The Jiangmeng Underground Neutrino Observatory (JUNO)

Alberto Garfagnini

Università degli studi di Padova

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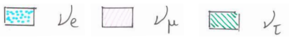
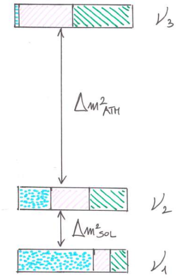
Neutrino Mixing

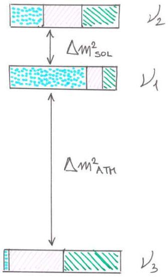
- three Flavour Eigenstates
- three Mass Eigenstates

$$|\nu_\alpha> = \sum_{i=0}^{3} U_{\alpha,i}|\nu_i>$$





Normal Hierarchy



Inverted Hierarchy

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{-i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric | Reactor (L$\sim$ 1 km) | Solar

Open questions in neutrino physics

- What is the correct mass hierarchy :
- ✓ Normal Hierarchy versus Inverted Hierarchy

- Is there a CP violation in the neutrino sector ? ($e^{-i\delta}$)

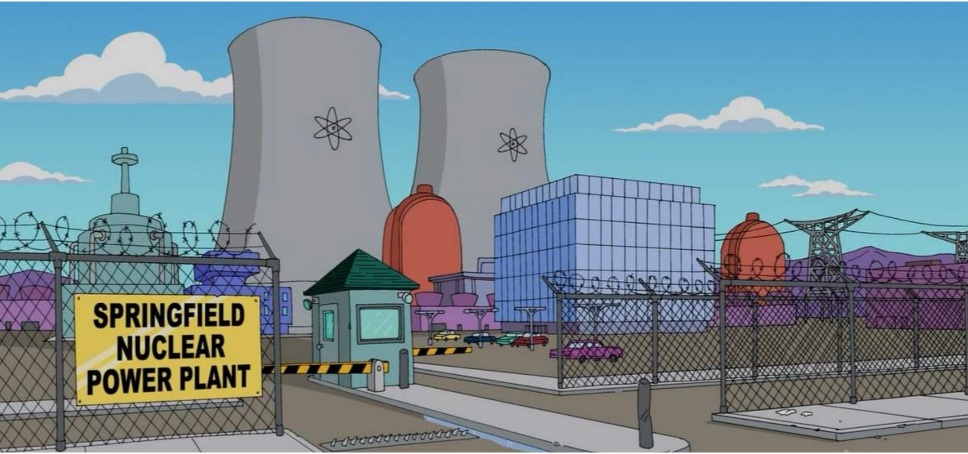
- Is there new physics beyond the three neutrino model ?

$$|U_{e1}|^2 + |U_{e2}|^2 + |U_{e3}|^2 = 1 \text{ (PMNS Unitarity) ?}$$

$$\Delta m^2_{13} + \Delta m^2_{21} + \Delta m^2_{32} = 0 \text{ ?}$$

- Can we use neutrinos as messengers to understand our Universe ?
- ✓ look inside the core of a collapsing Supernova
- ✓ look at the Earth's composition (Mantle & Core)

The JUNO approach: detect reactor $\overline{\nu}_e$



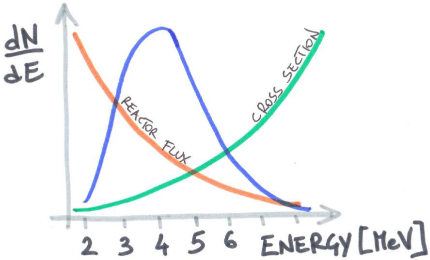
Reactor neutrinos

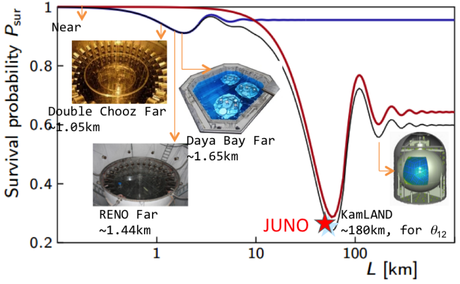
Nuclear Power Plants

- ✓ produce energy by breaking heavy nuclei
- ✓ fission fragments are unstable
- ✓ main production mechanism: beta decay

  $n \rightarrow p + e^- + \overline{\nu}_e$

➜ 3 GW reactor : $\sim 10^{20}\ \overline{\nu}_e/\text{s}$





Detection mechanism

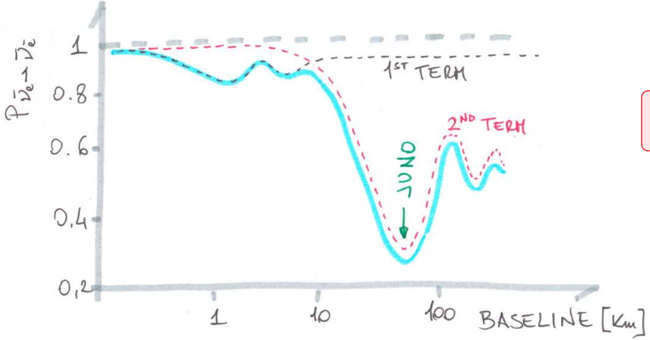
- ✓ Inverse Beta Decay :

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

- e^+ → $e^+ + e^- \rightarrow 2\gamma$
- n → captured on H or Gd

➜ but traveling, $\overline{\nu}_e$ oscillate . . .

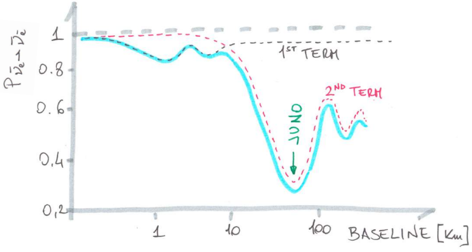
Reactor $\overline{\nu}_e$ survival probability

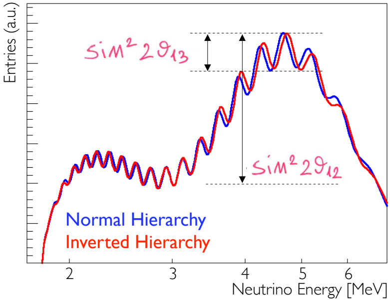


$$\Delta_{ij} = \Delta m^2_{ij} \frac{L}{4E}$$

$$\begin{aligned} P\left(\overline{\nu}_e \to \overline{\nu}_e\right) &= 1 - (P_{31} + P_{32}) - P_{21} \\ &= 1 - \sin^2 2\theta_{13} \cdot \sin^2 \left(\cos^2\theta_{12} \sin^2\Delta_{31} + \sin^2\theta_{12} \sin^2\Delta_{32} \right) \\ &\quad - \sin^2 2\theta_{12} \cdot \cos^4\theta_{13} \sin^2\Delta_{21} \end{aligned}$$

