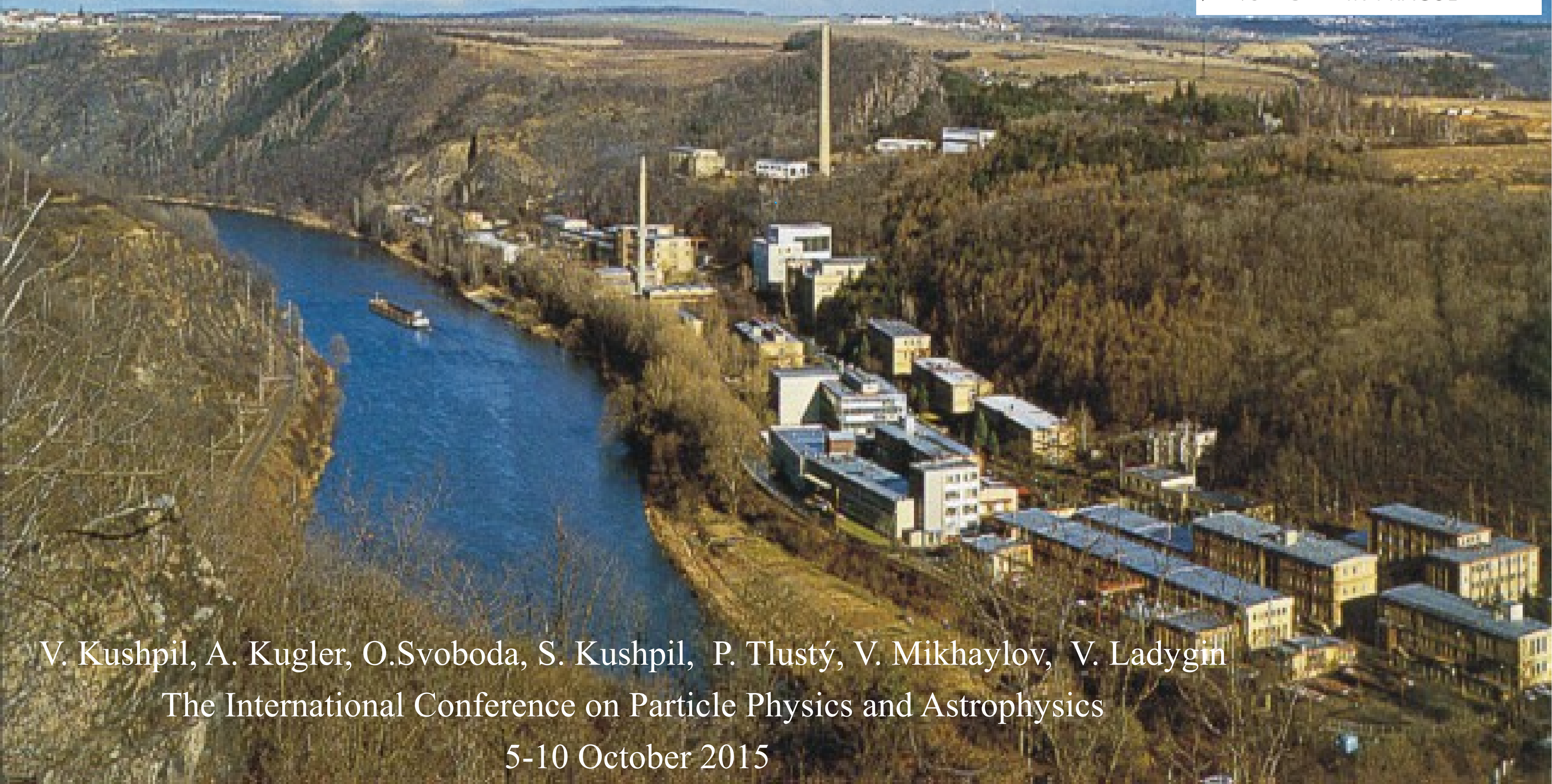
# Radiation hardness of semiconductor avalanche detectors for calorimeters in future HEP experiments

CZECH TECHNICAL UNIVERSITY IN PRAGUE



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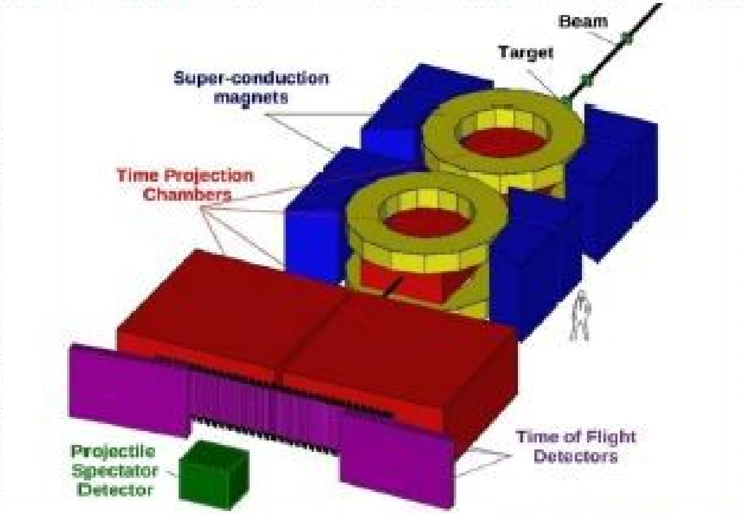
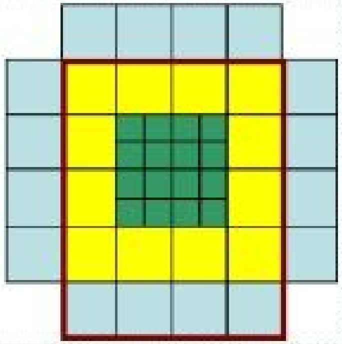
The International Conference on Particle Physics and Astrophysics

