Investigation of avalanche photo detectors in NPI Řež in frame of collaboration work with JINR in 2014

CZECH TECHNICAL UNIVERSITY IN PRAGUE

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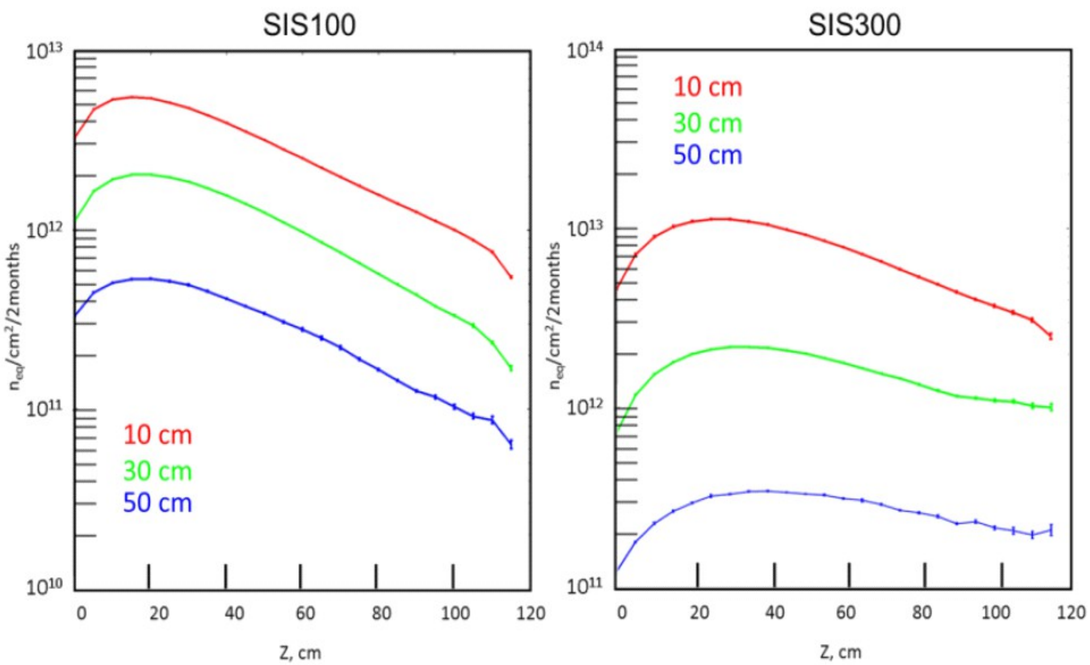
Motivation for investigations

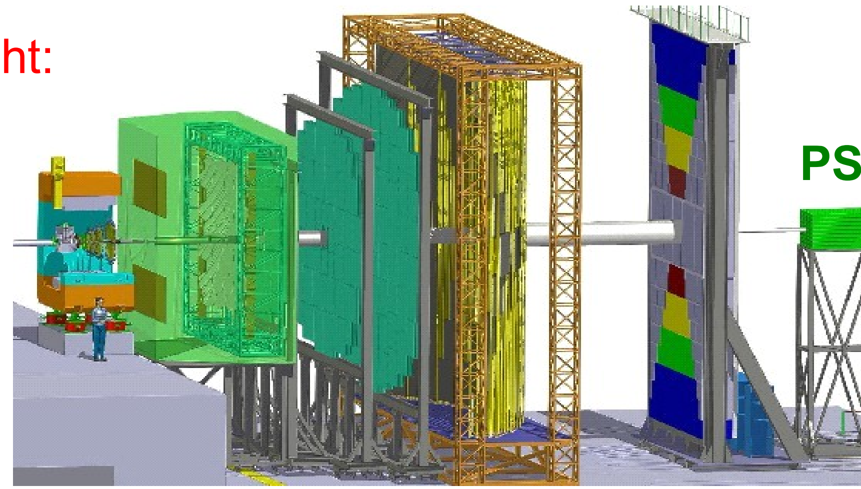
The PSD detector from CBM will be used to explain basic goals of program:

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

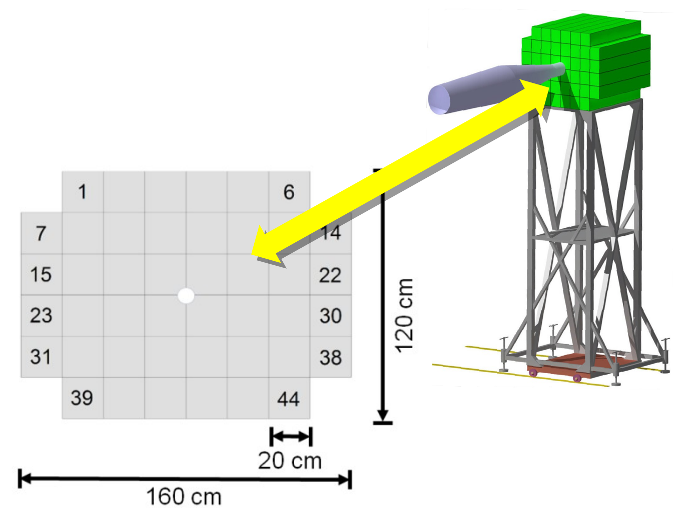
The simulation shows that supposition above is right:



