# SIMULATION OF A FAST TIMING MICRO-PATTERN GASEOUS DETECTOR FOR TOF-PET


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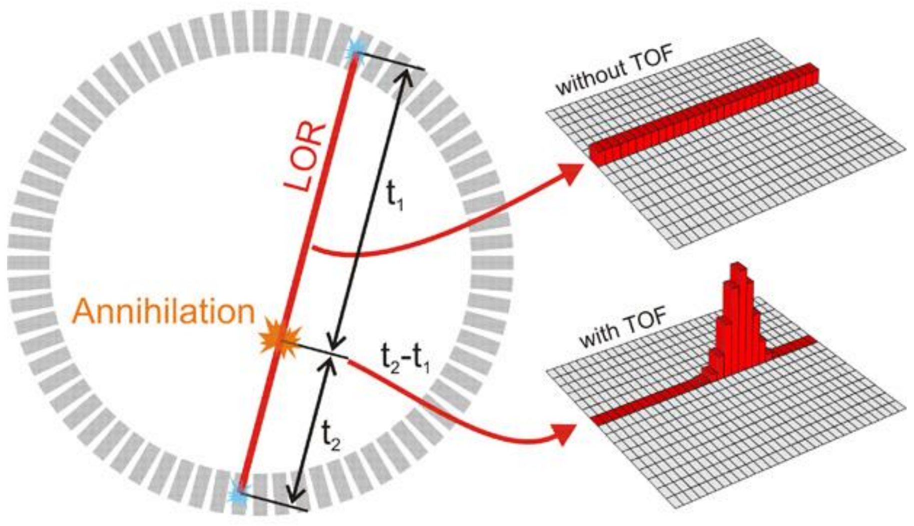
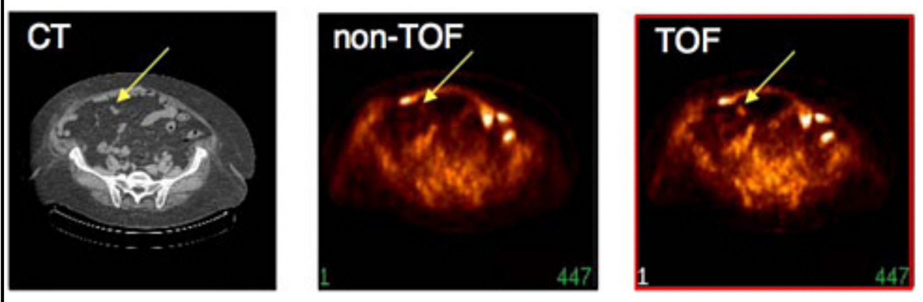
## Abstract

The design and development of a new affordable gas detector, combining high time resolution with high spatial resolution, while exploiting the advantages of a reasonable energy resolution, will be a boost for the design of affordable TOF-PET systems. The use of a gas detector allows to instrument on the one hand large areas in a cost-effective way, and to increase in image contrast for shorter scanning times (lowering the risk for the patient) and better diagnosis of the disease. In this report a dedicated simulation study is performed to optimize the detector design in the contest of the INFN project MPGD-Fatima. The final detector layout will be trade-off between fast time & good energy resolution. Results obtained with ANSYS, COMSOL, GARFIELD++ and GEANT4 simulation tools are presented.


## Time-Of-Flight Positron Emission Tomography




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

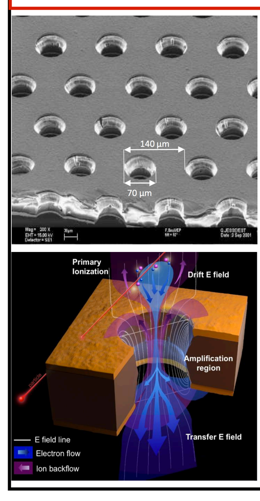



PET scans of a patient with colon cancer. The use of TOF improves the lesion detectability (arrow).
[source: doi.org/10.17226/11985]

