

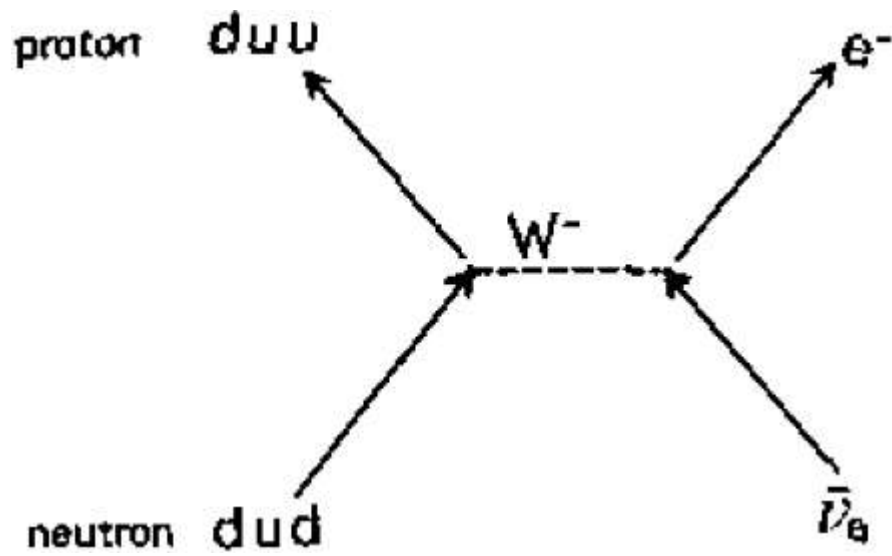
# Neutron lifetime and experimental density of states of fluoropolymers at low temperatures.

E.A. Goremychkin and Yu.N. Pokotilovski

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Short analysis is given of the experimental situation in the neutron lifetime. We report the inelastic neutron scattering measurement of the density of vibrational states  $G(\omega)$  of four fluoropolymers which differ by chemical composition, molecular weight and solidification temperatures.

These polymers are promising for the storage of ultra cold neutrons in closed volumes covered with polymer film. From inferred  $G(\omega)$  we calculate the expected UCN loss coefficients and compare them with the existing experimental data.



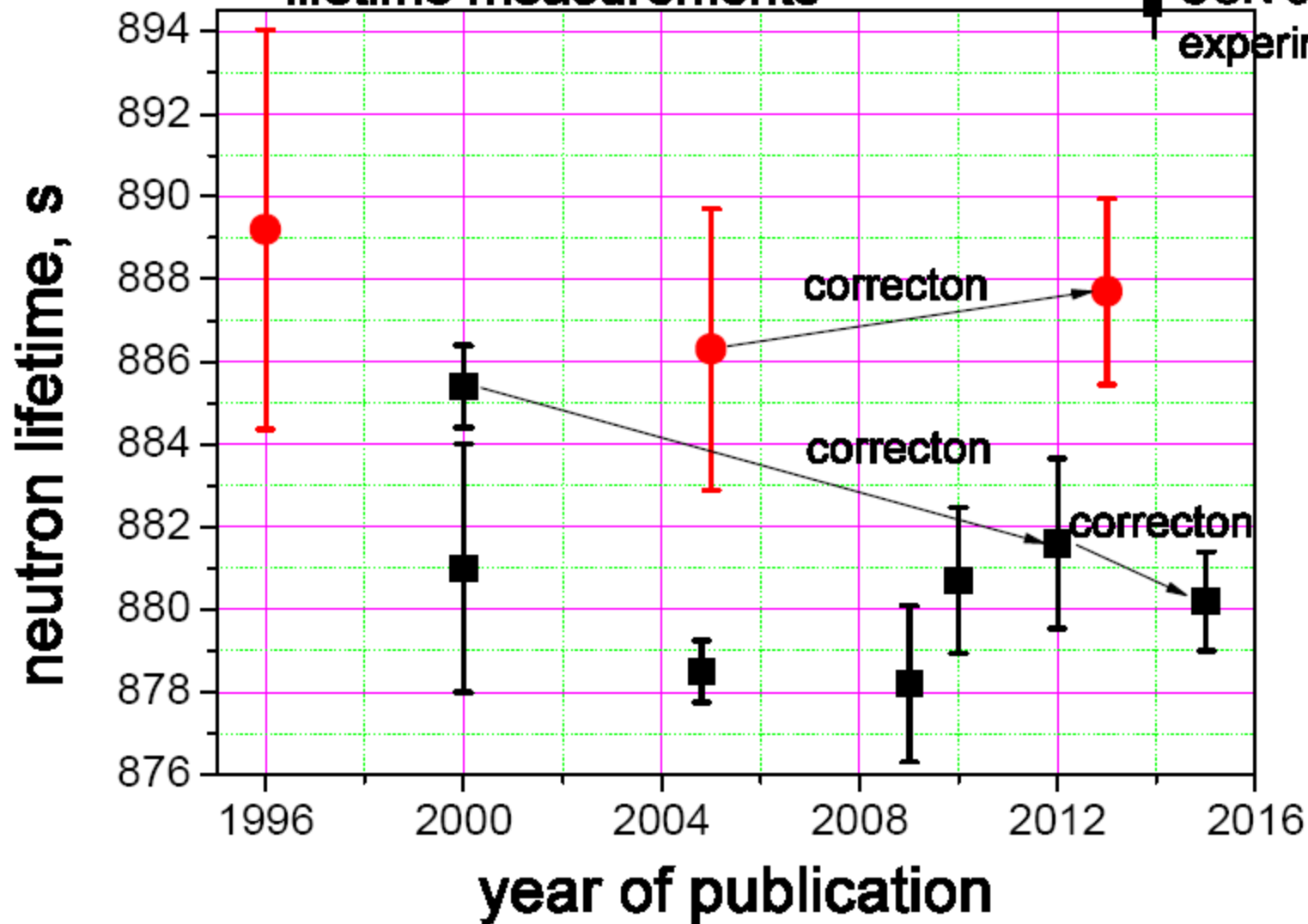
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$|V_{ud}|^2 = \frac{G_V^2}{G_F^2(1 + \Delta_R)} = \frac{2\pi^2}{G_F^2 m_e^5 \tau_n (1 + 3\lambda^2) f^R (1 + \Delta_R)}$$

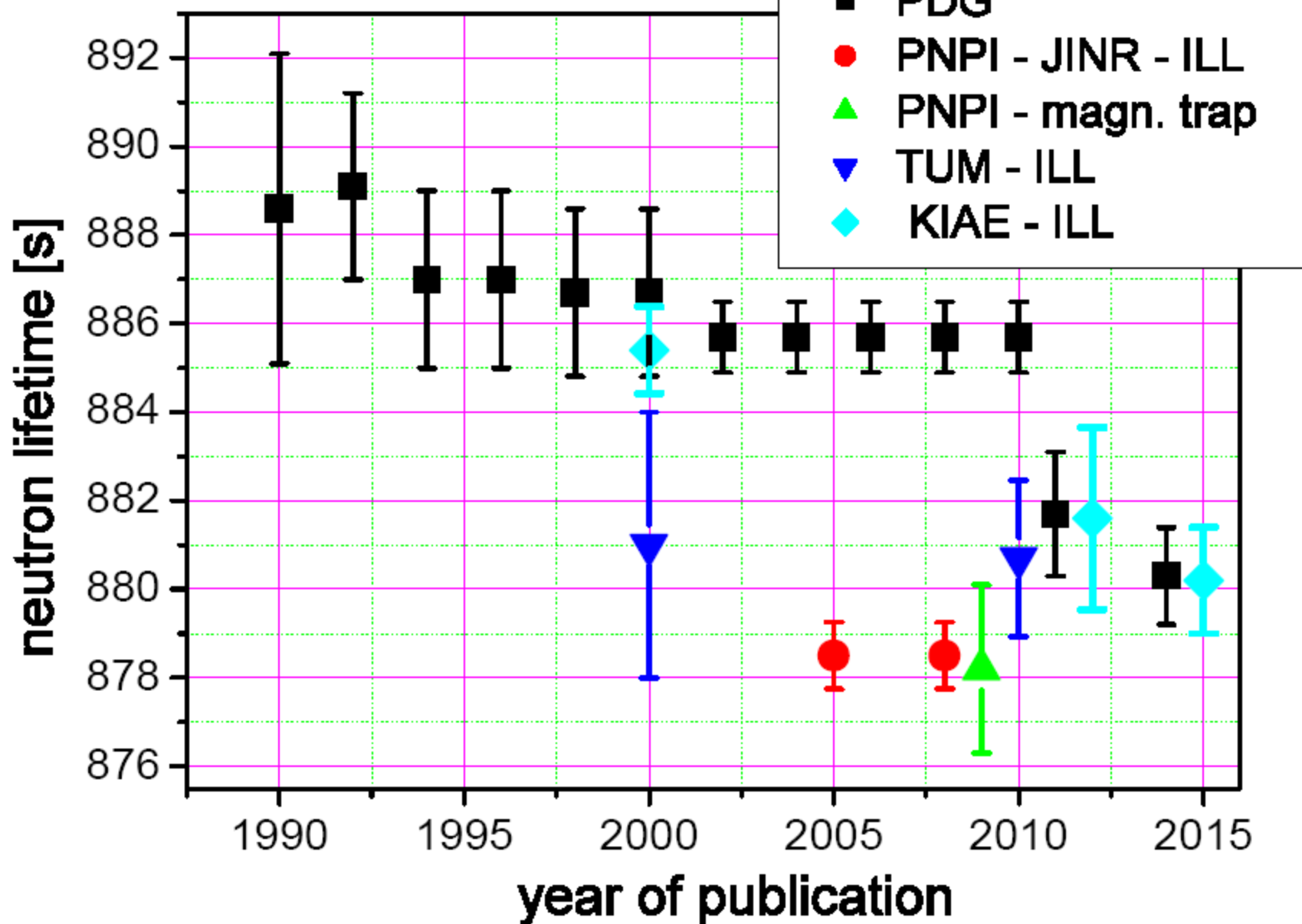
$$|V_{ud}|^2 = \frac{(4908.7 \pm 1.9)}{\tau_n (1 + 3\lambda^2)} \quad A_0 = -2 \frac{\lambda(\lambda + 1)}{1 + 3\lambda^2}$$

# Chronology of the neutron lifetime measurements

● beam experiments  
■ UCN storage experiments



# UCN-experiments & PDG neutron lifetime vs publication year



$$\tau_{\text{st}}^{-1} = \tau_{\text{decay}}^{-1} + \tau_{\text{loss}}^{-1}$$

$$\tau_{\text{st},i}^{-1} = \tau_{\text{decay}}^{-1} + \eta\gamma_i$$

UCN loss coefficient  $\eta_{storage}$  from UCN storage experiments and  $\eta_{theor,trans}$  from cold neutron transmission and dynamic model calculations.

