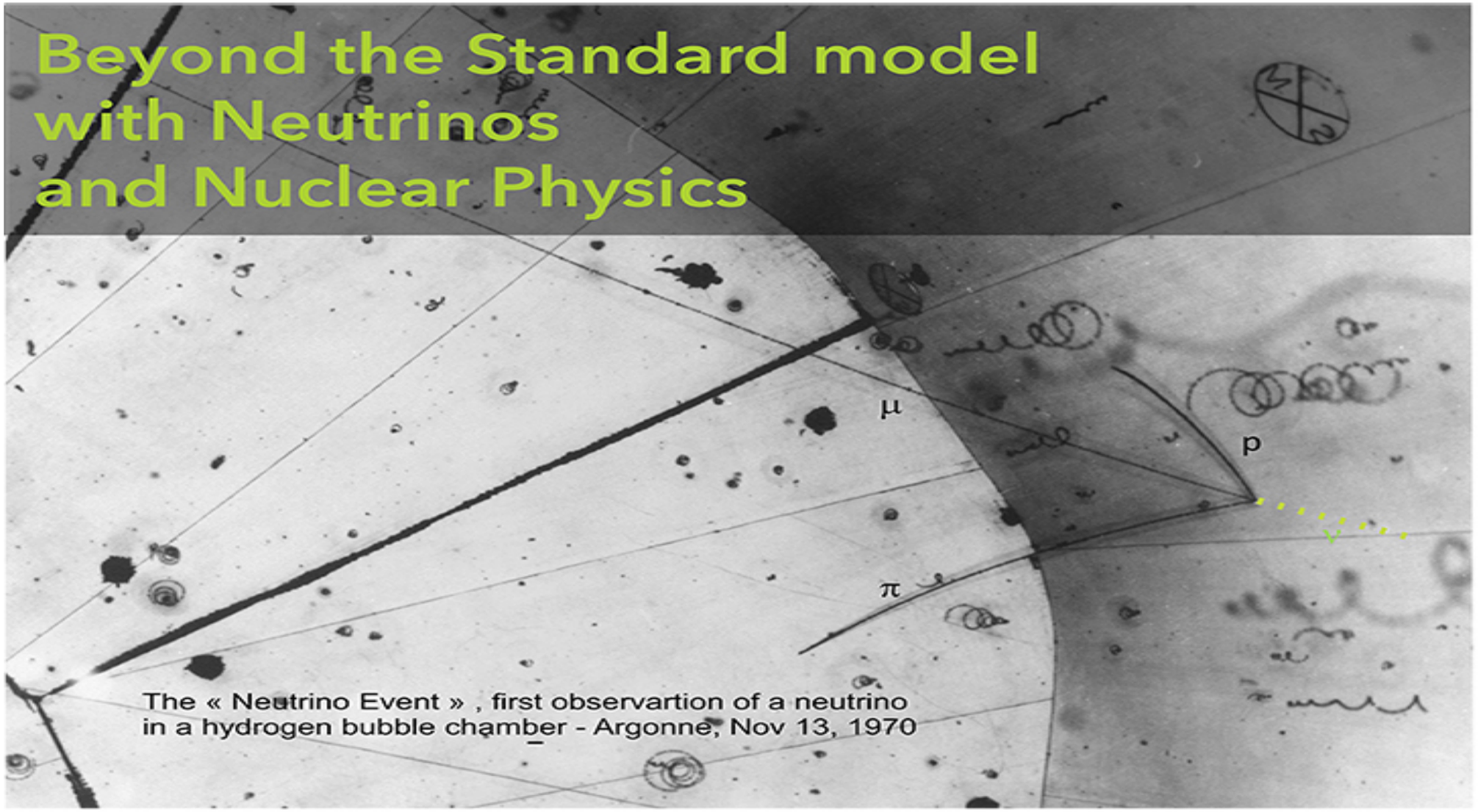


The SOX experiment

Stefano Davini
(on behalf of the Borexino-SOX collaboration)
Brussels, December 1st 2017

Beyond the Standard model with Neutrinos

Neutrino **masses** call for physics beyond Standard model

Either **right-handed** neutrinos for Dirac mass term

or Majorana fields for **Majorana** mass term and possibly explain small mass through **See-Saw**

A few experimental results do not fit well with the standard 3 neutrino mixing …

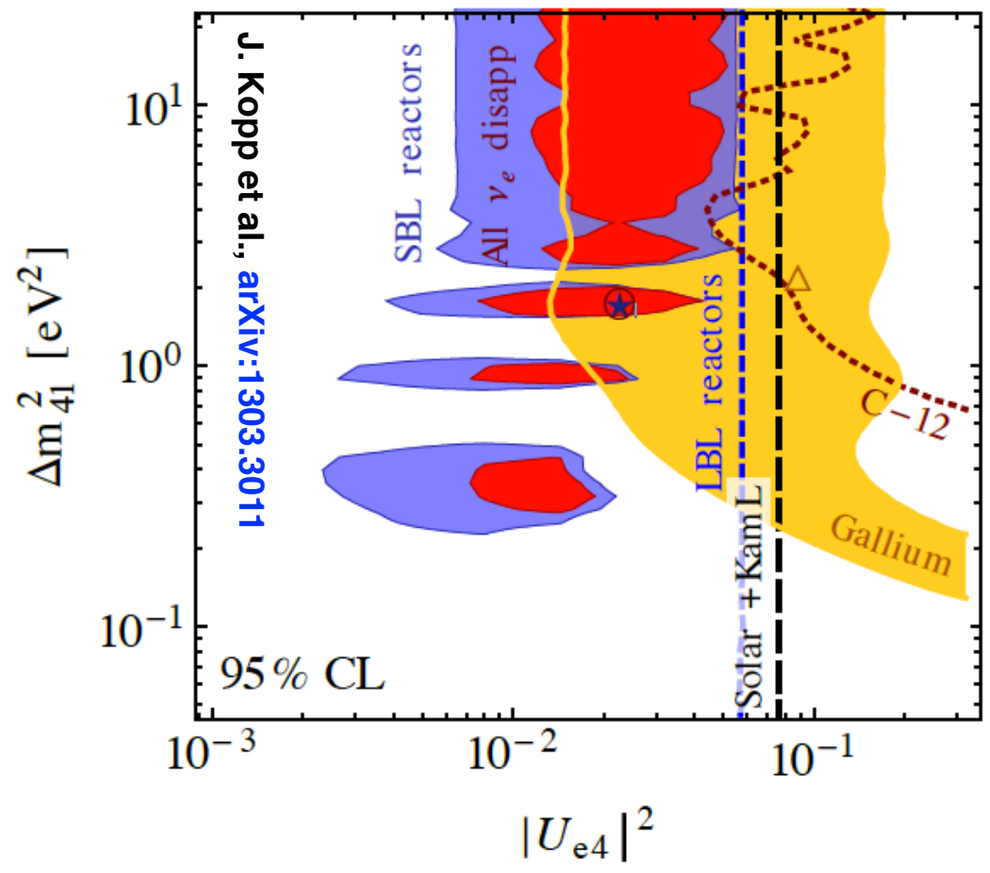
Beyond 3 neutrino mixing

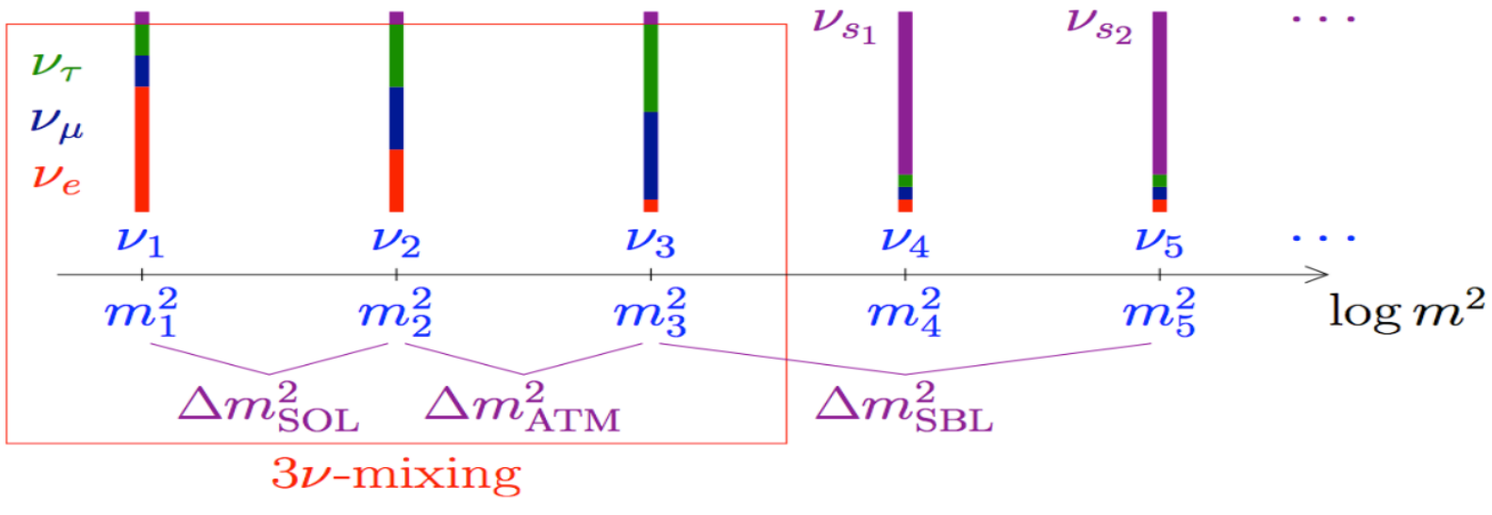
Anomalies at small L/E may be **interpreted** as **mixing** between know states with **sterile** state(s)

LSND/MiniBOONE (appearance)
Short **B**ase**L**ine **reactor** anomaly
^{51}Cr an ^{37}Ar sources in **Gallium**

same L/E ~ 1m/MeV points to **eV mass scale** …

… although reactor anomaly strongly weakened by Daya Bay (arXiv 1704.01082)



