Resistive charge-division readout for position-sensitive detector

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Motivation

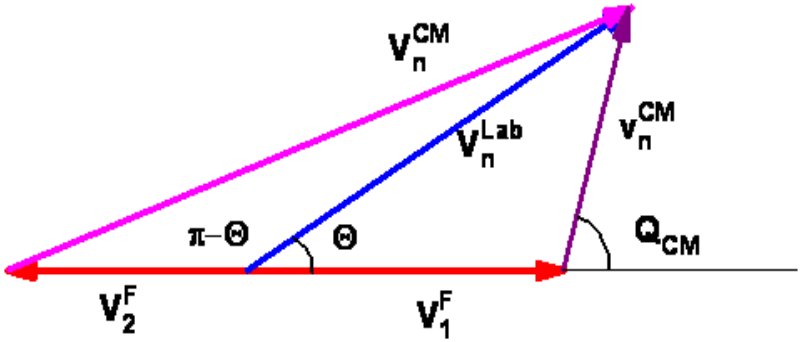
Experiments with simultaneous measurement of FF, kinetic energies, mass and the FF emission angle in coincidence with PFN emission provides data suitable for full reconstruction of PFN emission kinematics. The experiment recently was further elaborated by implementing digital pulse processing (DPP).

The PFN emission investigation in $^{252}Cf(sf)$ *and* $^{235}\mathrm{U}(\mathrm{n_{th}}, f)$ reactions already was implemented with use of DPP. Thanks to two most essential advantages of DPP over conventional analog electronics:

- The possibility of repeated analysis of the same data set with a different pulse processing algorithms.
- The higher precision of data analysis and the flexibility of data treatment provides diversity of information available thanks to digital pulse processing

essential improvement of obtained data were achieved. The next modification of the method was intended to overcome the limitation in the PFN detection efficiency by adding neutron detectors allocated in most efficient way around the FF detector. Such modification will improve the quality of experiments with targets of “non zero thickness” like ^{239}Pu, ^{235}U and so on. In addition we developed position sensitive detector suitable for applications not only in nuclear physics but in the fields like the neutron imaging, tomography and so on.

PFN emission kinematics

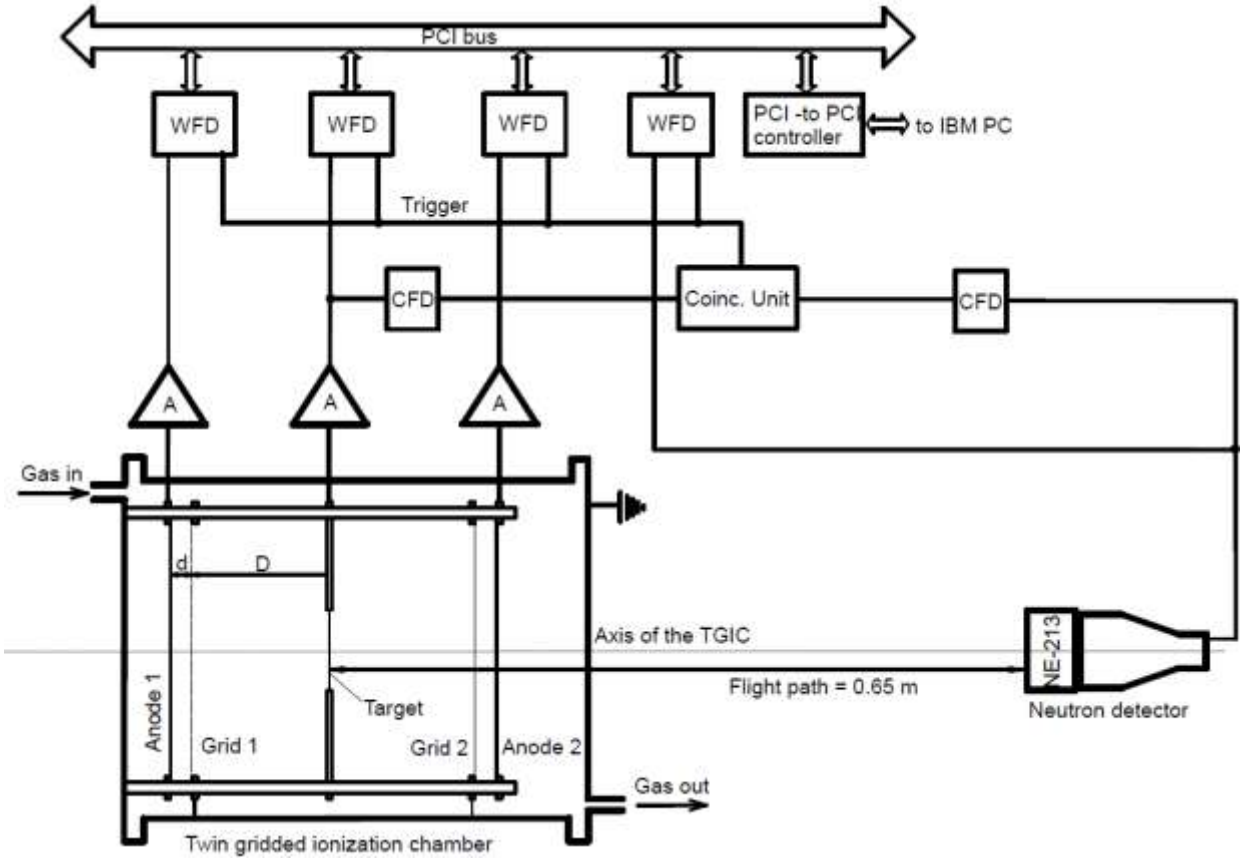


The detailed information on PFN emission in fission is available from the measured dependence of the number of PFN emitted by the FF with the mass number A and the TKE release of two complementary FF. This information can be evaluated from measurement of correlated FF kinetic energies, masses and PFN emission angle and the velocities as depicted in the vector diagram above. If such information is available, then one can evaluate the $v(A,TKE)$ and $Y(A,TKE)$ in the reference frame of the selected FF's centre-of-mass. Then using the formulas below one can obtain the averaged values interesting for comparison with theory:

$$\bar{v}(A) = \frac{\int_0^\infty v(A,TKE)Y(A,TKE)dTKE}{\int_0^\infty Y(A,TKE)dTKE} \quad \text{or } \bar{v}(TKE) = \frac{\int_0^\infty v(A,TKE)Y(A,TKE)dA}{\int_0^\infty Y(A,TKE)dA}$$

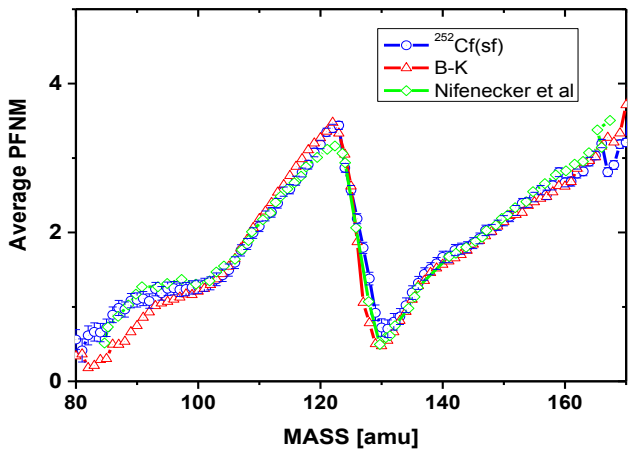
$$\bar{v} = \int_0^\infty v(A,TKE)Y(A,TKE)dTKEdA, \quad 200 = \int_0^\infty Y(A,TKE)dTKEdA$$

