Position Sensitive Detector for Prompt Fission Neutron Investigations

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Application Of Nuclear Techniques, Crete, June 11-17, 2017

Motivation

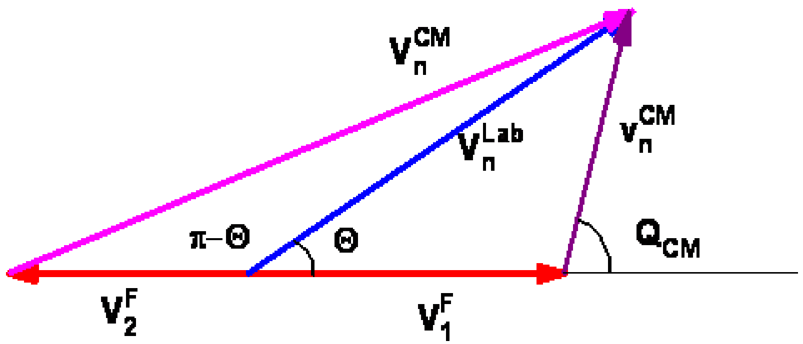
Experiments with simultaneous measurement of FFs kinetic energies, mass and the PFN emission angle along with its kinetic energy provides data suitable for reconstruction of PFN emission kinematics. The method first proposed by B&K was further elaborated by implementing digital pulse processing.

In our previous works we have used digital pulse processing, implemented for 252Cf(SF) and 235U(n,f) reactions investigation. Two most essential advantages of DPP over conventional analog electronics were demonstrated:

- The possibility of repeated analysis of the same data set with a different pulse processing algorithms.
- Higher precision of calculations and the flexibility of data treatment provided diversity of information available.

The next modification of the method was intended to overcome the limitation of the method by increasing 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, ^{237}Np and so on. The developed position sensitive detector can be used in applications like the neutron imaging, tomography and so on.

PFN emission kinematics

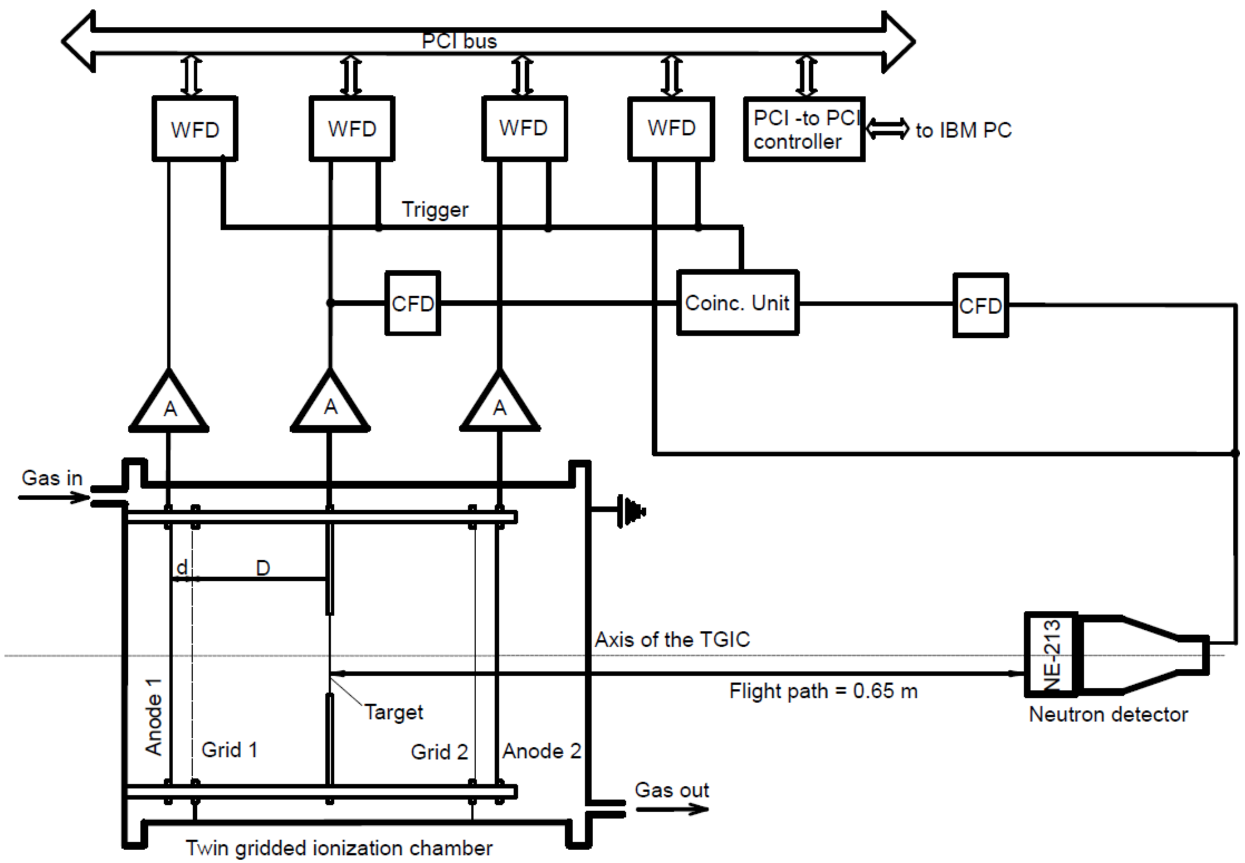


The detailed information on PFN emission in fission is available from the measured dependence of average number of PFN emitted by the FF with mass number A and the TKE release of two fission fragments.

