Challenges and scheme in performing inertial sensing measurements on the positronium beam

S. Sharma

on behalf of the J-PET collaboration

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Applications of radiation detection techniques in fundamental physics, food control, medicine and biology

Outline

Why to **study inertial sensing** on **anti-matter ?**

Positronium atoms (Ps) can be a potential probe?

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Producing Ps beam:

Requires producing Ps in long lived states (Expertise in dealing with lasers is essential !!)

Atomic interferometery:

Understanding of how atomic interferometers works and optimization of sensitive parameters involved

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- **Potential position sensitive detectors**

  Modular J-PET detectors ?

Inertial Sensing ?

Galileo observed that the free-fall trajectory of a body is independent of its mass :
`principle of universality of the free-fall`

Equivalence between
Inertial and **gravitational** mass

Inertial force and gravitational force are same

Inertial $m_i a$ = Gravitational $m_g g$

Or

Acceleration and **gravity** are same

Einstein Equivalence Principle : a homogenous gravitational field is locally equivalent to a uniformly accelerated reference frame.

The equivalence between gravitational and inertial masses has been tested very accurately with matter systems. In contrary, study for validation of WEP on antimatter are very scare due to experimental limitations in producing anti-matter objects and handling them.

To **measure** the **inertial sensing** on **Ps** and, in perspective, a **direct test of Einstein's equivalence principle**, **i.e. equivalence between inertial and gravitational mass, by measuring the vertical displacement of a long-lived Ps beam and thus**

insights into the behavior of antimatter in the gravitational field of the earth

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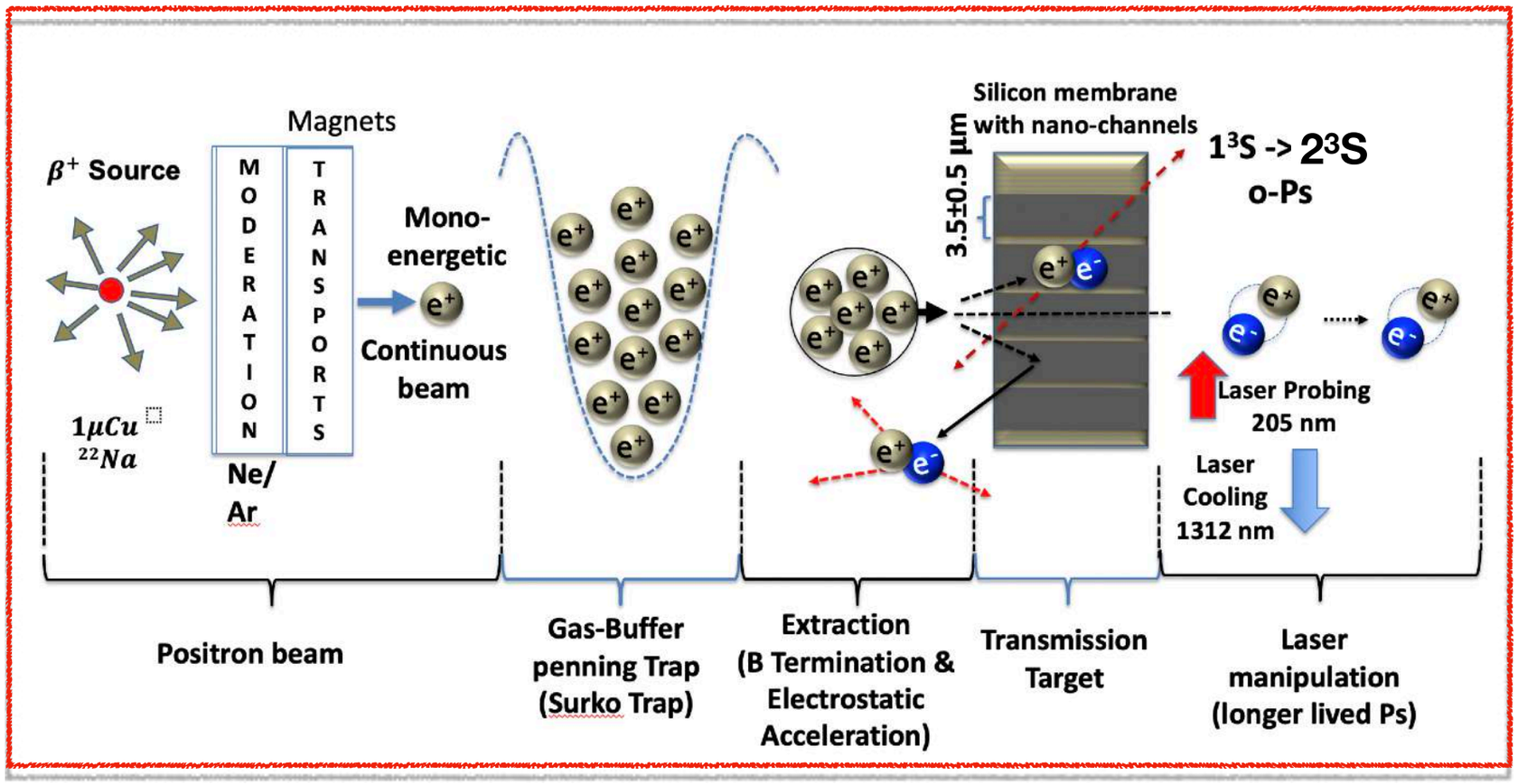
Measuring the **inertial sensing** on **Ps** atoms, in perspective, a **direct test of Einstein's equivalence principle**, **i.e. equivalence between inertial and gravitational mass, by measuring the vertical displacement of a long-lived Ps beam and thus insights into the *behavior of antimatter in the gravitational field of the earth.***

