The SOX experiment

Status & perspectives

WIN 2017: Workshop on Weak Interactions and Neutrinos
18-24 June 2017
University of California Irvine

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on behalf of the *BOREXINO/SOX* collaboration

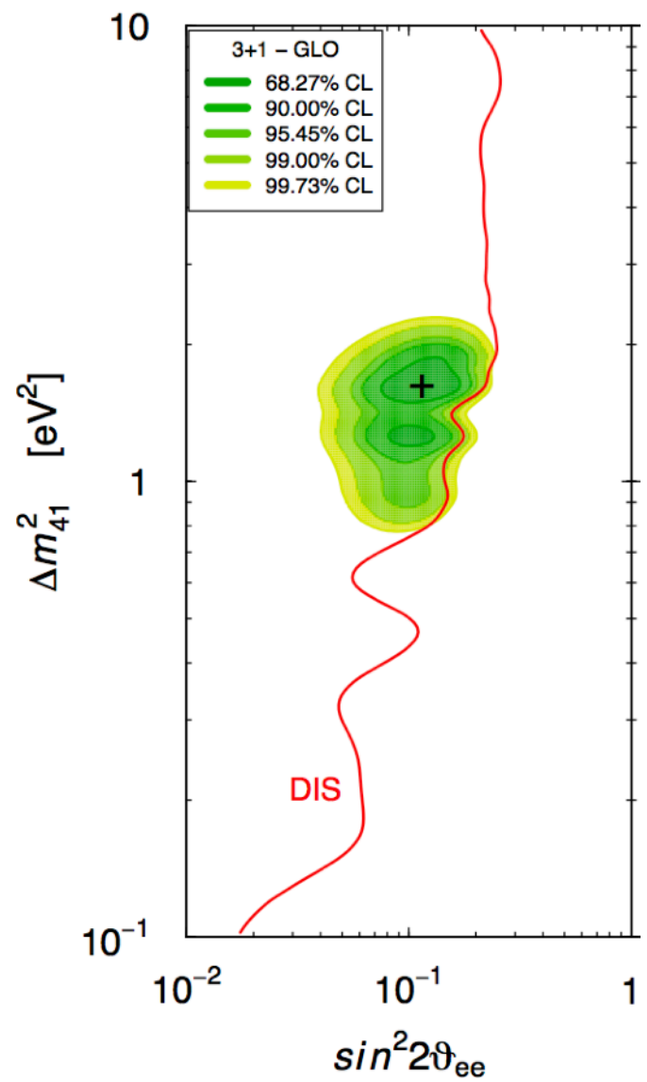
Motivation

experimental hints:

- $\nu_e/\overline{\nu}_e$ - disappearance:
  reactor anomaly (≈2.5 σ) and GALLEX/SAGE anomaly (≈3 σ)
- $\nu_e/\overline{\nu}_e$ - appearance:
  miniBooNE and LSND accelerator anomalies (3.8 σ)
- possible solution: sterile neutrino in eV mass range, either in (3+1) -, (3+2) - or (3+1+1) - scenario

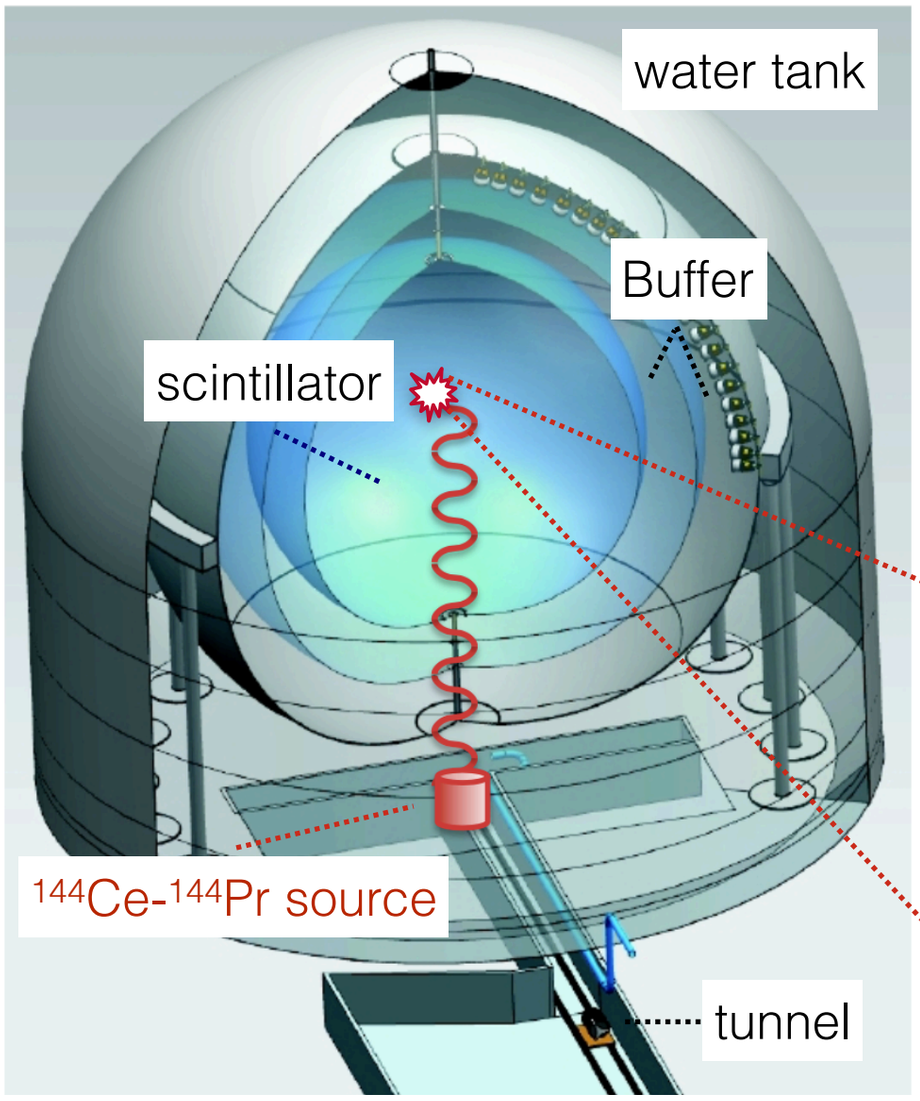
global fit:

- $0.82 < \Delta m_{41}^2 < 2.14$ eV^2 (3σ)
- more experimental data needed: short-baseline experiments
  - further reactor experiments
  - SOX

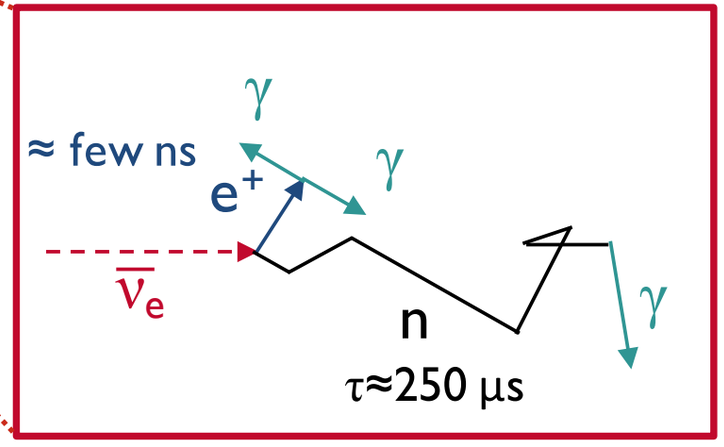


C.Giunti, M.Laveder,Y.F. Li,H.W.Long arXiV:1308.5288 v3 [hep-ph], Phys.Rev.D 88, 073008 (2013)

