

# WEIGHING ANTIMATTER

the AEGIS experiment at CERN

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On behalf of the AEGIS collaboration

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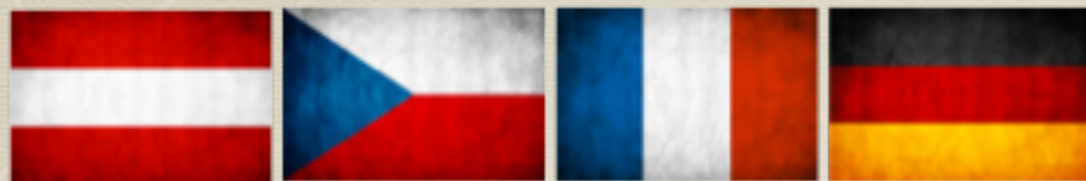


# Outline

- Motivation
- The AD and its experiments
- AEgIS
- The gravity measurement
- Positron spectroscopy
- Summary







# A E $\bar{g}$ I S 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 Heidelberg	 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			

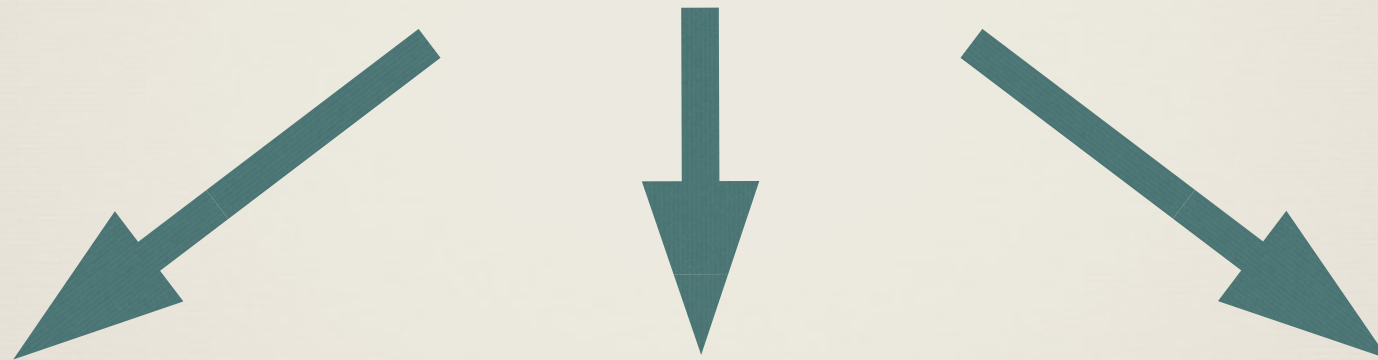


# Why do antimatter research?

Why there is a matter/antimatter asymmetry in the universe?



Looking for fundamental matter/antimatter asymmetries:



Quantum theory  
(CPT)  
violations?

Gravitational  
asymmetries?

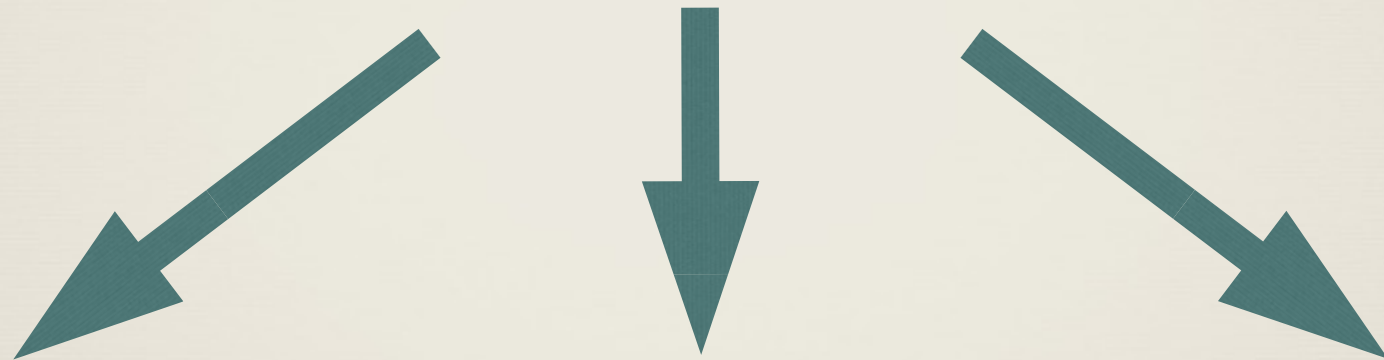
AOB... ?

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AOB... ?



# Motivation - new physics?

- \* General relativity is a classic (non quantum) theory
- \* Einstein Equivalence Principle violations may appear in some quantum theories
- \* New quantum scalar and vector fields are allowed in some models (Kaluza Klein ...)

Einstein field:                  Tensor graviton (spin 2)  
  
   + Gravi-vector (spin 1)  
  
   + Gravi-scalar (spin 0)

These fields may mediate interactions violating the equivalence principle.

M. Nieto and T. Goldman - Phys. Rep. 205, 5 221-281 (1992)

Scalar: “charge” of particle equal to “charge” of antiparticle (attractive force)

Vector: charge of particle opposite to charge of antiparticle (repulsive/attractive force)

