CeSOX

CSTS SPP
14/11/2014

Th. Lasserre

Double Chooz By-Product

PHYSICAL REVIEW C **83**, 054615 (2011) → **245 citations**

Improved predictions of reactor antineutrino spectra

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(Received 14 December 2010; revised manuscript received 9 March 2011; published 23 May 2011)

PHYSICAL REVIEW D **83,** 073006 (2011) → **374 citations**

Reactor antineutrino anomaly

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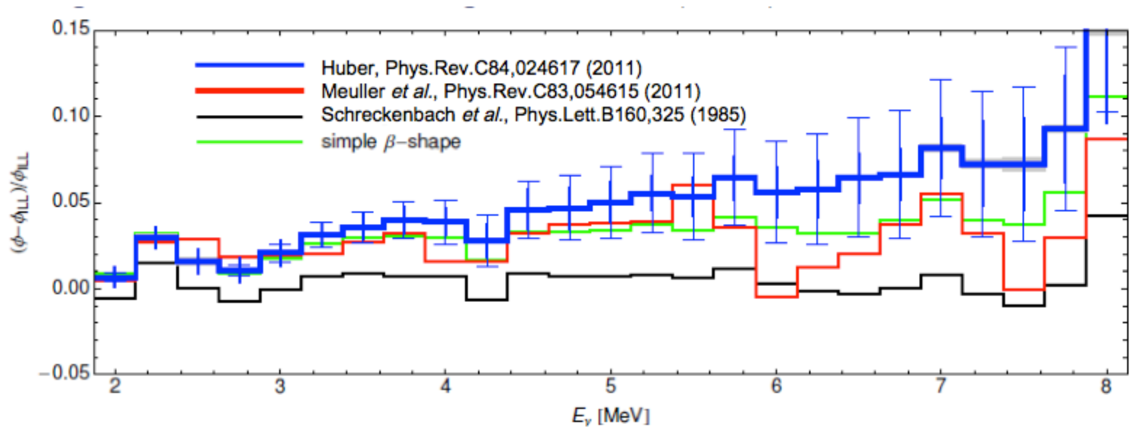
(Received 14 January 2011; published 29 April 2011)

The Reactor Anomaly

i) $\nu_{emission}$: **Improved reactor neutrino spectra → +4%**



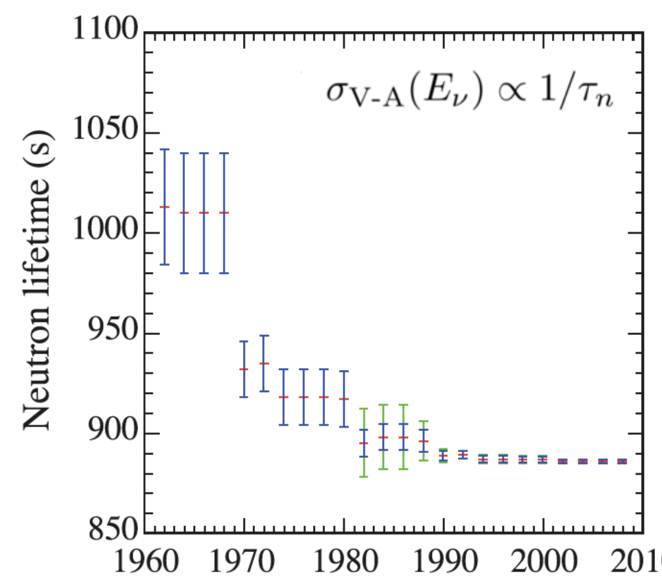
PRC83, 054615 (2011)

PRC84, 024617 (2011)

ii) $\nu_{detection}$: **Reevaluation of σ_{IBD} → +1.5%**

Evolution of the neutron life time

PRD 83, 073006 (2011)

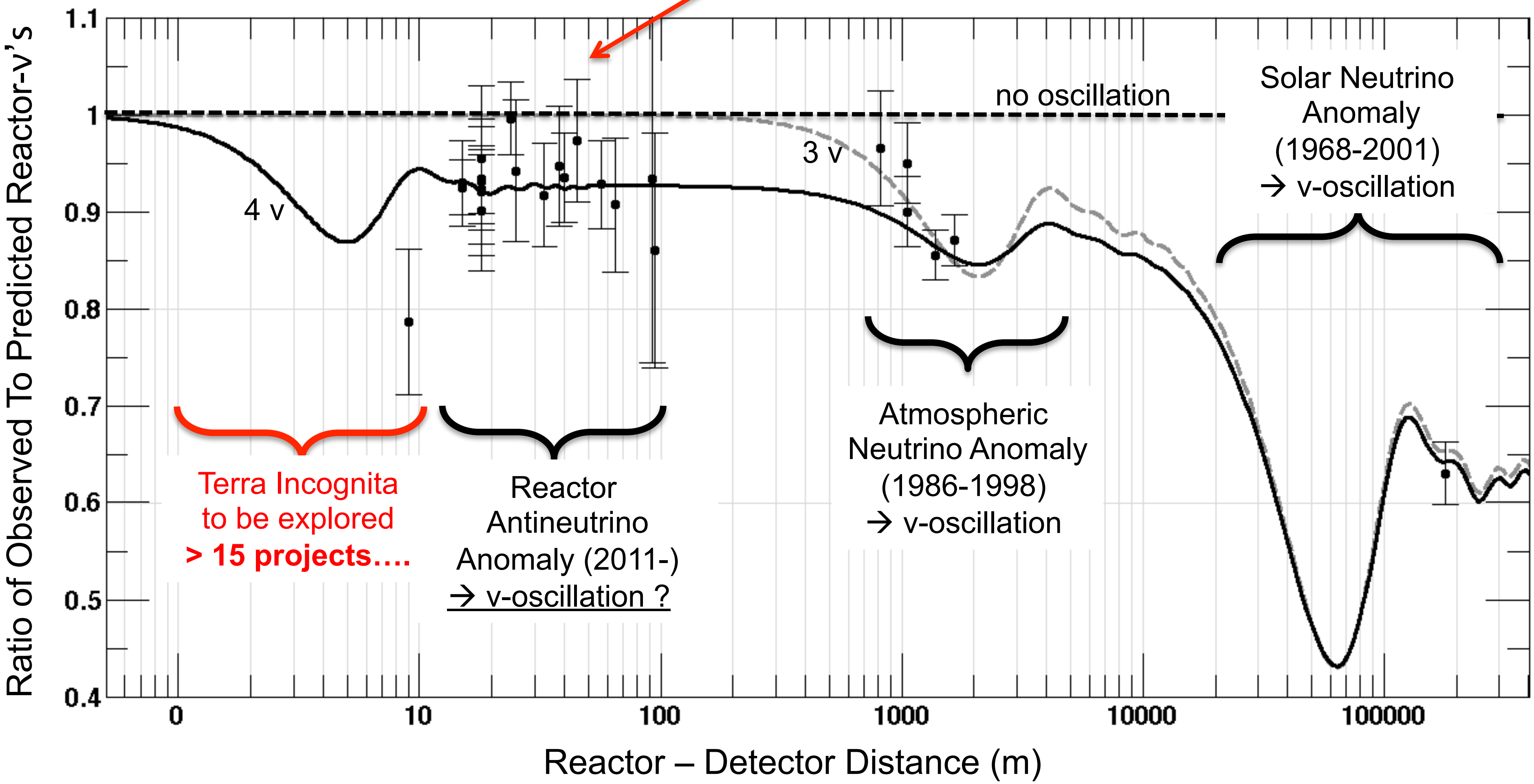


iii) $\nu_{detection}$: **Accounting for long-lived isotopes in reactors → +1%**

PRD 83, 073006 (2011)

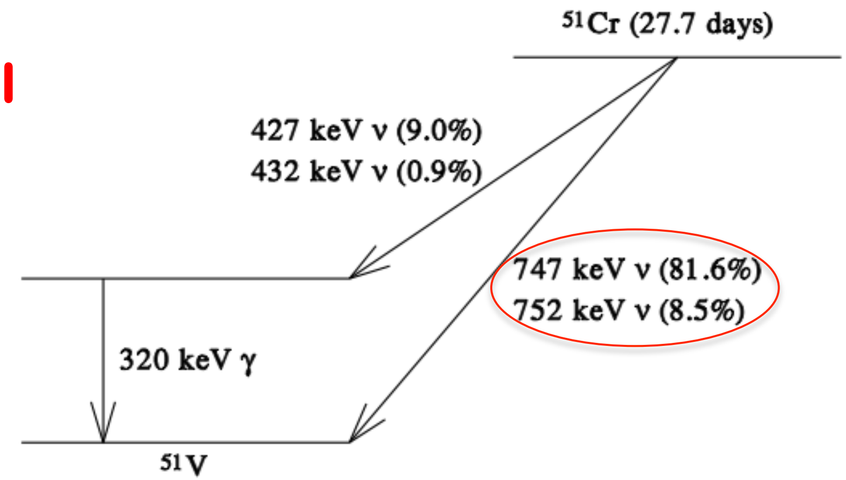
The Reactor Anomaly

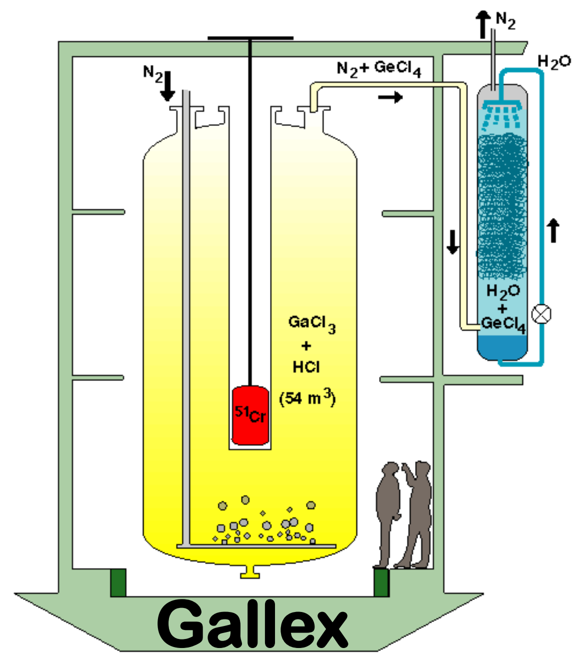
- **Observed/predicted averaged event ratio: R=0.938±0.023 (2.7 σ)**



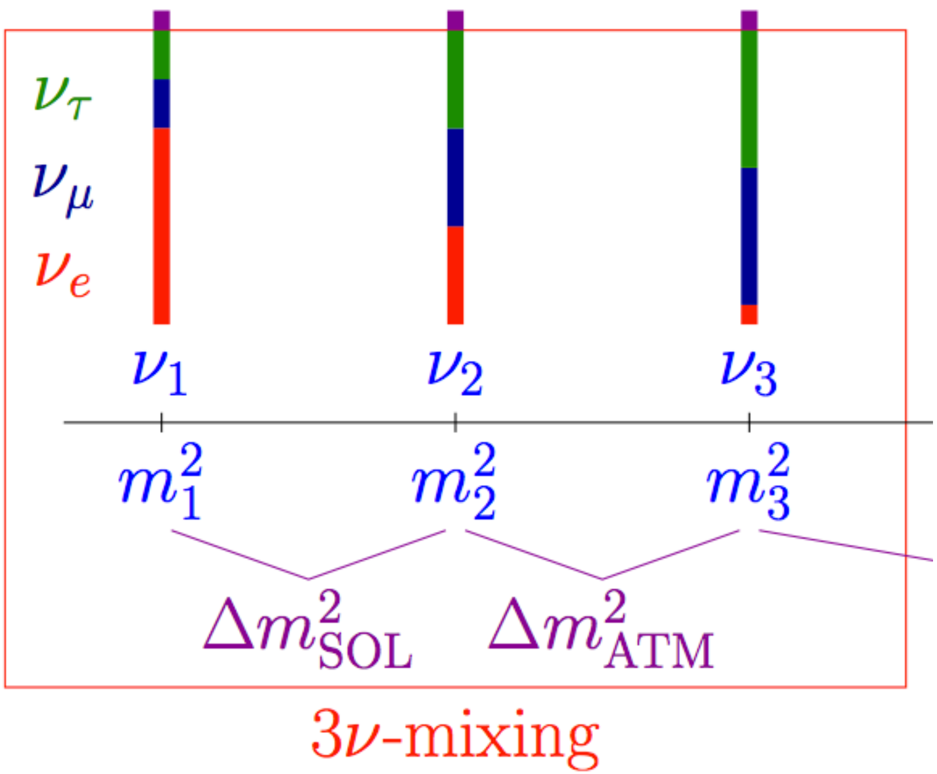
The Gallium Anomaly

- **Test of solar neutrino radiochemical detectors GALLEX and SAGE**
  - $^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$
- **4 calibration runs with 20-60 PBq Electron Capture ν_e emitters**
  - Gallex, <L>=1.9 m
    - ^{51}Cr, 750 keV
  - Sage, <L>=0.6 m
    - ^{51}Cr & ^{37}Ar (810 keV)
- **Deficit observed**
  - 3σ anomaly
  - Supported by new ^{71}Ga (^3He,^3H) ^{71}Ge cross section measurement

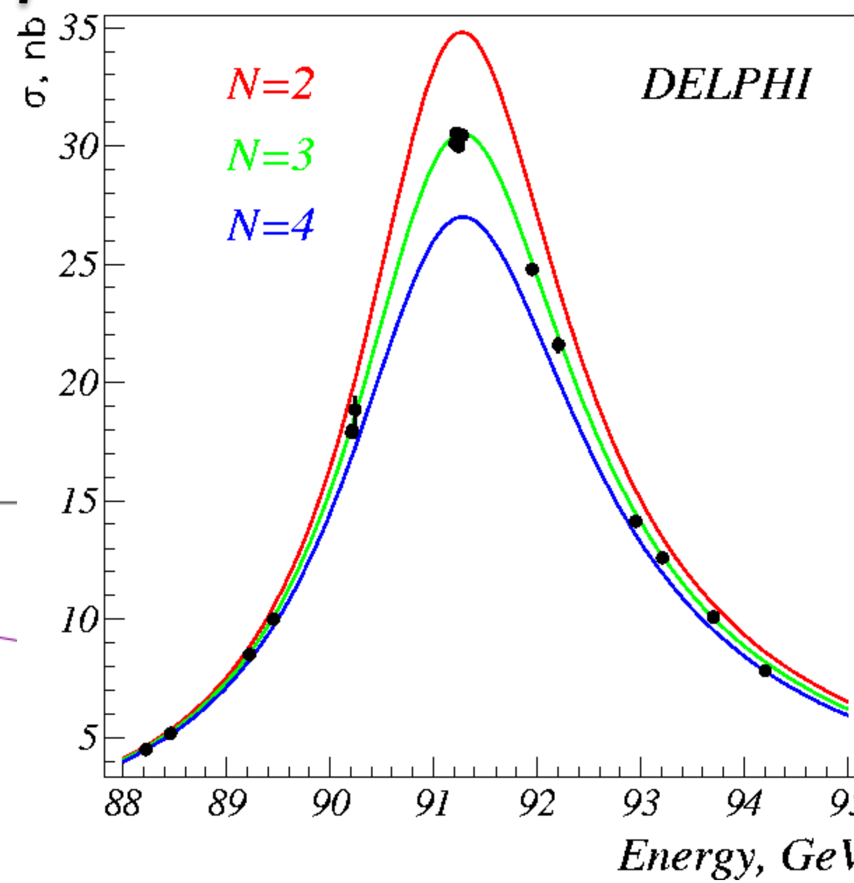




Active Neutrinos

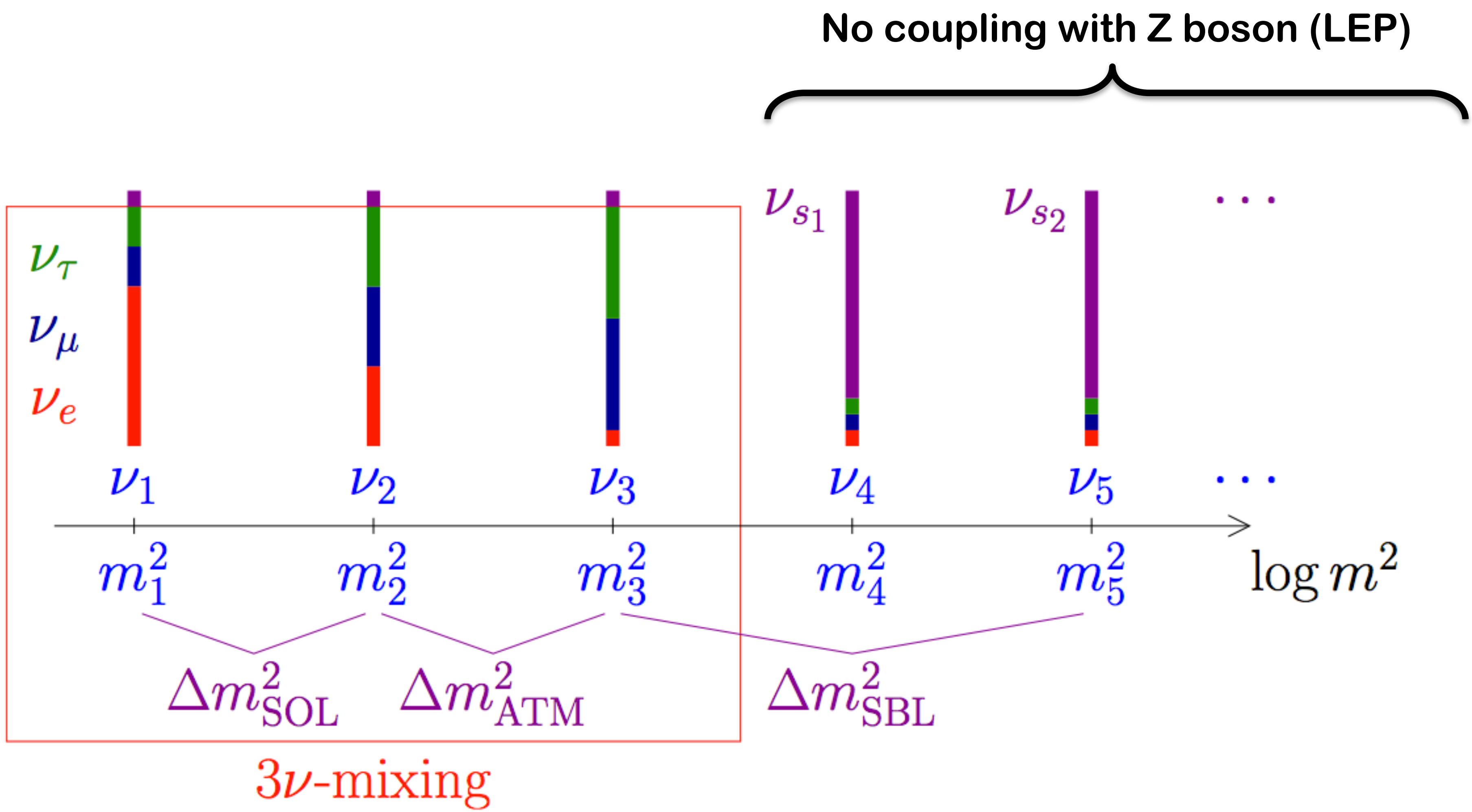


Only 3 light ν's coupling to Z boson



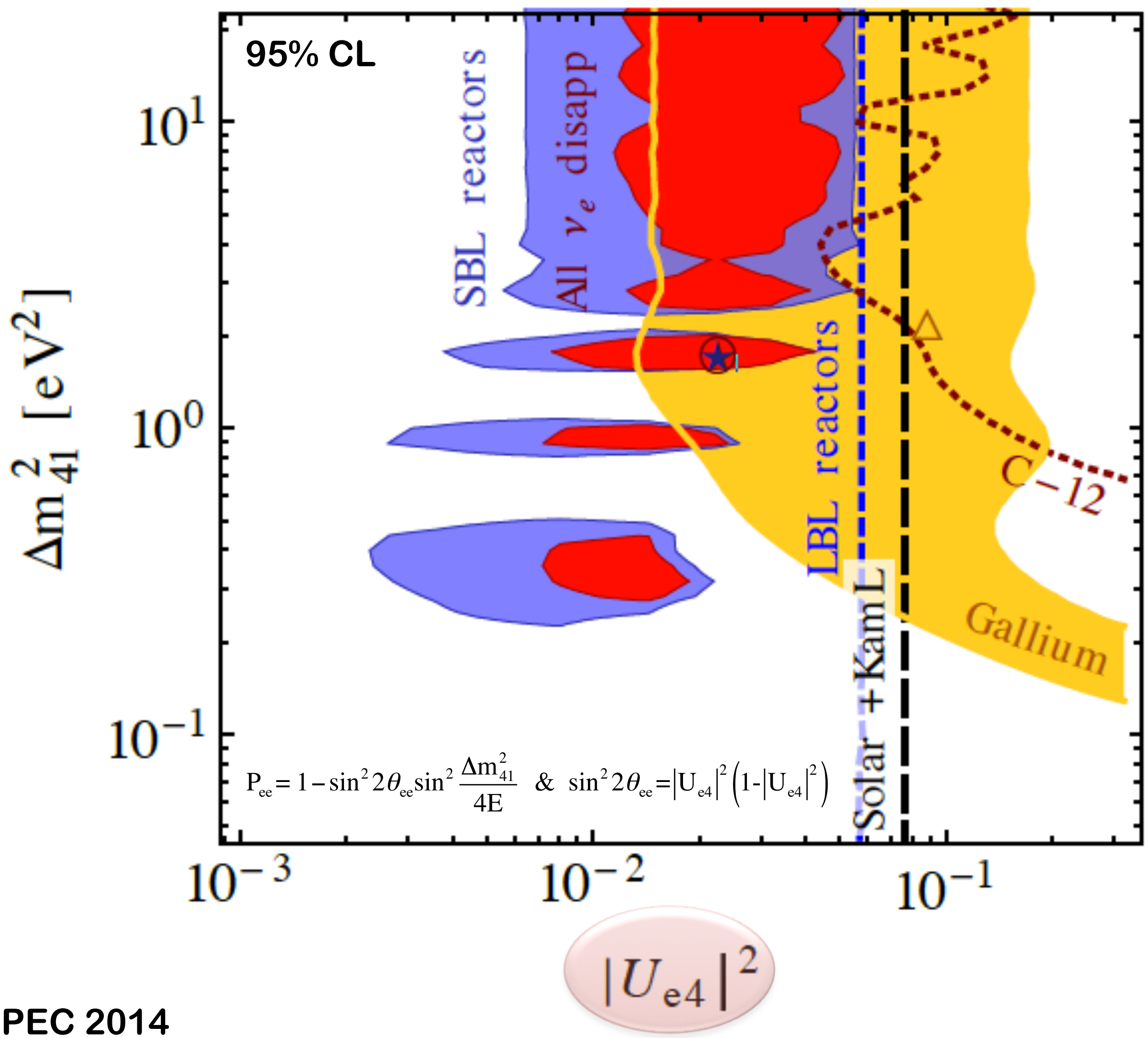
Adding Sterile Neutrinos

But maybe light ν_R? No SM interactions. Mixing with active ν' s



$\overset{(-)}{\nu}_e$ disappearance (3+1)

Data consistent with $\overset{(-)}{\nu}_e$ disappearance at L/E≈1 m/MeV



J. Kopp et al., arXiv:1303.3011

Anomalous & Regular Results

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	$\nu_\mu \rightarrow \nu_e$	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

CeSOX: Concept

^{144}Ce-^{144}Pr to search for a 4th ν

PRL **107,** 201801 (2011) PHYSICAL REVIEW LETTERS week ending 11 NOVEMBER 2011

Proposed Search for a Fourth Neutrino with a PBq Antineutrino Source

Michel Cribier,[1,2] Maximilien Fechner,[1] Thierry Lasserre,[1,2,*] Alain Letourneau,[1] David Lhuillier,[1] Guillaume Mention,[1] Davide Franco,[2] Vasily Kornoukhov,[3] and Stefan Schönert[4]

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(Received 12 July 2011; published 7 November 2011)

Several observed anomalies in neutrino oscillation data can be explained by a hypothetical fourth neutrino separated from the three standard neutrinos by a squared mass difference of a few eV^2. We show that this hypothesis can be tested with a PBq (ten kilocurie scale) ^{144}Ce or ^{106}Ru antineutrino beta source deployed at the center of a large low background liquid scintillator detector. In particular, the compact size of such a source could yield an energy-dependent oscillating pattern in event spatial distribution that would unambiguously determine neutrino mass differences and mixing angles.

