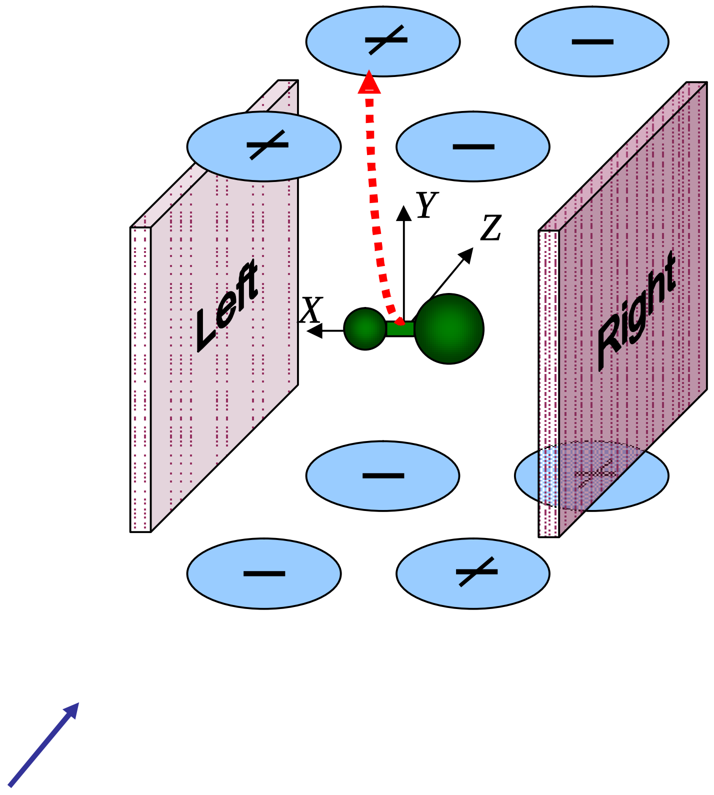
Rotation of Nuclear System

in Monte-Carlo Calculations of α-Particle and Fission Fragments Trajectories

Experimental Setup for Search of the TRI-Effect



Search for a TRIple correlation B :

$B = (\boldsymbol{\sigma}\cdot[\mathbf{p}_{LF} \times \mathbf{p}_{TP}])$

(note: all vectors are unit vectors)

Angular distribution of TPs :

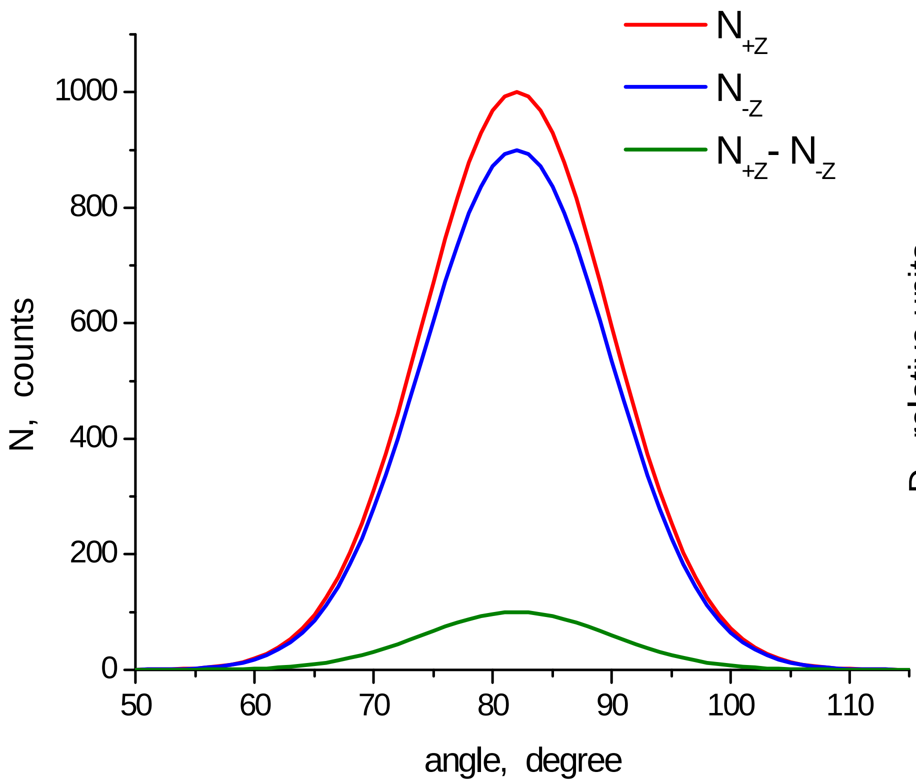
$W(\theta)\, d\Omega \sim \{1 + D\cdot B(\theta)\}\, d\Omega$

where D measures size of correlation.

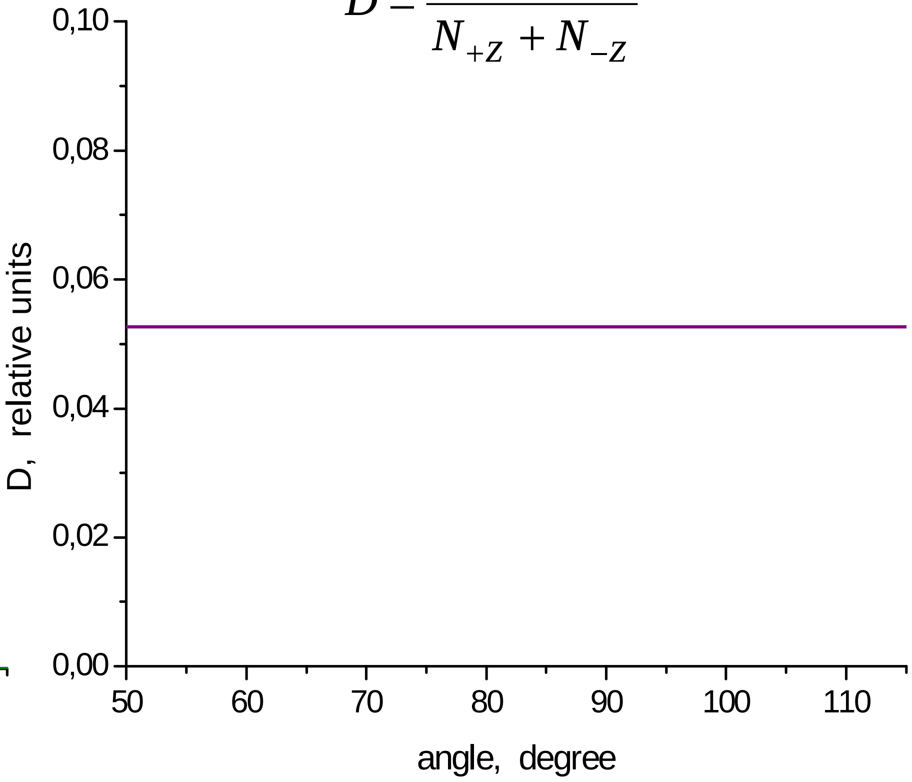
Experiment: $D = (N_{+z} - N_{-z}) / (N_{+z} + N_{-z})$

Result : **count rates** for LF to the Left and TP upwards are **different** for $s_Z = +\frac{1}{2}\hbar$ and $s_Z = -\frac{1}{2}\hbar$,

