ANGULAR CORRELATIONS BETWEEN FRAGMENT SPINS AND PROMPT NEUTRONS IN SPONTANEOUS FISSION OF ^{252}Cf.

Yu. Kopatch[1], L. Stuttge[3], F.Goennenwein[4], M. Mutterer[5], O. Dorvaux[3], S.Telezhnikov[1], E. Chernysheva[2], F. Hanappe[6], and F.-J. Hambsch[7]

[1]Frank Laboratory of Neutron Physics, JINR, 141980 Dubna, Russia

[2]Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia

[3]Institut de Recherches Subatomiques, F-67037 Strasbourg Cedex, France

[4]Physikalisches Institut der Universität, D-72076 Tübingen, Germany

[5]Institut für Kernphysik, Technische Universität, D-64289 Darmstadt, Germany

[6]Universite Libre de Bruxelles, 1050 Bruxelles, Belgium

[7]EC-JRC-Institute for Reference Materials and Measurements, Retieseweg 111, B-2440 Geel, Belgium

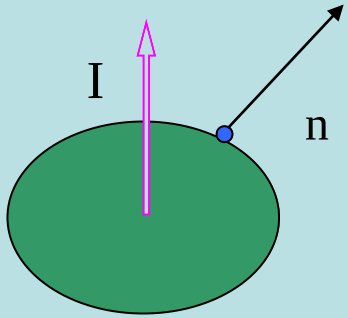
Content

1. Introduction / Motivation.
2. Experiment.
3. Methodical studies. Monte Carlo simulations.
4. Data evaluation.
5. Summary & outlook.

Introduction

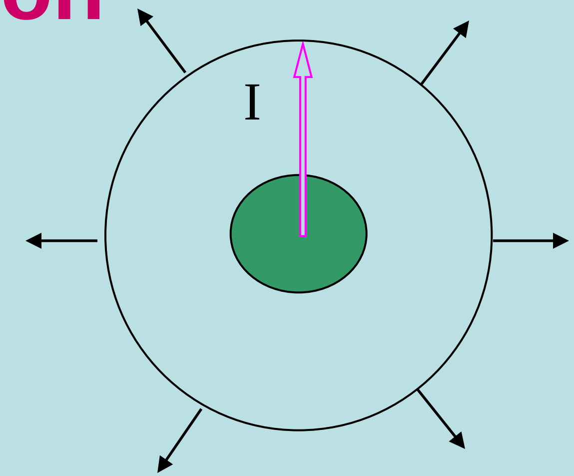
- It is well known that fission fragments are formed with rather high angular momenta (spins).
- Fragment spins are aligned perpendicular to the fission axis.
- Fragment spin properties (population, alignment etc) are usually probed by the correlation measurements of gamma-rays, emitted from fission fragments.
- Neutrons are emitted with a strong anisotropy in the laboratory system due to kinematic focusing in the direction of accelerated fragments.
- In analogy with gamma-rays, some anisotropy of the neutron emission can be expected with respect to the direction of the fragment spin.
- There are theoretical arguments / calculations, as well as indirect experimental evidences that such an anisotropy should exist. However, no direct observation of this effect is known until now.

