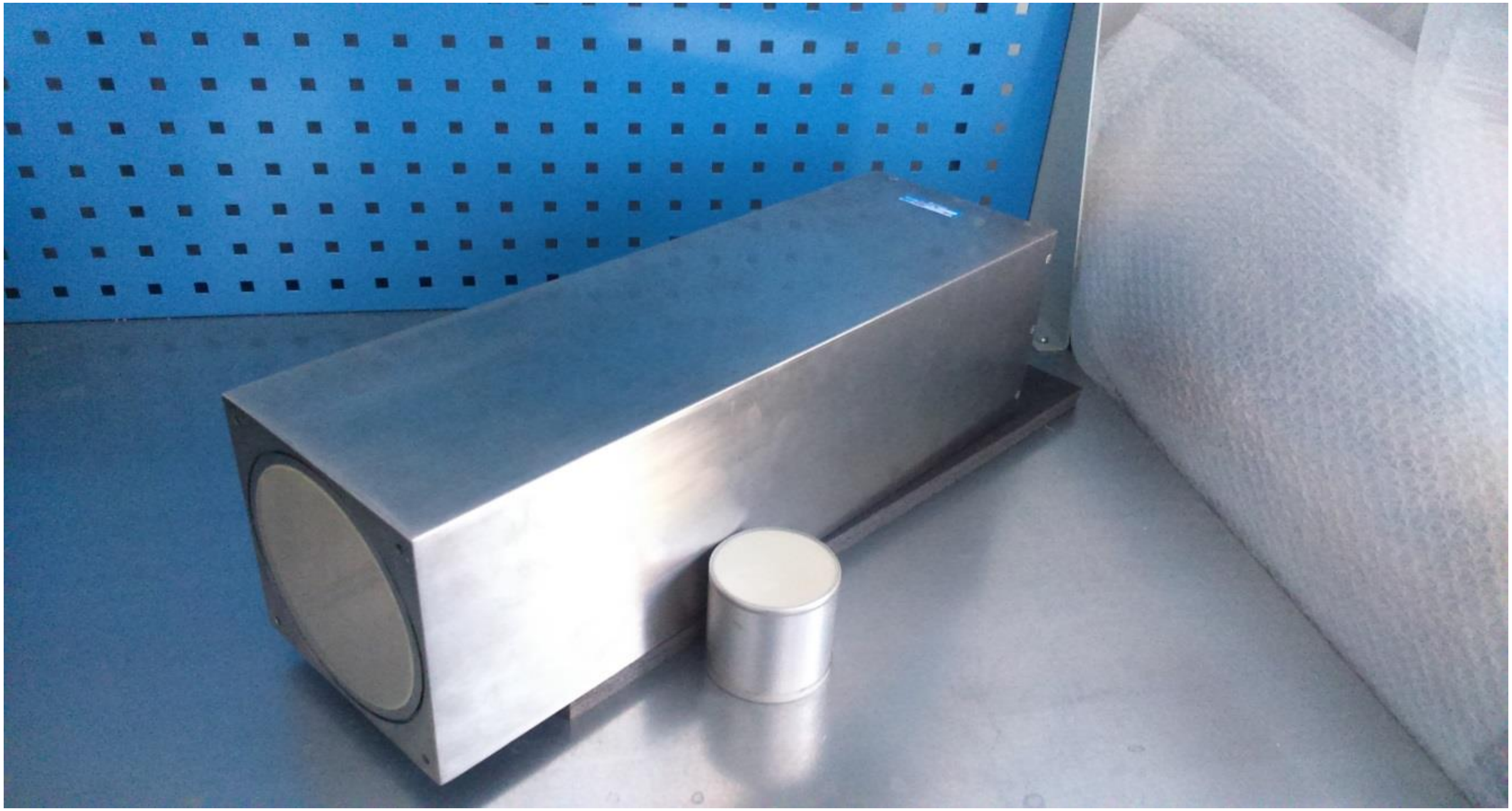
Sensitive neutron detection method using iodine-containing scintillators



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^{3}He Detectors and need for an alternative

- Gas proportional detectors
- Golden standard for neutron measurements
- Thermal neutron cross section of ^{3}He = 5333±7 barns

- $n + {}^3He \rightarrow {}^3H + {}^1H + 764keV$

- Negligible sensitivity to gamma rays
- Increased gas pressure per volume → more sensitive detector

Drawbacks:

- ^{3}He proportion in natural He gas=0,000137 %
- Artificially produced from tritium decay in nuclear reactors
- Low availability
- Costs up to $2,000/L
- Not only needed for neutron detection
- Diameter of the detector is small (maximum 5 cm)
- Limited export of ^{3}He

Motivation of neutron measurements with NaI(Tl), CsI(Tl), CsI(Na), CsI scintillation detectors

- widely available,
- simple to use,
- relatively cheap,
- relatively easy to produce,
- can be very radioactive clean,
- highly efficient for γ- detection (multipurpose)

