Craig Evans

On behalf of the AEgIS collaboration

Towards the first measurement of matter-antimatter gravitational interaction

AEgIS

POLITECNICO MILANO 1863

INFN Istituto Nazionale di Fisica Nucleare

CERN



AEgIS Collaboration

~80 Collaborators
18 Institutions

University of Bergen

University of Brescia

CERN, Geneva

University of Genova

Heidelberg University

Max Planck Institute for Nuclear Physics, Heidelberg

University College London

Lyon 1
University of Lyon 1

University of Milano

Politecnico di Milano

Institute of Nuclear Research of the Russian Academy of Science, Moscow

University of Oslo

université PARIS-SACLAY
University Paris-Saclay and CNRS

University of Pavia

Czech Technical University, Prague

University of Trento

ÖAW SMI
Stefan Meyer Institute, Vienna

ETH Zurich

INFN Sections of Genova, Milano, Padova, Pavia, Trento






Outline

1. A Short History of Antimatter
2. Goal
3. AE$\bar{g}$IS Experimental Apparatus
4. Antiproton System
5. Positron System
6. Anti-hydrogen Production Trap
7. Positronium
8. Improvements
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9. Conclusion
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A Short History of Antimatter (Charged)

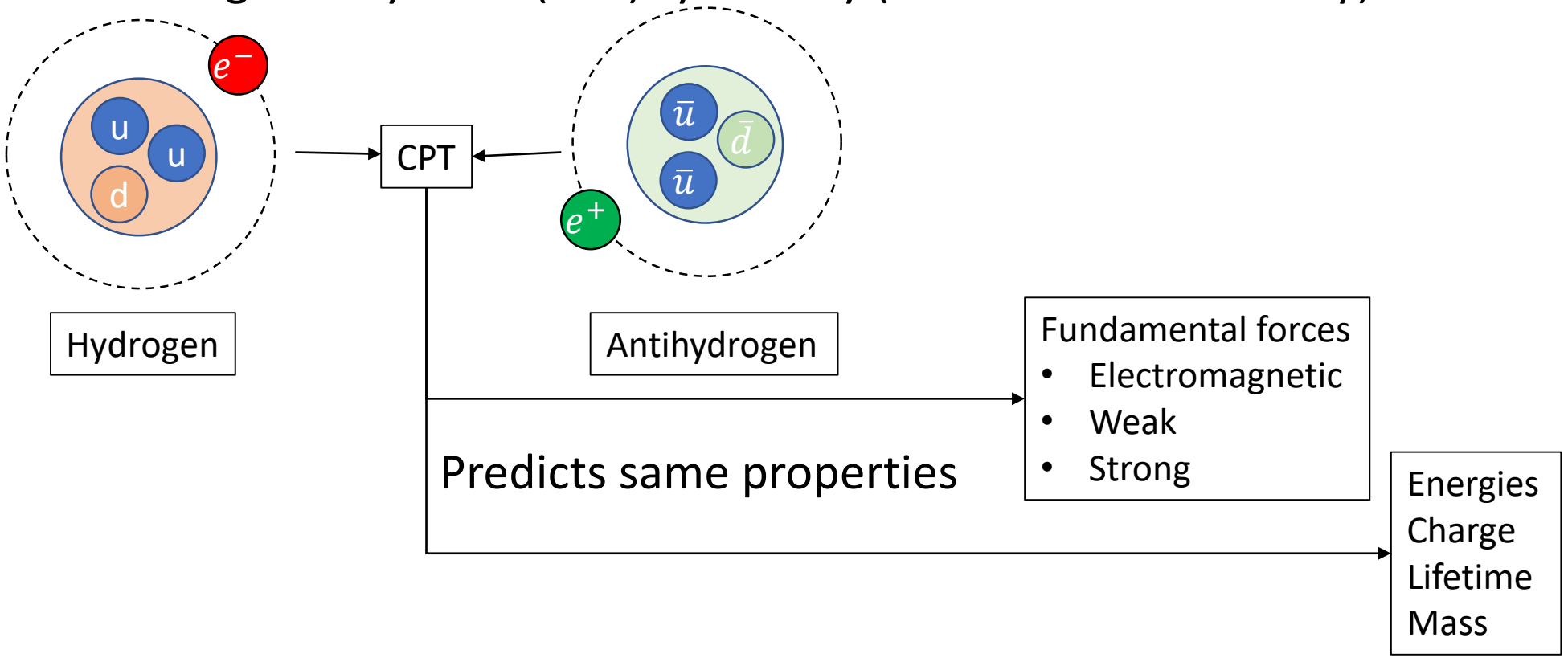
- **1928 - 1931:**Prediction of antimatter (Dirac, Oppeheimer, Weyle)
- **1932:** Discovery of positrons in cosmic rays (Anderson)
- **1955:** Antiproton discovery (Segrè, Chamberlain, Wiegand, Ypsilantis
- **1995:** Mass of antiproton to 1 part in 100,000 (TRAP, LEAR)
- **2013:** Antiproton magnetic moment (ATRAP)
- **2015:** Comparison of the antiproton-to-proton charge-to-mass (BASE)

A Short History of Antimatter (Neutral)

- **1934:**Prediction of positronium (Mohorovičić, Anderson)
- **1951:** Discovery of Ps (M. Deutche)
- **1996 & 1998:** Creation of high-energy antihydrogen ($\bar{H}$) (CERN (LEAR), Fermilab)
- **2002:** Creation of 10 k antihydrogen (ATHENA, ATRAP)
- **2011:** Antihydrogen confinement of 1000 s (ALPHA)
- **2017:** Observation of the 1S – 2P transition for antihydrogen (ALPHA)

Goal

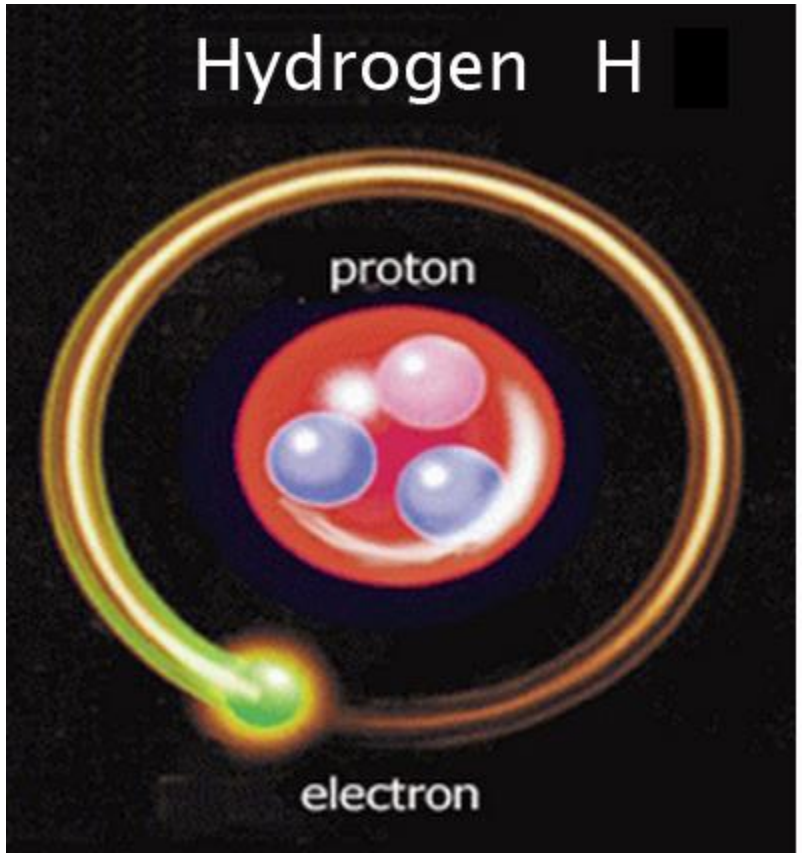
Charge Parity Time (CPT) symmetry (Quantum Field Theory) defines antimatter entirely