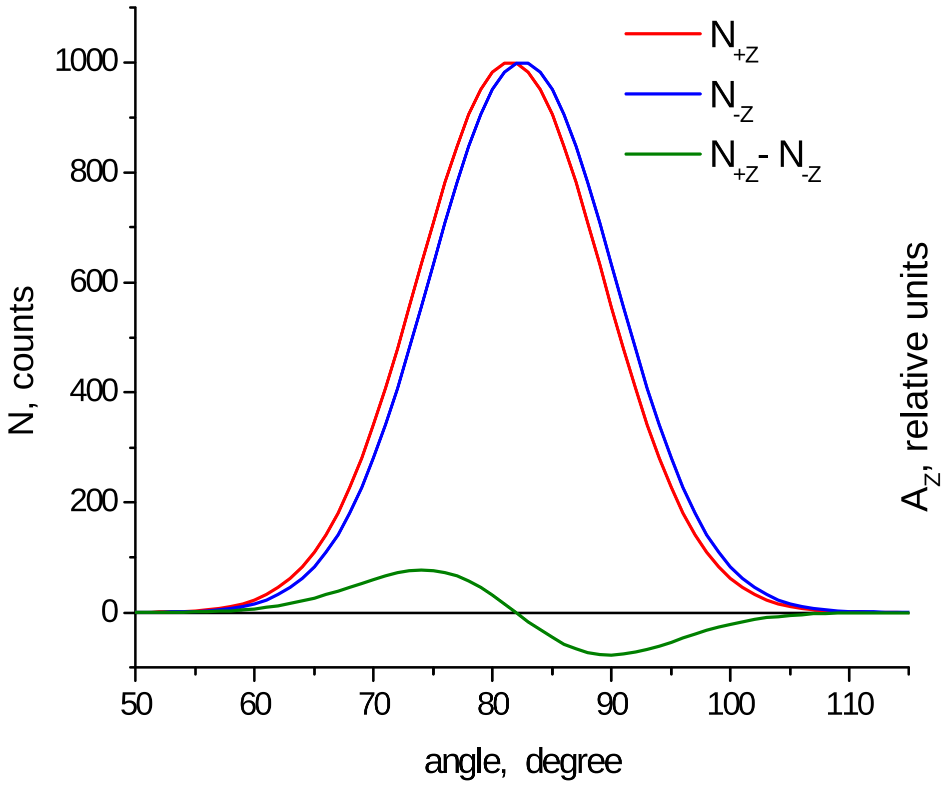
TRI-effect
Angular Distributions for Detector Combination: Left-Up.
Red line - $P_Z>0$ ($s_Z=+1/2\hbar$), blue line – $P_Z<0$ ($s_Z=-1/2\hbar$), (D>0).



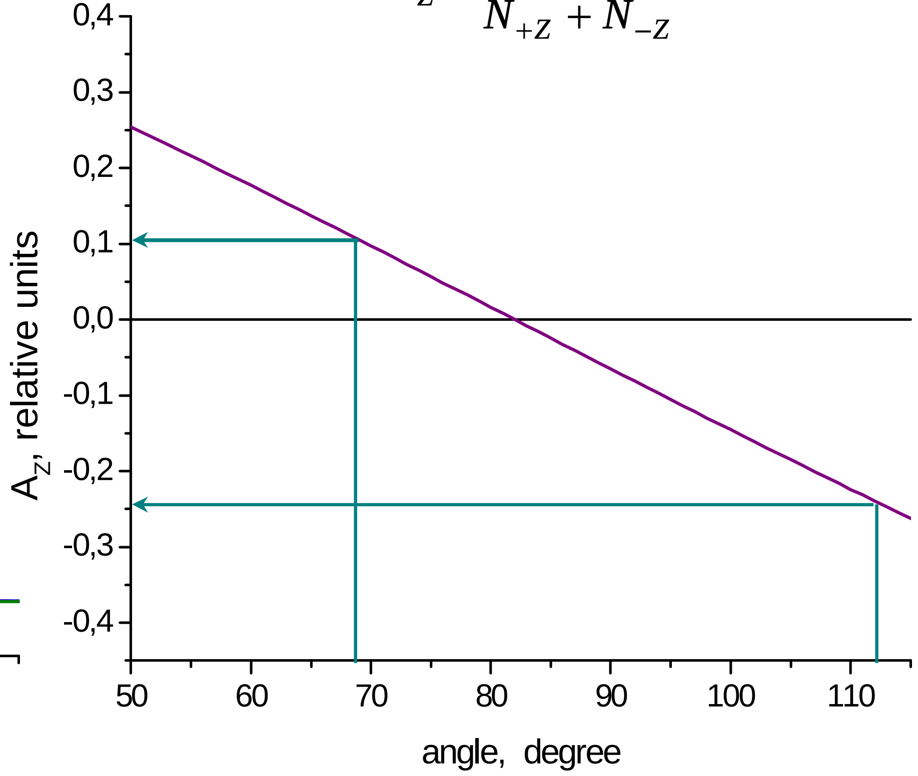
$$D = \frac{N_{+Z} - N_{-Z}}{N_{+Z} + N_{-Z}}$$



ROT-effect for Z-polarization. Angular Distributions for Detector Combination: Left-Up. Red line - $P_Z>0 \leftrightarrow \omega_Z>0$, blue line – $P_Z<0 \leftrightarrow \omega_Z<0$



$$A_Z = \frac{N_{+Z} - N_{-Z}}{N_{+Z} + N_{-Z}}$$



Rotation motion in deformed nuclei

$$E_{rot} = \frac{\hbar}{2\Im}\cdot(J(J+1)-K^2),$$

$$\vec{R} = \vec{J} - K\cdot\vec{n}$$

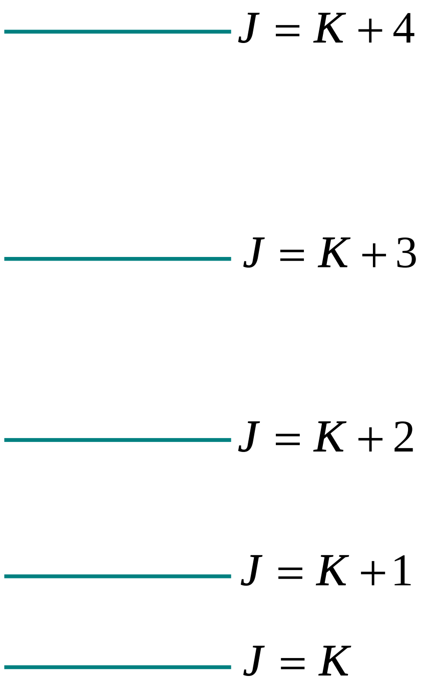
$$\omega^2\Im^2 = \hbar^2(J(J+1)-K^2)$$

$where\ J - total\ momentum,$

$K - its\ projection$

$\Im - moment\ of\ inertia$

$$J^+ = I + 1/2 \qquad J^- = I - 1/2$$



$J = K+4$

$J = K+3$

$J = K+2$

$J = K+1$

$J = K$

$$P(J^+) = \frac{2I+3}{3\cdot(2I+1)}\cdot P_n \quad for \quad J^+ = I + 1/2$$

$$P(J^-) = -\frac{1}{3}\cdot P_n \quad for \quad J^- = I - 1/2$$

Parameters for target nucleus ^{235}U:

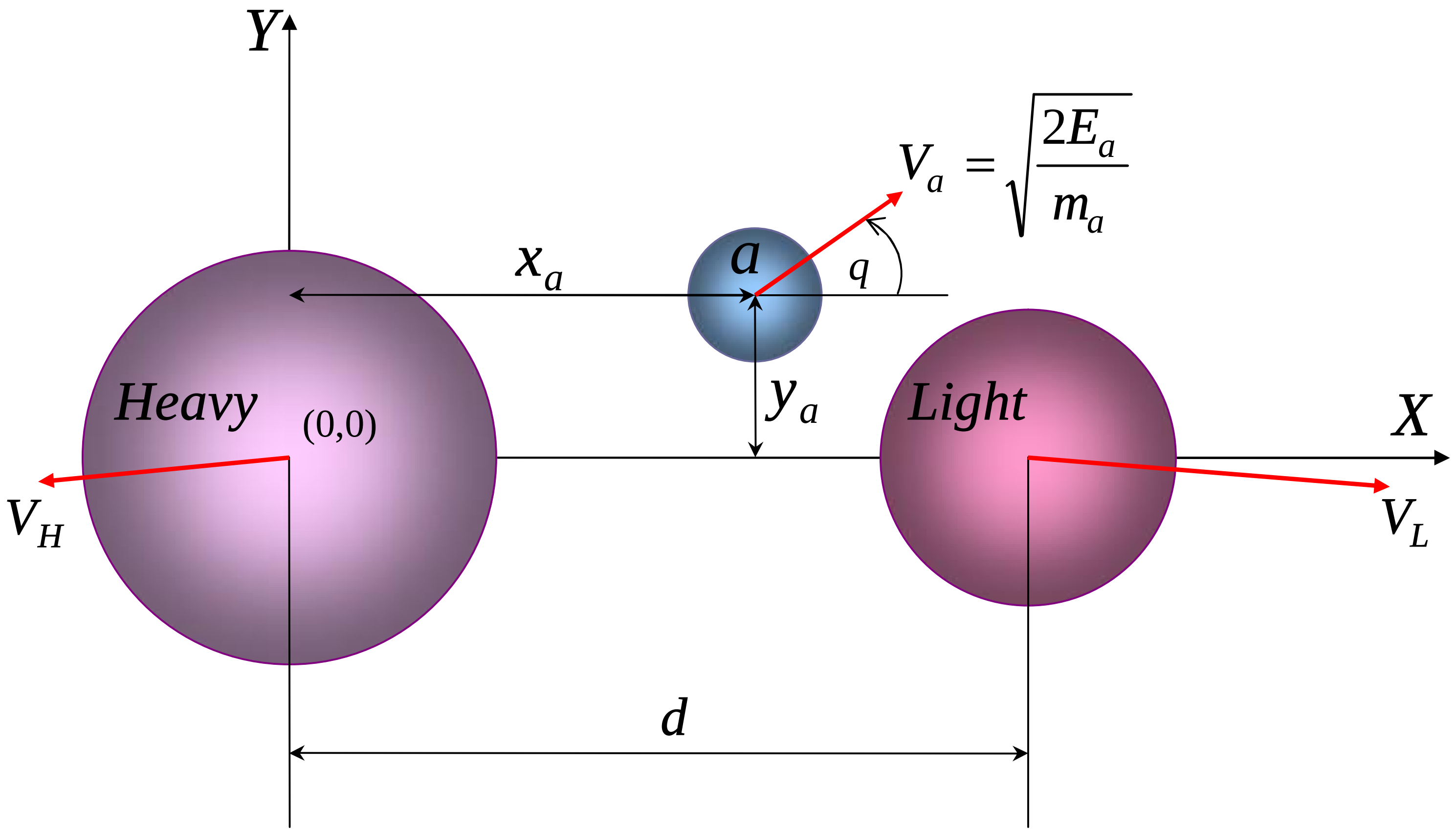
Angular momentum of target nucleus *I* =7/2

The contributions of $\sigma(J^+)$ and $\sigma(J^-)$ to the fission cross-section:

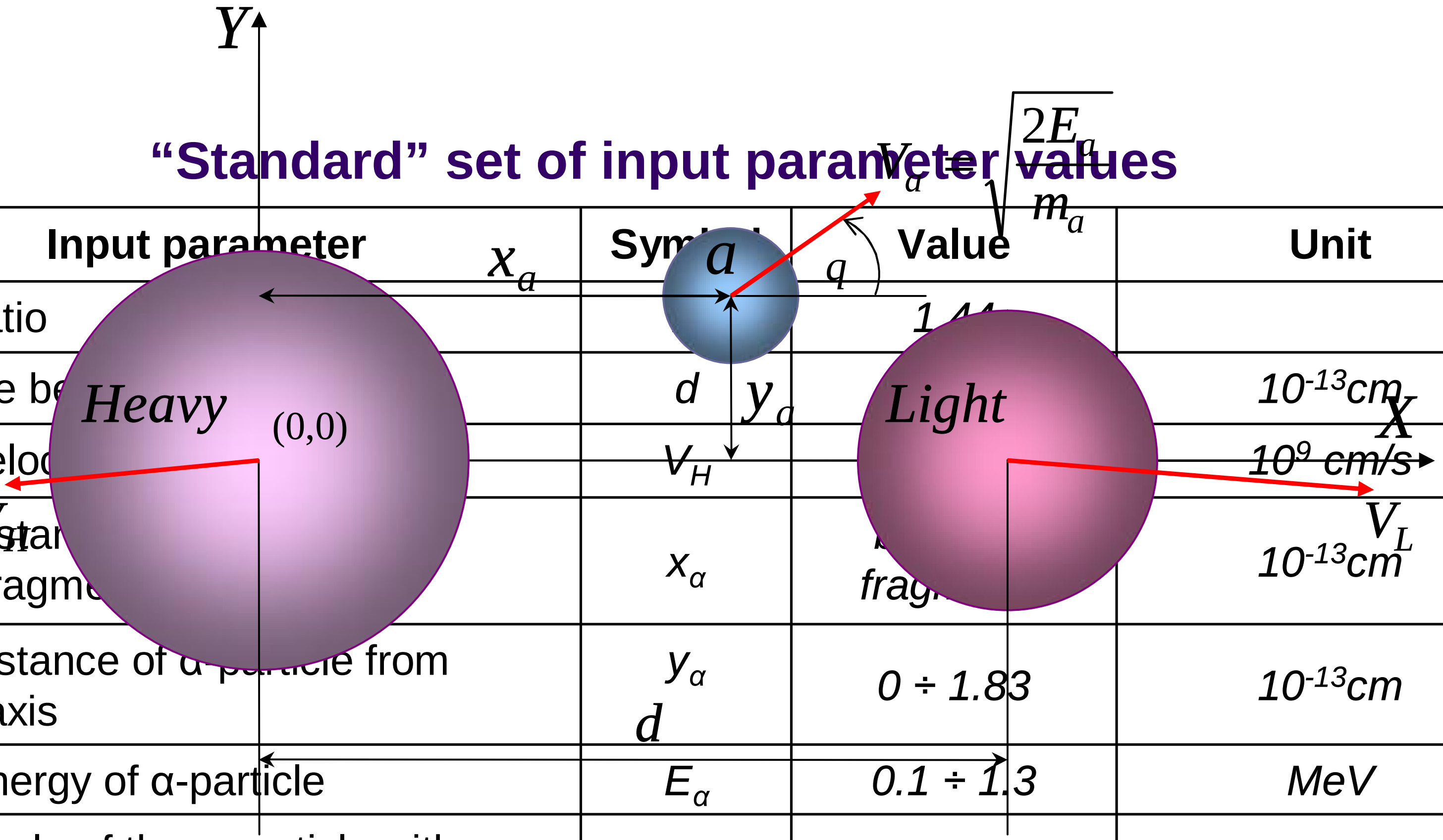
$$\sigma(J^+ = 4) = 553\,b \quad and \quad \sigma(J^- = 3) = 323\,b$$

$$P(J^+) = 5/12\cdot P_n \qquad P(J^-) = -1/3\cdot P_n$$

Schematic diagram of the initial parameters of the calculation



“Standard” set of input parameter values



Input parameter	Symbol	Value	Unit
Mass ratio		1.44	
Distance be	*d*		10^{-13}cm
Initial veloc	V_H		10^{9} cm/s
Initial dista heavy fragme	x_α	frag	10^{-13}cm
Initial distance of α-particle from fission axis	y_α	0 ÷ 1.83	10^{-13}cm
Initial energy of α-particle	E_α	0.1 ÷ 1.3	MeV
Initial angle of the α-particle with respect to the fission axis	θ_α	0 ÷ 180	degree

The motion of the three fragments under the influence of their mutual Coulomb interaction cannot be calculated in closed form. The trajectories must therefore be calculated numerically.

The equations of motion are:

$$\frac{dX_{ij}}{dt} = V_{ij}$$

$$m_i \frac{dV_{ij}}{dt} = F_{ij}$$

where

X_{ij} is the jth coordinate X_j of ith particle,

V_{ij} the j component of the velocity V_i

F_{ij} the j component of the force F_i acting on the ith particle,

m_i its mass.

These equations are replaced by the difference equations:

$$X_{ij}^{n+1} = X_{ij}^{n} + \tilde{V}_{ij}^{n}\Delta t,$$

$$V_{ij}^{n+1} = \tilde{V}_{ij}^{n} + \frac{1}{2m_i}F_{ij}^{n}\Delta t,$$

where $\tilde{V}_{ij}^{n} = V_{ij}^{n} + \frac{1}{2m_i}F_{ij}^{n}\Delta t$

and F_{ij}^{n} is the j component of the force acting on particle i at the position X_i^n

$$\vec{F}_i^{\,n} = e^2 Z_i \sum_{k=1}^{2} Z_k \frac{\vec{X}_i^{\,n} - \vec{X}_k^{\,n}}{\left|\vec{X}_i^{\,n} - \vec{X}_k^{\,n}\right|^3}$$

The subscript k refers to the two other particles, and the superscript n refers to the value of the parameter after nth time interval.