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



CBM experimental facility with the muon detection system

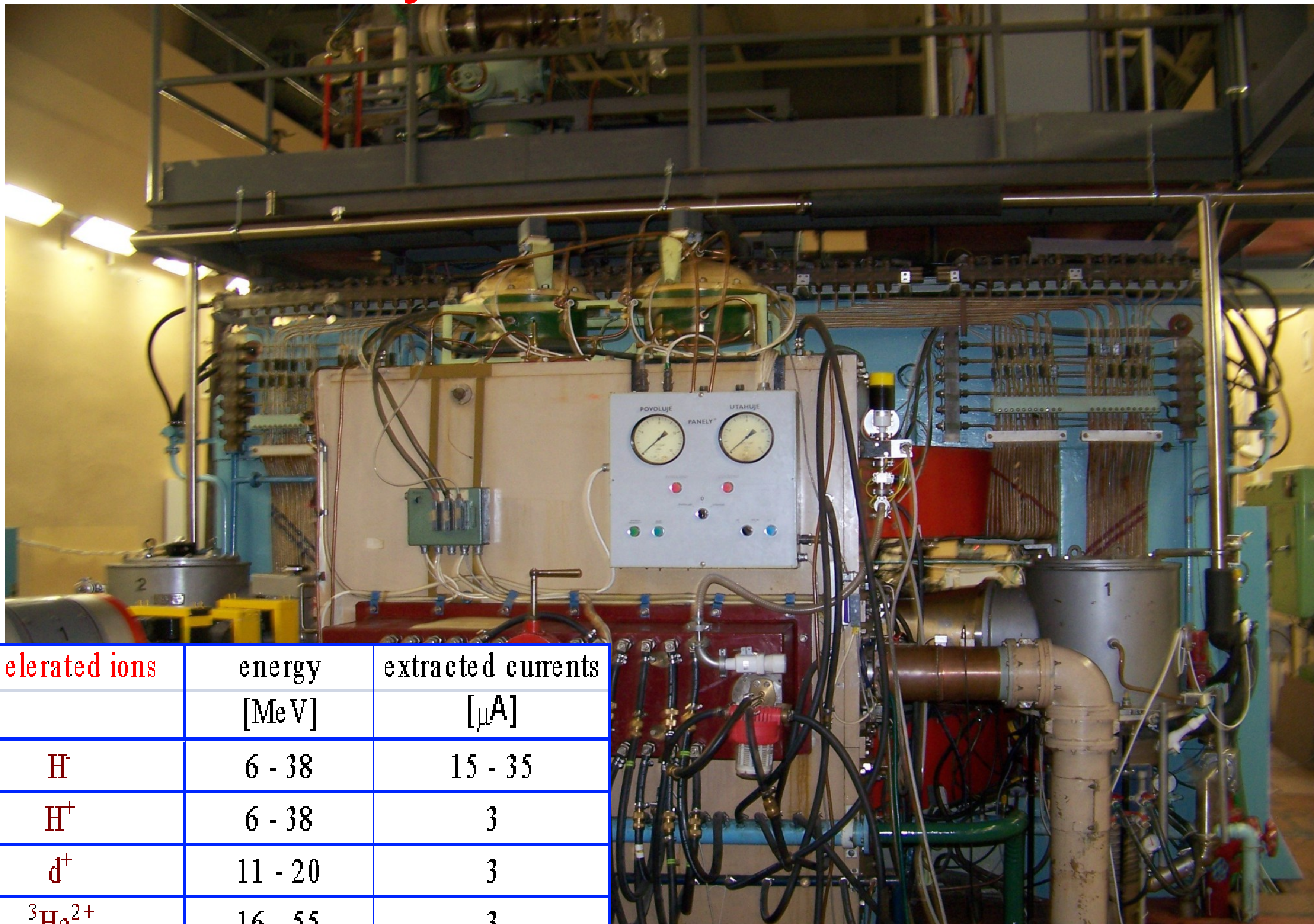


New PSD geometry

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

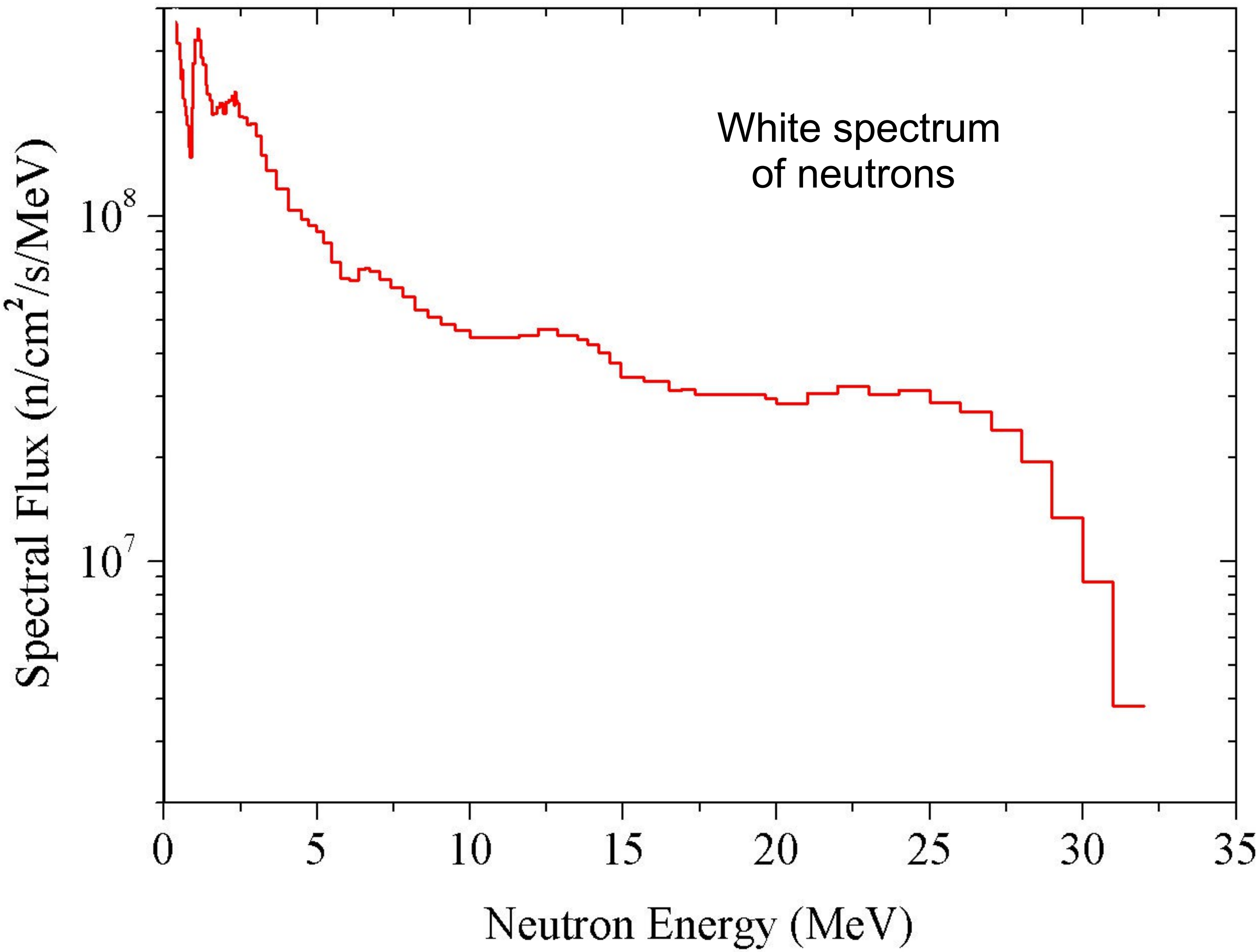
- 10^{12} n/cm² for E_{beam}(Au) 4 AGeV
- 4×10^{12} n/cm² for E_{beam}(Au) 35 AGeV

Cyclotron U120M



accelerated ions	energy [MeV]	extracted currents [μA]
H^-	6 - 38	15 - 35
H^+	6 - 38	3
d^+	11 - 20	3
$^3He^{2+}$	16 - 55	3
$^4He^{2+}$	22 - 40	3

Cyclotron U120M (p + D_2O)



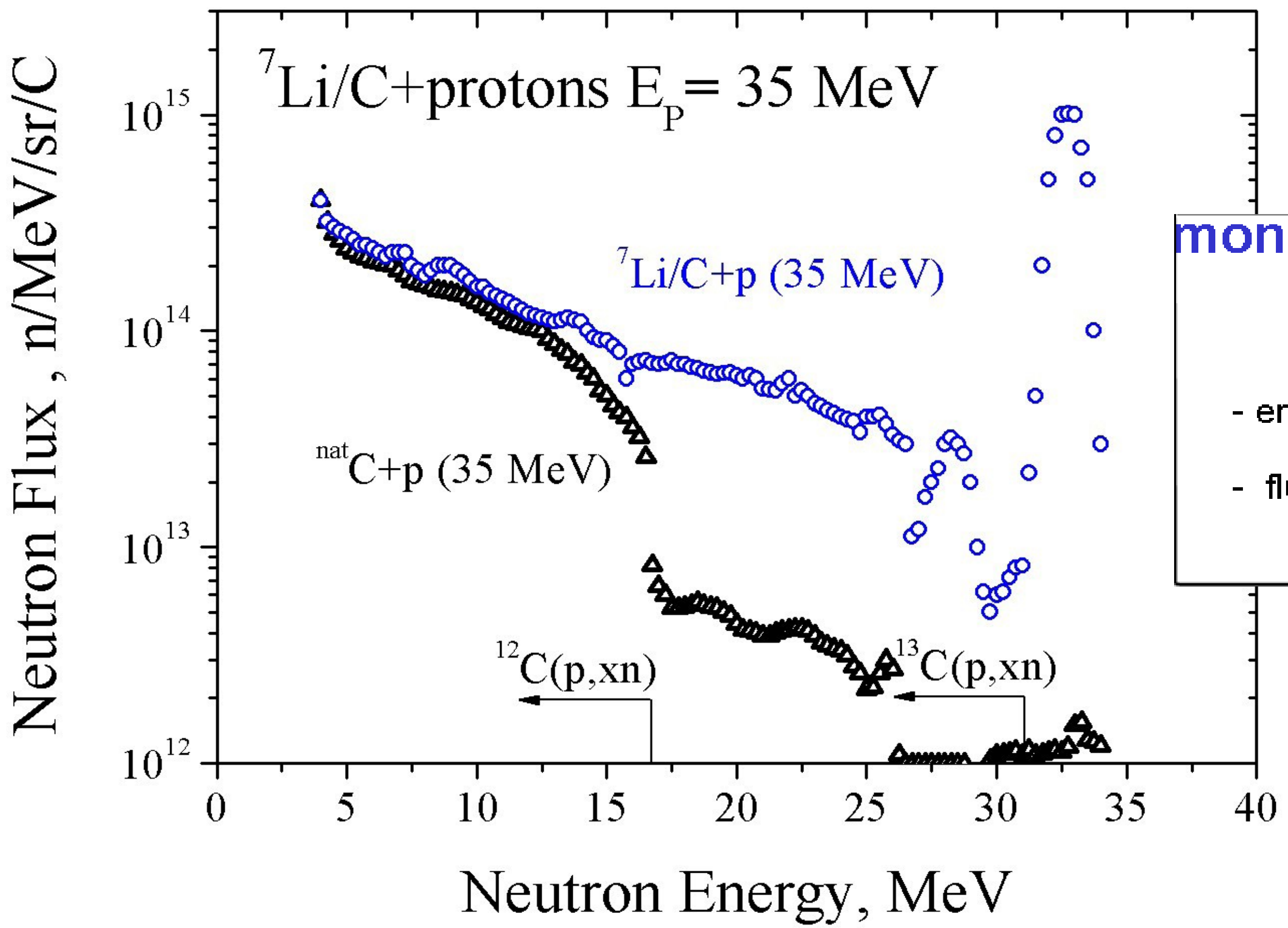
For source NG1
Maximum of Flux

~10^8 - 10^9 -
[n/cm²/s]

For source NG2
Maximum of Flux

~10^{11} [n/cm²/s]

Cyclotron U120M (p + $_7$Li)



mono-energetic 20-37 MeV

Source reaction p+7Li

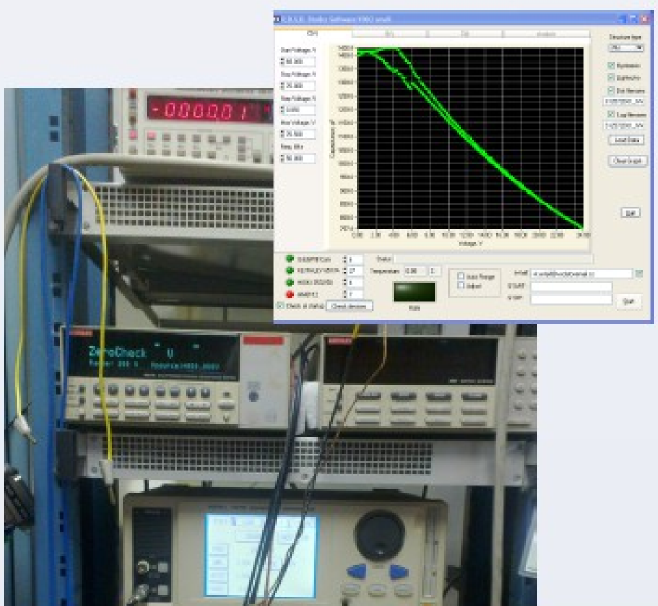
- energy range **20 - 37 MeV**
- flux density

