The JUNO experiment and its electronics readout system

PLAN:

- Introduction
- The JUNO detector
- The JUNO electronics readout

Barbara Clerbaux
IIHE, Université libre de Bruxelles (ULB)
For the JUNO Collaboration
What is JUNO?

**JUNO = Jiangmen Underground Neutrino Observatory**

- JUNO is a “medium-baseline” (53km) reactor neutrino experiment located in China, under construction (data taking foreseen in 2021)
- JUNO will be the largest Liquid Scintillator detector ever built (20kt)
- Goals: Measurement of the neutrino mass hierarchy (NMH) and oscillation parameters + astroparticle and rare processes
Neutrino Mass Hierarchy

• Neutrinos are observed via Inverse Beta Decay (IBD):
  \[ \bar{\nu}_e + p \rightarrow e^+ + n \]
  \[ \tau \approx 200\mu s \]
  \[ n + p \rightarrow d + \gamma \]

→ Very clean signature
E range : 2 to 8 MeV

• Neutrino energy spectrum:
The Pee survival probability in vacuum:

\[ P_{ee}(L/E) = 1 - P_{21} - P_{31} - P_{32} \]
\[ P_{21} = \cos^4(\theta_{13}) \sin^2(2\theta_{12}) \sin^2(\Delta_{21}) \]
\[ P_{31} = \cos^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{31}) \]
\[ P_{32} = \sin^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{32}) \]
\[ \Delta_{ij} = 1.27 \Delta m^2_{ij} L/E \]

\[ \Delta m^2_{31} = \Delta m^2_{32} + \Delta m^2_{21} \]

NH : \[ |\Delta m^2_{31}| = |\Delta m^2_{32}| + |\Delta m^2_{21}| \quad \omega P_{31} > \omega P_{32} \]
IH : \[ |\Delta m^2_{31}| = |\Delta m^2_{32}| - |\Delta m^2_{21}| \quad \omega P_{31} < \omega P_{32} \]

Key issues:
• Energy resolution and scale
• Statistics
JUNO Collaboration and timescale

- 2013        Funding approved
- 2014        Collaboration officially formed
- 2014-20    Civil construction
- 2016-20    PMT production
- 2020-21    Detector assembly & installation
- 2021        Liquid scintillator filling
- 2021        Start of data taking

77 institutions, from 17 countries, more than 600 scientists

Surface Campus

Slope Tunnel: 1340 m

Vertical Tunnel: 611 m

Overburden: 720 m
## The JUNO detector

**Detector performance goals:**

<table>
<thead>
<tr>
<th></th>
<th>JUNO</th>
<th>KAMLAND</th>
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</thead>
<tbody>
<tr>
<td><strong>Energy Resolution</strong></td>
<td>6% @ 1MeV</td>
<td>3% @ 1MeV</td>
</tr>
<tr>
<td><strong>LS mass</strong></td>
<td>~1 kt</td>
<td>20 kt</td>
</tr>
<tr>
<td><strong>LS Attenuation/Diameter</strong></td>
<td>15m / 16m</td>
<td>&gt;20m / 35m</td>
</tr>
<tr>
<td><strong>Photocathode Coverage</strong></td>
<td>32%</td>
<td>75%</td>
</tr>
<tr>
<td><strong>QE x CE</strong></td>
<td>25% x 60%</td>
<td>40% x 60%</td>
</tr>
<tr>
<td><strong>Photon collection</strong></td>
<td>250 p.e./MeV</td>
<td>1200 p.e./MeV</td>
</tr>
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</table>

→ An unprecedented LS detector!
Detector main components

**Electronics**

**Central detector:**
- Acrylic sphere (35.4 m diameter)
- Filled with 20kt LAB LS
- 18000 20” PMTs and 25600 3” PMTs

**Calibration**
- 4-complementary Calibration systems

**Muon veto:**
- Top Tracker
- Water Cherenkov Veto
  - 20kt ultrapure water and 2000 20” PMTs

**Magnetic Field Compensating Coil**
Detector main components

- **Central detector**:
  Acrylic sphere and stainless steel truss
  Liquid Scintillator (LS) large volume → for the statistics

  **Double calorimetry**:
  → 18000 large PMTs (20") → 75%
  → 25600 small PMTs (3") → 2.5%
  High light coverage (78%)
  and double calorimetry system → for the energy resolution

- **Muon veto**:
  TT: use OPERA tracker layers
  Reject 50% of the muons
  Provide tagged muon sample to study muon reconstruction
  and bg contamination with the central detector

- **Calibration**:
  4-complementary systems: Automatic calibration unit (1D- central axis scan), Cable loop system and guide tube calibration system (2D), remote operated veicules (3D) – radiative sources (photon, positrons, neutrons)

