

An X-ray Scanner Prototype Based on a Novel Hybrid Gaseous Detector

C. Iacobaeus¹, T. Francke², B. Lund-Jensen³, V. Peskov⁴

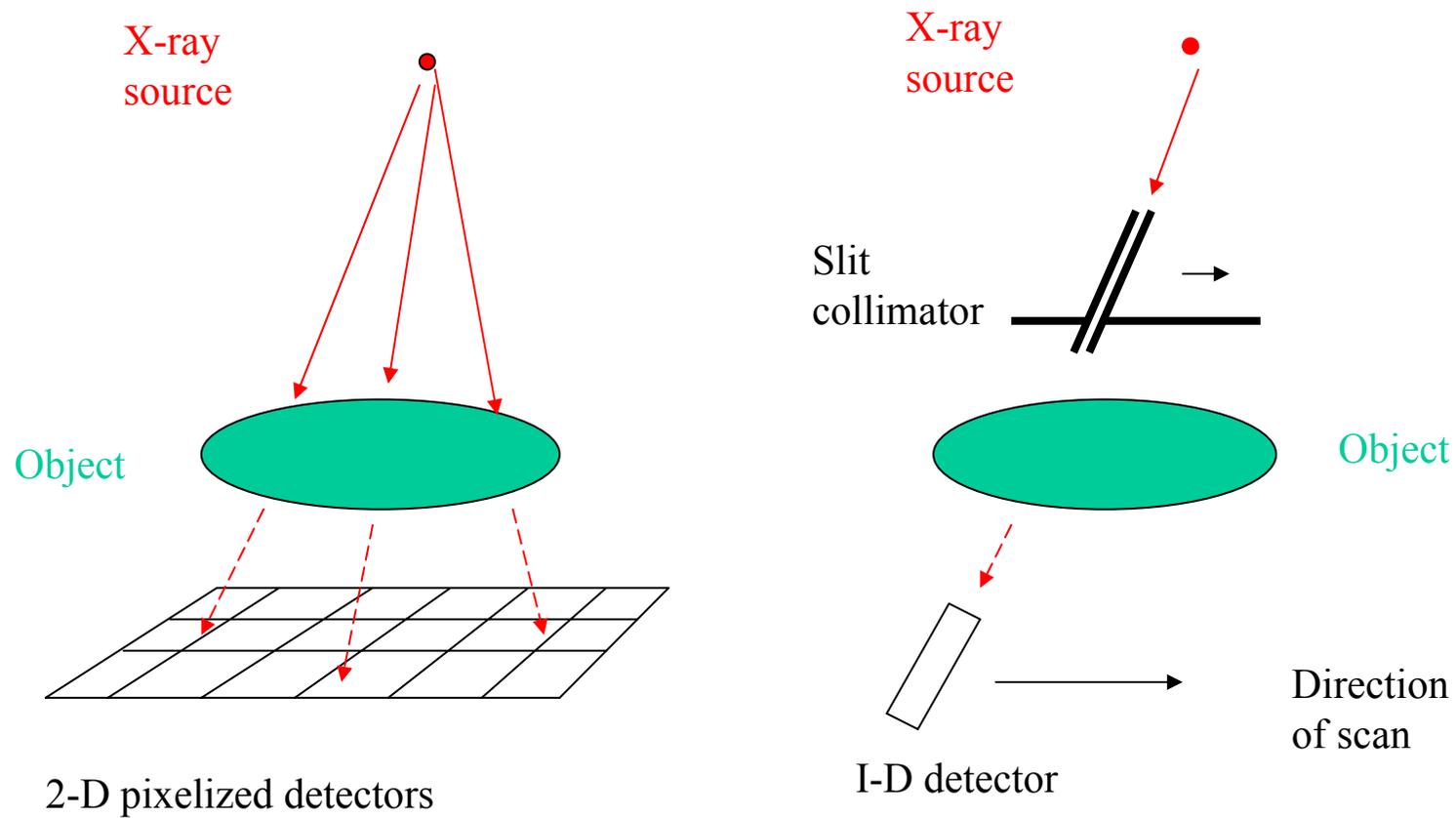
¹Karolinska Institute, Stockholm, Sweden

²XCounter AB, Danderyd, Sweden

³Royal Institute of Technology, Stockholm, Sweden

⁴Leonard de Vinci University, Paris, France

In last decade there has been a fast development of X-ray imaging techniques as a result of which traditional films began to be replaced by electronic devices. The main efforts were concentrated on the development of 2D pixelized imaging systems. However, for some applications, for example airport security devices or radiology, 1D scanning systems were developed as well.



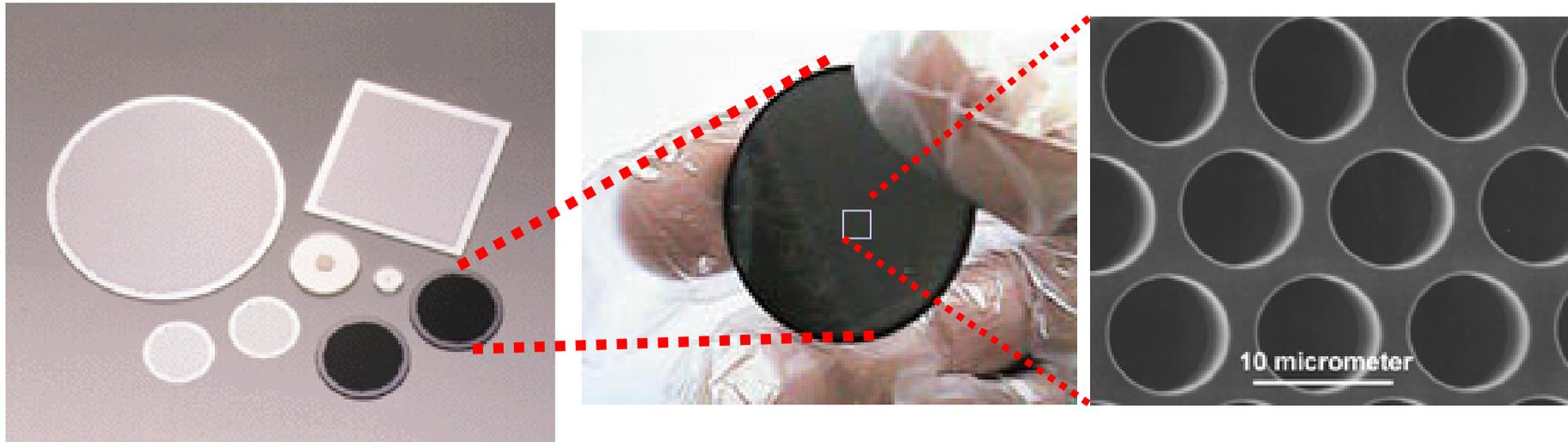
Scanning systems

- Scanning systems allow a very efficient rejection of the scattered radiation, improving contrast and the signal to noise ratio.
- The other important feature of the scanning systems is that they have much simpler electronics and as a result a possibility of simultaneous photon counting and measuring of their energy.
- The cost of the scanning system is usually much lower than for the 2-D imagers.
- For these reasons they are very attractive for mammographic applications. Nowadays advanced mammographic scanning systems which are under tests in Laboratory and some of them even in clinics, are either solid state (Si, GaAs) or high pressure gaseous detectors.
- Each of these detectors has advantages and disadvantages, for example high pressure devices are bulky and finally much more expensive than gaseous detectors operating at 1 atm.

- **The ideal approach of course will be to develop large -area avalanche solid- state detectors and these affords under way now, however the price of this device will be very high**

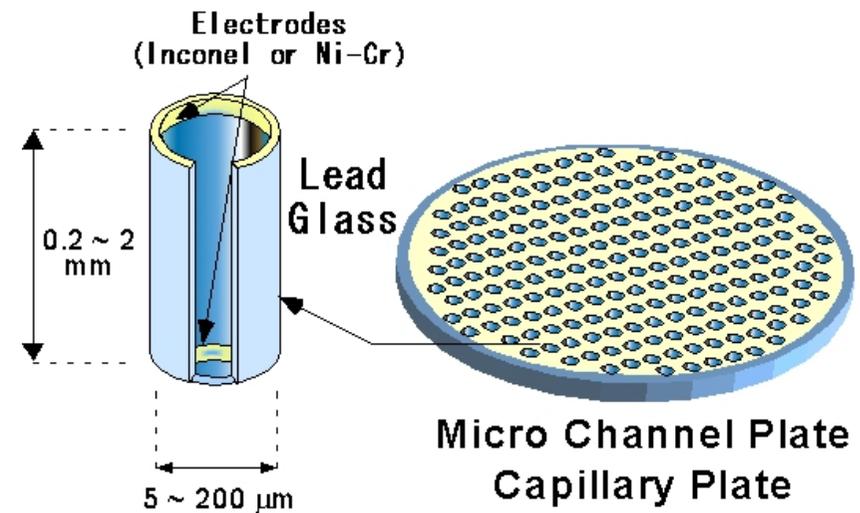
- Discovery that capillary plates (CPs) could be used as gaseous amplification structure (A. Del Guerra et al IEEE trans. Med. Im, MI-1,1982,4,
- H. Sakurai et al., NIM A374 1996 341) made big impact on development of gaseous detectors.

