# Non-standard GEM foils for the gaseous detectors

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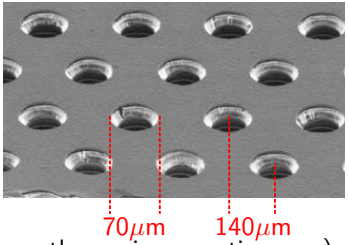
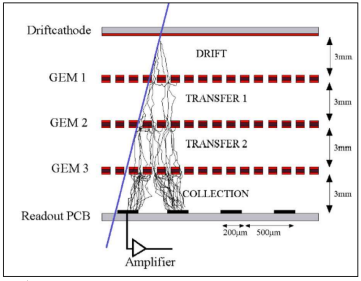
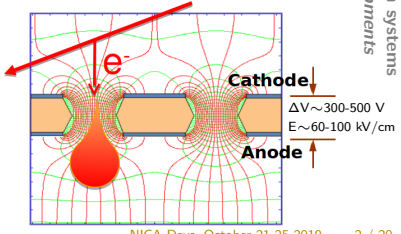
# Standard Gas Electron Multiplier

– thin (**50**$\mu m$) metal-coated polymer (Kapton) foil chemically pierced by a high density of holes
Sauli, NIMA 386 (1997) 531



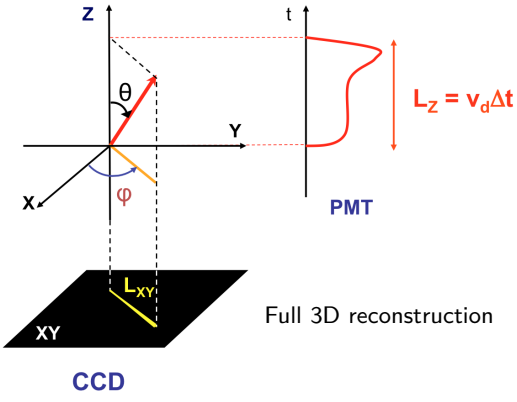




- Large area (200×50 cm currently maximum active area)
- High rate (up to 1 MHz/mm$^2$)
- High Spatial Resolution (≈40 $\mu$m)
- High gas gain ($\sim 10^3 - 10^4$ single-stage, $10^6 - 10^7$ multi-stage)
- 15-20% energy resolution (5.9 keV X-rays)
- Flexible detector shape and readout patterns

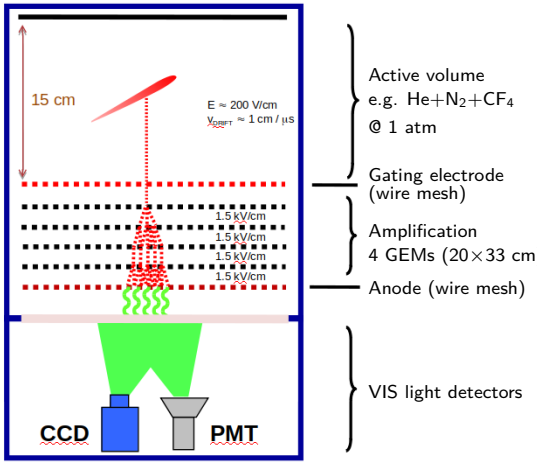



GDS coupling to auxiliary detection systems
M. Cortesi: *Trend and new developments in gas amplifiers*

# GEM-based Optical Time Projection Chamber for exotic nuclei decays study




Full 3D reconstruction

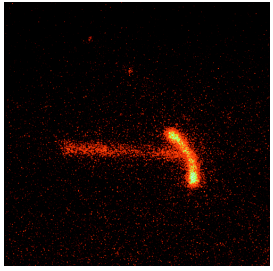


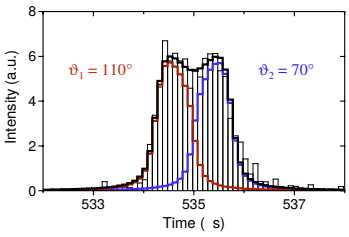

M. Ćwiok et al., IEEE TNS 52 (2005) 2895

K. Miernik et al., NIMA 581 (2007) 194

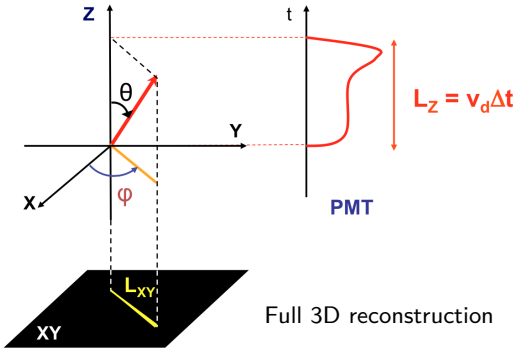
# GEM-based Optical Time Projection Chamber for exotic nuclei decays study

