The AEḡIS experiment at CERN

Germano Bonomi
University of Brescia & INFN Pavia

on behalf of the AEgIS collaboration

The 2nd international conference on particle physics and astrophysics

10-14 October 2016
Milan Hotel
Europe/Moscow timezone

- Overview
- Bulletin n. 1
- Scientific Programme
- Call for Abstracts
  - View my Abstracts
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- Timetable (preliminary)
- Participant List
- Visas
- Financial Supports
- Conference Venue
- Accommodation
- Conference proceedings
- Remote session via AdobeConnect
- The previous ICPPA conference
- Conference Poster

Support
icppa2016@mephi.ru

The 2nd International Conference on Particle Physics and Astrophysics

The 2nd International Conference on Particle Physics and Astrophysics (ICPPA-2016) will be held in Moscow, Russia, (from the 10th to 14th of October). The conference is organized by the National Research Nuclear University "MEPhI". The aim of the Conference is to promote contacts between scientists and to develop new ideas in fundamental research. Therefore we will bring together experts and young scientists working in experimental and theoretical aspects of nuclear physics, particle physics (including astroparticle physics), and cosmology. ICPPA-2016 aims to present the most recent results in astrophysics and collider physics from the main experiments actively taking data as well as any upgrades for the methods of experimental particle physics. Furthermore, one special workshop will be held within the framework of this conference: «SiPM development and application». The working language of the conference is English.

Physics motivations

Scientific goal

- The primary scientific goal of AEgIS is the direct measurement of the gravitational acceleration (g) on antihydrogen in the earth field [test of the WEP]

Such measurement would represent the first precise direct determination of the gravitational effect on antimatter

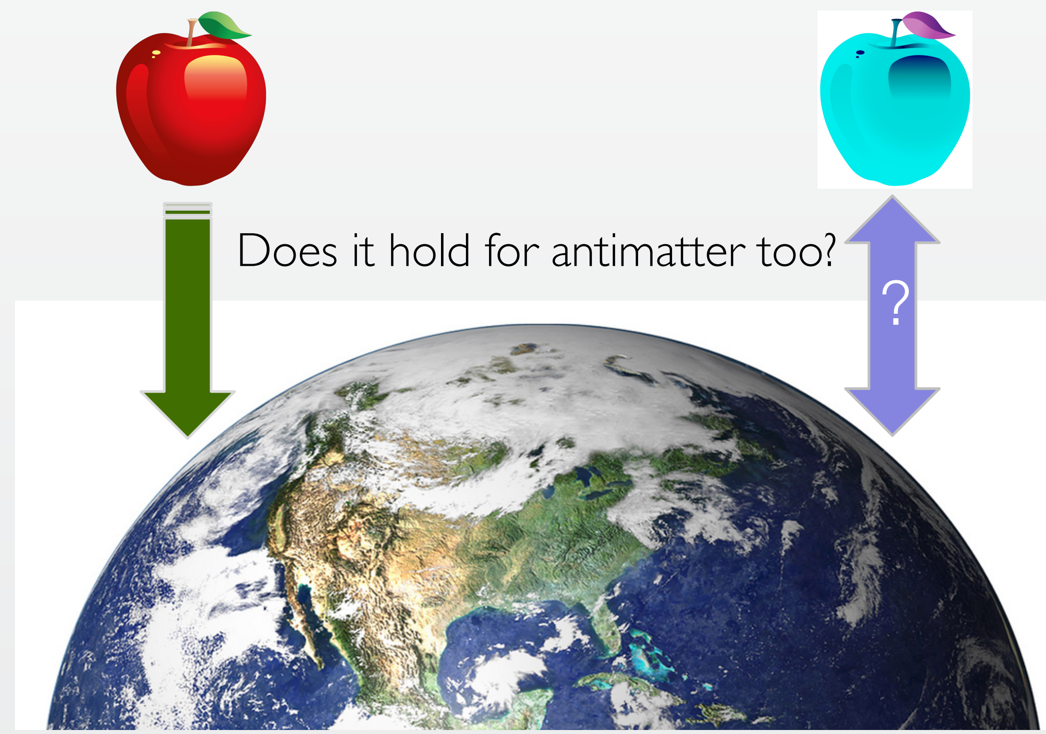
Weak equivalence principle (WEP) - Cornerstone of Einstein Theory of Relativity

$$m_i = m_g$$

Universality of free fall established by Galileo and Newton

- Unique behavior:

electric field:	gravitational field:
$\mathbf{F} = q \cdot \mathbf{E}$	$\mathbf{F} = m \cdot \mathbf{G}$
$\lvert\mathbf{E}\rvert \sim \frac{Q}{r^2}$	$\lvert\mathbf{G}\rvert \sim \frac{M}{r^2}$
$\lvert\mathbf{a}\rvert \sim q$	$\lvert\mathbf{a}\rvert \neq \mathcal{F}(m)\,,\; a = const.$



[Antimatter was discovered **after** Theory of Relativity]

- Long term goal (phase 2): test of CPT (anti-hydrogen spectroscopy)

$\bar{g}$

WEP for antimatter: why to test it

- Our attempts for a quantum theory of gravity typically result into new interactions which may violate the WEP (ex. **Kaluza-Klein theory**)

Int. J. Mod. Phys. D18, 251–273 (2009)

- Some open questions (like **dark matter** and **baryogenesis**) could benefit from a direct measurement

Astrophys. Space Sci. 334, 219–223 (2011)

JHEP 1502, 076 (2015)

- Some studies explicitly talk about "anti-gravity"

G. Chardin - **Phys.Lett. B282 (1992) 256-262**

- WEP violation is *not excluded* and no direct measurements are available …

- Previous attempts:
  - **1967**: **Fairbank** and **Witteborn** tried to use positrons

    Phys. Rev. Lett. 19, 1049 (1967)

  - **1989**: PS-200 experiment at CERN tried to use (4 K) antiprotons

    Nucl. Instr. and Meth. B, 485 (1989)

  - Both **unsuccessful** because of stray E and B fields

    Highest precision reachable with neutral antimatter

  - **2013**: ALPHA experiment at CERN set limit on m_g/m_i for $\overline{\text{H}}$

    Nature Communications 4, 1785 (2013)

    m_g/m_i > 110 excluded at 95% CL

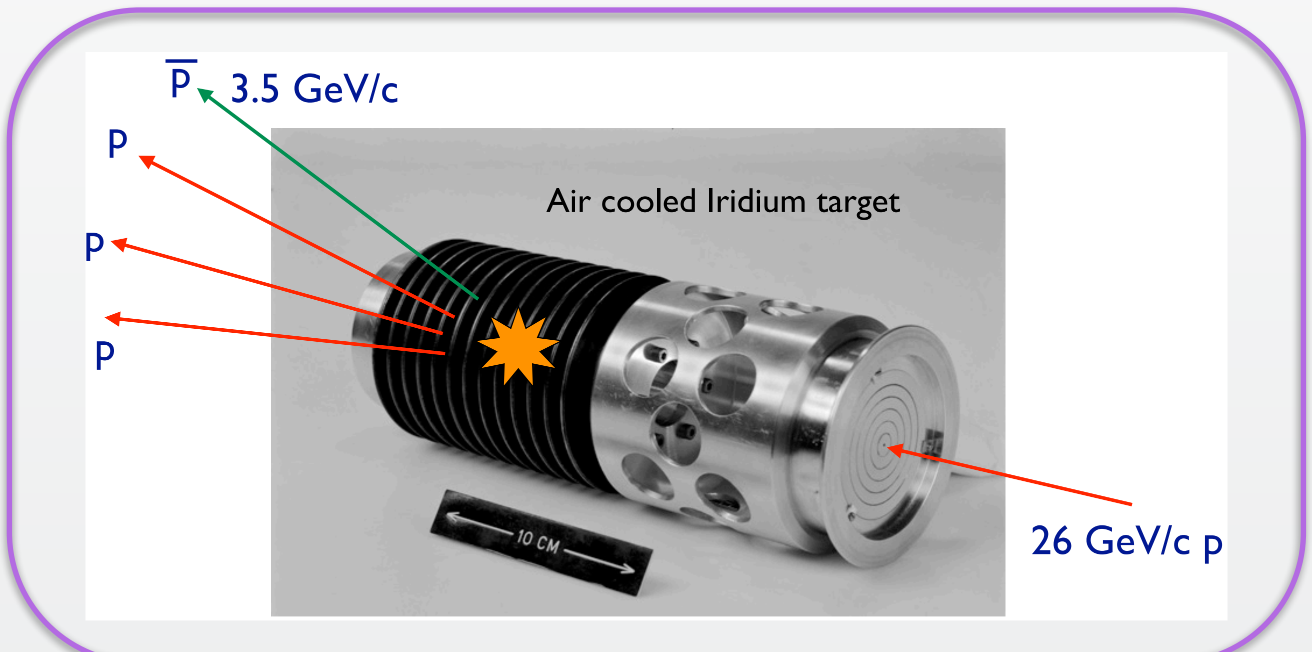
The AEgIS experiment @ CERN

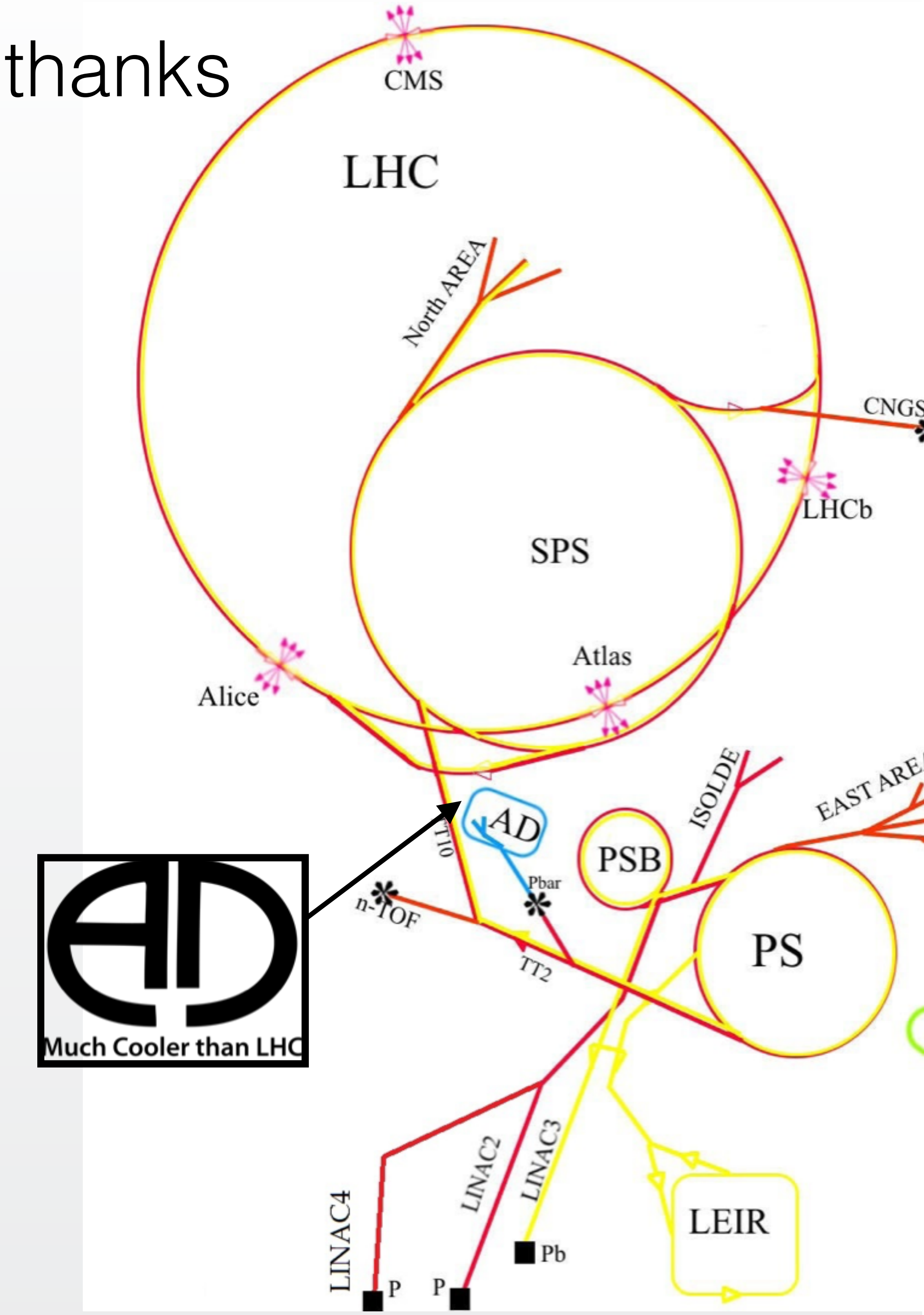
The Antiproton Decelerator (AD - Antimatter factory @ CERN)