DOI: 10.1103/PhysRevLett.107.201801 PACS numbers: 14.60.Lm, 14.60.Pq, 14.60.St

→ Funding through ERC-2012-StG 307184

Testing $\overset{(-)}{\nu}_e$ disappearance anomalies

- GA & RAA : comparison between data and event prediction
  - Search for L, E, L/E pattern (shape only)
  - Complement with a rate analysis

- Input from Sterile Neutrino Fits
  - $\Delta m^2 \approx 0.1\text{-}10\ eV^2 \rightarrow\ L_{osc}(m) = 2.5 \frac{E(MeV)}{\Delta m^2(eV^2)} \approx 1-10\ m$
  - $\sin^2(2\theta_{new}) \approx 0.01 - 0.2$

- Experimental Specifications
  - $\Delta m^2 \approx eV^2$: compact source << 1m & vertex resolution << 1m
  - $\sin^2(2\theta_{new})$: experiment with few % stat. syst. uncertainties

ν Generator Proposals

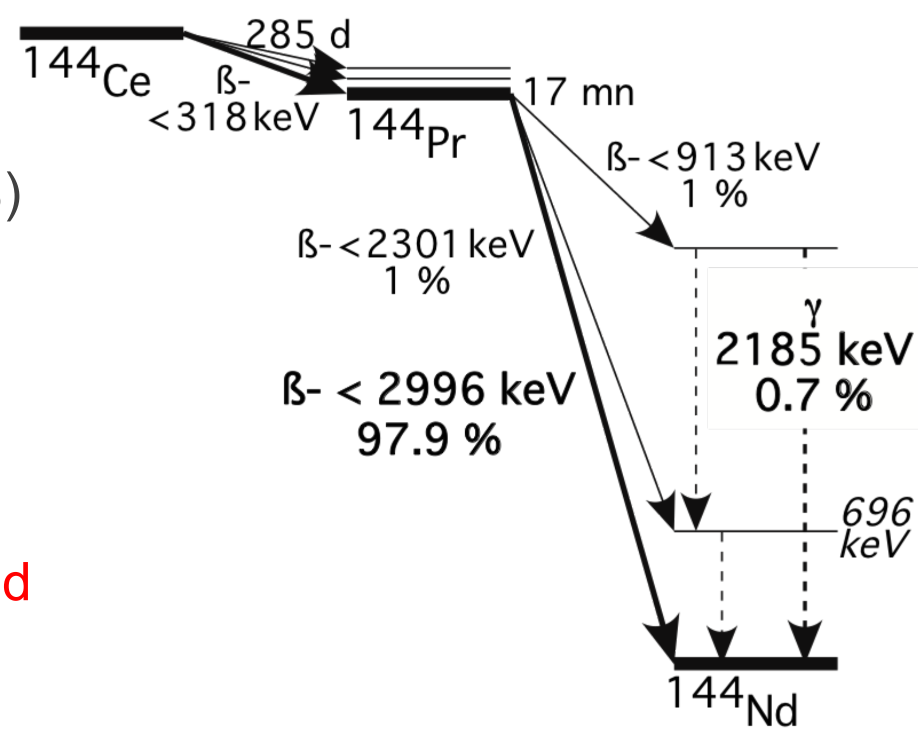
Type	Detection	Background	Isotope	Production	Activity	Projects
ν_e	$\nu_e e \rightarrow \nu_e e$ 5% E_{res} 15cm R_{res} or Radio-chemical	Detector Radioactivity Solar ν (irreducible) ν generator impurities	^{51}Cr 0.75 MeV $t_{1/2}$=26d	n_{th} irradiation in Reactor	>110 PBq	Sage LENS
					>370 PBq	CrSOX (SNO+)
			^{37}Ar 0.8 MeV $t_{1/2}$=35d	n_{fast} irradiation in Reactor (breeder)	>37 PBq	-
					185 PBq	Ricochet
$\bar{\nu}_e$	$\bar{\nu}_e p \rightarrow e^+ n$ E_{th}=1.8 MeV (e^+,n) 5% E_{res} 15cm R_{res}	reactor ν, geo ν, ν generator impurities	^{144}Ce E<3MeV $t_{1/2}$=285d	spent nuclear fuel reprocessing + REE extraction	3.7-5 PBq	CeLAND CeSOX
					18.5 PBq	Daya-Bay
			^{90}Sr ^{106}Rh		-	-
	$^3H \rightarrow He\ e^- \bar{\nu}_e$ EC/β-decay	Kink search	^3H E<18 keV	Irradiation in reactors	110 GBq	KATRIN (Mare/Echo)

Antineutrino Source: ^{144}Ce-^{144}Pr

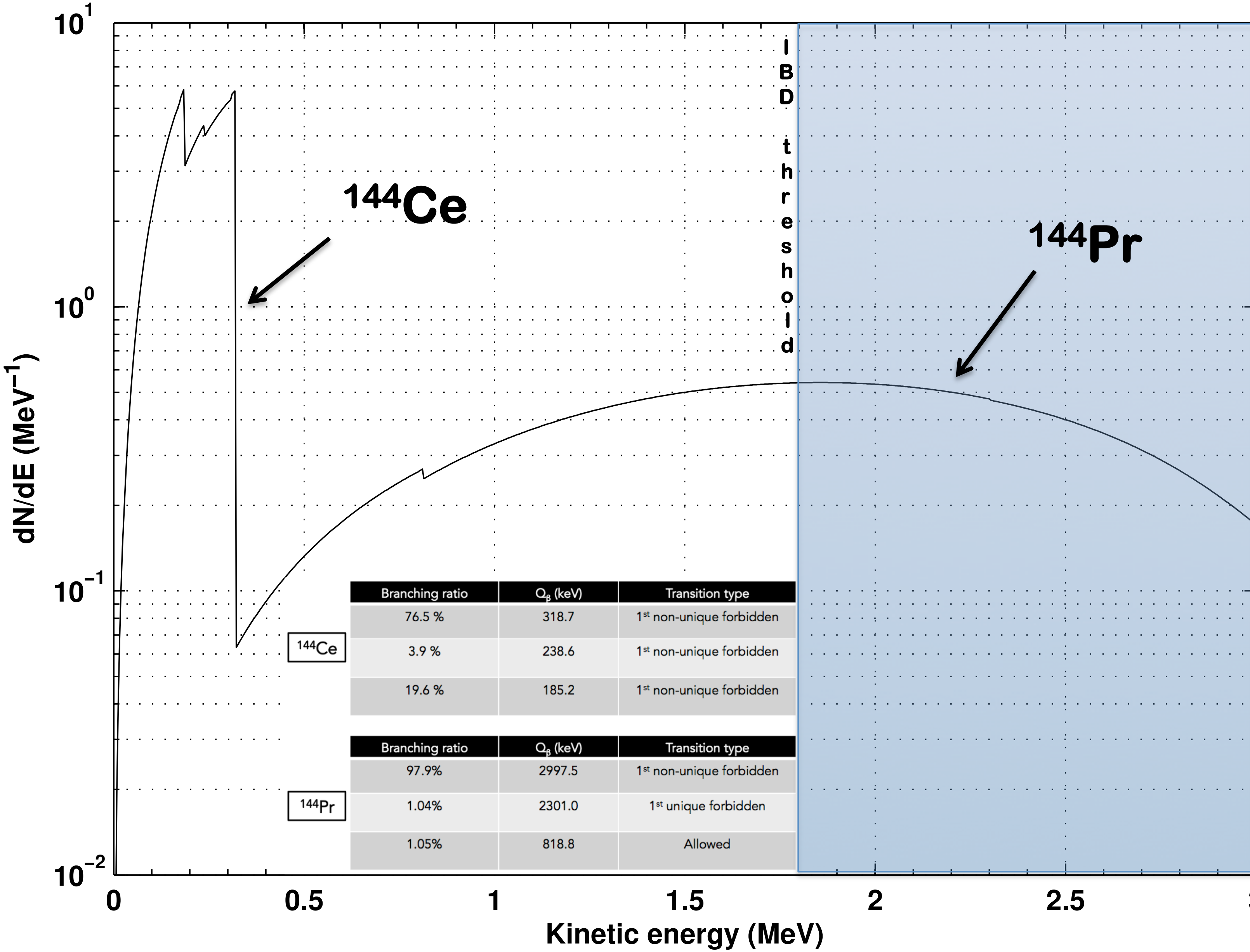
(ITEP N°90 1994, PRL 107, 201801, 2011)

- $\bar{\nu}_e$ **source detected via** $\bar{\nu}_e + p \rightarrow e^+ + n$ **(Q=1.8 MeV)**
  - **High IBD cross section → 3.7 – 5 PBq activity**
  - **(e^+,n) detected in coincidence → low backgrounds**

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



^{144}Ce-^{144}Pr ν Spectra



^{144}Ce

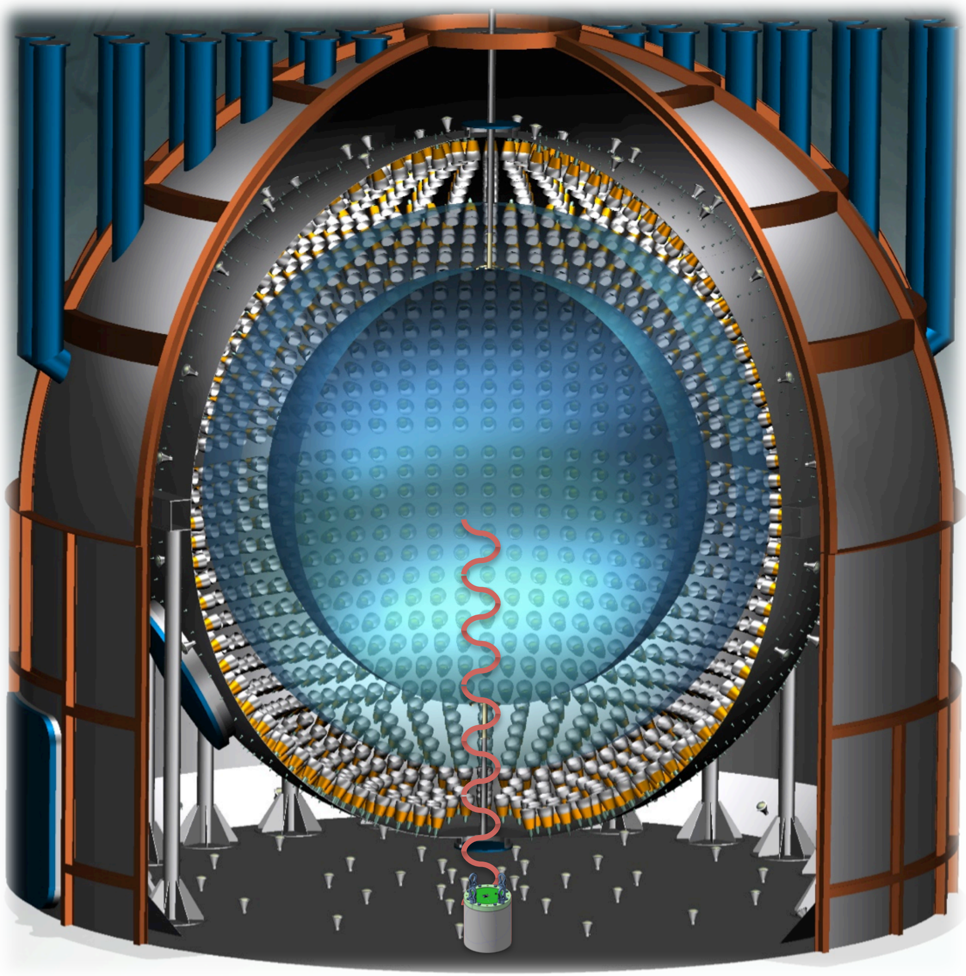
Branching ratio	Q_β (keV)	Transition type
76.5 %	318.7	1st non-unique forbidden
3.9 %	238.6	1st non-unique forbidden
19.6 %	185.2	1st non-unique forbidden

^{144}Pr

Branching ratio	Q_β (keV)	Transition type
97.9%	2997.5	1st non-unique forbidden
1.04%	2301.0	1st unique forbidden
1.05%	818.8	Allowed

Oscillometry in BOREXINO

Search for an oscillation pattern inside LS target
Compare observed to expected ν rate



Experimental layout

- Radioactive ν source in tunnel below the detector (d=8.3 m)

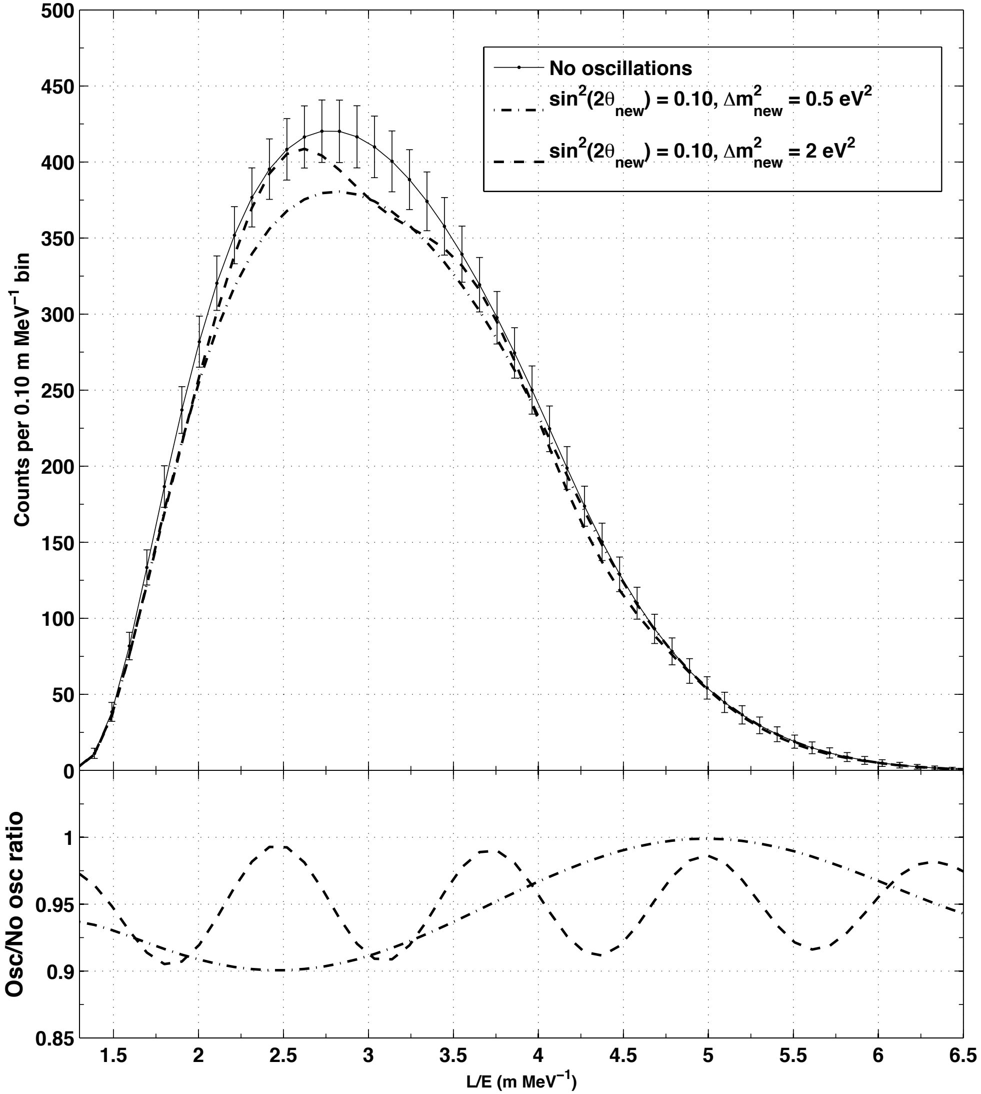
Detector Specifications (1 MeV)

- Energy resolution: 5%
- Vertex resolution: 15 cm

Antineutrino Generator

- ^{144}Ce/Pr β^- E_ν < 3 MeV
- 3.7 – 5 PBq
- Exposure: 1.5 yrs
- Fiducial mass: 280 tons
- Events (1.5yrs) ~10^4

Expected $\nu_e \rightarrow \nu_s$ Oscillation Signal



- ^{144}Ce-^{144}Pr: 3.7 PBq
- No background
- 8.3 m from Bx Center
- Fiducial volume
  - R<4.25 m
  - 280 tons – #H: 1.7 10^{31}
- Vertex resolution: 15 cm
- Energy resolution: 5%
- IBD expected: 10000/1.5y

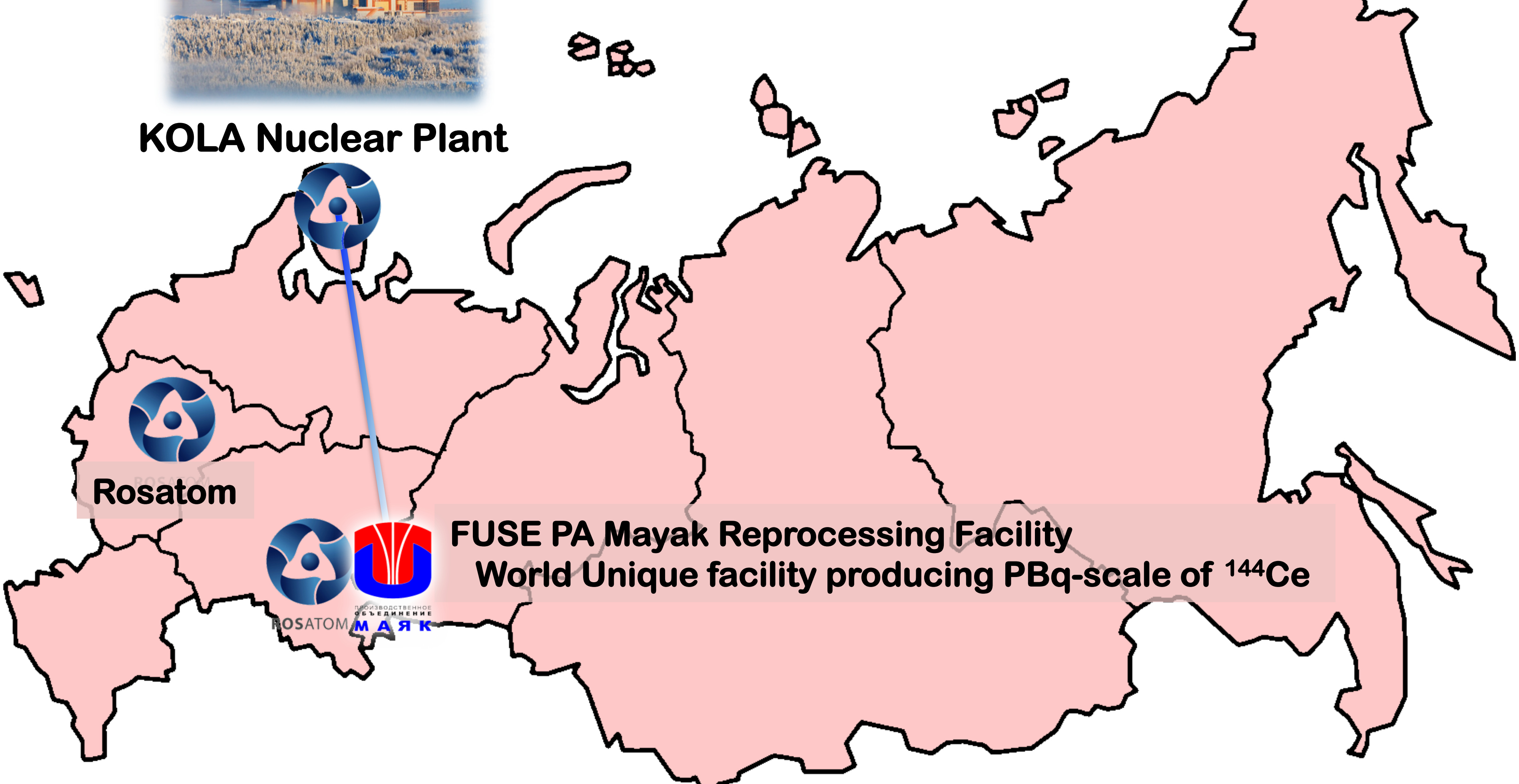
^{144}Ce-^{144}Pr Antineutrino Generator (CeANG) Production

CeANG: Specifications

- ß activity (in ^{144}Ce)
  - Between 3.7 and 5.5 PBq
- Extracted from fresh spent nuclear fuel (<2 years)
- Chemical form : cerium oxyde CeO_2
- Density : between 4 and 6 g/cm^3

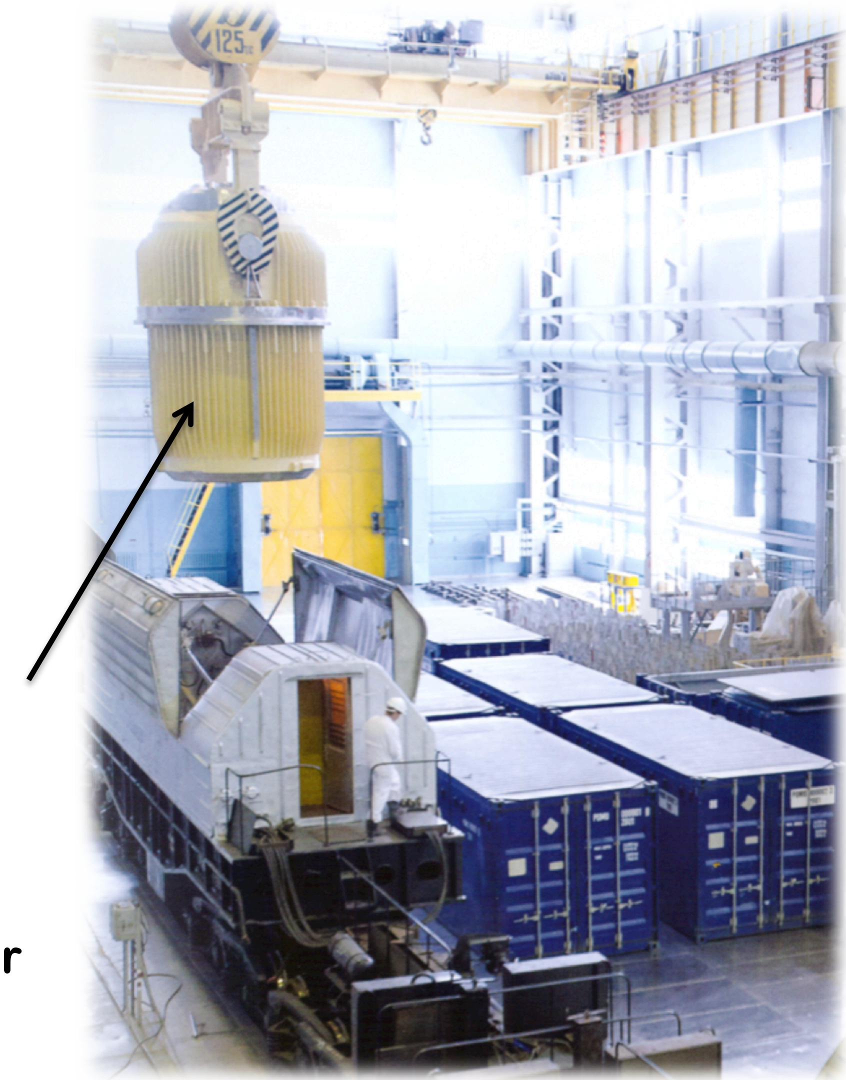
- Fitting inside a D:H=15:15 cm double capsule of Special Form of Radioactive Material (SFRM, IAEA regulation)
- Purity data from ^{147}Pm production line
  - Content of any others RE (*γ-emitters*) in *Ce* $\leq 10^{-3}$ Bq/Bq
  - Content of Pu and TPE (*n emitters*) in Ce $\leq 10^{-5}$ Bq/Bq

