**Nucl. Instr. and Meth. A547(2005)342**

# Detection of primary and field-enhanced scintillation in xenon with a CsI-coated GEM detector

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**Abstract**

We report the observation of radiation-induced primary and field-enhanced gas scintillation in xenon with a Gas Electron Multiplier (GEM) detector, having an internal CsI photocathode. The measurement of the time lag between prompt and delayed pulses can be exploited to reduce the parallax error in X-ray detectors having thick conversion volumes.

*Key words: Gas Electron Multiplier, GEM, CsI photocathode, Xenon scintillation*
*PACS: 29.40.Cs*

The Gas Electron Multiplier (GEM) is a thin, metal-clad polymer foil chemically etched with a high density of tiny holes [1]. On application of a voltage difference between the conducting sides, in a proper gas environment, each hole acts as an independent proportional counter; electrons released in the gas volume drift into the channels, multiply in avalanche and transfer, amplified, into the following region. With several electrodes in sequence, large amplification factors can be attained, with a strong suppression of photon and ion-mediated feedback [2]. Coating the first GEM in a cascade with a CsI photosensitive layer (Fig. 1), efficient and fast single photon detection can be achieved, with excellent position resolution [3].

Aside from being ionized, gases are excited by radiation and emit photons in characteristic continua. For xenon at moderate to high pressures, primary and field-enhanced (secondary) emission occur between 150 and 180 nm, a spectral region where the CsI photocathode has quantum efficiency between 20 and 30% [4]. The GEM device described above is well suited for detection of the internally emitted UV photons. At the collecting anode, one gets a prompt signal corresponding to photoelectrons produced by the primary light emission, followed by a later pulse with a delay corresponding to the drift time of ionization electrons in the detection gap. The detector can be used to

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determine the time of conversion of neutral radiation, and therefore the penetration depth, potentially allowing correcting the parallax error intrinsic in thick gaseous devices. The principle was demonstrated long ago with the so-called scintillating drift chamber, making use of an external photomultiplier to detect the primary light flash [5]. Recently, the same approach is used in dual-phase detector, where the primary scintillation in liquid xenon is exploited in conjunction with the measurement of drift time of ionization electrons extracted from the liquid into the gas phase, where the charge can be multiplied and detected [6, 7]. Various types of gas devices with internal CsI photocathodes are also described in [8], reporting also the observation of primary scintillation for low energy X-ray sources, albeit with rather low efficiency.

To investigate this possibility, we have mounted a small size (3x3 $cm^2$ active) multi-GEM detector in a vacuum-grade vessel having signal and HV feed-through; the vessel could be evacuated before gas filling. All measurements have been done in pure xenon at one bar. X-rays are converted in a 5 mm thick drift gap, followed by four multipliers at 2 mm spacing; the top electrode of the first GEM is coated with CsI. Drift field values up to 3 kV/cm could be reached in the conversion gap, permitting to largely enhance the photon yield by secondary emission. Signals are collected on the last electrode, a single pad with the size of the multipliers. For the present study, the detector has been exposed to 5.9 keV X-rays, emitted by an internal collimated $^{55}$Fe, and 22 keV X-rays from an external $^{109}$Cd source.

Fig. 2 shows examples of prompt scintillation signals, followed by the main charge pulse, for two values of drift field (200 and 2000 V/cm). In the first case, the early pulse is due to primary scintillation, while the ramping signal at higher field is due to the insurgence of secondary scintillation, produced by inelastic collisions of drifting electrons (existing data indicate a threshold for its onset at around 800 V/cm in xenon at one bar [9]). Notice also the small after-pulses; they are probably due to secondary electron extraction from the photocathode by positive ion produced in the first GEM [10], and probably set a limit to the maximum gain of the structure.

Dividing the amplified signals into two channels, sent to separate discriminators set at very low and high threshold respectively, we recorded the time difference between the early and main pulse. Figs. 3 shows the resulting distributions for the 5.9 and 22 keV sources at low drift fields; the dashed line corresponds to time distribution measured for the $^{55}Fe$ source in the detector without CsI photocathode, and has a width dominated by noise. Assuming a cut-off between prompt and delayed pulses at -100 ns, and integrating the spectra, we estimate the detection efficiency for primary scintillation of 5.9 and 22 keV X-rays to be 2% and 10%, respectively.

The efficiency for the prompt scintillation signal can be largely enhanced by secondary emission increasing the drift field, as shown in Fig. 4 for the $^{55}Fe$ source; at high fields, with an increase of photon emission, the electron collection time decreases due to faster drift velocity. Integration of the early part of the spectra, up to a cut-off around -100 ns, normalized to the total number of counts, provide an estimated detection efficiency for 5.9 keV of 20, 66 and 76%, respectively, at 1.3, 1.9 and 2.5 kV/cm. Secondary scintillation photons are of course emitted all along the drift (see also Fig. 2), but if detected in sufficiently large number, the prompt signal pertains the original time information albeit with some added dispersion. This is confirmed by the shape of the time distributions, having an almost constant plateau as seen in the figure.

