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Silicon Vertex Detector for the detection of antihydrogen in the ALPHA II

JTK McKENNA

ALPHA

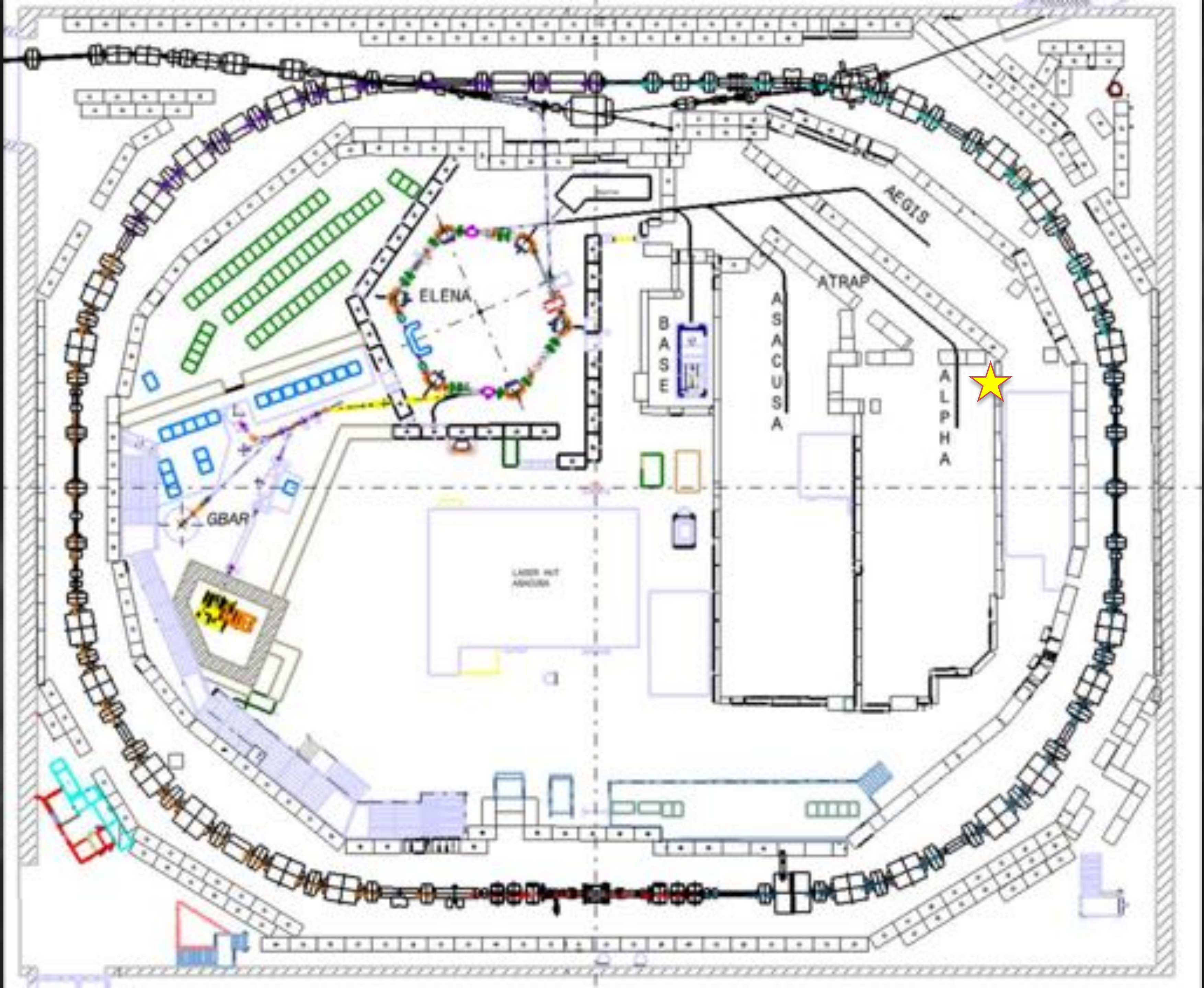
CERN

AARHUS UNIVERSITET

Overview

- Introduction and background
- Core of ALPHA Apparatus
- Experimental procedure
- Detector and Analysis details
- Experimental data examples
- Discuss cosmic suppression
- Conclusion

ALPHA Introduction


ELENA
AEGIS
ATRAP
BASE
ASACUSA
ALPHA
GBAR

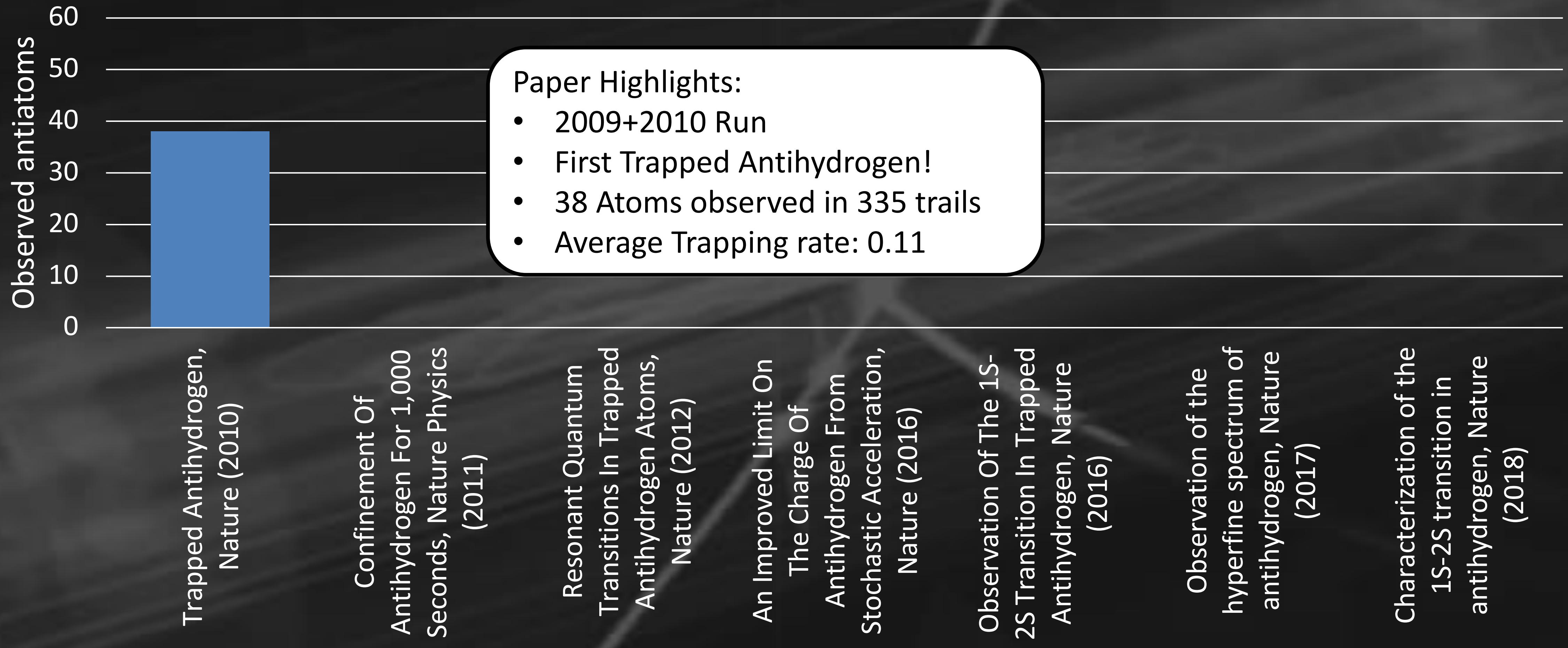

ALPHA

Overall Goals

Perform precision experiments with antihydrogen

- Laser spectroscopy
- Microwave spectroscopy
- Charge neutrality tests
- Gravity

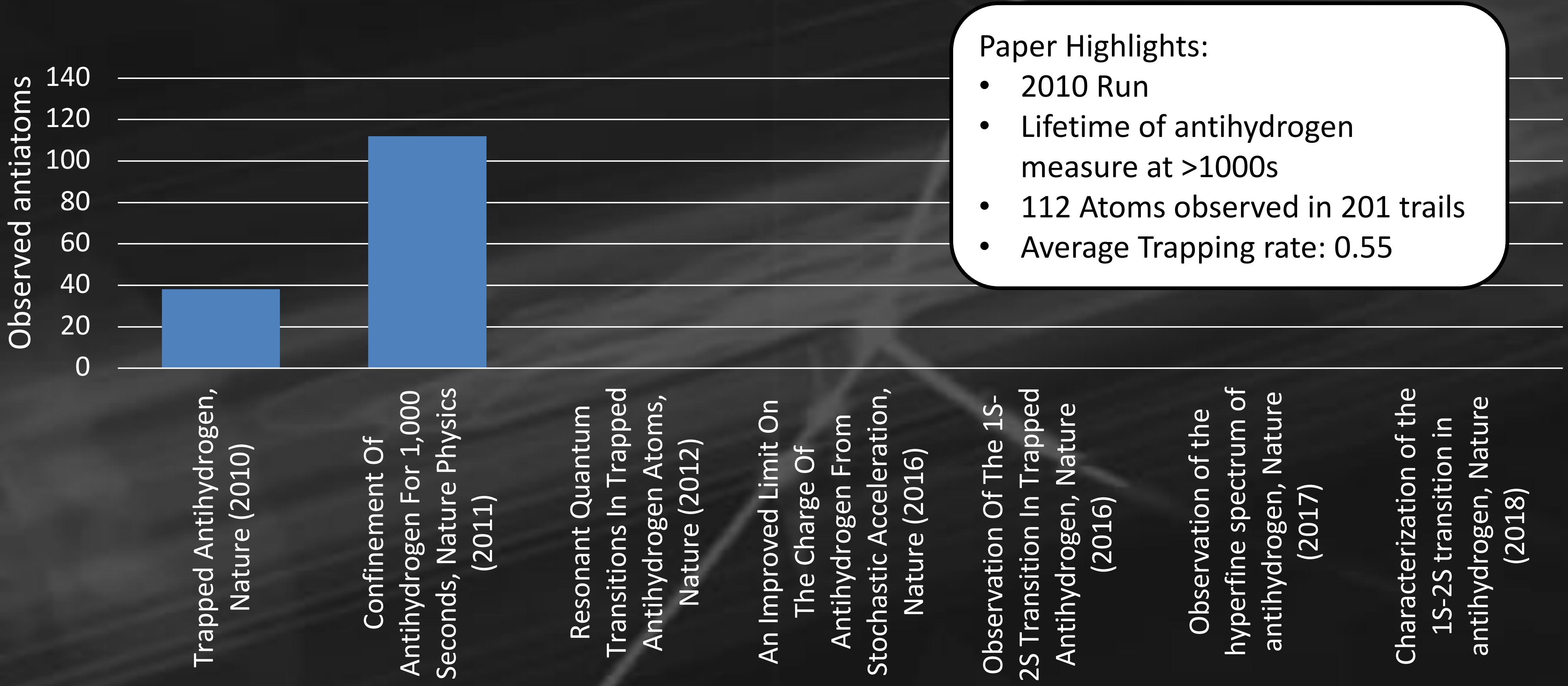
Milestones and achievements



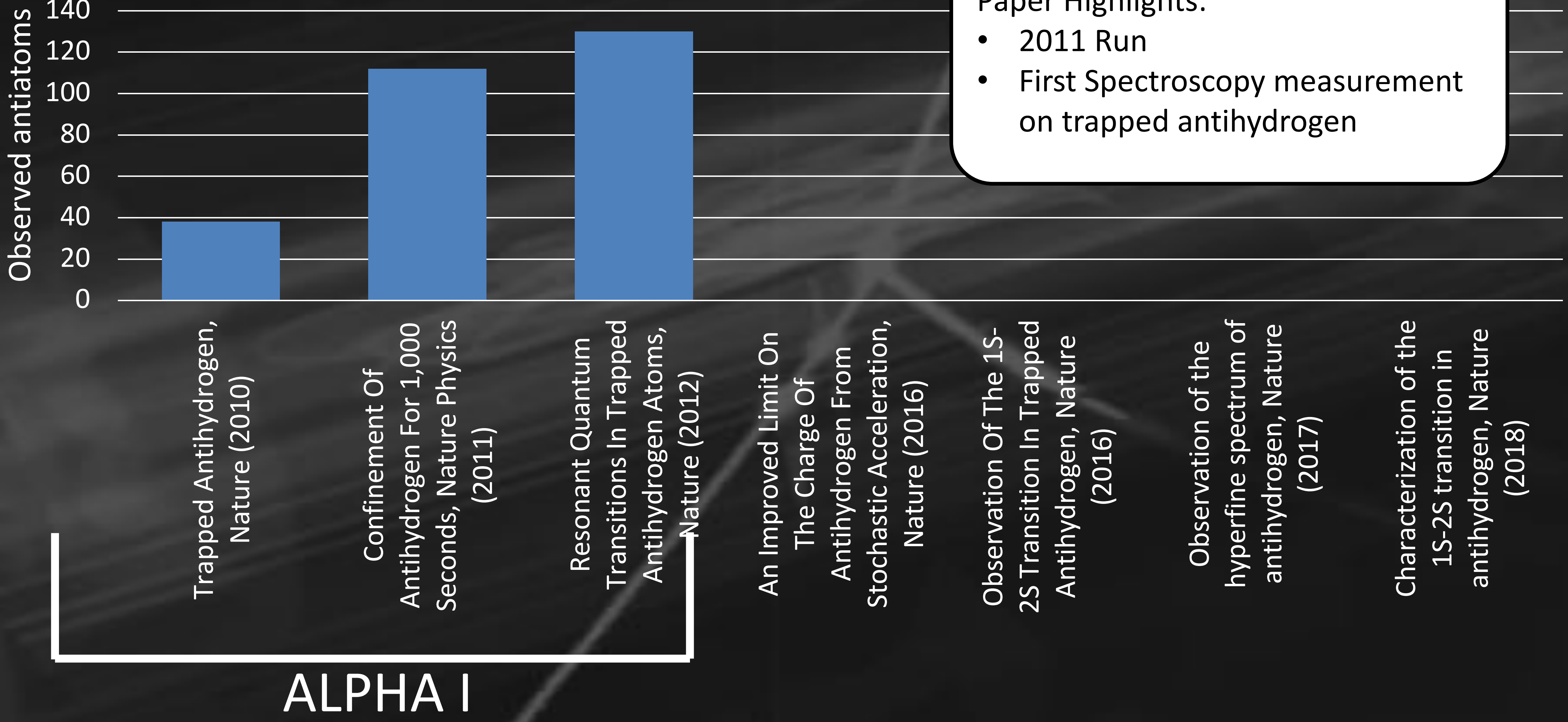
Paper Highlights:

- 2009+2010 Run
- First Trapped Antihydrogen!
- 38 Atoms observed in 335 trails
- Average Trapping rate: 0.11

Milestones and achievements



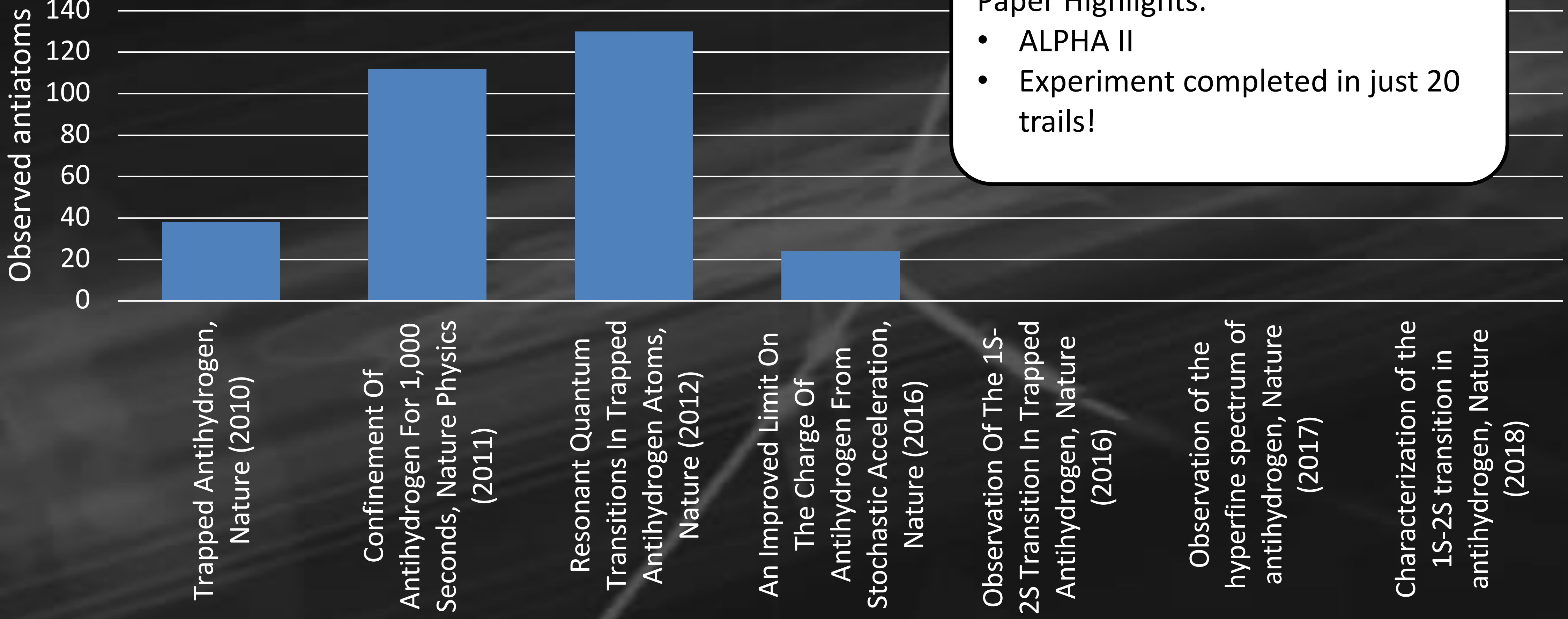
Milestones and achievements



Paper Highlights:

- 2011 Run
- First Spectroscopy measurement on trapped antihydrogen

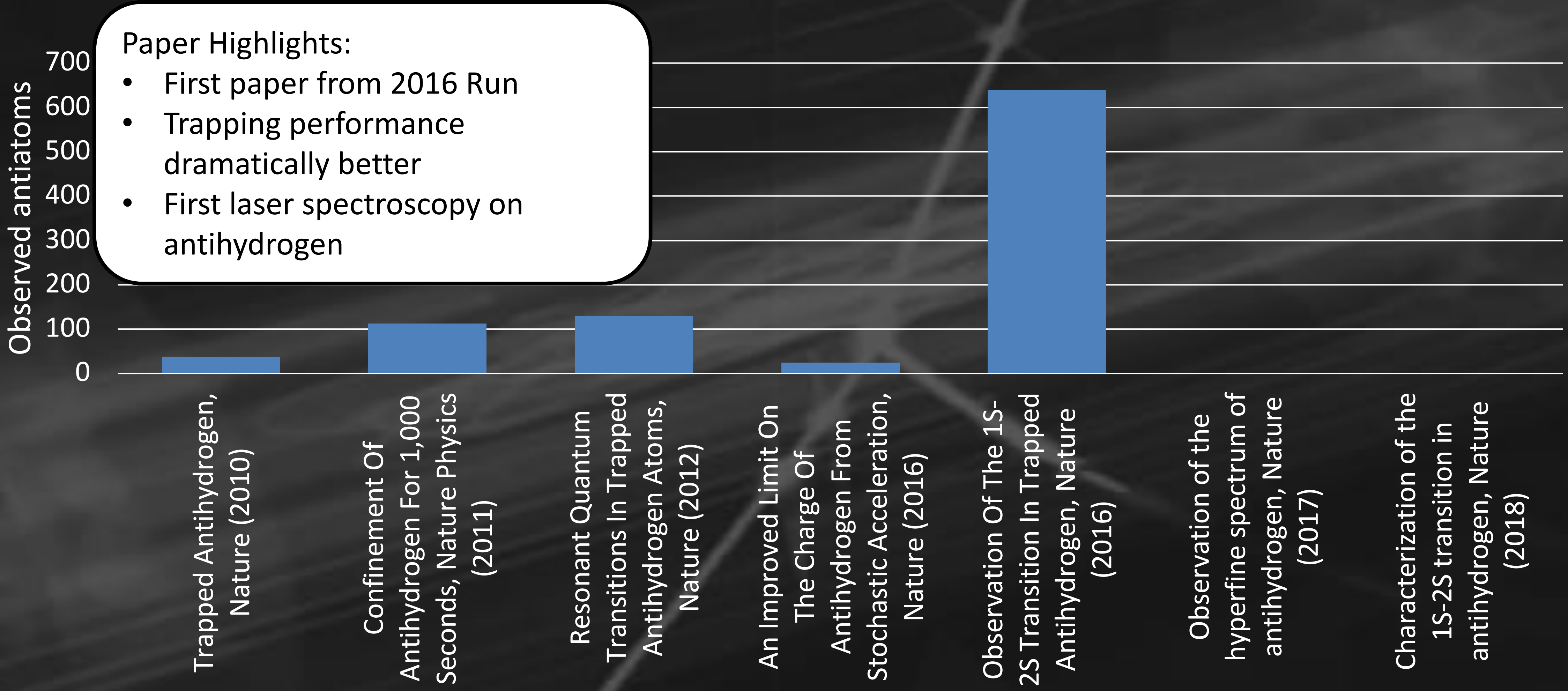
Milestones and achievements



Paper Highlights:

- ALPHA II
- Experiment completed in just 20 trails!

