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

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R&D Proposal - INFN PD - GR. V

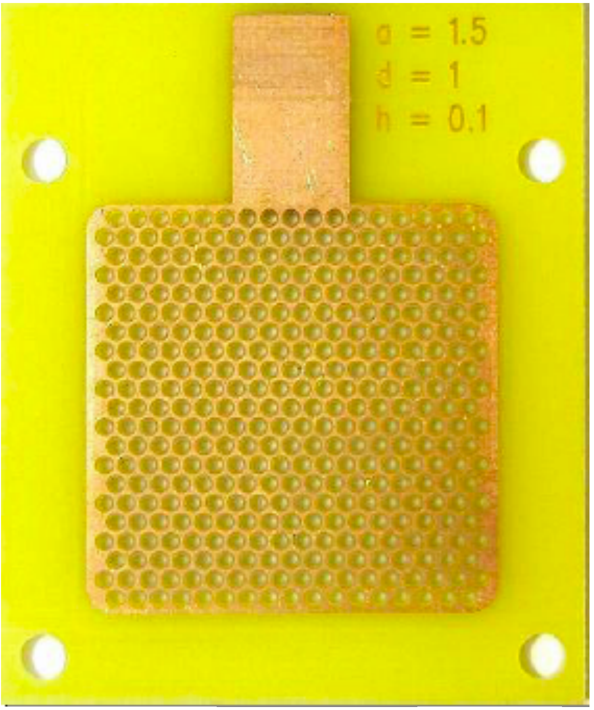
Padova, 7 - 6 - 2006

Outline

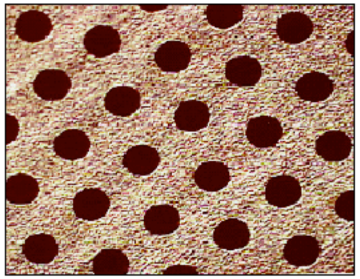
- **The basic idea:**
    - Macroscopic version of hole Gas Electron Multipliers (GEM's)
        - ~mm hole size in standard double-face Cu-clad Printed Circuit Board (PCB)
        - Characteristics & performance under investigation by several collaborations
- **Goals:**
    - Stable High gain (> 10^4 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

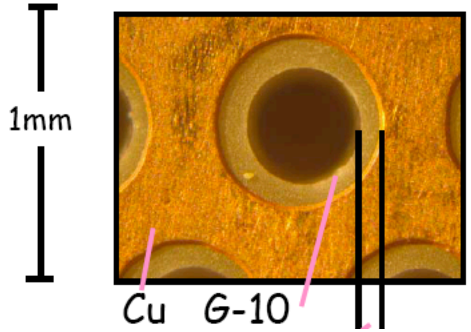
- A thick GEM-like gaseous electron multipliers made of standard printed-circuit board perforated with sub-millimeter diameter holes, chemically etched at their rims
  - In-house fabrication using automatic micromachining
  - Self-supporting
  - Extremely resistant to discharges (low capacitance)
- First introduced within the ICARUS R&D group
  - for double phase noble gasses TPC's in the keV region
    - H. Wang, PhD Thesis, UCLA, 1999
    - L. Periale et al, 2000.
- 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.



Standard GEM



LEM

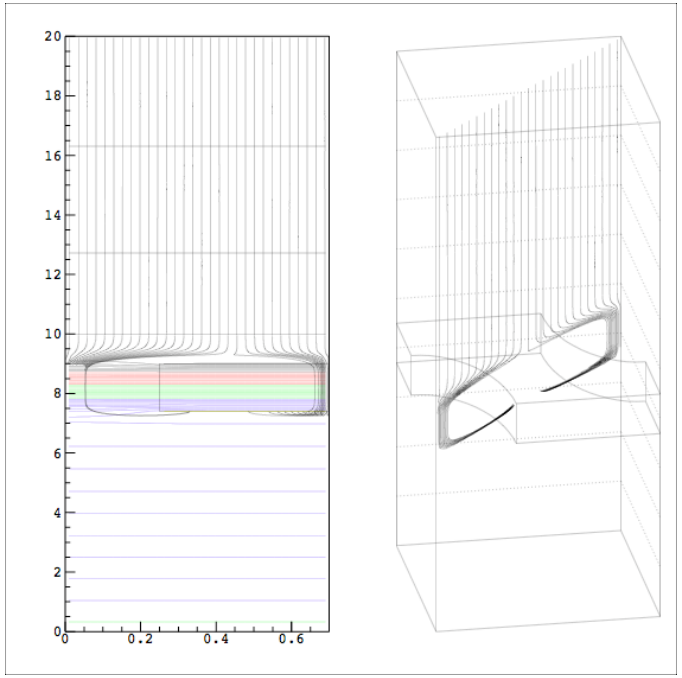


LEM: principle of operation

- Upon application of a voltage difference across the LEM, a strong dipole field E_{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_{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

