Work Package 4

(Large-Volume) Tracking TPCs

Participating institutes:

Universidade de São Paulo (USP)
Carleton University (U Carleton)
Institute of High Energy Physics (IHEP/CAS)
Tsinghua University (U Tsinghua)
Helsinki Institute of Physics (HIP)
University of Jyväskylä (U Jyväskylä)
IRFU, CEA, University Paris-Saclay (IRFU/CEA)
University of Bonn (U Bonn)
Technische Universität Darmstadt, Institut für Kernphysik (TUDa)
GSI Helmholtzzentrum für Schwerionenforschung (GSI)
Wigner Research Centre for Physics (RCP)
INFN Sezione di Bari (INFN-Bari)
INFN Sezione di Roma (INFN-Roma1)
Iwate University (IU)
European Organisation for Nuclear Research (CERN)
Paul Scherrer Institut (PSI)

DESCRIPTION OF THE PROJECT (AND POSITIONING W.R.T. THE ROADMAP)

Time Projection Chambers (TPCs) have been extensively studied and used in many fields especially in particle, nuclear and neutrino physics experiments. Also smaller size TPCs are a good choice for beam diagnostics operating in high particle rate environments. The ECFA detector R&D roadmap (2021 report: CERN-ESU-017. CERN, 2020, p. 248. DOI: 10.17181/CERN.XDPL.W2EX) mentions in chapter 1 for gaseous detectors four Detector Research and Development Themes:

DRDT 1.1 - Improve time and spatial resolution for gaseous detectors with long-term stability.

DRDT 1.2 - Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different readout schemes.

DRDT 1.3 - Develop environmentally friendly gaseous detectors for very large areas with high-rate capability.

DRTD 1.4 - Achieve high sensitivity in both low and high-pressure TPCs.
All four themes are relevant for the future developments of TPCs and therefore are priority topics in this work package. To improve time and spatial resolution (DRDT 1.1), MPGDs have already proven an excellent readout technology for TPCs as they improve the performance in all respects. The smaller feature size improves spatial resolution, a higher rate capability is reached and the ion backflow is reduced. The latter is an important aspect for TPCs to improve spatial resolution and stability, as the ions can introduce electrical field distortions in the drift volume. Therefore, TPCs are often operated in a gated mode, where a closed gating device is blocking ions from the gas amplification stage and is opened only on demand. New experiments require a continuous operation mode for increasing the fraction of sensitive time. MPGDs promise to reduce the ion backflow (IBF) by many orders of magnitude and therefore make a continuous operation a viable option.
Another advantage of TPCs is its contribution to PID by providing a precise dE/dx measurement, which can be further enhanced by cluster counting as pointed out by DRDT 1.2.
In particular highly pixelized readout structures like the GridPix, which is a combination of a Si-readout ASIC with a Micromegas gas amplification stage, feature the possibility of distinguishing single primary electrons, which can be used to record events with an unprecedented resolutions mentioned in DRDT1.1 and 1.2. For several future experiments like future e+e- collider or EIC a pixelTPC is considered as a possible tracker.
As low diffusion gases are needed for long drift distances, very specific quencher gases have been used sofar with low $\omega\tau$ to reduce the transverse diffusion in magnetic fields. These gases often have a higher GWP (e.g. CH_4: 28, CF_4: 6630). The search for alternatives as described in DRDT 1.3 is also of high importance for this work package. While most tracking TPC are operated at atmospheric pressures, and changing the gas pressure (DRDT 1.4) is mostly used in applications of WP8, also tracking TPCs might consider experiment specific gas pressures deviating from atmospheric pressures. Therefore, this aspect will also be considered in one of the tasks along the studying gas mixtures.

List of tasks:

T1: IBF reduction: Ion Backflow is defined as the number of ions reaching the drift volume over the number of ions created in the gas amplification. To minimize the electrical field distortions in the drift volume, the IBF has to be as low as possible. Depending on the experimental requirements active or passive measures to reduce the IBF can be taken. Most challenging is the passive reduction as only static fields can be used to guide the ions. This is necessary for a continuous readout of TPCs. In this task both approaches shall be studied to find solutions for both options.

