Influence of a PF-1000 vessel on the energy distribution of DD-fusion neutrons

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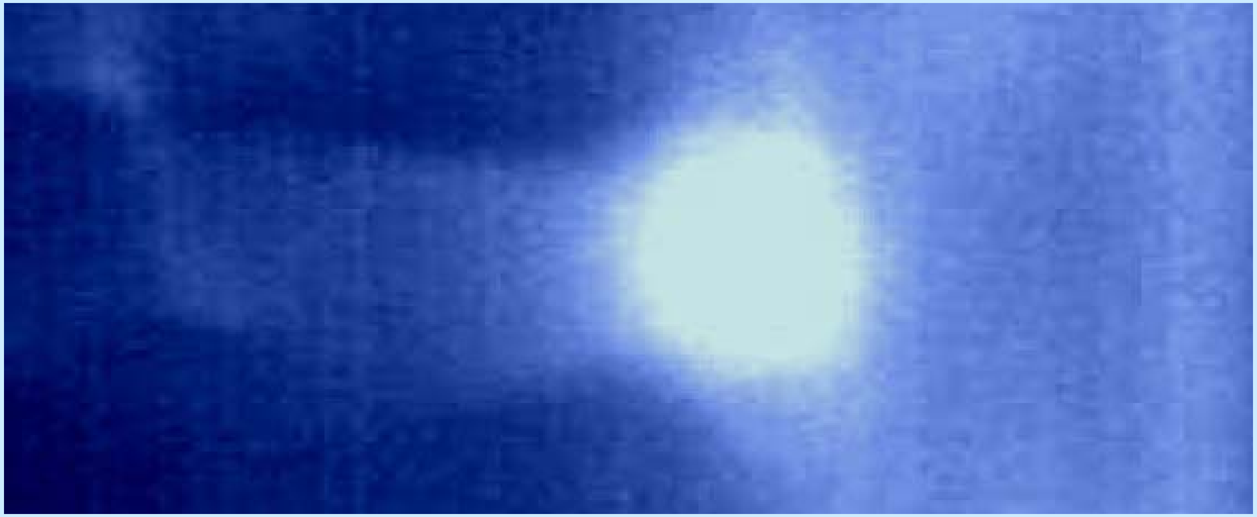
Emission of DD-neutrons from the PF-1000 device was measured with the use of

time-integrated detection systems

employing e.g. thermoluminescent (TLD) detectors

time-resolved detection systems

consisting of scintilators and PMP

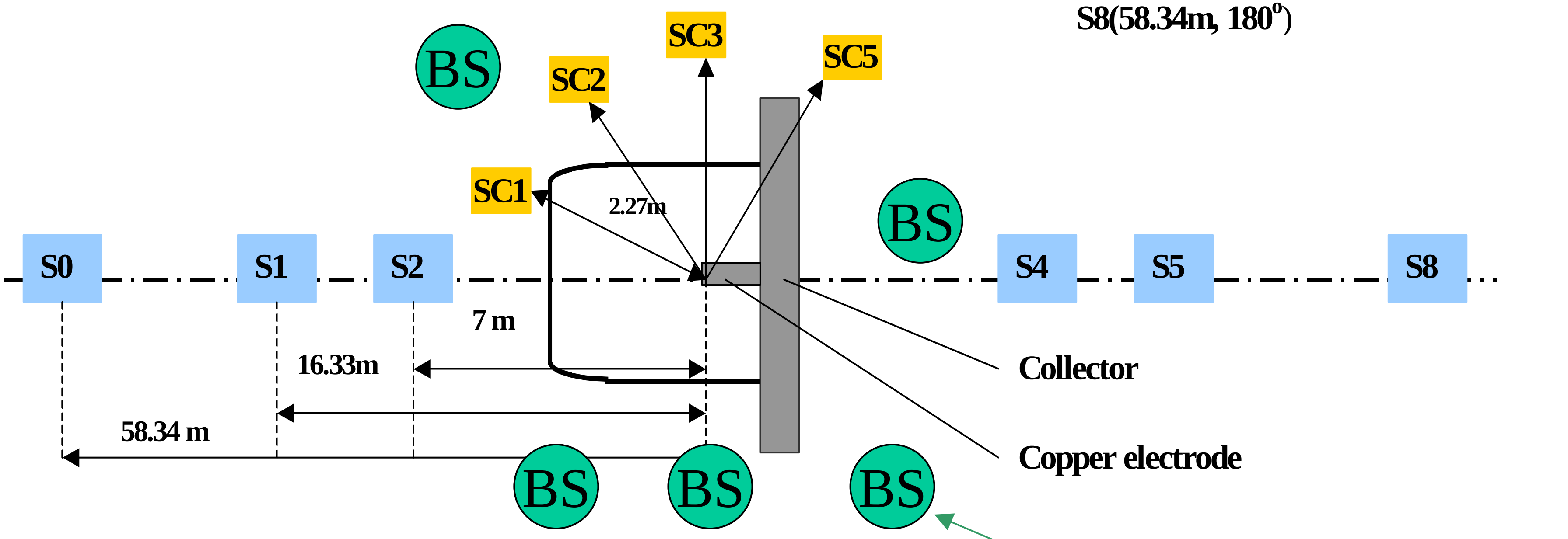


$$d + d \rightarrow n + He^3 + 3.27MeV$$

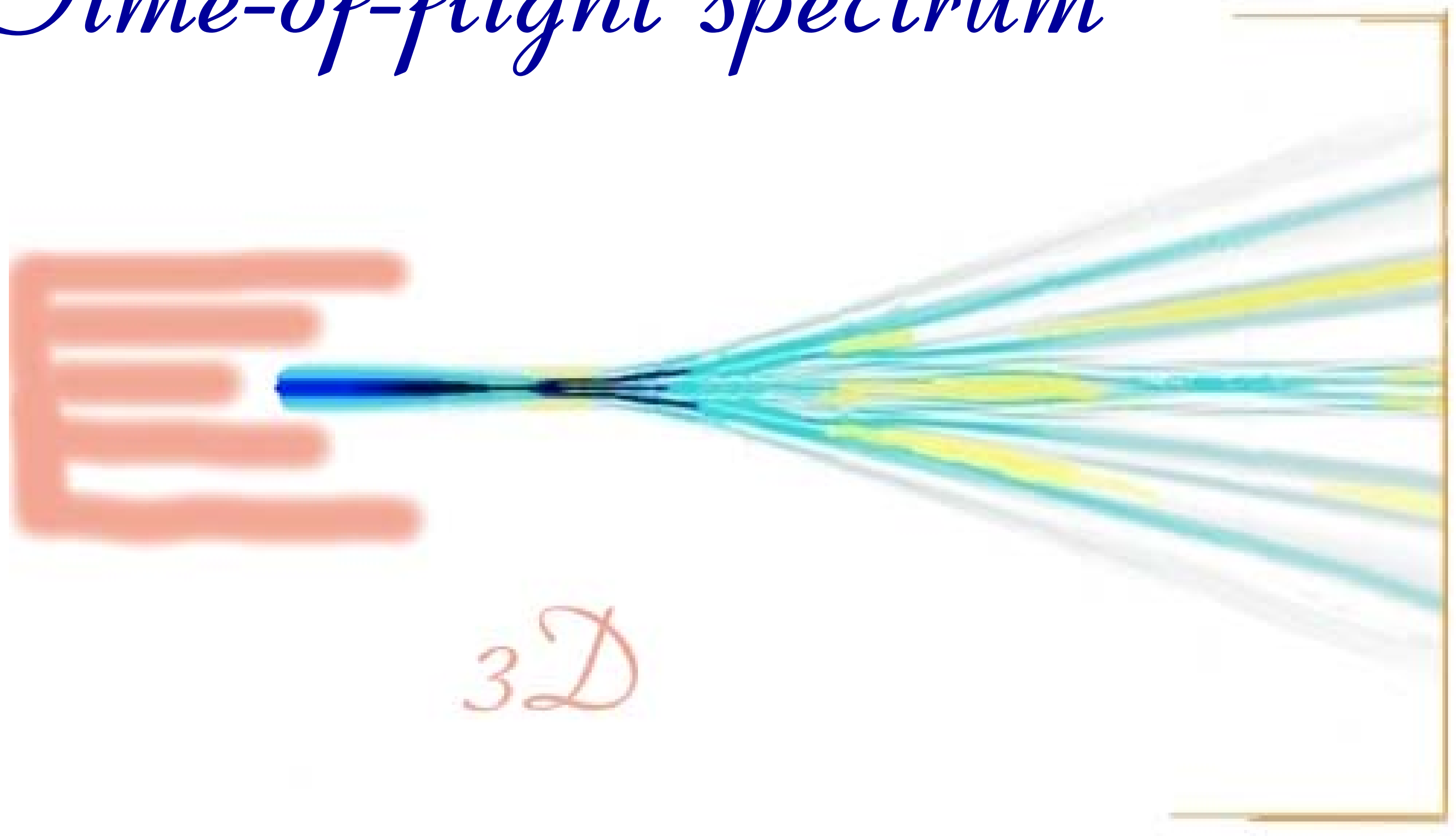
$$d + d \rightarrow p + H^3 + 4.03MeV$$

Activation silver counters:
SC1(30^o), SC2(60^o), SC3(90^o), SC5(150^o)

Scintillator PMP detectors:
S0(58.34m, 0^o), S1(16.33m, 0^o), S2(7m, 0^o), S4(7m, 180^o), S5(17m, 180^o), S8(58.34m, 180^o)



Time-of-flight spectrum



A simplest formula used for the neutron velocity distribution can be derived for one-dimensional experimental configuration:

$$\left|\frac{dn}{dv}\right| = \frac{dn}{dt}\left|\frac{dt}{dv}\right| = \eta(t)\frac{t^2}{L} \approx S(L,t)\frac{t^2}{L}$$

where η is the neutron flux and $S(L,t)$ is the scintillator PMP detector’s signal measured by an oscilloscope at a distance L from the electrode outlet.

