Sterile neutrino oscillometry with Jinping

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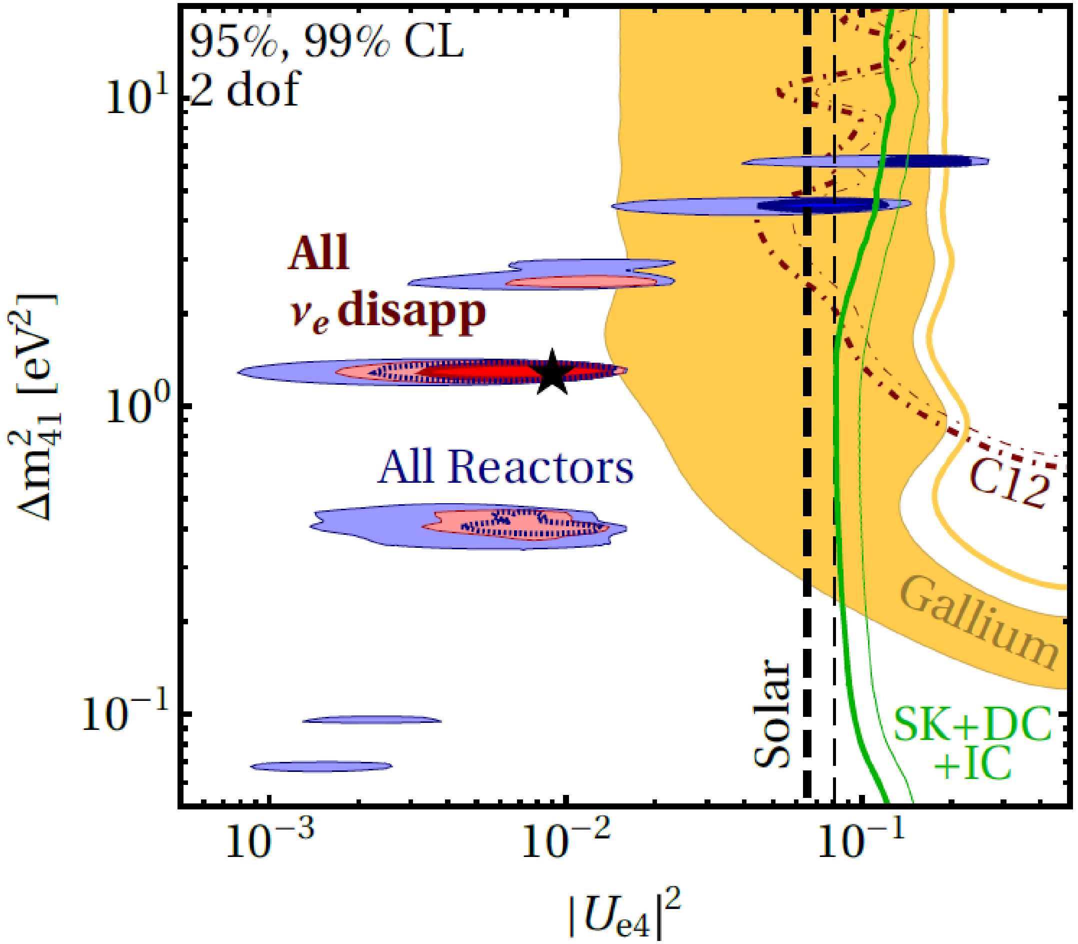
Current status of sterile neutrino



M. Dentler *et. al.*, JHEP **1808** (2018) 010

- "Gallium anomaly" solar neutrino experiments GALLEX&SAGE
- Beam experiments LSND&MiniBooNE
- Reactor antineutrino anomaly (RAA)

Best fit values:

$\sin^2(2\theta_{14}) \approx 0.035;\ \Delta m^2_{41} = 1.29\ \text{eV}^2$

SBL sterile neutrino experiments

Only disappearance channel

Reactor experiments

Name	L/E, [m/MeV]	Energy resolution, [%@1 MeV]	Mass, [t]
NEOS	**3.1 – 13.9**	**5**	**1**
DANSS	**1.25 – 6.7**	**34**	**0.9**
Neutrino-4	**0.75 – 6.1**	**16**	**1.5**
Stereo	**1.13 – 6.1**	**9-10**	**1.7**
SoLid	**0.75 – 5**	**14**	**1.6**
PROSPECT	**0.88 – 5**	**4.5**	**4**

Radioactive source experiments

Neutrino emitters: 37Ar, 51Cr
Antineutrino emitters: 144Ce-144Pr, 106Ru-106Rh, 90Sr-90Y, 8Li (IsoDAR)

Name	L/E, [m/MeV]	Energy resolution, [%@1 MeV]	Mass, [kt]
SOX	**1.58 – 6.8**	**5**	**0.272**
CeLAND	**1 – 8.9**	**7.5**	**1**
BEST	**0.53, 1.07**	**-**	**0.05**
JUNO	**0.77 – 21**	**3**	**20**
JUNO IsoDAR	**0.18 – 21**	**3**	**20**

arXiv:1906.01739

3+1 neutrino mixing

The simplest mixing scheme 3 active flavors plus 1 sterile flavor

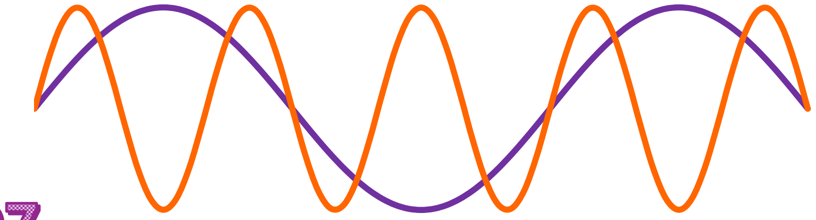
Disappearance probability:

$$P_{\alpha\alpha} \approx 1 - 4|U_{\alpha 4}|^2 \cdot (1 - |U_{\alpha 4}|^2)\sin^2\left(1.27\Delta m_{41}^2 \cdot \frac{L[\mathrm{m}]}{E[\mathrm{MeV}]}\right)$$

$$\sin^2(2\theta_{14}) = 4|U_{\alpha 4}|^2 \cdot (1 - |U_{\alpha 4}|^2)$$

Neutrino oscillometry

- Allows to observe the oscillation curve inside detector as a function of L or L/E variables
- Suitable for fast oscillations such as eV-scale neutrinos
- Requires liquid scintillator detector
- High intensity radioactive neutrino or antineutrino emitters



