrylic and 600 tons of steel

- **Temperature control:** 1°C → 20m³ LS volume change
- **Seismic load:** still need more test to understand the liquid case.

FEA shows maximum stress of acrylic **< 3.5Mpa** (as required) when tensile load < 8.2 ton.

Key features of filling and overflow system:

- ✓ Automatically
- ✓ Monitor: liquid level, flow and acrylic stress
- ✓ Nitrogen sealing



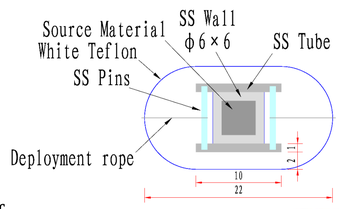
3. Calibration Systems

Goals

Overall energy resolution: $3\%/\sqrt{E}$
Energy nonlinearity: < 1%

Radioactive sources

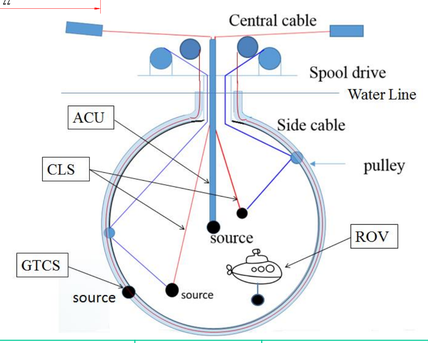
γ: ^{40}K, ^{54}Mn, ^{60}Co, ^{137}Cs
e^+: ^{22}Na, ^{68}Ge
n: ^{241}Am-Be, ^{241}Am- ^{13}C or ^{241}Pu- ^{13}C, ^{252}Cf

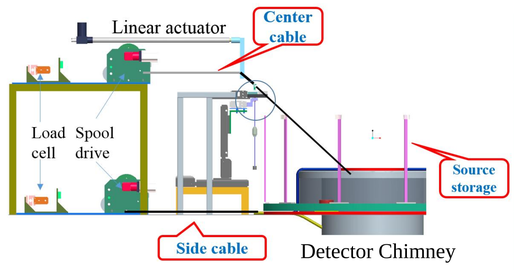


Radioactive source design
Based on MC simulation, energy bias is less than 0.2% .

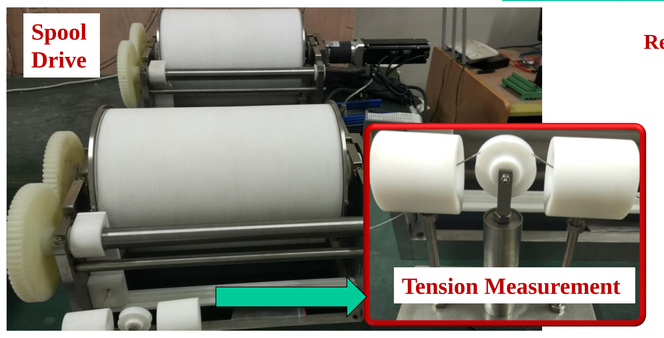
Position Control

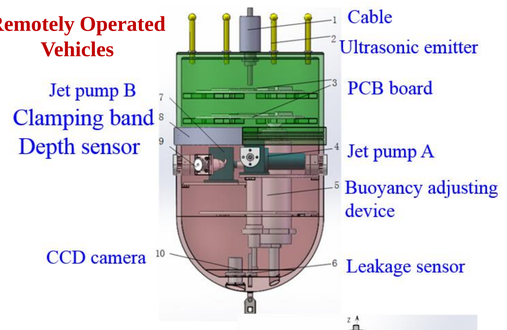
1-D: Automatic Calibration Unit (**ACU**) for central axis scan
2-D: Cable Loop System (**CLS**) for one vertical plane scan + Guide Tube Calibration System(**GTCS**) for CD outer surface
(ACU CLS and ROV can not reach CD boundary)
3-D: Remotely Operated under-liquid-scintillator Vehicles (**ROV**) for whole CD scan





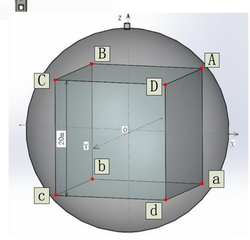
System	Position Control	Source change	Others
ACU	Spool drive (steel wire coated with Teflon Φ1.0) +Tension Control	Manual	All critical, have to be combined
CLS		Automatic	
GTCS		Manual	
ROV	Remotely Operated Vehicle	Manual	Insurance





