UNIVERSITY OF CALGARY

FACULTY OF Science, Department of Physics and Astronomy

ALPHA

Detection of 1S-2S Transition in Antihydrogen

Andrew Evans

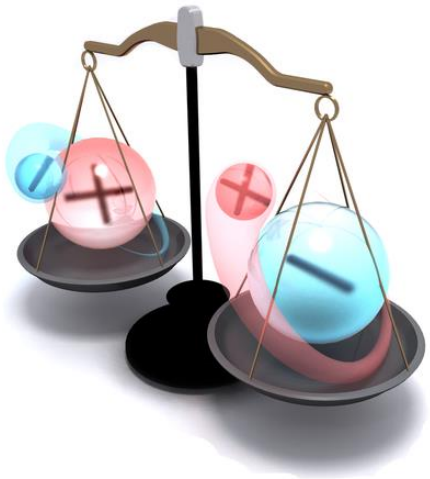
What is ALPHA?

- Antihydrogen Laser PHysics Apparatus (ALPHA)
- ~50 scientists from: Canada, Denmark, UK, US, Israel, Brazil, Sweden, and Japan
- Produce and study antihydrogen
- Made measurements of:
  - Trapping
  - Charge neutrality
  - Hyperfine transition

UNIVERSITY OF CALGARY

Why Is This Important

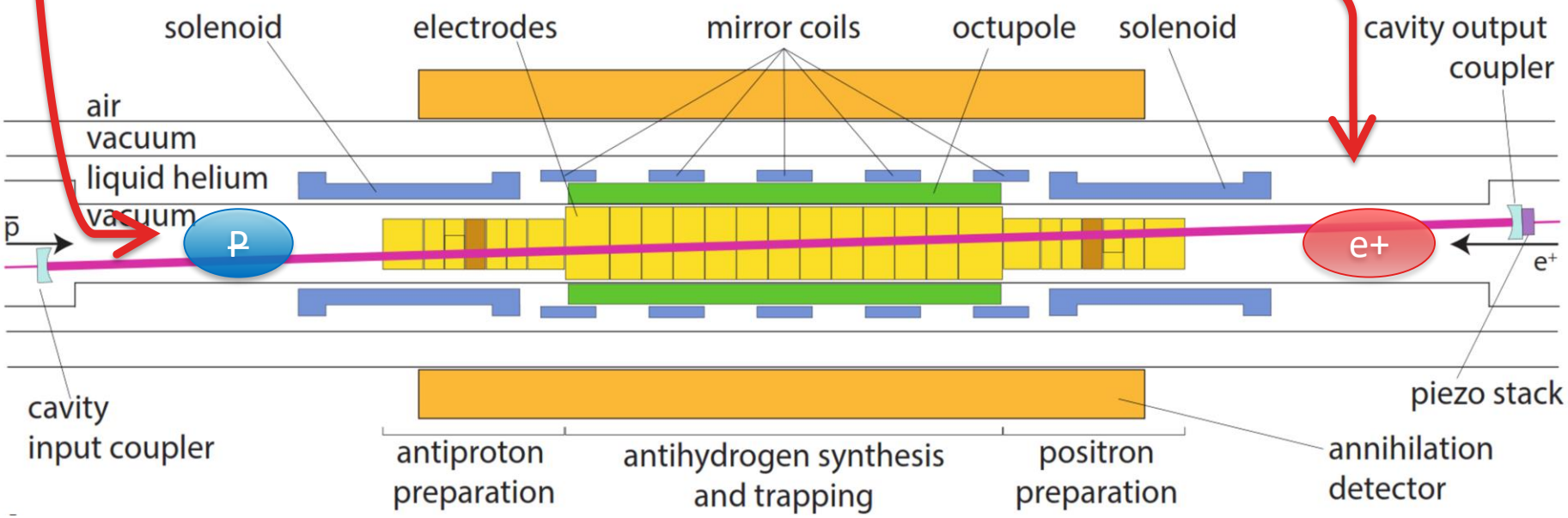
- Matter / Antimatter imbalance
- Optical transition in hydrogen measured to 15 digits
- CPT symmetry predicts hydrogen and antihydrogen to have the same atomic structure
- Discrepancies could indicate new physical principles



Antihydrogen Recipe

You need:

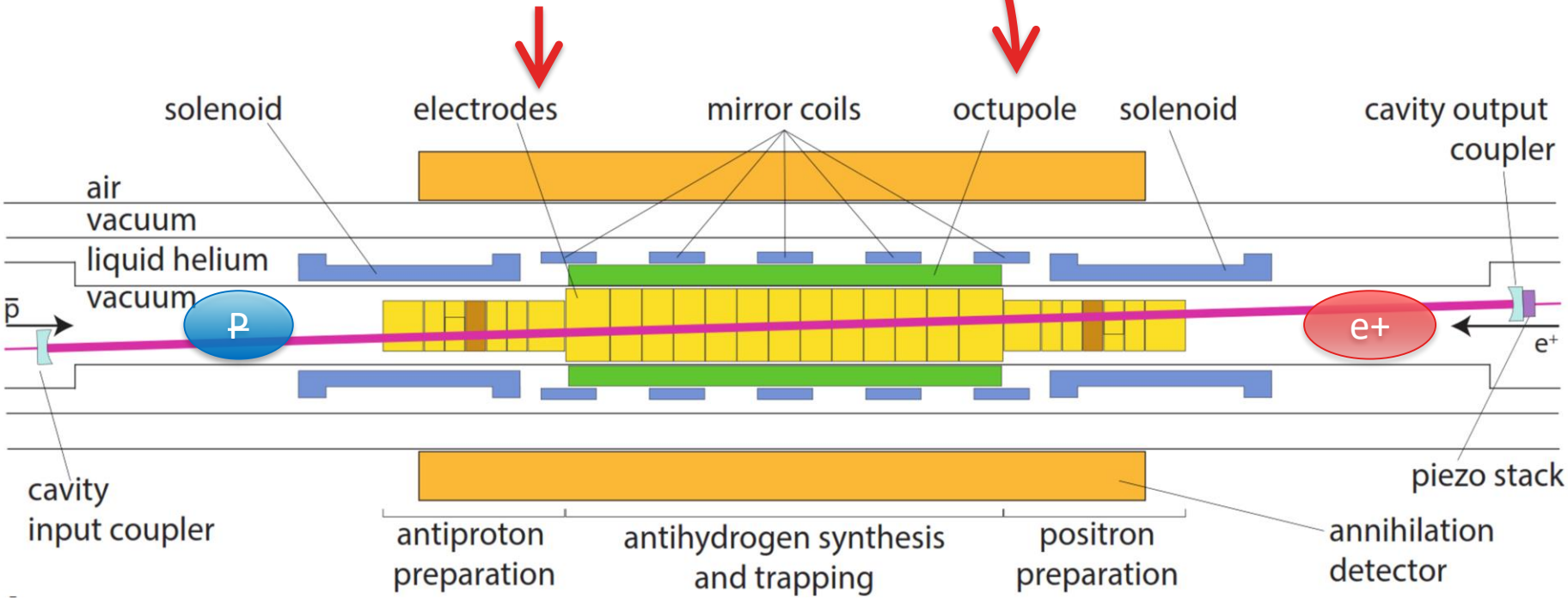
- Antiprotons from Antiproton decelerator (AD)
- Positrons from sodium22



Antihydrogen Recipe

You need:

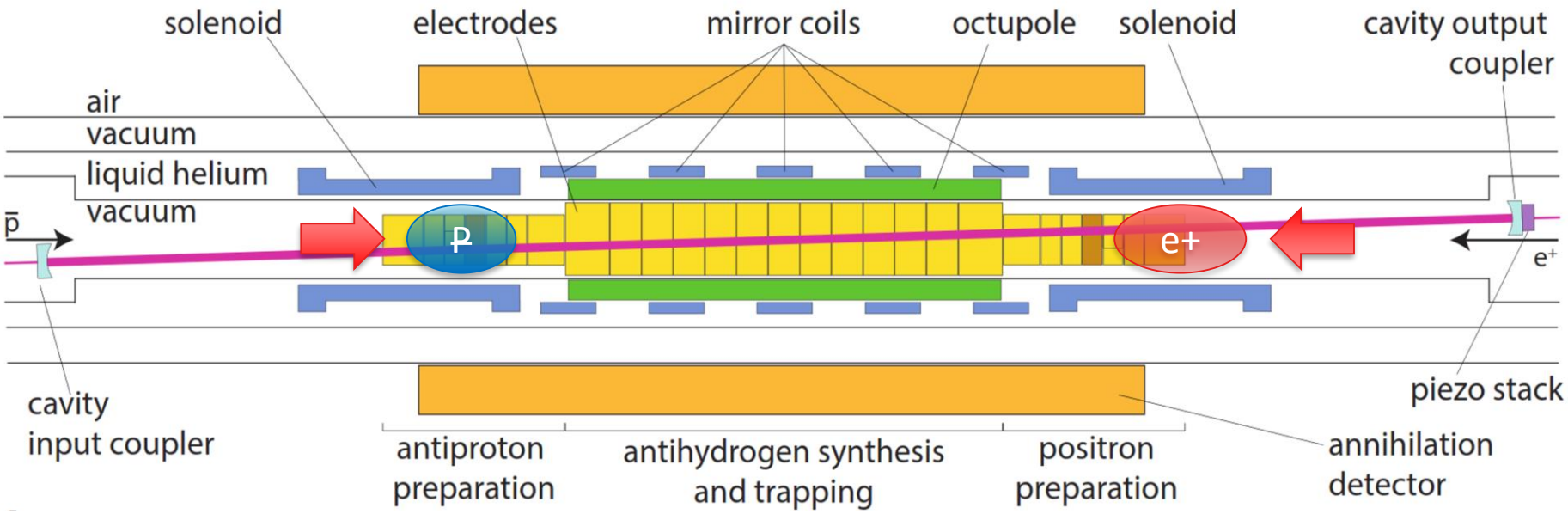
- Minimum B (neutral) trap
- Penning (charged) trap



