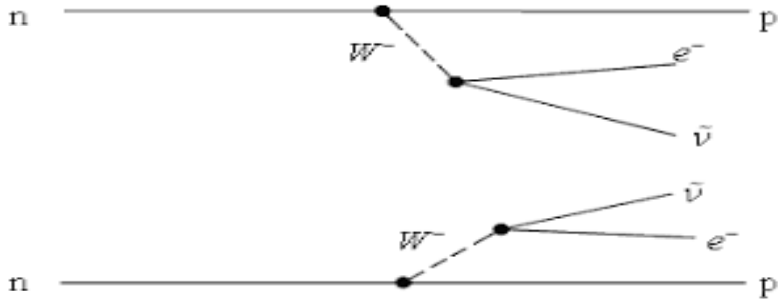


Investigation of the solar neutrino background in the GERDA experiment on the double beta decay of Ge-76

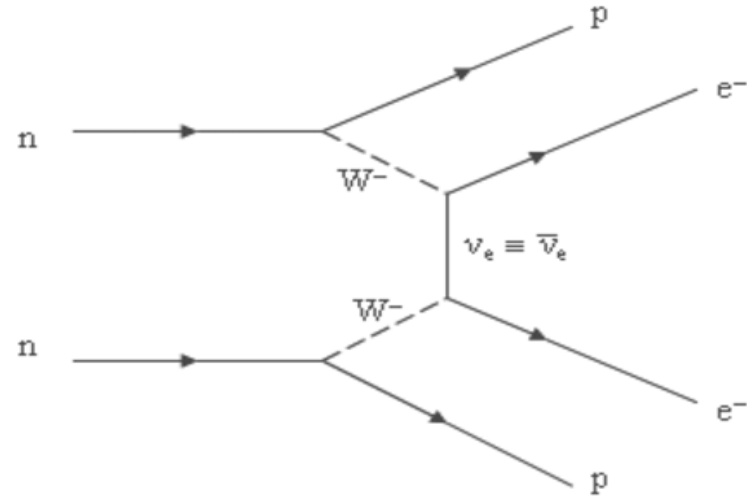


Double beta-decay



2ν2β decay

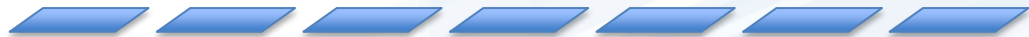
$$(A, Z) \rightarrow (A, Z+2) + 2e^{-} + 2\tilde{\nu}_e$$



0ν2β decay

$$(A, Z) \rightarrow (A, Z+2) + 2e^{-}$$

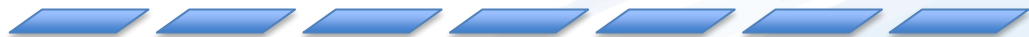
Neutrino is a Majorana particle



$m_\nu \neq 0$

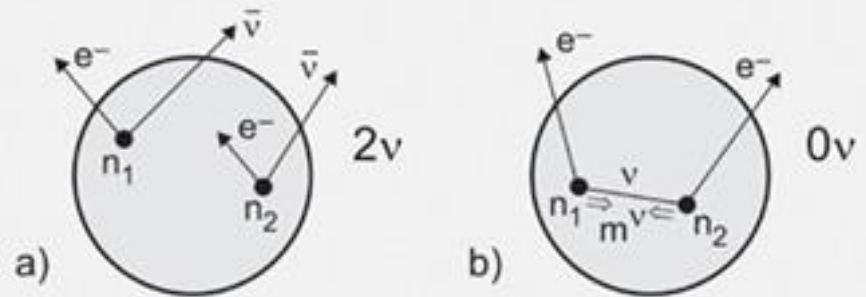


Prohibited in the Standard model ($\Delta L = 2$)



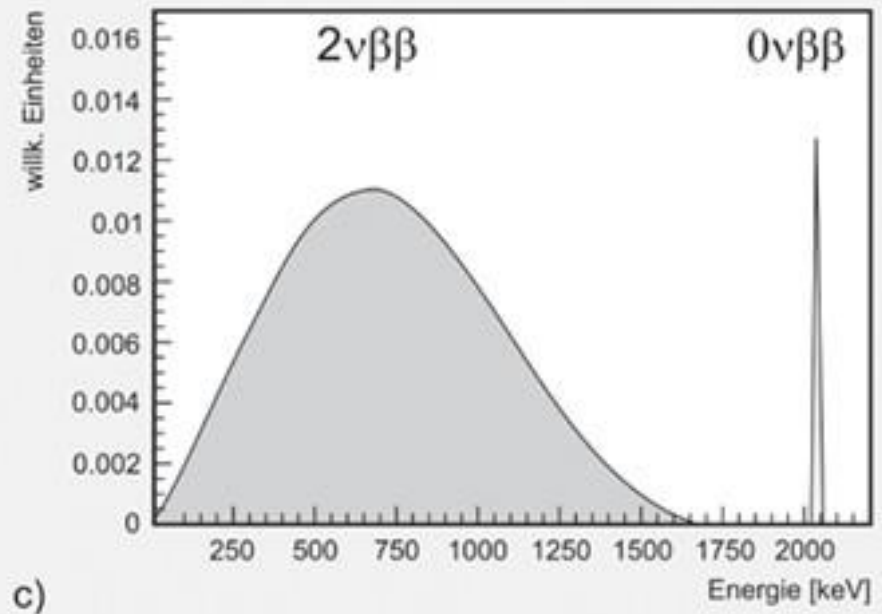
$2\nu\beta\beta$

- Continuous electron spectrum



$0\nu\beta\beta$

- Sharp peak at Q-value in energy sum spectrum



Experiment GERDA: ${}^{76}_{32}\text{Ge} \rightarrow {}^{76}_{34}\text{Se} + 2e^{-}$