*Cancellation between vector and scalar components is possible for matter!*

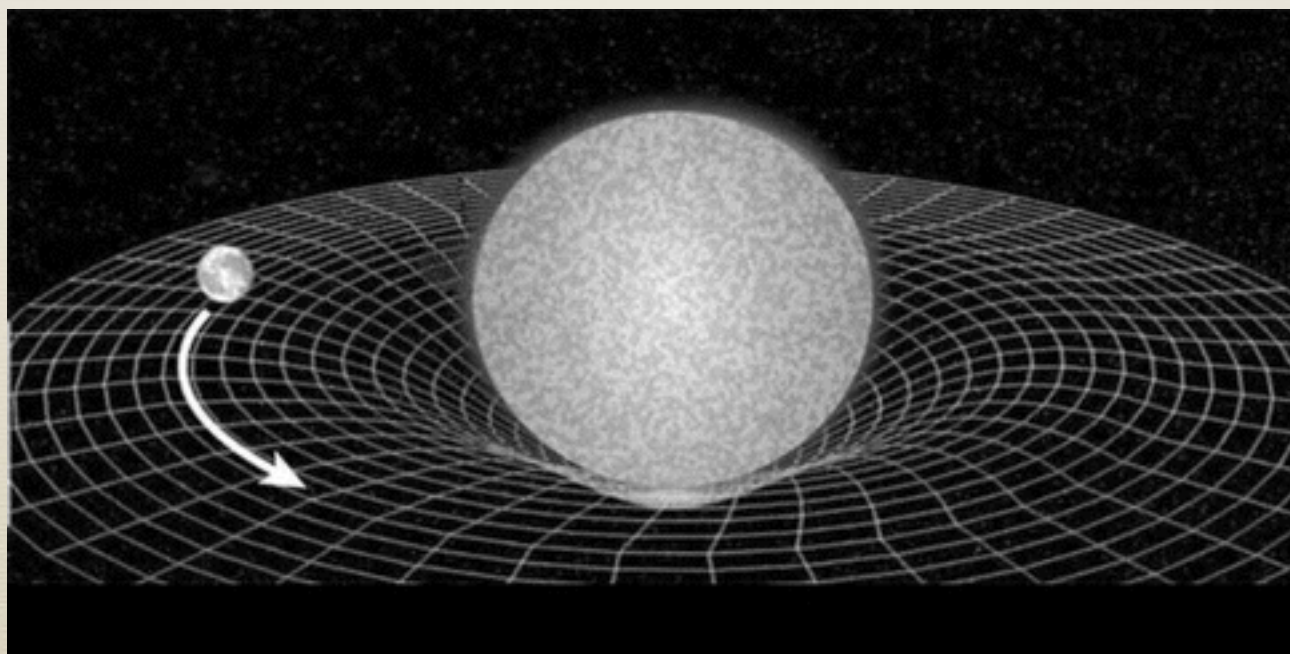


# Einstein Equivalence Principle

The Einstein Equivalence Principle is summarised by the following 3 principles

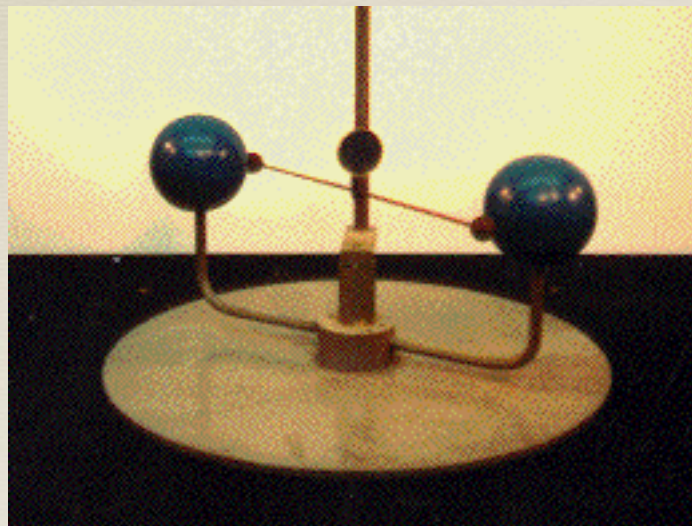
- ◆ Weak Equivalence Principle ( $m_i = m_g$ ) [*More details on this in next slides*] +  
For any non-gravitational experiment
- ◆ Lorentz Local Invariance (independence from any free falling frame of reference)
- ◆ Local Position Invariance (independence from position in the universe)

Verified e.g. through gravitational red shift





# WEP and matter

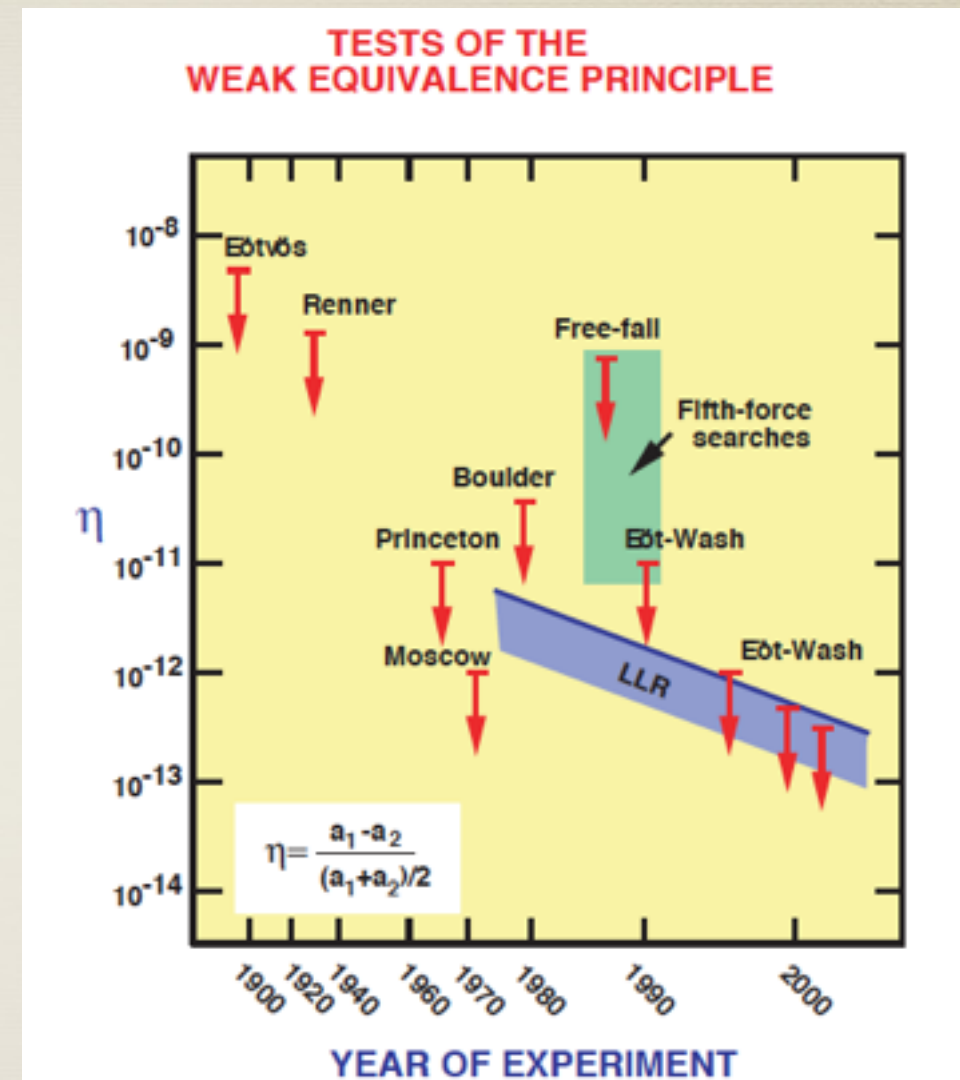


## Weak Equivalence Principle (WEP)

“The vacuum world line of a body immersed in a gravitational field is independent of all observable properties.”

Verification of the WEP for matter attained to  $10^{-13}$

No precise verification to date for antimatter.

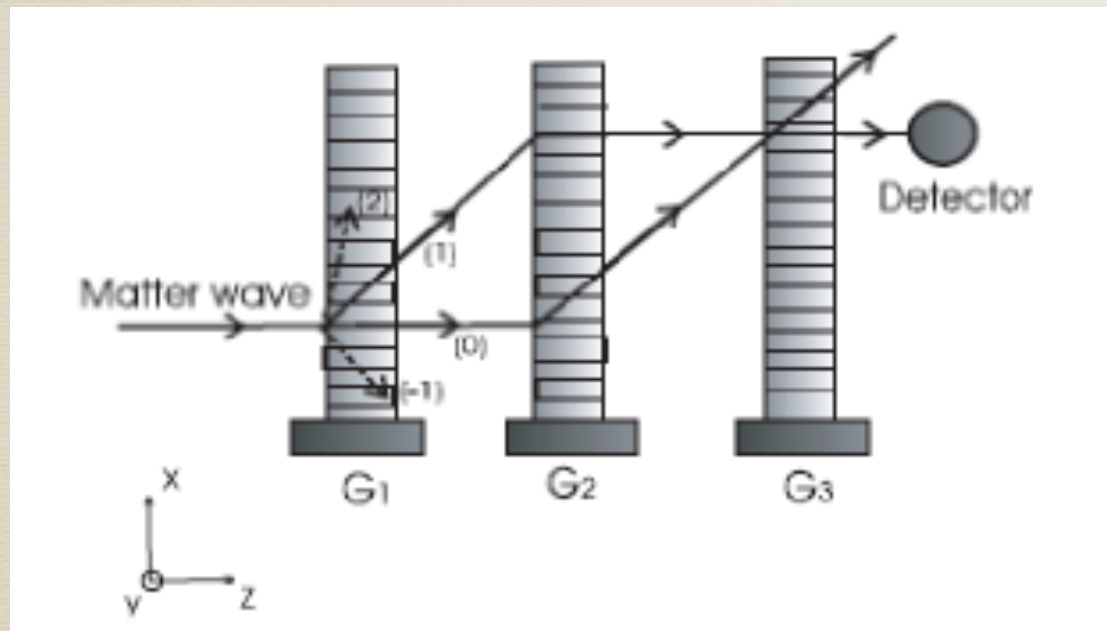


Clifford M. Will  
<http://www.livingreviews.org/lrr-2006-3>



We cannot build a torsion pendulum made of antimatter...