Antihydrogen Recipe

Prepare cold plasmas

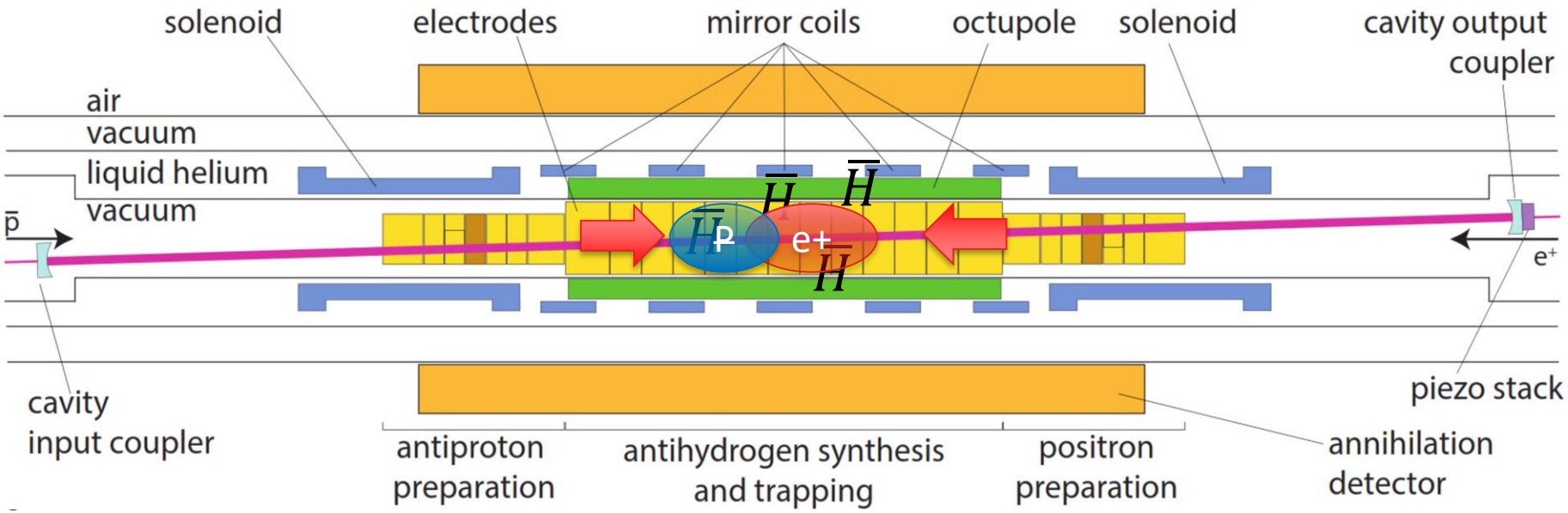
- Evaporative cooling
- Sympathetic cooling



Antihydrogen Recipe

Mixing

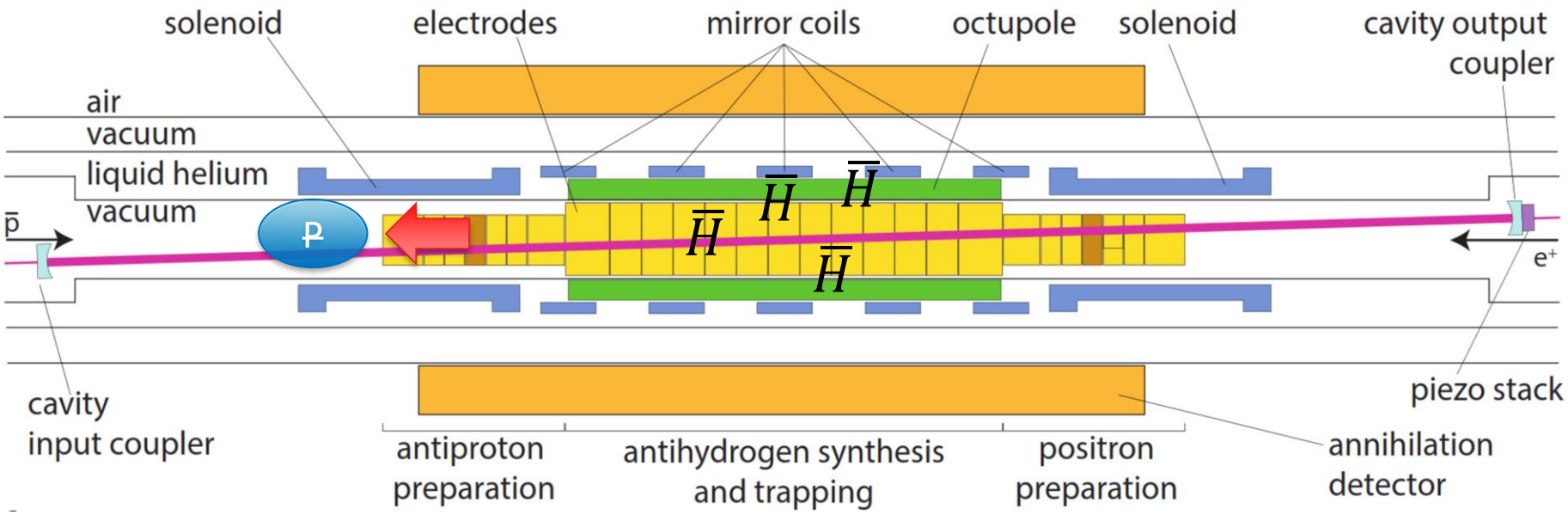
- Plasmas brought into contact
- Collisions form antihydrogen



