2nd International Workshop on Soft Xray Single order Diffraction Grating Development and Application at Coimbra (Portugal)

LIBPhys

SXSDG 2019

Coimbra Gas Radiation Detectors Heritage

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FCT Fundação para a Ciência e a Tecnologia

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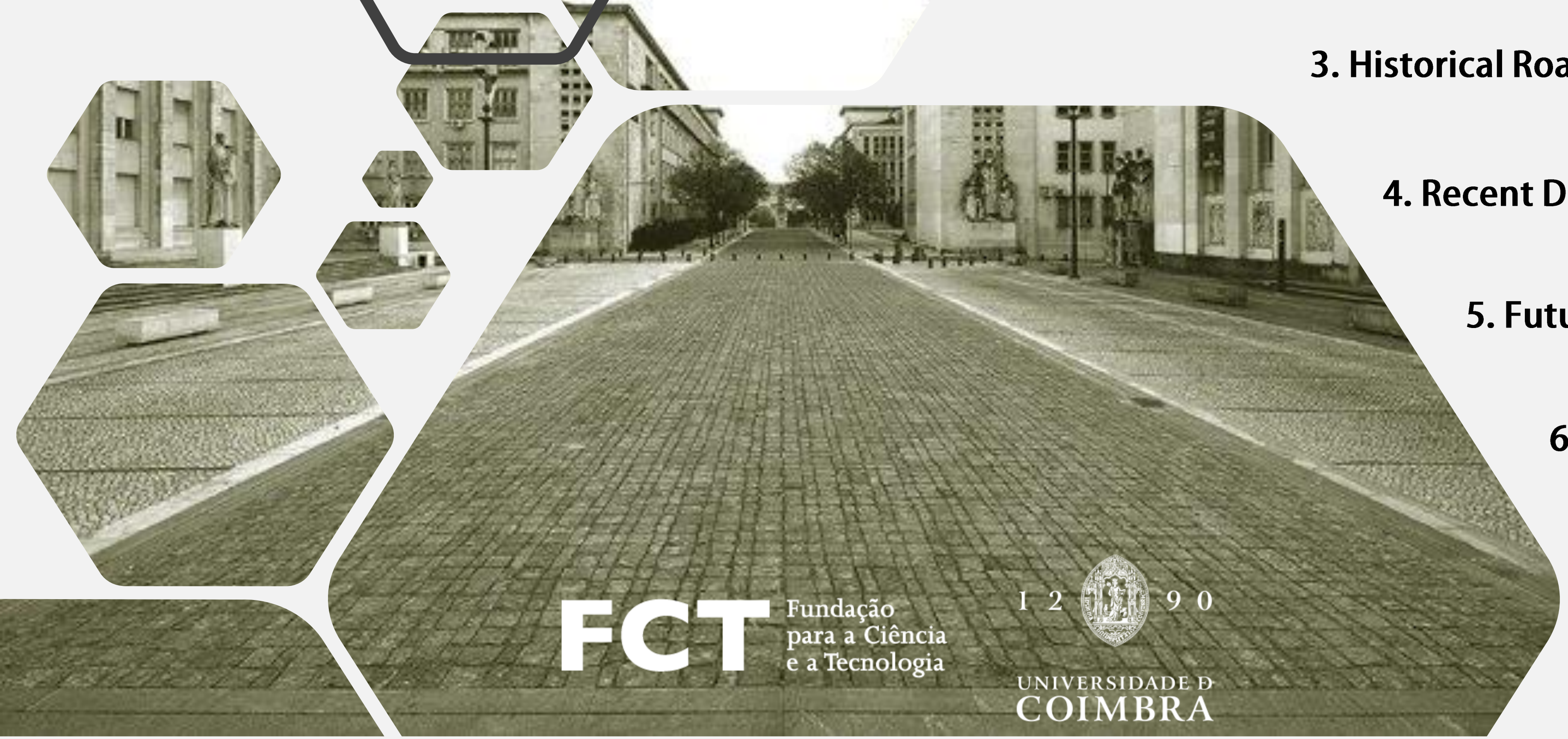
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Brief History of the University of Coimbra

Brief History of the University of Coimbra

- **1290** - Foundation of the **University of Coimbra** by **King Denis** I (1262-1325)

Initially estabilished in Lisbon its location was changed periodically between Coimbra and Lisbon until it was moved permanently to its current location in **1537** by royal decree from **King John III** (1502-1557).

- End of 18th century a **radical reform of the educational system** occurs by the hand of the **Marquis of Pombal (1699-1782) at that time the Minister of the Kingdom of Portugal**.

⇩

- 1772 – Foundation of the **Physics Cabinet** by **Dalla Bella** (1730-1823)

⇩

Dedicated to Experimental Physics

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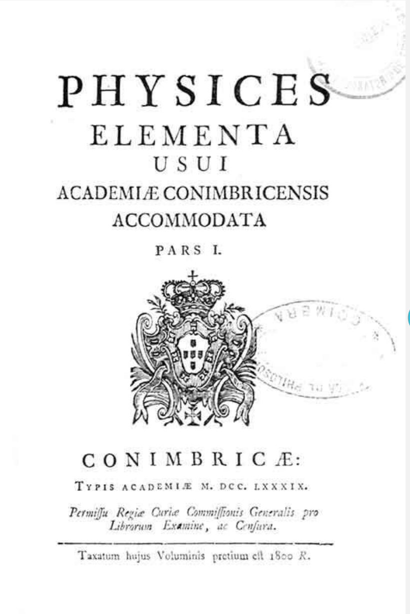
Important Remarks

- First Portuguese University
- One of the oldest in continuous operation in the World (Top 10)
- UNESCO World Heritage Site since 2013

Brief History of the University of Coimbra

- 1772 – Foundation of the **Physics Cabinet** by **Dalla Bella** (1730-1823)
- First facility completely dedicated to the teaching of experimental physics.

Dalla Bella was a Professor (Experimental Physics) at the University of Coimbra from **1772 to 1790**, being responsible for **one of the biggest collections of physics instruments** from the **late 18th** century, currently in exibihition at the University of Coimbra.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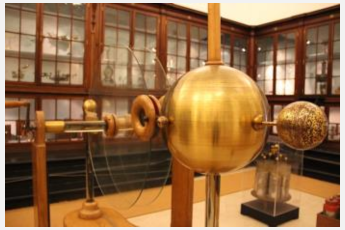
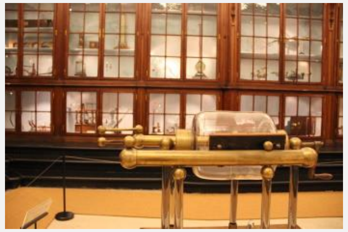
Just to get na idea...

The Physics Cabinet in 1936...

...and nowadays...





Electroluminescence
The Legacy of Manchester

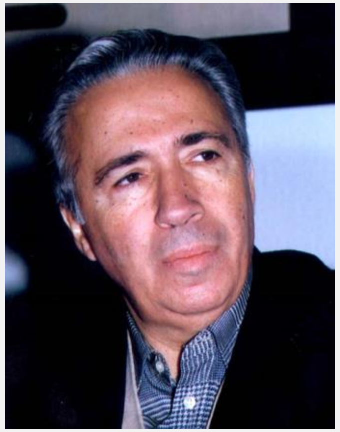
Electroluminescence – The Legacy from Manchester

- **In 1948, Almeida Santos** who had worked previously with **William Lawrence Bragg** (1890-1971) at the University of Manchester, becomes head of the Physics Laboratory.

Nobel Prize in Physics in 1915
for the "analysis of crystal structure by means of X-rays"

- Influenced by his predecessor, **Almeida Santos** looked for young talented minds in the University of Coimbra and sent them to different Universities across the UK to bring knowledge to Coimbra.
- Among those brilliant students were:

Carlos Conde (1935-Present) and **Armando Policarpo** (1935-Present)



Joined the **Nuclear Physics Group** at the **University of Manchester** in **1959,** having concluded their PhD Thesis with success in **1965**, and returning afterwards to Coimbra, where they will greatly influence the research on gas radiation detectors.

Electroluminescence – The Legacy from Manchester

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- **Carlos Conde** and **Armando Policarpo** focused their research on studying direct interaction processes leading to the discovery/understanding of the electroluminescence phenomenon.

Although the first known observations of the phenomenon were made by **Harold Edgerton (1903-1990).**

What is electroluminescence?

Following excitation and ionization of the gas atoms by electron impact in a gas detector, scintillation photons are emitted – **the Primary Scintillation**:

Excitation and Ionization of gas atoms → Deexcitation → Scintillation photons are emitted

Excitation luminescence

$e^- + X \rightarrow X^* + e^-$	Excited atoms	$X^* \rightarrow X + h\nu$ atomic lines (<50 Torr)
$X^* + 2X \rightarrow X_2^* + X$	Excited dimers/excimers	$X_2^* \rightarrow X + X + h\nu'$ continuum (>100 Torr)

Recombination luminescence

$e^- + X \rightarrow X^+ + 2e^-$	Atomic Ions	$e^- + X^+ \rightarrow X^* \rightarrow X + h\nu$
$X^+ + 2X \rightarrow X_2^+ + X$	Diatomic Ions	$X_2^+ + e^- \rightarrow X_2^* \rightarrow X + X + h\nu'$

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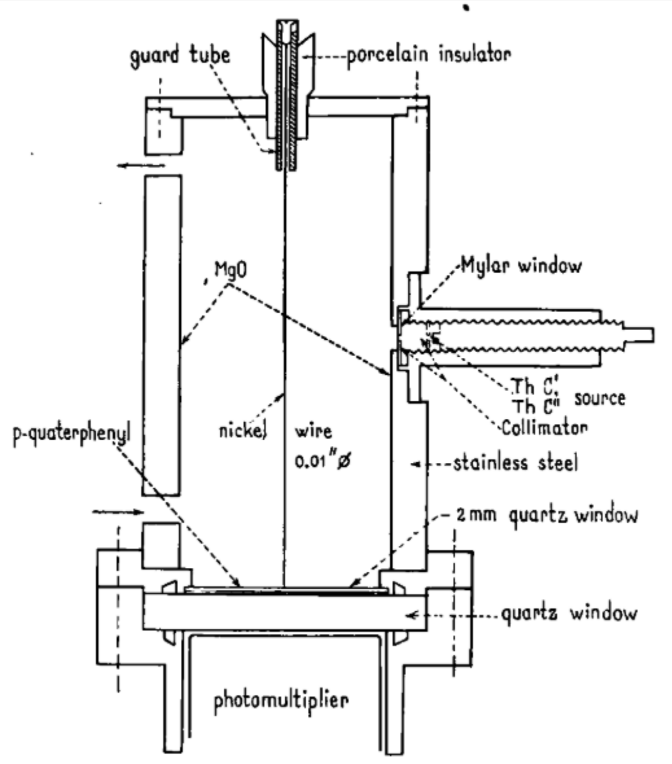
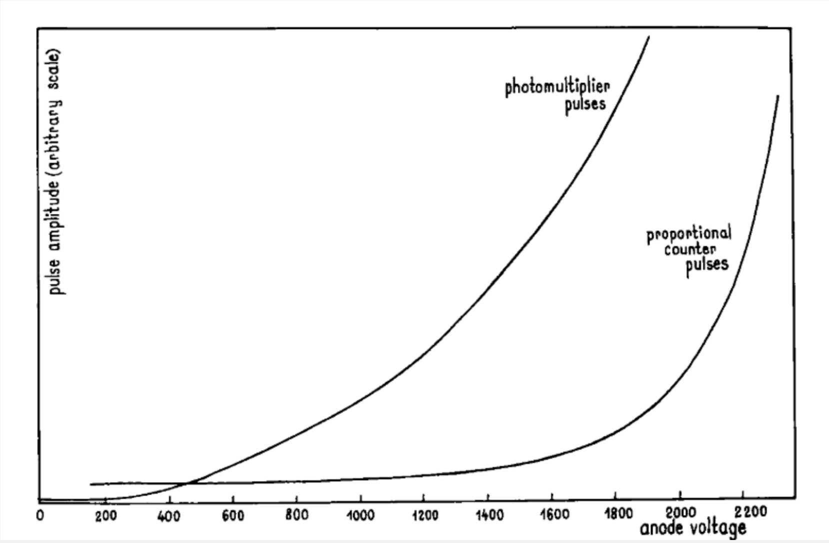
Electroluminescence – The Legacy from Manchester

But what they learned was far more interesting…

- Adapting the concept of Proportional Counter (using a PMT simultaneously) they were able to observe that:



- Two scintillation signals ;
- The secondary scintillation only appeared above a certain threshold (excitation threshold);
- Appeared to be independent of the charge signal (read at the anode);
- Proportional to the incident radiation energy;
- Could be enhanced by applying the conditions that favour its occurrence;



Good energy resolution

(already comparable with Proportional Ionization Counters)

Electroluminescence – The Legacy from Manchester

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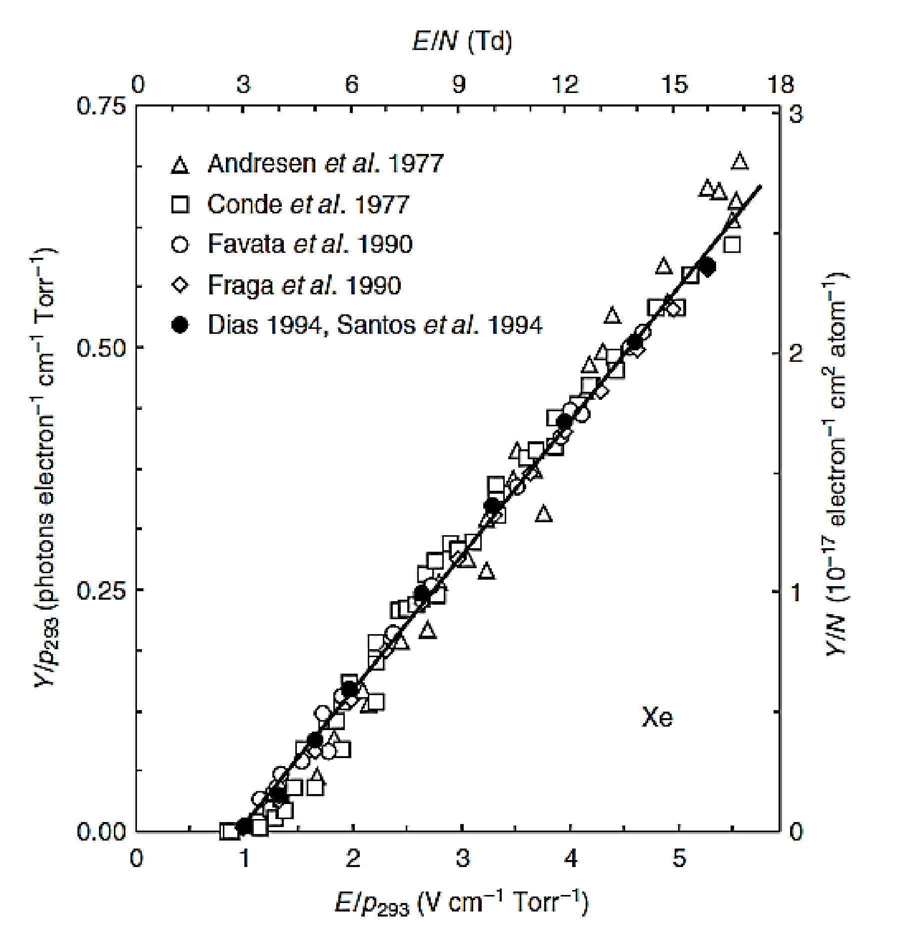
Conde and Policarpo also understood something important:



For E/p ≈ 1-6 V cm-1 Torr-1:

The light signal depends **linearly** with the pressure-reduced electric field (E/p) applied in the scintillation region.

From these studies they were able to obtain the empirical expression that allows to estimate the scintillation yield (Y).

$$\frac{Y}{p}(293\ K) = A\frac{E}{p} - B_{(photons\ electron^{-1}cm^{-1}Torr^{-1})}$$

Note: A and B are constants that depend on the gas.

