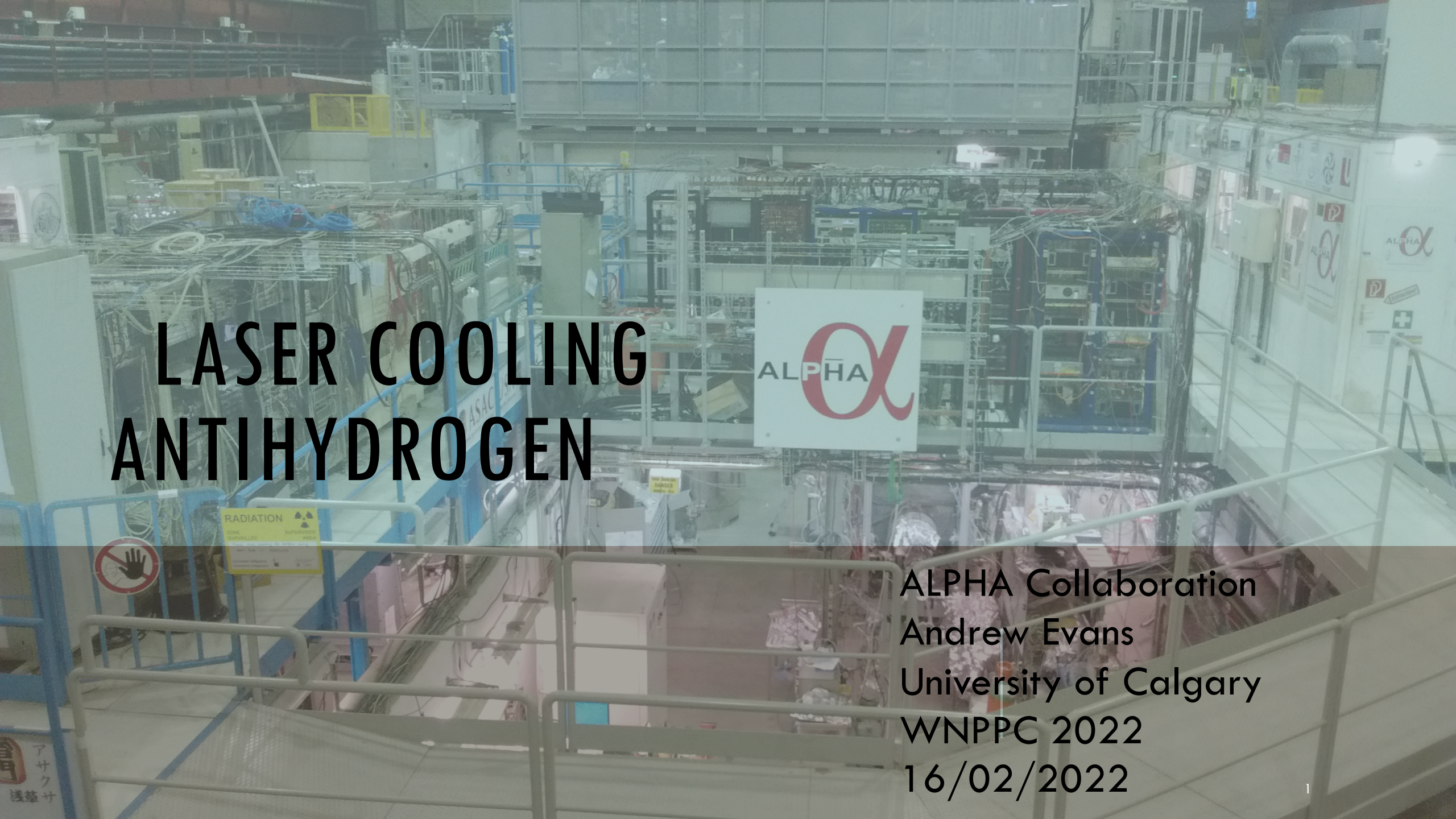


LASER COOLING ANTIHYDROGEN

ALPHA Collaboration
Andrew Evans
University of Calgary
WNPPC 2022
16/02/2022

WHY STUDY ANTIMATTER AND ANTIHYDROGEN?

- Study Matter-antimatter asymmetry
  - Why is the universe filled only with matter?
- Use antihydrogen to search for CPT violations
  - Antiprotons, positrons and hydrogen are well understood
  - A separate check on high energy studies
- Study the atomic transitions
  - **Measured already to high precision in hydrogen**

Antihydrogen Laser PHysics Apparatus

50 people, 8 countries

Large Canadian presence

- UBC, SFU, UofC, York, TRIUMF

At CERN (to be close to the antiprotons)

LASER COOLING

Ubiquitous in atomic physics

Necessary for high precision spectroscopy

Helpful for high precision gravitational measurements

Being able to laser cool antihydrogen is a game-changing breakthrough in the study of antimatter