CDR http://arxiv.org/abs/1508.07166
JUNO electronics specifications

What we need:
- Excellent energy resolution, especially at low energy (for NMH)
- Excellent photons arrival time measurement (for good vertexing)
- A large dynamic range (for atm-, geo-, and supernova neutrinos)
- A negligible deadtime (for supernova events lasting up to few seconds)

Specifications:
- Provide full waveform digitization with high speed (1 Gsample/s), high resolution (12 bits) ADC
- Measure photon pulses with high resolution (full dynamic range: 1-4000 pe)

Main concern:
Reliability of Under Water (UW) electronics (not accessible after installation)
→ goal: less than 1% PMT + underwater electronics failure over 6 years
   (calculation + laboratory reliability/aging tests + redundancy)
Readout of the 20” PMTs

Under Water Electronics

Dry Electronics

Signal + HV

High Voltage Unit

Global Control Unit

FPGA

LV

Back End Card

CLK

TRG

Gbit Enterprise Switch

DAQ

Up to 80m CAT5 + low impedance power cable

Sync link

Up to 80m CAT5

Async link
Global Control Unit (GCU)

ADU (Analog to Digital Unit)
PMT current signal is conditioned, duplicated in two streams and converted to voltage (low-gain and high-gain TIAs):
- Low gain (8:1) 0-1000 pe
- High Gain (1:1) 1-128 pe

Each stream is digitized with a 12-bit 1 Gsample/s custom designed ADC.

Digital signal is then processed in FPGA (Xilinx kintex7): reconstructed (timestamp, charge) and the digitized waveform is stored locally (2 GB DDR RAM).

All GCU (about 6000) synchronised < 16 ns window.

- in 'Global-Trigger' running mode, a local TRG signal is sent to the Global Trigger and, if validated, data are transferred to DAQ through Ethernet.
- in 'Auto-Trigger' mode, fixed window waveform (300 ns) are sent to the DAQ every time a local trigger is issued.
Outside water electronics

Up to 80 meter CAT5 cables:
- **Asynchronous Link**: variable latency ethernet link
  Data readout and slow control
  Protocol: IPBUS - Nominal link speed: 1Gbps

- **Synchronous link**: fixed latency link
  Timing Trigger and Control (TTC) protocol

TTIM (Trigger/Timing interface mezzanine)

BEC (Backend Card)
Receive 48 Ethernet cables from the underwater boxes
Distributes CLK signal to GCUs
Transfers TRG signal between Global Trigger and GCUs
Global trigger scheme

- Design completed for most of the components
- Validation and integration tests are being carried on
Readout of the small PMTs

ABC front-end card with CATIROC ASIC

10m coax. cable

x 128

High Voltage / Signal Splitter

same High Voltage than for the Large PMT

same Global Control Unit than for the Large PMT

200 UWB → 5 BEC

Under Water Box
Conclusions

- JUNO is an unprecedented liquid scintillator detector (size & resolution)
- Required to reach 3% energy resolution at 1MeV
- The design of the electronics is almost completed, all the different components have been validated and a full integration test is being performed
- Production of the individual parts will follow
OTHER JUNO TALKS/POSTERS at EPSHEP2019

See Talks:
• *JUNO potential for neutrino oscillation physics*, Marco Grassi, Neutrino session
• *Atmospheric neutrino spectrum reconstruction with JUNO*, Giulio Settanta, Astroparticle session

See Posters:
• *Detection of supernova neutrinos with JUNO*, Mario Buscemi
• *Reactor Neutrino Spectrum Uncertainty and Mass Hierarchy Determination*, Emilio Ciuffoli
• *Current status of JUNO Top Tracker*, Qinhua Huang
• *Study on HQ-LAB for the JUNO experiment*, QI Ming
• *Water Cherenkov detector of the JUNO Veto system*, Ruiguang Wang
• *The electronics readout system of the JUNO experiment*, Pierre-Alexandre Petitjean
BACKUP
JUNO TAO

TAO = Taishan Anti-neutrino Observatory
TAO will measure the anti-neutrino spectrum at % level, to provide:
- a model-independent reference spectrum for JUNO
- a benchmark for investigation of the nuclear database

Detector concept:
2.6 t Gd-loaded LS @ -50°C + SiPM
700k/year @ 40m from Taishan
20x JUNO 6-year data in 3 year
Energy resolution: $1.5% / \sqrt{E}$

Status:
Design and R&D on the way:
- LS works in -50°C
- SiPM & its readout electronics
- Mechanical design
- Measured onsite muon/neutron flux
- Prototype a low temperature LS detector