3 10^9 n/cm^2/s

Methods of APD investigation

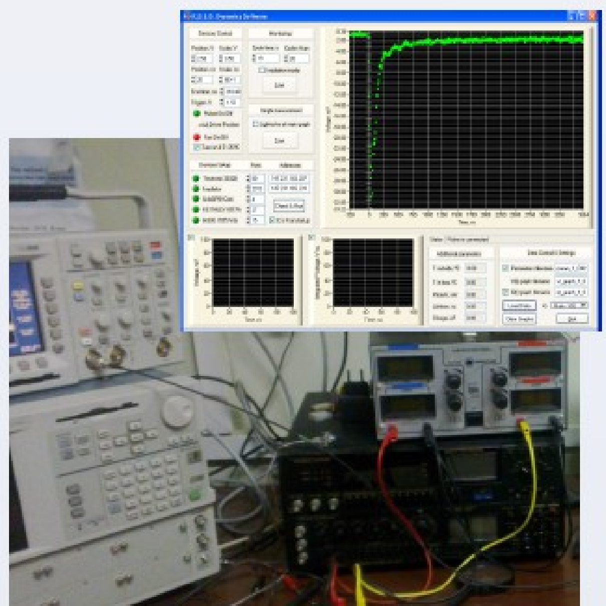
Static characteristics (C-V, C-F, I-F)

- investigation of internal structure of APD
- studying of the behaviors of impurities during APD operation
- measurement of the parameters of APD for equivalent circuit of APD in SPICE



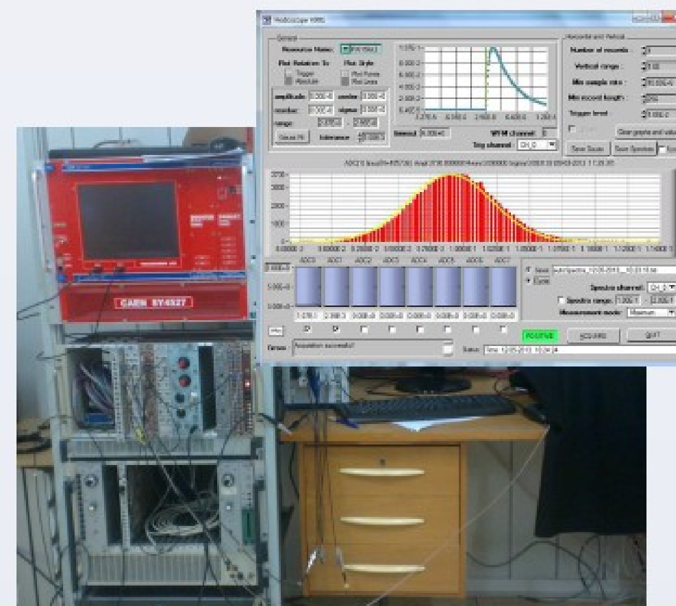
Dynamic characteristics (transient effects)

- investigation of generation and recombination processes into APD bulk
- studying of noise sources behaviors of APD
- measurement of the parameters of noise sources for SPICE model of APD

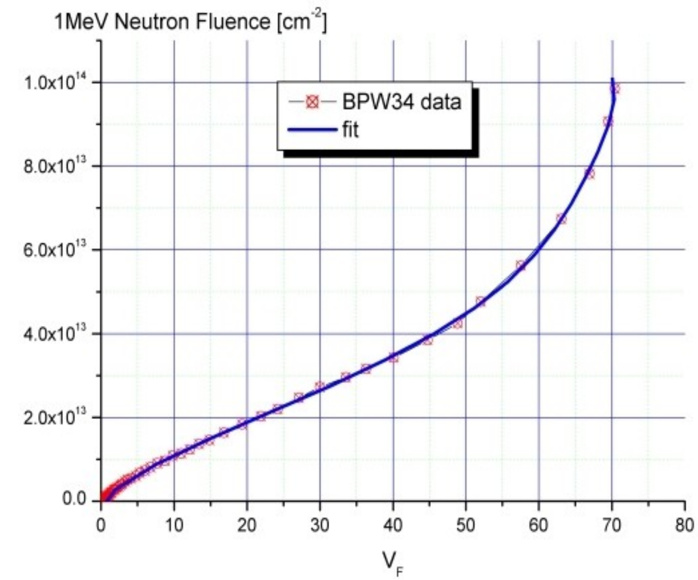


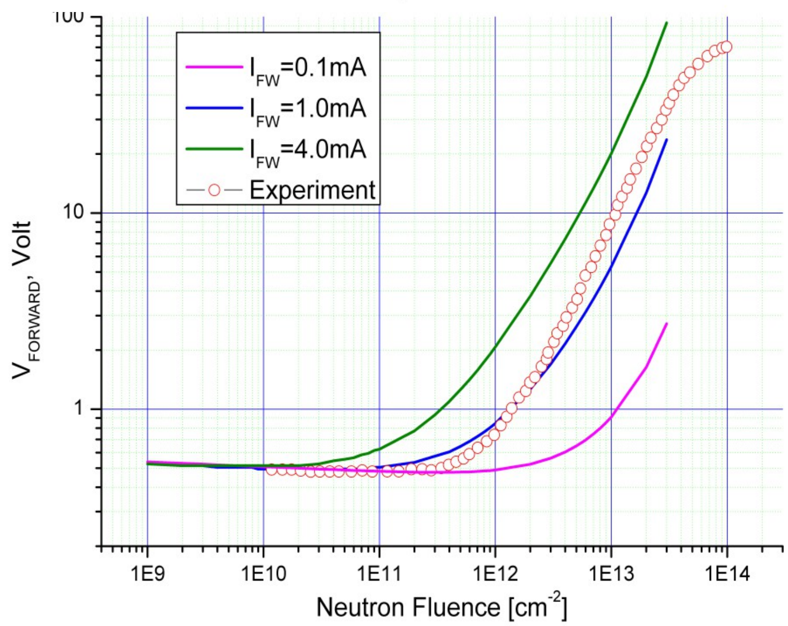
Operation of APD

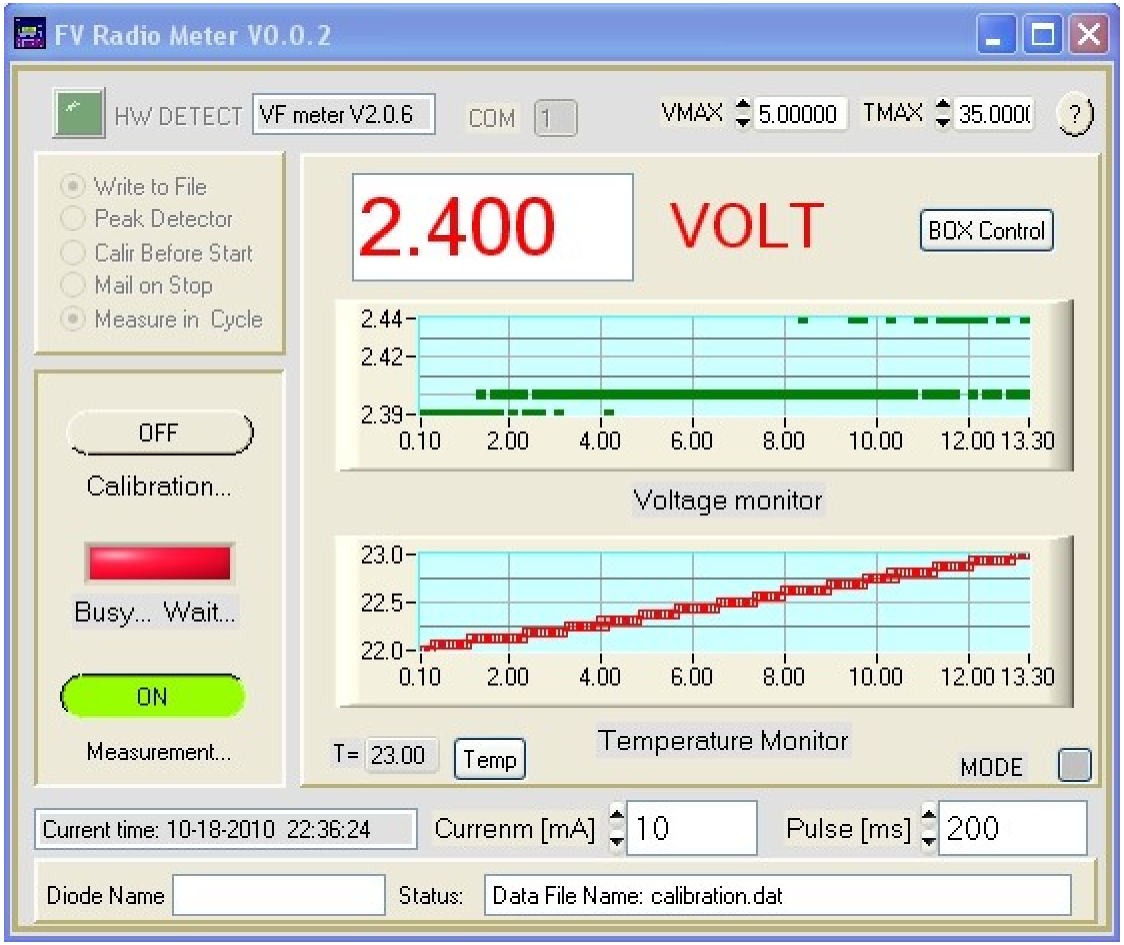
- single photon spectrum measurement with LED
- investigation of APD with scintillator and radioactive sources in laboratory
- investigation of APD with scintillator for cosmic rays