High precision anti-atom spectroscopy will soon become possible

LASER COOLING

Use photon collisions to slow trapped atoms

Drive a detuned optical transition

- Doppler cooling

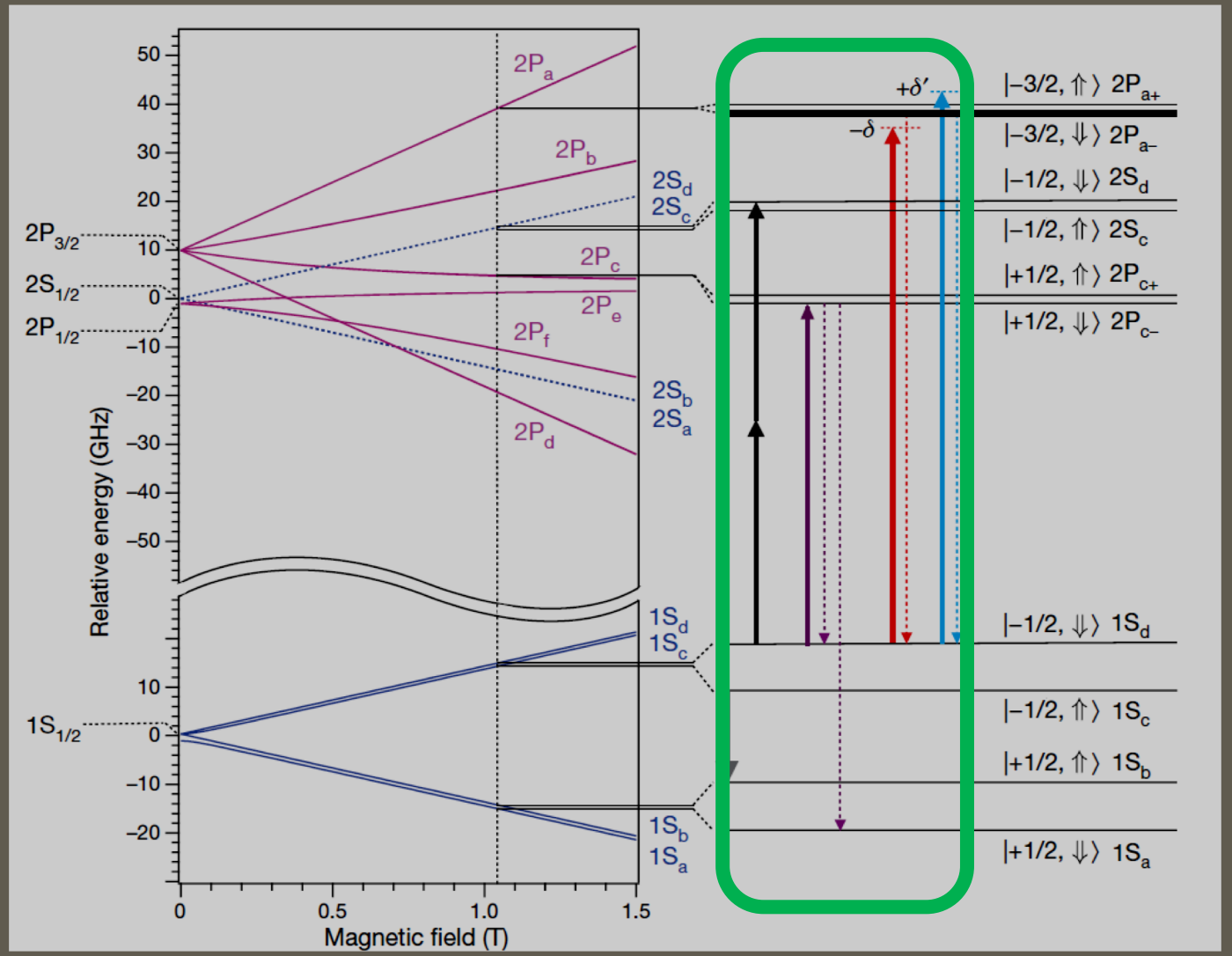
Not many transition choices in hydrogen

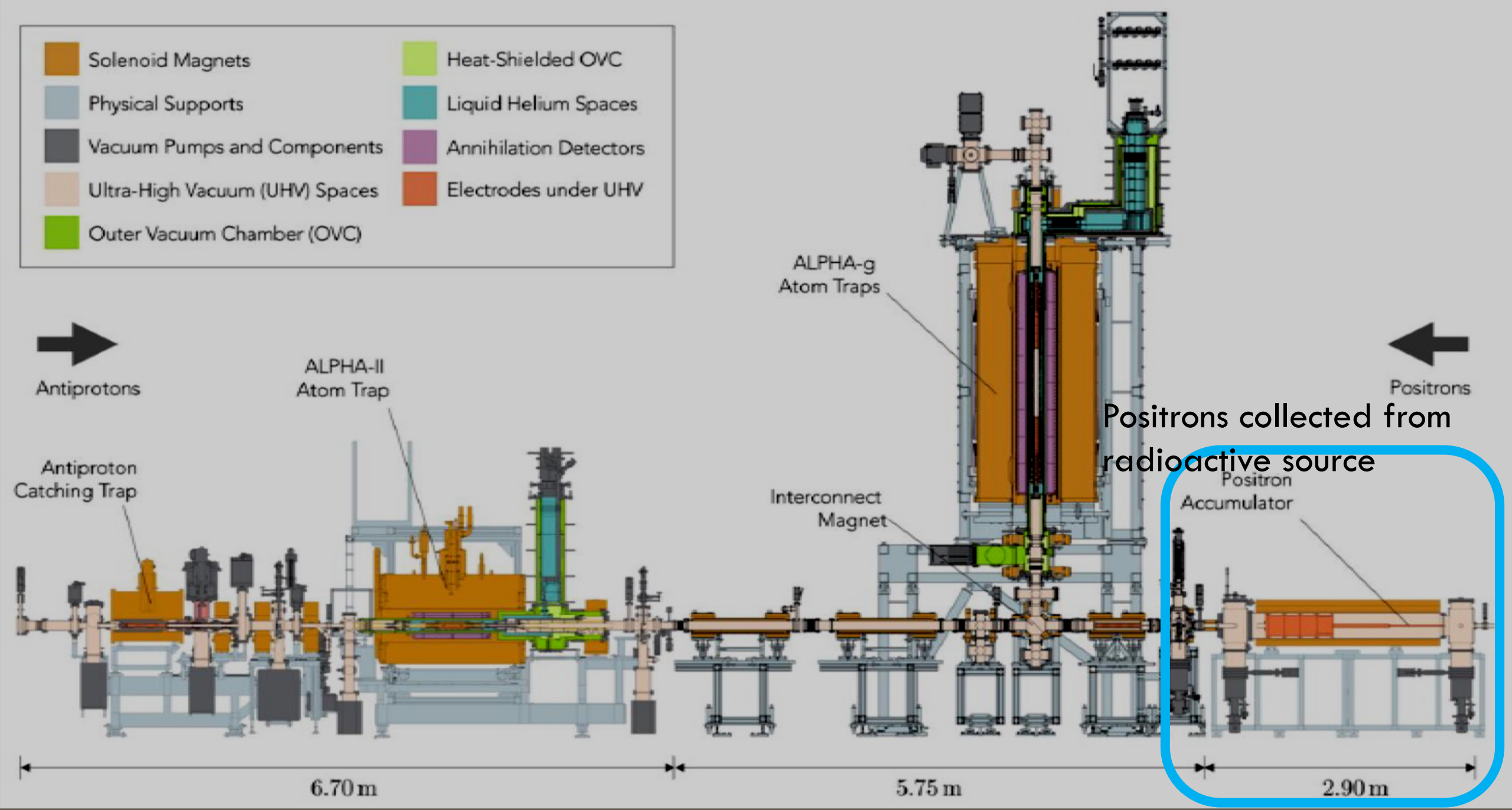
- Energy level difference between ground and first excited state is large

