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

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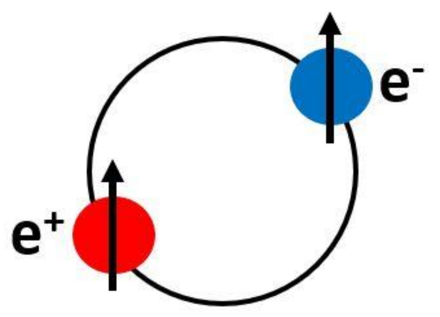
on behalf of the AEḡIS collaboration

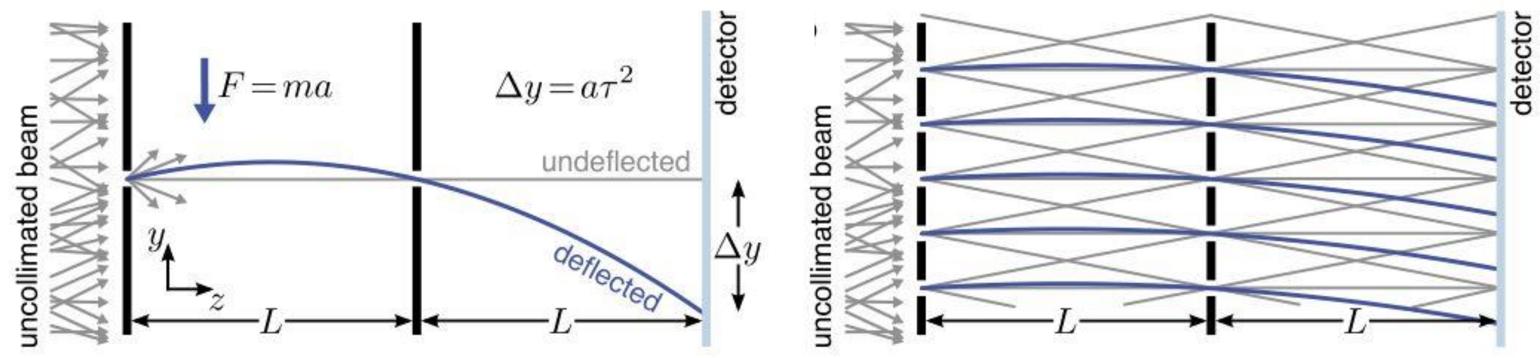
Positronium

- Positronium (Ps) is a metastable hydrogen-like matter-antimatter bound state of an electron and a positron.
- It exists in two different ground states:
  - Singlet 1^1S (para-Ps) with a lifetime of 0.125 ns
  - Triplet 1^3S (ortho-Ps) with a lifetime of 142 ns
- Excitation of Ps to Rydberg states (Ps*) increases its lifetime up to several tens of microseconds.
- Next to antihydrogen and muonium, positronium is considered a suitable candidate to measure the gravitational interaction between matter and antimatter [1].