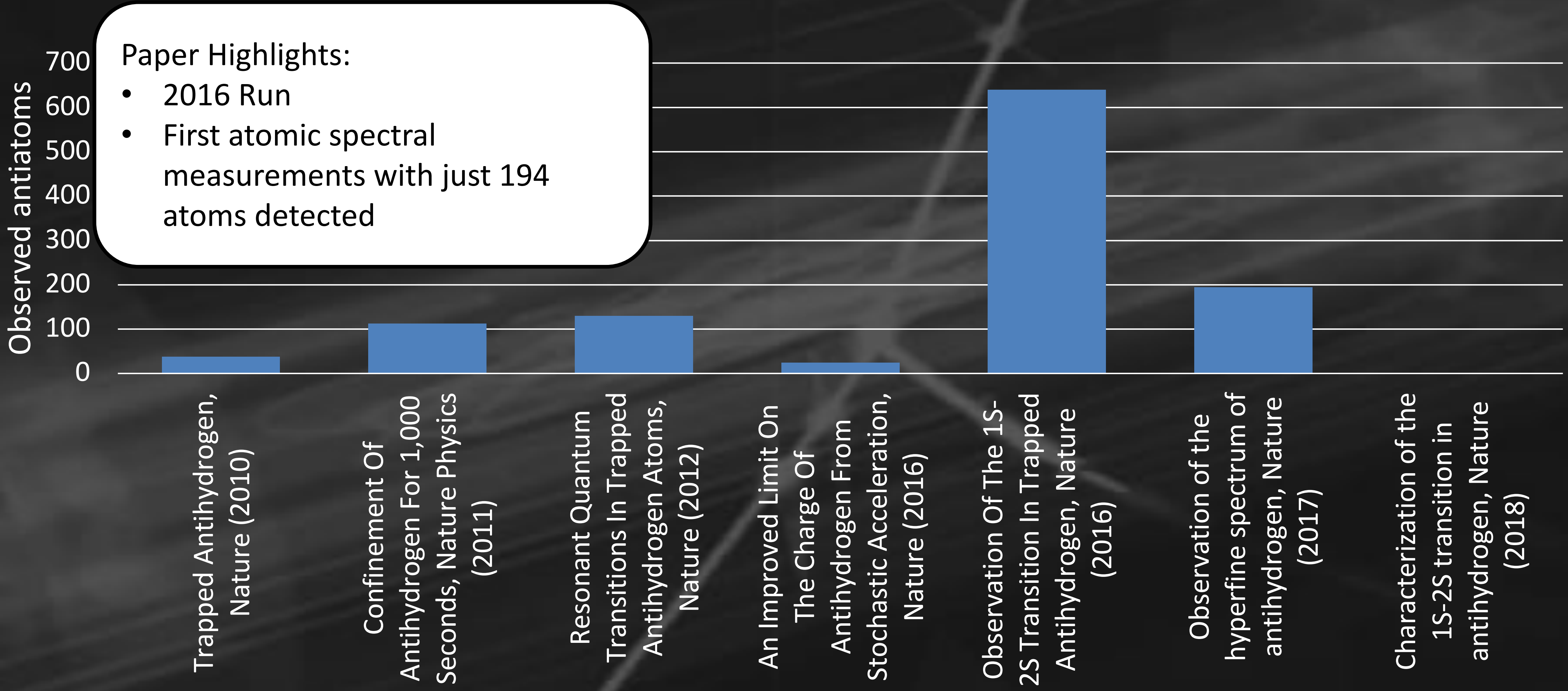
Milestones and achievements



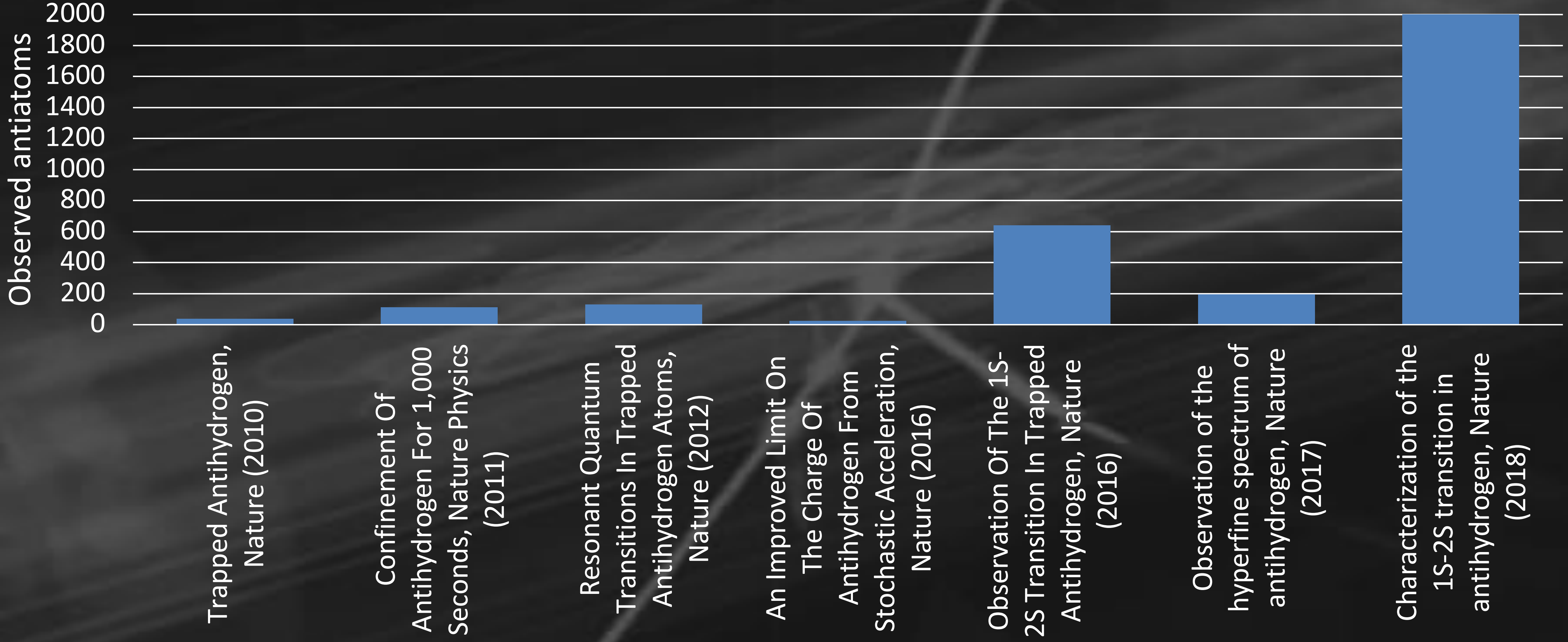
Paper Highlights:

- First paper from 2016 Run
- Trapping performance dramatically better
- First laser spectroscopy on antihydrogen

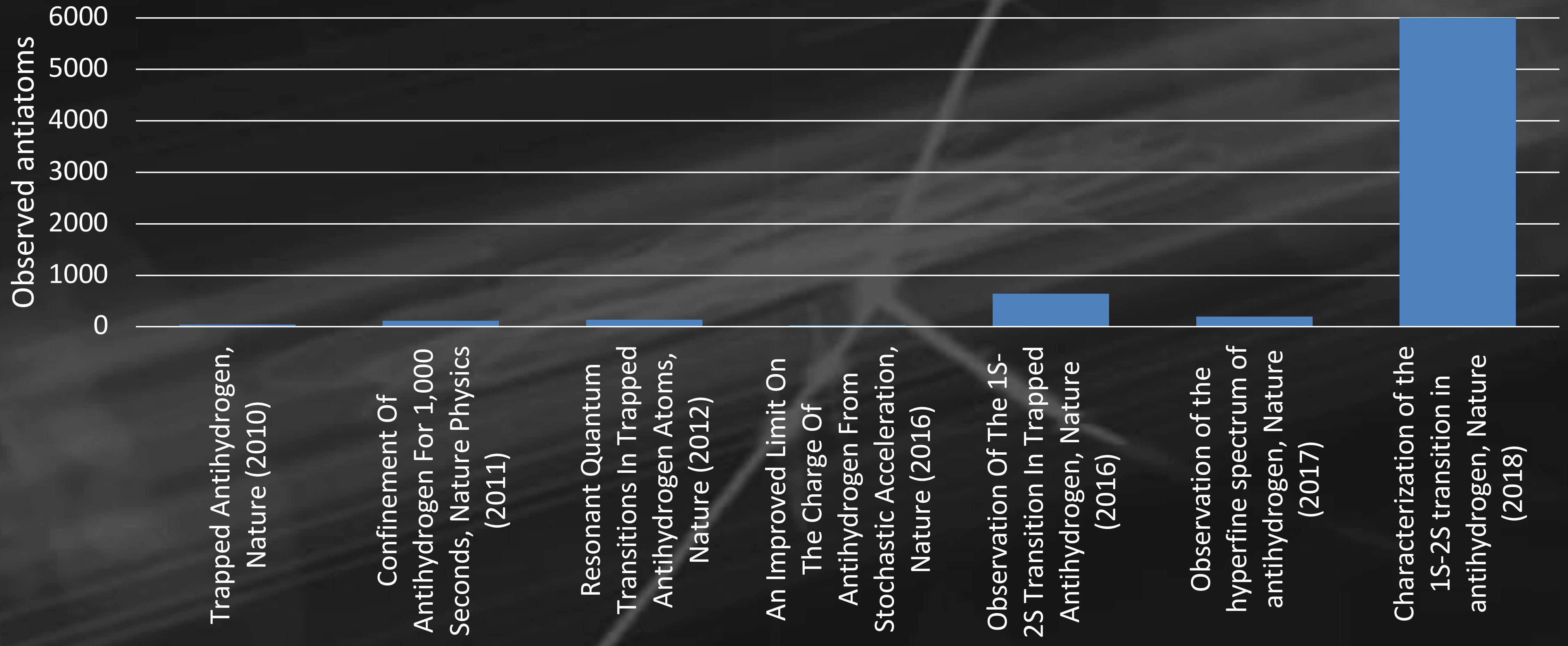
Milestones and achievements



Milestones and achievements



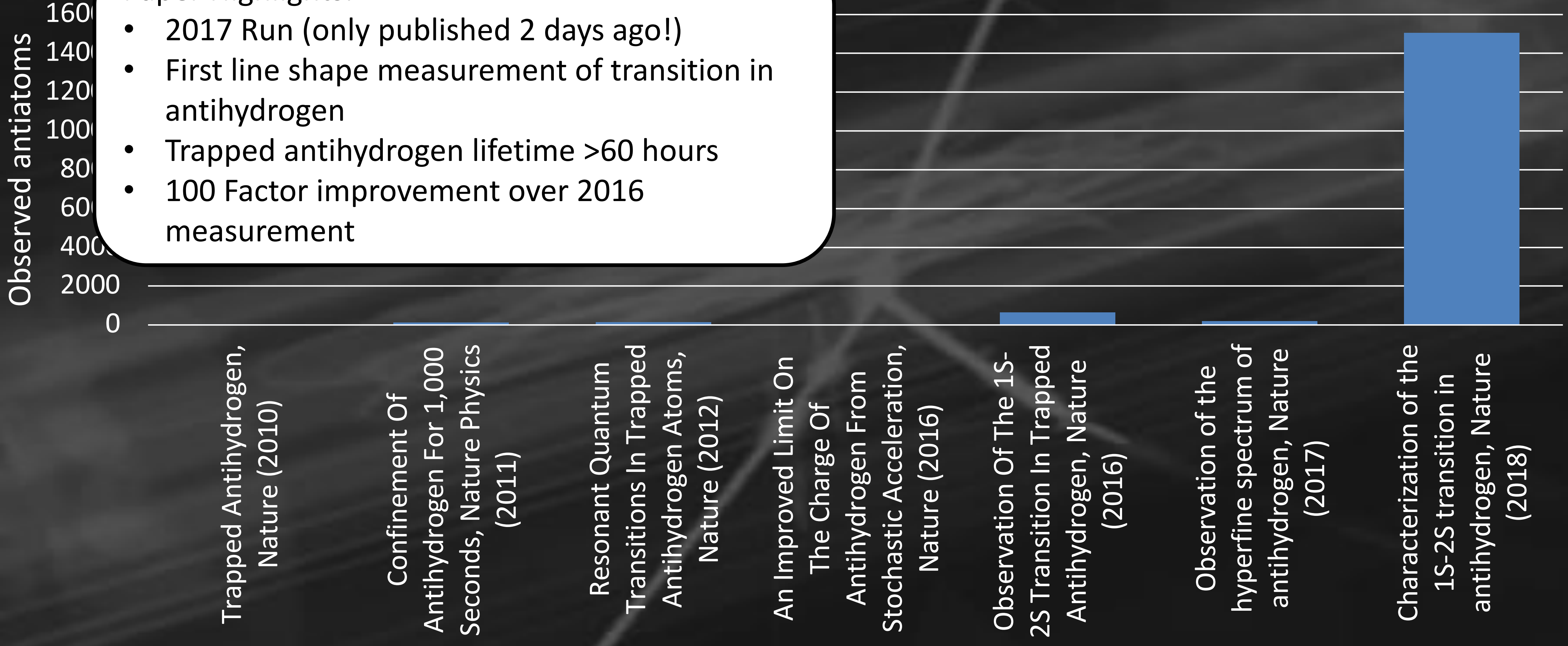
Milestones and achievements



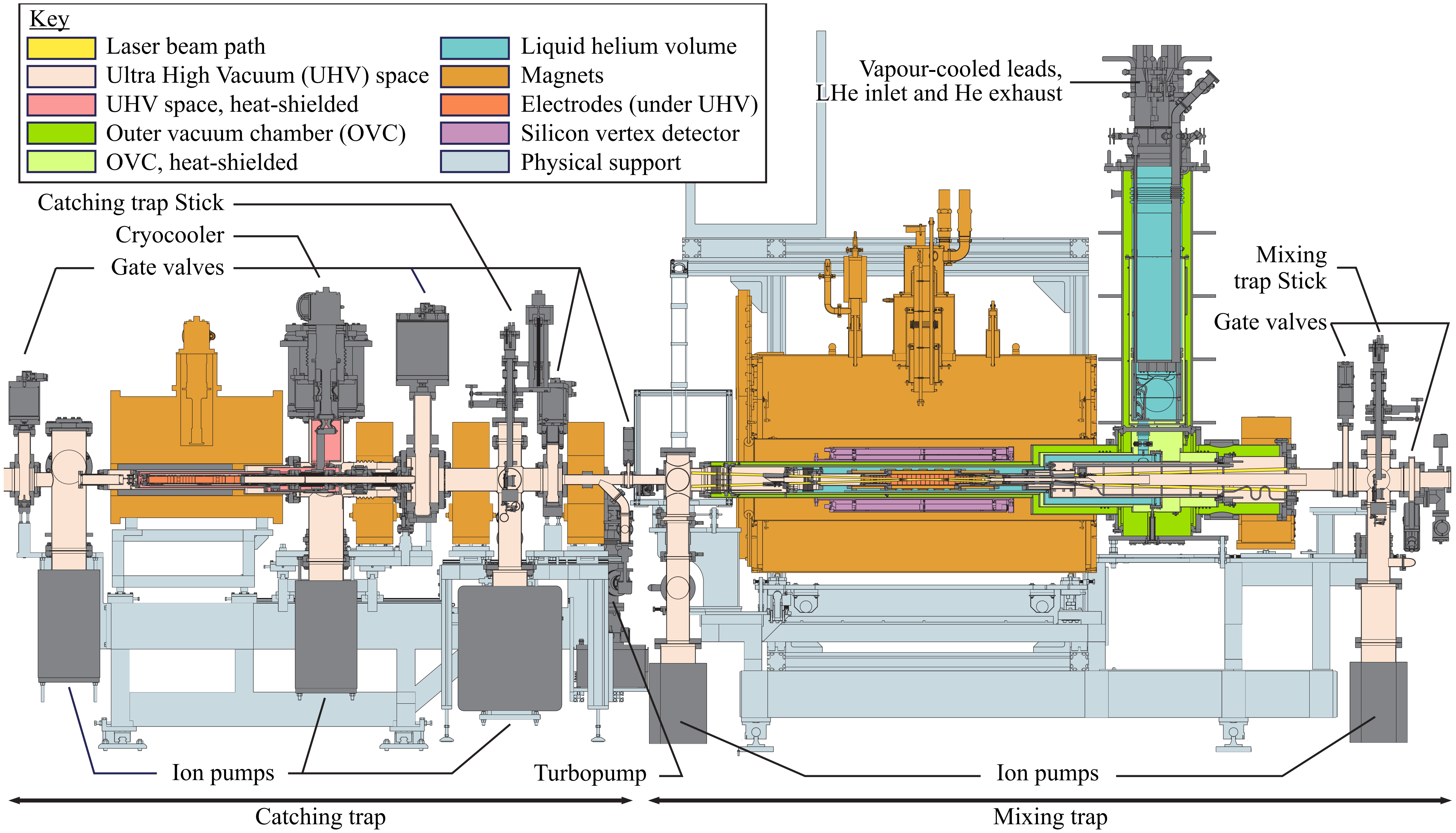
Milestones and achievements

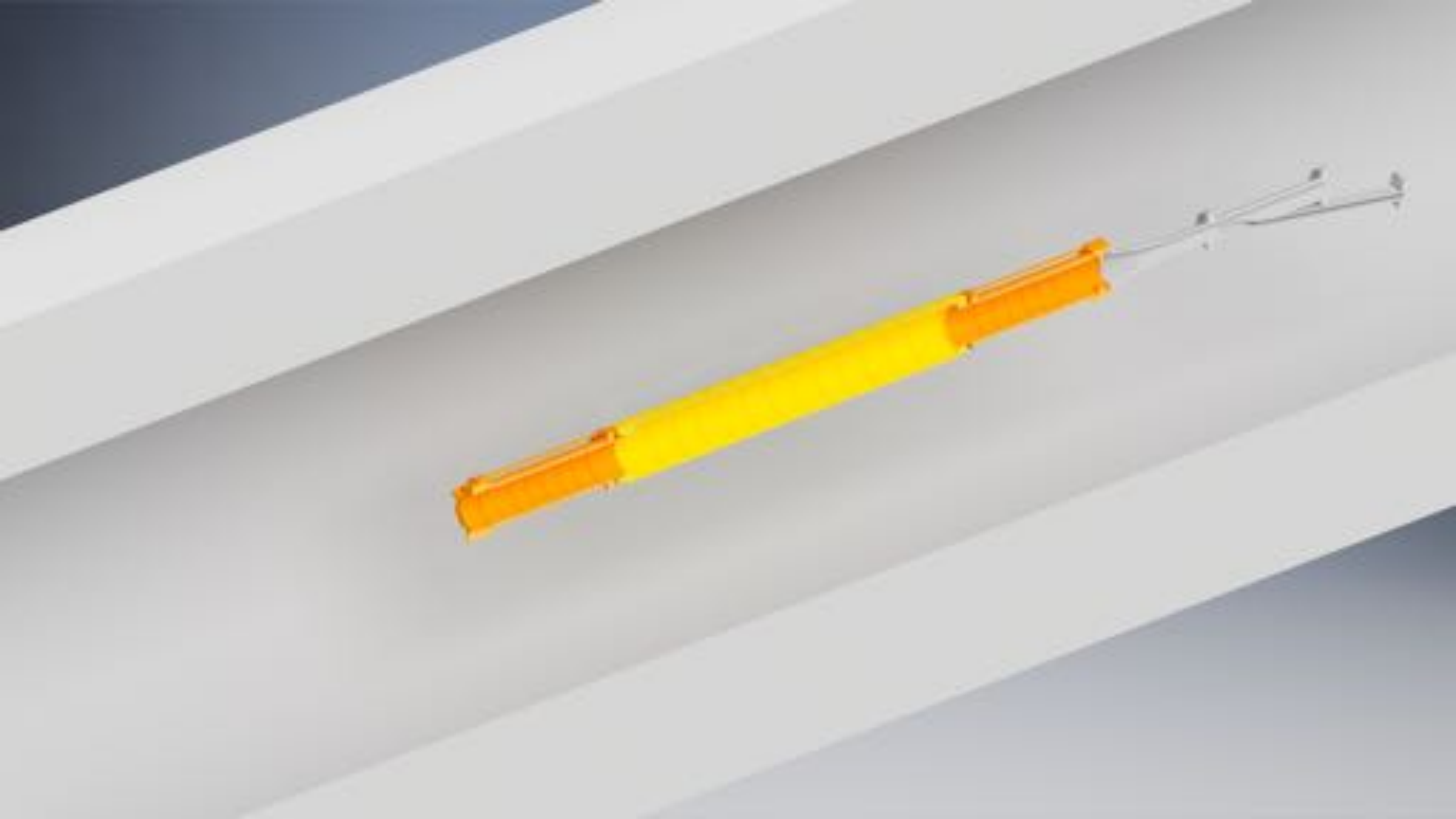
Paper Highlights:

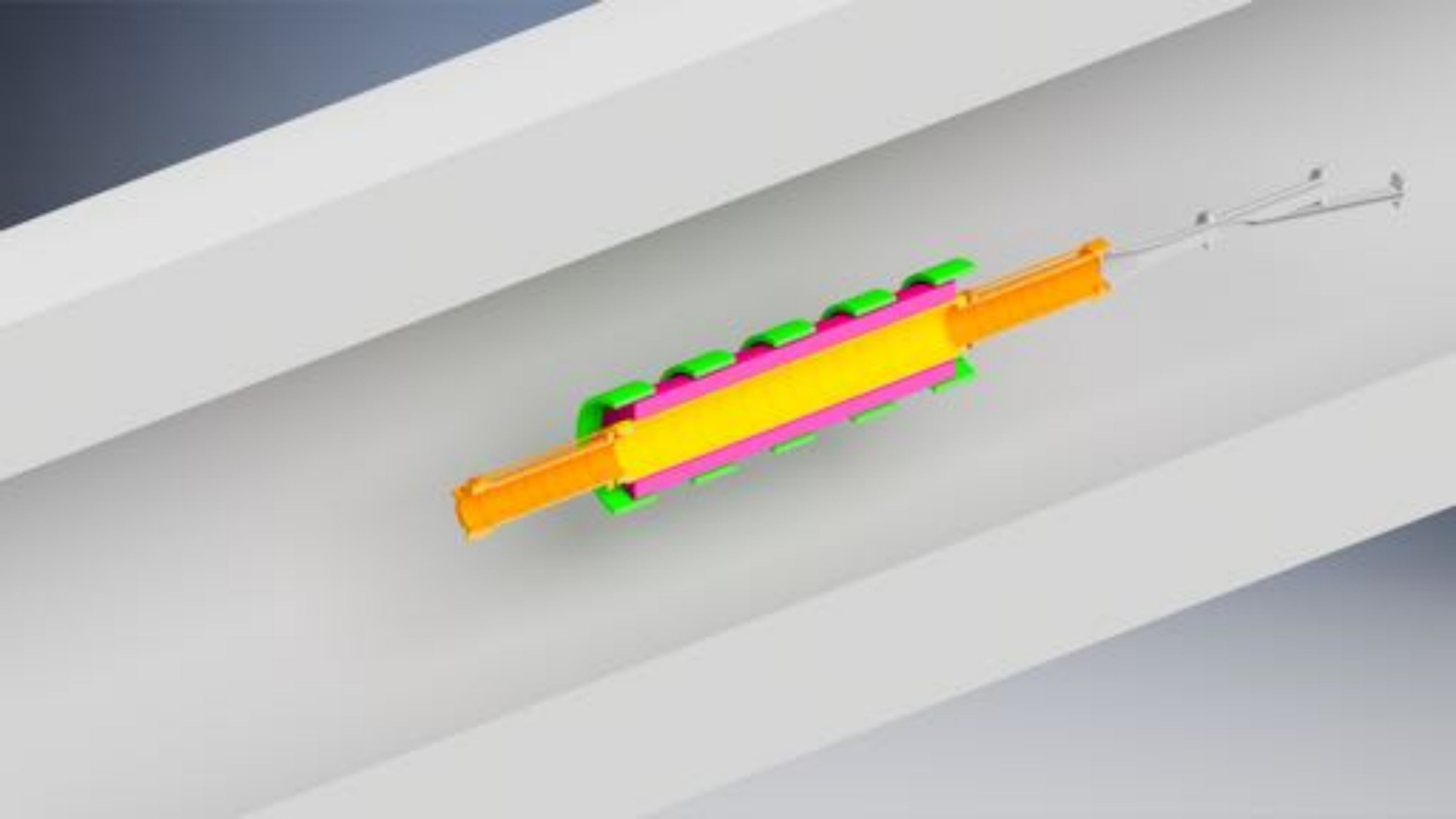
- 2017 Run (only published 2 days ago!)
- First line shape measurement of transition in antihydrogen
- Trapped antihydrogen lifetime >60 hours
- 100 Factor improvement over 2016 measurement

