

PAPER • OPEN ACCESS

## Development of a detector for inertial sensing of positronium at AEgIS (CERN)

To cite this article: L. T. Glöggler *et al* 2022 *J. Phys.: Conf. Ser.* **2374** 012037

View the [article online](#) for updates and enhancements.

You may also like

- [Energy and comfort management of the educational spaces through IoT network for IAQ assessment in the eLUX lab](#)  
L C Tagliabue, F Re Cecconi, S Rinaldi et al.
- [Analysis of the temperatures measured in very thick and insulating roofs in the vicinity of a chimney](#)  
M Neri, D Luscietti, S Bani et al.
- [A Comparison of Photometric Redshift Techniques for Large Radio Surveys](#)  
Ray P. Norris, M. Salvato, G. Longo et al.

### ECS Toyota Young Investigator Fellowship



For young professionals and scholars pursuing research in batteries, fuel cells and hydrogen, and future sustainable technologies.

At least one \$50,000 fellowship is available annually.  
More than \$1.4 million awarded since 2015!



Application deadline: January 31, 2023

**Learn more. Apply today!**

# Development of a detector for inertial sensing of positronium at AEGIS (CERN)

L. T. Glöggler <sup>(1)(2)</sup>, R. Caravita <sup>(3)</sup>, B. Bergmann <sup>(4)</sup>, G. Bonomi <sup>(5)(6)</sup>,  
R. S. Brusa <sup>(3)(7)</sup>, P. Burian <sup>(4)</sup>, A. Camper <sup>(8)</sup>, F. Castelli <sup>(9)</sup>, P. Cheinet <sup>(10)</sup>,  
D. Comparat <sup>(10)</sup>, G. Consolati <sup>(11)(12)</sup>, M. Doser <sup>(1)</sup>, H. Gjersdal <sup>(8)</sup>,  
L. Graczykowski <sup>(13)</sup>, F. Guatieri <sup>(7)</sup>, S. Haider <sup>(1)</sup>, S. Huck <sup>(1)(14)</sup>, M. Janik <sup>(13)</sup>,  
G. Kasprowicz <sup>(12)</sup>, G. Khatri <sup>(1)(7)</sup>, G. Kornakov <sup>(12)</sup>, C. Malbrunot <sup>(1)</sup>,  
S. Mariazzi <sup>(3)(7)</sup>, G. Nebbia <sup>(15)</sup>, L. Nowak <sup>(1)</sup>, D. Nowicka <sup>(13)</sup>, E. Oswald <sup>(1)</sup>,  
D. Pagano <sup>(5)(6)</sup>, L. Penasa <sup>(3)(7)</sup>, S. Pospisil <sup>(4)</sup>, L. Povolo <sup>(3)(7)</sup>, F. Prezl <sup>(12)</sup>,  
B. Rienäcker <sup>(1)</sup>, O. M. Röhne <sup>(8)</sup>, H. Sandaker <sup>(8)</sup>, I. Stekl <sup>(4)</sup>, D. Tefelski <sup>(13)</sup>,  
I. C. Tietje <sup>(1)</sup>, M. Volponi <sup>(1)(7)</sup>, T. Wolz <sup>(1)</sup>, C. Zimmer <sup>(1)(8)(11)(16)</sup>  
and N. Zurlo <sup>(5)(17)</sup>

## (The AEGIS collaboration)

- (1) Physics Department, CERN, 1211 Geneva 23, Switzerland
- (2) Department of Physics, Technical University Berlin, Hardenbergstr. 36, 10623 Berlin, Germany
- (3) TIFPA/INFN Trento, via Sommarive 14, 38123 Povo, Trento, Italy
- (4) Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, Prague, Czech Republic
- (5) Department of Mechanical and Industrial Engineering, University of Brescia, via Branze 38, 25123 Brescia, Italy
- (6) INFN Pavia, via Bassi 6, 27100 Pavia, Italy
- (7) Department of Physics, University of Trento, via Sommarive 14, 38123 Povo, Trento, Italy
- (8) Department of Physics, University of Oslo, Sem Sælands vei 24, 0371 Oslo, Norway
- (9) Department of Physics, University of Milano, via Celoria 16, 20133 Milano, Italy
- (10) Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, 91405, Orsay, France
- (11) Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy
- (12) INFN Milano, via Celoria 16, 20133, Milano, Italy
- (13) Warsaw University of Technology, Pl. Politechniki 1, 00-661 Warsaw, Poland
- (14) Department of Physics, University of Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany
- (15) INFN Padova, via Marzolo 8, 35131 Padova, Italy
- (16) Department of Physics, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany
- (17) Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, via Branze 43, 25123 Brescia, Italy

[lisa.gloggler@cern.ch](mailto:lisa.gloggler@cern.ch), [ruggero.caravita@cern.ch](mailto:ruggero.caravita@cern.ch)

**Abstract.** The primary goal of the AEGIS collaboration at CERN is to measure the gravitational acceleration on neutral antimatter. Positronium (Ps), the bound state of an electron and a positron, is a suitable candidate for a force-sensitive inertial measurement by means of deflectometry/interferometry. In order to conduct such an experiment, the impact position and time of arrival of Ps atoms at the detector must be detected simultaneously. The detection of a low-velocity Ps beam with a spatial resolution of  $(88 \pm 5) \mu\text{m}$  was previously demonstrated [1]. Based on the methodology employed in [1] and [2], a hybrid imaging/timing detector with increased spatial resolution of about  $10 \mu\text{m}$  was developed. The performance of a prototype was tested with a positron beam. The concept of the detector and first results are presented.



