Upper Bound on Neutrino Magnetic Moment

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Outline

- Scientific motivation
- History
- Measurement under reactor
- GEMMA
- Perspectives

Scientific motivation

- Minimally extended Standard Model (MSM):

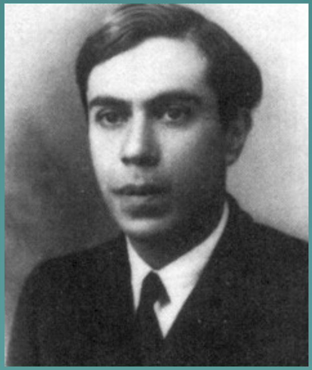
$$\mu_\nu \sim \mathbf{10^{-19}}\ \mu_B \times (m_\nu / 1\text{eV})$$

Bohr magneton $\mu_B = e \cdot h / 2\, m_e$

Scientific motivation

- Beyond the MSM:

$\mu_\nu \leq \mathbf{10^{-14}}\ \mu_B \times (m_\nu / 1\text{eV})$



$\mu_\nu \sim \mathbf{10^{-10}}\ \textbf{-}\ \mathbf{10^{-11}}\ \mu_B$

Scientific motivation

in case $\mu_\nu \sim \mathbf{10^{-11}}\text{-}\mathbf{10^{-12}}\ \mu_B$:

- Neutrino nature
- Λ parameter
- Astrophysical interest

First reactor experiments

1976 – Savannah River. ***The first observation of the ν-e scattering***

F. Reines et al. [P.R.L.37,315(1976)].

~ 16 kg plastic scintillator, ν flux of $2.2\times10^{13}\ \nu / cm^2 / s$

1989 – ***A revised analysis by P. Vogel and J. Engel [P.R.,D39,3378(1989)] gave a limit***

$$\mu_\nu \le (2-4)\times 10^{-10}\ \mu_B$$

1992 – Krasnoyarsk. ***G.S. Vidykin et al. [Pis'ma v ZhETPh, 55,206(1992)]***

~ 100 kg liquid scintillator C_6F_6, 254 days "on" / 78 days "off "

$$\mu_\nu \le 2.4\times 10^{-10}\ \mu_B \quad (90\%\ CL)$$

1993 – Rovno. ***A.V. Derbin, L.A. Popeko et al. [JETP Letters, 57,768(1993)]***

75 kg silicon multi-detector, 600 Si(Li) cells,

ν-flux of ~ $2\times10^{13}\ \nu / cm^2 / s$, 30 days "on"/17 days "off "

$$\mu_\nu \le 1.9\times 10^{-10}\ \mu_B \quad (95\%\ CL)$$

μ_ν upper bounds

	μ_ν upper limit	Comments
Solar	**$<4*10^{-10}$**	
SK+KamLand	**$<1.1*10^{-10}$**	
White dwarfs	**$<10^{-11}$**	
Red giants	**$<3*10^{-12}$**	**model dependent**
Supernova 1987A	**$<3*10^{-12}$**	
"Cosmological" limit	**$<1.5*10^{-11}$**	*should not be violated by more than two neutrino species*
BOREXINO	**$<5.4*10^{-11}$**	
TEXONO	**$<7.2*10^{-11}$**	
MUNU	**$<9*10^{-11}$**	

μ_ν measurement under reactor

- The effects can be searched in the recoil electron energy spectrum from the

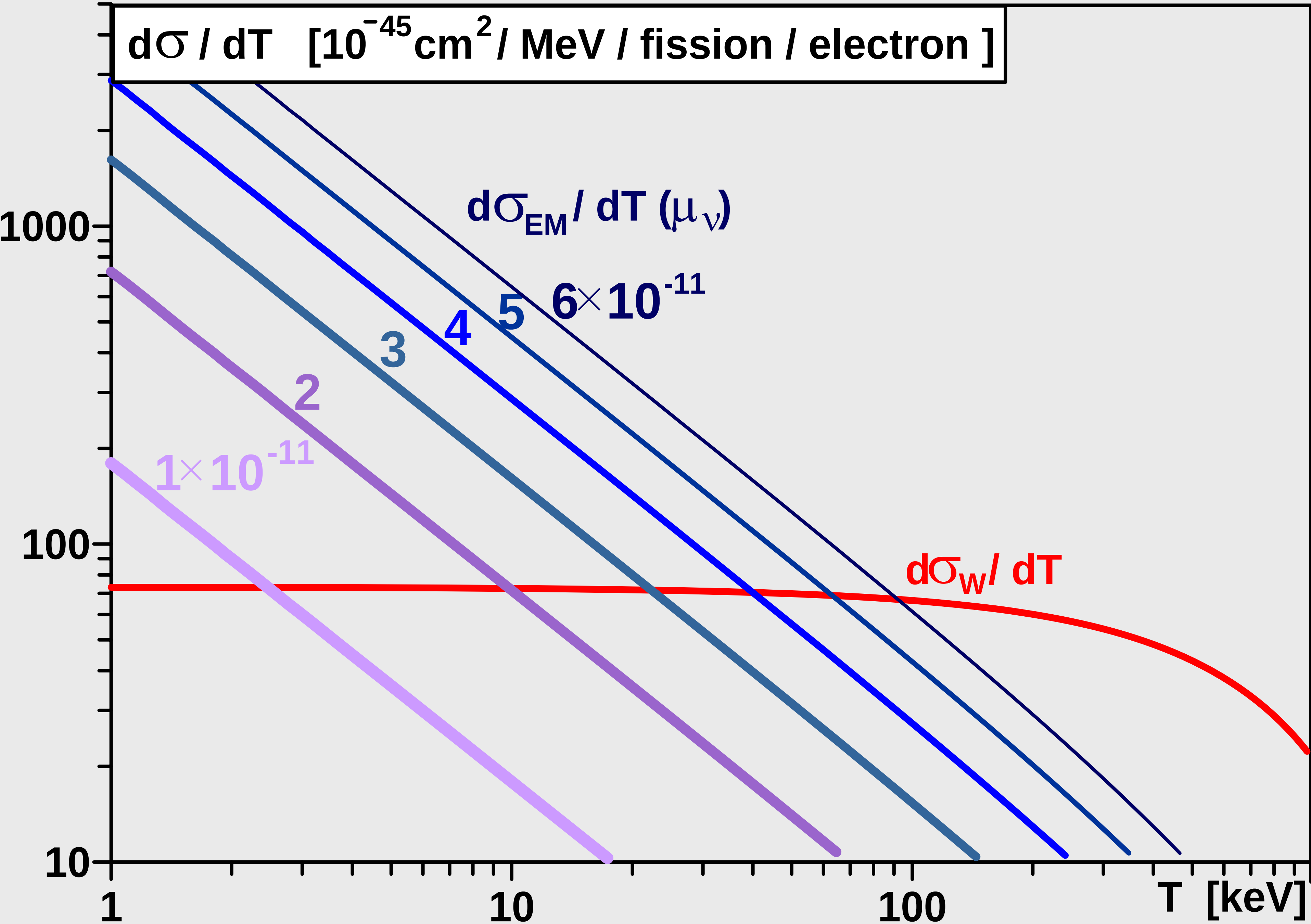
  ν - e scattering

  measured when the reactor is ON and OFF.

