Calculation of the neutrino-nuclear reaction cross-sections for Ge^{76} nuclei and estimation of the solar neutrino background in the *GERDA*/LEGEND experiments

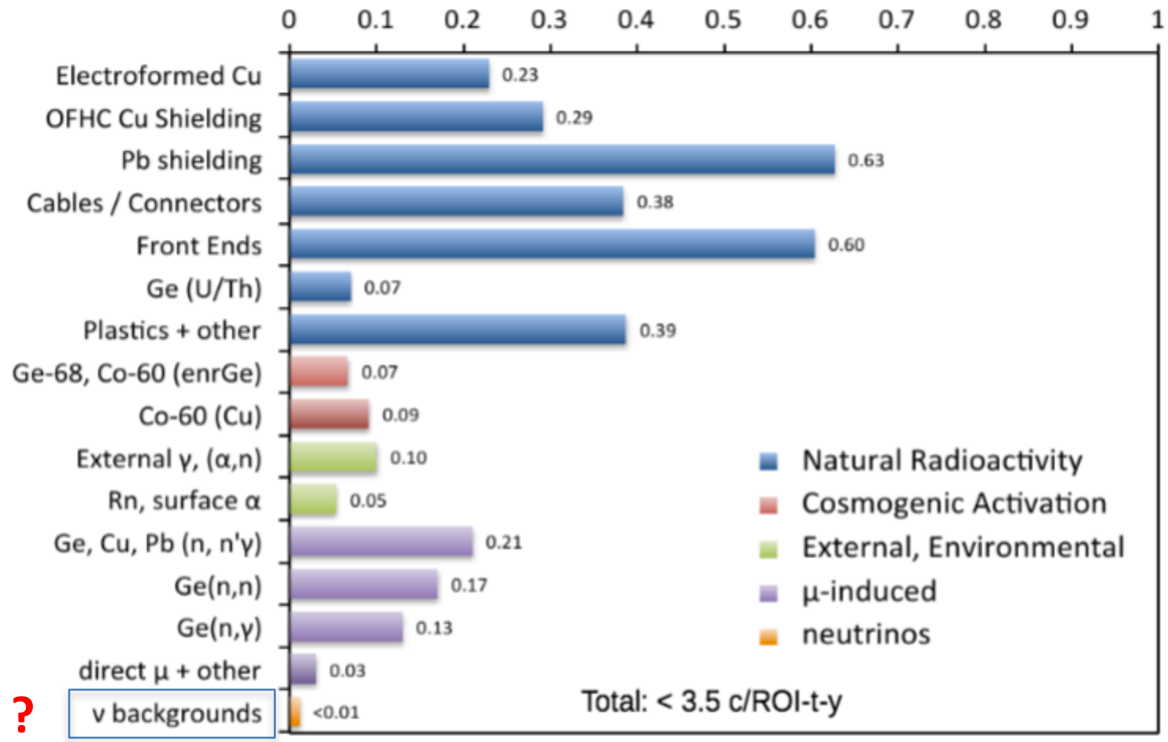
A.N. Fazliakhmetov, G.A. Koroteev
Yu.S. Lutostansky, A.K. Vyborov

Motivation for theoretical investigation

GERDA (Phase II) (2018):
Exposure: 0.0589 $t*y$
BI: $\sim 2.4^{+1.6}_{-0.8}\ cnts/(t*yr*ROI)$

