

WG1 (Paul Colas, Ingo Deppner, Luca Moleri, Filippo Resnati, Michael Tytgat, Peter Wintz)

A large variety of technologies have to be developed to cover the needs of future experiments with cost-awareness and sustainability concerns. Improving existing detectors to make them larger, working at higher rates or lower background, with better stability and improved performance, will require new technologies and development.

Working group 1 will study and monitor the progress in wire, RPC, MPGD and TPC technologies.

Wires: Since the invention of the Multi-Wire Proportional Chamber (MWPC) at CERN by Charpak et al. in 1968, the technology of wire-based gaseous detectors has been continuously further developed and improved to achieve new capabilities. The MWPC technology led to the development of Drift chambers (DC, 1973) for higher-resolution particle tracking, Cathode-Strip Chambers (CSC, 1977) and Thin-Gap Chambers (TGC, 1983) for tracking with much shorter timing, and (Muon-) Drift Tubes (DT, 1980) or Straw Tube Chambers (1989) with robust mechanical and electrostatic shielding of the anode wire in the center of the cathode tube. All listed technologies, with substantial and continuous technical improvements and enhancements since their invention, are to date widely used in current state-of-the-art HEP and non-HEP experiment installations.

Typical spatial resolutions of these detectors are about 100 - 150 μm with drift time ranging from about 100 ns (Straws, DT) up to μs for DC. Examples of future wire-based detector concepts include: an ultra-low mass and large-volume drift chamber (35 m^3) as central tracker with PID (IDEA at FCC-ee); Muon detector systems (DT, CSC, TGC) with higher rate capability, large size and short timing (FCC-ee, FCC-hh); a self-supporting, low-mass central straw tracker with 4D-tracking (space and time) and PID for Hadron physics (PANDA at FAIR); a large-area straw detector (50 m^2) in vacuum for Dark Matter searches (SHiP) and straw trackers in vacuum with minimal material budget for rare event searches (COMET, Mu2E-II, HIKE) and straw detectors in neutrino experiments (DUNE).

(t)RPC: Introduced in 1981 by Santonico and Cardarelli, Resistive Plate Chambers (RPCs) are parallel-plate counters consisting of a thin (about 1-2 mm) gas volume at near-atmospheric pressure, enclosed by two electrodes made of high-resistive materials (orders of 10^9 to 10^{13} Ωcm bulk resistivity), such as glass or High Pressure Laminate (HPL), across which a high voltage is applied up to about 50 kV/cm. RPCs are characterized by an excellent spatial resolution of the order of a few 100 μm , a good time resolution of the order of 1 ns, a high detection efficiency (more than 95%) and rate capability up to about 1 kHz/ cm^2 . Double-gap configurations exist to enhance the detection efficiency. In the year 2000, timing-RPCs (often called tRPCs), have been developed by Fonte, Smirnitisky and Williams, where the active volume consists of multiple (up to more than 20) small size (about 100-300 μm) gas gaps, leading to superior time resolutions down to 20-150 ps.

(t)RPCs make it possible to instrument very large active areas with chambers of up to a few square meters in size. The fabrication procedure is relatively simple, cheap and little demanding in terms of mechanical precision. Those features are at the basis of the popularity of (t)RPCs in HEP

experiments. Currently, RPCs appear in experiments for muon tracking/triggering (e.g. CMS, ATLAS), time of Flight (e.g. ALICE, STAR, HARP, FOPI, HADES, SHiP, BGO-EGG, CBM, CEE, Pi20,...), calorimetry (e.g. CALICE SDHCAL), cosmic ray experiments (e.g. EEE, Pierre Auger Observatory) and non-HEP applications in e.g. positron emission tomography (PET), gamma tomography, muon radiography (mostly RPCs used so far, e.g. Tomuvol).