The size of time interval is not chosen to be constant.
The total time t_n after n time intervals is an exponential function of n:

$$t_n = t_0 e^{na},$$

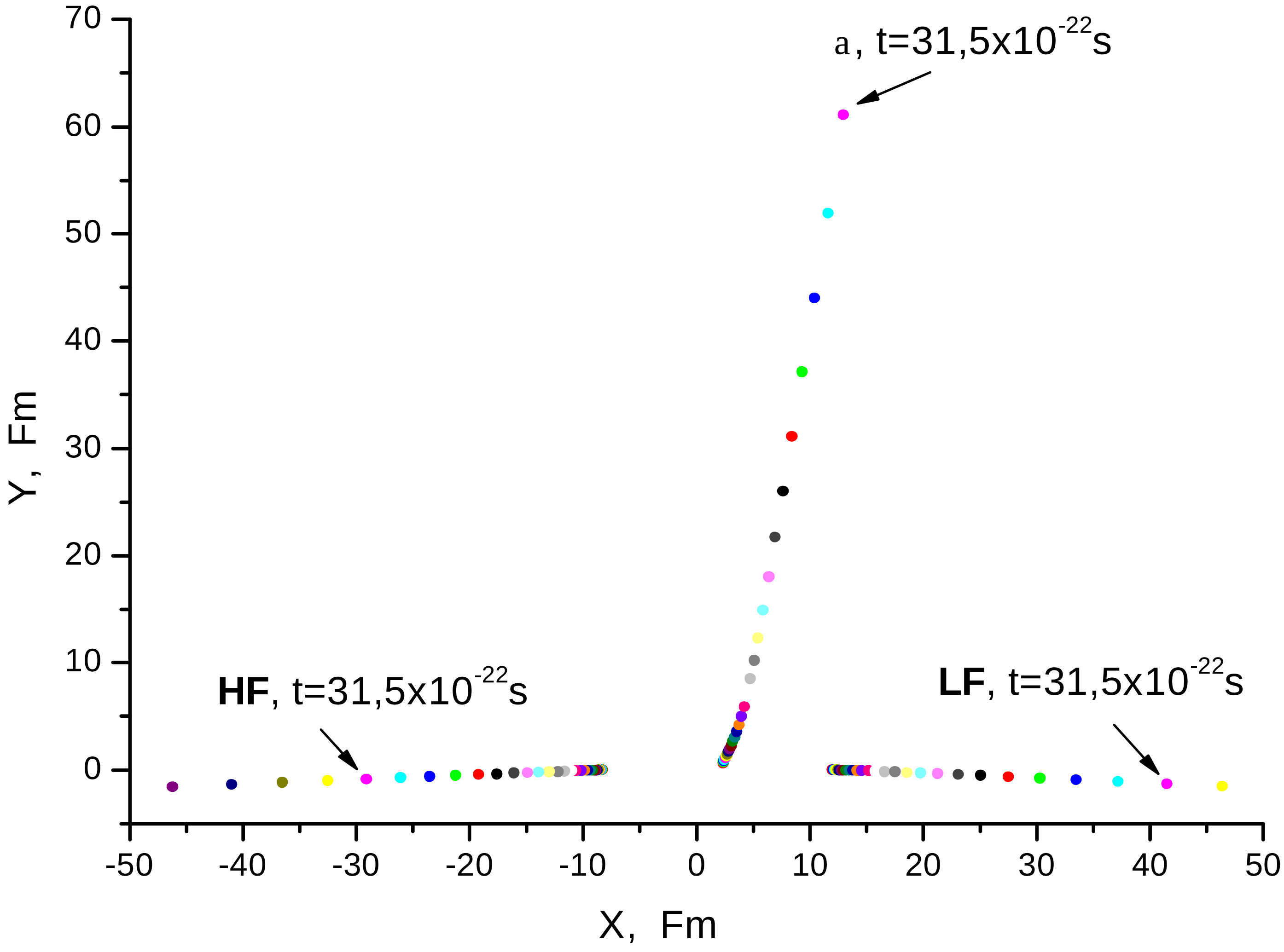
and hence the size of the nth time interval is given by

$$\Delta t_n = t_n - t_{n-1} = t_{n-1}(e^a - 1)$$

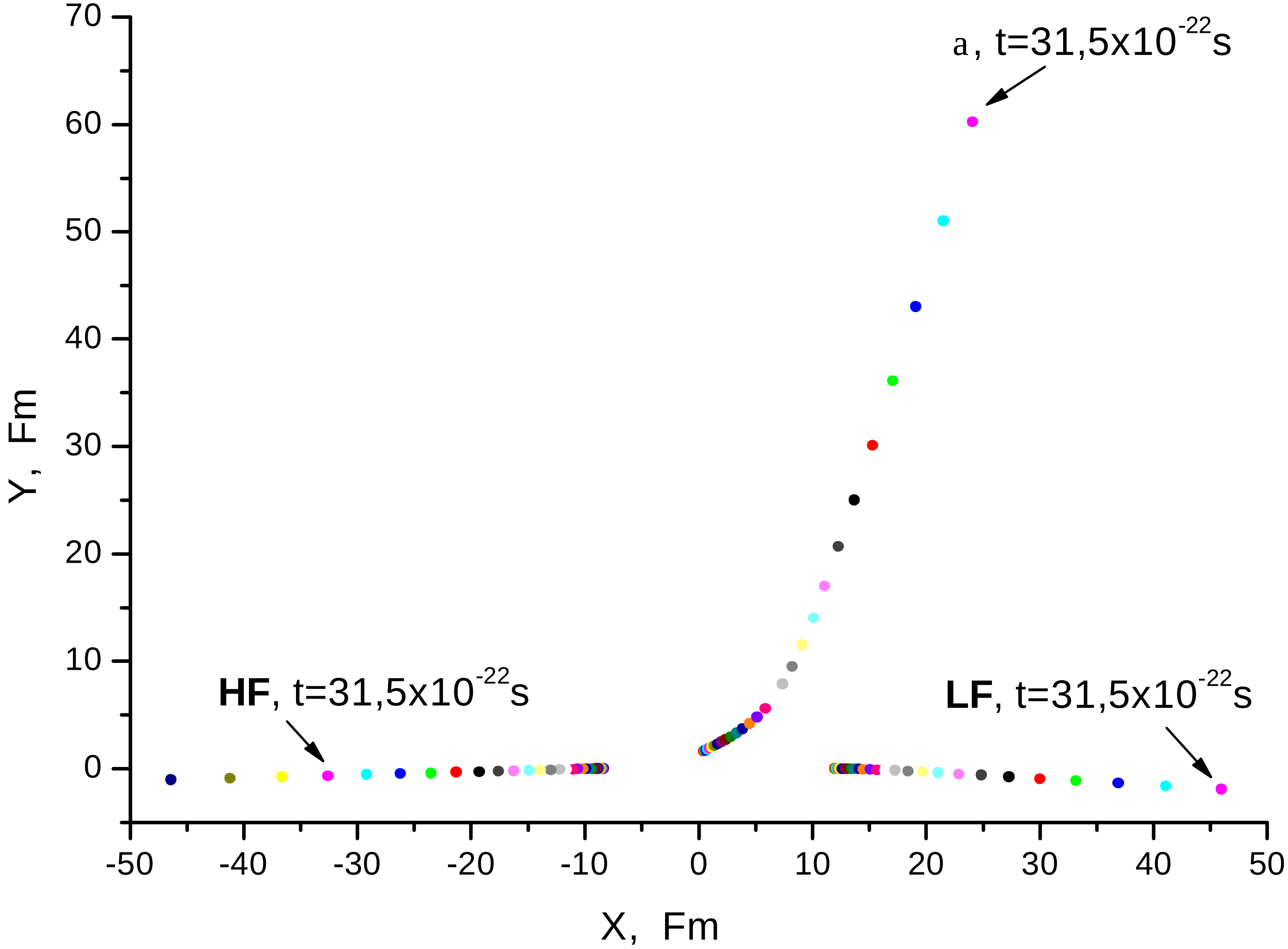
The parameter t_0 determines the accuracy of the calculation at the beginning of the trajectory ($t = 0$).