Antihydrogen Recipe

Remove leftover antiprotons

- Antihydrogen has the same annihilation reaction



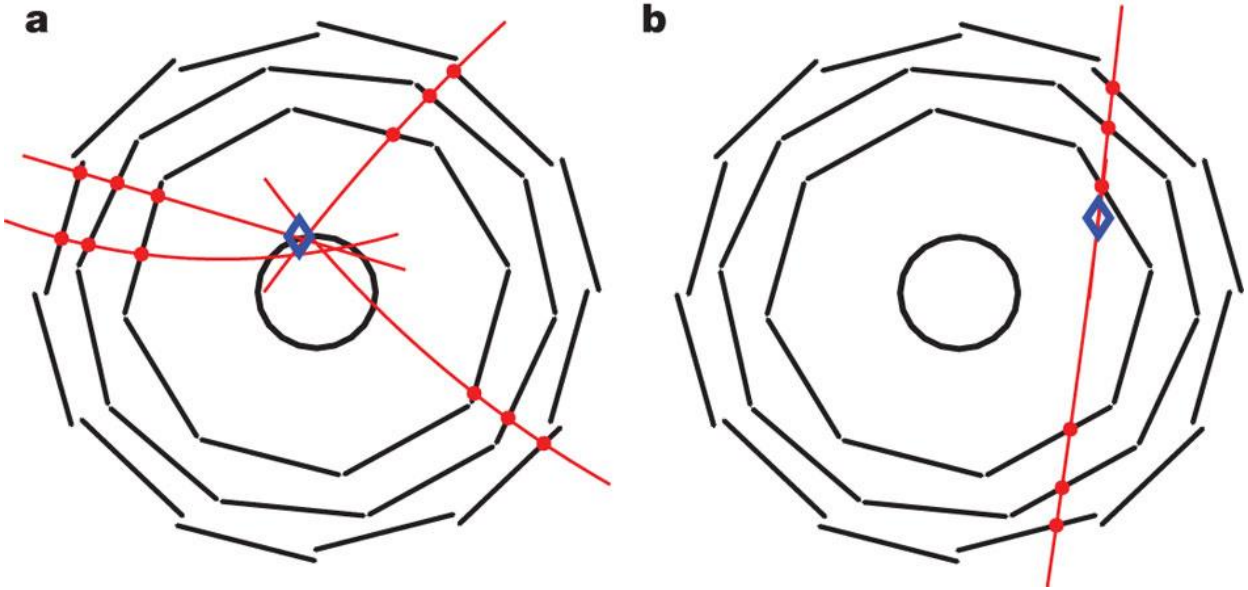
UNIVERSITY OF CALGARY

Challenges in Antihydrogen Spectroscopy

- Longer observation window
  - More sensitive detector software
- Low number of atoms
  - “New” mixing method
  - Stacking antiproton bunches
  - More consistent plasma preparation
- Optical cavity in tricky environment
  - Power build-up problems
  - Alignment problems

ALPHA Detector and Software

- Silicon vertex detector
- Reconstructs tracks of charged particles
- Gives location and time of matter-antimatter annihilations



a) Annihilation event b) Cosmic event

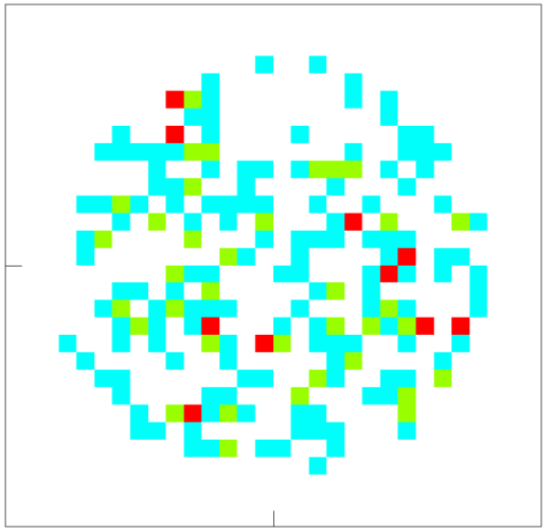
Machine Learning Classifier (MVA)

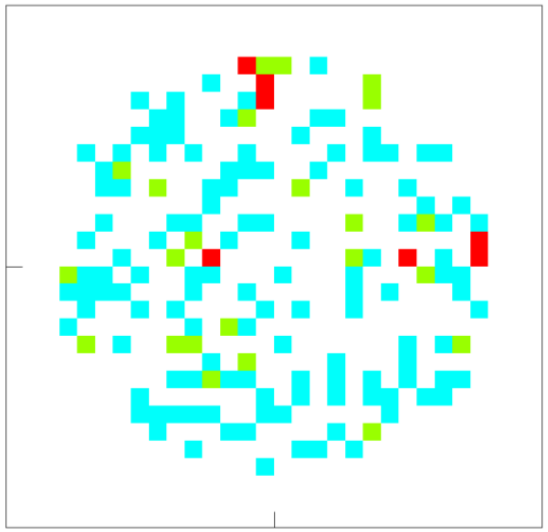
- A random forest algorithm is used
- The Punzi figure of merit is maximized $S/(\sqrt{B}+\frac{a}{2})$

S- Signal events
B- Background events
α- Significance of signal

- Variable Control over background noise

X-Y Event Cross-section (arbitrary units)