Lyman alpha transition (Nature 2018)

Lamb shift (Nature 2020)

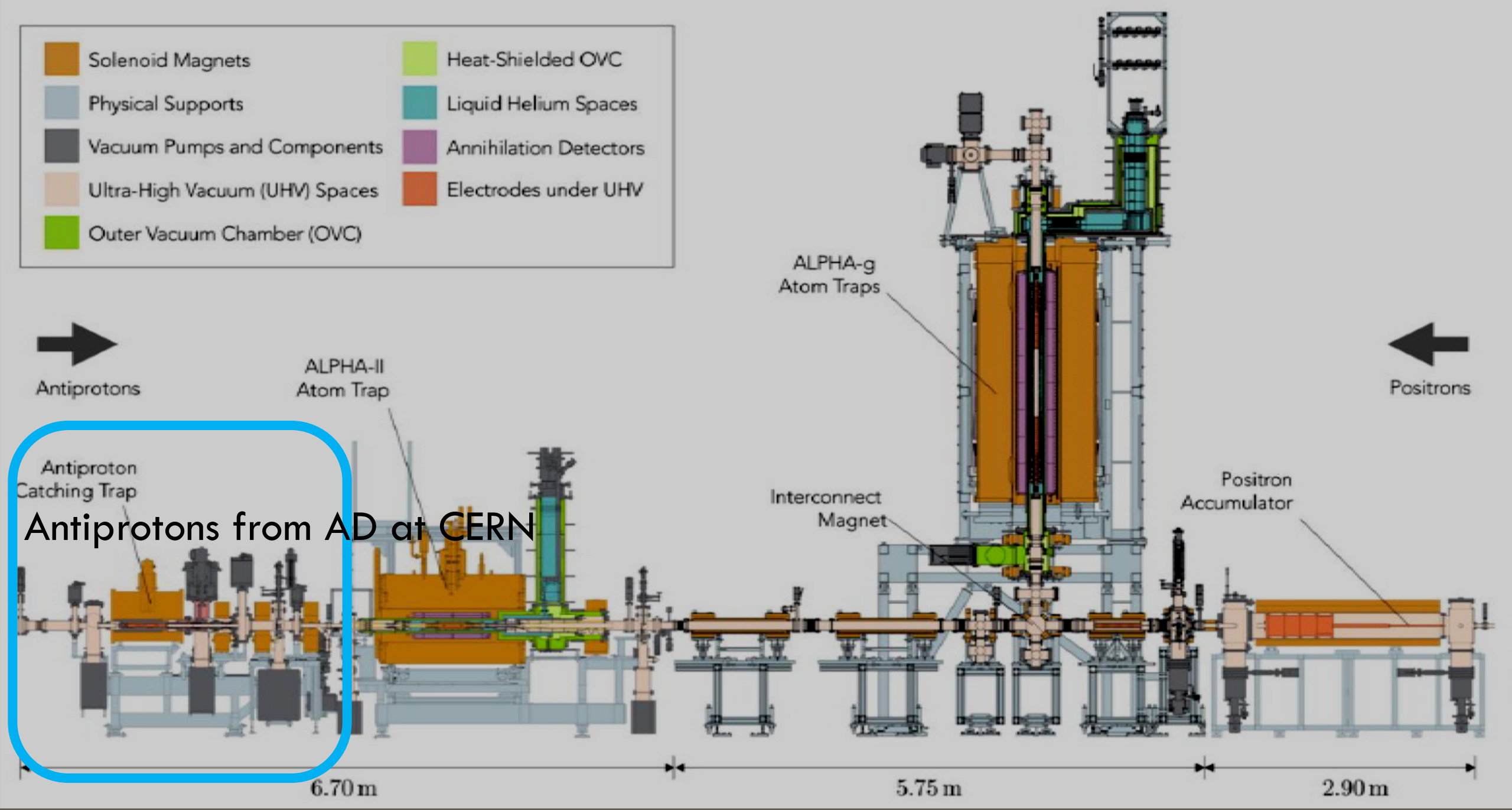
Breit Rabi diagram for hydrogen





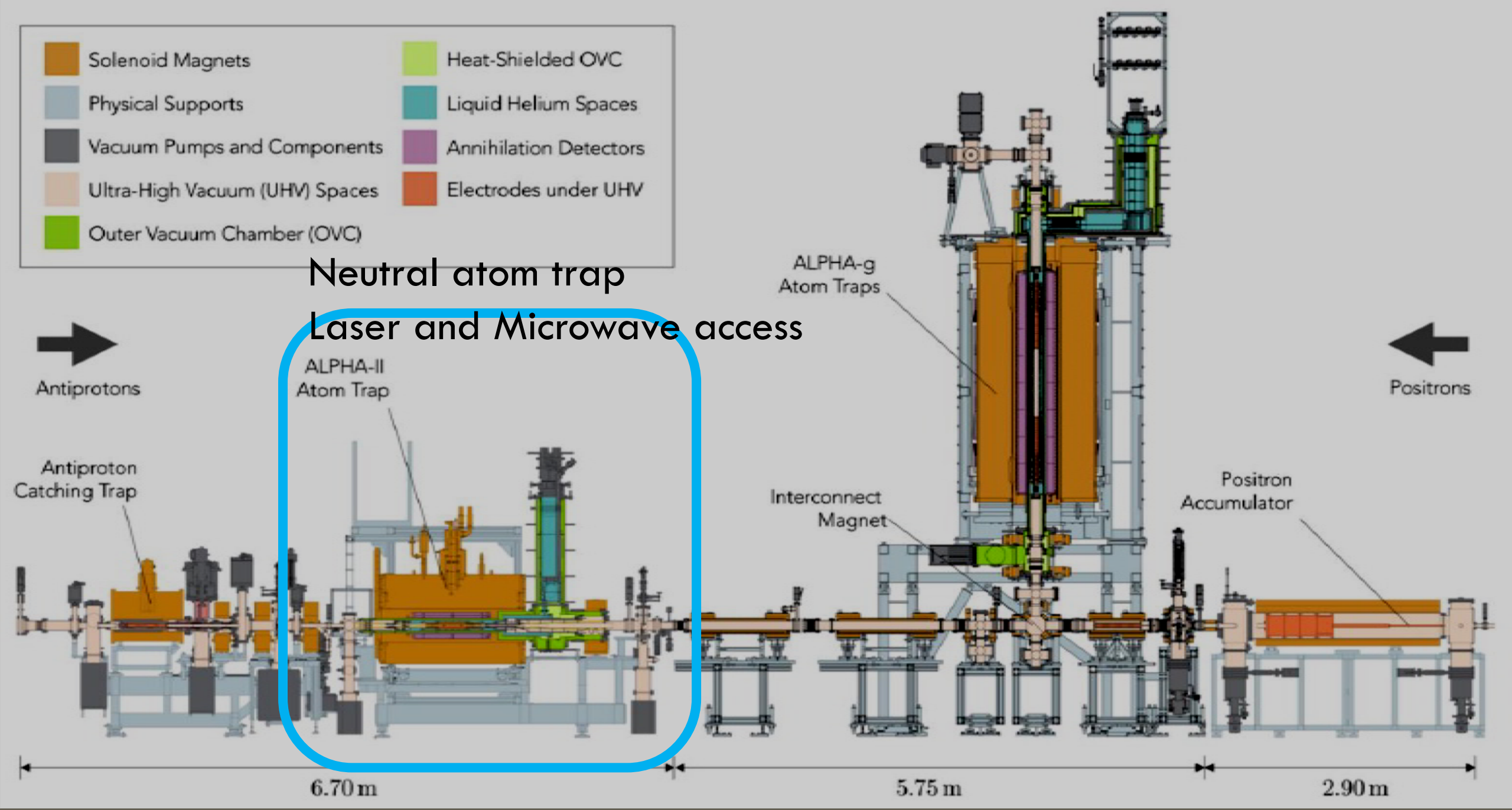
Positrons collected from radioactive source