Transition from 1D to 3D space

Substituting $$n(L_0, t_0) \times (t_0 / t)^3 = n(L, t)$$

in $$\eta(L,t) = \frac{L}{t^2} \left| \frac{dn}{dv} \right|$$

we obtain $$\eta(L,t) \propto \frac{L\, t_0^3}{t^5} \left| \frac{dn}{dv} \right|_{t_0}$$

The procedure for deducing the exact expression for the TOF signal induced by a **flux of neutrons**

$$d\eta = d\vec{v} \times v_x dn$$

with the velocity distribution function $f(\vec{v})$

$$\eta(t) \propto v_x f(\vec{v})\, d\vec{v} \propto \frac{L^2}{t^5} f\left(\frac{L}{t}\right)$$

which was done by Kelly et al. for ions emitted by a laser-produced plasma.

Kelly & Dreyfus model of TOF spectrum

R. Kelly, R.W. Dreyfus, Surf. Sci. **198** (1988) 263

is based on the shifted Maxwell-Boltzmann distribution:

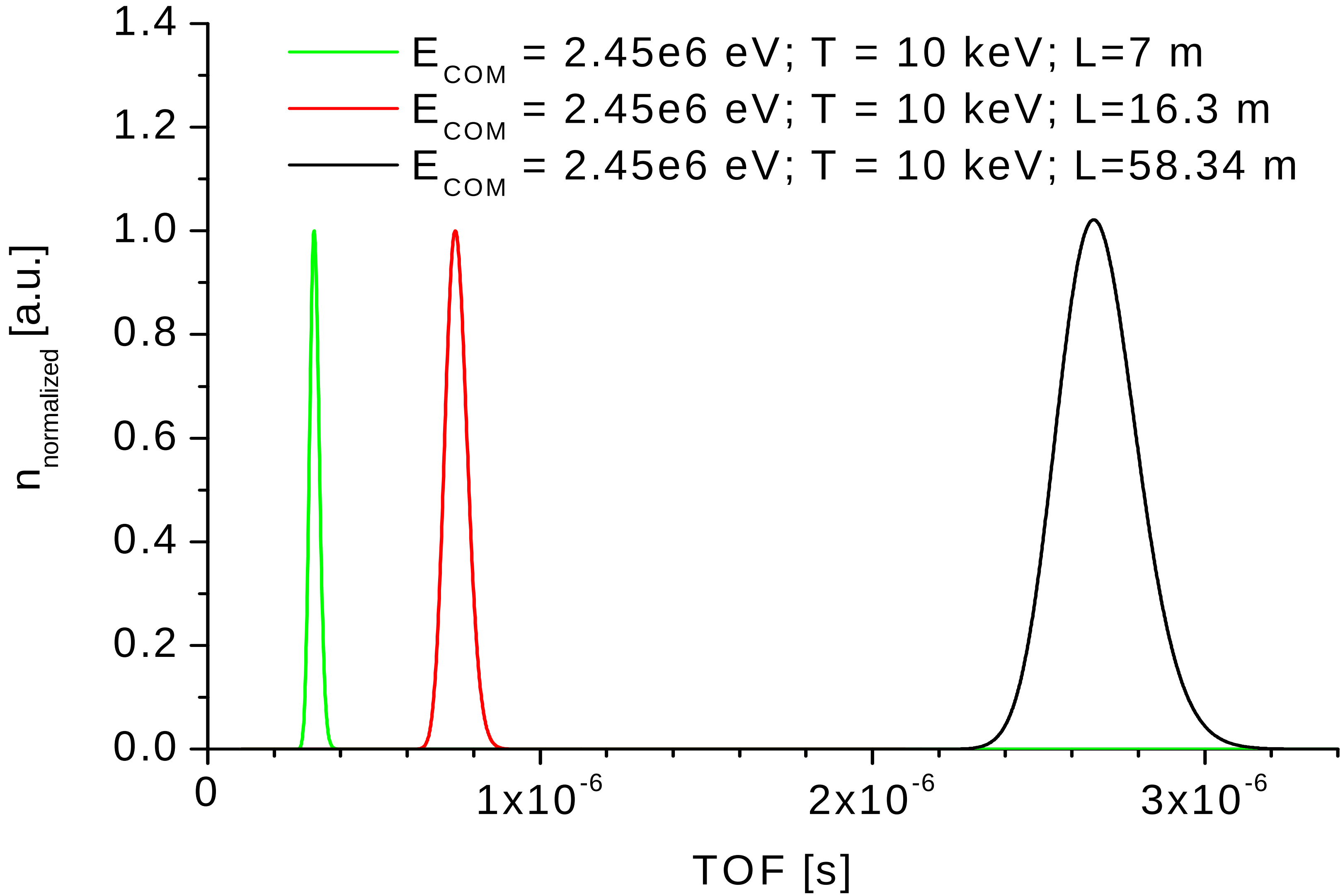
$$n(L,t) \propto L t^{-4} \exp[-\beta^2 (L/t - u_{COM})^2]$$

If a stream (velocity) sensitive detector is used:

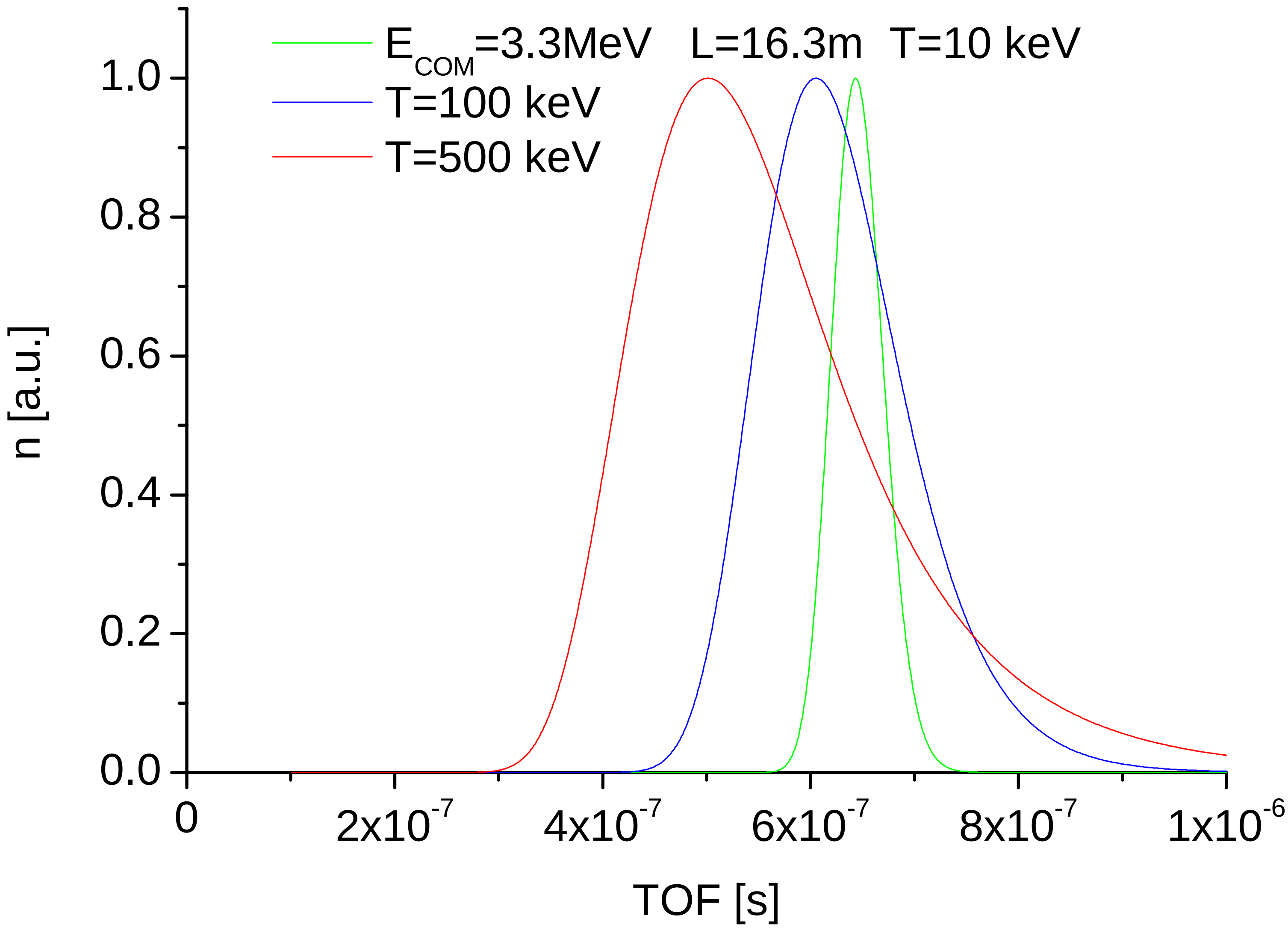
$$\eta(L,t) \propto L^2 t^{-5} \exp[-\beta^2 (L/t - u_{COM})^2]$$

The condition for an application is: emission time << TOF.