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

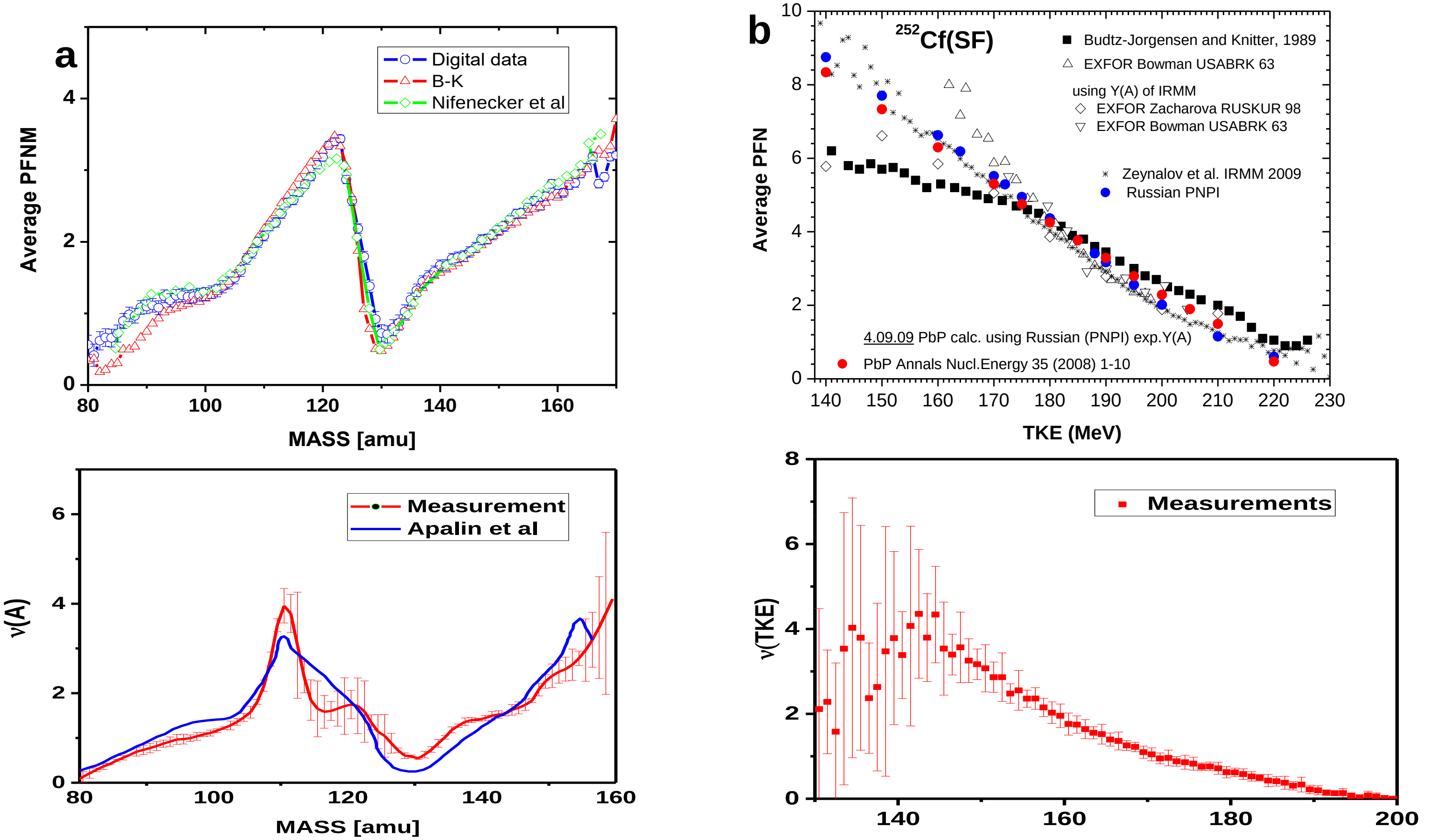
$$\bar{\nu} = \int_0^\infty \bar{\nu}(A,TKE)Y(A,TKE)dTKEdA, \quad 200 = \int_0^\infty Y(A,TKE)dTKEdA$$

Traditional Digitization Data Acqusition System



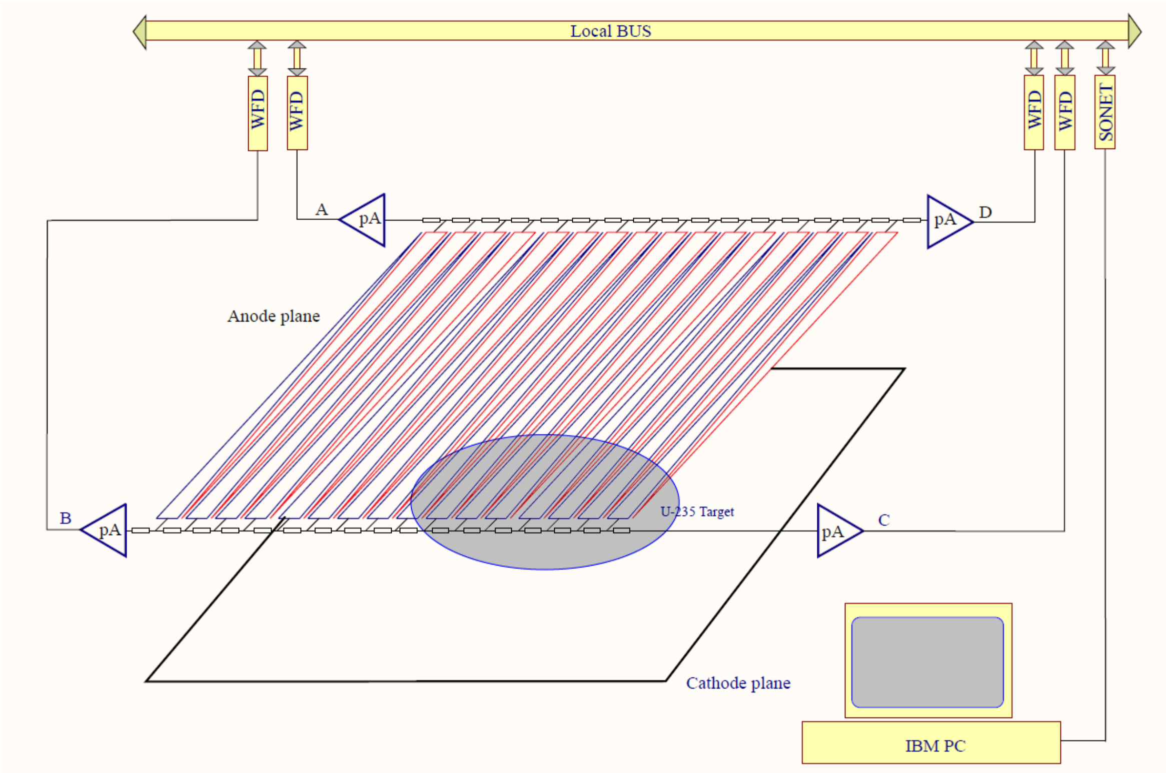
The data acquisition system for prompt fission neutron using traditional double Frisch gridded ionization chamber and digital pulse processing electronics usually consists of four channel synchronous waveform digitizers (WFD). This setup was used for measurements in reactions 252Cf(SF) and thermal neutron induced fission of 235U