Credit Mark Johnson

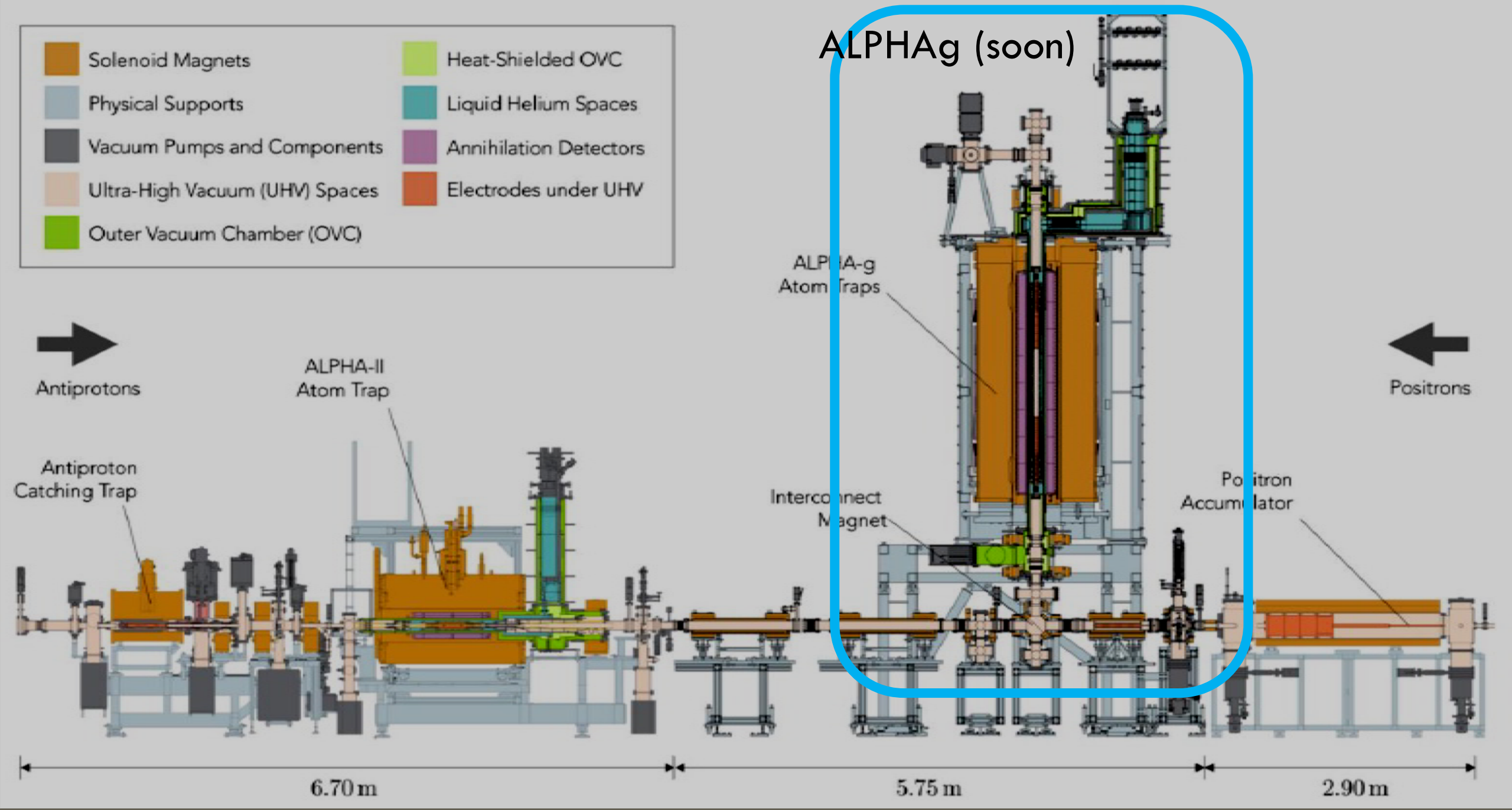


Antiprotons from AD at CERN

Credit Mark Johnson

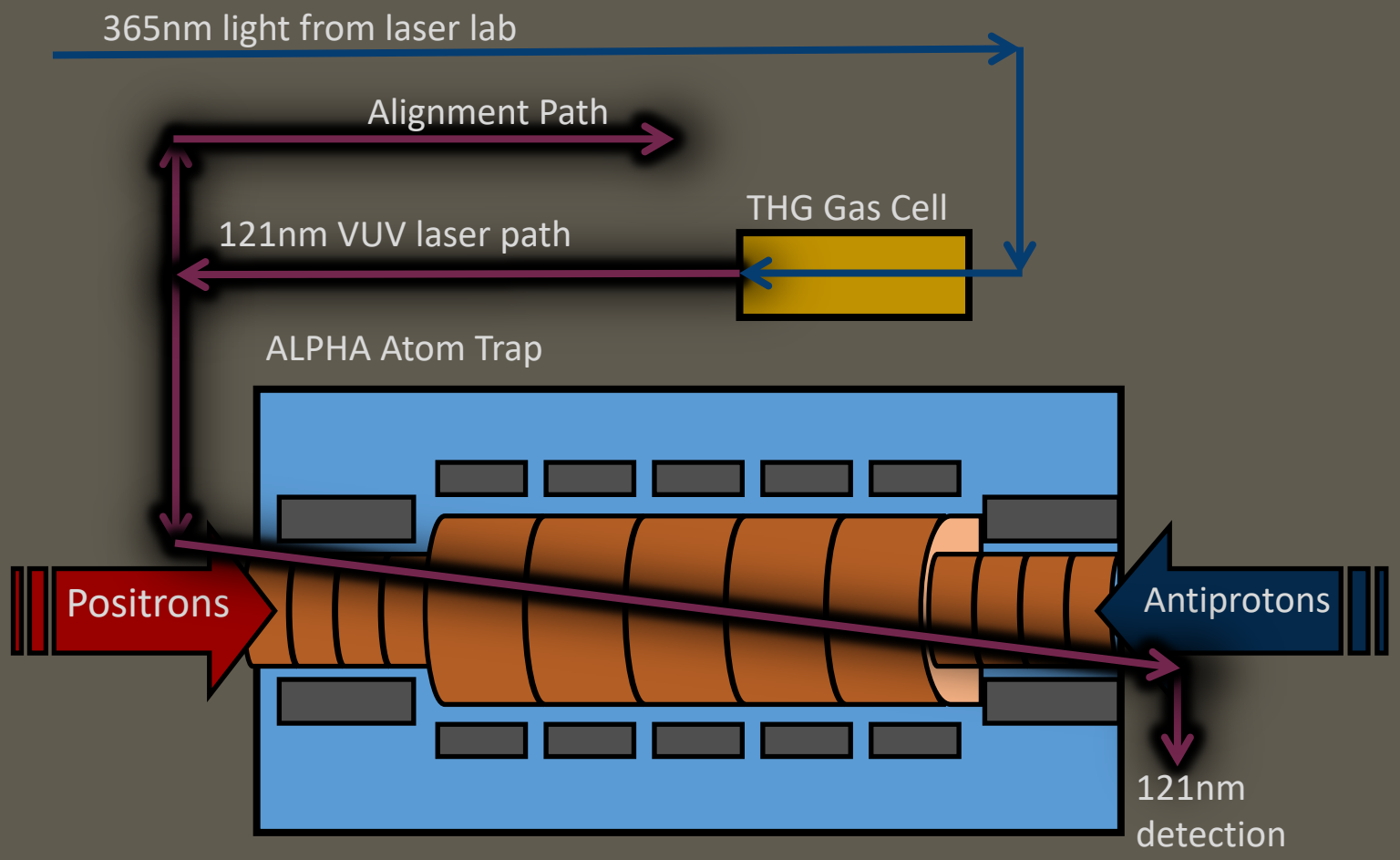


Credit Mark Johnson



Credit Mark Johnson

121NM LASER



Short wavelength light is hard to produce at high powers!!

