A multigap RPC based detector for gamma rays

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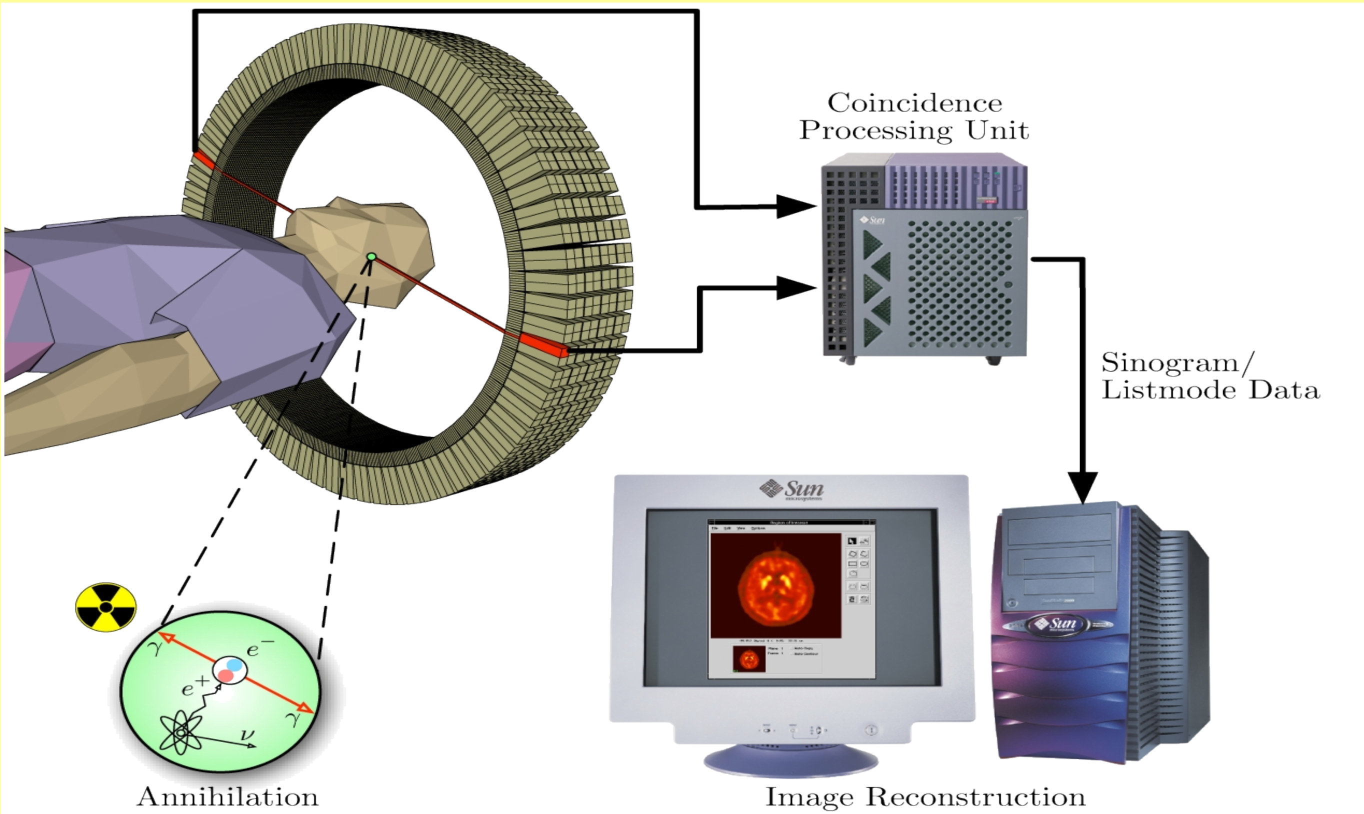
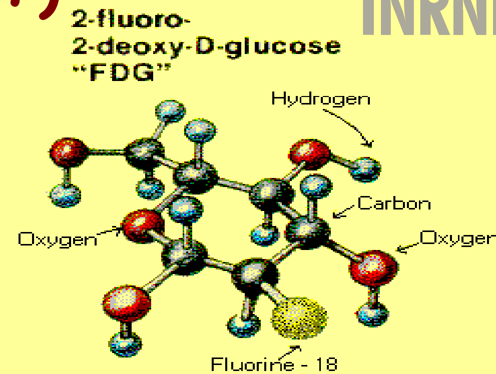
Content

The aim is to use RPC in a PET system

- Positron Emmision Tomography (PET)
- Why to use RPCs in a PET system ?
- Different designs
- Simulation results
- Conclusions

Positron-Emission Tomography (PET)





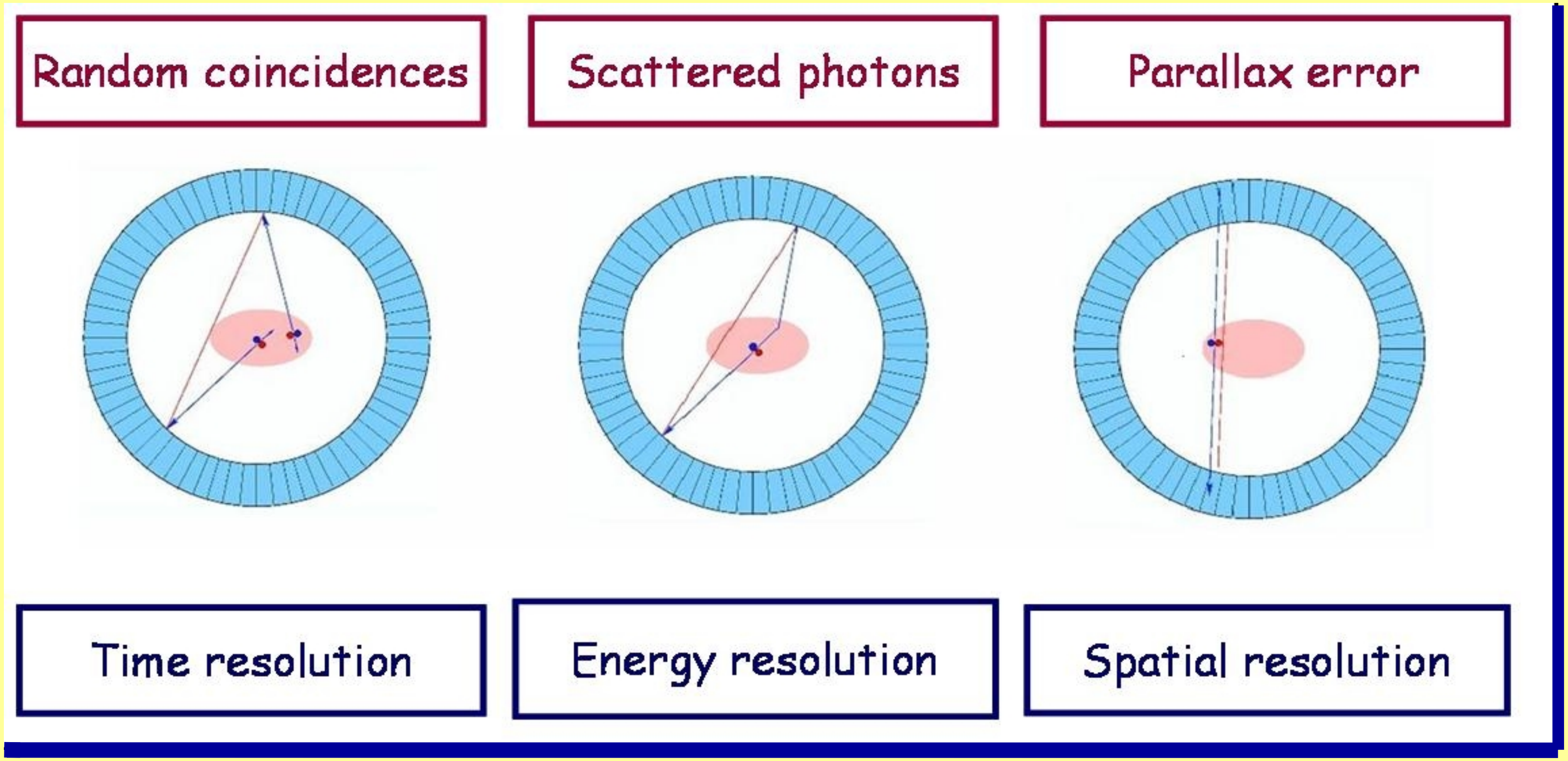
Isotope	half-life
^{11}C	20.3 min
^{15}O	2.03 min
^{18}F	109.8 min
^{75}B	98.0 min
^{13}N	~10 min

The concept of emission and transmission tomography was introduced by David E. Kuhl, Luke Chapman and Roy Edwards in the late 1950s.

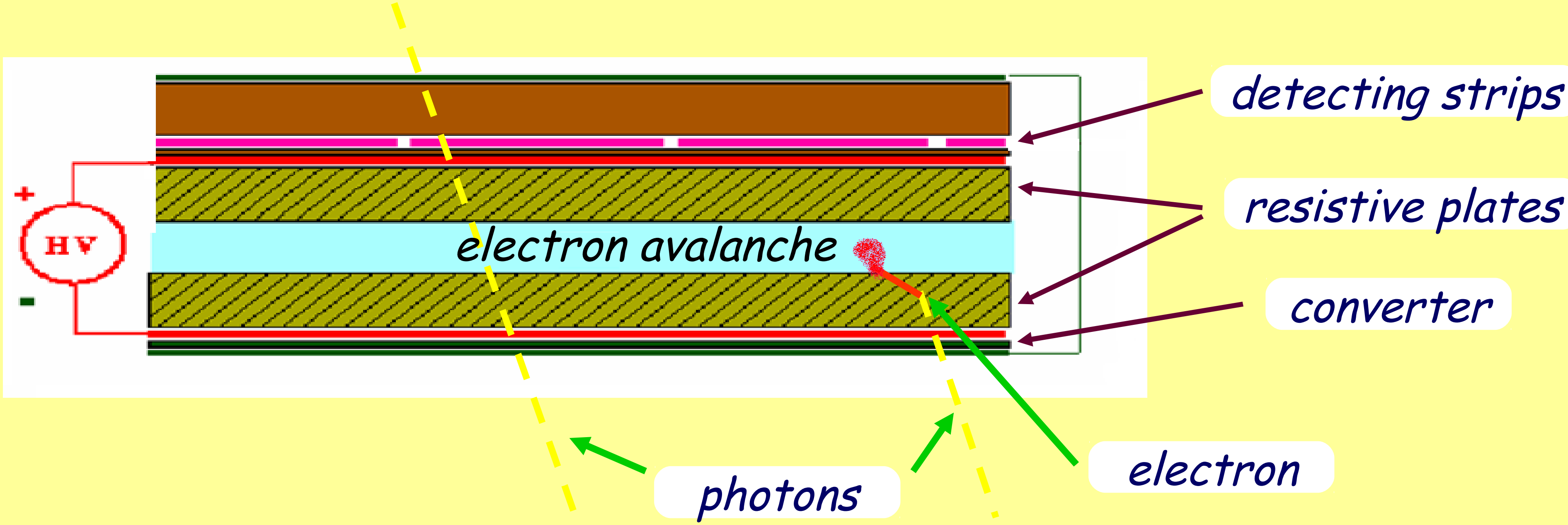
A good PET description:

- G. Muehllehner, J.S. Karp, *Phys. Med. Biol.* **51** (2006) R117-R137
- T.K Lewellen, *Phys. Med. Biol.* **53** (2008) R287-R317

PET – physical limitations & problems



- B.J. Pichler, H.F. Wehrl, M.S. Judenhofer, *J. Nucl. Med.* **49/2** (2008) 5–23
- N.E. Bolus et al., *J. Nucl. Med. Technol.* **37/2** (2009) 63-71



- P. Fonte, A. Smirnitski, M.C.S. Williams, *NIM A* **443**, 201-204 (2000)

- A. Blanco et al., *Nucl. Instr. Meth.* **A508**, 88-93 (2003)

Scintillator-based vs RPC-based PET

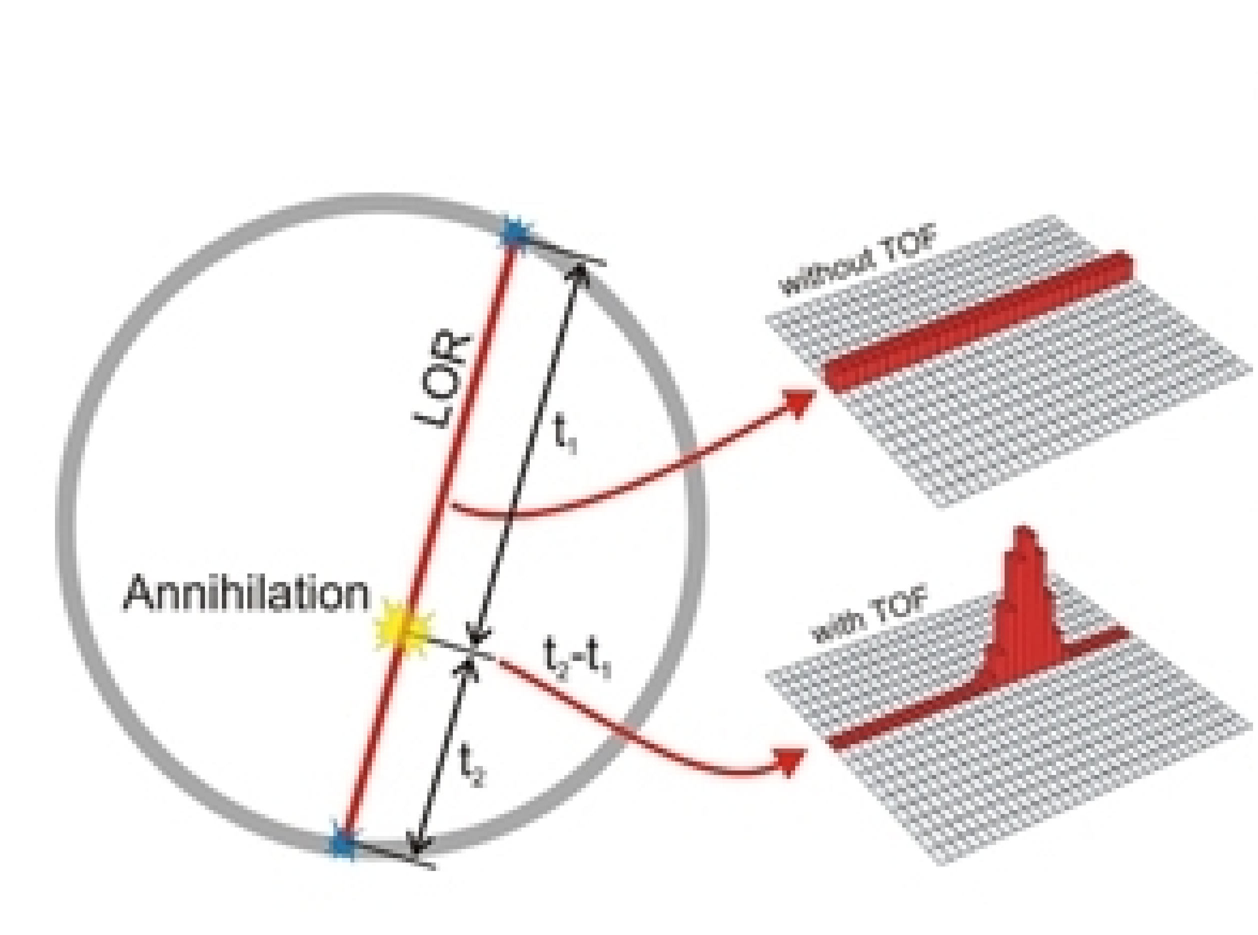
- High price
- Higher sensitivity for scattered photons
- Energy measurement
- Parallax error
- Time resolution > 200 ps
- Spatial resolution ~ 2-3 mm
- PMT, APD, ...
- FOV 16-25 cm

- Much cheaper
- Sensitivity decreases with E
- Practically no parallax
- Time resolution ~ 30 ps* , even 20 ps, Williams et al. Nucl. Instr. Meth. A 594 (2008) 39-43
- Spatial resolution ~ 300 μm
- No need of PM
- Not affected by magnetic fields
- Large area → large FOV ~ 1 m
- Main problem: increase efficiency for 511 KeV photons

*The quoted resolution is for charged particles and is not so good for gammas:

- C. Lippmann et al., Nucl.Instr. Meth. A 602 (2009) 735-739
- L. Lopez et al., Nucl.Instr. Meth. A 573 (2007) 4-7.
- A. Blanco et al., Nucl. Instr. Meth. A 508 (2003) 70-74.

PET ToF



Without ToF:
ΔZ = LOR (~70 cm)

With ToF:
$\Delta Z = C.(t_2 - t_1)/2$

if Δt ~100 ps =>
ΔZ ~ 2 cm

RPC

RPC PET R&D @ Sofia University

- **Two main goals:**

To increase the efficiency for 511 keV photons

To suppress Compton scattered photons

- Photon spectrum simulation (done)
- GEANT simulation of different RPC designs (done)
- GEANT simulation of multigap RPC (done)
- Prototype building and tests (in progress ...)

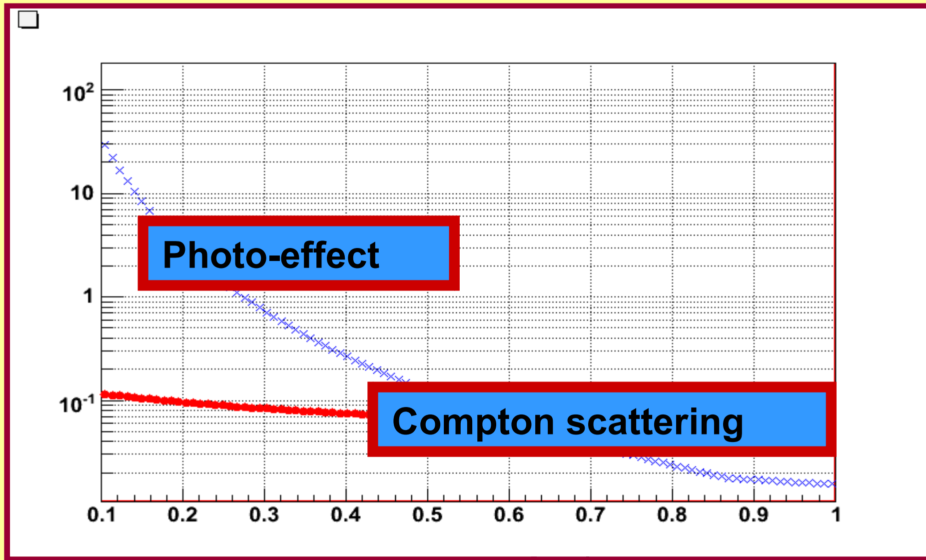
RPC-PET: design & optimization

- *The simulations are performed, using* Geant 4 (http://www.geant4.org/geant4/)
  - ***Compton scattering, photo-effect***
  - ***multiple scattering, ionization, Bremsstrahlung***
- Detector „basic unit":

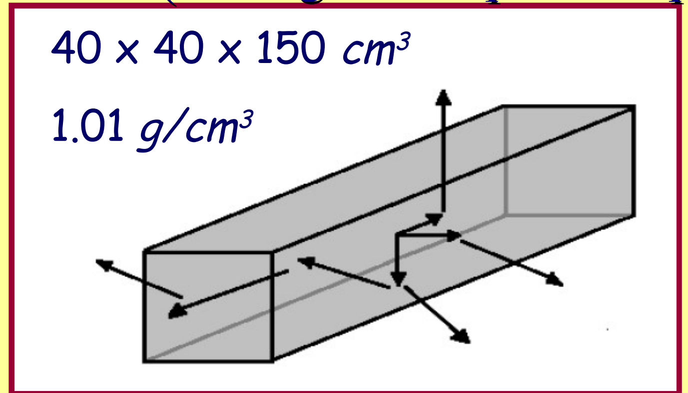
  two glass plates, 2 *mm*

  gas gap 300 *μm*
- Gas composition (for material budget): 85% $C_2H_2F_4$ + 5% i-C_4H_{10} + 10% SF_6
- *Two designs are considered:*
  - *Gas-Converter (GC)*
  - *Gas-Converter-Insulator (GCI)*