Neutron emission

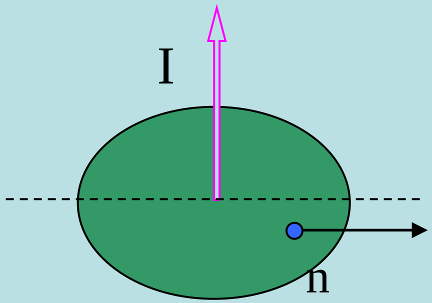


s-neutrons

l=0

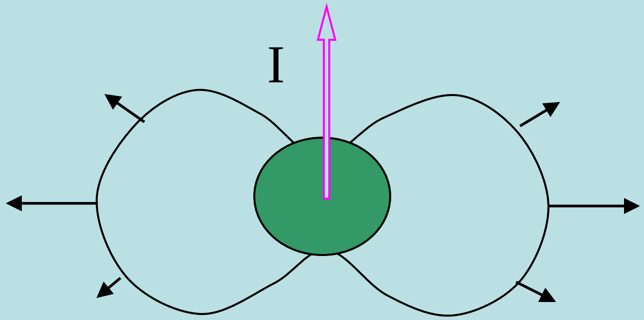


Isotropic neutron emission



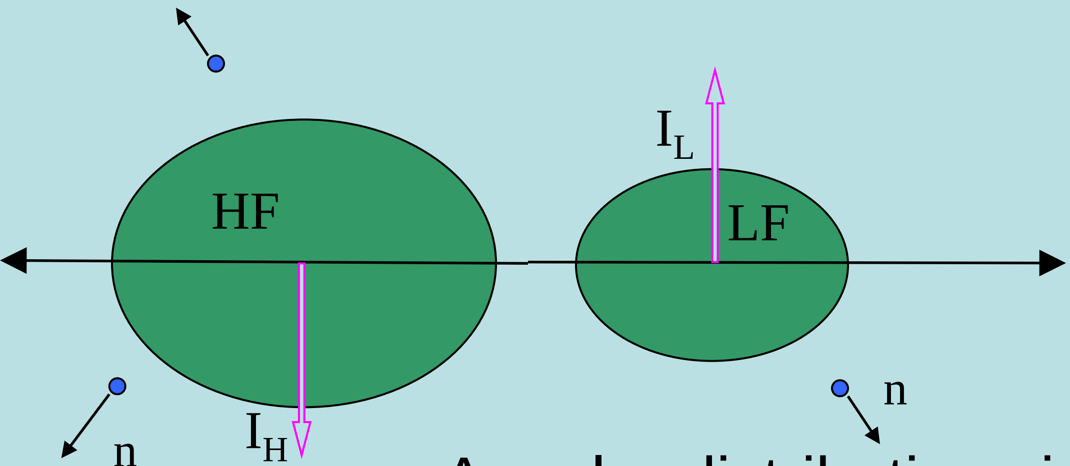
p-,d-,… neutrons

l=1,2,…



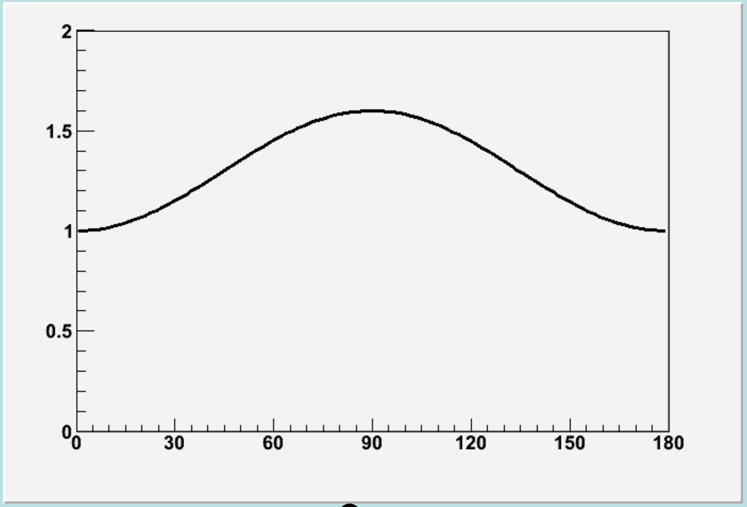
Unisotropic neutron emission

Neutron anisotropy in fission

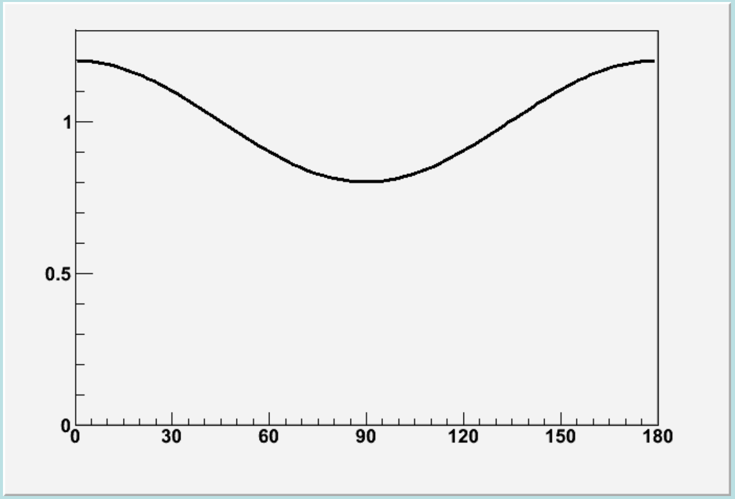


Only neutrons with l≠0 contribute to the anisotropy

Angular distributions in the c.m. system



$\theta_{n,l}$

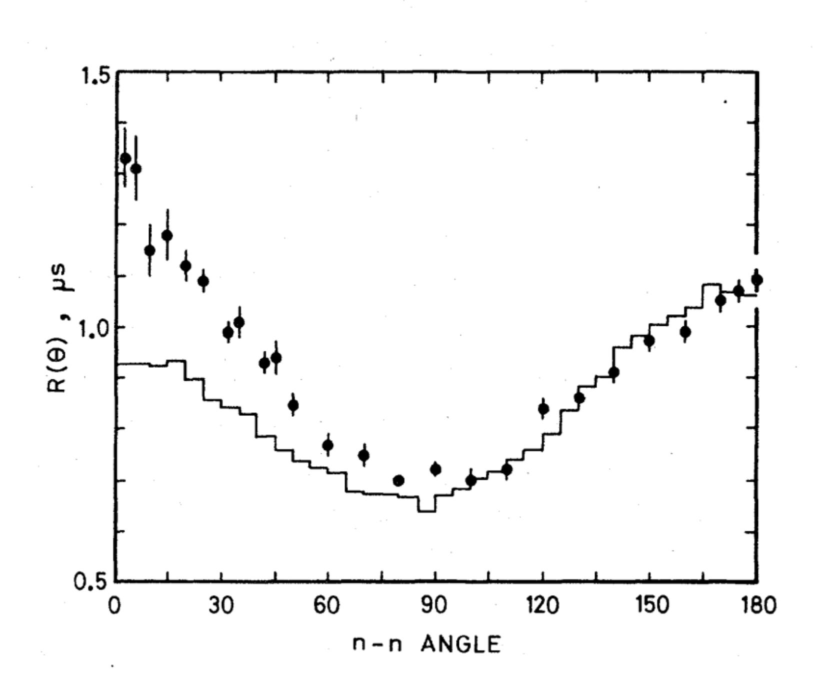


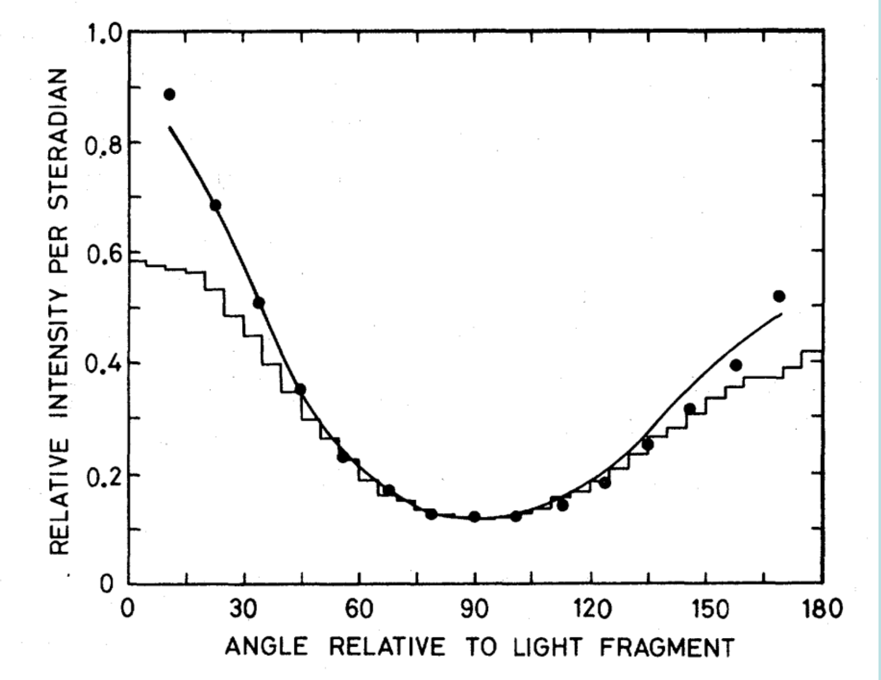
$\theta_{n,FF}$

Experiments

Angular Correlation of Neutrons from Spontaneous Fission of ^{252}Cf

J. S. Pringle and F. D. Brooks
Physics Department, University of Cape Town, Rondebosch, 7700, South Africa
Phys. Rev. Letters, 1975





THE ESTIMATION OF SCISSION NEUTRON PARAMETERS FROM N-F AND N-N ANGULAR CORRELATIONS IN $^{235}U(n_{th},f)$ REACTION

I.S. Guseva, A.M. Gagarski, V.E. Sokolov, G.A. Petrov, D.O. Krinitsin, G.V. Val'ski, A.S. Vorobyev, O.A. Scherbakov

*Petersburg Nuclear Physics Institute of Russian Academy of Sciences
Gatchina, Leningrad District, 188300, Russia*

Isinn16

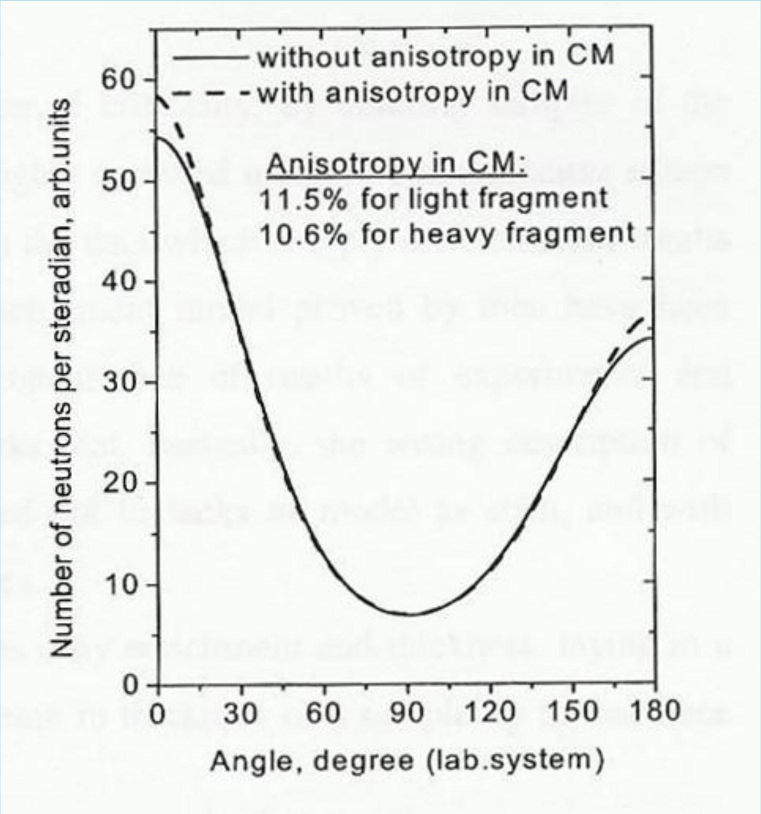
Theoretical calculations

ANGULAR ANISOTROPY OF NEUTRONS EVAPORATED FROM FISSION FRAGMENTS

V.E.Bunakov[1], I.S.Guseva[1], S.G.Kadmensky[2], G.A.Petrov[1]

[1]Petersburg Nuclear Physics Institute, Gatchina, 188300, Russia; [2]Voronezh State University, Voronezh, Russia

Isinn13



Possible reasons for discrepancy:

• Emission of neutrons from not fully accelerated fragments

•Scission neutrons

• Angular anisotropy with respect to the FF spins

Theoretical calculations

ANGULAR ANISOTROPY OF NEUTRONS EVAPORATED FROM FISSION FRAGMENTS

V.E.Bunakov[1], I.S.Guseva[1], S.G.Kadmensky[2], G.A.Petrov[1]

[1]*Petersburg Nuclear Physics Institute, Gatchina, 188300, Russia;*
[2]*Voronezh State University, Voronezh, Russia*

Isinn13

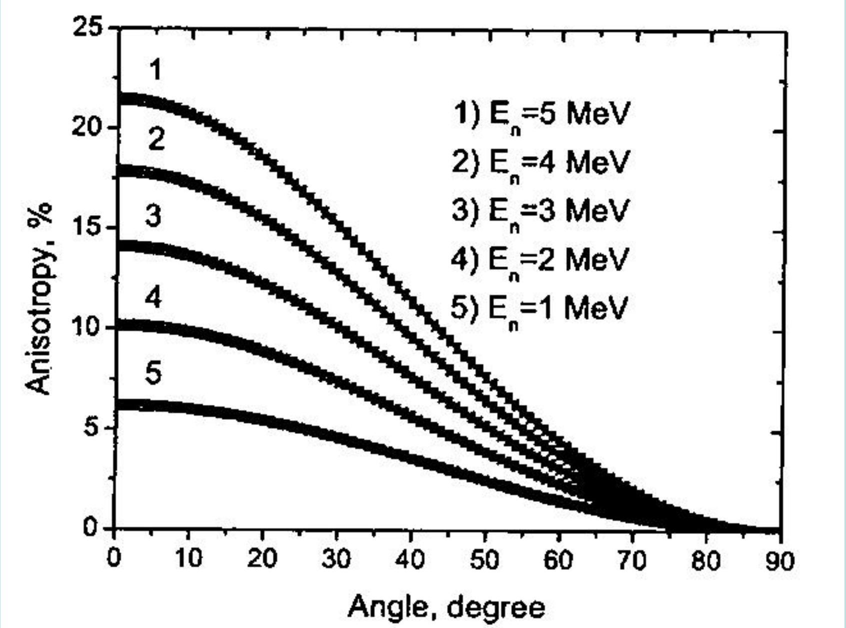


Fig. 11. Energy dependence of angular anisotropy in SMS.