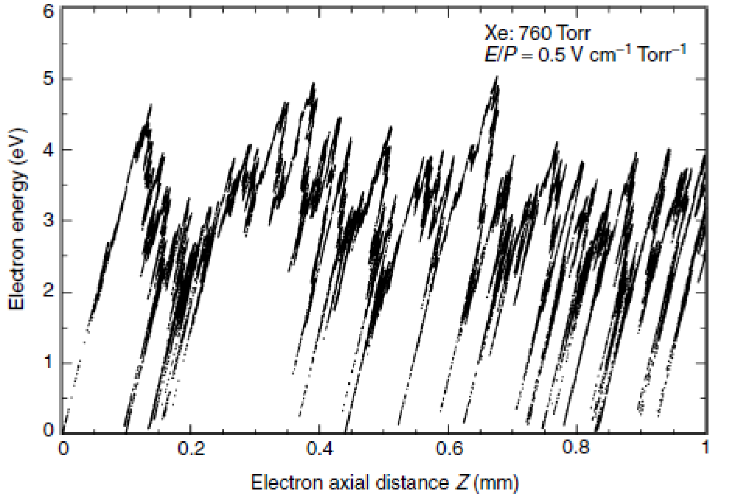
Years later detailed Monte Carlo simulation study would explain these experimental results (Dias et al 1994 and Santos et al, 1994).

Electroluminescence Legacy of Manchester in the University of Coimbra

To understand the importance of this mechanism we need to look at what happens to the electrons…

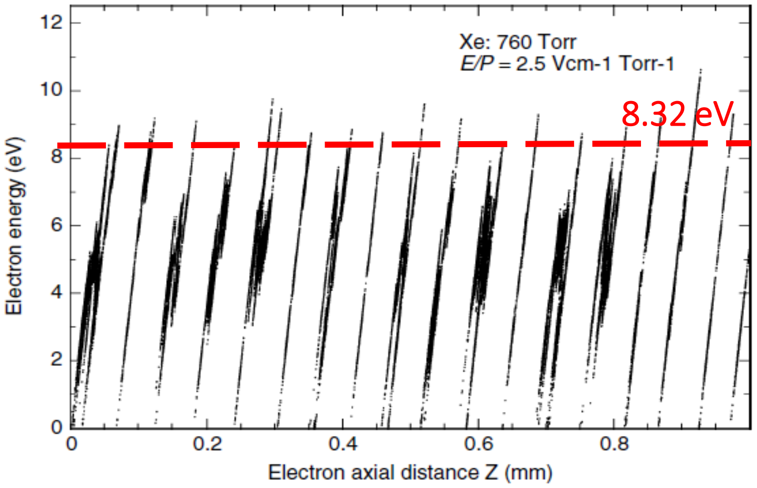
For $\frac{E}{p} < 1\ V\ cm^{-1} Torr^{-1}$:

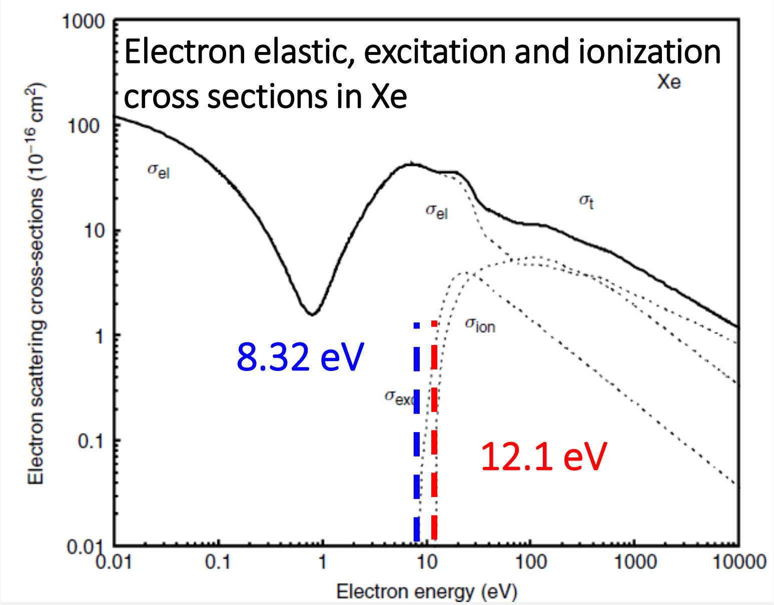
- Electrons gain energy from the field between collisions
- Electrons loose energy in elastic collisions
- Energy gain between collisions is below excitation level 8.32 eV



For $\frac{E}{p} > 1\ V\ cm^{-1} Torr^{-1}$:

- Electrons loose little energy in elastic collisions;
- But now energy gain between collisions is higher, allowing ε to reach 1st excitation level 8.32 eV:
- one excitation → one EL VUV photon:
- High gas purity required !





- EL is an efficient process

+

- Few statistical fluctuations

Energy resolution
(close to the intrinsic)

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Historical Roadmap of GPSCs

Historical Roadmap of Gas Proportional Scintillation Counters

A Contribution from the University of Coimbra

Using the knowledge from their previous experience both Conde and Policarpo decided to develop new gas radiation detector

Gas Proportional Scintillation Counters (GPSCs)

- Making use of this characteristic as an amplification stage in Gas Detectors for the 1st time (Conde and Policarpo, 1967);
- Testing different **geometries**;

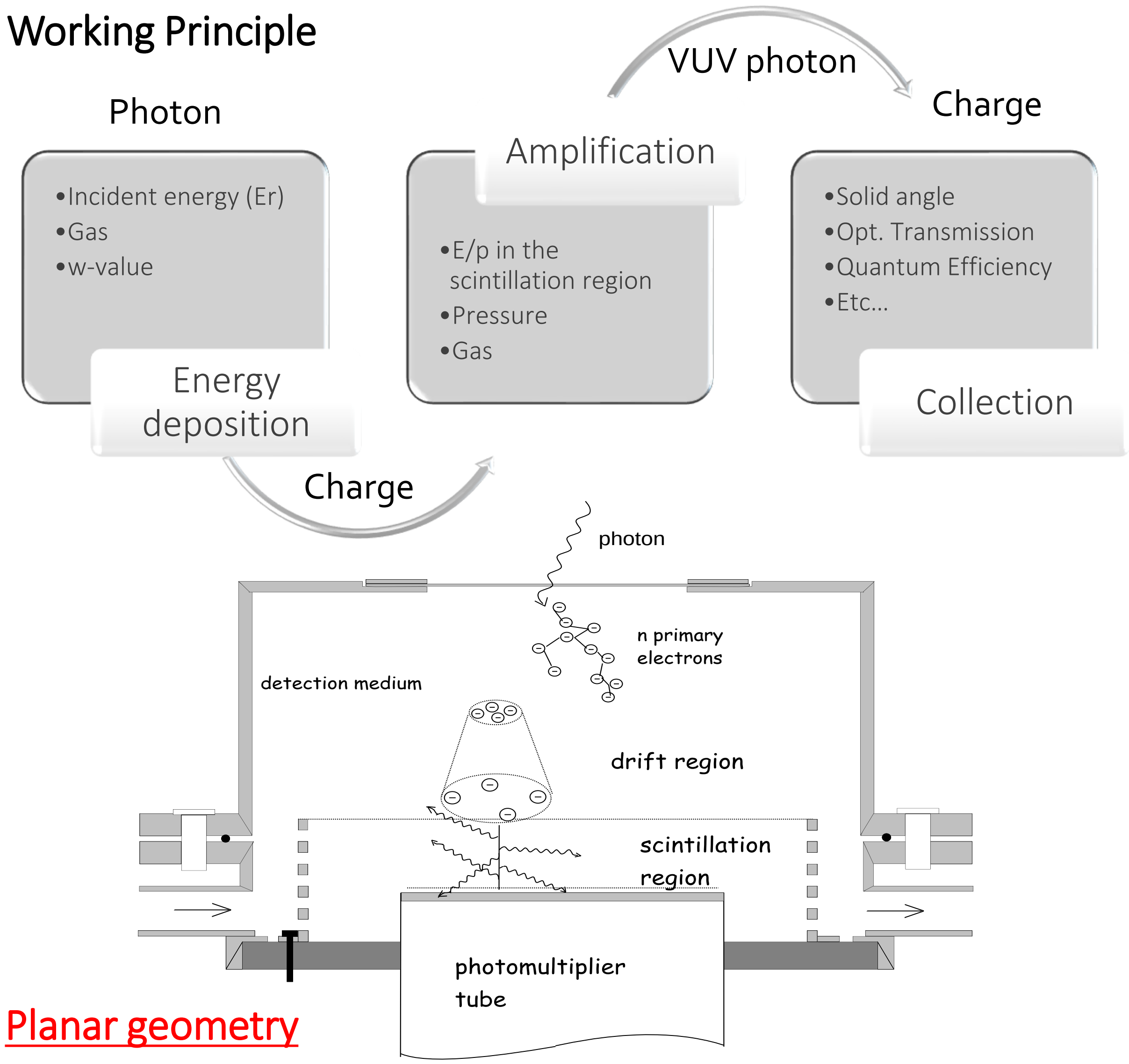
Cylindrical geometry

Planar geometry

Spherical geometry

The end of the **1960s** would represent the start of an **golden era** for **detector development** as we will see.

Working Principle



Planar geometry

NUCLEAR INSTRUMENTS AND METHODS 53 (1967) 7–12; © NORTH-HOLLAND PUBLISHING CO.

A GAS PROPORTIONAL SCINTILLATION COUNTER

C. A. N. CONDE* and A. J. P. L. POLICARPO*

The Physical Laboratories, The University of Manchester, U.K.

Received 21 February 1967

The effect of a radial electric field on the scintillations produced in argon by alpha particles from a ThB source was studied. Following the fast primary scintillation there is a second slower component that increases with the field and shows an intrinsic energy resolution of about 2.3%. The performance of this scintillation counter is analysed and it is shown that it can be favourably compared with most scintillation and proportional counters. A preliminary discussion on the light production mechanism is given.

NUCLEAR INSTRUMENTS AND METHODS 55 (1967) 105–119; © NORTH-HOLLAND PUBLISHING CO.

THE ARGON-NITROGEN PROPORTIONAL SCINTILLATION COUNTER

A. J. P. L. POLICARPO, M. A. F. ALVES and C. A. N. CONDE

Laboratório de Fisica, Universidade de Coimbra, Portugal

Received 25 April 1967

The characteristics of a gas proportional scintillation counter are studied for various argon-nitrogen mixtures at total pressures of around 1000 Torr, using α-particles. Measurements of the delay between the primary and the secondary scintillation pulses show that most of the secondary light is produced close to the

be limited by the appearance of the higher order components, the light collection efficiency and the photomultiplier. The extrapolation of the data shows that if the first factor can be eliminated the resolution will be limited by the total number of photons produced and not by a scintillator intrinsic resolution

Gas Proportional Scintillation Counter

Configuration of Gas Proportional Scintillation Counters

Geometry

- Cylindrical
- Spherical
- Plannar

Absorption Stage

- Standard
- Driftless

Amplification Stage

- Scintillation
- Hybrid (light plus charge)

Readout Stage

- Photosensors
- MPGDs
- Photocathode Film

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1970s – Understanding Electroluminescence

Topics addressed:

- Charge and light gains
- Energy resolution
- Linearity

- Energy,
- Mean counting rate,
- Ionization length
- Distribution along the wire
- anode voltage

- Gain and resolution (still worse than PIC) could be improved
- Charge and light signals were correlated
- Good linearity

Deviations were identified as coming from: **space charge effects**

- use of an anode voltage as low as possible;
- increase of the anode wire diameter;
- use of lighter gases;

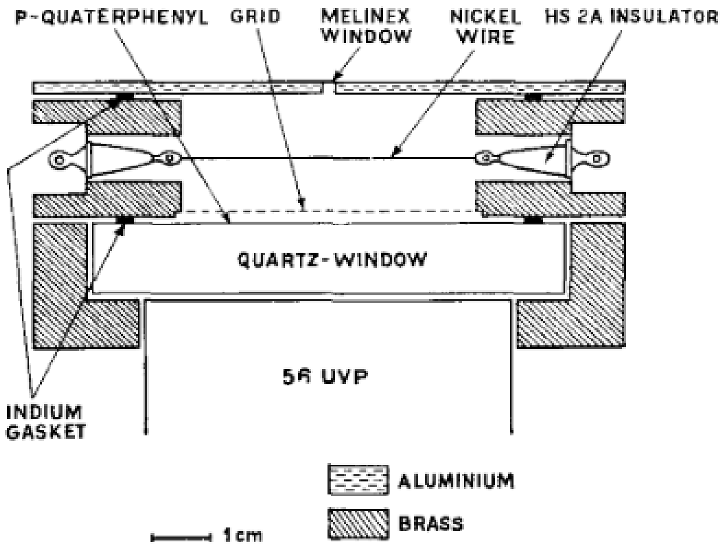


Fig. 1. The gas proportional scintillation counter.

(Policarpo et al 1970)
(Policarpo et al 1971)

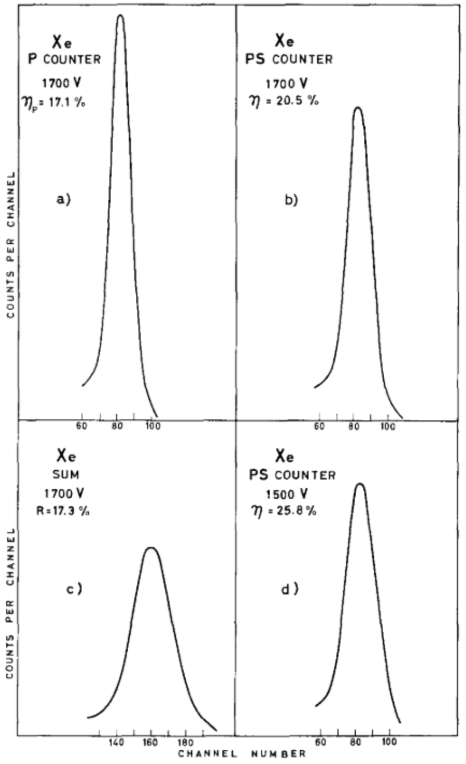


Fig. 2a, b, d. Typical pulse height distributions of the 5.9 keV X-ray from a ⁵⁵Fe source. c. Pulse height distribution of the electronic sum of a and b.

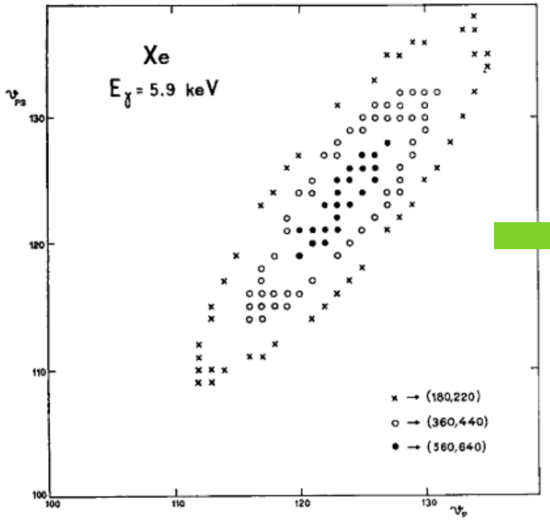


Fig. 5. Bidimensional analysis of the charge pulse amplitude (v_P) and the light pulse amplitude (v_{PS}). The number of counts are indicated.