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

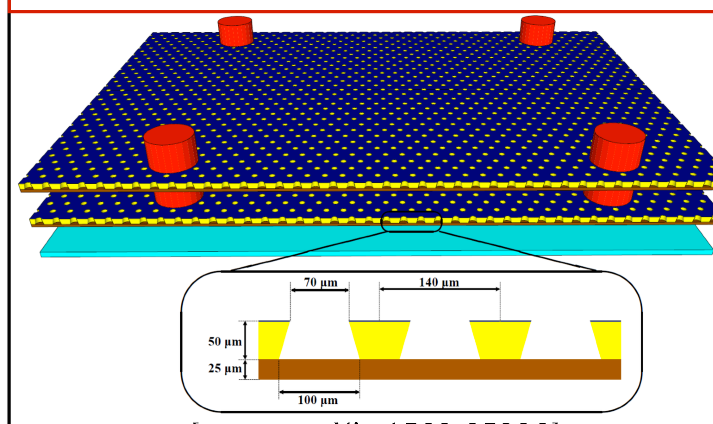
- $\beta^+$ sugar (FDG) is administered to a patient and concentrates at high metabolic activity regions (tracer)
- $e^+$ is released and looses energy during travel (~1mm) before annihilation
- 2$\gamma$ (511 keV) are emitted back to back, their coincident detection determines the Line of Response (LOR)
- **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

## Micro Pattern Gaseous Detector (MPDG)



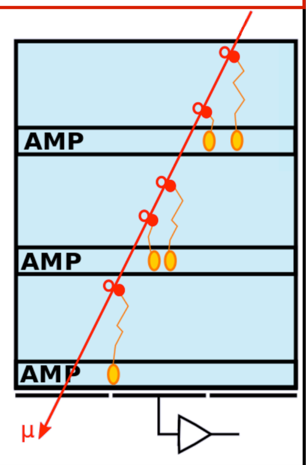
- Photo-lithographic techniques allowed to produce Micro Patterned detectors
- charged particles ionize the gas in the drift region producing $e^-$ multiplied in the gain region
- MPGD time resolution driven by fluctuations in creation of e-ion pairs
- Characteristics: high rate capability (> 50 MHz/cm²), good spatial resolution (50 μm), high efficiency (≥ 95%), time resolution of $\mathcal{O}$(5 ns), good energy resolution (~ 20% for X-ray γ)

## Fast Timing MPDG for charged particles




[source: arXiv:1503.05330]

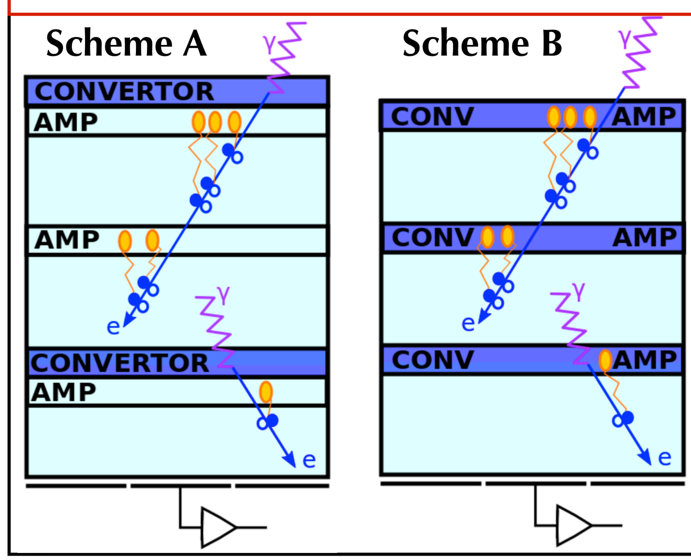
- Improve time resolution by reducing distance of closest e-ion pair to the gain region
- resistive structure→ signal from any layer induced in external pickup strips
- split drift volume in N layers, each with own amp. structure→ improved time resolution
- low operational potentials $\mathcal{O}$(500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




## Ideal TOF-PET detector

| 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 resolution 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) | ✓ |

