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**Secondary Emission Gaseous Detectors: A New Class
of Radiation Imaging Devices**

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Secondary Emission Gaseous Detectors: A New Class of Radiation Imaging Devices

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A new class of fast radiation imaging detectors is described. Radiation-induced photoelectrons, or secondary electrons, emitted from a thin convertor are multiplied in gas. The surface conversion, emission and multiplication of these eV electrons is characterized by a subnanosecond response and a high resolution parallax-free localization. The low-pressure operation considerably reduces the sensitivity to direct gas ionization and permits the operation at very high radiation flux, with a reduced occupancy.

The properties of UV, X-ray and thermal neutron imaging detectors based on this principle are reviewed. Fast RICH and TRD devices are discussed as well as other potential applications.

1. INTRODUCTION

Successes in future particle physics experiments rely on advanced detection techniques, capable of coping with the constantly increasing particle rates and multiplicities. Novel techniques are required for particle tracking and calorimetry and moreover for ultrarelativistic particle identification. Here, most demanding are techniques like Ring Imaging Cherenkov (RICH) counters (and other Cherenkov detectors) and Transition Radiation Detectors (TRD). Fast trackers which can measure the time-of-flight of the particle with resolution better than 0.1 ns could also be instruments of choice in future generations of experiments.

Not less important are radiation imaging devices employed in other fields of basic and applied research. Good examples are X-ray diffraction studies at intense Synchrotron Radiation sources incorporating also time-resolved experiments, thermal neutron diffraction, high resolution real-time radiography and tomography, etc.

Wire chambers, introduced by Charpak in 1968, massively employed in these many fields, have some inherent drawbacks. Most of them are derived from the fact that radiation-induced charges deposited in the gas are in most cases relatively slowly (tens to hundreds of ns) collected

from their production location, prior to their multiplication. This affects their occupancy time, prohibiting their use at very high repetition rates; it also prevents their use for fast timing purposes. Electron diffusion during this drift process limits the localization accuracy. The latter is also limited by particle-induced δ -electron emission or by the finite range in the gas of X-ray-induced photoelectrons or neutron-induced charged particles.

In many cases the localization accuracy is seriously affected under angular incidence of the radiation, causing parallax errors which are function of the detector geometry. The detection process of low energy quanta, i.e., UV photons in RICH or soft X-rays in TRD, is often affected by intense charged particle background accompanying the signal to be detected. This puts a serious load on the detector, often limiting its gain and performance. In addition, wire chambers, unless operated at very low gas pressure, suffer serious counting-rate limitations due to space-charge effects during the avalanche process. This prohibits their operation at high radiation flux.

To overcome most of these drawbacks we have recently introduced a new philosophy in radiation detection. We propose a novel class of radiation detectors, based on secondary electron emission (SEE) from thin solid convertors. The secondary electrons (SE) are emitted into a gaseous imag-

Figure 1. The operation principle of the secondary emission detector. Incident radiation, converted in a thin solid film, induces the emission of multiple low-energy secondary electrons. They start a multiplication process at the vicinity of the convertor surface and are further multiplied and localized in a second amplification stage.

ing electron multiplier in which amplification is initiated at the convertor surface [1].

The detector principle is illustrated in fig. 1. Radiation (in the present example soft X-rays) interacts with a solid convertor, inducing the emission of multiple low-energy (eV) secondary electrons per converted photon. The electrons are multiplied in a two-stage avalanche chamber, operating at low-gas pressure (10-20 Torr) [2]. An avalanche is initiated close to the emission location at the convertor surface. The avalanche electrons are further multiplied in a second amplification stage, providing signals that permit one to accurately determine the incident photon location and its interaction time.

We have demonstrated that such low-pressure gaseous electron multipliers can operate at very high gain, efficiently detecting a single or few electrons [4]. The fast multiplication process developing at low gas pressure (at very high reduced electric fields) provides time resolutions in the sub-nanosecond scale [4]. Single electrons can be localized with accuracies reaching 100 μm . The de-

tectors can operate at very high radiation flux ($> 1 \text{ MHz/mm}^2$) due to the absence of space-charge effects during the very fast avalanche buildup [5].

