Antihydrogen 1S-2P Spectroscopy and Lamb Shift Measurement

WNPPC 2019

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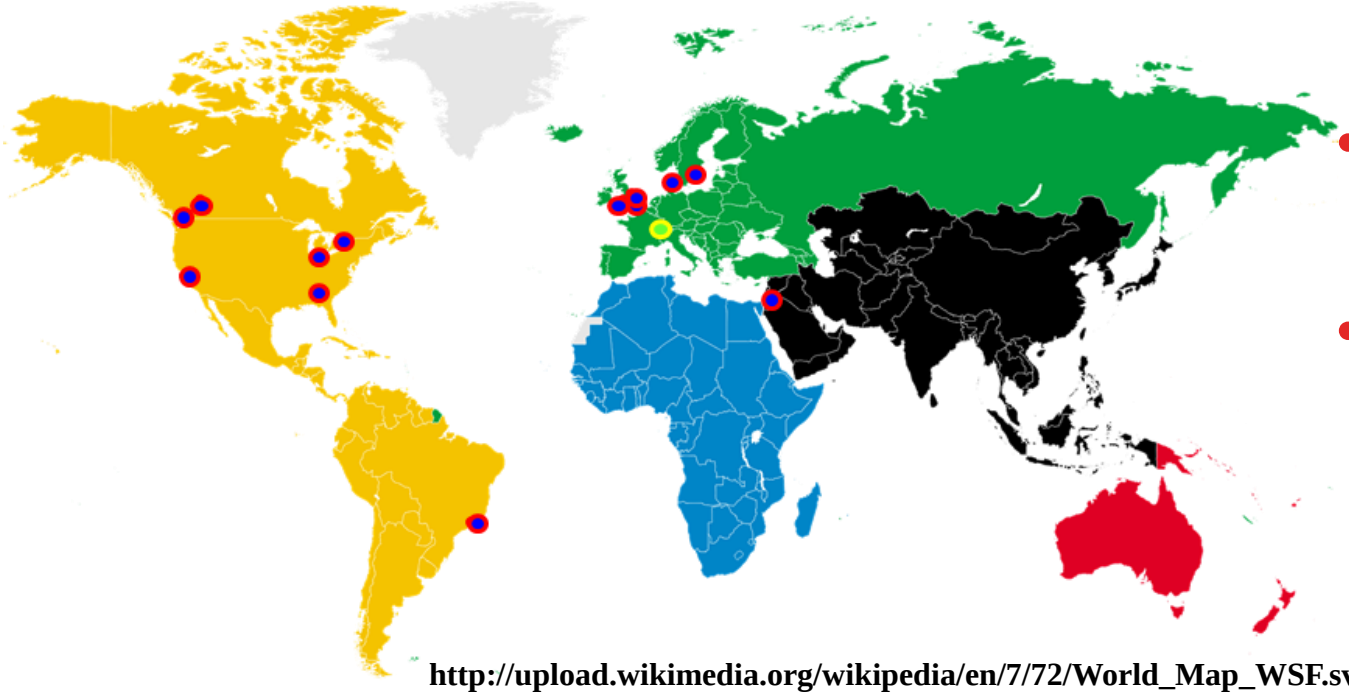
ALPHA



- Antihydrogen Laser Physics Apparatus
- Experiment at CERN
- 7 countries, 13 universities, about 50 people
- Produce, trap, and study antihydrogen
- Searching for CPT violations

http://upload.wikimedia.org/wikipedia/en/7/72/World_Map_WSF.svg.png

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Why Antimatter?

- Mirror to matter; same mass but opposite charge
  - Other basic properties of matter and antimatter (mass, lifetime) seem identical
  - So far…
- Observable universe is dominated by matter
- Antiproton decelerator (AD) at CERN produces low energy antiprotons
  - Started operation in 2000
- Cold antiprotons and positrons are key to producing ***trappable antihydrogen***
- One of many measurements ALPHA has been working on