Example reconstruction of 2p decay event of $^{45}$Fe:






$E_p \approx 0.6$ MeV




Full 3D reconstruction

K. Miernik et al., Phys. Rev. Lett. 99, 192501

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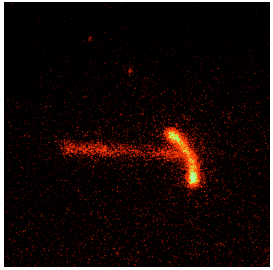

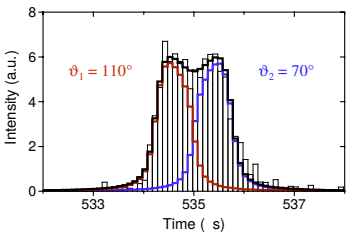


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K. Miernik et al., Phys. Rev. Lett. 99, 192501

Several TPCs with optical readout constructed since 2004 for:

- **two-proton radioactivity**
  2p of $^{45}$Fe and $^{48}$Ni @ NSCL/MSU
  2p of $^{54}$Zn @ BigRIPS/RIKEN
- **$\beta$–delayed multi-particle emissions**
  $\beta$3p of $^{31}$Ar @ FRS/GSI
  $\beta$p of $^{59,60}$Ge @ NSCL/MSU
  $\beta$p of $^{11}$Be @ Isolde/CERN
  $\beta$p of $^{27}$S @ Acculinna/JINR
  $\beta$–multi–p of $^{22,23}$Si @ MARS/TAMU
- **rare decays of He isotopes**
  $^{6}$He $\rightarrow \alpha$+d @ Isolde/CERN
  $^{8}$He $\rightarrow \alpha$+t+n @ Acculinna/JINR

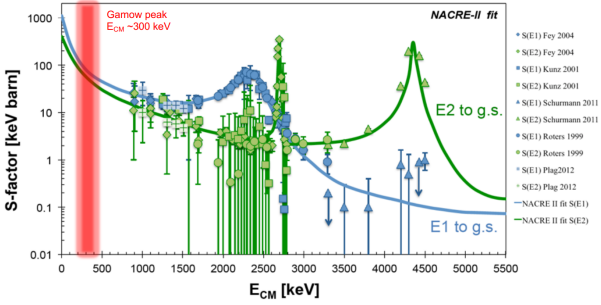
# GEM-based Active Gas Target TPC for nuclear reactions at astrophysical energies

**Physics goals:**

- study $(\alpha,\gamma)$ and $(p,\gamma)$ reactions of current astrophysical interest:
  – burn helium $\rightarrow$ C/O ratio in the Universe
  – burn $^{18}O \rightarrow {}^{16}O/{}^{18}O$ ratio in the Universe
- particular effort on $^{12}C(\alpha,\gamma)^{16}O$ reaction at Ecm$\sim$1 MeV

**Approach:**

- capture vs. **photo-disintegration** reactions
- **monochromatic gamma-ray beams** @ ELI-NP
- **active-target** TPC for measuring kinematics of low-energy charged particles




Current extrapolations of p-wave (E1) and d-wave (E2) astrophysical S-factors for the Gamow peak (red bar) in red giant stars have uncertainty of 40 – 80%

