Swansea University
Prifysgol Abertawe

ALPHA

ALPHA: Antihydrogen

and fundamental physics

Prof. Niels Madsen
Swansea University

and the ALPHA collaboration

Low Energy Antiproton Physics conference, Uppsala, Sweden, 10 June 2013

Brief History of Antihydrogen

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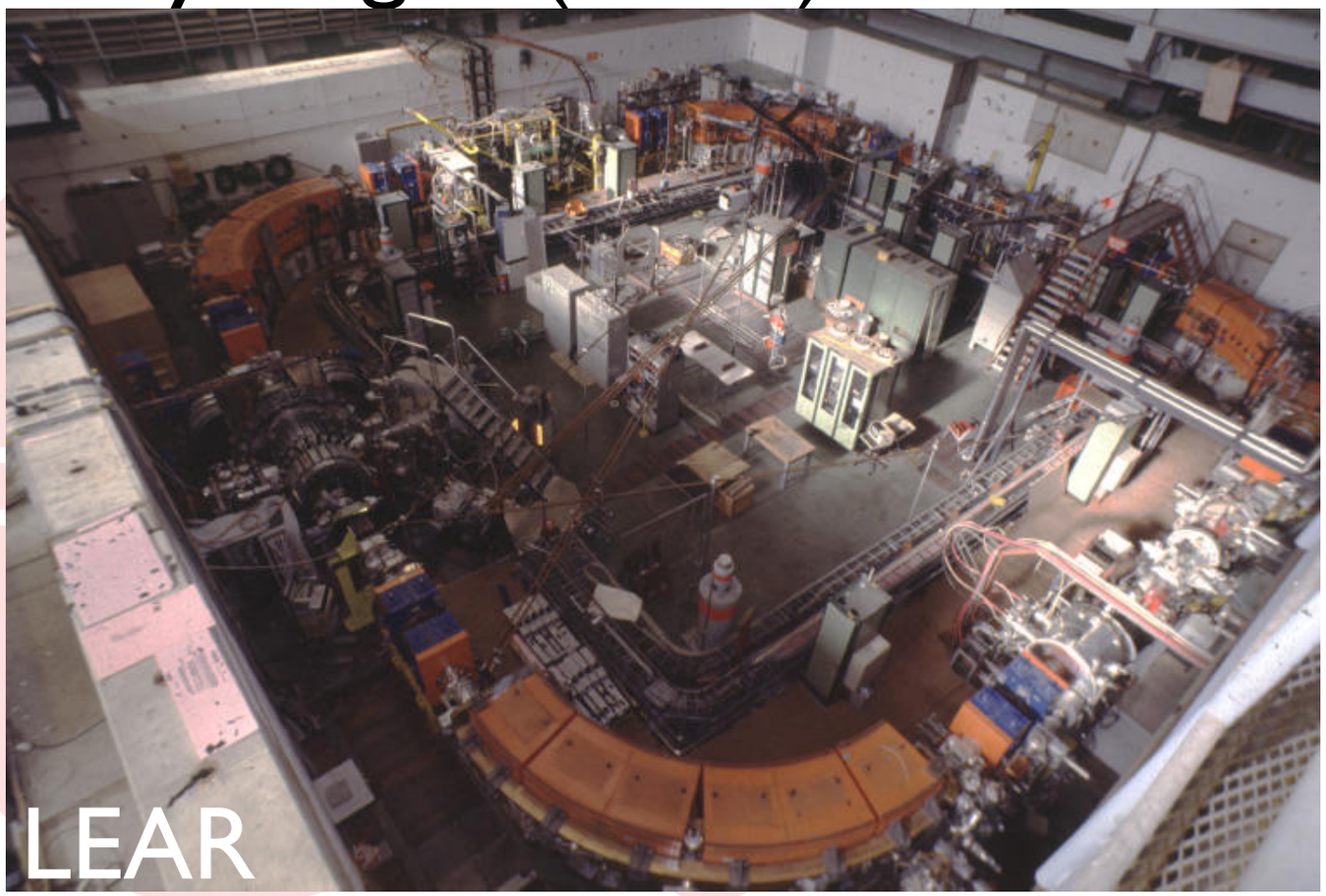

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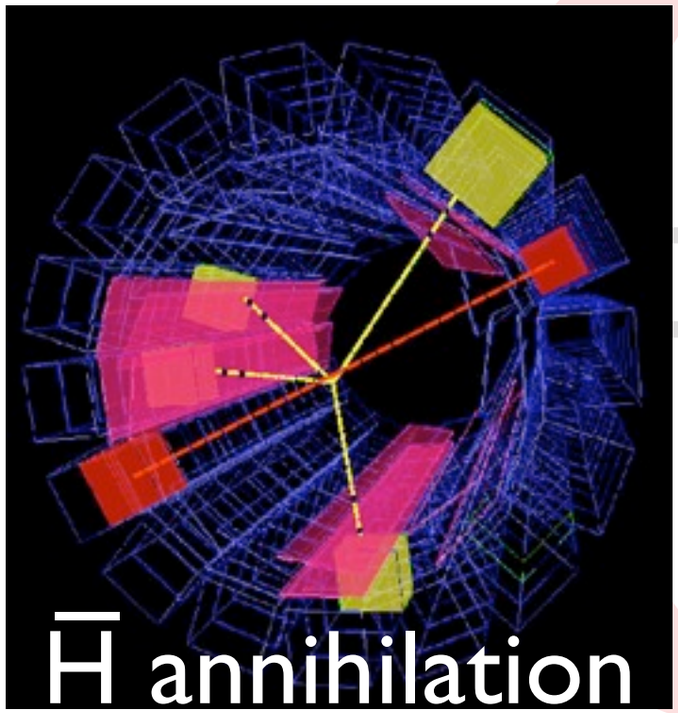