We have to “borrow” another way of doing the WEP measurement from atomic physics



A. Peters et al, Nature 400 (1999) 849

Split and recombine the atomic wave function in presence of gravity

$$\Delta\phi_g = kgT^2 = \frac{2\pi}{a}gT^2$$

Quantum interference if

$$a = \frac{2\pi}{k} \ll \sqrt{\lambda_{DB}L}$$

Very cold atoms are needed with a very collimated beam



# From atoms to antiatoms interferometry

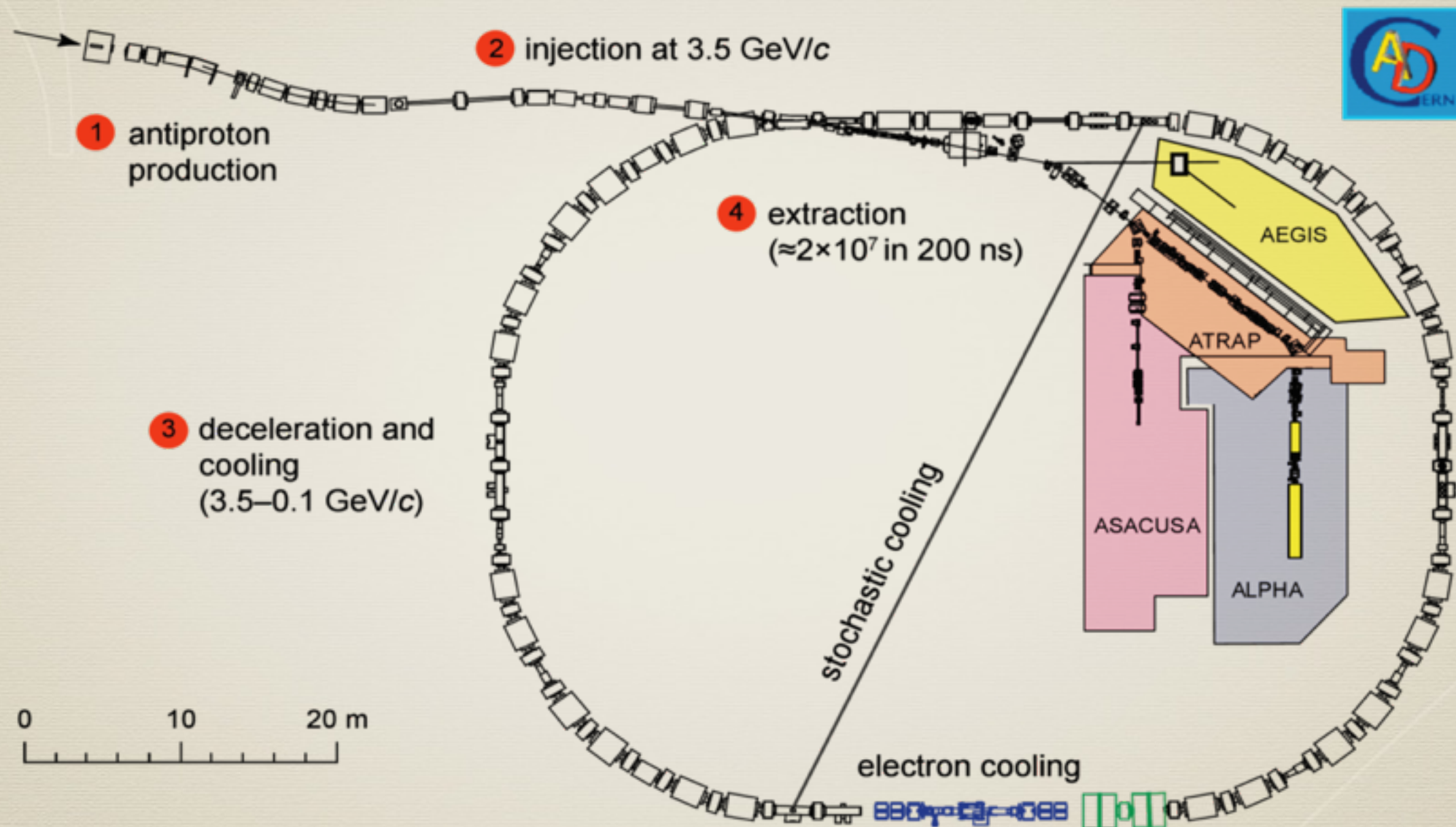
- ◆ We cannot get to  $\mu\text{K}$  /  $\text{nK}$  temperatures required for quantum interference
- ◆ Difficult to have good collimation

## The AEgIS way:

- ◆ Use a two grating configuration with classical interferometry (grating pitch  $\sim 40 \mu\text{m}$ )
- ◆ Aiming at an initial accuracy of 1%
- ◆ Good collimation of the beam is not necessary (advisable only for statistical arguments)



# The Antiproton Factory: The CERN AD





# A short history of antihydrogen production

- ◆ Antiproton decelerator started operation in 2000
- ◆ 2002: ATHENA (and then ATRAP) successfully produce millions of Hbars
- ◆ temperature few tens to hundred K (Athena Collaboration - Nature 419, 456-459 (2002))



