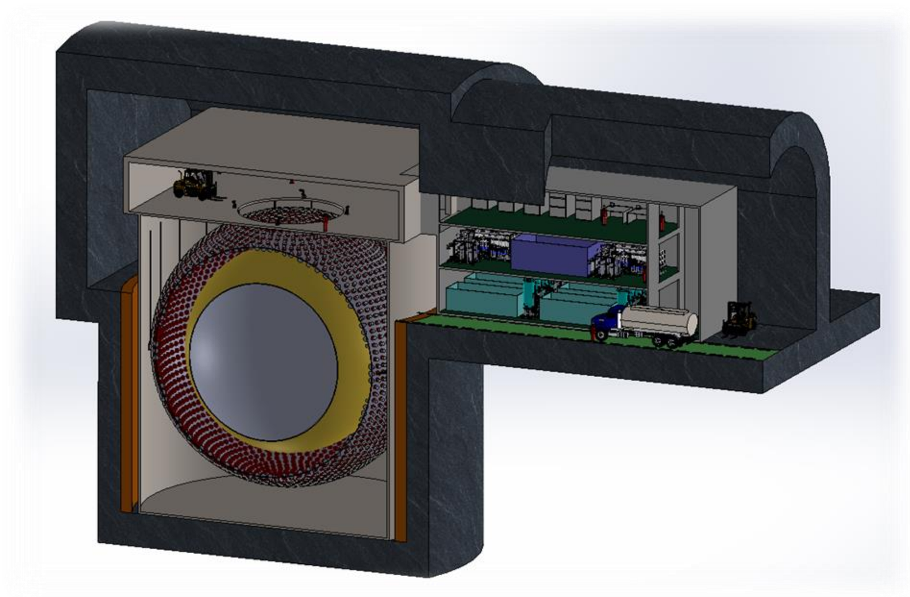
Jinping, and the solar neutrinos



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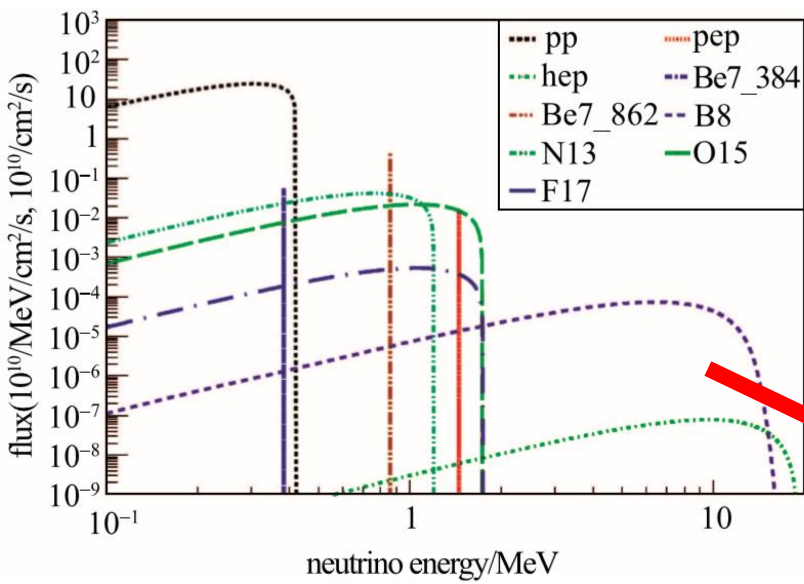
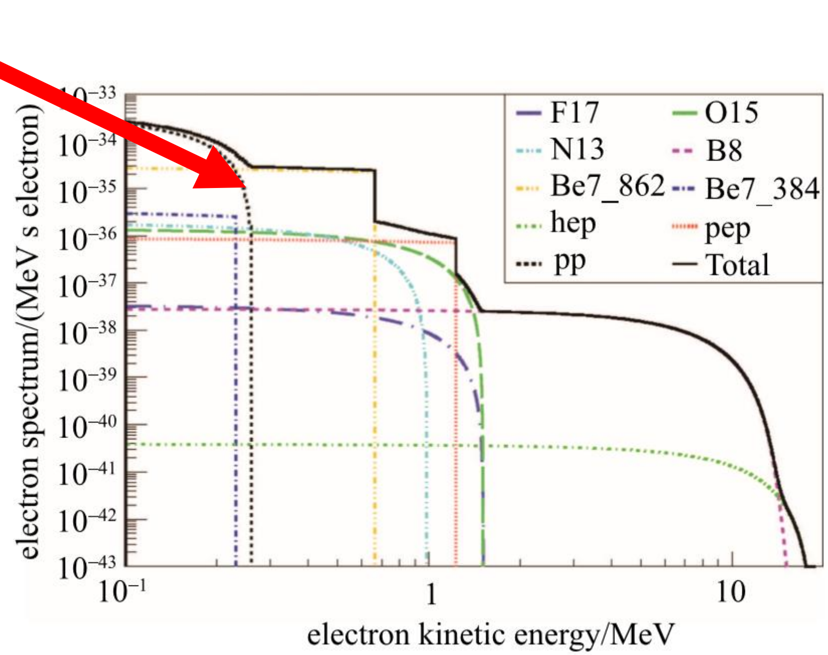
Solar neutrino signals

