Workshop on MPGD Applications Beyond Fundamental Science

First results of a combined fast-neutron & gamma-ray LXe imaging detector with gaseous photomultiplier readout

I. Israelashvilli[a,b], A.E.C. Coimbra[a], D. Vartsky[a], L. Arazi[a], E. N. Caspi[b], A. Breskin[a]

[a] Weizmann Institute of Science, Rehovot, Israel

[b] Nuclear Research Centre - Negev, Beer-Sheva, Israel

Artur Coimbra

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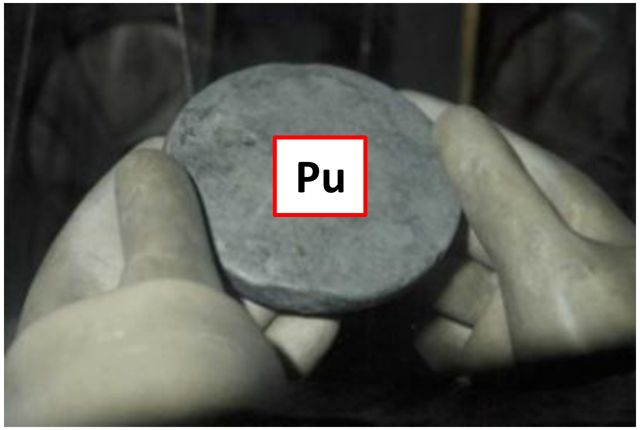
Goal

Development of a novel method for SIMULTANEOUS imaging and spectroscopy of Fast Neutrons & Gammas

➔ Search for hidden explosives and nuclear materials in cargo

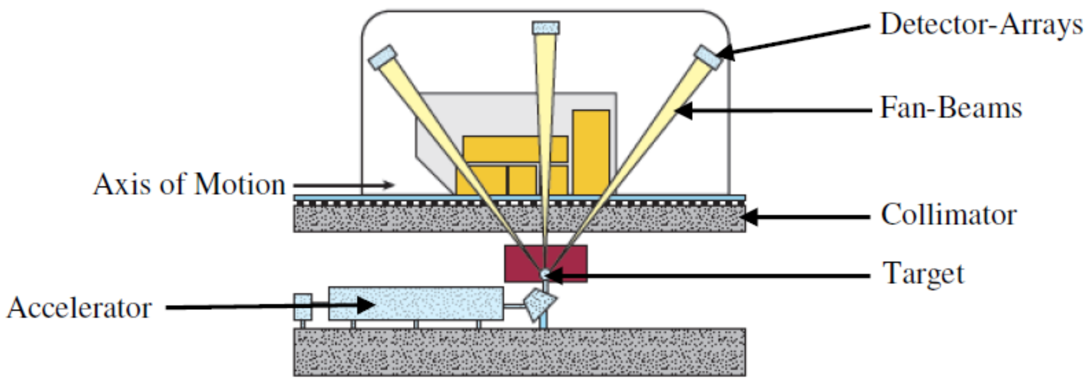
Requirements from a modern inspection system

- Explosives (low-Z) in cargo and luggages (>150g).
- Special nuclear materials (high-Z) in trucks, containers (>1kg).
- Large-area scans (>20x160 cm^2)
- High detection efficency (>10%) for γ and fast-n
- Spatial resolution: 5 – 10 mm
- Good discrimination between gammas and neutrons
- Short inspection time ➔ High rate capability



Gamma radiography

- High resolution imaging of shape and density.
- Incapable of distinguishing organic materials of similar density but different chemical composition.
- Discrimination of common high-Z materials (Pb, W) from special nuclear materials can be achieved by **Dual-Discrete-Energy Gamma Radiography (DDEG) ***
- Reaction $^{11}B(d, n+\gamma)$ provides 4.4 MeV and 15.1 MeV gamma as well as quasi-continuous neutron energy spectrum (1 – 17 MeV).



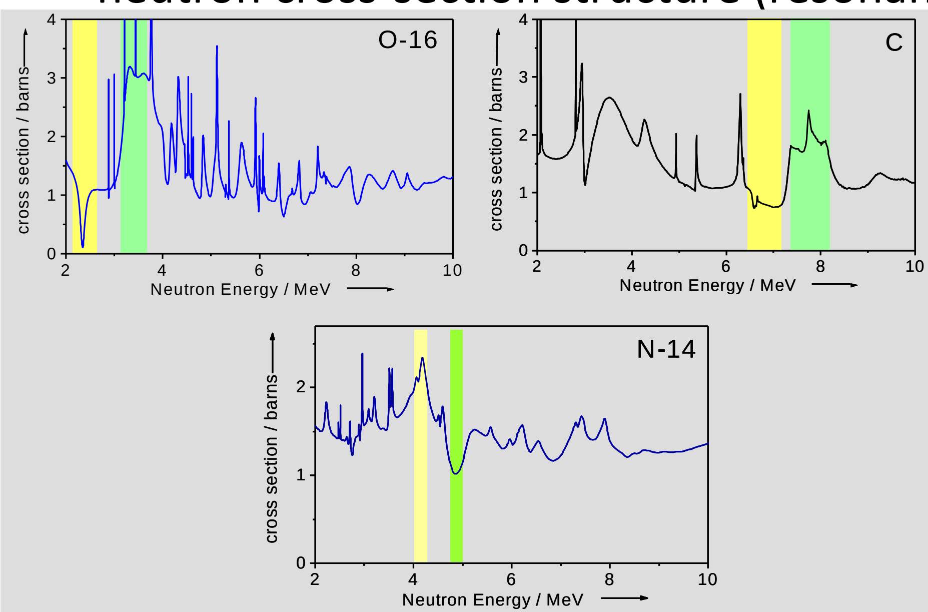
* M. B. Goldberg, Method and System for Detecting Substances such as Special Nuclear Materials, U.S. Patent 7381962 (2008)

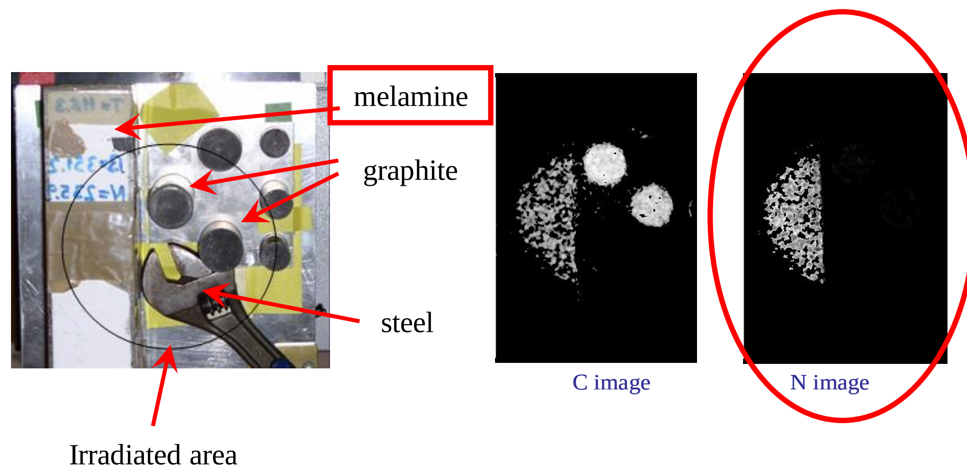
Fast neutron imaging

- Provides sensitive probe to materials rich in low-Z elements.
- Hydrogen, carbon, nitrogen or oxygen principal elements in plastic explosives/narcotics.
- All military explosives are nitrogen rich
- **Fast–Neutron Resonance Radiography (FNRR) *** provides elementally resolved images employing different neutron energies, selected to exploit the characteristic neutron cross-section structure (resonances) of low-Z elements.

