A FAST TIMING MICRO-PATTERN GASEOUS DETECTOR FOR TOF-PET

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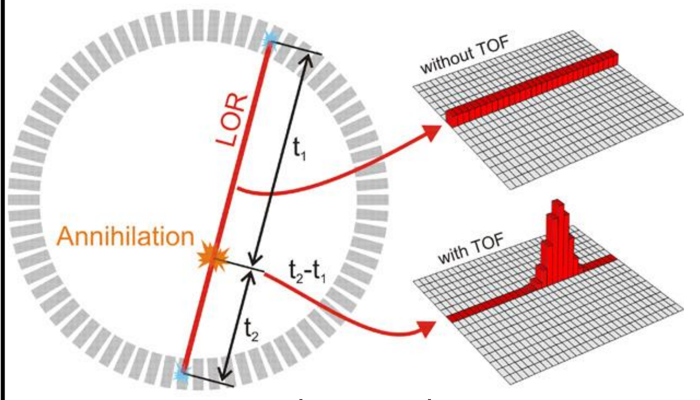
14th Pisa Meeting on Advanced Detectors (PM2018), 27 May - 2 June 2018 La Biodola, Italy

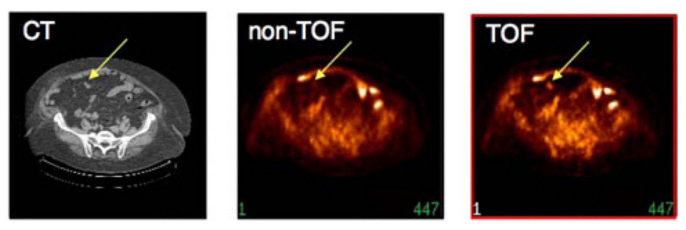
Abstract

A new generation of gaseous detectors, named Micro-Pattern Gas Detectors (MPGDs), has been developed thanks to an improved micro-structure technology. A new detector layout, named Fast Timing MPGD (FTM), has been recently proposed. The FTM would combine both the high spatial resolution (100um) and high rate capability (100MHz/cm^2) of the MPGDs with a high time resolution of 100ps. This new technology consists of a stack of several coupled layers where drift and multiplication stages alternate in the structure, yielding a significant improvement in timing properties due to competing ionization processes in the different drift regions. This contribution introduces the FTM technology as an innovative PET imaging device concept

Time-Of-Flight Positron Emission Tomography



PET principle, w/ and w/o TOF.
[source: srs.fbk.eu/projects/sublima]



PET scans of colon cancer. The use of TOF improves the lesion detectability (arrow).
[source: doi.org/10.17226/11985]

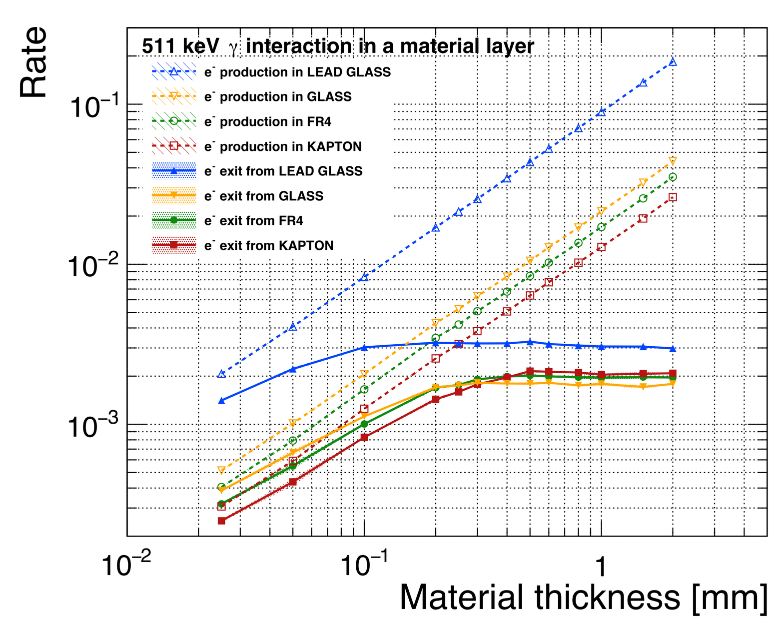
PET is a non-invasive technique to visualize organs with high metabolic activity

