AE$\bar{g}$IS: tests of gravitation with a beam of $\bar{H}$

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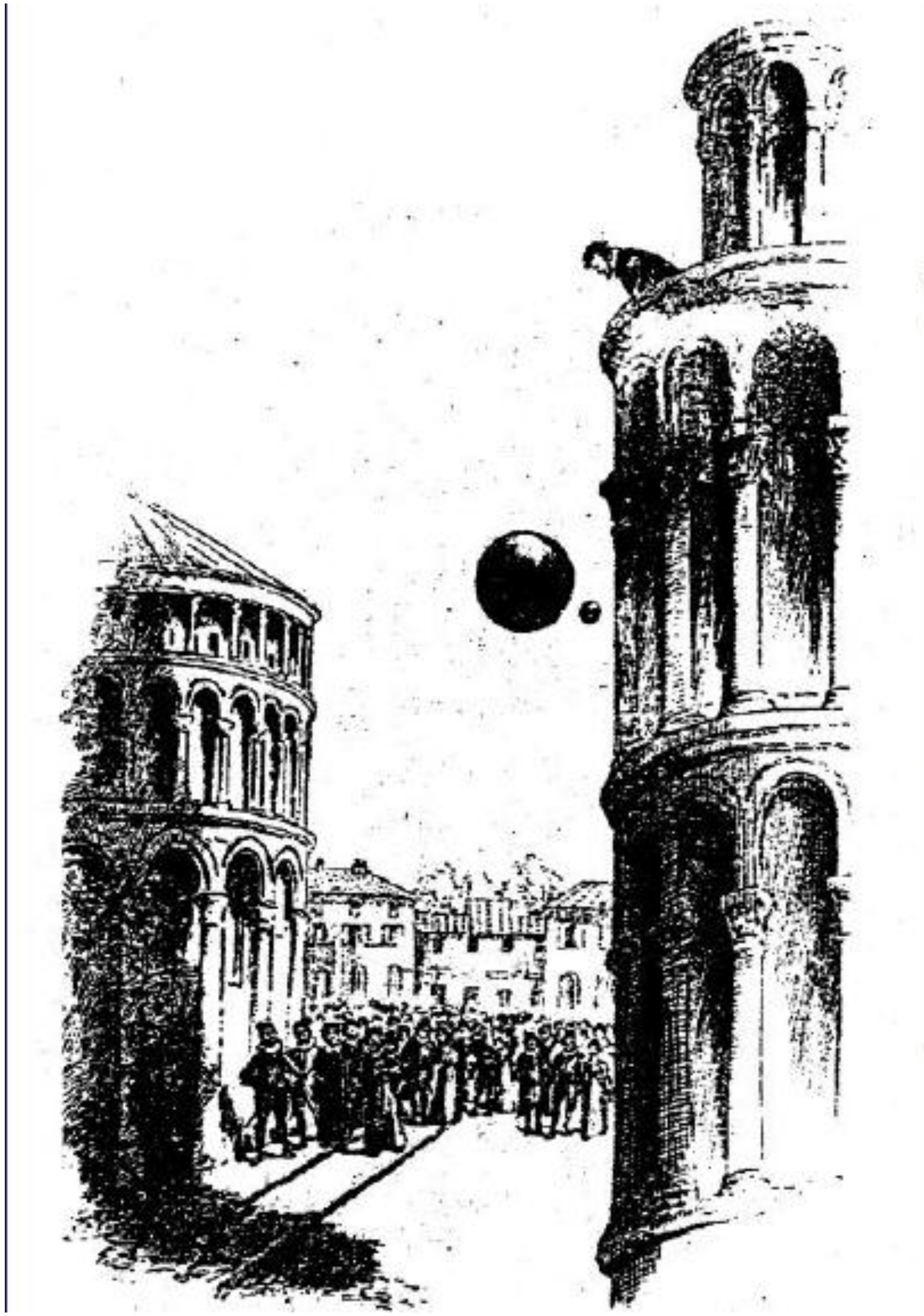
AEgIS: a beam of $\bar{H}$ to test gravity