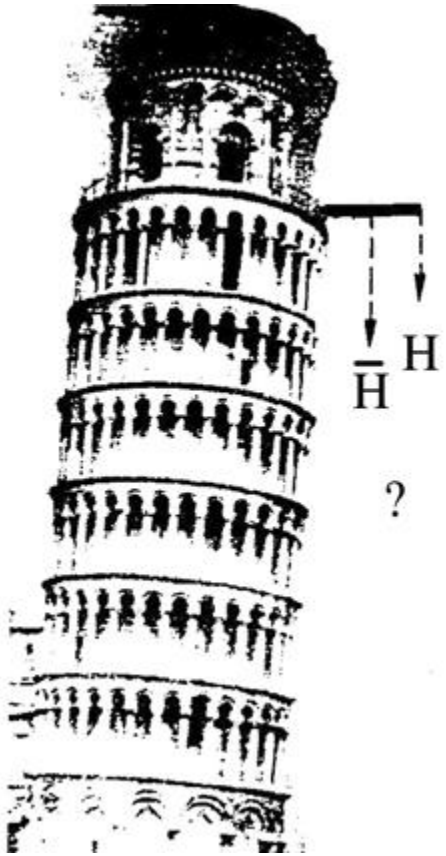


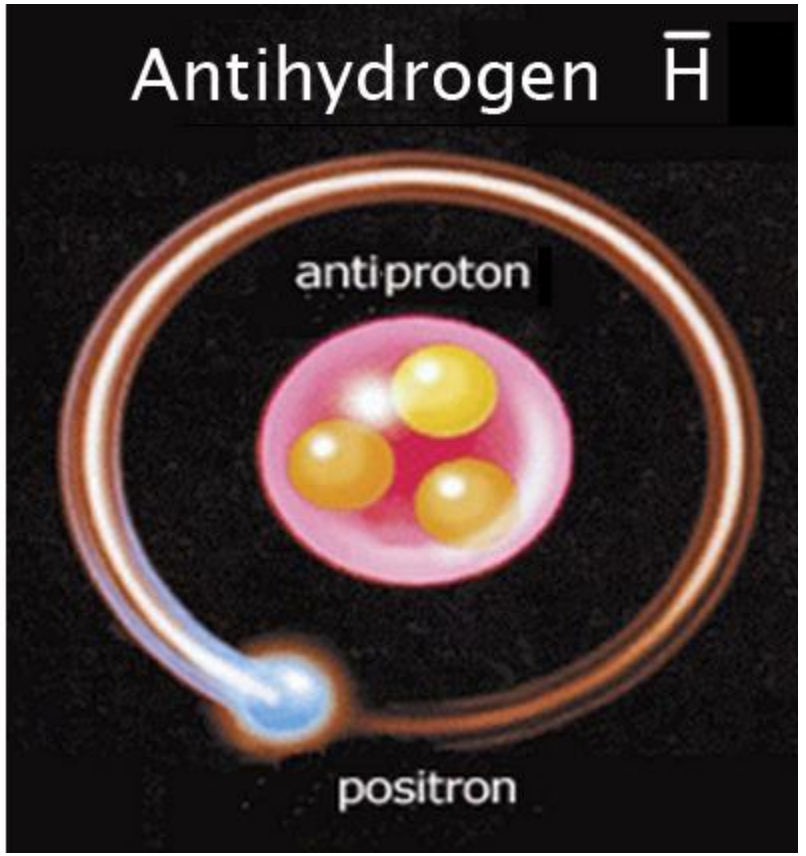
Weak Equivalence principle. (the universality of free fall, General relativity)

Goal

How does antimatter interact with gravity?



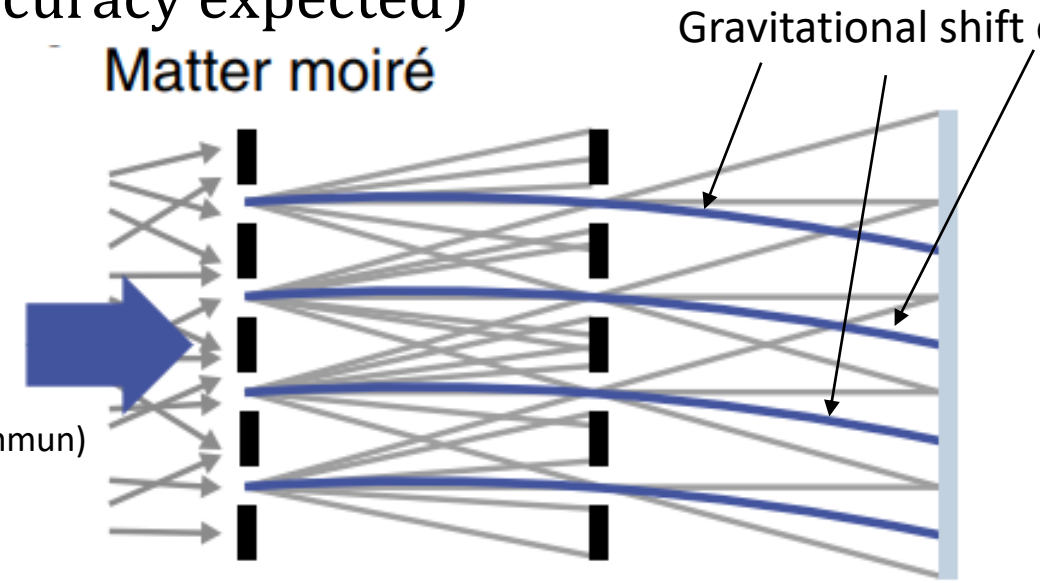




Goal

The main goal is to directly measure the gravitational constant on antimatter.
What is needed?

- Pulsed cold Anti-hydrogen beam (few 100 m/s)
- Implement a Moiré deflectometer to observe the vertical deflection of the beam (1% accuracy expected)



Anti-proton fringe pattern and gravitational shift observed (Nature Commun)

Nat. Commun vol 5 4538 (2014)

Phase shift

$$\Phi\left(T^2\right) - \Phi_0 = \frac{2\pi}{d} g T^2 = k g T^2$$

Goal

$$Ps^* + \bar{p} \rightarrow e^- + \overline{H^*}$$

Rydberg Positronium

Cold Antiprotons

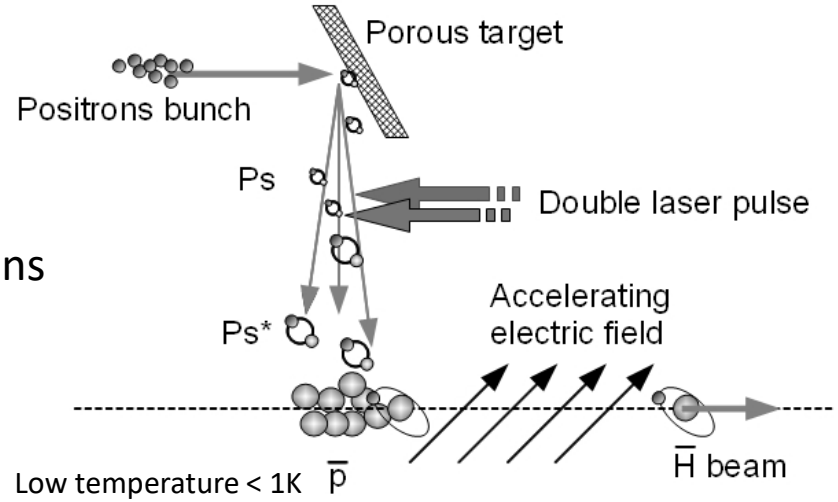
Electron

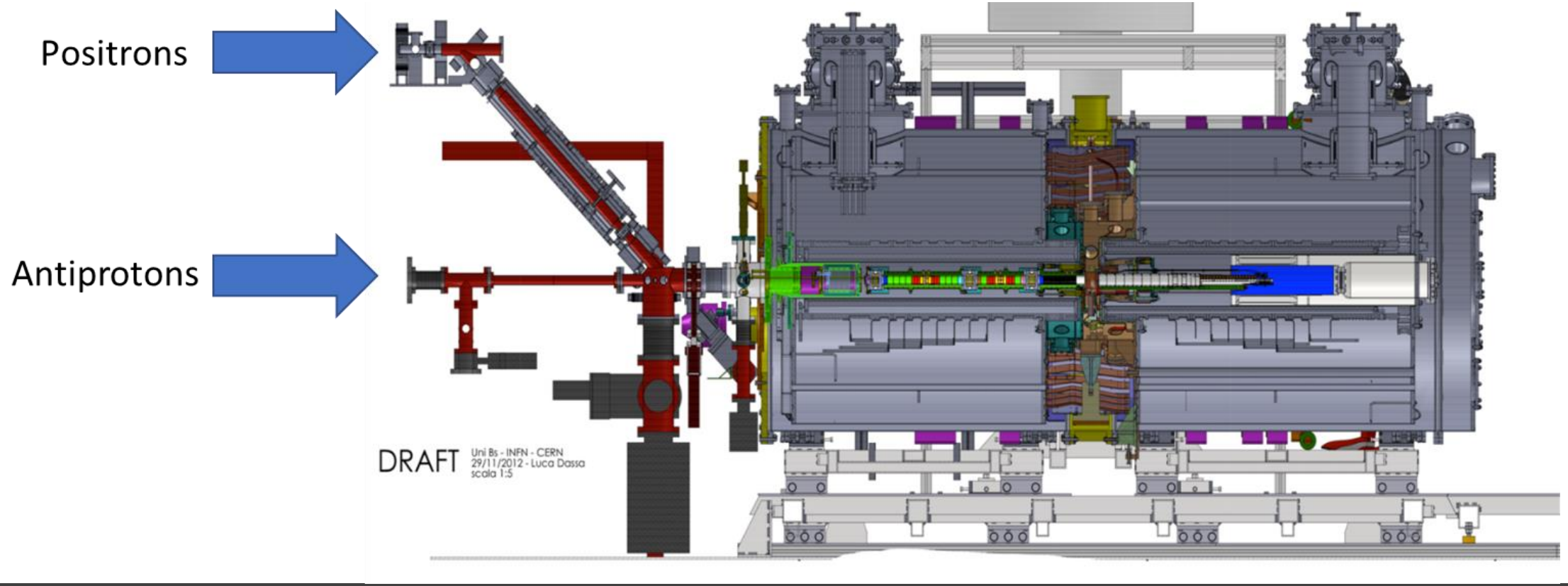
Rydberg anti-hydrogen

Production via charge exchange

- Pulsed source of Rydberg antihydrogen
- Temperature of Anti-hydrogen relies on the temperature of anti-protons
- Strong Dipole moment allowing Stark Acceleration of atoms (Beam)

