SOX:
SHORT DISTANCE NEUTRINO OSCILLATIONS WITH BOREXINO

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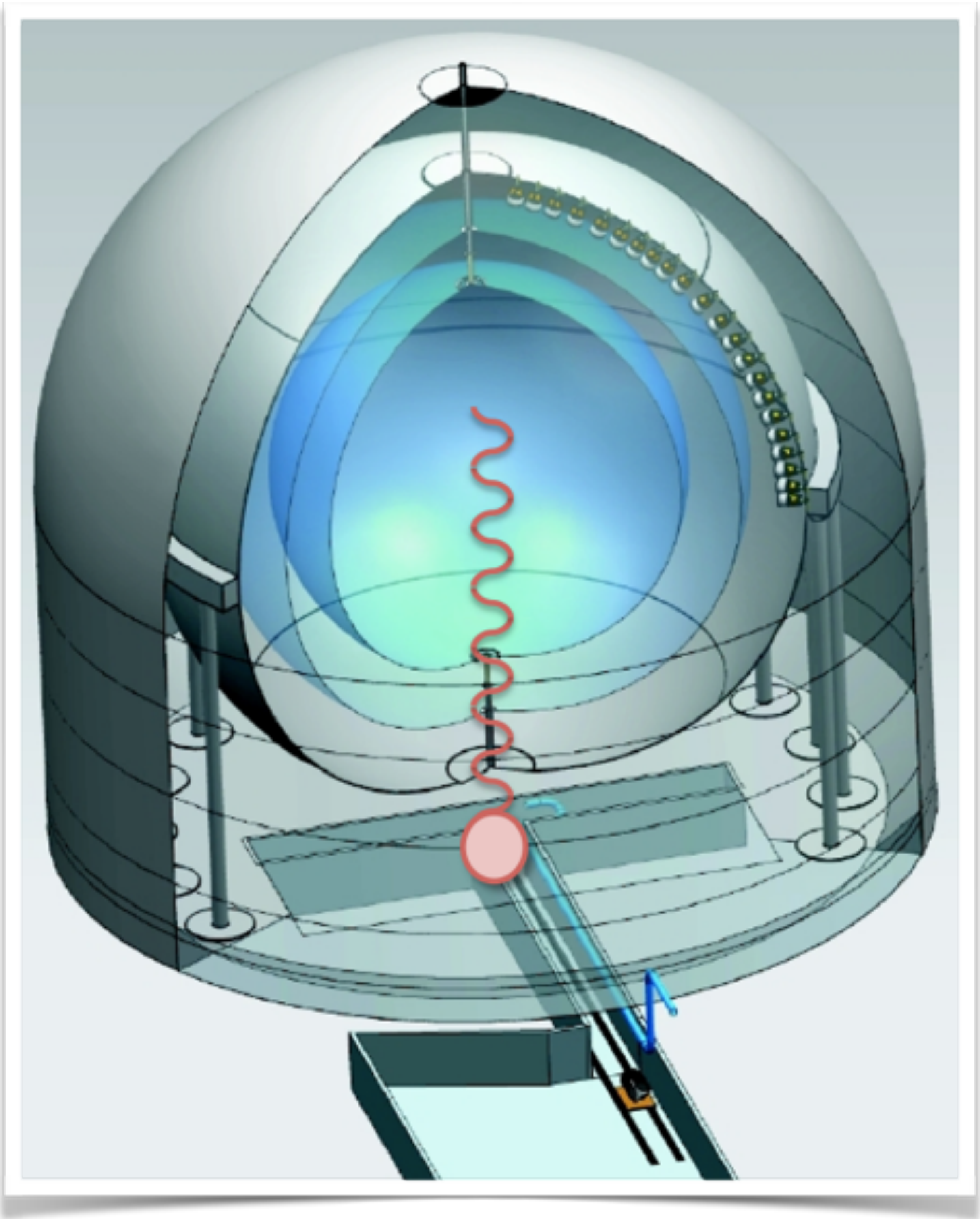
on behalf of the Borexino/SOX Collaboration

