Antimatter freefall:
The $AE\bar{g}IS$ experiment at CERN

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On behalf of the **AEgIS collaboration**

from

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OUTLINE

- The AEgIS experiment
- The role of Positronium in the AEgIS experiment
- Current status: latest results

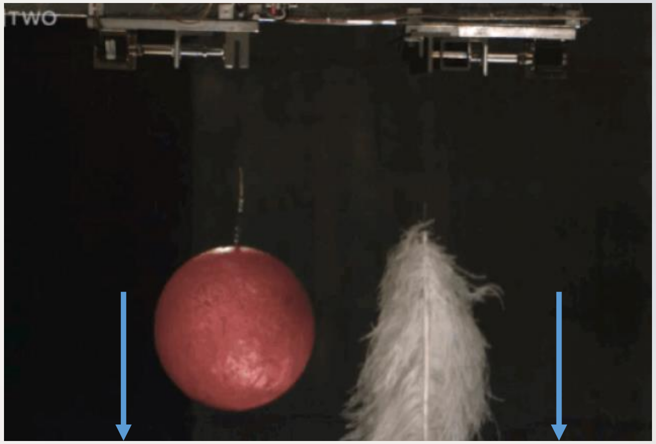
The physics of the AEgIS experiment

The weak equivalence principle (WEP)

CPT symmetric situation

All *matter* bodies at the same space-time point in a given *matter* gravitational field will undergo the same acceleration

All *antimatter* bodies at the same space-time point in a given *antimatter* gravitational field will undergo the same acceleration



The weak equivalence principle (WEP)

All *matter* bodies
space-time poir
matter gravitati
undergo th
accelera

Will *antimatter* bodies at the same space-time point in a given *matter* gravitational field undergo the same acceleration?

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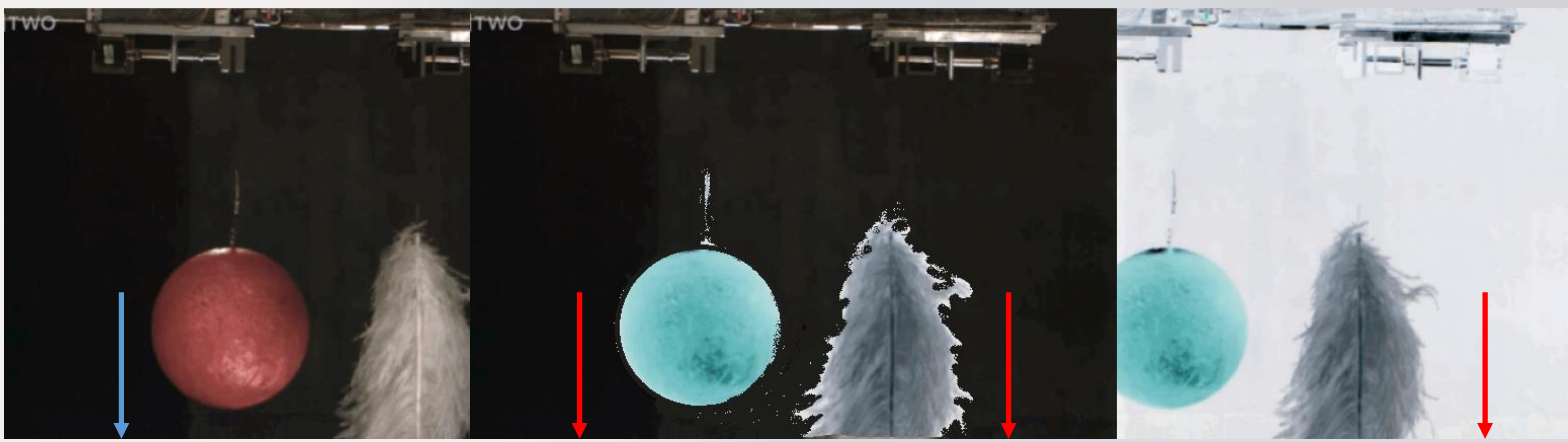


AEgIS collaboration

Stefan Meyer Institute

CERN

Czech Technical University

ETH Zurich

University of Genova

University of Milano

University of Padova

University of Pavia

Institute of Nuclear Research of the Russian Academy of Science

Max-Planck Institute Heidelbert

Politecnico di Milano

University College London

University of Bergen

University of Bern

University of Brescia

Heidelberg University

University of Lyon 1

University of Oslo

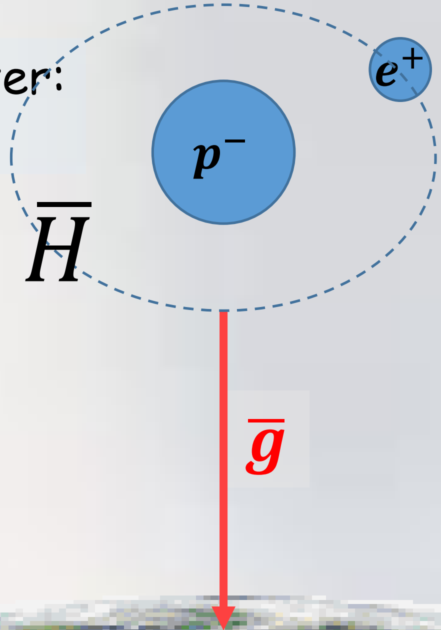
University of Paris Sud

University of Trento

INFN sections of: Genova, Milano, Padova, Pavia, Trento

The main goal of AEgIS

Neutral antimatter:
Antihydrogen



Measurement of the gravitational acceleration $\bar{g}$ of the antimatter into the Earth gravitational field

Antihydrogen production

Charge exchange with Positronium

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

AEgIS strategy

PROMISING TECHNIQUE

- Control of the antihydrogen quantum state
- Cold antihydrogen atoms ($v_{antihydrogen} \sim v_{antiproton}$)
- *Advantages in the cross section (see later)*

$$\sigma \sim 10^{-13} cm^2$$

Antiprotons and positrons Recombinations

$$\bar{p} + e^{+} \rightarrow \bar{H} + h\upsilon$$

and

$$\bar{p} + e^{+} + e^{+} \rightarrow \bar{H} + e^{+}$$

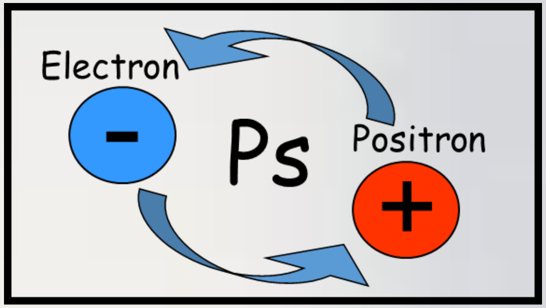
Other strategies

- The second seems to be the dominant process (highly exicited antihydrogen)
- Antihydrogen atoms warmer than trapped antiprotons (Hbar production when $v_{antiproton} \sim v_{positron}$)
- *Cross section*