- At CERN antimatter studies are possible thanks to the **Antiproton Decelerator (AD)**

- 26 GeV/c p from PS used to produced $\bar{p}$

  (~10^{13} p per bunch -> ~ 10^{7} $\bar{p}$ per bunch)

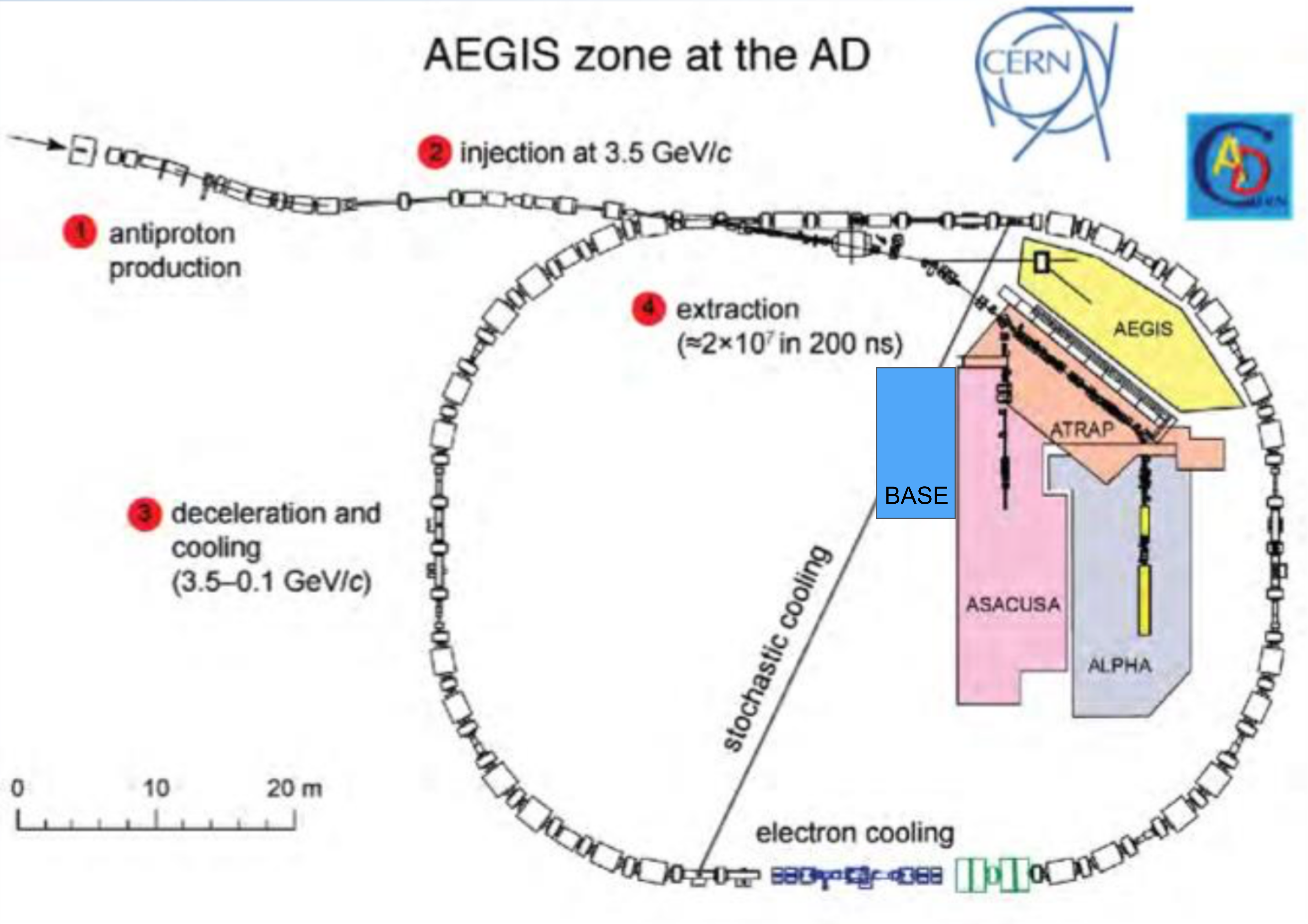


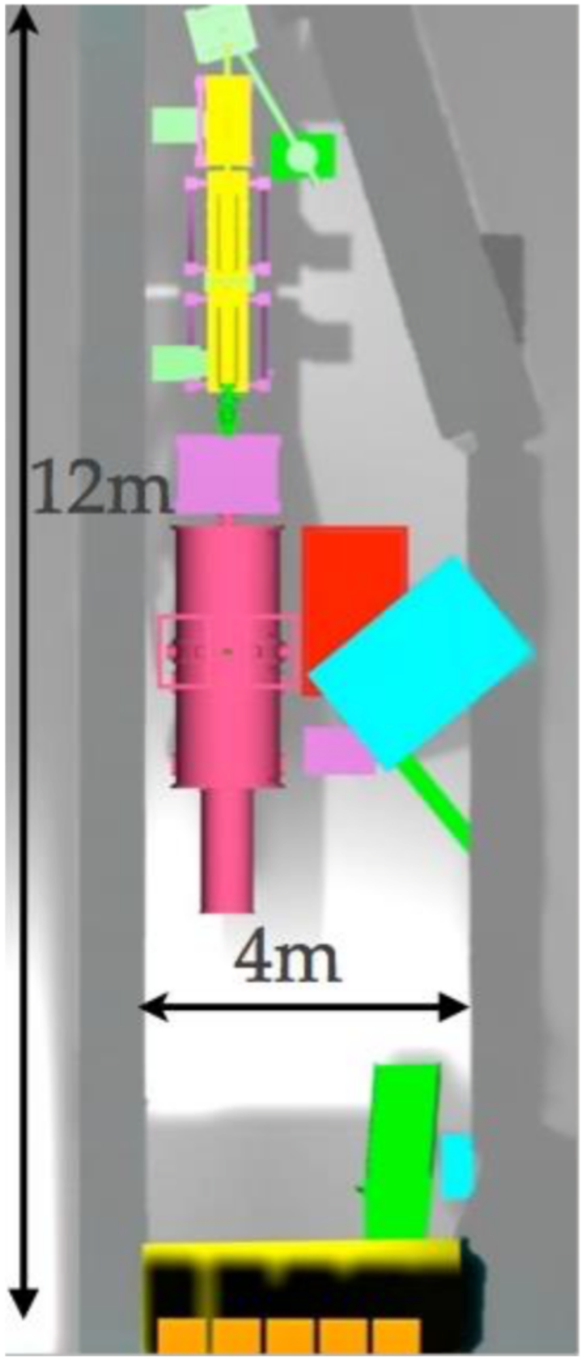


- AD slows down $\bar{p}$ to ~100 MeV/c in a 100 s cycle

- Approximately 3 x 10^{7} $\bar{p}$ delivered each cycle to the experiments

The Antiproton Decelerator (AD - Antimatter factory @ CERN)



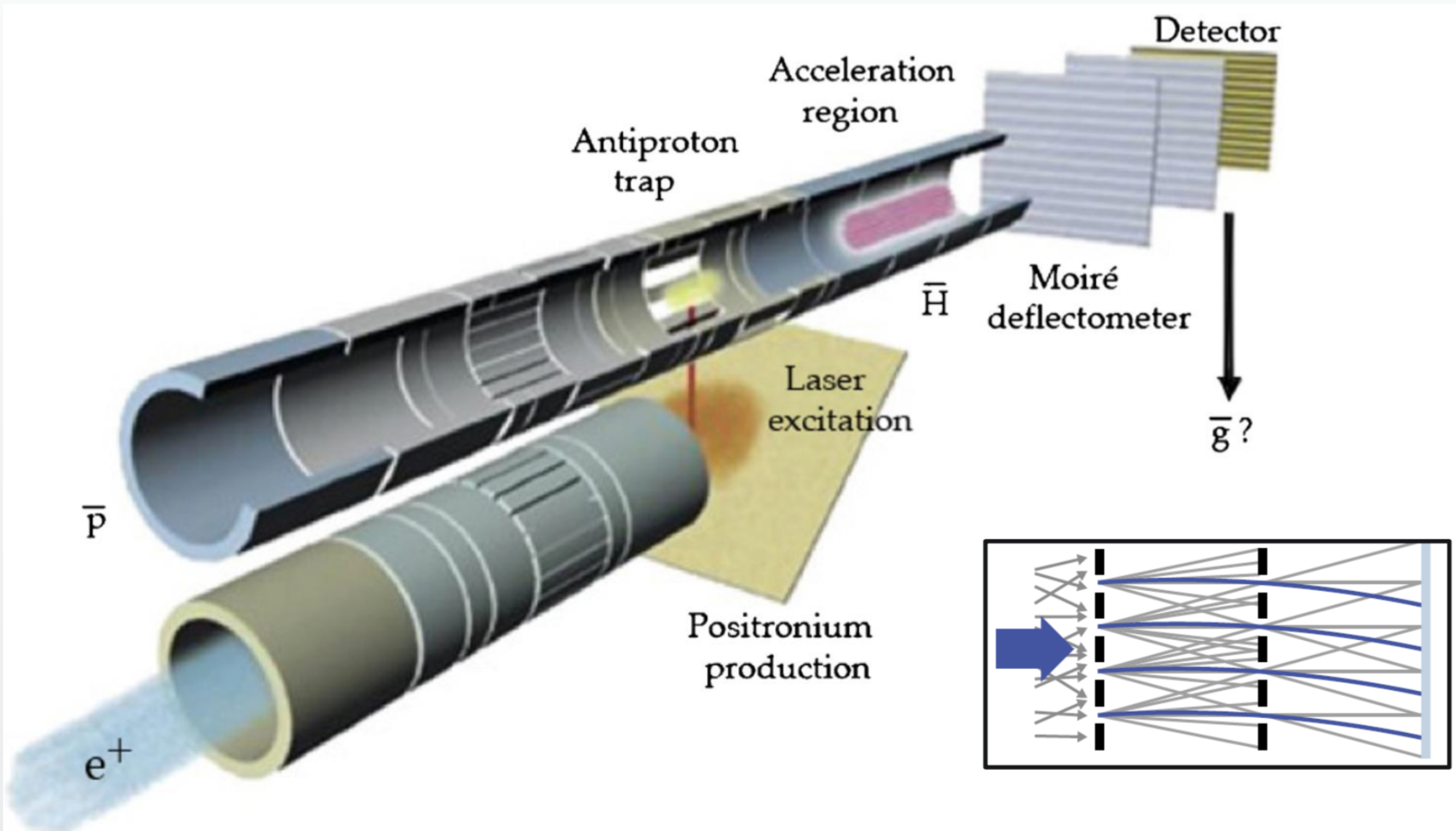


$\bar{g}$

AEgIS overview

- AEgIS measurement overview

- Produce a beam of antihydrogen, let it fly and measure its "fall" [see details below]



- It would be the first precise (few %) direct measurement for antimatter -> with no theoretical assumptions