- The total cross-section $d\sigma/dT$ is a sum of two:

  $$(d\sigma/dT)_{weak} + (d\sigma/dT)_{EM}$$

  depending on the recoil energy T in different ways



dσ / dT [10^-45 cm^2 / MeV / fission / electron]
dσ_EM / dT (μ_ν)
6×10^-11
5
4
3
2
1×10^-11
dσ_W / dT
1000
100
10
1
10
100
T [keV]

GEMMA

Search for the Neutrino Magnetic Moment

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[c] - **YerPhI** (Yerevan Physics Institute, Yerevan, Armenia).

Reactor unit #2 of the "Kalinin" Nuclear Power Plant (400 km North from Moscow)

Power: 3 GW

ON: **315** days/y

OFF: **50** days/y

Total mass above

(reactor, building, shielding, etc.):

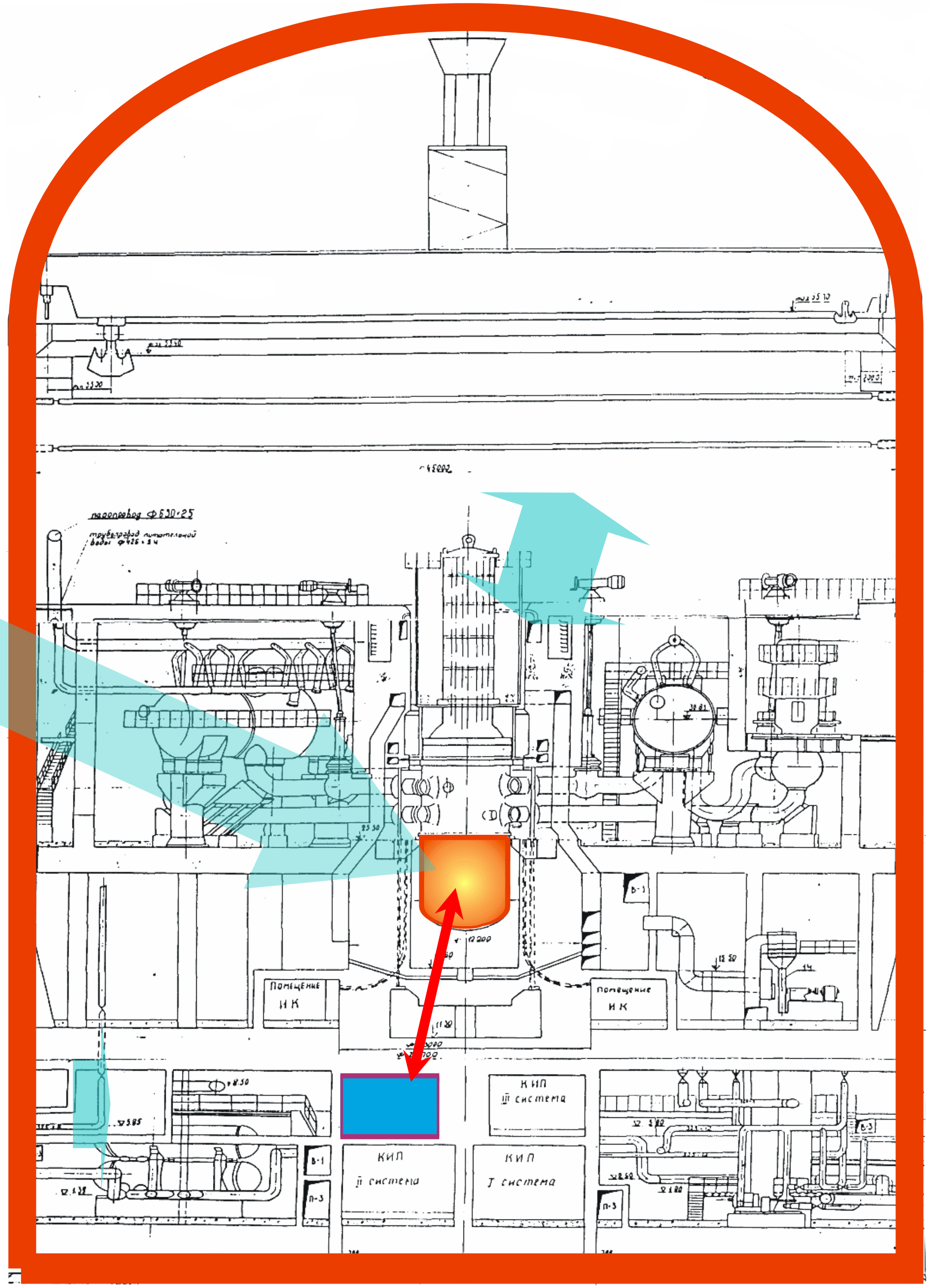
~70 m of W.E.

Technological room

just under reactor

14 m only!