T2: pixelTPC development: A highly pixelized TPC readout promises the best possible resolution in both space and energy only limited by the diffusion. Therefore, this approach should be studied in more detail in this task. Various approaches will be tested and the structures shall be optimized with respect to resolution and IBF.

T3: Optimization of the amplification stage and its mechanical structure, and development of low X/X_0 field cages (FC): One additional advantage of TPCs is their light and homogenous structure. Filled only with gas, they have no mechanical structures except the field cage (here both the electrical and mechanical aspects are referred to) and the endcaps. In this task new ideas shall be developed and investigated to further increase the homogeneity of the FC and to lower the material budget of both components.

T4: FEE for TPCs: The traditional TPC readout is based on a continuous sampling of the baseline and signals after an event trigger. This concept is not applicable any more for a continuous readout, but a self-triggered zero-suppressed readout has to be used. Nevertheless, sampling of the signals is highly favoured to identify double tracks, measure dE/dx more precisely and to get hints of the longitudinal diffusion. Standard tracking electronics does not fulfil these requirements and dedicated TPC electronics is necessary. Most of this electronics, however, is experiment specific and not easily available and usable. Therefore, this task is dedicated to develop an SRS-based readout system for smaller scale experiments and test setups with TPCs. It also includes the development of low power electronics and Front End Electronics cooling.

T5: Gas mixture: Because of the long drift distances (up to 2.5 m) specific gas mixtures with low diffusion coefficients are needed to improve the spatial resolution of a TPC. As most tracking TPCs are embedded in a magnetic field parallel to the electric drift field, gases with a high $\omega\tau$ are sought, because the transverse diffusion is suppressed in this configuration. In this task new gases suitable for TPC applications are studied. A particular attention will be given to a low environmental impact (e.g. low GWP) and the effect of varying the gas pressure will also be studied.

List of deliverables:

D1. Demonstrator MPGD-TPC commissioned for studies of tracking performance at high rates using different types of amplification stages and readout electronics
This deliverable is related to the assembling of a TPC prototype, using any type of MPGD amplification stages and also readout electronics, to target high rate capability. This was based on the feedback given by most of the groups, where it was stated the assembling of various types of MPGD- based TPCs.
The main idea behind this deliverable is to group all the different prototypes into one, which can be available for different tracking studies and in synergy with the groups involved.

D2. Report on Ion backflow studies as a function of particle rate including measurements and simulations for its reduction.

D3. Report on the tracking performance with using high density readout electronics and different readout structures with large dynamic range.

D4. Construction of new highly pixelized readout structures.

D5. Develop new high-density electronics for TPCs for both pixelized and standard pad readout with low-power consumption, low noise, high dynamic range and cooling.

List of milestones:

Milestones are defined as intermediate steps towards the deliverables. Therefore, the milestone numbering is correlated to the numbering of the deliverables.

M1. Demonstrator MPGD-TPC produced and ready to be commissioned.

M2. Setup for IBF measurements are ready to measure.

M3. Prototype including readout structure and electronics ready for test beam.

M4. First prototypes of pixelized structures - not necessarily functional.

M5. First prototype of next generation FEC produced.

LIST OF PARTICIPATING INSTITUTES/LABS WITH A SHORT DESCRIPTION

INSTITUTE 1: *Universidade de São Paulo (USP) – São Paulo, Brazil*

The contact person at USP is Marco BREGANT (bregant@usp.br). The group, that was responsible for the SAMPA development, includes researchers from the Physics Institute (IFUSP) and from the Engineering School (EPSUP). The group is presently involved in the development of a new versatile ASIC for gaseous detectors. The IFUSP has also some activities in IBF and optimization of GEM-based detectors.