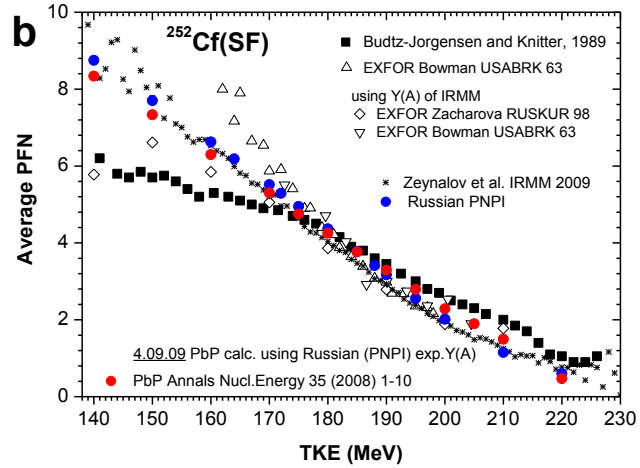
Traditional Digitization Data Acqusition System

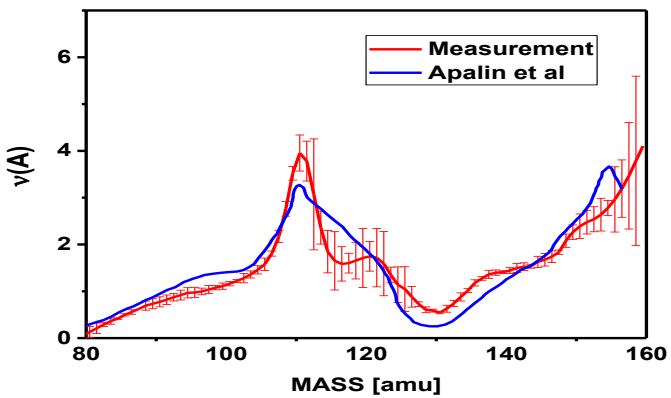


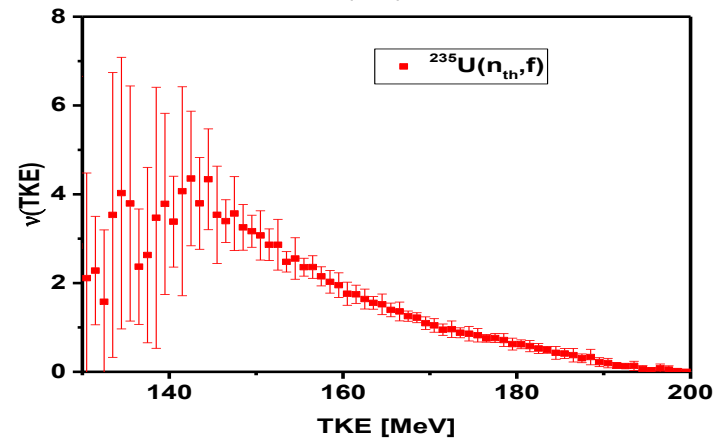
The data acquisition system for prompt fission neutron using traditional double Frisch gridded ionization chamber and digital pulse processing electronics shown in above figure. Usually four channel synchronously digitizing waveform digitizers (WFD) were used for measurement in reactions 252Cf(SF) and thermal neutron induced fission of 235U . Because of fast neutron detector WFD was chosen with 250 MHz sampling frequency and 12 bit pulse height resolution

