GASEOUS RADIATION DETECTORS

Widely used in high-energy and particle physics, gaseous radiation detectors are undergoing continuous development. The first part of this book provides a solid background for understanding the basic processes leading to the detection and tracking of charged particles, photons, and neutrons.

Continuing then with the development of the multi-wire proportional chamber, the book describes the design and operation of successive generations of gas-based radiation detectors, as well as their use in experimental physics and other fields. Examples are provided of applications for complex event tracking, particle identification, and neutral radiation imaging. Limitations of the devices are discussed in detail.

Including an extensive collection of data and references, this book is ideal for researchers and experimentalists in nuclear and particle physics.

This title, first published in 2015, has been reissued as an Open Access publication on Cambridge Core.

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GASEOUS RADIATION DETECTORS

Fundamentals and Applications

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Contents

Acronyms

ADC:	analogue to digital converter
ASIC:	application specific integrated circuit
ATLAS:	one of the LHC experiments at CERN
BNL:	Brookhaven National Laboratory, USA
CAT:	compteur à trous
CEN-Saclay:	Centre d'Etudes Nucléaires, Saclay, France
CERN:	European Organization for Nuclear Research, Geneva, Switzerland
CGS:	electrostatic units: centimetres, grams, seconds
COG:	centre of gravity
CRID:	Cherenkov ring imaging detector
CSC:	cathode strip chamber
CsI:	caesium iodide
CVD:	carbon vapour deposition
DC:	drift chambers
DME:	dimethyl ether $(CH_3)_2O$
FERMILAB:	Fermi National Laboratory, Batavia, Illinois, USA
FGLD:	field gradient lattice detector
FWHM:	full width at half maximum
GDD:	Gas Detectors Development group at CERN
GEM:	gas electron multiplier
GSPC:	gas proportional scintillation counter
HADC:	high-accuracy drift chamber
HBD:	hadron blind detector
HMPID:	high momentum particle identification detector
IHEP:	Institute of High Energy Physics, Protvino, Russia Federation
ILC:	International Linear Collider
ILL:	Institut Laue-Langevin, Grenoble, France

INFN:	Istituto Nazionale di Fisica Nucleare, Italy
ISIS:	identification of secondary particles by ionization sampling
IVI:	interaction vertex imaging
KEK:	High Energy Accelerator Research Organization, Kamiokande, Japan
LAr:	liquid argon
LBL:	Lawrence Berkeley Laboratory
LEM:	large electron multiplier
LEP:	Large Electron–Positron collider at CERN
LHC:	Large Hadron Collider at CERN
LNF:	Laboratori Nazionali Frascati, Italy
LNGS:	Laboratori Nazionali Gran Sasso, Italy
MDT:	monitored drift tubes
Micromegas:	micro-mesh gaseous structure
MIPA:	micro-pin array
MPGD:	micro-pattern gas detector
MRPC:	multi-gap resistive plate chamber
MSC:	multi-step chamber
MSGC:	micro-strip gas counter
MWDC:	multi-wire drift chamber
MWPC:	multi-wire proportional chamber
μPIC:	micro-pixel chamber
NSR:	nuclear scattering radiography
NTP:	normal temperature and pressure: 0°C, 1 atmosphere
PEP:	Electron Positron Collider at SLAC
PET:	positron emission tomography
PPAC:	parallel plate avalanche counter
PRR:	proton range radiography
PST:	plastic streamer tubes
P10:	mixture of 10% methane in argon
QE:	quantum efficiency
RHIC:	Relativistic Heavy Ion Collider, Brookhaven, USA
RICH:	ring imaging Cherenkov counter
RMS (rms):	root mean square (Gaussian standard deviation)
RPC:	resistive plate counter
SLAC:	Stanford Linear Accelerator Center
SLHC:	Super LHC at CERN
SPECT:	single photon emission computed tomography
SQS:	self-quenching streamer
SSC:	Superconducting Supercollider