CPT tests possible



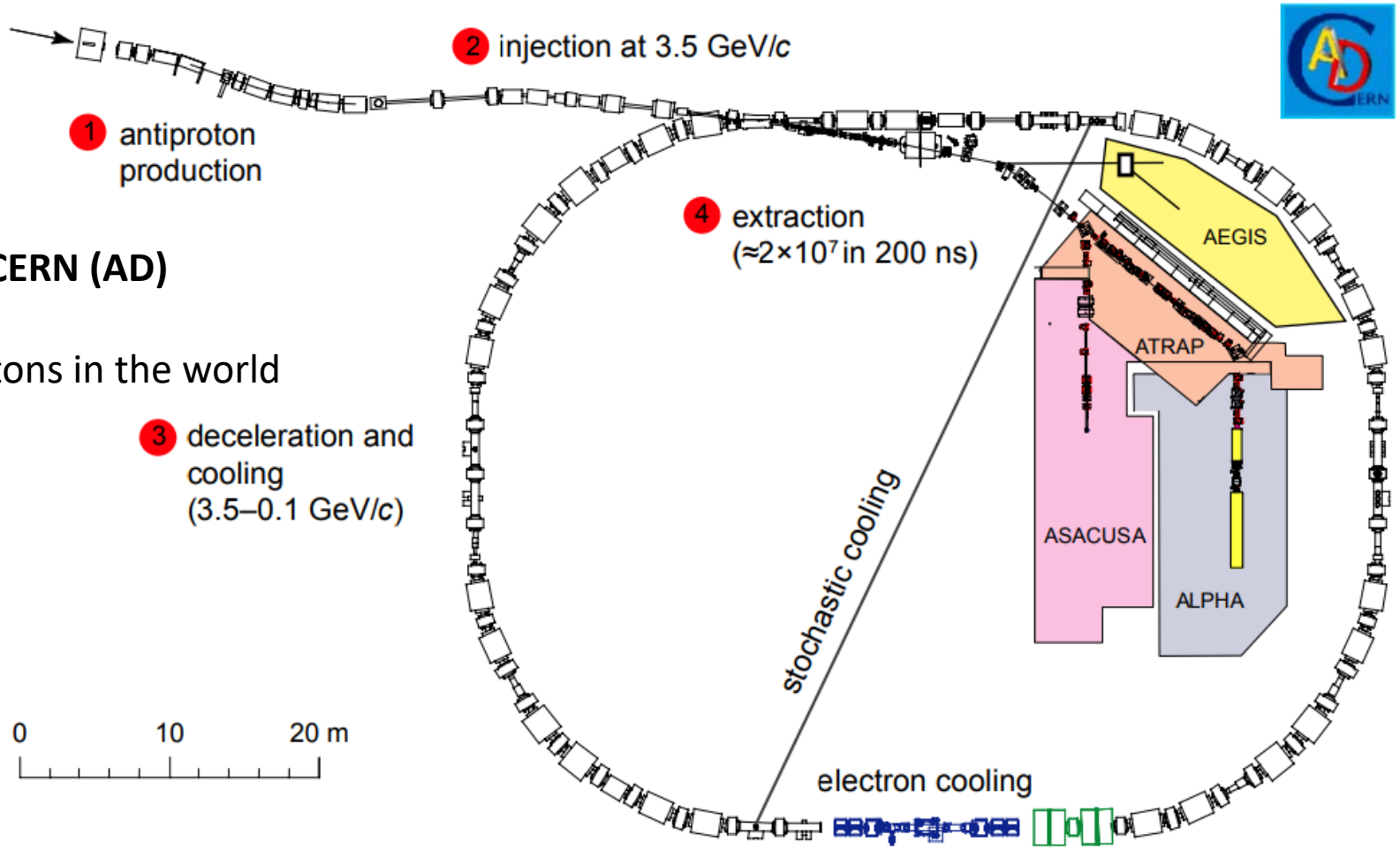


AE$\bar{g}$IS Experimental Apparatus

Antiproton System

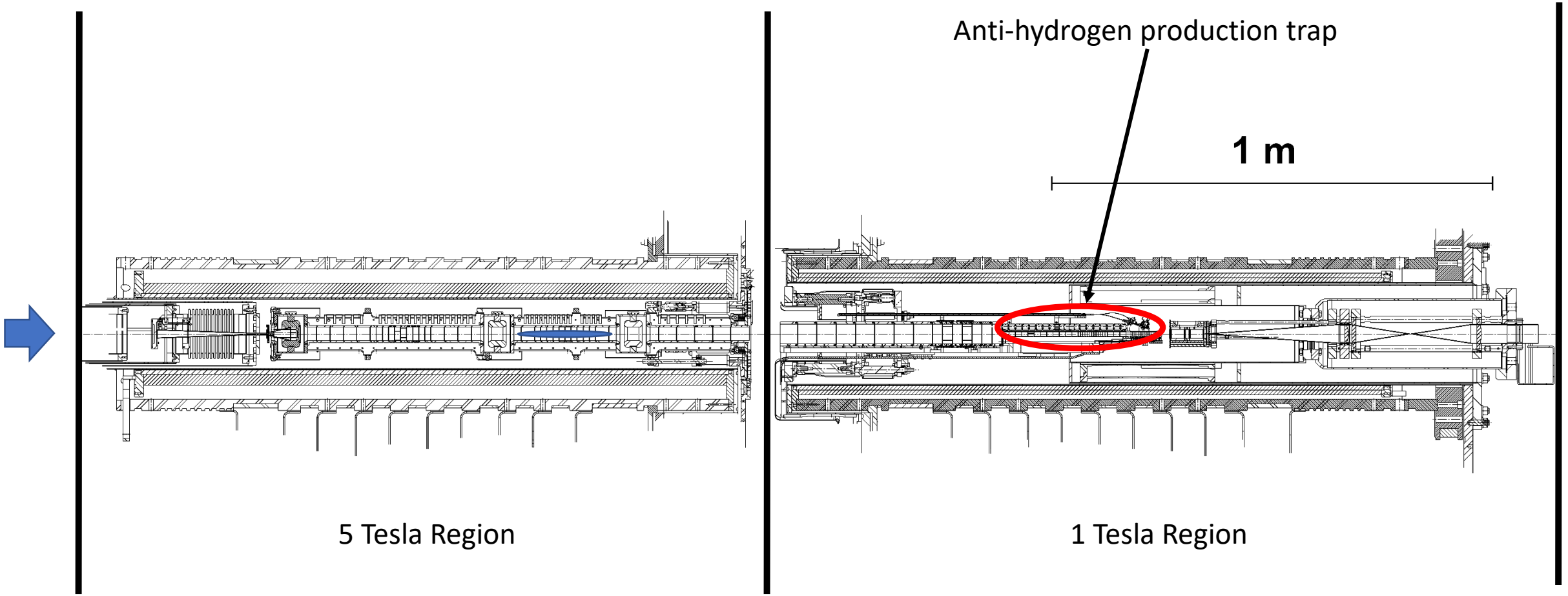
Anti-proton Decelerator at CERN (AD)

Only source of cold anti-protons in the world



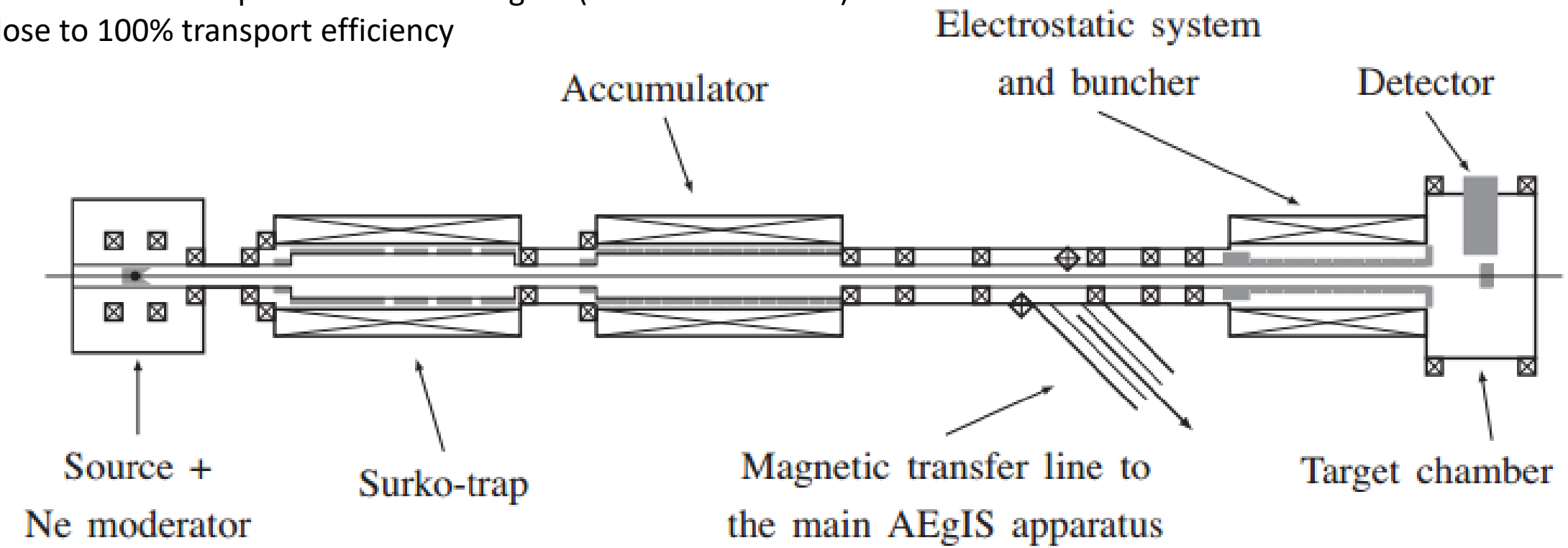
J.Y. Hénery & S.Maury, Nucl. Phys. A **655** (1999) 345c