We propose using radioactive source and short baseline setup:

◆<*E*> around 2 MeV

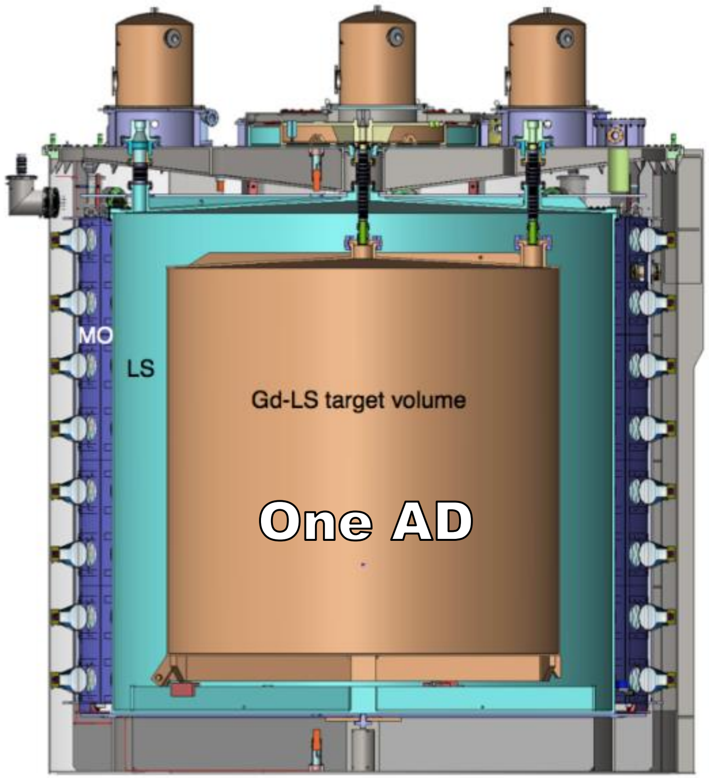
◆*L* : 3-20 m

◆Sensitive to Δm^2_{41} ~ 0.1-10 eV^2

arXiv:1103.5307

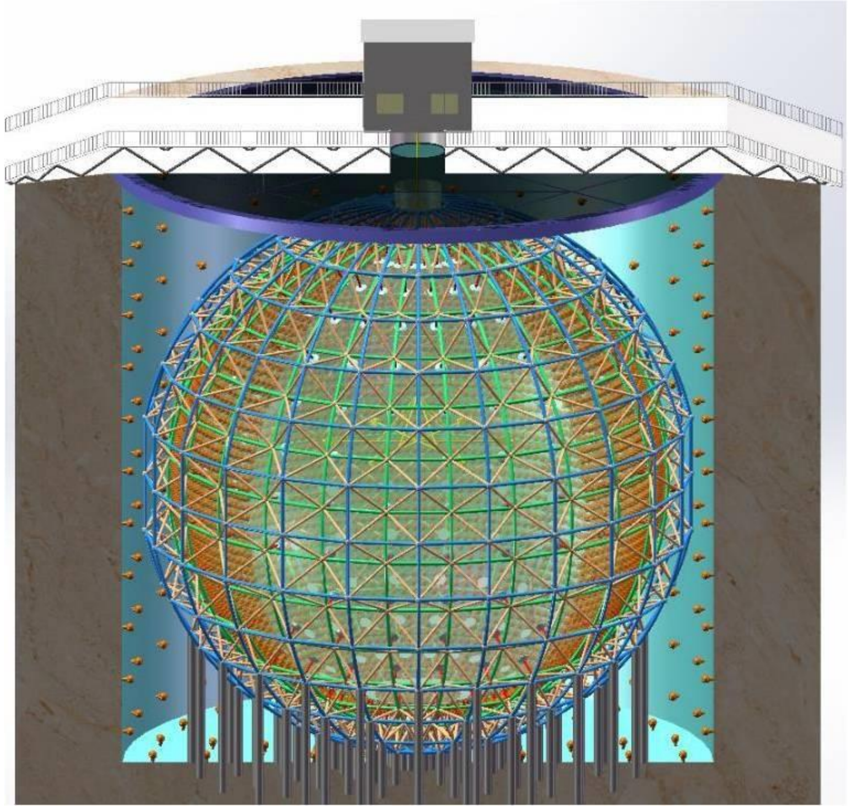
LSc detectors in China

Daya Bay



8x20 ton of LSc+Gd
It's almost finished working. Main result is precise measuring of θ_{13}.
It was proposed for radioactive source experiment with 0.5 MCi 144Ce-144Pr.
arXiv:1109.6036

JUNO



20 kton of LSc. It is under construction now. It will be the largest LSc detector in the world. Main goals are mass hierarchy and precise measurements of oscillation parameters. It has a proposal with the same source and activity ~100 kCi.
arXiv:1507.05613

What else?