Scheme of Inertial Sensing on Ps atoms

Scheme can be *divided in two challenges* :



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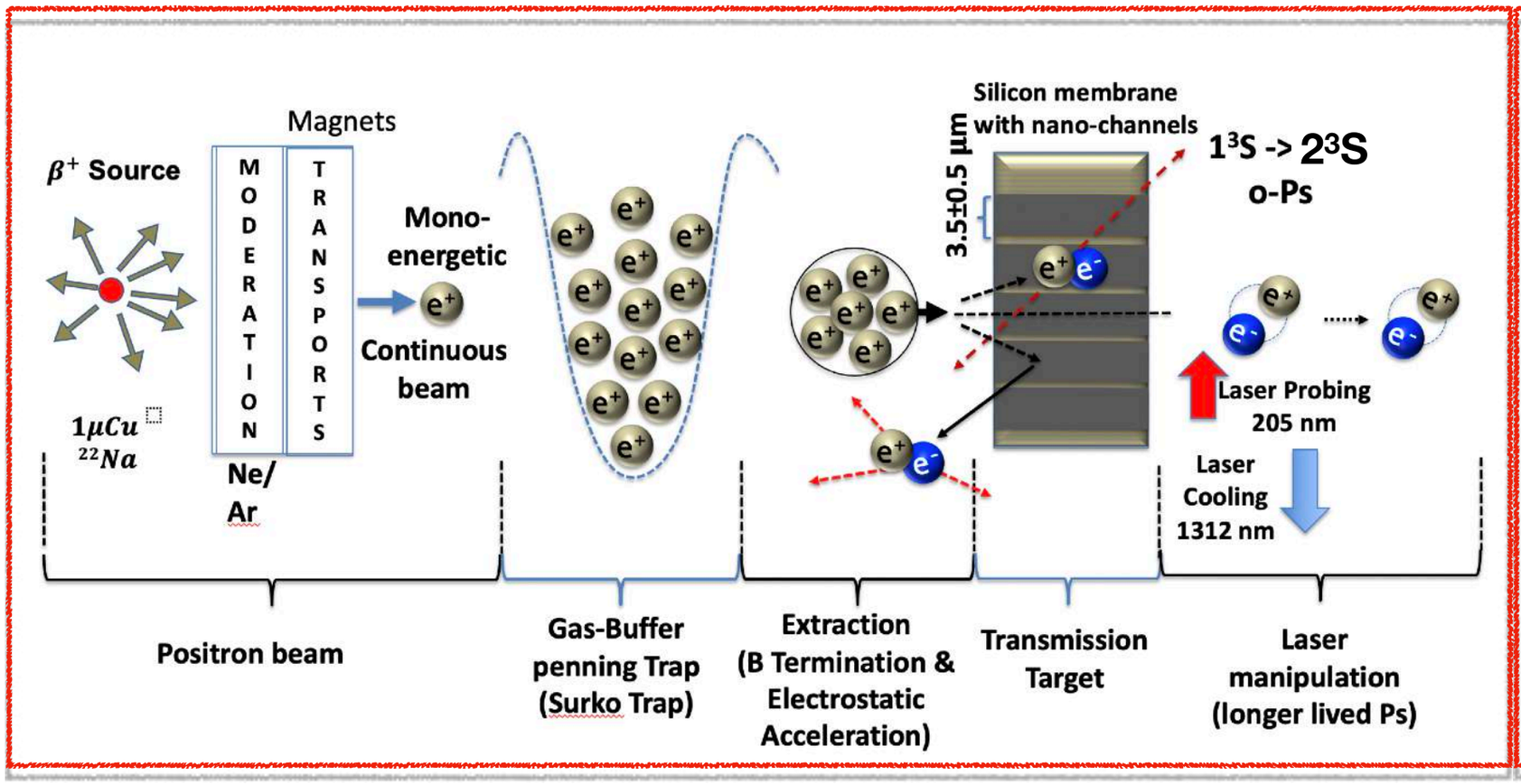
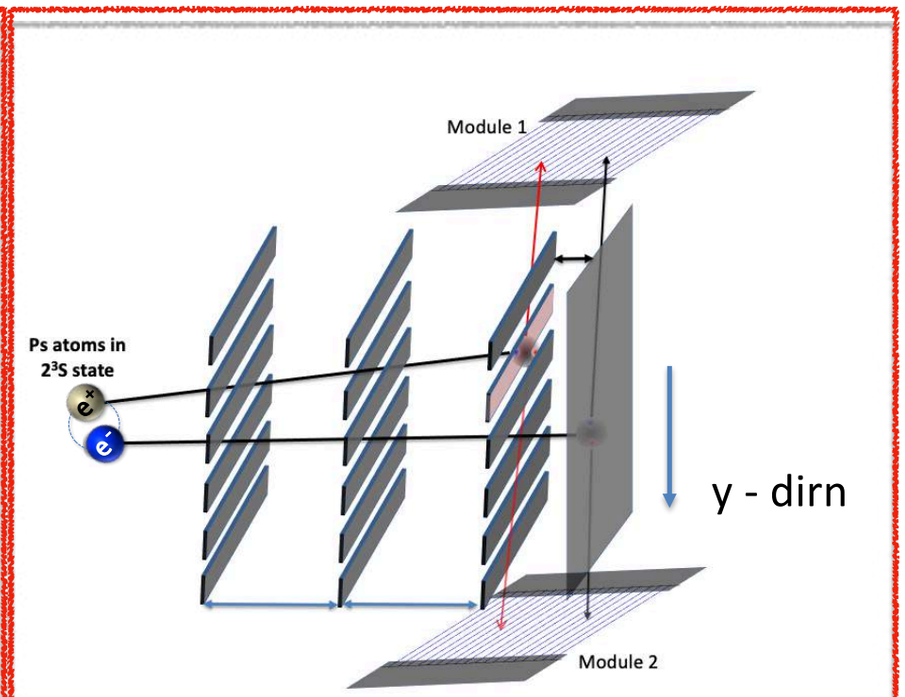
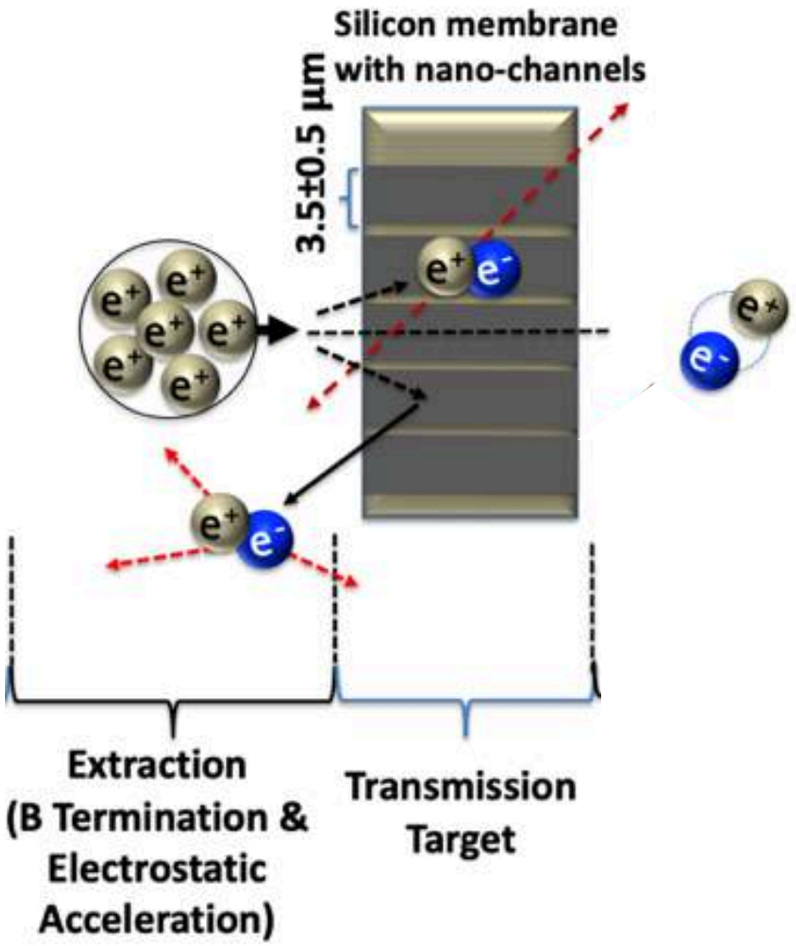