Technical University of Munich

SHORT DISTANCE NEUTRINO OSCILLATIONS WITH BOREXINO



(anti)-neutrino source

Borexino detector

→ oscillatory pattern in energy and space

THE ANTINEUTRINO SOURCE

activity: (100-150) kCi ≈ (3.7-5.5) PBq

^{144}Ce $\xrightarrow{\beta^-}$ ^{144}Pr $\xrightarrow{\beta^-}$ ^{144}Nd

$T_{1/2}$=285d
Q ~0.3 MeV

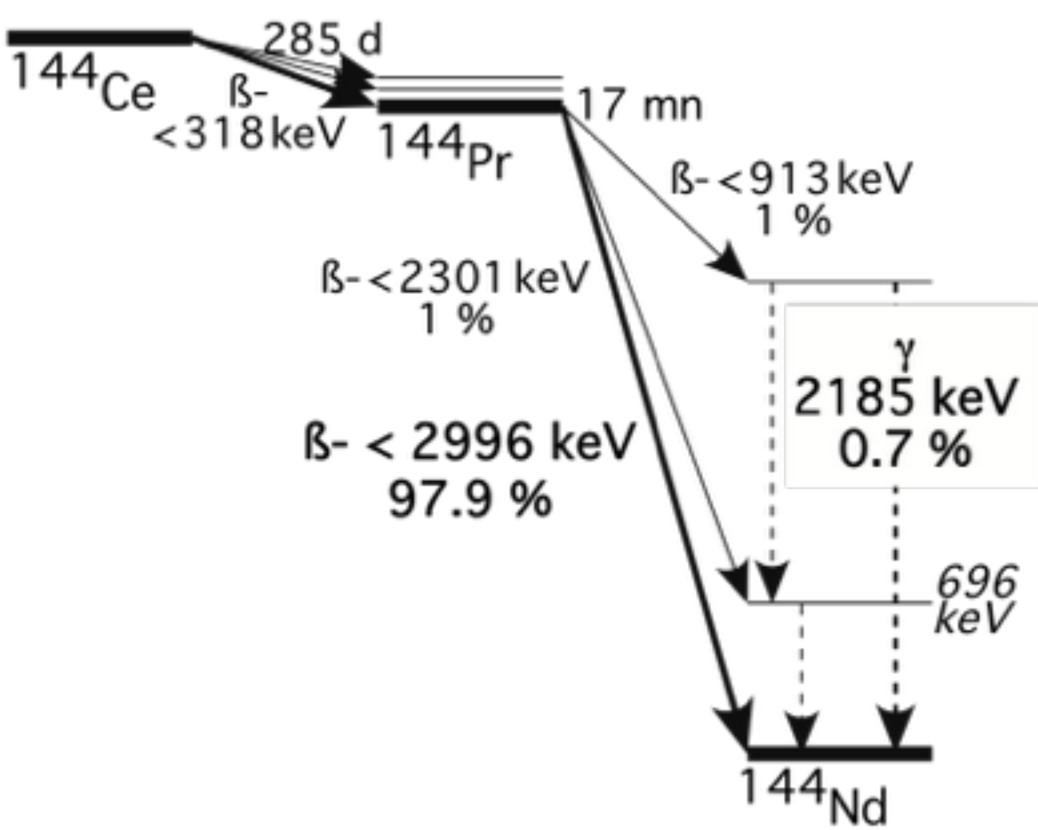
$T_{1/2}$=17min
Q ~ 3 MeV

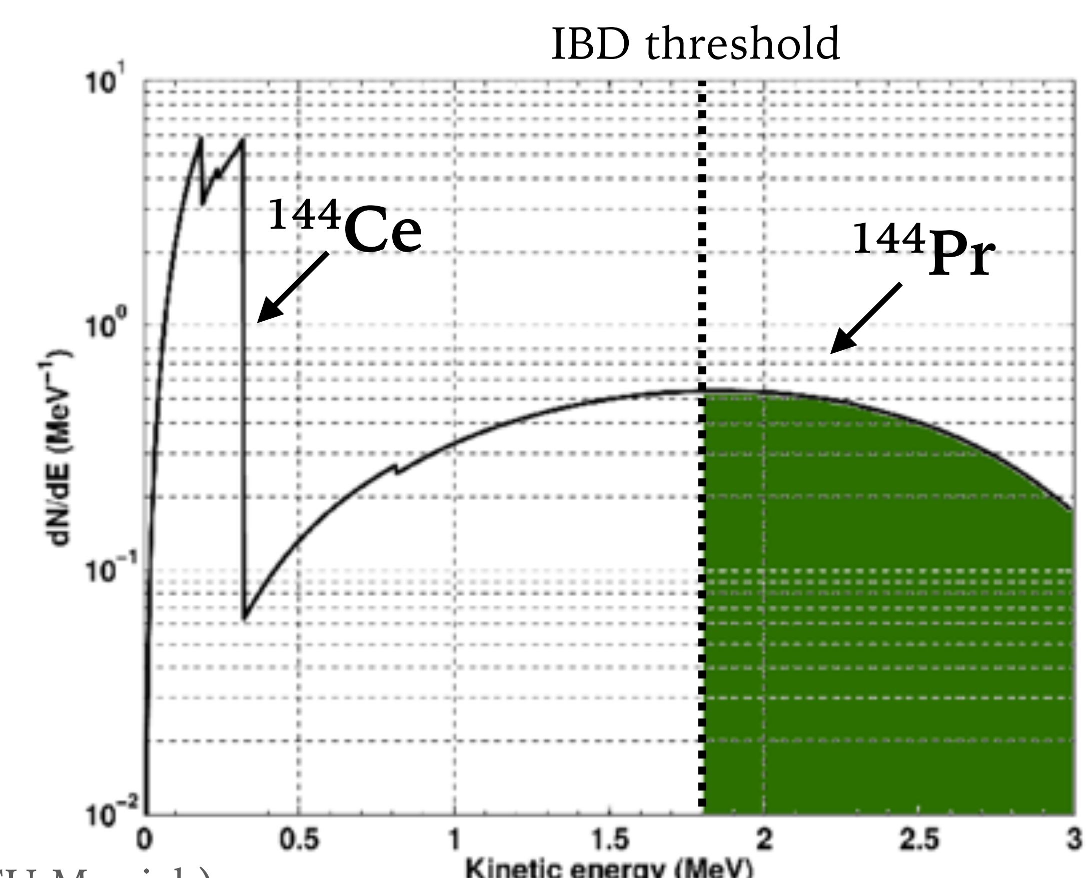
long life time

- production
- transportation
- measurement

high Q value

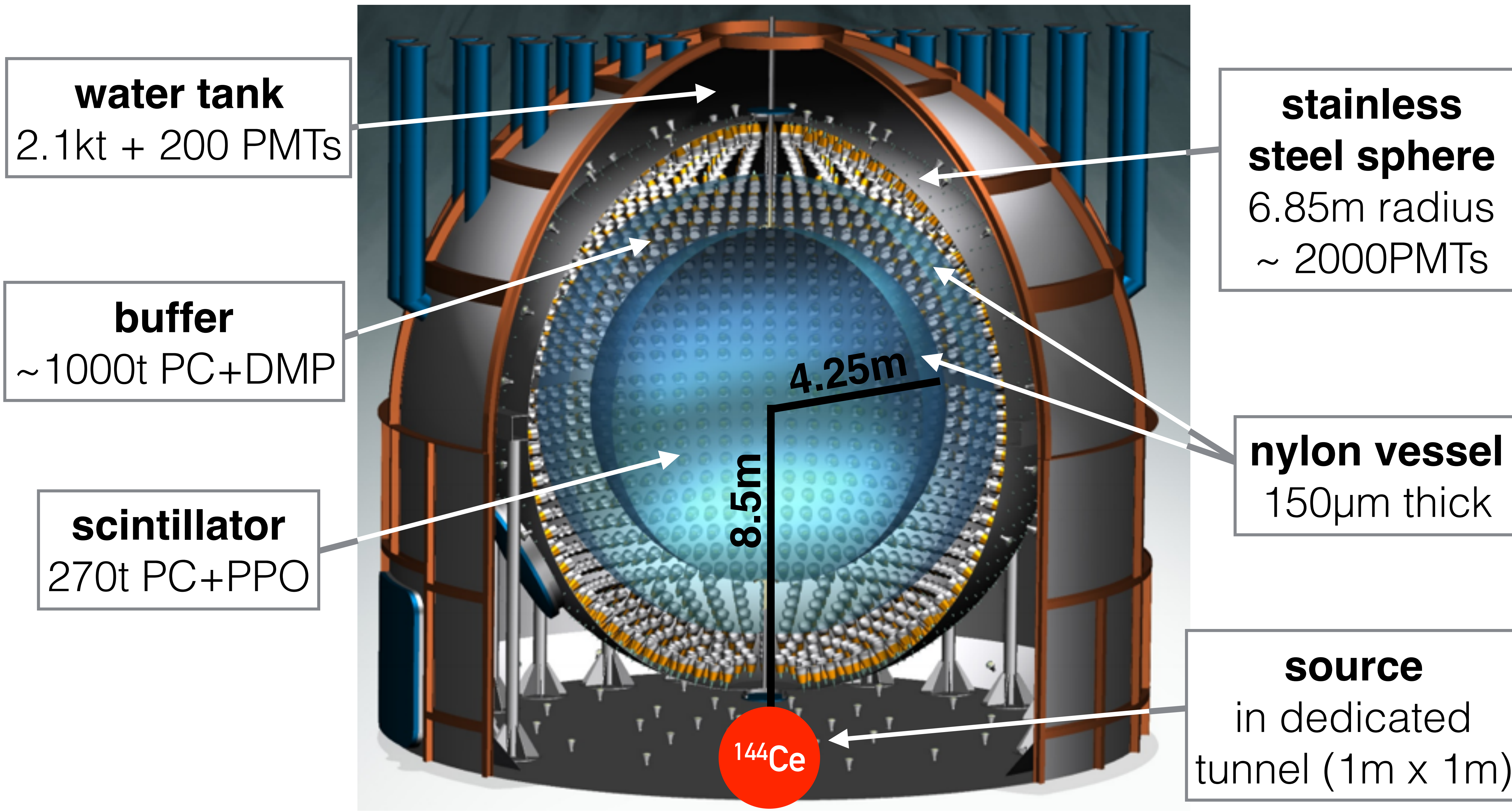
- antineutrinos above IBD threshold





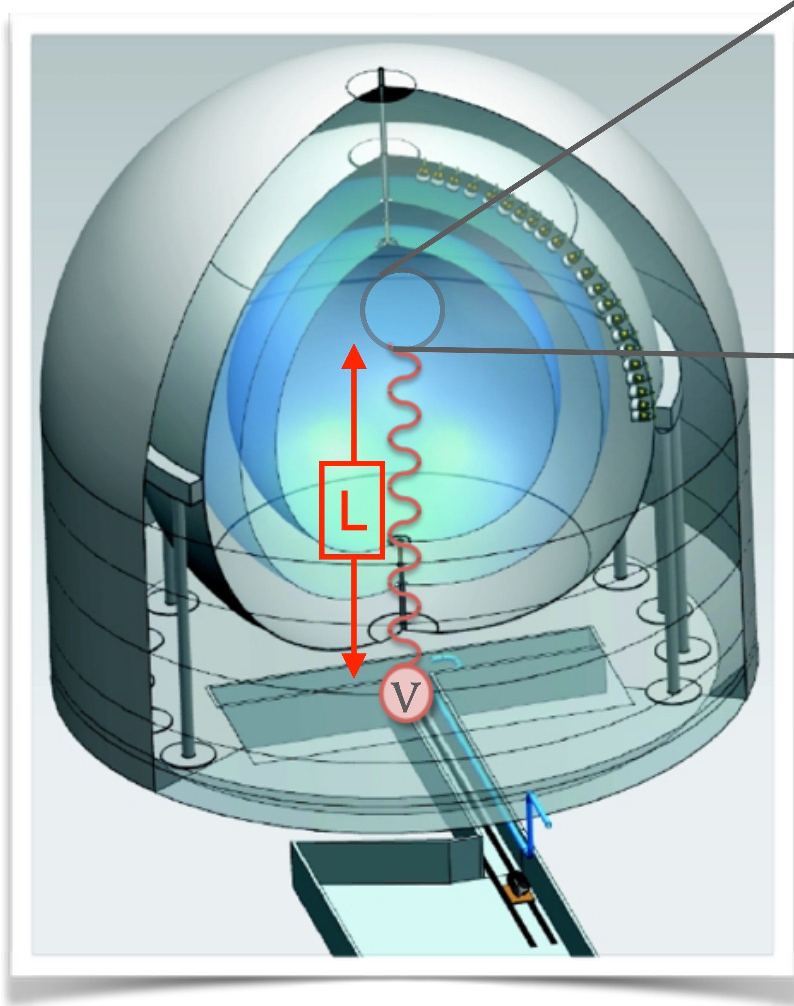
THE BOREXINO DETECTOR *talk by Davide D'Angelo, this morning*

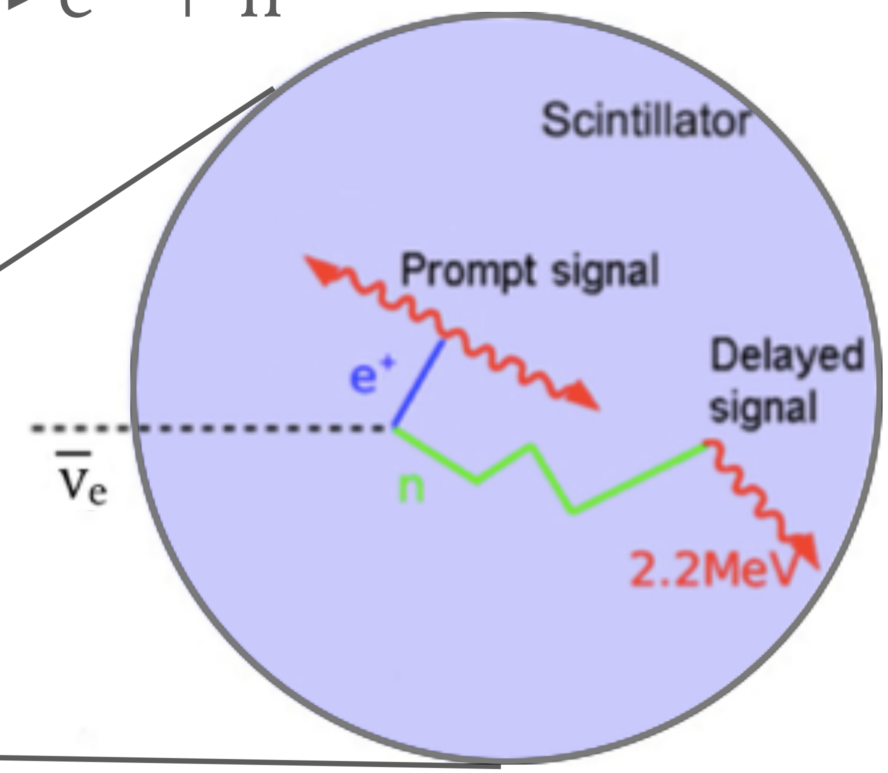
located at LNGS (3800 m.w.e)



DETECTION MECHANISM

- Inverse Beta Decay (IBD): $\overline{\nu}_e + p \longrightarrow e^+ + n$
  - e^+: E & L info about $\overline{\nu}_e$
  - n: coincidence in time and space
    - background free



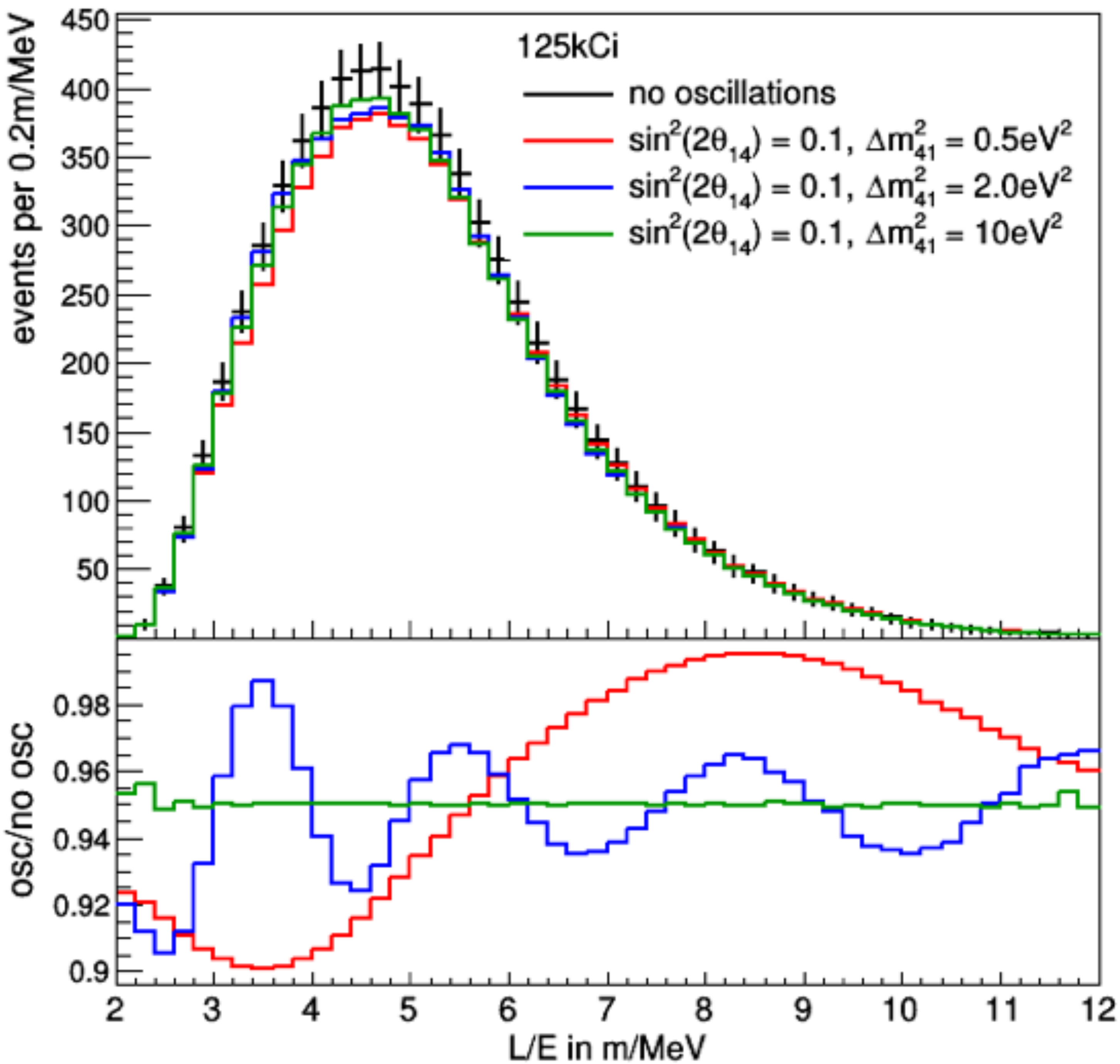


- PMTs collect scintillation light
  - energy E (5% @ 1MeV)

time of flight
  - position L (10cm @ 1MeV)
- measurement of count rate: N(E,L)

STERILE NEUTRINO SIGNATURE

$\sim 10^4$ events for 1.5y measurement time



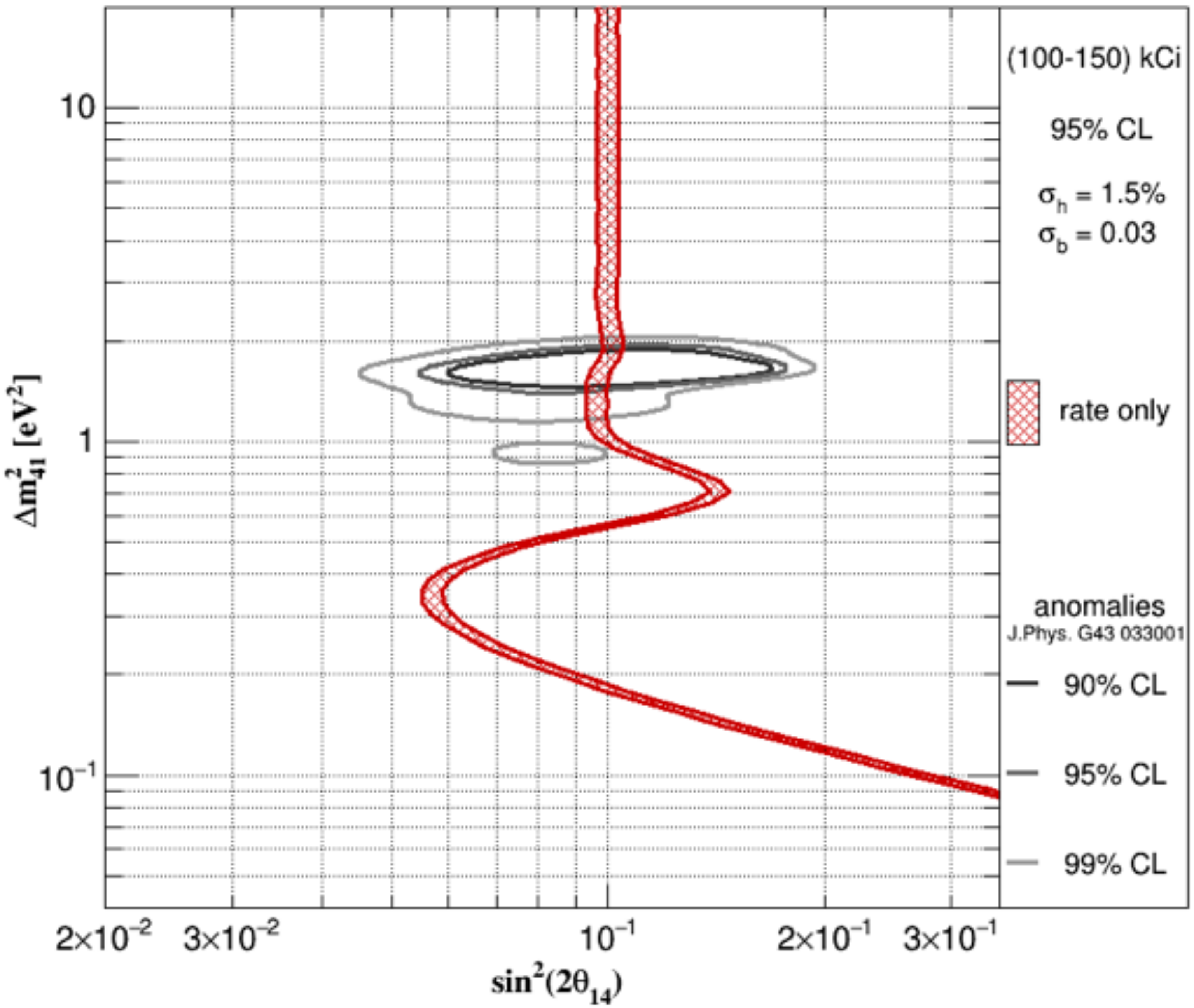
survival probability in a 3+1 model:

$$P_{ee} \approx 1 - \sin^2(2\theta_{14})\sin^2\left(\frac{1.27\Delta m^2_{41}(eV^2)L(m)}{E(MeV)}\right)$$

Oscillations in:

- **rate**
  - disappearance
  - for all Δm^2 - values
- **shape**
  - spatial waves
  - for $\Delta m^2 \sim O(eV^2)$
  - $L_{osc} >$ spatial resolution & $L_{osc} <$ detector size
  - smoking gun signature