Photon propagation in the human body



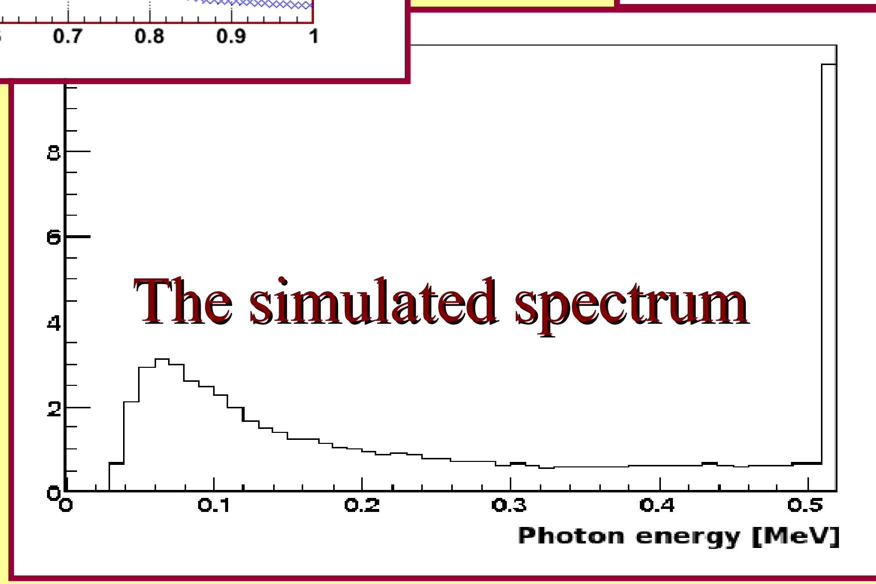
The body model
(homogeneous parallelepiped)



38% are absorbed

82% of the remaining are with E < 511 *KeV* (*or* 51% of the initial gammas)

18% of the remaining (*or* ***11%*** *of the initial gammas) are suitable for PET*



Contents:

O	*61.4 %*
C	*22.9 %*
H	*10.0 %*
N	*2.6 %*
Ca	*1.4 %*
P	*1.1 %*
K	*0.2 %*
S	*0.2 %*
Na	*0.1 %*
Cl	*0.1 %*

Electron yield in the gas

Successful photons conversion : at least one interaction within the converter has lead to the ejection of an electron into the gas gap:

- photon interaction in the converter
- electron propagation to the gas

$$\frac{dN}{dx} = kN_\gamma - sN$$

$$N = a(1 - e^{-x/b})$$

$$N = a(e^{-x/c} - e^{-x/b})$$

k photon interaction coefficient

N_γ number of photons at *x*

s electron interaction coefficient

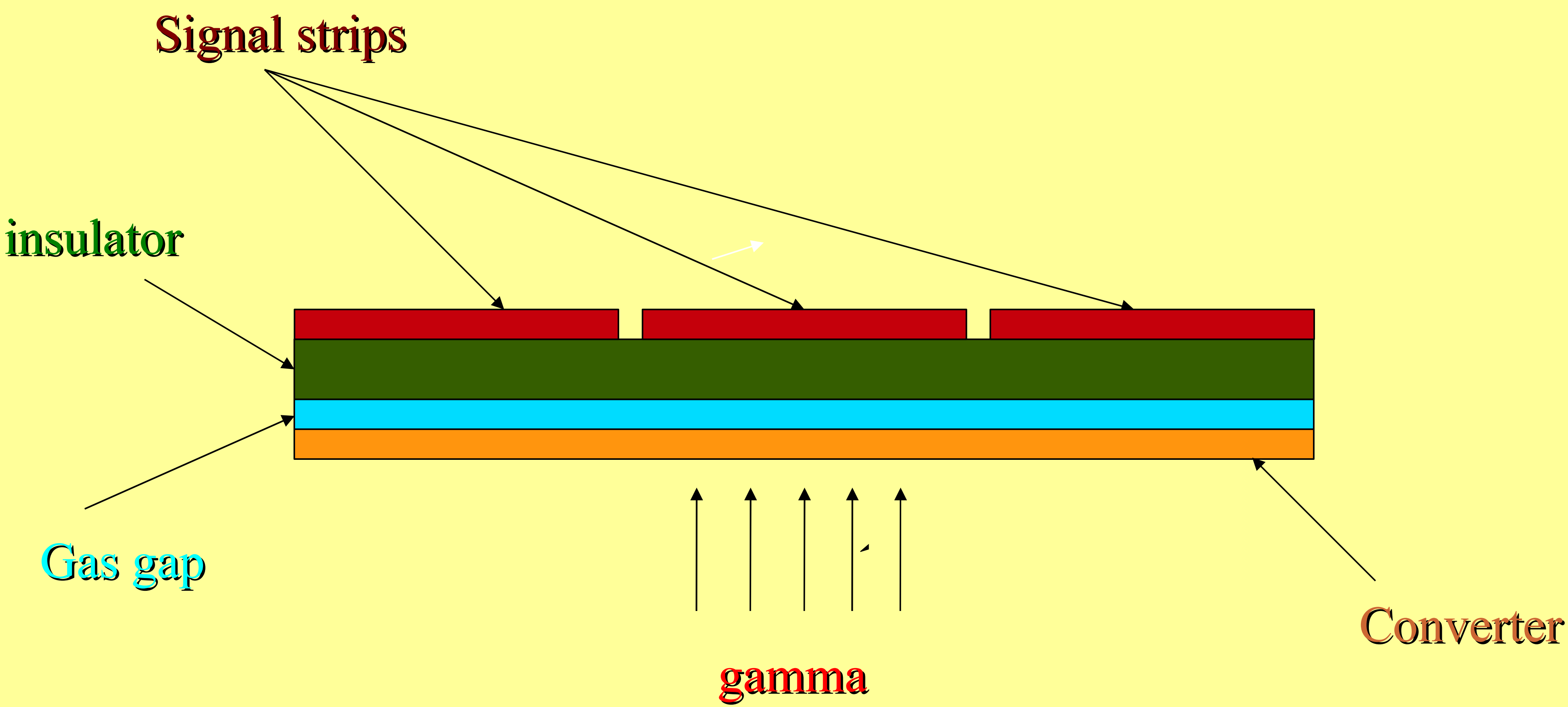
N number of electrons, entering the gas

C photon attenuation coefficient

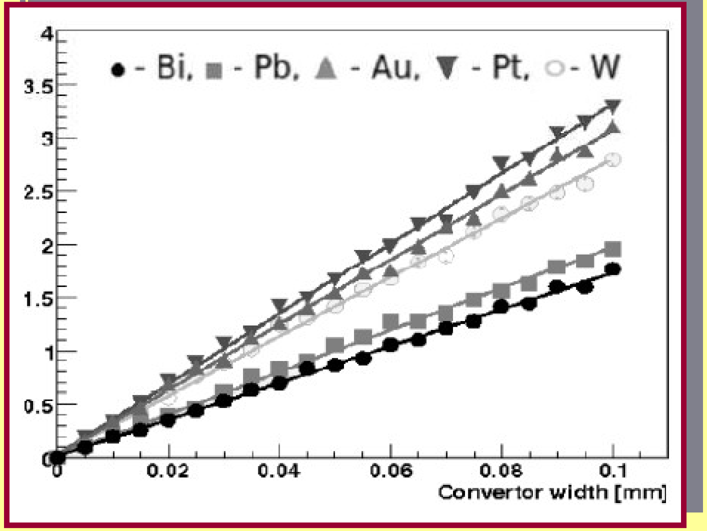
Thin converter; **a** is max e yield;
saturation → 95% yield thickness

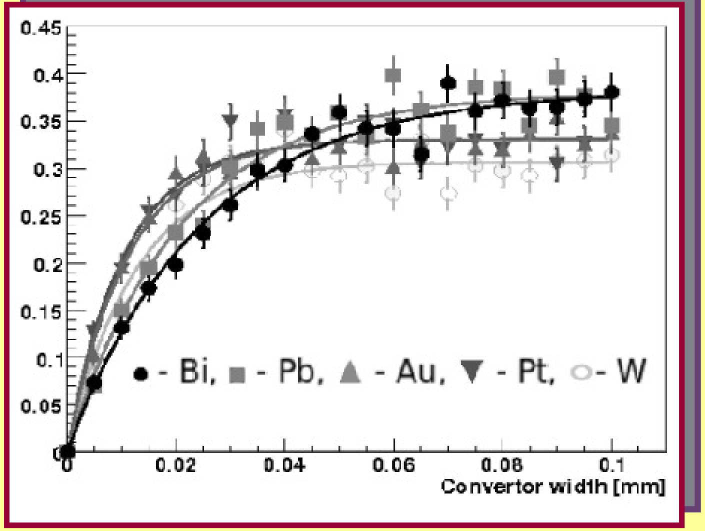
Gas – converter design

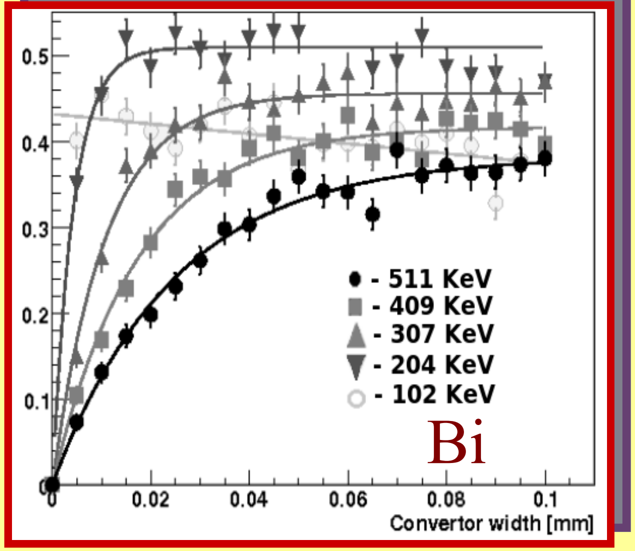
Maximal electron yield (0.3 ÷ 0.38) %



Gas – converter design







e^- yield for 5 different converter materials

(% from the initial photon number)

e^- yield and ejected electrons for 5 different converter materials.