$$\sigma < 10^{-33} cm^2$$

Positronium atom

Purely leptonic atom



Ps n-level energy

$$E_{Ps_n} = \frac{E_{H_n}}{2}$$

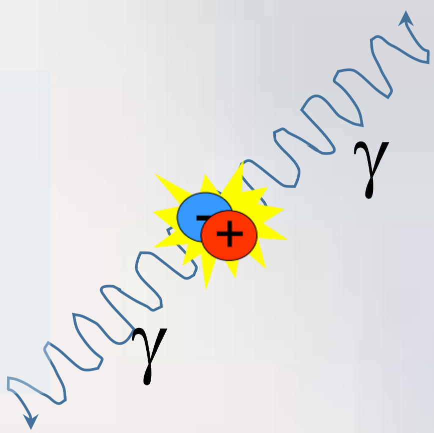
para-Ps

Singlet state

Mean lifetime

0,125ns

2γ annihilation



γ Energies = 511keV

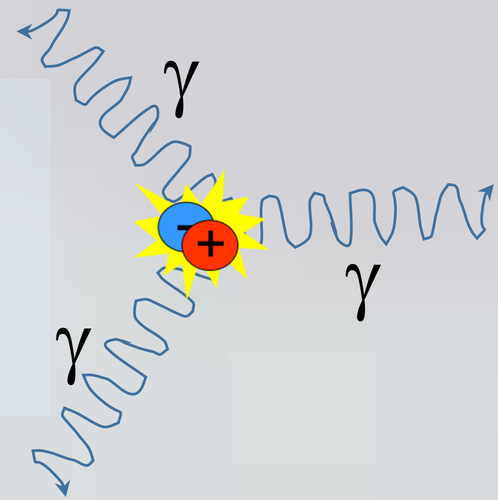
orto-Ps

Triplet state

Mean lifetime

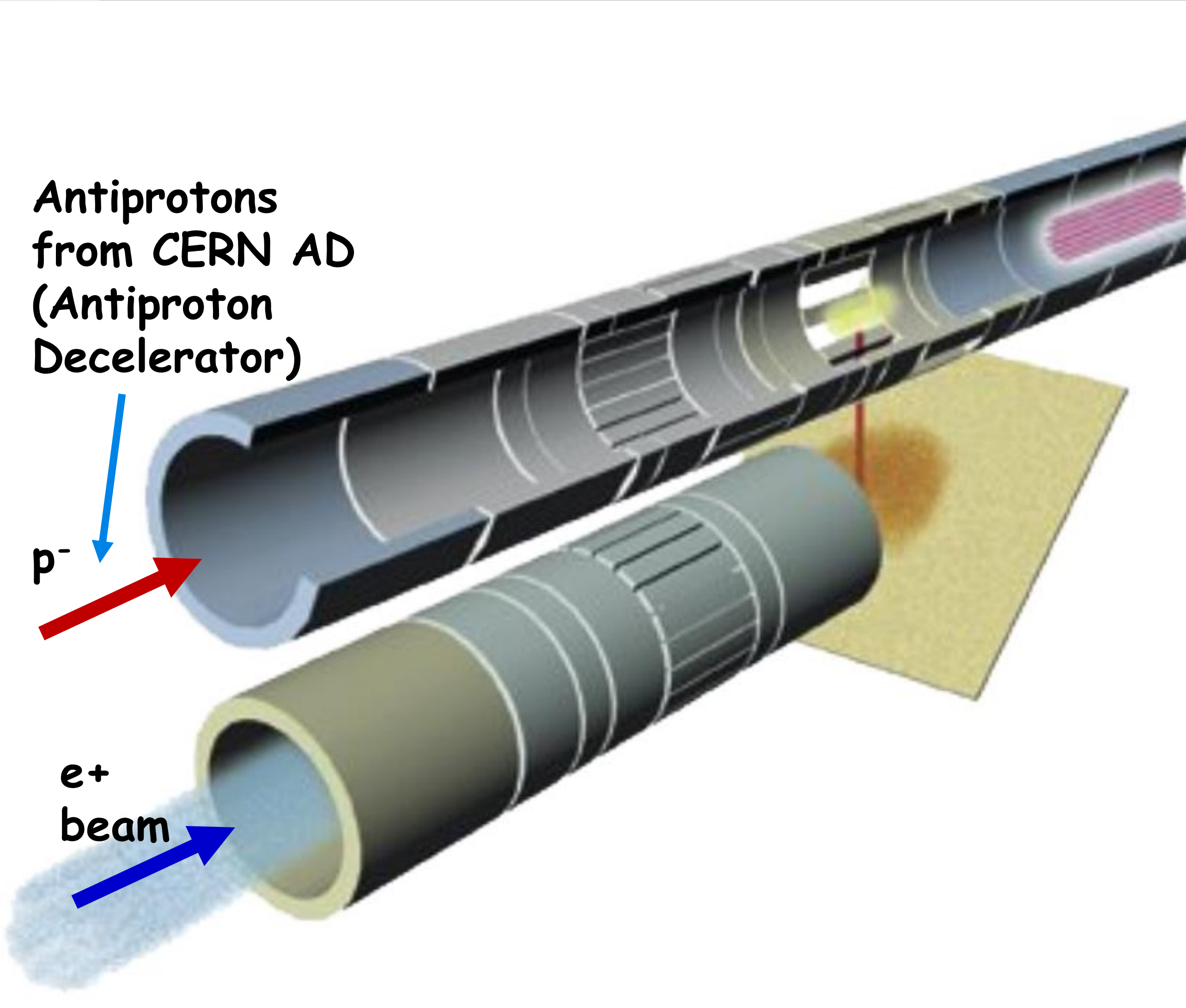