Ideal Oscillated Spectrum



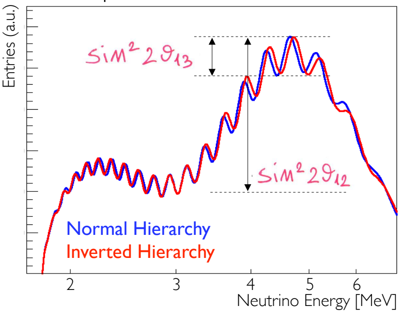


$$
\begin{aligned}
P(\overline{\nu}_e \to \overline{\nu}_e) &= 1 - (P_{31} + P_{32}) - P_{21} \\
&= 1 - \sin^2 2\theta_{13} \cdot \sin^2 \left(\cos^2\theta_{12} \sin^2\Delta_{31} + \sin^2\theta_{12} \sin^2\Delta_{32}\right) \quad \text{FAST} \\
&\quad -\sin^2 2\theta_{12} \cdot \cos^4\theta_{13} \sin^2\Delta_{21} \quad \text{SLOW}
\end{aligned}
$$

Combined role of Δm^2_{atm} and Δm^2_{sol}

Determine Mass Hierarchy with Reactors

Spectrum at 50 km baseline



- ✓ precision energy spectrum measurement
- ✓ interference between P_{31} and P_{32}
- ➜ relative measurement

- ✓ further improvements with $\Delta^2_{\mu\mu}$
- ✓ constraint from accelerator experiments
- ➜ absolute measurement

$$\Delta m^2_{ee} = \cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32}\,.$$

$$|\Delta m^2_{ee}| - |\Delta m^2_{\mu\mu}| \quad = \quad \pm\Delta m^2_{21}(\cos 2\theta_{12} - \sin 2\theta_{12}\sin\theta_{13}\tan\theta_{23}\cos\delta)$$

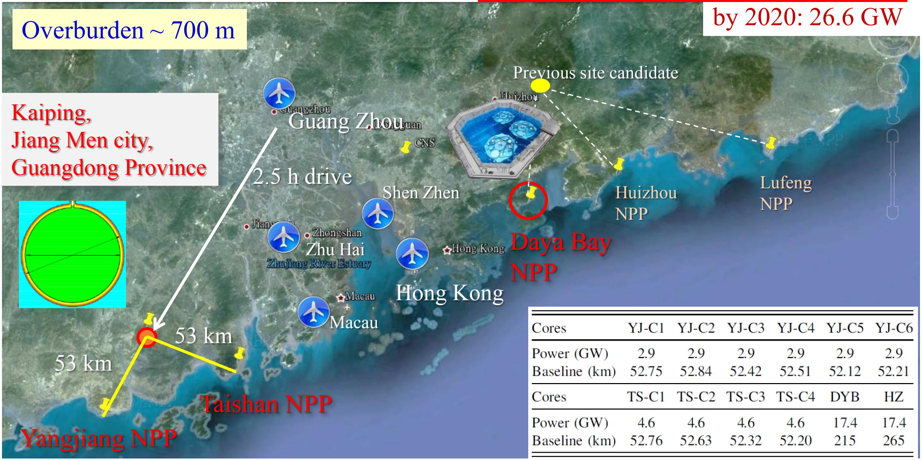
Requirements

- ✓ Baseline : 45 - 60 km
- ✓ Energy resolution : 3% at 1 MeV
- ✓ Large active mass : 20 kton × 35 GW × 6 yr = 100 k events

The Baseline

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW

by 2020: 26.6 GW

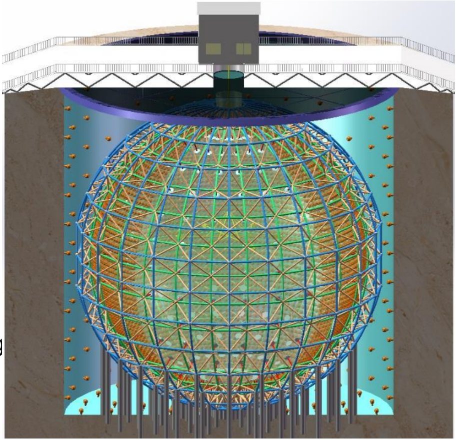


Cores	YJ-C1	YJ-C2	YJ-C3	YJ-C4	YJ-C5	YJ-C6
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9
Baseline (km)	52.75	52.84	52.42	52.51	52.12	52.21
Cores	TS-C1	TS-C2	TS-C3	TS-C4	DYB	HZ
Power (GW)	4.6	4.6	4.6	4.6	17.4	17.4
Baseline (km)	52.76	52.63	52.32	52.20	215	265

The JUNO Detector

- ✓ 20 kt Liquid Scintillator
  - LAB based scintillator in a 35 m diameter Acrylic Sphere
- ✓ 18000 20" high-QE PMTs
  - 75-80% coverage
- ✓ water buffer
  - mitigate PMT radioactovity
  - suppress fast neutrons
- ✓ Water Cherenkov (μ VETO)
  - 200 PMT in ultrapure water
- ✓ TOP tracker (μ tagger)
  - plastic scintillator (from OPERA Targ Tracker)
- ✓ 700 m rock overburden
  - shallow underground site

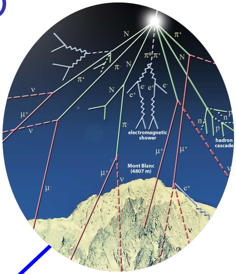
JUNO CDR arXiv:1508.07166

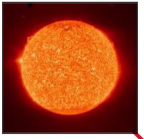


Neutrino event rates in JUNO

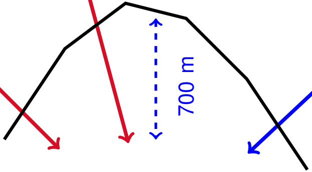
supernova νs,
5k in 10s @ 10 kpc

atmospheric νs,
several/day



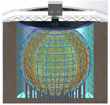


solar νs,
10-1000/day

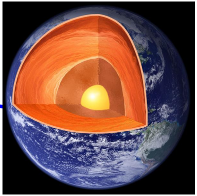


cosmic muons
$\sim$ 250/day,
0.003 Hz/m^2
215 GeV
10% muon bundles

reactor νs, $\sim 40-60$/day



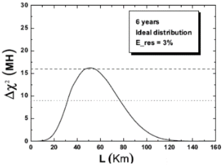
geo νs
$\sim 1-2$/day



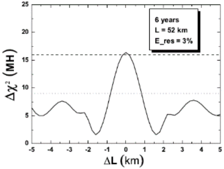
JUNO Yellow Book of Physics arXiv:1507.05613