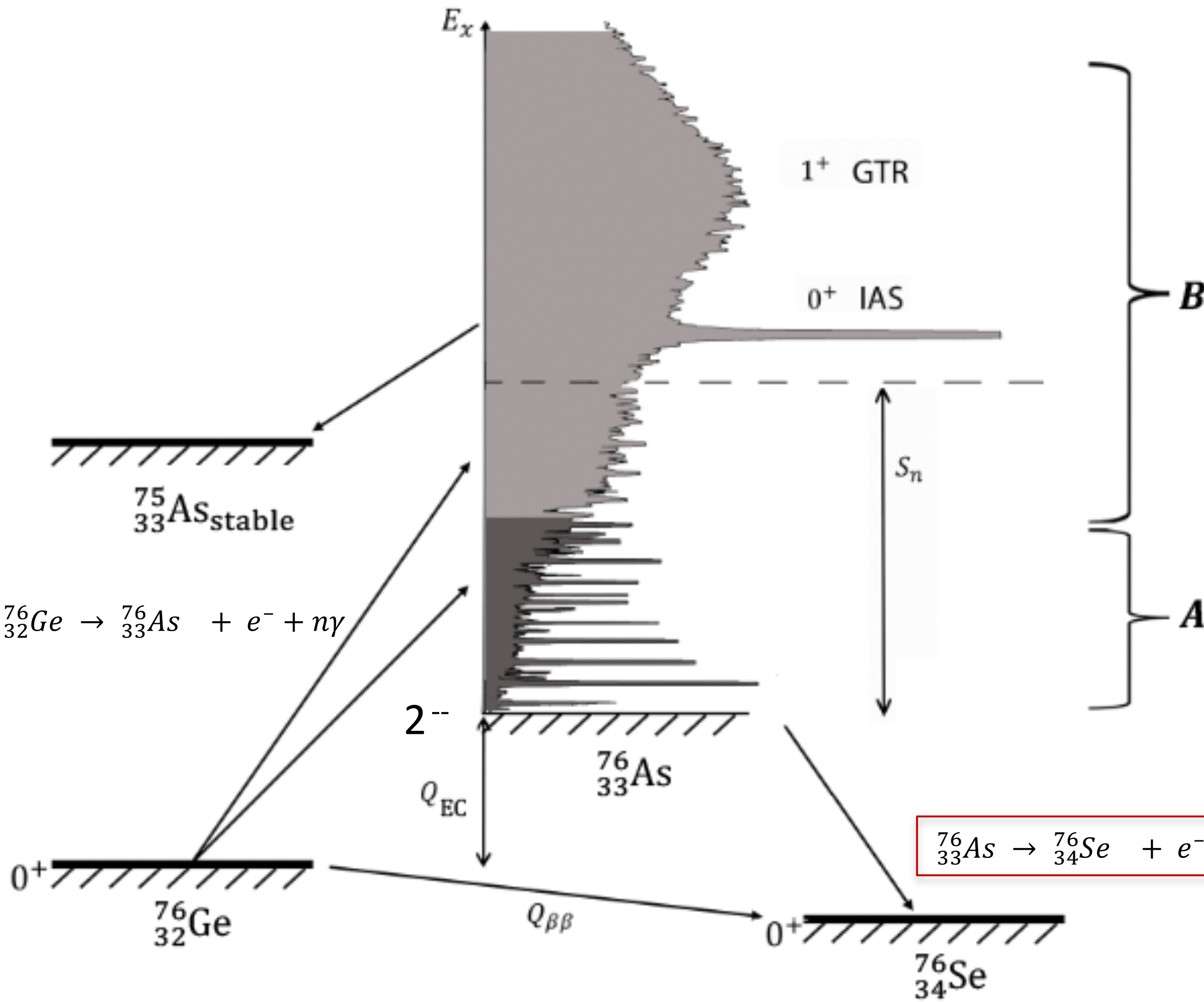
LEGEND goal (the second stage):
Exposure: 10 $t*y$
BI: 0.1 $cnts/(t*yr*ROI)$

- Solar neutrino background is not removable
- Main channels: elastic scattering by electrons and **capture by Ge^{76} nuclei** (with transition to discrete or resonant states of As^{76})
- **How much does considering of resonance states increase the total cross section?**



The list of background events in MAJORANA experiment (report from 2017)

Nuclear Resonances for ^{76}As



$\nu_e^{\text{солн.}} + {}^{76}_{32}Ge \rightarrow {}^{76}_{33}As + e^- + n\gamma$

B – resonances domination region (> 5 MeV)

A – discrete levels domination region (< 5 MeV)

$^{76}_{33}As \rightarrow {}^{76}_{34}Se + e^- + \overline{\nu_e} + m\gamma$

(ν,e) cross-section

$$\sigma_{total}(E_\nu) = \sigma_{discr}(E_\nu) + \sigma_{res}(E_\nu)$$

$$\sigma_{discr}(E_\nu) = \frac{1}{\pi}\sum_k G_F^2 \cos^2\theta_C\, p_e E_e F(Z,E_e)[B(F)_k + (\frac{g_A}{g_V})^2 B(GT)_k]$$