AEgIS procedure

Capture of antiprotons from the CERN-AD

Cooling of the trapped antiprotons

Positronium (e^+e^-) production by e^+ on SiO_2

Ps laser excitation to Rydberg state

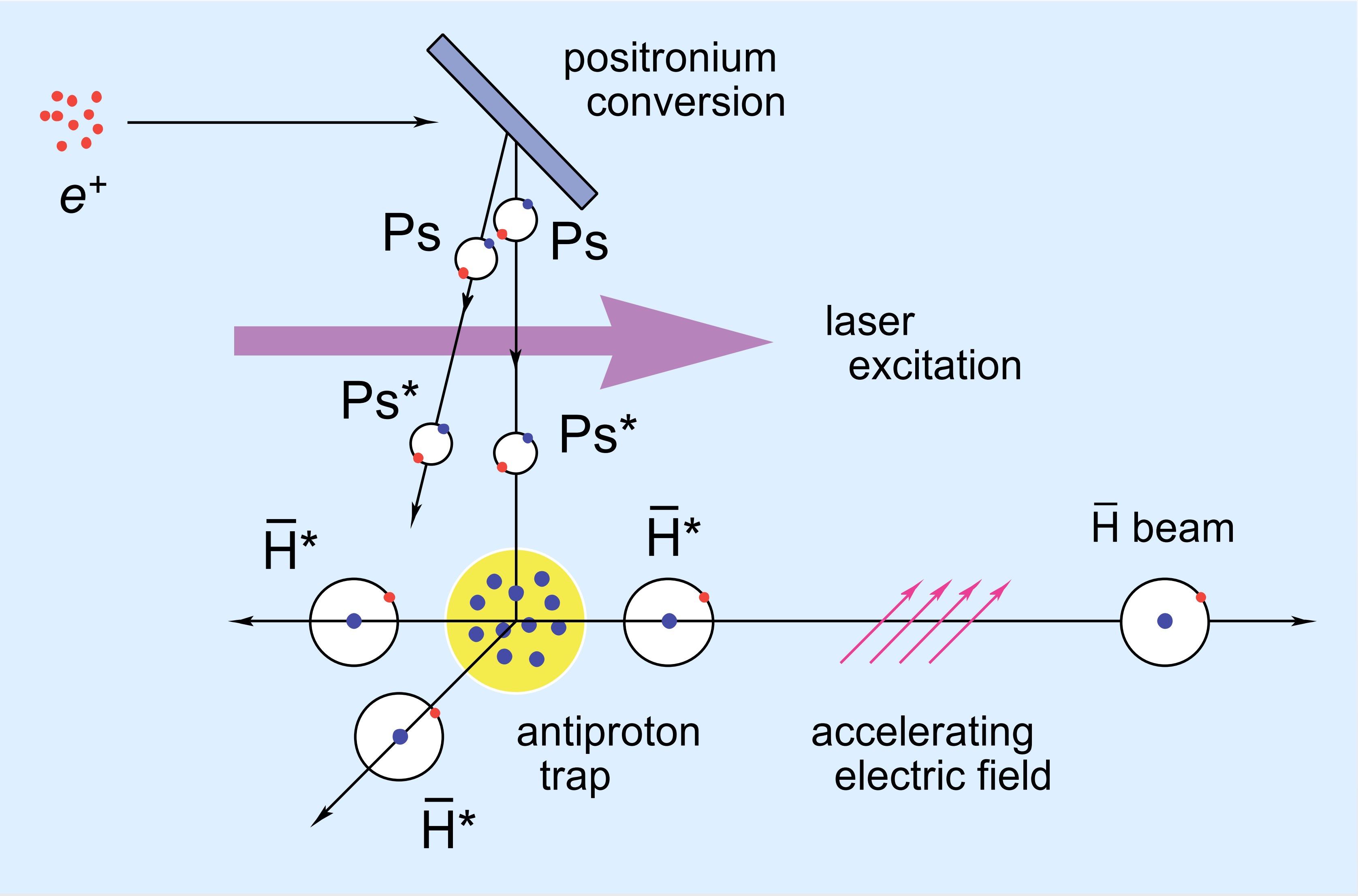
Interaction of Ps* with the antiproton cloud

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

Positronium charge exchange reaction
[*conceptually similar to a charge exchange technique based on Rydberg cesium performed by ATRAP C. Storry et al., Phys. Rev. Lett. 93 (2004) 263401*]

ADVANTAGES
- Large cross section $\sigma \propto (n_{Ps})^4$
- Narrow and well defined band of final states ($n_H \approx \sqrt{2} n_{Ps}$, with a rms of few units)

Antihydrogen is then accelerated and fly toward the moiré deflectometer



fall detection - moiré deflectometer

PHYSICAL REVIEW A VOLUME 54, NUMBER 4 OCTOBER 1996

Inertial sensing with classical atomic beams

Markus K. Oberthaler, Stefan Bernet, Ernst M. Rasel, Jörg Schmiedmayer, and Anton Zeilinger
Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25 A-6020 Innsbruck, Austria

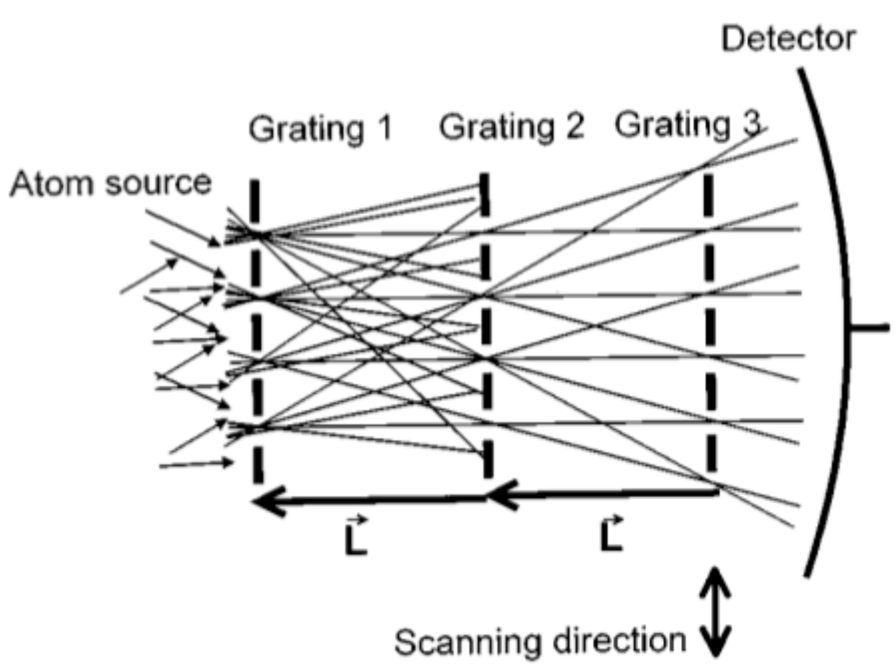
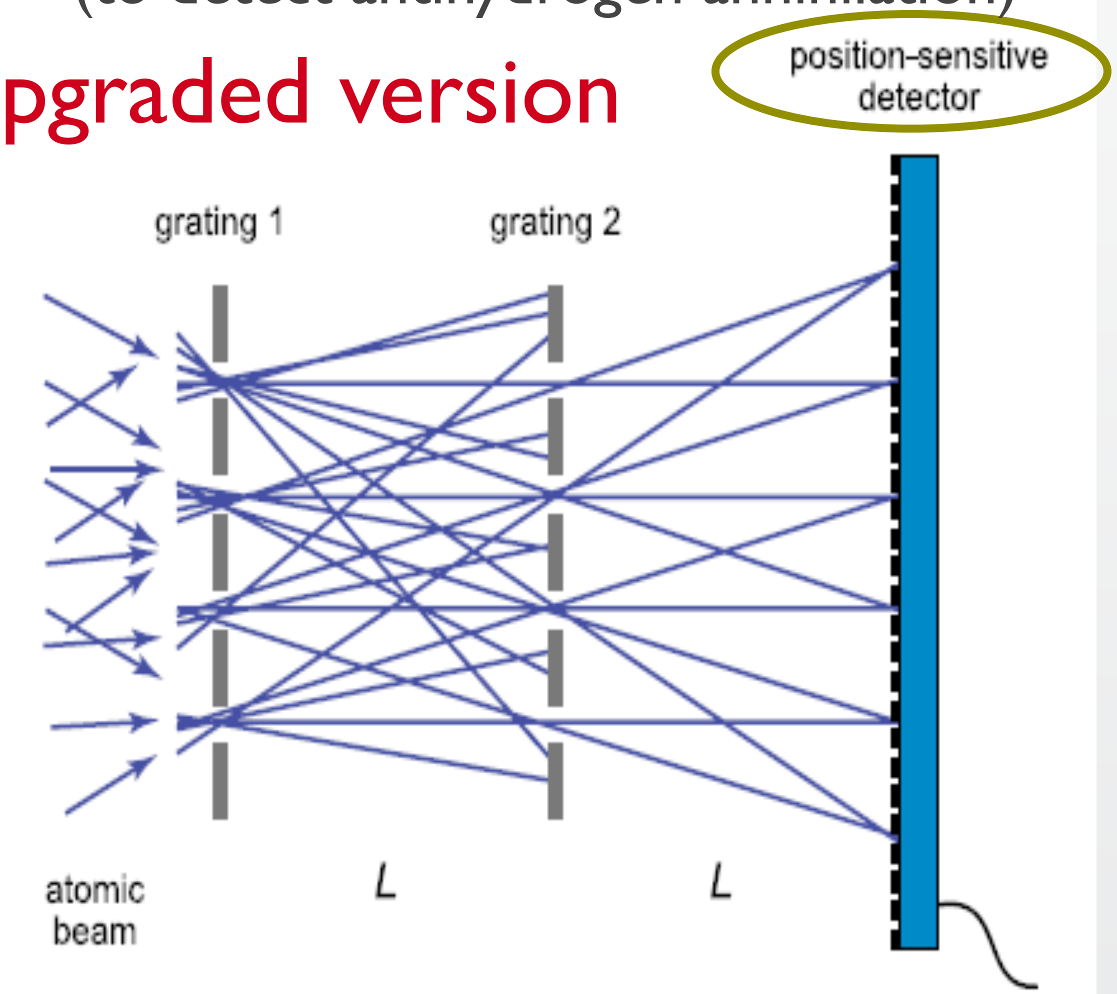


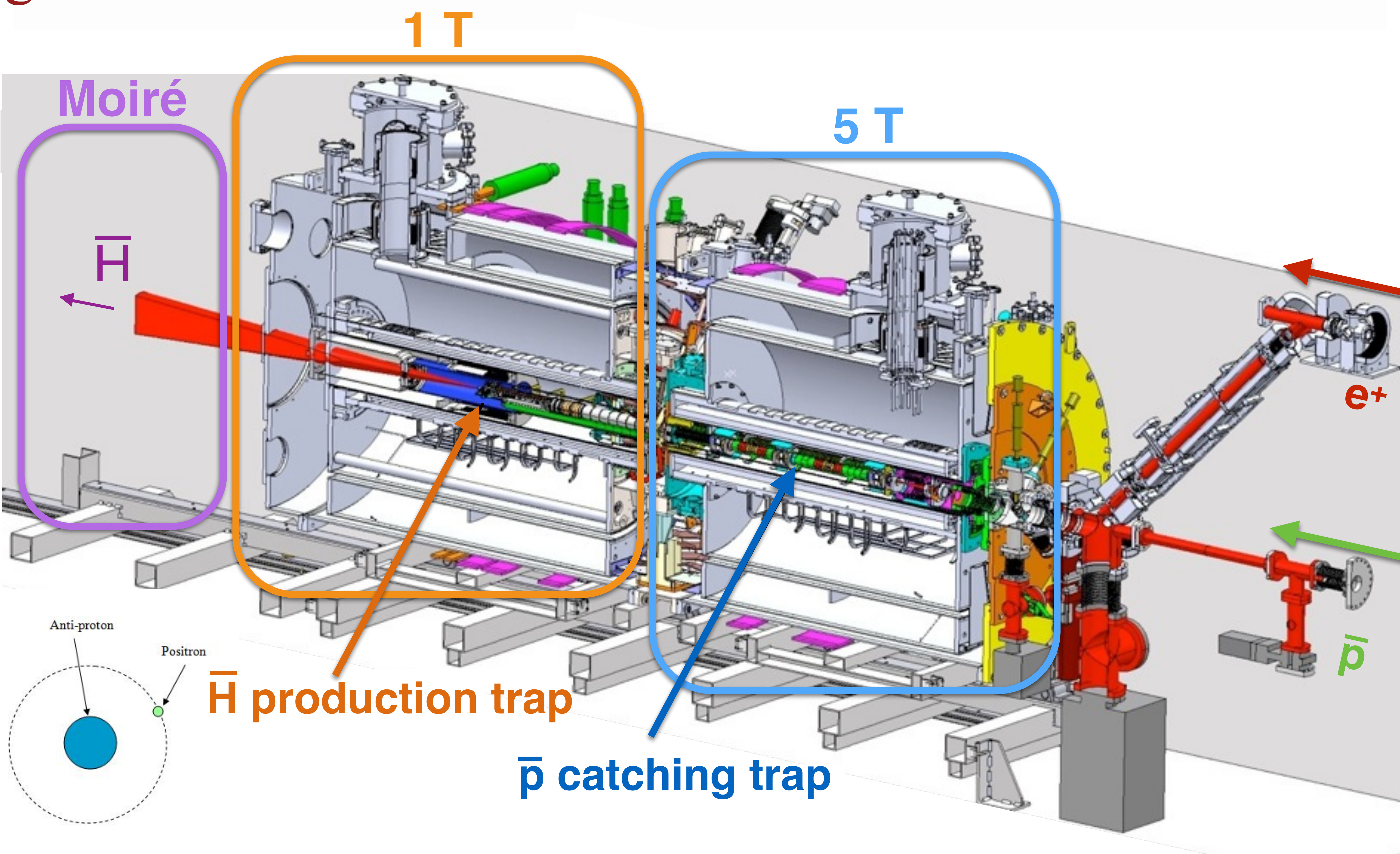
FIG. 1. Principle of a Moiré deflectometer. The first two identical gratings collimate the originally undirected atoms into various directions. After a distance *L* corresponding to the distance between the first two gratings, an image of the collimation gratings is formed. At this position, a third identical probe grating is placed. Its translation along the indicated direction leads to a periodic modulation of the transmitted intensity.

