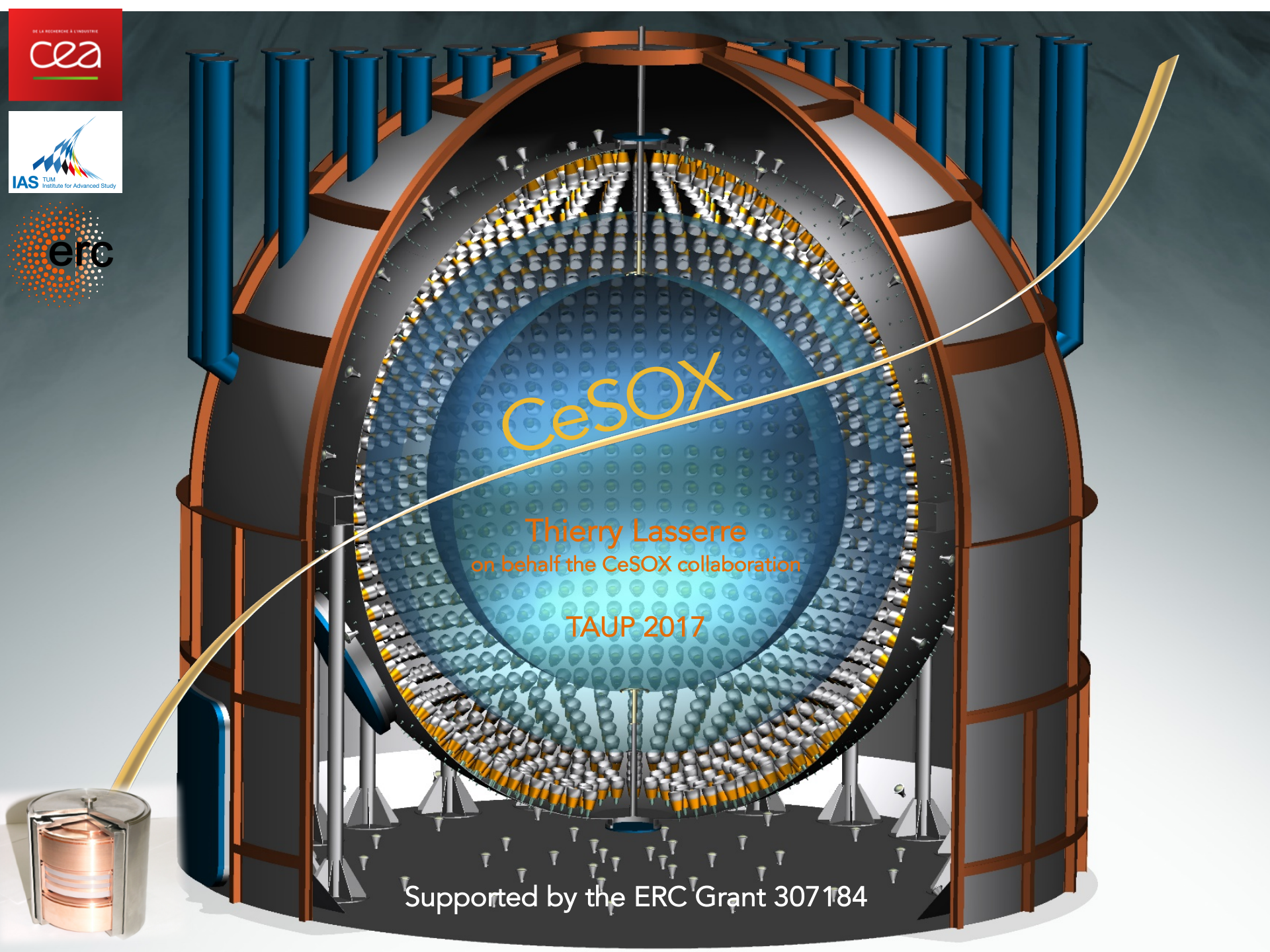
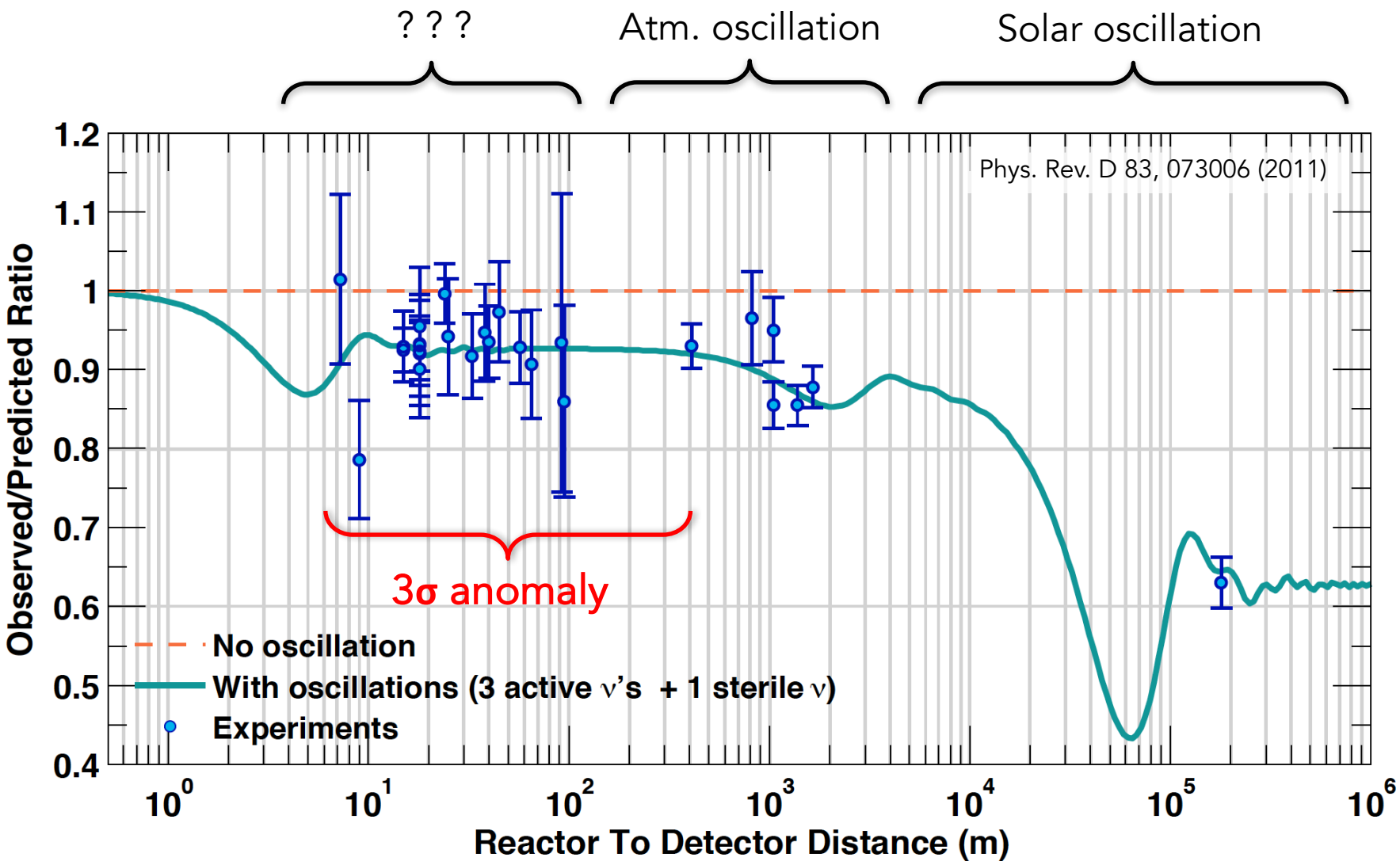
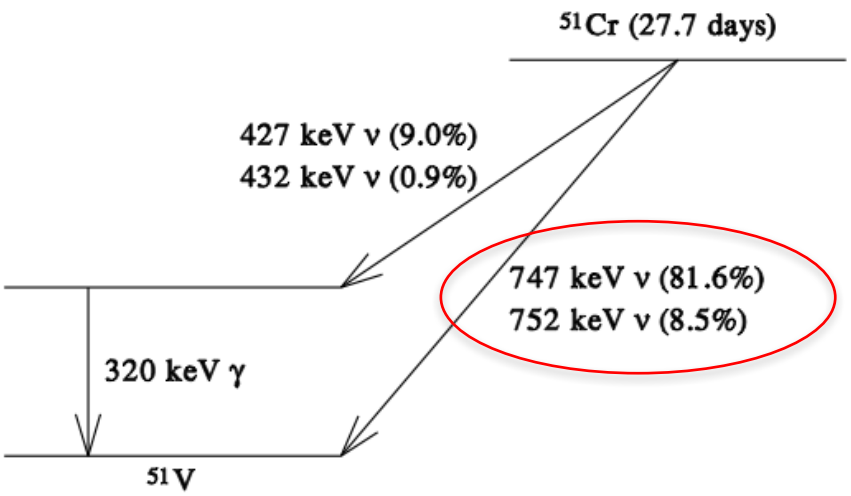

CeSOX
Thierry Lasserre
on behalf the CeSOX collaboration
TAUP 2017
Supported by the ERC Grant 307184

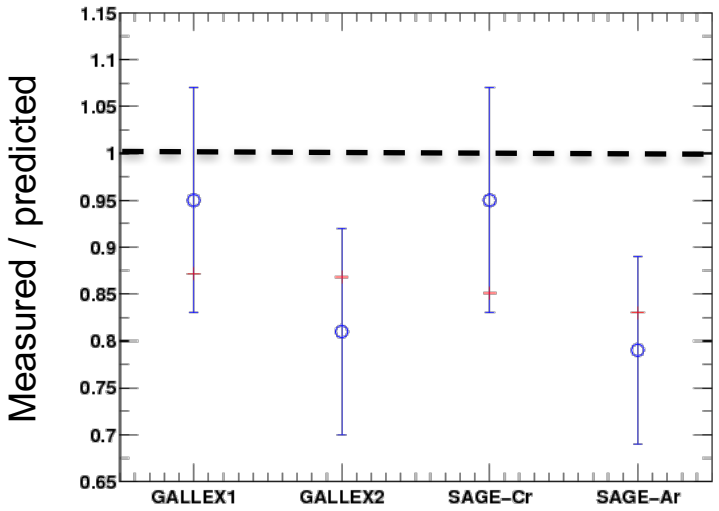
The Reactor Anomaly (RAA)



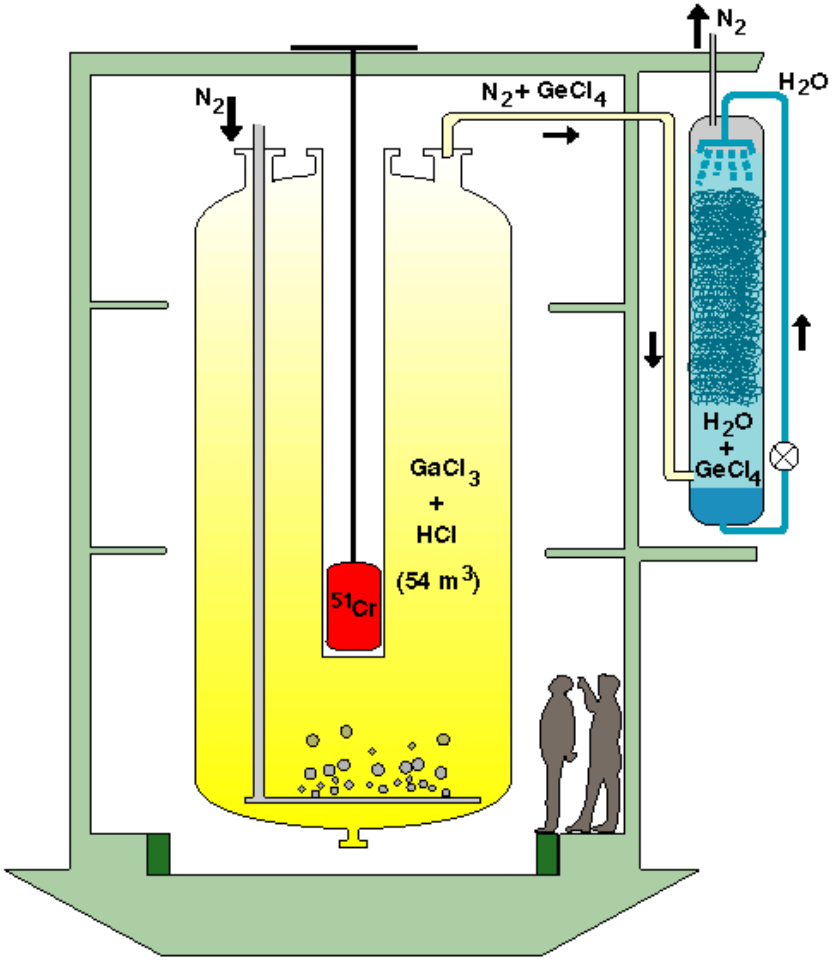
The Gallium Anomaly (GA)