STP: standard temperature and pressure: 20°, 1 atmosphere
SWDC: single-wire drift chambers
TEA: triethyl amine $(C_2H_5)_3N$
TEC: time expansion chamber
TERA: Fondazione per Adroterapia Oncologica, Novara, Italy
TGC: thin-gap chambers
TGEM: thick gas electron multiplier
TMAE: tetrakis dimethyl amino ethylene $C[(CH_3)_2N]_4$
TPC: time projection chamber
TRIUMF: Canada’s National Laboratory for Particle and Nuclear Physics, Vancouver
TRT: transition radiation tracker
UV: ultra-violet
VUV: vacuum ultra-violet
WIMP: weakly interacting massive particle
WLS: wavelength shifter

Preface

Major scientific advances are the result of interplay between ground breaking theoretical intuitions and experimental observations, validating or contradicting the predictions. In elementary particle physics, the commissioning of high-energy accelerators and colliders demanded the development of innovative detectors capable of recording increasingly complex events; in astrophysics, where the scope is to detect radiation from remote sources, or ubiquitously present in the Universe but with little if any interaction with ordinary matter, the focus is rather on the realization of large volume, low noise devices capable of revealing rare events obscured by diffuse backgrounds. In both cases, dedicated gas-filled detectors have demonstrated their flexibility of conception and excellent performances.

Starting with Ernest Rutherford's original development of the single-wire proportional counter in the early 1900s, through the multi-wire and drift chambers introduced by Georges Charpak in the late sixties, to the powerful new tracking devices collectively named micro-pattern gas chambers, the development of gaseous detectors has been a continuous story of success and, sometimes, disappointments.

While many textbooks exist on gaseous detectors (see the Further Reading section), most of the information on recent progress in the field is scattered in thousands of articles, conference records, doctoral theses and other documents. This book aims to collate selected information in an organized way, reproducing relevant data on the various developments, providing extended references to published material as well as links to useful web-based tools and databases. The content is largely based on the many courses given by the author at CERN and various universities and research laboratories worldwide, and greatly profits from constructive interactions with the students. Whenever possible, simplified, back-of-the-envelope calculation examples are provided as a complement to more rigorous algorithms.

After a recall of the major processes of interaction between charged particles, photons and neutrons with the medium, releasing detectable messages in matter, the first part of the book follows the fate of the ionisation yields, released in a counter's gas, under the effect of externally applied electric and magnetic fields, from simple collection to charge multiplication and breakdown. Depending on the counter geometry and field strength, a detector can be made then to operate in simple charge collection, in a regime of avalanche charge multiplication with the detected charge proportional to the primary ionisation, or in gain-saturated regimes providing conveniently large signals, almost independent from the original charge. Primary or field-enhanced photon emission can also be exploited for detection. Each mode has its own advantages and disadvantages, discussed in the subsequent chapters, which have to be thoroughly analysed to best cope with the experimental needs.

Associated for many years with Georges Charpak's research group at CERN, I was easily fascinated by his enthusiasm in searching new directions for the development and applications of detectors, mostly based on the use of a gas as sensitive medium; a short personal recollection of my participation to these research efforts is illustrated in the first chapter of the book. Over the years, the activity of the group attracted many young scholars, who contributed to the various developments before returning to their home institution, often subsequently creating their own research team while keeping friendly and constructive contacts with our group; this book is dedicated to them and their works, with apologies for any mistake or omission.

I am particularly grateful to Ugo Amaldi, who hosted me in the TERA Foundation premises at CERN during the final drafting of the book; a warm word of appreciation goes to many colleagues who provided scientific help and support in obtaining original documents and reprint permissions: Marcello Abbrescia, Ugo Amaldi, Elena Aprile, Tullio Basaglia, Malte Hildebrandt, John Kadyk, Salete Leite, Eugenio Nappi, Anna Peisert-Elliott, Archana Sharma, Emile Schins, Graham Smith, Jerry Va'vra, and many others.

Last but not least, warm thanks to my daughter Raffaella who undertook the strenuous task of improving the language on a subject rather extraneous to her field of expertise.