SENSITIVITY

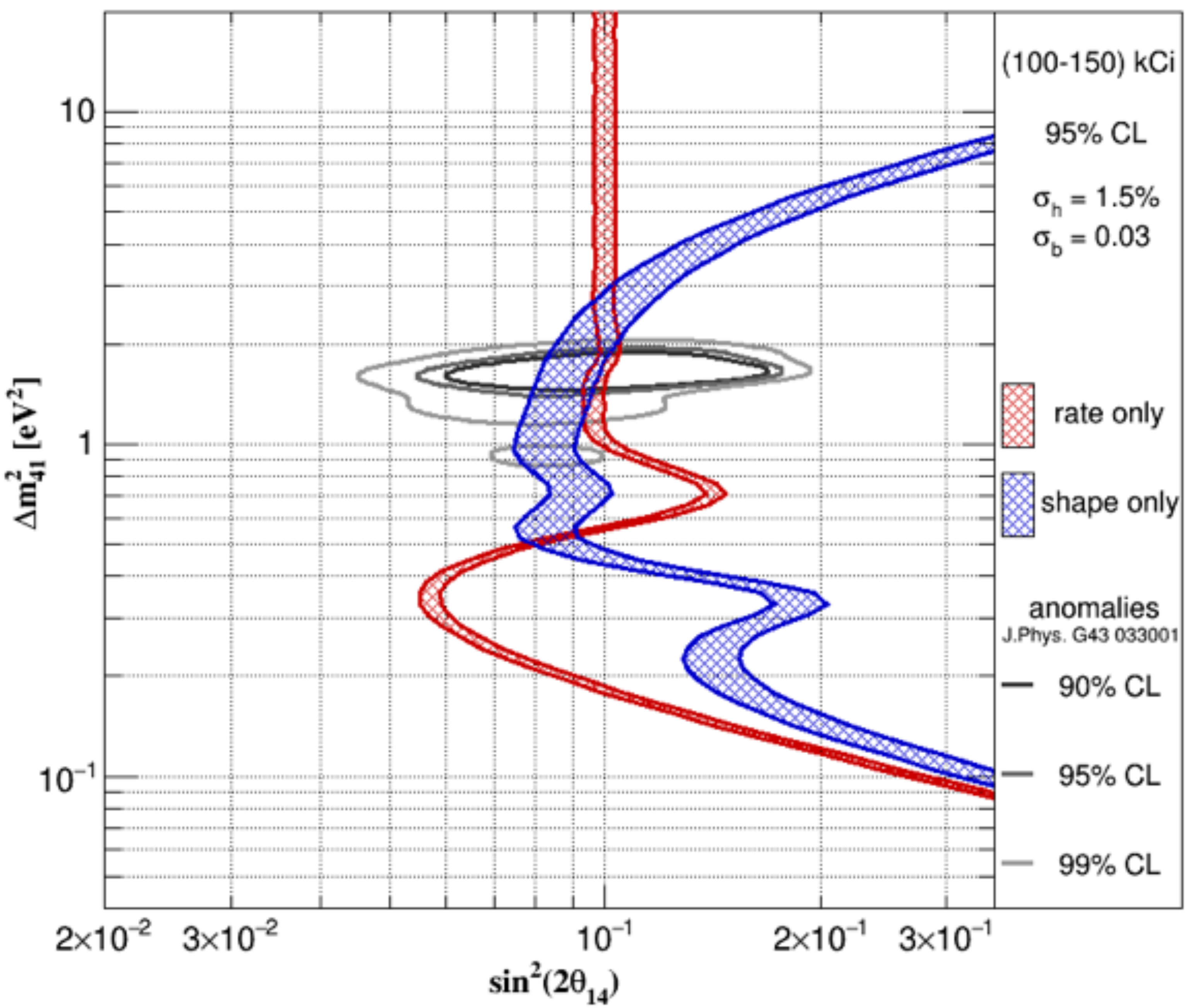


Analysis in:

- **rate**

  precise knowledge of
  - activity
  - neutrino spectrum
  - fiducial volume

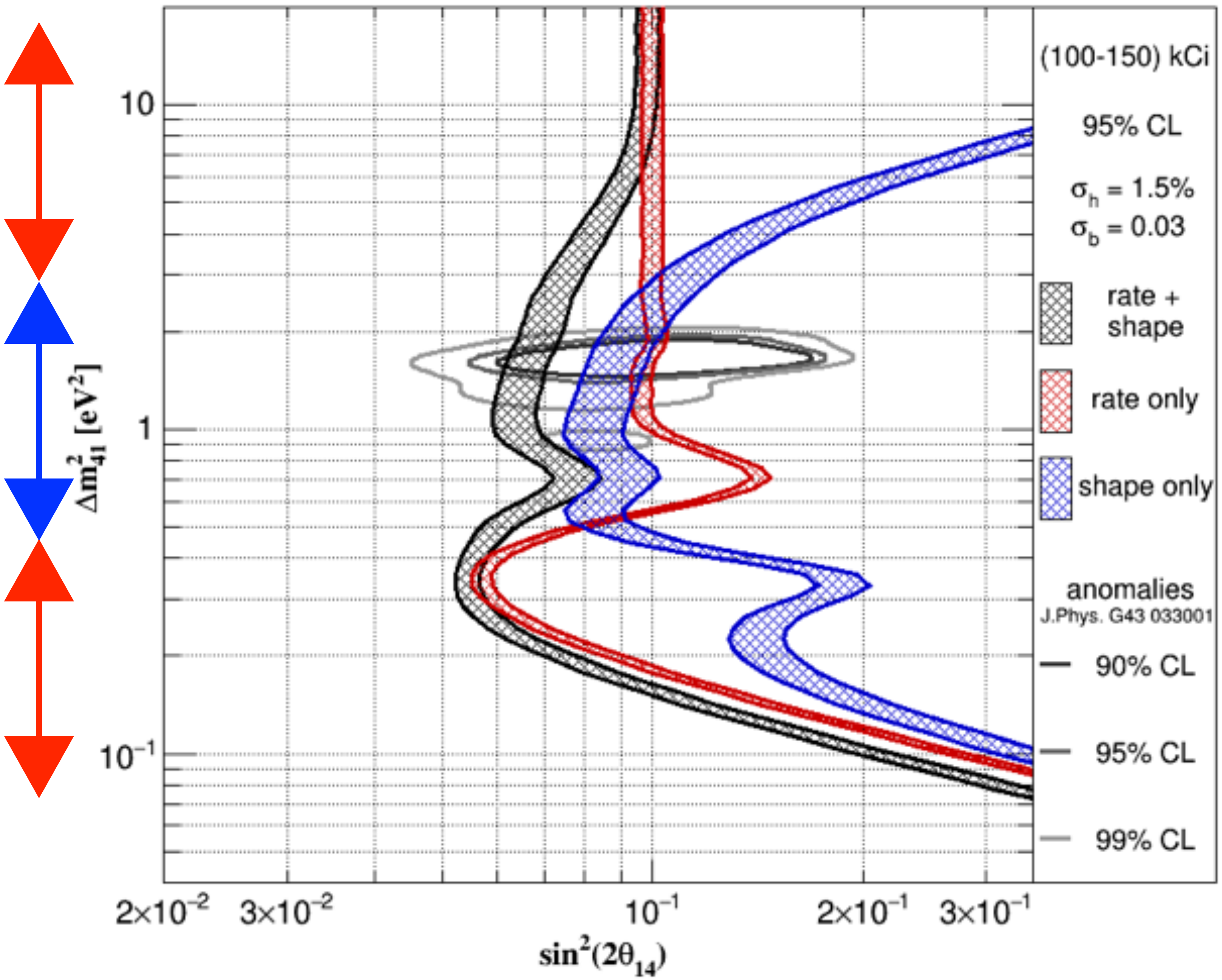
SENSITIVITY



Analysis in:

- **rate**
  precise knowledge of
  - activity
  - neutrino spectrum
  - fiducial volume
- **shape**
  no dependence on systematics in scale

SENSITIVITY



Analysis in:

- **rate**
  precise knowledge of
  - activity
  - neutrino spectrum
  - fiducial volume
- **shape**
  no dependence on systematics in scale
- **rate + shape**
  combination

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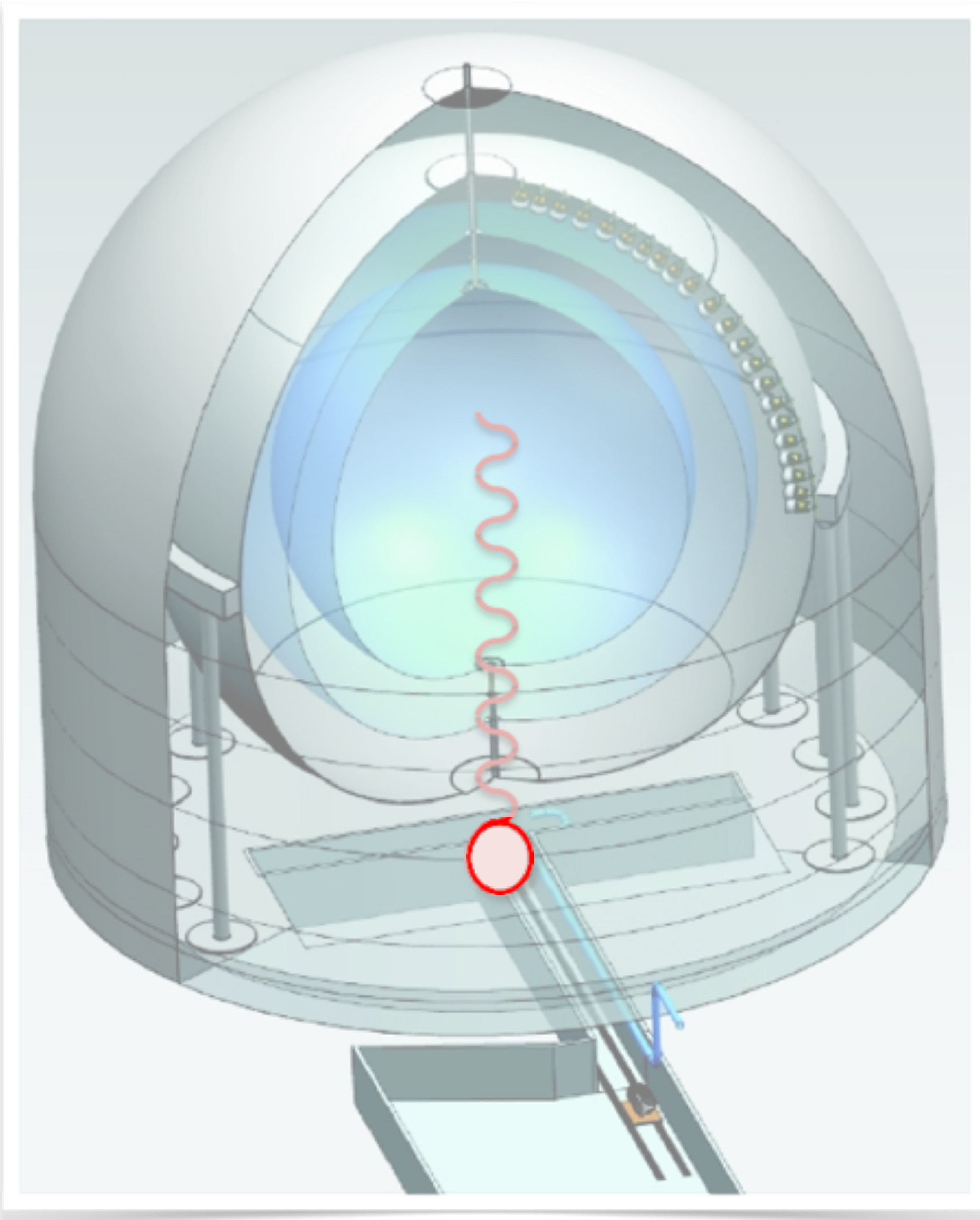
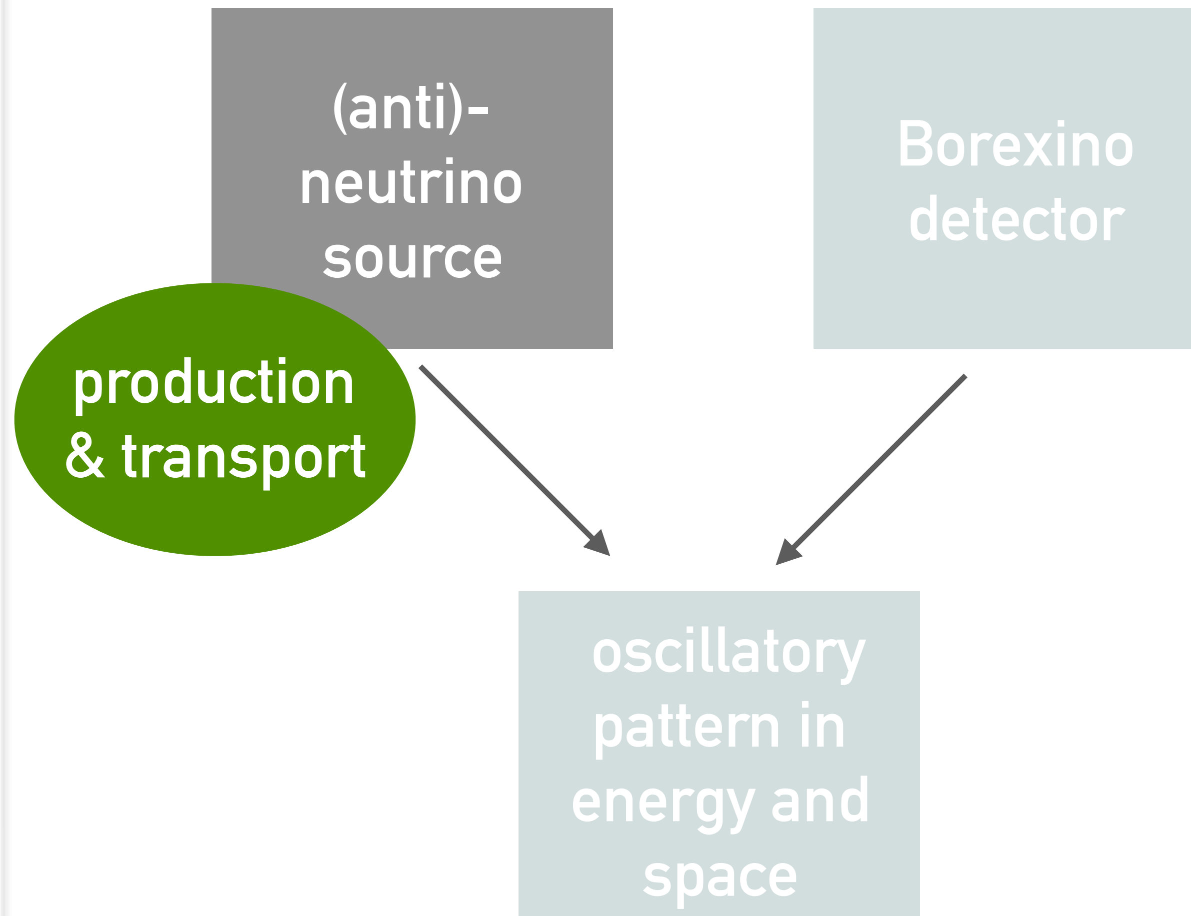
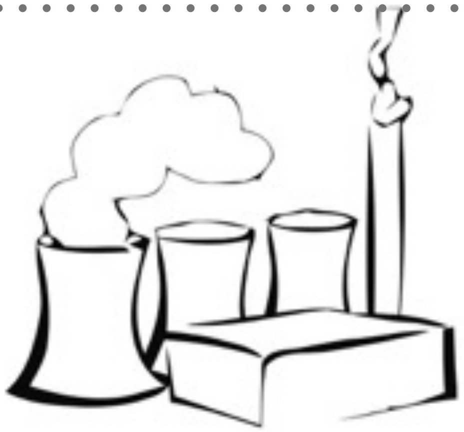