GERDA (Phase I) (2011-2013):

23.5 kg · yr of exposure

$T_{1/2} (0\nu) > 2.1 \cdot 10^{25}$ years

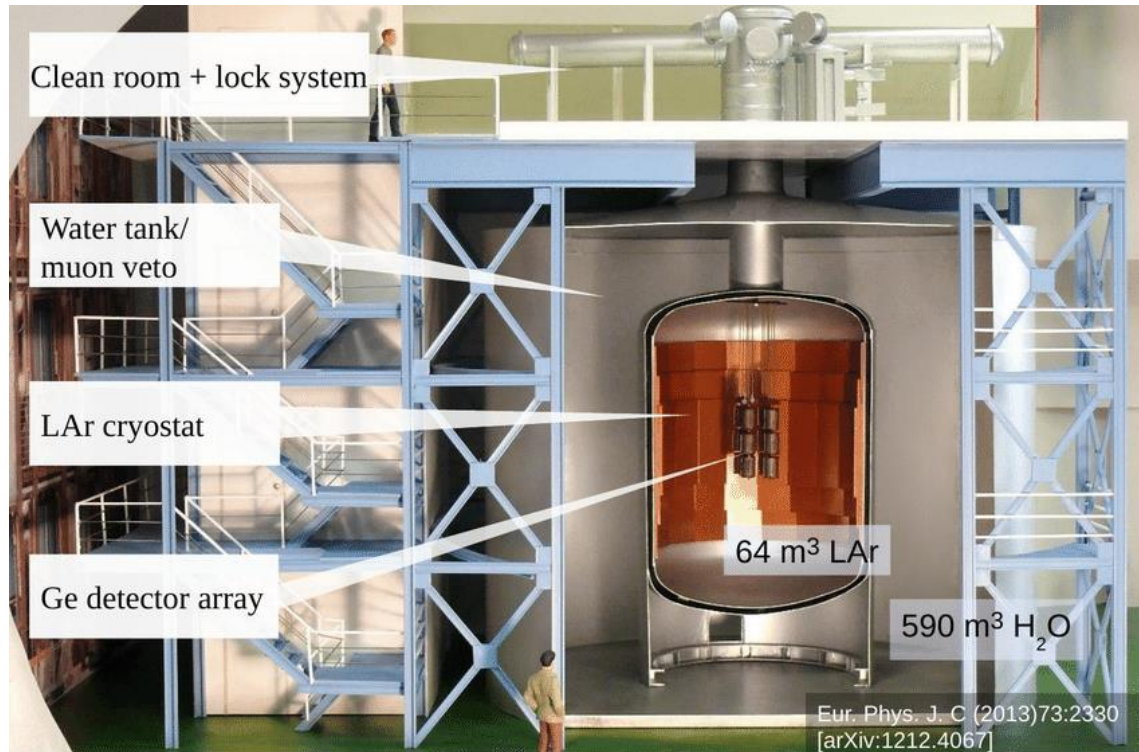
$\langle m_{\nu} \rangle < (0.2 \div 0.4)$ eV

GERDA (Phase II) (2015-2020):

100.2 kg · yr of exposure

$T_{1/2} (0\nu) > 1.8 \cdot 10^{26}$ years

$\langle m_{\nu} \rangle < (0.079 \div 0.180)$ eV



Motivation for theoretical investigation

GERDA (Phase II) (2020):

Exposure: $0.0589 \text{ t} \cdot \text{y}$

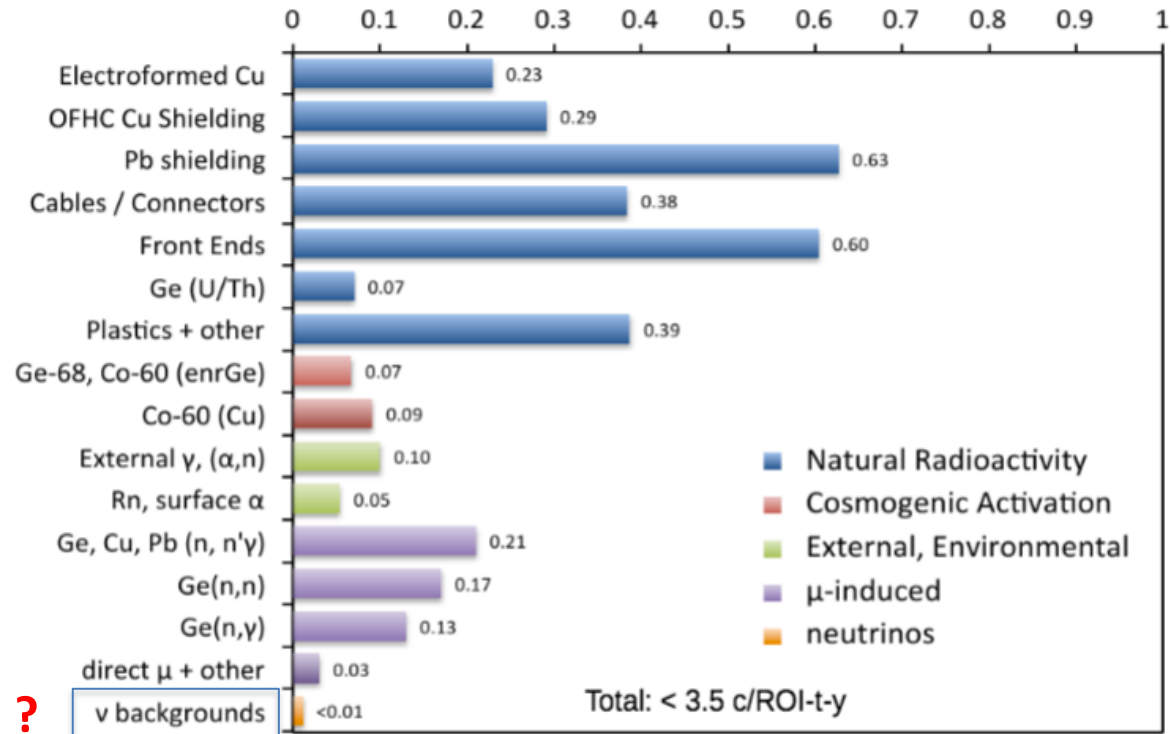
BI: $\sim 2.08_{-0.8}^{+1.6} \text{ cnts}/(\text{t} \cdot \text{yr} \cdot \text{ROI})$