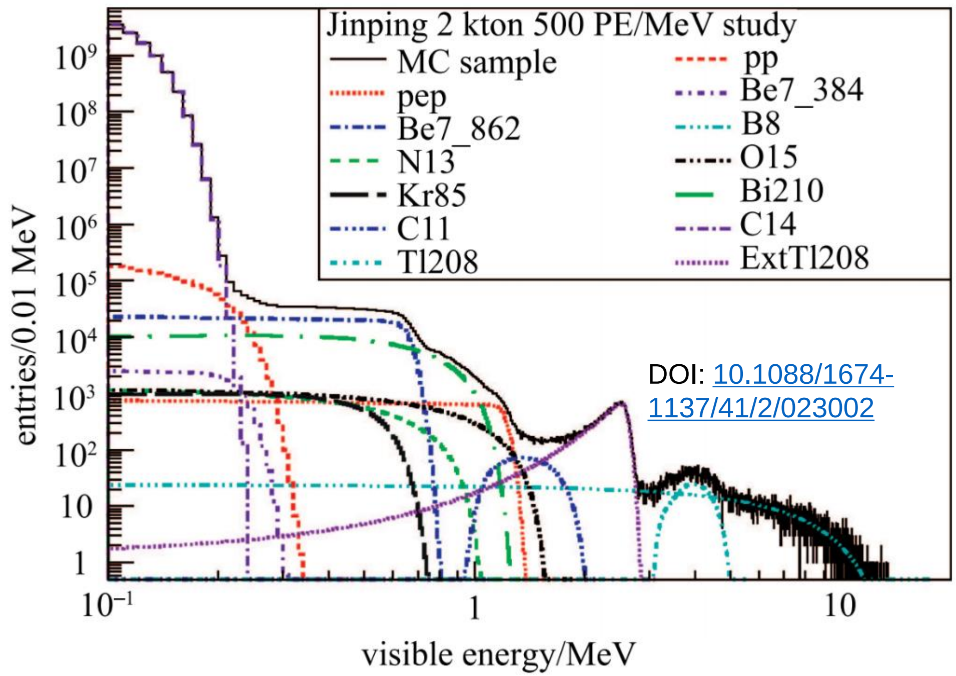


Signal predicted from GS98 (AGSS09) solar model.
Possible observations (and not that possible):
pp, pep, Be7, CNO (N13), B8, (hep)



The corresponding electron kinetic energy (detectable energy) is shown.
Expected energy window:
200 keV to 20 MeV

Backgrounds at Jinping



- ➢ Overburden: 6,720 m.w.e.
- ➢ Muon flux: $2.0 \times 10^{-10} cm^{-2} s^{-1}$

- ➢ Internal radioactivity bkg (^{210}Bi etc.): same level as Borexino-II.
- ➢ External radioactivity bkg (^{208}Tl etc.): scaled to the surface area from Borexino-II. Exponential approximation for attenuation in buffer.
- ➢ Spallation induced bkg (^{11}C etc.): scaled to the Jinping muon rate.

