Introduction into Gaseous Scintillation Proportional Counters

F. A. F. Fraga, A. Morozov, L. M. S. Margato , M. M. F. R. Fraga, R. Ferreira Marques

LIP Coimbra, Universidade de Coimbra

LIP Coimbra

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

Optical versus charge mode

- Advantages of optical readout
  - Electronics decoupled from detection media
  - No induced breakdown
  - Insensitive to electronic noise or RF pickup signals
  - Real multi hit capability with true pixel readouts - complex events, image redundancy
  - Large areas without dead spaces - optical systems (lenses, mirrors, fibbers and tapers)

- Disadvantages
  - Transparent windows are needed
  - Efficiency of optical elements can be low
  - Optics are difficult to design and assemble
  - Size
  - Price

Gaseous scintillation

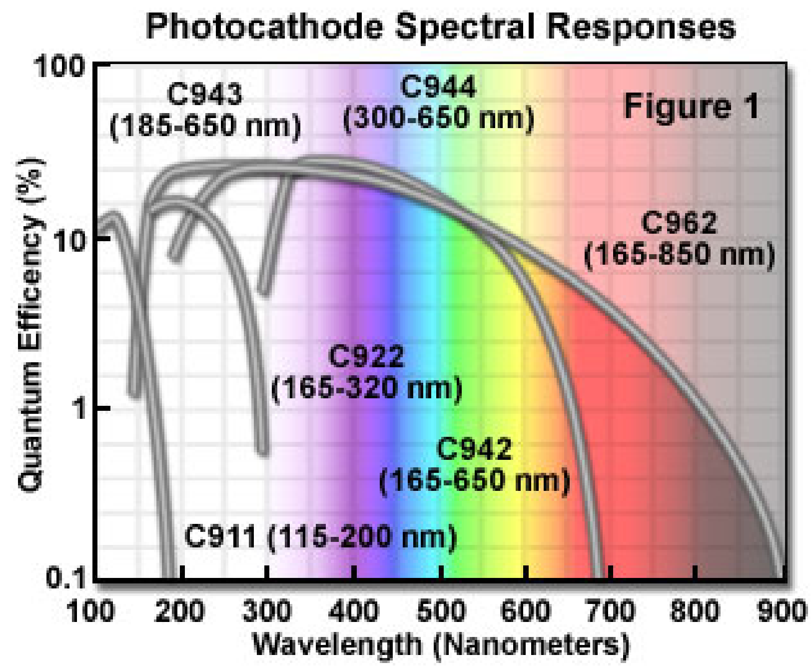
- Primary (direct) scintillation
  - Due to de-excitation of gas atoms/molecules
  - Scintillation yield of Xe ~10^4 photons/ MeV

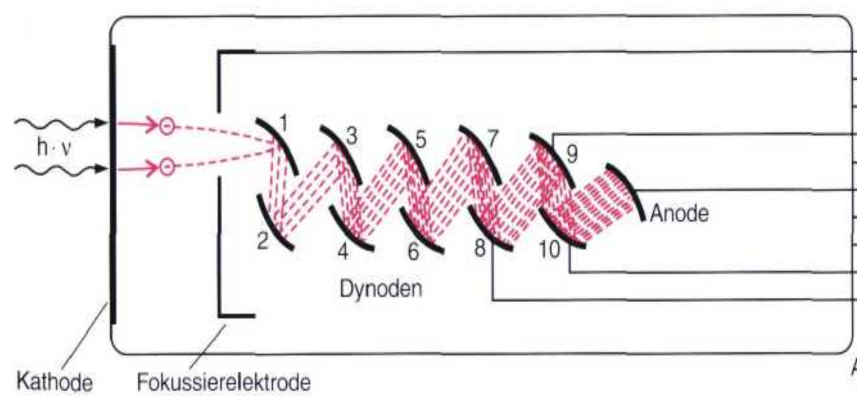
- Secondary scintillation
  - Without ionization (no multiplication)
  - accelerated electrons suffer inelastic radiative collisions
    - *High number of photons* ~ 100-500 ph/cm in Xe
    - Improved energy resolution – *no avalanche gain fluctuations*
    - *Only in noble gases, UV light*

  - With multiplication
    - Low photon yield ~ .01 – 1 ph/ sec. electron
    - Possibility of high gas gain ~ 10^4
    - UV and visible light

Photomultipliers (PMTs)

- QE at peak ~25%
- Spectral sensitivity 160 – 1000nm, typically 300-500 nm
- High gain up to 10^7
- Fast signals 1-5 ns
- Dark current can be < 1 nA
- Noise dominated by spontaneous emission by photocathode
- Background <10 c/s
- Size from 1.25 to 50cm diameter (but path length differences of ~5ns!)
- Square shape