MPGD: The concept of Micro-Pattern Gaseous Detectors (MPGDs) was born with the Micro-Strip Gas Chambers (MSGCs) in 1988 to cope with high particle fluxes. The micro-electrodes used to multiply charges in gas were created on different substrates, exploiting technologies from the semiconductor industry (Photolithography, Etching, ...). From the MSGC developments, a number of new structures were conceived: 1) micro-gap, micro-dot, microgroove, microWELL, ... with amplification around micro electrodes and 2) MicroMegs, GEM, ThGEM, ... with amplification in semi-uniform electric field.

The R&D done in the last years, in particular within the work of the RD51 Collaboration, aimed to develop MPGDs for applications in High Energy Physics (HEP) and Nuclear physics experiments.

Some notable examples of the employment of MPGDs are the Atlas New Small Wheel and the CMS forward muon detector systems, and ALICE TPC. MPGDs are also largely exploited in non-collider physics experiments, such as neutrino oscillation experiments, and direct dark matter searches, as well as for applications beyond particle physics. For instance MPGDs are used in X-Ray polarimeter experiments, and muography.

The popularity of MPGD is due to some intrinsic qualities of the technology, like the high spatial resolution, high particle-flux capability, large active area with small dead surface, and resilience to radiation. Operating MPGDs with stable and uniform gain in certain conditions (e.g. highly ionizing environment, variable irradiation fluxes) remains a challenge to be addressed by future development.

Another reason for the large spread of MPGDs is the constant and cross-field R&D focusing on developments of new amplification structures, studies of new materials and coatings (resistive, low outgassing, ...), and selection of the appropriate gas mixtures. This makes MPGD concepts particularly versatile for various conditions of operation and physics performance requirements.

TPC: A Time Projection Chamber (TPC) is a drift chamber where the timing of events is used to reconstruct one of the spatial coordinates. The concept of a TPC was introduced in 1974 by Nygren and it finds nowadays application in Particle Physics at Colliders, fixed-target experiments, Nuclear Physics, Non-accelerator physics and societal (e.g. muography).

Until the end of the 1990s TPCs at colliders were read out exclusively by multi-wire chambers (e.g. DELPHI and ALEPH TPCs at LEP, the first ALICE TPC at LHC, NA61). Since the invention of MPGDs, many projects focused on their application as a TPC readout. Some of the advantages could be an improved spatial resolution, reduced ion backflow and mechanical robustness of large detectors. In 2009 the T2K/ND280 TPC was read out by Micromegas, and in 2023 the ALICE readout was changed into 4-GEMs. Additional TPCs for T2K/ND280 under construction apply the ERAM technique with resistive anode invented for ILC.

As an alternative to the standard charge readout, optical readout of TPCs is developing rapidly, thanks for example to the R&D for CYGNO, DUNE and MIGDAL experiments. Optical readout can also find application in polarimetry.

New charge-amplification techniques have been introduced in the last decade.

Two examples:

- 1) Spherical Proportional Chambers where a small ball maintained at a positive high voltage ensures the amplification for electrons drifting from a large sphere. The advantage of this configuration is that the drift field is very weak near the surface of the external sphere, lowering the sensitivity to radioactive background coming from this surface, and the detector capacitance is very small, allowing a very reduced electronic noise.
- 2) TIPSIT, with 'tynodes' (micropatterned ultra-thin dynodes), aiming at amplification in vacuum as done in a photomultiplier tube.

Challenges and work packages

For all the abovementioned technologies, new challenges appear. Some of those are common, while others are depending on the specific detector concept. Future higher particle-rate environments require reducing the occupancy by minimizing the detector granularity. Reduction of material budgets (X/X_0) by new composite structures and reduced material thickness is a general prerequisite. Gas mixture components with high Global Warming Power, e.g. CF_4 , SF_6 and $\text{C}_2\text{H}_2\text{F}_4$ have to be replaced and flammable admixtures to be avoided or reduced to a minimum and enclosed in a recirculating gas system.

Wires: Future experiments require smaller wire cell sizes, with high mechanical precision ($<50\mu\text{m}$) over large wire and detector lengths up to 5 m. Specific R&D topics for large-volume drift chambers with orders of 10^5 anode and field wires are new wiring systems (robots) and the design of modular units of drift cells to facilitate the detector assembly. The technique of ion cluster counting for higher-resolution PID has to be exploited with single-cluster sensitive readout electronics.

