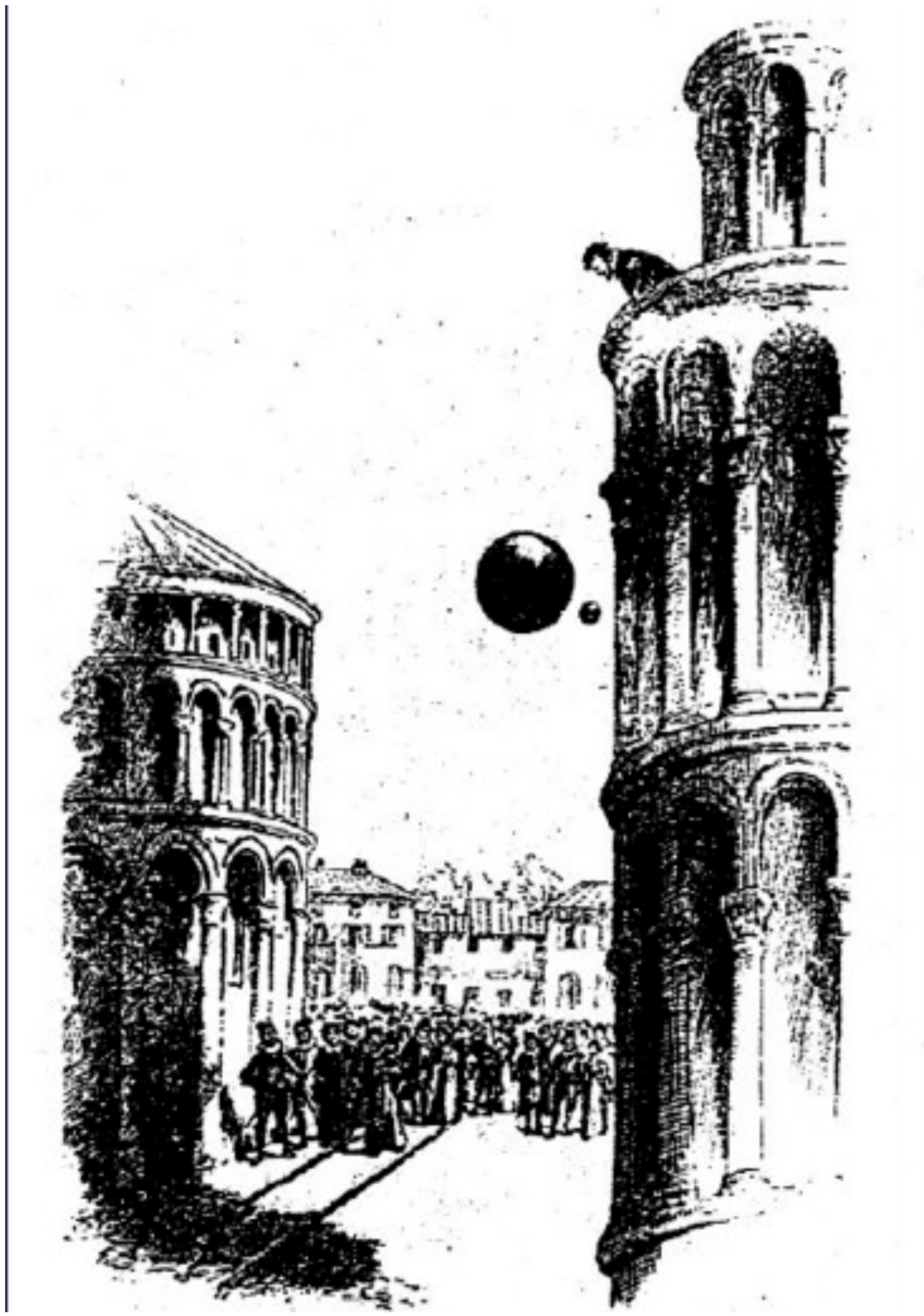
AEḡIS: a beam of $\bar{H}$ to test gravity

Michael Doser /CERN on behalf of the AEgIS collaboration



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

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

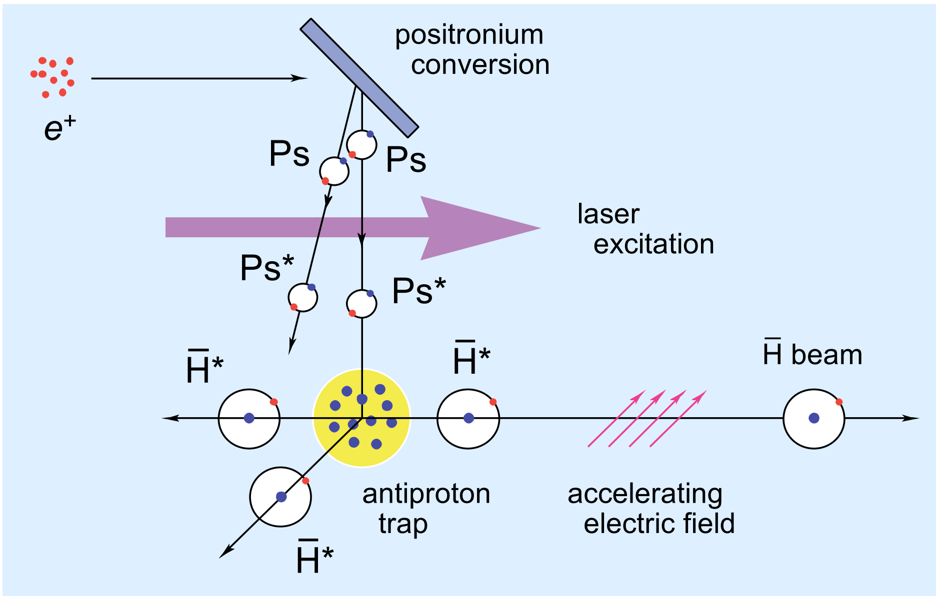
Experimental goal: g measurement with 1% accuracy on antihydrogen

(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

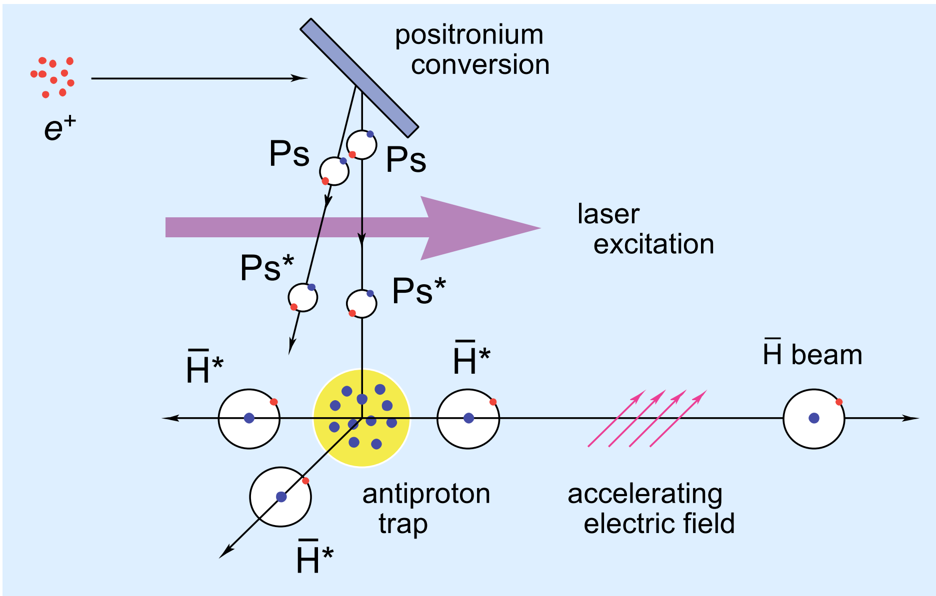


Charge exchange reaction

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

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

Step i) antihydrogen formation



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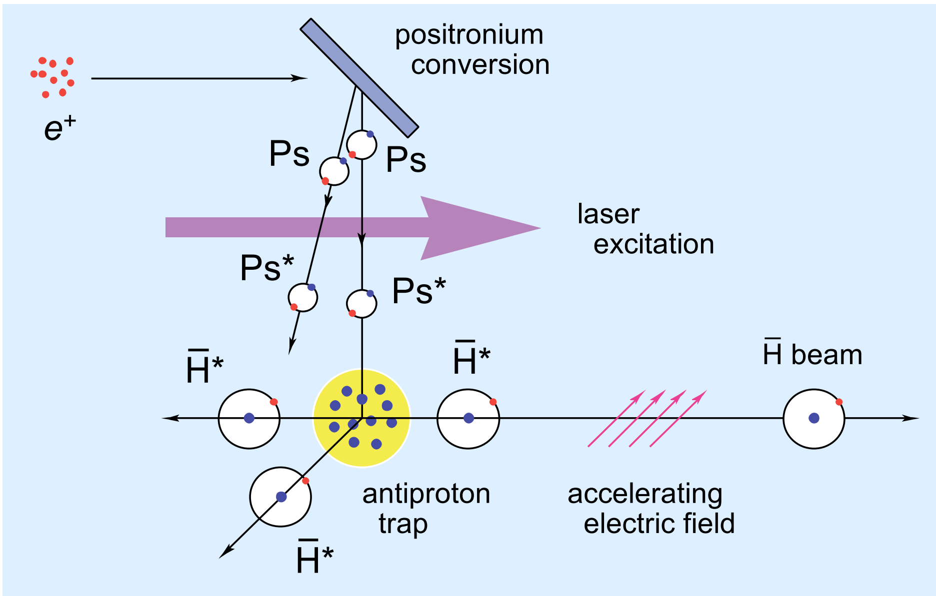
Step ii) beam formation

Stark acceleration of Rydberg antihydrogen (electric dipole)

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

Step i) antihydrogen formation



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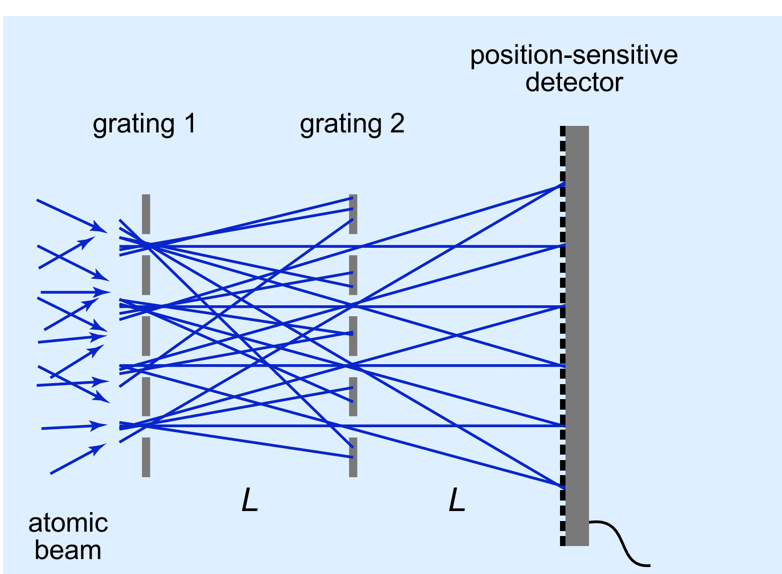
Step iii) trajectory measurement



