Use of Hybrid Photon Detectors in scintillation studies and imaging applications

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Basic concept of Hybrid Photon Detection (HPD) is known more than 50 year but their intense use started 20 years ago with research and development of scintillators for CERN application:

"New generation of electromagnetic calorimeters at LHC"

This poster has three main goals:

- to descibe Hybrid Photon Detection (HPD), especially Hybrid PhotoMultipliers (HPMT)
- gamma spectroscopy of scintillators including measurements of scintillation properties using HPMT
- to describe and characterize the newest systems as X-Ray-Sensitive Hybrid Photon Detectors or Tubes and their possible use in X- and γ- Ray detection and imaging (LHCb project, medicine, etc.)

SCINTILLATION - SCINTILLATION DETECTION

Excitation — Emission

1 photon → CRYSTAL → n photons → Detector

Radiation – photons of keV, MeV, GeV,….. X- γ- α-rays or ions

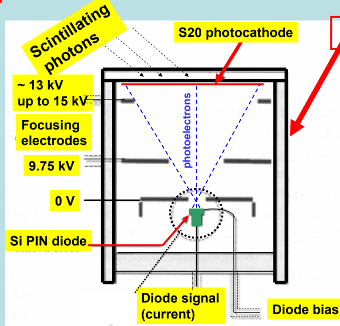
Output – photons of UV, visible or near IR energy

Detectors as PMT, PSPMT, Si-PIN, APD

Characterization – scintillation properties (response)
- light or photoelectron yield (L.Y. ph/MeV or N_{phels}/MeV)
- energy resolution (FWHM in %)
- proportionality (important for scintillation detectors) – calculated to yield of 662 keV energy line of ^{137}Cs
- time dependences including scintillation decay

→ X- γ- α- or ion spectroscopies

HYBRID PHOTON DETECTION - light conversion of scintillationg photons into photoelectrons at a photocathode and their detection at Si-PIN anode



Hybrid PhotoMultiplier(HPMT)

HPMT consists of only
- vacuum-sealed photocathode
- Si-PIN diode as anode
Photoelectrons are accelerated by an electric field
No dynodes are present

Advantages (compared to PMT):
- *high photoelectron resolution*
- *good timing*
- *less noise than PMT*

But it is necessary to amplify signal of HPMT

GAMMA SPECTROSCOPY OF SCINTILLATORS

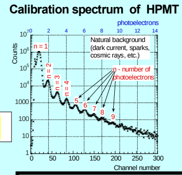
Gamma spectroscopy measurements (set-up)

As excitation sources we use different individual energy lines of radionuclides (see below)

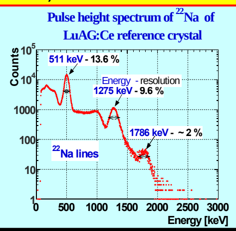
Excited lines of (all energies in keV) Cu (8.16), Rb (13.6), Mo (17.8), Ag (22.6), Ba (32.9), and Tb (45.5) and the following ones as ^{241}Am (59.6 keV) ^{57}Co (122), ^{22}Na (511 and 1275), ^{137}Cs (662) and ^{60}Co (1173.2 and 1332.5)

Source of X- or γ- ray → *reflection tape* / *Sample* → scintillating photons → *HPMT* → *preamplifier* → *amplifier-shaper* → *multichannel analyzer* → PC → *Pulse height spectra*

Calibration spectrum of HPMT

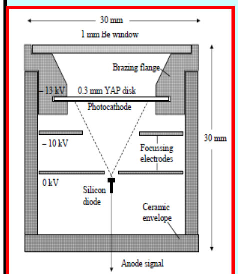


Pulse height spectrum of ^{22}Na of LuAG:Ce reference crystal

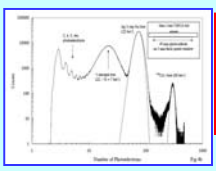


X-Ray-Sensitive Hybrid Photon Detectors with Be-Window

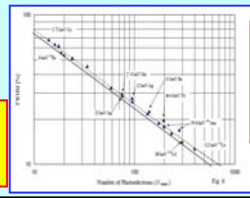
Schema and possibilities of Be-YAP:Ce configuration in Hybrin Photon Detector



Layout of HPMT sealed with 1 mm thick Be entrance window followed by a 0.3 mm thick YAP:Ce detector