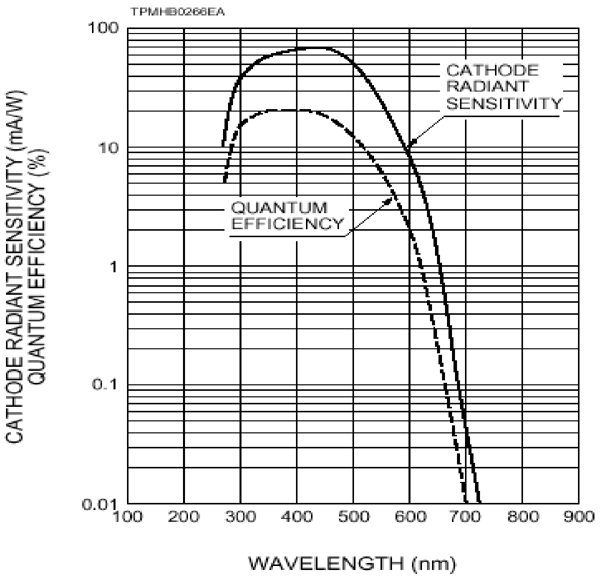




Position sensitive PMTs

- Multiple anode wires crossing one another in the X and Y directions
- Must be calibrated for gain uniformity

Figure 1: Typical Spectral Response



HAMAMATSU

PRELIMINARY DATA
OCT.1998

POSITION SENSITIVE PHOTOMULTIPLIER TUBE
R7600-00-C12

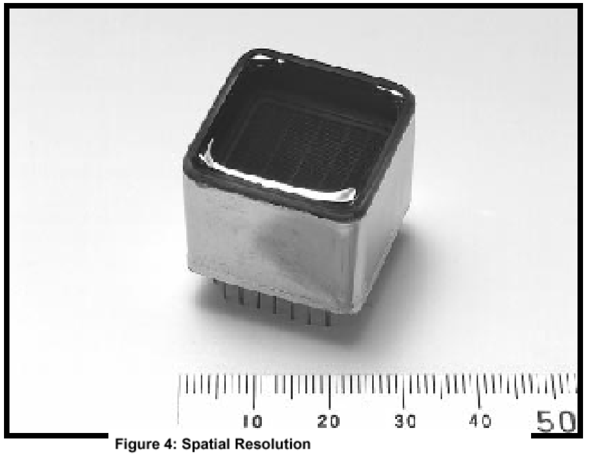
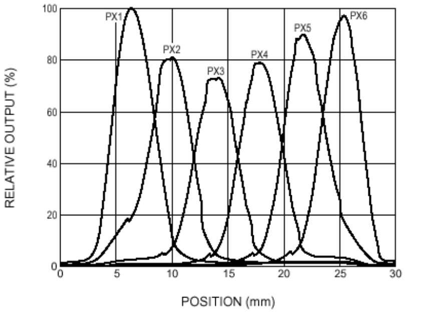


Figure 4: Spatial Resolution

X-Axis

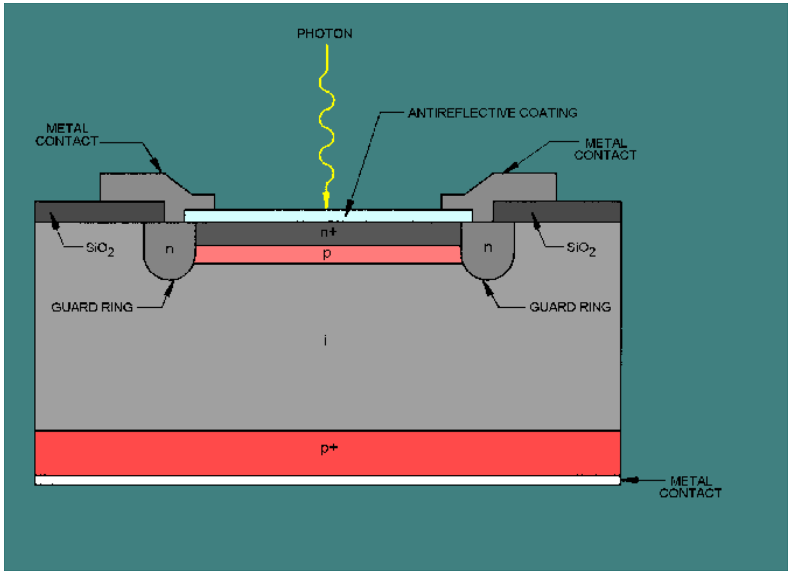


FEATURES

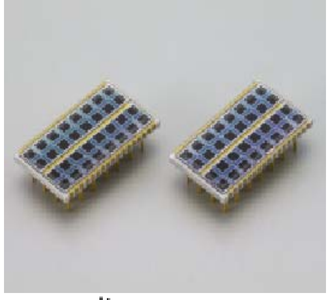
- 6 + 6 Cross Plate Anode
- Newly developed "Metal Channel Dynode"
- High Speed Response
- Flangeless Type

APDs

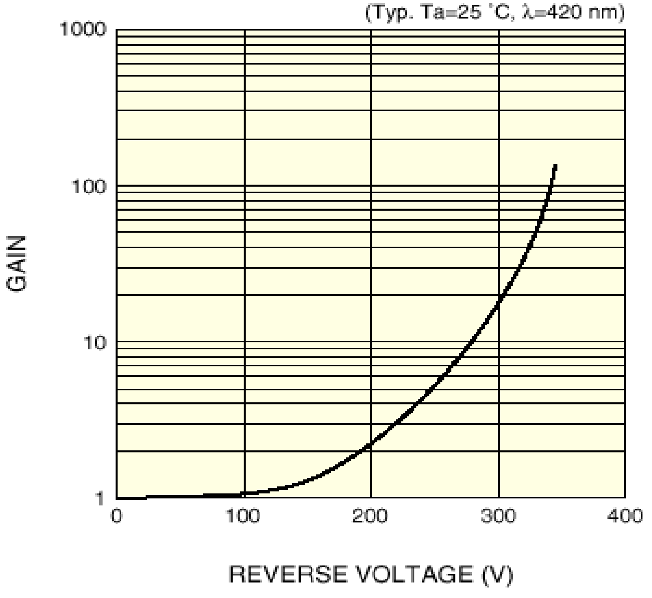
- An avalanche photodiode (APD) is a photodiode that internally amplifies the photocurrent by an avalanche process
- High efficiency for $\lambda > 300$ nm
- Gain ~100
- Noise is dependent on gain
  - $I_N = [2q(I_{DS}+I_{DB}M^2F)B]^{1/2}$
  - Bulk leakage afected by an excess noise factor F (F tip.~ 5)
  - Surface leakage
- Detection of 10 photon, 20 ns pulses
- Small size < 1 cm
- Manufactured with light materials
- Expensive