Tests of gravity require very cold trapped $\bar{H}$ or a pulsed cold beam of $\bar{H}$

G ~ 100nV/m on $\bar{p}$

Experimental goal: g measurement with 1% accuracy on antihydrogen

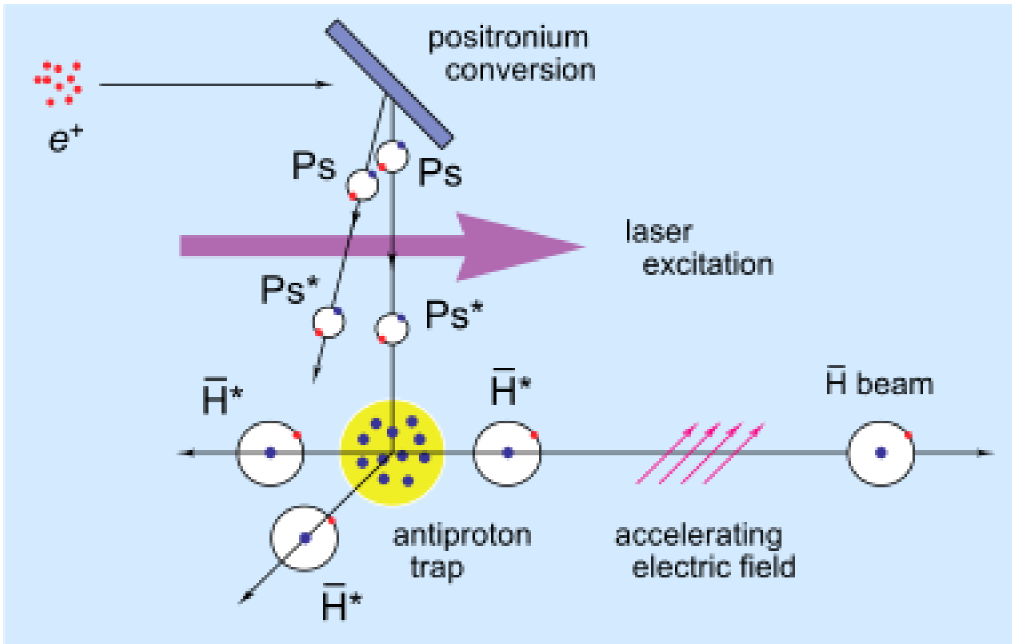
(first direct measurement on antimatter)

a) production of a pulsed cold beam of antihydrogen (T~0.1K)

b) measurement of the beam deflection with a Moiré deflectometer

Step i) antihydrogen formation

- Charge exchange reaction:



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

- cold antiprotons (T~0.1K)
- production of Rydberg positronium
- production of antihydrogen atoms

- Principle demonstrated by ATRAP (Cs* → Ps* → $\bar{H}$*)
  [C. H. Storry *et al.*, Phys. Rev. Lett. **93** (2004) 263401]

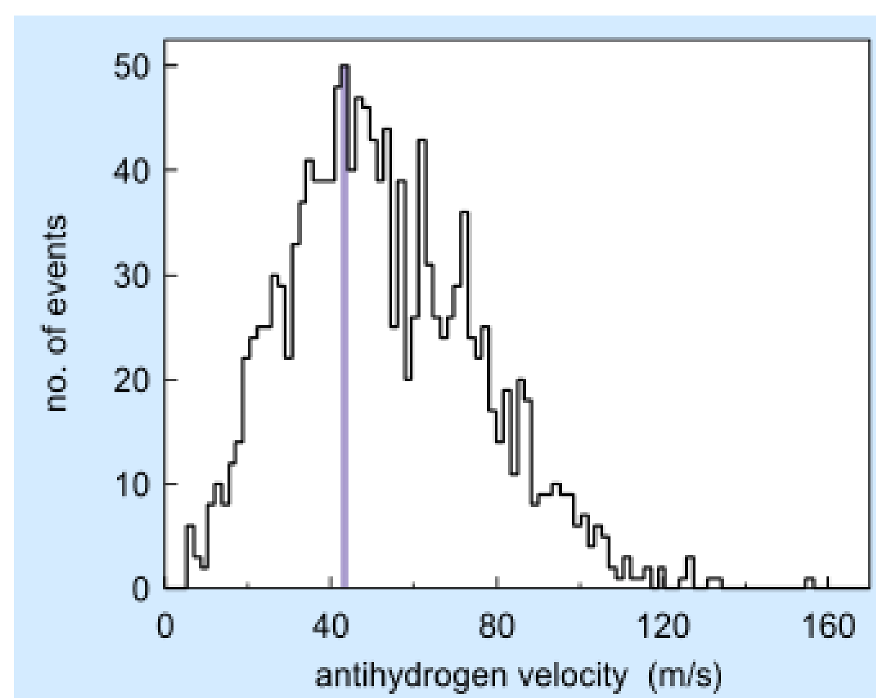
- Advantages:

– Large cross-section: $\sigma \approx a_0 n^4$

– Narrow and well-defined $\bar{H}$ *n*-state distribution

– $\bar{H}$ production from $\bar{p}$ at rest → ultracold $\bar{H}$

- pulsed production of $\bar{H}$



At *T*(p) = 100mK,
n(Ps) = 35
® *v*(H) ≈ 45 m/s
T(H) ≈ 120mK

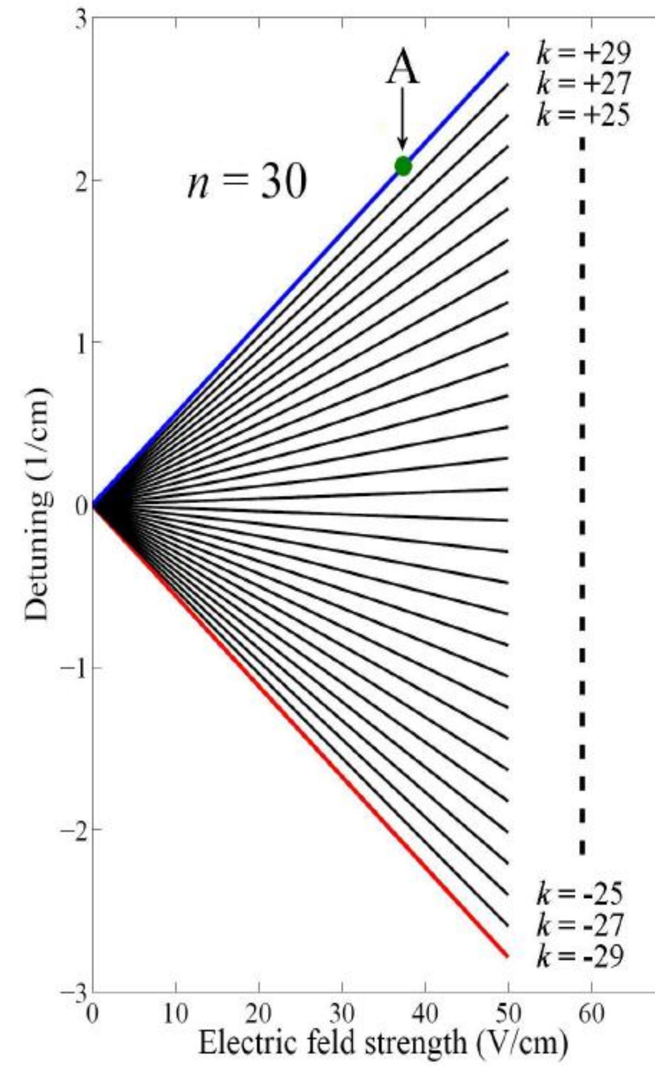
Step ii) beam formation

- Neutral atoms are not sensitive to static electric and magnetic fields
- Electric field gradients exert force on electric dipoles:

$$E = -\frac{1}{2n^2} + \frac{3}{2} nkF$$

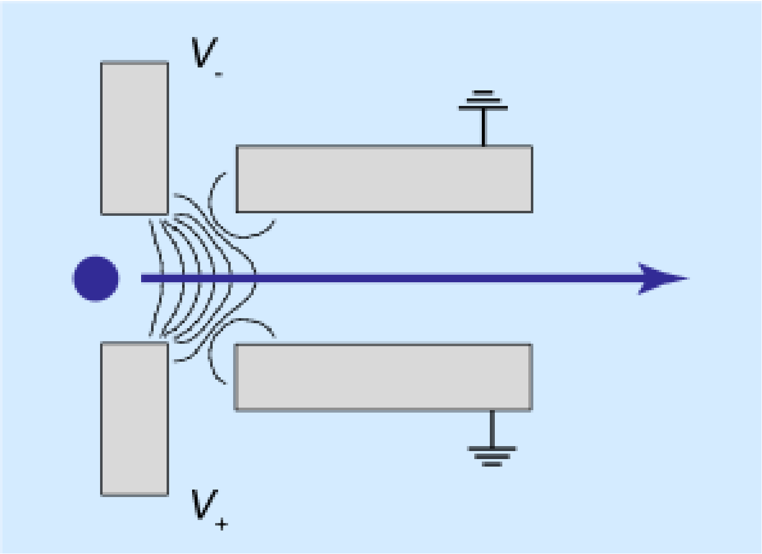
$$Force = -\frac{3}{2} nk\vec{\nabla} F$$

®Rydberg atoms are very sensitive to inhomogeneous electric fields



- Stark deceleration of hydrogen demonstrated

[E. Vliegen & F. Merkt, J. Phys. B **39** (2006) L241 - ETH Physical Chemistry]