RDX – $C_3H_6N_6O_6$

Ethanol – C_2H_6O





Pre-requisite: measuring neutron energy

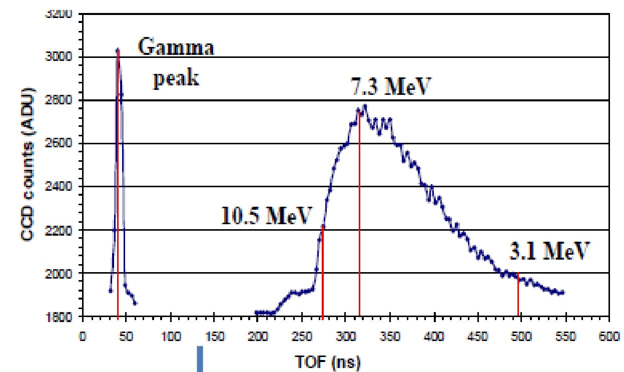
Automatic detection

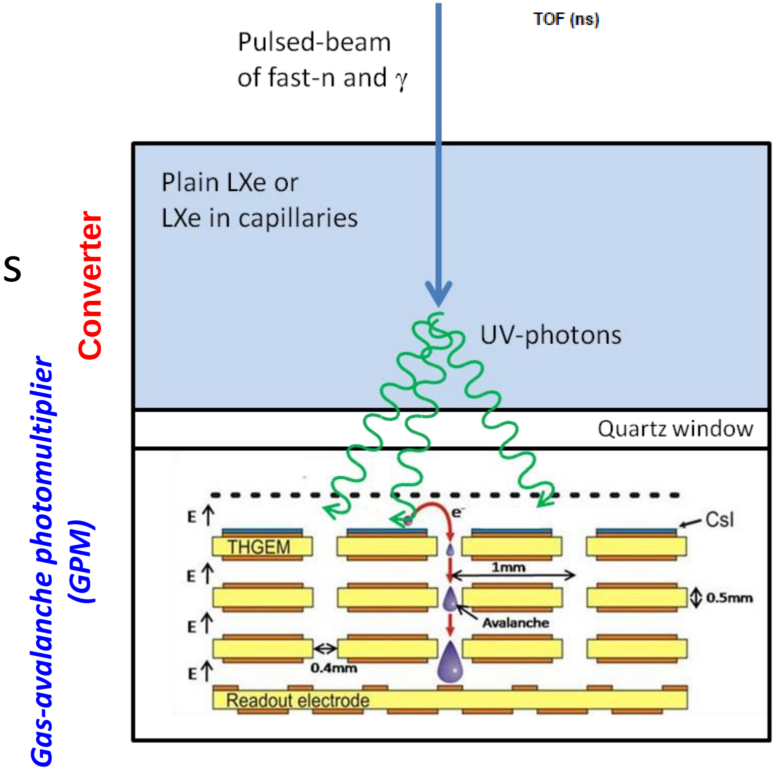
* D. Vartsky et al., Proceedings of "International Workshop on Fast Neutron Detectors and Applications" PoS(FNDA2006) 064. http://pos.sissa.it//archive/conferences/025/084/FNDA2006_084.pdf

Combined neutron and gamma detector concept

- **Liquid Xenon scintillator/converter** coupled to **gaseous photon imaging detector: a Gaseous Photomultiplier (GPM)** *.
- **Neutrons:** energy selection by time-of-flight (TOF)
- **Gammas:** pulse height measurements of 4.4 and 15.1 MeV
- **Both detected by the same detector**
- LXe contained within “fiber-like” capillaries
- LXe technology: mastered cryogenics, scalable, efficient

  ➔ **suits large systems!**



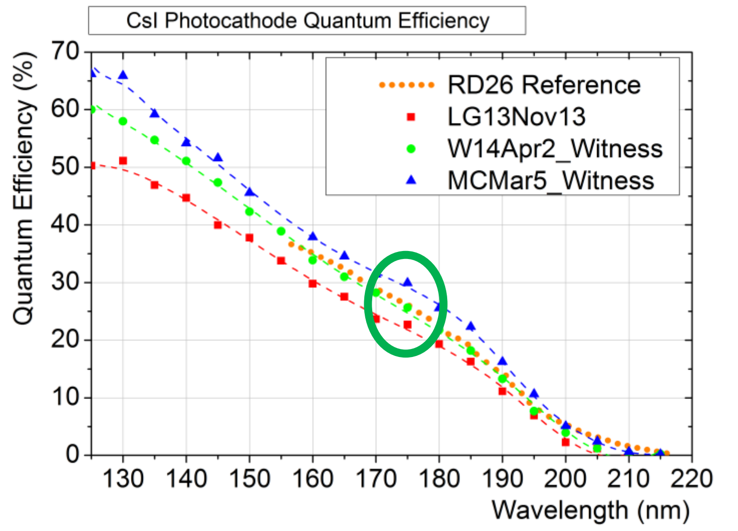


* L. Arazi et al. JINST 10 (2015) no.10, P10020 arXiv:1508.00410

Liquid xenon scintillator

- High density (**2.85 g/cm3**)
- Fast (**2ns**)
- Cryogenic (-100ºC)
- Scintillation light matches CsI-photocathodes:

  QE~25% @ 175nm



- Scintillation yield *:

  Gammas: **20 photons per deposited KeV**

  Neutrons: **7 photons per deposited KeV** **(E_{recoil} <10 keV)**

  9 photons per deposited KeV **(E_{recoil} >10 keV)**

- 5cm LXe in capillaries:

  High detection efficiencies:

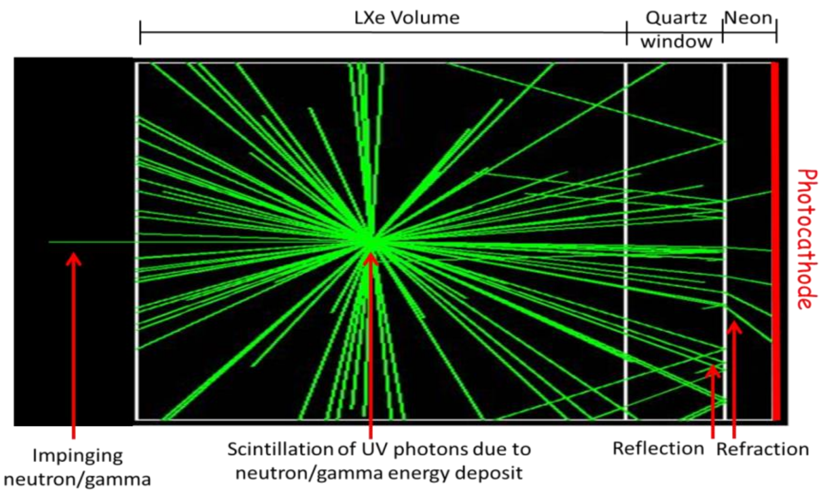
  n: ~20% **(2-14 MeV)**

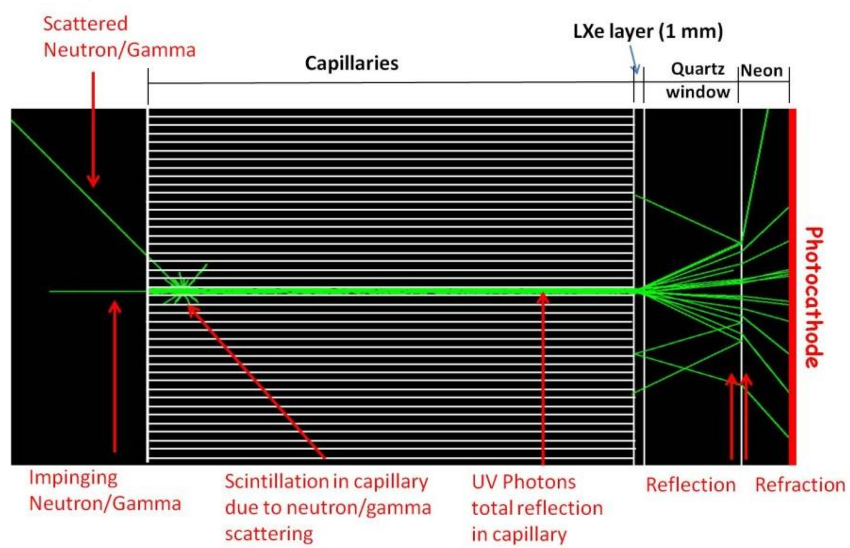
  γ: ~30% **(2-14 MeV)**

* E. Aprile et al. 2009 Phys. Rev. C79, 045807

Liquid xenon scintillator optimization*

- Simulated several concepts of detector in GEANT4





- Disregarding scattering from surrounding materials
- Four configurations were simulated:
  - Plain LXe volume
  - Polyethylene capillaries
  - Teflon
  - **Tefzel** **(contains H_2)**