Monitoring of absorbed dose

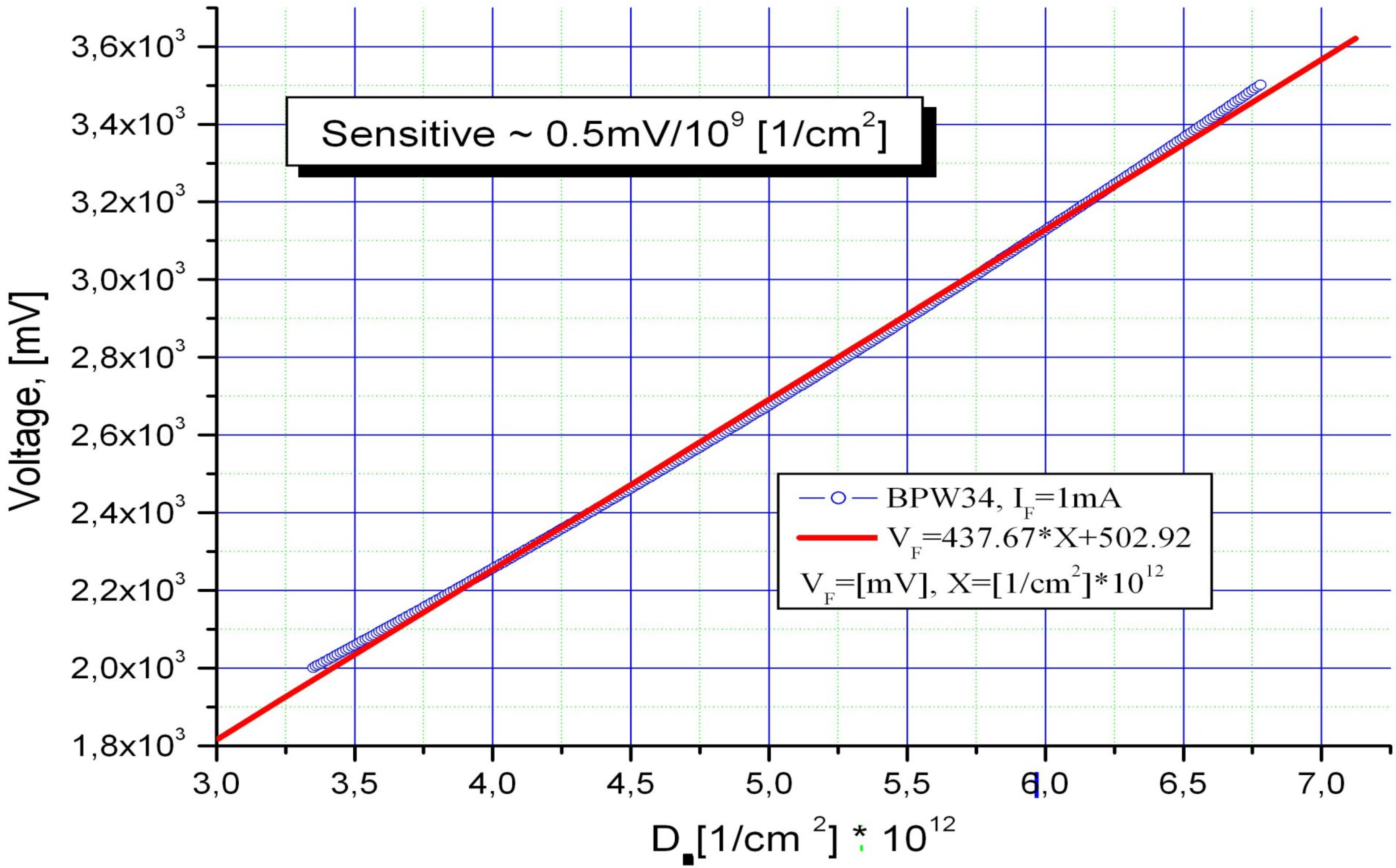






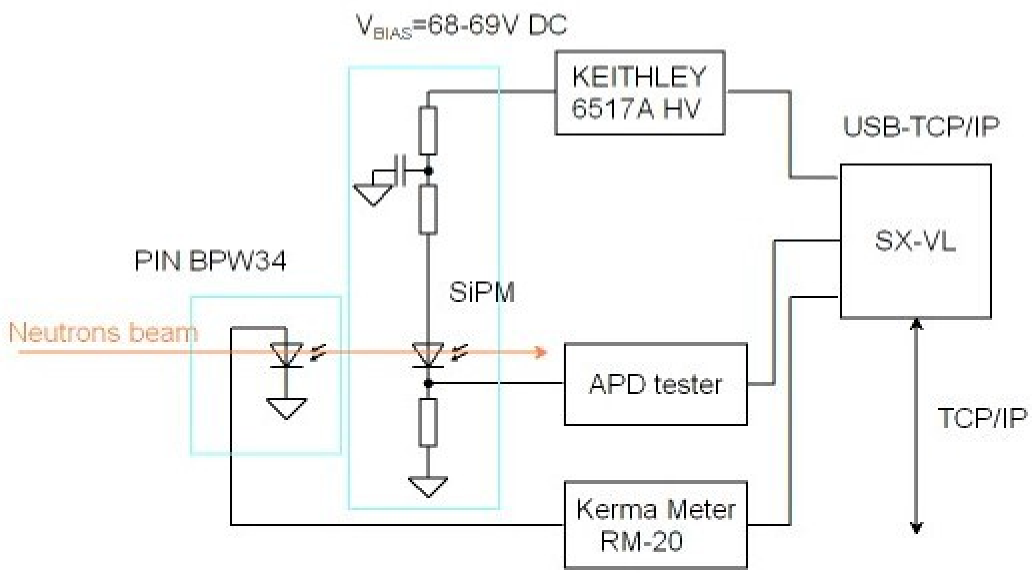
Presented in October 2010 (Rome)
International Conference on Environmental Radioactivity – New Frontiers and Developments

Monitoring of absorbed dose



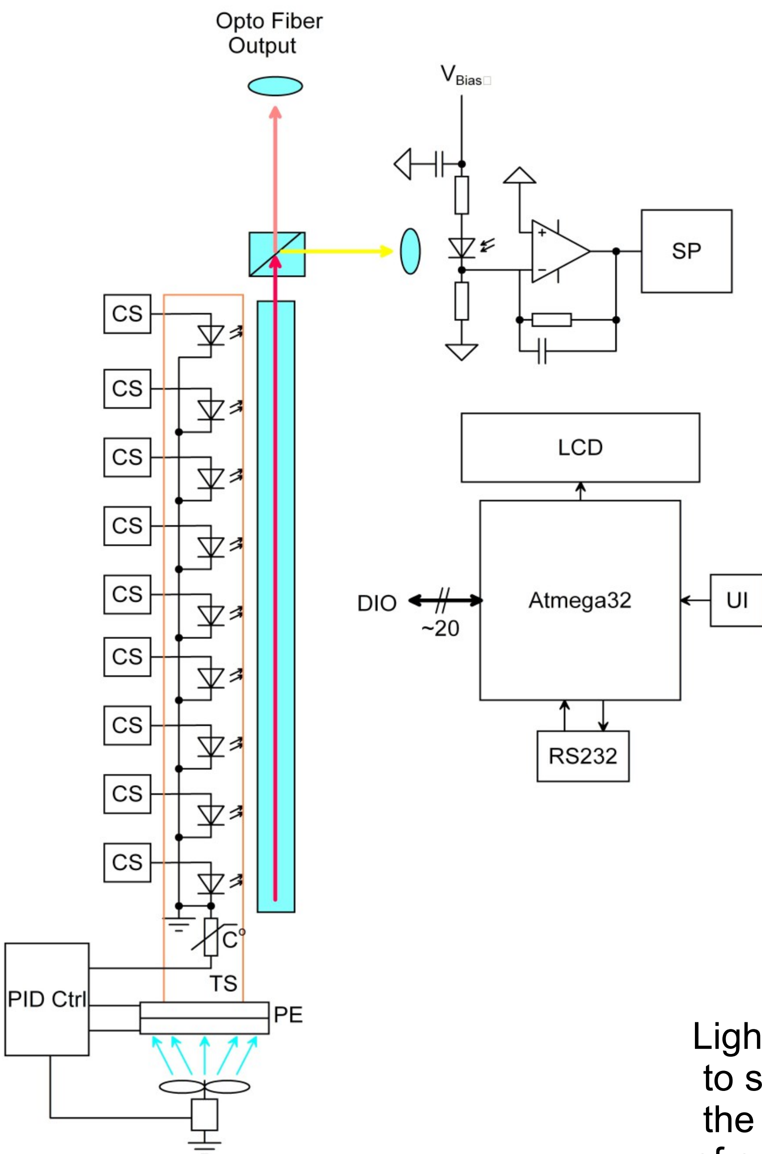
We will use Improved method of measurement of voltage and expect to reach sensitivity of monitoring ~ 1mV/10⁹ n/cm²

