**Template JRA**

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| **Work package number** | WP31 | **Start date** | 01/06/2019 |
| **Activity Type** | Joint Research Activity | | |
| **Work package acronym** | JRA13-P3E | | |
| **Work package title** | Polarized Electrons, Positrons and Polarimetry | | |

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.]*

The P3E Joint Research Program aims at pushing further the intensity frontier of polarized electron/positron sources and the precision frontier of electron polarimetry on the basis of novel methods and innovative technologies developed by the P3E partners.

The interest in polarized and unpolarized intense positron beams for the experimental investigation of the physical world ranges from the macroscopic molecular scale accessible at eV energies down to the most elementary scale of fundamental symmetries probed with hundreds of GeV lepton beams. The production of high-quality polarized positron beams relevant to these many applications is one concern of the P3E project which will benefit facilities including but not limited to MAMI, MESA, CEBAF, and EIC. It relies on the demonstrated PEPPo method that is the efficient polarization transfer from a polarized electron beam to the positrons generated by the Bremsstrahlung radiation of the electron beam in a high Z target.

Precision experiments with polarized electrons and positrons require the best possible measurement of the polarization. The current state of the art is an uncertainty of 0.6% for 1.165 GeV electrons achieved using the combination of a conventional Møller polarimeter and a Compton polarimeter for the Q-weak parity violation experiment at TJNAF. Future parity violation experiments such as P2 at MESA aim for a knowledge of the polarization with an uncertainty on the 0.1% level at much lower beam energies. This requires a new approach in the form of a Hydro-Møller Polarimeter.

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

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

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| --- |
| ***Task 1: High intensity polarized electron source*** |
| The modelling of the quantum efficiency of photocathodes cross-checked by proof-of-concept experiments was successfully completed. It is now serving the development of the high intensity, high polarization and long life-time polarized electron source of the Ce+BAF project at Jefferson Lab (JLab). This source constitutes the first element of the positron injector which was studied as part of the objectives of the JRA13-P3E. |
| ***Task 2: High intensity polarized positron source*** |
| The design of a novel positron injector to permit the achievement of a unique experimental program at CEBAF was completed, together with the publication of the White Paper of the Positron Physics Scientific Program of JLab. The three scientific pillars of this program (Two-photon Exchange physics, Generalized Parton Distributions, Tests of the Standard Model) were further validated by the JLab Program Advisory Committee (PAC) in the form of the approval and high rating of experimental proposals.  Following the conceptual evaluation of a high-power target for the production of positrons, experimental tests have been performed at MAMI to study the sensitivity of different materials (W, Ta, Ti alloys) to the effects of high radiation levels produced by an electron beam. These measurements are intending to serve the selection of the most appropriate material for the production of positrons. |
| ***Task 3: High precision electron polarimetry: this task consists in the design of the detector system for Hydro-Møller Polarimeter using high-voltage monolithic active pixel sensors (HV-MAPS)*** |
| In this task we developed a Geant4-based simulation package for the Møller polarimeter and the associated magnet and detection systems. The simulation implements both the Hydro-Møller option and the option to use a more conventional iron foil target for Møller scattering. The simulation models for both the signal process and backgrounds from (radiative) Mott scattering were extensively verified and different generators cross checked against each other. The simulation was then used to develop a system of magnets and collimators that lead to high signal-to-background ratios at the detectors. That magnet and collimator system was optimized in an iterative process in order to match the tight space constraints in the MESA/P2 beamline and allow for the use of easy to build magnets without negatively affecting the performance. In parallel we have developed a series of HV-MAPS silicon pixel sensors which are one potential detector technology. The P2Pix sensors with wide applications in parity violation experiments is currently under production. |

**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*.*]*

***Charge lifetime of GaAs photocathodes***: The charge lifetimes of a high polarization photocathode were measured over two years, demonstrating an improvement >50% when the photo-gun anode is biased. A new simulation code to model the measurements was created and compared successfully. The results were submitted to Phys. Rev. Accel. And Beams and are in review.

***Positron physics program at JLab***: The publication of the JLab Positron White Paper as a 2022 topical issue of the European Physics Journal A was a major achievement of a group of physicists including JRA13-P3E partners which goes much beyond the boundaries of the STRONG 2020 program. However, this result was a major step in the scientific motivation of the Ce+BAF positron injector which was further assessed and confirmed by the approval of positron beam experiments by the JLab PAC (PAC51).