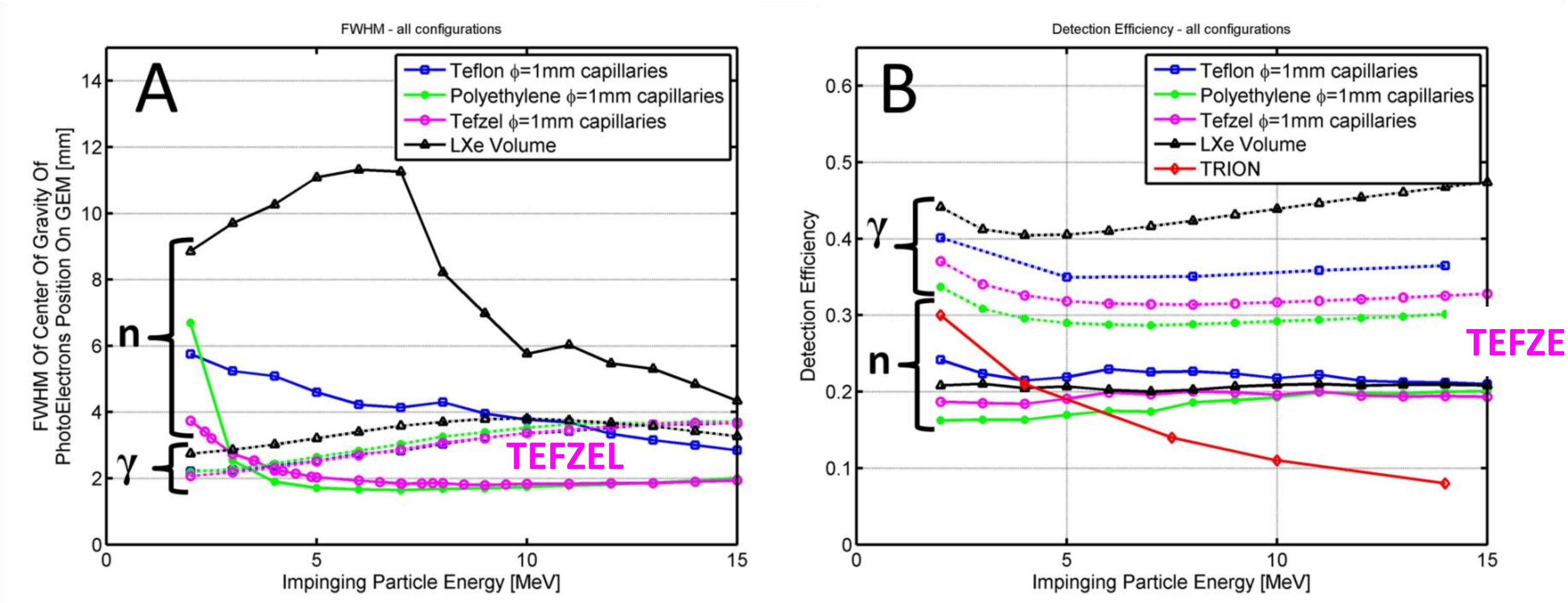
Reduces mean free path of neutrons;
Higher efficiency of neutron energy transfer

Parameters:
- Energy deposition spectra (gamma, n)
- Counting/Imaging of scint. photons
- Spatial resolution
- Detection Efficiency

* Israelashvili, I. et al. JINST 10 (2015) no.03, P03030 arXiv:1501.00150

Liquid xenon scintillator optimization*

- FWHM of center of gravity distribution and detection efficiency as a function of energy of impinging neutrons and gammas.



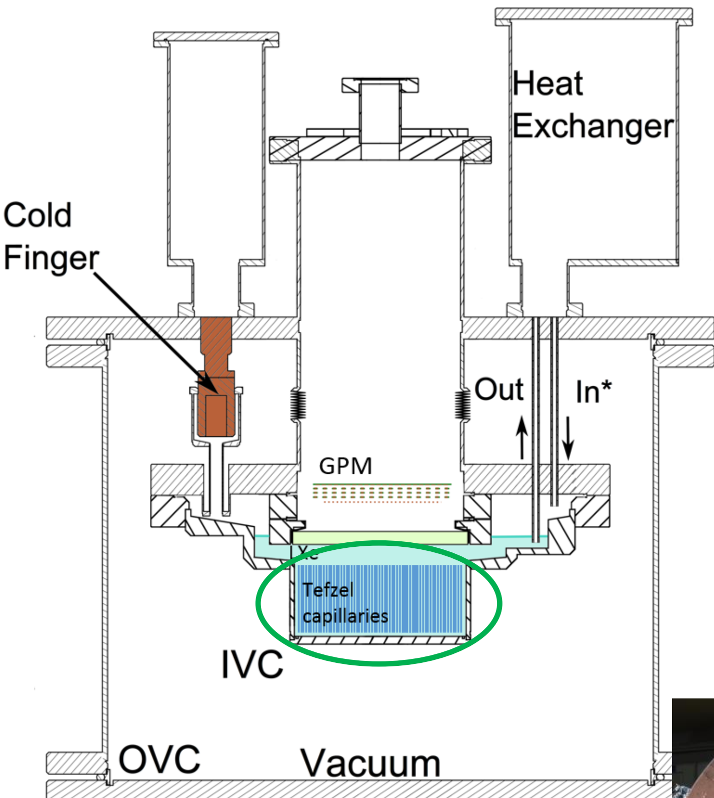
- Reduction of neutron scattering length ➔ spatial resolution significantly improved.
- Capillaries “transparent” to gammas, similar resolution for all materials

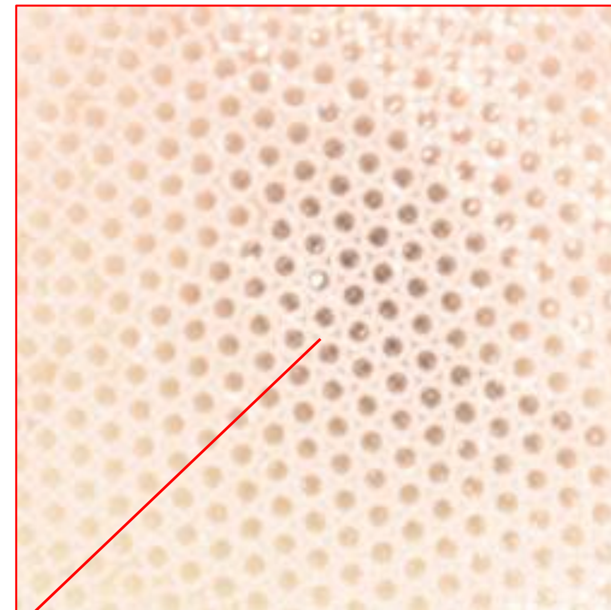
- High detection efficiencies
  - **~20%** for fast neutrons
  - **~30%** for gammas
- Low density capillaries reduces efficiency for gammas by ~10%

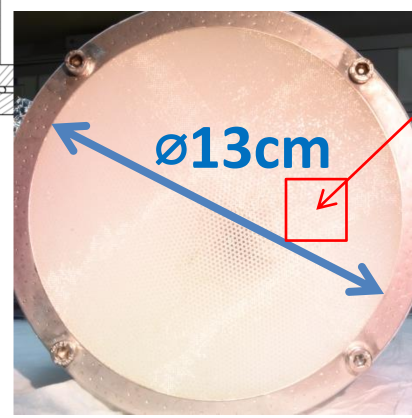
* Israelashvili, I. et al. JINST 10 (2015) no.03, P03030 arXiv:1501.00150