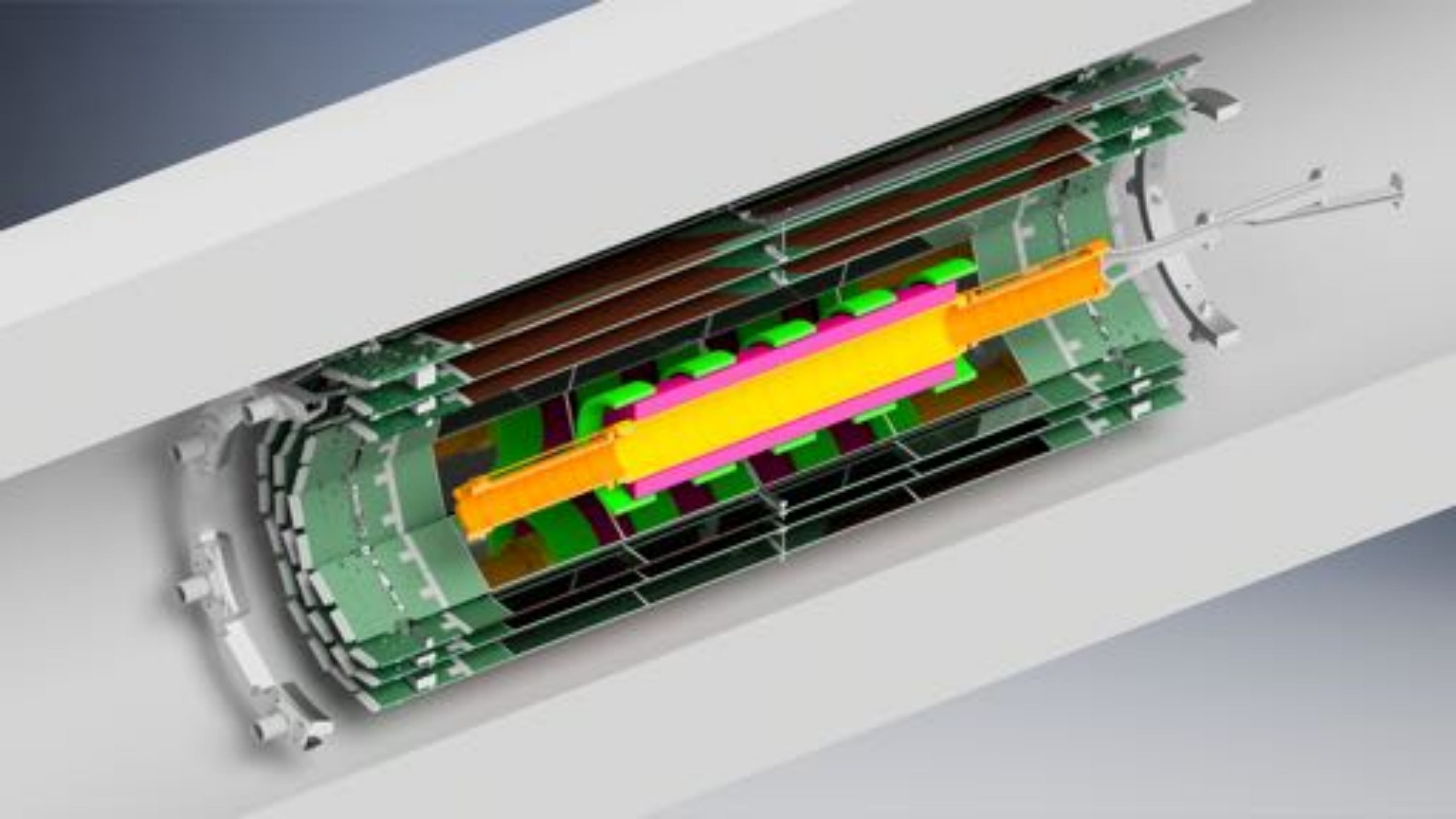


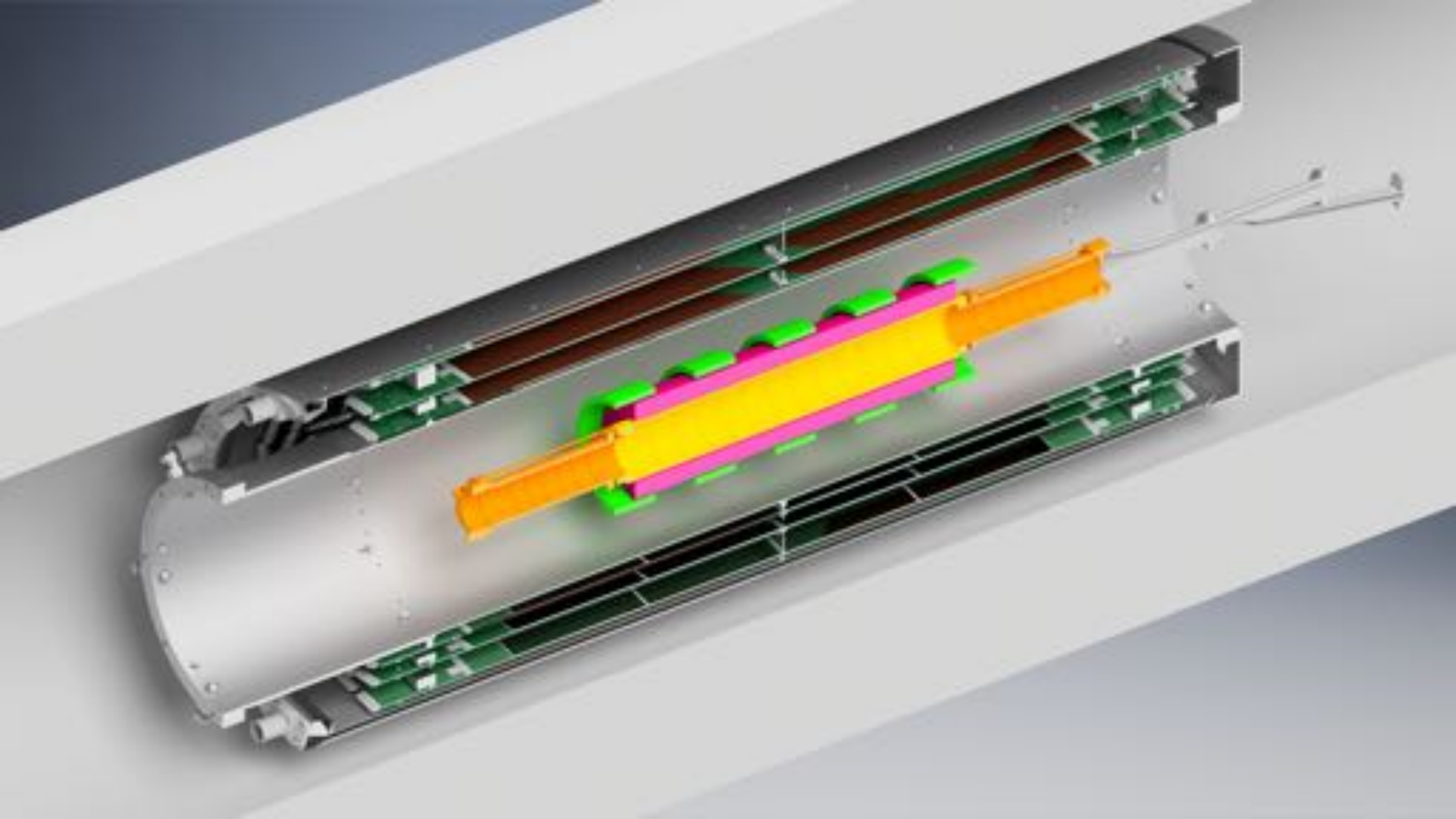
Experiment Overview



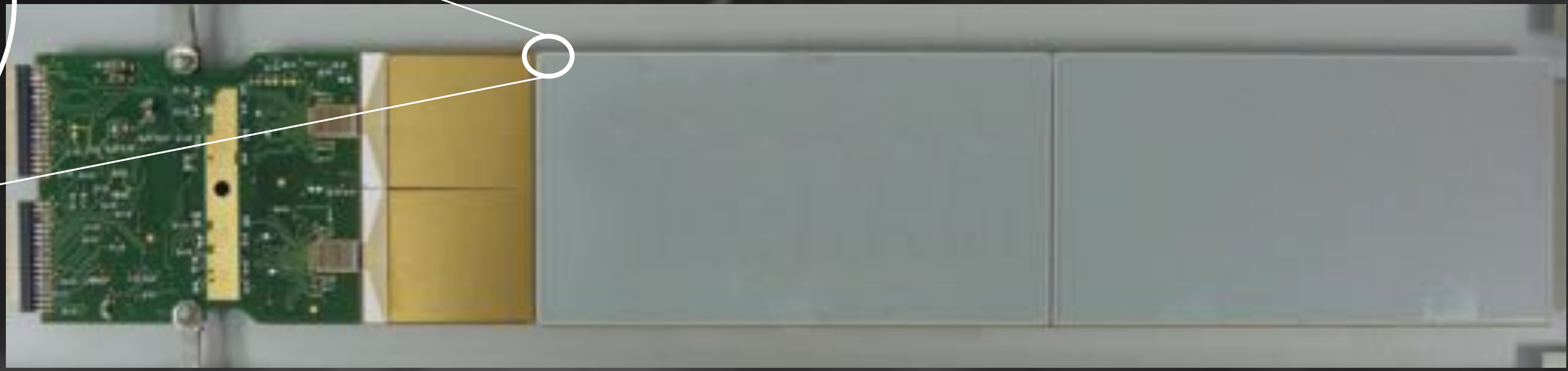




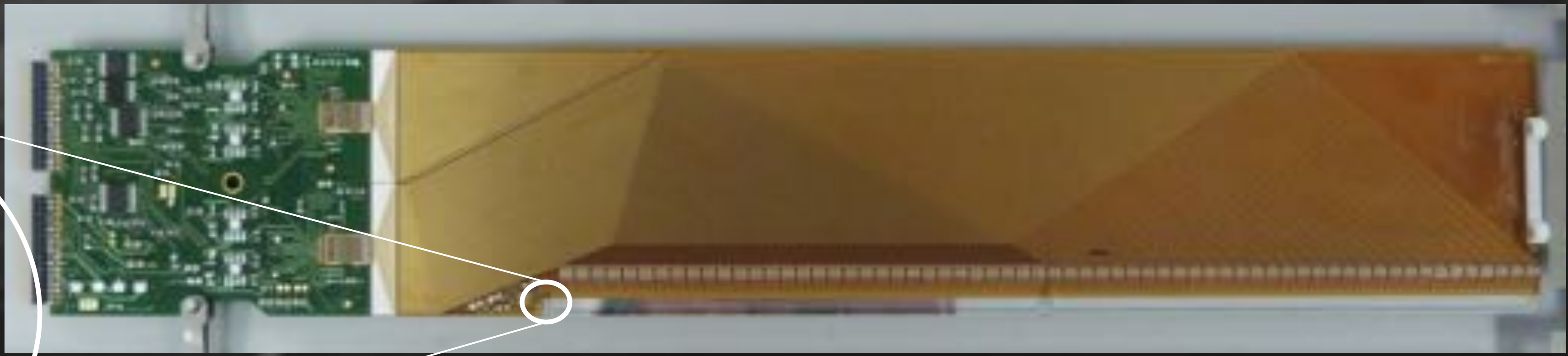


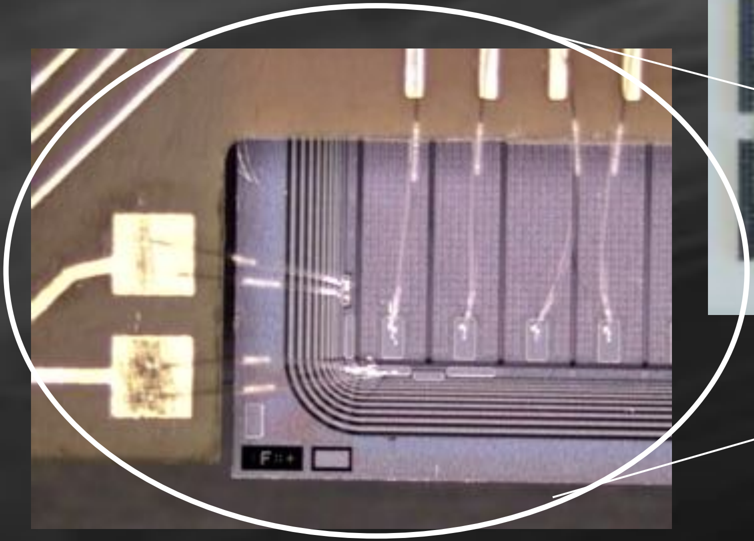


Silicon Hybrid

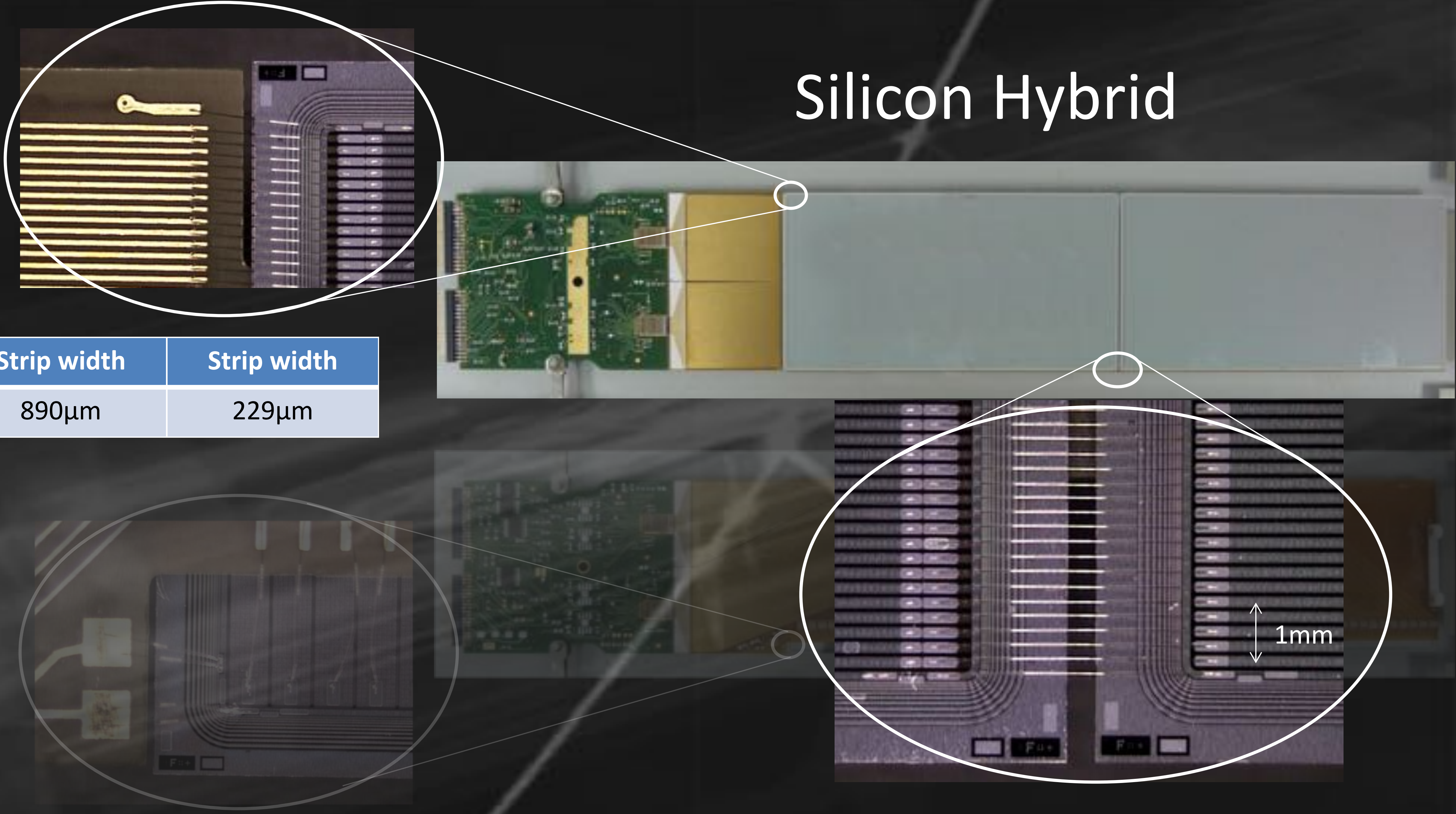


Strip width	Strip width
890µm	229µm





Silicon Hybrid



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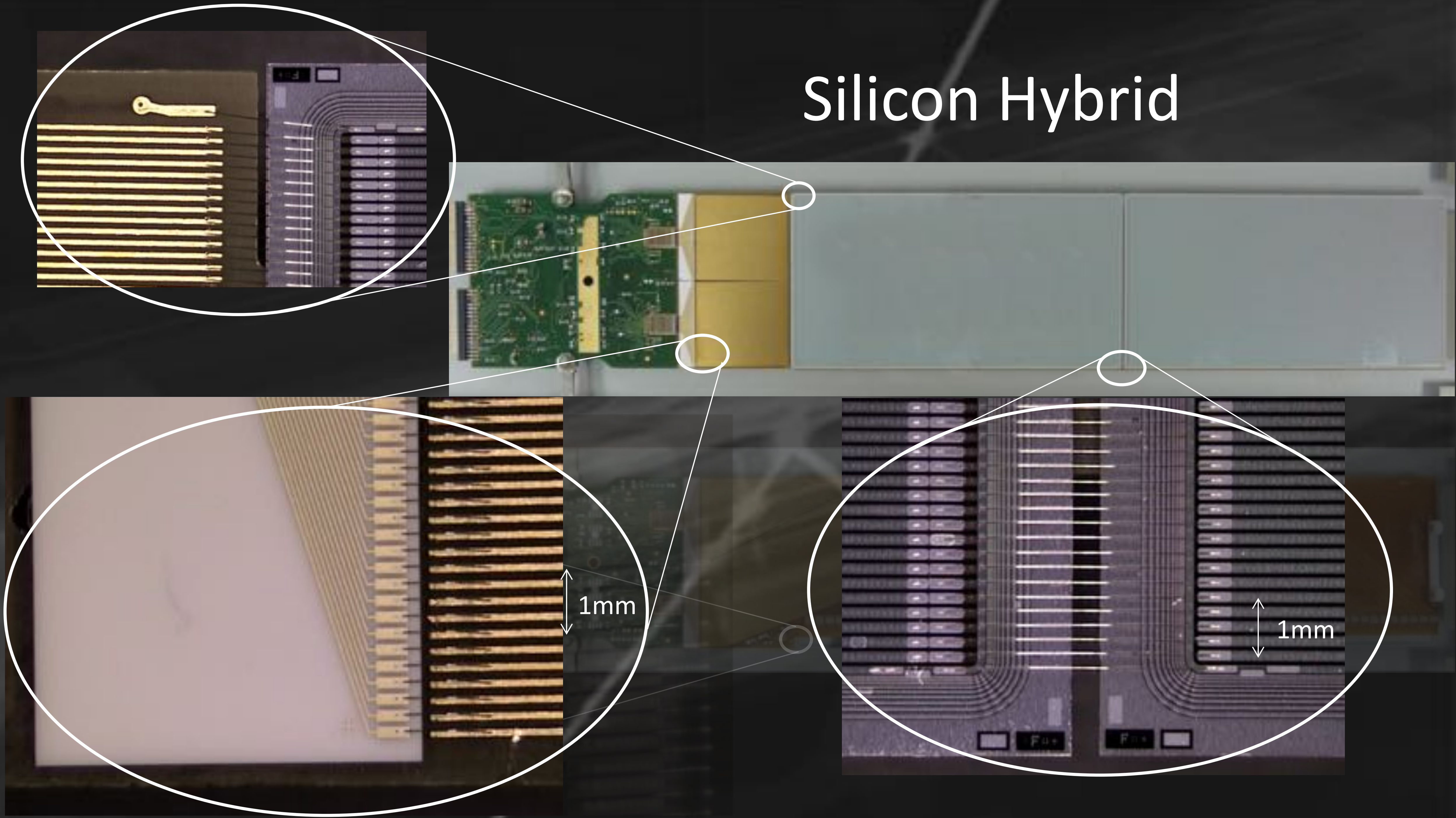
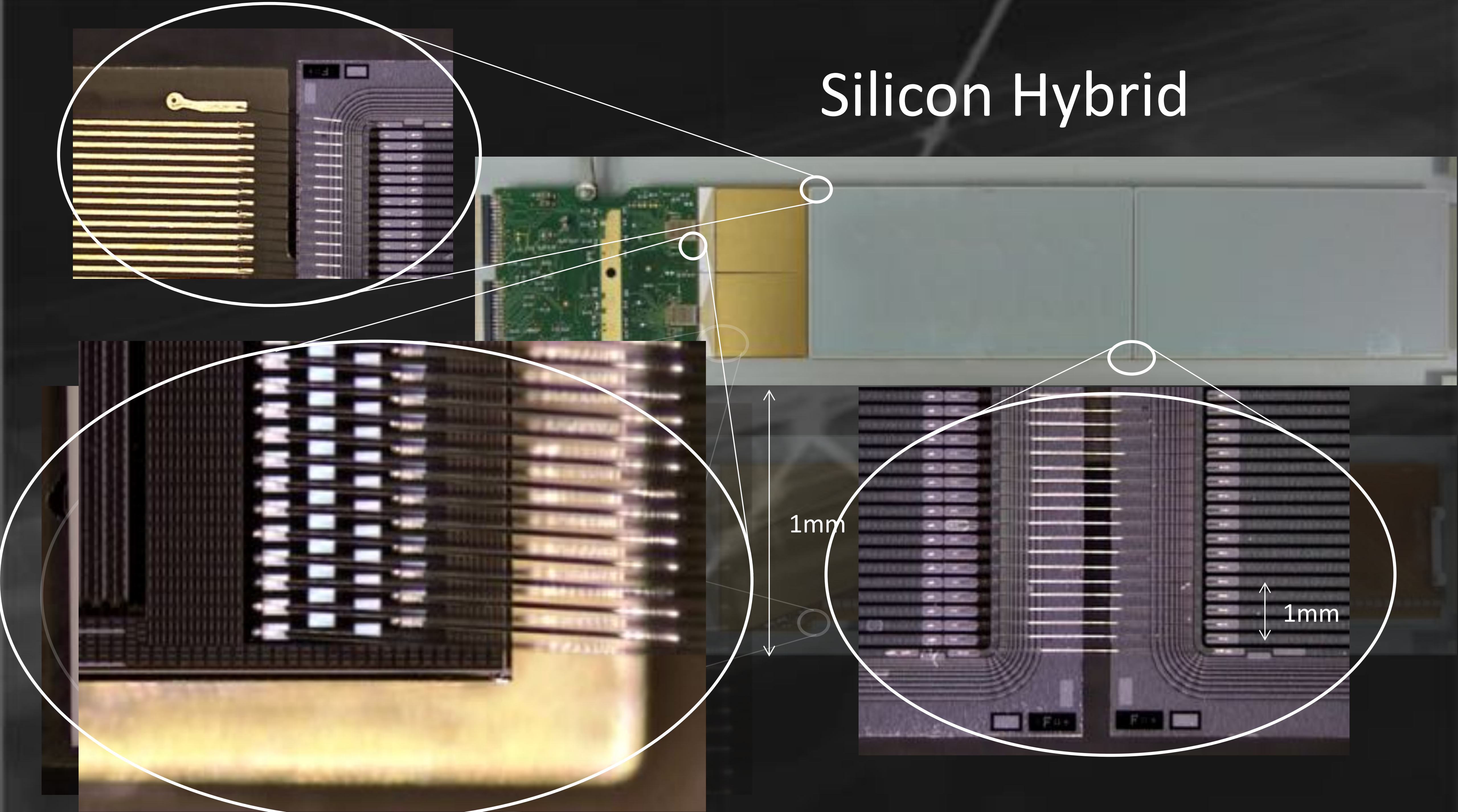
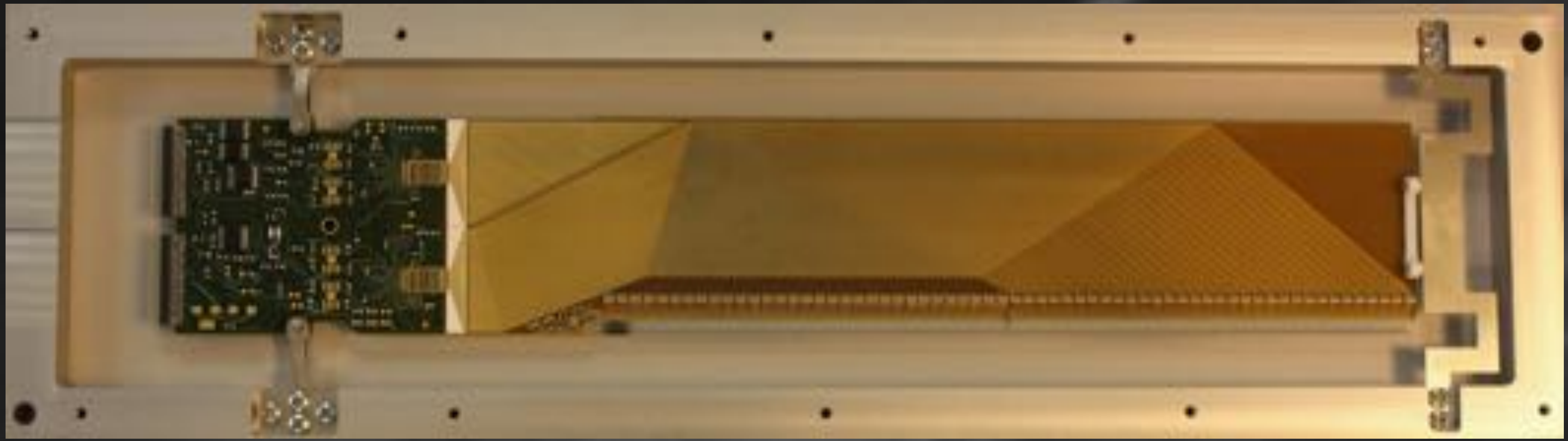
Silicon Hybrid