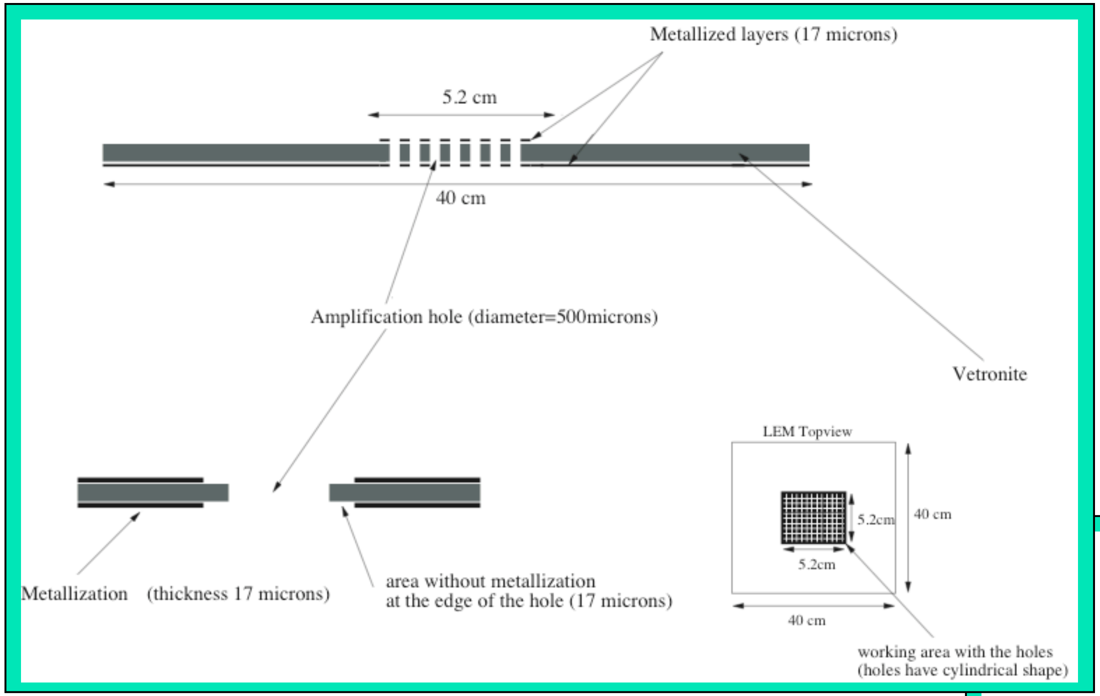
- Characteristics:
  - 100% transparency to incoming electrons
    - Full detection efficiency
  - Strong constant field well confined inside hole
    - Avalanche confinement, stable gain
  - Uniform field across hole diameter
    - Uniform multiplication factor, good resolution



