Search for Solar Axions with GERDA

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11.06'08

GERDA Meeting
LNGS 9-11 June 2008

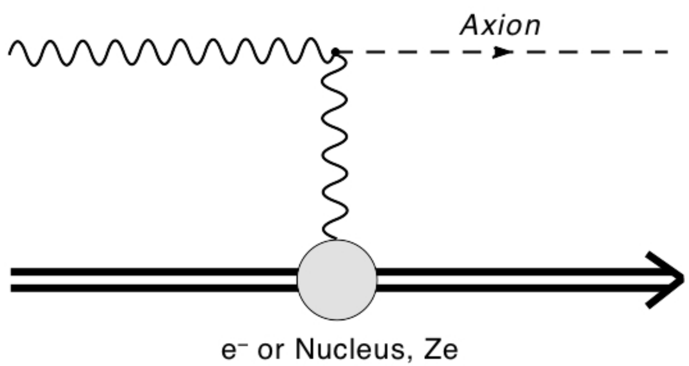
Overview

- What are Solar Axions
- Principle of Detection
- Why Solar Axions
- Expected conversion rates
- Prospects for GERDA
- What should be done

What are Solar Axions

Peccei-Quinn, 1977

CP conservation in QCD → <u>Axion</u>



Coupling constant:

$$g_{a\gamma\gamma} = 0.19 \cdot \frac{m_a}{eV} \left(\frac{E}{N} - 2/3 \cdot \frac{4+z}{1+z}\right) \cdot 10^{-9} GeV^{-1}$$

<u>Primakoff Effect</u> Conversion γ → Axion $z = m_u/m_d \sim 0.56$

for example in

- Early Universe
- Stars
- Red Giants
- Supernovae

Conversion rate ($\gamma \rightarrow$ axion): $R=R(E_\gamma, N_j)$

N_j: density of charged particles with charge $Z_j e \sim 10^{31}/m^3$

E_γ: photon energy

E_a: axion energy

Core of the sun:

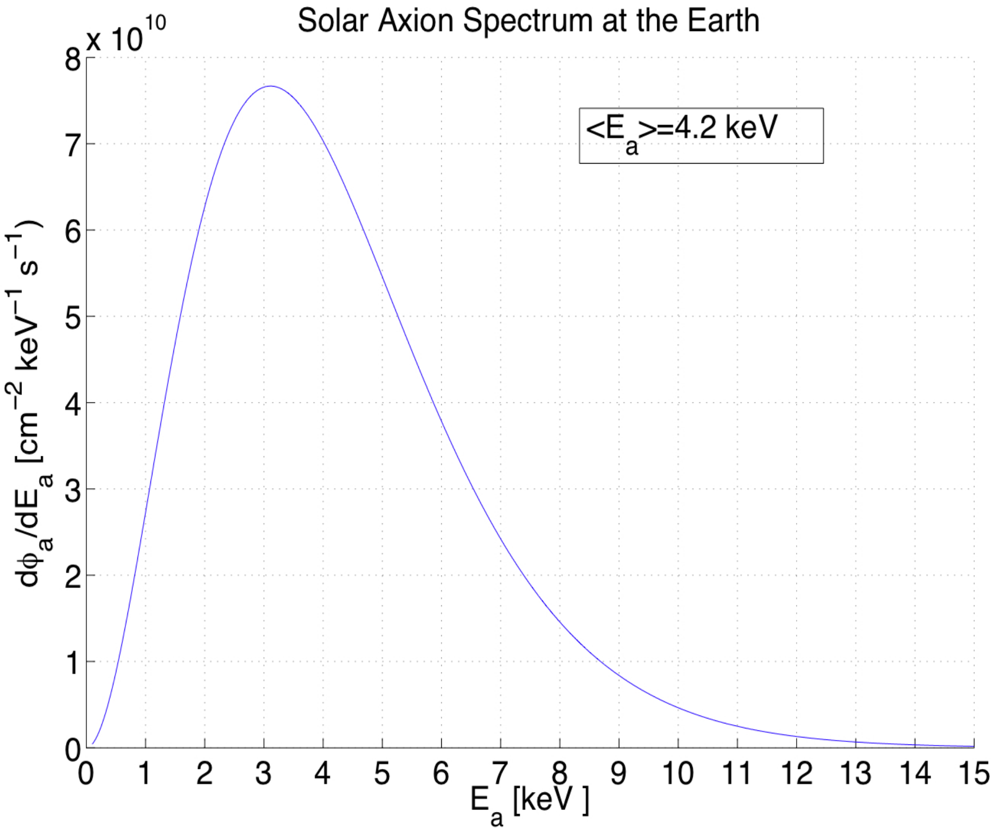
T~1.3 keV = 1.5*10 ^{7} K

Blackbody distribution

At Earth:

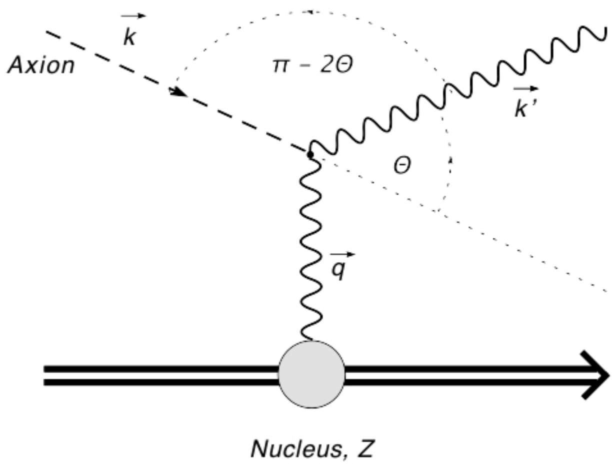
$$\frac{d\phi_a}{dE_a} = \sqrt{\lambda} \cdot \frac{\phi_0}{E_0} \cdot \frac{E_a/E_0{}^3}{E_0 \cdot e^{E_a/E_0 - 1}}$$

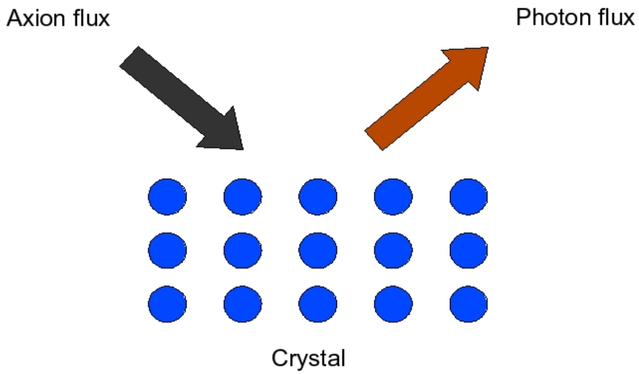
$$\lambda = (g_{a\gamma\gamma} \cdot 10^8/\mathrm{GeV}^{-1})^4$$



$g_{a\gamma\gamma} = 1 \cdot 10^{-10}\ \mathrm{GeV}^{-1}$

Principle of Detection





$$R(E_1, E_2) = \int_{E_1}^{E_2} dE \int_0^{\infty} dE_\gamma \frac{dR(E_\gamma)}{dE_\gamma} \cdot \frac{1}{\sigma_d \sqrt{2\pi}} \cdot exp[-\frac{1}{2}(\frac{E - E_\gamma}{\sigma_d})^2]$$

Gaussian

$d\Phi/dE_a$, $d\sigma/d\Omega$ (F)

Form factor

F(φ)

Electrical potential

φ(S,G)

Structure function, Reciprocal vector

$$R(E) = (2\pi) \cdot \frac{2\hbar c V}{v_c^2} \sum_G |S(G)|^2 \frac{d\sigma}{d\Omega} \frac{1}{|G|^2} \frac{d\phi}{dE} \cdot [erf(\frac{E_a - E_1}{\sqrt{2} \cdot \sigma_d}) - erf(\frac{E_a - E_2}{\sqrt{2} \cdot \sigma_d})]$$

$$S(\vec{G}) = [1 + e^{\frac{i\pi}{2}(h+k+l)}] \times [1 + e^{i\pi(h+k)} + e^{i\pi(h+l)} + e^{i\pi(k+l)}]$$

$$E_a = \hbar\omega\frac{|\vec{G}|^2}{2\vec{k}\vec{G}} = \hbar c\frac{|\vec{G}|^2}{2\vec{u}\vec{G}}$$ ⟷ Bragg condition

$$\Delta\vec{k} = \vec{k}' - \vec{k} = \vec{q} = \vec{G} \qquad \Rightarrow (\vec{k} + \vec{G})^2 = |\vec{k}'|^2 = |\vec{k}^2|$$

Elastic conversion
$E_a = E_\gamma$

$$2\vec{k}\vec{G} = |\vec{G}|^2 \Rightarrow E_a = \hbar\omega\frac{|\vec{G}|^2}{2\vec{k}\vec{G}} = \hbar c\frac{|\vec{G}|^2}{2\vec{u}\vec{G}}$$