- Mach-Zehnder interferometer
- detection of vertical impact coordinate with a high-resolution detector (silicon microstrip or similar)

Step i) antihydrogen production

1) positron accumulation

2) antiproton accumulation

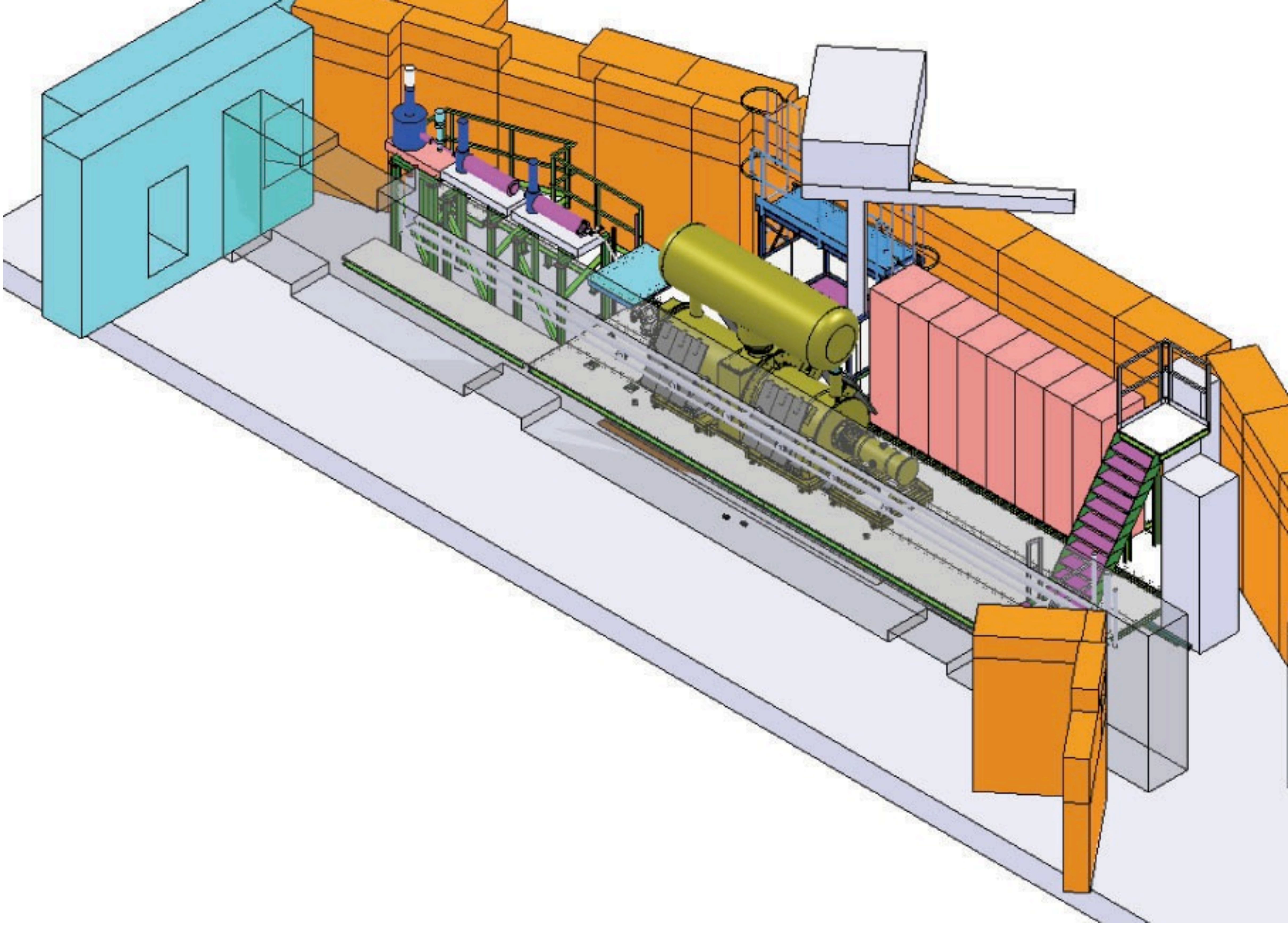
3) positronium formation

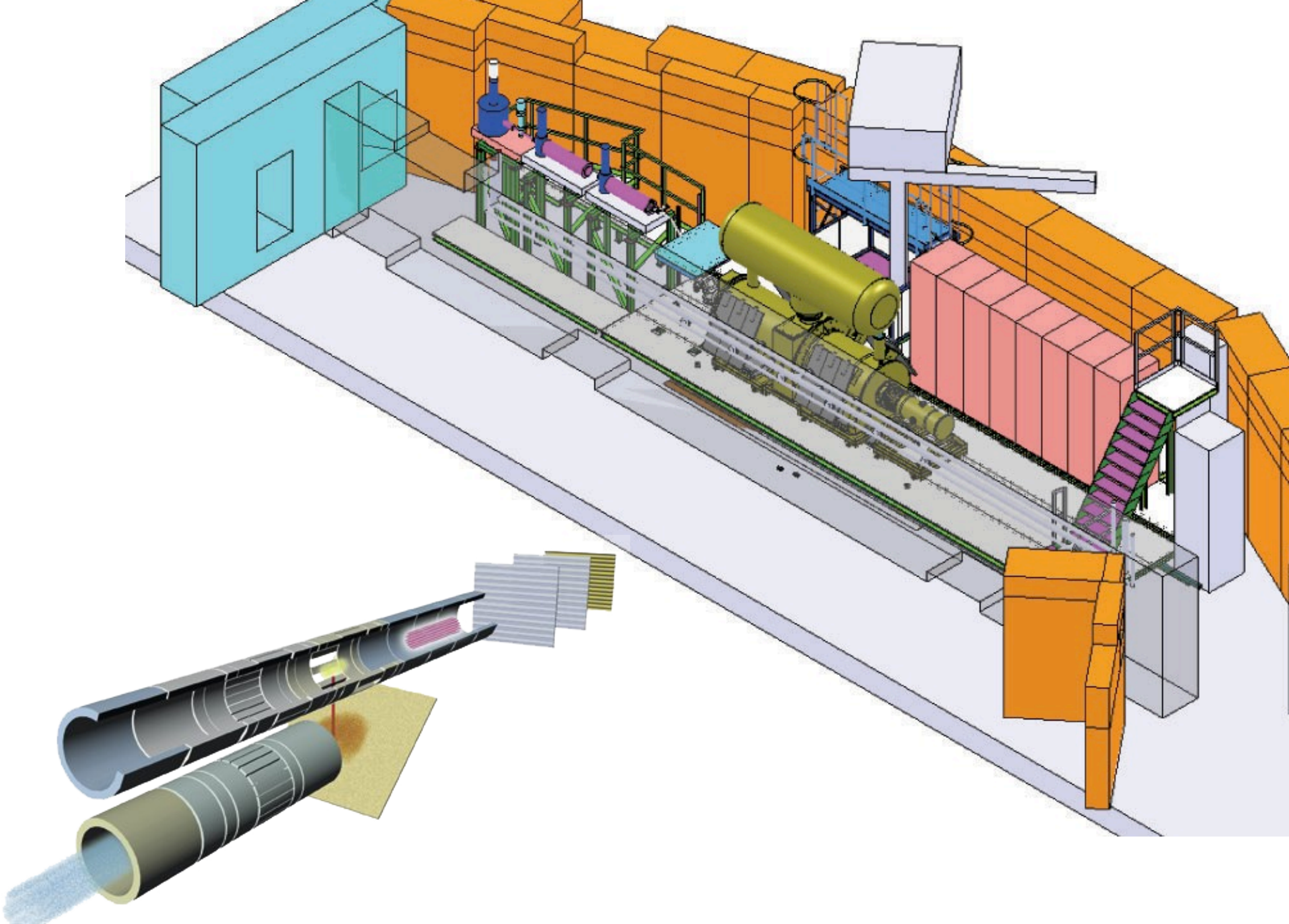
4) positronium excitation

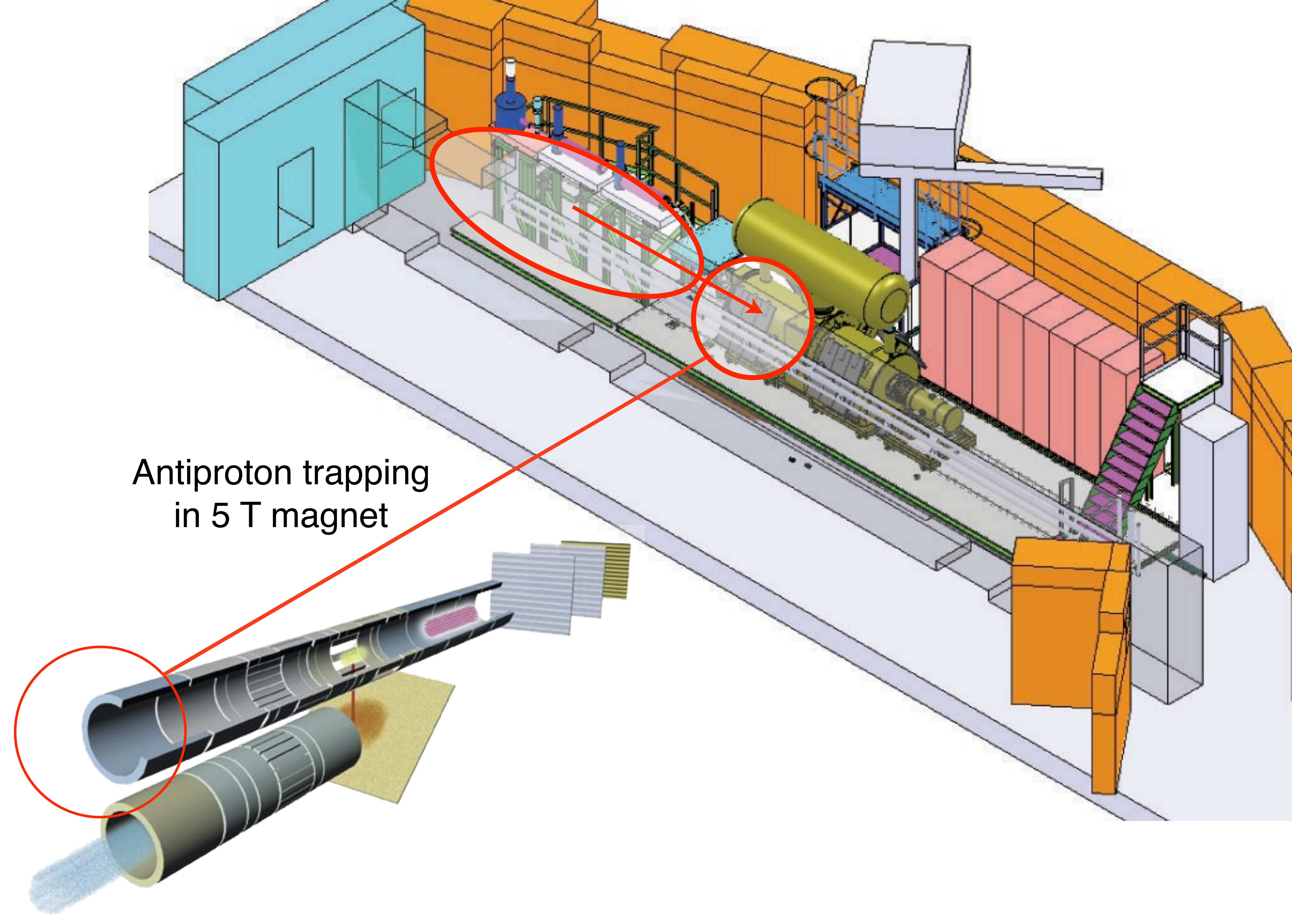