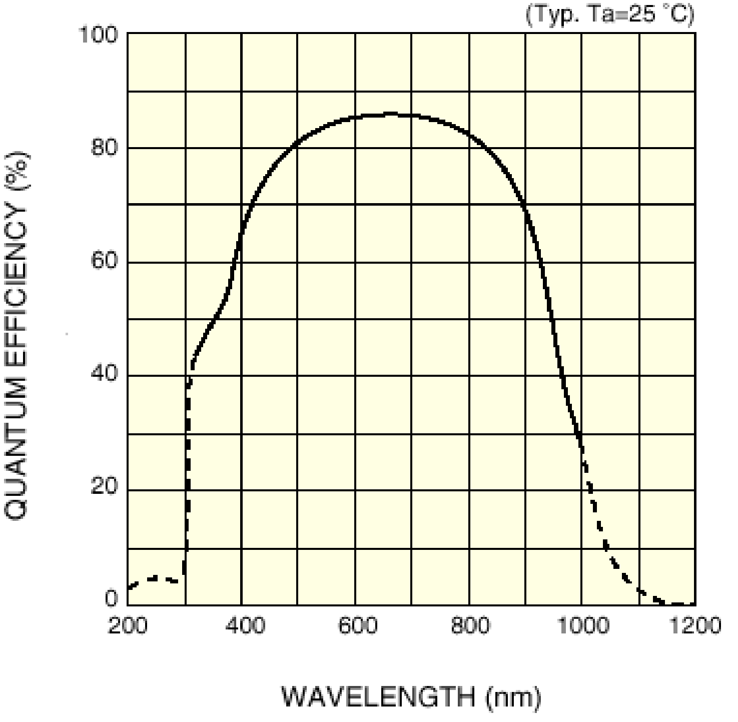
Photon-counting position sensitive devices APD arrays



■ Gain vs. reverse voltage



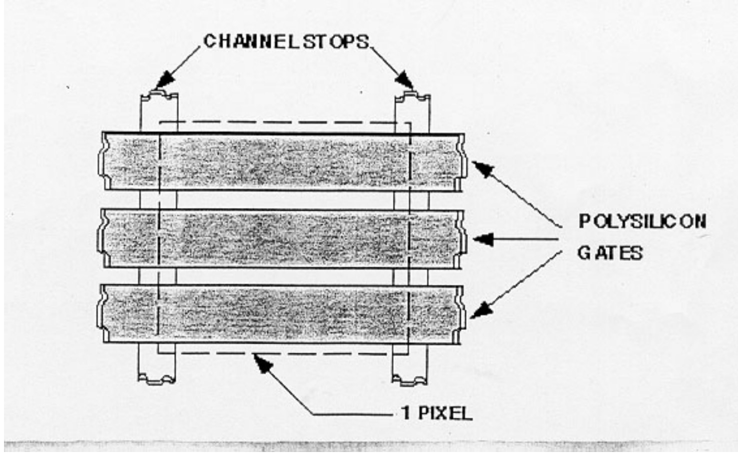
■ Quantum efficiency vs. wavelength

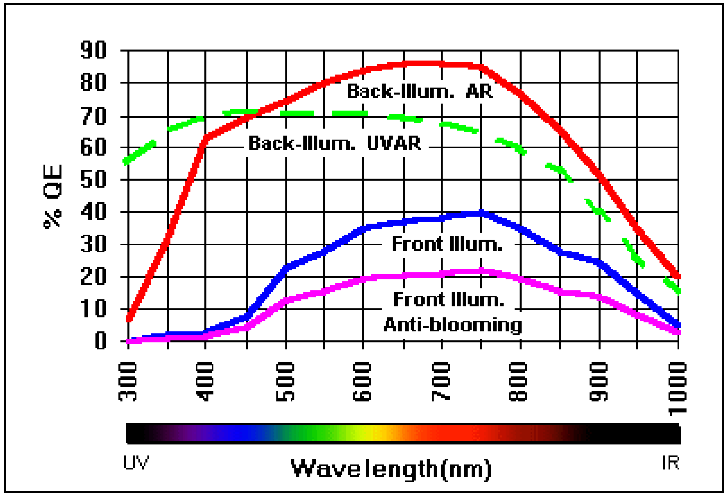


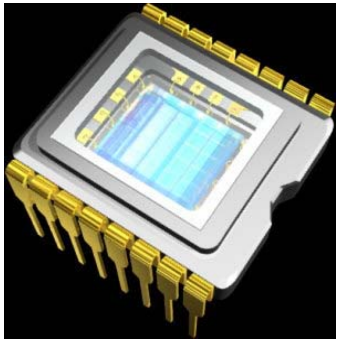
- Hamamatsu S8550
- Still expensive
- Impressive recent results obtained in PET detectors