5-10 October 2015

# PSD and ZDC

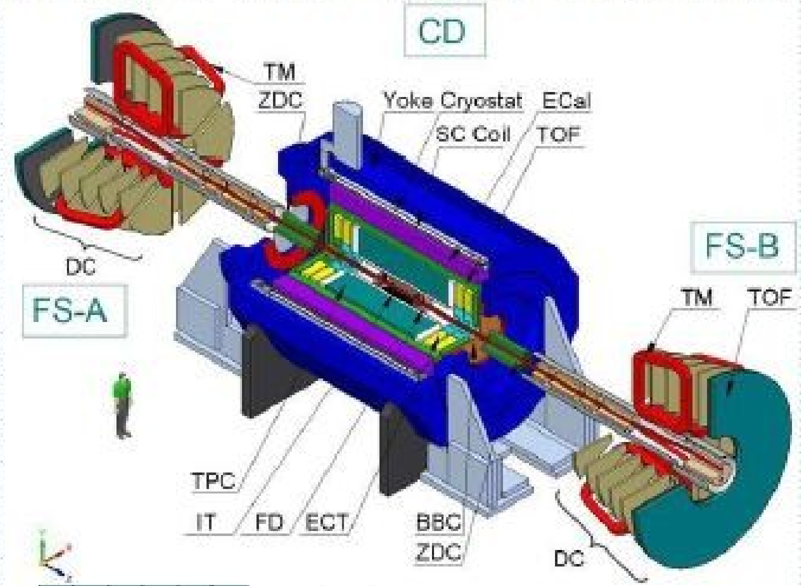
## NA61 Projectile Spectator Detector

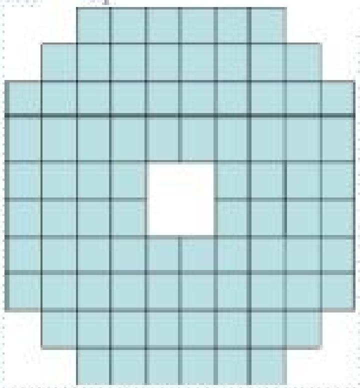


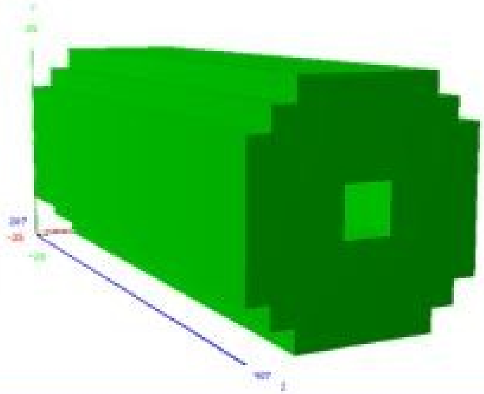



60 sandwiches in one module
16 inner modules of 10 x 10 x 120 $cm^3$
28 outer modules of 20 x 20 x 120 $cm^3$
Total weight ~ 17 tons, 17-25 m from target
No beam hole for intensity up to $2x10^5$ ions/sec
NA61 beam energy up to 150 AGeV

## NICA MPD Zero Degree Calorimeter





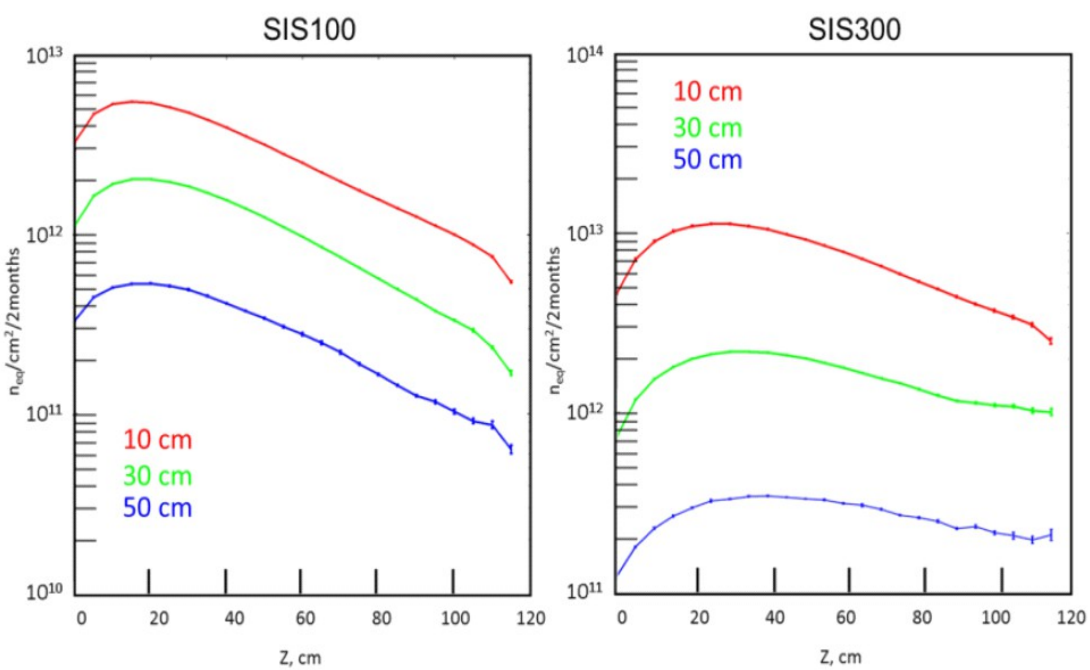
60 sandwiches in one module
16 modules of 5 x 5? x 120 $cm^3$
Total weight ~ 10 tons, 28 m from collision estimate
Beam hole (10x10 cm) for intensity up to $1x10^9$ ??? ions/sec
NICA beam energy up to $\sqrt{s_{NN}}$ =11GeV?(~ $E_{beam}$=63 AGeV)

# Neutrons – new factor

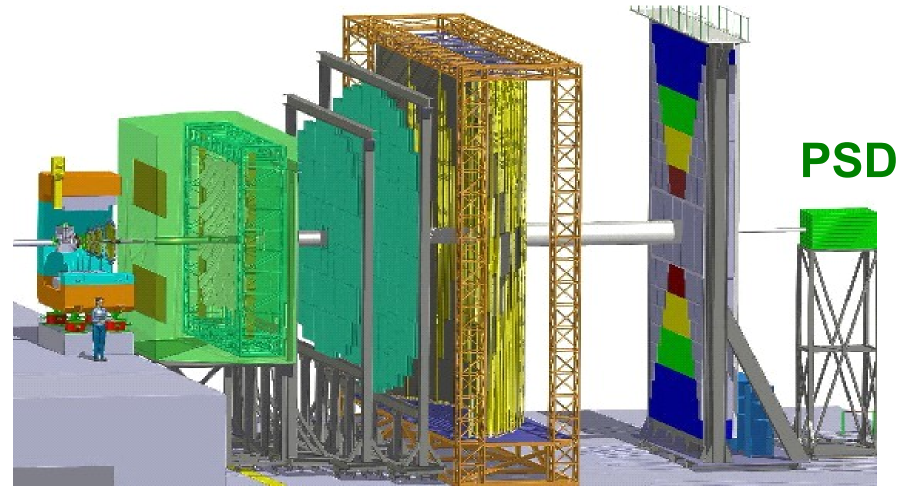
The PSD detector from CBM will be used to explain basic goals of program:

From geometry of PSD we can see that neutrons is most important type of particles which will define radiation hardness of APD.