Inertial sensing of positronium

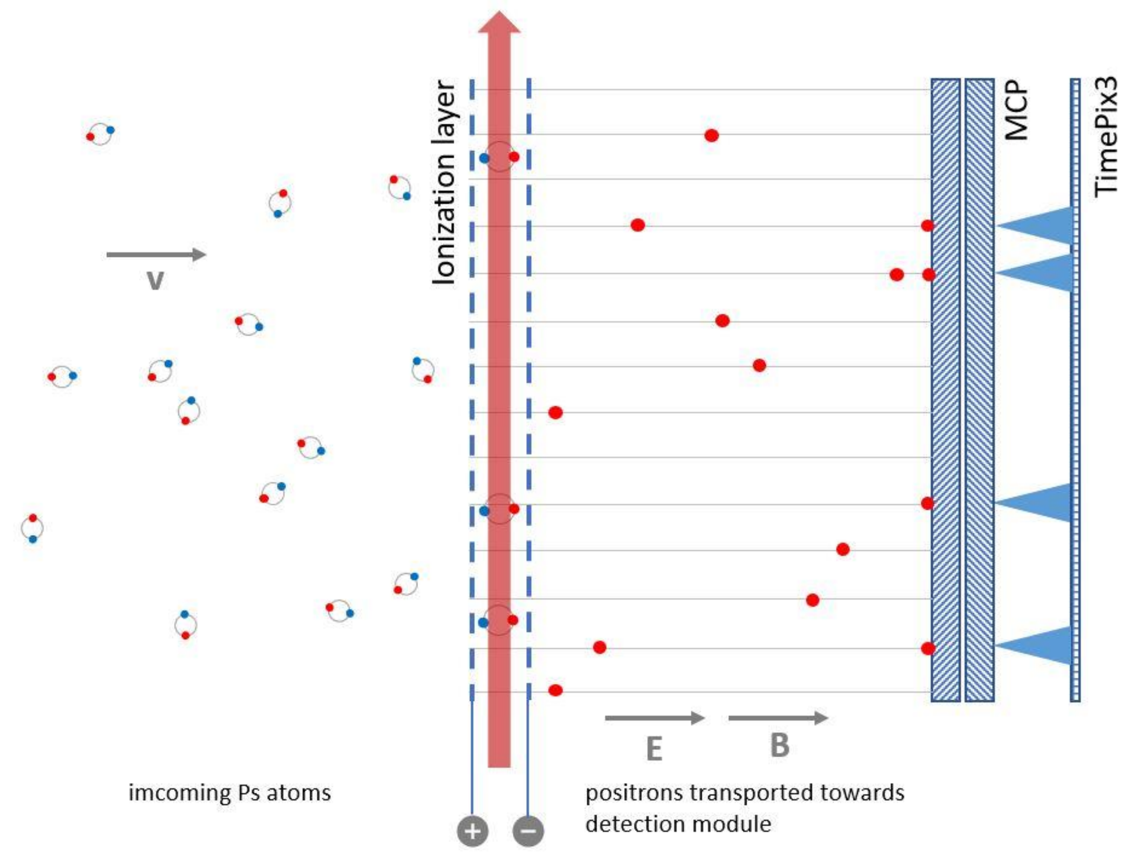
Image: [2]



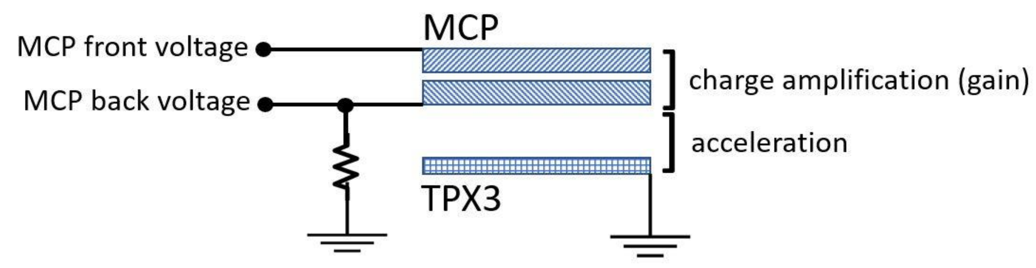
An inertial-sensing device can be composed of two gratings and a detector. Particles not being stopped or deflected from either of the gratings generate a periodic pattern on the detector plane.
An external force, like a magnetic force or gravity, acting on the particles will shift the position of this pattern. Information about this force can be extracted from the magnitude of the shift [3]. To measure the deplacement, an atomic detector with a spatial resolution in the order of 10 µm is required.

