**Template JRA**

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| **Work package number** | WP32 | **Start date** | 01/06/2019 |
| **Activity Type** | Joint Research Activity | | |
| **Work package acronym** | JRA14-MPGD\_HP | | |
| **Work package title** | Micropattern Gaseous Detectors for Hadron Physics | | |

1. Work carried out and overview of progress
   1. **Project objectives**

*[Please give an overview of the project objectives for the third reporting period (June 2022 – July 2024), with regard to the overall objectives as described in the Annex 1 of the Grant Agreement and summarized below.]*

There are currently many open fundamental questions and puzzles in physics, which require input or progress in hadron physics. One example is the transverse-momentum dependent inner structure of the proton, which, apart from being a fundamental question of QCD itself, is relevant for many analyses at proton colliders such as the LHC. Another example is the proton radius puzzle, where a very large discrepancy between its determination from elastic electron scattering and a new result from the spectroscopy of muonic hydrogen is yet unexplained. A third example is the question of the existence of exotic bound states of quarks and antiquarks. Progress towards answering these questions requires detectors with improved capabilities in tracking, identification of charged particles, photon detection and timing in the picosecond region. A coherent effort towards these goals by world experts in MPGDs is proposed in this JRA. Our contribution to the proton radius puzzle, which is also the focus of a networking activity within STRONG-2020, the PREN Work Package, will be the simulation and optimization of a TPC for measuring the proton radius via elastic scattering of high-energy muons at CERN.

* 1. **Progress made during the reporting period towards the objectives**

*[Please describe the progress made during the third reporting period in line with your Gantt chart and the project overall tasks as described in the Annex 1 of the Grant Agreement and summarized below.]*

