Proposal for development of a coordinate detector with a linear resolution 3 μm

R. Makarov, E. Syresin, B. Zalikhanov

Physical limitations on the coordinate measurement accuracy at the synchrotron radiation energy >20 keV

The limitations are the physical processes – photoeffect end Compton scattering, which make they possible to reveal γ–quanta

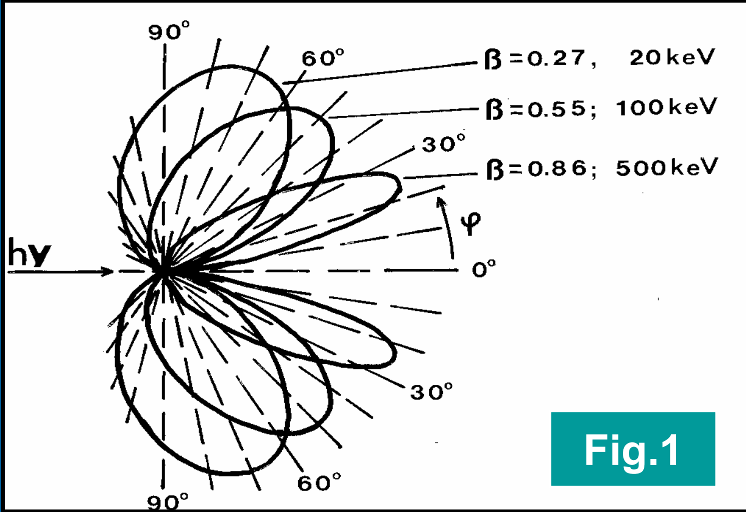


Fig.1

The main physical limitations imposed on the required coordinate detector with a resolution about 1 μm by the photoeffect are spatial distributions of photoelectrons and their path lengths in the material of the detector (fig.1)

At small energies the photoelectron escape direction is mainly perpendicular to the direction of γ-quanta at large energies it is practically the forward escape.

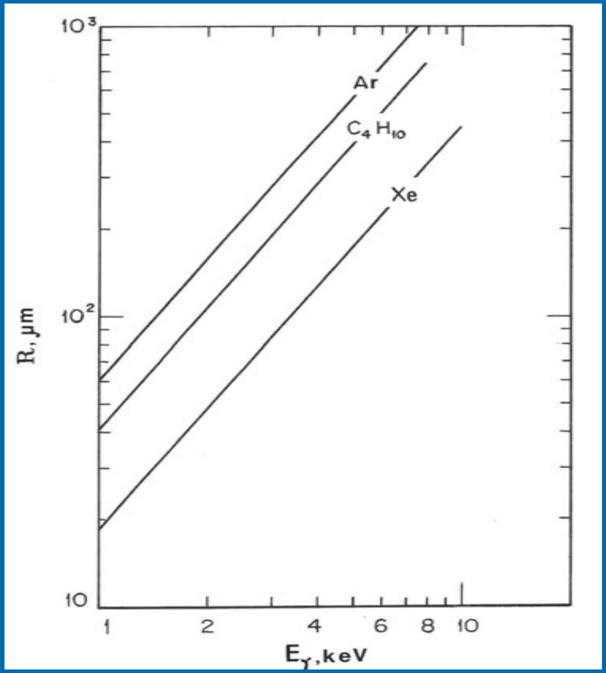


Fig.2 shows paths of electrons arising from γ-quanta of various energies in various gases at atmospheric pressure. Note that the photo-electron in a gas at the atmospheric pressure is about 1 mm in Ar at E_γ = 20 keV and approximately 1 mm in Xe at E_γ = 40 keV .

Fig.2

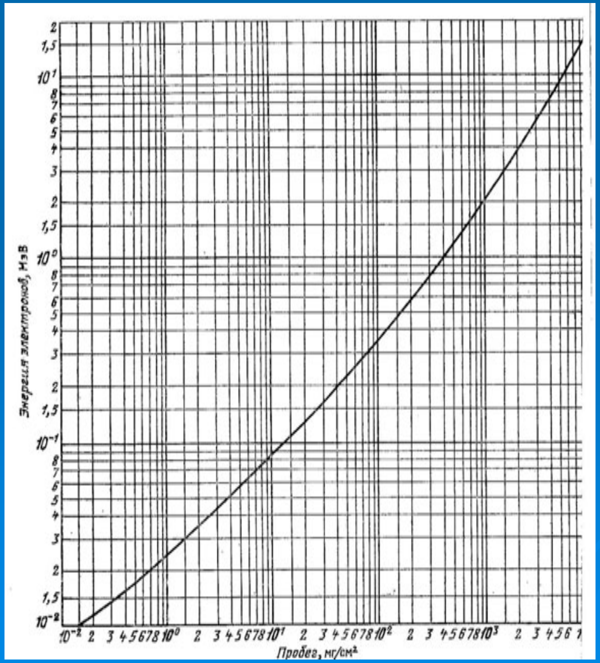


Fig.3 shows the extrapolated path of electron in aluminium as a function of their kinetic energy. The path of the 20 keV electron in aluminium is seen to be about 2.6 μm.

Fig.3

Thus, even the above brief review clearly shows that to obtain a resolution of 1 - 3 μm in the synchrotron radiation energy range 20 – 100 keV is quite a problem.