WIS Liquid Xenon (WILiX) facility

- Schematic of WILiX including GPM assembly with capillaries



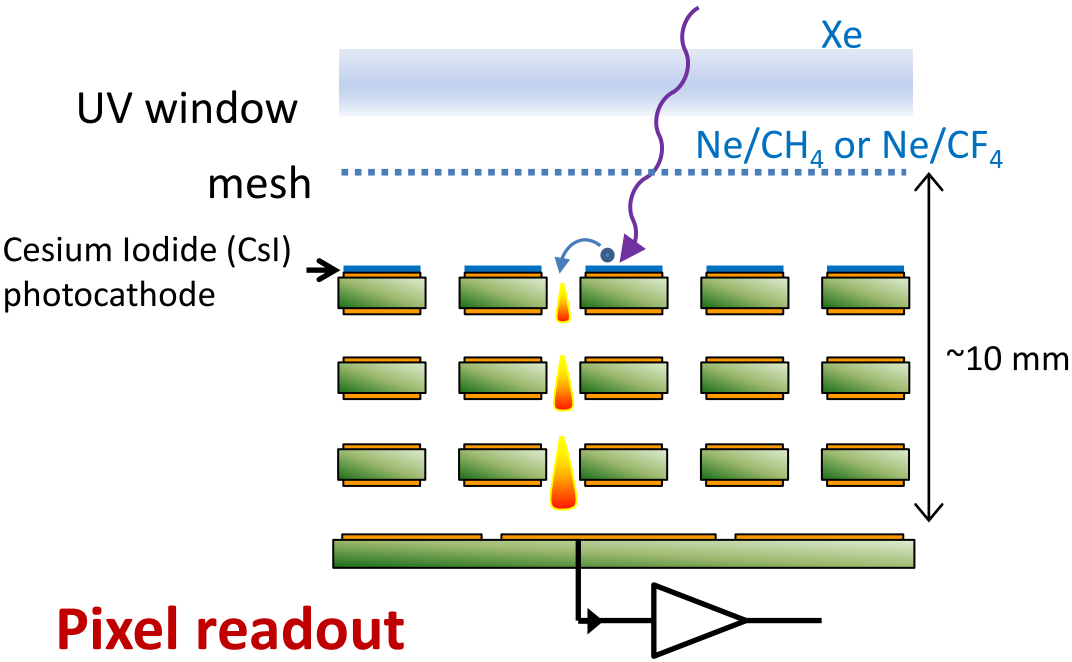


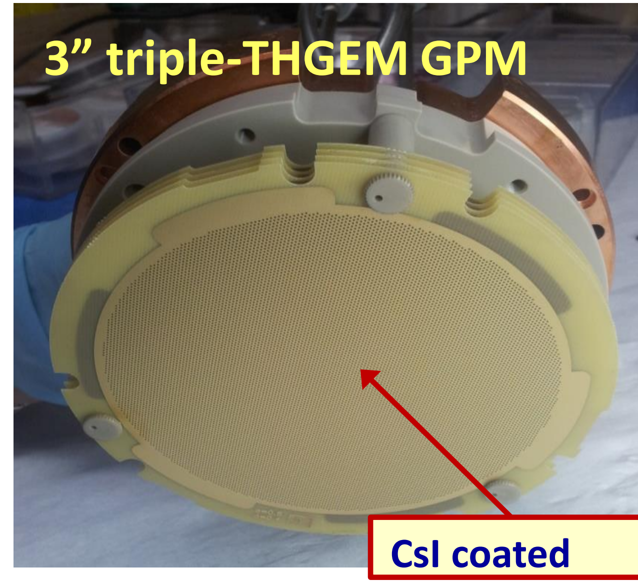


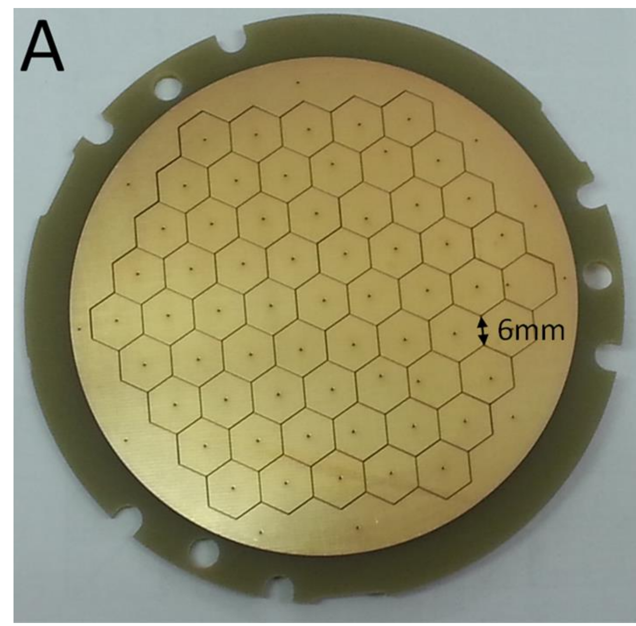
- **~5500 Tefzel capillaries**
- **OD=1.6mm, ID=1.0mm, l=70mm**
- **Immersed in LXe**

GPM*: Triple THGEM/CsI

*Gaseous Photomultiplier







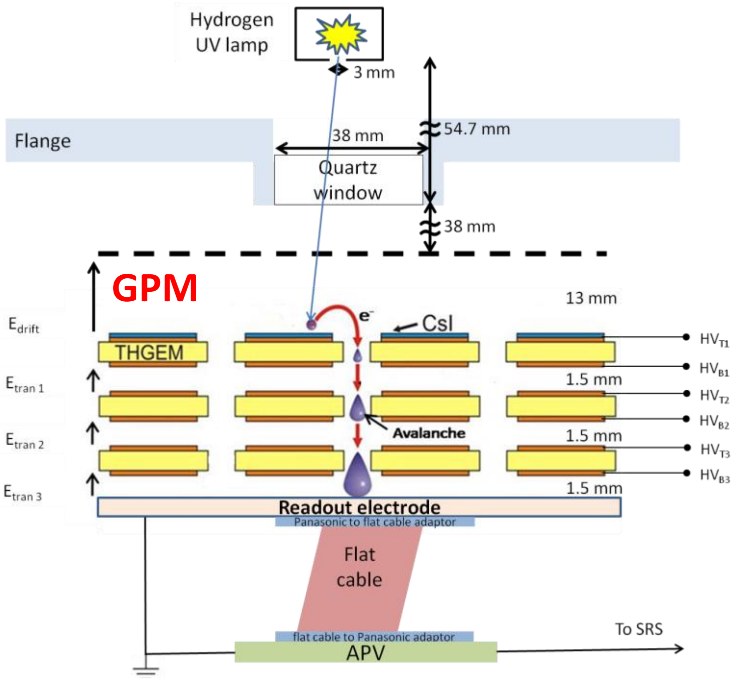
- **61 hexagonal pads (pixels) electrode**
- **Low noise readout electronics**

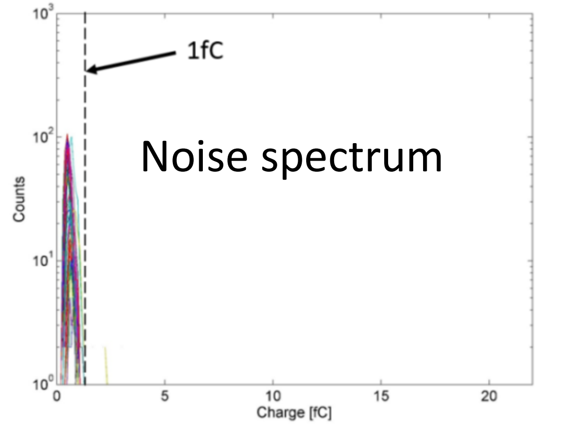
* L. Arazi et al. JINST 10 (2015) no.10, P10020 arXiv:1508.00410

* D. Vartsky et al. Nucl. Instrum. Meth. A824 (2016) 240

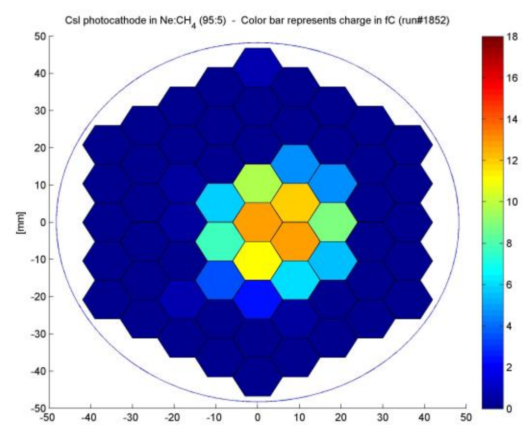
Triple-THGEM/CsI GPM

- Imaging of **UV photons** was done using a **flashed hydrogen lamp**
- Emitted photoelectrons are multiplied by the **GPM**; signals collected on hexagonal pads
- Low noise electronics for data acquisition





- Typical single event
- Color bar represents charge in fC
- Center-of-gravity (CoG) calculated for each event

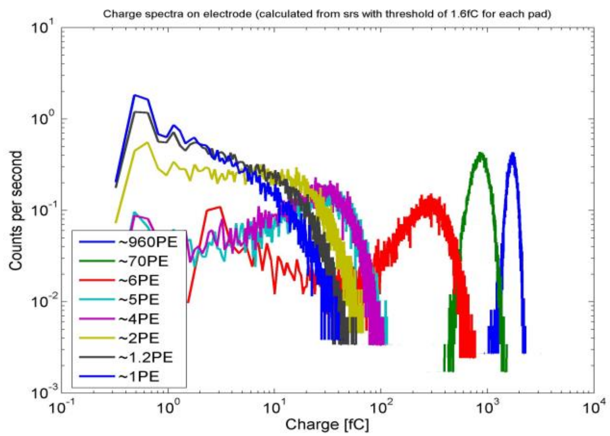


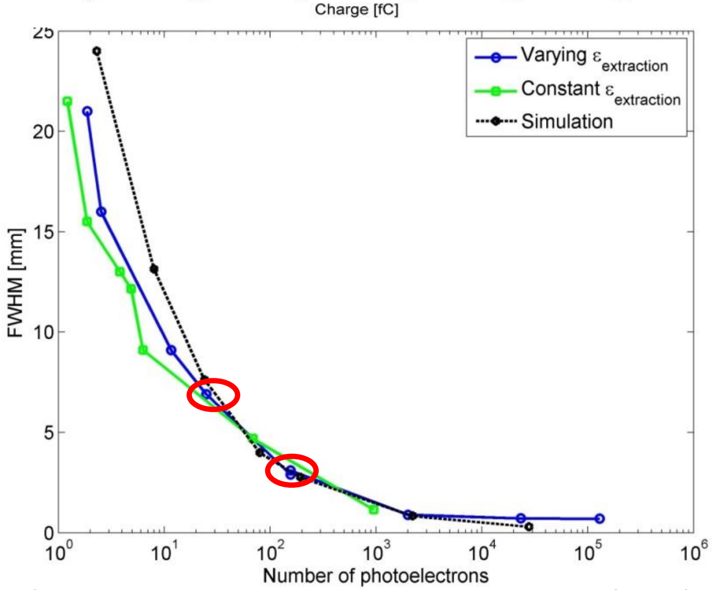
$$\overrightarrow{COG_i} = \frac{\sum_{j=1}^{j=61} \overrightarrow{P_j} \cdot Q_{i,j}}{\sum_{j=1}^{j=61} Q_{i,j}}$$