Silicon Hybrid



ALPHA – hybrids – additional information



- 300μm p on n doubled sided strip detector
- 256x128 strips, pitches 229/890μm
- Sensor size 60x115mm, active 58x112mm
- Module alignment (15 ± 2.5) / (32 ± 2.5)μm

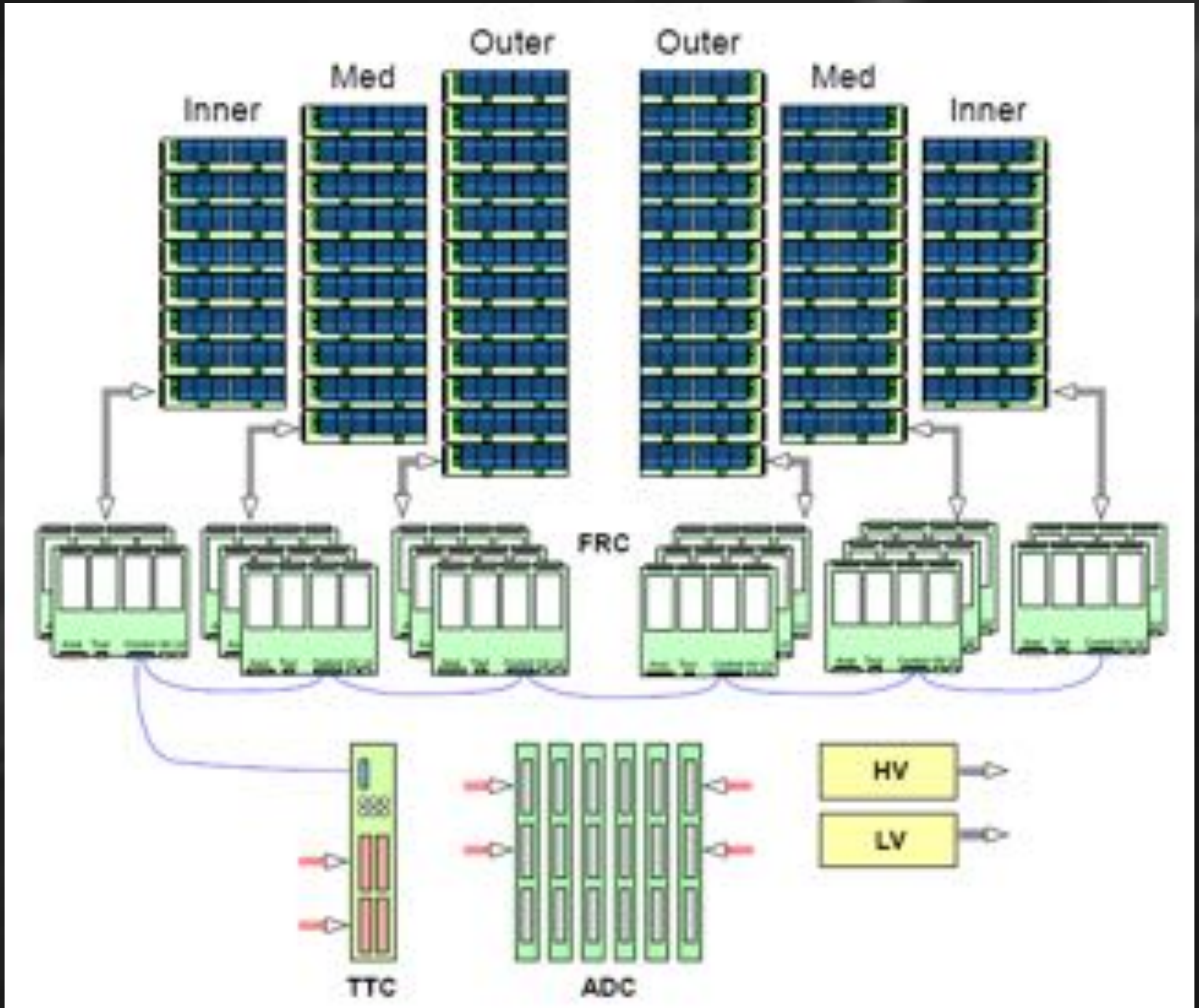
- 1600μm PCB, Nelco 4000 material
- Copper wiring thorough the PCB on the n-side
- N –side externally AC coupled
- 1144 ultrasonically bonded wires per hybrid

- Sensor size 60x115mm, active 58x112mm

- Four Va1Ta 128 channel ASICs
- Fast trigger shaper (75ns) / slow analogue shaper (typically 1μs)
- Programmable shaping parameters
- Dynamic range ± 10MIPs

JINST 7 C01051 (2011)

Readout Diagram



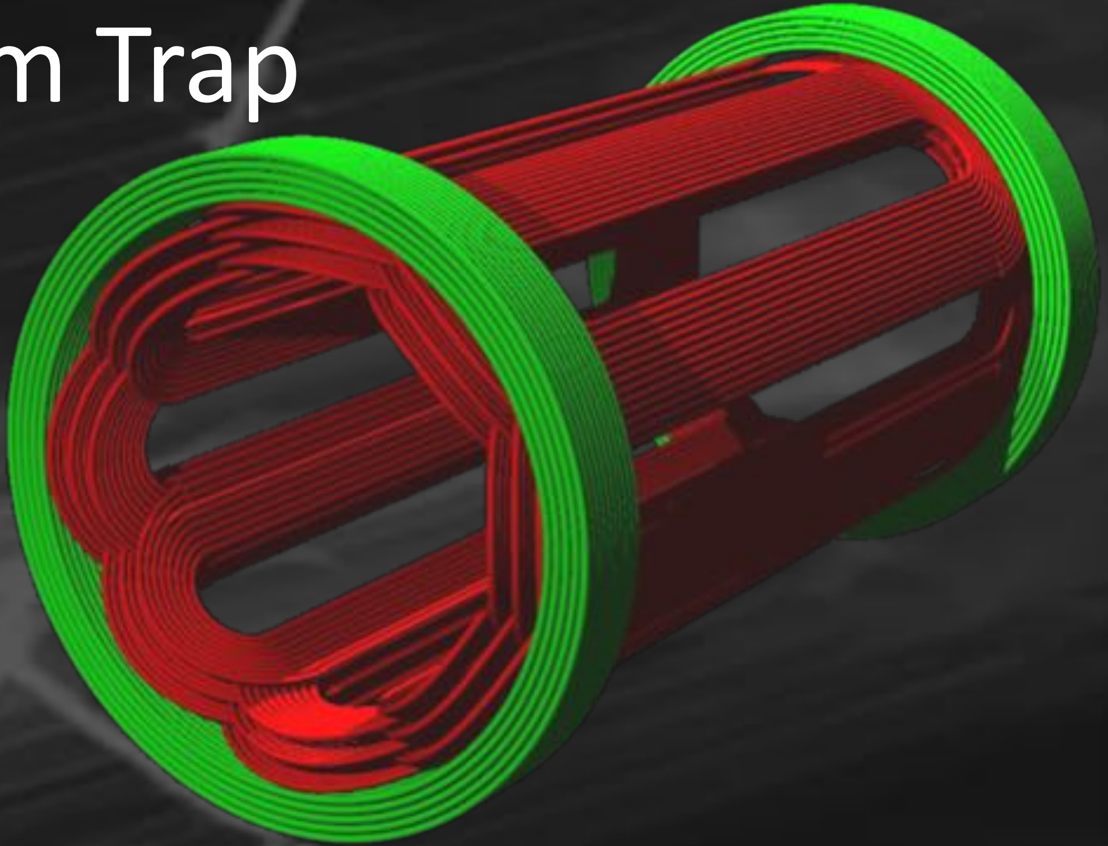
Detector Performance Range

	ALPHA I	ALPHA II
Number of Hybrid Modules	60	72
Number of Layers	3	3
Length (mm)	600	600
Inner Radii (mm)	75	89
		94.5
Middle Radii (mm)	95.5	108
		113.5
Outer Radii (mm)	109	127
	114	132.5
Solid angle coverage	72%	77%
Reconstruction resolution	~600 µm (Experimental)	~850 µm (Simulation)
Readout rate	470Hz	600Hz
Air cooled	1 Vortex Tube	2 Vortex Tubes

NIM A,**735** 319–340 (2014). Nucl. Inst. Method in Phys. Res. A 732 134-136 (2013).

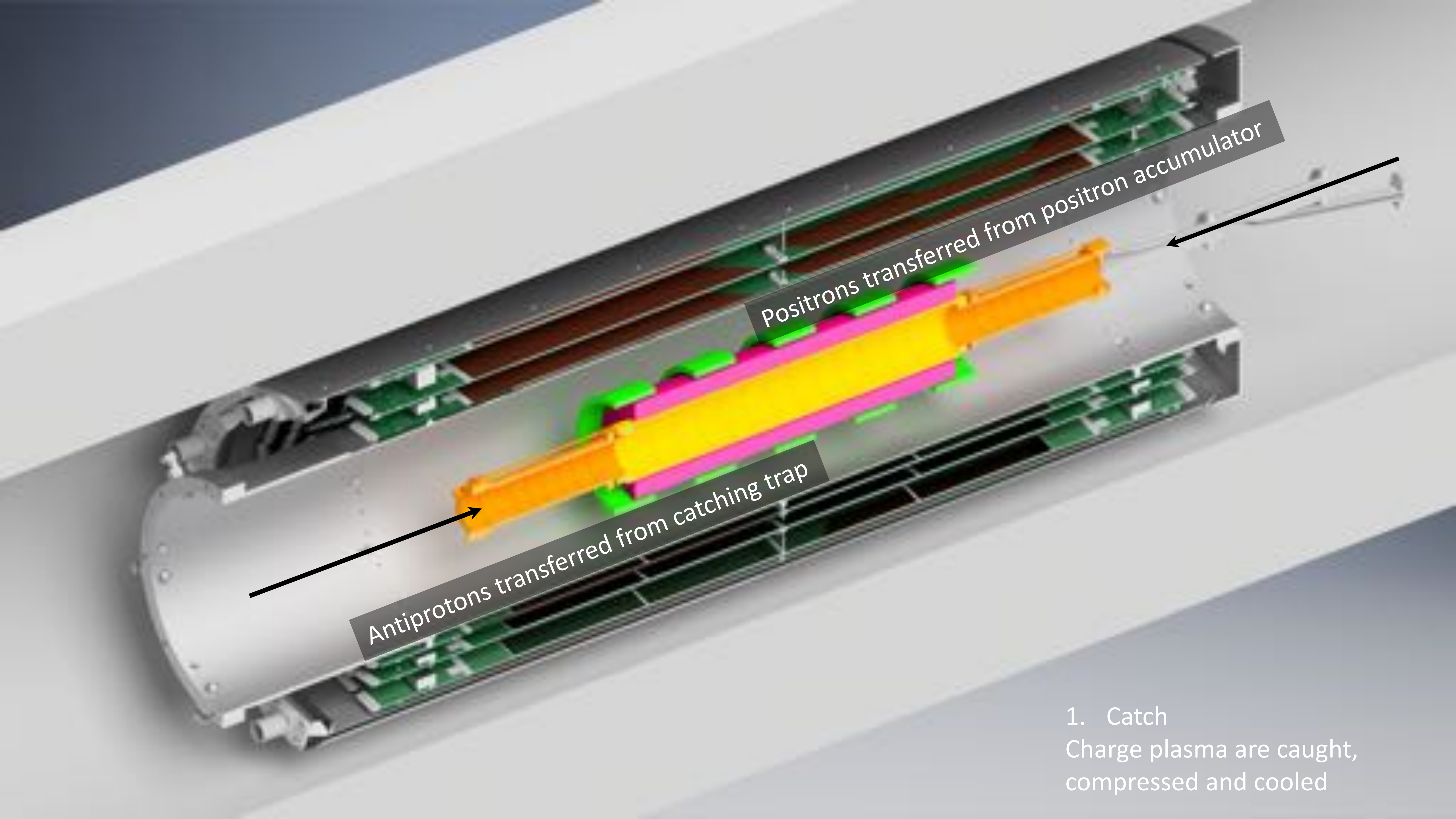
Neutral Atom Trap

- Ioffe-Pritchard trap
- Confining depth of 0.5K for Antihydrogen
- Magnetic minima traps half of the spin states of antihydrogen



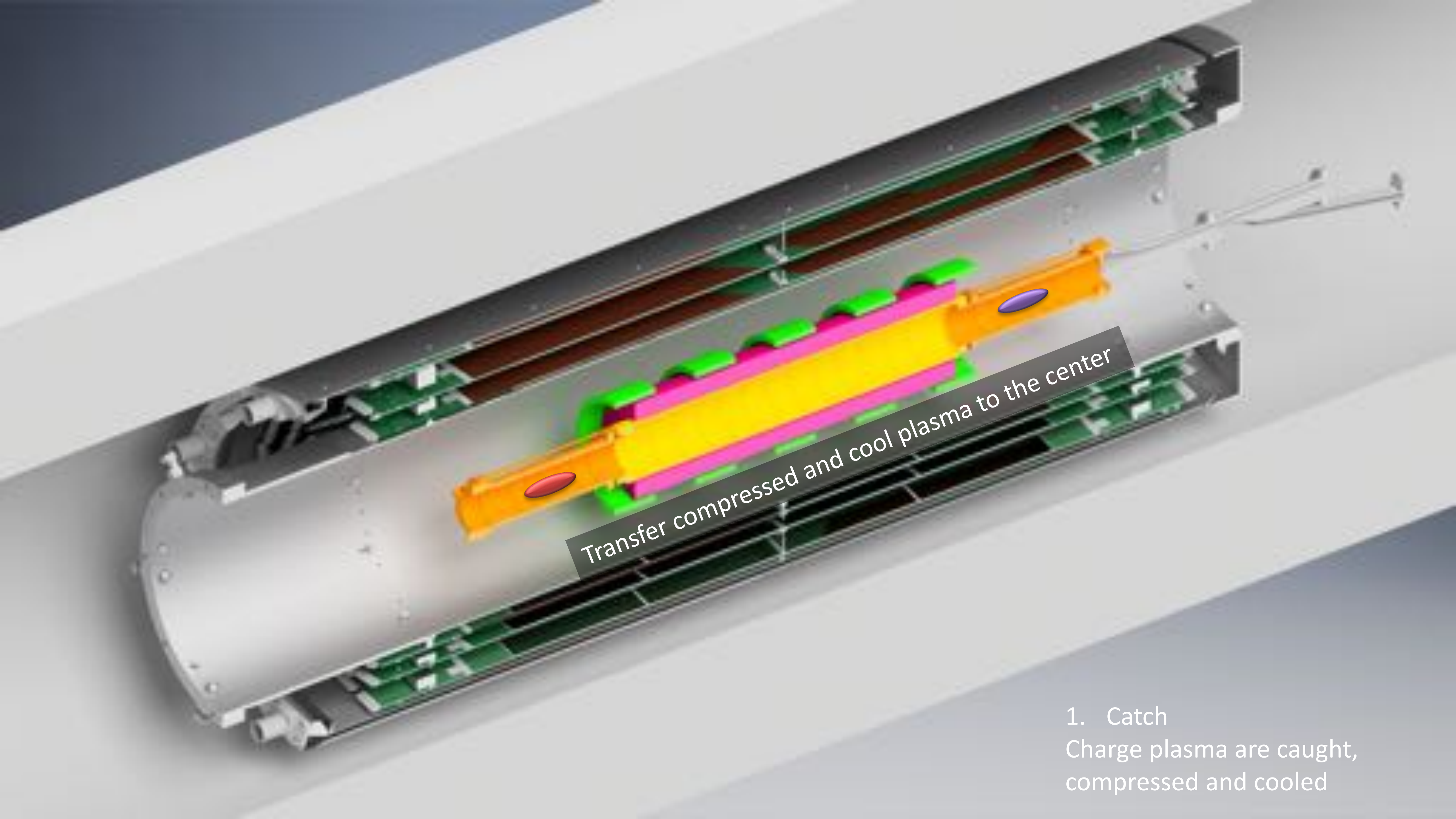
Experimental Procedure

1. Catch, compress and cool antiprotons and positrons
2. Mix
3. Perform Experiment – Counts may ‘appear’
4. Turn off trap – Antihydrogen lost would have ‘disappeared’