Sensitivities from a fast simulation

Statistics: **5 years live time**.

^{15}O sensitivity here refers to ^{15}O + ^{17}F flux.

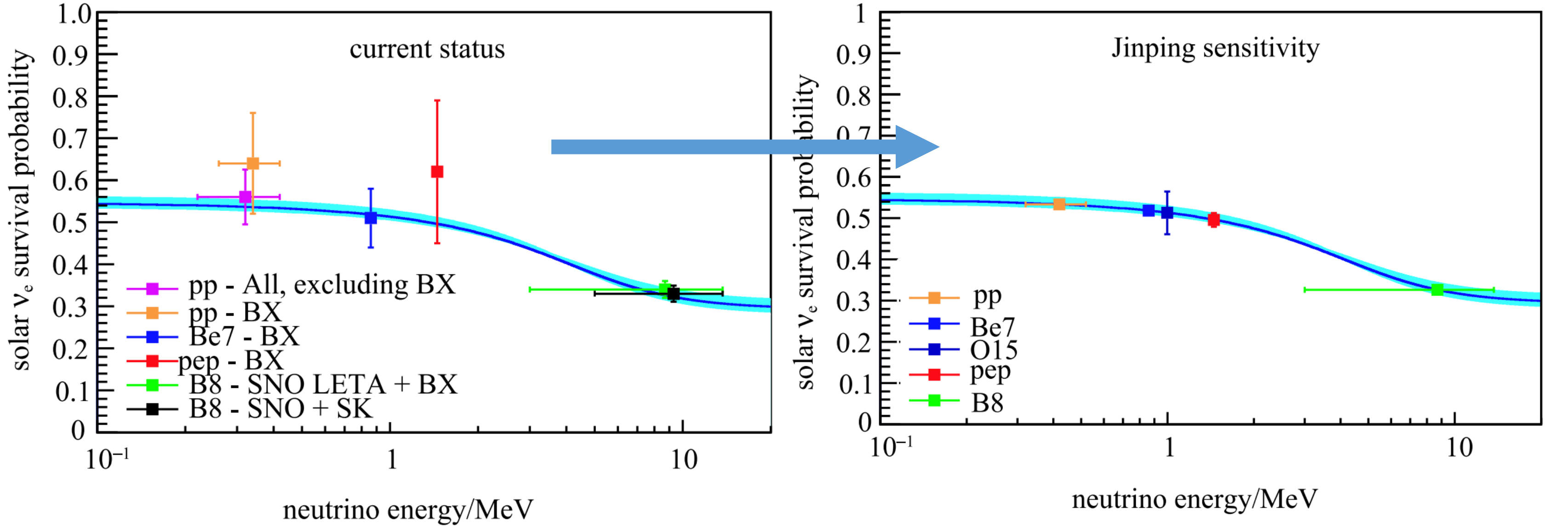
A conservative systematics assumption at 1.5%.

Finally decided at **500 p.e./MeV** with **2 kton fiducial**.

DOI: 10.1088/1674-1137/41/2/023002

		energy resolution/PE/MeV		
		200	500	1000
fiducial mass 1000 ton	pp	0.02	0.007	0.005
	^{7}Be	0.007	0.006	0.005
	pep	0.07	0.05	0.04
	^{13}N	NA	0.5 (NA)	0.3 (0.4)
	^{15}O	0.3	0.2 (0.4)	0.1 (0.2)
	^{8}B	0.02	0.02	0.02
fiducial mass 2000 ton	pp	0.01	0.005	0.004
	^{7}Be	0.005	0.004	0.004
	pep	0.06	0.03	0.03
	^{13}N	0.4	0.3	0.2 (0.3)
	^{15}O	0.2	0.1	0.08 (0.1)
	^{8}B	0.02	0.02	0.02
fiducial mass 4000 ton	pp	0.01	0.004	0.003
	^{7}Be	0.004	0.003	0.003
	pep	0.04	0.03	0.02
	^{13}N	0.3	0.2 (0.3)	0.2 (0.3)
	^{15}O	0.1 (0.2)	0.07 (0.1)	0.06 (0.09)
	^{8}B	0.01	0.01	0.01