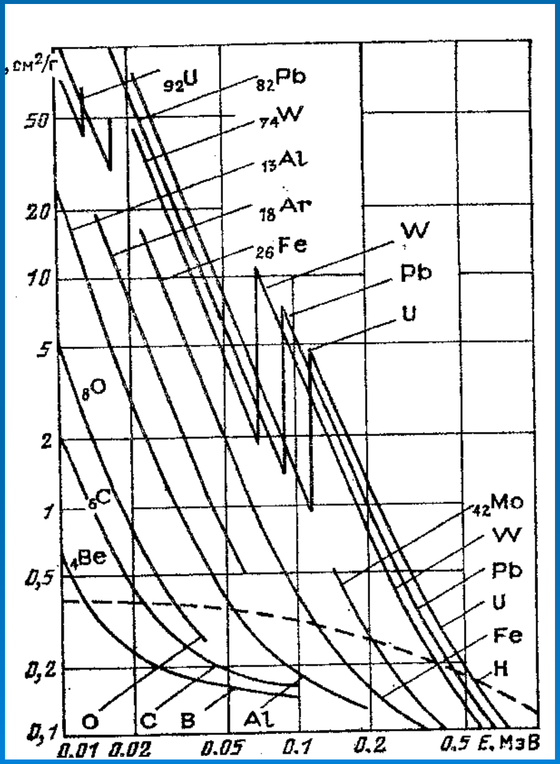


Fig.4

A more hopeful range is 1 – 20 keV. For example, from the dependence for Al in fig.4 and expression

$$N(x) = N_0 \exp(-\mu x)$$

it follows that γ-quant of energy 10 keV are totally absorbed in Al of thickness t_γ = 1.3 mm. The path of 10 keV electron in Al absorber is, according to fig.2, R_e = 0.4μm. The same situation has be-en in Xe at the pressure of (100 – 150) atm.

2. Experimental conditions

At the intensity of electron in the bunch 2 x 10^10 at the energy of 250 GeV the approximate number of γ-quanta with energies renging (0.001 – 30) MeV produced in the synchrotron radiation fan will be N_0 =3 x 10^10. The number of γ-quanta in the range ε ~ 1-20 keV will be $N_\gamma = N_e (\Delta\varepsilon/\varepsilon_{cr}) (\varepsilon/\varepsilon_{cr})^{(1/3)} \sim 2 \times 10^6$, where ε ~ 1 - 20 keV ; $\Delta\varepsilon/\varepsilon_{cr} \approx 7 \cdot 10^{(-4)}$; ε_{cr} = 28 MeV.

From the comparison of N_γ and N_0 it follows that the background component is much greater that the number of useful γ-quanta. Therefore, a highly selective reflecting mirror should be used to separate γ-quanta with energy ε ~ 1-20 keV .

For mirrors with a large atomic number Z the critical angle below which total external reflection occurs is $\varphi_{max} \approx \{0.08/E_\gamma(keV)\}$rad. For angles below the critical one reflectivity is close to unity.

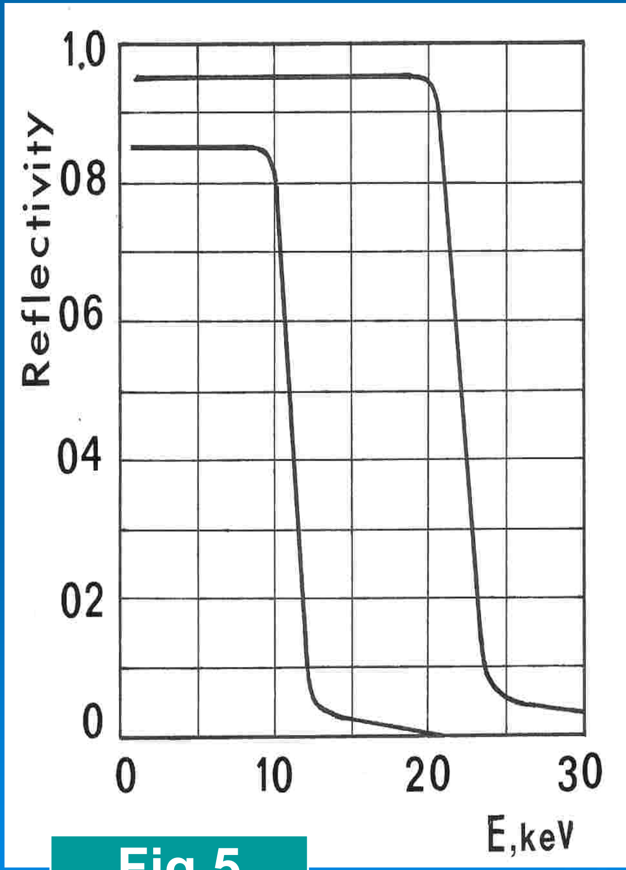


Fig.5

In our case the rhodium (Rh) surfase is an ideal reflecting mirror in the range $\varepsilon \approx 1 - 20$ keV. Its reflectivity as a function of the radiation energy is shown in fig.5.

The reflector may be placed in the BMP4 region on the way of the radiation at the angle of incidence 0.5 mrad (fig.6). Y-quanta of energy > 20 keV will pass through the reflector and γ energy ≈ (1 – 20) keV will be shifted from the main stream toward the periphery by 40 mm at a distance of 80 m from the reflector.