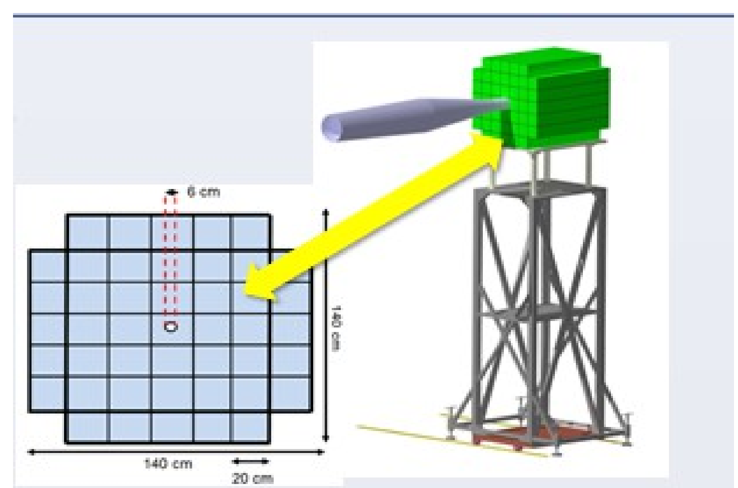
The simulation show that this is true supposed




**Distributions of the neutron flux (n/cm2/s) through the PSD calorimeter at radius 10, 30 and 50 cm**




**BM experimental facility with the muon detectio system**



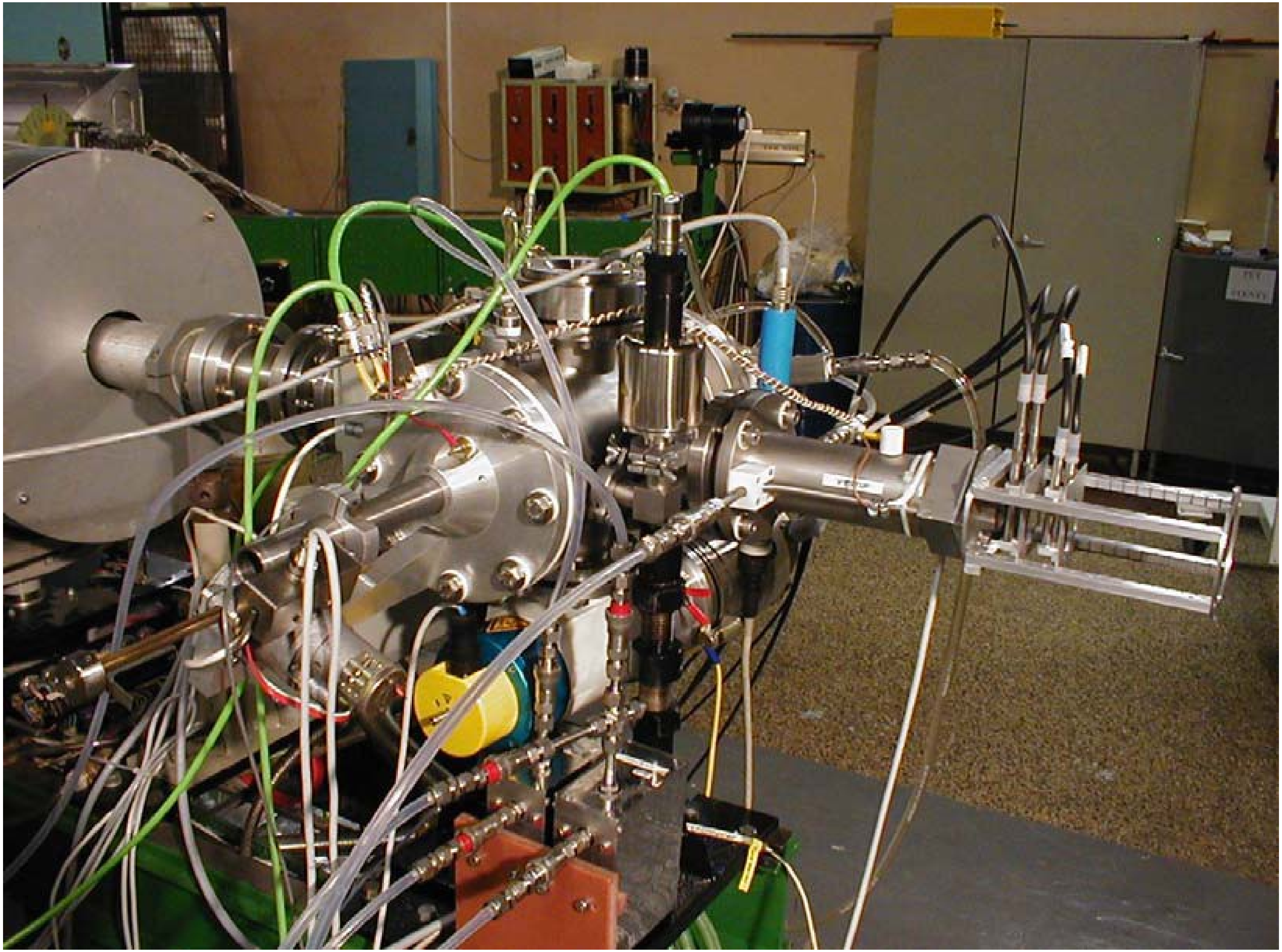

PSD with the reduced beam hole

FLUKA simulation results:
Flux near the beam hole after 2 months of CBM run at the beam rate $10^8$ ions/s:

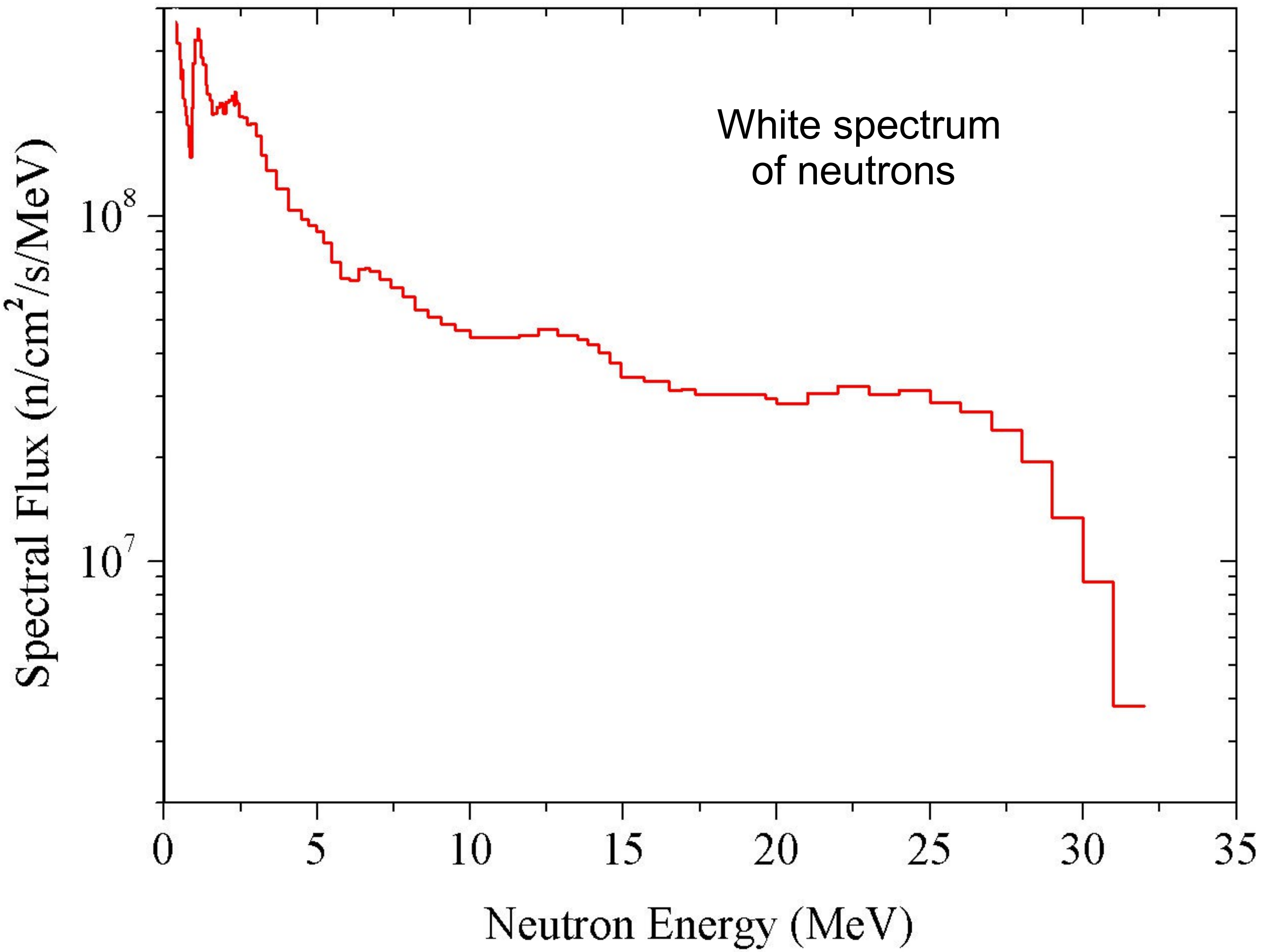
$10^{12}$ n/cm2 for $E_{beam}$(Au) 4 AGeV

