Development of position sensitive neutron detectors

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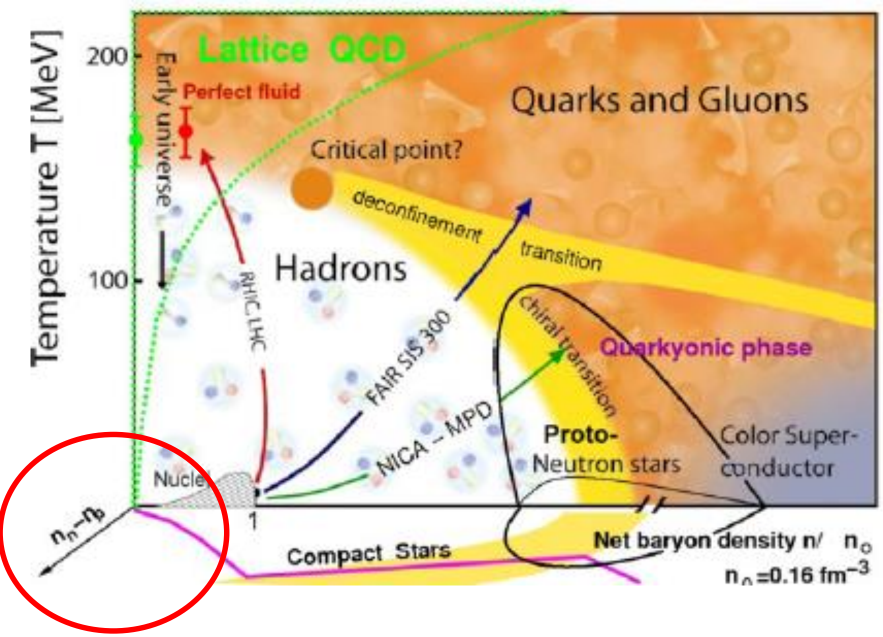
Motivation



1. Neutron is one of the main particle specie for AA collision at Nuclotron-NICA energy range;
2. State of nuclear matter depends on n/p ratio;
3. To identify some strange particles one need identify neutrons (for example $\Sigma^+ \to n\pi^+$);
4. Femtoscopy measurements: space time parameters for np and pp, nn are different.

$\Rightarrow$ **Need to measure neutrons**

Accuracy and kinetic energy range?

Temperature of the order of **100 MeV**

=>**Energy range** for neutron

Ekin~ 10 – 200MeV

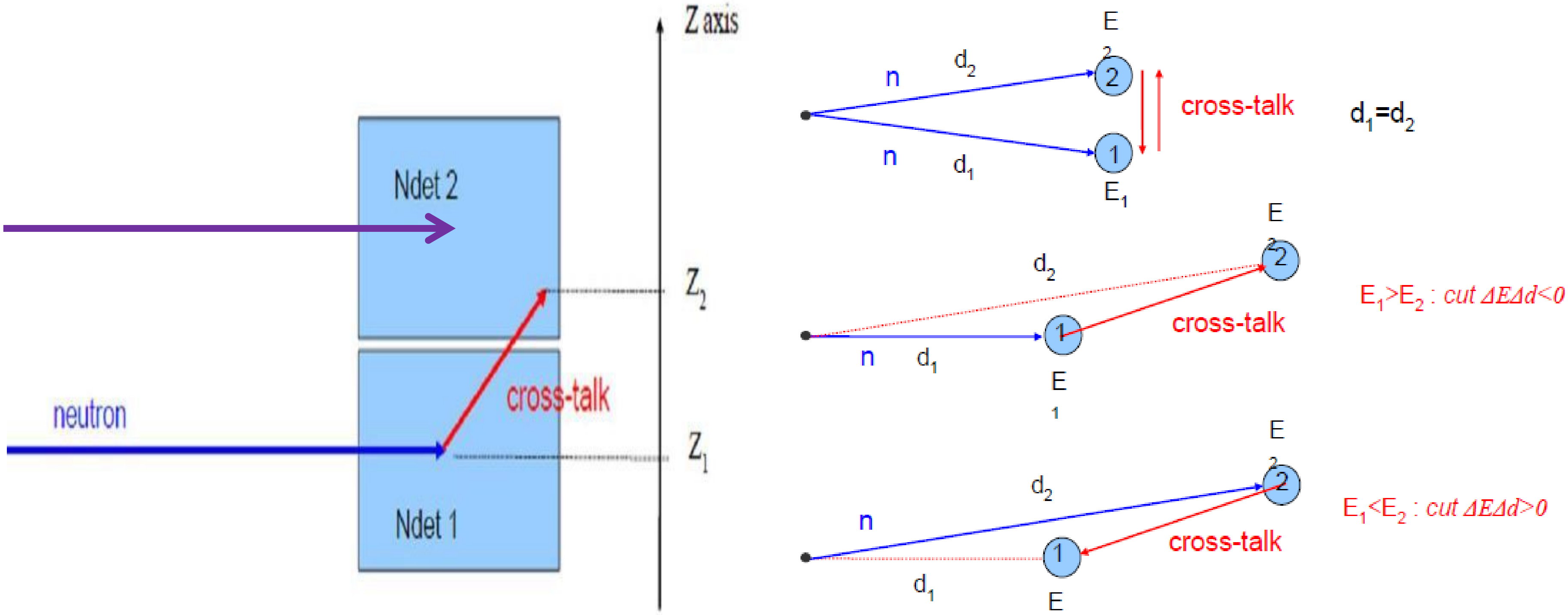
Femtoscopy : the **width** of the effect

~**30MeV/c** => **Δp~10 MeV/c,**

cross-talk problem

Cross-Talks problem

If the same neutron is registered in two or more detectors –
the cross-talk effect occurs.
It simulates registration of two or more neutrons in neighbor modules
$\rightarrow$ to a strong false correlation. In case of single particle measurements
the cross-talk effects are usually small, but in femtoscopy measurements
this effect is quite important and dangerous.

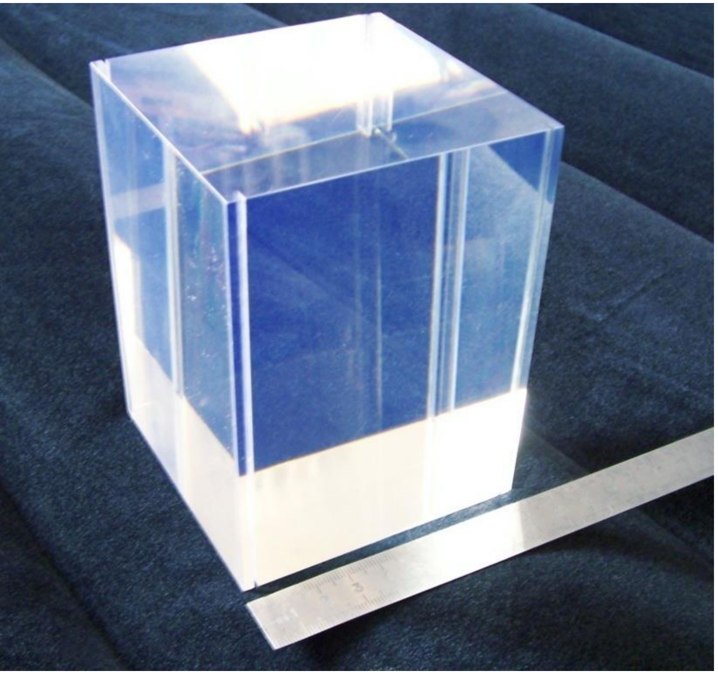


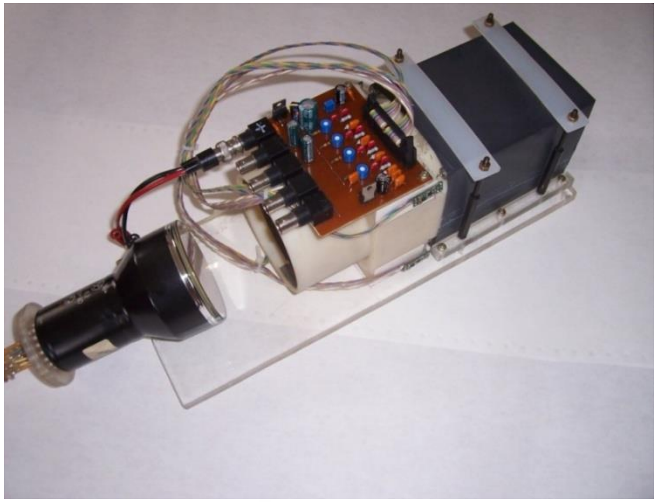
Solution: position sensitive detector

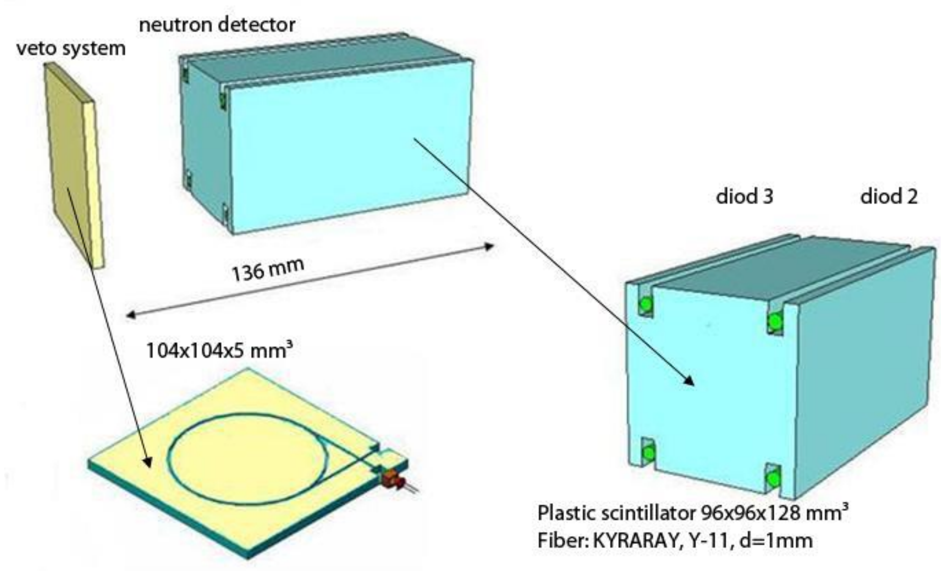
Required features for new created detector

- Neutron energy range of 10 MeV to 200 MeV
- Accuracy for neutron momentum 10-20 MeV/c
- Modular structure of detector for corelation measurements
- Compact installation modules to create large acceptance detector
- Position resolution one order better than module size (about 1 cm)
- Compact module

Neutron detector (prototype 1)-ITEP







Plastic Scintillator 96 * 96 * 128 mm^3

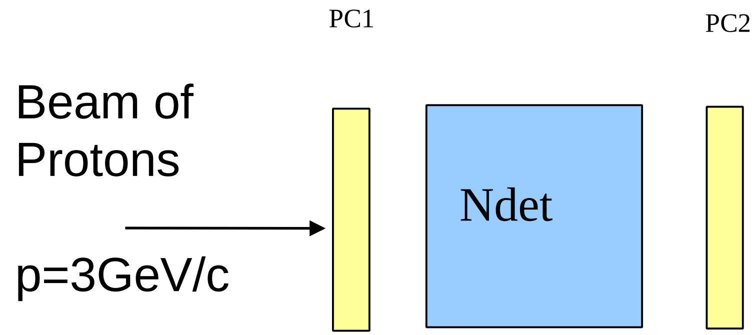
Fiber: KYRARAY,Y-11,d =1mm,

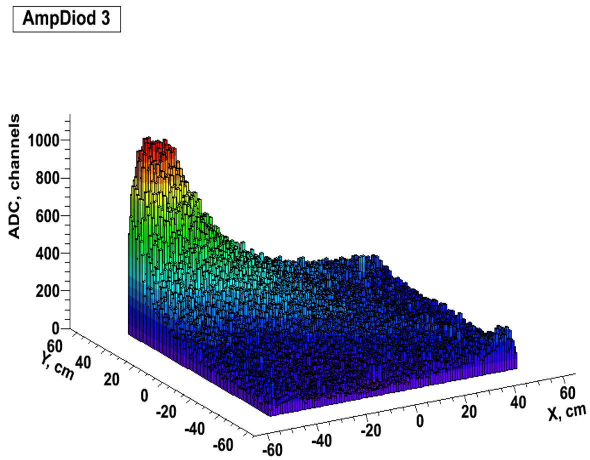
wavelength shift

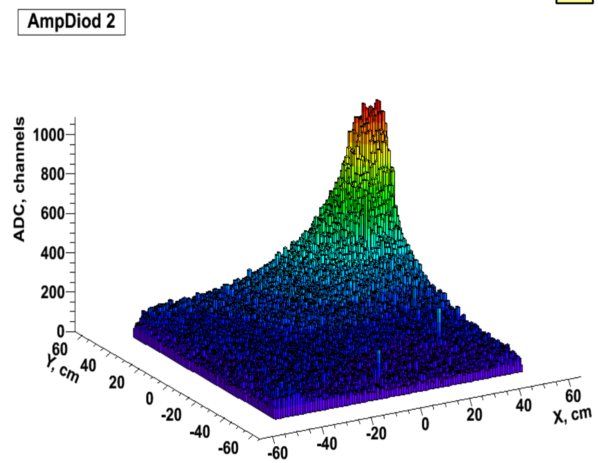
4 SiPM & Amplifier - CPTA(Golovin)