5) antihydrogen formation

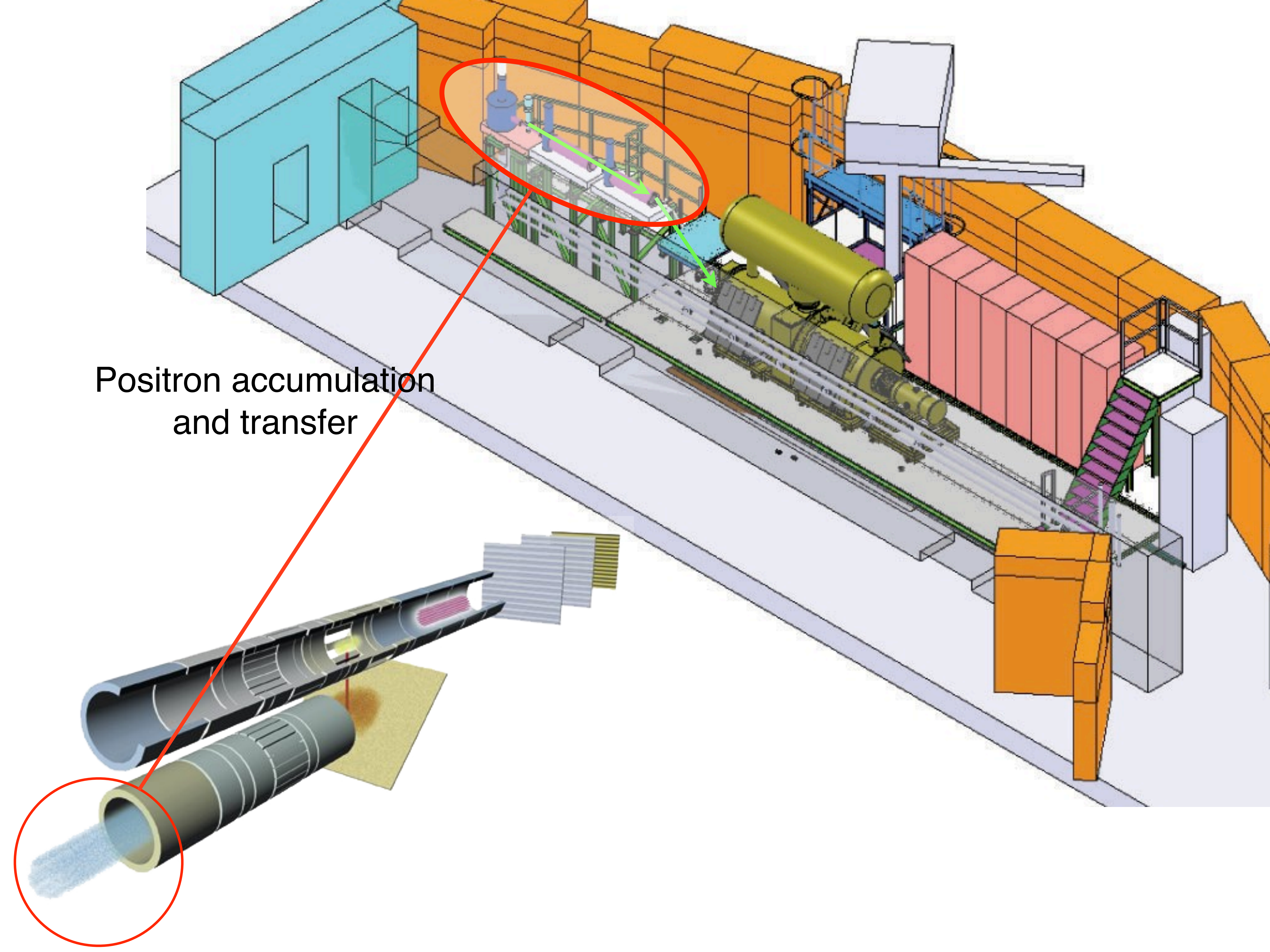
Step ii) antihydrogen beam

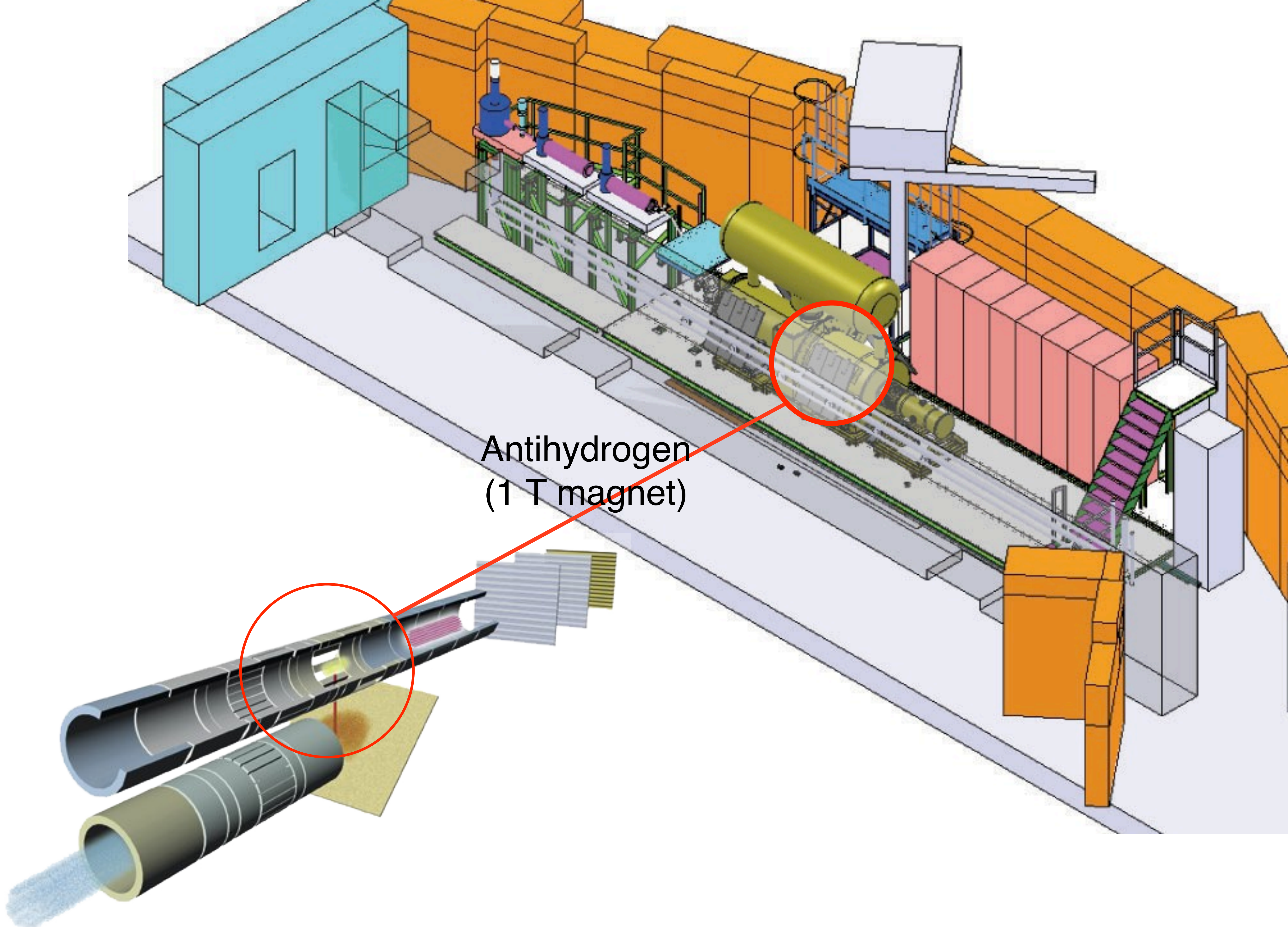
Step iii) trajectory measurement

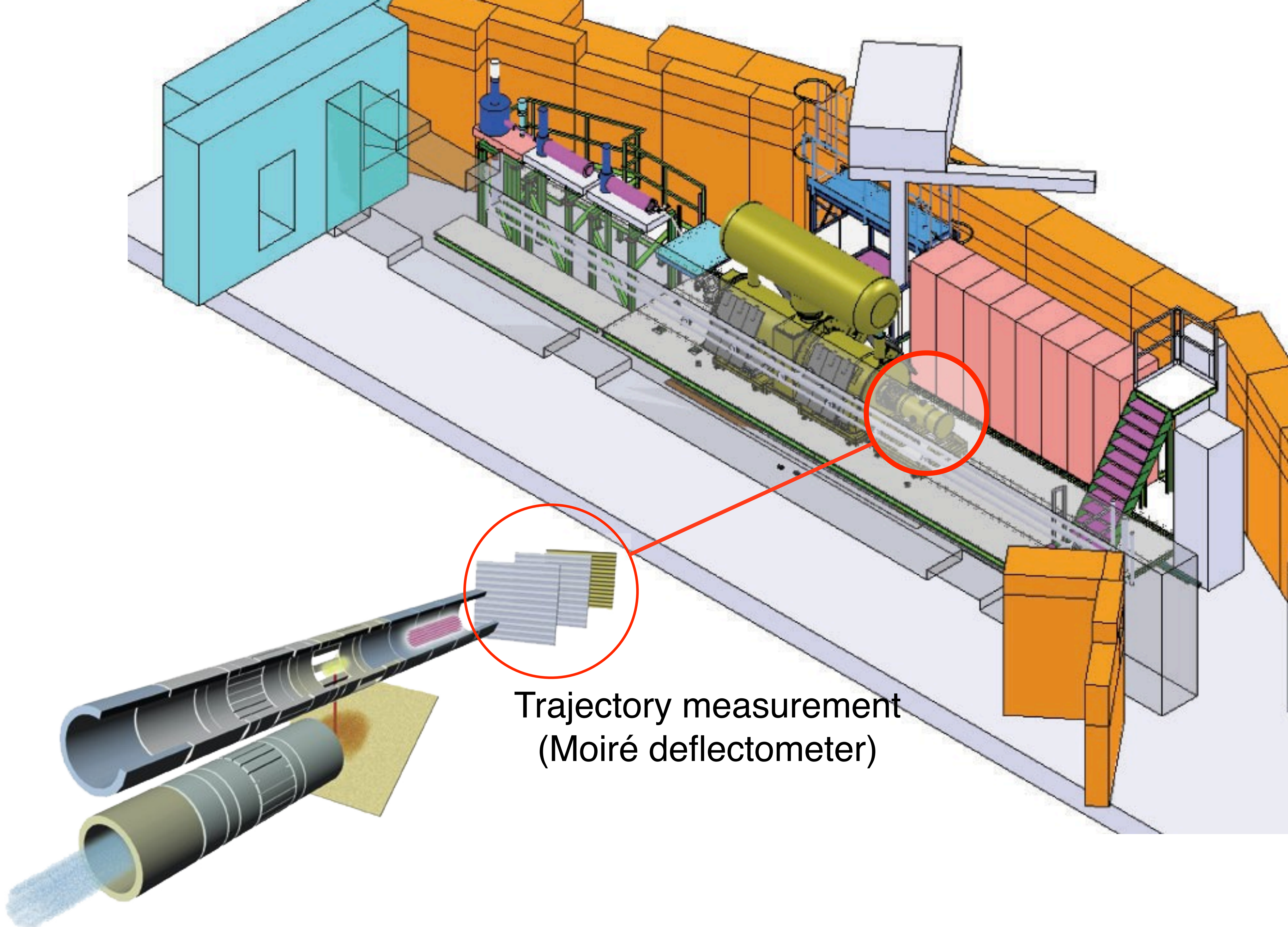





Antiproton trapping
in 5 T magnet


Positron accumulation
and transfer


Antihydrogen
(1 T magnet)


Trajectory measurement
(Moiré deflectometer)

1) positron accumulation