$4\times10^{12}$ n/cm2 for $E_{beam}$(Au) 35 AGeV

# Cyclotron U120M(fast neutrons)



# Cyclotron U120M(p + Be)



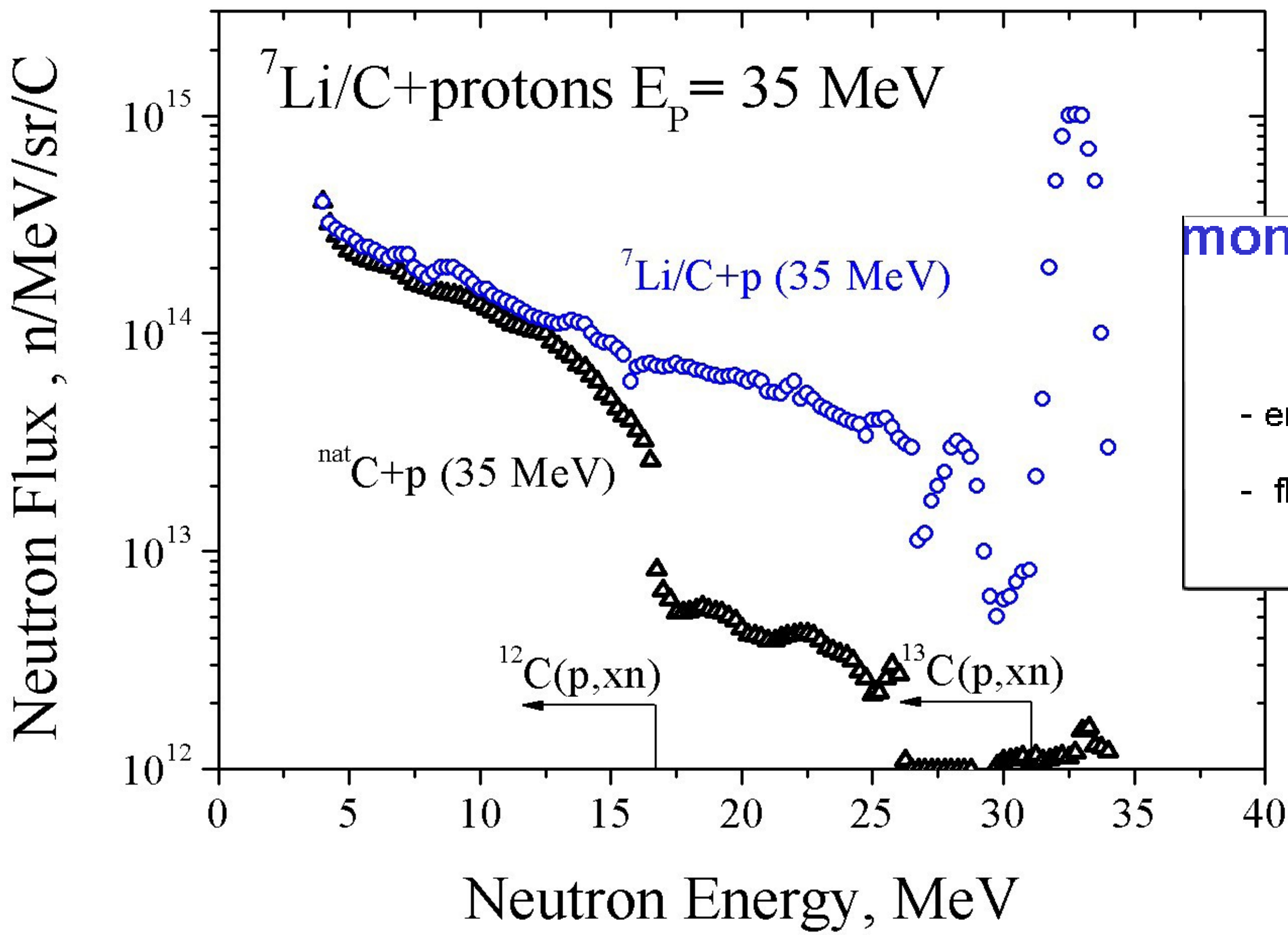

**For source NG1**
Maximum of Flux

**~$10^8$ - $10^9$ - [n/cm²/s]**

**For source NG2**
Maximum of Flux