Substance	$\eta_{storage}$	$\eta_{theor,trans}$
Be(6.5 K)	$3.2 \times 10^{-5}$ [1]	$3 \times 10^{-7}$ (Debye model calc.)
Be(300 K)	$4 \times 10^{-5}$ [2]	$5 \times 10^{-6}$ (cold neutron cross sections[9])
Be(10 K)	$3.0 \times 10^{-5}$ [2]	$3 \times 10^{-7}$ (Debye model calc.)
O <sub>2</sub> (10 K)	$6 \times 10^{-6}$ [2]	$6 \times 10^{-7}$ (magnon spectrum calc.[3, 4])
C (100 K)	$5 \times 10^{-5}$ [6]	$2 \times 10^{-6}$ (cold neutron cross sections[9])
D <sub>2</sub> O(80 K)	$9.4 \times 10^{-6}$ [6]	$\leq 2 \times 10^6$ (cold neutron cross sections[7, 8])
D <sub>2</sub> O(90 K)	$\sim 6 \times 10^{-5}$ [5]	$\leq 2 \times 10^6$ (cold neutron cross sections[7, 8])
D <sub>2</sub> O(7 K)	$\sim 6 \times 10^{-5}$ [5]	$\leq 2 \times 10^6$ (cold neutron cross sections[7, 8])

## References

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## **ULTRACOLD NEUTRON STORAGE IN A FLUID-WALLED BOTTLE**

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Received 18 December 1981

Revised manuscript received 1 February 1982

Theoretically possible wall-loss probabilities for ultracold neutrons stored in solid-walled bottles have not been achieved in practice, but preliminary measurements with a fluid-walled bottle seem promising.

## NEUTRON LIFETIME FROM A LIQUID WALLED BOTTLE

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The neutron lifetime has been measured in a storage experiment by counting the ultra-cold neutrons remaining in a fluid walled bottle as a function of the duration of storage. Wall losses are eliminated by varying the bottle volume to surface ratio. Our result is  $\tau_{\beta} = (887.6 \pm 3)$  s.



## UCN losses in Fomblin

At room temperature  $\eta = 1.6(0.1) \times 10^{-5}$

(W.Mampe et al., Phys Rev Lett. **63** (1989) 593)

$\eta = 2.3(0.1) \times 10^{-5}$  (Fomblin oil)

$\eta = 1.8(0.1) \times 10^{-5}$  (Fomblin grease)

(D.J. Richardson et al., Nucl. Instr. Meth. **A308** (1991) 568.

$\eta = 1.8(0.1) \times 10^{-5}$  (at 22° C)

$\eta = 1.4(0.1) \times 10^{-5}$  (at 10° C)

$\eta = 1.3(0.1) \times 10^{-5}$  (at 4° C) (all Fomblin oil)

(A.Pichlmaier, Dissertation, TU Munich 1999)

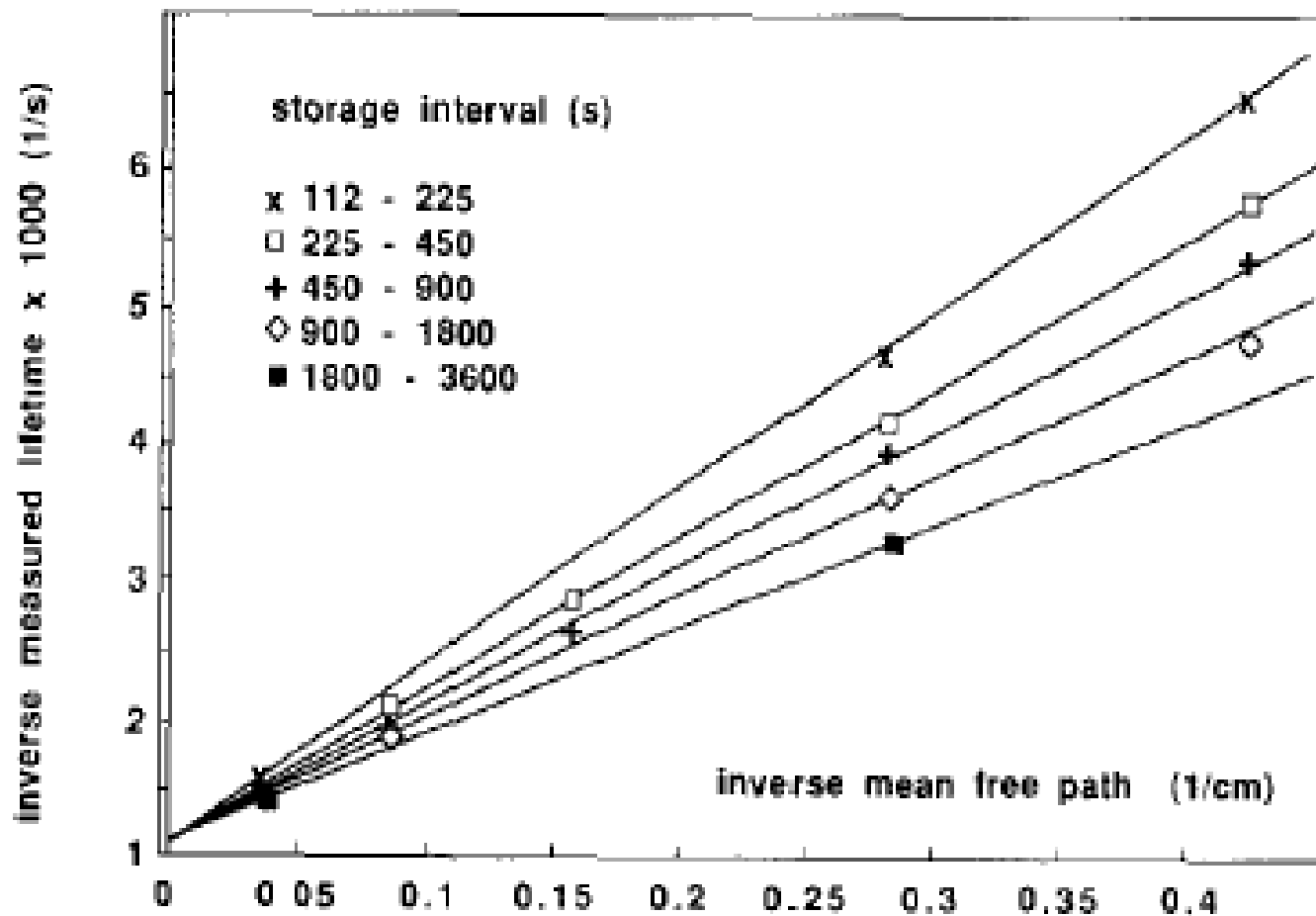


Fig. 2. Measured inverse bottle lifetimes as a function of the bottle inverse mean free path and for different storage intervals. The data are from a one week running period. Almost all the error bars are smaller than the data points.

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NUCLEI, PARTICLES,  
AND THEIR INTERACTION

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# Investigation of Liquid Fluoropolymers as Possible Materials for Low-Temperature Liquid-Wall Chambers for Ultracold Neutron Storage<sup>†</sup>

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Received April 27, 2002

**Abstract**—Several hydrogen-free liquid low-temperature fluoropolymers are investigated from the point of view of their possible use as the material for walls of ultracold neutron traps with low losses. Viscosity was measured in the temperature range 150–300 K, and neutron scattering cross sections were measured in the temperature range 10–300 K and in the neutron wavelength range 1–20 Å. Some conclusions are made for their possible ultracold neutron bottle properties. Quasi-elastic neutron reflection from the surface of a viscous liquid is considered in the framework of the Maxwell dynamic model. © 2003 MAIK “Nauka/Interperiodica”.