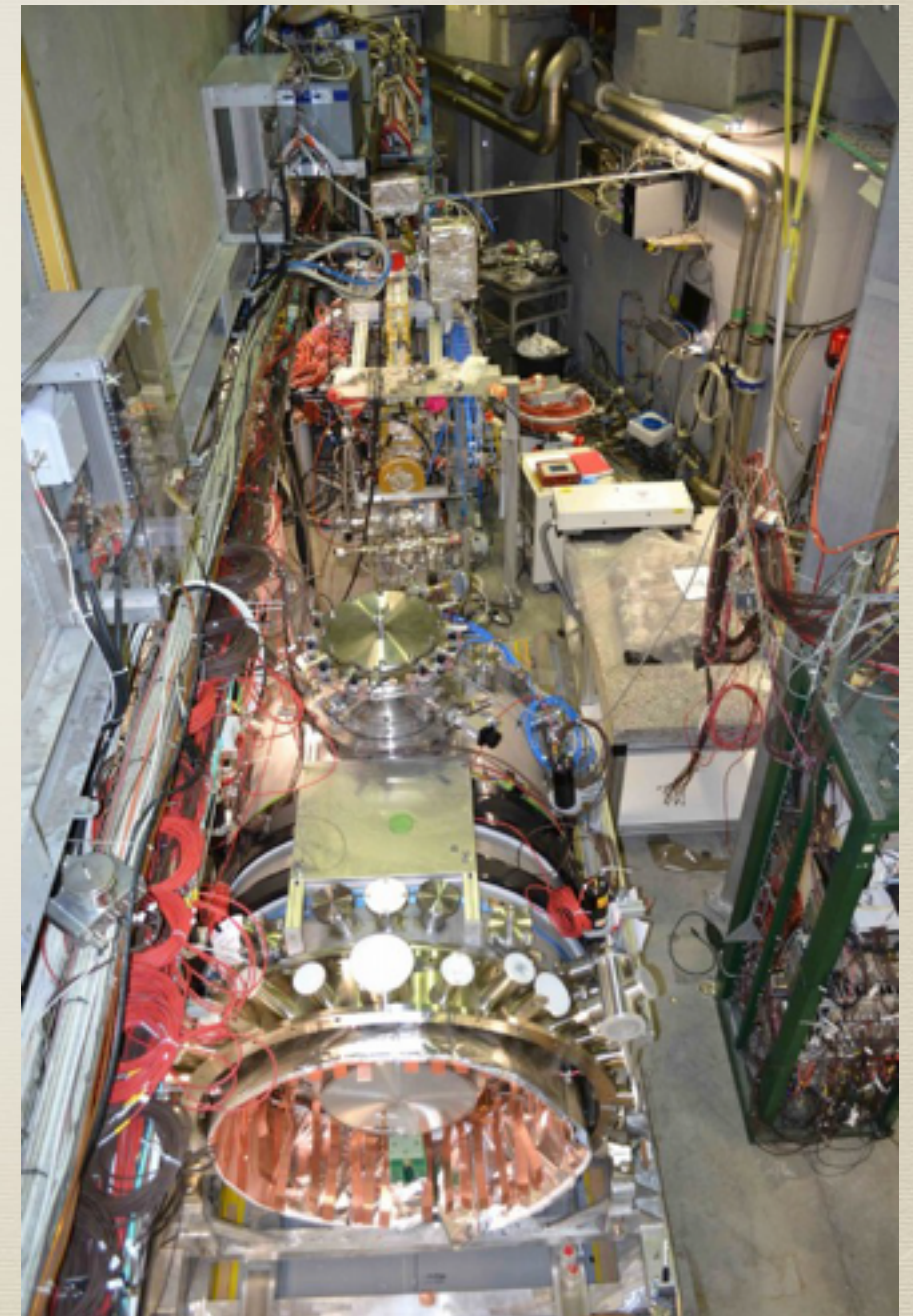
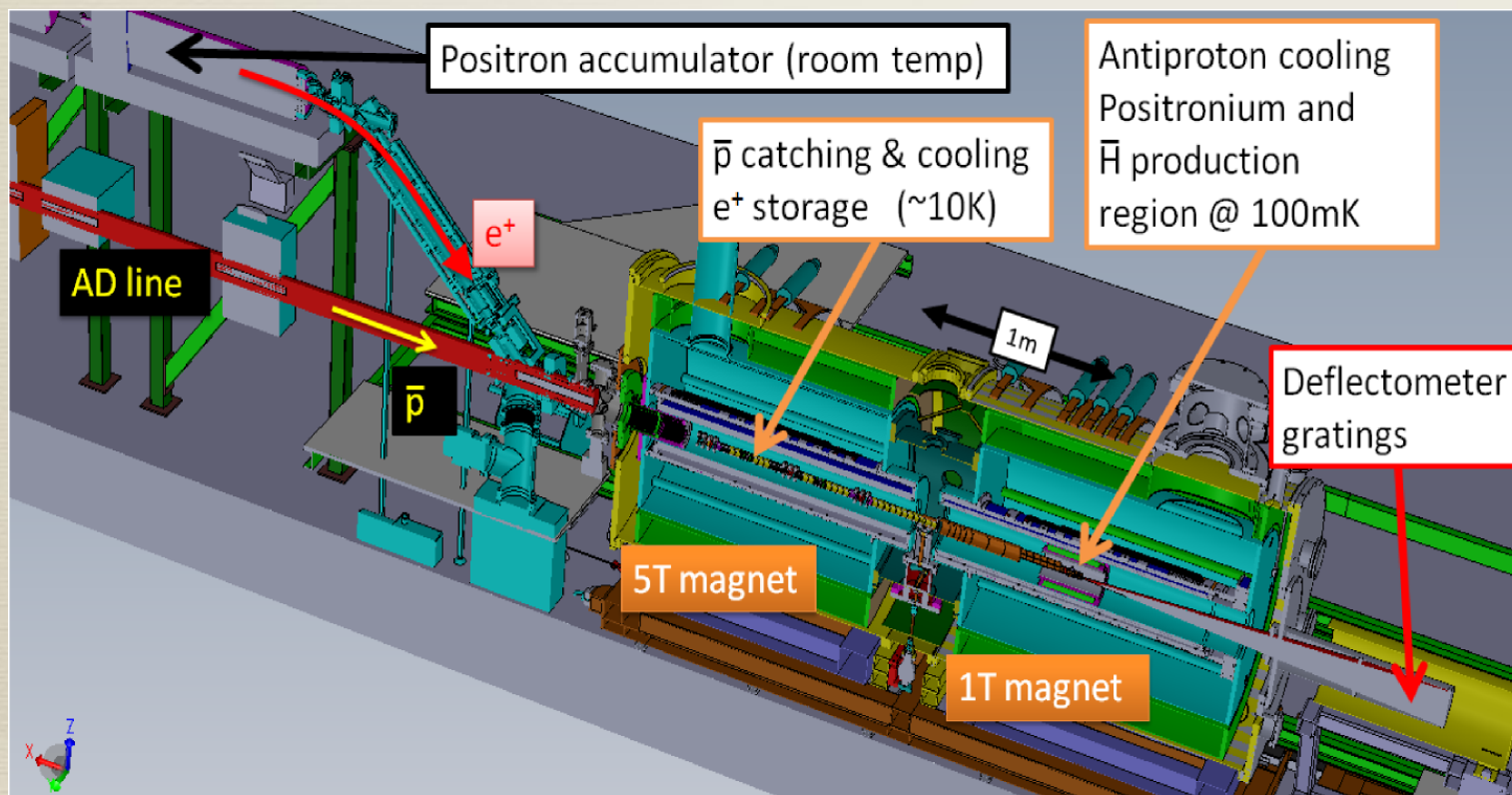
Current experiments for Hbars (Pbars) studies at CERN

- ◆ ALPHA, ATRAP (trapping Hbar for spectroscopy)
- ◆ ASACUSA - Beam for HFS spectroscopy, exotic atoms (antiprotonic He)
- ◆ AEgIS: Production of a ultra-cold Hbar beam for gravity measurements and HFS
- ◆ BASE: Measuring antiproton characteristics such as the magnetic dipole momentum