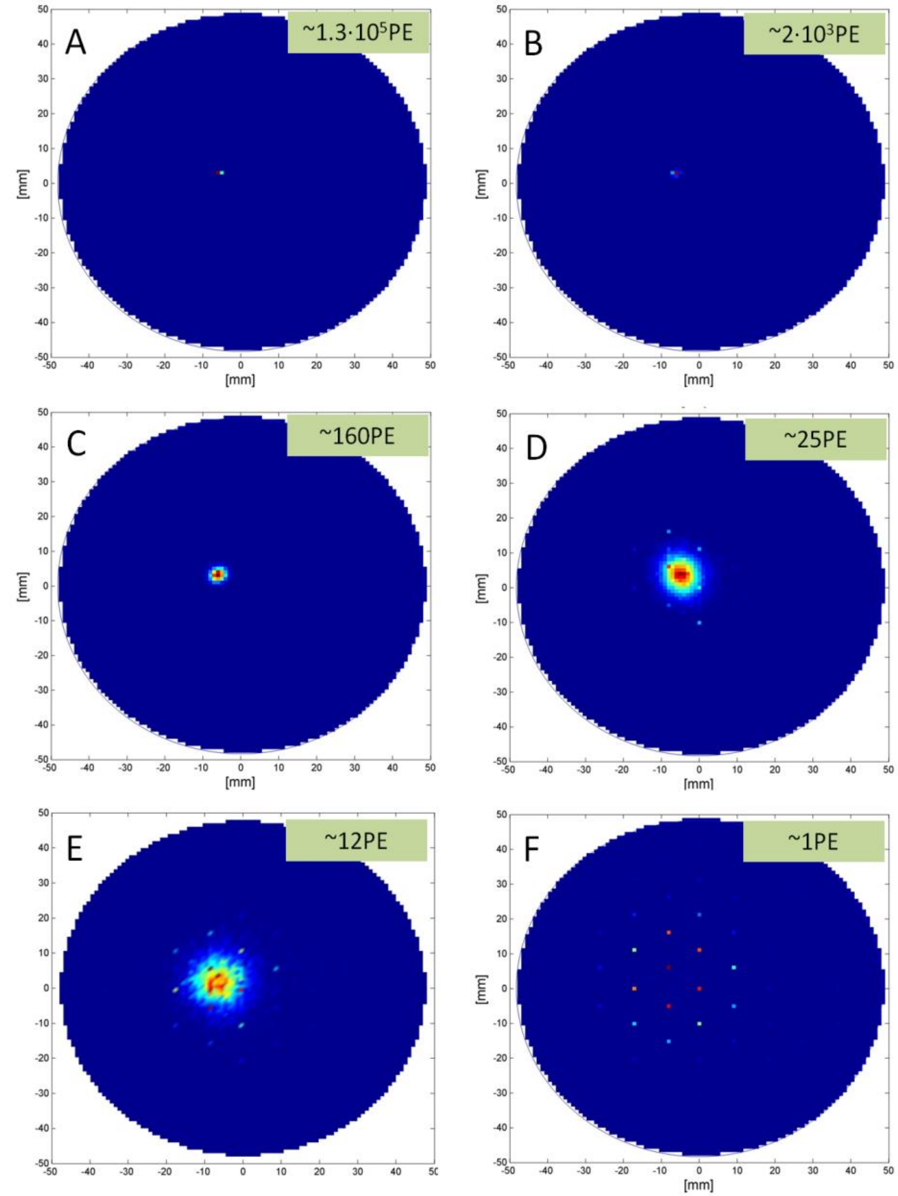
- Fixed collection photoelectron collection efficiency ➔ voltage on first stage constant

Triple-THGEM/CsI GPM

- Center-of-gravity 2D histograms for different numbers of photoelectrons, down to single PEs
- FWHM of CoG distributions vs photoelectrons



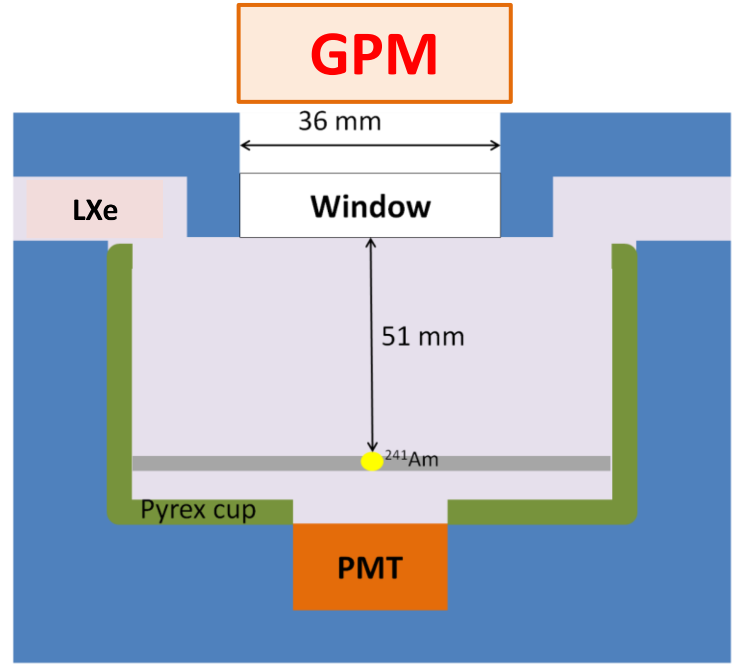




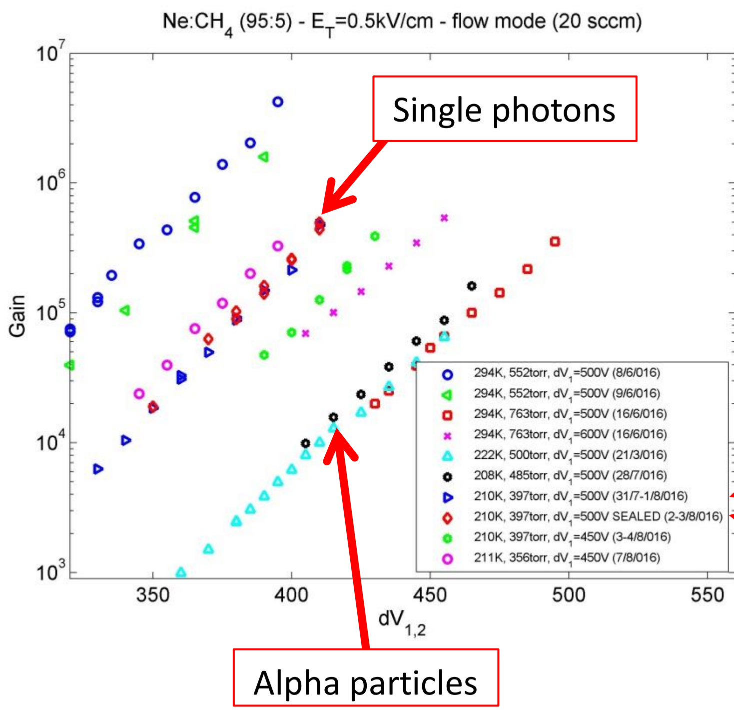
* D. Vartsky et al. Nucl. Instrum. Meth. A824 (2016) 240

^{241}Am source imaging

- Experimental setup
  - Spectroscopic ^{241}Am alpha source immersed in Lxe
  - 5.5 MeV alphas stopped within 40 µm
  - PMT used as trigger
  - GPM above window



- GPM working point

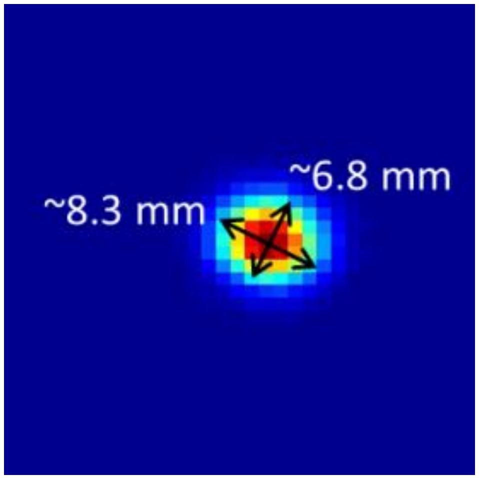


Corresponding to roughly the same gas density as in 1.1 bar at room temperature.