We need it for very long runs (>10 hours)

The ALPHA trap is NOT in a laser lab

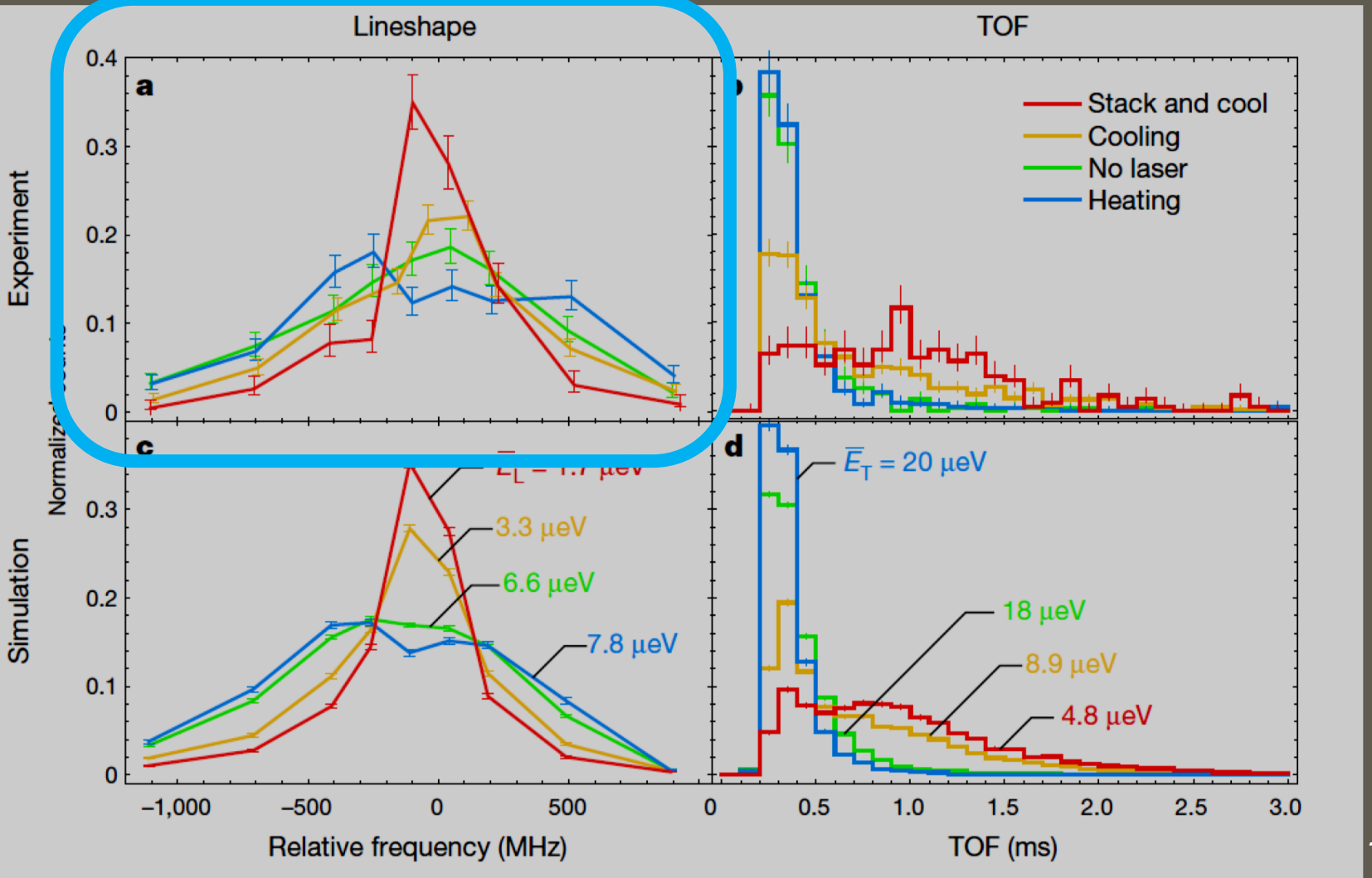
RESULTS

Laser cooling

- Measure transition line width with / without cooling
  1S-2P
  1S-2S
- Pulsed laser time-of-flight