## 1. Introduction

Positronium is a hydrogen-like matter-antimatter bound state of an electron and a positron. In the ground state, it exists in two different spin configurations:

- Singlet  $1^1S$  (para-Ps) with a lifetime of 0.125 ns
- Triplet  $1^3S$  (ortho-Ps) with a lifetime of 142 ns

The long-lived  $2^3S$  state of Ps has a lifetime of 1.14  $\mu\text{s}$  and excitation of Ps to Rydberg states (Ps\*) increases its lifetime up to several tens of microseconds. With their increased lifetimes, Rydberg positronium and  $2^3S$  Ps are of interest for inertial measurements, where the effects of an external force exerted on the matter/antimatter atoms are studied. Rydberg Ps and  $2^3S$  Ps both have previously been produced at AEGIS (CERN) [3][4][5].

Inertial measurements can be performed with inertial sensitive devices such as a classical moiré deflectometer or a Mach–Zehnder interferometer. These devices can be composed of two gratings and a detector. Particles not being stopped or deflected from either of the gratings generate a periodic pattern on the detector plane. An external force, like a magnetic force or gravity, acting on the particles will shift the position of this pattern. Information about this force can be extracted from the magnitude of the shift [6].

## 2. Time- and position-sensitive detector for neutral low-energy matter/antimatter atoms

To measure the displacement of the atoms induced by an external force, an atom detector with a spatial resolution in the order of 10  $\mu\text{m}$  and a temporal resolution better than 100 ns would be of great benefit. We report on a prototype fulfilling these requirements, combined with a high detection efficiency. It consists of three main elements: an ionization stage, a drift region for the ionized particles and a detection module. The spatial resolution and efficiency of the detection module were tested with a low-energy positron beam.

### 2.1. Detection principle

The detection principle is illustrated in Fig. 1. It is based on the methodologies described in [1] and [2]. The incoming Ps atoms are ionized by means of a combination of field- and photoionization. The positrons freed in this process are transported towards a spatial- and time-sensitive detection module. In the drift region, a uniform magnetic field perpendicular to the surface of the detection module traps the positrons on their cyclotron orbit. Therefore, the spatial position of the Ps atoms in the plan transverse to the magnetic field is conserved in the spatial position of the positrons.

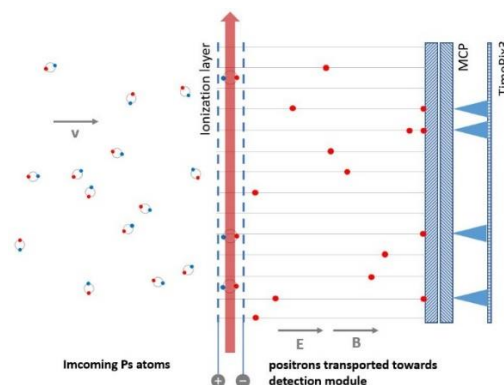


Figure 1: Schematic of experimental setup and detection principle: Incoming positronium atoms are ionized, followed by the detection of the ionization products.

The positrons are imaged by a detection module, which consists of a microchannel plate (MCP) chevron stack read out by a TimePix3 ASIC (TPX3) [7]. An image of the detection module is shown in Fig 2a. The two plates have a channel diameter of 10  $\mu\text{m}$  and a channel pitch of 12  $\mu\text{m}$ . TPX3 is a 256 x 256 matrix of pixels with a size of 55 x 55  $\mu\text{m}^2$ .

Positrons impinging with a few hundred eV on the MCP release secondary electrons which get amplified in the channels. In the gap between MCP and chip the resulting electron clouds expand and cover multiple pixels at the level of the chip. The charge amplification and the acceleration of the electron cloud in the gap between the MCP and TPX3 can be controlled by the voltages applied to the MCP front face and MCP back face, as illustrated in Fig. 2b. For the tests presented here, the MCP gain voltage was varied in a range of 1150 V and 1400 V and the acceleration voltage was between 100 V and 600 V.

Sub-pixel resolution is achieved by reconstructing the impact position of the positrons on the surface of the MCP with an event centroiding algorithm.