Antiproton System



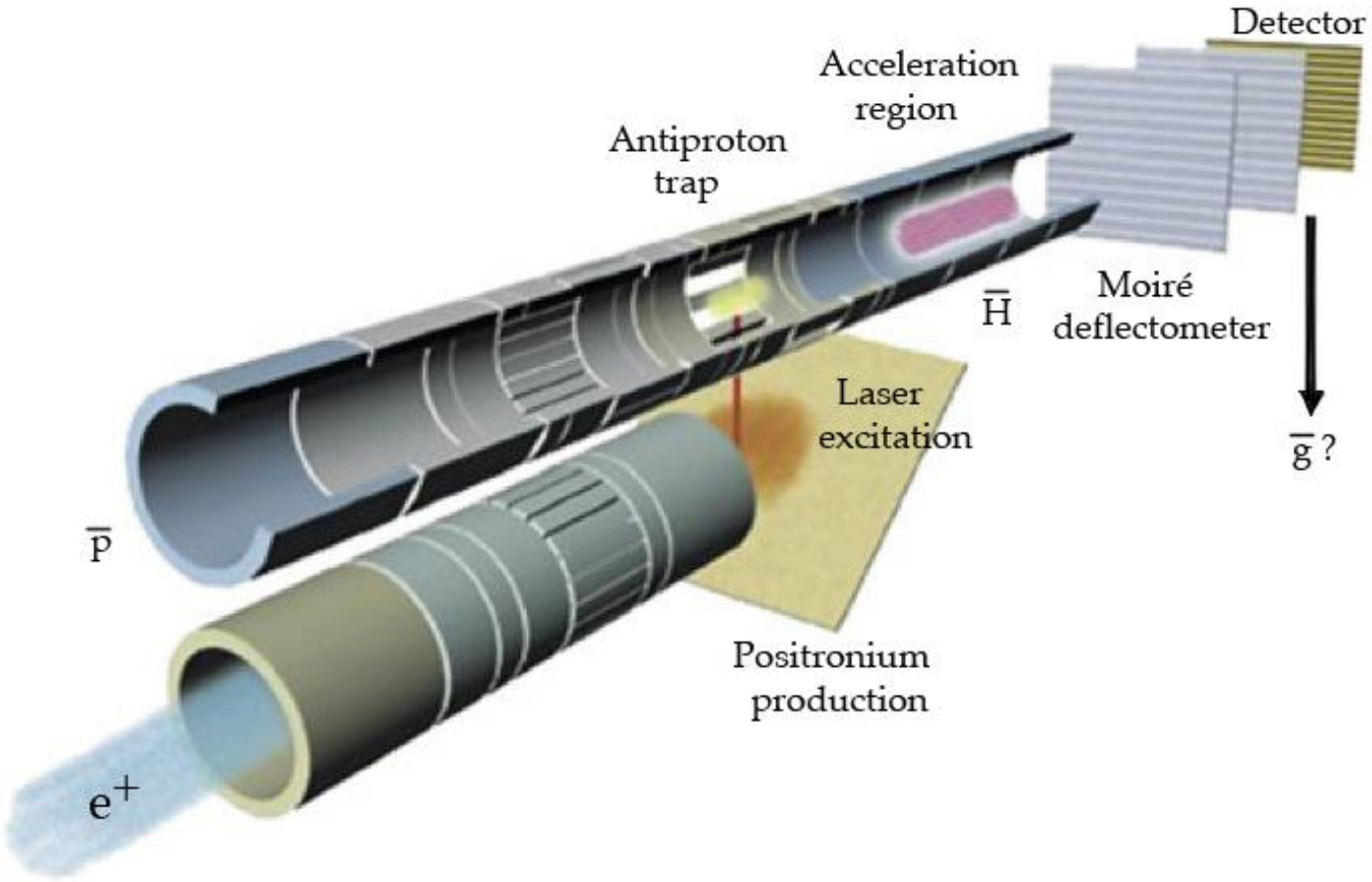
Positron System

Positrons are transported to 1 Tesla region (2 minute bunches)
Close to 100% transport efficiency

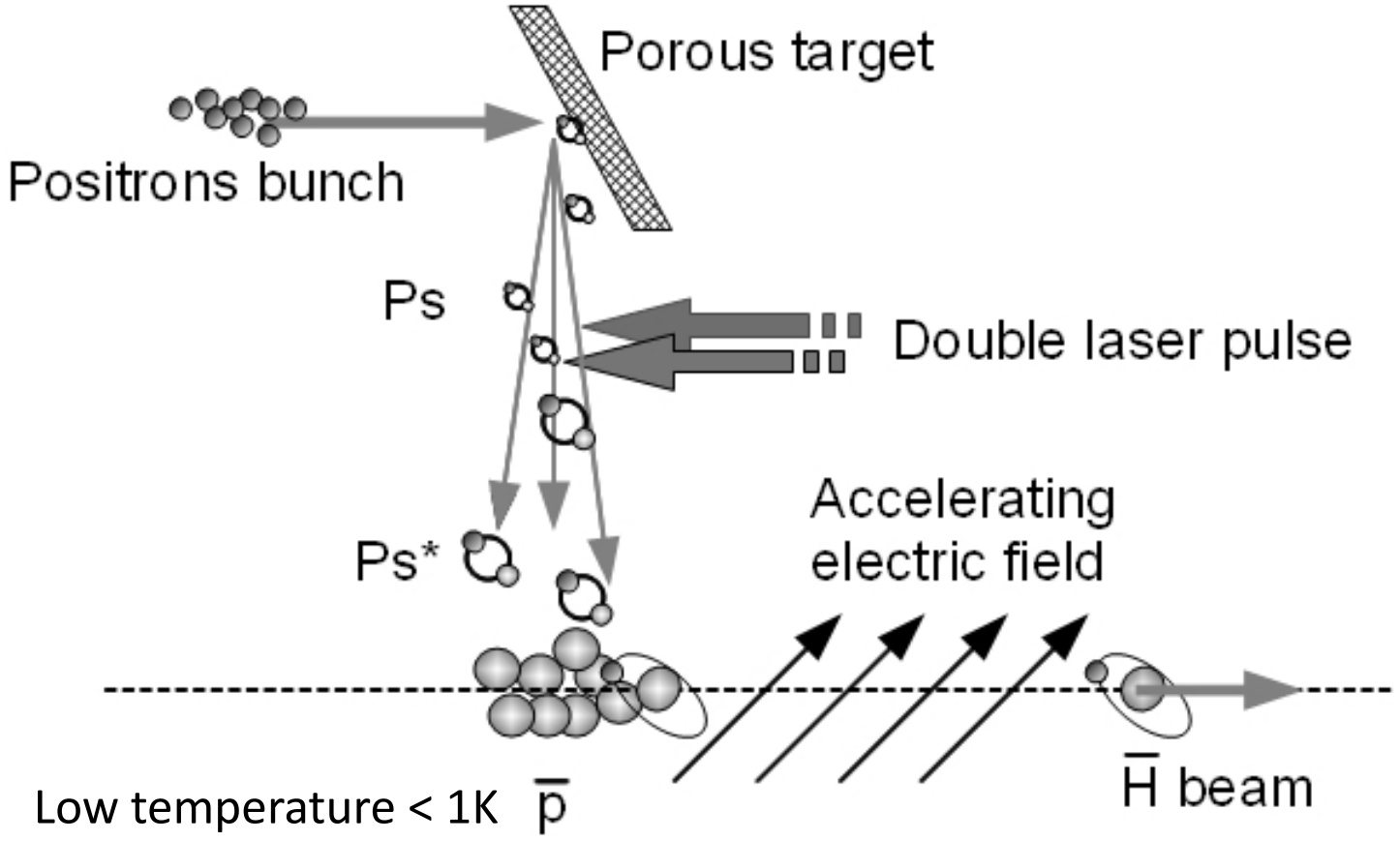


Nucl. Instrum. Meth. in Phy. Res Sect. B 362:86 92, (2015)

