DETERMINATION OF A SCISSION NEUTRON YIELD IN ^{252}Cf SPONTANEOUS FISSION FROM THE EXPERIMENT ON MEASURING THE ANGULAR DEPENDENCE OF COINCIDENCES BETWEEN FISSION NEUTRONS

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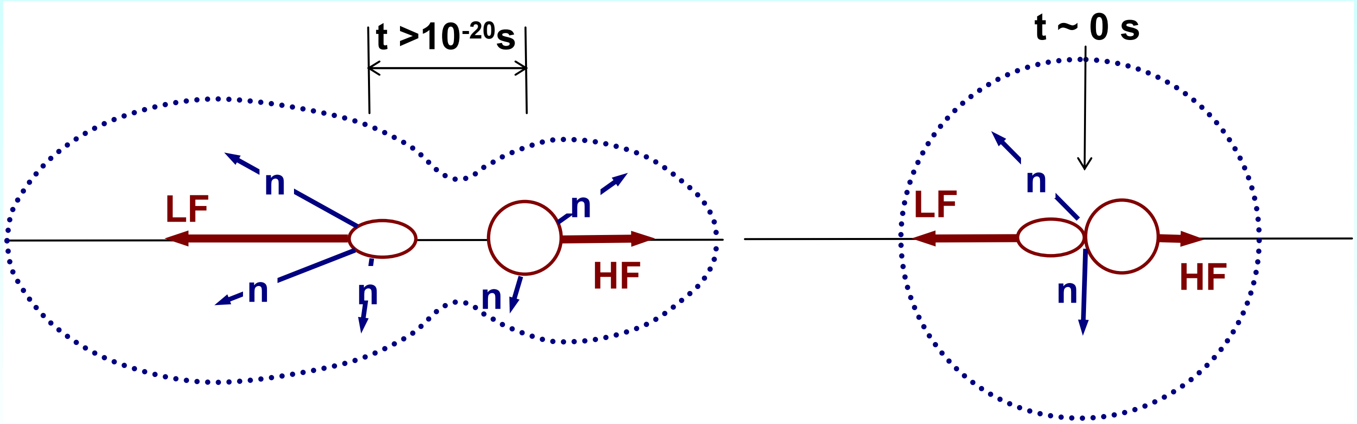
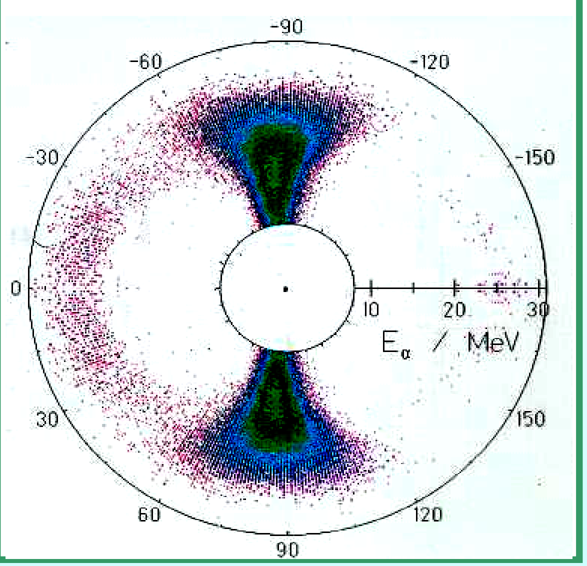
Scission neutrons – Theoretical expectations



The Scission Neutrons characteristics (yield, energy and angular distributions) are closely related with fission dynamics.

Ternary α particles from ^{252}Cf



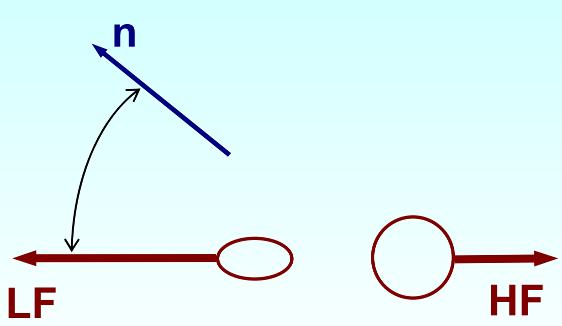
Theoretical predictions:

1. From extrapolation of ternary particles yields (statistically):
   ~5% for 252Cf(sf) and ~20% for 235U(n_{th},f).
   [G.V. Val'sky, Physics of Atomic Nuclei. Vol. 67 (2004) 1264]

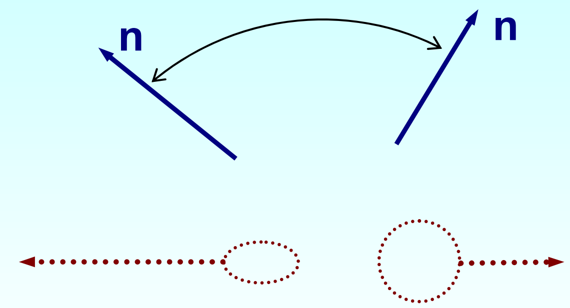
2. Quantum mechanical analysis of non-adiabatical change of nuclear potential ("sudden" approximation):
   Up to 30% of the total number of neutrons for 235U(n_{th},f).
   [N. Carjan, et al., Nuclear Physics A 792 (2007) 102.]

Scission neutrons – Ways to study

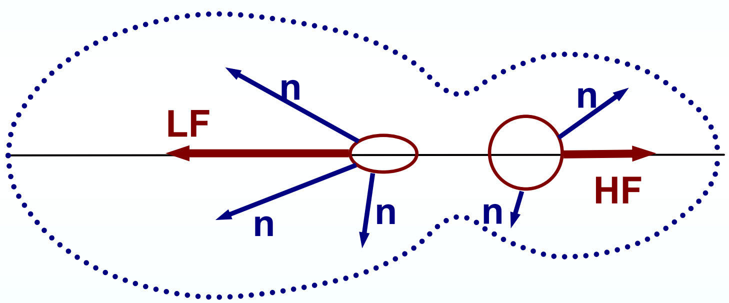
Measurements of angular and energy correlations in the prompt neutron yields.

