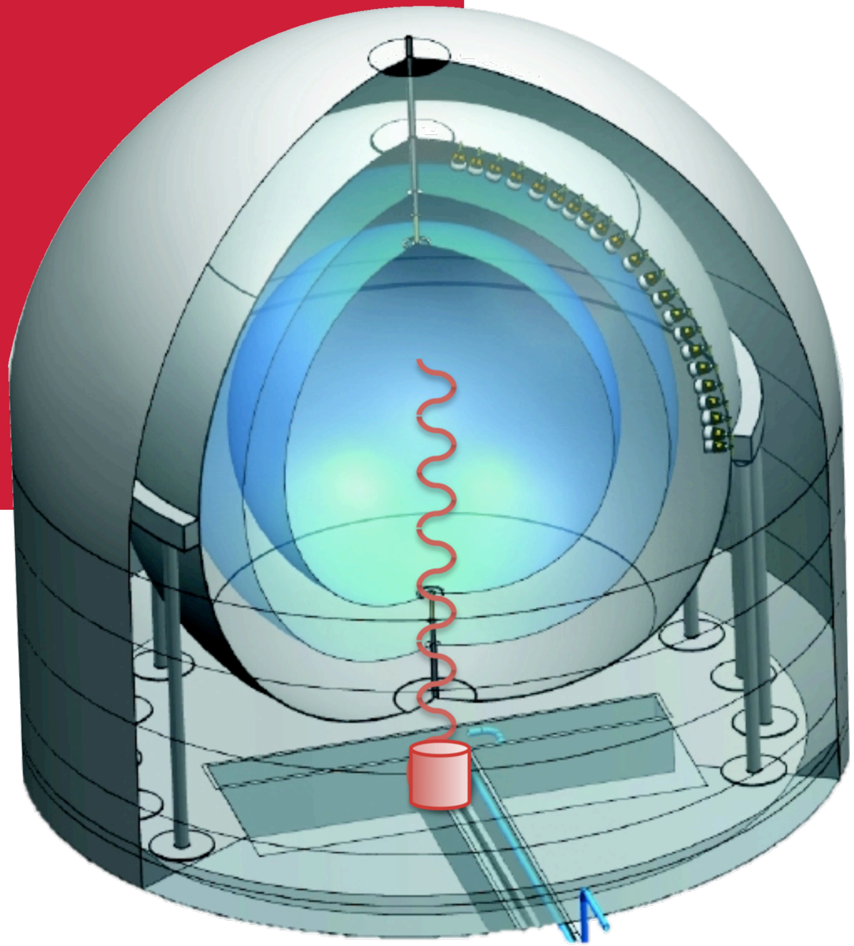
SOX

Short-baseline oscillations in Borexino

Michael Wurm
WIN | Heidelberg | 9 June 2015



on behalf of the Borexino/SOX collaboration

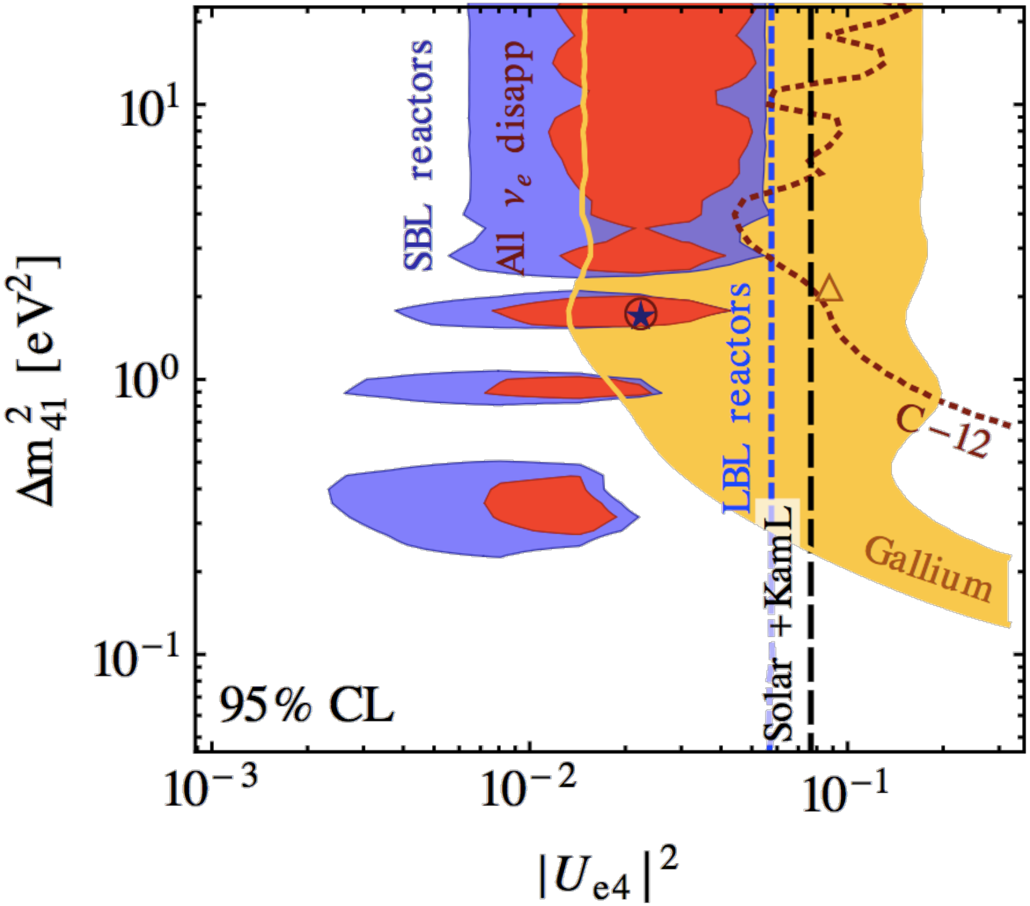
PRiSMA

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

Testing the reactor/gallium anomalies

Parameter space favored by anomalies



Kopp, Machado, Maltoni, Schwetz (2013)

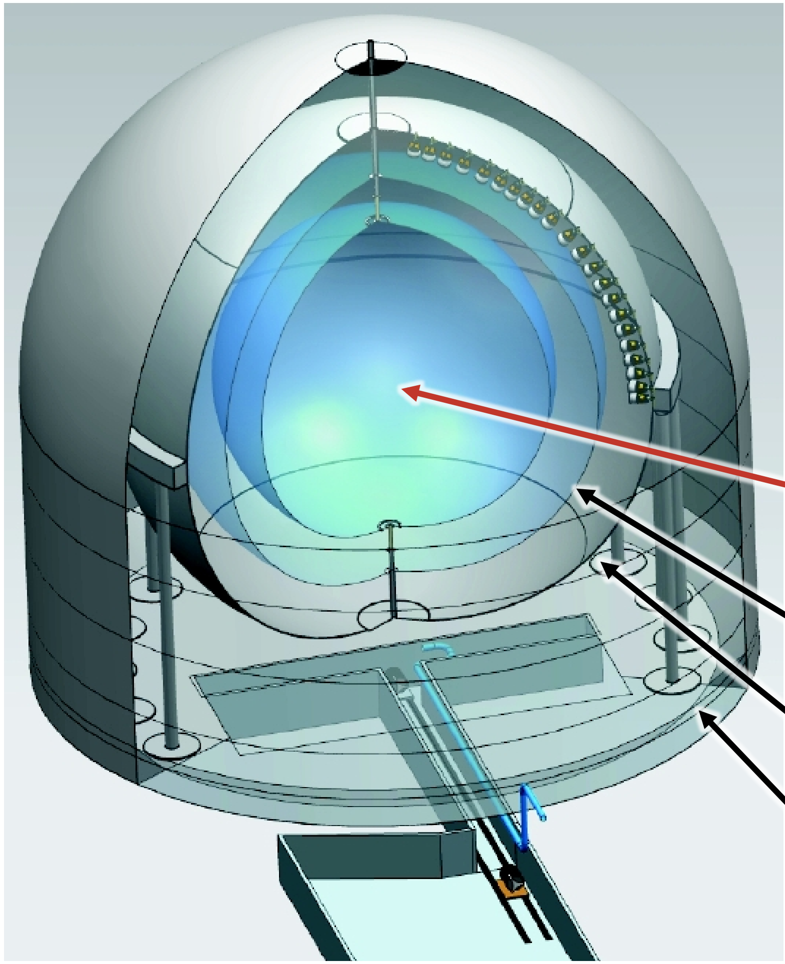
Both anomalies:

- not (yet) excluded by other data
- only based on **rate deficits**.