***Table 1.2 Progress made during the reporting period for each task***

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| ***The proposed activities are organized in four tasks.***  ***Task 1: Compact micro-pattern TPC for high-rate experiments. Goal: Prepare foundations for 3D continuous tracking with minimal material budget in environments with extremely high intensities and track densities*** |
| The prototype for the high-rate TPC including a laser calibration system was built and tested successfully (Deliverable D32.3). The TPC is designed for standard-sized 10 10 cm2 amplification structures employing GEM foils. In the present configuration it uses a hexagonally segmented padplane combined with readout electronics using the AFTER-chip and a DAQ equivalent to the one used by the FOPI-TPC at GSI. With regard to high-rate capabilities of TPCs at collider experiments, a system to calibrate the electric drift field using the photoelectric effect was implemented, with the main goal of measuring static field distortions. To this end, laser light was conditioned and guided through various optical components and a bundle of optical multimode fibers in order to uniformly illuminate the detector cathode. In order to generate artificial field distortions, the field configuration inside the detector was deliberately misadjusted. The resulting deviations could be clearly observed using the known calibration pattern. Moreover, the drift time of photoelectrons was measured varying the detector pressure in order to derive a drift velocity calibration. The concept can easily be extended to future TPCs to be used at high-luminosity fixed-target or collider experiments.  One of the future applications of a high-rate TPC is a new detector (multiple time projection chamber, mTPC) that is being designed for upcoming meson structure studies in tagged deep inelastic scattering at Jefferson Lab Hall A. For this detector, GEANT4 and GARFIELD++ simulations were performed and completed to optimize the TPC design. Based on the simulations, a prototype detector was built by colleagues at University of Virginia and the device is currently being tested at JLab. |
| ***Task 2: Active target TPC. Goal: Develop TPC which acts as an active target and at the same time performs tracking of low-energy recoil particles from interactions in the active volume*** |
| The simulations on energy ranges and resolutions in an active-target TPC were completed (Deliverable D32.4). The layout of the TPC Pad Plane was updated to make use of all 64 available readout channels. An additional pad was added to the second-most outer ring to reduce electronic noise, which depends on the pad area. The rotations of the rings were slightly changed to account for the additional pad.  The simulations of the muon reconstruction were extended to study the geometrical acceptance as well as the efficiencies and resolutions over a wide range of the squared four-momentum transfer . The geometrical acceptance allows us to look into the effects of -bin migration due to multiple scattering and reconstruction uncertainties. We plan to fill the space between the Unified Tracking Stations with helium instead of air to reduce multiple scattering. There are several options for the material and shape of these so-called Helium Tubes. We started to test the impact of these options using the updated simulation.  The TPC trigger threshold from the Pilot Run 2021 was studied and used to update the expected number of events for this measurement. This has also started a separate analysis and tuning of the TPC trigger parameters for the final setup. |
| ***Task 3: Photon detectors for PID. Goal: Develop a modular hybrid MPGD (Micromegas + THGEM or GEMs) with high-granularity readout elements for the detection of single photons in harsh environment*** |
| The Modular Minipad Photon Detector Demonstrator was built and fully characterized (Deliverable D32.1). The detector consists of a THGEM coated with CsI photoconverter material, a Micromegas and readout pads. To equip the modular hybrid MPGD with readout electronics suitable for triggerless streaming data taking a second prototype has been built and tested in the laboratory using both APV25-based frontend and VMM3-based frontend. The comparison of performance demonstrated the full compatibility of VMM3-based readout with hybrid MPGD photon detectors.  Alternative photocathode materials were investigated. For the first time, the possibility to use hydrogenated nanodiamond-based (H-ND) photocathodes in gaseous detectors was validated. A prototype detector was built and tested with different gas mixtures up to gains of . The systematics of the response of H-ND in different gas mixtures was tested. Aging studies revealed that H-ND is ten times more robust than CsI. The results on the H-ND were published (Deliverable 32.5). A new campaign of H-ND photocathode tests has been performed, with the production of semi-transparent photocathodes deposited on MgF2 substrates, with different H-ND thickness, to optimize their performance in the context of fast-timing gaseous photon detector development. |
| ***Task 4: Very fast timing/tracking by Micromegas-based Cherenkov photons detectors. Goal: establish a new tracking technology based on sub-100 ps timing resolution and high rate capability*** |
| A large prototype of the Picosec detector was built. The detector employs the detection of Cherenkov light produced in a radiator equipped with a transparent photocathode (CsI) to achieve a time resolution of the order of a few 10 ps for charged particles. To realize this resolution over a larger area requires extremely uniform gaps and a flatness of electrode structures better than . For the first prototype, a ceramic board was employed, which, however, is not suitable for applications in hadron physics experiments because of the large material budget. The Picosec FR4 prototype makes use of a printed circuit board made of FR4 material instead. The detectors are built from PCB boards of two thicknesses, 0.8 and 1.6mm, stiffened with a 1-cm thick Rohacell layer. Their active areas are covered with a diamond-like carbon (DLC) layer manufactured at CERN, while the bulk Micromegas structure was added at Saclay. With the stiffener a very good planarity with a sigma of the Z values at the level of 6.6µm on the 1.6mm thick PCB prototype, and at the level of 7.9µm on the 0.8mm PCB, was achieved. A preliminary value for the time resolution for the DLC layer was measured on a few channels at the level of 44ps. Even though this value is a bit worse than the prototypes with ceramic board and CsI photoconverter, the feasibility of such detector was demonstrated (Deliverable 32.2). Several areas for improvement have been identified, such that an even better time resolution can be expected in the future. |

**1.3 Highlights of significant results**

*[Include an overview of the project results towards the objectives in line with the structure of the Annex 1 to the Grant Agreement*.*]*

All deliverables were achieved. Parts of the results obtained in this JRA were published in refereed journals.