The parameter a determines the accuracy of the calculation at the end of the trajectory ($t = \infty$).

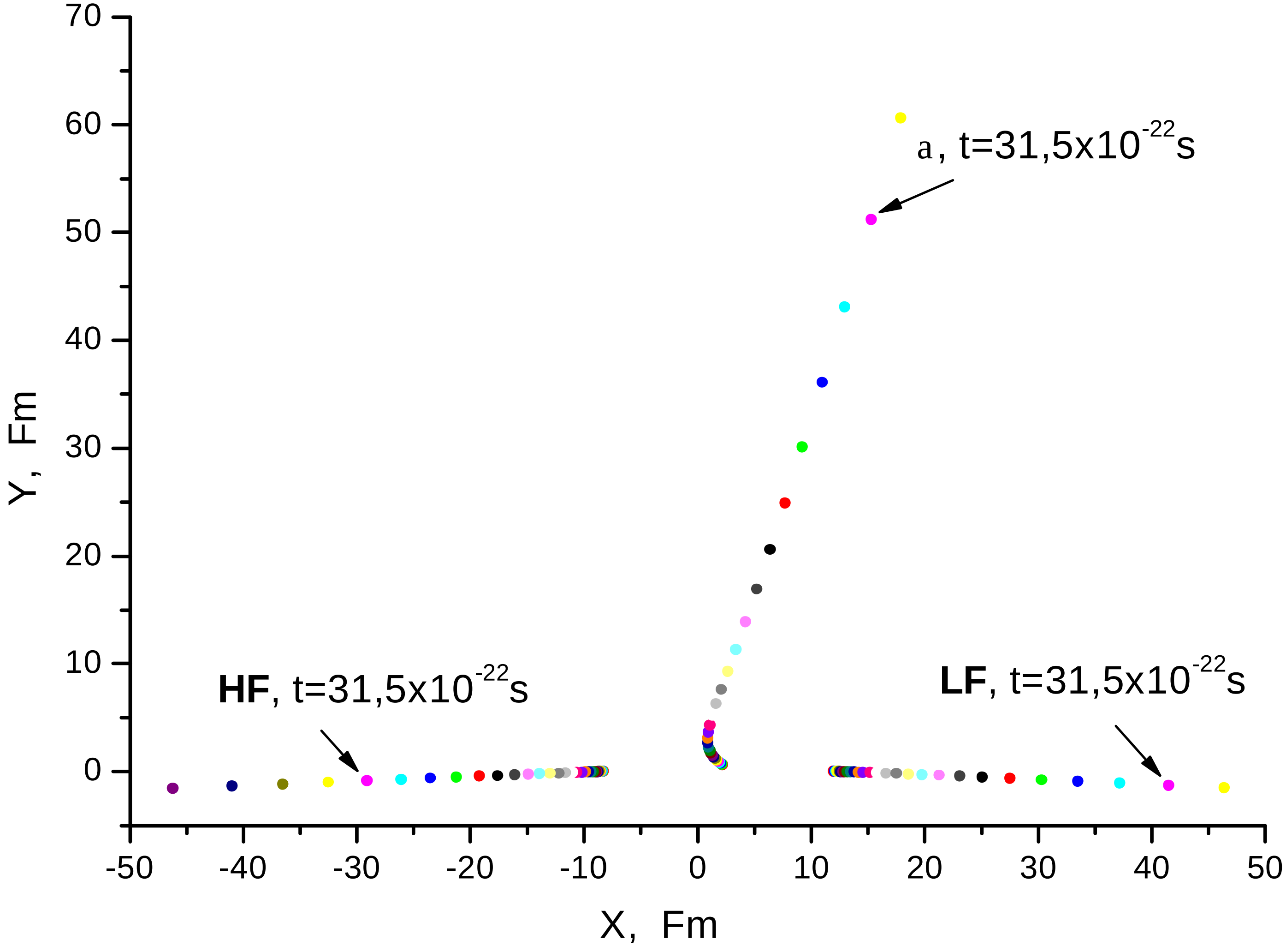
Patterns of LF, HF and α-particle Trajectories