It should be noted that an estimate of the drift velocity from the width of the plots provides values about two times higher than those expected for pure xenon. As drift velocity in noble gases is strongly affected by pollutants [11], we have indications that our conditions were not sufficiently clean, possibly affecting also the scintillation efficiency; the most likely culprit is the quality of the xenon used for the measurements. Work is in progress to clarify this issue.

While the depth of conversion could not be measured in the present set-up, the relative length of the raising edge in the histograms, compared to the known conversion gap thickness (5 mm) permits to infer an sub-mm intrinsic accuracy in the estimate of penetration, even with simple threshold discrimination; this could be improved by a better waveform analysis. A modified experiments set-up is in preparation, that will allow collimating the X-ray sources in the direction parallel to the gap, thus providing conversions at a known distance.

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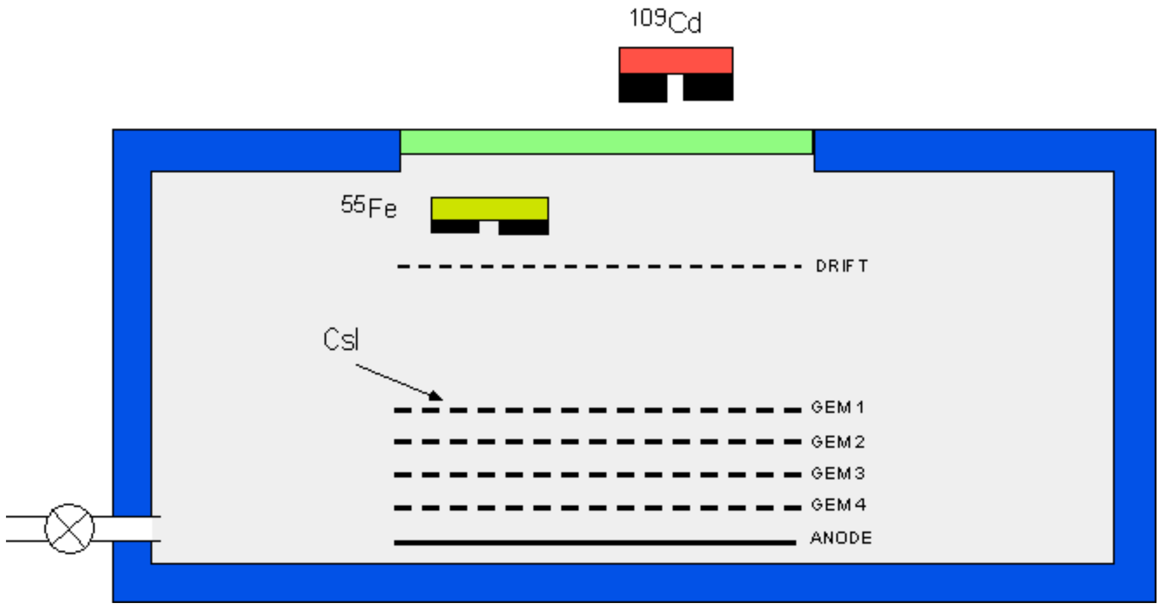


Fig. 1: Schematics of the multi-GEM detector used for the measurements. The first GEM in the cascade is coated with a CsI photocathode.

