V.Egorov

JINR Dubna
ITEP Moscow

GEMMA

search for the Neutrino Magnetic Moment

Science motivation of the searching for μ_ν

- minimally-extended Standard Model:

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

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

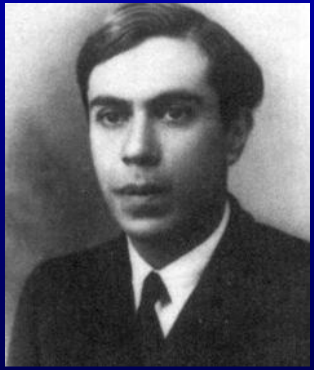
$$\mu_\nu \equiv \mathbf{0}$$

Science motivation of the searching for μ_ν

- number of extensions beyond the MSM:

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

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



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

- Observation of ($\mu_\nu \sim \mathbf{10^{-12}}$) => D/M preference

Limits for the NMM from astrophysics **(model dependent !!!)**

The neutrino interactions are very important for stars evolution in their late stage (90% of energy emission in old stars is done by neutrinos)

- He star $\mu_\nu \le (0.1 - 0.03) \times 10^{-10}\, \mu_B$ core mass at the flash
- White dwarf $\mu_\nu \le (0.4 - 0.05) \times 10^{-10}\, \mu_B$ luminosity function
- SN 1987 A $\mu_\nu \le (0.4 - 0.05) \times 10^{-10}\, \mu_B$ E_ν in neutrino burst

The model dependence:

…… *a slight decrease in temperature leads to significant suppression in neutrino emission….* *(M. Fukugita)*

…… SN 1987 limits apply only for Dirac neutrino ……

Limits for the NMM from astrophysics **(model dependent !!!)**

Limits for the NMM from solar data

- Resonance and non-resonance spin – flavor precession in solar magnetic field can excite distortion of neutrino spectra.
- The spectrum distortion analysis of SK and BOREXINO electron recoil spectrum can allow to set limit for μ_ν :

$$\mu_\nu \leq \mathbf{1.1 \times 10^{-10}} \mu_B \quad (90\%\ CL)$$

– SK + constrains from the other solar neutrino and KamLAND results.

$$\mu_\nu \leq \mathbf{5.4 \times 10^{-11}} \mu_B \quad (90\%\ CL)$$

– BOREXINO data

There are bounds on Majorana neutrino transition moments obtained both from

……solar neutrino data alone (*J.F. Beacom, P. Vogel)*

…..and using solar neutrino data combined with the results of the reactor experiments (*W. Grimus at al.)*

Limits for the NMM from astrophysics **(model dependent !!!)**

Limits for the NMM from solar data

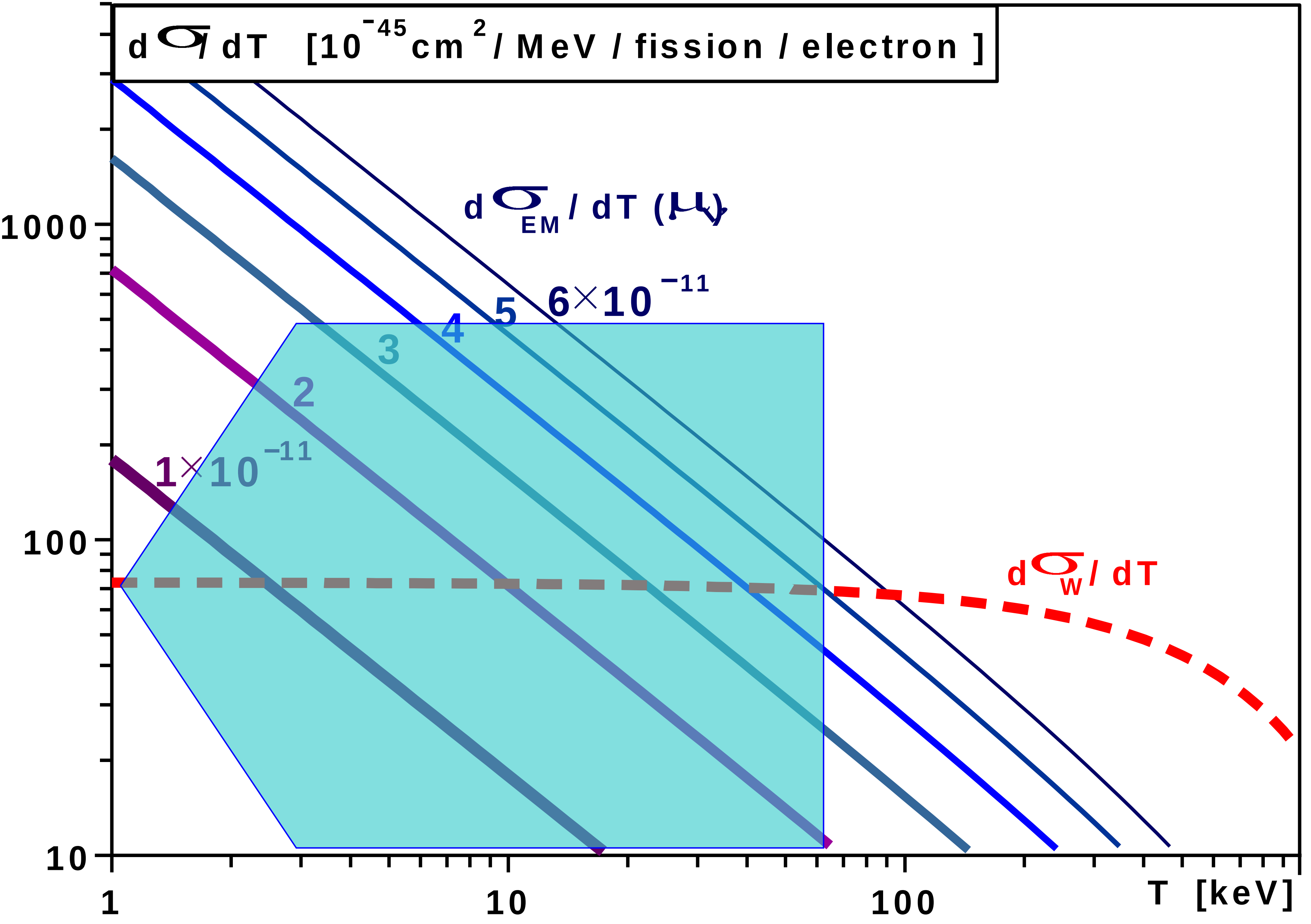
Reactor measurements of the NMM

- The effects of the NMM can be searched for in the recoil electron energy spectrum from the $\nu - e$ scattering measured with the reactor **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 a very different way



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]

The 30y history of the 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 2.2×10 ^{13} ν / cm ^{2} / s

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

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

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 "

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

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 ~ 2×10 ^{13} ν / cm ^{2} / s , 30 days "on"/17 days "off "

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

The 30y history of the reactor experiments

2001-2005 – Bugey. ***The MUNU experiment.***

Z. Darakchieva et al. [P.L.B. 615 (2005)].

~ 11.4 kg CF_4 TPC, 66.6 days "on" / 16.7 days "off "

$\mu_\nu \leq 9 \times 10^{-11} \mu_B$

1989 – Moscow. Proposed to detect (ν– *e*) scattering with low-background HPGe.

A.Vasenko et al. [P.T.E.(rus), 2,56(1989)]

2001- … – Taiwan. ***The TEXONO experiment***

H.T.Wong et al. [P.R. D75 (2007)]

1 kg HPGe detector, ν-flux of ~ 6.4×10^{12} ν / cm^2 / s

570 days "on" / 127 days "off "

$\mu_\nu \leq 7.4 \times 10^{-11} \mu_B$ (90% CL)

2005- … – Udomlya. ***The GEMMA experiment***

A.Beda et al. [P.A.N. (rus), 70(2007)]

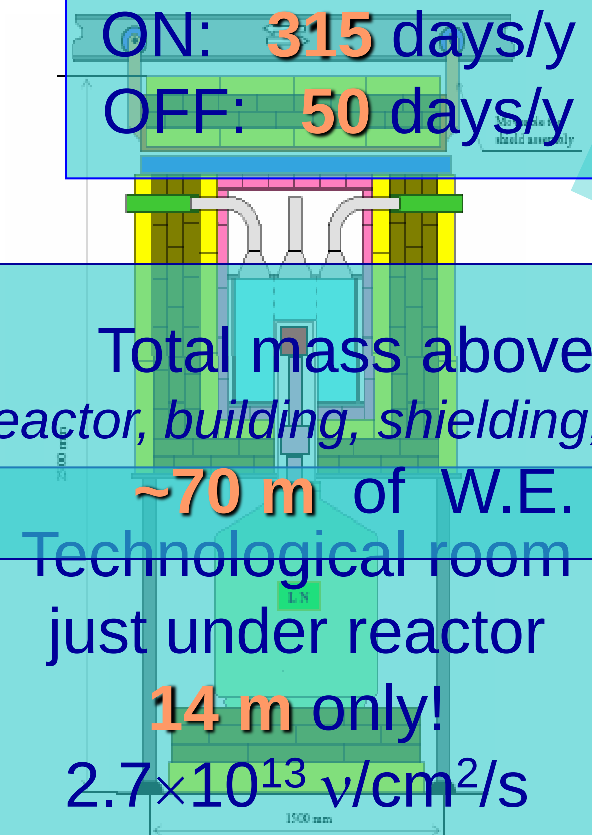
1.5 kg HPGe detector, ν-flux of ~ 2.7×10^{13} ν / cm^2 / s ,