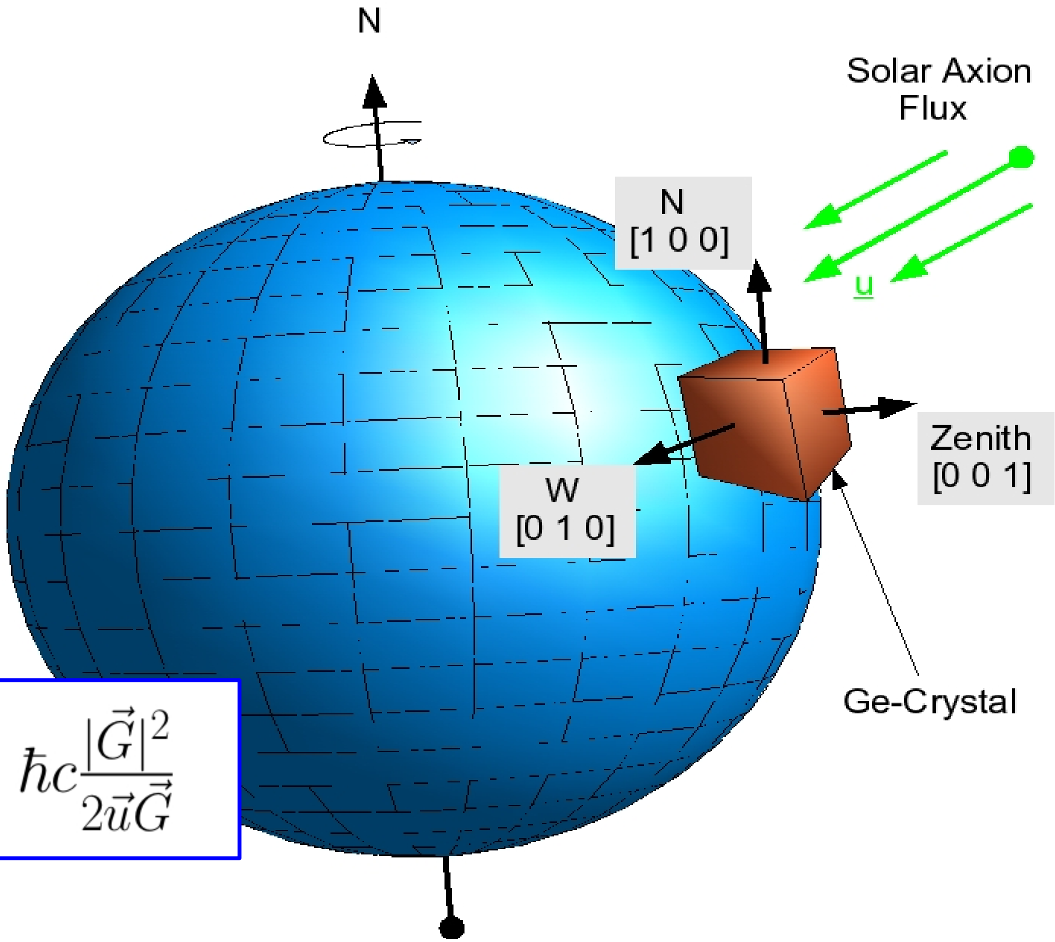
Sun is biggest axion source in the neighbourhood:

$$\phi_{tot} \approx 3.9 \cdot 10^{13} cm^{-2} s^{-1} \quad \text{at} \quad g_{a\gamma\gamma} = 1 \cdot 10^{-10}\ \mathrm{GeV}^{-1}$$

Rate of photon emission depends on:

- Crystallographic properties
- Conversion cross section
- Axion energy distribution
- Crystal orientation with respect to the Sun
- Coupling constant

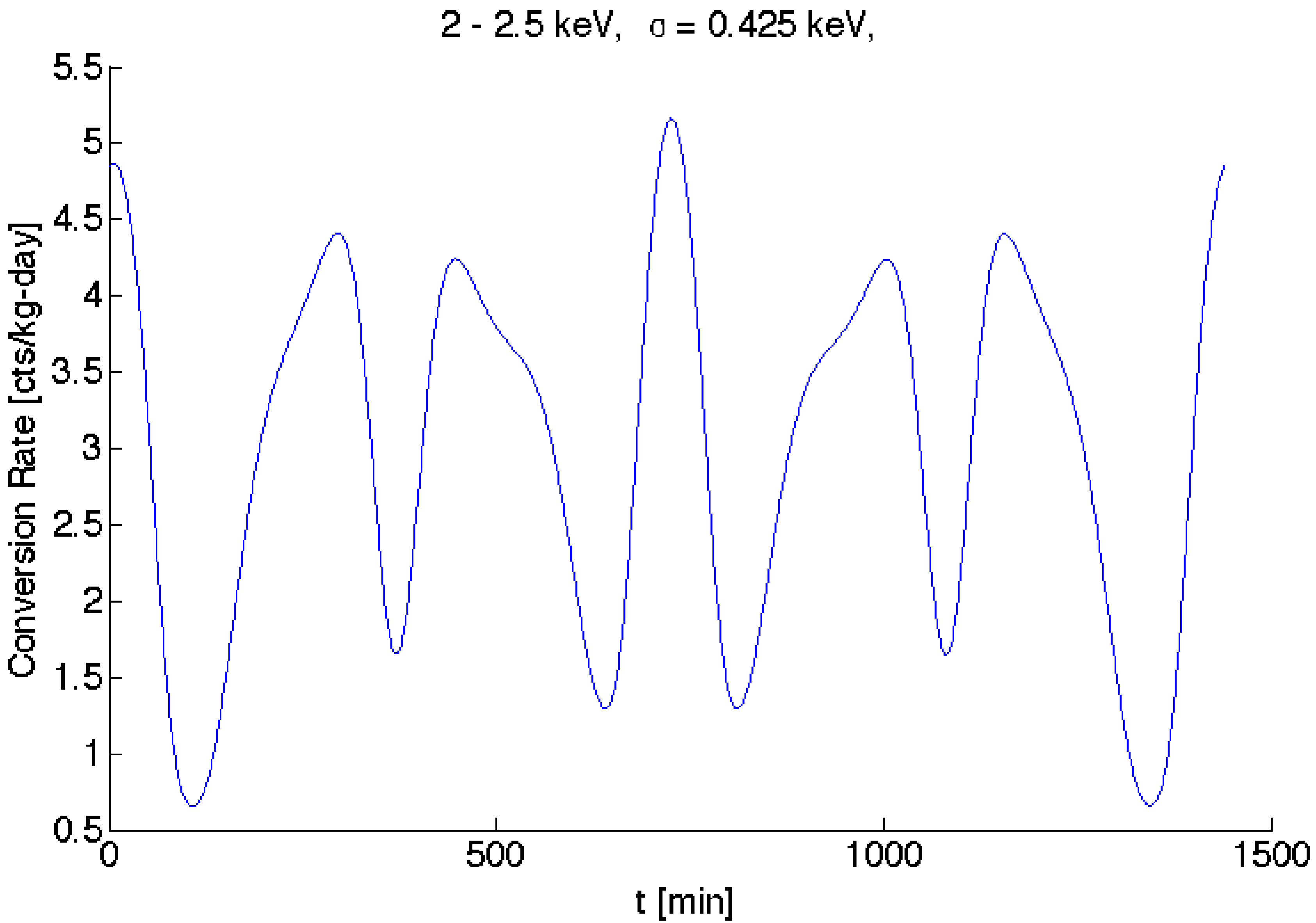
LNGS Coordinates
Longitude:13°31'
Latitude:42°25'
Altitude: 895 m