INSTITUTE 2: *Carleton University (U Carleton) – Ottawa, Canada*

The contact person at Carleton is Jesse Heilmann (JesseHeilman@cunet.carleton.ca). The group consists of 2 members. It has an extensive background in gas detector production and simulation including contributions to ATLAS-NSW. The main R&D interests are now GridPixes.

INSTITUTE 3: *Institute of High Energy Physics (IHEP/CAS) - Beijing, China*

The contact person at IHEP is Huirong Qi (qihr@ihep.ac.cn). The group has 8 members and is dedicated to design a TPC for the CEPC and is studying the performance of a TPC operated in continuous mode at a circular collider. Most notably the electrical field distortions because of ions and the necessary reduction of the IBF will be investigated, but also other aspects like different pad sizes down to highly pixelated readout.

INSTITUTE 4: *Tsinghua University (U Tsinghua) - Beijing, China*

The contact person at the Tsinghua University is Zhi Deng (dengz@mail.tsinghua.edu.cn). He is working very closely with Institute 2 (IHEP/CAS) and develops low power readout electronics for TPCs.

INSTITUTE 5: *Helsinki Institute of Physics (HIP) - Helsinki, Finland*

The contact person at HIP is Francisco Garcia (francisco.garcia@cern.ch). The group has three members and was involved in the development of gaseous detectors for CMS, TOTEM and Super-FRS. The research aim is to develop TPCs for heavy ion experiments.

INSTITUTE 6: *University of Jyväskylä (U Jyväskylä) - Jyväskylä, Finland*

The contact person at U Jyvsäskylä is Tuomas Grahn (tuomas.grahn@jyu.fi). The group has two members and was involved in the ALICE and ISOLDE experiments and FAIR.

INSTITUTE 7: *IRFU, CEA, University Paris-Saclay (IRFU/CEA) - Saclay, France*

The contact person if IRF/CEA is Esther Ferrer Ribas (esther.ferrer-ribas@cea.fr). The group is dedicated to Micromegas readout structures and has contributed to many large volume tracking TPCs for different experiments like T2K and LCTPC. The current focus is on the T2K upgrade, the DUNE ND (Sand) and ND280. The main focus will be on IBF reduction with different blocking layers and cooling of the FEE.

INSTITUTE 8: *Physikalisches Institut of University of Bonn - Bonn, Germany*

The contact person at the University of Bonn is Klaus Desch (desch@physik.uni-bonn.de). The group has two permanent members and a varying number of Master and PhD students (5-8 on average). It has a long history of producing and applying highly pixelized readout structures to various applications, in particular TPCs. Bonn is interested in transferring the GridPix production process from Berlin to Bonn and to optimize the structures for different applications.

INSTITUTE 9: *Technische Universität Darmstadt, Institut für Kernphysik (TUDa) - Darmstadt, Germany*

The contact person at TU Darmstadt is Alexandre Obertelli (aobertelli@ikp.tu-darmstadt.de). The group designs and performs experiments to explore phenomena of many-body nuclear systems far away from the valley of the stable nuclei. The group has a broad portfolio in building instrumentation for nuclear physics experiments and is currently involved in major developments of MPGD_based tracking TPCs for PUMA experiment at CERN and HYDRA experiment at R3B/FAIR.

INSTITUTE 10: *GSI Helmholtzzentrum für Schwerionenforschung (GSI) - Darmstadt, Germany*

The contact person of GSI is Bernd Voss (B.Voss@gsi.de). The GSI group dedicated to TPCs is one person, who will develop together with HIP a TPC for beam monitoring at the Super-FRS. GSI will develop dedicated low noise electronics and perform studies on discharges and IBF reduction.

INSTITUTE 11: *Wigner Research Centre for Physics (RCP) - Budapest, Hungary*

The contact person at RCP is Dezso Varga (Dezso.Varga@cern.ch). The Innovative Detector Development “Momentum” Research Group has 10 permanent members and 4 PhD students. THe group gas participated in the upgrade of the ALICE TPC, and built various sub-systems for the NA61 experiment, and contributed to RD51 activities. Main interests are now the development of a smaller TPC for NA49, where a low IBF and new readout structures are the main focus.