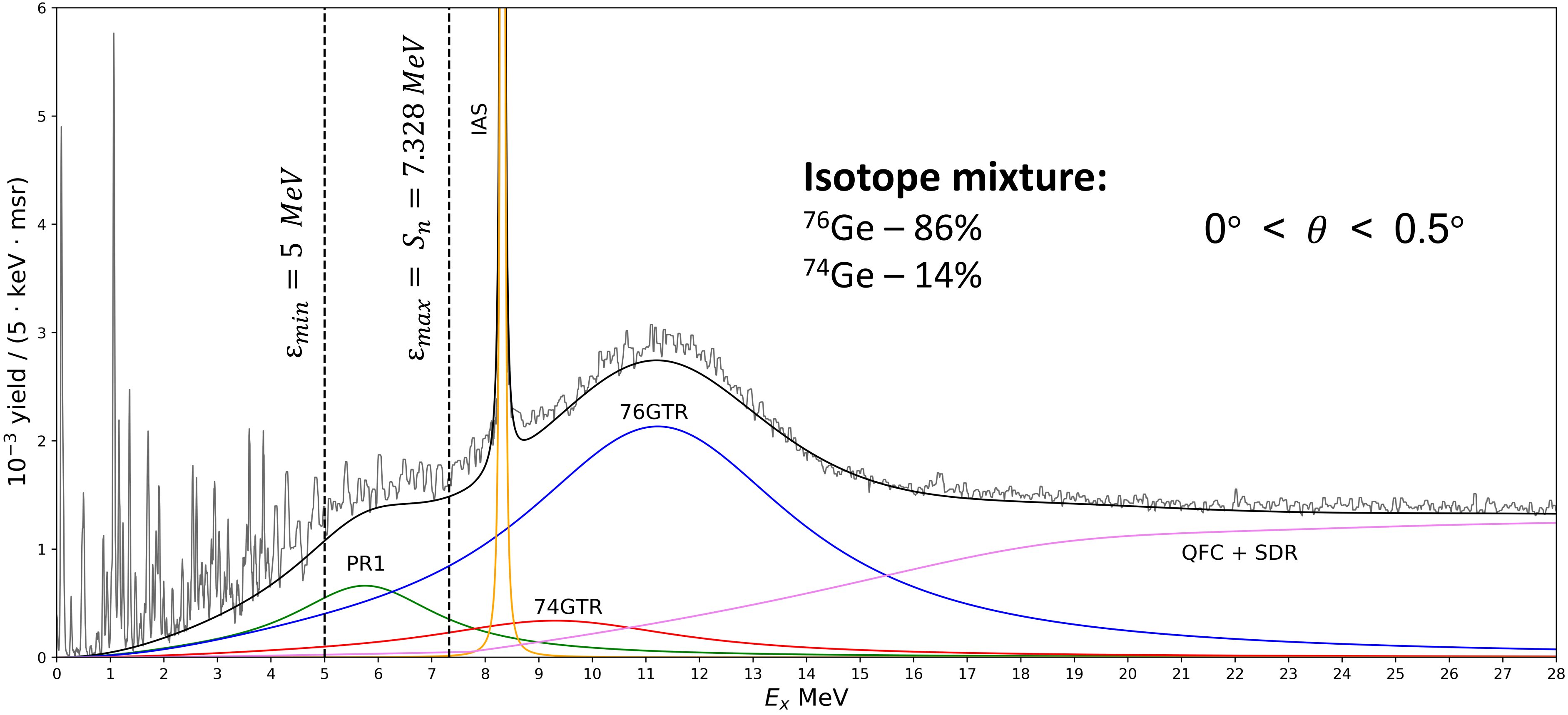
$$E_e - m_e c^2 = E_\nu - Q_{EC} - E > 0$$

$$\sigma_{res}(E_\nu) = \frac{1}{\pi}\int_{\varepsilon_{min}}^{\varepsilon_{max}} G_F^2 \cos^2\theta_C\, p_e E_e F(Z,E_e) S(E) dE$$

A.K. Vyborov et. Al, Phys. Atom. Nucl. 82 (2019) 5, 477-482

Experimental data and Fitting
$^{76}Ge(^{3}He,t)^{76}As$

J. Thies, D. Frekkers et al. Phys. Rev. C. 86. 10.1103/PhysRevC.86.014304



Isotope mixture:

^{76}Ge – 86%

^{74}Ge – 14%

$0° < \theta < 0.5°$

Fitting parameters

$$S_i(E) = M_i^2 \cdot \frac{\Gamma_i(1-\exp(-(E/\Gamma_i)^2))}{(E-w_i)^2+\Gamma_i^2}$$

- shape form for all the resonances. 3 free parameters: the centroid energies, the widths, and the amplitudes.

$$\frac{d^2\sigma}{dEd\Omega} = N_0 \frac{1-\exp[(E_t-E_0)/T]}{1+[(E_t-E_{QF})/W^2]}$$

- QFC background shape *J. Jänecke et al. Phys. Rev. C* ***48****, 2828 (1993)*

Only N_0 and E_{QF} are used as free parameters.

Data for the fit is taken from *J. Thies, D. Frekkers et al. Phys. Rev. C. 86. 10.1103/PhysRevC.86.014304.*