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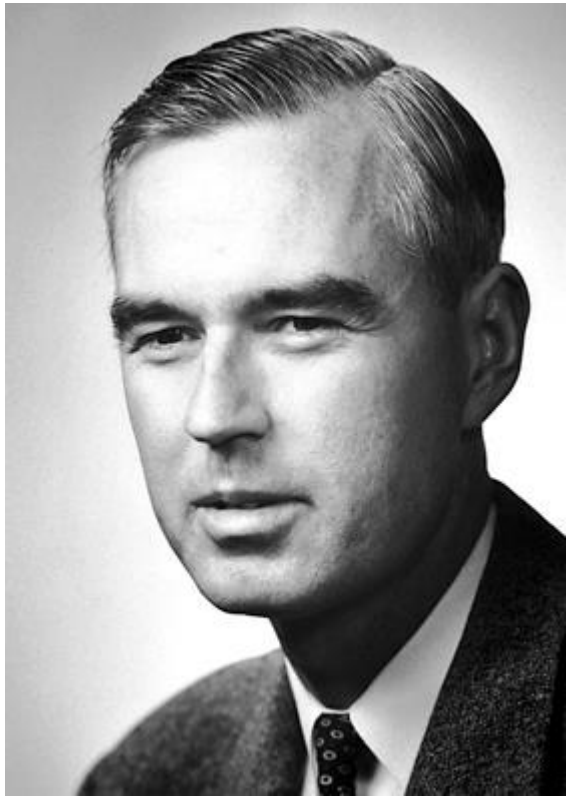
Lamb Shift

- Willis Lamb
- Reported in 1947
- Energy level difference between energy levels of the same J state (spin ½)
  - $2S_{1/2}$ and $2P_{1/2}$ energy levels
- This difference showed that the Dirac equation was insufficient
  - Explained by quantum electrodynamic interactions between the proton and electron
- First measurement of this in antihydrogen