(% from the initial photon number)

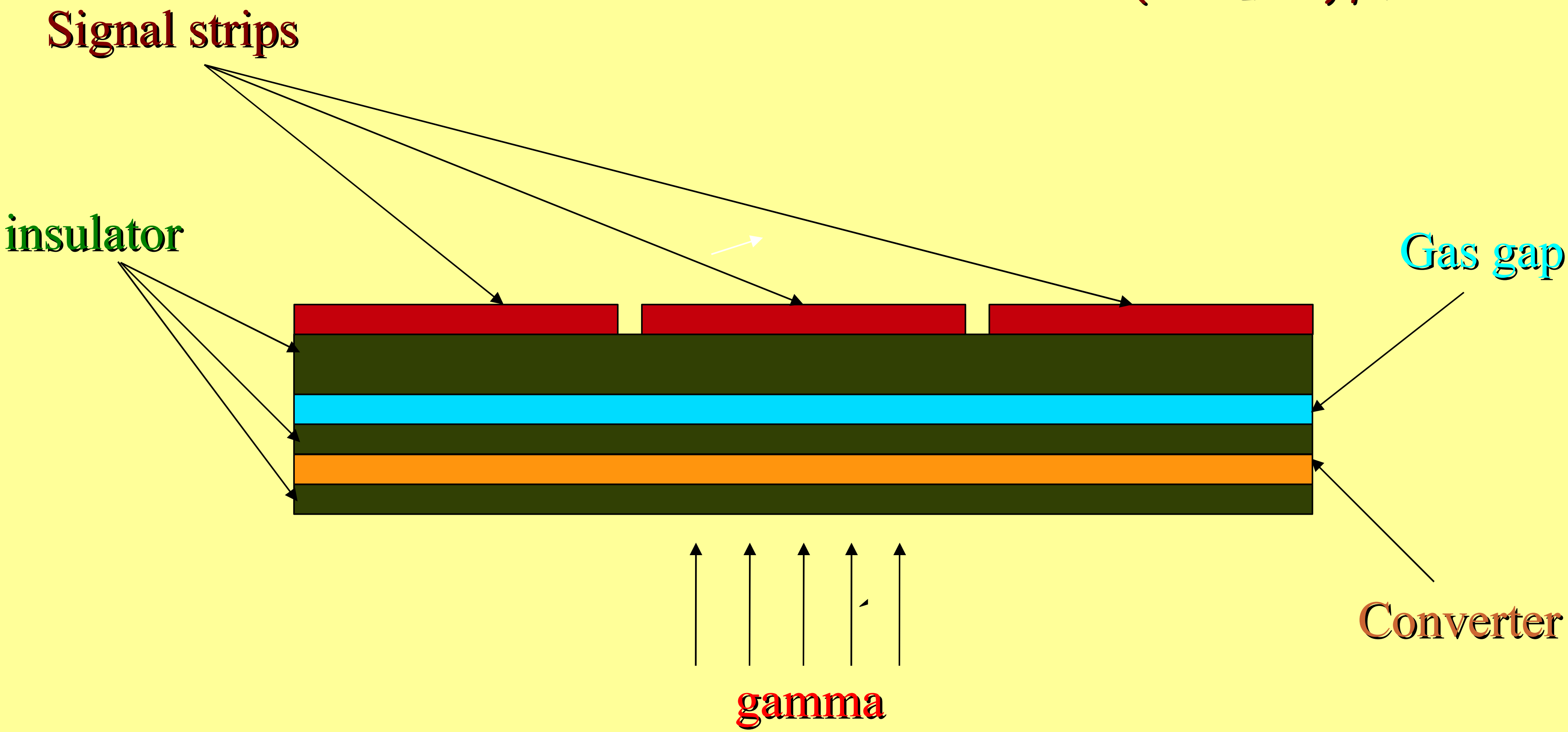
BUT higher sensitivity for scattered in the body photons !

Gas – insulator – converter design

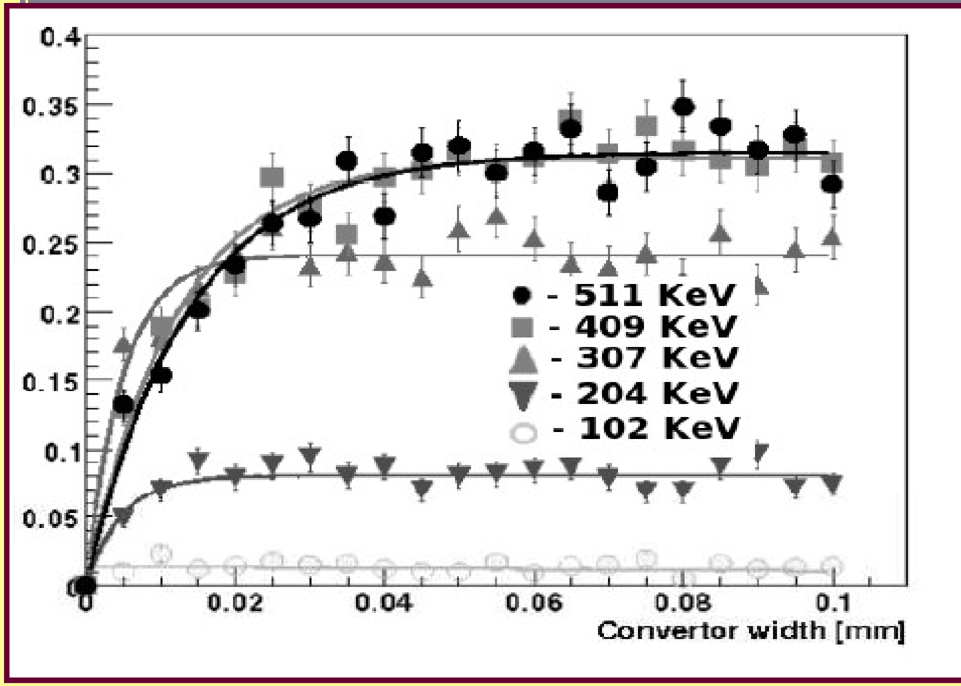
Maximal electron yield for 511 *KeV* photons (0.315 ± 0.005) %