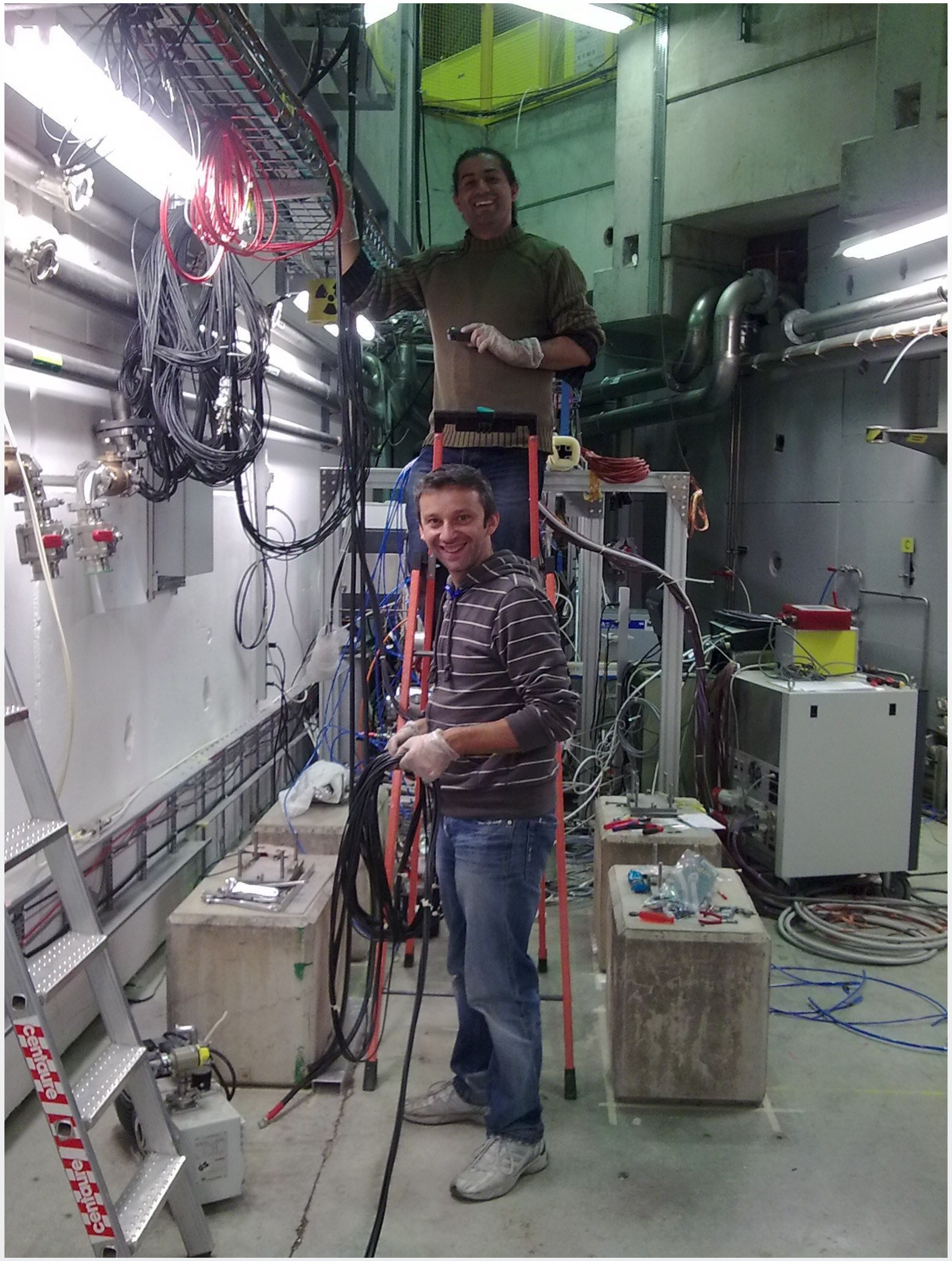
new position-sensitive detector
(to detect antihydrogen annihilation)