Method of Measurement



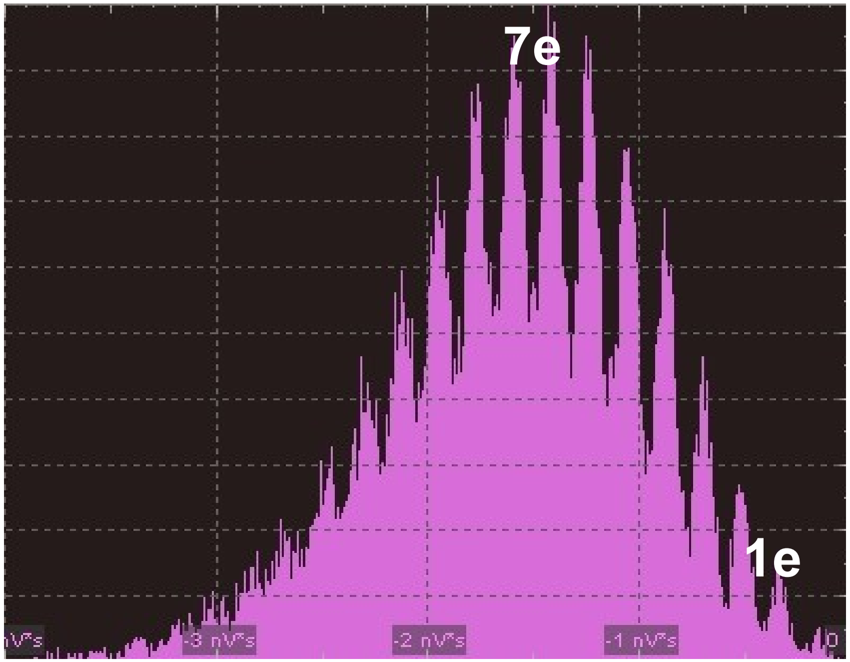
New configuration of measurement setup is ready to be tested in October

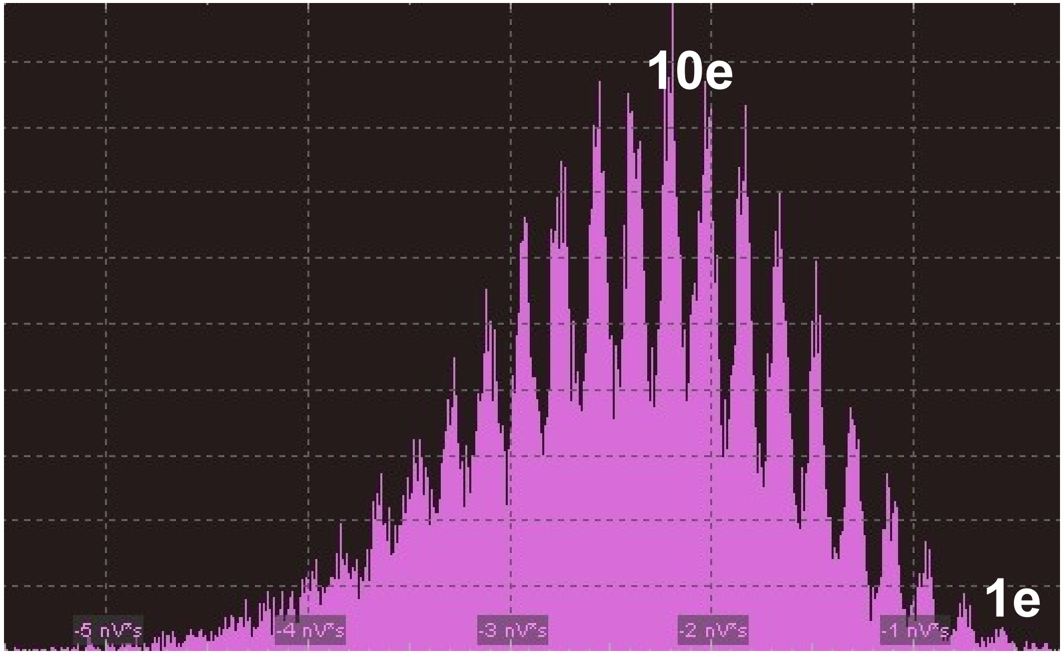
Programmable photon source

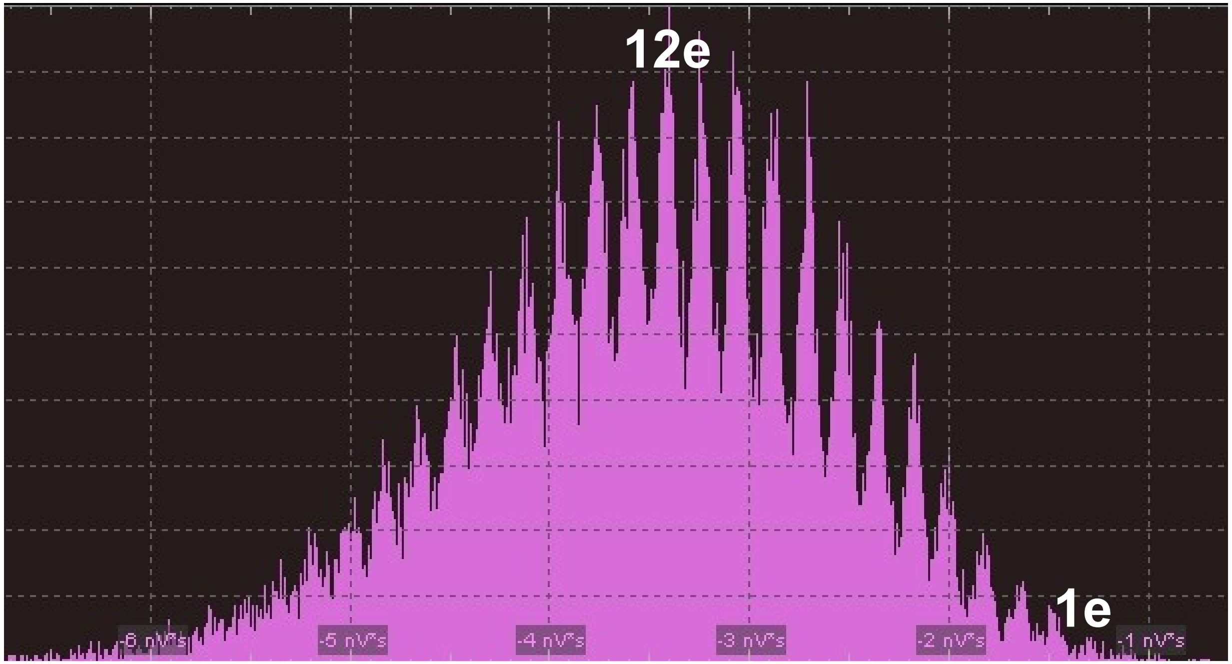


Light emitting diode is placed in a thermostat with a Peltier element to stabilize the temperature, while special electronic circuit controls the pulse width and voltage amplitude. Monitoring the effectiveness of emission is carried out by avalanche photodetector registering the part of emitted photons flux. Also, this avalanche photodetector is Temperature-controlled jointly with the emitting diode.

Programmable photon source (results)



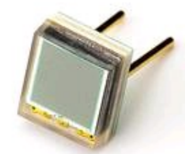




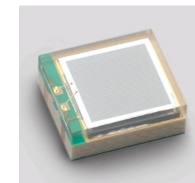
APD for test

- We investigated:
  - 5 MAPD-3N (ZECOTEK) Gain~10000, 65um/cell;
  - 7 SiPM PM3375 (from 10) Gain~10E6, KETEK 50um/cell;
  - 2 MPPC S12572 (from 10) Gain~10E6 (HAMAMATSU) 10um/cell;