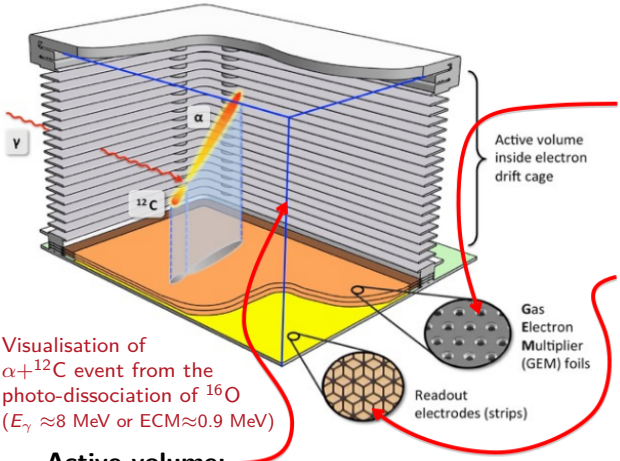
# Footnote on Extreme Light Infrastructure – Nuclear Physic

Bucharest-Magurele, Romania

- Warm LINAC + electron storage ring
- 2 laser wavelengths (IR + green)
- Time structure: 35.7 MHz (semi-continuous beam!)
- Total flux: $\geq 10^{11}$ $\gamma$/s
- FWHM energy bandwidth: $\leq 0.5\%$ @ 10 m
- FWHM beam spot: $\leq 1.5$ mm @ 10 m
- Linear Polarization: $\geq 95\%$

http://www.eli-np.ro/

# GEM-based Active Gas Target TPC – detector design




Visualisation of $\alpha+^{12}$C event from the photo-dissociation of $^{16}$O ($E_\gamma \approx 8$ MeV or ECM$\approx$0.9 MeV)

**Active volume:**

33×20 cm$^2$ (readout)×20 cm (drift)
gas pressure ∼100 mbar

**Charge amplification:**

- three Gas Electron Multipliers (GEM) foils standard CERN technology (50-$\mu$m thick)

**Readout:**

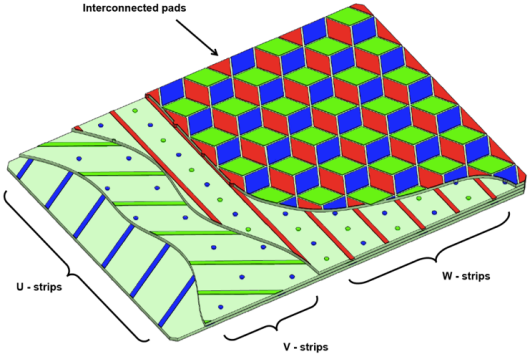
- planar, 3-coordinate, redundant strip arrays
- about 1000 channels
- GET electronics for signal amplification & digitization
- self- or external triggering

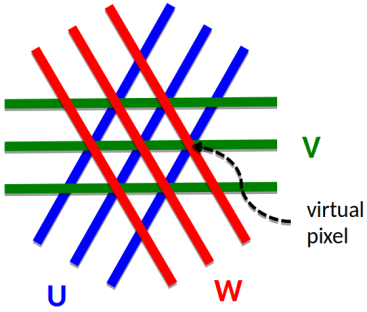
O.Tesileanu et al., Romanian Rep. in Phys. 68 Supplement (2016) S699

# GEM-based Active Gas Target TPC – readout concept

The readout concept based on 3 grids of strips – crossed at 60°:

- 3-coordinate, planar, redundant strip readout, 1.5 mm strip pitch
- **U-V-W** strip arrays on XY plane + Z-coordinate from drift time → **virtual 3D pixels**
- Simple event topologies → expect only few tracks per event
- Moderate cost of electronics

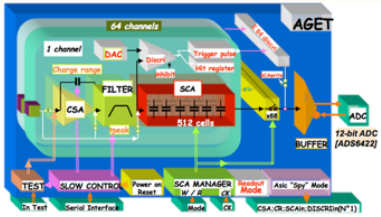



S. Bachmann et al., NIMA 478 (2002) 104
V. Ableev et al., NIMA 535 (2004) 294
M. Ćwiok, Acta Phys. Pol. B 47 (2016) 707

# Footnote on Generic Electronics for Time Projection Chambers

- Developed by: CEA/IRFU, CENBG, GANIL, MSU/NSCL
  - flexible sampling frequency: 1 - 100 MHz
  - 512 time-cells per channel, analog SCA memory
  - 4 dynamic ranges per channel: 120 fC - 10 pC
- 256-ch front-end board (AsAd = ASIC & ADC):
  - 4 AGET chips
  - 12-bit ADC, one channel per AGET chip
- Data concentration, timing & trigger boards:
  - big systems: uTCA crate, CoBo boards, MuTant boards (up to 32,000 channels) – based on Virtex-5 FPGAs
  - small systems: standalone FPGA boards (usually 256 channels) – based on Virtex-5 or Zynq-7000