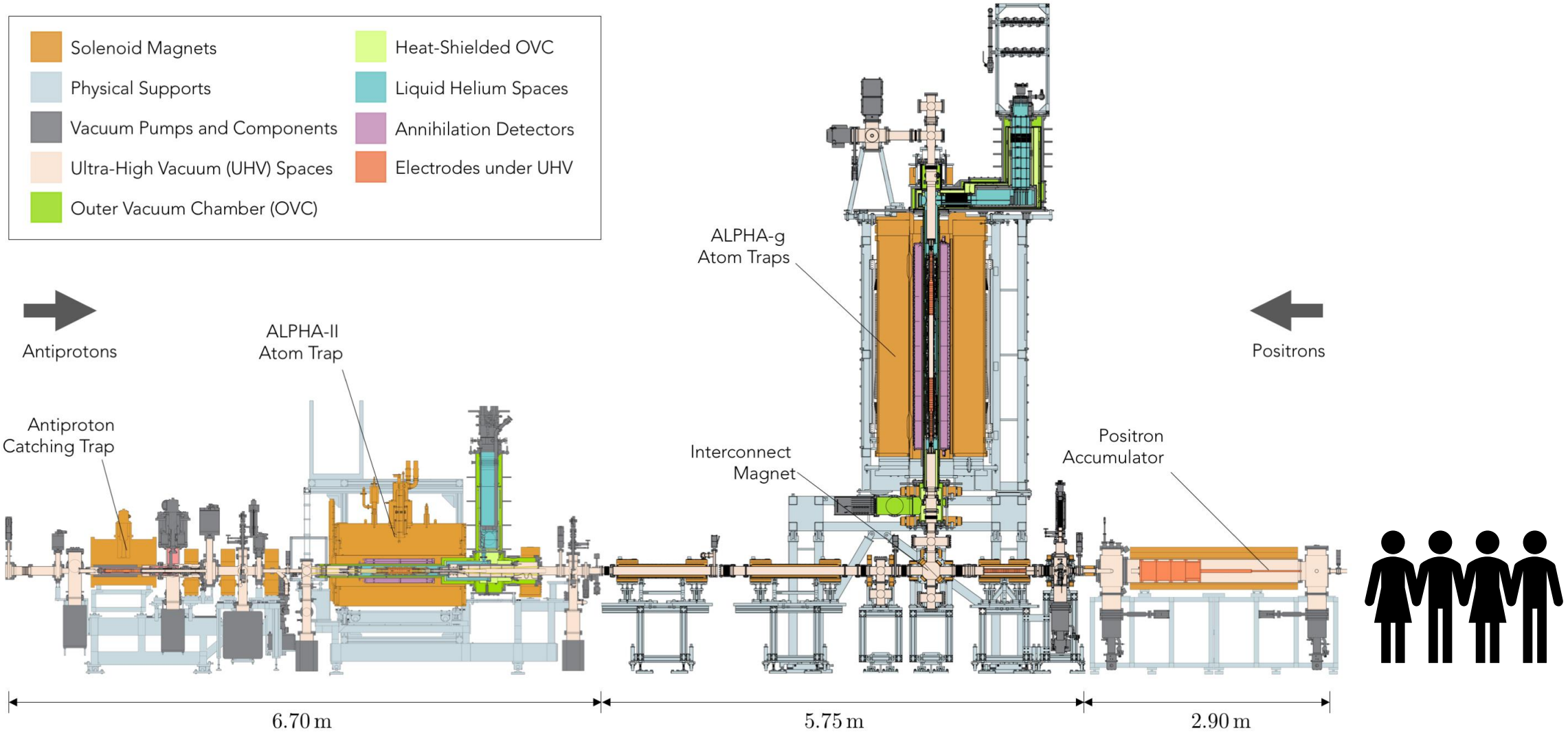


https://en.wikipedia.org/wiki/Willis_Lamb


This is ALPHA-2


It looks like a mess, but
it works

Here is a better picture (as of 2019!)



By: Mark Johnson

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Previous ALPHA-2 work

- Observation Of The 1S–2P Lyman-A Transition In Antihydrogen (**2018**)
- Characterization Of The 1S–2S Transition In Antihydrogen (**2018**)