CCDs

- Pixel type silicon light sensitive detector
- High number of pixels up to 4000 x 4000
- High quantum efficiency - up to 90% - but no gain
- Integrating type device - exposure time from ms to minutes
- Limited range - well depth ~230000 e-
- Low noise - cooling can be needed
- Pixel sizes up to 30 x 30 μm – small chip area – needs optics
- Analog-digital serial readout – 10 – 1000 ms







Neutron Detectors

- Nuclear reactions to convert neutrons
  - Scintillation detectors (solid or liquid)
  - Gas proportional counters and ionization chambers

- n + 3He $\rightarrow$ 3H + 1H + 0.764 MeV
- n + 6Li $\rightarrow$ 4He + 3H + 4.79 MeV
- n + 10B $\rightarrow$ 7Li* + 4He$\rightarrow$7Li + 4He + 0.48 MeV γ +2.3 MeV (93%)
  $\rightarrow$ 7Li + 4He +2.8 MeV (7%)
- n + 155Gd $\rightarrow$ Gd* $\rightarrow$ γ-ray spectrum $\rightarrow$ conversion electron spectrum
- n + 157Gd $\rightarrow$ Gd* $\rightarrow$ γ-ray spectrum $\rightarrow$ conversion electron spectrum
- n + 235U $\rightarrow$ fission fragments + ~160 MeV
- n + 239Pu $\rightarrow$ fission fragments + ~160 MeV

Scintillators for Neutron Detectors

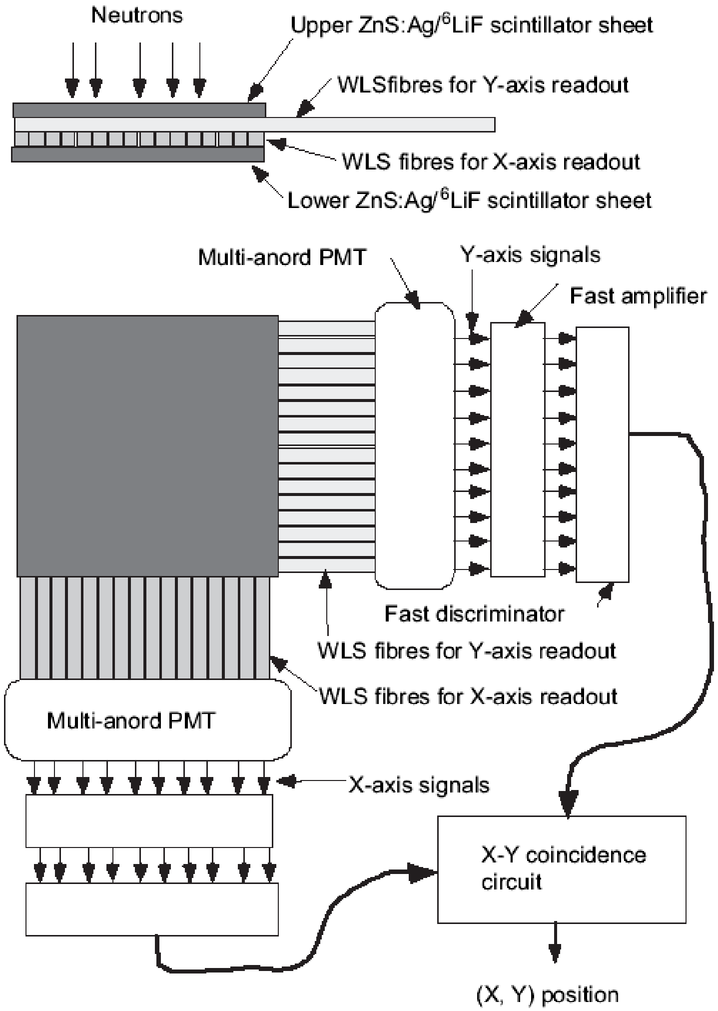
Table 1
Traditional and new thermal-neutron scintillators

Host	Dopant (conc mol%)	Density ρ (g/cm^3)	ρZ_{eff}^4 ($\times 10^{-6}$)[a]	Abs. Length at 1.8Å (mm)	Light yield photons per Neutron	Light yield photons per MeV gamma	α/β Ratio	λ_{em} (nm)	τ (ns)
^{6}Li-glass	Ce	2.5		0.52	~6000	~4000	0.3	395	75
^{6}LiI	Eu	4.1	31	0.54	50,000	12,000	0.87	470	1400
^{6}LiF/ZnS	Ag	2.6	1.2	0.8	160,000	75,000	0.44	450	>1000
$LiBaF_3$	Ce,K	5.3	35		3500	5000	0.14	190–330	1/34/2100
$LiBaF_3$	Ce,Rb	5.3	35		3600	4500	0.17	190–330	1/34/2400
$^6Li_6^{dep}Gd(^{11}BO_3)_3$	Ce	3.5	25	0.35	40,000	25,000	0.32	385,415	200/800
$^6Li_6^{dep}Gd(^{11}BO_3)_3$	Ce	3.9		1	40,000	30,000		420	200/800
$+Y_2SiO_5$	Ce				—	30,000		420	70
$Cs_2^6LiYCl_6$	Ce (0.1)	3.3		3.2	70,000	22,000	0.66	380	~1000
					—	700		255–470	3
$Cs_2^6LiYBr_6$	Ce (1)	4.1		3.7	88,000	23,000	0.76	389,423	89/2500