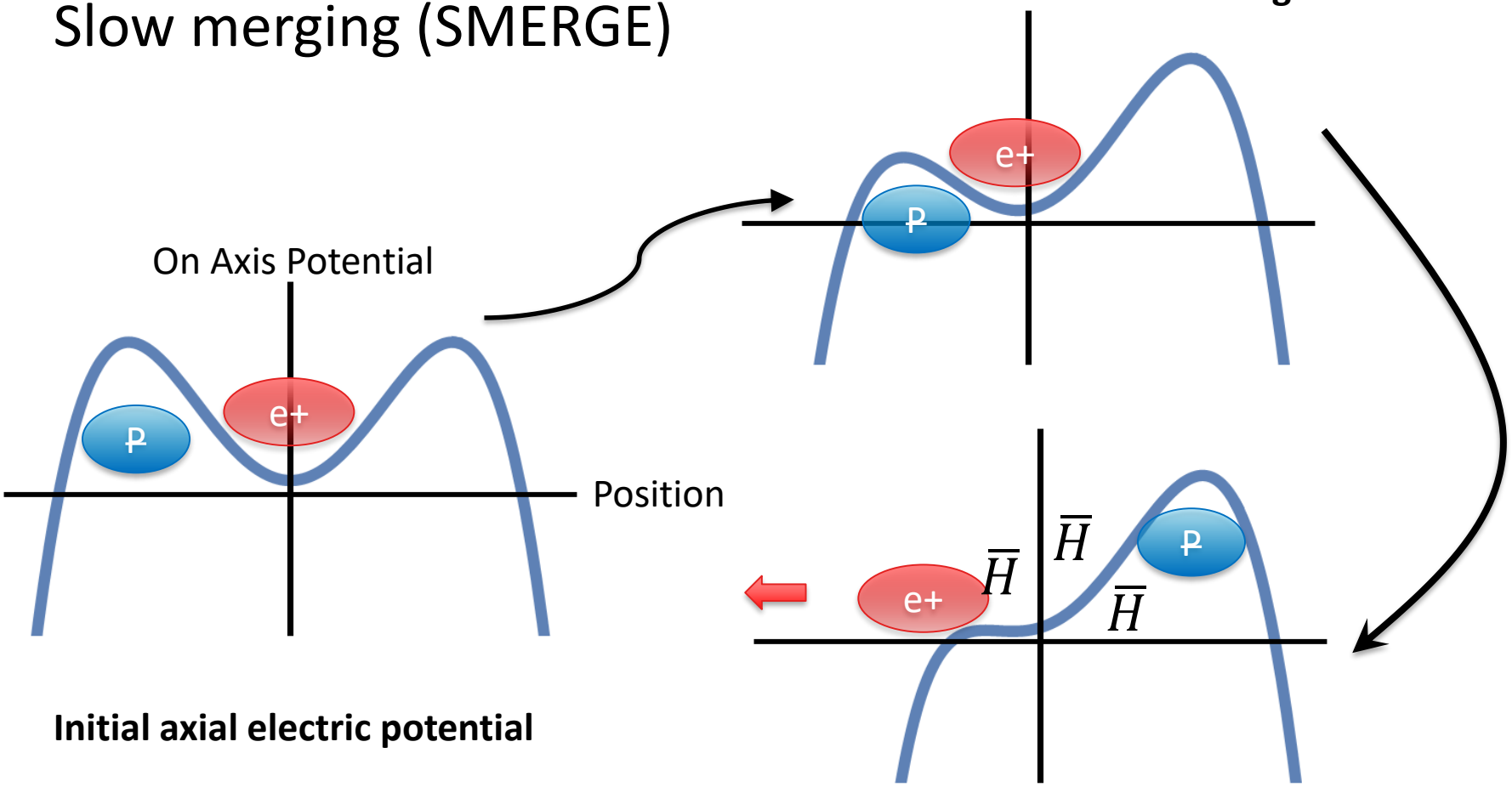




Plots of events in long observation period. Existing classification scheme insufficient to distinguish two distributions.

Plasma Mixing

Slow merging (SMERGE)