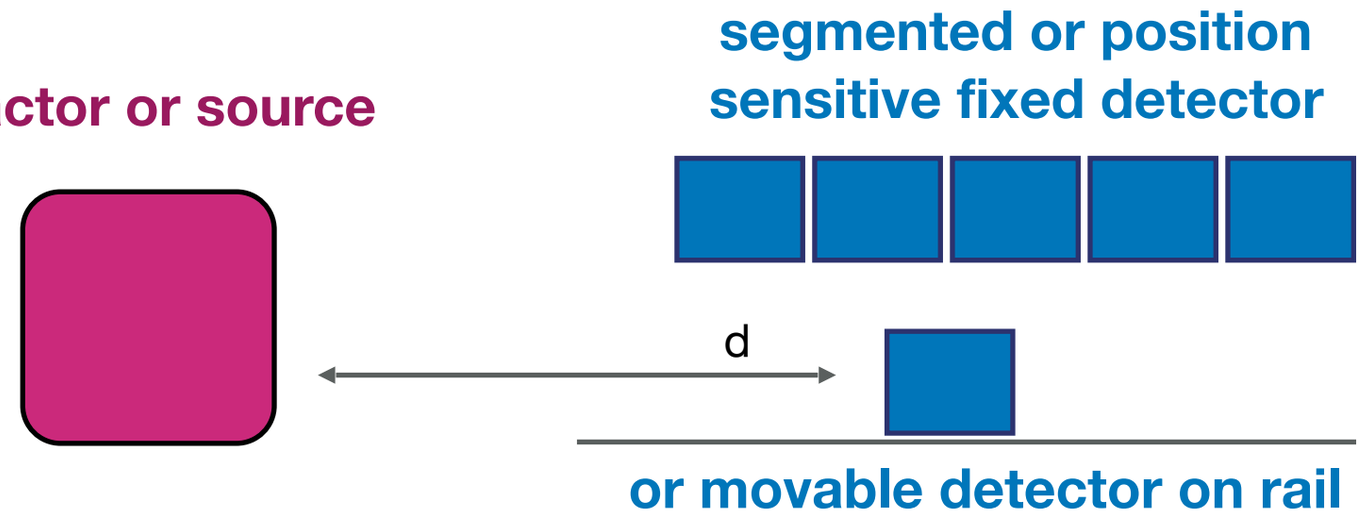


Towards sterile neutrino oscillation measurements

Elements needed

a **reactor** (anti-ν_e) or powerful **source** (ν_e or anti-ν_e)

measuring interaction **rate vs distance** from source



Experimental signatures

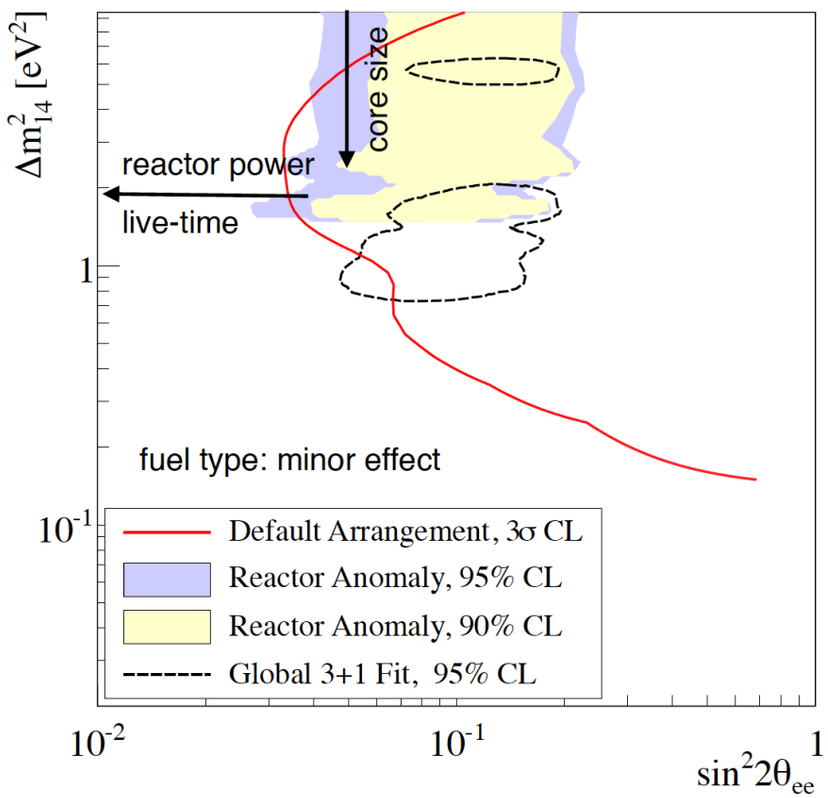
deviation of $1/d^2$ counting rate "*disappearance*"

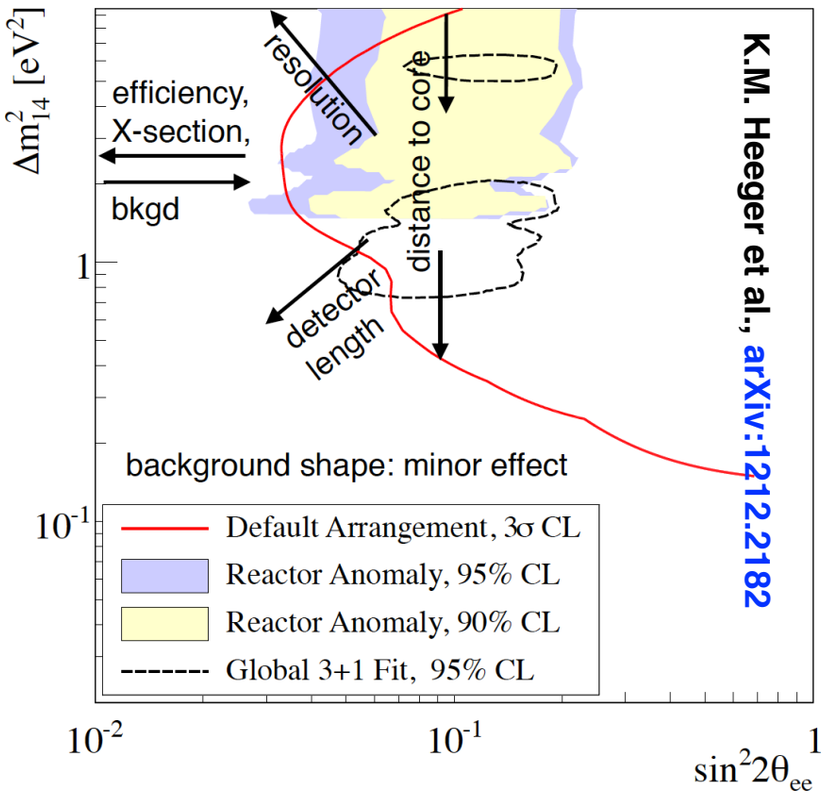
direct observation of oscillation pattern "*spatial waves*"

Towards a source experiment

- Smaller **size** -> smaller Δm^2
- Smaller **distance**: few meters
- **No** source **background**: shielded
- **No** μ, **cosmogenic** bkg: underground
- Decay **spectrum less complicated** than reactor's

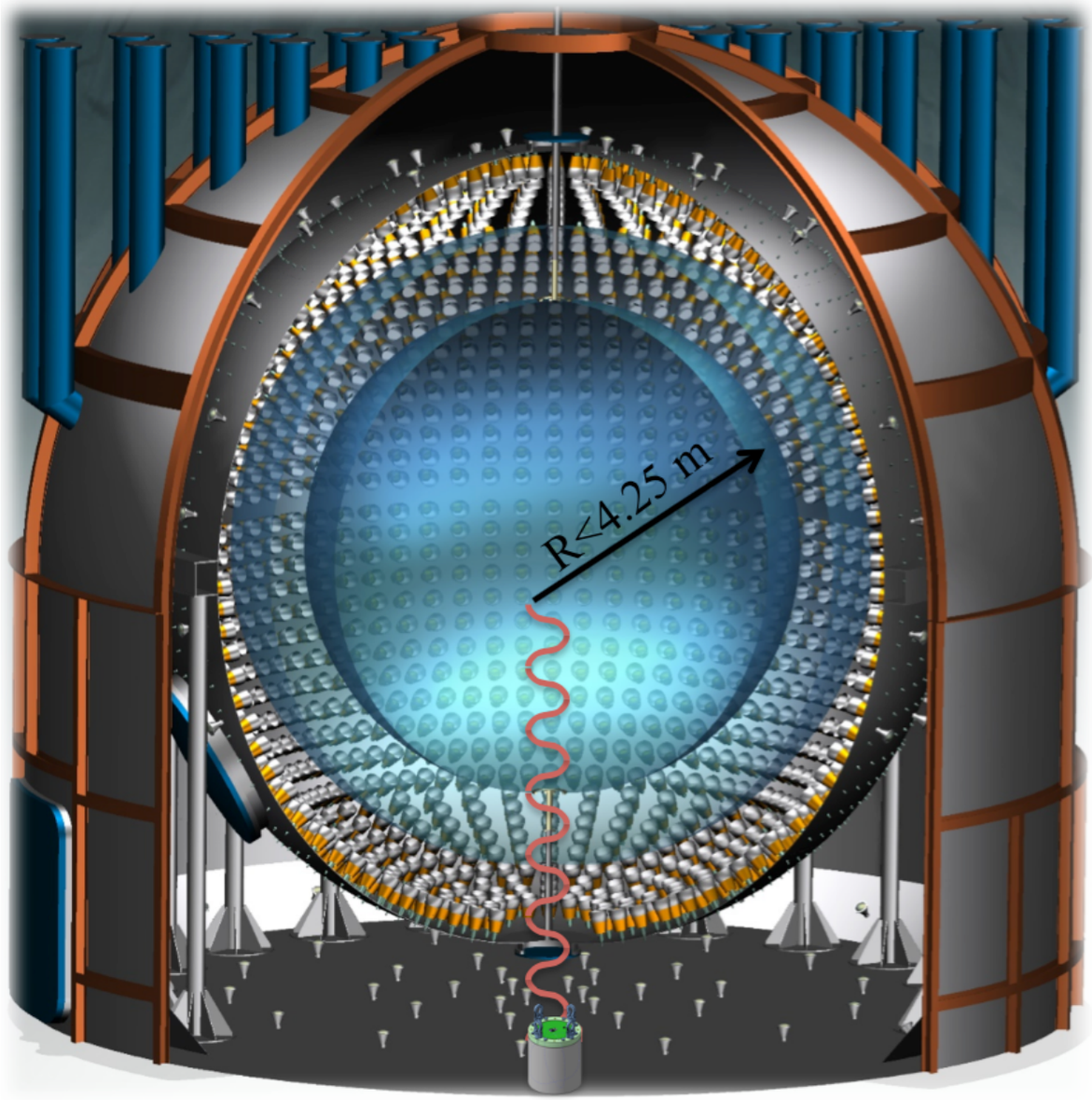
- **Lower flux** than reactor: 150 kCi max because of heat
- **Live-time limited**: source decays
- **Challenging**: making, authorisation, transportation ….