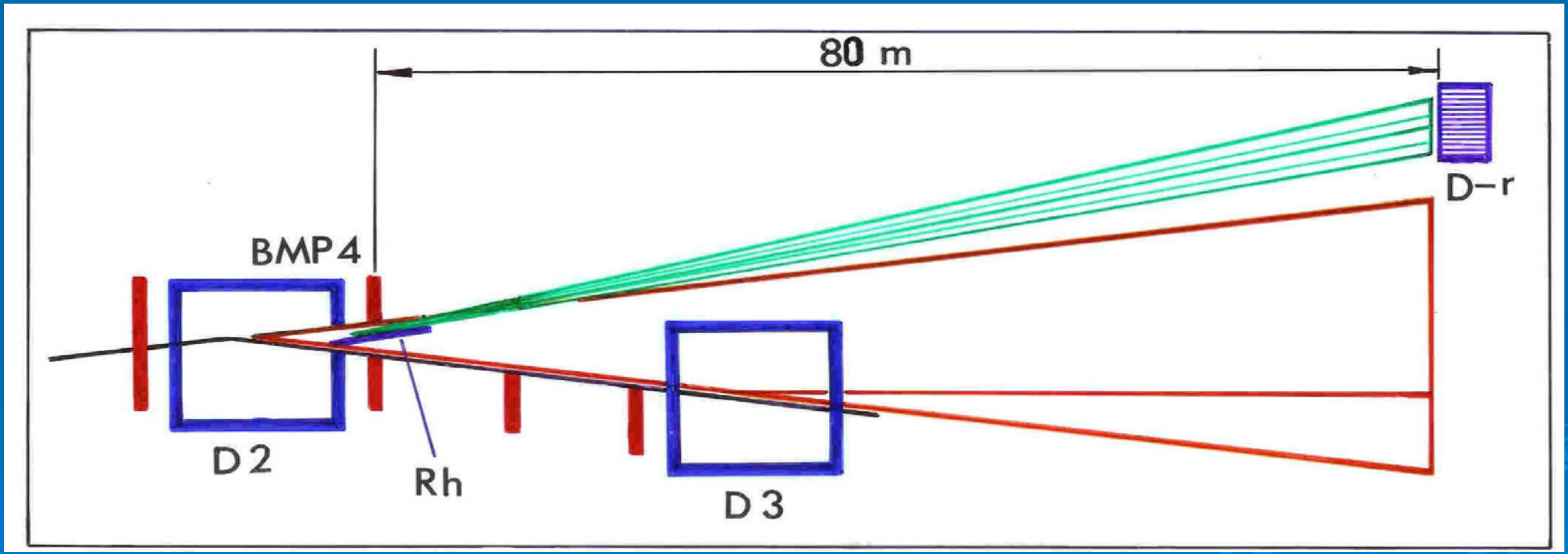


Fig.6

3. EXPERIMENTAL POSSIBILITY

It is not required to determine the conversion point of each γ-quante with an accuracy ~ 3 μm. Necessary onli the width of the distribution of synchrotron radiation should be measured with this accuracy.

It follows that the detector should be similar to the measuring ruler with the least division of 3 μm.

Under the ideal conditions synchrotron radiation should be uniformly distributed within the solid angle and have sharply defined boundaries For example, as follows from the calculation by K.Hiller (fig.7 and 8), at the electron energy 250 GeV the distribution with sharply defined boundaries has a width of 71.4 mm.