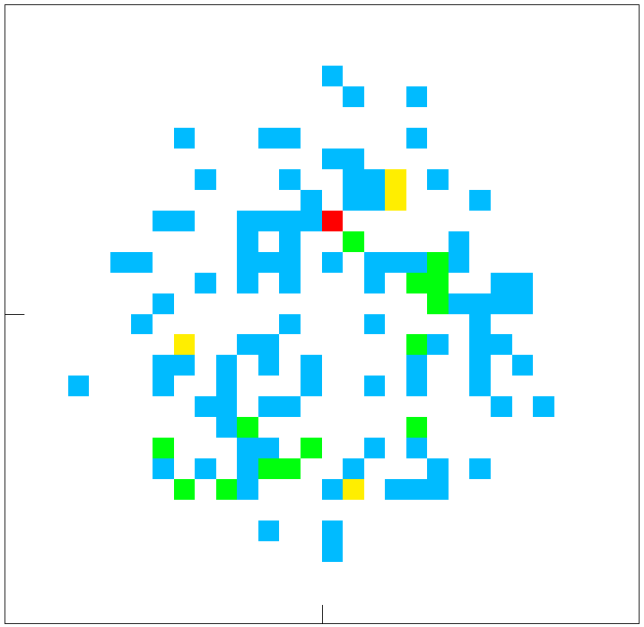
Initial axial electric potential

Plasmas slowly pass through each other
More than doubles trapping rate

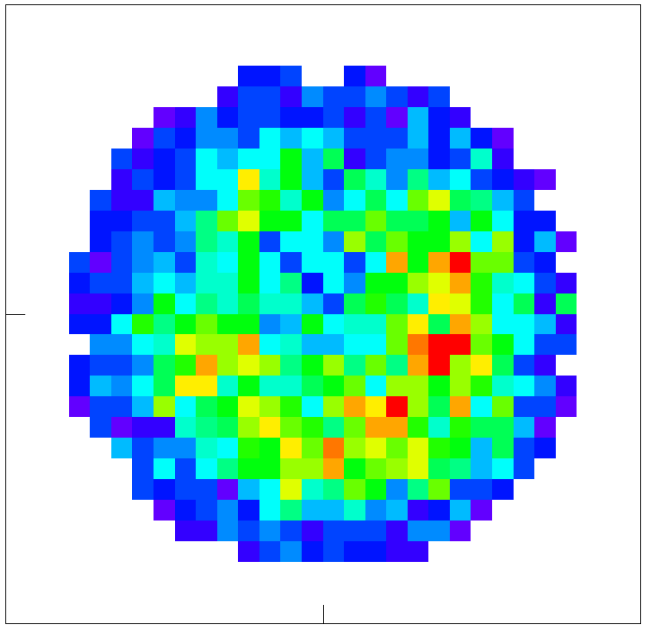
2016 In Comparison

- 140 events in 2014
- 7784 events in 2016

X-Y Event Cross-section (arbitrary units)