Decisive tests require observation of **oscillation patterns.**

→ *new short-baseline oscillation experiments*

The BOREXINO detector at LNGS



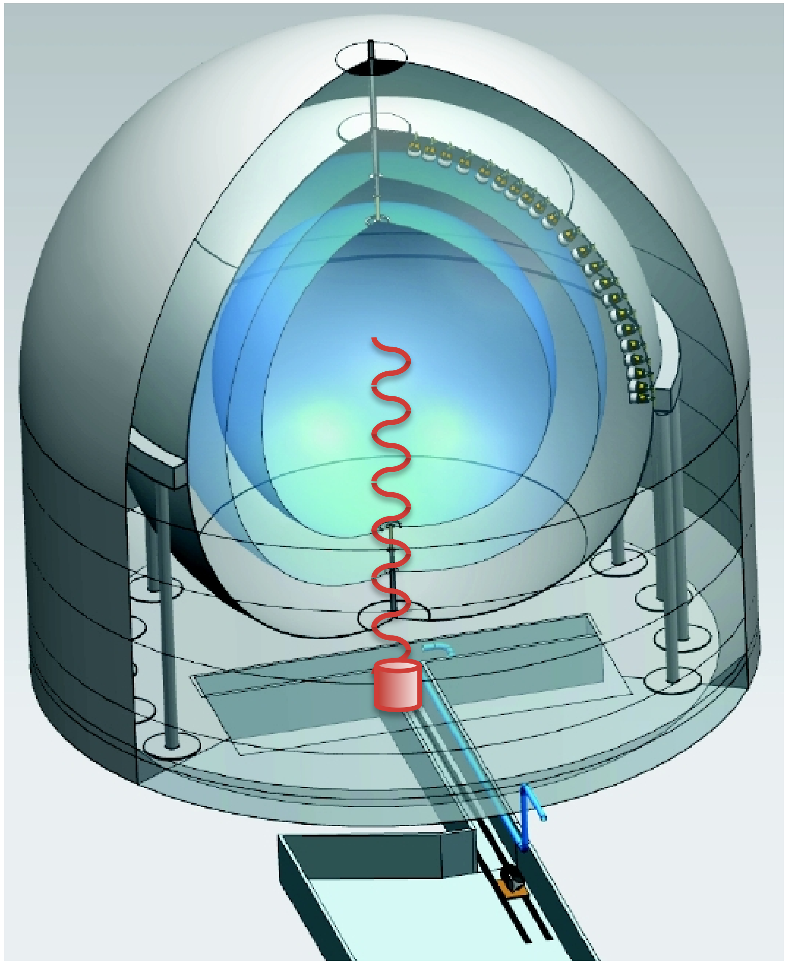
Active volume
270t of ultrapure scintillator
in nylon vessel (ø 8.5m)

Inactive buffer volumes
shielding external γ-rays

Stainless steel sphere (ø 13.7m)
with 2200 photomultipliers

Outer water tank(ø 18m)
Cherenkov muon veto

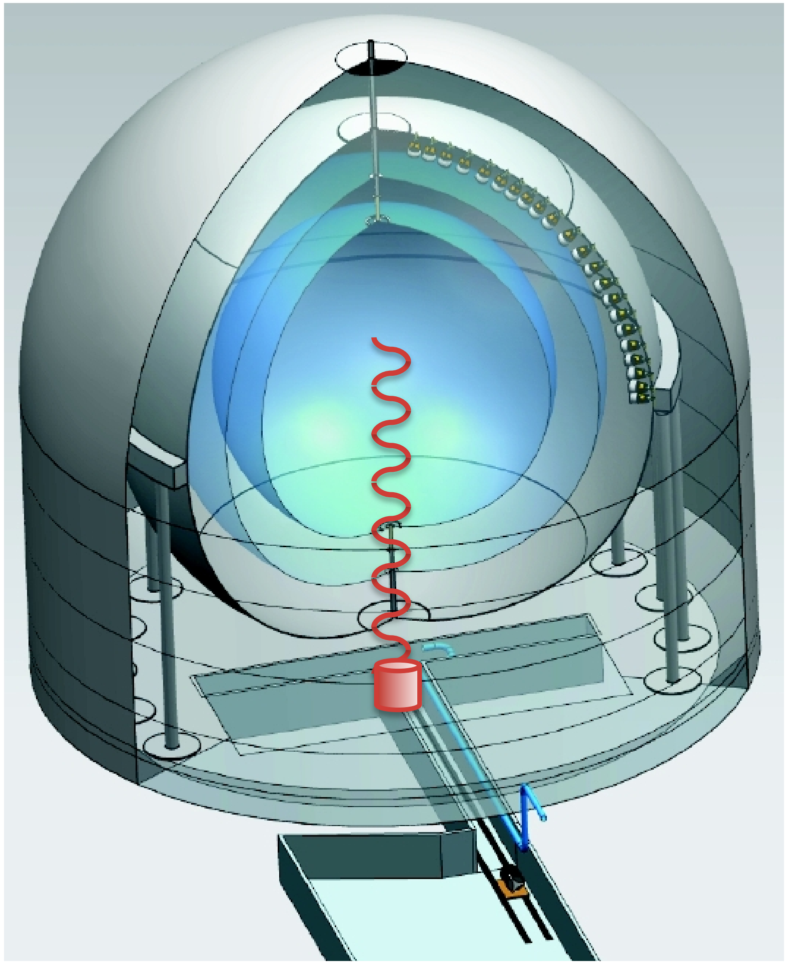
SOX in a nut-shell

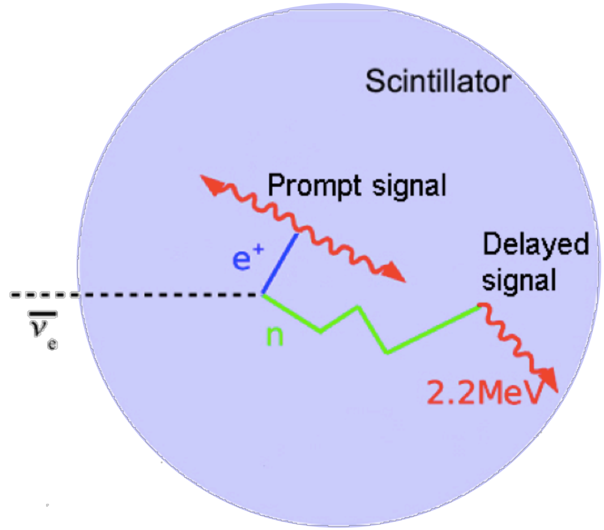


- **radioactive neutrino source** in pit below the detector (8.5m)
- First phase: **Ce-source** (100 kCi)
  $^{144}Ce \rightarrow {}^{144}Pr + e^- + \bar{\nu}_e$
  $^{144}Pr \rightarrow {}^{144}Nd + e^- + \bar{\nu}_e$
- disappearance oscillations $\bar{\nu}_e \rightarrow \bar{\nu}_s$
  → **$\bar{\nu}_e$ rate deficit**
- E_ν<3 MeV, oscillation length ~1m
  → **oscillation pattern within the scintillator volume**

→ **clear signature of sterile neutrinos**

Electron antineutrino detection





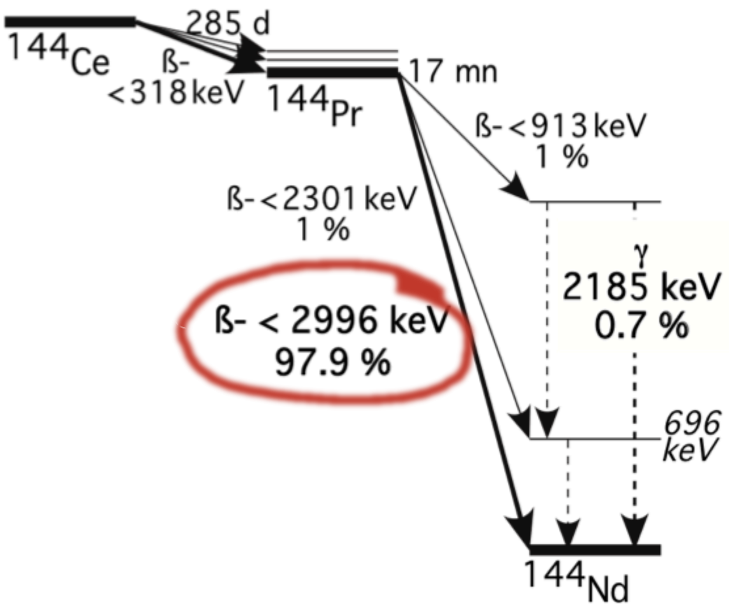
Detection channel: inverse beta decay

- $\bar{\nu}_e$ energy from prompt e^+ signal
- position resolution: ~10 cm
- almost background-free: ~10/yr