- Production of beam of Ps atoms
- Atomic deflectometery/interferometery

Ps production and manipulation into 2^3S states



- **Ps Can be formed in two ground states, undergoes <u>self-annihilation</u> into gamma quanta.**

p-Ps (S=0, L=0) Lifetime = .125 ns

o-Ps (S=1, L=0) Lifetime = **142 ns**

S. Mariazzi, .., S. Sharma et al. Phys. Rev. B 105 (2022) 115422

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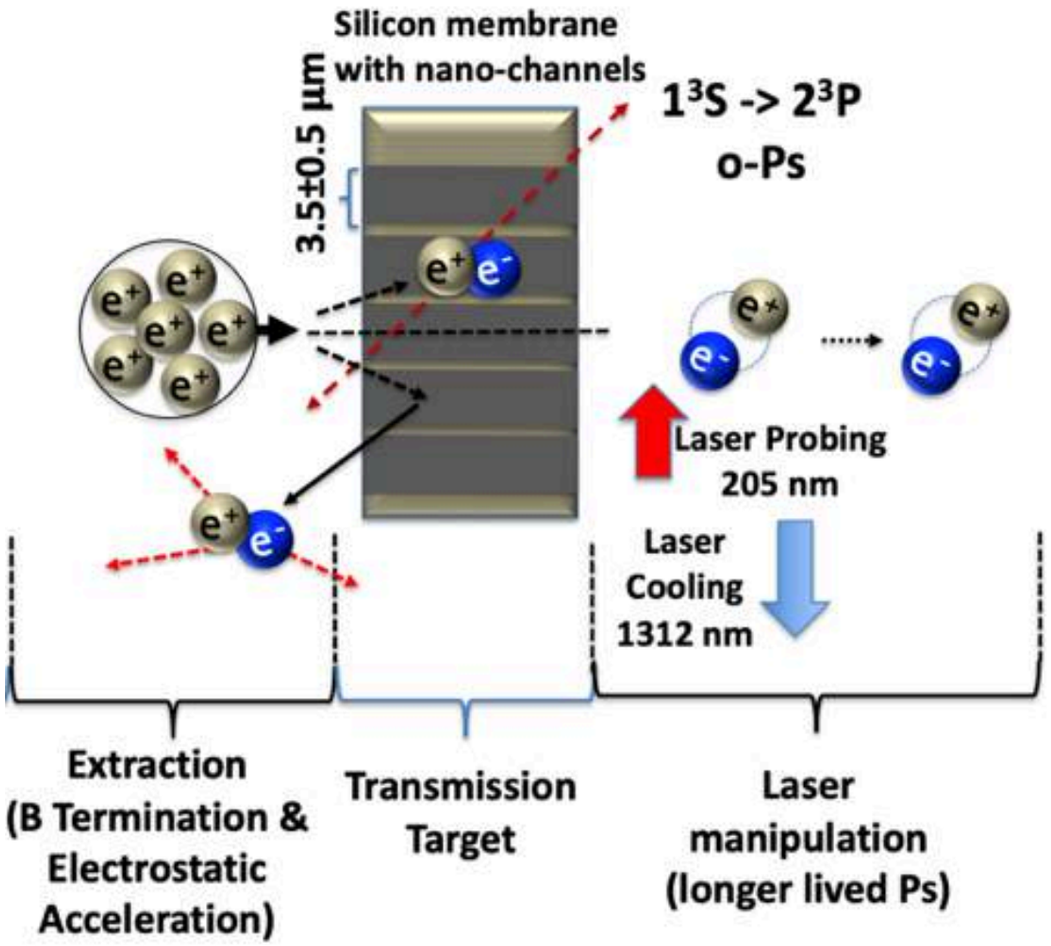

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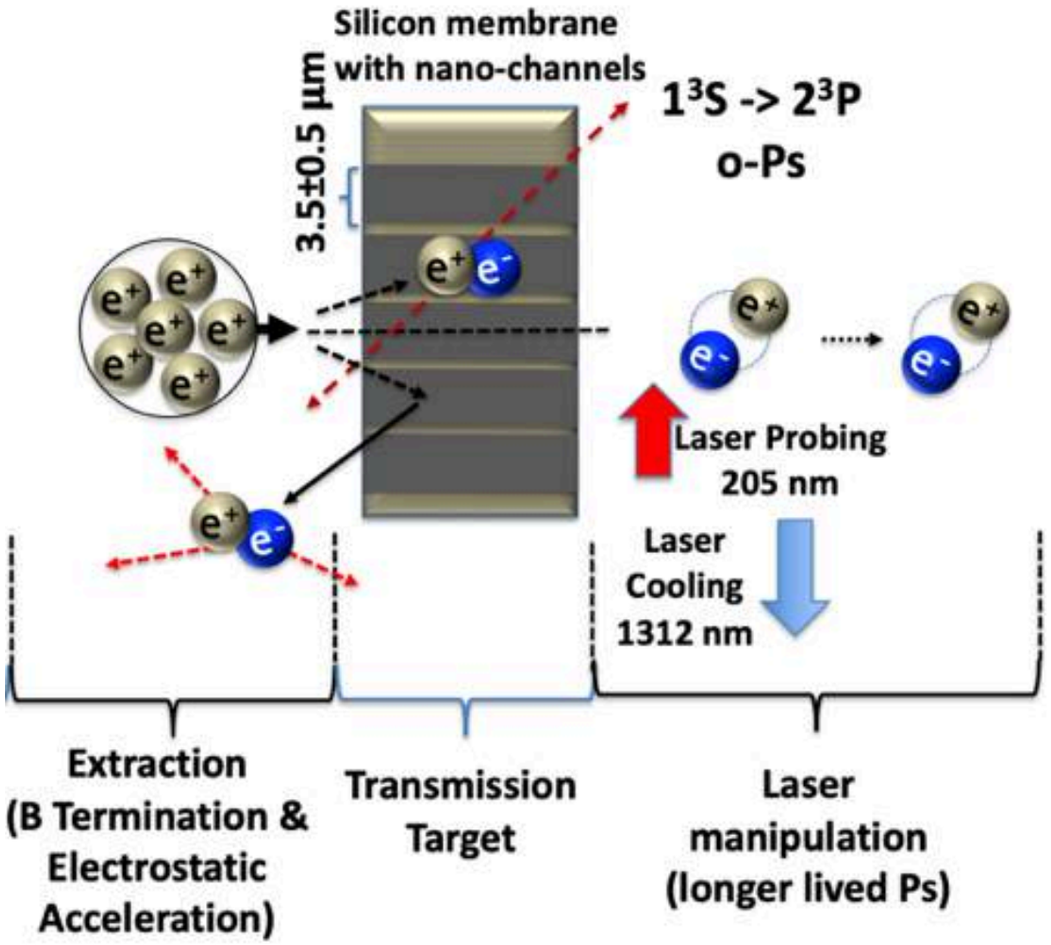