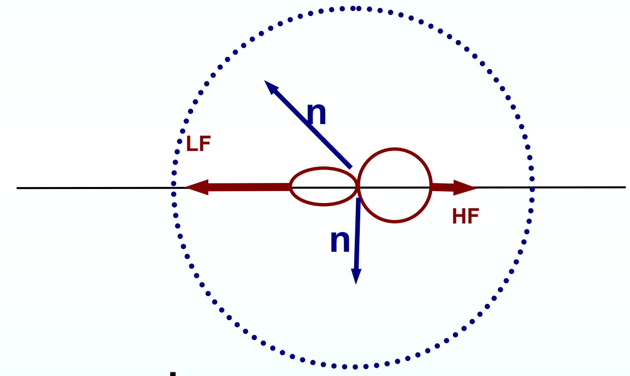


Neutron-Fragment

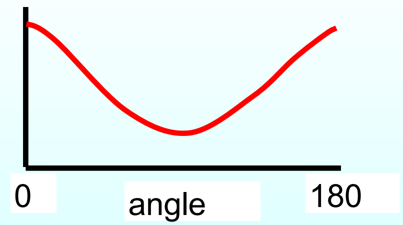


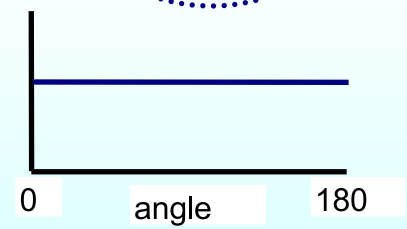
Neutron-Neutron

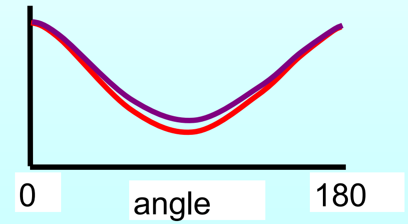




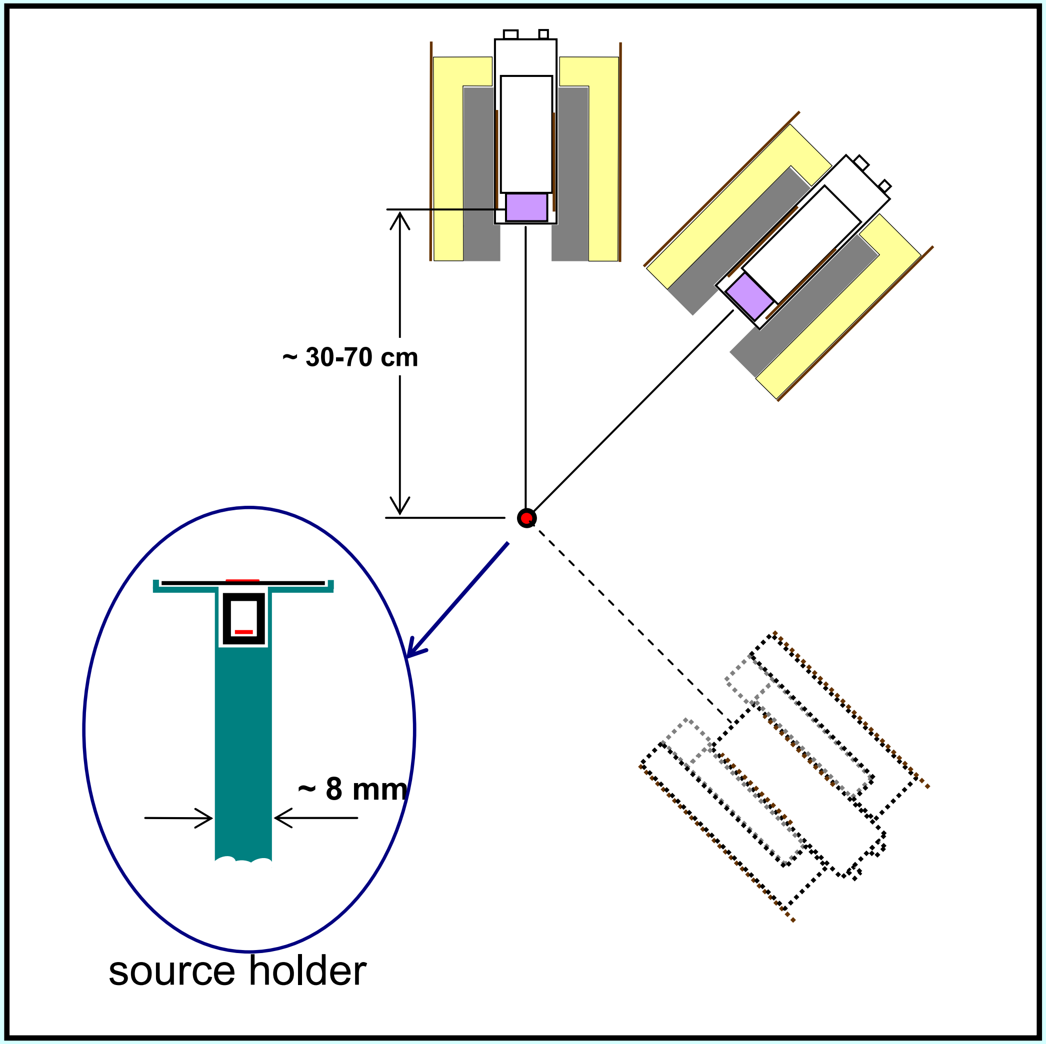
The SNs manifest themselves as a deviation of the measured distributions from ones calculated in assumption that all neutrons are emitted from accelerated fragments.