Capillary Plate/ Micro Channel Plate



Physical Parameter of MCP and CP

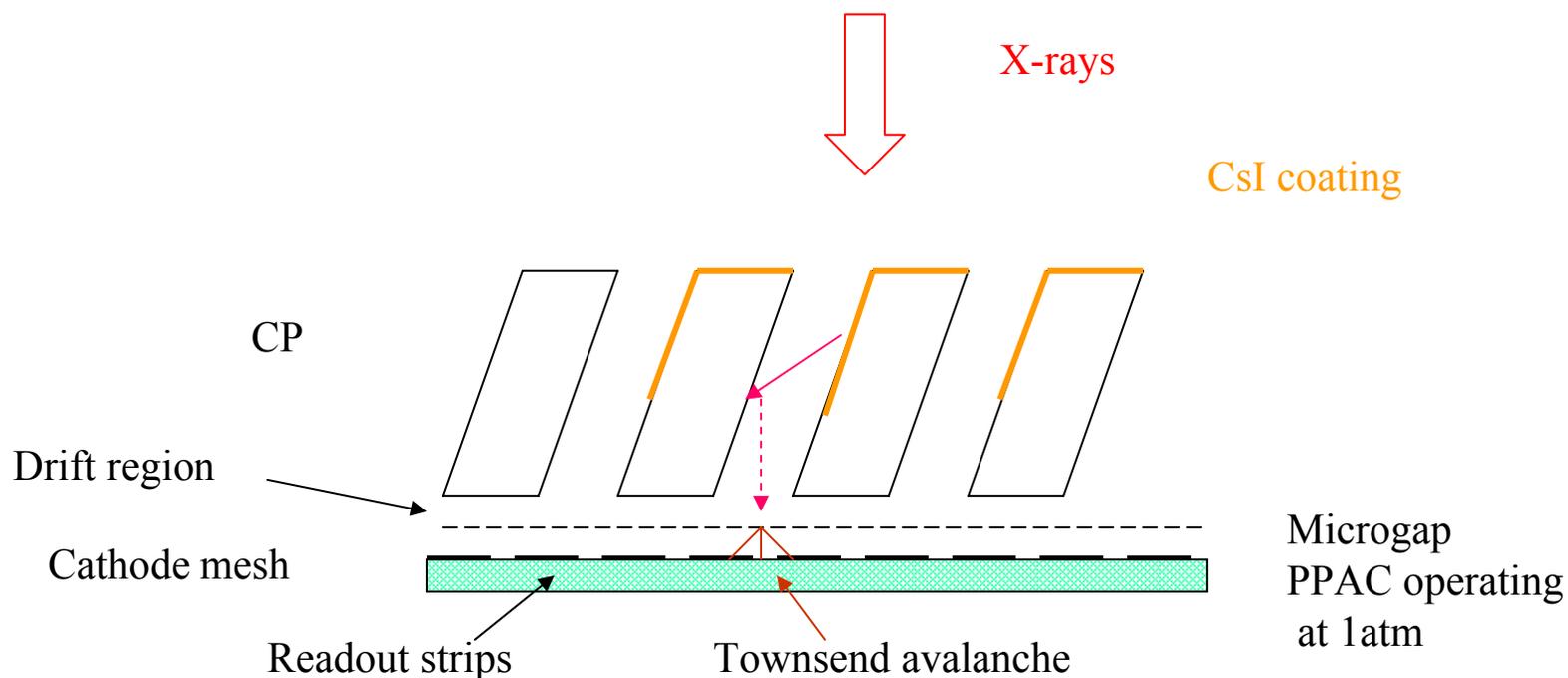
Material	Lead Glass
Outer Diameter (mm)	10~100
Package Density (cm⁻²)	~10⁶
Thickness (mm)	0.2~2
Channel Diameter (μm)	5~200
Electrode Material	Inconel or Ni-Cr
Resistivity (Ω)	10⁶~10¹⁰ : 10¹⁵
Bias Angle (degree)	5~15 : 0



- Several new devices based on CP were suggested, for example gaseous photomultipliers sensitive to visible light
- In this work we exploited CPs as X-ray converters operating in gas atmosphere

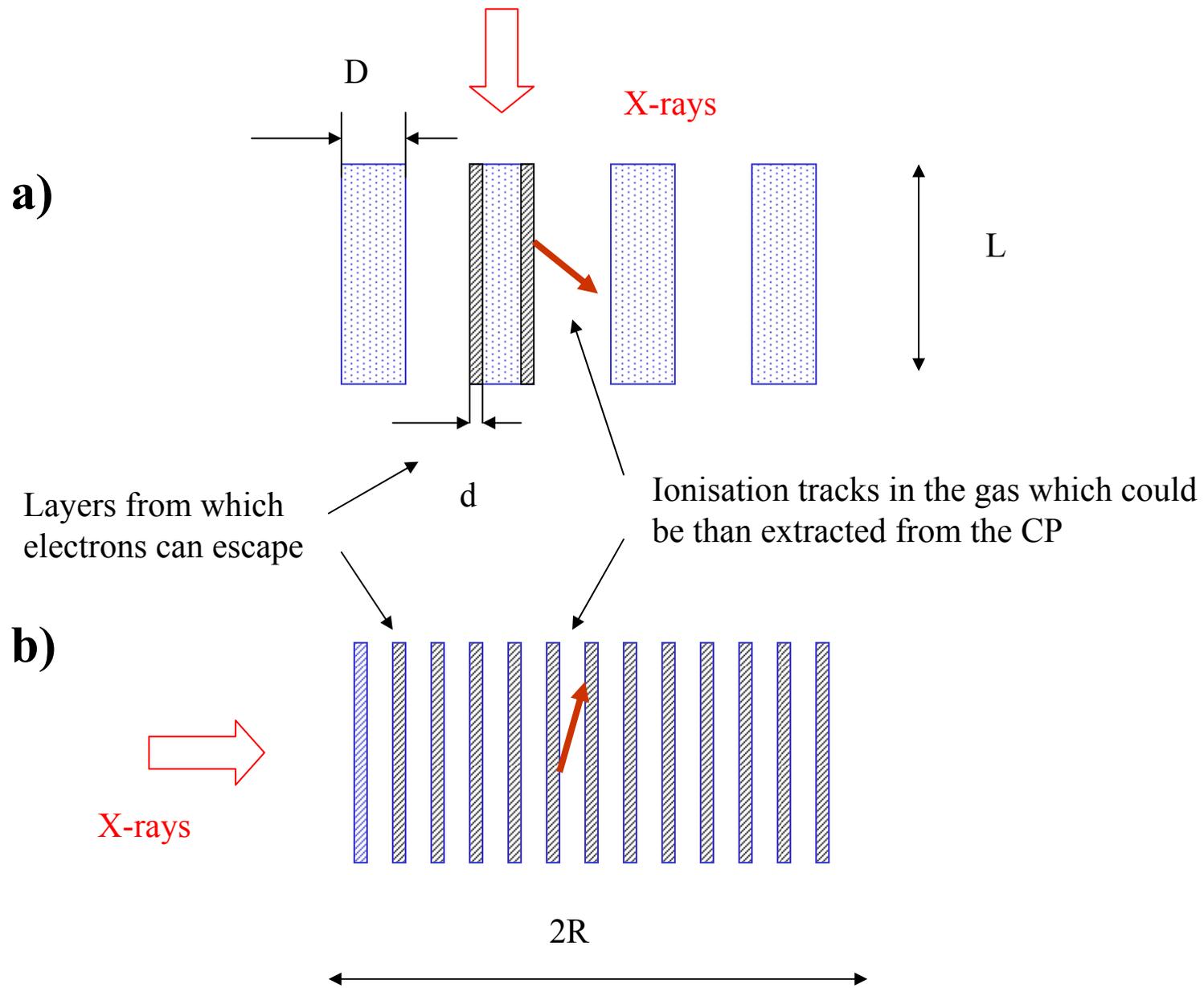
Top illuminated CPs operating at 1 atm

Several year ago we have already demonstrated that CsI coated thick wall ($\sim 20 \mu\text{m}$) capillary plates (CPs) can be used as converters of soft X-rays and be combined with microgap gas multiplication structures operating at 1atm (see [rev.paper in NIM A518,2004,406](#)). This may offer another way to build large -area avalanche X-ray detector. This hybrid detector had excellent position resolution of 50-150 μm , however the efficiency was low: around 3-8% for soft X-rays ($<10\text{keV}$) and only $\sim 1\%$ at 60 keV.



In this work we made several essential modifications:

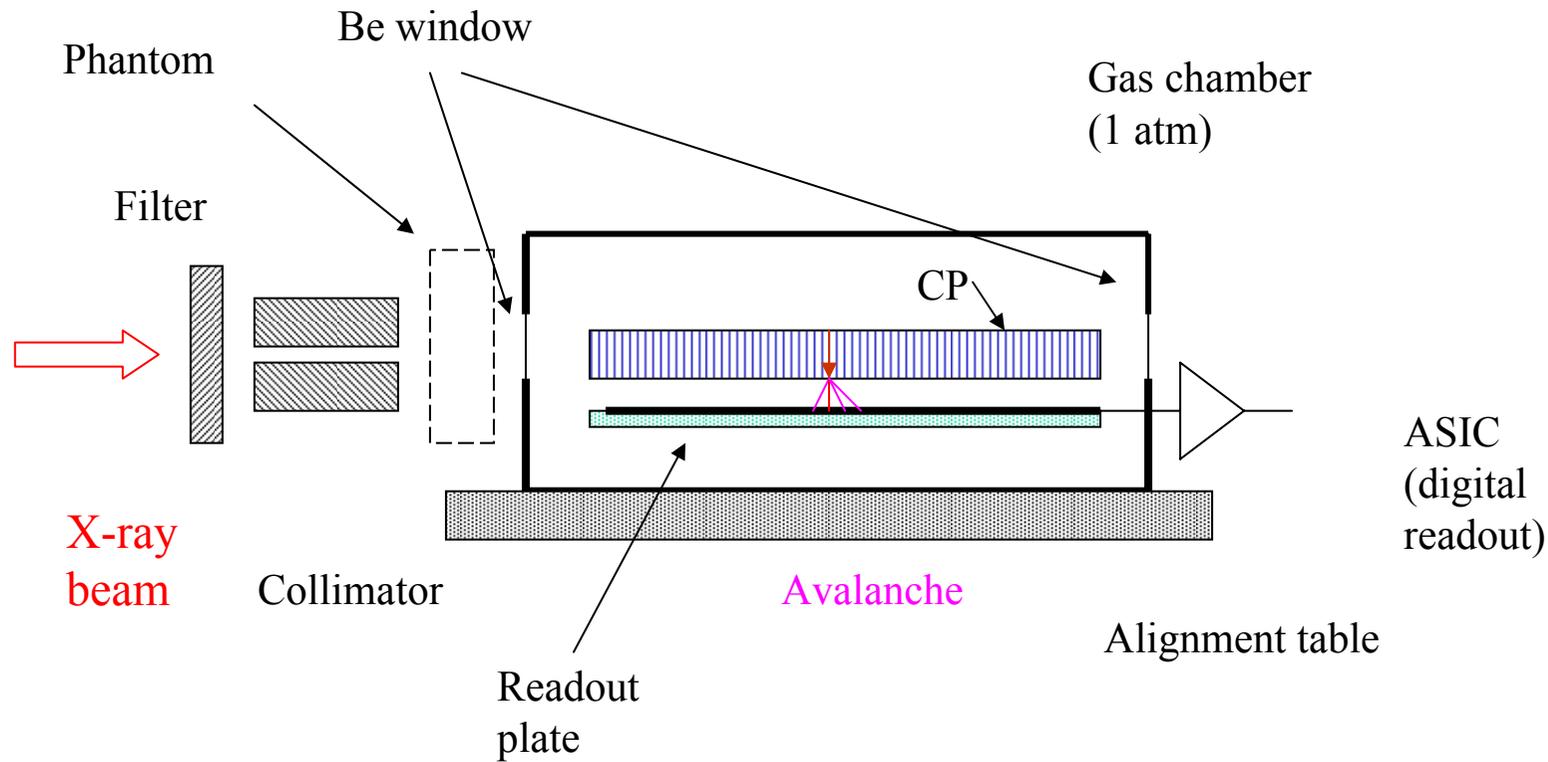
- For the first **time thin wall CP** were tested and used
 - **No CsI coating** was applied
- No cathode mesh, **no drift space** resulting in higher gas gains achieved
 - **Edge illuminated** geometry
- **Results obtained with this innovative device are quite encouraging:**
 - Rather **high efficiency** was achieved for low and high energy X-rays
 - **Simplicity** and low cost
 - Potentially could be made with **large sensitive area**