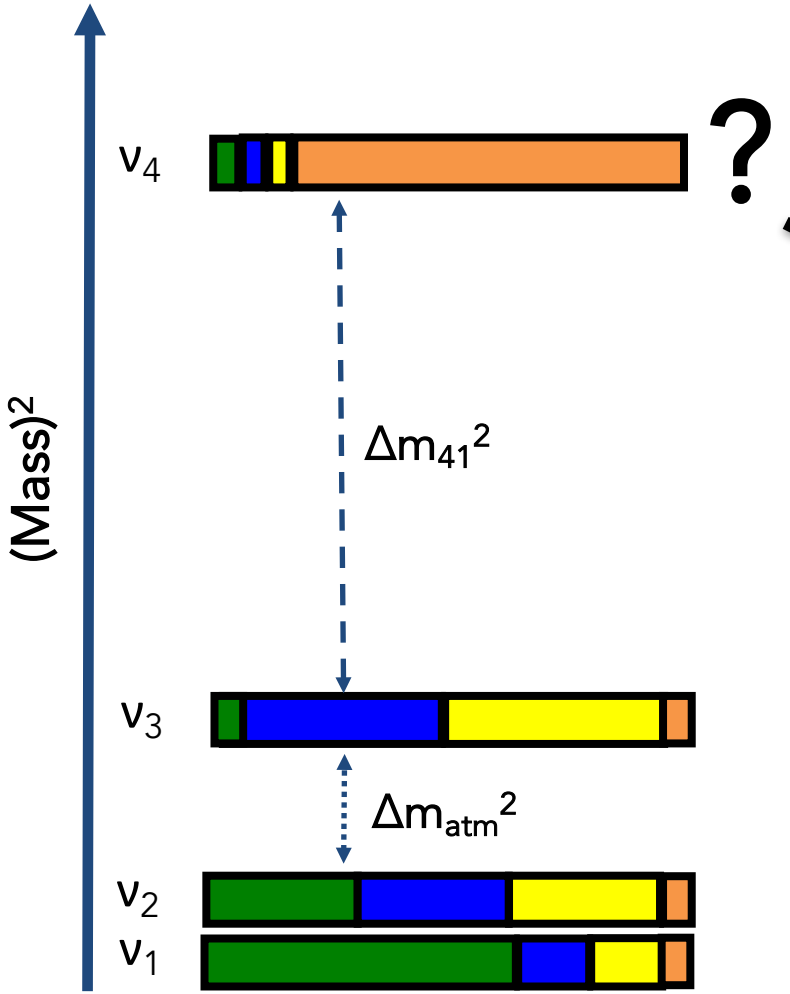
3σ anomaly



Gallex



eV-scale massive neutrino? (mainly sterile)



$$U = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix}$$

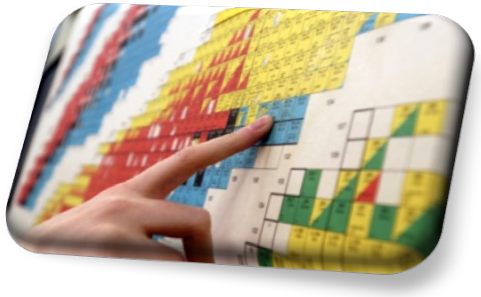
Mixing with active ν's

ν_e $|U_{ei}|^2$ ν_μ $|U_{\mu i}|^2$ ν_τ $|U_{\tau i}|^2$ ν_s $|U_{si}|^2$

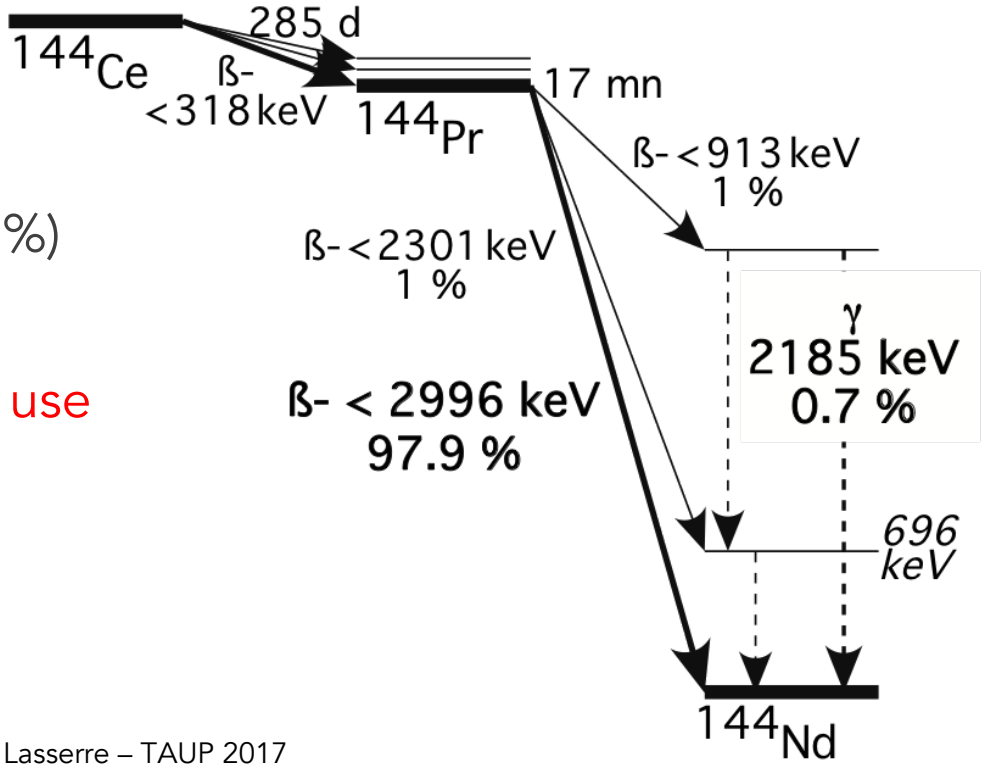
^{144}Ce-^{144}Pr Antineutrino Generator

(ITEP N°90 1994, PRL 107 201801, 2011)

- $\bar{\nu}_e$ detection: $\bar{\nu}_e + p \rightarrow e^+ + n$
  - $\sigma \sim 10^{-42}\ cm^2$ → 5 PBq (only) needed
  - (e^+,n) coincidence → mitigate backgrounds

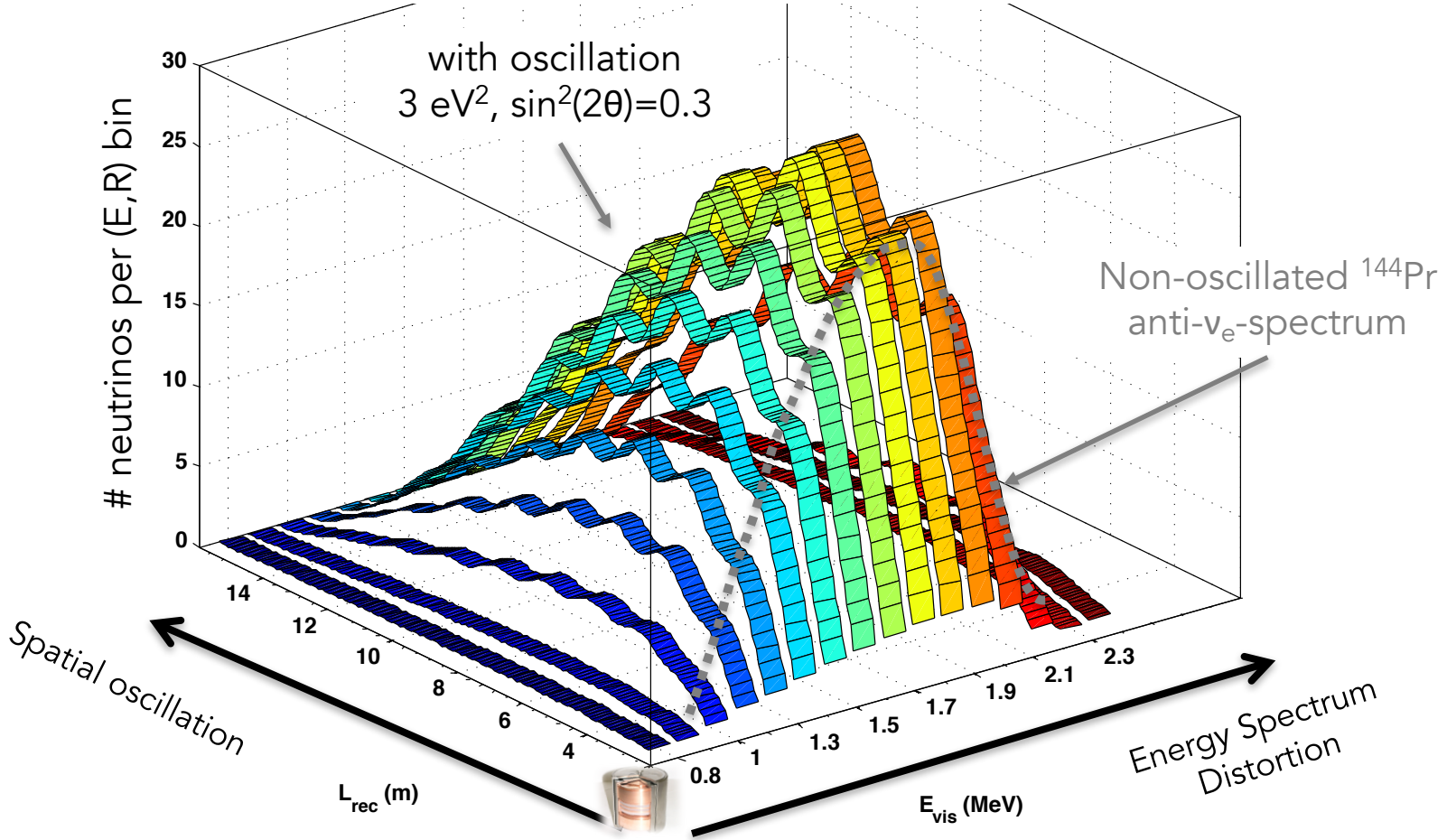


- ^{144}Ce-^{144}Pr
  - abundant fission product (5%)
  - ^{144}Ce: long-lived & low-Q_β
    time to produce, transport, use
  - ^{144}Pr: short-lived & high-Q_β
    $\bar{\nu}_e$ above IBD threshold



CeSOX Concept

$$\frac{\mathrm{d}^5 N_{\bar{\nu}_e}}{\mathrm{d}t\,\mathrm{d}E\,\mathrm{d}^3\mathscr{V}_{\mathrm{det}}} = \mathcal{A}_0\, e^{-t\,\lambda_{\mathrm{Ce}}}\,\eta_p\,\varepsilon\,\frac{1}{4\pi L^2}\,\sigma_{\mathrm{IBD}}(E)\,S_{\mathrm{Ce}}(E) \times \mathcal{P}(L,E)$$