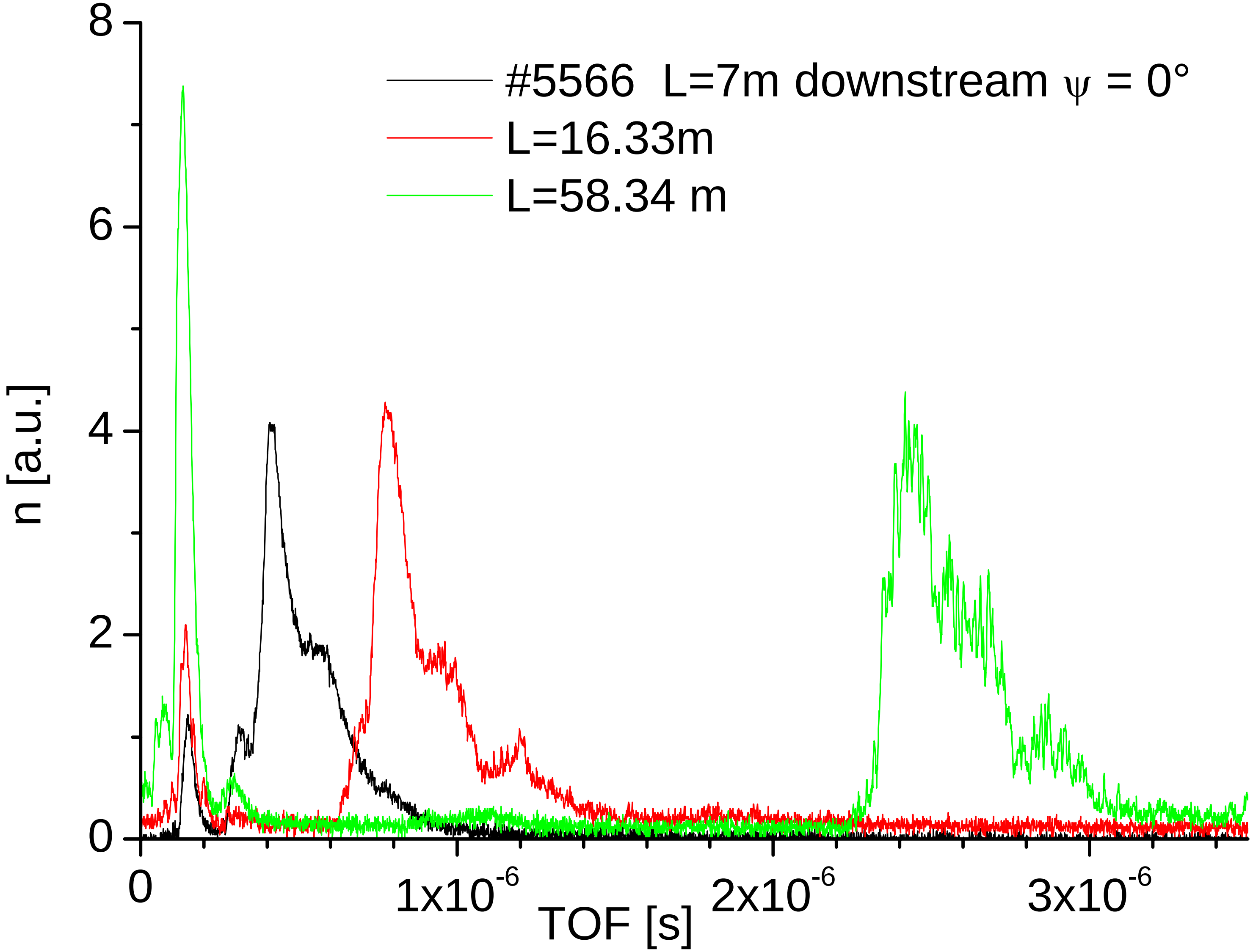
TOF spectra of particles with a shifted Maxwell-Boltzmann velocity distribution



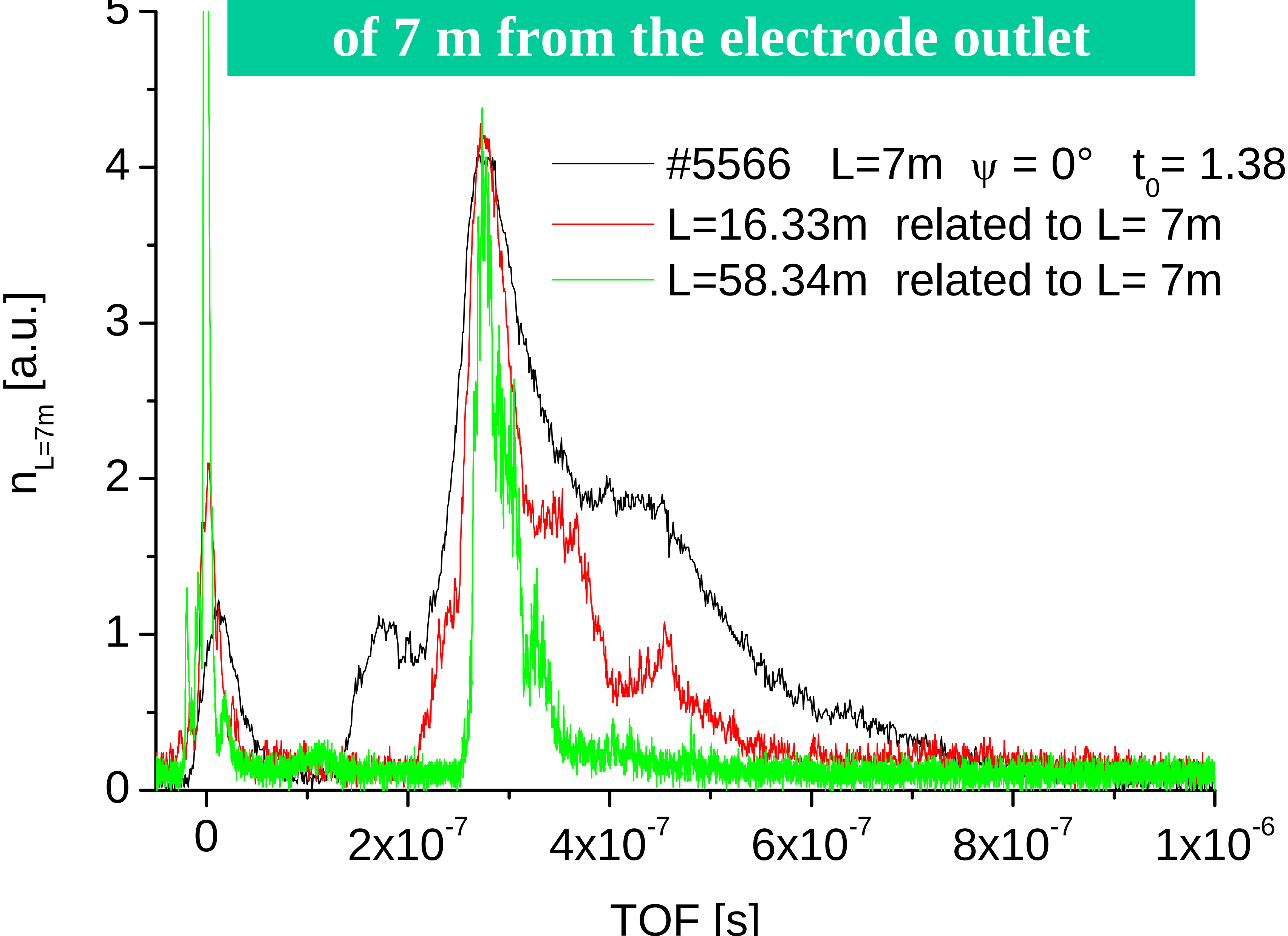
The effect of the temperature on the TOF spectrum

