Non-standard GEM foils for the gaseous detectors

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Standard Gas Electron Multiplier

– thin (50 µm) 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/mm²)
- High Spatial Resolution (≈40 µm)
- High gas gain (∼10³ – 10⁴ single-stage, 10⁶ – 10⁷ multi-stage)
- 15-20% energy resolution (5.9 keV X-rays)
- Flexible detector shape and readout patterns
GEM-based Optical Time Projection Chamber for exotic nuclei decays study

Full 3D reconstruction

Active volume e.g. He+N$_2$+CF$_4$ @ 1 atm
Gating electrode (wire mesh)
Amplification 4 GEMs (20×33 cm)
Anode (wire mesh)
VIS light detectors

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

$\theta_1 = 110^\circ \quad \theta_2 = 70^\circ$

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

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
  $\beta$–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 \(^{18}\text{O}\) \(\rightarrow\) \(^{16}\text{O}/^{18}\text{O}\) ratio in the Universe
- particular effort on \(^{12}\text{C}(\alpha,\gamma)^{16}\text{O}\) reaction at \(E_{\text{cm}}\sim 1\) 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 Physics

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

Active volume:

\[ 33 \times 20 \text{ cm}^2 \times 20 \text{ cm} \text{ (drift)} \]
\[ \text{gas pressure } \sim 100 \text{ mbar} \]

Charge amplification:

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

Readout:

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

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
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

\[ n + {}^{16}\text{O} \rightarrow {}^{17}\text{O} \]
\[ {}^{17}\text{O} \rightarrow {}^{13}\text{C} + \alpha \]

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 µm)* metal-coated polymer (Kapton) foil chemically pierced by a high density of holes
• High gas gain *(∼ 10^5 double and triple-stage – tested at absolute pressure of 100 mbar of pure CO₂)*
• ∼17% energy resolution *(4.9 keV semi-monochromatic X-rays)*
• Current limitation of a single active area 30 × 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: $\phi 5 \text{ cm} \times 10 \text{ cm}$ (drift)
- Gas pressure range: 50 mbar – 1 atm
- Amplification 3 Thicker-GEM foils (125 $\mu m$)
- Soft X-rays ($\sim 5 \text{ keV}$) $\Rightarrow$ gas gain, energy resolution
- Alpha-particle source ($\sim 5.5 \text{ MeV}$) $\Rightarrow$ electron drift velocity, diffusion
Thicker-GEM performance – gas gain

- Test provided with pure CO₂
- Absolute gas pressure 100 mbar
- Safe working conditions → 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!

- $\text{CO}_2$ @ 100 mbar
- $E_p = 70 \text{ V/cm}$
- $E_T = 1.5 \text{ kV/cm}$

GAIN $\sim 3000$

Triple N-STD GEM

Charge [arb.u.]

Events / bin

FWHM 20%

Charge [arb.u.]

Events / bin

FWHM 20%

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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!

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Additional slides
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)

Detector

16-ch Preamp

NIM Time-Shaping Amplifier

1-ch MCA

PC

X-ray lamp

Settings:
- HV = 10 kV
- I = 40 µA
- Filter = 110 µm Ti foil + 50 µm Kapton window

Settings:
- Fine gain = 29
- Coarse gain = 20
- Shape time = 0.5 µs
- BLR = auto
- Polarity = neg.
- Delay = up

Settings:
- Nchan = 8192
- Thr = 120 counts

MESYTEC MPR-16L
Radiation source:

- Amptek MiniX generator: Ag target, Be window, $U_{X\text{RAY}} = 10$ kV
- XRF fluorescence filters: 110 $\mu$m Ti + 50 $\mu$m Kapton
- Quasi-monochromatic X-ray spectrum: peak @ 4.9 keV (9% FWHM)
- Conversion rate @ 100 mbar CO$_2$: 12-70 Hz for $I_{X\text{RAY}} = 40 - 200$ $\mu$A

Spectrum from Amptek Si-det (air, 1 atm)

$\chi^2$/ndf 58.54/37
Constant 93.24 ± 3.52
Mean 4.929 ± 0.012
SigmaL 0.3026 ± 0.0119
SigmaR 0.08447 ± 0.00821