Status of JUNO

Zeyuan Yu, IHEP
On behalf of JUNO collaboration
2023-01-17

The 2nd IAEA Technical Meeting on Nuclear Data Needs for Antineutrino Spectra Applications

Jiangmen Underground Neutrino Observatory

Vertical tunnel: 563 m

Overburden ~650 m (1800 m.w.e.)

Slope tunnel：1265 m @ slope of 42%

Civil construction finished in Dec, 2021

JUNO collaboration

74 institutes and 709 collaborators

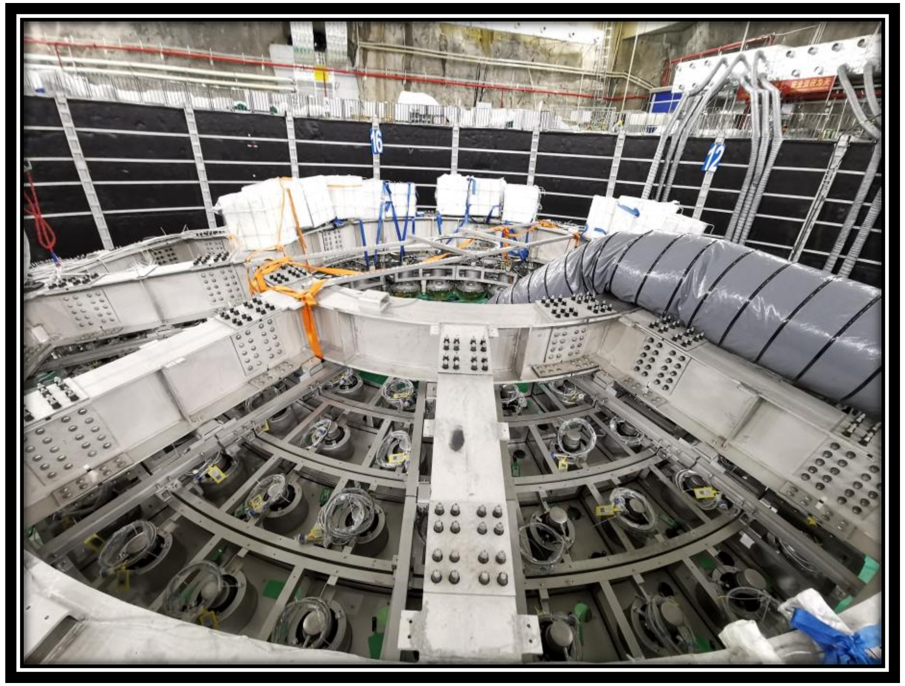
Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	**China**	Tsinghua U.	**Germany**	U. Tuebingen
Belgium	Universite libre de Bruxelles	**China**	UCAS	**Italy**	INFN Catania
Brazil	PUC	**China**	USTC	**Italy**	INFN di Frascati
Brazil	UEL	**China**	U. of South China	**Italy**	INFN-Ferrara
Chile	PCUC	**China**	Wu Yi U.	**Italy**	INFN-Milano
Chile	SAPHIR	**China**	Wuhan U.	**Italy**	INFN-Milano Bicocca
China	BISEE	**China**	Xi'an JT U.	**Italy**	INFN-Padova
China	Beijing Normal U.	**China**	Xiamen University	**Italy**	INFN-Perugia
China	CAGS	**China**	Zhengzhou U.	**Italy**	INFN-Roma 3
China	ChongQing University	**China**	NUDT	**Latvia**	IECS
China	CIAE	**China**	CUG-Beijing	**Pakistan**	PINSTECH (PAEC)
China	DGUT	**China**	ECUT-Nanchang City	**Russia**	INR Moscow
China	Guangxi U.	**Croatia**	PDZ/RBI	**Russia**	JINR
China	Harbin Institute of Technology	**Czech**	Charles U.	**Russia**	MSU
China	IHEP	**Finland**	University of Jyvaskyla	**Slovakia**	FMPICU
China	Jilin U.	**France**	IJCLab Orsay	**Taiwan-China**	National Chiao-Tung U.
China	Jinan U.	**France**	LP2i Bordeaux	**Taiwan-China**	National Taiwan U.
China	Nanjing U.	**France**	CPPM Marseille	**Taiwan-China**	National United U.
China	Nankai U.	**France**	IPHC Strasbourg	**Thailand**	NARIT
China	NCEPU	**France**	Subatech Nantes	**Thailand**	PPRLCU
China	Pekin U.	**Germany**	RWTH Aachen U.	**Thailand**	SUT
China	Shandong U.	**Germany**	TUM	**U.K.**	U. Warwick
China	Shanghai JT U.	**Germany**	U. Hamburg	**USA**	UMD-G
China	IGG-Beijing	**Germany**	FZJ-IKP	**USA**	UC Irvine
China	SYSU	**Germany**	U. Mainz		

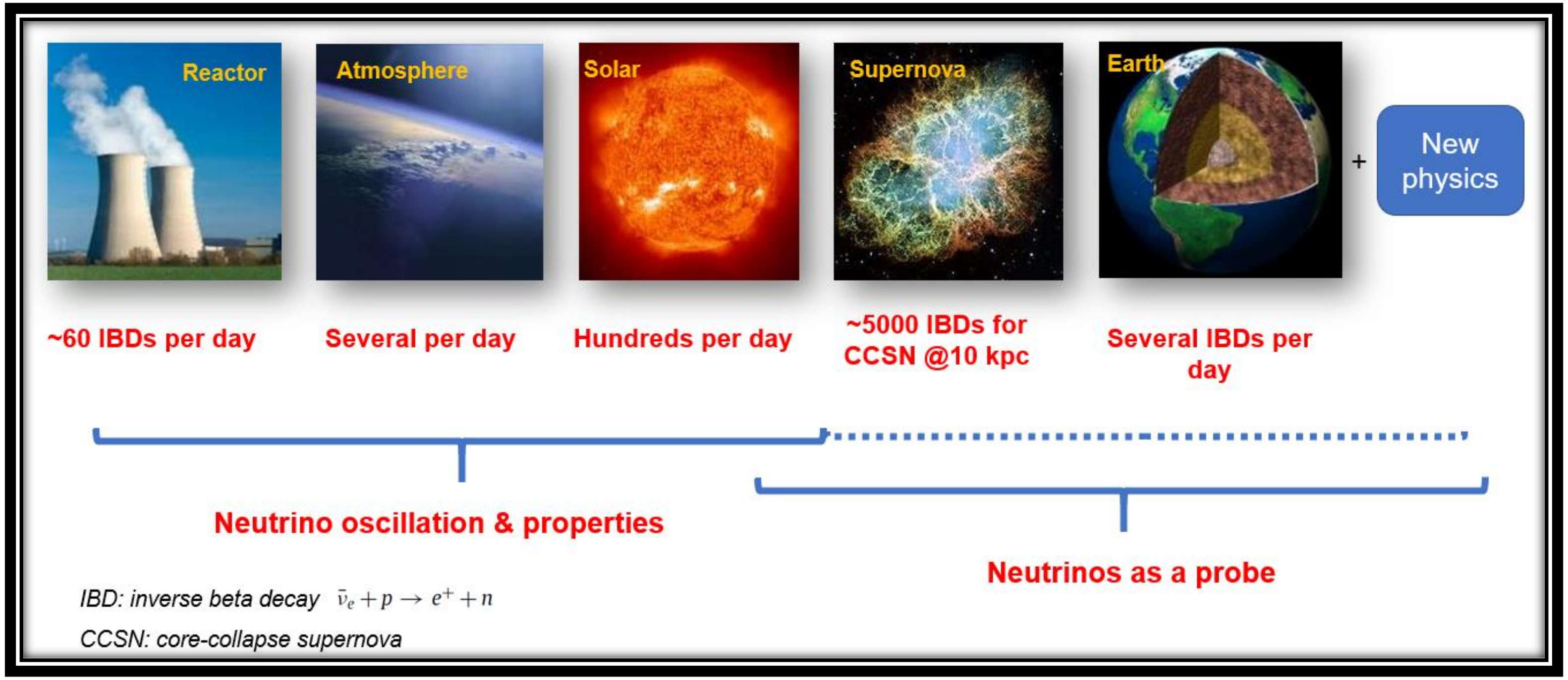
Since first IAEA TM in 2019

Smooth detector assembling

Expect to finish by end of 2023

Physics sensitivities have been thoroughly studied





IBD: inverse beta decay $\bar{\nu}_e + p \rightarrow e^+ + n$

CCSN: core-collapse supernova

PMT characterization EPJ C 82 (2022) 12, 1168, NIM A 1005 (2021) 165347

Radio purity JHEP 11 (2021) 102

Electronics NIM A 985 (2021) 164600

Calibration JHEP 03 (2021) 004 and others

Reactor neutrino oscillation Chin.Phys.C 46 (2022) 12, 123001

Solar neutrino oscillation Chin.Phys.C 45 (2021) 2, 023004

Atmospheric neutrino flux Eur.Phys.J.C 81 (2021) 10

Diffuse supernova neutrinos JCAP 10 (2022) 033

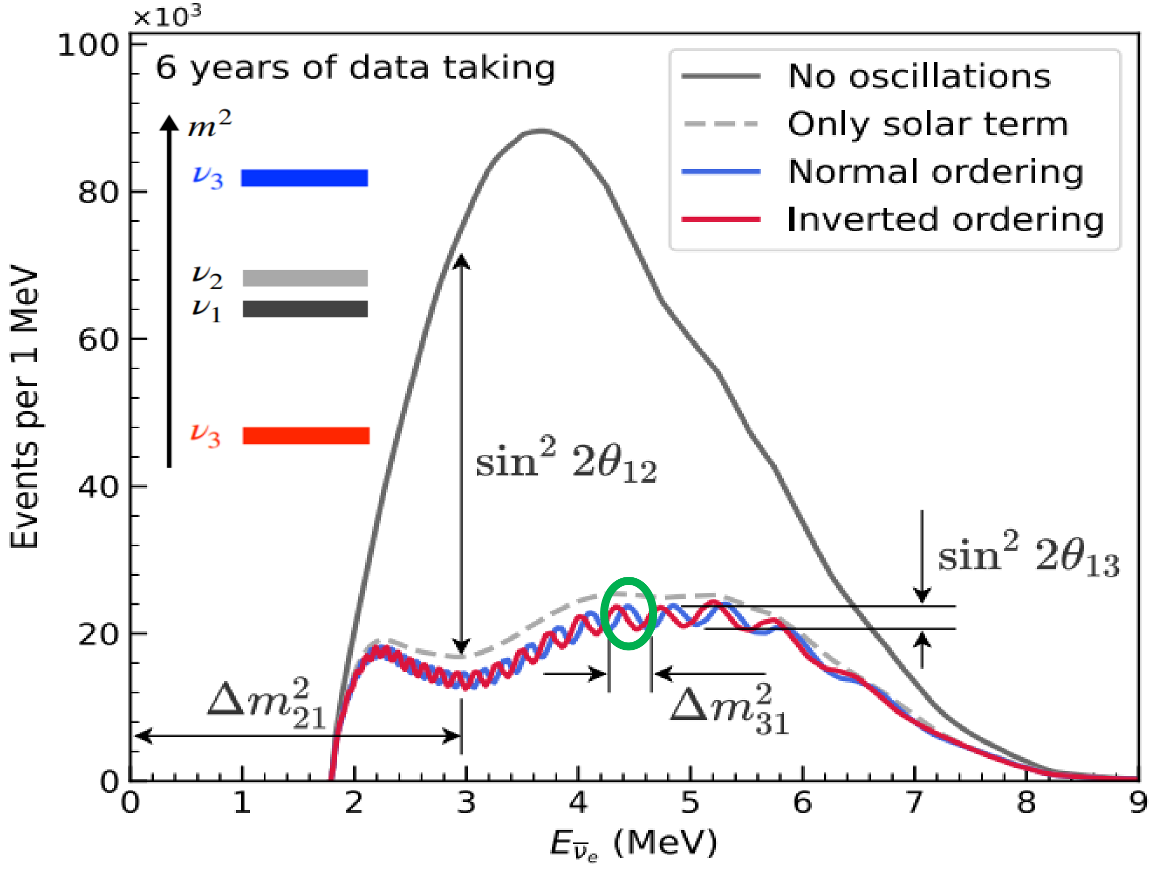
Proton Decay arXiv: 2212.08502 and others

Precision reactor neutrino oscillation

In six years:

determine neutrino mass ordering at 3σ

precision of $\sin^2\theta_{12}$, Δm^2_{21}, $|\Delta m^2_{32}|$ < 0.5%



Requirements

1. Statistics

20 kt liquid scintillator

26.6 GW_{th} power

2. Energy measurement

Energy resolution 3% at 1 MeV

Energy scale calibrated to 1%

3. Spectral shape of reactor neutrinos

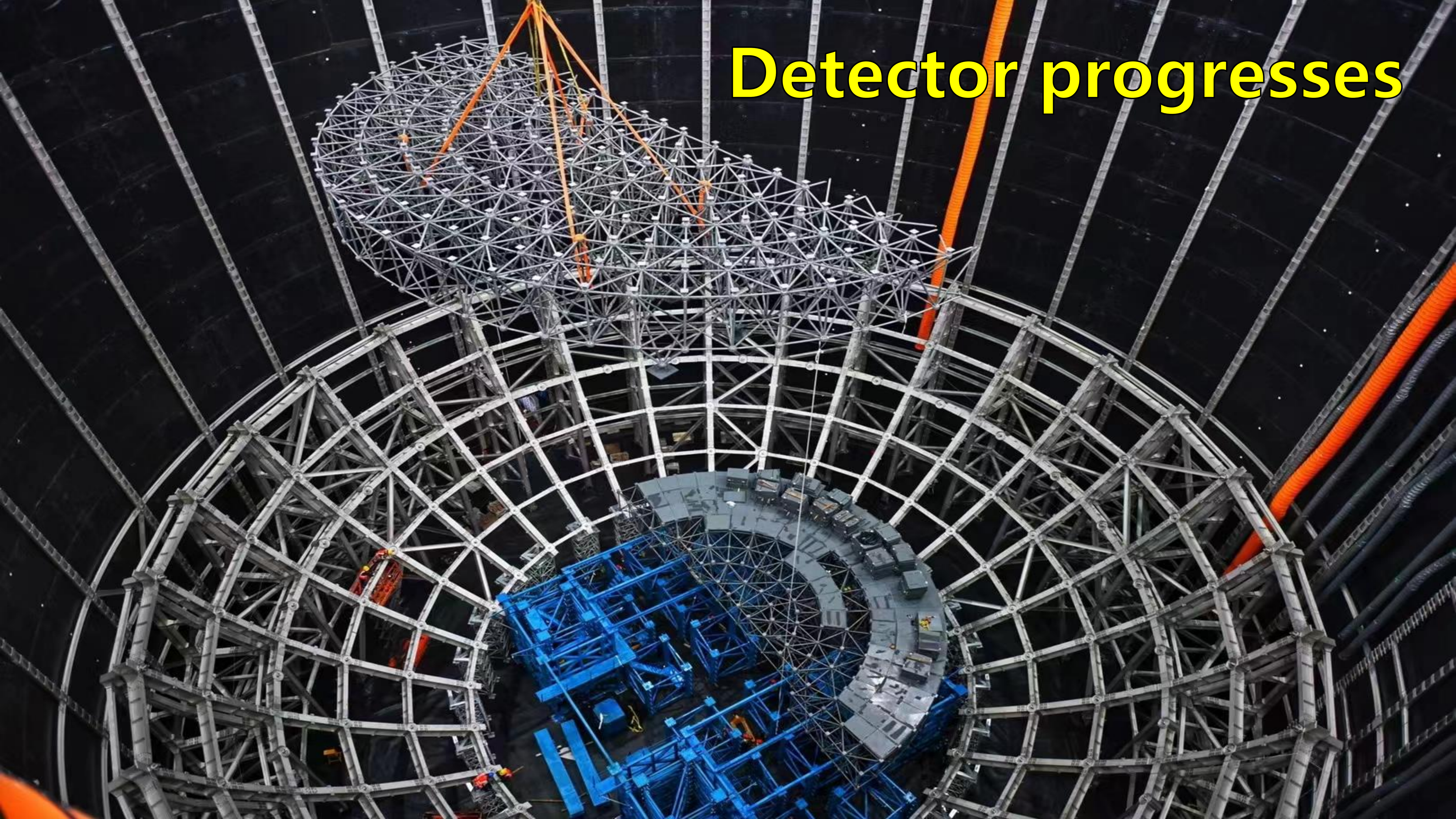
In [2.5,6] MeV, 1% uncertainty

constrained by TAO (Ruhui’s talk)

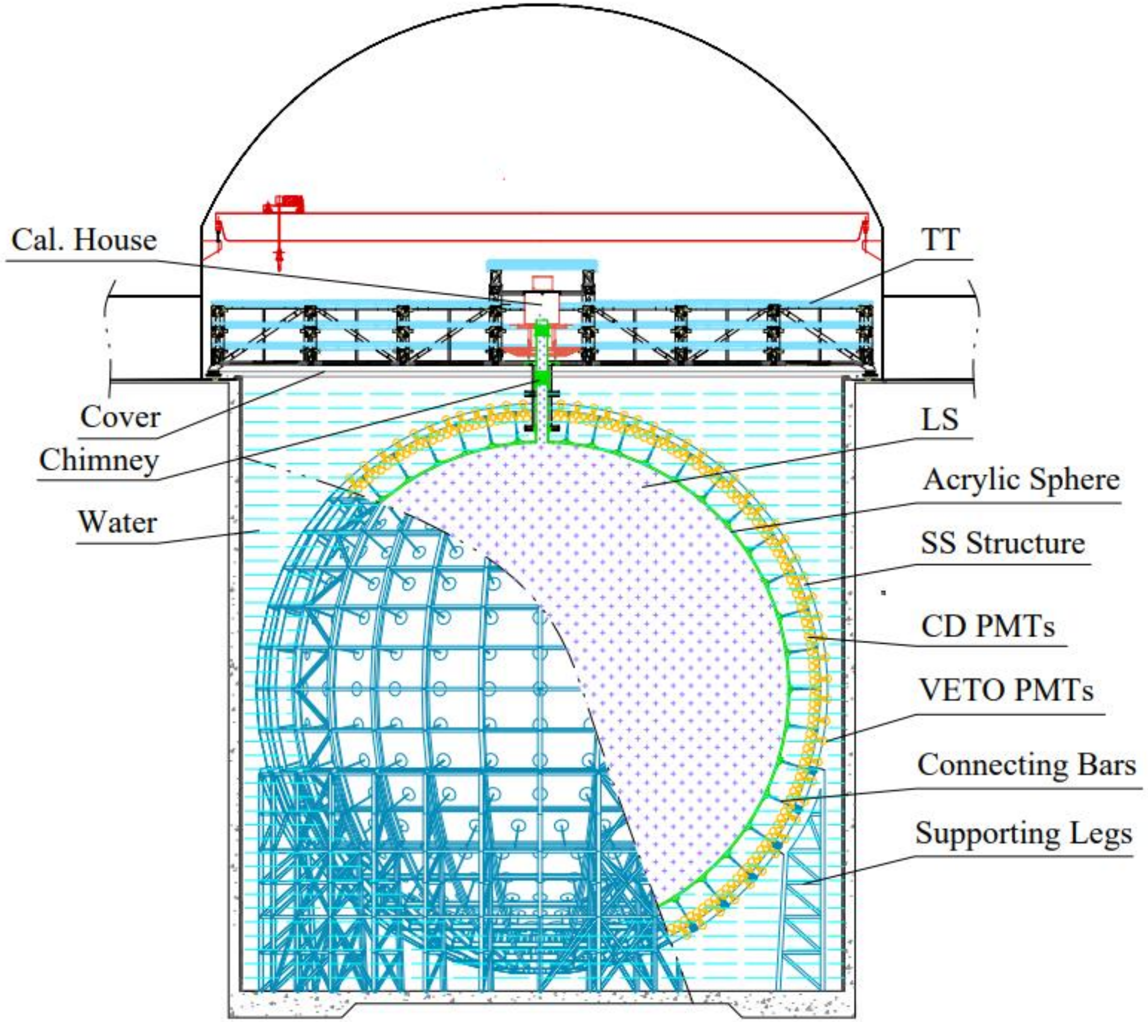
4. Background control

Material screening, clean installation, etc.