→ enlarged fiducial volume: radius ~4m, mass ~240t

Antineutrino energy spectrum

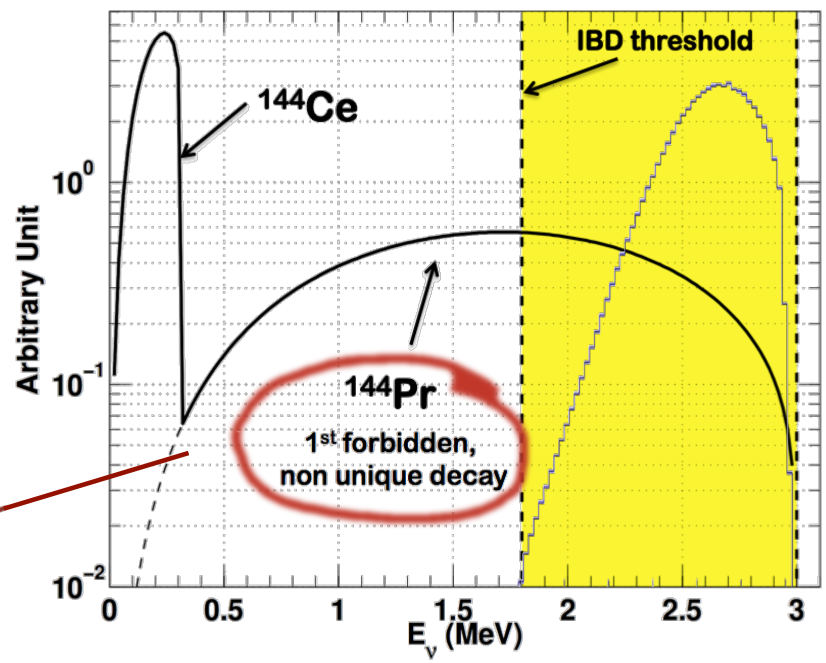
^{144}Ce-^{144}Pr decay scheme



IBD cross section:

$$\sigma_{\text{IBD}} \approx 9.5 \cdot 10^{-45}\,\text{cm}^2 \left(E - 1.8\,\text{MeV}\right)^2$$

Expected energy spectrum

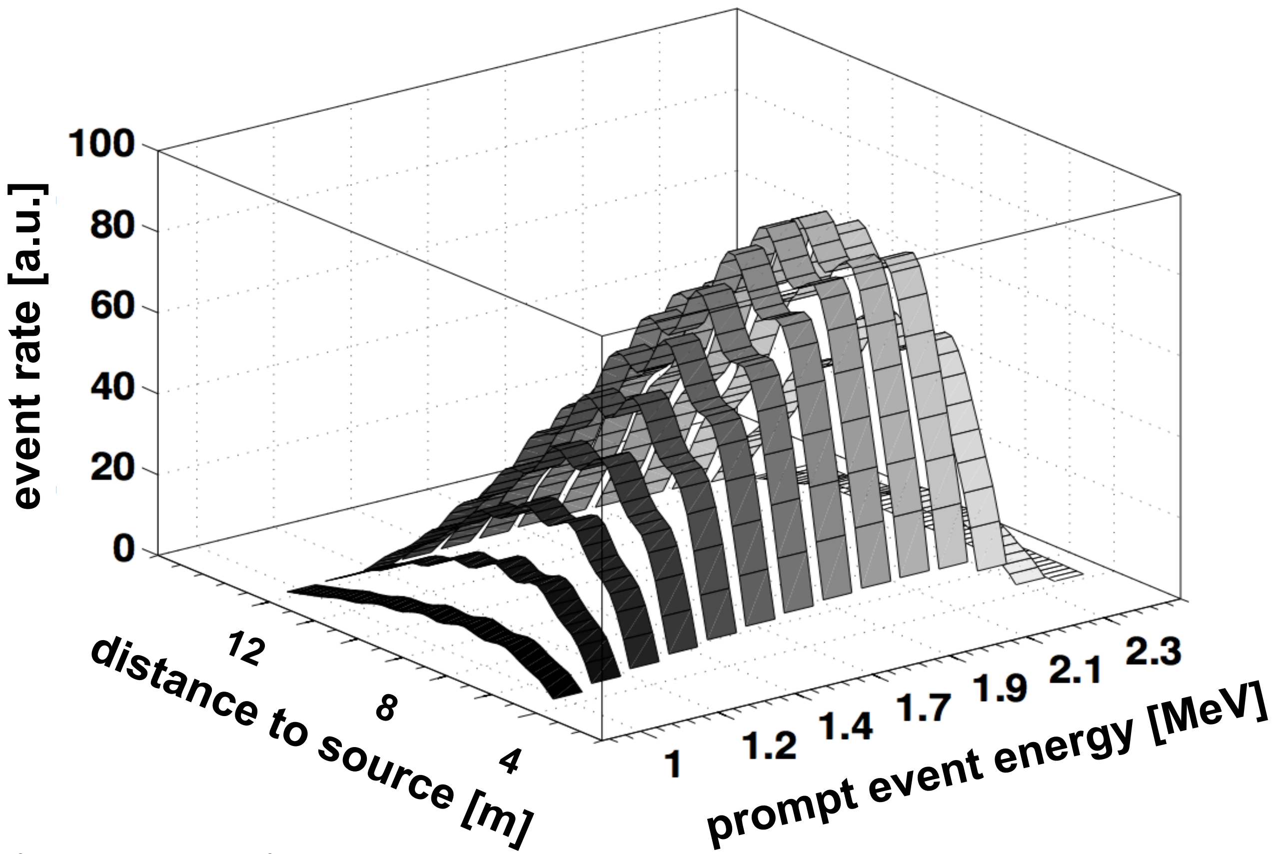


spectral shape is important

→ lab measurements on-going

Disappearance oscillation pattern

$$P(\nu_e \to \nu_s) = 1 - \sin^2(2\theta_{14})\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$



→ oscillation pattern in both distance and energy

→ required event statistics: ~10^4

^{144}Ce source production

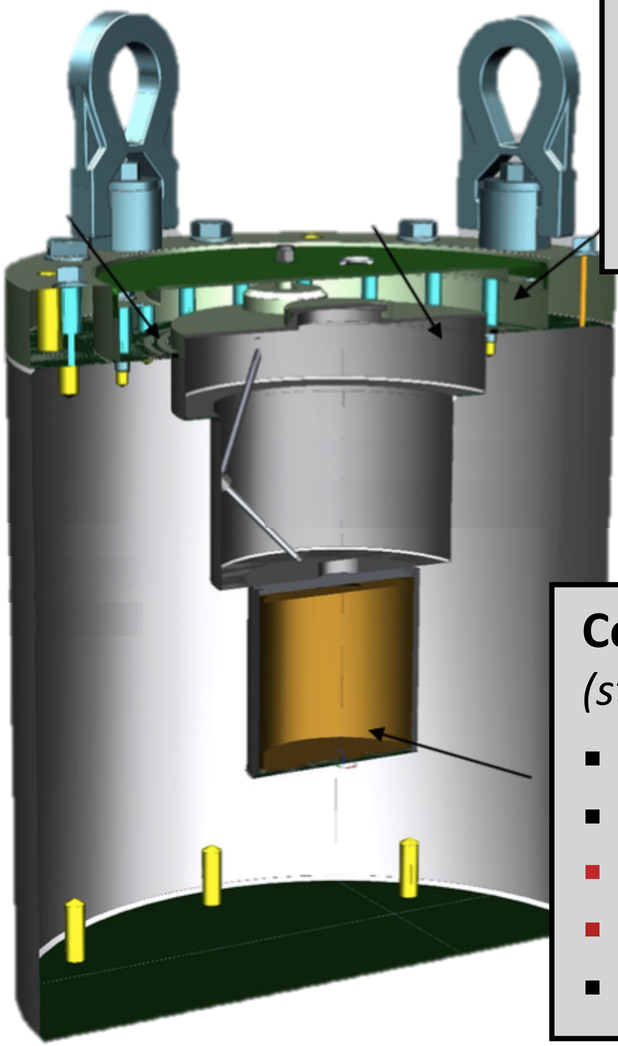
Producer: FSUE Mayak PA. (Russia)

1) Starting material: 2.8t of spent nuclear fuel (1.65 yrs of cooling time) from Kola NPP
2) Cutting, digestion and PUREX® process → concentrate of lanthanides and actinides
3) Displacement chromatography → extraction of all cerium (~5kg) → 30g of ^{144}Ce
4) Calcination in CeO_2, pressing, encapsulation, insertion in tungsten shielding