216 days "on"/ 77 days "off "

$\mu_\nu \leq 5.8 \times 10^{-11} \mu_B$ (90% CL)

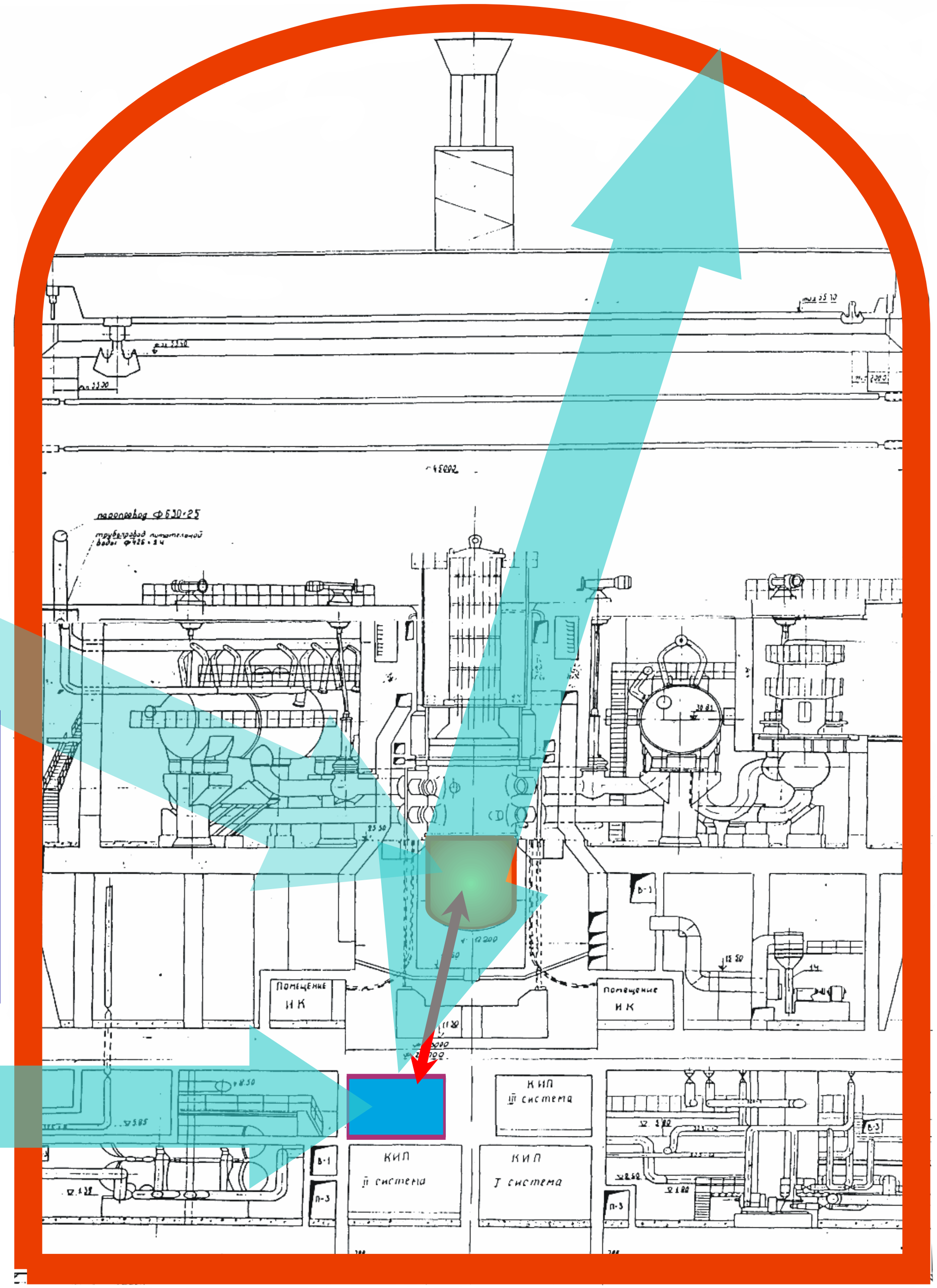
Reactor unit #2 of the "Kalinin" Nuclear Power Plant (400 km North from Moscow)

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!
$2.7 \times 10^{13}\ \nu/cm^2/s$



Phase-1: 13 months (08.2005-09.2006)
= 216 days ON + 77 days OFF

Phase-2: 19 months (09.2006-05.2008)
= 283 days ON + 42 days OFF

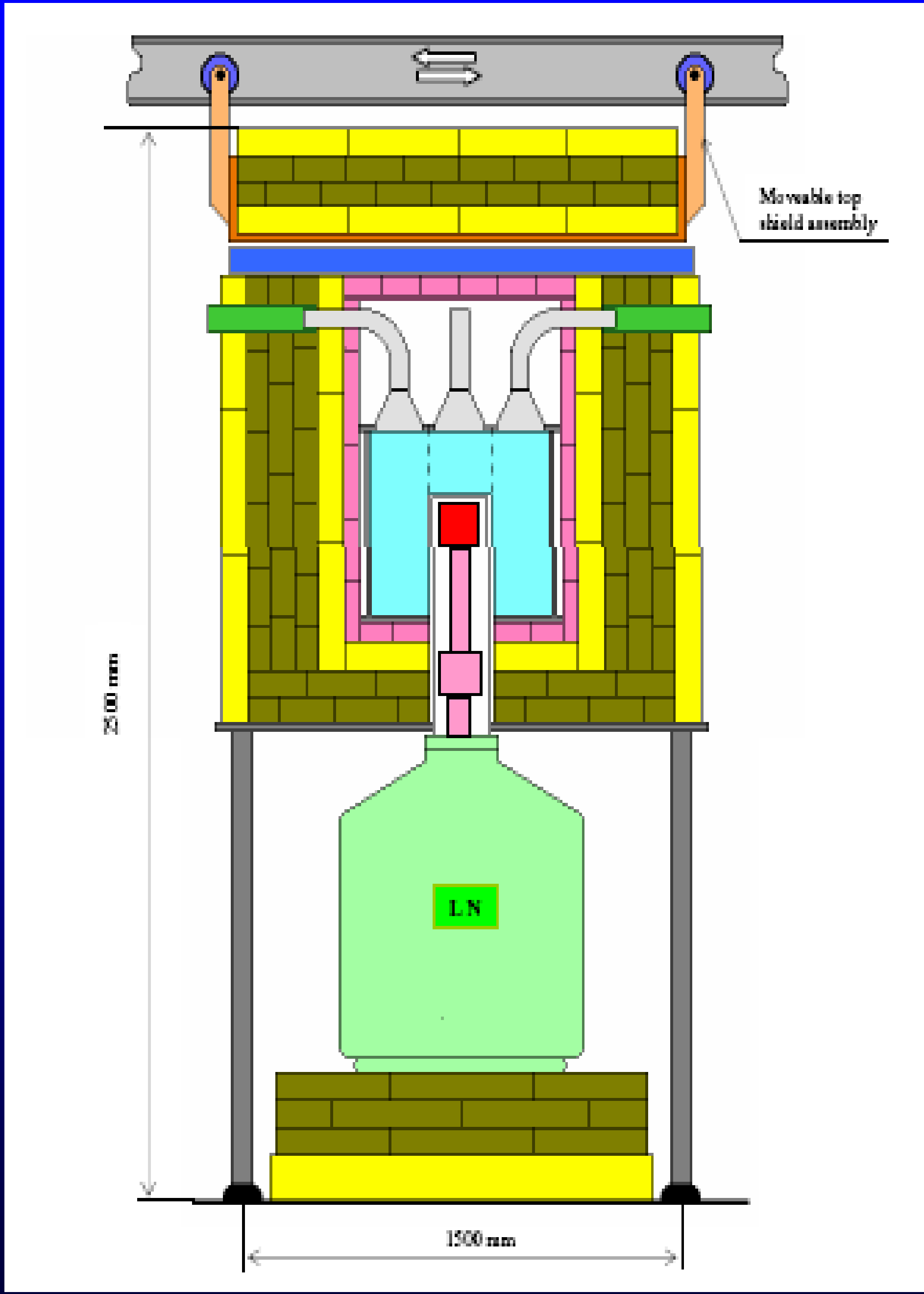
Phase-3: 18 months (05.2008-11.2009)
– *data analysis is in progress…*