$$E_a = \hbar\omega \frac{|\vec{G}|^2}{2\vec{k}\vec{G}} = \hbar c \frac{|\vec{G}|^2}{2\vec{u}\vec{G}}$$

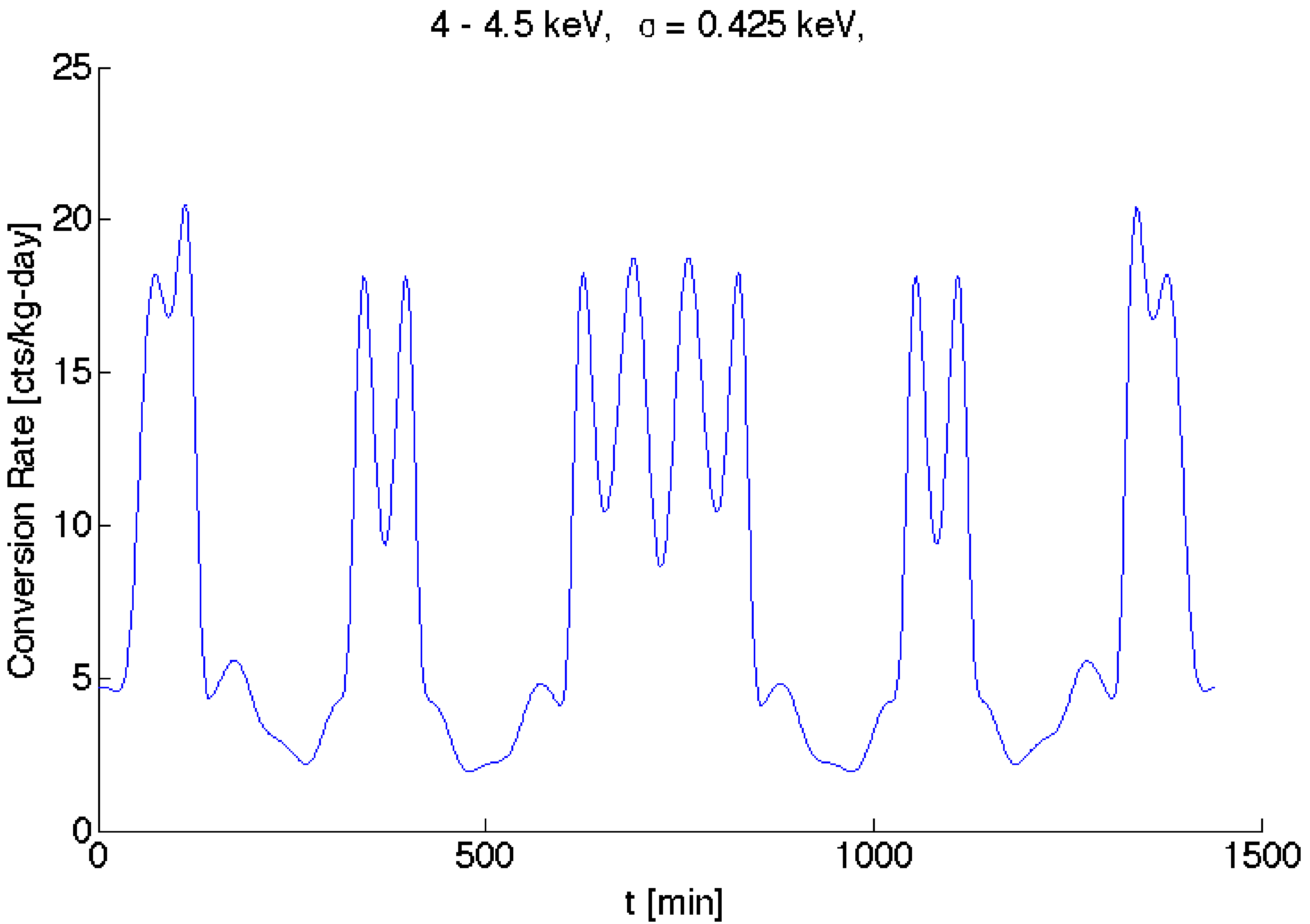
$$R(E) = (2\pi) \cdot \frac{2\hbar c V}{v_c^2} \sum_G |S(G)|^2 \frac{d\sigma}{d\Omega} \frac{1}{|G|^2} \frac{d\phi}{dE} \cdot [erf(\frac{E_a - E_1}{\sqrt{2} \cdot \sigma_d}) - erf(\frac{E_a - E_2}{\sqrt{2} \cdot \sigma_d})]$$