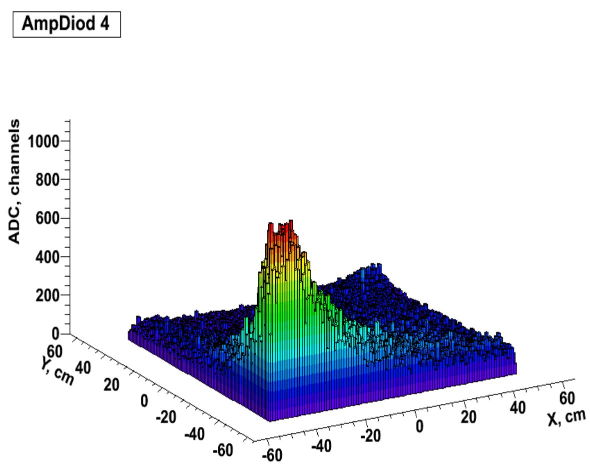
Efficiency (estimate) 15%

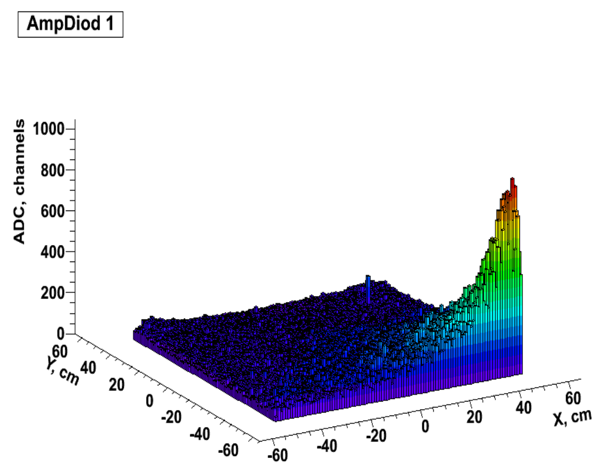
Tests of prototype 1 with proton beam(ITEP)



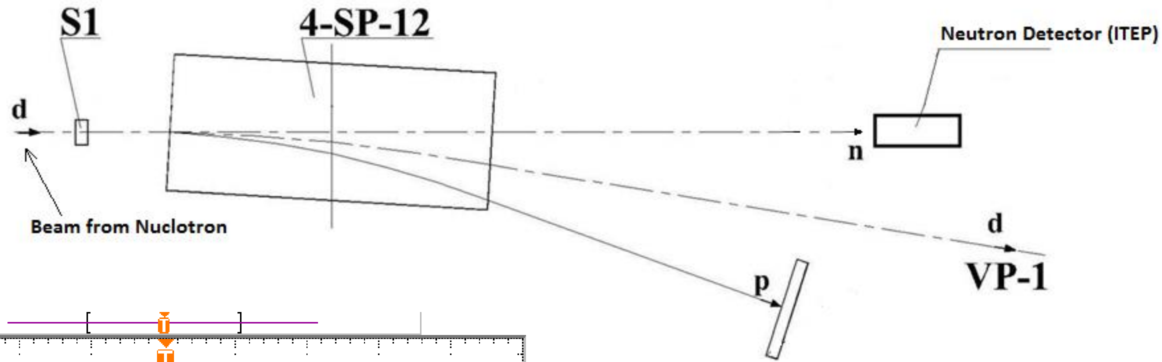


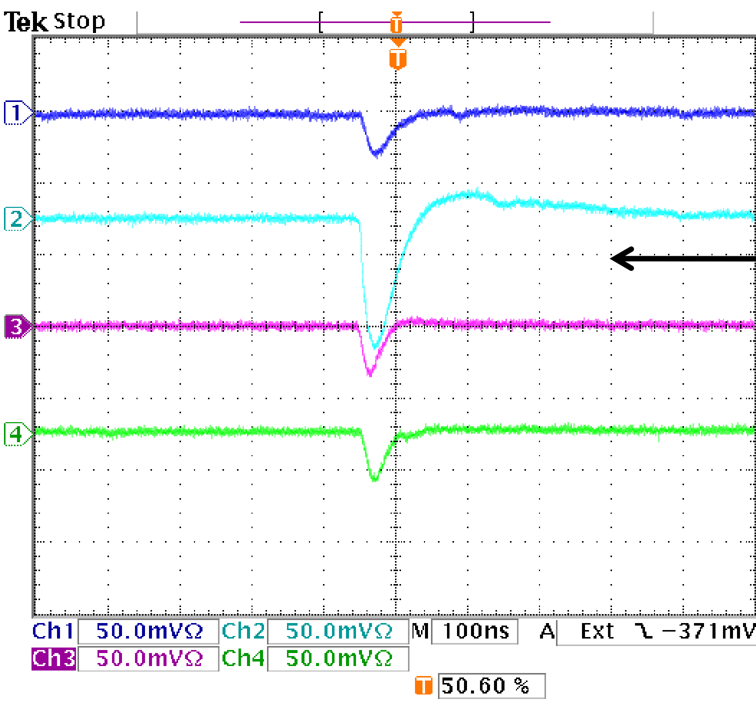




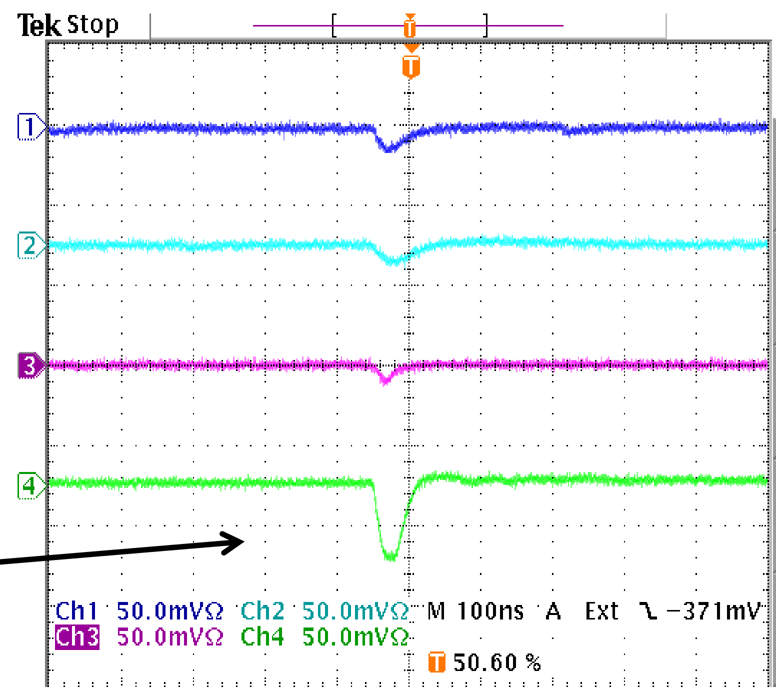


Tests of prototype 1 with neutron beam (MARUSYA)



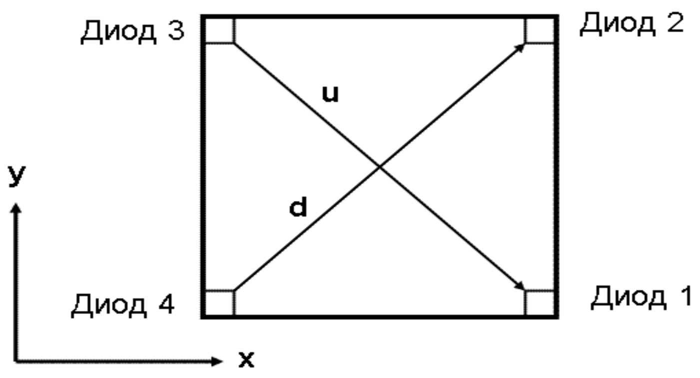


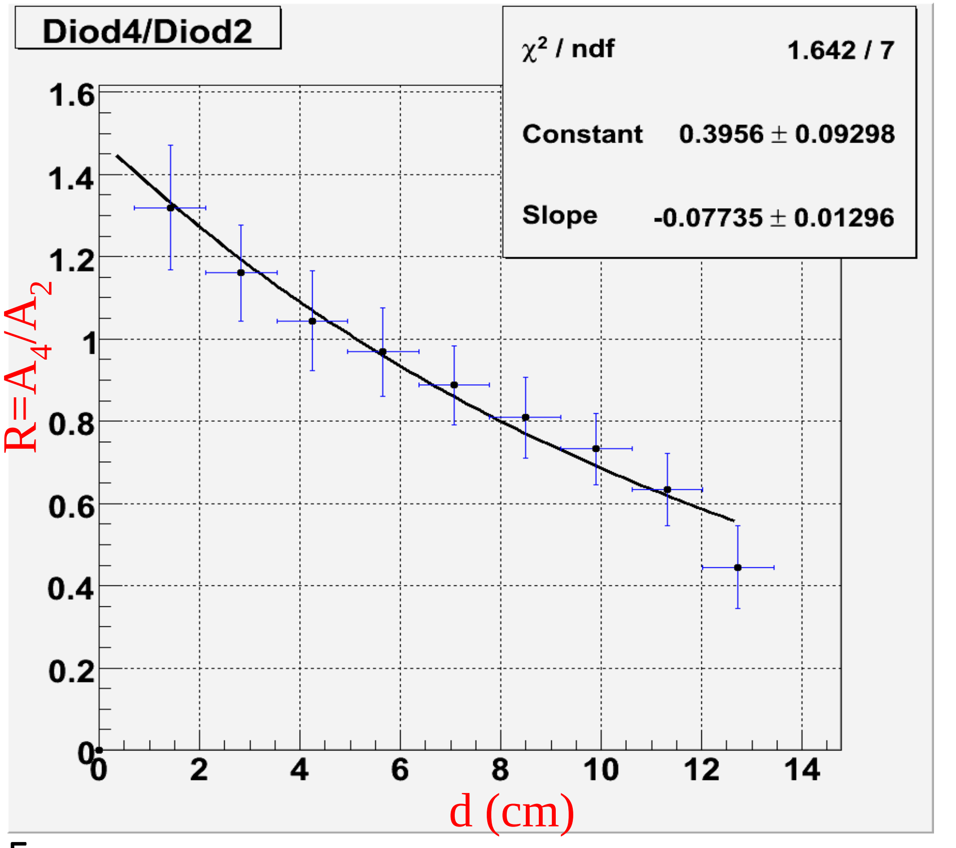
Neutron near 2 diode



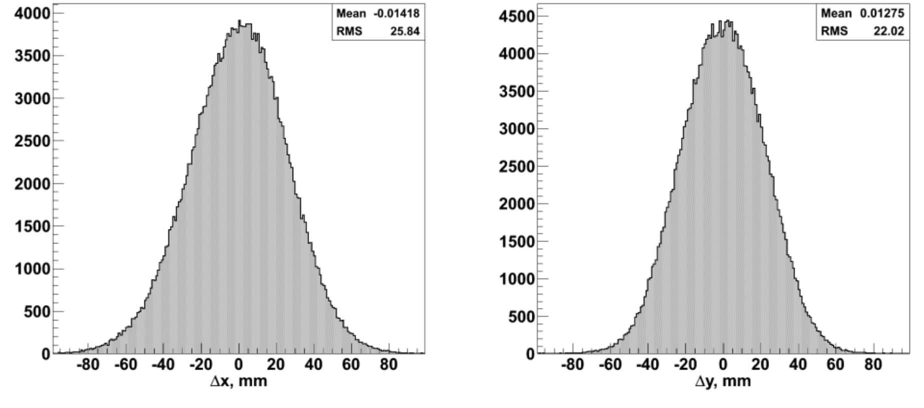
Neutron near 4 diode

Neutron detector (prototype 1)





spatial resolution for the first prototype ~ 2.5 cm



Next step to improve spatial resolution from 2,5 to 1,5 cm.