142ns

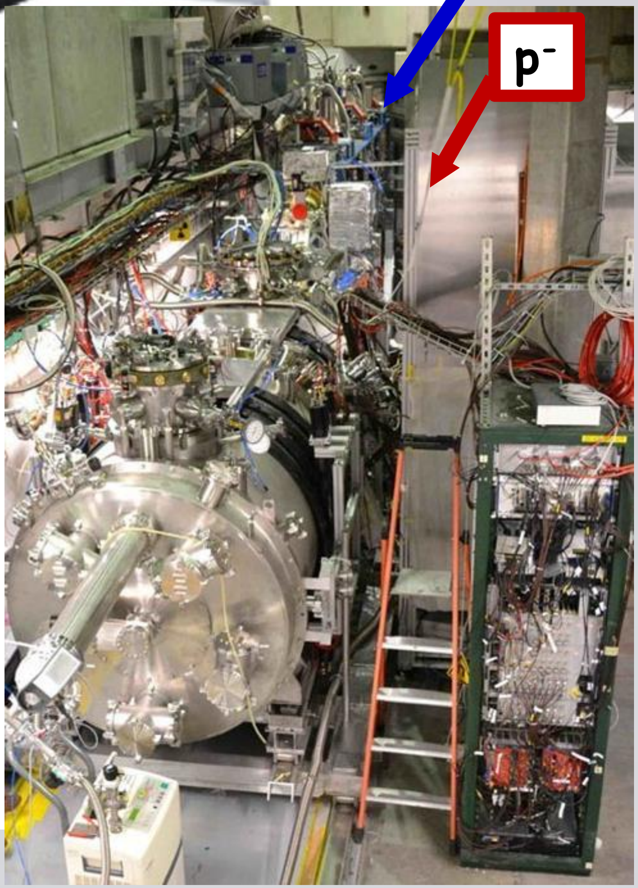
3γ annihilation



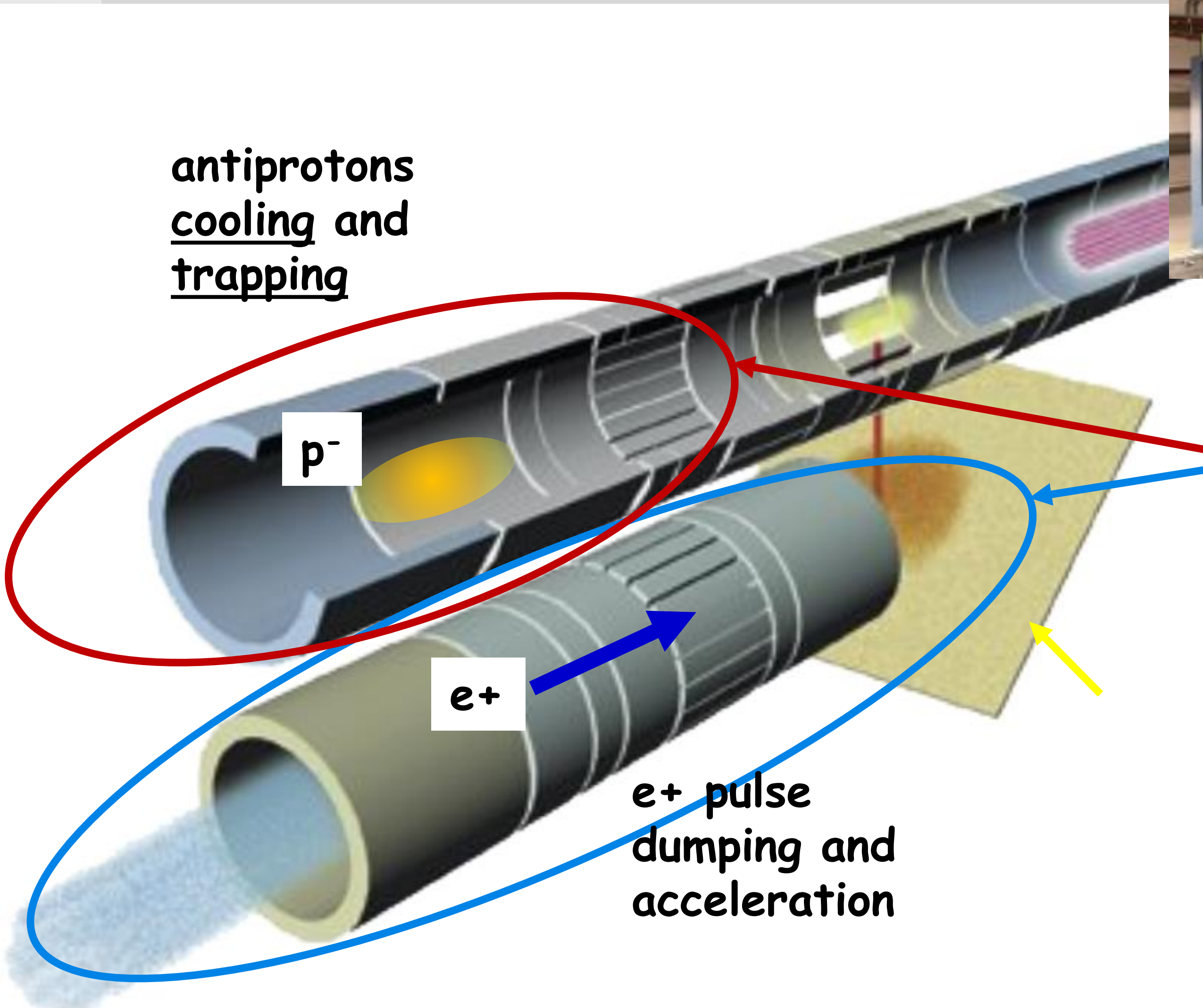
γ Energies < 511keV

AEgIS in short

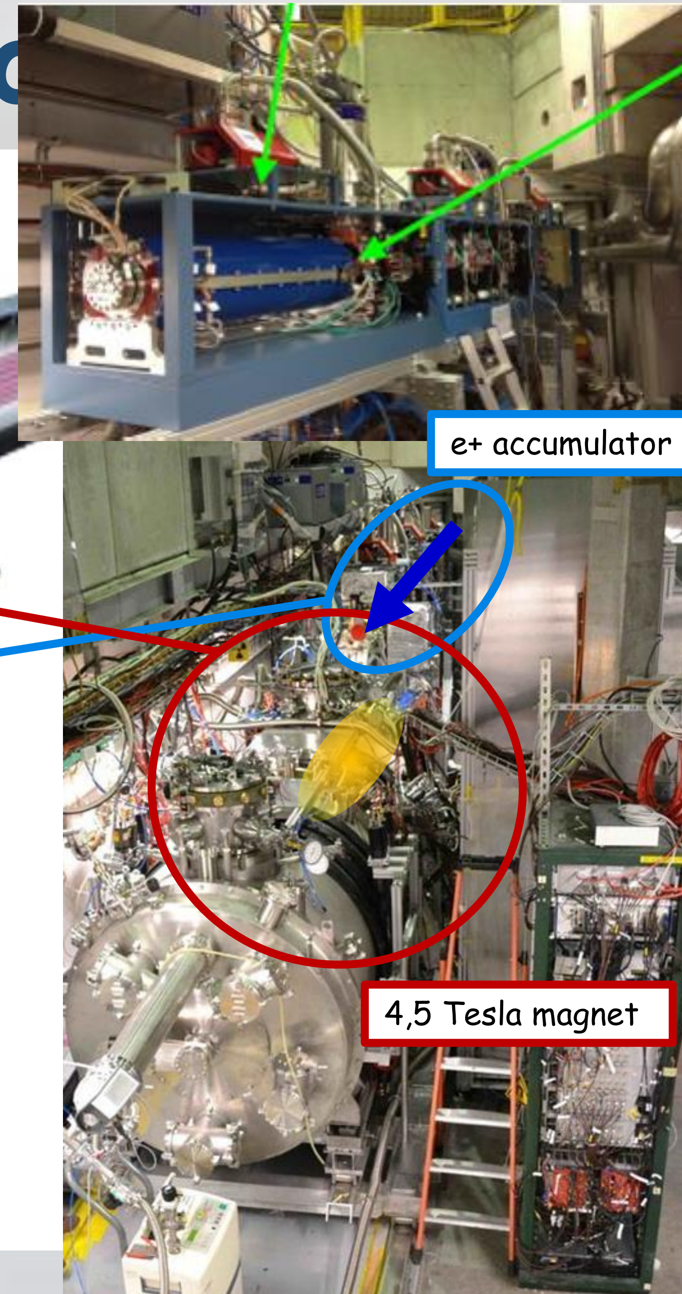




AEgIS in sh

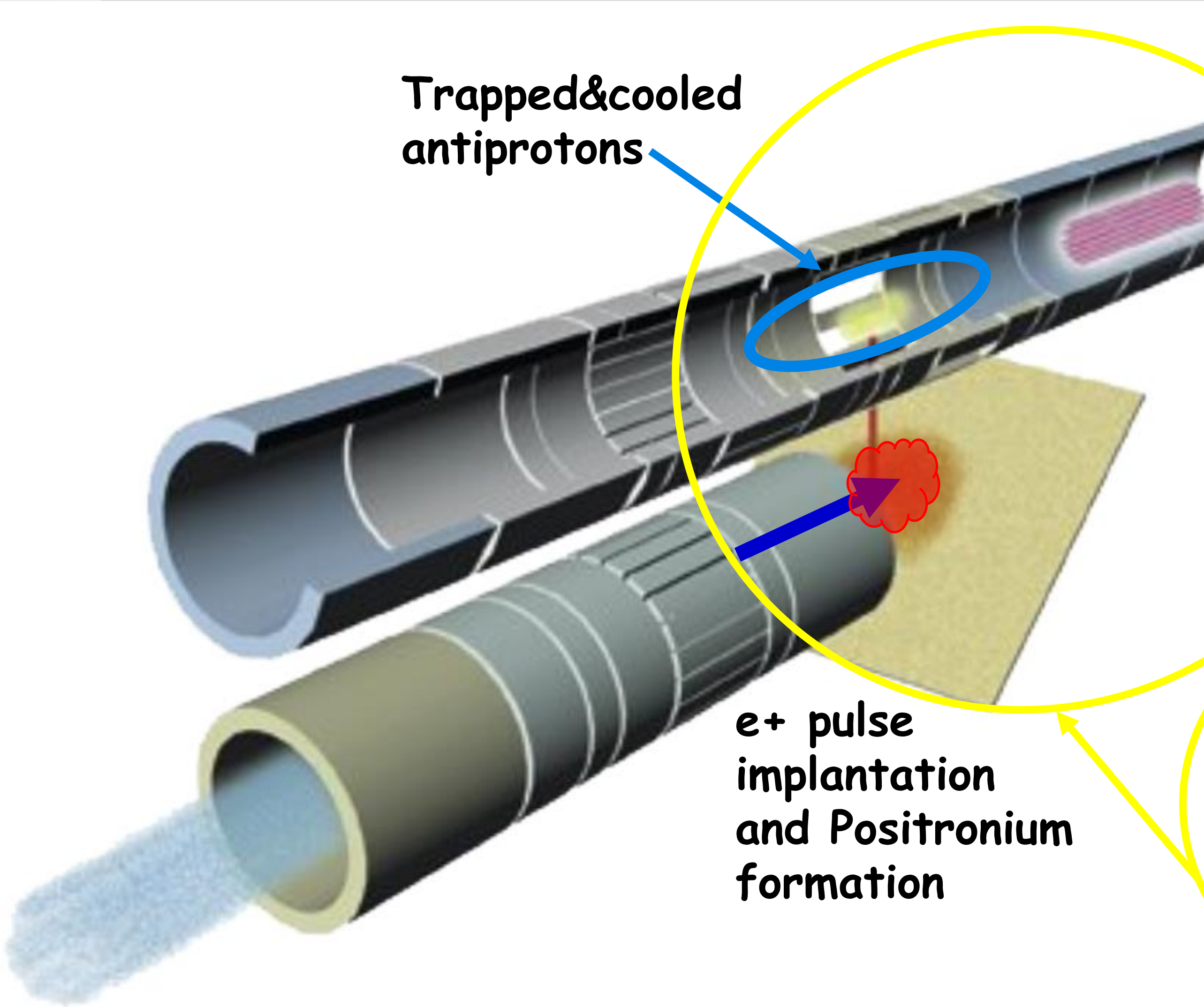


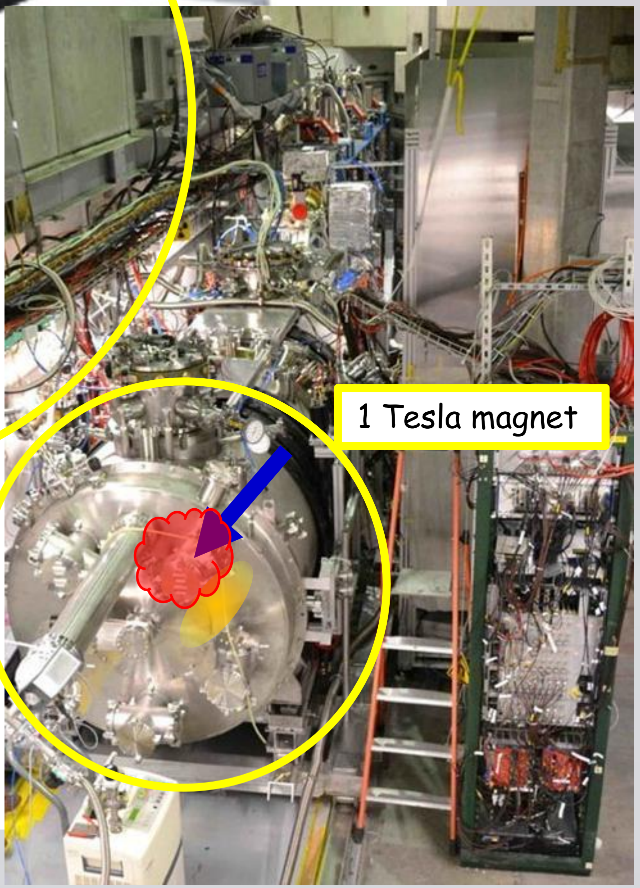
antiprotons cooling and trapping
p-
e+
e+ pulse dumping and acceleration