Experiment **GEMMA1**

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

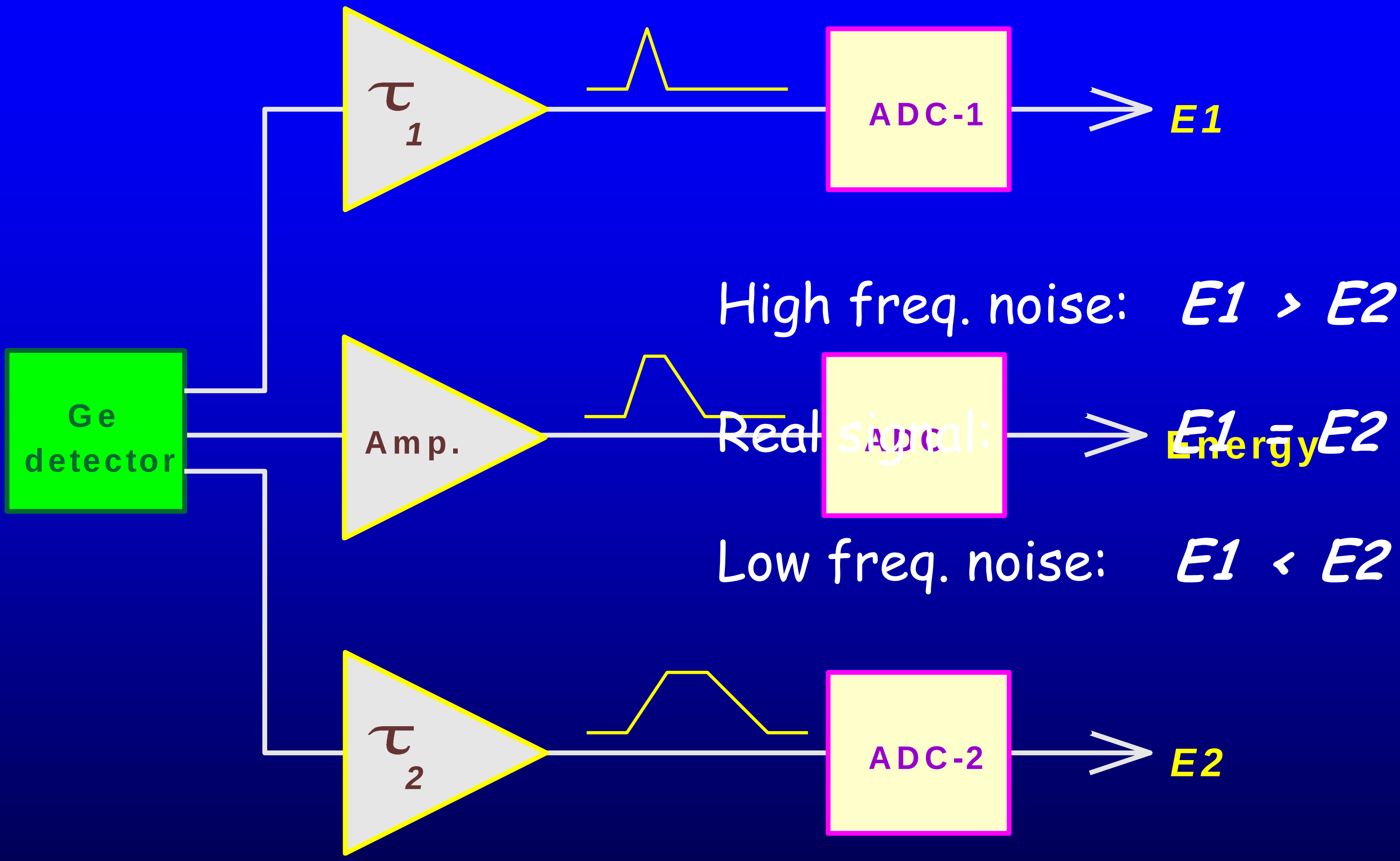
*[Phys. of At. Nucl.,**67**(2004)1948]*

- 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.

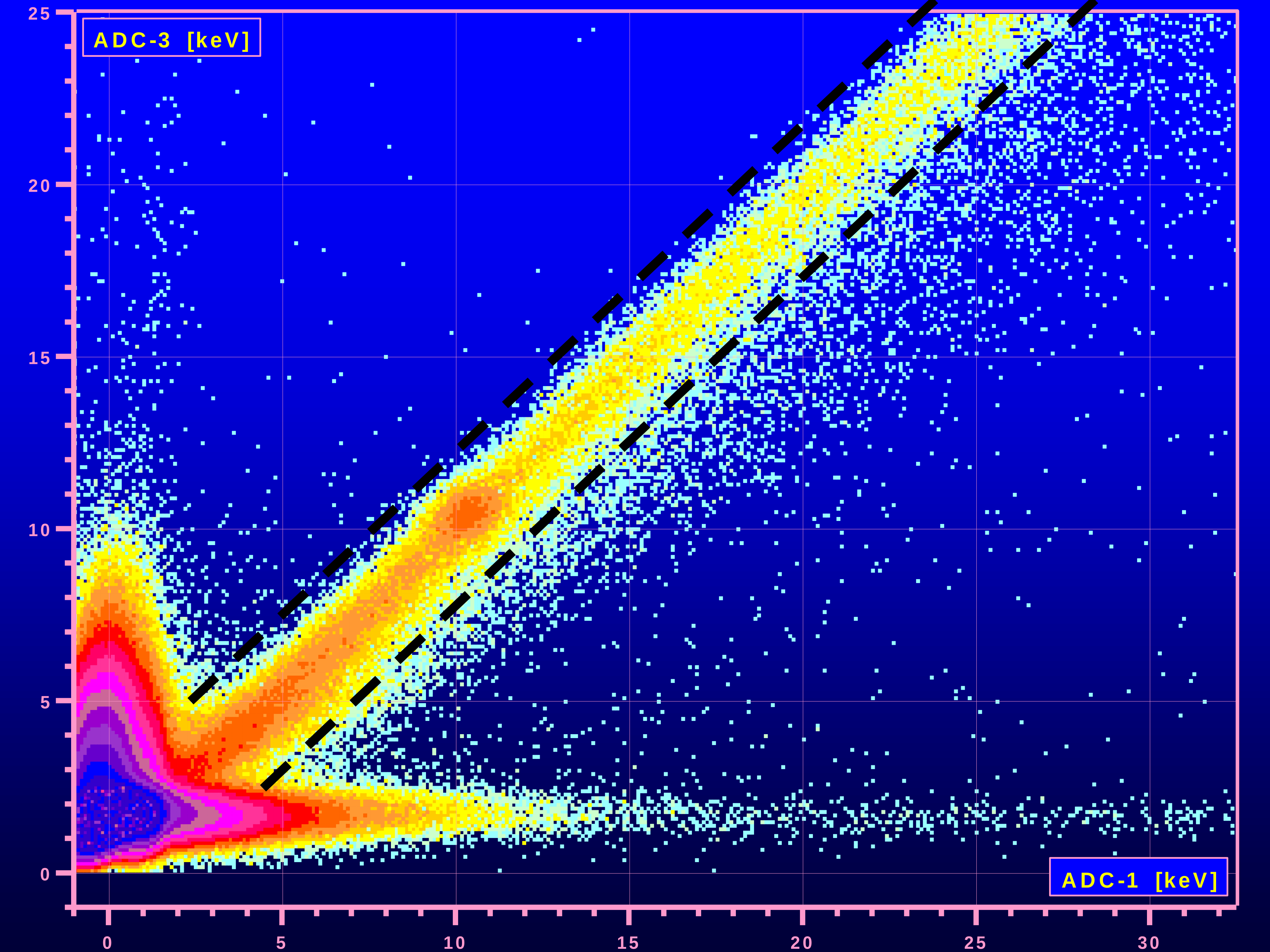


GEMMA background conditions

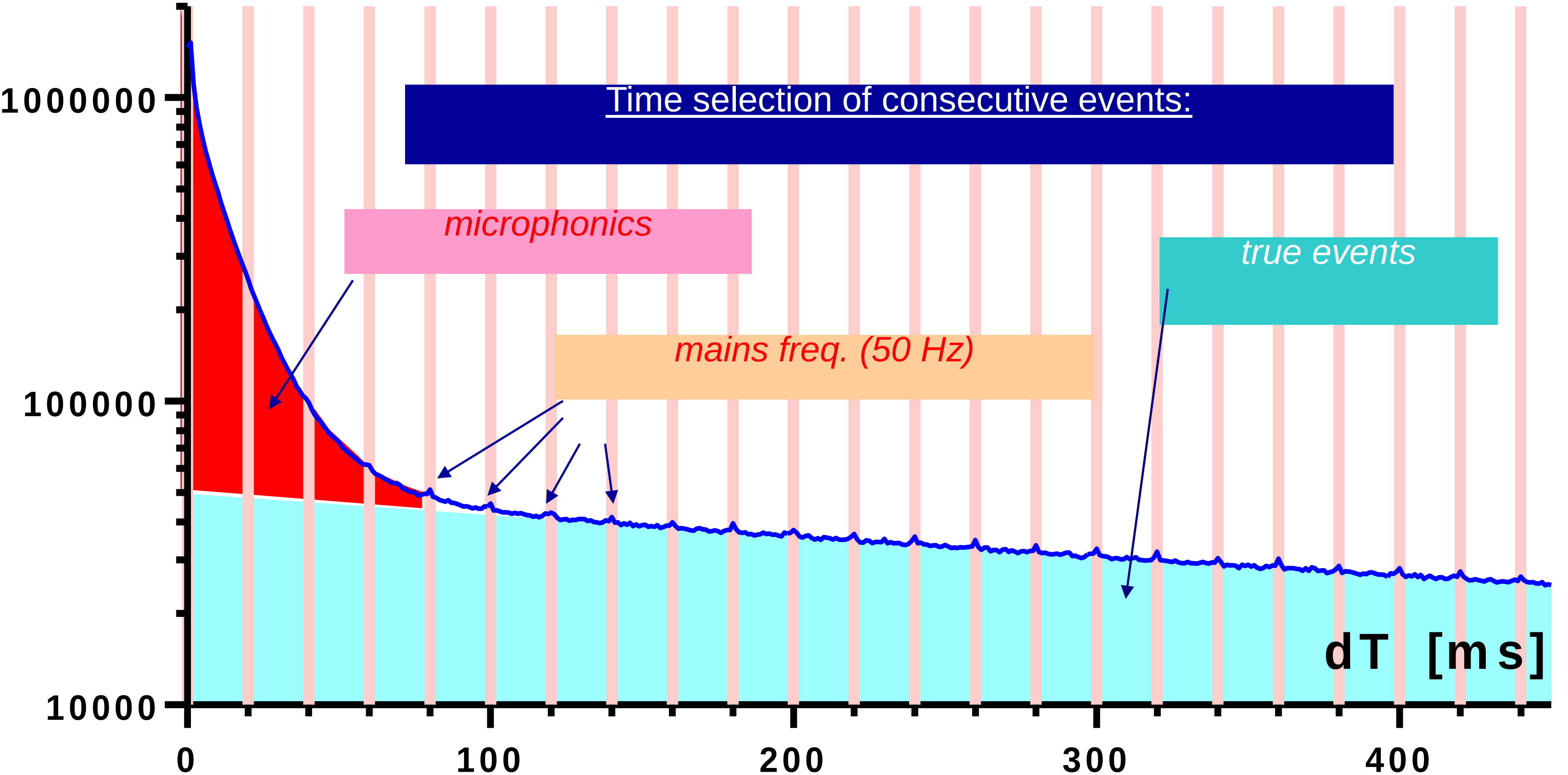
- **γ-rays** were measured with Ge detector. The main sources are: **^{137}Cs , ^{60}Co, ^{134}Cs.**
- **Neutron** background was measured with ^{3}He counters, i.e., thermal neutrons were counted. Their flux at the facility site turned out to be **30 times lower** than in the outside laboratory room.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