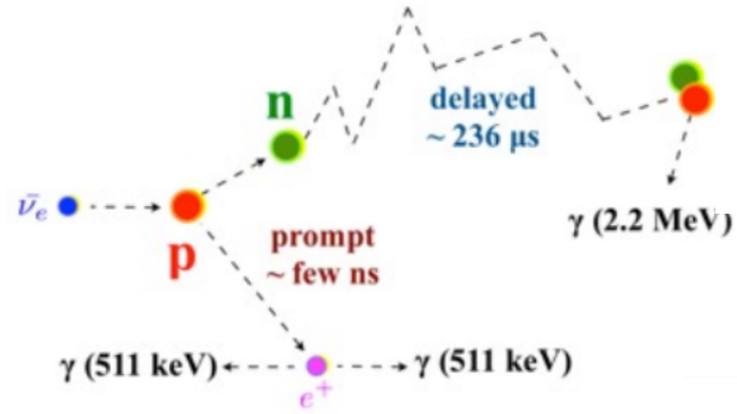




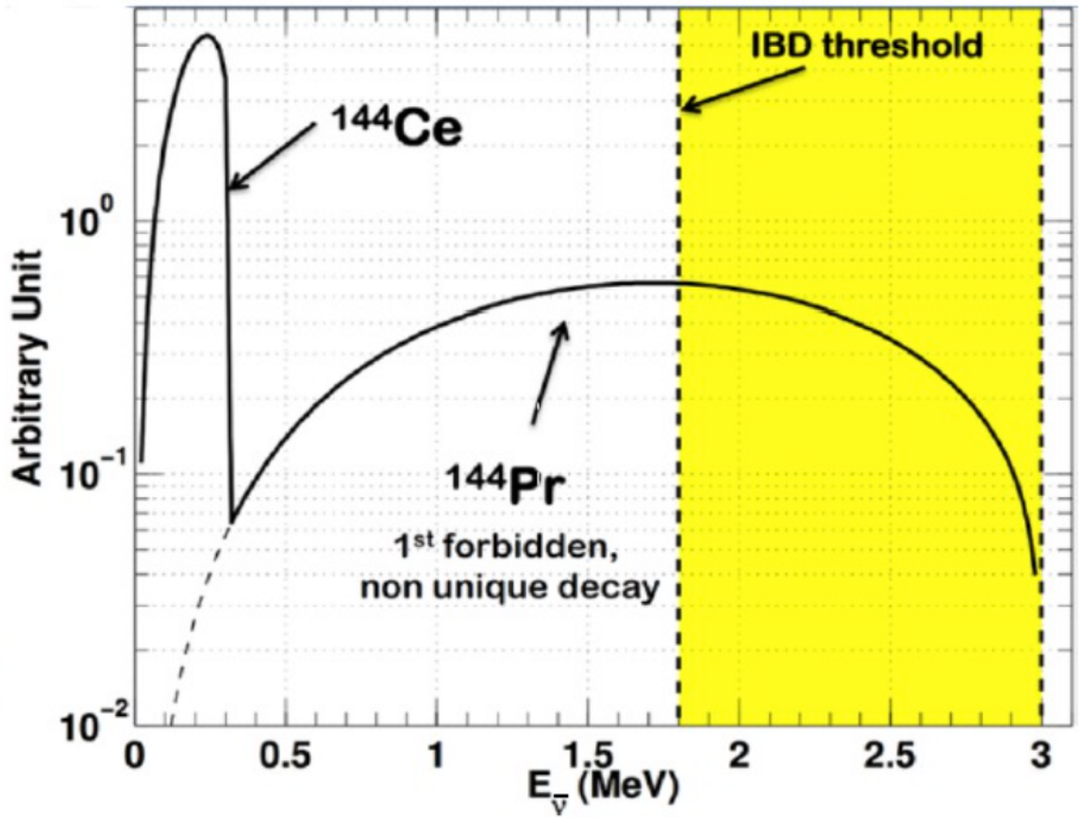
The SOX experiment

Measuring oscillation space waves in the Borexino detector …





… tagging with Inverse β Decay …



… using a ^{144}Ce-Pr anti-ν_e source

SOX history

Idea of ν_e or anti-ν_e source within Borexino dates back to the birth of the project (1991)

SOX Proposal **E**uropean **R**esearch **C**ouncil 320873 - February 2012, P.I. Marco Pallavicini

Original proposal: ^{51}Cr ν_e or ^{144}Ce anti-ν_e source

Agreement between **CEA** and **INFN** and **Borexino** Collaboration in 2014: merging CELAND proposal with SOX

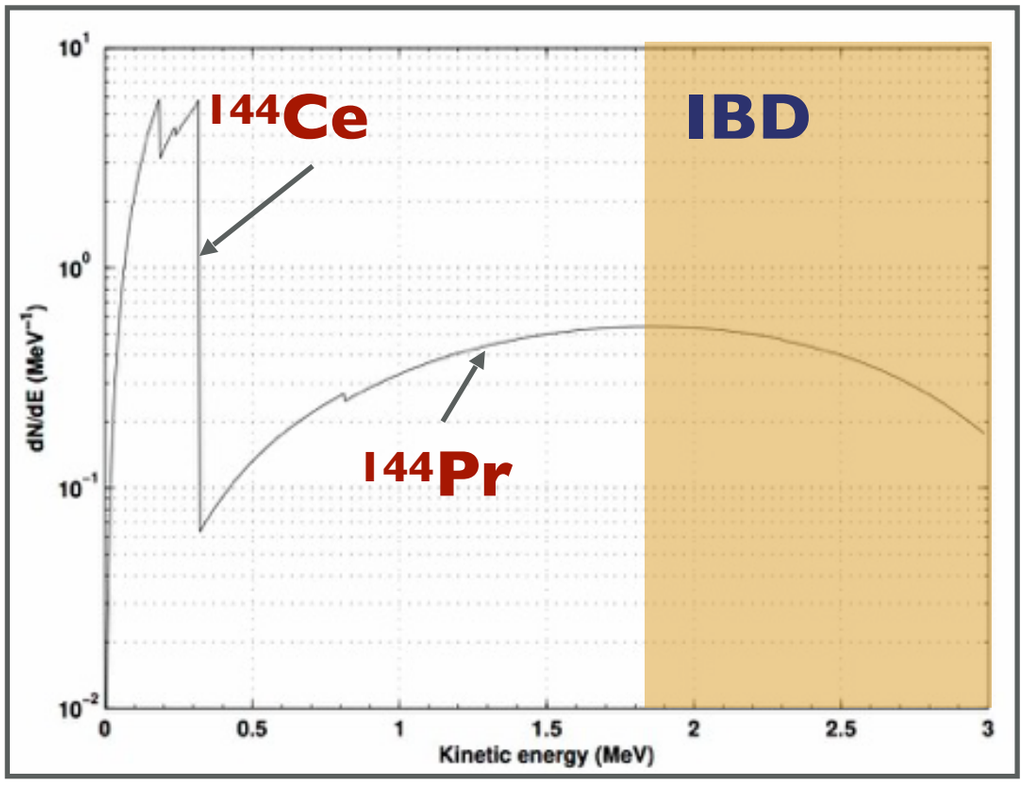
CeSOX using the ^{144}Ce source proposed and developed by CEA, based on another ERC project P.I. Thierry Lassere

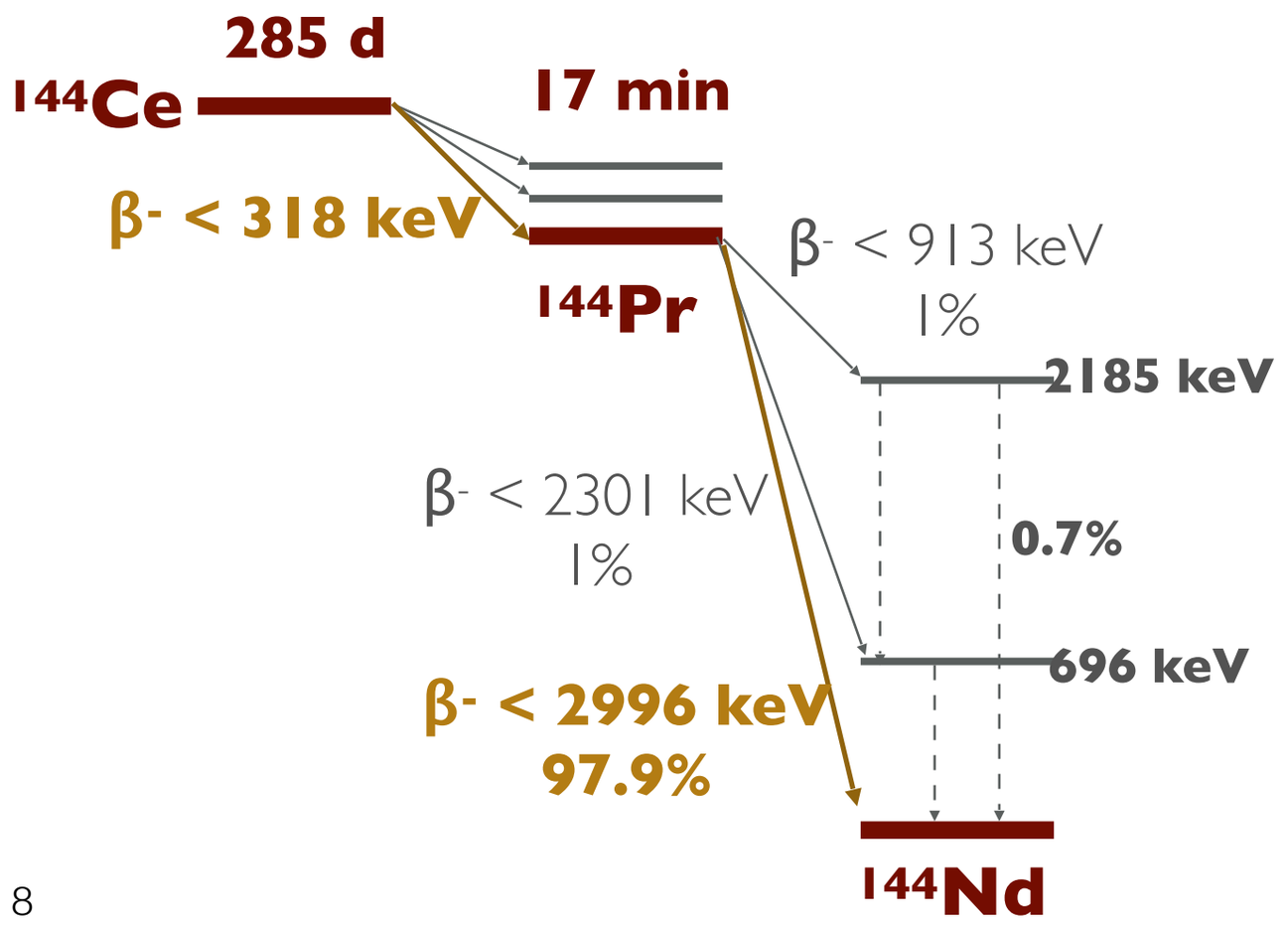
The SOX anti-ν_e source

^{144}Pr β-decay: Q-value ~ 3 MeV, τ ~ 17 minutes
replenished by **^{144}Ce** β-decay: τ ~ 285 days