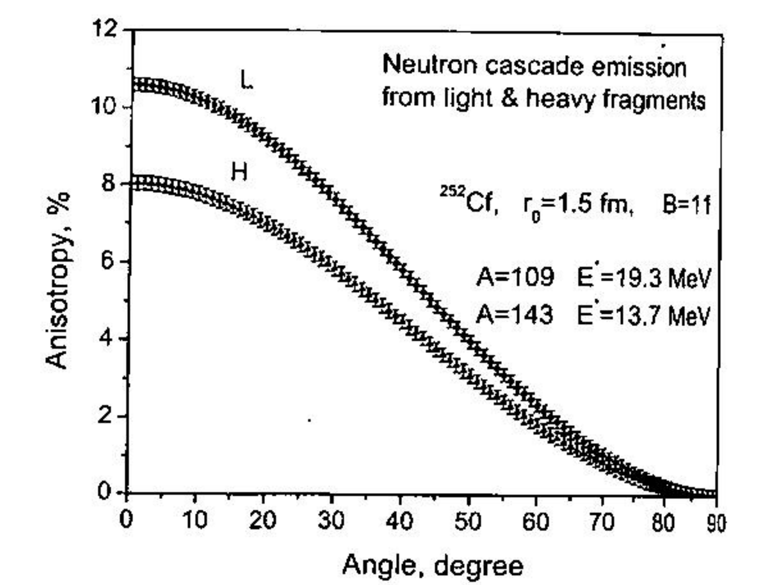


Fig. 10. The average angular anisotropy in CMS for light (L) and heavy (H) fragments of ^{252}Cf.

ROT-effect in neutron emission

Is supposed to be observed due to the neuron angular anisotropy with respect to the fragment spins

ISINN-18

THE ESTIMATION OF ROT-EFFECT FOR NEUTRONS EVAPORATED FROM FULLY ACCELERATED FRAGMENTS IN BINARY FISSION

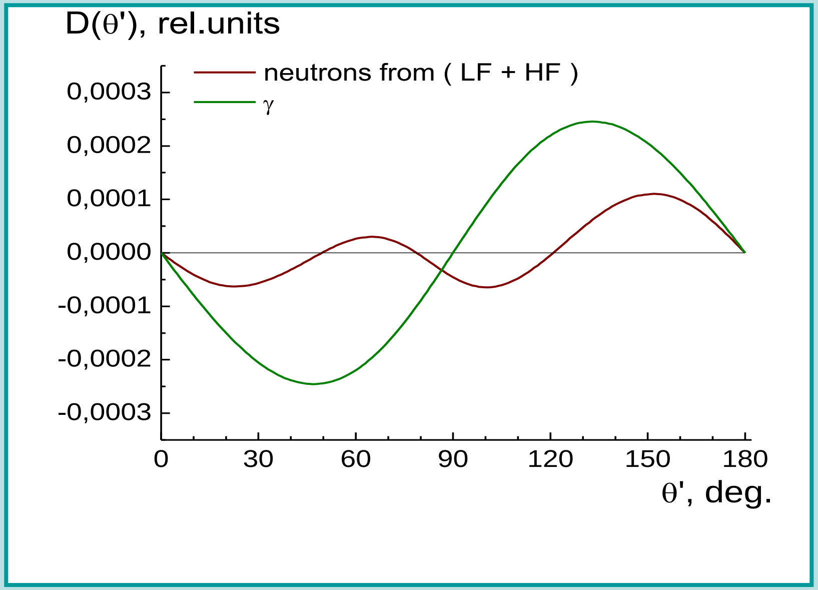
I.S. Guseva

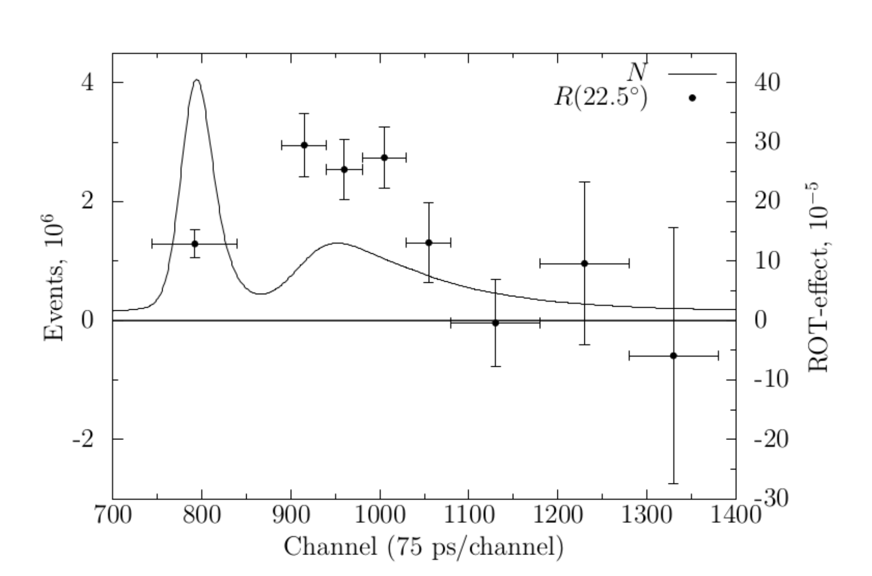
Petersburg Nuclear Physics Institute of Russian Academy of Sciences
Gatchina, Leningrad District, 188300, Russia

ISINN-19

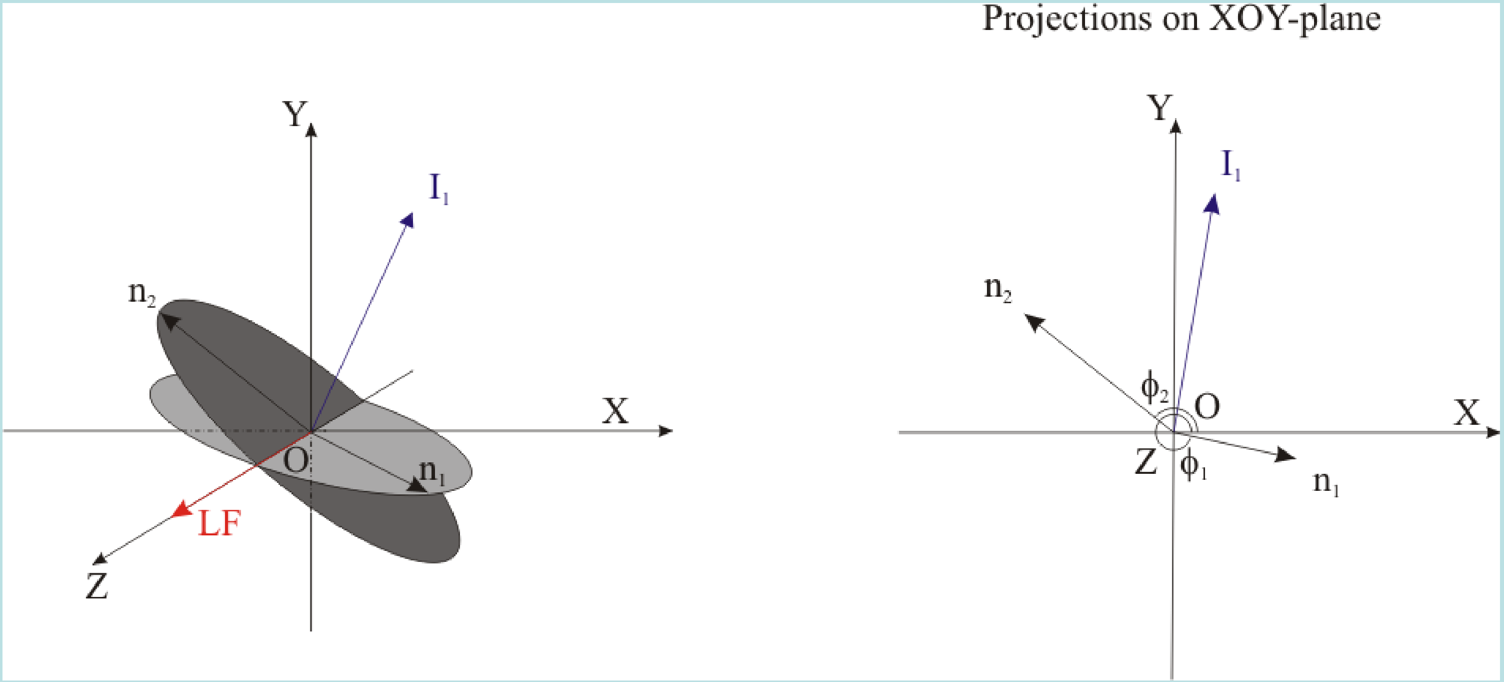
T-ODD ANGULAR CORRELATIONS IN THE EMISSION OF PROMPT NEUTRONS IN ^{235}U FISSION INDUCED BY POLARIZED NEUTRONS