Detector progresses



JUNO detector in a good shape



- ✓ **All 265 acrylic panels produced**
  - **Assembly and bonding is in good shape**
- ✓ **Stainless Steel structure**
  - **Assembly finished in Sept. 2022**
- ✓ **20012 20’’ PMTs + 25600 3’’ PMTs**
  - **Production and performance test done**
  - **More than 300 PMTs have been installed**
- ✓ **Liquid scintillator**
  - **Commissioning of purification plants to be started**

Underground experimental hall

In the water pool, temperature 21±1℃, class of cleanness better than 100,000

LS hall

Electronics room

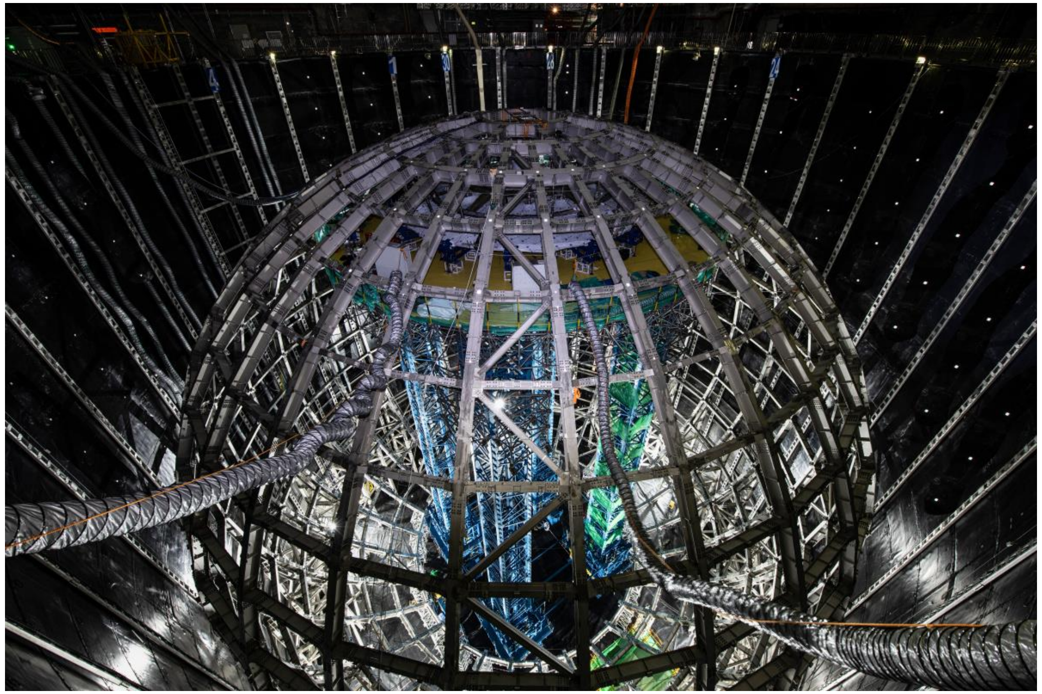
Water room

Central detector -- SS structure

A D = 40.1 m stainless steel structure supports the acrylic vessel via 590 connecting bars

- ✓ No wielding was used during the assembly.
- ✓ Natural radioactivity level smaller than 1 ppb for supporting SS bars.
- ✓ High assembly precision achieved to ensure the 3 mm gaps among PMTs.

March 2022



August 2022

Central detector – acrylic vessel

Acrylic container:

- ✓ Inner diameter: 35.40±0.04 m
- ✓ Thickness: 124±4 mm
- ✓ Light transparency > 96% @ LS
- ✓ Radiopurity: U/Th/K reached 1 ppt

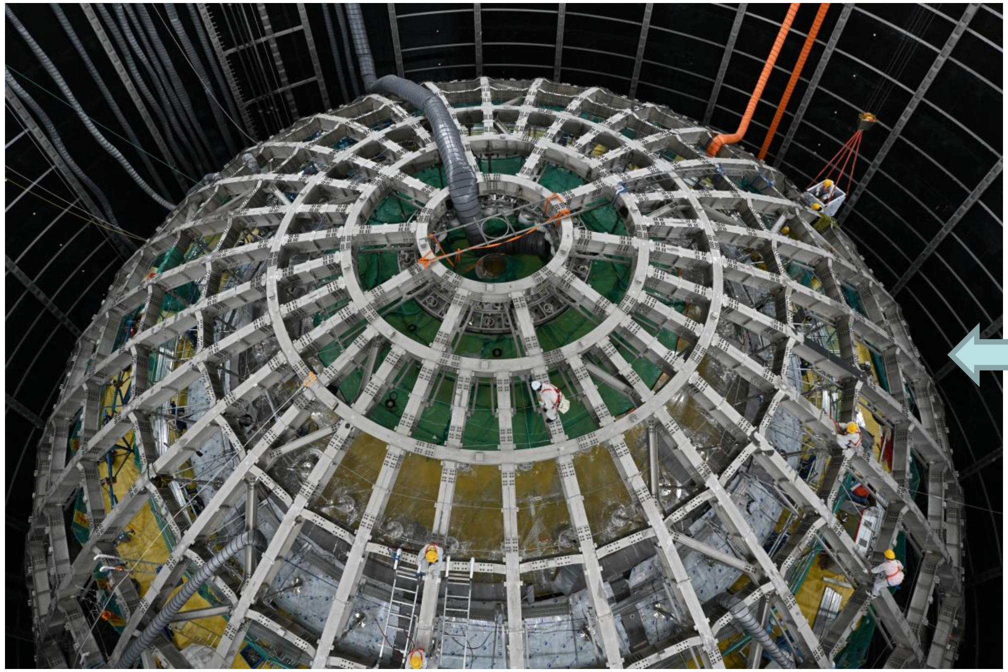
Pre-assembly at Donchamp

Polishing

Cleaning

50 µm PE film protection

Assembly and bonding



Liquid scintillator

20 kt liquid scintillator: LAB based, PPO as fluorescence, bis-MSB as wavelength shifter

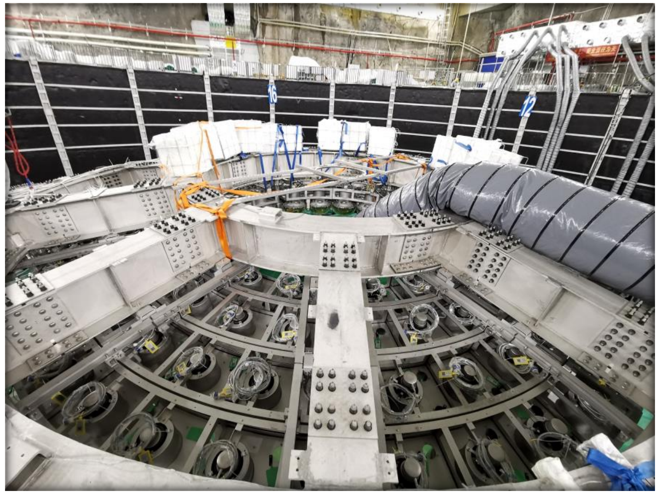
- ✓ Good transparency: attenuation length > 20m @ 430 nm, no doping, Al_2O_3 purification and distillation
- ✓ Ultrapure: required radioactivity 10^{-15} g/g for reactor and 10^{-17} g/g for solar, distillation and others
- ✓ Full system commissioning will start soon

All the LS related systems will finish assembly in summer.

Photomultiplier tubes

Synergetic 20-inch and 3-inch PMT systems to control systematics

All PMTs produced, tested, and instrumented with waterproof potting. More than 300 tubes installed

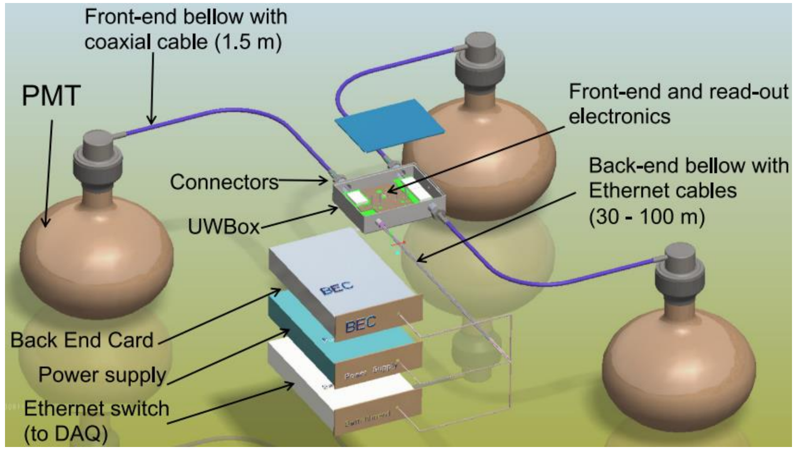


		LPMT (20-inch)		SPMT (3-inch)
		Hamamatsu	NNVT	HZC
Quantity		5000	15012	25600
Charge Collection		Dynode	MCP	Dynode
Photon Detection Efficiency		**28.5%**	**30.1%**	25%
Mean Dark Count Rate [kHz]	Bare	15.3	49.3	0.5
	Potted	**17.0**	**31.2**	
Transit Time Spread (σ) [ns]		1.3	7.0	1.6
Dynamic range for [0-10] MeV		[0, 100] PEs		[0, 2] PEs
Coverage		75%		3%
Reference		EPJC 82, 1168 (2022)		NIM.A 1005 (2021) 165347

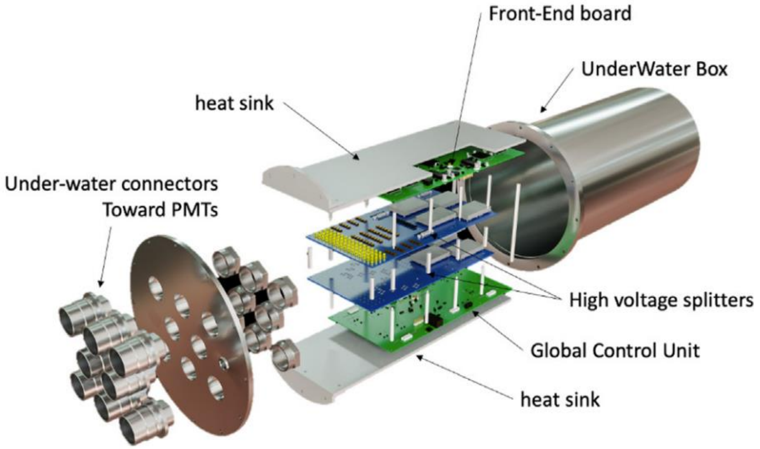
12.6k NNVT PMTs with highest PDE are selected for light collection from LS and the rest are used in the Water Cherenkov detector.

Electronics

Underwater electronics to improve signal-to-noise ratio for better energy resolution

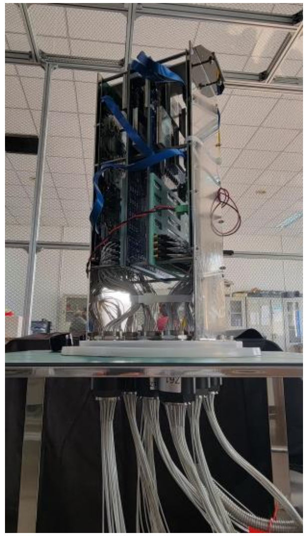


3 20-inch PMTs connected to one underwater box



128 3-inch PMTs connected to one underwater box

1 GHz waveform digitization, expected loss rate < 0.5% in 6 years



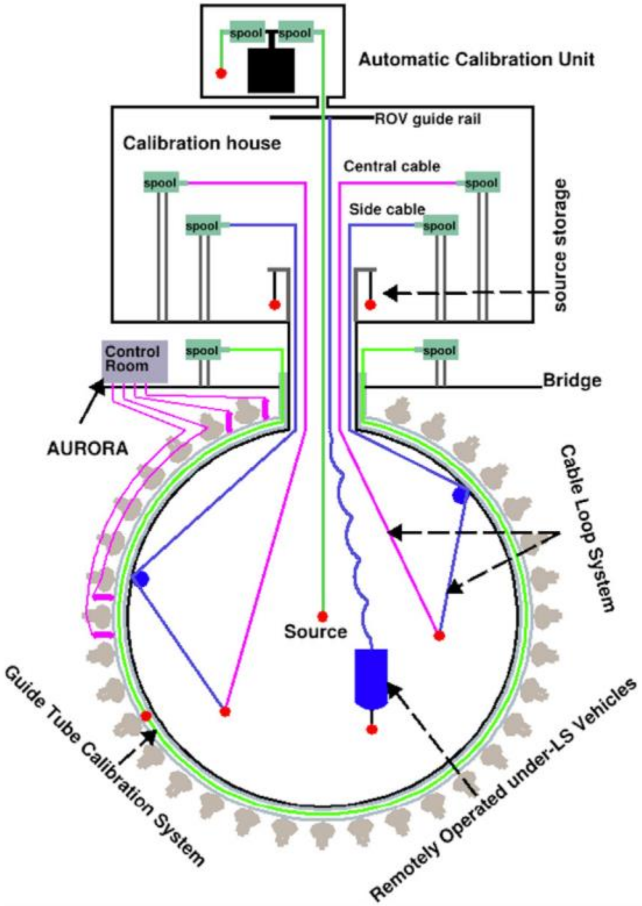
↑

Electronics assembly and tests done

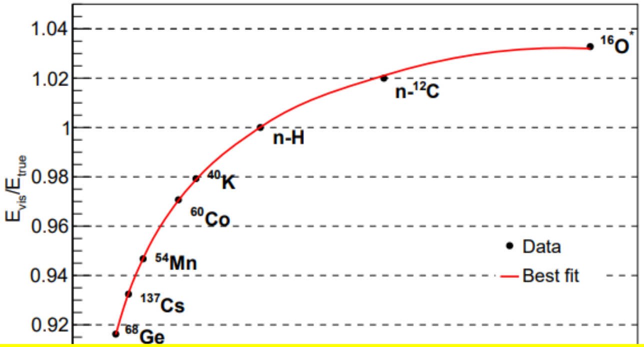
Calibration

1D,2D,3D scan systems with multiple calibration sources

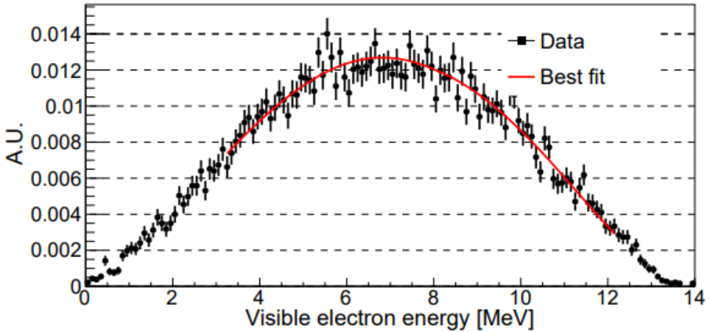
Cable system finished prototype test



Calibrate energy scale to better than 1% using gamma peaks and cosmogenic ^{12}B beta spectrum



A general interest:
Precise prediction of beta shapes of cosmogenic light isotopes

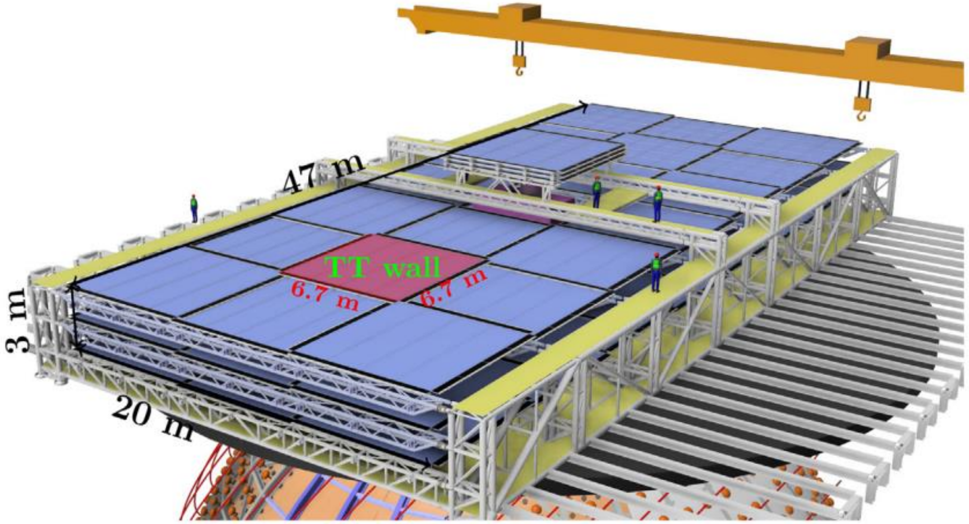


JHEP 03 (2021) 004

Muon veto system

~650 m rock overburden (1800 m.w.e.) → R_{μ} = 4 Hz in LS, $< E_{\mu} >$ = 207 GeV

- ✓ **About 127 ^{9}Li and 40 ^{8}He isotopes, but 57 antineutrinos per day**
- ✓ **Effective veto strategy keeps 47.1 antineutrinos but only 0.8 residual Li/He bkg**



35 kton of ultrapure water serving as passive shield and water Cherenkov detector.