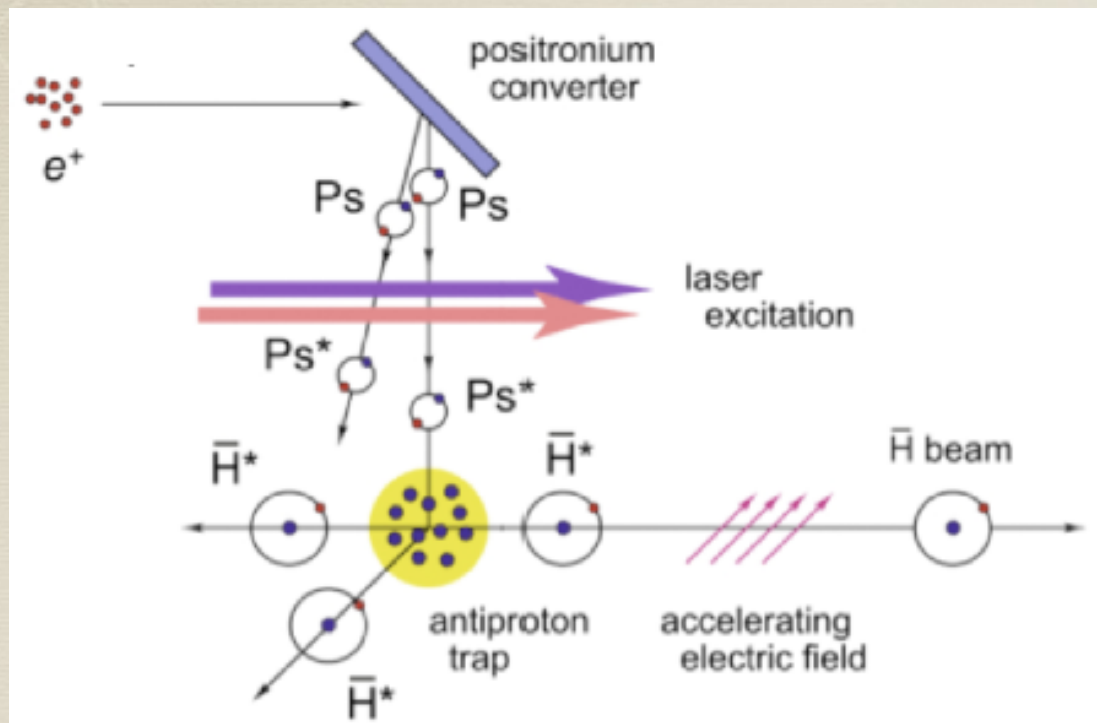
# AEgIS

- ◆ Antimatter Experiment: **g**ravitation, **I**nterferometry, **S**pectroscopy
  - ◆ Aim: measure the gravitational acceleration for antihydrogen in Earth's gravitational field
  - ◆ Aim: Hyperfine Spectroscopy of antihydrogen (long term)
  - ◆ Aim: Spectroscopy of  $1s \rightarrow 2s$  transition (long term)





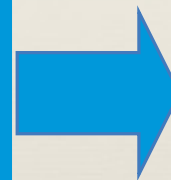
# Antihydrogen production



- Positrons incoming from a  $\beta^+$  hit a silicon microporous target, where they capture an electron and Positronium (Ps) is created.
- Positronium is excited in Rydberg states with laser light (Ps\*)



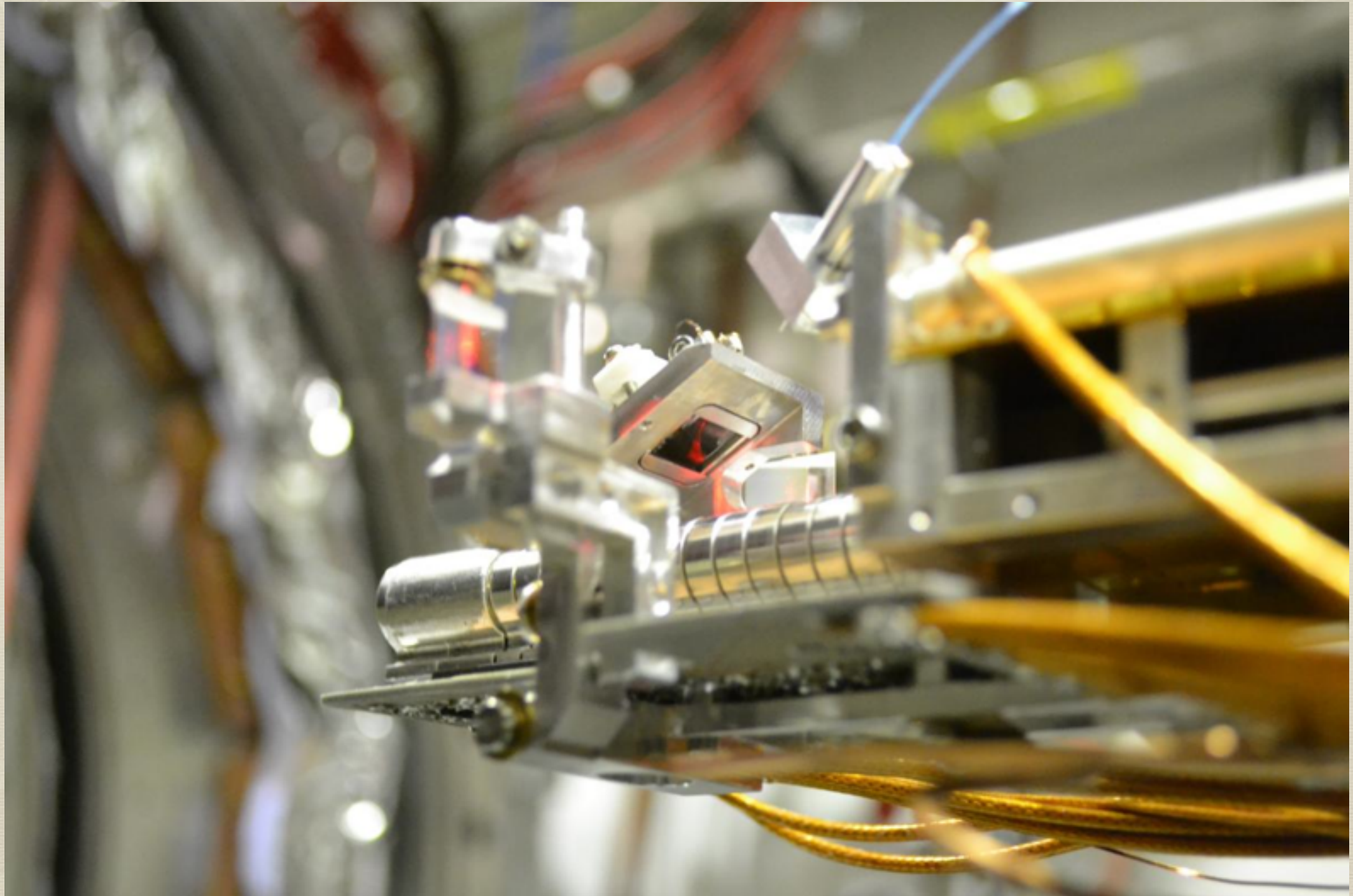
- Antiprotons coming at  $\sim 5$  MeV are slowed down by degraders to  $\sim 100$  keV and a fraction is trapped in a penning trap.
- Several bunches can be collected in the trap to increase the spatial density.