Anti-hydrogen Production Trap



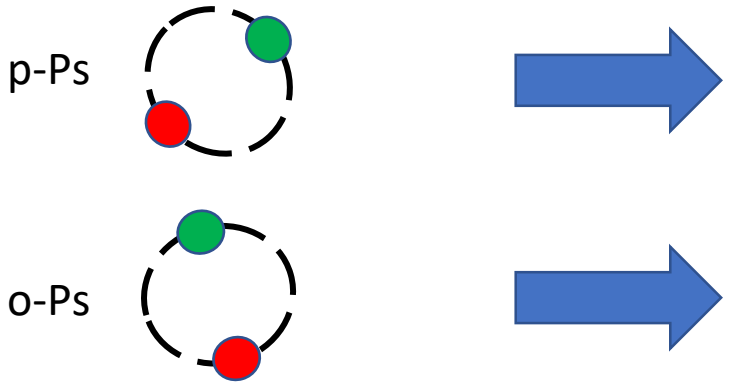
Anti-hydrogen Production Trap

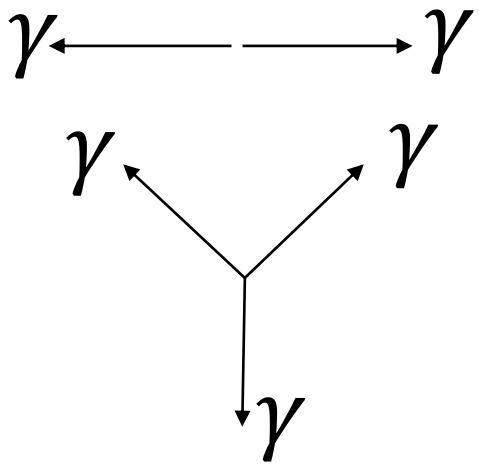


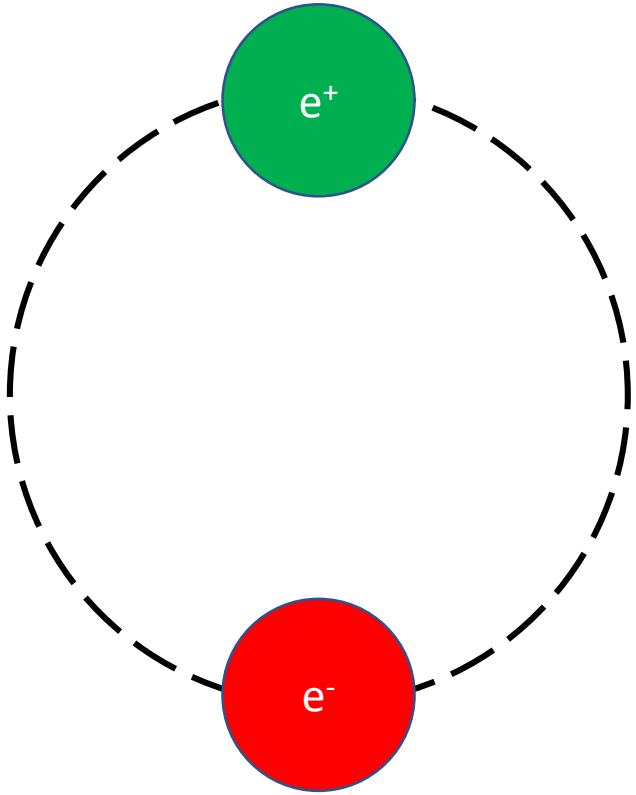
Positronium

What is Positronium?

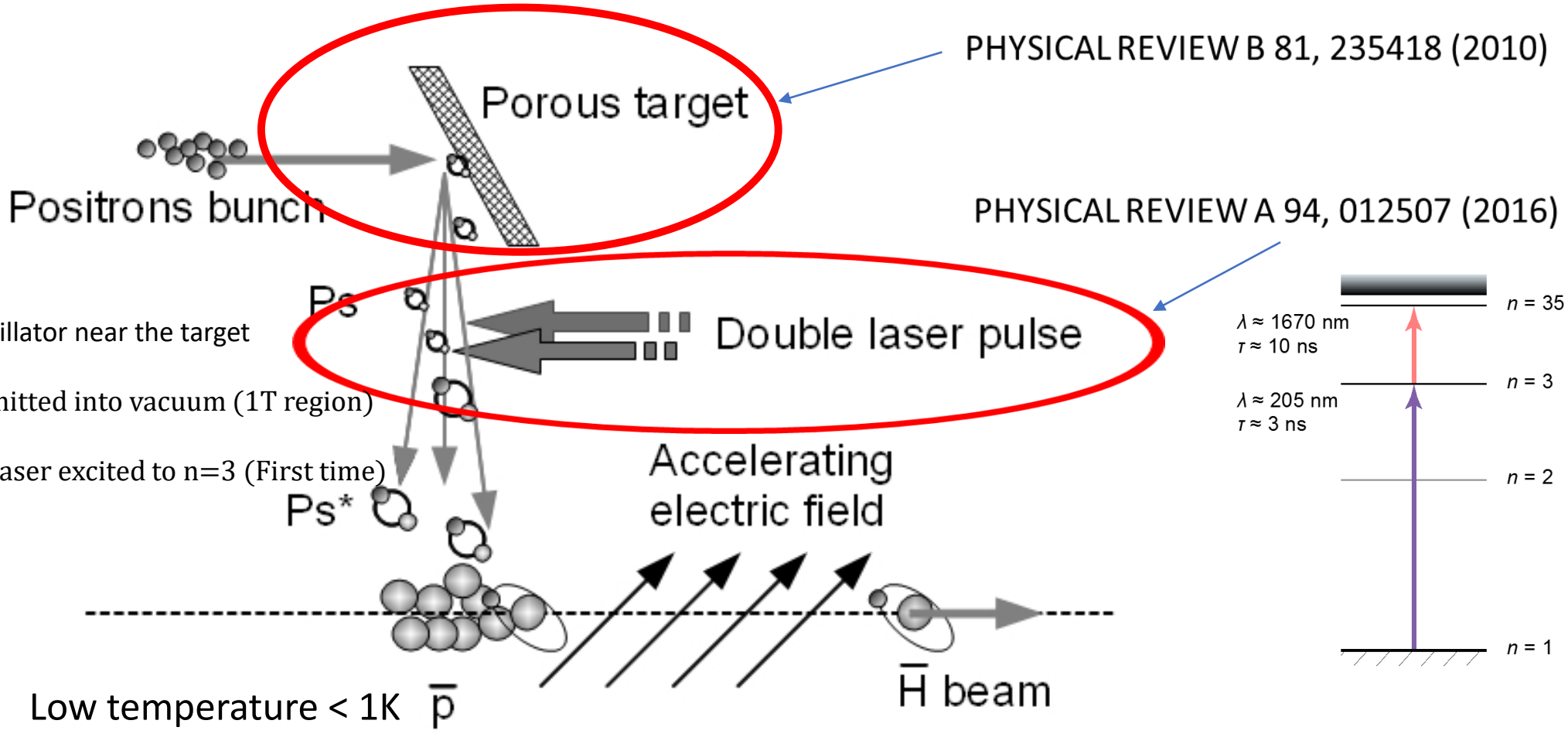
- Electron and Positron bound together
- Produced in two spin states.
- Singlet State - Para-Positronium, Lifetime = 125 ps
- Triplet State - Ortho-Positronium, Lifetime = 142 ns







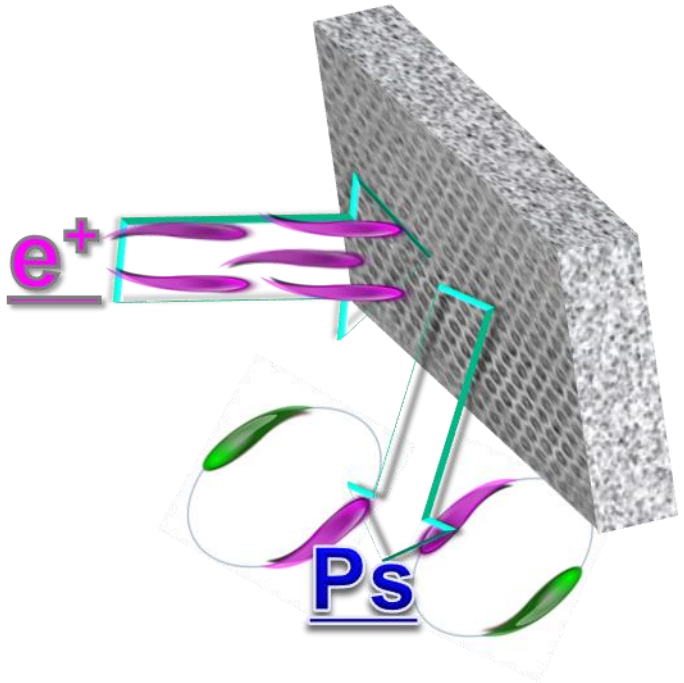
Anti-hydrogen Production Trap



- Detected by a PbF2 scintillator near the target
- e/Ps efficiency ∼20% emitted into vacuum (1T region)
- Emitted ortho-Ps was Laser excited to n=3 (First time)