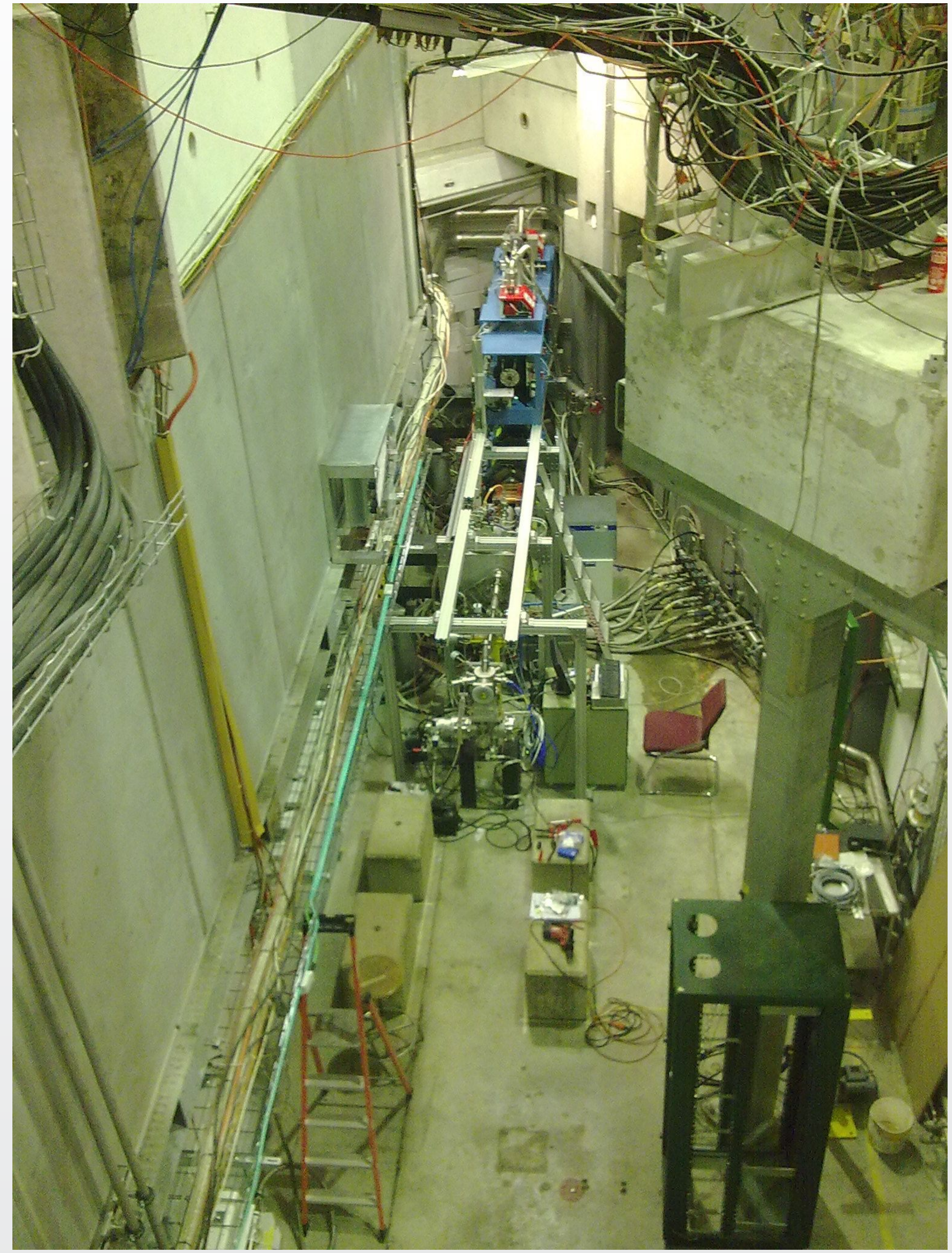
upgraded version

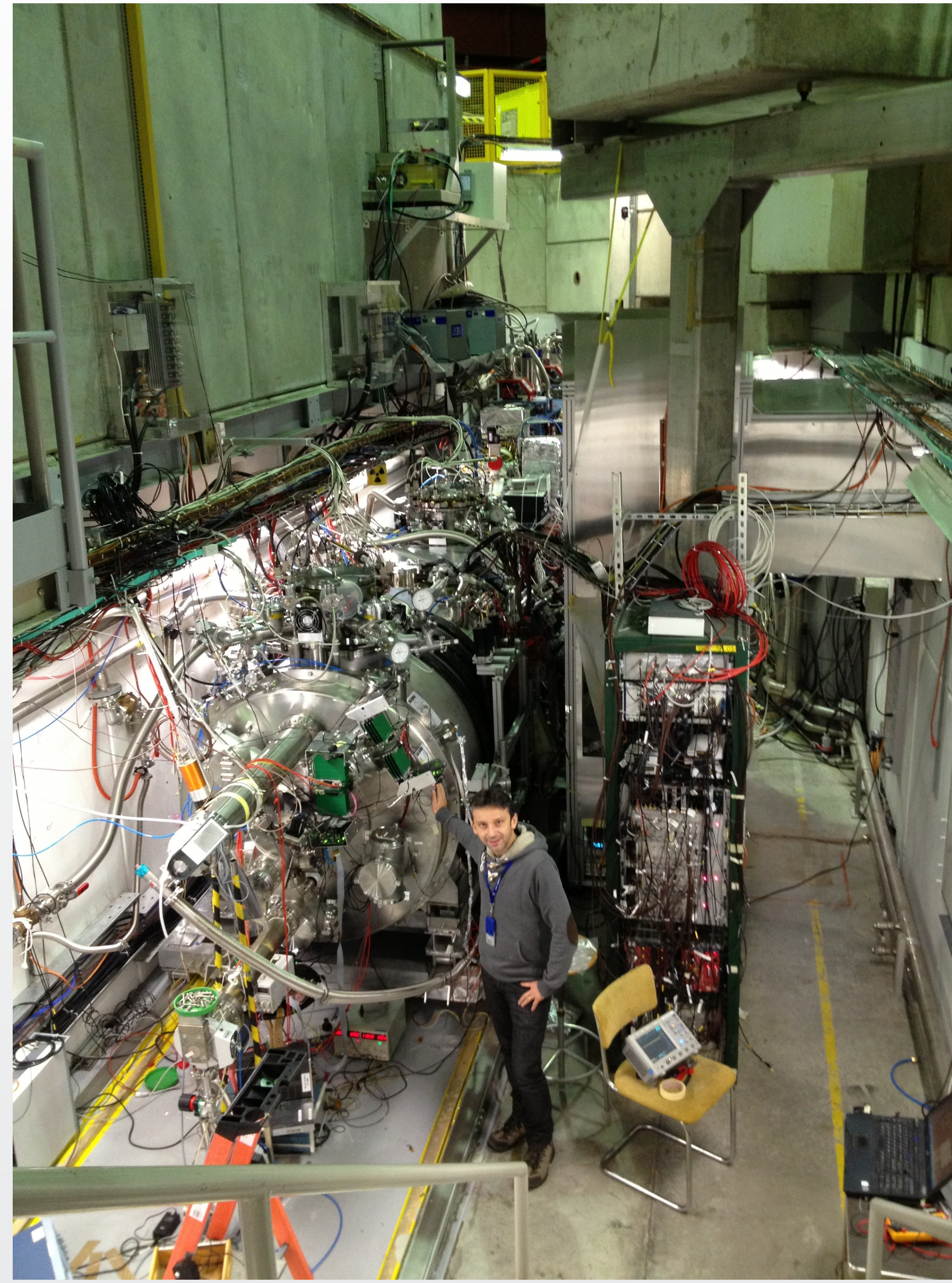


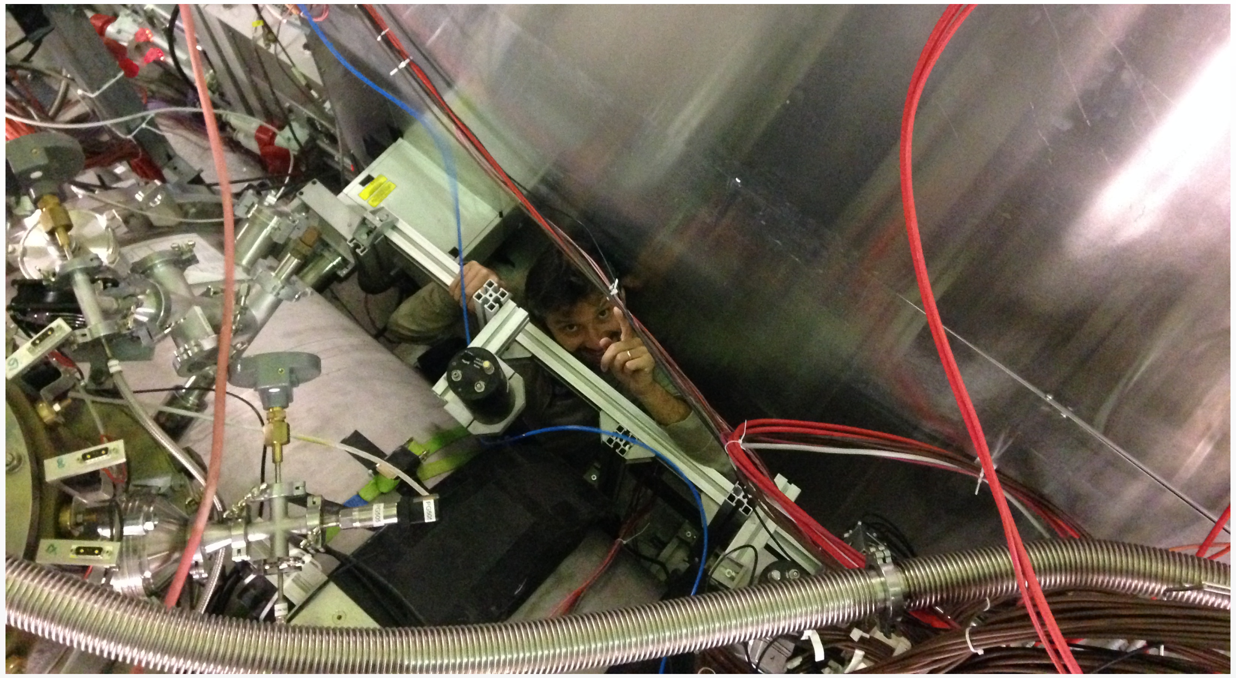
the AEgIS apparatus

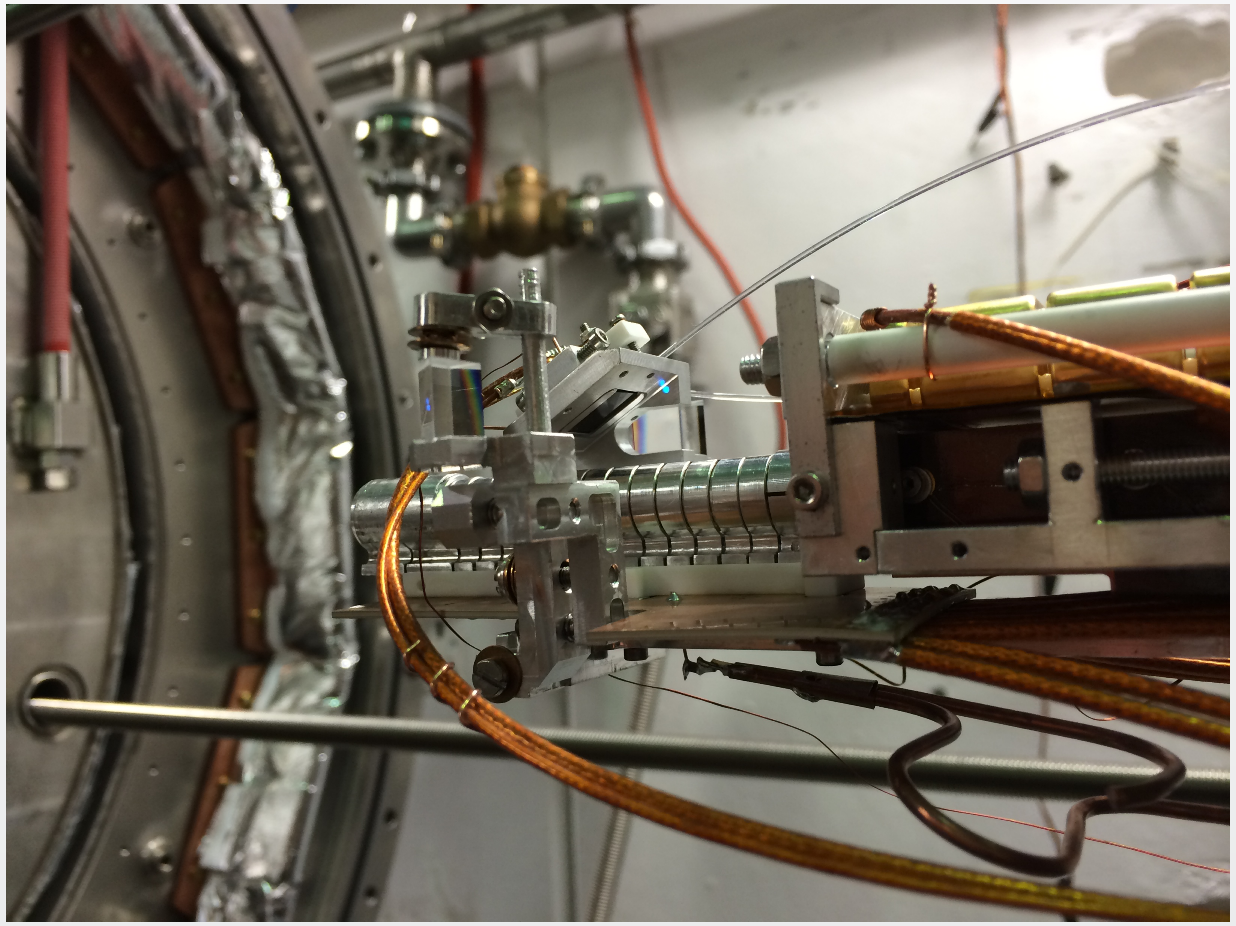


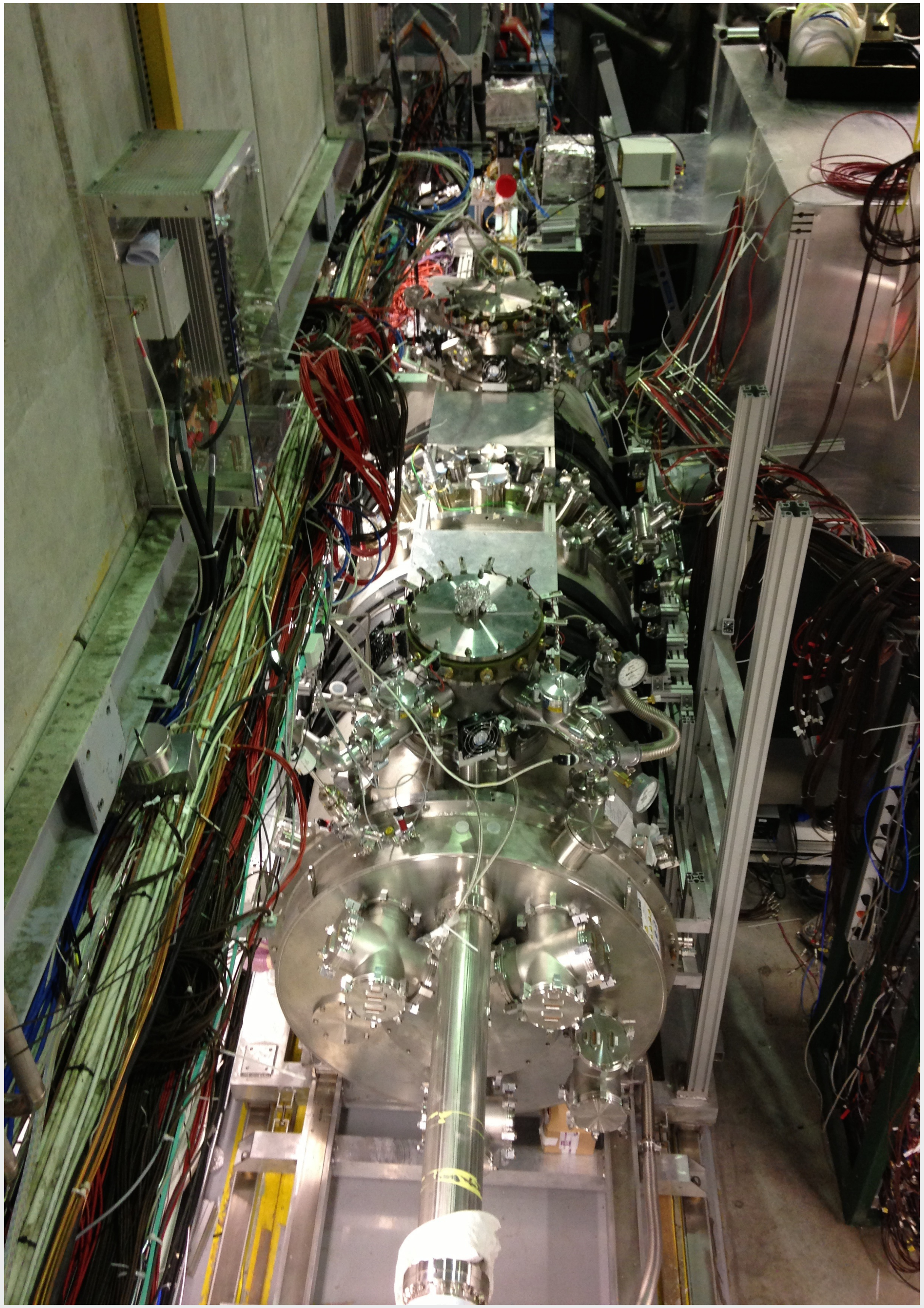












First results

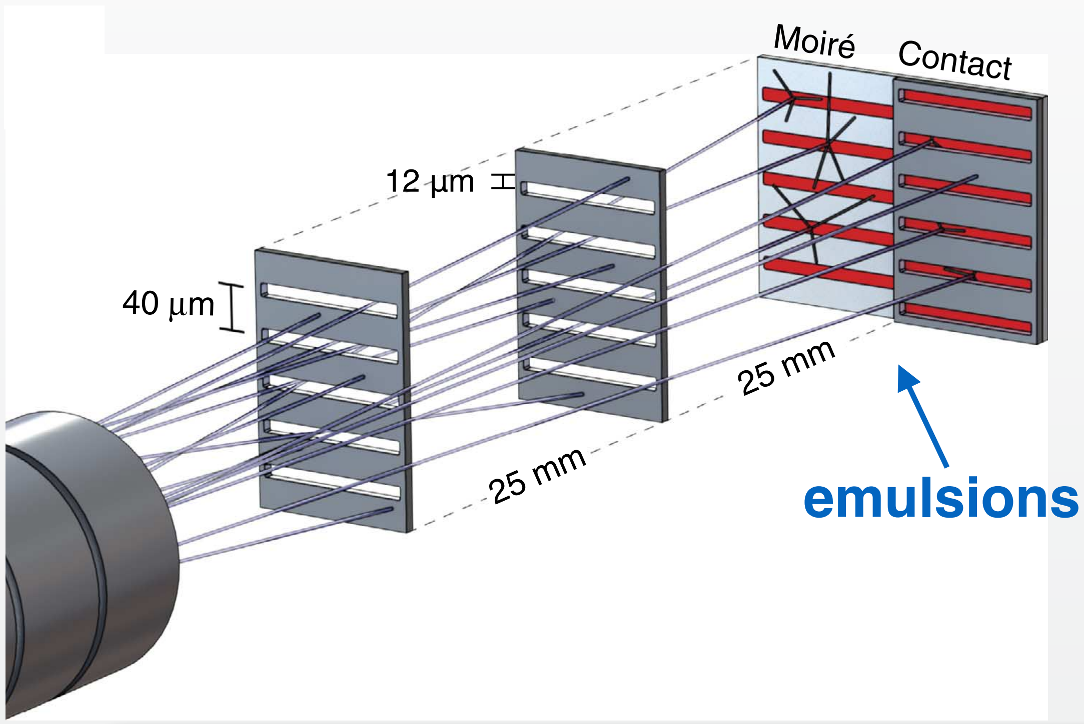
gravity measurement proof of principle

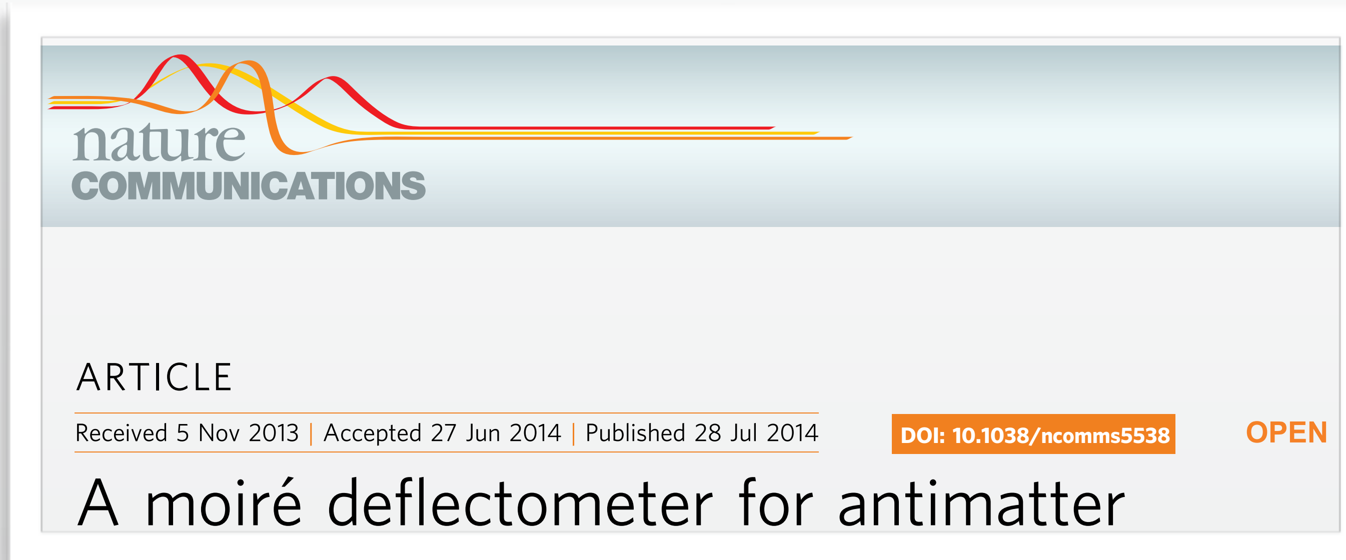
AEgIS experiment is taking data
($\bar{H}$ production expected in 2016/17)