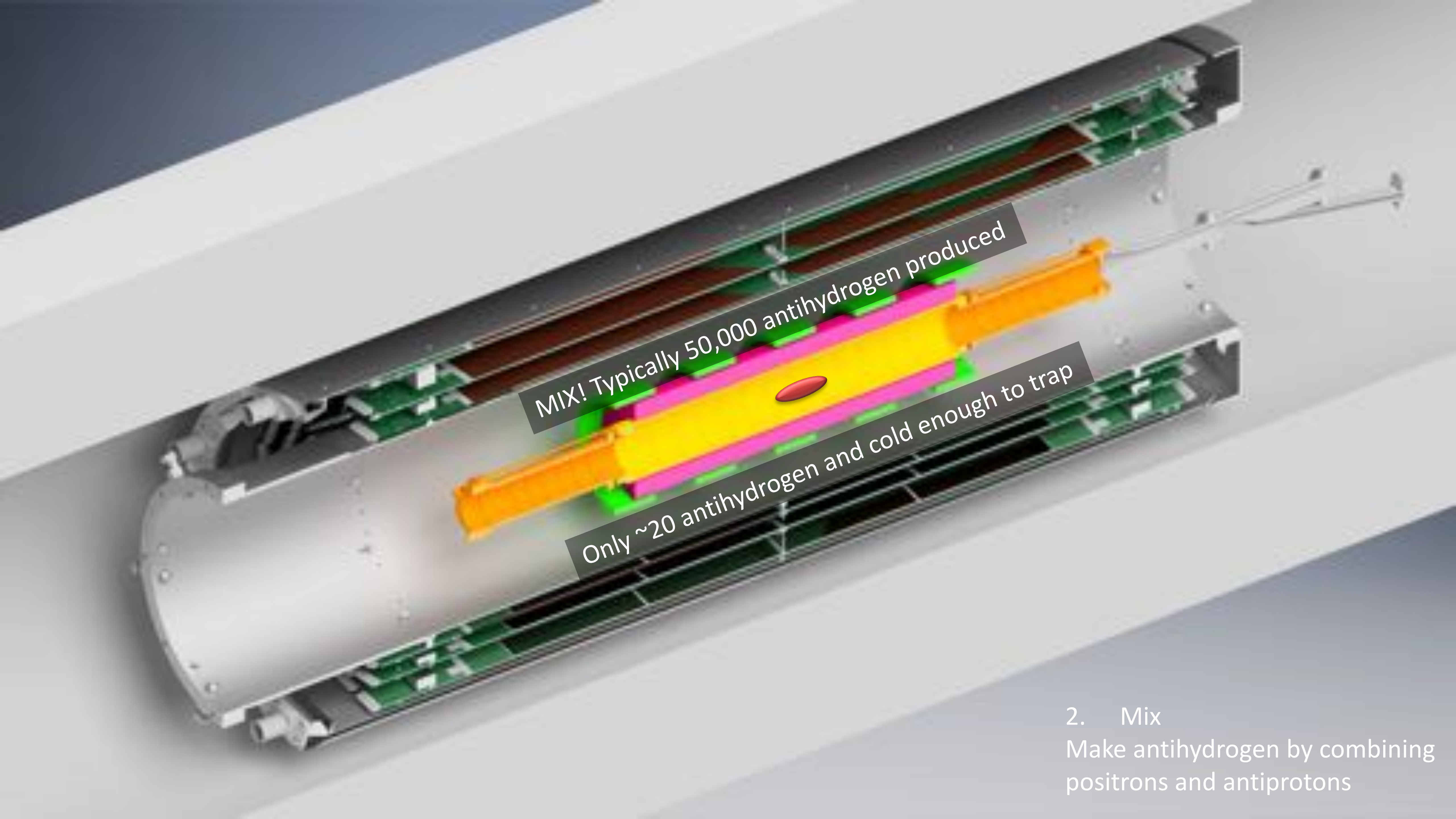
1. Catch

Charge plasma are caught, compressed and cooled



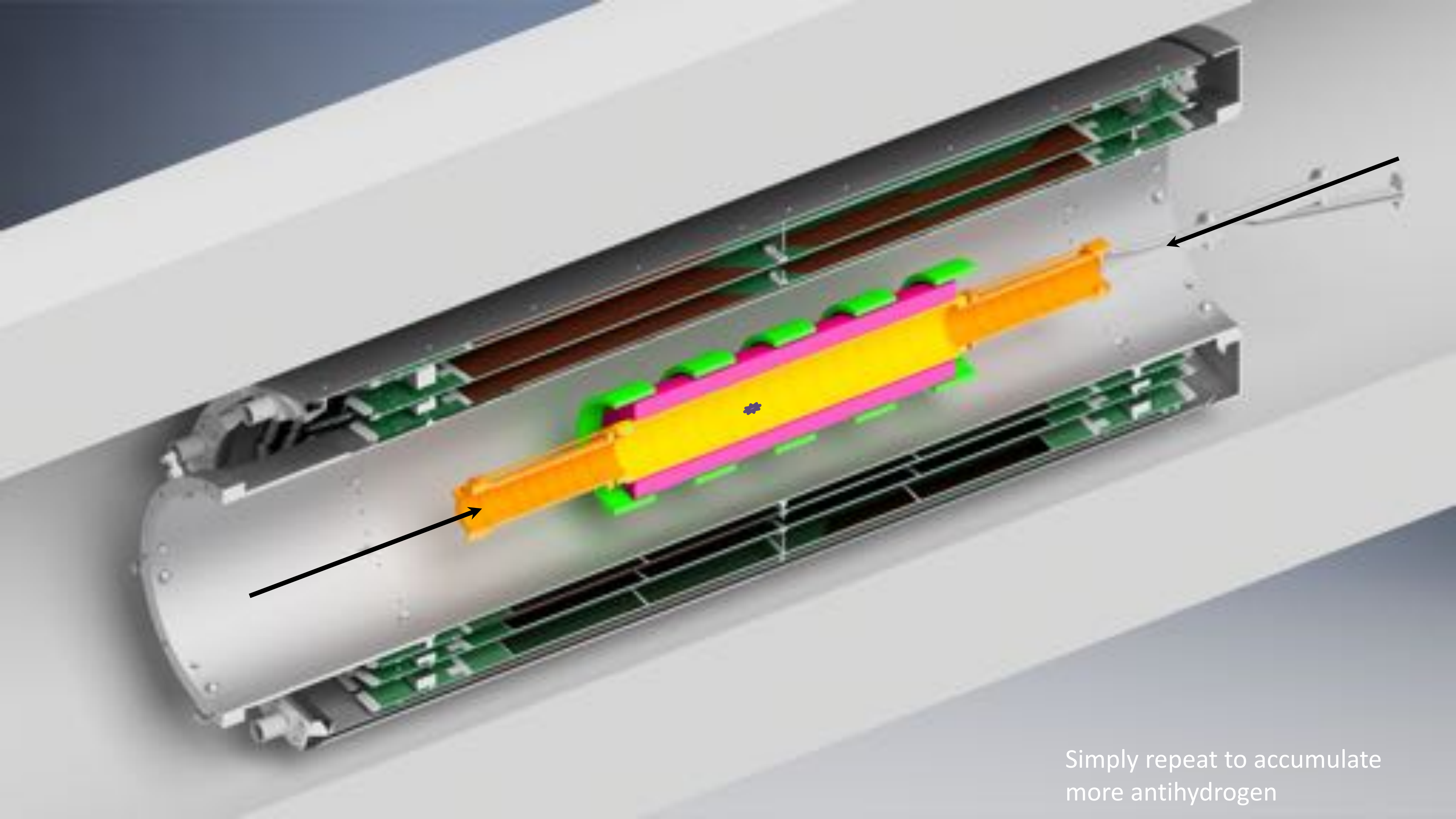
1. Catch

Charge plasma are caught, compressed and cooled

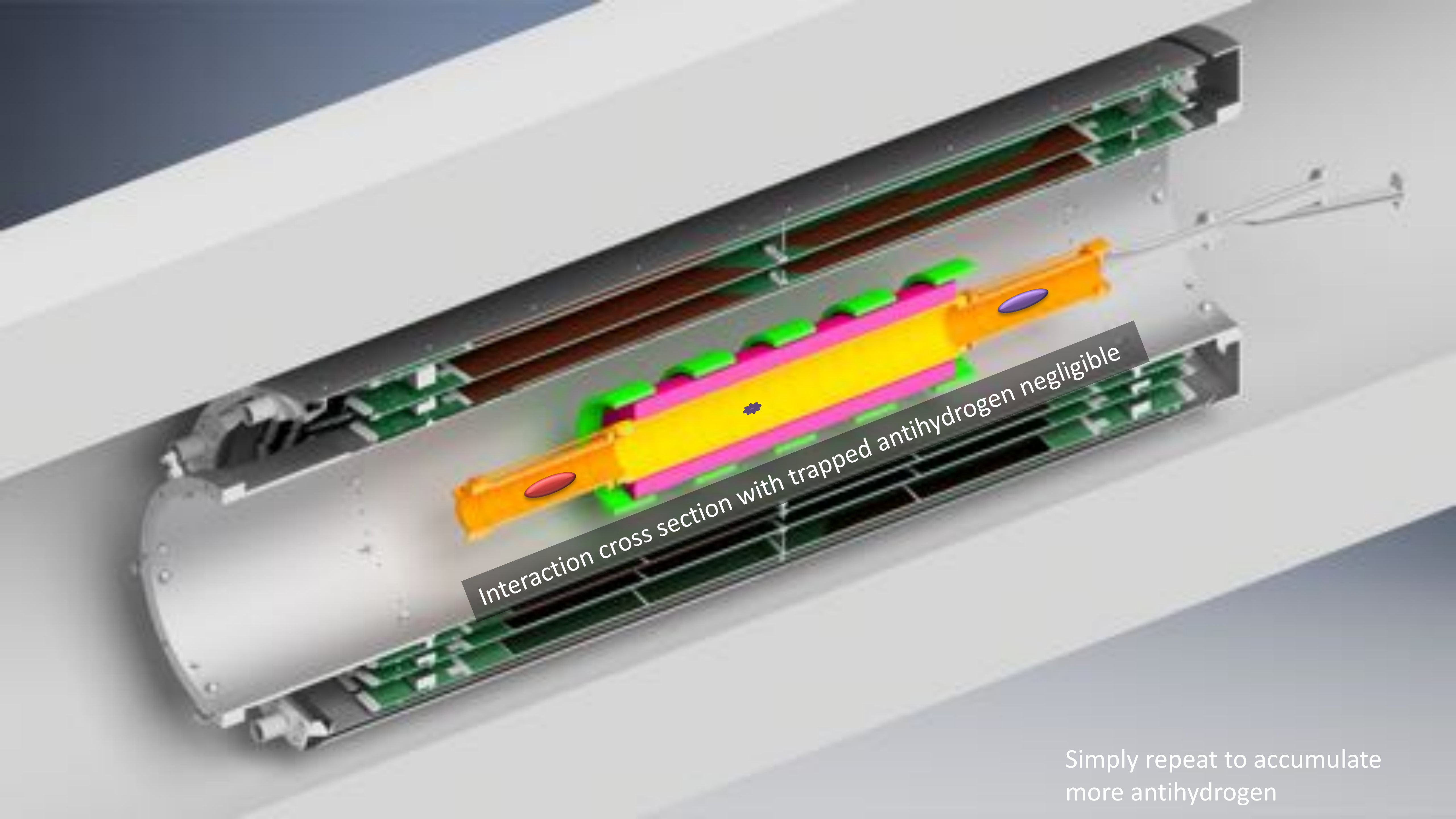


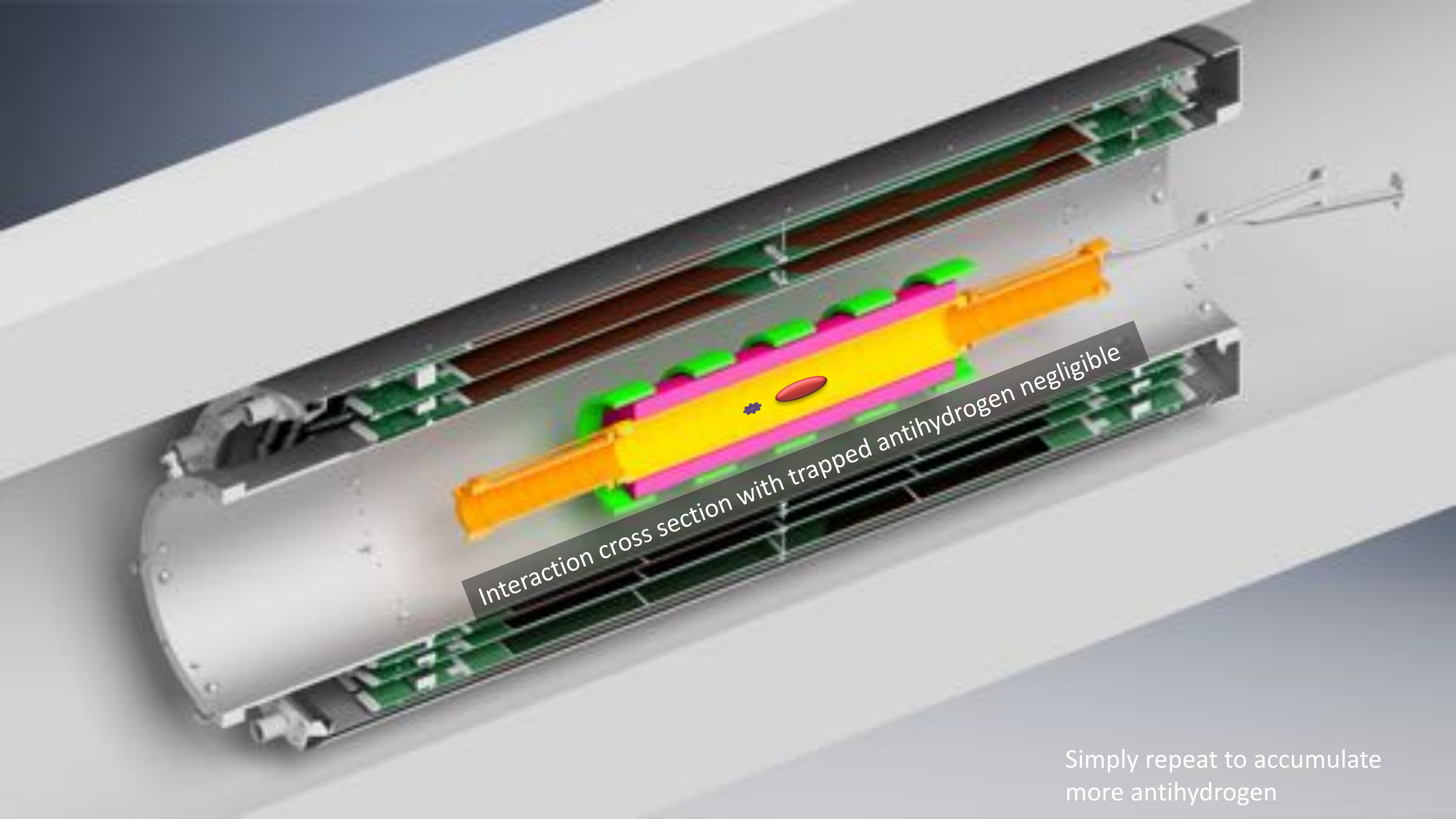
2. Mix

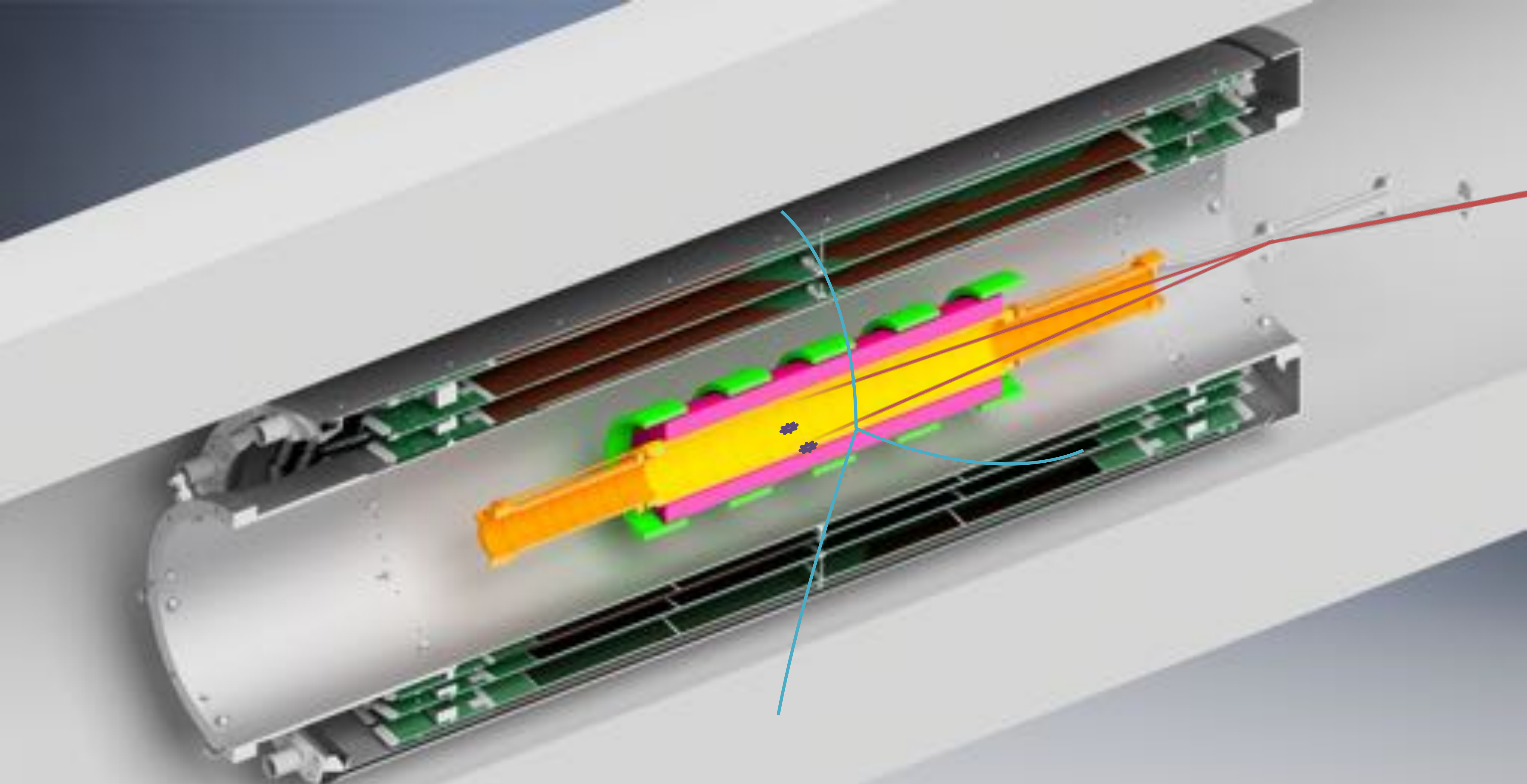
Make antihydrogen by combining positrons and antiprotons



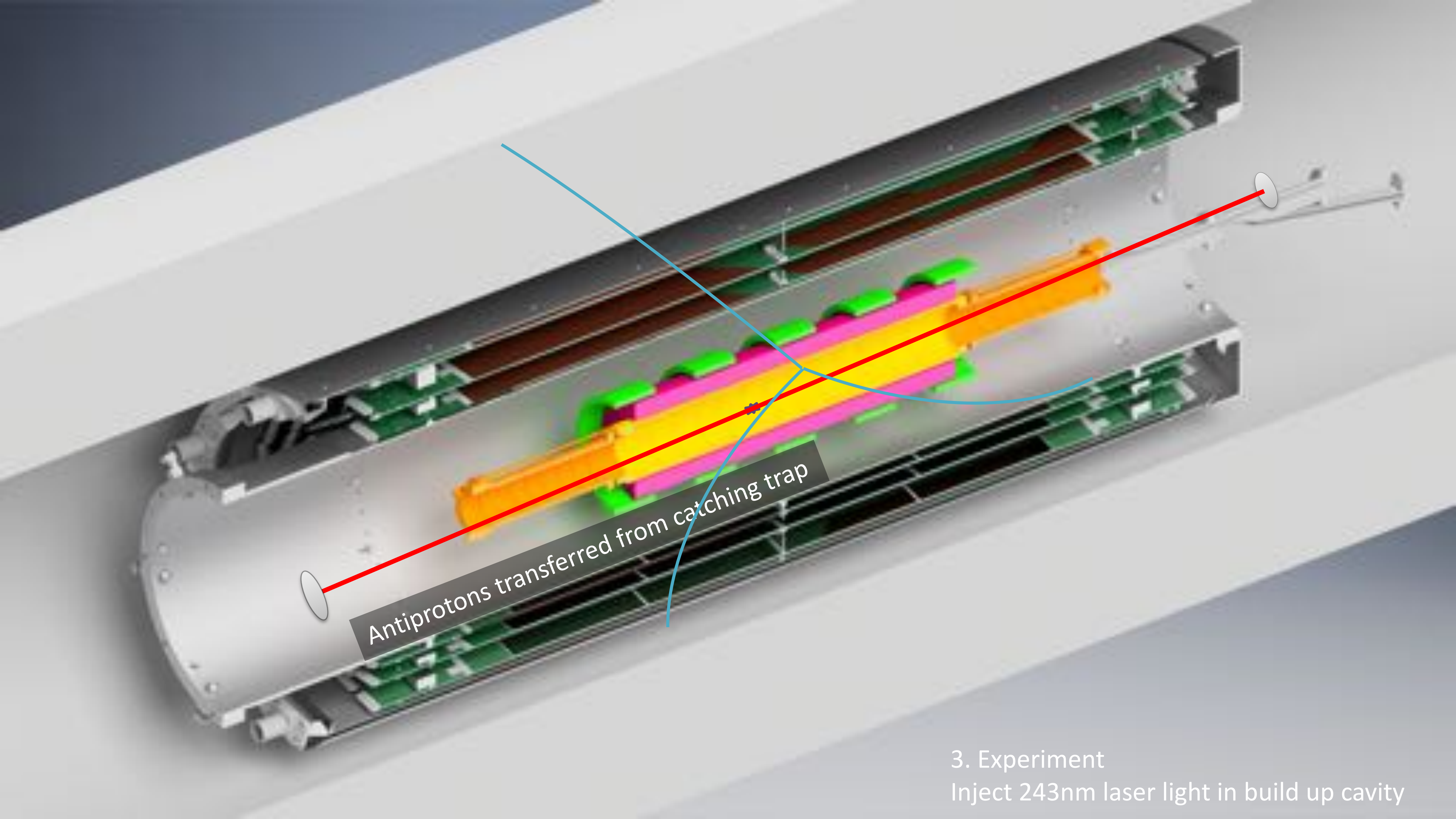
Simply repeat to accumulate more antihydrogen


Interaction cross section with trapped antihydrogen negligible
Simply repeat to accumulate more antihydrogen


Interaction cross section with trapped antihydrogen negligible
Simply repeat to accumulate more antihydrogen



3. Experiment
Inject microwaves with dedicated feed through



3. Experiment
Inject 243nm laser light in build up cavity

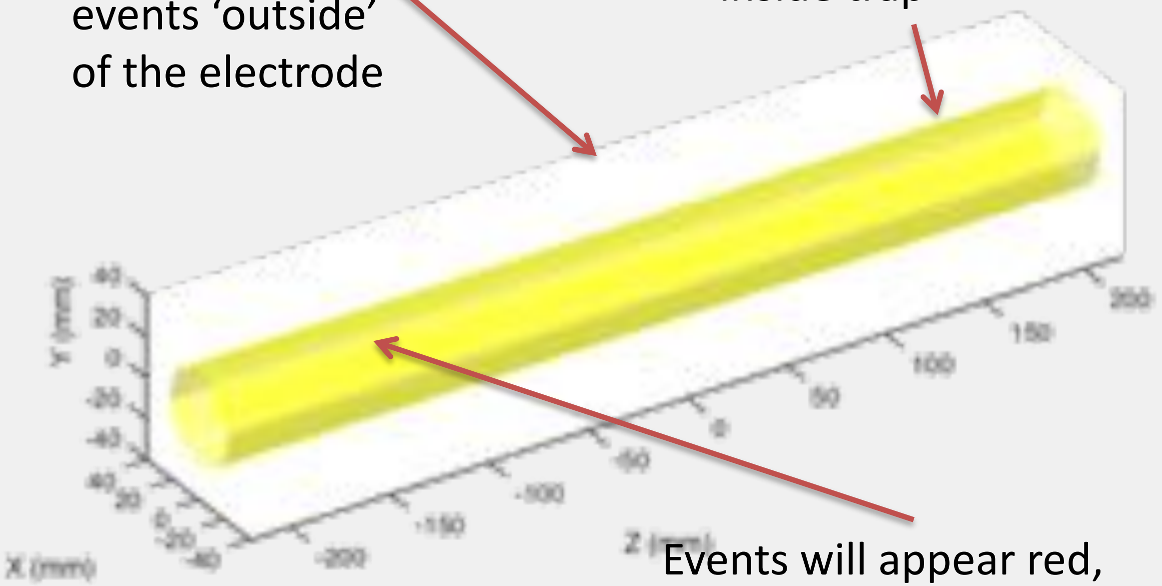
'live' view

Accumulative projection view

T: 0.00s Detected Antihydrogen: 0

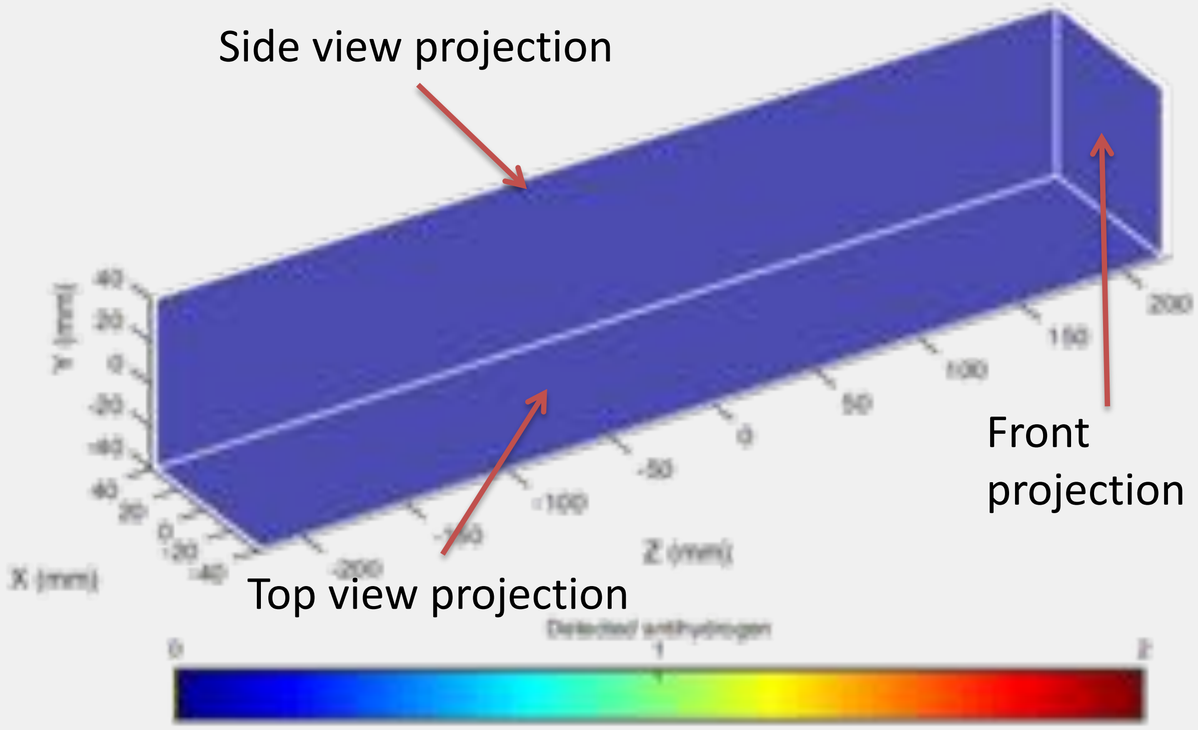
Limited resolution will have some events 'outside' of the electrode