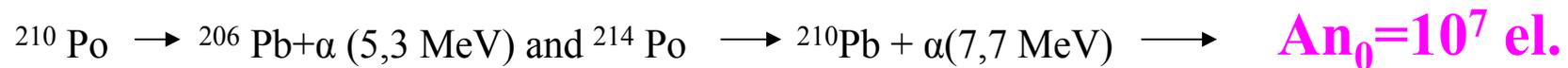
- Of course, top illuminate MCP operating in vacuum were used as X-ray converters for a long time (see for example [G.W. Fraser et al., NIM A224,1984, 272](#)), but it is not easy to build from them large- area, high sensitivity 2-D detector, also such attempts were recently made (see for example [P. Shikhaliev et al., Med Phys 31, 2004 1061](#))

- The important advantage of our detector is 1 atm operation which has potential for building large-area device. **One atm** also simplifies all feet through and windows issues.

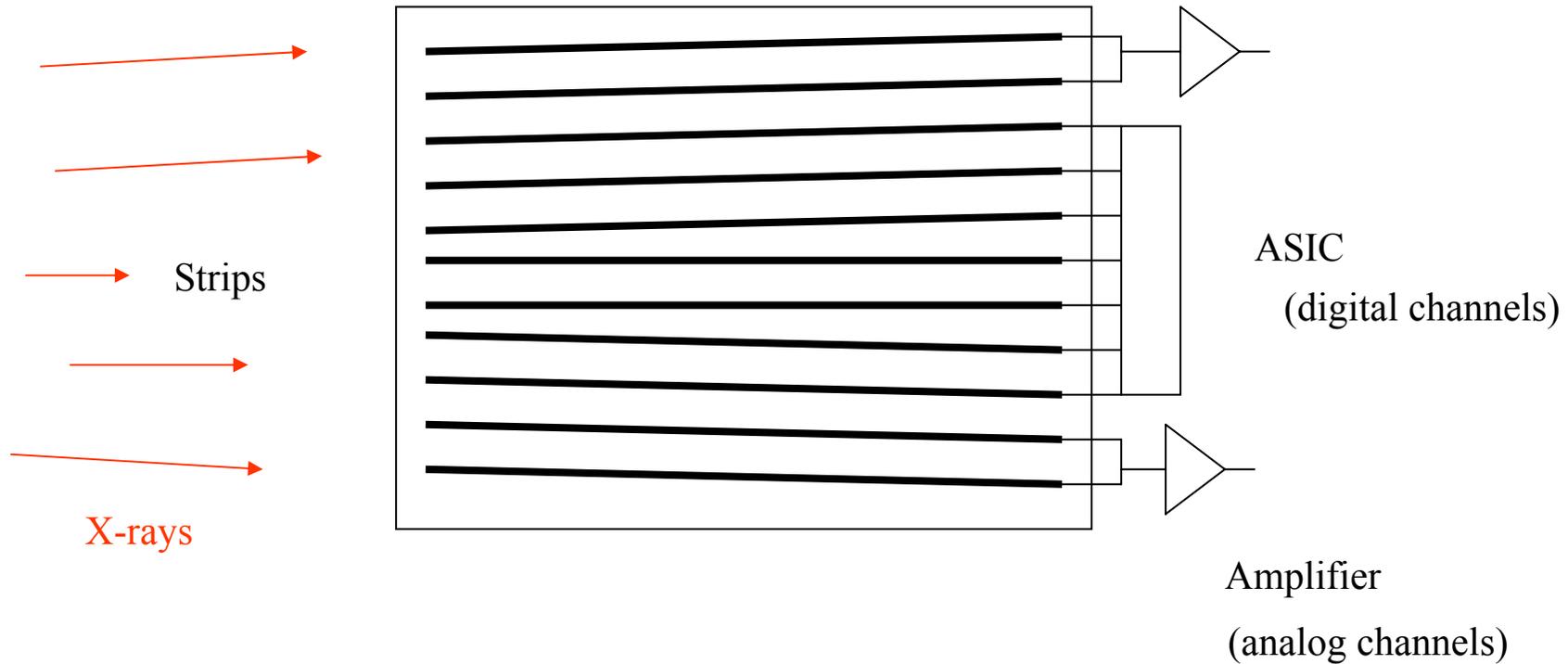
A schematic drawing of scanner based on edge-on illuminated CP



Essential: the removal of the drift region reduced the risk of sparks, produced by alphas from the lead glass