$2.7\times10^{13}\ \nu/cm^2/s$

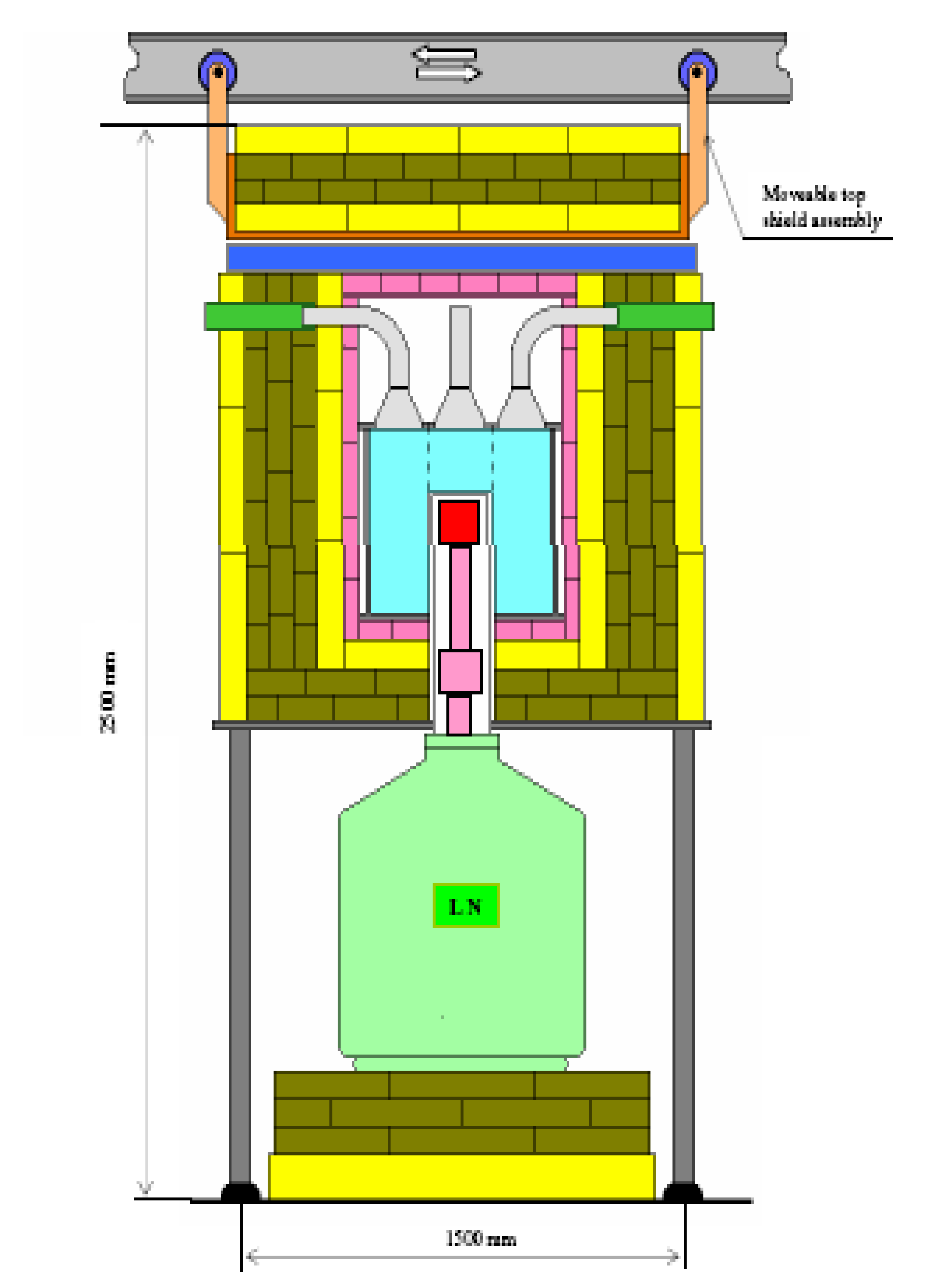


Experiment **GEMMA**

(**G**ermanium **E**xperiment for measurement of **M**agnetic **M**oment of **A**ntineutrino)

*[Phys. of At. Nucl.,**67**(2004)1948]*

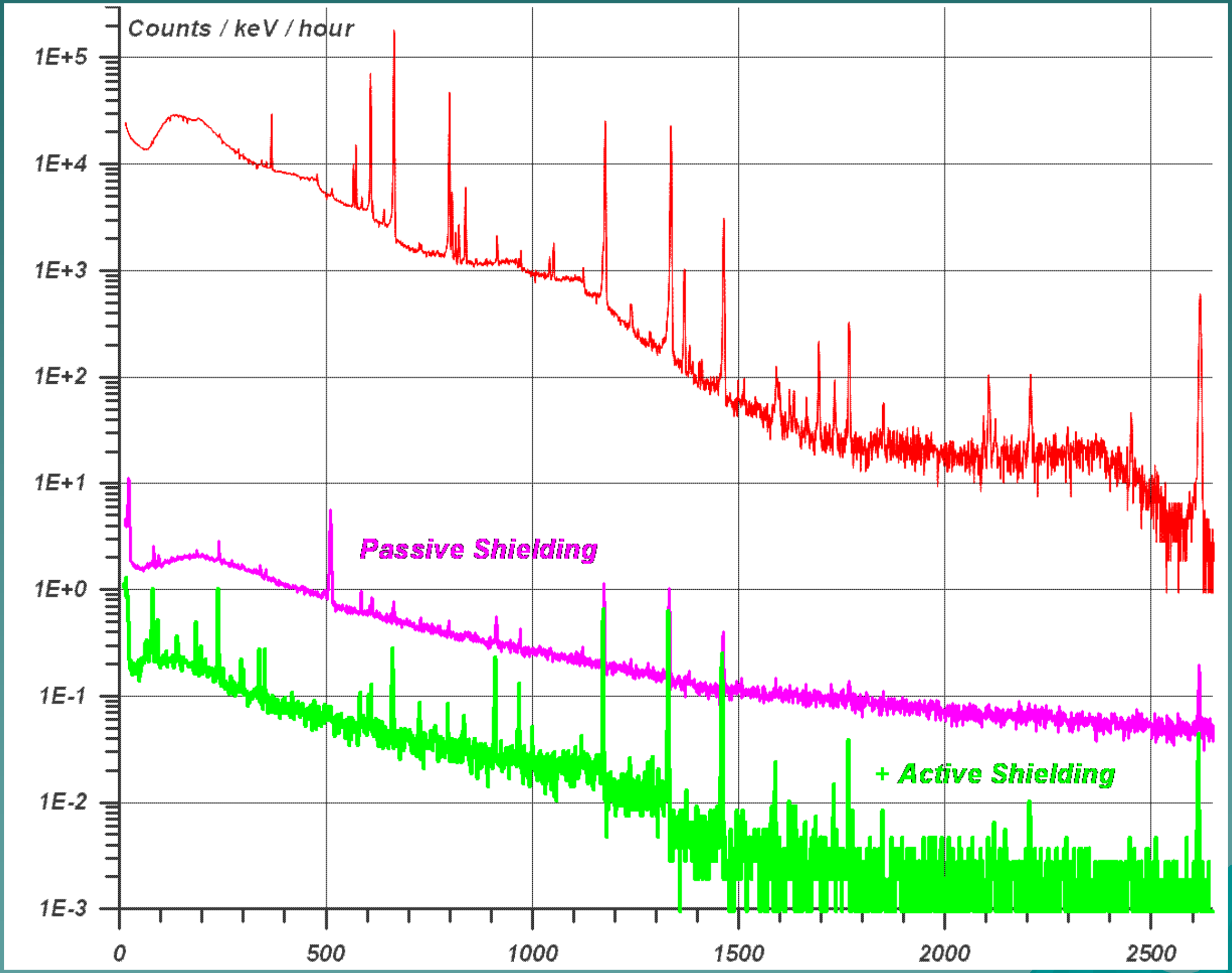
- Spectrometer includes a HPGe detector of 1.5 kg installed within NaI active shielding.
- HPGe + NaI are surrounded with multi-layer passive shielding : electrolytic copper, borated polyethylene and lead.