Main Results Available from The PFN Investigation Experiments



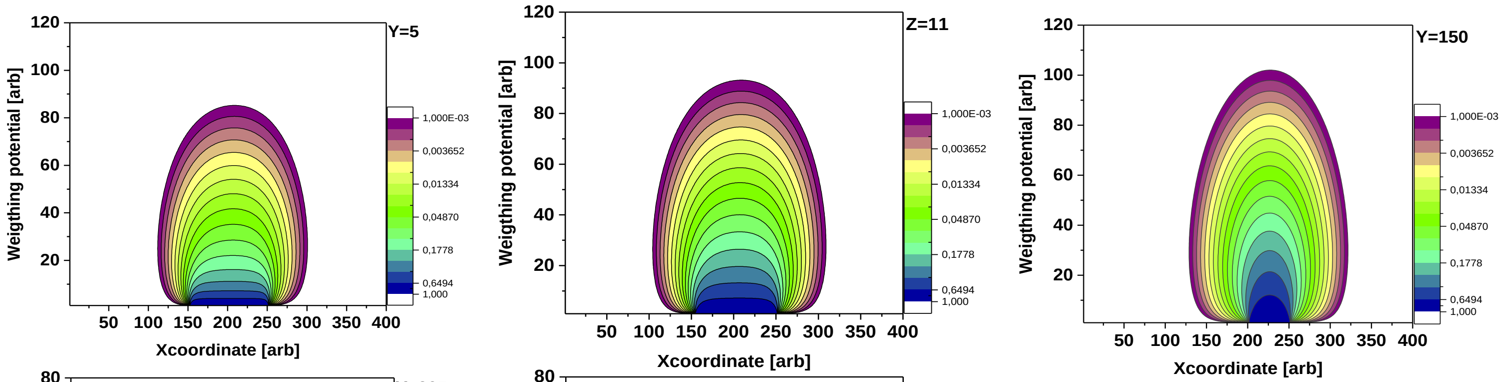
Average PFN multiplicity dependence on mass split and TKE obtained from measured matrix $\nu(A,TKE)$, integrated over A or TKE. On the right side average PFN multiplicity plotted versus TKE for the selected mass regions, indicated on the plot. These plots were used to calculate the slopes and maximum 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

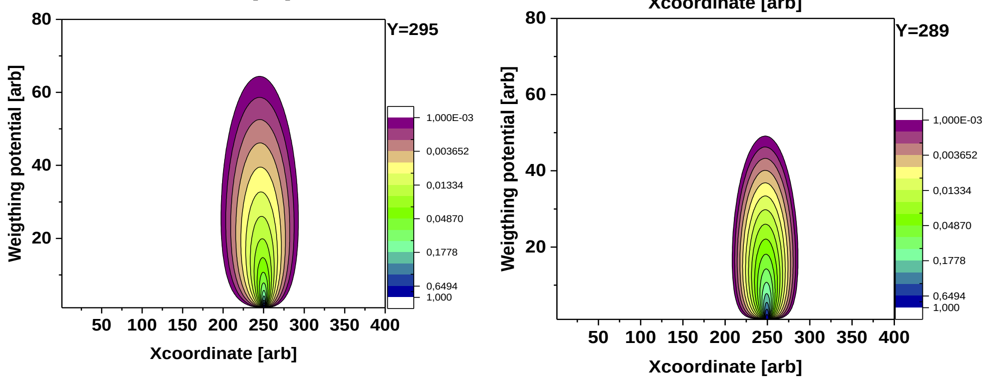
Modified TIC for PFN Investigation Experiments



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 the use of as much ND as possible to allocate around the FF detector. We developed the parallel plate detector with the anodes made of rectangular strips divided along the diagonal to make two isolated Δ-electrodes. Electrical contacts are made to each Δ-electrode. Double charge division method was used to measure the 2D coordinates of charge centroide of FF induced on the chamber anode.

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

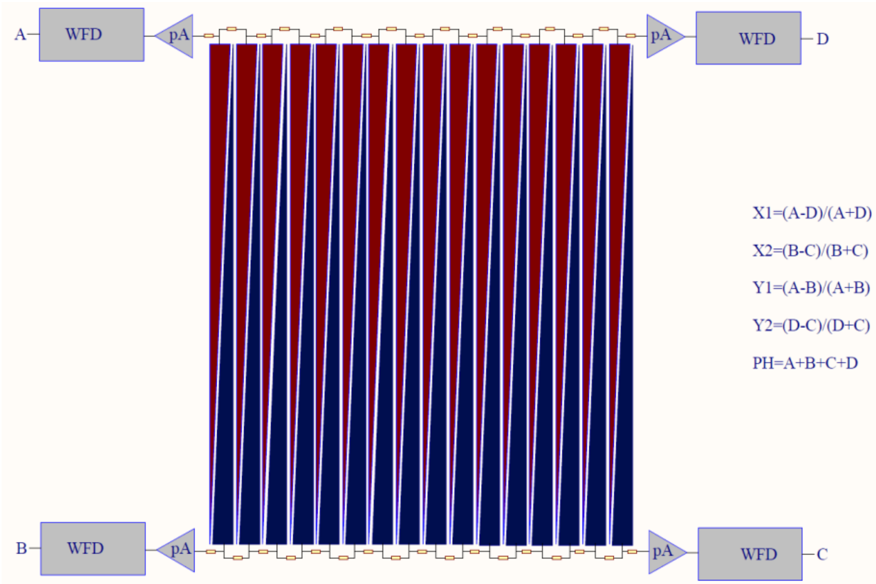


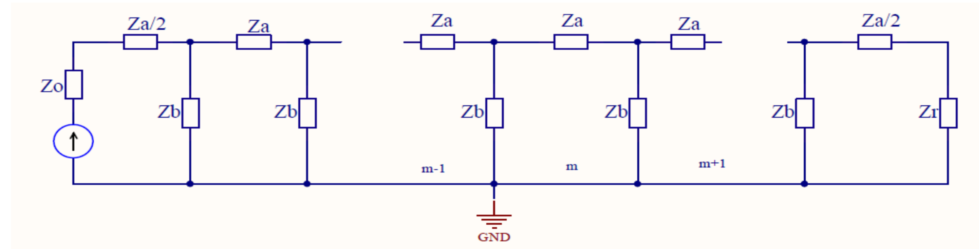


The weighting potential is shown in the Close vicinity of the Δ-electrodes. The upper and the lower plots were calculated for two Δ-electrodes , composing each rectangular strip

Using Ramo-Shockley theorem 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 that are parallel to each other and perpendicular to the anode surfaces. The charge Q, induced on the Δ-electrode then can be found using the following formula: $Q = q \cdot \Delta\Phi$, ,where q – is the charge value and the $\Delta\Phi$ is the difference of weighting potentials between the charge origin and the end points . It is clear that the charge induction mainly happen in the close vicinity of the anode plane.