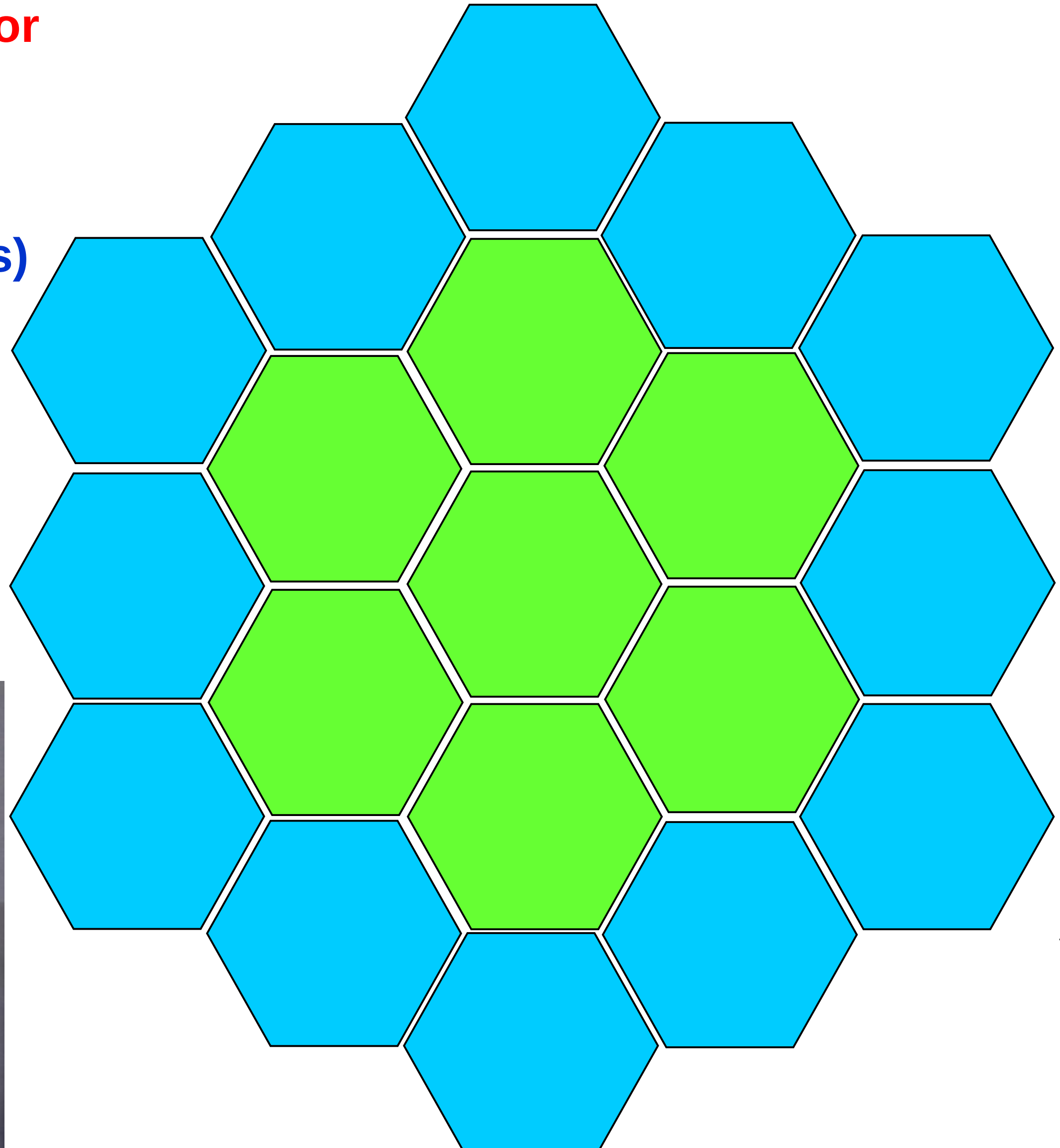
Prototype1 4 diodes * 1 mm^2

Prototype2 6 diodes * 4 mm^2

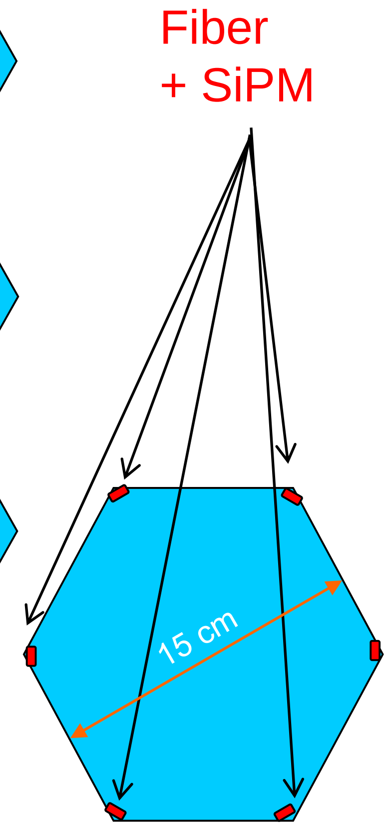
Neutron detector for MARUSYA-FLINT

Stage 1(7modules)

Stage 2(19modules)

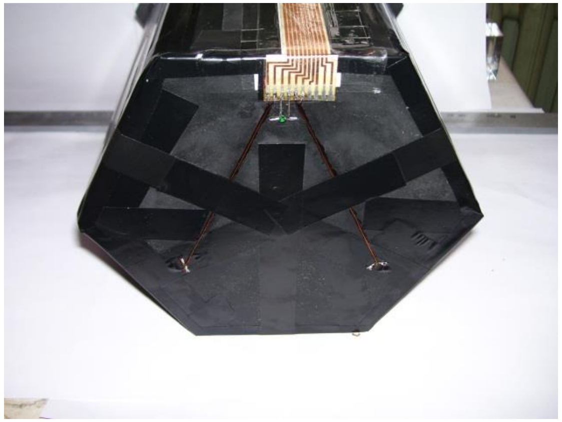


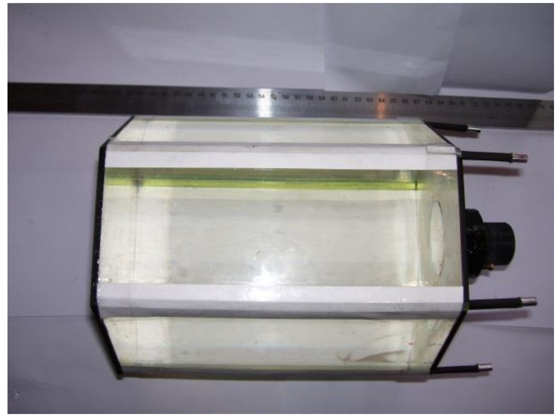
Distance from the target 240cm; Detector thickness 20cm