Transport from Mayak to LNGS

arrival date at LNGS: August 2016

Ce source in tungsten shielding



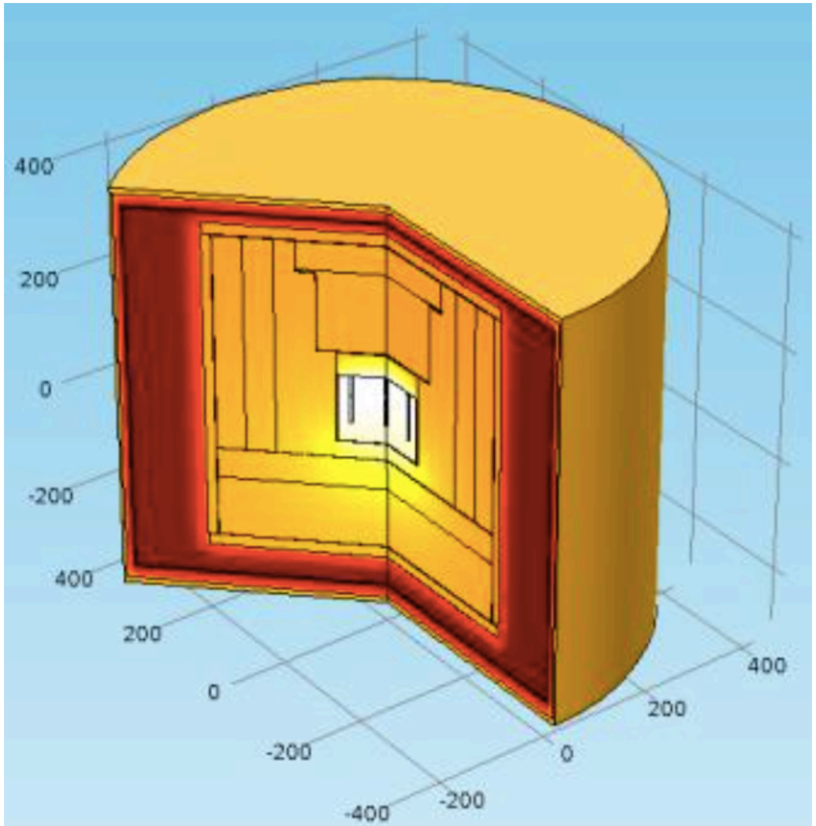
Tungsten shielding

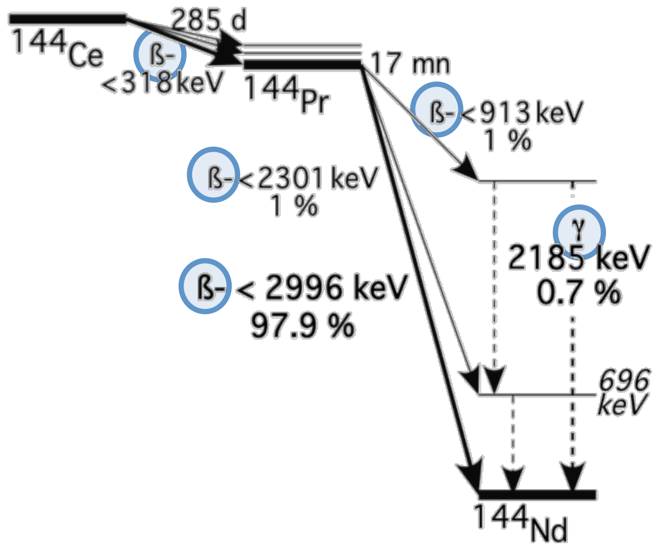
- dimensions 55cm
- wall thickness 19cm
- mass 2tons
- surface activity 200Bq

CeO_2 source
(steel container)

- dimensions 15cm
- density ~4.5kg/l
- ^{144}Ce 30g
- activity 4×10^{15}Bq
- half life 285d

Heat generated by Ce decays





- **β,γ activity** absorbed by source/shielding:

  100 kCi → 900 W

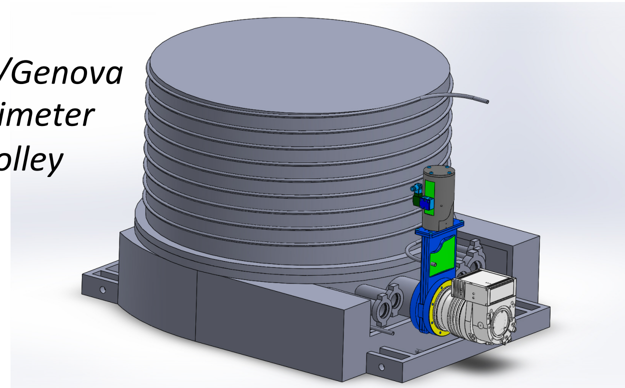
- surface temperature of W shield: ~70°C

→ measurement of source activity from heat power

Source calorimetry

Two calorimeters for independent measurements of thermal power (~1%)

- **Calorimeter inside SOX-Pit**
  German groups/Genova
- **Calorimeter outside PIT/in Mayak**
  CEA Saclay

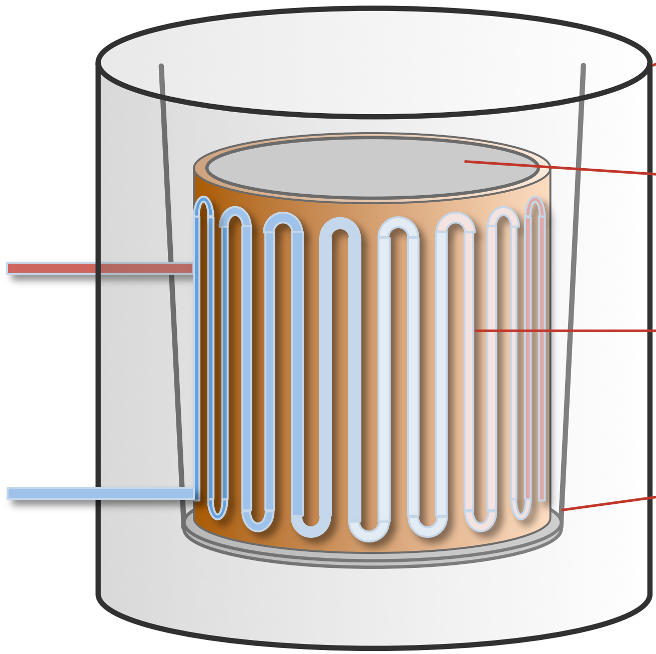


TUM/Genova calorimeter on trolley

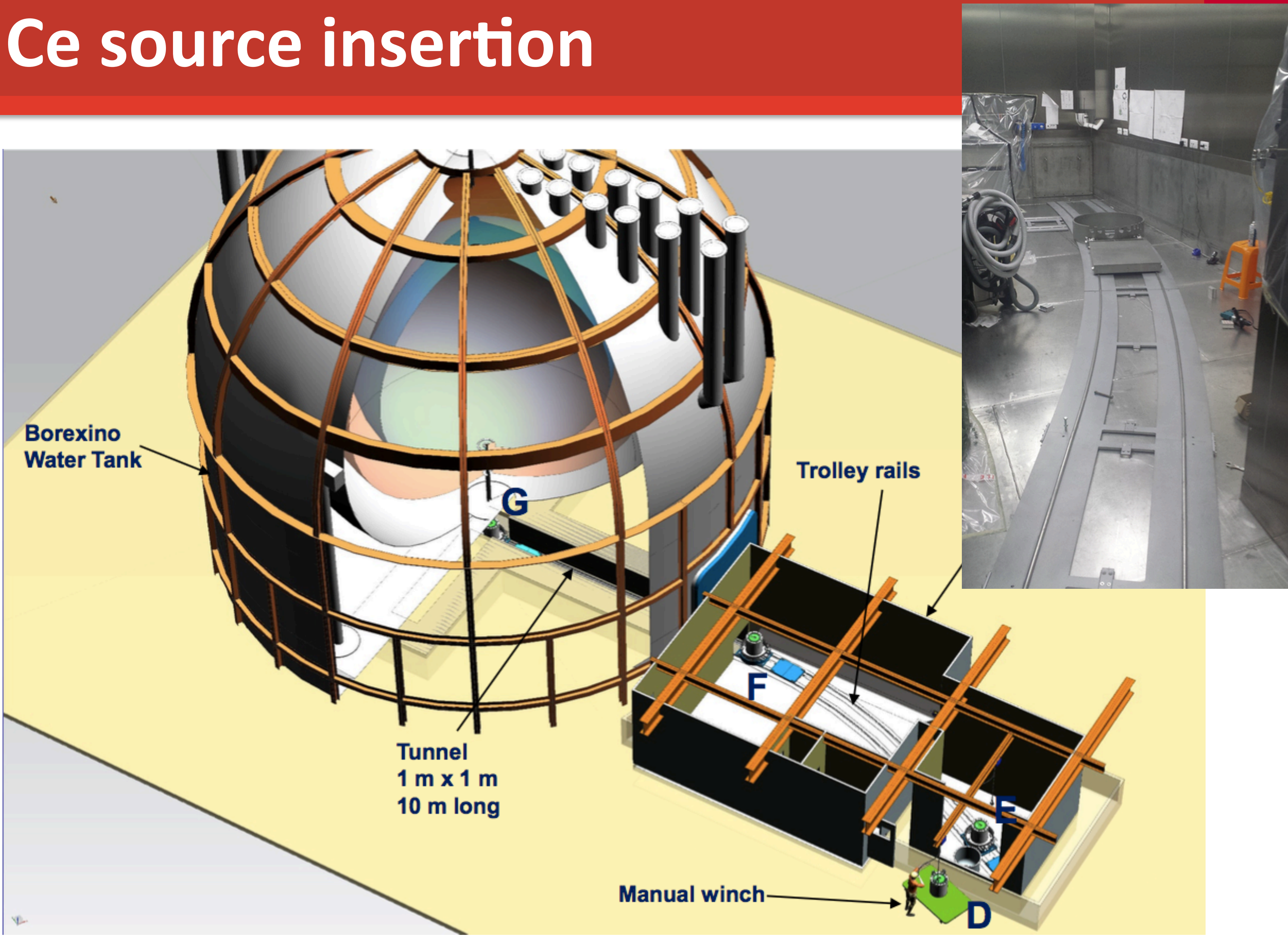
Measurement strategy

- insulate source from surroundings
- circulate water through loop around W shielding
- measure mass flow Φ and temperature increase ΔT