- ✓ 2400 20-inch MCP PMTs, detection efficiency of cosmic muons larger than 99.5%

Plastic scintillator from the OPERA

- ✓ About 50% coverage on the top, three layers to reduce accidental coincidence
- ✓ All scintillator panels arrived on site in 2019

Radiopurity control

Reduced by 15% compared to the design. Ref: *JHEP* 11 (2021) 102

Singles (R < 17.2 m, E > 0.7 MeV)	Design [Hz]	Change [Hz]	Comment
LS	2.20	0	
Acrylic	3.61	**-3.2**	10 ppt -> 1 ppt
Metal in node	0.087	**+1.0**	Copper -> SS
PMT glass	0.33	**+2.47**	Schott -> NNVT/Ham
Rock	0.98	**-0.85**	3.2 m -> 4 m
Radon in water	1.31	**-1.25**	200 mBq/m^3 -> 10 mBq/m^3
Other	0	**+0.52**	Add PMT readout, calibration sys
Total	8.5	**-1.3**	

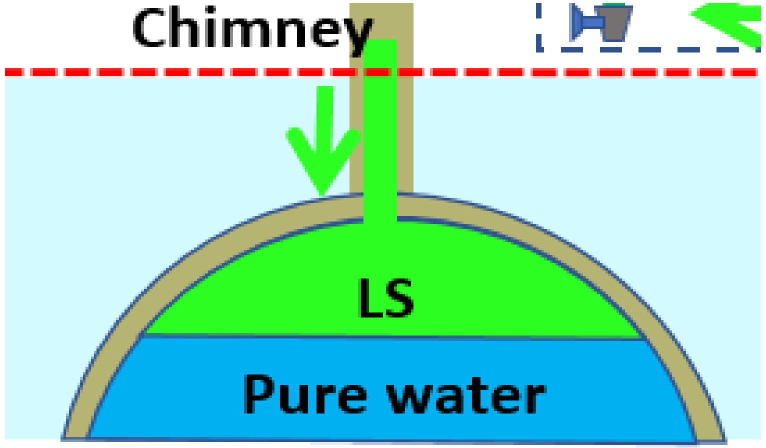
Radiopurity control on raw material:

- ✓ Careful material screening
- ✓ Meticulous Monte Carlo Simulation
- ✓ Accurate detector production handling

Liquid Scintillator Filling

- ✓ Recirculation is impossible at JUNO due to its large size
- → Target radiopurity need to be obtained from the beginning
- ✓ **Strategies:**

1. **Leakage** (single component < 10^{-6} mbar·L/s)
2. **Cleaning vessel** before filling
3. **Clean environment**
4. **Water/LS filling**



Watching nuclear reactors, the Solar System, and the Milky Way at Jiangmen

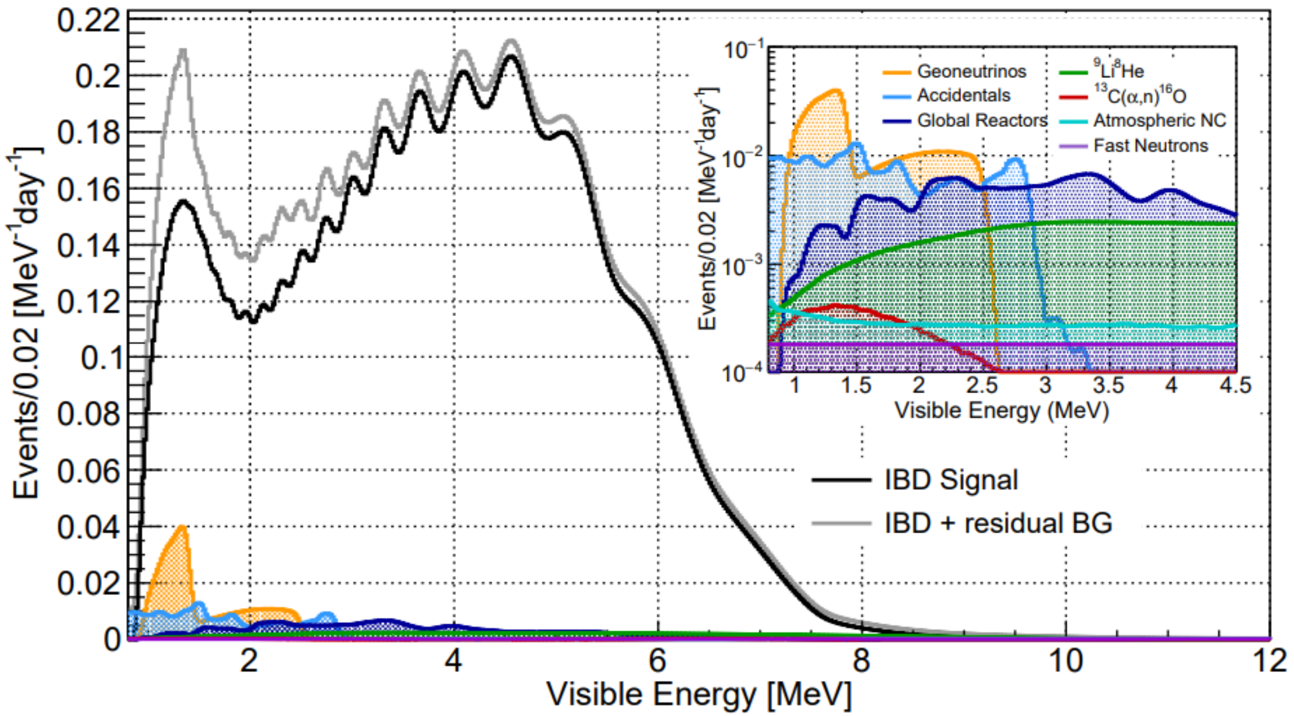
Reactor neutrino oscillation

Inverse beta decay reaction

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

$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e} = 1 - \sin^2 2\theta_{13}(\cos^2\theta_{12}\sin^2\Delta_{31} + \sin^2\theta_{12}\sin^2\Delta_{32}) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21}$$

(matter effect contributes maximal ~4% correction at around 3 MeV, *arXiv:1605.00900, arXiv:1910.12900*)



Event type	Rate [/day]	Relative rate uncertainty	Shape uncertainty
Reactor IBD signal	60 → 47	-	-
Geo-ν's	1.1 → 1.2	30%	5%
Accidental signals	0.9 → 0.8	1%	negligible
Fast-n	0.1	100%	20%
^{9}Li/ ^{8}He	1.6 → 0.8	20%	10%
$^{13}C(\alpha, n)^{16}O$	0.05	50%	50%
Global reactors	0 → 1.0	**2%**	**5%**
Atmospheric ν's	0 → 0.16	**50%**	**50%**

Design in Physics book → **this update**

J. Phys. G 43:030401 (2016)

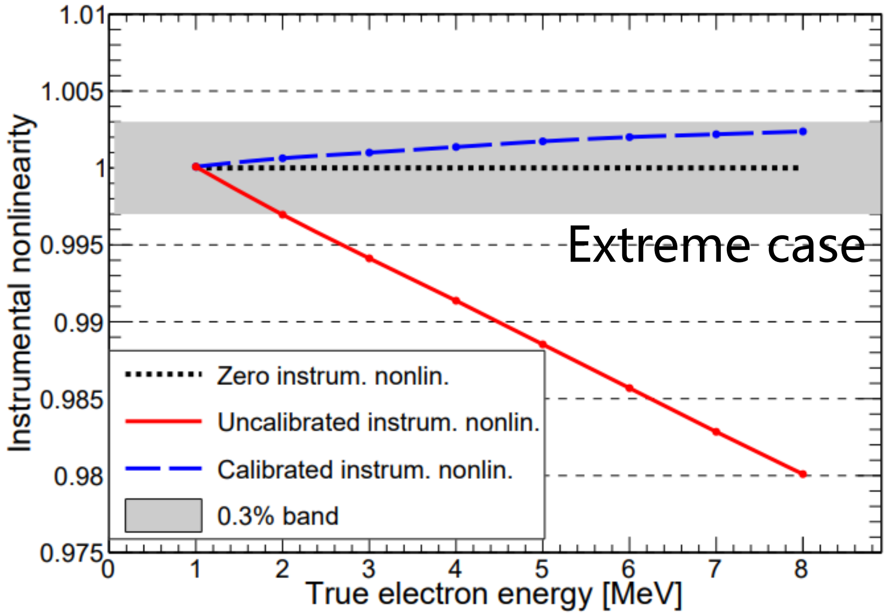
Energy nonlinearity

Energy nonlinearity: instrumental charge measurement and LS nonlinear light output

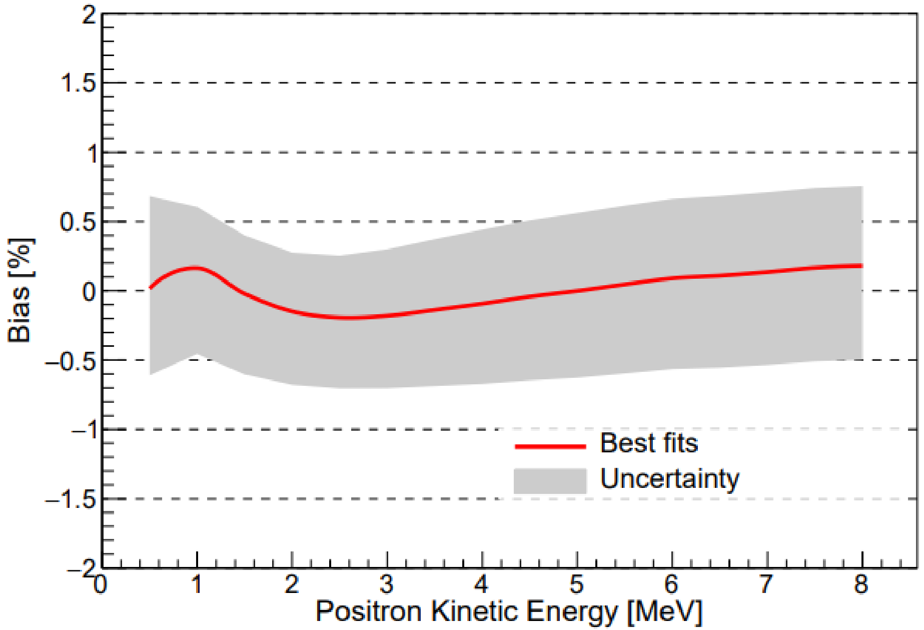
- ✓ **Instrumental nonlinearity calibrated with synergetic 20-inch and 3-inch PMT systems**
- ✓ **LS nonlinearity calibrated with gamma sources and cosmogenic ^{12}B isotopes**

Prospects

- ✓ **Better understanding and bench-top measurements of LS optical properties**
- ✓ **Use more cosmogenic isotopes in the energy calibration, ^{10}C, ^{11}C, ^{12}N, ^{6}He and others**



JHEP 03 (2021) 004



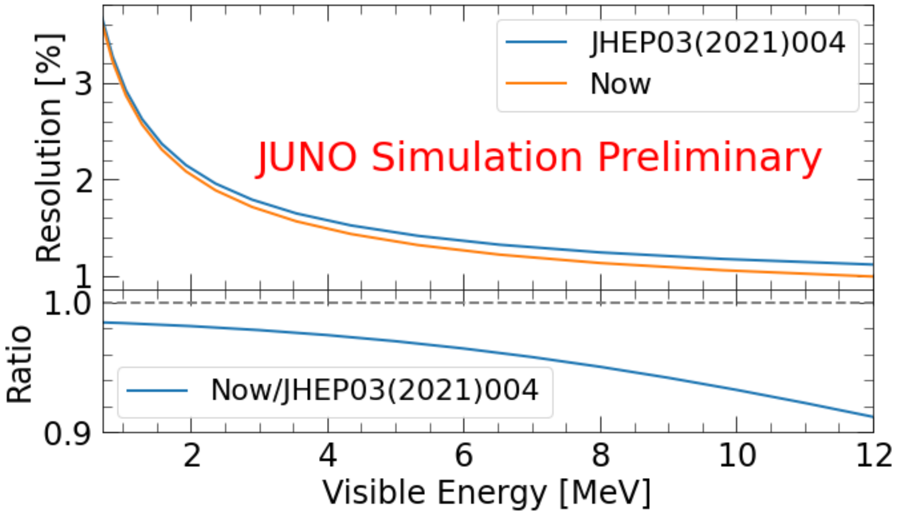
Update of energy resolution

Change	Light yield in detector center [PEs/MeV]	Energy resolution	Reference
Previous estimation	1345	3.0% @1MeV	*JHEP03(2021)004*
Photon Detection Efficiency (27%→30%)	+11%↑	**2.9% @ 1MeV**	arXiv: 2205.08629 *EPJC 82 329 (2022)*
New Central Detector Geometries	+3%↑		
New PMT Optical Model	+8%↑		

Positron energy resolution is understood:

$$\frac{\sigma}{E_{\mathrm{vis}}} = \sqrt{\left(\frac{a}{\sqrt{E_{\mathrm{vis}}}}\right)^2 + b^2 + \left(\frac{c}{E_{\mathrm{vis}}}\right)^2}$$

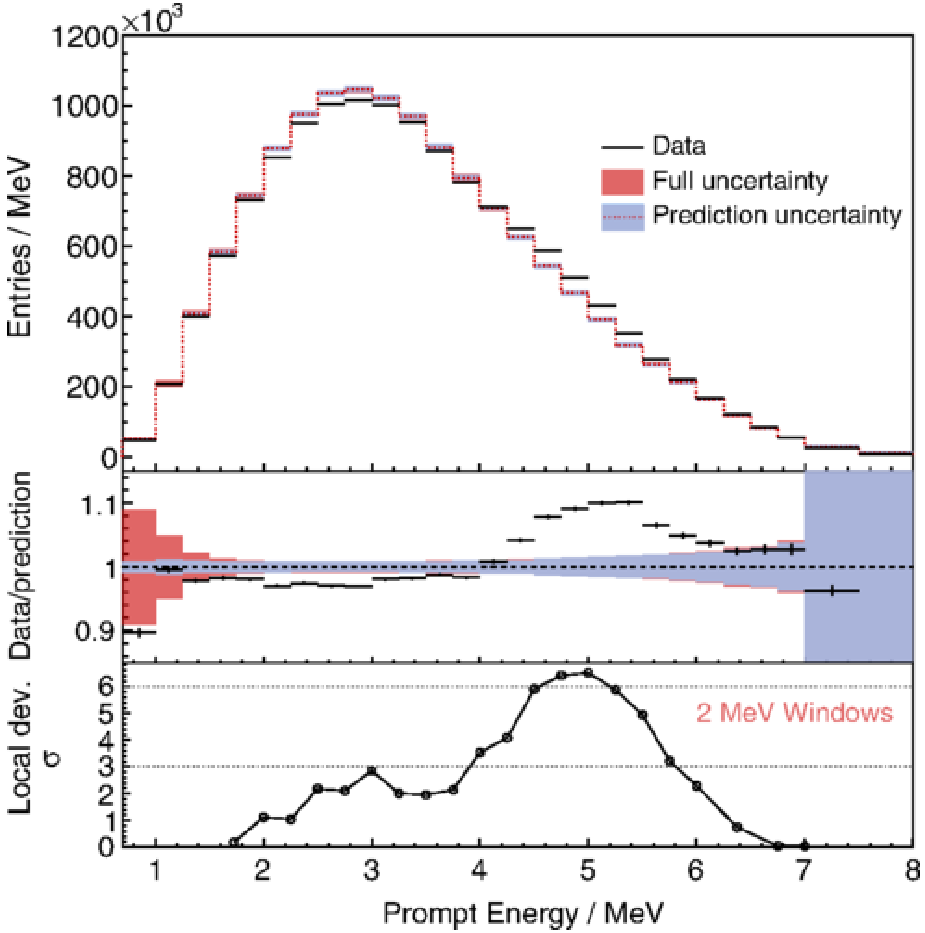
- **Photon statistics**
- **Annihilation-induced γs**
- **Dark noise**
- **Scintillation quenching effect**
  - LS Birks constant from table-top measurements
- **Cherenkov radiation**
  - Cherenkov yield factor (refractive index & re-emission probability) is re-constrained with Daya Bay LS non-linearity
- **Detector uniformity and reconstruction**



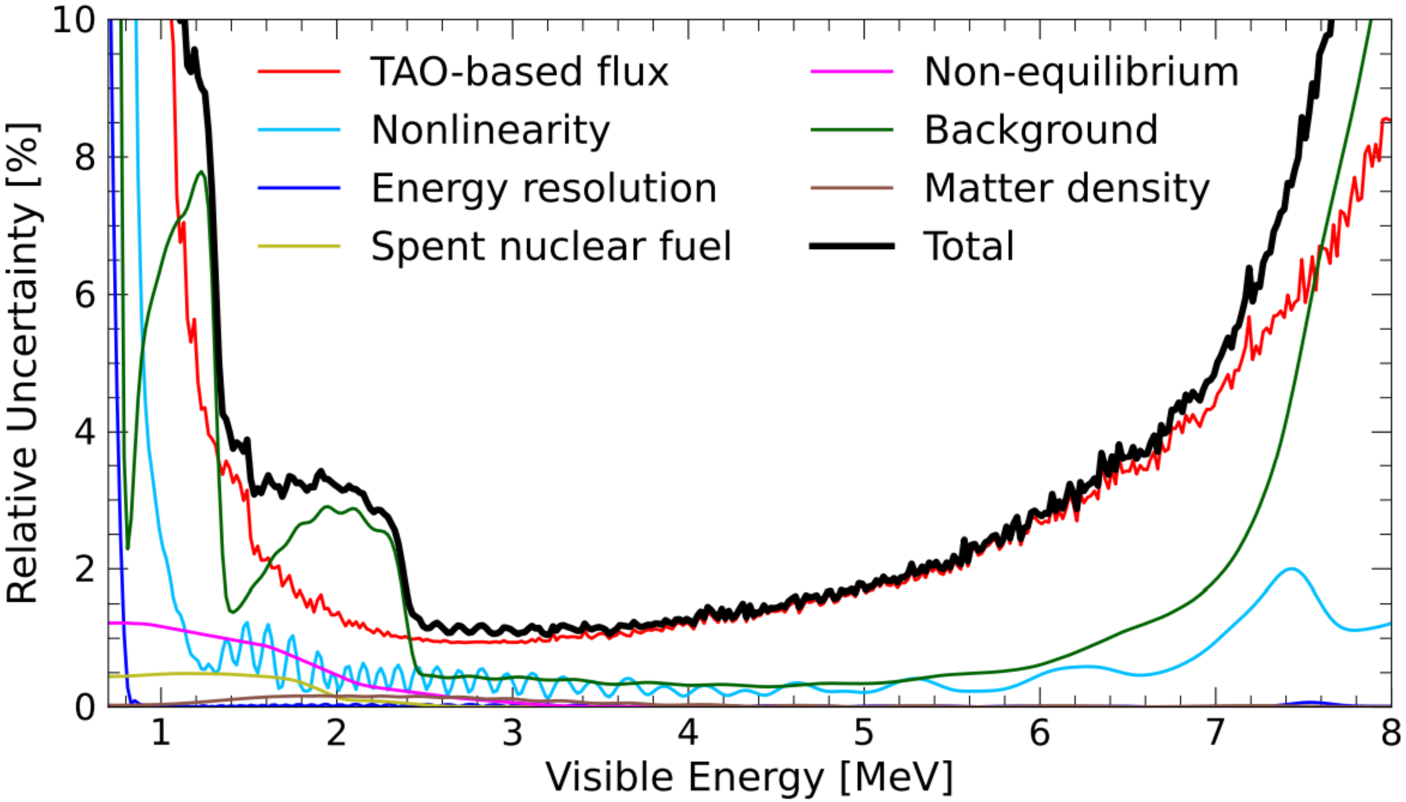
JUNO and TAO combined analysis

Precise measurement of neutrino oscillation requires precise reactor neutrino shape
Fitter level joint analysis between JUNO and TAO