- Antiprotons in the trap take the positron from Ps\* through charge-exchange reaction and form Rydberg anti-H
- Antihydrogen is then accelerated forward through Stark acceleration



# The production trap

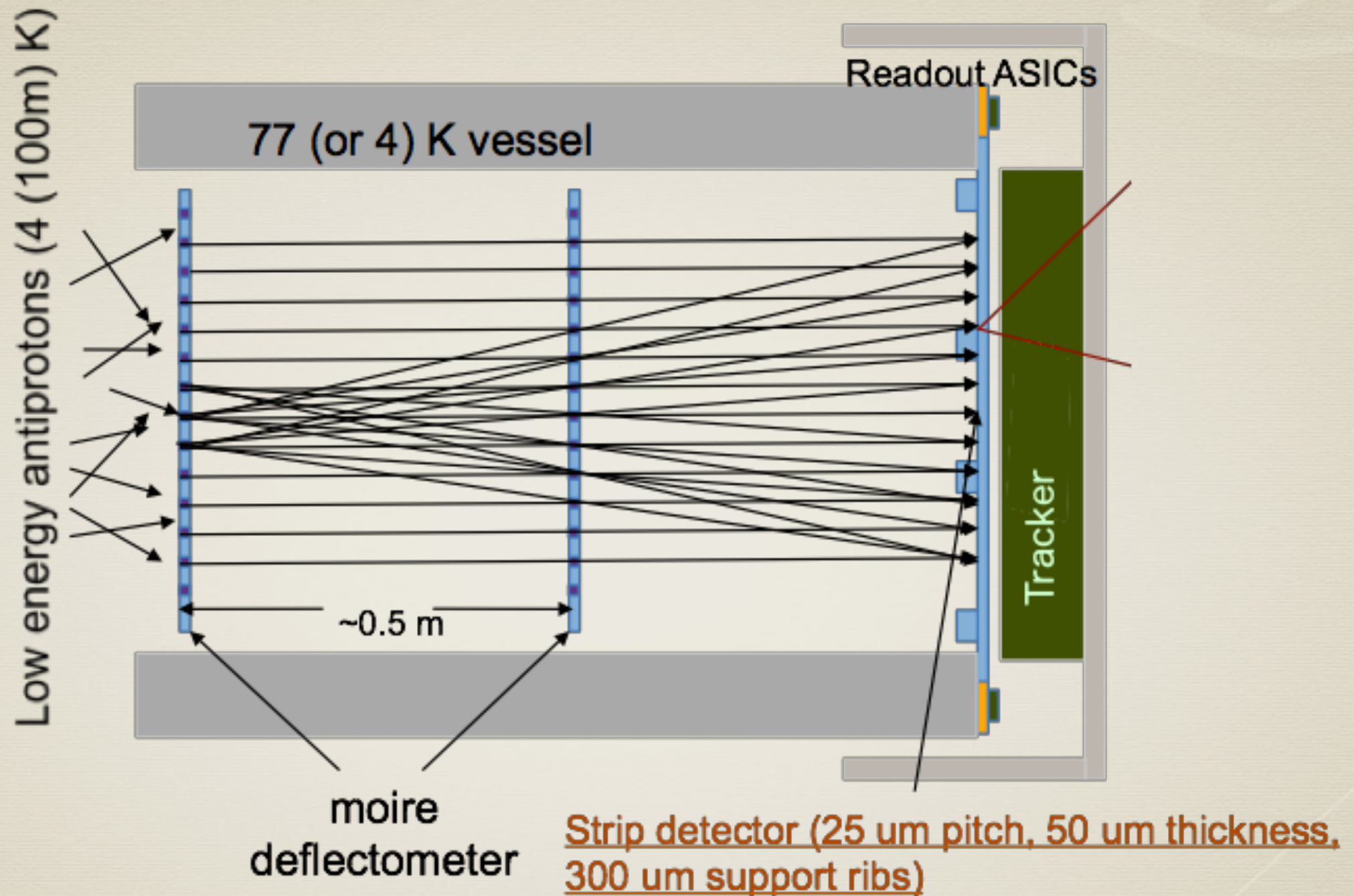




# INTO THE GRAVITY MEASUREMENT



# The AEgIS gravity module



Detection of anti hydrogen through a hybrid detector:

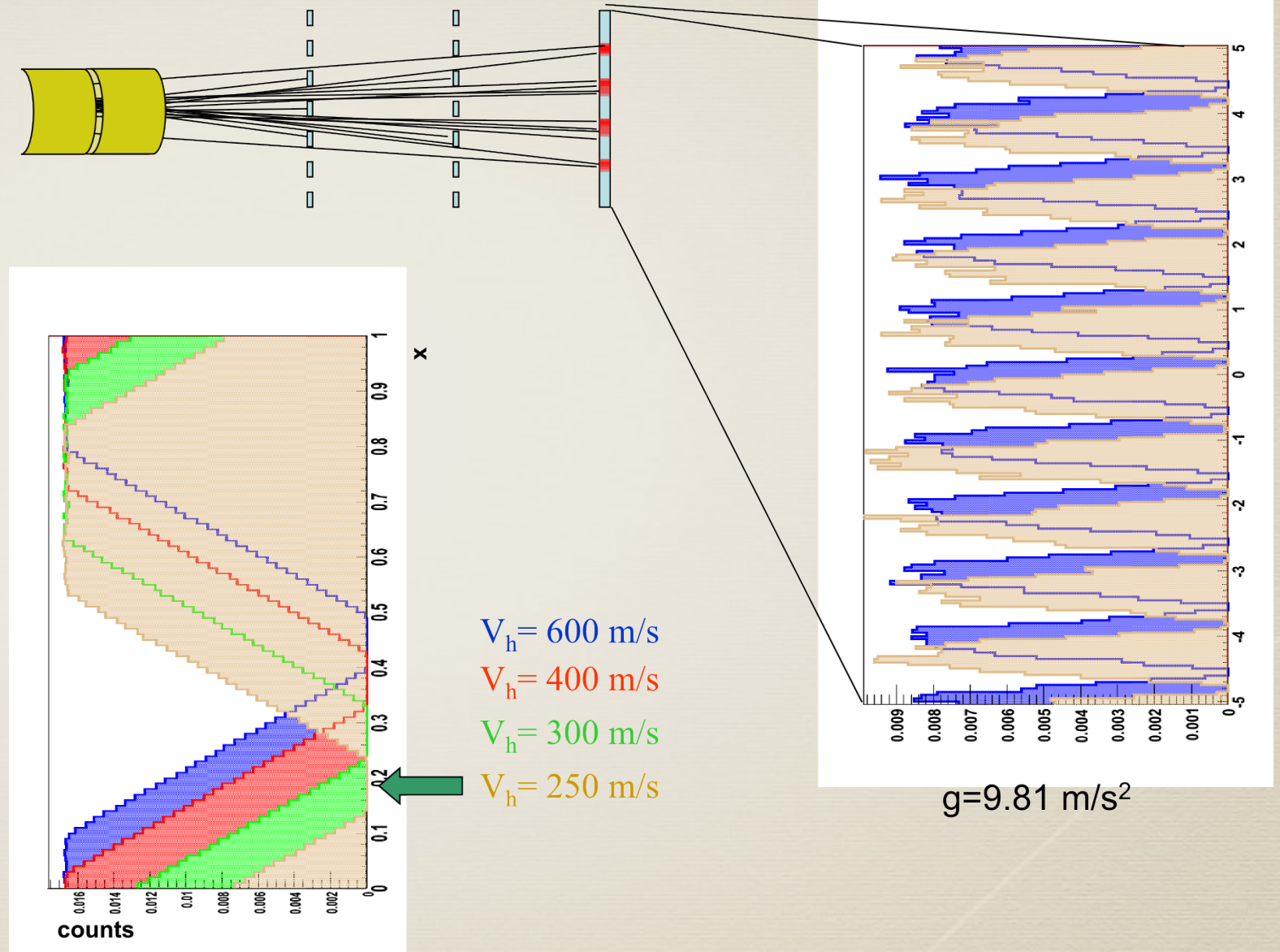
- Silicon (position, TOF) - resolution down to ~7 um
- Downstream tracking for resolution, tagging, TOA.