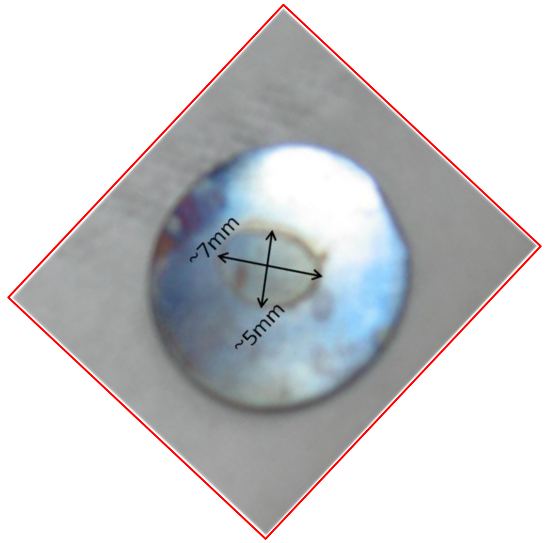
- We imaged the deposited active spot with the GPM

^{241}Am source: imaging & time resolution

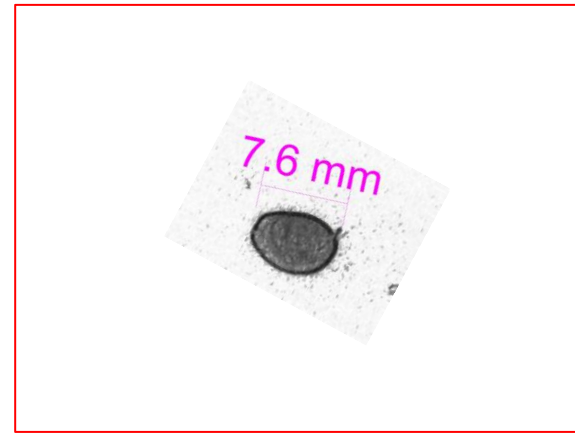
- **GPM image:**



- **Real picture:**

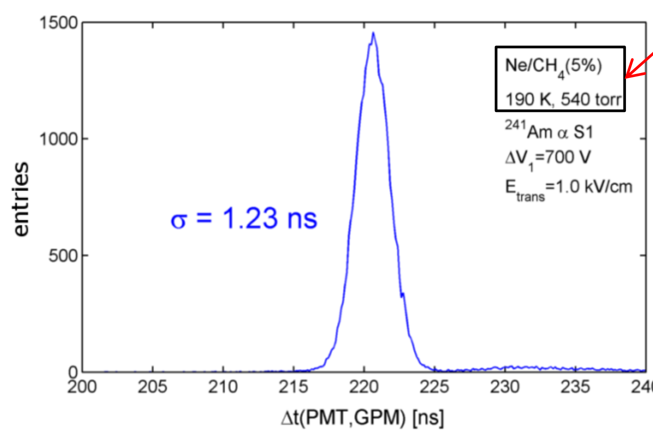


- **Digital radiography plate (Fuji) image**



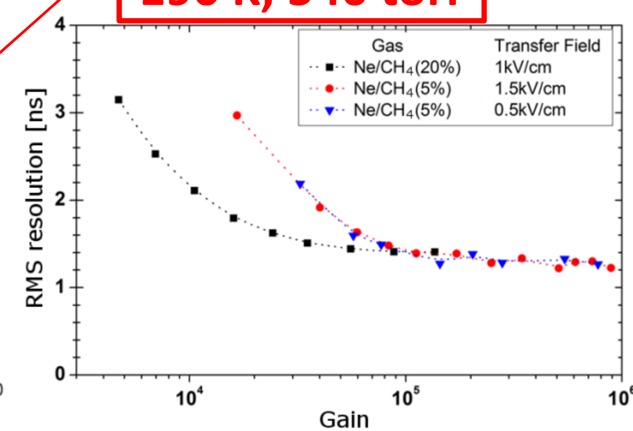
- **Time resolution:**
  - Time jitter of **~1.2 ns**

Approx. 300 photoelectrons/pulse



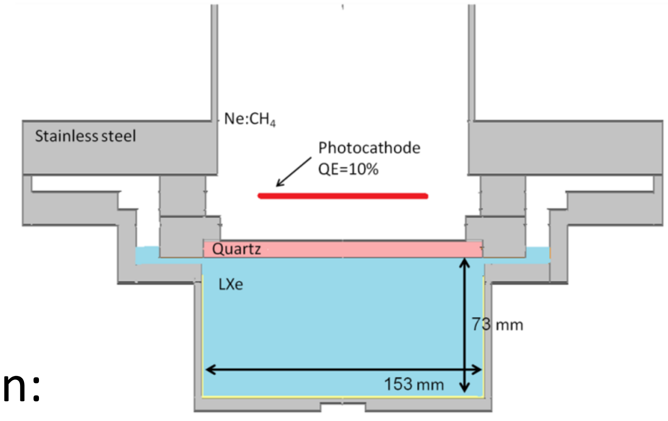
Ne/CH$_4$(5%)

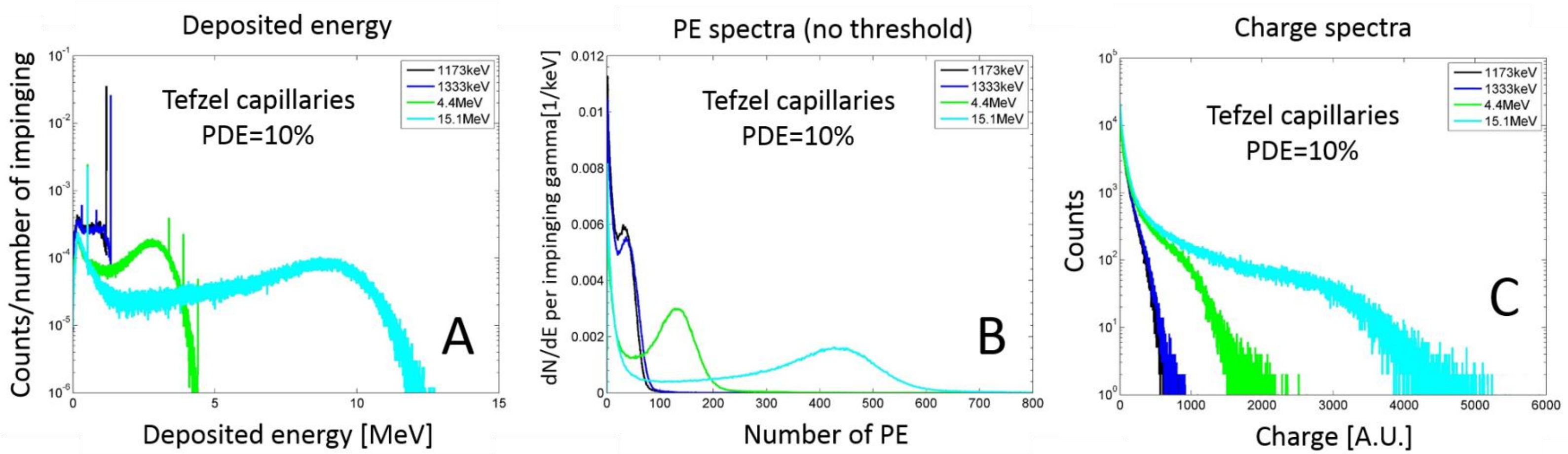
190 K, 540 torr



Position resolution simulations for Gammas

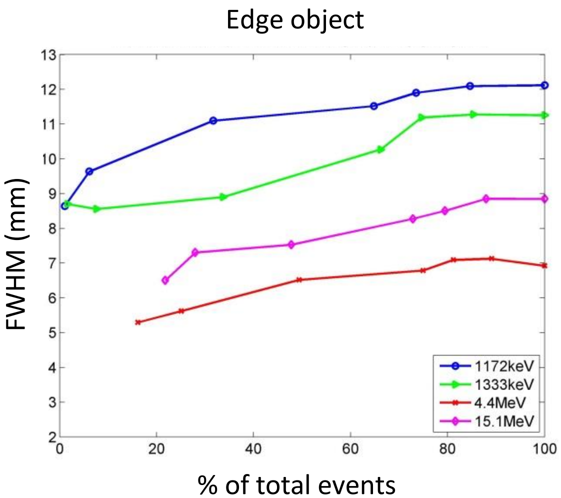
- Simulated resolution (FWHM) of gamma radiation **1.1 - 15.1 MeV**
  - Edge object
  - 3 mm collimated beam
  - Pencil beam
- Detector geometry defined in detail, including surrounding materials.
- Simulated deposited energy, photoelectron spectra and charge spectra after amplification:

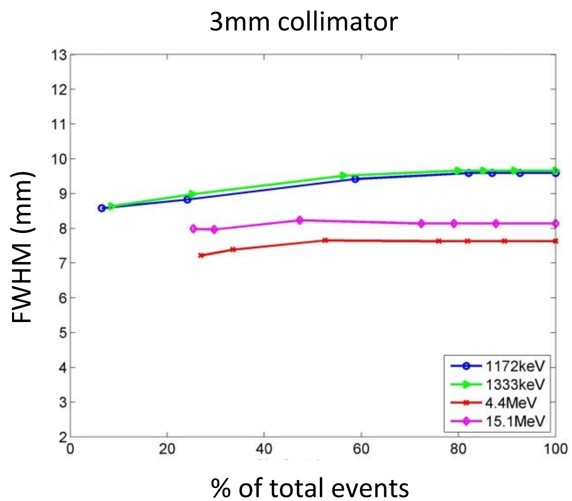


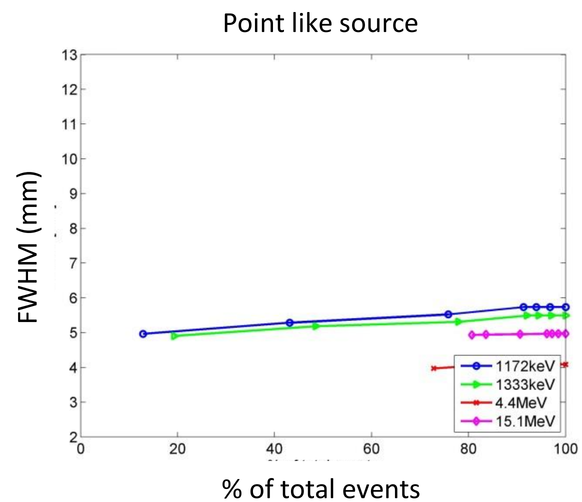


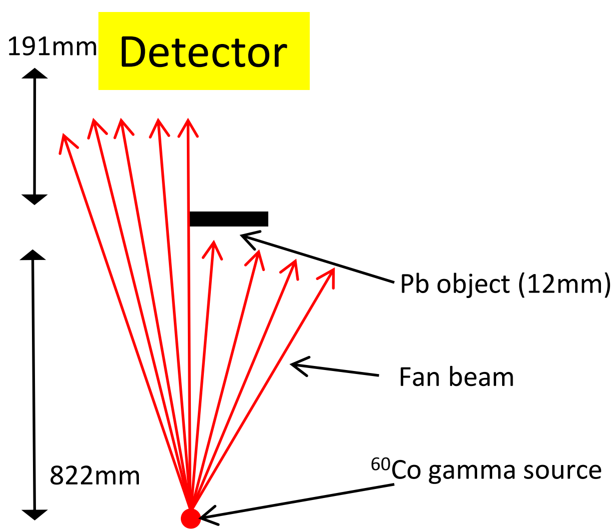
Position resolution simulations for Gammas

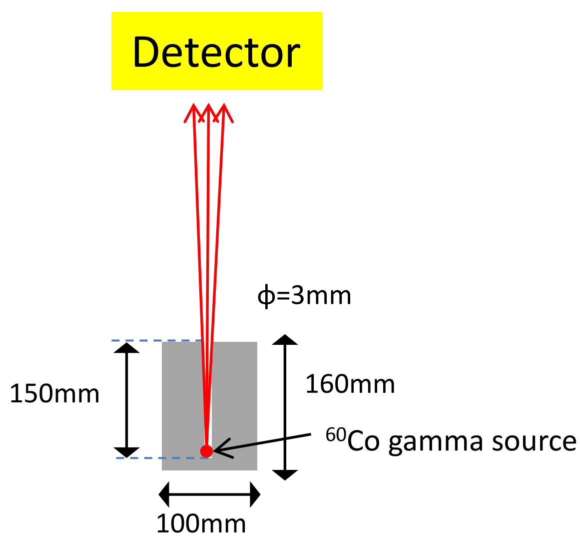
- Simulated resolution (FWHM) of gamma radiation **1.17-15.1 MeV**

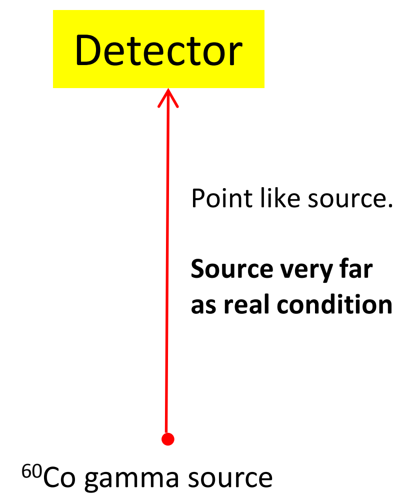






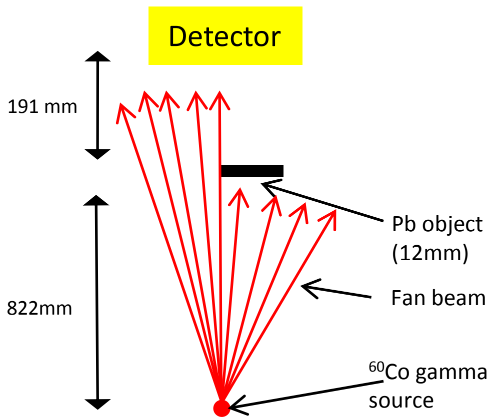


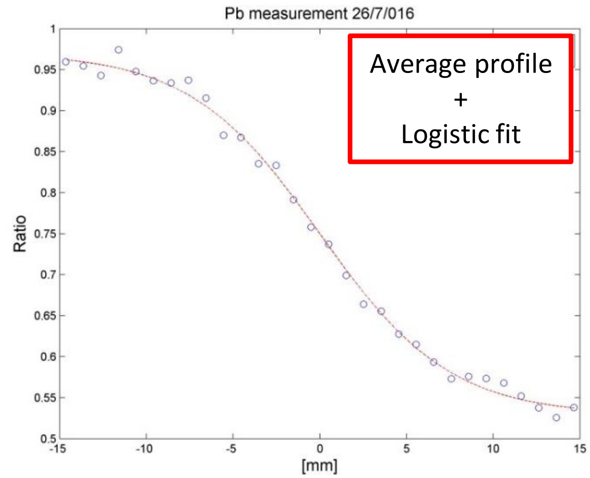


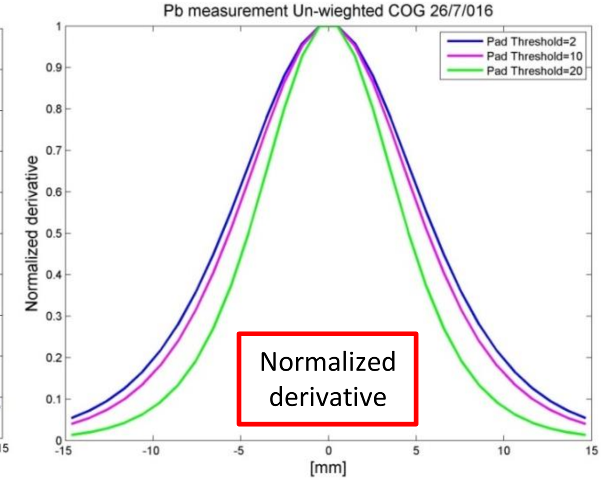


Experimental Pb object edge imaging

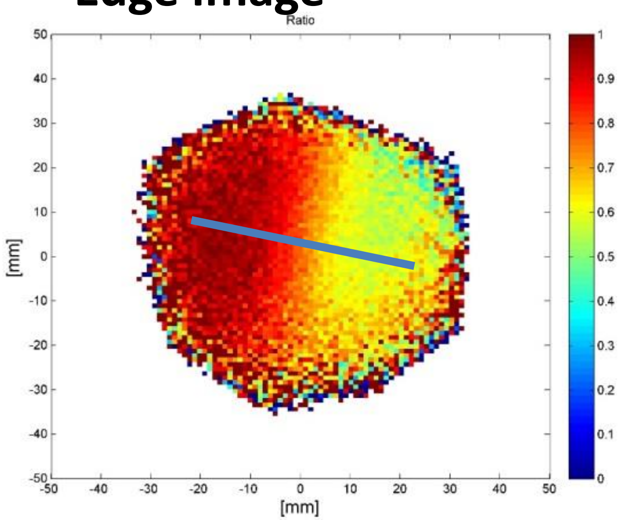
- **Setup scheme**







- **Edge image**



Object image: $I_{Obj} - I_{Bkg} / I_{Flat} - I_{Bkg}$

Sub-optimal configuration:
Source very close to detector ➔ large beam spread.
Large amount of Compton scattering.