Main Results Available from The PFN Investigation Experiments



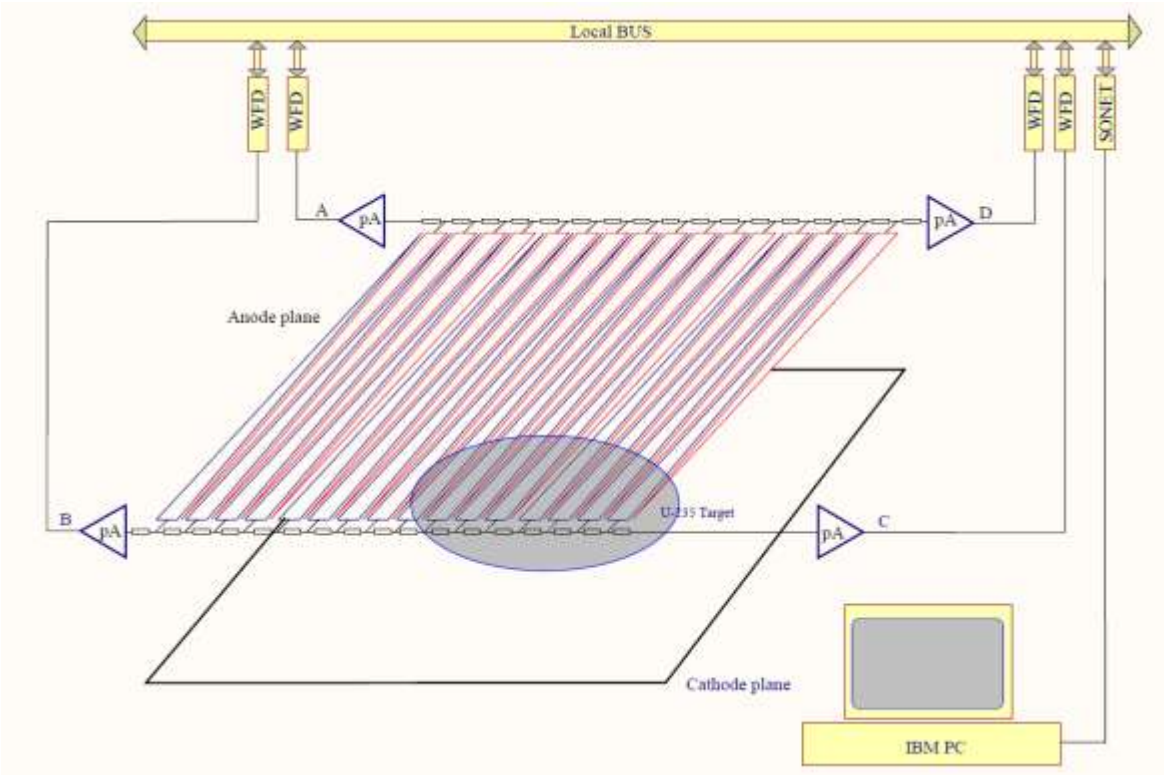






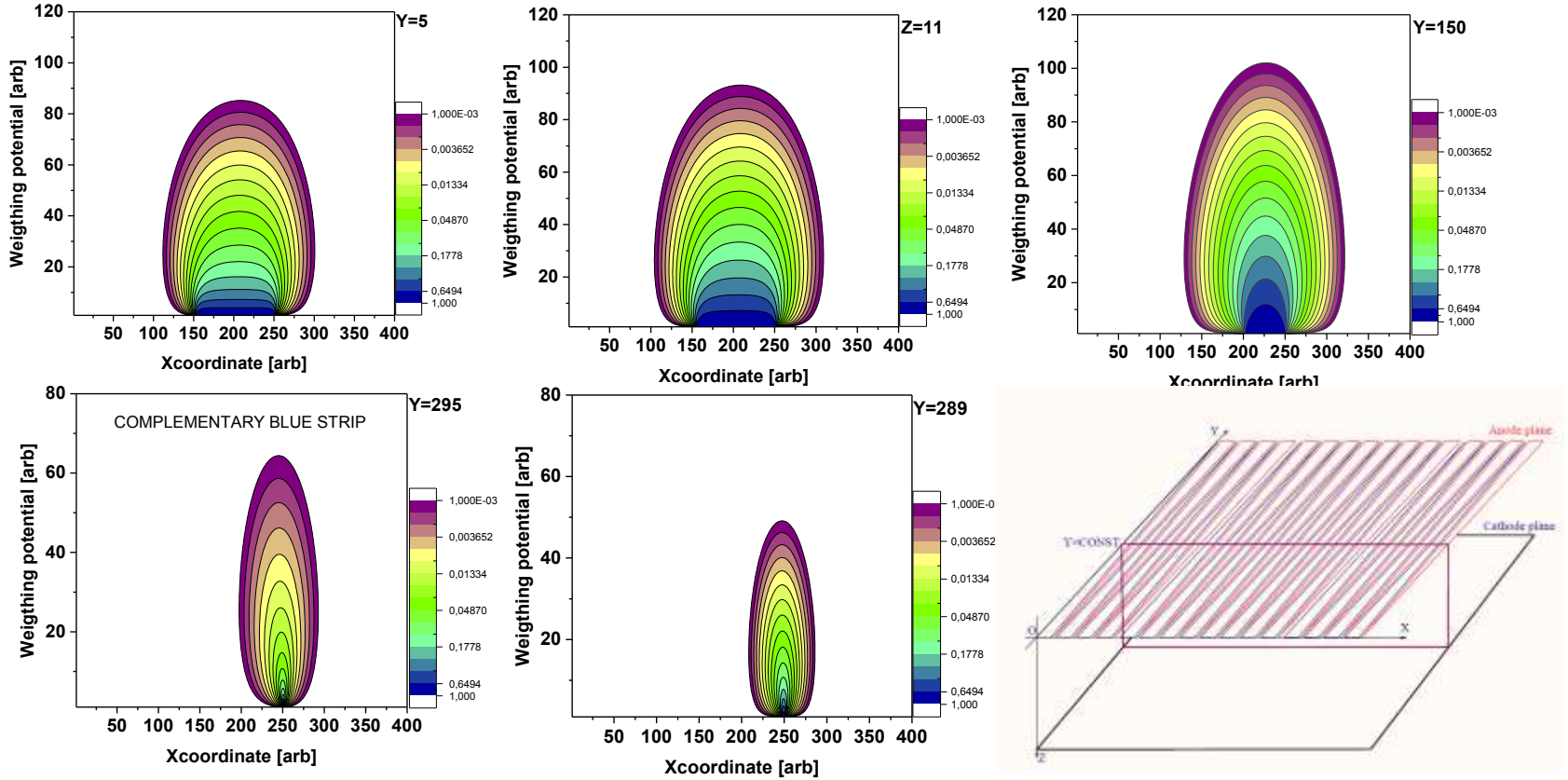
Average PFN multiplicity dependence on mass split and TKE obtained from measured matrix $\nu(A,TKE)$, integrated over A or TKE. On the right side average PFN multiplicity plotted versus TKE. These plots can be used to calculate the slopes and maximum value of TKE when the PFN emission stops for different mass values and plotted on the left side of the slide. Presented data are of great interest for comparison with theoretical calculations

Modified TIC for PFN Investigation Experiments



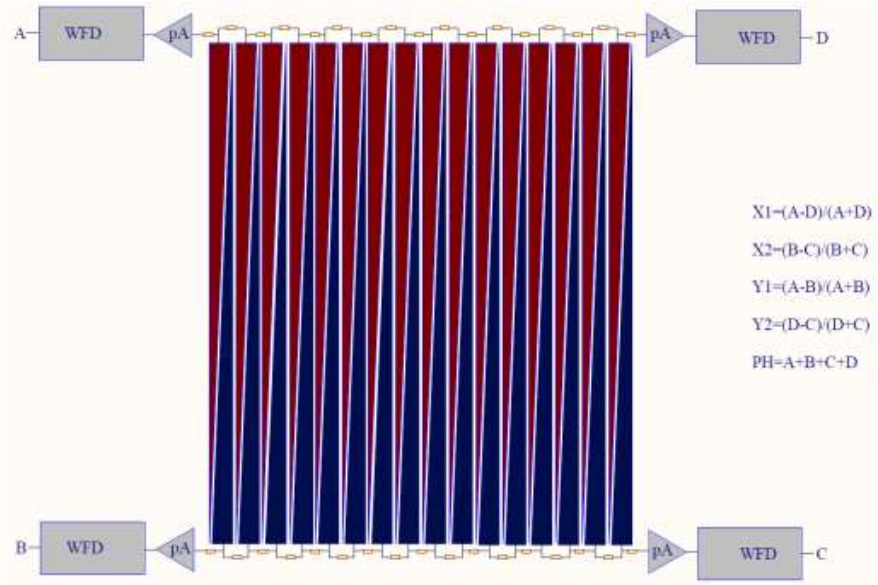
The traditional method assumed no more than two ND allocated along the TIC axis opposed to each other. If the FF detector would provide the possibility of measurement the FFs orientation in 3D, then the efficiency of experiment (data taking statistics) could be improved by use of as much ND as possible. Additionally, the allocation of ND around the FF detector has no special demands. We developed the parallel plate ionization chamber with the anodes made of rectangular strips divided along the diagonal. In this way we make two isolated Δ-electrodes composing each strip. Electrical contacts were made to each Δ-electrode, connected to RC chain filter. Signals from the both sides of the chain convey information both on the FF kinetic energy and 2D Cartesian coordinates.

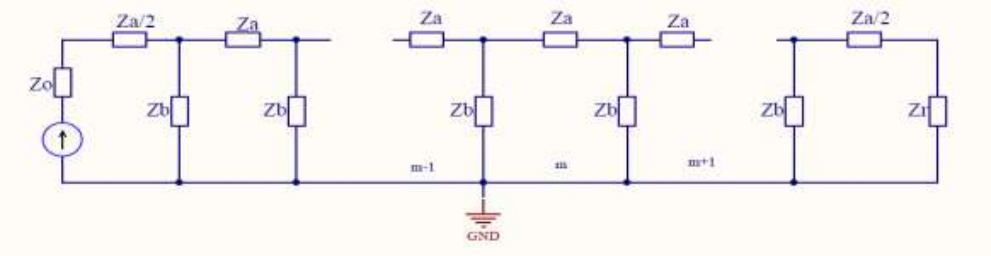
Application of Ramo-Shokley Theorem to Signal Formation in Modified TIC



Using the Ramo-Shokley theorem we calculated so called weighting potential in 3D carthesian coordinate system. The weighting potential in the TIC volume was calculated for one Δ-electrode potential raised to 1, leaving other electrodes grounded. If the strips are operated at positive potential relative to the cathode surface, then ionization electrons will be attracted along the real field lines (calculated for homogeneous electric field between anode-cathode). Figures demonstrate the weighting potential $F(x,y,z)$ variation in the square cross section outlined on the right lower corner. According to Ramo-Shokley theorem the charge induced on the strip is $Q = q \cdot \Delta F$. Using calculated potentials we have found a linear charge division of induced charge on the Y-coordinate of complementary Δ-electrodes.