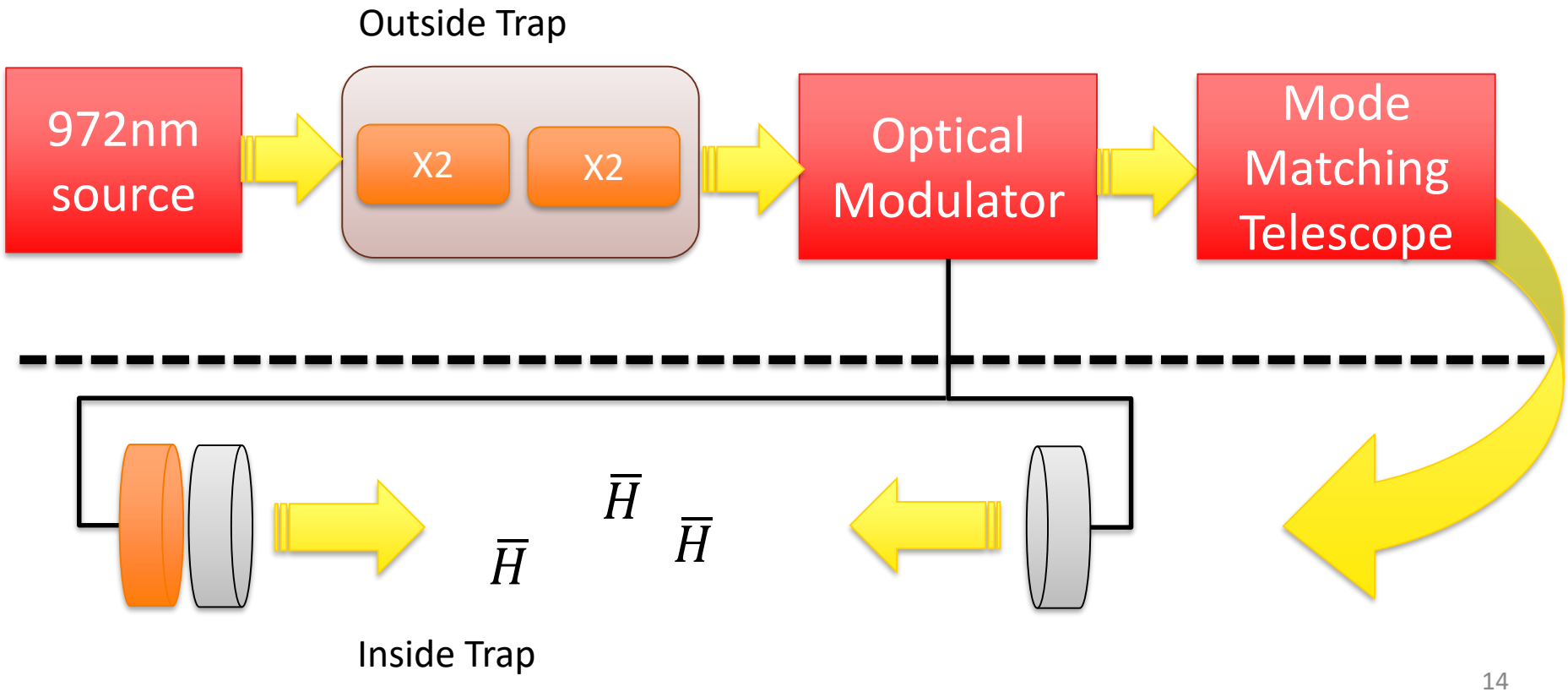
2014



2016

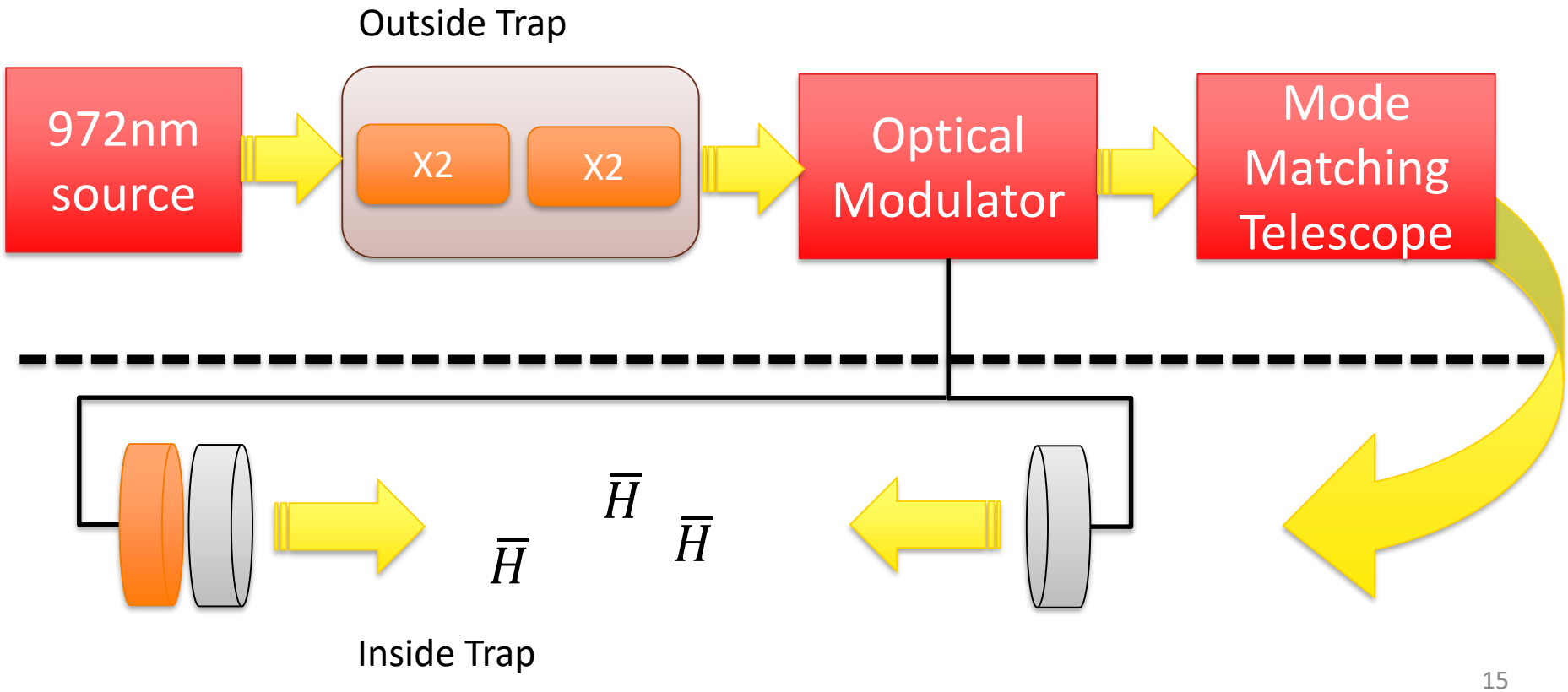
The Optical Cavity

- Light provided at 972nm diode laser
- Doubled twice to produce 243nm photons



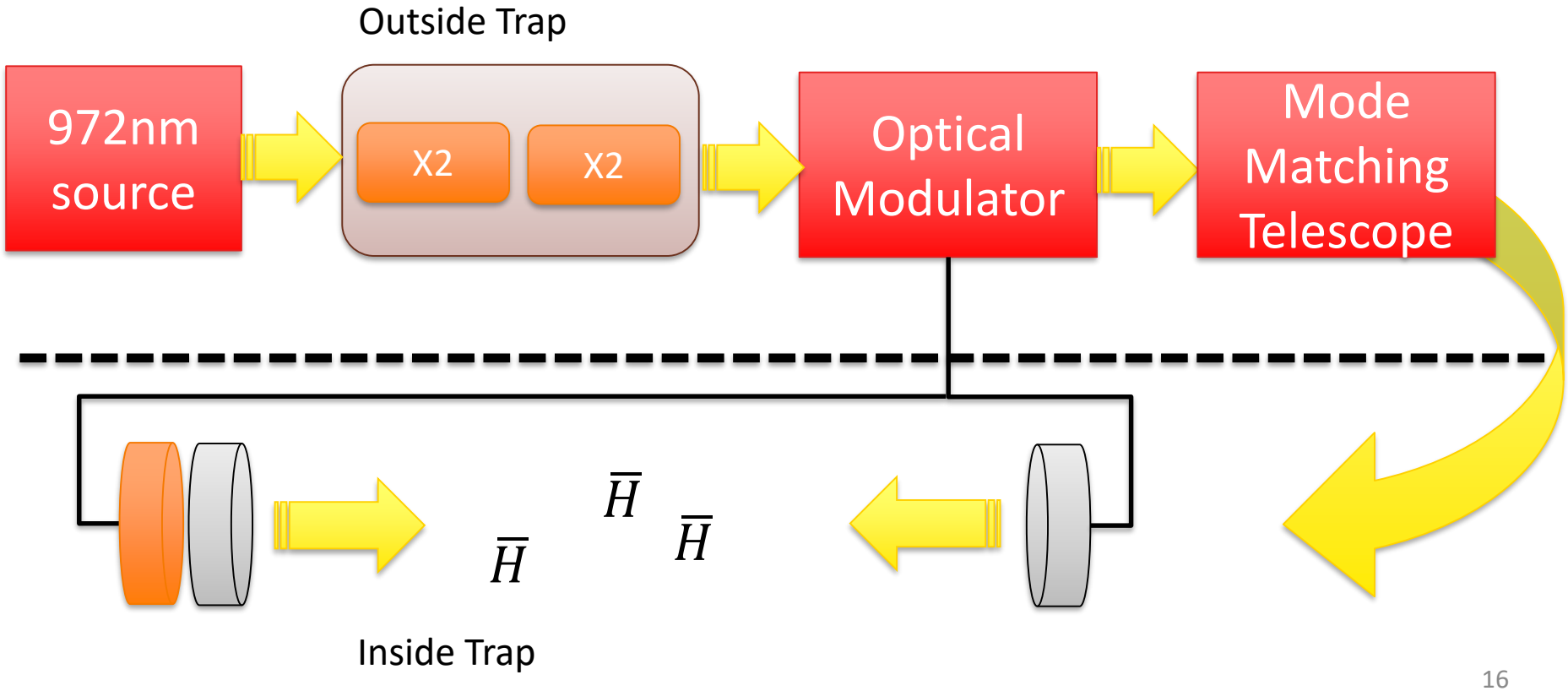
The Optical Cavity

- Feedback system used to maintain cavity resonance
- Optical cavity inside trapping volume

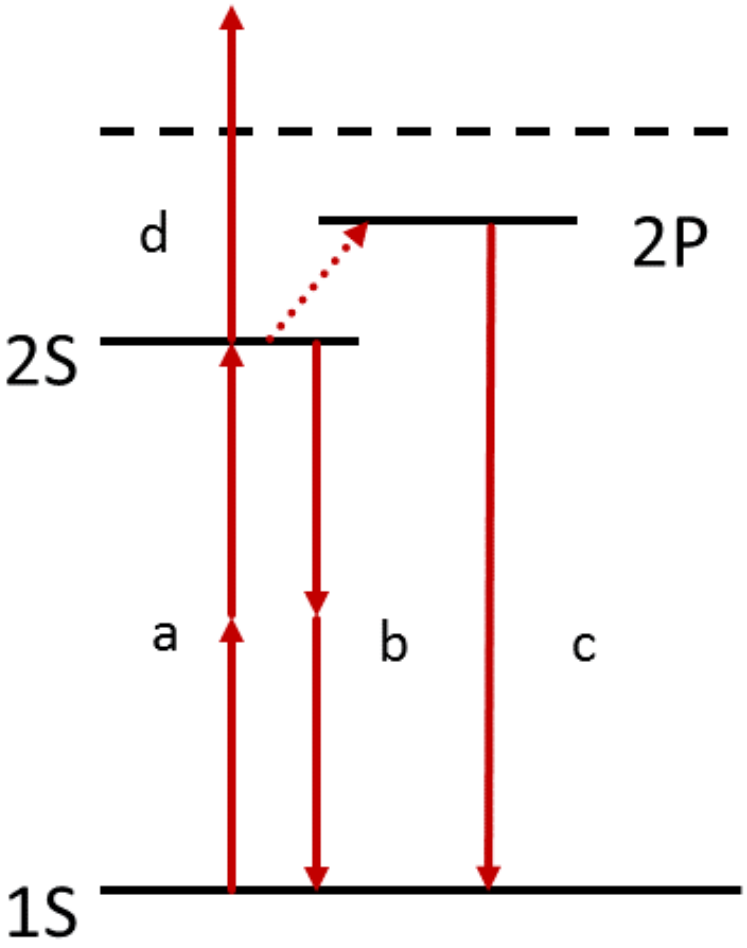


The Optical Cavity

- Brining experiment to cryogenic temperatures changes mirror alignment
- Running optical cavity degrades Hbar production



1S-2S Antihydrogen Transition



- Measure the change in trapping rates (particles that survive)
- Measure events during the laser interrogation (particles that annihilate)

a) 1S-2S 243nm transition
b) Two photon decay (survives)
c) One photon decay (annihilation)
d) Ionization (annihilation)

UNIVERSITY OF CALGARY

1S-2S Antihydrogen Transition

Disappearance Measurement

- Observation made during ramp down of magnets (1.5s)
- Three types of experiment, 33 runs total
- Interchanged types to avoid systematic error

Results

Type	Number of Events	Background
Off Resonance	159	0.7
On Resonance	67	0.7
No Laser	142	0.7

1S-2S Antihydrogen Transition

Appearance Measurement

- Observation made during laser interrogation (600s)
- New background in MVA chosen

- Confirm CPT symmetry to 2*10^-10

Results

Type	Number of Events	Background
Off Resonance	27	28.4
On Resonance	79	28.4
No Laser	30	28.4

UNIVERSITY OF CALGARY

Future Work

- Line shape measurement of 1S-2S transition
  - 10KHz measurement
- 1S-2P (121nm) transition
  - Laser cooling, needed for gravitational measurements
- Gravitational interactions (ALPHA-g)
  - Symmetry breaking through gravitational interactions (EEP)

UNIVERSITY OF CALGARY

Summary

- 2016 was a successful year
- Antihydrogen spectroscopy confirms CPT symmetry to 2*10^-10
- Developments in software, technique, and hardware push limits in achievable measurements and accuracy
- Successful demonstration of antihydrogen spectroscopy opens doors to many other studies

Sources

- M. Ahmadi et al. , “Observation of the 1S–2S transition in trapped antihydrogen” Nature 541, 506–510 (26 January 2017)

Thanks to:

- University of Calgary
- NSERC
- NRC
- CERN technical staff