JUNO Mass Hierarchy Sensitivity

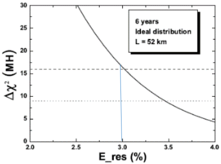
➜ 6 years of data taking (100 k $\overline{\nu_e}$ IDB events collected)



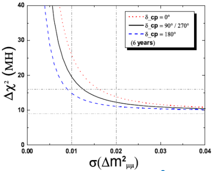
Baseline: JUNO 52.5km



Equal baselines



3% energy resolution



Inputs of $|\Delta M^2_{\mu\mu}|$

- 3σ with the spectrum measurement
- 4σ with external input of $|\Delta M^2_{\mu\mu}|$

	Ideal	Core distr.	Shape	B/S(stats.)	B/S(shape)	$\lvert\Delta M^2_{\mu\mu}\rvert$
Size	52.5km	Real	1%	4.5%	0.3%	1%
$\Delta\chi^2_{MH}$	+16	-4.7	-1	-0.5	-0.1	+8

Precision measurements

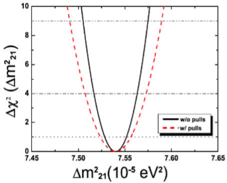
✓ JUNO will allow to probe the U_{PMNS} unitarity down to 1%

➜ it will be more precise than the CKM matrix elements!

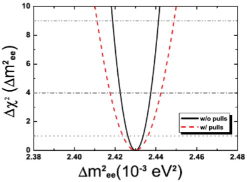
	Δm^2_{21}	$\lvert\Delta m^2_{31}\rvert$	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
Exp	KamLAND	MINOS	SNO	DayaBay	SK/T2K
Exp 1 σ	2.7%	4.1%	6.7%	6%	14%
Global 1 σ	2.6%	2.7%	4.1%	5%	11%

JUNO	Nominal	+ BGB
$\sin^2\theta_{12}$	0.54%	0.60%
Δm^2_{21}	0.24%	0.27%
$\lvert\Delta m^2_{ee}\rvert$	0.27%	0.31%

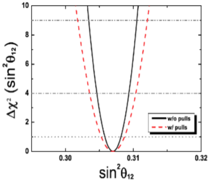
Δm^2_{21}



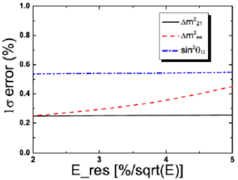
Δm^2_{ee}



$\sin^2\theta_{12}$



E resolution

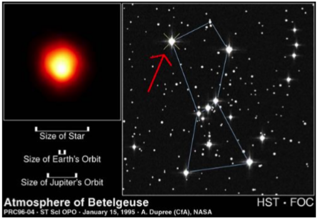


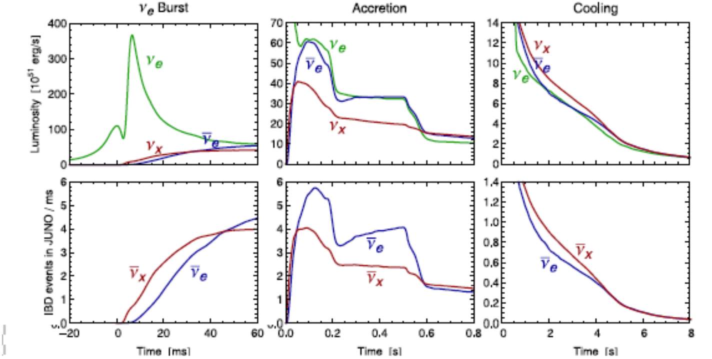
Supernova Neutrinos

✓ less than 20 events observed so far

Assumptions

- ➜ distance : 10 kpc (our Galaxy center)
- ➜ energy : 3×10^{53} erg
- ➜ L_ν the same for all types





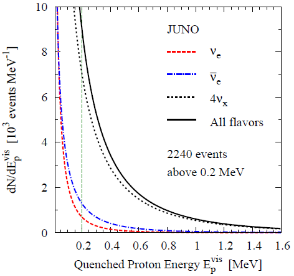
Supernova Neutrinos in JUNO

Estimated numbers of neutrino events in JUNO

Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \to e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \to \nu + p$	NC	6.0×10^2	1.2×10^3	2.0×10^3
$\nu + e \to \nu + e$	NC	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \to \nu + {}^{12}C^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}C \to e^- + {}^{12}N$	CC	4.7×10^1	9.4×10^1	1.6×10^2
$\overline{\nu}_e + {}^{12}C \to e^+ + {}^{12}B$	CC	6.0×10^1	1.1×10^2	1.6×10^2

LS detector vs. Water Cerenkov detectors: much better detection to these correlated events

→ Measure energy spectra & fluxes of almost all types of neutrinos

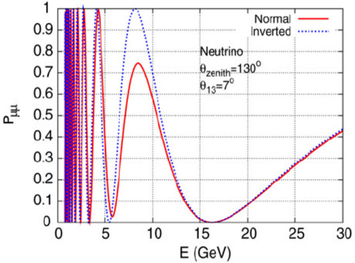


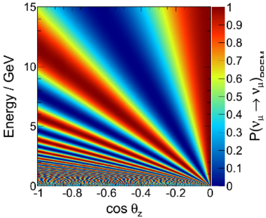
- ν mass: < 0.83±0.24 eV at 95% CL (arXiv:1412.7418)
- Locating the SN: ~9°
- Pre-SN ν (> 1 day)
- SN Nucleosynthesis via ν_x spectra
- Collective ν oscillation
- MH

Mass Hierarchy from ν_{atm}

- Due to matter effect, oscillation probability of atmospheric muon neutrino when passing the Earth depends on mass hierarchy

- JUNO will have 1-2 σ sensitivity.
  - ⇨ Measure both lepton and hadron energy
  - ⇨ Good tracking and energy resolution





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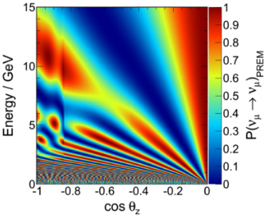