Symbolic Calculus Application to Chain Filter Response Function





$$i_m(t) \supset \frac{\xi(p)}{(Z_0 + \sqrt{Z_1 \cdot Z_2} \cdot \sqrt{\alpha^2+1}) \cdot (\alpha + \sqrt{\alpha^2+1})^{2m}}$$

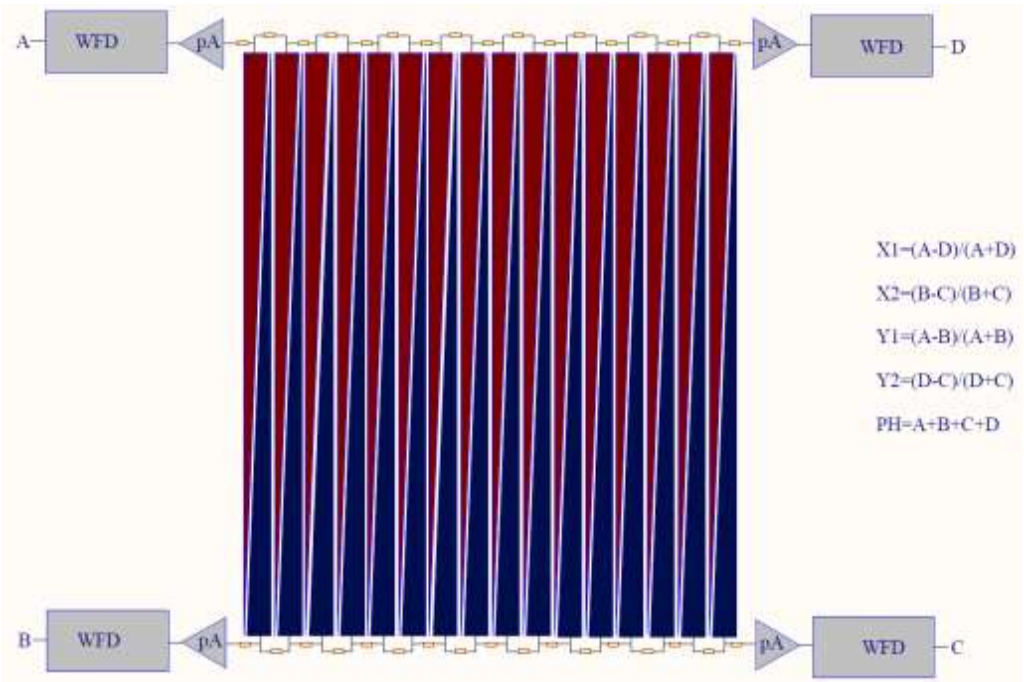
where $Z_w = \sqrt{\frac{Z_1^2}{4} + Z_1 \cdot Z_2}, \quad \frac{Z_1}{Z_2} = 4 \cdot \alpha^2$

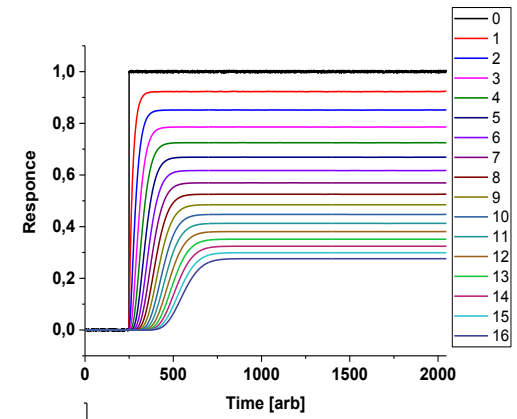
Now we have to investigate the charge division along X- coordinate. The response function of chain filter was calculated using symbolic calculus theory. The chain filter consisted of the complex resistors Z_a *and* Z_b and the voltage $\xi(t)$ applied at time instance $t=0$. To do calculation we need to apply the Laplace transform to the linear differential equations , describing currents and voltages across the circuit. Thanks to the transform we have got system of linear equations, which easily could be solved for the symbolic current $i_m(p)$ analytically. Applying reveres transform we have got $i_m(t)$. It should be noticed exponential term, playing important role for in the pulse height analysis in further discussion.

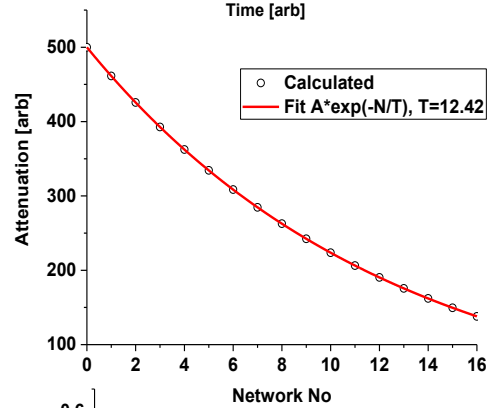
$$i_m(t) = \sqrt{\frac{C}{L}} \int_0^t \exp(-\frac{R}{L}t) \cdot J_{2m}(\frac{t}{a}) d(\frac{t}{a}),$$

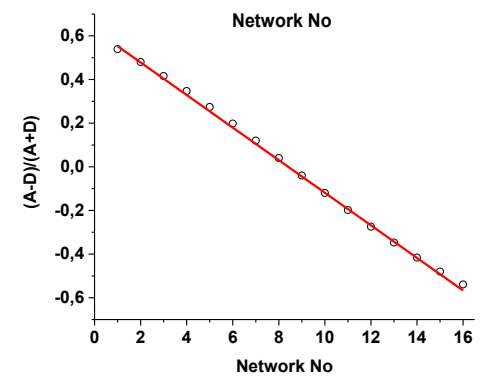
where $a = \frac{\sqrt{LC}}{2}$ and $Z_w = \sqrt{\frac{R^2}{4} + \frac{i\omega L + R}{i\omega C}}$

Numerical Calculation of the Step Pulse Applied to the Chain Filter (pulse height)