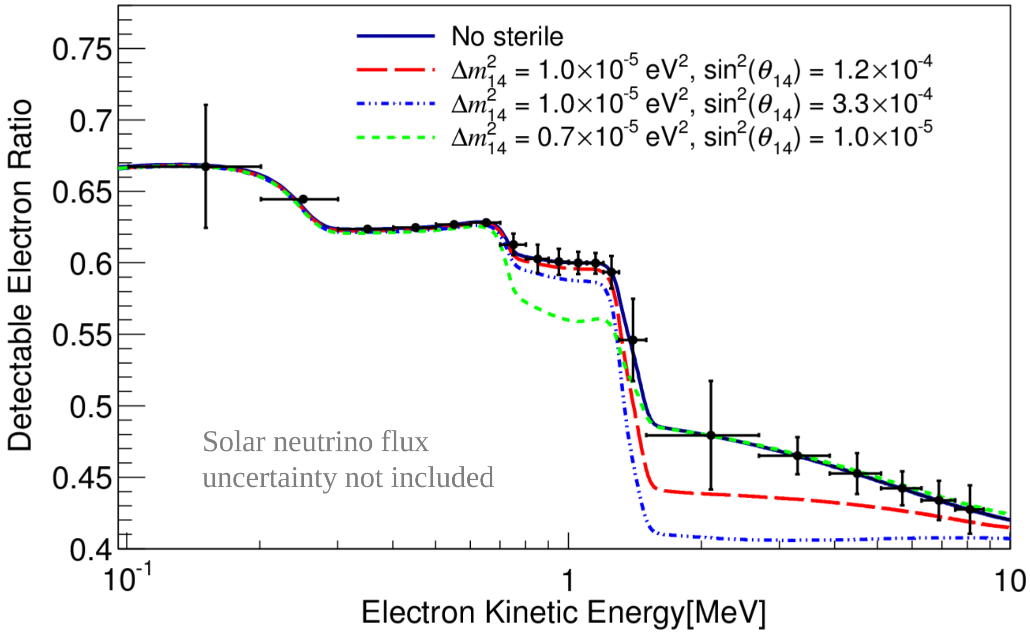
Solar upturn



Transition of oscillation probability from the matter-governed region to the vacuum-like region.

Precise measurement of solar neutrinos will constrain the upturn. The contribution of Jinping would be significant in the constraint on low energy electrons from B8 neutrinos.

Sterile neutrino sensitivity



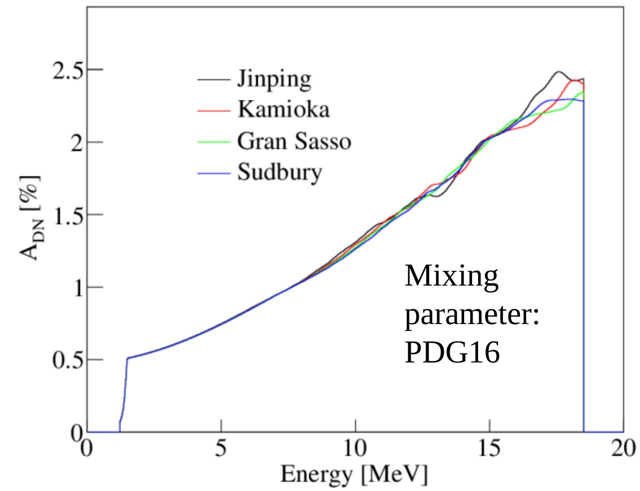
A 4th generation of **sterile neutrino** indicates an **additional resonance** inside the Sun, and the upturn shape changes for different mixing parameter sets.