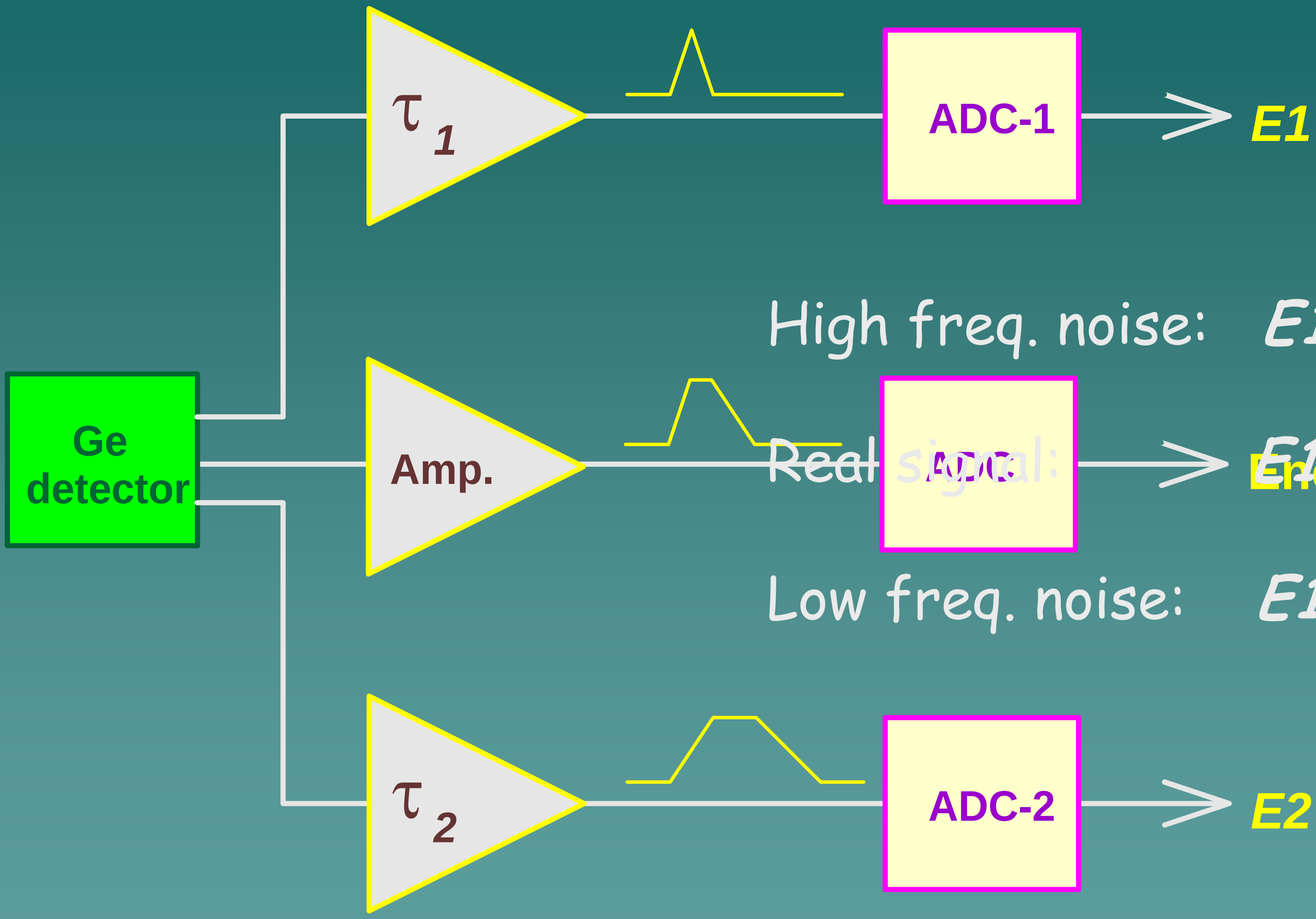


GEMMA background conditions

- **γ-rays** were measured with Ge detector. The main sources are: **^{137}Cs , ^{60}Co, ^{134}Cs.**
- **Neutron** background was measured with ^{3}He counters, i.e., thermal neutrons were counted. Their flux at the facility site turned out to be **30 times lower** than in the outside laboratory room.
- **Charged** component of the cosmic radiation (**muons**) was measured to be **5 times lower** than outside.