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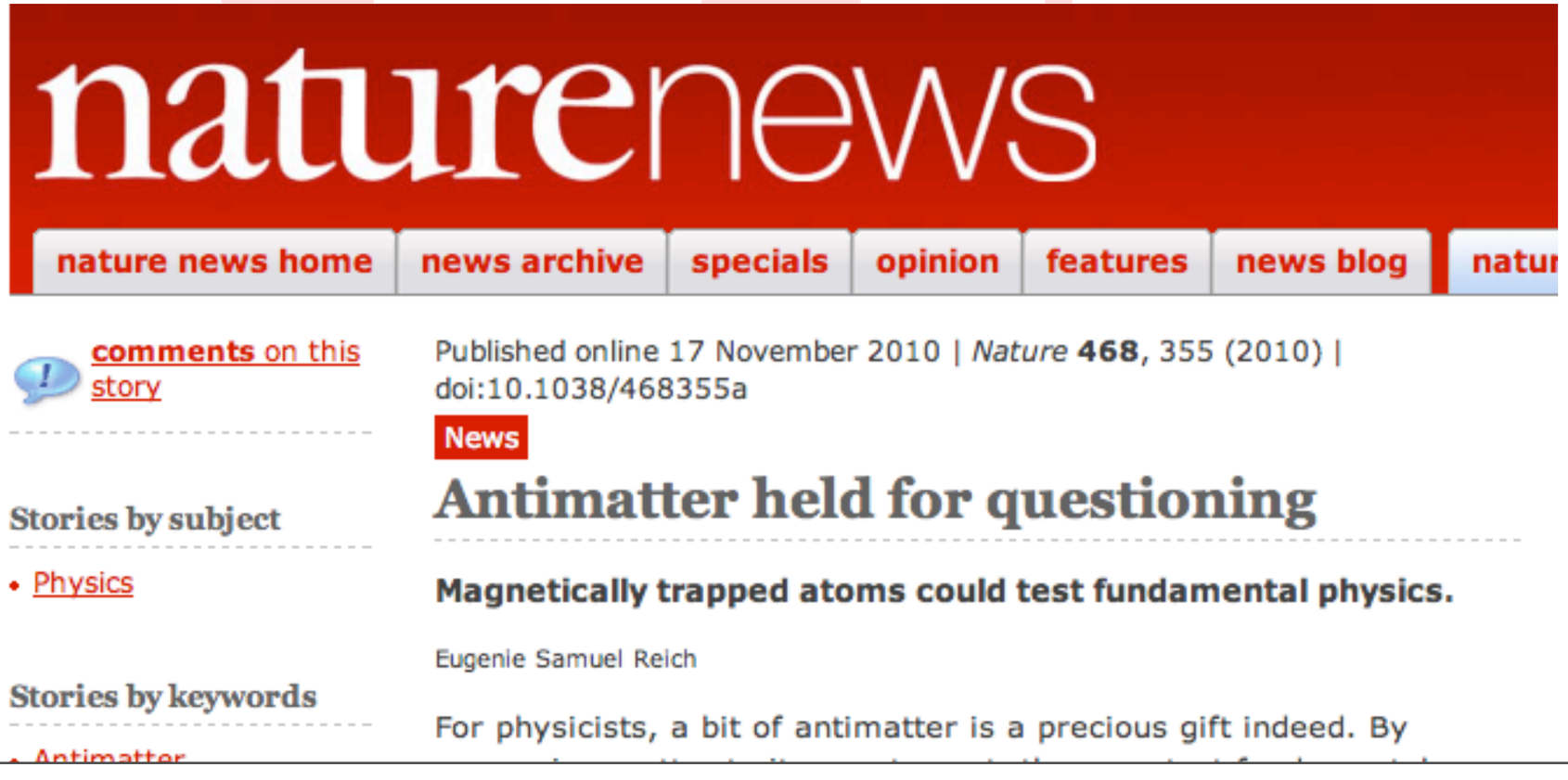

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- Physics

Stories by keywords

- Antimatter

Published online 17 November 2010 | *Nature* **468**, 355 (2010) | doi:10.1038/468355a

News

Antimatter held for questioning

Magnetically trapped atoms could test fundamental physics.

Eugenie Samuel Reich

For physicists, a bit of antimatter is a precious gift indeed. By

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2013: ALPHA: New method for gravitational measurements.

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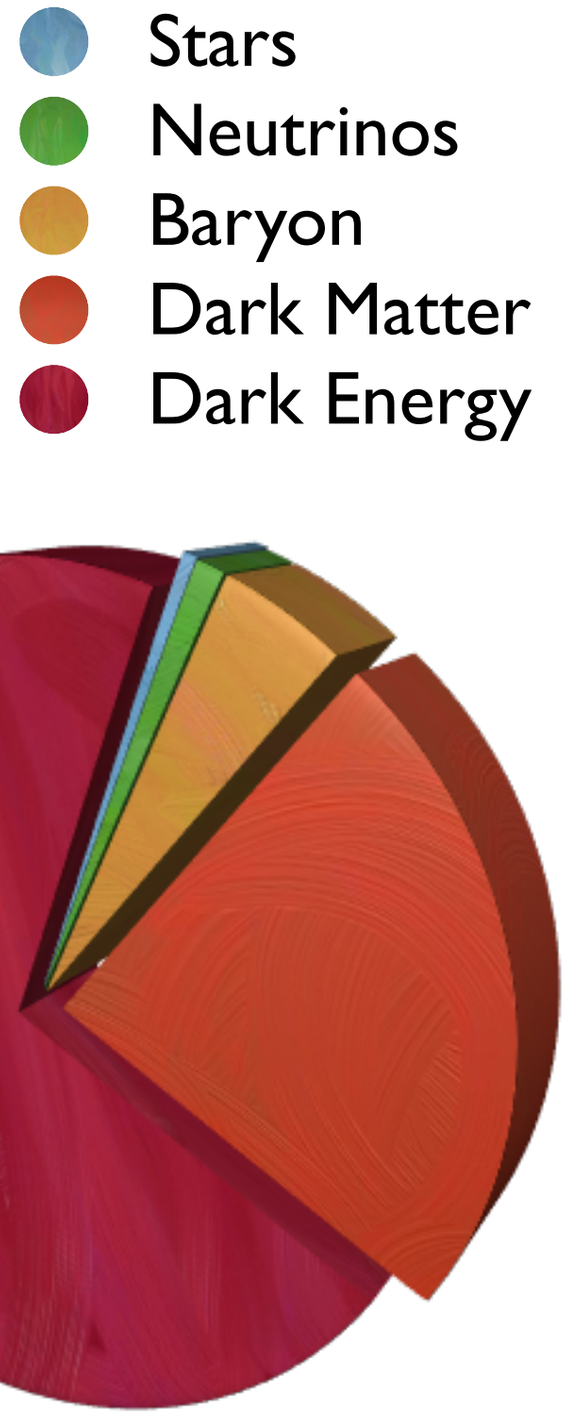
- Gravity: How does antimatter respond to gravity? Weak equivalence principle! Insights for quantum gravity?
- Note: ANY difference between $\bar{H}$ and H will imply new physics!

Energy Budget of Universe

- Stars and galaxies ~ 0.5%
- Neutrinos ~0.1-1.5%
- Rest of ordinary matter (electrons, protons & neutrons) ~ 4.4%
- Dark Matter ~ 23%
- Dark Energy ~ 73%
- Antimatter 0% ?