Straw tube developments include smaller diameter (5 mm), shorter time range (less than 80 ns) for event timing, ultra-thin straw films ($15\mu\text{m}$) with radiation length minimal and comparable to the gas layer, and long straw lengths with precise wire centering. Operation in vacuum is a unique application of straw detectors and will be extended to ultra-long straws up to 5 m and large detector gas volumes of 25 m^3 . R&D goals are high fluxes of the order of 100 kHz/cm^2 capability and aging resistivity for high charge loads of the order of 10 C/cm , both which are about a factor of ten higher than current standards.

Research of new wire materials, e.g. new alloys or metallized carbon monofilament with higher strength (Young's modulus) to reduce sag and electrostatic deflection are needed. Wire and cathode coating studies to further improve resistivity against high irradiation and high charge loads are continuously needed.

(t)RPC: The possible usage of RPCs in high luminosity, high background rate environments (e.g. the HL-LHC, FAIR and other future facilities) has triggered a number of new efforts to improve the (t)RPC rate capability and to mitigate possible aging effects. Those include searches for new electrode materials with lower (compared to regular float glass or HPL) or tunable resistivity such as Fe-doped

glass, vanadate-based glasses, ceramics, DLC, Si-GaAs wafers; the development of low noise, i.e. low threshold, and faster readout electronics with a few ps time resolution and high bandwidth; studies of outgassing and material aging effects. In addition, following European regulations which increasingly ban the emission of greenhouse gasses, RPCs are facing an important challenge to replace the standard, tetrafluoroethane-based gas mixture with a more eco-friendly alternative. Parallel efforts to limit the gas consumption or emission using recirculation and recuperation systems are ongoing. Closely related are the studies to operate RPCs with low flow or even in sealed mode, which are of particular interest also for non-HEP applications of RPCs. Finally, new chamber geometries such as cylindrical or single-electrode RPCs are being developed to enhance specific performance features.

MPGDs: The challenges for the next generation MPGDs are to achieve precise timing (aiming at less than 20 ps) in conditions dictated by the next collider experiments. The typical sturdiness of the MPGD amplification structures makes them appealing for environments with harsh conditions (high radiation, cryogenics, high and low pressures). The studies of new materials opens up the doors to new fabrication techniques, like 3D-printing, and additive fabrication, which in turns open up the possibility to unprecedented structure geometries.

TPCs: To extend the use of TPCs at higher luminosity and in more noisy environments (e.g. FCC and BELLE II) , ion backflow must be minimized. Moreover, electric field distortions created by the space charge of drifting ions have to be mitigated and corrected for in real time. Low-radioactivity materials will be needed in TPCs for rare events and negative-ion TPCs. The latter also require solutions for the environmental consequences of using some electro-negative glasses (greenhouse gasses like CF_6).

To help tackle these challenges, WG1 plans to have regular meetings with representatives of all the communities working with various technologies, where new ideas, new structures, goals, challenges and realizations will be presented, favoring cross-fertilization. They will allow a follow-up of projects, from start to several years of operation, paying a particular attention to the feedback from experience.

Possible work packages (with other working groups) to be extended/iterated :

- Portable detectors (sealed detectors, HV on battery)
- New generation Gaspix
- Multiplexed detector
- Fast and precise timing
- High-rate capable detectors
- High Voltage stable and aging-resistive detectors
- Detectors incorporating new resistive materials

These can be considered as tasks and integrated in broader Work packages, as new generation TPCs, or Muography.