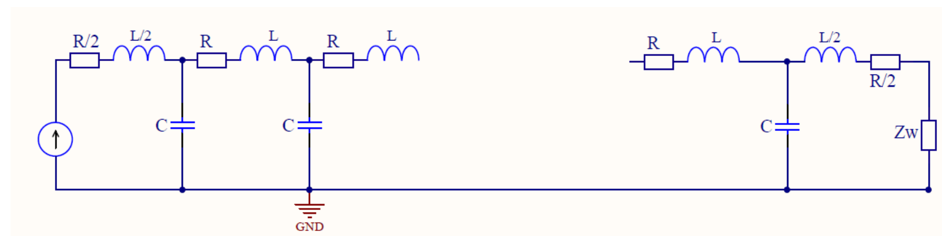
RC-chain Response to Unity Step Pulse Calculation





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

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

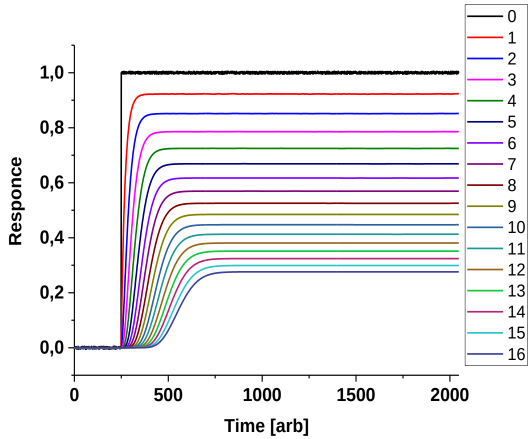


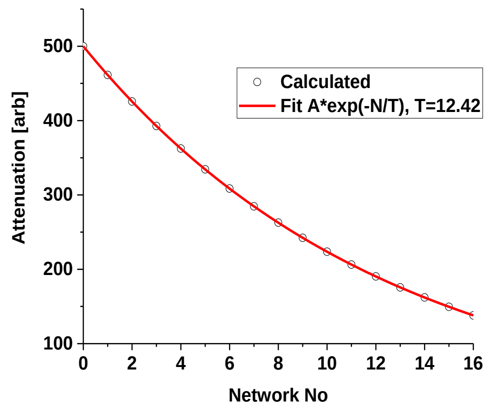
$$i_m(t)=\sqrt{\frac{C}{L}}\int_0^t \exp\left(-\frac{R}{L}t\right)\cdot J_{2m}\left(\frac{t}{a}\right)d\left(\frac{t}{a}\right),$$

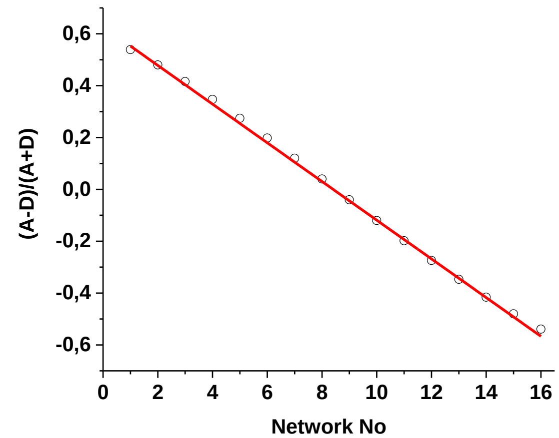
where $a=\frac{\sqrt{LC}}{2}$ and $Z_w=\sqrt{\frac{R^2}{4}+\frac{i\omega L+R}{i\omega C}}$

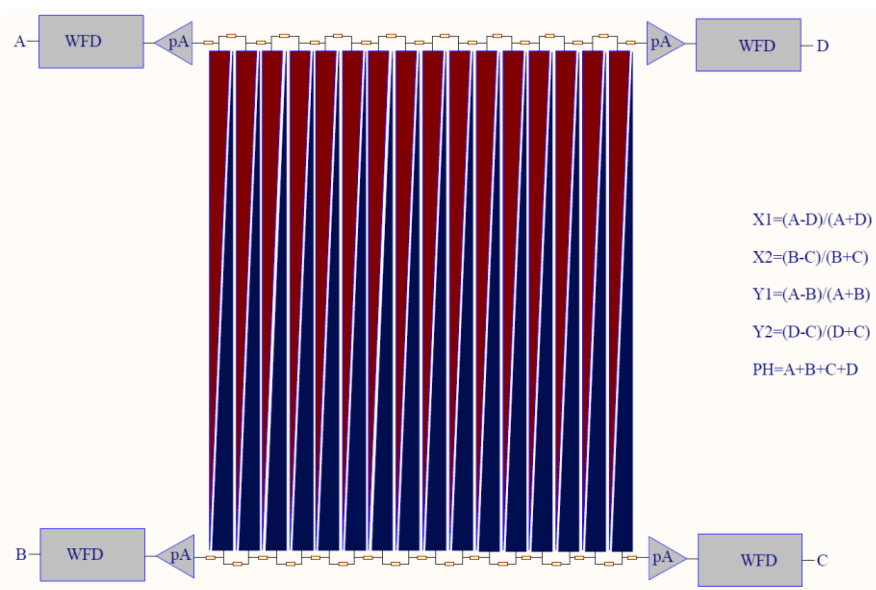
The charge division between adjacent Δ-electrodes is the linear function of distance in vertical coordinate. The charge division In horizontal coordinate produced by the RC-chain filter

Unit Step Signal Transformation After RC-chain Filter Passage









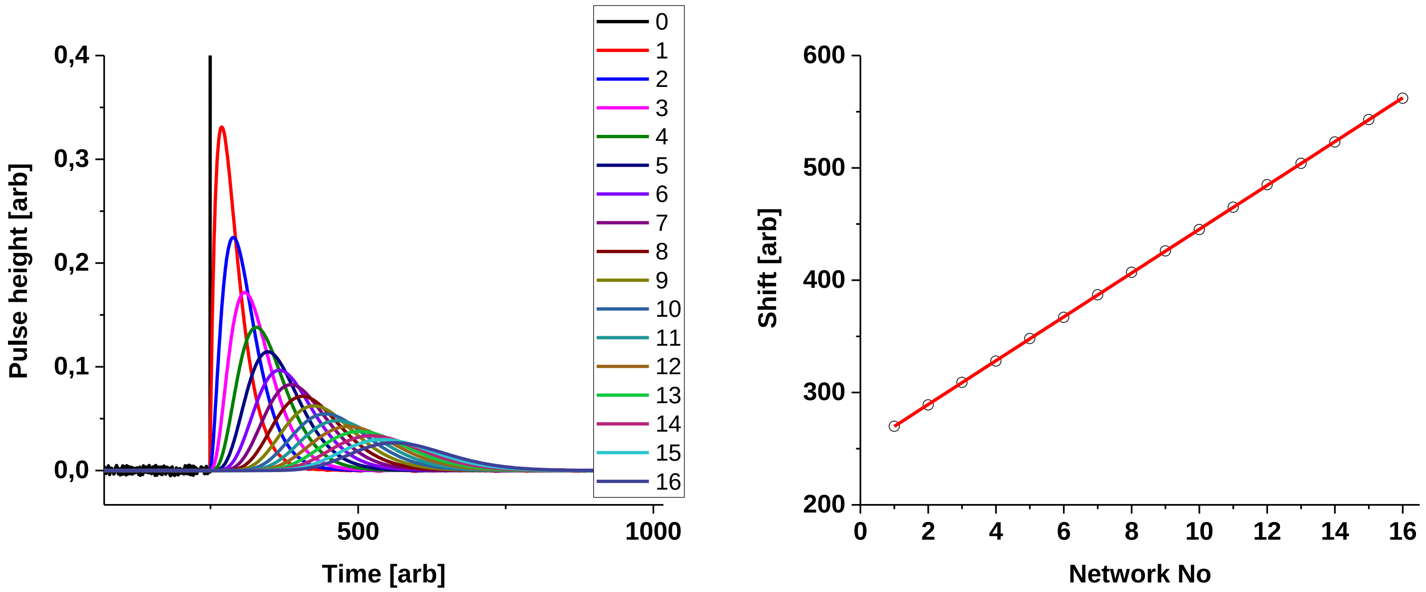
The pulse height attenuation of the signal depended on the number of two-port networks passed .