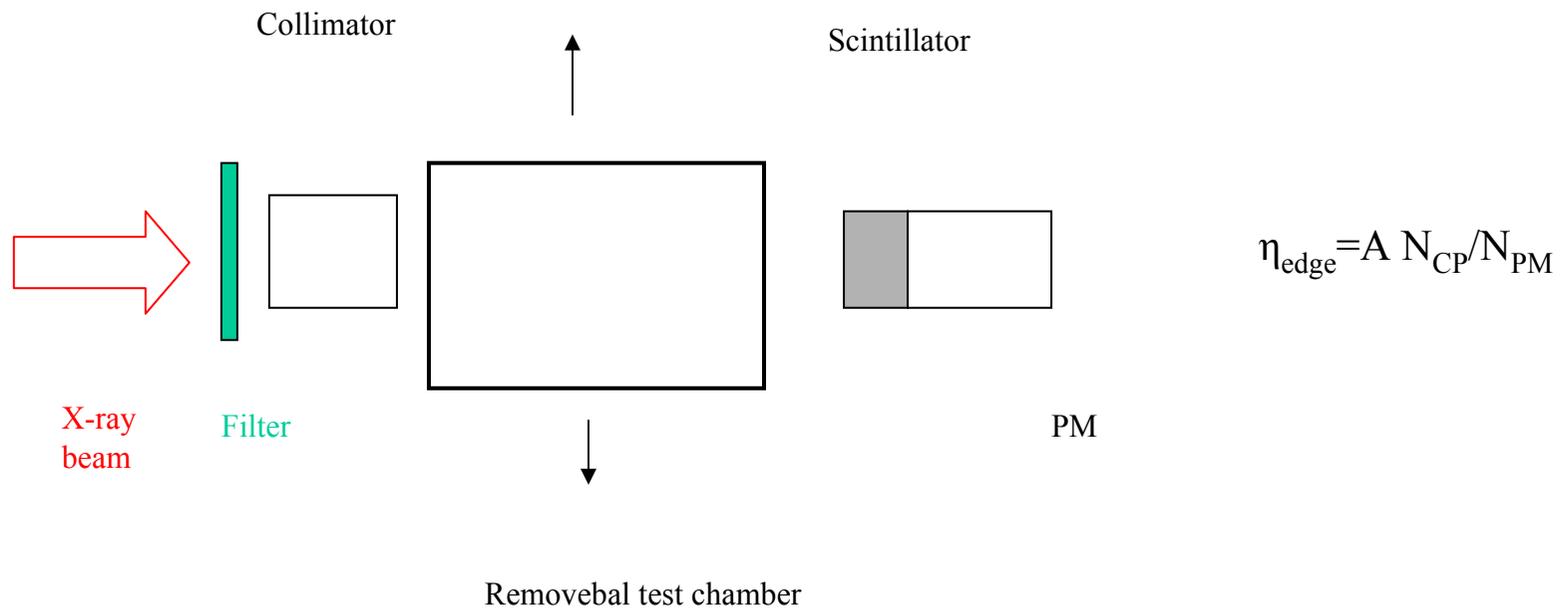
Readout plate



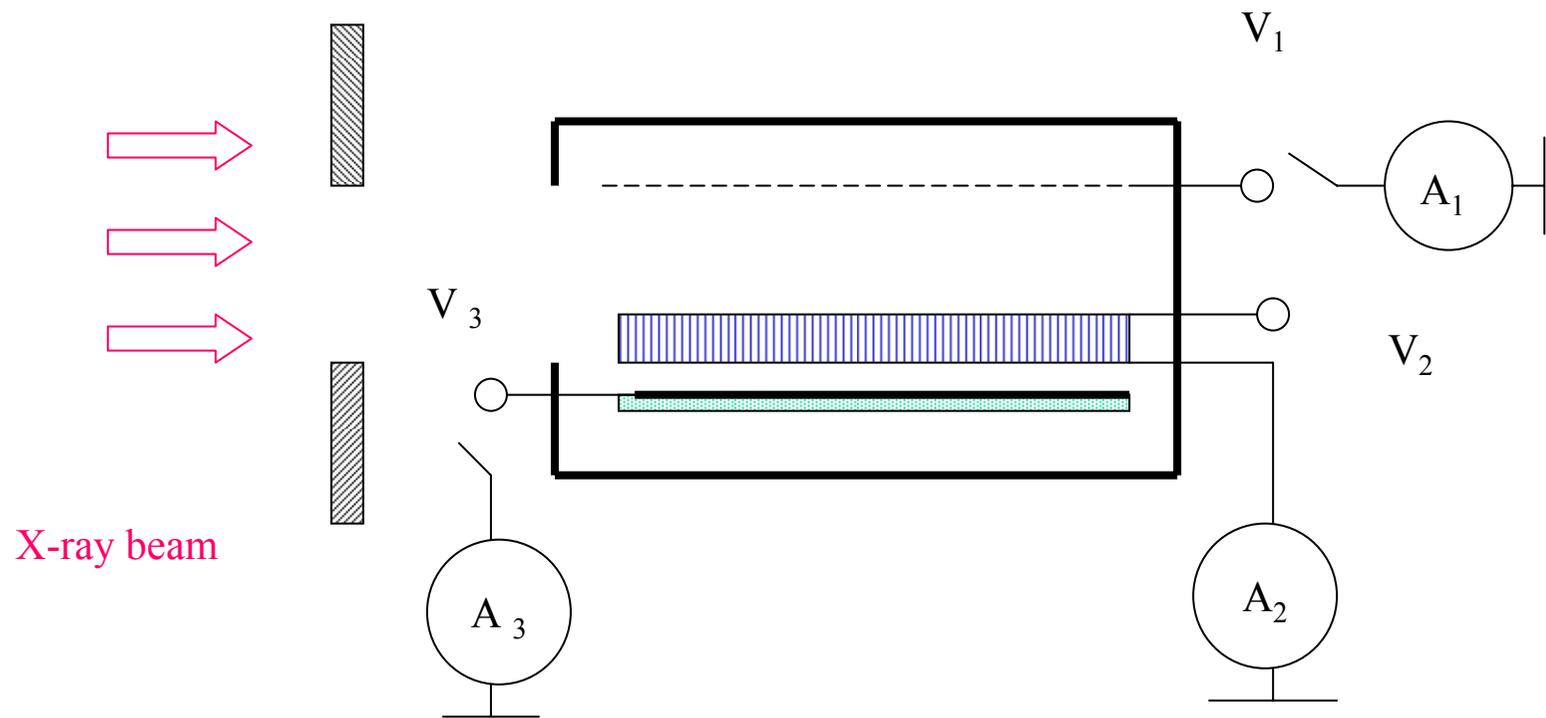
Ceramic plate with Al strips $50\mu\text{m}$ in pitch

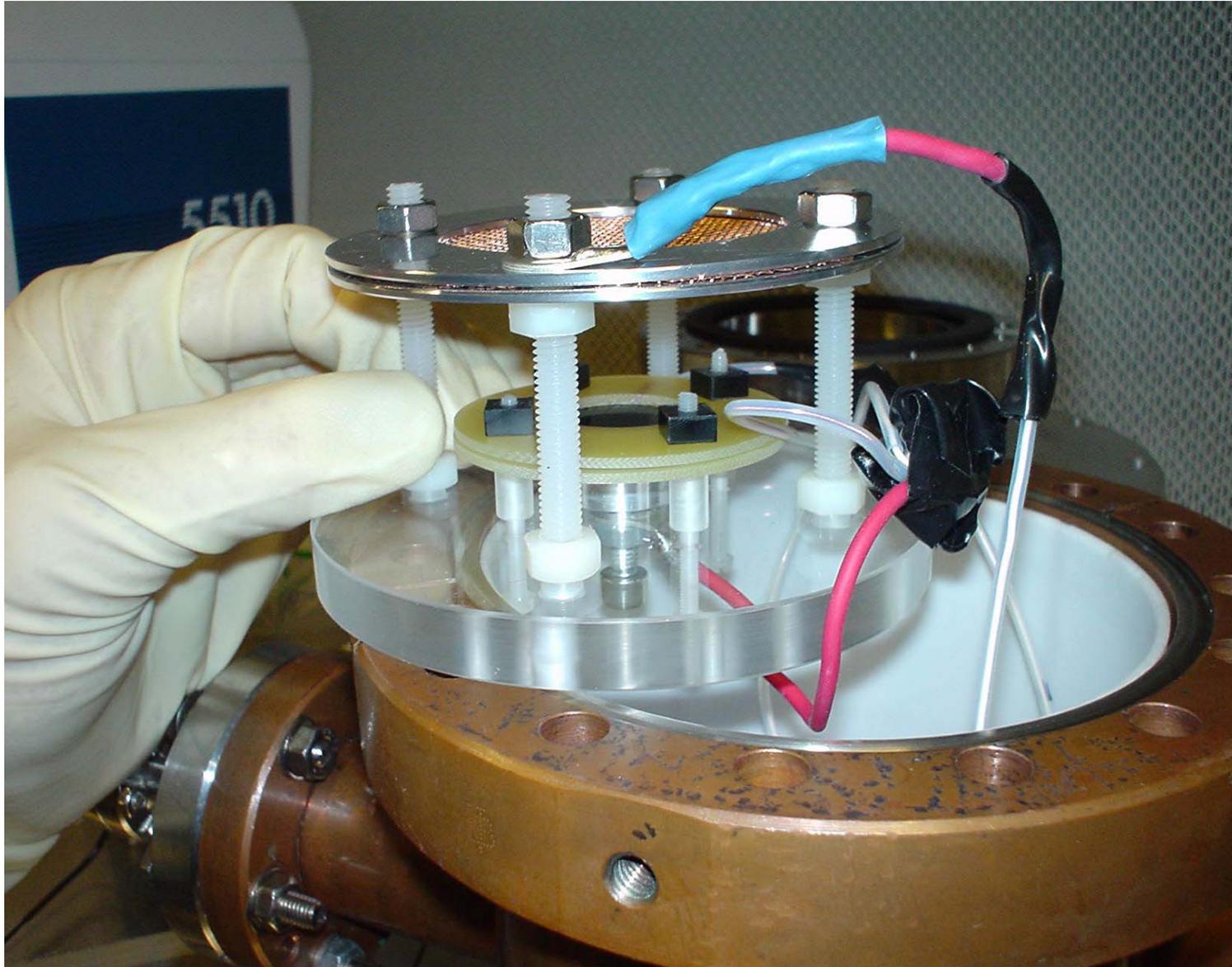
« focused » on 78 cm distance

At high photon energies (30-60 keV) a PM with a scintillator, operating in counting mode, were used for the measurements of the X-ray beam intensity

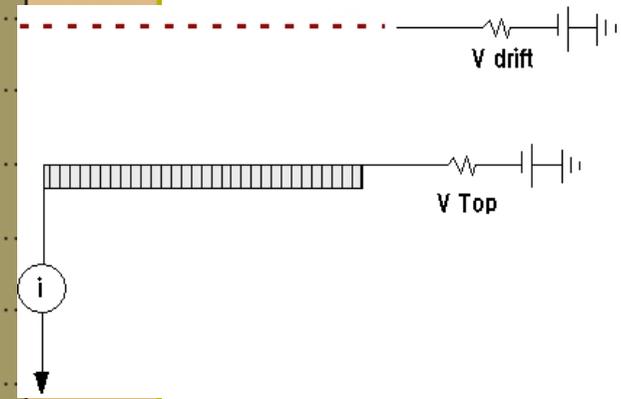
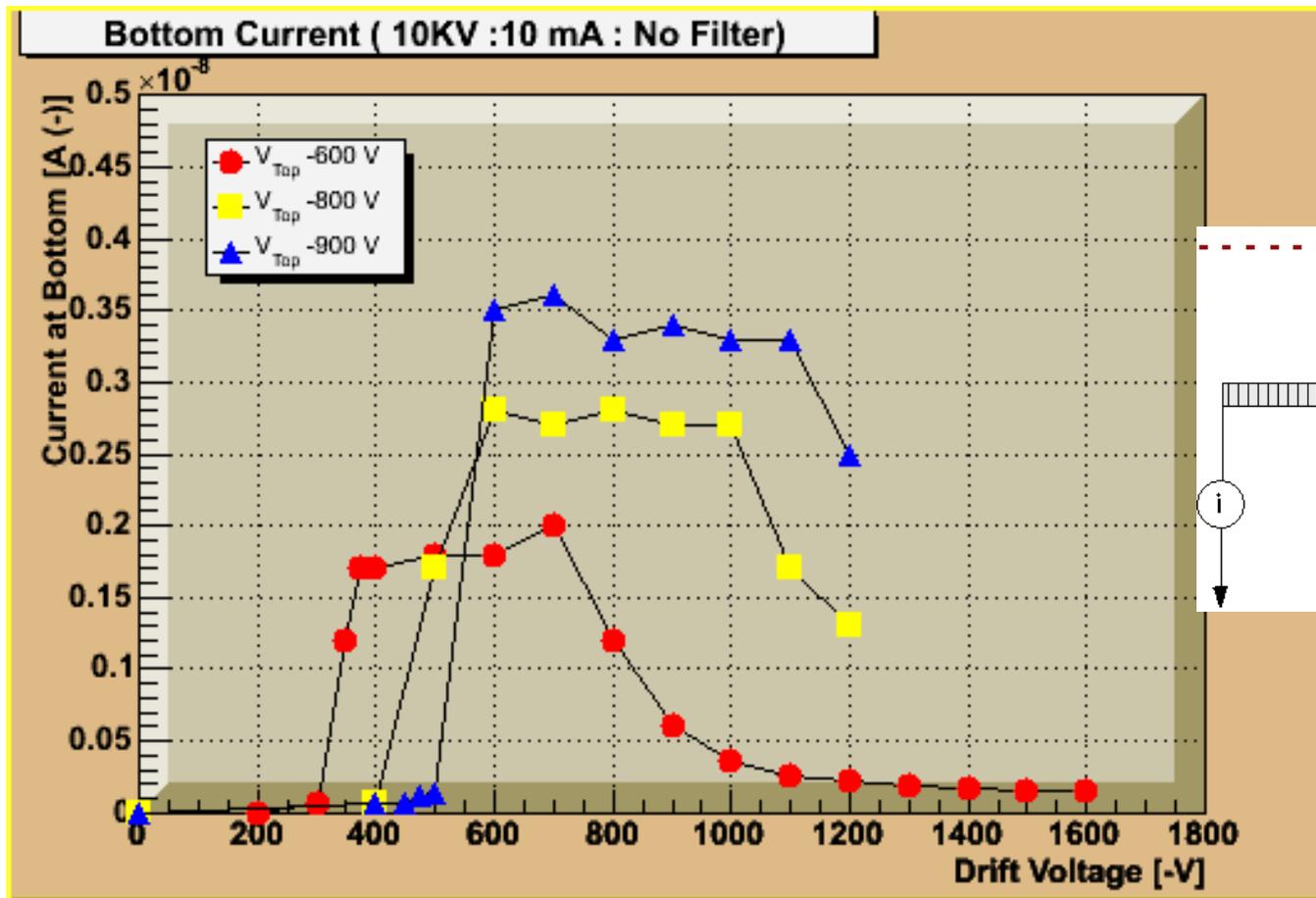