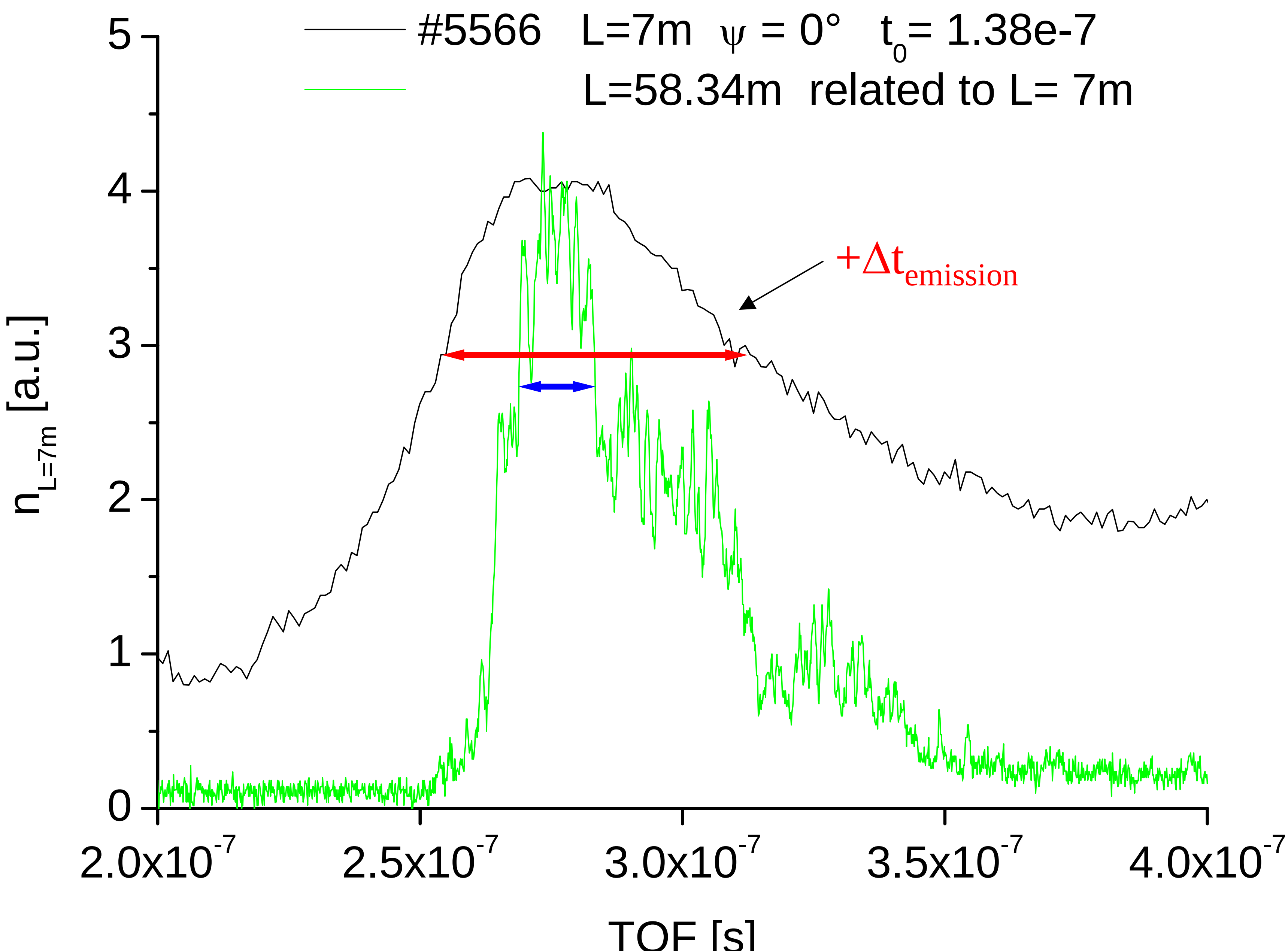


TOF spectra of neutrons measured at various distances from the electrode outlet

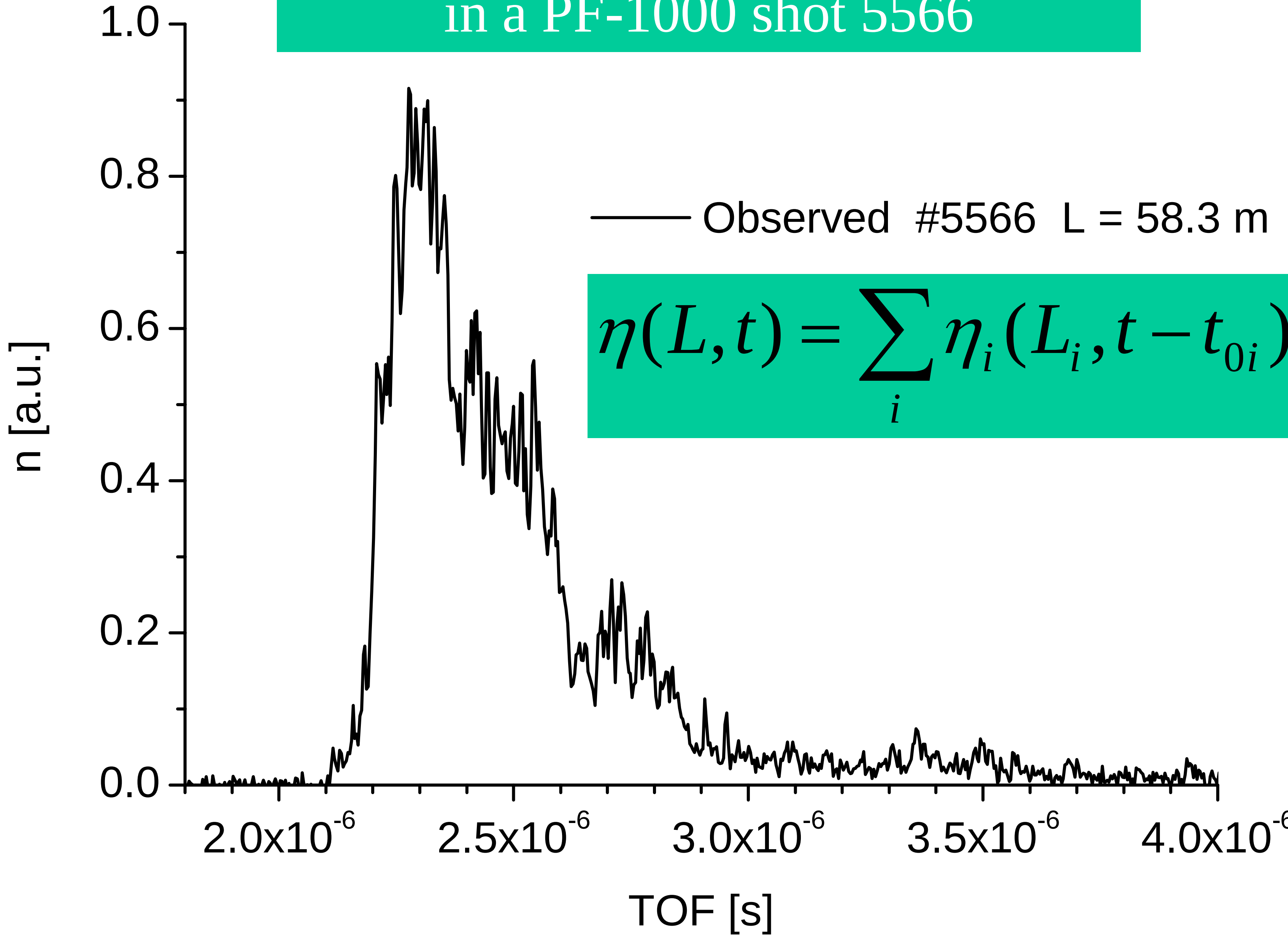


TOF spectra transformed to a distance of 7 m from the electrode outlet

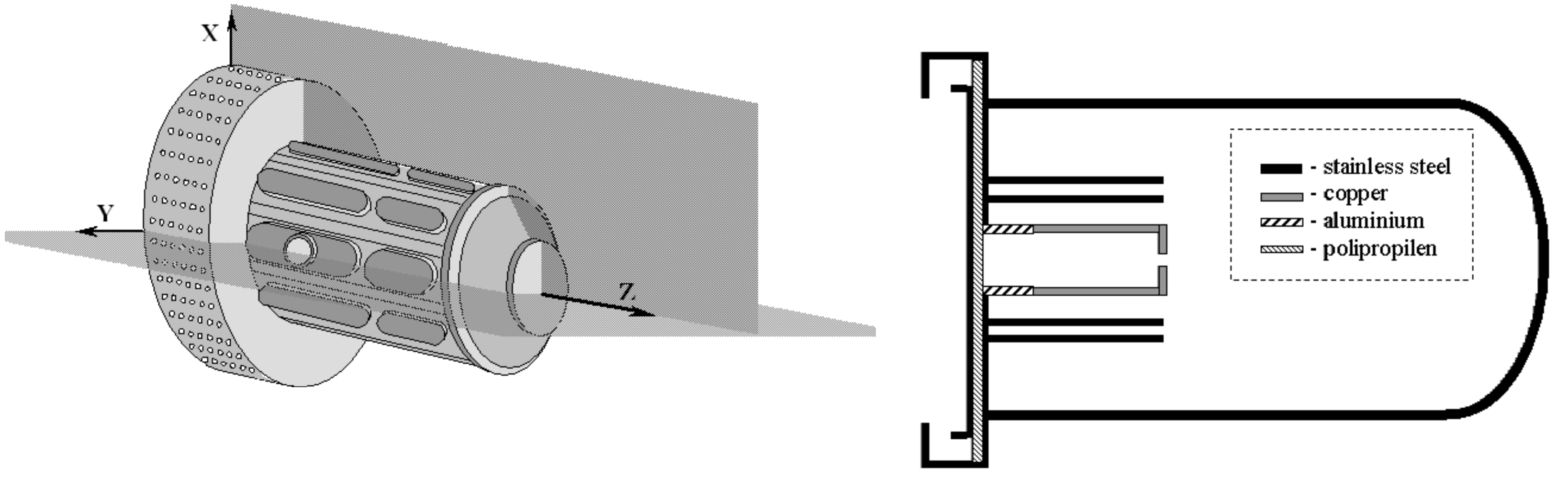



#5566 L=7m ψ = 0° t0= 1.38e-7
L=58.34m related to L= 7m
+Δtemission
5
4
3
2
1
0
nL=7m [a.u.]
2.0x10-7
2.5x10-7
3.0x10-7
3.5x10-7
4.0x10-7
TOF [s]

TOF spectrum of neutrons observed in a PF-1000 shot 5566



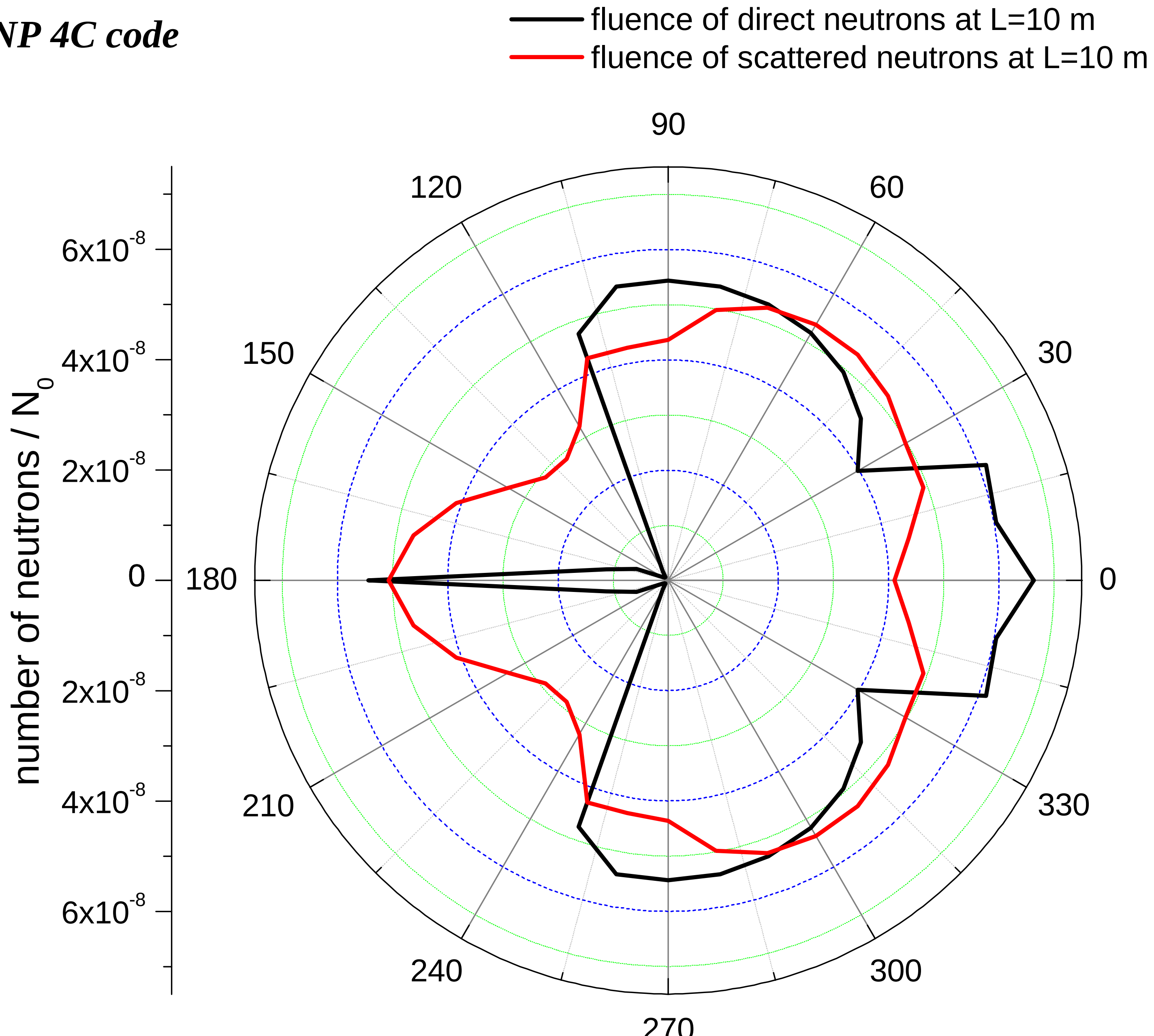
$$\eta(L,t) = \sum_i \eta_i(L_i, t - t_{0i})$$