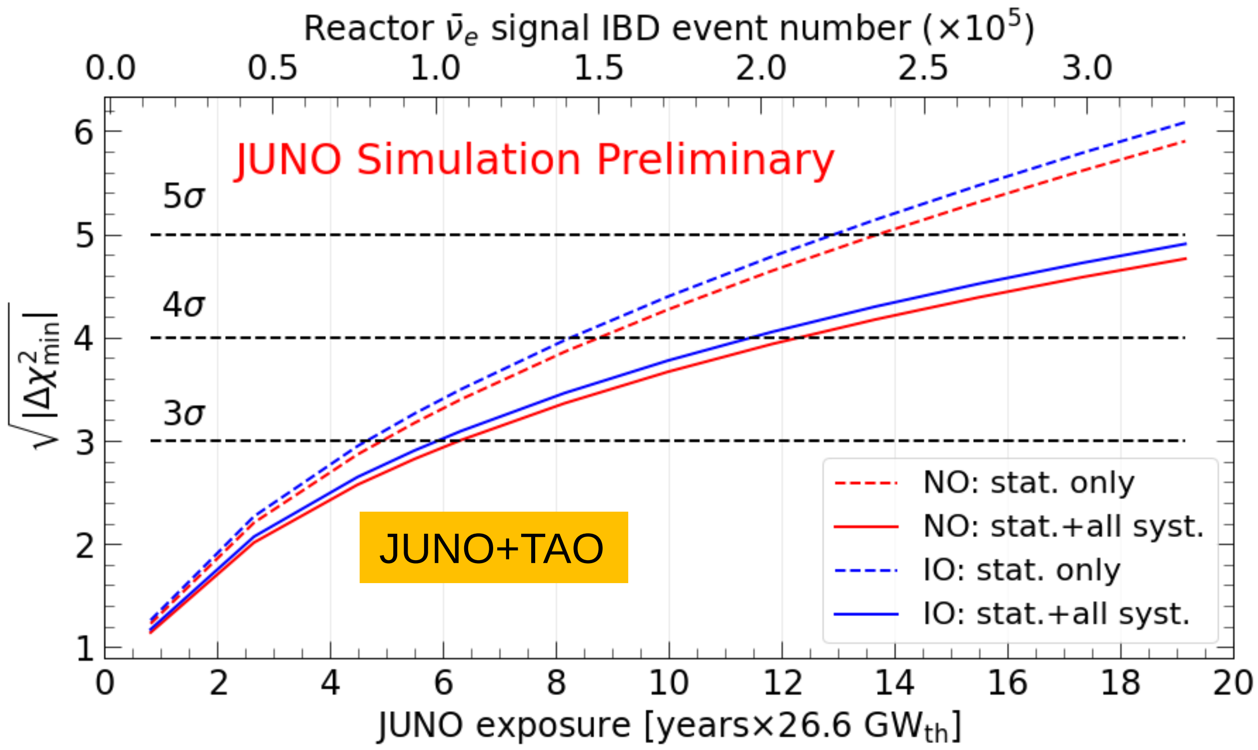
From Daya Bay Phys. Rev. Lett. **123**, 111801



TAO will measure the shape to 1% precision



Neutrino Mass Ordering

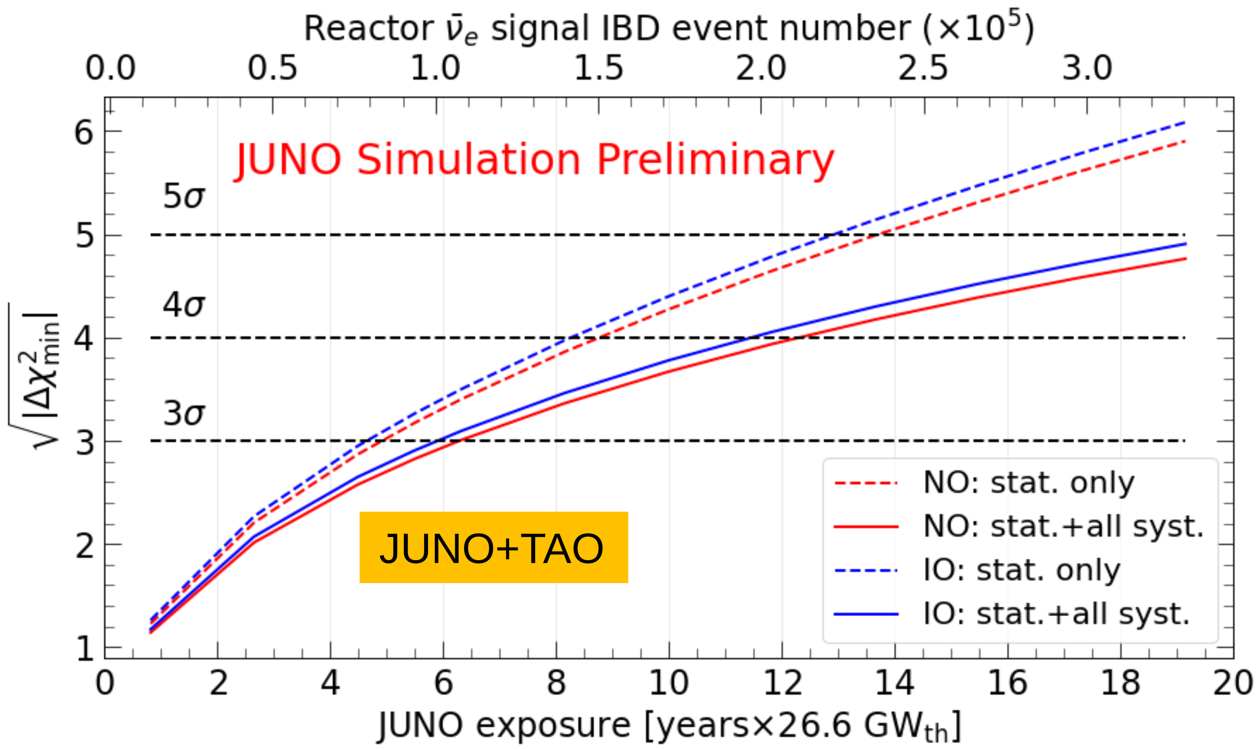


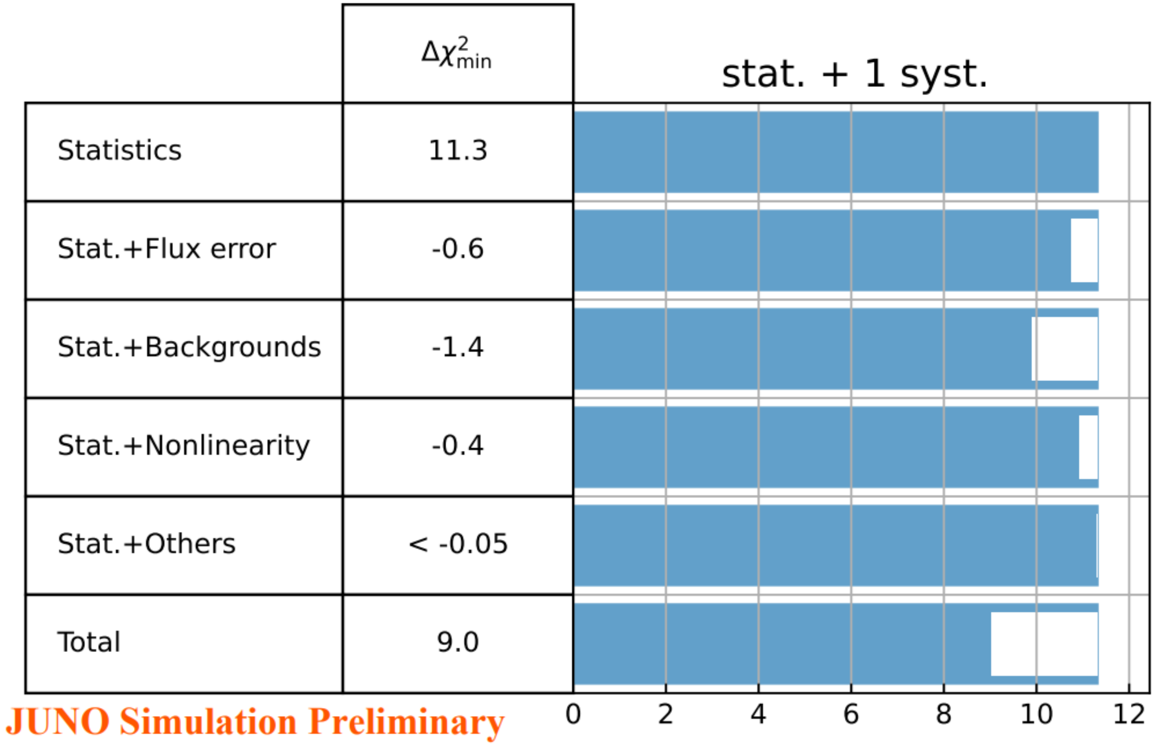
	Design (**J. Phys. G 43:030401 (2016)**)	**Now (2022)**
Thermal Power	36 GW_{th}	**26.6 GW_{th} (26%↓)**
Overburden	~700 m	~650 m
Muon flux in LS	3 Hz	**4 Hz (33%↑)**
Muon veto efficiency	83%	**93% (12%↑)**
Signal rate	60 /day	**47.1 /day (22%↓)**
Backgrounds	3.75 /day	**4.11 /day (10%↑)**
Energy resolution	3% @ 1 MeV	**2.9% @ 1 MeV (3%↑)**
Shape uncertainty	1%	**JUNO+TAO**
3σ NMO sensitivity exposure	< 6 yrs × 35.8 GW_{th}	~ 6 yrs × 26.6 GW_{th}

JUNO sensitivity on NMO: **3σ (reactors only) @ ~6 yrs * 26.6 GW_{th} exposure. Paper coming soon.**

Estimation of NMO sensitivity with combined reactor + atmospheric neutrino analysis under preparation

Neutrino Mass Ordering





	$\Delta\chi^2_{\mathrm{min}}$
Statistics	11.3
Stat.+Flux error	-0.6
Stat.+Backgrounds	-1.4
Stat.+Nonlinearity	-0.4
Stat.+Others	< -0.05
Total	9.0

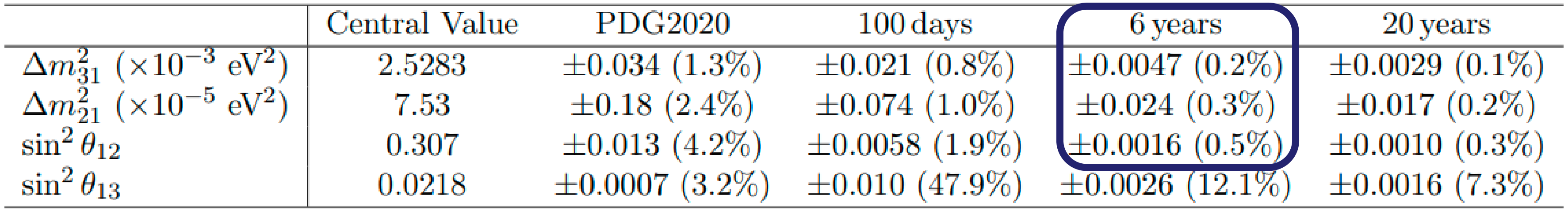
JUNO sensitivity on NMO: **3σ (reactors only) @ ~6 yrs * 26.6 $\mathrm{GW_{th}}$ exposure. Paper coming soon.**

Estimation of NMO sensitivity with combined reactor + atmospheric neutrino analysis under preparation

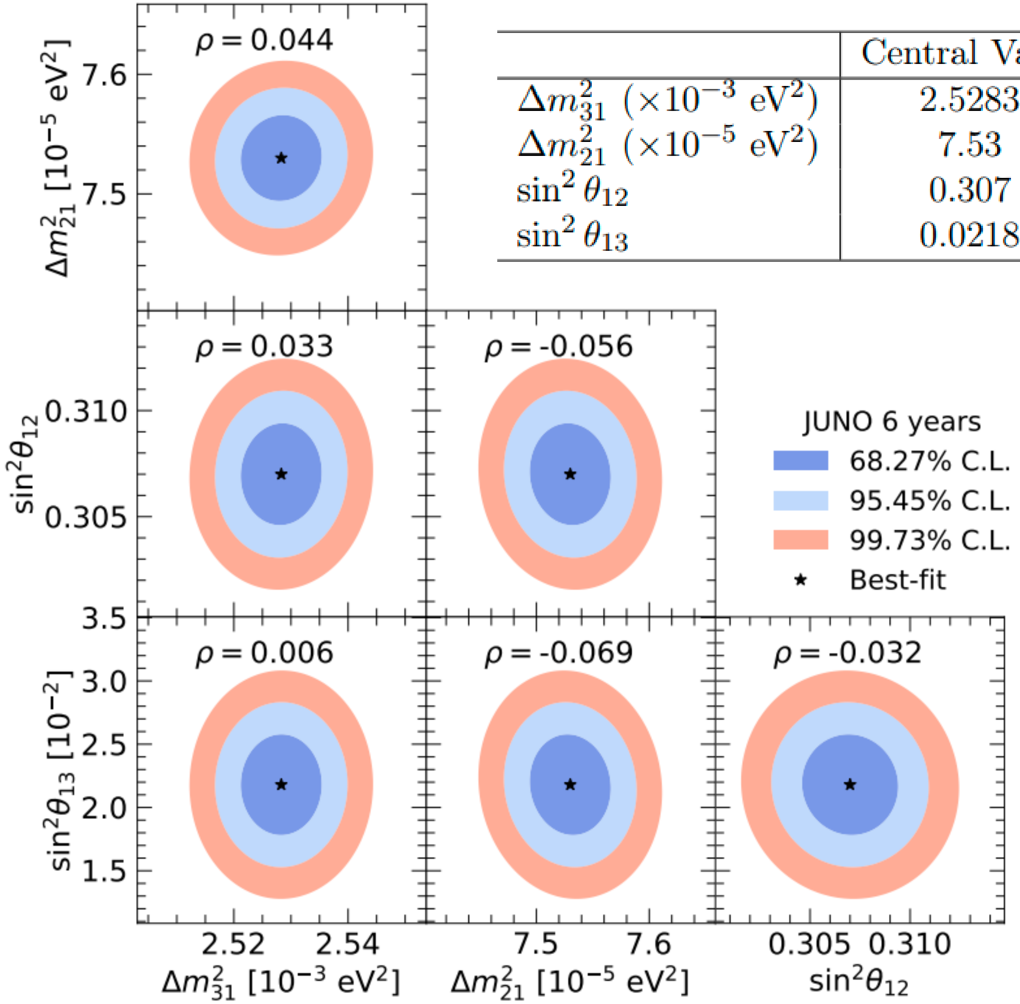
Neutrino oscillation parameters

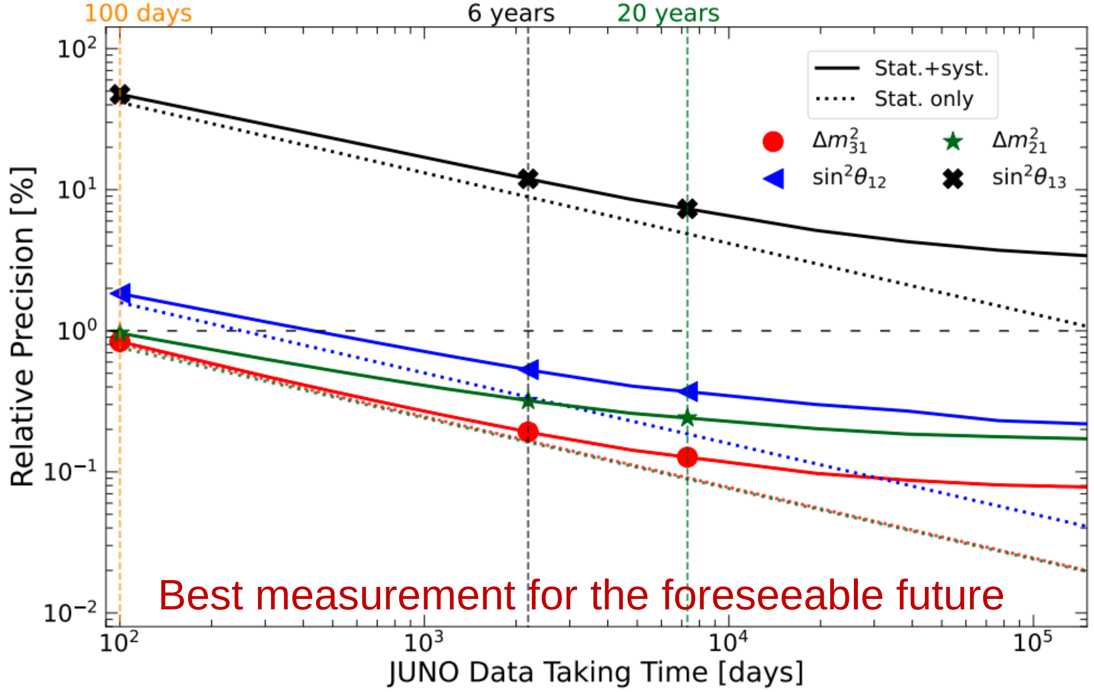
Chin.Phys.C 46 (2022) 12, 123001

Precision of $\sin^2 2\theta_{12}$, Δm^2_{21}, $|\Delta m^2_{32}|$ < 0.5% in 6 yrs



	Central Value	PDG2020	100 days	6 years	20 years
Δm^2_{31} ($\times 10^{-3}$ eV^2)	2.5283	±0.034 (1.3%)	±0.021 (0.8%)	±0.0047 (0.2%)	±0.0029 (0.1%)
Δm^2_{21} ($\times 10^{-5}$ eV^2)	7.53	±0.18 (2.4%)	±0.074 (1.0%)	±0.024 (0.3%)	±0.017 (0.2%)
$\sin^2\theta_{12}$	0.307	±0.013 (4.2%)	±0.0058 (1.9%)	±0.0016 (0.5%)	±0.0010 (0.3%)
$\sin^2\theta_{13}$	0.0218	±0.0007 (3.2%)	±0.010 (47.9%)	±0.0026 (12.1%)	±0.0016 (7.3%)