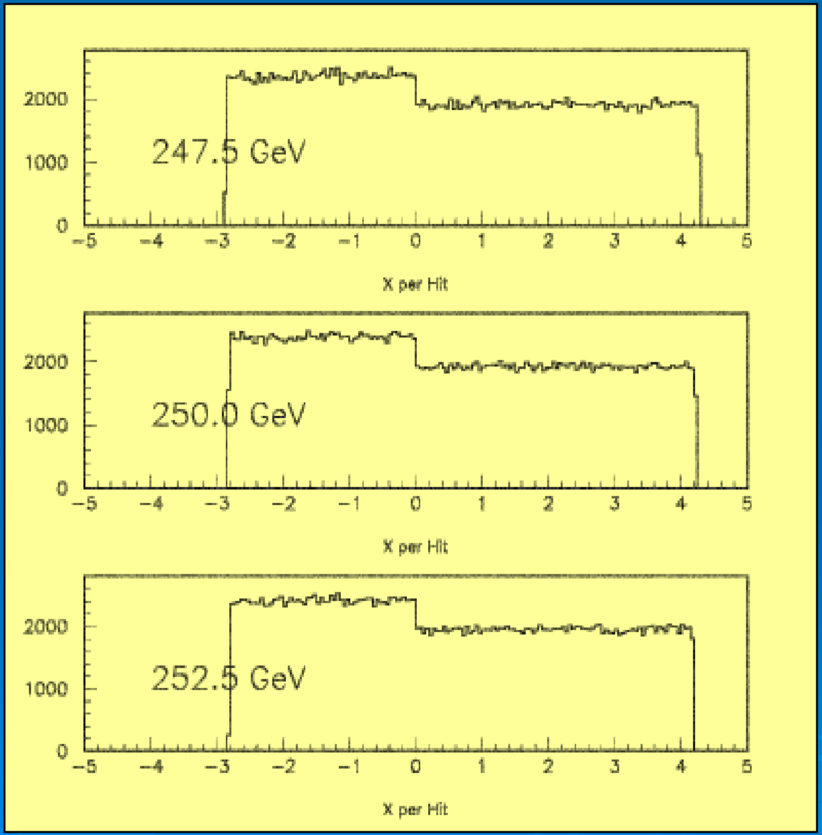


Fig.7

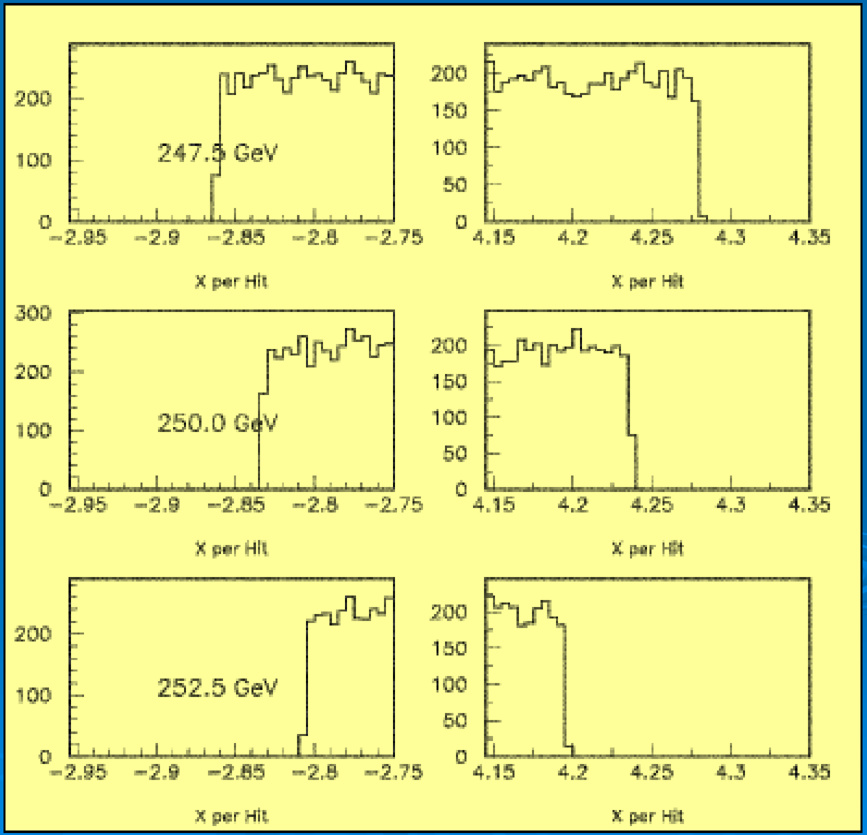


Fig.8

However, real experimental conditions are less favourable. The electron energy spread in the bunch is $dE/E \approx 10^{-3}$. Additional electron energy spread at the level $\Delta\varepsilon/\varepsilon \approx 10^{-4}$ is caused by the magnetic spectrometer under the effect of the synchrotron radiation. Electron energy loss to synchrotron radiation in the magnet causes a change in the curvature of the radius. There arise ≈ 1.5 photons per electron in the magnet, and they may be produced at any point of the magnet. Finally, a background from interaction on the vacuum tube walls is unavoidably present.

All these factors lead to washing-out the synchrotron radiation boundaries, and, as a result, we get distribution like that:

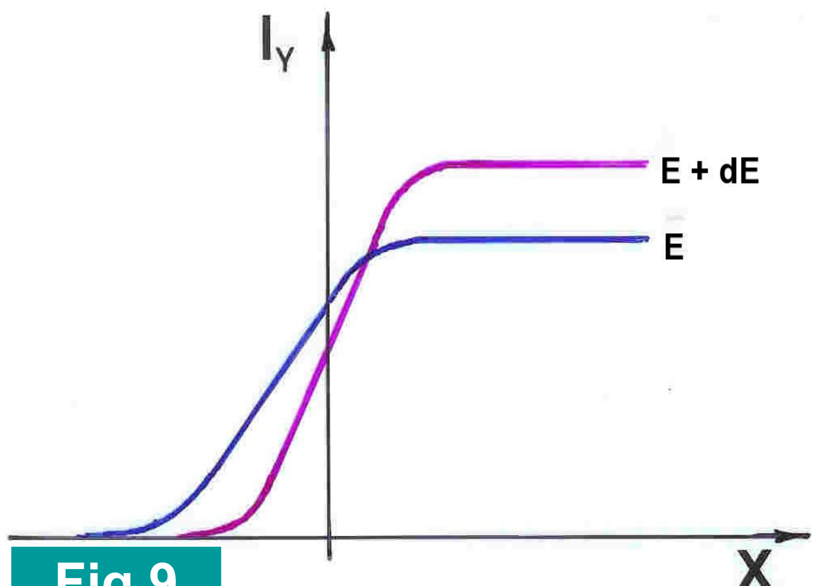


Fig.9

Such a distribution can be ob – tained if the charge produced by γ-quanta in the detector is measured at many points (in a step of ≈ 3 μm) of the increasing distribution.

Here one can get reliable information on the electron energy in each bunch by measuring the position of the distribution centre with respect to a reference point of the detector to an accuracy of 3 μm. Yet, this is possible if the boundary of the synchrotron radiation is described by the Gaussian distribution. In this case, for determining the centre of gravity to an accuracy $\leq \Delta x$ it is enough to measure the charge at 10 – 20 points.