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## Measurement of the neutron lifetime using a gravitational trap and a low-temperature Fomblin coating

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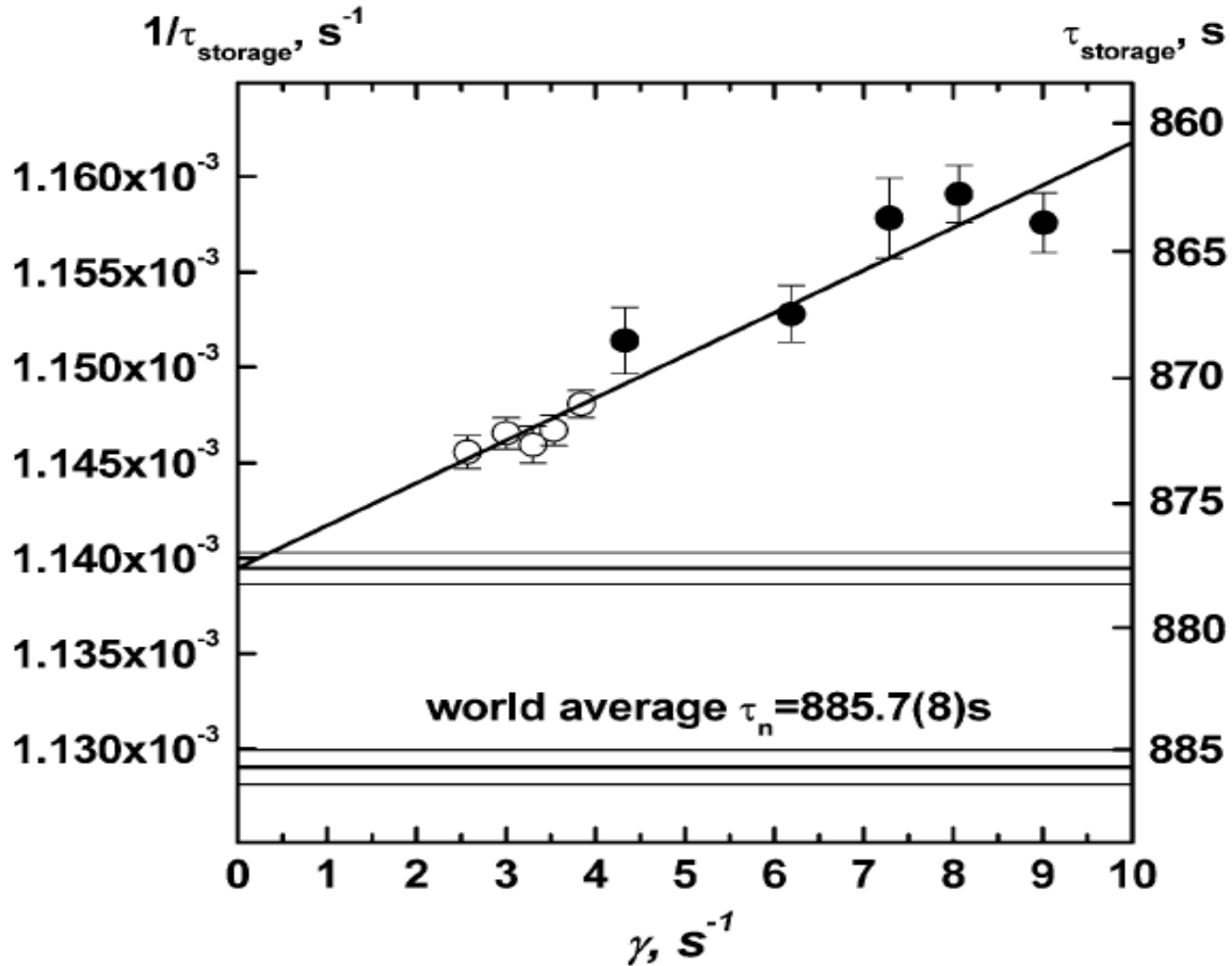
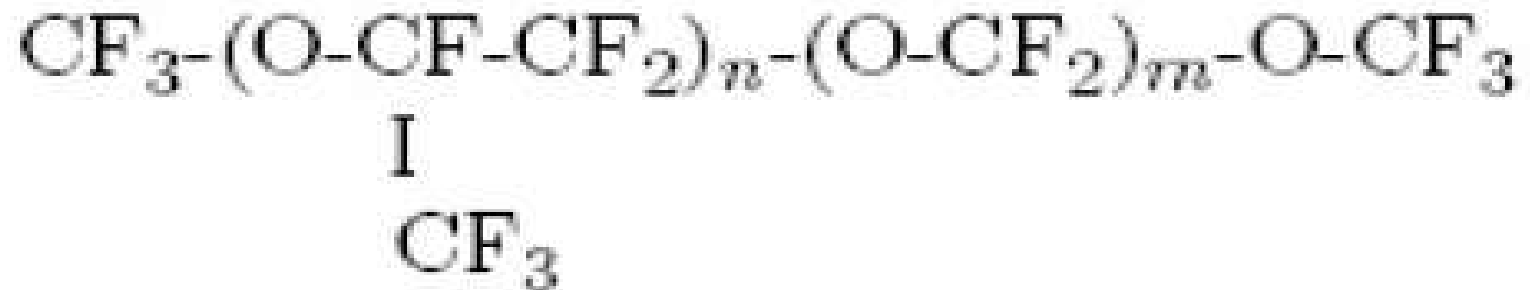


Fig. 3. Result of extrapolation to the neutron lifetime using joint energy and the size extrapolation method. Measurements made with a spherical (open circles) and cylindrical (filled circles) traps.

# Fomblin Y



$n/m=20-40$ , ( $\approx \text{C}_3\text{OF}_6$ ), molecular weight  $\sim 3000$

Perfluoropolyethers (or fluoropolyoximethylenes)



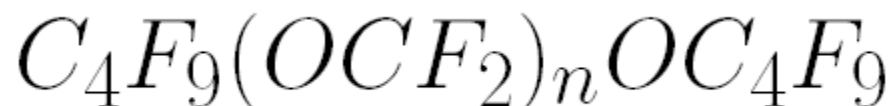
with  $m_1 + m_2 \approx 60.5$ ,  $n \approx 3.14$  and molecular weight 4500.

## Synthesis and Physical Properties of Novel Perfluorinated Methylene Oxide Oligomers. The Ultimate Low Temperature Fluids

**Kuangsen Sung and Richard J. Lagow\***

*Contribution from the Department of Chemistry and Biochemistry, The University of Texas at Austin, Austin, Texas 78712–1167*

*Received August 18, 1994*<sup>®</sup>



**Abstract:** Perfluorinated polyethers are a class of substances which are extremely inert and have both extraordinary high temperature stability and low temperature properties. The synthesis of perfluorinated polyformaldehydes with the highest oxygen content was designed to give the maximum liquid range and low temperature properties. Novel low molecular weight perfluorinated polyformaldehydes with stable and unreactive perfluoro-*n*-butyl end groups were prepared by liquid-phase direct fluorination. The boiling point of these compounds increases by approximately 20 °C with the addition of each difluoromethylene oxide unit. This trend does not continue for longer chain lengths ( $n > 4$ ) where the increase in boiling point per CF<sub>2</sub>O unit diminishes. The average increase of melting temperature is ~1–2 °C as the perfluorinated polyformaldehyde chain increases one difluoromethylene oxide unit. The new perfluoropolyether fluids produced have melting points ranging from –145 to –152 °C.



# **A New Perfluorinated Grease for High-Vacuum Technology**

**G. Caporiccio,\* C. Corti, and S. Soldini**

*Monteflous SpA, Montedison, Research Development Center, Milano, Italy*

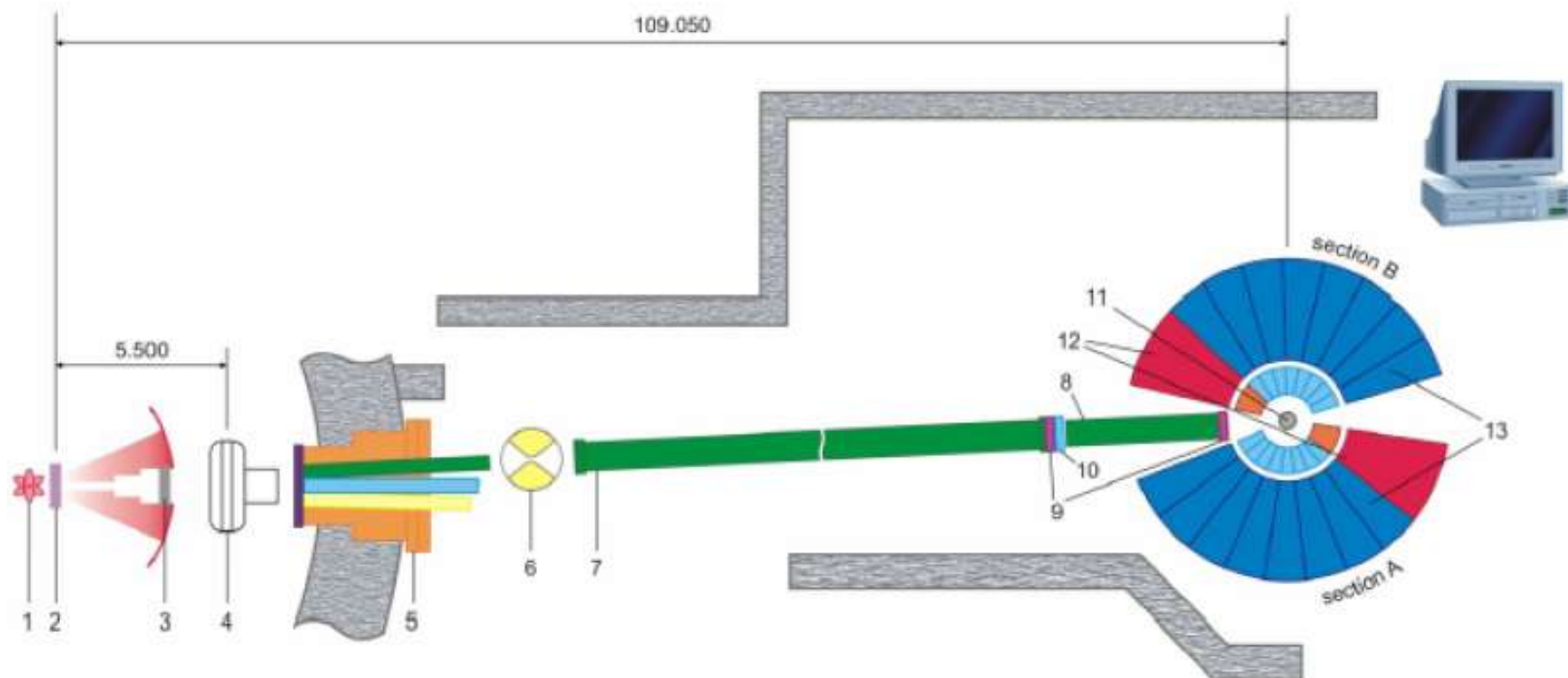
**A. Rolando**

*ROL, Lubricant Research Laboratories, Viguzzolo, Italy*

Advances on fluorinated materials allowed the development of a new grease, compounded by low vapor tension perfluoropolyether liquid and special PTFE. Chemical composition, physical, rheological, and antiwear properties, and chemical and thermooxidative stability compared with other conventional lubricants resulted in attractive properties to utilize the new grease for high-vacuum technologies where residue pressures of aggressive chemical agents or energetic particles or radiations are involved. A brief account on topical high-vacuum application of the new lubricant is summarized.