1. Critical Implementation risks and mitigation actions

**2.1 Risk materialization**

*[Provide the information on the project risks described in Annex 1 to the Grant Agreement*.*]*

1. Failure in correctly measuring the diamond photoconverter (low)

Whether the risk has materialized? (Yes/No)

No

**2.2 Risk-mitigation measures applied**

*[Please indicate whether the risk-mitigation plan described in Annex 1 to the Grant Agreement and corresponding to the risk number was applied in the reporting period*.*]*

1. Campaign of measurements in different conditions on various substrates and samples performed by world experts.

Whether the risk-mitigation plan was applied? (Yes/No)

No

**2.3 Comments/new risk-mitigation measures proposed**

*[Provide any significant comments on the risks encountered and the mitigation plan applied. Give any unforeseen risks encountered during the reporting period and not mentioned above*.*]*

3. Deviations from Annex 1 (Description of Action) and Annex 2 (Estimated budget for Action) (if applicable)

**3.1 Deviations from planned objectives and tasks, and their impact on the progress of the work package**

*[Explain the reasons for deviations, the consequences and the proposed corrective actions.]*

The Deliverable 32.3 (Fast Cherenkov Micromegas Detector) was finished 6 months later than the originally foreseen date (delivered in month 48 instead of 42). The reason for the delay was a combination of many factors, in particular lack of manpower who were also busy with other projects, delay induced by the pandemic, and several problems on the design which took time to be solved. The extension of the STRONG-2020 project allowed us to meet this deliverable within the project duration.

**3.2 Deviations between actual and planned person months**

*[Explain deviations between actual and planned person-months. If applicable, propose corrective actions.]*

1. Deliverables and milestones tables

**4.1 Deliverables**

*[Please list all the deliverables due in this reporting period, as indicated in Annex I.*

*Deliverables must also be accompanied by a short report (deliverable description and technical documentation, such as photo, list of publications, etc.), so that the European Commission has a record of their existence.]*

***Table 4.1 List of deliverables***

| **Deliverable No.** | **Deliverable name** | **Lead Beneficiary** | **Nature** | **Dissemination level[[1]](#footnote-1)** | **Delivery month from Annex I** | **Delivered**  **(yes/no)** | **Actual delivery month** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| D32.2 | Fast Cherenkov  Micromegas Detector | 24 - CEA | Demonstrator | PU | 42 | yes | 54 | Uploaded report |
| D32.3 | A small-scale prototype of the high-rate TPC | 13 - TUM | Demonstrator | PU | 48 | yes | 48 | Uploaded report |
| D32.4 | Simulation results on energy ranges and resolutions in active target TPC | 10 - UBO | Report | PU | 48 | yes | 48 | Uploaded report |
| D32.5 | Publication of the  diamond-based  photoconverter  performance in gaseous PDs | 30 - INFN | Report | PU | 48 | yes | 48 | Paper published |

*In case a deliverable has been delivered in the reporting period and a report exists in the Participant Portal, you can indicate “uploaded report” in correspondence of a deliverable*

**4.2 Milestones**

*[Please complete the table if milestones are specified in Annex I.*

*Milestones will be assessed against specific criteria and performance indicators as defined in Annex I.]*