An alternative way of multiplying surface-emitted electrons is based on a Microstrip Gas Chamber operated at low gas pressure [6]. Due to a fast two-stage multiplication mechanism of the surface-emitted electrons (fig. 2), gains of the order of 10^5 are reachable. The rapid ion collection on cathode strips induces high amplitude fast current pulses at relatively low gains, which permits a stable operation.

Figure 2. The principle of the two-stage multiplication mechanism in a low-pressure gaseous micro-strip chamber. The high electric field across the gas gap permits preamplification of radiation-induced surface-emitted charges, which are further multiplied at the anode strips.

Most important in the new method is the surface conversion, followed by a surface SE emission. One should therefore clearly distinguish here between this technique, in which eV electrons initiate an avalanche close to the convertor surface, and other detectors equipped with solid convertors, where energetic radiation-induced charged particles (electrons, alphas, tritons, etc.) further ionize the detector gas, affecting the localization resolution [7]. Multistep

gas chambers coupled to solid convertors partially solved this problem due to the exponential avalanche buildup starting close to the particle emission location [8].

The fact that the avalanche is initiated at the convertor surface, makes the detector's localization and time resolutions insensitive to the angle of incidence of the radiation. It should be added that the exponential avalanche growth, initiated by surface-emitted electrons in a low density gas, makes this detector practically insensitive to direct ionization of the electron multiplier gas [9]. Therefore such photon (UV, X-ray) detection devices can operate in a stable way at very high particle background.

The convertor material is chosen according to the source of radiation. The interaction of radiation with the convertor results in the creation of primary electrons, which by a cascade of elastic and inelastic collisions in the solid induce the emission of low-energy secondary electrons. The SEE process is very effective in insulators and particularly in alkali halides [10,11]. This is due to their low electron affinity and to a particularly long electron escape length from the solid. The latter is due to low energy losses of electrons having an energy below the energy gap (a few eV in alkali halides), which mostly undergo electron-phonon interactions in the solid. The SEE yields in alkali halides are by an order of magnitude larger than in metals [11].

One of the most interesting convertor/emitter materials is CsI. It has been widely used in combination with vacuum electron multipliers [12]. It is relatively air-stable [13] and was proven to operate in a stable way in a gas multiplication mode. It has good photoemission properties in the UV (140-220 nm) [14] and its high quantum efficiency (QE) makes it an excellent candidate for UV-photon imaging with gaseous photomultipliers [4]. On the other hand, it is a good soft X-ray convertor ($Z=54$). A single converted 8 keV X-ray induces on the average the emission of a few tens of SEs [10]. Their average energy, similar to that of a UV-induced photoelectron, is of the order of 1 eV [15]. These electrons have a very short path in a gas, which therefore does not affect the timing and localization properties

of electron multipliers based on gas amplification.

Over the last few years we have been intensively studying the radiation-induced SEE and photoemission processes in alkali halides, both theoretically and experimentally. We developed a new microscopic model, based on first principles. It takes into account the primary interaction of radiation (relativistic particles, UV-photons, X-rays, electrons) with the solid and follows the slowing-down of the primary electrons and the development of the secondary electron cascades, via different elastic and inelastic mechanisms. Finally it provides the secondary electron emission characteristics, namely, the electron escape length, emission yields, the cascade size and the energy spectrum of the SEs [16-19]. The model reproduces with good agreement experimental data of X-ray-induced SE yields. In a recent work [19] we demonstrated that the model accurately predicts the UV quantum efficiency of CsI. The model was recently expanded for calculations of new composite thermal neutron convertors, combining CsI-coated Li and Gd films [20], as discussed below. We have extensively investigated the properties of UV, X-ray and thermal neutron detectors based on the SEE principle. The principal results of these studies will be presented in the following. We will discuss the possible application of this technique to fast particle tracking and other fields.