- 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

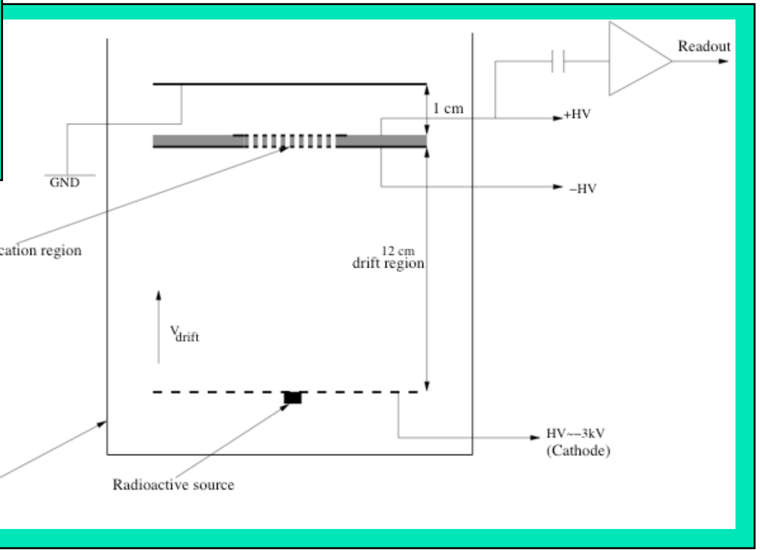


LEM prototypes

Thickness = 1.0, 1.6, 2.4 mm

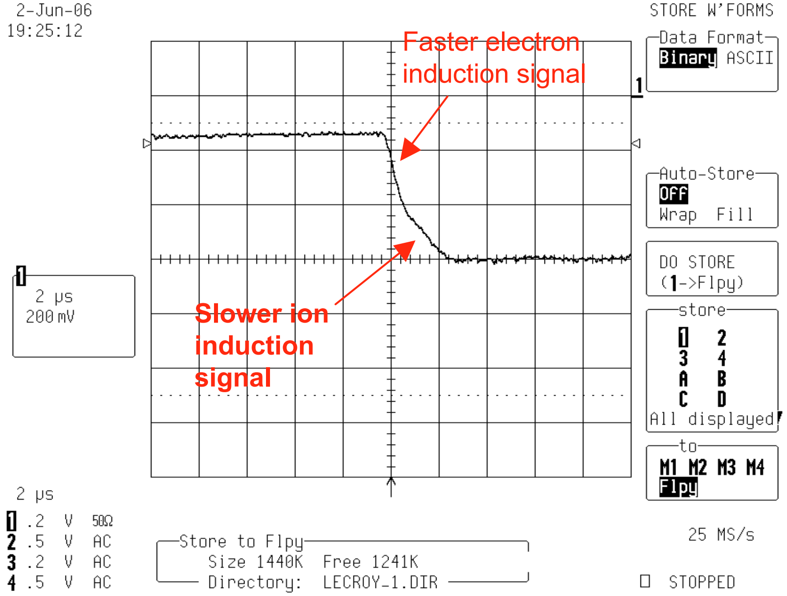
Hole diameter = 0.5 mm

Test set-up

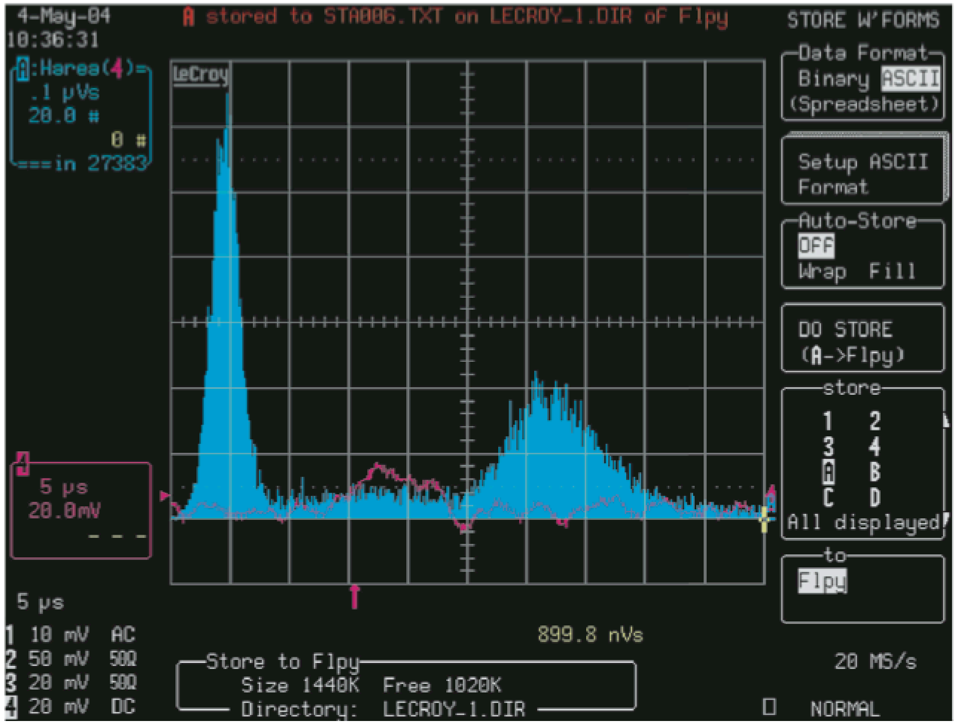


Typical signals and Spectra (Fe^{55})

Pure Argon (1 bar)


Faster electron induction signal

Slower ion induction signal

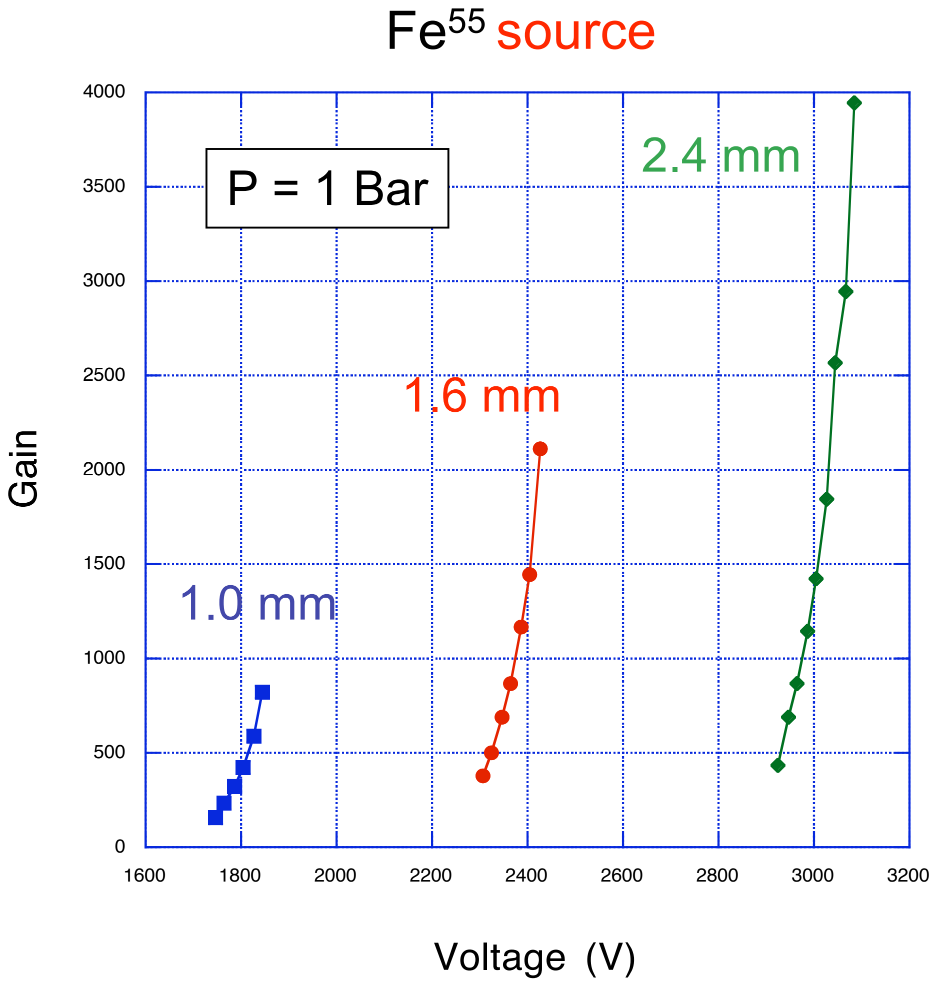


Gain > 1000

Resolution ~ 30% FWHM

(15-20 % expected)

LEM gain (pure Argon)



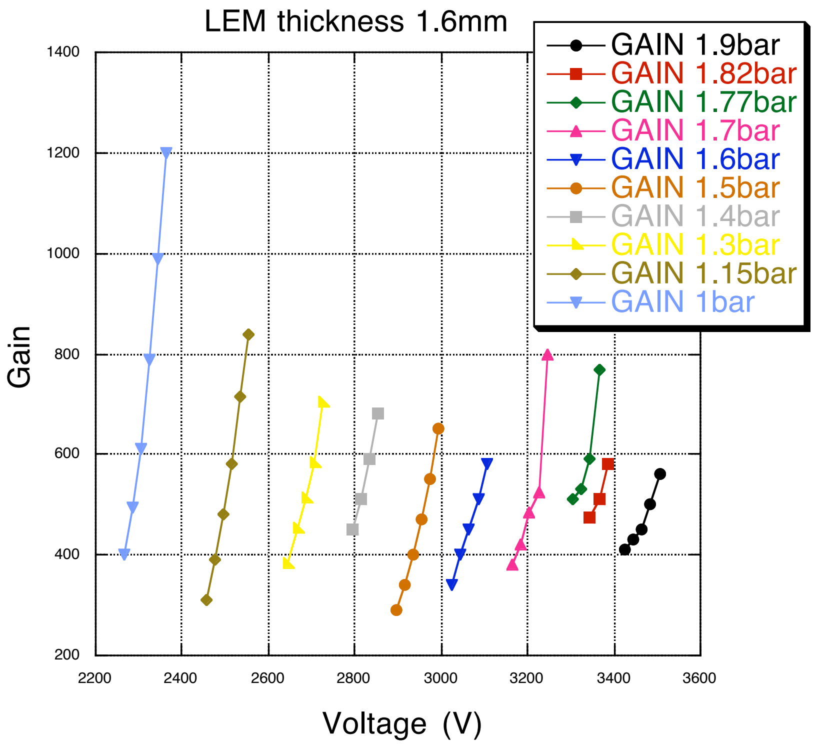
- Gain behaviour
  - Exponential grow in uniform electric field (parallel plate chamber)