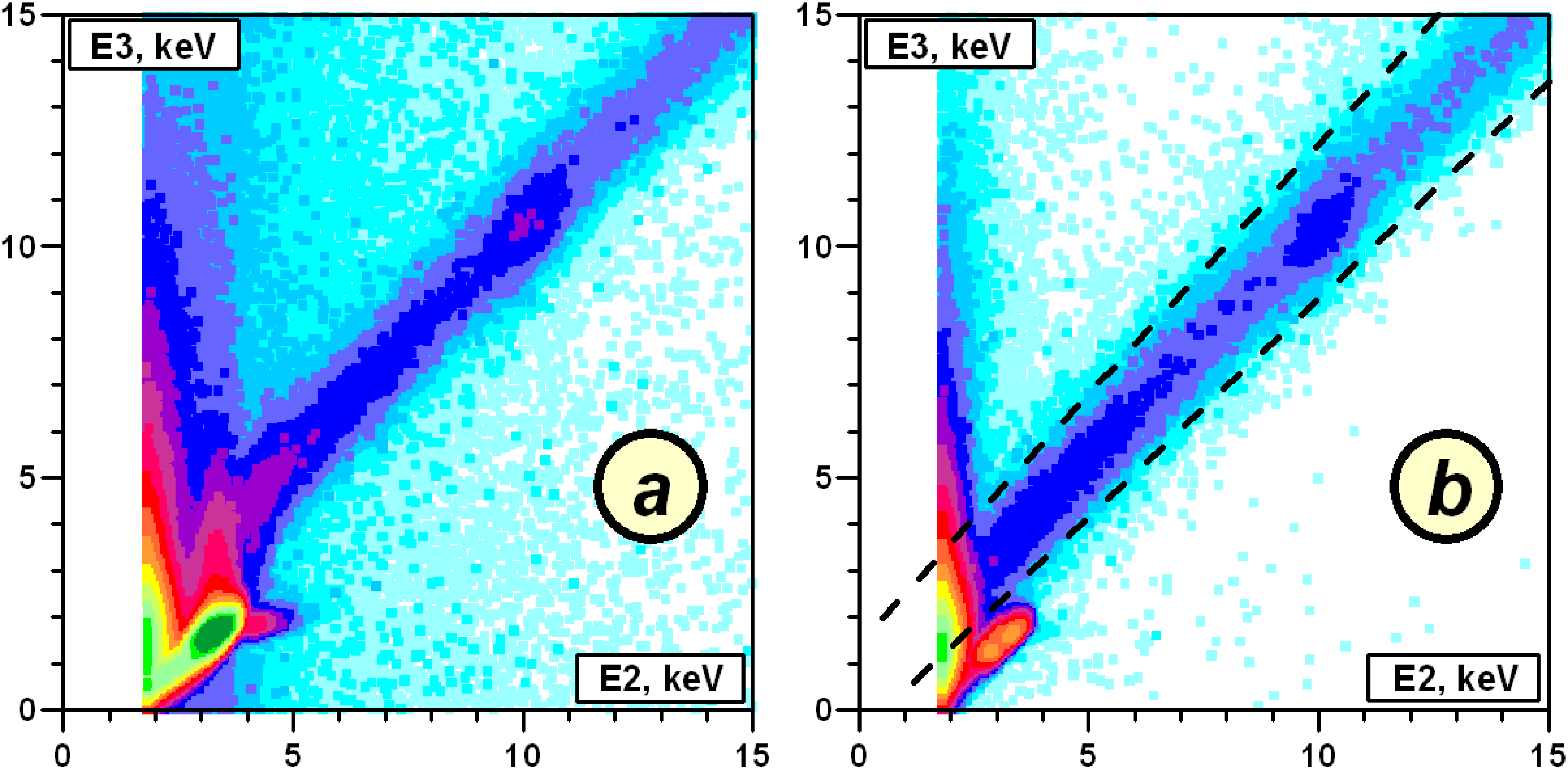
*E.Garcia e.a. NPB **28A**(1992)286*



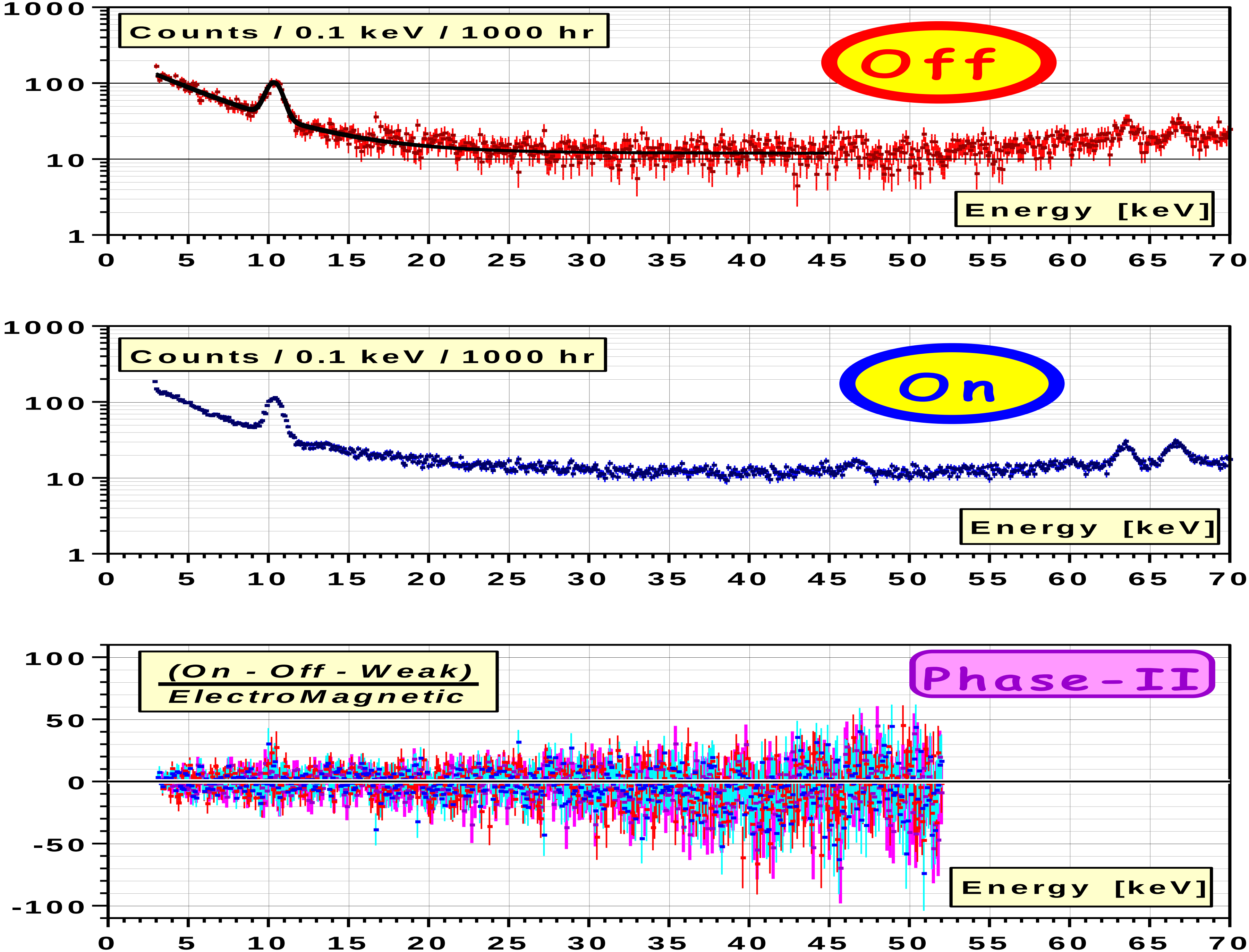
ADC-3 [keV]
ADC-1 [keV]
0
5
10
15
20
25
30