Russian Institutions & Facilities



Spent Nuclear Fuel

- ^{144}Ce: 5.5% / 3.7% in the fission products of U / Pu
- ^{144}Ce: 411 d half-life. 3 years after last irradiation
  - m(^{144}Ce)/m(all Ce) = 1 / 130
- Selection of best SNFE at Cola NPP (fresh fuel)
  - 5 tons – 1.7 y cooling
  - 66 Ci/g of Ce isotopes
- Delivery of SNF from Cola NPP to FSUE "Mayak" PA (3000 km)
  - TUK-6 container
- PA Mayak will receive fresh fuel for ^{144}Ce prod. in Feb. 2015

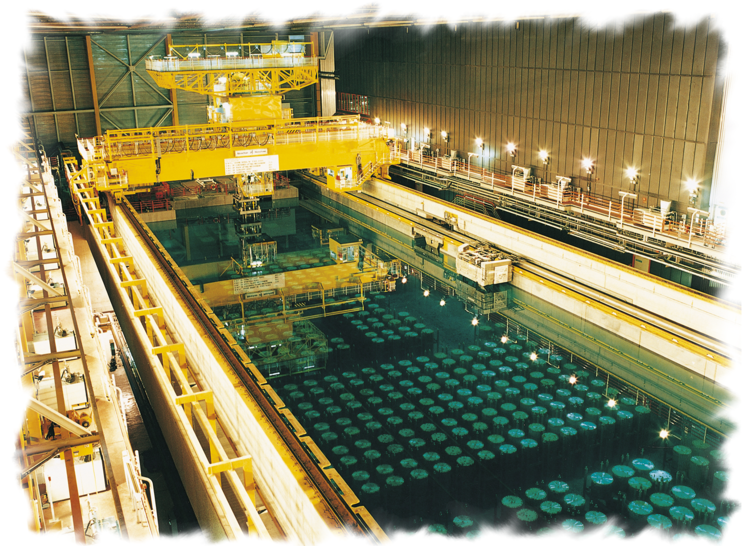


Overview of the process

- Radiochemical Plant
  - Standard radiochemical re-processing of SNF (Purex)
  - Separation of CeO_2
  - Primary encapsulation
  - Activity measurement (5%)

- Radioisotope Plant
  - Source manufacture
  - Certification ISO 9978
  - Loading into HDTAS
  - Loading into transport cask

- Upgrade of PA Mayak facilities for CeANG production ongoing

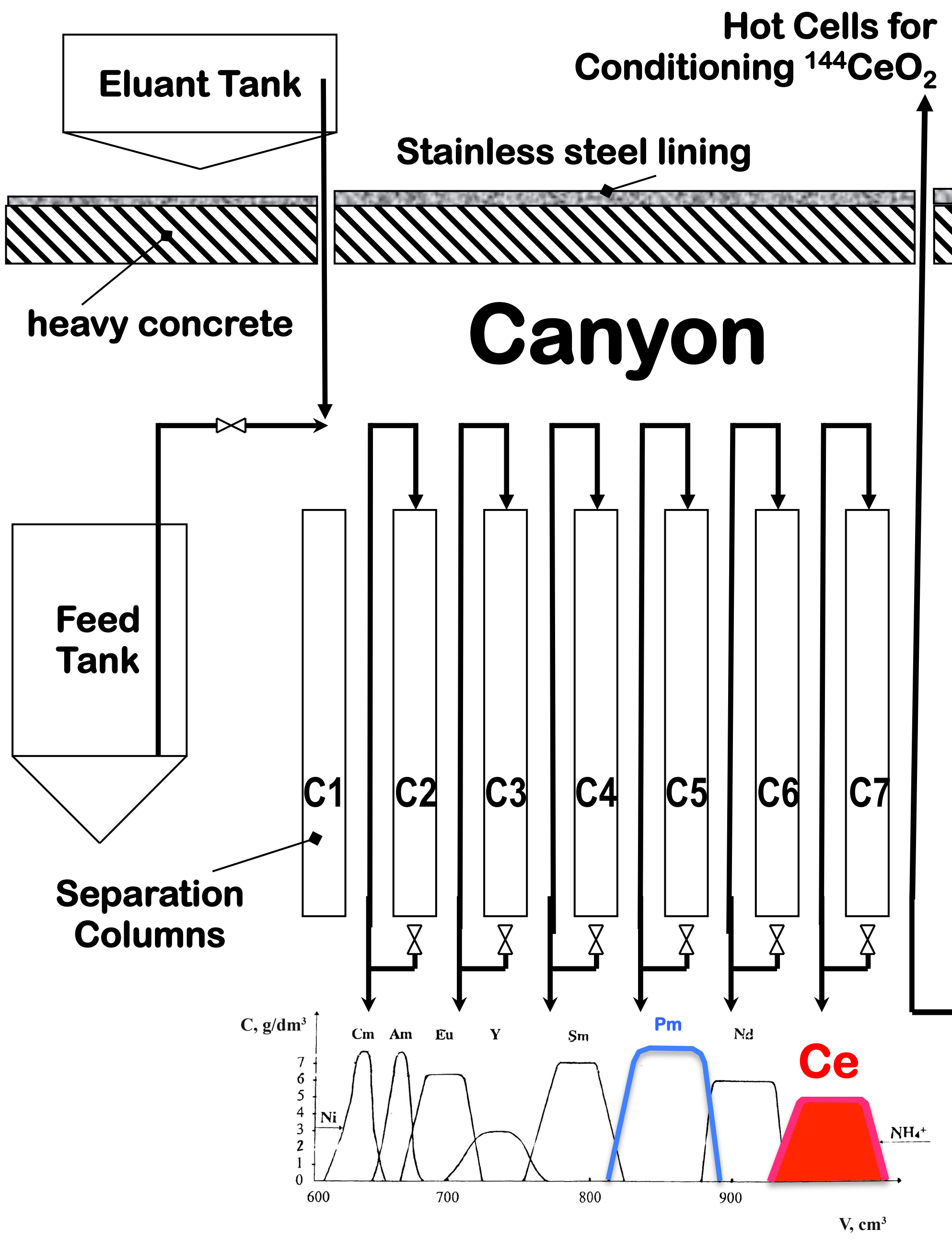


Extraction of Cerium Solution

- Complexing agent displacement chromatography for Rare Earth elements (REE)

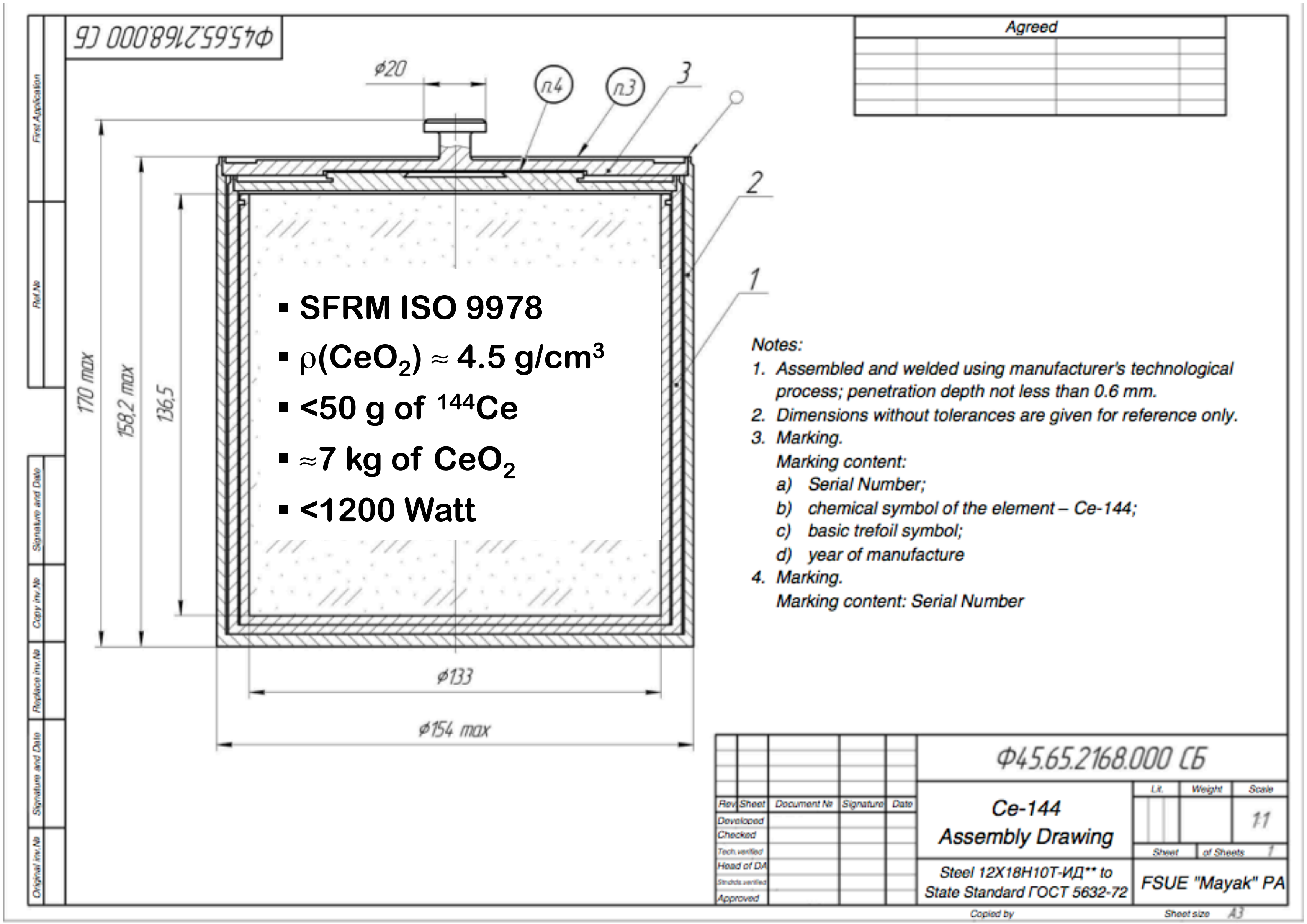
- VVR-440 Spent Nuclear Fuel:
  - PA Mayak: 100 t SNF/y
  - 1 ton SNF:
    - 13 kg REE
    - 22 g ^{144}Ce (3 y, 70 kCi)

- Production
  - Start in Feb. 2015
  - 9 months → Nov. 2015
  - Material for up to 175 kCi
  - Schedule to be consolidated



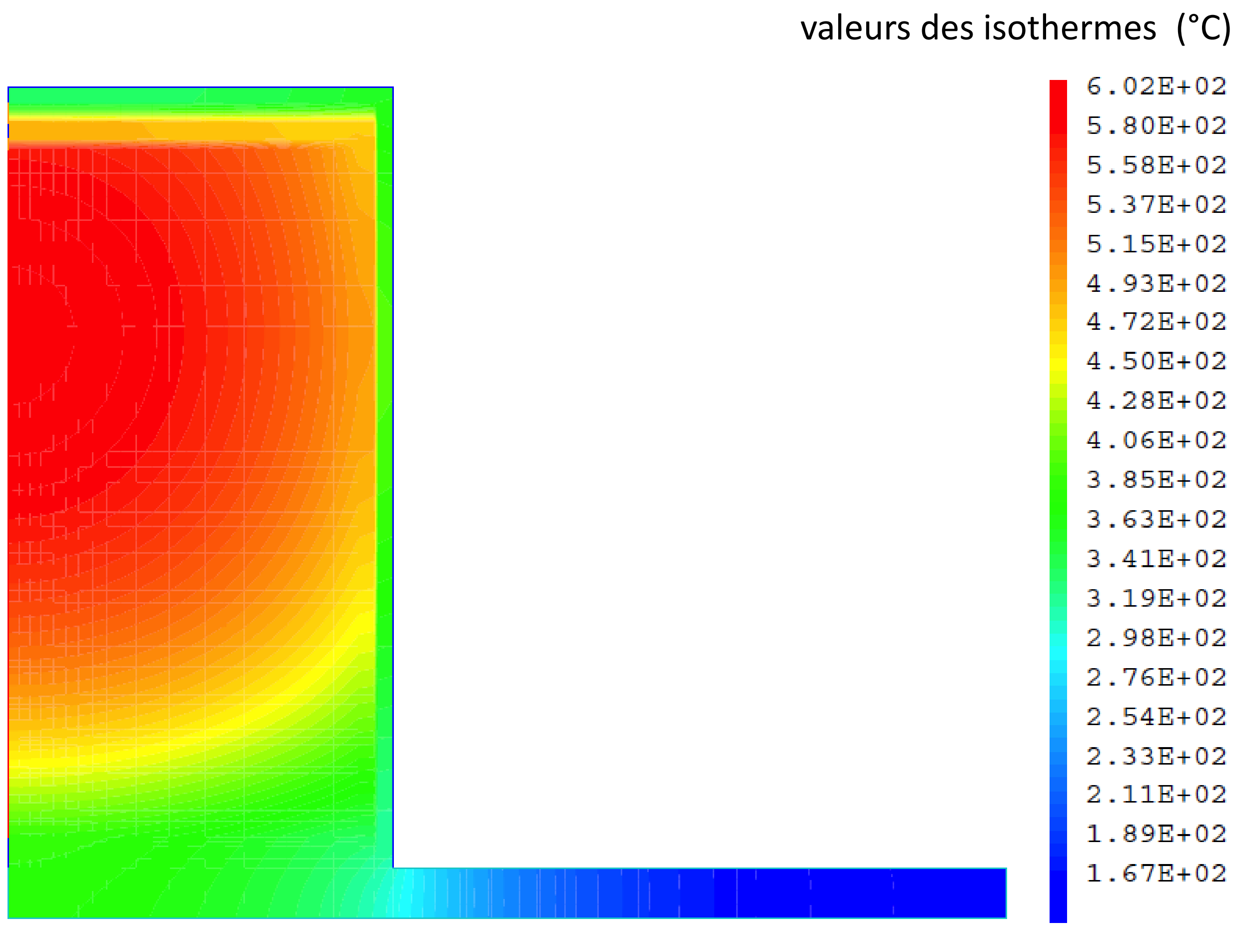
^{144}Ce-^{144}Pr SFRM capsule

- SFRM ISO 9978
- $\rho(CeO_2) \approx 4.5\ g/cm^3$
- <50 g of ^{144}Ce
- $\approx$7 kg of CeO_2
- <1200 Watt



CeANG Thermal Features

4.6 PBq (1000 W) CeANG temperature distribution alone in air at 38°C, lying on a massive steel supporting structure.



T°C max in Cerium	Averaged T°C in Cerium	T°C max on internal capsule	T°C max on intermediate capsule	T°C max on external capsule	T°C min on steel support
605	509	502	401	384	149

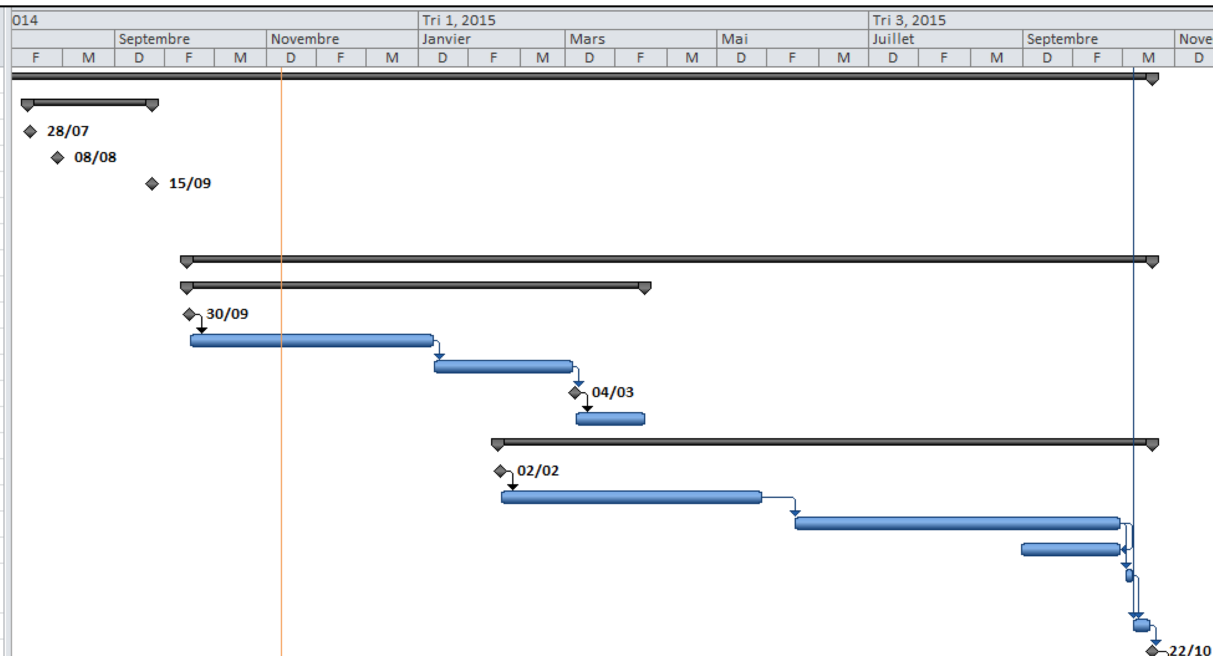
CeANG: Status

- **Advanced develoment services contract ongoing**
  - Finalization of specifications based on ^{144}Ce pilot extraction
  - Assessment of impurity content base on 2014 fresh SNF
  - Assessment of the final CeO_2 density and thermal conductivity
  - CeANG capsule manufacturing - SFRM capsule certification → 04/2015

- **CeANG purchasing contract**
  - Draft ready - Under negotiation with PA Mayak

- **Risks: control the specifications (A, ^{244}Cm), Schedule**

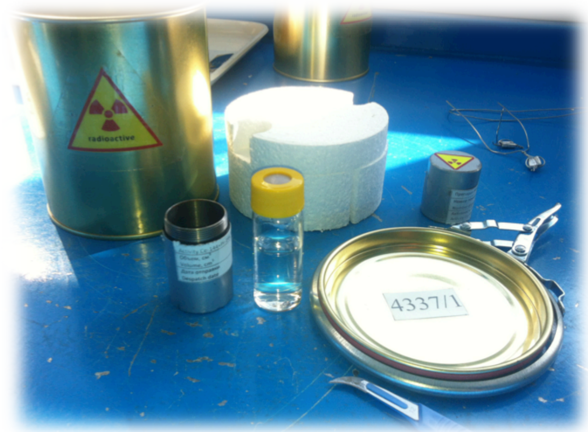
Source realization (SNF 1st batch)	**474 jours?**	**Lun 25/11/13**
Order #2a (impurities, density, conductivity)	**36 jours?**	**Lun 28/07/14**
Technical specification transmitted to SC	1 jour?	Lun 28/07/14
Tender sent by SC	1 jour?	Ven 08/08/14
Offer from Mayak for development phase	1 jour?	Lun 15/09/14
Order #2b (source pilote, capsule SFRM)	1 jour?	Lun 25/11/13
Order #3 (production)	**253 jours?**	**Mar 30/09/14**
Contract	**122 jours?**	**Mar 30/09/14**
First draft of the contract by SC	1 jour?	Mar 30/09/14
Contract evolution	60 jours	Mer 01/10/14
CCM preparation	40 jours	Mer 07/01/15
CCM presentation	1 jour?	Mer 04/03/15
Contract signed	20 jours	Jeu 05/03/15
Production	**174 jours?**	**Lun 02/02/15**
Spent fuel delivery (1.8 years old)	1 jour?	Lun 02/02/15
First stage (Purification of REE and TPE)	75 jours	Mar 03/02/15
Second stage (chromatography)	80 jours	Lun 01/06/15
Additional 3 cycles	30 jours	Lun 31/08/15
Third stage (Oxalation, filtering, calcination)	3 jours	Lun 12/10/15
Forth stage (compactization)	5 jours	Jeu 15/10/15
Source ready	1 jour?	Jeu 22/10/15



^{144}Ce-^{144}Pr Antineutrino Generator (CeANG) Characterization

^{144}Ce-^{144}Pr samples spectroscopy

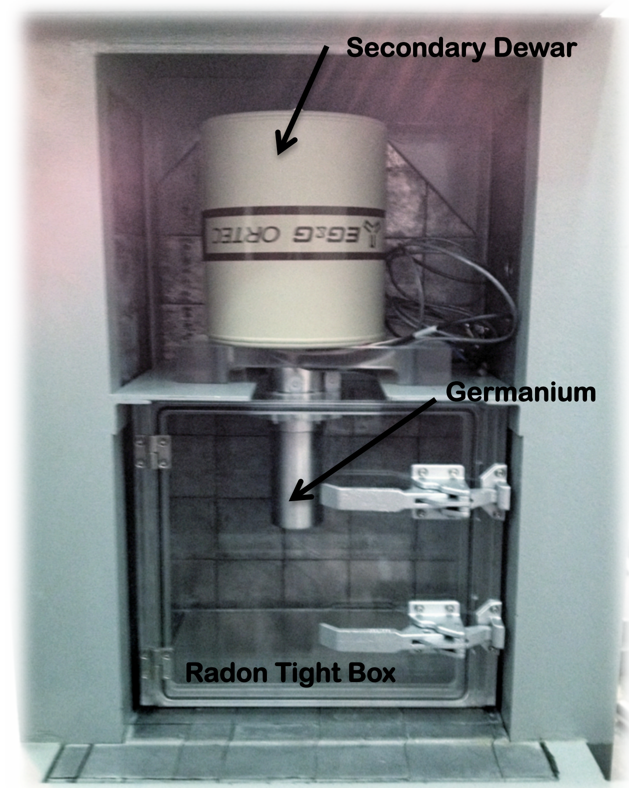
- 3 x 10 cm^3 $Ce(NO_3)_3$ - 59 KBq in ^{144}Ce each



- γ–spectroscopy (Bat. 538 – Labo D. Motta)
  - Goal: Characterization of β/γ impurity content
- β–spectroscopy (Bat. 538 - LNHB)
  - Goal: Measure ^{144}Ce & ^{144}Pr β–spectra. Predict the ^{144}Pr ν–spectrum
  - Realization of β–spectrometers
    Collaboration with Laboratoire National Henri Becquerel & TU Munchen
- ICPMS mass spectroscopy
  - Goal: characterization of neutron impurity content
    Collaboration with CEA/DEN/DPC/SECR

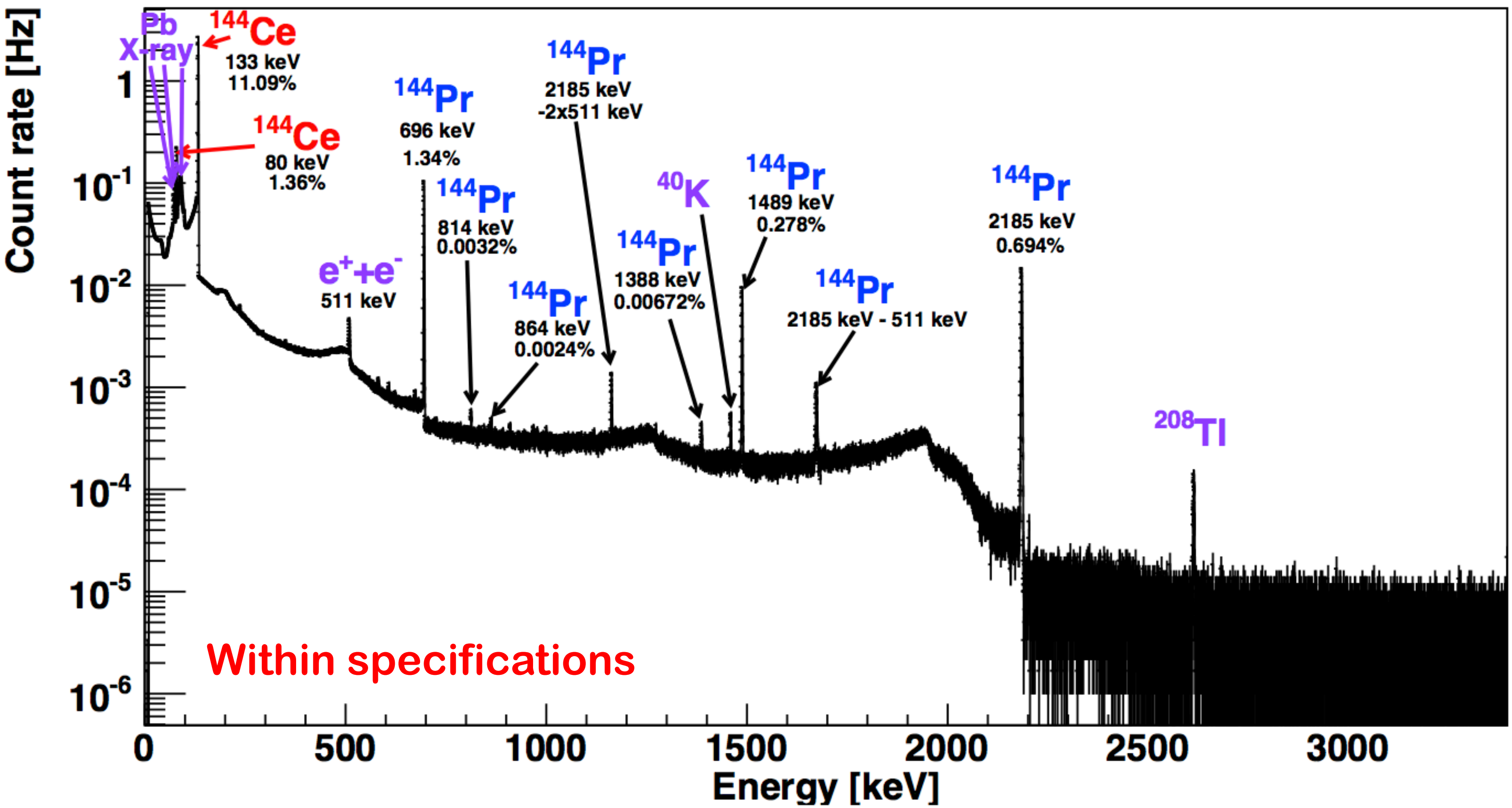
Dario Motta Laboratory

- New shallow underground laboratory (Bat. 538)
  - Muon flux attenuation: x2 + hadronic component
  - Clean room
- Facilities: Ge-counter, Stéréo proto., β-spectrometer