$$G = \exp(\alpha d)$$

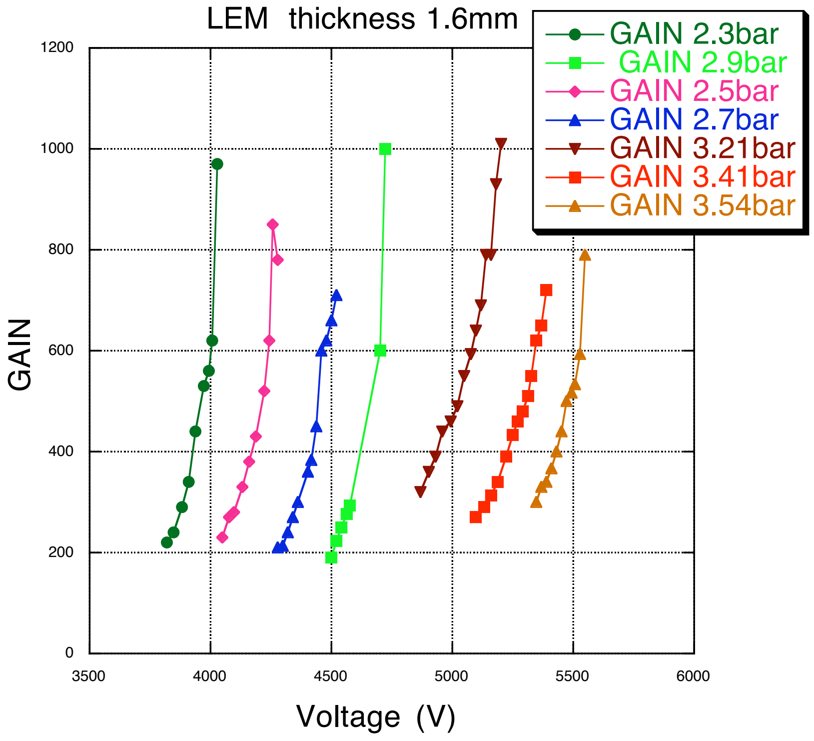
    - d = detector thickness
    - α = Townsend coefficient (depends on E,p,d)
- Max gain
  - Increases with thickness
    - Geometrically reduced photon feedback
- Time stability
  - Guaranteed if no discharges
    - Far from brake-down voltage
  - Sudden degradation after several occasional break-down
    - hole walls carbonization

High pressure gain (pure Argon)