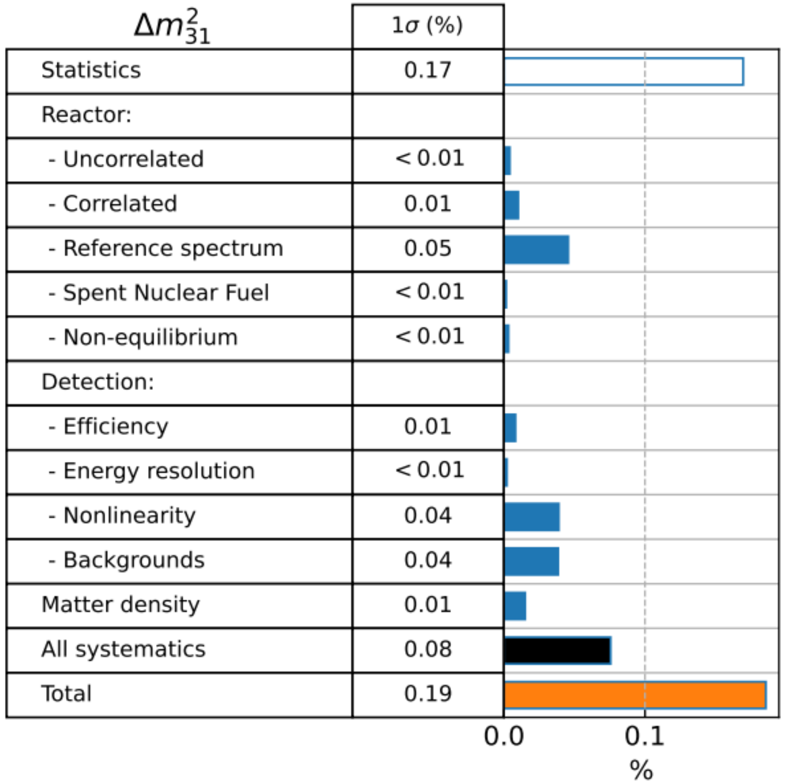


Best measurement for the foreseeable future

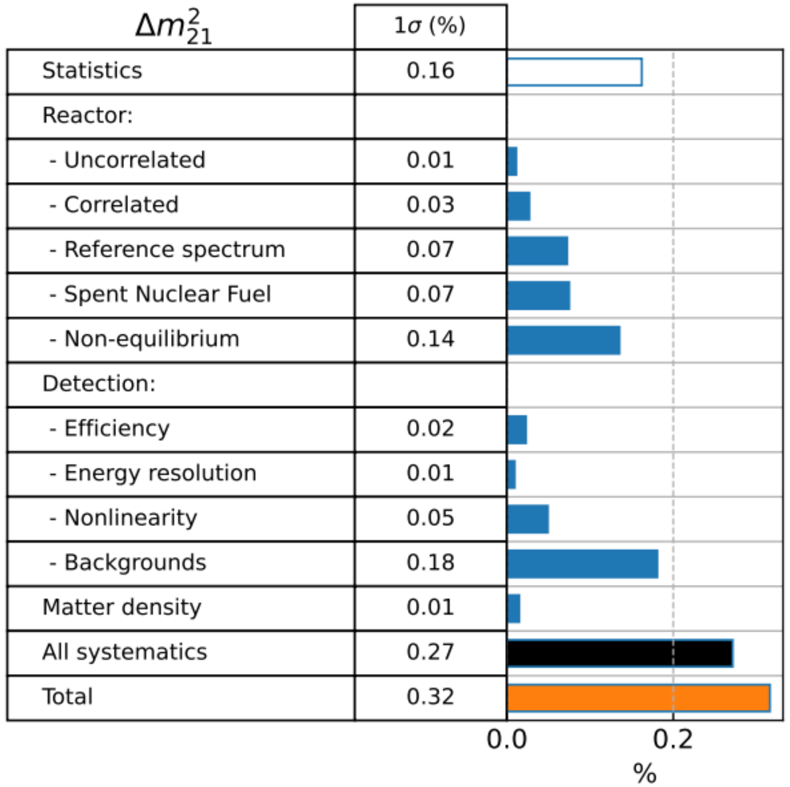
The improvement in precision over existing constraints will be about one order of magnitude

Neutrino oscillation parameters

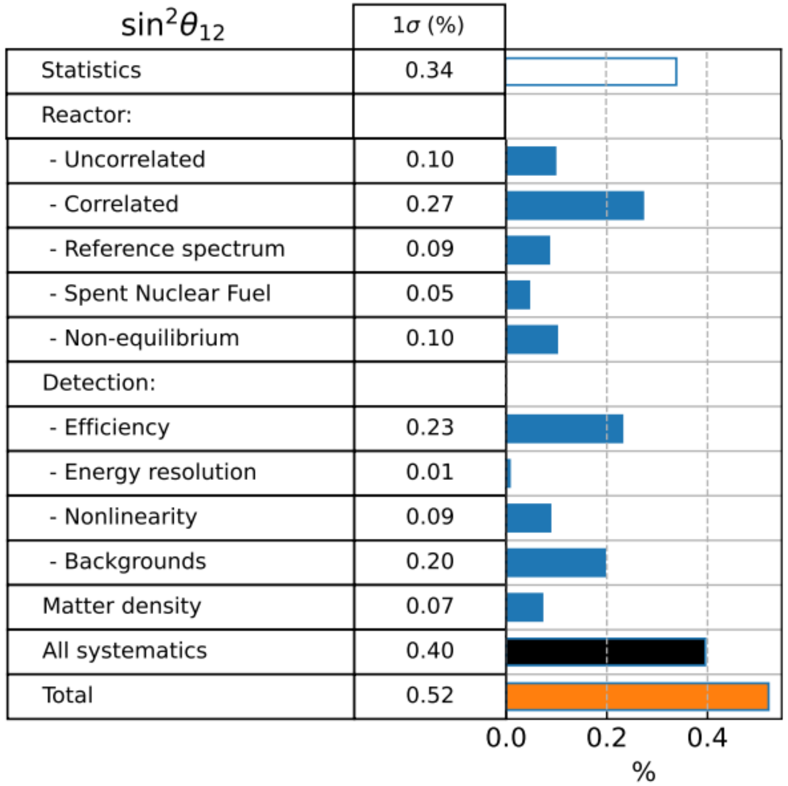
- Solar parameters, θ_{12} and Δm^2_{21}, dominated by systematics
    - Improving reactor-related systematics, such as SNF and Non-equilibrium, both with 30% input uncertainties, could slightly improve Δm^2_{21} precision



Δm^2_{31}	1σ (%)
Statistics	0.17
Reactor:	
- Uncorrelated	< 0.01
- Correlated	0.01
- Reference spectrum	0.05
- Spent Nuclear Fuel	< 0.01
- Non-equilibrium	< 0.01
Detection:	
- Efficiency	0.01
- Energy resolution	< 0.01
- Nonlinearity	0.04
- Backgrounds	0.04
Matter density	0.01
All systematics	0.08
Total	0.19



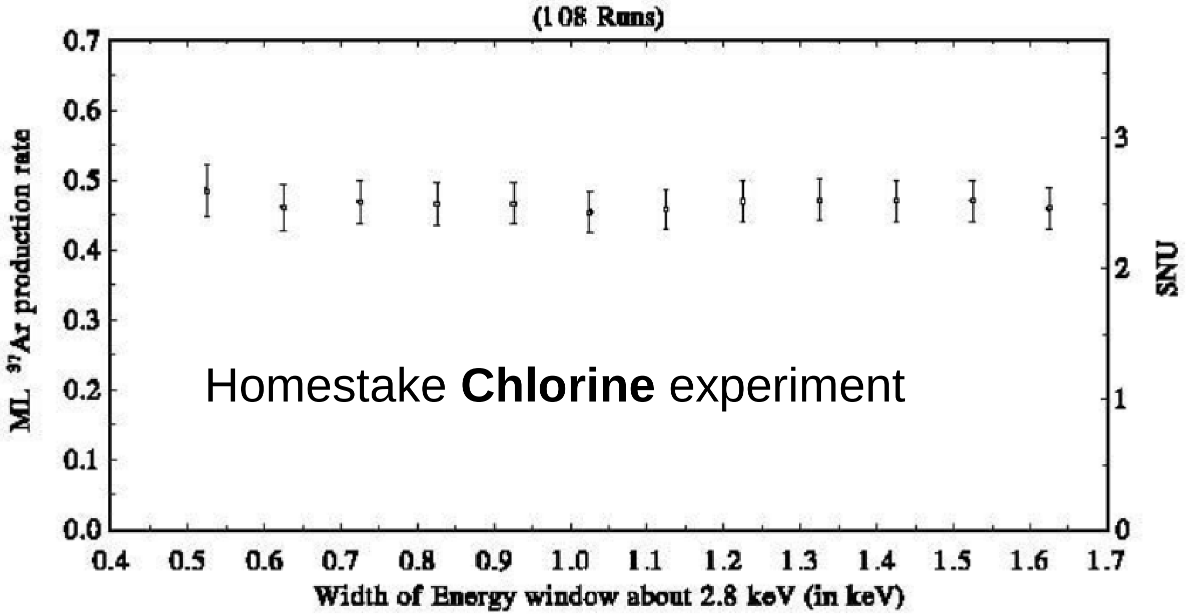
Δm^2_{21}	1σ (%)
Statistics	0.16
Reactor:	
- Uncorrelated	0.01
- Correlated	0.03
- Reference spectrum	0.07
- Spent Nuclear Fuel	0.07
- Non-equilibrium	0.14
Detection:	
- Efficiency	0.02
- Energy resolution	0.01
- Nonlinearity	0.05
- Backgrounds	0.18
Matter density	0.01
All systematics	0.27
Total	0.32



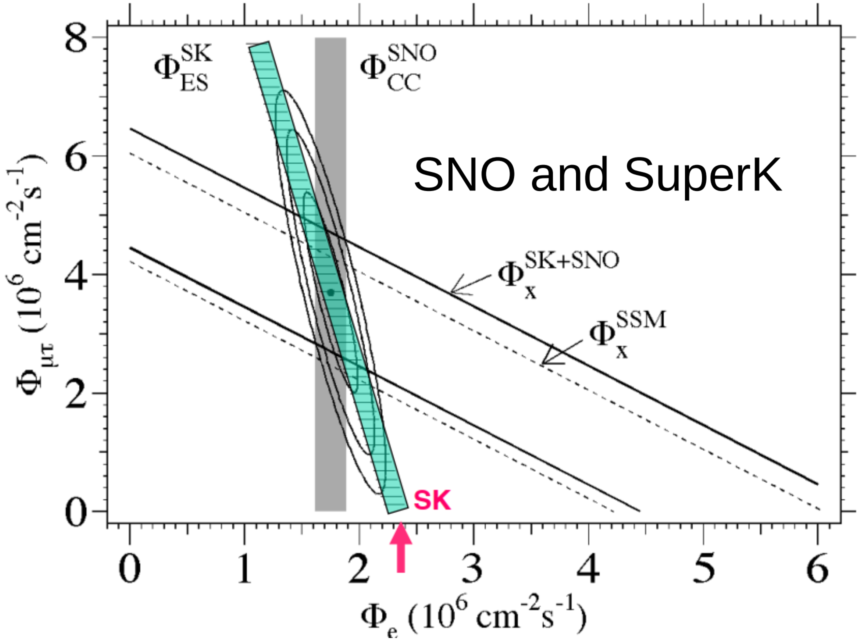
$\sin^2\theta_{12}$	1σ (%)
Statistics	0.34
Reactor:	
- Uncorrelated	0.10
- Correlated	0.27
- Reference spectrum	0.09
- Spent Nuclear Fuel	0.05
- Non-equilibrium	0.10
Detection:	
- Efficiency	0.23
- Energy resolution	0.01
- Nonlinearity	0.09
- Backgrounds	0.20
Matter density	0.07
All systematics	0.40
Total	0.52

Solar neutrinos

A research area that neutrino and nuclear physics collaborated well



Homestake **Chlorine** experiment

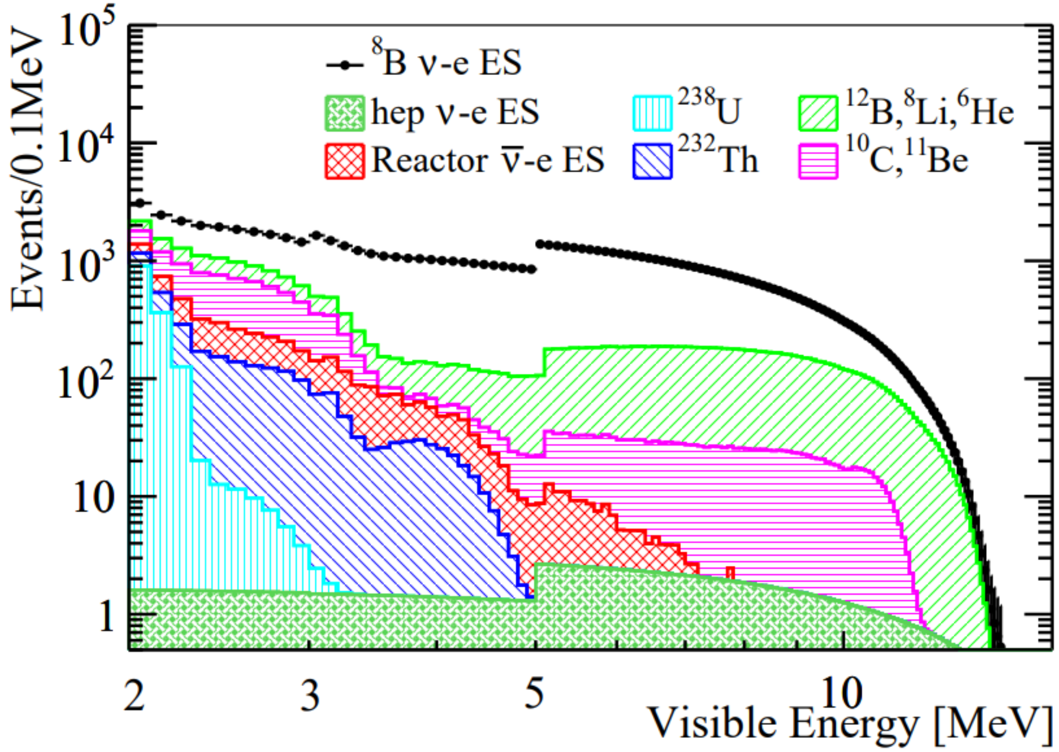


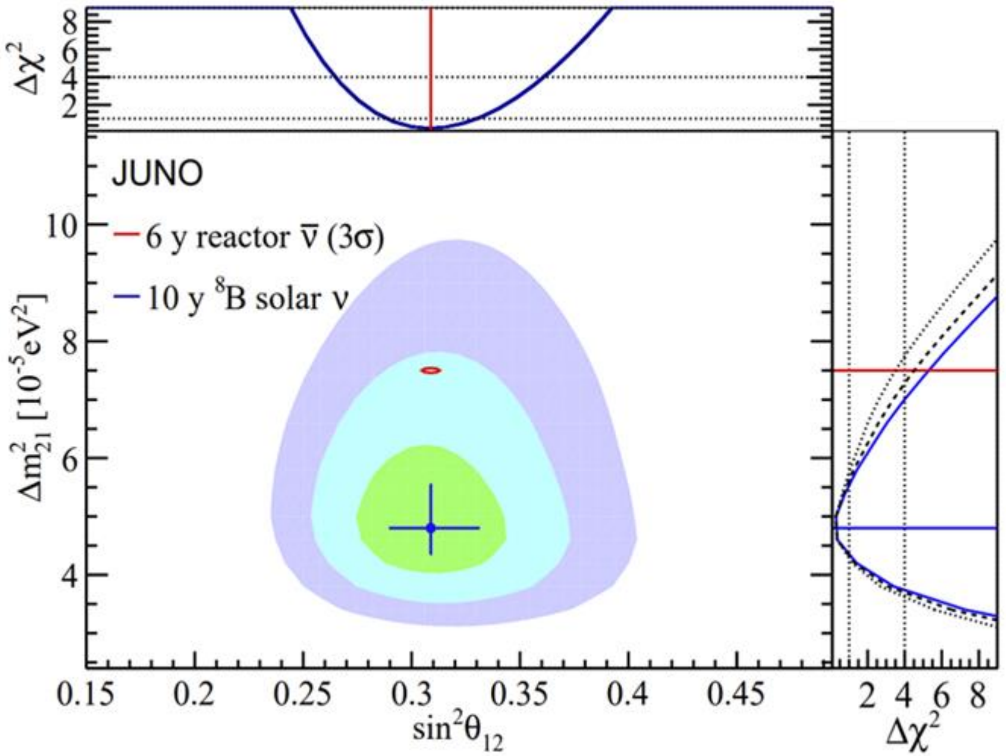
SNO and SuperK

- ✓ Large ^{3}He + ^{4}He fusion sigma, 1958
- ✓ Transition from (g.s) of ^{37}Cl to 5.1MeV state of ^{37}Ar is super allowed, 1963
- ✓ Improvements of ^{8}B neutrino shape prediction from 1980s to 2010s
  - ✓ Energy level distributions of ^{8}Be first excited state

Plots from the 5th solar neutrino conference in 2018

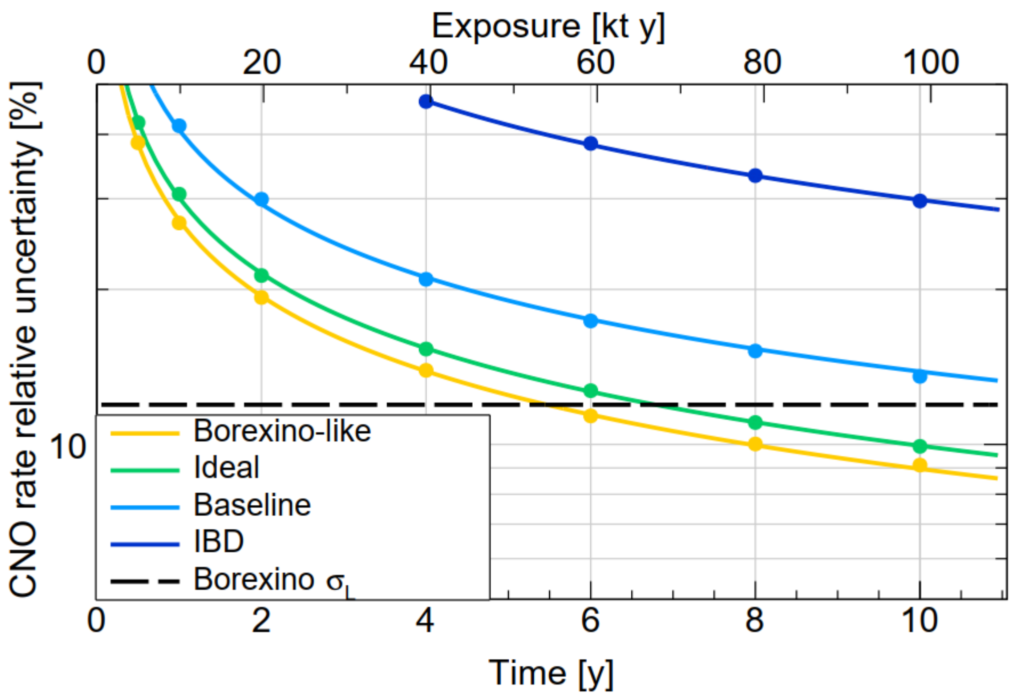
^{8}B solar neutrinos in JUNO

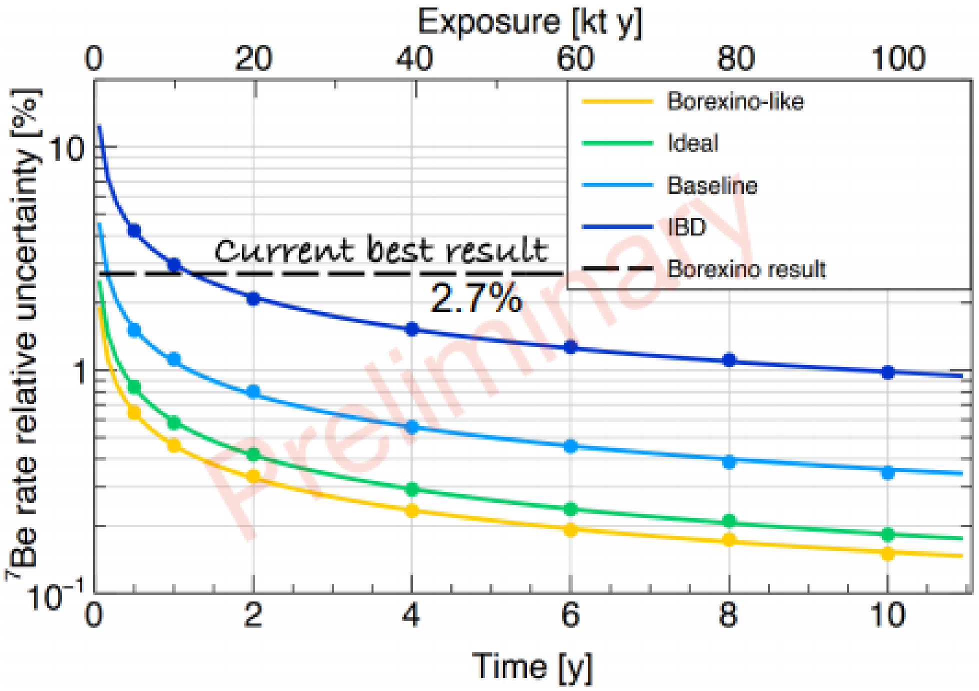




- Use ^{8}B solar neutrinos to measure θ_{12} and Δm^2_{21}, similar precision with current solar experiments
- Dominated background：cosmogenic light isotopes