$$P = \Phi \cdot C \cdot \Delta T$$

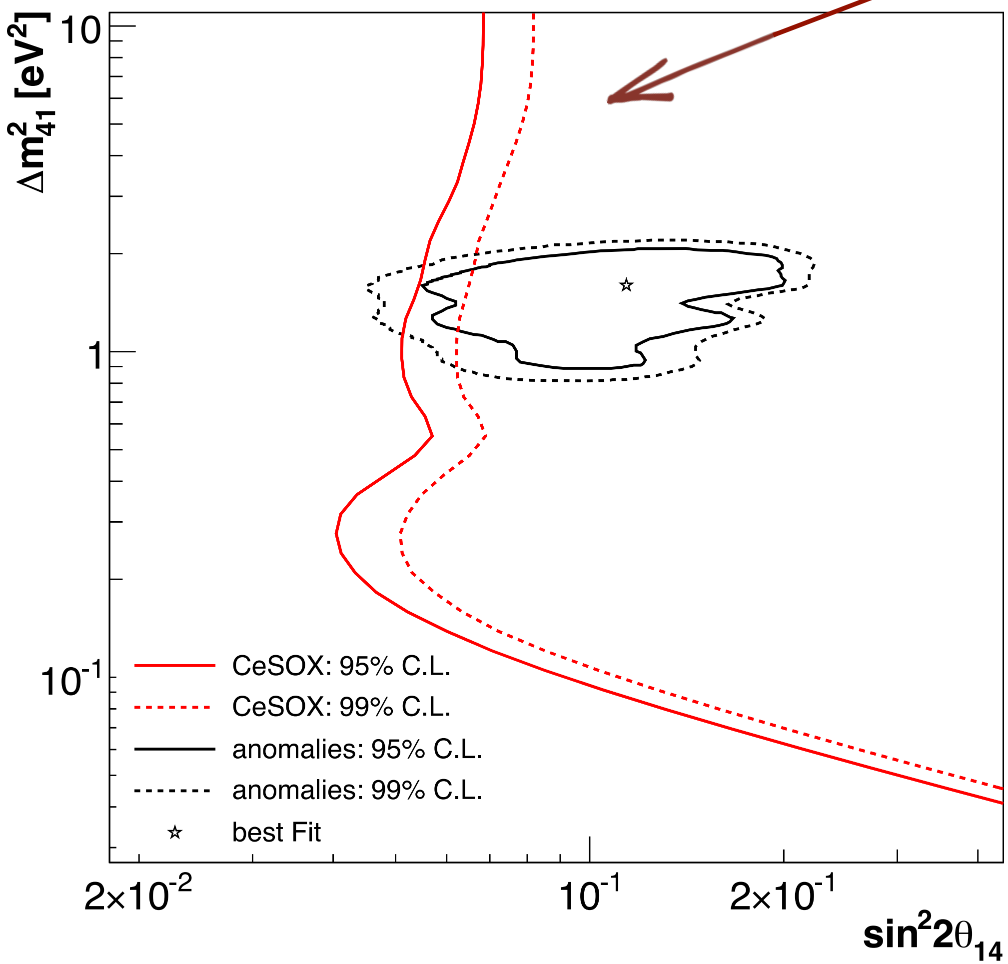


Ce source insertion



SOX sensitivity

$$P(\nu_e \to \nu_s) = 1 - \sin^2(2\theta_{14}) \sin^2 \left(\frac{\Delta m_{41}^2 L}{4E} \right)$$



- **1st Phase: CeSOX,** from '16
  ^{144}Ce-^{144}Pr $\bar{\nu}_e$-source

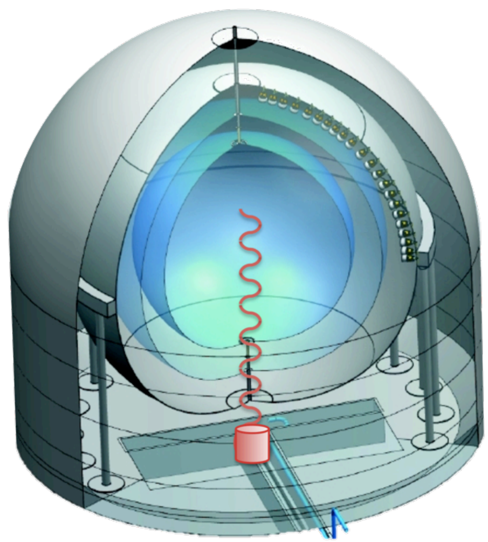
Activity:	100 kCi
Exposure:	1.5 yrs
total event number:	~10^4
Distance to center:	8.5 m
Fiducial radius:	4 m
Uncertainty	
- on activity:	1%
- on fiducial volume:	1%
no background	

- **2nd Phase? ^{51}Cr ν_e-source**
  comparable sensitivity in $\sin^2 2\theta$ for activity of 10MCi

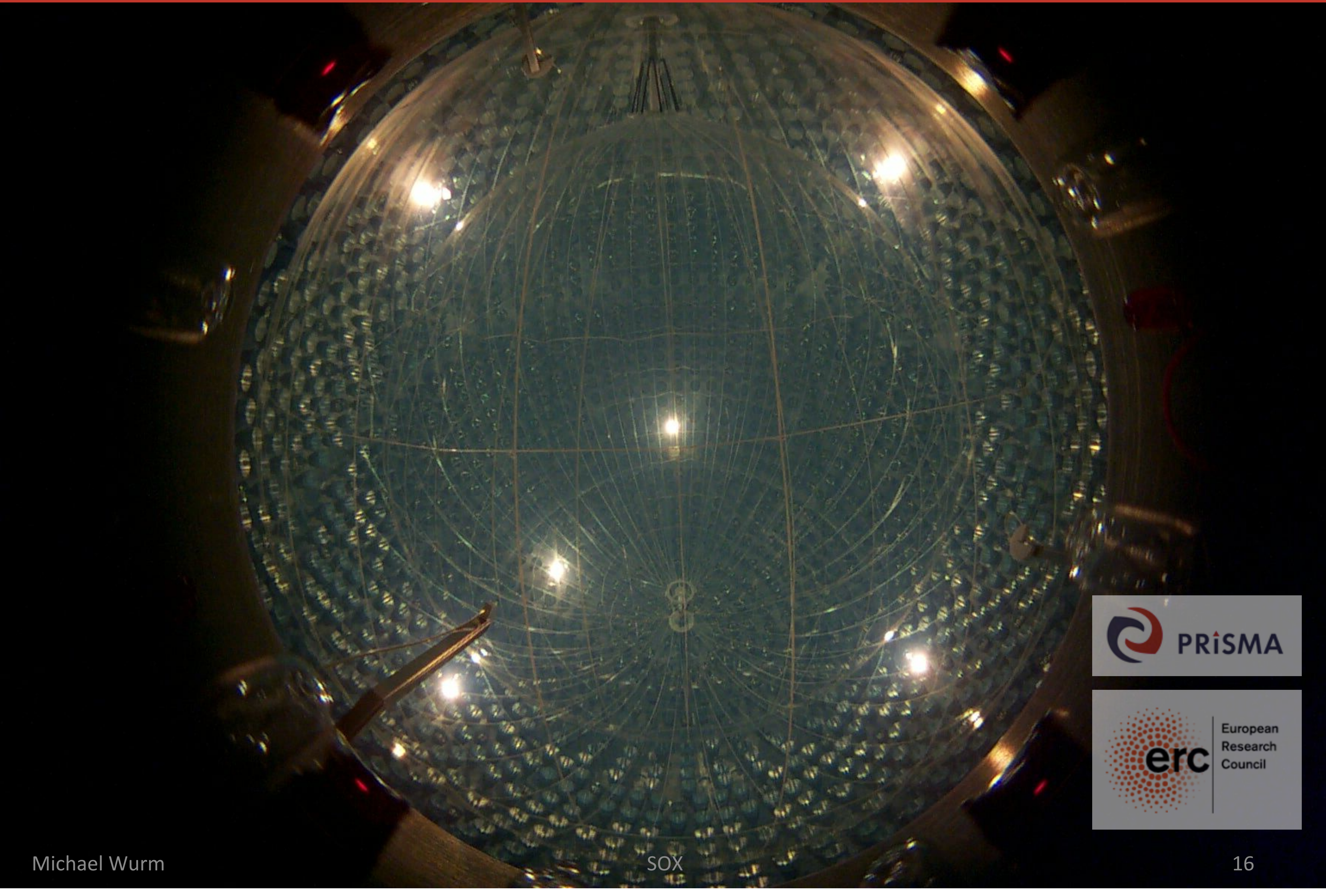
- **3rd Phase??**
  ν-source at detector center