Fe^{55} source

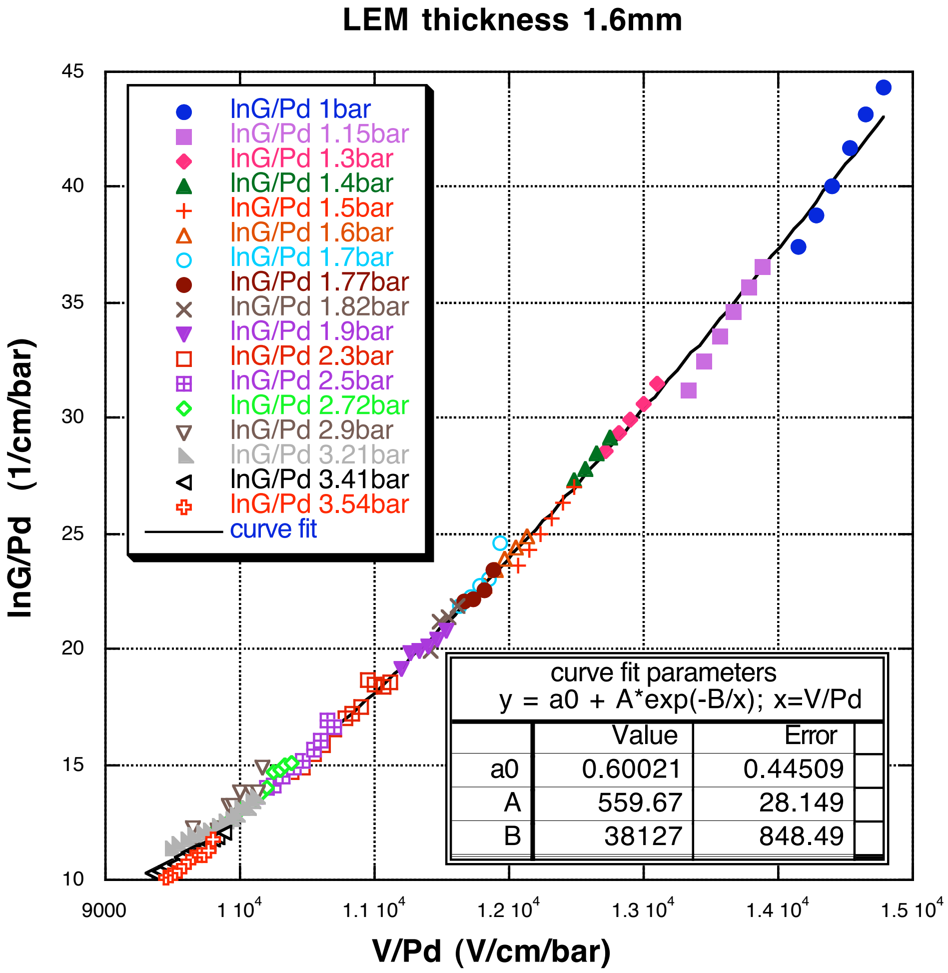


Cd^{109} source



- 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

Gain scaling vs pressure and field



curve fit parameters
y = a0 + A*exp(-B/x); x=V/Pd

	Value	Error
a0	0.60021	0.44509
A	559.67	28.149
B	38127	848.49

- Gain behaviour

$$G = \exp(\alpha d)$$

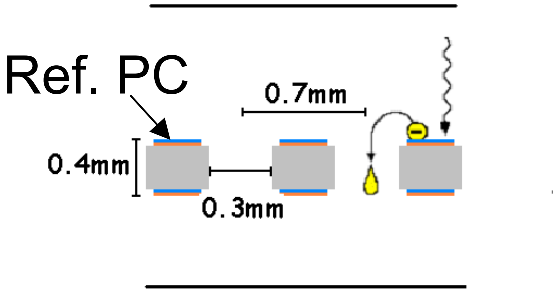
- Townsend coefficient α well described by Rose-Kroff law

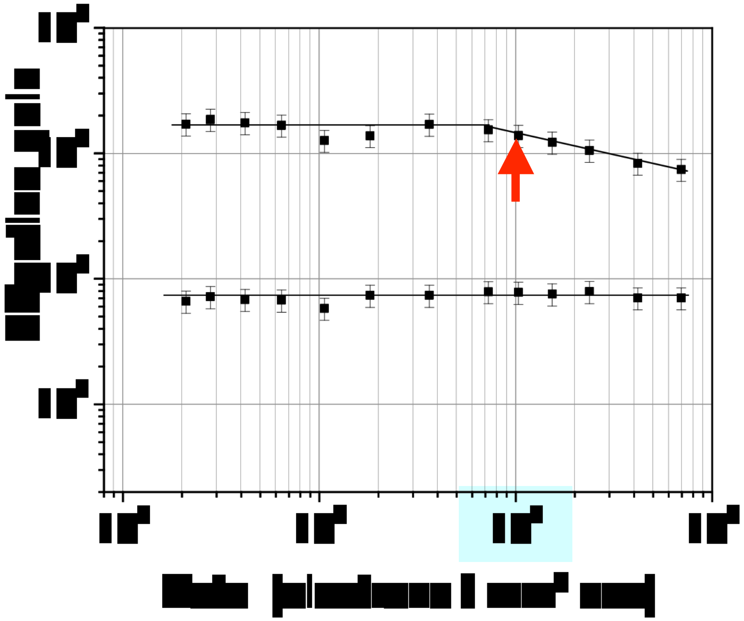
$$\alpha = Ap\exp(-Bp/E)$$

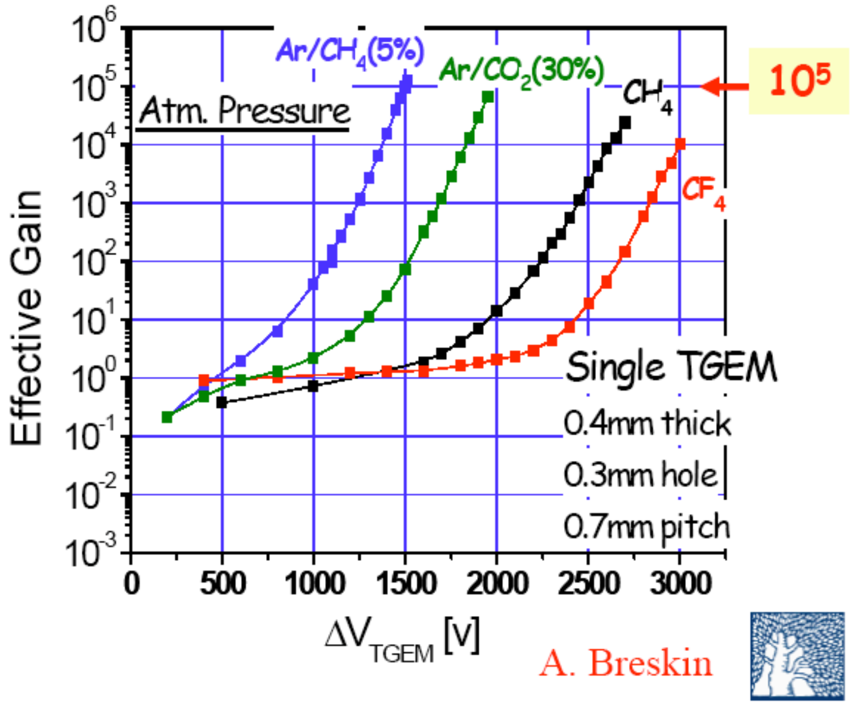
  - d = detector thickness
  - E = electric field
  - p = pressure
  - A,B = parameters depending on gas mixture
- Not very significant deviation from expectations in wide range of E,p,d
  - Easily predictable gain and break-down value for different LEM layout

LEM with gas mixtures

Example: LEM photon detector with reflective CsI photocathode.