## Fast Timing MPDG for photons

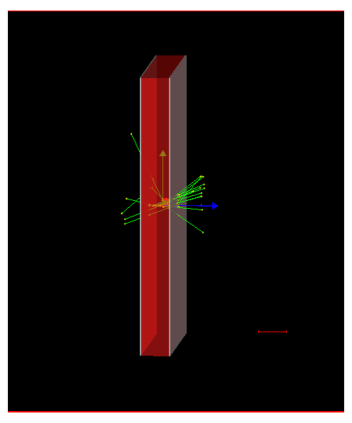



- Adapt structure to detect 511 keV γ from PET
- Two scheme under study:
  - A. photon converted in high-Z resistive material + several thin amplification layers
  - B. γ can convert in each amp. layer (only resistive material allowed)
- sub-relativistic e has high ionization density
- inverted order of drift and gain region → fast signal

## FTM for PET: from Simulation to Prototypes

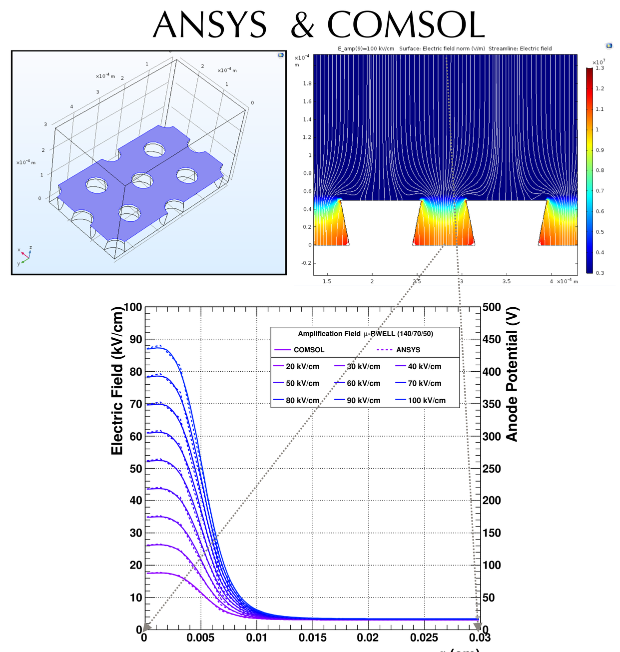
- **Photon conversion** (GEANT4):
  - estimate the conversion probability in resistive materials and obtain electron energy spectrum
  - trade-off between many detection layers (time resolution) vs large drift regions (energy resolution)
- **Electric field inside the detector** (ANSYS, COMSOL)
- **Primary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

GEANT4



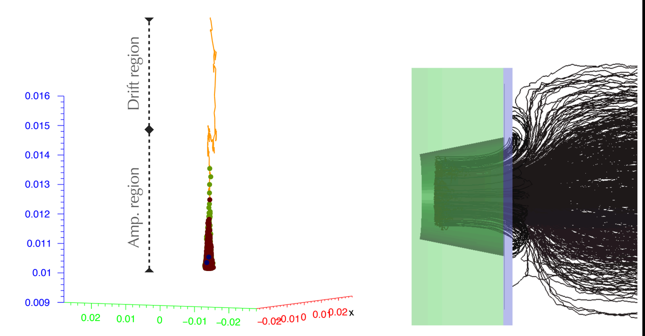
Interaction of 511 keV γ in 1 mm PCB

ANSYS & COMSOL




FTM geometry and Electric field.
COMSOL/ANSYS comparison (3 kV/cm drift, 20-100 kV/cm amp).