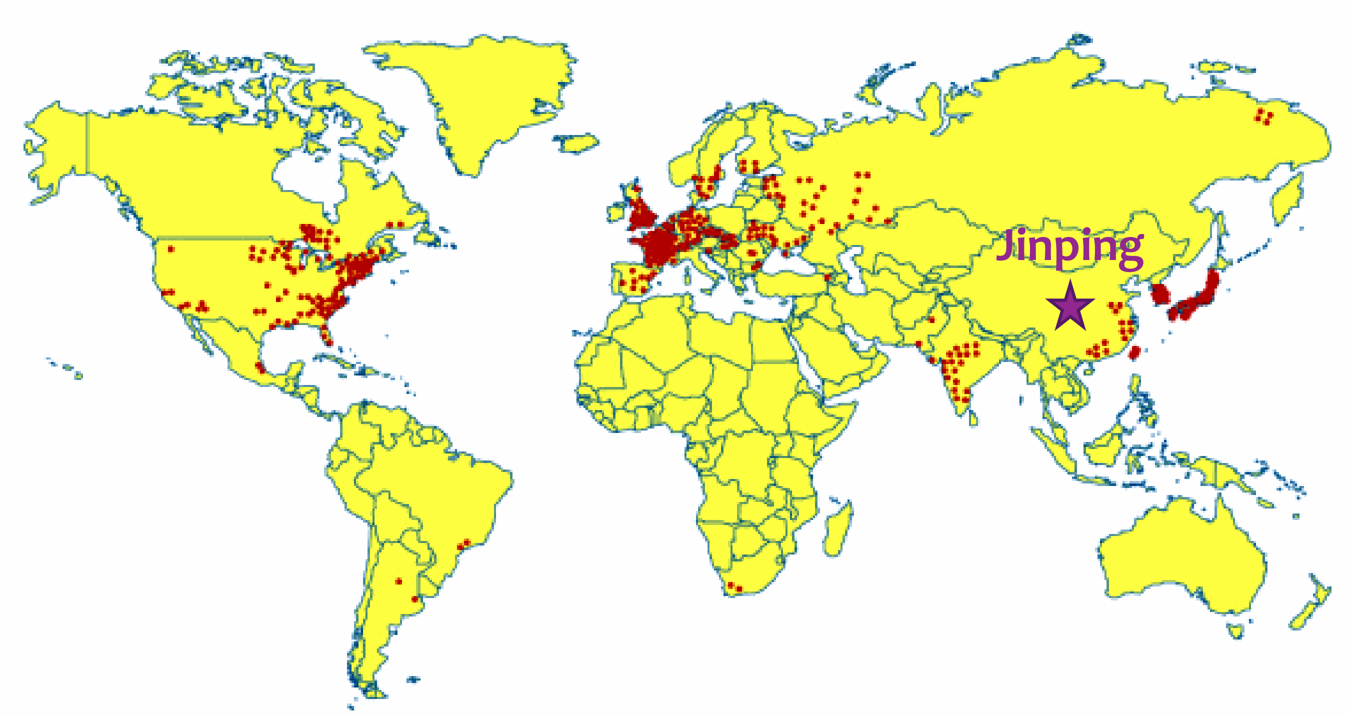
Jinping

Proposal of new LSc detector for low energy neutrino physics

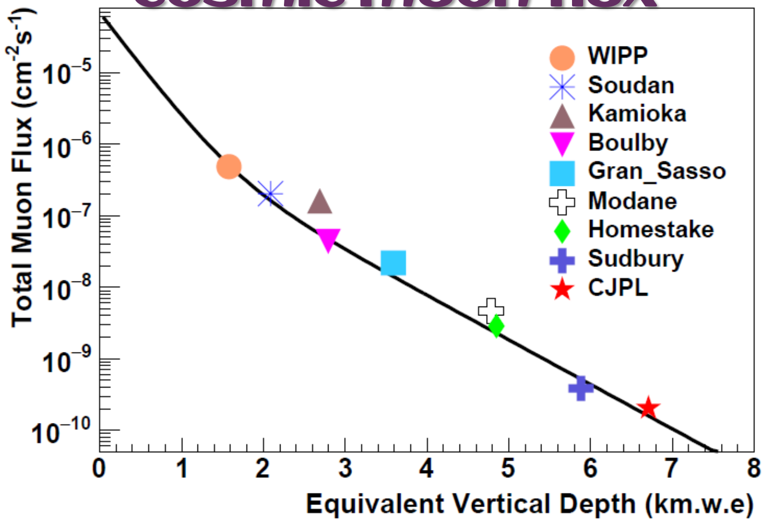
arXiv:1602.01733

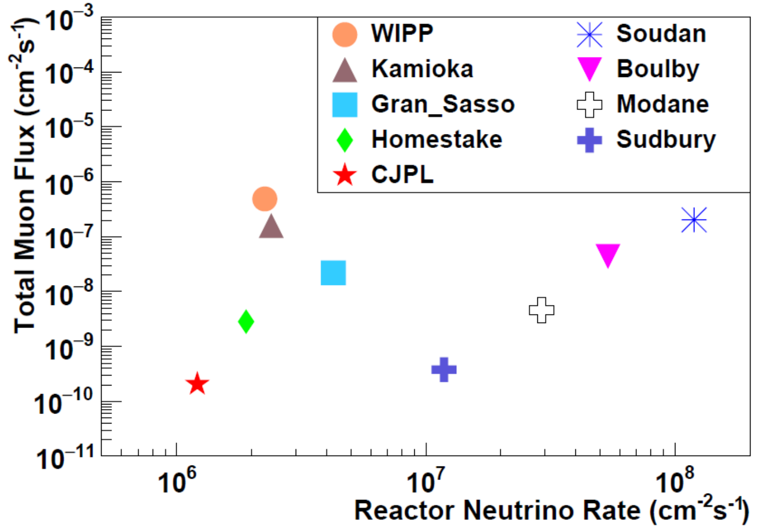
Ideal location for low energy neutrino physics!