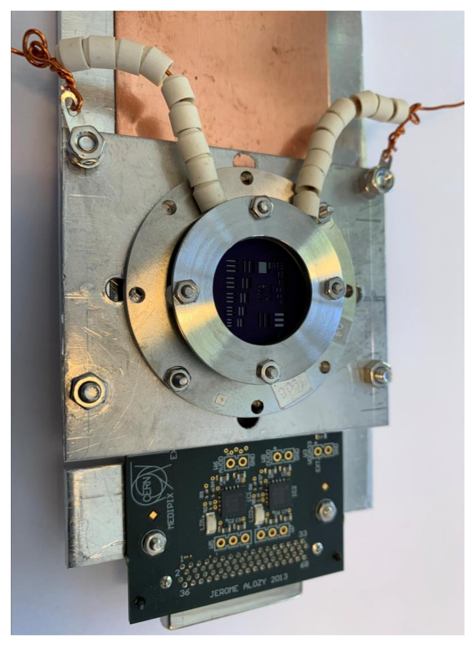
Time- and position-sensitive detector for neutral low-energy (anti-)atoms

The detection principle is based on the methodologies described in [4] and [5].



1. The incoming Ps atoms are ionized by a combination of field- and photo-ionization, followed by the detection of the ionization products released in this process.
2. The spatial position of the Ps atoms in the detector plane is conserved by the positrons being bound to magnetic field lines during transport to the detection module.
3. The positrons are imaged by the detection module, which consists of a microchannel plate (MCP) read out by a TimePix3 ASIC (TPX3). With the TPX3 chip as a readout anode, the device provides a time resolution on a ns-scale.
4. Sub-pixel resolution is achieved by means of an event centroiding algorithm, reconstructing the impact position with high accuracy.

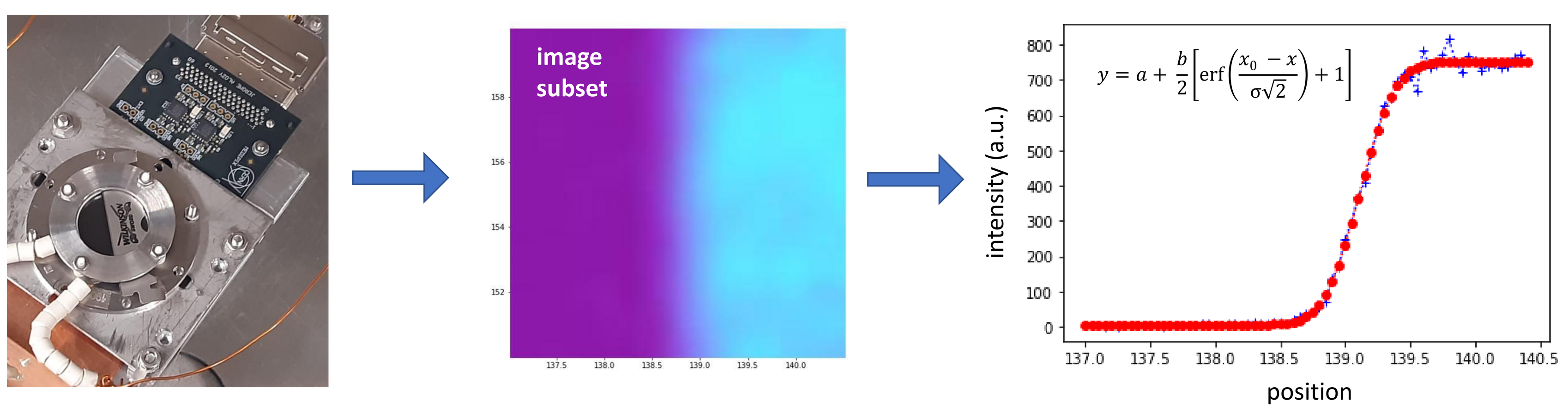




MCP chevron stack:
- 10 µm channel diameter
- 12 µm channel pitch
- 18.6 mm active area

TimePix3 ASIC:
- 130 nm CMOS technology
- Matrix of 256 x 256 pixels
- 55 x 55 µm² pixel size
- 1.562 ns timing resolution