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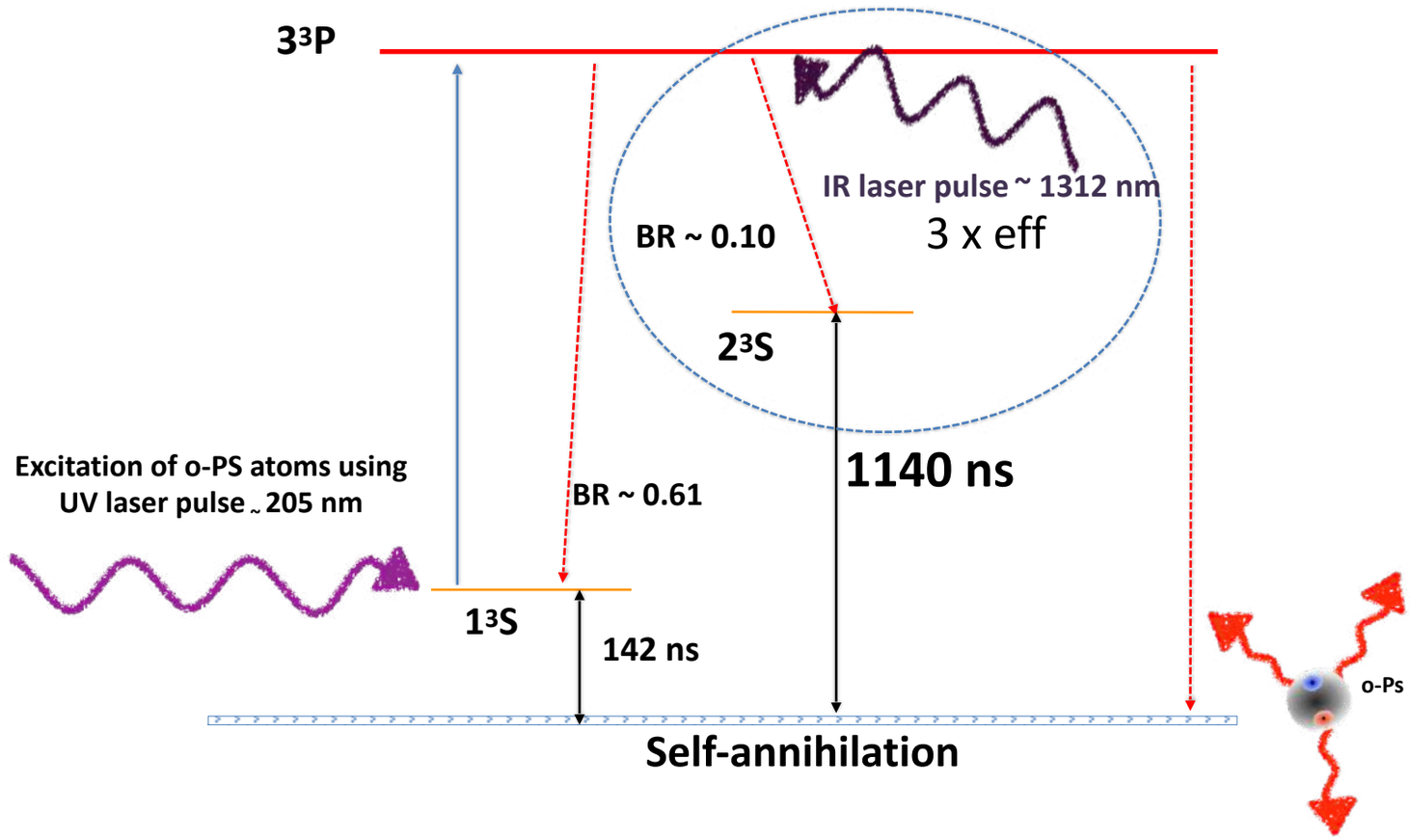


M. Antonello et al., Physical Review A 100, 6 (2019) 63414

Using short duration of the laser pulse used to excite Ps to the 3^3P states allowed selecting a fraction of the Ps cloud with a **quasi-monochromatic velocity distribution**.