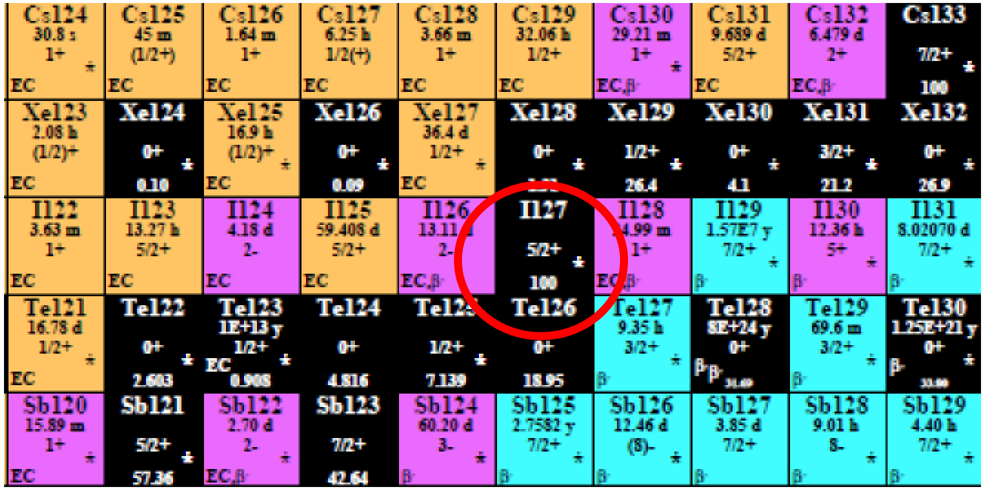
Detector	Neutrons	Short Description
NaI(Tl)	thermal	boron lining with available NaI detectors
NaI(Tl)	thermal	high-energy photons following (n,γ) reaction on ^{23}Na
NaI(Tl)	thermal	triple β-γ-γ coincidences in two detectors following (n,γ) reaction on ^{23}Na
NaI(Tl)	thermal	activated NaI detector(^{128}I β-decay, $T_{1/2}$ = 25min and ^{24}Na β-decay, $T_{1/2}$ = 15h)
CsI(Na)	fast	57.6keV signal from ^{127}I(n,n')inelastic scattering
NaI(Tl), CsI(Tl)	fast	1-200MeV neutrons, (n,p) and (n,α) reactions, pulse-shape discrimination

NaI (solid) has **545** times as many moles as an equal volume of ^{3}He (gas, normal pressure)

Iodine has only one stable isotope: **^{127}I**
σ_γ = 6.2(2) barn (**860** times lower than ^{3}He)

Efficiency of thermal neutron capture in 1 kg NaI detector is ~50% (almost all captures will be on iodine because for ^{23}Na: σ_γ = 0.9(1) barn)