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
0
5
10
15
E3, keV
E2, keV
b


Counts / 0.1 keV / 1000 hr
Off
Energy [keV]
Counts / 0.1 keV / 1000 hr
On
Energy [keV]
(On - Off - Weak) / ElectroMagnetic
Phase-II
Energy [keV]

Spectrum measured with the reactor being in operation

Spectrum measured with the reactor being shut down

Weak contribution

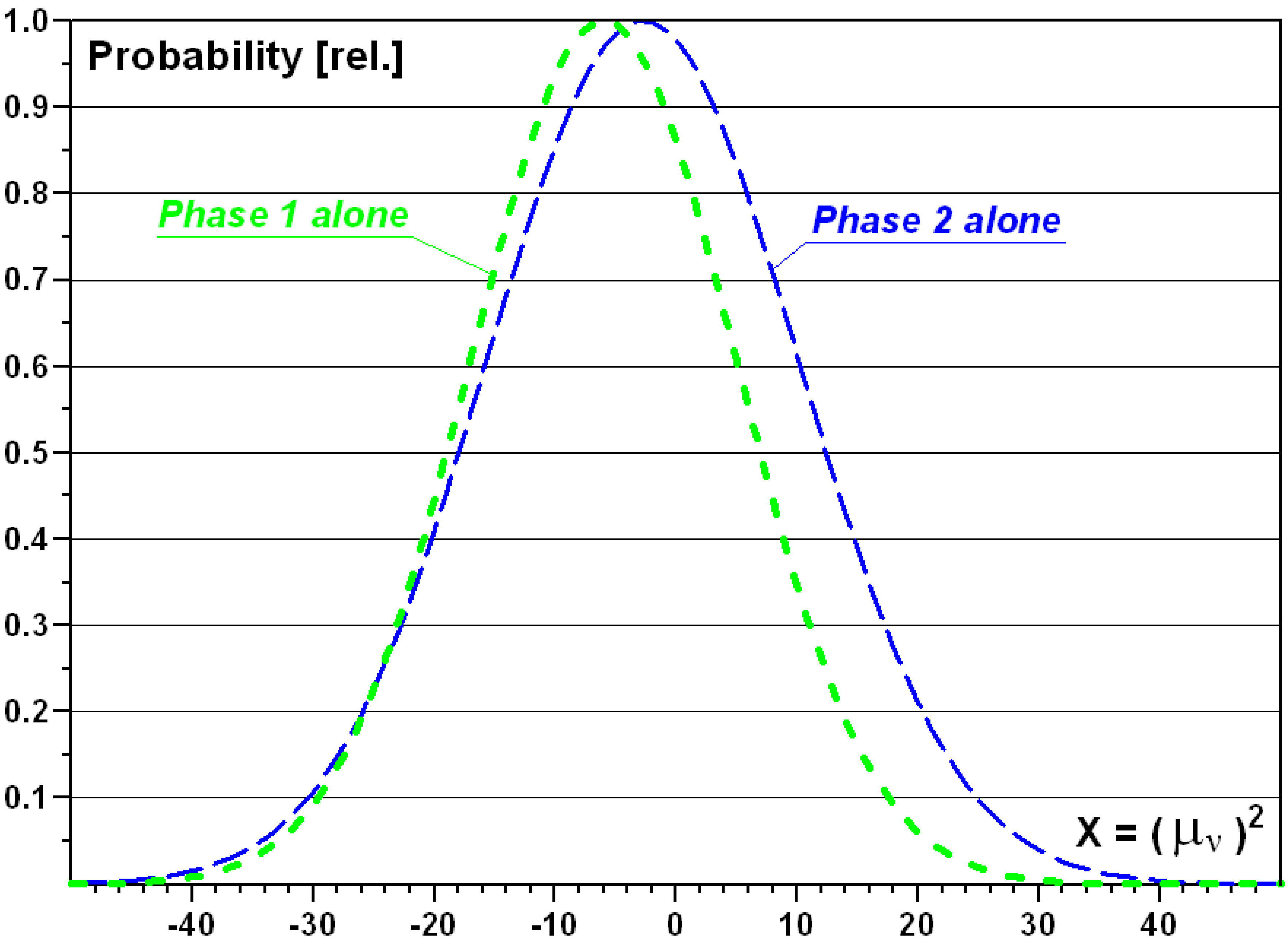
ElectroMagnetic cross-section

$$\mathrm{ON} = \mathrm{norm} \cdot \left[\mathrm{OFF} + \mathrm{W} + \mathrm{X} \cdot \mathrm{EM}\right]$$

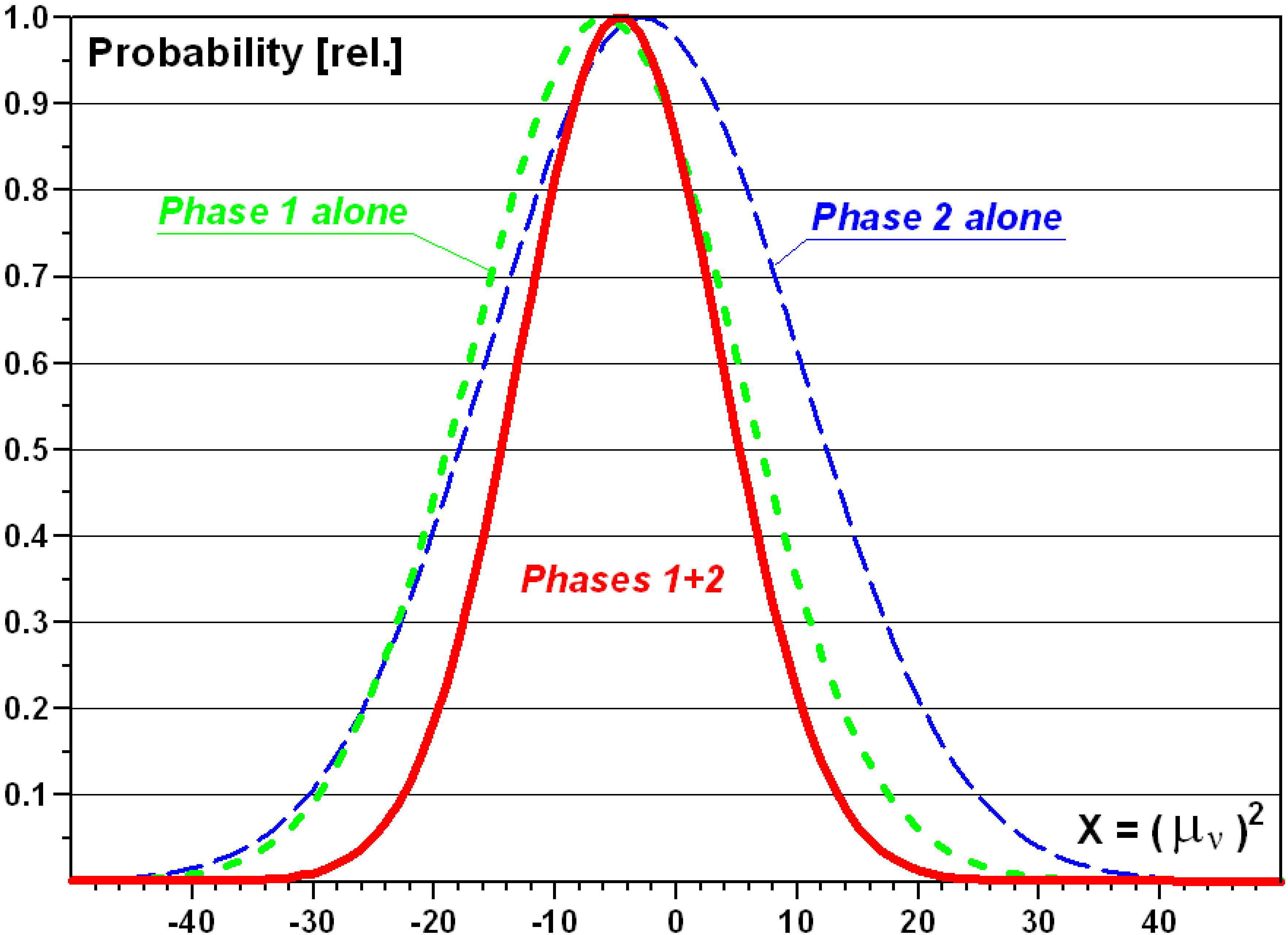
(Free parameters)