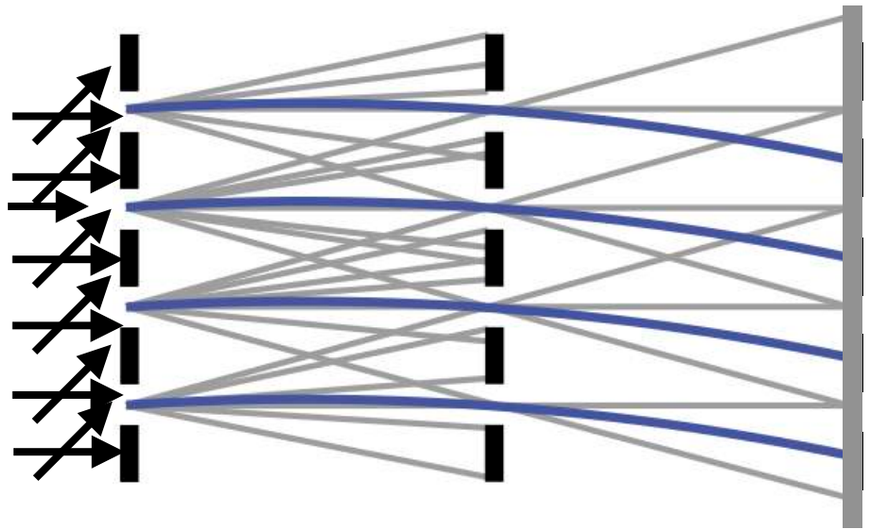
Atomic interferometry on Ps atoms

- Atom interferometry uses the coherent splitting and recombination of atoms to make precision measurement of gravity acceleration on matter and anti-matter systems

- At the output an interference fringe pattern observed, which is sensitive to different path connecting the initial and final state of system.