e+ accumulator
4,5 Tesla magnet

AEgIS in short

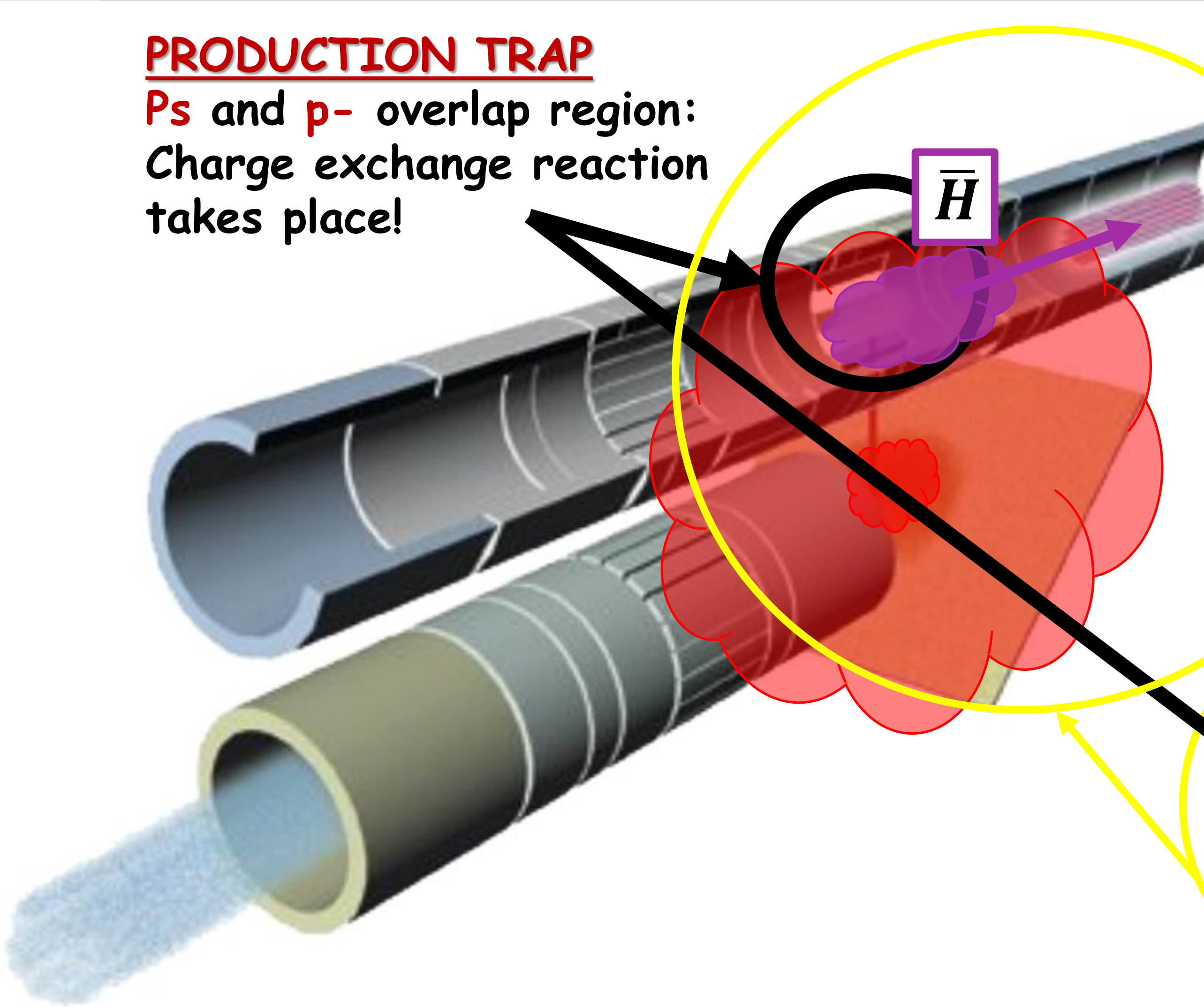


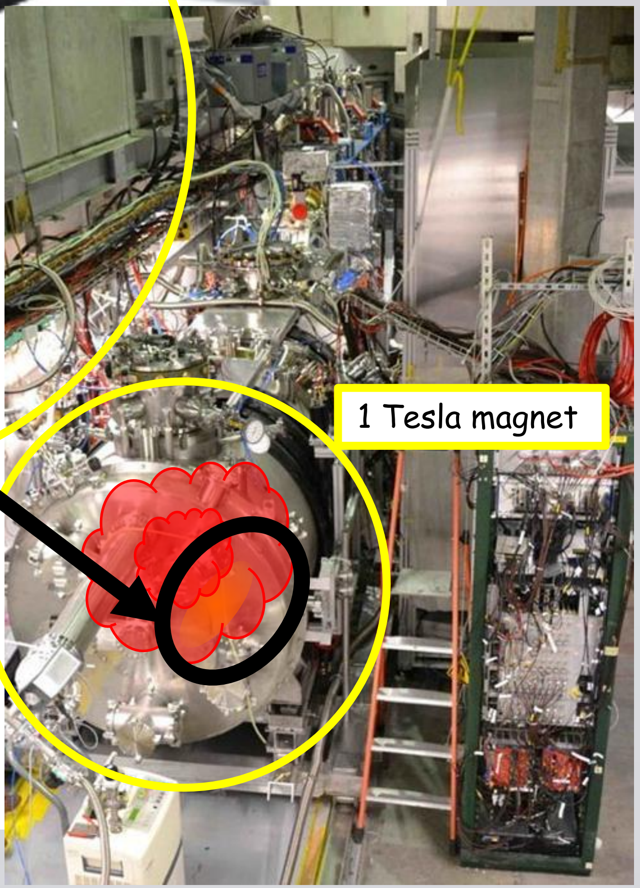


AEgIS in short

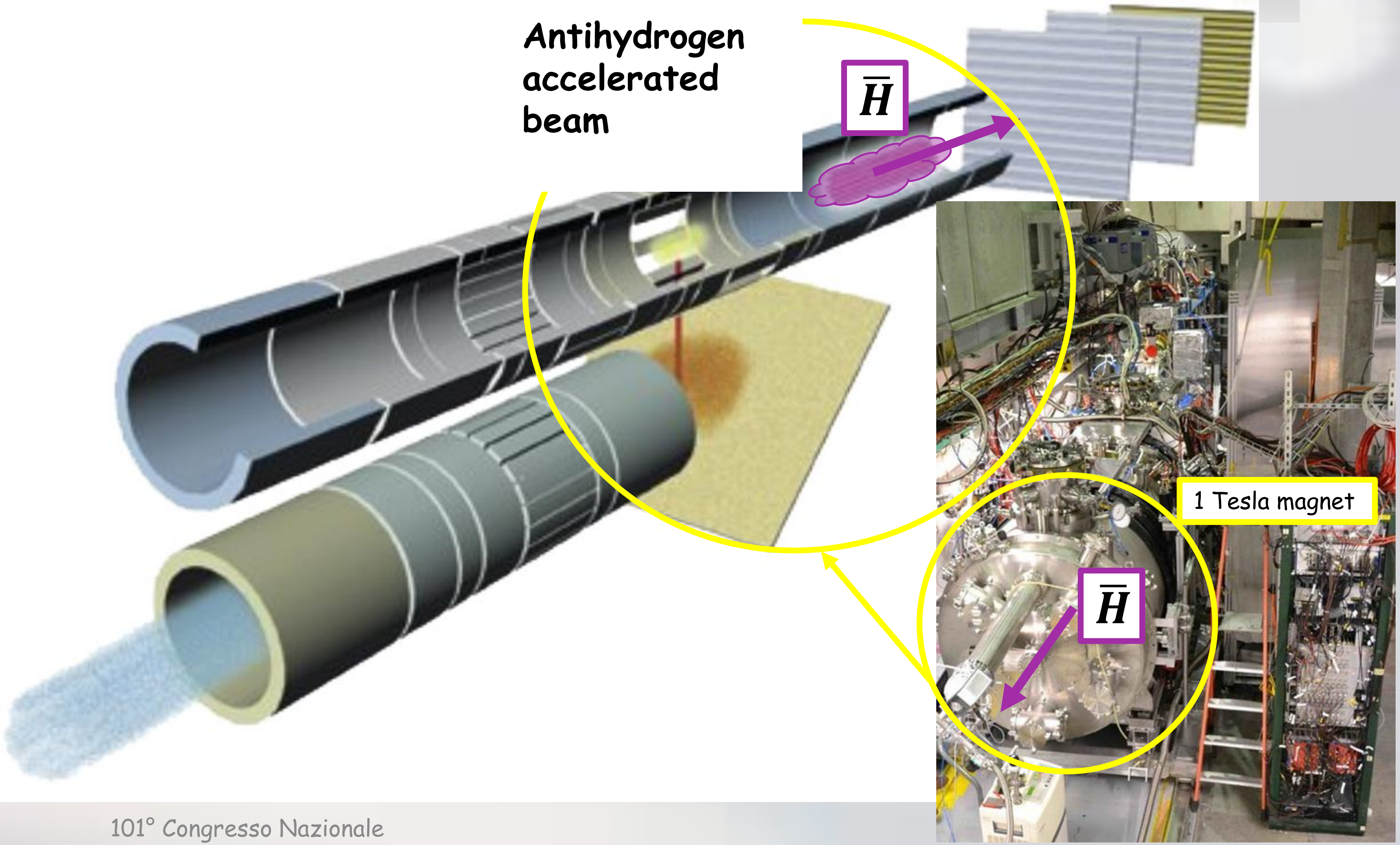
PRODUCTION TRAP

Ps and p- overlap region:
Charge exchange reaction takes place!