- Enhanced Control And Reproducibility Of Non-Neutral Plasmas (**2018**)
- Observation Of The Hyperfine Spectrum Of Antihydrogen (**2017**)
- Observation Of The 1S-2S Transition In Trapped Antihydrogen (**2016**)

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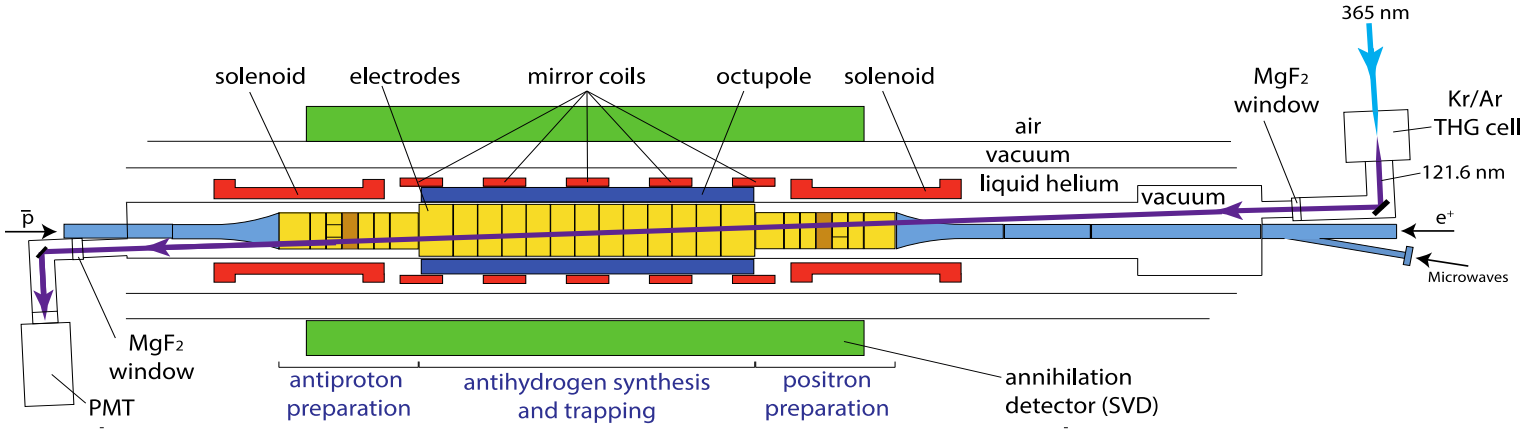
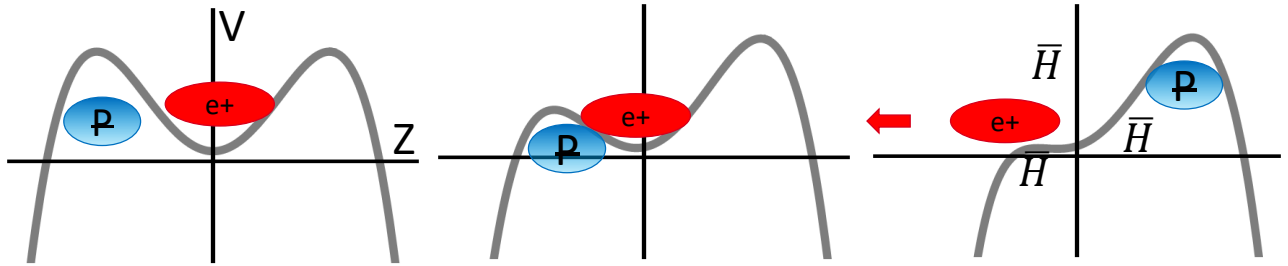
Making Antihydrogen