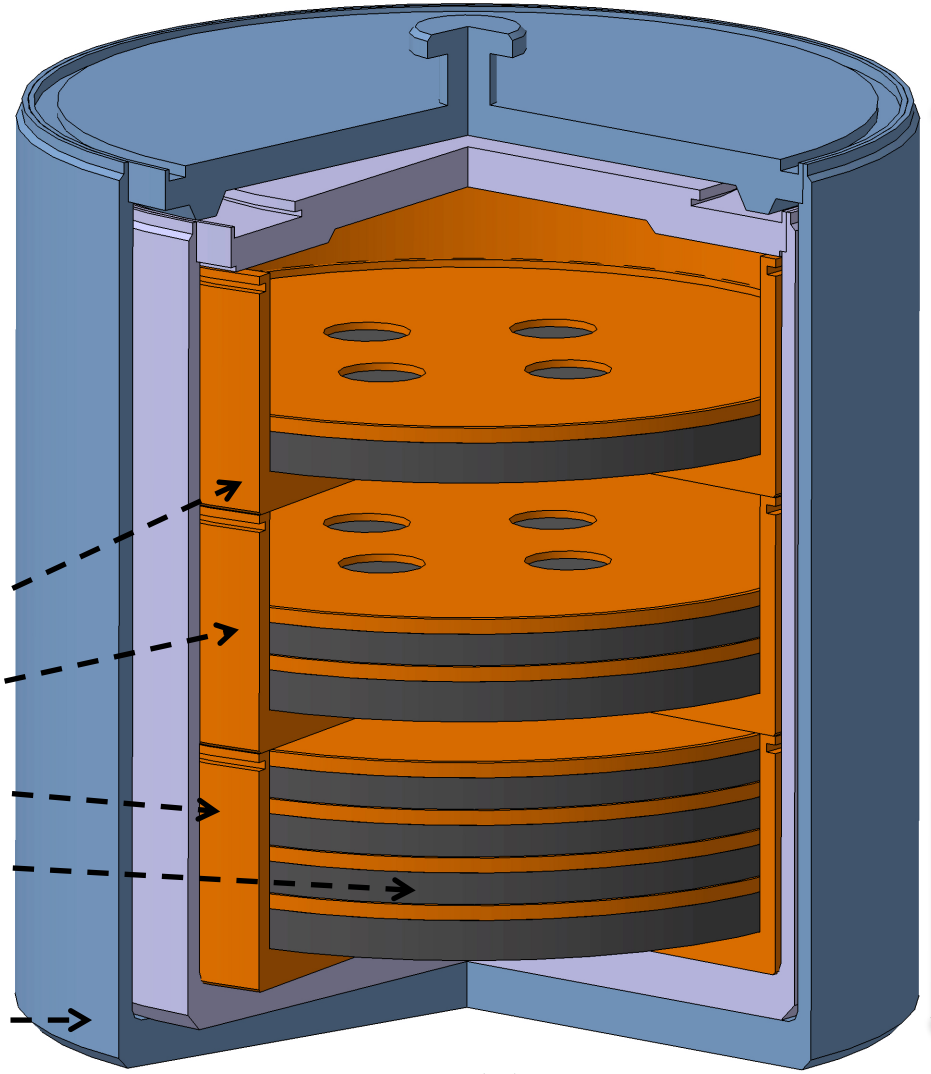
^{144}Ce Production – PA Mayak

- **Seed: spent nuclear fuel (HEU)**
  - High ^{144}Ce – Low Cm/Am
- **Radiochemical Plant** - Mayak
  - U and Pu recovered - Purex®
  - Removal of ^{137}Cs, ^{90}Sr, ^{106}Ru, Al
  - Extraction of Cerium
  - Primary encapsulation
  - Activity measurement (5%)
- **Radioisotope Plant** - Mayak
  - Secondary encapsulation
  - Certification SFRM / ISO
  - Loading into tungsten shield
  - Loading into transport cask
- 2012-15: R&D. 2017: production

Source Encapsulation

- ^{144}Ce
  3.7 – 5.5 PBq – 1200 W

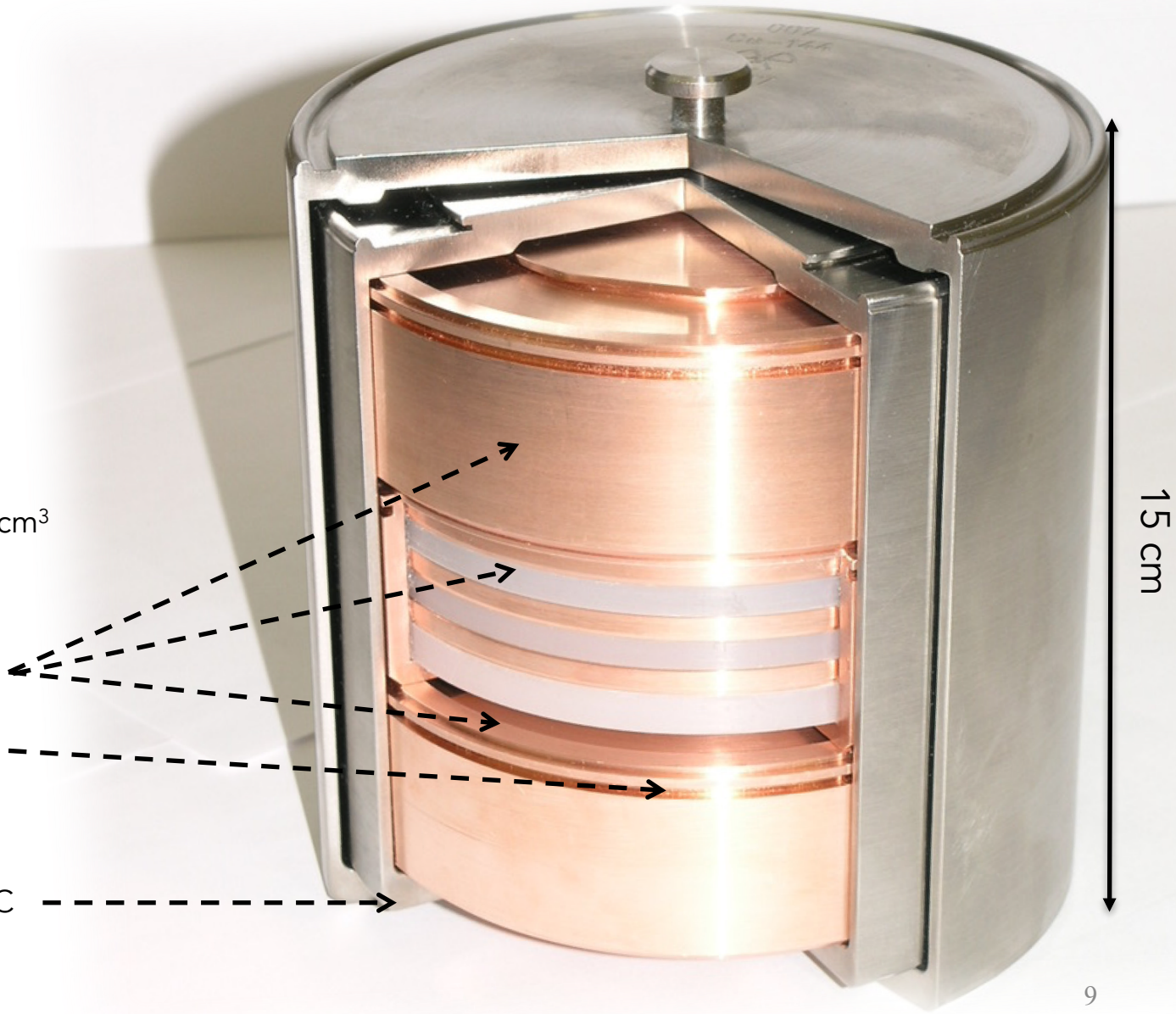
- Sketch of CeO_2 inside capsule
  - CeO_2 pellets 2.5 g/cm^3
  - Cu-disk radiators
  - 3 Cu-capsule
  - T(CeO_2) < 600 °C
  - T(Out Cap) < 500 °C



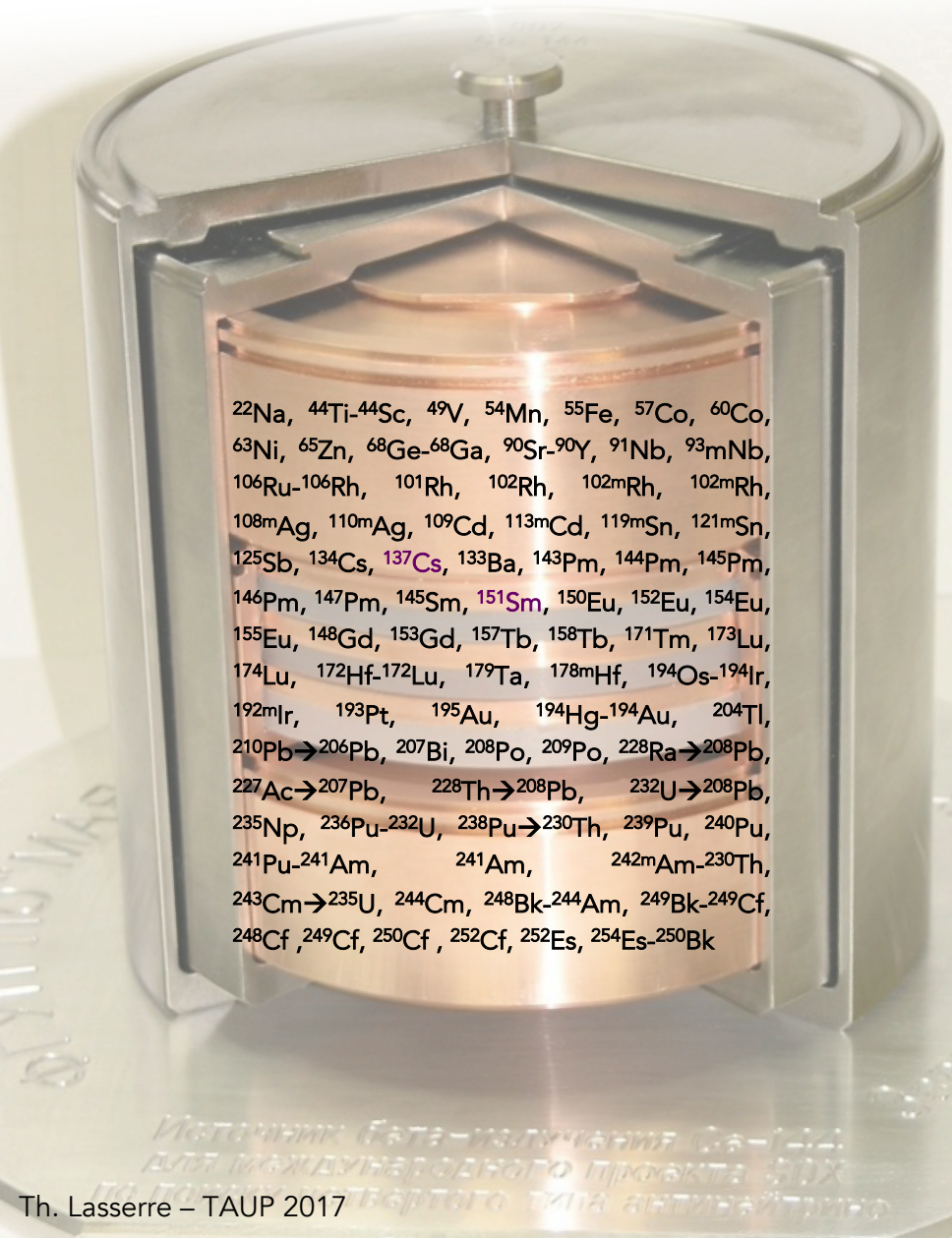
ISO 9978:1992(E) – ISO 2919
Special Form Radioactive Material

Dummy Source Delivered

- Sketch of CeO_2 inside capsule
  - CeO_2 pellets 2.5 g/cm^3
  - Cu-disk radiators
  - 3 Cu-capsule
  - T(CeO_2) < 600 °C
  - T(Out Cap) < 500 °C



Stringent Specifications



^{144}Ce activity: $3.7 - 5.5$ PBq

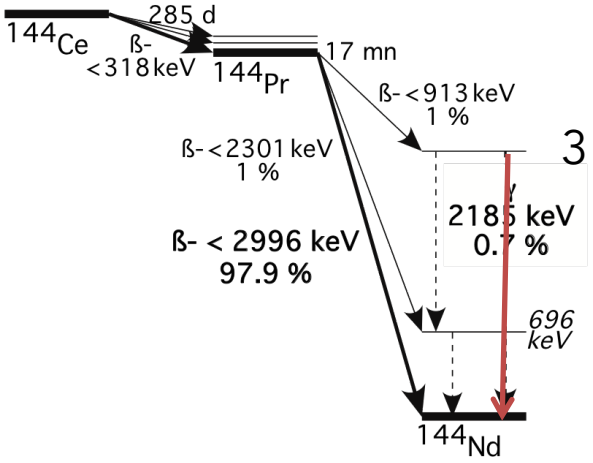
$$\frac{\alpha,\beta,\gamma \text{ impurities}}{^{144}\text{Ce} + 144\text{Pr}} < 10^{-3} \text{ W/W}$$