Solar neutrinos in JUNO





- Could measure simultaneously ^{7}Be, pep and CNO solar neutrinos with highly improved accuracy with respect to current state-of-the-art in the solar neutrino field
- Could be sensitive to ^{13}N and ^{15}O neutrinos
- Provide probes of solar physics

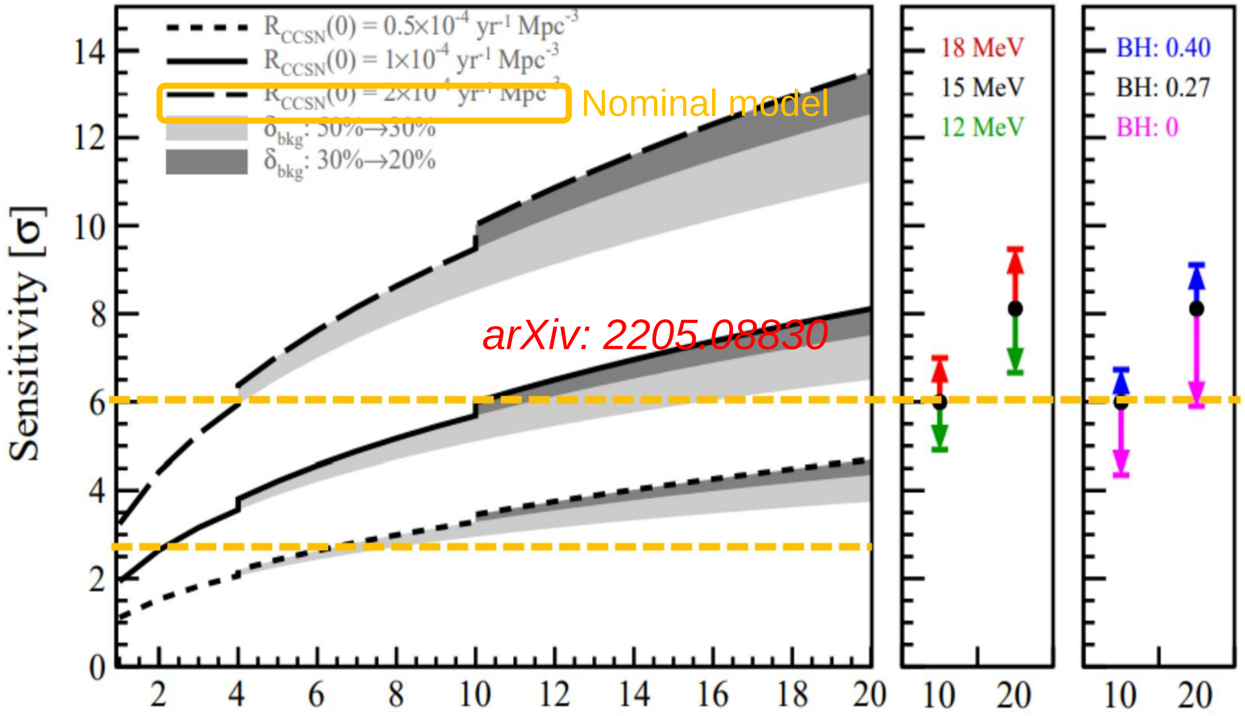
Diffuse Supernova Neutrino Background

Improvements: background evaluation (0.7 per year → 0.54 per year),

pulse shape discrimination (signal efficiency 50%→80%),

better DSNB signal model (non-zero fraction of failed Supernova)

S/B improved from 2 to 3.5

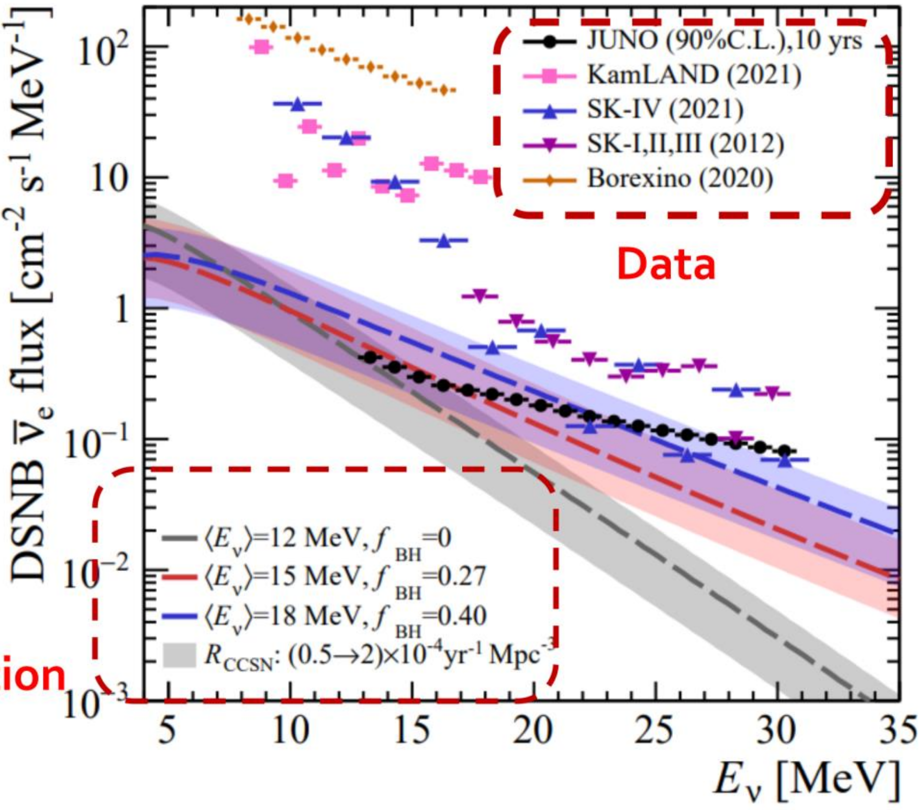


Nominal model

arXiv: 2205.08830

DSNB discovery potential: 3σ in 3 yrs with nominal model

JCAP 10 (2022) 033

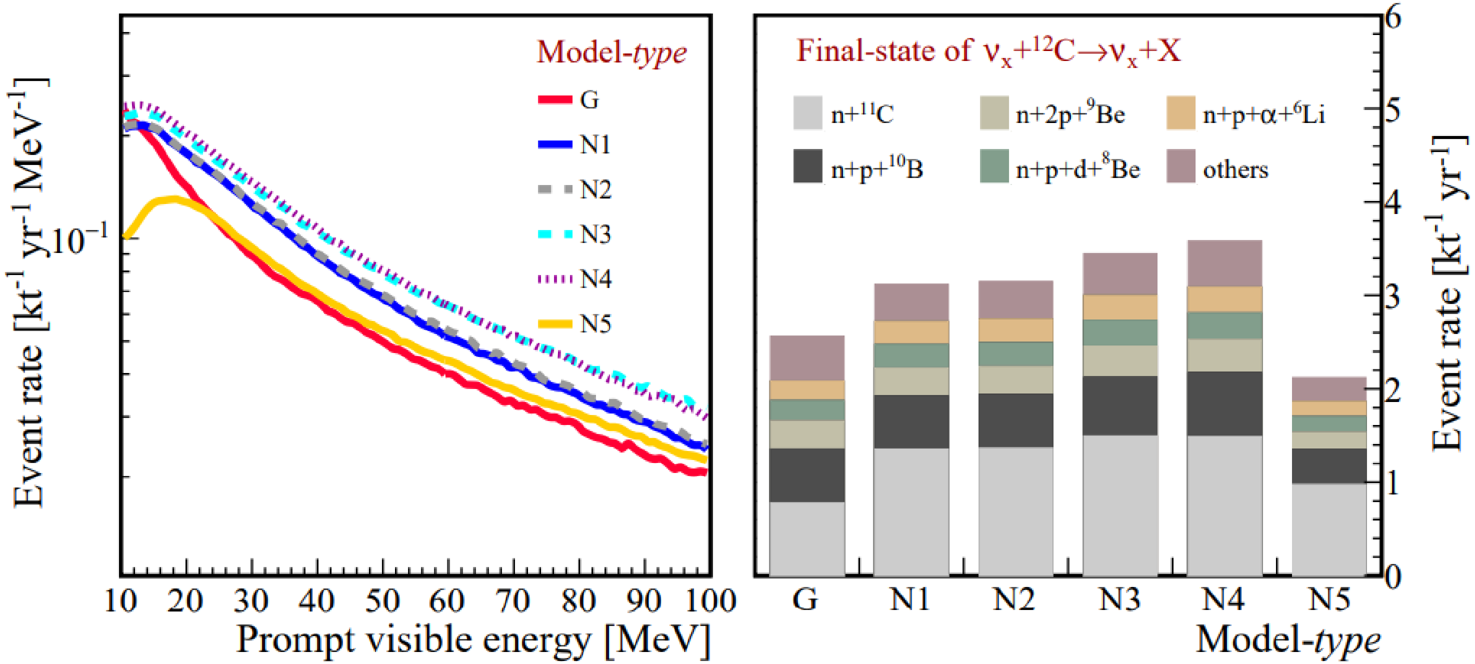


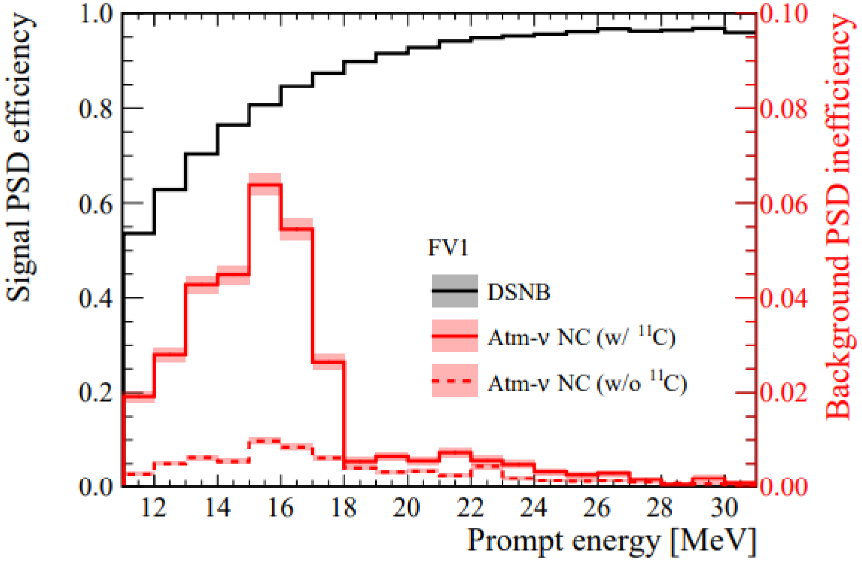
Data

Model prediction

Diffuse Supernova Neutrino Background

- Dominated background: neutral current of atmospheric neutrinos and ^{12}C nuclei
- Use common generator GENIE and NuWro to predict neutrino interactions
  - A statistical configuration model to determine the pdf of excited states in the final-state nuclei
- Use TALYS to perform de-excitation
  - De-excited gammas induce the energy-dependent background rejection ratio

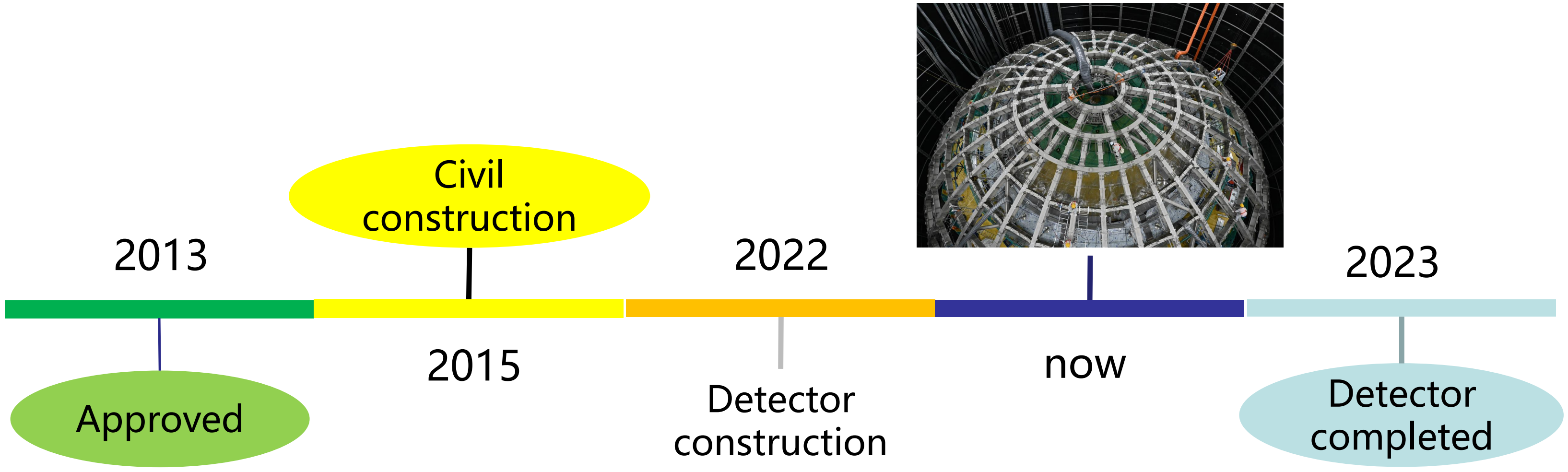




Summary

- ✓ **Detector assembly is moving forward smoothly, expected to finish in this year**
- ✓ **Physics sensitivities have been investigated thoroughly**

- **Neutrino physics in JUNO will gain benefits from nuclear community**
  - **Briefly summarized in this talk, of course not all topics are covered**