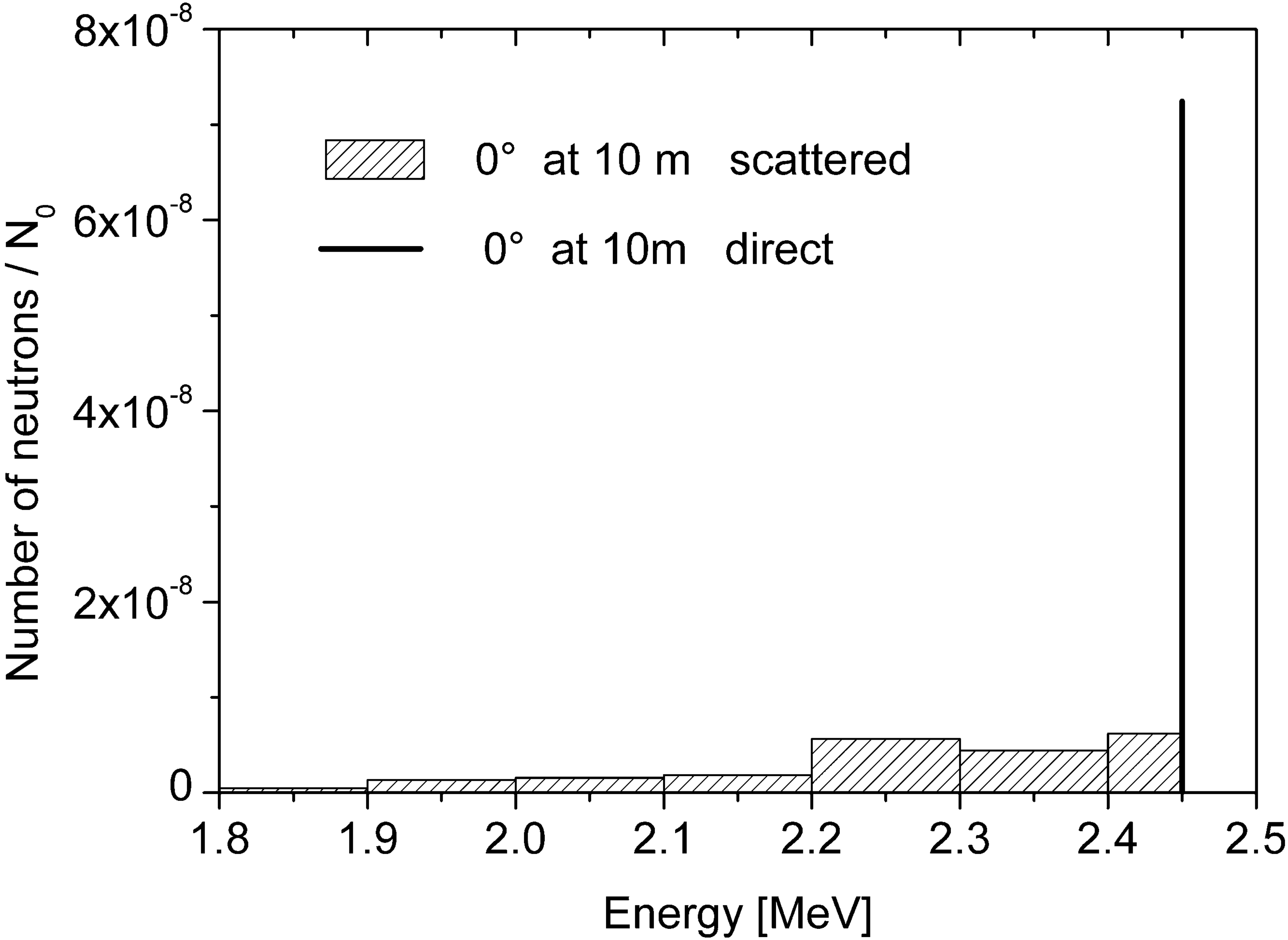
Schema of the discharge chamber: (a) positions of planes at which neutrons were measured, (b) simplified geometry of the chamber for computing the neutron scattering.