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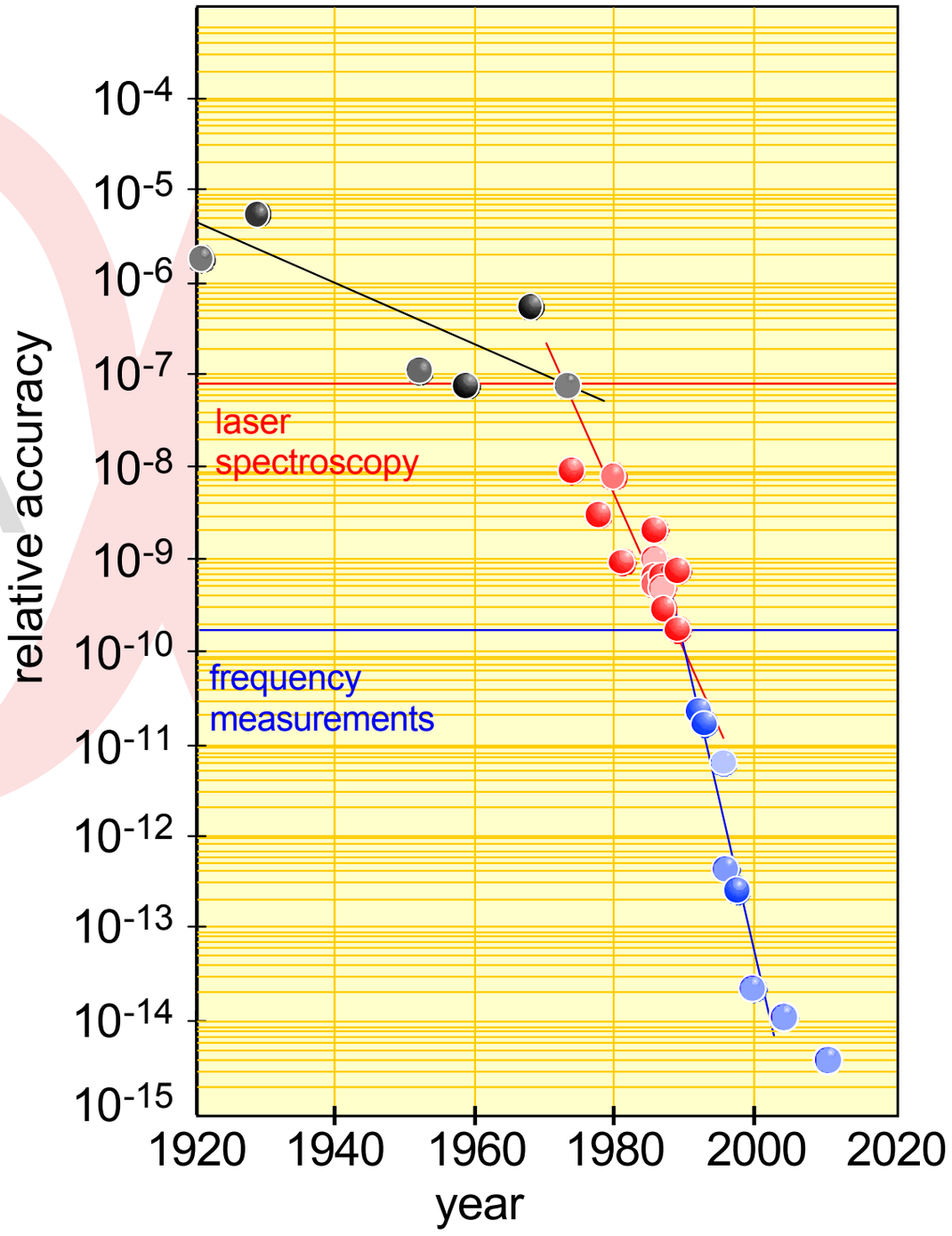
- Ex: H-$\bar{H}$ comparison by 1s-2s two photon spectroscopy.



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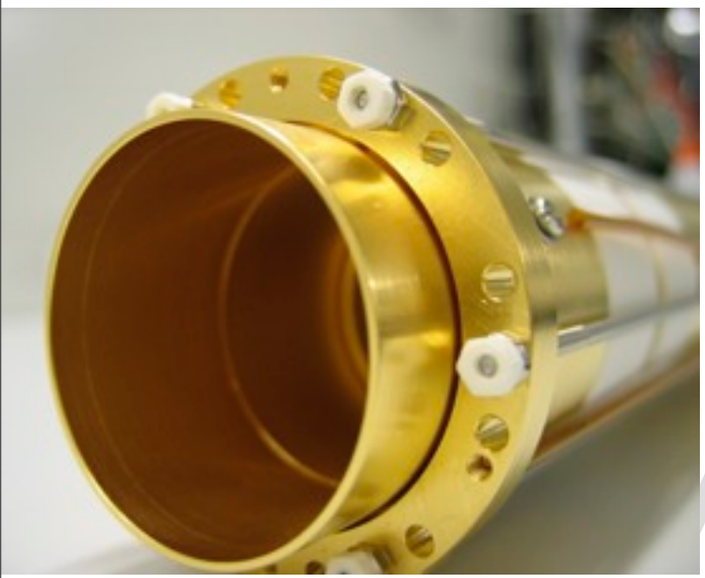
- We must form $\bar{H}$ cold and trapped.

Charged Particle Traps

- All our traps are Penning-Malmberg traps



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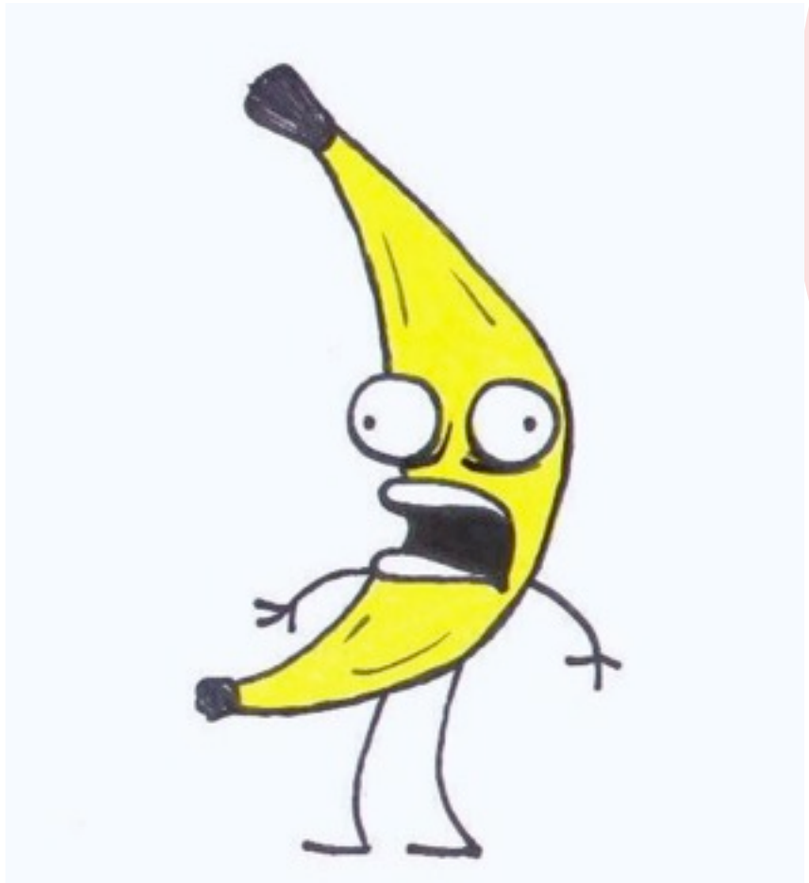
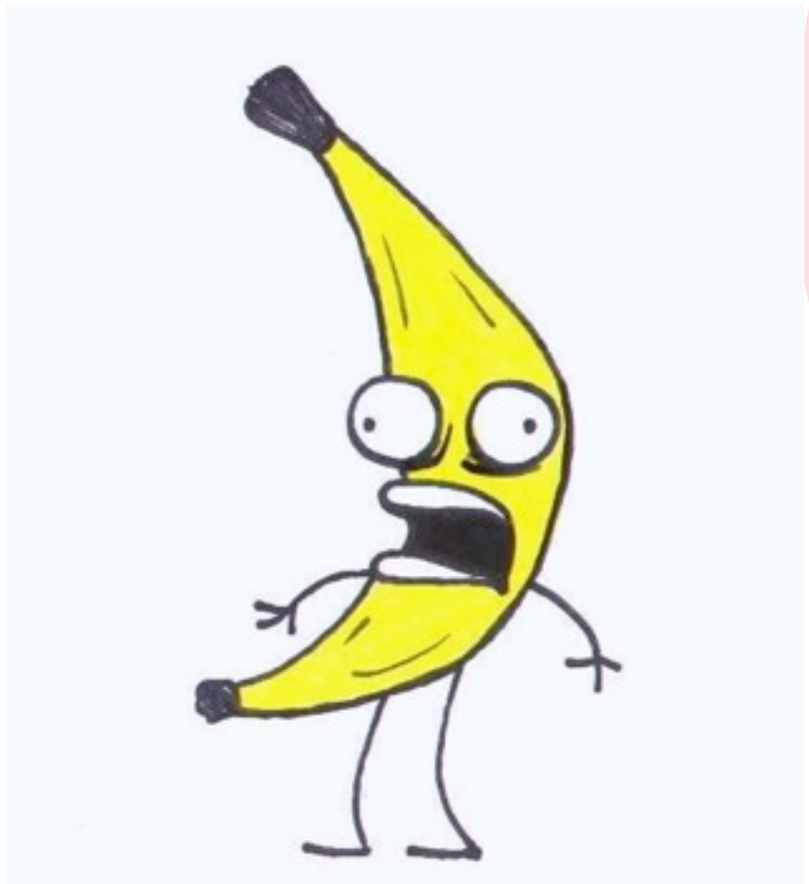


"I am a banana!" Don Hertzfeld

Where do Positrons come from?