Correlation clearly visible

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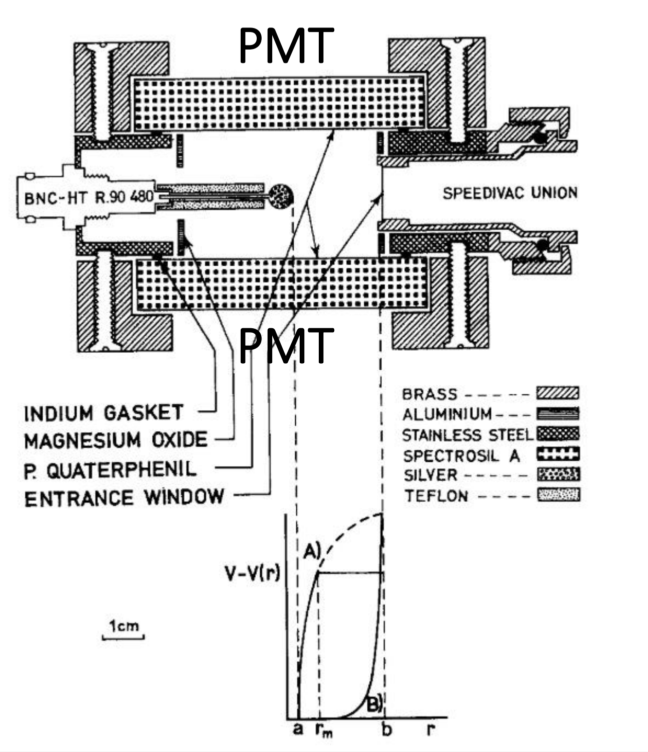
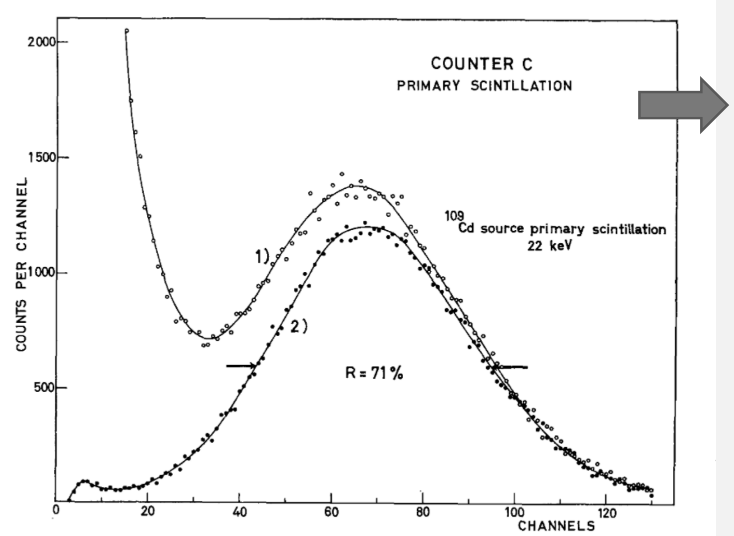
Historical Roadmap of Gas Proportional Scintillation Counters

The Spherical GPSC

(Policarpo et al 1972)



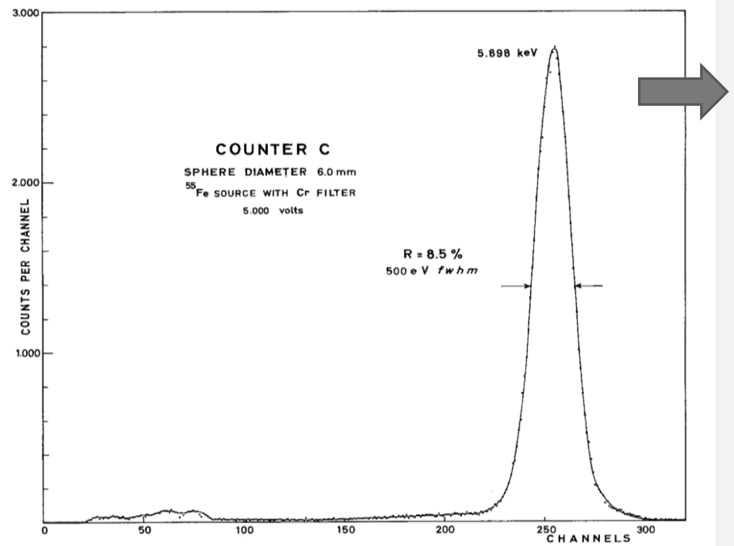
- Scintillation occurs in the vicinity of the anode;
- No variation of the solid angle;
- Use of 2 PMTs allowed to reduce noise;



- R=71% for 22 keV (primary scintillation)
- Poor energy resolution
- Little interest
- Could be used for fast coincidence

Curve 1 represents the spectrum without coincidences
Curve 2 represents the spectrum with coincidences

Removes almost completely the background arising from the PMTs dark current



- R=8.5% for 5.898 keV
- Energy resolution comparably better than existing technologies

Advantages:

- Calculation of w-value and Fano factor possible.

Limitations:

- Limited absorption region;
- Limited gain → Limited scintillation region
- Problems with discharges;

Historical Roadmap of Gas Proportional Scintillation Counters

Uniform-Field GPSC

(Conde et al 1975)

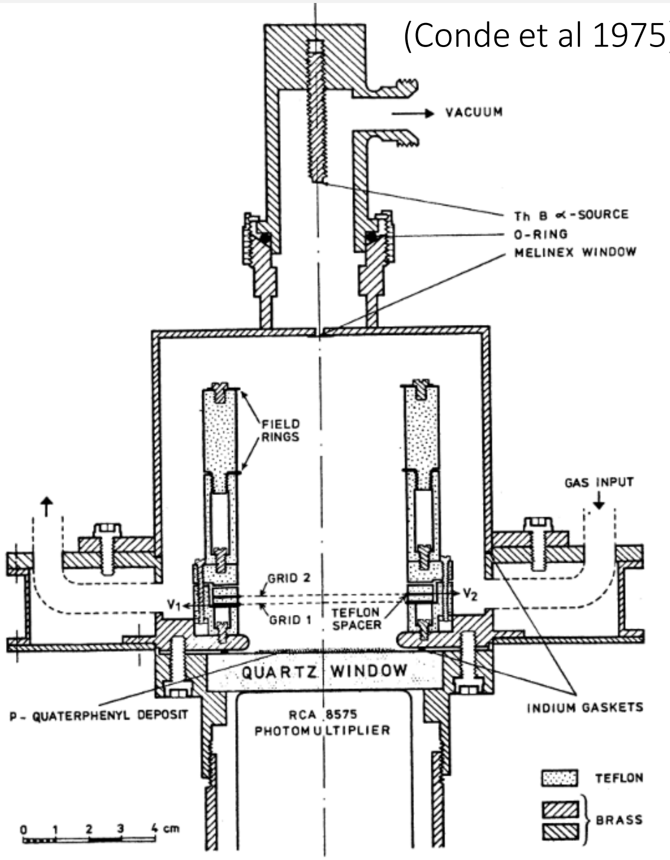


Fig. 2 - Cross section of the uniform field gas proportional scintillation counter.

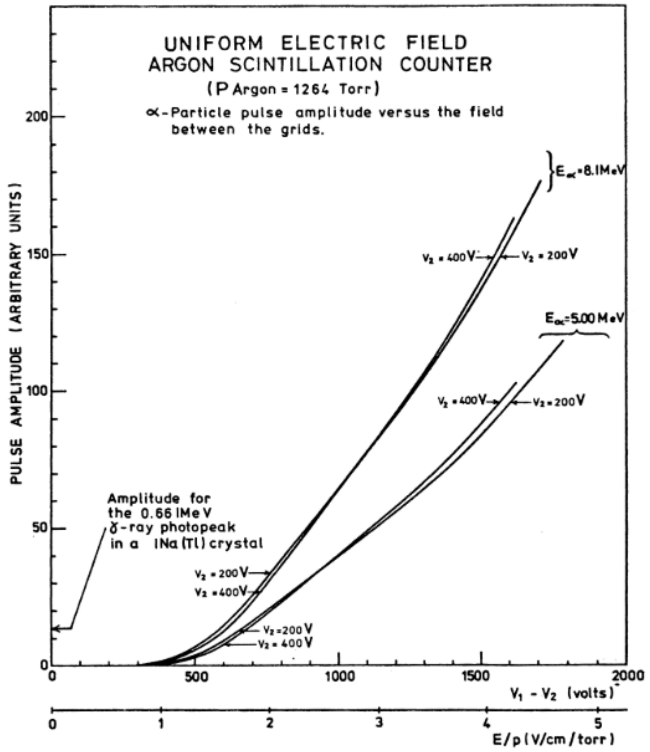


Fig. 3 - Variation of the secondary scintillation pulse amplitude with the difference of potential between the grids (and the reduced electric field: E/p) for argon at 1264 Torr.

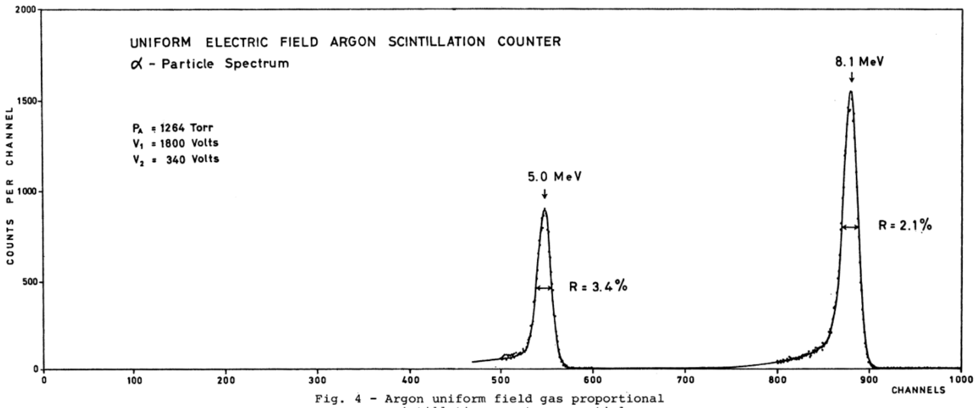


Fig. 4 - Argon uniform field gas proportional scintillation counter α particle spectrum.

Why choosing a uniform-field configuration?

- Ideal to study the mechanism of secondary scintillation
- Enables to increase the optical gain

- Results show significant improvements in terms of energy resolution;

- Based on the Frish Ionization Chamber;
- Scintillation region is well defined;
- Problem with the absorption region solved;

- Production of light is limited to a small volume of the counter

- Variable solid angle
- Rise time in the order of tens of microseconds

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1970s

Topics addressed:

(Policarpo et al 1975)

NUCLEAR INSTRUMENTS AND METHODS 128 (1975) 49–51; © NORTH-HOLLAND PUBLISHING CO.

LOCALIZATION OF IONIZING PARTICLES WITH THE GAS PROPORTIONAL SCINTILLATION COUNTER

A. J. P. L. POLICARPO, M. A. F. ALVES and M. SALETE S. C. P. LEITE

Departamento de Fisica, Universidade de Coimbra, Coimbra, Portugal

Received 5 May 1975

The gas proportional scintillation counter (PS counter) enables localization of tracks of ionizing particles by timing the primary and the secondary scintillation.

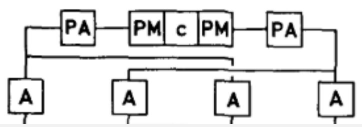
Previous work[1–7]) with the gas proportional scintillation counter (PS counter) has shown that it features good energy resolution, the relative standard deviation of the pulses being $0.081\,E^{-1/2}$ (E in keV), good high rate capabilities due to the absence of space charge effects, energy linearity, a minimum detection energy of about 25 eV, and offers the possibility of relatively large detection areas.

In this work another feature of the detector is put in evidence, making use both of the primary scintillation, the light flash associated to the track of the ionizing particle and the secondary scintillation, associated to the drifting of the primary electrons in the light production region[1]). As essentially no light is produced by the drifting of the primary electrons in the so called detection region[1]), the secondary scintillation is delayed relatively to the primary one by the drifting time of the primary electrons in this region. Measure-

tion and proper timing with the timing single channel analyser. For the primary light and to ensure a quick recovery from the saturating secondary light pulse, a double delay line mode was chosen. The coincidence unit suppresses photomultipliers noise, of importance to low energies.

Fig. 2 shows the time distribution (experimental data) for those X-rays in the multichannel analyser.

If the electric field in the detection region were uniform, the spectra would show the exponential absorption of those X-rays in xenon, as drifting time would be proportional to distance. If the electric field



First mention to the possibility of tracking ionizing particles using electroluminescence.

Principle of operation of Optical Time Projection Chambers used nowadays.

Historical Roadmap of Gas Proportional Scintillation Counters

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Electroluminescence studies in the 1970s – Integration of the GPSCs with other detectors

- Hybrid detectors **GPSC+PID**

- Use of Photoionization Detectors (PID)* coupled to a Gas Proportional Counter to surpass the limitations of using a wavelength shifter.

➔ Opened the opportunity to perform particle tracking choosing an adequate readout

*(Seguinot and Ypsilantis 1977)

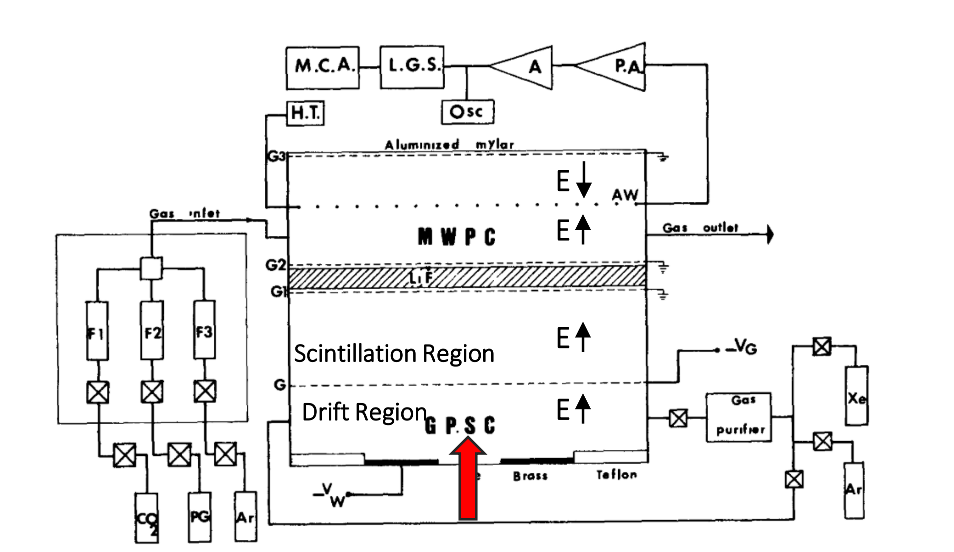
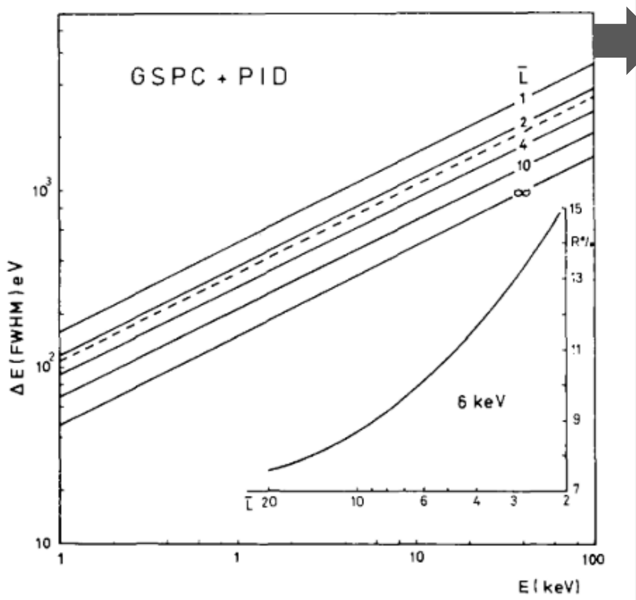


Fig 2. Schematic representation of the experimental set-up. MCA–multichannel analyzer, LGS–linear gate and stretcher, AW–anode wires; G_i–grounded grids, F_i–fluximeters, PG–photoionizing gas.