$$\frac{\gamma \text{ impurities}}{^{144}\text{Ce}} < 10^{-3} \text{ Bq/Bq}$$

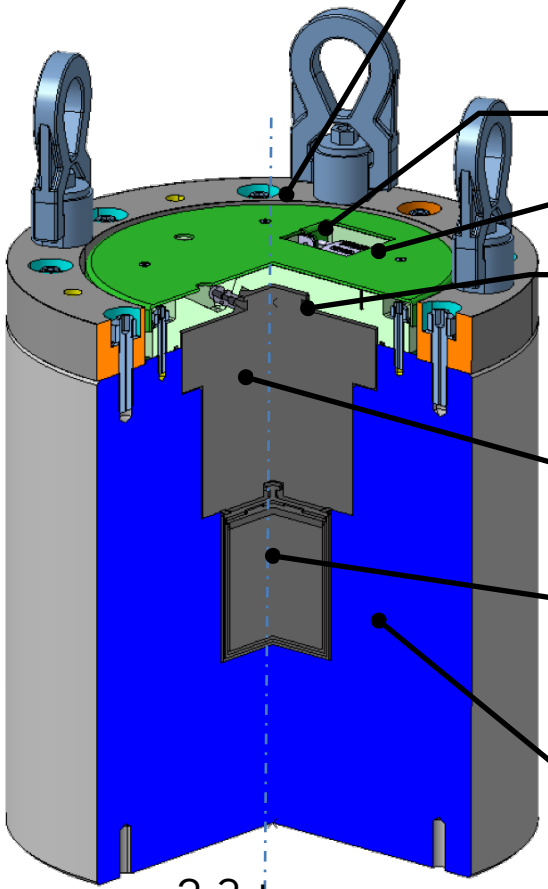
$$\frac{^{244}\text{Cm}}{^{144}\text{Ce}} < 10^{-5} \text{ Bq/Bq}$$

$$\frac{^{241}\text{Am}}{^{144}\text{Ce}} < 5.10^{-3} \text{ Bq/Bq}$$

High Density Tungsten Shield



3 10^{10} γ/sec



Handling crown

Top lid

Closure flange

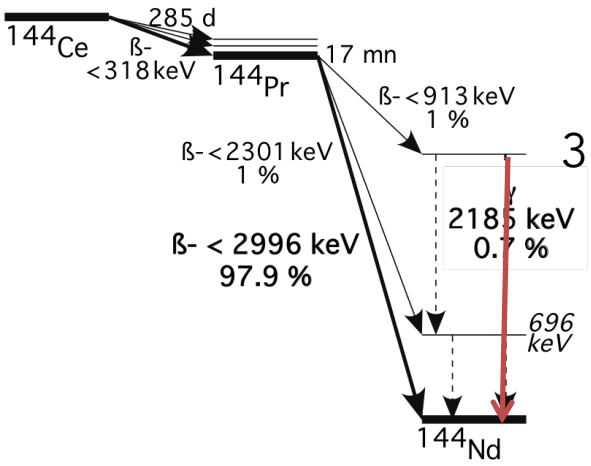
18.g/cm^3 W alloy Plug

Cerium source

19 cm of W alloy 18.g/cm^3

2.3 tons

High Density Tungsten Shield



3 10^{10} γ/sec

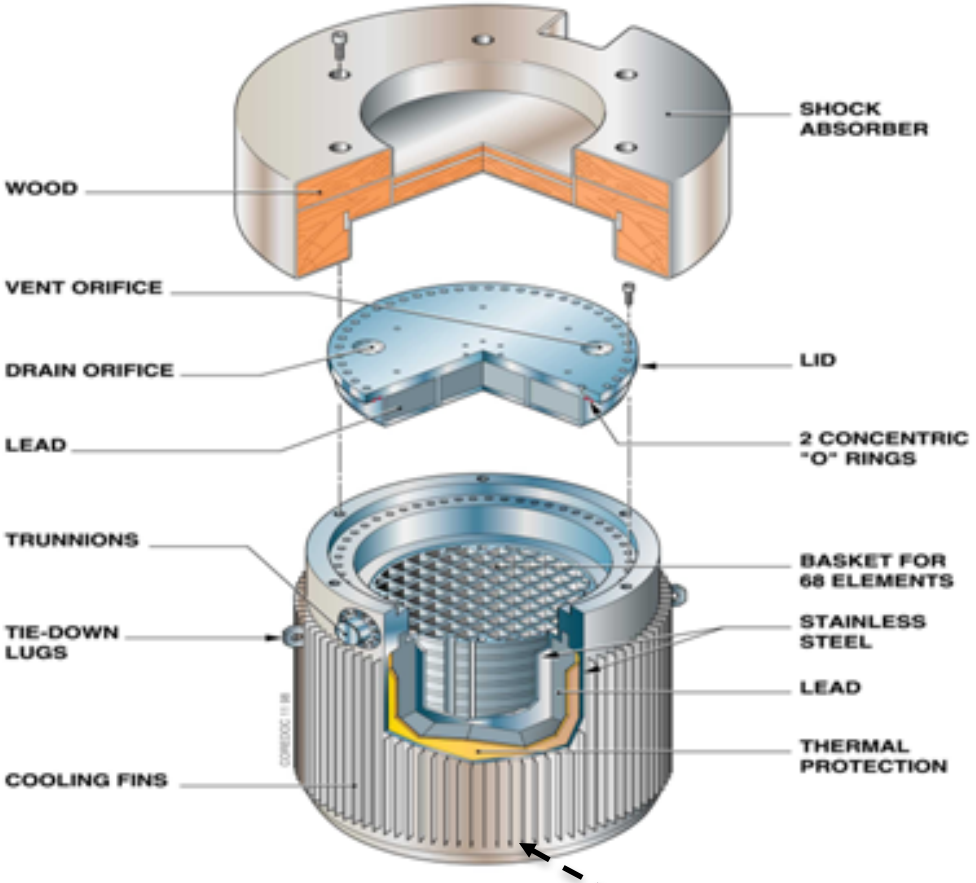
10^{7} attenuation for 2.2 MeV γ's

< 8 μSv/h @1 m

<80°C

Transportation cask – TN MTR

25 g of ^{144}Ce – 25 ton cask – Certified for CeSOX



insertion test

tungsten shield

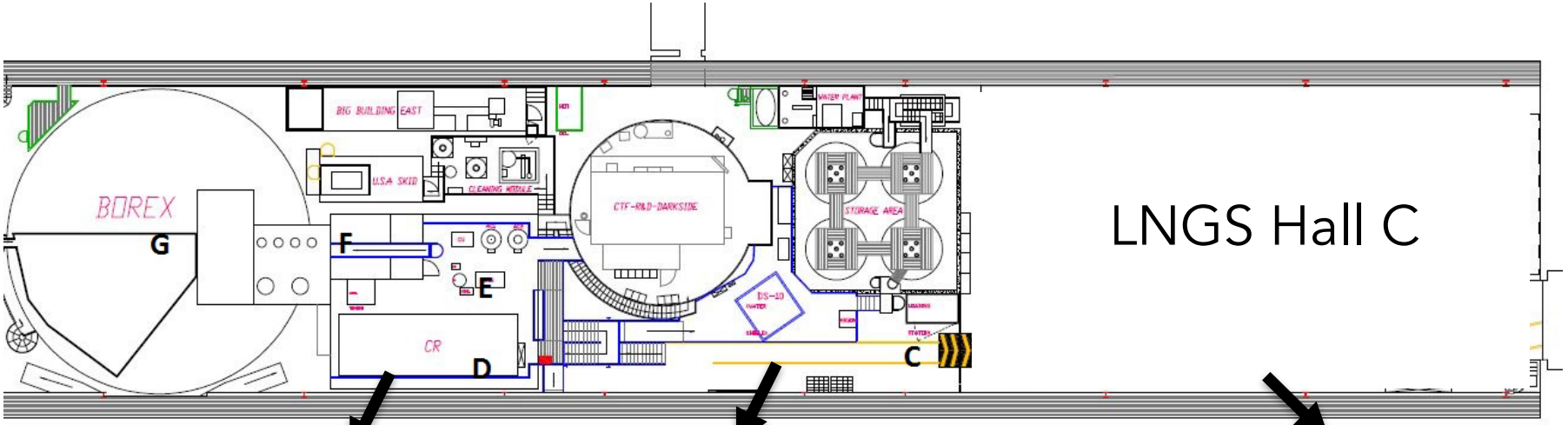
Transportation Routes

Under the responsibility of AREVA & CEA

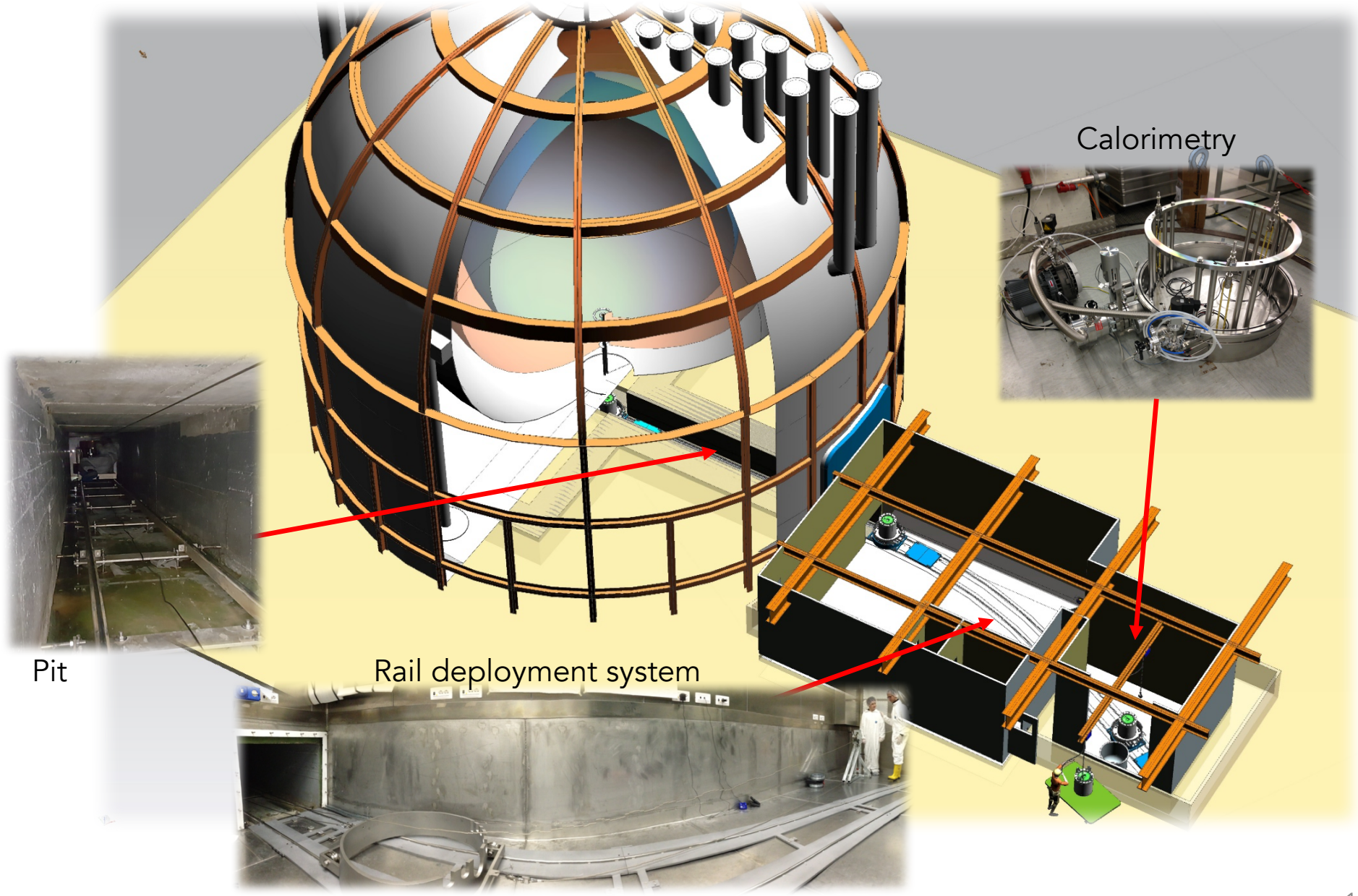
A 3 week journey through Russia (train), France (boat), and Italy (truck)