2. GASEOUS PHOTOMULTIPLIERS WITH SOLID PHOTOCATHODES

Single VUV photons, in the wavelength range of 120-220 nm are commonly localized with gaseous detectors filled with photosensitive gases (usually mixtures containing TEA or TMAE vapours [21]). The considerable spread out of this technique was motivated by the applications to RICH, proposed by Seguinot and Ypsilantis [22]. Large area UV-photon imaging devices have numerous potential applications in many other fields.

As mentioned above the gaseous photoconversion, though very efficient, is characterized by a considerable time jitter and parallax localization errors. These drawbacks, combined with

the somewhat uneasy handling of photosensitive liquids, are at the origin of the development of gaseous photomultipliers comprising solid photocathodes [57,24,2]. Several photosensitive materials have been investigated [25] including organic vapours adsorbed on metal surfaces [26]. However, the most interesting material so far has been CsI. Its photoemission properties in gas media were investigated originally in a few parallel works [13,27,28]. Its ability to operate in a stable way under high gas multiplication was demonstrated in a practical device, recording UV-photons from a Xe-filled scintillator [13].

These early works demonstrating the potential of CsI-based UV-detectors have triggered a considerable interest in this technique, principally directed towards the application to RICH [14]. The QE of CsI over the spectral range of 140-220 nm is lower, but not very different, compared to that of TMAE, as shown in fig. 3.

Figure 3. The quantum efficiency (QE) of reflective CsI films measured at the Weizmann Institute (WI) and at Ecole Polytechnique (EP) [56]. The data are compared with that of Anderson et al. [57] and Seguinot et al. [27]. The QE of TMAE [58] is provided for comparison.

The differences between QE values of CsI photocathodes reported by various groups usually originate from differences in the preparation and operation modes of the photocathodes and, moreover, from different calibration procedures. These are discussed in detail in ref.14. A practical and proven way of obtaining high QE values is to evaporate CsI on hot (60°C) substrates, following an annealing procedure under the same temperature during a few hours in high vacuum, as shown in fig. 4 [29].

Figure 4. QE spectra of CsI, after evaporation and as function of annealing time at 60°C.

Very reproducible results have been obtained over several tens of photocathodes made in this way. It was recently shown that surface effects play an important role on the QE. For example, high QE values, similar to that shown in fig. 3. (on a polished stainless steel substrate) were reached on Ni or Ni/Au [30] and on polished Sn/Pb [31] substrates, deposited on standard printed boards; photocathodes deposited on Cu/Au-coated printed boards yielded about 30% lower values. This makes practical the use of CsI-coated pad readout electrodes in wire chambers.

Contrary to previous statements, it was confirmed that the highest QE values of CsI are measured in vacuum. Under gas operation, the detector gas plays a considerable role on the emission

yield from solid convertors [32]. For example, the photoemission yield in He-based mixtures, measured in a charge collection mode, is about twice lower compared to that in CH_4 -based gas mixtures, which is comparable to the vacuum value [30]. This is attributed to an enhanced backscattering of photoelectrons. At high electric fields, under gas amplification this difference disappears and the photoyield in all gases investigated resembles the vacuum one [32]. This is an important parameter in gaseous photomultipliers, suggesting the advantage of CH_4 -based mixtures; other gases can be employed, but with multiplication elements allowing for high electric fields at the convertor surface. UV imaging detectors combining Ni/CsI (vacuum heat-enhanced) pad electrodes and thin wire chambers, developed for fast RICH devices by the CERN RD-26 collaboration, recently yielded remarkable results, operated with CH_4 at atmospheric pressure. Cherenkov rings induced by 3 GeV/c pions in a proximity focussing RICH are shown in fig. 5. It is a very encouraging fact that the estimated QE of CsI in these new beam experiments is very close to the one measured in the laboratory with high quality samples [30].