Vertical slit collimator



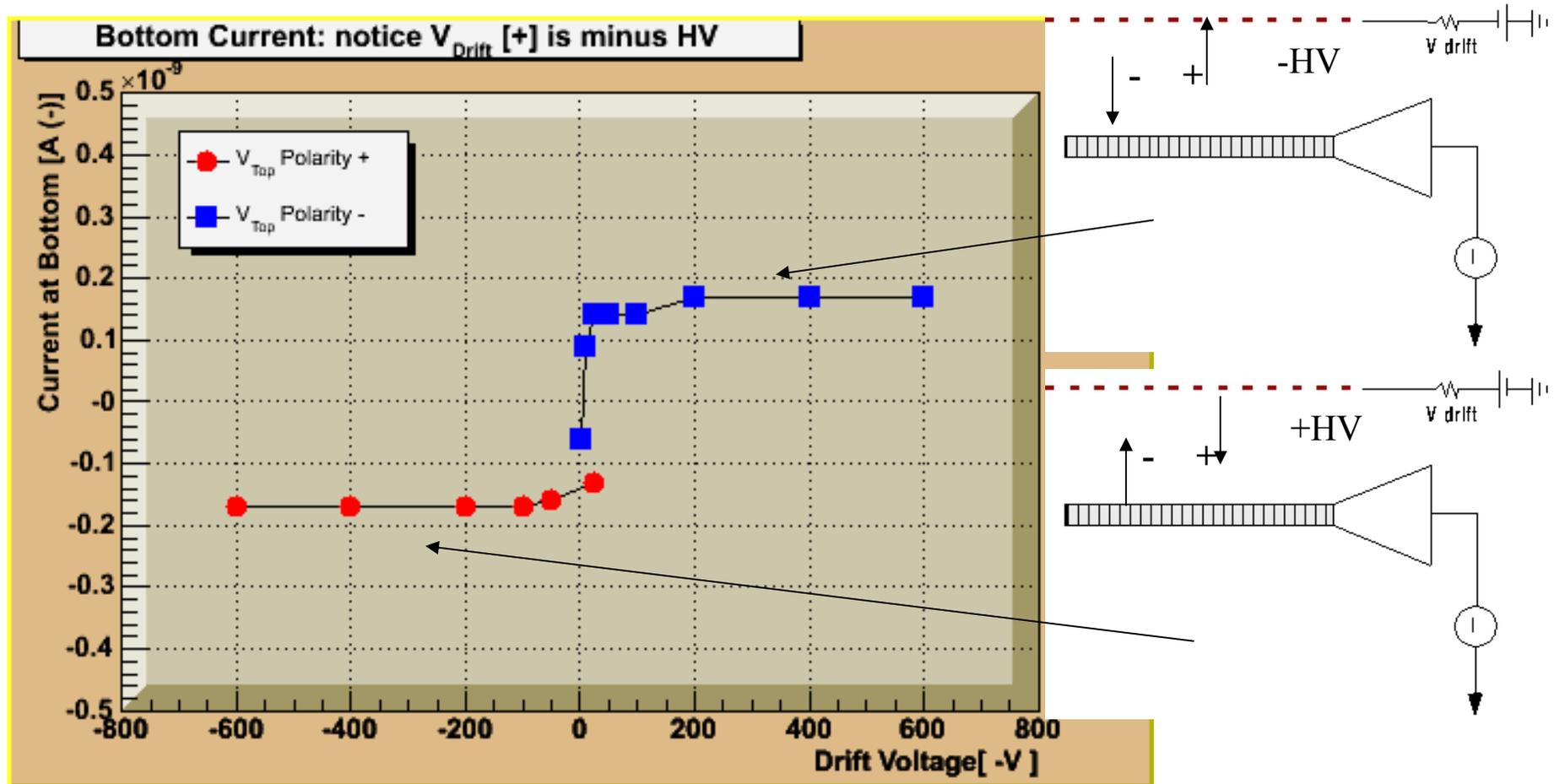


Examples of efficiency
measurements at low photon
energy ($<30\text{keV}$) in ionisation
chamber mode

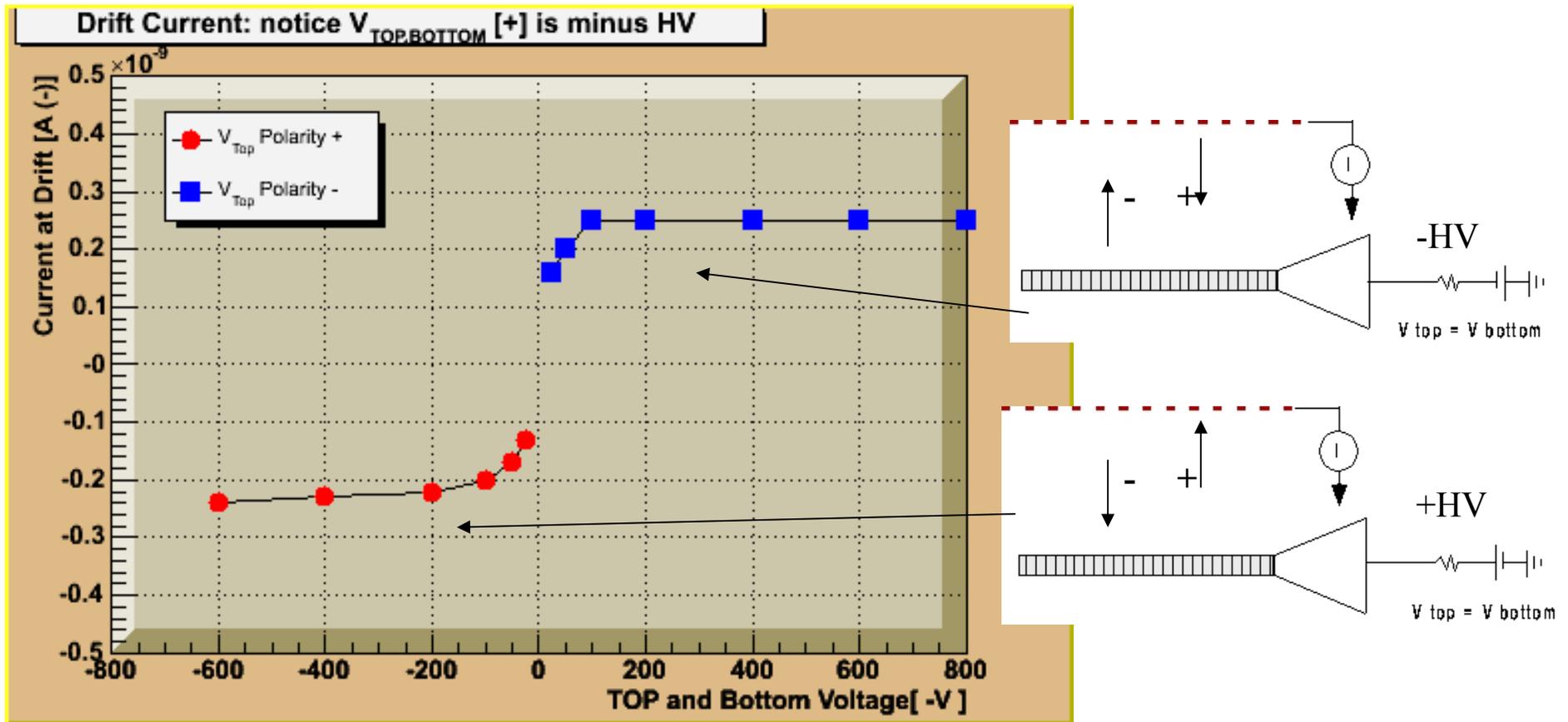


The measured current from the CP bottom, in a range of values for the gap voltage between CP-top and CP-bottom, is shown as a function of the the Drift voltage. With increase of the drift voltage more and more field lines terminate on the top of the CP and as a result the current from the bottom decreases

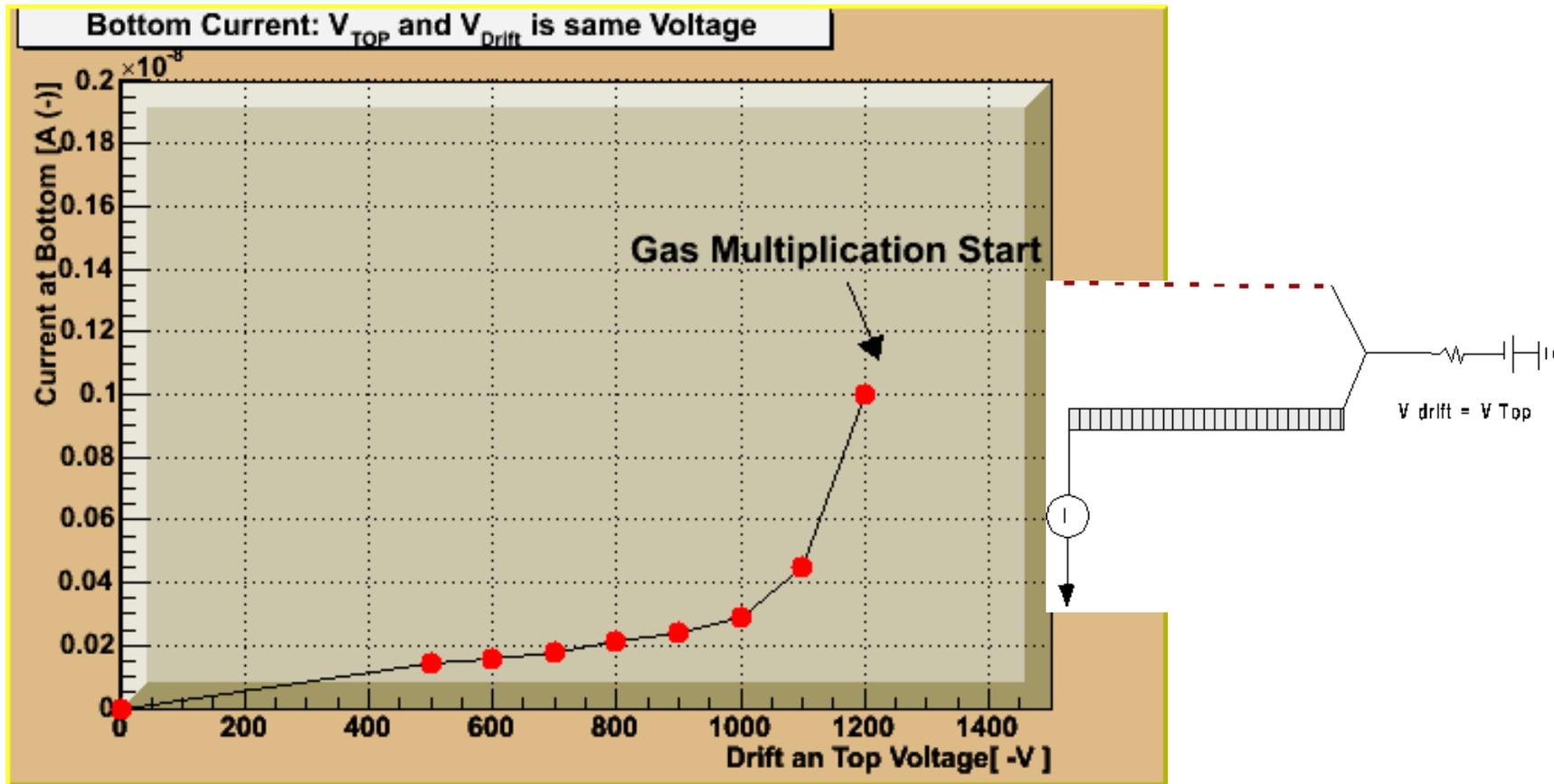
Measurements in “ionisation chamber mode”: #1