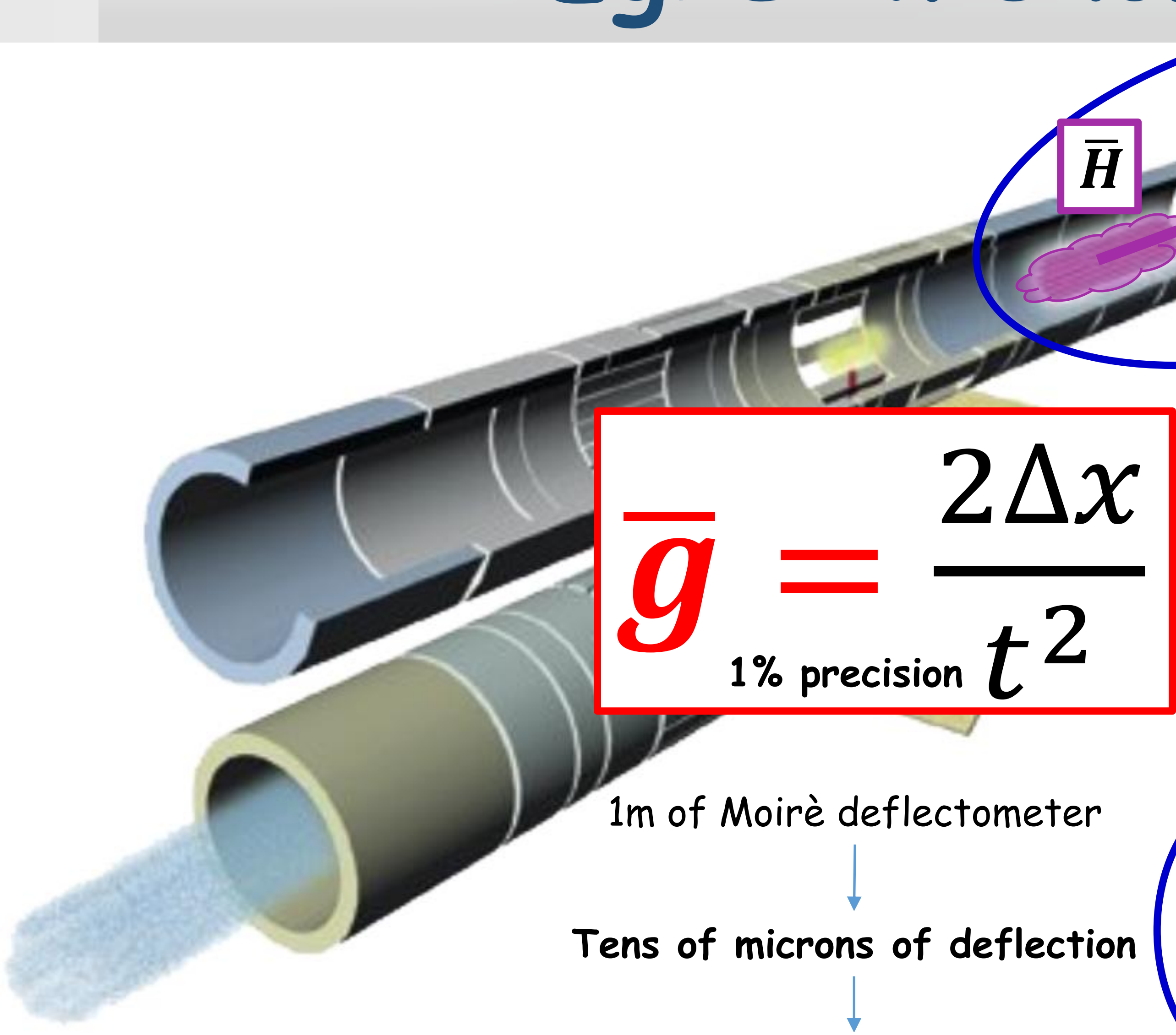




AEgIS in short



AEgIS in short



$$\bar{g} = \frac{2\Delta x}{t^2}$$

1% precision

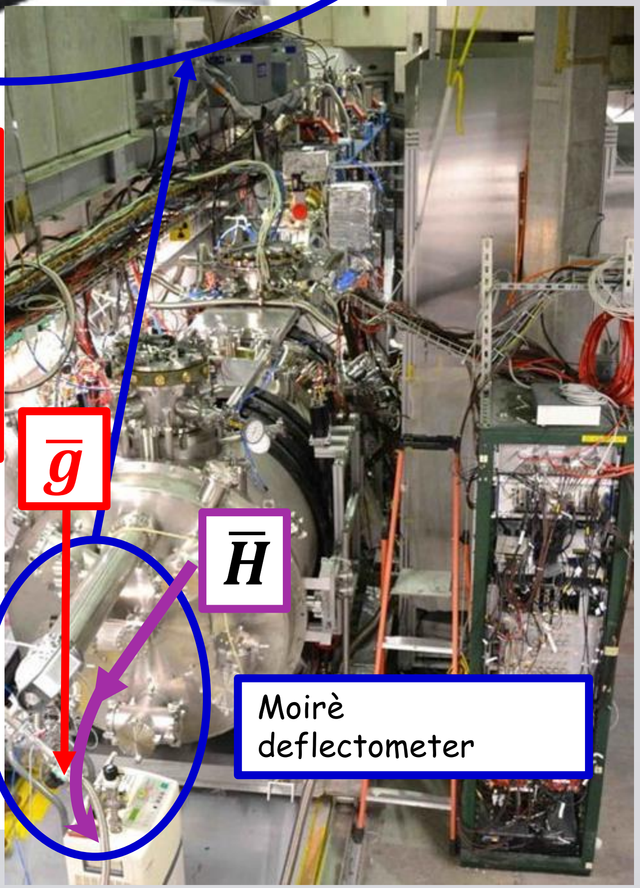
1m of Moirè deflectometer

↓

Tens of microns of deflection

↓

Use of emulsions

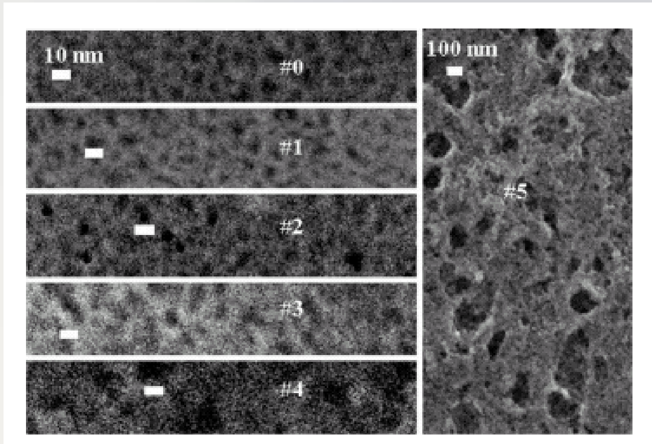


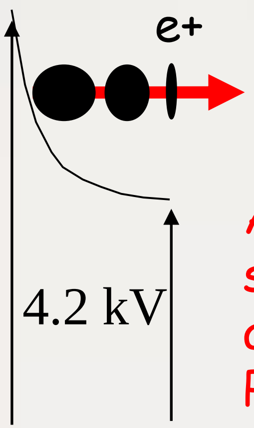
Role of Positronium in AEgIS

The Positronium production

e+/Ps converter

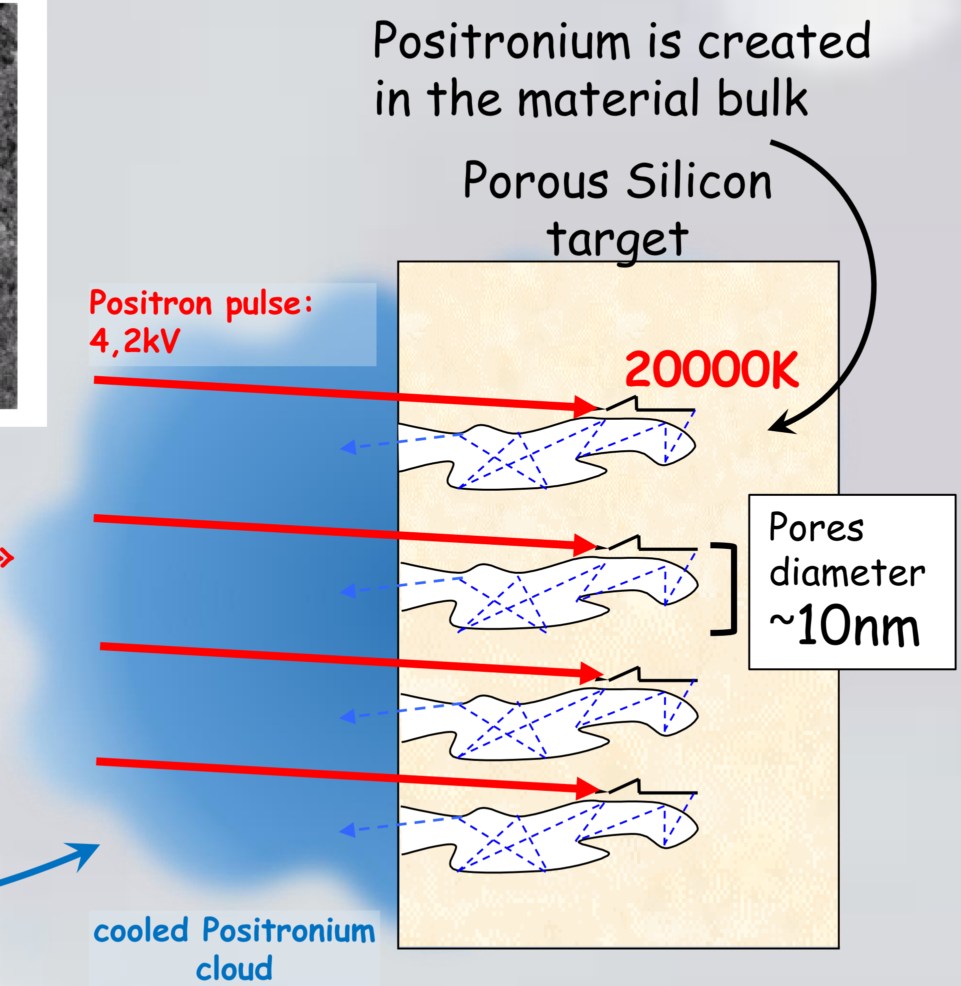
Nanochanneled Si
Frontal view





A bunched positron beam is sent toward a porous «target» able to convert positrons into Positronium.

A fraction of the Ps exiting the target is thermalized into the target pores



The role of Positronium in AEgIS

Ps is needed to generate Antihydrogen in the **Charge exchange reaction**

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

The **cross section** of this reaction increases with the Ps principal quantum number:

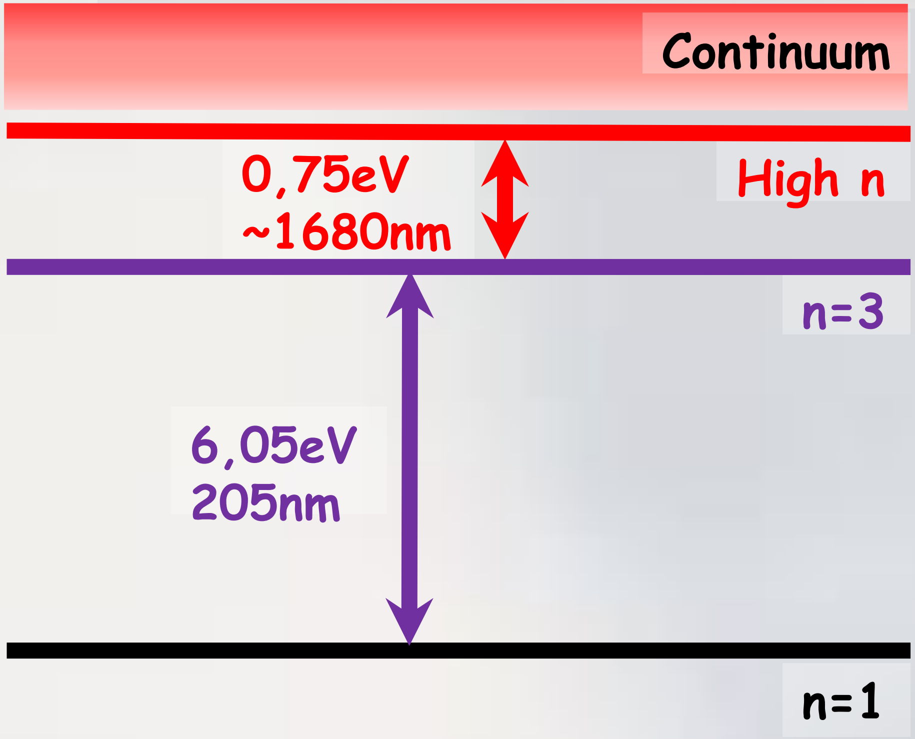
$$\sigma \sim a_0^2 n^4$$

Required Ps excitation to Rydberg levels (n=15...24) !!!