I Natkaniec<sup>1,2</sup>, D Chudoba<sup>1,2</sup>, L Hetmańczyk<sup>1,3</sup>, V Yu Kazimirov<sup>1</sup>, J Krawczyk<sup>1,4</sup>,  
I L Sashin<sup>1</sup> and S Zalewski<sup>1,5</sup>

## Parameters of the NERA spectrometer for cold and thermal moderators of the IBR-2 pulsed reactor

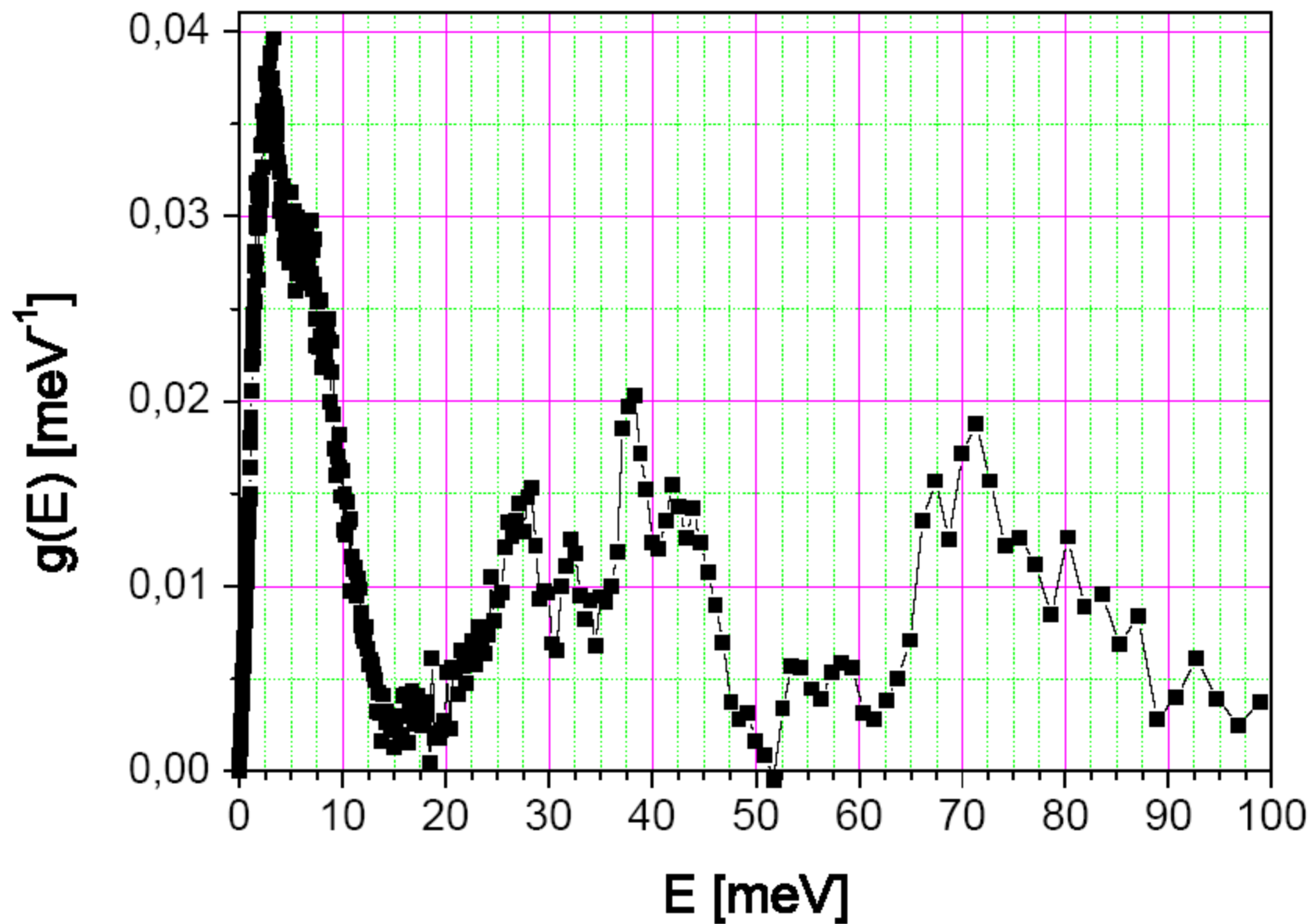


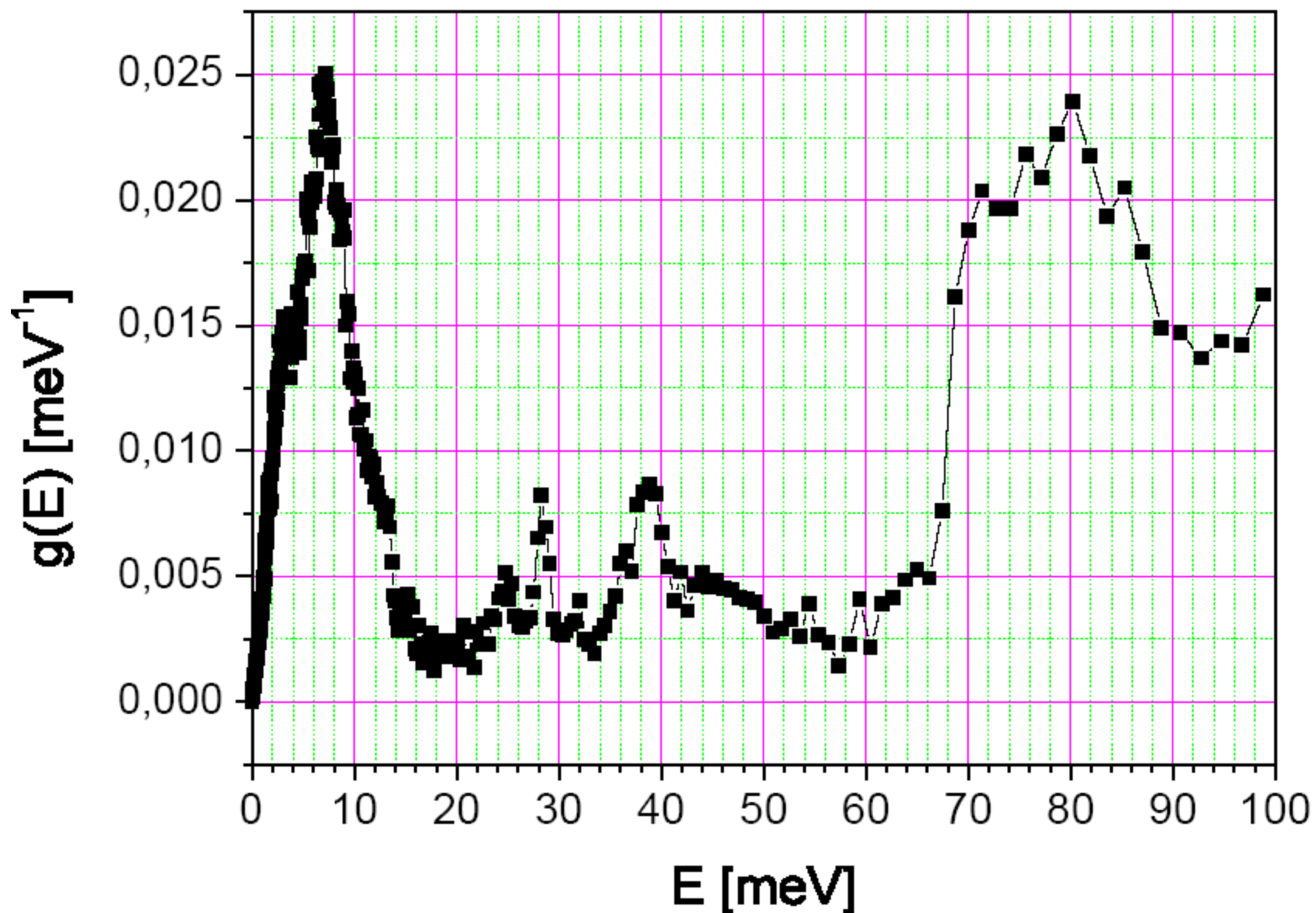
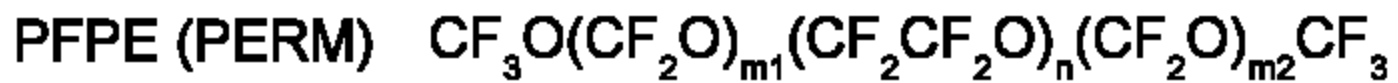
$$I(t, \theta, T) \Delta t = \Delta t \iiint \sigma(E_i, E_f, \theta, T) \Phi(E_i) R(E_i, E_f, t_0, t) \\ \times dE_i dE_f dt_0,$$