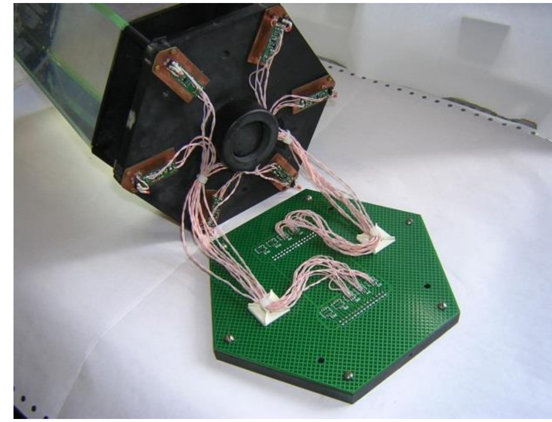


Neutron detector (prototype 2)-ITEP

During the assembling





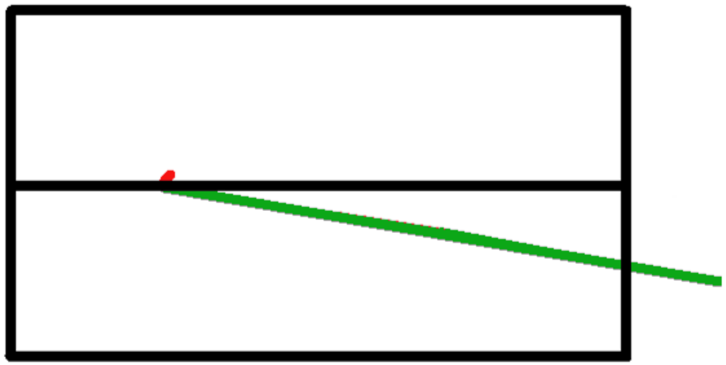


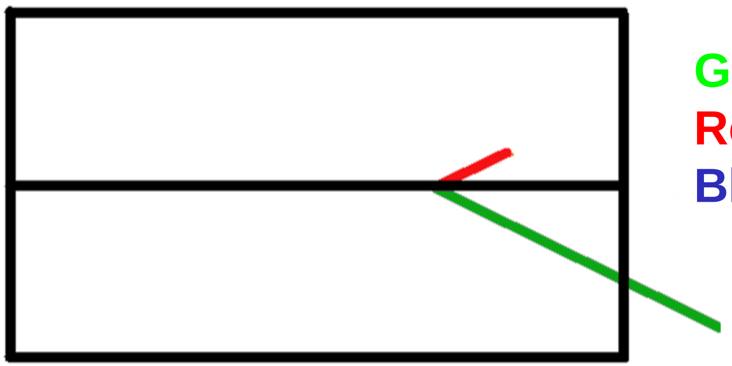
Front

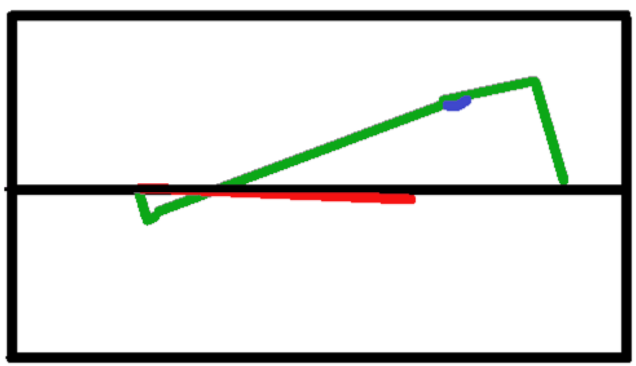
Side

Back

Principal restriction for neutron coordinate resolution

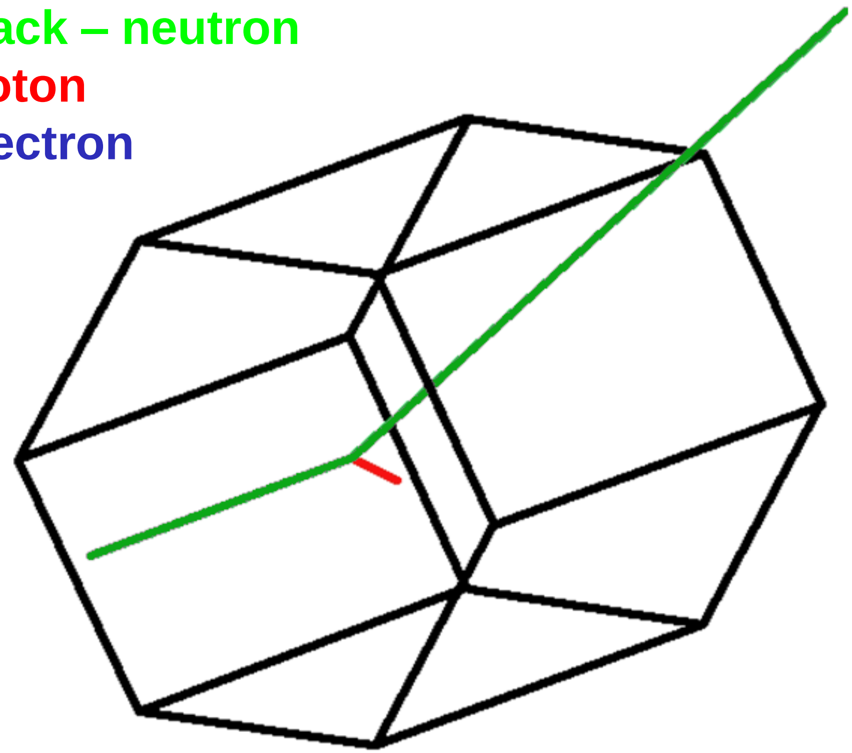






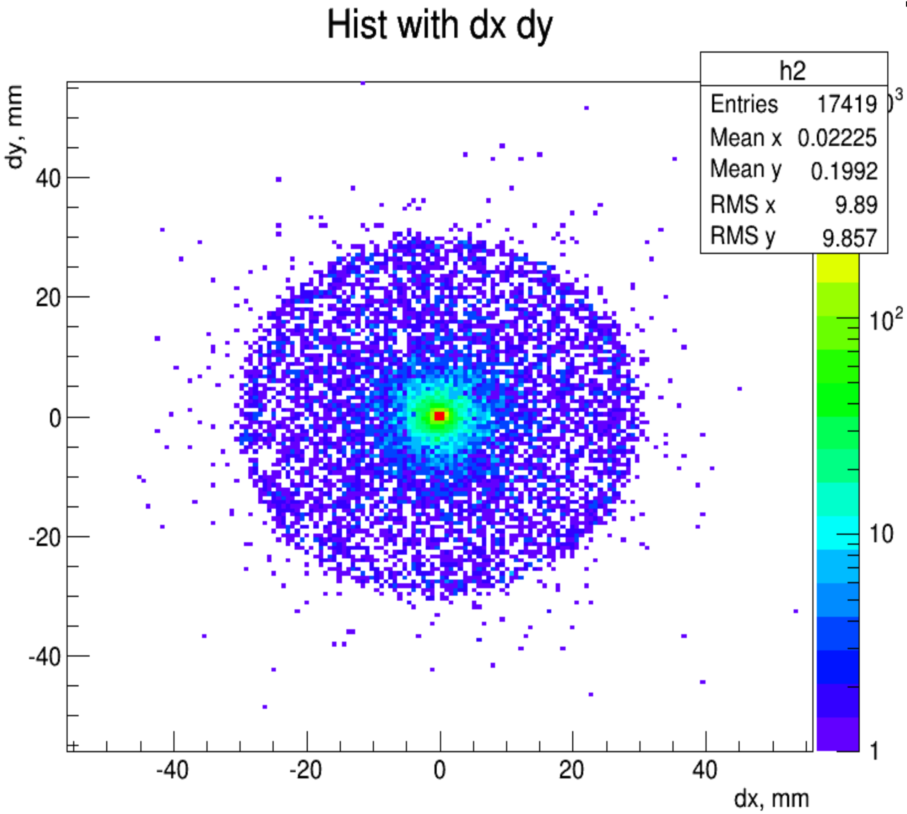
Purpose of simulation – estimation difference between neutron coordinate and recoil proton coordinate.
In framework Geant4 n+detector interaction for different neutron energy was simulated. H/C ~ BC400 (1.103). 10^5 neutrons for each energy. Neutrons shoot to detector centre. Event selection criteria: one proton realize after first interaction.

Green track – neutron
Red - proton
Blue - electron

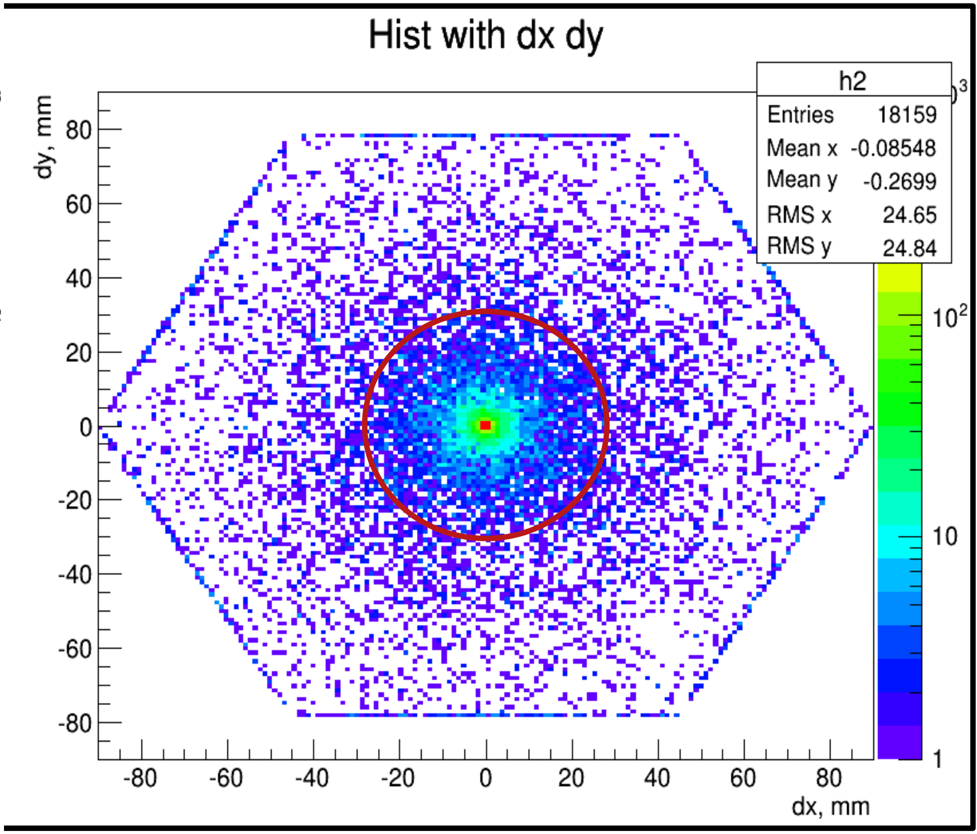


Simulation neutron detector (prototype 2)-ITEP

150MeV

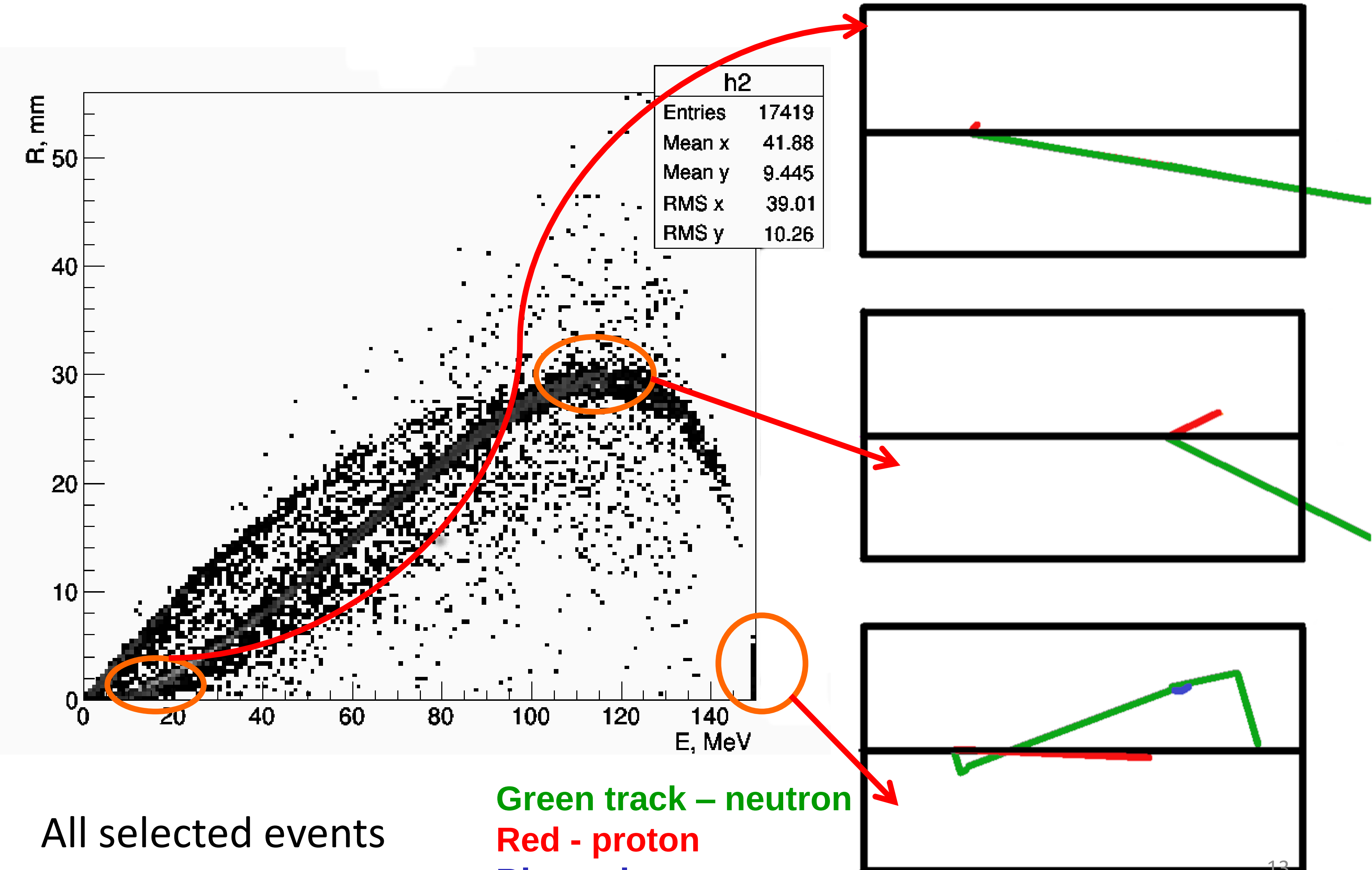


300MeV



Distribution of secondary protons in the transverse coordinates

Dependence of maximum deviation protons from deposit energies (neutron energy 150 MeV)