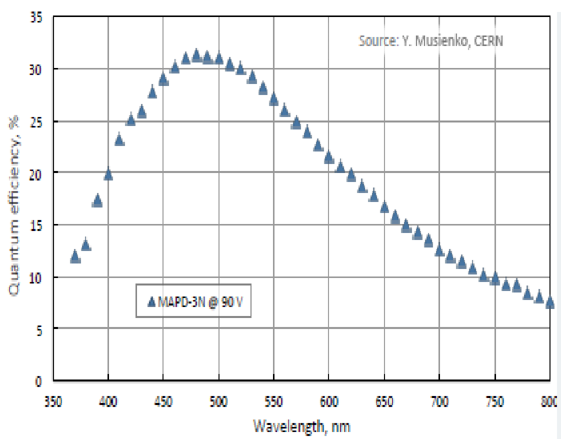
MAPD-3N

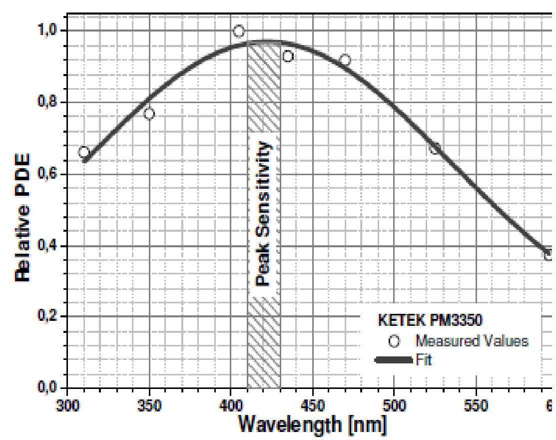


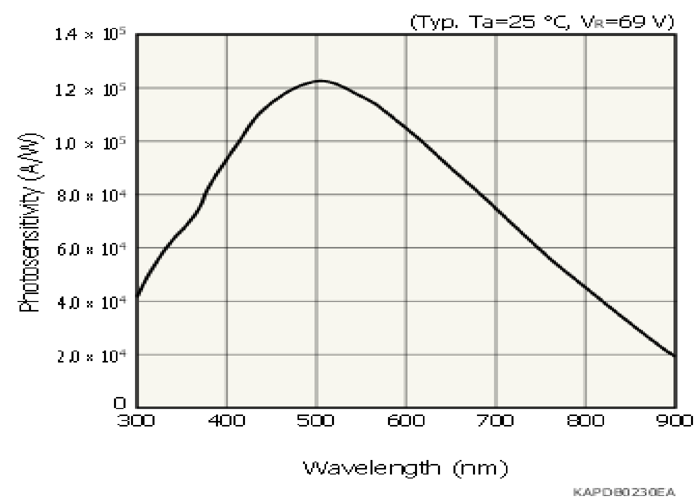
PM3375



S12572





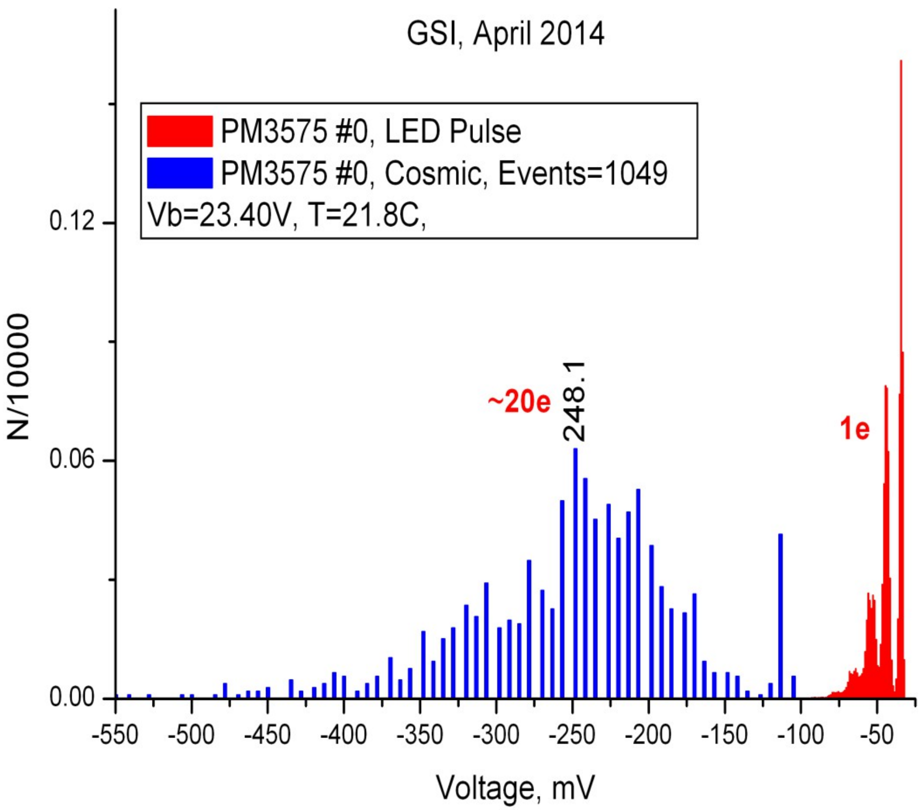


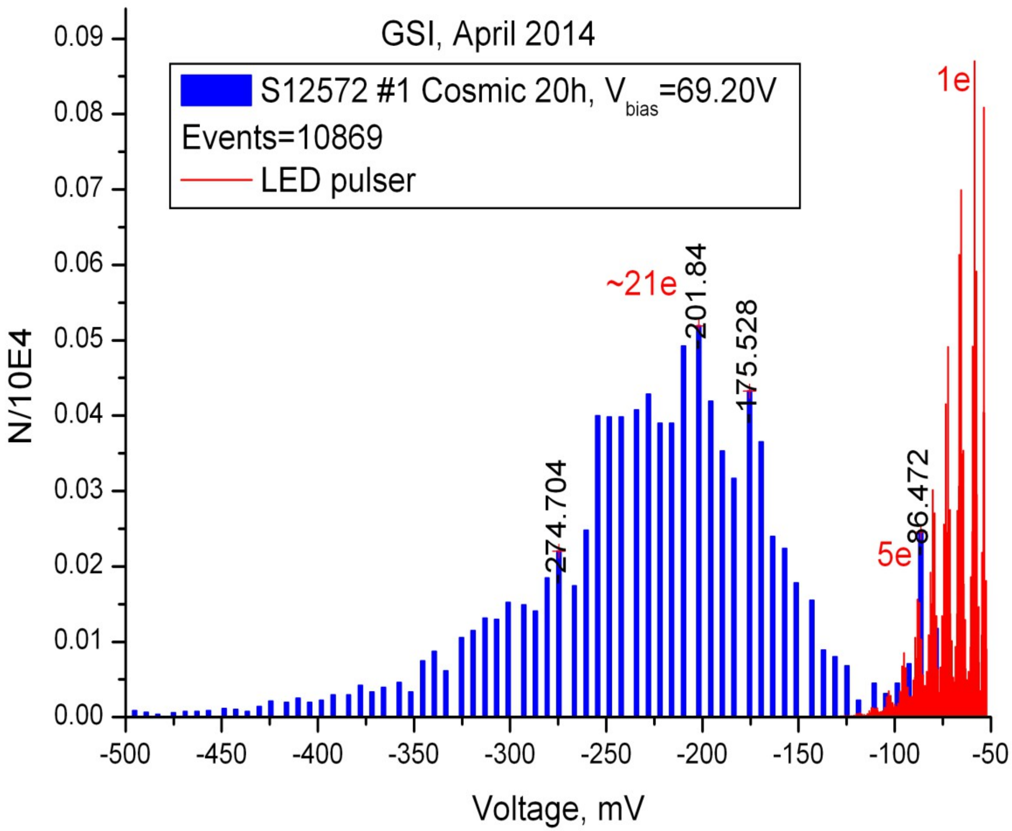
2 APD PM3375 and 1 APD MAPD-3N were irradiated by neutrons with equivalent dose for 1MeV neutrons:

PM3375 $2.5\pm0.2\ 10^{12}$ n/cm^2

MAPD-3N $3.4\pm0.2\ 10^{12}$ n/cm^2

Single Photons/Cosmic Detection





Static characteristics after irradiation

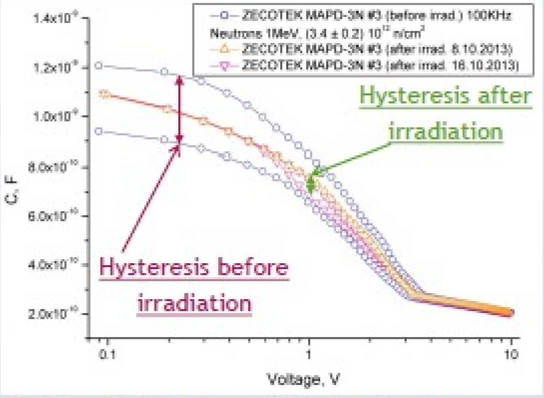
Ketek and Zekotek APDs were irradiated by neutrons with equivalent dose for 1MeV neutrons [4]:

1 Zekotek APD irradiated with dose 3.4±0.2x10^{12} n/cm^2 (T = 22±0.5 °C)

2 Ketek APDs irradiated with dose 2.5±0.2x10^{12} n/cm^2 (T = 22±0.5 °C)

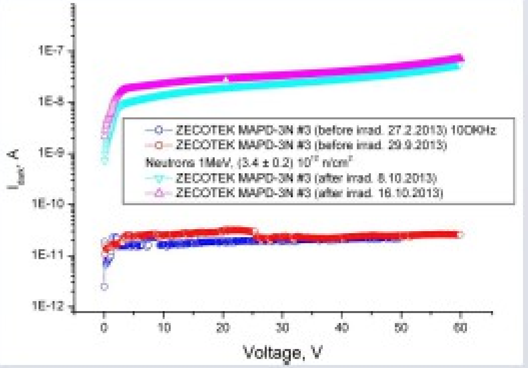
Zecotek APDs

Capacitance-Voltage characteristics:



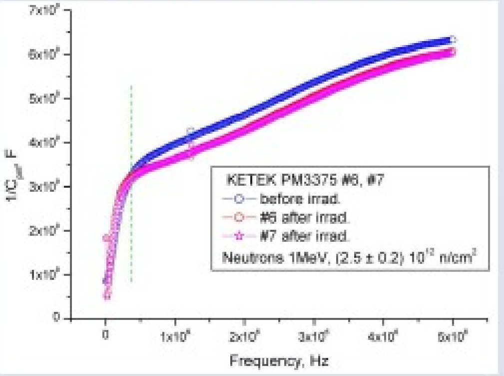
Significant decrease of the hysteresis at low voltages after irradiation.