Background suppresion



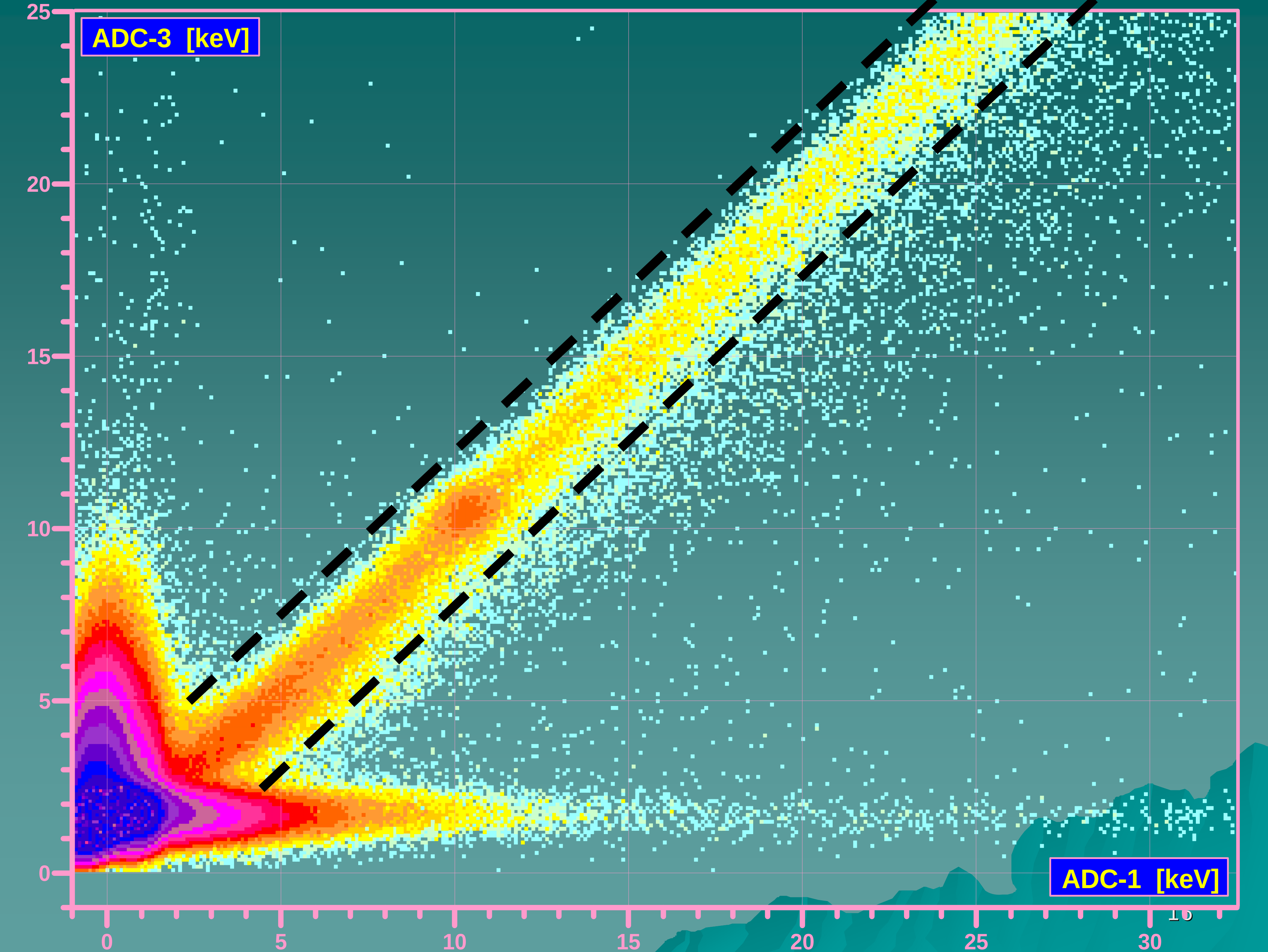


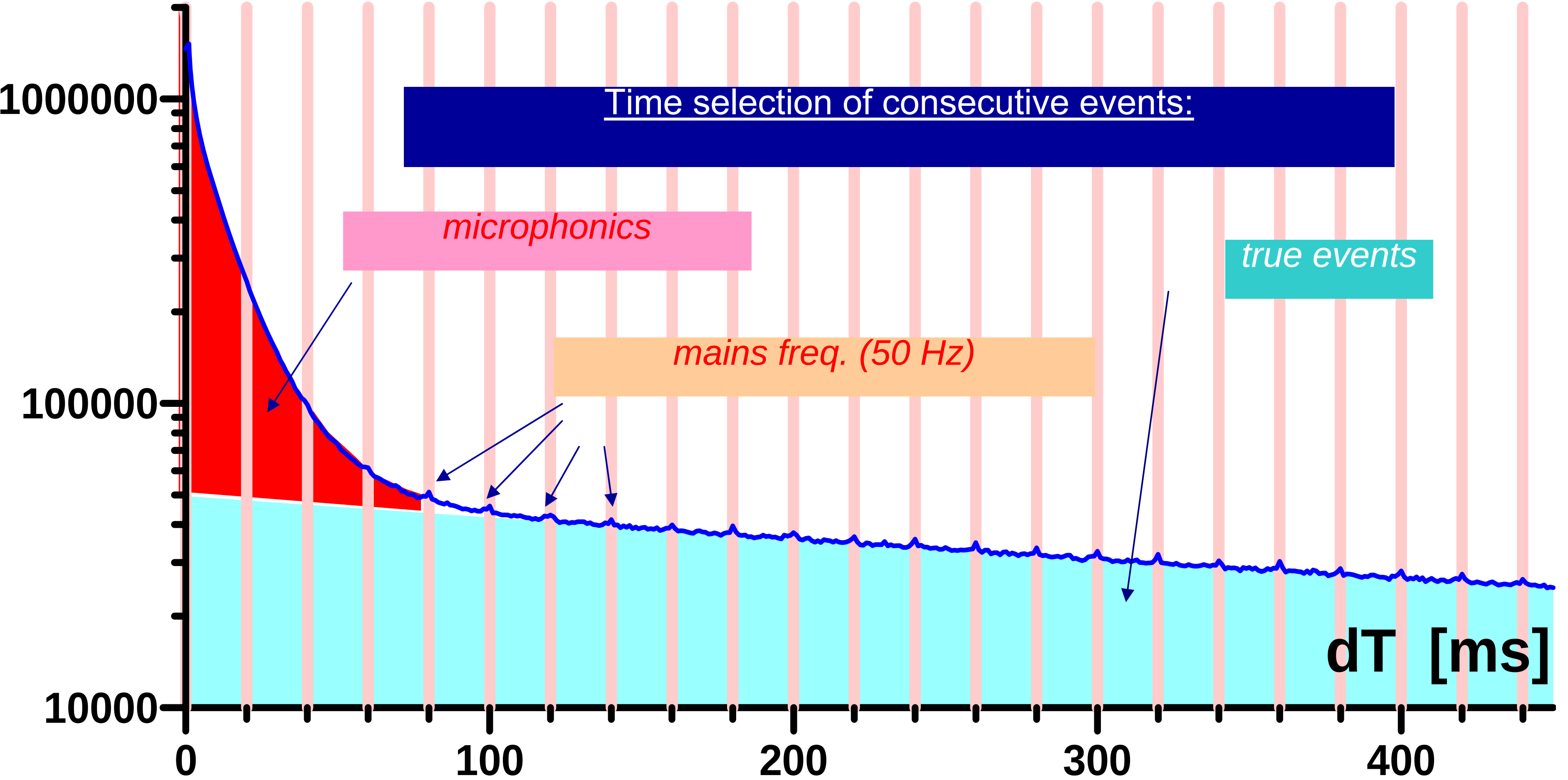
High freq. noise: E1 > E2

Real signal: E1 = E2

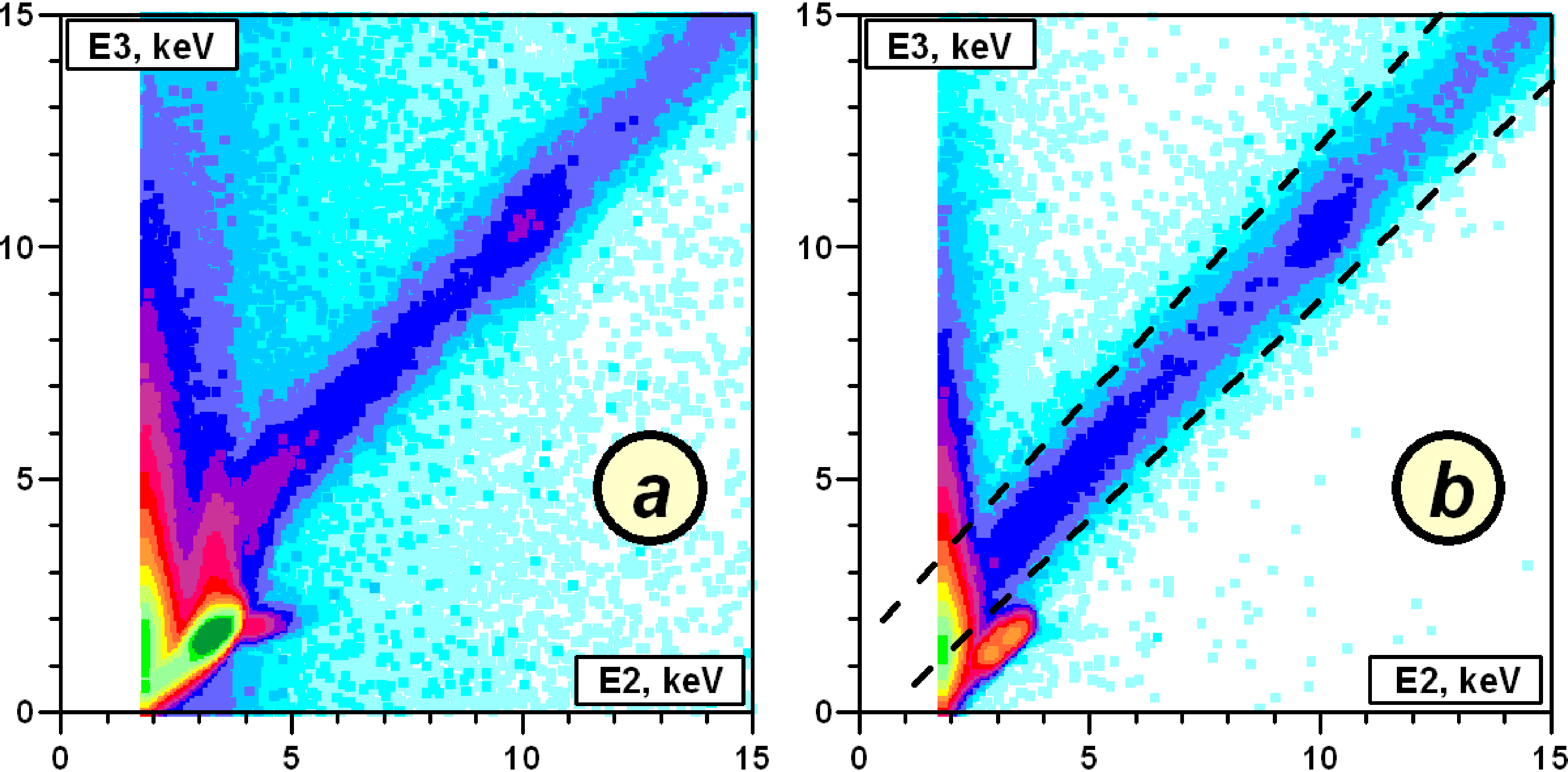
Low freq. noise: E1 < E2

E.Garcia e.a. NPB ***28A*** *(1992)286*