2013

Approved

2015

Civil construction

2022

Detector construction

now

2023

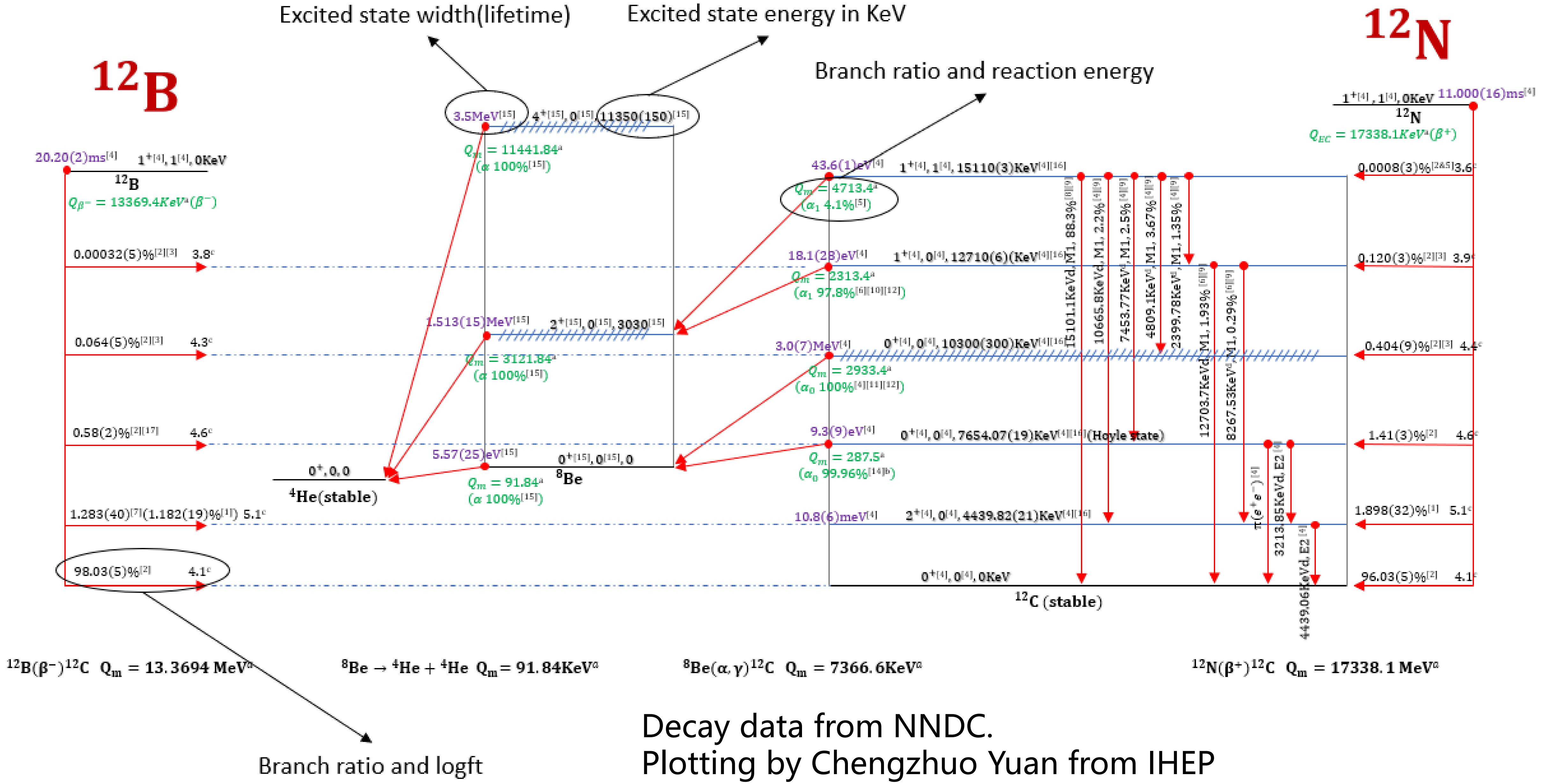
Detector completed

Light unstable isotopes

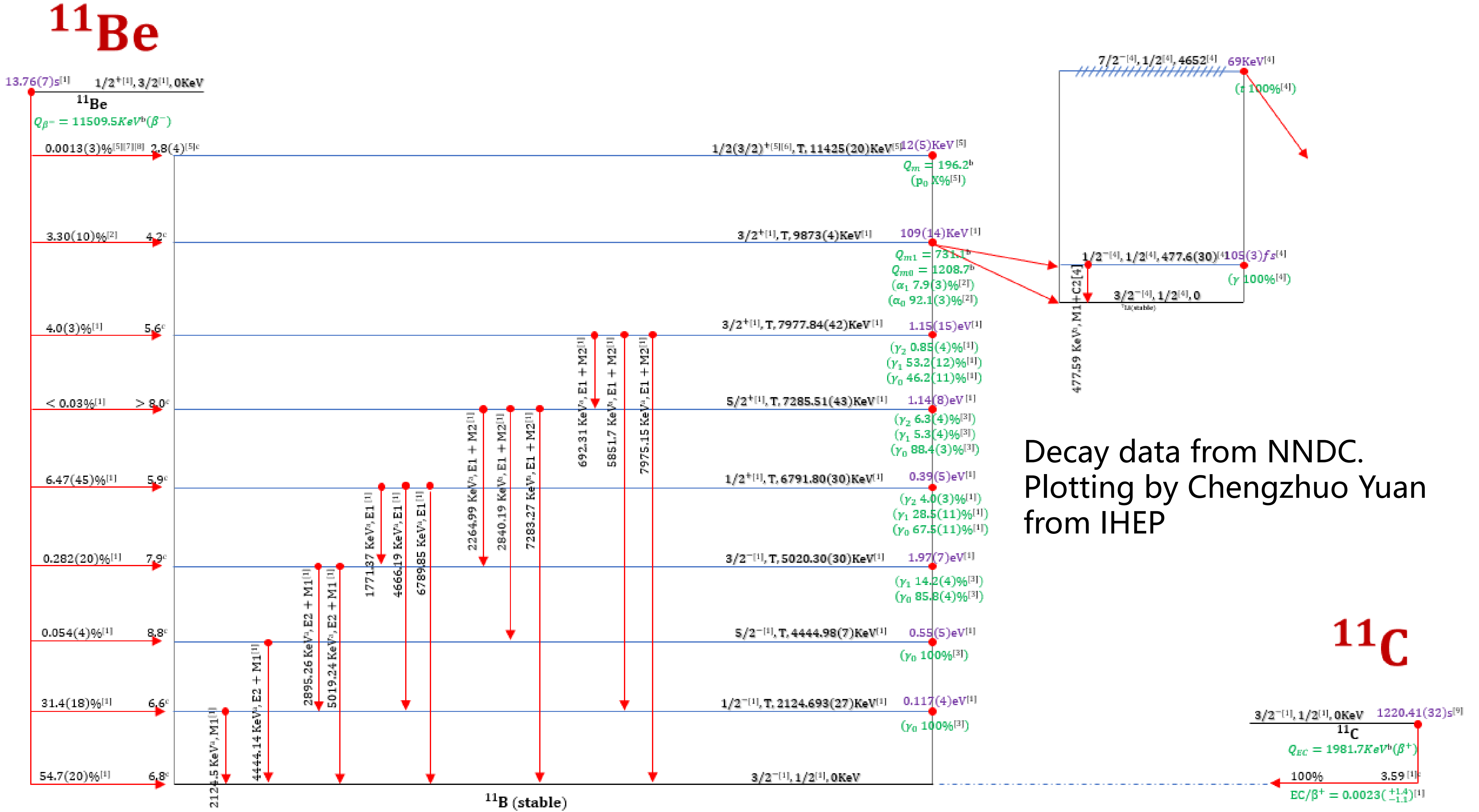
	Lifetime	Radiation energy (MeV)	Primary process	
Neutron	30us in GdLS 200us in LS	8 (nGd) 2.2 (nH)	$\pi^- + {}^1H$	
^{12}N	15.9 ms	17.34 (β^+)	$^{12}C(p,n)^{12}N$	Calibration
^{12}B	29.1 ms	13.37 (β^-)	$^{12}C(n,p)^{12}B$, $^{12}C(\mu^-,\nu_\mu)^{12}B$	Calibration
^{8}He	171.7 ms	10.65 $(\beta^- n)$	$^{12}C(\pi^-,nppp)^{8}He$	Critical bkg
^{9}C	182.5 ms	16.50 (β^+)	$^{12}C(\pi^+,{}^3H)^{9}C$	Critical bkg
^{9}Li	257.2 ms	13.61 $(\beta^- n)$	$^{12}C(\pi^-,{}^3He)^{9}Li$	Critical bkg
^{8}B	1110 ms	17.98 $(\beta^+\alpha)$	$^{12}C(\pi^+,{}^2H{}^2H)^{8}B$	Critical bkg
^{8}Li	1210 ms	16.00 $(\beta^-\alpha)$	$^{12}C(n,p\alpha)^{8}Li$	Critical bkg
^{11}Be	19.9 s	11.50 (β^-)	$^{12}C(n,pp)^{11}Be$	Critical bkg
^{10}C	27.8 s	3.65 $(\beta^+\gamma)$	$^{12}C(\pi^+,np)^{10}C$	Calibration?
^{11}C	29.4 min	1.98 (β^+)	$^{12}C(\gamma,n)^{11}C$	Calibration?

Discussions

- **Our needs**
  - **Precise shape predictions, not only for beta spectra, but also for accompanying alphas and neutrons.**
  - **Critical for detector calibration and background understanding**
- **Our questions and current problems**
  - **How to estimate shape uncertainties for the common beta shape prediction methods?**
    - **Fermi function + several corrections**
  - **Can we rely on the J^{π} in the nuclear database and calculate beta shape correction?**
  - **Decay generators, such as BetaShape, Geant4 don't fine tune the shape of light nuclei**



Decay data from NNDC.
Plotting by Chengzhuo Yuan from IHEP



Decay data from NNDC.
Plotting by Chengzhuo Yuan
from IHEP

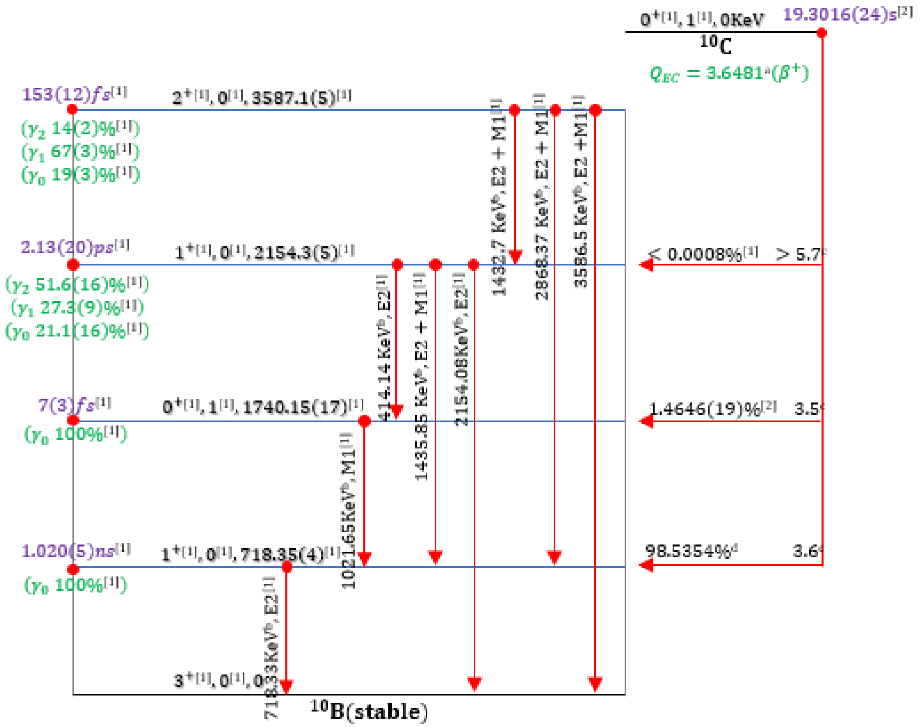
$^{11}Be(\beta^-)^{11}B$ $Q_m = 11.5095\ MeV^b$

$^{7}Li(\alpha,\gamma)^{11}B$ $Q_m = 8.6643MeV^b$
$^{10}Be(t,\gamma)^{11}B$ $Q_m = 11.2238MeV^b$
$^{10}Be(p,\gamma)^{11}B$ $Q_m = 11.2288MeV^b$
$^{10}Be(n,\gamma)^{11}B$ $Q_m = 11.4542MeV^b$

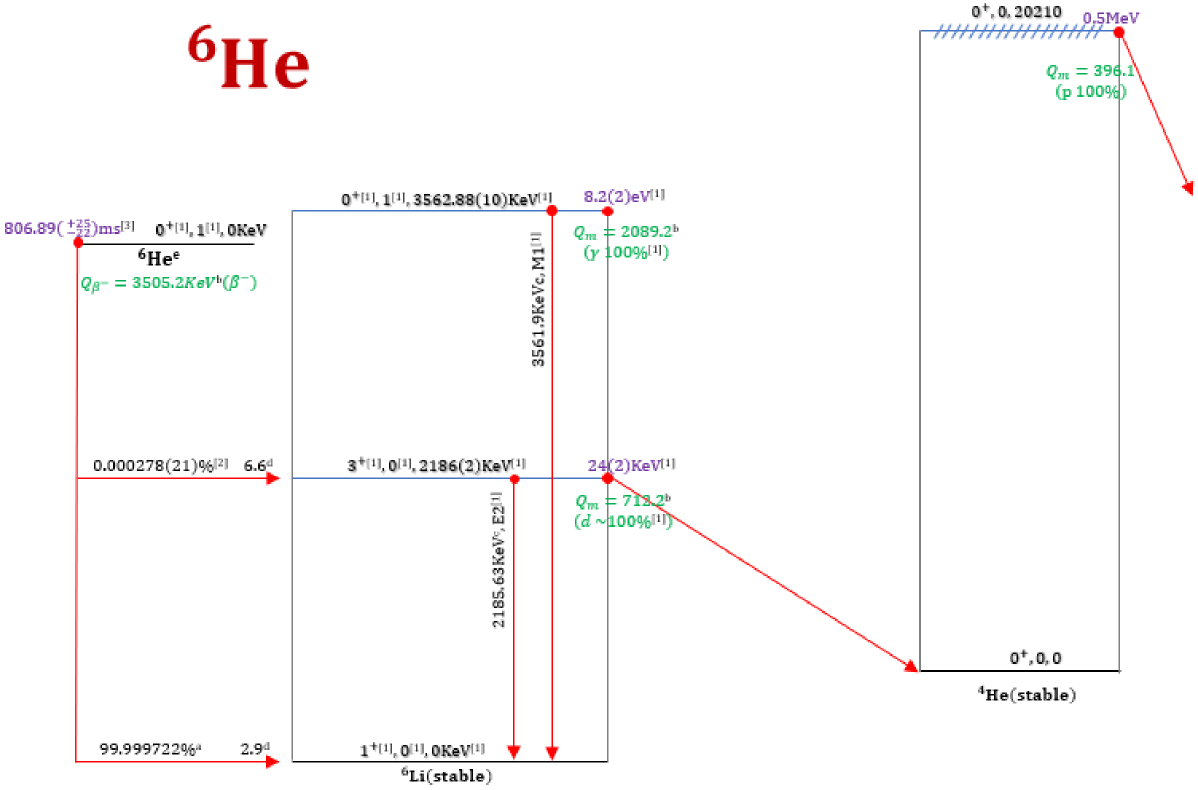
$^{3}H(\alpha,\gamma)^{7}Li$ $Q_m = 2.4676MeV^b$

$^{11}C(\beta^+)^{11}B$ $Q_m = 1.9817\ MeV^b$

^{10}C



^{6}He



$^{6}Li(\alpha,\gamma)^{10}B \quad Q_m = 4.4612MeV^{a}$

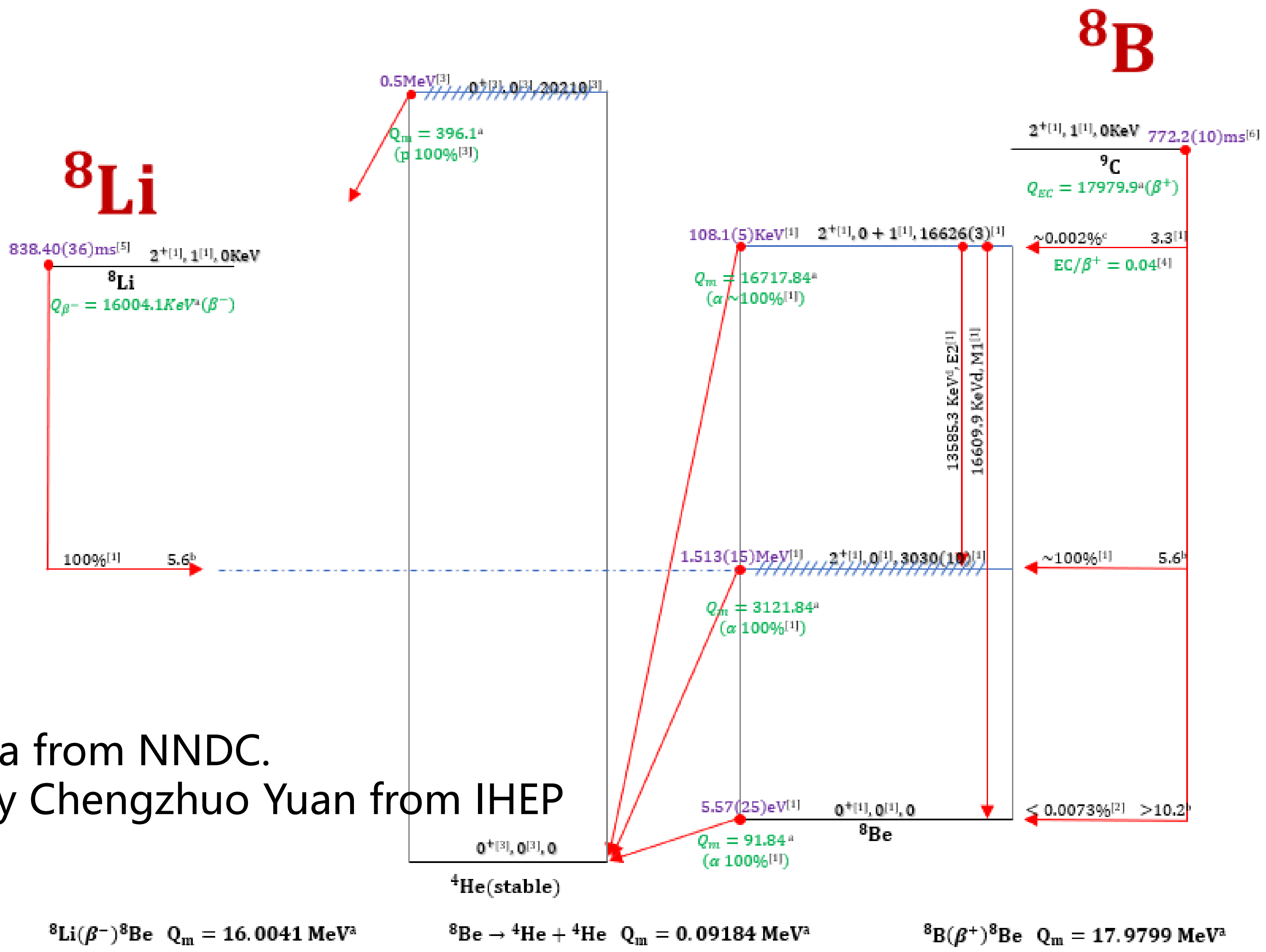
$^{10}C(\beta^{+})^{10}B \quad Q_m = 3.6481MeV^{a}$

$^{6}He(\beta^{-})^{6}Li \quad Q_m = 3.5052\ MeV^{b}$

$^{6}Li(\gamma,d)^{4}He \quad Q_m = -1.4738MeV^{b}$
$^{6}Li(\gamma,np)^{4}He \quad Q_m = -3.6983MeV^{b}$

$^{3}H(p,\gamma)^{4}He \quad Q_m = 19.8139\ MeV^{b}$

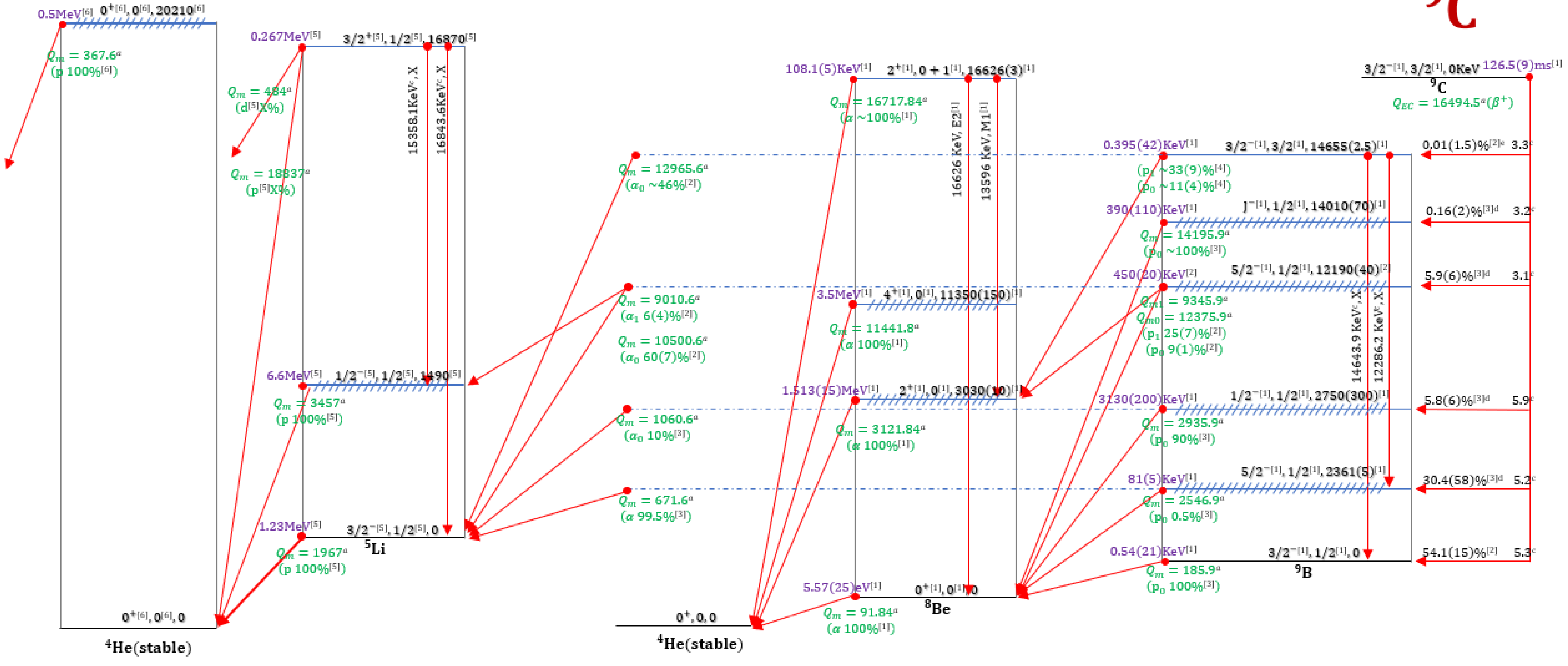
Decay data from NNDC.
Plotting by Chengzhuo Yuan from IHEP