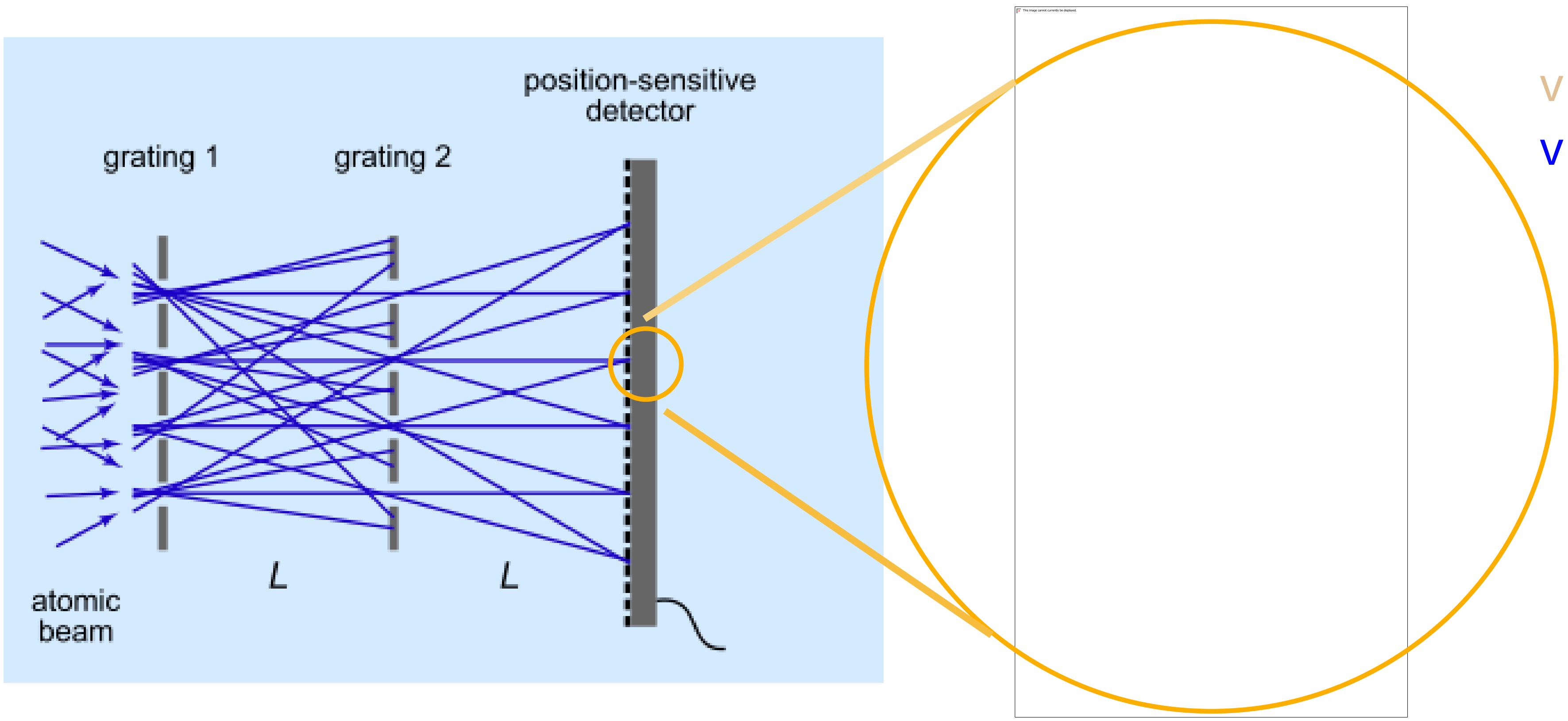


- n = 22,23,24
- Accelerations of up to 2×10^8 m/s^2 achieved
- Hydrogen beam at 700 m/s can be stopped in 5 μs over only 1.8 mm
- ongoing work on Zeeman deceleration, Stark deceleration and trapping of H

Step iii) trajectory measurement

- Classical counterpart of the Mach-Zehnder interferometer
– Decoherence effects reduced
– “Self-focusing” effect – beam collimation uncritical

Fringe phase <u>and</u> phase shift identical to Mach-Zehnder interferometer!



v =250 m/s
v =600 m/s

$$\delta = \frac{gt^2}{a}$$

- Replace the third grating and detector by position-sensitive detector

  ® Transmission increases by ~ factor 3

- Has been successfully used for a gravity measurement with ordinary matter, $\sigma(g)/g = 2 \times 10^{-4}$
- with 10^5 $\bar{H}$ at 100mK, $\sigma(g)/g$ = 1% (expected)

[M. K. Oberthaler *et al.*, Phys. Rev. A **54** (1996) 3165]

[A. Kellerbauer *et al.*, Phys. Rev. A **54** (1996) 3165]

challenges (pour fixer les ideeés):

10^5 $\bar{H}$ at 100mK @ 1 Hz ®10^4 $\bar{H}$ reach target in 10^5 s

- production rate lower ®linear increase in required time
- temperature higher ® higher beam divergence