^{144}Ce extracted from spent nuclear fuel,
activity up to **150 kCi** (4.5 10^{15} Bq)

anti-ν_e from ^{144}Pr detected via Inverse Beta Decay in Borexino



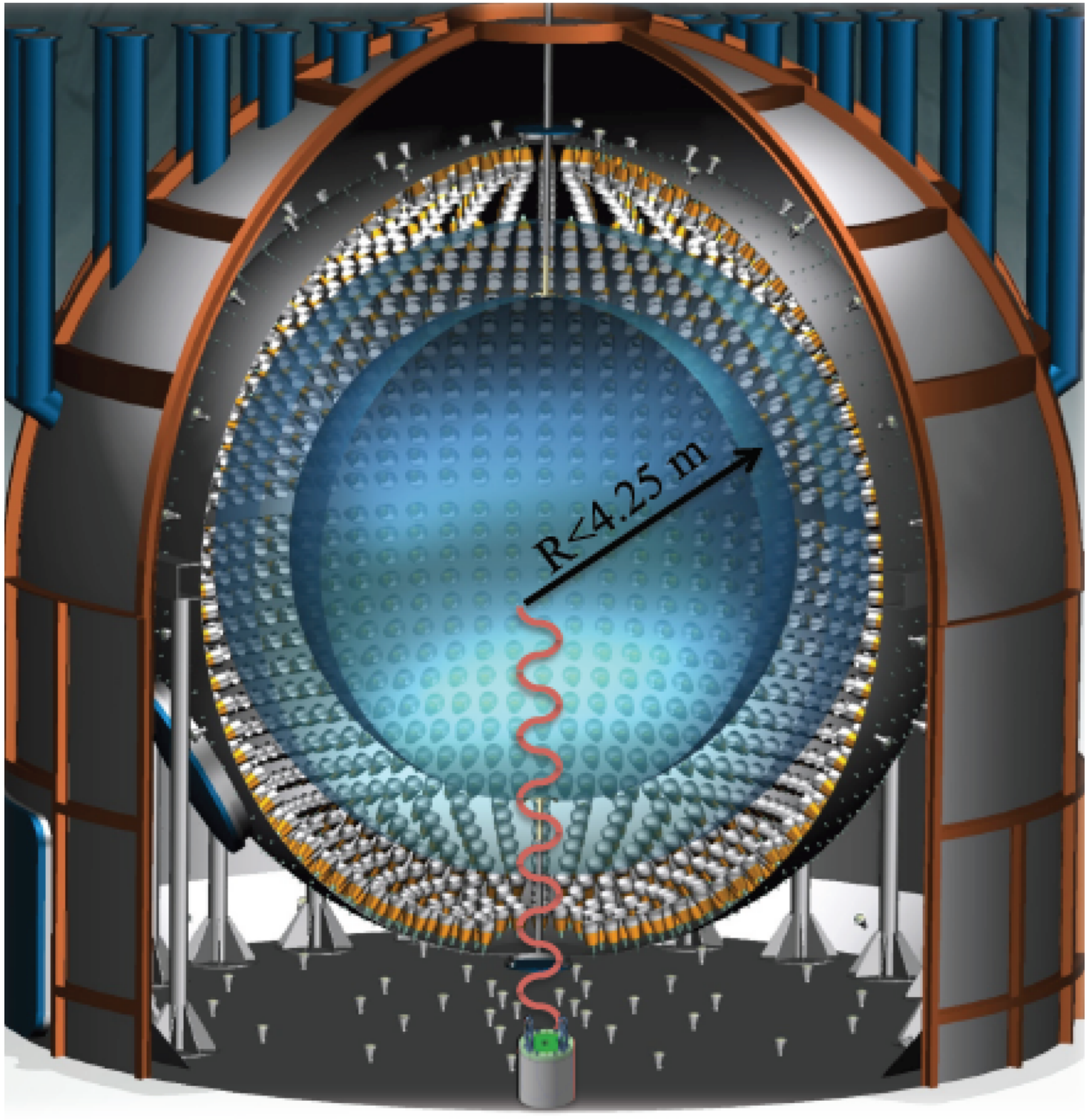


Borexino and SOX

270 ton Liquid Scintillator

1000 ton Buffer Fluid

External Water Tank



150 µm Nylon Vessels

2200 PMTs

SOX source under the floor

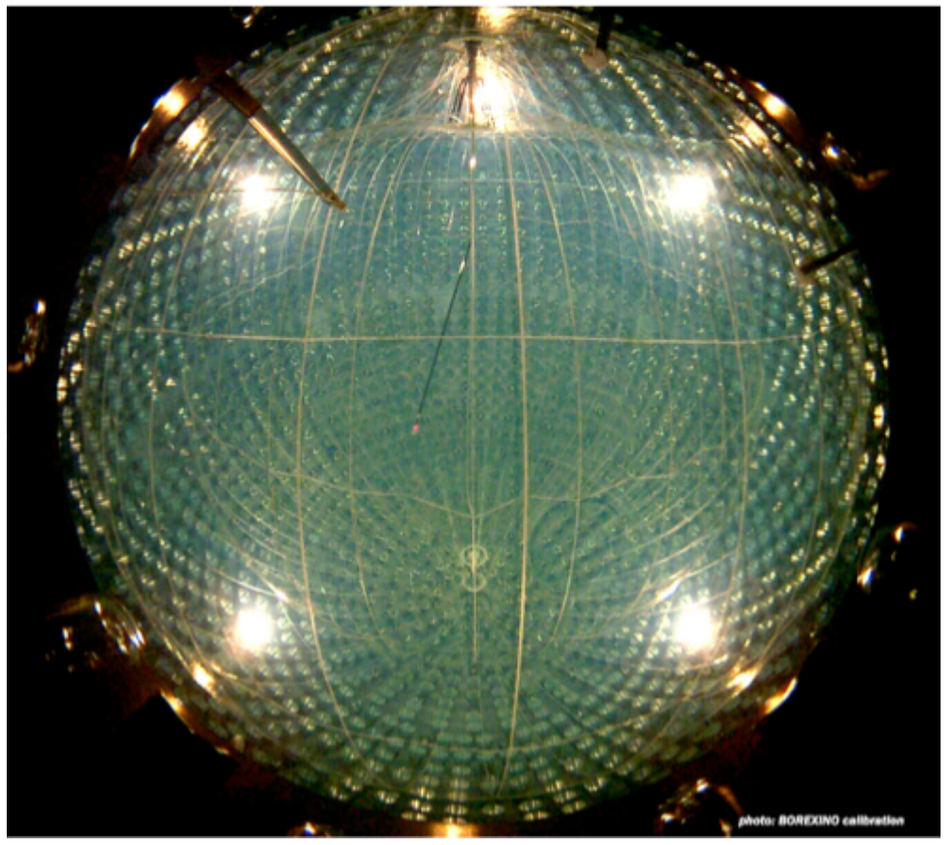
Anti-ν_e detection in Borexino

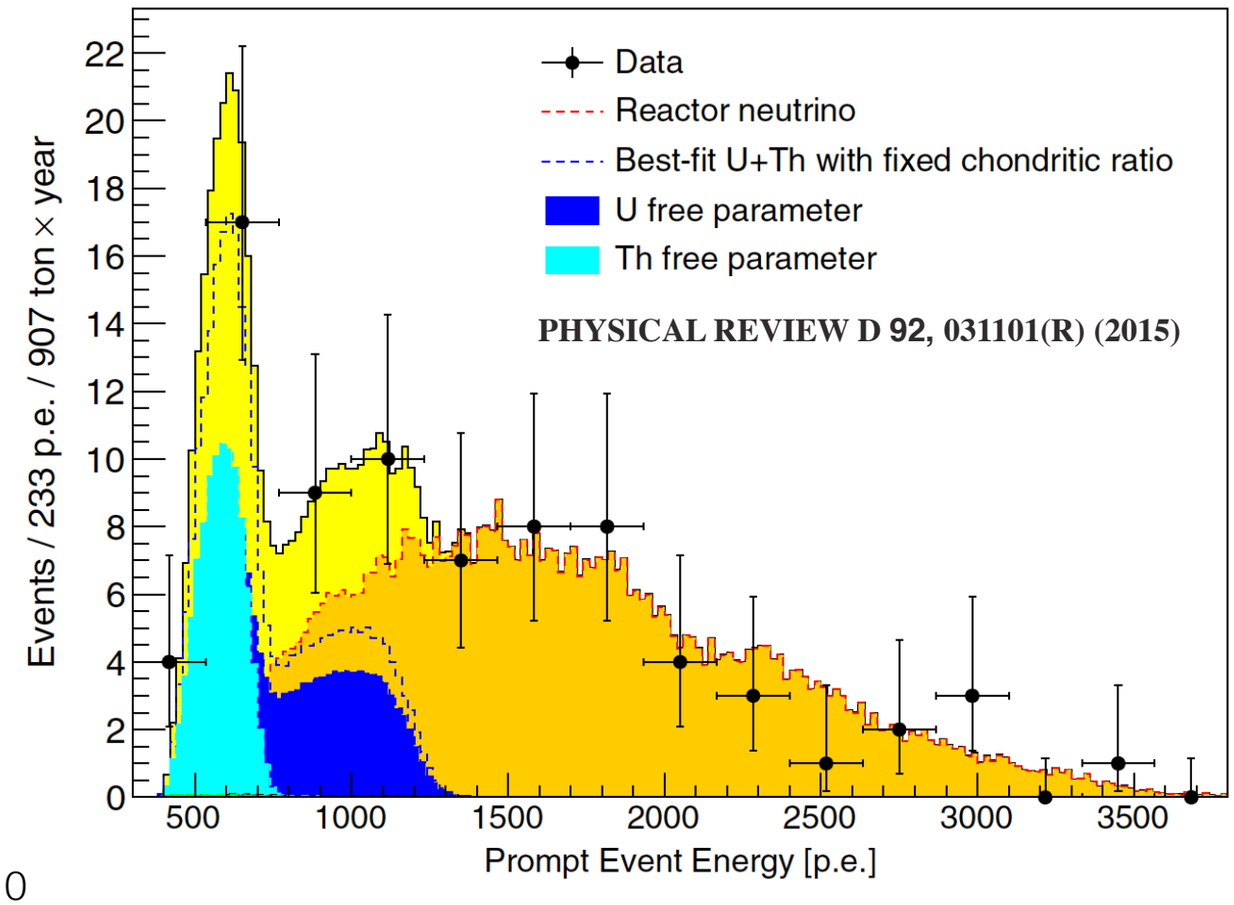
Anti-ν_e from ^{144}Pr source detected via Inverse Beta Decay in Borexino