(Policarpo et al 1978 and M. Salete Leite et al 1980)



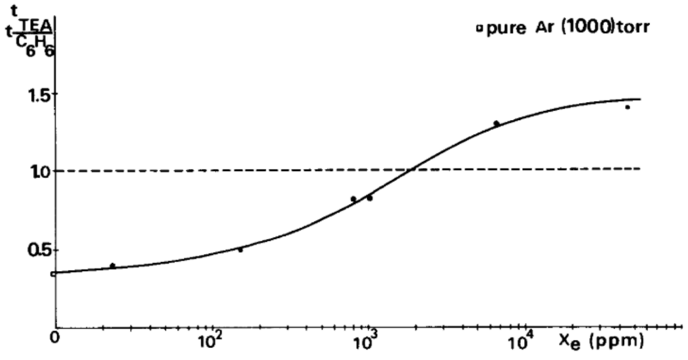


Fig 3. Values of transfer efficiency t measured with TEA in argon-xenon mixtures as a function of xenon density, normalized to the value of t measured with benzene in pure argon (argon pressure was 1000 Torr)

Improving the Energy Resolution

- Dashed line corresponds to the behaviour of a proportional counter
- L10 corresponds to the best resolutions of the GPSC

$$L = \frac{N_2}{N_1}$$

N_2 - Number of ion pairs formed in the PID

N_1 - Number of ion pairs formed in the GPSC

Advantages

- Improve energy resolution
- Provide tracking capability and particle identification

Limitations

- Complexity
- Not fully integrated
- Low photoionization efficiency

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1980s

Topics addressed:

- Monte Carlo Simulations (in Xenon)

- Secondary scintillation;
- Efficiency for light production;
- Electron drift time, average number of collisions, induced charge pulse amplitude are also calculated

Model the fundamental processes taking place in these detectors.

Enabled the calculation of the absolute number of excited species per drifting electron

(Teresa H.V.T. Dias et al 1983)

Table I

Summary of the results for Xe at 760 Torr and 300°K

(1 electron drifting a distance of 1.5 mm)

$\frac{E}{p}$ ($V\ cm^{-1} Torr^{-1}$)	Average Values Between Two Successive Inelastic Collisions: Number of Elastic Collisions ($\times 10^3$)	Drift Time (ns)	Drift Distance (μm)	Reduced Light Output (photons/electron) $m^{-1}\ Torr^{-1}$	Efficiency for Light Production (%)
7.0	6.3 ± 4.2	1.3 ± 1.1	18.3 ± 3.4	546*	67
6.0	7.5 ± 5.2	1.7 ± 1.4	21.3 ± 3.2	550*	72
5.0	12.0 ± 9.1	2.5 ± 2.0	25.1 ± 3.1	51.8	74
4.0	19.0 ± 16.2	4.0 ± 3.9	35.8 ± 7.9	41.2	74
3.0	30.5 ± 28.2	6.3 ± 5.4	42.4 ± 5.6	30.7	74
2.0	73.2 ± 52.0	18.8 ± 15.6	69.4 ± 10.3	18.4	68
1.0	417.8 ± 529.0	118.6 ± 94.3	236.7 ± 88.7	3.9	40

*Events with electron avalanche included.

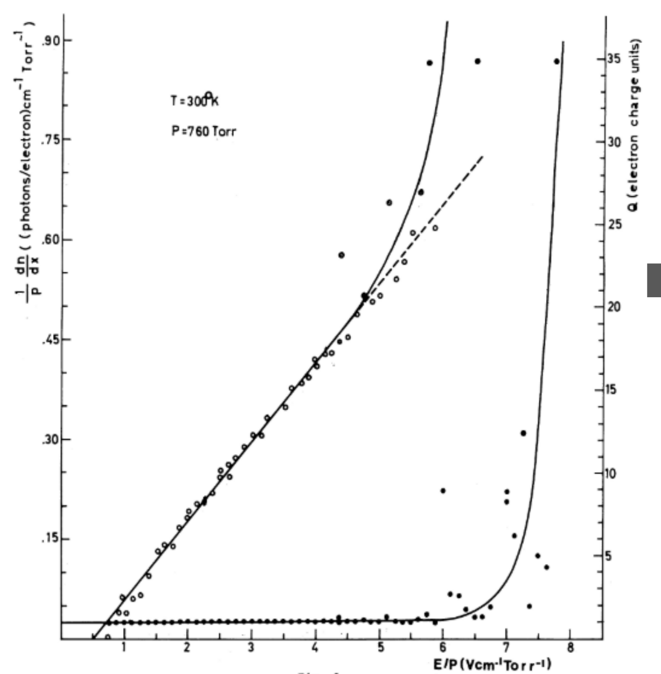


Fig. 6

Agrees with experimental data

- Good quantitative approach
- Provide already some information on the charge transport properties

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

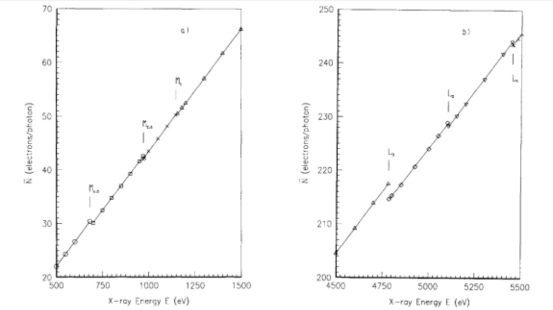


Fig. 1. Calculated average number of primary electrons, $\bar{N}$, produced per X-ray photon absorbed in gaseous xenon as a function of the photon energy, E, for the ranges: (a) 500 to 1500 eV; (b) 4500 to 5500 eV.

Development of Gas Proportional Scintillation Counters

Monte Carlo Simulation

- Energy linearity
- w-value and Fano Factor
- Photoelectron collection efficiency
- Effect of electron multiplication on the electroluminescence yield

Experimental Studies

- Energy linearity;
- w-value and Fano Factor;

Detector Development

- Large area detection
- Study of new MPGDs
- Optical coupling techniques

Model the fundamental processes taking place in these detectors.

Basis of a new generation of hybrid GPSCs

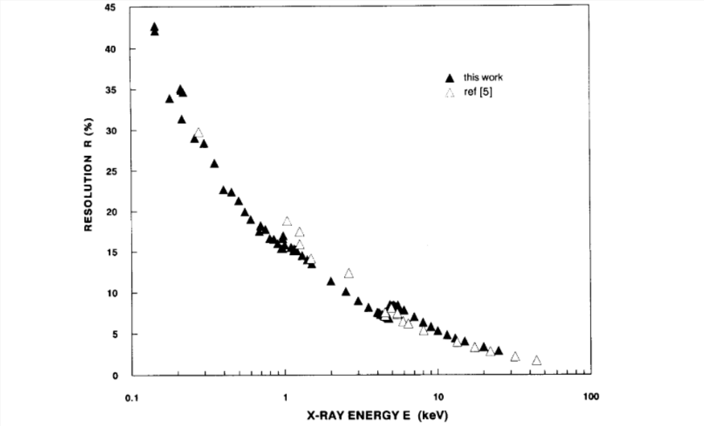
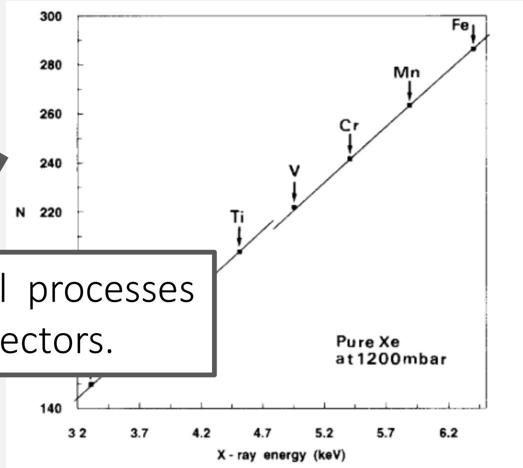


Fig. 1. Experimental [5] and calculated energy resolution of a xenon gas proportional scintillation counter for X-rays in the 0.1 to 25 keV energy range.



Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

Topics addressed:

- Solid angle compensation

- In uniform electric field GPSCs, the amount of light that reaches the photomultiplier decreases, due to solid angle effects, as the radial distance of the interaction point increases.

➡ Increases fluctuations in the pulse amplitude

⬇

Deterioration of the energy resolution .

The way found to solve this problem was by using a curved grid to define the scintillation region (**G1** and **G2**):

- **G1** - Grid with a spherical shape (20 mm radius)
- **G2** - Parallel grid (flat) to the PMT surface

↳ Changes the electric field

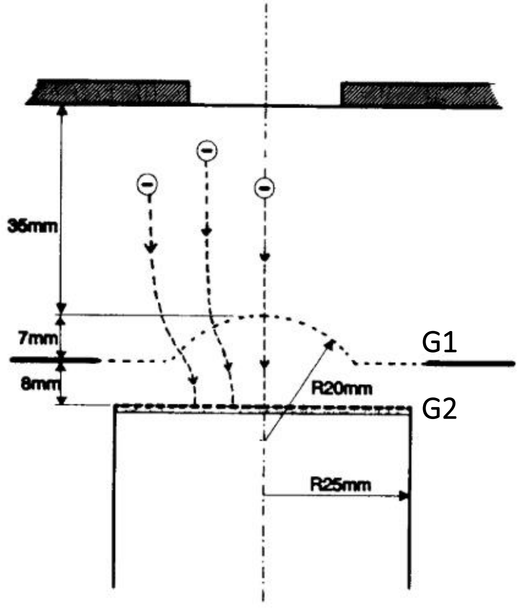
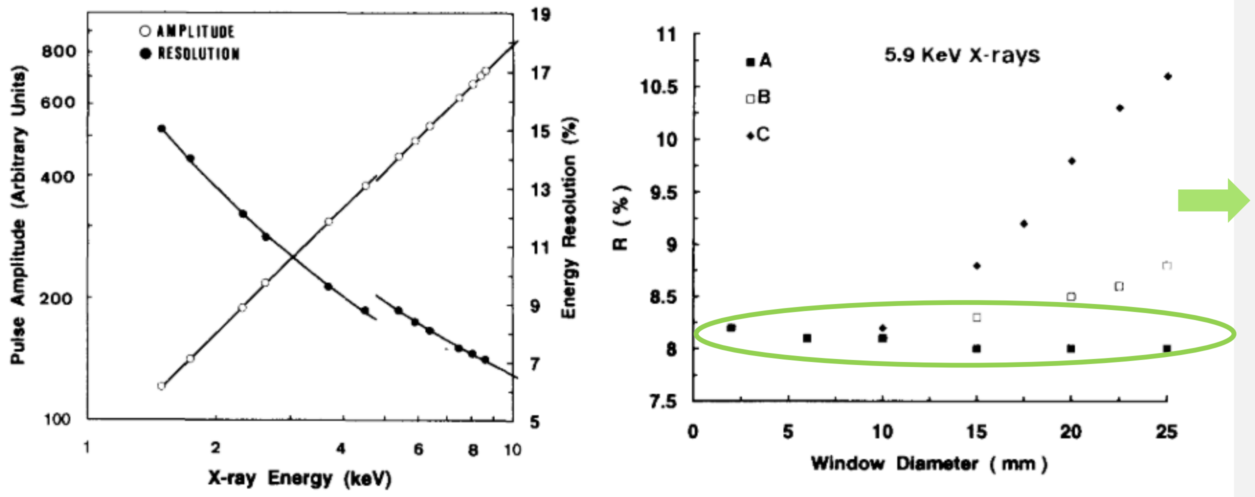


Fig. 1. The curved grid gas proportional scintillation counter.

(J.M.F. Santos, 1994)



➡ Problem solved

- Good energy resolution
- Good linearity

⬇

- Enables the development of Large Area Detectors
- PMT is still a problem

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

Topics addressed:

- Alternative readout solutions

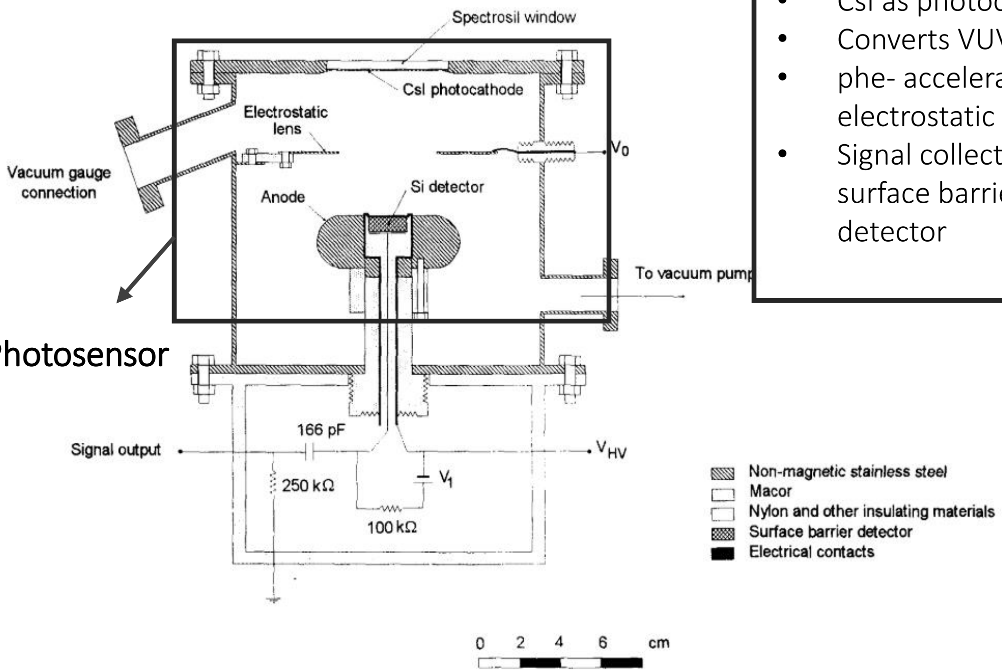
- A new photosensor based on CsI as a conversion stage for the VUV scintillation and using a single surface barrier detector was developed.

➡ Enables the development of large-area detectors based on electroluminescence

⬇

Without significant deterioration of the energy resolution

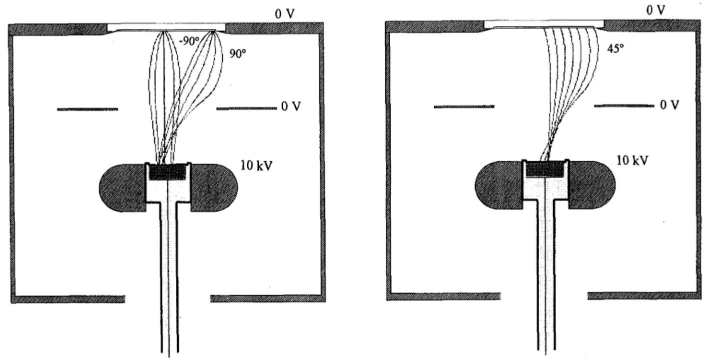
(J.A.M. Lopes and C.A.N. Conde 1995)



Photosensor

Working Principle*

- CsI as photocathode
- Converts VUV in phe-
- phe- accelerated using electrostatic lens
- Signal collected in a Si surface barrier detector



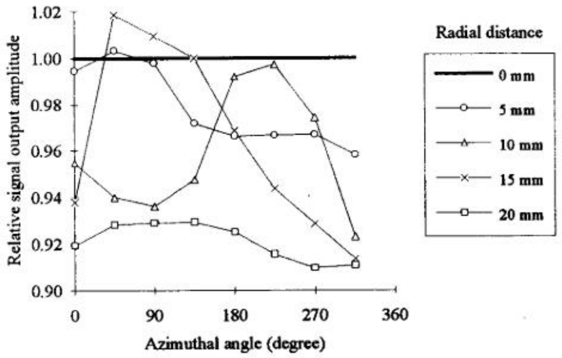


Fig. 5 - Relative signal output amplitude for 5 radial distances(0, 5, 10, 15 and 20 mm) and 8 azimuthal positions (equally spaced by 45°) for each radial distance.

*Original idea from J.M. Abraham et al. in 1966

Advantages

- Pulse amplitude does not depend on the position where the electrons hit the sensitive area of a surface barrier detector
- Constant pulse amplitude can be achieved
- Simplicity – uses single aperture lens
- Decrease the cost

Does not allow to fully integrate the readout in a GPSC as it has a window separating it from the scintillation region.

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

Despite these effort **PMT** was a problem and **Hybrid GPSCs** were not fully integrated…

- Fragility
- High cost for large area detection
- Could not work in the presence of magnetic fields

- Systems physically separated
- Complex
- Photon detection

Amos Breskin

The studies of photocathodes (CsI) by Amos Breskin in the Weizmann Institute, that would allow to create fully integrated GPSCs.

But three important events would shape the course of GPSCs history in different ways…

Georges Charpak

Nobel Prize in Physics in 1992

Development of the MWPC by Georges Charpak that would lead to the development of the MPGDs in the late 1980s and 1990s, that will be part of the hybrid GPSCs.