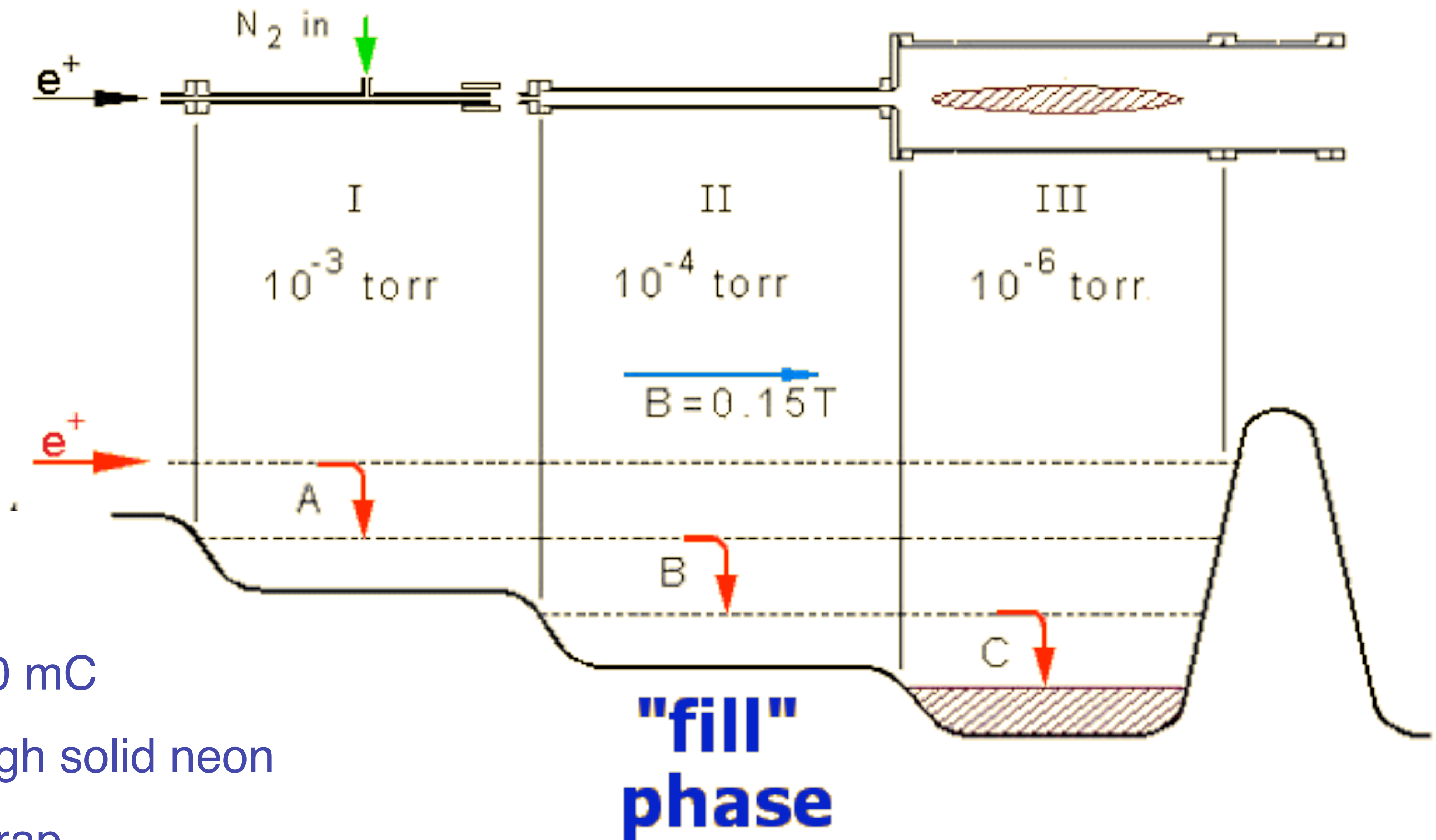
2) antiproton accumulation

3) positronium formation

4) positronium excitation

5) antihydrogen formation

"Surko type" positron accumulator:

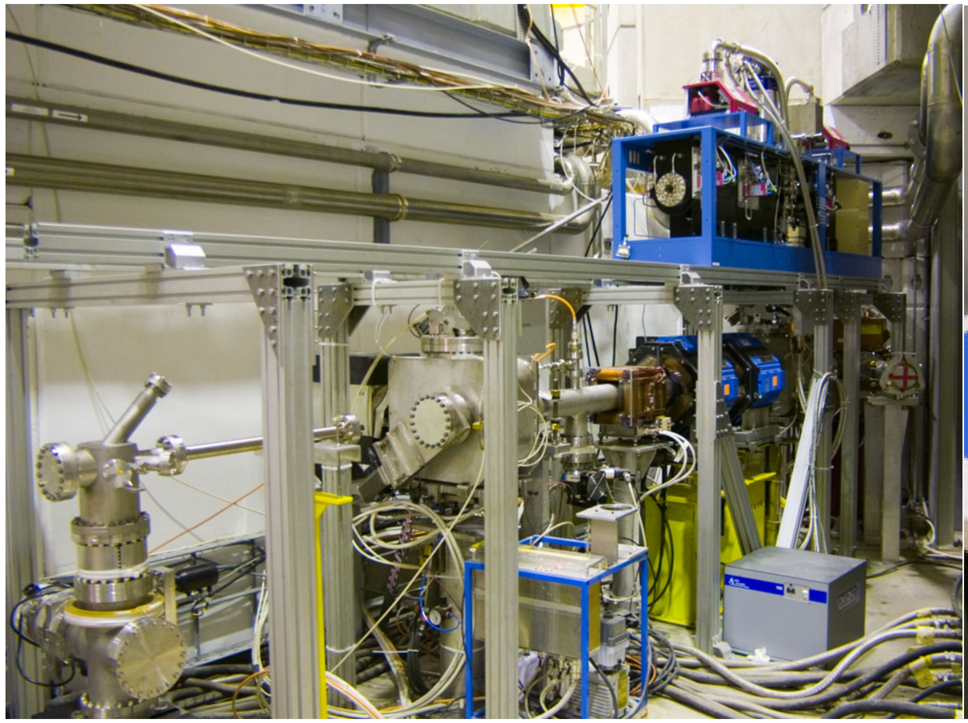


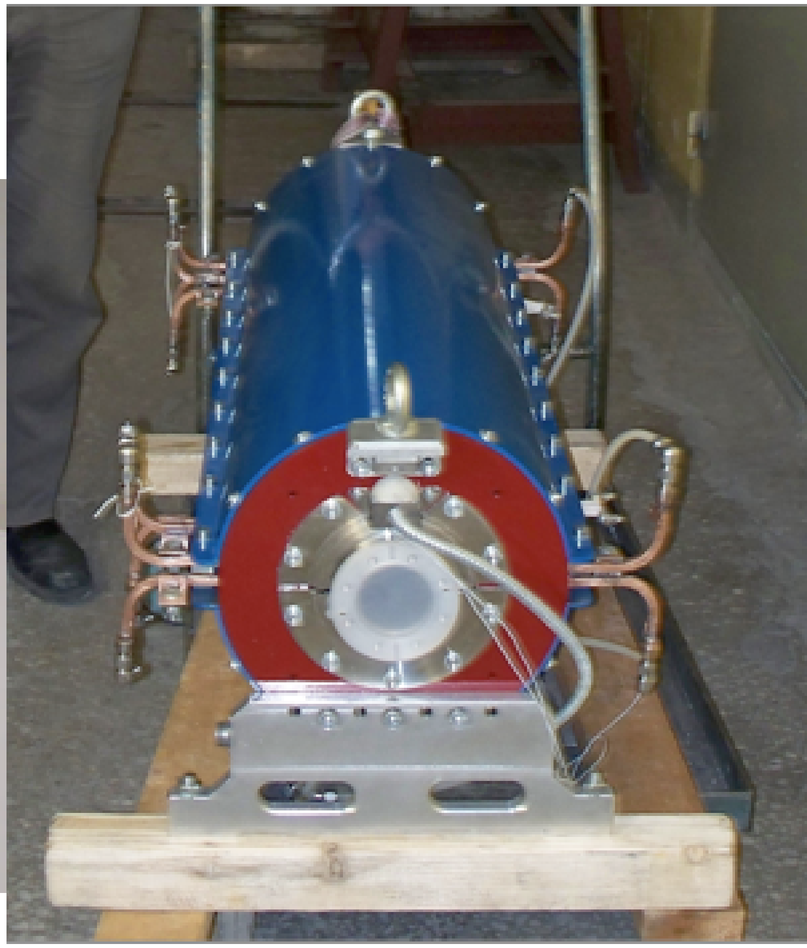
- ^{22}Na source: ~ 50 mC
- Moderation through solid neon
- Accumulation in trap
- Buffer gas cooling
- 3 10^8 e^+ in few minutes
- B= 0.15 -0.2 T