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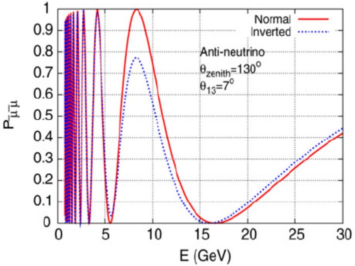
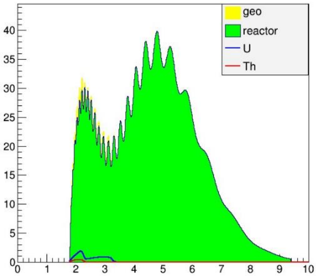


Geo neutrinos in JUNO

- **Geo-neutrinos**
  - ⇨ Current results
    KamLAND: 30±7 TNU *(PRD 88 (2013) 033001)*
    Borexino: 38.8±12.2 TNU *(PLB 722 (2013) 295)*
    Statistics dominant
  - ⇨ Desire to reach an error of 3 TNU
  - ⇨ JUNO: ×20 statistics
    - Huge reactor neutrino backgrounds
    - Need accurate reactor spectra



Source	Events/year
Geoneutrinos	408 ± 60
U chain	311 ± 55
Th chain	92 ± 37
Reactors	16100 ± 900
Fast neutrons	3.65 ± 3.65
^{9}Li - ^{8}He	657 ± 130
$^{13}C(\alpha, n)^{16}O$	18.2 ± 9.1
Accidental coincidences	401 ± 4

Combined shape fit of geo-ν and reactor-ν

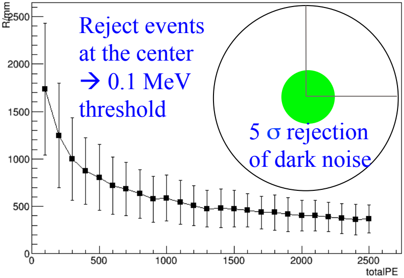
	Best fit	1 y	3 y	5 y	10 y
U+Th fix ratio	0.96	17%	10%	8%	6%
U (free)	1.03	32%	19%	15%	11%
Th (free)	0.80	66%	37%	30%	21%

Solar neutrinos and other physics

- **Solar neutrino**
  - ⇨ Metallicity? Vacuum oscillation to MSW?
  - ⇨ ^{7}Be and ^{8}B at JUNO
  - ⇨ Threshold
  - ⇨ Backgrounds

Source	Rate [cpd/1kt]
pp	1337
^{7}Be [line 0.384 MeV]	19
^{7}Be [line 0.862 MeV]	475
pep	28
^{8}B	4.5
^{13}N	25
^{15}O	28
^{17}F	0.7

Liquid Scintillator	U238	Th232	K40	Pb210 (Rn222)	Ref.
No Distillation	10^{-15}	10^{-15}	10^{-16}	$1.4\cdot10^{-22}$	Borexino CTF, KamLAND
After Distillation	10^{-17}	10^{-17}	10^{-18}	10^{-24}	



- **Sterile ν, Indirect dark matter, Nucleon decay, etc.**

The JUNO Central Detector

Specs

- ➜ Target Mass : 20 kton LS
- ➜ BKG/Signal : accidentals (10%), ^{9}Li/^{8}He ($<$ 1%), fast neutrons ($<$ 1%)

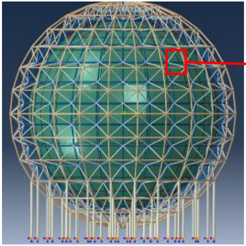
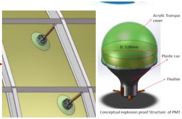
A Huge Detector in a Water Pool

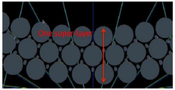
- ➜ Acrylic Tank (35 m) + Stainless Steel Truss

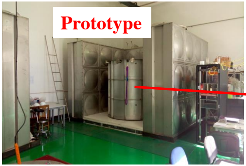
Challenges

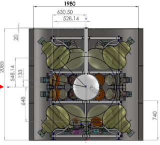
- ➜ Engineering : mechanics, safety, lifetime, . . .
- ➜ LS : high transparency, low background
- ➜ PMT : high QE, large coverage

Design and Prototyping underway



Add 3-inch PMTs in the gaps




The Liquid Scintillator

Recipe

- LAB + PPO + bisMSB
- no Gd loading

Liquid Scintillator L2:
G.Ranucci (IT)

Increase Light Yield

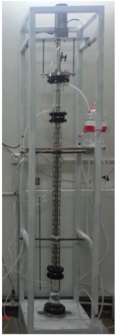
- optimization of flourine concentration

Increase Transparency

- good raw solvent : LAB
  - improve production process
- online handling/purification
  - distillation, filtration, water extraction, nitrogen stripping, . . .

Reduce Radioactivity

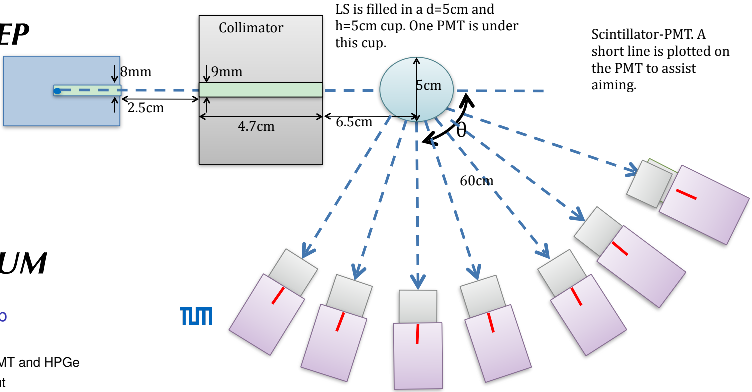
- less risky, no Gd
  - intrinsic single rates : < 3 Hz (above 0.7 MeV) if ^{40}K/U/Th $< 10^{-15}$ g/g



Linear Alkyl Benzene (LAB)	Att. Length @ 430 nm
RAW	14.2 m
Vacuum distillation	19.5 m
SiO_2 column	18.6 m
Al_2O_3	25 m

JUNO LAB Characterization measurements

Setup I: IHEP

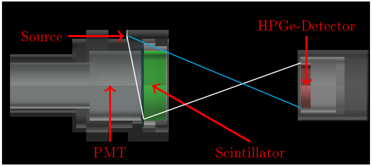


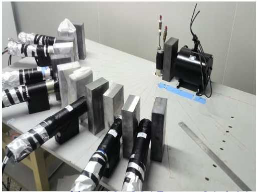
7 LaBr-PMT

Setup II: TUM

Electron quenching: set-up

- Conincidence between PMT and HPGe
- PMT signal ⇒ Light output
- HPGe signal ⇒ Deposited energy