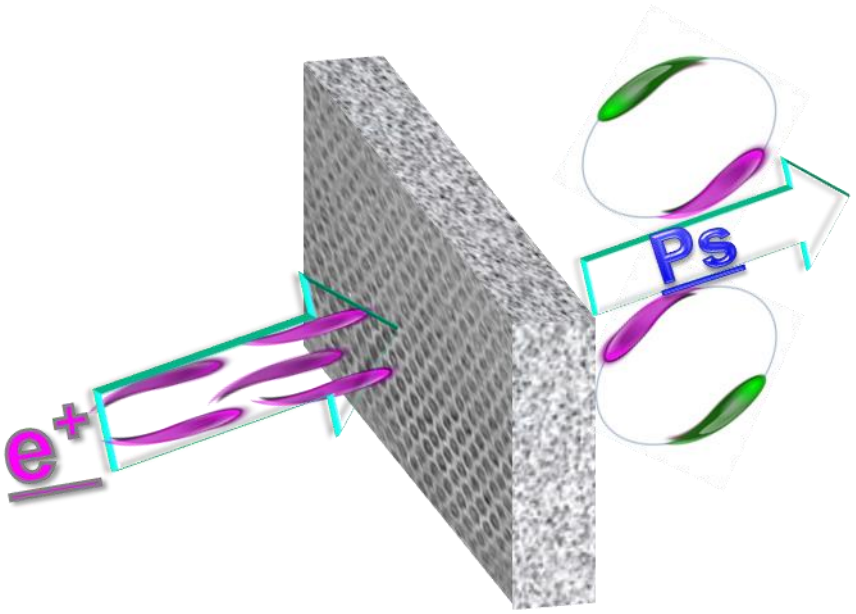
Improvements

Ps Transmission Target

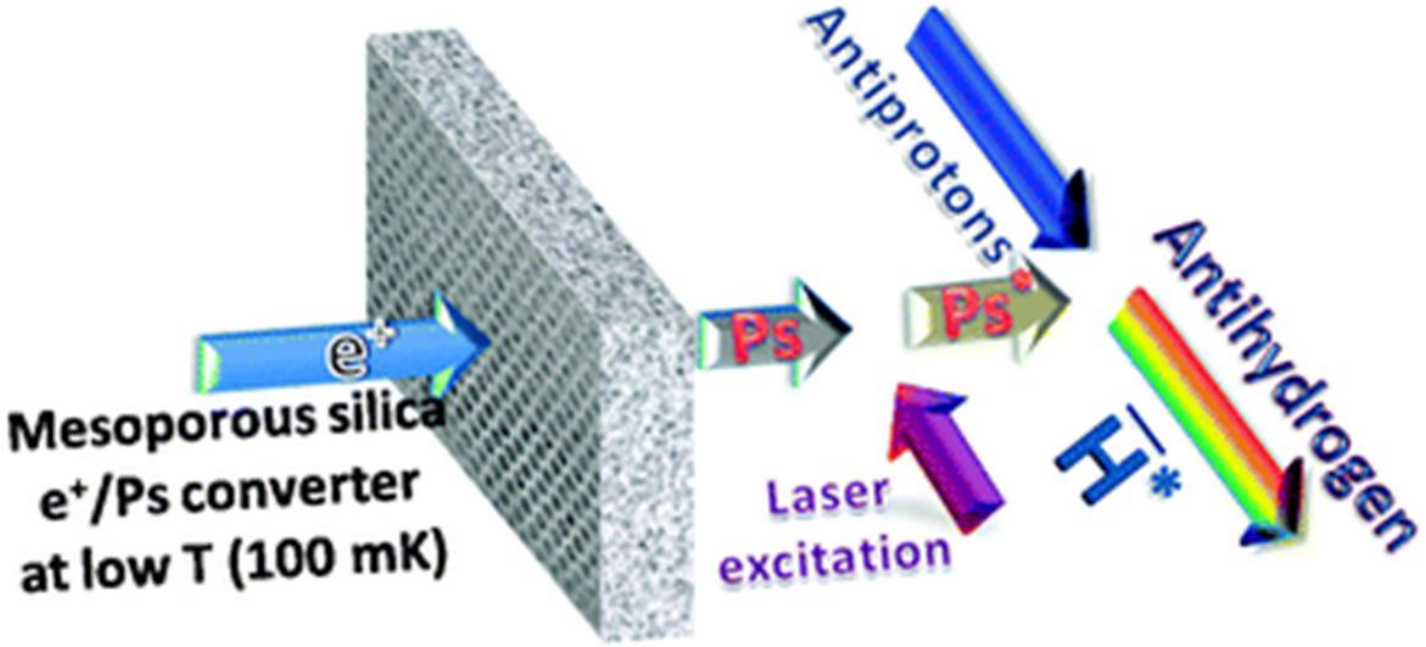


Reflection

Transmission



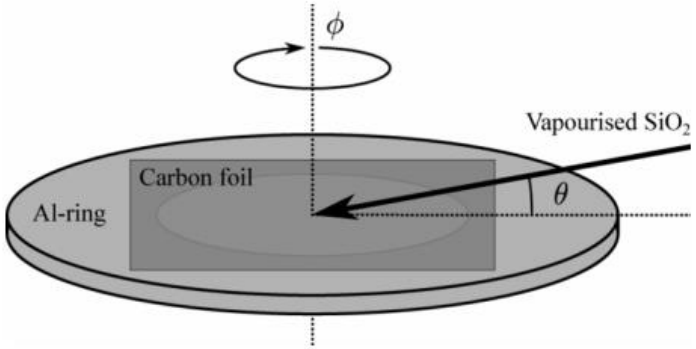
Ps Transmission Target



Ps Transmission Target

Ps Transmission directions

Carbon-Supported



Eur. Phys. J. D (2014) 68: 124

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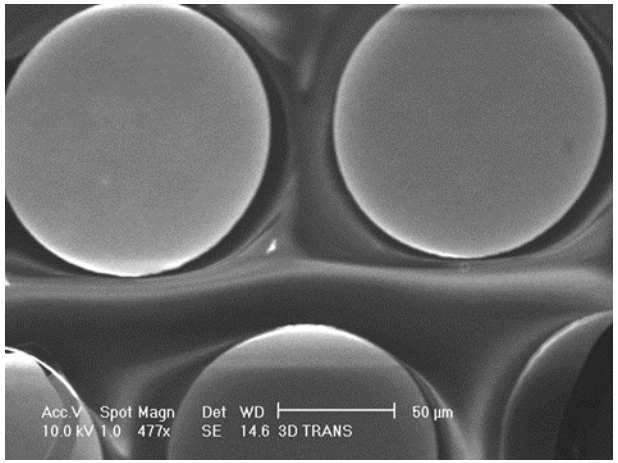
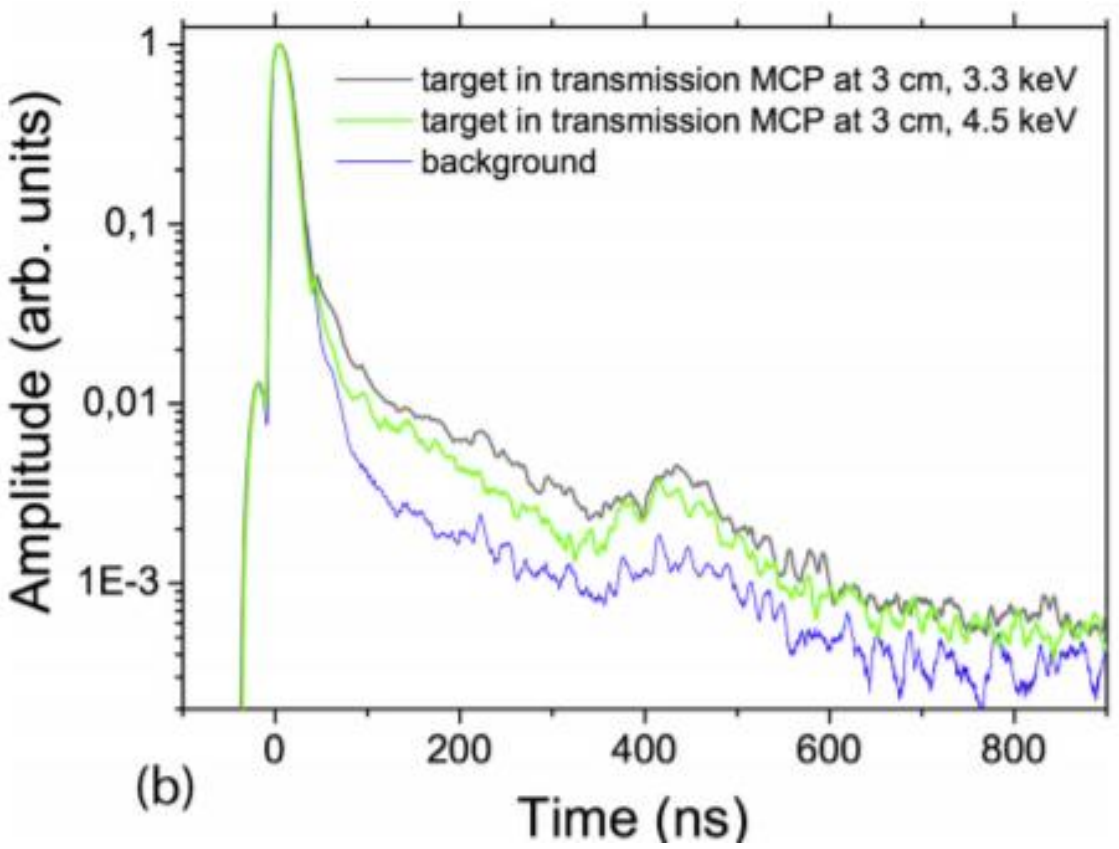
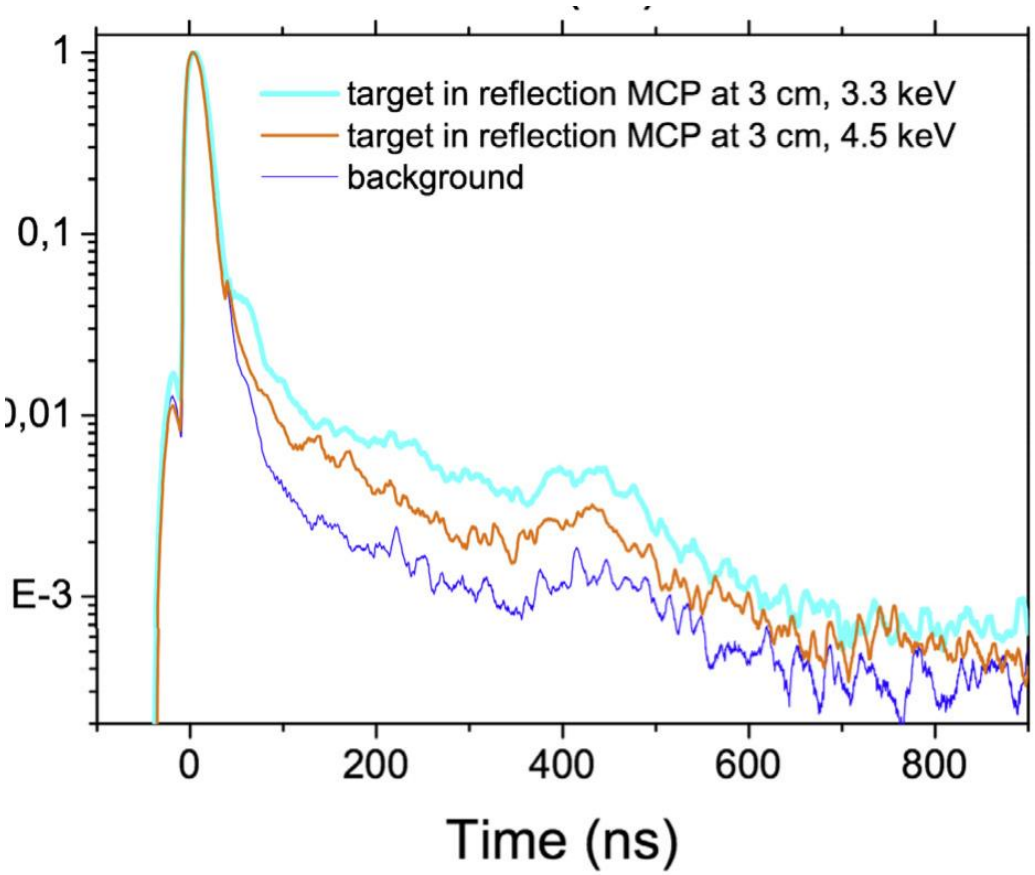
Self-standing