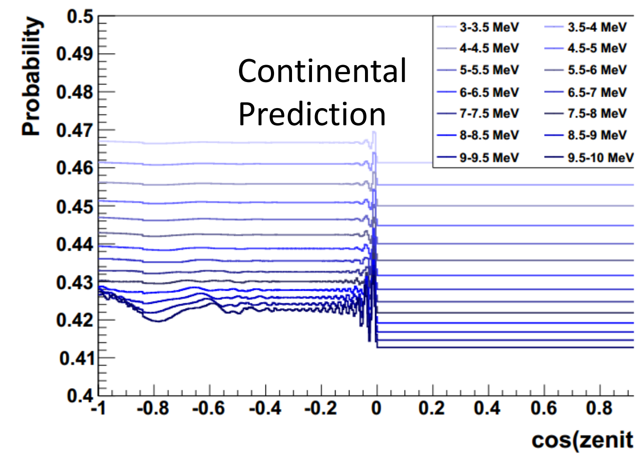
Jinping will be sensitive to exclude a large parameter space for sterile neutrinos.

Day-night asymmetry

Experiment	Measurement
SK[1]	$(-3.2 \pm 1.1 \pm 0.5)\%$
SNO[2], Borexino[3]	Within 1 σ to null hypothesis
Global[4]	$\sim 2\%$

- The day/night asymmetry is sensitive to Δm^2_{21} and the density profile of Earth surface near the detector.
- The statistics of B8 at Jinping in 5 years is not sufficient for a conclusive measurement.





[1] Phys. Rev. Lett. 112, 091805 (2014) [2] Phys. Rev. C72. 72. 055502 (2005)
[3] Phys. Rev. D89. 11. 112007 (2014) [4] Eur. Phys. J. A52 (2016)

Solar angle cut

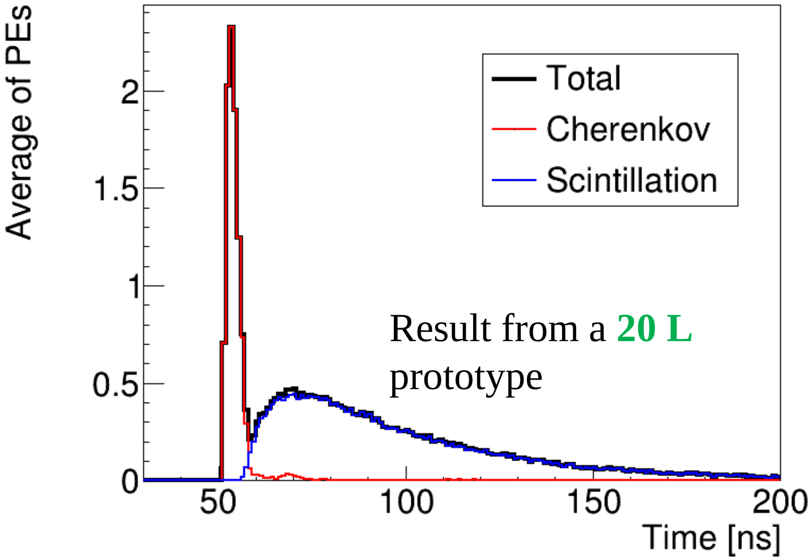
- Cherenkov detector can suppress backgrounds by **solar angle**. However, a low energy Cherenkov ring is smeared due to **multiple scattering**.
- Scintillator light does not contain direction information, and thus cannot use solar angle cut.

- Vertex: **scintillation light**
  - Higher light yield, thus higher precision.
- Energy: **scintillation light**
  - Lower energy threshold, thus better linearity.

Correlated

- Direction: **Cherenkov light**
  - Using scintillation light to provide vertex, solar angle can be better reconstructed. The S/B ratio is expected to be enhanced by ~1.5 for 1.6 MeV electron with a loose forwardness angle cut.

Jinping: Cherenkov + scintillation



The time profile of **Cherenkov (fast)** and **scintillation (slow)** components in LAB can be distinguished.
Additional PPO needed to improve light yield.