Danilyan G.V.[1], Klenke J.[2], Krakhotin V.A.[1], Kopatch Yu.N.[3], Novitsky V.V.[3], Pavlov V.S.[1], Shatalov P.B.[1]





New method – triple FF-n-n correlations



Advantage: the effect doesn't depend on fission fragment and neutron relative velocities

CORA experiment

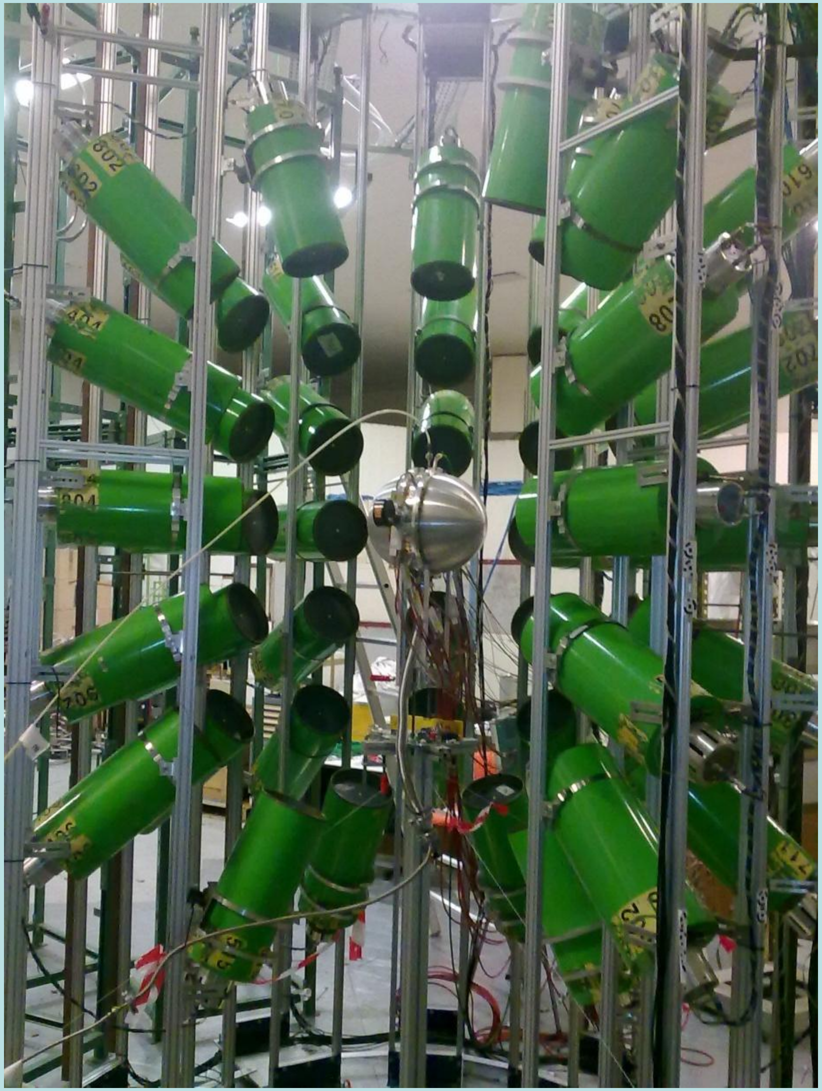
CORrelation Angles

CORA experiment

Two walls arrangement

New measurement

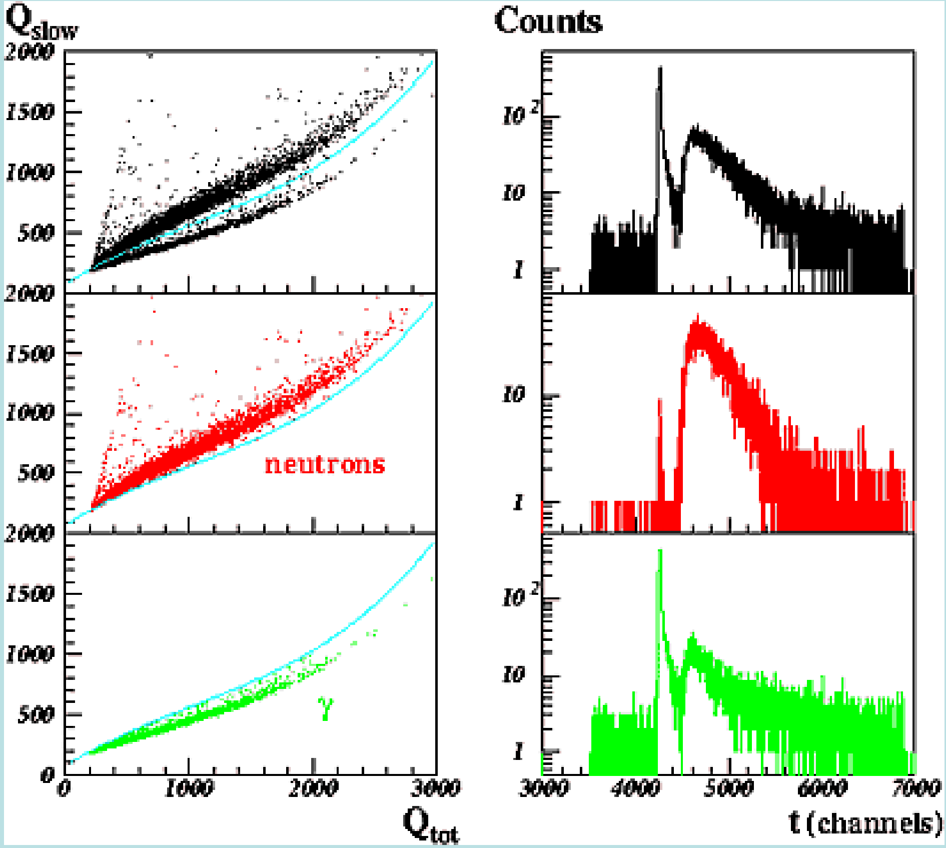
Quasi-spherical arrangement



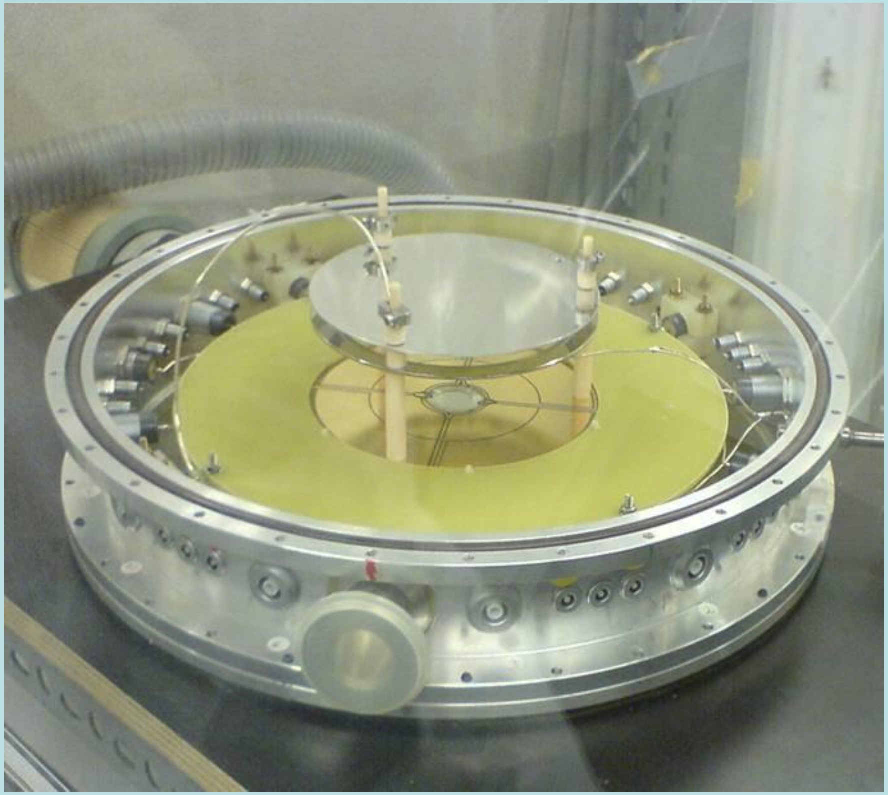
DEMON DETECTORS

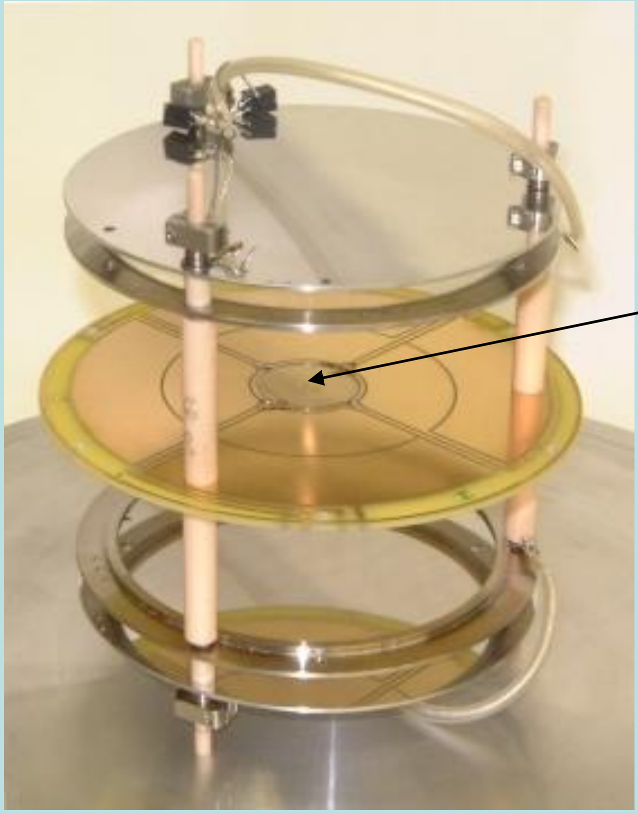
DEMON consists of ~100 individual large size NE213 liquid scintillator cells. Each cell is 20 cm long, has a diameter of 16 cm and contains 4.5 liters of a liquid rich in Hydrogen.

The n-γ discrimination is obtained by a pulse shape analysis by comparison of the slow component of the charge to the total one.



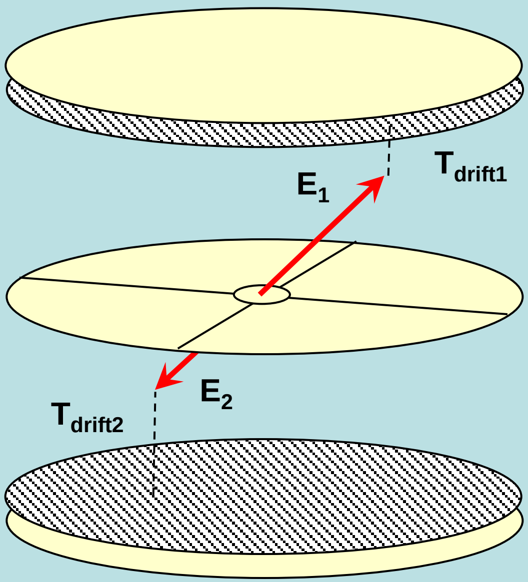