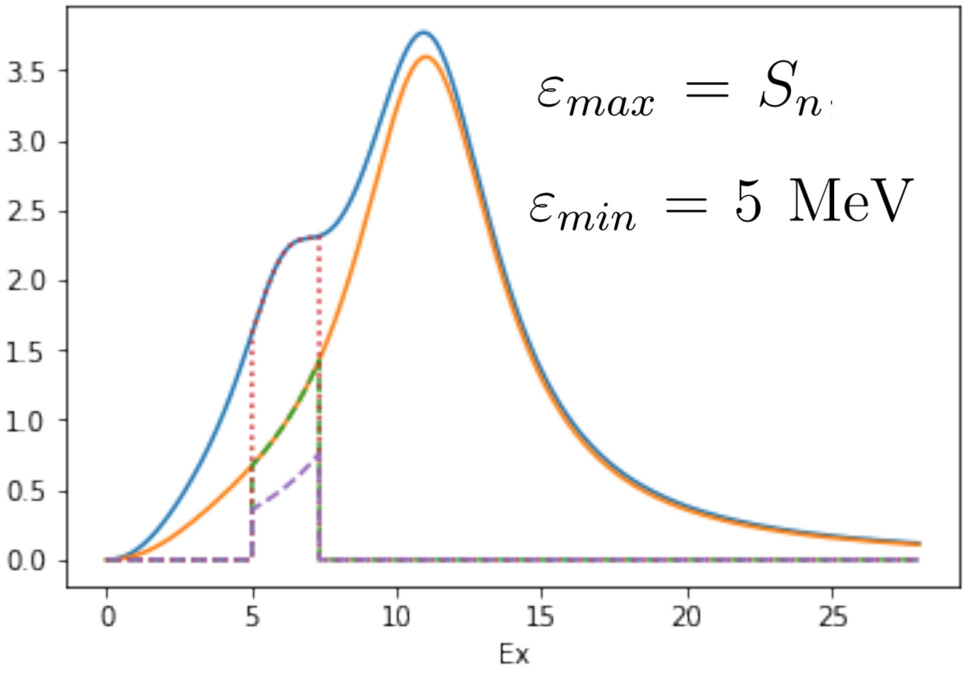
Simultaneous fit for 3 angles: $(0.0° - 0.5°)$, $(0.5° - 1.0°)$ and $(1.0° - 1.5°)$.
Same shape parameters, only amplitudes are independent

Normalization and Quenching effect

$$\sum_i M_i^2 = \sum_k B(GT)_k + \int_{\Delta_{min}}^{\Delta_{max}} S(E)dE = 3 \cdot (N - Z) \cdot q_{exp} = 36 \cdot q_{exp}$$