Positioning

Method	System
Rope Length Calculation	CLS, ACU and GTCS
Ultrasonic receiver	ROV, CLS
CCD(Independent)	ROV, CLS



Ultrasonic Receiver Array for ROV and CLS

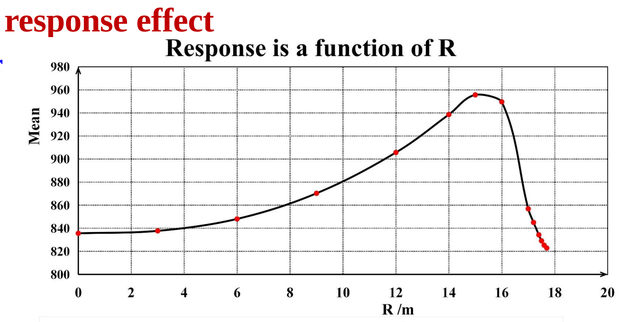
4. Preliminary Simulation

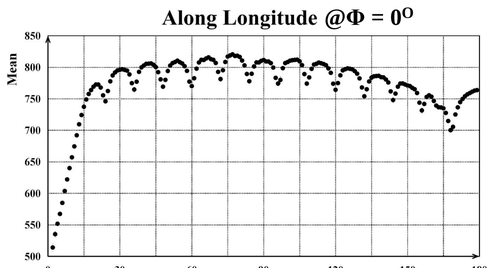
Investigation of position-dependent response effect

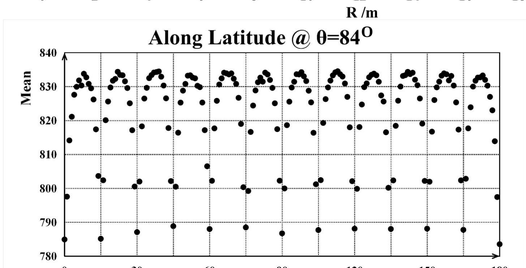
- ✓ **Peak of full absorption spectrum is used for measurement.**
- ✓ **Spectrum fitted with Gaussian + Compton tail**

Boundary Effect Sources

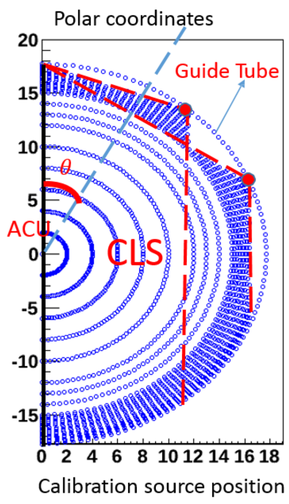
- ✓ **Chimney**
- ✓ **Fasteners**
- ✓ **PMT Distribution**



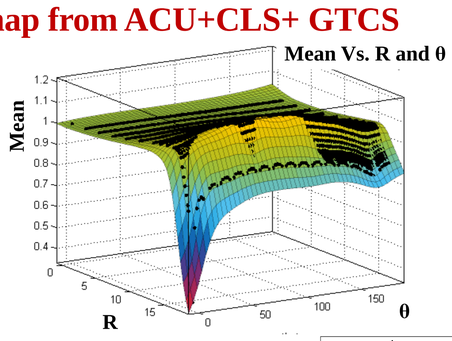


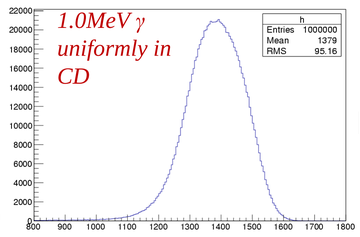


Preliminary correction using non-uniformity map from ACU+CLS+ GTCS

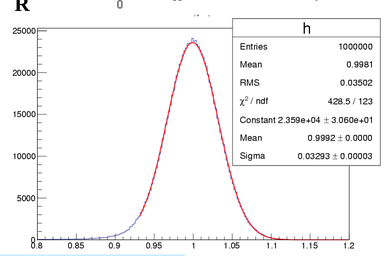


Ratio of (R,θ) to center is a function of R and θ **f(R,θ)**, which is obtained by calibration data and then used for correction





Corrected
With f(R,θ)



Preliminary Results

- ➢ **Peak Bias is 0.08%**
- ➢ **Energy resolution is 3.29%@1.0MeV (γ)**

Further improvements and more work are needed and undergoing.

ICHEP2016CHICAGO

38th International Conference on High Energy Physics, Aug. 3-10, 2016, Chicago, USA