- Penning trap
- Evaporatively cooling positron into antiprotons
- Minimum B trap for antihydrogen
- Optical path is near parallel to Z
- Can trap about 20 antihydrogen 4 minutes
  - Up from 0.1 every 30 min in 2014
  - This is pretty awesome!





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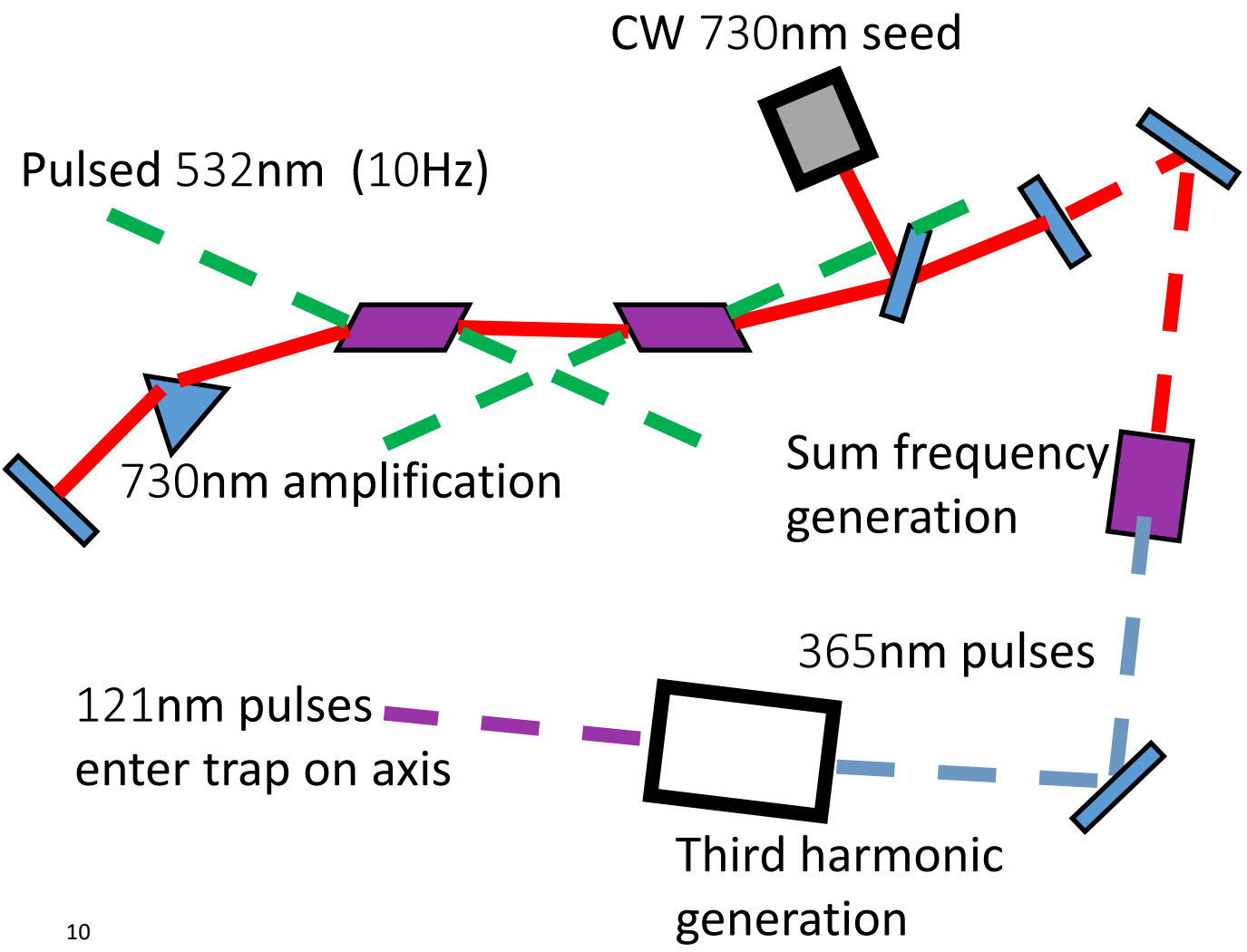
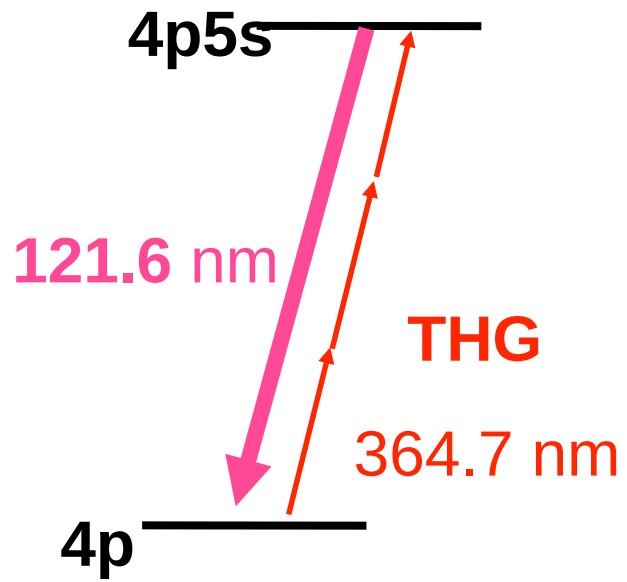
The Laser