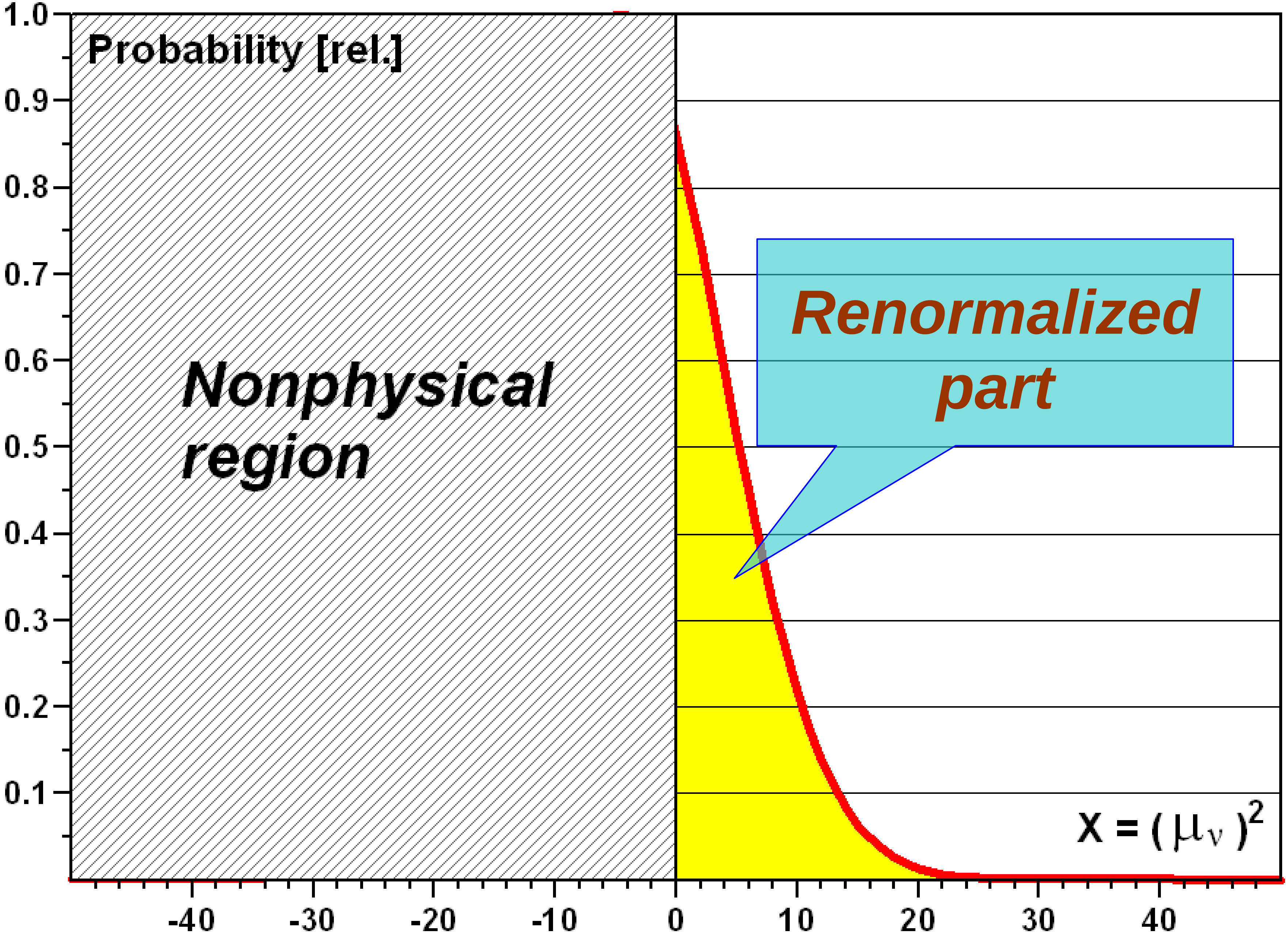
Normalization factor =
= T(ON) / T(OFF)

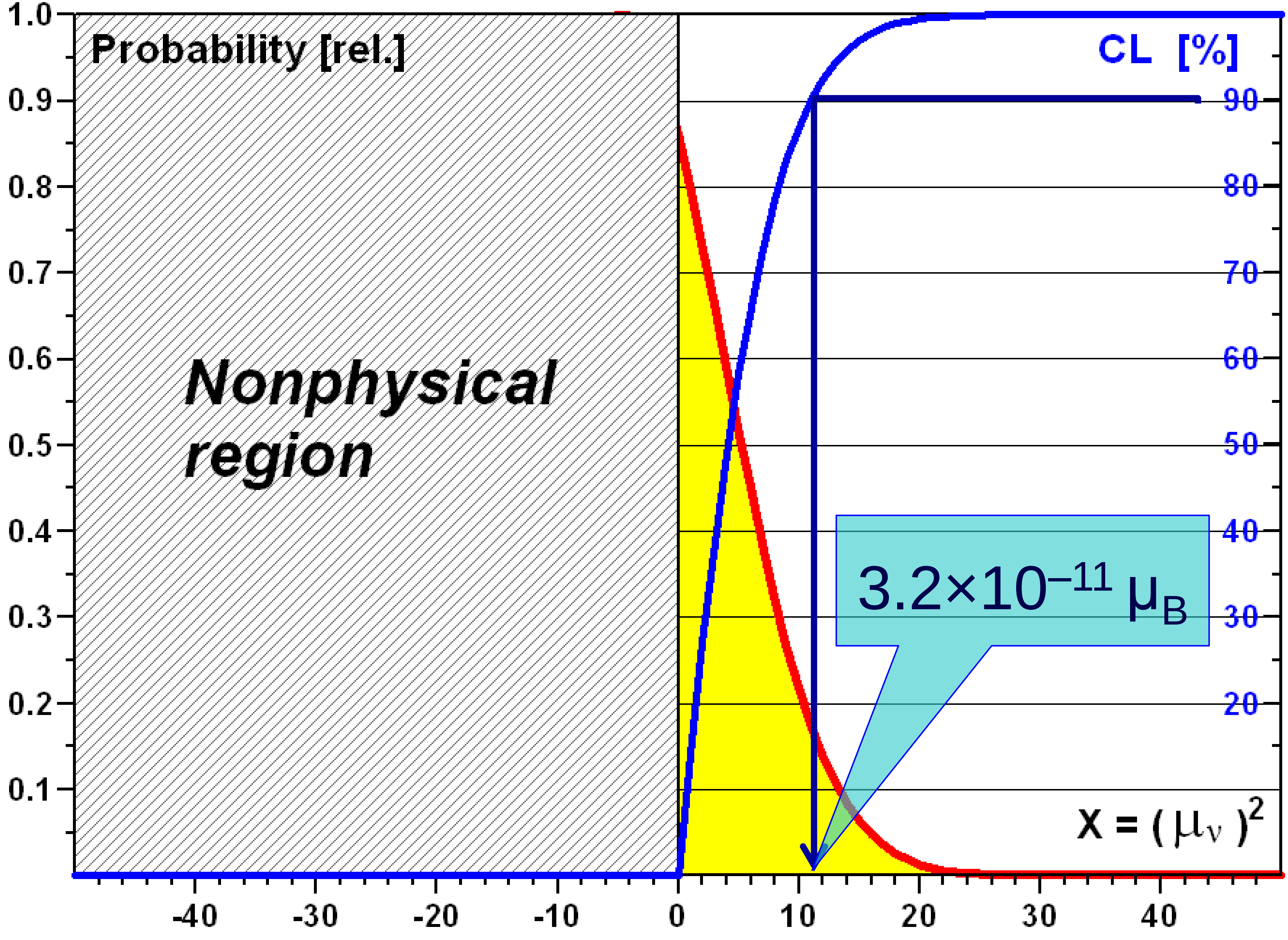
Amplitude of the EM-contribution =
$= \left(\mu_\nu / 10^{-11}\,\mu_B\right)^2$



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Probability [rel.]
Phase 1 alone
Phase 2 alone
X = (μν)2
-40
-30
-20
-10
0
10
20
30
40