An important observation recently made is also related to the role of the electric field at the photoemitter surface. It was demonstrated that the photoemission yield can be enhanced to a large extent under very high electric fields. An enhancement factor of 1.5-25 was measured over a respective wavelength range of 160 to >200 nm, in vacuum, at 500 kV/cm [33,34]. This enhancement, that could have some very practical implications in detection science [29], is attributed to a field modification of the electron affinity of CsI. Other recent progress in this field is related to the protection of CsI and other photocathodes with thin insulator films (MgF_2 , LiF) [29]. It was recently demonstrated that visible photocathodes have a very limited lifetime in the presence of gas [35]. Such a method, if successful, could open new avenues towards the operation of air-sensitive visible photocathodes in gas media.

Figure 5. Single events of Cherenkov rings induced by 3 GeV/c pions in a proximity-focusing RICH. Photons from a C_6F_{14} radiator are converted in a CsI layer, deposited on a pad readout electrode. The pad pattern shows the central particle cluster surrounded by single photoelectron clusters [30].

3. SEE X-RAY IMAGING DETECTORS

The large local secondary electron yield following the interaction of a soft X-ray with CsI, permits its localization with very good resolutions in space and in time. The detection efficiency depends on the convertor thickness, which is optimized according to the photon energy, as shown in fig. 7. The thickness is dictated by the range of the photoelectron in the solid and by the escape length of the SEs. Best results are obtained at low photon energies (<10 keV). Considerably larger efficiencies can be obtained under a grazing incidence [1,36]. The emission yields from CsI decrease with increasing photon energy [17], as shown in fig. 7, which also affects the localization resolution. This is due to the enhanced role of the more energetic escaping primary electrons, which have a longer range in the gas.

Figure 6. Experimental efficiency of the CsI-based SEE X-ray detector (shown in fig. 1) as function of the photoconverter thickness for various X-ray energies.

Figure 7. Calculated mean number of primary, $\bar{n}_p$, and secondary, $\bar{n}_s$, electrons emitted in one cluster, following the absorption of X-ray photons of different energies. One experimental point at 8 keV is from G.W. Fraser [55].

We found that at higher energies metal converters like Ag or Ta could replace CsI films [37].

Despite their lower X-ray induced SE yield good localization resolutions are reached, as shown in table 1. It is related to the larger achievable gain in the first amplification stage (close to the converter surface). Here the gain is not limited by photon feedback effects, typical to detectors operating with photosensitive gas or solid converters. The larger exponential avalanche growth in this case enhances the contribution of the first ionization electrons, deposited by primary electrons escaping into the gas. This limits the deterioration of the resolution, typical to a low gain operation.

The 2D imaging capability of the SEE detector, equipped with a thin Ag converter is demonstrated in the radiographic images shown in fig. 8. Recent comparison with radiographic films revealed that images of an equivalent contrast can be obtained with the present technique at considerably reduced radiation doses, up to an order of magnitude lower, both for soft X-rays [5] and more energetic photons (60 keV) [38]. Digital images of a better resolution compared to that of screen-enhanced films were obtained, but at the expense of larger doses [37].

The 0.4 mm (FWHM) spatial resolution obtained at 60 keV is of interest for applications in real-time radiography and tomography. Regular wire chambers could provide similar resolutions operating at pressures of several atmospheres of Xenon, and selecting events within the "escape peak" [39]. The counting rate would be lower in this case by 1-2 orders of magnitude, due to space charge effects. The spatial resolution of MWPCs deteriorates rapidly down to a few mm for more energetic photons.