- Fairly Easy: Positive β^+ decay in radioactive isotopes
  - Potassium-40 in Bananas: ~ 15 Positrons / sec
  - We use Sodium-22 source: ~ 10 M / sec

$$^{22}\mathrm{Na} \rightarrow {}^{22}\mathrm{Ne} + e^+ + \nu_e + \gamma$$



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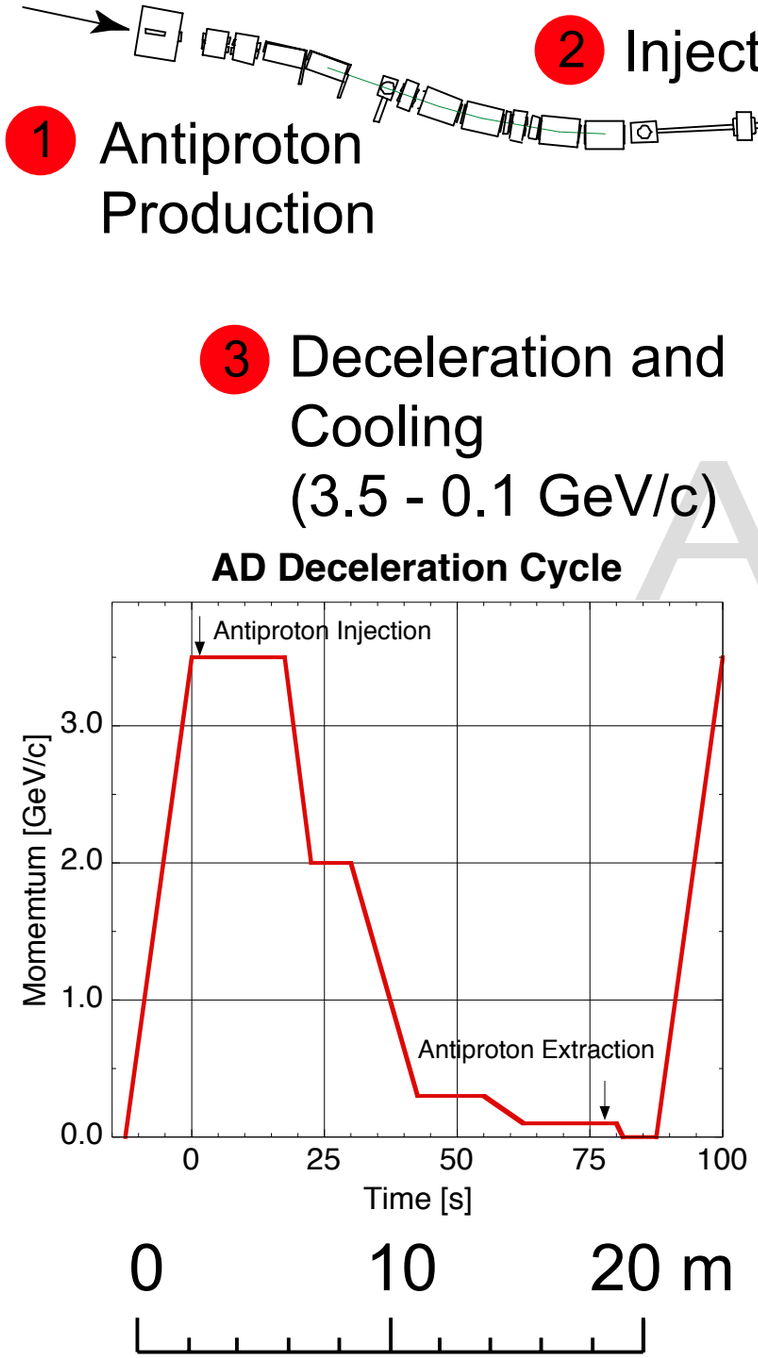
Antiproton Decelerator