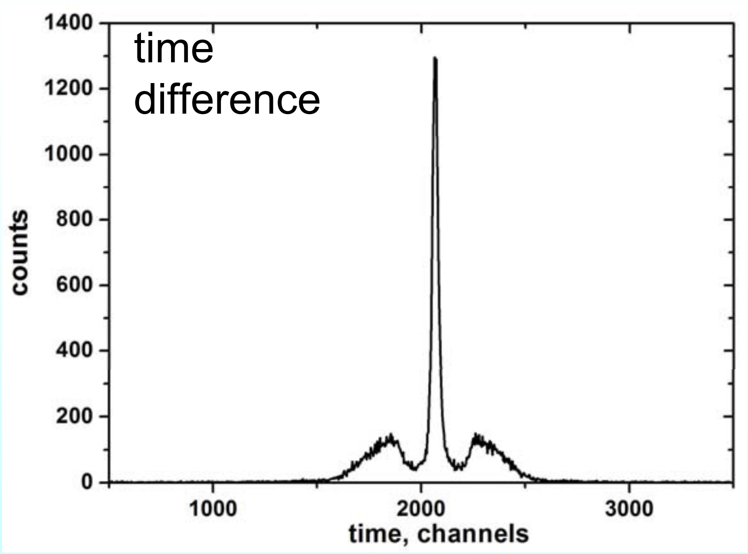




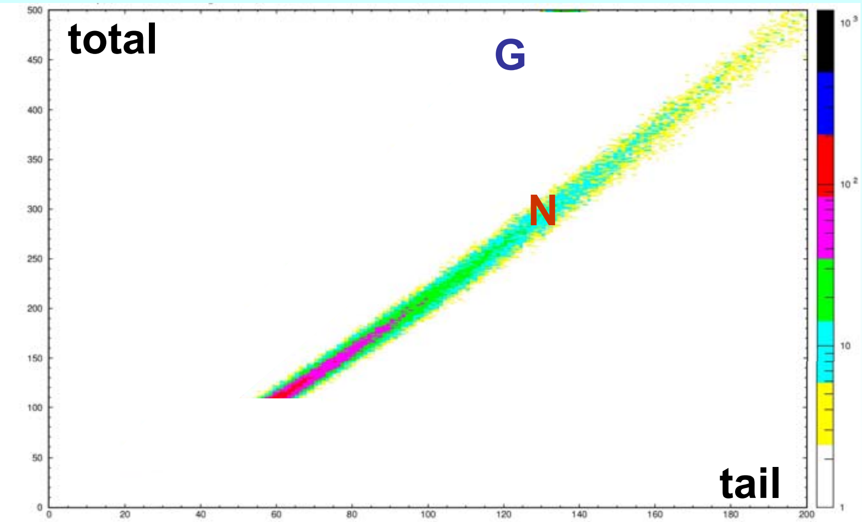
Experimental setup

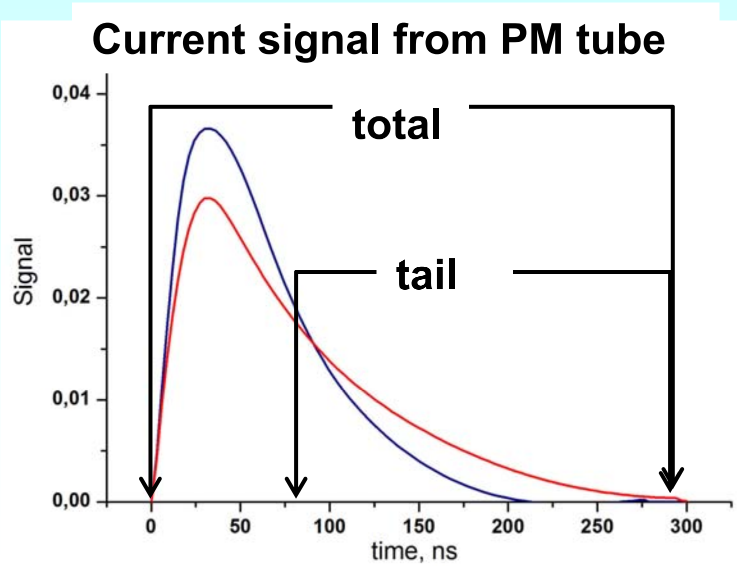


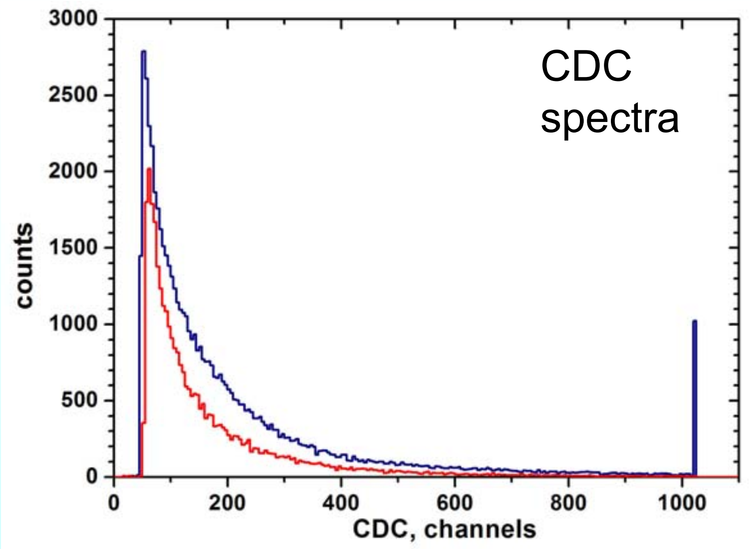
- Two Stilbene crystals D60 x H40 mm
- PM tubes (Hamamatsu R1307)
- Polyethylene and Lead shielding
- μ-metal magnetic shielding
- ^{252}Cf source ~4×10^5 fission/s consisting of 2 parts: one open source on 0.3 mm stainless steel backing, another closed in 1 mm thick stainless steel container.
- Everything on 8 mm thick Aluminum table.

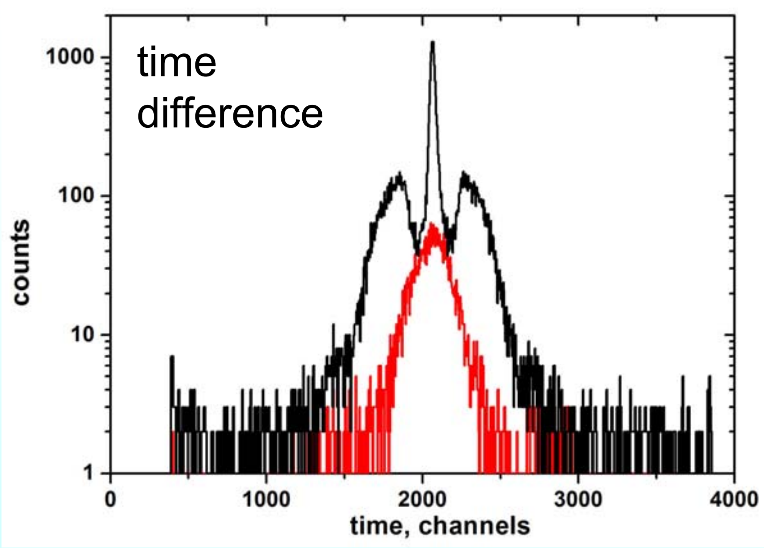


Gamma-neutron separation

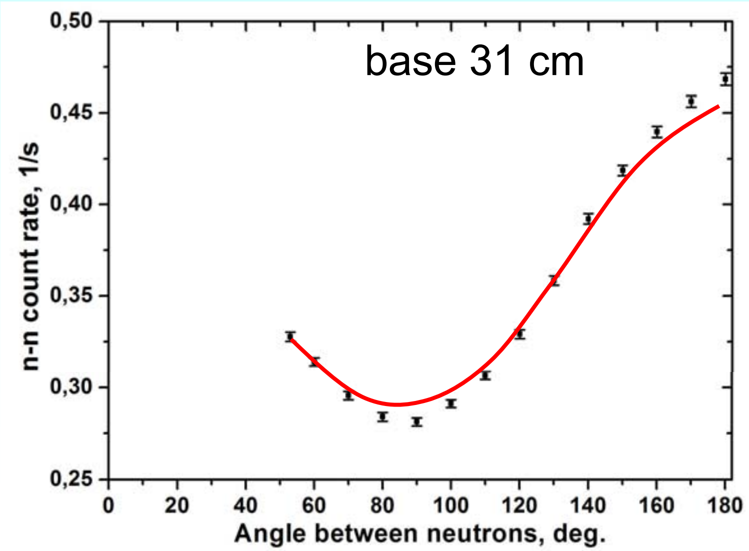


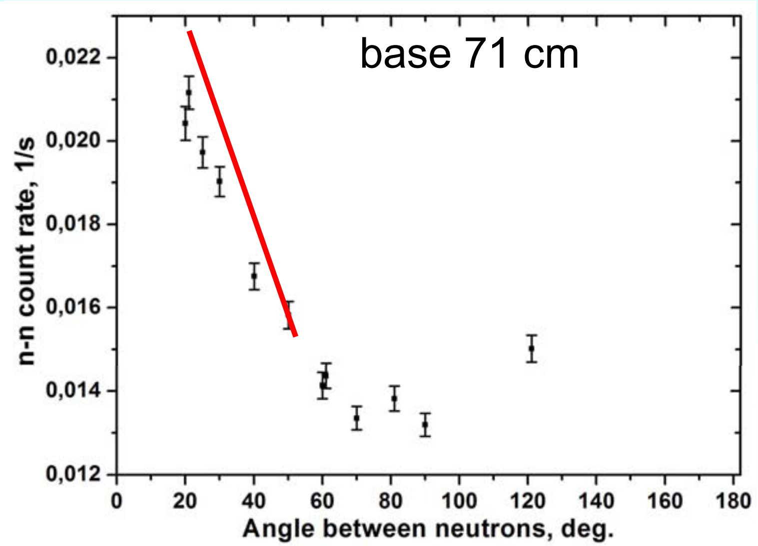






Results – Possible systematical errors





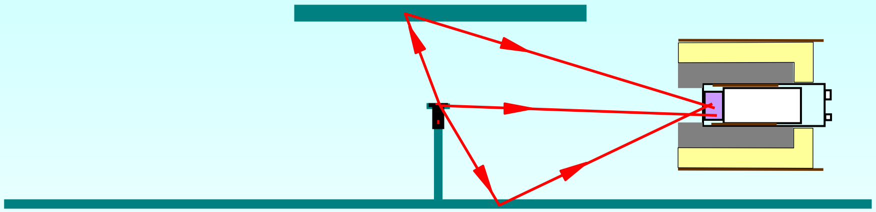
Before to fit the experimental angular distributions we should carefully analyze possible experimental effects which can distort the experimental distributions.