All selected events

Green track – neutron

Red - proton

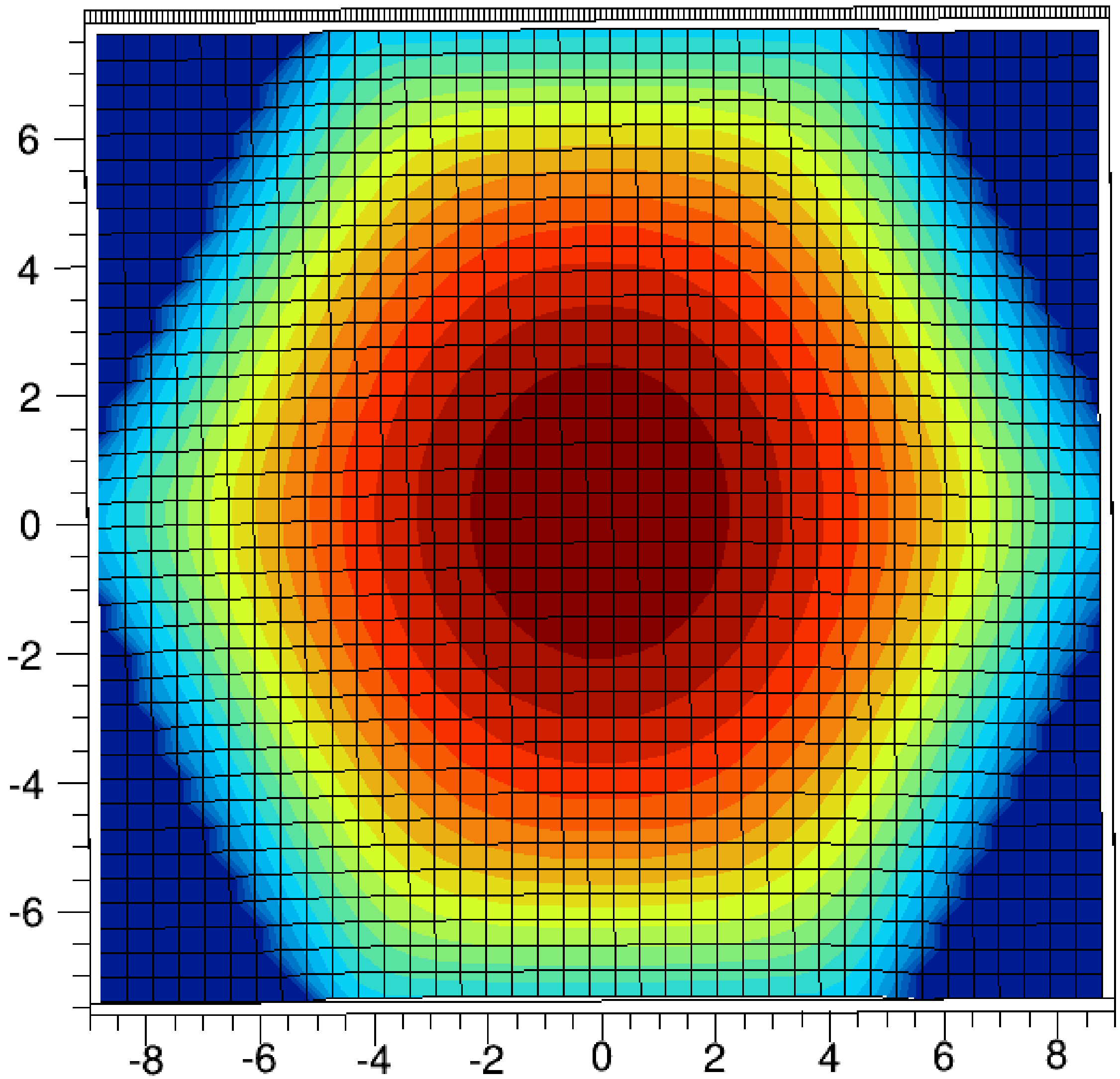
Blue - electron

Results of the simulations

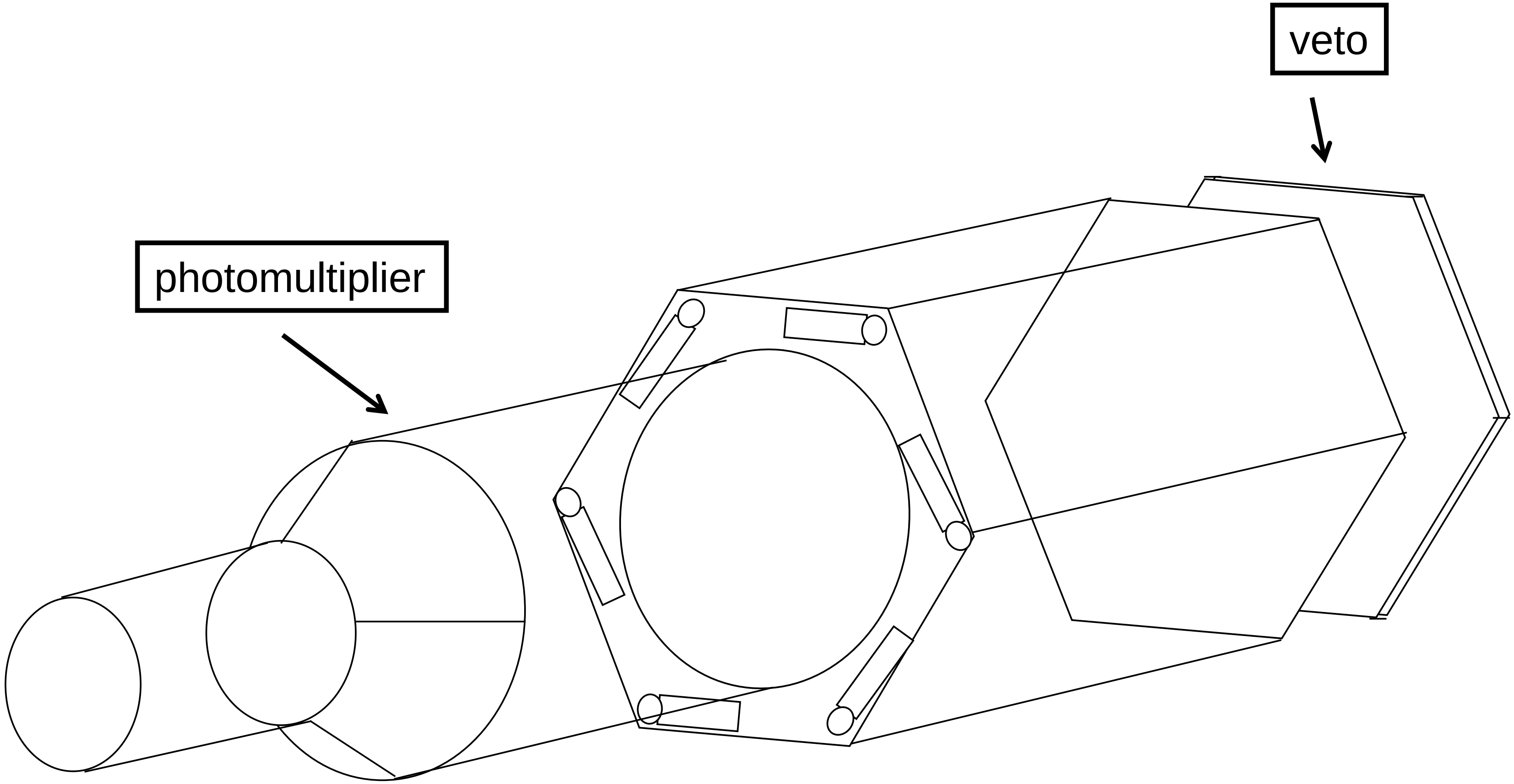
Neutron energy, MeV	50	100	150	200	300
mean deviation of protons track, mm	0,6	2,4	4,8	7,5	12,2

Amplitude spectrum for prototype 2

σ=0,056



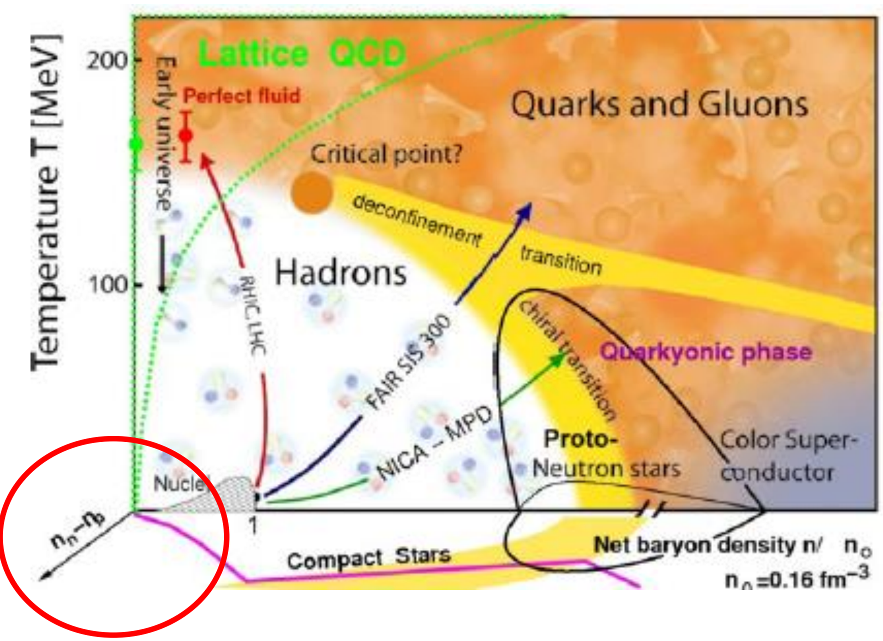
Next step – prototype 3



Conclusions

1. The prototype 1 was designed, constructed and tested. Beam tests was made at ITEP(2011) and JINR(2012-2013).
2. The results of beam tests was used in simulations of the prototype 2.
3. All characteristics of the prototype 2, obtained from this simulations, are in accordance with designed goals.
4. Prototype 2 is constructed and ready for the beam test at Nuclotron (MARUSYA)

Physical need to create neutron detector



Femtoscopy baryon matrix

-----track----------- ----photon------neutron--

10 18(13) 18(13)

photon+neutron (4)

photon or neutron (5)

	p	Λ	Ξ-	Ω	Ξ0	Σ0	Σ+	n	Σ-
p	X	X	X	X	X	X	XX	X	X
Λ		X	X	X	X	X	XX	X	X
Ξ-			X	X	X	X	XX	X	X
Ω				X	X	X	XX	X	X
Ξ0					X	X	X	X+X	X+X
Σ0						X	X	X+X	X+X
Σ+							XX	X	X
n								X	X
Σ-									X

Neutron detectors(1)