#2



“Extraction” current vs. voltage till the amplification starts



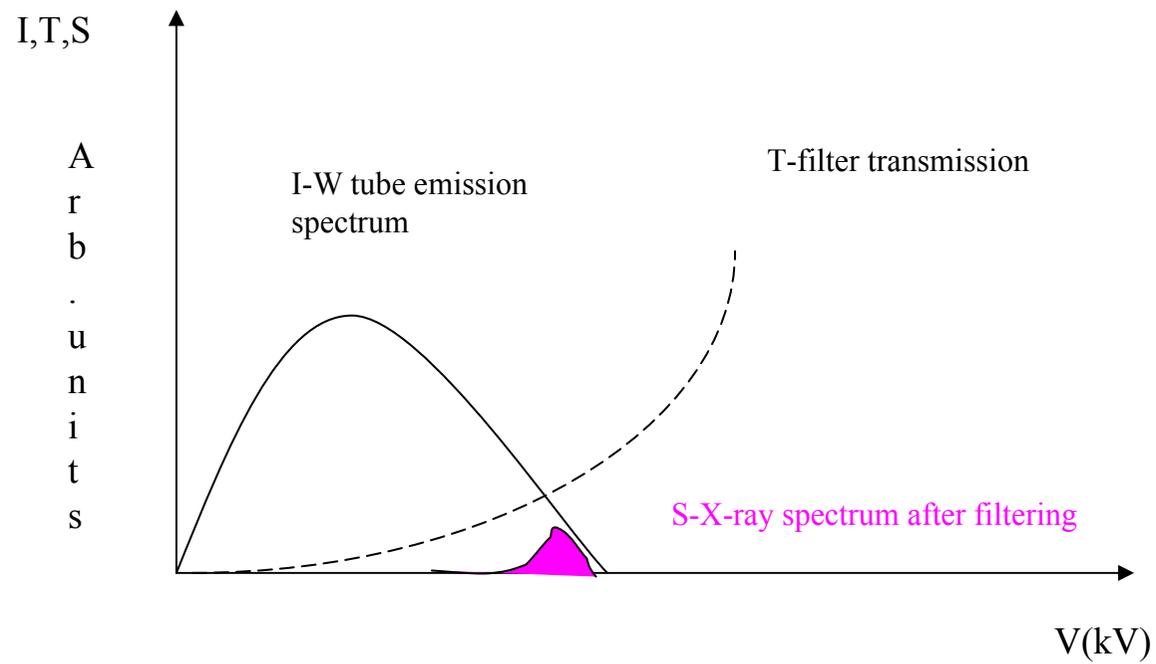
$$\eta_{\text{edg}} = A \{1/\xi(1-e^{-kx})\}, \text{ where } \xi = I_s/I_{\text{CP}}$$

Results of efficiency measurements in He+10% CH₄ at 1atm

Capillary type	Efficiency η (%)			
	for different angles φ (data in brasket-X-ray tube voltage in kV):			
Hole's diameter, μm :	$\varphi=0^\circ$	$\varphi=30^\circ$	$\varphi=45^\circ$	$\varphi=90^\circ$
12	$\eta=2.1$ (22) $\eta=12.8$ (35) $\eta=37$ (60)	$\eta=9.3$ (30)	$\eta=7.5$ (30)	$\eta=3.2$ (10) $\eta=6.3$ (30) $\eta=3.75$ (60)
30	$\eta=5.2$ (35) $\eta=23$ (60)	$\eta=3.8$ (35)	$\eta=3.2$ (35)	$\eta=2$ (10) $\eta=2.8$ (35) $\eta\sim 1$ (60)
100	$\eta=0.1$ (10) $\eta=0.8$ (30) $\eta=6$ (60)	$\eta=1.8$ (10)	$\eta=2.2$ (10)	$\eta=2.6$ (10) $\eta=1.5$ (30) $\eta=0.8$ (60)

Note: 22 and 60 keV were produced by Cd and Am sources
Others- heavily filtered X-ray gun radiation (W target)

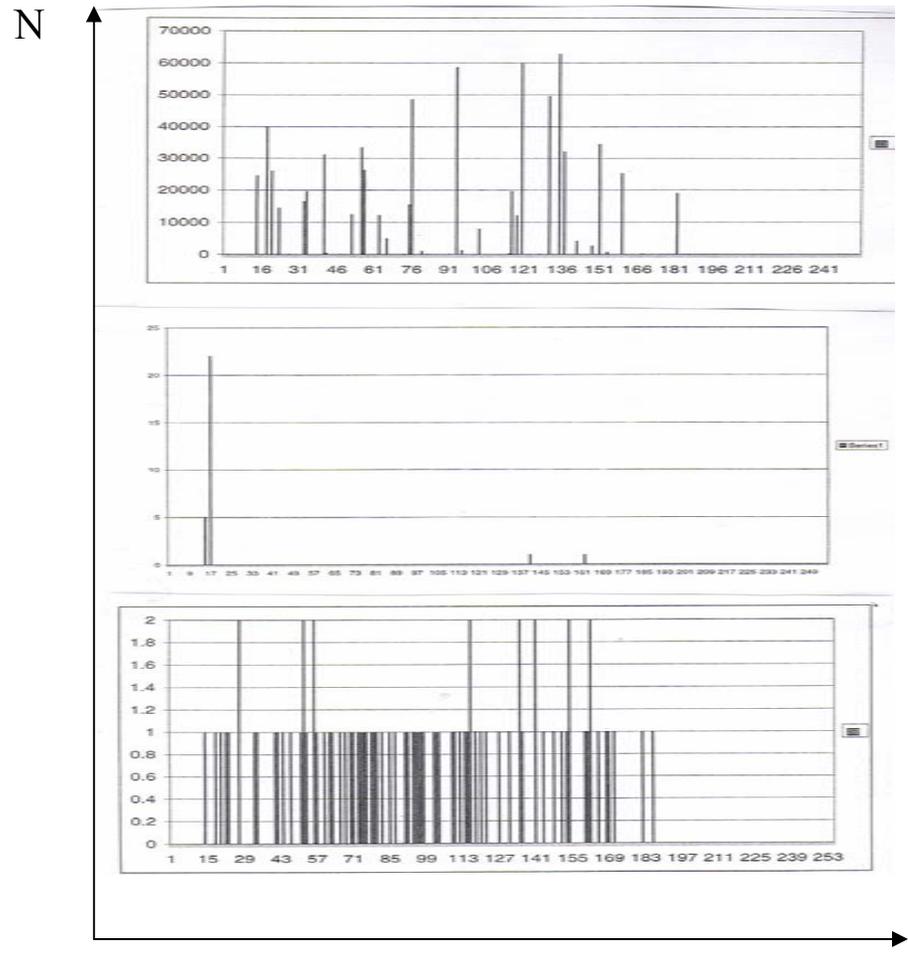
Spectrum « monochromatisation » due to the filtering effect



Results of efficiency measurements in Xe+10% CH₄ at 1atm

Capillary type	Efficiency η (%) for different angles φ (data in bracket-X-ray tube voltage Vg in kV)	
Hole's diameter in μm	$\varphi=0^\circ$	$\varphi=90^\circ$
12	$\eta=23$ (22) $\eta=17,2$ (30) $\eta=43$ (60)	$\eta=7,1$ (30) $\eta=4,2$ (60)
30	$\eta=12,2$ (30) $\eta=26,1$ (60)	$\eta=3,2$ (30) $\eta=1,3$ (60)
100	$\eta=9,2$ (30) $\eta=11,8$ (60)	$\eta=2$ (30) $\eta=1,2$ (60)