World Nuclear Power Reactors



cosmic muon flux

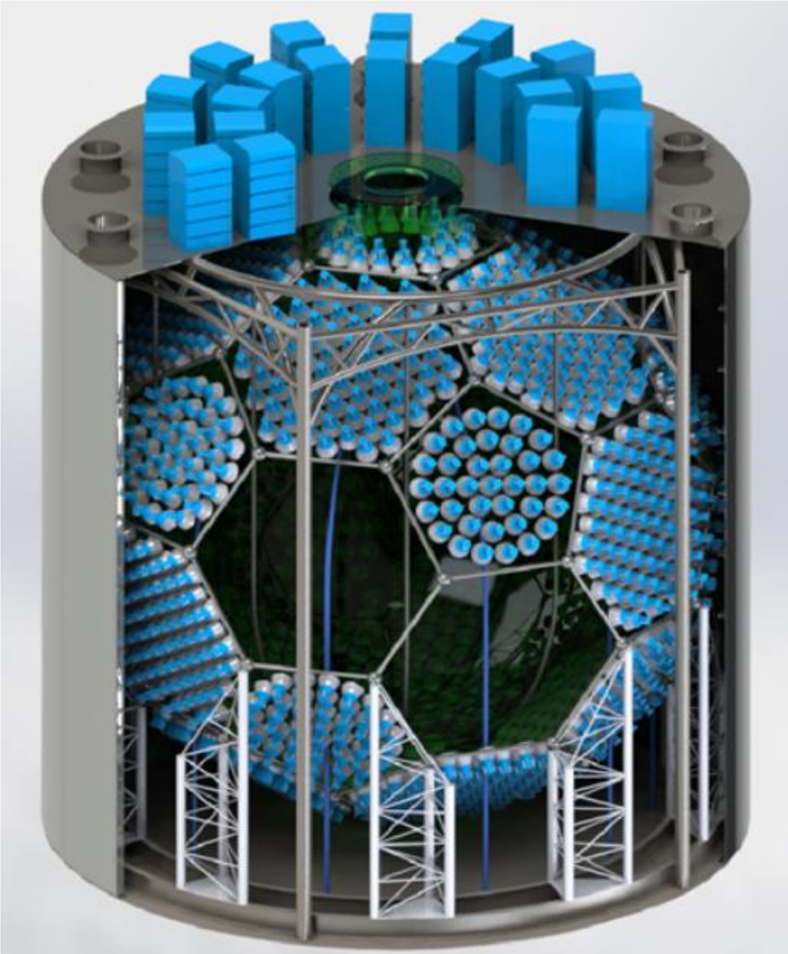


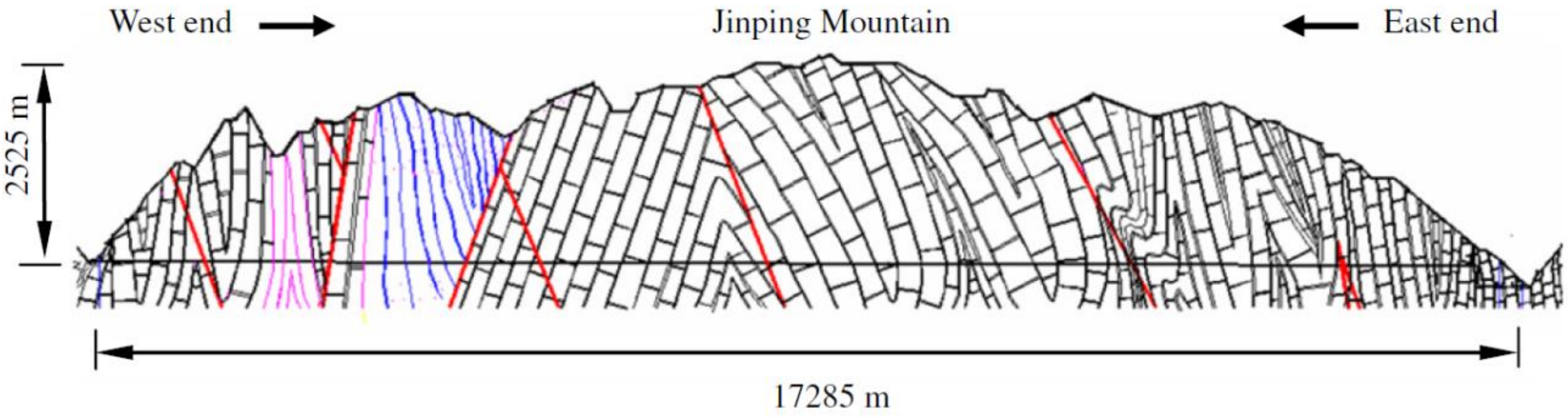


arXiv:1602.01733

Jinping neutrino detector

Spherical detector





- ❖Two possible detector shapes: cylinder or sphere
- ❖Slow liquid scintillator as a target material
- ❖Total mass 2-3 kt
- ❖ ~2400 m overburden → very low background
- ❖500 p.e./MeV or energy resolution ~5%@1 MeV
- ❖Vertex resolution ~10 cm

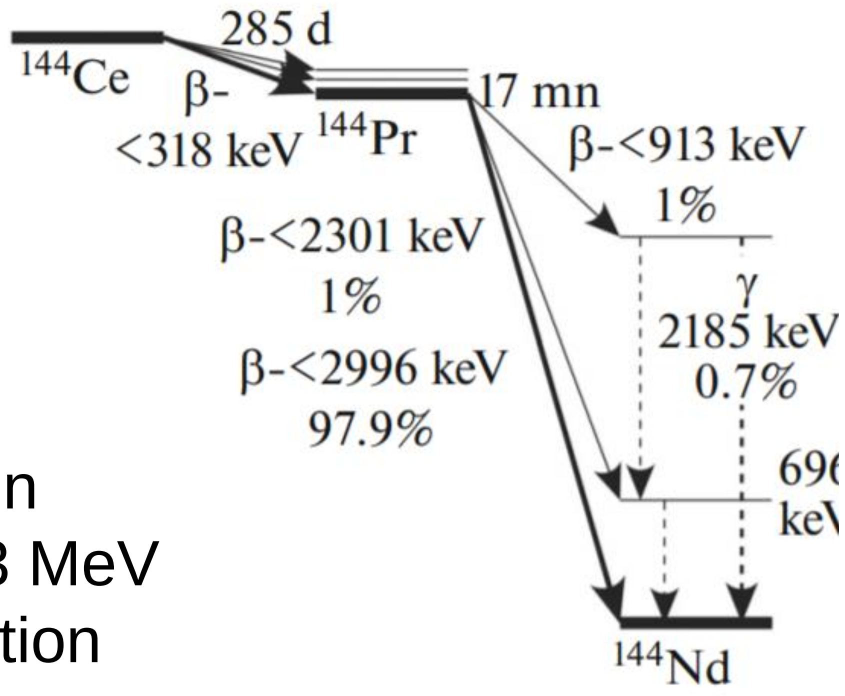
arXiv:1602.01733

Antineutrino radioactive source

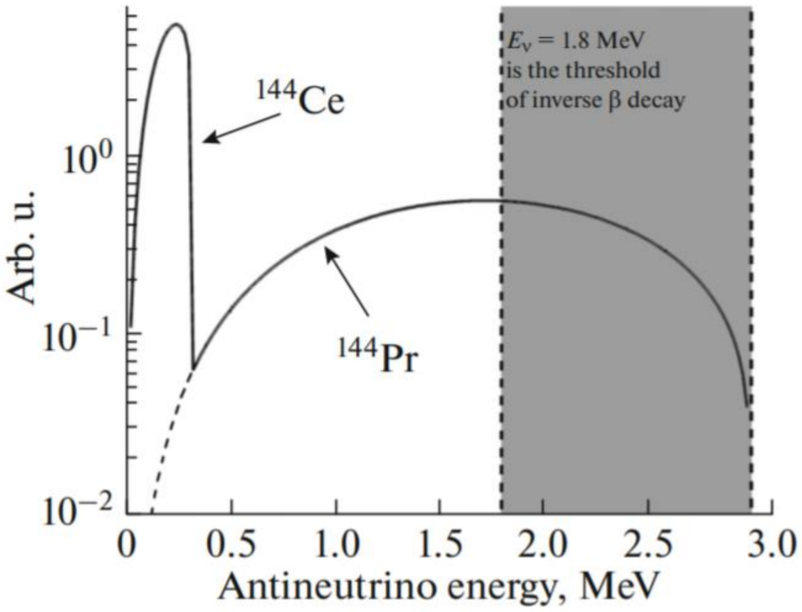
Well known isotopes chain 144Ce-144Pr

Source parameters:

- Compact size (like a point source)
- $T_{1/2} \approx 285$ days
- Initial activity: 50-100 kCi
- Exposure time: 450 days
- Gamma shielding: Tungsten
- Antineutrino energy 1.8 – 3 MeV
- Two options of source location (center and outside)



Antineutrino energy spectrum

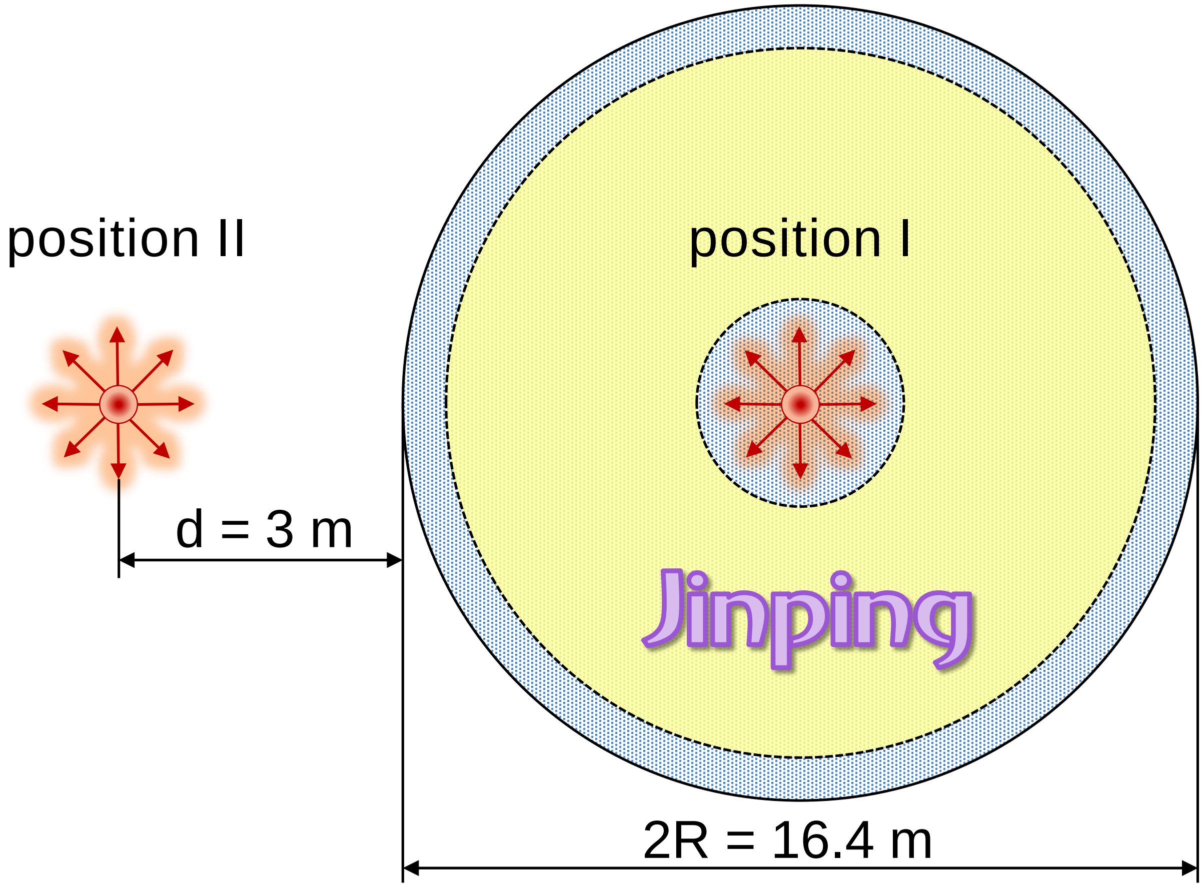


Other proposals using 144Ce-144Pr with very short baseline setup:

- Borexino: SOX-experiment, 50-100 kCi, 1.5 year, 4.25 m between source and inner edge
- KamLAND: CeLAND-experiment, 75 kCi, 1.5 year, distance to the edge is 3 m
- JUNO: 100kCi, 1.5 year, distance to the edge is 2.3 m

[SOX] JHEP 1308 (2013) 038
[CeLAND] arXiv:1309.6805
[JUNO] J.Phys. G43 (2016) no.3, 030401

Layout of the experiment



Used assumptions:

IBD detection channel

450 days exposure time

Total background ~100 events

Position I

- **Activity 50 kCi**
- **Inner cut 1 m**
- **Outer cut 0.7 m**
- **Expected event rate 72k**