SOURCE PRODUCTION



2t *spent nuclear fuel from research reactor*

PUREX®

PUREX raffinate

rare earth precipitation

solution of lanthanides

displacement chromatography

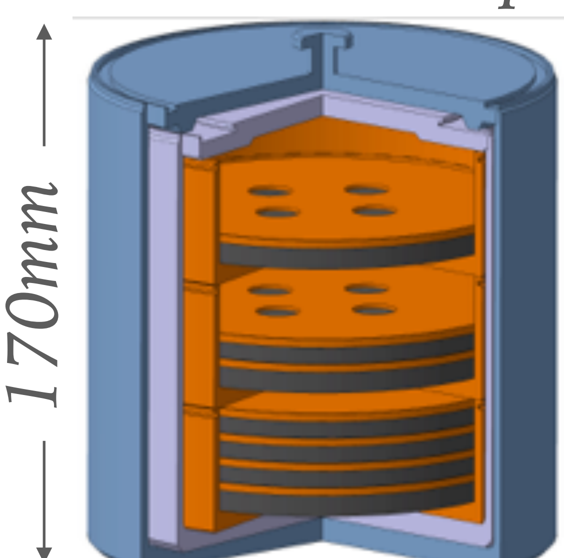
Cerium oxalate

calcination

***~4kg** CeO_2*

***~40g** ^{144}Ce*

stainless steel capsule



one facility worldwide producing PBq-scale of ^{144}Ce: FUSE PA Mayak

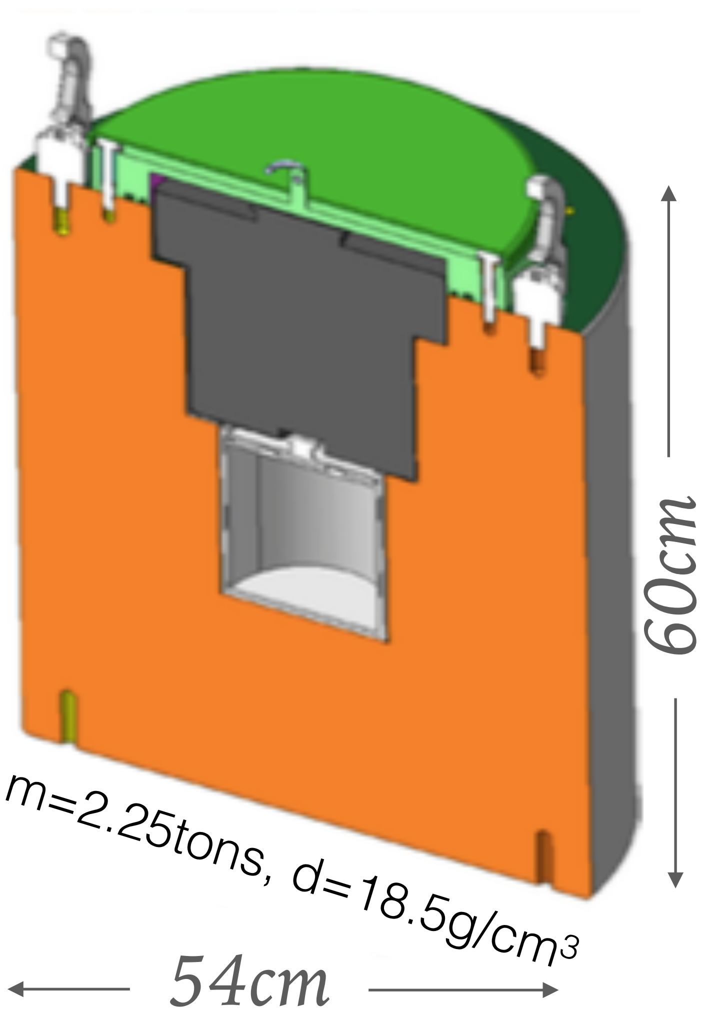
SOURCE SHIELDING AND TRANSPORTATION

shielding:

- attenuation factor for 2.2MeV-γ: $>10^{12}$
- 19cm thick W-alloy shield
- manufactured at Xiamen Ltd., China

transportation:

- few boarder crossings
- total transportation time less than 3 weeks



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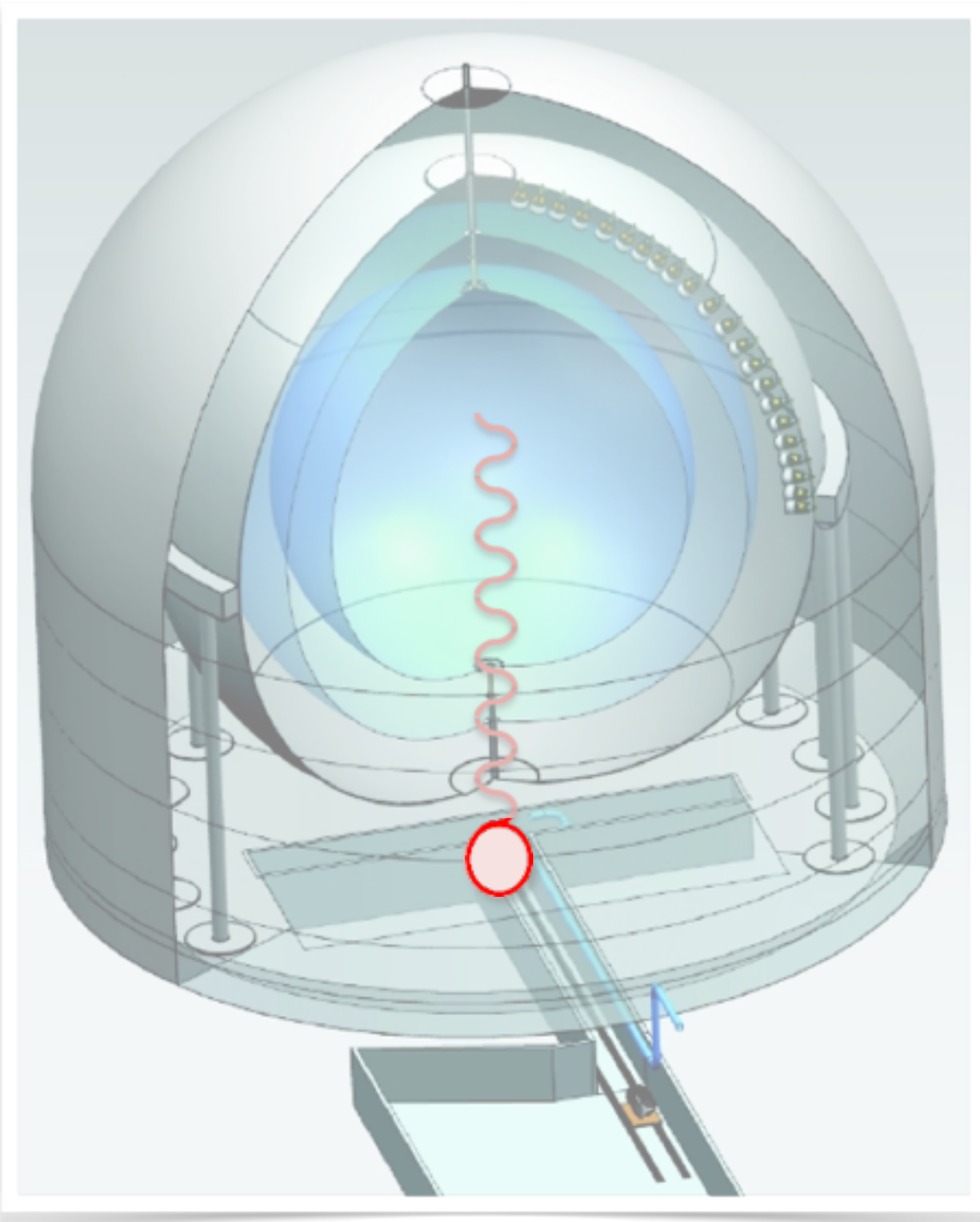