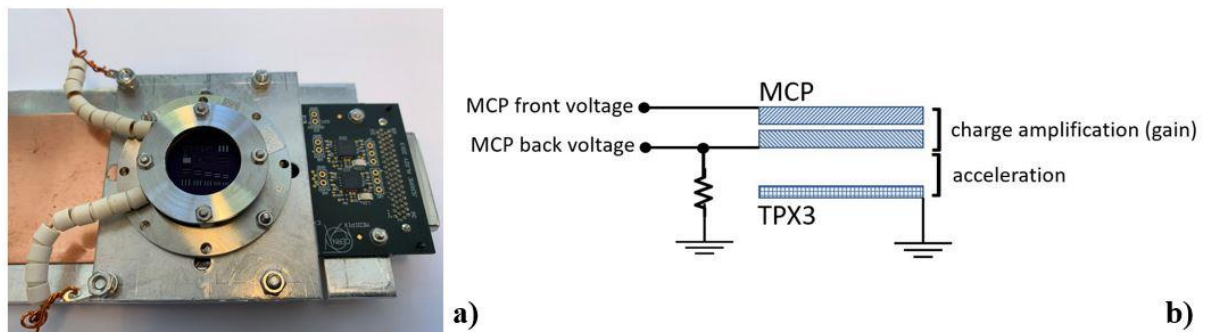


Figure 2: a) MCP chevron stack mounted on a TimePix3 chip, b) Electronic schematic of the detection module

### 2.2. Spatial resolution of the detection module

The spatial resolution of the detection module was determined with the edge spread function method. An image of a sharp edge was obtained by imaging a positron beam of 0.5 keV. The image intensity is integrated along the edge and fitted with an error function:

$$y = \frac{a}{2} \left[ \operatorname{erf} \left( \frac{x_0 - x}{\sigma\sqrt{2}} \right) + 1 \right],$$

where  $a$  is the amplitude,  $x_0$  the mean and  $\sigma$  the standard deviation of the corresponding gaussian distribution function. The resolution is extracted from the fit by multiplying the standard deviation  $\sigma$  with the pixel size.

The results show a strong tendency towards better resolutions with an increased electric field in the gap between MCP and chip, where the electron cloud emitted by the MCP is concentrated on a smaller number of pixels and the centre-of-mass of the cluster can be reconstructed more accurately. The best resolution of  $(10.5 \pm 1.1) \mu\text{m}$  in this configuration was obtained with a MCP gain voltage (MCP front voltage) of 1250 V and an acceleration voltage (MCP back voltage) of 500 V.

### 2.3. Temporal resolution of the detection module

TPX3 has a temporal resolution of 1.56 ns. The temporal resolution of the detection module however is limited by the time spread of the electron clouds arriving at the chip. The time spread depends on the cluster size which is a function of the MCP gain voltage and the acceleration voltage. Depending

on these parameters, the temporal resolution is in the order of 30 ns for low MCP gain- and acceleration voltages (small clusters) and 170 ns for high MCP gain- and acceleration voltages (large clusters).

#### 2.4. Efficiency of the detection module

The efficiency of the detection module was measured as the ratio of positrons impinging on the surface of the MCP and the number of clusters registered by the device. The number of positrons was measured with a calibrated NaI scintillator coupled to a photomultiplier tube.

The efficiency of the detection module is dependent on the MCP gain voltage and the acceleration voltage. Maximising those parameters in the given range yields a positron detection efficiency of  $(41.1 \pm 2.1) \%$ .

### 3. Conclusion

A hybrid imaging/timing detector with simultaneous high spatial and temporal resolution for low-intensity and low-energy beams of neutral matter/antimatter atoms, similar to that demonstrated in [8] yet allowing event-by-event identification, was developed. Enabling inertial measurements and counting experiments, it is a versatile device suitable for a broad range of applications in positronium research. Such detector could also find application in measurements involving other antimatter systems like antihydrogen or protonium.

### Acknowledgements

This work was sponsored by the Wolfgang Gentner Programme of the German Federal Ministry of Education and Research (grant no. 05E18CHA) and supported by the European's Union Horizon 2020 research and innovation program under the Marie Skłodowska Curie grant agreement No.754496, FELLINI.

We thank the Medipix collaboration for kindly providing us with a TimePix3 chip and readout system and for their support.

### References

- [1] C. Amsler et al., NIM in Ph. Research B 457 (2019) 44-48
- [2] J. Vallerga et al., JINST 6 (2011) C01049
- [3] S. Aghion et al. (AEgIS collaboration), Phys. Rev. A 98 (2018) 013402
- [4] C. Amsler et al. (AEgIS collaboration), Phys. Rev. A 99 (2019) 033405
- [5] M. Antonello et al. (AEgIS collaboration), Phys. Rev. A 102 (2020) 013101
- [6] S. Mariazzi et al., Eur. Phys. J. D 74 (2020) 79
- [7] T. Poikela et al., JINST 9 (2014) C05013
- [8] R. Caravita et al., Acta Phys. Pol. A 137 (2020) 96-100