The SOX experiment



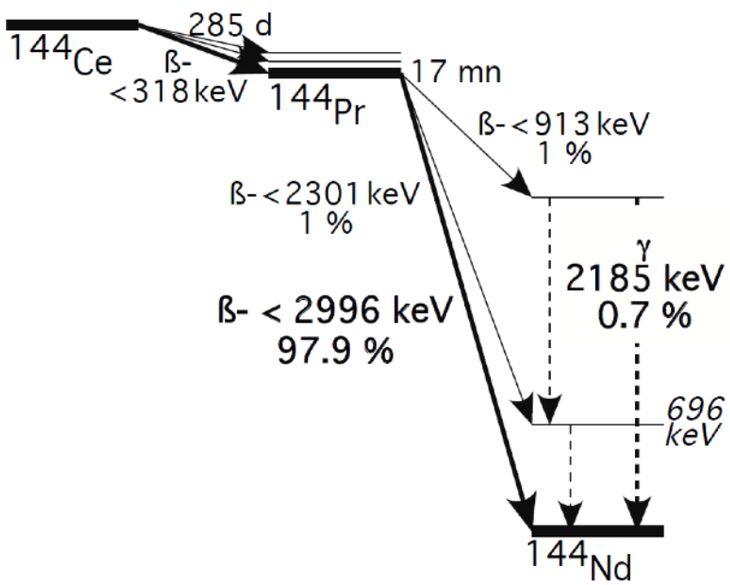
- detection of $\overline{\nu}_e$- events with the Borexino detector, located at LNGS in Gran Sasso (Italy)
- properties of the Borexino detector:
  - liquid scintillator detector (PC+PPO) aimed for detection of solar neutrinos
  - 2214 PMTs mounted on Spherical Steel Sphere (SSS)
  - Light Yield: ≈ 500 p.e./MeV
  - σ(E) = 5% (at 1 MeV)
  - σ(x) = 10 cm (at 1 MeV)



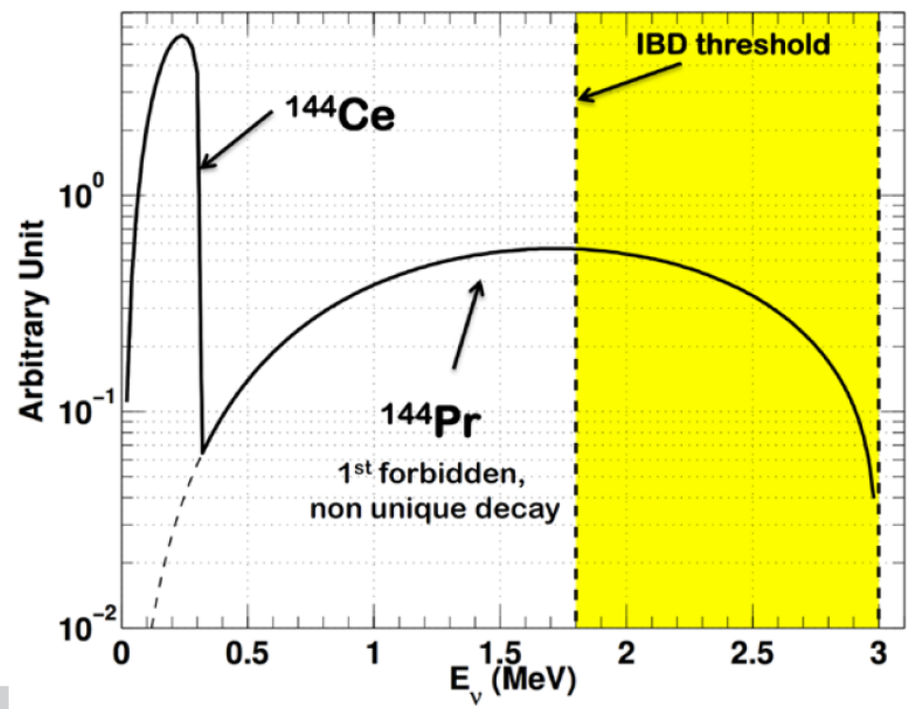
detection mechanism:
Inverse Beta Decay (IBD)

- clear coincidence signature
- excellent background discrimination
- ultra-low background environment

$^{144}Ce/^{144}Pr$ - spectrum

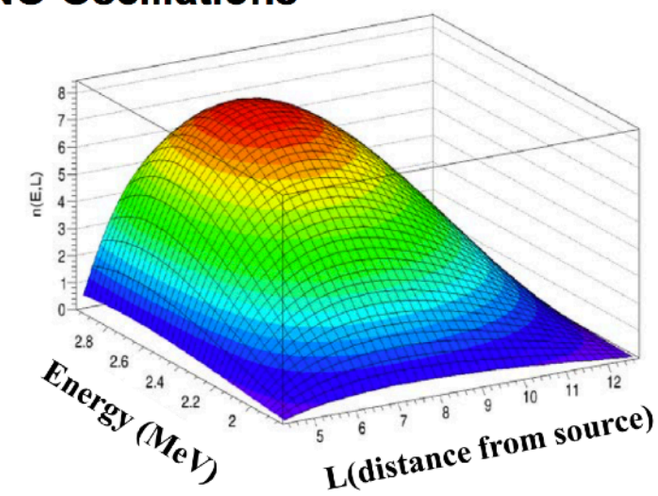


Q	2996 keV
$T_{1/2}$ (^{144}Ce)	285 d
$T_{1/2}$ (^{144}Pr)	17 min
decay mode	β^-
production	extraction from nuclear fuel
initial activity	100-150 kCi

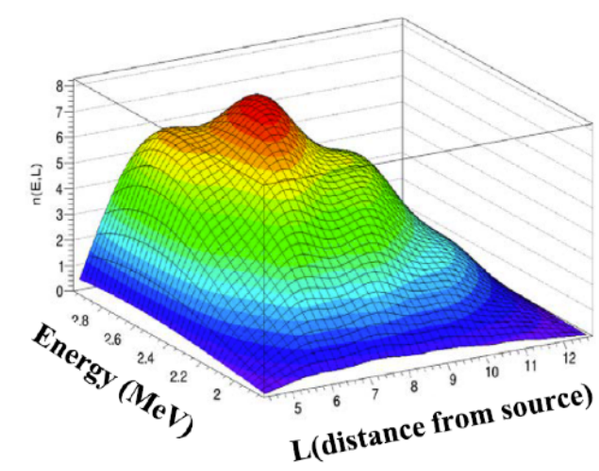


- IBD threshold: 1.8 MeV
- 1st forbidden decay makes theoretical modelling difficult → spectral measurement

NO Oscillations



Oscillations (Δm^2=2.5 eV^2, $\sin^2(2\theta)$=0.14)