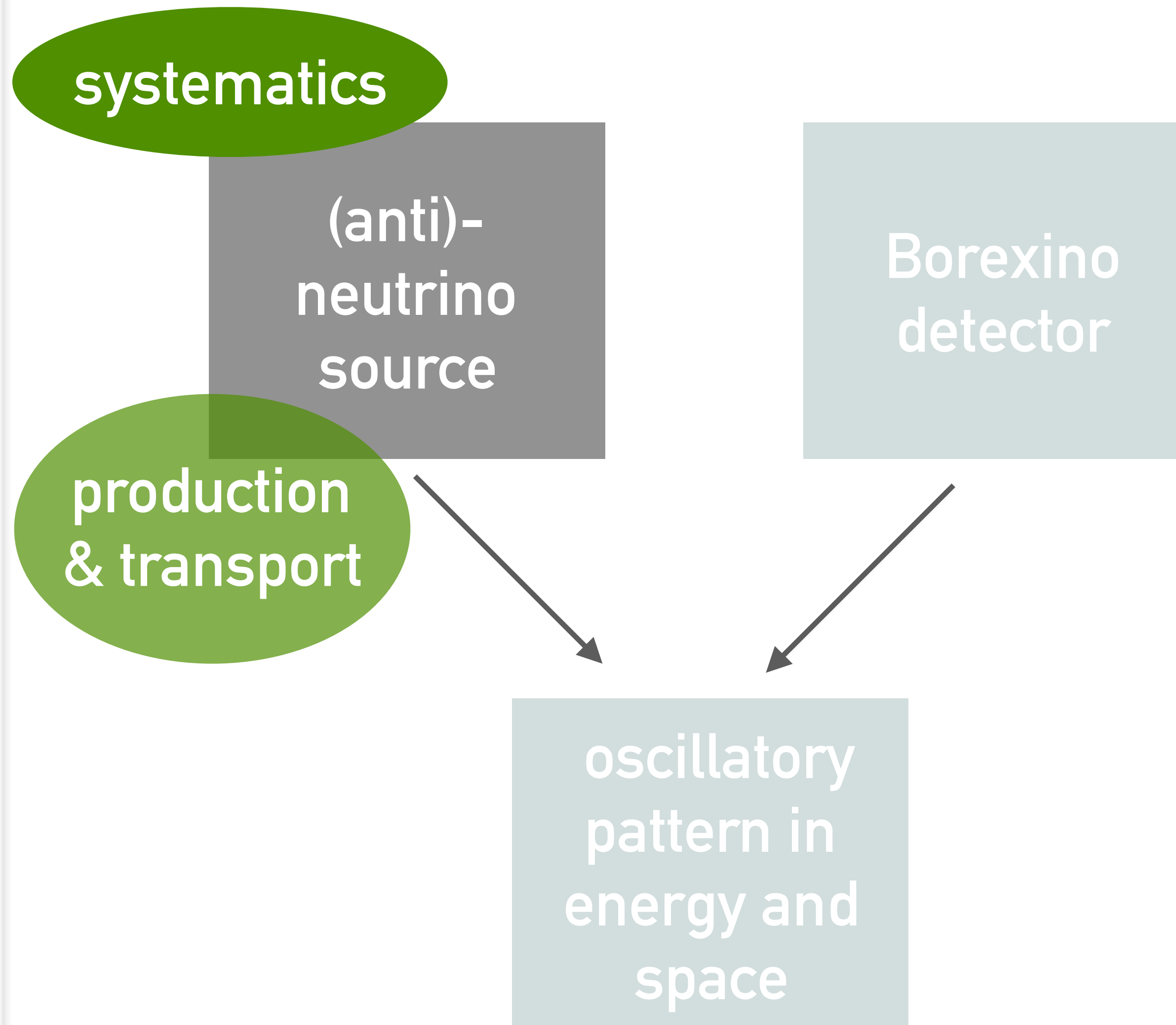

SOURCE RELATED SYSTEMATICS

$N(E,L,t) \sim A(t)$

↘ $P(t)$

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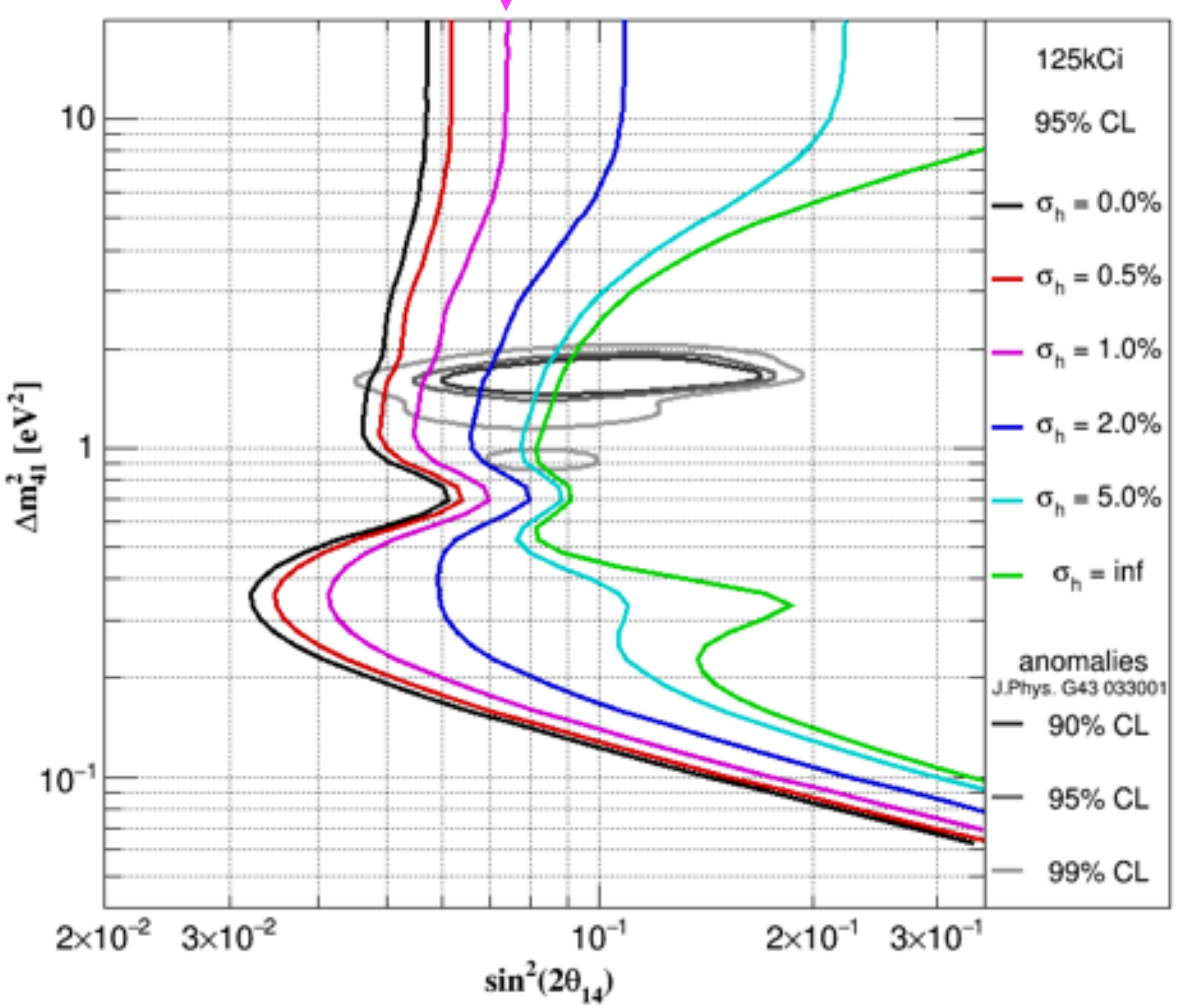
goal: 1%