Decay data from NNDC.
Plotting by Chengzhuo Yuan from IHEP

Decay data from NNDC.
Plotting by Chengzhuo Yuan from IHEP

^{9}C



^{3}H(p, γ)^{4}He $Q_m = 19.8139\ \mathrm{MeV}^a$
He(n, γ)^{4}He $Q_m = 20.5776\ \mathrm{MeV}^a$

^{1}H(α, γ)^{5}Li $Q_m = -1.9670\ \mathrm{MeV}^a$
^{3}He(d, γ)^{5}Li $Q_m = 16.3860\ \mathrm{MeV}^a$

$^9\mathrm{B} \rightarrow \alpha + {}^5\mathrm{Li}$ $Q_m = -1.6894\ \mathrm{MeV}^a$

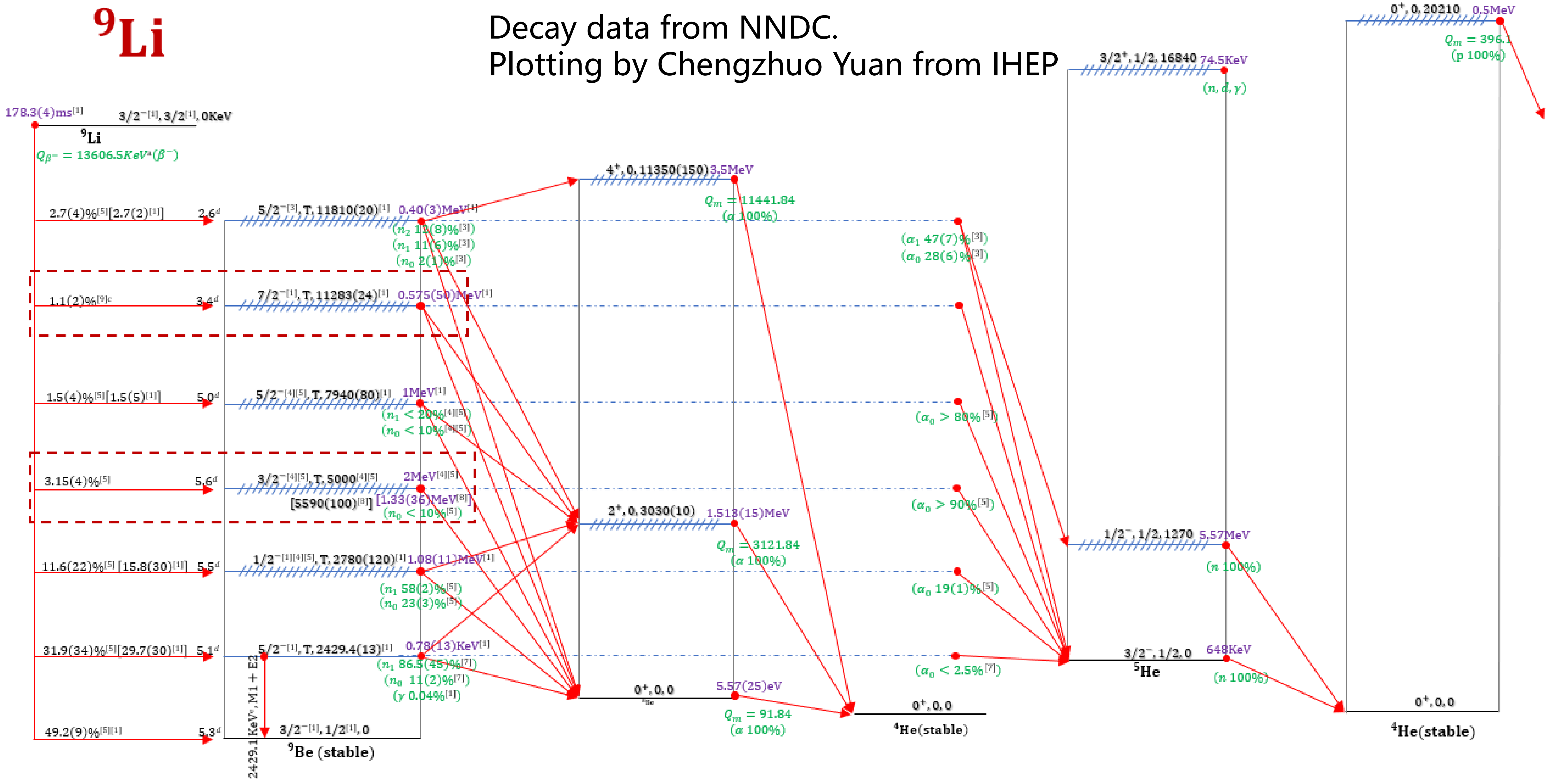
$^8\mathrm{Be} \rightarrow {}^4\mathrm{He} + {}^4\mathrm{He}$ $Q_m = 91.84\ \mathrm{KeV}^a$

$^9\mathrm{B} \rightarrow \mathrm{p} + {}^8\mathrm{Be}$ $Q_m = 0.1859\ \mathrm{MeV}^a$

^{9}C(β$^+$)^{9}B $Q_m = 16.4945\ \mathrm{MeV}^a$

^{9}Li

Decay data from NNDC.
Plotting by Chengzhuo Yuan from IHEP



$^{9}\mathrm{Li}(\beta^-)^{9}\mathrm{Be}\ \ Q_m = 13.6065\mathrm{MeV}^a$

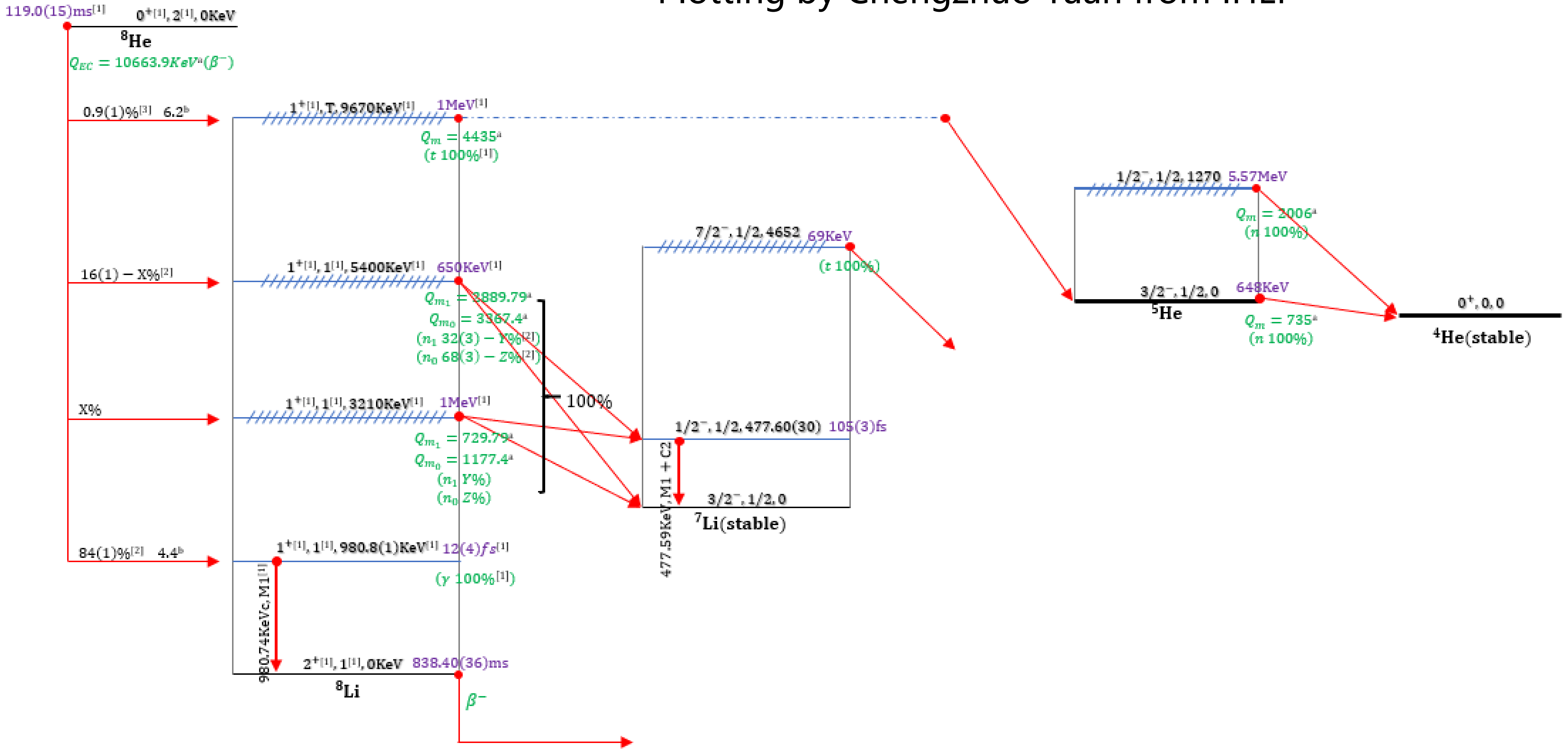
$^{9}\mathrm{Be}(\gamma, n)^{8}\mathrm{Be}\ \ Q_m = -1.6645\mathrm{MeV}^a$
$^{9}\mathrm{Be}(\gamma, \alpha)^{5}\mathrm{He}\ \ Q_m = -2.308\mathrm{MeV}^{ab}$
$^{9}\mathrm{Be}(\gamma, p)^{8}\mathrm{Li}\ \ Q_m = -16.8863\mathrm{MeV}^a$
$^{9}\mathrm{Be}(\gamma, n)^{4}\mathrm{He}^{4}\mathrm{He}\ \ Q_m = -1.5727\mathrm{MeV}^a$

$^{8}\mathrm{Be} \rightarrow {}^{4}\mathrm{He} + {}^{4}\mathrm{He}\ \ Q_m = 91.84\mathrm{KeV}^a$

$^{5}\mathrm{He} \rightarrow {}^{4}\mathrm{He} + n\ \ Q_m = 0.735\mathrm{MeV}^a$

^{8}He

Decay data from NNDC.
Plotting by Chengzhuo Yuan from IHEP



$^{8}He(\beta^-)^{8}Li \quad Q_m = 10.6639\ MeV^a$

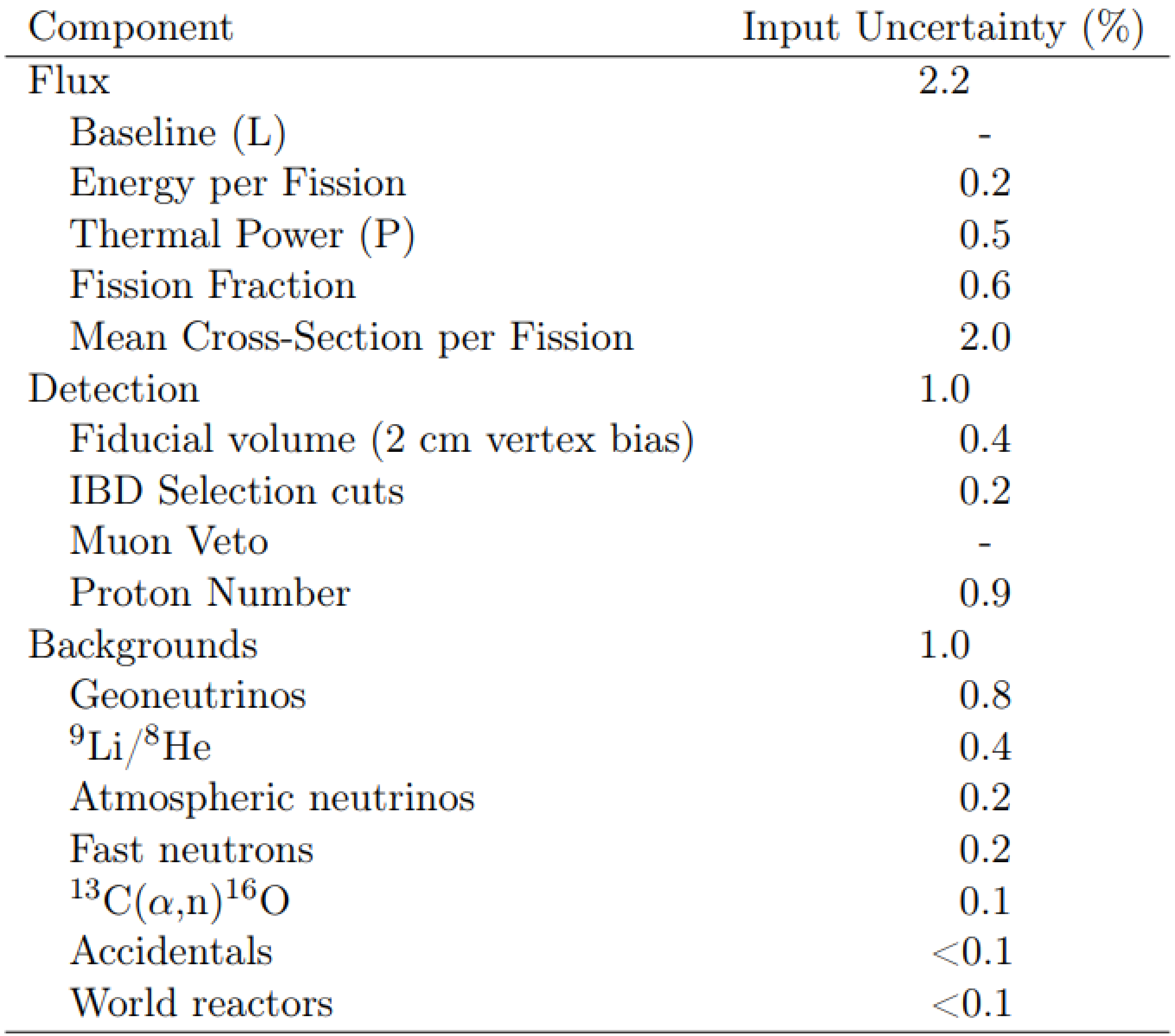
$^{7}Li(n,\gamma)^{8}Li \quad Q_m = 2.0326MeV^a$

$^{3}H(\alpha,\gamma)^{7}Li \quad Q_m = 2.4672MeV^a$
$^{6}Li(n,\gamma)^{7}Li \quad Q_m = 7.2511MeV^a$
$^{6}He(p,\gamma)^{7}Li \quad Q_m = 9.9740MeV^a$

$^{8}Li \rightarrow t + {}^{5}He \quad Q_m = -5.235MeV^a$

$^{5}He \rightarrow n + {}^{4}He \quad Q_m = 0.735\ MeV^a$

Input uncertainties of oscillation



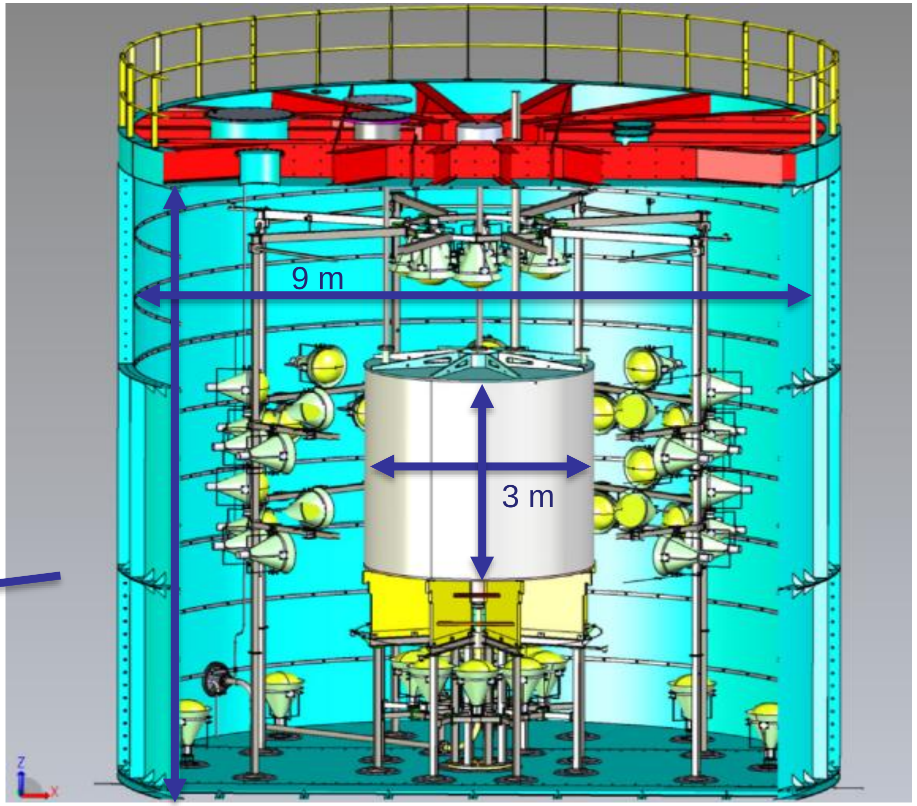
Component	Input Uncertainty (%)
Flux	2.2
Baseline (L)	-
Energy per Fission	0.2
Thermal Power (P)	0.5
Fission Fraction	0.6
Mean Cross-Section per Fission	2.0
Detection	1.0
Fiducial volume (2 cm vertex bias)	0.4
IBD Selection cuts	0.2
Muon Veto	-
Proton Number	0.9
Backgrounds	1.0
Geoneutrinos	0.8
^{9}Li/^{8}He	0.4
Atmospheric neutrinos	0.2
Fast neutrons	0.2
^{13}C(α,n)^{16}O	0.1
Accidentals	<0.1
World reactors	<0.1

Online Scintillator Internal Radioactivity Investigation System (OSIRIS)

A 20-t detector to monitor radiopurity of LS before and during filling to the central detector

- ✓ Few days: U/Th (Bi-Po) ~ 1 × 10^{-15} g/g (reactor baseline case)
- ✓ 2~3 weeks: U/Th (Bi-Po) ~ 1 × 10^{-17} g/g (solar ideal case)
- ✓ Other radiopurity can also be measured: ^{14}C, ^{210}Po and ^{85}Kr

Eur.Phys.J.C 81 (2021) 11, 973



Expect to start commissioning in July.

Possible upgrade to Serappis (SEarch for RAre PP-neutrinos In Scintillator): *arXiv: 2109.10782*

- ✓ A precision measurement of the flux of solar *pp* neutrinos on the few-percent level