Development of “Large gas Electron Multiplier” (LEM) detectors for high gain operation in ultra-pure noble gasses

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Outline

- **The basic idea:**
  - Macroscopic version of hole Gas Electron Multipliers (GEM’s)
    - ~mm hole size in standard double-face Cu-clad Printed Circuit Board (PCB)
    - Characteristics & performance under investigation by several collaborations

- **Goals:**
  - Stable High gain (> $10^4$ up to streamer regime) in pure noble gasses
    - quenching gas replaced by UV photon absorption in hole walls
  - Good energy resolution
    - negligible charge loss due to electron diffusion and avalanche size (small wrt hole size)
  - Direct readout of LEM electrodes
    - X-Y segmentation

- **Possible applications:**
  - Cryogenic double phase TPC’s
    - low energy (~keV) event localization (Dark Matter, Solar Neutrinos)
  - High pressure TPC for medical imaging
    - R&D activity fully funded in PD by PRIN 2005
  - Photosensitive large area detectors, RICH
    - coupling with radiation conversion detectors (CsI photocathodes)
What is a LEM

- A thick GEM-like gaseous electron multipliers made of standard printed-circuit board perforated with sub-millimeter diameter holes, chemically etched at their rims
  - In-house fabrication using automatic micromachining
  - Self-supporting
  - Extremely resistant to discharges (low capacitance)

- First introduced within the ICARUS R&D group
  - for double phase noble gasses TPC’s in the keV region

- Developed also as GEM alternative
  - Coarser resolution
  - Low rate physics (slower signals)
    - A. Rubbia et al.
  - Photo conversion detectors
    - Breskin et al.
    - Policarpo et al.
LEM: principle of operation

- Upon application of a voltage difference across the LEM, a strong dipole field $E_{\text{hole}}$ is established within the holes.
  - Electrons deposited by ionizing radiation in a conversion region above the LEM, or produced on a solid radiation converter, are drifting towards the LEM under $E_{\text{drift}}$ and are focused into the LEM holes by a strong electric field inside the holes.
  - Electrons are multiplied within the holes under the high electric field (~25-50 kV/cm)
  - Avalanche electrons are collected on the LEM bottom electrode (a fraction could also be further transferred to a collecting anode or to a second, possibly similar, multiplier element).

- Each hole acts as an independent multiplier.
  - A more favorable hole aspect ratio allows better avalanche confinement, reducing photon-mediated secondary effects.
  - This leads to higher gains in LEM wrt GEM with similar gas mixtures and to high-gain operation in a large variety of gases, including highly scintillating ones like pure noble gasses or CF4.
LEM: E-field, Avalanche

- Characteristics:
  - 100% transparency to incoming electrons
    - Full detection efficiency
  - Strong constant field well confined inside hole
    - Avalanche confinement, stable gain
  - Uniform field across hole diameter
    - Uniform multiplication factor, good resolution

- In pure Argon the development of the avalanche is well confined inside the hole (0.5 mm diameter)
  - At 1bar: avalanche lateral size (incl. diffusion) ~300µm
  - Higher pressure squeezes the avalanche size

Negligible charging-up of hole walls
Preliminary study of LEM in Ar

**LEM prototypes**
Thickness = 1.0, 1.6, 2.4 mm
Hole diameter = 0.5 mm

Test set-up
Typical signals and Spectra ($\text{Fe}^{55}$)

Pure Argon (1 bar)

Gain > 1000
Resolution ~ 30% FWHM
(15-20 % expected)
LEM gain (pure Argon)

Gain behaviour
- Exponential growth in uniform electric field (parallel plate chamber)
  \[ G = \exp(\alpha d) \]
  - \( d \) = detector thickness
  - \( \alpha \) = Townsend coefficient (depends on \( E, p, d \))

Max gain
- Increases with thickness
  - Geometrically reduced photon feedback

Time stability
- Guaranteed if no discharges
  - Far from break-down voltage
- Sudden degradation after several occasional break-down
  - hole walls carbonization

Fe\(^{55}\) source

\[ G = \exp(d) \]

P = 1 Bar

1.0 mm

1.6 mm

2.4 mm

Gain

Voltage (V)
High pressure gain (pure Argon)

- **Fe\textsuperscript{55} source**
  - LEM thickness 1.6mm

- **Cd\textsuperscript{109} source**
  - LEM thickness 1.6mm

- LEM thickness optimization for high pressure operation
  - 2.4 mm: too high voltage for reasonable gain
  - 1.0 mm: too high photon feed-back; early appearance of discharges

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Gain scaling vs pressure and field

- Gain behaviour

\[ G = \exp(\alpha d) \]

- Townsend coefficient \( \alpha \) well described by Rose-Kroff law

\[ \alpha = A p \exp(-Bp / E) \]

  - \( d \) = detector thickness
  - \( E \) = electric field
  - \( p \) = pressure
  - \( A,B \) = parameters depending on gas mixture

- Not very significant deviation from expectations in wide range of \( E,p,d \)

  - Easily predictable gain and break-down value for different LEM layout
**LEM with gas mixtures**

Example: LEM photon detector with reflective CsI photocathode.