CODIS - double ionization chamber with sectored cathode





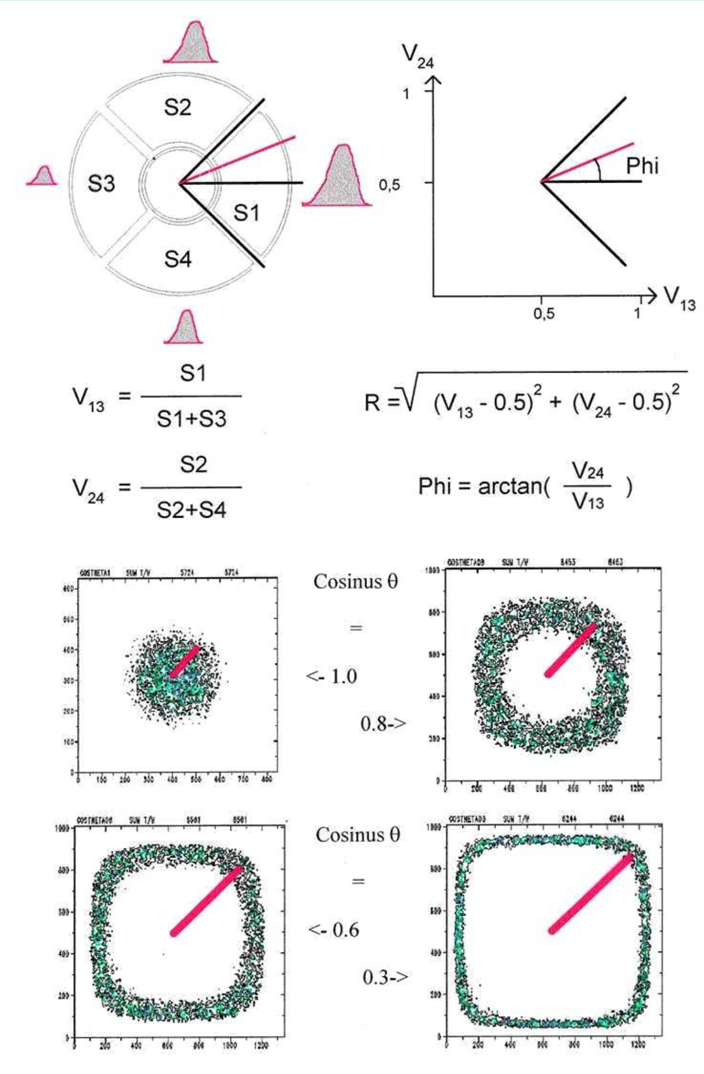
Allows to measure FF energies (masses) and flight direction (polar and azimuthal emission angles).

CODIS - double ionization chamber with sectored cathode



$E_1,E_2, M_1,M_2, \theta_1,\theta_2$

φ_1, φ_2



Monte Carlo simulations

The model:

- One fission fragment (FF) is emitted isotropically and detected in the ionization chamber with perfect angular resolution.
- FF spins are perfectly aligned in the plane perpendicular to the fission axis.
- Neutrons are emitted anisotropically with respect to the fragment spin:

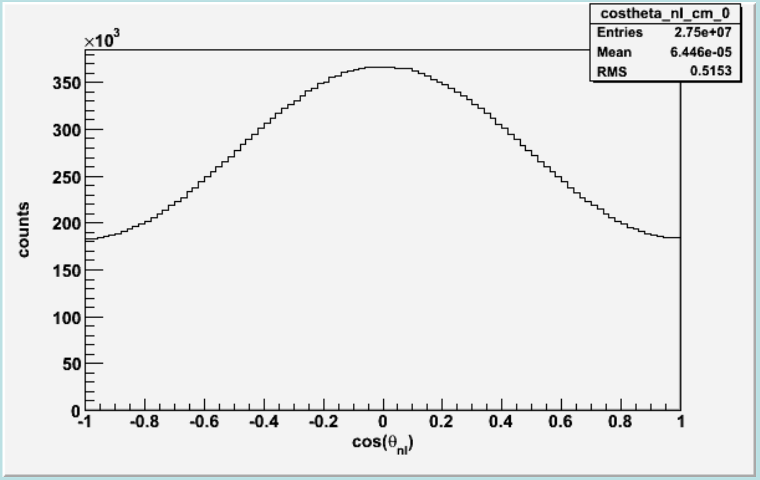
$$W \propto 1 + A \cdot \sin^2 \theta$$

θ - angle between n and I

A – anisotropy coefficient (can be varied)

- Neutrons are detected with 100% efficiency, no cross-talk between neighboring detectors
- Double neutron coincidences are simulated.
- “Control” simulation is performed with zero anisotropy