***Ce+BAF positron injector performance***: The full design and evaluation of the new positron injector for CEBAF has also been a significant step not-only with respect to the objectives of the JRA13-P3E but also for the whole Ce+BAF project, particularly showing that an optimized design is capable to achieve high enough performances to efficiently complete the proposed JLab positron experimental program.

***Conceptual evaluation of a positron production target***: The completion of a finite element modelling of a positron production target has been an essential step into the practical evaluation of a conceptual target, the identification of the different technical/mechanical/thermal issues, and the validation of possible solutions. It was shown that a disk rotating with a moderate speed of 4 turn/s and cooled by water is able to dissipate the 17 kW thermal power deposited by the electron beam in the target. The expected life-time of such a system corresponds to about one year of Ce+BAF operation.

***Positron target irradiation damages***: The mechanical and thermal properties of the positron production material are particularly important to optimize the life-time of a target. An electron beam traversing the target produce a high level of radiation and may also activate the target material which result in a progressive destruction of the target. The first experiments to identify the damages to materials resulting from exposure to an electron beam were performed at MAMI and further characterized at PETRA-III. An unexpected signal of the unsensitivity of Tantalum under the Ce+BAF operating conditions was obtained, opening new prospects for positron target materials.

***High precision electron polarimetry***: A detailed simulation framework for Møller polarimeters using large solenoidal magnetic fields was created; the physics models used for Møller and Mott scattering were thoroughly validated; a working geometry for collimators and magnets to be used in the polarimeter was developed, delivering excellent signal to noise ratios; HV-MAPS sensors suitable for the detection system were developed and are being produced; the polarimeter design was summarized in a technical design report.

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. Unavailability of UITF beam for experimental studies (low)

Whether the risk has materialized? No

1. Unavailability of MAMI beam for target tests (low)

Whether the risk has materialized? No

1. Unavailability of MAMI beam for polarimeter detector tests (low)

Whether the risk has materialized? 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. Move experiments at the CEBAF injector

Whether the risk-mitigation plan was applied? No

1. Move beam tests to different site (DESY, Frascati)

Whether the risk-mitigation plan was applied? No

1. Move beam tests to different site (DESY, Frascati, Orsay, PSI etc.)

Whether the risk-mitigation plan was applied? No

There were HV-MAPS test beams at DESY and PSI, complementary to the ones at MAMI. These beam times were however scheduled regularly and not as a response to MAMI not being available*.*

**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*.*]*

None

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.]*

None

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

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

A deviation between the planned (9.6 p.m) and actual (7 p.m) work-force at the University of Hamburg was observed. This deviation can be explained by the increase of personnel costs following the increase of salaries in Germany. The allocated funds for the University of Hamburg allowed to support only 7 p.m instead of the initially planned number. Prof. Gudrid Moortgat-Pick and her team compensated this reduction with an increased involvement such that the goals and contributions of the University of Hamburg have been completely fulfilled.

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** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| D31.1 | Feasibility Report  for an Intense Polarized  Electron Source | 1 - CNRS | Report | PU | 54 | yes | 36 | PhD Thesis of  J. Yoskowitz  (Old Dominion  University, Norfolk VA,USA) |
| D31.2 | Feasibility Report  for an Intense Polarized  Positron Source | 1 - CNRS | Report | PU | 54 | yes | 54 | Doctorat of  S. Habet (Université Paris-Saclay, Orsay, France) |
| D31.3 | Technical Design Report for the polarimeter detector | 9 - JGU MAINZ | Report | PU | 54 | yes | 54 | Uploaded report |

*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** |
| --- | --- | --- | --- | --- | --- | --- |
| MS76 | Charge lifetime experiments | 1 - CNRS | 39 | yes | 36 | As a result of this work the CEBAF photo-gun is only operated with a biased anode. The new ion-tracking software IONATOR was created and is used in other projects. |
| MS77 | Simulation package of the  positron source | 1 - CNRS | 45 | yes | 45 | The positron injector model was elaborated, implemented within the ELEGANT beam optics platform, and coupled to GEANT4 simulations of the production of positrons. The full package was used to optimize the parameters of the different components of the injector and determine final performances. |
| MS78 | Simulation package of the  target stress | 1 - CNRS | 42 | yes | 38 | This implies an appropriate modelling of the positron production target and its operational implementation within the ANSYS finite elements simulation package to allow us to perform systematic studies, performance evaluation, and optimization. |