Spatial resolution of the detection module



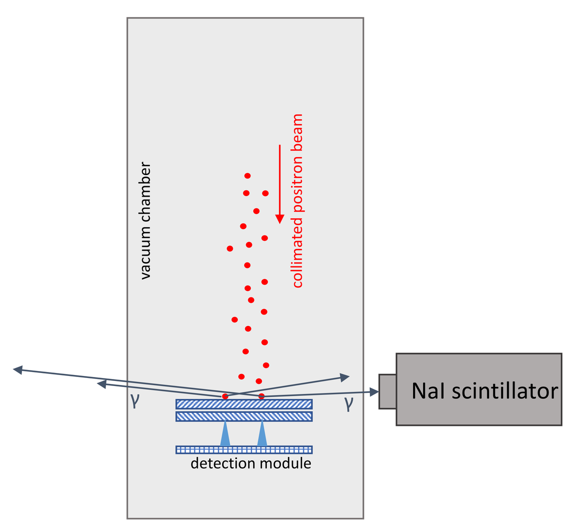
The spatial resolution of the detection module was determined with the edge spread function method. An image of a sharp edge was obtained with a positron beam of 0.5 keV. The image intensity along the edge is integrated and fitted with an error function. The resolution is extracted from the parameters of the fit.
Displayed below are the results as a function of the MCP gain factor and the acceleration voltage between the MCP back face and the TPX3 ASIC.

acceleration voltage (V) \ MCP gain voltage (V)	1150	1200	1250	1300	1350	1400
100	-	-	-	20.2 ± 1.6	20.3 ± 1.8	16.8 ± 1.5
200	-	-	13.4 ± 1.6	14.1 ± 0.7	14.6 ± 0.5	16.8 ± 0.7
300	-	15.3 ± 1.1	14.3 ± 0.7	12.8 ± 0.4	14.7 ± 0.5	14.3 ± 0.9
400	-	13.3 ± 0.9	12.0 ± 1.4	14.3 ± 0.9	12.6 ± 0.4	16.2 ± 0.6
500	-	12.4 ± 1.3	12.6 ± 0.5	11.3 ± 0.9	13.5 ± 0.9	13.9 ± 0.5
600	12.8 ± 1.6	11.8 ± 0.7	10.5 ± 1.1	11.9 ± 0.4	11.1 ± 0.3	12.5 ± 0.6

Table 1: Spatial resolution of the detection module in µm as a function of MCP gain voltage and acceleration voltage

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 results, as in table 2, show a strong dependence on the MCP gain voltage and the acceleration voltage between the MCP back face and the TPX3 ASIC.



acceleration voltage (V) \ MCP gain voltage (V)	1150	1200	1250	1300	1350	1400
100	-	-	-	< 1	3.9 ± 0.8	10.8 ± 1.1
200	-	< 1	1.9 ± 0.4	9.8 ± 1.4	23.7 ± 1.9	-
300	-	< 1	8.5 ± 1.3	20.1 ± 1.6	32.6 ± 1.6	-
400	< 1	2.4 ± 0.5	12.7 ±1.3	26.4 ±2.1	38.1 ± 1.9	-
500	< 1	4.9 ± 0.7	17.6 ± 1.8	31.5 ± 1.6	40.4 ± 0.8	-
600	< 1	7.1 ±1.1	20.1 ± 1.6	33.0 ± 1.7	41.1 ± 2.1	-

Table 2: Detection efficiency of the detection module in % as a function of MCP gain voltage and acceleration voltage

Conclusion

A hybrid imaging/timing detector with simultaneous high spatial and time resolution for low-intensity and low-energy beams of neutral (anti-)atoms was developed. This is a versatile device suitable for a broad range of applications in Ps research. It enables inertial measurements and counting experiments.

References

[1] A. Mills Js, M. Leventhal: Can we measure the gravitational free fall of cold Rydberg state positronium?, NIM in Physics Research B 192 (2002) 102–106
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[3] S. Mariazzi et al.: Toward inertial sensing with a 23S positronium beam, Eur. Phys. J. D 74 (2020) 79
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[5] J. Vallerga et al.: MCP detector readout with a bare quad Timepix at kilohertz frame rates, JINST 6 (2011) C01049

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