# The moire fringe pattern: the needed path selection

- ◆ Antihydrogen can pass only through holes in the grating.
- ◆ Observe the number of particles arriving at a distance L from the second grating ( $N(x)$ )
- ◆  $N(x)$  shows a periodical structure with a period

$$\Delta x = gT^2 = g \left( \frac{L}{v_h} \right)^2$$



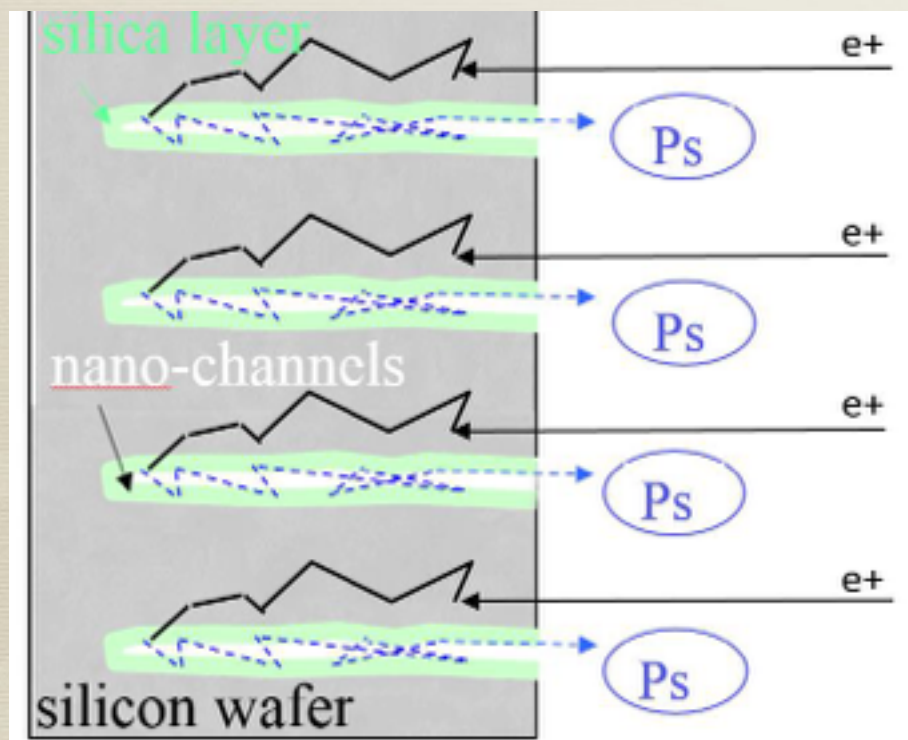
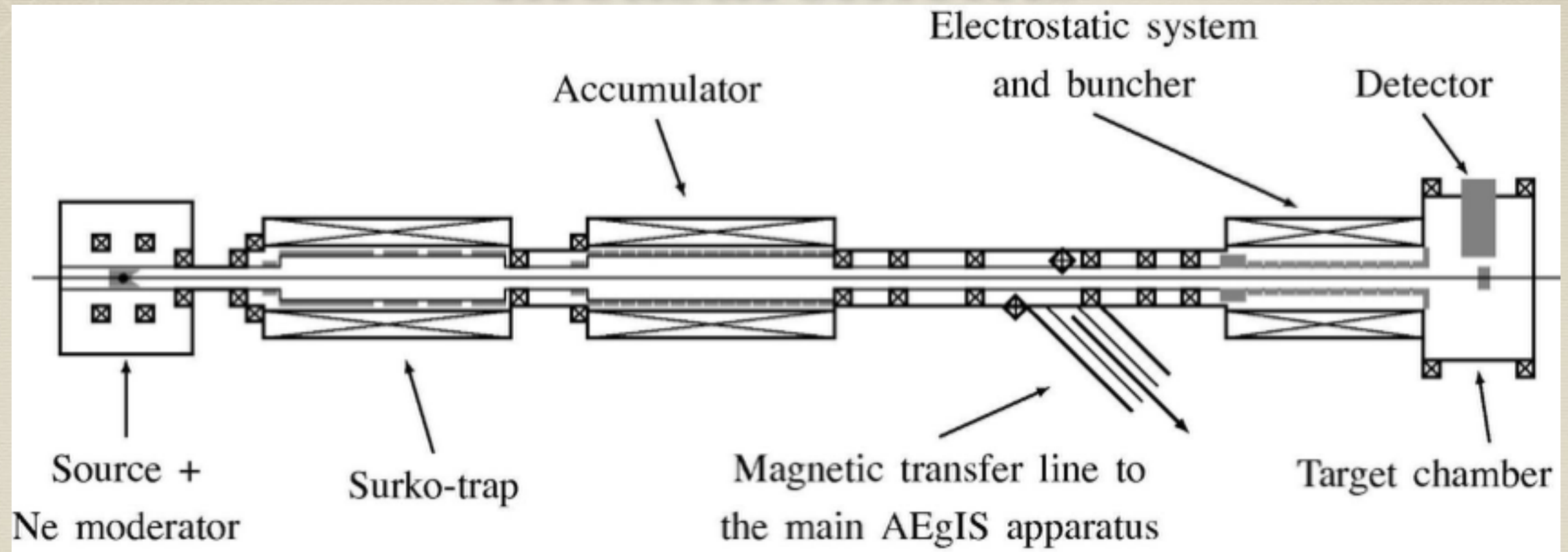
Needed: deflection magnitude, time of flight  $\Delta x = 17.4 \mu\text{m} @ v_h = 300 \text{ m/s}$   
Not needed: collimated beam, quantum regime, hyperfine gratings