$$\Delta_{min} = 0 \text{ MeV}$$

$$\Delta_{max} = 28 \text{ MeV}$$

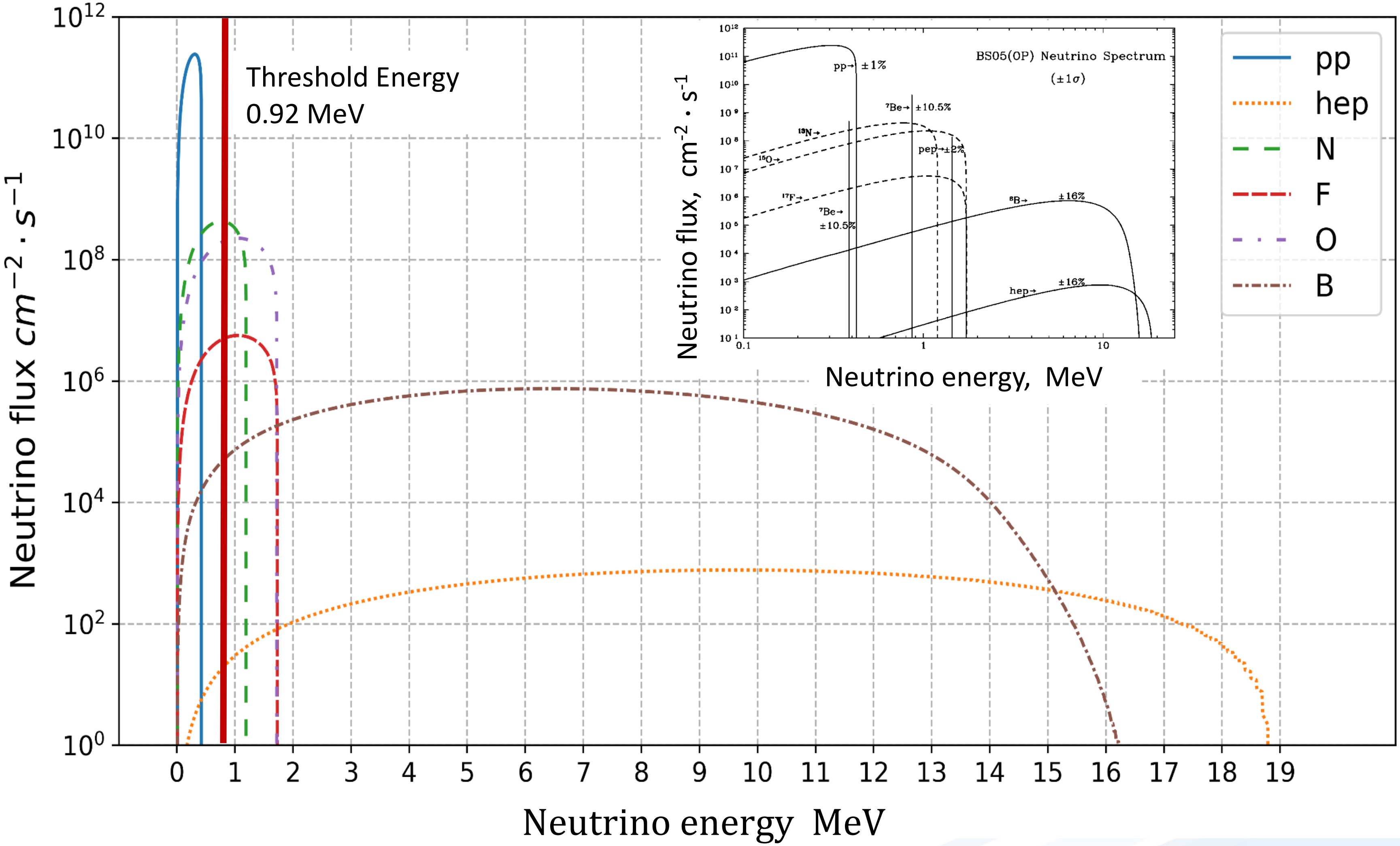


$$q_{exp}^{min} = 0.55$$

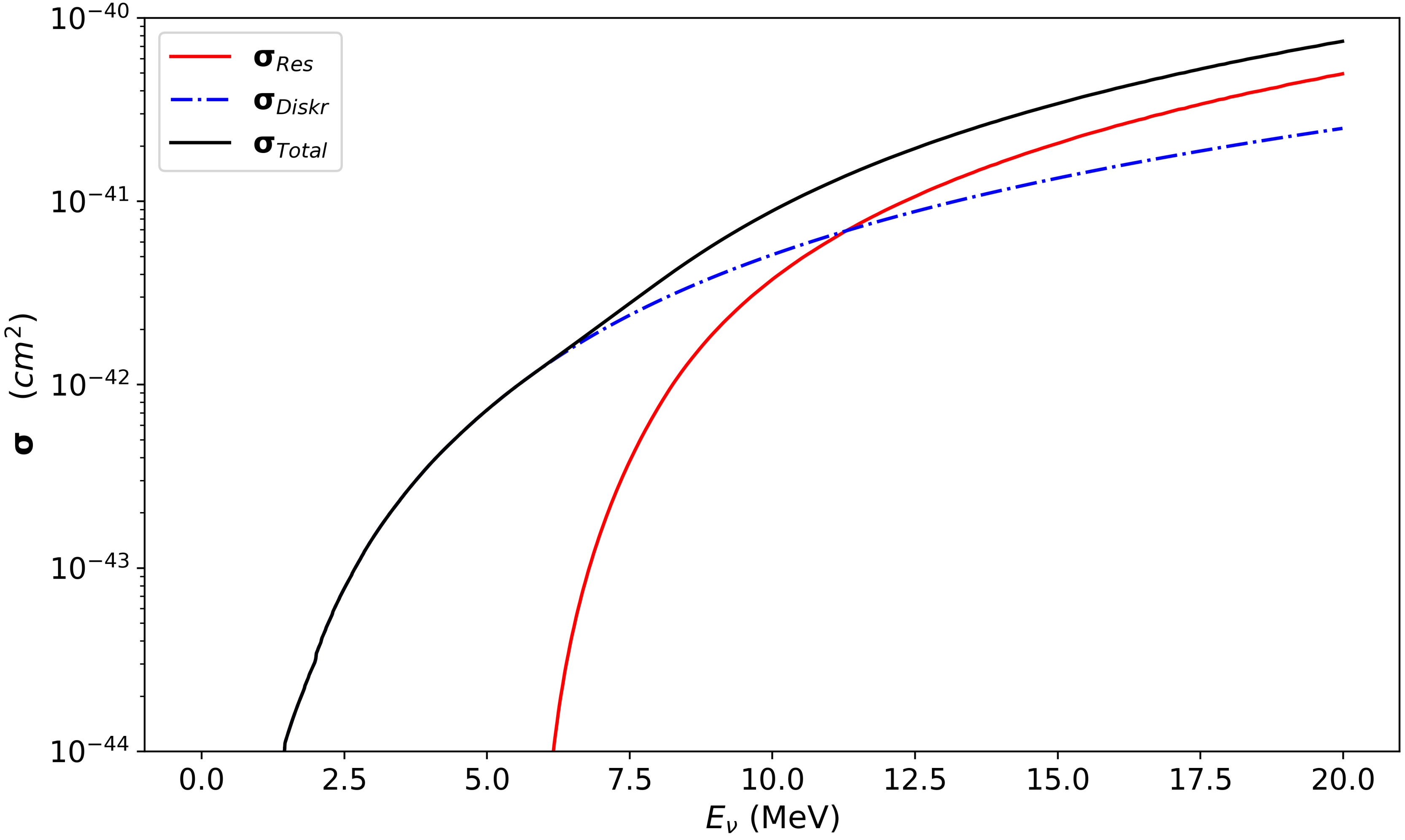
$$q_{exp}^{max} = 1$$

*R. Madey et al. Phys. Rev. C **40**, 540 (1989)*

Flux density of incident neutrinos
$(BS05\ model)$



Neutrino capture cross-section for ^{76}Ge



Solar neutrino capture rate

$$R = \int_0^{E_{max}} \rho_{solar}(E_\nu)\sigma_{solar}(E_\nu)dE_\nu \qquad E_{max} = 18.79$$

$$R_{total} = R_{discr} + R_{res}$$

Capture rate [SNU]	pep	hep	^{13}N	^{17}F	^{15}O	^{8}B	Total capture rate
R_{discr}	1.369	0.045	0.102	0.021	0.828	13.542	15.9 *
R_{res}, $q_{exp} = 1$	0.0	0.051	0.0	0.0	0.0	7.595	7.645
R_{GTR}, $q_{exp} = 1$	0.0	0.023	0.0	0.0	0.0	3.438	3.461
R_{res}, $q_{exp} = 0.55$	0.0	0.027	0.0	0.0	0.0	4.044	4.071