- β^+ sugar (FDG) is administered to a patient and concentrates at high metabolic activity regions (tracer)
- e^+ is released and looses energy during travel (~1mm) before annihilation
- 2γ (511 keV) are emitted back to back, their coincident detection determines the Line of Response (LOR)
- **w/o TOF** equal probability assigned to each point along the LOR
- **w/ TOF** few 100 ps measurement will lead to ~5 cm precision along the LOR
- use of **fast timing** in PET results in **high contrast** images

Ideal TOF-PET detector	LYSO crystal	MRPC	fast MPDG
high detection efficiency for γ	✓	≈ 0.66% (4 layers)	?
high spatial resolution	$\mathcal{O}$(5) mm	$\mathcal{O}$(0.5) mm	$\mathcal{O}$(0.1) mm
good energy res. to reject scattered γ's	✓ (≤10%)	✗	moderate
high time resolution	400-600 ps	≤ 200 ps	$\mathcal{O}$(200) ps
inexpensive to produce	✗	✓	✓
easy operation	✓	✗ (HV)	✓

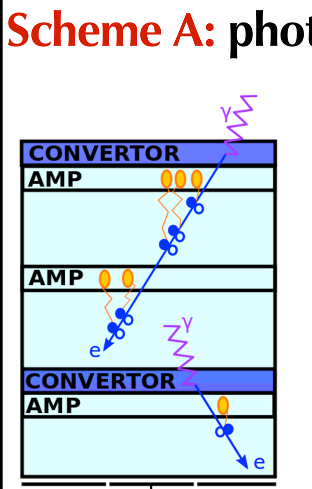
Photon Conversion

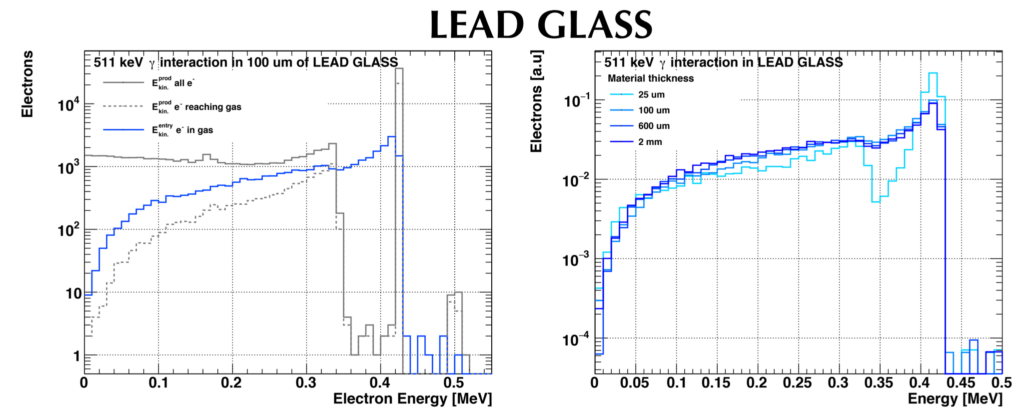
- GEANT4.10.03 version used
- FTFP_BERT_HP physics list
- Simulation of 511 keV γ interaction in different materials and thicknesses:
- PCB (FR4), kapton, glass (G4_GLASS_LEAD), lead glass (G4_GLASS_PLATE)
- **Adapt structure to detect 511 keV γ from PET**