Patterns of LF, HF and α-particle Trajectories

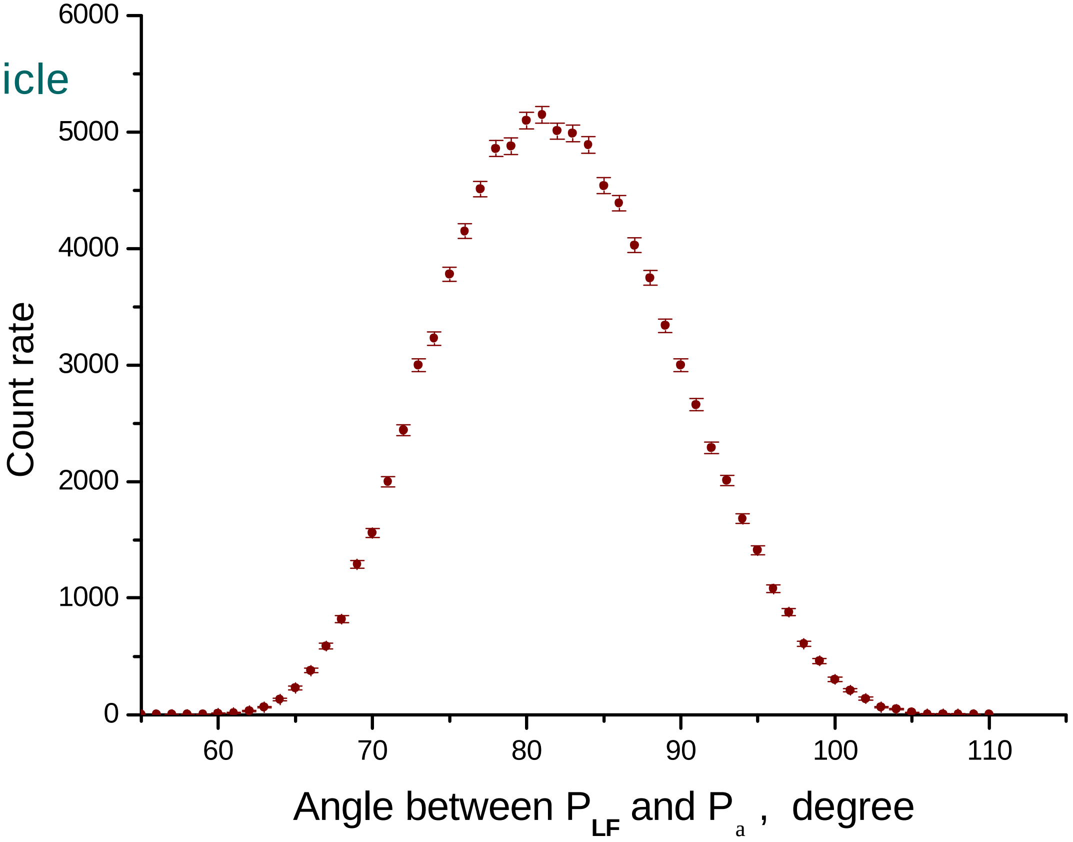


Patterns of LF, HF and α-particle Trajectories

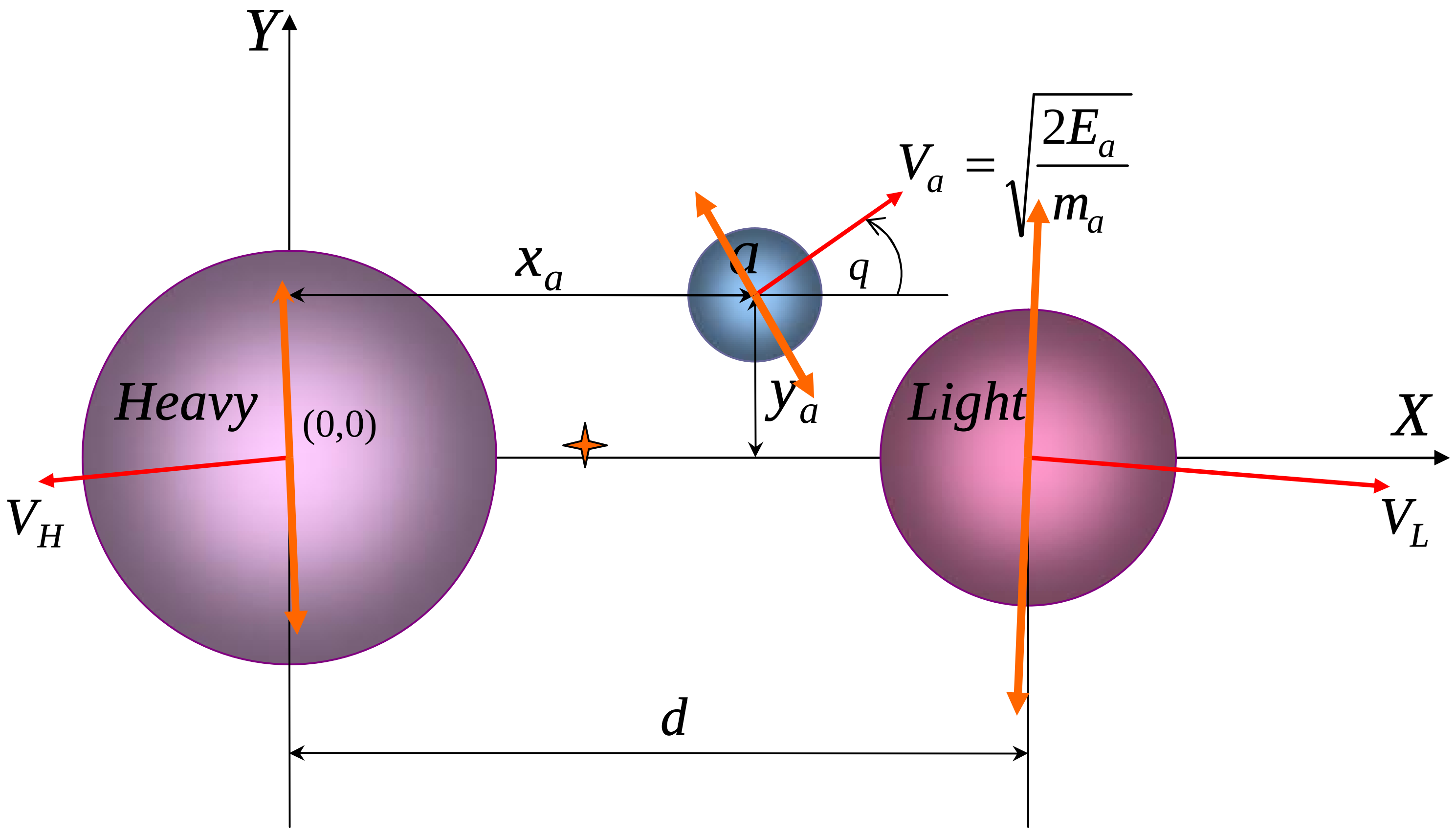


The choice of initial parameters must led up to a coincidence experimental and calculated distributions:

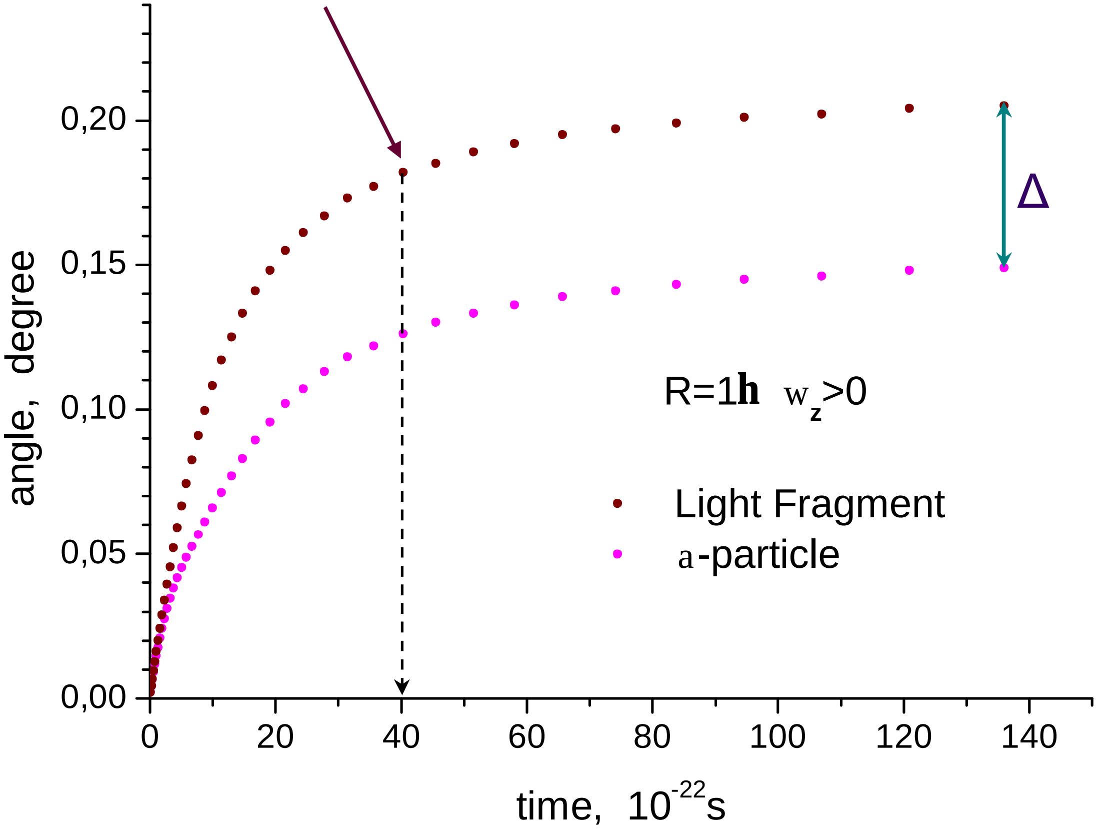
- Light and heavy fragment's mass distributions
- Total kinetic energy distribution
- α-particle energy distribution
- Angular distribution of α-particle



Schematic diagram of the initial parameters of the calculation in case of nuclear system rotation

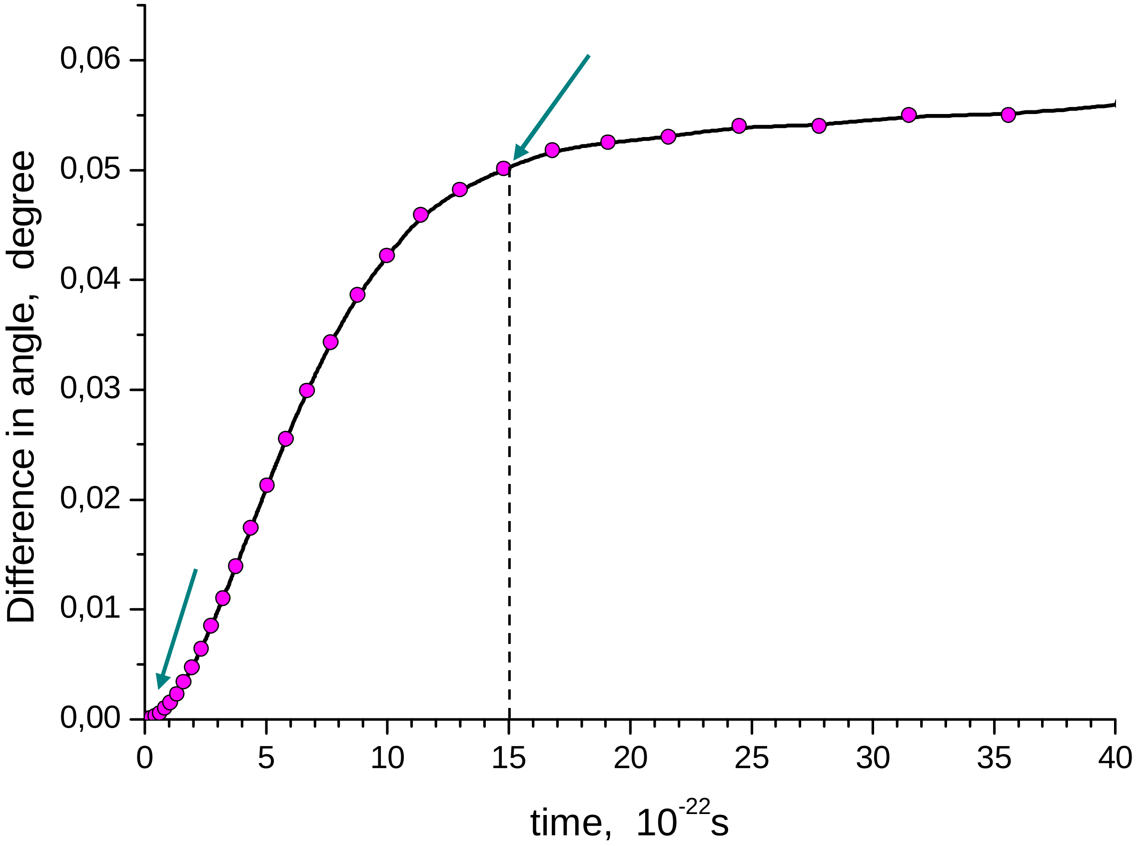


Angels of rotation of the Light fragment and α-particle in laboratory coordinates system. While system rotates α-particle carried along, but lags behind.