***Table 4.2 List of milestones***

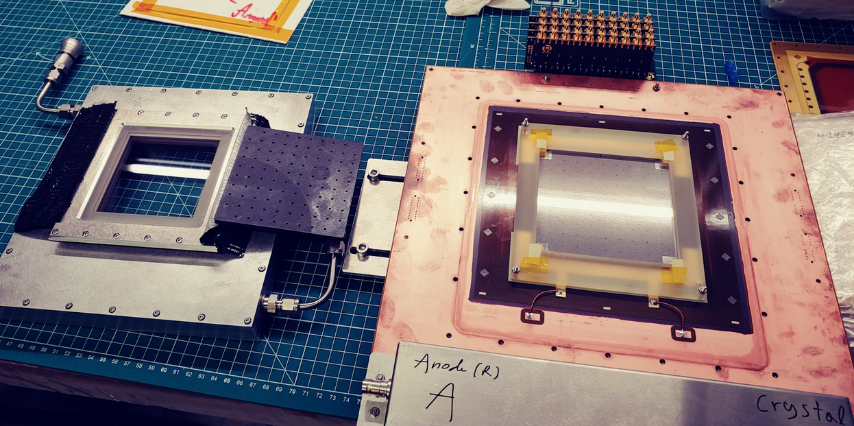
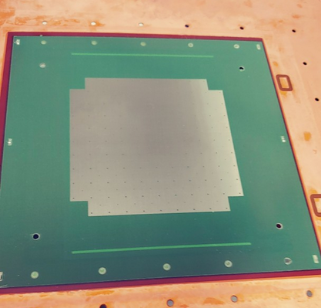
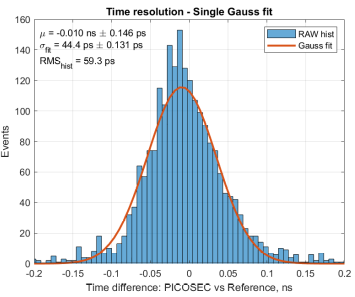
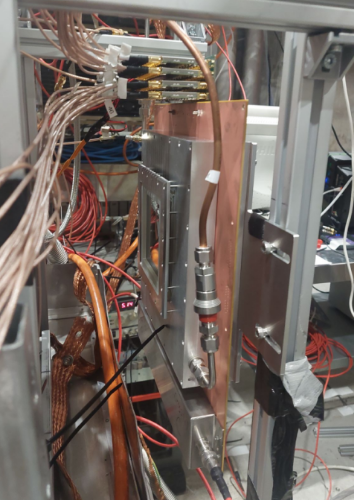
| **Milestone number** | **Milestone name** | **Lead beneficiary** | **Delivery month from Annex I** | **Delivered**  **(yes/no)** | **Actual delivery month** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- |
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**No Milestones in the RP3 (months 37-62)**

**4.3 Deliverable Reports**

*[Please provide, per each deliverable listed in Table 4.1, a brief description, including if possible some technical documentation (photos, list of publications, etc.). Use as many pages as needed per each report.]*

**4.3.1 Deliverable D32.2**

The 10x10cm² picosec prototypes were finally built and tested ! The last elements were received in June and my colleagues went to CERN for quick beam tests end of June. They plan to do new ones end of September for a longer period, and hopefully less operational troubles.  
  
Concerning the prototypes, they are built from PCB boards of two thickness, 0.8 and 1.6mm, stiffened with a 1-cm thick Rohacell layer. Their active area are covered with a DLC layer done at CERN, and then bulked at Saclay. Two mechanics are available for the moment, allowing to mount two detectors. Here is the picture of one of them:  
  
  
  
and a view of the bulked active area:  
  
  
A lot of efforts were done to get a good planarity of the PCB in order to optimize the homogeneity of the time response. With the stiffener my colleagues got a sigma of the Z values at the level of 6.6µm on the 1.6mm thick PCB prototype, and at the level of 7.9µm on the 0.8mm PCB, which is very good.  
  
Beam tests were done on two prototypes on muon beam at CERN end of June. Only one third of the pads were equipped with electronics, due to the lack of readout cards. They were equipped with crystals covered with a photoemissive layer. The ones covered with CsI didn't produce results as the CsI layer was destroyed within a very short period of time, most probably due to humidity coming from the resistive layer. Fortunately the prototypes with crystals with DLC worked normally, although such a layer produces less electrons. The time resolution was measured on a few channels at the level of 44ps, not as good as the previous prototypes but this is a very preliminary result with a non-optimized setup. Crystals with B4C were not available yet during the tests, they were just received at the beginning of this week, and they will be tested at the next beam tests. Here a picture of one of the prototype during the beam test, and a plot of the time resolution.  
  
  
  
The next beam tests foreseen end of September are planed to last during a longer period, and will include B4C-covered crystals, and hopefully more electronics to connect all the 96 pads. My colleagues expect to get better results with more optimized setup and HV tuning in particular.

**4.3.2 Deliverable D32.3**

See attached PDF.

**4.3.3 Deliverable D32.4**

See attached PDF.

**4.3.4 Deliverable D32.5**

See publication in <https://www.sciencedirect.com/science/article/pii/S0168900223005661>

1. PU = Public

   PP = Restricted to other programme participants (including the Commission Services).

   RE = Restricted to a group specified by the consortium (including the Commission Services).

   CO = Confidential, only for members of the consortium (including the Commission Services). [↑](#footnote-ref-1)