power



SOURCE RELATED SYSTEMATICS

$N(E,L,t) \sim A(t) \cdot S_\nu(E,b)$

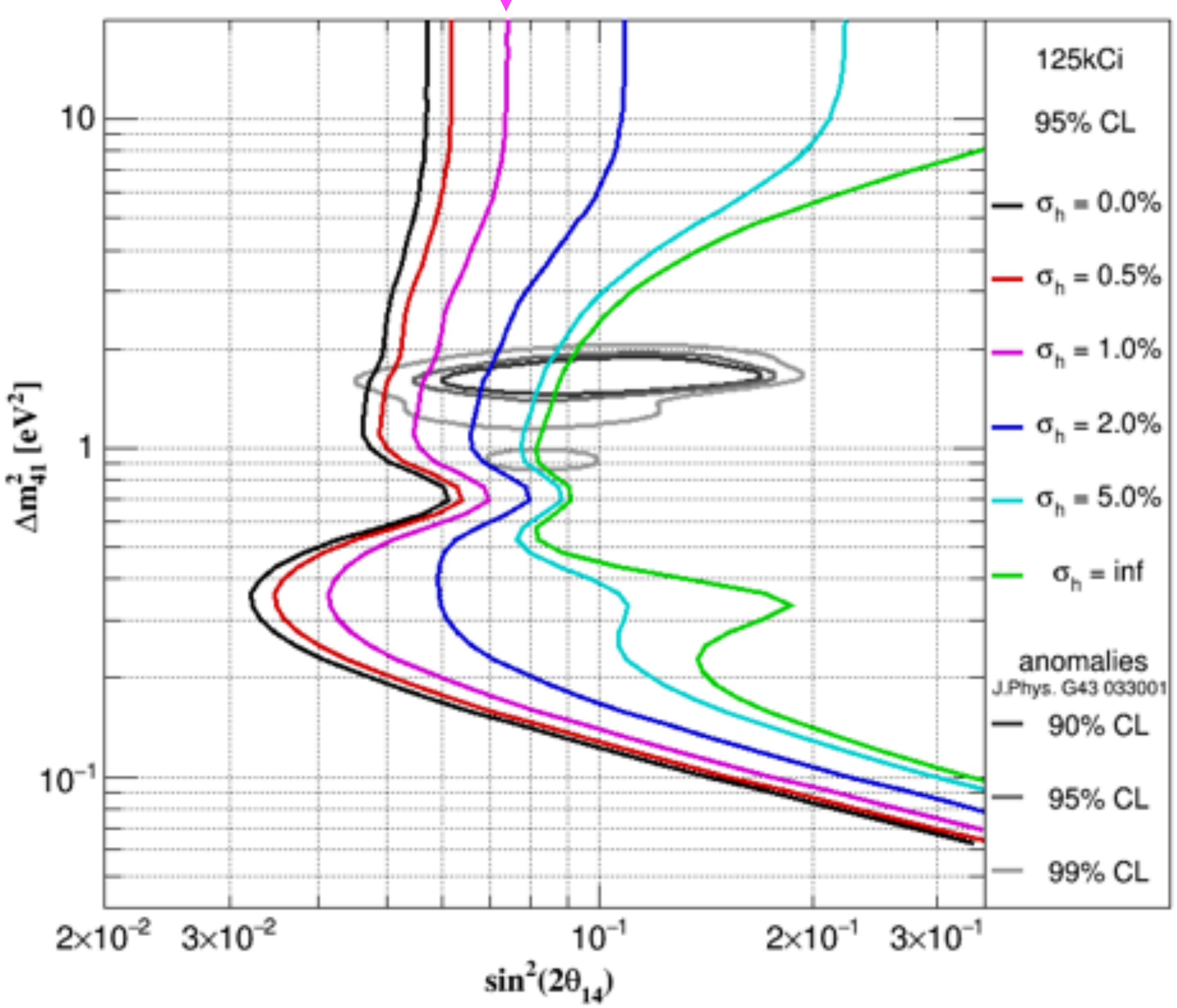
$P(t)/\langle E(b) \rangle$

1st forbidden non unique decay

- *large theoretical uncertainties*
- *previous measurements differ up to 10%*

goal: 1%

power



SOURCE RELATED SYSTEMATICS

$N(E,L,t) \sim A(t) \cdot S_{\nu}(E,b)$

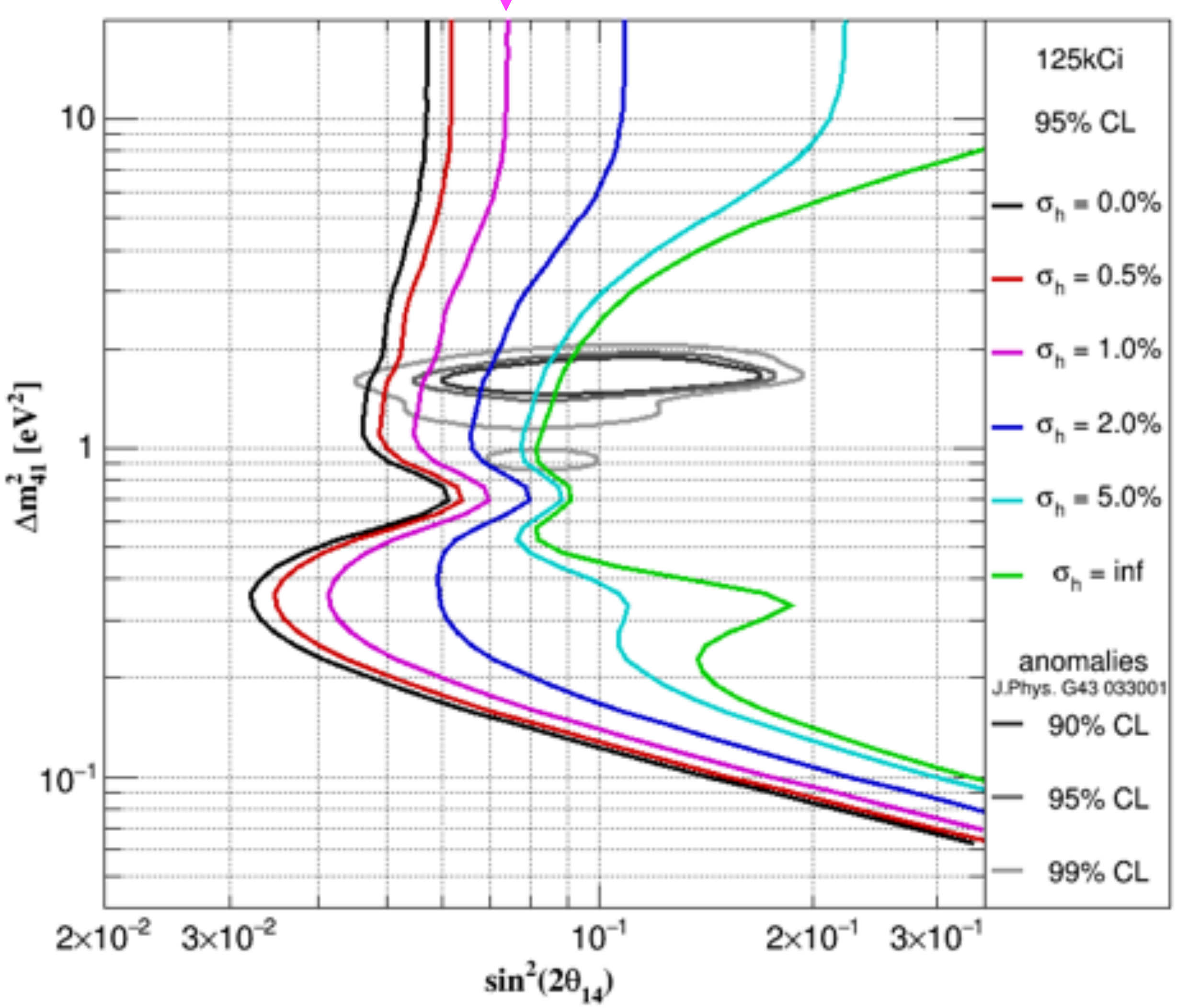
$P(t)/\langle E(b) \rangle$

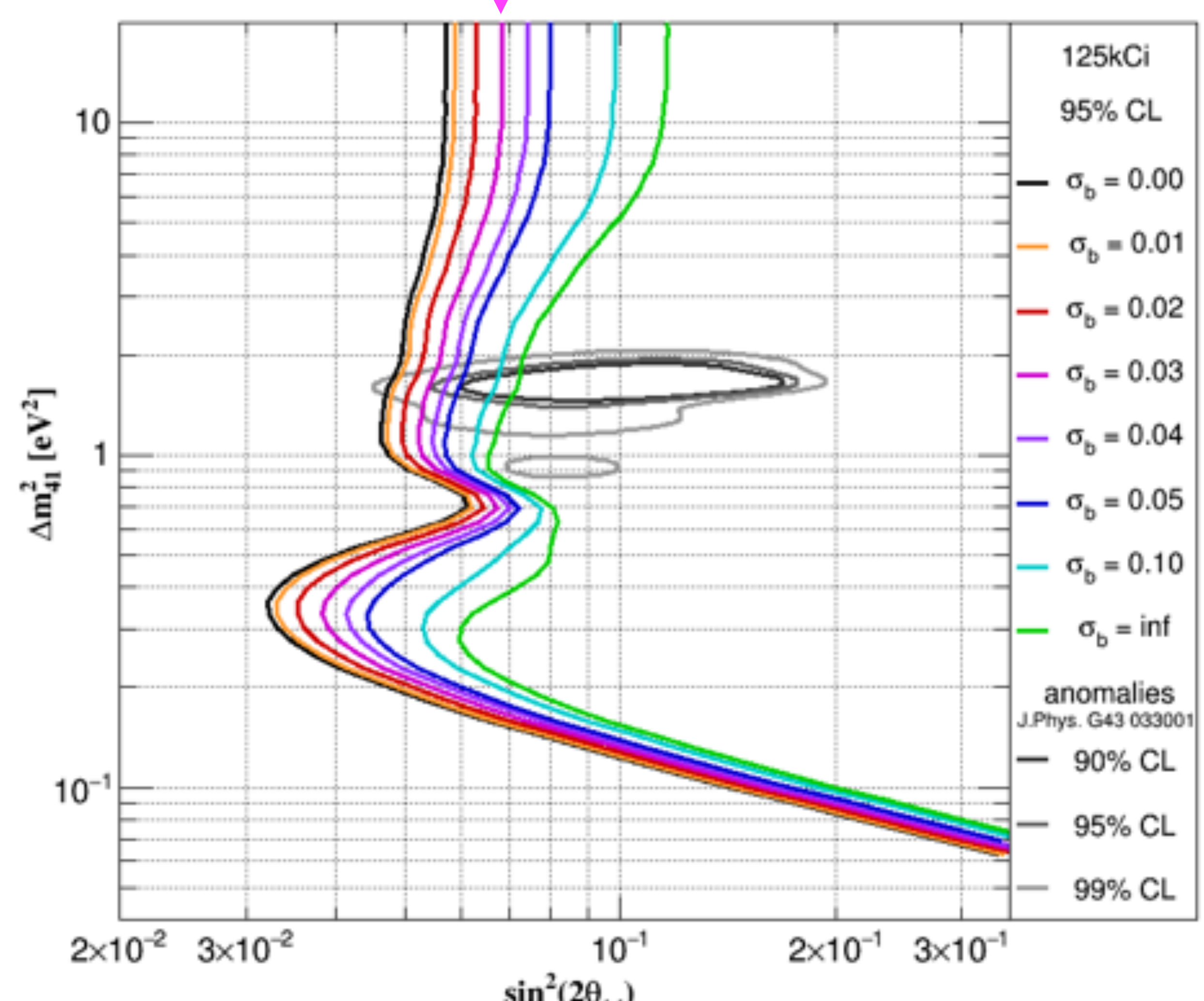
1st forbidden non unique decay

- *large theoretical uncertainties*
- *previous measurements differ up to 10%*

goal: 1% — power

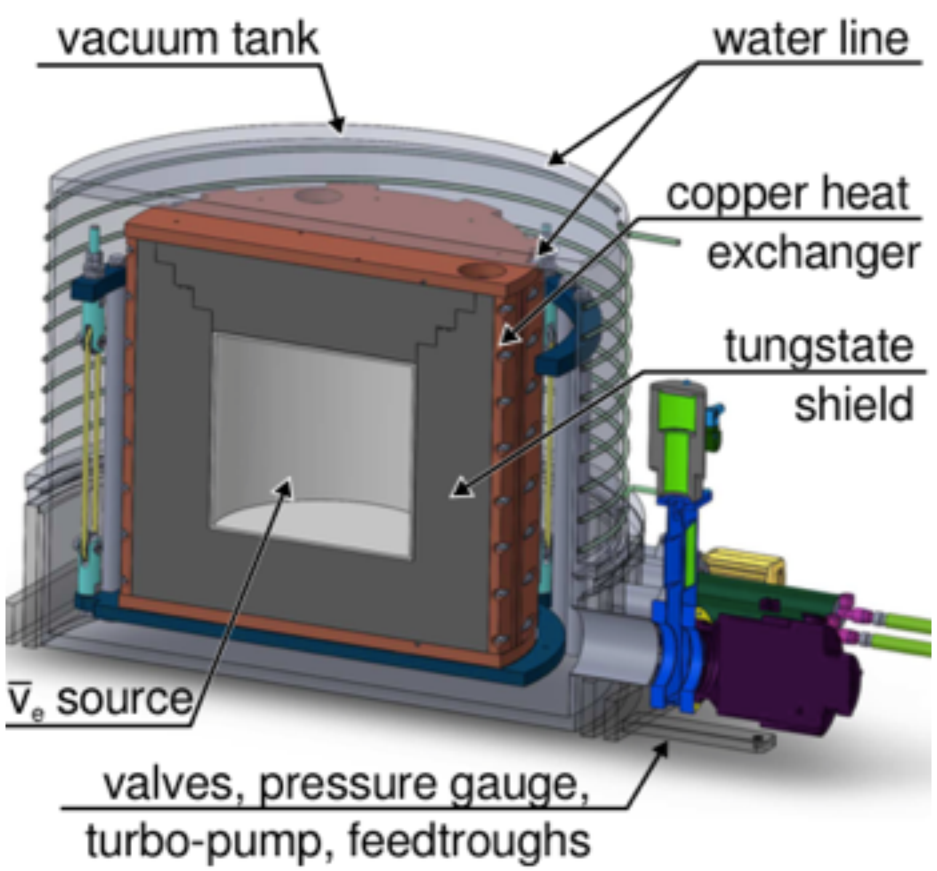
goal: 0.03 — spectral shape



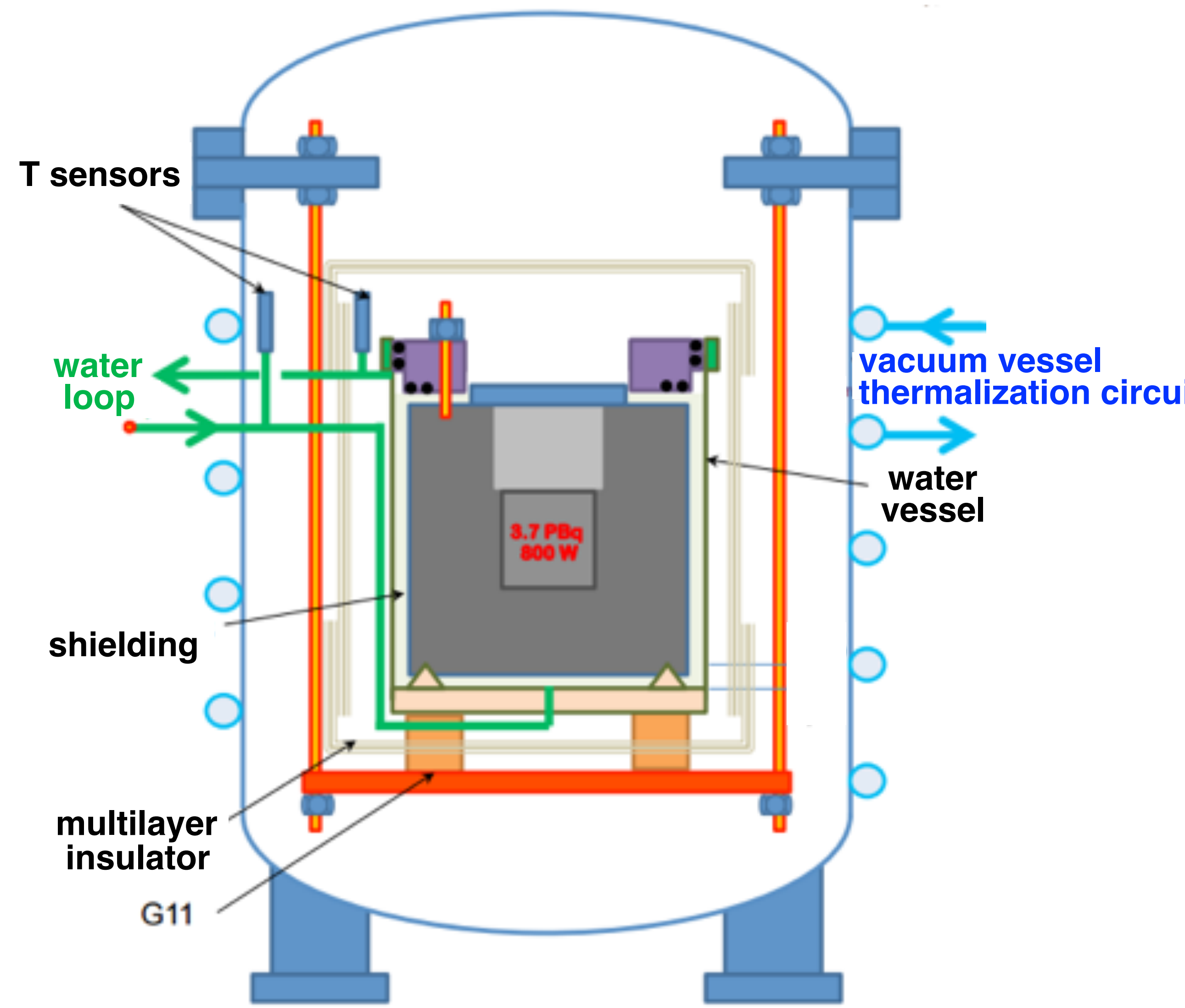


POWER MEASUREMENT

- Measurement of heat extracted by a water flow: $P \sim \dot{m} \cdot \Delta T$
- initial power ~ 1kW
- 2 calorimeters in preparation

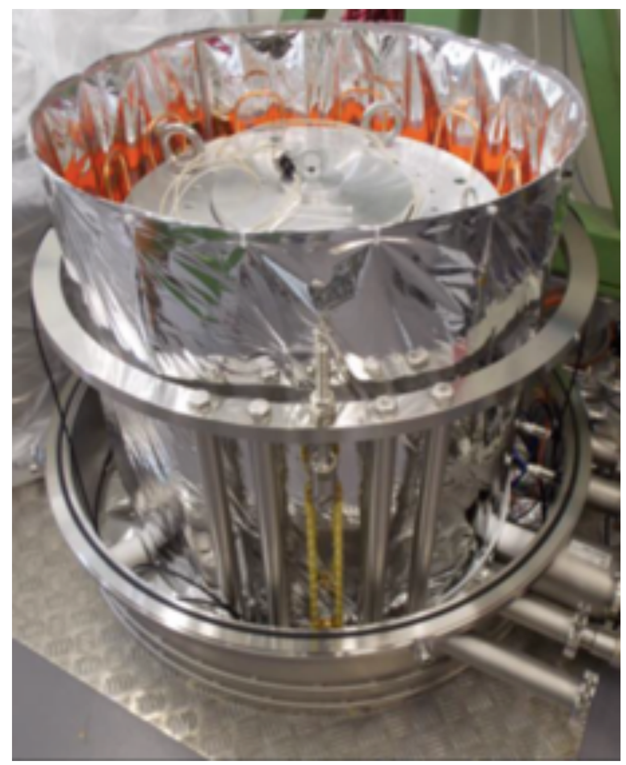


TUM/Genova Calorimeter



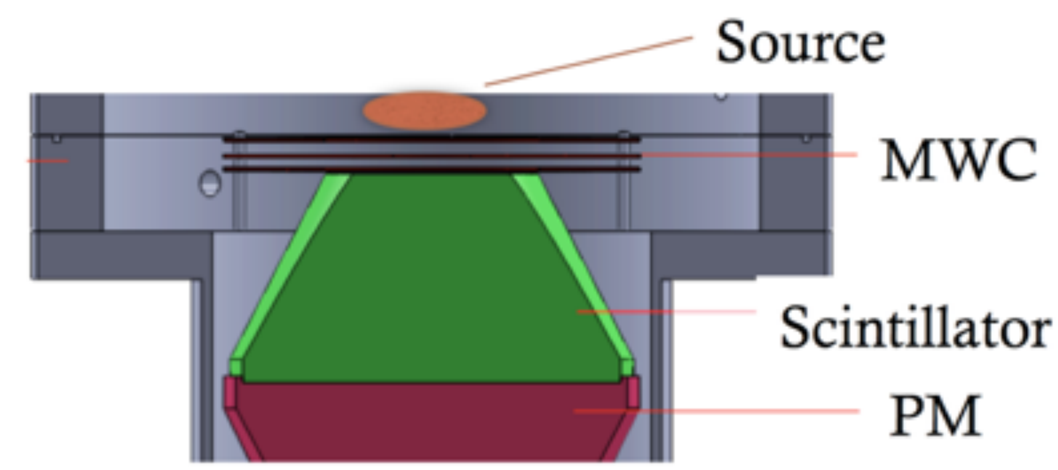
CEA Calorimeter

MINIMIZATION OF HEAT LOSSES

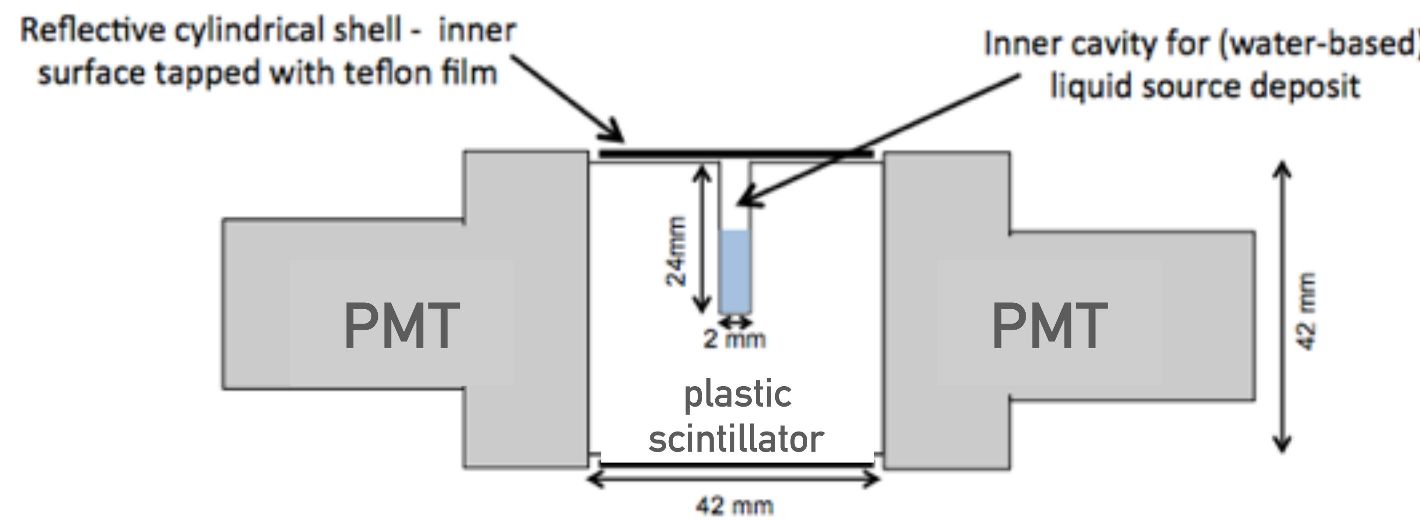
convection	radiation	conduction
		
vacuum tank p < 5·10⁻⁵ mbar	**super insulator** 2 x 10 foils	**suspension platform** **+ kevlar ropes**