3 parts: RGM(incl. source); ABPS; Accumulator

RGM(& source): ^{22}Na source (25 mCi)
order for a 2nd stronger source (75mCi) is in the pipeline (2013)

ABPS: installed and operational at AD





Accumulator: under test; will arrive at AD in April 2012 several 10^6 e^+/s

3 parts: RGM(incl. source); ABPS; Accumulator

RGM(& source): ^{22}Na source (25 mCi)

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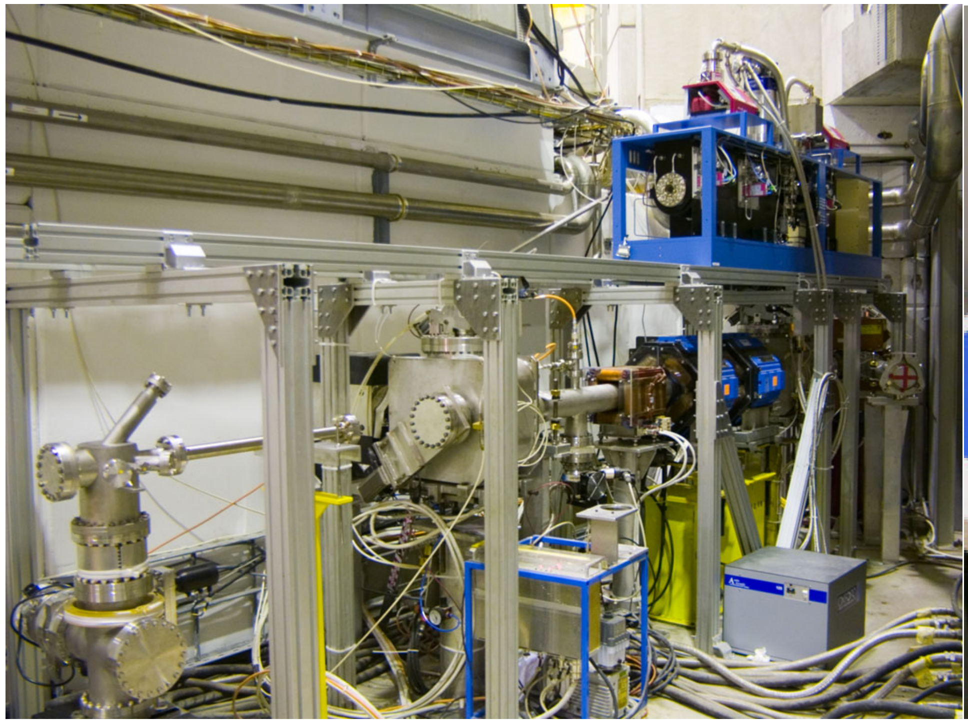
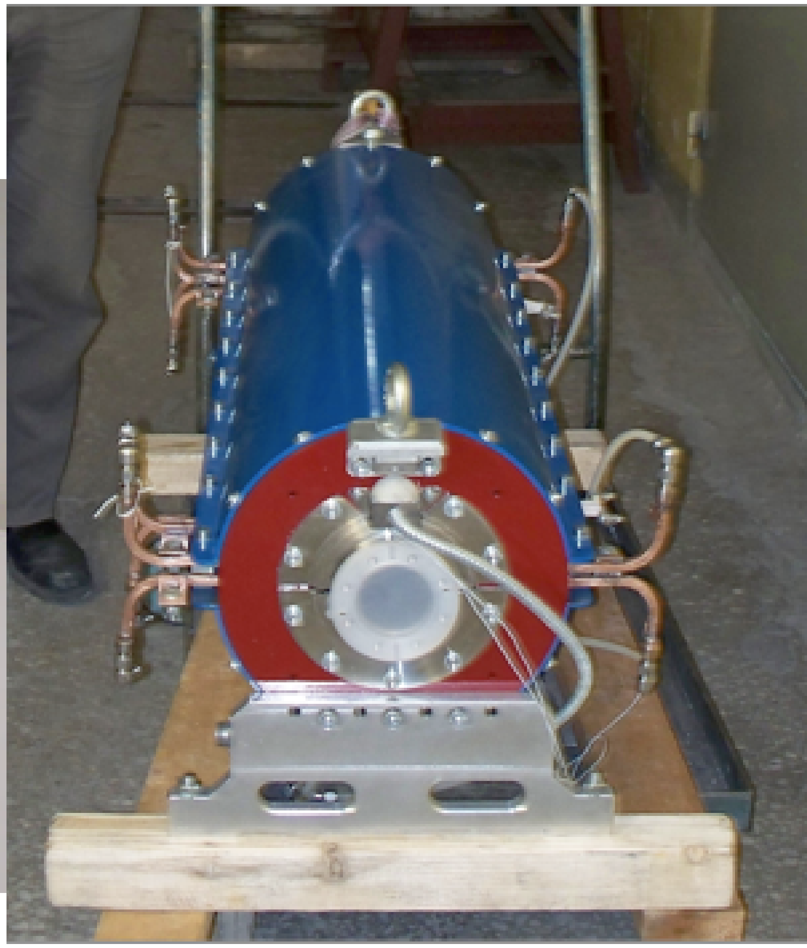
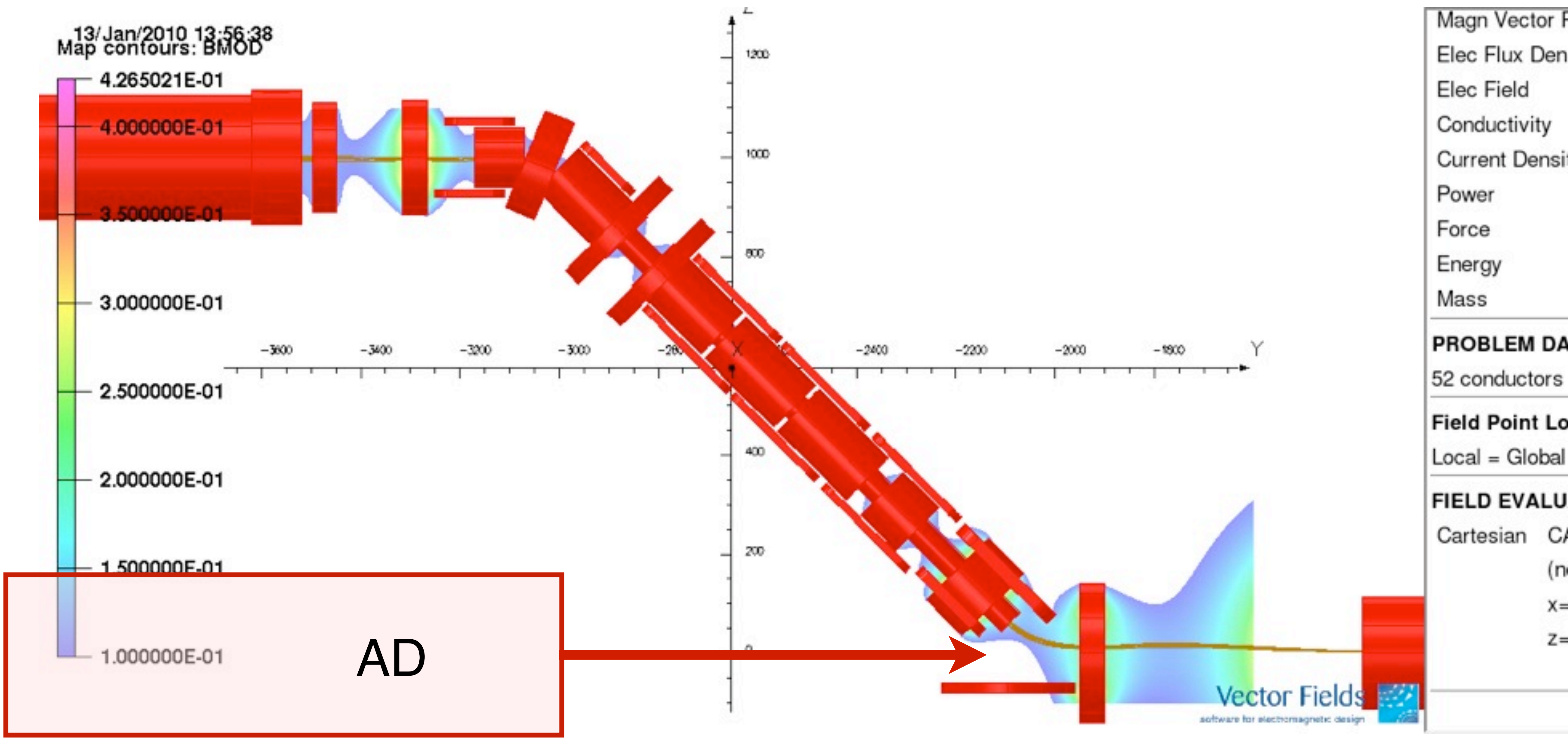