Detector preparation

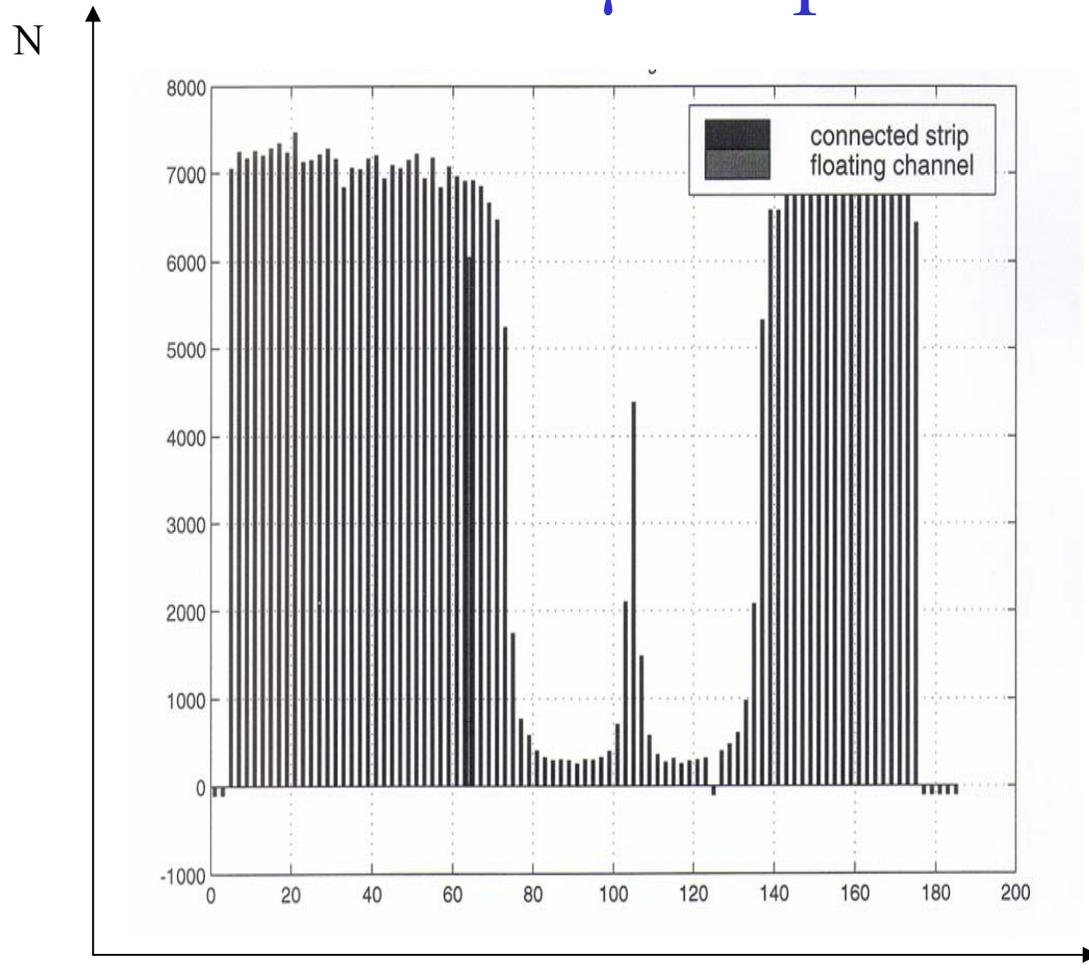


- Microparticles removal procedure
- Assembling in a clean room
- Training by discharges

- (N-number of counts, n-ASIC channel number)

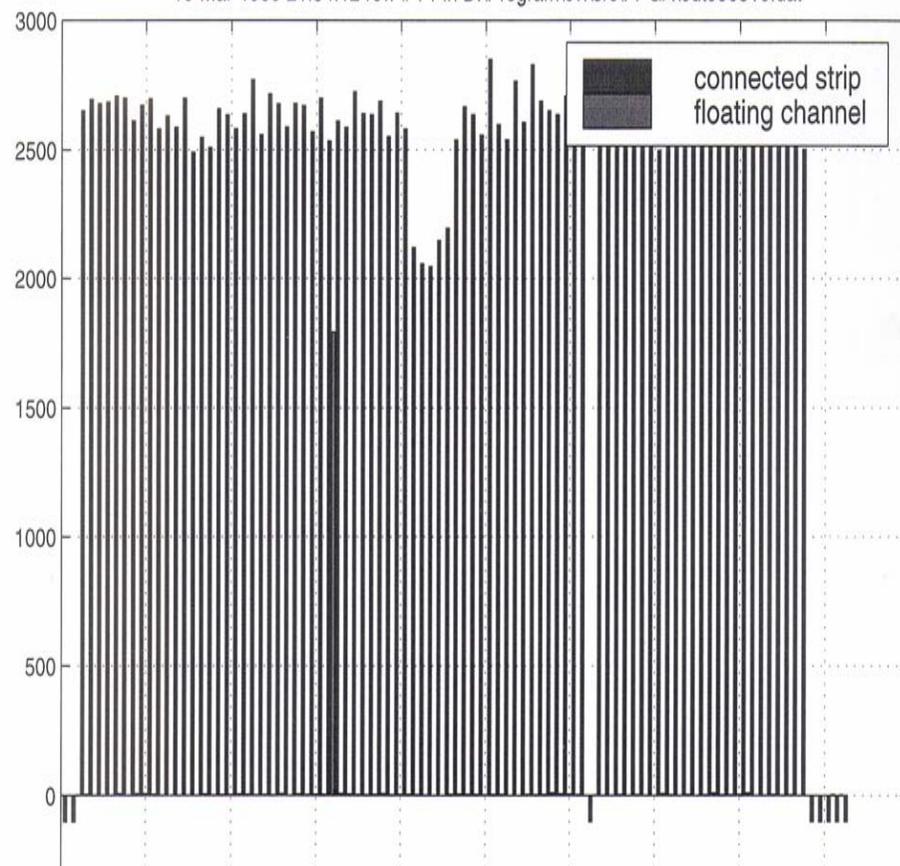
n

On line 1-D digital image of two wires 50 μm apart each others



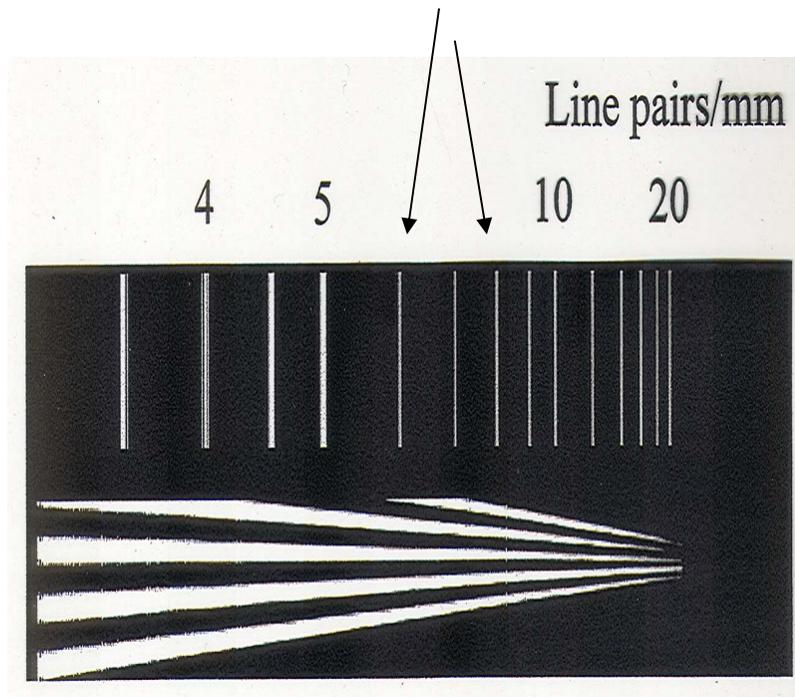
- One can see that position resolution of about 50 μm in digital form was achieved

Mammographic phantom: on line 1-D digital image of microcalcification of 0.54 mm size

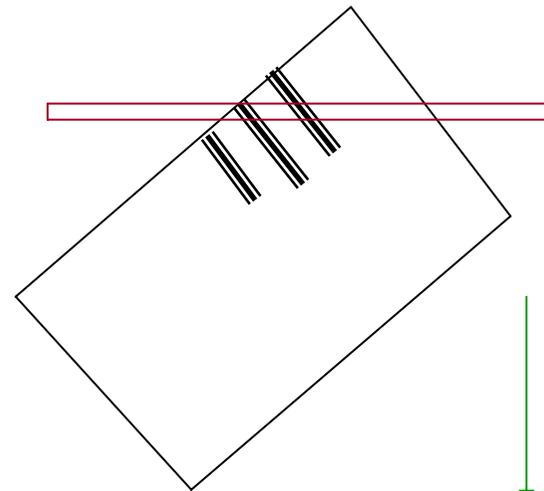


- One can see that the large contrast objects could be resolved without any problems