^{144}Ce-^{144}Pr samples: γ spectroscopy

- Absence of impurities emitting γ's
  - $<10^{-4}$ Bq/Bq of ^{144}Ce for E>500 keV
  - $<10^{-3}$ Bq/Bq of ^{144}Ce for E<500 keV
- Activity measurement
  - 01/10/2014
  - 58,9 (2.5) kBq in ^{144}Ce



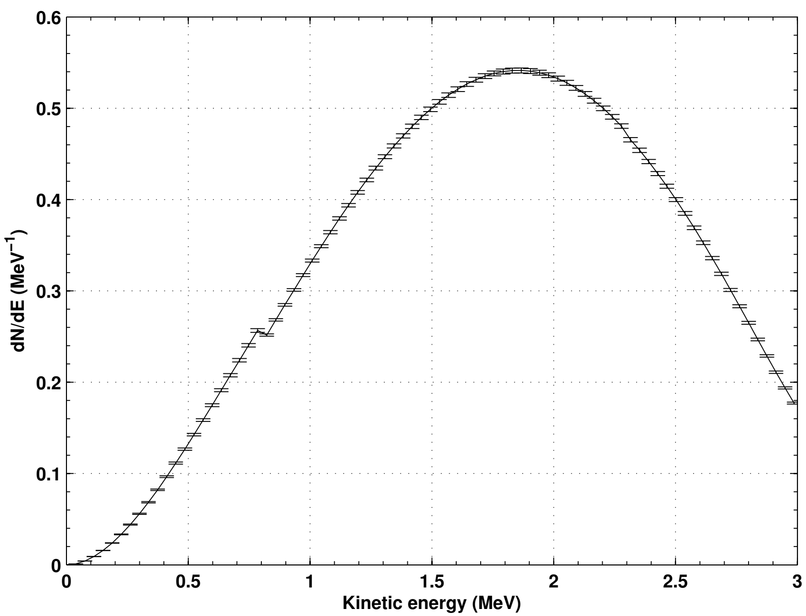
^{144}Pr Antineutrino Spectra

- ^{144}Ce-^{144}Pr β/ν spectra needed with %level precision
  - Power-to-activity conversion factor: 216.0 ± 1.2 W/PBq
  - Prediction of the IBD rate depends on the ^{144}Pr spectral shape

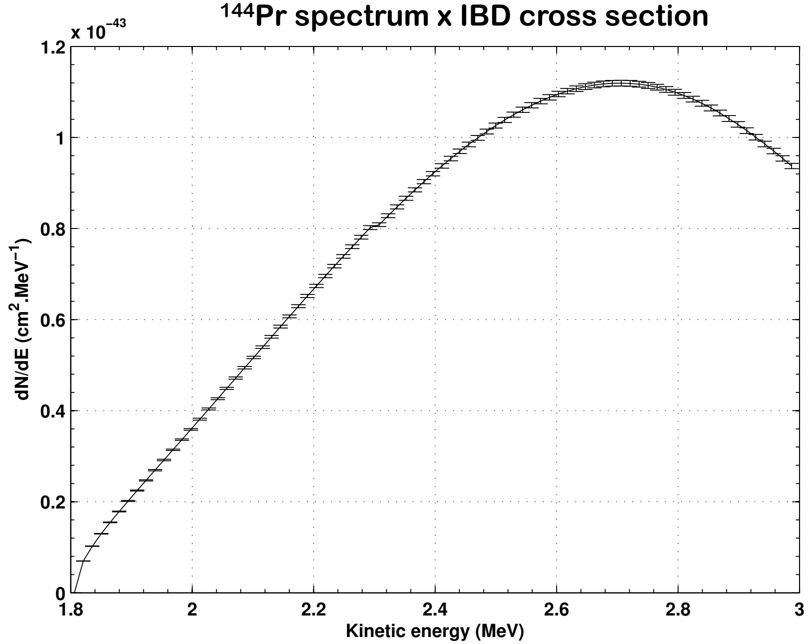
- Modeling of the ^{144}Ce-^{144}Pr β/ν spectra
  - Fermi theory + nNucleus finite-size effects + screening + QED corrections + weak magnetism + recoils and mass effects → 1% uncertainty (theory)

- But forbidden β-branches→ need for a measurement (shape factor, 10%)

Simulation of ^{144}Pr from nuclear database data



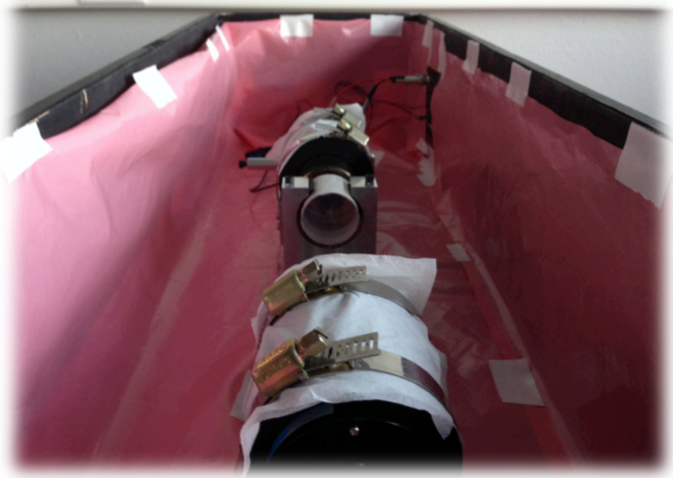
^{144}Pr spectrum x IBD cross section



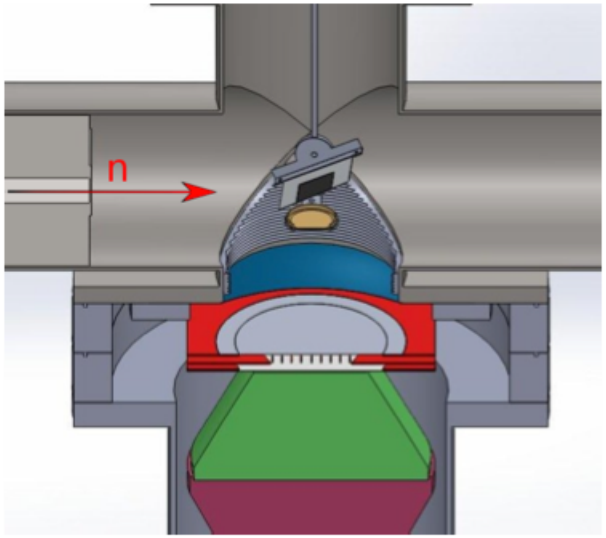
^{144}Ce-^{144}Pr samples: β spectroscopy

- ^{144}Ce-^{144}Pr (Bat. 538)
  - Liquid/Plastic spectro (CEA)
  - Use of TUM spectro
  - But low energy β's from ^{144}Ce pollute the determination of the ^{144}Pr-ν
- ^{144}Pr only (LNHB)
  - Need chemical separation of ^{144}Pr from ^{144}Ce (LNHB)
  - But ^{144}Pr mean life time: 17 min
  - Move the β-spectro @LNHB
  - Detection methods:
    - $(^{144}Pr)_l$ in LS + PMTs
      - need reliable simulation
    - new $(^{144}Pr)_s$ in PS + PMTs
    - $(^{144}Pr)_s$ onto silicium detector
      - backscattering?
- 1st measurements in 2014. Need by 2016

CEA spectrometer (under construction)



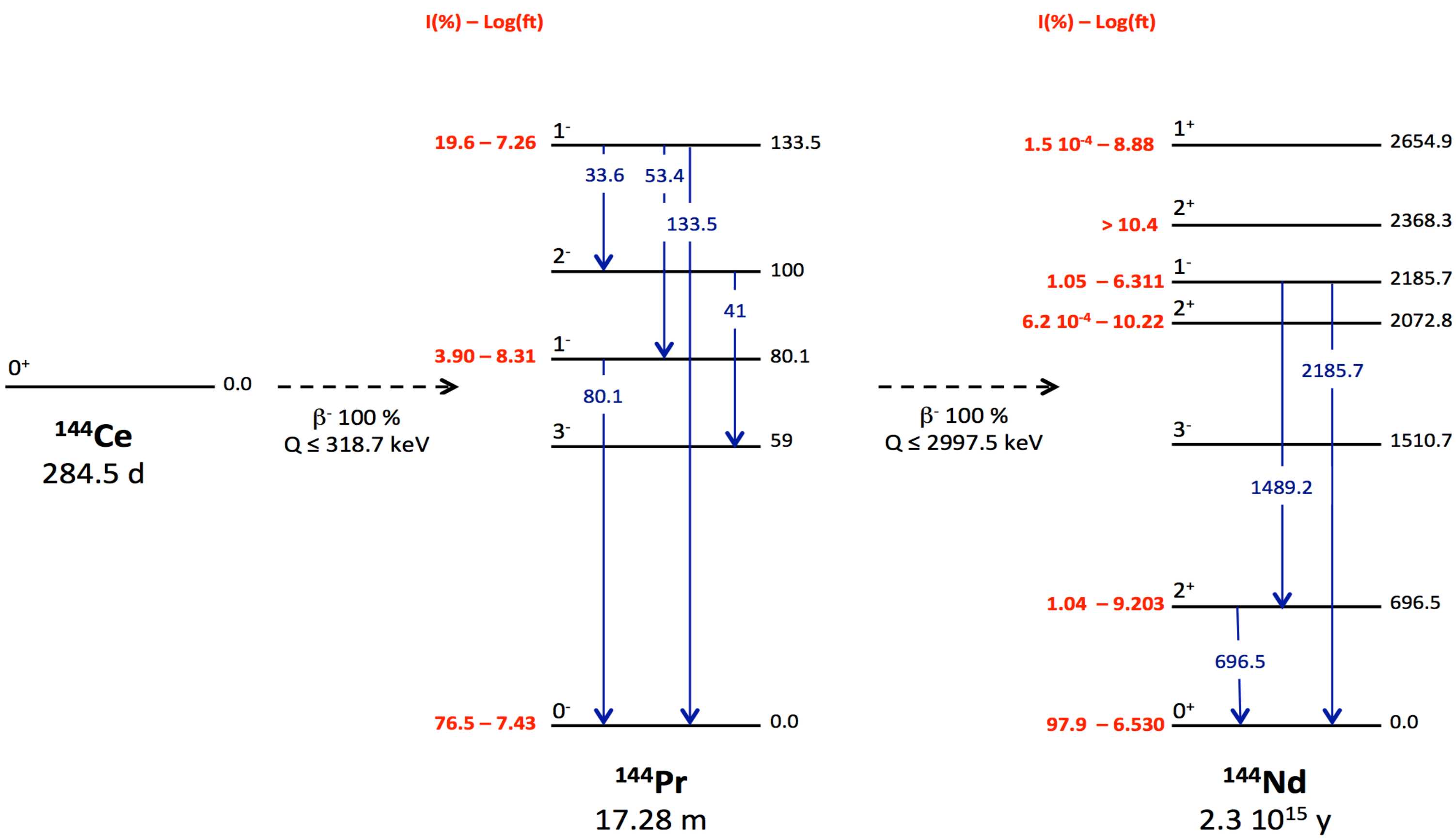
TUM spectrometer (PRL. **112**, 122501)



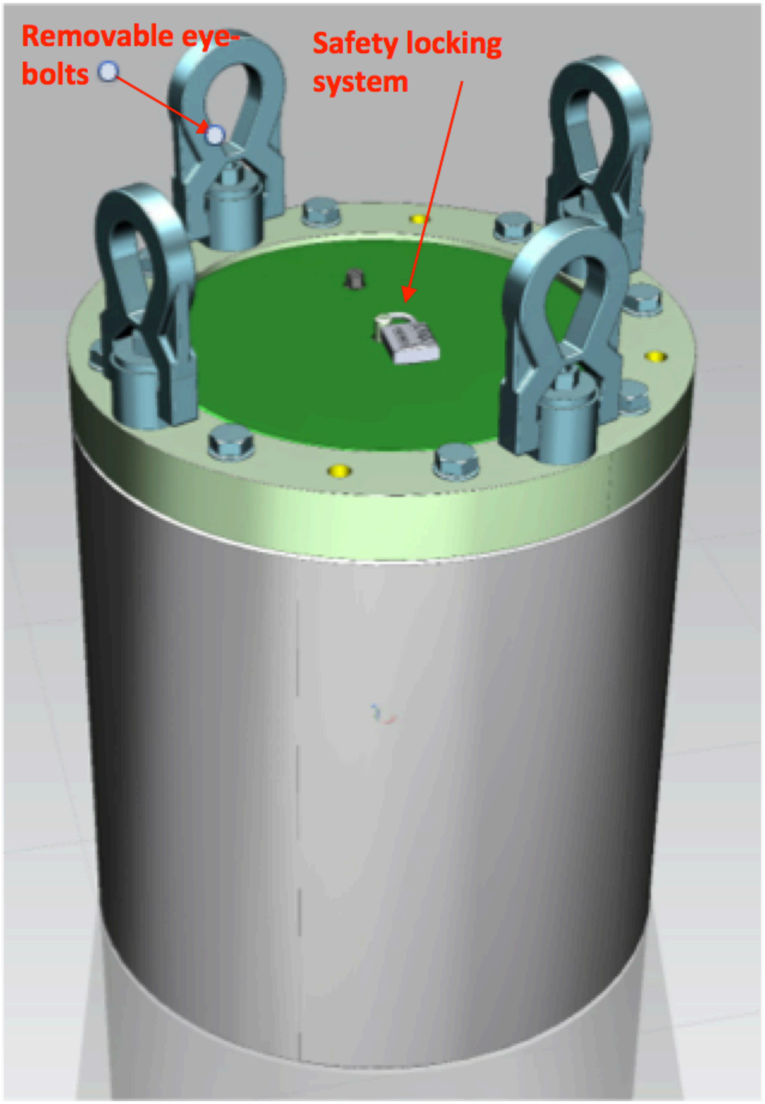
High-Density Tunsten Alloy Shielding (HDTAS)

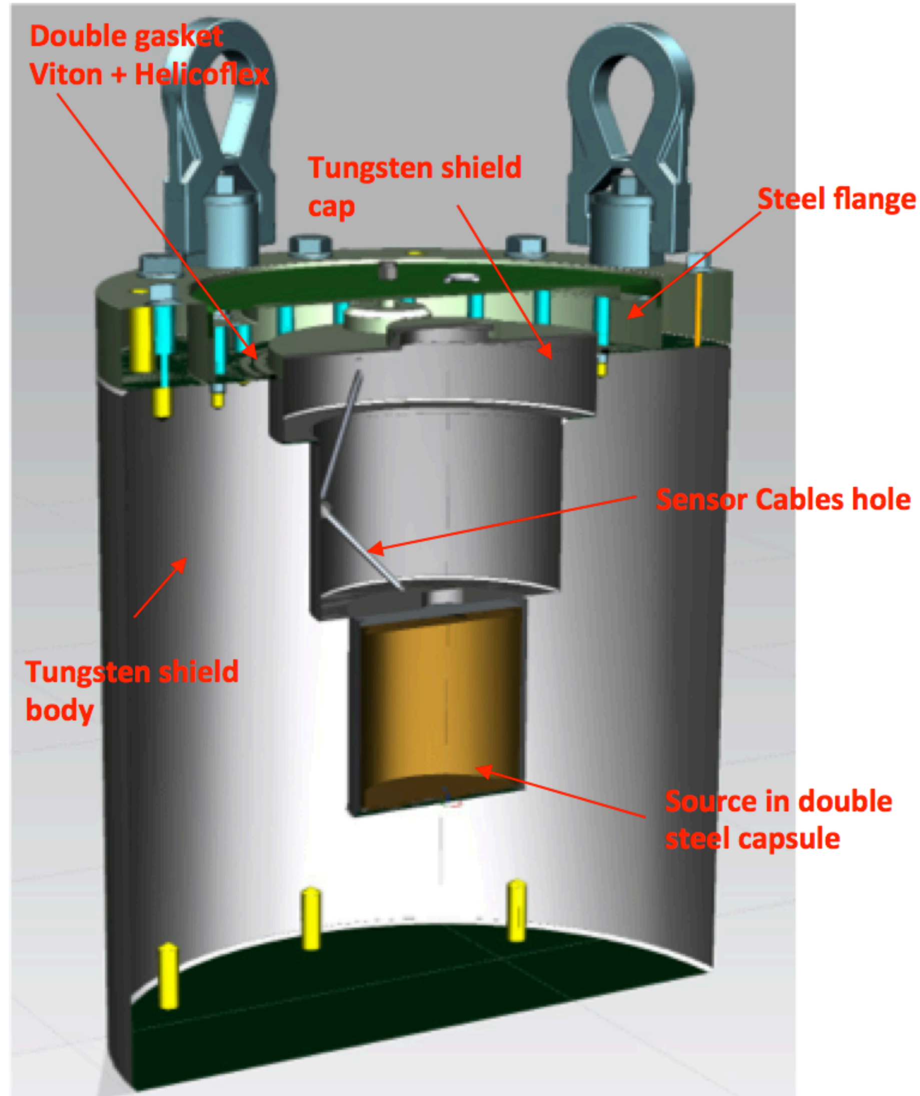
Gamma Backgrounds of ^{144}Ce-^{144}Pr

- γ rays produced by the decay through excited states of ^{144}Pr
  - Intensity γ >1 MeV
    - 1380 keV – 0.007 %
    - 1489 keV – 0.3 %
  - Intensity γ >2 MeV
    - 2185 keV – 0.7 %
    (2.10^{10} γ /sec for 3.7 PBq)