Expected conversion rates



$$g_{a\gamma\gamma} = 1 \cdot 10^{-8}\ \mathrm{GeV}^{-1}$$

Expected conversion rates



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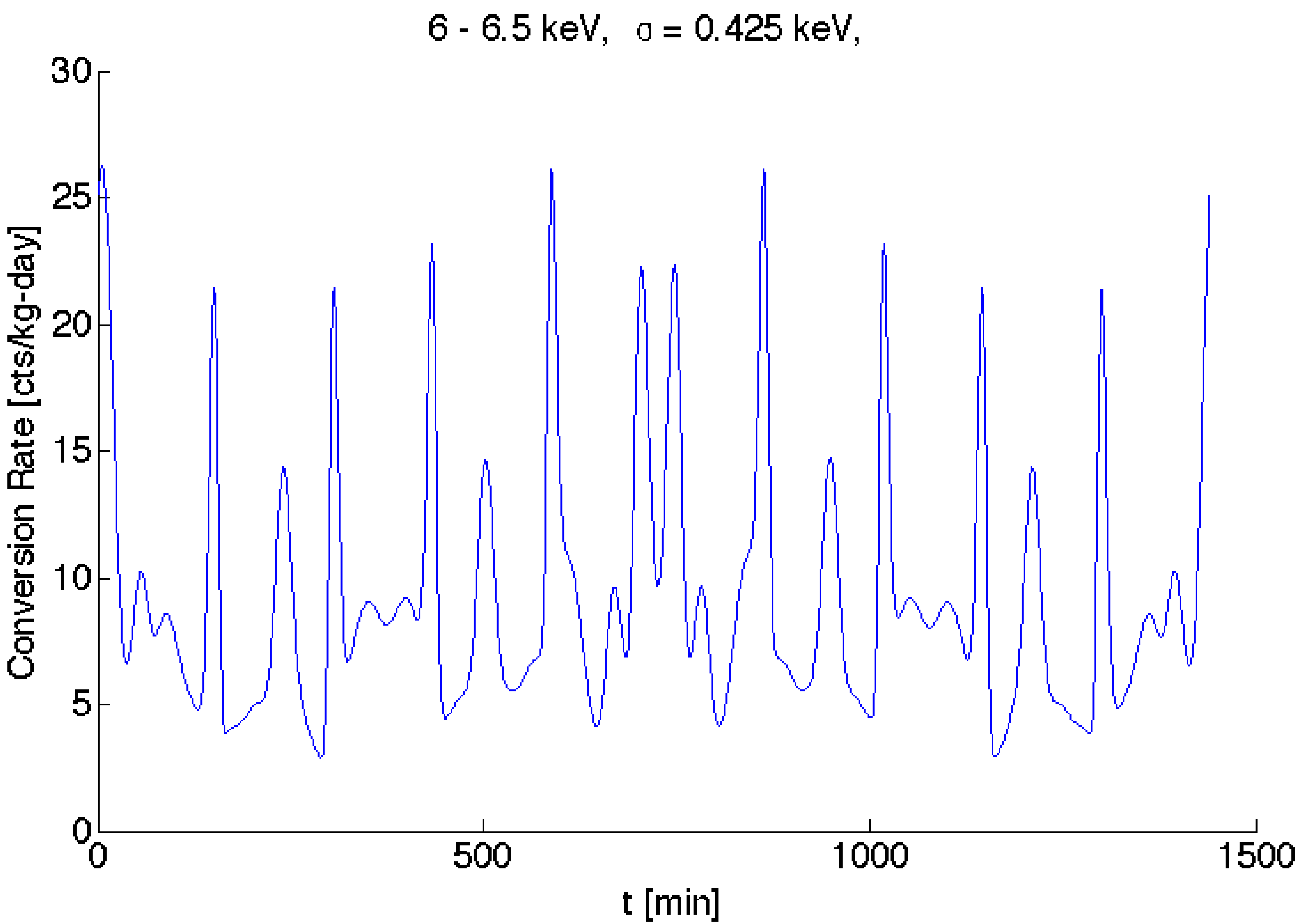