A. Breskin

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

R. Chechik et al. Physics/0502131 & NIMA i.p.

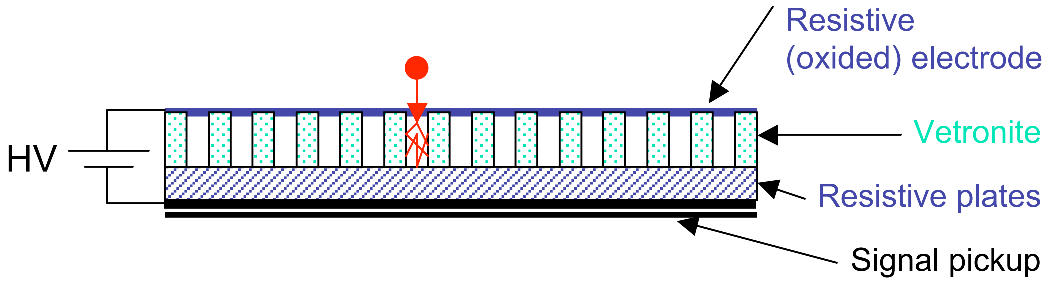
Open problems for further R&D

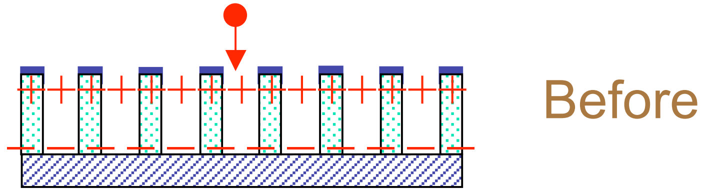
- Residual charging-up of holes walls due ions/electrons diffusion especially at high rate and residual photon feed-back in pure noble gasses, affecting:
  - Maximum Gain
  - Energy resolution
  - Time stability
- Possible fields of investigation:
  - LEM geometry (including multi-step)
    - To reduce 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

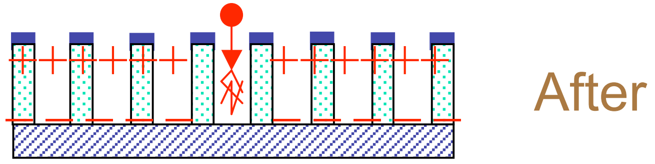
- Hybrid RPC concept:
  - Resistive layer “quenches” the electron avalanche
  - Vetronite holes “limit” the photon propagation and after pulses
- Goal
  - It Should allow gains up to streamer mode (maybe limited by photon feed-back through hole input)
- Disadvantages
  - Choice of resistive material critically depending on rate and gain (resistive materials from Quadrant Technology, ranging from 10^5 to 10^{15} Ω-cm, under investigation)

Preliminary results:
Gain >> 10^4 easily reached





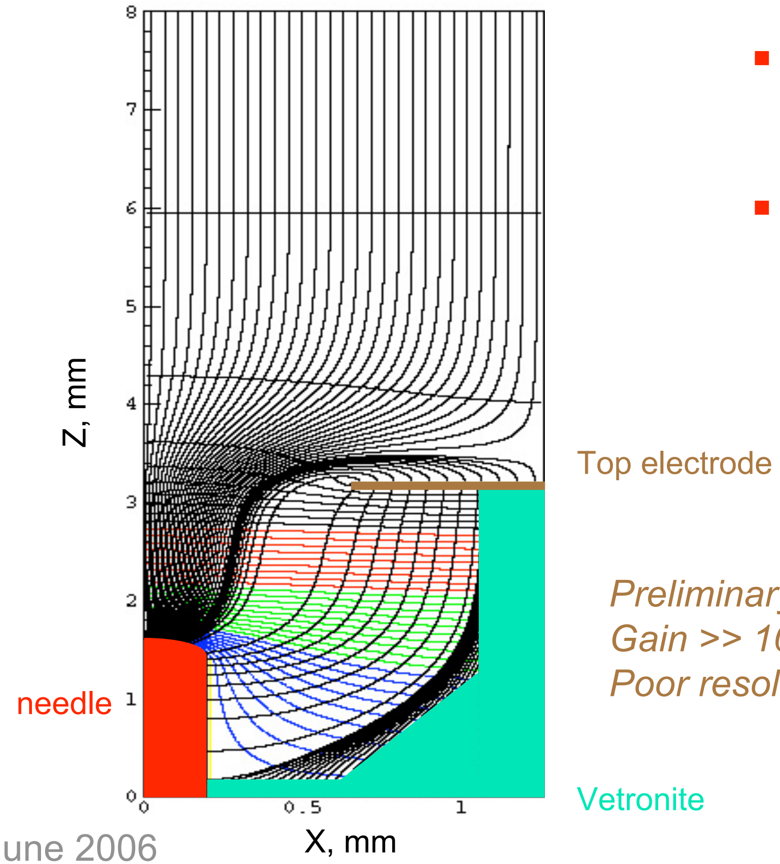
A charged particle entering the hole induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally (~1 hole) available charge is consumed. Photons are blocked by vetronite walls.



The discharged area recharges slowly through the high-resistivity plates.

Needle-LEM

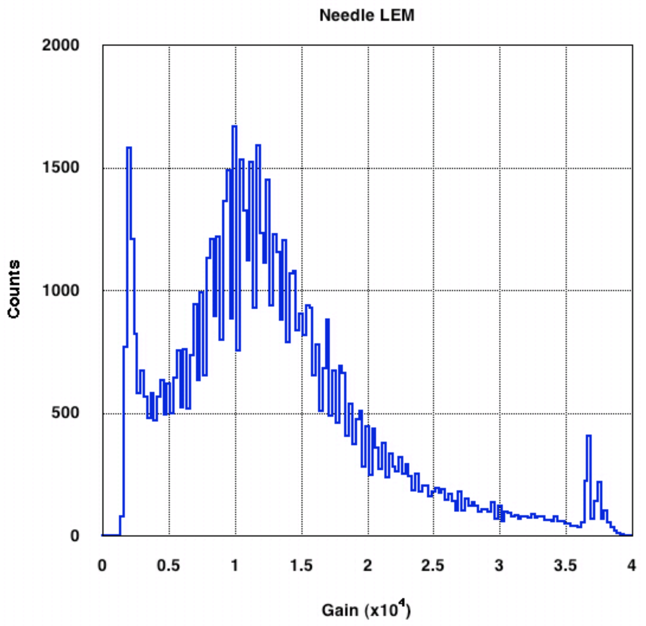
- Coupling of a LEM with a needle array and oxided-Cu (or resistive) layer



- 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)



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, cabable 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