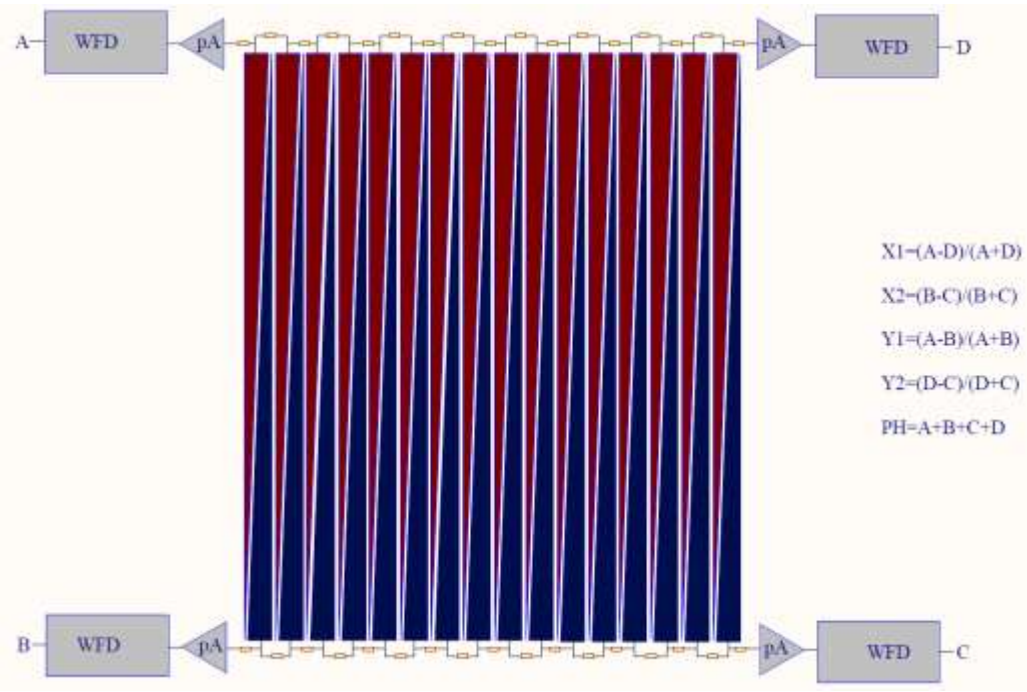


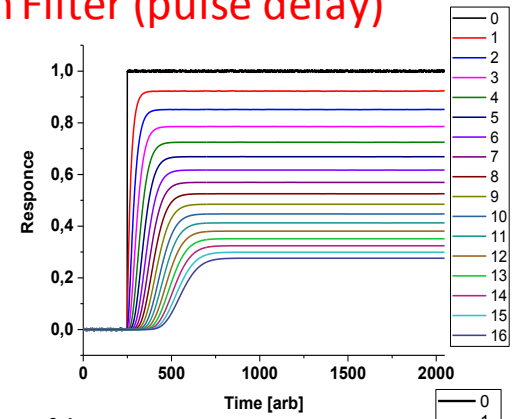


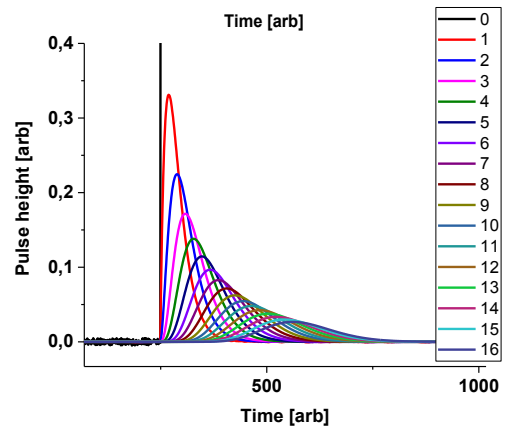


The dependence of output pulse height on the sequential number of two-port network, composing the chain filter plotted in upper figure. The calculation was done using formulas derived in previous slide. The next low figure demonstrates the pulse height attenuation when the unity step signal pass the chain filter. The exponential attenuation exp(-N/T) on the network number N was observed and the T value was found by fitting. The T parameter then should be used to correct the attenuation of total charge induced on the strips. The coordinates X,Y of the charge "centre of gravity" evaluated from the simulated pulses demonstrated almost perfect linear dependence on the network number.

Numerical Calculation of the Step Pulse Applied to the Chain Filter (pulse delay)



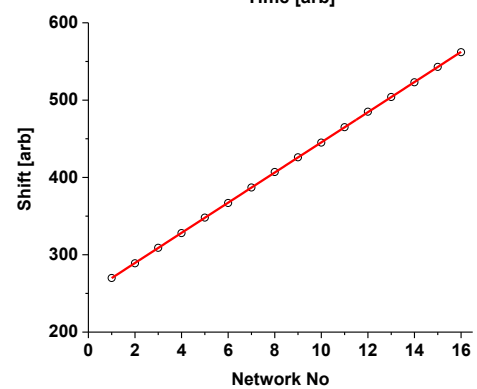




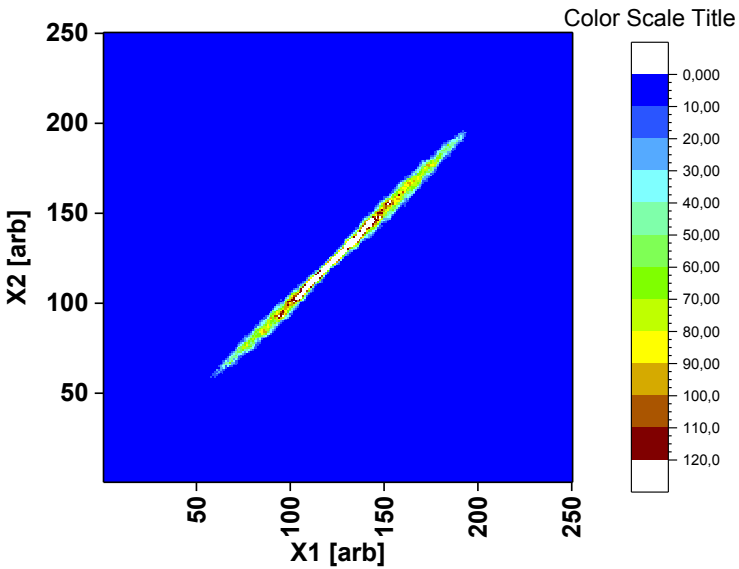
The dependence of output pulse time shift on the on the sequential number of two-port network comprising chain filter plotted in upper figure was used to evaluate the unit pulse response delay on the network number. This was done by passing the respective response trough digital differentiating filter as:

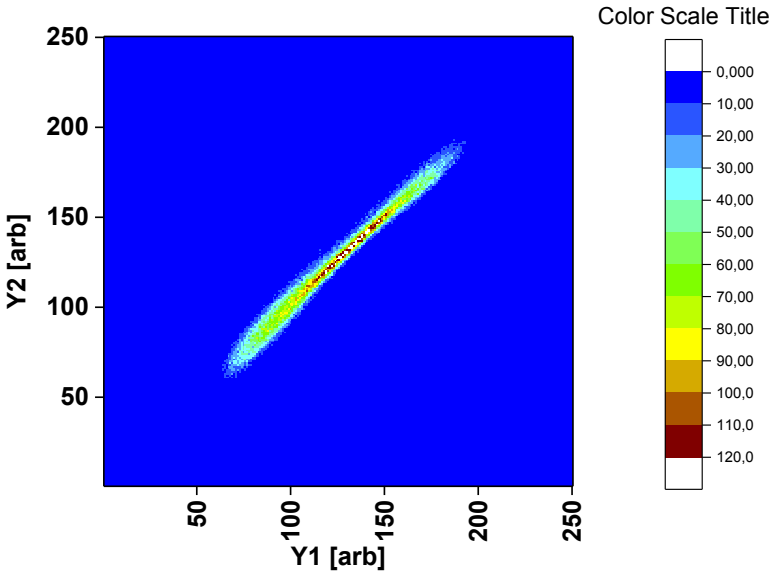
$$W_{out}[i+1] = \exp(-\frac{1}{\Delta}) \bullet (W_{out}[i] + W_{in}[i+1] - W_{in}[i])$$

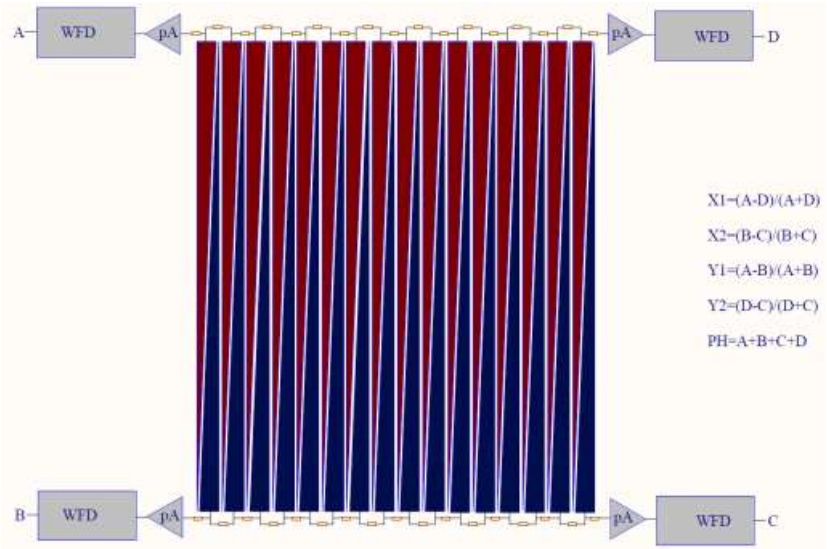
Results were presented in the next to lower figure. In the lower figure the shift of the peak value of the output signal of differentiating operator is plotted. It is perfectly linear function, which can be used to evaluated the network number in different from the way, demonstrated in previous slide.