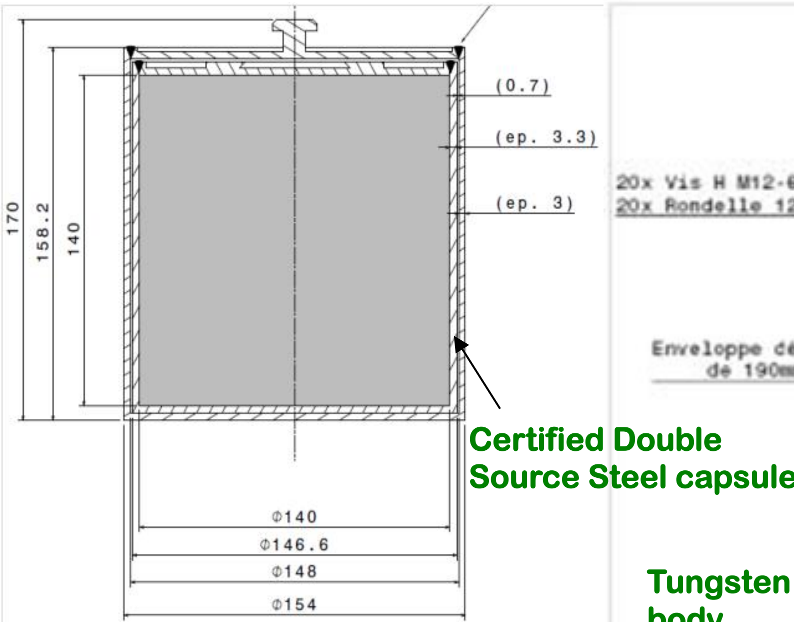


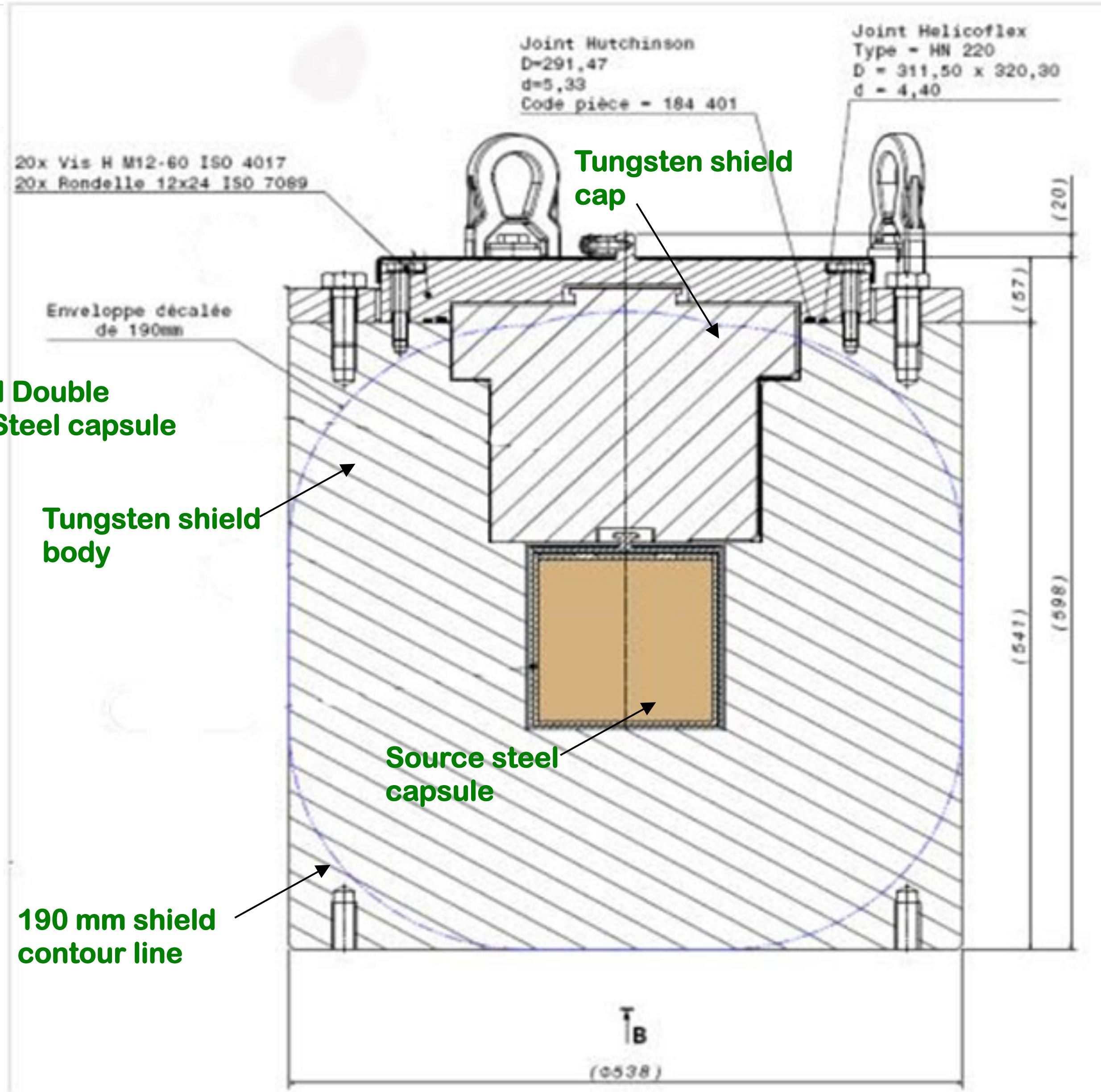
HDTAS: Mechanics





HDTAS: Drawings





Tungsten container

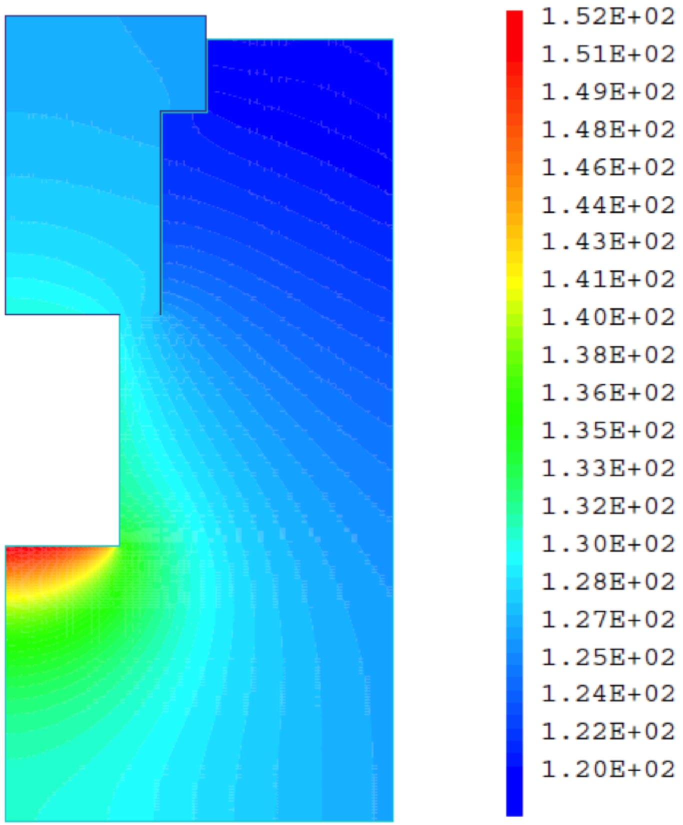
H = 598 mm
D = 538 mm

Total weight = 2260 kg

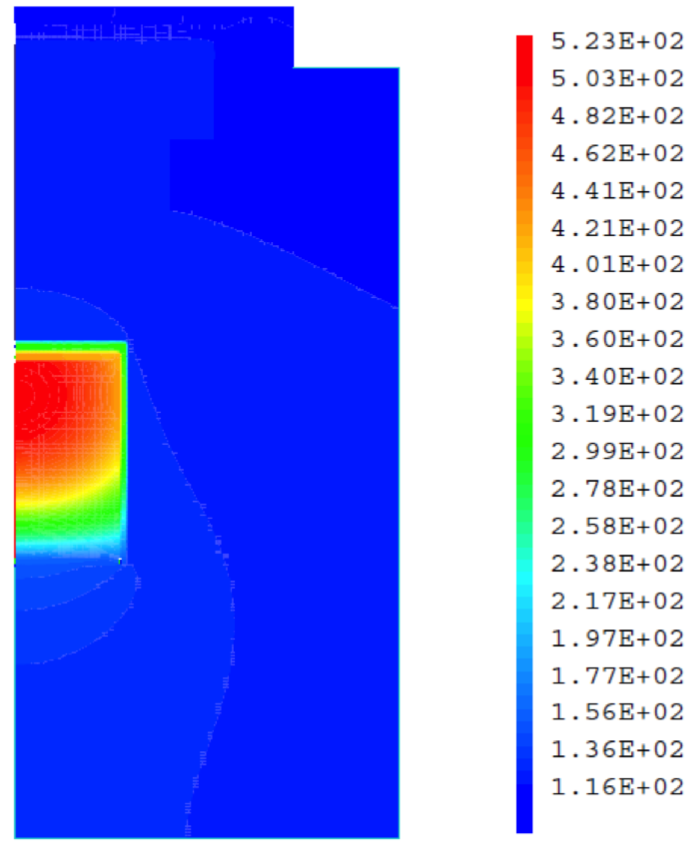
HDTAS: Thermal Features

4.6 PBq (CeANG)-W temperature distribution alone in air at 38°C. Assuming a temperature of 20°C. The temperature of the shield surface will be 80°C.

valeurs des isothermes (°C)



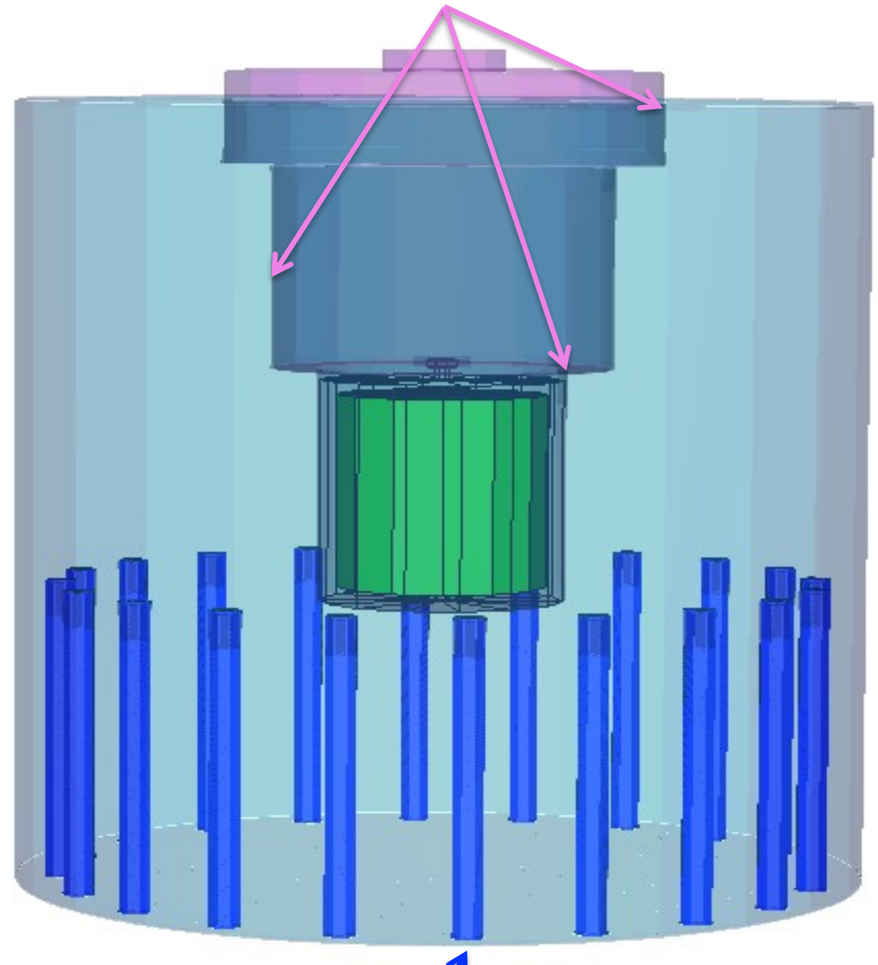
valeurs des isothermes (°C)



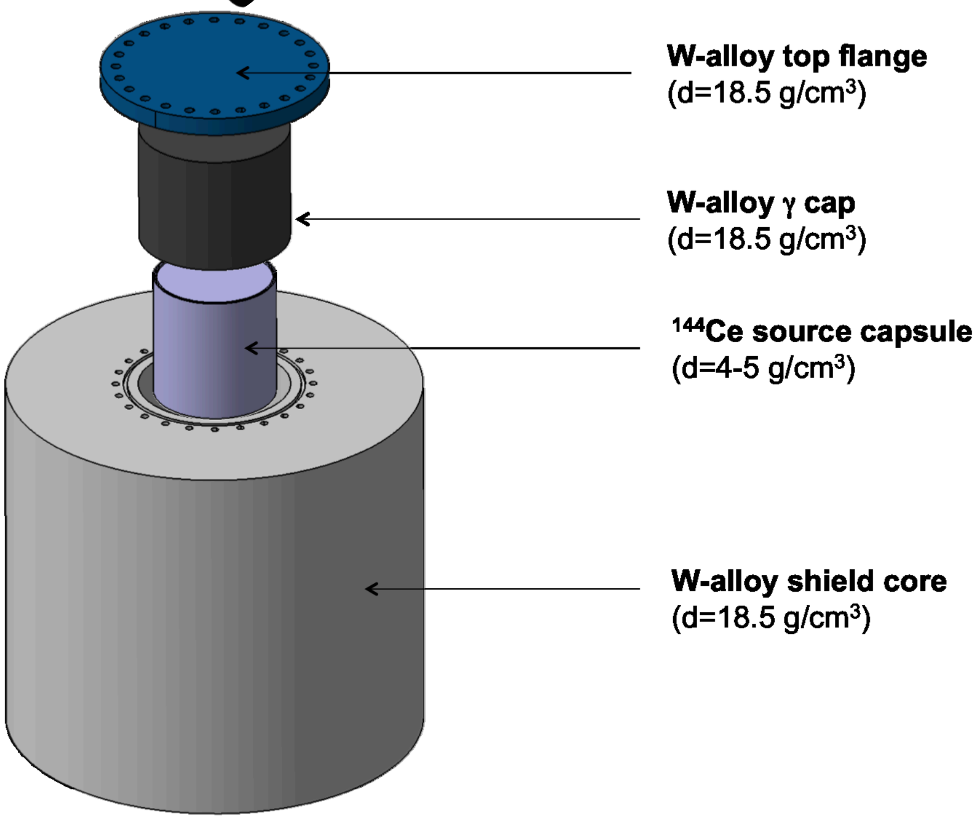
	HDTAS			HDTAS + Capsule	
T°C max in Cerium	Averaged T°C in cerium	T°C max of inner capsule	T°C max of external capsule	T°C max of HDTAS	External HDTAS T°C
526	398	434	338	153	119

HDTAS: Radiation Dose

- **Computation by CEA/SPR**
  - Code Mercurad v1.10
  - Code MCNPX v2.7.0
- **Hypothesis**
  - 5.5 PBq in ^{144}Ce
  - γ-emitters in Ce < 10^{-3} Bq/Bq
  - n emitters in Ce < 10^{-5} Bq/Bq
- **Gamma Radiation dose**
  - at contact <120 μSv/h
  - at 1 m <7 μSv/h
  - Source: ^{144}Pr de-excitation
- **Neutron Radiation dose**
  - 'at contact' <100 nSv/h
  - at 1 m <4 nSv/h
  - Source: ^{244}Cm SF (2.10^4 n/s)



CeANG insertion into HDTAS

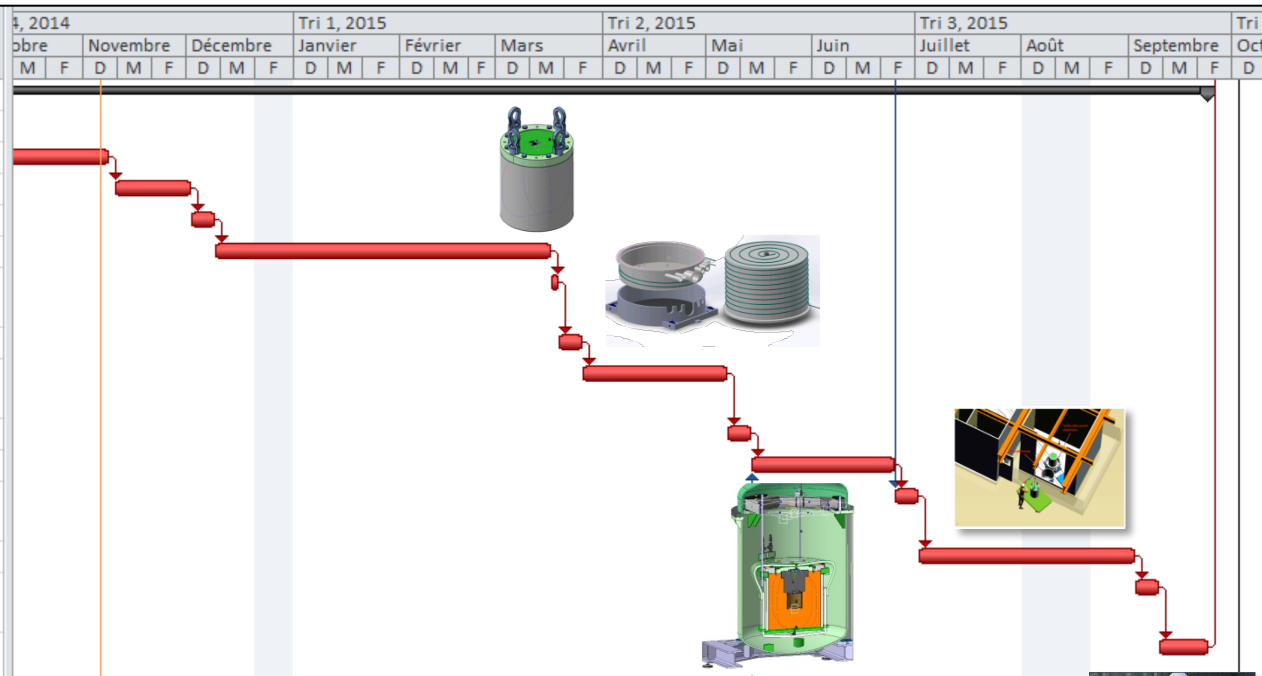


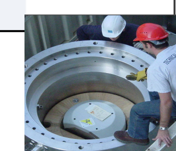
Handling inside hot cell at Mayak

HDTAS: Status

- Design completed by July 2014 (Irfu/SIS/SPP)
- Call for Tender sent on October 8th (30 days)
  - Plansee & Xiamen answered
- Risks: Delivery schedule / Review of design by ASN

Shielding	**308 jours?**	**Lun 16/06/14**
Final design	1 jour?	Lun 16/06/14
Tender	23 jours	Mer 08/10/14
Choice of the manufacturer	16 jours	Lun 10/11/14
Order	5 jours	Mar 02/12/14
Manufacturing	60 jours	Mar 09/12/14
Control and blank mounting in production site	2 jours	Mar 17/03/15
Delivery in Munich	5 jours	Jeu 19/03/15
Tightness test + calo tests + handling tests	30 jours	Jeu 26/03/15
Shielding transportation to Saclay	5 jours	Jeu 07/05/15
Test in Saclay calo	30 jours	Jeu 14/05/15
Shielding transportation to Gran Sasso	5 jours	Jeu 25/06/15
Handling tests in GS + calorimetry	30 jours	Jeu 02/07/15
Transportation To Marcoule or Cad.	5 jours	Jeu 03/09/15
Handling with TN MTR + Mayak tec training + deployment tests	10 jours	Jeu 10/09/15

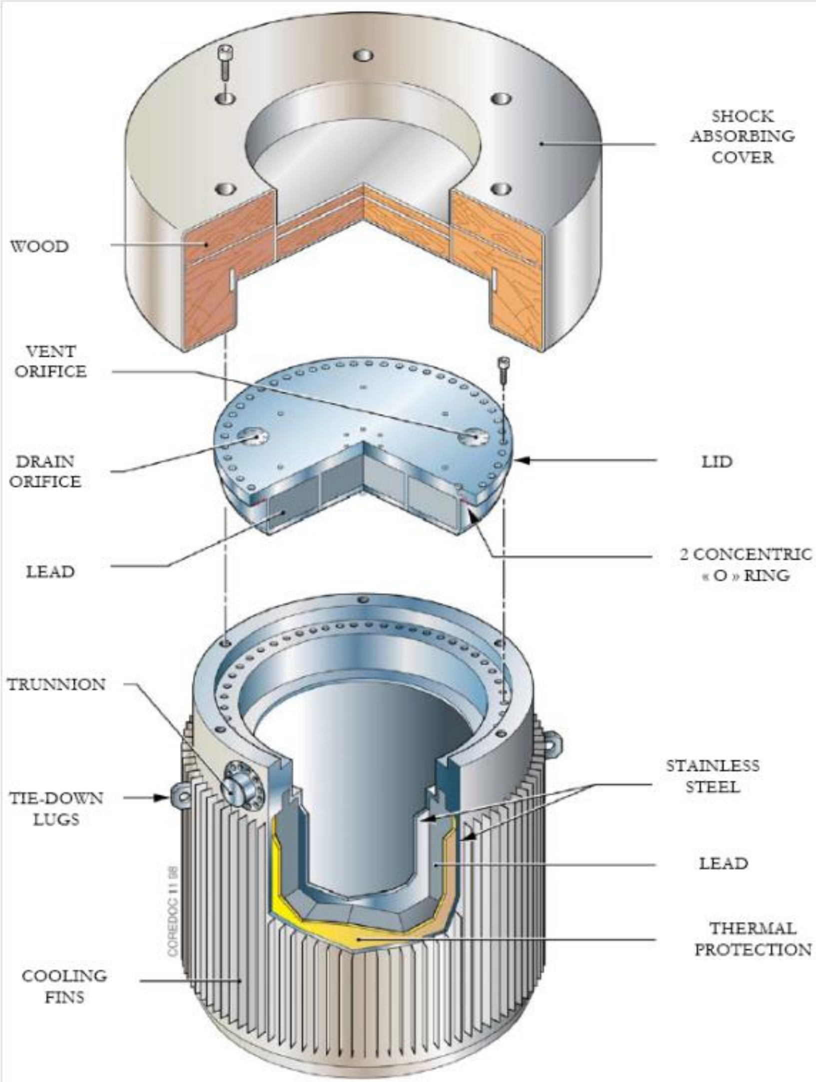




Th. Lasserre – CSTS – 14/11/2014

^{144}Ce-^{144}Pr Antineutrino generator transportation

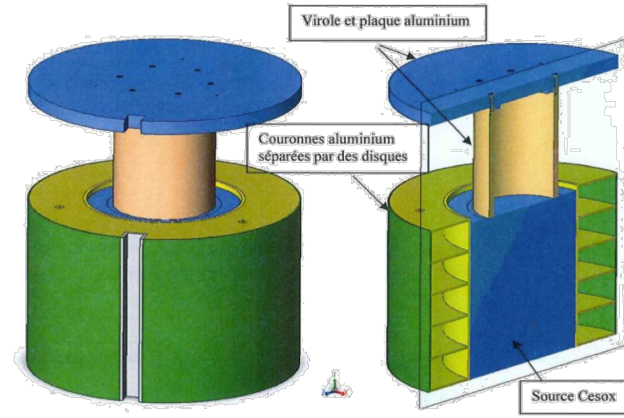
TN MTR Transport Cask



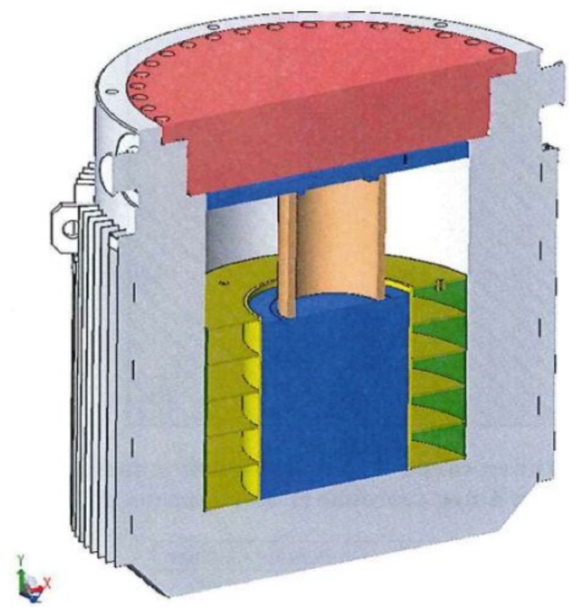
Custom AREVA spreader

TN MTR Licensing Extension

- Suitable Container for Nuclear Fuel
  - Current certificate valid until 31/01/2016
  - Renewal of the certificate ongoing
  - One cask own by CEA



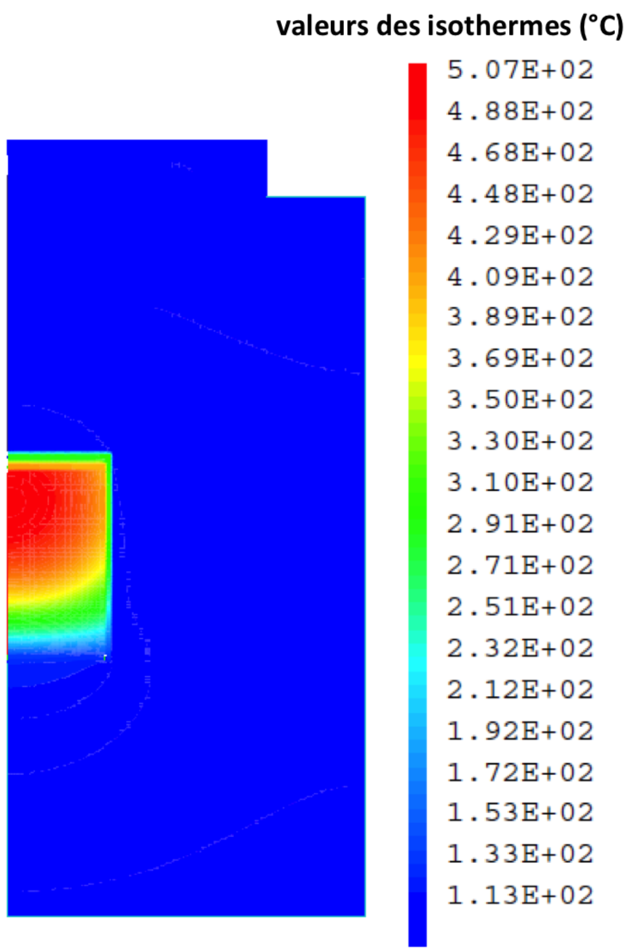
- Dedicated extension of the certification
  - Engineering by AREVA TN
  - Dedicated basket to hold the HDTAS
  - Thermal & Radioprotection studies

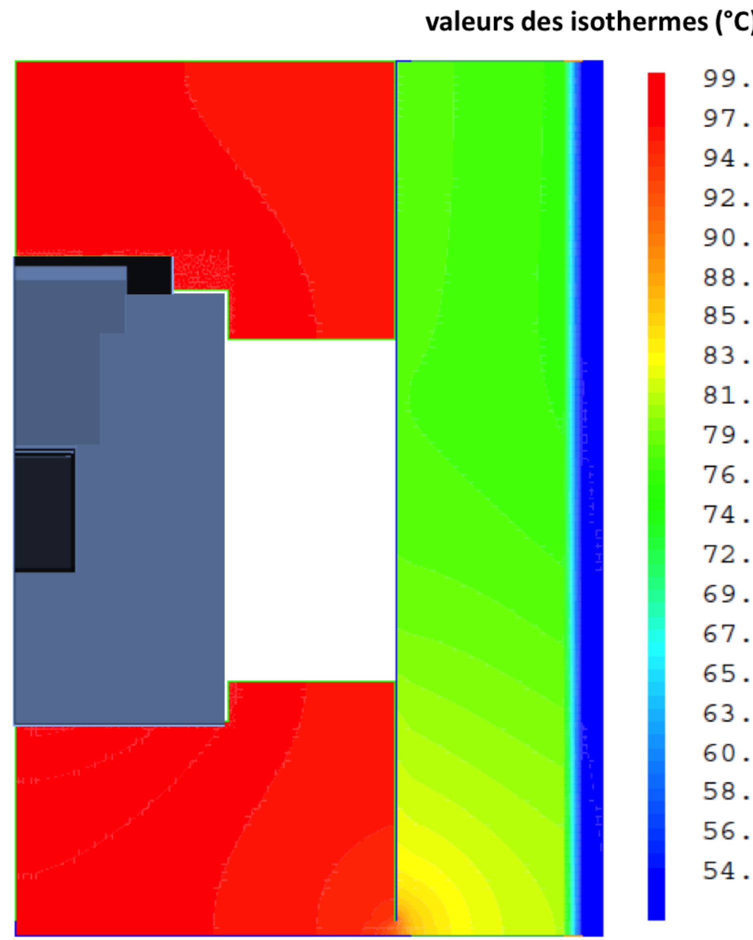


- Schedule
  - Request submitted to ASN/IRSN on 7/11/14
  - Validation expected by April 2014
  - Need a validation by Italy (+4 months)