SPECTRAL MEASUREMENTS

- 2 independent measurements (TUM & CEA)

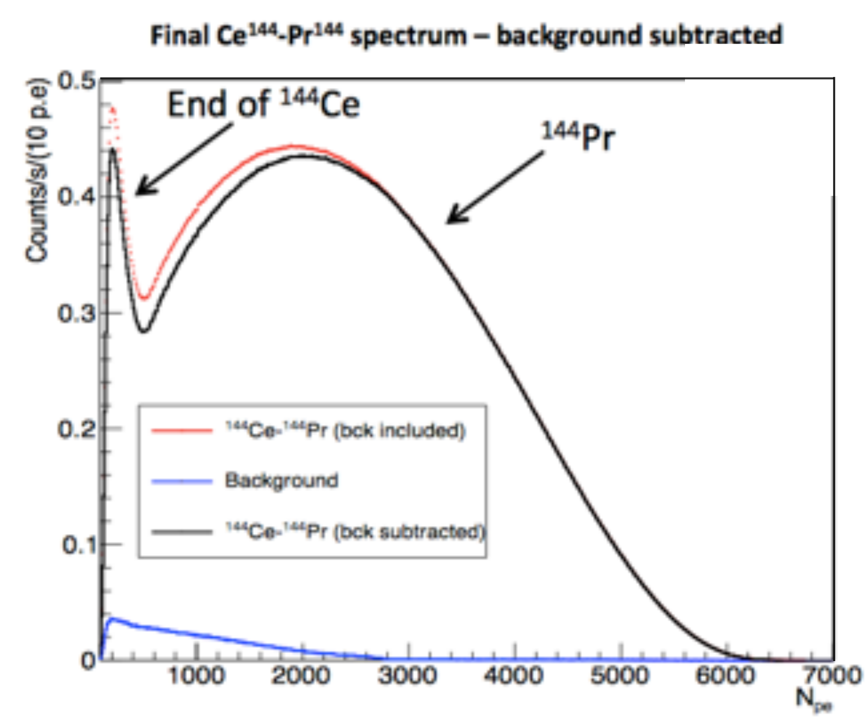


TUM Setup



CEA Setup

- measurements are ongoing
  - characterization & calibration of detectors
  - first measurements with a ^{144}Ce sample
- precision measurement planned with PERKEO III at TUM



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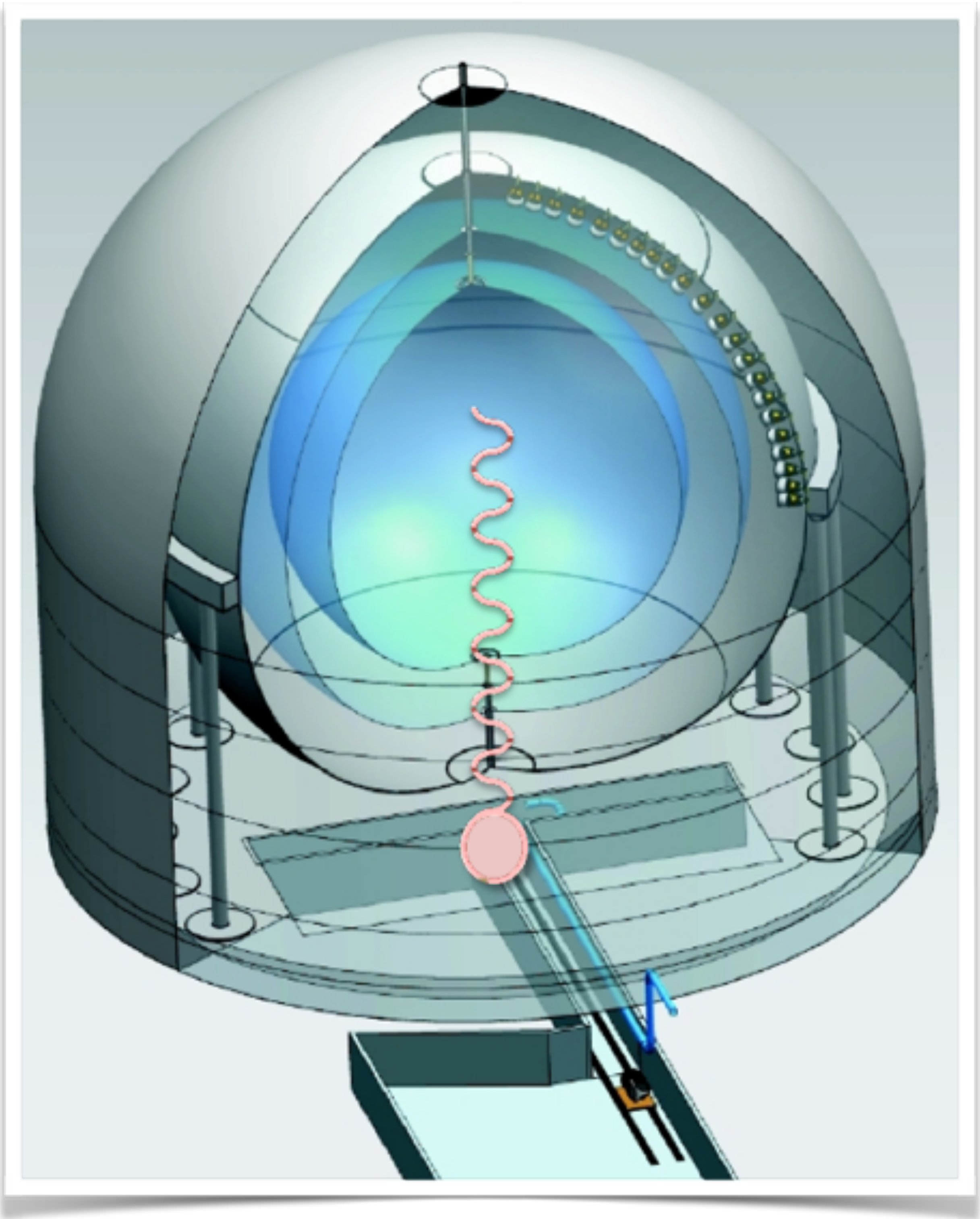
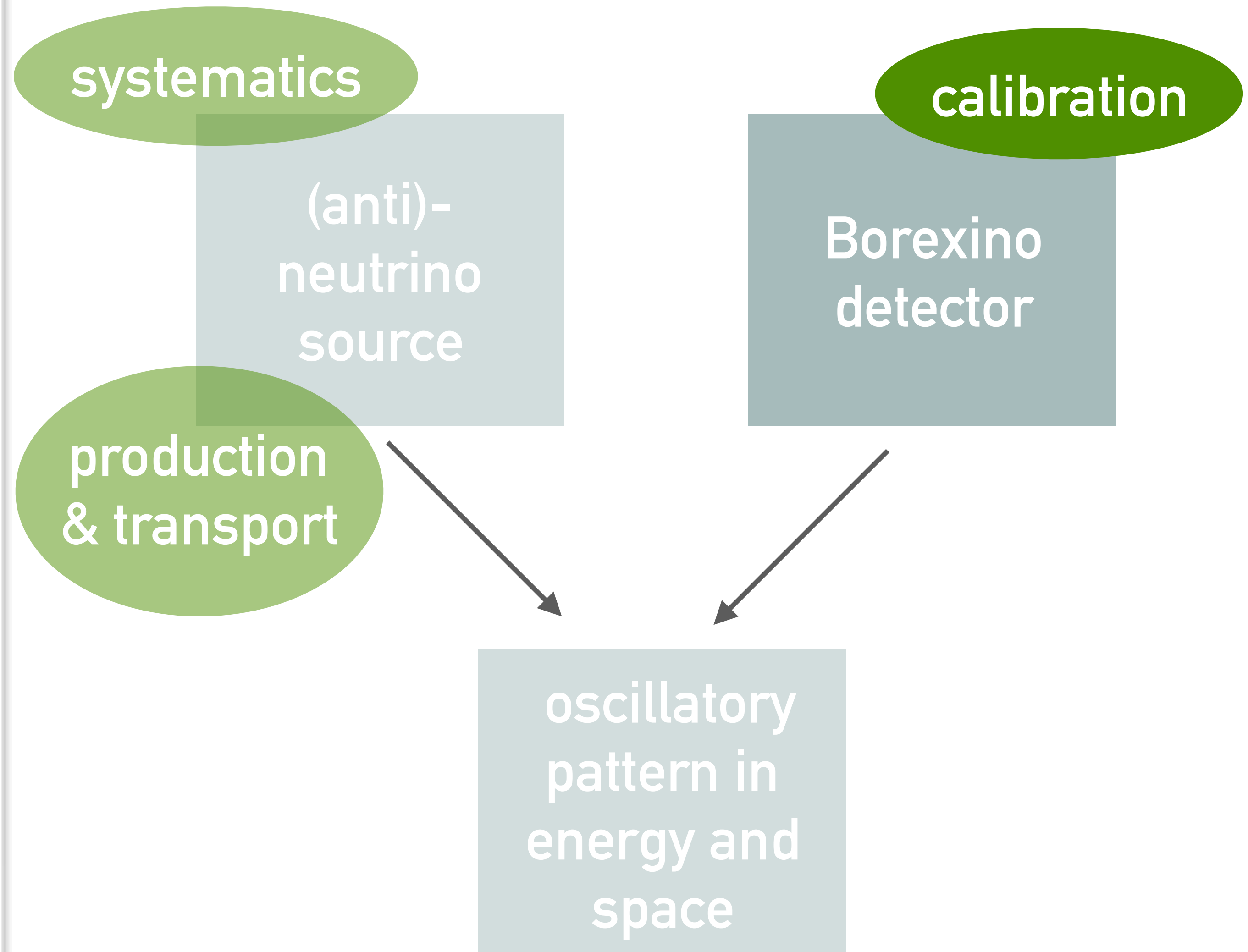
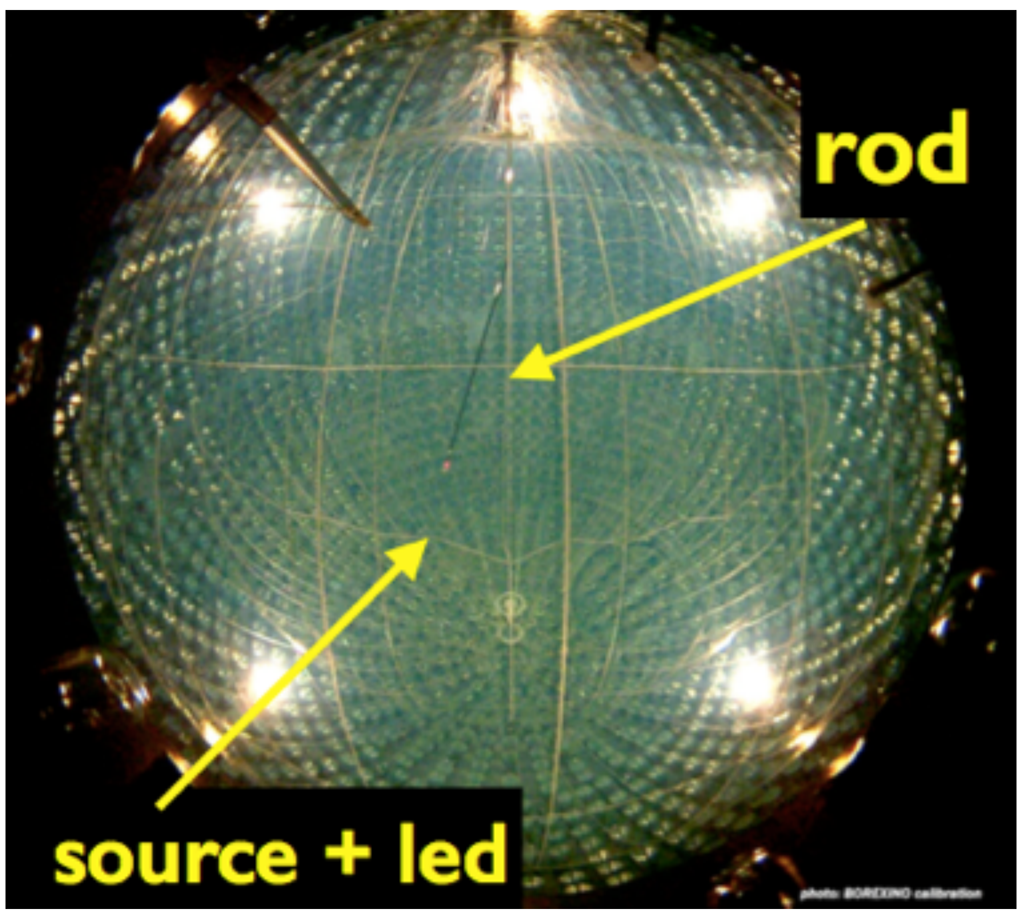