Conclusions

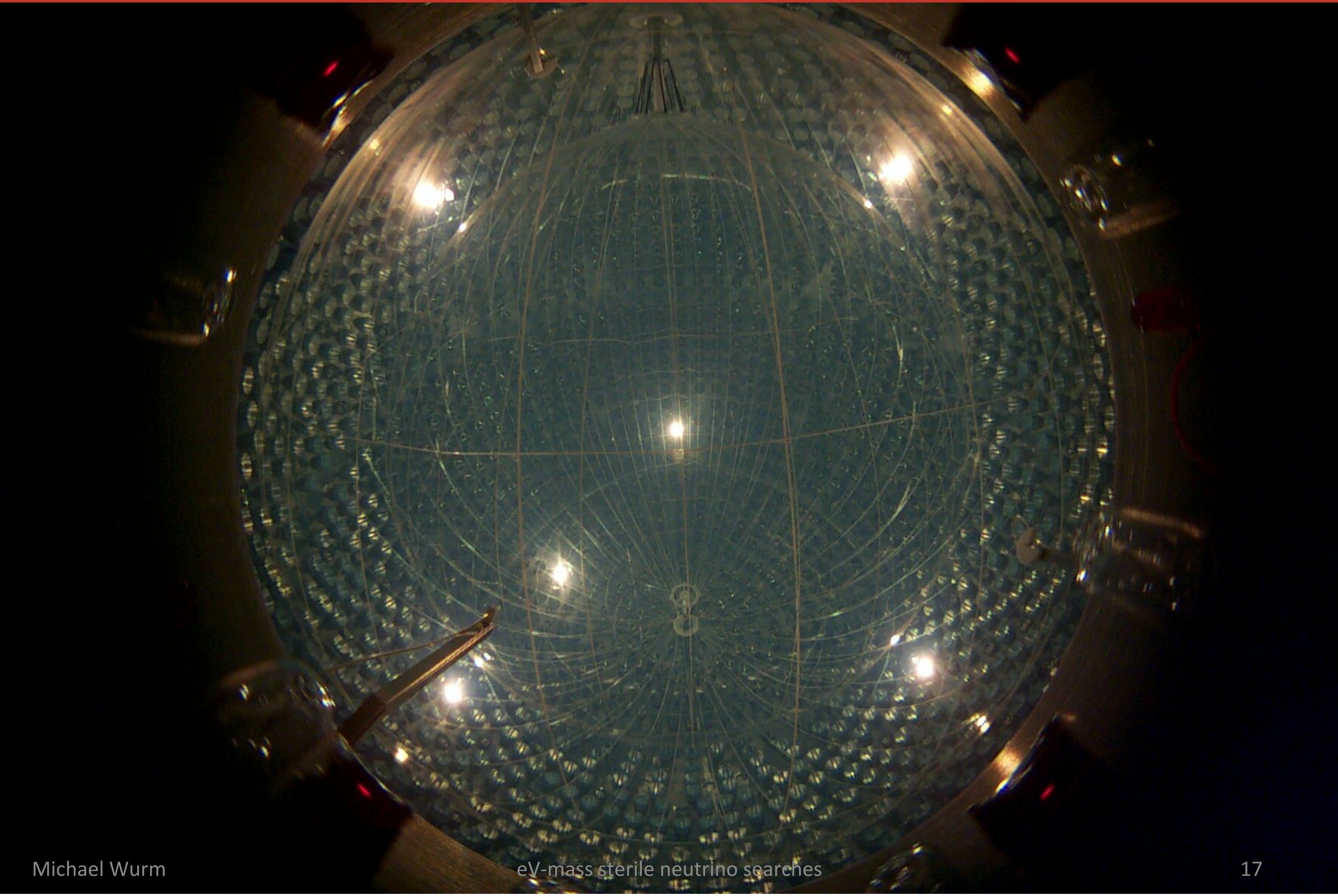
- SOX will test the current reactor and gallium anomalies by a short-baseline $\bar{\nu}_e \rightarrow \bar{\nu}_s$ disappearance experiment
- disappearance oscillation pattern inside the target volume
  → distinctive signature of oscillations
- CeSOX: 1st phase with ^{144}Ce-^{144}Pr antineutrino source below the detector, activity of 100kCi
- start in 09/16,
  1.5 yrs of data taking for ~10k events



Thank you!