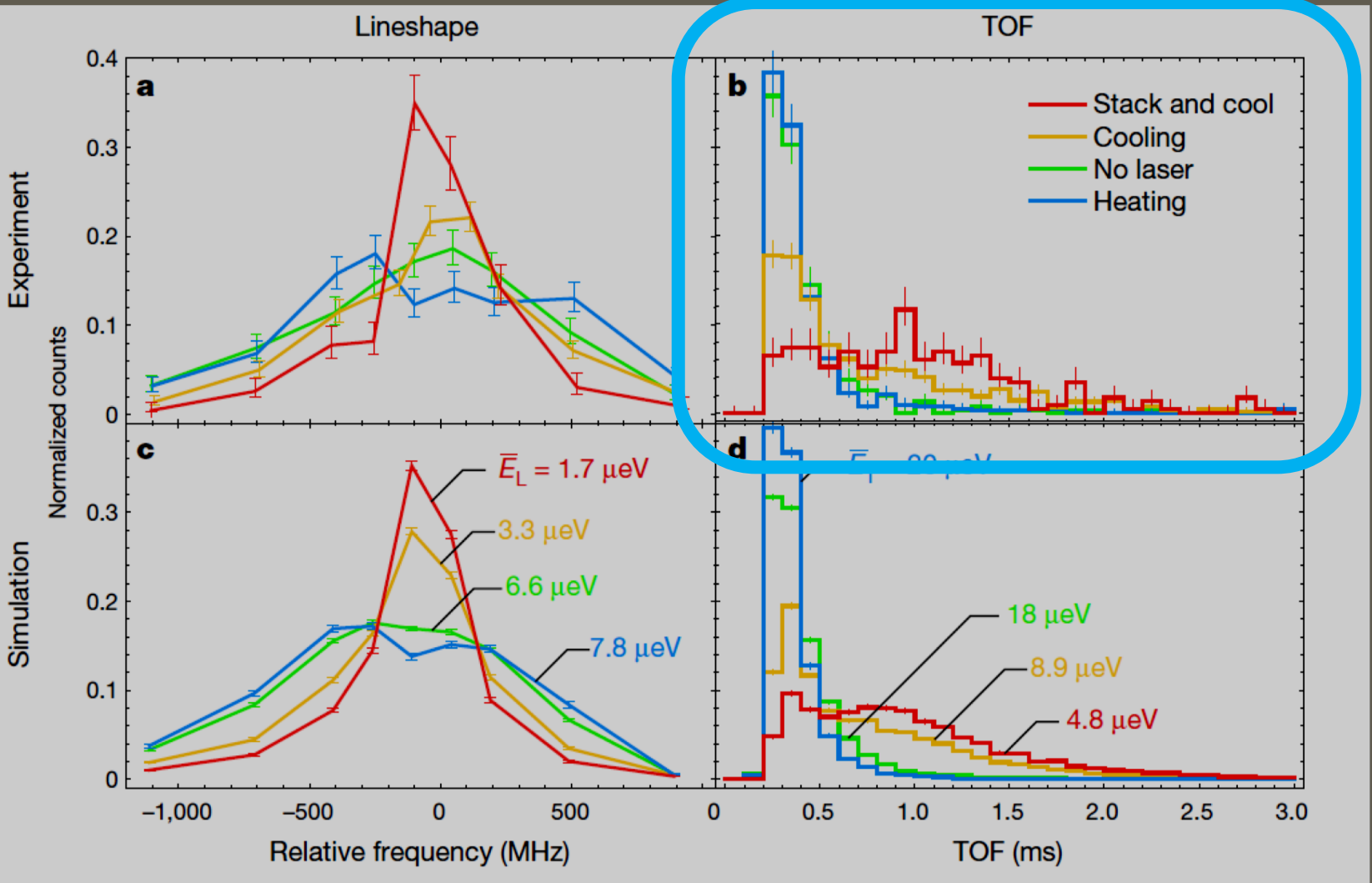
LASER COOLING

- We see a change in the spectrum line-width



1Sd-2Pc-

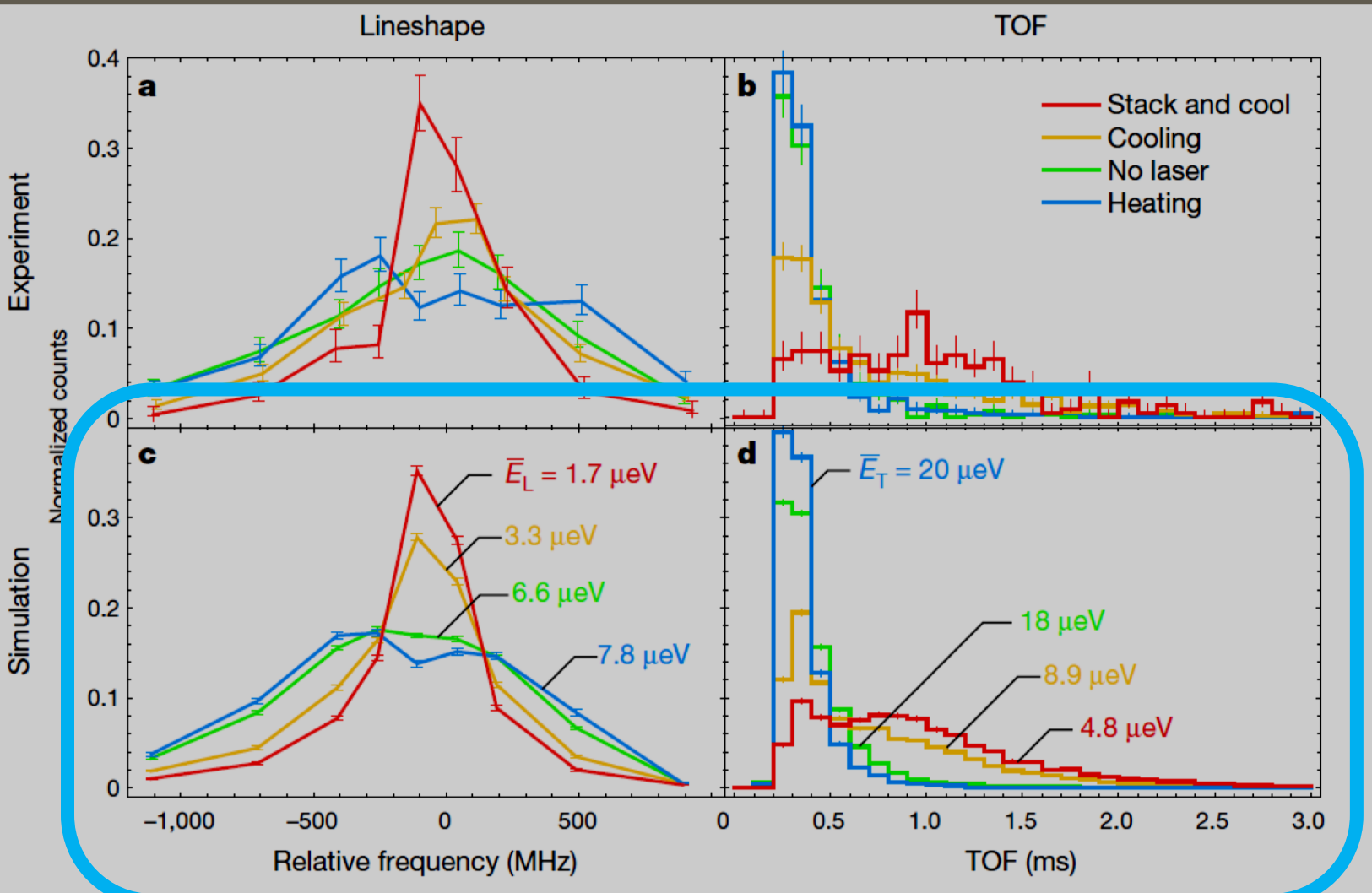
LASER COOLING



- We see a change in the spectrum line-width
- Timing of the laser pulse and the detector event give us a time-of-flight