TN MTR : Thermal Features

Temperatures of the CeANG, its shield and the TN-MTR during transportation





	HDTAS			TN-MTR transport container		
T°C max in cerium	Averaged T°C of cerium	T°C max of capsules	T°C max of HDTAS	External HDTAS T°C	T°C max of TN-MTR	External T°C of TN-MTR
512	380	419	127	97	97	52

Transport Routes

- IAEA Regulations for the Safe Transport of Radioactive Material
- Train / Dedicated vessel / Truck : AAPC published on 15/10/2014

Transport Routes: Logistics

- Empty cask + HDTAS from Marcoule to Mayak
  - CEA-Cadarache to St Petersburg (resp. CEA)
  - St Petersburg to Mayak (resp. Mayak)

- CeANG in HDTAS, HDTAS in cask, cask to LNGS
  - Mayak to St Petersburg (resp. Mayak)
  - St Petersburg to Le Havre (resp. CEA)
  - Le Havre to CEA (resp. CEA)
  - Temporary storage at CEA-Saclay (resp. CEA)
  - CEA to Gran Sasso (resp CEA + INFN)

- Empty cask from LNGS to CEA-Marcoule (resp. CEA)

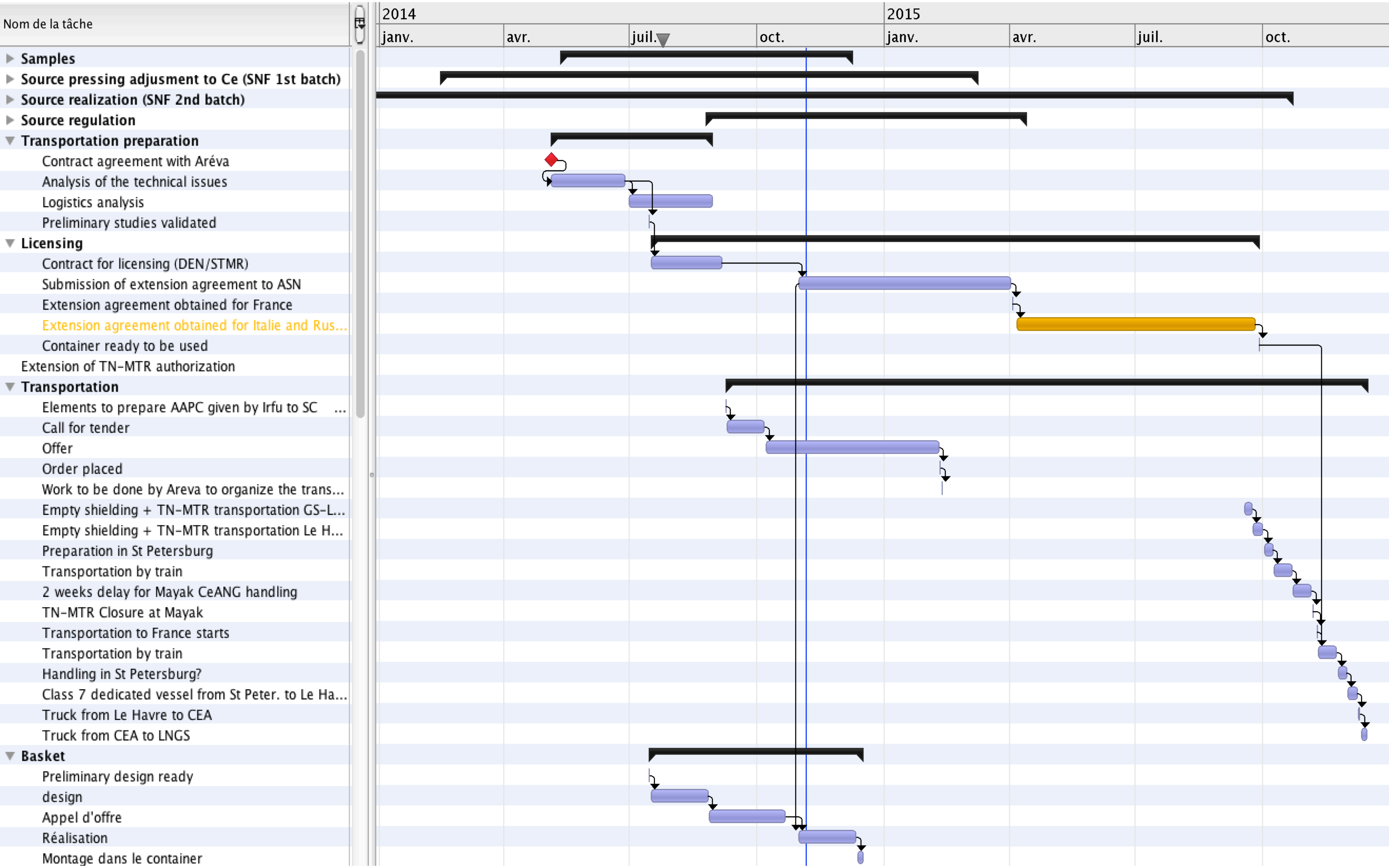
- CeANG disposal (resp. CEA)
  - In France
  - In Russia

Storage of the (CeANG)-W in Saclay

- Possible temporary of the CeANG in Saclay
- Authorization request sent to the prefecture on Oct. 24th 2014

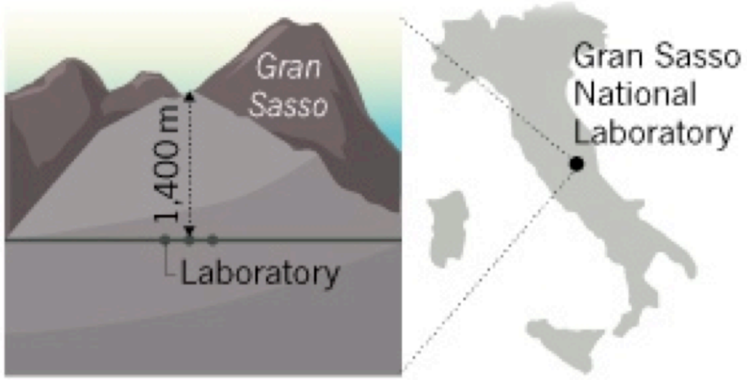
- Alternative solution at INB 72 under study with CEA/DEN

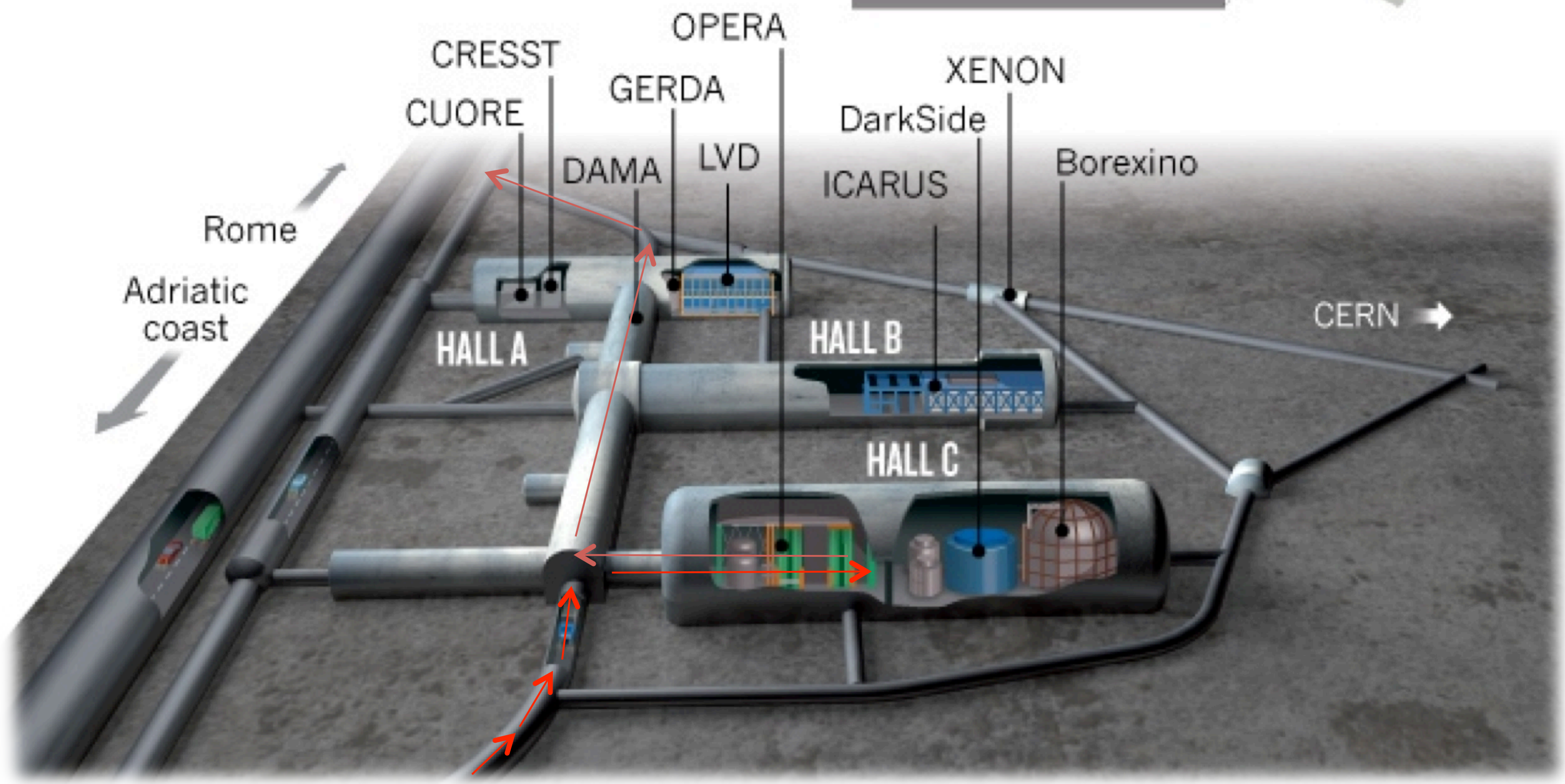
Transportation: schedule



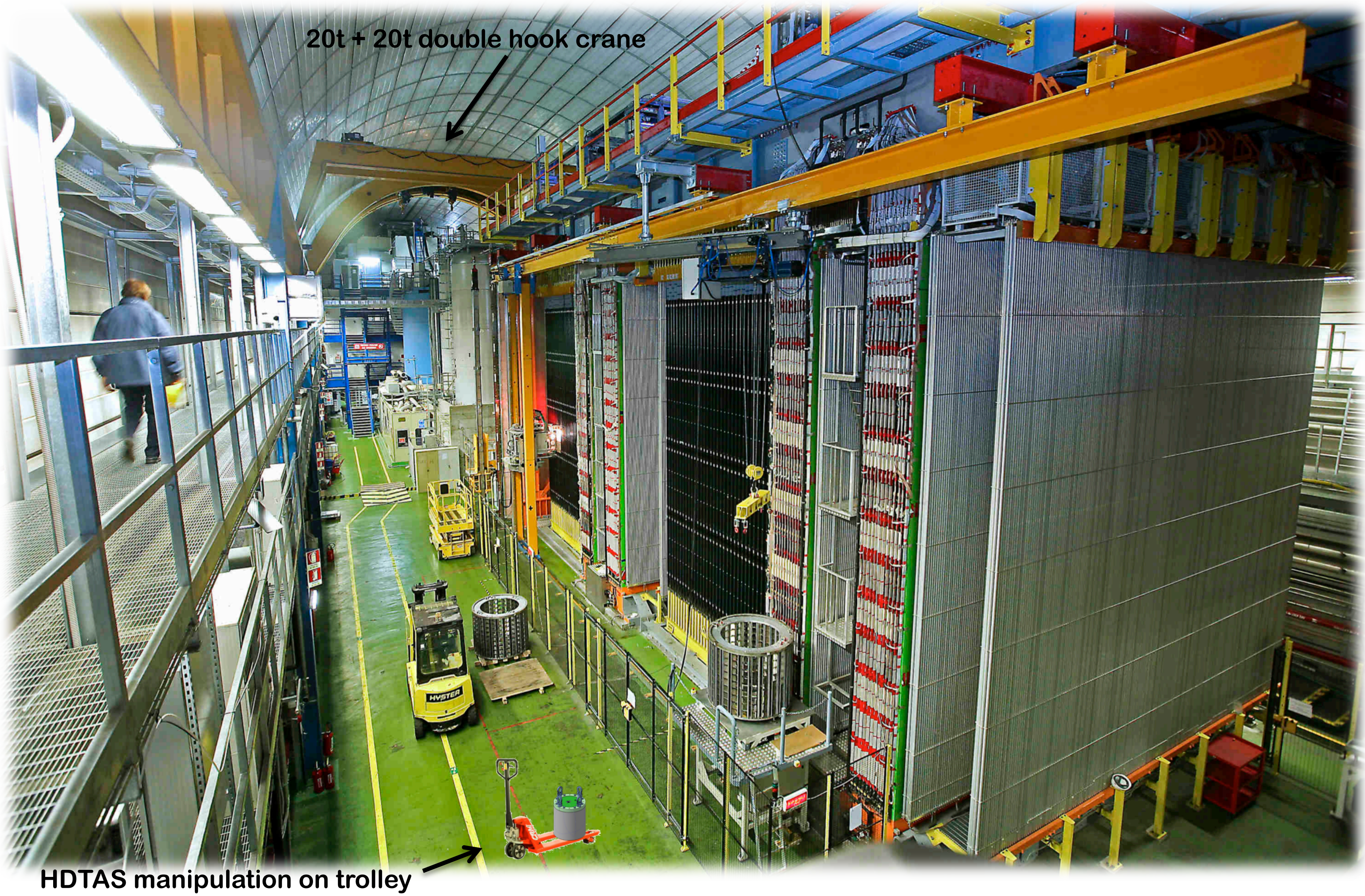
Arrival of the CeANG at LNGS

1. Truck enter the underground Lab from highway tunnel
2. Truck enter Hall C and stop in front of Opera experiment
3. Unload of the transportation container with 25t crane
4. Open TNMTR. Move the source with crane on a (trolley)



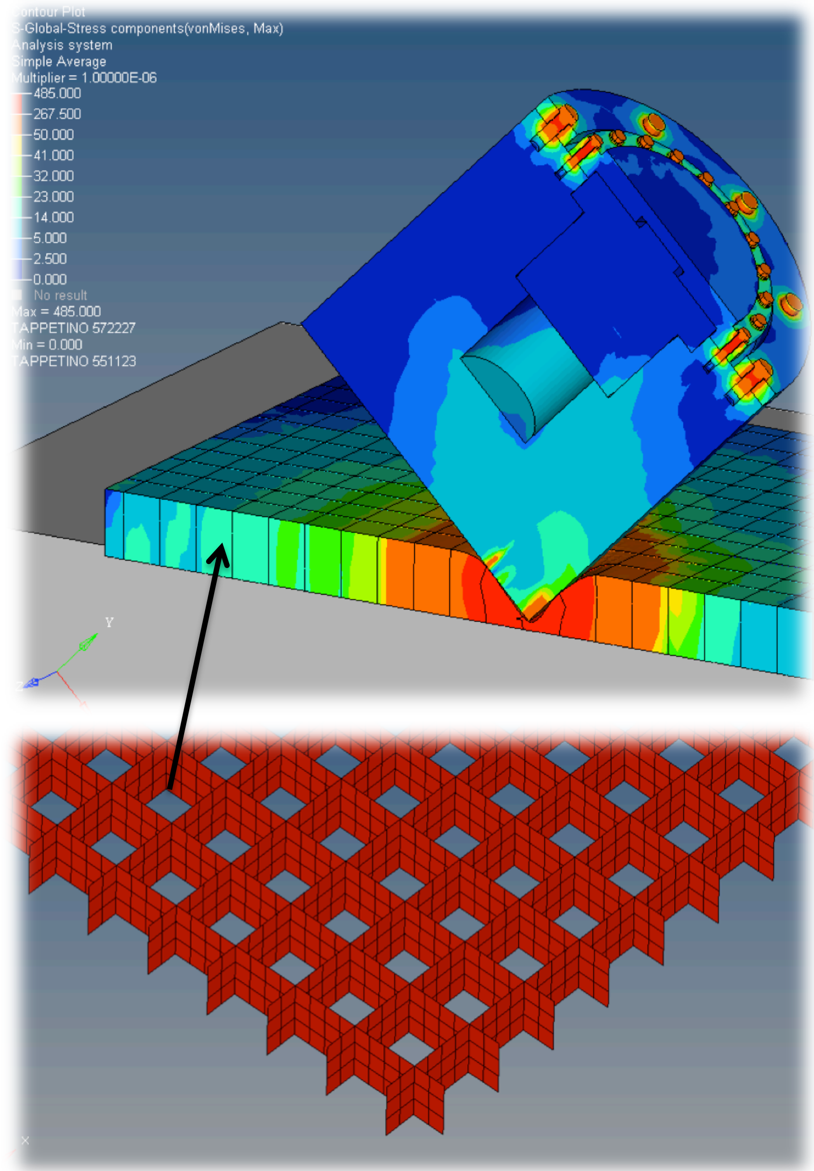


Moving the CeANG in Hall C

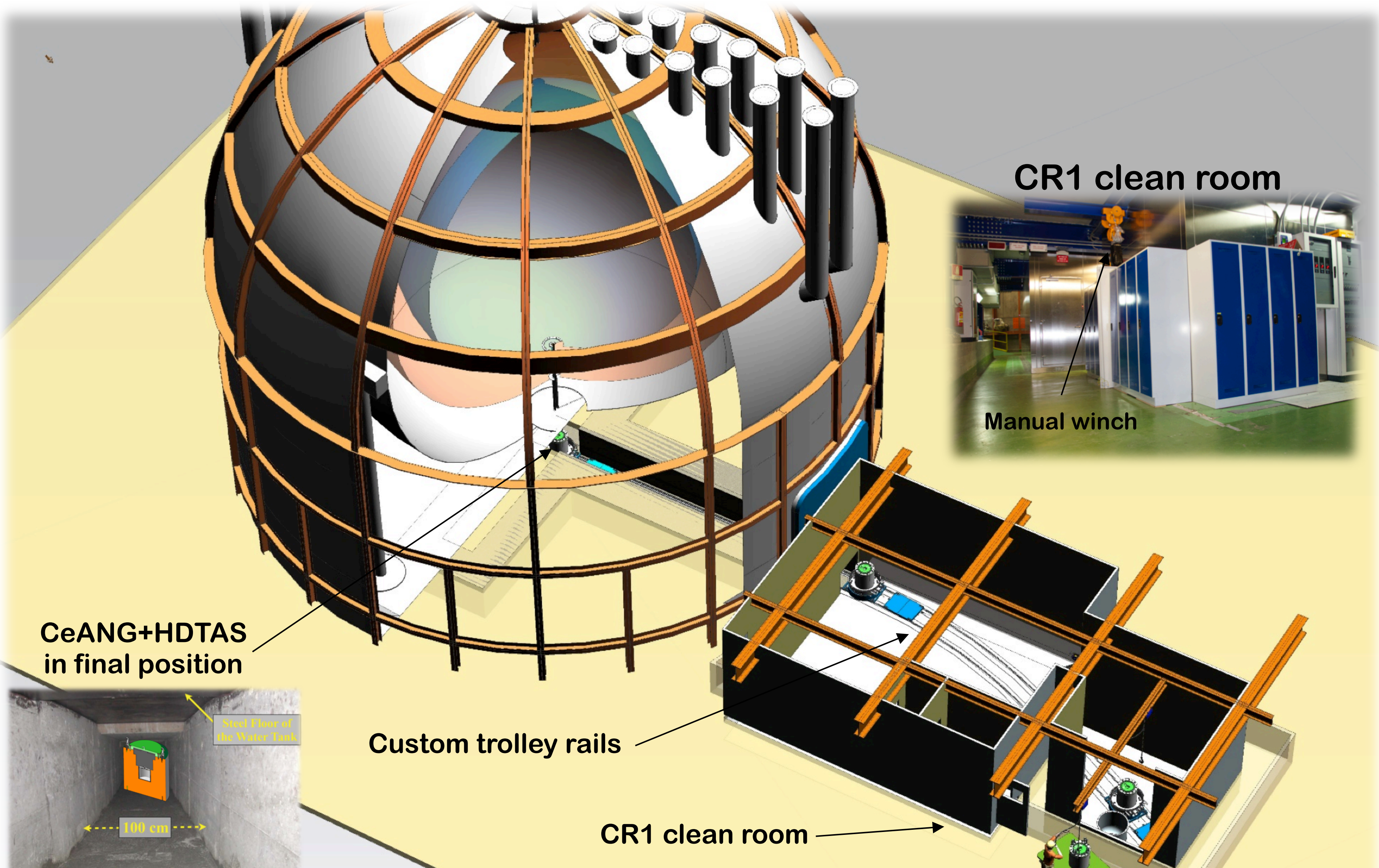


Safe unloading of the CeANG

- Risk of HDTS fall on the floor
- Impact FE Analysis done by Nucleco /CCRI
- Penalizing configuration
  - 2 m fall
  - 45° incidence angle
  - ~6.3 m / s (free fall)
- Design of a carpet absorber
- HDTAS and bolts do not undergo plastic deformation due to the impact
- Carpet absorber could be used in Saclay (if any storage)