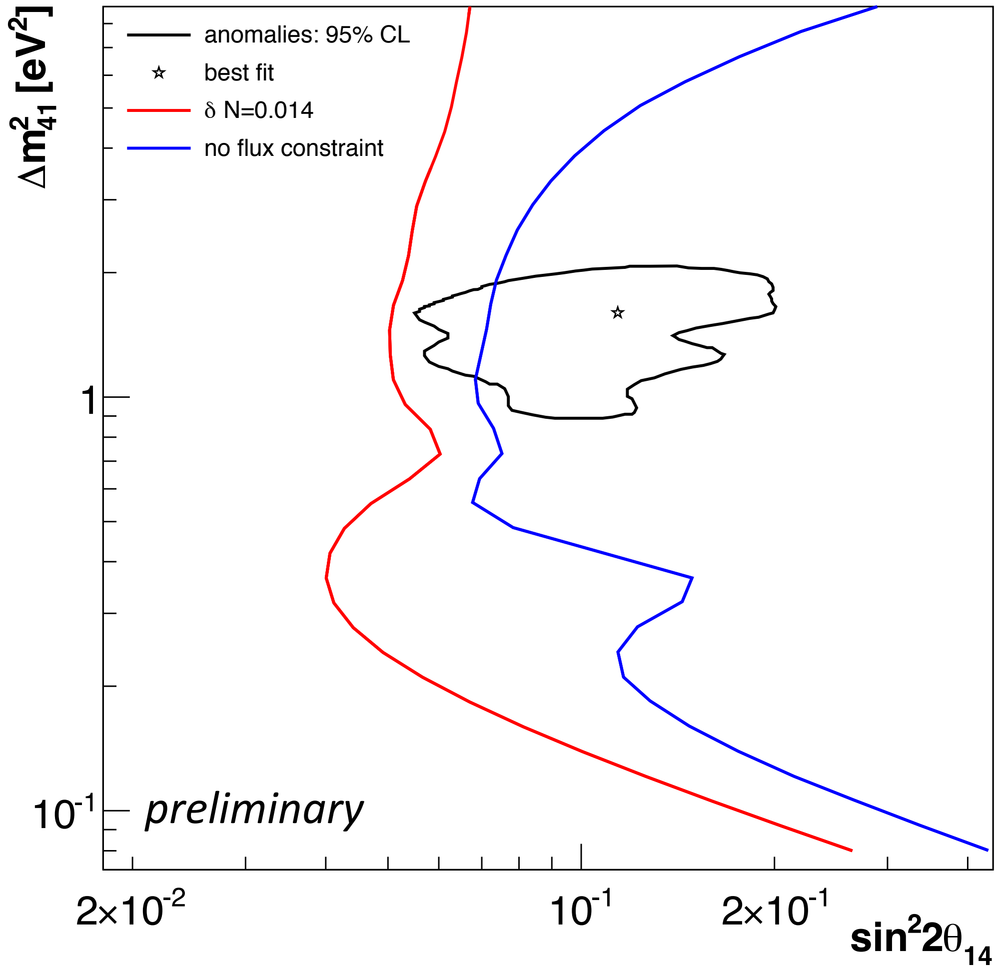


Backup Slides

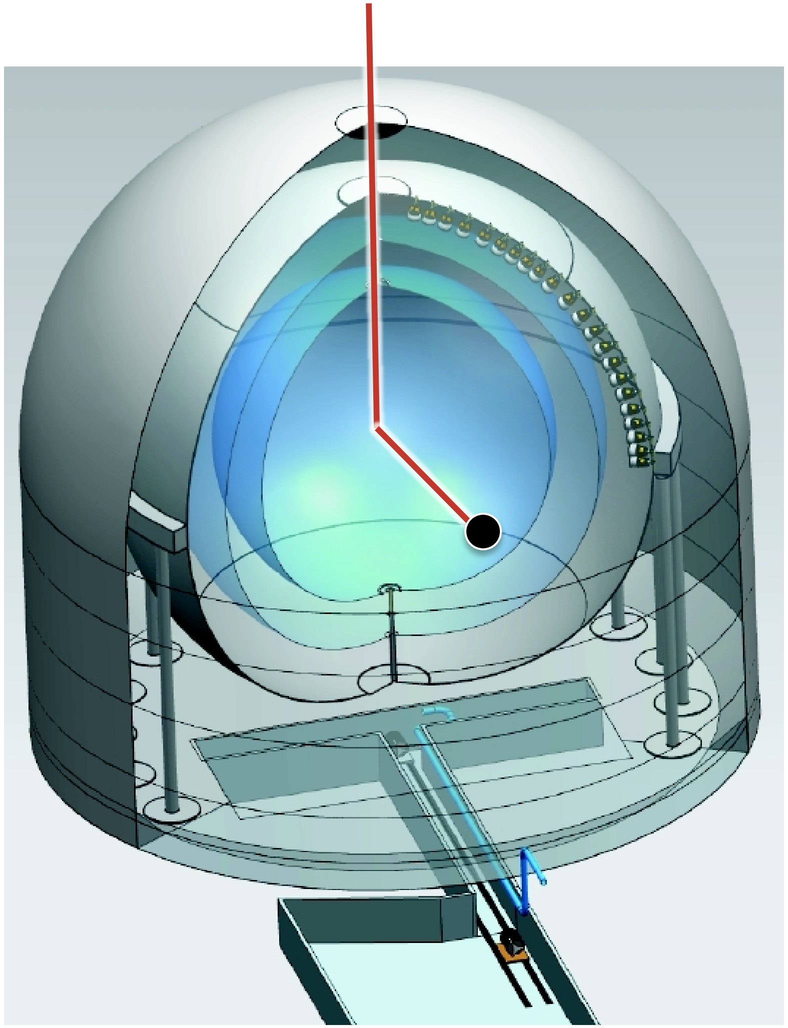


CeSOX shape-only sensitivity

$$P(\nu_e \to \nu_s) = 1 - \sin^2(2\theta_{14})\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$



Systematics: Detector response

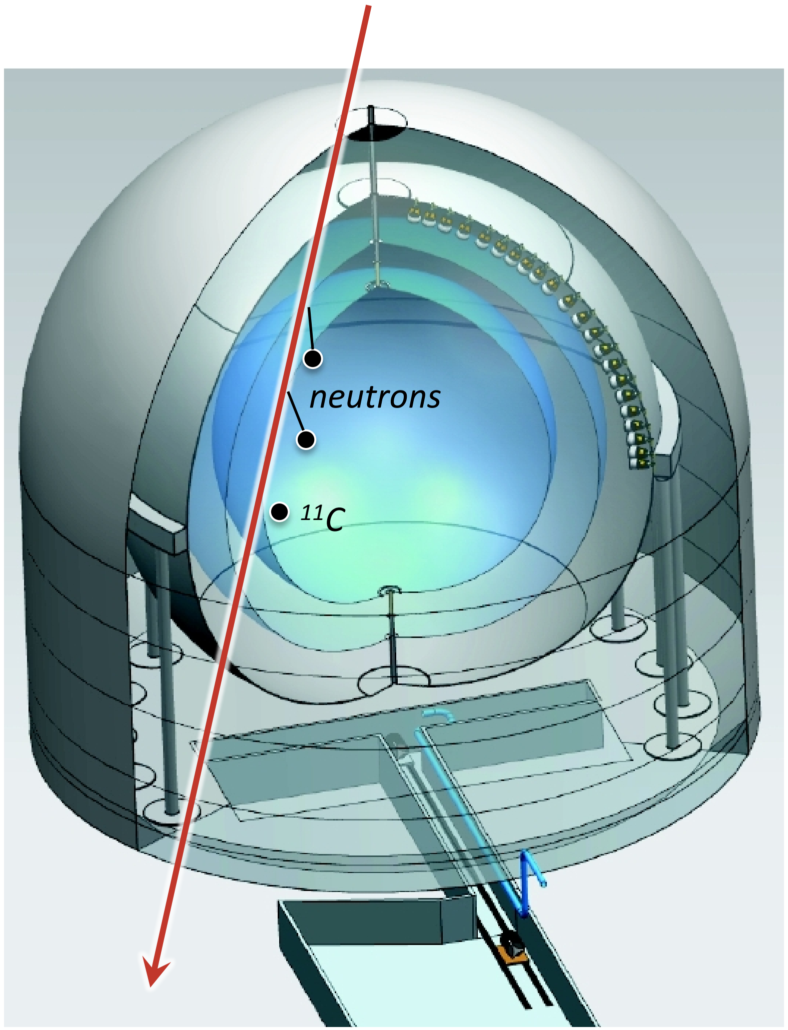


Detector response to be mapped close to the verge of the scintillator volume

Calibration campaign inserting weak radioactive sources (β^+, γ, n)

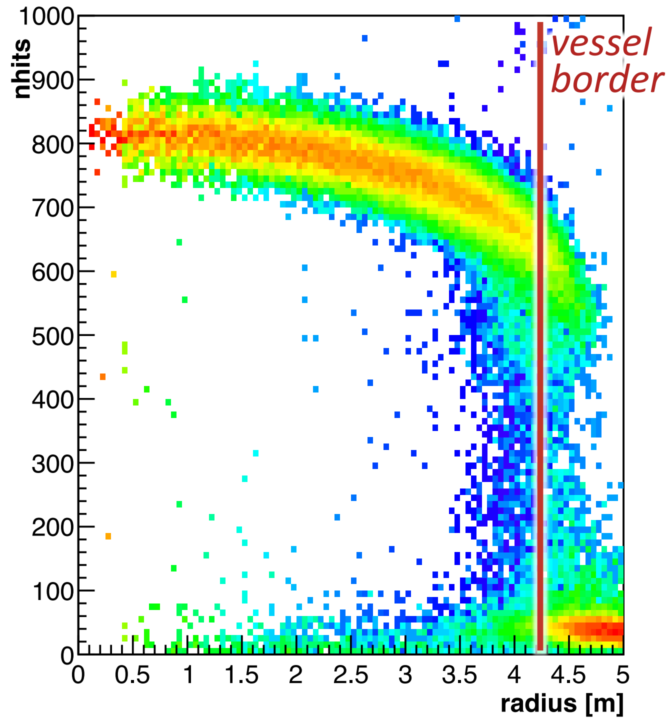
- uniformity of detection efficiency: radial dependence of light collection, spill-out effects etc.
- systematic shifts in spatial/energy reconstruction
- influence of vessel shape, PMT acceptance

Systematics: Detector response

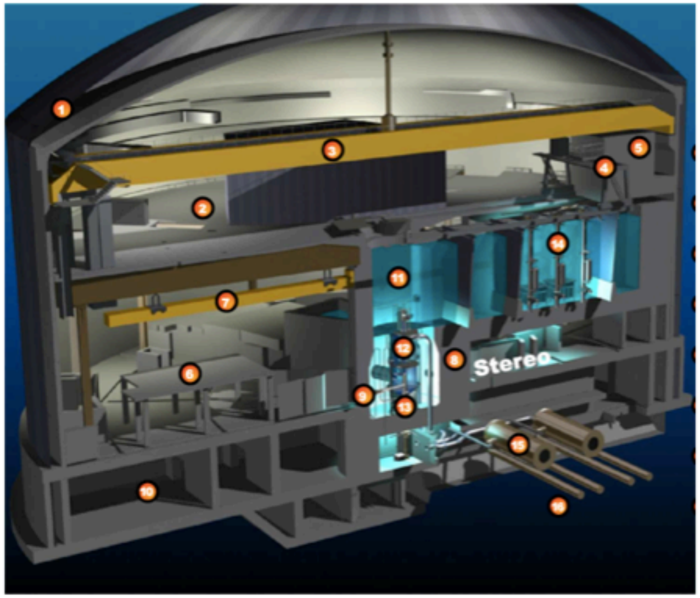


Detector response to be mapped close to the verge of the scintillator volume

- **Calibration campaign**
- **Detector self-calibration**
  e.g. by cosmogenic neutrons, isotopes