INSTITUTE 12: *INFN Sezione di Bari (INFN-Bari) - Bari, Italy*

The contact person at INFN-Bari is Emilio Radicioni (emilio.radicioni@cern.ch). The group has 35 members of which 6 are dedicated to TPC development, mostly for neutrino oscillation experiments. The main R&D interests are gaseous detectors in general and charge and optical readout of TPCs in particular. The optimization and comparison of charge and optical readout in particular for dE/dx and dN/dx measurements are targeted in this work package.

INSTITUTE 13: *INFN Sezione di Roma (INFN-Roma1) - Rome, Italy*

The contact person of INFN-Roma1 is Francesco Renga (francesco.renga@roma1.infn.it). The group has 3 members and has worked on various detectors for inner tracking with wires, GEMs and recently with GridPixes. The current main interest is on exotic geometries like radial TPCs. Another area of interest are extremely light and ecofriendly gas mixtures for low energetic muons and pions.

INSTITUTE 14: *Iwate University (IU) - Iwate, Japan*

The contact person at Iwate is Shinya Narita (narita@iwate-u.ac.jp). The group has 2 staff members and a few Master students. The group has been involved in the LCTPC collaboration and dedicated to R&D of GEM-based TPC detector, especially optimizing GEM module design and developing a gating device for blocking IBF.

INSTITUTE 15: *European Organisation for Nuclear Research (CERN) - Geneva, Switzerland*

The contact person at CERN is Eraldo Oliveri (Eraldo.Oliveri@cern.ch). The CERN group includes the EP-DT Gaseous Detector Development (GDD) team, the Gas Systems (GS) group and the Micro Pattern Technology (MPT) workshop. It has a long tradition and outstanding experience (including a nobel price) in building gaseous detectors of all kinds. In this task a new variation of highly pixelated readout should be developed.

INSTITUTE 16: *Paul Scherrer Institut (PSI) - Villigen, Switzerland*

The contact person at PSI is Malte Hildebrandt (malte.hildebrandt@psi.ch). The group has three permanent members with ample experience in building various gas detectors with wire readout.

APPENDIX: PARTICIPATING INSTITUTES AND THEIR RESOURCES

Project name: (Large-Volume) Tracking TPCs	
Tasks	T1: IBF reduction T2: pixelTPC development T3: Optimization of the amplification stage and its mechanical structure, and development of low X/X_0 field cages T4: FEE for TPCs T5: Gas mixture
Deliverables	**2026:** **D1.** Demonstrator MPGD-TPC **D2.** Report on Ion backflow studies **D3.** Report on the tracking performance **D4.** Construction of new highly pixelized readout structures **D5.** Develop new high-density electronics for TPCs **≥ 2027** envisioned are larger scale prototypes with which the scalability of the ideas defined in the previous period can be tested. In particular larger area pixelized and optical readouts.
Milestones	**2024:** M5

	2025: M2, M3, M4 **2026:** M1
Description of Technology	Tracking TPCs with various readout structures, very low IBF and reduced material budget of the supporting structures like field cage and end caps.
Targeted DRDT	1.1, 1.2, 1.3, 1.4
Supporting DRD1 WGs	WG1 - Development of new readout structure, in particular with high pixelization, measurement of IBF WG3 - Gas studies (task 5), finding an eco-friendly gas mixture with low diffusion coefficients, or low ωτ, developing low X_0 field cage and endcap WG4 - Simulation of drift properties of gases, effect of field distortions on drifting electrons, calculation of IBF WG5 - Development of FEE for TPCs (Task 4) WG6 - Production of highly pixelated readout structures and IBF reduction stages WG7 - Testing detectors
Connection to other DRDs	DRD5 - PID