Images of the line phantom



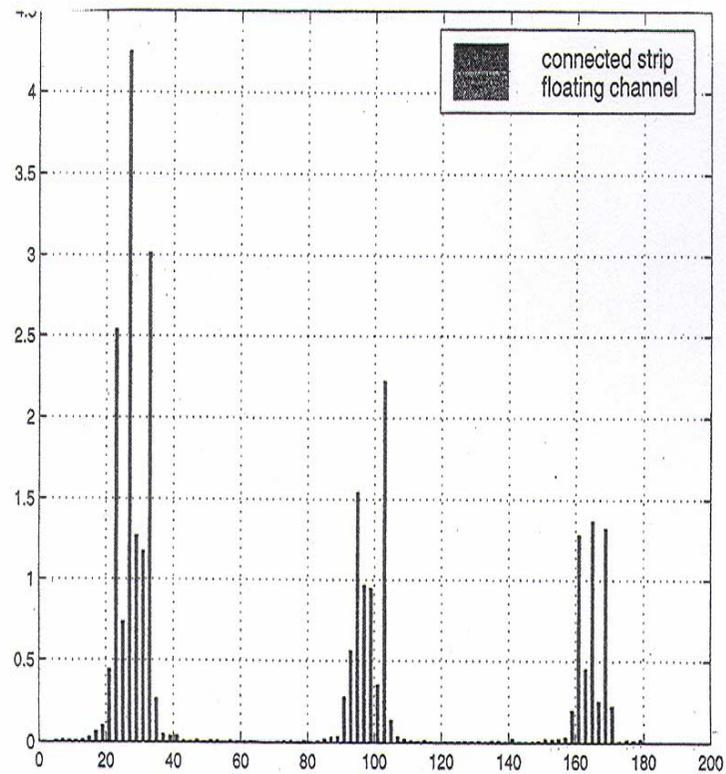
Slit collimator 50 μm in width



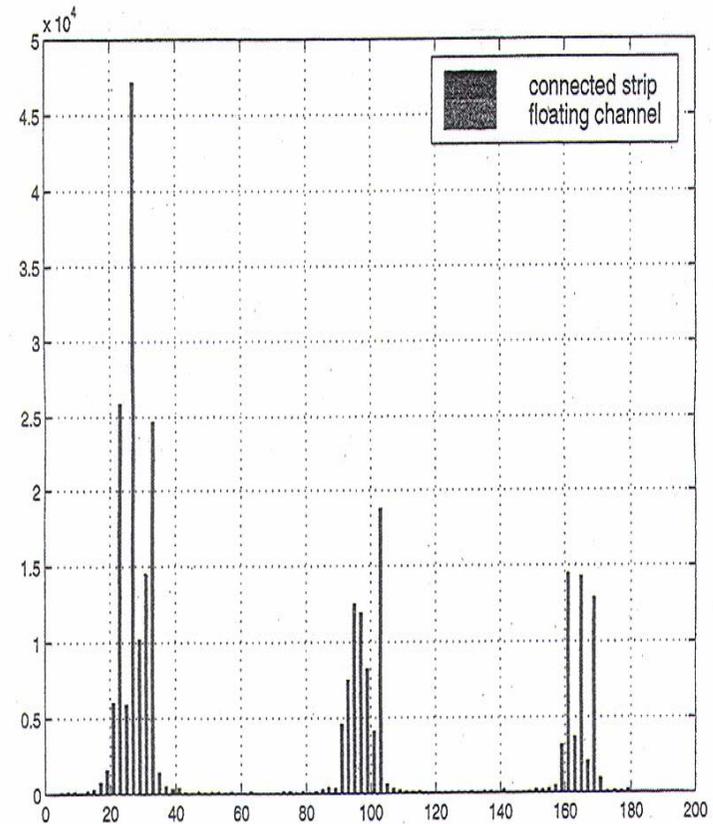
Phantom

Direction of scan (50 μm steps)

Set of 1-D digital images obtained with 50 μm steps

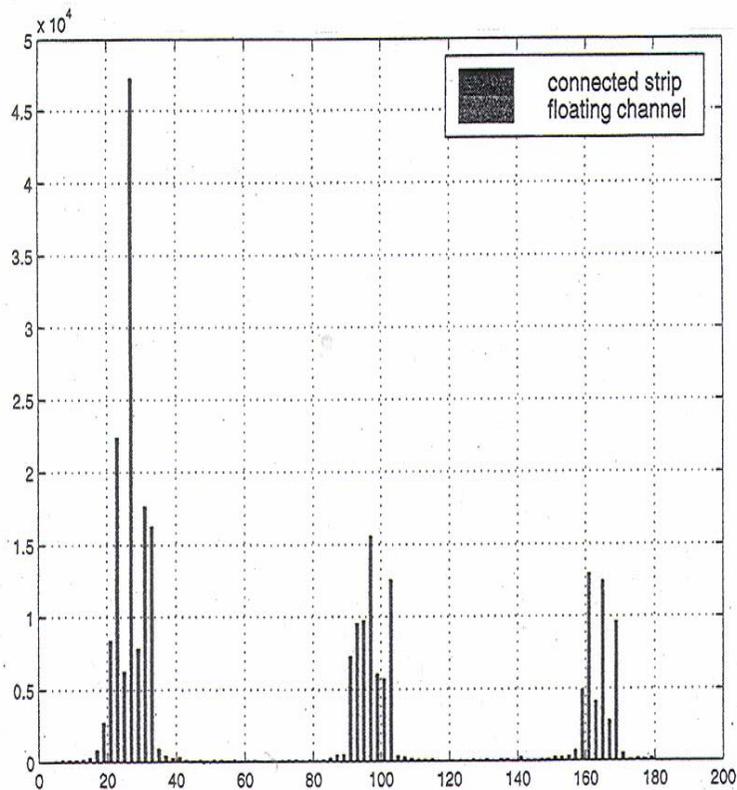


Position « 0 »



Position « + 50 μm »

Such measurements could be continued as much as needed-there is no limits on the length of the vertical scan



Position « + 100 μm »

- From sets of 1D imaged a 2D image than could be formed
- As an example next fig shows a 2D image of mamamographic phantom

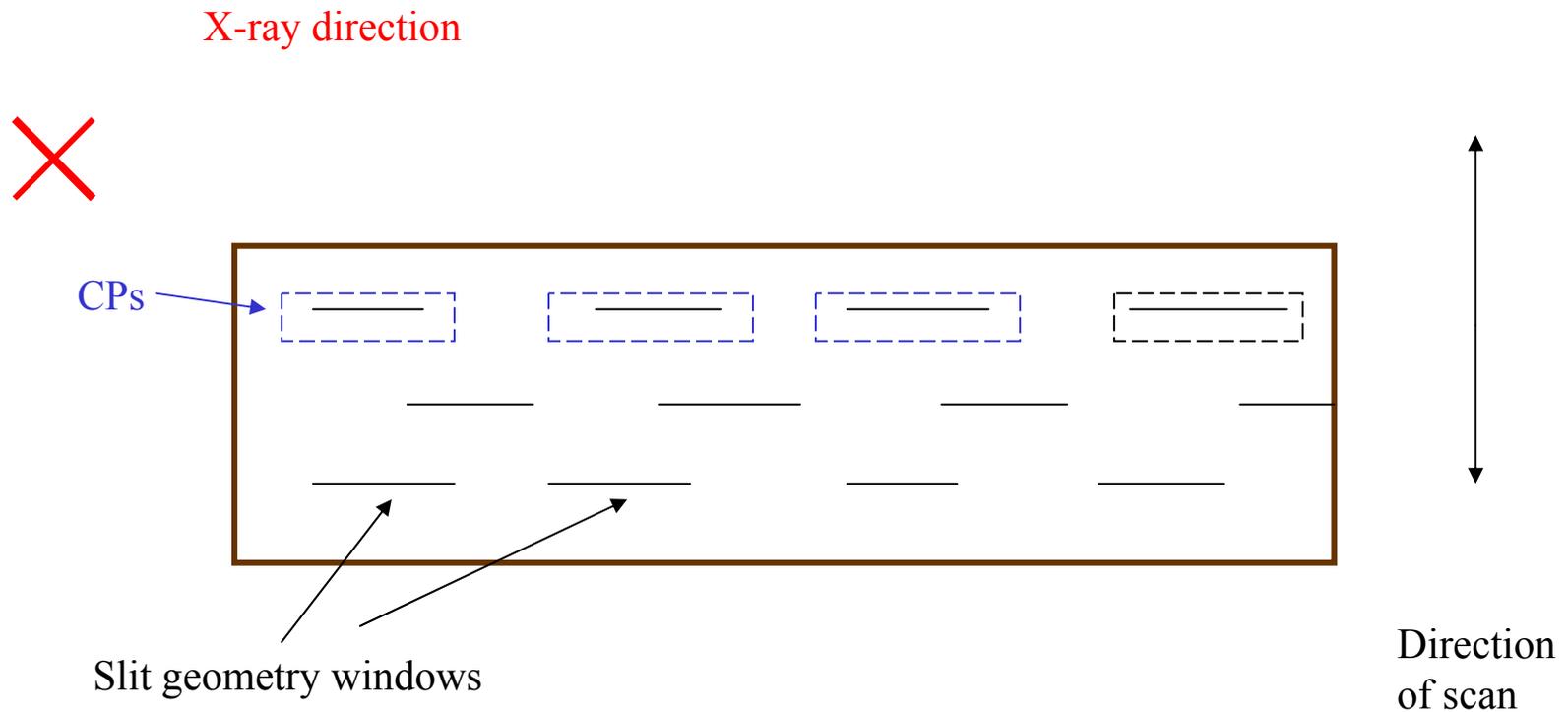
2d digital image of the mammographic phantom object #16:

- In the phantom description it is written that if the most “difficult” object #16 is resolved,
- the detector fits the mammographic requirements

Examples of possible applications:

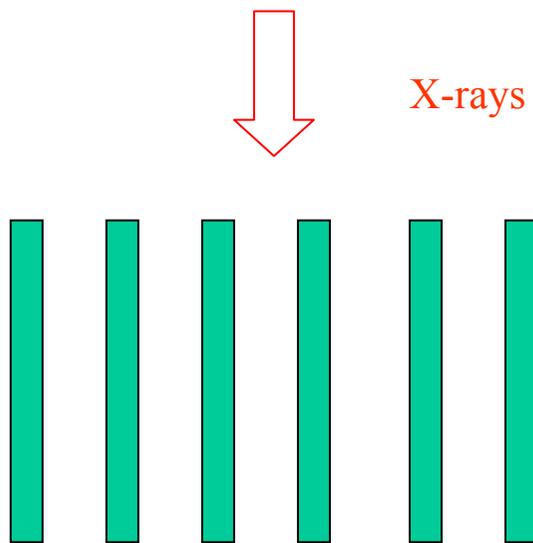
1. A mammographic scanner (in side on illumination mode of operation),
2. A multilayer convertor of X-rays for Electronic portal imaging detector (top illumination mode mode) (see M. Danielsson et al., NIM A518, 2004,406)

Large-area scanner

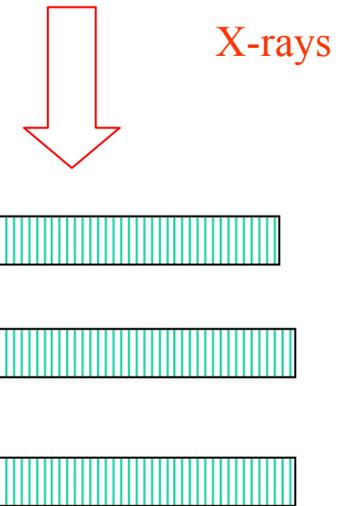


Under tests now: cascaded CPs with misaligned holes

Traditional geometry (Perez-Medez et al., Charpak-Jevan)



Optical transmission is high → efficiency is low



Efficiency of ~20% was already achieved for 60 keV, which is more than enough for portal imaging applications

Conclusions:

- **Results obtained in this work clearly demonstrate the potentials of our hybrid detector:**
- **It operates in « noise free » photon counting mode**
- **It have a rather high efficiency and excellent position resolution**
- **Potentially can get images at reduced dose**
- **It has very simple design (1 atm)**

- **So it is in fact an avalanche detector with a rather high efficiency(solid converters), cheap and potentially could be done with large sensitive area**

- **The developed detectors may open new possibilities for medical imaging (for example in mammography or portal imaging), radiography (including security devices), crystallography and many other applications.**