IBD Threshold: 1.8 MeV
Spatial resolution: ~12 cm at 2 MeV, **comparable** to **source size**

Anti-ν_e detection capability demonstrated by geo-neutrino detection
geo-ν: ~5 ev/y in 300 t, distant reactors: ~10 ev/y in 300 t

SOX is **background free**: expected 10^4 events in 1 year in 300 t

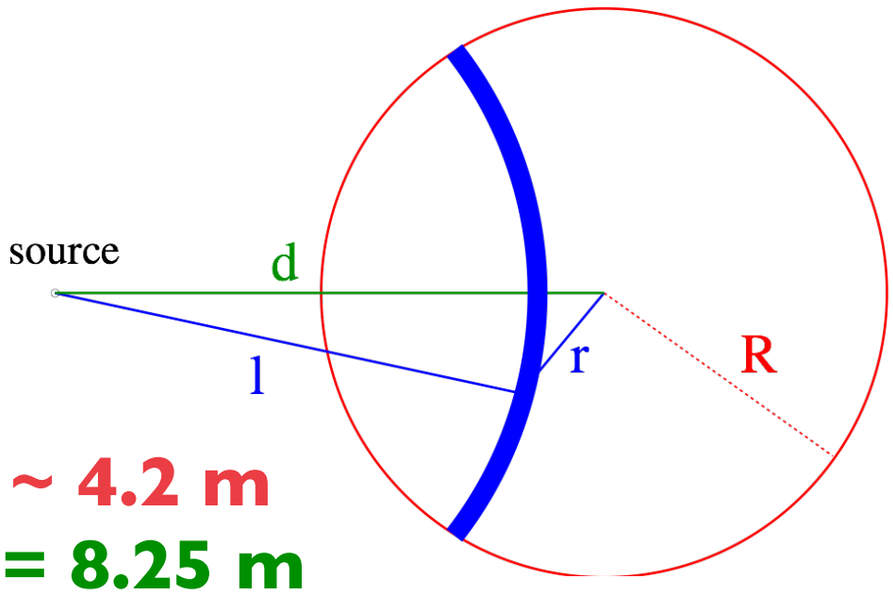




The signals in SOX (I)

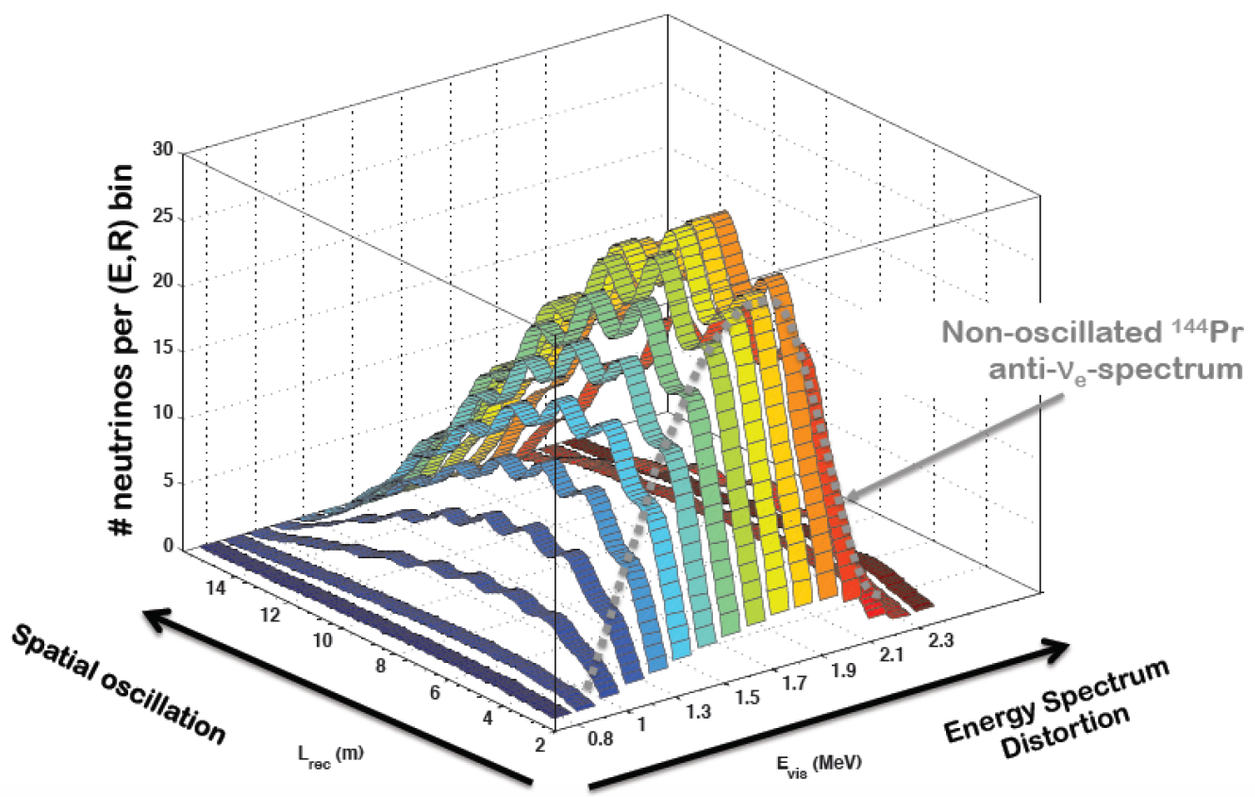
Disappearance: depends on θ_s **and** (weakly) Δm^2
Sensitivity depends on source activity, FV determination

Spatial oscillation waves: independent measurement of θ_s and Δm^2
For Δm^2 ~1eV -> oscillation λ ~ 15 cm
smaller than detector size (~7 m),
larger than position resolution plus source size (~15 cm)
Distribution of anti-ν_e **count** vs **distance** -> **oscillation** pattern
No dependence on source activity, FV determination