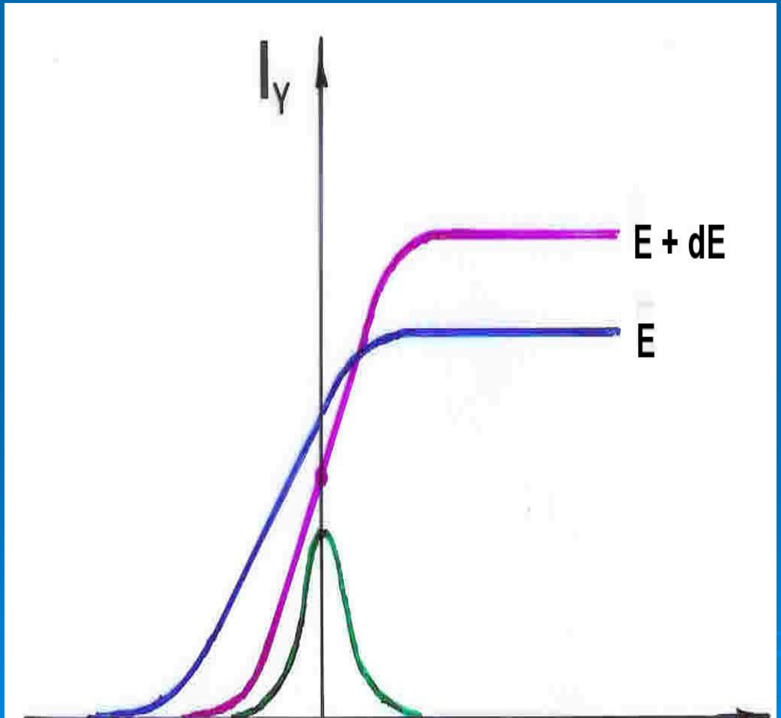


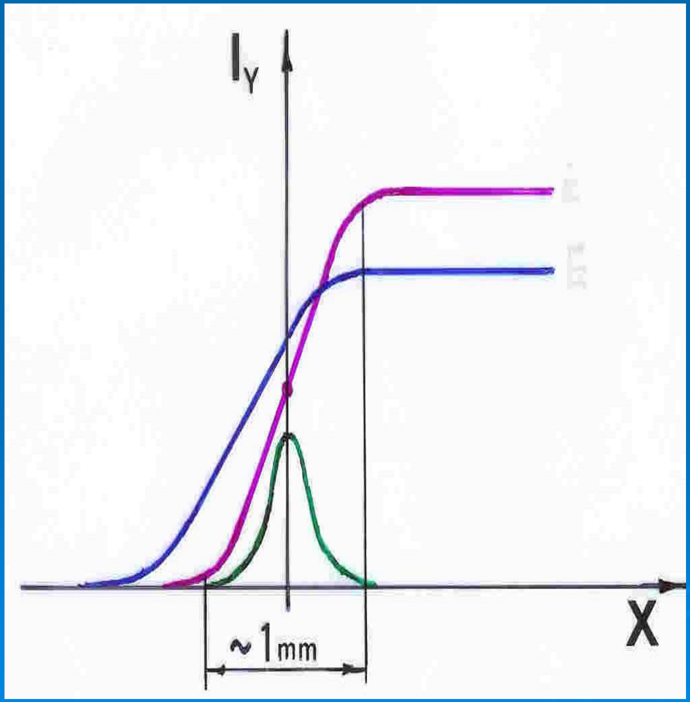
Fig.10

If the distribution is asymmetrical, the radiation boundary will have to be measured at many points, and the accuracy be higher the more points are measured.

Thus, even if we have a detector with a resolution ≈ 1 μm, it does not mean that the desired value is measured to that accuracy.

It has need of the proof

To have a clear idea of the detector structure and be certain about the measurements, it is necessary, as much as possible, to taken into account all factors leading to energy and space distribution of electrons and γ – quanta.



SR spot size

Horizontal spot size:

$X \approx L \cdot \alpha \approx 4$ cm. $L = 80$ m, $\alpha = 0.5$ mrad.

Vertical spot size:

$\theta \approx 0.5(\lambda/R)^{1/3} \approx 12$ μrad,

at $\lambda \approx 0.6$ A, ($E = 20$ keV) and $R = 5$ km.

$Y \approx L \cdot \theta \approx 1$ mm

4. Structure of the Detector.

Version 1. **Tentative schematic view of the detector. Its sensitive region contains N_x Si layers 3 μm thick.**

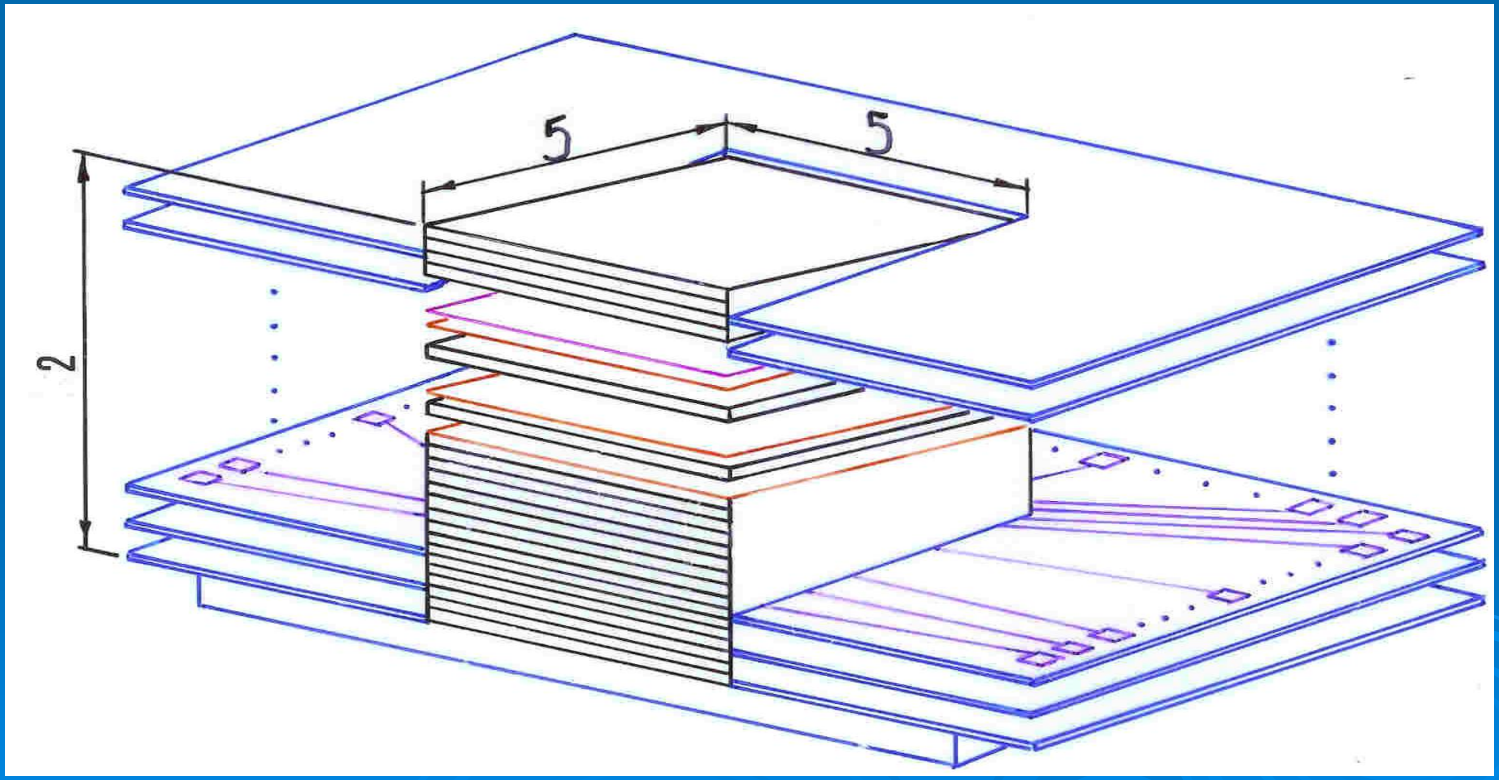


Fig.11

The structure of the detector shown in fig.12. Its sensitive layers prepare of Si 3 μm thick . There are gold electrodes on the surface of layers to supply the high voltage and to read out information. The anode electrodes are separated with dielectric SiO_2 ≈ 300 A thick.