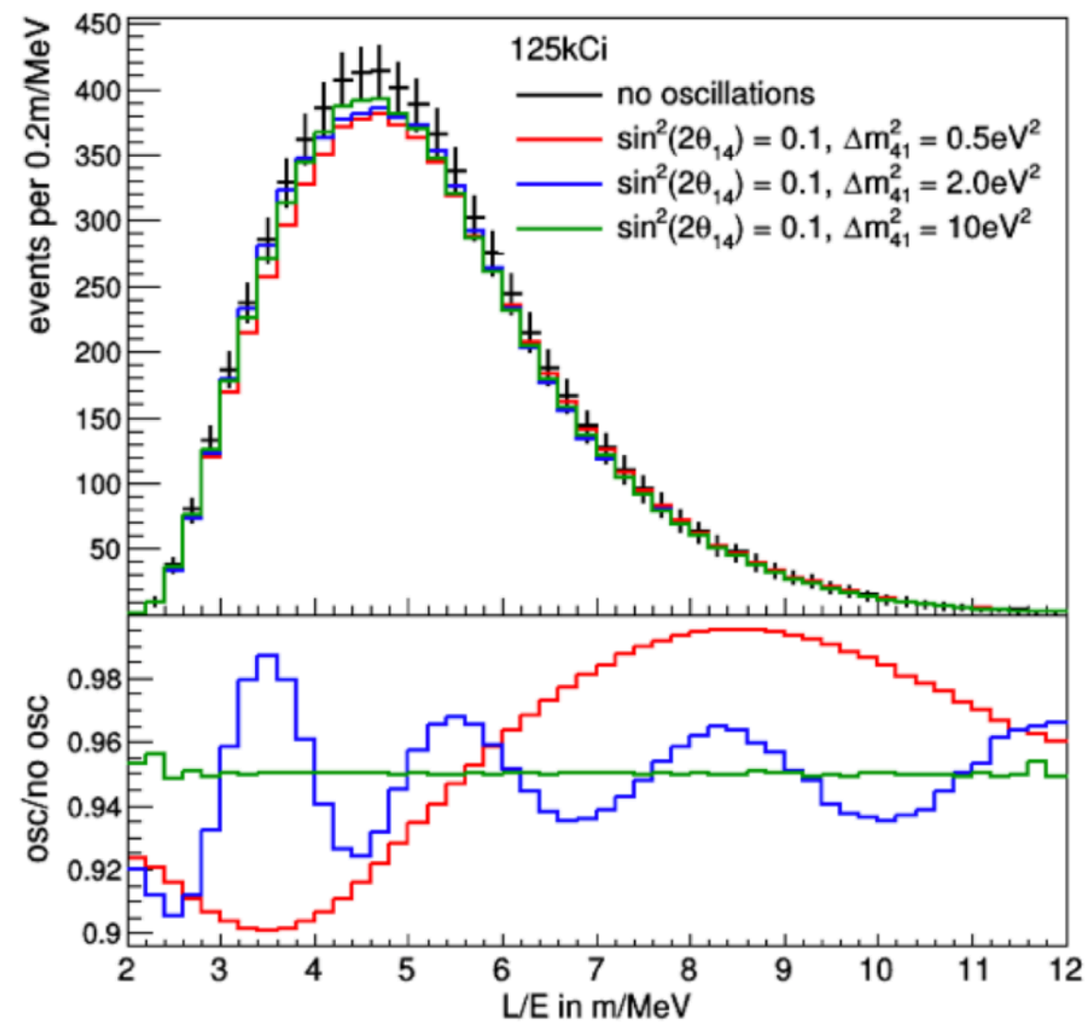


Sensitivity - Oscillations

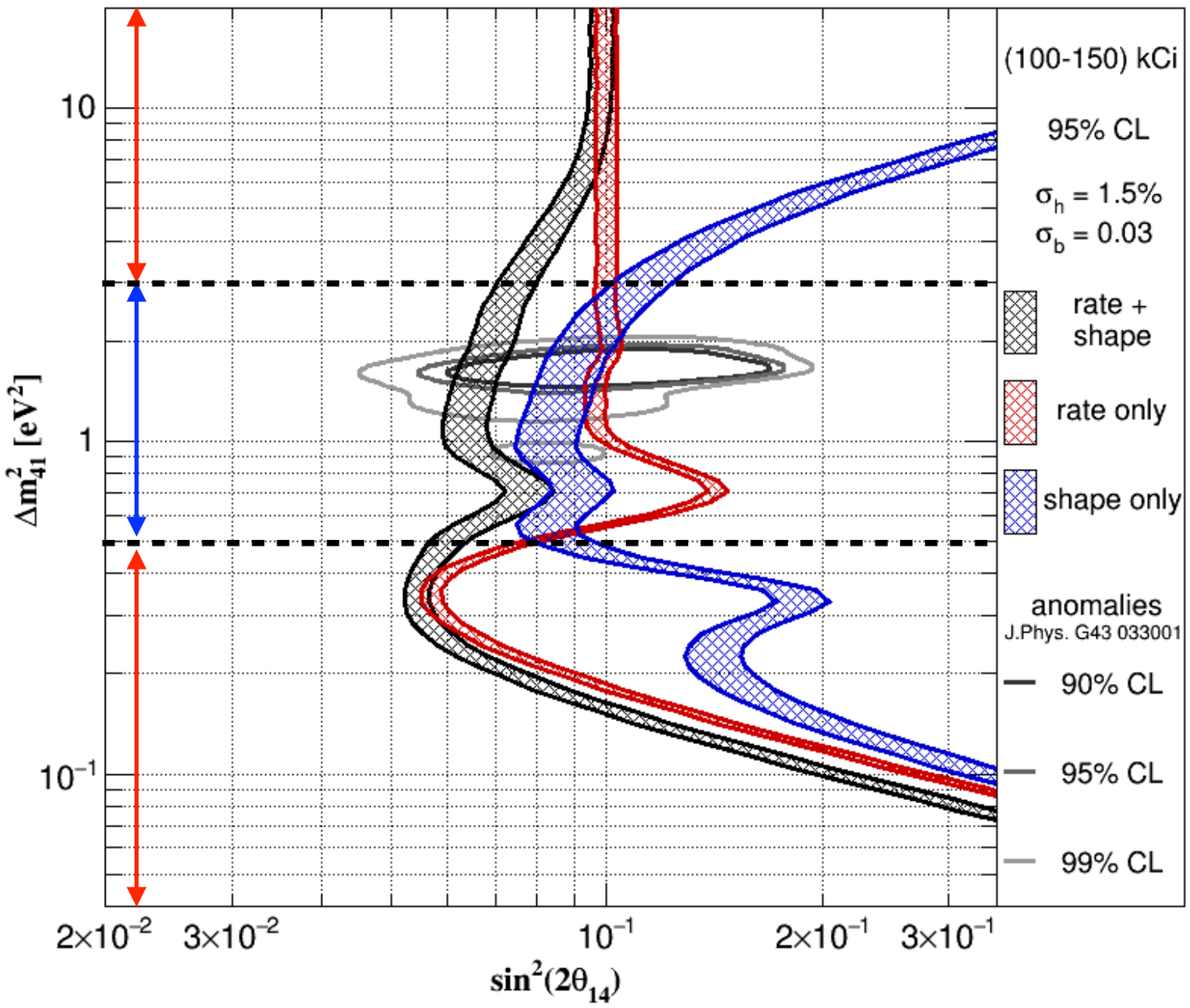
- oscillation probability (3+1 model):

$$P_{ee} = 1 - \sin^2(2\theta_{14}) \sin^2(1.27\Delta m^2\,[eV^2]\cdot L[m]/E\,[MeV])$$

- 2-fold way to observe oscillations:
  - ✦ rate analysis:
    - ✦ disappearance channel
    - ✦ expected number of events (1.5 years): 10,000
  - ✦ shape analysis:
    - ✦ oscillation length L_{osc} for anomaly region in meter range
    - ✦ observe oscillations directly in space and energy



Sensitivity

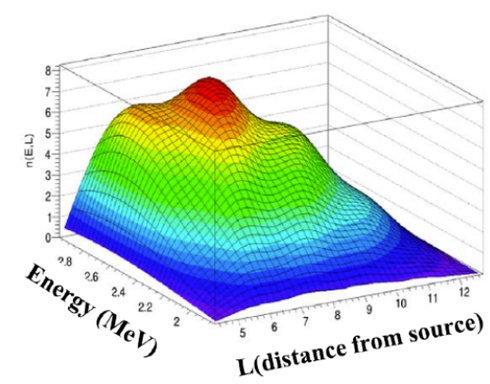


more sensitive approach:
$\Delta m^2 > 3\,eV^2$ and $\Delta m^2 < 0.5\,eV^2$: rate
$3\,eV^2 > \Delta m^2 > 0.5\,eV^2$: shape

rate: precise knowledge of activity, energy spectrum and detection efficiency

shape: oscillation visible in (E,L) - plane

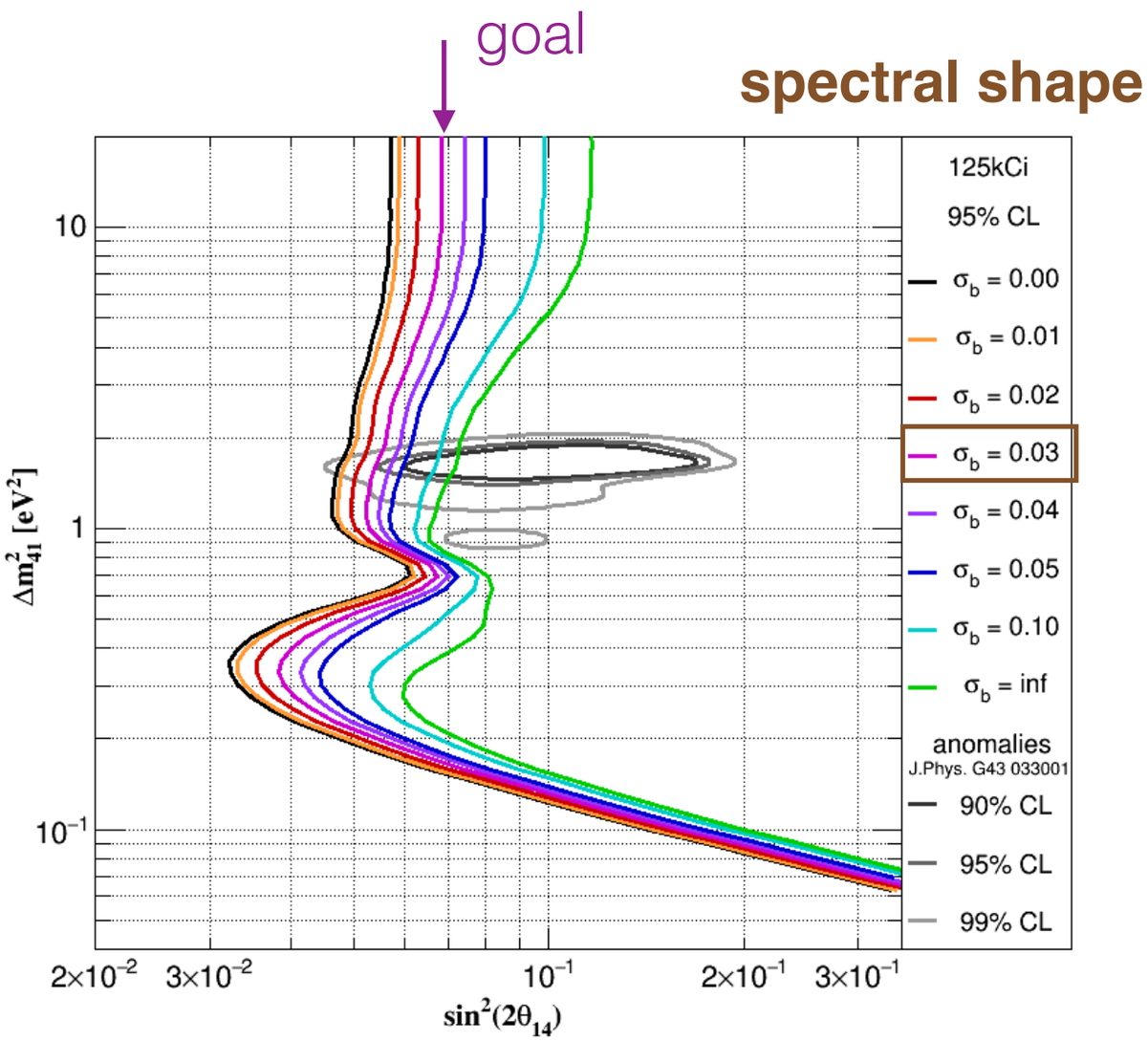
Oscillations (Δm^2=2.5 eV^2 $\sin^2(2\theta)$=0.14)