- The gravity acceleration (**g**) produces a phase shift at the interferometer output.
  Measuring it, the effect can be estimated.

Fringe patterns
without force
with force (F)



$$\Delta y = \frac{F}{m} t^2$$

$$= \alpha\, t^2$$

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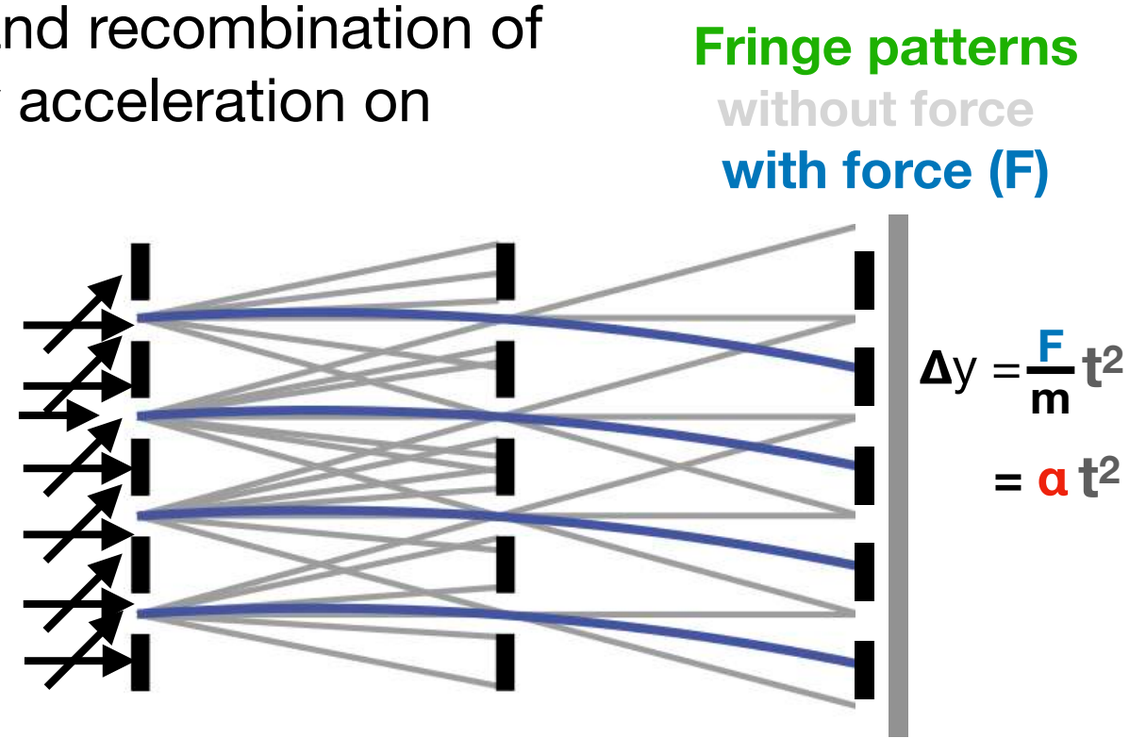
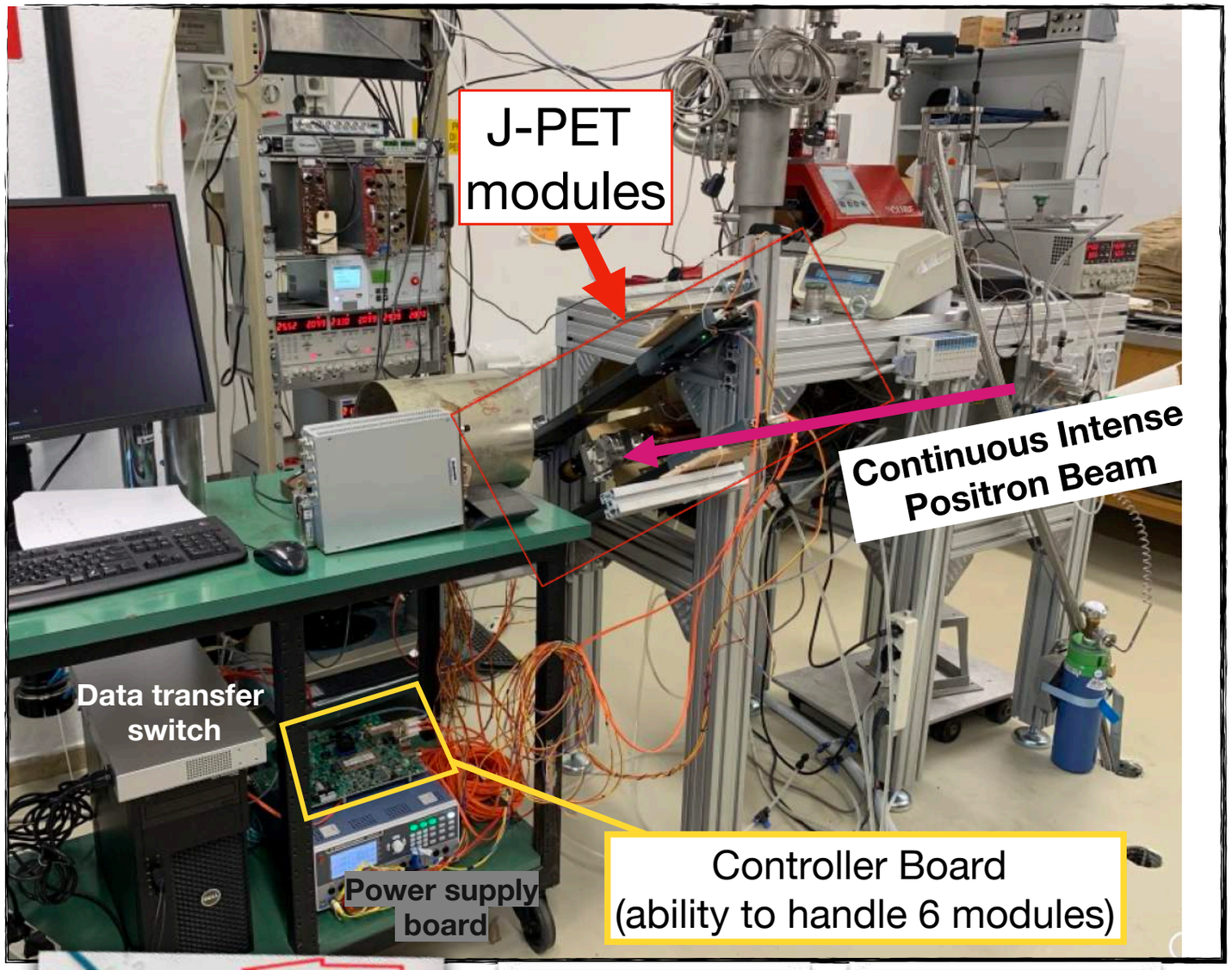