<u>Main problems are:</u>

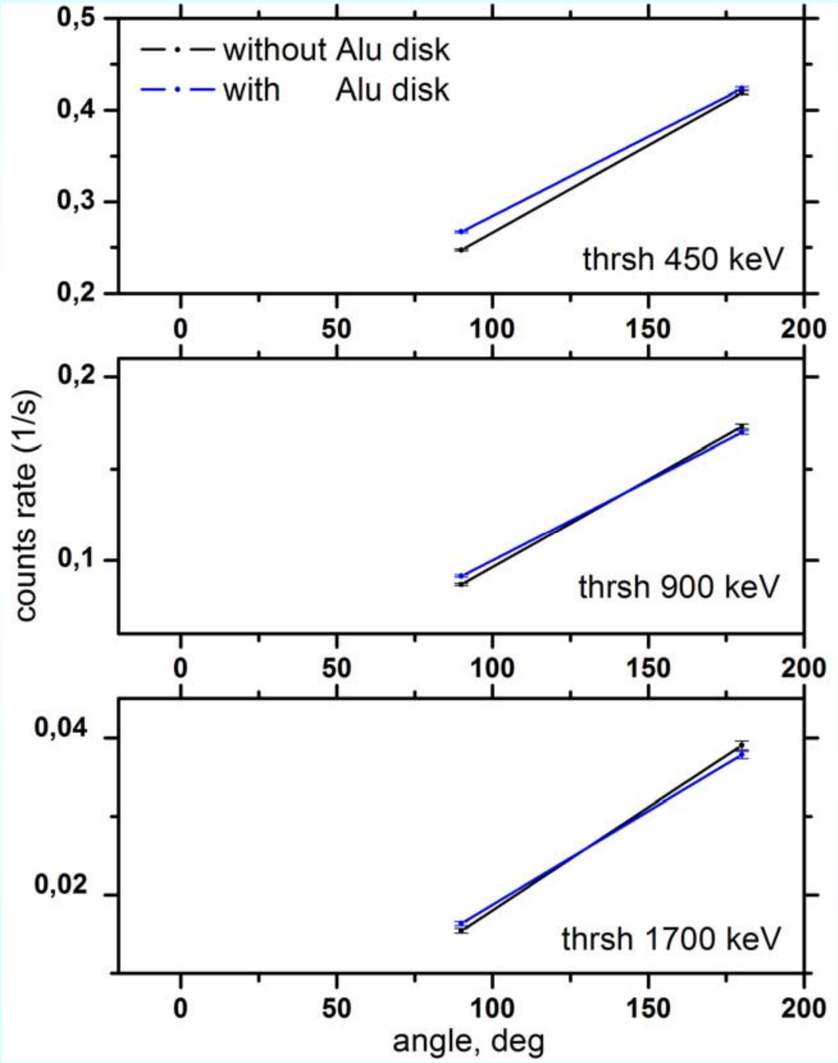
- **Angular resolution of the detectors,**
- **Neutron scattering in the fission source and other surrounding materials,**
- **“Cross-talks” between neutron detectors,**
- **Stability of the energy calibration (effective threshold)**
- **Decay of the 252Cf source have to be taken into account.**

Each of these effects can give influence onto coincidence rate ~few percents!

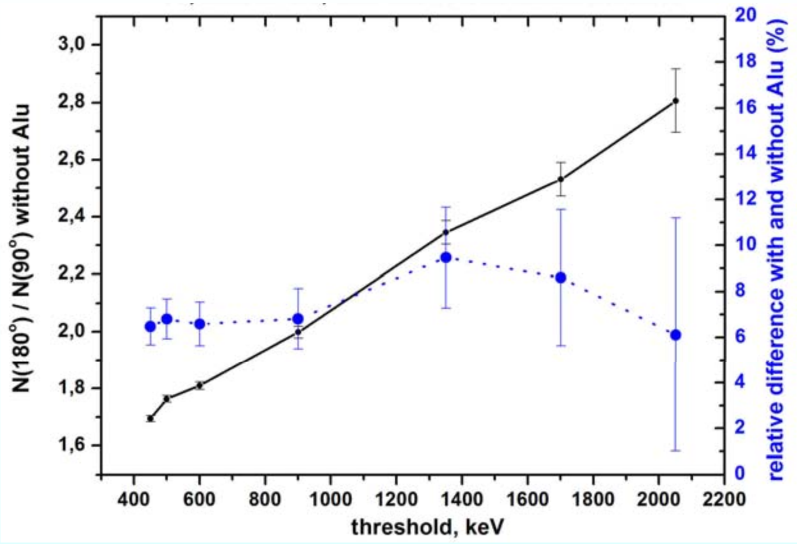
Neutron scattering on the aluminum table