Result of neutron capture is ^{128}I in 6.8 MeV excited state



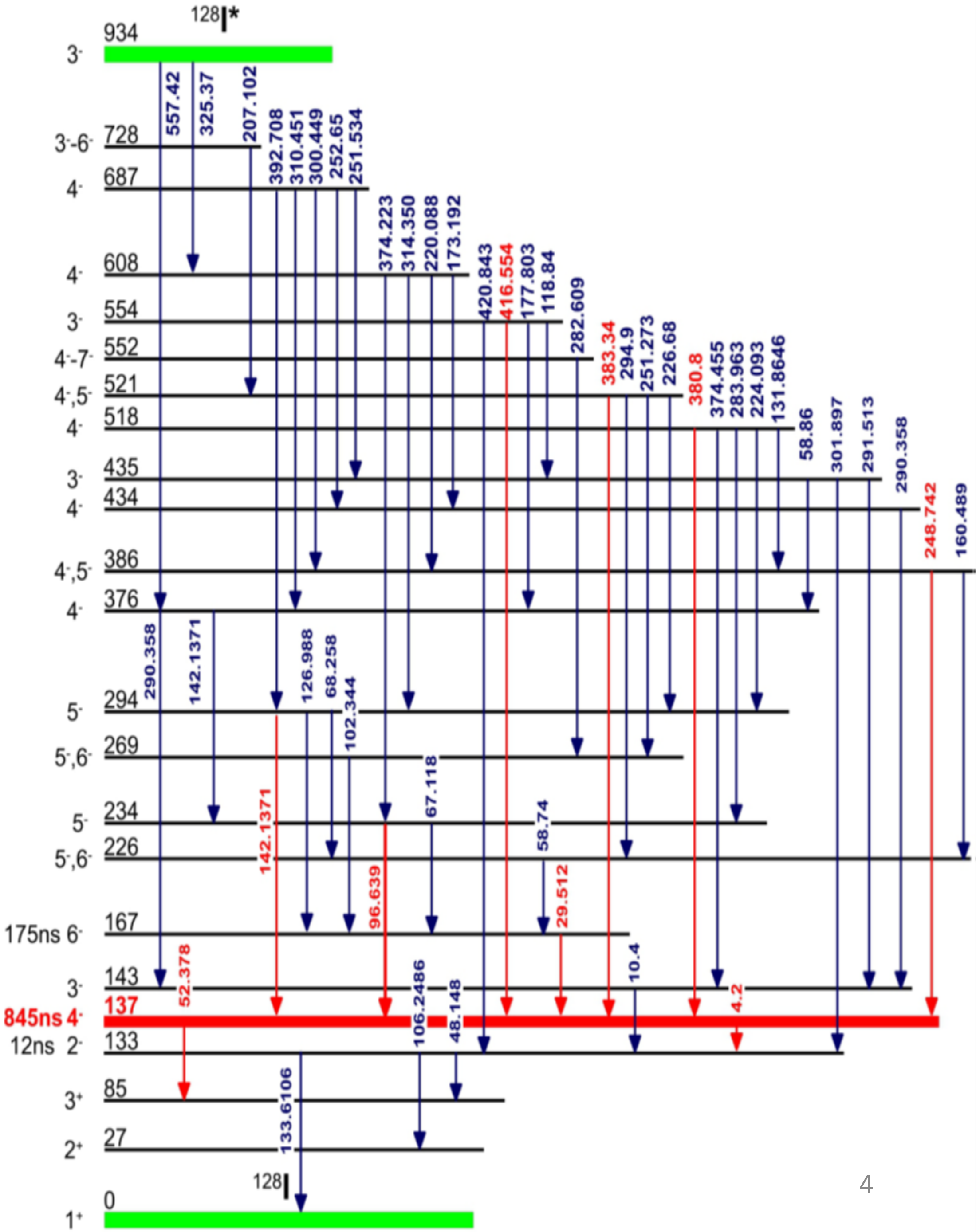
Cs124 30.8 s 1+ EC	Cs125 45 m (1/2+) EC	Cs126 1.64 m 1+ EC	Cs127 6.25 h 1/2(+) EC	Cs128 3.66 m 1+ EC	Cs129 32.06 h 1/2+ EC	Cs130 29.21 m 1+ EC,β-	Cs131 9.689 d 5/2+ EC	Cs132 6.479 d 2+ EC,β-	Cs133 7/2+ 100
Xe123 2.08 h (1/2)+ EC	Xe124 0+ 0.10	Xe125 16.9 h (1/2)+ EC	Xe126 0+ 0.09	Xe127 36.4 d 1/2+ EC	Xe128 0+ [illegible]	Xe129 1/2+ 26.4	Xe130 0+ 4.1	Xe131 3/2+ 21.2	Xe132 0+ 26.9
I122 3.63 m 1+ EC	I123 13.27 h 5/2+ EC	I124 4.18 d 2- EC	I125 59.408 d 5/2+ EC	I126 13.11 2- EC,β-	I127 5/2+ 100	I128 24.99 m 1+ EC,β-	I129 1.57E7 y 7/2+ β-	I130 12.36 h 5+ β-	I131 8.02070 d 7/2+ β-
Te121 16.78 d 1/2+ EC	Te122 0+ 2.603	Te123 1E+13 y 1/2+ EC 0.908	Te124 0+ 4.816	Te125 1/2+ 7.139	Te126 0+ 18.95	Te127 9.35 h 3/2+ β-	Te128 8E+24 y 0+ β-β- 31.69	Te129 69.6 m 3/2+ β-	Te130 1.25E+21 y 0+ β- 33.80
Sb120 15.89 m 1+ EC	Sb121 5/2+ 57.36	Sb122 2.70 d 2- EC,β-	Sb123 7/2+ 42.64	Sb124 60.20 d 3- β-	Sb125 2.7582 y 7/2+ β-	Sb126 12.46 d (8)- β-	Sb127 3.85 d 7/2+ β-	Sb128 9.01 h 8- β-	Sb129 4.40 h 7/2+ β-

Description of the method

- ^{128}I decay to the ground state proceeds through a series of low-energy levels
- ^{128}I has 137.8 keV isomeric state
- $T_{1/2}$ = 0.845(20) μsec
- ~40% de-excitations pass through the 137.8 keV level
- Delayed coincidences to identify neutrons

^{128}I excited energy levels below 200 keV and their decay transitions

Energy level in ^{128}I (keV)	$T_{1/2}$ (ns)	Energy levels following decay (keV)
180		160.8, 85.5, 27.4
167.4	175 ± 15	137.8
160.8		27.4, 0
151.6		85.5, 27.4
144.0		133.6
137.8	**845 ± 20**	**133.6, 85.5**
133.6	12.3 ± 0.5	85.5, 27.4, 0
128.2		85.5
85.5		27.4
27.4		0
0		