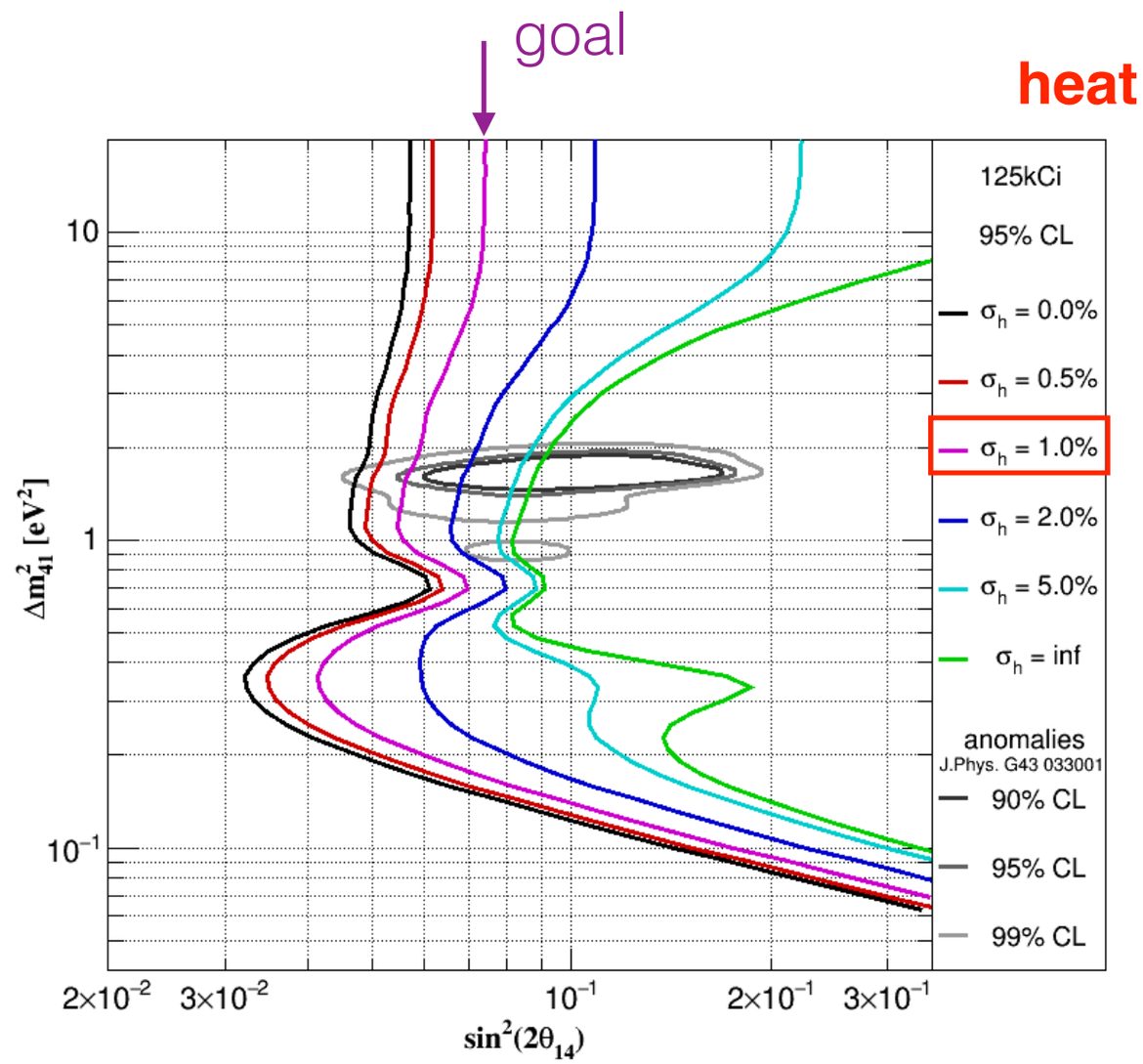


rate+shape: combined information

exclusion of almost whole 99% CL anomaly region possible!

Sensitivity - systematics





- expected # events: **N(E,L,t)** = $A(t)\cdot S_\nu(E,\mathbf{b})$ = **P(t)**/<E(**b**)>$\cdot S_\nu(E,\mathbf{b})$
- precise knowledge of source activity and spectral shape important!

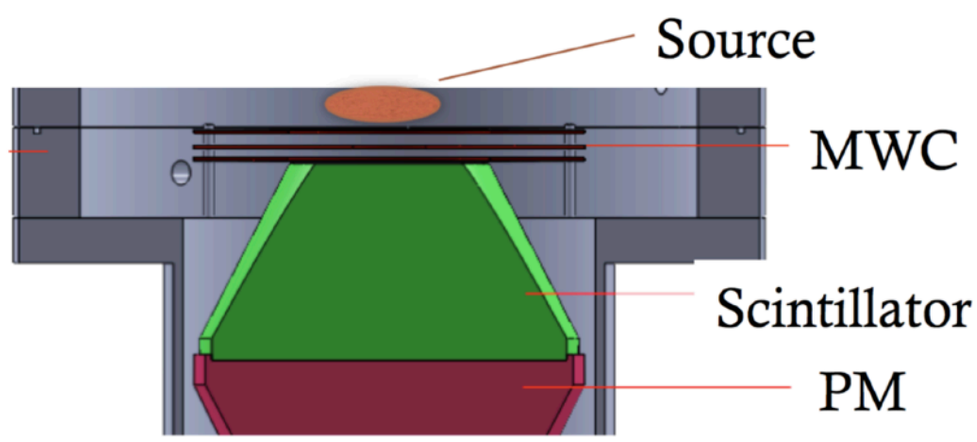
Source - spectral shape

- spectrum for 1st forbidden decay ($0^+ \rightarrow 0^-$): $\boxed{S_\beta = W \cdot p \cdot (W-W_0)^2 \cdot F(W,Z) \cdot C(W)}$