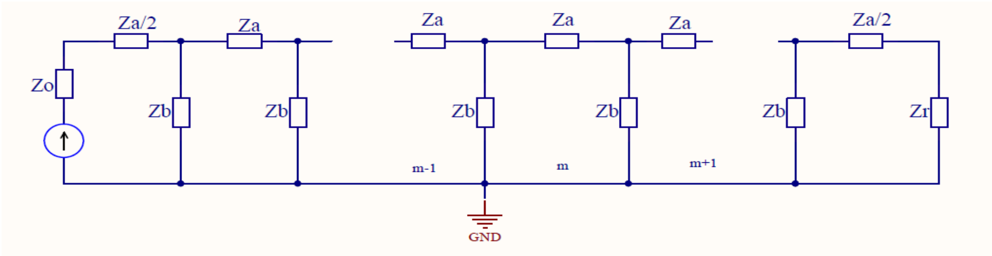
Two-port network number calculated using the following formula :

$$X = \frac{A - B}{A + B}$$

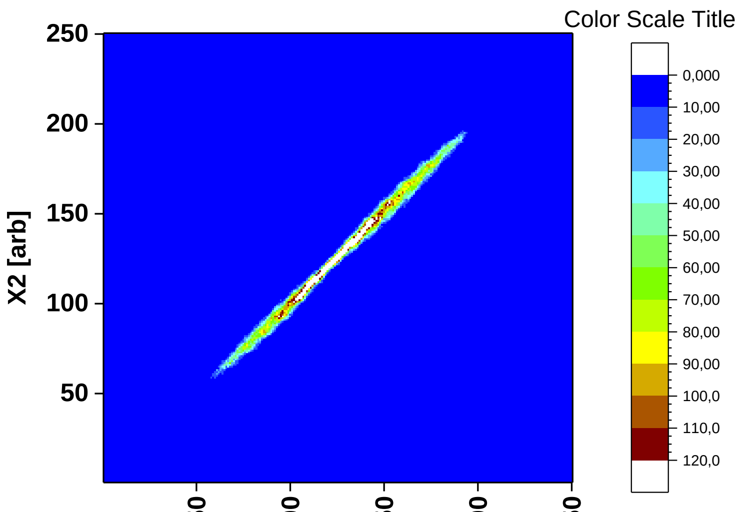
demonstrates good linearity

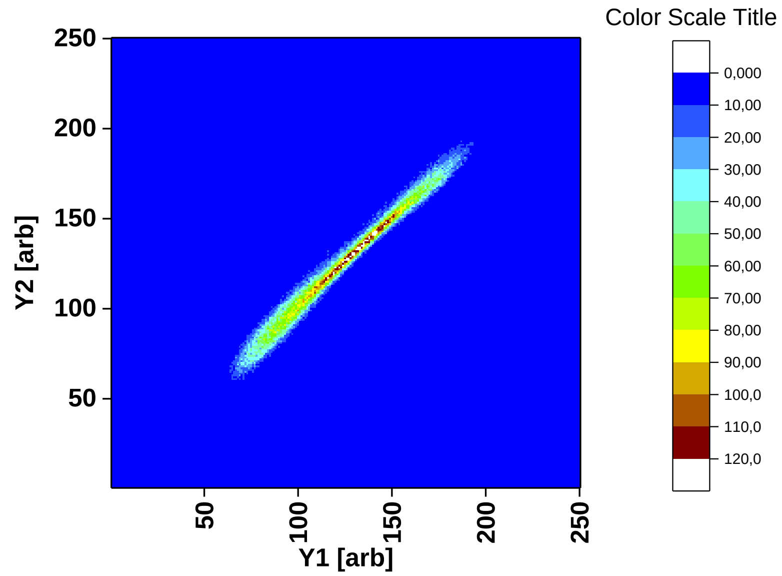