**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.]*

***D31.1***: Charge lifetime of a highly spin polarized GaAs/GaAsP superlattice photocathode operating in a high voltage dc-photo-gun at the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab was improved by repelling ionized gas from entering the photo-gun accelerating gap. GaAs photocathodes in DC high-voltage photo-guns are highly susceptible to ion back-bombardment (Fig. 1, left), which reduces the photocathode quantum efficiency and limits the useful operating lifetime for producing polarized electron beams. This work demonstrated that applying a small positive bias voltage +1kV to the photo-gun anode can significantly suppress ion back-bombardment and increase charge lifetime. In contrast to a grounded anode (0 V) where positively ionized gas would be accelerated to the photocathode the positively biased anode creates a positive potential of 100’s of Volts in the volume downstream of the anode repelling ionized gas from entering the cathode/anode gap (Fig. 1, right). This technique was studied extensively using the CEBAF photo-gun while operating at -130kV, where highly polarized electron beams created using a strained-superlattice GaAs/GaAsP photocathode were used and charge lifetimes improved by almost a factor of 2. A new simulation code IONATOR was developed to model ion production and tracking in order to better understand and explain the factors that led to performance improvement.

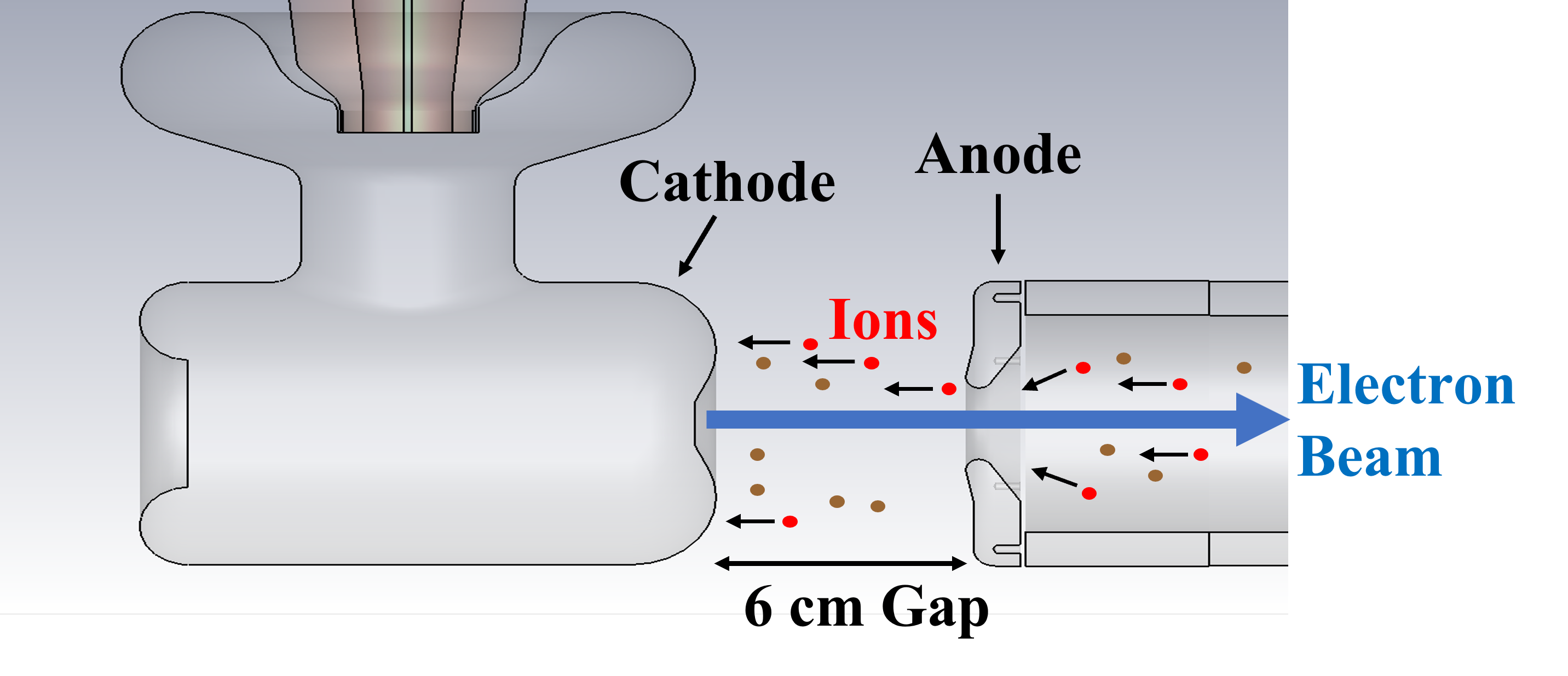
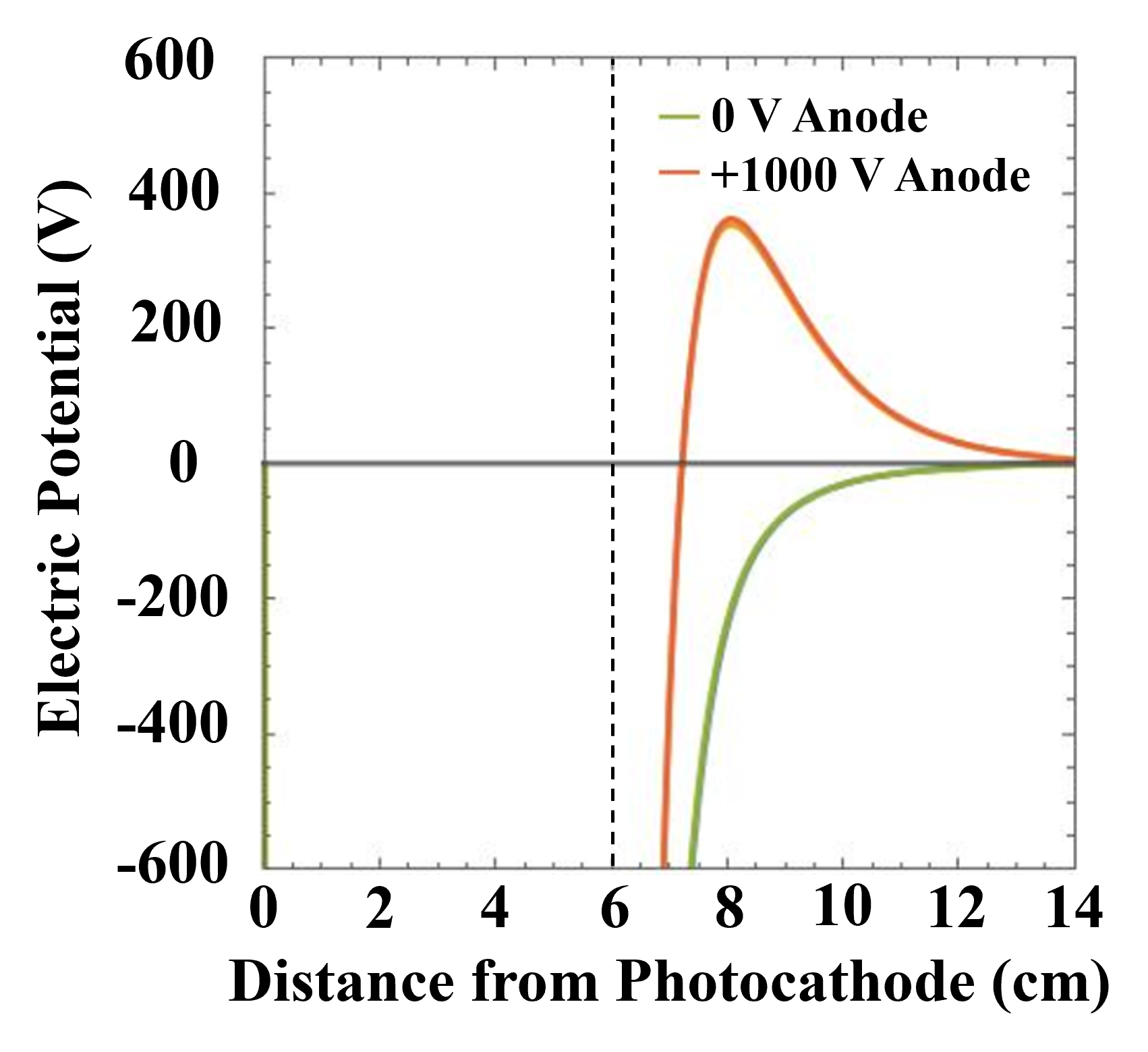
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Figure 1: Conceptual schematic of ion-bombardment in a dc high-voltage photocathode with grounded anode (left) and a plot of the electric potential downstream of the anode when the anode is grounded or positively biased for ion repulsion (right).

The document describes the many steps of this research which experimental and simulation results were submitted for publication in June 2024 and are currently undergoing final revisions.