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.

Current-Frequency characteristics:

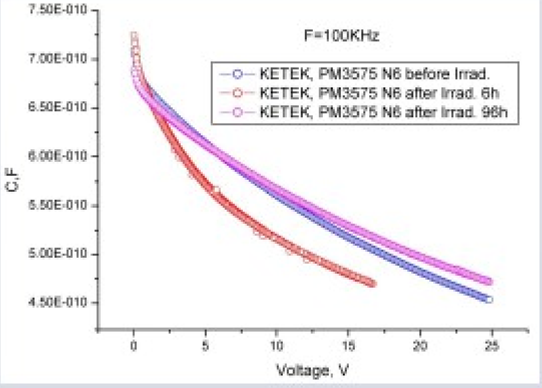


N_{traps} with τ_t > 2.5 μs decreased

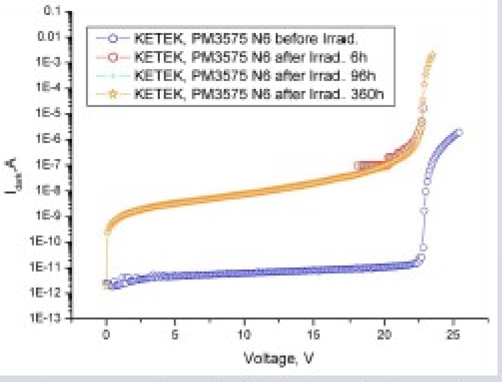
N_{traps} with τ_t < 2.5 μs increased

according to $\frac{1}{C_{pmf}}(f) = k \cdot \frac{\tau_t}{N_t} \cdot f$ [5]

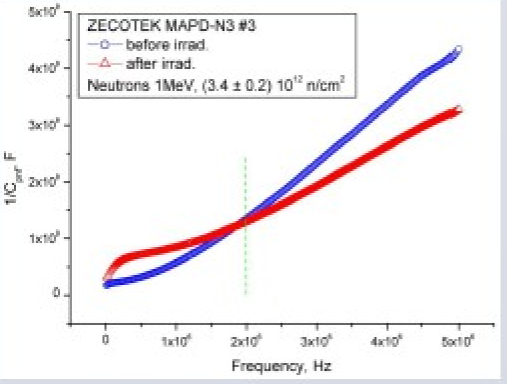
Ketek APDs



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 τ_t > 0.5 μs decreased

N_{traps} with τ_t < 0.5 μs increased

Method of simple C-F analysis (1)

While we used the common methods for C-V and I-V data analysis, we used a new method of C-F data analysis, which requires further explanations. Dynamical process describing variation of nonequilibrium carriers due to recharge of traps' levels in silicon volume is depicted in [5]. Here is presumed that measured capacitance C and geometrical capacitance are connected in parallel. For the measured capacitance C being bigger than geometrical one, variation of nonequilibrium carriers' concentration Δn is with lifetime τ is described by following equation:

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

where e is elementary charge and J_n is the current through p-n junction.

Multiplying the left part by $\partial\varphi/\partial\varphi$ and e/e, substituting $\partial\Delta n$ by $\partial q \cdot e$ and assuming $\partial J_n/\partial x$ tending to zero due to small gradient of current across p-n junction, one can achieve:

$$\frac{\partial \Delta n}{\partial t} \cdot \frac{\partial \varphi}{\partial \varphi} \cdot \frac{e}{e} = \frac{\Delta n}{\tau} \Rightarrow \frac{\partial q}{\partial \varphi} \cdot \frac{\partial \varphi}{\partial t} = e \cdot \frac{\Delta n}{\tau}$$

Method of simple C-F analysis (2)

Here we can move from ∂ increments tending to zero to small but measurable Δ increments: $\partial q \to \Delta q$, $\partial\varphi \to \Delta\varphi$, $\partial t \to \Delta t$, where $\Delta\varphi$ is voltage modulation applied to p-n junction for time Δt and inducing charge change Δq. Finally, substituting time interval Δt by frequency f to move from the time representation to frequency representation and substituting $\Delta q/\Delta\varphi$ by p-n junction capacitance C, one can achieve:

$$\frac{\Delta q}{\Delta\varphi}\cdot\frac{\Delta\varphi}{\Delta t} = e\cdot\frac{\Delta n}{\tau} \Rightarrow C\cdot\Delta\varphi\cdot f = e\cdot\frac{\Delta n}{\tau}$$

We assume that carriers' concentration Δn is proportionally equal to traps' levels concentration $<N_t>$ as all the traps' level are ionised for the given temperature. Here, traps' levels concentration $<N_t>$ and traps' levels lifetimes $<\tau>$ are considered as averaged values for all the different traps' levels in the p-n junction. Substituting Δn by $<N_t>$ and τ by $<\tau>$ we can rewrite achieved formula in final variant as:

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

DAQ development for laboratory

Requirements to readout system:

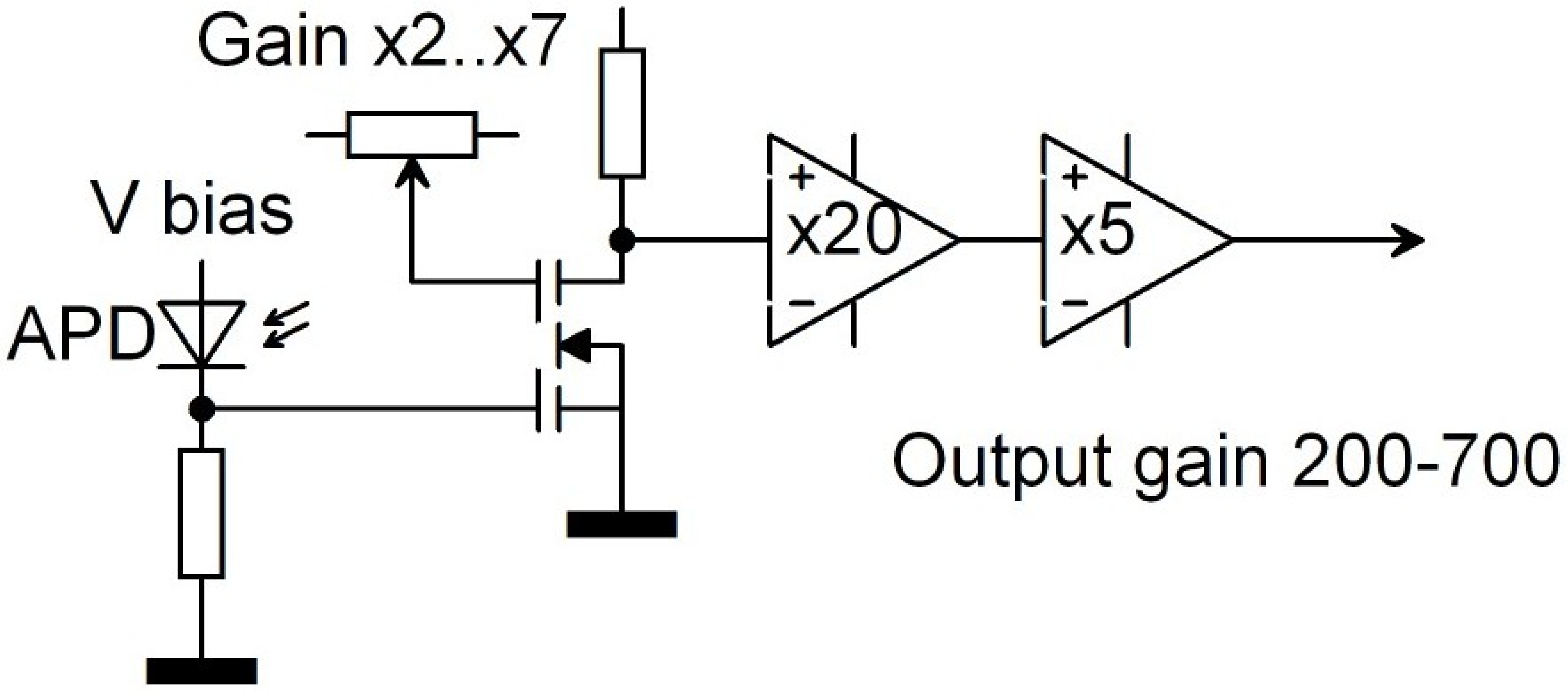
1 Must be operated with APD gain 10^4-10^6
(wide band and low noise amplifier with variable gain);