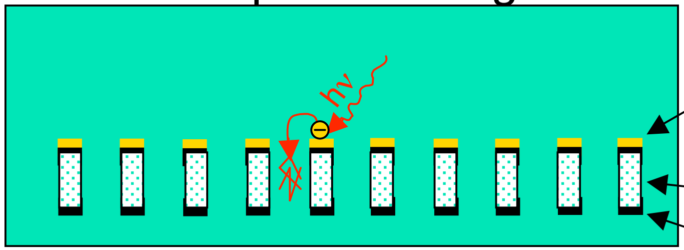
- Xenon TPC's (CARDIS-PRIN2005) for fast medical imaging
  - Photoelectic e$^-$ from ~10^2 KeV γ's (Tantalium, Tecnetium)
    - Moderate gain required: 10^2 - 10^3
    - High density (pressure >6 bar): high absorption efficiency
    - Good event localiziation: limited e$^-$ diffusion allows mm size pixel
  - Compton rejection
    - Requirements: good energy resolution.
- Segmented LEM could match detector requirements:
  - Design with ~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

LEM with pure noble gasses



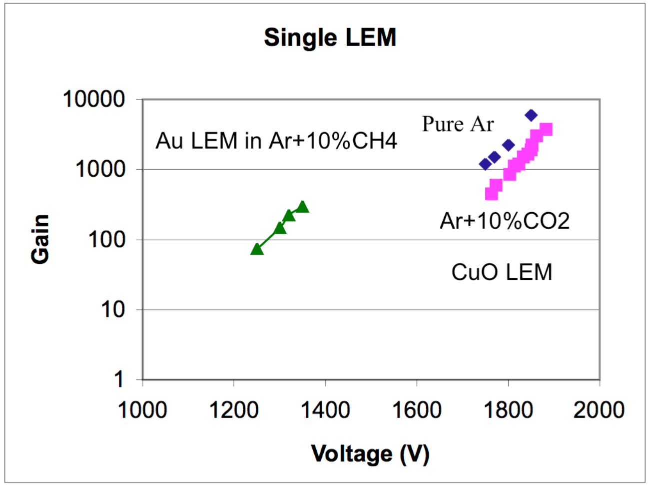
CsI reflective photocathode

G-10 LEM

Resistive/oxided coating

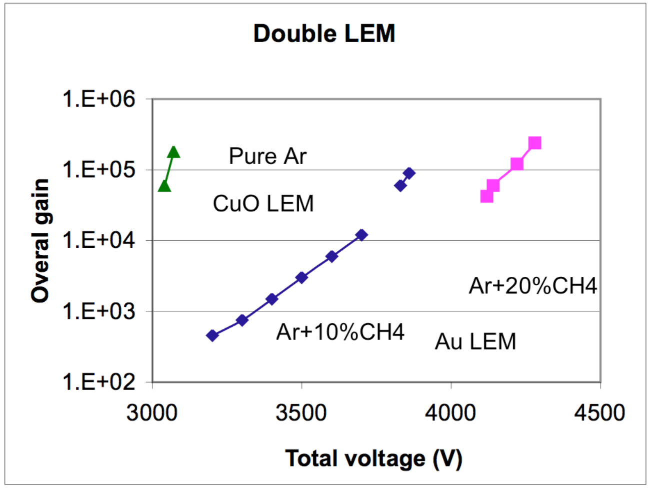
- High CsI q.e. in Ar and Xe (> 20%)
- Gain >10^4 allows sensitivity to single photo-electron
- Good event localization (down to mm^2 size)

Single LEM



Preliminary results

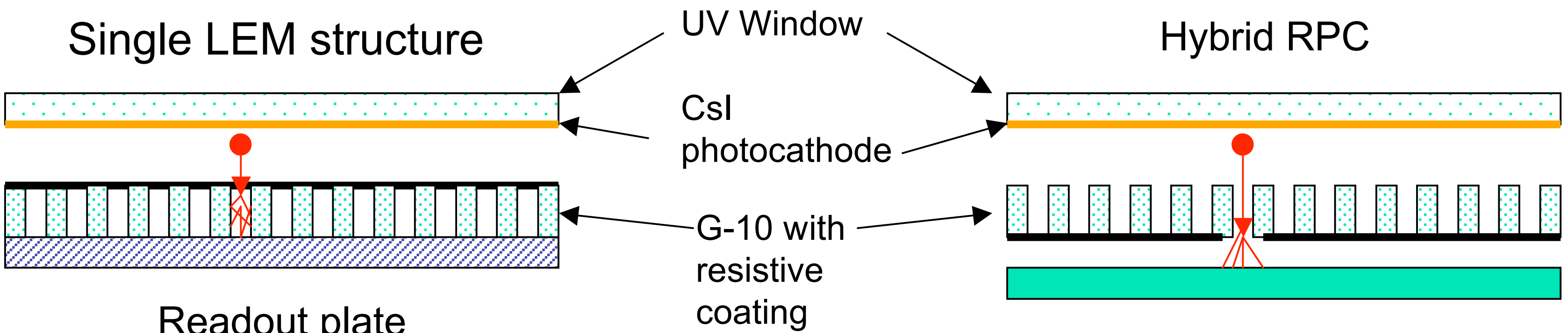
Double LEM



LEM with resistive coating

P.Fonte et al.