LANS(LINP-1980) large acceptance neutron spectrometer

V.N.Baturin et al., LINP-594,1980

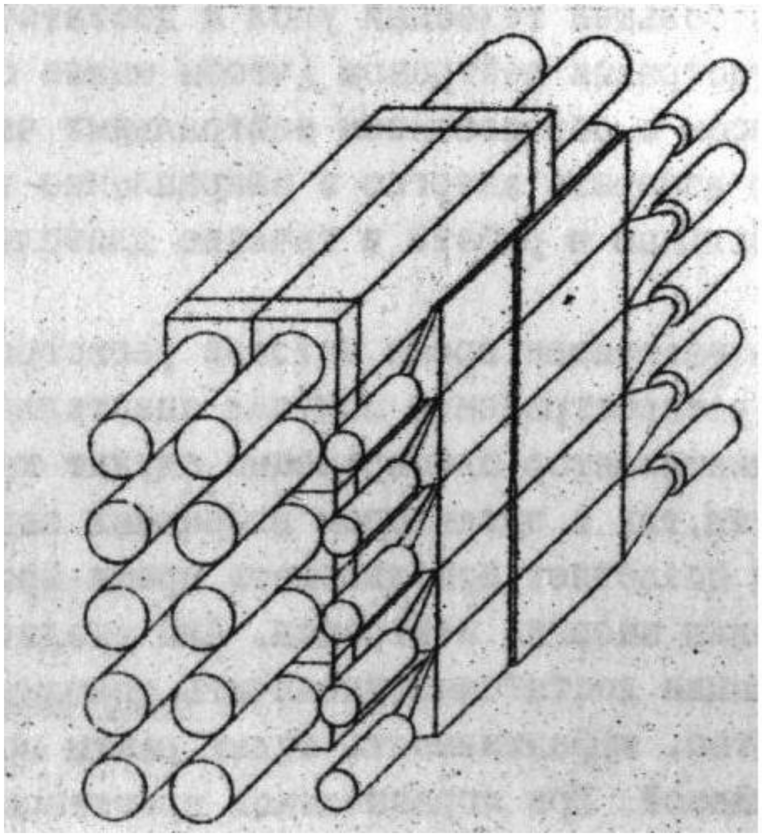
$V(L_xL_yL_z)=200x200x1000mm^3$

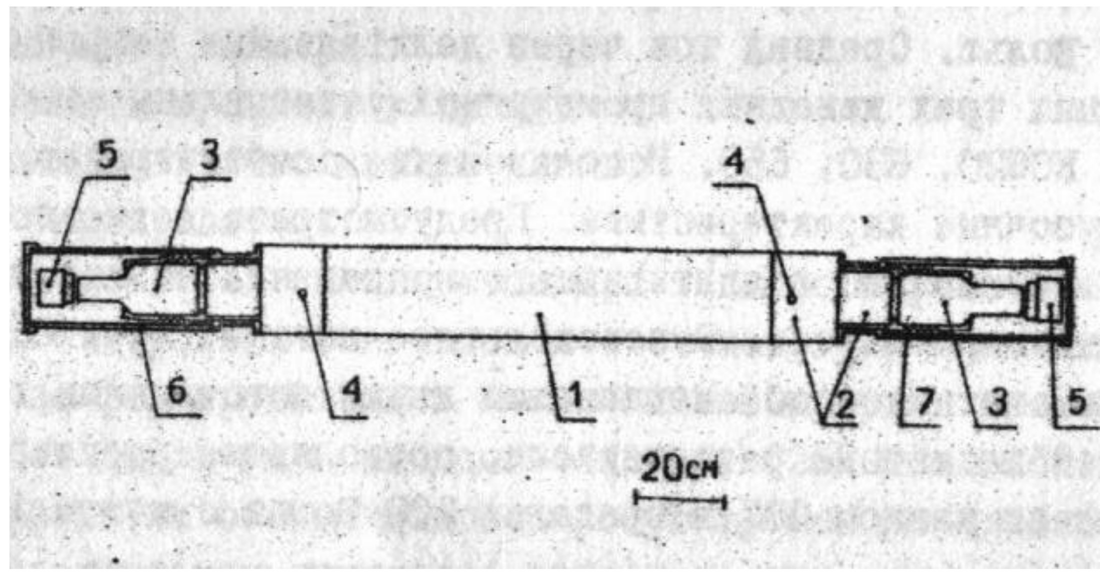
σ_τ=2nsec

ε_n =35% for neutrons of T_n=300MeV

2 neutrons in 1 module register like 1 neutron

Position resolution – module size





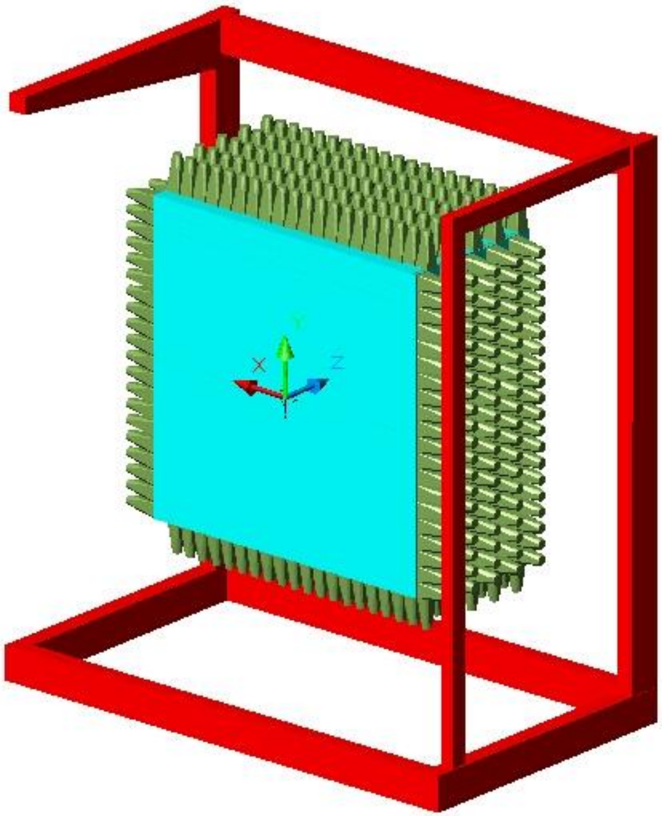
1.scintillator 2.lightguide

3.photomultipliers 4.photodiodes

5. voltage divider

6.magnetic screen 7. spring

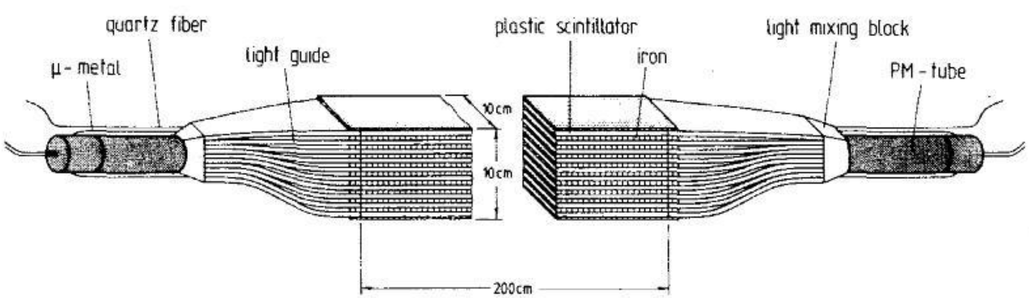
Neutron detectors(2)



LAND

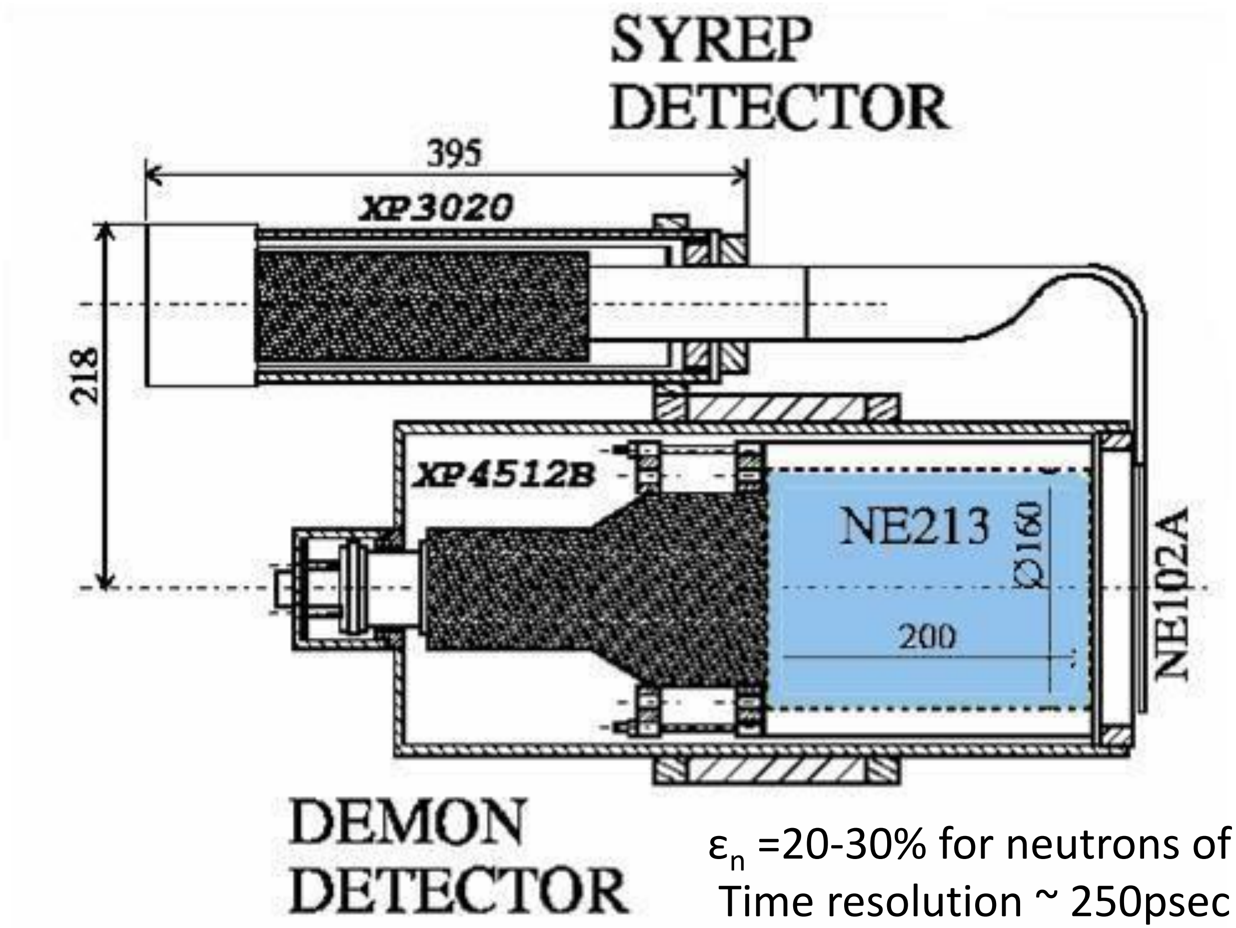
Large area detector for high-energy neutrons
$\Delta T_n/T_n$ = 5.3% for neutrons of T_n = 1 GeV
angular resolution: 0.2° for a flight path of 15 m
! ε_n ~100% for neutrons of T_n= 1 GeV
ε_n ~60% for neutrons of T_n= 0.2 GeV

400 photomultipliers



. Sketch of one neutron detector paddle. The layer structure is shown together with the bent light guide strips, light mixing blocks, quartz glass fibers, and photomultipliers.

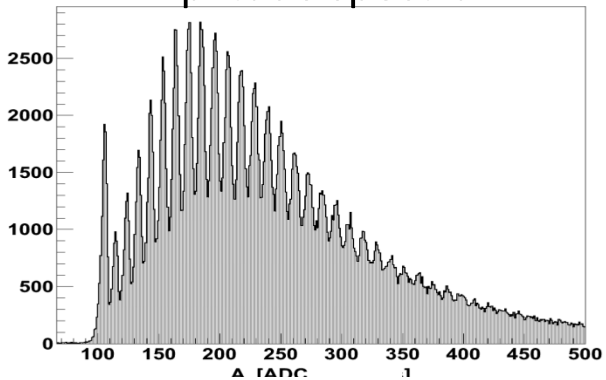
Neutron detectors

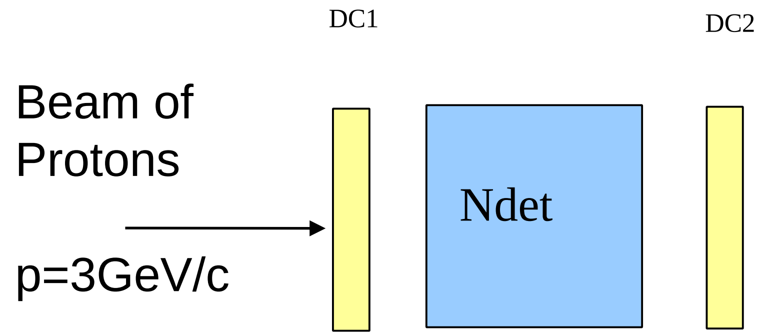


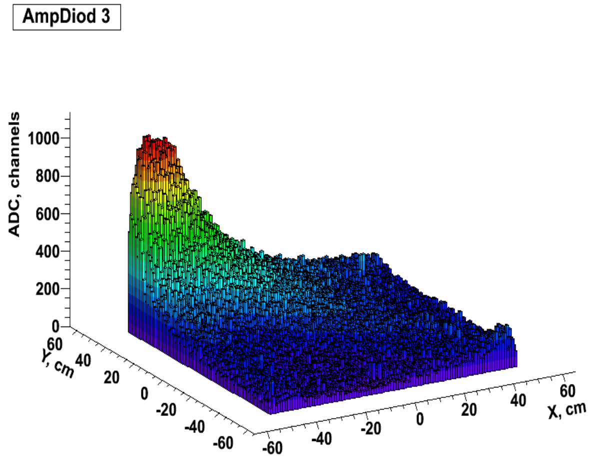
ε_n =20-30% for neutrons of Tn=60-250MeV
Time resolution ~ 250psec
Liquid scintillator
Divide signals by form
Large total volume V ~ 50 dm^3 and small sensitive volume V ~ 4 dm^3
[Tilquin I. et al., Nucl. Instrum. Methods A365, 1995, p.446]