[a] As an indication of gamma-ray detection efficiency by photoelectric effect ρZ_{eff}^4 values are presented

CWE van Eijk, NIM A529(2004)260-267

- number of photons,
- decay time

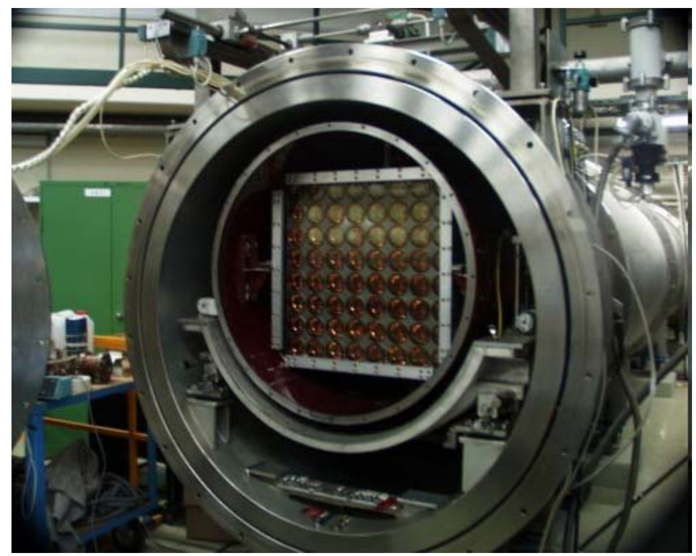


- Wavelength shifting fibers with two scintllator sheets
- .8mm resolution

Nuclear Instruments and Methods in Physics Research A 573 (2007) 149–152
M. Katagiri, T. Nakamura, M. Ebinea, A. Birumachi, S. Sato, E.M. Shooneveld, N.J. Rhodes

A new two-dimensional scintillation detector system for small angle neutron scattering experiments
Kemmerling, G.; Engels, R.; Bussmann, N.; Clemens, U.; Heiderich, M.; Reinartz, R.; Rongen, H.; Schelten, J.; Schwan, D.; Zwoll, K.
Nuclear Science Symposium Conference Record, 2000 IEEE
Volume 1, Issue , 2000 Page(s):6/68 - 6/71 vol.1

- $60 \times 60\ cm_2$
- ^{6}Li-glass
- efficiency of 96%
- 8mm resolution



2-D Scintillation Position-Sensitive Neutron Detector

Patrick M. De Lurgio, *Member, IEEE,* Kelly A. Farrar, Andrew S. Kreps,
Timothy J. Madden, *Member, IEEE,* Istvan Naday, John T. Weizeorick, *Member, IEEE,*
John P. Hammonds, Martha E. Miller, and Arthur J. Schultz

***Abstract*— A new 2-dimensional scintillation Position-Sensitive Neutron Detector (PSND) with an active area of 155 × 155 mm^2 was developed for use on the Single Crystal Diffractometer at the Intense Pulsed Neutron Source at Argonne National Laboratory. The detector is based on the well-proven Anger camera technique and uses a ^{6}Li glass scintillator as the neutron converter. This PSND incorporates a 6 x 6 PMT array with 29.6 mm pitch and optimized optics to achieve an average spatial resolution of 1.75 mm full width at half maximum. The detector read-out has separate electronics for each PMT and the neutron position is calculated by a microprocessor during acquisition. A newly developed position extraction algorithm makes use of an analytical calculation to determine the event position. This new method improves the linearity of the calculated position, provides a slight improvement in resolution, and in principle allows for the correct determination of position to the edge of the scintillator. The design of the detector enclosure allows multiple detectors to be tiled with minimal dead space between them. In addition, the design incorporates a means of attaching external shielding plates that minimizes the shielding surface area required.**