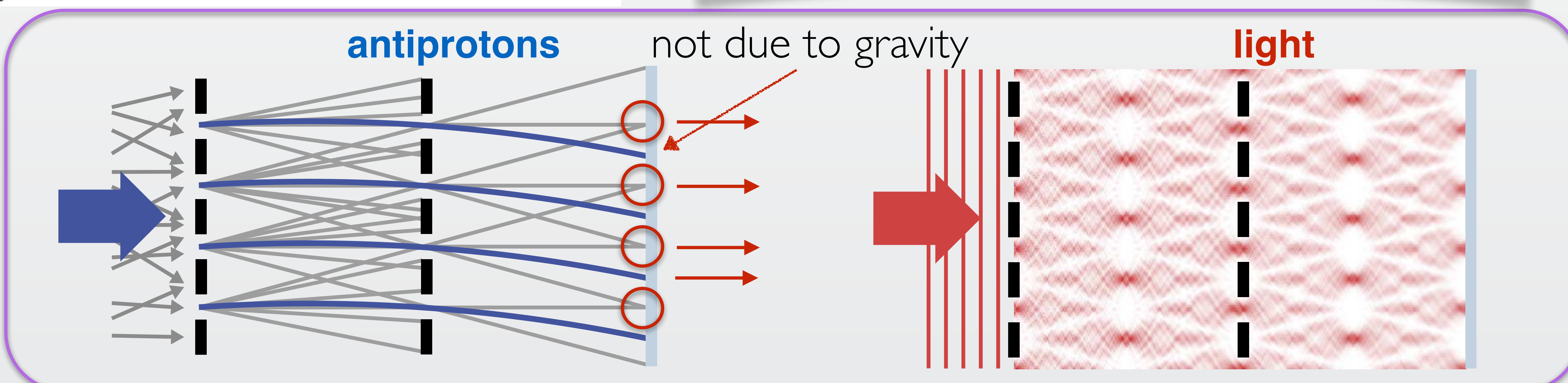
Small-scale test of the moiré deflectometer with $\bar{p}$ was performed

Mini-moiré deflectometer

- distance 25 mm
- slit 12 μm, pitch 40 μm, 100 μm thick
- pbar beam E~(100±150) keV traversing 1T magnet
- light reference: Talbot-Lau
- emulsion detector



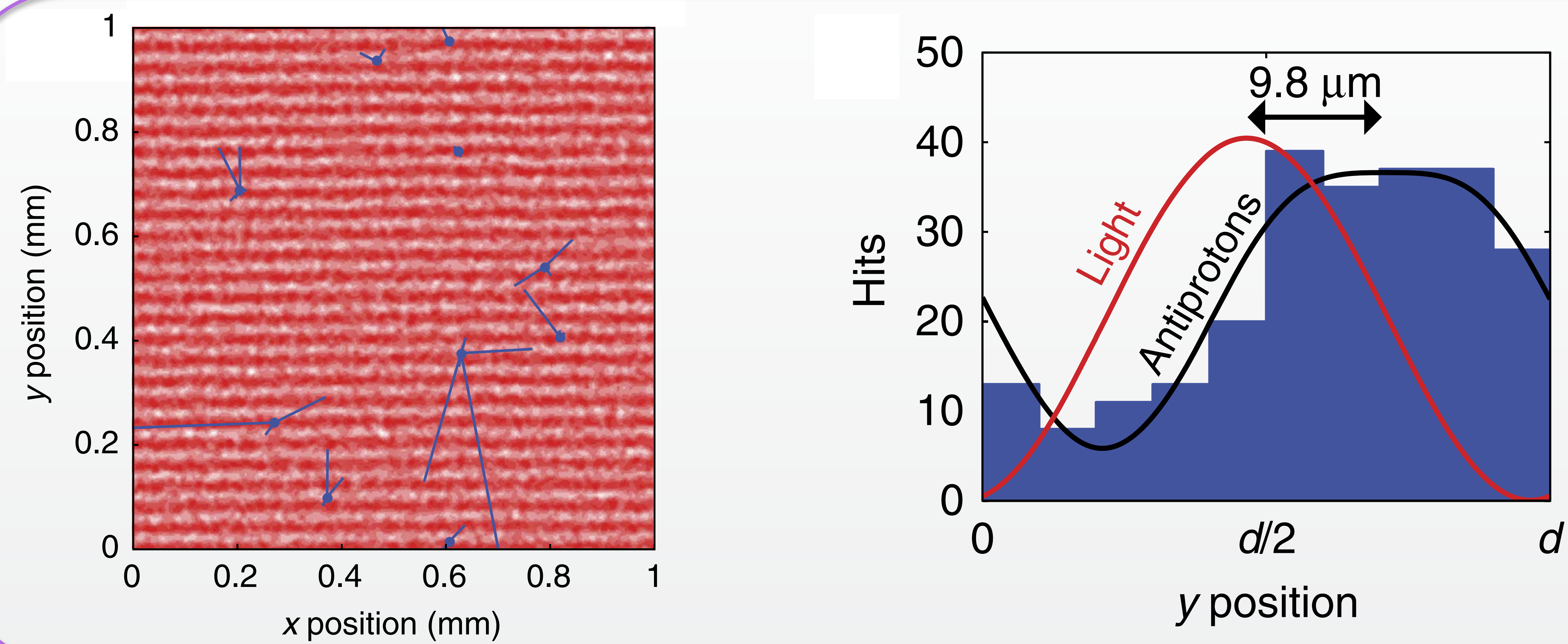




$\bar{g}$

gravity measurement proof of principle

- 146 antiprotons recorded (emulsion detector with 1-2 um resolution!)



$\Delta y = 9.8 \pm 0.9(\mathrm{stat}) \pm 6.4(\mathrm{syst})\ \mu m$

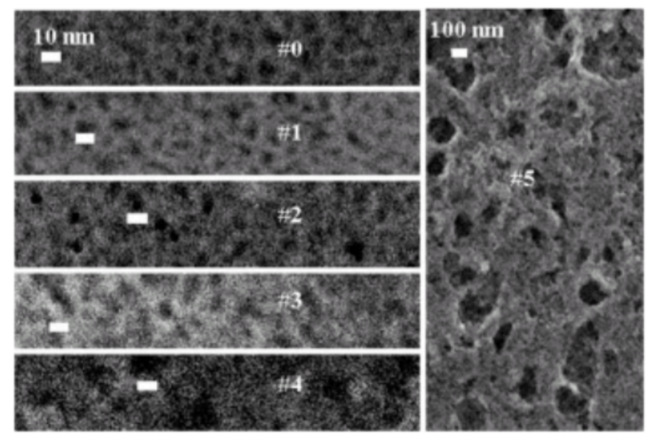
- $F = 530 \pm 50\,\mathrm{aN}\ (\mathrm{stat.}) \pm 350\,\mathrm{aN}\ (\mathrm{syst.})$
- consistent with a B ~ 7.4 G

B ~ 10 G measured at the moiré position

positronium production

Positronium (Ps) production by implanting e+ in a nanochanneled Si target

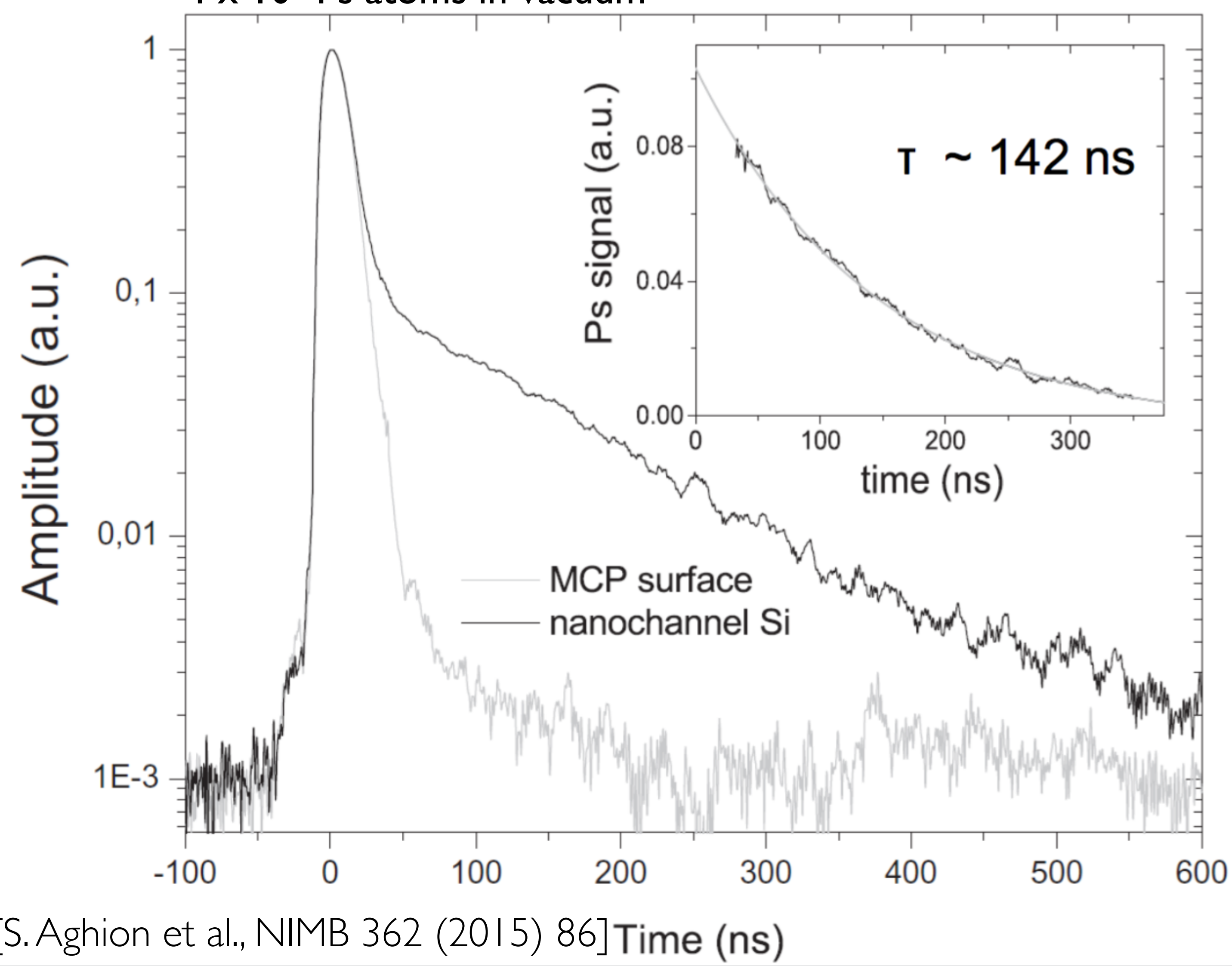
e^+/Ps converter



nanochanneled Si
(5-100 nm range, depth 2 um)

[S. Mariazzi et al., Phys. Rev. B 81 (2010) 235481]

4 x 10^6 Ps atoms in vacuum



[S. Aghion et al., NIMB 362 (2015) 86]