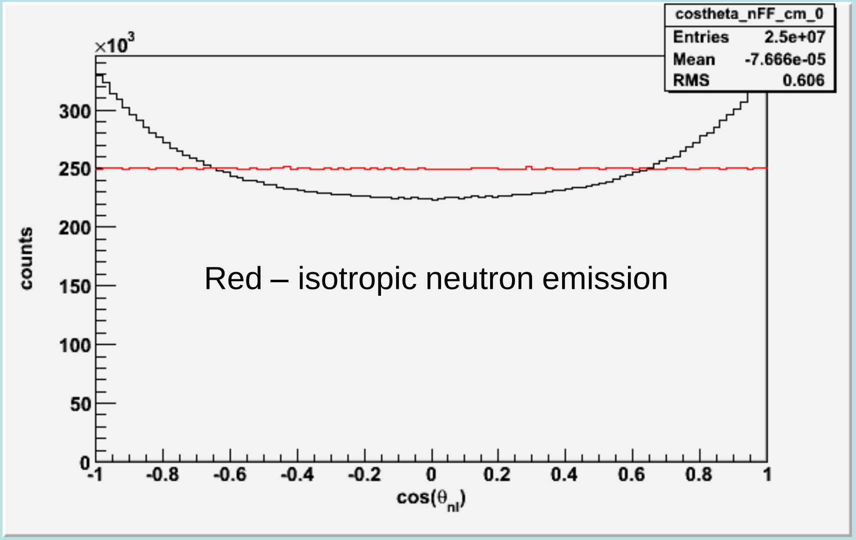
Monte Carlo simulations



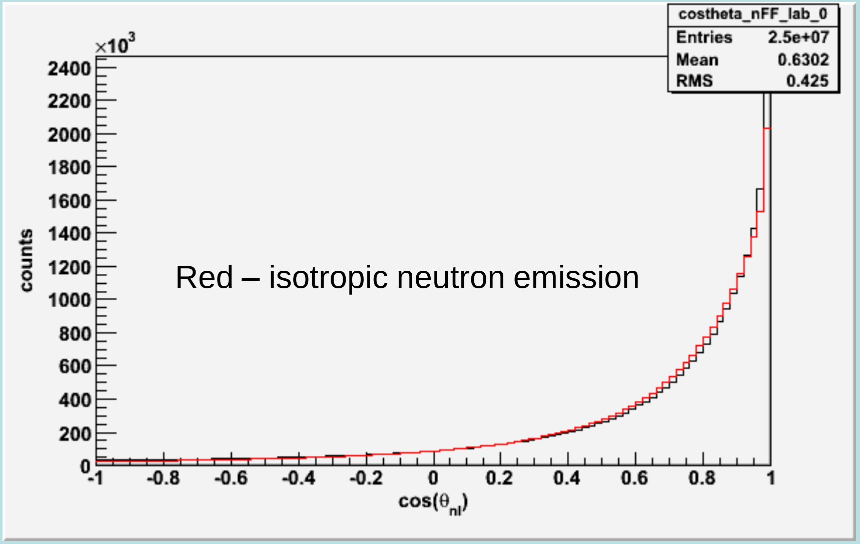
Angle between neutron and fragment spin (c.m. system) A=1.

$$W \propto 1 + A \cdot \sin^2 \theta$$

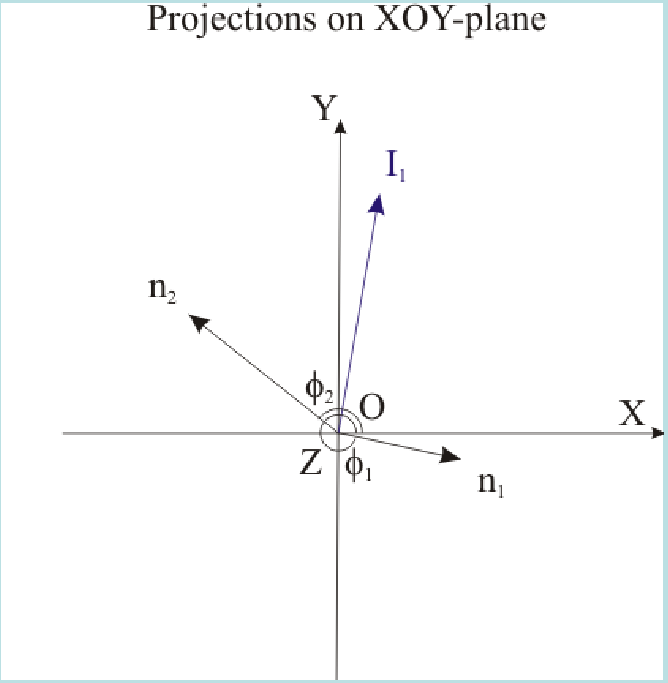
Angle between neutron and FF (c.m. system) A=1.

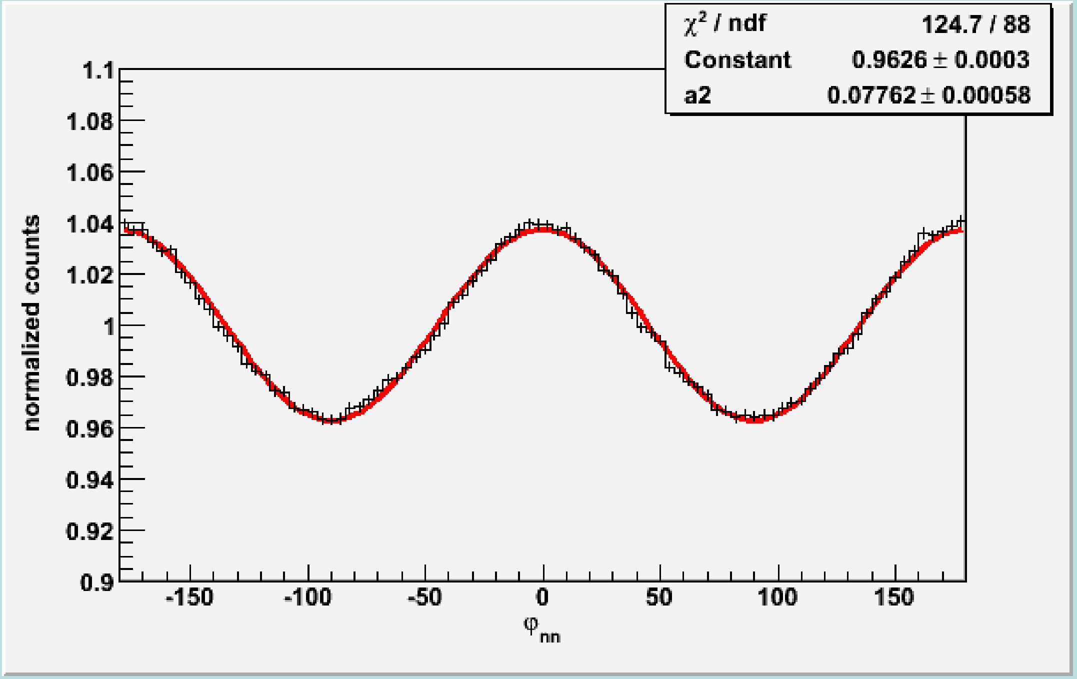


Angle between neutron and FF (lab system) A=1.



Monte Carlo simulations



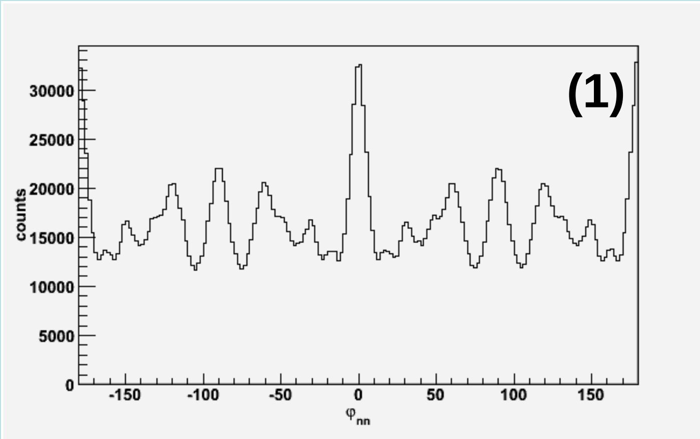


Projection of the n-n angular distribution onto the XY plane (perpendicular to the fission axis).

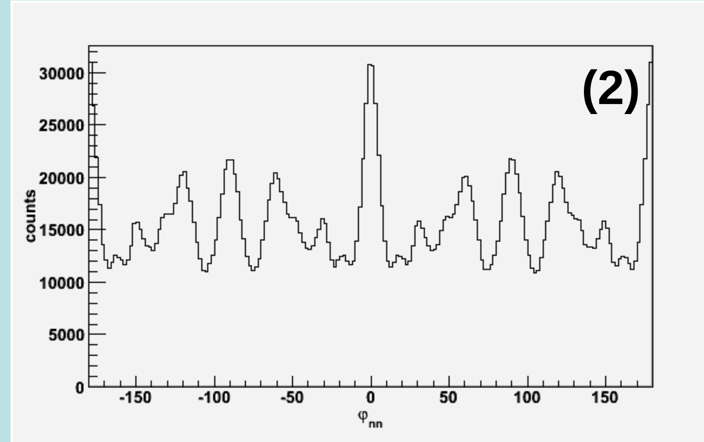
Original distribution θ_{nl} $W \propto 1 + A \cdot \sin^2 \theta$ A=1 A=0.08