NN counts rate at 90° and 180°

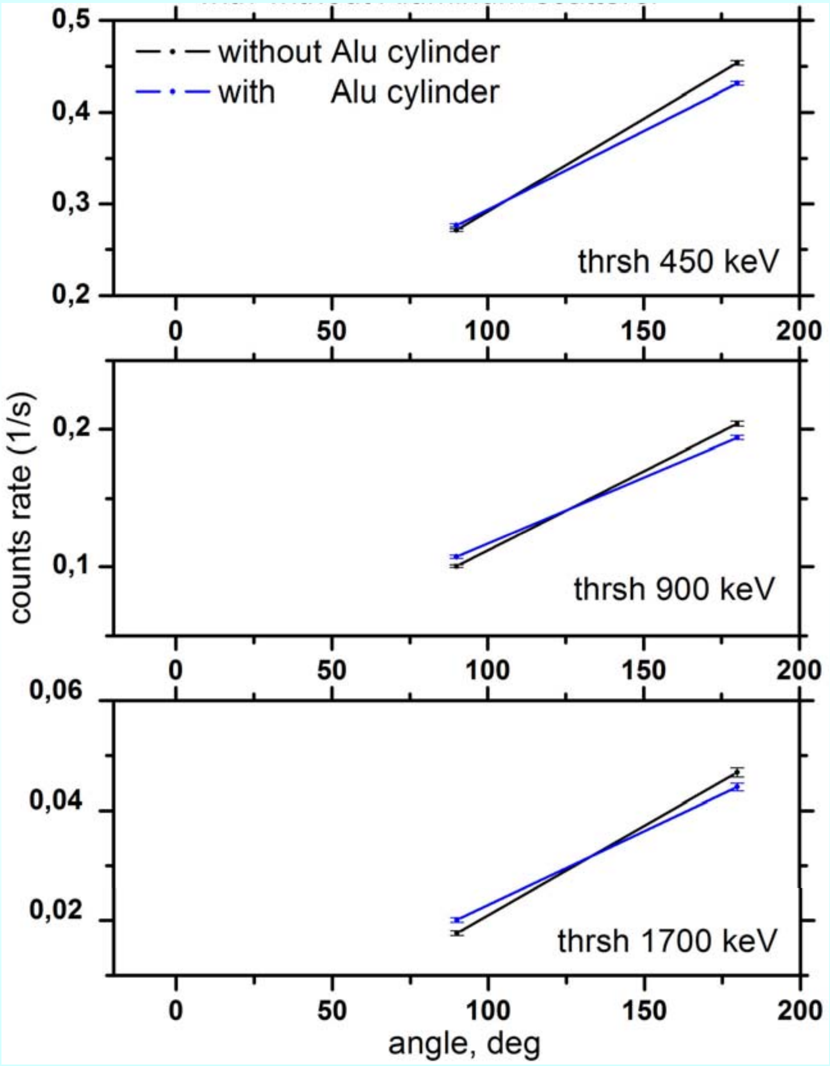


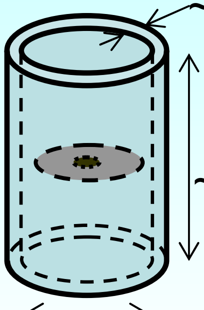
$F = N(180^o)/ N(90^o)$



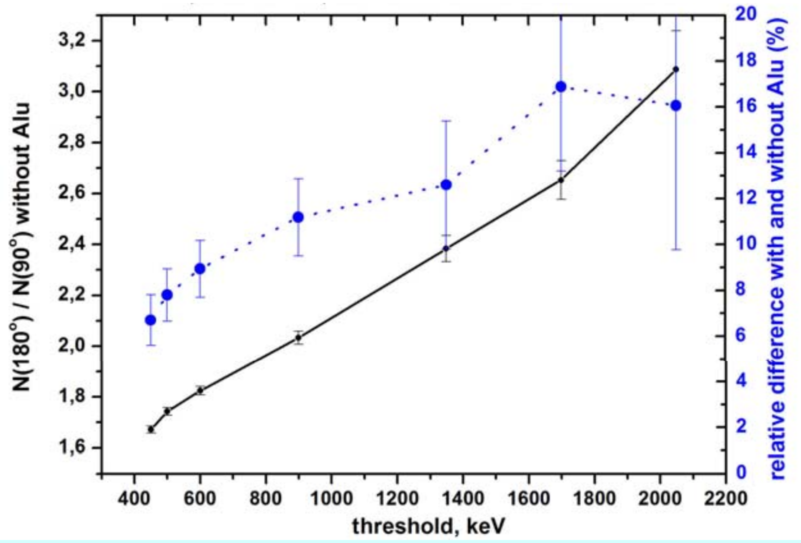
Neutron scattering on the container and support

NN counts rate at 90^o and 180^o

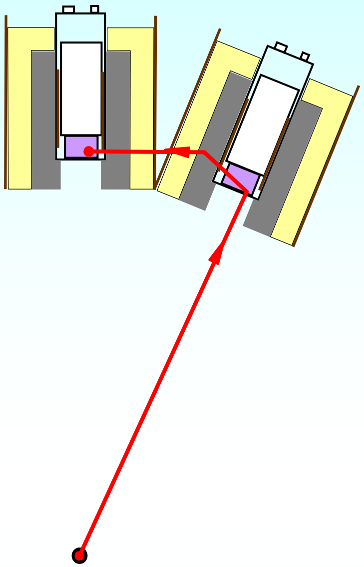


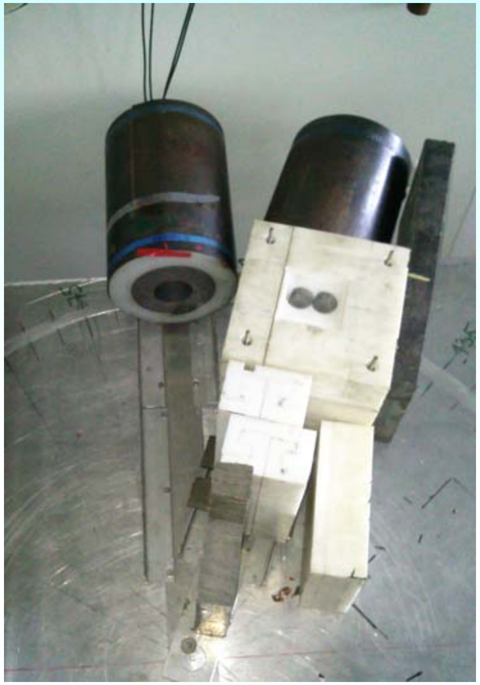


F = N(180^o)/ N(90^o)

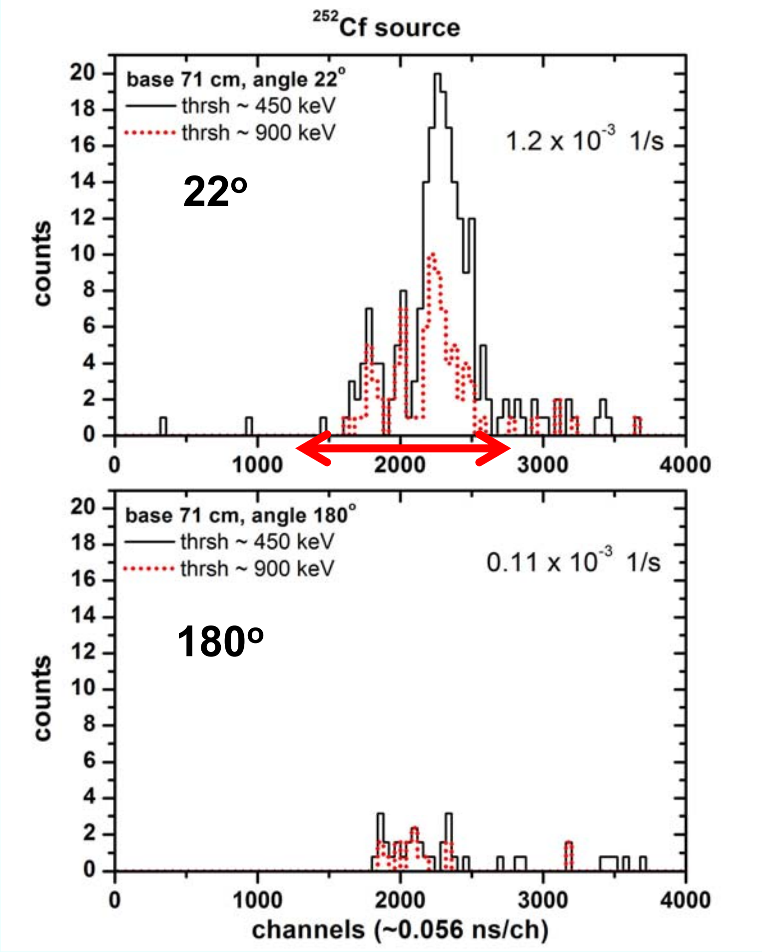


Cross-talks of the detectors at small angles





NN counts rate at 22° and 180°



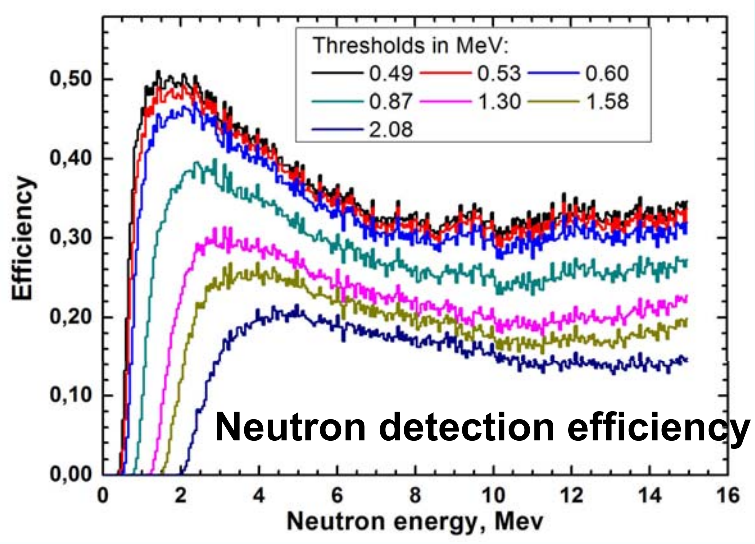
Cross-talk fraction in the count rate for the long base 71 cm