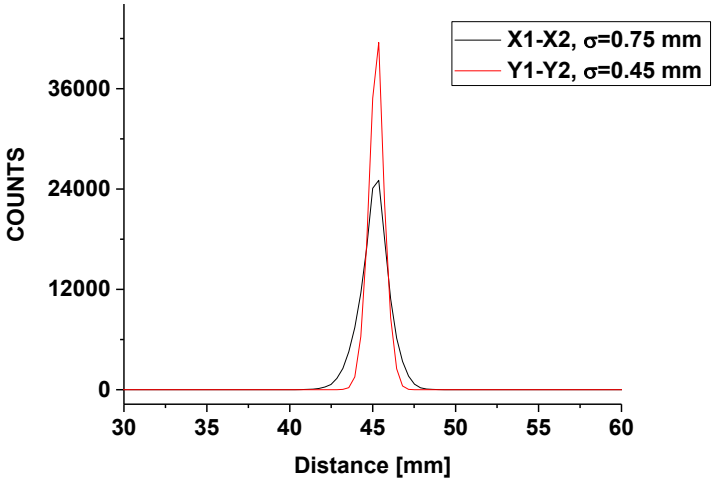


Experimental Results with Fission Fragment Detection (precision)

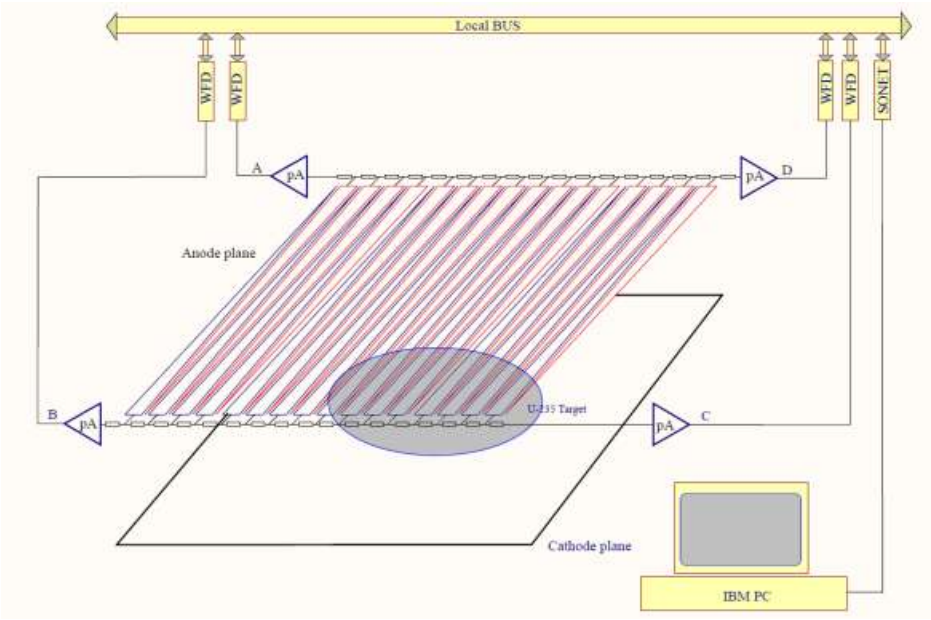


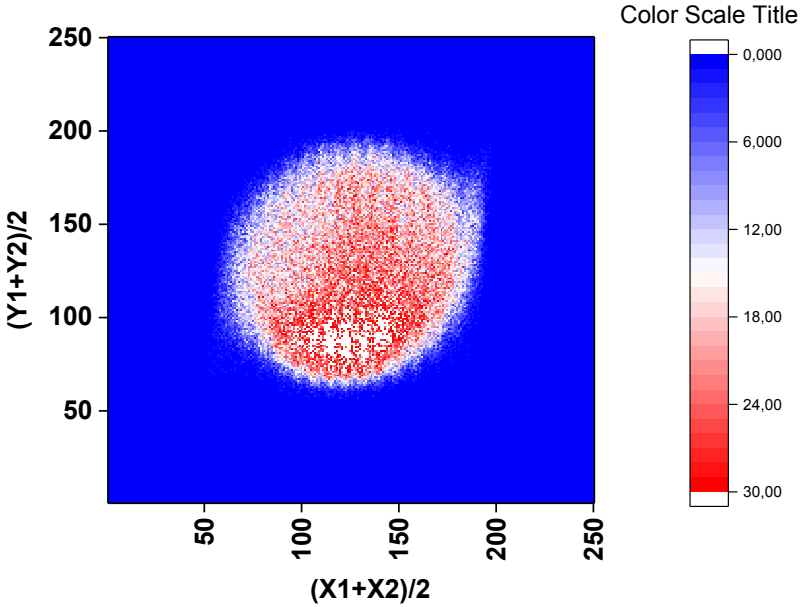




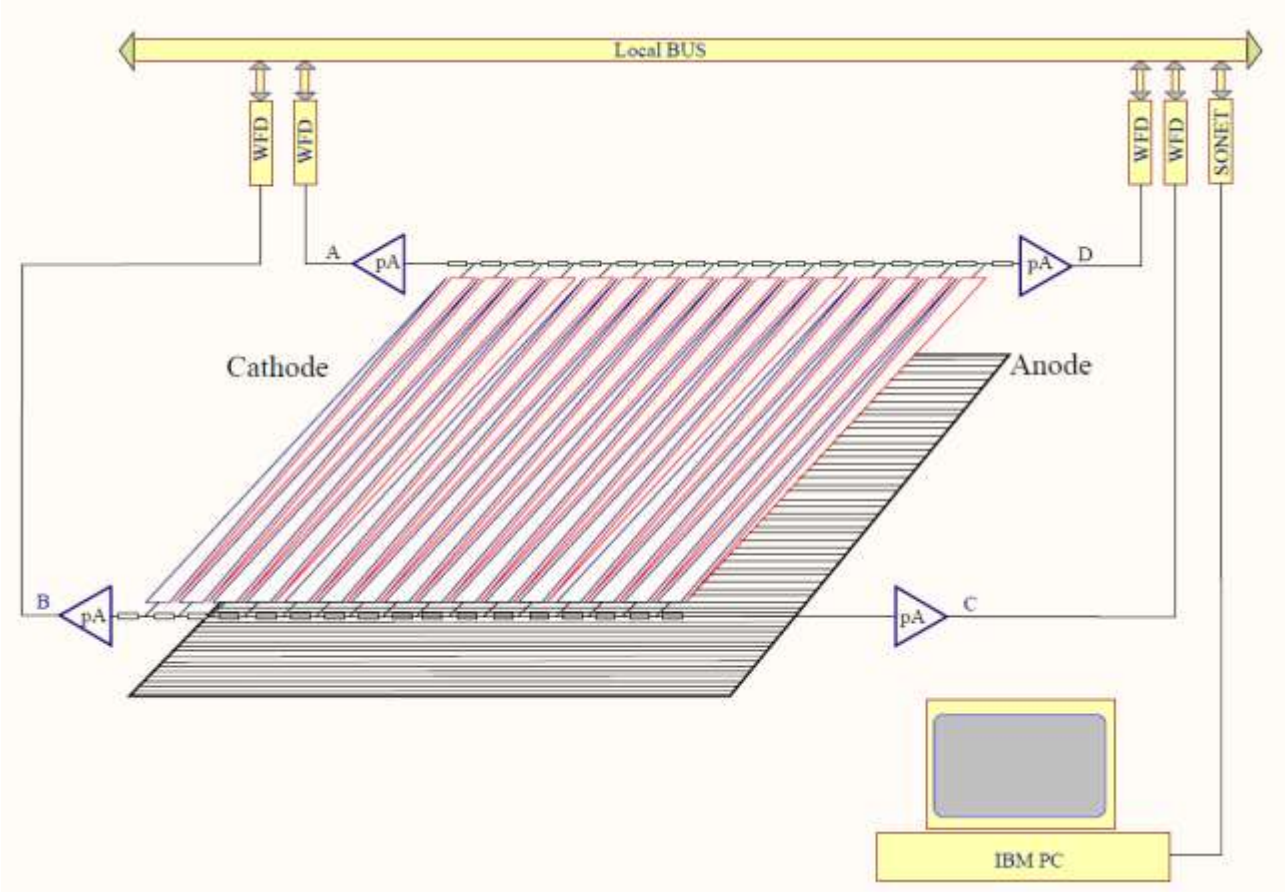


U-235 Target Image Obtained Using Thermal Neutrons

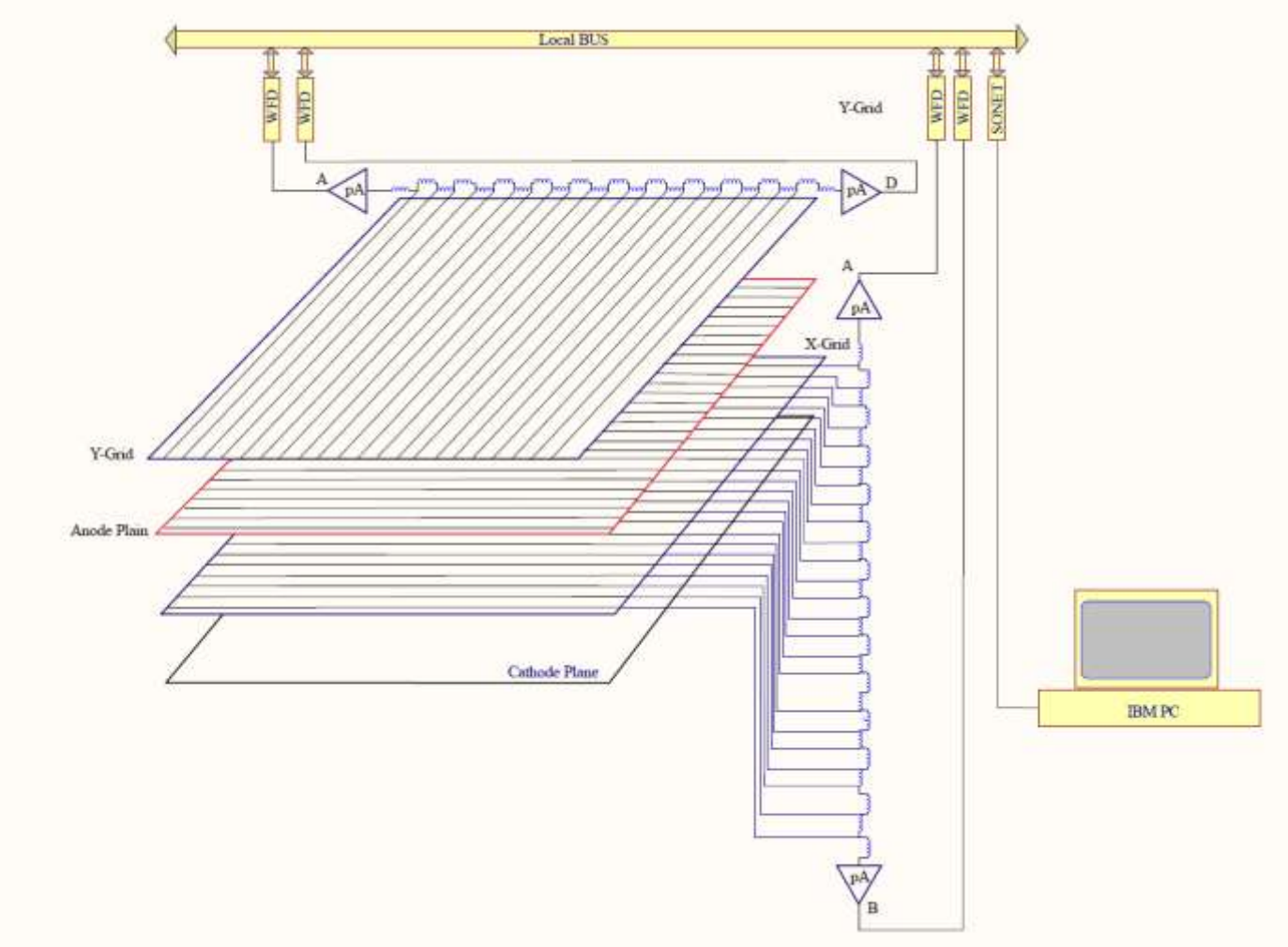




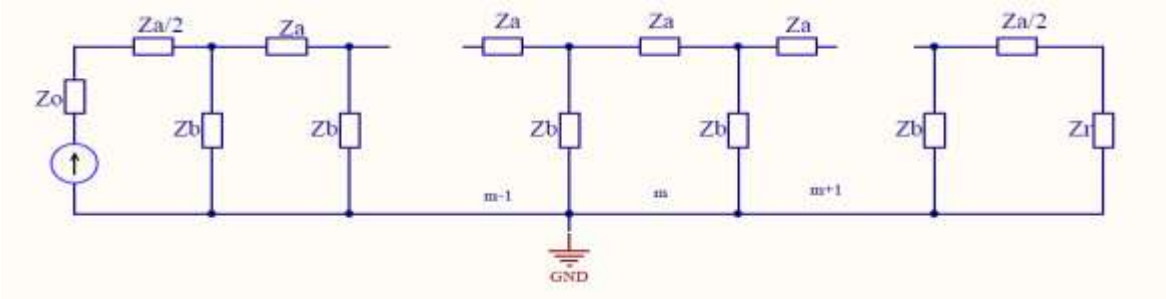
The New Design of Thermal Neutron Imager With He-3 filled Proportional Chamber



