Background suppression in the JUNO experiment

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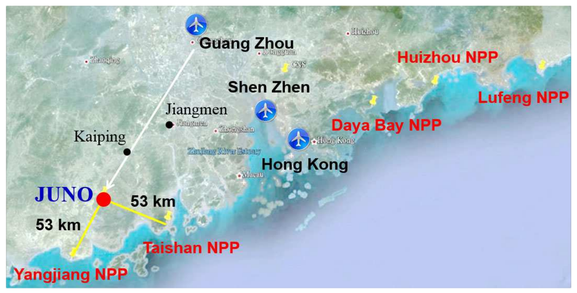
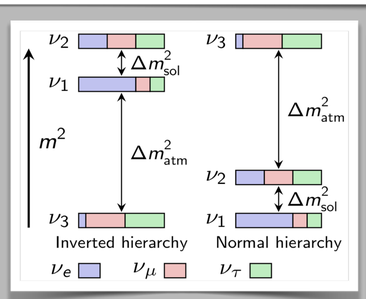
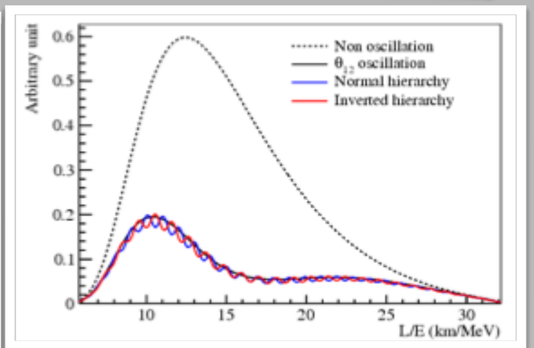
JUNO (**J**iangmen **U**nderground **N**eutrino **O**bservatory) is a multi-purpose neutrino experiment designed to measure very precisely energies of electron neutrinos and antineutrinos. The measurements of electron antineutrinos from the Yangjiang and Taishan Nuclear Power Plants in the south of China will allow revealing the neutrino mass hierarchies, to improve the knowledge of neutrino oscillation parameters and to probe unitarity of the PMNS lepton mixing matrix.



The JUNO detector consists of a spherical acrylic vessel of 35.4 m diameter filled with 20 kt of the target liquid scintillator (Central Detector) placed in a cylindrical volume with ultra-pure water. In total ~17000 large PMTs of 20" diameter cover ~75% of the container surface to achieve the needed energy resolution of 3% at 1 MeV. System of ~34000 small PMTs of 3" diameter improves parameters of the Central Detector e.g. dynamic range, time resolution and linearity. The Central Detector is surrounded by a Water Čerenkov Muon Detector equipped with ~2000 20" PMTs. From the top the detector setup will be covered by a Top Tracker made of plastic scintillators.



Normal and inverted neutrino hierarchies generate different survival antineutrino spectra – see the figure. To recognize the hierarchy type at 3-4 sigma significance the survival spectrum of the antineutrino has to be measured not only with ultimate energy resolution and high statistics, but with as low as possible background as well. In case of JUNO, the major sources of the background will be suppressed and controlled by dedicated veto system down to the level of ~6%.



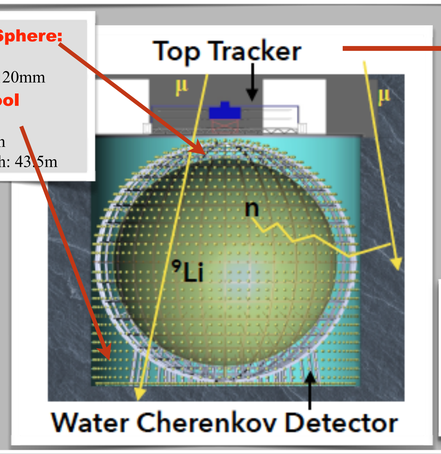
The JUNO experiment will be equipped with two **veto detectors** for cosmic muon detection and background reduction: **Water Cherenkov** and **Top Tracker** detectors

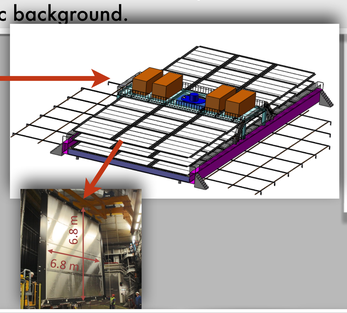
- Cosmogenic isotopes (^{9}Li/^{8}He) are produced in nuclear spallation process when cosmic muons go through the Central Detector. Their decay produces signals indistinguishable of the antineutrino signals (IBD) requires a precise muon track reconstruction (Top Tracker+ Water Cherenkov+CD)
- Fast neutrons background rejection → passive shielding and possible tagging (Water Cherenkov + Top Tracker)
- Radioactivity from rock → passive shielding by water (Water Cherenkov)

Top Tracker Detector (TT):

The detector re-uses Target Tracker plastic scintillator walls of the OPERA experiment. The 62 TT walls (~50m^2 each) will cover half of the top area. The TT will be organized in 3 layers separated by 1 m, each layer has x,y readout with about 10 mm spatial resolution. The TT performs a precise muon tracking (about 20 cm at the bottom part of the CD) and provides valuable information on cosmic muon induced ^{9}Li/^{8}He background, most dangerous for the goals of JUNO. TT will allow measuring of distribution of the ^{9}Li/^{8}He events in space and in time with respect to the muons and therefore will provide a better accuracy on the measurement of residual cosmogenic background.