Gold electrodes inside trap



Events will appear red, turn blue then fade

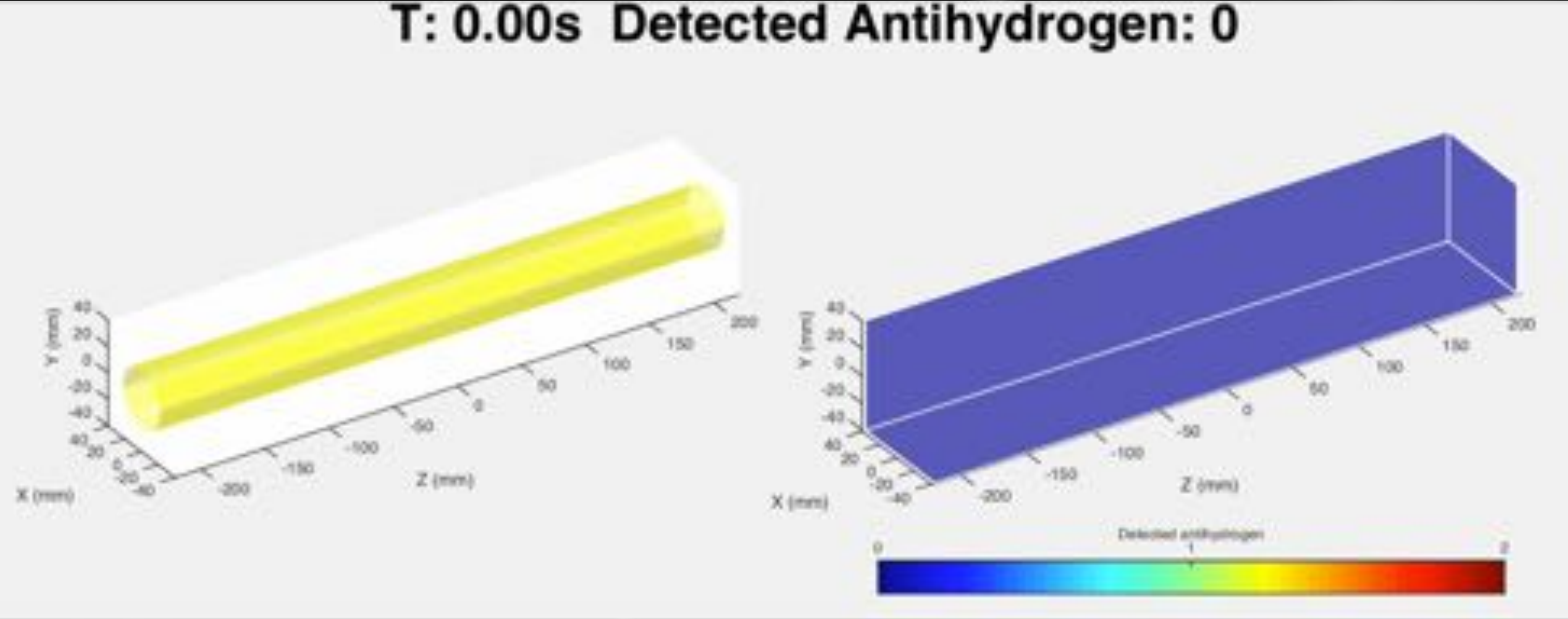
Side view projection



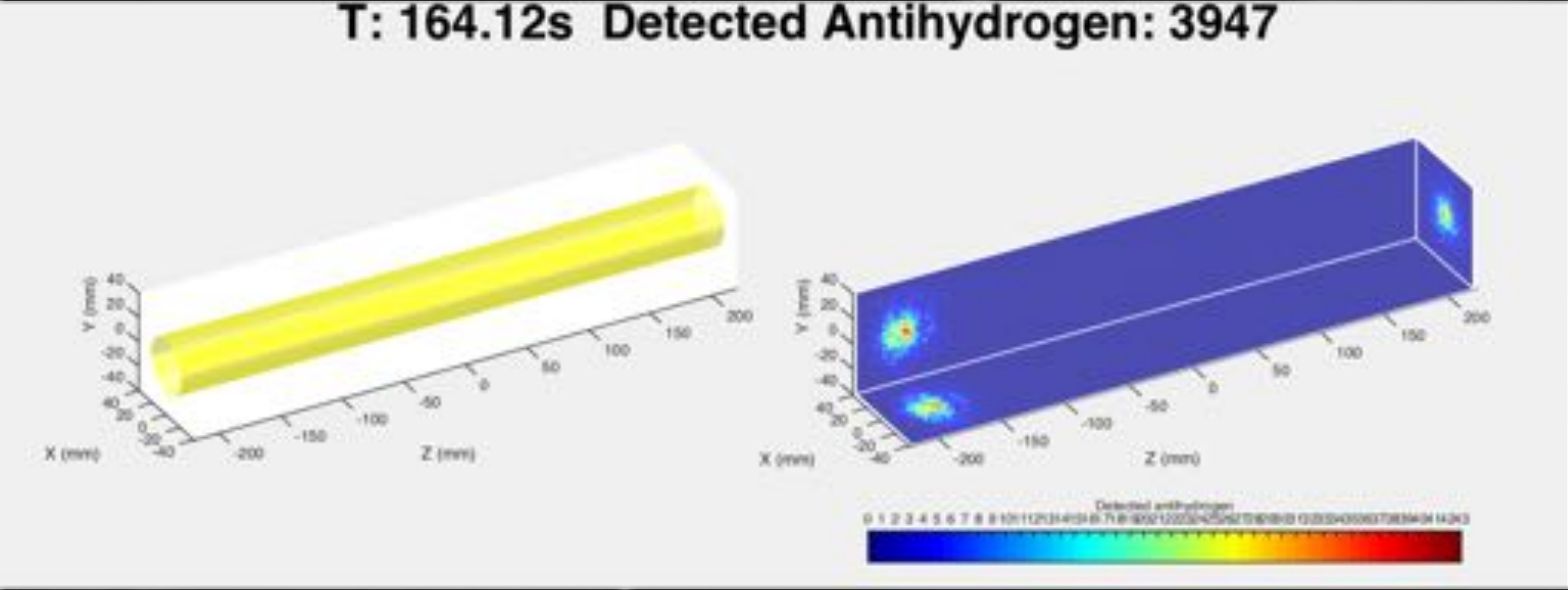
Front projection

Top view projection

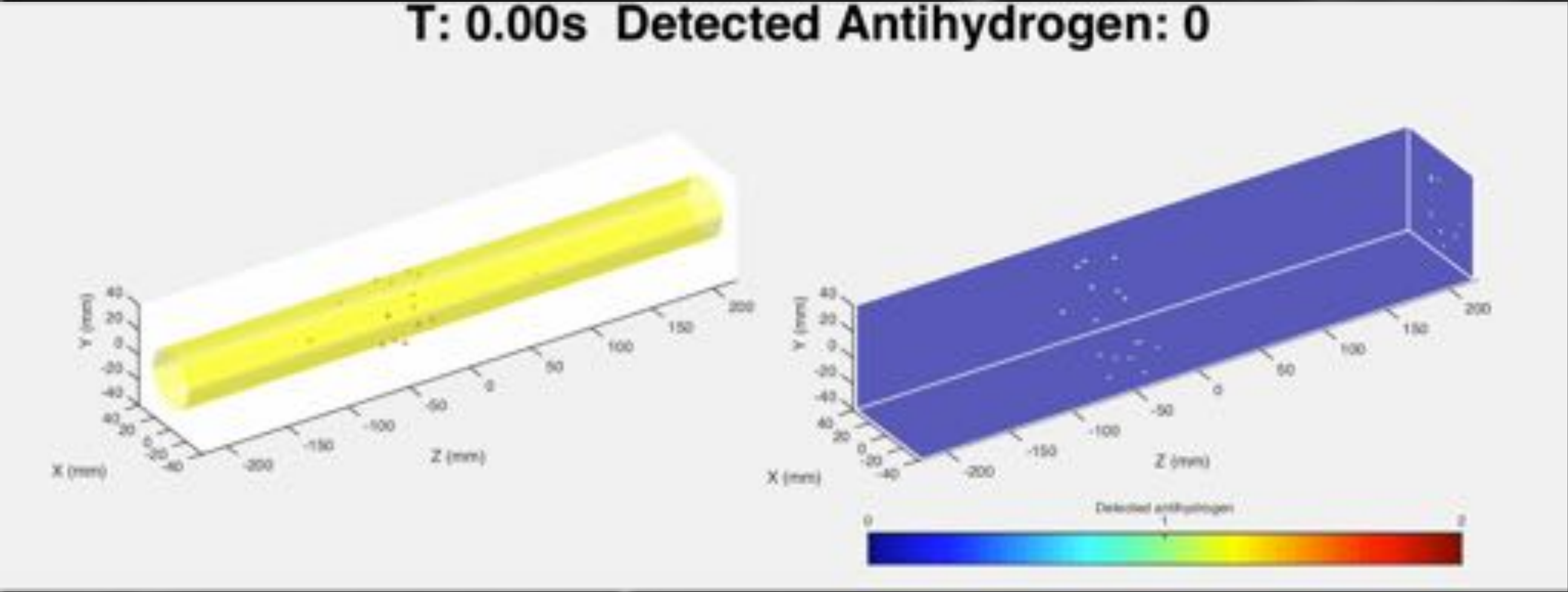
1. Catch, compress and cool



1. Catch, compress and cool



2. Mix positrons and antiprotons



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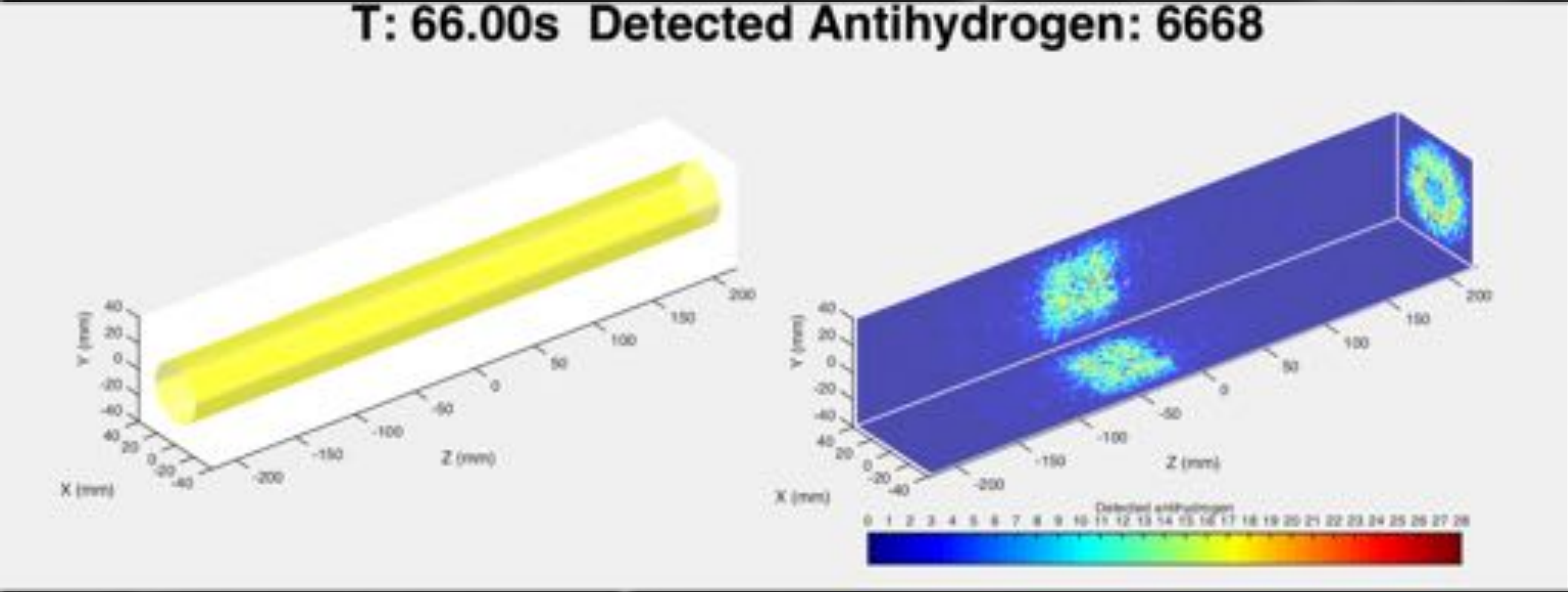
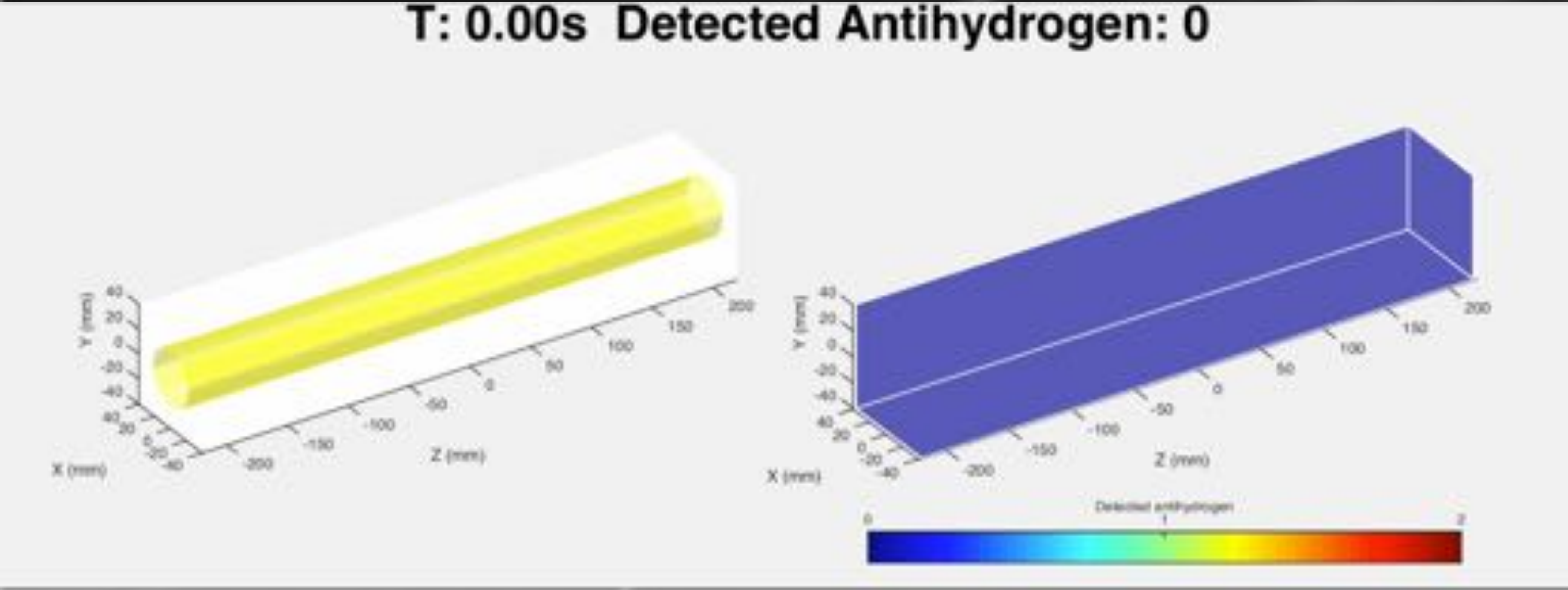


3. Run experiment with antihydrogen

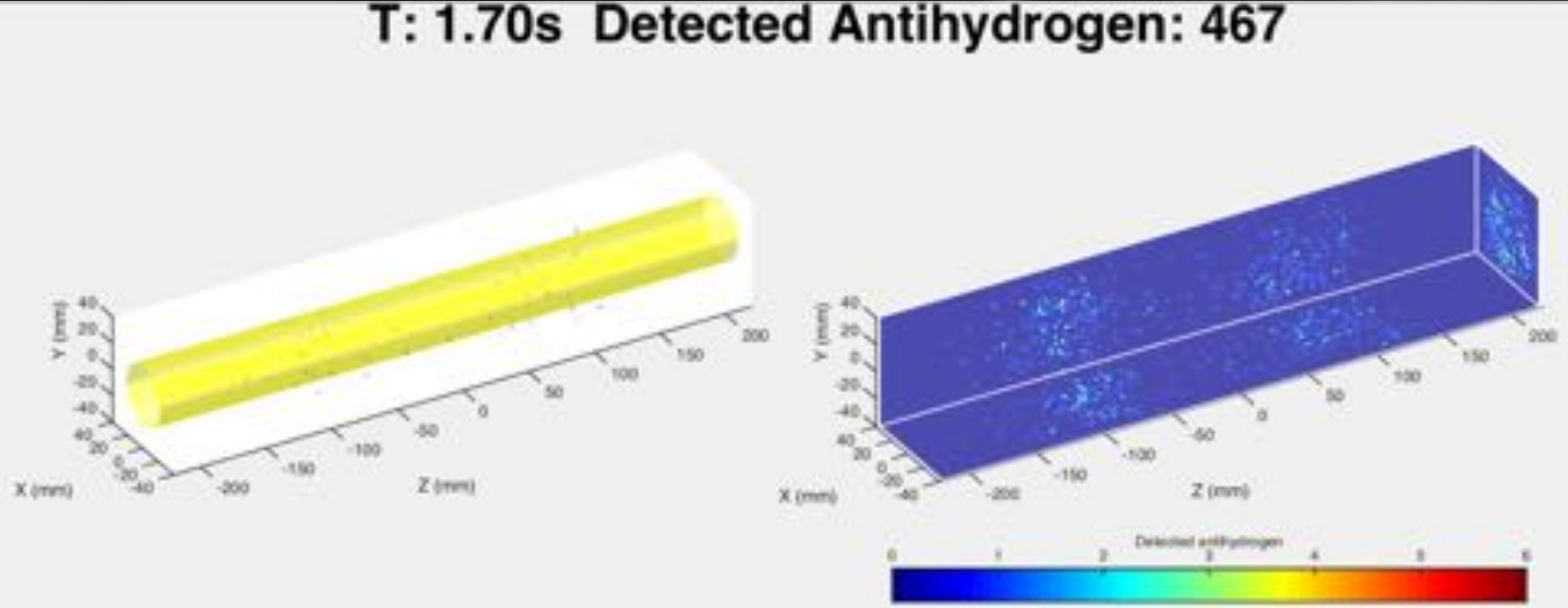
This can include and combination of:

- Injecting microwaves
- Injecting laser light
- Manipulating electric field
- Reconfiguring magnetic field
- Waiting