The relatively low conversion efficiency of a single layer X-ray SEE detector (6% - 0.6% at respective energies of 6-60 keV) is largely compensated in most cases by the detector ability of operating under very high radiation flux, reaching 1 MHz/mm², and with resolution times below 1 ns (FWHM). This provides the possibility of studying with great accuracy fast time-evolving phenomena. These detectors, are a good alternative to presently employed imaging techniques in the field of X-ray diffraction. Their ability to provide high resolution large area parallax-free images, under high operation flux, makes them

Table 1

Typical optimal thickness, maximum conversion efficiency and localization resolution for CsI and metals, at normal incidence

Photon energy [keV]	CsI convertor			Metal convertors		
	Optimal thickness [nm]	Conversion efficiency %	Resolution (FWHM) [mm]	Optimal thickness [nm]	Conversion efficiency %	Resolution (FWHM) [mm]
5.9	200-300	4.9		70(Ag)	2.5	
8	300	2.5	0.19	150(Ag)	2.1	0.29
17.5	900	0.8	0.28	1000(Ag)	1.1	0.32
60	4000	0.6	0.5	5000(Ta)	0.8	0.4

Figure 8. Radiographic images of plastic-made syringe, ink-pen and a wrist-watch, obtained with the SEE X-ray detector equipped with an Ag convertor. The images were obtained using a 15-30 kV X-ray generator.

instruments of choice in crystallography studies at intense Synchrotron Radiation Sources. Recent preliminary tests of this technique in protein crystallography, a field with a constantly growing

interest, yielded very encouraging results. Images with superior signal-to-noise characteristics and with equivalent resolution, compared to Image Plates, were recently obtained by us in real-time [40].

We proposed to implement these detectors in ultrafast Hadron-Blind Transition Radiation Detectors (TRD) for ultrarelativistic particle identification in future high energy physics experiments [41]. The TRD comprises foil-radiators followed by CsI-based SEE TR-photon detectors. Its main advantages, compared to presently employed Xe-filled TR detectors are the ns resolution, good spatial accuracy, high rate capability and the very low occupancy. The latter, resulting from the very low particle-induced direct gas ionization and secondary electron emission [9], permits the operation of such TRDs under very high hadronic background, with high detection efficiency of energetic electrons (fig. 9). The electron trajectories can be accurately measured by tracking the TR-photon induced avalanches in successive detector modules. The results of our detailed studies of TRDs based on this new technique are presented in a separate work within these proceedings [42].

4. THERMAL NEUTRON IMAGING

Thermal neutron imaging has many applications in basic and applied research. Typical examples are astrophysics, biology and industrial radiography [43]. Neutron localization can be achieved over large area by coupling thin convertor foils (Gd, Li, B etc.) to gaseous detectors [44],

Figure 9. The novel TRD, comprising a repetitive sequence of radiators and SEE detectors, is shown on top. At the bottom is a simulation of the performance of a 2 meter long TRD based on this principle, comprising 200 Li foils in each radiator. Shown is the efficiency for detection of pions as function of their energy for different system parameters; $\epsilon_1, \epsilon_{100}$ are the efficiencies to detect 1 and 100 GeV electrons [42].

sensitive to the neutron-induced charged particles. The most interesting technique is based on multistep avalanche chambers [8]. The exponential charge multiplication in the first stage, makes these multipliers more sensitive to ionization electrons deposited by the charged particle in the gas close to the surface of the convertor. However,

due to the range and the isotropic emission of the charged particles, this method has a limited localization accuracy.

An improved localization of the origin of the emitted charged particle, namely of the converted neutron location, can be reached by enhancing the number of electrons deposited in the gas at the vicinity of the convertor surface. This can be reached with composite neutron convertors (CNC) combining a first neutron conversion foil coated by a second, highly electron emissive film [20]. A charged particle emitted from the first convertor element induces the emission of multiple low-energy secondary electrons (SE) into the multiplier gas. These initiate an avalanche at the convertor surface in a similar way compared to the SEE X-ray detector described above; a second multiplication stage enlarges the avalanche to a detectable size (see fig. 10). Due to the exponential avalanche growth, the ionization electrons, deposited by the charged particle in a low-pressure gas, will induce smaller avalanches compared to that initiated by the SEs (see fig. 10). This will not seriously affect the localization resolution, as discussed above.