Acrylic Sphere:
ID: 35.4m
Thickness:120mm
Water pool
ID: 43.5m
Height: 44m
Water Depth: 43.5m

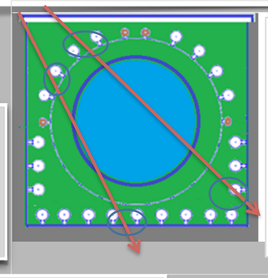


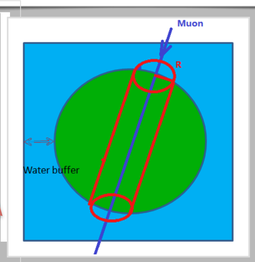


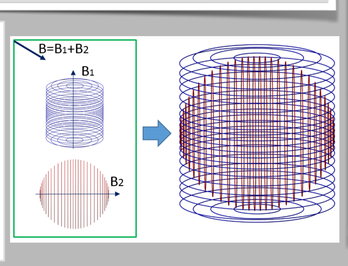
The muon rate in the CD is 3-4 Hz. Measurement of muon track with TT and Water Cherenkov detectors will allow to apply a volume veto on the IBD-like events around the muons (3 m) and for 1 s, thus essentially decreasing associated dead time.

Water Cherenkov detector:

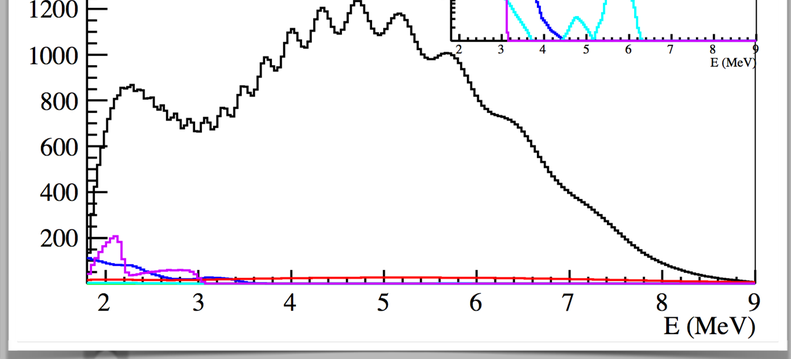
The JUNO CD is placed in a volume («water pool») filled with 20-30 kton of ultra pure water which protect CD against the radioactivity and fast neutrons from muon interactions in surrounding rock.
About 2000 of 20 inch MCP-PMT placed on the sphere and the wall of the water pool provide registration of the Cherenkov light of cosmic muons, thus reducing cosmogenic background related to them. Circulation water system (~2 week one volume circulation) to keep a good water quality including radon control (<0.2 Bq/m^3)
Tyvek reflecting film coats the surface to increase light collection efficiency.
Compensation coils system used for earth magnet field shielding to keep PMT performance.
Detector muon efficiency is expect to be > 98%
Fast neutron background ~0.1/day
Water buffer is 3.2m from rock to central detector decreases radioactive background from rock to 7.4 Hz







Antineutrino survival spectrum and contribution of most important backgrounds regarding their expected levels in JUNO



All the materials and parts of the detector are a subject of radioactive isotopes contamination control.

Material	Mass	Upper limit					Singles(Hz)	
		^{238}U	^{232}Th	^{40}K	^{222}Rn (^{210}Pb)	^{60}Co	All volume	Fiducial volume
LS	20kt	10^{-6}ppb	10^{-6}ppb	10^{-7}ppb	1.4×10^{-13}ppb		2.39	2.2
Acrylic	561t	1ppt	1ppt	1ppt			6.92	0.36
Oxygen-free copper	10t	0.099ppb	0.1ppb	0.14ppt		1.8mBq/kg	2.44	0.2
Dust							1	0.1
ılley and Ultrasonic receiver Array							1	0.1
SS tank	350t	0.097ppb	1.97ppb	0.05ppb		2.0mBq/kg	0.89	0.087
PMT glass	156t	400ppb	400ppb	40ppb			17.93	2.42
		50ppb	50ppb	20ppb				
PMT potting sealant	6.6t	12ppb	26ppb	25ppb			1	0.1
PMT protection cover	177.5t	10ppt	10ppt	10ppt				0.01
PMT potting shell	177.5t	10ppt	10ppt	10ppt				
Cable								0.01
CUU								
Radon in water	35kt				0.2Bq/m^3		16	1.3
Rock		10ppm	30ppm	5ppm			7.4	0.984
						Sum	57.0	7.9

Cut selection of the antineutrino events and background suppression. Efficiencies and event statistics per day. The most important background of ^{9}Li/^{8}He isotopes is well suppressed by the Veto System.

Selection	IBD efficiency	IBD	Geo-νs	Accidental	^{9}Li/^{8}He	Fast n	(α, n)
-	-	83	1.5	$\sim 5.7 \times 10^4$	84	-	-
Fiducial volume	91.8%	76	1.4	410	77	0.1	0.05
Energy cut	97.8%	73	1.3		71		
Time cut	99.1%						
Vertex cut	98.7%			1.1			
Muon veto	83%	60	1.1	0.9	1.6		
Combined	73%	60	3.8				