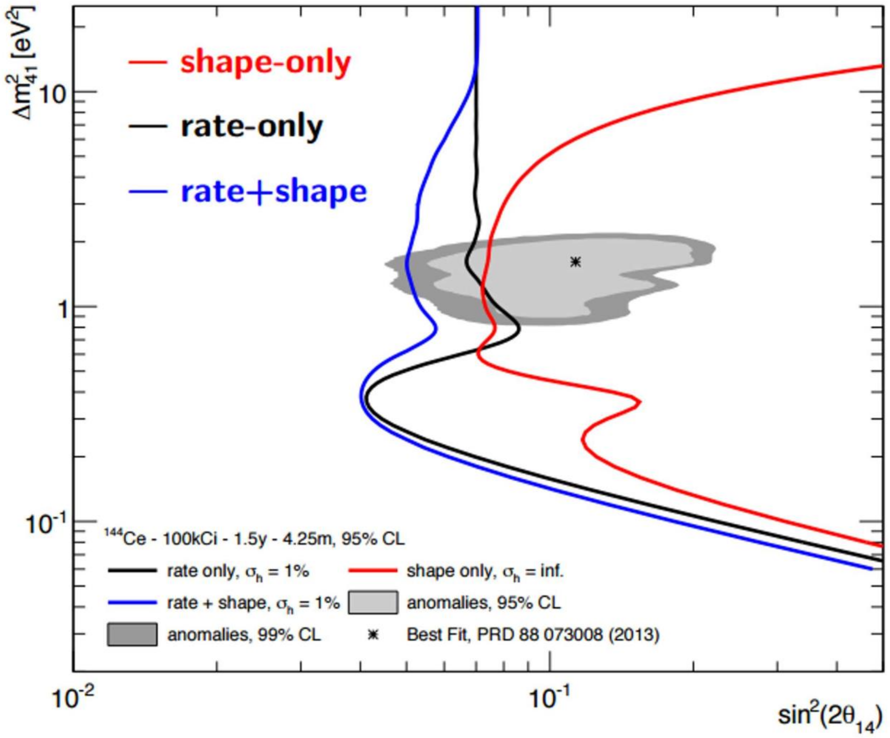
Position II

- **Activity 100 kCi**
- **Outer cut 0.7 m**
- **Expected event rate 37k**

Comparison with SOX setup

	Our Proposal	SOX-experiment
Detector	Jinping	BoreXino
Target material	Slow liquid scintillator	Liquid scintillator
Target mass	2 kton	270 ton
Source	144Ce-144Pr	144Ce-144Pr
Initial activity	50-100 kCi	50-100 kCi
Baseline	3.7 m – 18.7 m	4.75 m – 12.25 m
Exposure time	450 days	1.5 years
Accidental background	Negligible	Negligible
Energy resolution	4.5-5%	5%
Position resolution	10 cm	15 cm
Total non oscillation event rate	38k	10k

Only SOX project with antineutrino source was very close to realization. It had problems with source production and the project was closed.



Event rate calculation

$$dN(L, E_\nu) = \Phi(L) \cdot \rho_{fp} \cdot \sigma_{IBD}(E_\nu) \cdot \mathcal{P}(L, E_\nu) \cdot S(E_\nu) dV dE_\nu$$

$$\Phi(L) = \frac{A_0 \cdot (1 - e^{-\lambda T})}{4\pi L^2 \cdot \lambda} [\mathrm{m}^{-2}]$$

A_0 – initial activity [Bq]

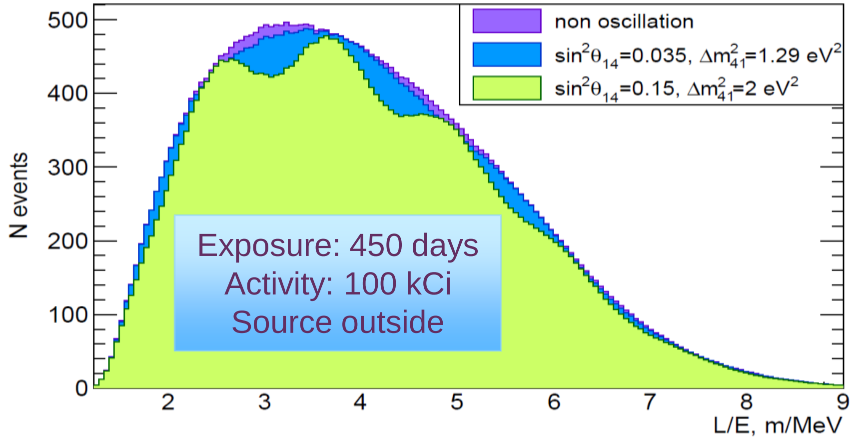
λ – decay constant [s^{-1}]

ρ_{fp} – density of free protons [m^{-3}]

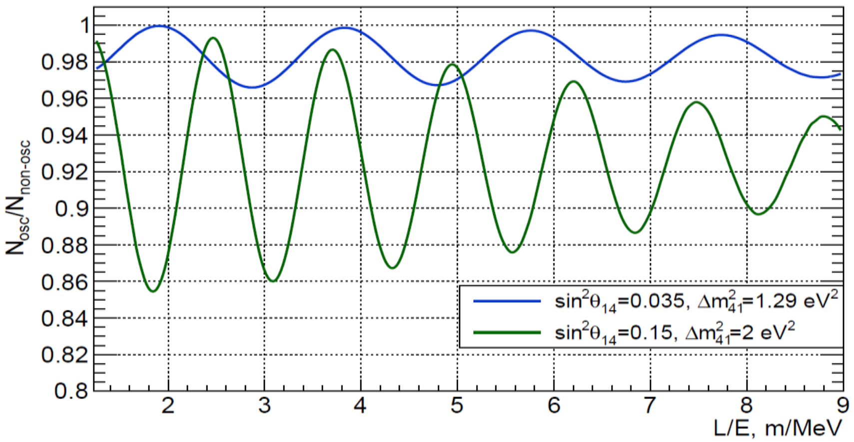
$\sigma_{IBD}(E_\nu)$ – IBD cross-section [m^2]

$\mathcal{P}(L, E_\nu)$ – probability function

$S(E_\nu)$ – shape of antineutrino spectrum



oscillation curves



Systematic uncertainties

Neutrino flux
Mostly comes from source activity. Conservative assumption 1.5%

Neutrino interaction
IBD efficiency ~90%
Spill in/out effects do not have strong influence to the result

Detection process
10 cm as position resolution 5%@1 MeV energy resolution
Energy-scale might change the spectrum shape. Taking to account it, 2% bin-to-bin uncorrelated uncertainty was added