Preferable thermal neutron convertors are ^{157}Gd and ^6Li , coated with CsI. ^{157}Gd has the advantage of a very high thermal neutron capture cross-section of 74000b at 0.1 nm, and it emits electrons in the energy range of 30-180 keV. ^6Li has a lower cross-section, of 520b at 0.1 nm, emitting α -particles and tritons. To compensate for its lower cross-section, thicker ^6Li foils can be used. As the detection is based mostly on the emitted tritons, the foil thickness is limited by the triton range which is of the order of 140 μm ($E_{\text{max}} = 2.74 \text{ MeV}$).

The escape probabilities of electrons from ^{157}Gd and of tritons from ^6Li are given in fig. 11. Assuming a full efficiency for charged particles and SE detection, the escape probabilities correspond to the neutron detection efficiencies. The optimal thicknesses for the detection of 0.18nm neutrons with ^{157}Gd and ^6Li foils, for a double-side operation mode, of the detector (fig. 10) are 2 and 120 μm respectively. The average number of SEs emitted from a $^{157}\text{Gd}/\text{CsI}$ convertor (1 μm of CsI), is about 5 per converted neutron. For ^6Li ,

Figure 10. The operation principle of the thermal neutron imaging detector based on a composite neutron converter (CNC). Avalanches induced by multiple secondary electrons emitted from the CNC, following the thermal neutron conversion, provide an accurate localization. Smaller avalanches, originating from direct gas ionization by charged particles, play a minor role.

there are on the average 60 triton-induced SEs escaping the CsI film per each converted neutron. In both cases the effect of gas ionization electrons will be negligible.

Detectors of this type, with single sided converters, have been tested. They operated for a long term and in a stable way in a neutron beam, at the gain of $5 \cdot 10^6$. Pulse-height spectra recorded with Gd and Gd/CsI converters, indicated a considerable enhancement in the detector response due to SEs originating from the CsI film. The neutron detection efficiencies, measured with thin natural Gd and Li converters, are consistent with our calculated data [20].

Best localization properties were obtained with the Li/CsI converter. Fig. 12 shows a projected slit image with an intrinsic resolution of 0.4 mm (fwhm). Fig. 13 shows 2D images of various objects, recorded with the SEE detector and with a neutron-sensitive film. Though preliminary and

Figure 11. Calculated n-induced escape probabilities of tritons and electrons from ^6Li and ^{157}Gd respectively, as function of the foil thickness, for two neutron energies. Forward (F), backward (B) and total (T) probabilities are shown.

unprocessed, these images demonstrate the good imaging properties of the new device.

The new, high flux, neutron imaging concept is practically not limited by size or geometry. It provides submillimeter localization properties and due to the small converter thickness it is free of parallax errors, even in divergent neutron beams. Its time resolution is only determined by the neutron conversion depth within the converter foil. Therefore, resolutions of the order of a few tens of ns are achievable.

The neutron detection efficiencies expected, for a single detector module comprising a CNC with electron multipliers at its two sides, are of 12% and 25% with $^6\text{Li}/\text{CsI}$ and 36% and 52% with $^{157}\text{Gd}/\text{CsI}$ converters at respective wavelengths of 0.1 and 0.25 nm. The detection efficiencies can be improved by cascading multiple foil/multiplier elements. Detectors based on ^6Li converters are practically insensitive to intense gamma background.

There is a variety of potential applications, operating the detectors either in current or in

Figure 12. A projected slit (0.4 mm) image obtained with a detector (fig. 10) equipped with a 60 μm Li/CsI convertor. The intrinsic resolution is 0.4 mm (FWHM) [20].

pulse counting modes. The latter has the advantage of detecting fast time-resolved phenomena. The proposed technique is suitable for real-time neutron radiography and tomography at pulsed beams from reactor and spallation sources, fast coincidence experiments where scattered neutrons have to be recorded in correlation with other particles, time-of-flight experiments, neutron diffraction studies at very high flux etc.