Here one example of footnote¹ and references [III.a-1]

¹ Here the footnote

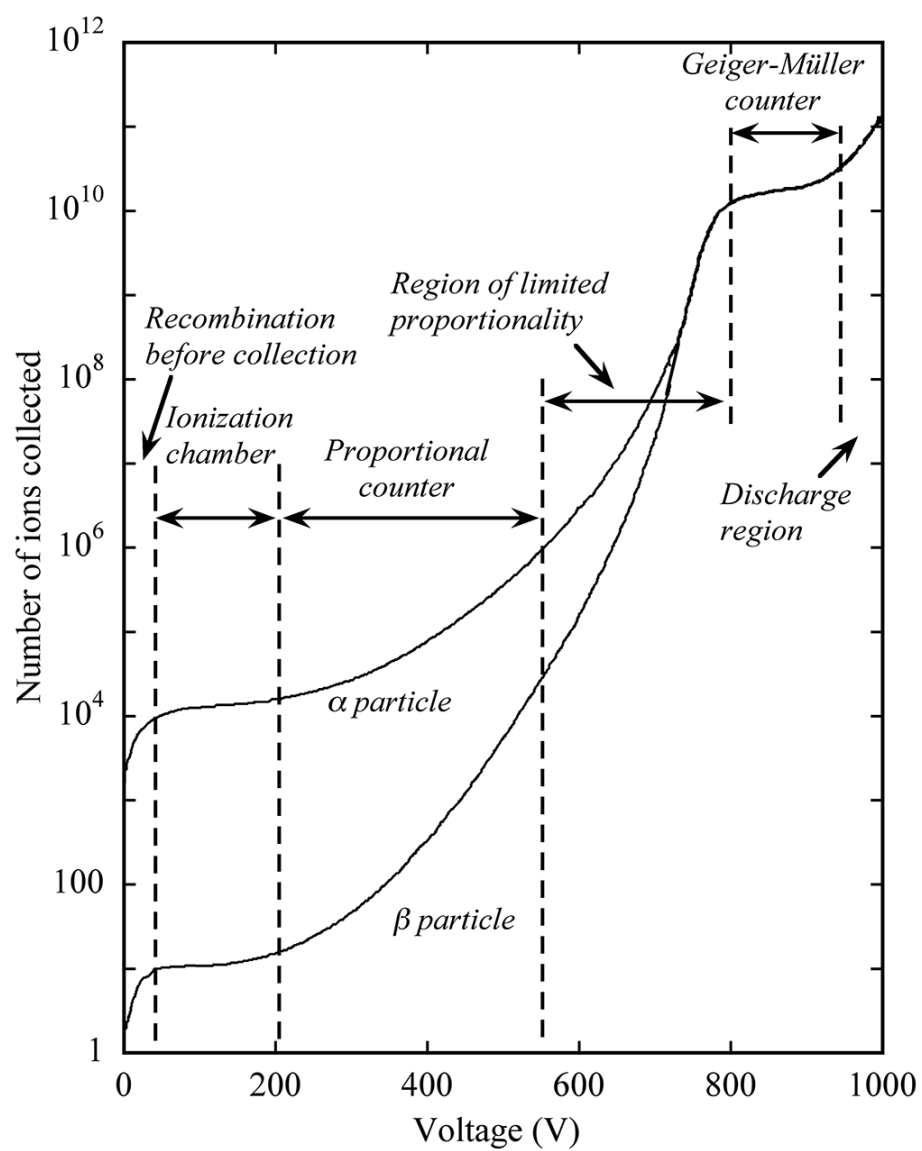


Fig. III.a-1: Voltage dependence of detected charge in a proportional counter

Table				
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Table III.a-1: List of Technologies

References

[III.a-1] M. Chefdeville et al., *Development of Micromegas detectors with resistive anode pads*, [Nucl. Instrum. Meth. A **1003** \(2021\) 165268](#).

Topics:

WG1: Technologies

Includes experimental detector physics aspects

- MPGD
- RPC and MRPC
- Wire chambers (incl. Straws, TGC, CSC, ..)
- Large Volume Detectors (drift chambers, TPCs)
- New amplifying structures

Survey:

Technologies of interest

Please select one or more technologies of interest for your group and add in the comment section more information or remarks and notes if needed.

Technologies of interest*

- MPGD
- RPC and MRPC

- Wire chambers (incl. Straws, TGC, CSC, ..)
- Large Volume Detectors (drift chambers, TPCs)
- New amplifying structures
- Other

Comments/Notes

Please add any relevant comment/remark on technologies of interest