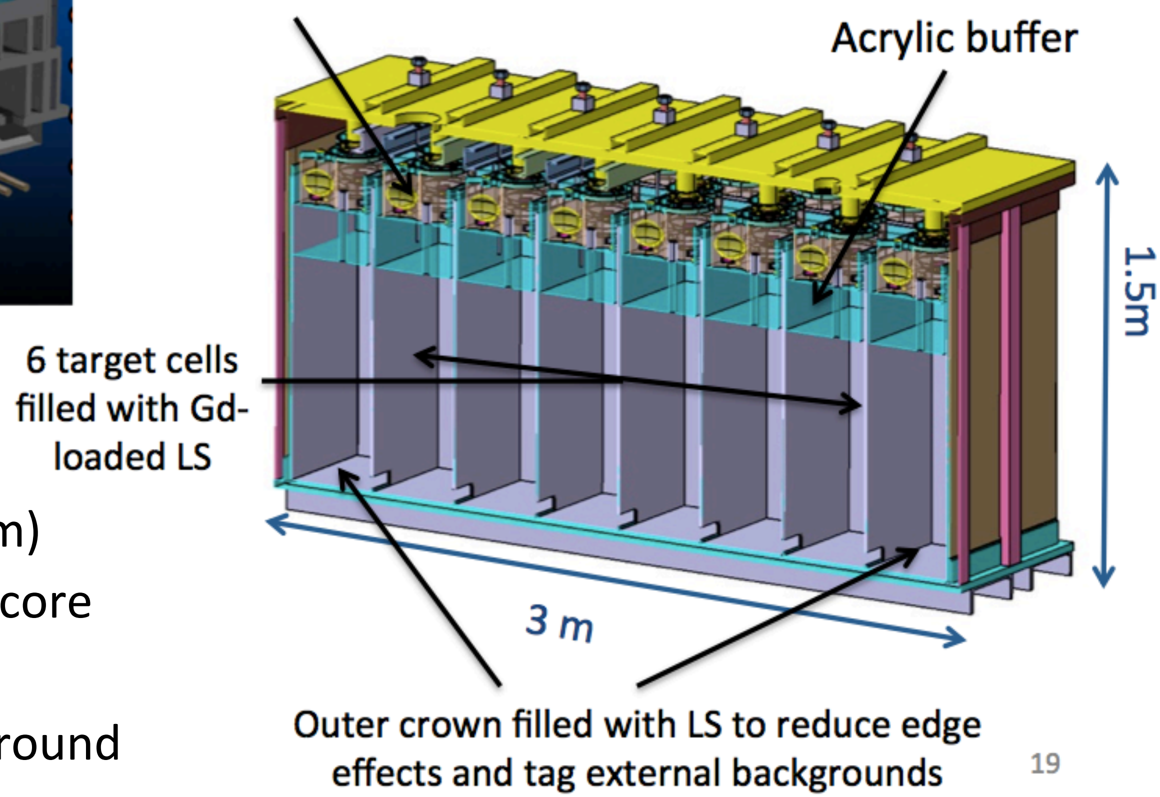


STEREO at ILL Grenoble



Detector

- Gd-doped liquid scintillator for $\overline{\nu}_e$ detection
- segmented
- active vetoes for radiation/μ's

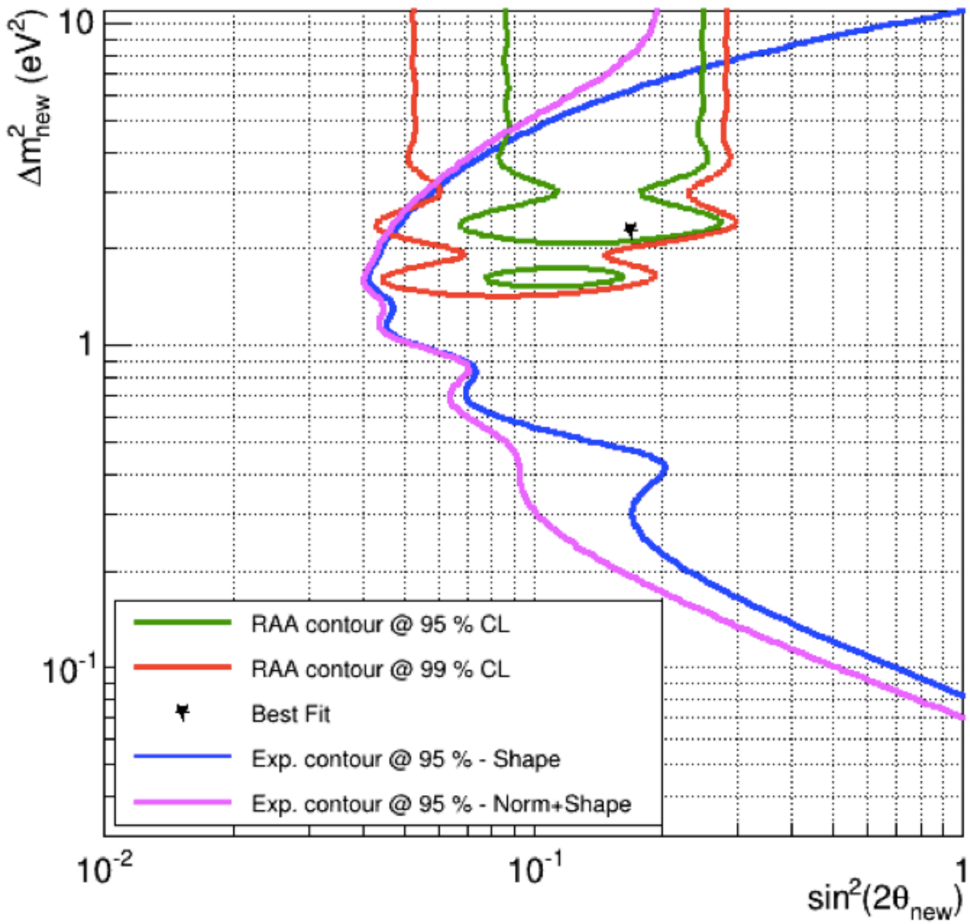


ILL reactor

- 57 MW, compact core (<1m)
- experiment [9-11] m from core
- 15 mwe overburden
- high level of reactor background

STEREO – Expected sensitivity

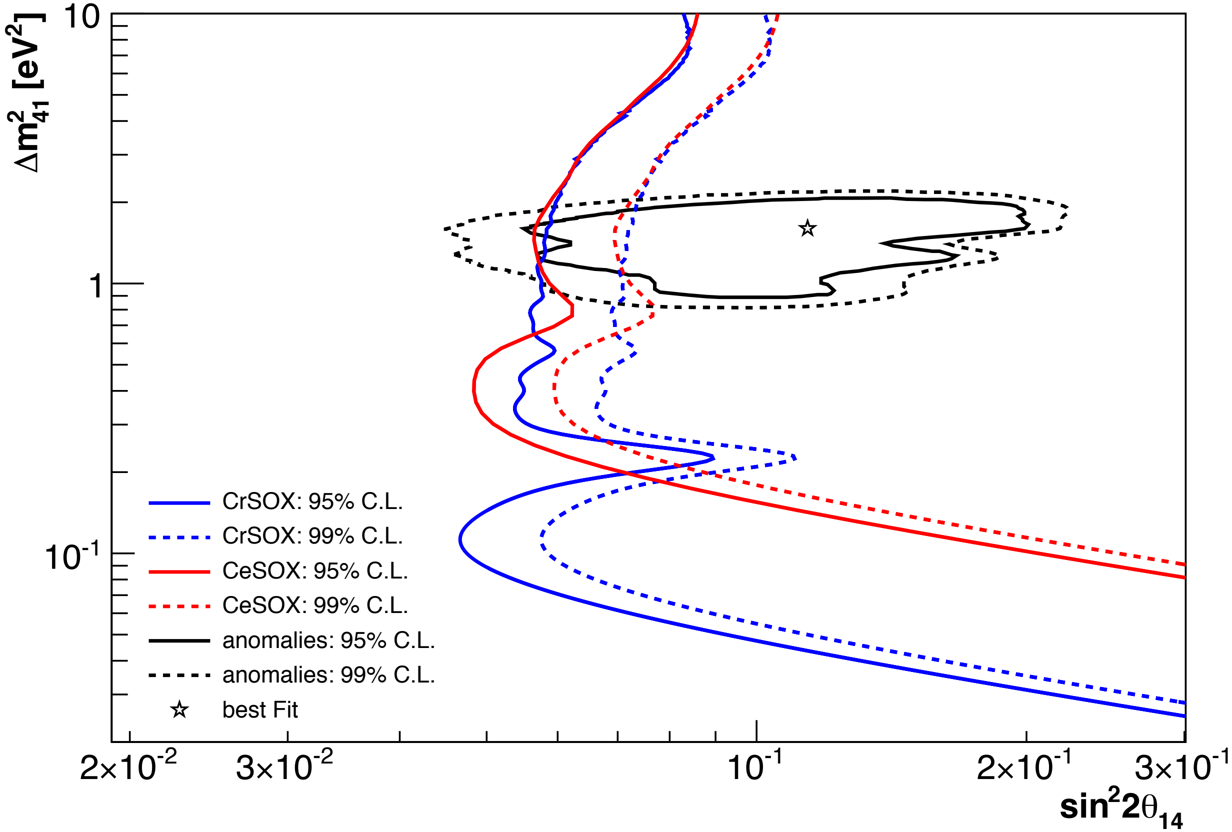
[Lhuillier, Neutrino 2014]



Experimental parameters

- 300 days, L_0 = 10 m
- E_{prompt}>2 MeV, $E_{delayed}$>5 MeV
- ~410ν_e/day
- δE_{scale} = 2%
- All syst. of predicted spectra
- S/B = 1.5, 1/E+flat model
- Norm 4%
- Start data taking in 2015

Projected sensitivity of CeSOX/CrSOX



CrSOX
Activity: 10 MCi
Fiducial radius: 3.3 m
1% source error
1% FV error
1% background error

CeSOX
Activity: 100 kCi
Fiducial ra dius: 4 m
1% source error
1% FV error
no relevant background

→ SOX could discover/exclude best fit value at ~5σ

→ 95% C.L. region of anomalies can be covered