2 Must allow obtaining signal from APD without distorting
(wide band amplifier with shaping and without shaping);

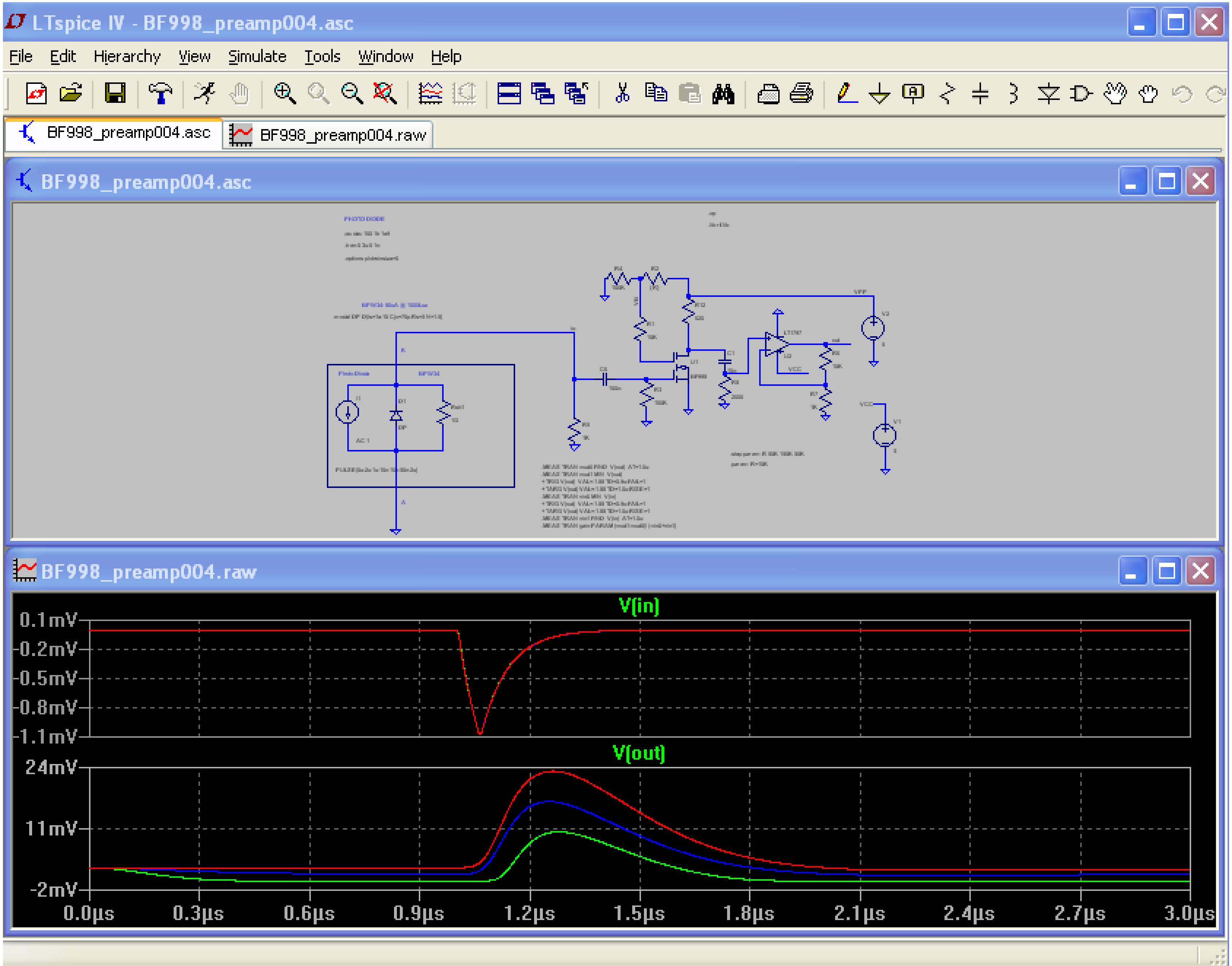
3 Must be flexible for modification
(Not large data stream but possibility to use different methods to transform the signal);

Amplifier for APD DAQ

The double gate MOS FET as variable gain amplifier?

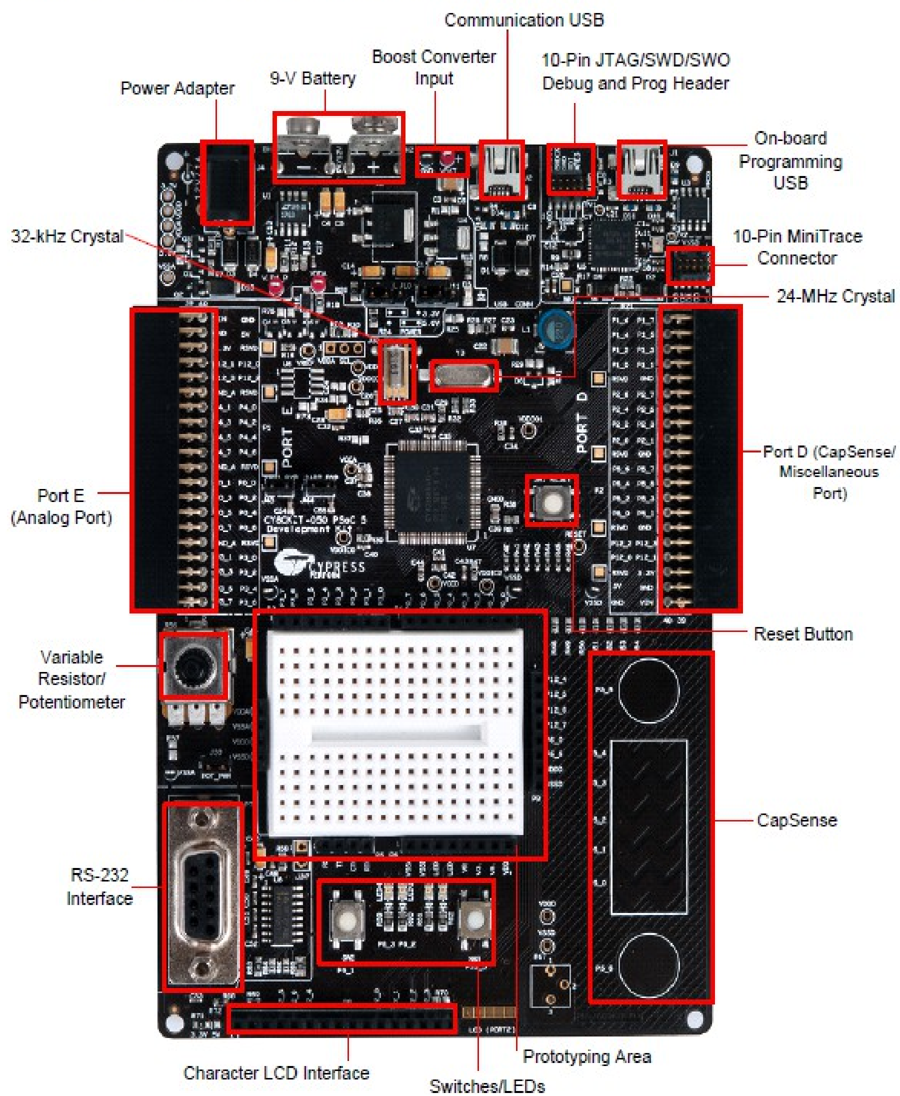


Amplifier for APD (simulation)



DAQ based on PSoC5

Figure 4-1. PSoC 5LP Development Kit Details



PSoC 5LP is now available with a faster ARM 7 Cortex CPU core, clocked at 80MHz,
Unmatched precision analog integration
Best-in-class ADCs
- 2x12-bit 1Msps SAR ADCs
- 20-bit DelSig ADC

1.024V ±0.1% on-chip reference
Precision Analog
OpAmps, Comparators, I/VDACs, CapSense®, and more
Fully functional analog from 1.71 – 5.5V

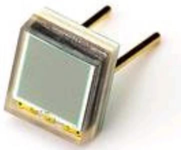
The most flexible low power PSoC
- 0.5V start-up Boost
- 300nA low leakage Hibernate
- Widest operating range 0.5V to 5.5V

100+ production-ready components

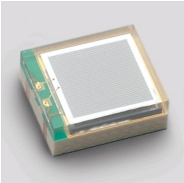
- CapSense® touch sensing
- Segment LCD display
- Trans-impedance amplifier

PsoC = Programmable System-on-Chip

Conclusion and plan

- Were irradiated:
  1 MAPD-3N (ZECOTEK) 65um/cell
  2 SiPM PM3375 (from 10) KETEK 50um/cell



- Were tested before irradiation: 2 MPPC S12572 (from 10) (HAMAMATSU) 10um/cell;

- Was tested controlled photon source;

- Was modified kerma-meter RM20 to sensitivity 0.5 mV/10^9 [n/cm^2];

- Was simulated APD preamplifier with variable gain and tested prototype (gain varies in range of 150-450, band ~200MHz)
  Started work with PSoC5 DK to develop 8channel APD DAQ

Plan for next year...

- Finish 8channel APD DAQ ;
- Production of 8channel Pre-amplifier for APD with regulated gain;
- Modify SW to realise online Signal Shape Analysis;
- Setup for investigation of scintillators for APD;
- Continue radiation test of APD.