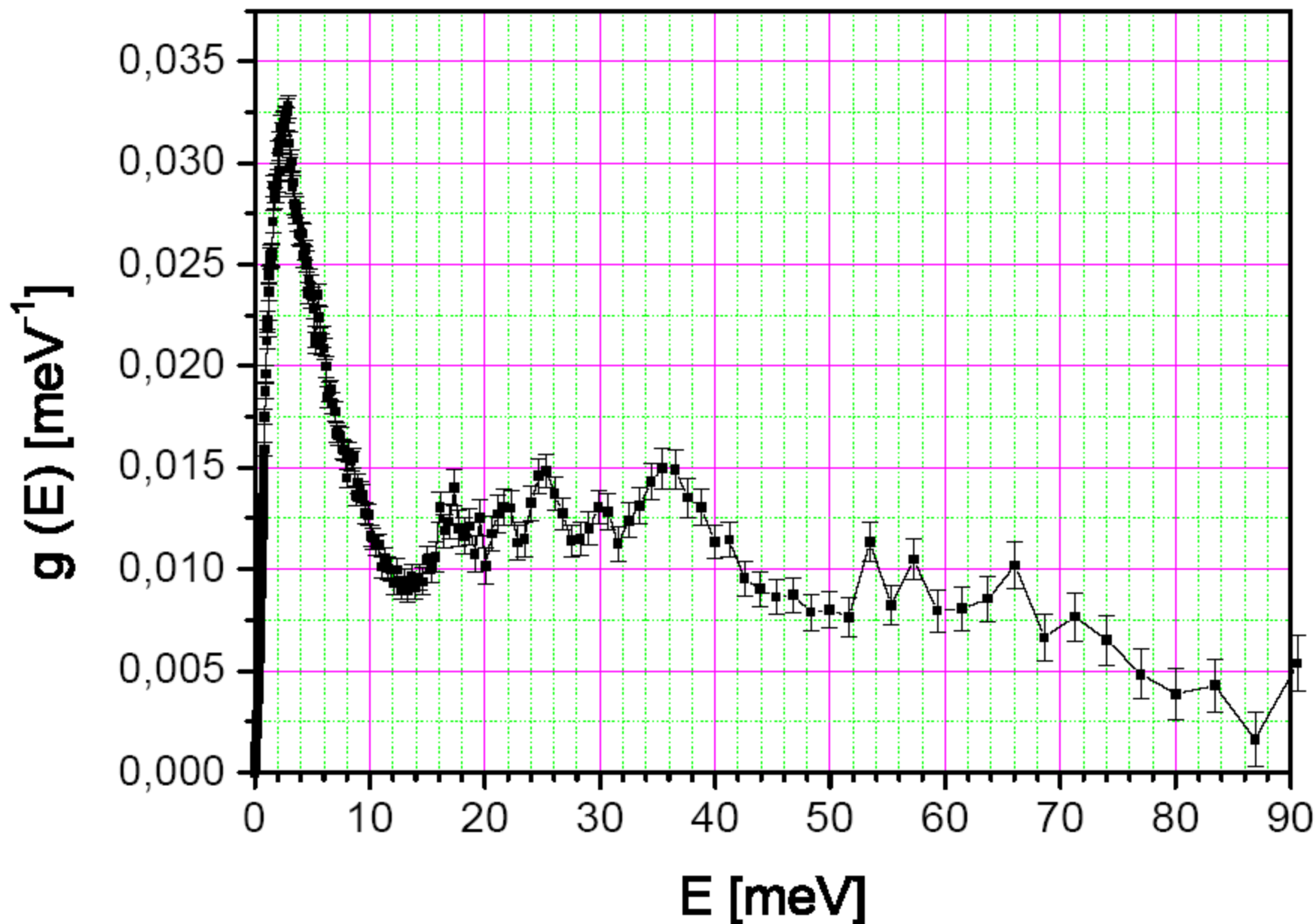
$$\sigma_1^{\text{inc}}(E_i, E_f, \theta, T) \approx \sqrt{\frac{\bar{E}_f}{E_i}} \frac{\hbar |Q(E_i, E_f, \theta)|^2}{\omega} \sum_n \frac{(b_n^{\text{inc}})^2}{M_n} \\ \times \frac{\exp(-2W_n)}{1 - \exp(-\hbar\omega/k_B T)} G(\omega),$$

$$G(\omega) = \sum_n \sum_j \int d^3q [A_j^n(q)]^2 \delta[\omega - \omega_j(q)],$$