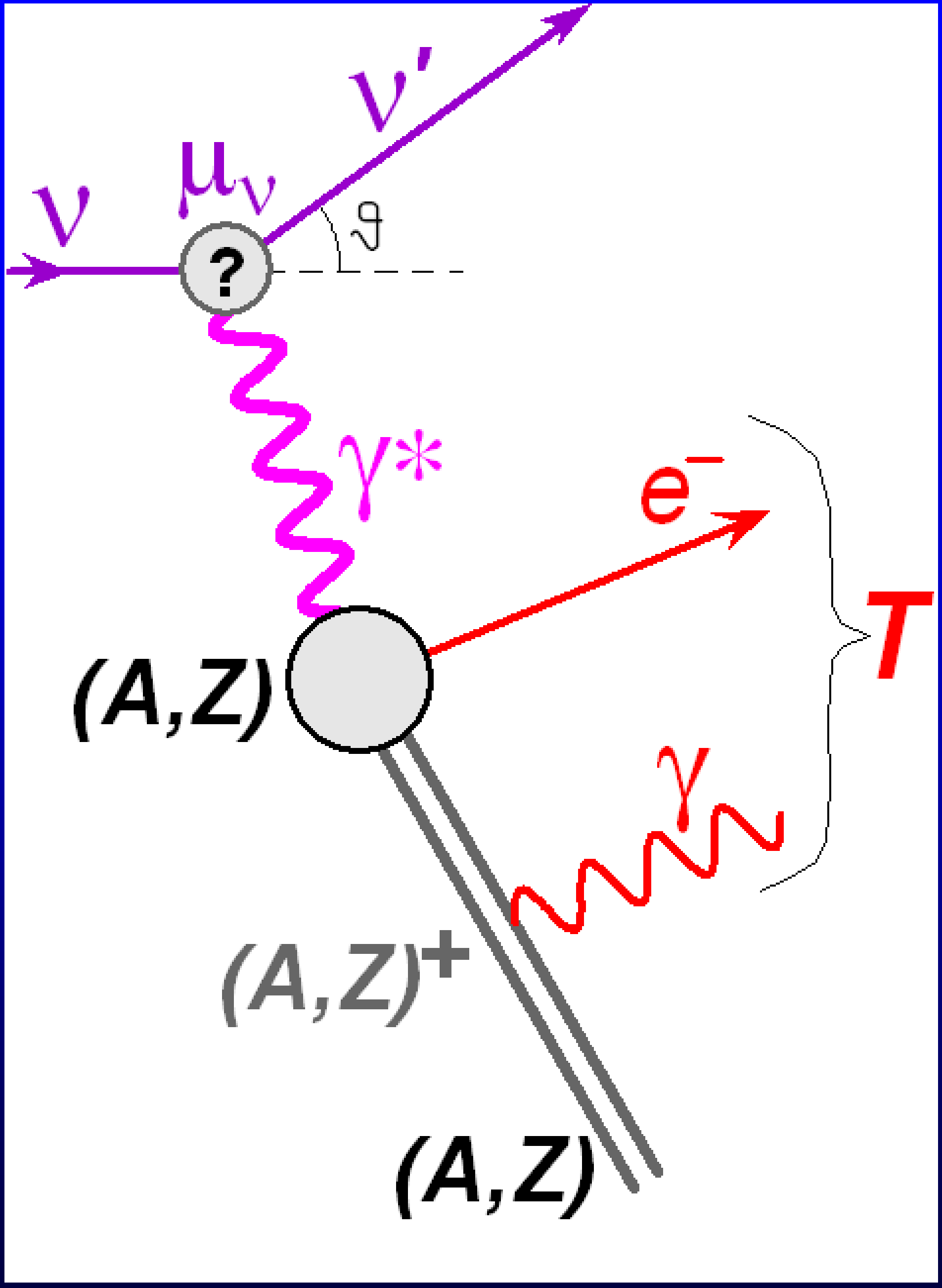

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Probability [rel.]
Phase 1 alone
Phase 2 alone
Phases 1+2
X = (μ_ν)^2
-40
-30
-20
-10
0
10
20
30
40

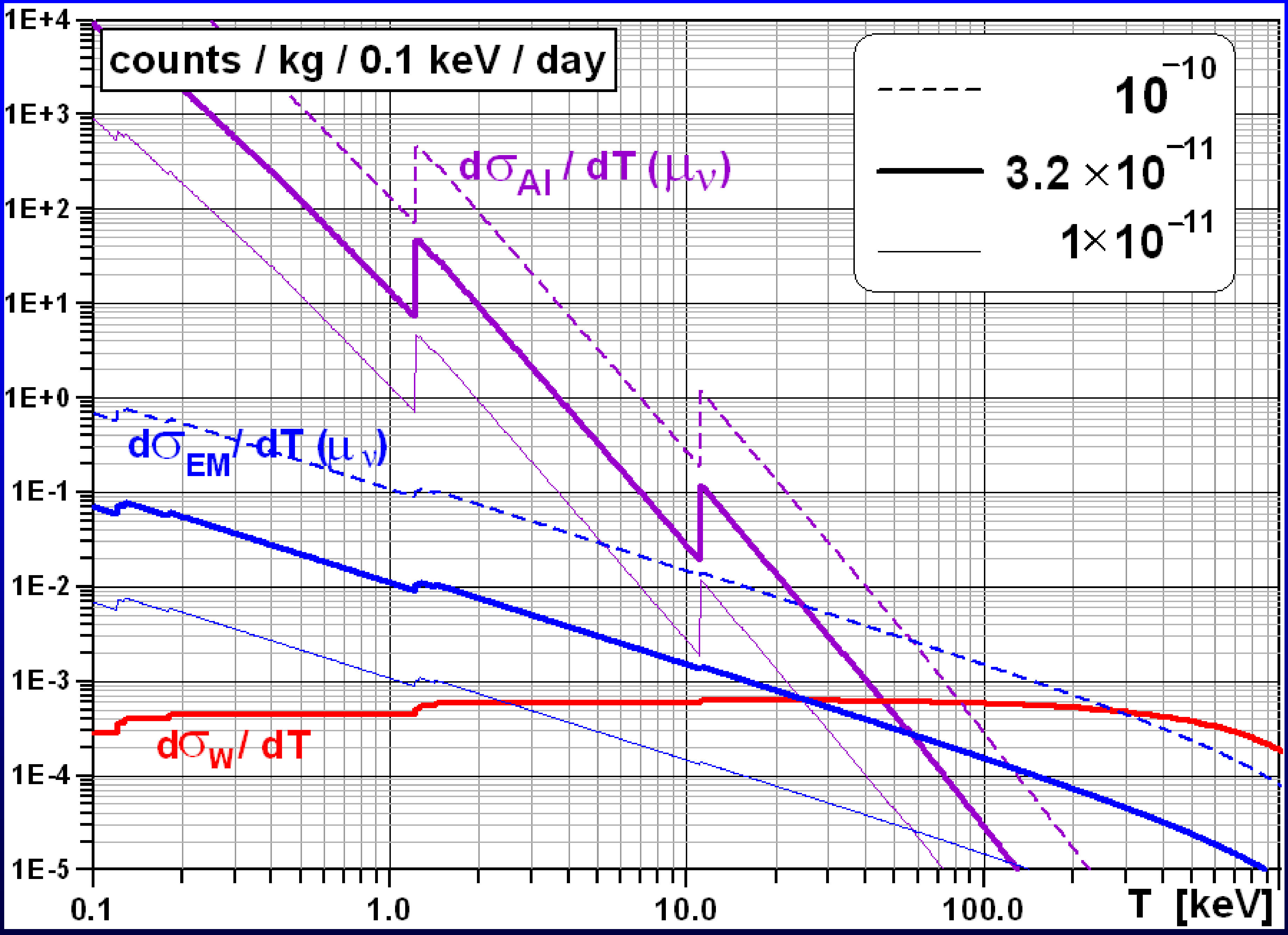

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Probability [rel.]
Nonphysical region
Renormalized part
X = (μν)²
-40
-30
-20
-10
0
10
20
30
40



Probability [rel.]
CL [%]
Nonphysical region
$3.2\times10^{-11}\ \mu_B$
$X = (\mu_\nu)^2$
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
90
80
70
60
50
40
30
20
-40
-30
-20
-10
0
10
20
30
40

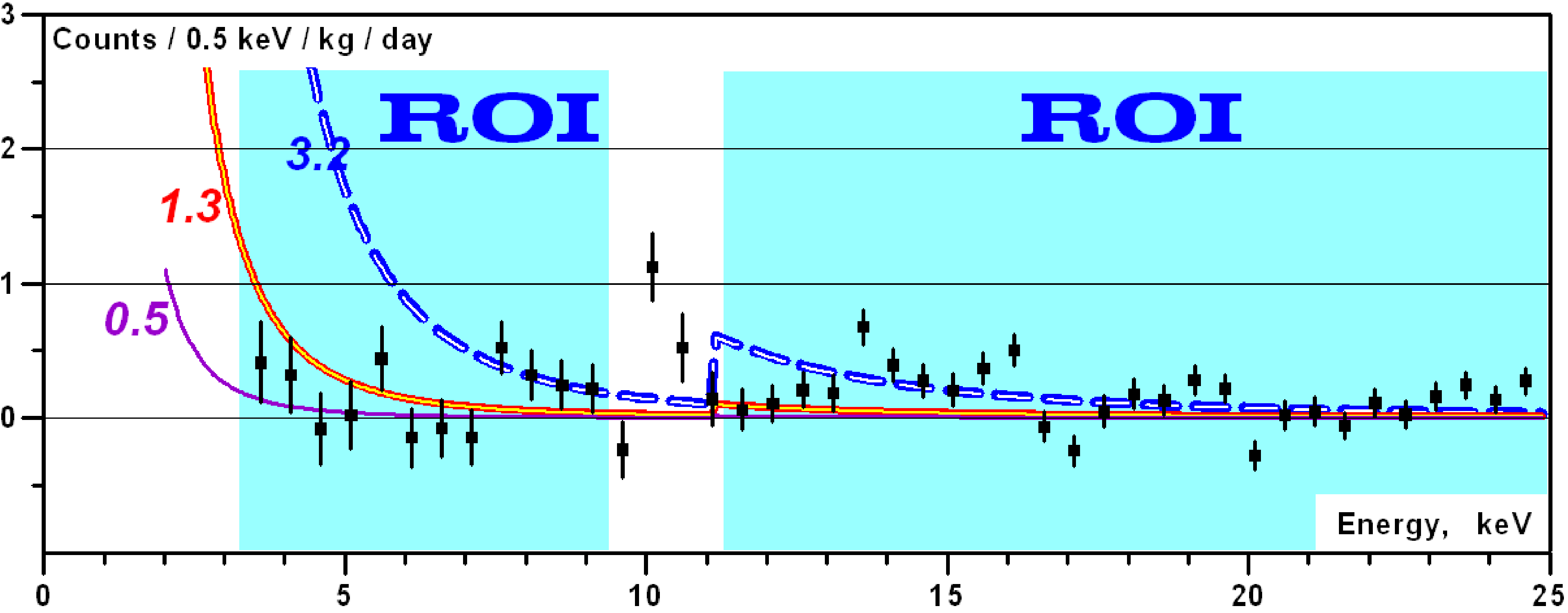
When the wavelength of the virtual photon γ^* becomes comparable to an atomic size (i.e., at T< 10 keV), it can interact with the atom as a whole and cause photoelectric effect





counts / kg / 0.1 keV / day
10^{-10}
3.2×10^{-11}
1×10^{-11}
$d\sigma_{Al}$ / dT (μ_ν)
$d\sigma_{EM}$ / dT (μ_ν)
$d\sigma_W$ / dT
1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
0.1
1.0
10.0
100.0
T [keV]

expected


Counts / 0.5 keV / kg / day
ROI
ROI
3.2
1.3
0.5
Energy, keV
0
1
2
3
0
5
10
15
20
25