The JUNO Photo Multiplier Tubes

- ➜ large (20") PMTs are mandatory to achieve a 75% photo-coverage
- ➜ R&D to develop high efficiency PMTs ongoing in China

20” Hamamatsu
PMT Dynode
Ellipsoidal Glass

20” IHEP MCP−PMT
Vertical MCPs
Sphere Glass

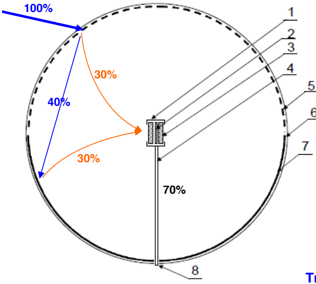
20” IHEP MCP−PMT
Horizontal MCPs
Ellipsoidal Glass

The JUNO PMT R&D Program

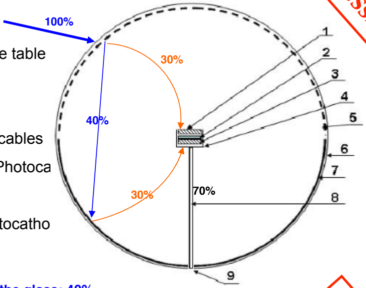
JUNO PMT Plan A progressing well

1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain

2) Using transmission photocathode (front hemisphere) and reflection photocathode (back hemisphere) } **Fully active sphere surface**



1.Insulated trestle table
2.Anode
3.MCP dodule
4.Bracket of the cables
5.Transmission Photoca
6.Glass shell
7.Reflection Photocatho
8.Glass joint



Transmission rate of the glass: 40%

Quantum Efficiency (QE) : of Transmission Photocathode 30% ; of Reflection Photocathode 30% ;

Collection Efficiency (CE) of MCP : 70%;

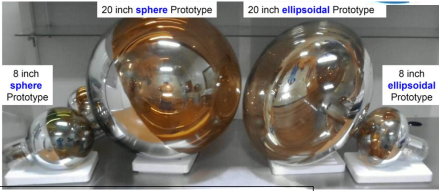
If nothing else changes, the detection efficiency (QE*CE) is nearly doubled by "saving" the ~40% transmitted photons.

- **JUNO PMT plan B: Photonis China PMTs**
- **JUNO PMT plan C: new 20" Hamamatsu SBA high QE PMTs**

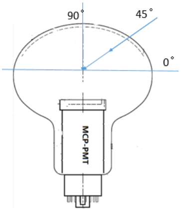
3 Plans in Parallel by Collaborators

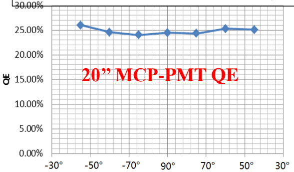
New HQE PMT results

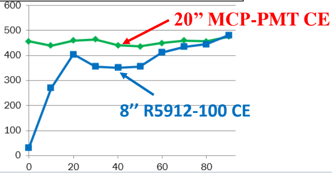
- A new design of using MCP
  - 4π collection, under development
  - Technical issues mostly solved, successful 8” and 20” prototypes.
- Alternative options: Hamamatsu or Photonics
- **News from 20” MCP-PMT:**
  - **Quantum Efficiency ~ 25% @ 410nm**
  - **Collection Efficiency ~ 100%**



Photon Detection Efficiency = QE*CE, @410nm, 20” MCP-PMT: ~25%, that in MC (slide 8): ~27%

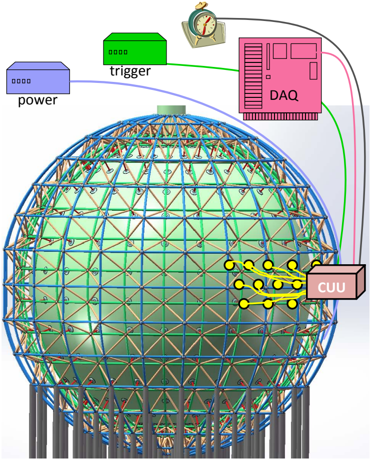






PMT tender procedure started, to be completed end 2015

The JUNO Large PMT Electronics



Electronics & Trigger L2: A.Stahl (DE)

Requirements

- ➜ all PMT FE electronics will be underwater
- ➜ 20 years livetime
- ➜ no access possible after installation

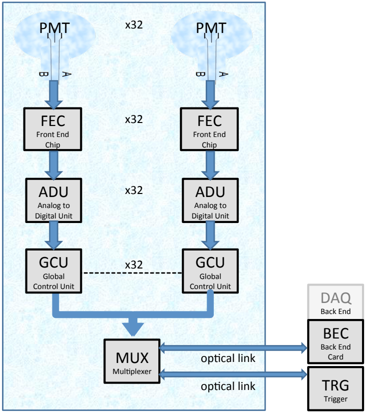
Under water

- ➜ ∼ 18000 PMTs (Central Detector) +
  ∼ 2000 PMTs (Water Cherenkov)
- ➜ PMT High Voltage
- ➜ FE electronics : signal amplification, ADC, digital processing and data reduction, trigger and digital data transmission

Above water

- ➜ DAQ back-end electronics, global trigger electronics, low voltage, clock & control and online DAQ farms

JUNO PMT Underwater Electronics



High Voltage

- ➜ baseline option : custom Cockcroft-Walton multiplier : convert AC low voltage to DC high voltage
- ➜ commercial system as backup option

Front End Card

- ➜ two ASICs developements in Europe and China

Analog to Digital Unit

- ➜ two ASICs developements in Europe and China and possible usage of commercial ADCs

Global Control Unit

- ➜ INFN strong interest (possible industrial partnership with R&D common program) and Chinese option

Multiplexer

- ➜ European and Chinese options under investigation

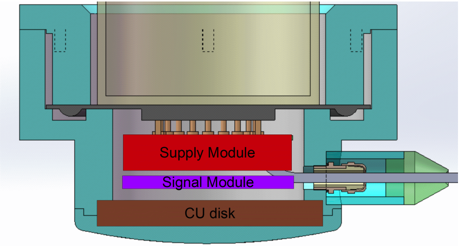
Large PMT electronics responsabilities

HV module :
- Dubna (RU),

ADC (Vulcan Chip) :
- Jülich (DE)