**~$10^{11}$ [n/cm²/s]**

# Cyclotron U120M(p + $D_2O$)



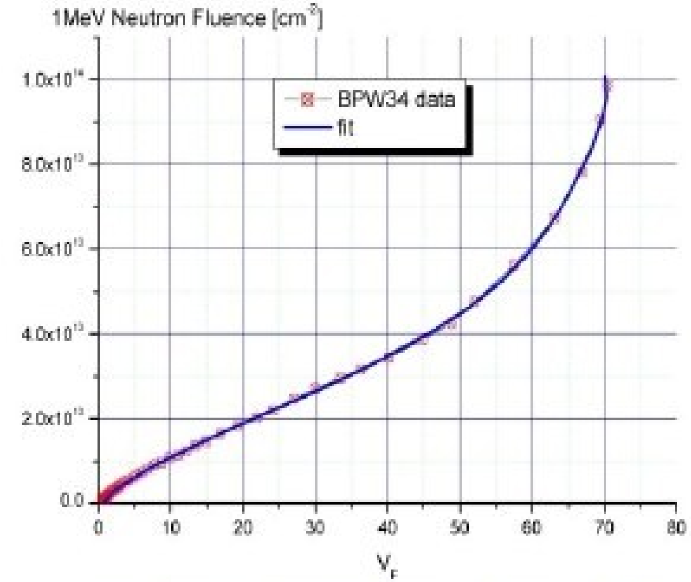

**mono-energetic 20-37 MeV**

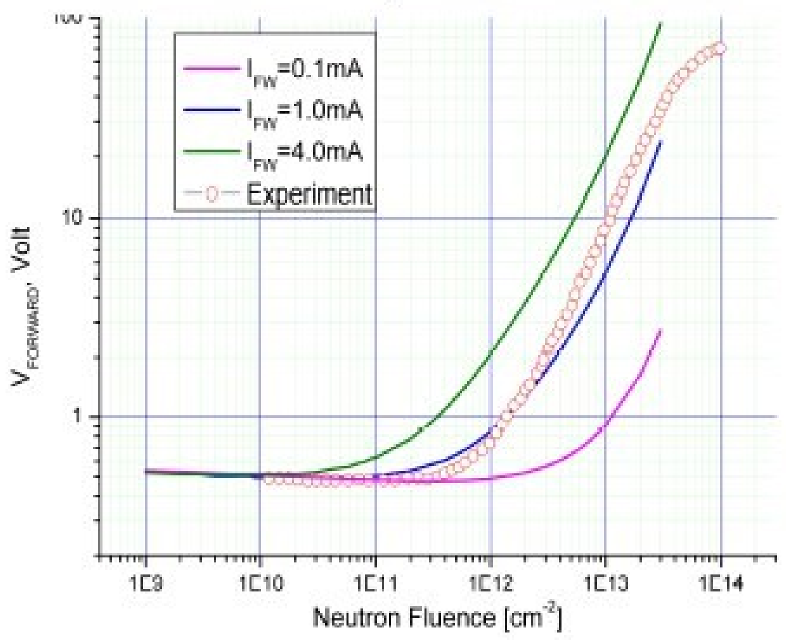
**Source reaction p+7Li**

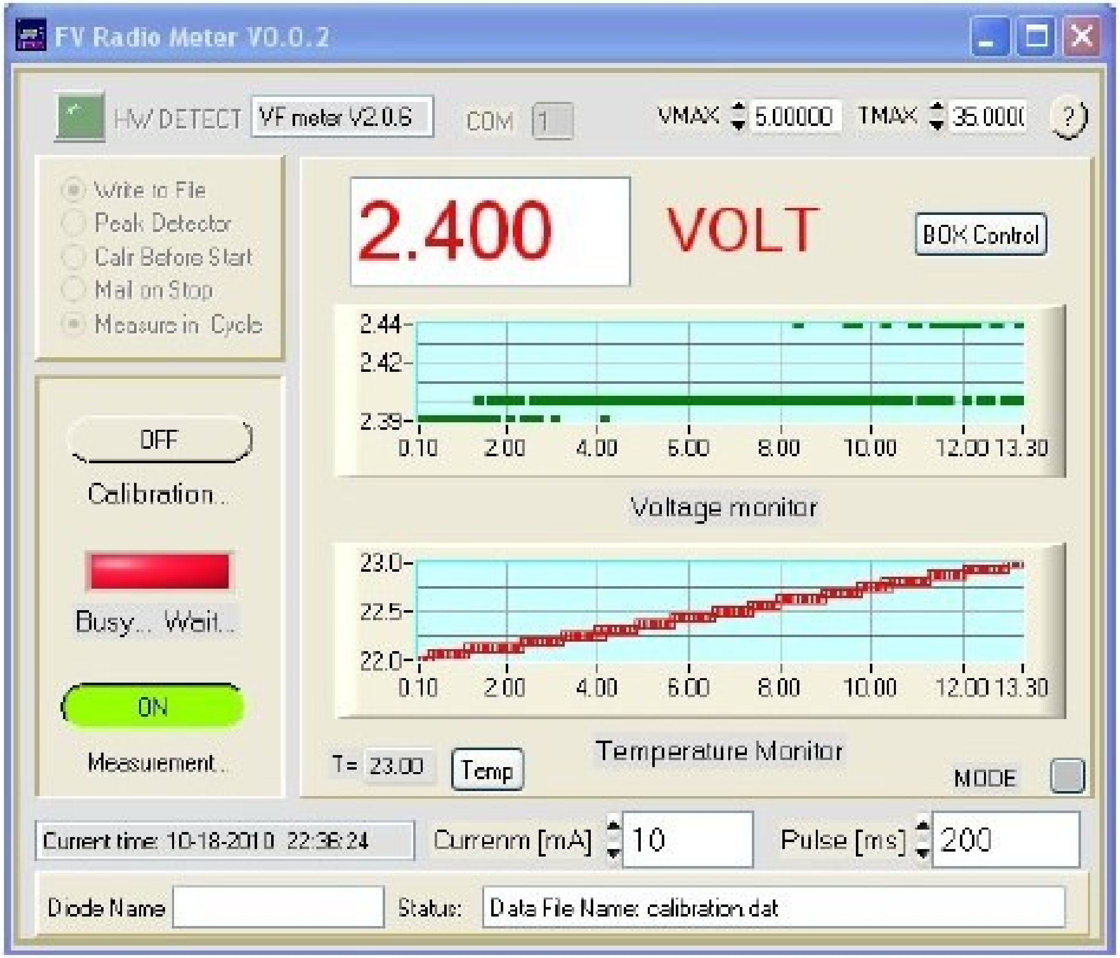
- energy range **20 - 37 MeV**
- flux density