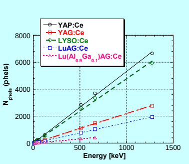
Spectrum of ^{109}Cd with small YAP:Ce disc on Quartz windoww of PP0470 HPMT – this is so called "standard" configuration



Measured Energy Resolutions (FWHM) versus N_{phels} number of photoelectrons obtained for energies of indicated elements

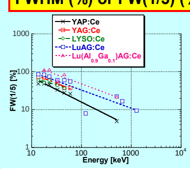
SCINTILLATION PROPERTIES OF SELECTED CRYSTALS

N_{phels} photoelectron yield



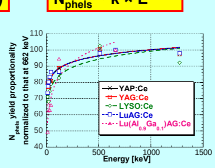
Generally, we measure N_{phels} photoelectron yield on thin crystal samples ~ 0.5- 1 mm. From the above given N_{phels}results the best yield exhibit (1 mm thickness) YAP:Ce - 5.32 phels/keV LYSO:Ce – 4.78 phels/keV (L.Y. above 20.10³ ph/MeV

Energy resolution – FWHM (%) or FW(1/5) (%)



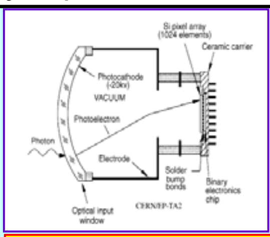
Energy resolution is important value, Especially in imaging applications. The best FWHM (FW(1/5)) exhibit YAP:Ce ~ 5 % at 662 keV energy line followed by LYSO:Ce and LuAG:Ce (FWHM ~ 10 %)

Proportionality N_{phels} ~ k × E

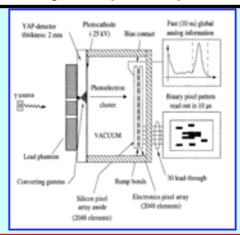


N_{phels} proportionality is important parameter, especially for scintillation detection – it is possible energy range of its using. YAP:Ce exhibit good proportionality in the range ~ 30 – 1300 keV. Also YAG:Ce has ~ good proportionality

Hybrid photon detectors with pixel arrays – special pixel array tubes



HPD used in RICH experiment at LHCb



YAP:Ce imaging silicon pixel array tube

Principal references

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[4] F. Cindolo, C. D'Ambrosio, F. De Notaristefani, H. Leutz, D. Piedigrossi, D. Puertolas and E. Rosso: *ISPA Tubes With Scintillating YAP:Ce Windows: X- and γ-Ray Imaging*. IEEE Trans. Nucl. Sci. 50 (2003), 126-132.

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Summary and conclusions

HPMT are sophisticated new photon detectors characterized by easy and reliable photoelectron calibration characterized by less noise compared with classical PMT's

- The largest use of HPD's (HPMT) is at LHCb experiment at CERN at the RICH detectors for particle identification (~ 500 HPD's). Each of HPD contains array of 8196 Si pixels instead of one Si-PIN diode as HPMT anode – *details of their use at CERN at LHCb RICH detector will be given in other talks of this conference.*

Possible imaging applications of scintillators, HPMT's or other detectors (e.g. CCD's)

Again, similarly as with the use of HPD (HPMT) at RICH LHCb project the HPD (HPMT) can also be used in imaging applications as well.

- Generally, (Y,Lu)Al garnets or perovskites are stable and hard crystals and it is no reason why they could be used as PMT window - especially YAP:Ce was tested as photocathode window (see [4-6]). *YAP:Ce crystals are produced by Crytur Ltd., Palackeho 175, 511 01 Turnov, Czech Republic.*
- ISPA tube (γ-ray optoelectronic camera) was tested ten years ago (see [4,6]). The tube consists of two principial parts: (i) YAP:Ce window (photocathode was evaporated on the inner side of the vacuum tube) or YAP:Ce array consisting of scintillating elements (pixels – here spatial resolution depends on profile of pixels but they are ~ 1 × 1 mm² of profile) and (ii) silicon anode is an array of Si-diode pixels (array chip) alike as is in HPD's of RICH LHCb detectors.

Long time research of Ce-doped inorganic scintillationg crystals (Y,Lu)Al garnets, perovskites and silicates show that Lu-containing ones should be used (they are heavier with higher Z_{eff} than (Y)Al ones) but it is necessary to eliminate their slow decay components due to present of shallow traps in (Lu)Al garnets, perovskites and silicates.

Now, it seems that YAP:Ce crystal was tested and is convenient in imaging applications (γ-camera, small animal PET).