Not too high, for ionization issues induced by the strong magnetic field inside the $\overline{H}$ production trap **(motional Stark field E)**

Positronium laser excitation and detection

AEgIS Ps Rydberg laser excitation strategy



Final Rydberg excitation efficiency for a TWO STEP STRATEGY
(simple 3-level model of Ps in field free environment)

1->3->n = 30%

PHYSICAL REVIEW A **78**, 052512 2008: **Efficient positronium laser excitation for antihydrogen production in a magnetic field**, F. Castelli, I. Boscolo, S. Cialdi, and M. G. Giammarchi, D. Comparat

NIMB 269 (2011) 1527–1533: **Efficient two-step Positronium laser excitation to Rydberg levels**, S. Cialdi, I. Boscolo, F. Castelli, F. Villa; G. Ferrari, M.G. Giammarchi

Current status for Positronium and antiprotons

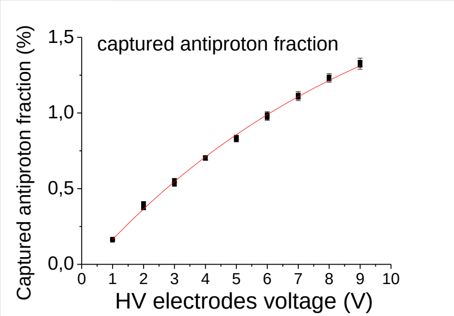
Achievements towards the gravity measurement

- Catching and cooling of large number of antiprotons
- Transfer of the antiproton plasma in the production trap
- Production, transfer and storage of a high number of positrons
- Studies of Ps formation and laser excitation to Rydberg levels[1]