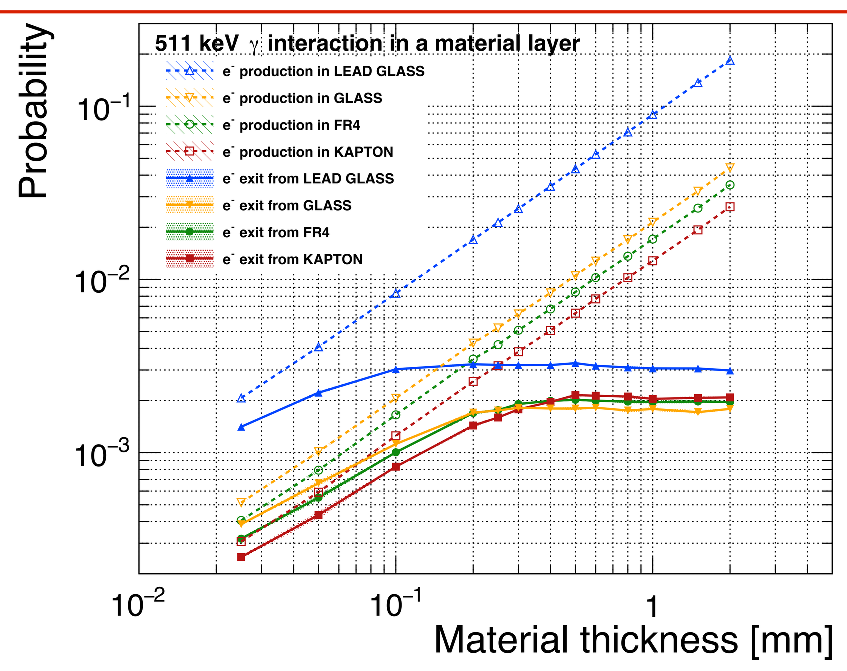
GARFIELD++ & ROOT

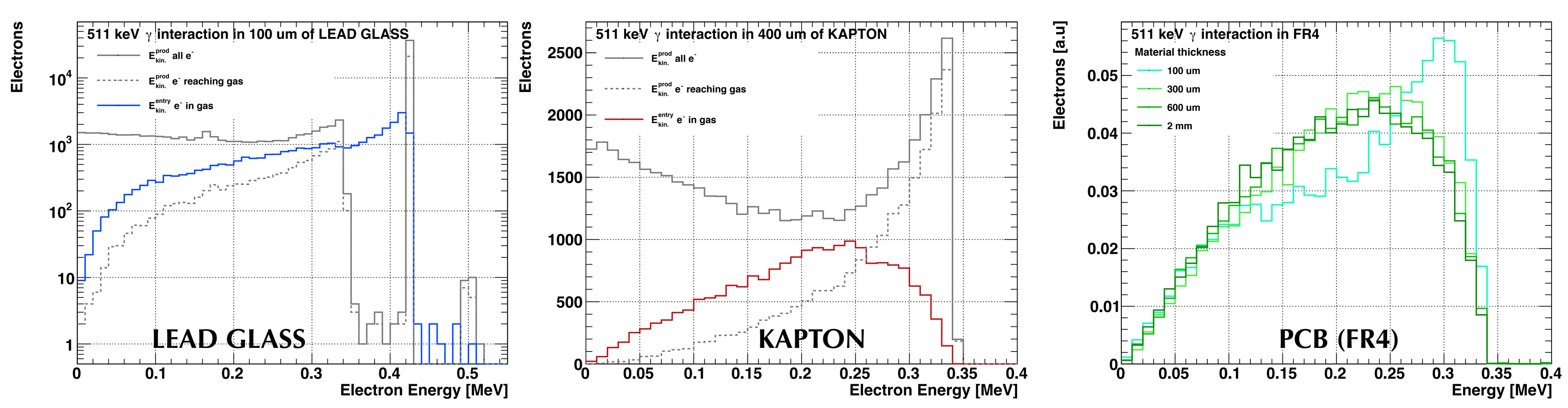



Drift of electron in the drift region and avalanche simulation in the amplification layer (Ar/CO2(70:30)).