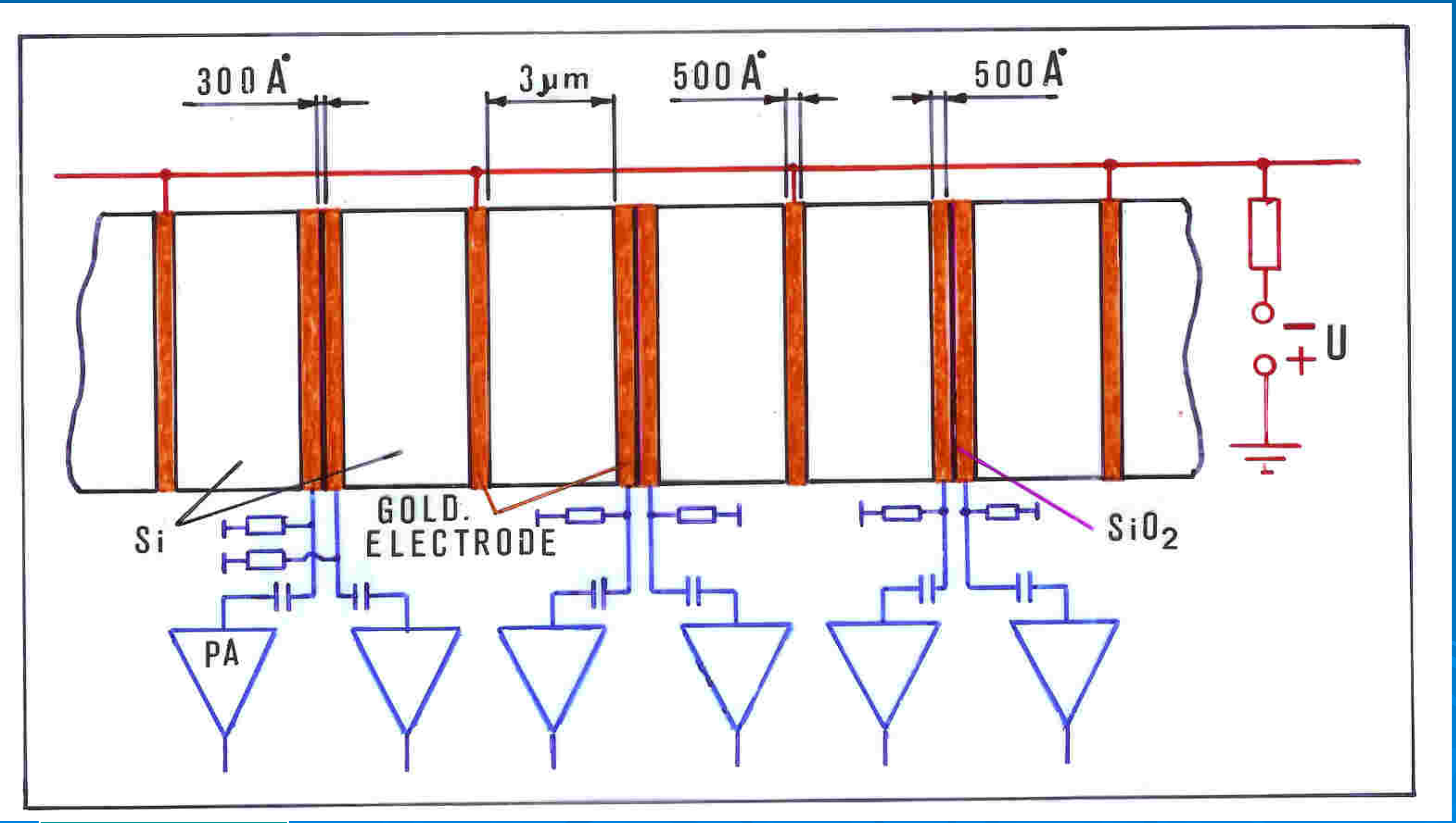


Fig.12

DETECTOR SYGNAL

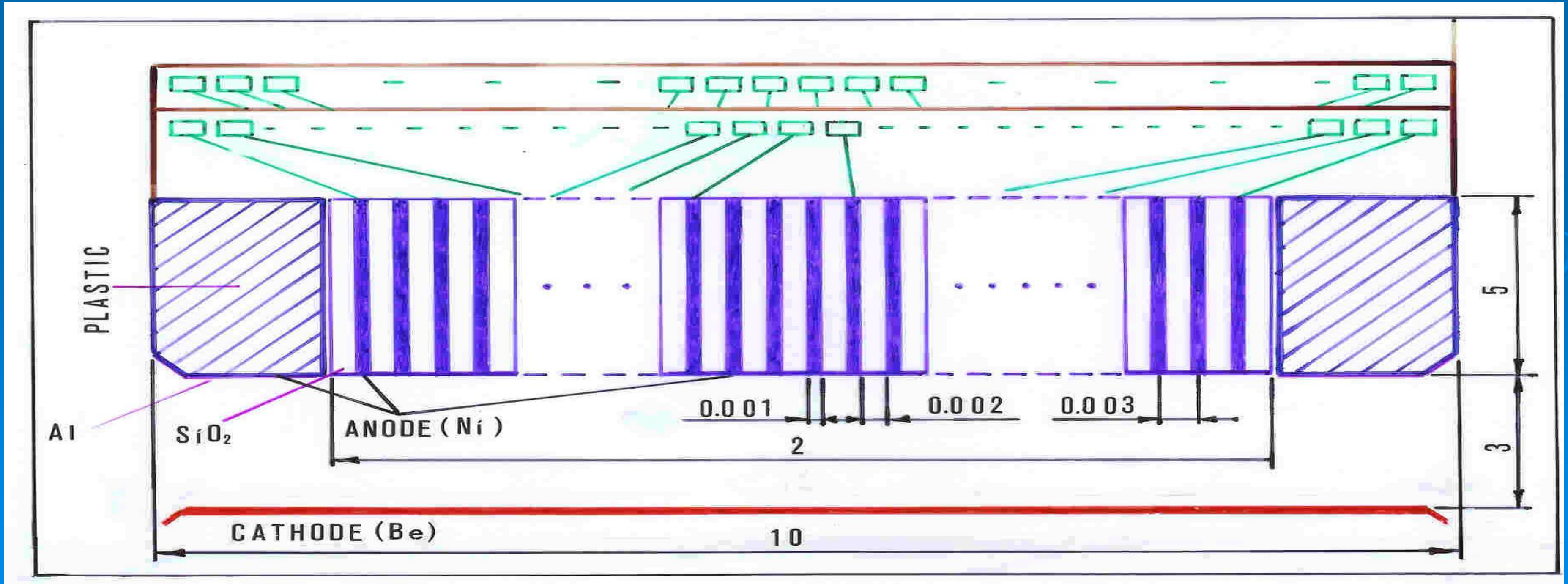
$N_\gamma \sim 2 \cdot 10^6$ at $\varepsilon_\gamma \sim 1 – 20$ keV , x = 40 mm , 3 μm — ≈ 10^2 γ
a photoelectron spends about 30% E_{fe} for on ionization in Si.
Then one electron produces an average of 100 — 1500 electrons in range 1 – 20 keV.
Eventually, about $N_e \approx 10^9$ electrons are produced inside the detector (if γ – quanta with different energy have been distributed even with the measuring interval).

Analyzed size in the detector is 1 mm, at 700 tracks each track contains about 10^5 electrons.
At the amplifier gain 15 mV/fC the input charge of 10^5 e will produce an output signal with the amplitude