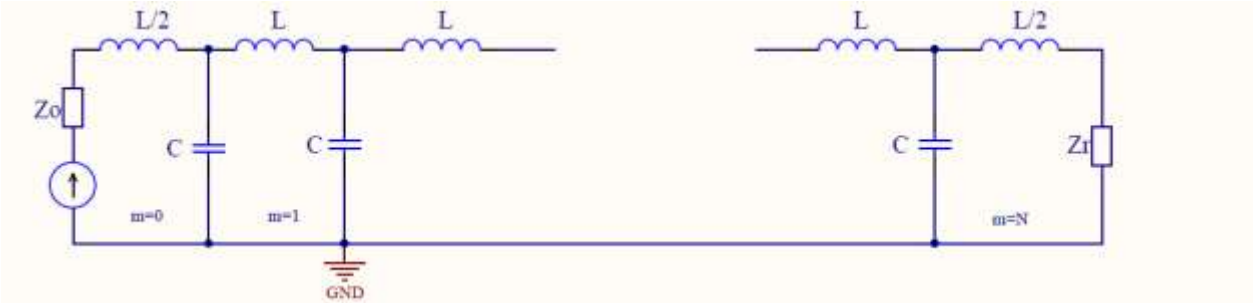
Measurements with conventional He-3 Filled PSD-proportional Chamber



PSD-proportional He-3 Chamber Theory



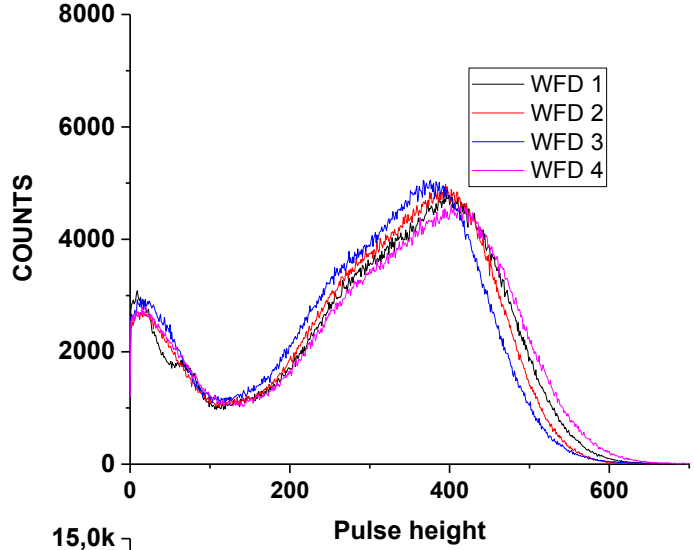
$$i_m(t) \supset \frac{\xi(p)}{(Z_0 + \sqrt{Z_a \cdot Z_b} \cdot \sqrt{\alpha^2+1}) \cdot (\alpha + \sqrt{\alpha^2+1})^{2m}} \qquad Z_w = \sqrt{\frac{Z_a^2}{4} + Z_a \cdot Z_b}, \quad \frac{Z_a}{Z_b} = 4 \cdot \alpha^2$$