GEMMA NME limits (Phases 1+2)

NMM interaction taken into account

FE	FE+AI
$3.2 \times 10^{-11}\ \mu_B$	$5.0 \times 10^{-12}\ \mu_B$

mainly SYSTEMATIC

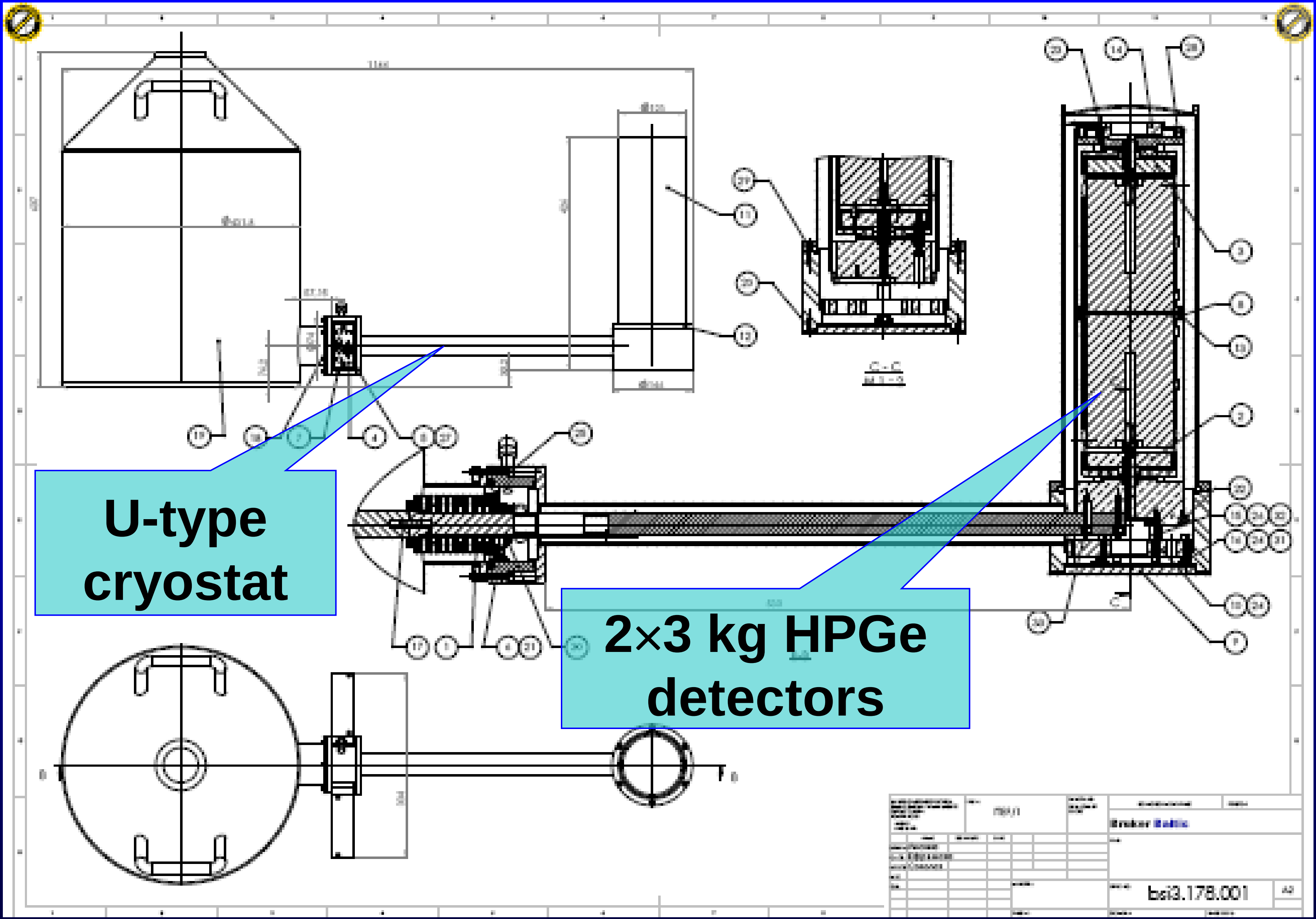
The low energy region is much more important than even was expected…

We are close to a principle limitation of the existing apparatus

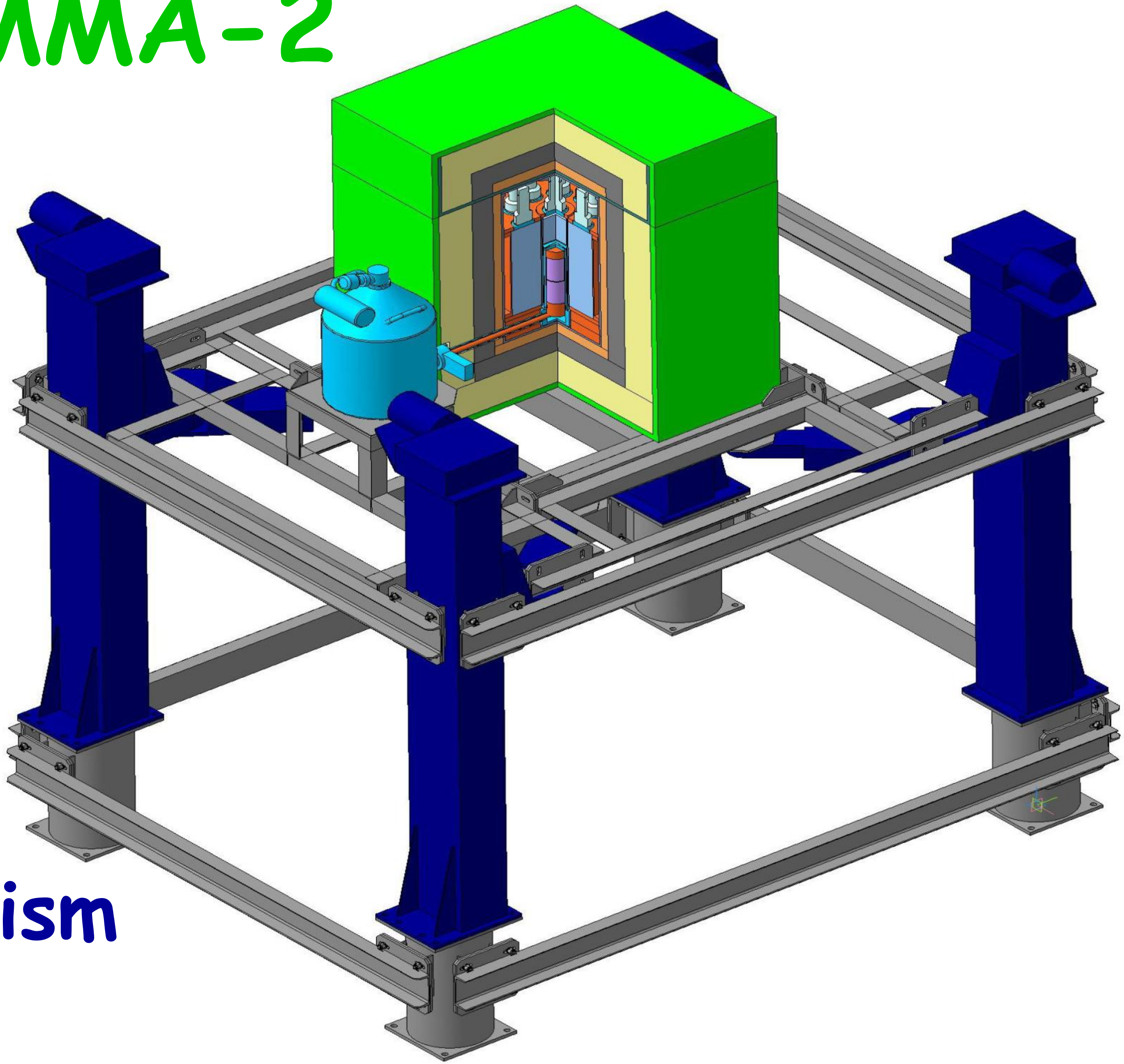
↓

need to upgrade

GEMMA-1 → GEMMA-2


U-type cryostat
2×3 kg HPGe detectors
Bruker Baltic
bsi3.178.001

GEMMA-2



Lifting mechanism


#2: 14 m
#3: 10 m
KNPP
Udomlya
Russia

Upgrade 2010': GEMMA-2

HPGe:	1.5 kg ⇒ 6 kg
E-threshold:	3.0 ⇒ 1.5 keV
Cryostat:	std ⇒ U-type
Reactor unit:	#2 ⇒ #3
Distance:	14 m ⇒ 10 m (movable)
ν-flux:	2.7 ⇒ 5.0 $\times 10^{13}$

Future perspectives

Ge detectors with very low threshold (~ 300 eV)

RFBR grant