R_{GTR}, $q_{exp} = 0.55$	0.0	0.012	0.0	0.0	0.0	1.831	1.843
R_{total}, $q_{exp} = 1$	1.369	0.096	0.102	0.021	0.828	21.137	23.552 **
R_{total}, $q_{exp} = 0.55$	1.369	0.072	0.102	0.021	0.828	17.586	19.977 **

$$1\,SNU = 10^{-36}\frac{1}{nucleus \cdot s}$$

* H. Ejiri and S. Elliott, Phys. Rev. C 89 , 055501 (2014)

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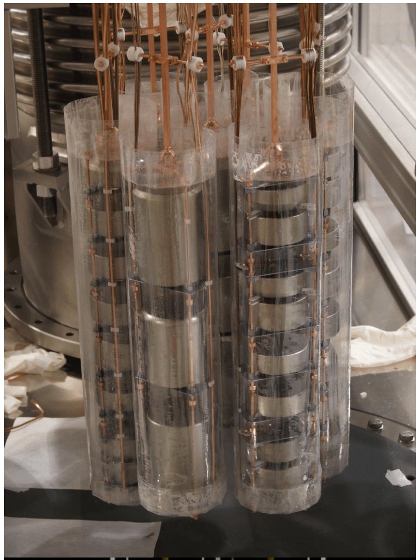
Geometry of the setup

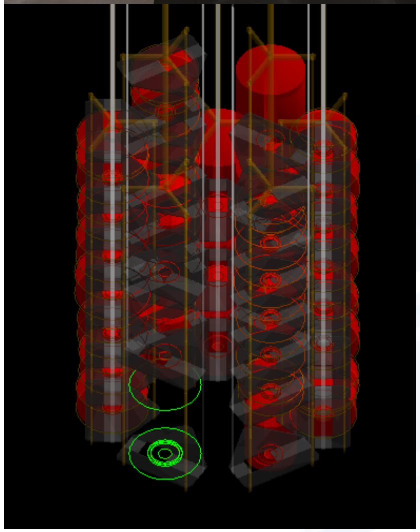
GERDA Phase II:

7 strings of sensitive Ge^{76} detectors:

- 30 enriched (86%) thick window BEGe (20 kg)
  Resolution at $Q_{\beta\beta}$: 3.0±0.2 keV
- 7 enriched (86%) semi-coax (15.8 kg)
  Resolution at $Q_{\beta\beta}$: 4.0±0.2 keV
- 3 natural semi-coax (7.6 kg)



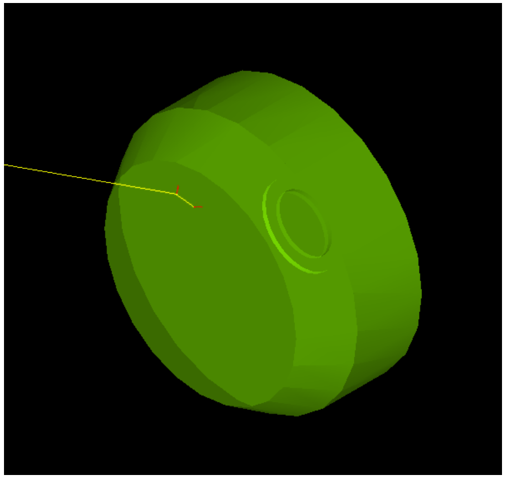
Real strings of Ge detectors in GERDA experiment