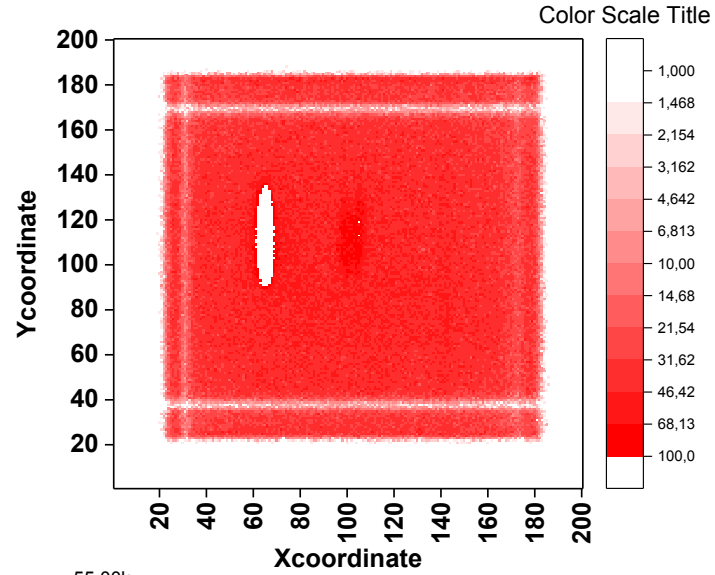


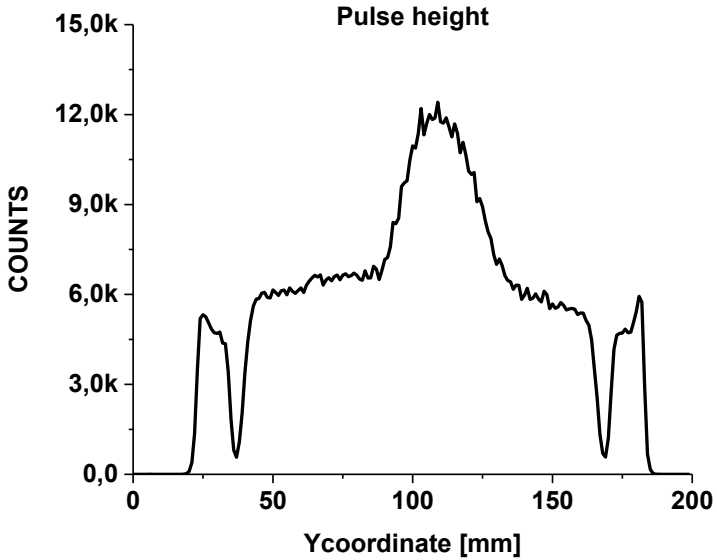
$$Z_0 = 0,\ Z_1 = Lp,\ Z_2 = \frac{1}{Cp},\ \frac{Z_1}{Z_2} = LCp^2,\ \alpha = \frac{p\sqrt{LC}}{2} \qquad i_m(t) \supset \sqrt{\frac{C}{L}} \frac{\xi(p)}{\sqrt{p^2 \cdot \alpha^2 + 1} \cdot (p \cdot \alpha + \sqrt{p^2 \cdot \alpha^2 + 1})^{2m}}$$

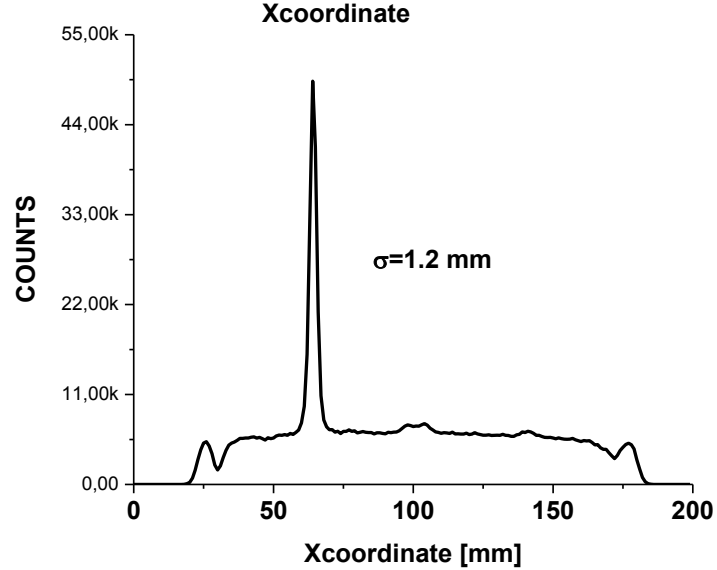
$$i_m(t) = \sqrt{\frac{C}{L}} \cdot \int_0^t J_{2m}\left(\frac{t}{a}\right) d\left(\frac{t}{a}\right) \Rightarrow \frac{\mathrm{m}}{\mathrm{t}} = \frac{1}{\sqrt{LC}}$$

PSD-proportional He-3 Filled Chamber Experiment



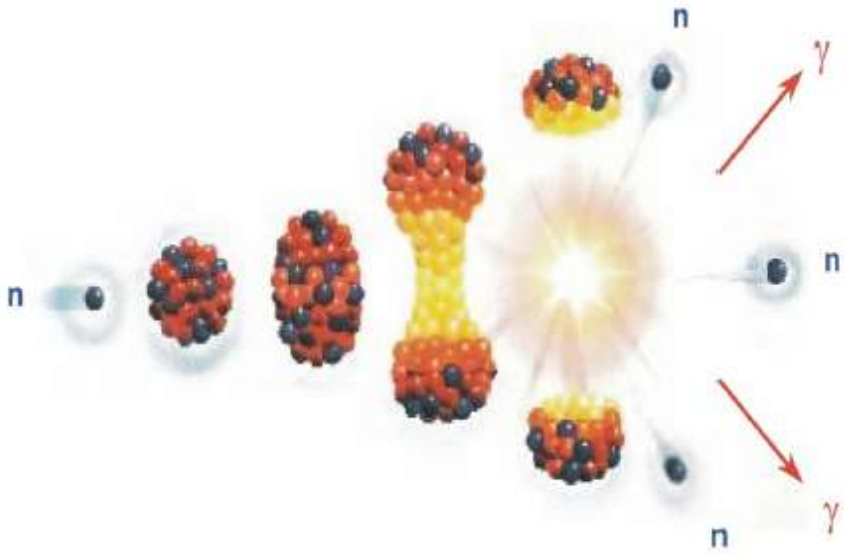






Conclusions and Outlook

1. Theoretical and experimental investigation of signal propagation trough the resistive chain filter was performed with objective of position sensitive ionization chamber design for PFN emission investigation with arbitrary allocated fast ND
2. Relations between 2D coordinate (X,Y) information and response of chain filter was found and investigated by digital simulation.
3. It was shown that coordinate information can be obtained by both the double charge division and time delay method. Implementing both methods provided better accuracy in coordinate measurement.
4. Dependence of pulse height data on coordinate was discovered for resistive chain filter. The procedure of pulse height data correction was developed
5. Measurement of neutron imaging with U-235 target was done to demonstrate the quality of the double charge division method for position sensitive ionization chamber.
6. Good position resolution was demonstrated: 0.7 mm for X and 0.5 mm for Y coordinates.
7. New design for He-3 imaging proportional chamber with double charge division method was suggested.
8. Digitization electronics was implemented for data acquisition system and data analysis software was developed and tested in experiments
9. The data analysis was done using DPP algorithms developed by authors as



Thank you for your attention ☺