≥ 100 mV.

Version 2

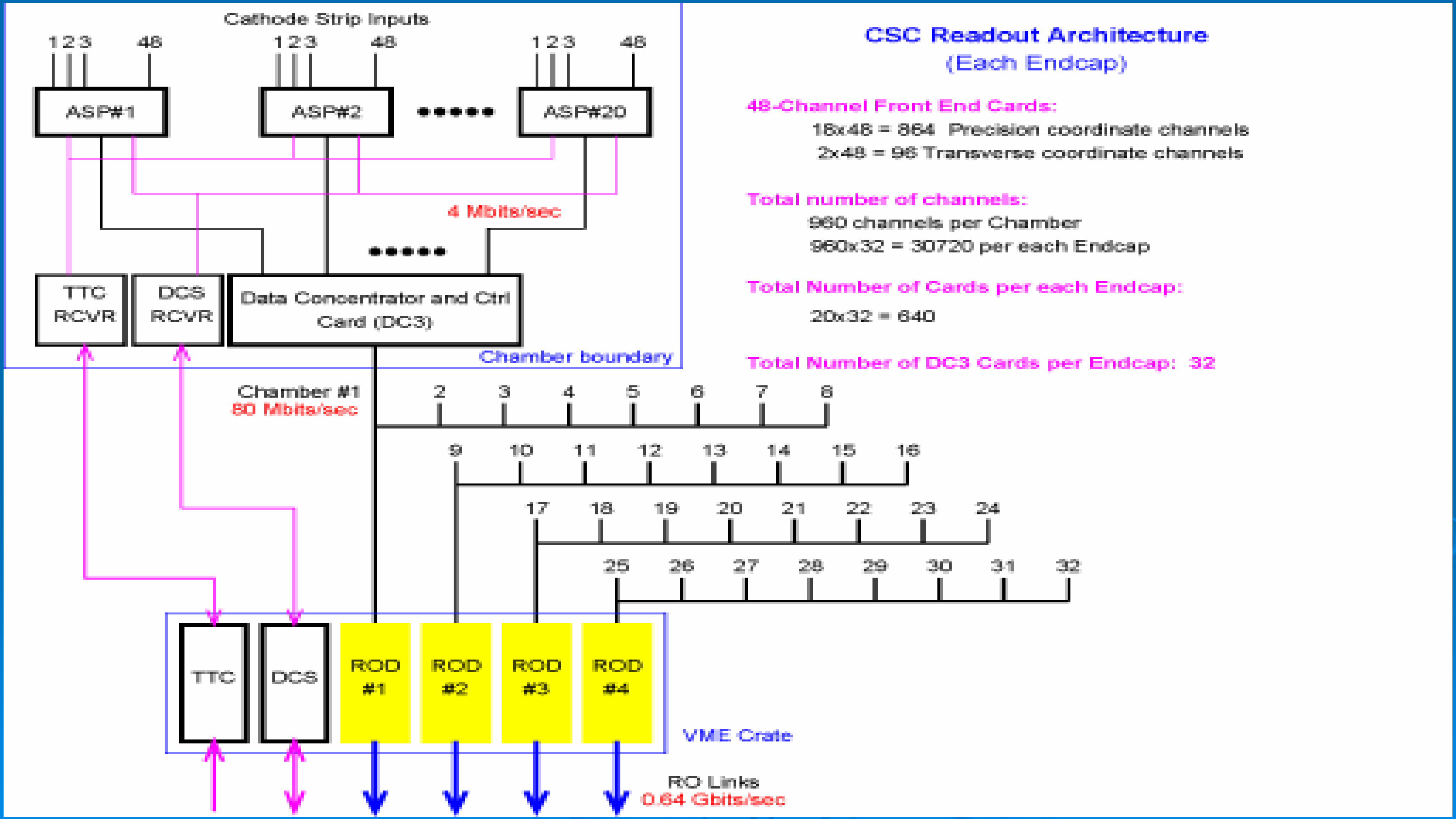
If for some reason the number of γ-quanta in the range 1 – 20 keV turns out to be insufficient for the effective operation of the version 1 detector, the insufficiency can be compensated for by gas amplification in the detector. Below a plane-parallel avalanche detector with gas amplification 10 - 100 and a linear resolution of 3 μm is proposed. Schematically, the avalanche detector is a flat capacitor filled with xenon at a pressure of ~ 50 atm. The anode plane of the detector comprises about 700 ~ Ni layers 1 μm thick and separated from each other by dielectric SiO_2 2 μm thick.