Pads in cluster	% of total events	FWHM [mm]	
		Un – weighted COG	Simulations
5	99.3	12.1	11.5
10	84.2	11.3	11
20	22.3	9.1	9.6

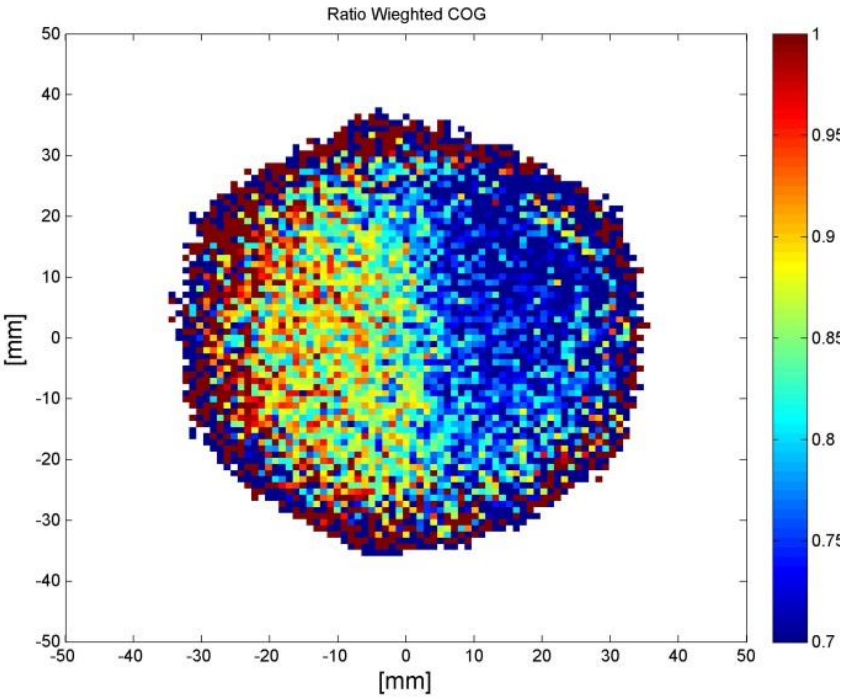
Good agreement with simulations!

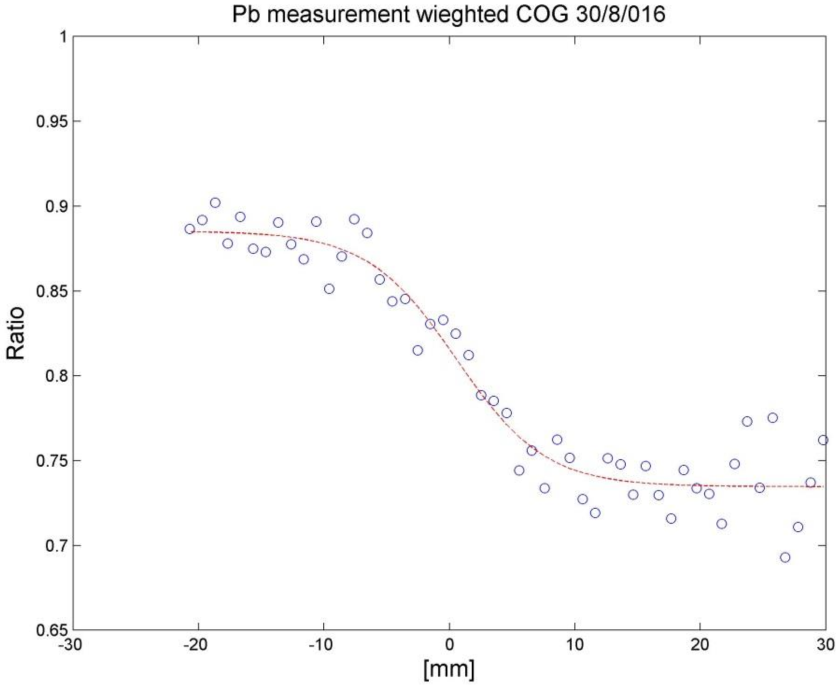
Imaging of Pb object AmBe– 30/8/016

Ne:CH4 (95:5), flow=20 sccm, 356 torr, 212K, Gain=~$2.4 \cdot 10^4$, Pb width=12mm.

Weighted COG

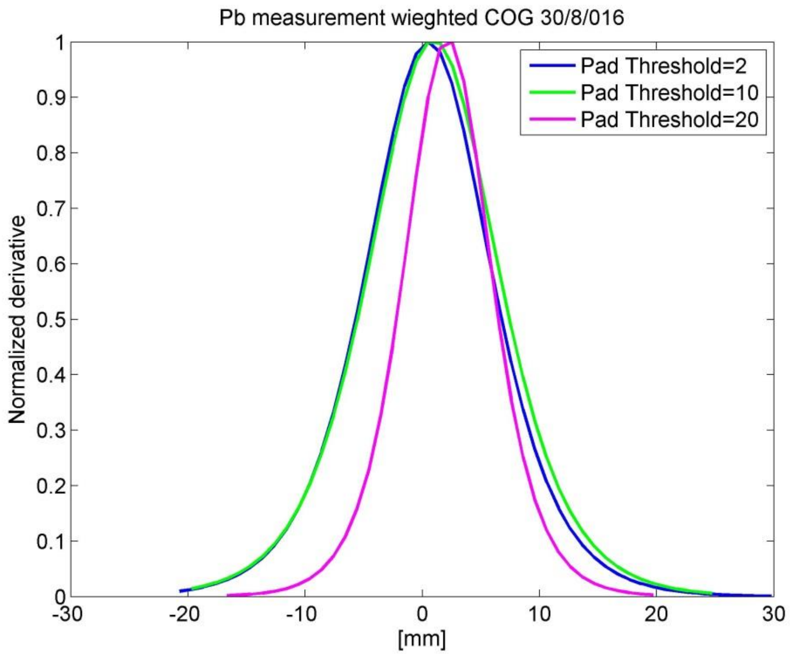
Latest preliminary result with AmBe neutron source mixed with 4.4 MeV gamma



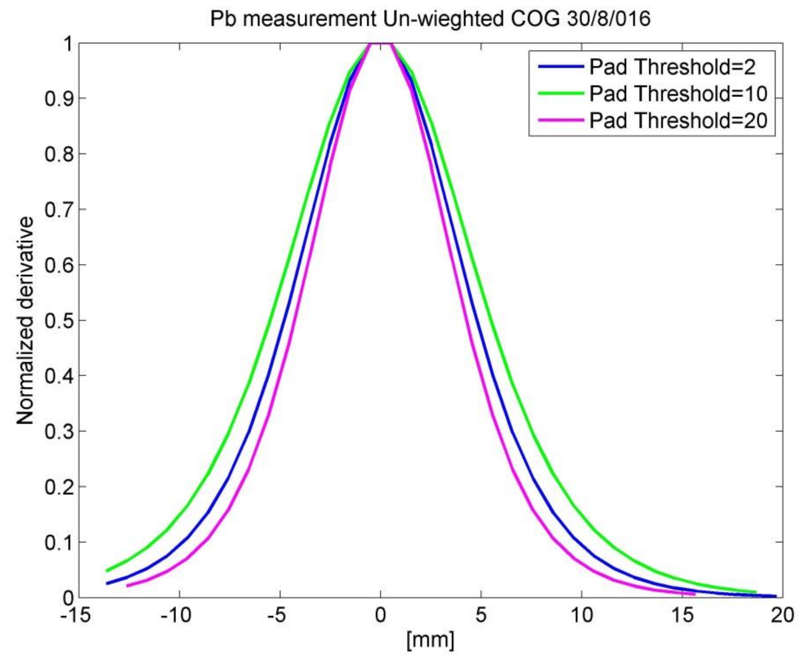


Normalized derivatives

Weighted COG



Un-weighted COG



Pad Threshold	FWHM [mm]		
	Weighted COG	Un – weighted COG	Simulations
5	13	10	
10	13	11	
20	9	9	

Summary

- Large-area robust detector concept, for simultaneous detection of hidden explosives (low-Z, with fast neutrons) and fissile materials (high-Z, with gammas).

- Encompasses efficient fast liquid-Xenon converter-scintillator (plain volume or capillaries), coupled to a UV-sensitive gaseous imaging photomultiplier (GPM) incorporating a CsI-coated triple-THGEM, here with APV/SRS readout.

- **Successful operation of the GPM/LXe scintillator, also with capillaries: High sensitivity, fast response, stability.**

- GEANT 4 simulations predict good imaging properties for gamma & fast-n + energy resolution for gammas.

- In a sub-optimal configuration, demonstrated position resolution of ~10mm FWHM with 1.1 and 1.3 MeV gammas from ^{60}Co ➔ agreement with simulations.

- **Measurements with energetic gammas and fast neutrons – in course.**

Thank you!