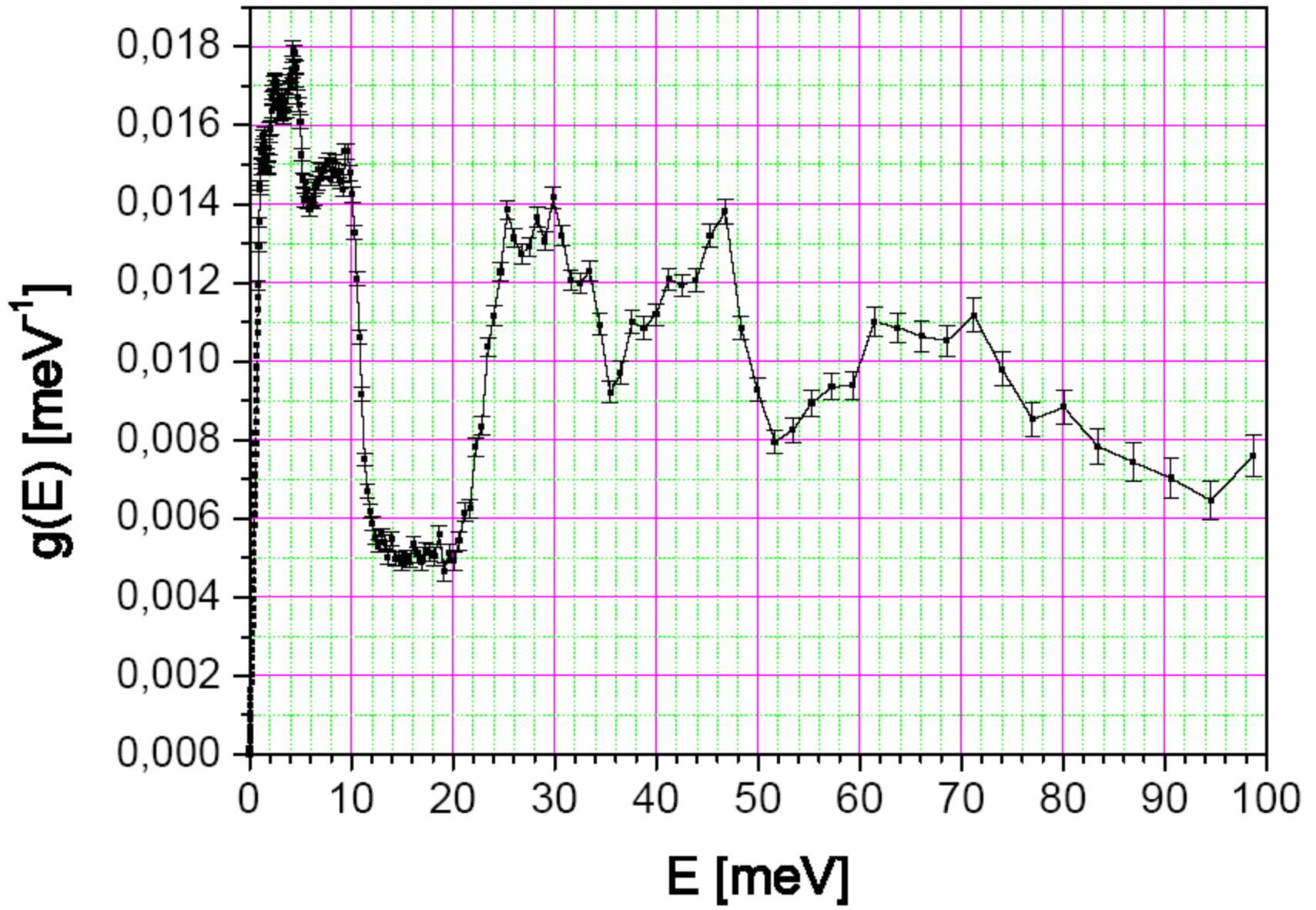
Fomblin



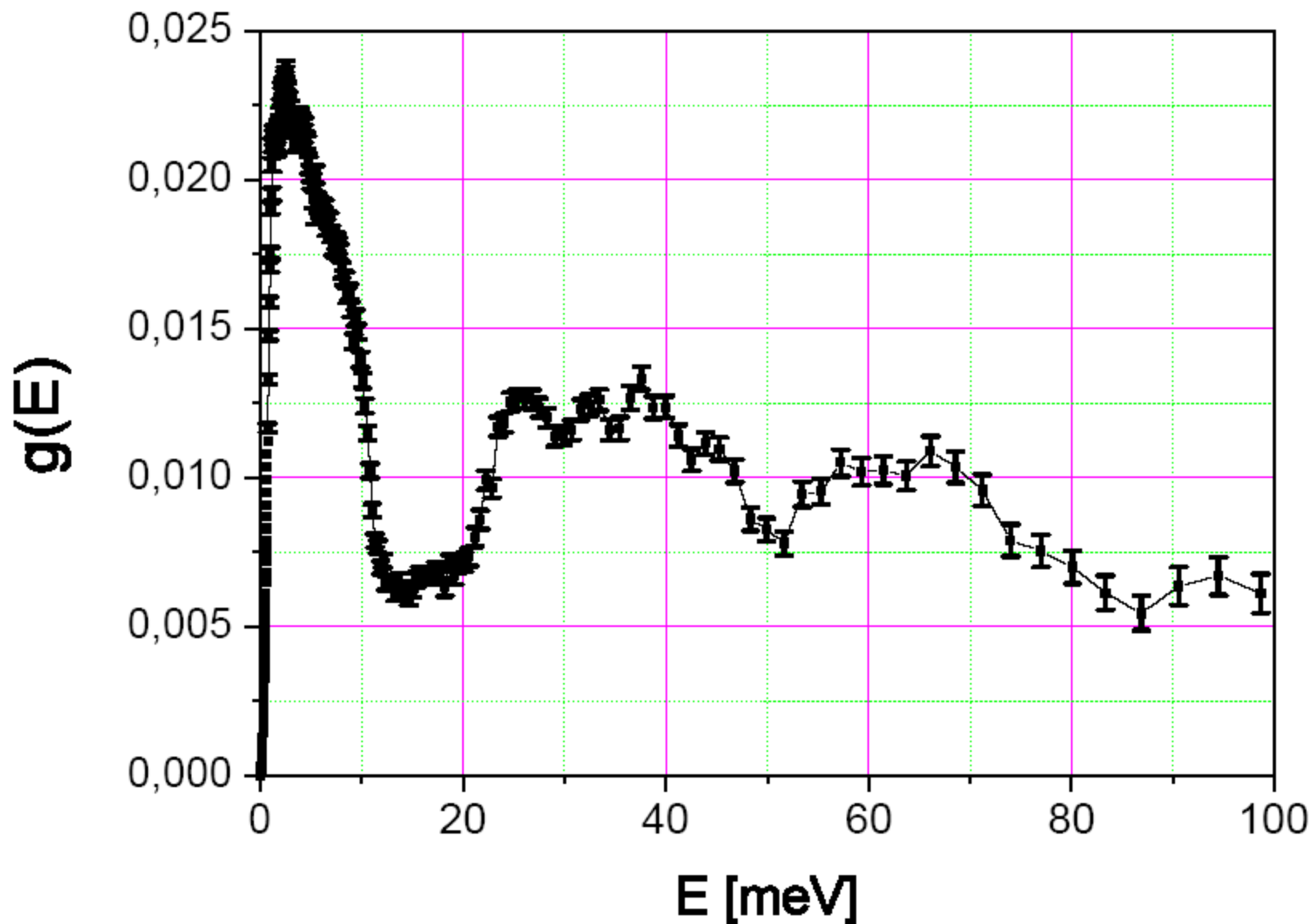




teflon

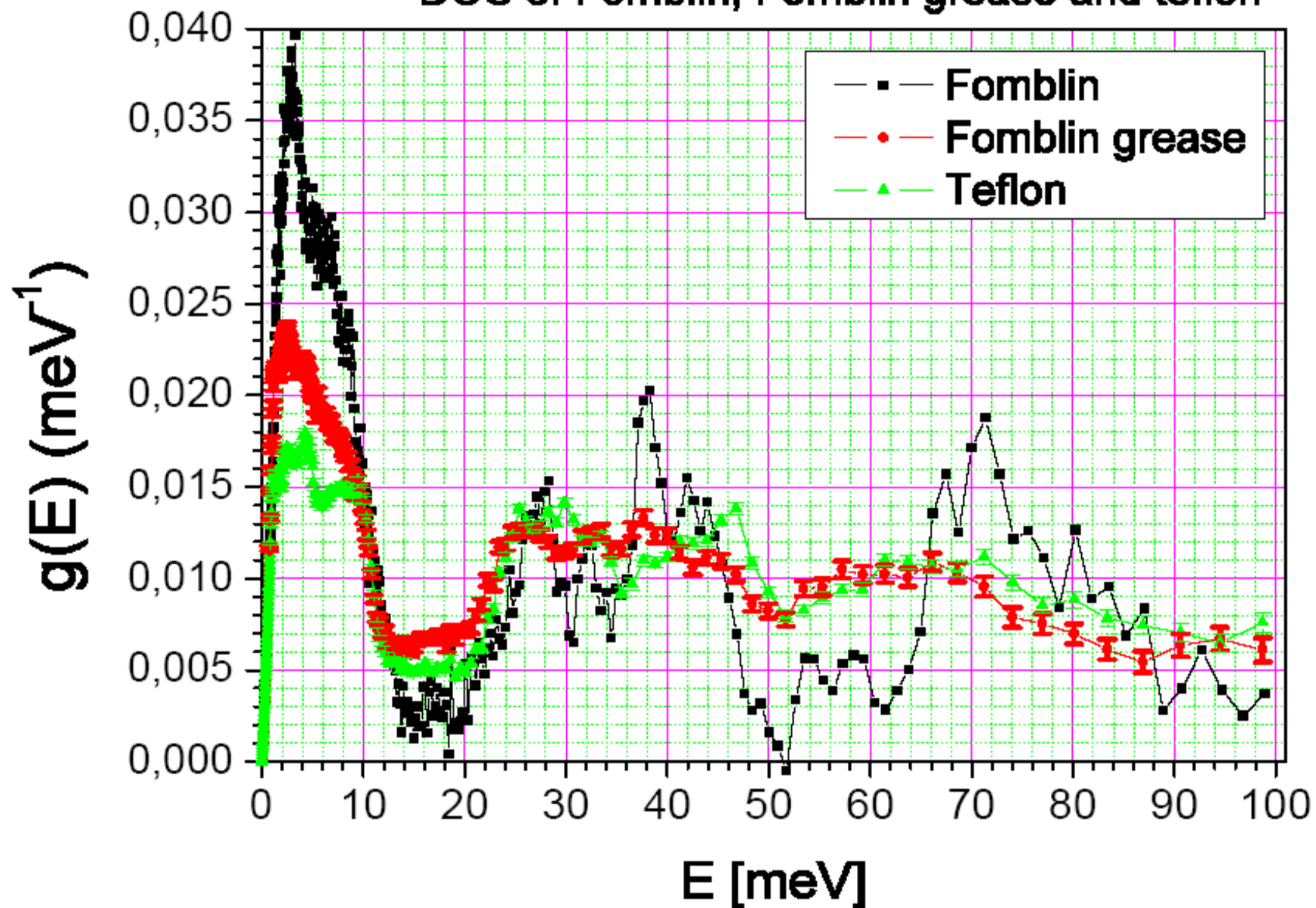


normalized (in 0-100 meV interval) DOS of Fomblin grease

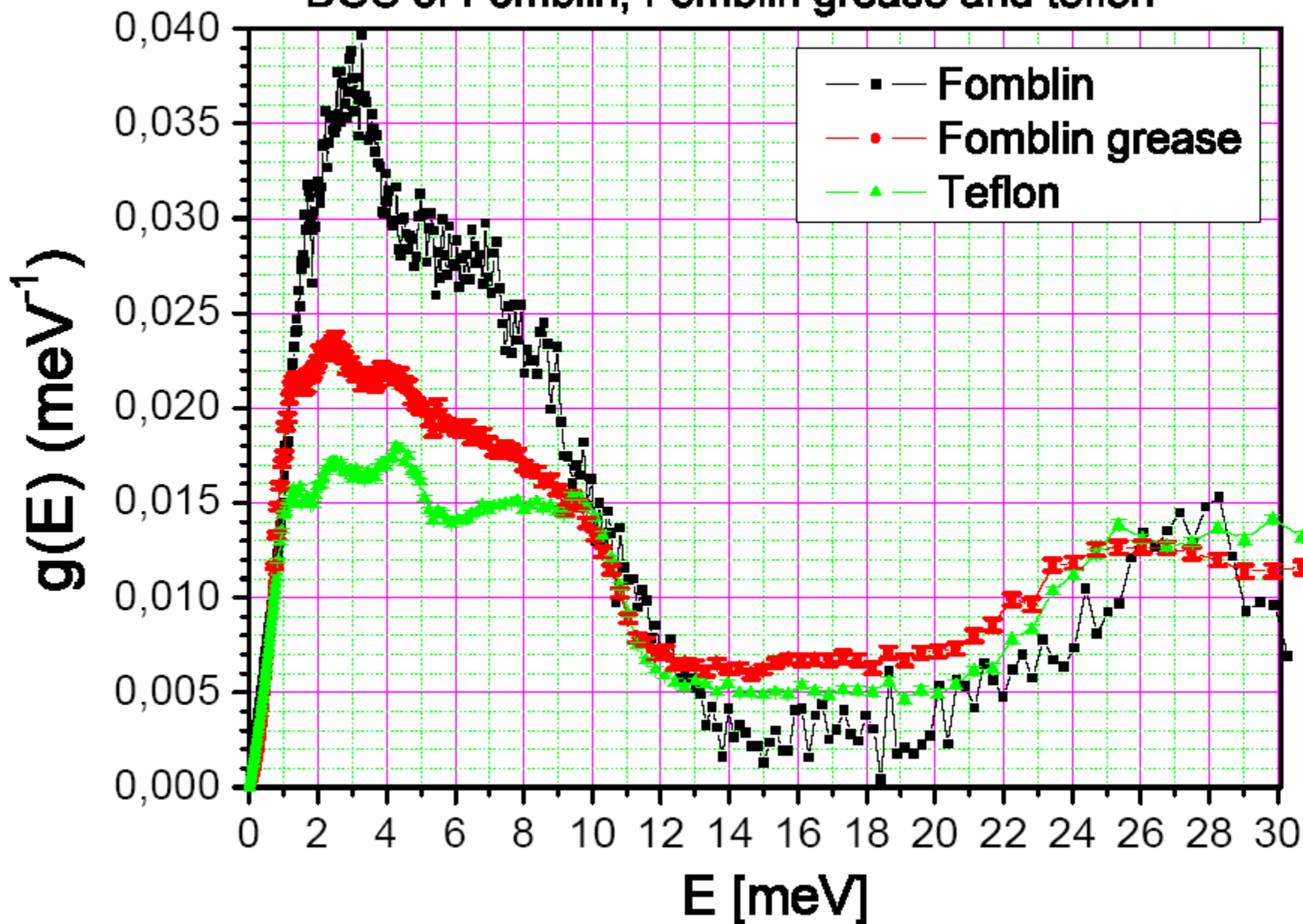




normalized (in 0-100 meV interval)  
DOS of Fomblin, Fomblin grease and teflon



normalized (in 0-100 meV interval)  
DOS of Fomblin, Fomblin grease and teflon



The loss probability (averaged over isotropic angular distribution) of neutrons with energy  $E$  in a trap with boundary energy  $U$  is:

$$\bar{\mu}(E) = 2\eta \left[ \frac{V}{E} \arcsin \left( \sqrt{\frac{E}{V}} \right) - \sqrt{\frac{V-E}{E}} \right].$$