DOI:
10.1016/j.nima.2016.05.132

A larger prototype of **1 ton** with 15% coverage is being tested in-situ, with energy resolution at **~100 p.e./MeV**.

The goal for energy resolution is **500 p.e./MeV**, achievable with 80% coverage and 15 m attenuation length.

A **fast** energy response model

A generic light yield model can be written as:

$$E_{\mathrm{obs}}(\vec{x}, E_{\mathrm{init}}, E_{\mathrm{dep}}) = E_0 \cdot R \cdot \boxed{C(\vec{x})}\boxed{T(\vec{x})} \cdot \boxed{[Y_s + f\ Y_C]\,(E_{\mathrm{init}}, E_{\mathrm{dep}})}$$

Coverage | **Optical response** | **Light yield**

When transforming into momentum, the m_k set is only dependent on **detector geometry**.

$$T(\lambda, l) = \exp(-l/L(\lambda))$$

$$T(\vec{x}) = 1 + \sum_{k=1}^{\infty}\left(-\frac{1}{L}\right)^k m_k(\vec{x}),$$

$$m_k(\vec{x}) = \frac{1}{n}\cdot\frac{1}{k!}\sum_{i=1}^{n}\left[l_i(\vec{x})\right]^k.$$

$$\frac{dY_s}{dx} = A\frac{dE/dx}{1 + k_B \cdot dE/dx},$$

$$\frac{d^2Y_C}{dx d\lambda} = \frac{2\pi\alpha q^2}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)$$

This is a **fast** analytical model accommodating time variation naturally.

DOI: 10.1016/j.nima.2018.02.077

Conclusion

- The proposed Jinping experiment will have the low spallation background, large volume, and good energy resolution required for the detection of CNO and precise measurement of other solar neutrinos.

- Jinping will be able to exclude a large parameter space for sterile neutrino and constrain solar upturn.

- Cherenkov + scintillation detection mode has been developed, enabling solar cut to enhance S/B ratio.

- A fast detector response model to control energy systematic uncertainty has been constructed.

Back up

Signal/background estimation

	mass/ 100 ton	time/ day	resolution/ PE/MeV	^{14}C	^{85}Kr	^{210}Bi	^{11}C	^{10}C	^{208}Tl	^{11}Be	Ext-^{208}Tl
				/counts/day/100 ton							
Borexino-I ^{7}Be	0.7547	740.7	500	3.46×10^{6}	31.2	41.0	28.5	0.62	0.084	0.032	2.52
Borexino-I pep	0.7130	290.2	500	3.46×10^{6}	31.2	41.0	2.48	0.18	0.084	0.032	2.52
Borexino-I ^{8}B	1	345.3	500	3.46×10^{6}	31.2	41.0	28.5	0.62	0.084	0.032	2.52
Borexino-II ^{7}Be	0.7547	1480	500	3.46×10^{6}	1	25.0	28.5	0.62	0.084	0.032	2.52
Borexino-II pep	0.7130	580	500	3.46×10^{6}	1	25.0	2.48	0.18	0.084	0.032	2.52
Borexino-II ^{8}B	1	690	500	3.46×10^{6}	1	25.0	28.5	0.62	0.084	0.032	2.52
SNO+	5	1500	1000	3.46×10^{6}	1	25.0	0.29	0.0062	0.084	0.00032	1.47
Jinping	scan	1500	scan	3.46×10^{6}	1	25.0	0.15	0.0031	0.084	0.00016	1.17