Calculated angular distribution of neutron emission by the PF-1000

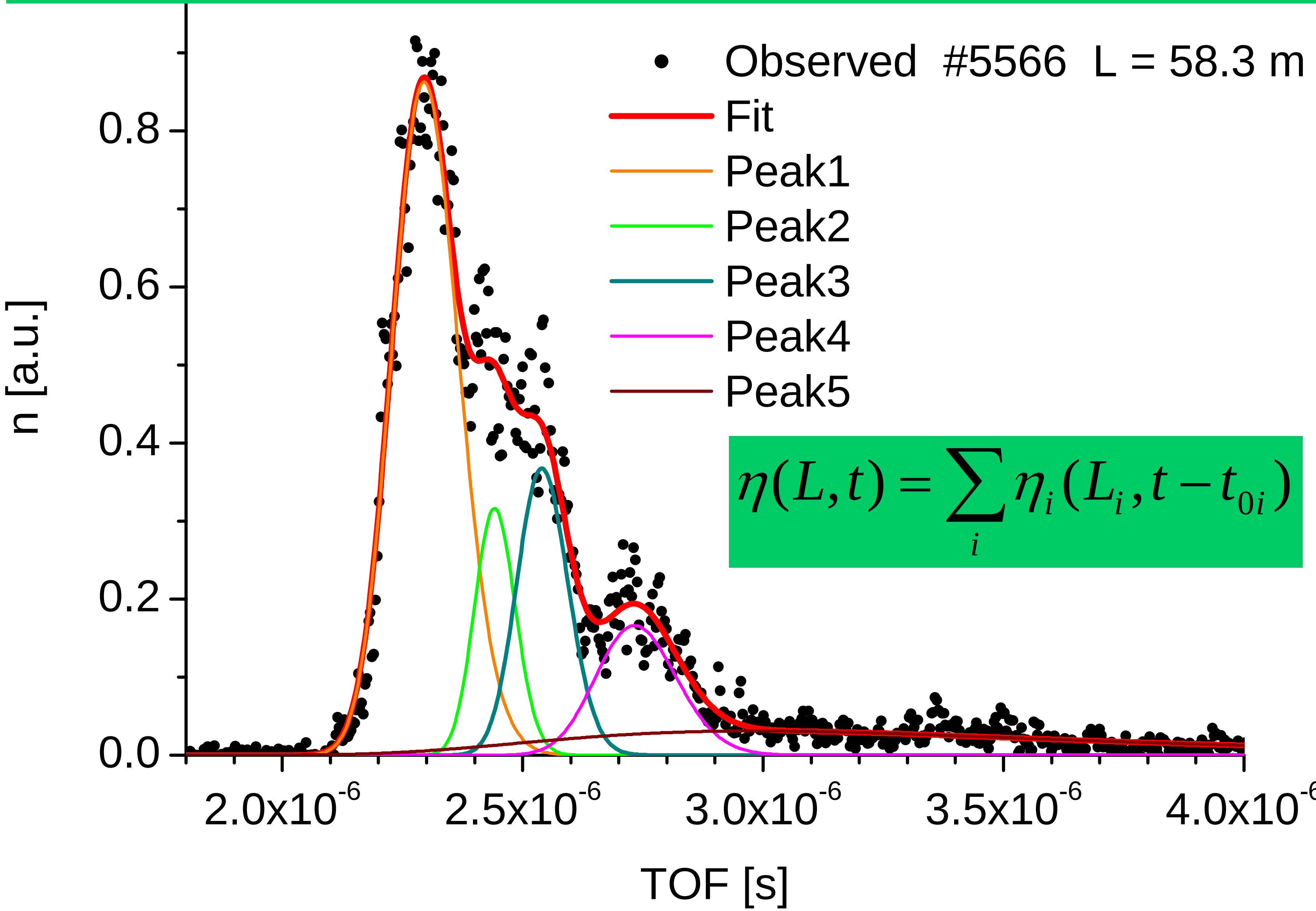
MCNP 4C code



Group spectrum of DD-neutrons emitted from the PF-1000 vessel



Deconvolution of a TOF spectrum of neutrons observed in a PF-1000 shot 5566



$$\eta(L,t) = \sum_i \eta_i(L_i, t - t_{0i})$$

Values of parameters of peaks fitted to TOF spectrum of neutrons

File Source: d58msh5566.dat

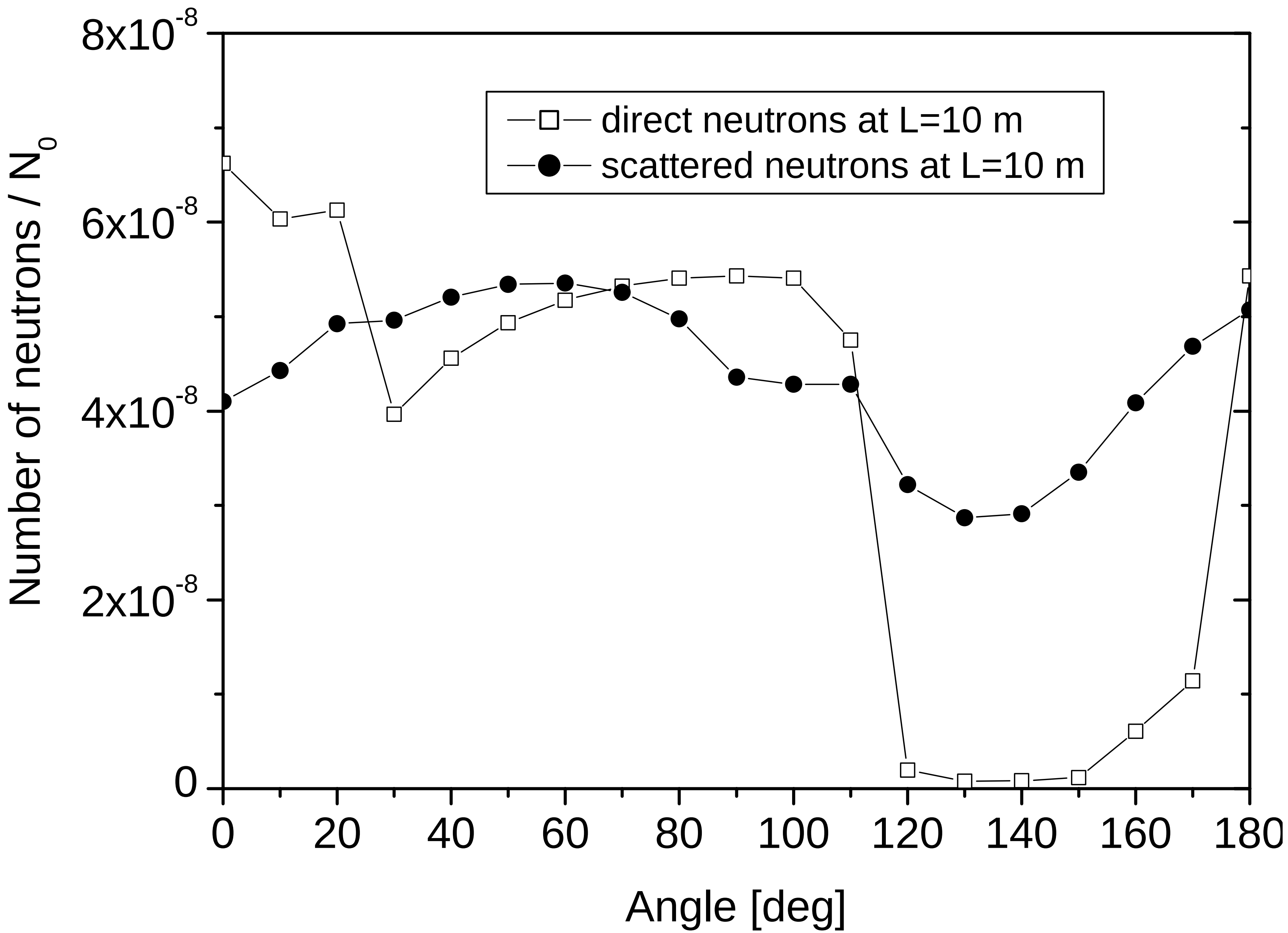
r^2 Coef Det	Fit Std Err	F-value
0.97755072	0.02754198	2373.19518

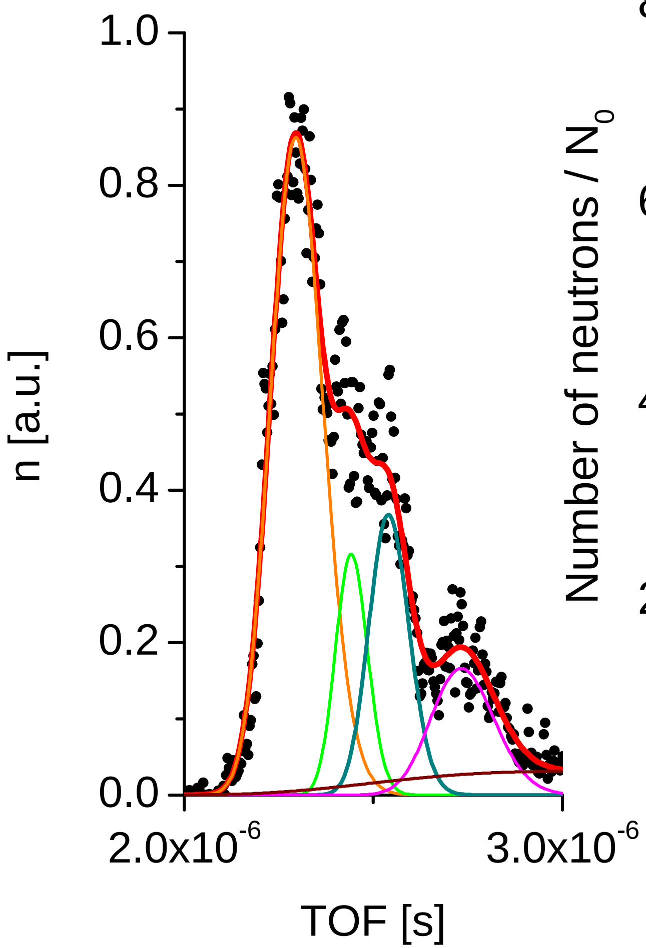
Fitted Parameters

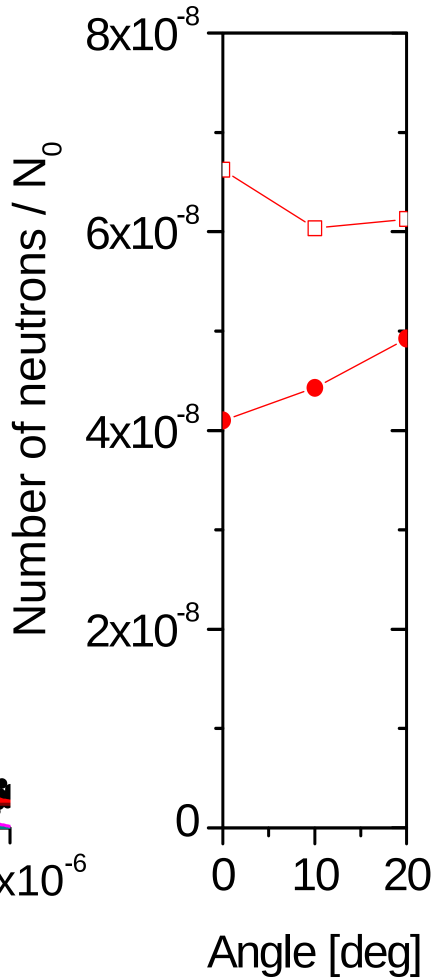
Peak	a0	T [eV]	COM-E	t0 [s]	Int Area [%]	
1	0.86	6077.46	3.3 MeV	0	47.9657064	P1/(P2+P3) = 1.82
2	0.316	1768.89	2.9	0	10.7273891	P2+P3 = 26.3
3	0.368	2497.34	2.8	3.02E-08	15.6616877	
4	0.166	5147.11	2.53	1.03E-07	11.1495014	
5	0.031	772 070	1.09	8.94E-07	14.4957154	

$$\eta(L,t) \propto L^2 t^{-5} \exp[-(m/2kT)^2 (L/(t-t_0) - u_{COM})^2]$$

Calculated angular distribution of neutrons emitted by the PF-1000







n_{dir} / n_{scat}

deconvol.: 1.82

computing: 1.6

comp (0.63-2.4MeV): 1.81

$$\int_{t_{TR}}^{t_{TR}+55s} S(L,t)\,dt$$

Řádek: Spotřeba materiálu, literatura

$$\int_{T_{TRIG}}^{T_{TRIG}+5\,\mathrm{min}} S(L,t)\,dt$$

Time-integrated measurement of neutron emission

Neutron dosimetry with TLDs

- The measurement of absorbed dose is based on a reaction of thermal neutrons with **$^{6}Li(n,\alpha)^{3}H$** in **LiF dosimeters containing both the ^{6}Li and ^{7}Li isotopes**.

The cross section of this reaction is **945 barn**. The cross section of the capture reaction **$^{7}Li(n,\gamma)^{8}Li$** is only **0.036 barn**.

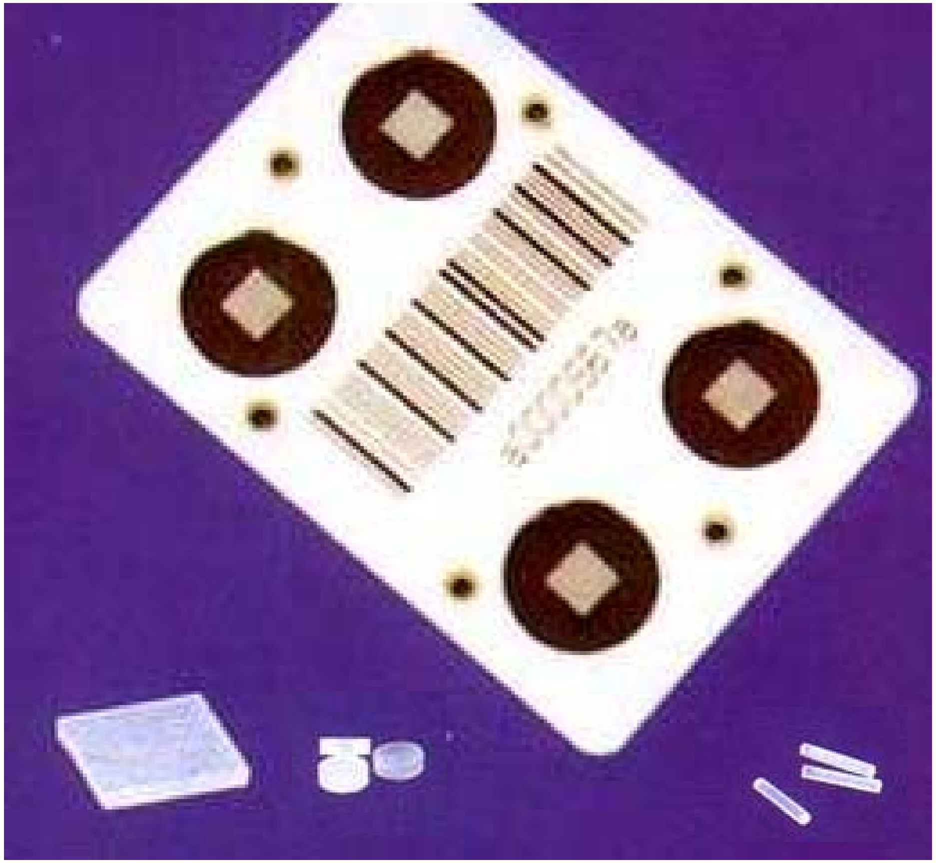
- It gives rise to the standardisation of the use of a couple of **^{6}LiF-^{7}LiF** dosimeters for dose determination in thermal neutron and gamma-ray fields for personal dosimetry.