- Pulsed 121nm light; 1nJ per pulse (on a good day)
- Third harmonic generation in a Kr/Ar mixture
- Aligning the laser to the sample volume is hard



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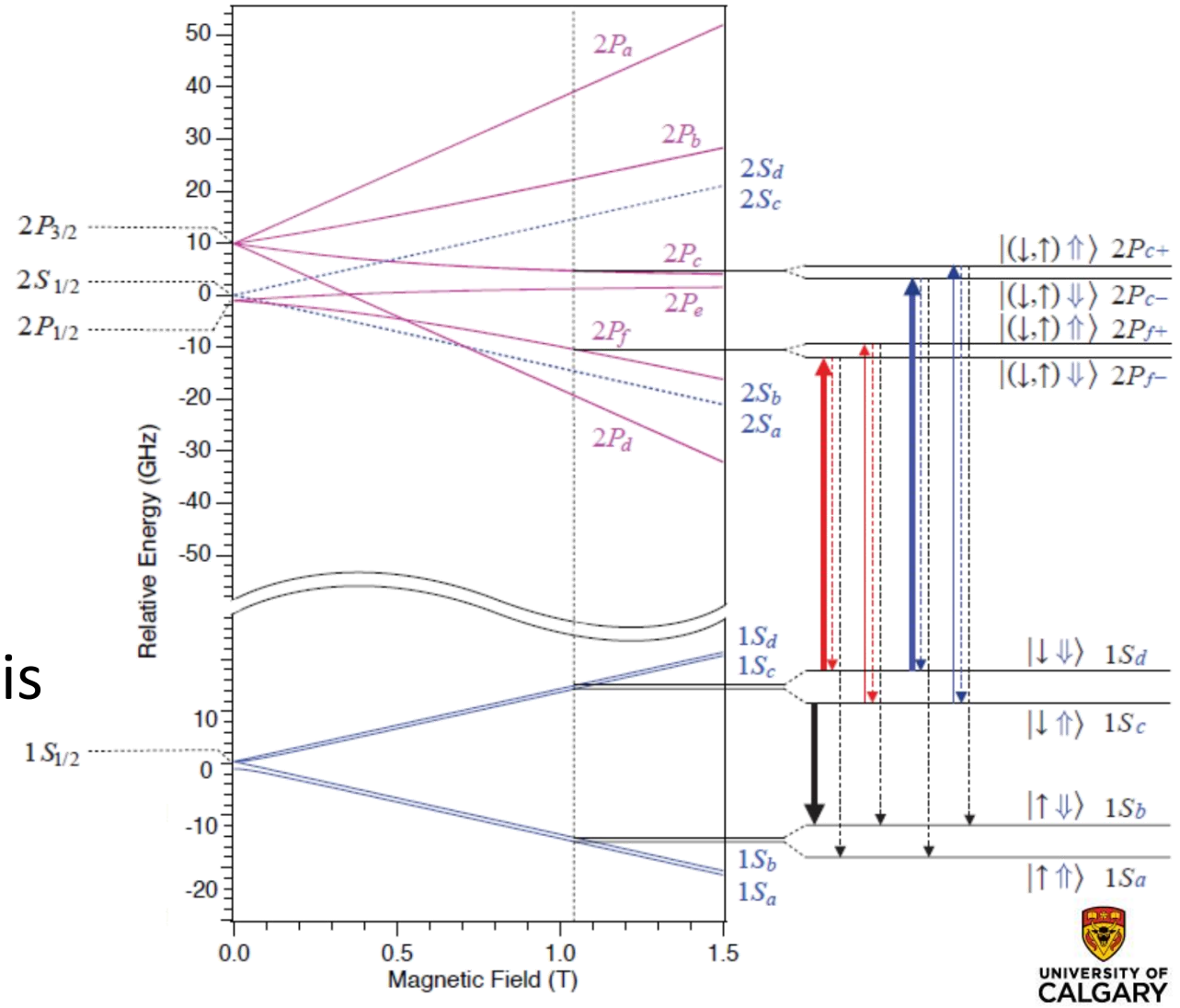
Our Lamb shift experiment

- First Lamb shift measurement was direct
- This is not a direct measurement
  - ALPHA is not an antimatter ion oven
  - We only have access to 1S atoms
- We measured the 1S-$2P_f$ and 1S-$2P_c$ transitions (red and blue lines)
- This along with the 1S-2S transitions is sufficient to calculate the lamb shift
- Assume Zeeman and hyperfine interactions in hydrogen



Our Lamb shift experiment

- We ran two types of experiment
- Singular and doubly spin polarized 1S samples
  - Positron spin polarized
  - Positron spin AND antiproton spin polarized
- The initial sample of antihydrogen was prepared the same way
  - About 500 antiatoms
- Microwave radiation was used to remove the antihydrogen that are not doubly polarized

Our Lamb shift experiment

- We are unable to resolve the two spectrum peaks in fig. a
  - Doppler broadening is too large
- Simulated data was fit with a four parameter function with the centre frequency being one
- The experimental data was fit with the same function using the three other parameters chosen by simulation fits

Our Lamb shift experiment

	Lamb Shift (GHz)	Hyperfine Splitting (GHz)
Antihydrogen		
Hydrogen		

Future Work

- CERN facilities shut down until 2020
  - Hardware upgrades
- Gravity measurement
- Laser cooling
- More microwave measurements
- Hydrogen spectroscopy??

Conclusion

- The first ever measurement of the lamb shift in antihydrogen was completed
- It is in agreement with the value measured for hydrogen
- Lots to get done between now and 2020
- More exciting results to come

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Thank You to:

- TRIUMF & CERN
- UofC
- Everyone in ALPHA
- NSERC
- CFI
  - + AB, BC, ON match

NSERC CRSNG

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Data collection specifics

- Twelve frequencies around the centroid peak for the transition in question were chosen
- Each frequency exposed for 20s, all of the frequencies are cycled through for a total time of 2 hours per trial
  - Exposure time was chosen to minimise depletion effect
  - Cycling through frequencies in this manor reduces systematic errors and removes the need to normalize between data sets
- Only a 1ms observation window after each laser pulse was used