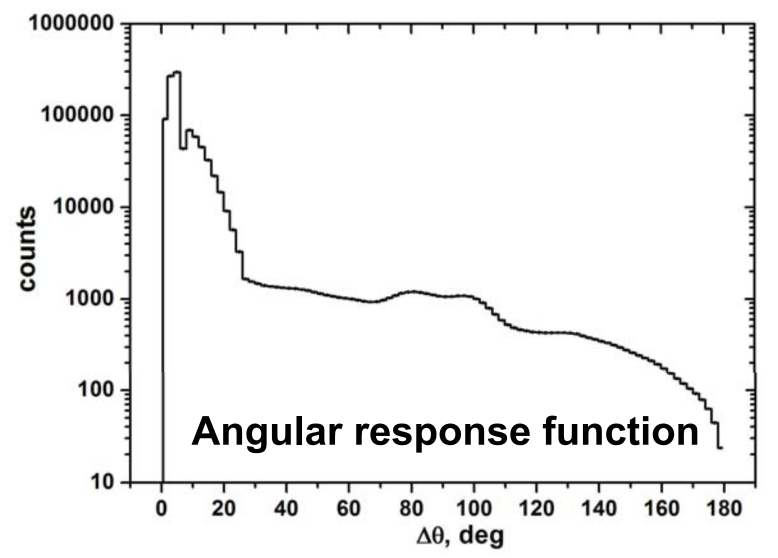
22° :	**11 ± 1%**
30° :	**6 ± 1%**
50° :	**1 ± 1%**

For short base 31 cm the cross-talk influence can be neglected

Geant4 simulation of the detectors efficiency and angular response function

Geant4 is a toolkit for the simulation of the passage of particles through matter

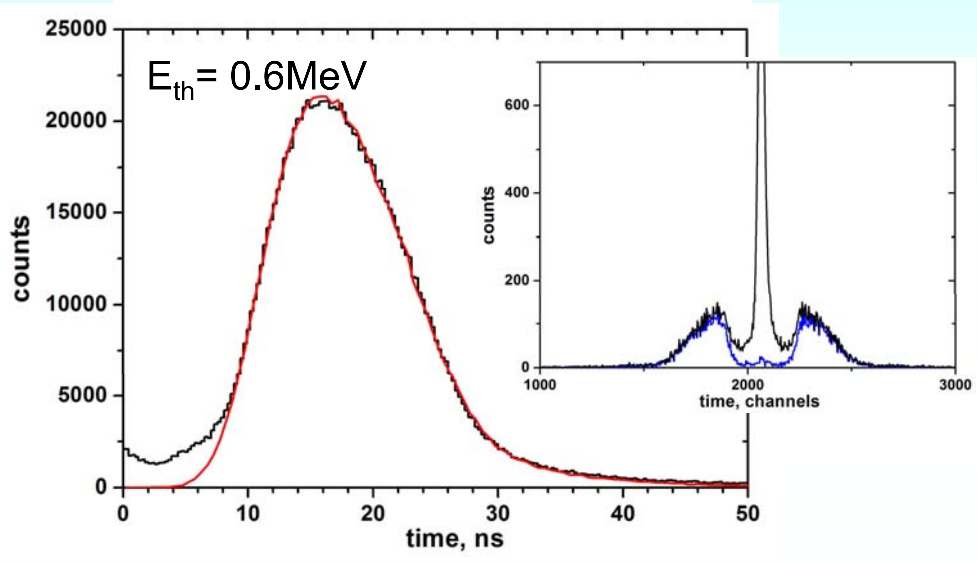




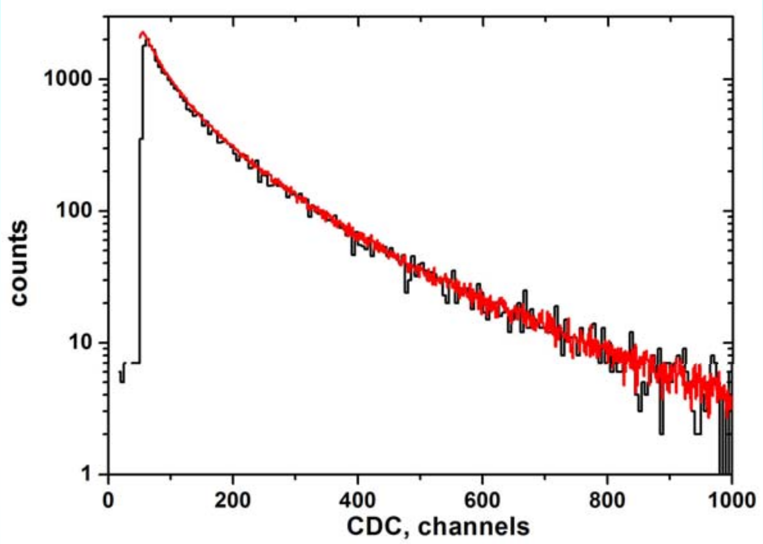
- **Real detectors geometry together with all shielding**
- **All registration processes and real light output for the recoil particles**

Geant4 simulation − Verification

Neutron time of flight spectra
in N-Gamma coincidences



CDC spectra for neutrons



•**Probability of cross-talk at 22º : (2.7 ± 0.1) x 10^{-5} (GEANT4) and (3.1 ± 0.3) x 10^{-5} (EXP)**

•**Efficiency gain due to the detector housing: ~33% (GEANT4) and ~31% (EXP)**

Model simulation − Monte-Carlo code

1. **Generate fission events (fragment masses, velocities, neutrons multiplicities, neutrons spectra, angles, etc.). Anisotropy of the neutron emission from fragments due to their spins was taken into account *). Part of the neutrons were taken to be emitting izotropicaly from the center of mass with Weisskopf energy spectra.**
2. **Trace each neutron from fission event using the efficiency and angular response functions calculated by GEANT4. (At this stage all experimental scattering and angular resolution is taking into account)**
3. **Sort the registered neutrons pairs into histograms according to their final mutual angles and 7 energy thresholds**
4. **The resulting 7 histograms are compared with experimental ones. (It is important to notice, that ALL calculated histograms are normalized to experimental ones with ONE common coefficient)**

Parameters:

$E_L / A_L = 0.975$ MeV

$E_H / A_H = 0.561$ MeV

$<\nu_L> = 2.056$	$<\nu_H> = 1.71$
$\sigma_L = 0.94$	$\sigma_H = 1.07$
$\rho = -0.21$	$(\sigma^2 = 1.6)$
$T_L = 0.9113$ MeV	$T_H = 0.9267$ MeV