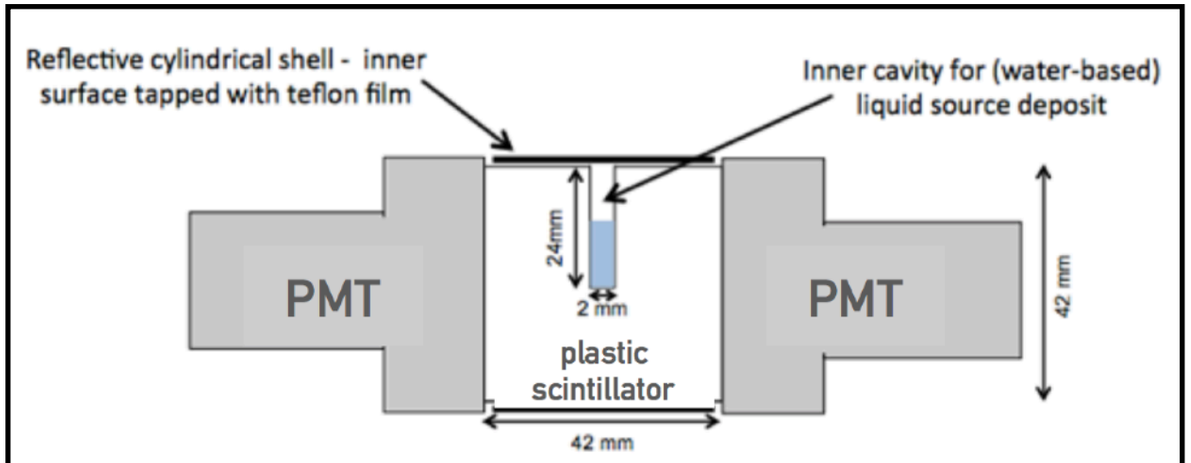
  statistical shape — Fermi function — shape factor

  with $C(W) = 1 + a \cdot W + b / W + c \cdot W^2$, *W: electron total energy, W_0: end point, p: electron momentum*

- Exact knowledge of spectrum necessary for
  - ✦ oscillation analysis
  - ✦ conversion power → source activity
  - ✦ expected number of events → rate analysis
- old shape factor measurements differ by 10 % → development of 2 new, independent setups:



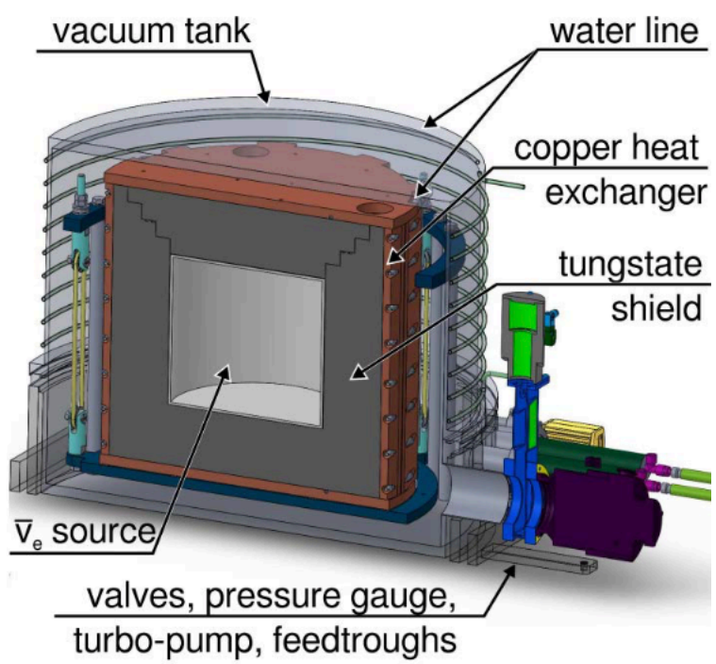
Munich



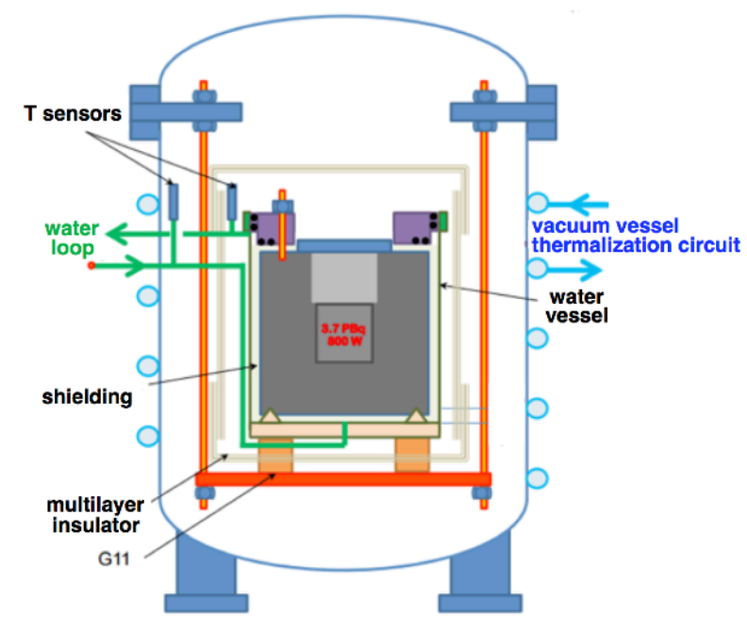
CEA Saclay

Source - activity

2 calorimeter setups to determine source activity



Munich/Genoa setup



CEA Saclay setup

- general principle: measure released heat from source: $P = \phi \cdot c \cdot \Delta T$

  $A = P/\langle E \rangle$
- copper heat exchanger: dissipation of heat
- Minimisation of heat losses due to radiation, convection and conduction
- achievable precision: <1% (mock setup)

Source - design & shielding

Radiopurity:

- ^{244}Cm activity ≤ 1 x 10^{-5} Bq/Bq
- ^{241}Am activity ≤ 5 x 10^{-3} Bq/Bq

2.3t W-alloy shield:

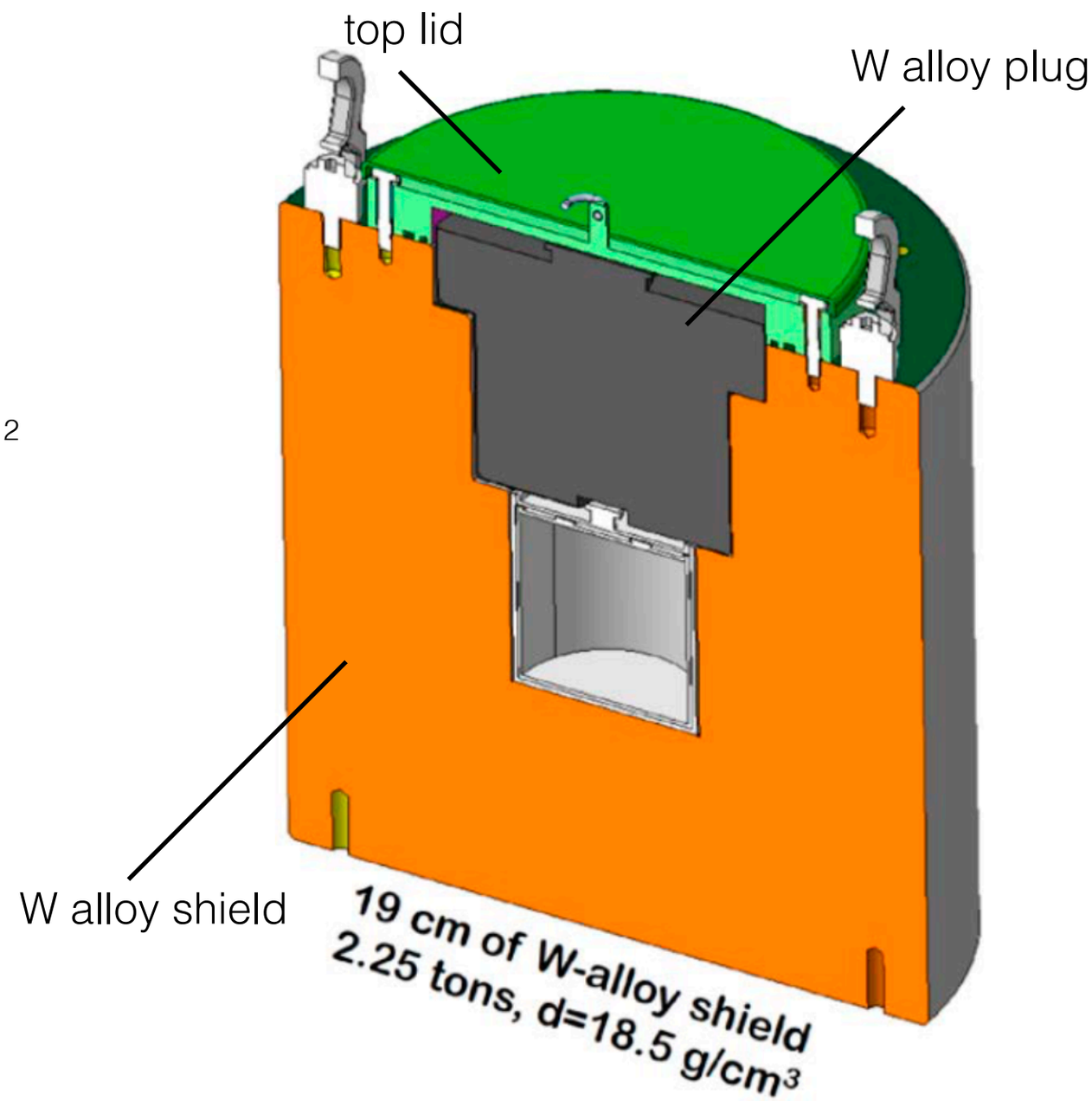
- attenuation for 2.2 MeV gammas: > 10^{12}

chemical composition:

- CeO_2
- decay: 2 CeO_2 → Pr_2O_3 + 1/2 O_2

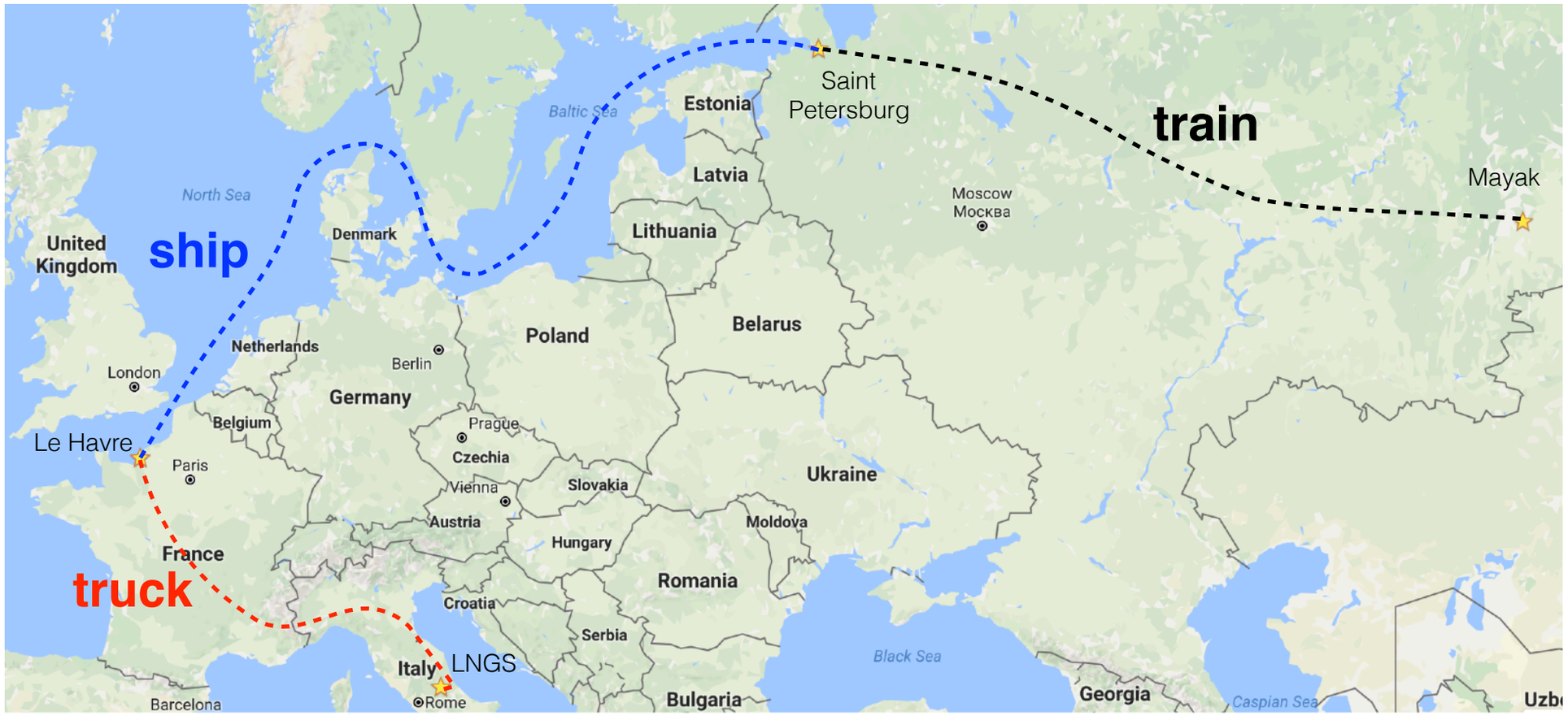
thermal power:

- ca. 1kW



Source - transportation

- considerations:
  - ✦ compliance with safety regulations for radioactive materials
  - ✦ minimal amount of border crossings

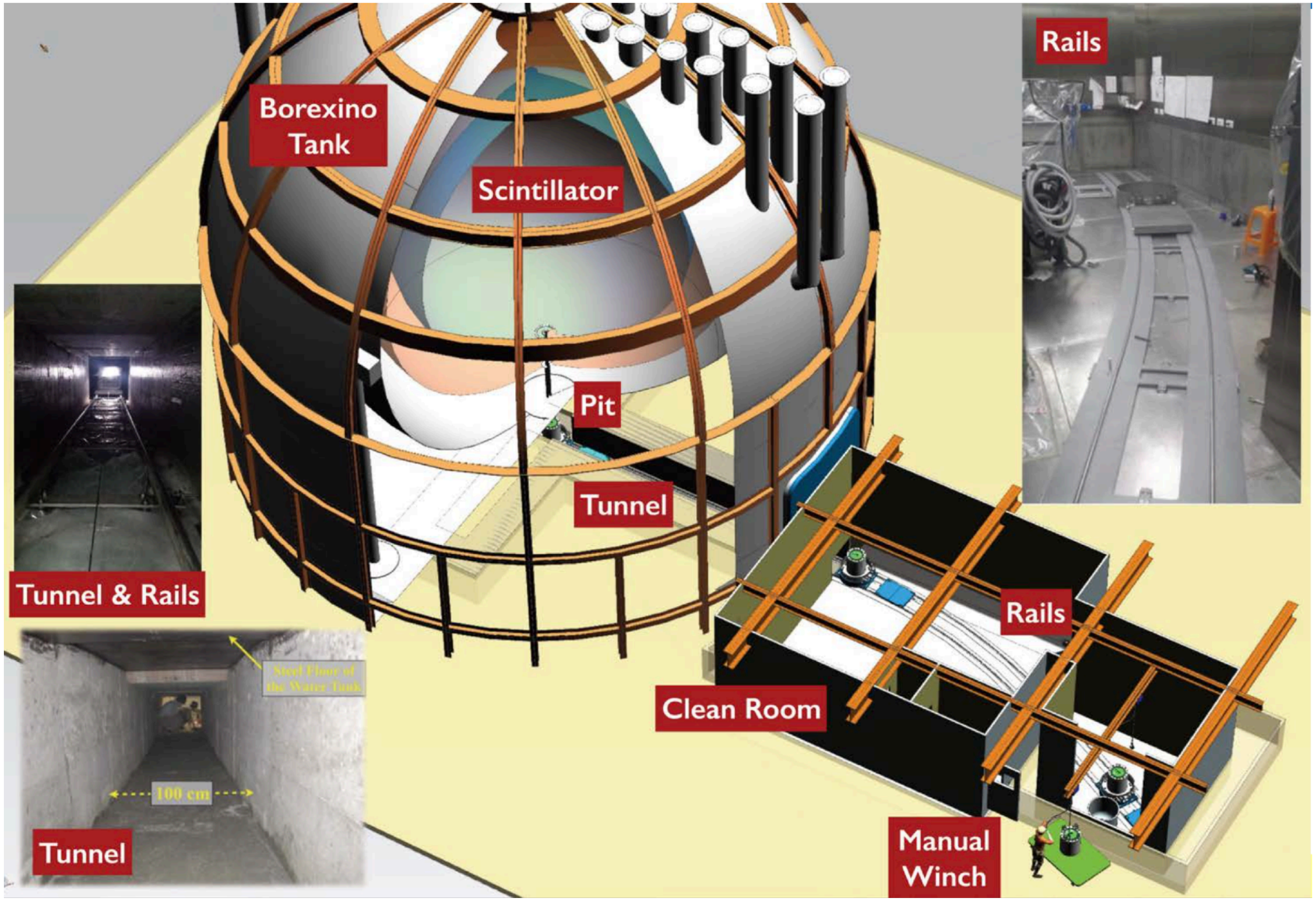


- transit time: 5days (train) + 3 days (ship) + 2 days (truck) = 10 days
- overall transport time: ≈ 3 weeks
- arrival at LNGS (Gran Sasso) at latest by **April 2018** with **activity loss** of **≈ 5%**

