Silicon Detector Based Beta-spectrometer

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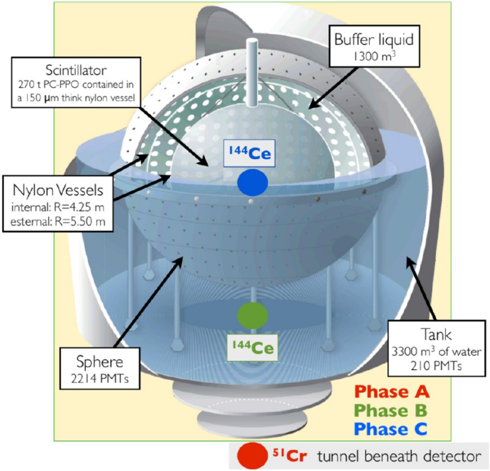
The 3rd International Conference
on Particle Physics and Astrophysics
Moscow, October 5, 2017

Overview

- Precision β-spectra measurements are important for several problems of fundamental physics.
- Magnetic/Electrostatic spectrometers – large-scale complex installations.
- Sterile neutrino searches require good understanding of neutrino spectrum shape.

Borexino SOX

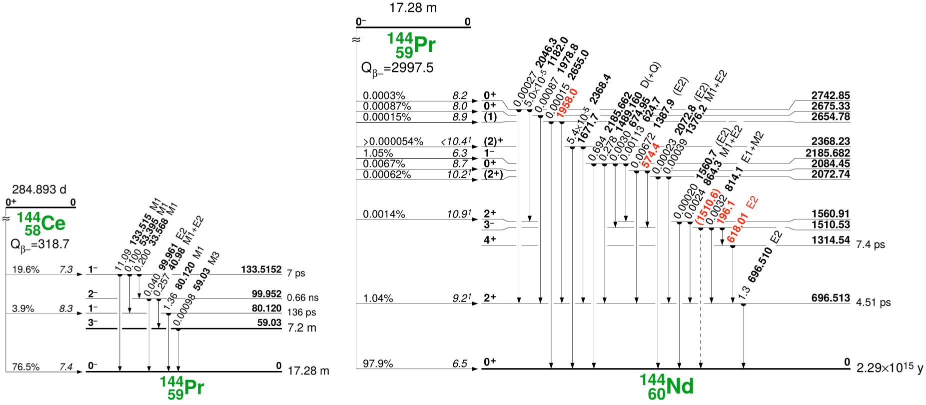
- Liquid scintillator detector (Borexino)
- Low-background facility (LNGS, Italy)
- Antineutrino source ^{144}**Ce**-^{144}**Pr**



G. Bellini *et al.* JHEP 2013

SOX: Short distance neutrino Oscillations with BoreXino

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



Q_β ^{144}Ce	Q_β ^{144}Pr	γ ^{144}Ce	γ ^{144}Pr
318.7(76.5%)	2997.5(97.9%)	133.5(11.1%)	696.5(1.3%)
185.2(19.6%)	2301.0(1.04%)	80.1(1.36%)	2185.7(0.69%)
238.6(3.9%)	811.8(1.05%)	41.0(0.26%)	1489.1(0.28%)

Beta-spectrum Description
Frobidden transitions, Shape Factor

Beta-spectrum shape

$$N(W) = K \cdot p^2(W - W_0)^2 \cdot F(Z,W) \cdot L_0(Z,W) \cdot C_{V|A}(Z,W) \cdot S(Z,W) \cdot G_\beta(Z,W) \cdot B(W) \cdot H(W)$$

- Phase space + Fermi function: $p^2(W - W_0)^2 \cdot F(Z,W)$
- E/M finite-size correction: $L_0(Z,W)$
- Weak finite-size correction: $C_{V|A}(Z,W)$
- Screening correction: $S(Z,W)$
- Radiative corrections: $G_\beta(Z,W)$
- Weak magnetism correction: $B(W)$
- **Shape factor**: $H(W) = 1 \pm a \cdot W \pm b \cdot W^{-1}[pm \ldots]$