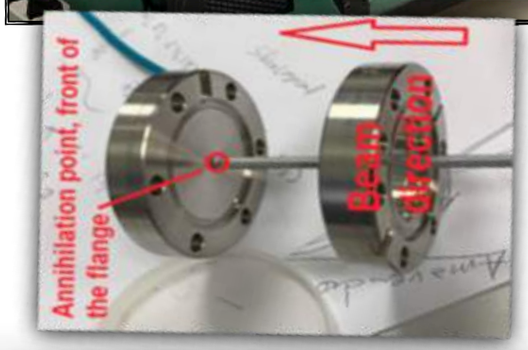
- It is proposed to probe the fringe pattern with a third grating followed by a stopper within a vicinity that Annihilation sports on third grating or stopper can be resolved.
  (Constrained on potential detectors)

- Counting the annihilation in the third grating and stopper by moving the third grating along the force direction within sub-nm accuracy of shift **Δ**y,
  spanning the full grating period.

Finally, comparing the probability distribution of impact annihilations on third grating and stopper allows to measure the strength of the investigated force.

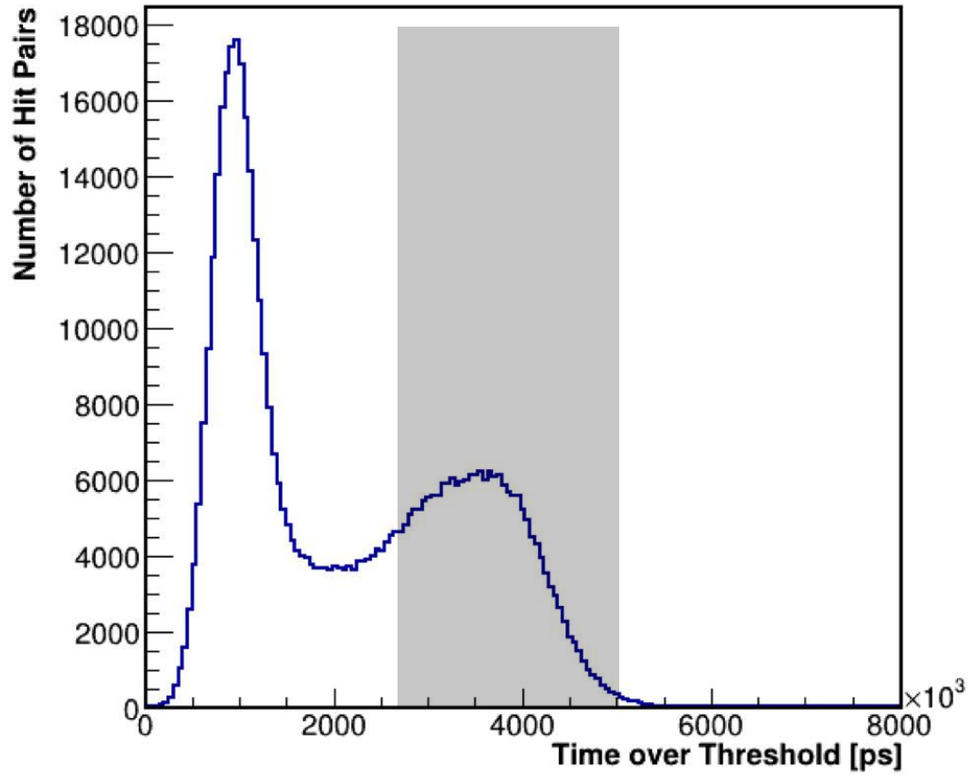
Test experiment with J-PET modules at AML





Preliminary results

Time Over Threshold as measure of energy deposition

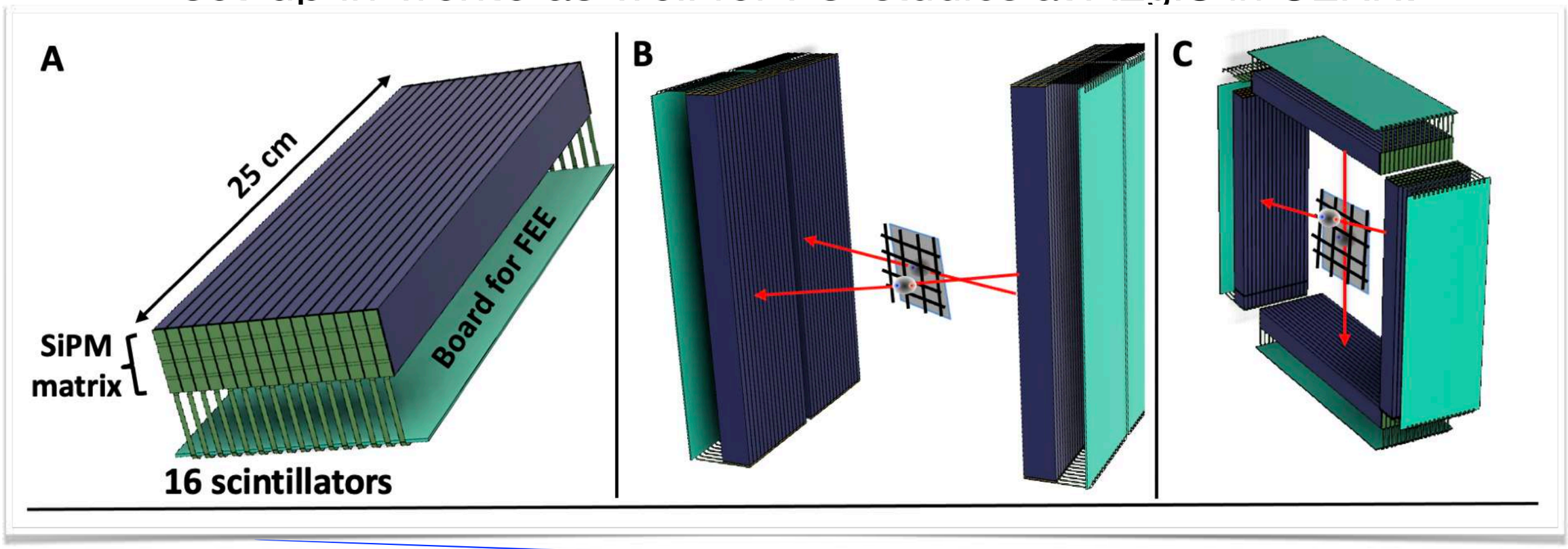


Analysis is going on to estimate the reconstruction efficiency of e^+ annihilations

Summary

- ☑ First test experiment was successfully performed at AML lab with e^+ beam at University of Trento.
- ☑ Preliminary results of the measurement are promising which is proof of principle that, J-PET modules can be potentially used for the proposed experiment for inertial sensing on Ps beam

New modules are planned to be designed, optimized for the experimental set-up in Trento as well for Ps studies at AEgIS in CERN.



Thank you on behalf of the

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