Rendering

Simulation of beta decay within a single detector

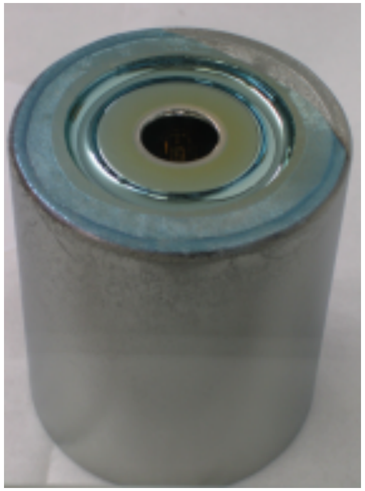
BEGe detectors:

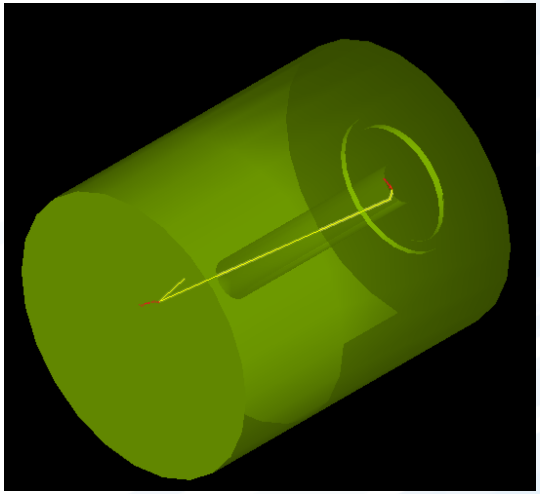


- Yellow lines: trajectories of gamma quantums
- Red lines: trajectories of primary and secondary electrons

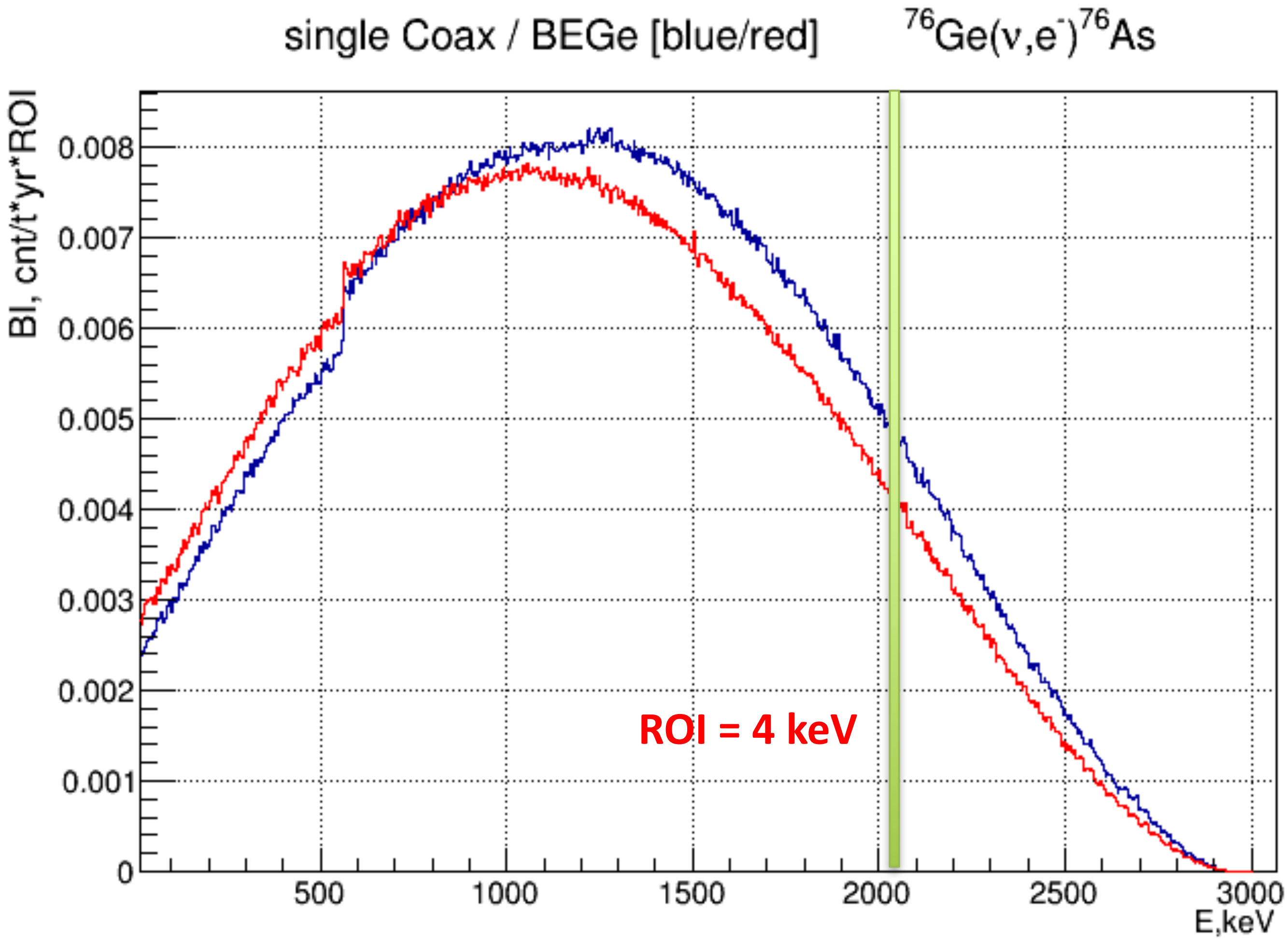
NB:
All results were done without PSD!