Single Shot Positron Annihilation Lifetime Spectroscopy (SSPALS) measurement
[D. B. Cassidy et al. NIMB 508 (2007) 1338]

Positrons impinging:
(a) passive surface (MCP)
(b) nanochanneled Si

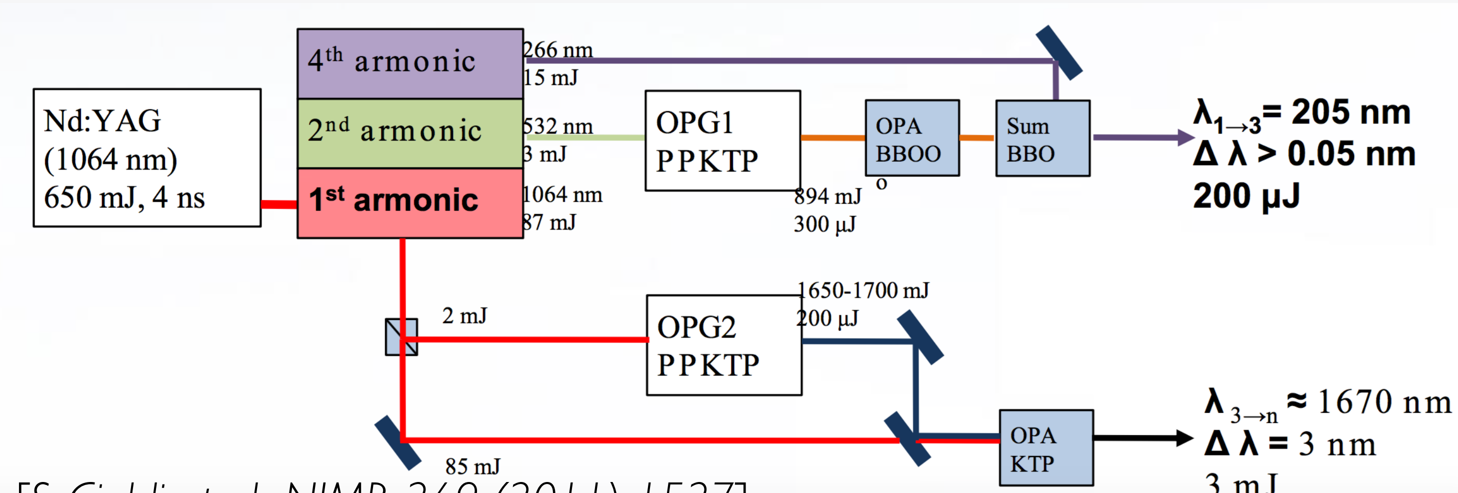
Comparing the two spectra and measuring the decay time of the signal showed that Ps was formed

demonstration of Ps n=3 laser excitation

Positronium (Ps) excitation with laser pulse

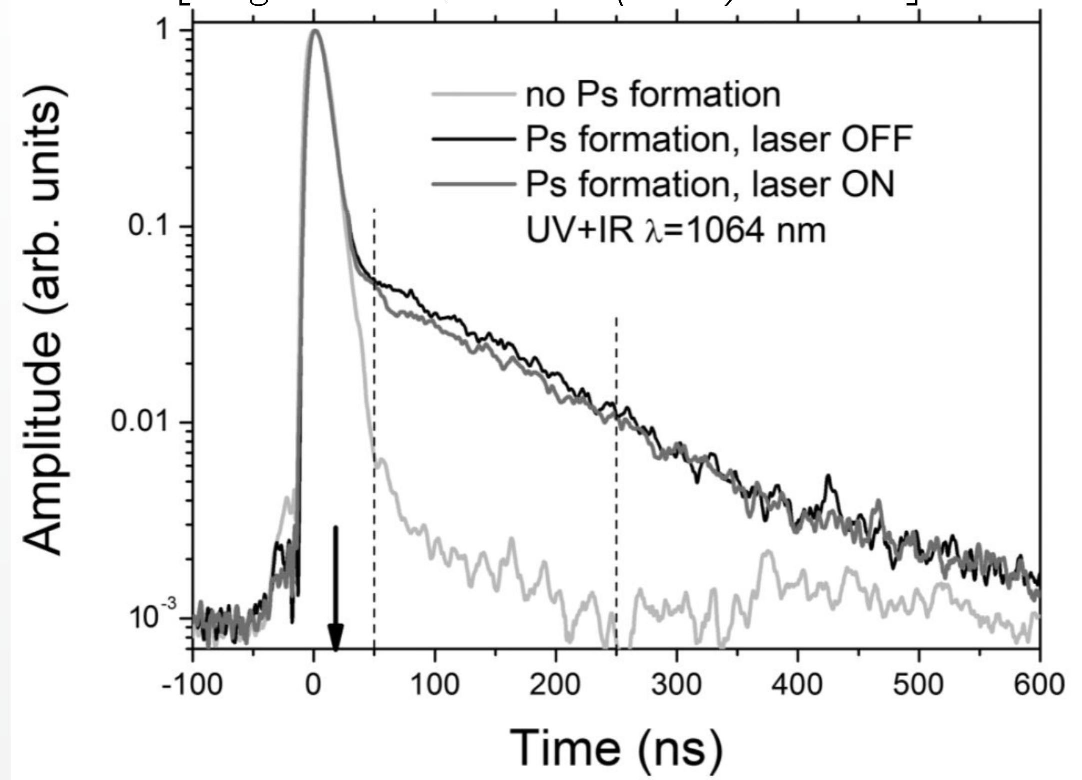
- 3P excitation line found at 205.5 +/- 0.02 nm
- excitation-ionisation efficiency ~ 15%

  (determined by ionisation by IR pulse)

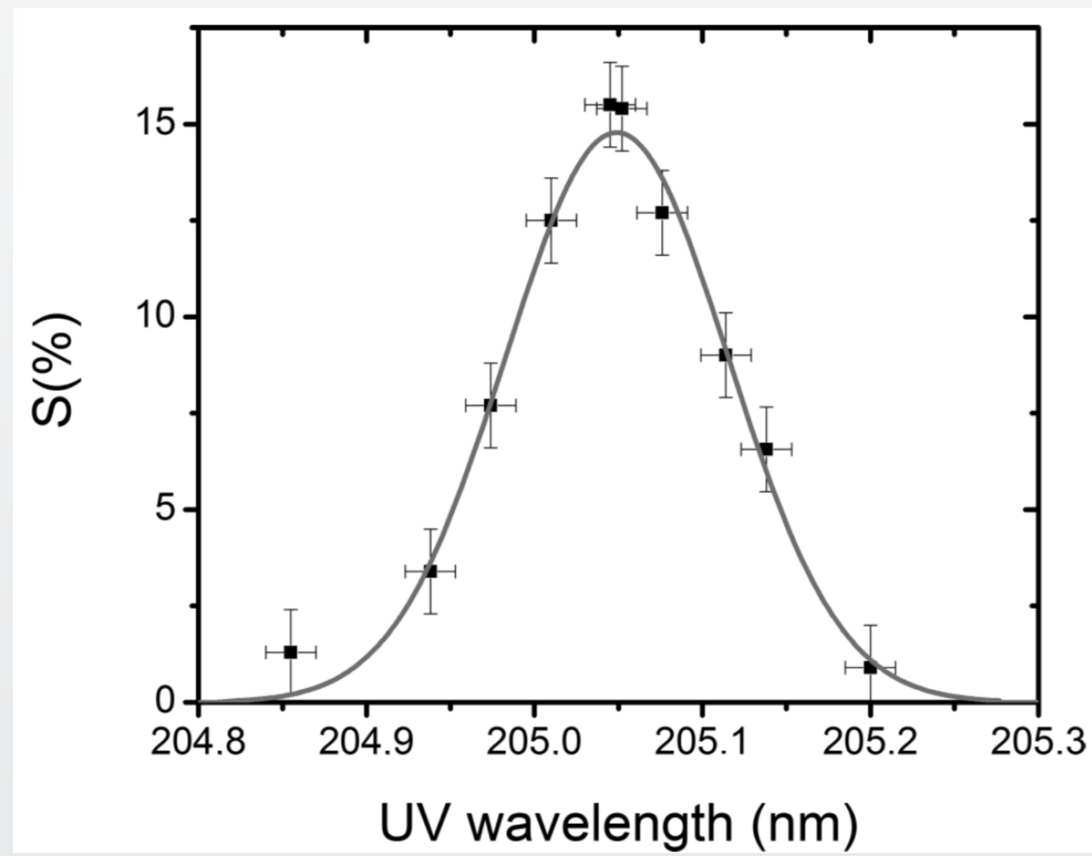


[S. Cialdi et al., NIMB 269 (2011) 1527]

[S. Aghion et al., PRA 94 (2016) 012507]



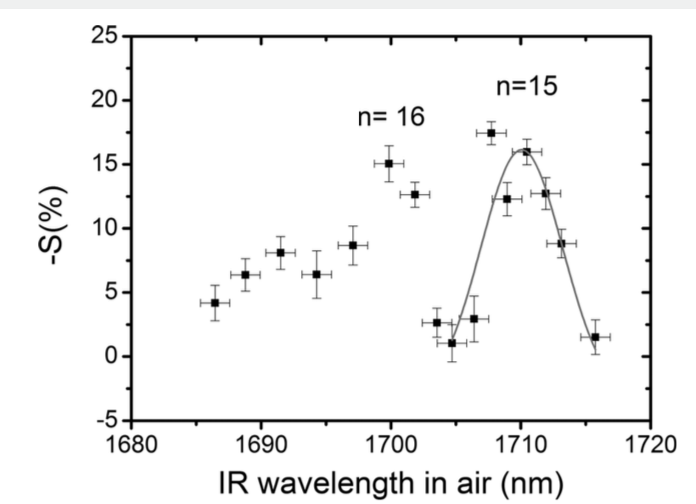
S(%) = (Area laser OFF-Area laser ON)/Area laser OFF