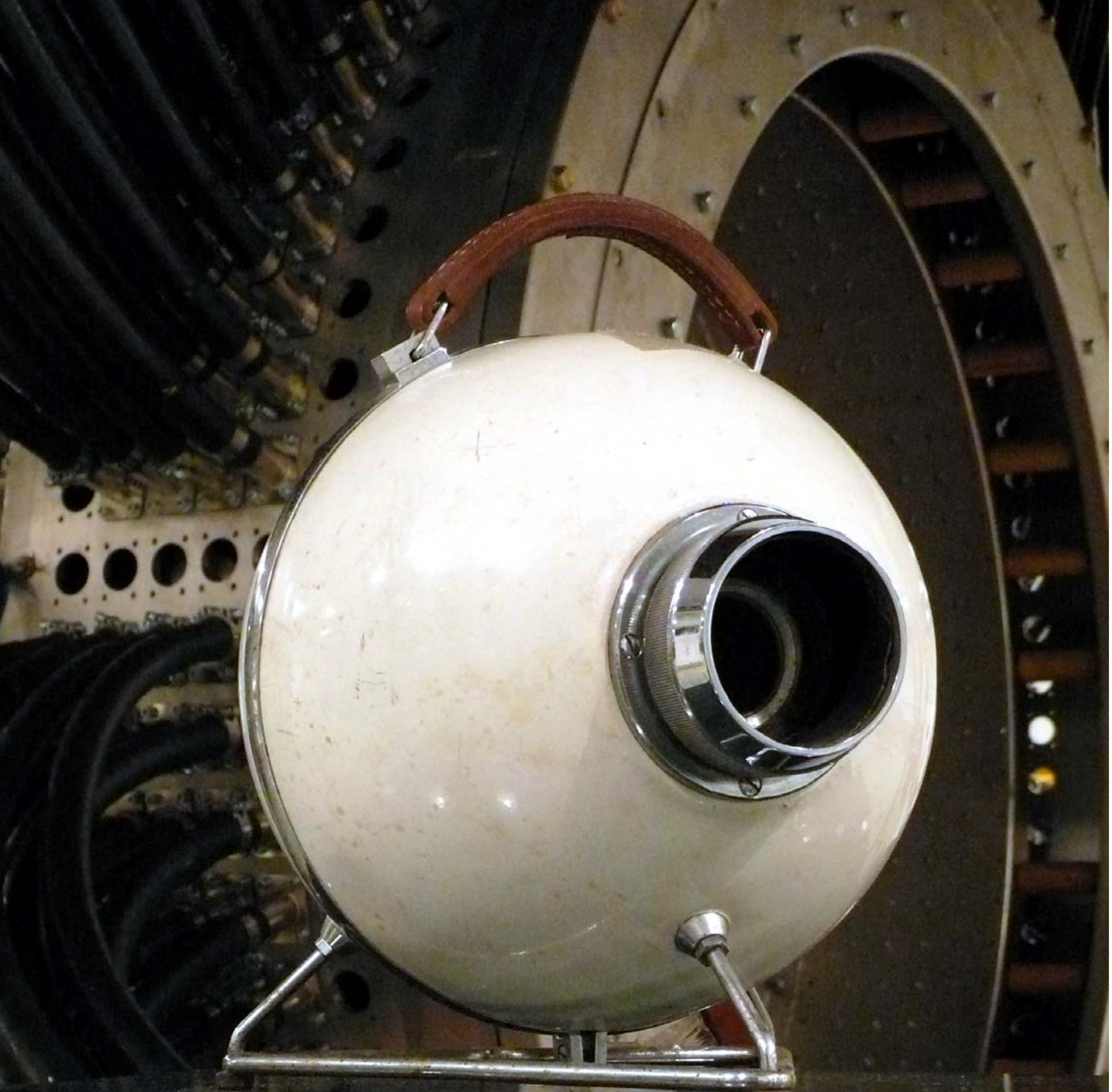
Bonner spheres for neutron moderation

$$R_{600}^{n} = R_{600}^{n+\gamma} - k\, R_{700}^{\gamma}$$

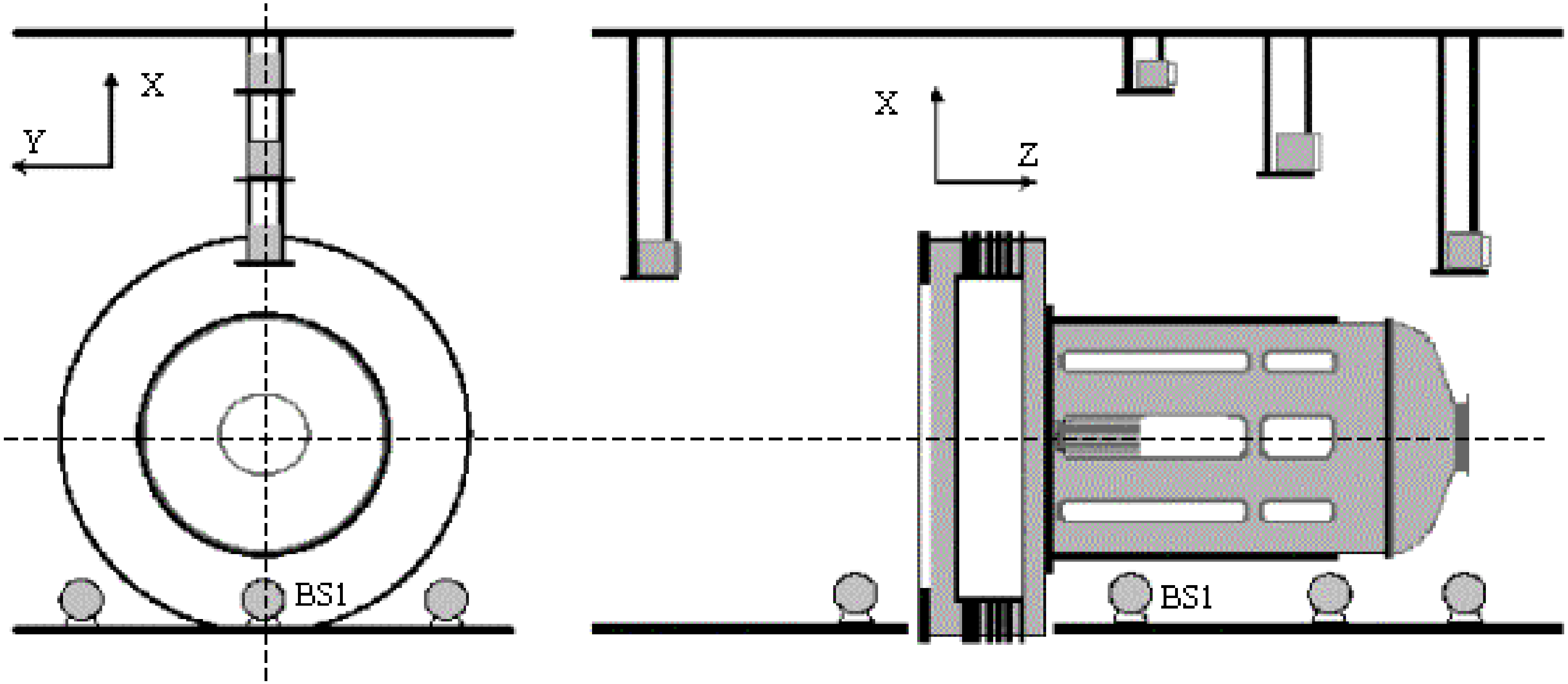
Use of thermoluminescent dosimeters

- Time integrating accurate detectors for X-, gamma, beta electron and neutron radiation according to choice of material.
- X-ray spectra of laser-produced plasma.
- personal neutron TLDs for space station.