Large area UV photosensitive detectors


Single LEM structure

UV Window

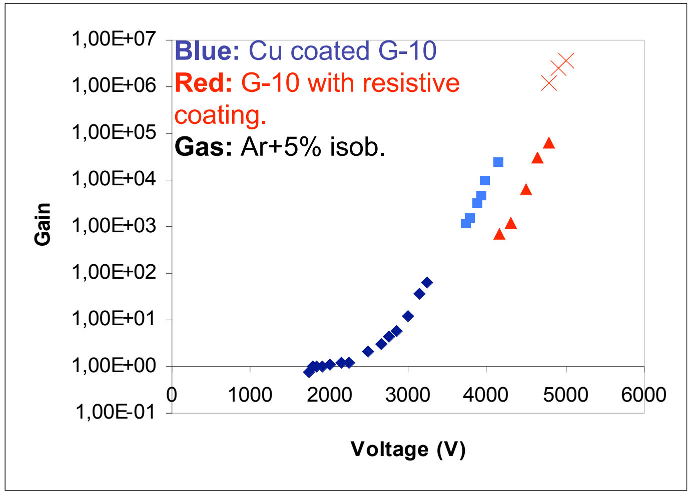
Hybrid RPC

CsI photocathode

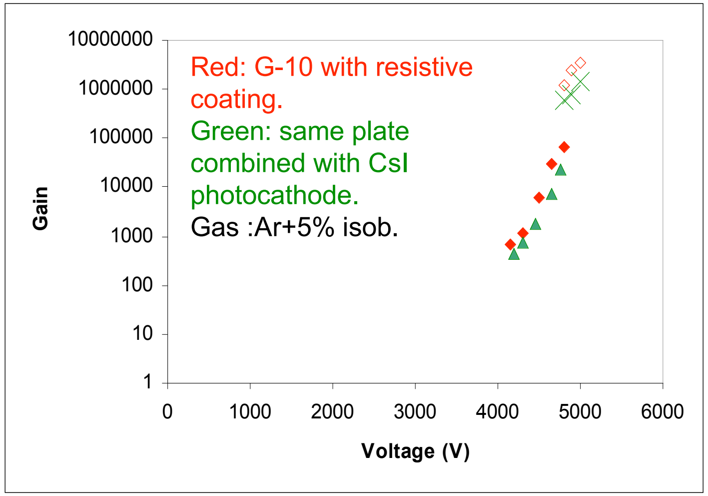
G-10 with resistive coating

Readout plate

Readout plate



Preliminary results

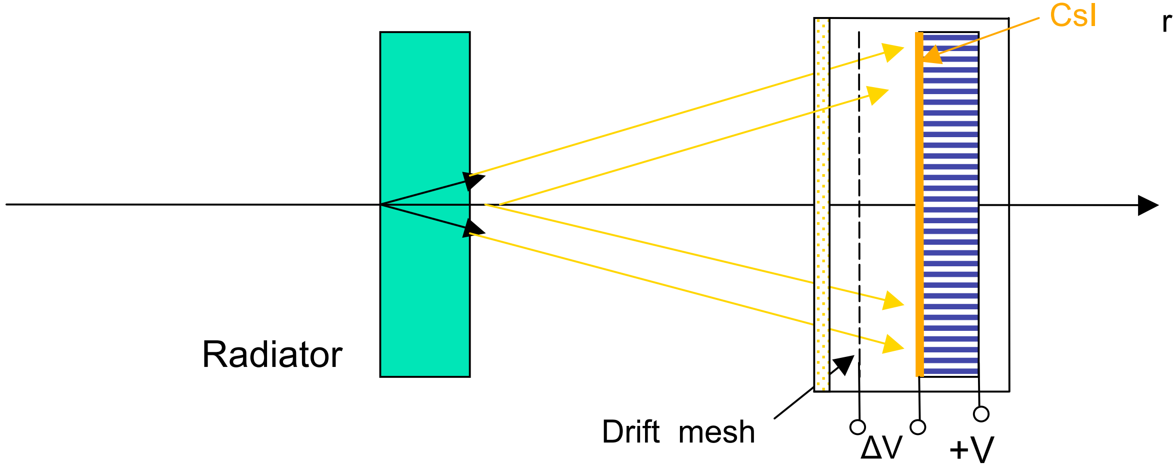


higher gains are possible with resistive coating

LEM and RICH

P. Martinengo et al. (CERN)

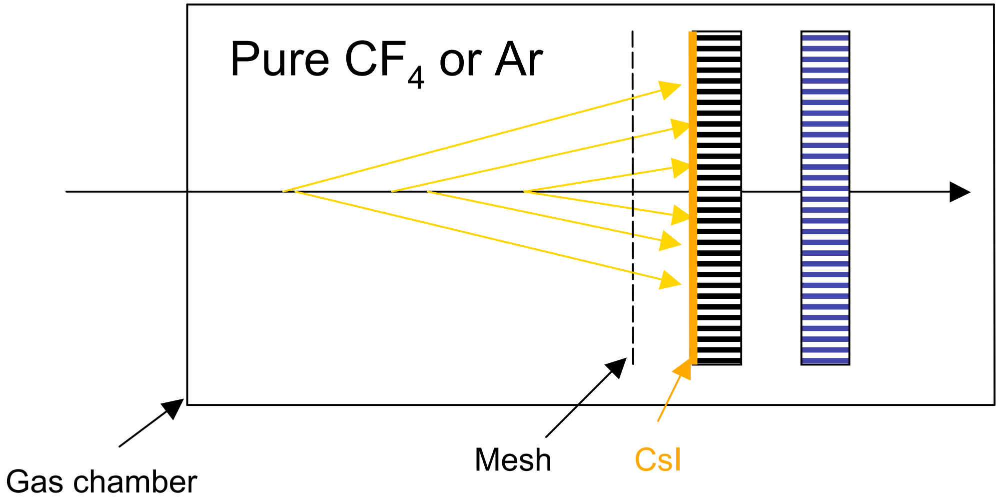
Possible application of LEM in “classical’ RICH



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

Advantages:
simpler design,
possibility to be
insensitive to charged
particles (at ΔV=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 ΔV=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
- Milestones:
  - Primo anno: Prototipi piccola scala (10x10 cm^2):
    - ottimizzazione layout LEM, LEM+needles, LEM resistive
      - Guadagno
      - Risoluzione
      - Stabilita temporale
      - Accoppiamento con fotoconvertitori per VUV
  - Secondo anno: LEM di medie dimesioni (30x30 cm^2):
    - Readout segmentato per:
      - Imaging medicale 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 €