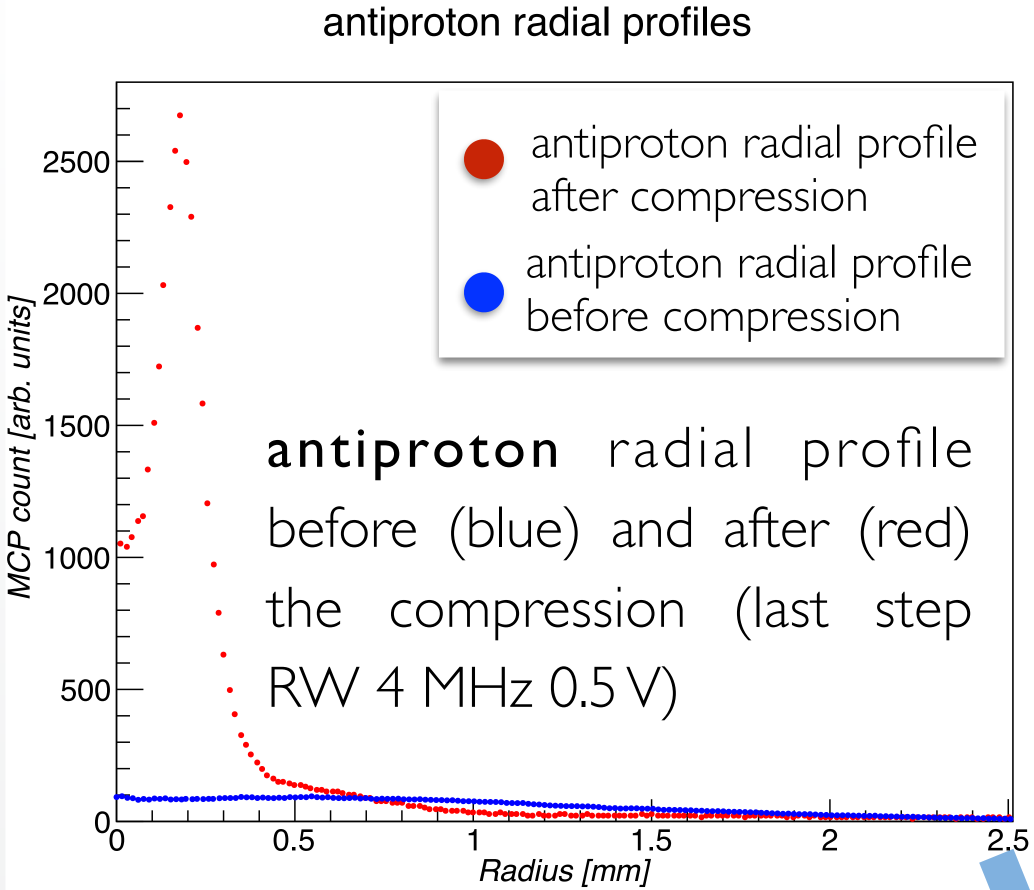
Evidence for n=15-18

Rydberg excitation by

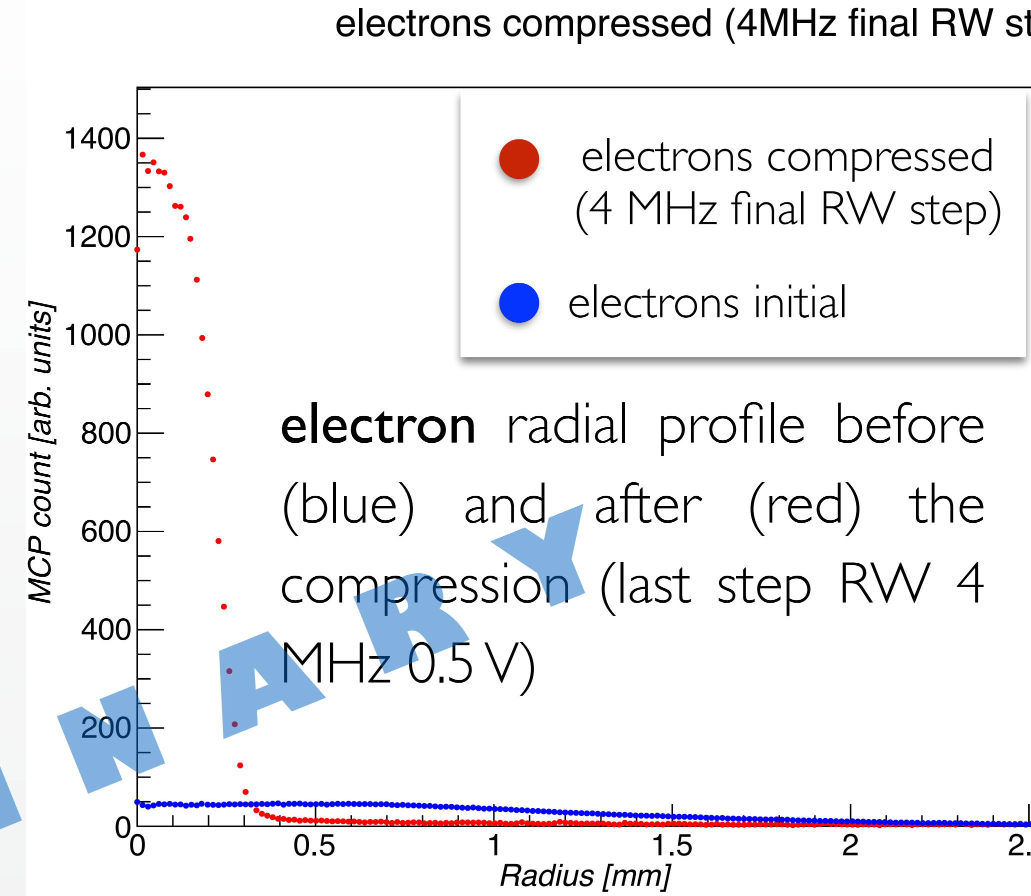
2-step laser excitation



antiprotons manipulation

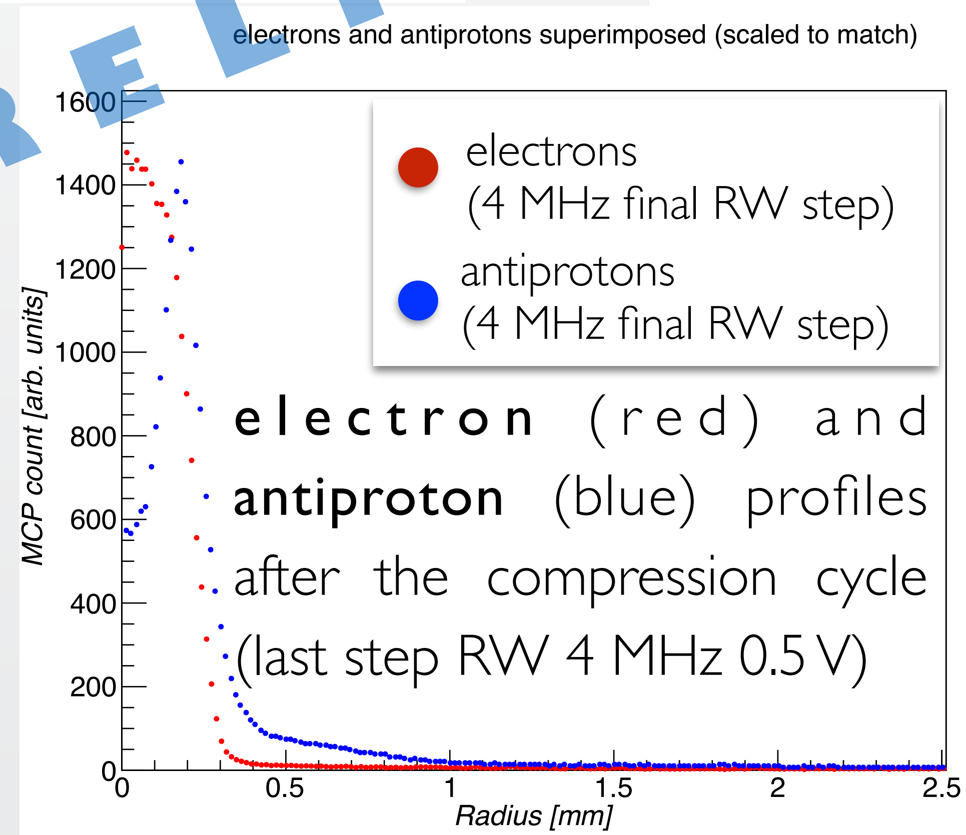


antiproton radial profile before (blue) and after (red) the compression (last step RW 4 MHz 0.5 V)



electron radial profile before (blue) and after (red) the compression (last step RW 4 MHz 0.5 V)

PRELIMINARY

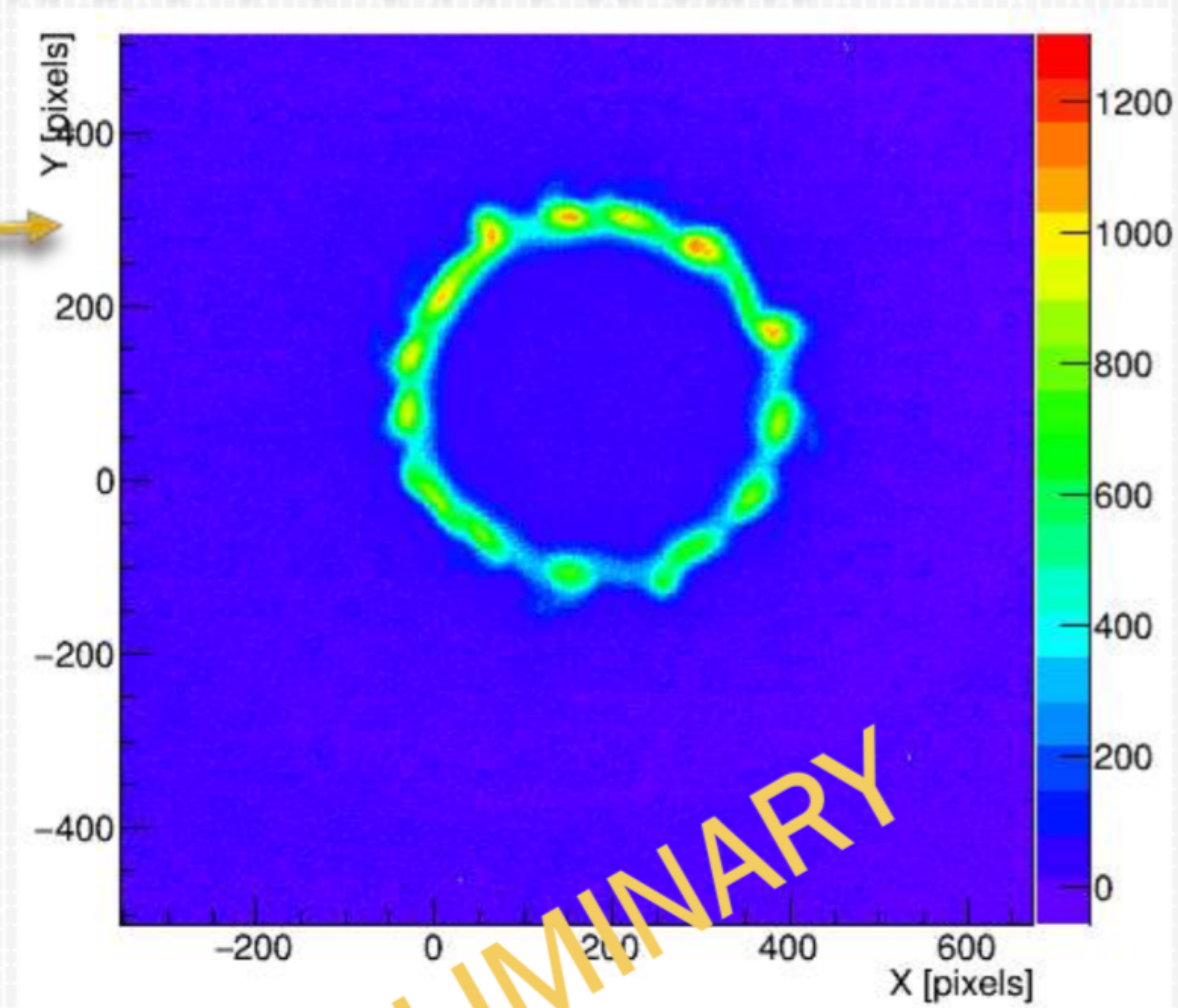


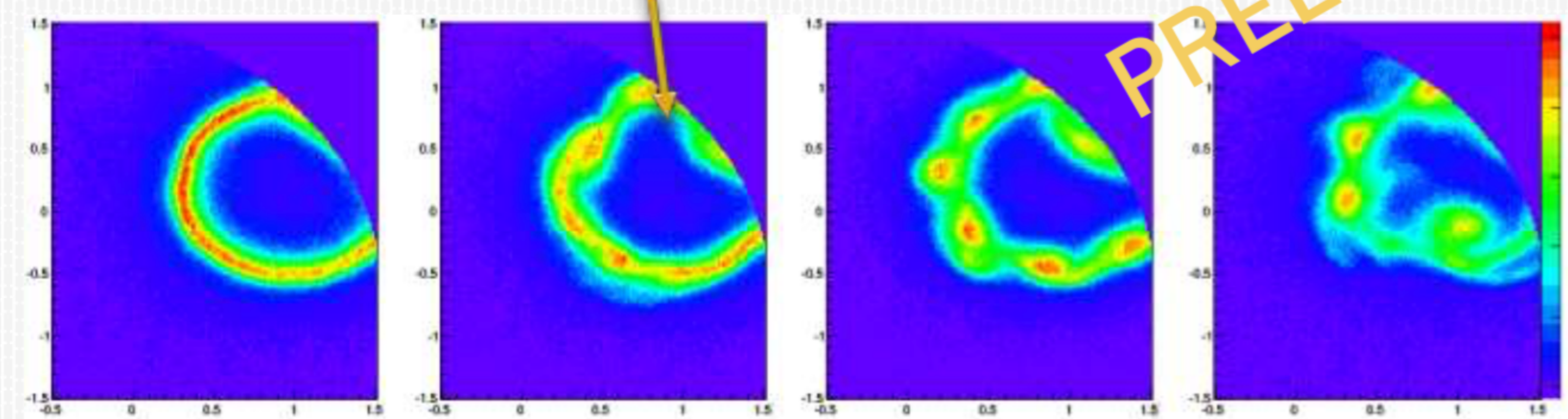
electron (red) and **antiproton** (blue) profiles after the compression cycle (last step RW 4 MHz 0.5 V)

antiprotons manipulation

- Observation of electron & antiproton centrifugal separation
  - -> expected effect in our experimental conditions

- Observation of antiproton ring decay through vortices





Conclusions and future plans

Goal

- AEgIS aims at probing the WEP on antimatter
  - No precise direct measurement so far

Results

- AEgIS is taking data
- The working principle tested using antiprotons
- Antiprotons are routinely trapped and "manipulated" in the traps
- Positronium have been formed and excited to Rydberg states

Future plans

- $\bar{\mathrm{H}}$ production expected to be achieved this/next year
- First gravity measurements planned for the next years
- Longer term plans also include H-$\bar{\mathrm{H}}$ spectroscopy (in particular HFS)

Спасибо за ваше внимание

the AEgIS collaboration

ÖAW
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

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