Accumulator: under test; will arrive at AD in April 2012 design requirement: >0.1T over whole beam line



constructed and ready for installation in April

1) positron accumulation

2) antiproton accumulation

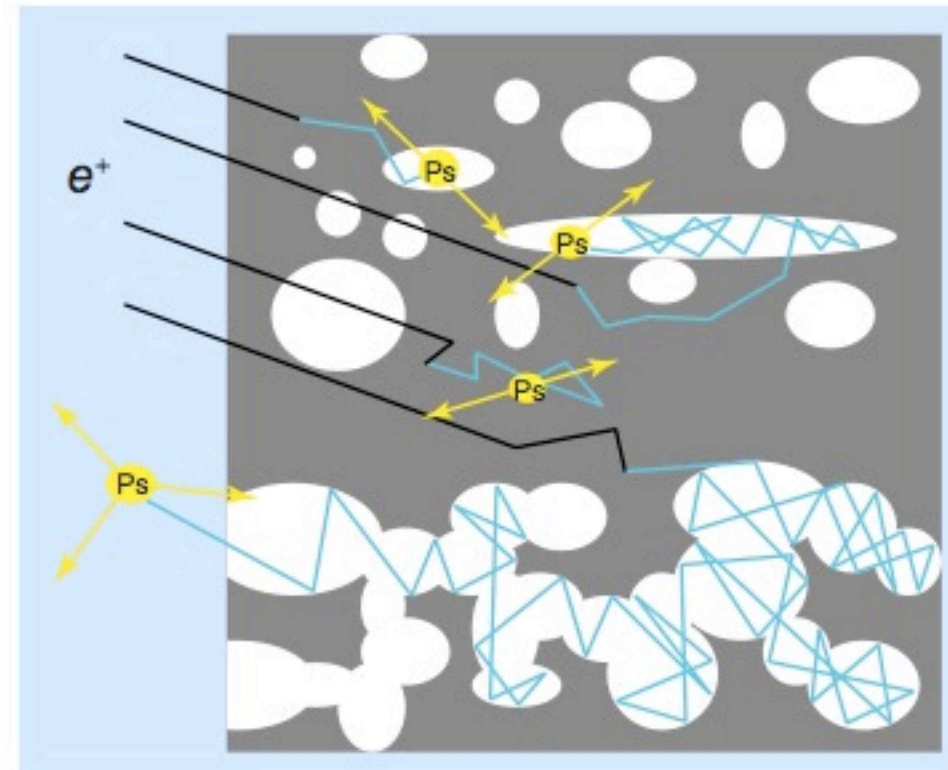
3) positronium formation

4) positronium excitation

5) antihydrogen formation

Ps formation in nanoporous insulators:

- Implanted positrons scatter off atoms and electrons, slow to eV in few ns
- Positronium formation by capture of bound electrons or free electron from collisions
- Reduced dielectric strength in defects
  ⇒ accumulation of positronium in voids
- If pores are fully interconnected, (almost) all *ortho*-Ps diffuses out of the film



[D. W. Gidley *et al.*, Annu. Rev. Mater. Res. **36** (2006) 49]

⇒ **High-efficiency positronium converter**

ortho-Ps yield and energy (velocity) distribution depend on

- Converter material
- Implantation depth (energy)
- Target temperature

→ R. Brusa's talk

1) positron accumulation

2) antiproton accumulation

3) positronium formation

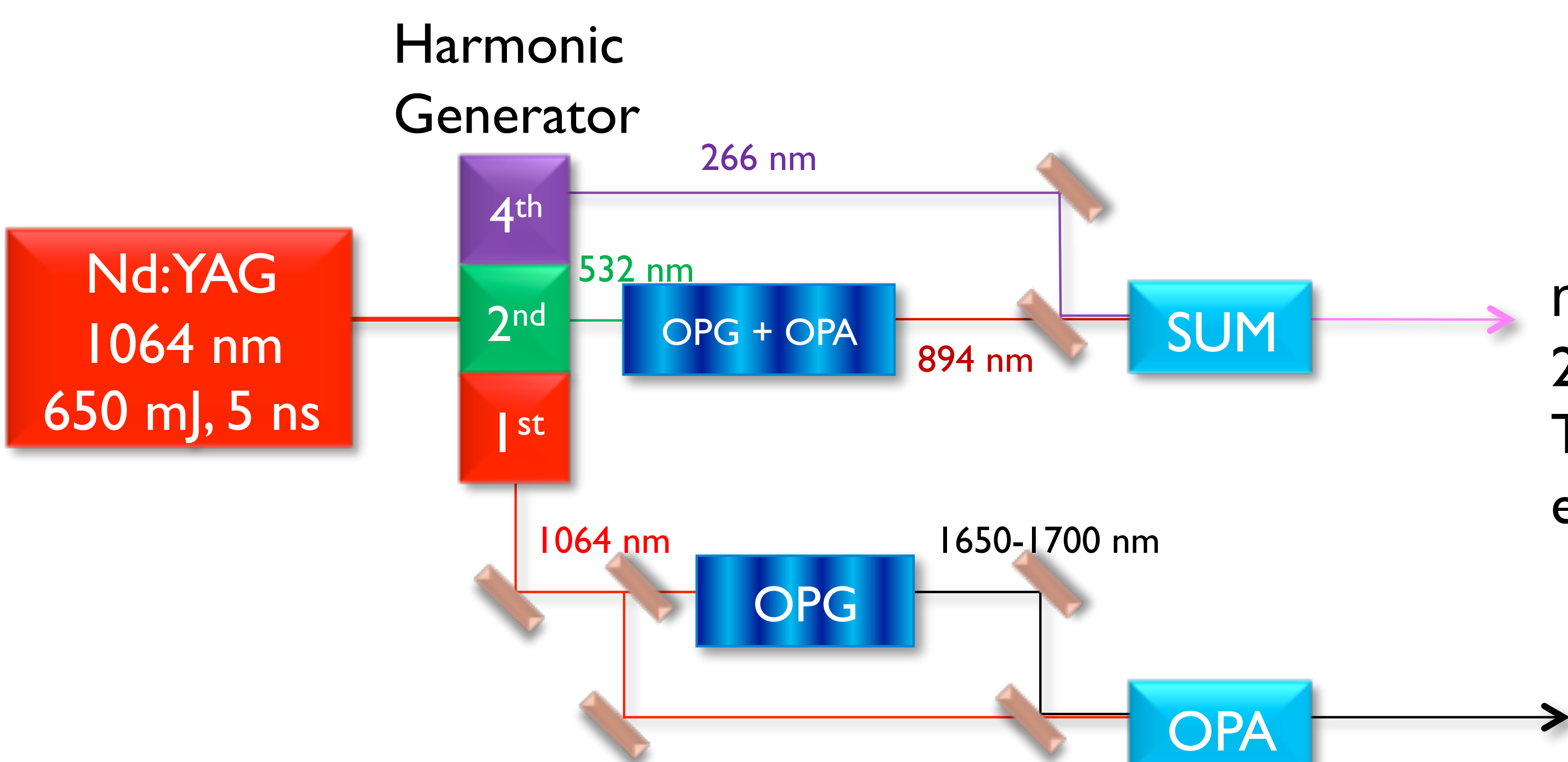
4) positronium excitation

5) antihydrogen formation

Rydberg excitation via a simultaneous two step incoherent process:
1 → 3 → Rydberg (wavelengths: 205 nm and 1650 - 1700 nm)

Main effects of level broadening:

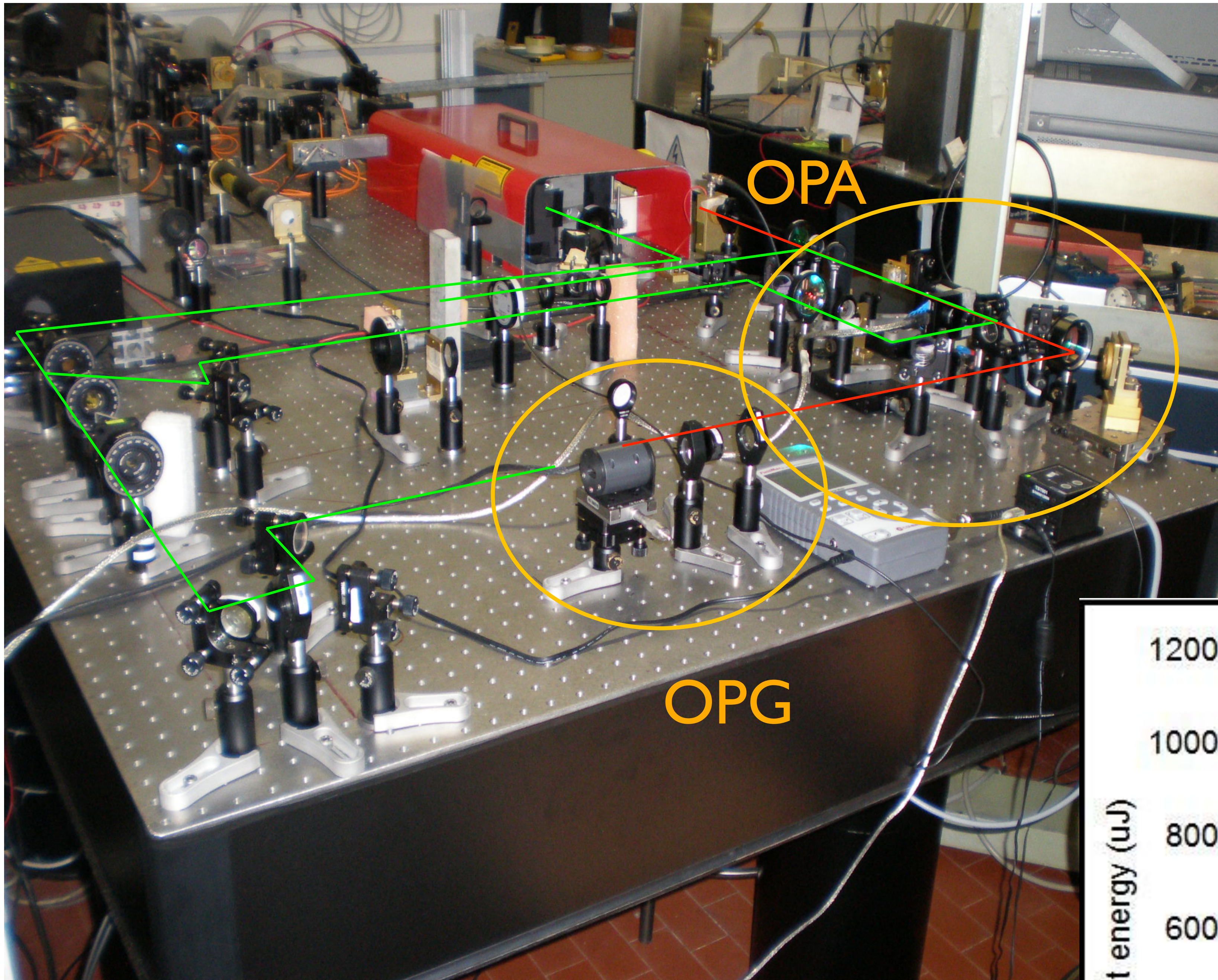
1 → 3: Doppler effect (~0.04 nm) due to velocity distribution of Ps
3 → Rydberg: Motional Stark effect (make a quasi-contiuum from n=17, each level is broadened to many nm) due to Ps movement in a strong **B** field