ADC-3 [keV]
ADC-1 [keV]
0
5
10
15
20
25
30
0
5
10
15
20
25

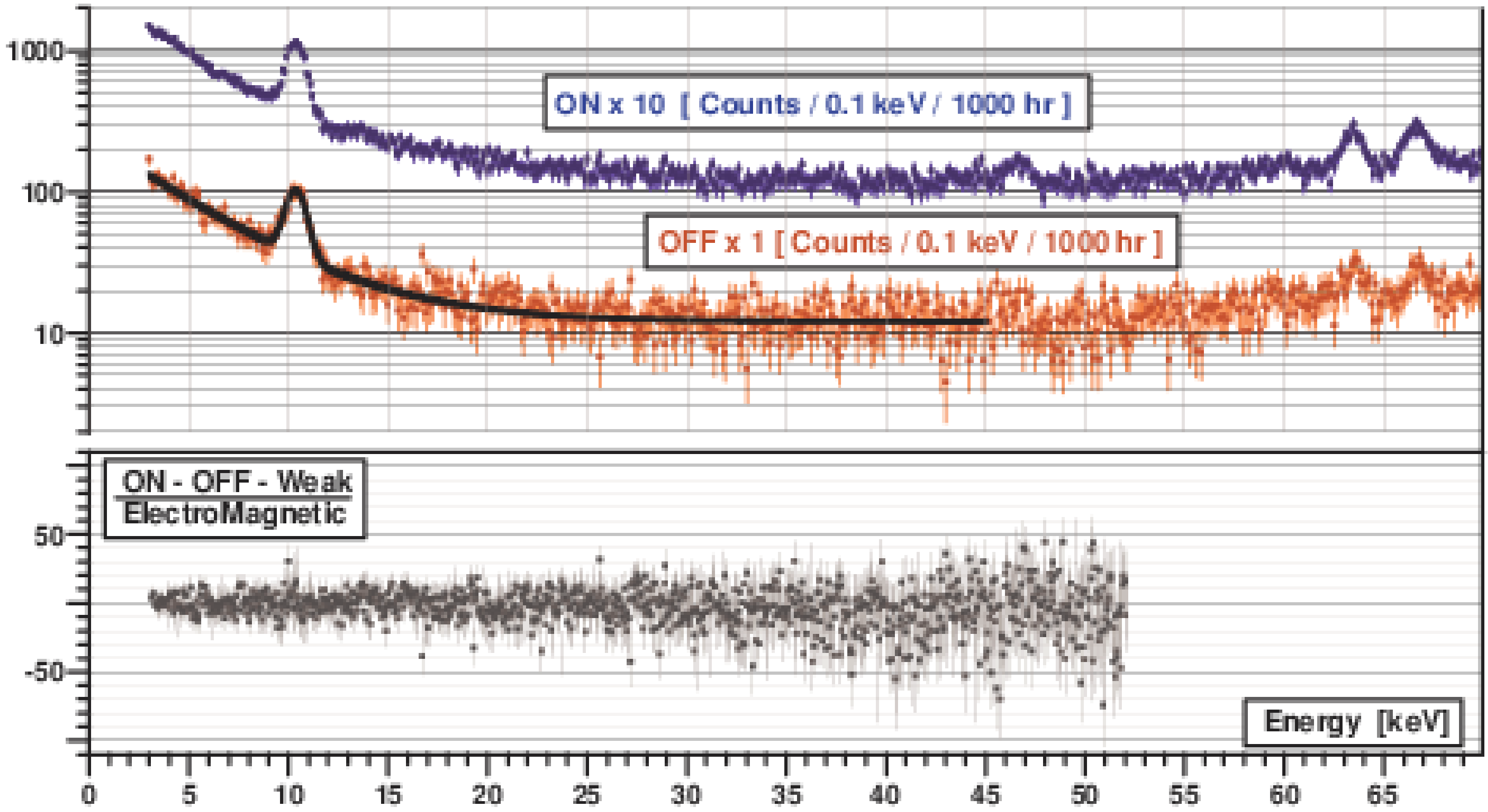


Time selection of consecutive events:
microphonics
true events
mains freq. (50 Hz)
1000000
100000
10000
0
100
200
300
400
dT [ms]