4. Turn off the atom trap

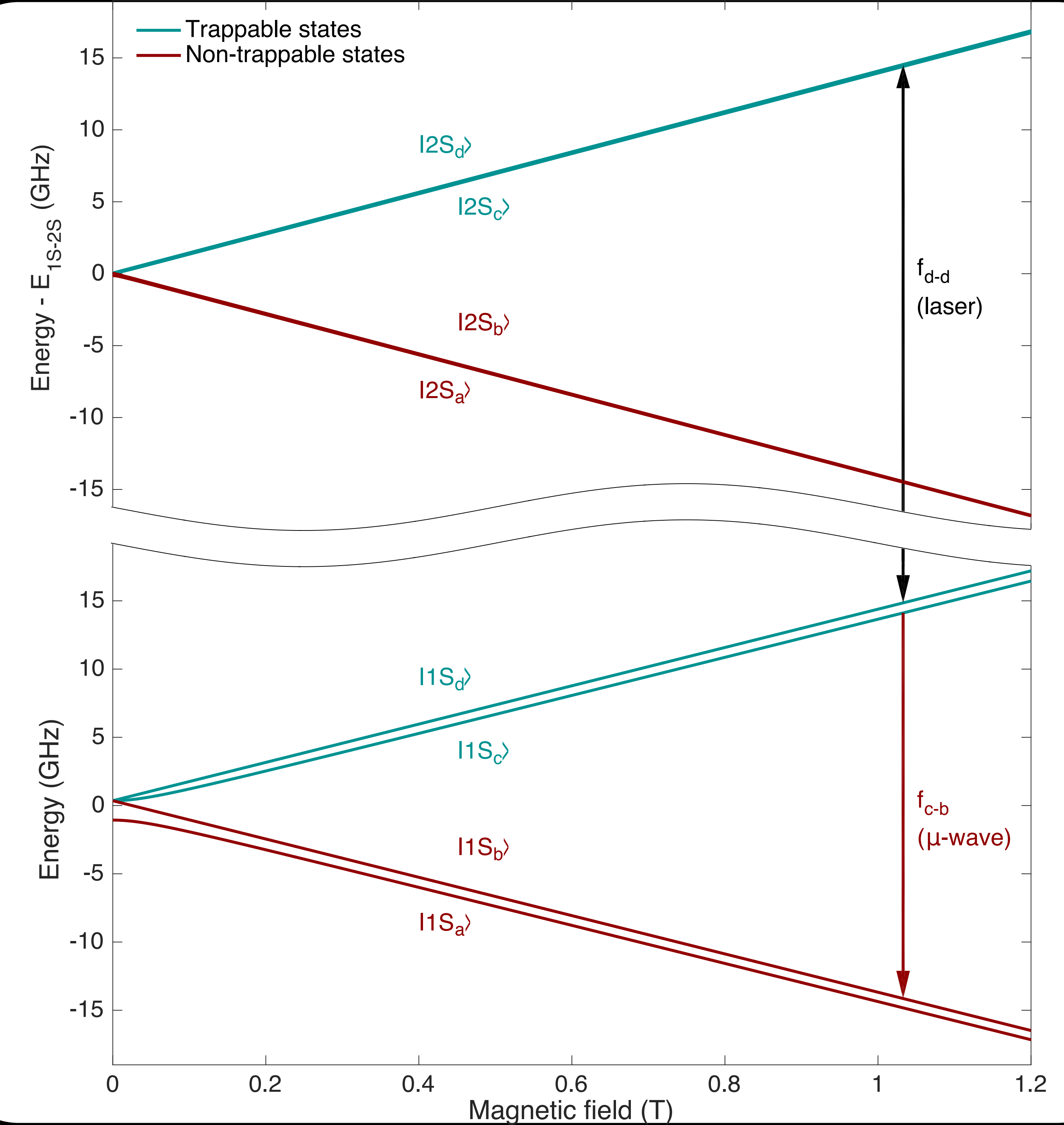


4. Turn off the atom trap



Summary results of 1S-2S paper

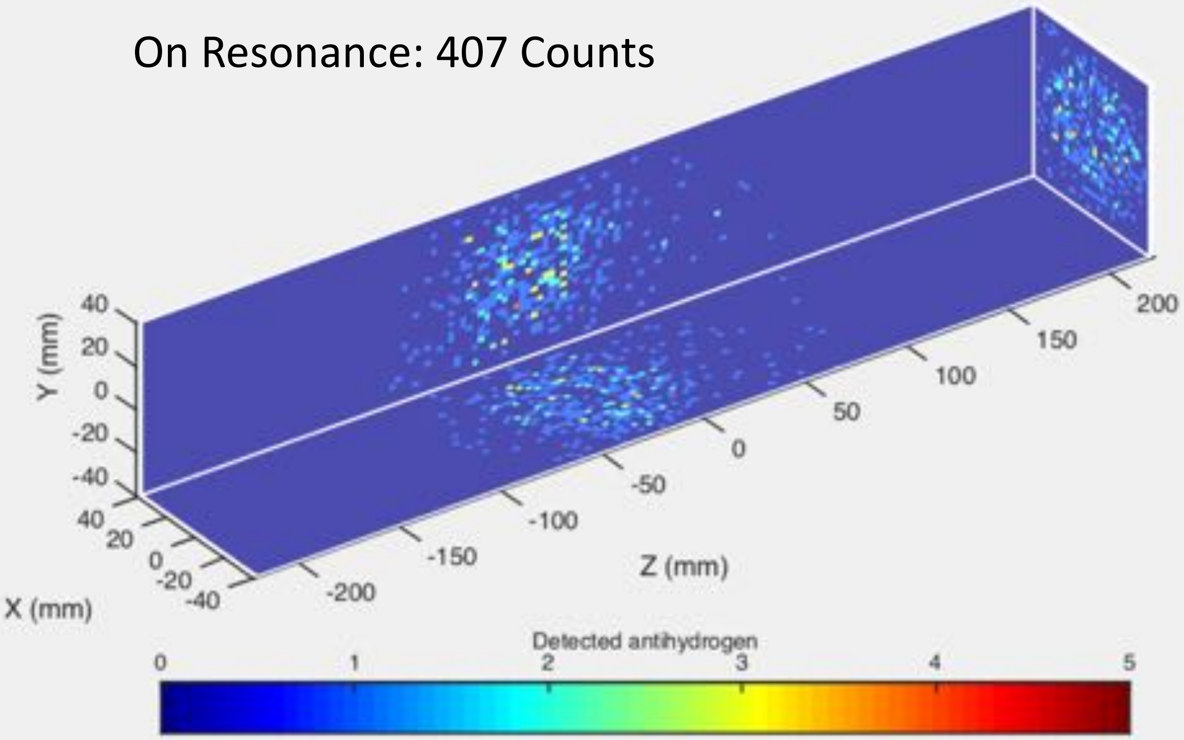
1. Catch cold antiprotons and positrons
2. Mix
3. Appearance experiment:
    1. Inject microwaves to clear out ‘C state’ atoms
    2. Inject laser at fixed frequency
4. Disappearance experiment:
    1. Ramp down neutral atom trap



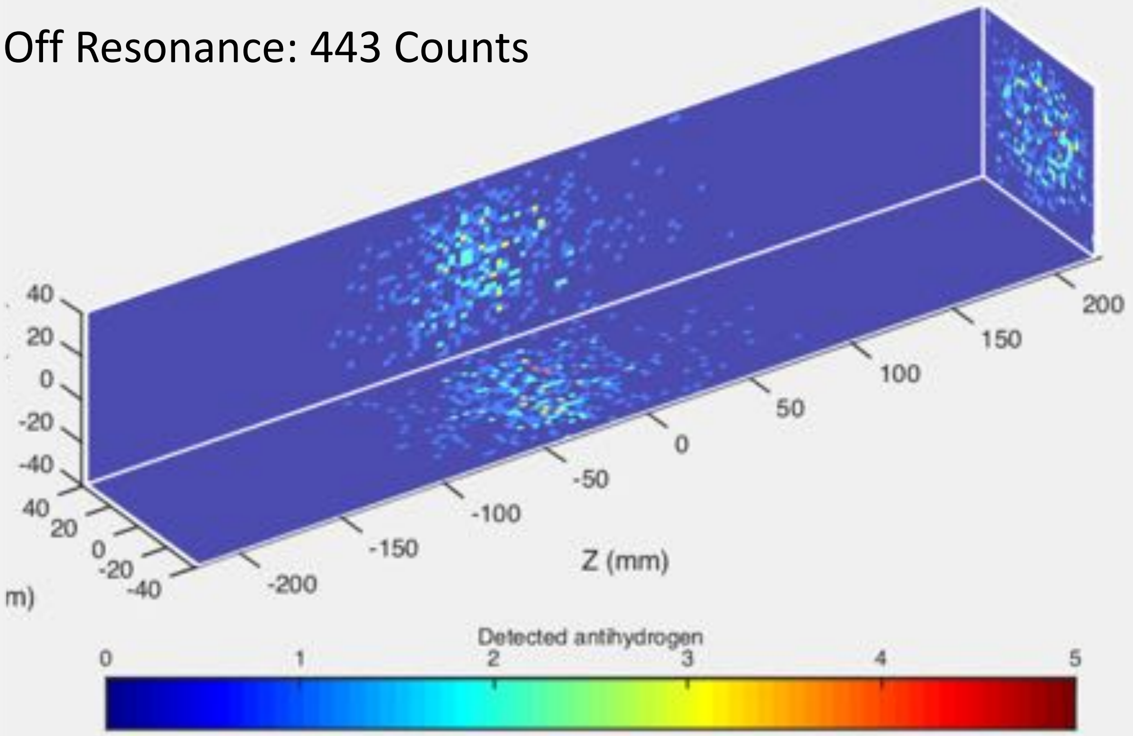
Trappable states
Non-trappable states
Energy - E_{1S-2S} (GHz)
15
10
5
0
-5
-10
-15
|2S$_d$⟩
|2S$_c$⟩
|2S$_b$⟩
|2S$_a$⟩
f_{d-d}
(laser)
Energy (GHz)
|1S$_d$⟩
|1S$_c$⟩
|1S$_b$⟩
|1S$_a$⟩
f_{c-b}
(μ-wave)
0
0.2
0.4
0.6
0.8
1
1.2
Magnetic field (T)

Microwaves before Laser On Res vs Off Res

On Resonance: 407 Counts

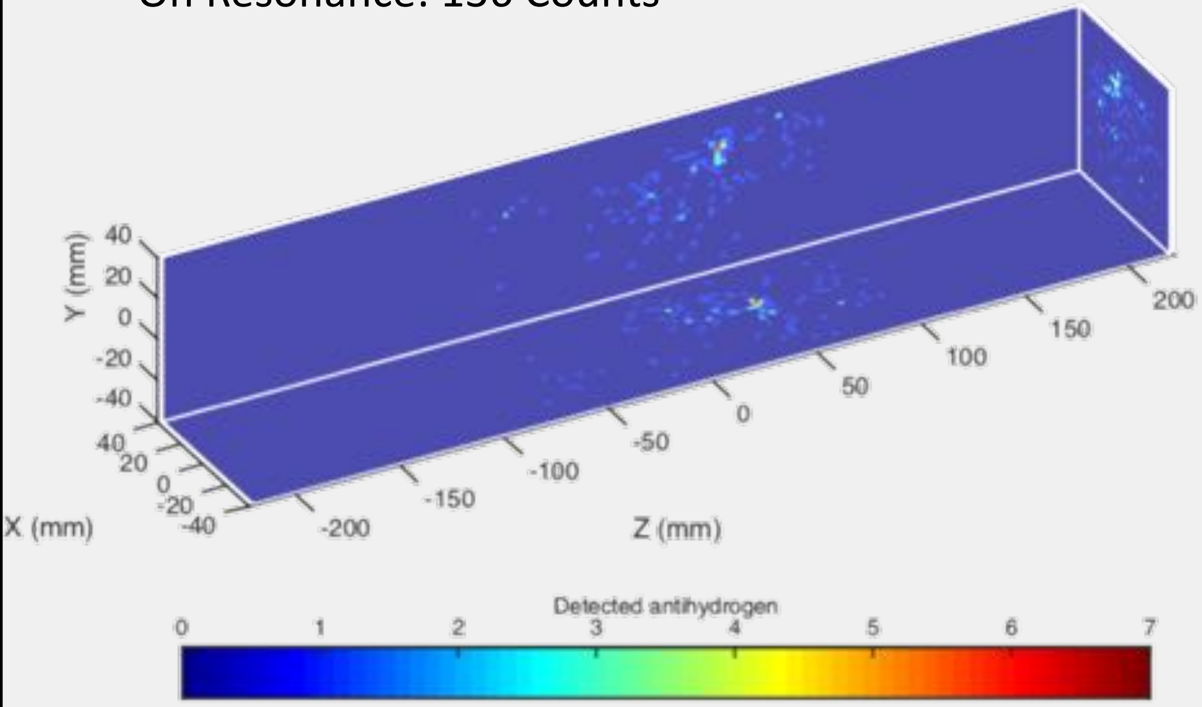


Off Resonance: 443 Counts

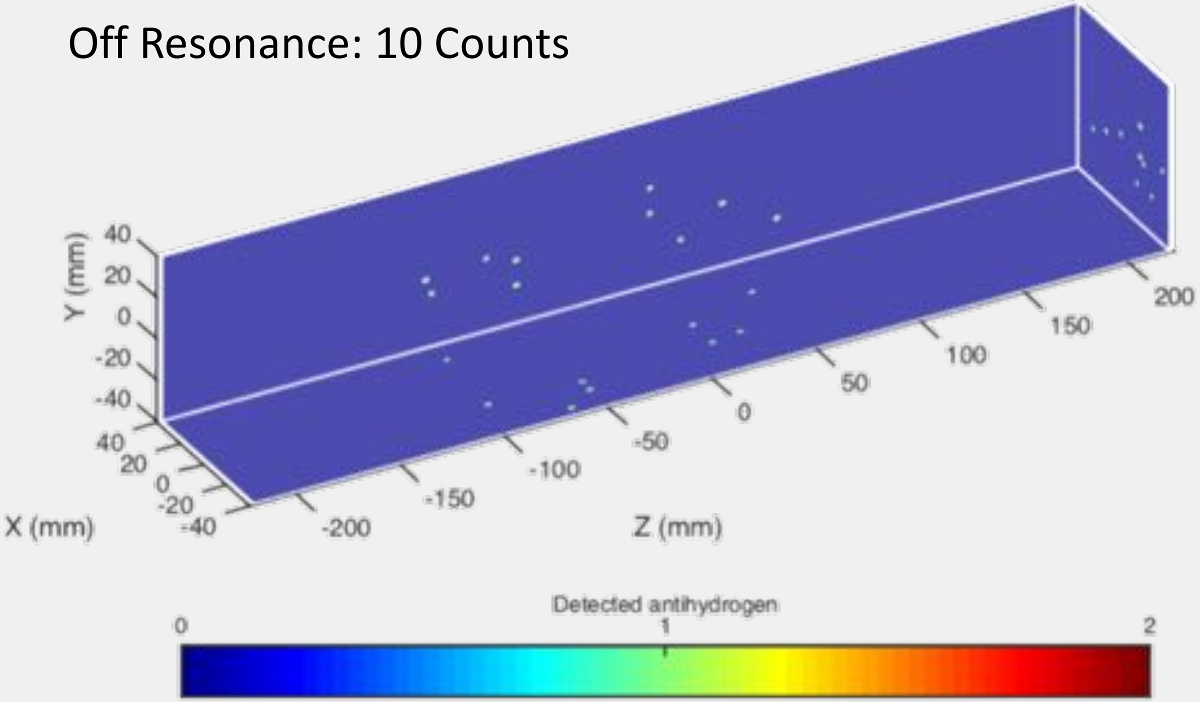


Appearance of Laser window On Res vs Off Res

On Resonance: 136 Counts

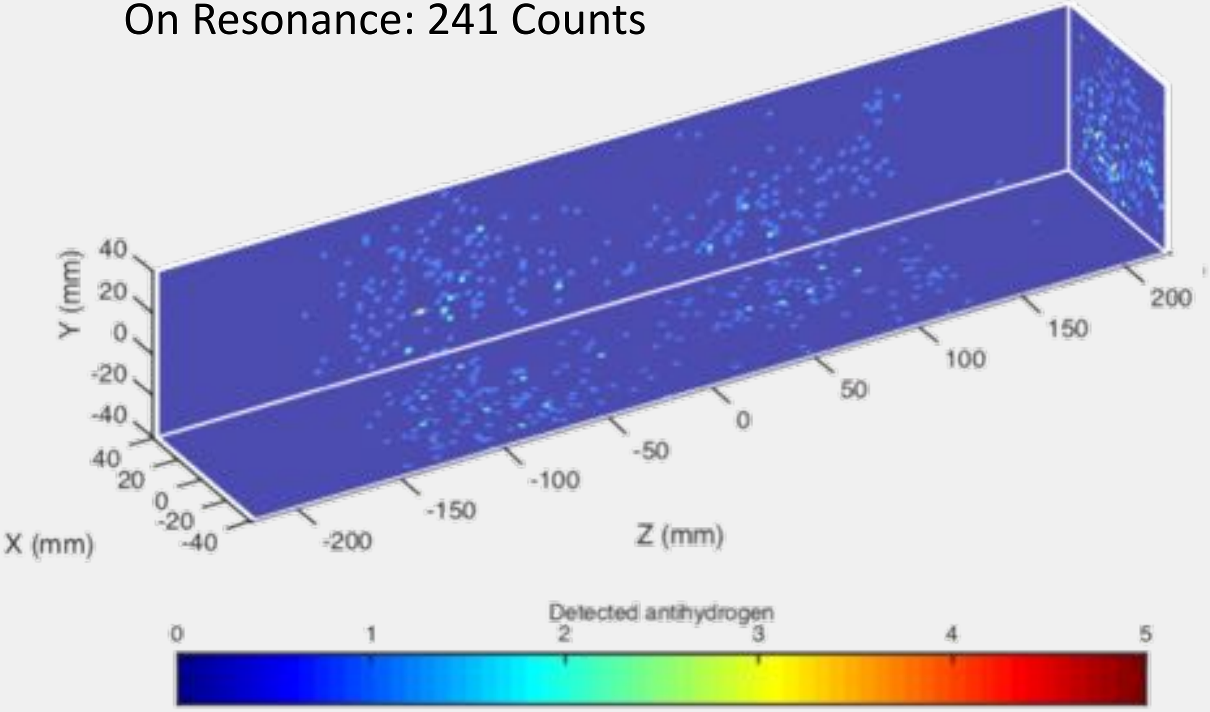


Off Resonance: 10 Counts

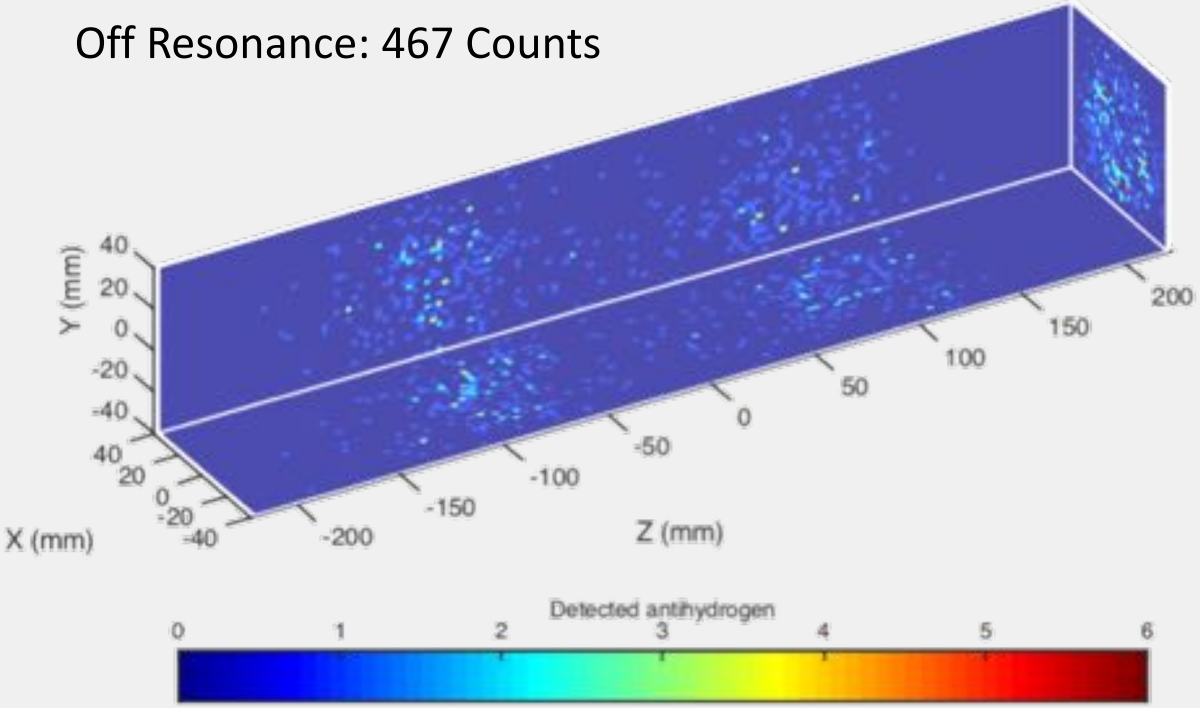


Disappearance after Laser On Res vs Off Res

On Resonance: 241 Counts

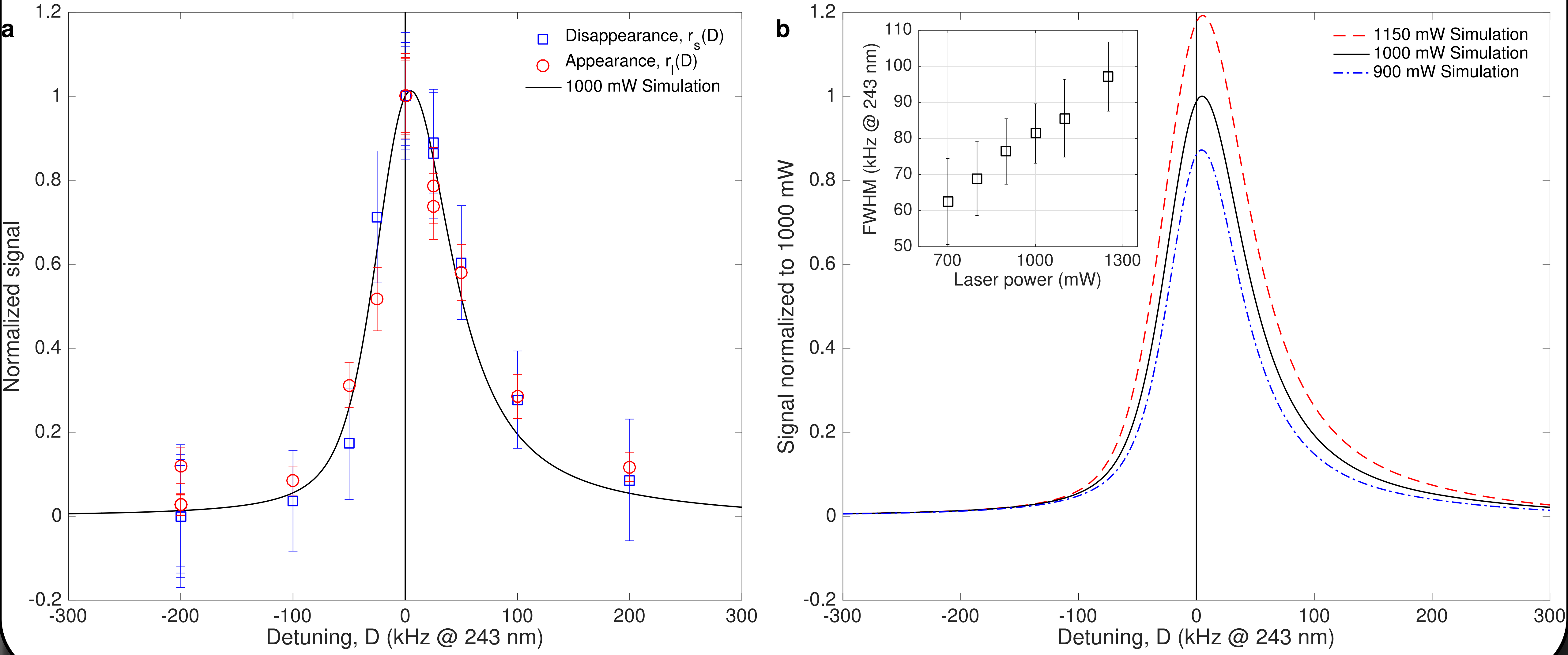


Off Resonance: 467 Counts



Example Summary: 21 Trails at 2 Frequencies

	On Resonance Counts	Off Resonance Counts
Microwave Counts	407	443
Appearance measurement	136	10
Disappearance measurement	241	467



a
Disappearance, $r_s(D)$
Appearance, $r_l(D)$
1000 mW Simulation
Normalized signal
Detuning, D (kHz @ 243 nm)
b
1150 mW Simulation
1000 mW Simulation
900 mW Simulation
FWHM (kHz @ 243 nm)
Laser power (mW)
Signal normalized to 1000 mW
Detuning, D (kHz @ 243 nm)