LEGEND goal (the second stage):

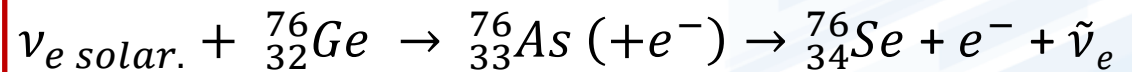
Exposure: $10 \text{ t} \cdot \text{y}$

BI: $0.1 \text{ cnts}/(\text{t} \cdot \text{yr} \cdot \text{ROI})$

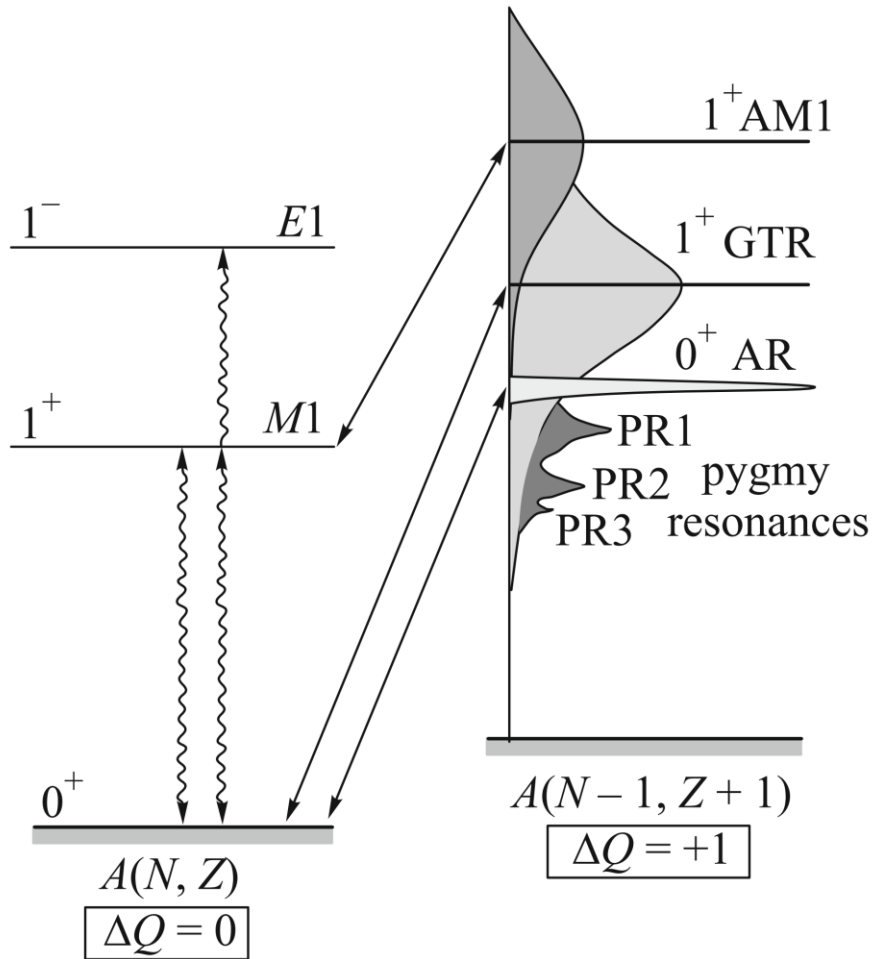
- Solar neutrino background is not removable
- Main channels: elastic scattering by electrons and **capture by Ge^{76} nuclei** (with transition to discrete or resonant states of As^{76})
- **How much does considering of resonance states increase the total cross section?**



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



Nuclear Resonances (general view)