Projection angle φ_{nn} $W \propto 1 + a \cdot \cos^2 \varphi$ a=0.08

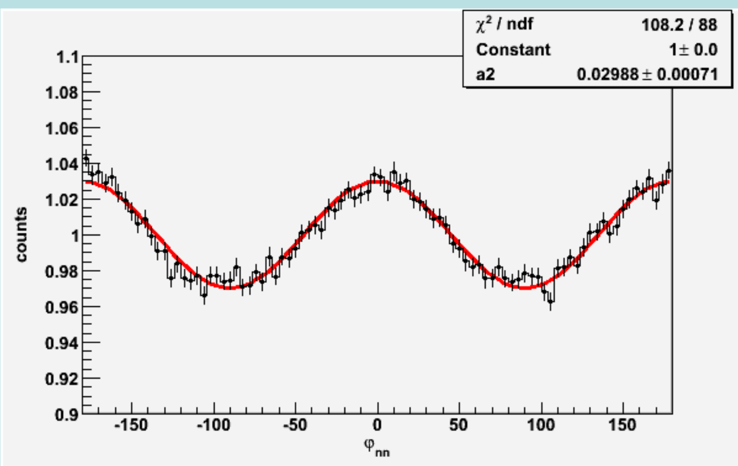
Monte Carlo simulations



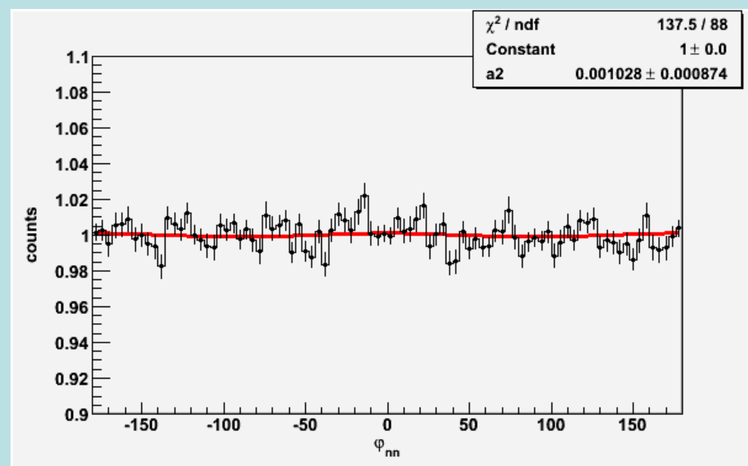
Distribution of angle φ_{nn} detected by DEMONs



Distribution of angle φ_{nn} for the isotropic emission.

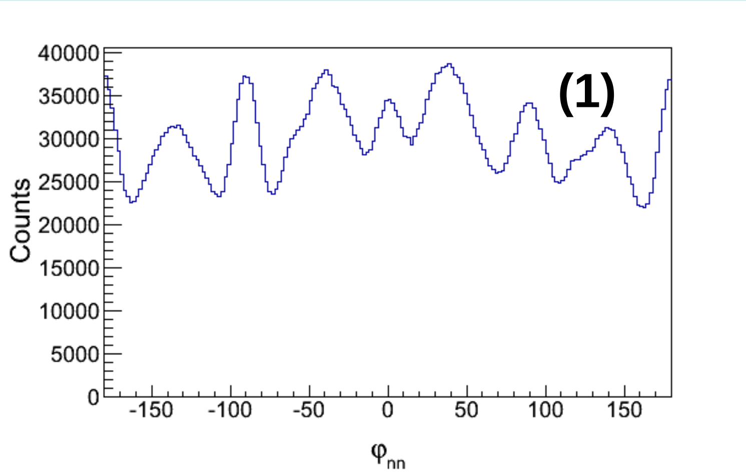


Normalized distribution (1)/(2)

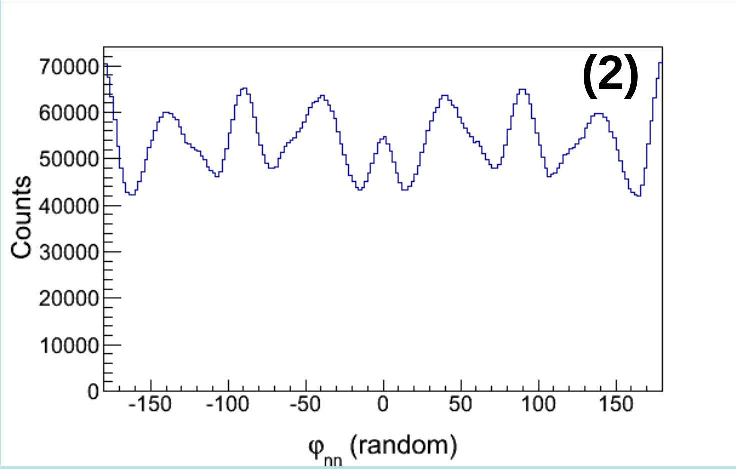


Normalized distribution with zero anisotropy

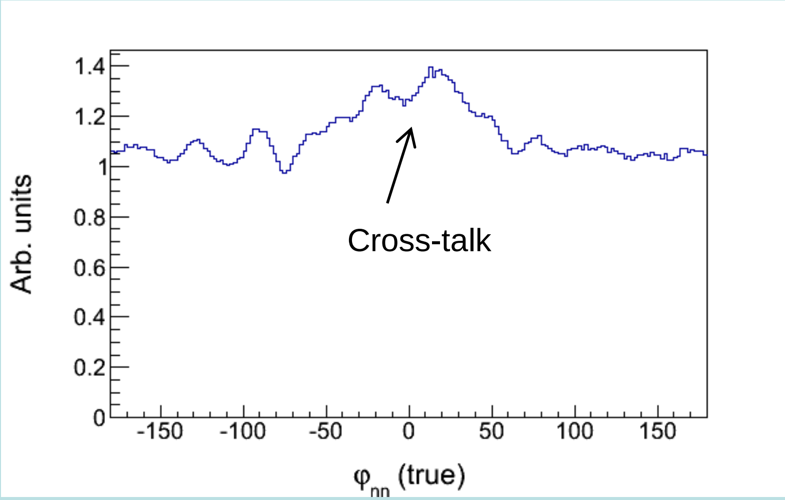
Experimental results



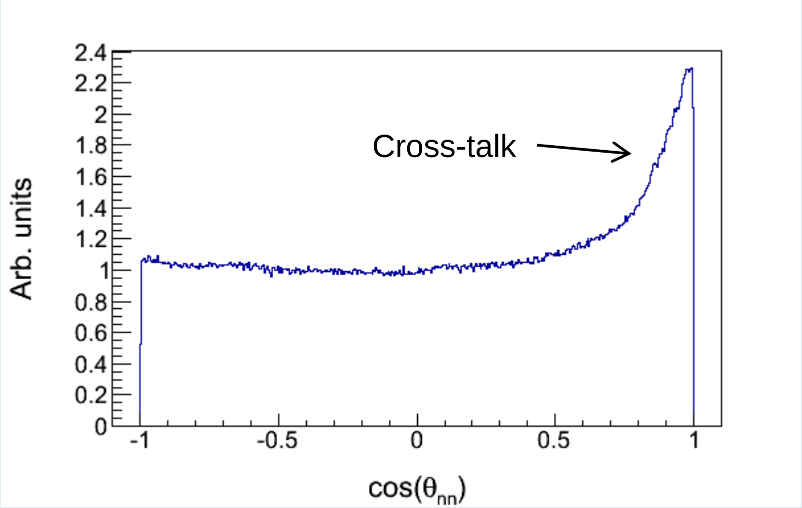
Distribution of angle φ_{nn} detected by DEMONs



Distribution of angle φ_{nn} from two different events.