Carbon-supported Transmission target





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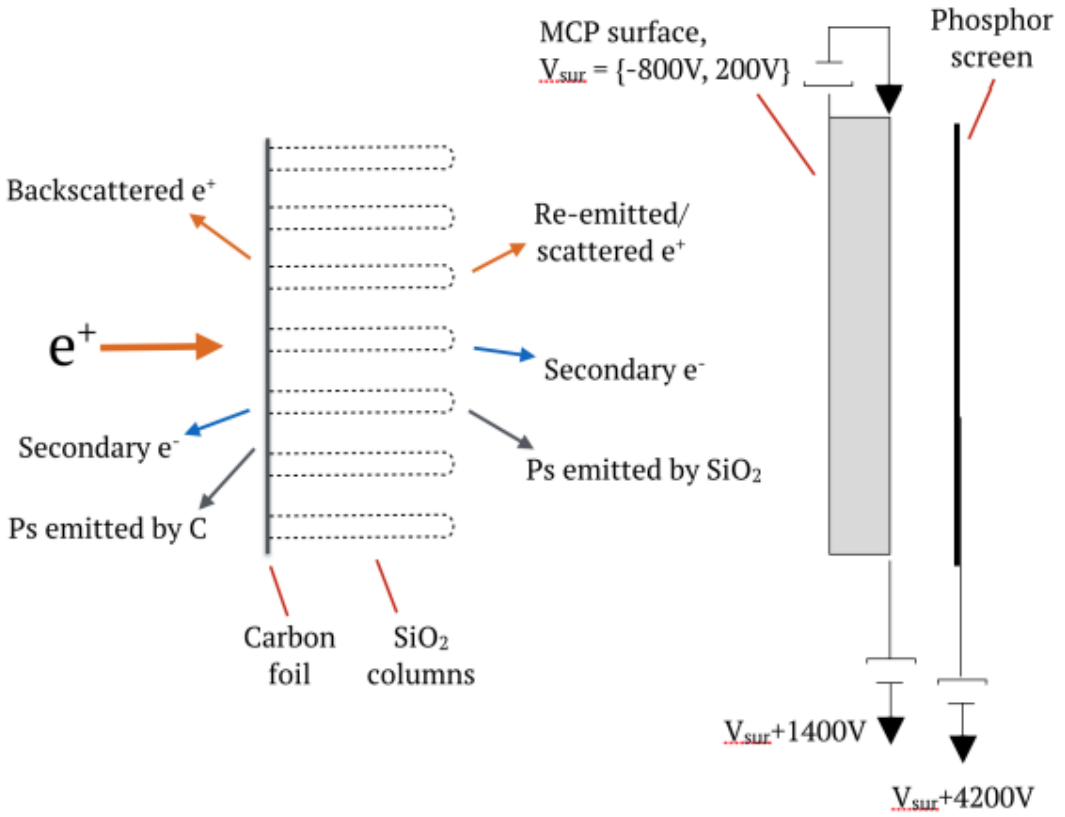
Carbon-supported Transmission target



(a) Transmission configuration

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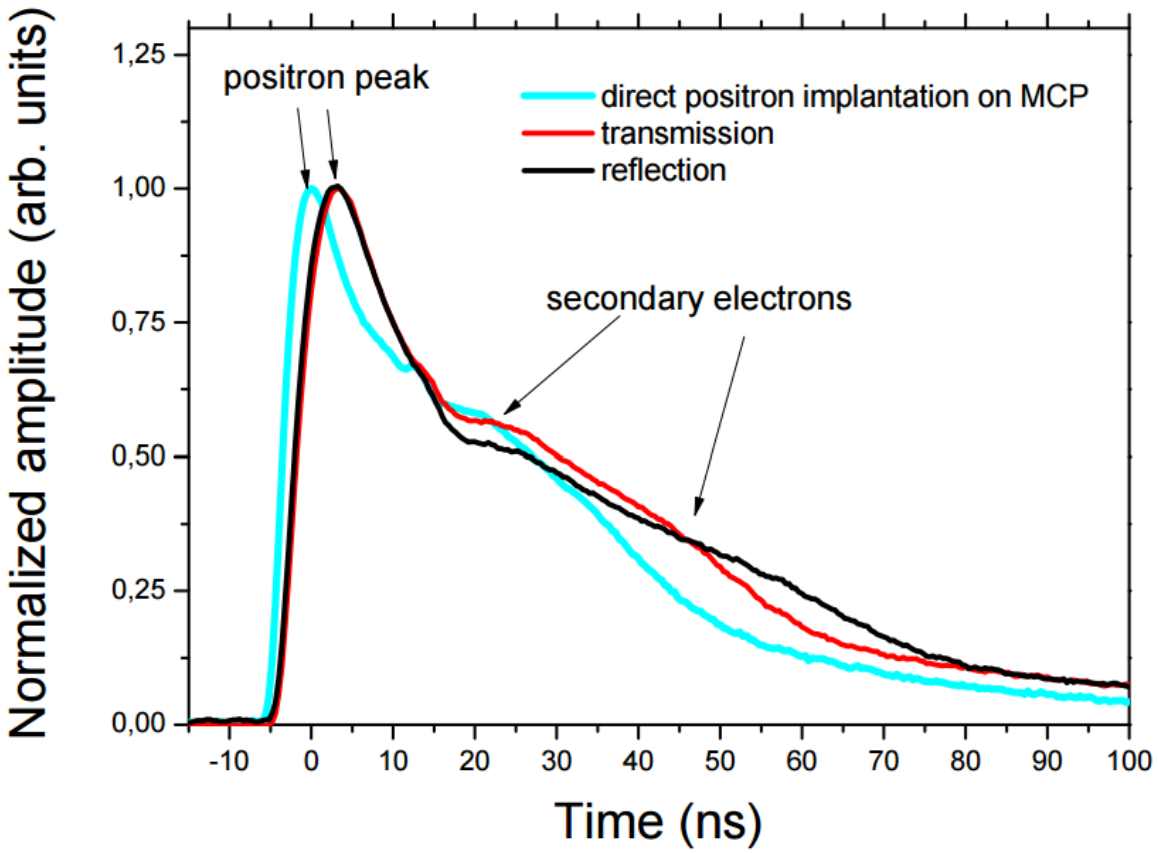
Carbon-supported Transmission target