Inserting the CeANG beneath BX

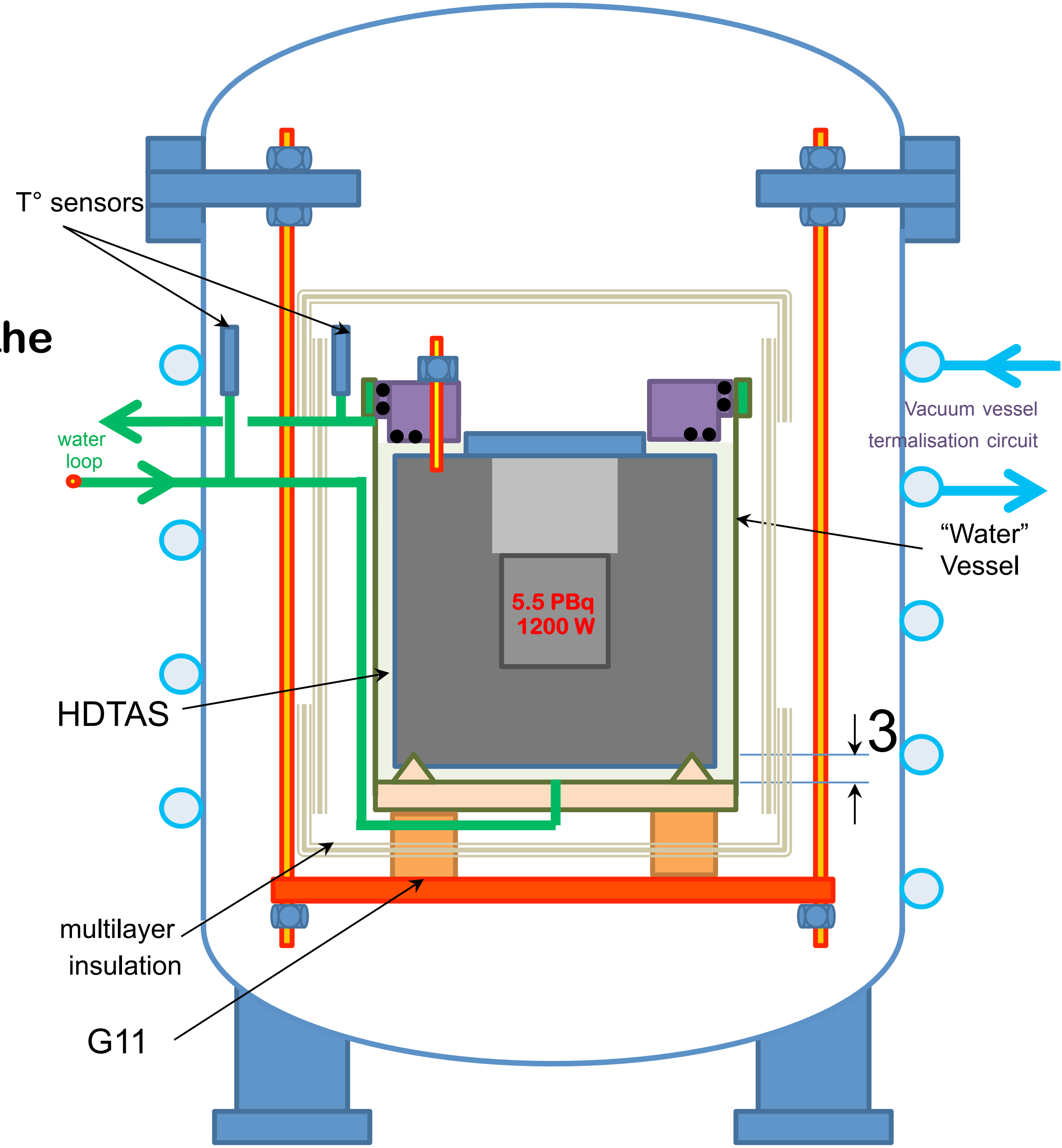


Neutrino Activity Measurement

CeANG inside SOX pit @ LNGS

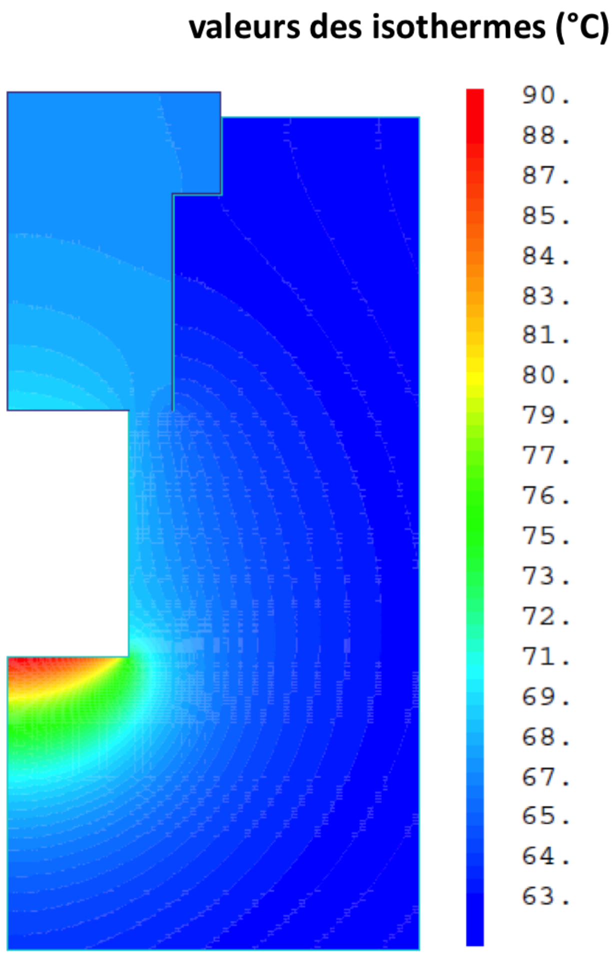
CEA Calorimeter

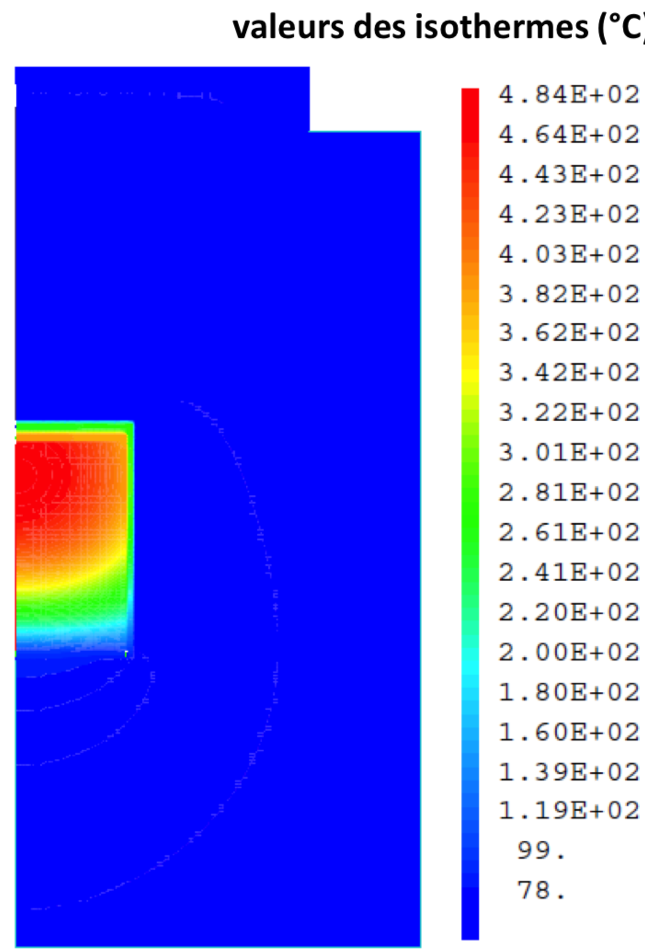
- **Measure CeANG Heat with a ≈1.5% precision**
- **Mesure water flow and T° at the in/outlets:** $\dot{Q} = \dot{m}C\left(T_{in} - T_{out}\right)$
- **Preventing heat leaks**
  - **Conduction**
    - Suspension platform
    - insulation
  - **Convection**
    - Vacuum vessel
  - **Radiation**
    - Multilayer insulation
    - Vessel thermalization
- **Calibration with a dummy electrical source**



Calorimeter: Thermal Features

Temperature in the calorimeter during the measurement



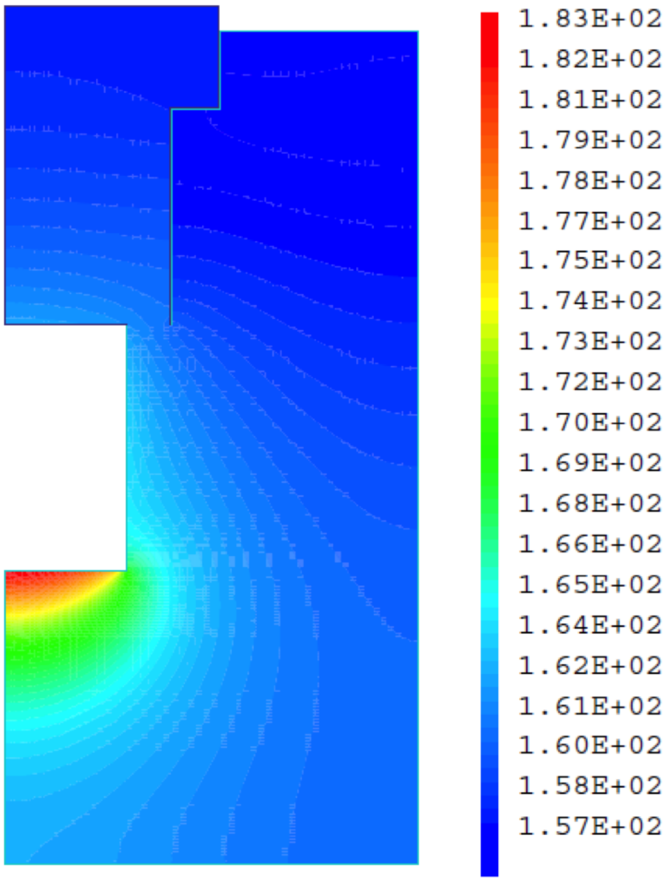


	HDTAS			HDTAS + CeANG	
T°C max of cerium	Averaged T°C of cerium	T°C max of middle capsule	T°C max of external capsule	T°C max of HDTAS	External HDTAS T°C
487	352	396	297	90	62

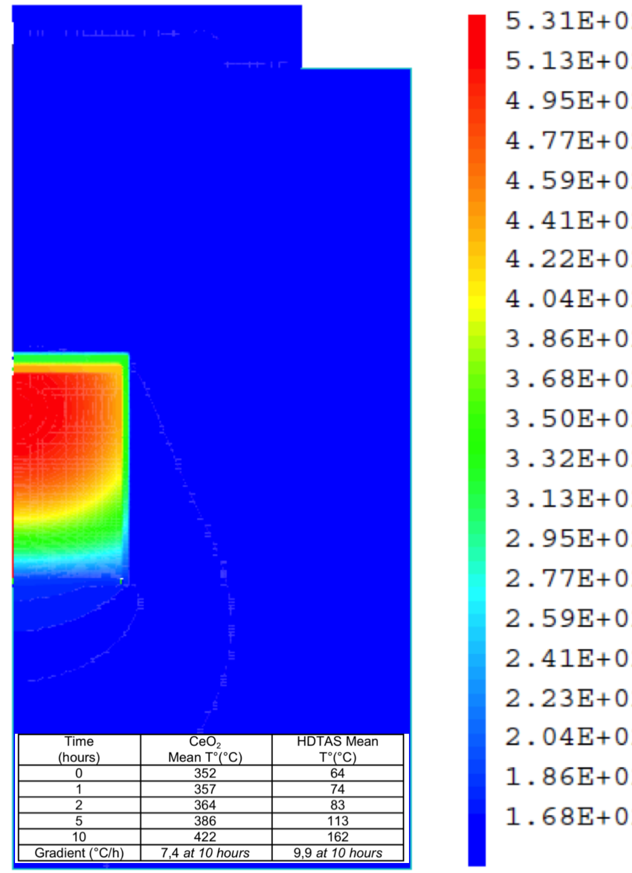
Calorimeter: Thermal Features

Temperature in the calorimeter **if cooling is lost for 10 h** (incident)

valeurs des isothermes (°C)



valeurs des isothermes (°C)



Time (hours)	CeO_2 Mean T°(°C)	HDTAS Mean T°(°C)
0	352	64
1	357	74
2	364	83
5	386	113
10	422	162
Gradient (°C/h)	7,4 *at 10 hours*	9,9 *at 10 hours*

HDTAS

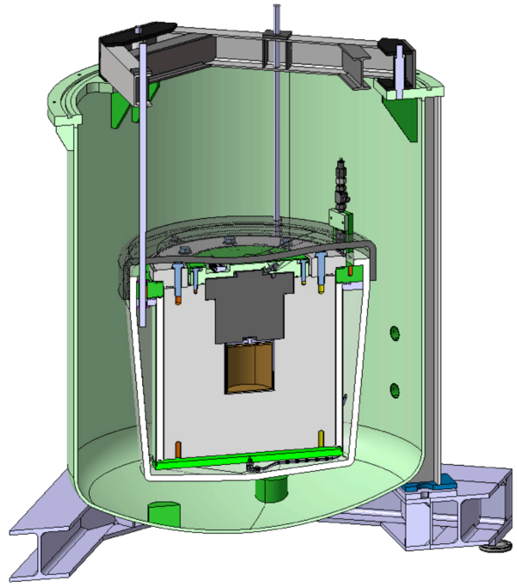
T°C max in cerium	Averaged T°C in cerium	T°C max of intermediate capsule
546	422	453

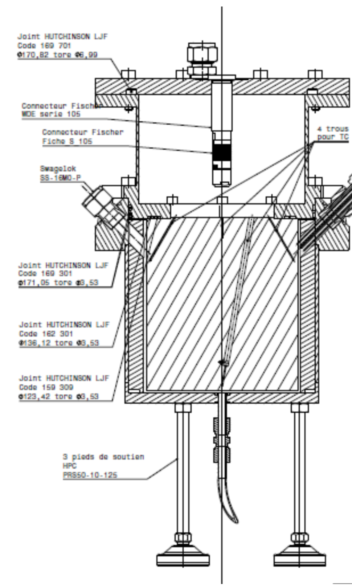
HDTAS + CeANG

T°C max of external capsule	T°C max of HDTAS	External T°C of HDTAS
359	187	159

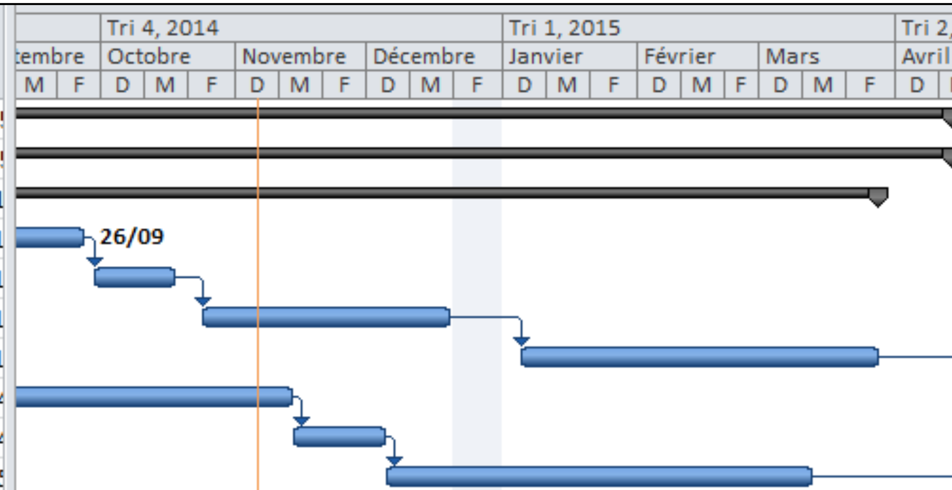
Calorimeter: Status

- **Mechanical / Thermal design completed by November 2014**
- **Instrumental Prototype**
  - Vacuum, insulation, thermometers, fluxmeters, DAQ, …
  - Delivery: 12/2014
- **Calorimeter Schedule**
  - Calibration summer 2015





Calorimeter	351 jours?	Lun 25/11/13	Lun 13/04/1
Saclay	351 jours?	Lun 25/11/13	Lun 13/04/1
Procurement phase	340 jours	Lun 25/11/13	Ven 27/03/1
Circulation loop design	220 jours	Lun 25/11/13	Ven 26/09/1
Circulation loop tender	15 jours	Lun 29/09/14	Ven 17/10/1
Circulation loop realization	41 jours	Ven 24/10/14	Ven 19/12/1
Circulation loop tests	60 jours	Lun 05/01/15	Ven 27/03/1
Vacuum vessel design	54 jours	Lun 01/09/14	Jeu 13/11/14
Vacuum vessel tender	15 jours	Ven 14/11/14	Jeu 04/12/14
Vacuum vessel realization	60 jours	Ven 05/12/14	Jeu 12/03/15



Data Taking

Experimental Parameters for a Cerium 144 Based Intense Electron Antineutrino Generator Experiment at Very Short Baselines

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M. Durero,[2] V. Fischer,[2] A. Letourneau,[2] and M. Vivier[2]

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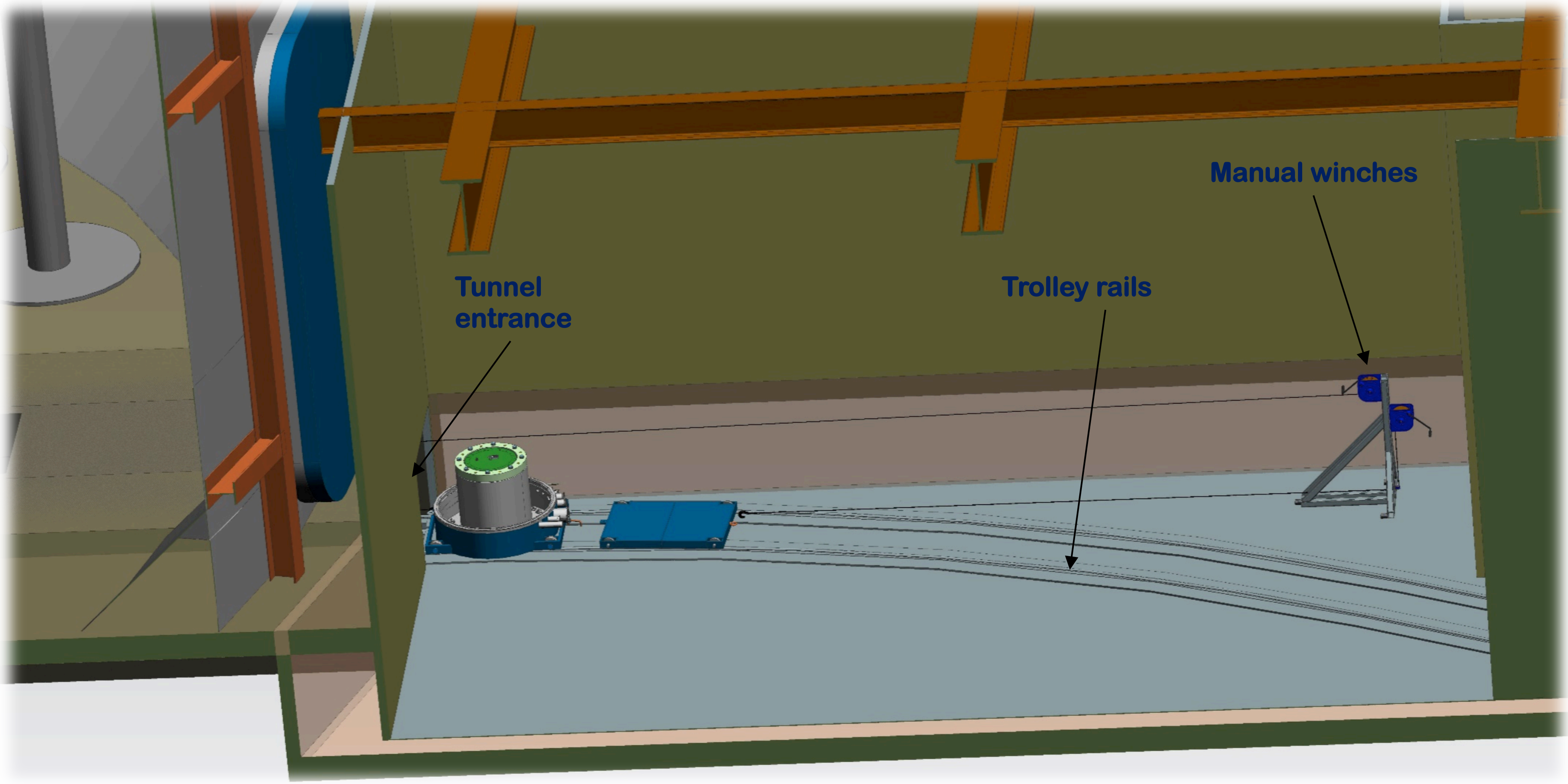
(Dated: November 13, 2014)

The standard three-neutrino oscillation paradigm, associated with small squared mass splittings $\Delta m^2 \ll 0.1\,\mathrm{eV}^2$, has been successfully built up over the last 15 years using solar, atmospheric, long baseline accelerator and reactor neutrino experiments. However, this well-established picture might suffer from anomalous results reported at very short baselines in some of these experiments. If not experimental artifacts, such results could possibly be interpreted as the existence of at least an additional fourth sterile neutrino species, mixing with the known active flavors with an associated mass splitting $\Delta m^2_{\mathrm{new}} \gg 0.01\,\mathrm{eV}^2$, and being insensitive to standard weak interactions. Precision measurements at very short baselines (5–15 m) with intense MeV $\bar{\nu}_e$ emitters can be used to probe these anomalies. In this article we study the $\bar{\nu}_e$ signal and the backgrounds of a generic experiment deploying an intense β^- radioactive source inside or in the vicinity of a large liquid scintillator detector. We identified the challenges to search for neutrino oscillations inside the detector, reviewing the possible source and detector induced systematics, and quantifying their impact on the sensitivity.

CeANG inside SOX pit @ LNGS

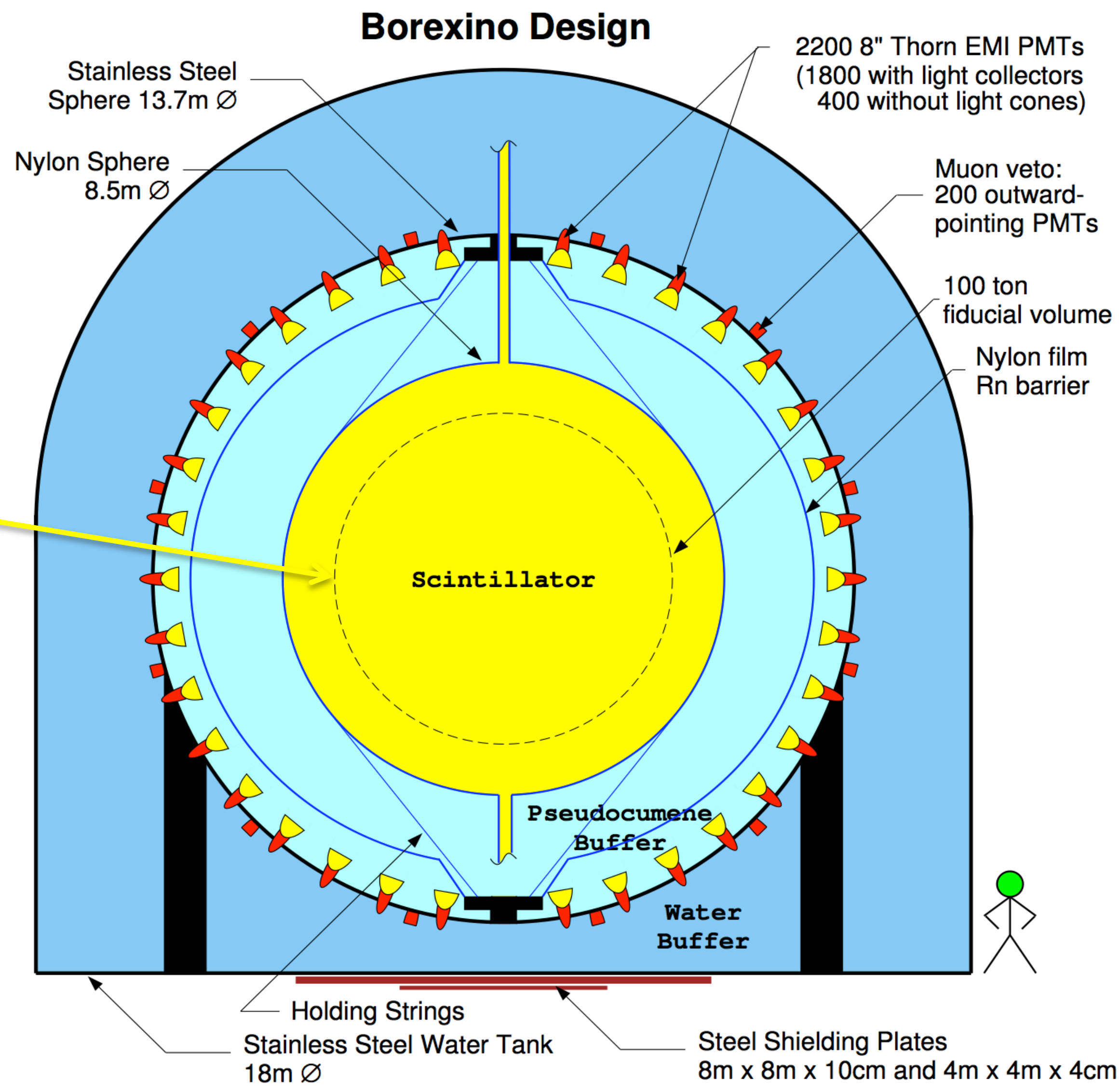
- Use the base of the Cr-Calorimeter as trolley & cooling device
- Slide the CeANG into the pit – Radiation dose controls (0.5 y)