Delay of the Unity Pulse in RC-chain

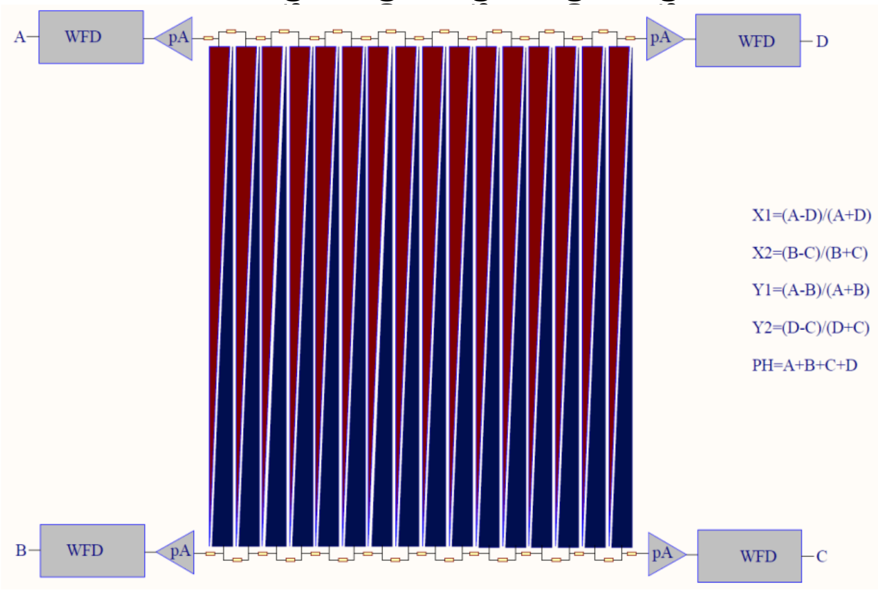


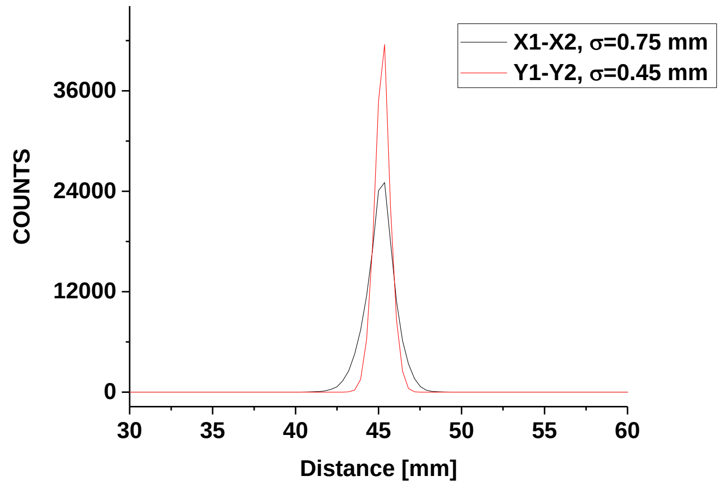


Measurement of Position Resolution in 2D

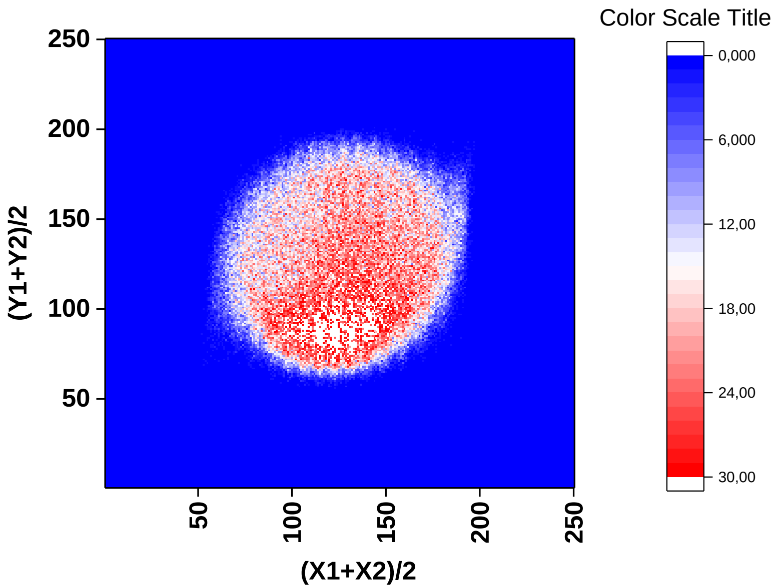




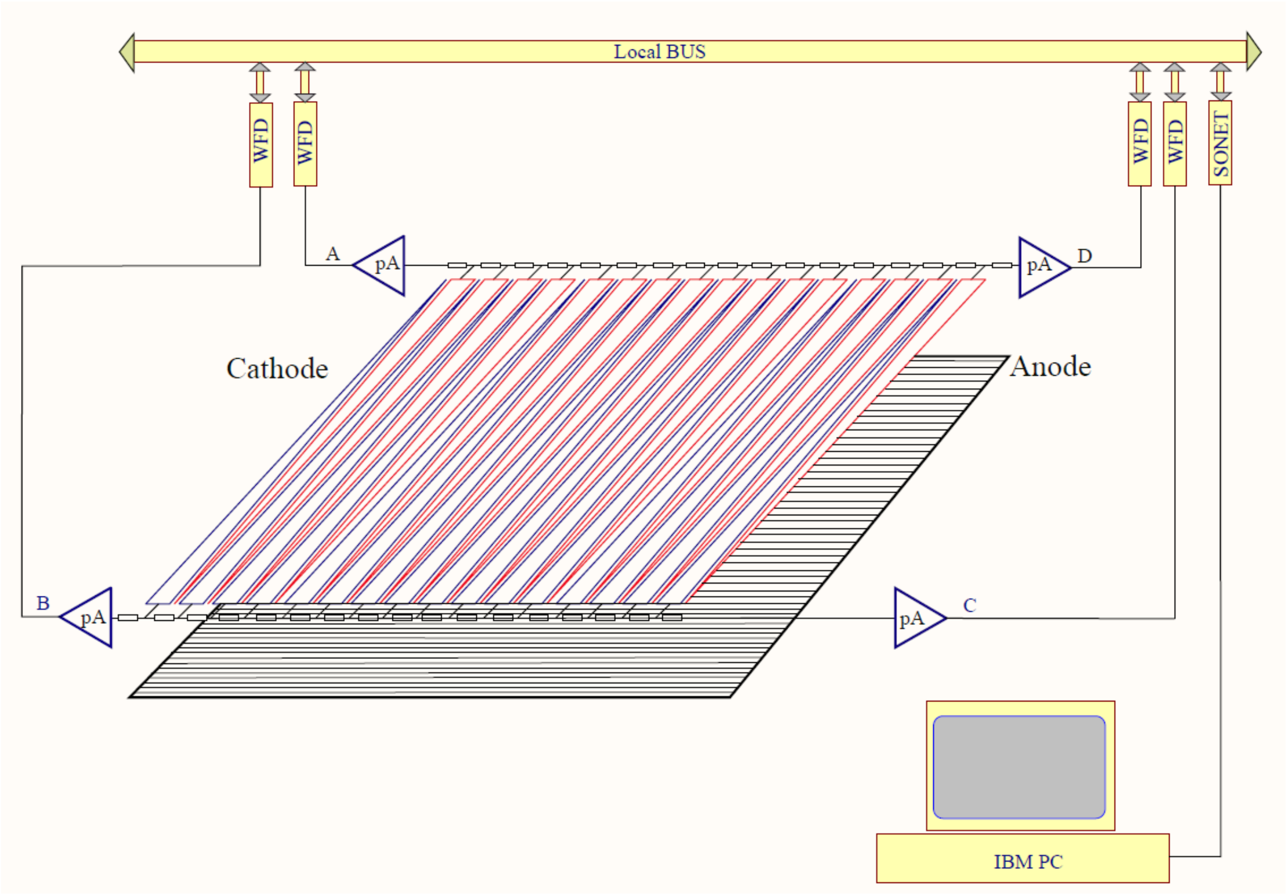




Neutron Image of 235U-Target