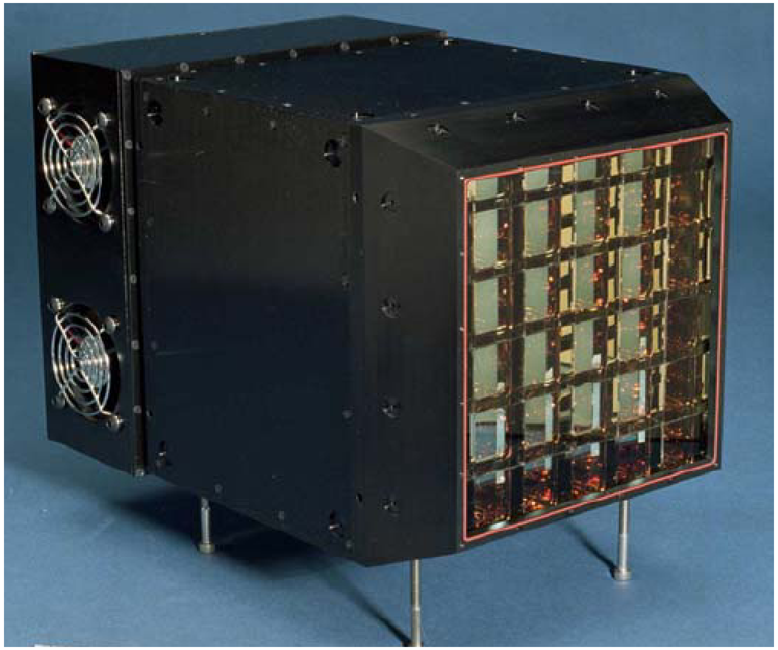
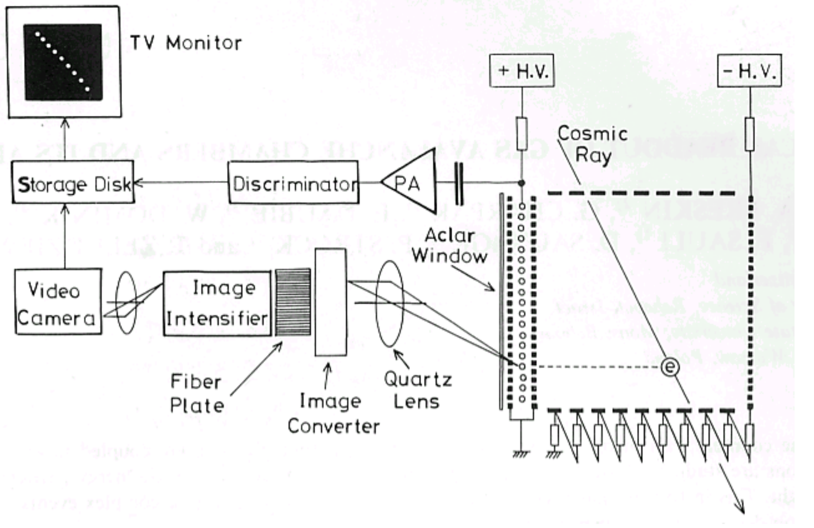


Fig. 1. Picture of PSND without front window, scintillator, and shielding plates attached. PSND enclosure is approx. L-200 x W-200 x D-300 mm^3.

Gaseous avalanche chambers with optical readout

- 2D gas scintillators with optical readout by PMs or intensified CCDs
- Initially used with wires and pure gases
  - Xe, Kr, Ar and He with the addition of N_2 – UV scintillation, inefficient and expensive optics, optical wavelength shifters
- Improvements
  - continuous amplifying structures (PPAC, grids)
  - gas mixtures scintillating at > 250 nm

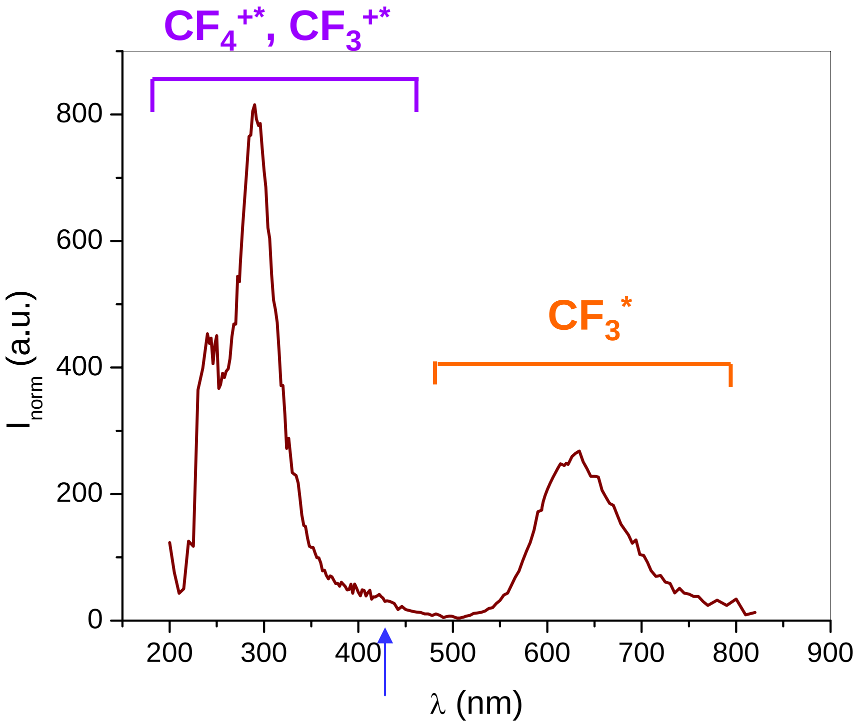


The gas proportional scintillation chamber, A.J.P. Policarpo, Space Sci. Instr. 3(1977)77