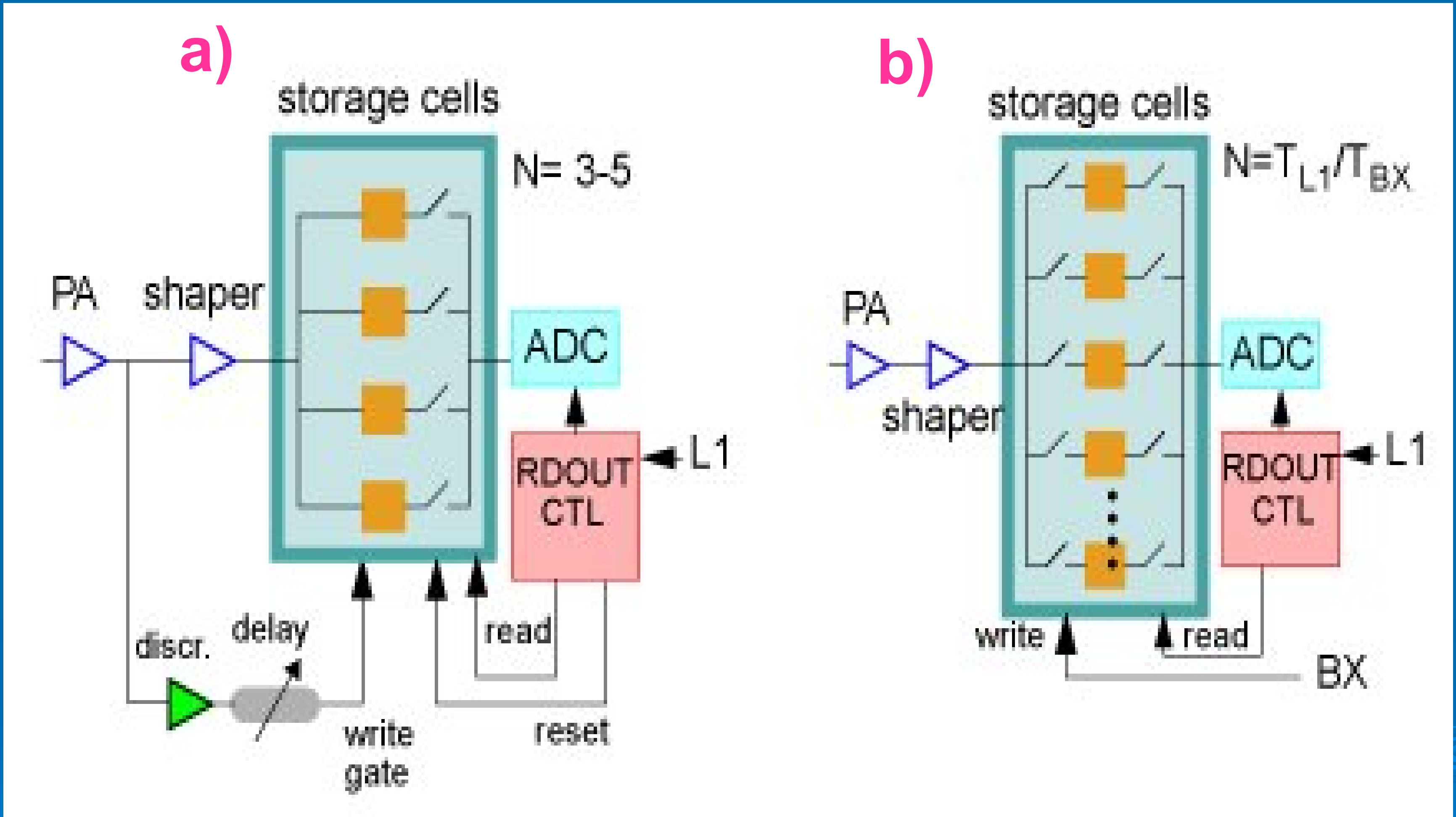


It is advisable that the detector be put in the magnetic field in order to remove the influence of the diffusion of electrons upon the detector resolution.

Readout electronics

The detecting and read-out electronics for the detector may be arranged as the simple and compact electronics used to read out information from the cathode strips of chambers at the ATLAS facility.





a). Data – Driven Sampling. Storage cells include peak detector

b). Clock – Driven Sampling. Storage cells are simple capacitors.

5. Conclusion

Technology for production of multilayer coatings is well developed and their structure is perfect from the point of view of crystallography. Methods electron-beam sputtering and laser-induced evaporation are used with the layer thickness precisely checked by a reflectometer.

Realization of any of the proposed versions of the synchrotron radiation detector will allow electron energy to be monitored with an accuracy ΔE/E ≈ (2 ÷ 5)•10^(-5). The detectors will have a high counting rate and adequate radiation resistance.