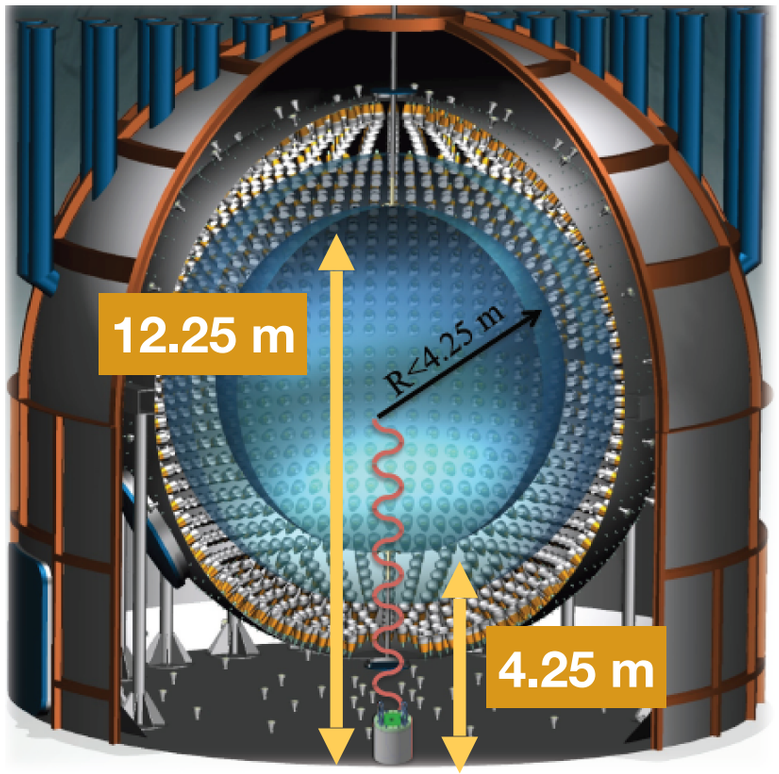


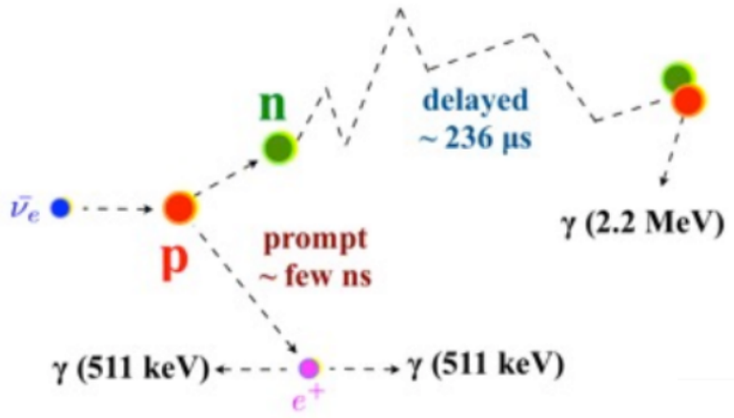
R ~ 4.2 m
d = 8.25 m

$$V(l) = 2\pi l^2 \left(1 - \frac{d^2 - R^2 + l^2}{2\,d\,l}\right)$$

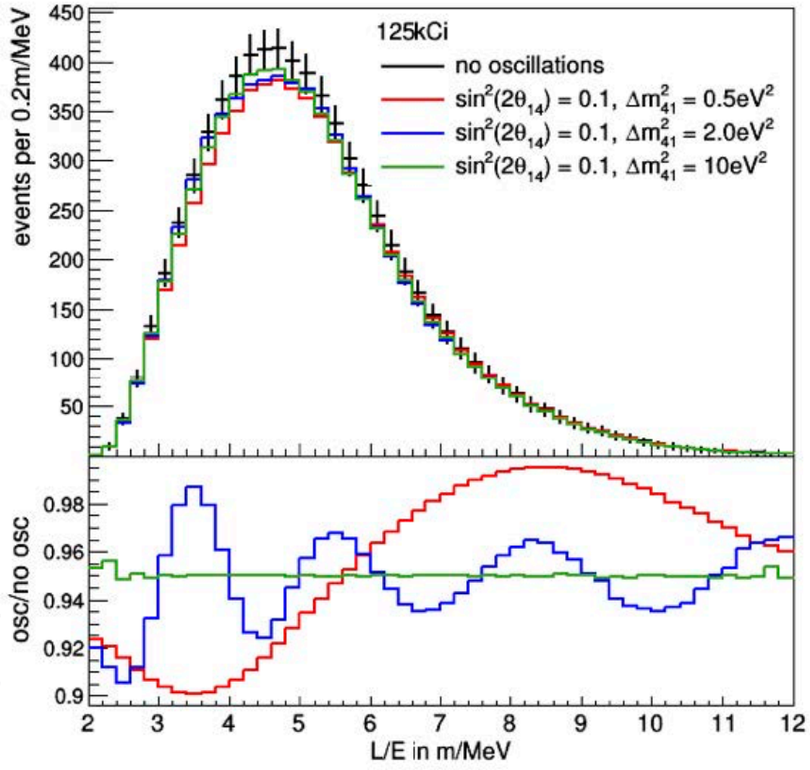


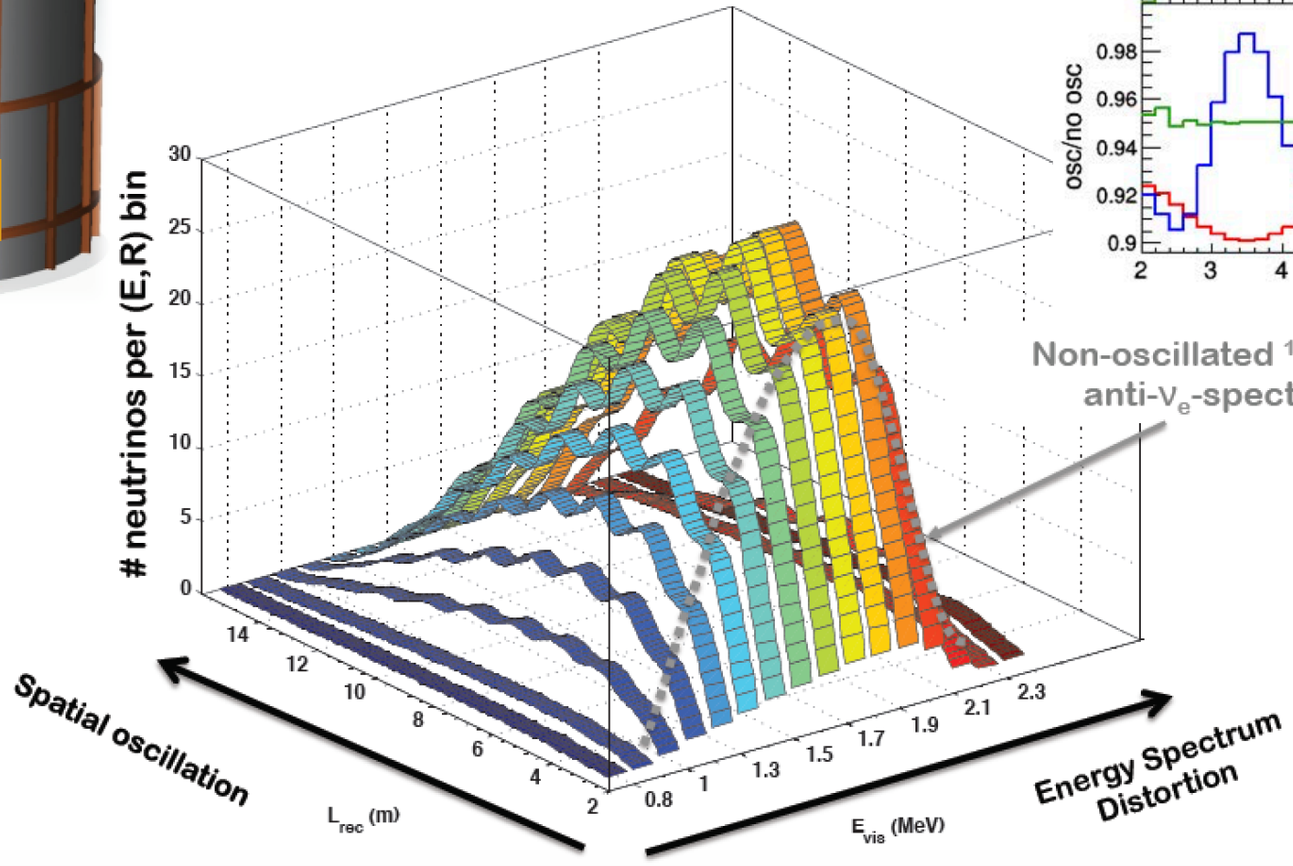
The signals in SOX (II)





$E_{vis} = E_{anti\text{-}ve}$ - 0.789 MeV





The making of SOX

Making of **100-150 kCi** ^{144}Ce source

manufactured by PA **Mayak** (Russia)

expected delivery at **LNGS** in April 2018

Challenges

source production

authorisation (Russia, France, Italy)

transportation

Synergy between CEA, INFN, and Borexino Collaboration

production and transportation (CEA, INFN)

site preparation at LNGS (INFN, Borexino)

calorimeter for source activity measurement (CEA, INFN, TUM)

detector, trigger, calibration, simulation and analysis tools (Borexino)

The making of the ^{144}Ce source

Fuel from Research Reactor (higher ^{235}U)

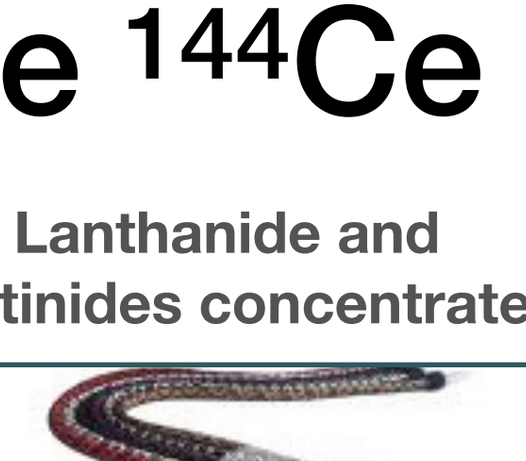
Cutting, digestion (Purex process)

Lanthanide and Actinides concentrate

Rare Earths Precipitation

Displacement Chromatography

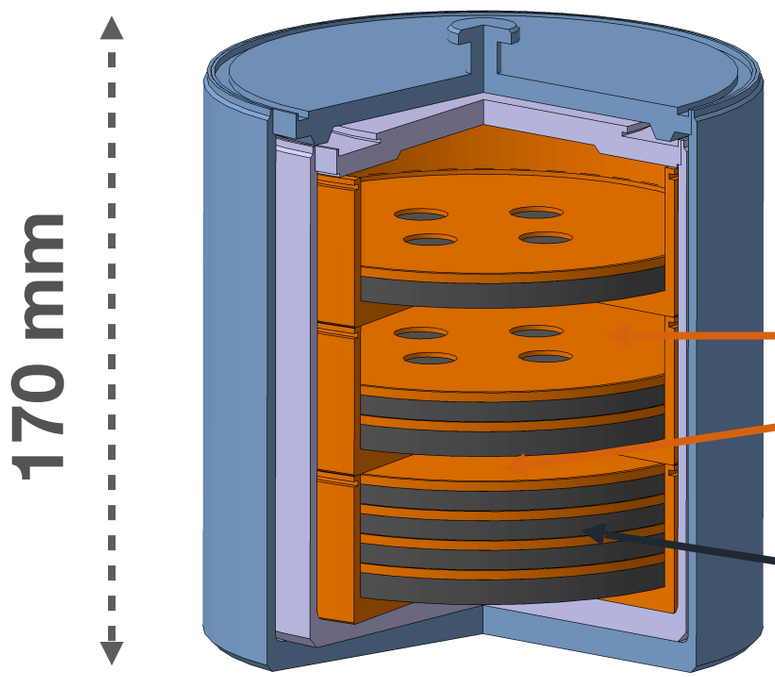
Separation



Calcination

At the END

The CAPSULE (few litres)

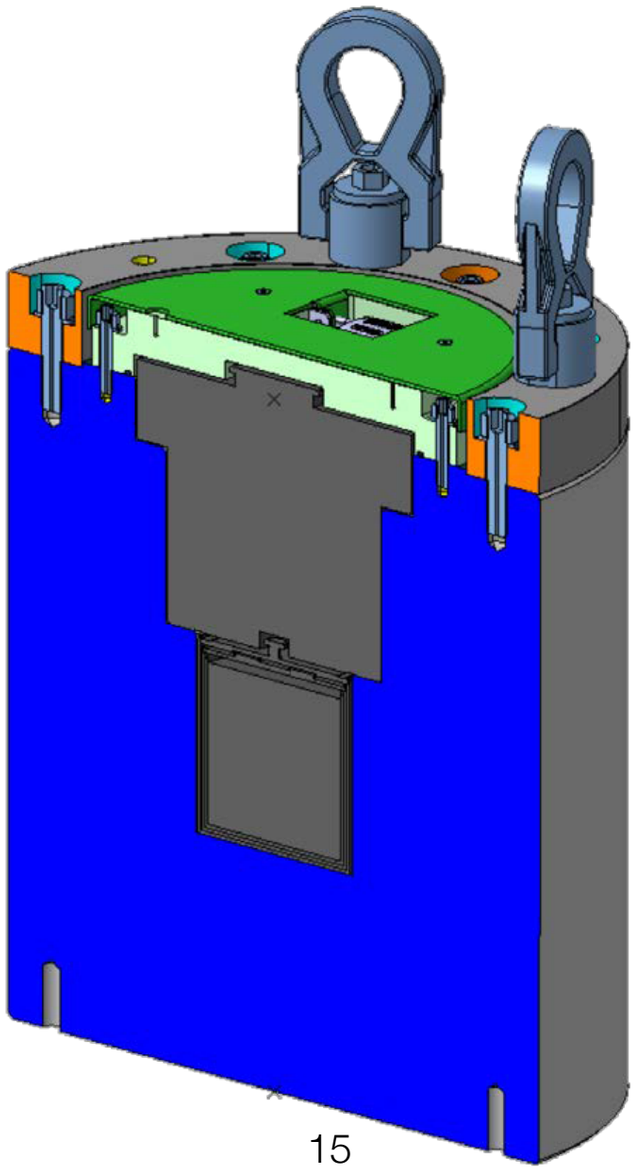


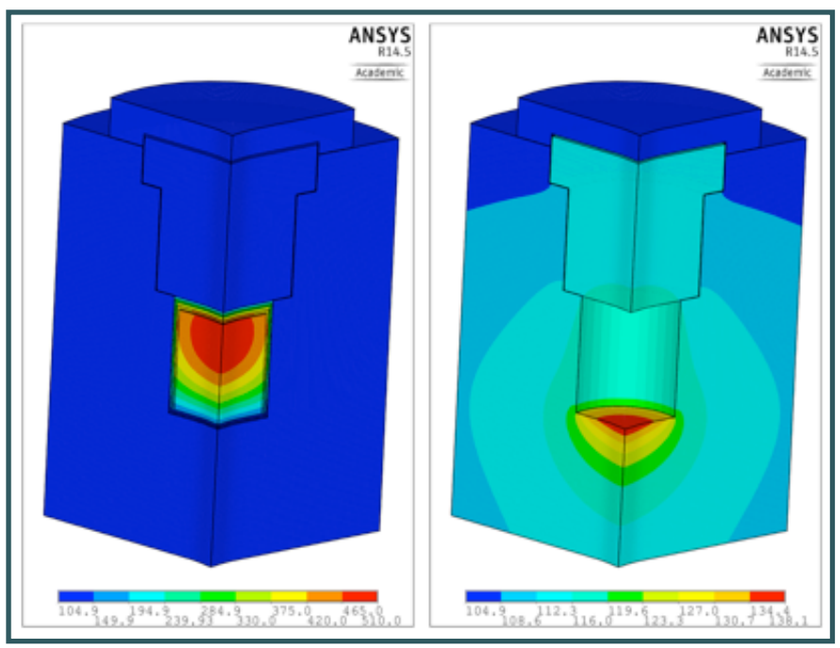
CeO_2 powder pressed in sealed stainless steel capsule with copper disks: heat transfer, internal free space for pressure control