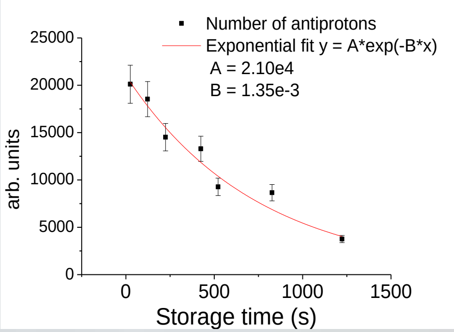
Antiprotons

Catching and cooling of large number of antiprotons

- 1.3% catching efficiency obtained at 9 kV, corresponding to around $4 \cdot 10^5$ pbars

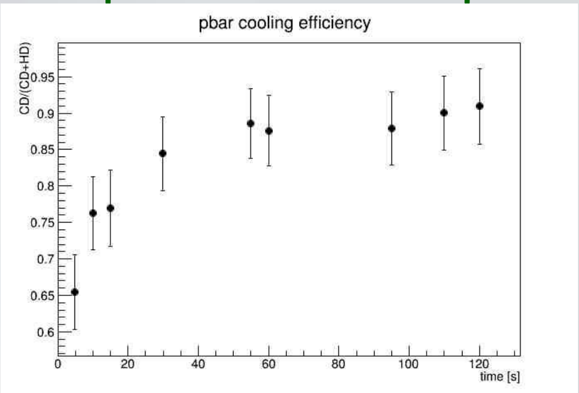


- Antiprotons stored with a lifetime $\tau = 13min$



Transfer of the antiproton plasma in the production trap

- 90% cooling efficiency
- temperature of 10-20K

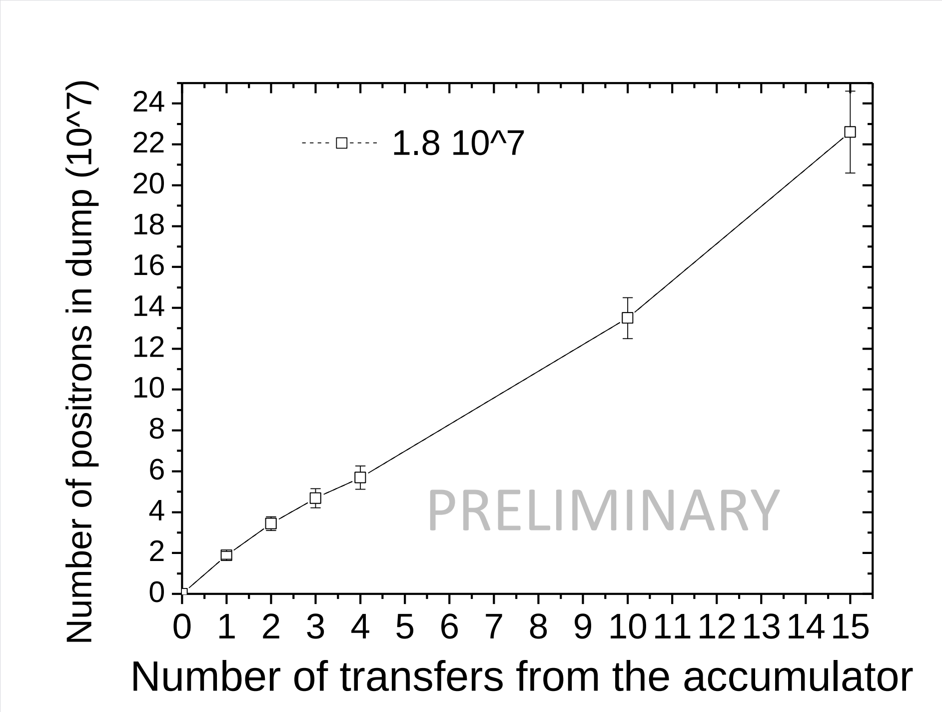


Positrons

Catching and cooling of large number of positrons

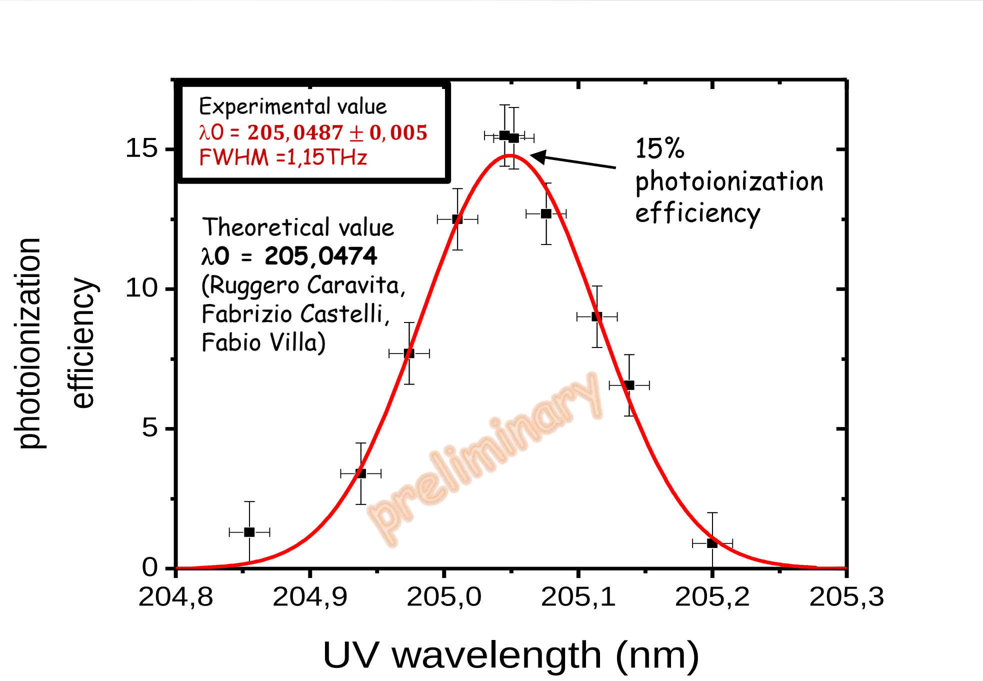
- $> 95\%$ transfer and cooling efficiency when more than $10^{\wedge}7 e^{+}/shot$ are manipulated

- $2{,}2 \times 10^{8} e^{+}$ stacked in 1hour

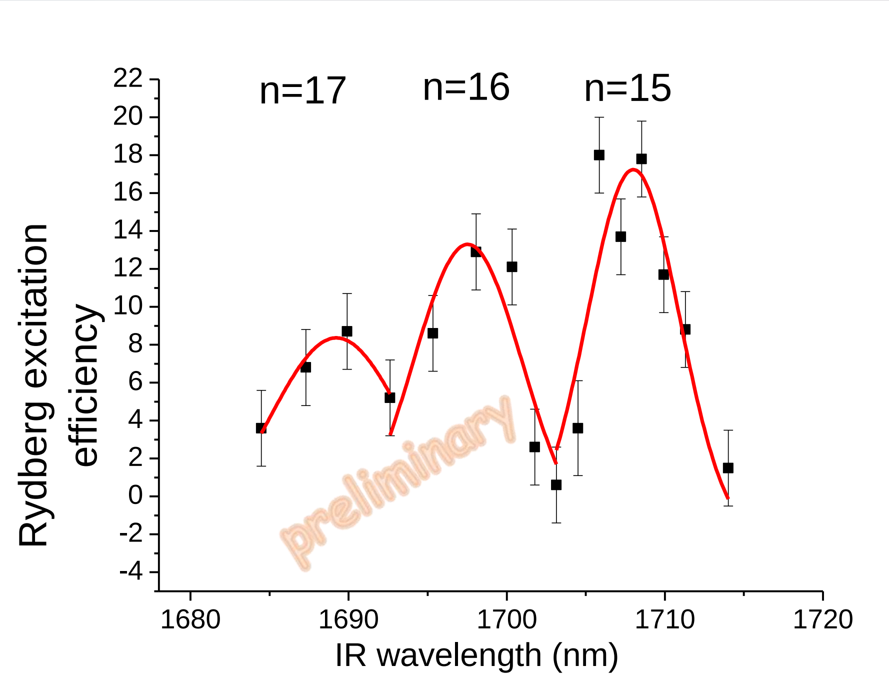


Positronium

n=3 excitation evidence



Rydberg n=15-16-17 excitation evidence



Conclusions & next goals

CURRENT STATUS

Antiprotons

- 1.3% catching efficiency obtained at 9 kV, corresponding to around $4 \cdot 10^5$ pbars
- Antiprotons stored with a lifetime $\tau = 13min$
- 90% cooling efficiency
- temperature of 10-20K

Positrons

- $> 95\%$ transfer and cooling efficiency when more than $10^\wedge 7e^+/shot$ are manipulated
- $2{,}2 \times 10^8 e^+$ stacked in 1hour