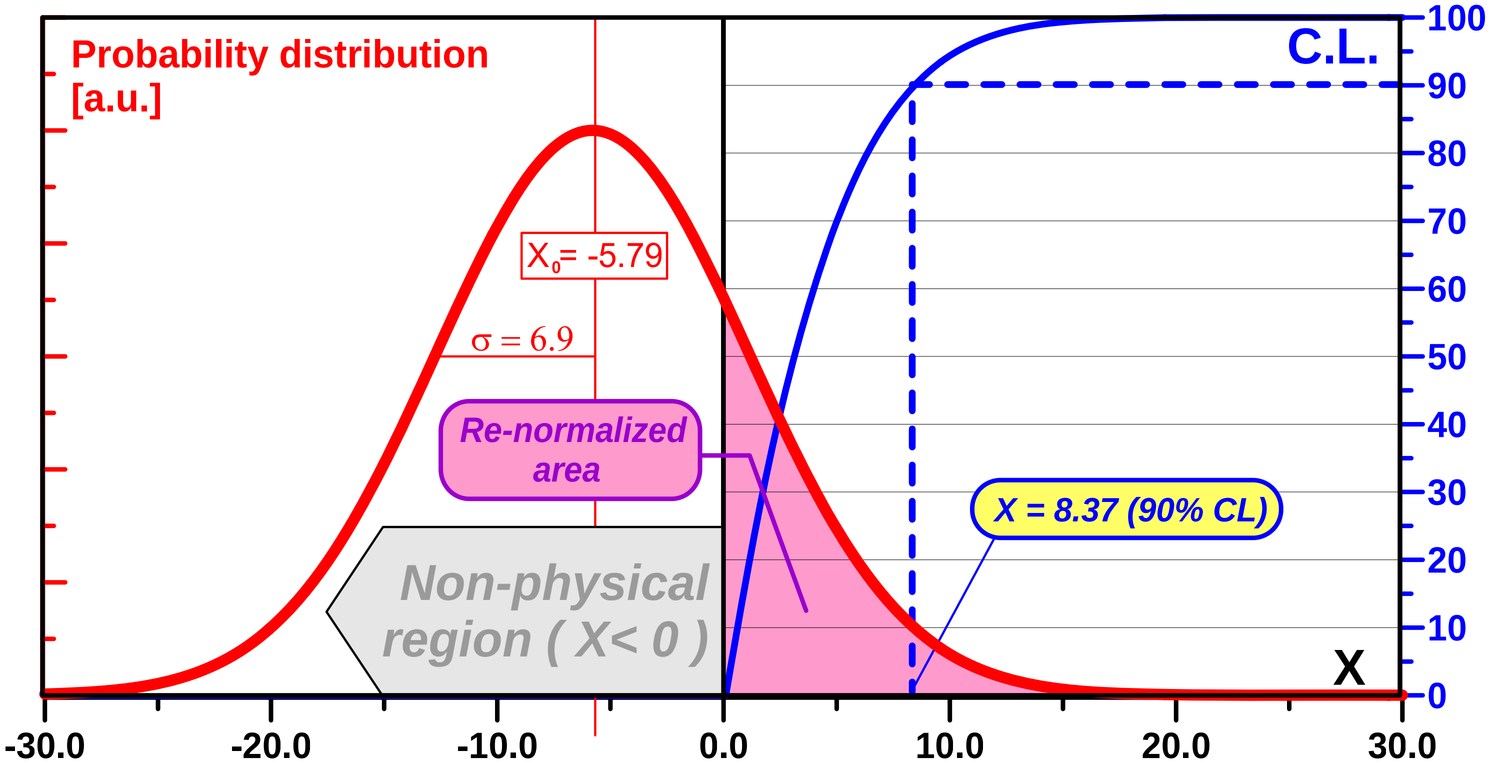


E3, keV
E2, keV
a
E3, keV
E2, keV
b
0
5
10
15

Final spectra



Final distribution



Experimental sensitivity

$$\mu_\nu \propto \frac{1}{\sqrt{N_\nu}} \left(\frac{B}{mt}\right)^{\frac{1}{4}}$$

- N_ν : number of signal events expected
- B : background level in the ROI
- m : target (=detector) mass
- t : measurement time

$N_\nu \sim \varphi_\nu\ (\sim Power / r^2)$

$\sim (T_{max} - T_{min} / T_{max} * T_{min})^{1/2}$

GEMMA I 2005 – 2009

- φ_ν ~ $2.7 \times 10^{13}\ \nu / cm^2 / s$
- t ~ 4 years
- B ~ 2.5 $keV^{-1}\ kg^{-1}\ day^{-1}$
- m ~ 1.5 kg
- T_{th} ~ 2.8 keV

$$\mu_\nu \leq 2.9 \times 10^{-11} \mu_B$$

Data Set

- I phase – 5184 h ON, 1853 h OFF

$$\mu_\nu < 5.8*10^{-11}\mu_B$$

- II phase – 6798 h ON, 1021 h OFF
- I+II – 11982 h ON, 2874 h OFF

$$\mu_\nu < 3.2*10^{-11}\mu_B$$

- III phase – 6152 h ON, 1613 h OFF
- I+II+III – 18134 h ON, 4487 h OFF

$$\mu_\nu < 2.9*10^{-11}\mu_B$$

Beda A.G. et al. // Advances in High Energy Physics. 2012. V. 2012, Article ID 350150.
Beda A.G. et al. // Physics of Particles and Nuclei Letters, 2013, V. 10, №2, pp. 139–143.