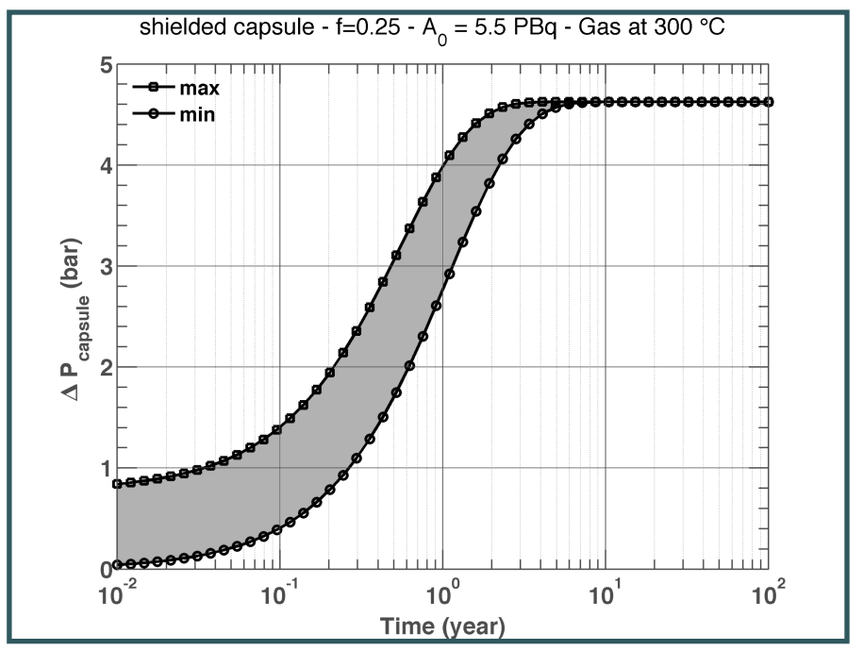
The CeANG

γ-rays must be **shielded**
capsule inserted into 19 cm thick **tungsten shield**

thermal power ~1 kW, internal T ~500 C, external T ~85 C
pressure from free O_2 in $4CeO_2 \rightarrow 2Pr_2O_3 + O_2$
careful design of capsule and shielding, safety certifications



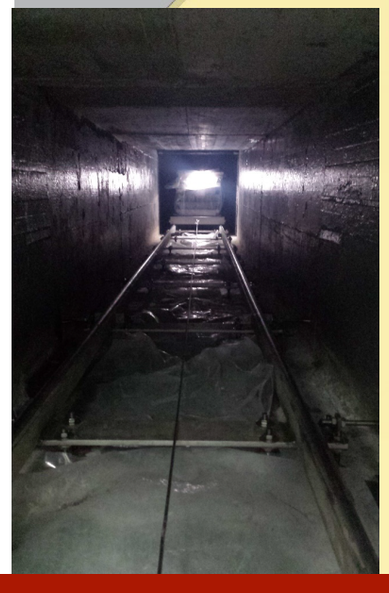




CeANG transportation

a pleasant three week trip across Europe

SOX at LNGS



Tunnel & Rails

Tunnel

Calorimetric measurement

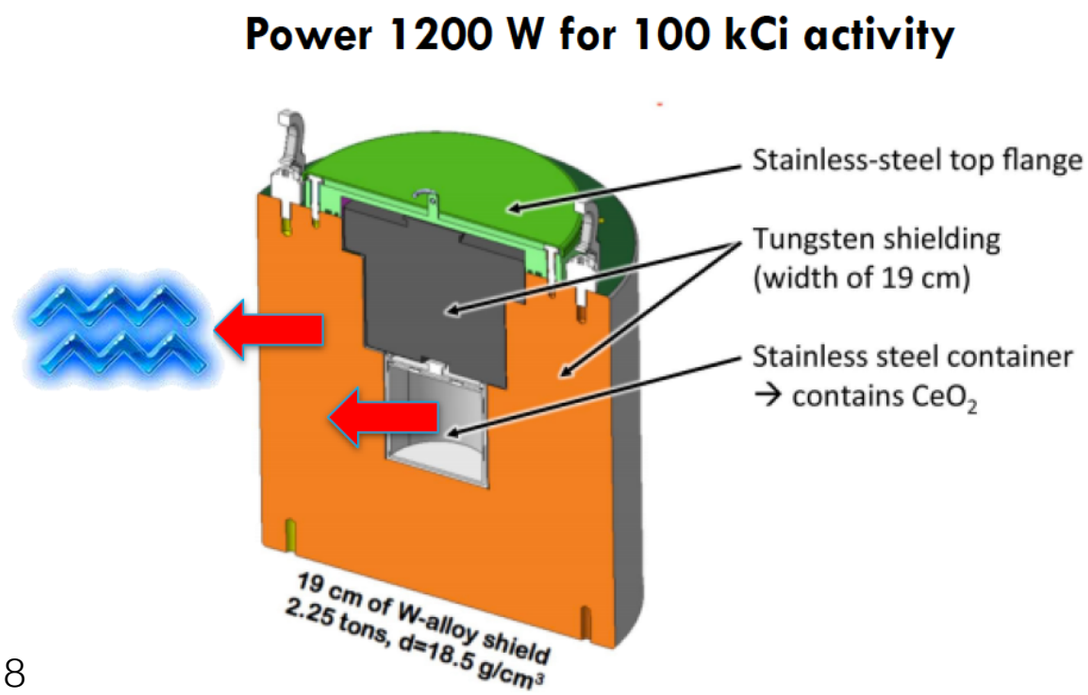
beta decays heat up source and shield
source activity measured by **heat** released in **shield** absorbed by water flow
resolution better than **1%**, obtained by decreasing heat losses

disappearance (rate only) measurement **sensitivity**
depends on accuracy on **activity**

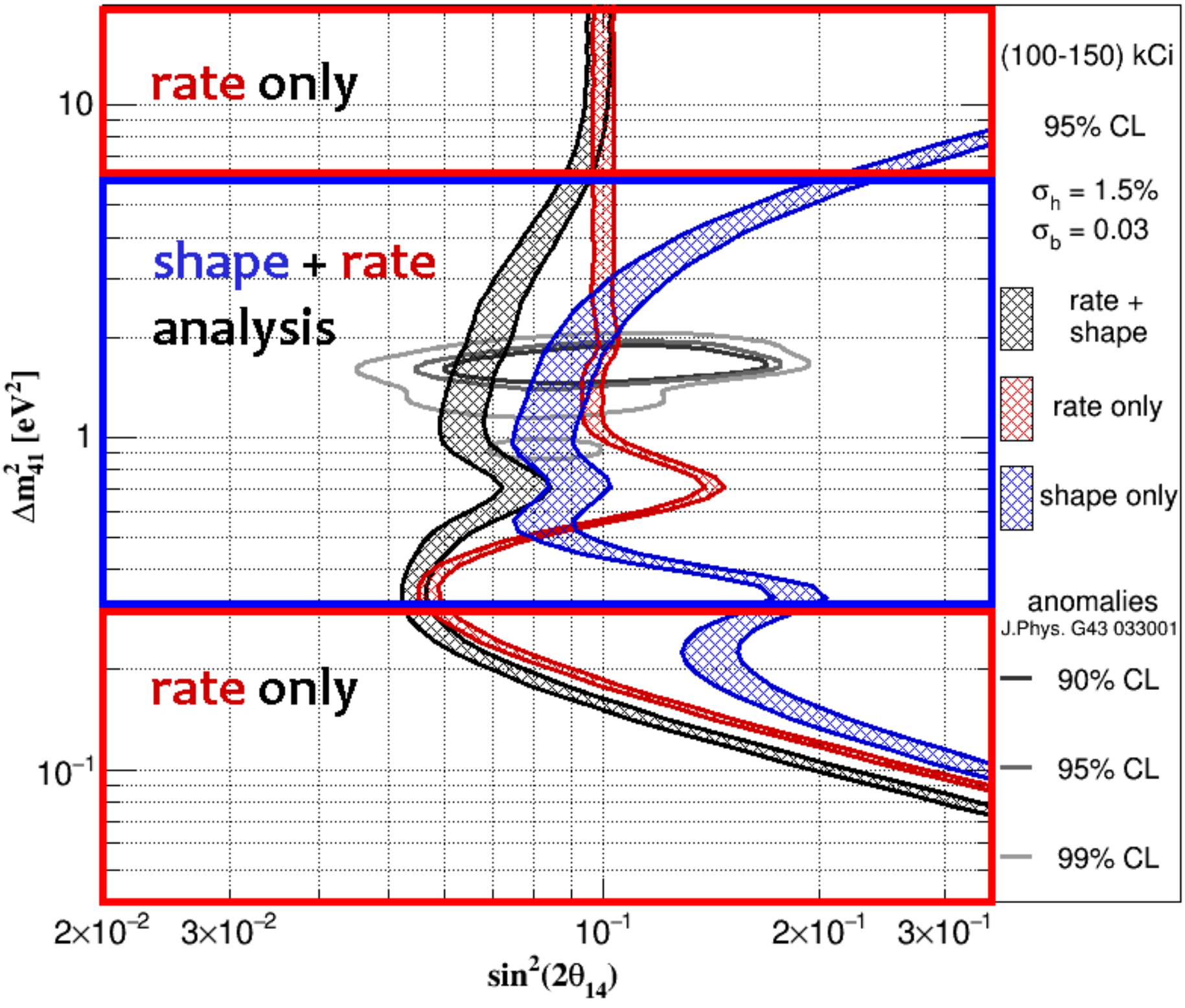
and **knowledge** of ^{144}**Ce** decay **spectrum**
ongoing **dedicated setups** measuring it