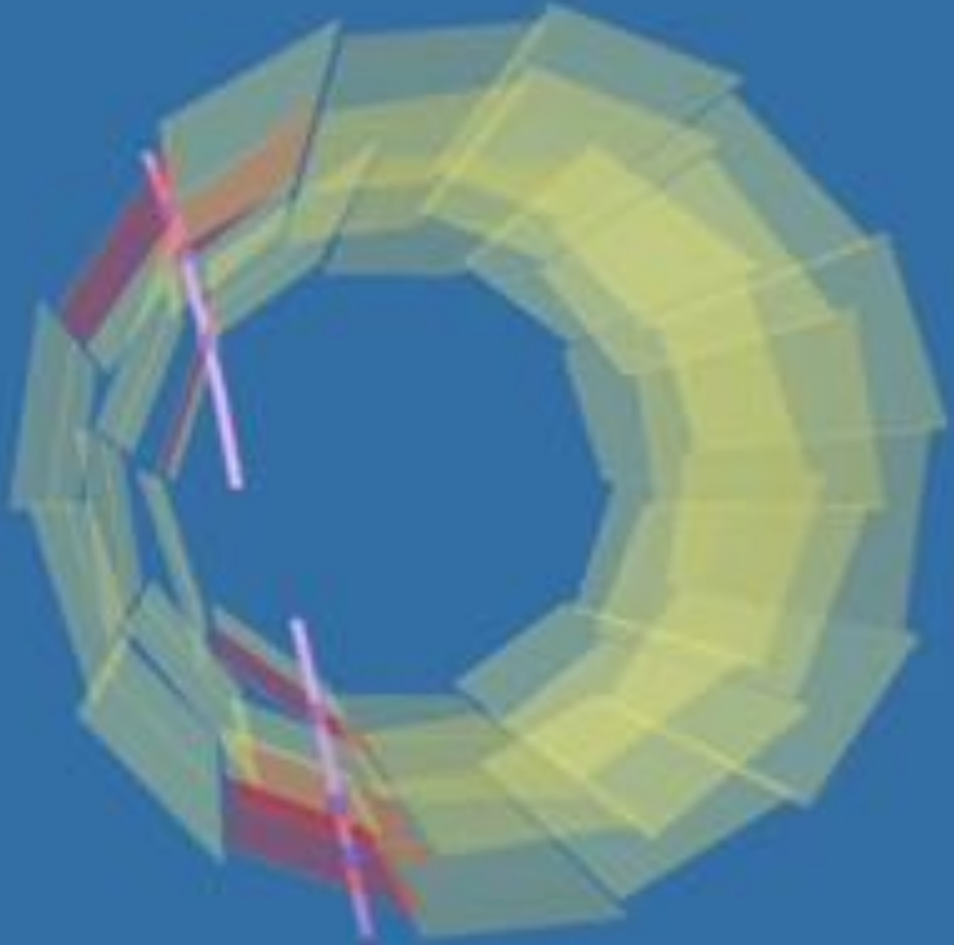
Detector and Analysis challenges

- Cosmic rate: 10Hz
- Expected signal: 250
- Expected Background: 330,000 counts

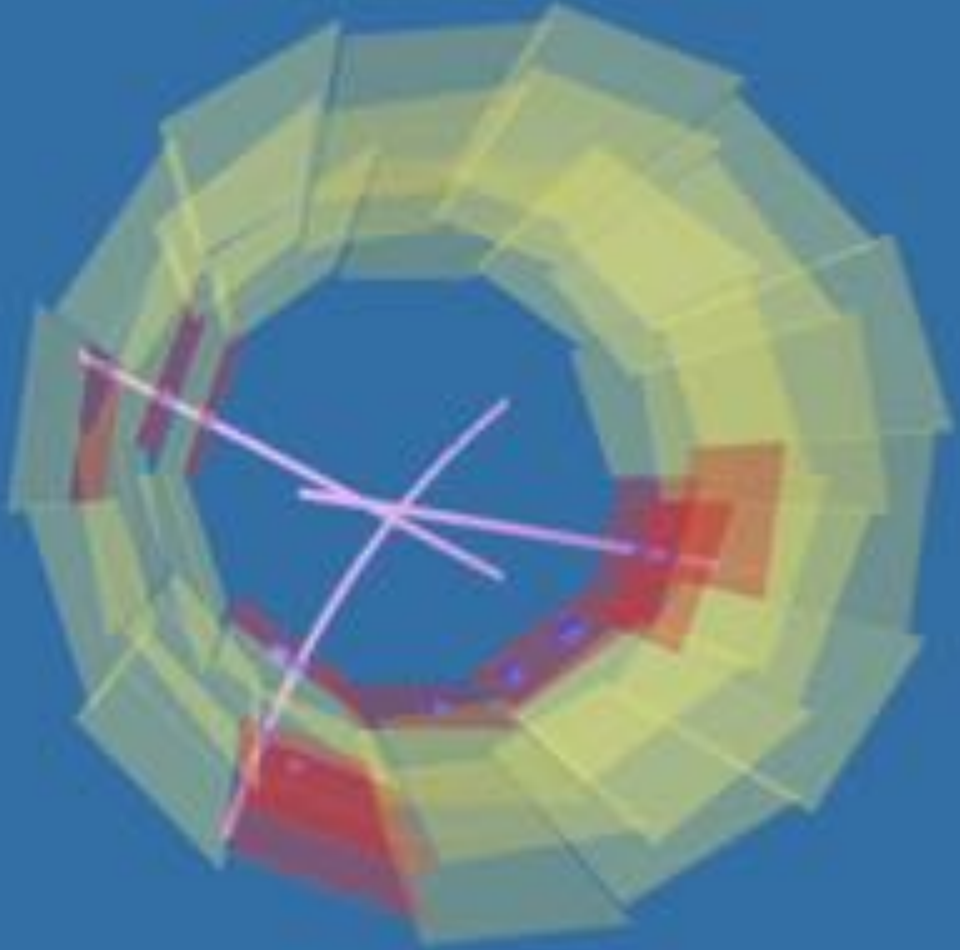
- Required background (optimising significance): 99.99% suppression

- Cut based online analysis has a 99.5% background suppression (45mHz)

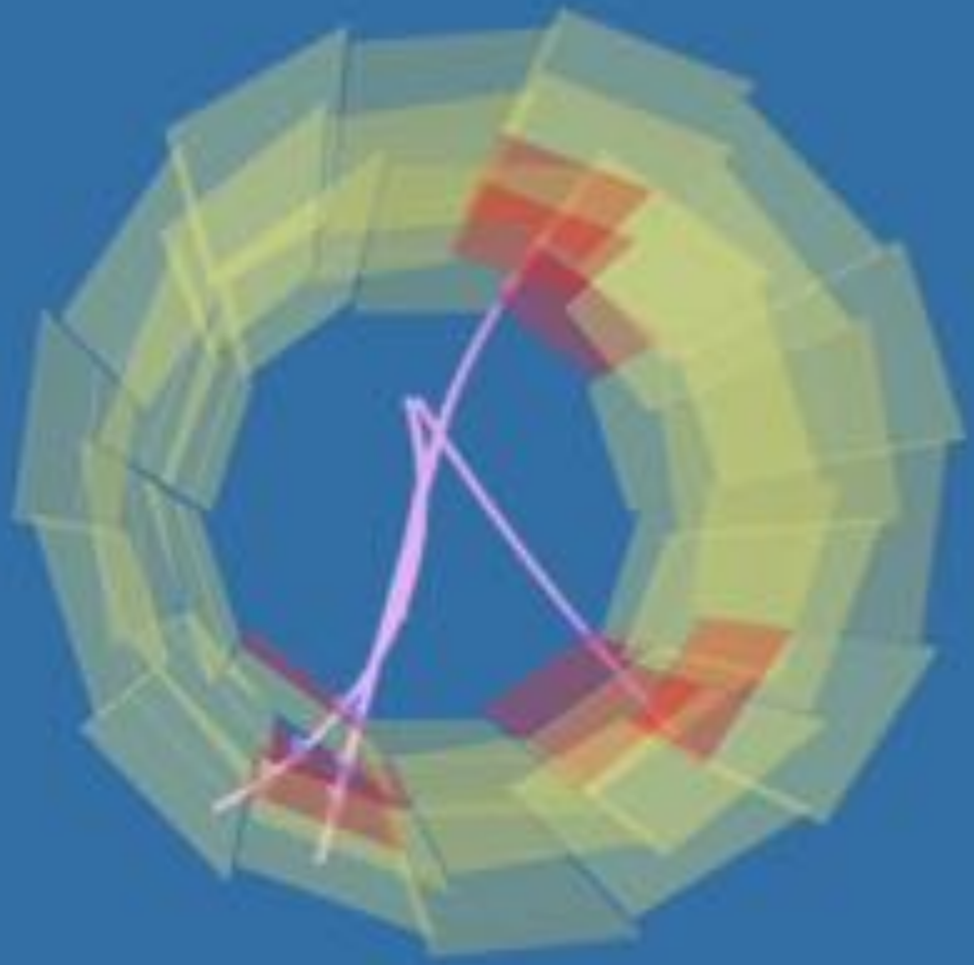
Cosmic Ray

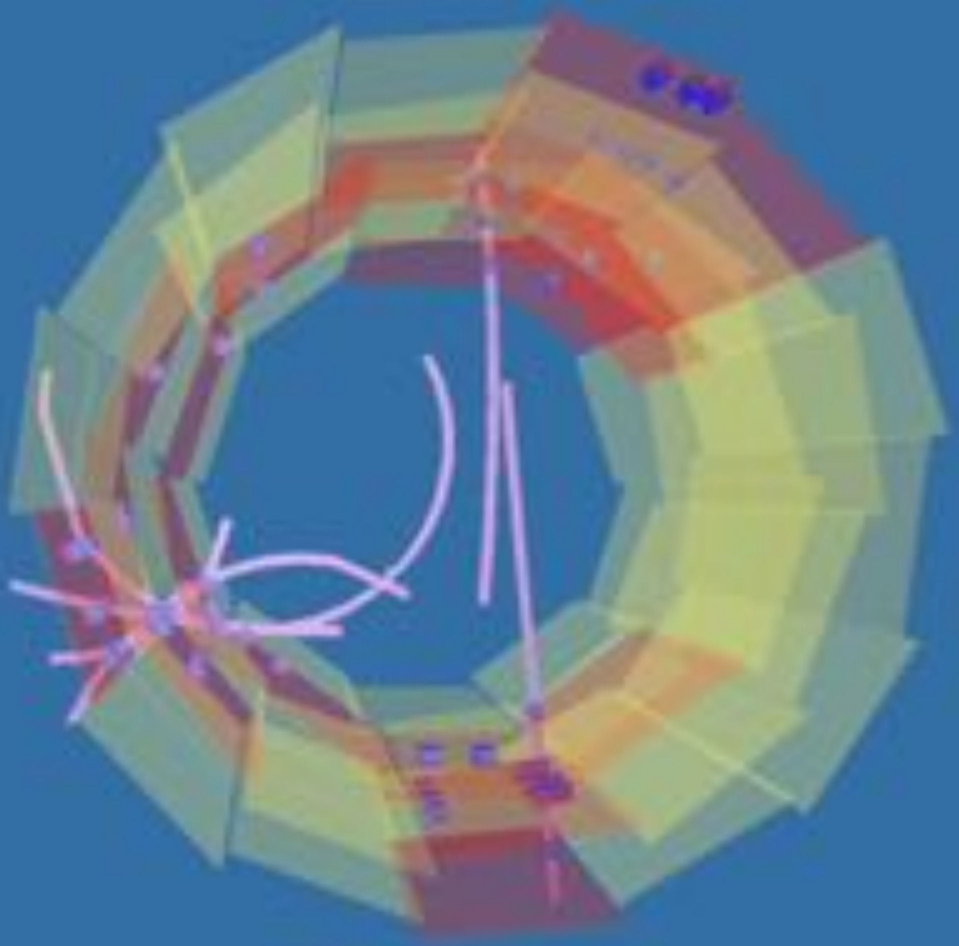


Anti-proton Annihilation



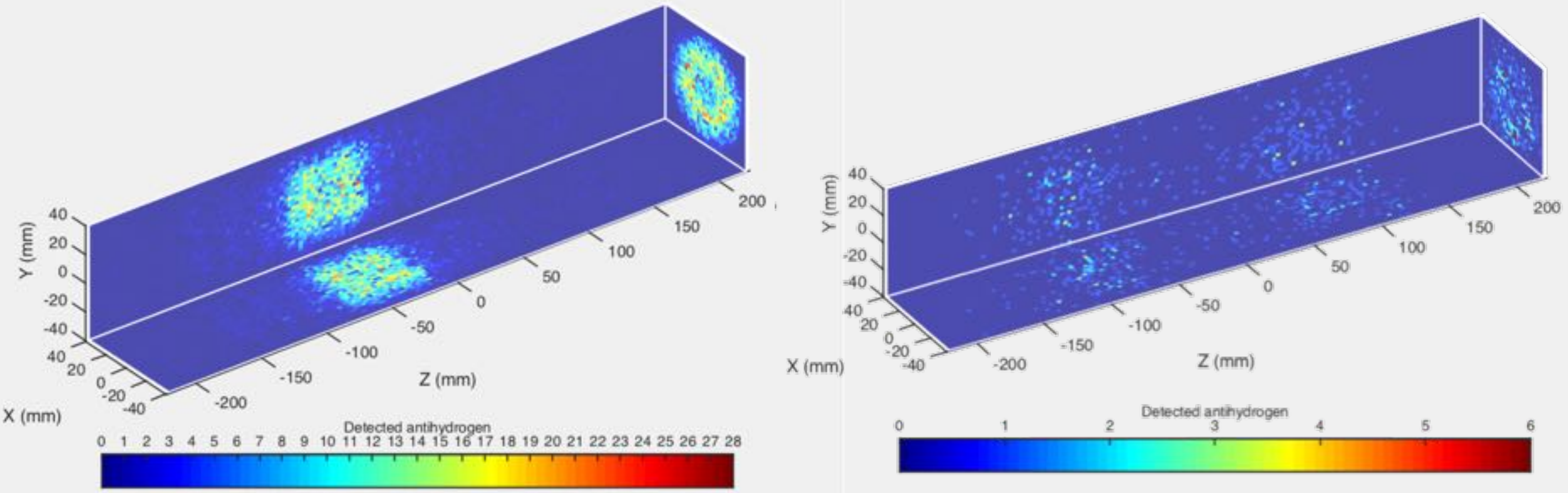
Harder to classify Cosmic Events





Machine learning

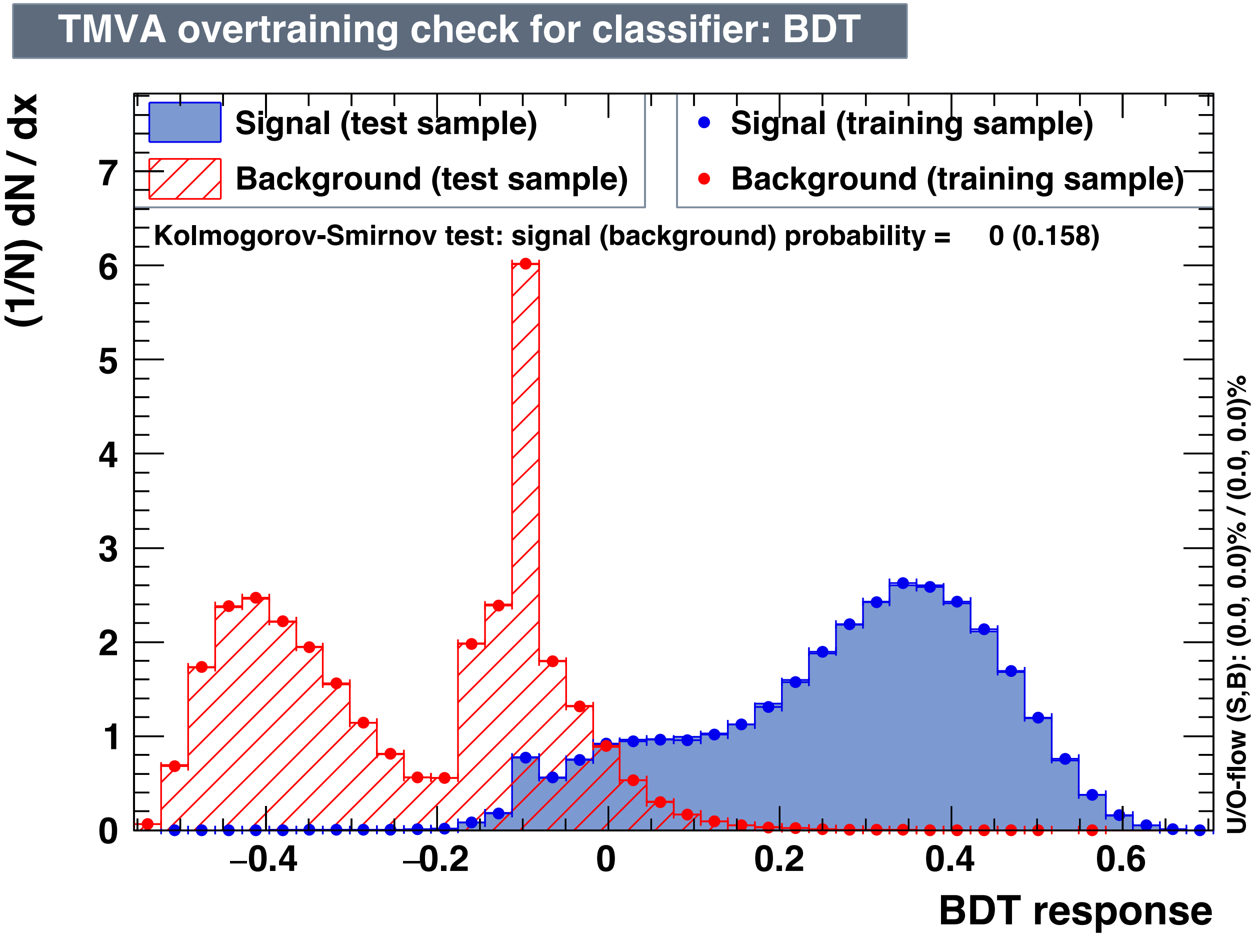
- Selection of training data
- Boosted decision tree classifier performance


Y (mm)
X (mm)
Z (mm)
Detected antihydrogen
Y (mm)
X (mm)
Z (mm)
Detected antihydrogen

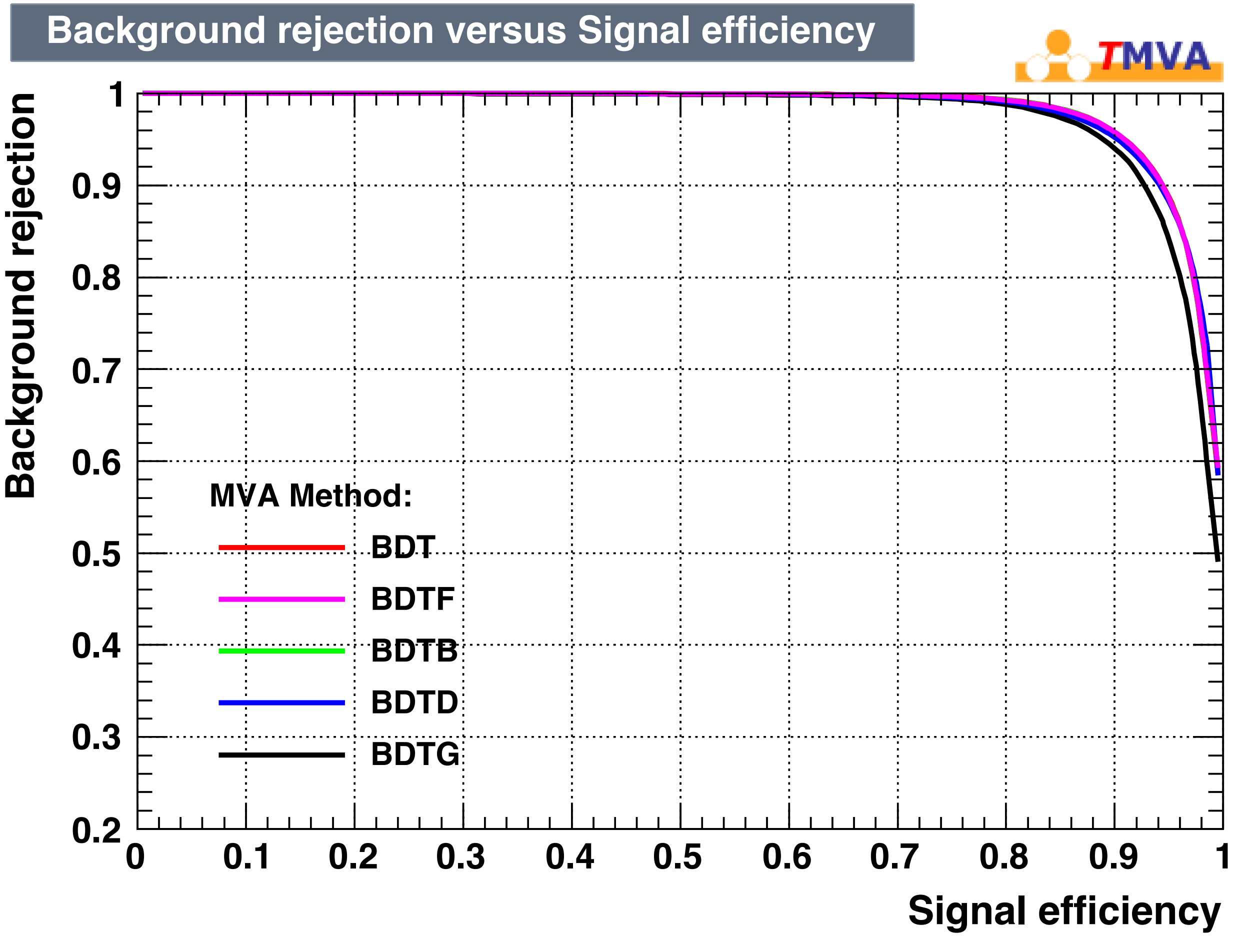
Training data

- Training data is very pure
  - Mixing - Sample 600 events (limited by readout rate)
    - 50,000 annihilations
    - 10 cosmic events
  - Signal purity >99.99%
  - Background purity: 100%

- No requirement for advanced monte carlo to generate training data



TMVA overtraining check for classifier: BDT
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0 (0.158)
(1/N) dN / dx
BDT response
U/O-flow (S,B): (0.0, 0.0)% / (0.0, 0.0)%



Background rejection versus Signal efficiency
TMVA
Background rejection
Signal efficiency
MVA Method:
BDT
BDTF
BDTB
BDTD
BDTG

	Efficiency	Uncertainty	Background rate (10^{-3} s^{-1})	Uncertainty (10^{-3} s^{-1})
Laser exposure (300 s)	0.472	0.001	1.04	0.11
Microwave exposure (32 s)	0.801	0.002	33.0	0.6
Release of surviving atoms (1.6 s)	0.852	0.002	191	1

doi:10.1038/s41586-018-0017-2

Conclusion

- Silicon Vertex Detector is key to precision measurements on antihydrogen
- Recent measurements would not have been possible without Machine learning
- Future prospects of machine learning are good, efficiencies will improve!

Thank you for listening

http://alpha.web.cern.ch/