Neutron gaseous detectors

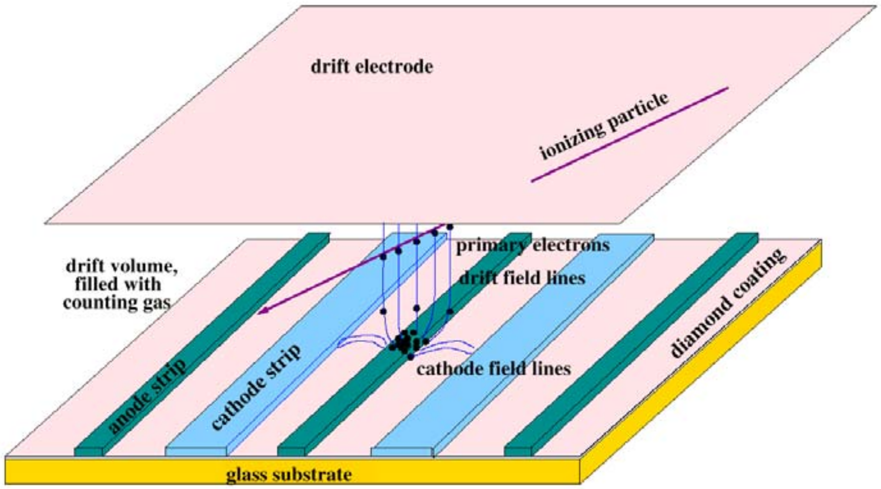
n + 3He → 3H + 1H + 0.764 MeV

CF_4 should be added to control the range *~3 bar 1mm FWHM*

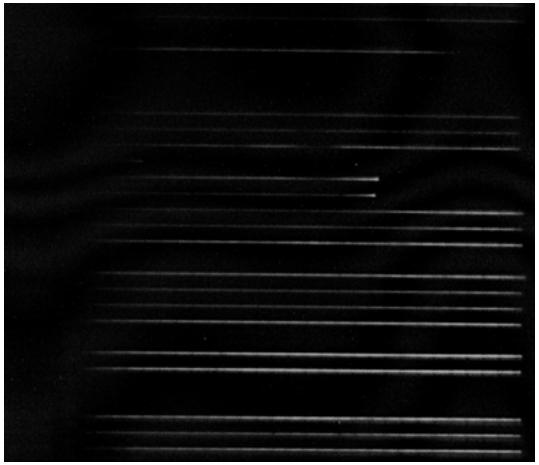


- CF_4 is a very good scintillator, but only a few primary photons per electron
- Secondary scintillation ~.2-.4 photon per secondary electron

Luminescence in microstrips



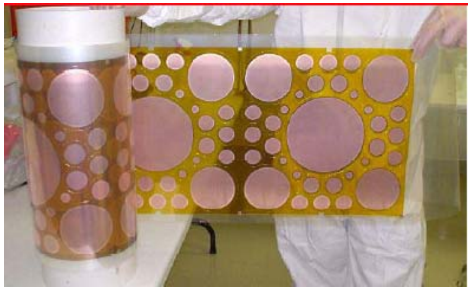
- 1993 A. Oed and P. Geltenbort reported high luminosity from pure gas mixtures
- 1998 We used scintillation to perform quality control of microstrips
  - CCD with Ar-2% Xe



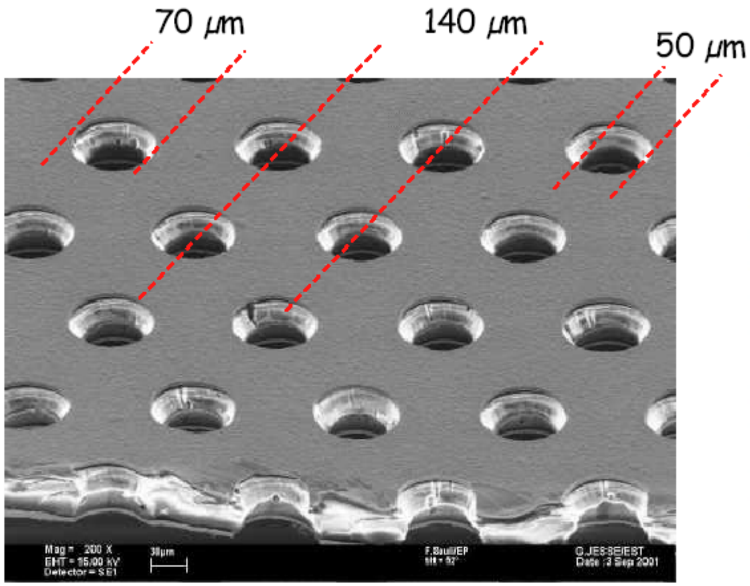
Microstrip operation in noble gases: an active scintillator, P. Geltenbort and A. Oed, Proceedings of the Workshop on Progress in Gaseous Microstrip Proportional Chambers, Grenoble, 21-23 June 1993

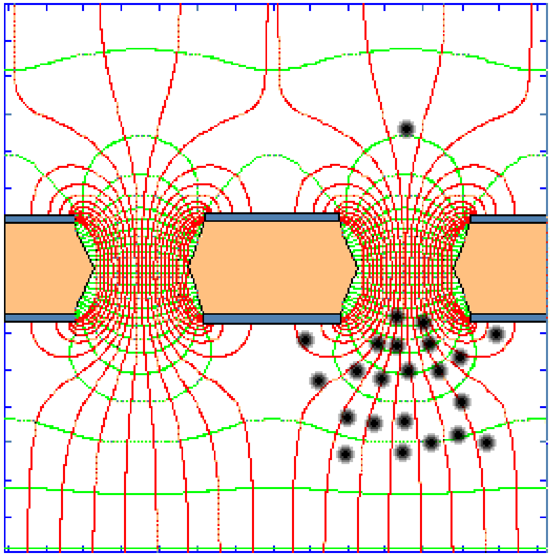
Towards a method for quality control of microstructures for gaseous detectors based on scintillation light, F.A.F. Fraga, M.M. Fraga, R. Ferreira Marques, J.R. Gonçalo, E. Antunes, C. Bueno and A.J.P.L Policarpo

