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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 established 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**

**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 exhibition at the University of Coimbra.

Just to get an 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.

• 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)

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

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.
Excitation and Ionization of gas atoms

Deexcitation

Scintillation photons are emitted

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

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

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

Excitation luminescence

\[ e^- + X \rightarrow X^+ + 2e^- \] Atomic Ions

\[ X^+ + 2X \rightarrow X_2^+ + X \] Diatomic Ions

\[ X^* \rightarrow X + h\nu \] atomic lines (<50 Torr)

\[ X_2^* \rightarrow X + X + h\nu' \] continuum (>100 Torr)

Recombination luminescence

\[ e^- + X^+ \rightarrow X^* \rightarrow X + h\nu \]

\[ X_2^+ + e^- \rightarrow X_2^* \rightarrow X + X + h\nu' \]
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)
Conde and Policarpo also understood something important:

For $E/p \approx 1-6 \text{ V cm}^{-1} \text{Torr}^{-1}$:

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 ($Y$).

$$\frac{Y}{p} (293 \text{ K}) = A \frac{E}{p} - B$$

(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 $\frac{E}{p} > 1 \text{ V cm}^{-1}\text{Torr}^{-1}$:
- Electrons lose little energy in elastic collisions;
- But now energy gain between collisions is higher, allowing $\epsilon$ to reach 1st excitation level 8.32 eV:
- One excitation $\rightarrow$ one EL VUV photon:
- High gas purity required!

For $\frac{E}{p} < 1 \text{ V cm}^{-1}\text{Torr}^{-1}$:
- Electrons gain energy from the field between collisions
- Electrons lose energy in elastic collisions
- Energy gain between collisions is below excitation level 8.32 eV

- EL is an efficient process
  + Few statistical fluctuations

Energy resolution
(close to the intrinsic)
Historical Roadmap of GPSCs
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.
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.

THE ARGON-NITROGEN PROPORTIONAL SCINTILLATION COUNTER
A. J. P. L. POLICARPO, M. A. F. ALVES and C. A. N. CONDE
Laboratório de Física, 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 gas interface. 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 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 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 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 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 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 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 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 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 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 appearance of the higher order components, the light collection efficiency and the photomultiplier.
Gas Proportional Scintillation Counter
Configuration of Gas Proportional Scintillation Counters

- Cylindrical
- Spherical
- Planar

- Standard
- Driftless

- Photosensors
- MPGDs
- Photocathode Film

- Scintillation
- Hybrid (light plus charge)
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;

Correlation clearly visible

Fig. 1. The gas proportional scintillation counter.

(Policarpo et al 1970)

(Policarpo et al 1971)
Historical Roadmap of Gas Proportional Scintillation Counters

The Spherical GPSC

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

(Policarpo et al 1972)

- 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

- 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

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

- Results show significant improvements in terms of energy resolution;

2nd International Workshop on SXSDG, Oct. 16-20 2019 at University of Coimbra (Portugal)
Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1970s

Topics addressed:

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

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)

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)

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

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

Monte Carlo Simulation

- Model the fundamental processes taking place in these detectors.

Development of Gas Proportional Scintillation Counters

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

Experimental Studies

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

Detector Development

Basis of a new generation of hybrid GPSCs
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

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

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.

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

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

(J.A.M. Lopes and C.A.N. Conde 1995)
Historical Roadmap of Gas Proportional Scintillation Counters

Electroluminescence studies in the 1990s

Despite these efforts, 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

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

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...

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

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

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.

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.

Fully integrated Hybrid Gas Proportional Scintillation Counter

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 marks:
- Multi-Wire Proportional Chamber introduced in 1968 by Georges Charpak

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

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

With a MSP
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 |

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;

![GEM Diagram]

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

Historical marks:

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

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 suppressed.
- Absence of relevant space charge effects
- Uniformity response over large areas.

Limitation

- Energy Resolution is still problematic.

241Am spectrum
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

(J.A.M. Lopes et al 2000)
Recent Developments
Recent Developments in Gas Radiation Detectors: Electroluminescence use in Time Projection Chambers

**Working Principle**

- Incident particle ionizes the gas volume
- Charge drifts to the electrodes
- Charge is amplified and then collected
- 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.

**Historical marks:**

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

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

Segmented readout Drift time

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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

Development of new micro-patterned gas radiation detectors in Coimbra

**Micro-Hole Strip Plate**

- 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

\[
\text{Gain} = 5 \times 10^4
\]

\[
\varphi = \beta_{MS} + \frac{1}{G_{MS}}
\]

\[
IBF = 1 \times 10^{-4}
\]

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

Historical marks:
• Micro-Hole and Strip Plate (MHSP) introduced in 2000 by João Veloso.
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

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

Gain $\sim 1 \times 10^5$
Recent Developments in Gas Radiation Detectors

Electroluminescence use in Time Projection Chambers – Ion Backflow Suppression

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.

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

Fluctuations in the signal formation

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

*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)

**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.

\[ IBF = 0 \]

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

(F.D. Amaro et al 2014)

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

- Increase the optical gain
- Validate for large areas
- Optimize the energy and position resolution
Recent Developments in Gas Radiation Detectors

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 (t₀) and S2 (energy);
- Tracking plane – detects S2: spatial resolution is important!

Xe136 that is a double beta emitter

\[ Q_{\beta\beta} = 2457.83 \text{keV} \]

\[ ^{136}\text{Xe} \rightarrow ^{136}\text{Ba} + 2\text{e}^- + 2\nu_e \]
\[ ^{136}\text{Xe} \rightarrow ^{136}\text{Ba} + 2\text{e}^- \]

\[ T_{1/2} > 6.5 \times 10^{25} \text{years} \]

\[ R < 1\% \at Q_{\beta\beta} \]

Good position resolution needed

*Located in the Underground Laboratory of Canfranc (Pirineus, border with France) NEXT Collaboration, 2013 JINST 8 T05002

NEXT Collaboration, 2013 JINST 8 T05002
Future Prospects
Opportunities for Gas Radiation Detectors based on Electroluminescence

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.

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;

Position resolution could be improved adding a highly electronegative dopant

New generation of Time Projection Chambers

Historical marks:
- Timepix introduced in 2008 by X. Llopast.

NITPC prototype with a GEMpix readout

(4 chips x 512 pixels, 56 μm pitch = 2.8 x 2.8 cm²)

(E. Baracchini et al 2018)
Opportunities for Gas Radiation Detectors based on Electroluminescence

Cygnus Collaboration

About 70 members
Steering group (alphabetically ordered):
- Elisabetta Baracchini (GSSI/INFN, Italy)
- Greg Lane (Melbourne, Australia)
- Kentaro Miuchi (Kobe, Japan)
- Neil Spooner (Sheffield, UK)
- Sven Vahsen (Hawaii, USA)

\[ \pm 80\% \text{ He} \pm 19\% \text{ CF}_4 \pm 1\% \text{ SF}_6 \]

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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...
Questions?

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)

Thank you!

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Questions?
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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.
**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.

**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.

**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

---

(D.S. Covita et al 2003)

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.
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 such a way 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.

Brief History of the University of Coimbra

- 19th century would be less prominent in the University of Coimbra mainly because of political and social upheaval. 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...

...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)  
  Nobel Prize in Chemistry in 1935  
  for the “synthesis of new radioactive elements”
  
  Irene Curie  
  (1897-1956)

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.
Gas Radiation Detectors
Origins and Developments
Golden era of detector development
The origin of Micro-Pattern Gas Detectors

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