Source - transportation

Logistics at LNGS:

source with calorimeter and shielding will be transported via rails to pit below detector



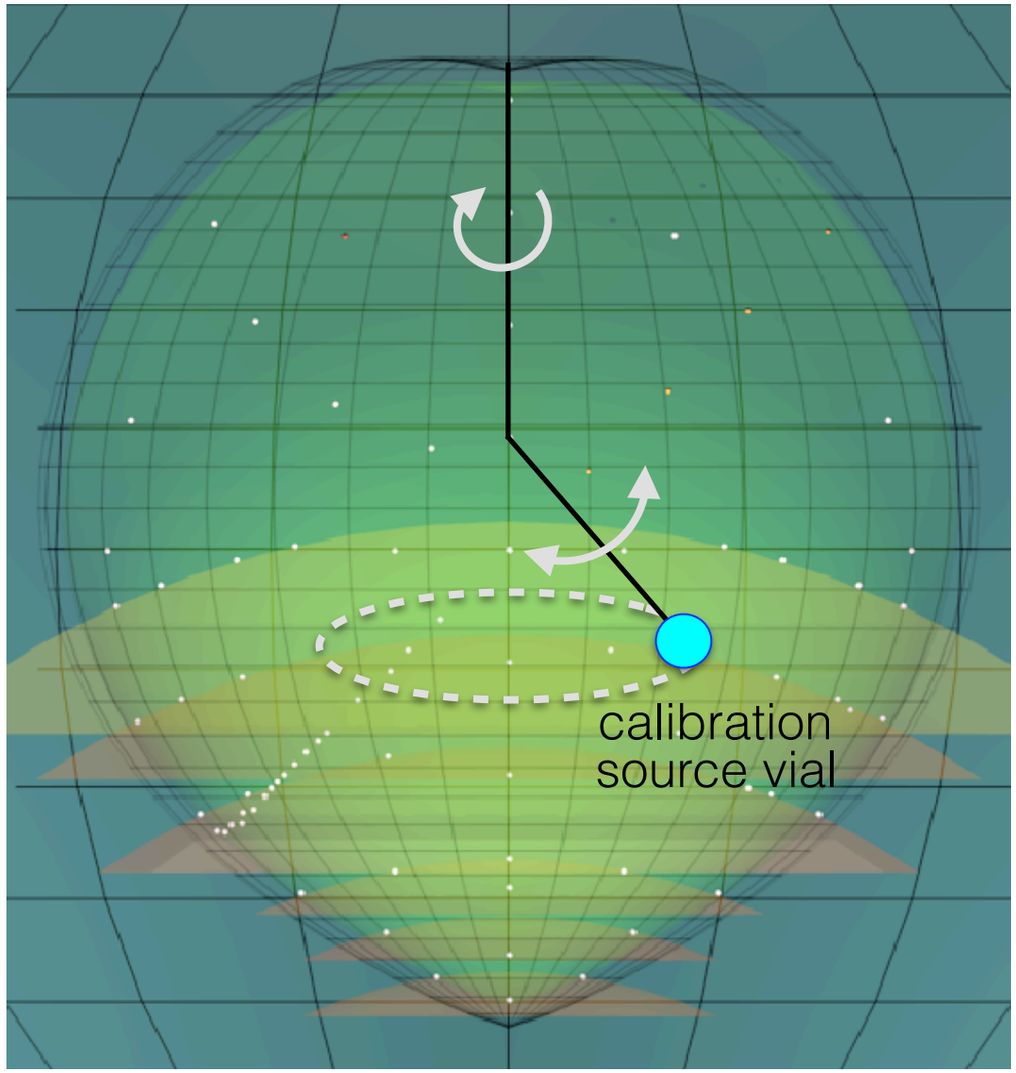
New calibration campaign

motivation:

- understand energy and position response precisely
  → oscillation analysis
- map detection efficiency at the vessel border
  → refined rate estimate
- planned calibration source types:
  - neutron calibration source: Am-Be
  - positron calibration source: ^{68}Ga-^{68}Ge
  - multiple γ sources for energy calibration

plan:

- use operational and well-tested Borexino calibration system
- calibration points on spheres from $\overline{\nu}_e$ source position
- 1 - 2 radial scans for efficiency study
- more points in the South compared to North (higher flux)



Summary & Outlook

- SOX: disappearance experiment with ^{144}Ce-^{144}Pr source, 1.5 years of data taking
- Systematic uncertainties:
  - ✦ Calorimeter setups tested & fully functional
  - ✦ Spectral measurements from 2 independent experiments ongoing
- experiment has sensitivity to exclude almost whole global fit anomaly region
- transportation from Mayak to LNGS and within LNGS planned in detail
- necessary hardware at LNGS already installed and ready
- dedicated calibration campaign this fall
- time schedule:
  - ✦ source arrival beginning 2018
  - ✦ start data taking: at the latest April 2018

Borexino and SOX Collaborations

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LNGS

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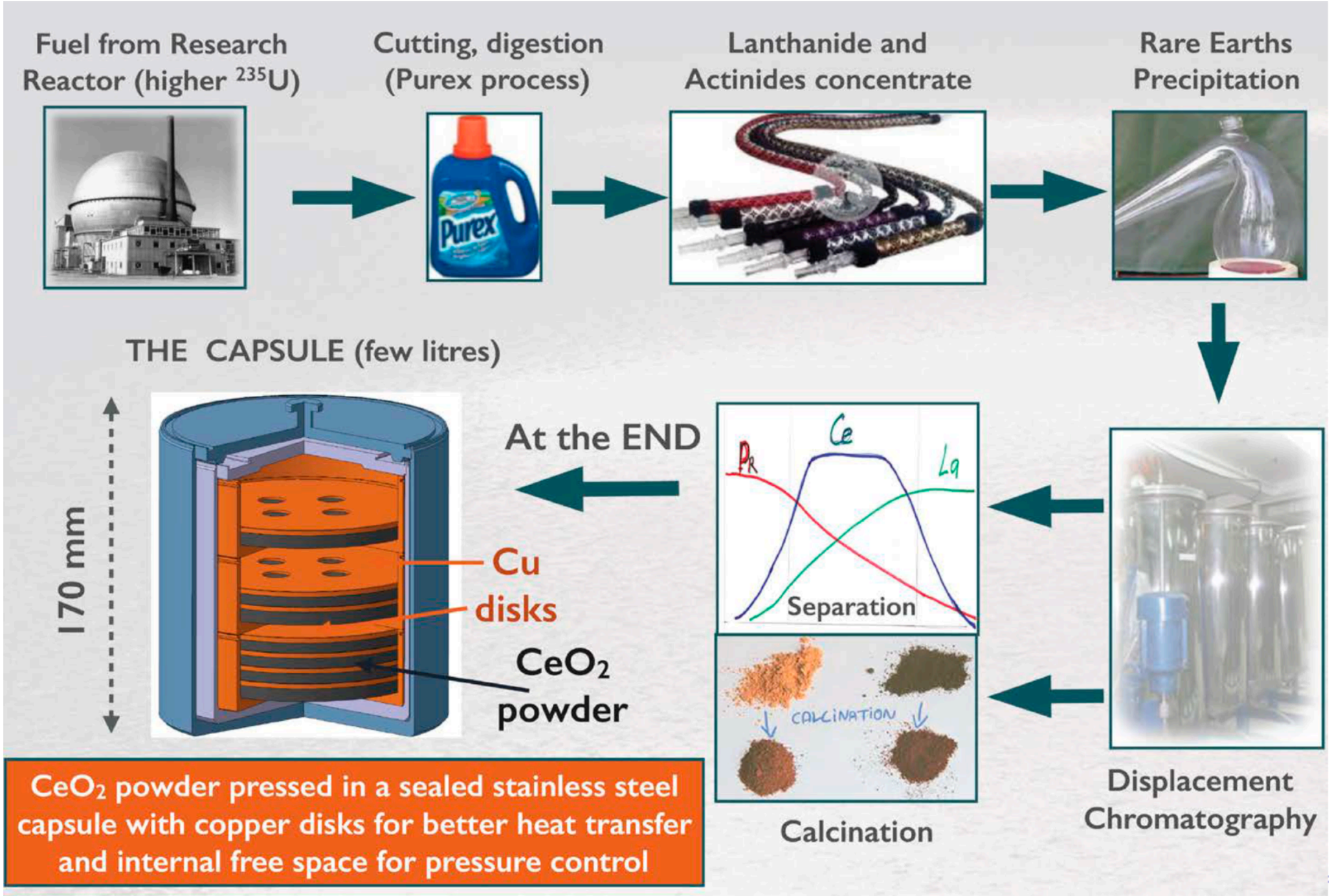
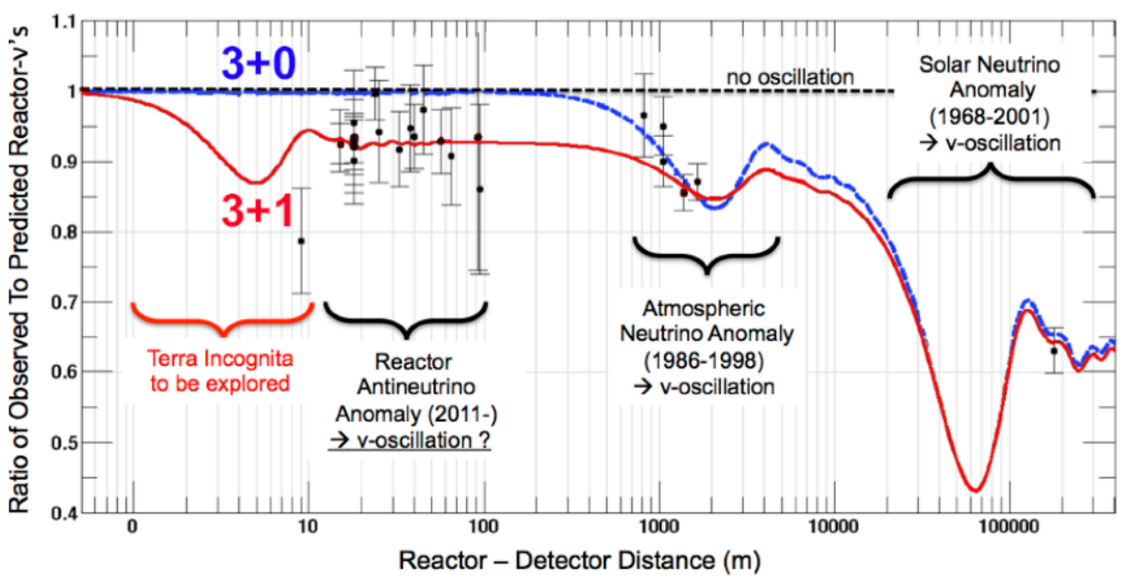
Backup