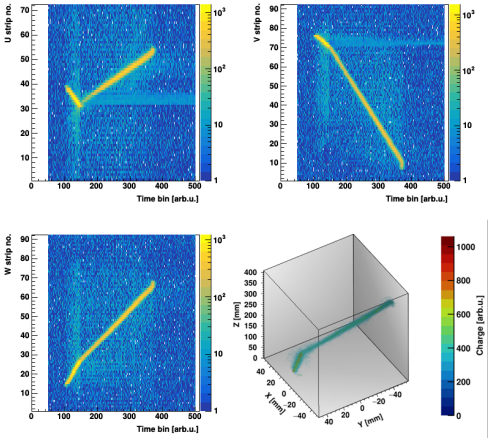



E. Pollacco et al., NIMA 887 (2018) 81

E. Pollacco et al., Physics Procedia 37 (2012) 1799

# GEM-based Active Gas Target TPC – demonstrator-detector beam tests

$$n + {}^{16}O \longrightarrow {}^{17}O$$
$$ {}^{17}O \longrightarrow {}^{13}C + \alpha$$

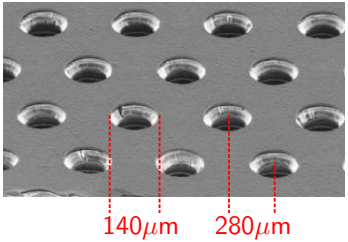



Beam test @ 3 MV Tandem
IFIN-HH, Romania – June 2018

# Further developments

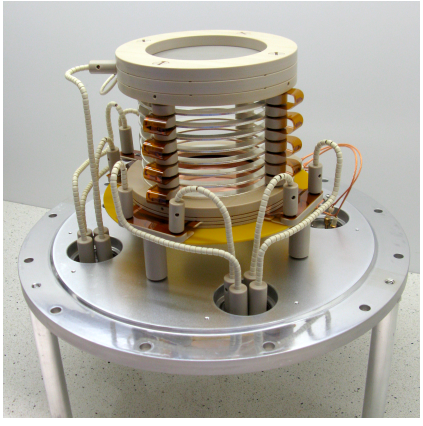
# Thicker-GEM – new development with well known technology

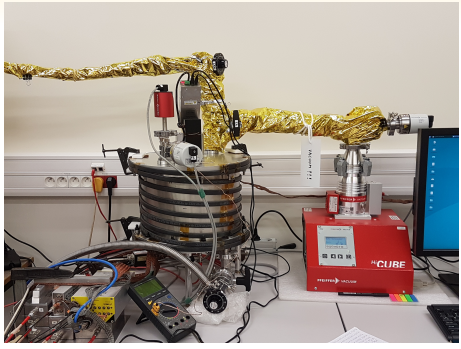
- A little bit **thicker** (**125** $\mu m$) metal-coated polymer (Kapton) foil chemically pierced by a high density of holes
- High gas gain ($\sim 10^5$ double and triple-stage – tested at absolute pressure of 100 mbar of pure $CO_2$)
- $\sim$17% energy resolution (4.9 keV semi-monochromatic X-rays)
- Current limitation of a single active area 30 $\times$ 30 cm
- Requires double mask technique
- Larger areas possible to obtain via connecting many single sections