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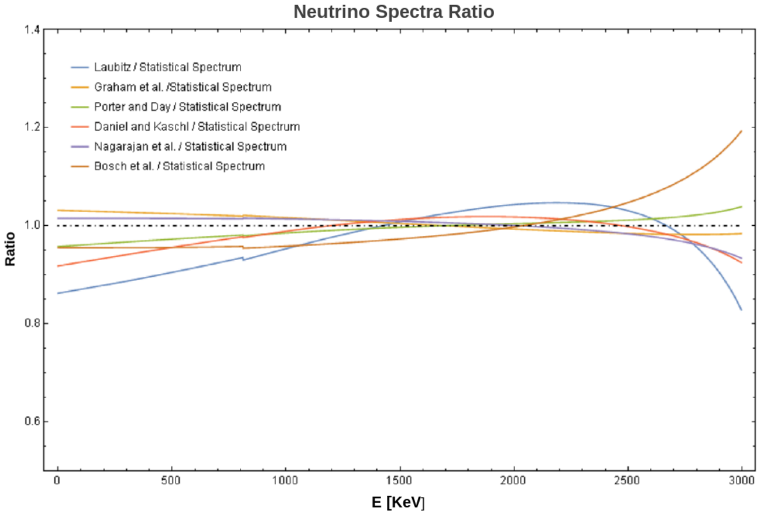
^{144}Ce: The Current State
Previous Measurements

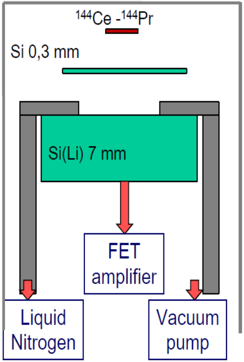
Authors	Year	Technique	Shape Factor	E_0 [keV]	SF change in [1-3]MeV
Laubitz	1956	Lens spectrometer	$1-0.058W-0.389W^{-1}$	2990 ± 10	$\Downarrow\sim 20\%$
Graham *et al.*	1958	Double lens spectrometer	$1+0.0146W+0.0283W^{-1}$	2984	$\Downarrow\sim 5\%$
Porter & Day	1959	Ar double lens spectrometer	$1-0.028W-0.0921W^{-1}-0.041W^2$	2992	$\Uparrow\sim 6\%$
Daniel & Caschl	1966	Heidelberg double lens spectrometer	$1+0.03W-0.118W^{-1}+0.008W^2$	2996 ± 3	$\Downarrow\sim 10\%$
Nagarayan *et al.*	1971	Intermediate image spectrometer	$1-(0.0975\pm 0.013)W^{-1}$	3000 ± 3	$\Uparrow\sim 2\%$
Bosch *et al.*	1973	Scintillating crystal	$1-0.33W^{-1}$	3002 ± 5	$\Downarrow\sim 5\%$

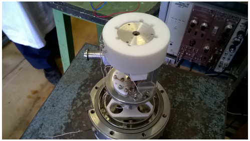
^{144}Ce: The Current State
SF Uncertainty

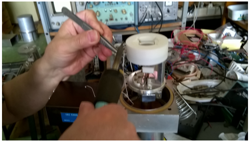


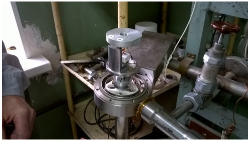
Significant SF variation is still present

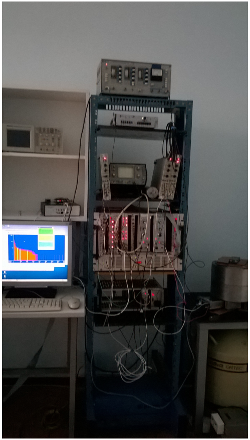
Spectrometer Setup
General Layout





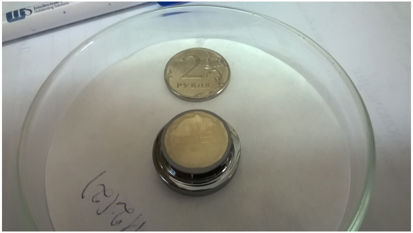


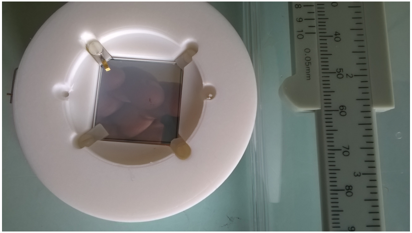




The SC Detectors

Full-absorption Si(Li) + Transmission (Si)