Deployment

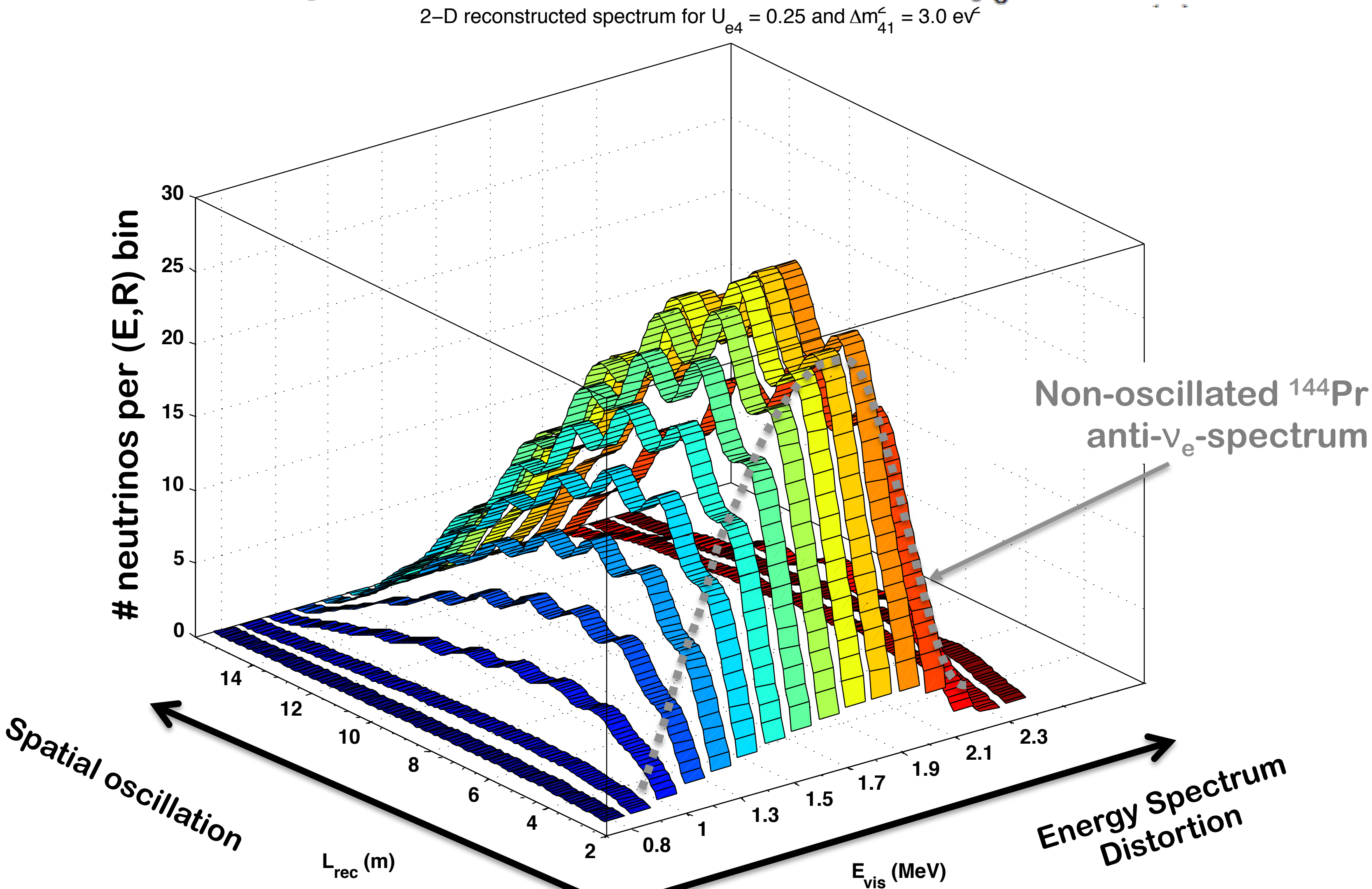
CeSOX target

- R < 4.25 m
- 280 tons
- C_6H_{12}
- #H: $1.7\ 10^{31}$



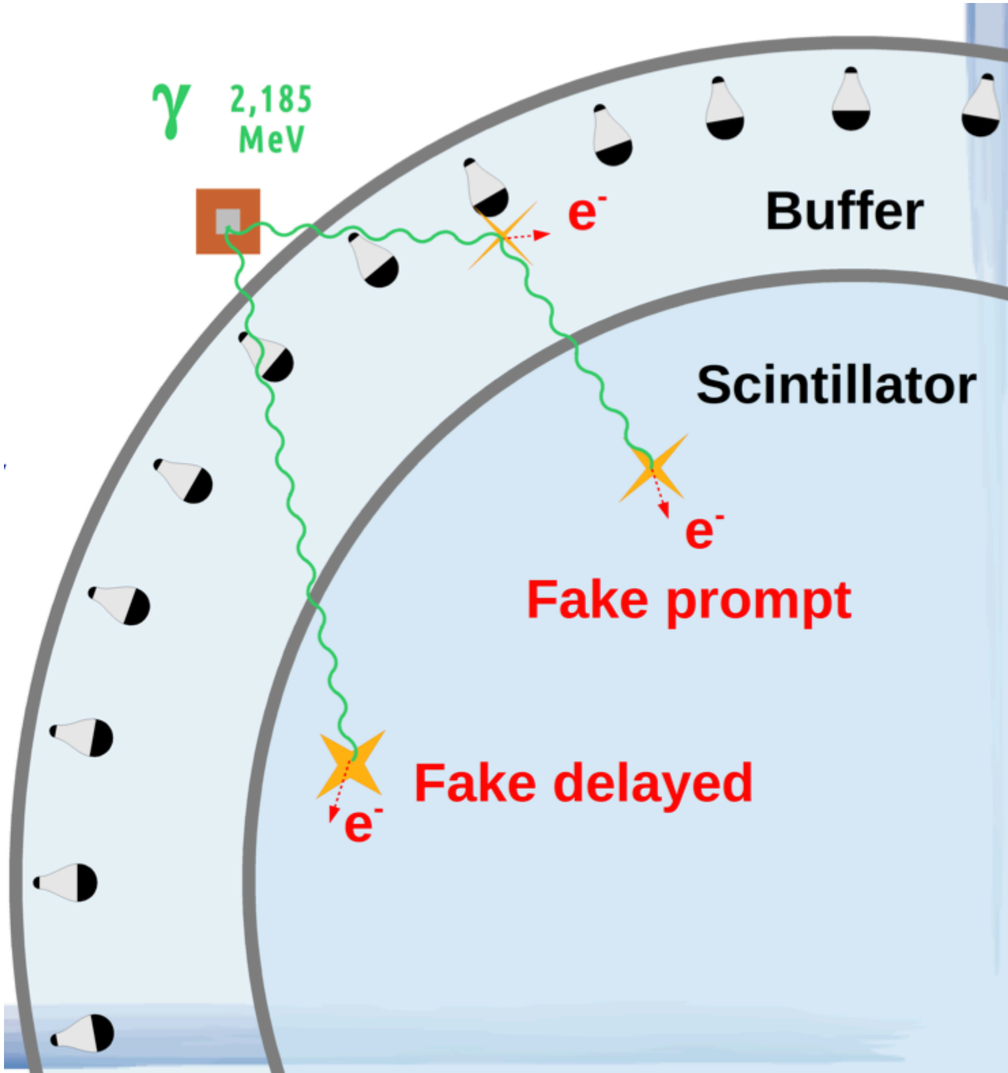
Expected Signal if Oscillation

$$\frac{d^2N(R,E_\nu)}{dRdE_\nu} = \mathcal{A}_0 \cdot n \cdot \sigma(E_\nu) \cdot \mathcal{S}(E_\nu) \cdot \mathcal{P}(R,E_\nu) \int_0^{t_e} e^{-t/\tau} dt,$$



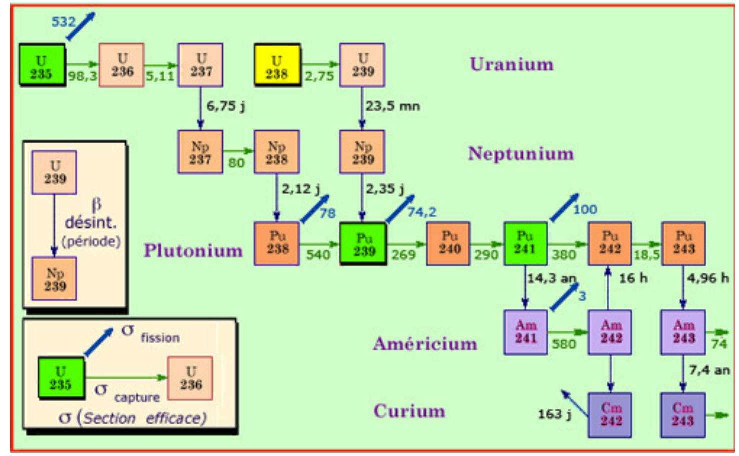
Gamma Background

- Random coincidence between two γ's from CeANG
- IDB-like event:
  - Prompt: $E_\gamma > 1$ MeV
  - Delayed: E_d in [2 – 2.4] MeV
  - Time window: 1 ms (3 τ)
- Simulations
  - GEANT4 (limited)
  - TRIPOLI-4
- Results:
  - 2 10^{-4} event/day (w/o E cut)
  - O(10^{-5}) event/day (w E cut)
  - 50% uncertainty
  - Negligible (HDTAS design)



Neutron Background

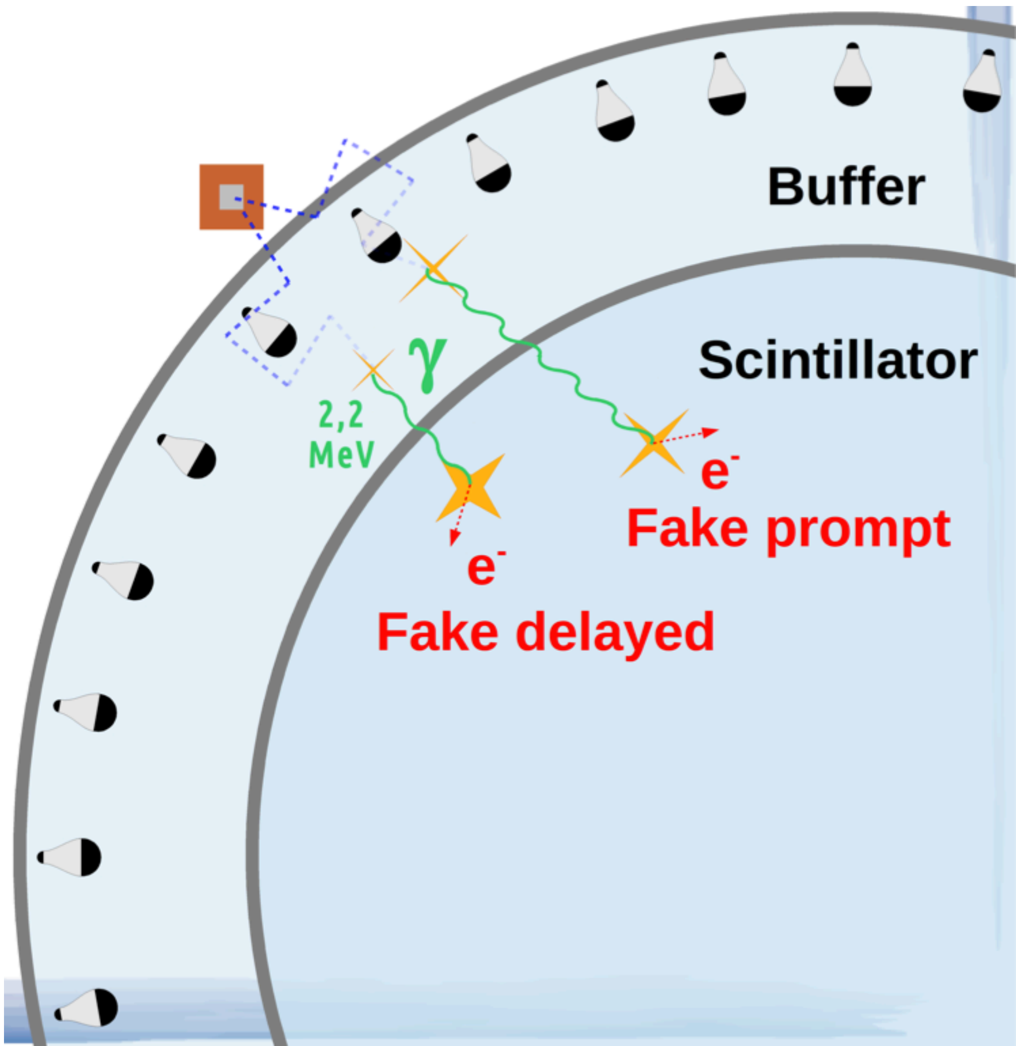
- **Traces of minor actinides**
  - Am, Cm, Bk, Cf,…
  - Spontaneous fission (SF)
    - Few neutrons released
  - (α,n) reaction
    - 2 orders of magnitude lower than SF rate (MePHI/SCALE 5)
- **Most dangerous nuclei: ^{244}Cm**
  - ^{244}Cm ~ all Cm after 3 years
  - T =18,1 y ; I_{SF} =1.4.10^{-6} ; 2,7 n/SF
  - Heavier minor actinides
    - Higher branching ratio to SF
    - But much less produced during irradiation
- **Measurement of MA traces**
  - Mass spectrometry
  - CEA/DEN - DPC/SECR



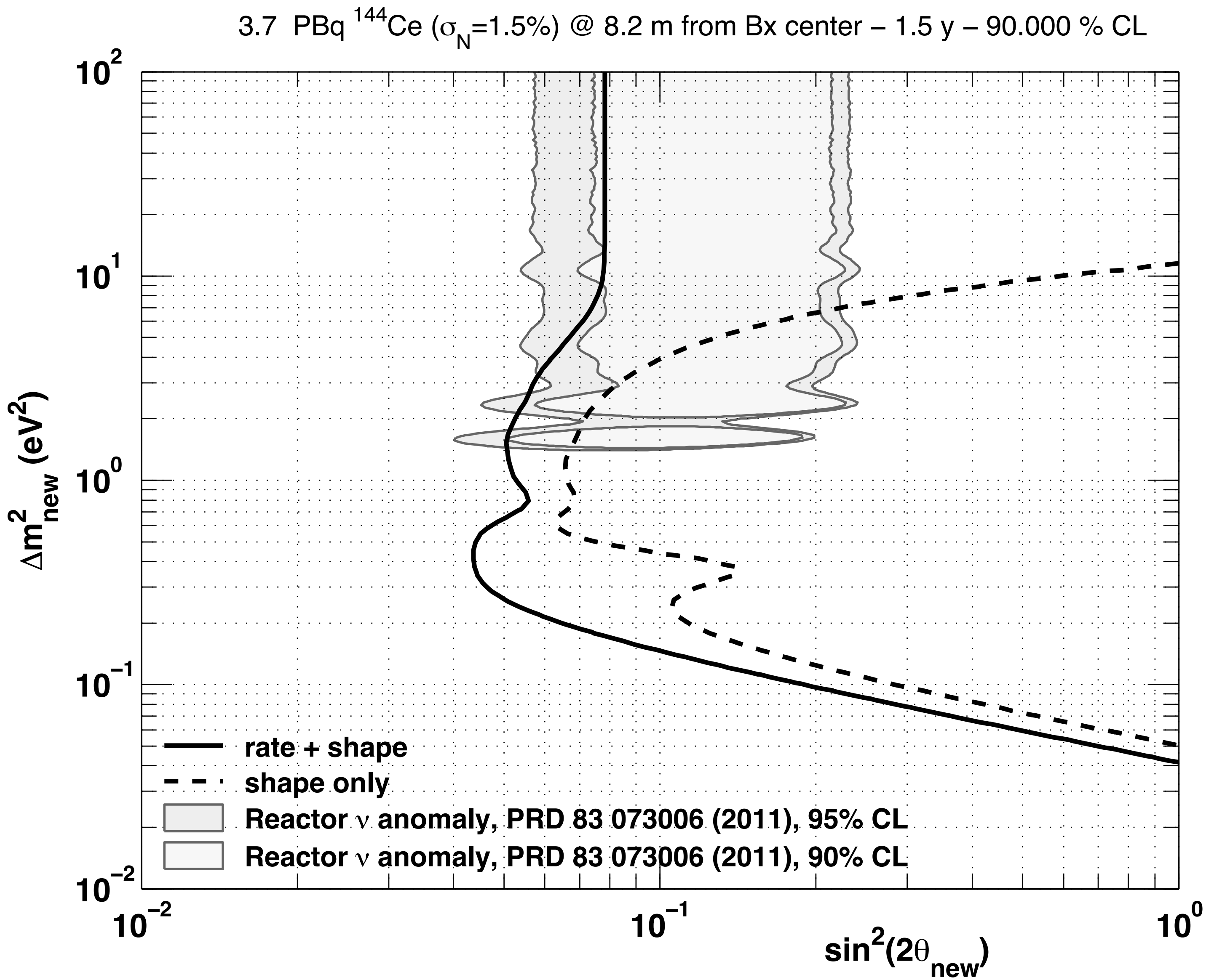
Isotope	Half-life	I_{SF} (%)	Specific neutron activity (n/g)
^{241}Am	432.2 y	$4.0\ 10^{-10}$	1.2
^{242m}Am	141 y	$4.7\ 10^{-9}$	46
^{243}Am	7370 y	$3.7\ 10^{-9}$	0.72
^{243}Cm	29.1 y	$5.3\ 10^{-9}$	$2.6\ 10^{2}$
^{244}Cm	18.10 y	$1.4\ 10^{-4}$	$1.6\ 10^{7}$
^{245}Cm	$8.5\ 10^{3}$ y	$6.1\ 10^{-7}$	$1.1\ 10^{2}$
^{246}Cm	$4.73\ 10^{3}$ y	$3.0\ 10^{-2}$	$1.0\ 10^{7}$
^{248}Cm	$3.40\ 10^{5}$ y	8.39	$4.2\ 10^{7}$

Neutron Background

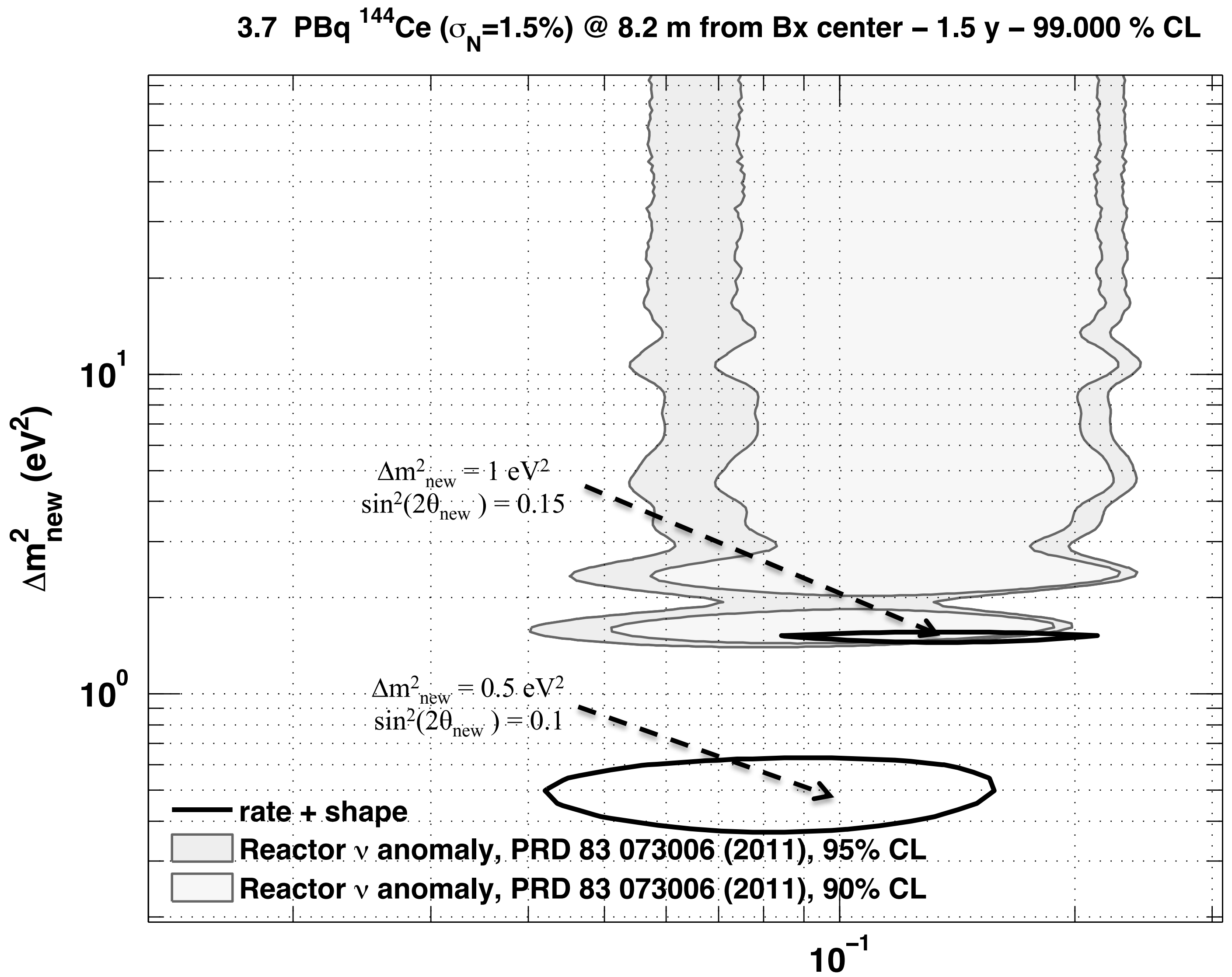
- **Minor actinides SF fission**
  - 10^{-5} Bq ^{244}Cm / Bq ^{144}Ce
- **2 neutrons captured in BX releasing 2 γ's**
- **IDB-like event:**
  - Prompt: E_{γ} > 1 MeV
  - Delayed: E_d in [2 – 2.4] MeV
  - Time window: 1 ms (3 τ)
- **Simulations**
  - TRIPOLI-4
- **Results:**
  - < O(10^{-2}) event/day
  - 50% uncertainty



Exclusion contour



Discovery Potential

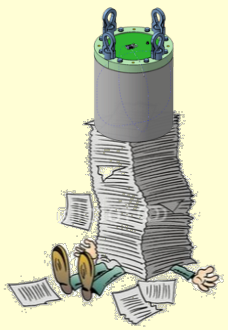


CeANG Disposal

- Option A: in Russia
  - Agreement by Rosatom & FUSE PA Mayak
  - Pros: Disposal done right after data taking
  - Cons: Russian facilities being created
  - Cons: Cost for transportation

- Option B: in France
  - 14 years storage at CEA (INB ATALANTE in Marcoule)
  - Final disposal at ANDRA
  - Pros: No expensive transportation
  - Cons: Unloading of the CeANG and handling on site
  - Cons: Management of the CeANG during 14 years
  - Cons: Need ASN approval

Legal authorizations

Item	Authorization	Responsability	Implemented by	Subcontractor	Competent regulation authority	Submission Date	Expected Review Time	Expected Agreement Date
CeANG	CeANG SFRM certificate	CEA	PA Mayak	none	Rosatom	déc-14	3 months	march-2015
	CeANG importation in France	CEA	CEA	none	ASN	26/10/2014	3 months	january-2015
	CeANG exportation to Italy	CEA	CEA	none	ASN	26/10/2014	3 months	january-2015
	Hosting CeANG at CEA	CEA	CEA	none	ASN/Prefecture	26/10/2014	3 months	january-2015
	CeANG use at LNGS	INFN	INFN	SRS	ISPRA / Minister of Economic Activities	nov-14	1 y?	?
Transportation: TN-MTR	CeSOX TN-MTR Licensing in France and Russia	CEA / INFN	AREVA / CEA	AREVA	ASN	31/10/2014	5 months	march-2015
	Validation of the CeSOX TN-MTR Licensing in Italy	CEA / INFN	AREVA / CEA	MIT	ISPRA	31/03/2015	6 months ?	sept-15
Transportation: Logistic	Transportation authorization from Mayak to St Petersburg	CEA / INFN	PA Mayak	SPB-Izotop	Rosatom	< 05/2015	6 months ?	sept-15
	Transportation authorization from St-Petersburg to France	CEA / INFN	AREVA / CEA	NSC or ASPOL (boat) / LBU (road)	ASN	< 05/2015	6 months ?	sept-15
	Transportation authorization in Italy	CEA / INFN	AREVA	MIT / LBU (road)	ISPRA/Minister of Transportation	< 05/2015	6 months ?	sept-15

Conclusion

- **Cerium Antineutrino Generator**
  - >3.7 PBq ^{144}Ce-^{144}Pr production in 2015 – Negotiation ongoing
- **Shielding:** Designed – Tender closed - To be ordered in November
- **Logistic**: TNMTR licensing ongoing. AAPC published for logistics
- **Activity Calibration**: Calorimeter being realized
- **Host Detector Deployment:** Borexino is getting ready
- **CeSOX Collaboration**
  - CEA: DSM-Irfu / DEN / SPR / LNHB
  - Borexino Collaboration + Hawaii Univ.
- **Goal: Start Data Taking by December 2015**
- **Risks:** CeANG specifications, authorizations, schedule