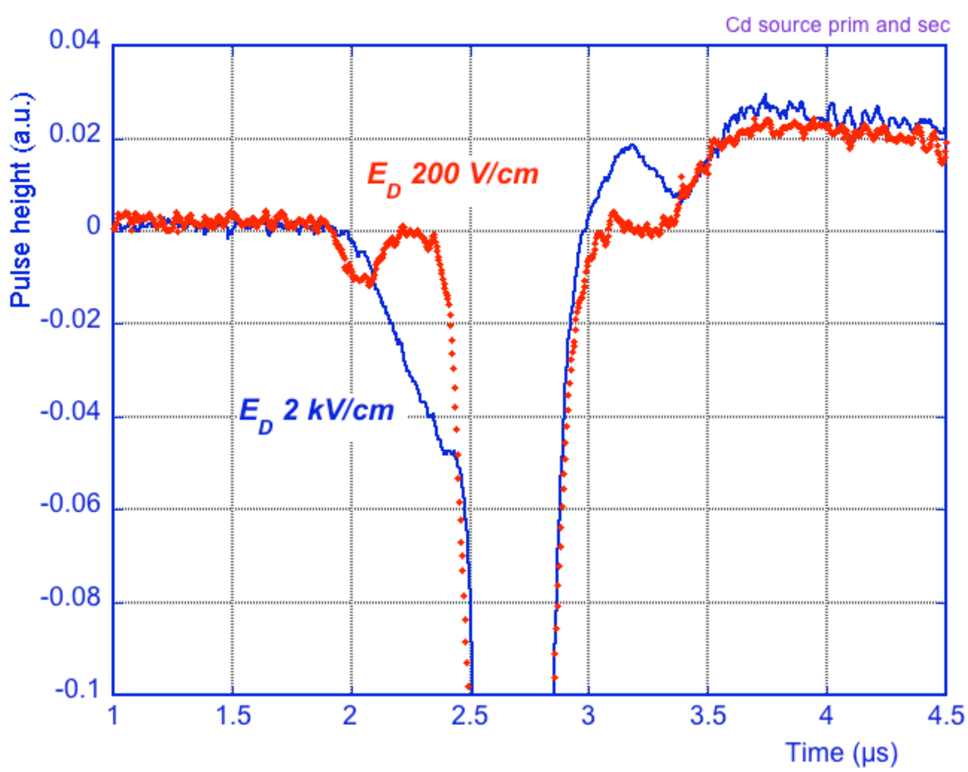


Fig. 2. Example of prompt scintillation followed by the main charge signal for 22 keV $^{109}$Cd X-rays, at a low and high value of drift field.

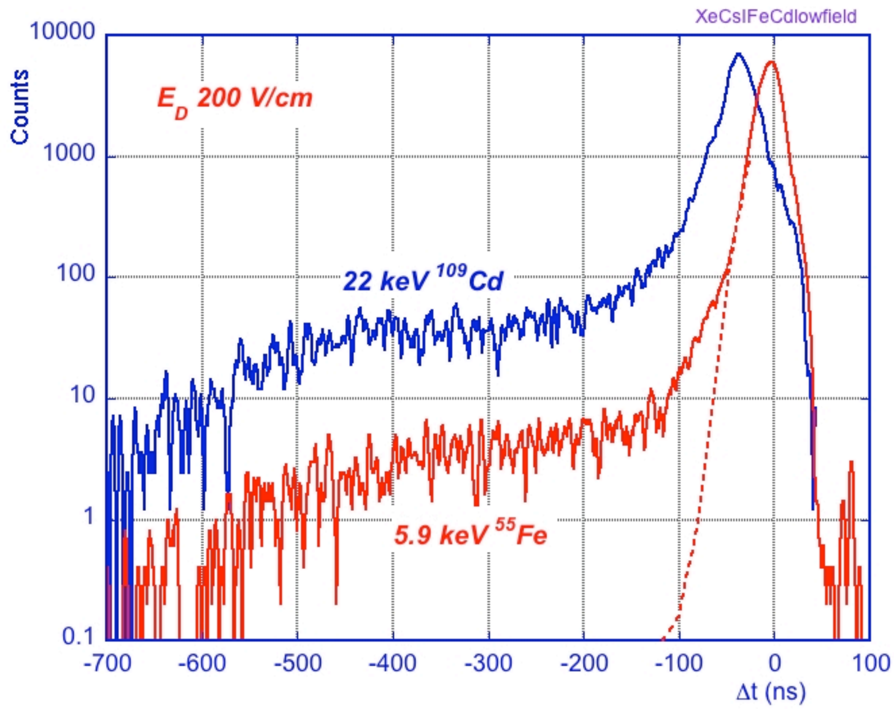


Fig. 3. Time difference between prompt and main signal for 5.9 keV and 22 keV X-rays at low field. The dashed line is the measurement in the same setup without CsI photocathode.

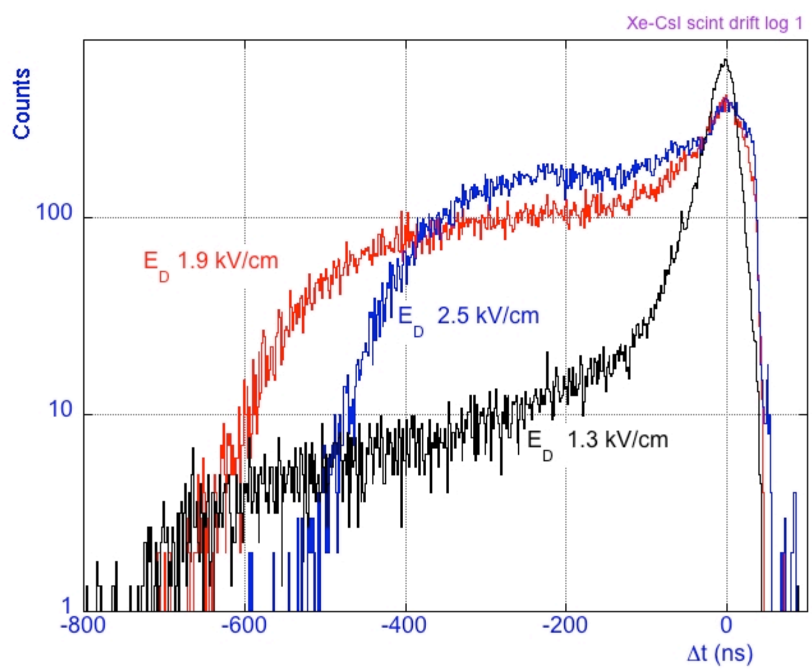


Fig. 4. Spectra of the time difference between prompt and delayed signal for three high values of drift field, above the onset of secondary scintillation (5.9 keV X-rays).