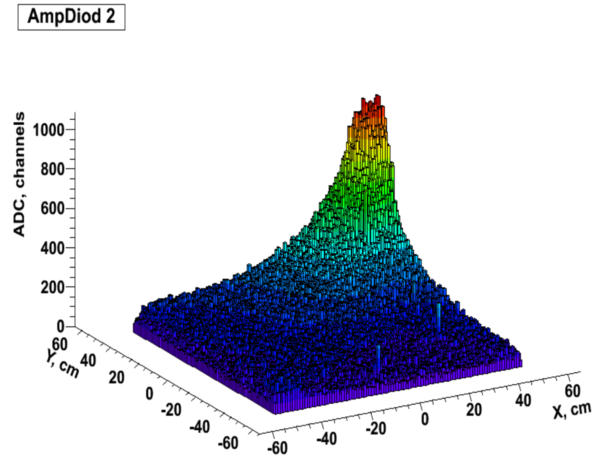
Beam tests of prototype 1

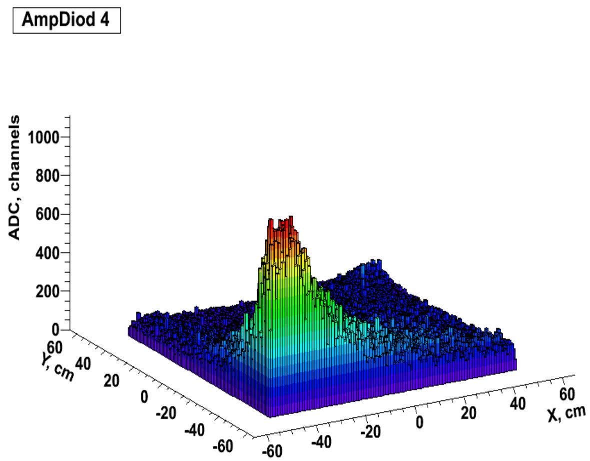
Amplitude spectrum

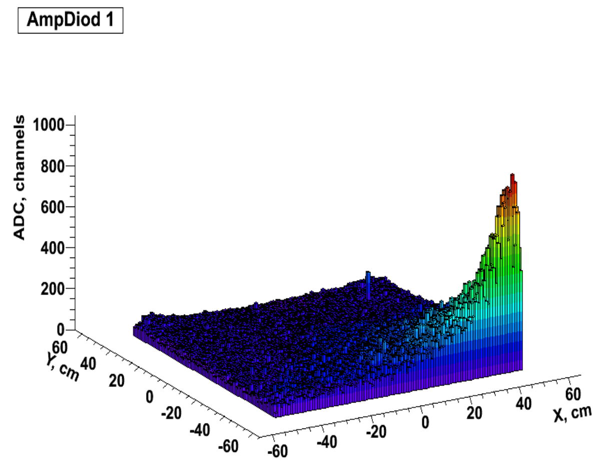






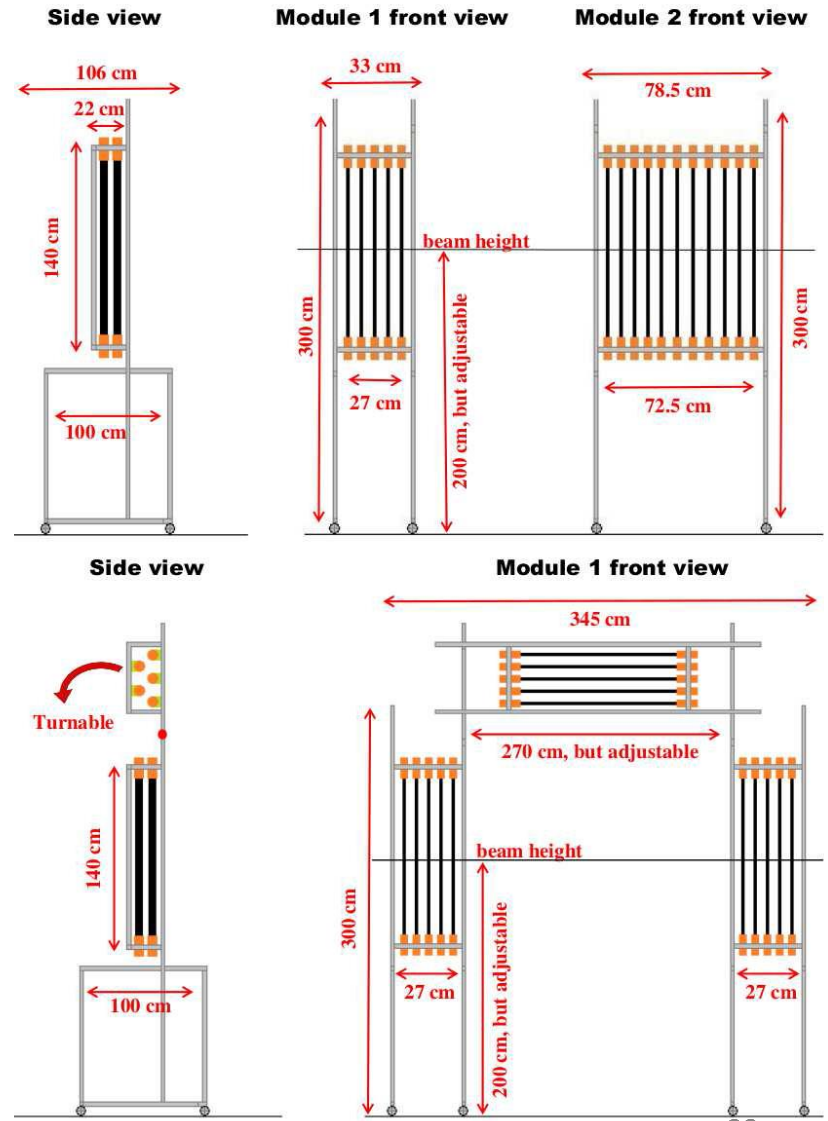






Neutron detectors(3)

ELENS



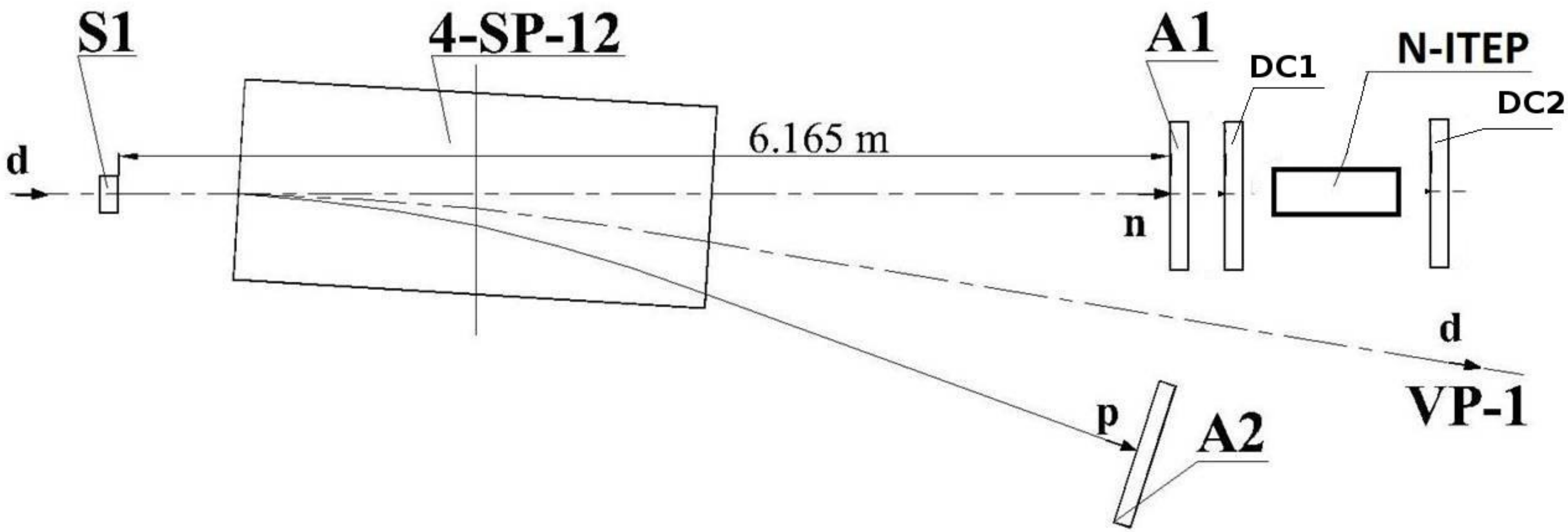
Neutron energy range of **100 keV** to 10 MeV
angular resolution of less than 1 degree
ε_n =25% for neutrons of Tn=500 keV
ε_n =40% for neutrons of Tn=1 MeV
Flight path 1-2 m
Time resolution 840 ps
Position resolution ~7,5 cm
Neutron energy is determined using ToF tecnique
Very good light-collection efficiency is required for the detection of these small signals, so a proper wrapping material and the tight fitting of the foil onto the plastic were important criteria for ensuring a sufficiently high-quality light connection.

Wrapping procedure let reduce energy threshold
Foil (VM2000) has a good reflection coefficient of *R* > 97% for ≥ 400 nm and R = (98.5 ± 0.3)% at 430 nm