electron event rate /day/100 ton	>0 keV (GS98) high metallicity	>0 keV (AGS09) low metallicity	>200 keV (GS98) high metallicity	>200 keV (AGS09) low metallicity
pp	132.59 ± 0.80	133.70 ± 0.80	4.557 ± 0.027	4.595 ± 0.028
^{7}Be (0.38 MeV)	1.93 ± 0.13	1.76 ± 0.12	0.228 ± 0.016	0.208 ± 0.015
^{7}Be (0.86 MeV)	46.9 ± 3.3	42.8 ± 3.0	31.6 ± 2.2	28.8 ± 2.0
pep	2.735 ± 0.033	2.792 ± 0.034	2.244 ± 0.027	2.291 ± 0.028
^{13}N	2.45 ± 0.34	1.80 ± 0.25	1.48 ± 0.21	1.09 ± 0.15
^{15}O	2.78 ± 0.42	1.95 ± 0.29	2.03 ± 0.31	1.42 ± 0.21
^{17}F	0.069 ± 0.012	0.0426 ± 0.0072	0.0506 ± 0.0086	0.0312 ± 0.0053
^{8}B	0.443 ± 0.062	0.364 ± 0.051	0.427 ± 0.060	0.351 ± 0.049
hep	0.0009 ± 0.0003	0.0009 ± 0.0003	0.0009 ± 0.0003	0.0009 ± 0.0003

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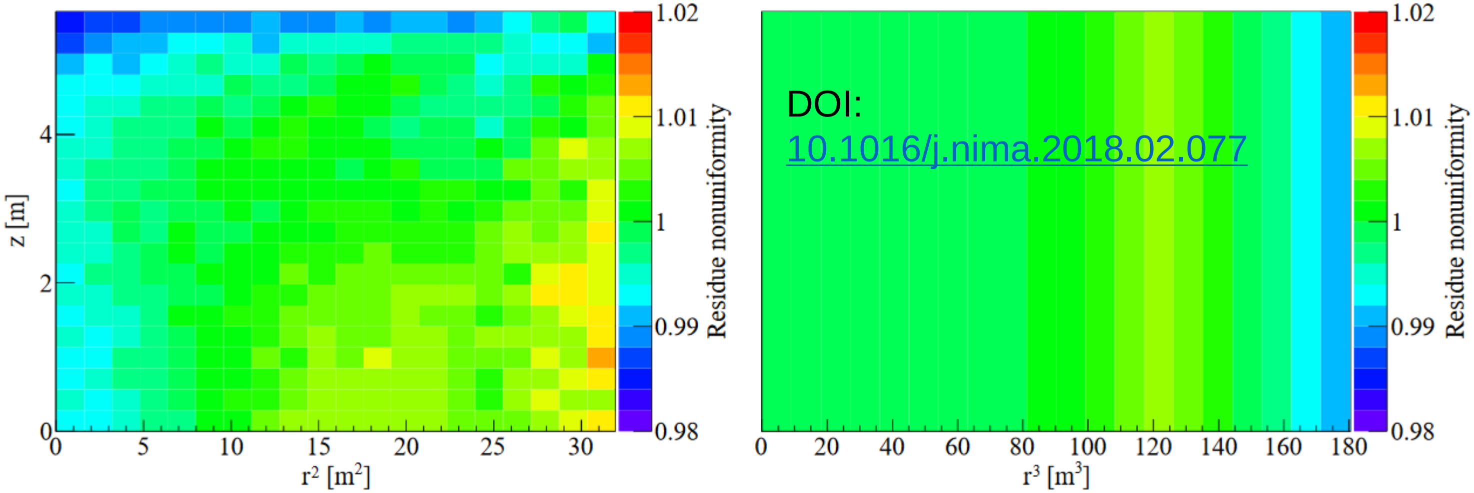
Residual systematics



This model can be easily applied to **different geometric setups** and **multi-volume scintillator detectors**, such as Daya Bay, KamLAND-Zen, and the 2-tank setup Jinping detector.

From a full simulation, the residual systematics after the correction from the fast energy response model for the cylindrical (left) and spherical (right) setup are **0.28%** and **0.26%**, respectively.
(w/o other correction or volume cut.)

Metallicity

- Jinping has 7.6 ~ 9.6 σ sensitivities with the fixed input of present mixing angles, w/o consideration of theoretical uncertainties in high/low metallicity model.

9.6 σ assuming no correlation between fluxes, and 7.6 σ assuming fully correlation between ^{7}Be and ^{8}B.