- Low energy limit of 1.4 – 2 keV needed to pass the carbon layer.
- This in turn allows a portion of positrons to be emitted.
- Secondary electrons are also emitted

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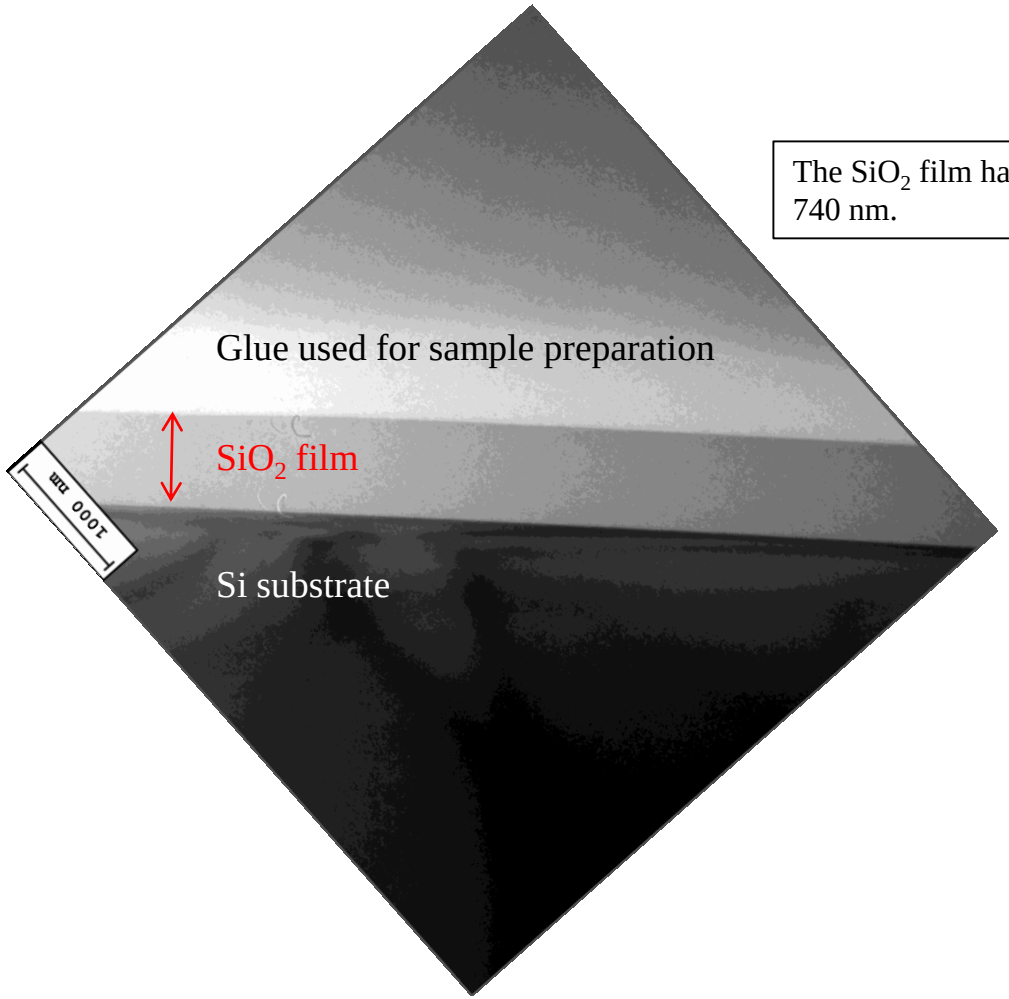
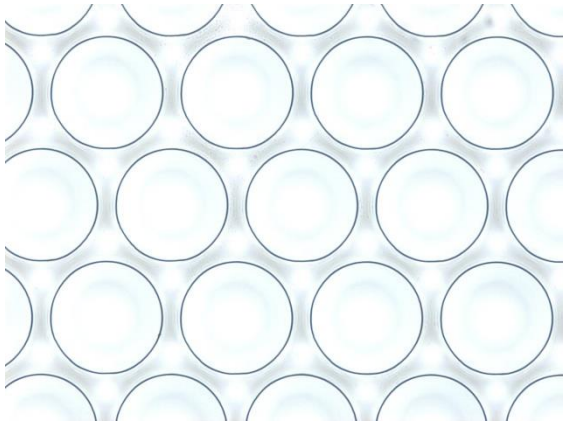
Self-standing transmission target



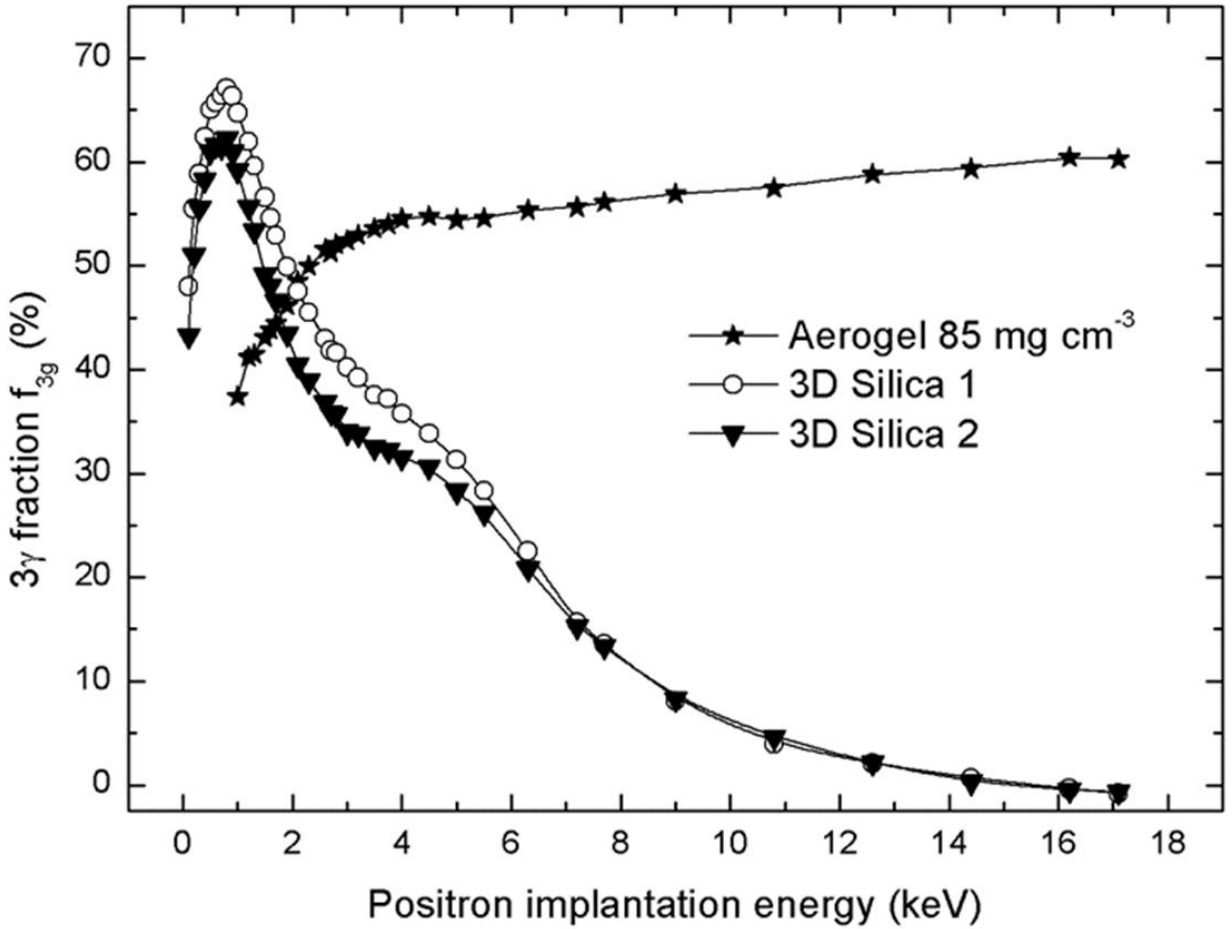
The SiO_2 film has a uniform thickness of about 740 nm.



Empty/cell area~68%

TOP: 130µm

Self-standing transmission target



- 68% o-Ps formation at low energies
- Thickness 740 nm
- Made self-standing via transferal
- No barrier to overcome
(lower implantation energies possible)

Conclusion

- Positrons were transported to the 1 T Ps converter to near 100% efficiency.
- Positronium was produced and excited to n=3 for the first time.
- Positronium Transmission Target was tested.
- New self-standing targets have been developed.

Future Work

- To excite Ps inside the Anti-hydrogen production trap
- Produce Rydberg anti-hydrogen via charge exchange
- Find way of eradicating secondary electrons and positrons from transmission target output
- Implement Ps transmission target inside 1T zone
- Test Self-standing Target at CERN (January, 2018)
- Observe the gravitational effect on anti-hydrogen

Thank you