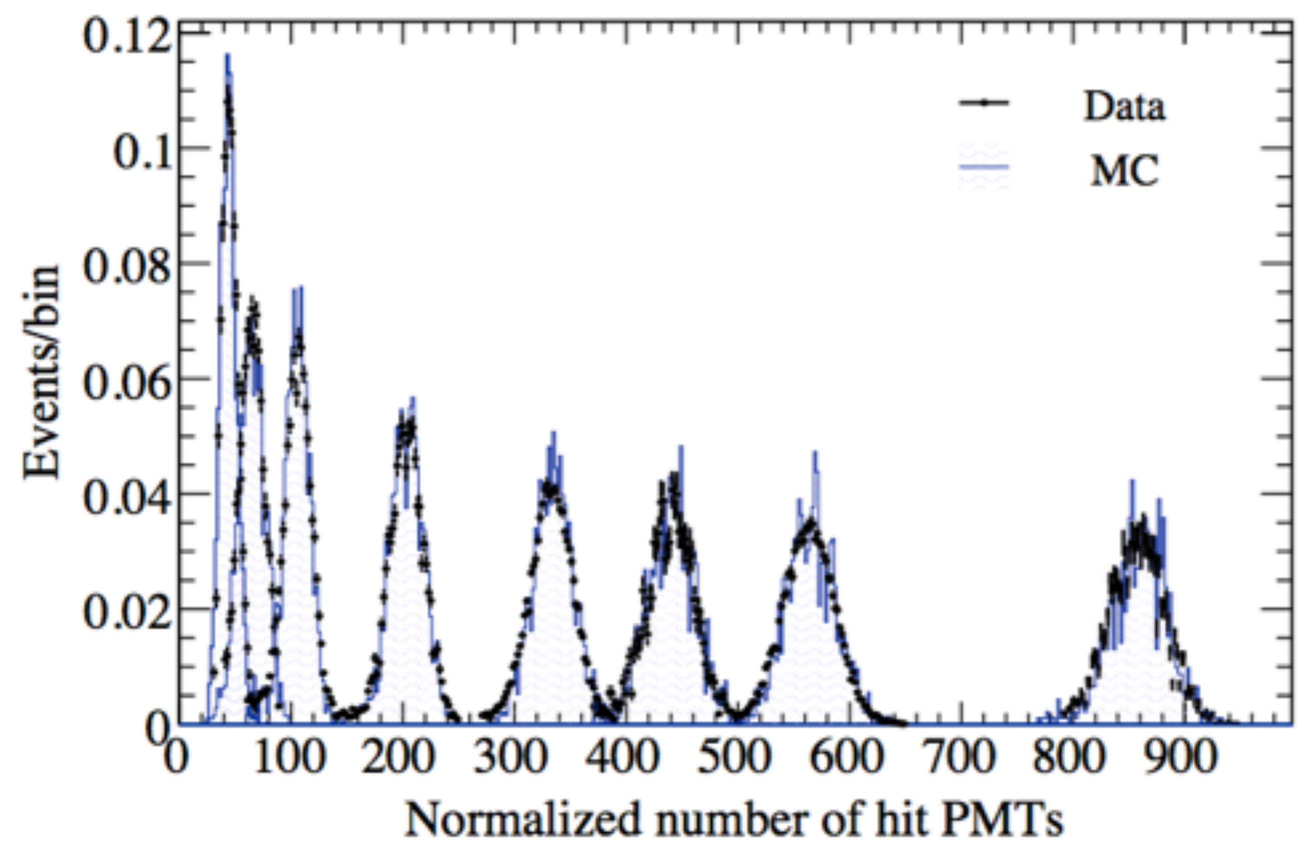
NEW CALIBRATION CAMPAIGN

focused on the outer volume not used in solar analysis

- energy scale
- uniformity of detector response
- position reconstruction ⟶ fiducial volume



energy scale test from last calibration



SUMMARY

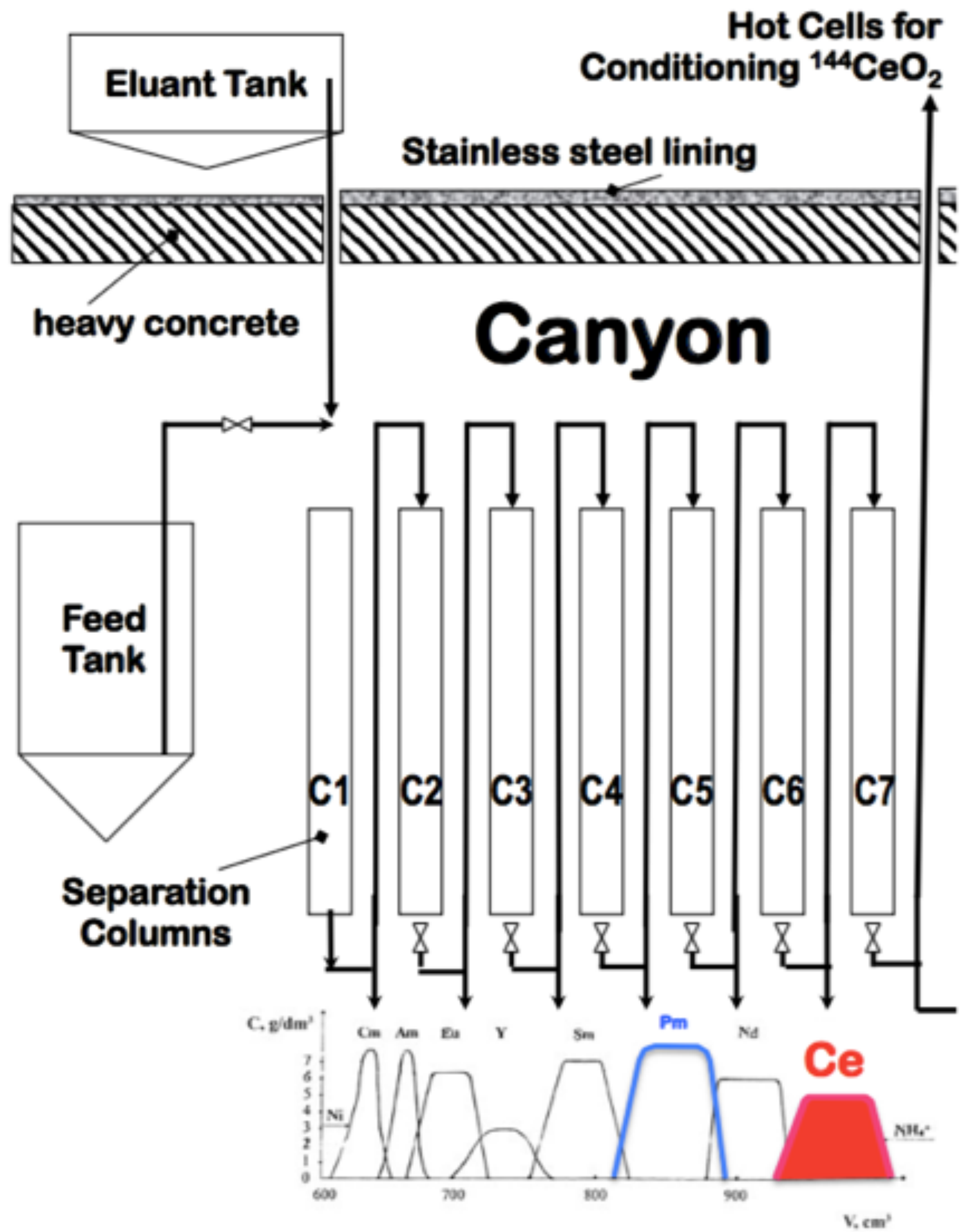
- **SOX**
  - (100-150)kCi ^{144}Ce $\overline{\nu}_e$-source
    (^{51}Cr ν_e-source in case of a positive signal)
  - Borexino: 270t liquid scintillator detector at LNGS
  - sterile neutrino signature is an oscillatory pattern in E & L
    - rate and shape analysis
- **minimization of systematic uncertainties**
  - power and spectral measurements in preparation
  - Borexino calibration campaign next year
- **start data taking end of 2017/ early 2018**
- **first results in 2018**

SOX: a project of the Borexino collaboration and CEA

INFN
Milano
München
Jülich
Hamburg
Mainz
Gran Sasso
L'Aquila
Genova
Napoli
Tübingen
Jagiellonian Kraków
Saclay
JINR Dubna
Virginia Tech
Oak Ridge
Paris
Princeton
UMass Amherst
ITEP Moscow
Kurchatov Moscow
Hawaii

BACK UP

DISPLACEMENT CHROMATOGRAPHIE

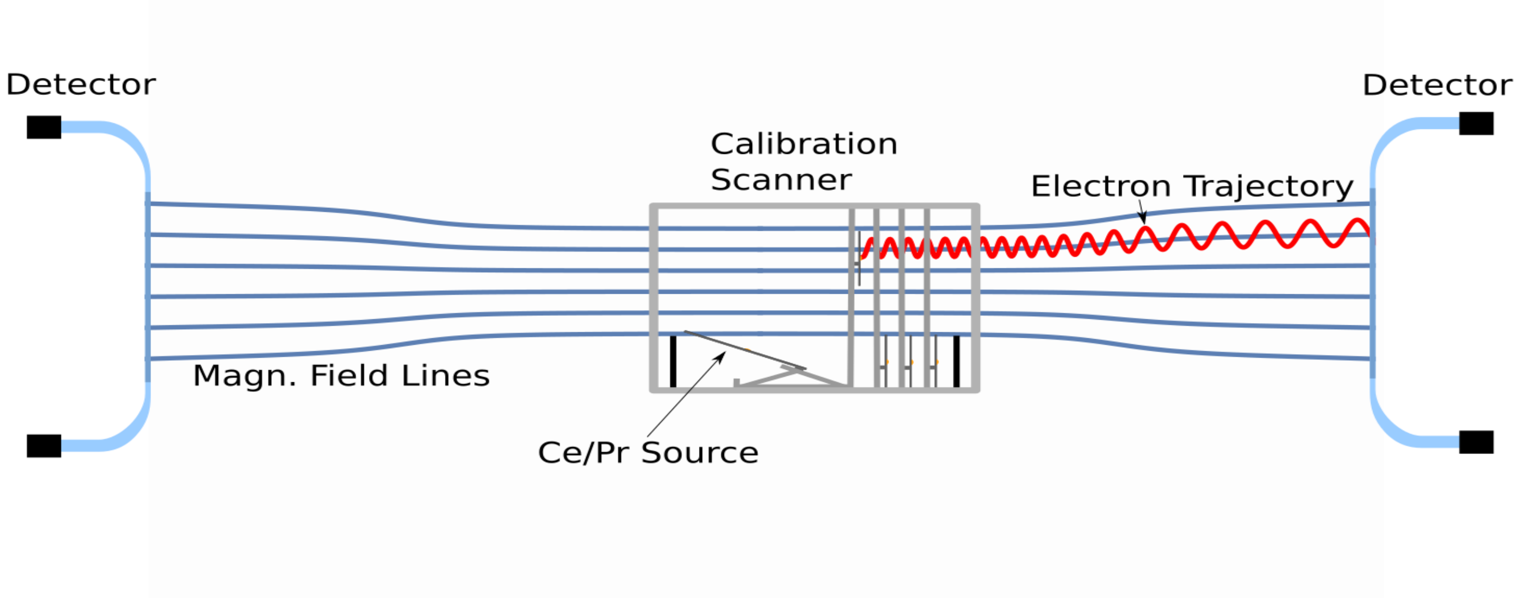


REQUIREMENTS ON SOURCE

- Ratio of the total thermal power released by <u>controllable</u> radionuclide impurities to the thermal power released by ^{144}Ce + ^{144}Pr $\leq 1 \times 10^{-3}$ (W/W)
- Ratio of the activity of impurities emitting gammas with $E \geq 1$ MeV to ^{144}Ce activity $\leq 1 \times 10^{-3}$ (Bq/Bq)
- Ratio of ^{244}Cm activity to ^{144}Ce activity $\leq 1 \times 10^{-5}$ (Bq/Bq)
- Ratio of ^{241}Am activity to ^{144}Ce activity $\leq 5 \times 10^{-3}$ (Bq/Bq)
- List of nuclei to check (γ,α,ICPMS)

  ^{22}Na, ^{44}Ti-^{44}Sc, ^{49}V, ^{54}Mn, ^{55}Fe, ^{57}Co, ^{60}Co, ^{63}Ni, ^{65}Zn, ^{68}Ge-^{68}Ga, ^{90}Sr-^{90}Y, ^{91}Nb, ^{93}mNb, ^{106}Ru-^{106}Rh, ^{101}Rh, ^{102}Rh, ^{102m}Rh, ^{102m}Rh, ^{108m}Ag, ^{110m}Ag, ^{109}Cd, ^{113m}Cd, ^{119m}Sn, ^{121m}Sn, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{133}Ba, ^{143}Pm, ^{144}Pm, ^{145}Pm, ^{146}Pm, ^{147}Pm, ^{145}Sm, ^{151}Sm, ^{150}Eu, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{148}Gd, ^{153}Gd, ^{157}Tb, ^{158}Tb, ^{171}Tm, ^{173}Lu, ^{174}Lu, ^{172}Hf-^{172}Lu, ^{179}Ta, ^{178m}Hf, ^{194}Os-^{194}Ir, ^{192m}Ir, ^{193}Pt, ^{195}Au, ^{194}Hg-^{194}Au, ^{204}Tl, ^{210}Pb→^{206}Pb, ^{207}Bi, ^{208}Po, ^{209}Po, ^{228}Ra→^{208}Pb, ^{227}Ac→^{207}Pb, ^{228}Th→^{208}Pb, ^{232}U→^{208}Pb, ^{235}Np, ^{236}Pu-^{232}U, ^{238}Pu→^{230}Th, ^{239}Pu, ^{240}Pu, ^{241}Pu-^{241}Am, ^{241}Am, ^{242m}Am-^{230}Th, ^{243}Cm→^{235}U, ^{244}Cm, ^{248}Bk-^{244}Am, ^{249}Bk-^{249}Cf, ^{248}Cf ,^{249}Cf, ^{250}Cf , ^{252}Cf, ^{252}Es, ^{254}Es-^{250}Bk

PERKEO III


Detector
Detector
Calibration
Scanner
Electron Trajectory
Magn. Field Lines
Ce/Pr Source