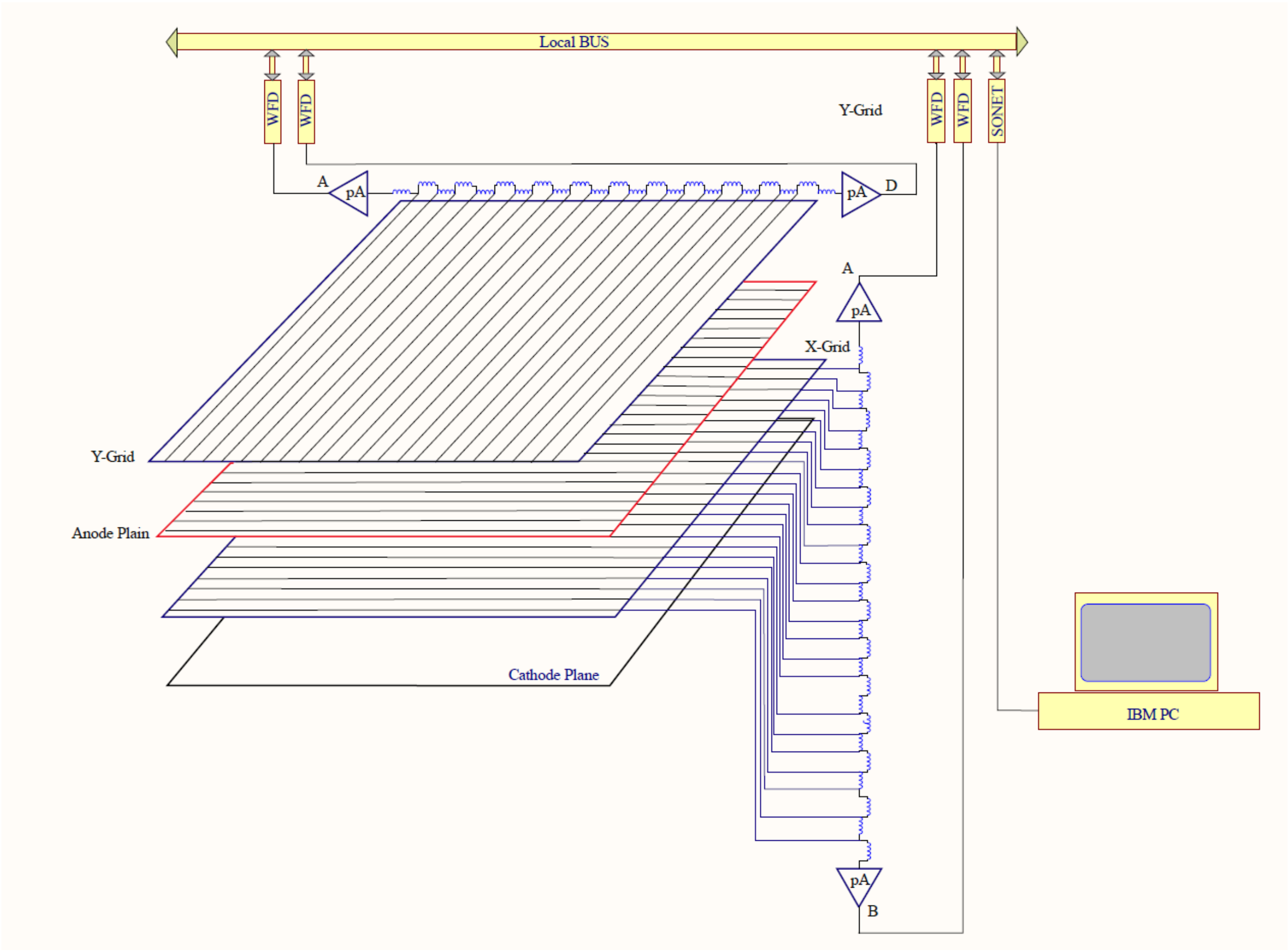


Proposal for He-filled 2D PSD Design

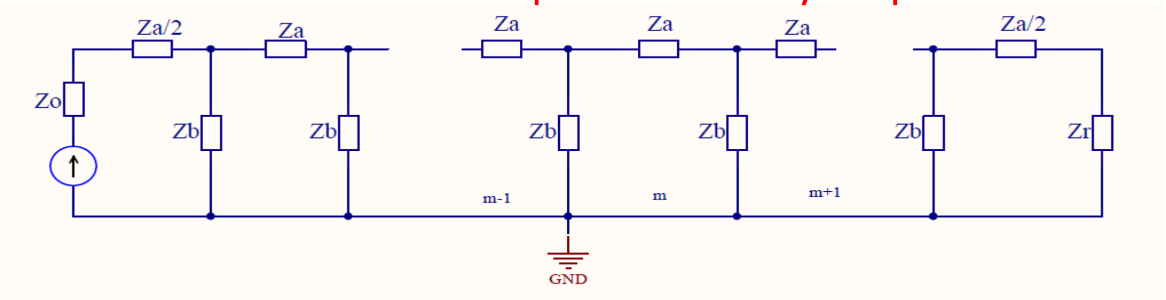


Prompt fission neutron investigation

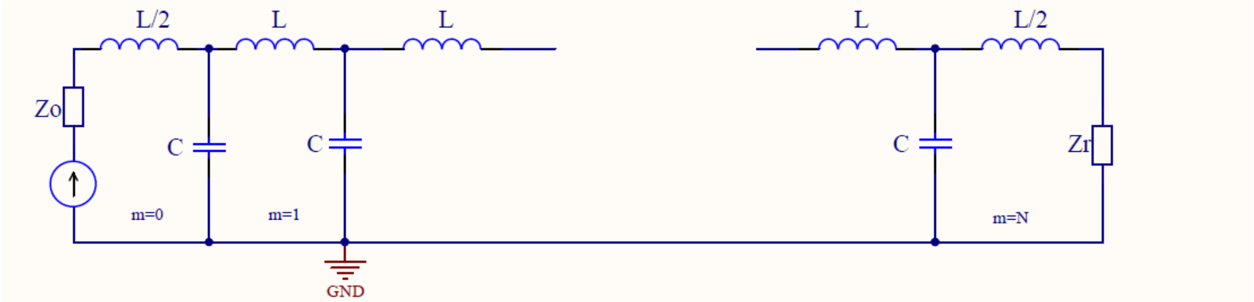
Traditional Double LC-chain He-filled PSD