**3 $10^9$ n/cm$^2$/s**

# Monitoring of absorbed dose

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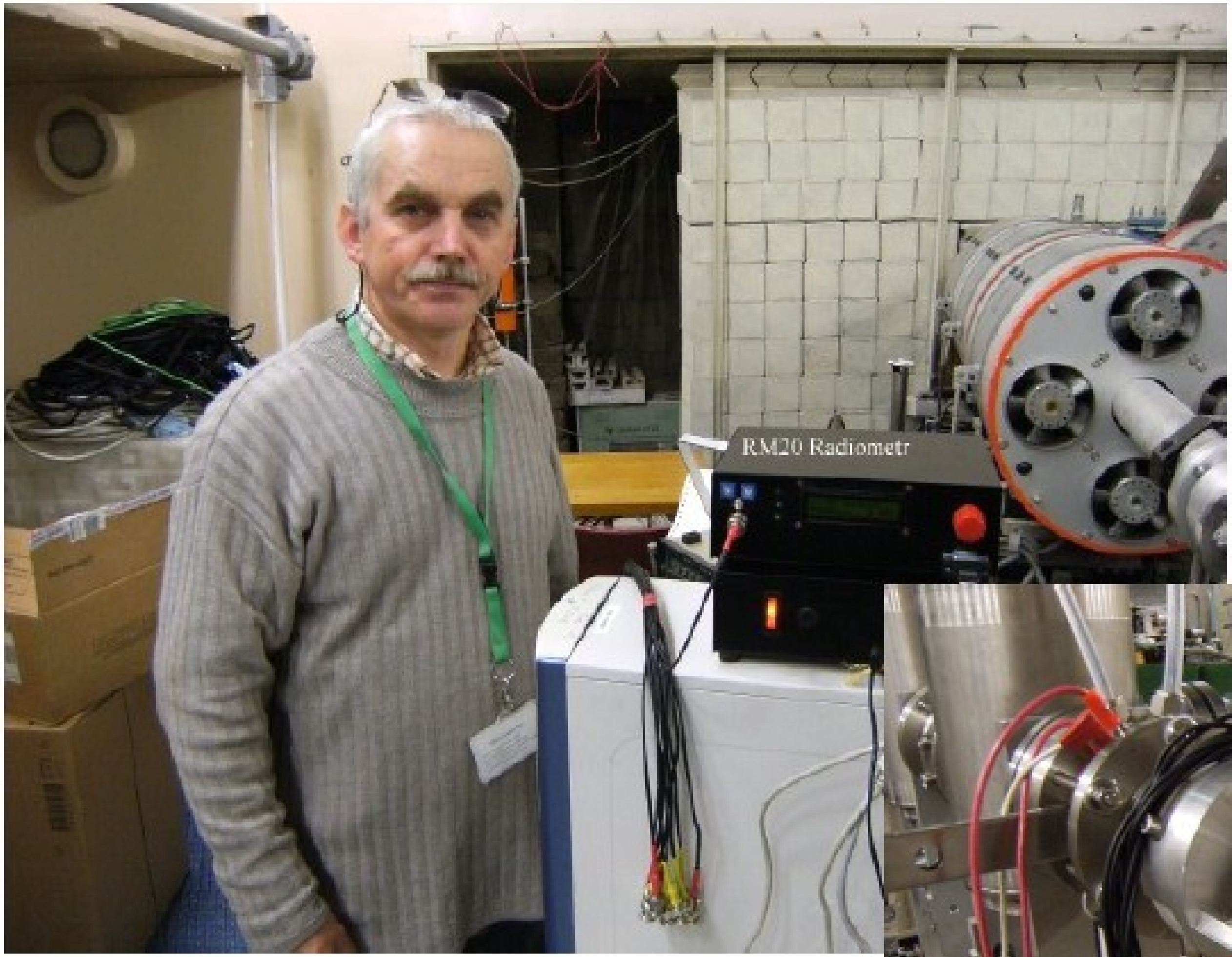
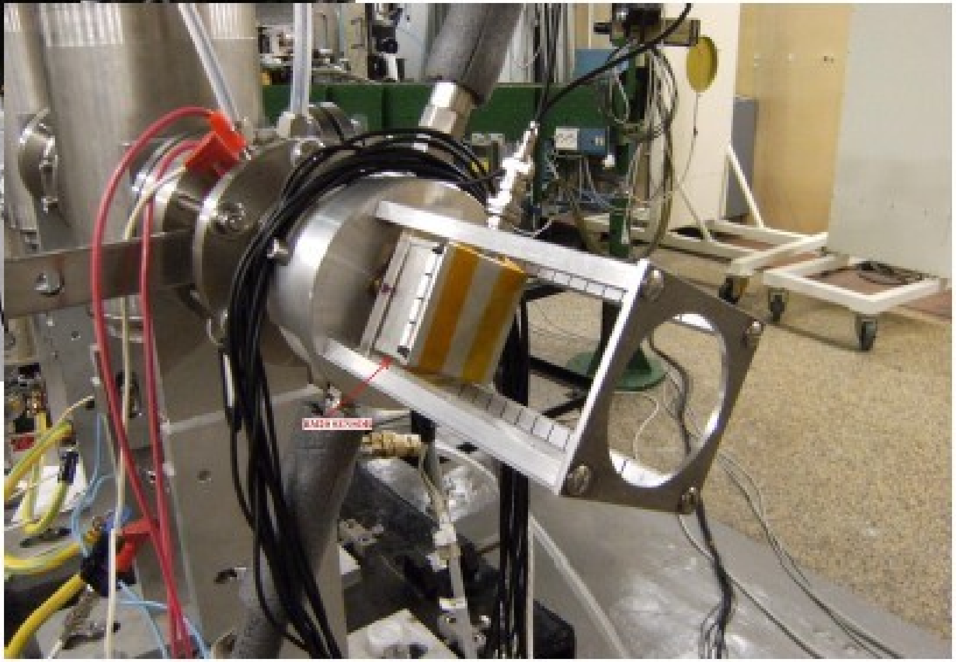
# Monitoring of absorbed dose



# What method to investigation?

C-V give information about internal structure
I-V give information about generation-recombination processes
C-F give information about life time of minority and carriers concentration in P-N junction
Q-T (transient effect) give information about live time of minority carriers

More interesting information is knowledge about dynamics minority carriers as basic of signal into detectors. But we need simple and understandable model... []

While we used common methods for C-V and I-V data analysis, we used a new method of C-F da
Explanations. Dynamical process describing variation of nonequilibrium carriers due to recharge o
depicted in [9]. Here it is presumed that measured capacitance C and geometrical capacitance ar
For the measured capacitance C being bigger than geometrical one, variation of nonequilibrium
with lifetime τ is described by following equation:

$$\frac{\partial \Delta n}{\partial t} = \frac{1}{e} \cdot \frac{\partial J_n}{\partial x} + \frac{\Delta n}{\tau}$$

$$\frac{1}{C}(f) = \frac{1}{e} \cdot \frac{\langle \tau \rangle}{\langle N_t \rangle} \cdot \Delta\varphi \cdot f$$

# KETEK, ZECOTEK

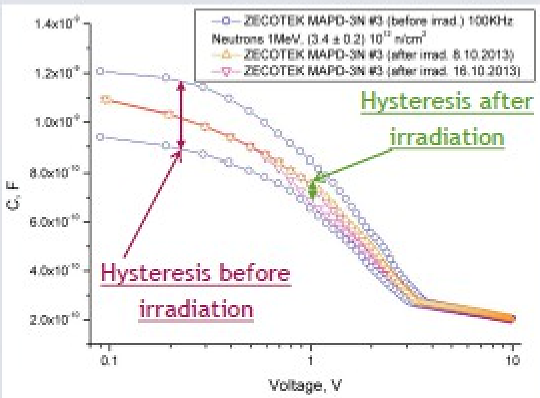
Ketek and Zekotek APDs were irradiated by neutrons with equivalent dose for 1MeV neutrons [4]:

1 Zekotek APD irradiated with dose $3.4\pm0.2\times10^{12}$ n/cm$^2$ (T = 22±0.5 °C)

2 Ketek APDs irradiated with dose $2.5\pm0.2\times10^{12}$ n/cm$^2$ (T = 22±0.5 °C)

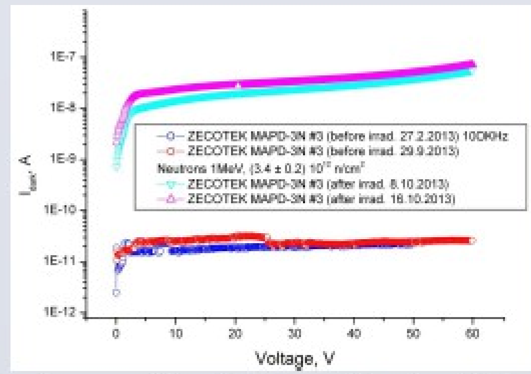
**Zecotek APDs**

### Capacitance-Voltage characteristics:



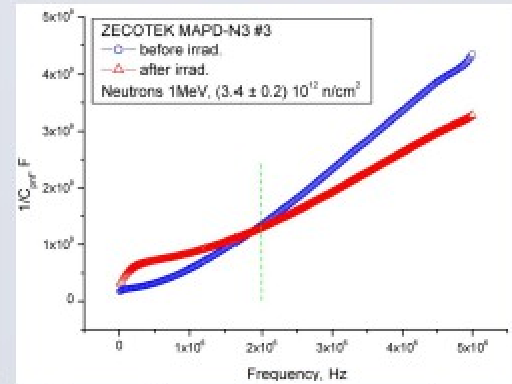

Significant decrease of the hysteresis at low voltages after irradiation.

### Current-Voltage characteristics:



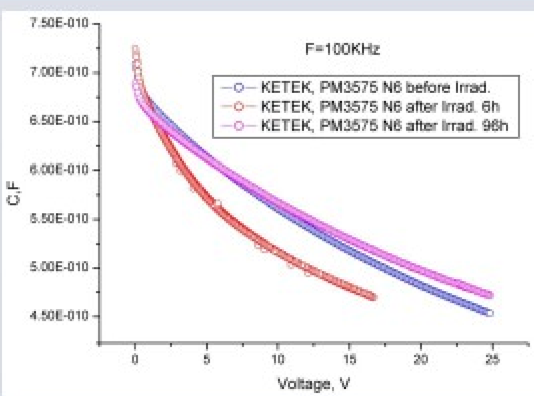

$I_{dark}$ increased in ~$10^3$ times after irradiation. Self-annealing: $I_{dark}$ *increased* a bit in a week time after irradiation.

### Capacitance-Frequency characteristics:

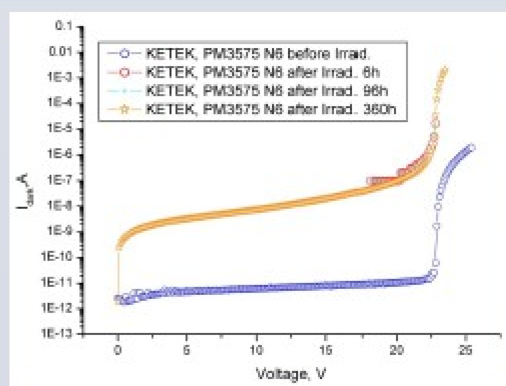



$N_{traps}$ with $\tau_t$ > 2.5 μs decreased
$N_{traps}$ with $\tau_t$ < 2.5 μs increased
according to $\frac{1}{C_{pnf}}(f)=k\cdot\frac{\tau_t}{N_t}\cdot f$ [5]