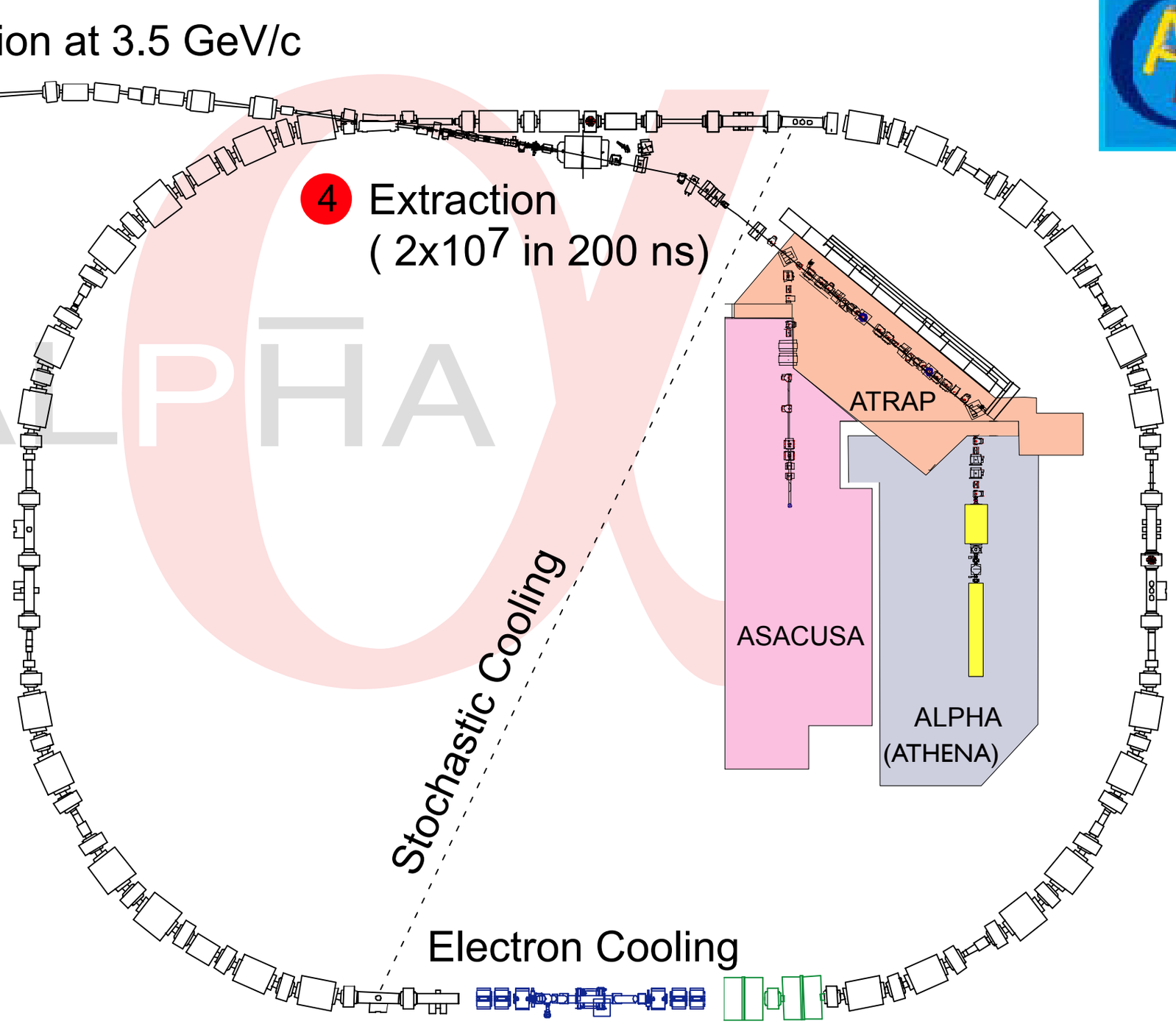
1 Antiproton Production

2 Injection at 3.5 GeV/c

3 Deceleration and Cooling (3.5 - 0.1 GeV/c)

4 Extraction (2×10^7 in 200 ns)





AD Experimental Area

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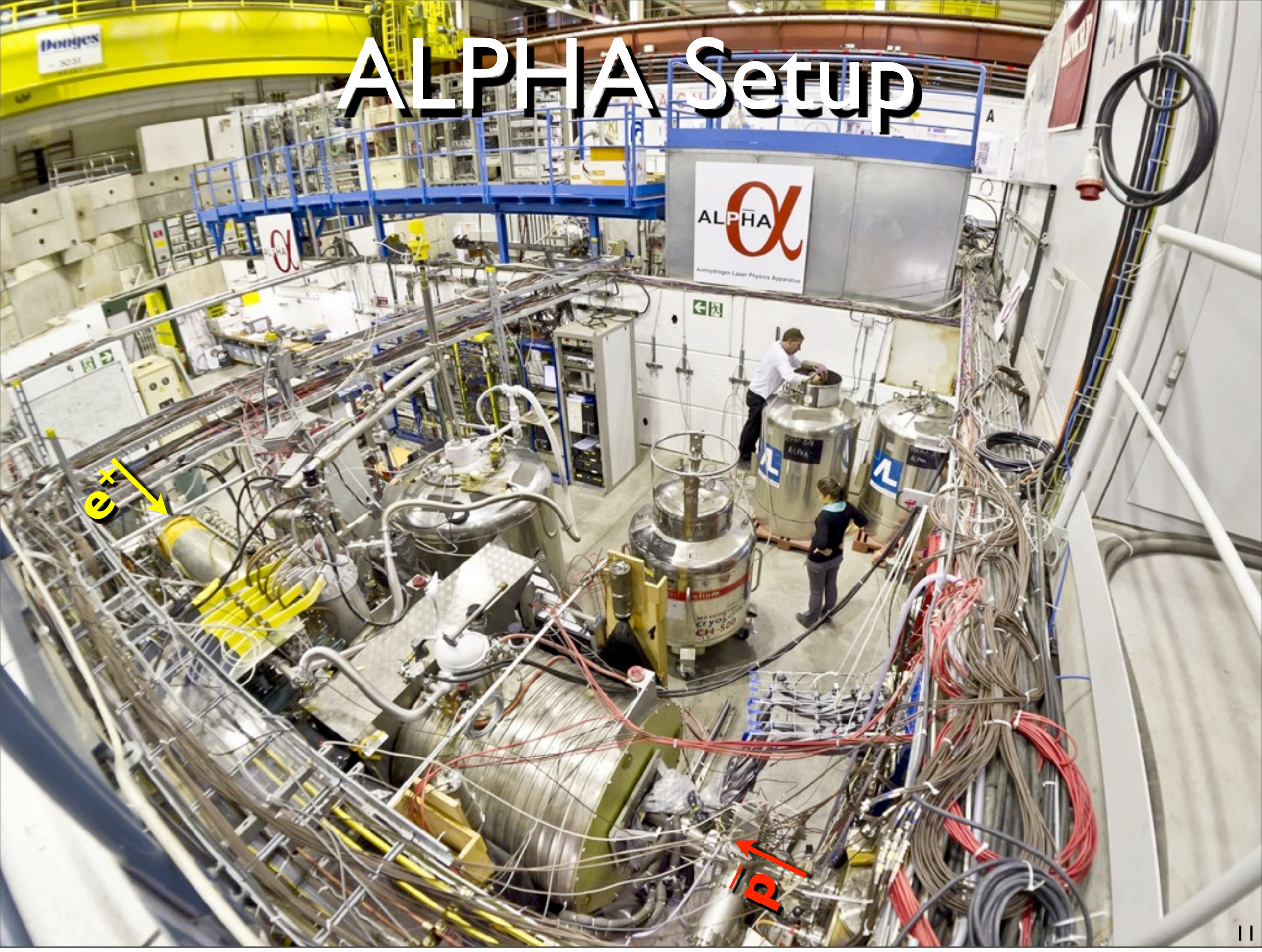
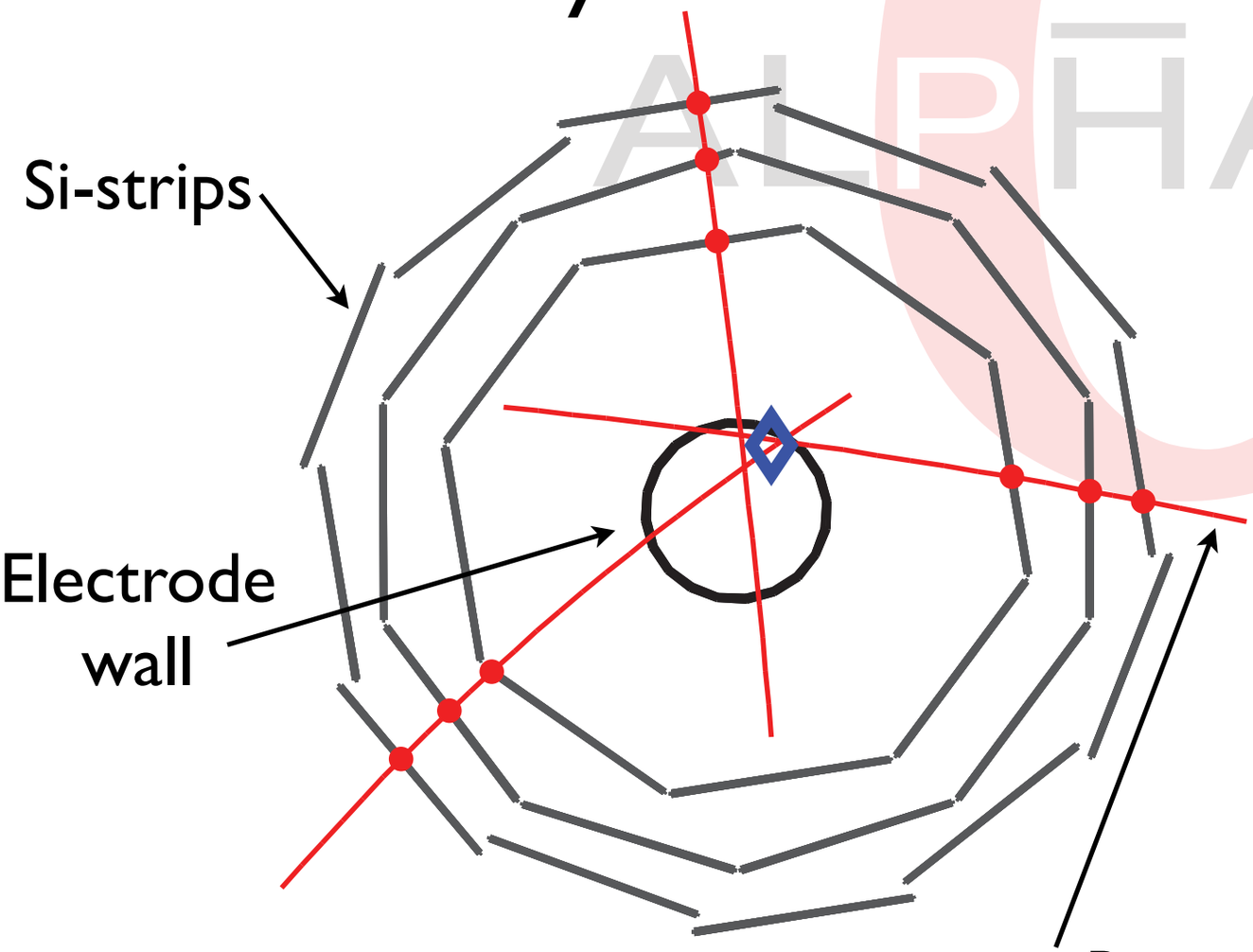
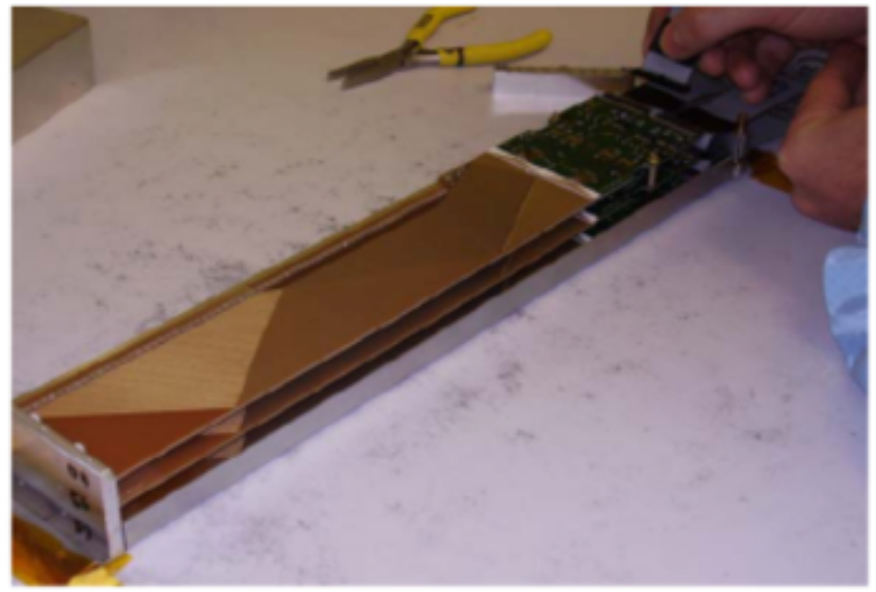
ALPHA Setup