TN-MTR Cask

Deployment Rehearsal – Oct. 2017



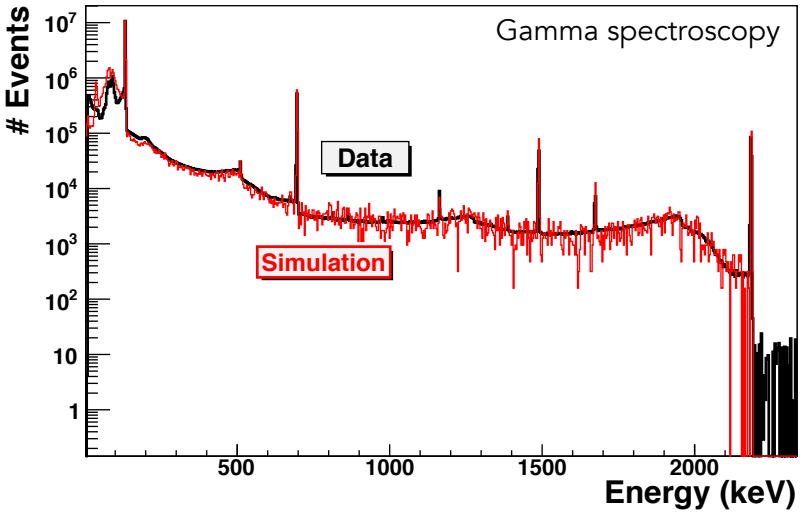
Borexino/SOX Facilities



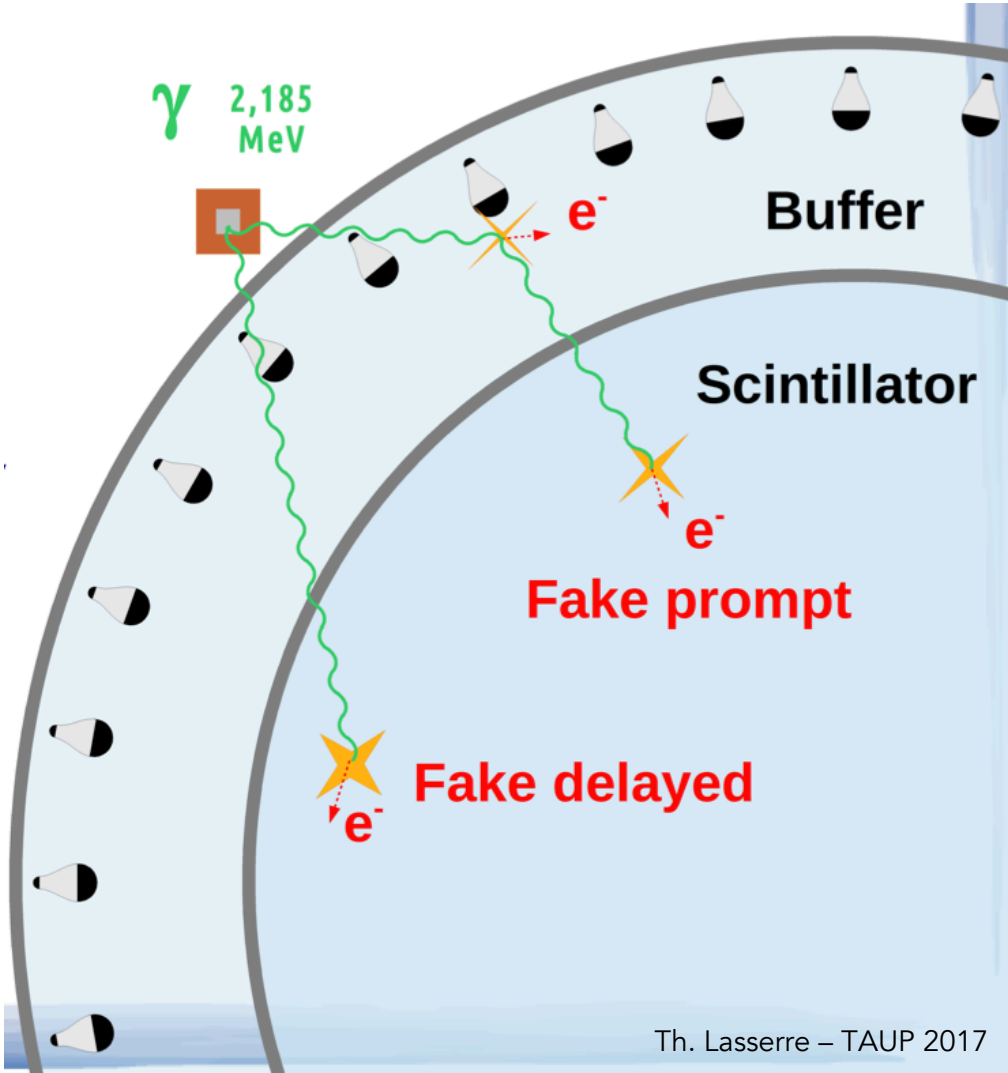
γ Induced Background

- Random coincidence between two γ's from the ^{144}Ce source

- ^{144}Ce pilot production



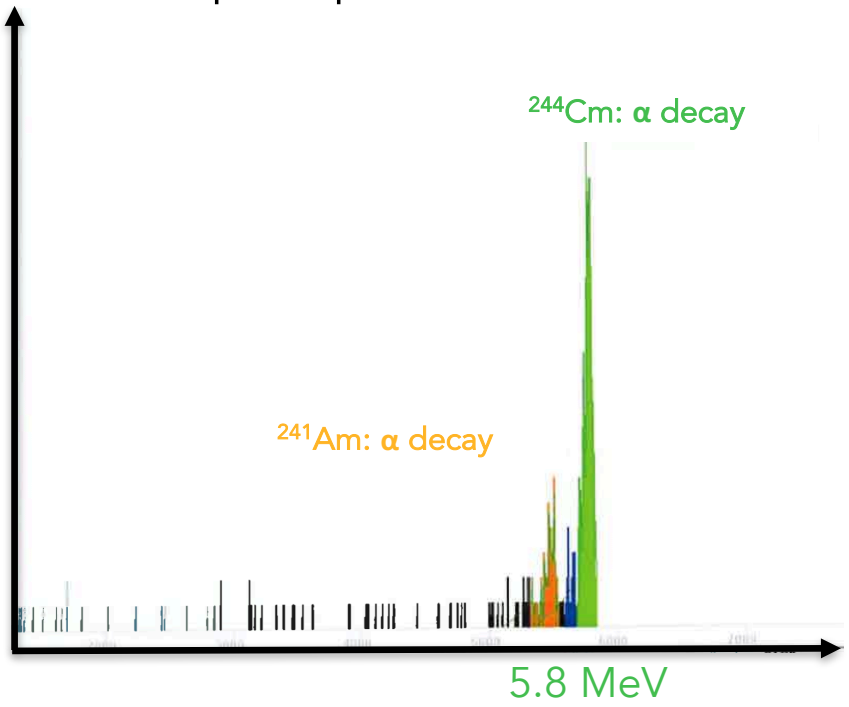
- No impurity at
  < 10^{-4} Bq/Bq of ^{144}Ce
  → negligible