The loss coefficient is expressed through the complex potential  $U$ , describing UCN interaction with the walls

$$\eta = -\operatorname{Im} U / \operatorname{Re} U; \quad U = (\hbar^2/2m)4\pi \sum N_i b_i; \quad \operatorname{Im} b = -\sigma/2\lambda,$$

where  $m$  is the neutron mass,  $N_i$  is the number of nuclei in a unit volume of a wall material,  $b_i$  is the coherent scattering length on a bound nucleus of the wall, and  $\sigma$  is the cross-section of inelastic processes for neutrons with wavelength  $\lambda$ .

The UCN upscattering cross sections were calculated in the one-phonon incoherent approximation:

$$\frac{d\sigma}{d\epsilon} = \sigma_0 \frac{k_1}{k_0} (1 - e^{-\epsilon/kT})^{-1} \frac{g(\epsilon)}{\mu} e^{-\gamma\epsilon},$$

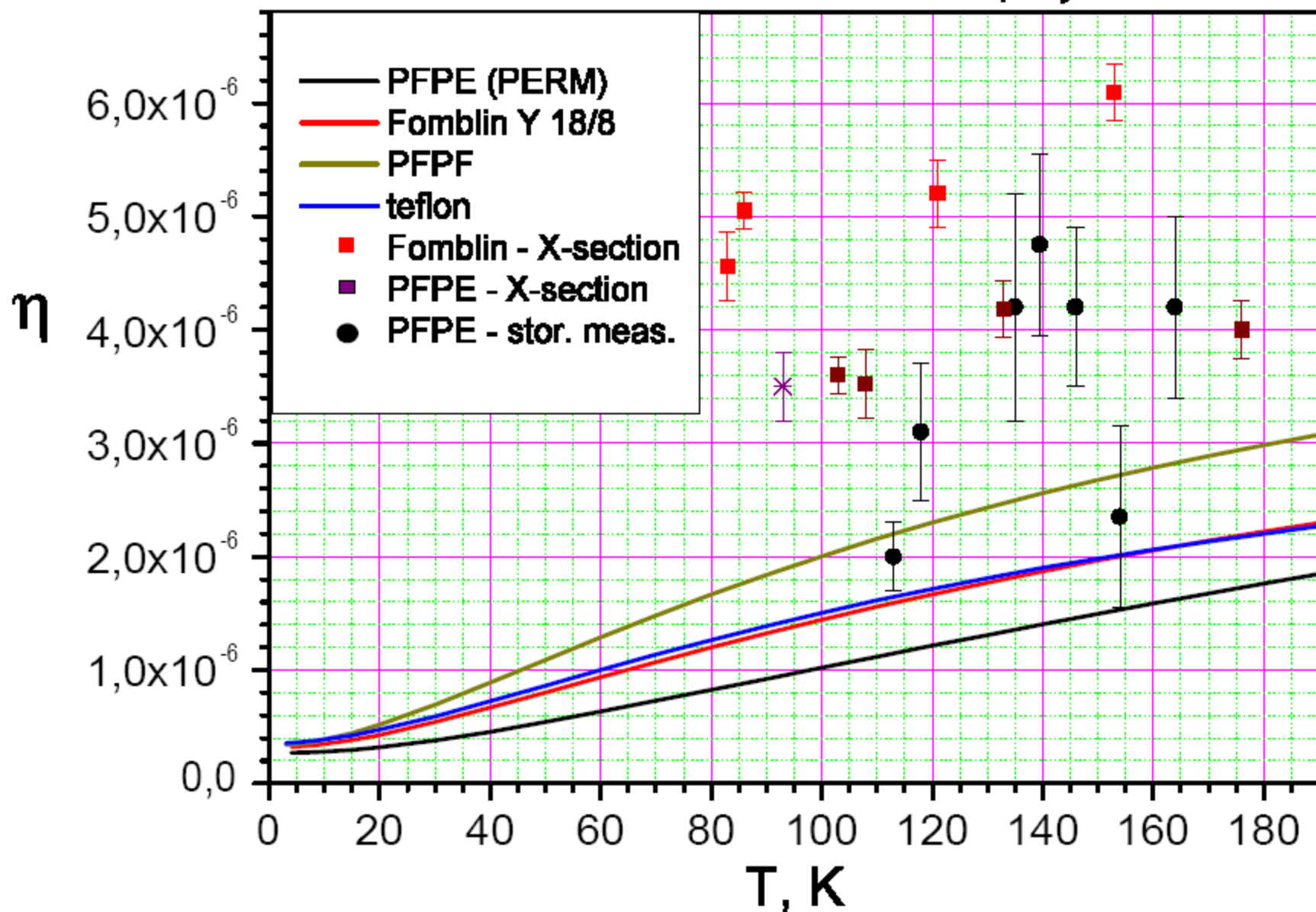
where  $\sigma_0 = 4\pi|b|^2$ ;  $b$  is the scattering amplitude for bound nuclei,  $k_1$  and  $k_0$  are the final and incident neutron wave vectors,  $\omega$  is the energy transfer,  $g(\omega)$  – the phonon density of states,  $\mu$  is the relative atomic mass,  $\gamma$  is the Debye-Waller factor:

$$\gamma = \frac{1}{\mu} \int_0^{\epsilon_D} \frac{g(t)}{t} \coth\left(\frac{t}{2kT}\right) dt.$$

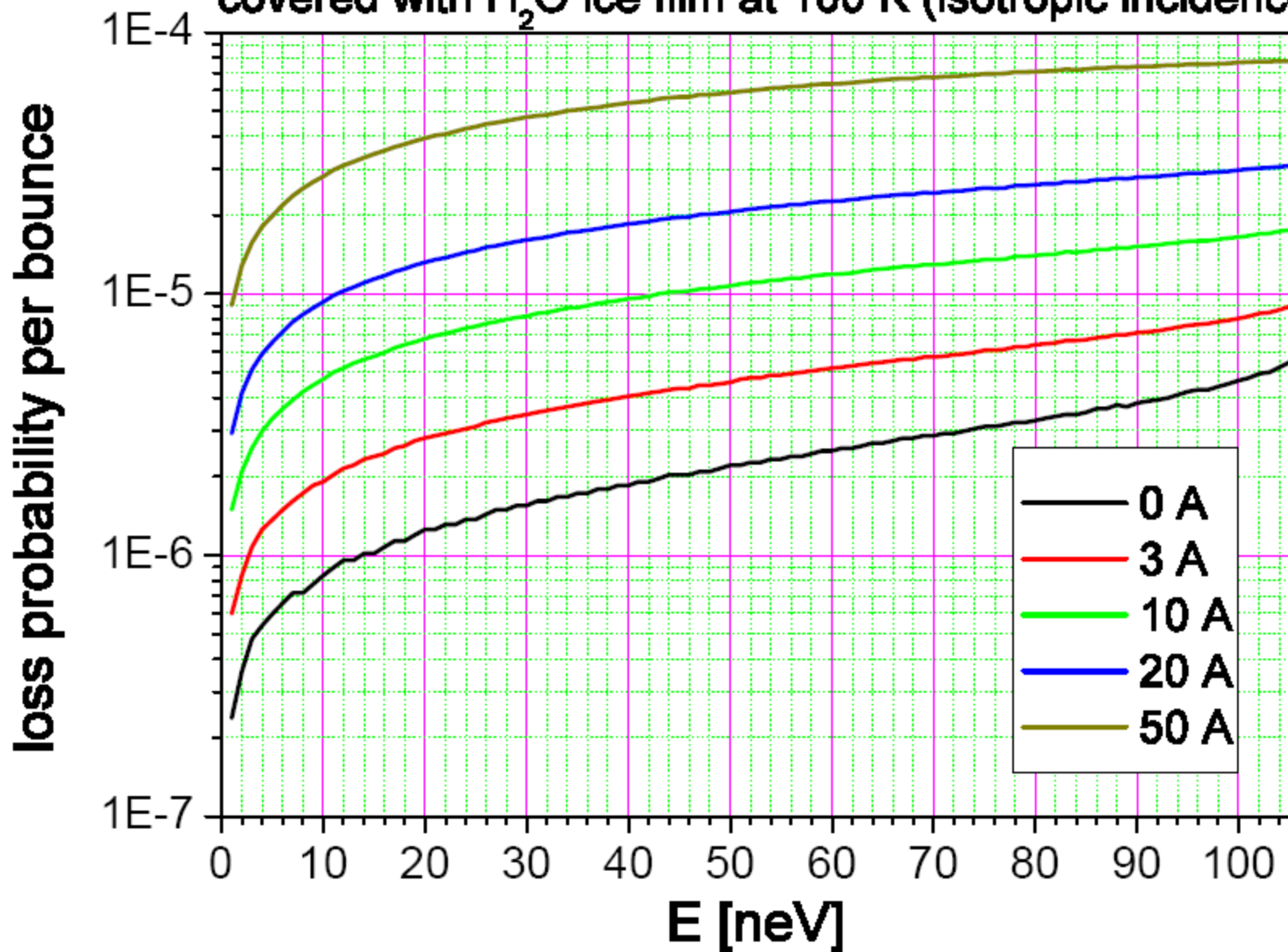
When  $k_1 \gg k_0$ , the up-scattering cross section is:

$$\sigma_{ups} = 4\pi \int \sum \frac{b_i^2 \epsilon^{1/2} e^{-\gamma\epsilon} g_i(\epsilon)}{\mu_i (e^{\epsilon/kT} - 1)} d\epsilon$$