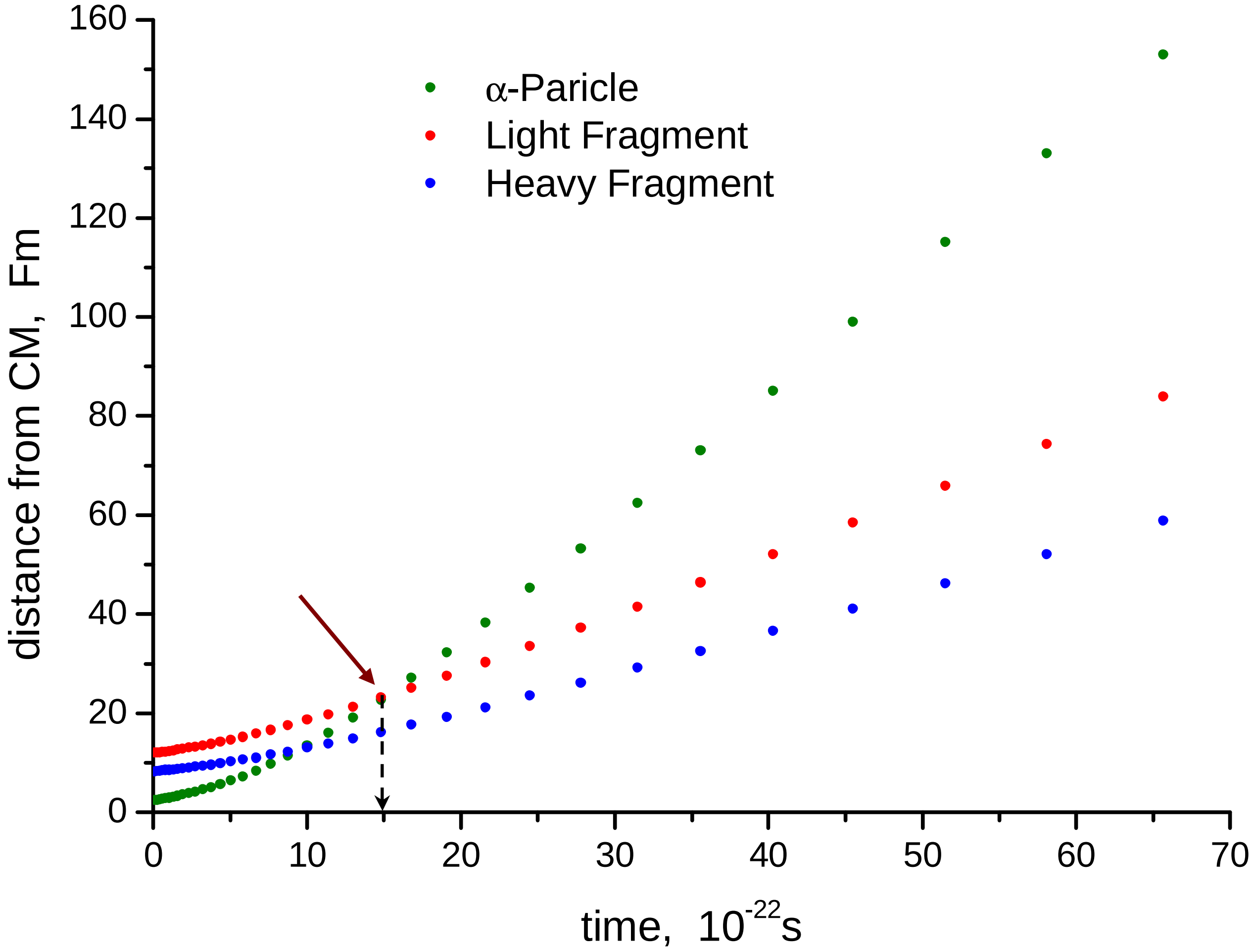


$A_Z \sim 2\Delta$

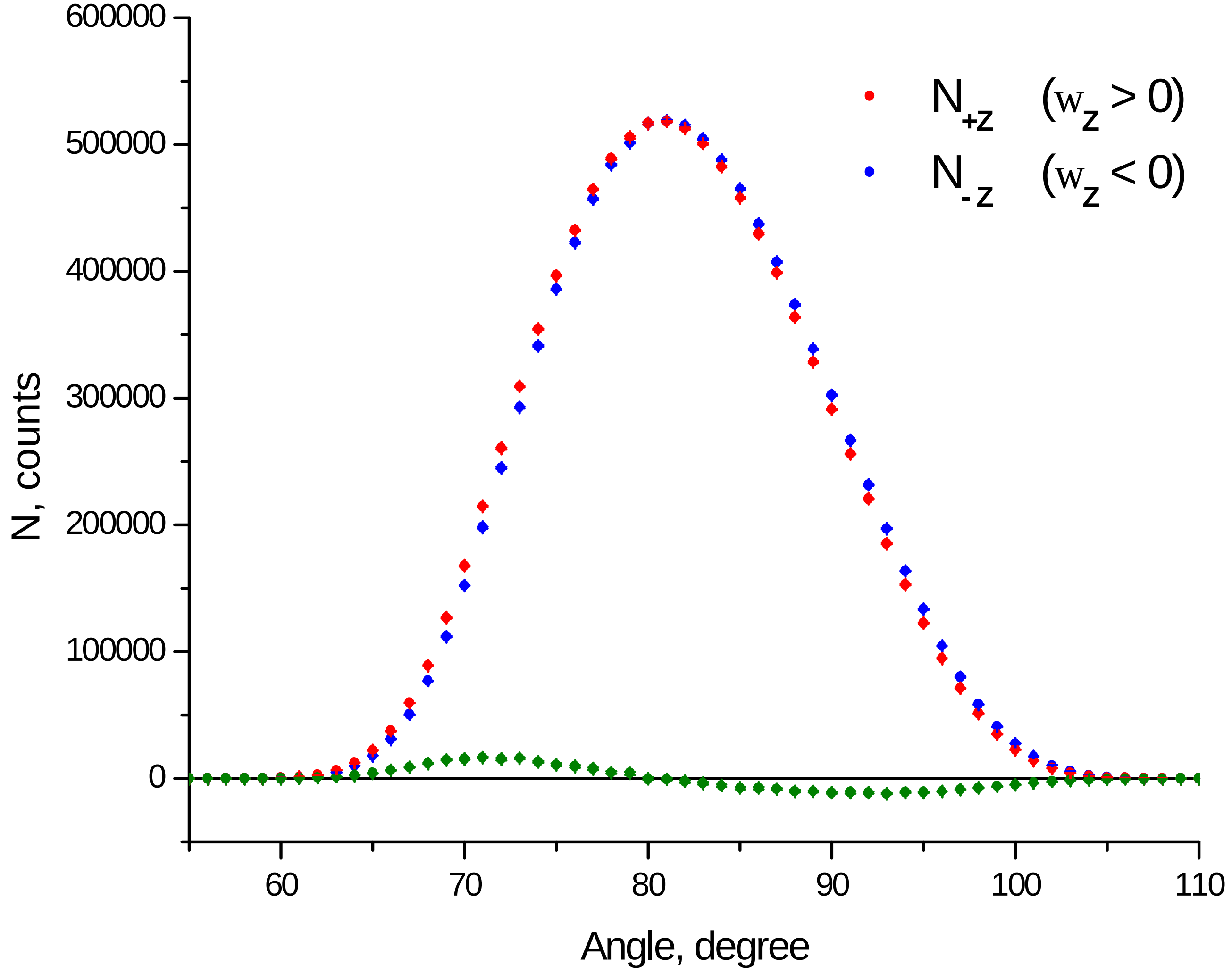
Difference in angle between Light fragment and α-particle as a function of time