Positronium

- n=3 excitation evidence (via photoionization)
- n=15-16-17 excitation evidence

NEXT STEPS

Main magnet (1T)

- Off-axis recapture of positrons: for Ps production inside the 1T magnet
- Ps excitation in the 1T magnet
- Antihydrogen production in the production trap

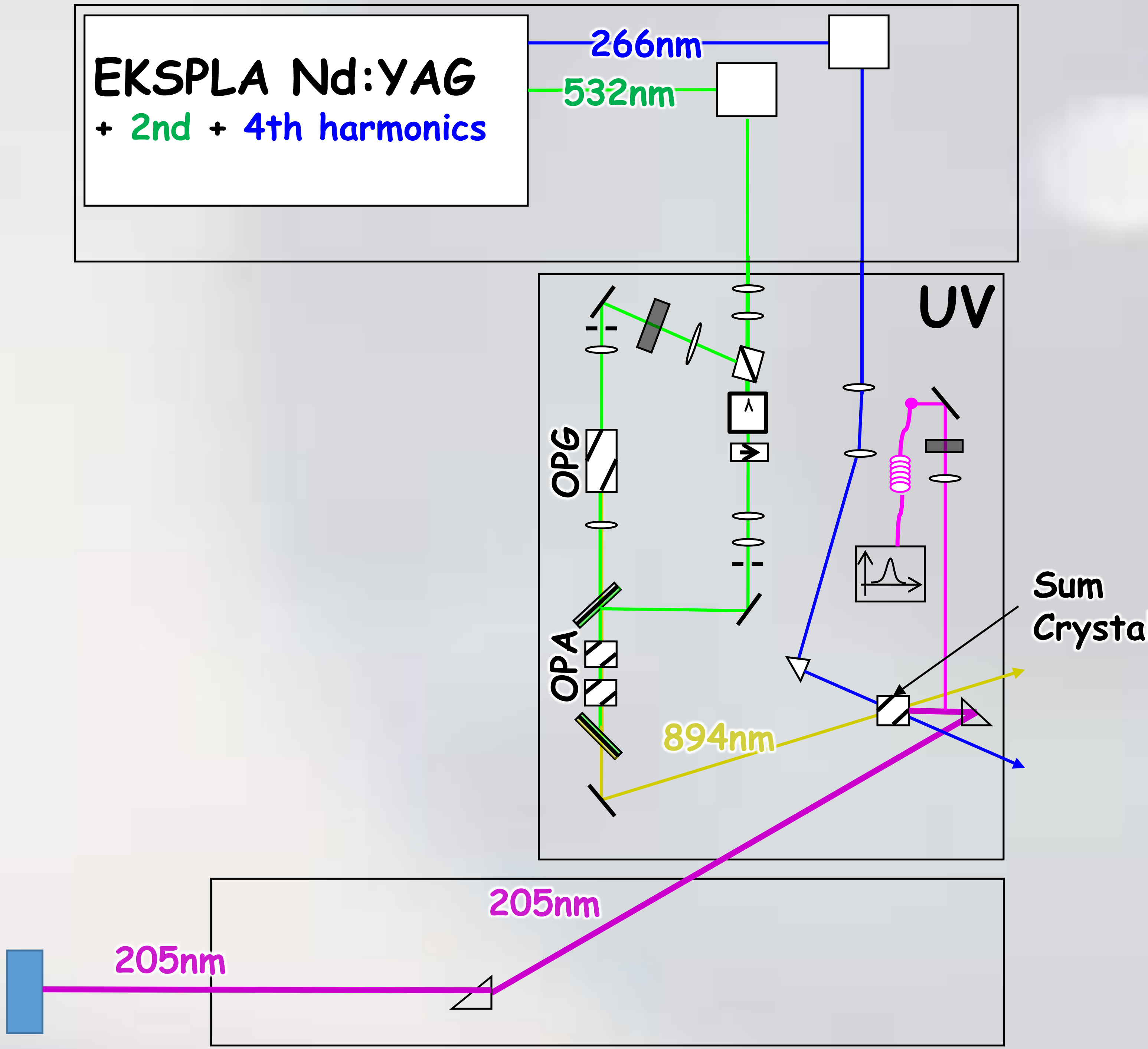
External Ps Experimental Chamber

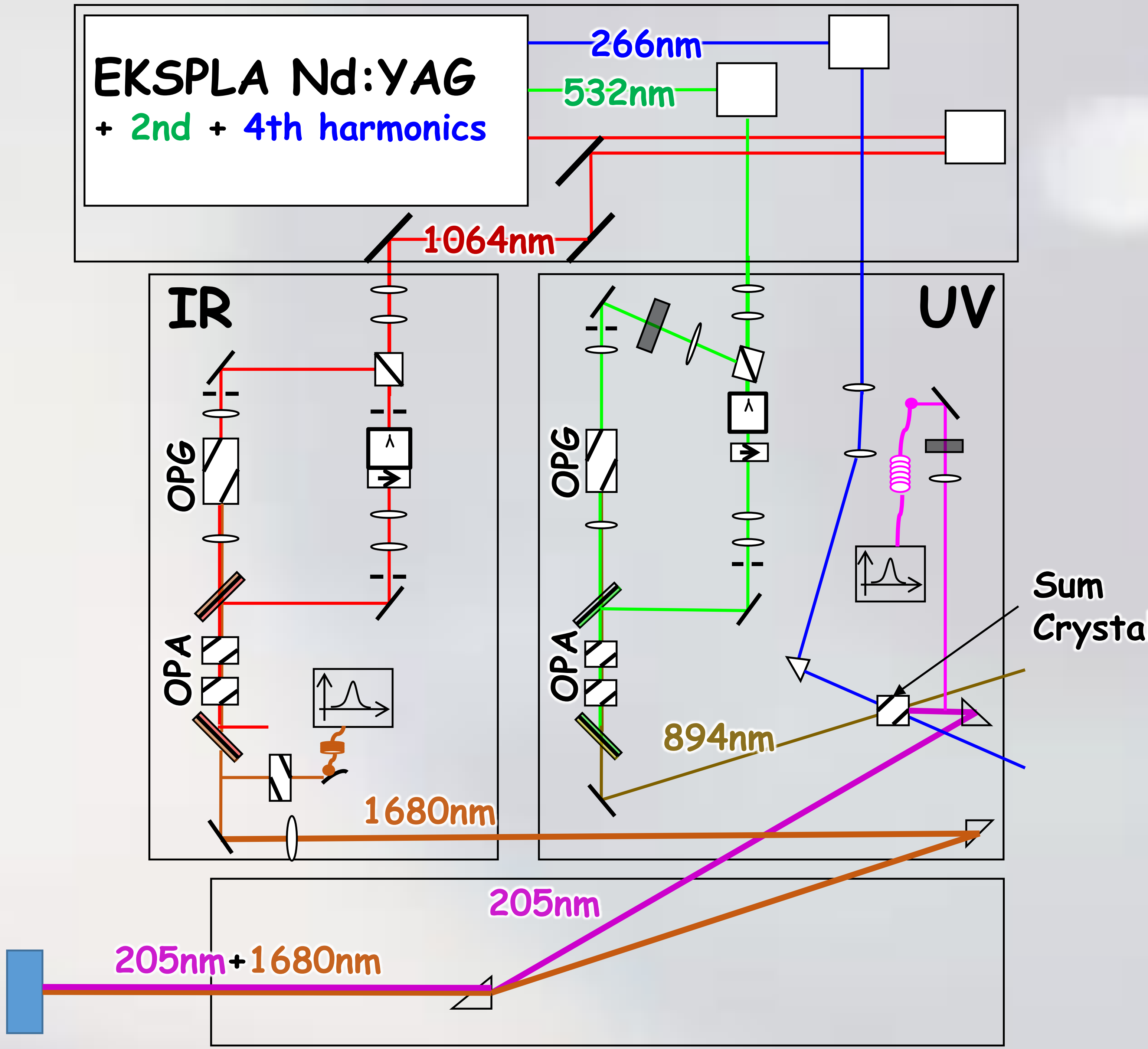
- Deeper study on Rydberg excitation efficiencies
- Resonance studies for chosing the best Ps converter for the 1T magnet

Thank you for your attention

1.The lasers

How we produce the two wavelength for n=3 and Rydberg excitation


EKSPLA Nd:YAG
+ 2nd + 4th harmonics
266nm
532nm
UV
OPG
OPA
Sum Crystal
894nm
205nm
205nm


EKSPLA Nd:YAG
+ 2nd + 4th harmonics
266nm
532nm
1064nm
IR
OPG
OPA
1680nm
UV
Sum
Crystal
894nm
205nm
205nm+1680nm