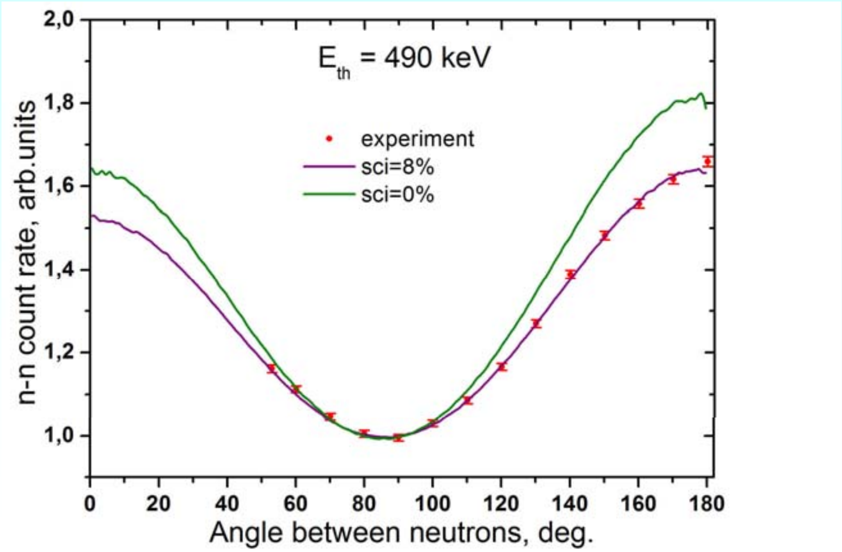
$p_{ScN} = 8 \pm 2$ %

$T_{ScN} = 1.2 \pm 0.1$ MeV (Weisskopf)

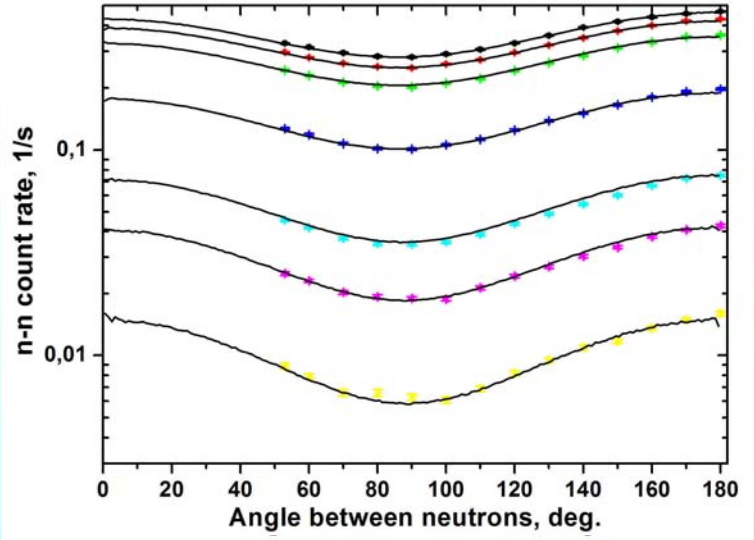
Fitting parameters

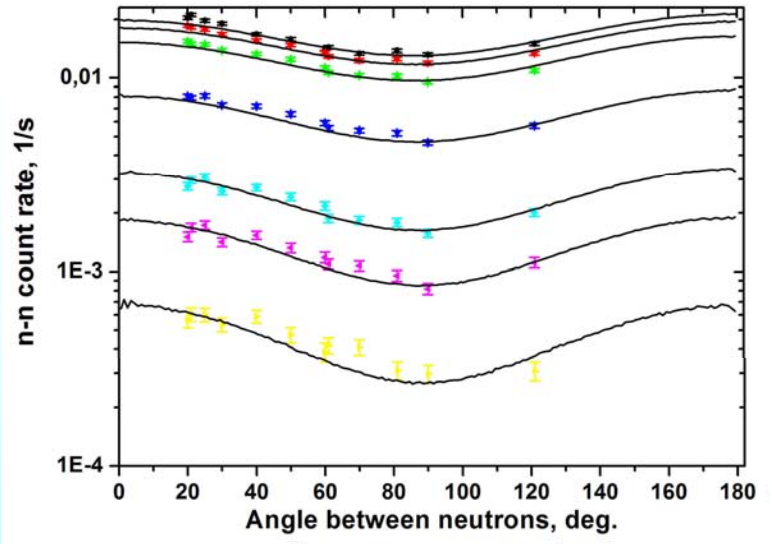
***) V.E. Bunakov, I.S. Guseva, et al, ISINN-13, p.293 (2005), Izv.Ross.Akad.Nauk, Ser.Fiz., 2006,70, p.1618.**

Model simulation − Results

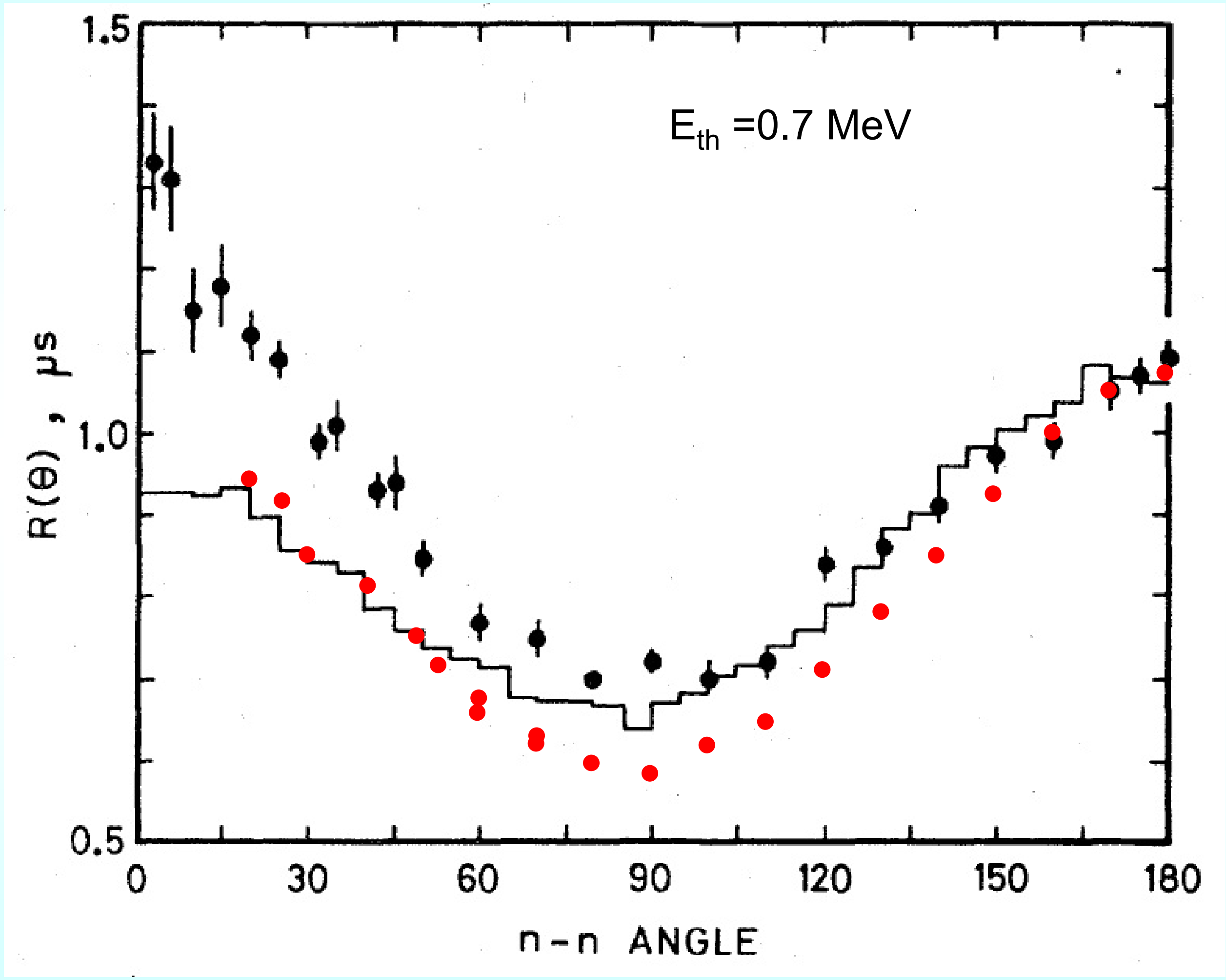


p_{ScN} = 8 ± 2 %
T_{ScN} = 1.2 ± 0.1 MeV (Weisskopf)