# Calculated (lines) and inferred from measurements (points) UCN loss coefficient for different fluoropolymers

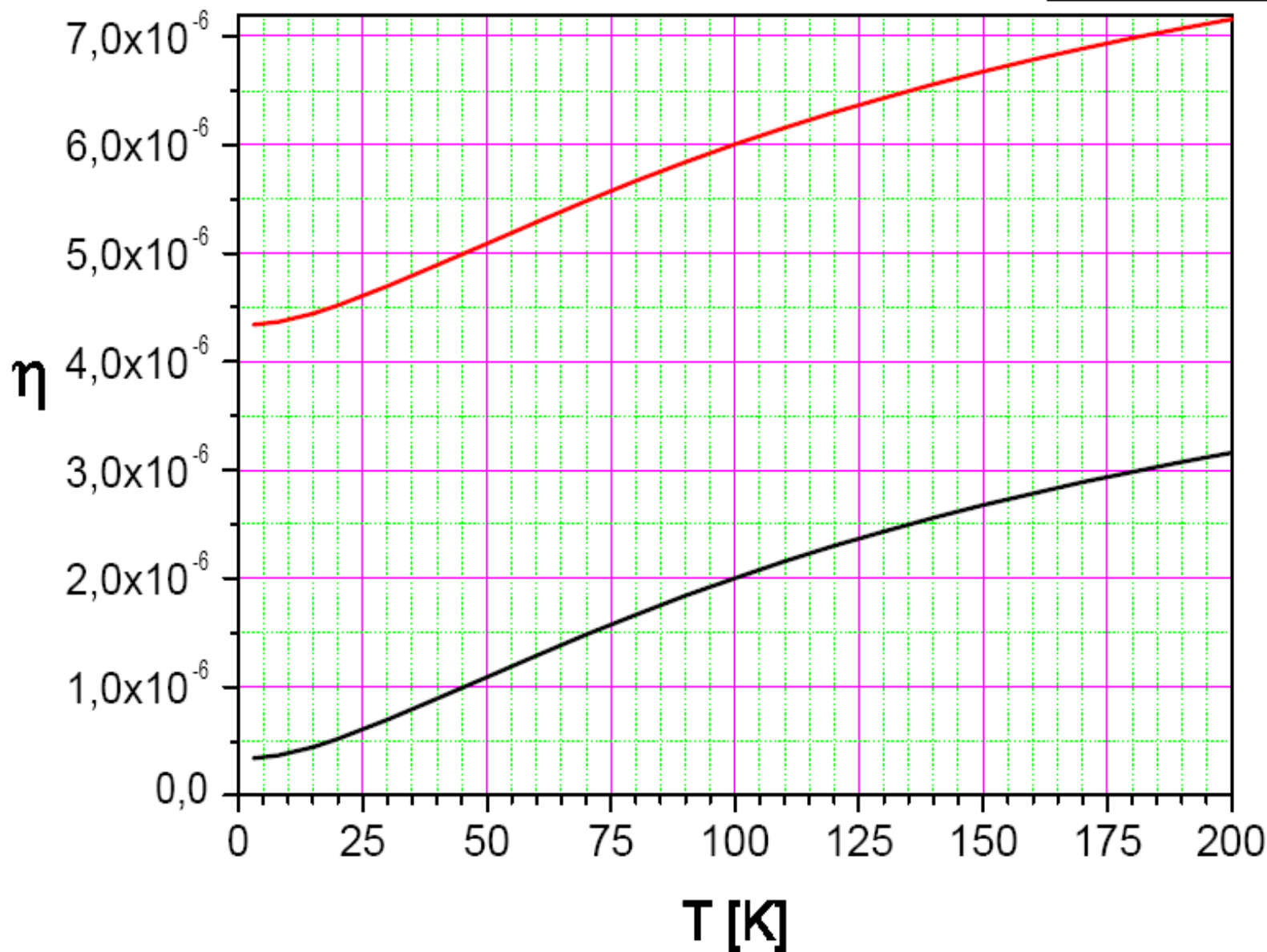


UCN loss probability at reflection from PFPE wall ( $\eta=2 \cdot 10^{-6}$ )  
covered with H<sub>2</sub>O ice film at 100 K (isotropic incidence)



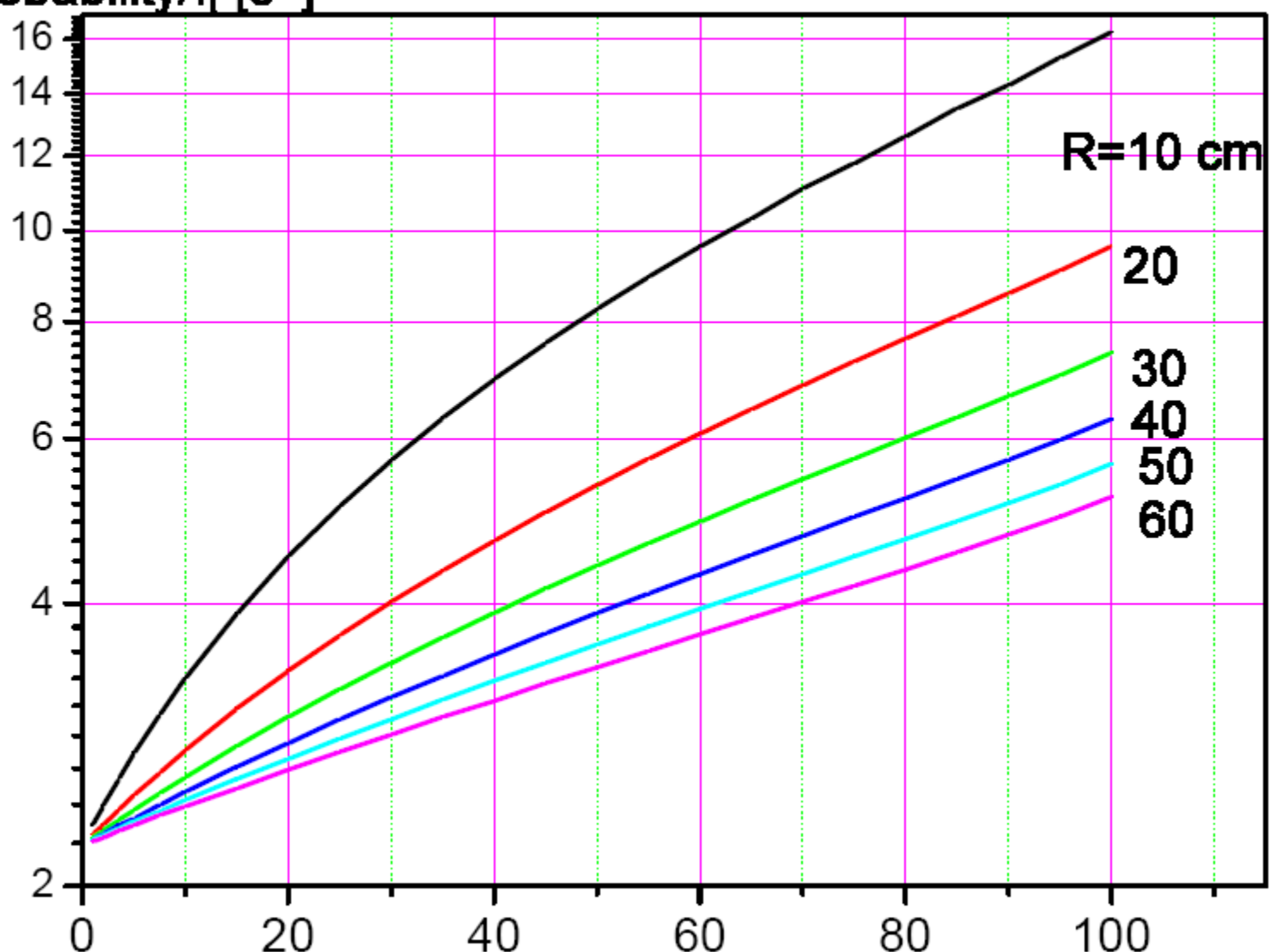
Effect of  $2.5 \times 10^{-3}$  Cl contamination in PFPF

— pure substance  
— contaminated



# vertical cylinder, spectrum $N(E) \sim E^{1/2}$

loss probability/ $\eta$  [ $s^{-1}$ ]



max. neutron energy at the bottom, neV



$$\tau_{\mu} = (2.1969811 \pm 0.0000022)\mu s \quad (10^{-6})$$

$$\tau_{\pi^{\pm}} = (2.6033 \pm 0.0005) \times 10^{-8} s \quad (2 \times 10^{-4})$$

$$\tau_{\tau} = (290.3 \pm 0.5) \times 10^{-15} s \quad (1.7 \times 10^{-3})$$

$$\tau_n = (880.3 \pm 1.1) s \quad (1.25 \times 10^{-3})$$