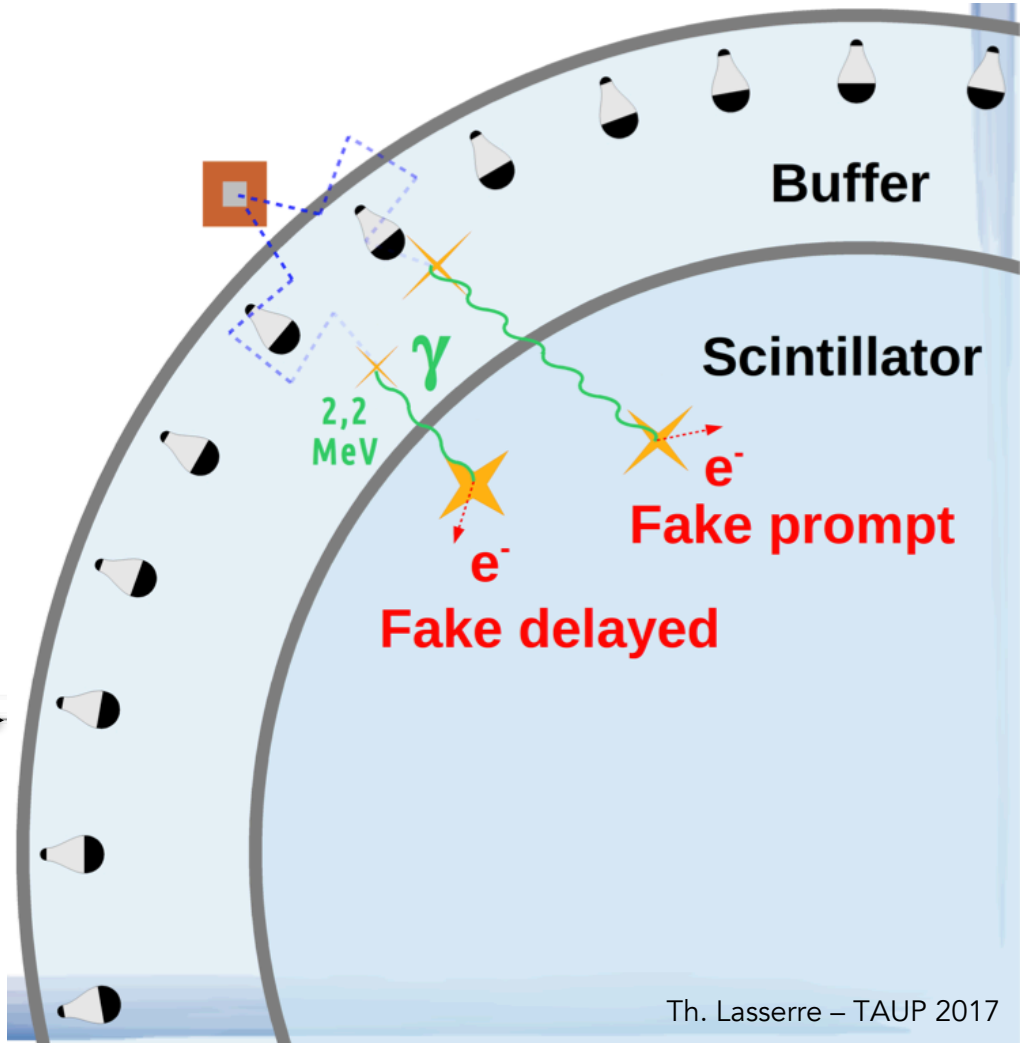
Neutron Induced Background

- Neutrons from spontaneous fission
  → 2 neutron captures → 2 γ's

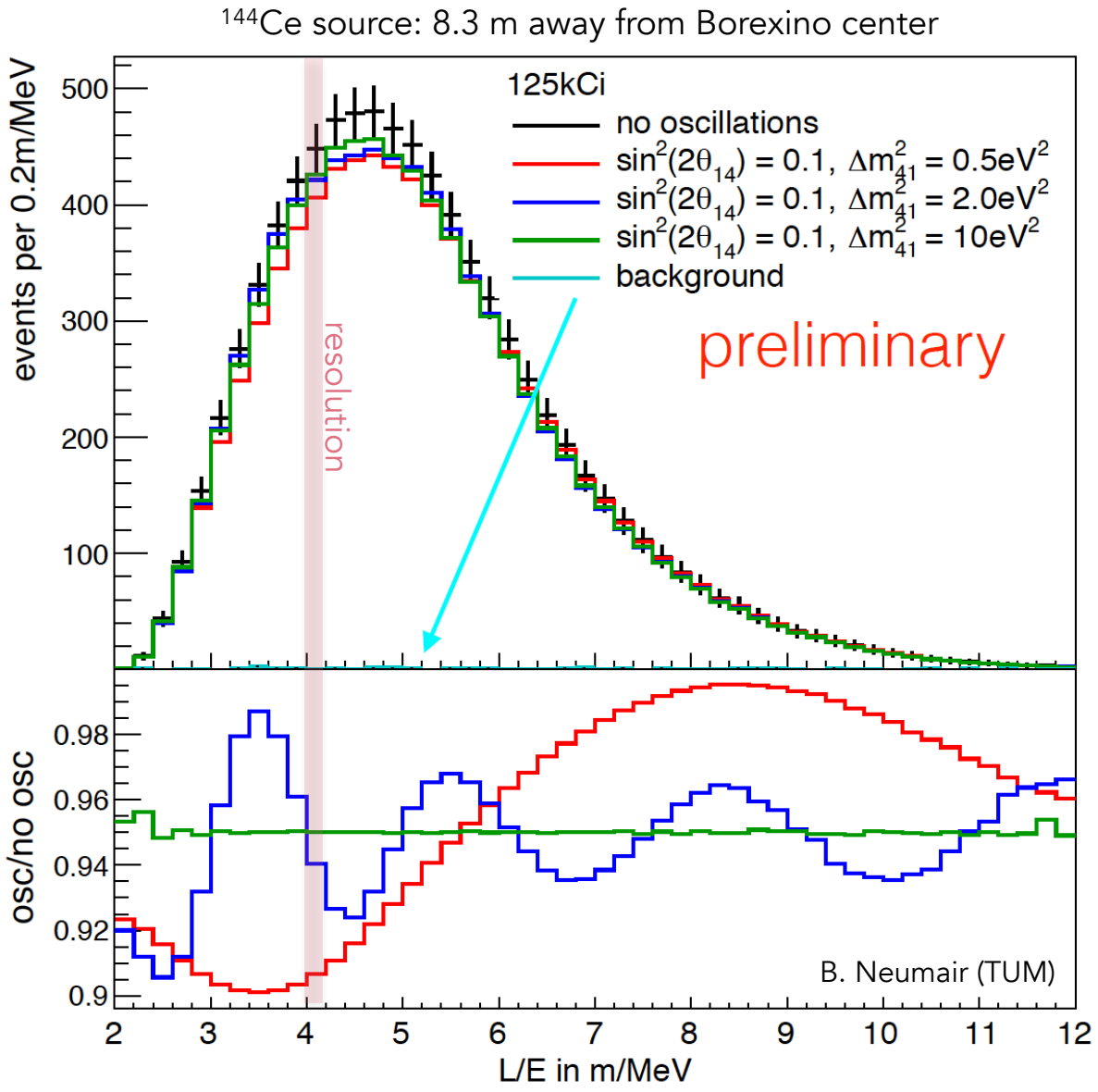
- ^{144}Ce pilot production



- 10^{-5} Bq ^{244}Cm / Bq ^{144}Ce
  → negligible

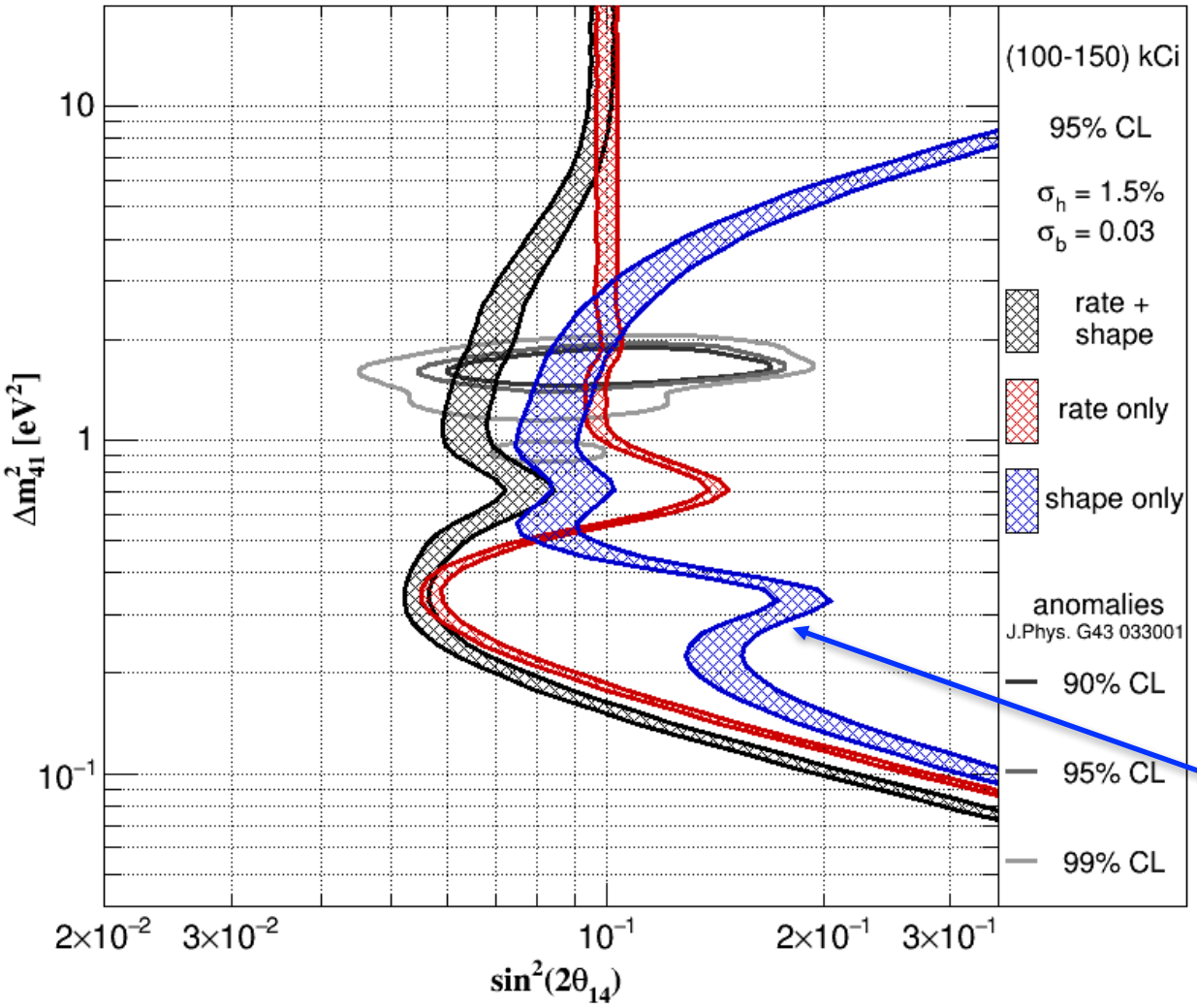


A background free sterile ν search

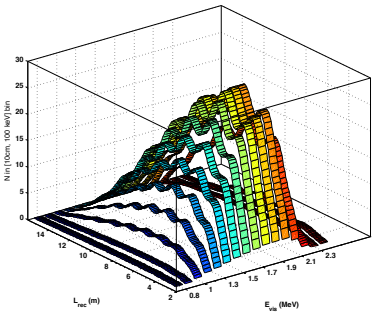


- 270 tons (4m radius)
  1.5 y - 90% efficiency
- ^{144}Ce Signal - 4.6 PBq
  - 8500 ν's
- Backgrounds
  - from detector
    < 50 (data)
  - from ^{144}Ce source
    < 1

"Shape-only" Sensitivity

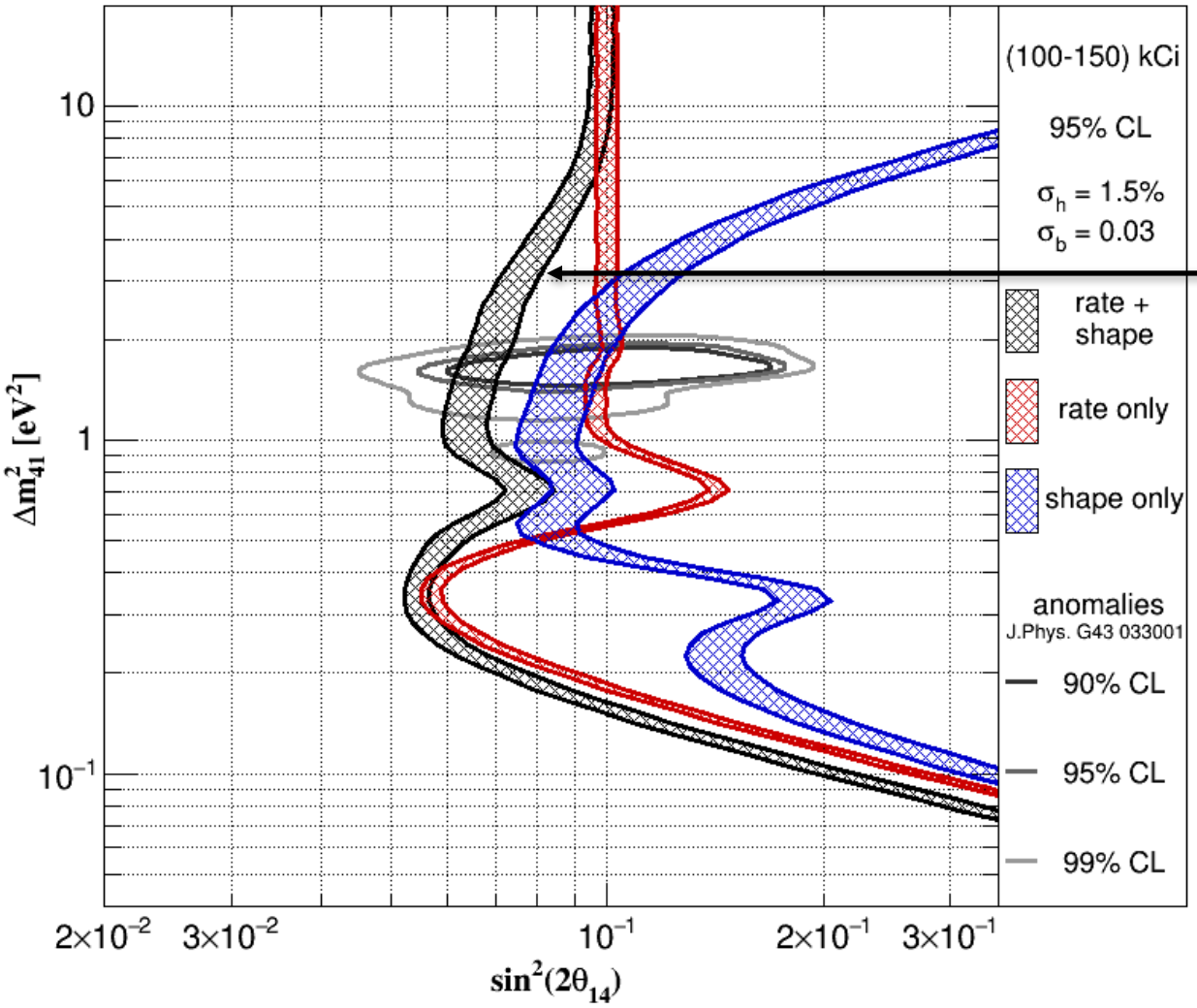


Vertex+Energy reconstruction

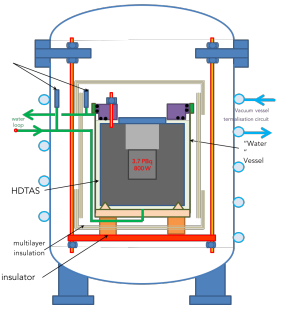


"Rate+Shape" Sensitivity

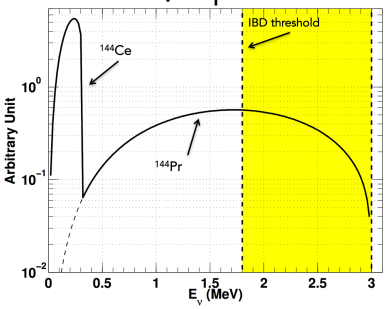
normalization uncertainty: 1.5%



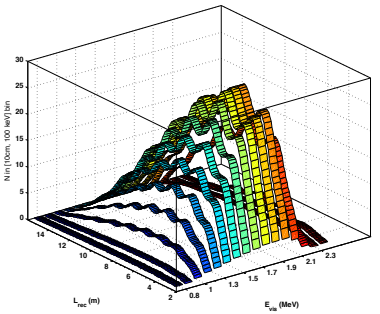
^{144}Ce activity



^{144}Pr β-spectrum



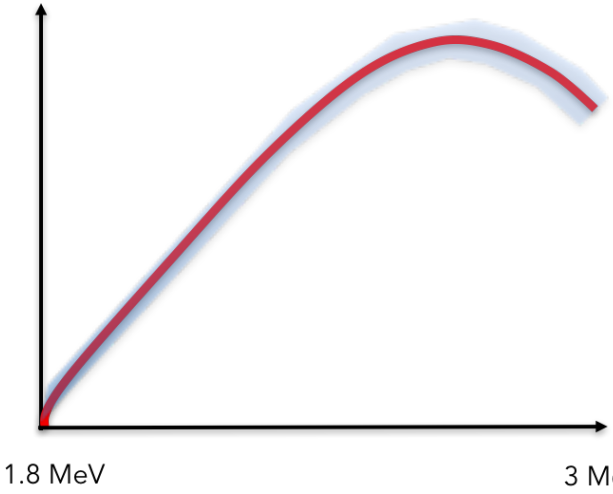
Vertex+Energy reconstruction



Absolute Normalization

^{144}Pr neutrino spectrum

in Borexino



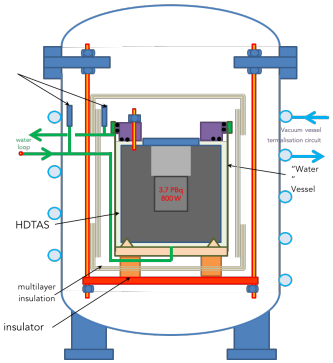
^{144}Ce activity – 0.2%

x ^{144}Pr spectrum – few %

x σ_{ibd} – 0.1 %

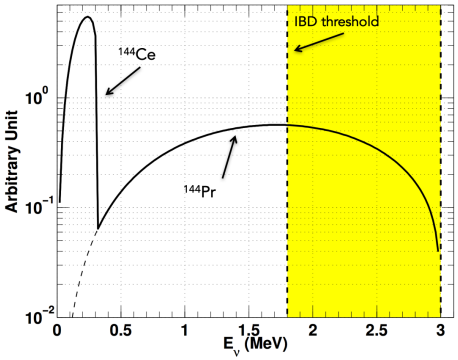
x efficiency – few %

^{144}Ce activity



Calorimetry (W)