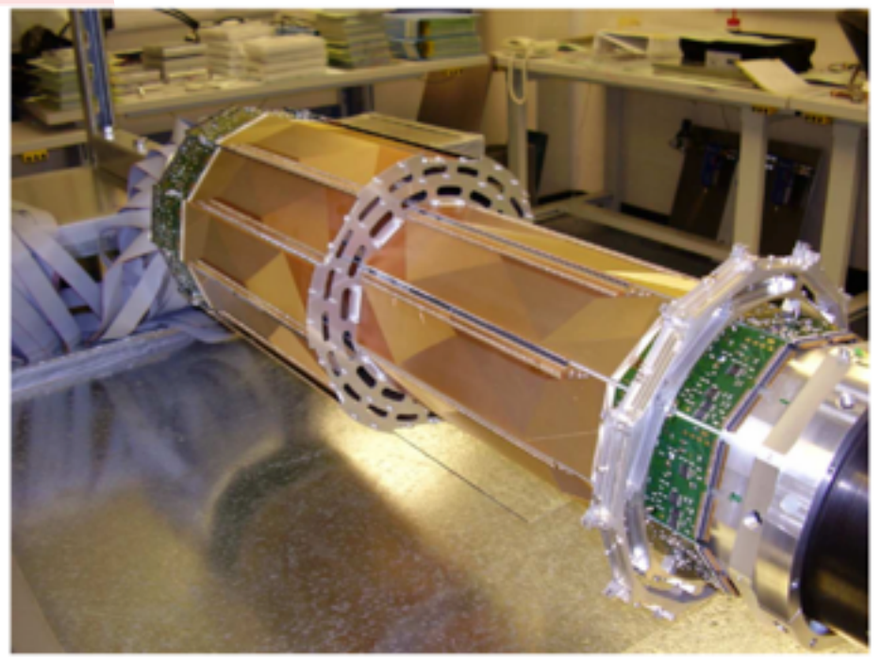


Annihilation Detection

- Si-strip detection
- Vertex resolution ~ 1mm
- Efficiency ~ 50%







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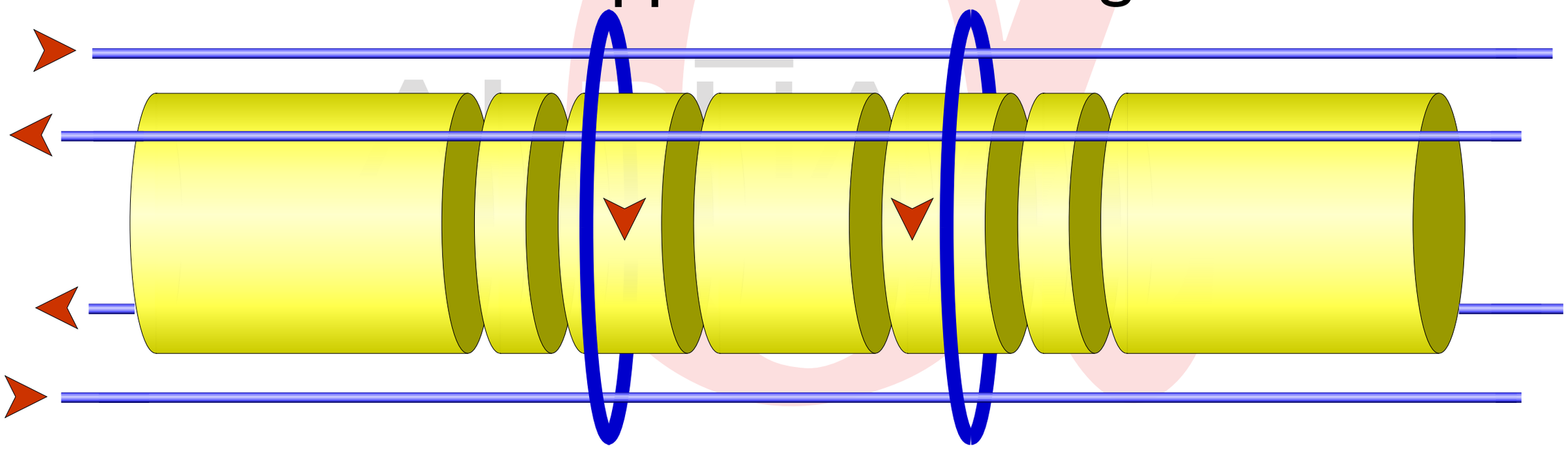