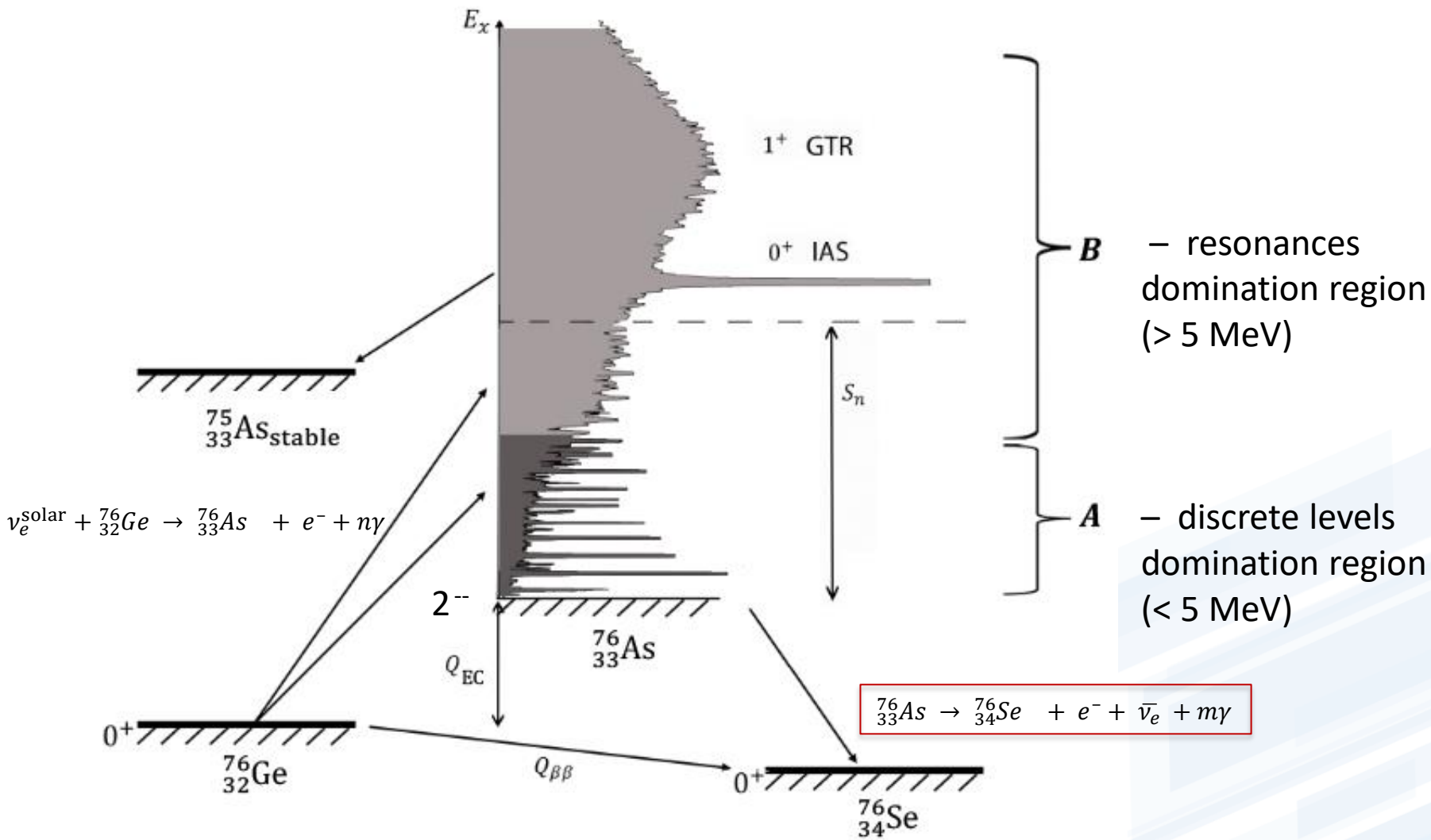
GTR predictions

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

PR calculations

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

Nuclear Resonances for ^{76}As



(ν, e) cross-section

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

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

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

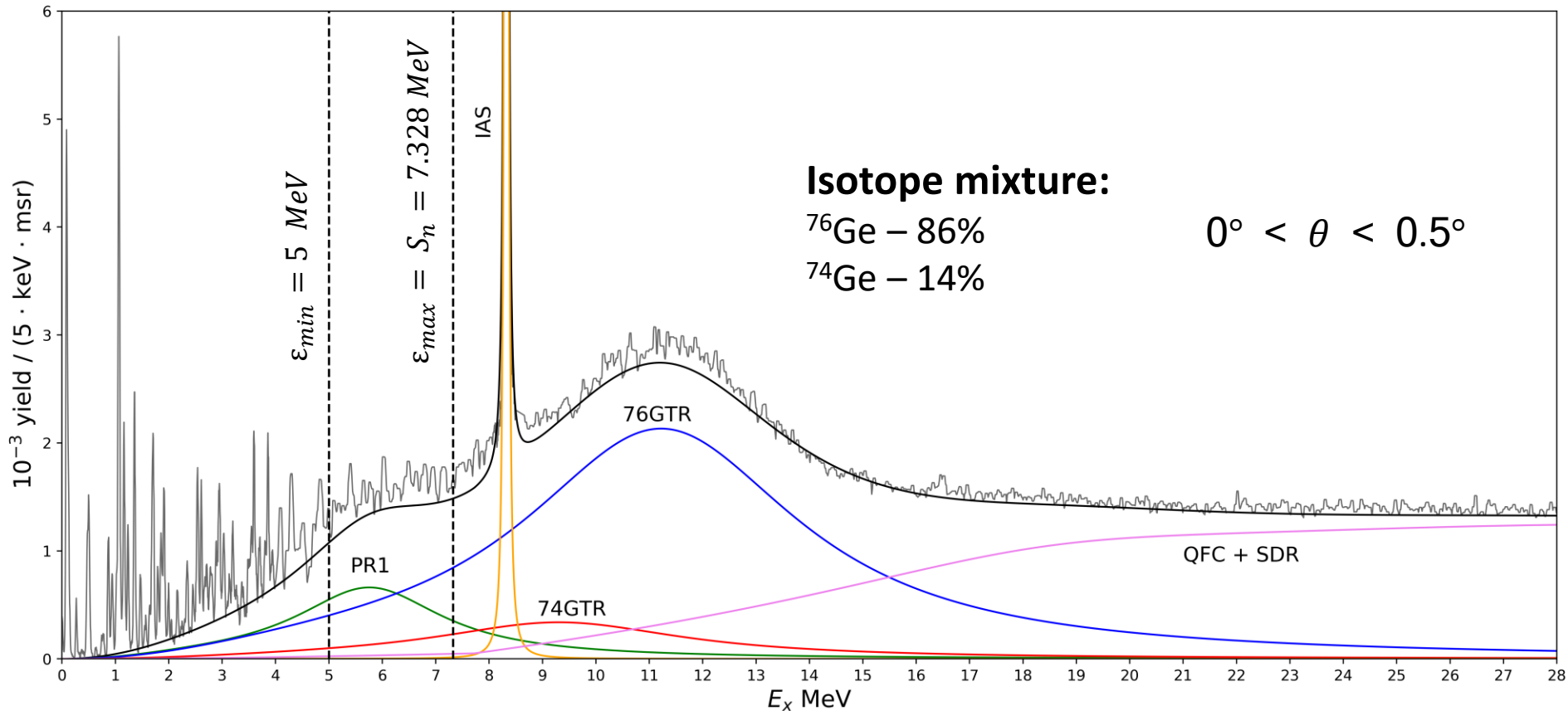
$$\sigma_{res}(E_\nu) = \frac{1}{\pi} \int_{\varepsilon_{min}}^{\varepsilon_{max}} G_F^2 \cos^2 \theta_C p_e E_e F(Z, E_e) S(E) dE$$