Test in Dubna in 2016

NaI(Tl) Ø63 mm x 63 mm
PMT Hamamatsu R6091
CAEN Multi channel
analyzer DT5780

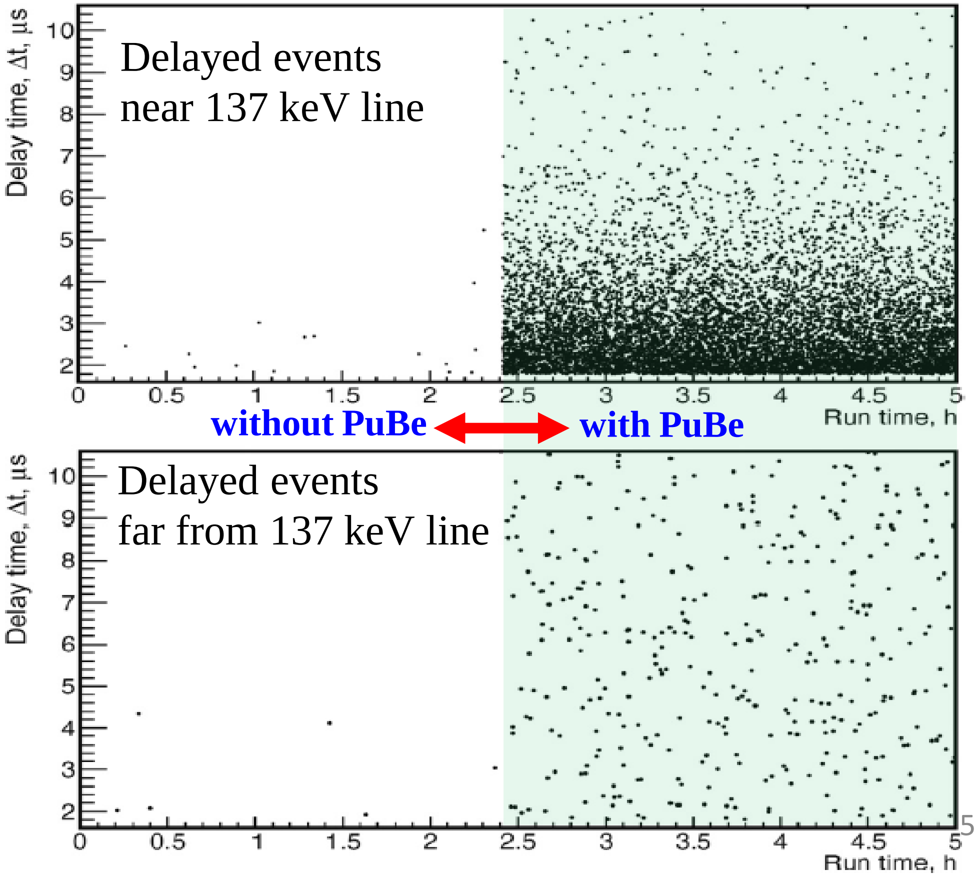
Data acquisition in list mode

Simultaneous measurement
with bare ^{3}He detector

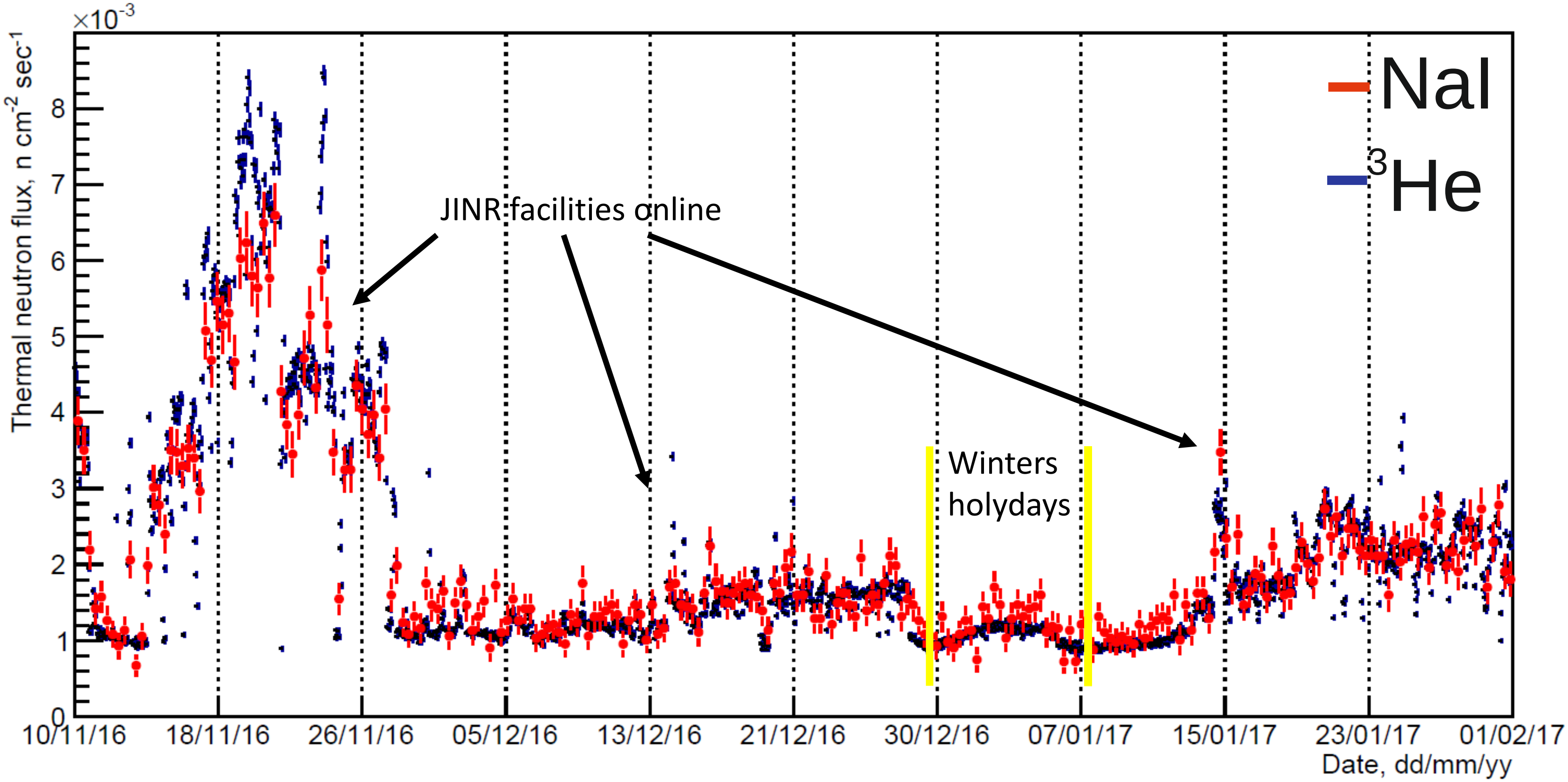
Energy scale calibration near
137 keV with ^{139}Ce
(166 keV γ-line)