GCU (FPGA + digital part) :
- Padova (IT)

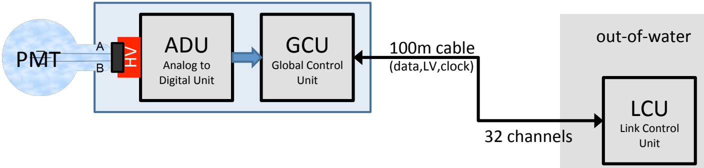
LCU :
- Bruxelles (BE)



Electronics scheme recently selected (JUNO Electronics Workshop, October 28-30 2015, Padova)

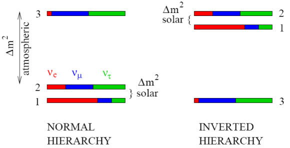
HV Unit
PMT connector
Base
HV-Module (Dubna)
Splitter

Signal Module
PCB with
(FEC), VULCAN, FPGA,
DC-DC power, clock, data links

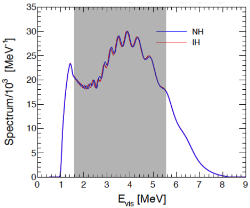


The Energy Resolution Challenge

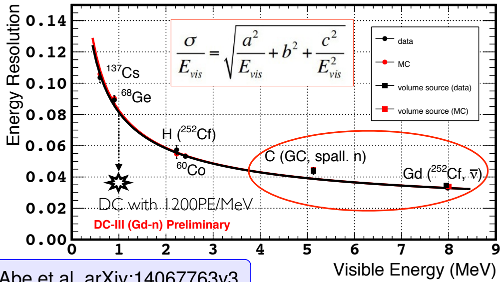
$\Delta m^2_{31}(IO) \neq \Delta m^2_{31}(NO) \Longrightarrow$ **δ~3%** (i.e. $\delta m^2/\Delta m^2$)



⊕



non-stochastic terms (b & c) have to be under control
and are very sensitive to the high energy level arm



a: statistical term
b: constant term
c: e.g. electric noise

Data
a=0.0773±0.0025
b=0.0182±0.0014
c=0.0174±0.0107

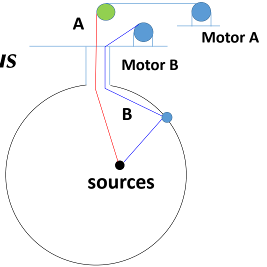
MC
a=0.0770±0.0018
b=0.0183±0.0011
c=0.0235±0.0061

Y. Abe et al, arXiv:14067763v3

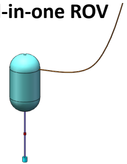
The Calibration system

- Point radioactive source calibration systemx :
  - ✓ an automatic rope system is the primary source delivery system
  - ✓ a ROV is more versatile
  - ✓ a guide tube system covers the boundaries and near boundary regions
- ✓ considering short-lived diffuse radioactive sources to calibrate the detector response
- ✓ a UV laser system is being designed to calibrate the LS properties *in situ*

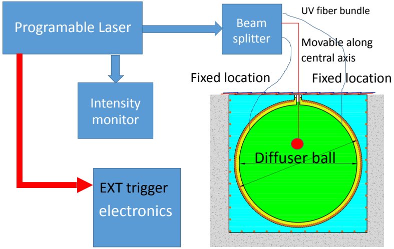
A-B rope synchronous motion



All-in-one ROV



sources



Pelletron as a positron beam calibration source

- Mature technology and commercially available:
  - ✓ is a positron gun to shoot positrons directly in the JUNO LS:
  - ✓ energy coverage: 0.5 – 6.5 MeV, uncertainty $< 10^{-4}$
  - ✓ can shoot both electrons and positrons and below 5 MeV cheaper than LINAC
  - ✓ energy can be calibrated with a dedicated system (Ge detector) to 0.1% level
  - ✓ excellent energy stability. Super-K LINAC e-beam calibration reached 0.6% absolute energy scale uncertainty

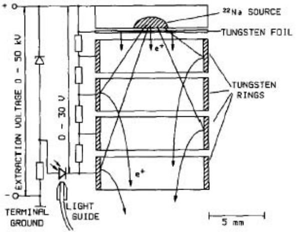
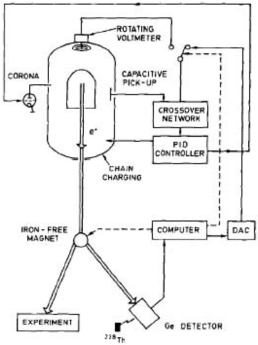
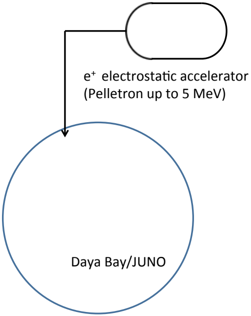


Fig. 1. Schematic of the slow-positron source with tungsten moderators.

Bauer et al, The Stuttgart positron beam, its performance and recent experiments, NIM B50, 300 (1990)





Backgrounds in JUNO

- expected IBD signal rate: $\sim 40 - 60$ events/day
- expected backgrounds :
  - ✓ accidentals
  - ✓ fast neutrons
  - ✗ cosmogenic ^{9}Li/^{8}He production

Rock overburden: 700 m
$< E_\mu > \sim 200$ GeV
$< R_\mu > \sim 3 - 4$ Hz

✓ accidentals will be reduced thanks to reduced PMT radioactivity and LS purification

✓ high muon detection efficiency is important for fast neutrons

✓ the biggest background contribution comes from cosmogenic ^{9}Li/^{8}He
muon tracking in JUNO (Central Detector and VETO detectors) is a key element

The VETO system in JUNO

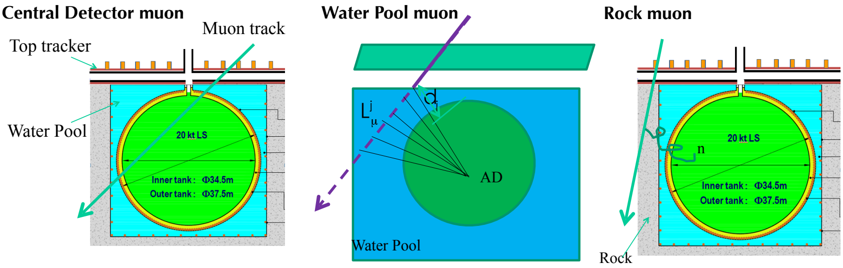
- the VETO system is an outer detector providing information to understand the cosmogenic background. It's made of:

✓ a Water Cherenkov

✓ a Top Tracker

VETO L2: M.Dracos (FR)

- simulation and design studies are on going in order to optimize the design. Several options for the Top Tracker are being considered:
  - ✓ the OPERA Target Tracker (scintillator bars) will be moved to JUNO
  - ✓ other detectors technologies are under investigation



Muon Veto : Top tracker

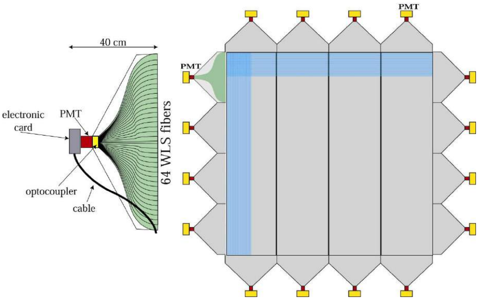
✓ use plastic scintillator walls from the OPERA Target Tracker (TT)

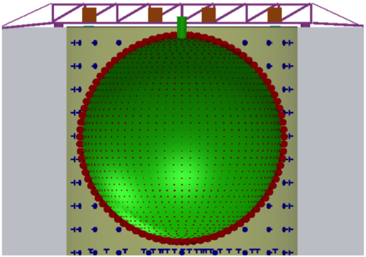
✓ module area : 7 $\times$ 7 m2

✓ aim : good muon tracking and gamma rejection (from rocks radioactivity)

➜ OPERA TT modules not enough to cover the whole JUNO surface

M.Dracos (IPHC-IN2P3, FR)

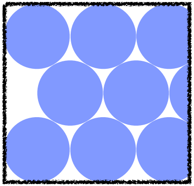


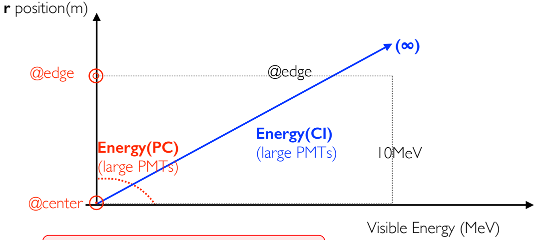


The JUNO Multi-calorimetry approach

Energy(Photo-Counting)→ small PMT (s-PMT system)
Energy(Charge-Integral)→ large PMT (L-PMT system)

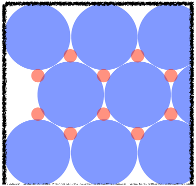
JUNO now
(single-calorimetry)

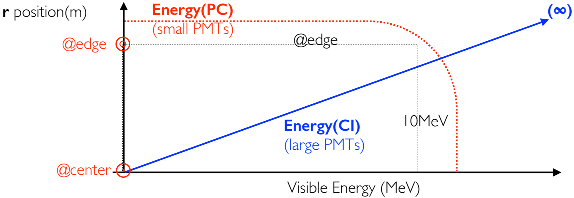




3" PMT L2: A.Cabrera (FR)

JUNO proposal
(multi-calorimetry)

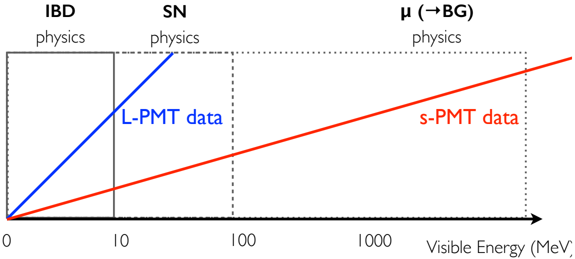




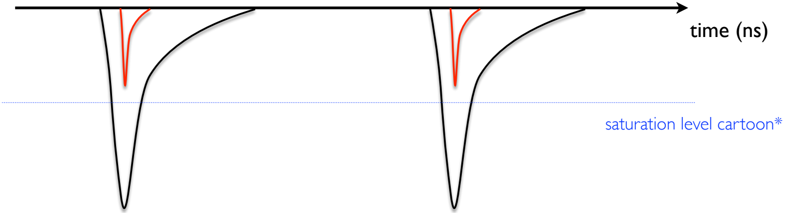
PC vs QI→ unique control of calorimetry systematics

Dynamic Range with L-PMT and s-PMT

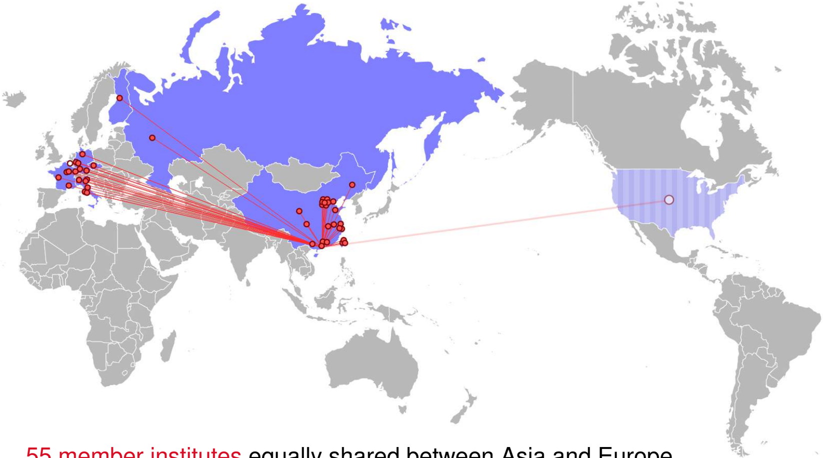
- **s-PMT** provides **natural extension of dynamic range** to detector
  - →stochastic resolution: **a~10%**
  - →s-PMT resolution for SN: ~3% (!!)
- **L-PMT focus on high precision** (high FADC sensitivity) on **IBD** (+SN) physics
  - →stochastic resolution: **a~3%**
- **complementarity over all dynamic range:** different saturation (s-PMT→negligible?), different life-time, different analogue Front-End (ringing after **μ**'s, etc), etc



cartoon of muons deposition… (even worse)



The JUNO International Collaboration



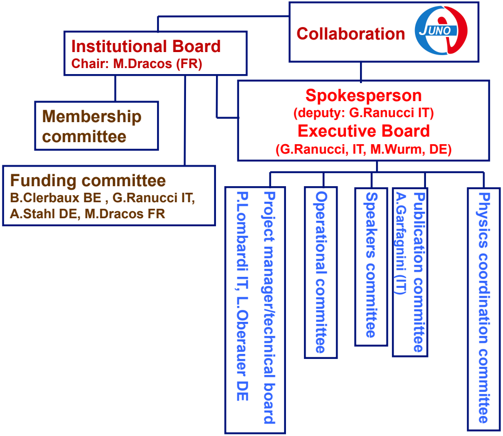
55 member institutes equally shared between Asia and Europe