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

Experimental data and Fitting

$^{76}\text{Ge}(^3\text{He},t)^{76}\text{As}$

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



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](https://arxiv.org/abs/10.1103/PhysRevC.86.014304).

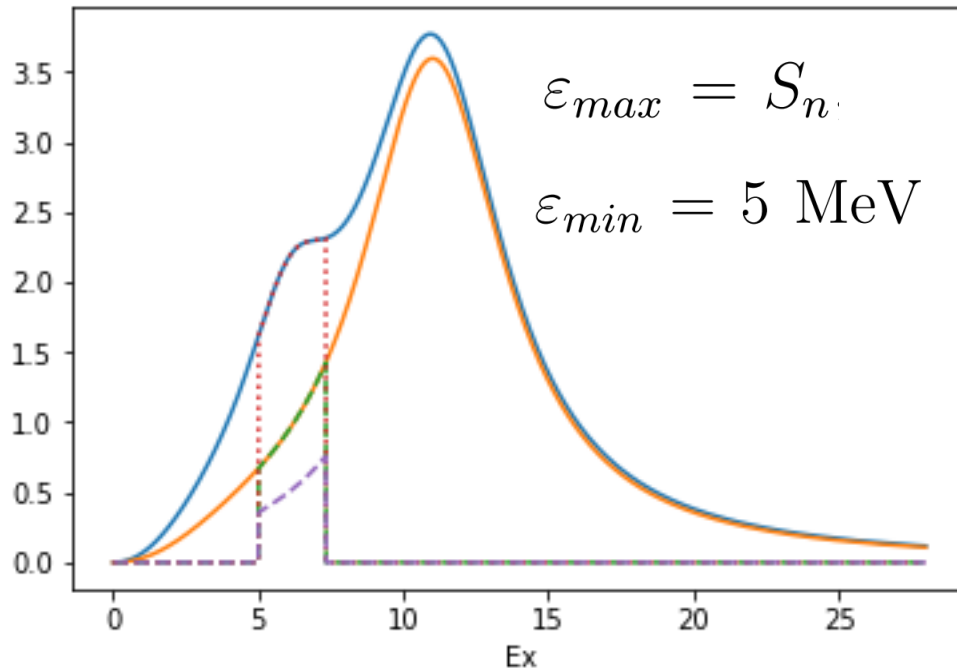
Simultaneous fit for 3 angles: $(0.0^\circ - 0.5^\circ)$, $(0.5^\circ - 1.0^\circ)$ and $(1.0^\circ - 1.5^\circ)$.
Same shape parameters, only amplitudes are independent