**The first proof of concept and performance tests performed at University of Warsaw!**

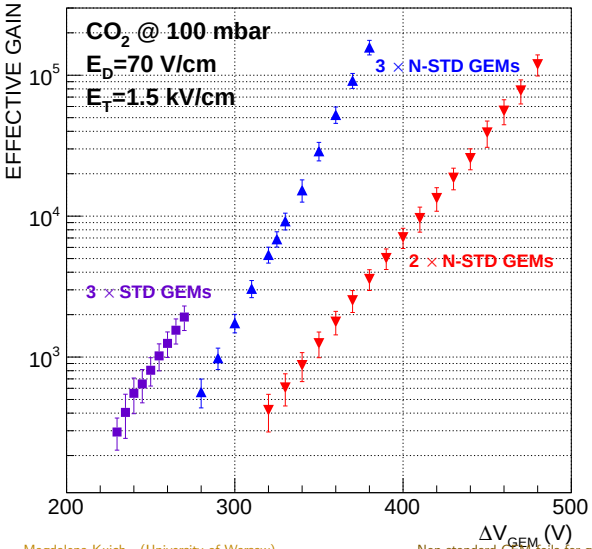
# Thicker-GEM test bench





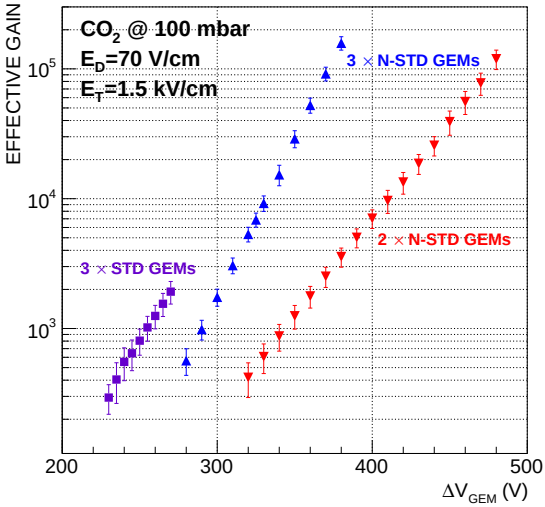

- Active volume: $\phi$5 cm$\times$10 cm (drift)
- Gas pressure range: 50 mbar – 1 atm
- Amplification 3 Thicker-GEM foils (**125** $\mu$m)
- Soft X-rays ($\sim$5 keV) $\Rightarrow$ gas gain, energy resolution
- Alpha-particle source ($\sim$5.5 MeV) $\Rightarrow$ electron drift velocity, diffusion

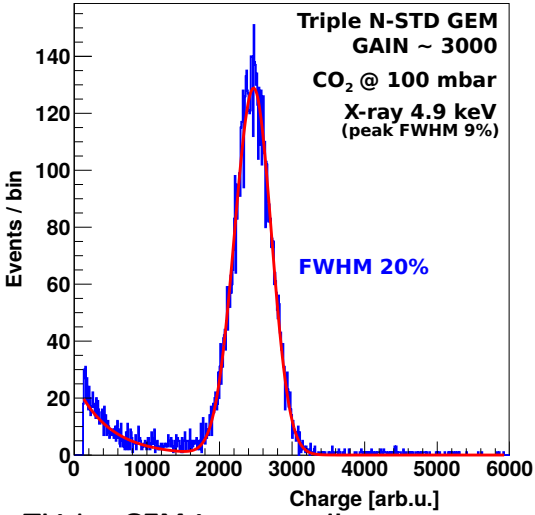
# Thicker-GEM performance – gas gain




- Test provided with pure $CO_2$
- Absolute gas pressure 100 mbar
- Safe working conditions
  $\longrightarrow$ **no discharges**
- **2 orders of magnitude higher gas gain** with respect to triple-stack of STD GEMs!

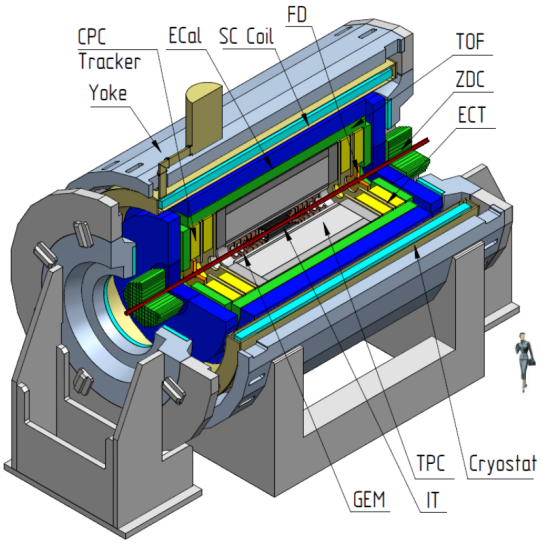
# Thicker-GEM performance – energy resolution




**Research on the performance of the Thicker-GEM just started!**

# GEM/Thicker-GEM as a possible solution for MPD




R&D of the (non-)standard GEMs technology is ongoing...
...keeping also in mind the needs of the future MPD experiment:

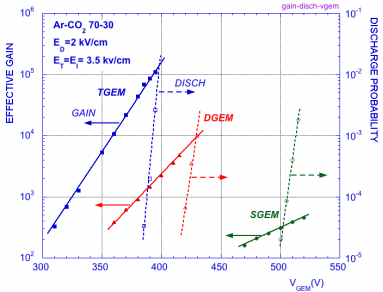
- **CPC tracker for MPD stage 2?**
- GEM tracker for MPD stage 2?
- **TPC readout chambers upgrade for MPD stage 2?**

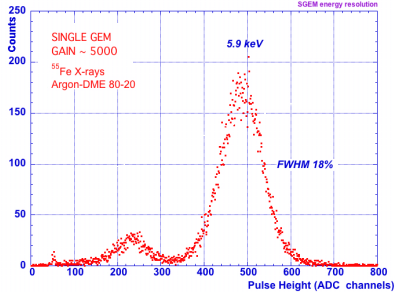
# Thank you!

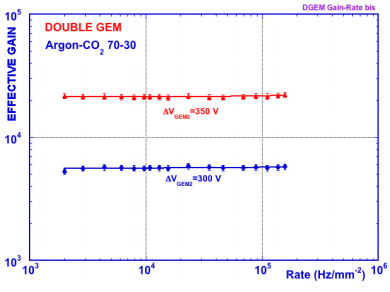
Work supported by the Polish Ministry of Science and Higher Education from the funds for years 2019-2021 dedicated to implement the international co-funded project no. 4087/ELI-NP/2018/0 and by University of Connecticut under the Collaborative Research Contract no. UConn-LNS_UW/7/2018.

# Additional slides

# GEM performance



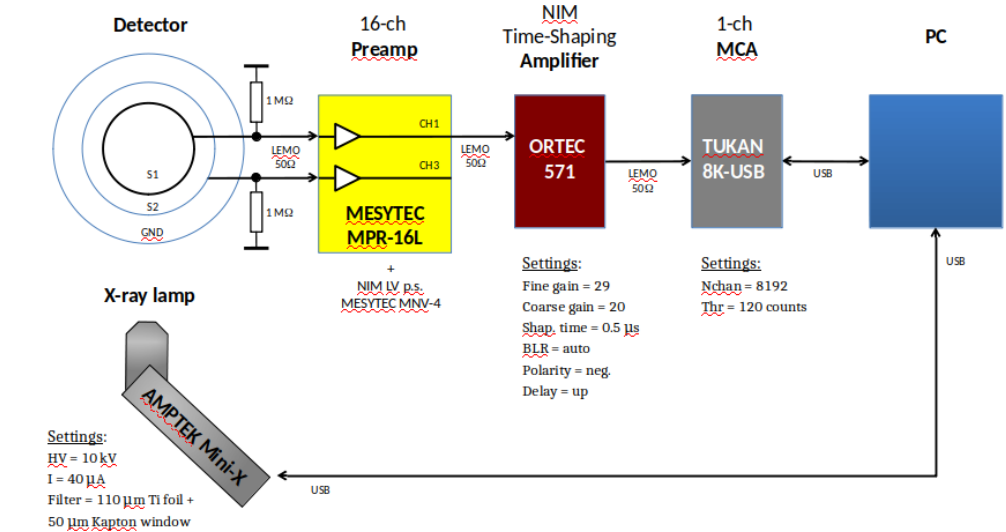




- With a Triple GEM, a gain well above $10^4$ can be sustained even in presence of heavily ionizing background.
- Energy resolution of a single GEM multiplier: FWHM $\sim$18% at 5.9 keV (gain $\sim 10^3$)
- Stable effective gain with increasing signal rate

https://gdd.web.cern.ch/GDD

# Thicker-GEM test bench (2)



## Radiation source:

- Amptek MiniX generator : Ag target, Be window, $U_{XRAY}$ = 10 kV
- XRF fluorescence filters : 110 µm Ti + 50 µm Kapton
- Quasi-monochromatic X-ray spectrum : peak @ 4.9 keV (9% FWHM)
- Conversion rate @ 100 mbar $CO_2$ : 12–70 Hz for $I_{XRAY}$ = 40 – 200 µA