## Photon Conversion

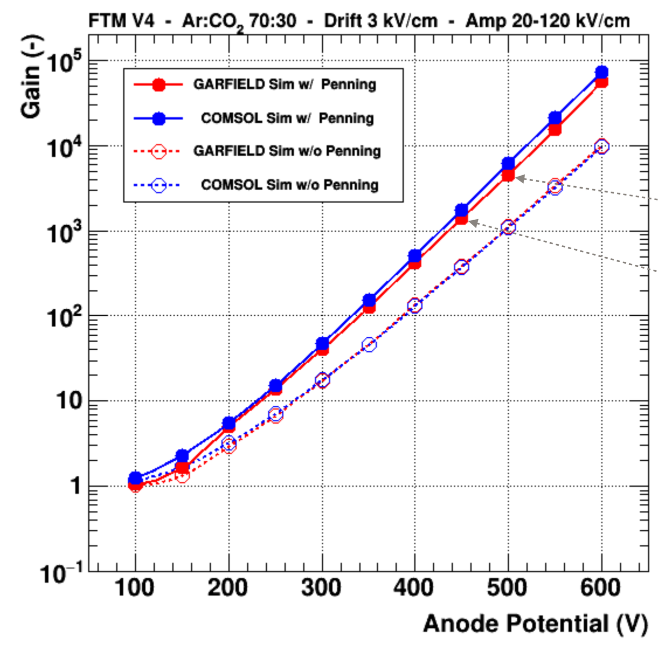
- Study to guide design of FTM for PET scheme, materials, geometry, …
- GEANT4.10.03 version used
- FTFP_BERT_HP physics list
- simulation of 511 keV γ interaction in different materials and thicknesses
  - PCB (FR4), kapton, glass (G4_GLASS_LEAD), lead glass (G4_GLASS_PLATE)

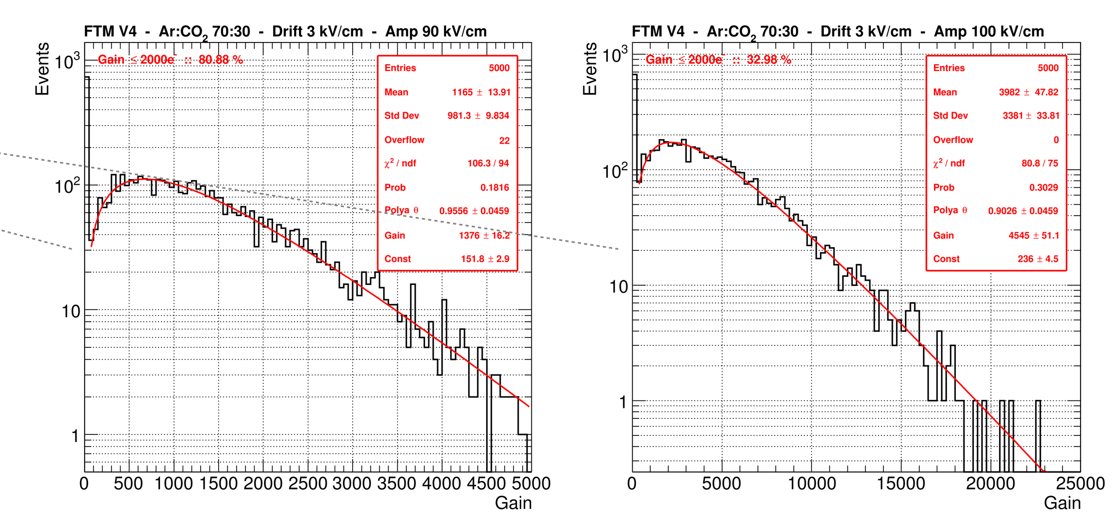



511 keV γ conversion in different materials is studied. Electron production probability and energy spectra for electrons entering the drift region.

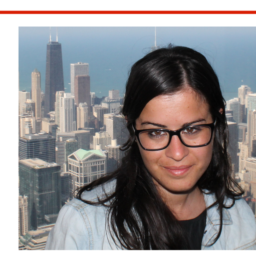
## Gain Estimation



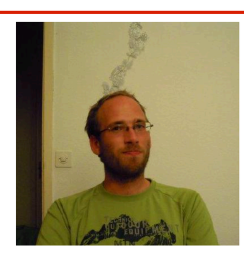




Gas gain estimated as a function of the amplification potential with GARFIELD and COMSOL.
With COMSOL the Penning-corrected Townsend coefficient is integrated, while in GARFIELD the avalanche is simulated with the Microscopic Tracking algorithm


## Contacts



Dr. Raffaella Radogna



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