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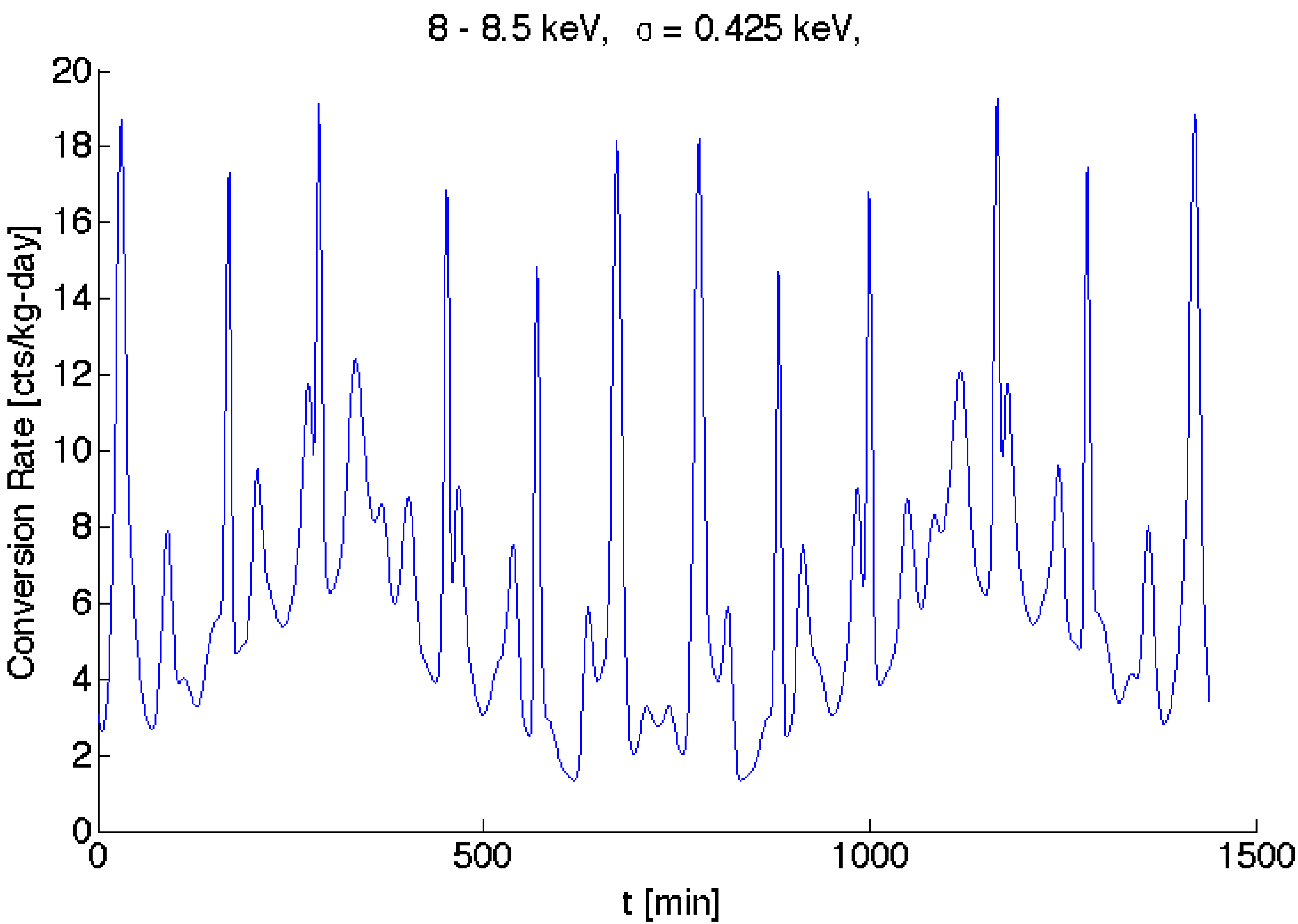

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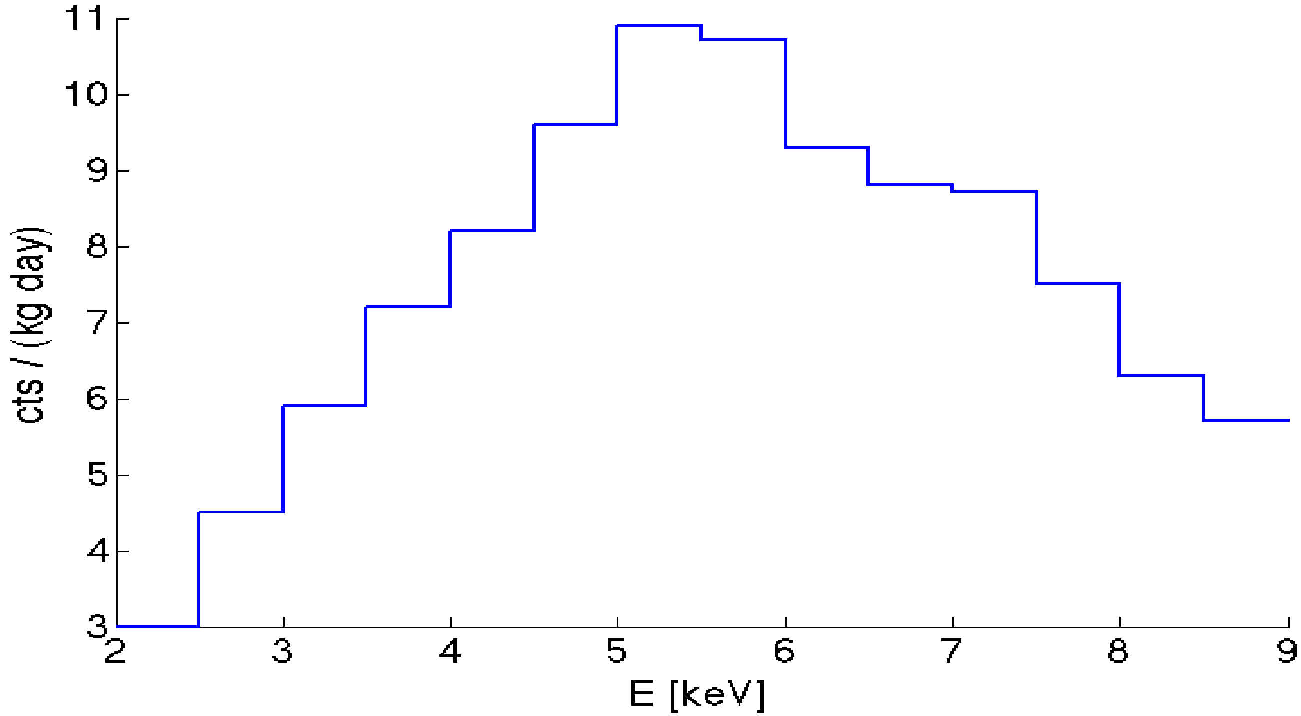
Expected conversion rates