Ioffe-Pritchard Geometry

$$\Delta B = \sqrt{B_{sol}^2 + B_{wall}^2} - B_{sol}$$

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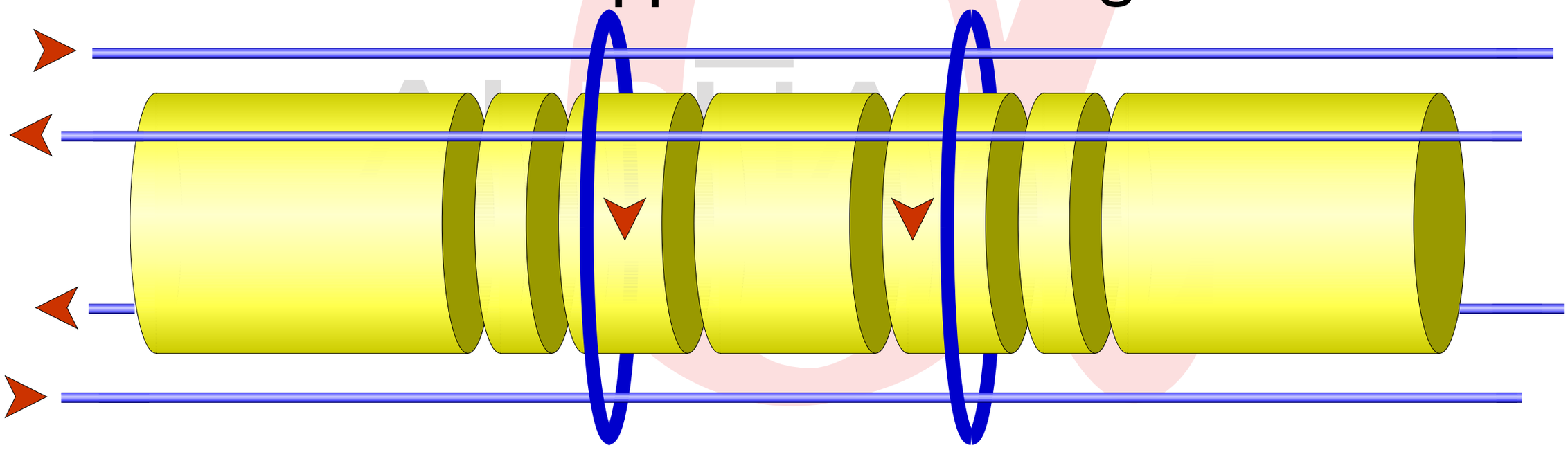

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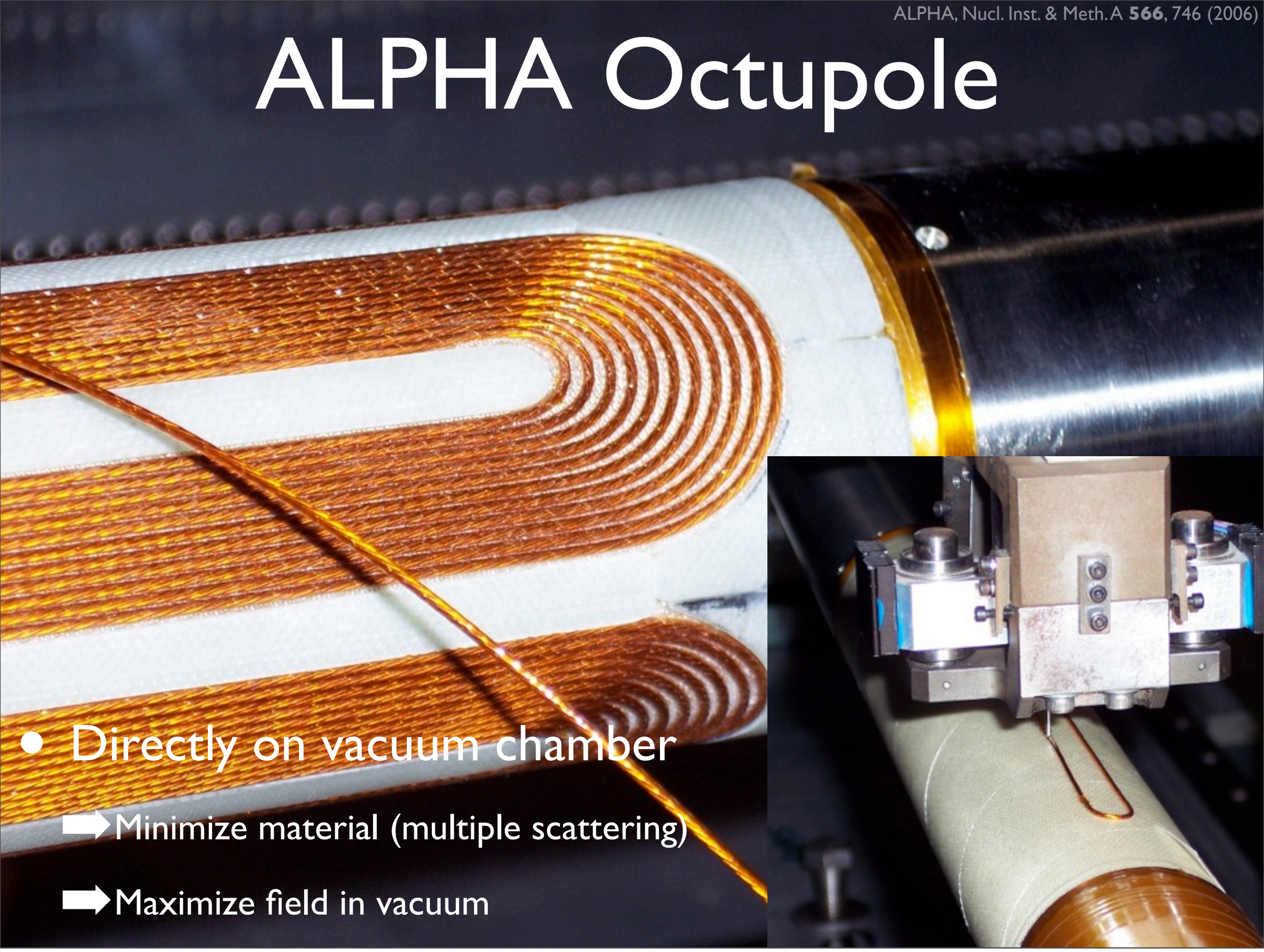
Shallow : ~ 0.7 K/T for H ground state

ALPHA, Nucl. Inst. & Meth. A **566**, 746 (2006)