~ 0.17% lower than in GC design

95% level (40.7 ± 3.0) *μm*



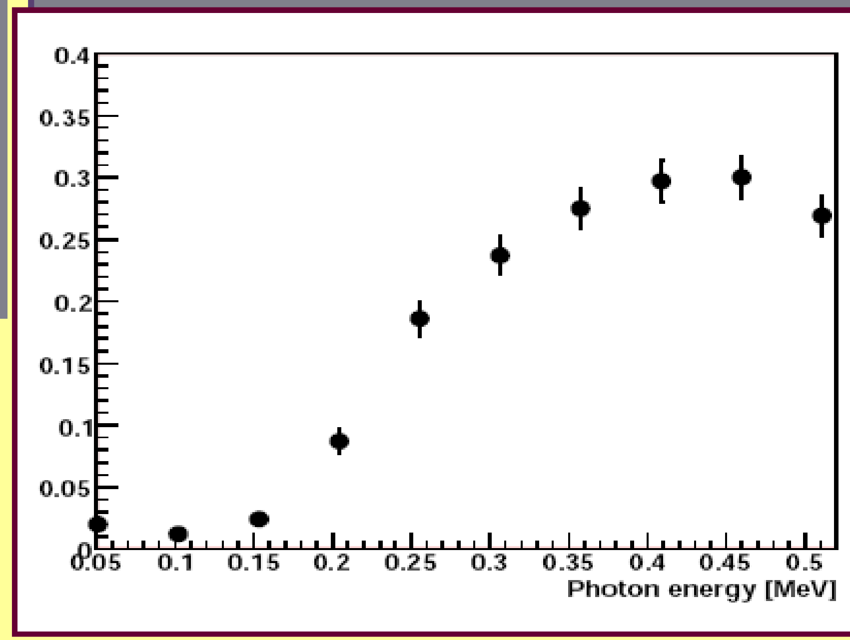
Gas – insulator – converter design



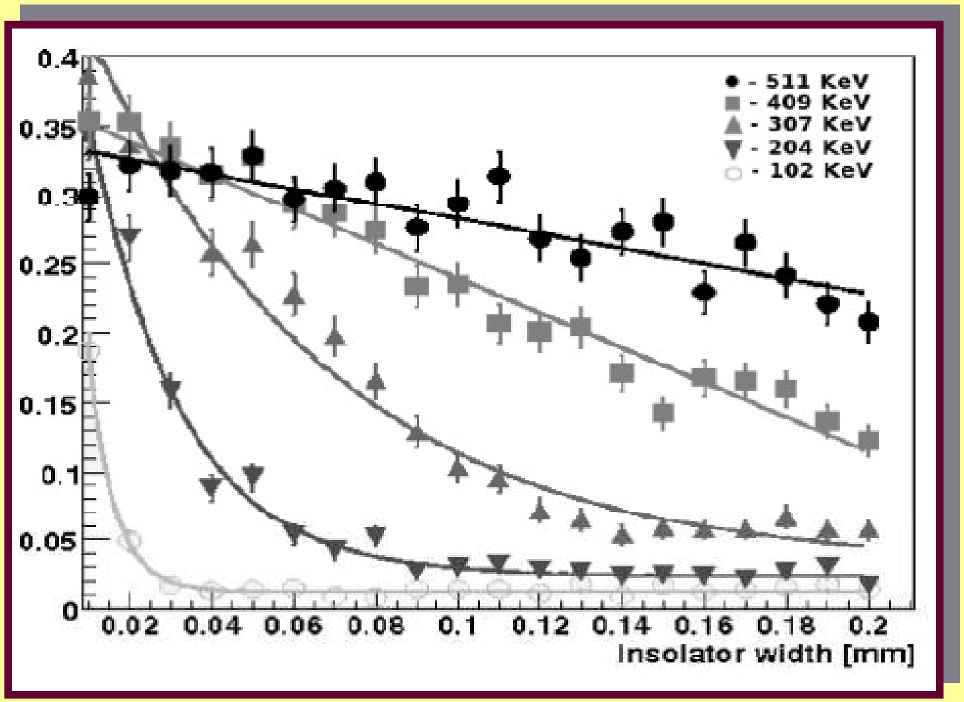
e$^-$ yield / converter width

40 μm

e$^-$ yield / photon energy / 40 μm



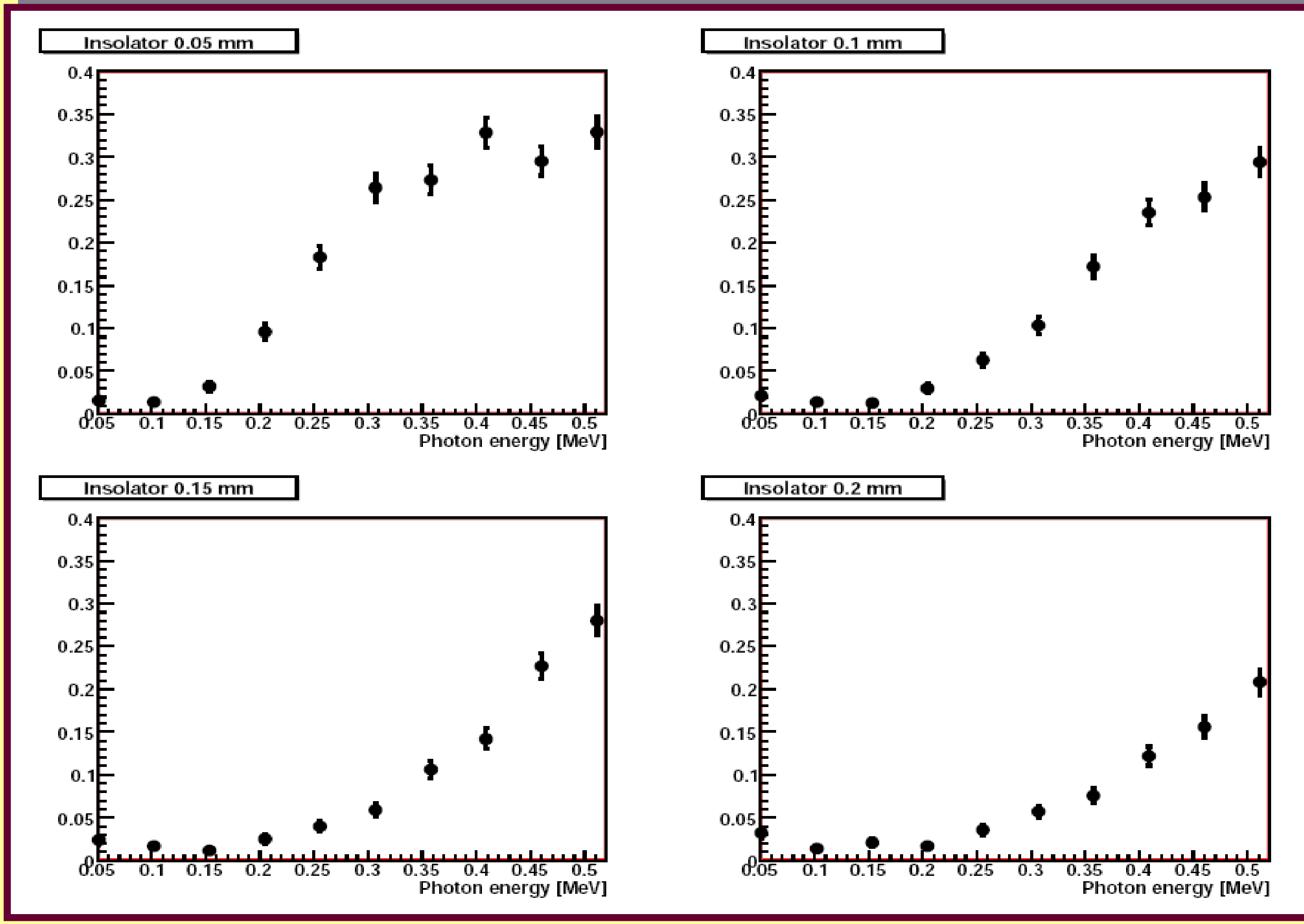
Gas – insulator – converter design



e⁻ yield / insulator width

100 ÷ 200 μm

Gas - insulator - converter design



0.1 *mm* insulator:

511 *KeV* -26% reduction

307 *KeV* -68% reduction

yield ~ 3:1

0.2 *mm* insulator:

511 *KeV* -40% reduction

307 *KeV* -90% reduction

yield ~ 5:1

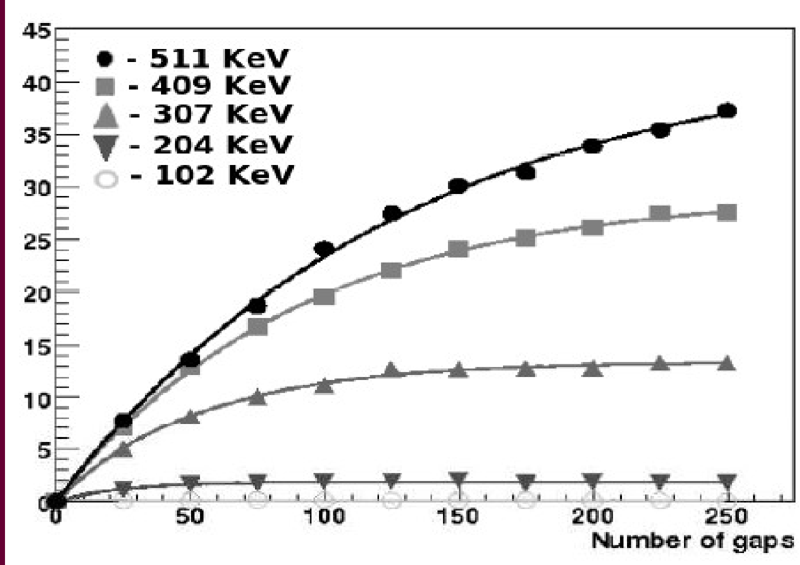
The reduction is in Comparison to GC design.

Multi-gap GIC design

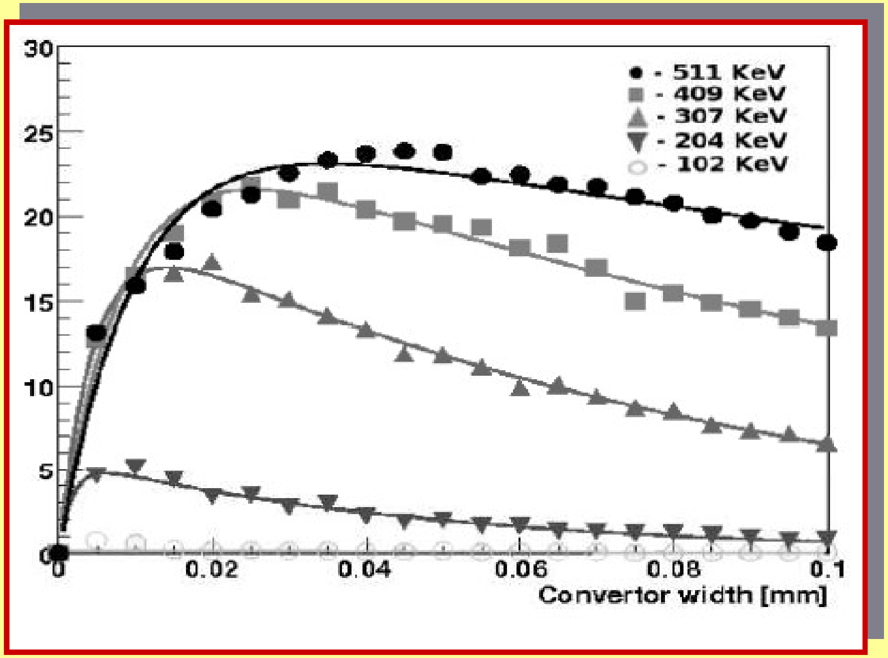
$$N = \Sigma_i a_0 e^{-(i-1)x/c}(e^{-x/c} - e^{-x/b})$$

max yield *511 KeV* ~ 43%,
95% level - at 381 ± 13 gaps

100 gaps provide sufficient
- amplification
- lower-energy photons suppression



Multi-gap GIC design



Max yield for 511 *KeV:*

(23.8 ± 0.4)%

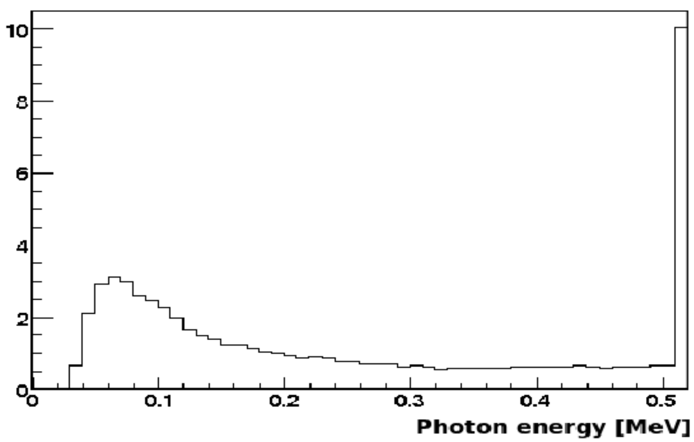
converter Bi, 50 *μm*

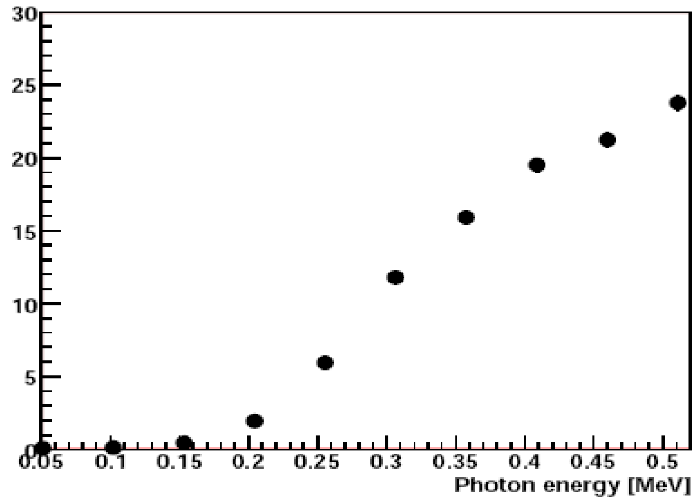
glass 50 *μm*

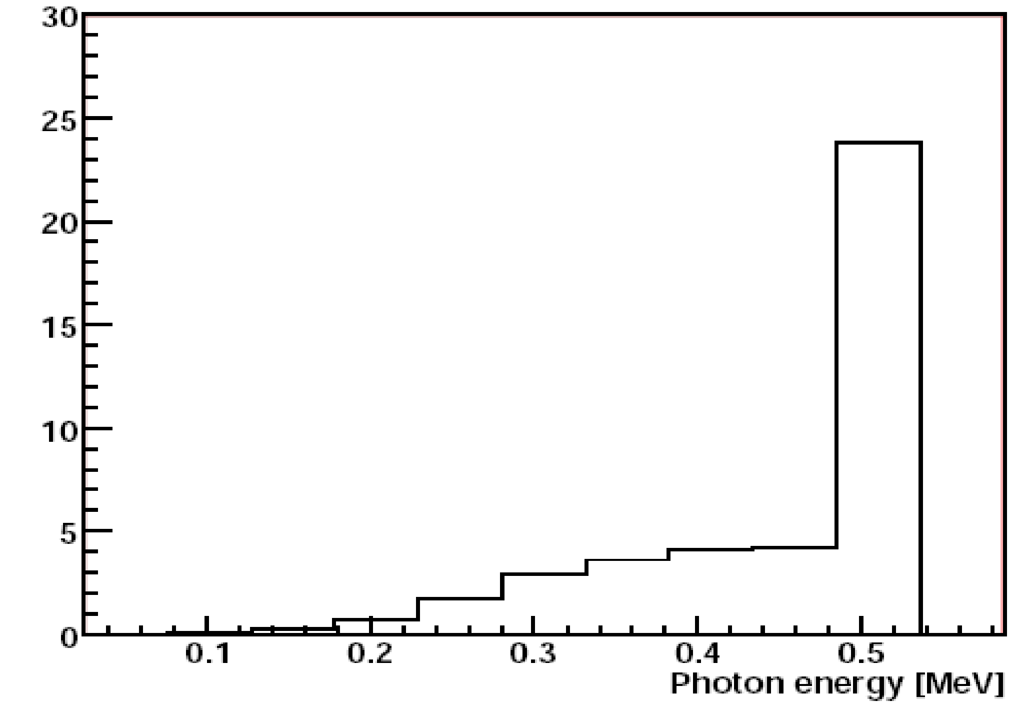
Highest sensitivity for 511 *KeV*

511 / 307 ~ 2:1

Multi-gap GIC design







86% from the registered photons have energies > 383 *KeV*

Conclusions

- Model investigations towards the design of an RPC-based PET detector;
- The intuitive direct-contact GC design is not optimal;
- For a sandwich-type GIC design the electron yield for 511 *KeV* photons decreases with 26%, but exceeds the one for 307 *KeV* photons by a factor of 2;
- In the multi-gap GIC design, the yield increases with the number of gaps, optimum ~ 100 gaps;
- Optimized in the context of PET purposes parameters:

  100 gaps; 50 *μm* Bi converter between 50÷100 *μm* glass plates

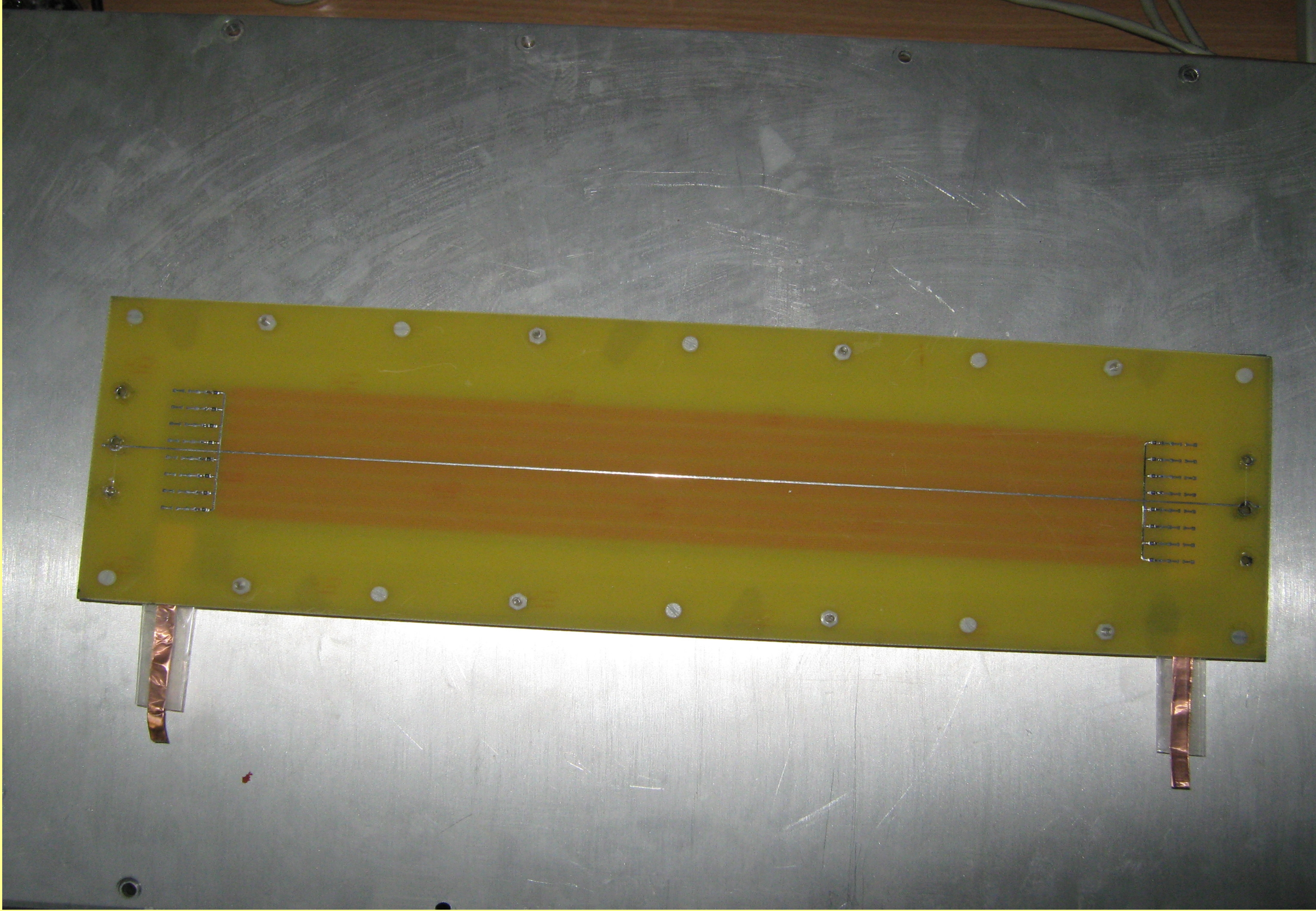
  the electron yield in the gas increases to 24%

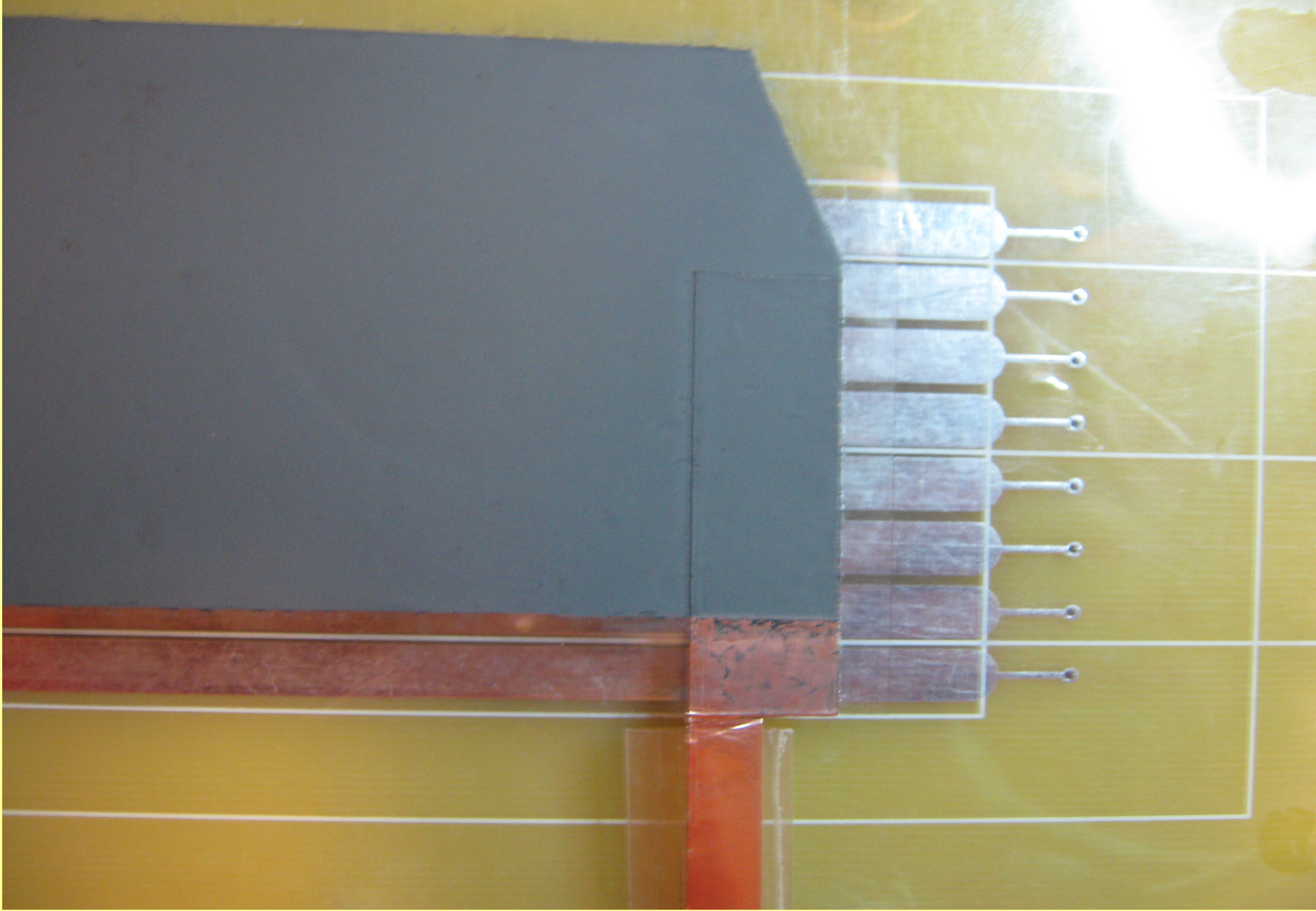
  sensitivity 511 *KeV* photons / 307 *KeV* photons ~ 2:1;
- About 86% of the registered in the PET process photons are with energies above 380 *KeV*.

This work is supported by Bulgarian National Science Fund (contract DO 02-183/2008).

Thank you !!!