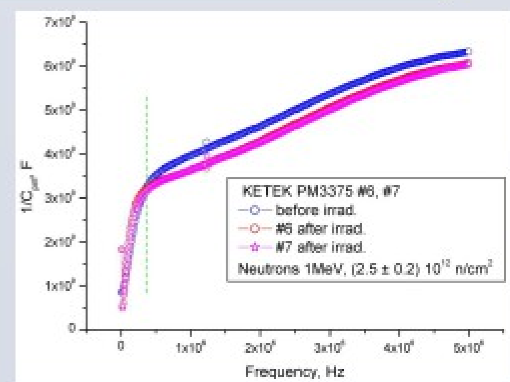
**Ketek APDs**




Self-annealing almost restores the initial state in 4 days after irradiation

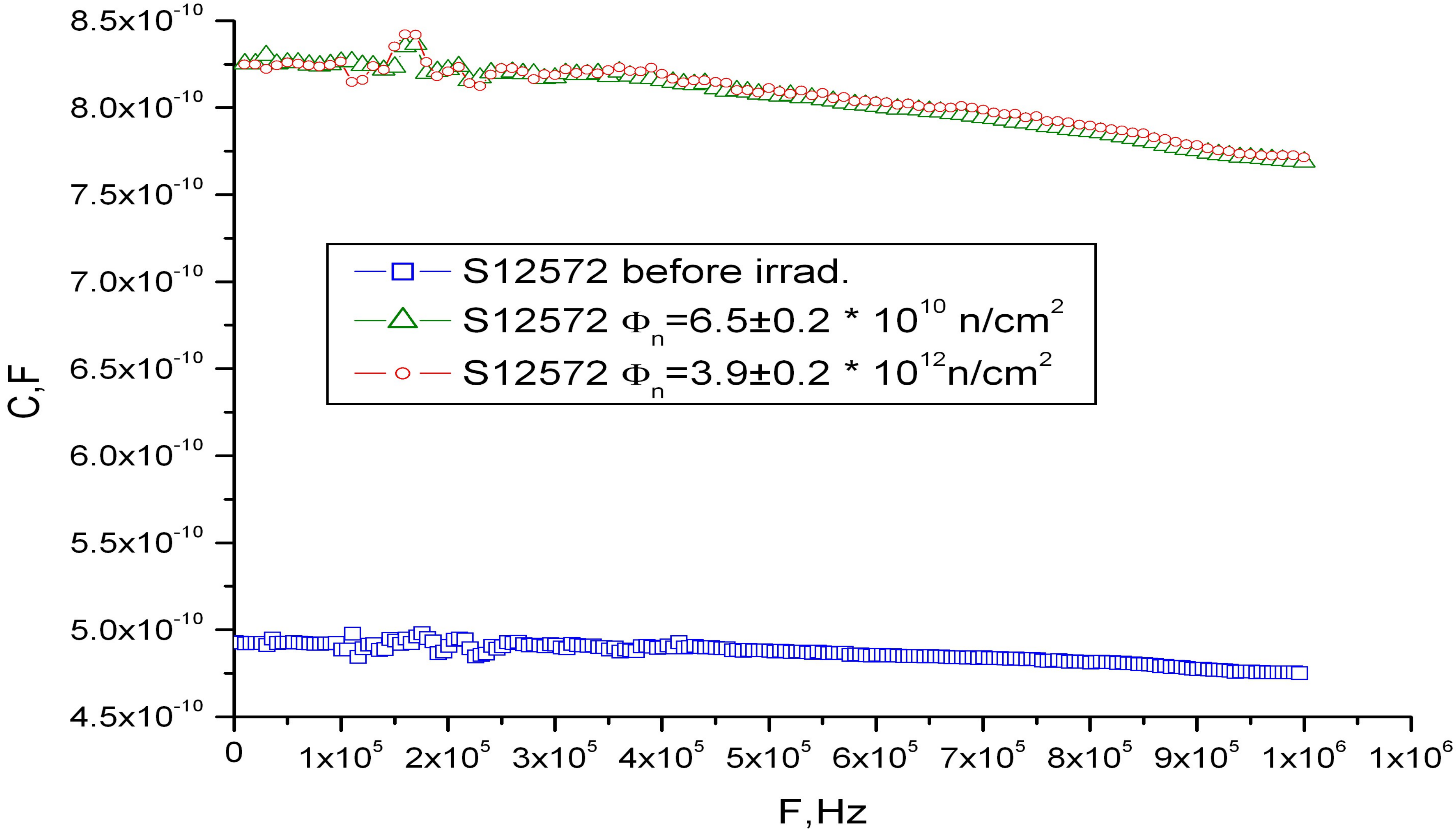



$I_{dark}$ increased in ~$10^3$ times after irradiation. Self-annealing: $I_{dark}$ *decreased* a bit in a week time after irradiation.



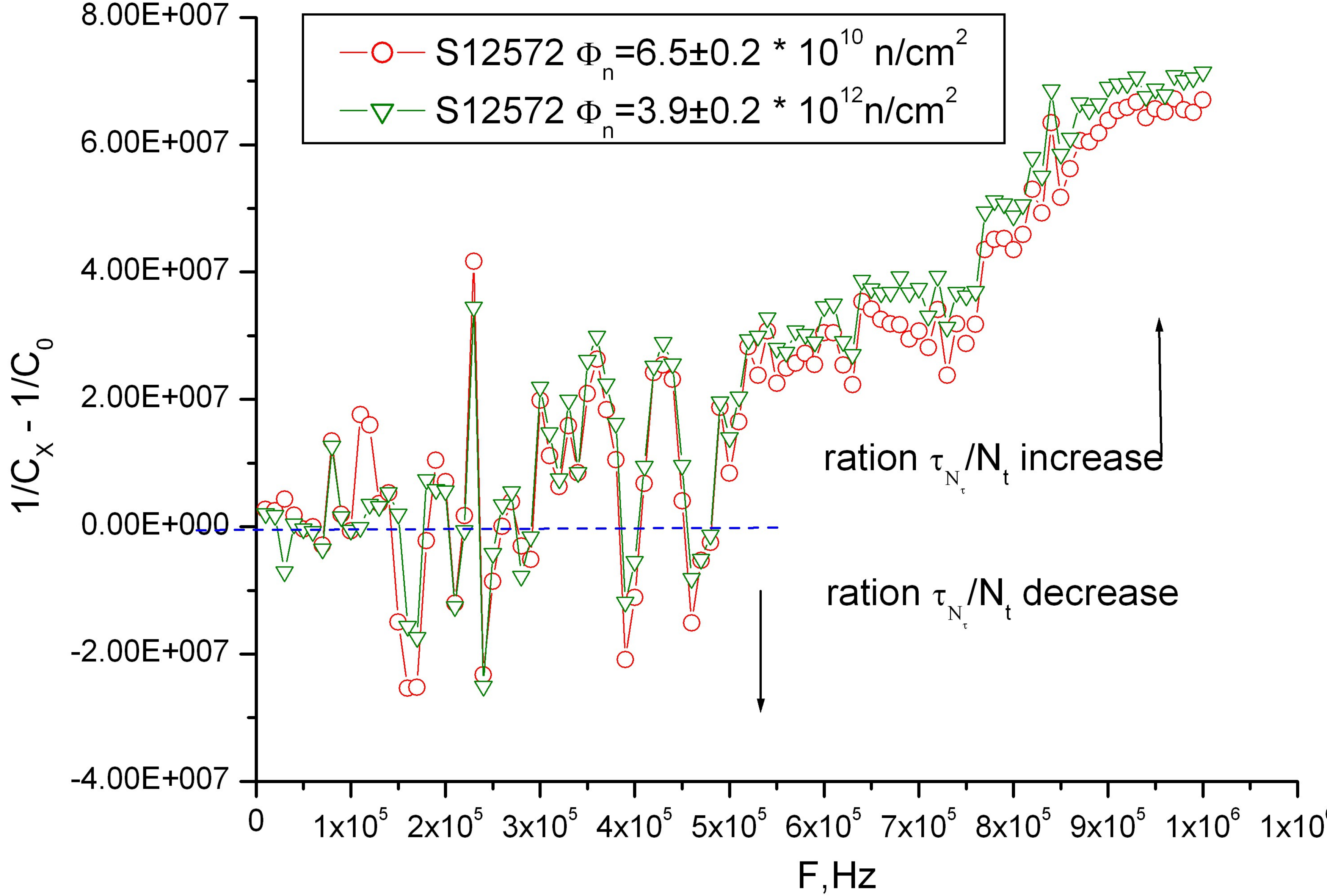

$N_{traps}$ with $\tau_t$ > 0.5 μs decreased
$N_{traps}$ with $\tau_t$ < 0.5 μs increased

# HAMAMATSU



C,F
F,Hz
8.5x10^-10
8.0x10^-10
7.5x10^-10
7.0x10^-10
6.5x10^-10
6.0x10^-10
5.5x10^-10
5.0x10^-10
4.5x10^-10
0
1x10^5
2x10^5
3x10^5
4x10^5
5x10^5
6x10^5
7x10^5
8x10^5
9x10^5
1x10^6
1x10^6
S12572 before irrad.
S12572 $\Phi_n$=6.5±0.2 * $10^{10}$ n/cm$^2$
S12572 $\Phi_n$=3.9±0.2 * $10^{12}$n/cm$^2$

# HAMAMATSU



S12572 Φn=6.5±0.2 * 10^10 n/cm^2
S12572 Φn=3.9±0.2 * 10^12 n/cm^2
8.00E+007
6.00E+007
4.00E+007
2.00E+007
0.00E+000
-2.00E+007
-4.00E+007
1/CX - 1/C0
0
1x10^5
2x10^5
3x10^5
4x10^5
5x10^5
6x10^5
7x10^5
8x10^5
9x10^5
1x10^6
1x10^6
F,Hz
ration τNτ/Nt increase
ration τNτ/Nt decrease

# Conclusion

Radiation hardness is depend on technology.
New methods must be used to understanding of processes inside SiPM
New methods of monitoring of neutrons fluence must be used.

Next step:

Improve method of investigation and analysis of data
More precision measurement neutron fields:

- thermal neutrons;
- profile of field;
- gamma rays;