Energy range [keV]	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5
Counts / (day kg)	3	4.5	5.9	7.2	8.2	9.6	10.9
Energy range [keV]	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8	8-8.5	8.5-9
Counts / (day kg)	10.7	9.3	8.8	8.7	7.5	6.3	5.7



$$g_{a\gamma\gamma} = 1 \cdot 10^{-8}\ \mathrm{GeV}^{-1}$$

Since no data yet available from GERDA

→ Statistical method to estimate the upper limit

$$\chi = \sum_{i=1}^{n}[\bar{R}(t_i) - <\bar{R}>] \cdot n_i$$

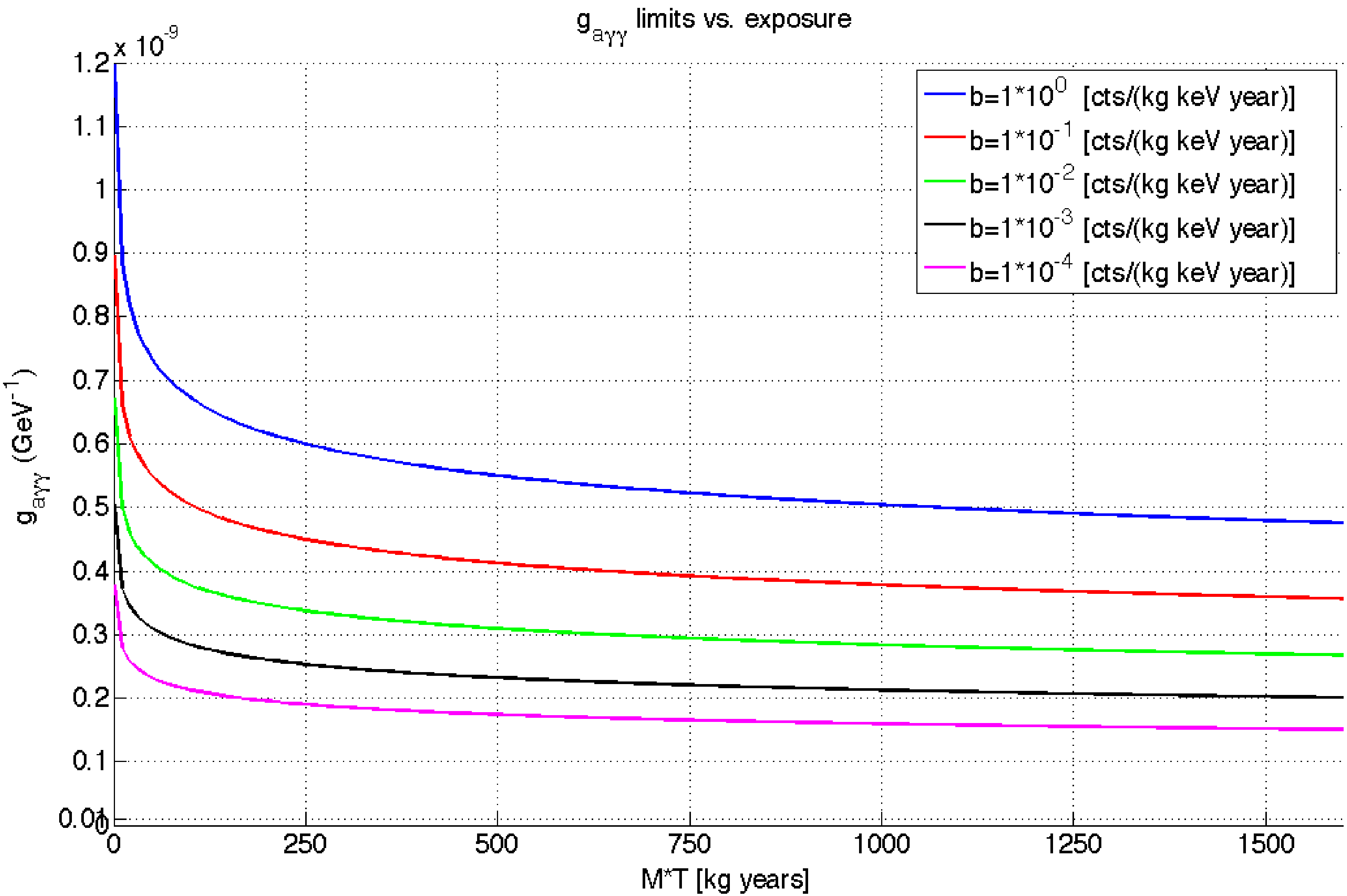
= 0 : no signal
≥ 0 : signal+noise

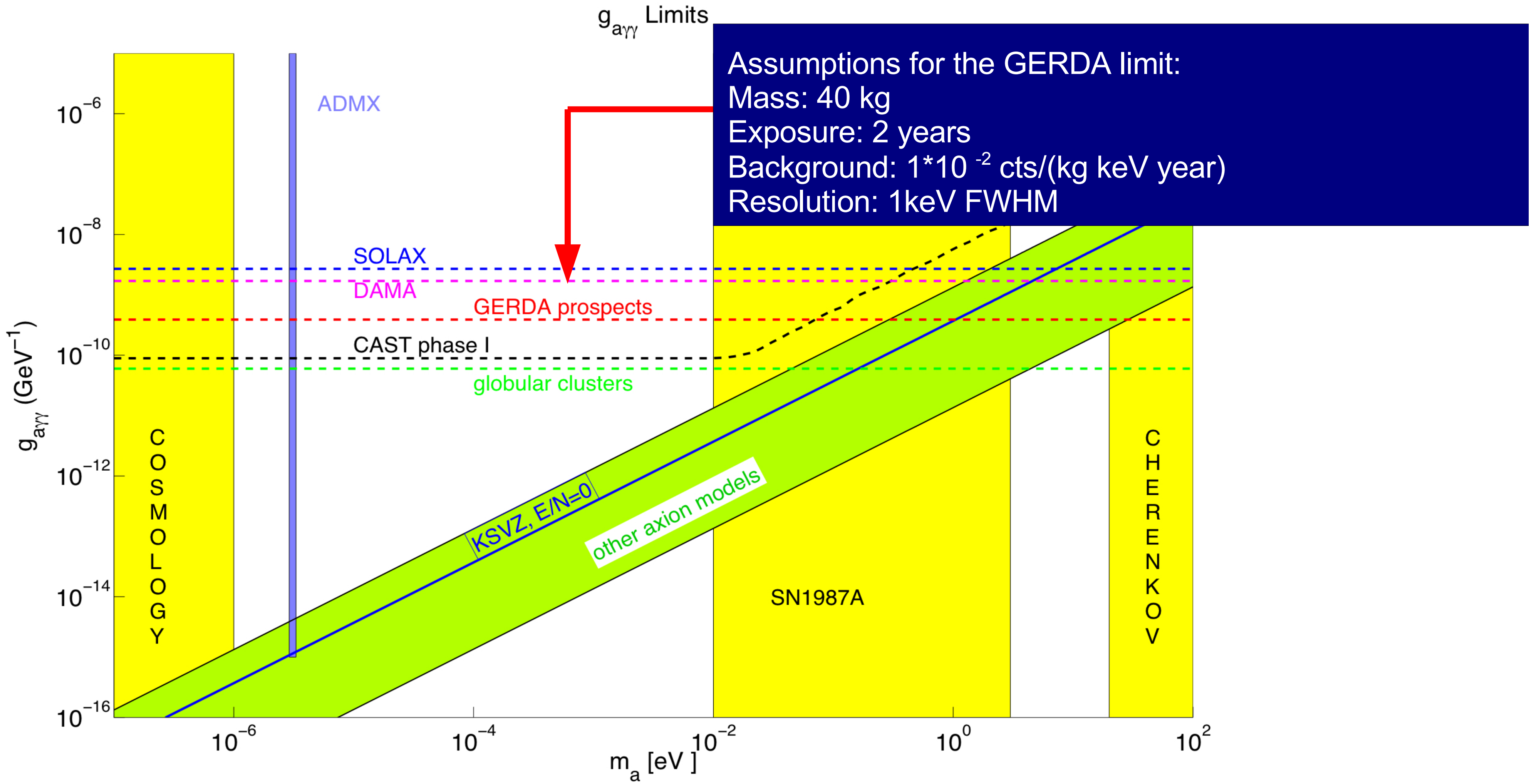
$$g_{a\gamma\gamma} \leq g_{a\gamma\gamma}^{lim} \simeq K(\frac{b}{\mathrm{cpd/kg/keV}} \times \frac{\mathrm{kg}}{M} \times \frac{\mathrm{years}}{T})^{1/8} \times 10^{-9}\mathrm{GeV}^{-1}$$

K=2.5 for Ge, M=detector mass, T=exposure time

Background [cts/(kg keV year)]	1	0.1	0.01	0.001