Backup slides






Голямо стъкло
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Малко стъкло


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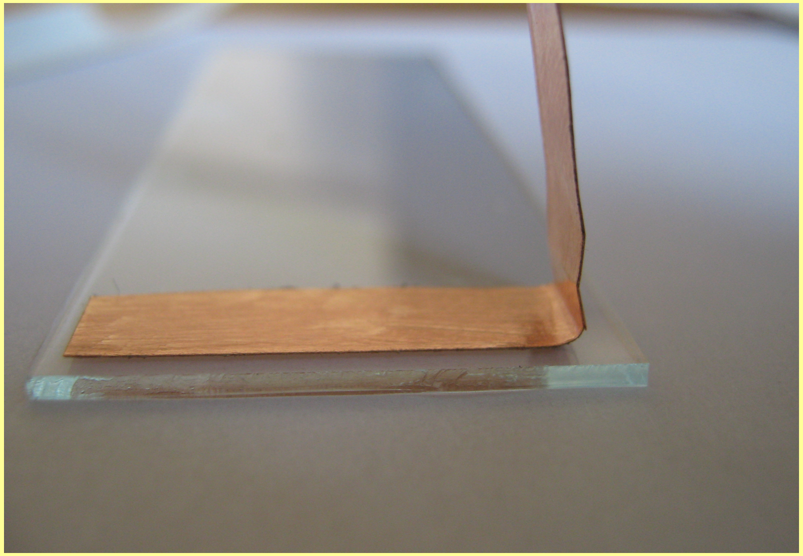
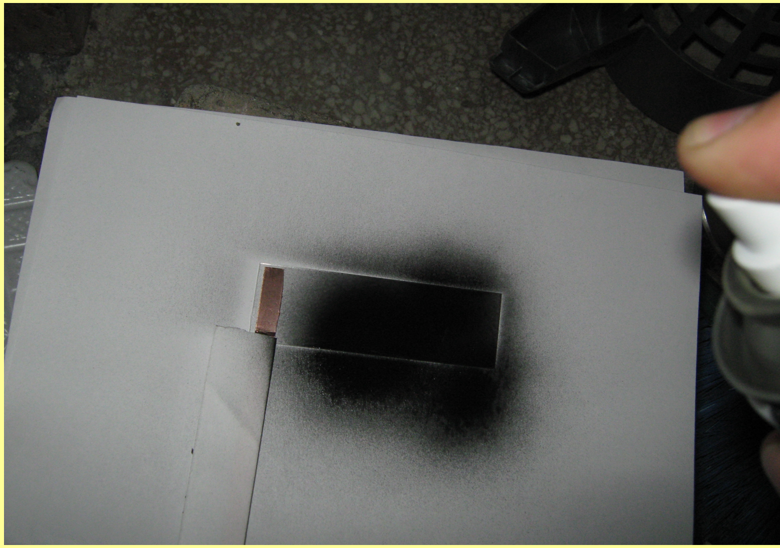
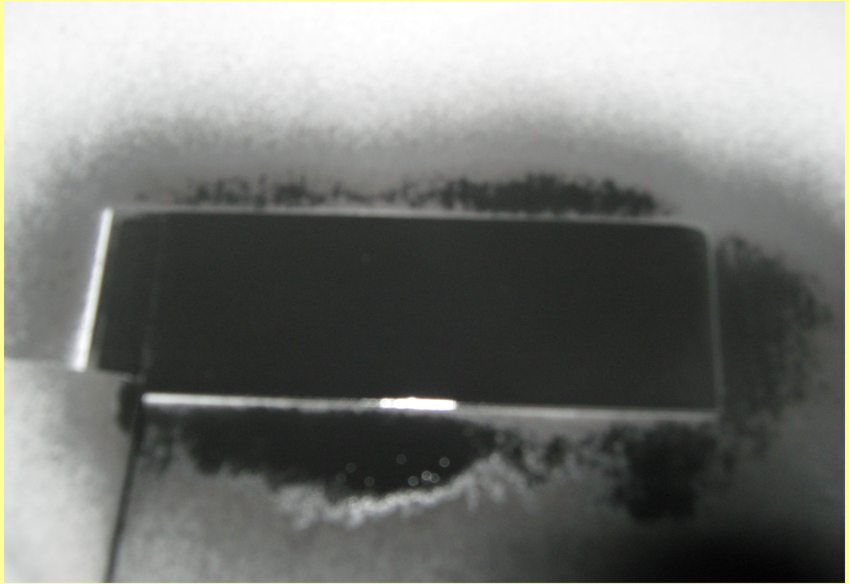
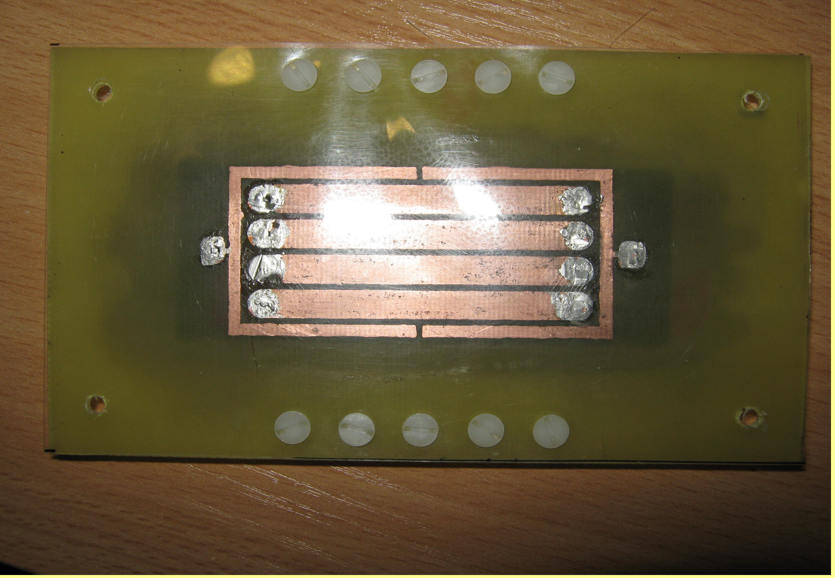


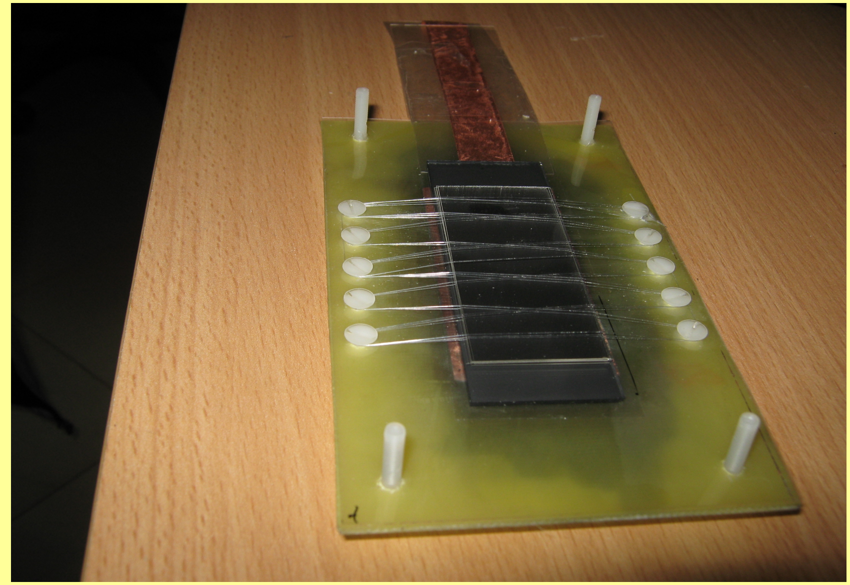
HV electrodes formation (small prototypes 120x70 mm)

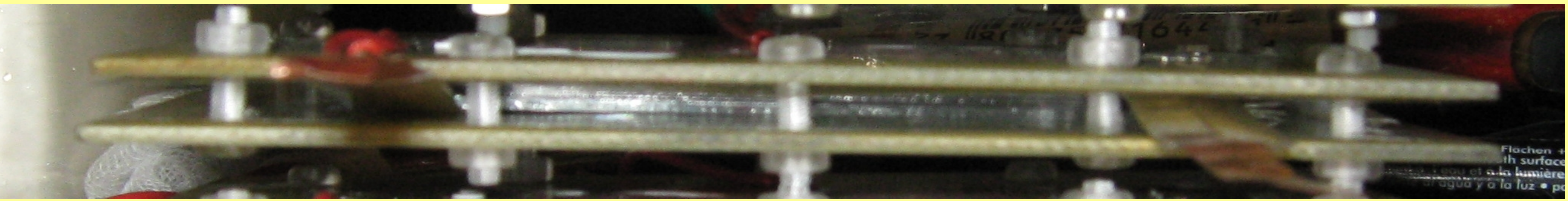


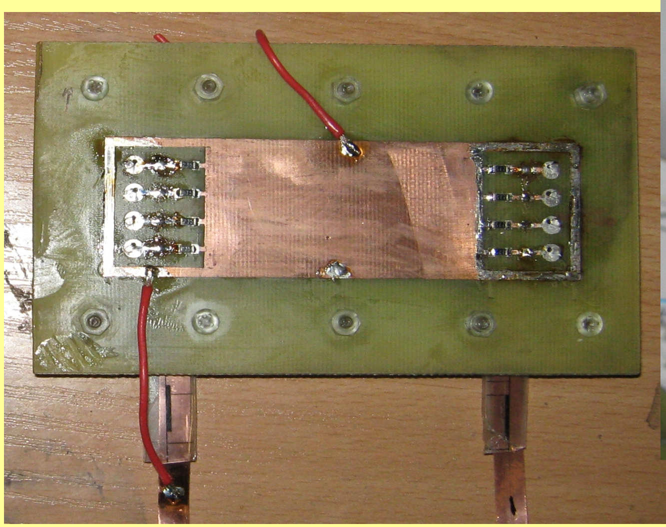


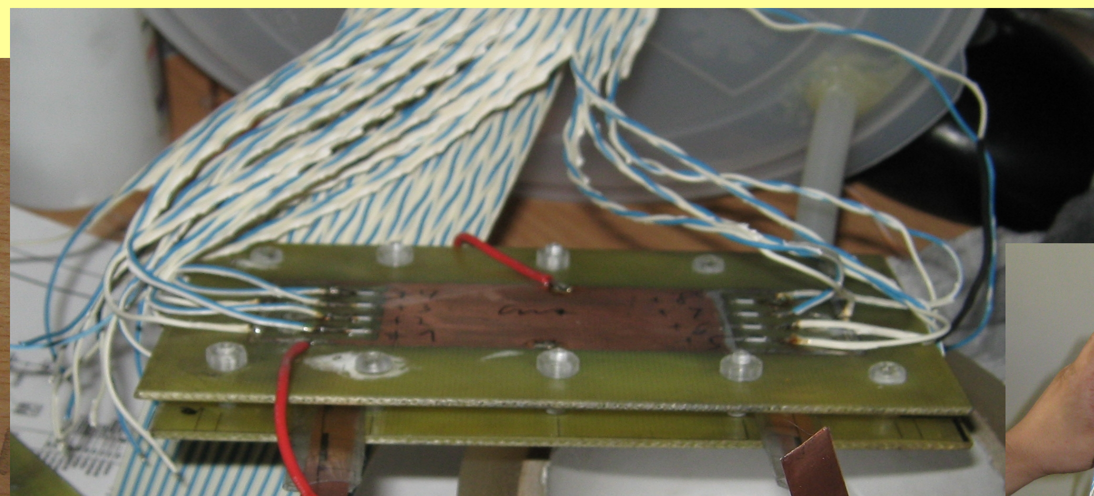


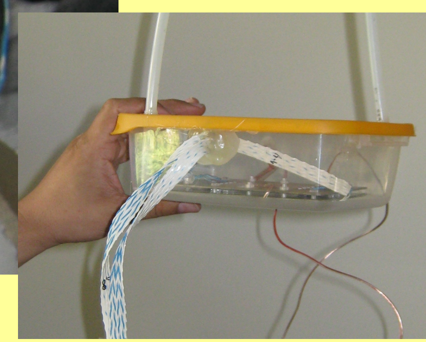
Strips layout and construction of small prototypes (120x70 mm)