***D31.2***: This document reports about the design, simulation, and optimization of a new positron injector delivering unpolarized and polarized positron beams to be accelerated by CEBAF. It addresses extensively the optimization of each successive step which constitutes the full system: the production target, the magnetic collection of positrons, their radio-frequency collection, their momentum selection with an appropriate magnetic chicane, and their matching to the CEBAF acceptance through an accelerating section and a bunch length reduction chicane. The association of these elementary components (Fig. 1) constitutes the full positron injector which optimization showed that an initial Continuous Wave (CW) electron beam of 120 MeV with 1 mA intensity and 90% polarization would provide a CW positron beam with 700 nA intensity and 60% polarization, or an unpolarized positron beam with 3 µA intensity depending on the momentum of collected positrons. Such beams will permit to perform a unique experimental program at CEBAF where the comparison of the response of a nuclear system to the excitation of lepton beams of opposite charges reveals unique features of the nuclear structure and possible deviations from the predictions of the standard model.

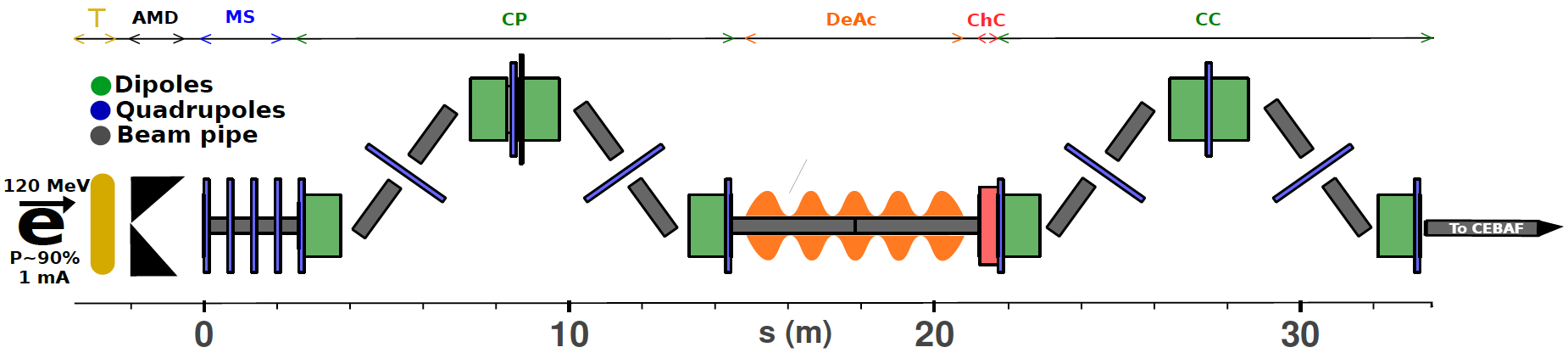


Figure 1: Conceptual layout of the CEBAF positron injector.

This work was presented and discussed at several conferences and led to several publications:

- Concept of a polarized positron source for CEBAF, S. Habet et al. JACoW IPAC2022 (2022) MOPOTK012

- Positron beams at Ce+BAF, J. Grames et al. JACoW IPAC2023 (2023) MOPL152

- Characterization of polarized and unpolarized positron production, S. Habet, A. Ushakov, E. Voutier, JLab-ACC-23-3794; arXiv:2401.04484.

***D31.3***: The technical design report for the Møller polarimeter detector is available in the participant portal. In it, we discuss the simulation models for Møller scattering and the important background of radiative Mott scattering in detail. Extensive simulation studies have led to the compact geometry and magnetic field set-up described in the report (Fig. 2). An optimized collimator geometry leads to large signal to background ratios on the detectors despite the much larger cross-section for Mott scattering (Fig. 3). By using a coincidence between the two Møller electrons, an almost background-free measurement can be achieved. The design thus fulfills the requirements of the P2 experiment at MESA and will be implemented in the coming years, first using an iron target and eventually using atomic hydrogen in a trap.

Preliminary versions of the design were presented at the spring meetings of the German physical society 2023 and 2024.

The report is being prepared for publication.

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*Figure 2: Schematic overview of the Møller polarimeter setup at MESA. The collimator geometry was optimized to produce the best possible signal-to-background ratios in the detector plane.*

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*Figure 3: Distribution of electrons in the detector plane for the Mott background (left) and the signal process (right) using the atomic hydrogen target. The proposed active area is shown with a red dashed rectangle.*

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)