LC-chain Response to Unity Step Pulse Calculation



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

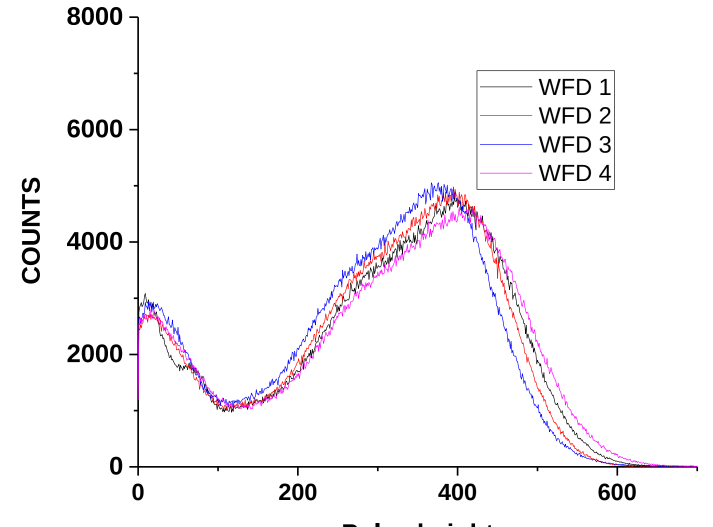


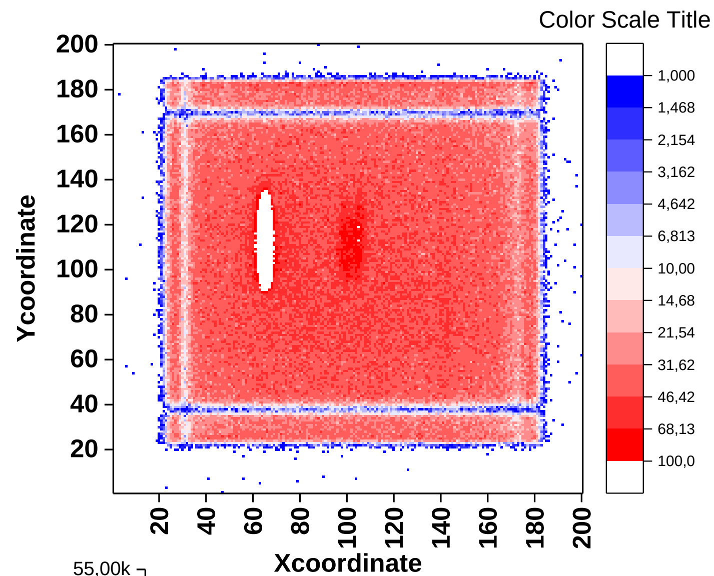
$$Z_0 = 0,\ Z_1 = Lp,\ Z_2 = \frac{1}{Cp},\ \frac{Z_1}{Z_2} = LCp^2,\ \alpha = \frac{p\sqrt{LC}}{2} \qquad i_m(t) \supset \sqrt{\frac{C}{L}} \frac{\xi(p)}{\sqrt{p^2 \cdot \alpha^2 + 1} \cdot (p \cdot \alpha + \sqrt{p^2 \cdot \alpha^2 + 1})^{2m}}$$

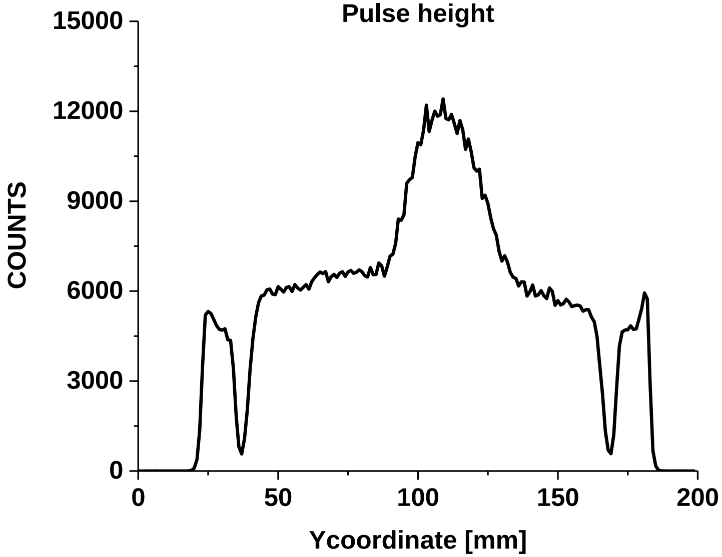
$$i_m(t) = \sqrt{\frac{C}{L}} \cdot \int_0^t J_{2m}(\frac{t}{a}) d(\frac{t}{a}) \Rightarrow \frac{\mathrm{m}}{\mathrm{t}} = \frac{1}{\sqrt{LC}}$$

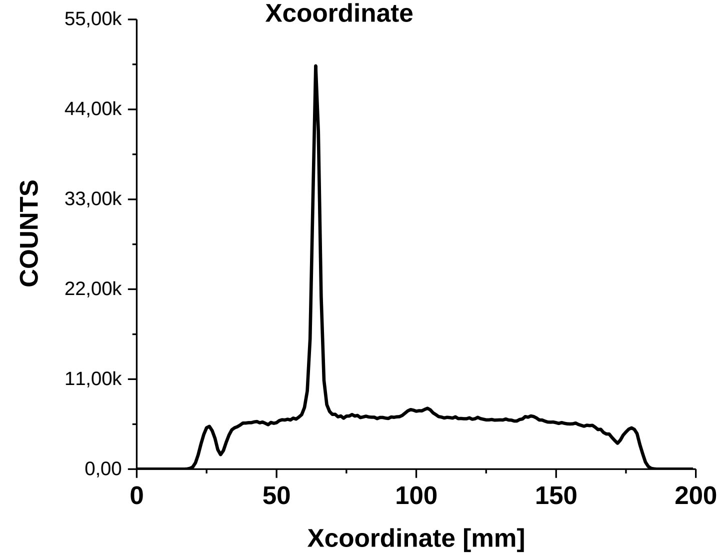
Prompt fission neutron investigation

Measurement with Double LC-chain He-filled PSD



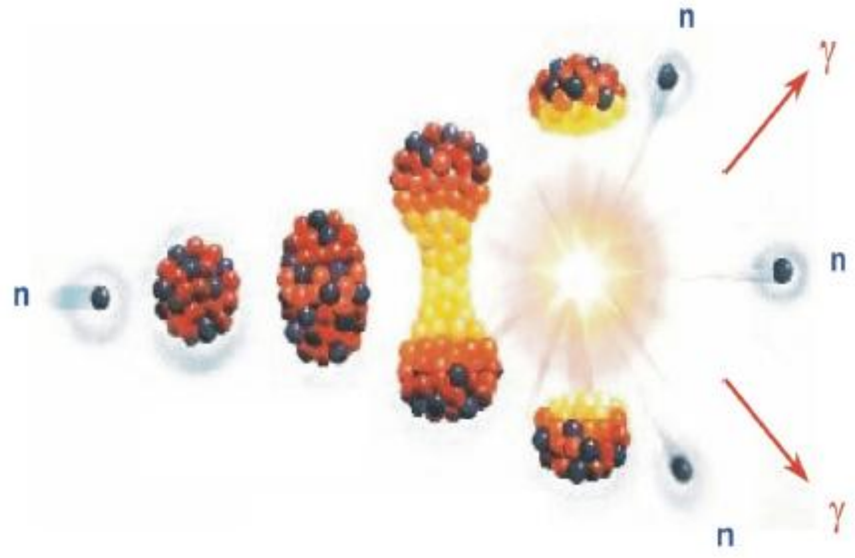






Conclusions and Outlook

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 the recursive procedures.



Thank you for your attention ☺