- Micro Strip Gas Chamber (1988)
- Micromegas (1996)
- GEM (1997)
- Etc…

David Nygren

Development of the TPC by David Nygren that would be the cornerstone of the TPCs based on electroluminescence.

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

Topics addressed:

- Alternative readout solutions

- Uses a microstrip plate with a CsI photocathode deposited directly onto its electrode surface* is used to replace the standard photomultiplier.

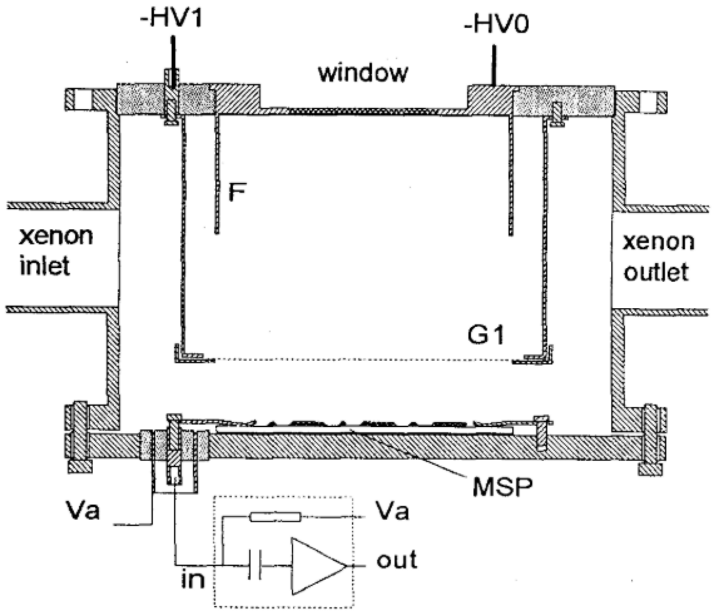
*First reported K. Zeitelhack et al 1994

→ First fully integrated Hybrid Gas Proportional Scintillation Counter

Historical marks:

- Microstrip gas chamber introduced in 1988 by **Anton Oed**

(J.F.C.A. Veloso et al 1996)



Working Principle

- CsI as photocathode converts VUV in phe-;
- phe- are accelerated by the intense electric field;
- Resulting e- are collected at the anode of the MSP;

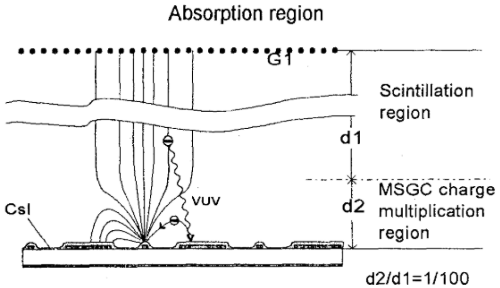
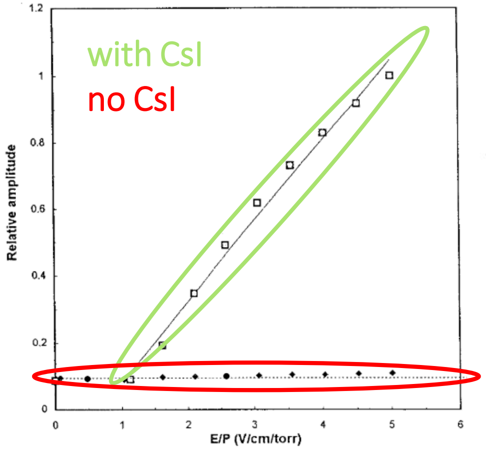
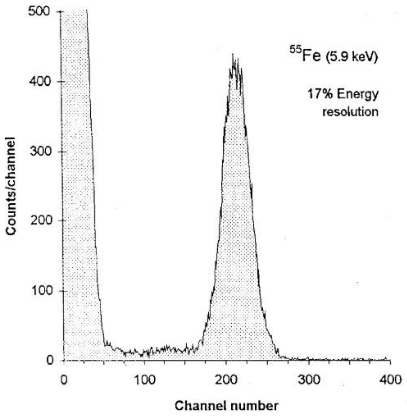


Fig.1-Schematic diagram of the operation process of a MSGC based GPSC with the electric field lines plotted.





What is a microstrip plate (MSP)?

- A MSP consists of thin metal electrode strips photolithographed onto an insulating substrate with a very small spacing between alternating anodes and cathodes.

Advantages

- Demonstrates the feasibility of using hybrid GPSCs with MSP with results similar to standard GPSCs.
- Attractive alternative to PMTs

Limitation

- Energy Resolution is worse

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

Topics addressed:

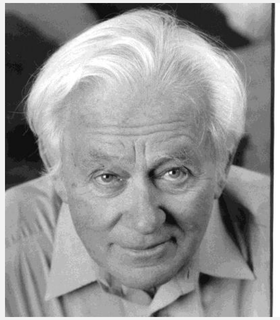
- Alternative readout solutions

- A CsI photocathode is deposited directly on an electrode surface (cathode) and a multi-wire plane is used to extract the resulting phe- providing additional charge gain.

→ Fully integrated Hybrid Gas Proportional Scintillation Counter

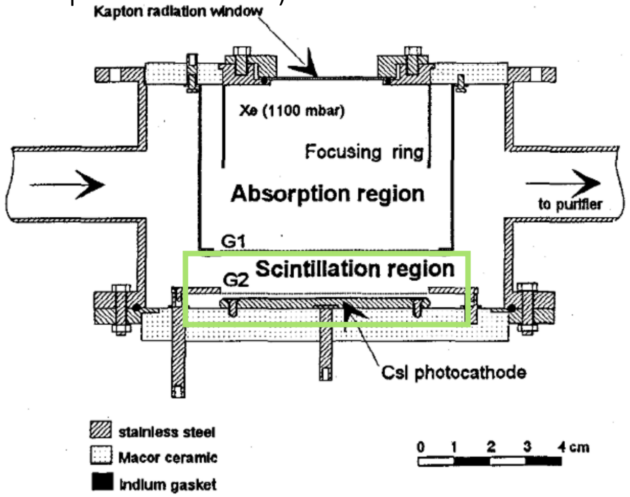
Historical marks:

- Multi-Wire Proportional Chamber introduced in 1968 by **Georges Charpak**



Well defined scintillation region

(J.A.M. Lopes et al 1997)



G2* is use as a second grid to clearly define the secondary scintillation region.

*G2 is a multiwire plane made of 25-µm-diameter, 1-mm-spaced, gold-plated tungsten wires.

Working Principle

- CsI as photocathode converts VUV in phe-;
- phe- are accelerated towards the multiwire plane (G2) where charge multiplication occurs;
- Resulting e- are collected at G2.

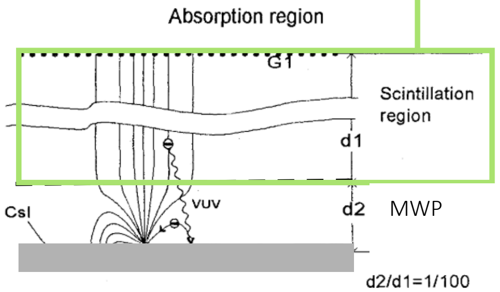
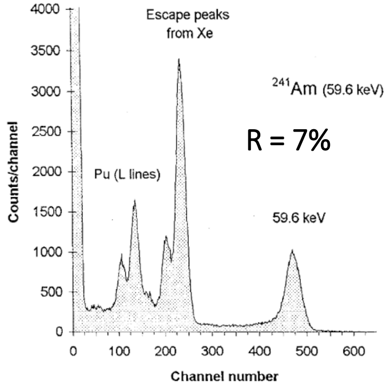
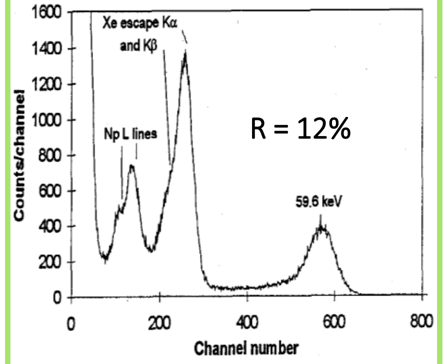


Fig.1-Schematic diagram of the operation process of a MSGC based GPSC with the electric field lines plotted.

With a MSP ←





What is a multiwire plane (MWP)?

- A MWP is based on the MWPC consists of thin metallic wires placed at high voltage and equally spaced with a metallic surface that serves as cathode in its vicinity.

Advantages

- Better uniformity achieved in the scintillation production

Limitation

- Energy Resolution is worse

↓

Contribution from optical feedback is worse (due to charge multiplication)

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

Topics addressed:

- Alternative readout solutions

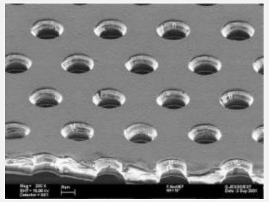
- A gas electron multiplier (GEM) with a CsI photocathode deposited directly onto its electrode surface is used along a multiwire plane to record the scintillation light from xenon.

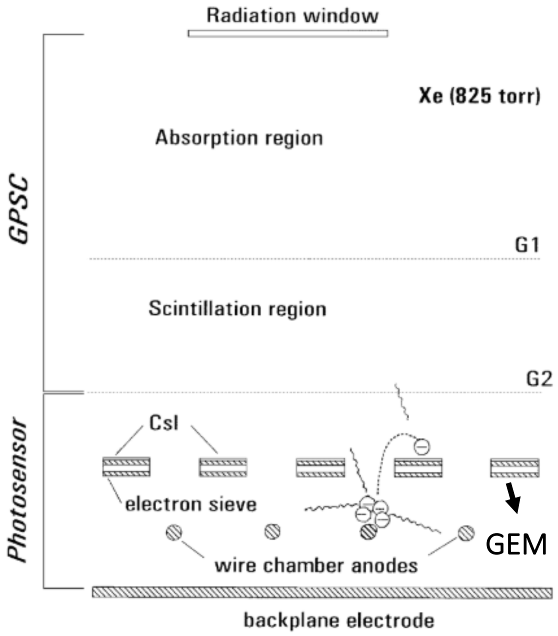
Hybrid triple amplification stage without positive optical feedback

Light → Charge → Charge

Historical marks:

- Gas Electron Multiplier (GEM) introduced in 1997 by **Fabio Sauli**

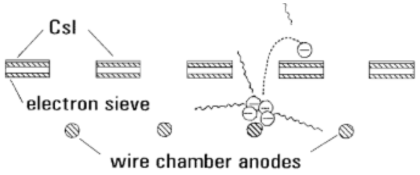


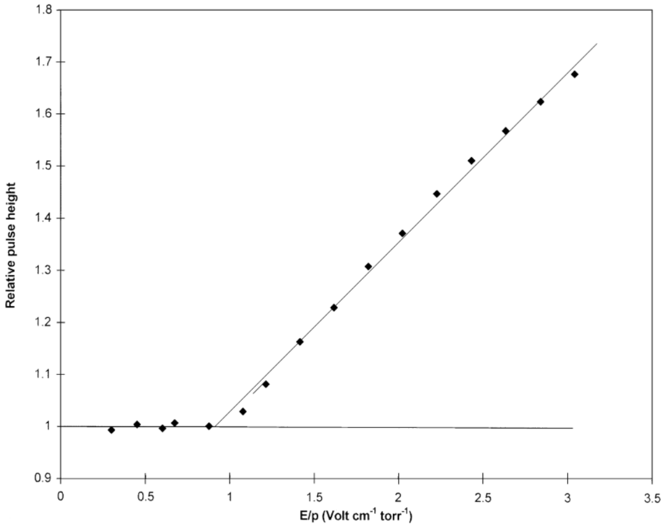


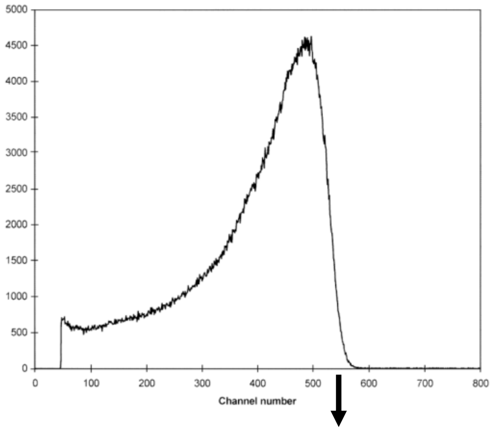
(J.A.M. Lopes et al 1999)

Working Principle

- CsI as photocathode converts VUV in phe-;
- phe- are accelerated by the intense electric field in the GEM holes;
- Resulting e- are then multiplied in the vicinity of the multiwire plane where they are collected;







241Am spectrum

What is a GEM?

- Made of a thin film (tens to hundreds of µm) of Kapton cladded on both sides with copper which is perforated µm-diameter holes.

Advantages

- Optical positive feedback is supressed.
- Absence of relevant space charge effects
- Uniformity response over large areas.

Limitation

- Energy Resolution is still problematic.

Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 2000s

Topics addressed:

- Alternative readout solutions

- A large area avalanche photodiode is used to replace the standard photomultiplier tube and record the scintillation light from xenon.

Fully integrated Hybrid Gas Proportional Scintillation Counter

Advantages over PMTs?

- Very low power consumption,
- High quantum efficiency
- Operated in high-intensity magnetic fields.

Historical marks:

- Avalanche photodiode introduced in 1952 by **Jun-ichi Nishizawa**

Why now?

- Operated outside the detector;
- Necessity of a wavelength shifter
- Placed on the inside of the scintillation window;
- A serious drawback for gas purity and long-term operation stability.

Advantages

- Attractive alternative to PMTs
- Good energy resolution even for low gains (~20)
- Light-to-charge conversion efficiency much larger than CsI

Limitation

- Limited particle tracking capabilities

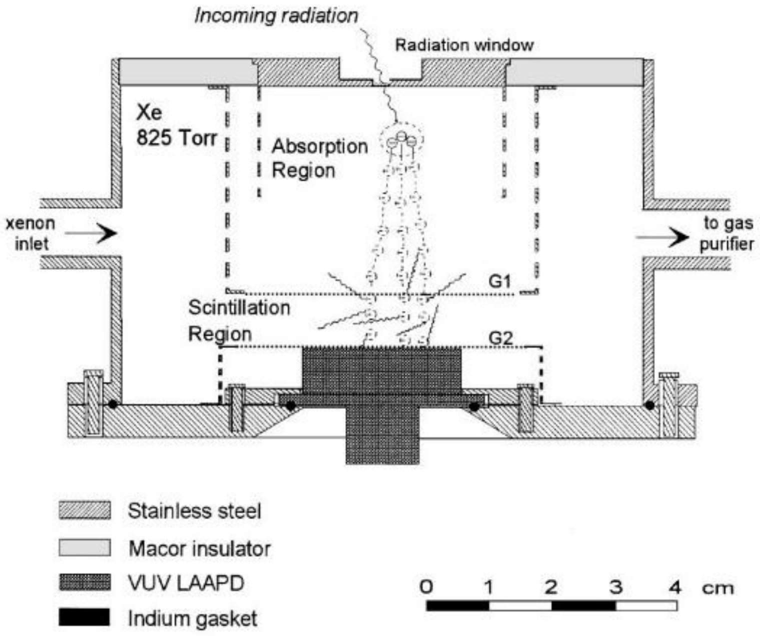
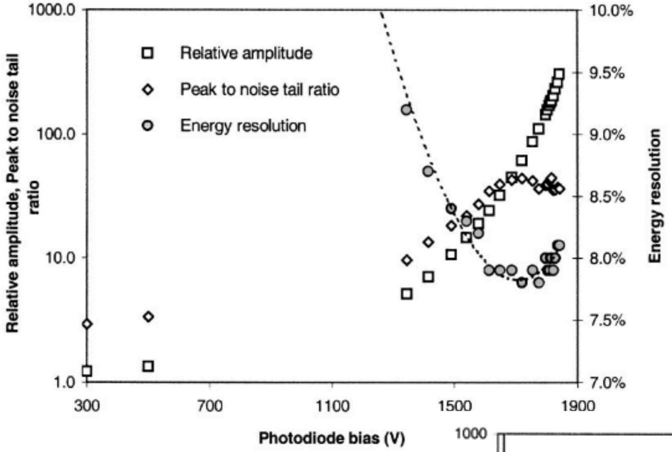
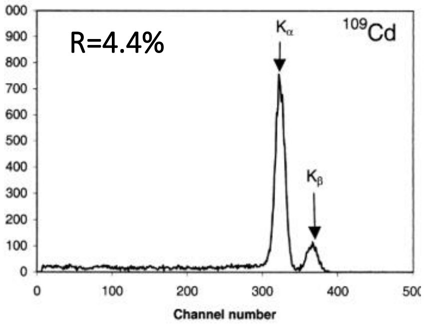
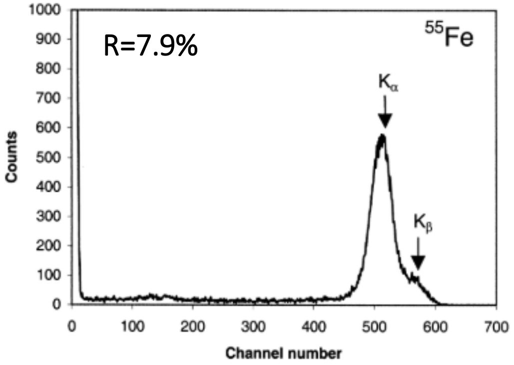


Fig. 1. Schematic of the GPSC with LAAPD photosensor.