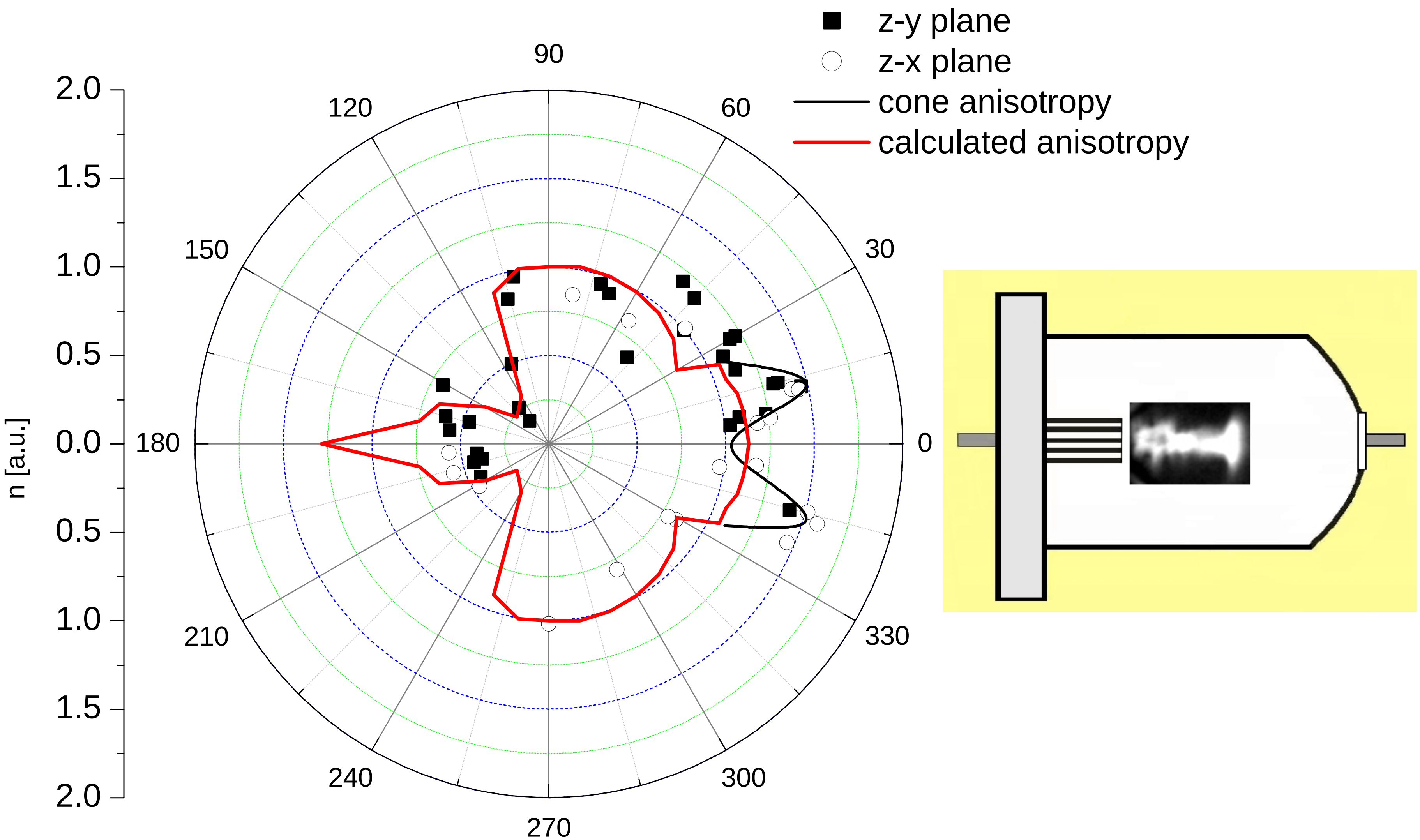




PF-1000

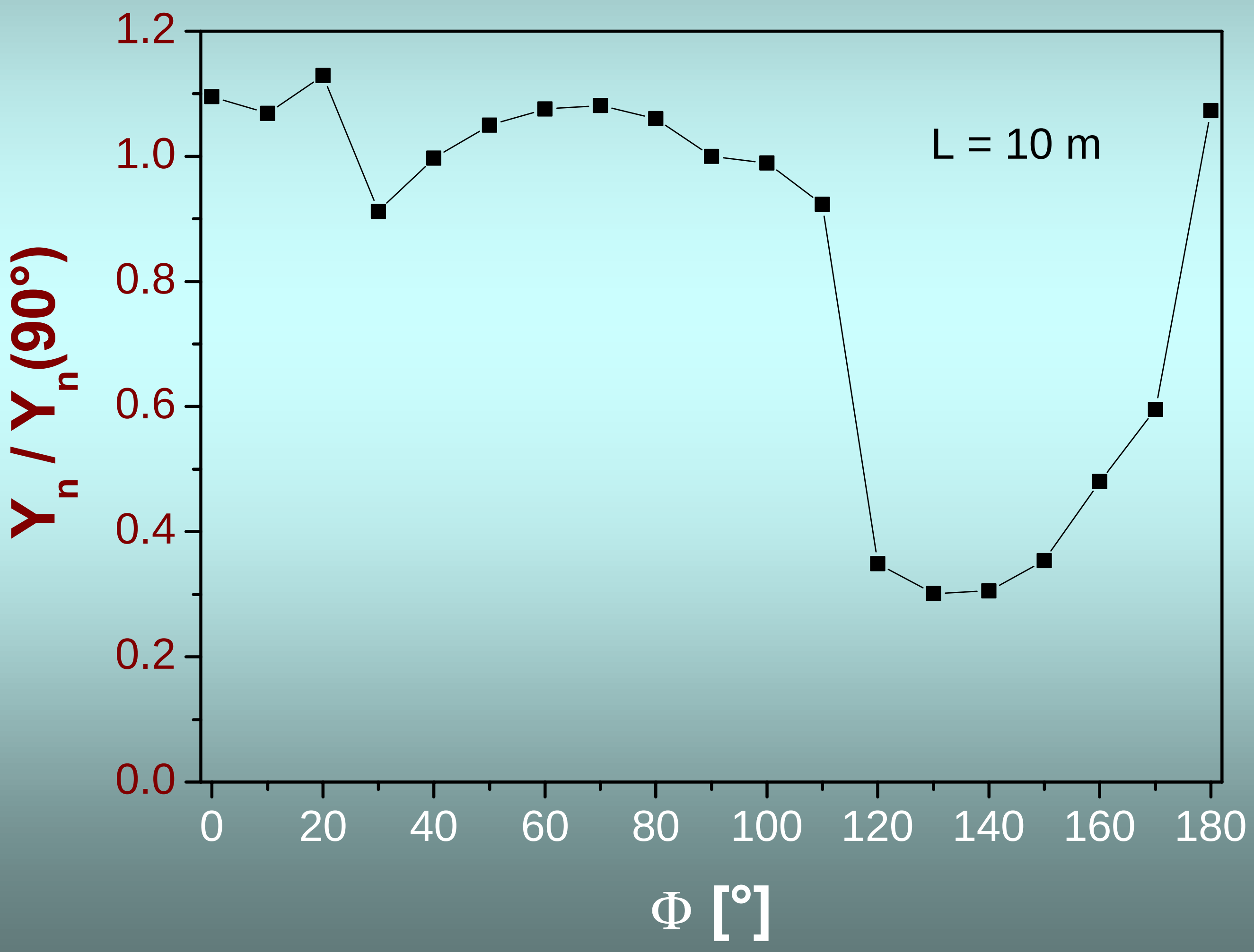


Experimental arrangement of the Bonner spheres (BS) containing dosimeters TLD 700H and TLD 600H. The reference BS1 positioned at 1-m distance below the electrode outlet was able to record a neutron yield higher than ≈5×10^9 neutrons/shot.



Anisotropy of the neutron emission from the PF-1000 device: solid line – **the anisotropy impressed by the PF-1000 vessel (computed with the use of the MCNP 4C code),** symbols – **observed anisotropy in x-z and y-z planes,** dotted line – **cone shape anisotropy.**

Neutron anisotropy impressed by the PF-1000 vessel



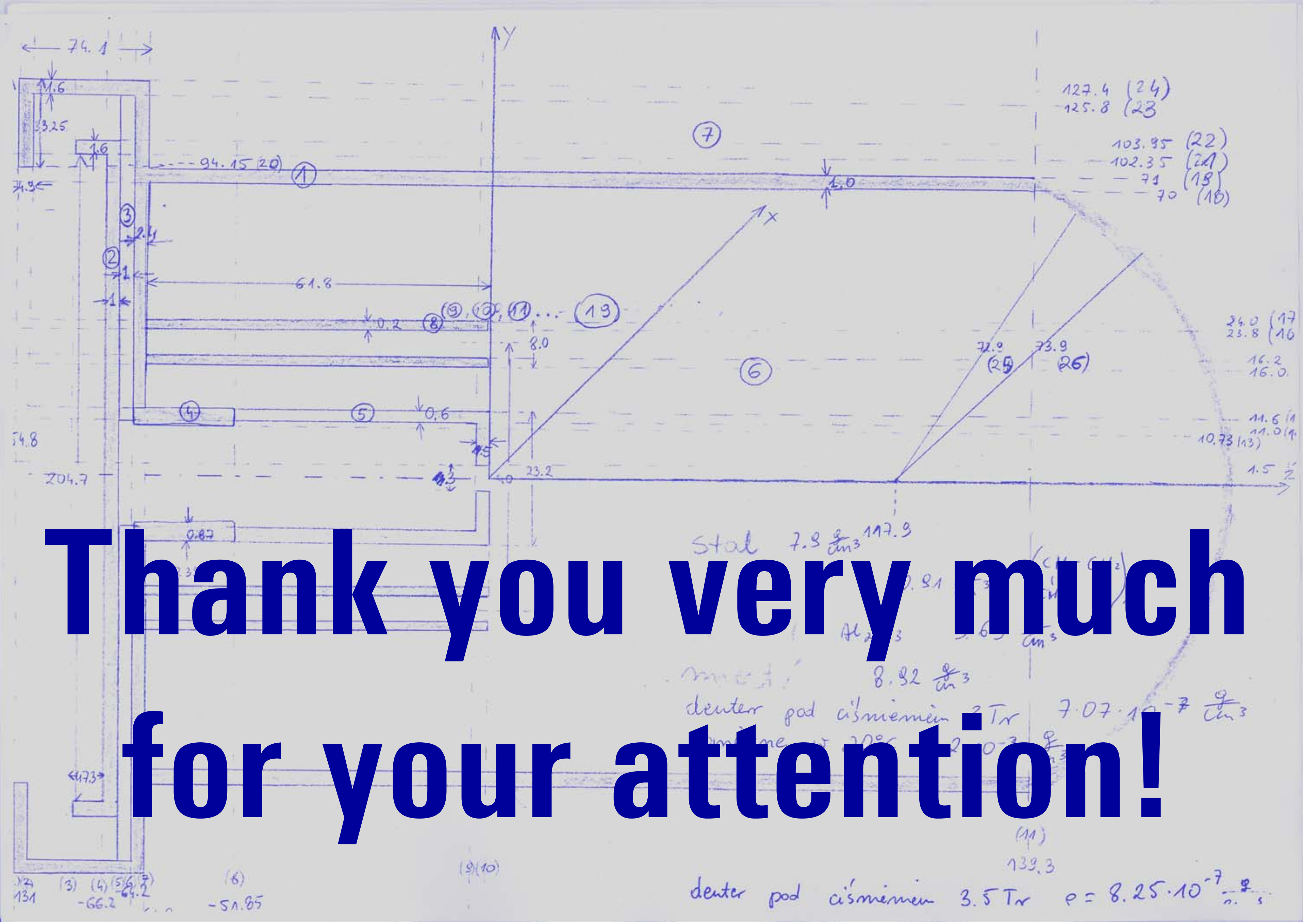
Conclusions:

Scattering of DD-fusion neutrons, which arises due to their passage through the discharge vessel walls, gives rise to the **anisotropy of neutron emission** from the PF-1000 device.

Overall **54%** of neutrons are scattered and thus slowed,
46% of neutrons are expanding in the original direction and with the original velocity (direct neutrons).

Time-of-flight spectra consist of a leading fast peak of direct neutrons followed by moderated ones.

Time-of-flight spectra of neutrons can be described by the Kelly's function derived from the shifted Maxwell-Boltzmann velocity distribution. The fitting of this function to observed signals makes the determination of the COM velocity (energy), the temperature, the time of their origin, and their abundance possible, if time-of-flight is much longer than their time-period of production.



Thank you very much for your attention!