# POSITRONIUM PHYSICS



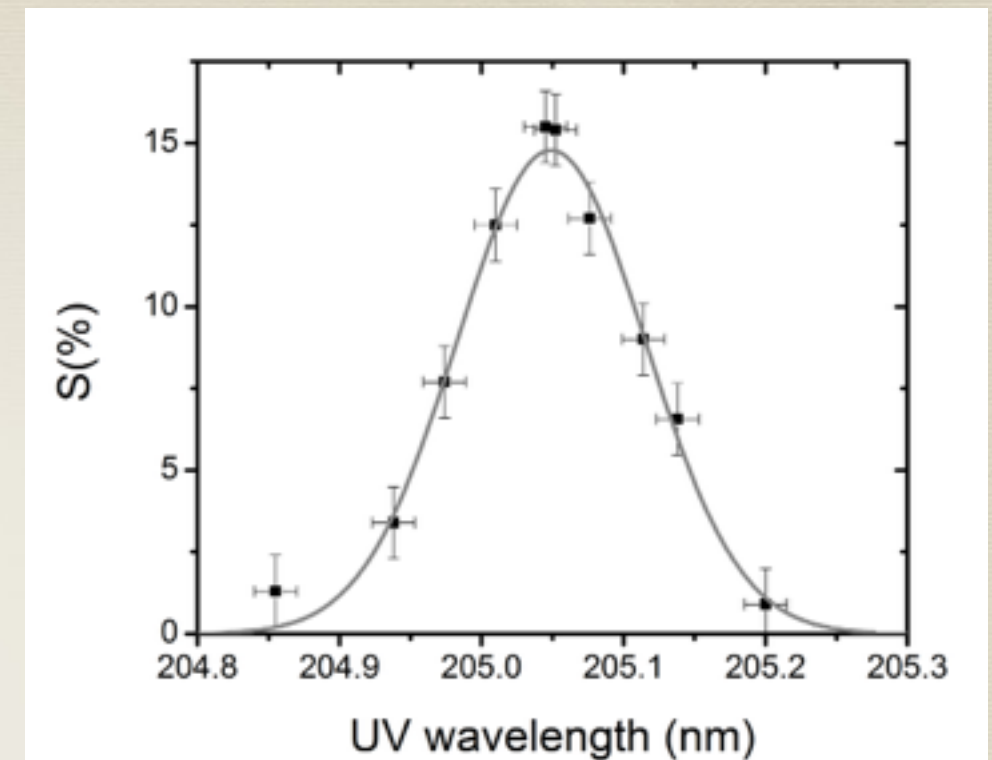
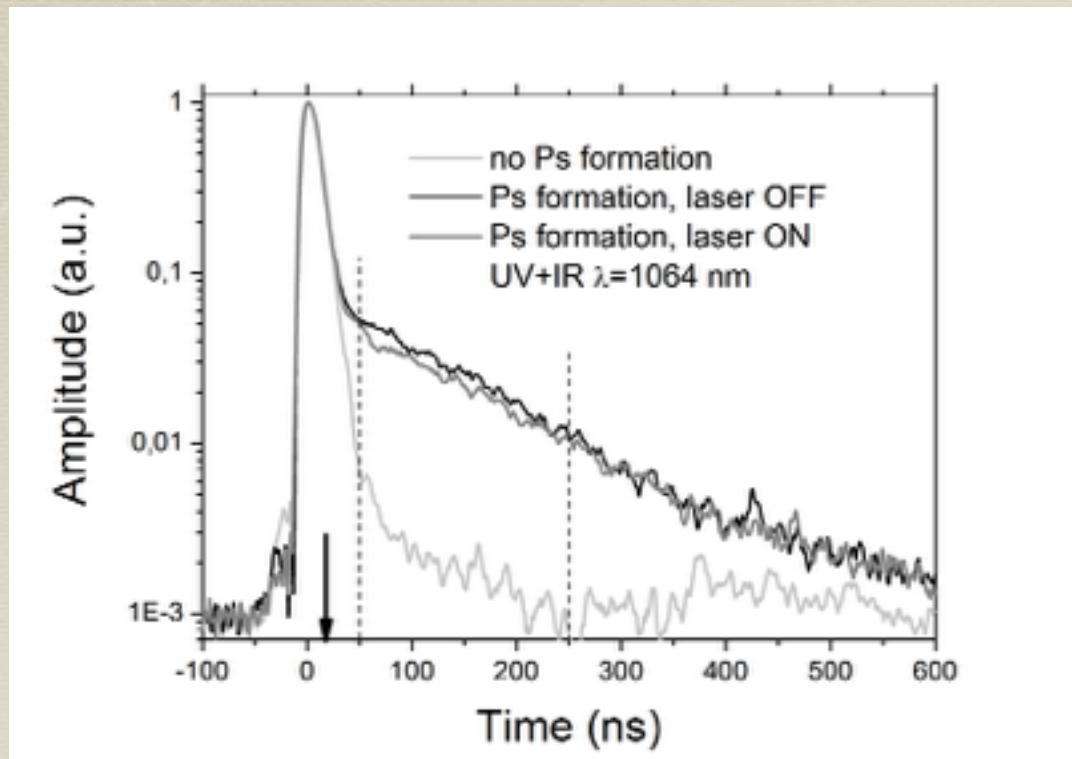
# Positronium formation and measurements



The setup exploits the same transfer line used to deliver positrons to the AEGIS main apparatus.



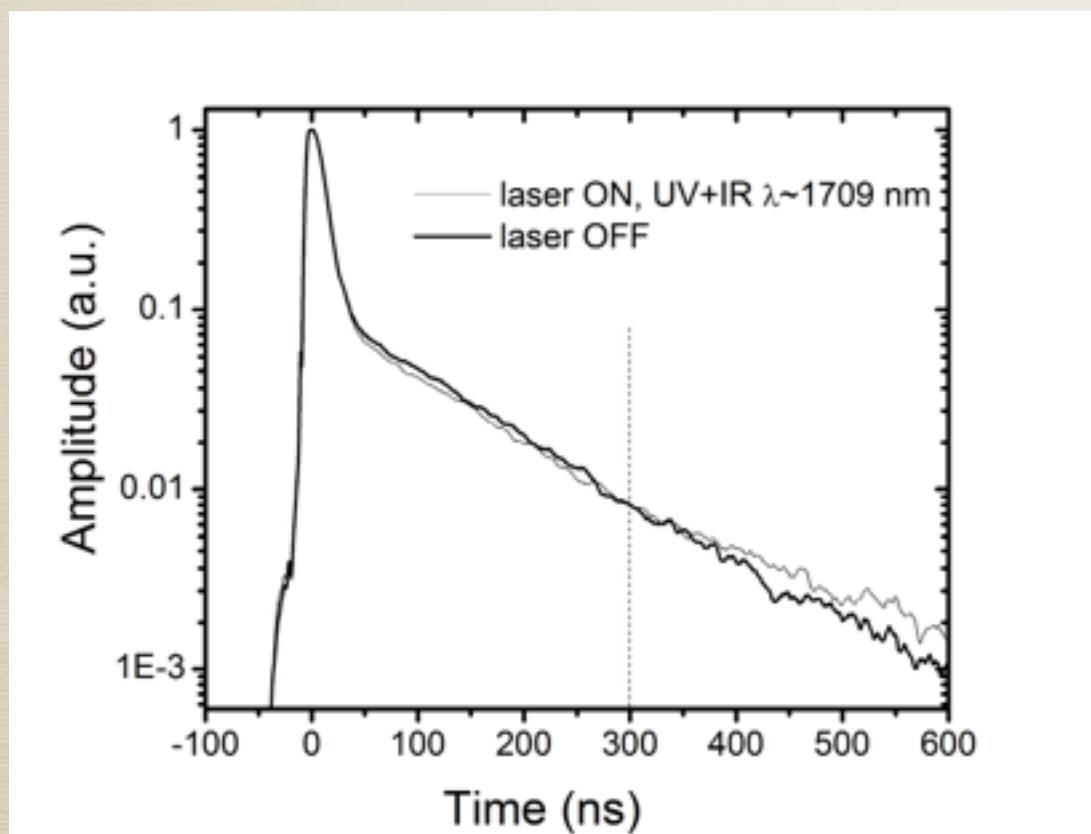
# Positronium $n=3$ measurements



◆ SSPals spectra (left) and  $1-(3s) \rightarrow 3(3P)$  excitation line centered at  $205.05 \pm 0.02$  nm (right)

◆ Scan of the S parameter versus the IR wavelength in the range  $n=15 \dots 17$

S. Aghion et al. - Physical Review A (Vol.94, No.1)





# Summary

- \* AEgIS is operating and catching antiprotons. Towards anti hydrogen formation soon.
- \* The apparatus is completed in most parts, the gravity module is under development (detector ready later in summer)
- \* This will be the first time antihydrogen will be formed in this fashion (charge exchange on nano porous silicon target). First pulsed antihydrogen beam.
- \* Gravity measurement will be performed in the next years
- \* Atomic and HFS spectroscopy measurements will also be feasible as soon as the Hbar beam is available.
- \* In parallel to the main goal, several interesting physics measurements, functional to AEgIS itself, are ongoing (e.g. Positronium spectroscopy)