1Sd-2Pc-

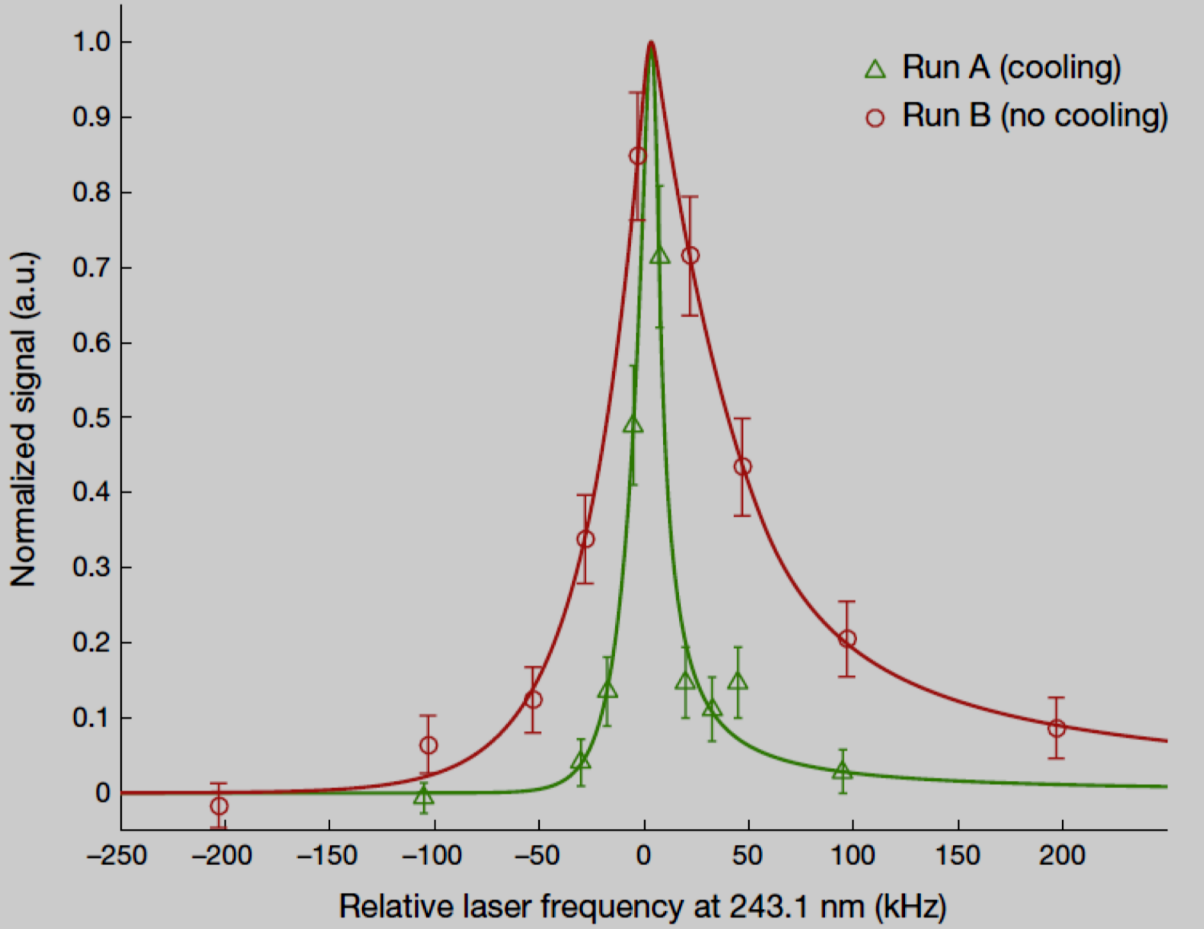
LASER COOLING



- We see a change in the spectrum line-width
- Timing of the laser pulse and the detector event give us a time-of-flight
- Computer simulations of laser cooling process qualitatively match experimental data