Source production



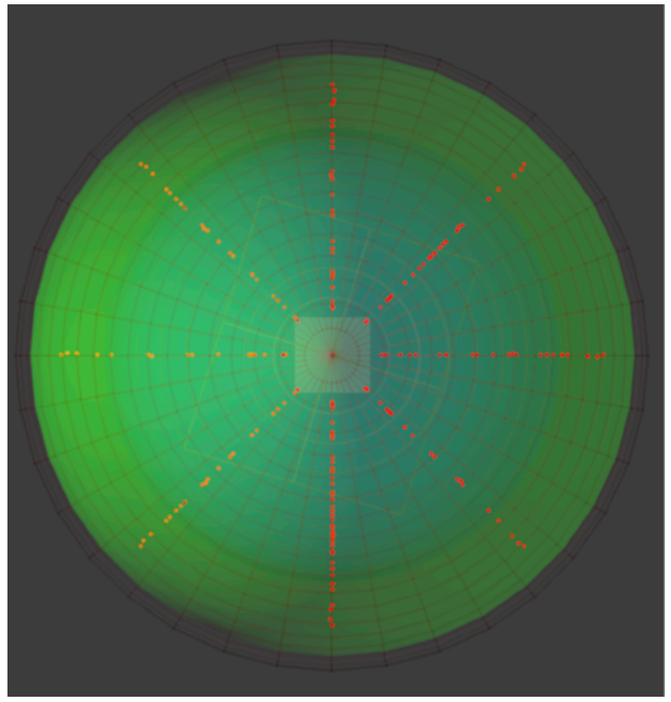
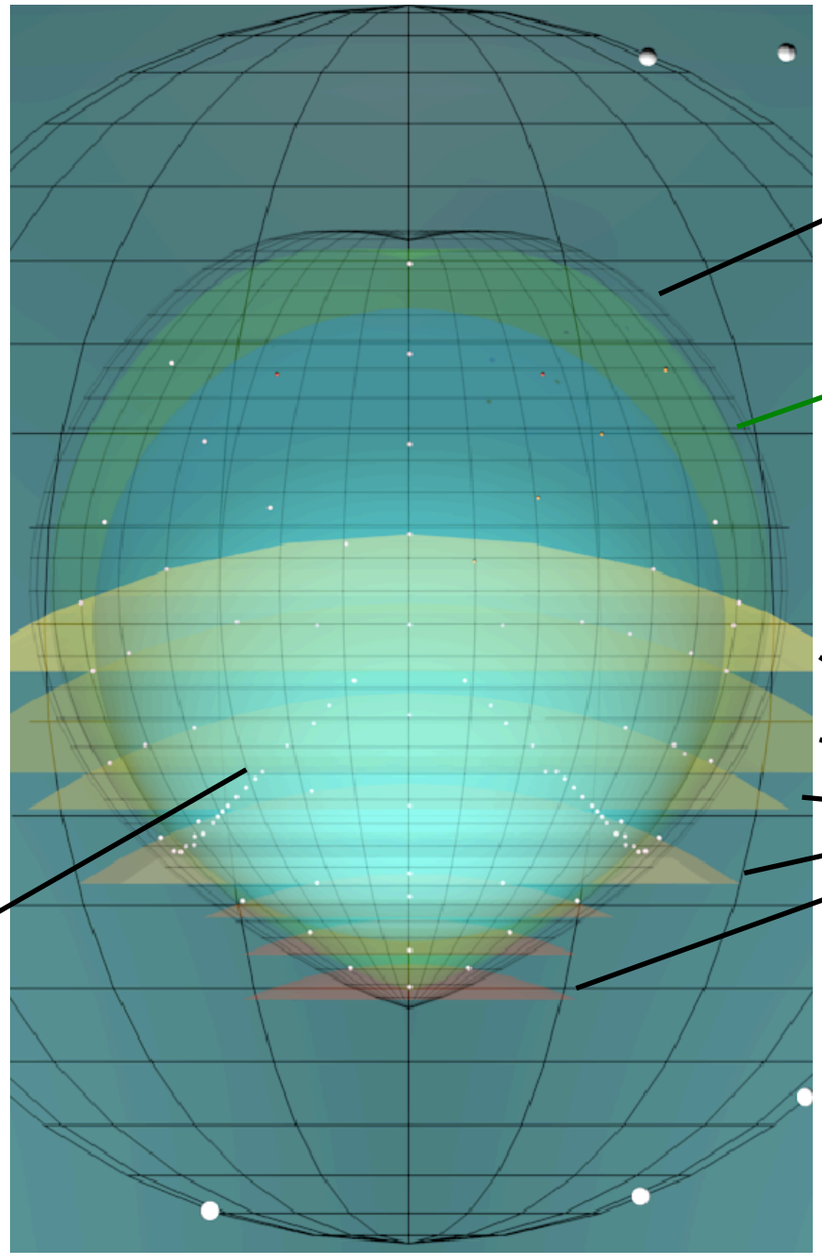
Anomaly regions



Anomalous	Source	Type	Signal	Channel	Significance
LSND	Meson Decay-at-Rest	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	Total Rate, Energy	CC	3.8 σ
MiniBooNE	Meson Decay-in-Flight	$\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e$	Total Rate, Energy	CC	3.8 σ
Gallium	Electron Capture	ν_e dis.	Total Rate	CC	2.7-3.0 σ
Reactor	Beta-decay	ν_e dis.	Total Rate, Energy	CC	2.7 σ

Regular	Source	Type	Signal	Channel
KARMEN Icarus/Opera	Meson Decay - at-Rest & Flight	$\nu_\mu \rightarrow \nu_e$	Total Rate, Energy	CC
CDHS/Minos/ MiniBooNE	Meson Decay-in-Flight	$\nu_\mu \rightarrow \nu_\mu$	Total Rate, Energy	CC
Minos	Meson Decay-in-Flight	$\nu_\mu \rightarrow \nu_s$	Total Rate	CC
T2K	Meson Decay-in-Flight	$\nu_e \rightarrow \nu_s$	Total Rate, Energy	CC

- ambiguous experimental situation
- further measurements needed for clarification

Calibration - details

- white dots: planned calibration spots
- each calibration point repeated every 45° in ϕ!