FTM for photons proposals

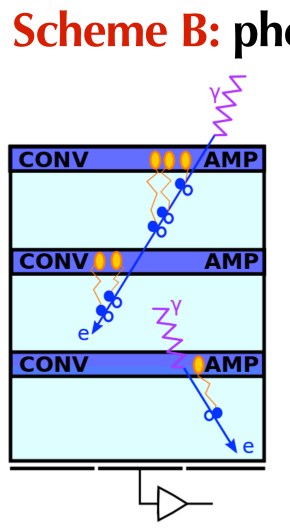
Scheme A: photon converted in high-Z resistive material + several thin amplification layers

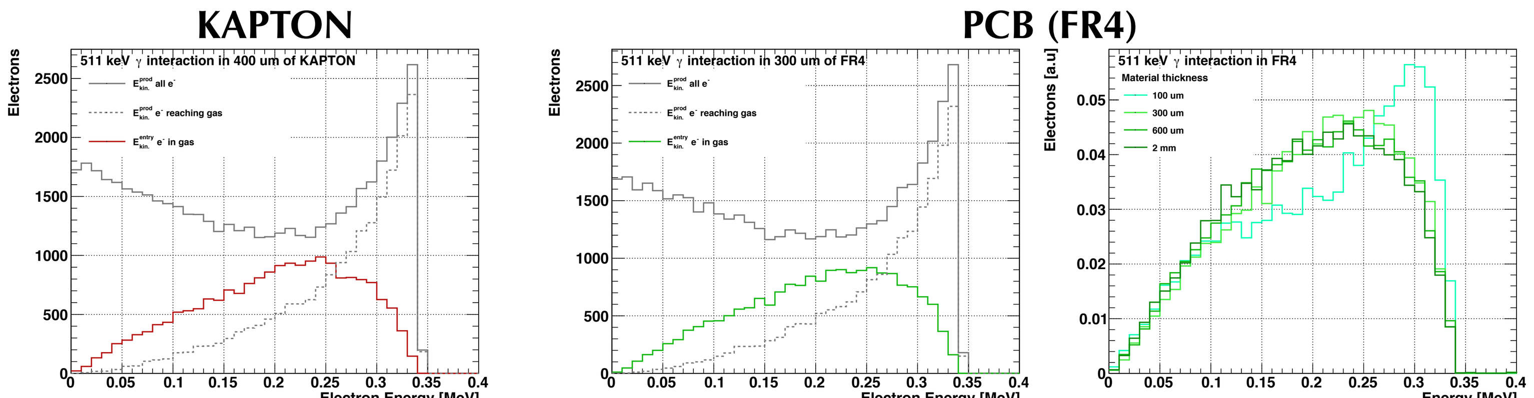




Electron production rate and energy spectra.

Scheme B: photon can convert in each amp. layer (only resistive material allowed)

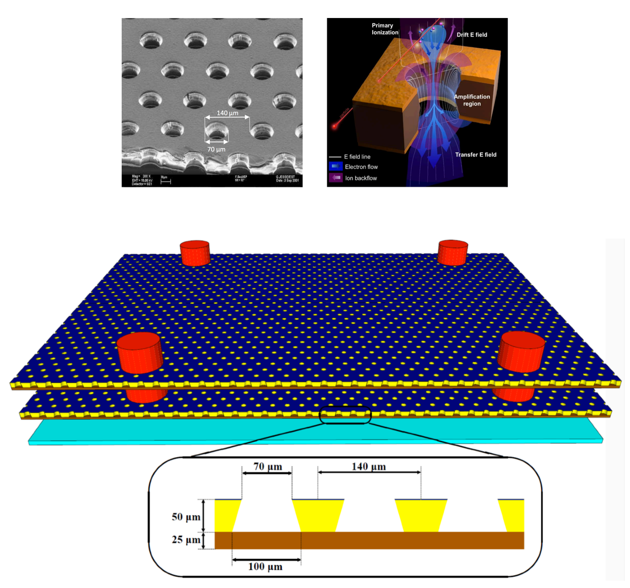




Electron production rate and energy spectra.