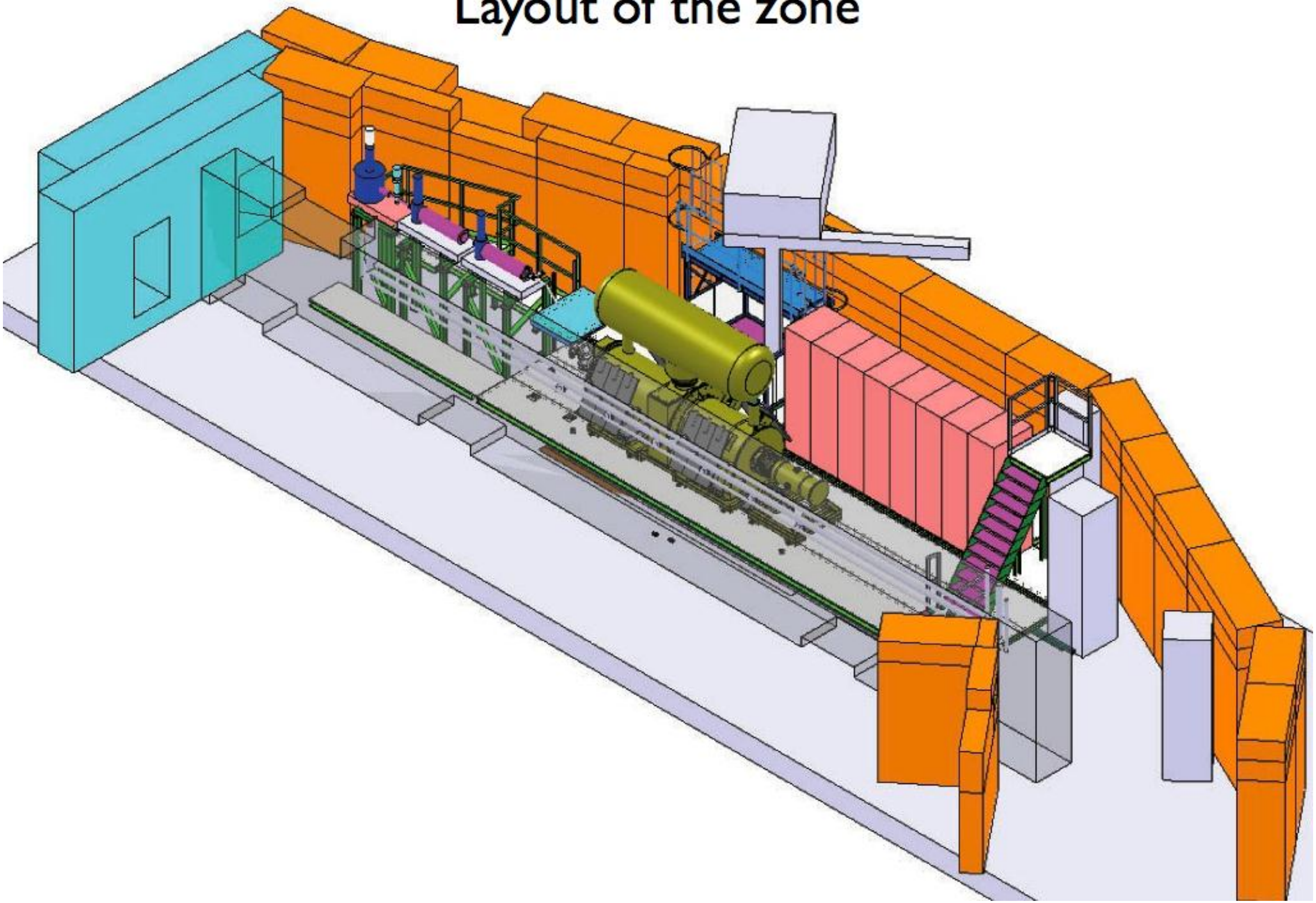
(assumption: all things being equal, systematics under contro

Increase in number of antihydrogen atoms scales with the number of cold (100 mK) antiprotons;