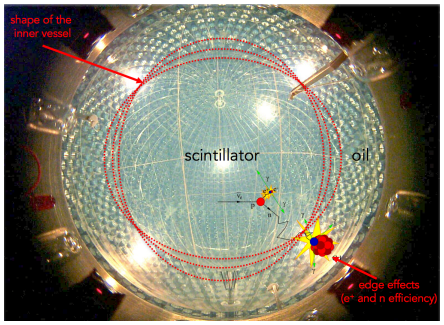
^{144}Pr spectrum



Bq/W conversion

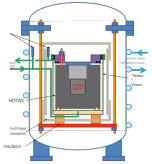
β spectroscopy

detector efficiency



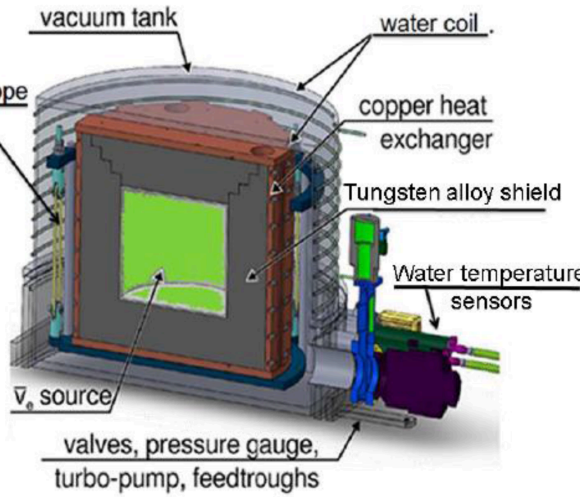
New calibration campaign

Calorimeters

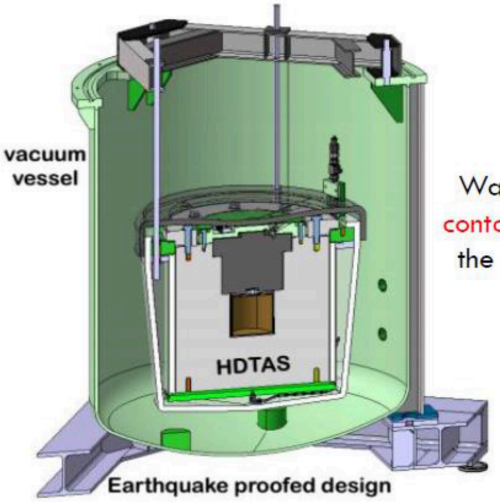


TUM/Genova

Water circulating in a coil embedded in a copper heat exchanger

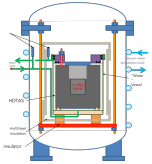


CEA-Saclay

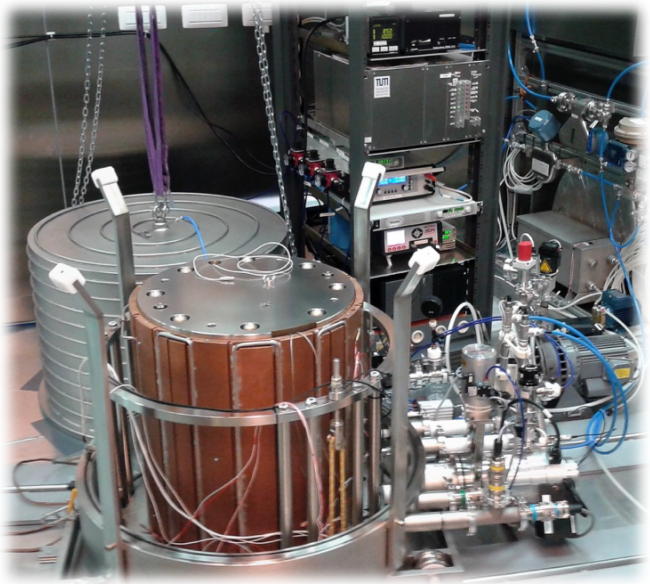


Water at contact with the shield

Calorimeters - Ready

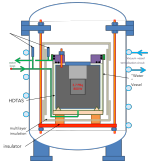


TUM/Genova

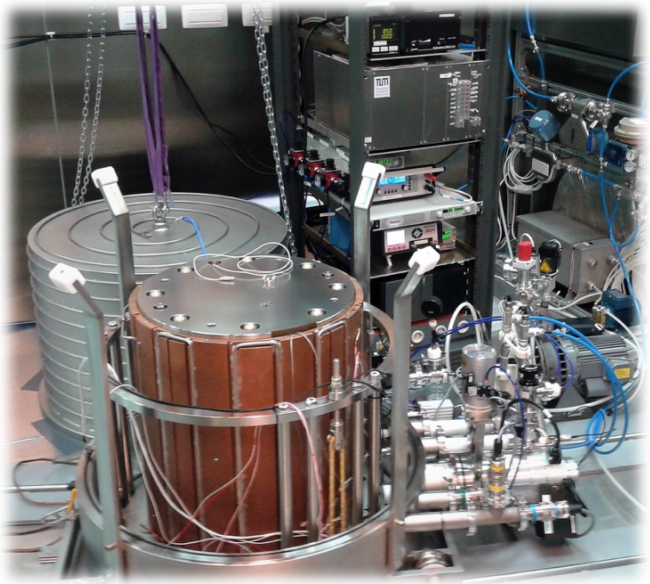


CEA-Saclay

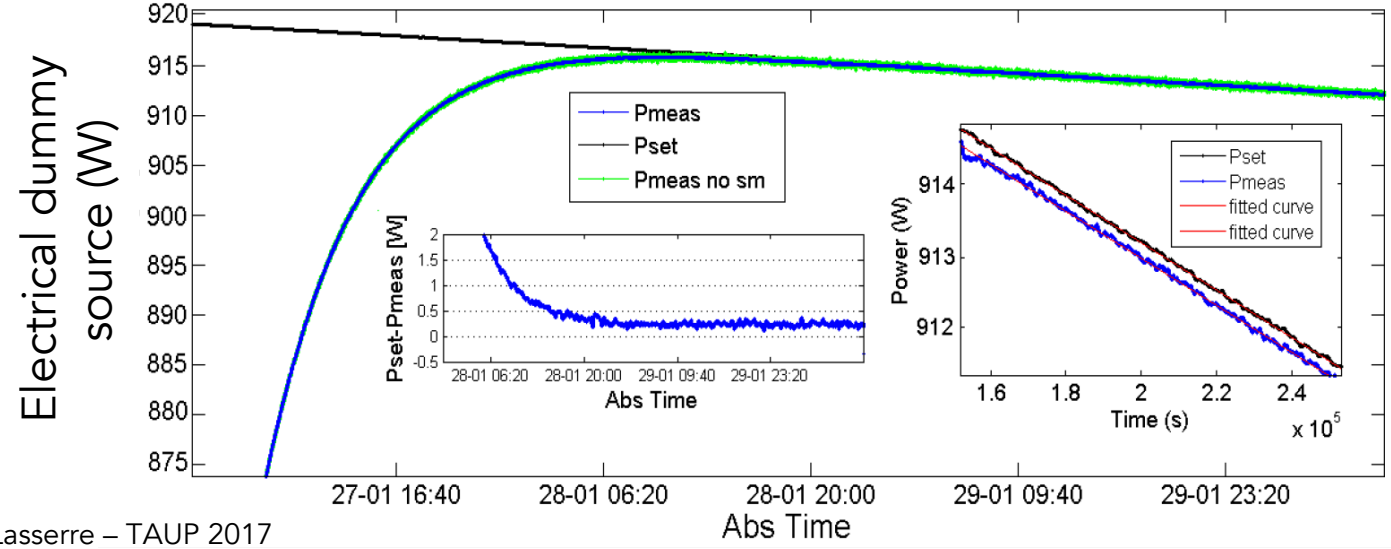
Calorimeters - Ready



TUM/Genova



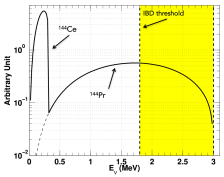
CEA-Saclay



Blind measurement:

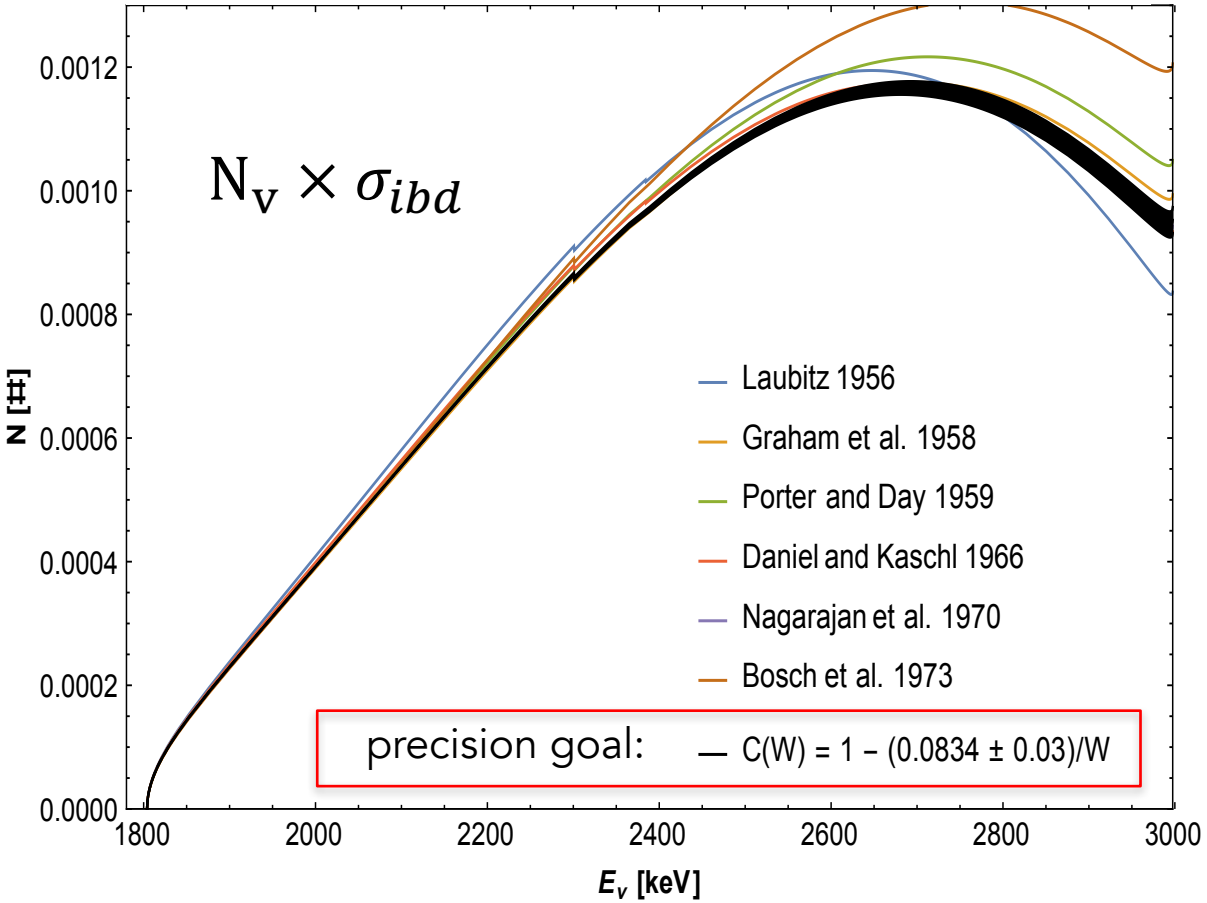
0.3% precision

β spectroscopy – 2017/18

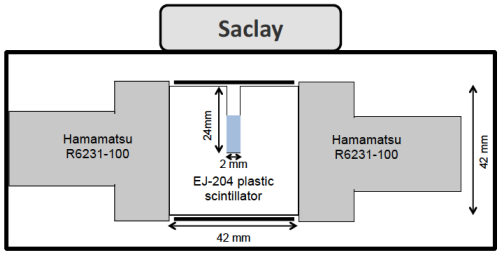


N_ν = Fermi Theory × shape factor C

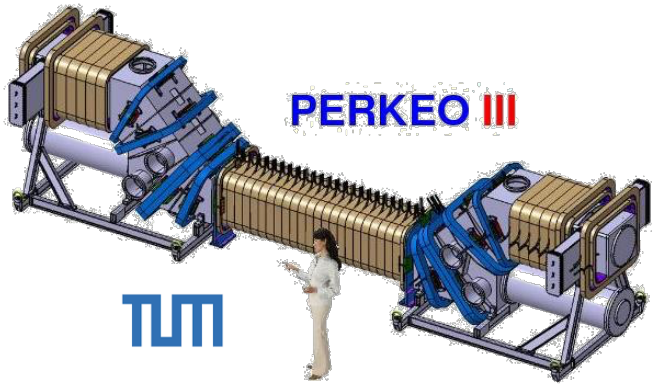
first forbidden non-unique decay



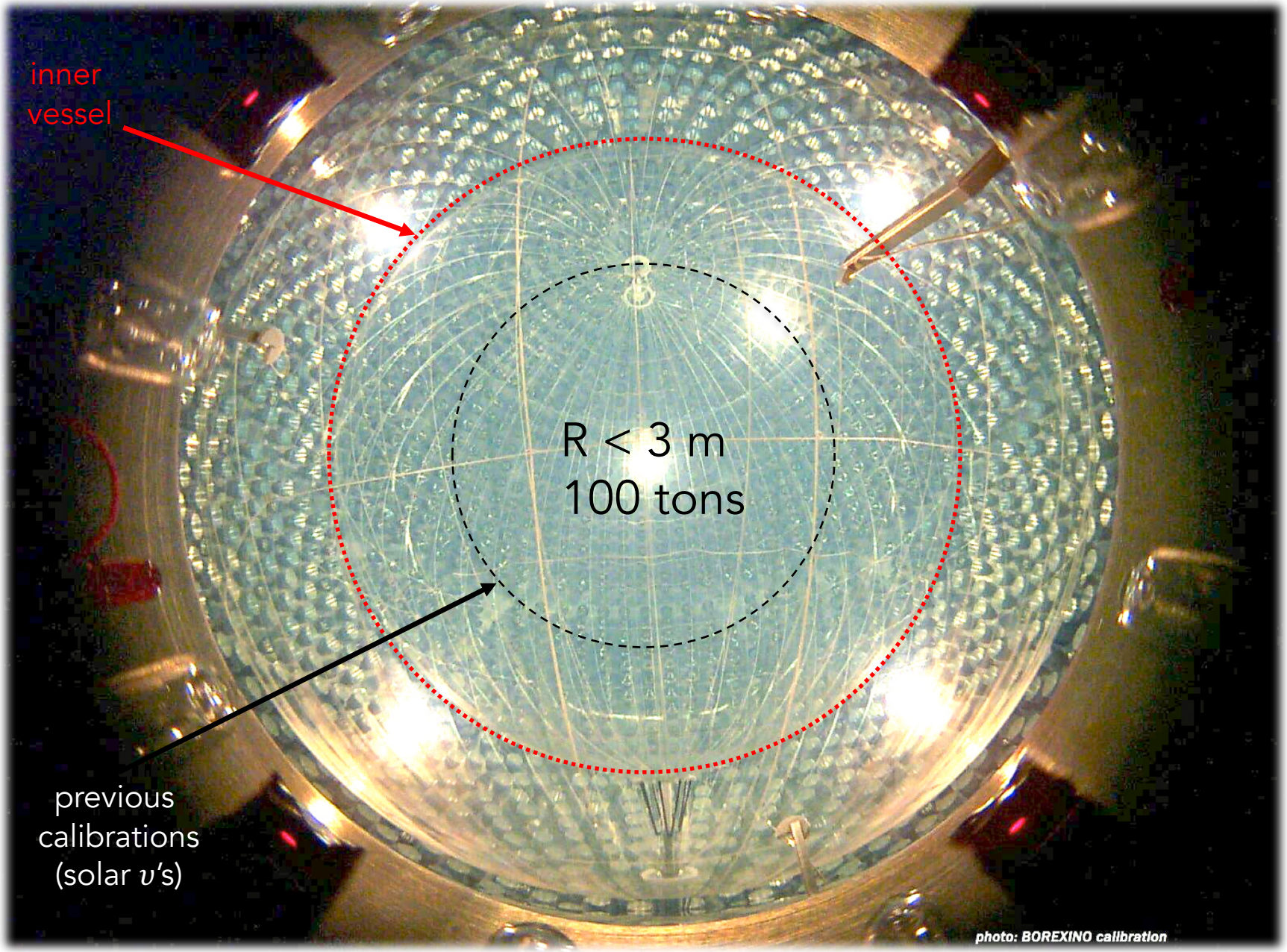
^{144}Pr



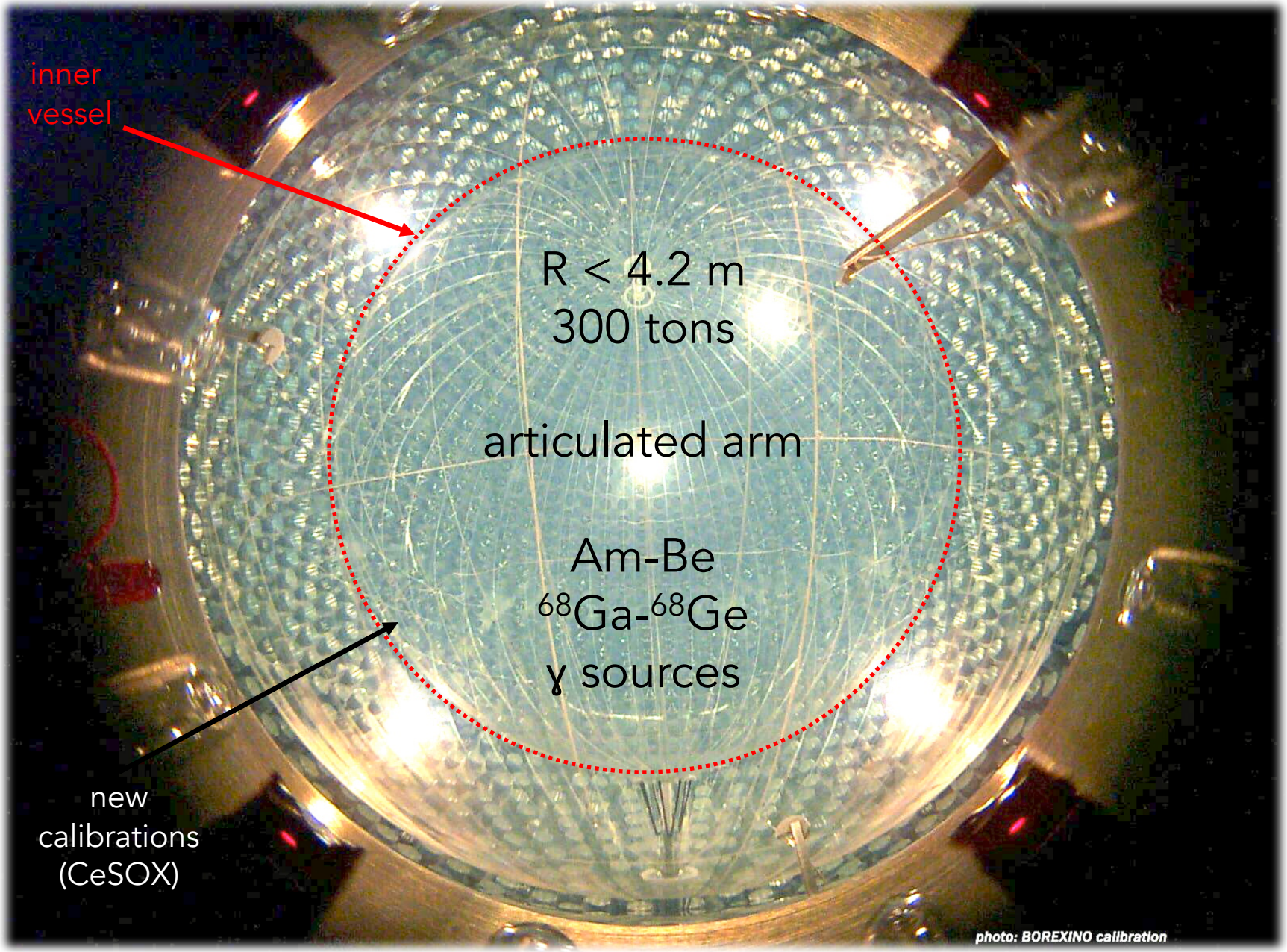
^{144}Ce-^{144}Pr



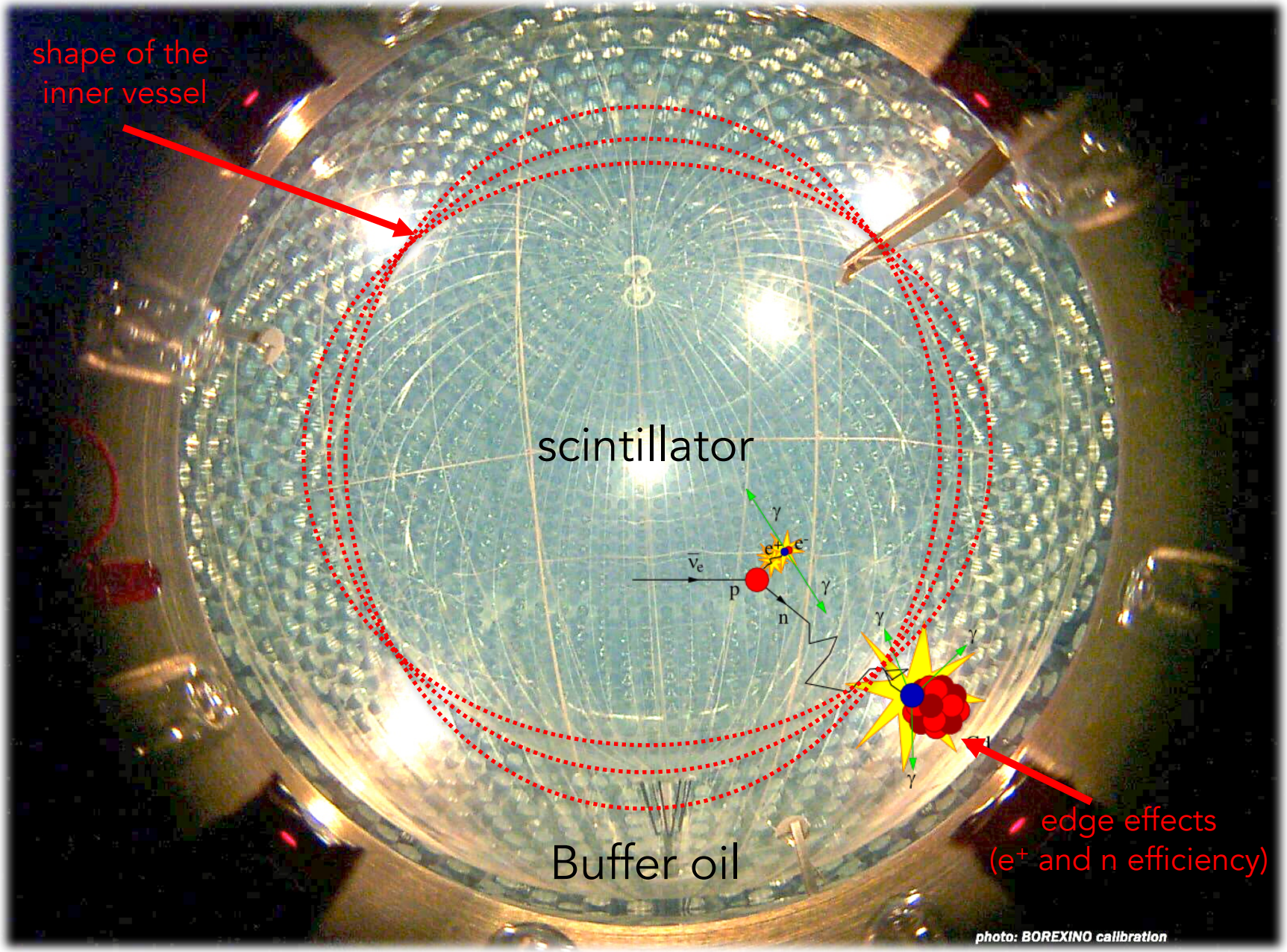
Detector Calibration



New Detector Calibration

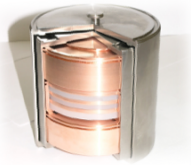


Mapping the SOX Fiducial Volume



CeSOX operational by spring 2018

- ^{144}Ce source in production – at Mayak



- Tungsten shield delivered – at LNGS

- Transport cask & basket ready – at CEA

- Borexino facilities ready – calibration in 2017
- Calorimeters being commissioned – at LNGS

- β-spectrometers under construction

- Many authorizations/certifications required – Underway

Thanks for your attention

Borexino and SOX Collaborations