1Sd-2Pc-

LASER COOLING



A set of laser cooled 243nm spectroscopy runs were performed using the same experimental procedure as the 121nm runs

The FWHM decreased by about a factor or four

We estimate a change in the kinetic energy by a factor of 16

FUTURE STUDIES OF ANTIHYDROGEN

Each year we get better and better at making antihydrogen

ALPHAg

- Gravitational measurement

ALPHA3

- Laser and metrology upgrade

HAICU (Hydrogen-Antihydrogen Infrastructure at Canadian Universities)

- Anti-atom fountain and interferometer

Hydrogen as a proxy for antihydrogen

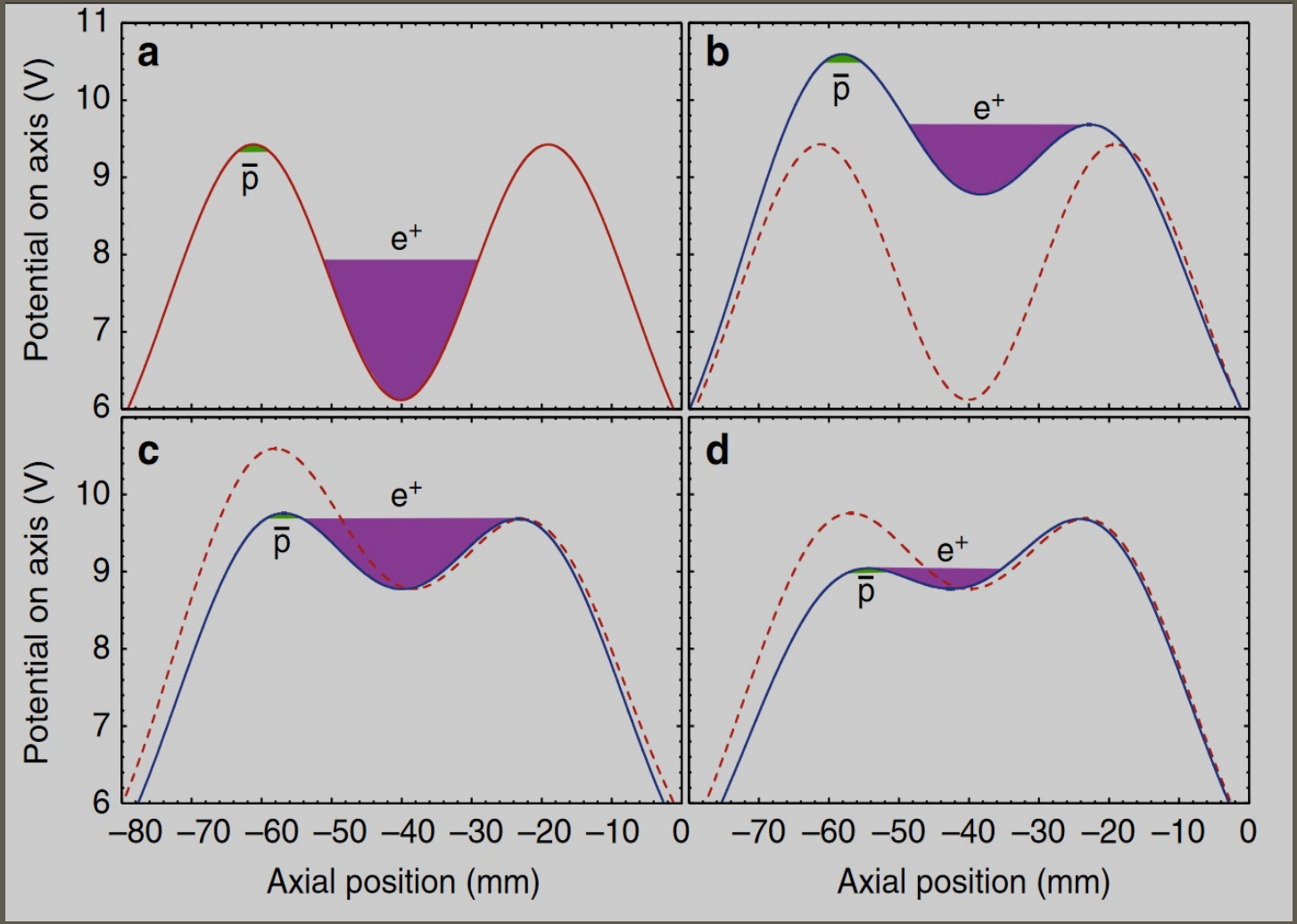
Exciting future for study of antihydrogen

PUBLICATIONS

Publications:

- Baker, C.J., Bertsche, W., Capra, A. *et al*. Laser cooling of antihydrogen atoms. *Nature* **592**, 35–42 (2021)
- The ALPHA Collaboration., Ahmadi, M., Alves, B.X.R. *et al*. Investigation of the fine structure of antihydrogen. *Nature* **578**, 375–380 (2020)
- Ahmadi, M., Alves, B.X.R., Baker, C.J. *et al*. Observation of the 1S–2P Lyman-α transition in antihydrogen. *Nature* **561**, 211–215 (2018)
- Ahmadi, M., Alves, B.X.R., Baker, C.J. *et al*. Characterization of the 1S–2S transition in antihydrogen. *Nature* **557**, 71–75 (2018)
- M. Ahmadi et al. (ALPHA Collaboration) Enhanced Control and Reproducibility of Non-Neutral Plasmas. Phys. Rev. Lett. 120, 025001 (2018)
- Ahmadi, M., Alves, B.X.R., Baker, C.J. *et al*. Antihydrogen accumulation for fundamental symmetry tests. *Nat Commun* **8**, 681 (2017)
- Ahmadi, M., Alves, B., Baker, C. *et al*. Observation of the hyperfine spectrum of antihydrogen. *Nature* **548**, 66–69 (2017)
- Ahmadi, M., Alves, B., Baker, C. *et al*. Observation of the 1S–2S transition in trapped antihydrogen. *Nature* **541**, 506–510 (2017)

MAKING ANTIHYDROGEN



- Penning trap for non-neutral plasma manipulations
- Antiprotons and positrons simultaneously held
- The positrons are evaporatively cooled, then brough into contact with antiprotons
- Can “reliably” produce samples >1000 antiatoms
- Multiple production steps repeated
- Lifetime for antihydrogen in the trap very long (>60 hours)