Strong PuBe neutron source
(10^4 n/sec) to verify the effect

Measurements of ambient
neutrons



Neutron monitoring in Dubna



Absolute sensitivity to thermal neutrons is **6.5 ± 1.0 counts sec^{-1}**
for thermal 4π neutron flux **1 n cm^{-2} sec^{-1}**

Accidental background for this detector and shield is **0.8 events day^{-1}**
for any delay time window at **1 μsec**

Potential for low neutron flux measurements

- Accidental background is almost quadratically proportional to the overall background signal.

- Thus decreasing overall background in ten times it decreases in hundred times background in neutrons signals.

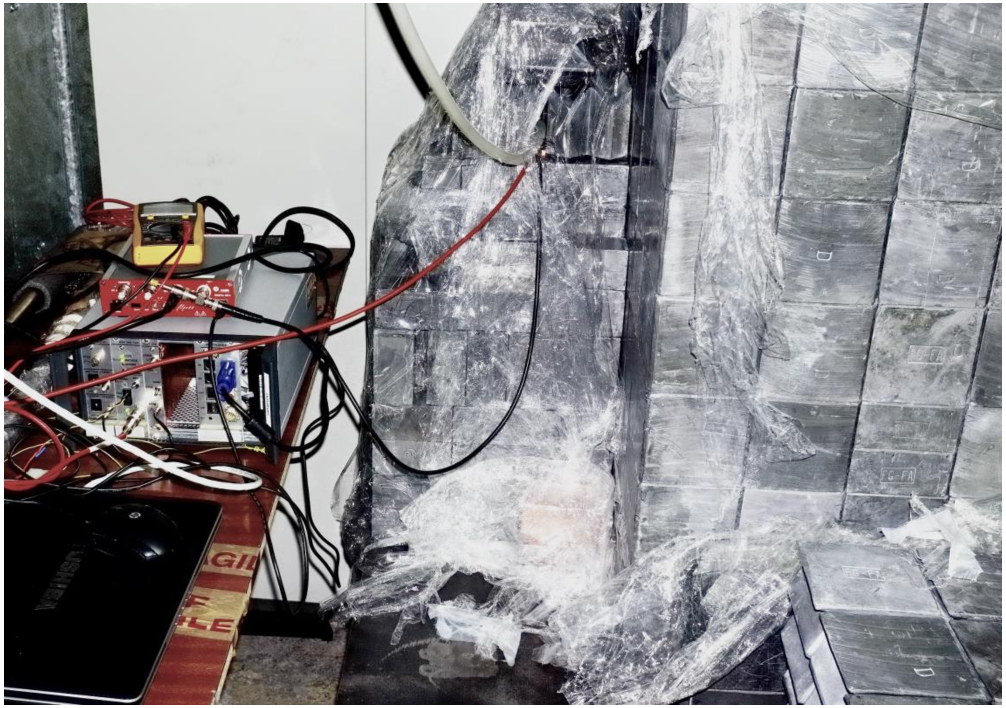
- Background less neutron measurements can be achieved by using high purity detectors and shielding.

Test in LSM (started in April 2017)