Normalization and Quenching effect

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

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

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

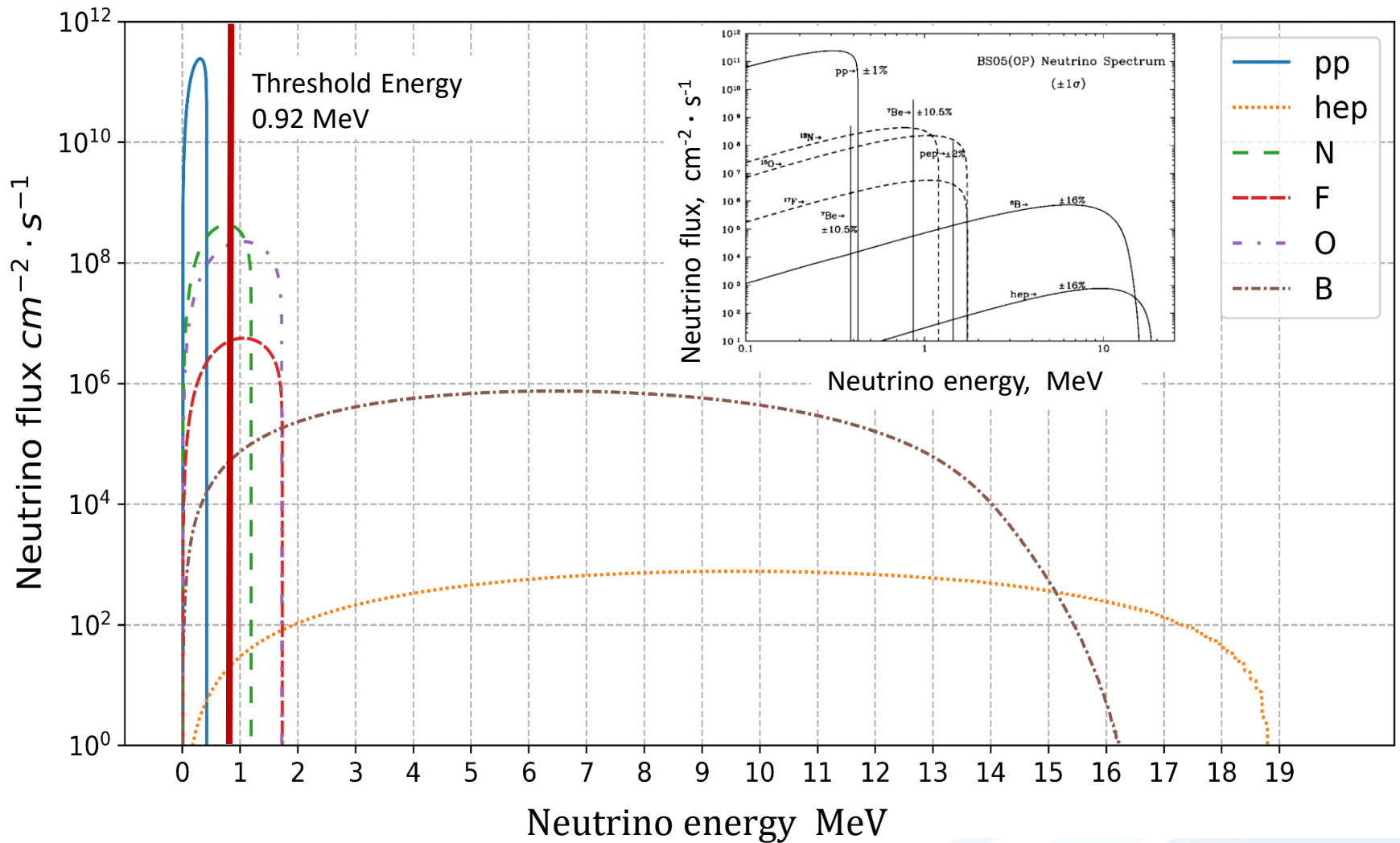


$$q_{exp}^{min} = 0.55$$

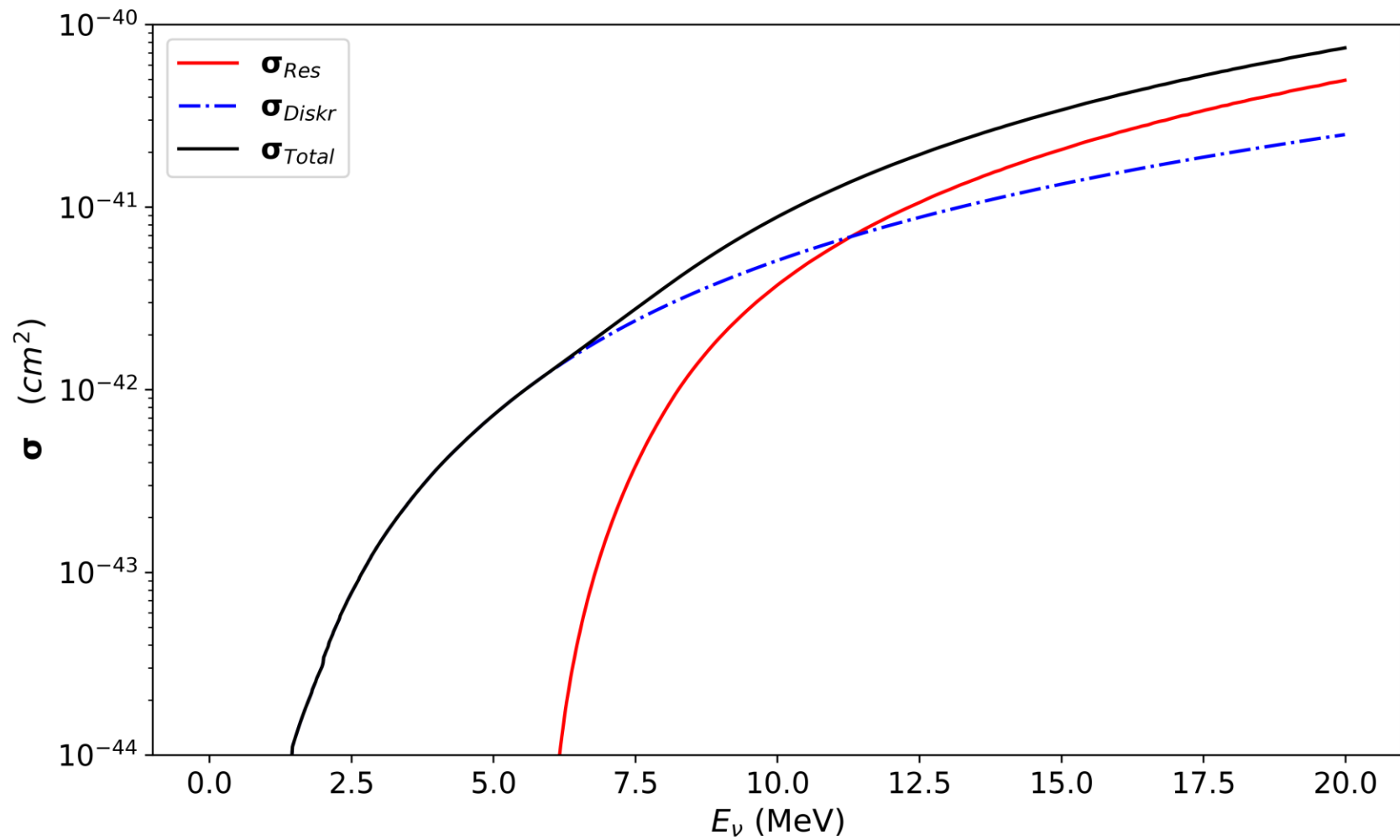
$$q_{exp}^{max} = 1$$

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

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

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