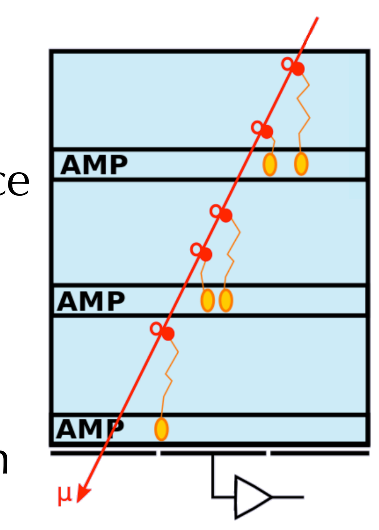
- Sub-relativistic e^- has high ionization density
- inverted order of drift and gain region → fast signal

Fast Timing Micro Pattern Gaseous Detector (MPDG) for photons



[source: arXiv:1503.05330]

- Charged particles ionize the gas in the drift region producing e^- multiplied in the gain region
- Improve time resolution by reducing distance of closest e-ion pair to the gain region
- resistive structure→ signal from any layer induced in external pickup strips
- split drift volume in N layers, each with own amp. structure→ improved time resolution
- low operational potentials $\mathcal{O}$(500 V)

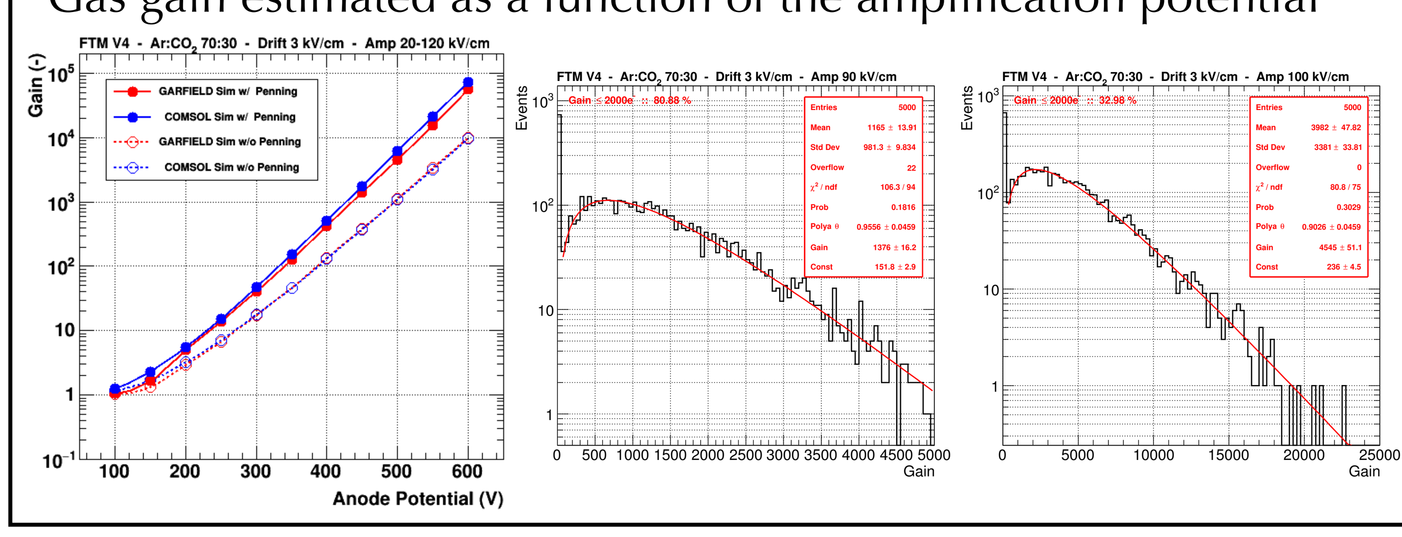


Fast Timing MPDG for photons: from Simulation to Prototypes

- **Photon conversion** (GEANT4):
  - estimate the conversion rate in resistive materials and obtain electron energy spectrum
  - trade-off between many detection layers (time res.) vs large drift regions (energy res.)
- **Electric field inside the detector** (ANSYS, COMSOL)
- **Primary ionization** (GARFIELD++, GEANT4):
  - number of primaries and first e-ion pair distance from amplification layer (time res.)
- **Energy resolution** with several small detection layers (GEANT4)
- **Drift and Avalanche** (GARFIELD++):
  - estimate gain of the detector and gain variation (energy res.)
  - simulation of signal formation and shape, spatial and time res. estimation
  - fast gain by integration of Townsend coefficient (COMSOL) corrected for Penning effect (MAGBOLTZ)
- **Final prototype performance estimation**