(and as well Borexino detector response, known well)

$$P = \int_{T_{in}}^{T_{out}} c_p(T)\ \dot{m}\ dT$$



Expected sensitivity



Conclusions and Outlook

- Source experiment as alternative to reactor experiment to test sterile neutrinos at m ~1 eV

- SOX ^{144}Ce source (100-150 kCi), to detect disappearance and spatial oscillation waves in Borexino

- Sensitivity for discovery of sterile neutrino of rejection of SBL anomaly

But …

- SOX under attack by massive campaign of mis-information in Italy

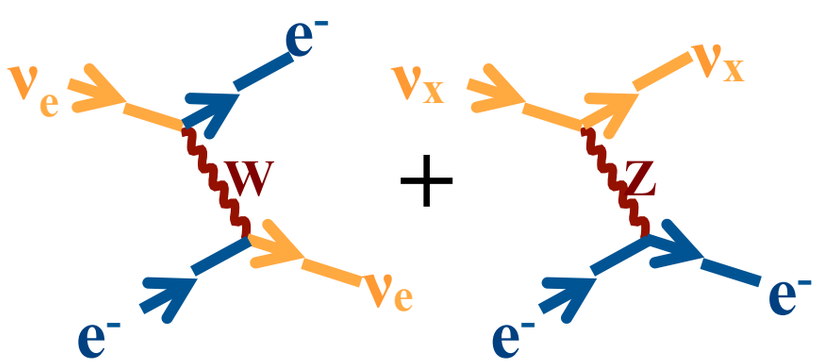
- Please support SOX signing the petition on change.org

- https://www.change.org/p/luciano-d-alfonso-continuazione-dell-esperimento-sox-nei-laboratori-infn-del-gran-sasso-abruzzo?utm_medium=email&utm_source=petition_signer_receipt&utm_campaign=triggered&share_context=signature_receipt&recruiter=838701645

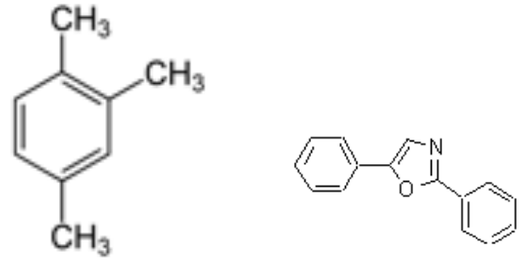
backup

slides

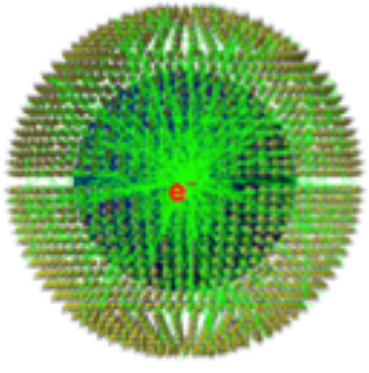
Solar ν detection in Borexino



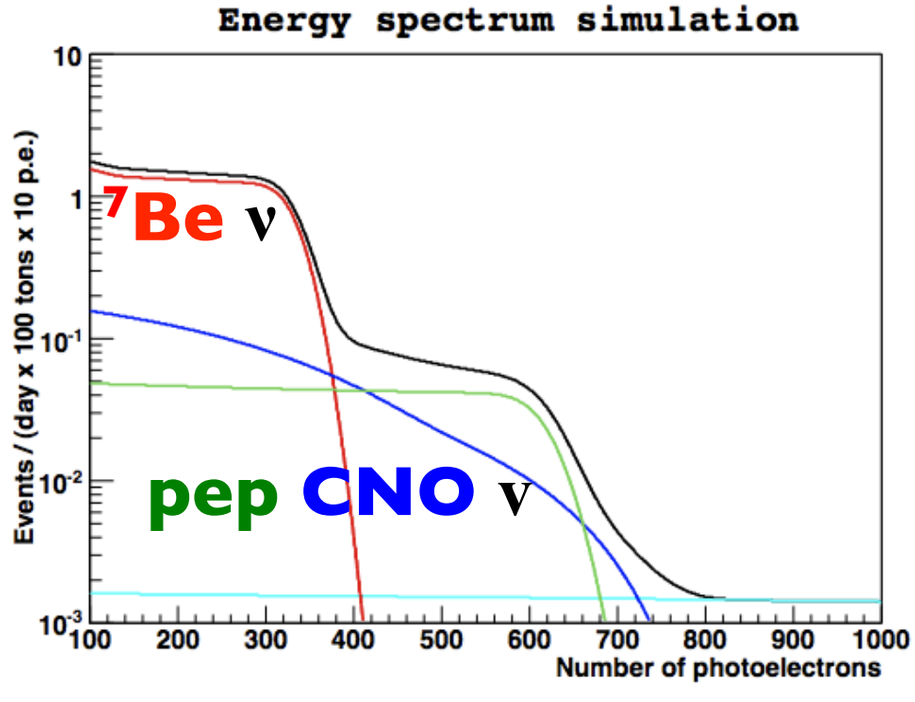
Elastic scattering
on **electrons** (ν_x-e^-)



Emission of **scintillation light**

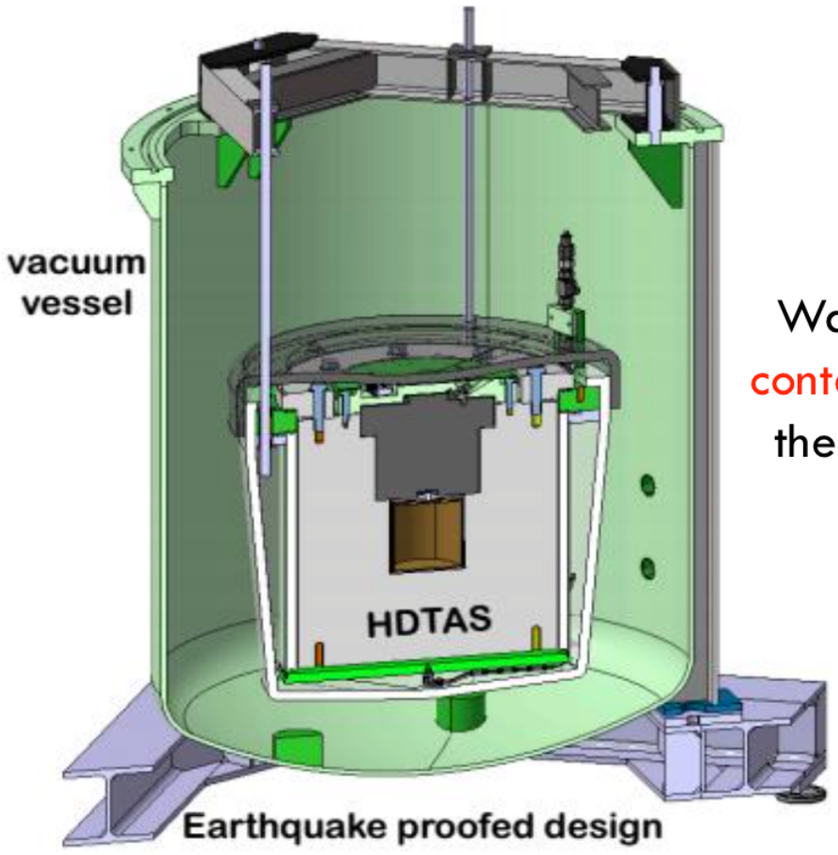


Scintillation light
detected by **PMTs**



SOX calorimeters

CEA calorimeter



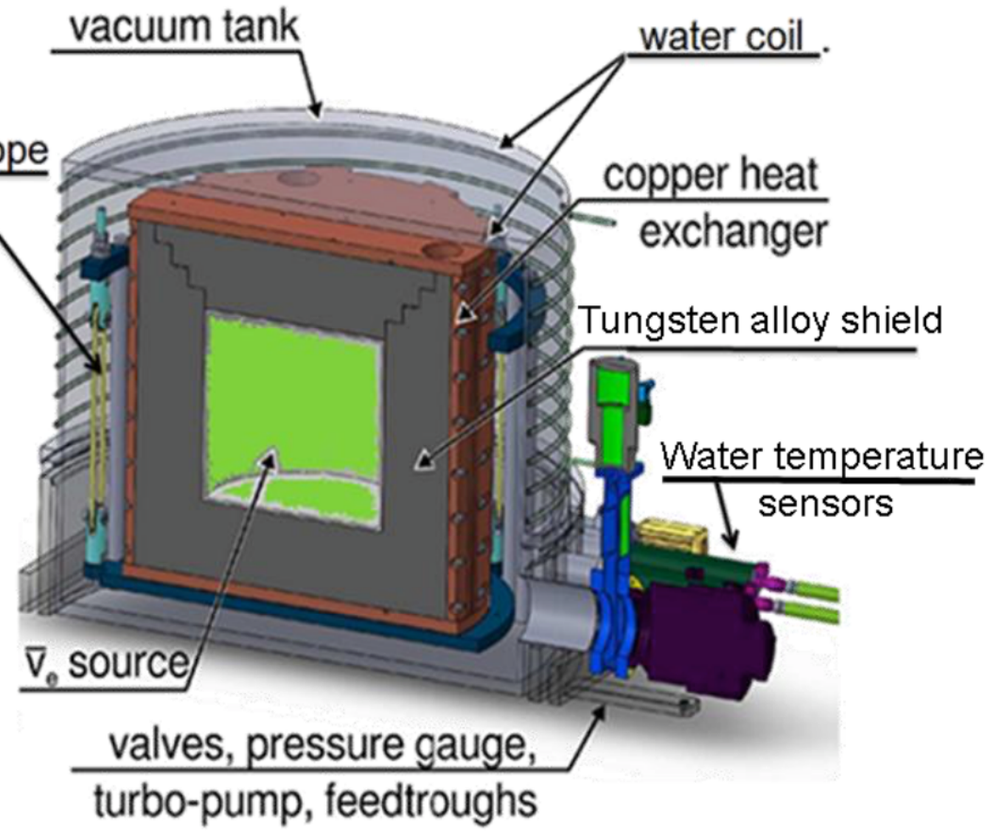
Water at contact with the shield

Mass flow: 1-2 g/s

Difference of temperature: 40-50 °C

INFN-TUM calorimeter

Water circulating in a coil embedded in a copper heat exchanger



Mass flow: 10 g/s

Difference of temperature: 25-30° C