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

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

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

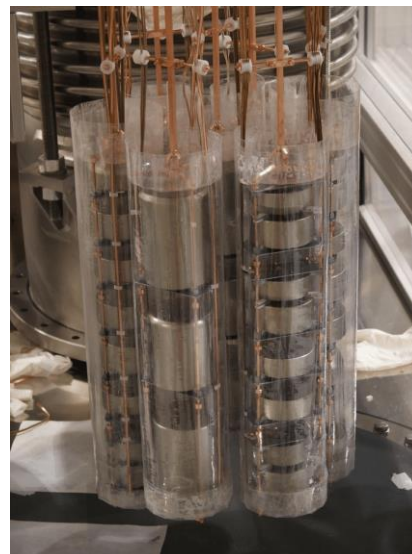
** A.K. Vaynshteyn et. al Phys. Atom. Nucl. 82 (2019) 5, 477-482

Geometry of the setup

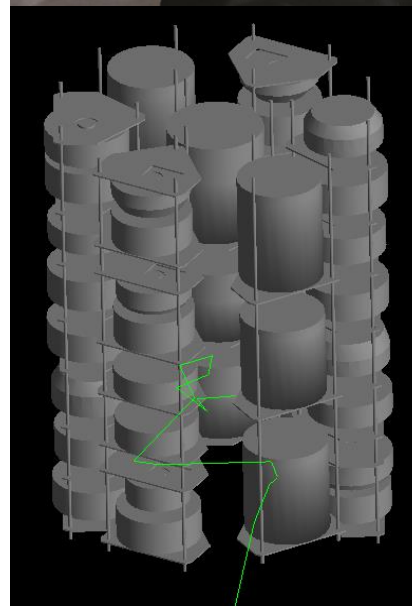
GERDA Phase II:

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

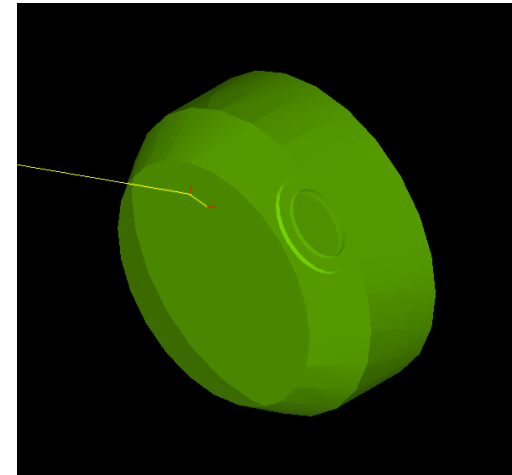
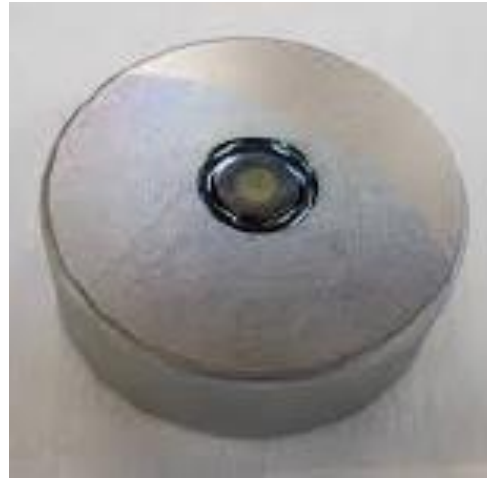