coaxial detectors:





Initial assessment of neutrino BI



CR = 19.977 SNU: Bi_{eff} = 0.0045 cnts/(t*yr*ROI)

[CR = 23.552 SNU: Bi_{eff} = 0.0053 cnts/(t*yr*ROI)]

+ elastic scattering on e^-: BI = 0.0011 cnts/(t*yr*ROI) *(A. Klimenko, NUCLEUS-2004)*

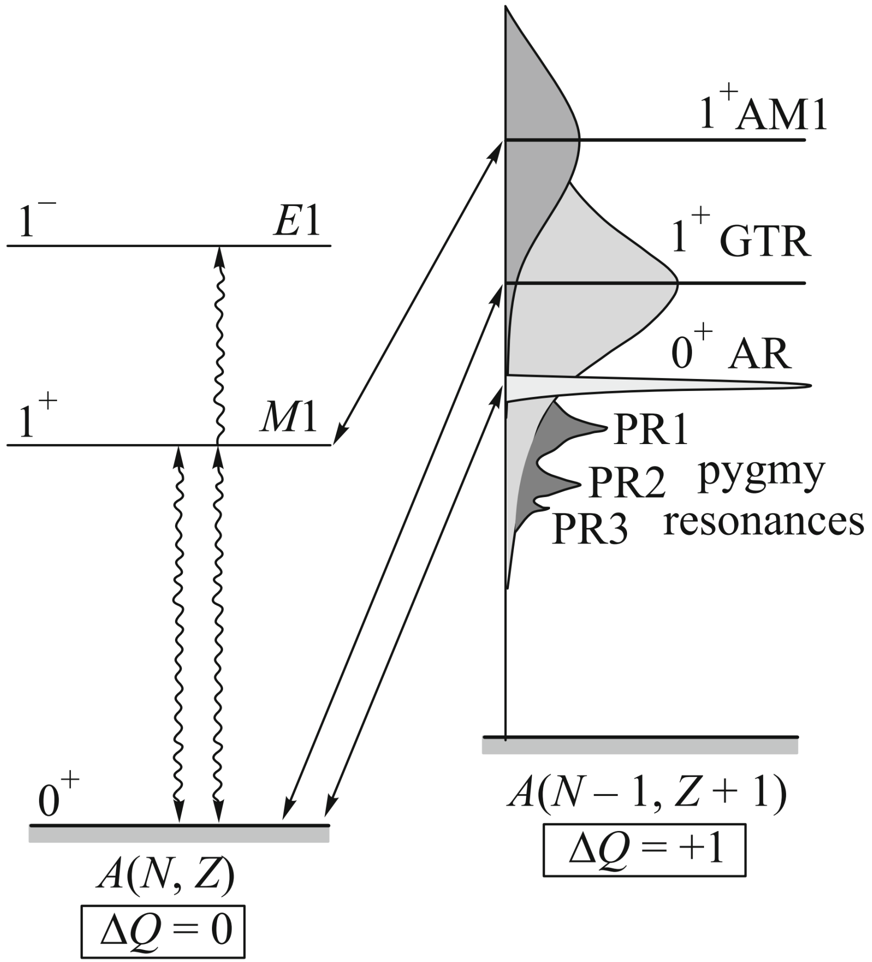
LEGEND goal (the second stage): 0.1 cnts/(t*yr*ROI)

SUMMARY

- Transitions into high-lying resonant GT states increase the total neutrino capture cross-section by **25%** or **50%**.
- The neutrino component of the background remains minor in GERDA/LEGEND experiment.
- The obtained background value can be improved by taking into account neutrino oscillations and the method of pulse shape discrimination.

Thank you for your attention!

Nuclear Resonances (general view)



GTR predictions

Yu. V. Gaponov,
Yu. S. Lyutostanskii,
***JETP Lett.* 15, 120 (1972).**

PR calculations

Yu. S. Lutostansky
***JETP Lett.* 106, 7 (2017)**