NaI(Tl)
Diameter 63 mm
Length 63 mm
~720 grams

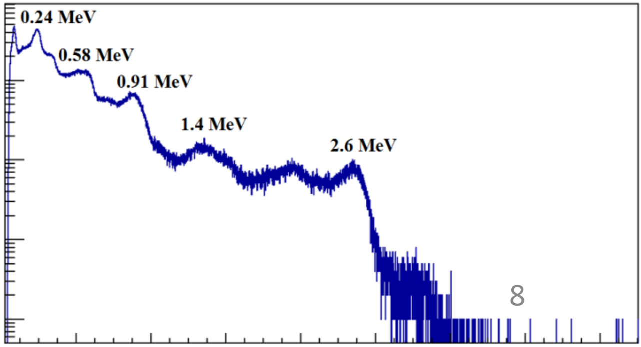
PMT
Hamamatsu R6091

CAEN
Multi channel analyzer DT5780

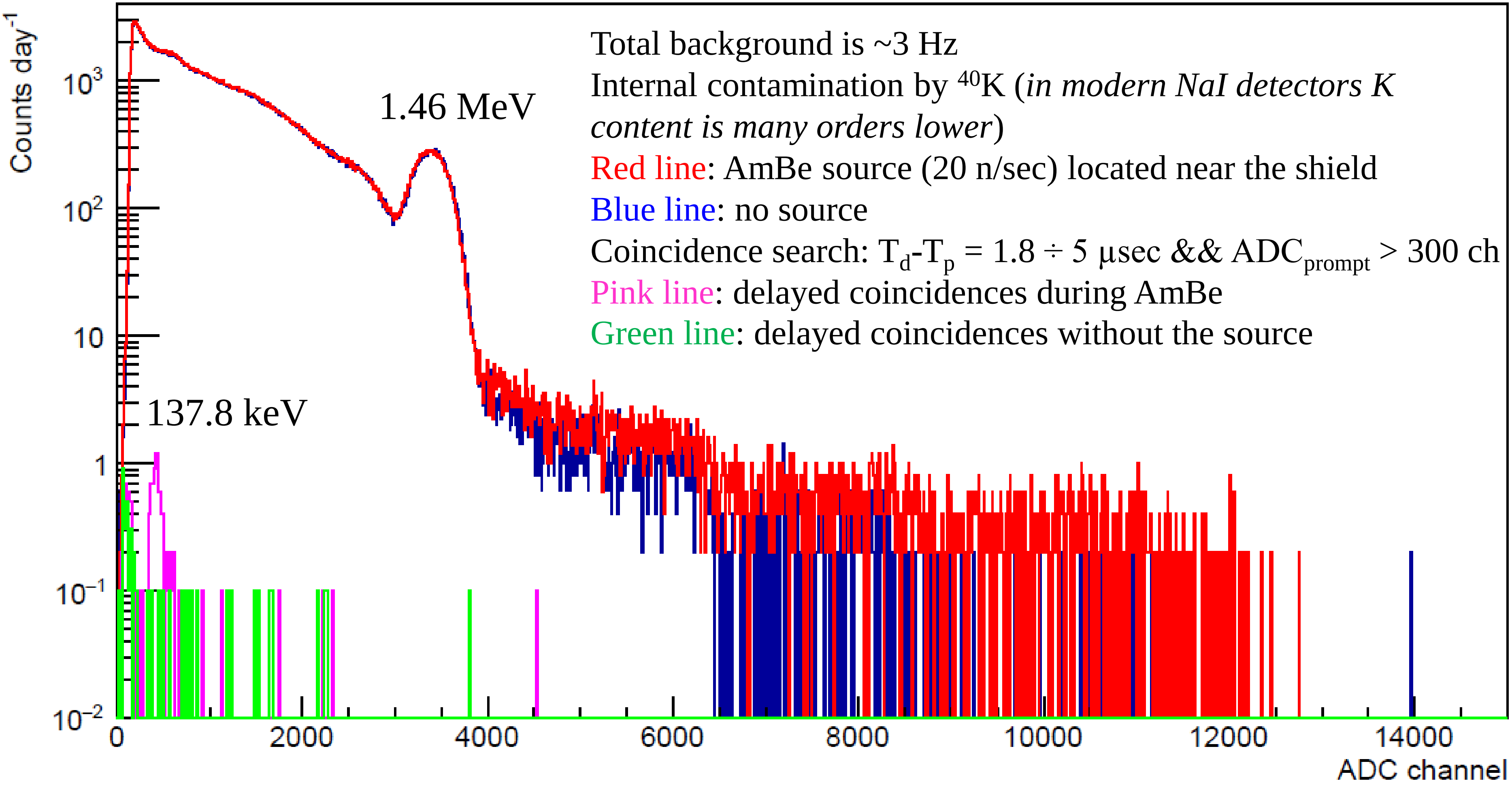


Shield
Simple Cu+Pb shield near EDW-I

Calibrations
γ : Th + K(internal)
Neutron : AmBe (20 n/sec)



First results in LSM / calibration



Total background is ~3 Hz

Internal contamination by ^{40}K (*in modern NaI detectors K content is many orders lower*)