Rendering

Simulation of beta decay within a single detector

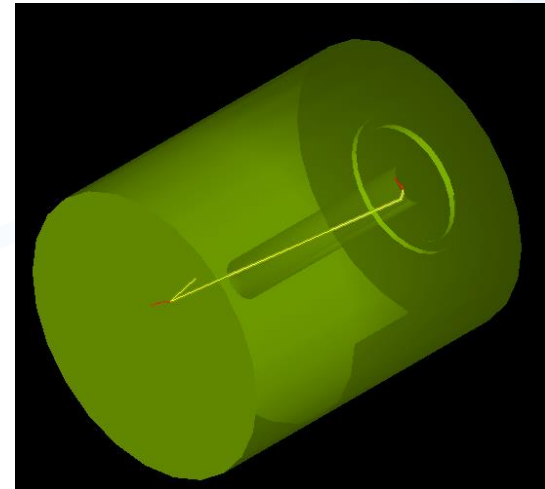
BEGe detectors:

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

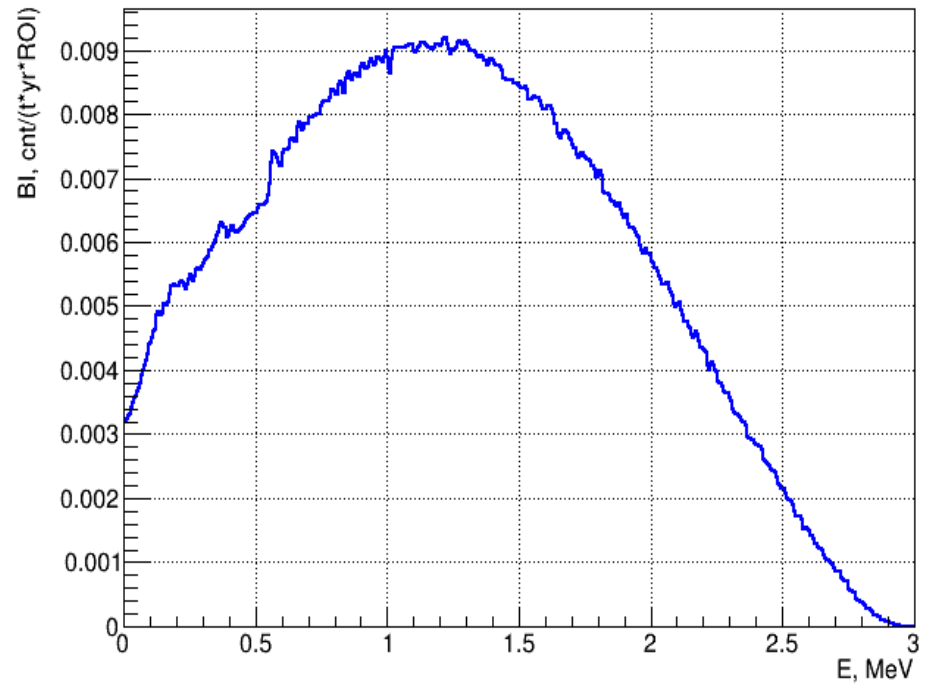
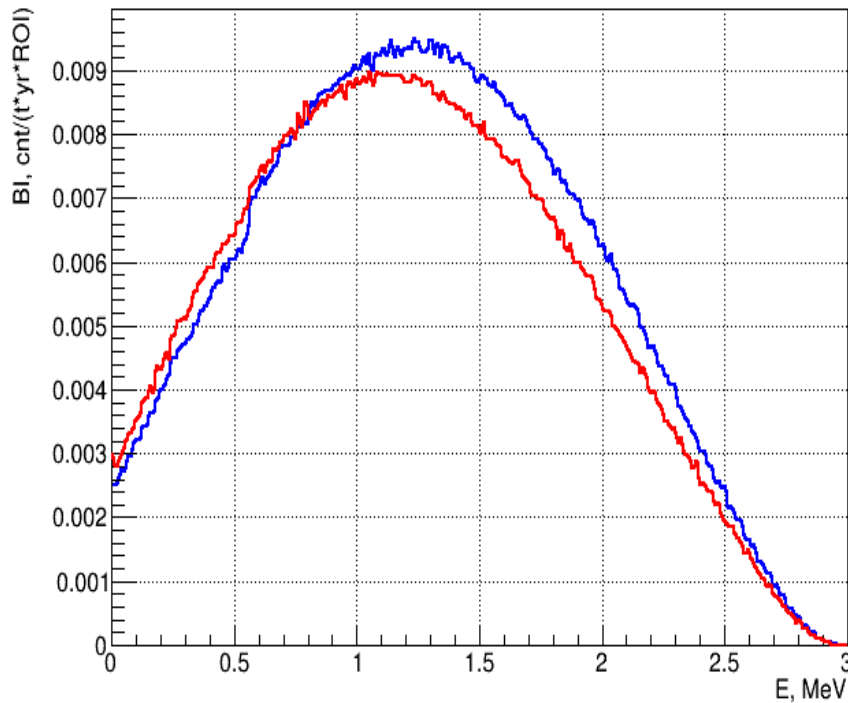


coaxial detectors:

NB:
All results were done
without PSD!



Initial assessment of neutrino BI



CR = 19.977 SNU:

[CR = 23.552 SNU:

+ elastic scattering on e^- :

$Bi_{\text{eff}} = 0.00541$ cnts/(t*yr*ROI)

$Bi_{\text{eff}} = 0.00637$ cnts/(t*yr*ROI)]

BI = 0.0011 cnts/(t*yr*ROI)

(A. Klimenko, NUCLEUS-2004)

Final value for GERDA: 2.08 cnts/(t*yr*ROI)

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.

Thank you for your attention!