(J.A.M. Lopes et al 2000)

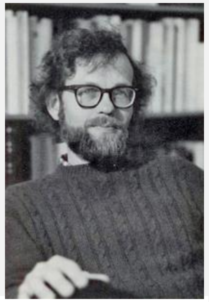
Recent Developments

Recent Developments in Gas Radiation Detectors

Electroluminescence use in Time Projection Chambers

Historical marks:

- Time Projection Chamber (TPC) introduced in 1977 by **David Nygren.**

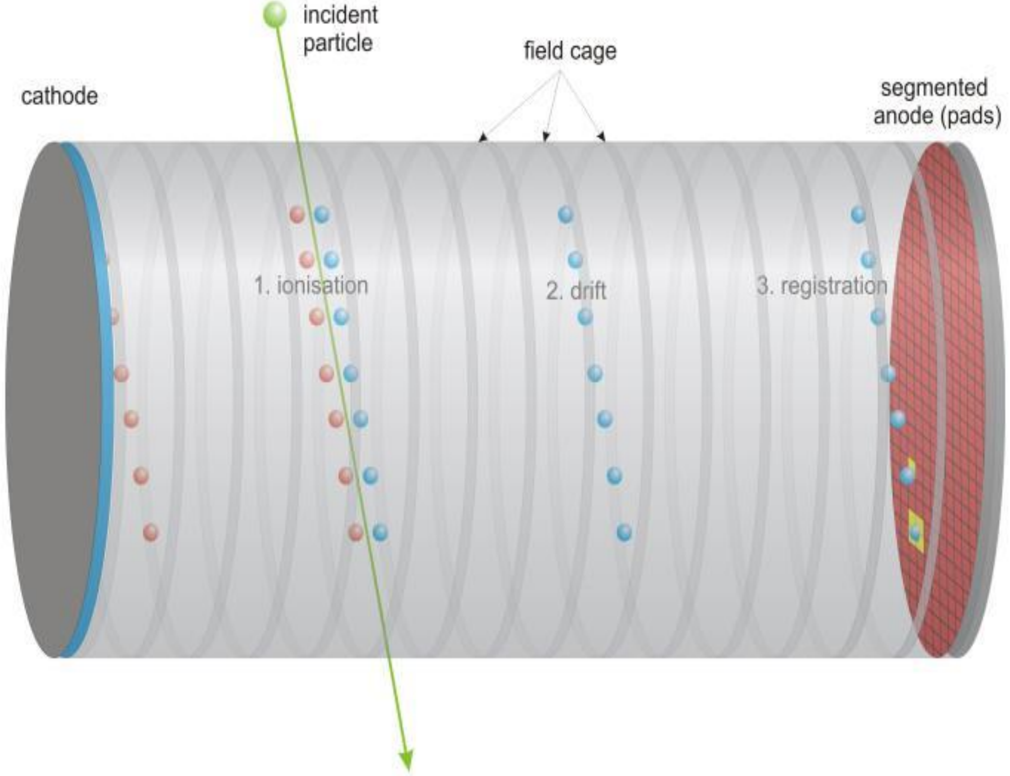


Each interaction is reconstructed as (x , y , z)

Segmented readout — Drift time

Working Principle

1. Incident particle ionizes the gas volume
2. Charge drifts to the electrodes
3. Charge is amplified and then collected
4. Tracks are reconstructed



Ion backflow

- Ions created during charge multiplication that return to the drift region.
- Drift field becomes distorted and the particles trajectory is affected.
- Ideally it should be reduced to the primary ionization: $IBF = \frac{1}{GAIN}$
- Still we have to ensure high gains, good tracking capabilities and energy resolution.

Recent Developments in Gas Radiation Detectors

Electroluminescence use in Time Projection Chambers – Ion Backflow Suppression

Main challenges:

- Reduce the ion backflow
- Good energy and position resolution

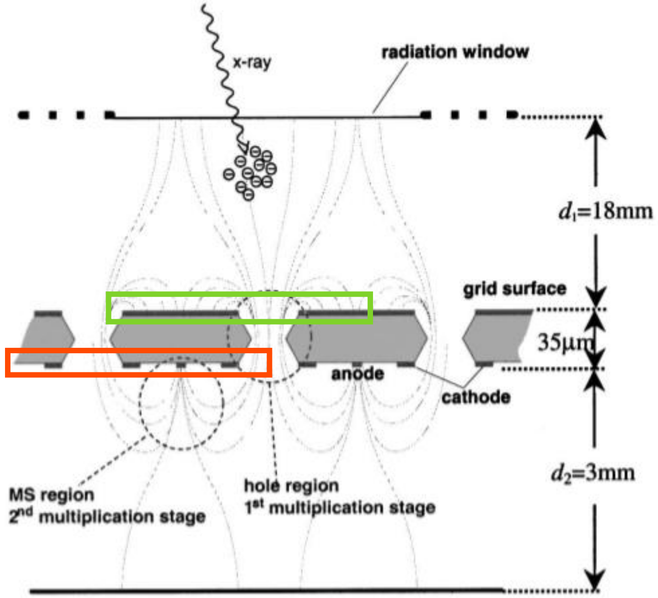
At high gains!

➡ Development of new micro-patterned gas radiation detectors in Coimbra

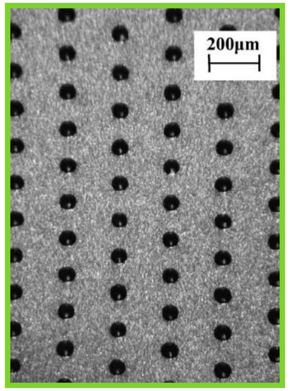
Historical marks:

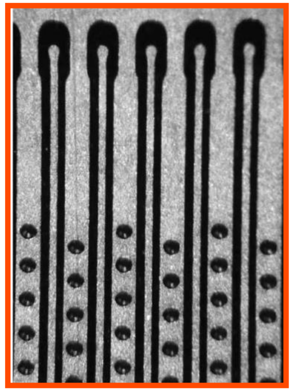
- Micro-Hole and Strip Plate (MHSP) introduced in 2000 by **João Veloso.**

Micro-Hole Strip Plate



$$Gain = 5 \times 10^4$$





- Combines the features of both GEM and MSGC (single double sided micro-structure)
- Two successive independent charge-amplification stages

⬇

- Preamplified within the GEM-like holes
- Further amplified in the bottom strips

- Gains similar or even higher than GEM and MSGC

- Configuration of the charge-amplification stages

⬇

Reduces the IBF

$$IBF = 1 \times 10^{-4}$$

$$\varphi = \beta_{MS} + \frac{1}{G_{MS}}$$

Advantages

- Very stable operation
- Optical feedback supressed
- Enables 2D reconstruction
- Biasing is independent for all electrodes

Limitation

- Some problems with electrical discharges
- Energy resolution

⬇

- Non uniformity of the electric field in the strip plane

Recent Developments in Gas Radiation Detectors

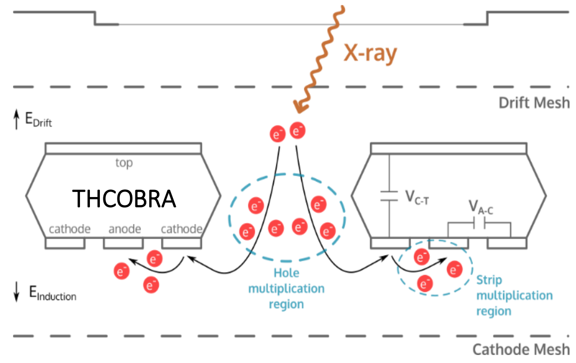
Electroluminescence use in Time Projection Chambers – Ion Backflow Suppression

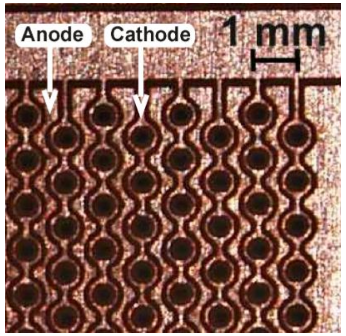
Main challenges:

- Some problems with electrical discharges
- Energy resolution
- Non uniformity of the electric field in the strip plane

→ Development of new micro-patterned gas radiation detectors in Coimbra

Thick-COBRA

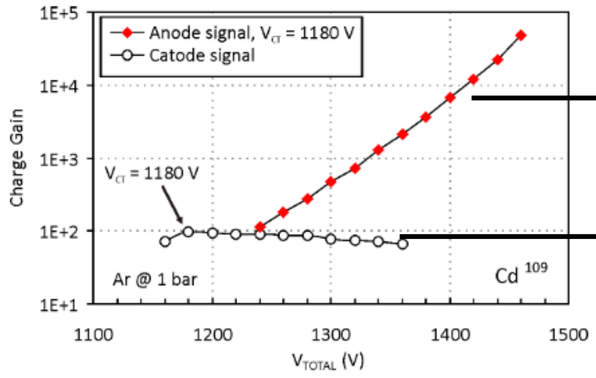




- Combines the features of both MHSP and THGEM (Thick-GEM) (single double sided micro-structure)
- Two successive independent charge-amplification stages
- Configuration of the charge-amplification stages

⬇

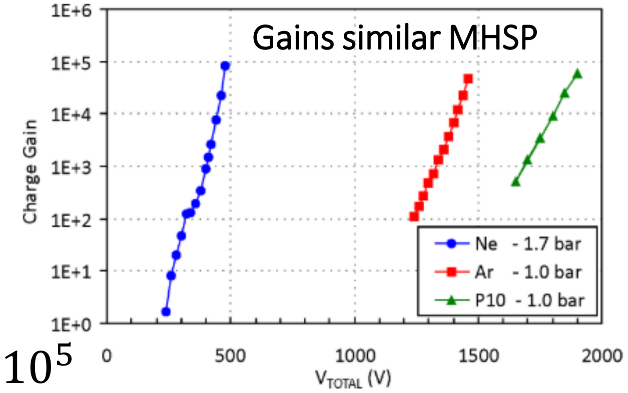
Reduces the IBF



→ Total Gain (Hole+Strips)

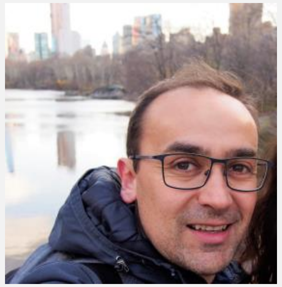
→ Hole Gain

$$Gain \sim 1 \times 10^5$$



Historical marks:

- Thick-COBRA (THCOBRA) introduced in 2010 by **Fernando Amaro.**



Advantages

- Robust and easy to produce
- Low cost (using standard printed circuit)
- Low bias voltage needed to achieve the same gains as in THGEM
- Very stable operation at high charge gains
- Enables 2D reconstruction
- Biasing is independent for all electrodes

Limitation

- Energy resolution
- Spatial resolution

⬇

- COBRA_125 (Presented this year in IBER 2019, Évora, Portugal)

Recent Developments in Gas Radiation Detectors

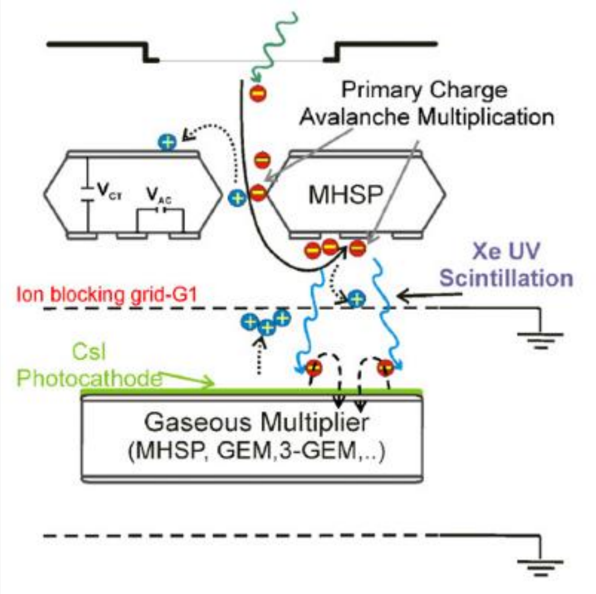
Electroluminescence use in Time Projection Chambers – Ion Backflow Suppresion

Typically IBF is efficiently suppressed using:

- Pulsed gates (efficient for freq. up to 10^5 Hz)

→ Interest in achieving the reduction of IBF at higher counting rates → Two techniques were developed in Coimbra.

PACEM – Photo Assisted Cascaded Electron Multipliers



- Photons are produced during charge multiplication;
- CsI converts the scintillation photons in photoelectrons;
- Photoelectrons are multiplied and collected

IBF minimization

The IBF is limited to the first element of the cascade and is independent on the total gain.

$$IBF = 10^{-4} \text{ to } 10^{-5}$$

*For gains of 10^4 and 10^6, and typical drift fields of TPCs (0.1 to 0.5 kV.cm-1

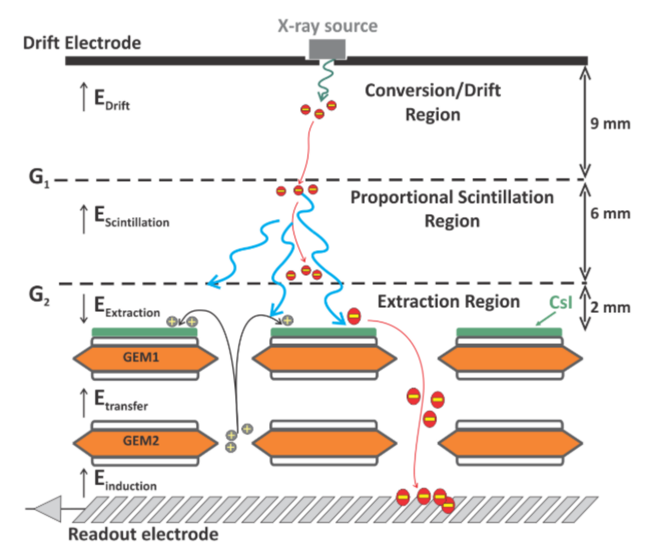
(J.F.C.A. Veloso et al 2006)

- **High optical gain (10^3)**
- Worse energy resolution

↓

Fluctuations in the signal formation

Zero-IBF – Zero Ion Backflow Electron Multiplier



- Photons are produced in the scintillation region;
- CsI converts the scintillation photons in photoelectrons;
- Photoelectrons are multiplied and collected

IBF minimization

There is no ion backflow resulting from the amplification stage.

$$IBF = 0$$

- Low optical gain (typically bellow 100)
- **Better energy resolution**

The Zero-IBF fully suppresses the IBF, being the obvious choice for high rate TPCs. →

- Increase the optical gain
- Validate for large areas
- Optimize the energy and position resolution

(F.D. Amaro et al 2014)