5. OTHER APPLICATIONS

Gaseous SEE detectors could be employed for fast tracking of relativistic particles [45]. In contrary to the previously discussed application, where the sensitivity to particles was kept intentionally as low as possible, the present aim should be finding efficient convertor materials providing high SE yields. Good candidates are low density (porous) alkali halide films, having enhanced emission properties, extensively studied in the past [46,47]. It was found that particles traversing porous KCl or CsI films, emit on the average several electrons into vacuum [48]. High detection efficiencies and subnanosecond timing properties were measured with such convertors coupled to

Figure 13. Comparative radiographic images of a small (25 mm in diameter) metal ball-bearing, made with thermal neutrons ($\lambda=0.2\text{nm}$) with a) a Polaroid Nr. 57 film preceded by a Li/ZnS convertor; b) an SEE detector equipped with a Li/CsI convertor. The images indicate clearly the presence (top) or the absence (bottom) of grease in the bearing.

small area vacuum MCP electron multipliers [49]. More recently, wire electrodes embedded in thick porous CsI layers were proposed as radiation detectors, but are drastically limited in counting rate [50]. Coupling porous CsI films to gaseous wire chambers would be an interesting solution to fast tracking of relativistic particles [45] provided such films can be operated in a stable way under high rate gas amplification.

Recent attempts in particle tracking with SEE detectors, combining low-pressure MSGCs and porous 10 μm thick CsI layers, were reported by Anderson [57]. Detection efficiencies of 45% were measured with MIPs. The authors propose the

use of CVD diamond convertors as possible air-stable highly emissive materials. Intensive experimental and theoretical investigations are required to find efficient and stable particle converter/emitter materials to make this method practical.

Another potential field of application of detectors equipped with surface emitters is in low-energy beta and gamma autoradiography - a widespread technique in life sciences. Compared to other techniques, like multistep avalanche chambers [52], better localization resolutions are expected due to the enhancement of the emission location of the beta-electrons from the biological sample. The use of CsI convertors will make possible the accurate localization of soft gammas, emitted from tracers like ^{125}I etc. This task cannot be fulfilled with wire chambers due to considerable parallax errors originating from the isotropic emission of the gammas.

Though good timing and localization properties of heavily ionizing particles are reached with MWPCs or multistep detectors operating at low gas pressures (a few Torr) [45,53], the introduction of thin solid convertors would dramatically increase the performance of such devices. The considerable emission yields ($10^2 - 10^3$ SEs/particle) induced by the interaction of a heavily ionizing particle, will permit a very stable operation at low detector gain.

6. SUMMARY

In this article we reviewed the principle, the properties and the applications of a novel class of fast radiation imaging detectors. The detectors are based on thin solid convertors coupled to low-pressure gaseous electron multipliers. The multiplication of radiation induced surface-emitted photoelectrons or secondary electrons in these multipliers has considerable advantages. The incident radiation (UV-photons, X-rays, thermal neutrons) can be accurately localized on a sub-nanosecond time scale and under very high repetition rates. The fast response and low sensitivity to particle background makes it possible to operate UV and X-ray detectors of this type in a stable way in RICH or TRD devices at future, high rate,

high energy physics experiments. Fast SEE-based particle trackers could also find important applications in this field. Fast time-resolved diffraction studies with intense X-ray and thermal neutron sources can add new dimensions to these important fields. The technique can be beneficial for X-ray and neutron radiography under very high radiation flux.

The accent in this work was put on electron multipliers based on low-pressure wire chambers and MSGCs. It should be remarked that we recently demonstrated that atmospheric pressure SEE-based multistep detectors operated with He-based mixtures, provide equally good X-ray localization resolution and detection efficiency [54]. As mentioned above, this gas mixture is less suitable for the detection of UV-photons, due to the high probability of losing part of the single emitted photoelectrons by backscattering to the photocathode. Time resolution, counting rate capability and the immunity to background radiation may be worse compared to the low-pressure operation mode. Considerable experimental efforts are investigated in this new field, accompanied by theoretical modelling of the production and emission of secondary electrons. Opt

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