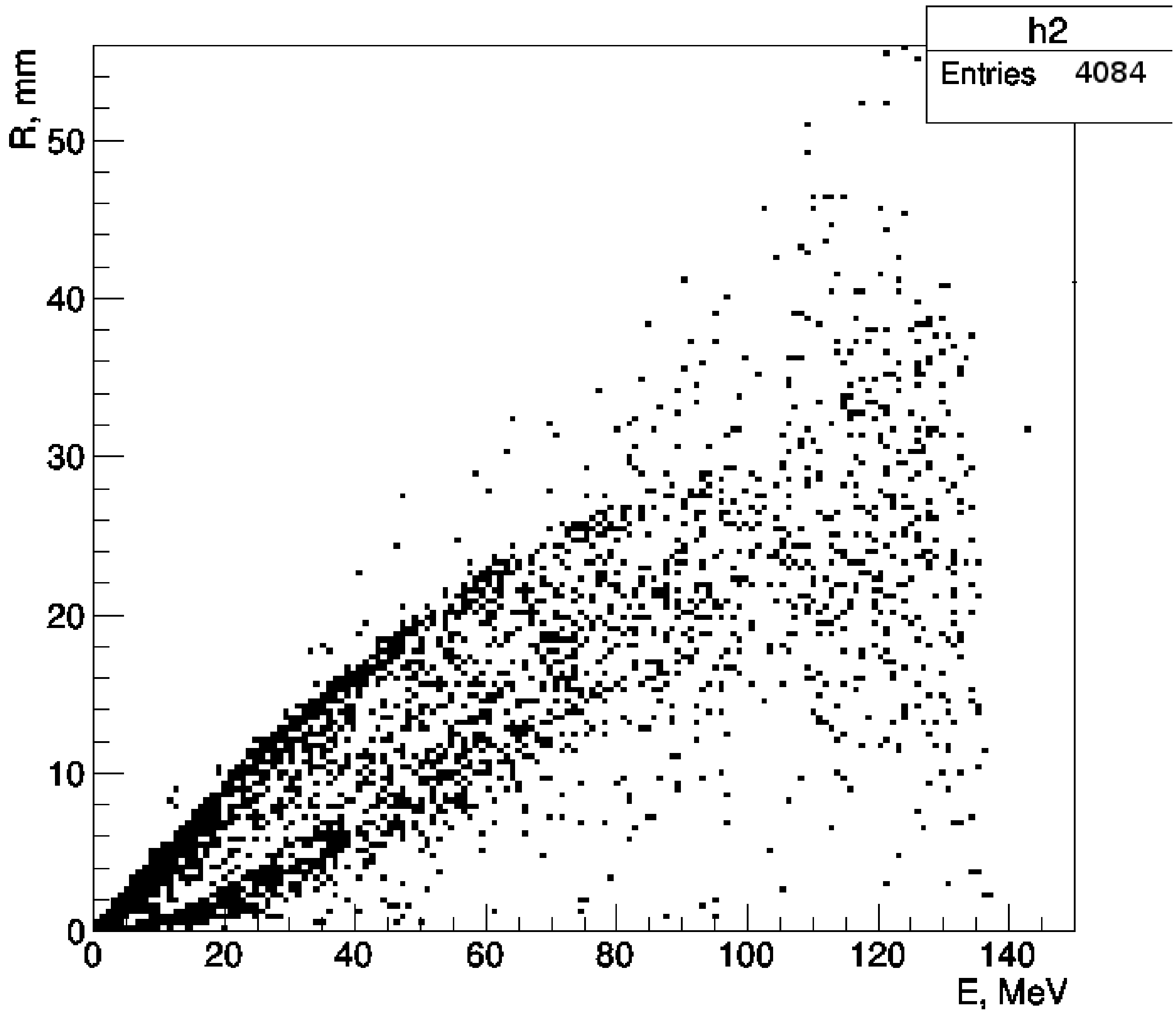
Calibration on neutrons

Neutron Beam test of prototype2@Nuclotron

$$d + C \rightarrow (pn) + X$$

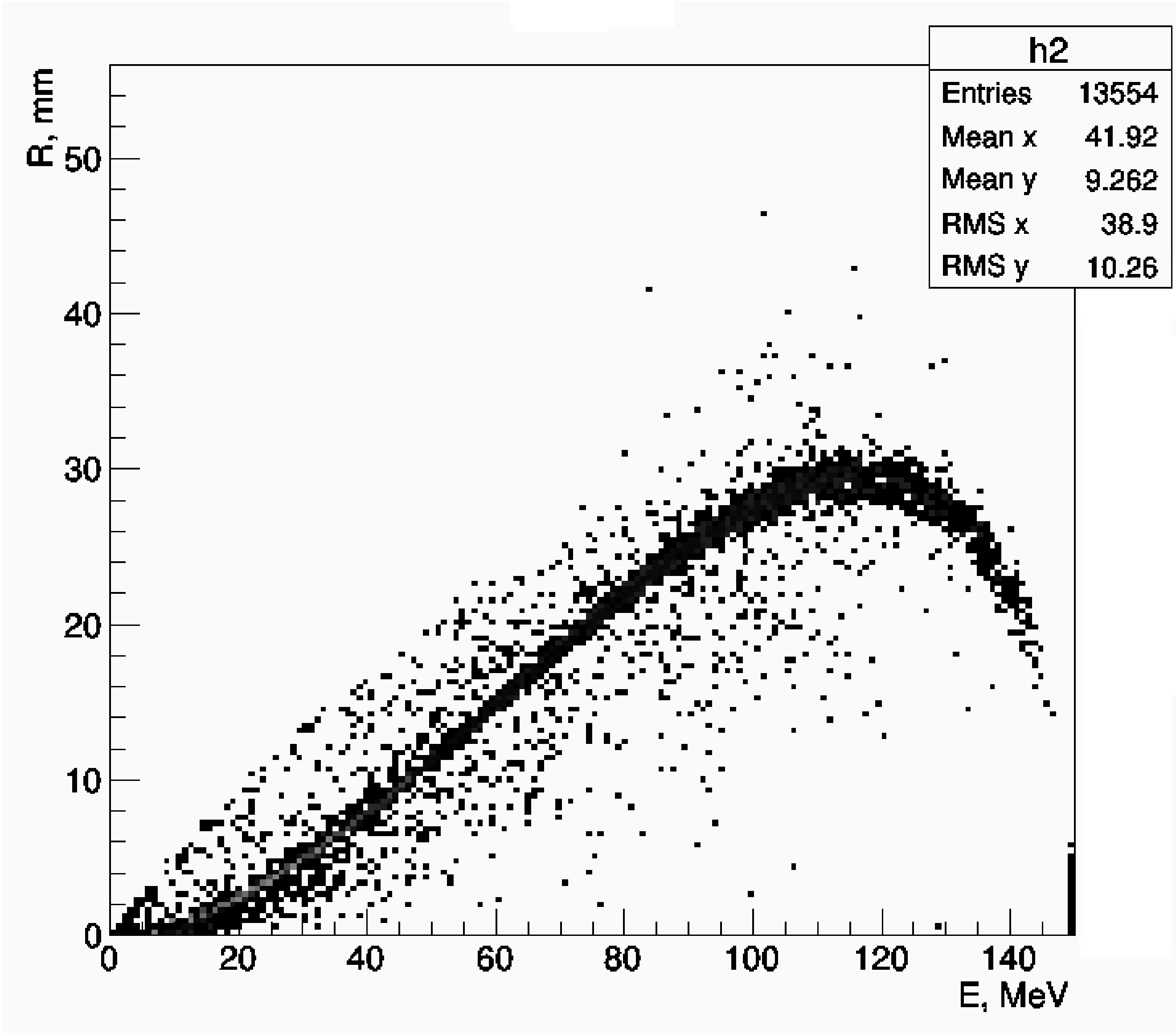


Dependence of maximum deviation protons from deposit energies



Back wall events and collision with nucleus events

Dependence of maximum deviation protons from deposit energies

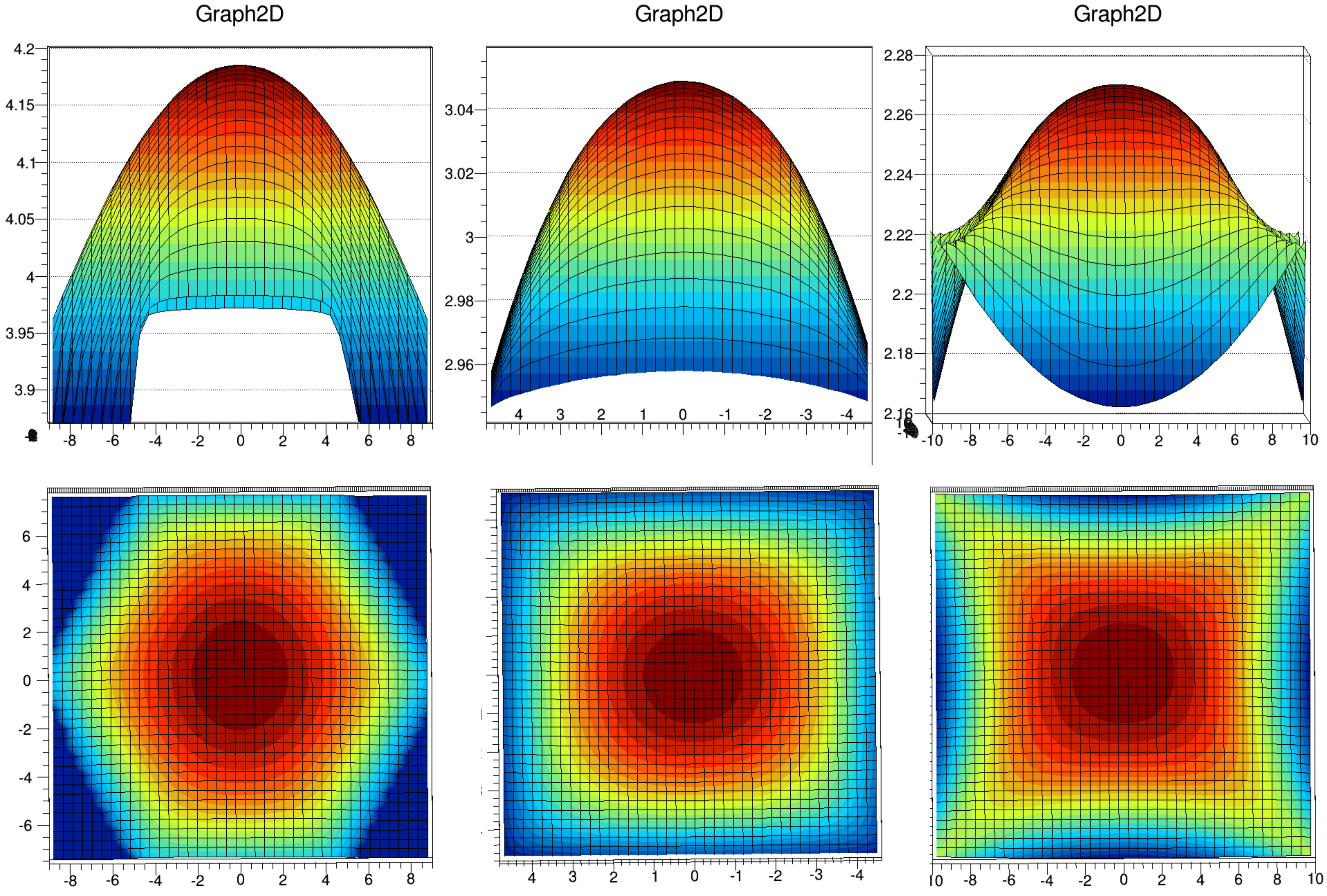


Main events

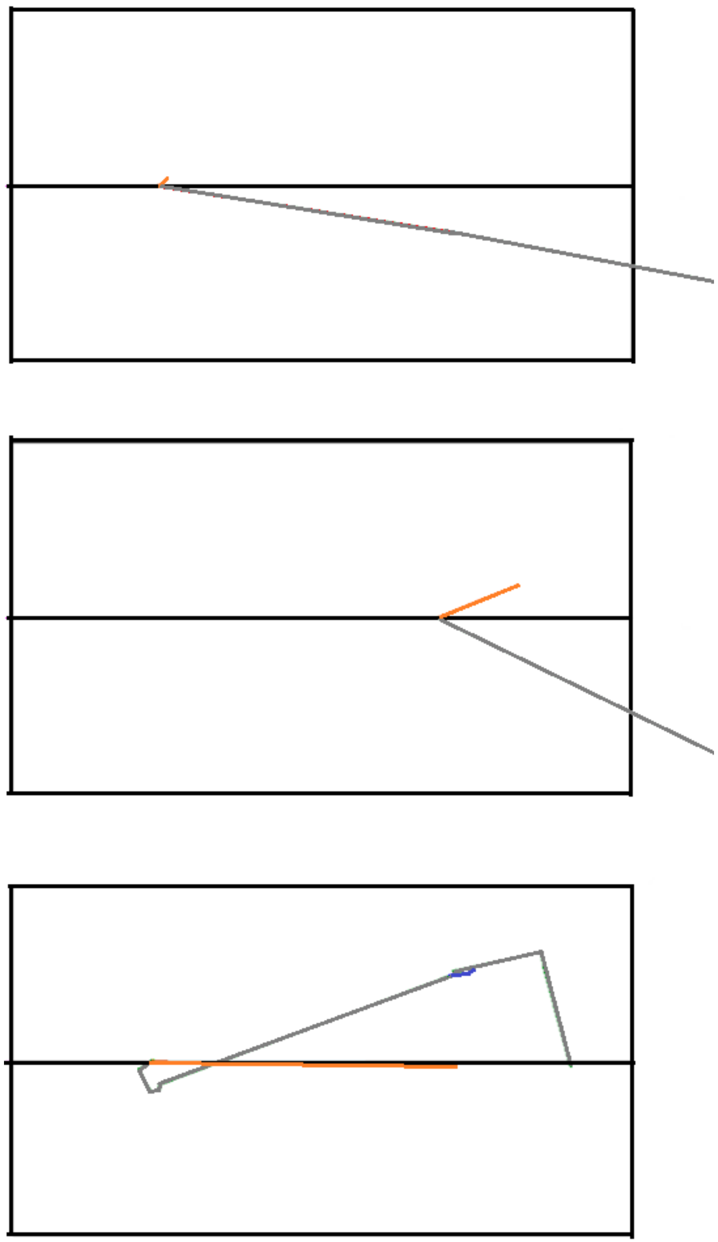
Results of the simulations

Neutron energy, MeV	50	100	150	200	300
% selected events	18,8	18,0	17,4	17,6	18,2
mean deviation of protons track, mm	0,6	2,4	4,8	7,5	12,2
maximum deviation protons, mm	5,7	25,3	50,2	80,2	90,0

Hexagon cube 96x96 cube 200x200



Simulation neutron detector (second prototype)-ITEP



Trajectories of the particles inside the detector. Green line - neutron trajectory, red - proton.

view of the model