Limit on $g_{a\gamma\gamma}$ [1/GeV], Phase I–18 kg,T=2	$7.64*10^{-10}$	$5.72*10^{-10}$	$4.3*10^{-10}$	$3.22*10^{-10}$
Limit on $g_{a\gamma\gamma}$ [1/GeV], Phase II–38 kg, T=2	$6.96*10^{-10}$	$5.22*10^{-10}$	$3.91*10^{-10}$	$2.93*10^{-10}$

Prospects for GERDA





Experiment	ADMX	SOLAX	CAST	DAMA	GERDA
Limit on $g_{a\gamma\gamma}$ [1/GeV]	$1*10^{-15}$	$2.7*10^{-9}$	$8.9*10^{-11}$	$1.7*10^{-9}$	$3.9*10^{-10}$?

9 June '08 - Tokyo Helioscope reports: $g_{a\gamma\gamma} < 6*10^{-10}$ 1/GeV for m_a: 0 – 0.27 eV

What should be done

- Analysing if an optimal crystal orientation exists
- Determining the orientation of the crystals before installing them
- Specifying the detector resolution in the low energy range ~[0 – 10 keV]
- Achieving a low energy threshold
- Background MC in the low energy range
- Get GERDA starting & collect data
- Time correlated background analysis in the low energy range

Thank you