Recent Developments in Gas Radiation Detectors

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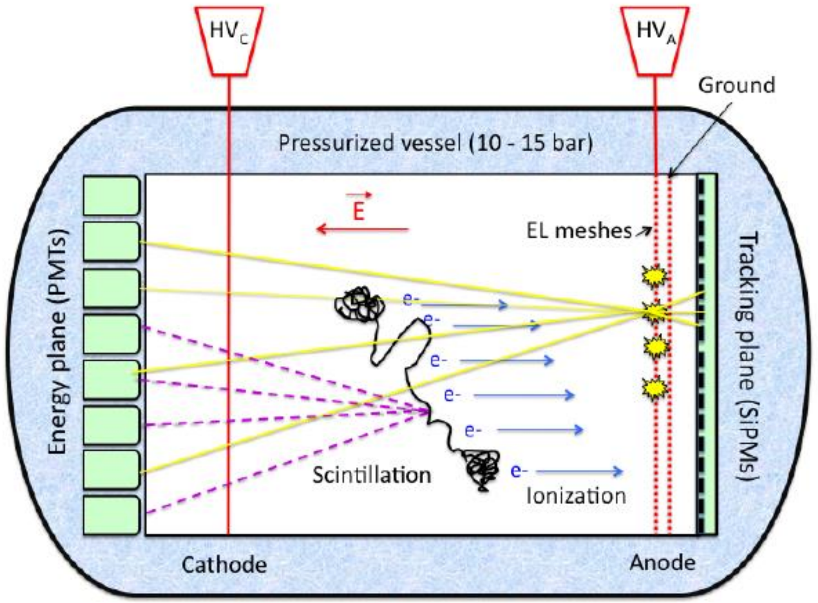
Electroluminescence use in Time Projection Chambers – The Optical Time Projection Chamber

- EL has been increasingly used in large volume detectors over the last decade in experiments such as LZ, XENON 1T, etc..
  - EL is a low fluctuation process
  - Gas detectors with Xe → most promising energy resolution

NEXT – Neutrino Experiment with a Xenon TPC



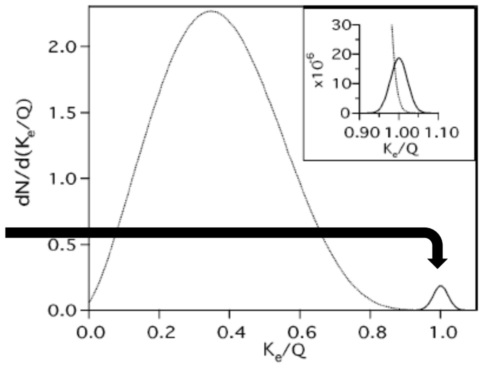
- Primary scintillation (S1) used as trigger;
- Secondary scintillation (S2) used for energy measurement and track reconstruction;
- Energy plane – detects S1 (t_0) and S2 (energy);
- Tracking plane – detects S2: spatial resolution is important!

*Located in the Underground Laboratory of Canfranc (Pirineus, border with France)

NEXT Collaboration, 2013 JINST 8 T05002

Xe136 that is a double beta emitter

$Q_{\beta\beta} = 2457.83keV$



$$^{136}Xe \longrightarrow {}^{136}Ba + 2e^- + 2\nu_e$$

$$^{136}Xe \longrightarrow {}^{136}Ba + 2e^-$$

$$T_{\frac{1}{2}} > 6.5 \times 10^{25} years$$

$$\mathcal{R} < 1\% \ @ \ Q_{\beta\beta}$$

Good position resolution needed

Future Prospects

Opportunities for Gas Radiation Detectors based on Electroluminescence

Historical marks:

- Timepix introduced in 2008 by **X. Llopart.**

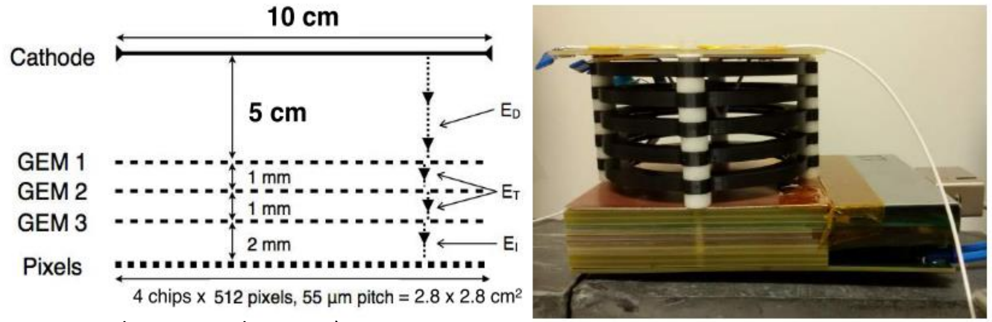
Negative Ion Time Projection Chambers

Time Projection Chambers (TPCs):

- inherently 3D tracking reconstruction,
- dE/dx measurement,
- particle identification capabilities
- versatility in terms of target gas → rare event searches.

Position resolution could be improved adding a highly electronegative dopant → New generation of **Time Projection Chambers**

NITPC prototype with a GEMpix readout



(E. Baracchini et al 2018)

Working Principle

- Electron ion pairs are formed;
- Electrons are captured by electronegative gas molecules (short range < 100 µm);
- Negative ions drift towards the readout plane;
- Electrons are stripped from the anions giving rise to an electron avalanche;

Advantages

- Diffusion of the charge carriers is strongly reduced (due to the ions greater mass)
- Attractive alternative to TPCs for rare event searches

Limitation

- Scope of applications;
- Drift of ions is 1000x slower than electrons;

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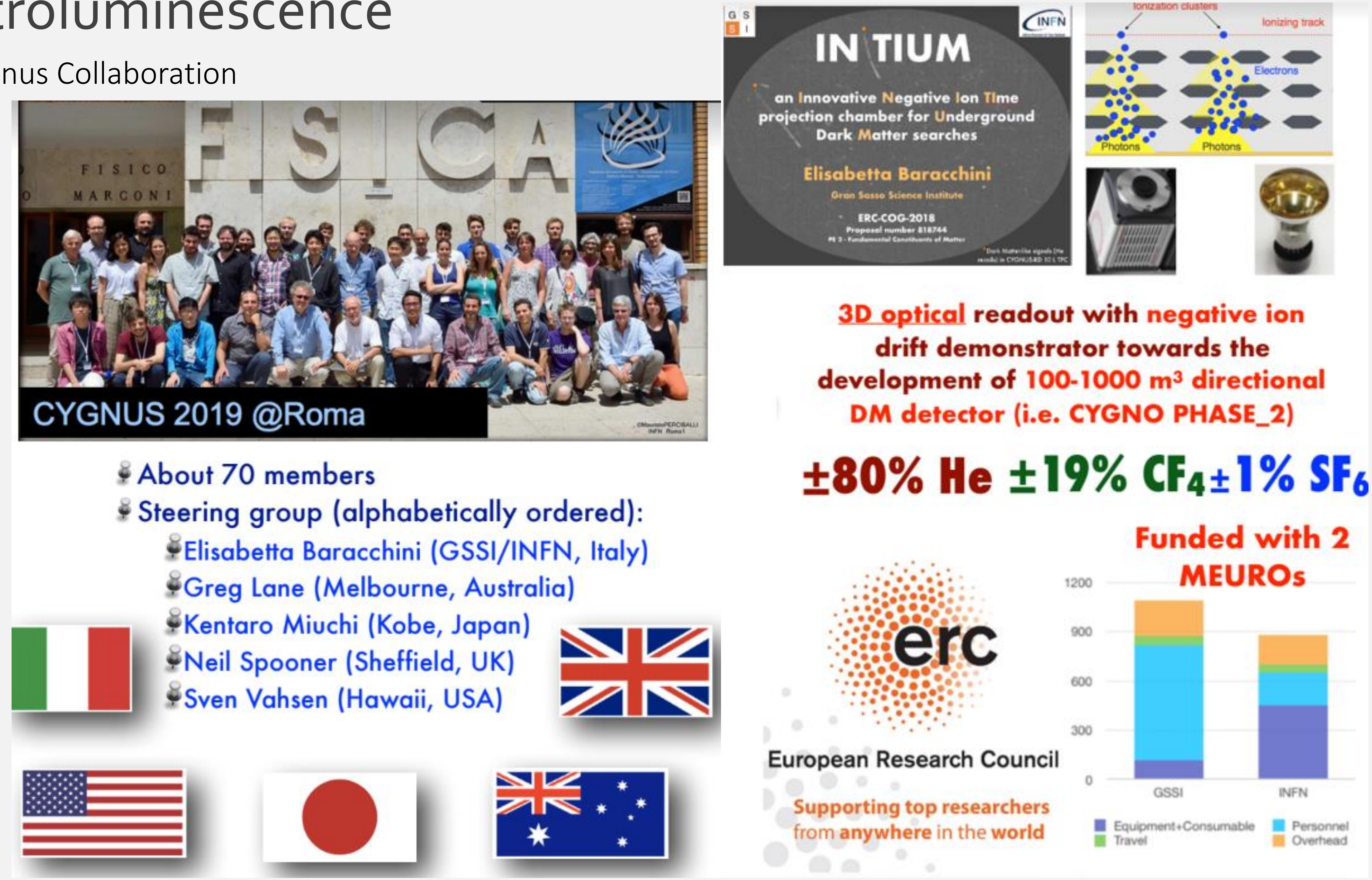
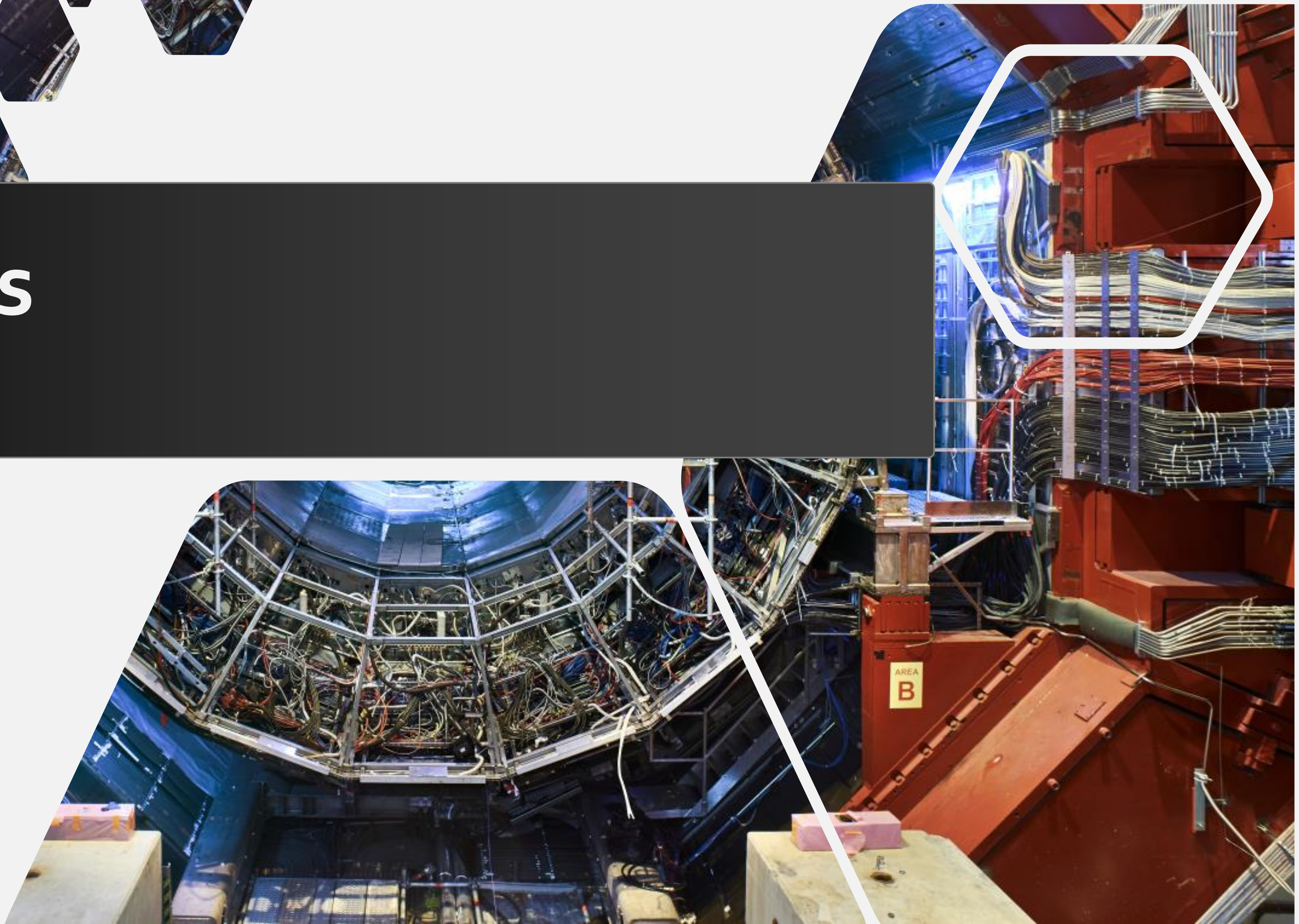
Opportunities for Gas Radiation Detectors based on Electroluminescence

Cygnus Collaboration



Conclusions



Summary

- Coimbra's efforts in the understanding of the electroluminescence mechanism resulted in several important scientific contributions (GPSCs, MPGDs and IBF Suppression Mechanisms) ;

- Opened the doors for Optical Time Projection Chambers;

- EL is widely used nowadays in Gas Radiation Detectors with excellent results:

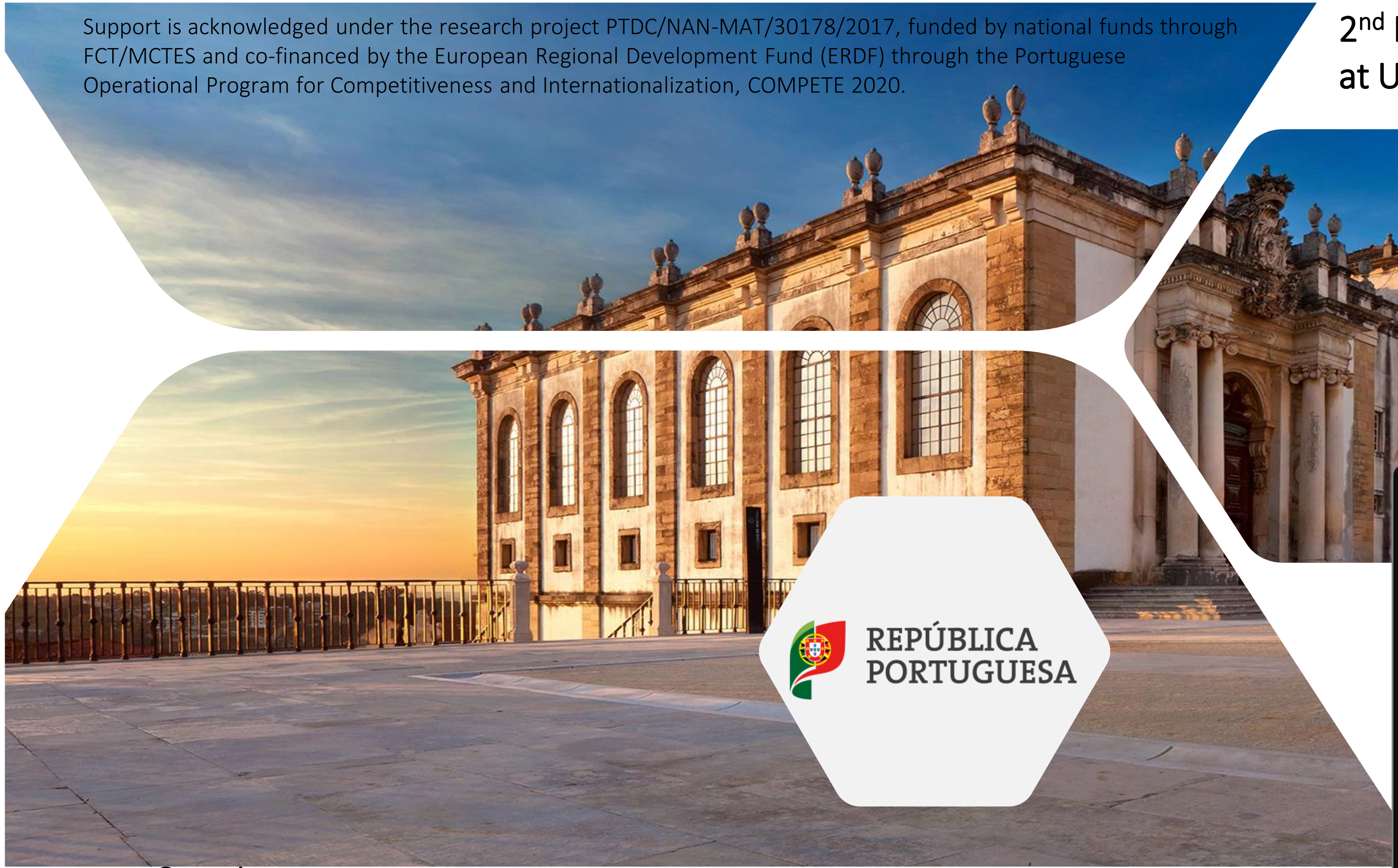
    - Energy resolution;
    - Large area detection;
    - Flexibility in the geometry definition;
    - Operation at room temperature;

- Future of EL based detectors is promising
    - NEXT,
    - XENON,
    - LZ
    - and more recently CYGNUS

Plenty opportunities to be explored...