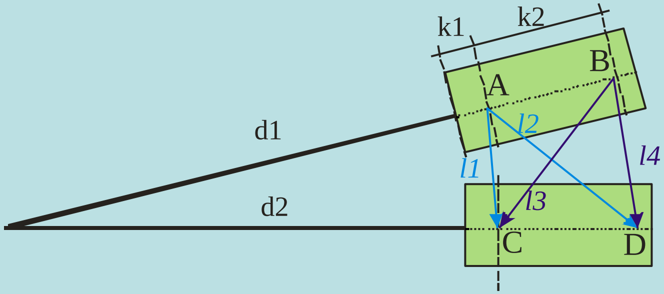


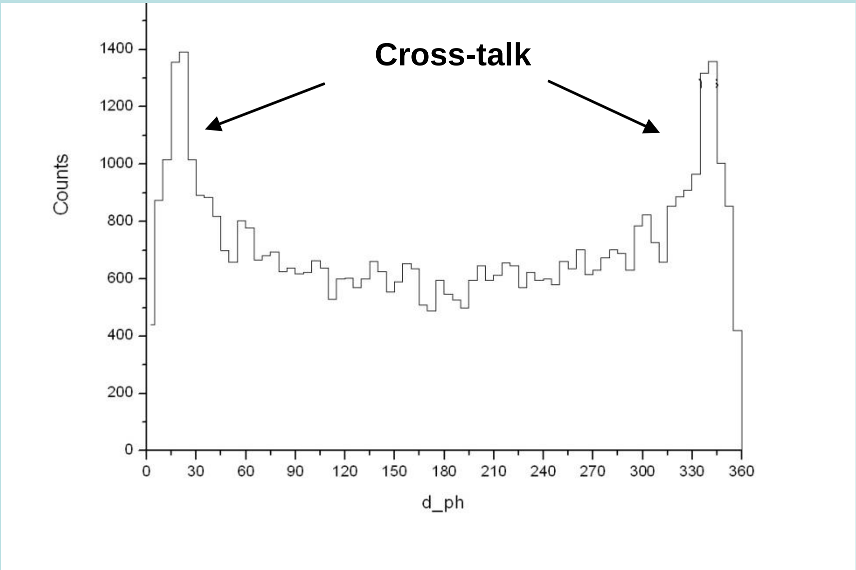
Normalized distribution (1)/(2)

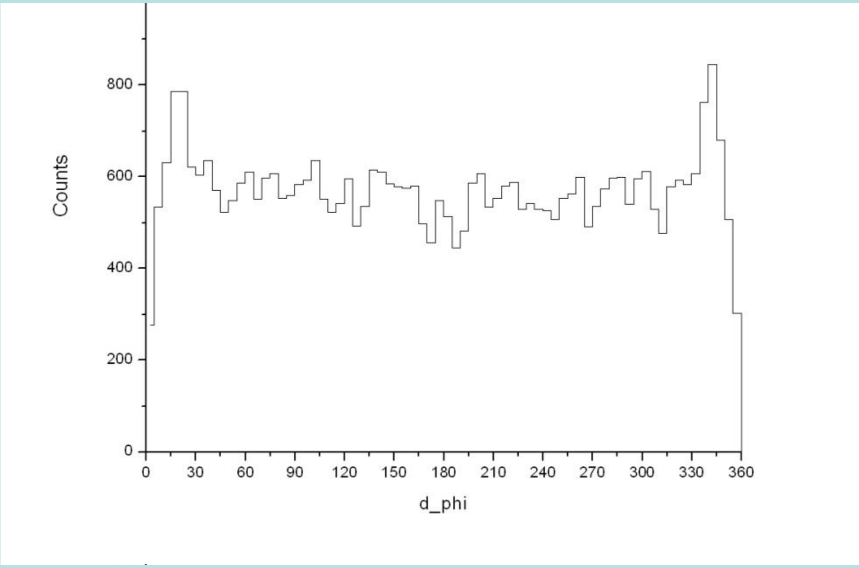


Cosine of angle between two neutrons

"Cross talk" rejection procedure



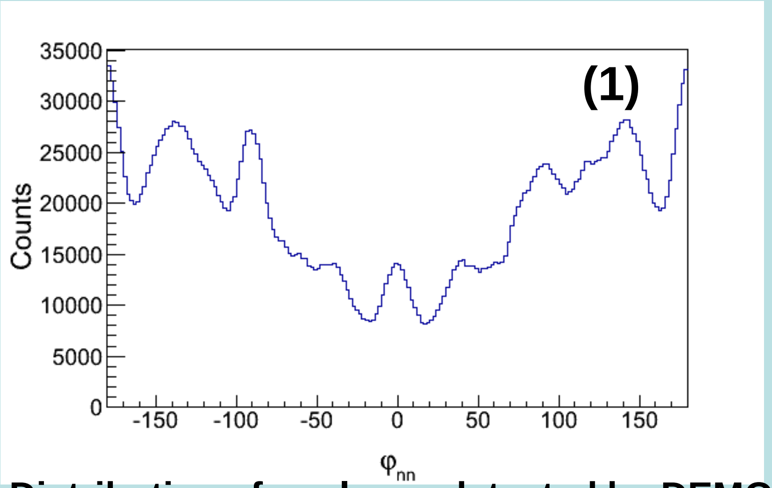




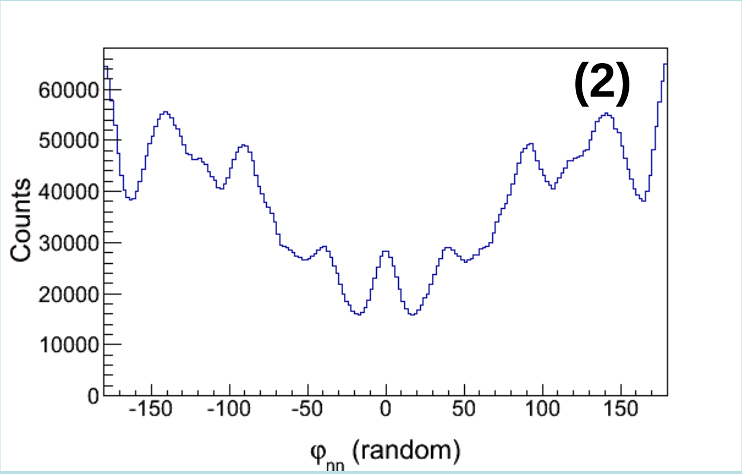
Distribution of φ angles between two neutrons

The same distribution after applying the cross talk rejection filter

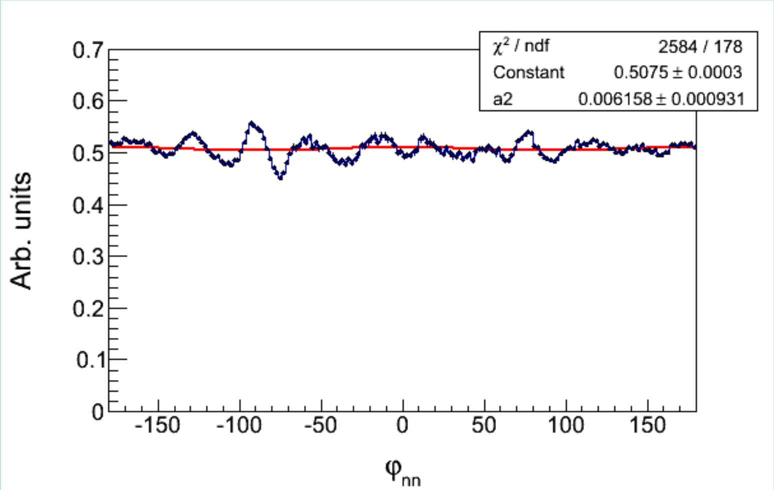
Experimental results – after elimination of the neutron "cross talk"



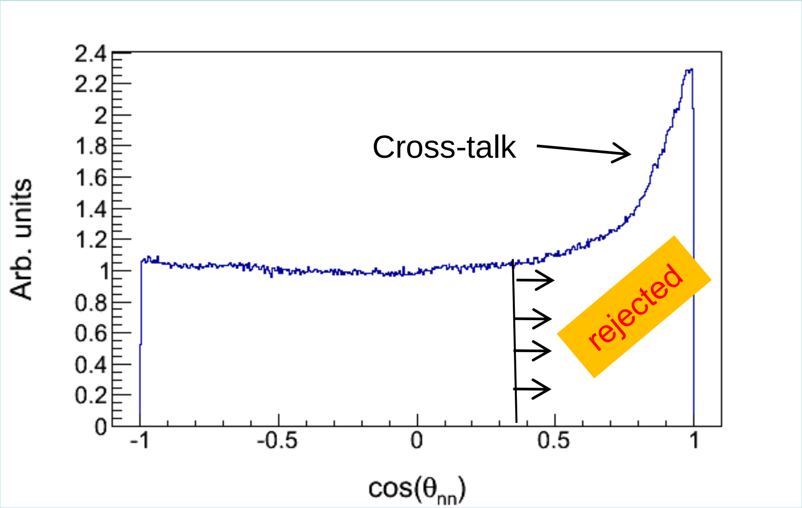
Distribution of angle φ_{nn} detected by DEMONs



Distribution of angle φ_{nn} from two different events.



Normalized distribution (1)/(2)



Cosine of angle between two neutrons

Summary

- A new type of experiment has been performed, which allows to measure triple neutron-neutron-fission fragment correlations.
- A new type of data evaluation procedure is proposed, which allows to take into account precisely the geometrical and intrinsic efficiency of the DEMON detectors.
- Statistical accuracy is sufficient to detect the effect at the level of $\sim 10^{-4}$.
- The anisotropy of neutron emission is directly observed in the plane perpendicular to the fission axis.
- The resulting a2 coefficient **$(6 \pm 3) \times 10^{-3}$** in the projection plane corresponds to the neutron emission anisotropy of about **8%.**
- The uncertainty of the obtained coefficient is mainly due to systematic errors caused by the “cross talk” between DEMON detectors and imperfectness of the geometry and efficiency correction procedure.

Thank you
for your attention!