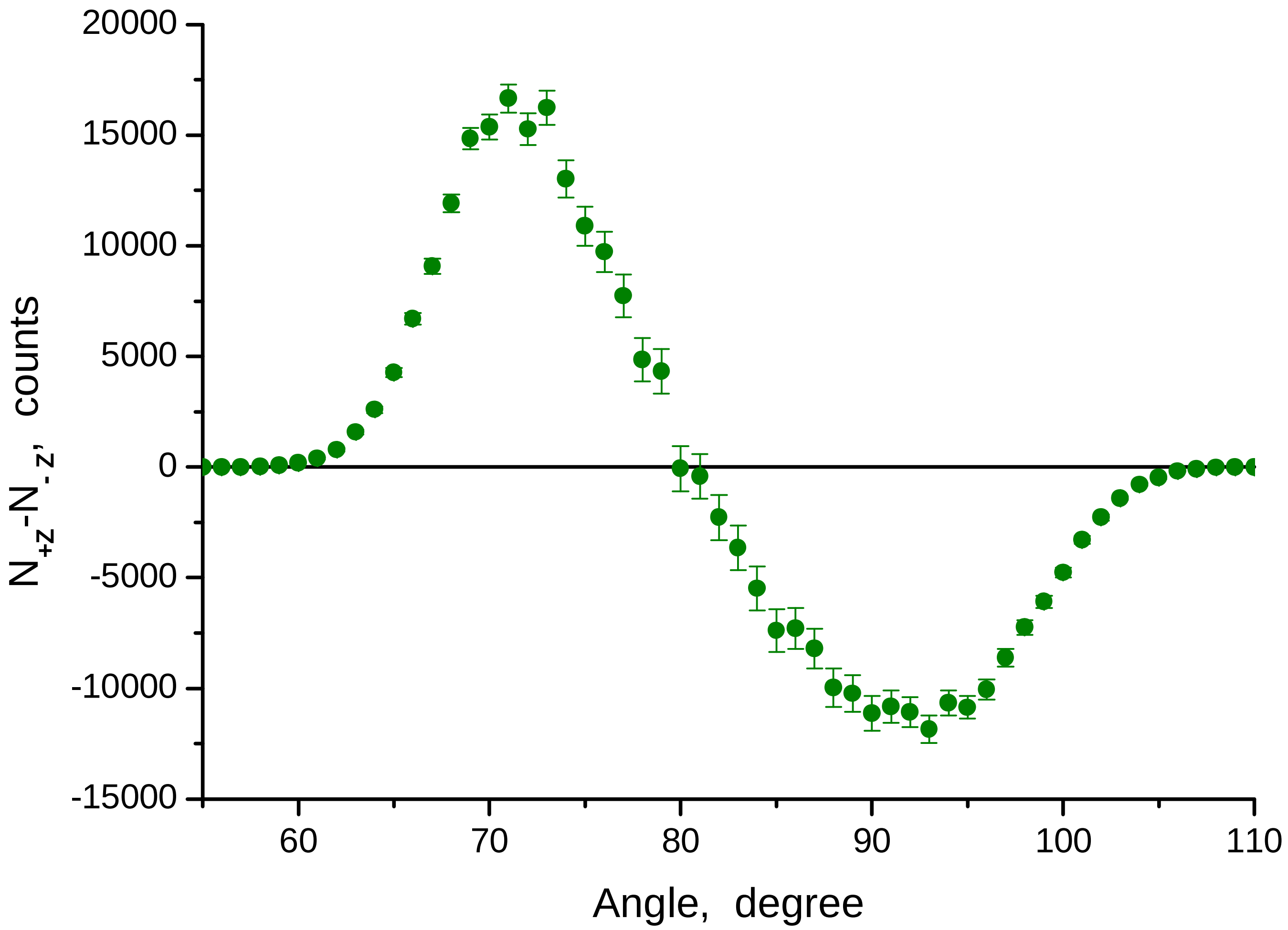
Distance of ternary fission products from center of mass



Influence of a nuclear system rotation on α-particle angular distributions (calculation with R=2ħ)



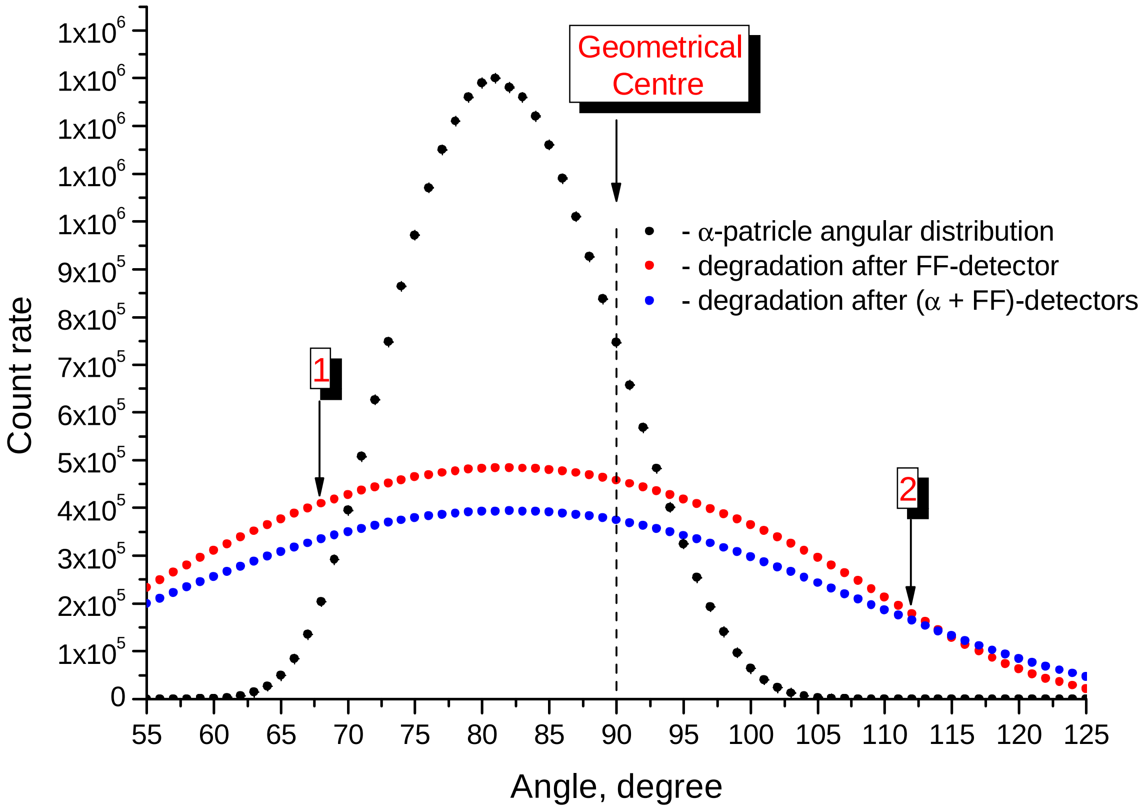
Difference between two α-particle angular distributions (calculation with R=2ħ)



Results for ^{235}U

Influence of linear dimensions of fission fragment's and α-particle's detectors on angular distribution

$$A_Z = \frac{N_{+Z} - N_{-Z}}{N_{+Z} + N_{-Z}}$$



Experiment

+0.0030(2) -0.0041(3)

ROT (MC-calculations)

+0.0013(3) -0.0036(4)

+0.0019 -0.0052

TRI effect

+0.0011

+0.0030 -0.0041

Thank you for your attention!