Support is acknowledged under the research project PTDC/NAN-MAT/30178/2017, funded by national funds through FCT/MCTES and co-financed by the European Regional Development Fund (ERDF) through the Portuguese Operational Program for Competitiveness and Internationalization, COMPETE 2020.

2nd International Workshop on SXSDG, Oct. 16-20 2019
at University of Coimbra (Portugal)



LIBPhys

SXSDG 2019

REPÚBLICA PORTUGUESA

Thank you!

andre.cortez@cern.ch

www.fisica.uc.pt

Questions?

Organizers:

DHC

CONFUCIUS INSTITUTE 孔子学院

LFRC 激光聚变研究中心 LASER FUSION RESEARCH CENTER

LIP
LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

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Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 2000s

Topics addressed:

- Alternative Configurations

New concept of driftless GPSC, where the absorption of radiation occurs in the scintillation region.

Development of compact GPSCs for soft X-ray spectrometry to solve problems with the low penetration depth in the gas and loss of primary electrons.

Deterioration of energy resolution
Increase the background

(D.S. Covita et al 2003)

How does it work?

Total amount of light produced depends:

- Distance traversed by the primary electrons in the scintillation region;
- Depth of interaction of the incident radiation photon;

Light pulse duration is proportional to the distance.

Timing analysis allows for pulse amplitude correction, making the amplitude independent of the initial interaction position.

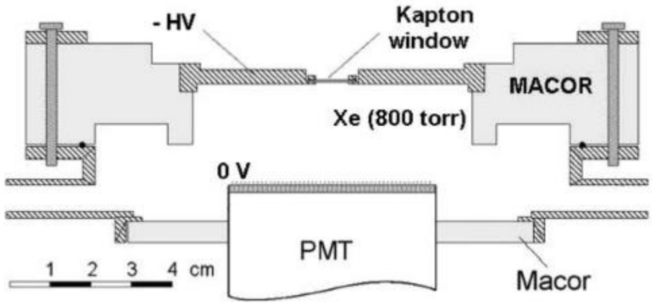
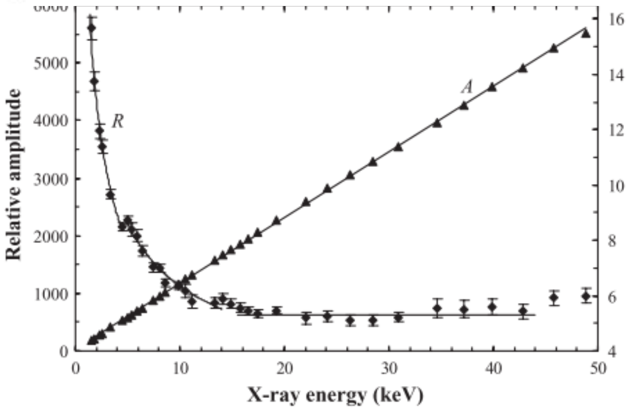


Fig. 2. Schematic diagram of the driftless GPSC used in the present work.



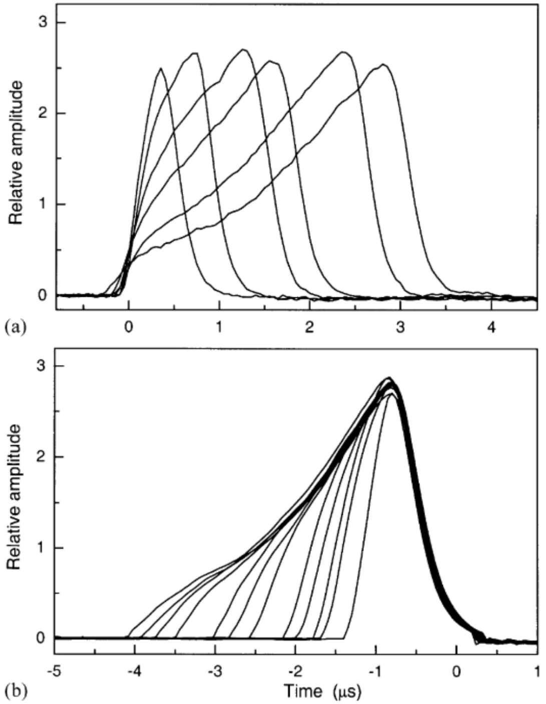
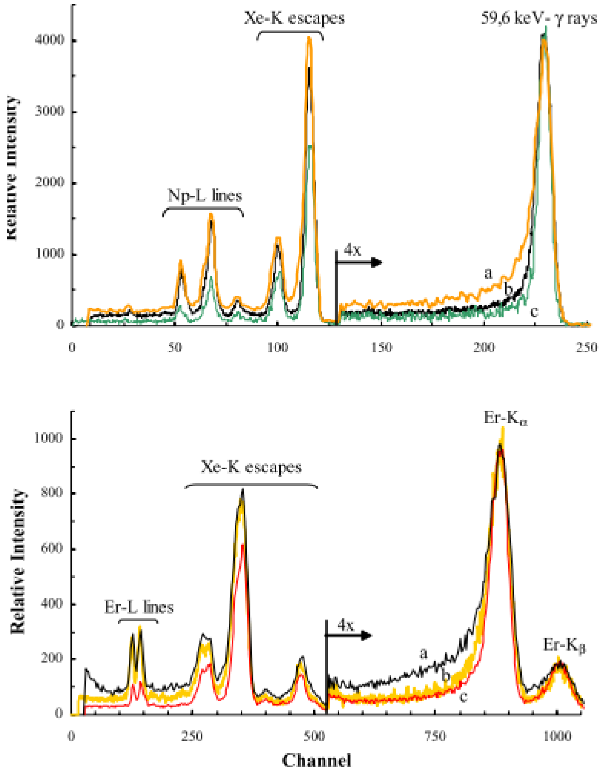


Fig. 3. Typical pulse shapes of the driftless GPSC. The selected pulses correspond to 22.1-keV X-ray interactions at different depths. In (b), the same pulses are aligned by their trailing edges.



Advantages

- Attractive alternative to low energy X-ray spectrometry
- Good energy resolution
- Enables the study of charge transport processes - drift and diffusion

Limitation

- Limited scope of application

Gas Proportional Scintillation Counter

Problems affecting large area detectors

Compensation of Solid Angle Effects

Existing techniques:

Electron focusing techniques

- Brings the electrons close to the detector axis to maximize the solid angle.

Curved-grid techniques

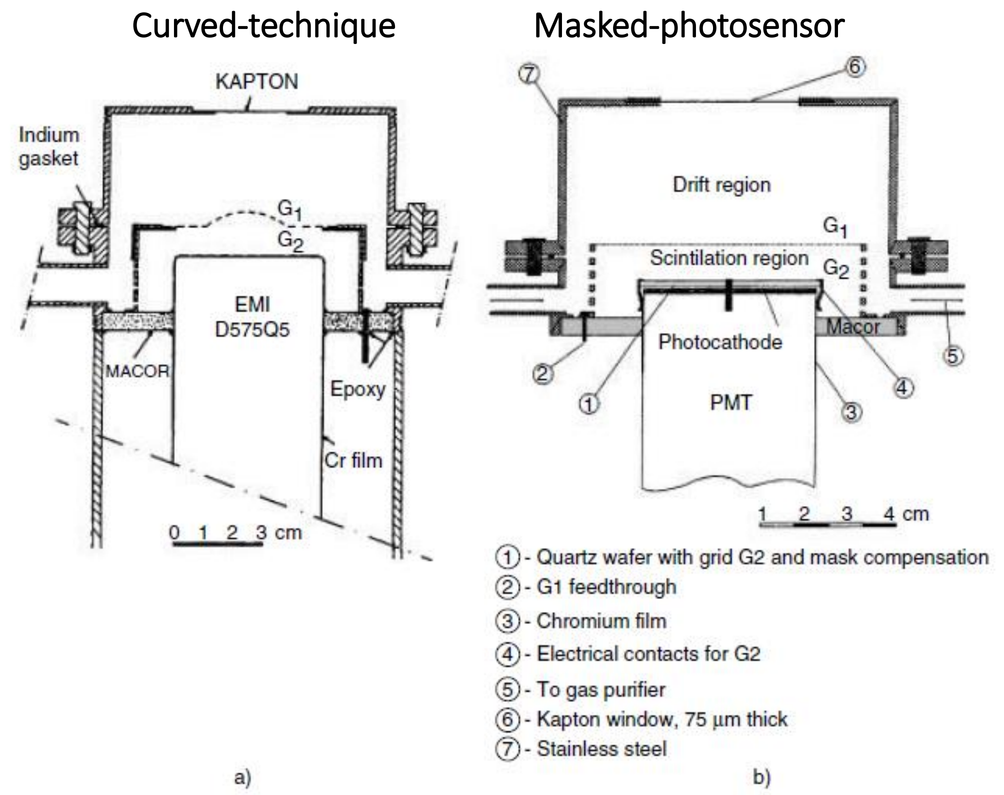
- Makes use of two grids, the first curved and the second planar, for the definition of the scintillation region in so that the electric field increases radially.

Masked-photosensor techniques

- Photosensor is covered with a mask with a light transmission that increases radially, that compensate the decrease in the solid angle.

So far only applied to detectors with planar geometry.

Examples



[dos Santos 2001] X-Ray Spectrom. 2001; 30: 373-381]

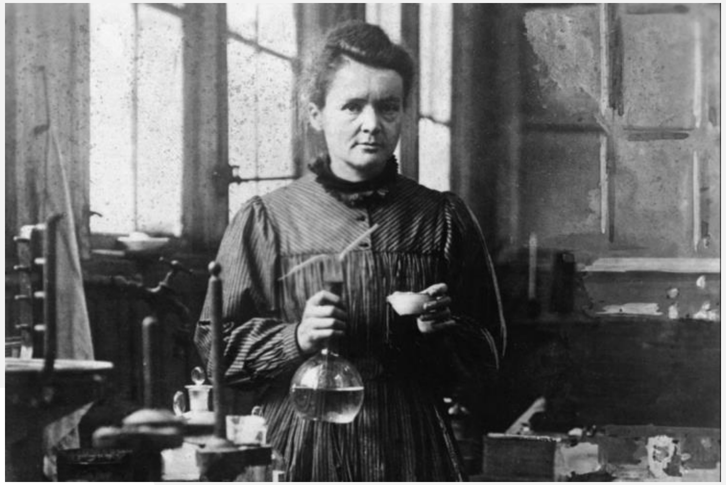
Brief History of the University of Coimbra

- 19th century would be less prominent in the University of Coimbra mainly because of political and social upheavel. In the 20th century one of the most prominent names of physics in Coimbra was **Mário Augusto da Silva** (1901-1977).

Who was **Mário Silva**?

- Portuguese scientist
- PhD student and research assistant of

none other than…



Marie Curie (1867-1934)

Nobel Prize in Physics in 1903

Nobel Prize in Chemistry in 1911

Historical remarks:

- Peninsular War (1807-1814)
- Independence of Brazil (1822)
- Liberal Wars (1828-1834)
- Portuguese 5 October Revolution (1910)

…in the former Institut du Radium (Paris).

As he described his experience "it was unique, a great environment to learn", often describing it as **enthusiastic** and **challenging.**

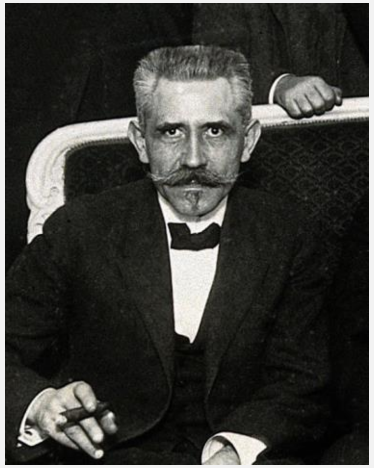
Unfortunately, there were no great discoveries during his stay there (1925-1930).

for the "researches on the radiation phenomena" and by the "discovery of radium and polonium…"

Brief History of the University of Coimbra

- Still **Mário Augusto da Silva** (1901-1977) had great masters surrounding him, which included:

Jean Becquerel* (1878-1953)



Paul Langevin (1872-1946)

Louis De Broglie (1892-1987)

and among his colleagues …

Jean Frédéric Joliot (1900-1958)

Irene Curie (1897-1956)

Nobel Prize in Chemistry in 1935

for the "synthesis of new radioactive elements"

This experience proved to be inspiring as he returned to Portugal to become a Professor at the University of Coimbra bringing with him the interest for **Atomic and Nuclear Physics**.

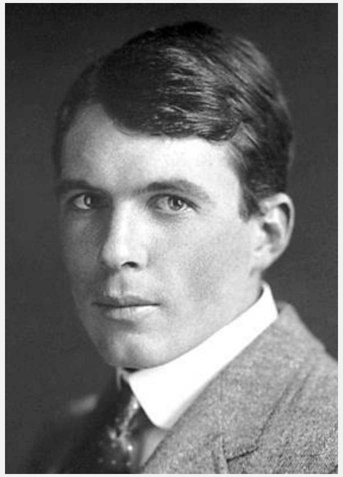
*Son of Antoine Henri Becquerel Nobel Prize in Physics in 1903 with Marie Curie.

Brief History of the University of Coimbra

- In 1930, upon returning to Coimbra **Mário Augusto da Silva** became Professor at the University of Coimbra, and soon after the **director** of the **Physics Laboratory** (Laboratório de Física).
- At this time the Physics Cabinet was obsolete and most of the original items and instruments from the 18th century were damaged, so he promoted their restauration setting the cornerstone for what would become today the museum of Physics.

↓

- **In 1947, Mário Augusto da Silva** is replaced as the head of the Physics Laboratory by **Almeida Santos** who had worked previously with **William Lawrence Bragg** (1890-1971) at the University of Manchester.



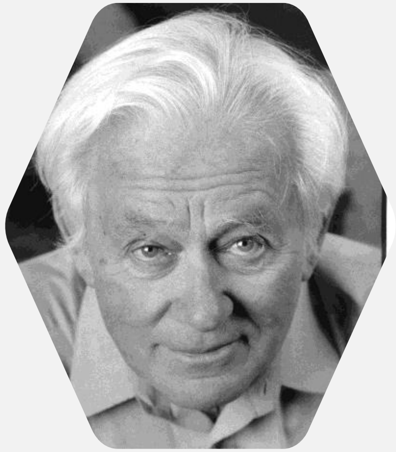
William L. Bragg
(1890-1971)
Nobel Prize in Physics in 1915
for the "analysis of crystal structure by means of X-rays"

Almeida Santos
(1906-1975)

Gas Radiation Detectors Origins and Developments

Golden era of detector development

The origin of Micro-Pattern Gas Detectors



- Geiger Counter
  - Proportional Counter
    - Multi-Wire Proportional Chamber
      - Microstrip Gas Chamber
      - Micromegas
      - Gas Electron Multiplier
    - Time Projection Chamber
  - Parallel Plate Counter
    - Pestov Counter
    - Resistive Plate Chambers