Red line: AmBe source (20 n/sec) located near the shield

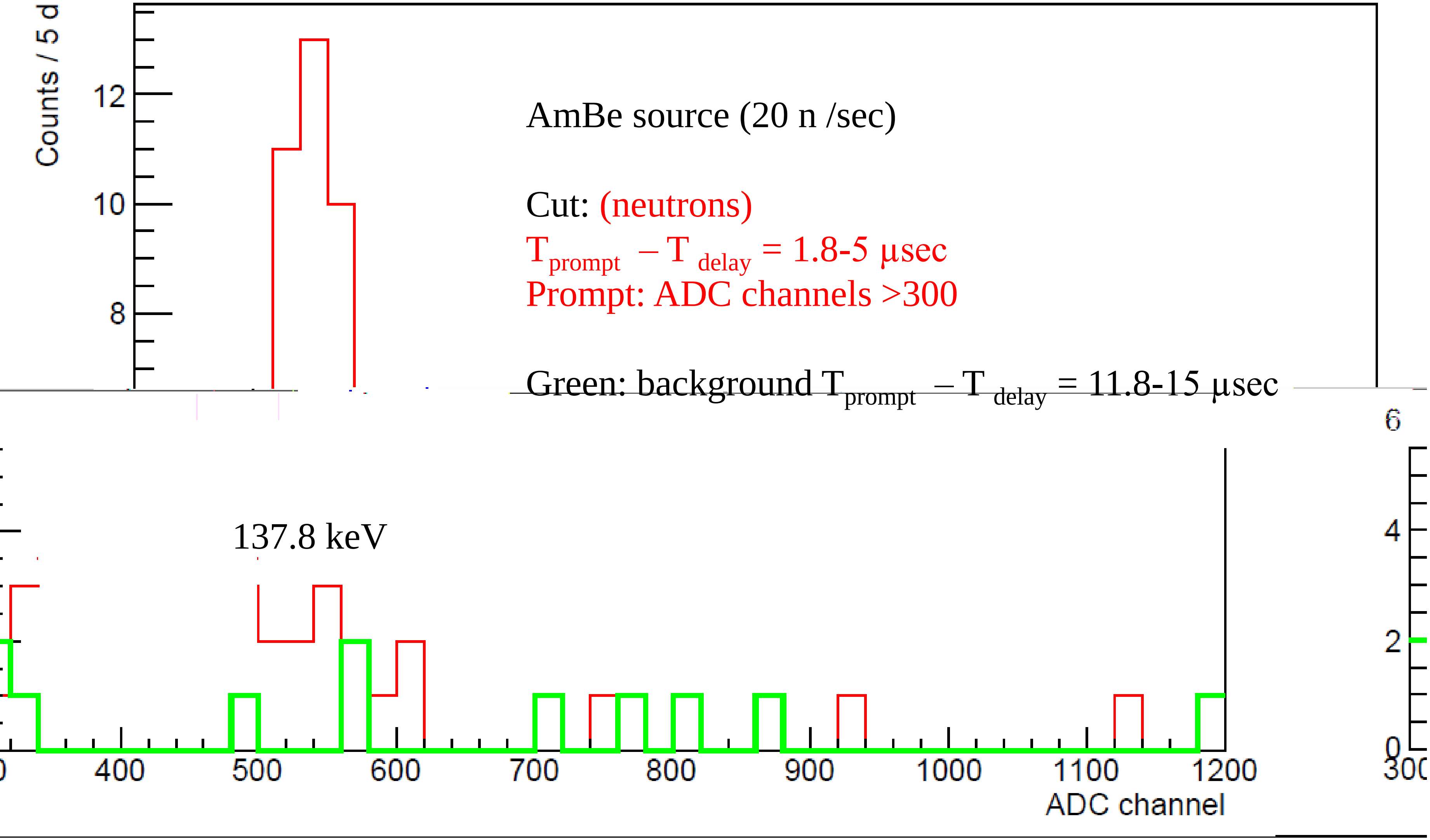
Blue line: no source

Coincidence search: T_d-T_p = 1.8 ÷ 5 μsec && ADC_{prompt} > 300 ch

Pink line: delayed coincidences during AmBe

Green line: delayed coincidences without the source

Results of first tests in LSM



AmBe source (20 n /sec)

Cut: (neutrons)

$T_{prompt} - T_{delay}$ = 1.8-5 µsec

Prompt: ADC channels >300

Green: background $T_{prompt} - T_{delay}$ = 11.8-15 µsec

137.8 keV

Result after 241.84 days

Cut:

$T_{\text{prompt}} - T_{\text{delay}}$ = 1.8-5 μsec, Prompt: ADC channels >300

Results:

For ADC channel (delayed) 380-460, i.e. neutrons

1.8 - 5 μsec: 67 events

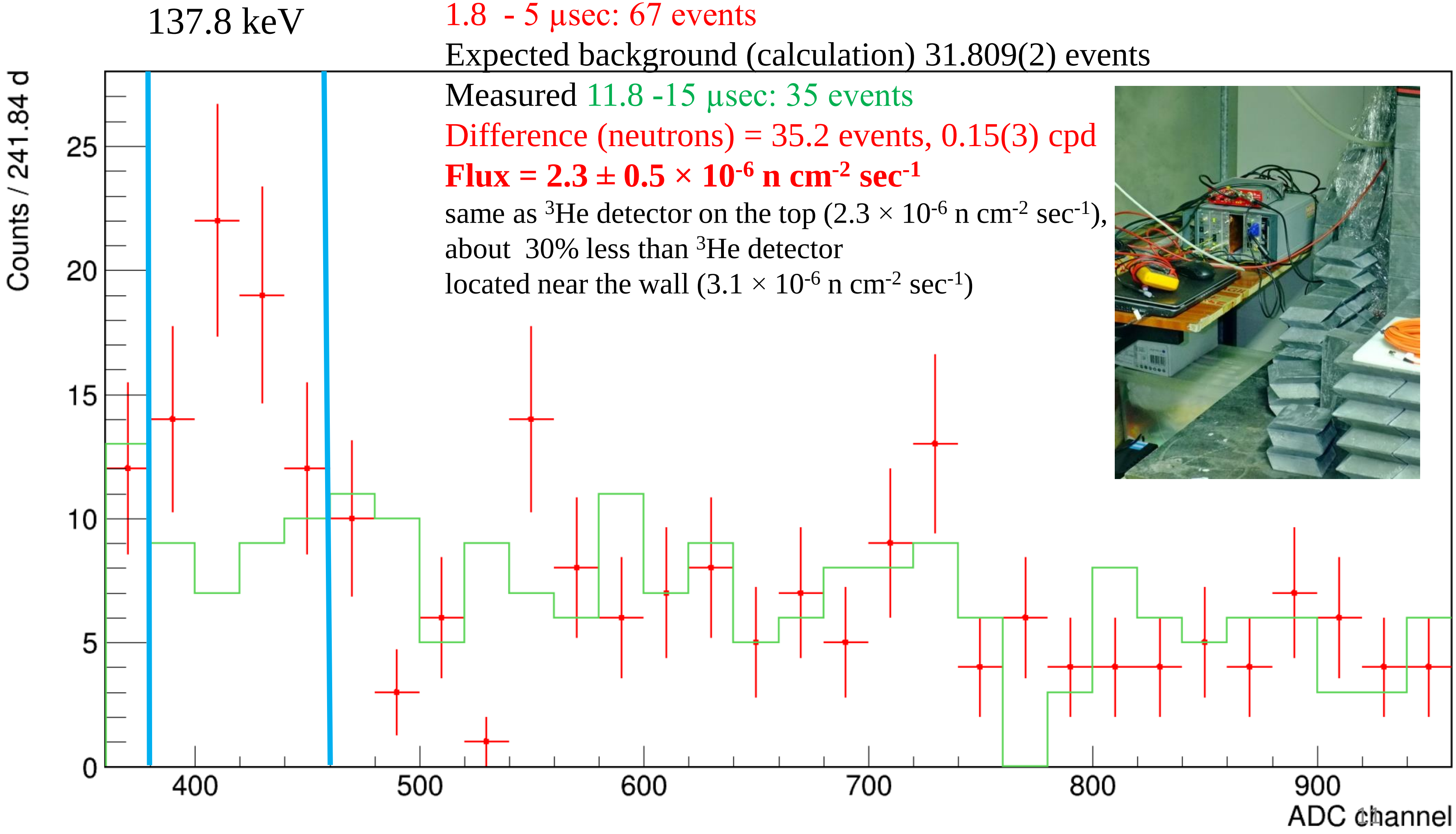
Expected background (calculation) 31.809(2) events

Measured 11.8 -15 μsec: 35 events

Difference (neutrons) = 35.2 events, 0.15(3) cpd

Flux = 2.3 ± 0.5 × 10^{-6} n cm^{-2} sec^{-1}

same as ^{3}He detector on the top (2.3 × 10^{-6} n cm^{-2} sec^{-1}), about 30% less than ^{3}He detector located near the wall (3.1 × 10^{-6} n cm^{-2} sec^{-1})



Conclusion and outlooks

- Measurements of low flux of thermal neutron with existing iodine containing detectors is revealed;

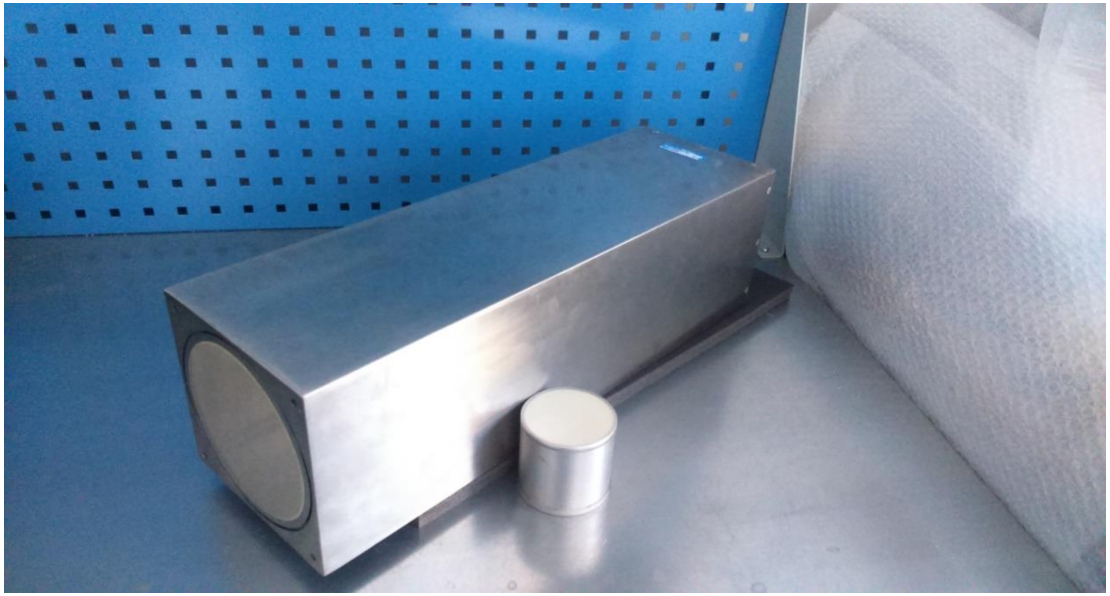
- For precise measurements we need bigger detector with low background;

- Several low background detectors with different sizes are already purchased;

- For low background environment 10^{-8} n cm^{-2} sec^{-1} neutron level could be possible to measure with bigger detector (100 kg), sensitivity will be comparable with ^{3}He;

- Simultaneous measurements of fast (57.6 keV line) and thermal (this method) neutrons are possible

- Tests in LSM will be continued.



Results in LSM