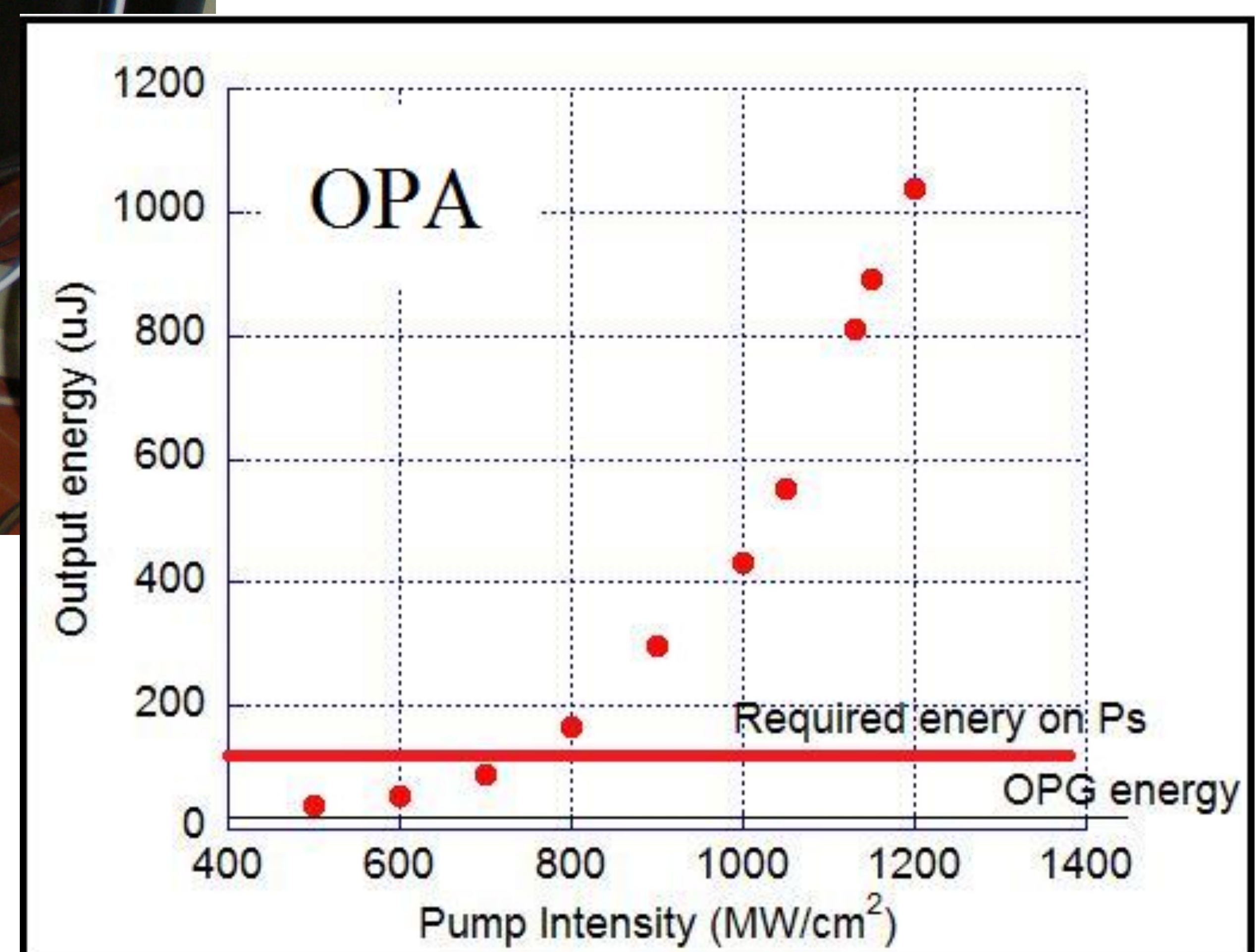


n=1 → n=3
205 nm
Transition saturation energy: ~2 μJ

n=3 → Rydberg
1650-1700 nm
Transition saturation energy: ~0.2 mJ

Goal of the apparatus:
About 10 times the saturation energy


OPA
OPG


OPA
Output energy (uJ)
Pump Intensity (MW/cm^2)
1200
1000
800
600
400
200
0
400
600
800
1000
1200
1400
Required enery on Ps
OPG energy

1) positron accumulation

2) antiproton accumulation

3) positronium formation

4) positronium excitation

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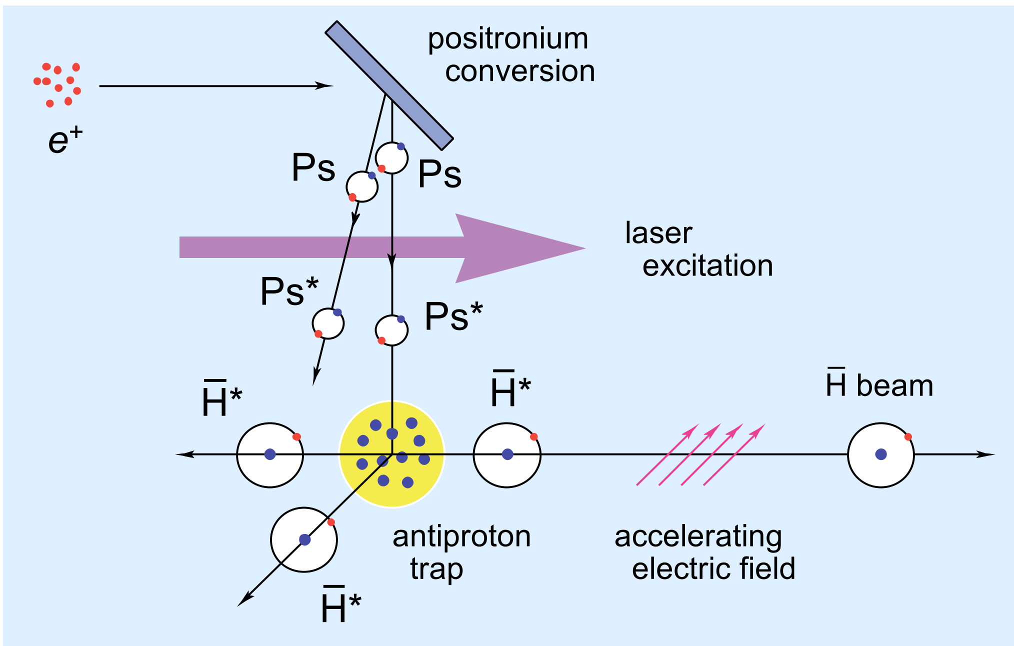
- Charge exchange reaction:



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

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

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

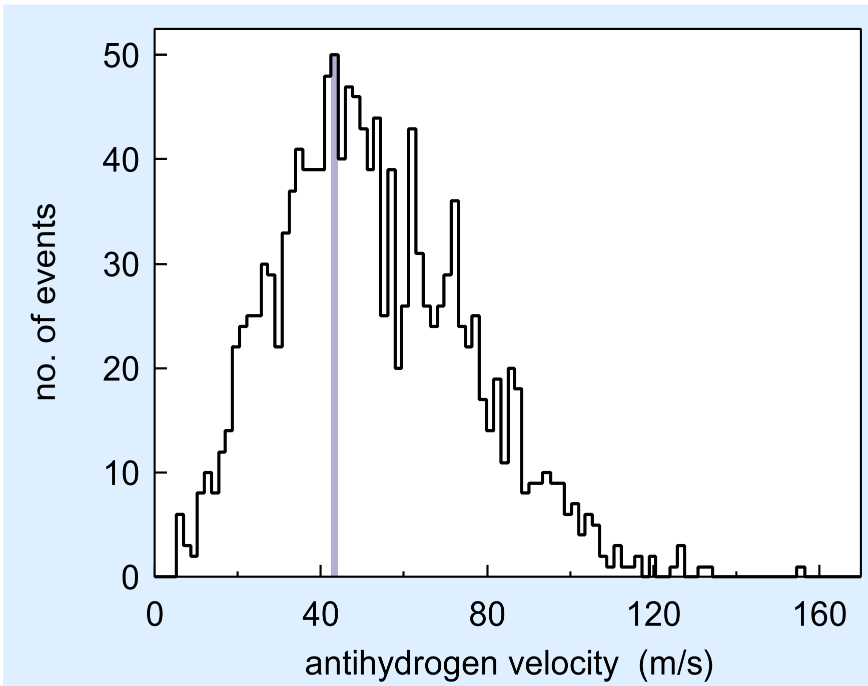
- Advantages:

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

– Narrow and well-defined H̄ *n*-state distribution

– H̄ production from ultracold p̄ → ultracold H̄

- pulsed production of H̄



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

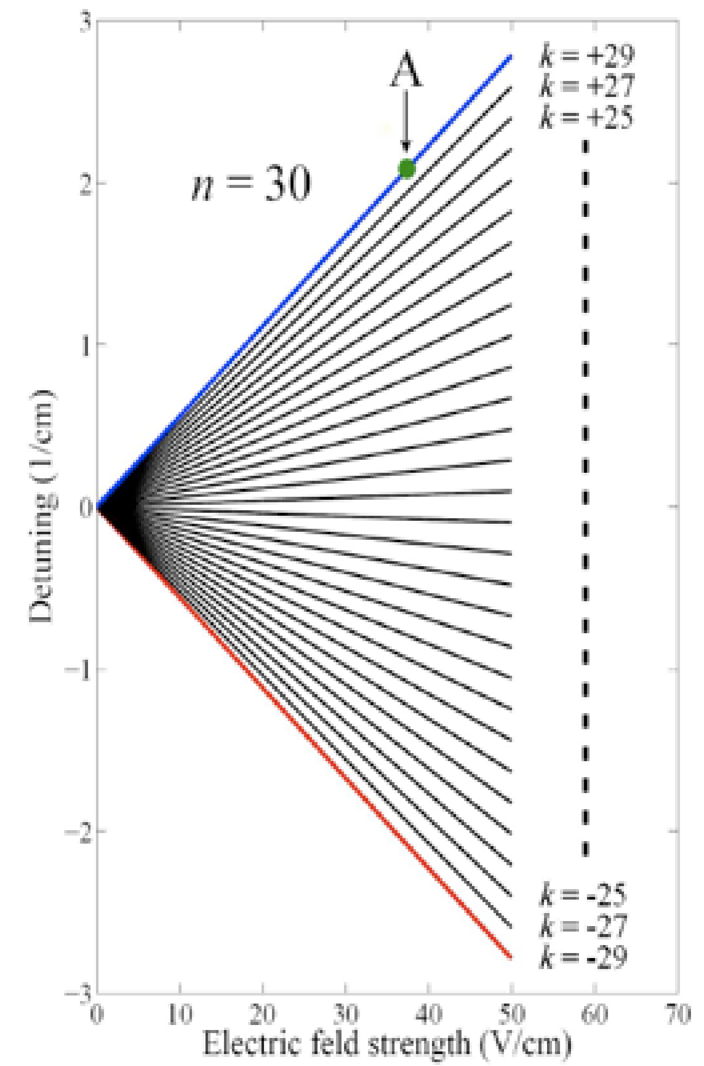
Step ii) beam formation

- Electric field gradients exert force on electric dipole moments of neutral atoms:

$$U = \frac{2}{3} e a_0 \boxed{n(n-1)} F$$

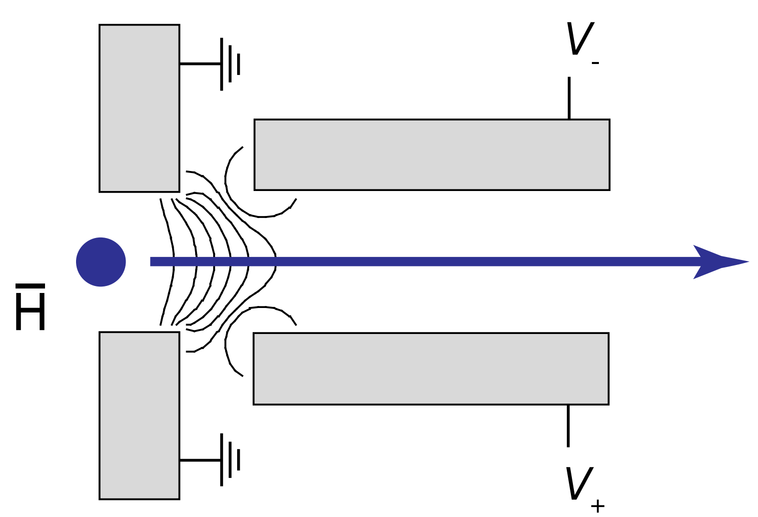
$$\boldsymbol{F} = -\frac{2}{3} e a_0 \boxed{n(n-1)} \nabla F$$

$\Rightarrow$ Rydberg atoms are very sensitive to inhomogeneous electric fields



- Stark deceleration of hydrogen demonstrated (ETH group).

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

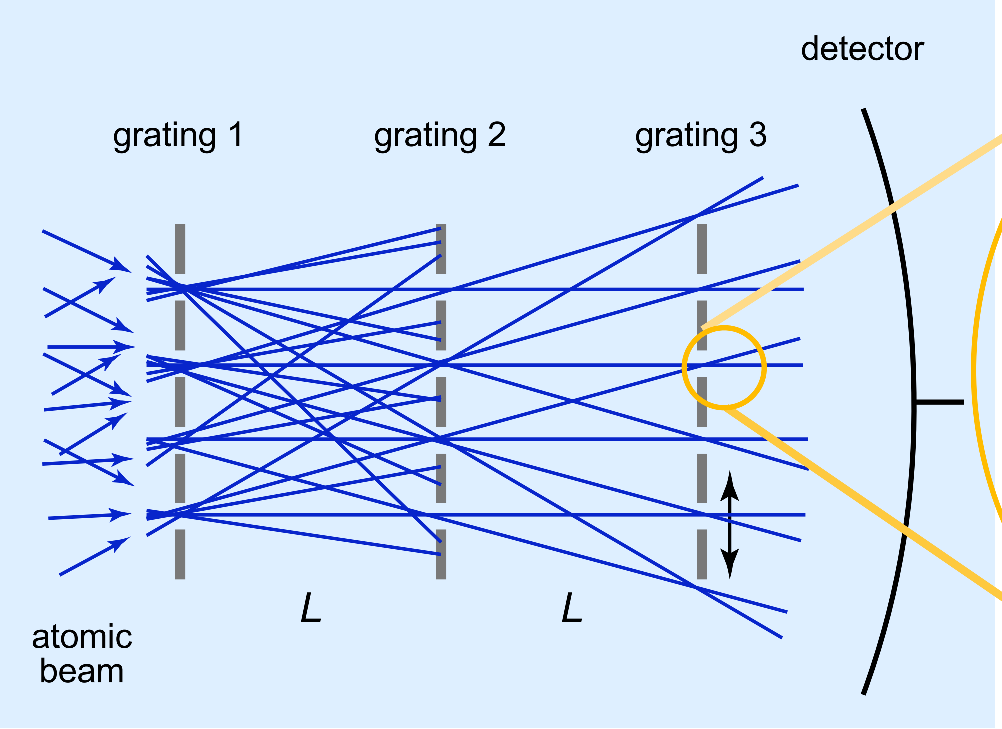


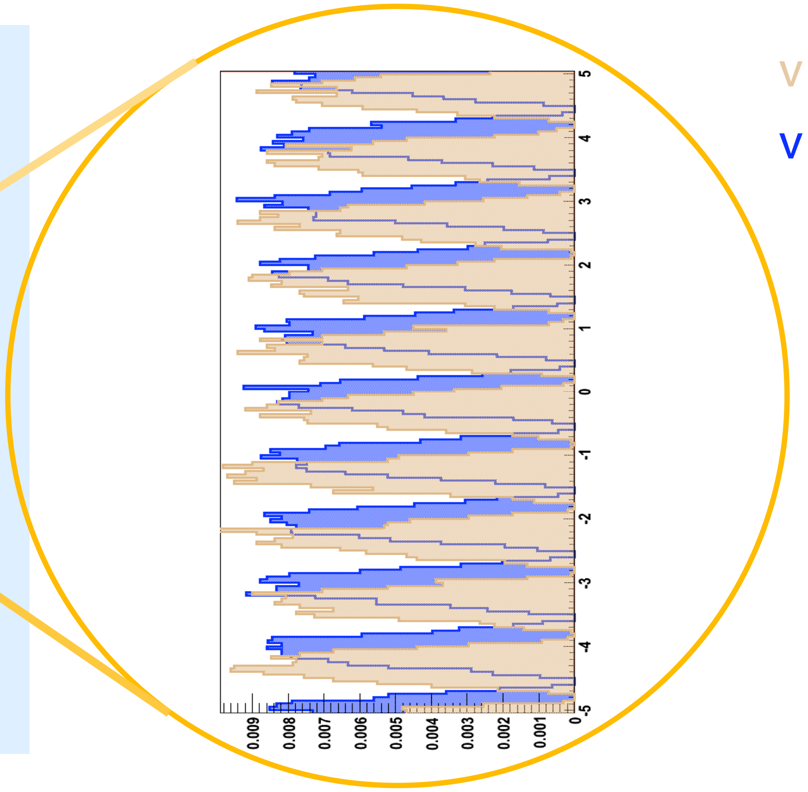
- n = 22,23,24
- Accelerations of up to 2×10^8 m/s^2 achieved
- Hydrogen beam at 700 m/s can be stopped in 5 μs over only 1.8 mm

Step iii) trajectory measurement

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

Fringe phase and phase shift identical to Mach-Zehnder interferometer





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

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

  $\Rightarrow$ Transmission increases by ~ factor 3

- Has been successfully used for a gravity measurement with ordinary matter, $\sigma(g)/g = 2\times10^{-4}$ [M. K. Oberthaler *et al.*, Phys. Rev. A **54** (1996) 3165]

- with 10^5 $\bar{H}$ at 100mK, $\sigma(g)/g$ = 1% (expected) [A. Kellerbauer *et al.*, Phys. Rev. A **54** (1996) 3165]

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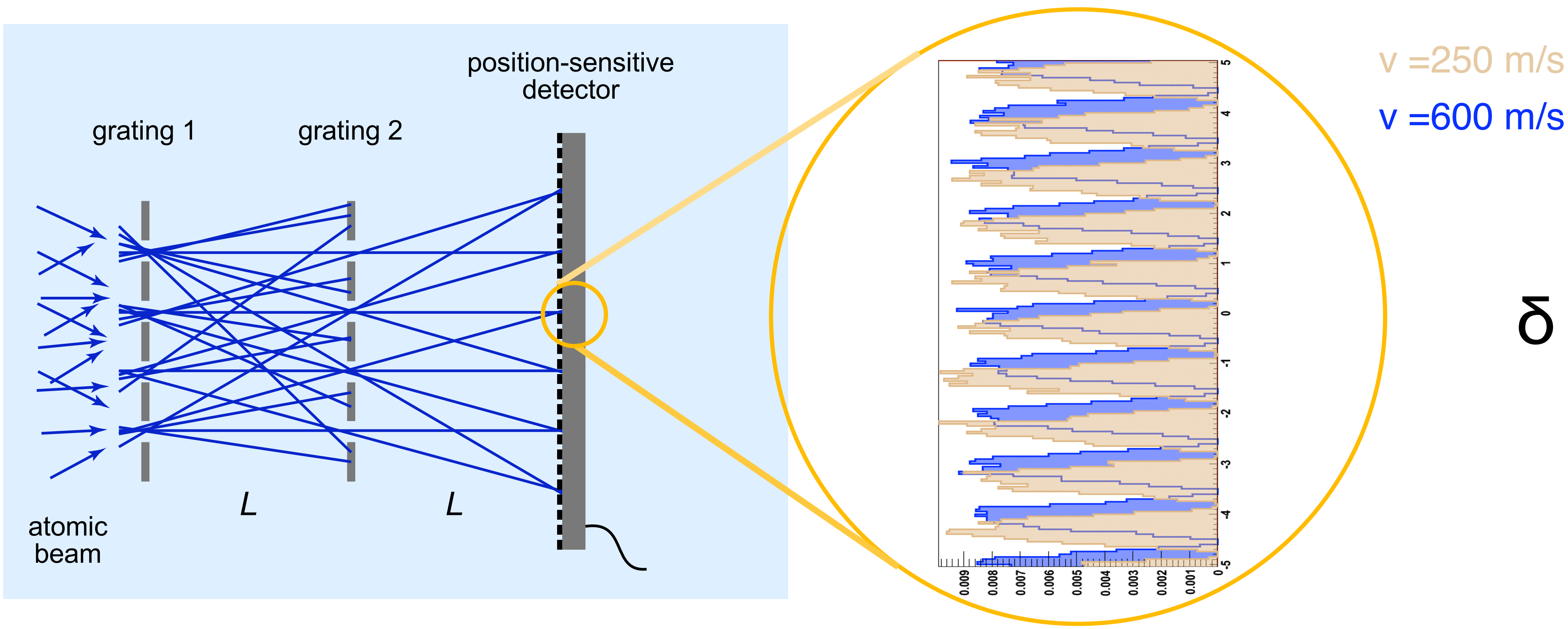

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Conclusions & outlook

- The effect of gravity on antimatter has never been measured
- Depending on the chosen model, effects could be nil or measurable at the 1% level
- The AEGIS experiment intends to measure $\delta g/g$ of antihydrogen to (initially) 1%
- Construction of AEGIS apparatus ongoing
- Schedule:
  - 2012: $\bar{p}$ capture, cooling and transfer; e^+ capture, accumulation and transfer; Ps formation and excitation; $\bar{H}$ formation and acceleration
  - 2014: First antimatter gravity experiment

the collaboration...

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