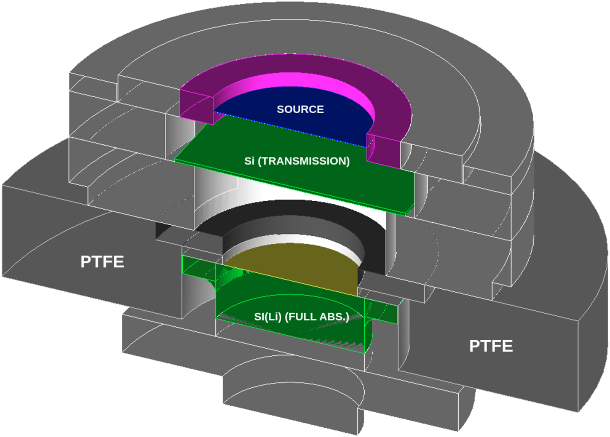
Full absorption Si(Li)

- Diameter: 16 mm
  Thickness: 7 mm
- $I = 10$ pA at 1000 V
- $C = 5$ pF
- production: PNPI

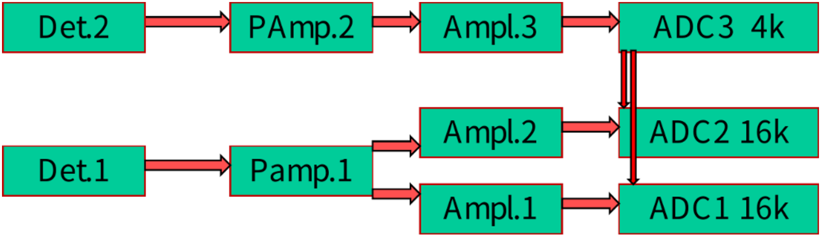
Transmission - Si (pure)

- Area: 24×24 mm^2
  Thickness: $300\ \mu$m
- $I = 2.3$ nA at 100 V
- $C = 90$ pF
- production: Zelenograd + Ioffe Inst.

Detector Assembly



Electronics & DAQ

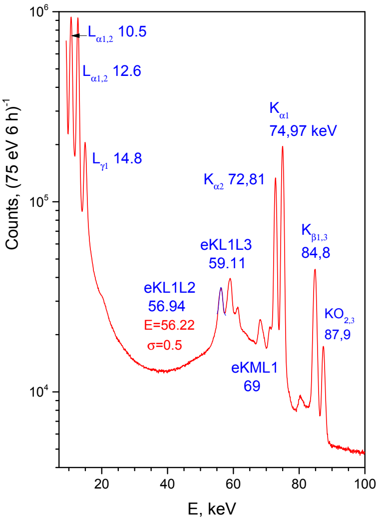


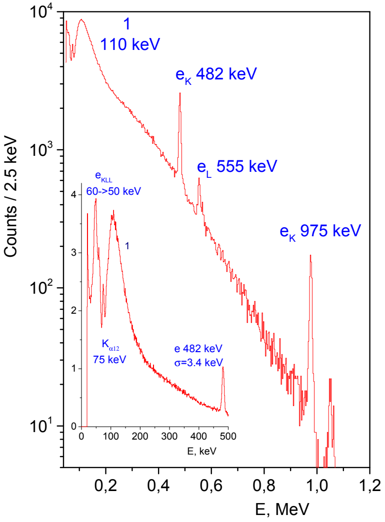
- ADC #1: spectrum in < 0.5 MeV
- ADC #2: spectrum in < 6 MeV

Det. 1 & Det.2:

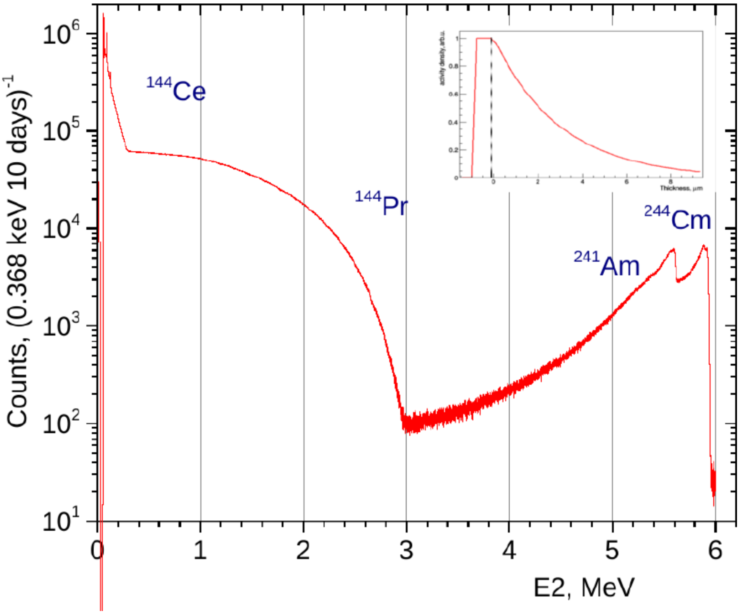
Anticoincidence scheme allows to identify γ-events

Calibration
^{207}Bi Source





Ce-Pr Measurements



Analisys challenges

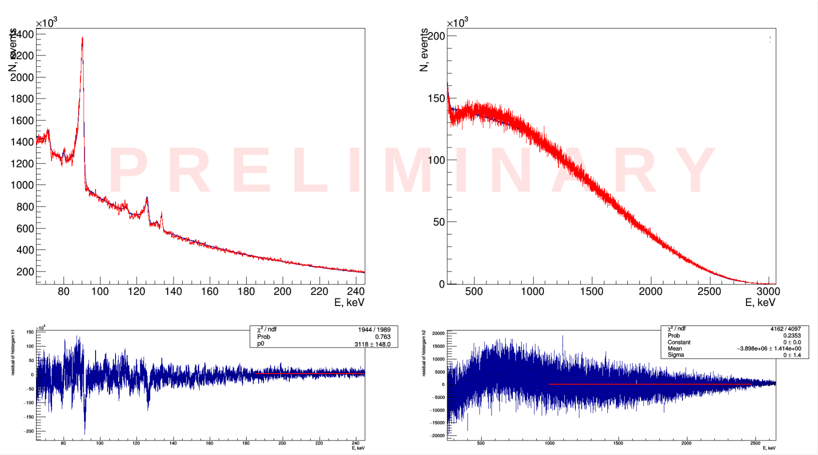
- Complex spectrum composition
  (backgrounds, γ-lines, conversion/Auger e^-)
- Detector response for mono-energetic e^-
- Selection of shape factor parameterization
- Organization of spectral fit to determine *shape factor*

Detector Responce
MC simulation

MC simulation is a critical point of the spectral analysis since the detector response is non-trivial. It includes:

- Livermore electromagnetic physics (preferred by [G. Soti et al., 2013])
- Tuned parameters:
  - dead layer thickness
  - thickness of metal-plated layers (Au, Pd)
  - thickness distribution of activity inside the source (by Am, Cm α-lines)
- Sufficiently detailed detector geometry.

Preliminary Fit



Achieved statistical sensitivity gives around 1% uncertainty on shape factor integral ratio for $[0 - 1.2]$ MeV and $[0 - 3]$ MeV intervals.

Next steps

Analysis:

- Correction calculations
- Increase MC statistics / Live time
- Better source (purity / activity)

Setup improvements:

- 4π-geometry with two Si(Li) detectors
- Radiochemical separation of ^{144}Pr

Thank you for attention!