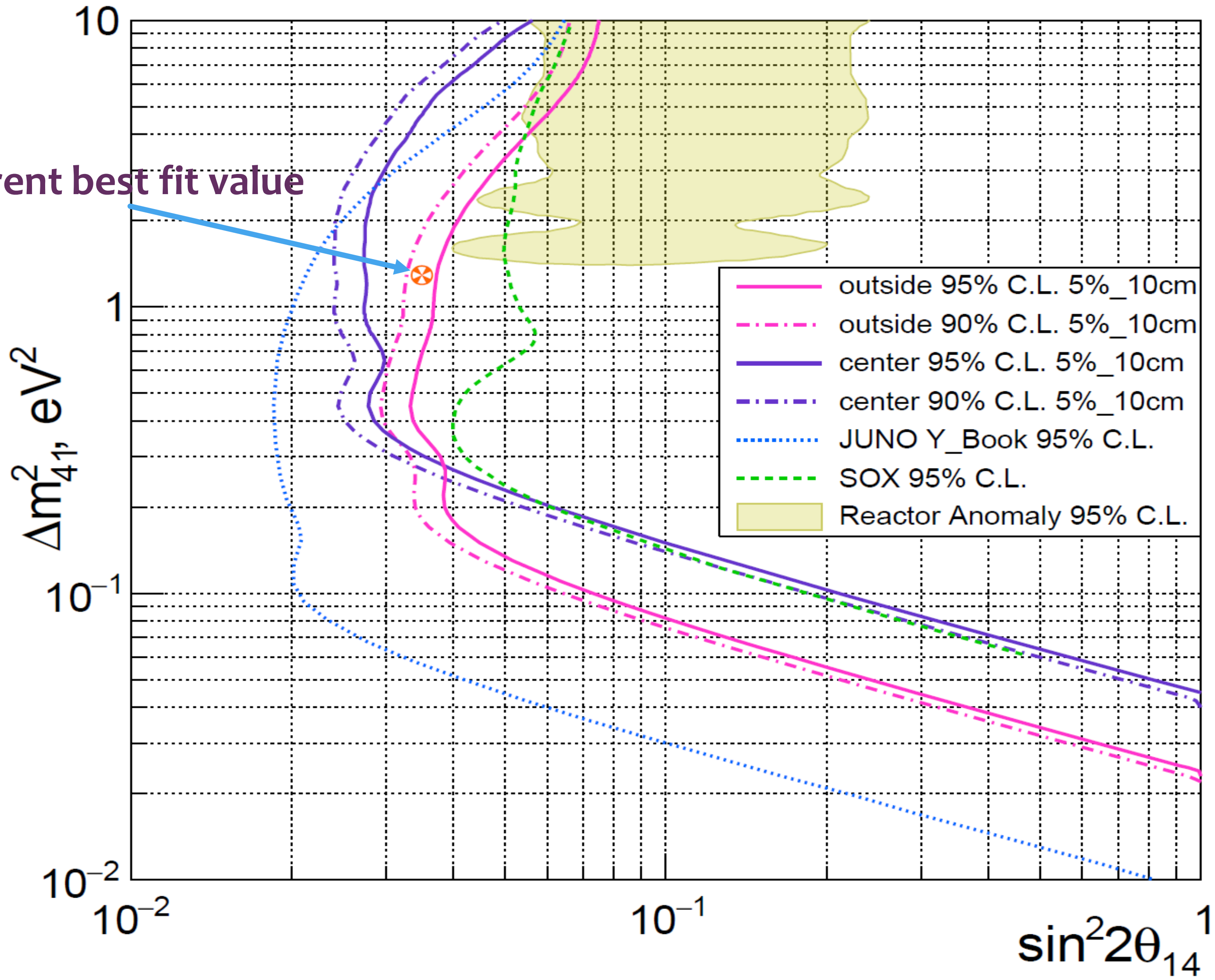
Definition of sensitivity

$$\chi^2 = \sum \frac{(N_i^{\mathrm{obs}} - N_i^{\mathrm{pre}})^2}{N_i^{\mathrm{pre}}(1 + N_i^{\mathrm{pre}} \cdot \sigma_b^2)} + \frac{\alpha^2}{\sigma_\alpha^2}, \qquad N_i^{\mathrm{pre}} = (1+\alpha)S_i,$$

α – nuisance parameter for flux

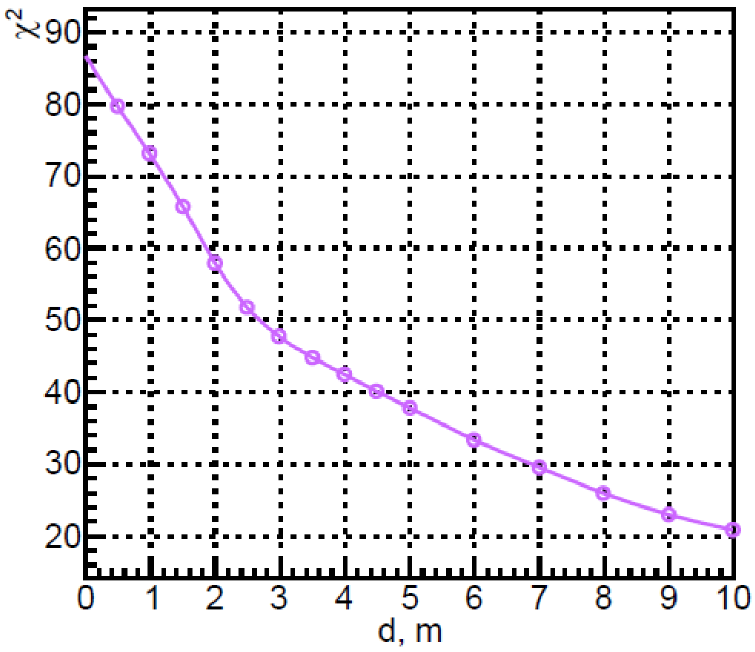
The expected sensitivity to sterile neutrino parameters