J. S. Pringle and F. D. Brooks, Phys.Rev.Lett. 35 (1975) 1563



Conclusions

- **Precise measurements of the angular dependence of *n-n* coincidences rate in 252Cf(sf) were performed.**
- **All possible experimental effects which can distort the experimental distributions were analyzed and taken into account with accuracy ~1% . (Control experiments and GEANT4 simulation)**
- **Experimental data on N-N angular correlation in ^{252}Cf are definitely not consistent with hypothesis where all 100% of neutrons are emitted from accelerated fission fragments.**
- **The distributions can be fitted if** *8 ± 2%* **of the total amount of fission neutrons are supposed to be emitted isotropically in the laboratory system having Weisskopf energy spectra with** $T_{ScN} = 1.2 \pm 0.1$ *MeV.* **These neutrons can be attributed as scission neutrons.**
- **Strong discrepancy with J. S. Pringle and F. D. Brooks data can be explained by strong systematical effects due to scattering and cross-talks in their experiment.**
- **The effects of neutron scattering can not be easily neglected in the data analysis for Neutron-Fragment correlation experiments.**

Thanks for attention

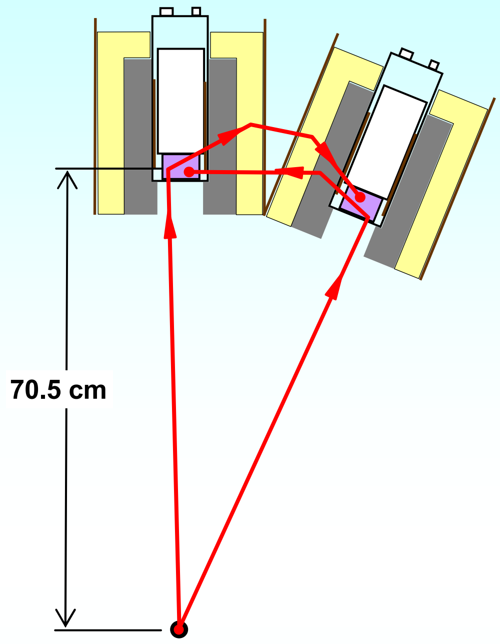
J. S. Pringle and F. D. Brooks, Phys.Rev.Lett. 35 (1975) 1563 – Criticism

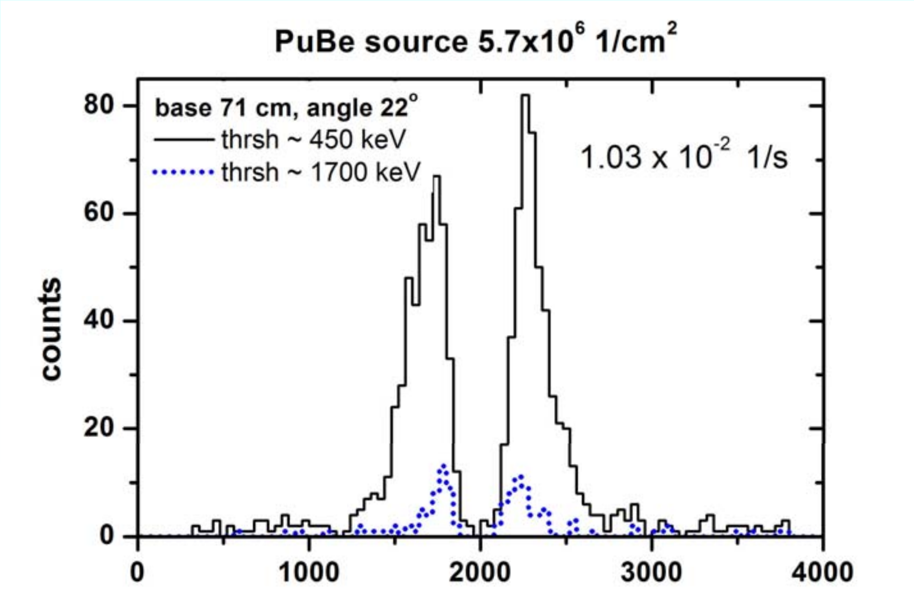
•"2 μg of 252Cf in the form of four 15-mm-long rods, each sealed in a 1-mm-diam platinum-iridium container". Looks not ignorable!

•"The distances from the source to the two scintillators were 30 cm for the measurements made at $\theta > 45^o$. For $\theta < 45^o$ one detector was moved back to 40-50 cm and a <u>shadow shield was inserted</u> between the two detectors to attenuate spurious coincidences arising from neutron scattering from one detector to the other. This scattering background was carefully investigated and the geometry and length of the shield were chosen to limit it to a negligible level." Looks like week point! Change of geometry, adding big scatterer → Change in efficiency curves. The problem of crosstalk <u>very probably</u> not solved.

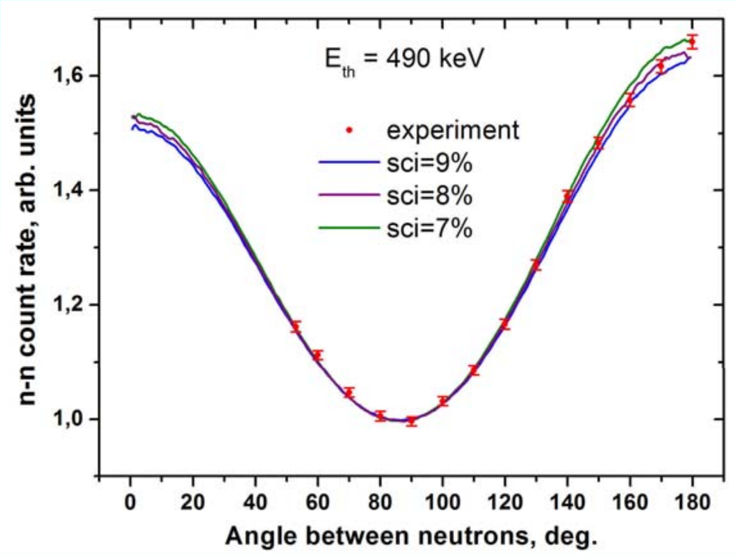
•Any other scaterers around are not discussed, but there obviously should be something for the detectors support.

PuBe – для базы 71 см





Additions



E_{th} = 490 keV
experiment
sci=9%
sci=8%
sci=7%
n-n count rate, arb. units
1,0
1,2
1,4
1,6
0
20
40
60
80
100
120
140
160
180
Angle between neutrons, deg.