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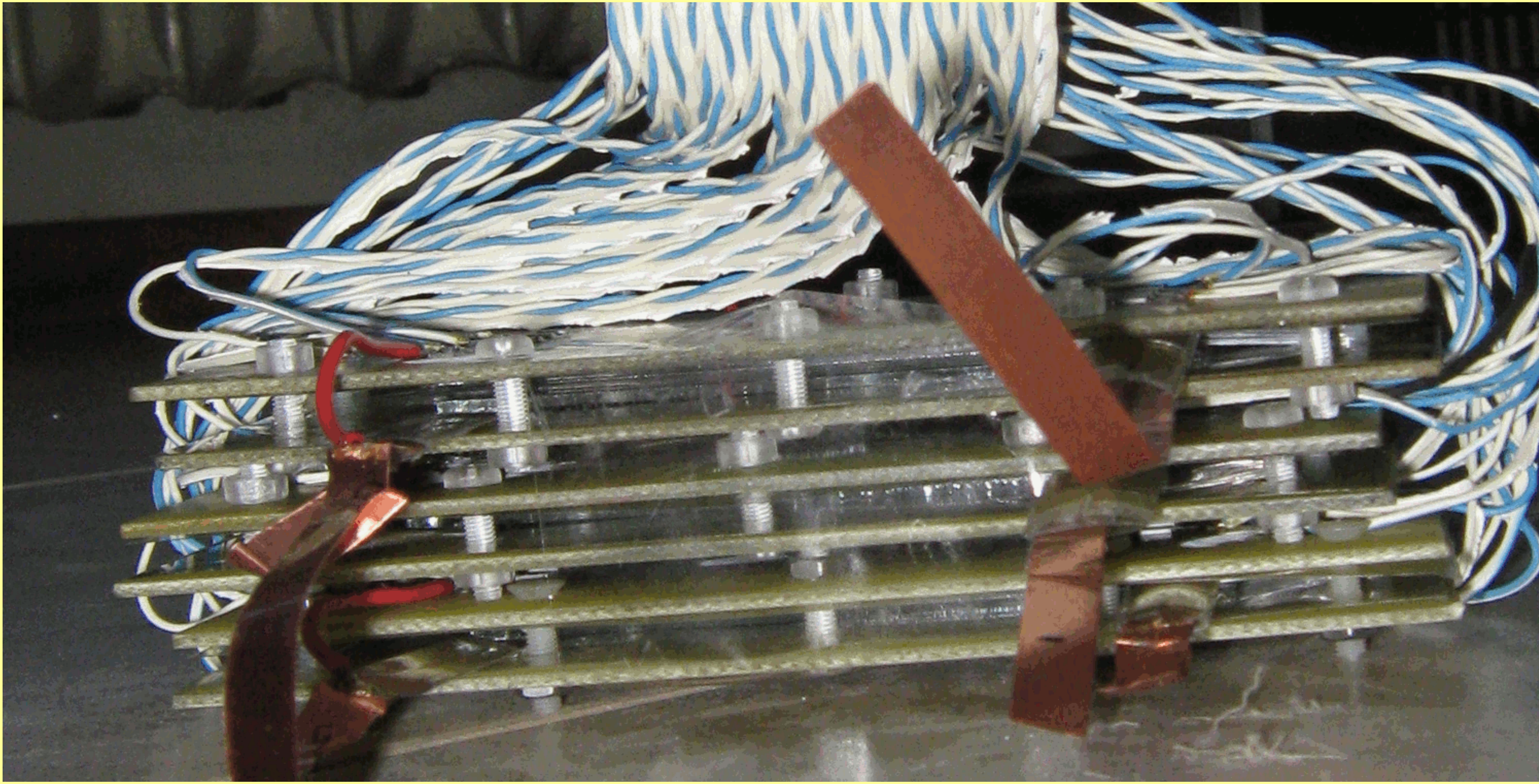
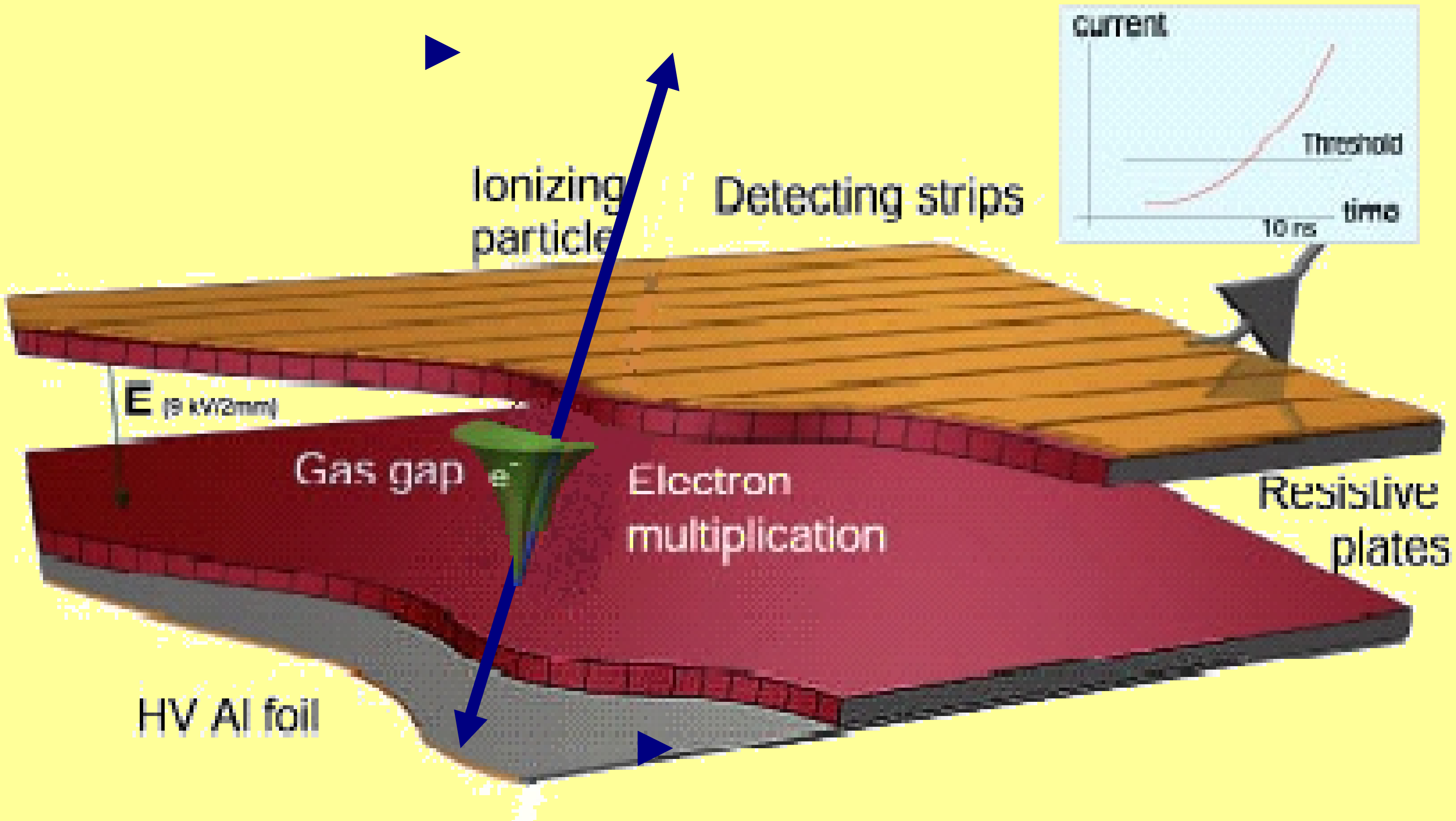
3 modules in a stack

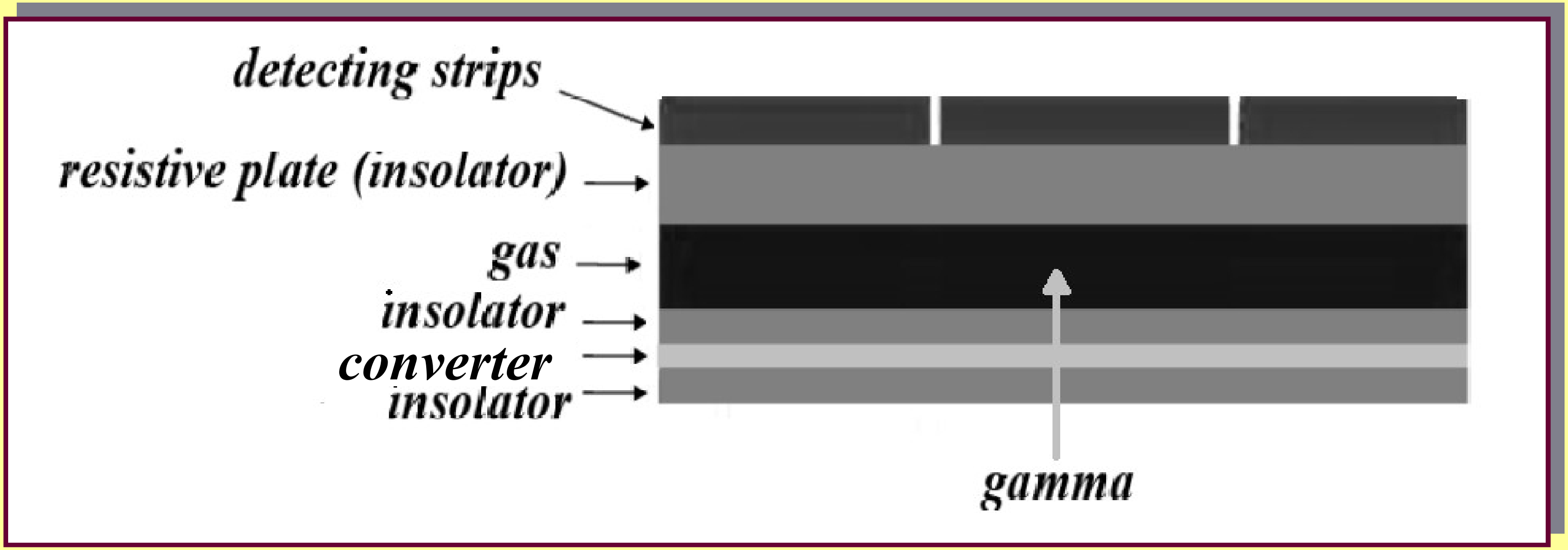


Resistive-Plate Chambers (RPC)



❖ R. Santonico and R. Cardarelli , *Nucl. Instr. Meth.* **A187**, 377-380 (1981)

Gas – insulator – converter design



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