- Gain $10^4$-$10^5$ (single electrons)
- Rise time < 10ns
- Rate capability: 10MHz/mm$^2$


A. Breskin
Open problems for further R&D

- Residual charging-up of holes walls due ions/electrons diffusion especially at high rate and residual photon feed-back in pure noble gasses, affecting:
  - Maximum Gain
  - Energy resolution
  - Time stability
- Possible fields of investigation:
  - LEM geometry (including multi-step)
    - To reduce diffusion effects
  - Electrodes oxidation
    - To minimize photon feed-back and electron extraction
  - Resistive electrodes
    - To improve “quenching” effect (RPC-like) and reach streamer mode gain
  - Needle-LEM
    - To avoid discharges and carbonization of LEM hole walls
Resistive electrodes

- Hybrid RPC concept:
  - Resistive layer “quenches” the electron avalanche
  - Vetronite holes “limit” the photon propagation and after pulses

- Goal
  - It should allow gains up to streamer mode (maybe limited by photon feed-back through hole input)

- Disadvantages
  - Choice of resistive material critically depending on rate and gain (resistive materials from Quadrant Technology, ranging from $10^5$ to $10^{15}$ $\Omega$-cm, under investigation)

*Preliminary results:*
*Gain $>> 10^4$ easily reached*
Needle-LEM

- Coupling of a LEM with a needle array and oxidized-Cu (or resistive) layer
- Advantages
  - much longer discharge path along hole walls
  - Ion trajectories ending onto electrodes (no charging-up)
  - More efficient photon trapping
- Disadvantages
  - Critical adjustment of needle height and shape: affecting gain uniformity

Preliminary results:
Gain >> 10^4 easily reached
Poor resolution (~50% FWHM)

X, mm
Z, mm
needle
Top electrode
Vetronite

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Specific applications

- Optimization of LEM’s in pure Noble gasses could lead to improvements in several detection fields
  - Avoiding quenching gas could allow
    - Higher yields
    - More stable performance (less degradation due to aging effects)
- Moreover, segmented LEM, capable of x,y localization, could find direct applications in:
  - High pressure Xenon TPC’s
    - Replacements of wires and strips in CARDIS chamber for fast medical imaging:
      - Better resolutions
      - Higher time stability
      - No polymerization of quenching gas
    - See PRIN 2005
  - Large area UV photodetectors
    - Coupling with CsI photocathodes
    - Reflective CsI coating for UV scintillation collection in TPC’s
LEM in TPC’s

- Xenon TPC’s (CARDIS-PRIN2005) for fast medical imaging
  - Photoelectic $e^-$ from $\sim 10^2$ KeV $\gamma$’s (Tantalium, Tecnetium)
    - Moderate gain required: $10^2 - 10^3$
    - High density (pressure >6 bar): high absorption efficiency
    - Good event localization: limited $e^-$ diffusion allows mm size pixel
  - Compton rejection
    - Requirements: good energy resolution.

- Segmented LEM could match detector requirements:
  - Design with $\sim$mm segmentation seems at reach
  - Gain under high pressure under investigation
    - Needle-LEM could be used to increase gain

- Double phase cryogenic TPC’s (Ar, Xe)
  - Similar requirements
    - High pressure = high density in cryogenic gas phase
LEM with CsI coating

V. Peskov et al. (CERN)

Large area UV photosensitive detectors

- High CsI q.e. in Ar and Xe (> 20%)
- Gain >$10^4$ allows sensitivity to single photo-electron
- Good event localization (down to mm$^2$ size)

Preliminary results
Large area UV photosensitive detectors

Single LEM structure

UV Window

CsI photocathode

G-10 with resistive coating

Hybrid RPC

Readout plate

Preliminary results

higher gains are possible with resistive coating
Possible application of LEM in “classical’ RICH

The main idea: replace the wire chamber with LEM’s

Advantages: simpler design, possibility to be insensitive to charged particles (at $\Delta V=0$)

New idea: radiator and detector placed in the same gas volume

Advantages: simpler design, more light, possibility to be insensitive to charged particles (at $\Delta V=0$)
Partecipanti, tempi, richieste

valutazione preliminare

- **Partecipanti:**
  - Padova
    - B. Baiboussinov
    - S. Centro
    - F. Pietropaolo (Resp.)
    - S. Ventura
    - G. Meng
  - LNF
    - G. Mannocchi
    - L. Periale
    - P. Picchi
  - CERN
    - R. De Oliveira
    - A. Di Mauro
    - P. Martinengo
    - V. Peskov

- **Richieste ai servizi:**
  - 2 mesi uomo Lab. Elettronico
  - 2 mesi uomo Officina Meccanica
  - 1 mese uomo Ufficio Tecnico

- **Trasferte:**
  - Interne: 3 mesi uomo (metabolismo + tests a LNL)
  - Estere: 1 mese uomo (progettazione PCB e deposizioni CsI)

- **Durata:** 24 Mesi

- **Milestone:**
  - Primo anno: Prototipi piccola scala (10x10 cm²):
    - ottimizzazione layout LEM, LEM+needles, LEM resistive
    - Guadagno
    - Risoluzione
    - Stabilità temporale
    - Accoppiamento con fotoconvertitori per VUV
  - Secondo anno: LEM di medie dimensioni (30x30 cm²):
    - Readout segmentato per:
      - Imaging medica in Xenon ad alta pressione (CARDIS)
      - Fotorivelatori a grande area
      - LAr-TPC doppia fase

- **Previsioni di spesa:**
  - Consumo (totale ~19000 €):
    - Forfait workshop PCB CERN (materiale + lavorazione) ~7000 €
    - Fornitura Argon e Xenon per test ~ 5000 €
    - Fornitura campioni materiale resistivo ~3000 €
    - Deposizione CsI al CERN (materiale + lavorazione) ~4000 €