current best fit value

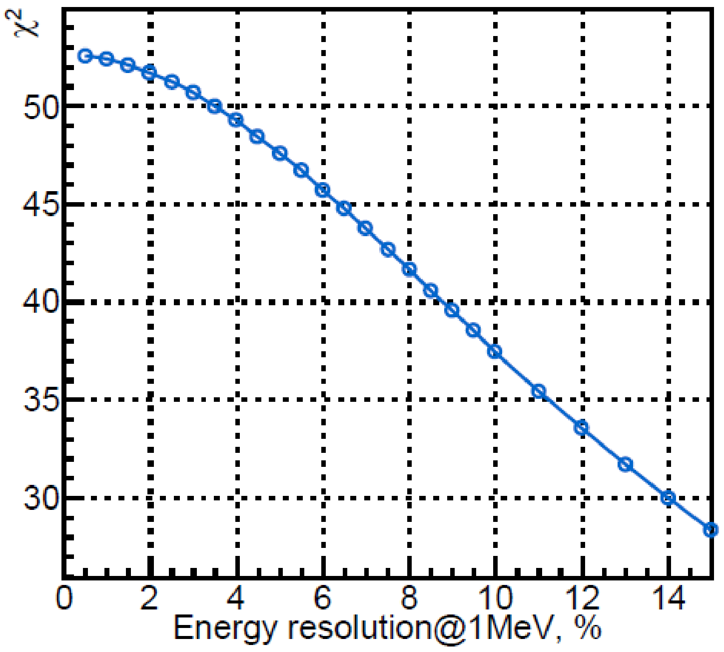


Influence of detector parameters to sensitivity

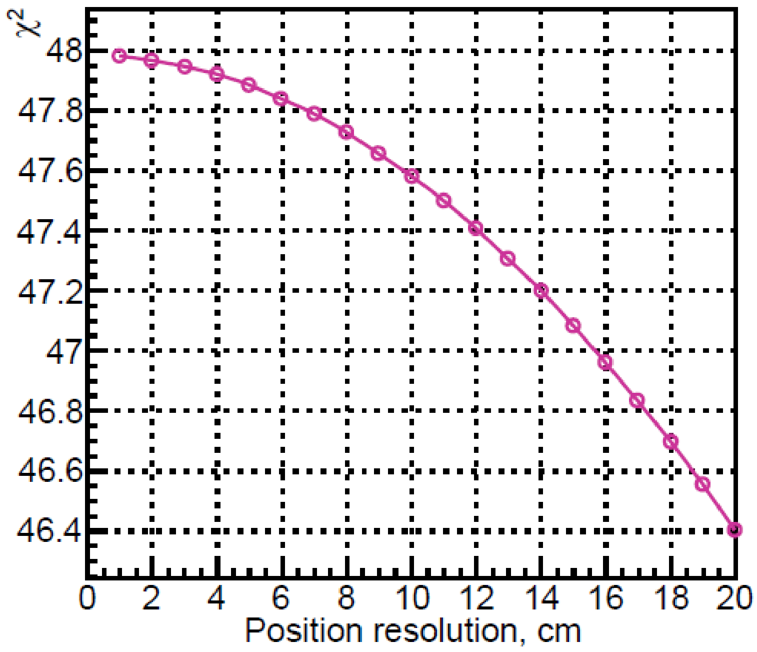
Distance between source and edge



Energy resolution



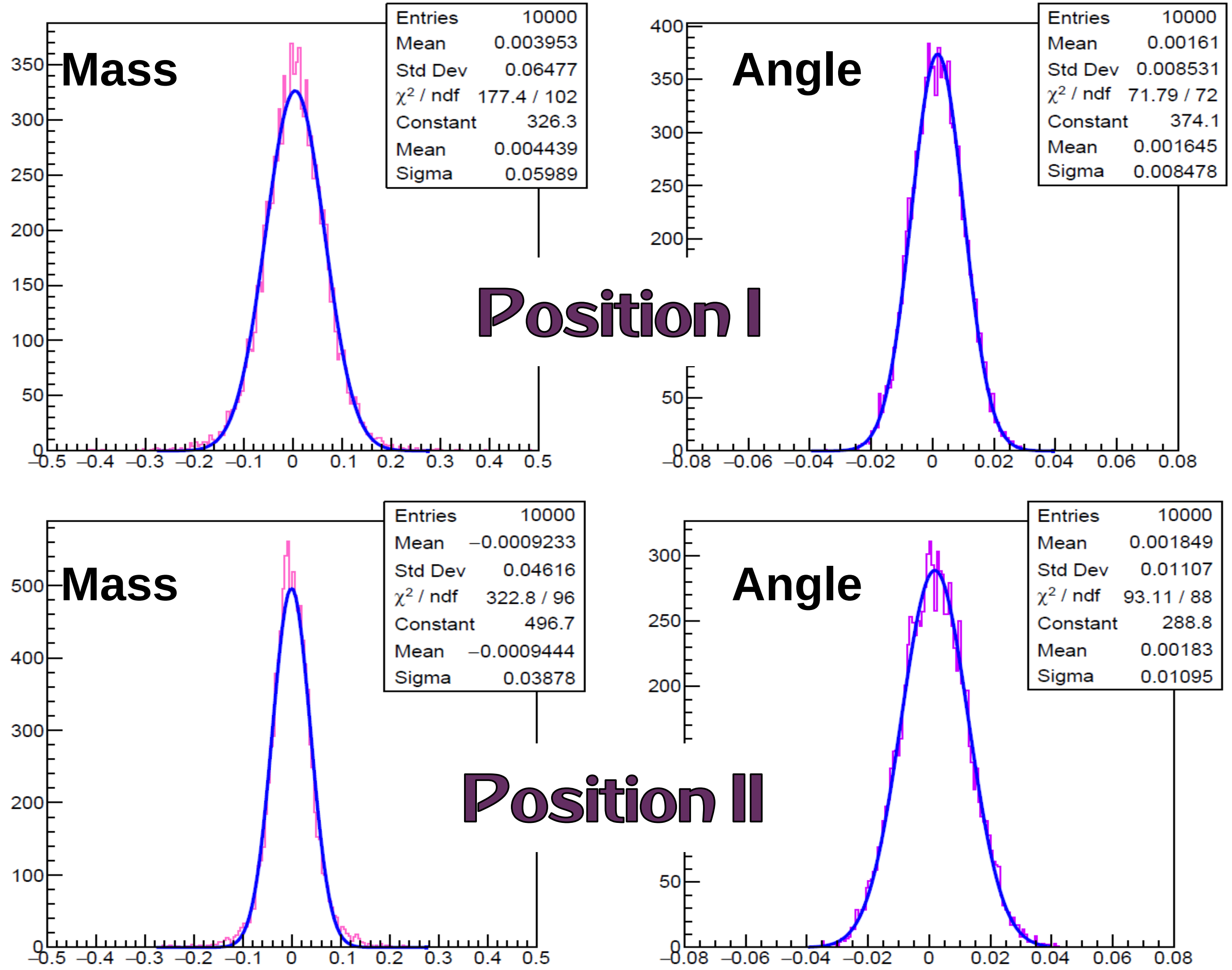
Position resolution



Fixed parameters: $\sin^2(2\theta_{14}) \approx 0.1;\ \Delta m^2_{41} = 1\ eV^2$

Source should be as much closer as possible. Energy resolution should be minimal!

Precise measurements of oscillation parameters



Current best fit value:

$\sin^2(2\theta_{14}) \approx 0.035;\ \Delta m^2_{41} = 1.29\ \mathrm{eV}^2$

Relative error

Parameter	Position I	Position II
$\sin^2(2\theta_{14})$	24.2%	31.3%
Δm^2_{41}	4.6%	3%

SUMMARY

- Advantages in comparison with conventional reactor experiments
    - Cover larger region of L/E variable
    - Well known spectrum shape of antineutrinos
    - High statistics
- One main difficulty is the source production
- Current work has shown that Jinping has a good potential for implementing neutrino oscillometry measurements with radioactive source
- It can cover reactor anomaly region with 90% C.L.

THANK YOU FOR ATTENTION!!!