Gain Estimation

Gas gain estimated as a function of the amplification potential

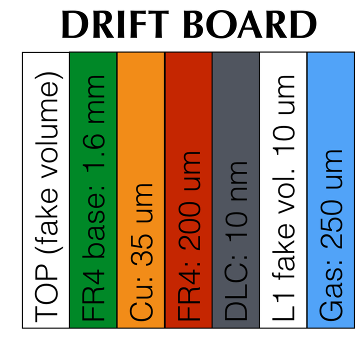


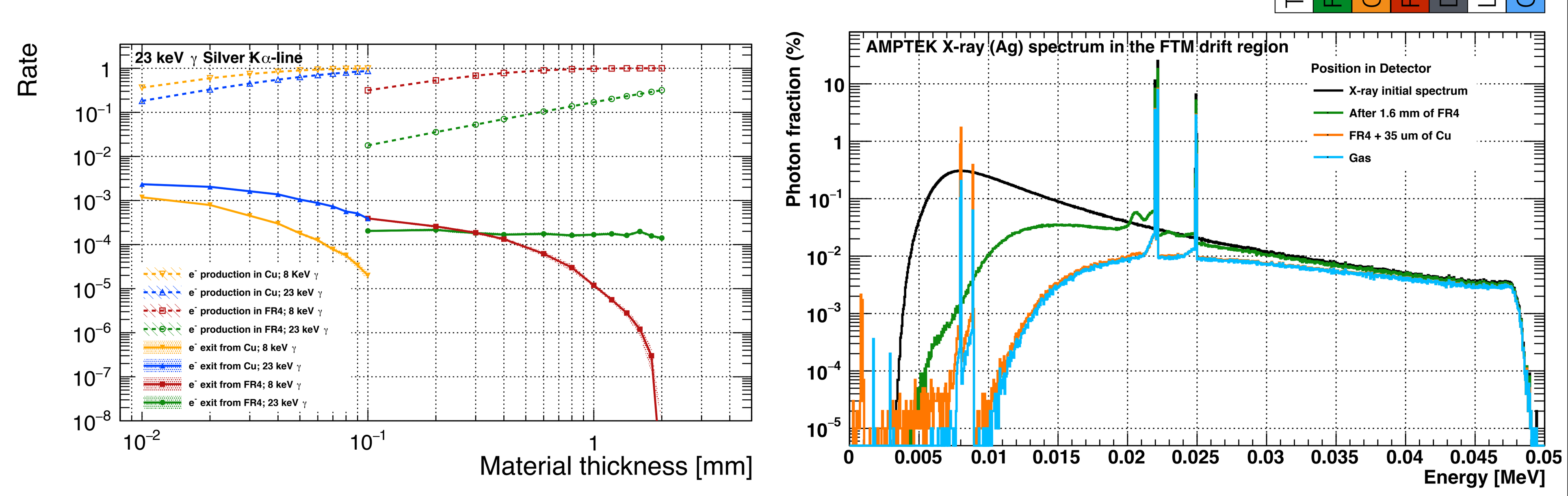
COMSOL: Penning-corrected Townsend coefficient is integrated.
GARFIELD: avalanche simulated with the Microscopic Tracking algorithm

Simulation Validation

- AMPTEK X-ray (Ag) passing the FTM drift board simulated using GEANT4
- Cu fluorecence activated
- Final spectra in the drift region available to simulate the final signal
- Comparison with data ongoing

DRIFT BOARD





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