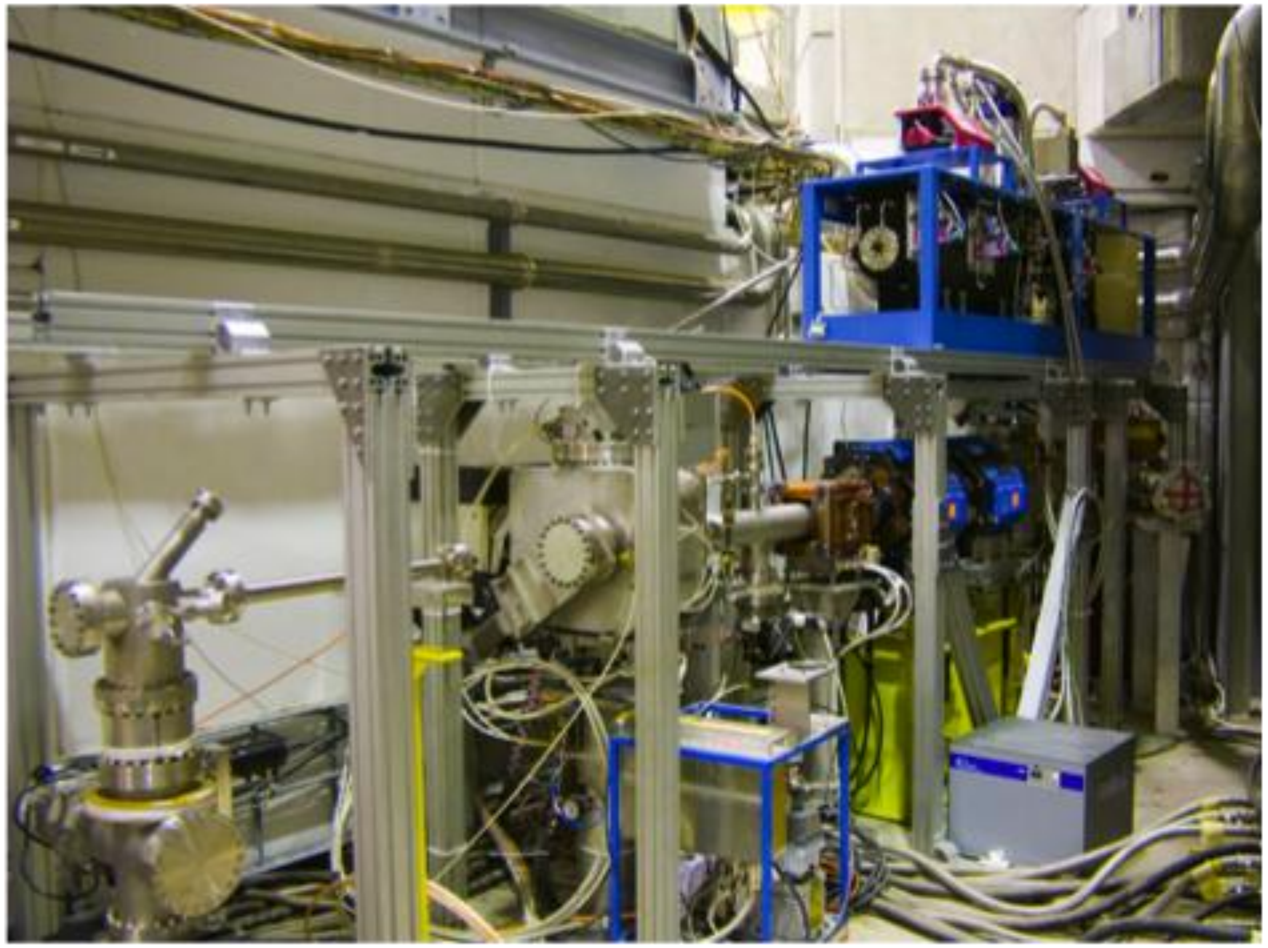
a factor of 100 increase should lead to a factor 10 improvement in sensitivity (although all atoms are produced simultaneously, little risk of pile-up)

Infrastructure today

Layout of the zone



Status of AEGIS apparatus



- Completed components:

  Positron source, rare-gas moderator and trap

  AD beam line and diagnostics

  5-T magnet and trap (completed, to be installed October 2011)

  Laser system
  1-T magnet
  } (completed, to be installed January 2012)

- Main components under design / construction:
  - Positron accumulator: ordered, delivery March 2012
  - Dilution cryostat: design completed, delivery 2012
  - Moiré deflectometer: prototype being tested in Heidelberg
  - Position-sensitive detector: tests with prototype by summer 2012
  - Antihydrogen detector: design completed, parts ordered, assembly by summer 2012
  - 1-T Penning traps: being designed

Time line

2011: trapping of antiprotons, detector tests

2012: positronium formation & excitation, antihydrogen production

2013: hydrogen beam commissioning & optimization

2014: antihydrogen beam, gravity measurements

2015: antihydrogen beam, gravity + other measurements

2016: improved measurements of gravitational coupling, …

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AEgIS will clearly benefit from ELENA…