The GEM



- Pre-amplifying structure
- Dielectric between electrodes – charging, high capacitance
- Manufactured using photolithographic etching techniques at CERN,and now by 3M reel to reel process





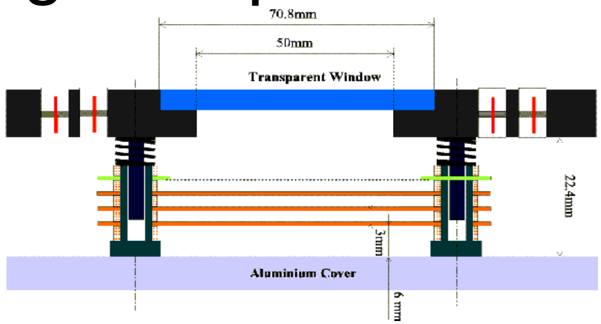
Kapton thickness = 50 µm

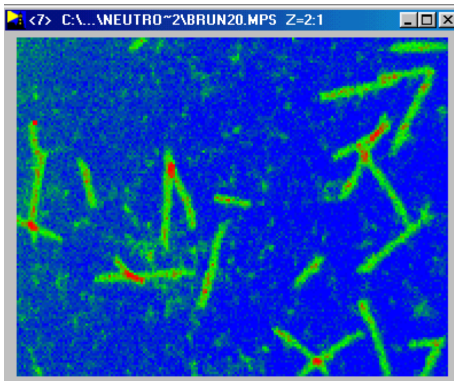
Copper thicness = 5 µm

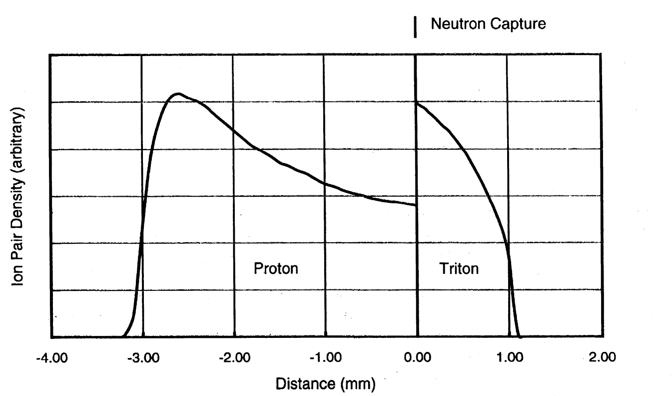
See http://gdd.web.cern.ch/GDD/

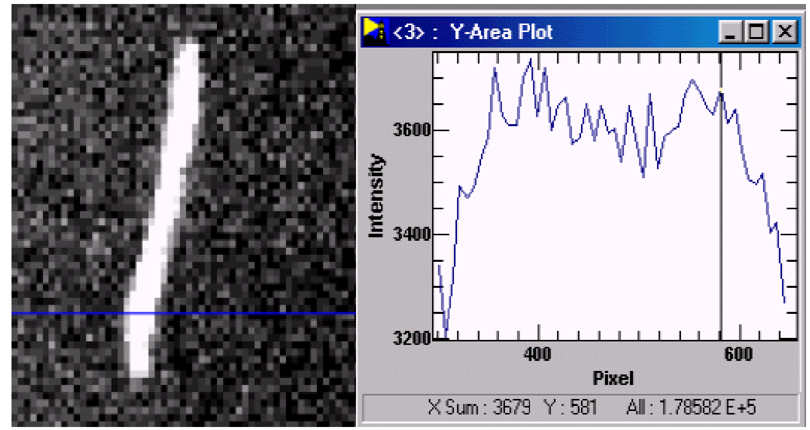
F.Sauli. NIMA386(1997)351

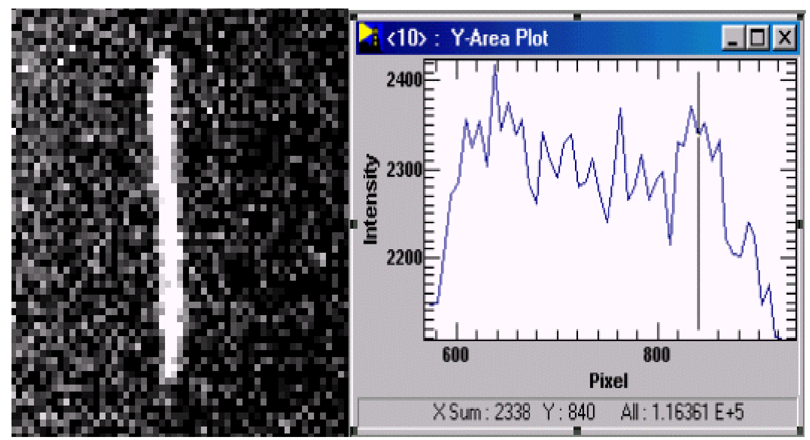
Images of proton and triton tracks in ^{3}He- 400 mbar CF_4











- Projection of the light intensity along the track as measured by the CCD

CCD readout of GEM based neutron detectors, F.A.F. Fraga, L.M.S. Margato, S. T. G. Fetal, M.M.F.R. Fraga, R. Ferreira Marques, A.J.P.L Policarpo, B. Guerard, A. Oed, G. Manzini and T. van Vuure, Nucl. Instr. and Meth. In Physics Research A 478 (2002) 357

Single GEM results at 3 bar CF_4