Only two US groups are participating

23 european institutions: 1 in Belgium, 5 in France

The JUNO International Collaboration

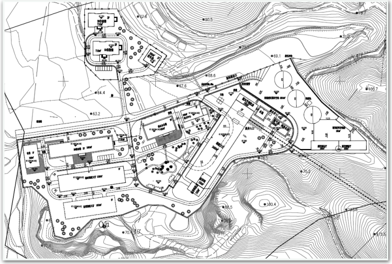
Country	Institutions	Members
Armenia	1	4
China	25	230
Taiwan	3	10
Belgium	1	3
Czech Republic	1	4
Germany	6	30
Finland	1	2
France	5	21
Italy	7	45
Russia	2	32
Chile	1	3
USA	2	4
SUM	55	388



L2 coordinators

✓ Civil, Central Detector, Veto (M.Dracos, FR), Liquid Scintillator (G.Ranucci, IT), MCP-PMT, PMT, 3" PMT (A.Cabrera, FR), Electronics & Trigger (A.Stahl, DE), Calibration, Integration, DAQ & Slow-Control (Y.Yang, BE), Offline & Computing

JUNO Civil Construction



JUNO Schedule

First get-together meeting

Funding(2013-2014) review approved

Geological survey and preliminary civil design

1st 20" MCP-PMT

Collaboration formed

Groundbreaking Ceremony

2013

Kaiping Neutrino Research Center established

Funding from CAS: "Strategic Leading Science & Technology Programme" approved (~CD1)

2014

Civil/infrastructure construction bidding

Yangjiang NPP started to build the last two cores

Civil design approved

- Civil construction：2015-2017
- Detector component production：2016-2017
- PMT production：2016-2019
- Detector assembly & installation：2018-2019
- Filling & data taking：2020

JUNO Competitors

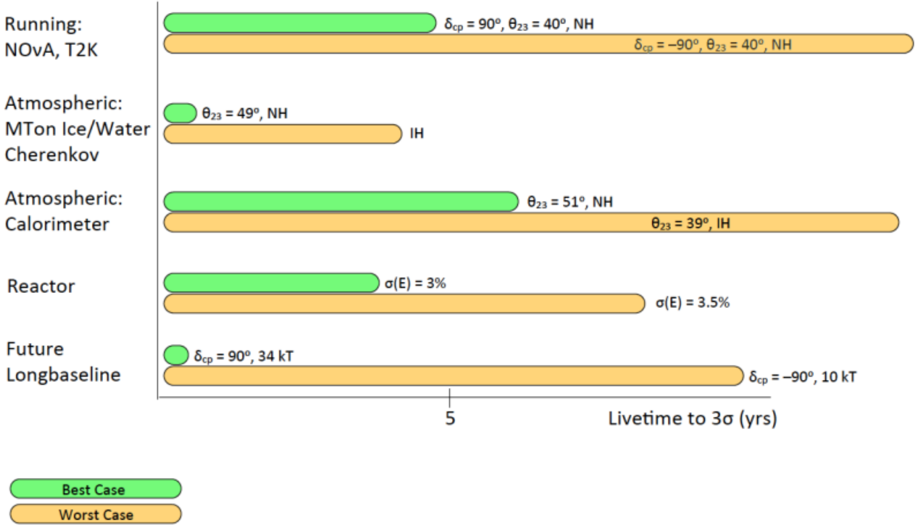
Different approaches to measure the Mass Hierarchy

- ✓ medium baseline reactor $\overline{\nu}_e \to \overline{\nu}_e$ oscillation experiments: JUNO, RENO-50
- ✓ long-baseline accelerator $\nu_\mu \to \nu_e$, $(\overline{\nu_\mu} \to \overline{\nu_e})$ oscillation experiments: T2K, NoνA, DUNE, Hyper-K
- ✓ atmospheric $\nu_\mu \to \nu_e$, $(\overline{\nu_\mu} \to \overline{\nu_e})$ oscillation experiments: INO, PINGU, ORCA, DUNE, Hyper-K

- ✓ The first method (reactors at a medium baseline) relies on the oscillation interference between Δm^2_{31} and Δm^2_{32}
- ➜ no dependences on : δ_{CP}, θ_{23} or 3 versus 4 oscillation pattern

- ✓ accelerator and atmospheric neutrino experiments depend on the matter effect in neutrino oscillations
- ➜ sensitivity depends strongly on δ_{CP} degeneracy and 3 versus 4 oscillation pattern

Sensitivity to the NMH for various techniques



Sources: arXiv:1311.1822, arXiv:1401.2046v1, arXiv:1406.3689v1, Neutrino 2014, LBNE-doc-8087-v10

Conclusions

✓ JUNO has been approved in February 2013 with a 300 M$ budget

➜ the physics reach is very broad : the first general-purpose neutrino detector (?)

➜ several challenging issues have to be faced

- . . . but preparation proceeds at high speed

  ➜ well defined detector R&D program

  ➜ CDR and Yellow Book of Physics published in arXiv

  ➜ groundbreaking cerimony on January 10th, 2015.
  Civil construction will be completed in three years

✓ a strong international collaboration is rapidly growing

➜ a new era of high precision neutrino physics is about to begin

Reserve Slides

JUNO backgrounds

Singles

Event Type	Raw rate	Reduction
Radioactivity (in FV <17.2m)	0.4 Hz (PMTs) 2.2 Hz (LS) 3.7 Hz (acrylic) 0.2 Hz (support) 1.3 Hz (Rn) ~ 0.03 (rock)	Use low radioactivity PMTs; LS raw material purification (w/o distillation after LS production)
Cosmogenic isotopes (delayed)	340/day	
Spallation neutron	1.8 Hz	

IBD bkg

Accidentals	~410/day	→ 1.1 /day w/ prompt-delayed distance $R_{p\text{-}d} < 1.5$m. Negligible.
Fast neutron	0.01/day	0.01/day (σ=100%)
^{9}Li/^{8}He	80/day	1.8/day after muon veto (σ=20%)
(a, n)	3.8/day (acrylic) 0.2/day (balloon)	→ 0.05 /day (acrylic), FV cut (σ=50%) → negligible (balloon), FV cut