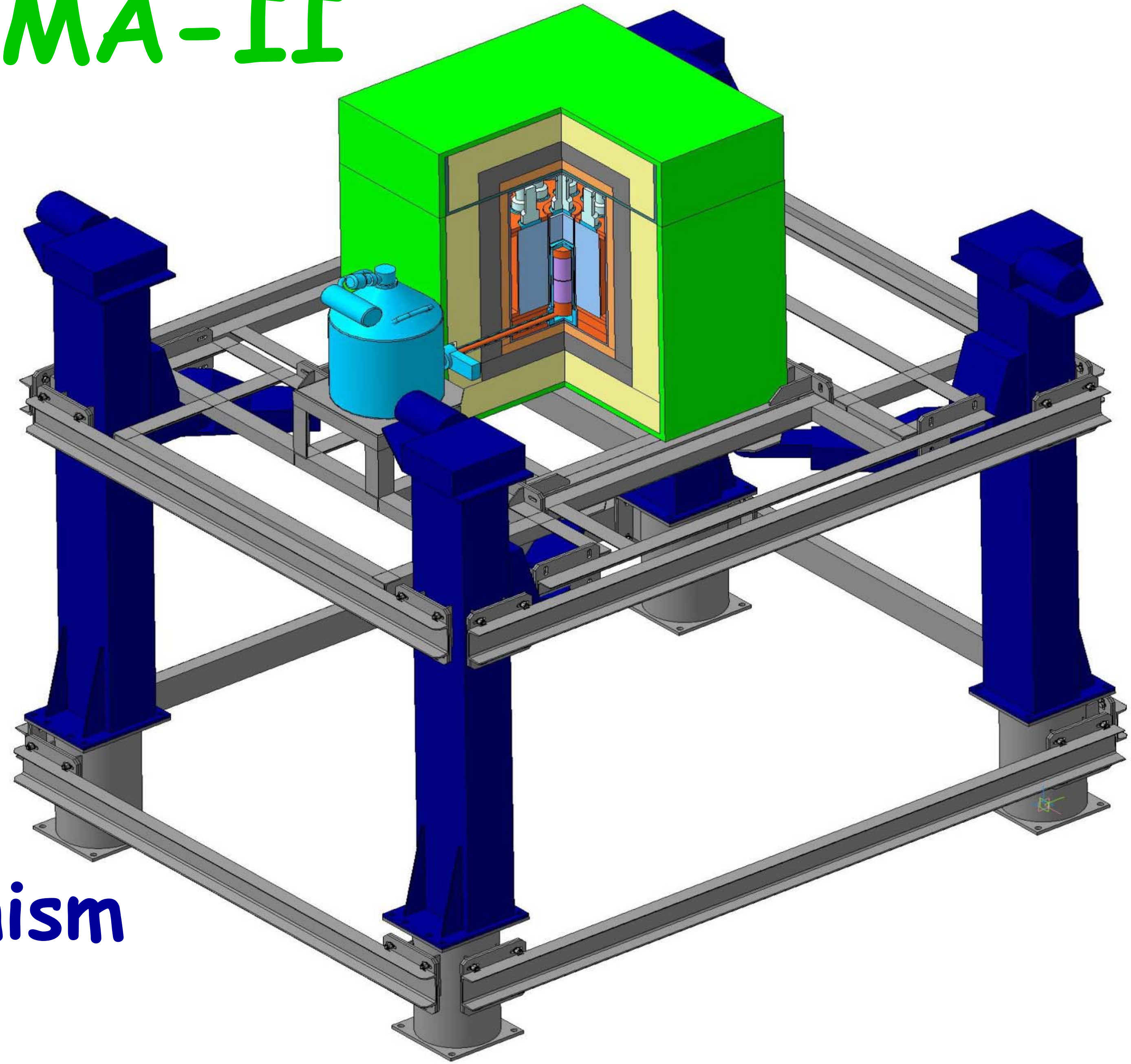
Perspectives

GEMMA II 2013

- φ_ν ~ $5 \times 10^{13}\ \nu\ /\ cm^2\ /\ s$
- t ~ 2 years
- B ~ 0.5 $keV^{-1}\ kg^{-1}\ day^{-1}$
- m ~ 6 kg (two detectors)
- T_{th} ~ 1.5 keV

$$\mu_\nu \leq 1.0 \times 10^{-11}\ \mu_B$$

GEMMA-II

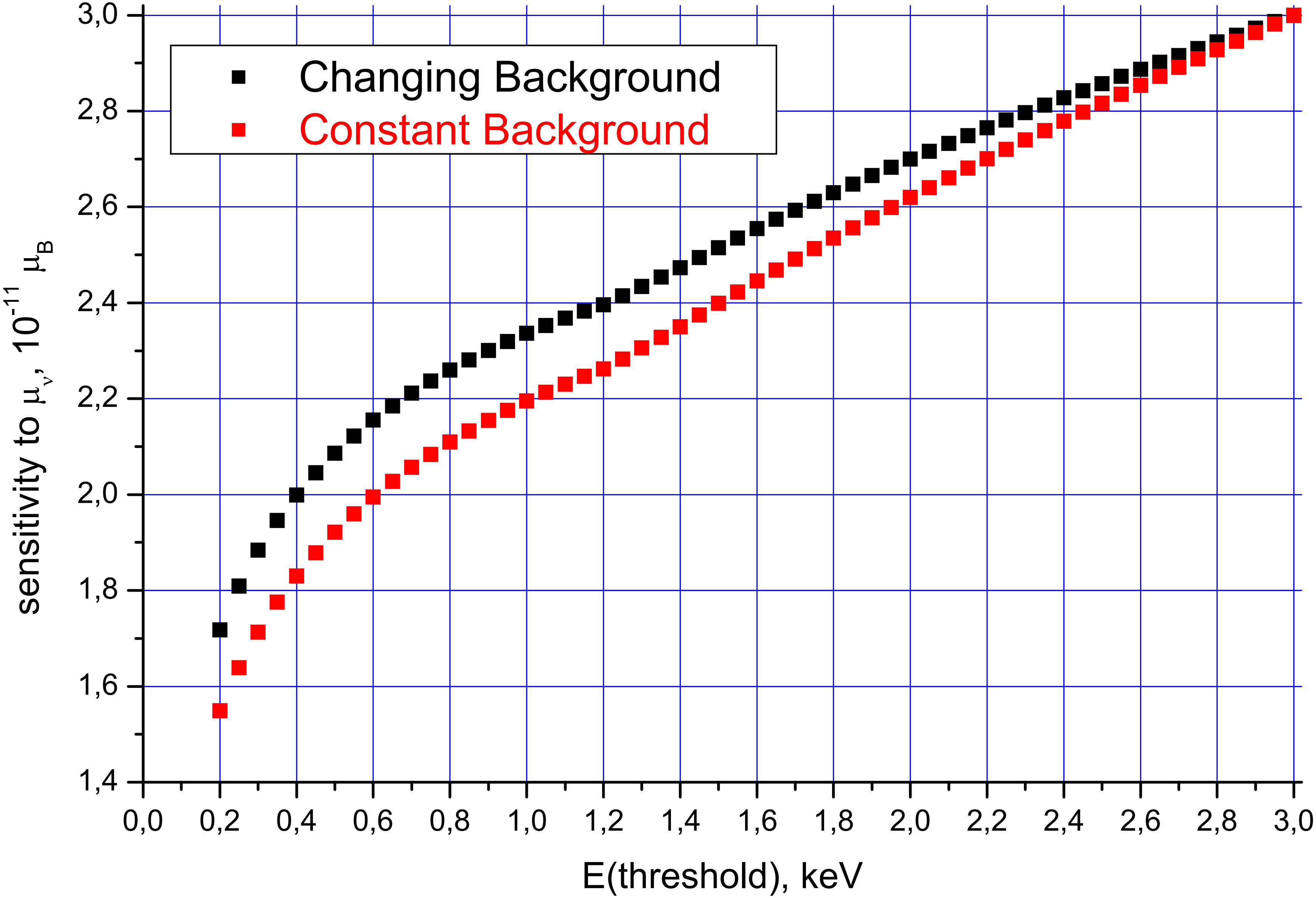


Lifting mechanism

Future detectors

Ge detectors with very low threshold (~ 300 eV)

RFBR grant



Changing Background
Constant Background
sensitivity to μ_ν, 10^{-11} μ_B
E(threshold), keV
3,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
1,4
0,0 0,2 0,4 0,6 0,8 1,0 1,2 1,4 1,6 1,8 2,0 2,2 2,4 2,6 2,8 3,0

Sensitivity of future experiments

B = 0.2 1/keV/kg/day

Mass, kg	Threshold, keV	Sensitivity, $10^{-12}\mu_B$
4.5	0.4	5.8
10	0.4	4.7
20	0.4	4.0
4.5	0.3	5.6
10	0.3	4.6
20	0.3	3.9