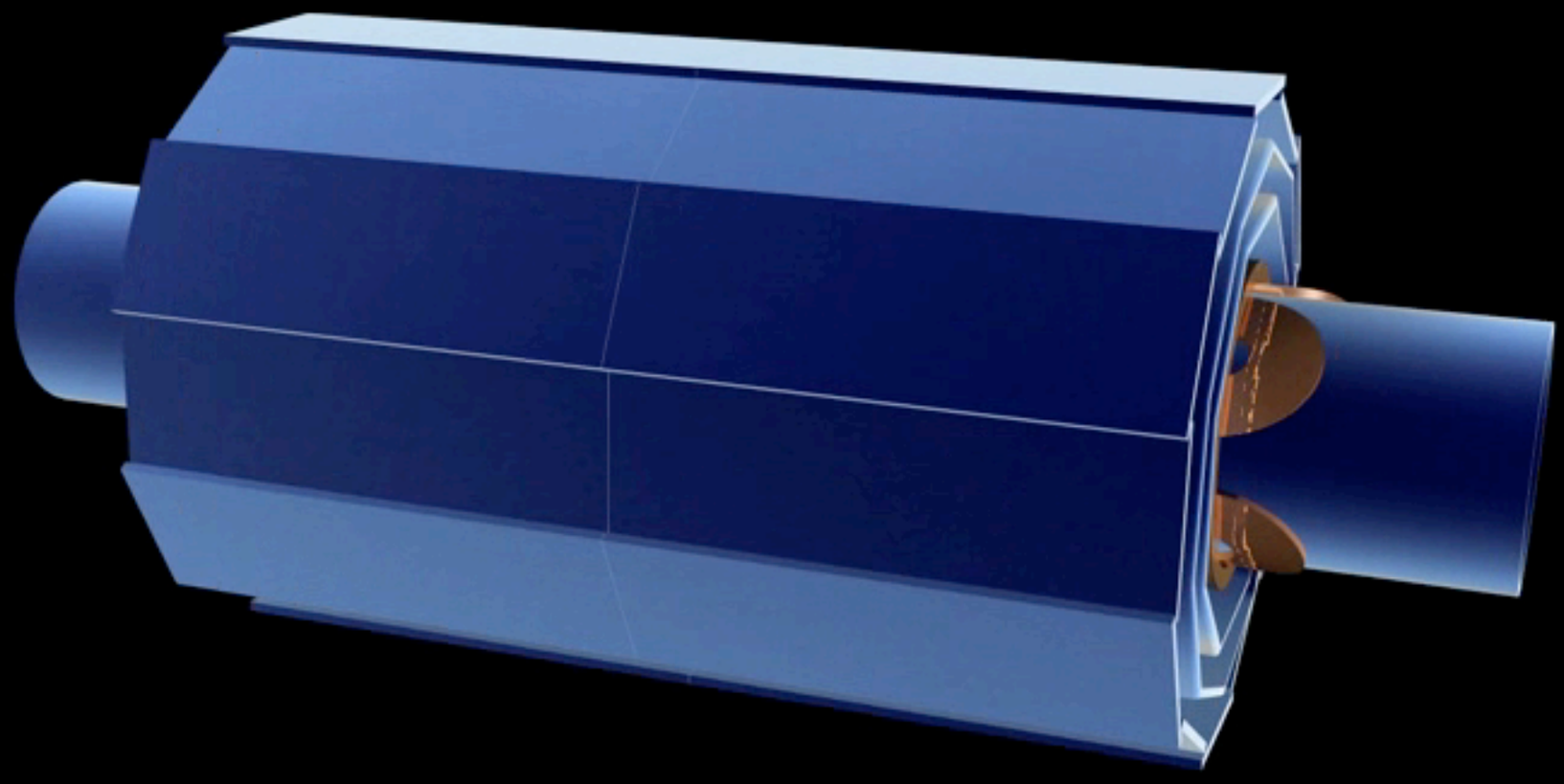
ALPHA Octupole



- Directly on vacuum chamber
  - ➡ Minimize material (multiple scattering)
  - ➡ Maximize field in vacuum

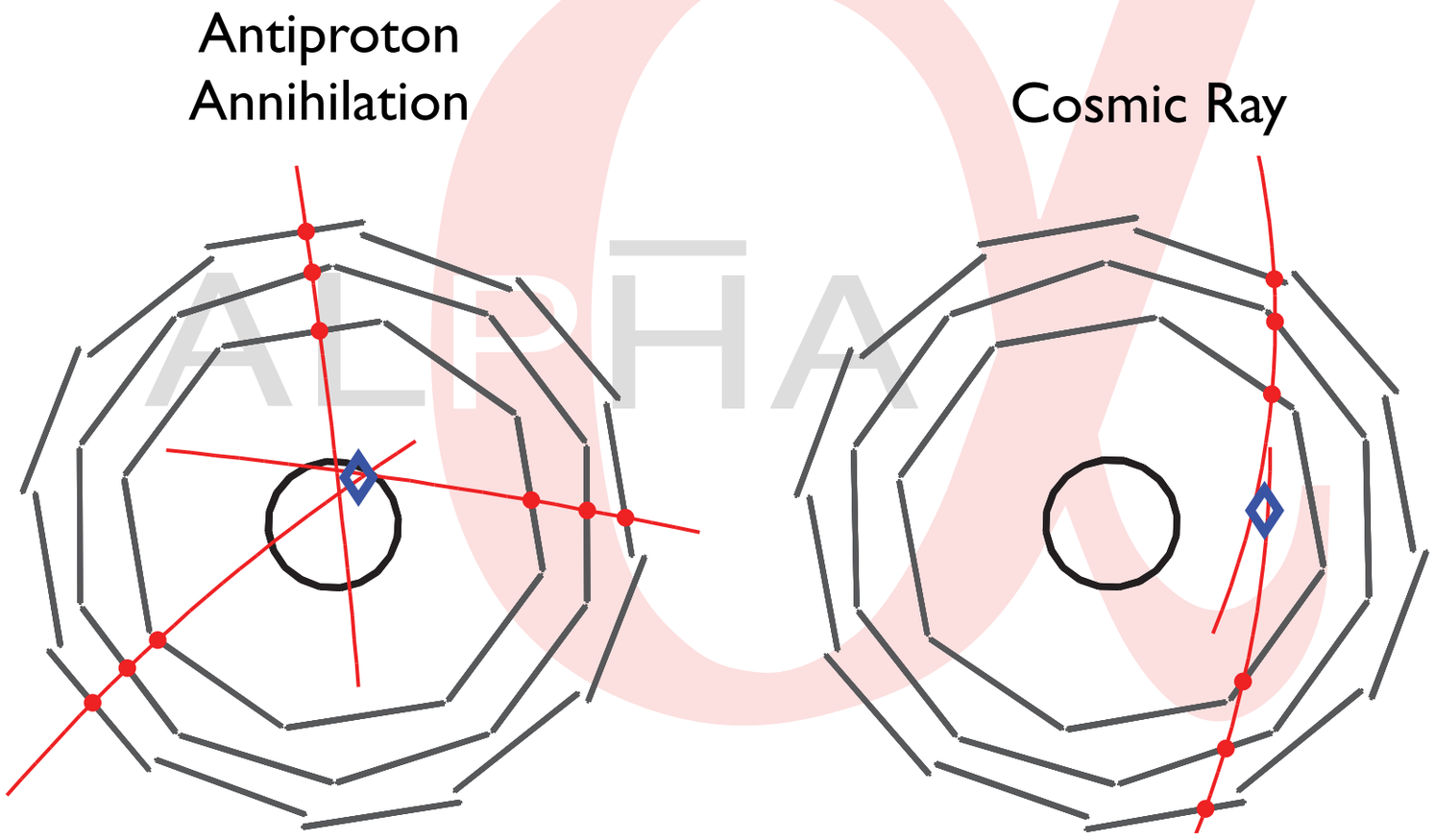
Antihydrogen trapping

GRALLATOR



Cosmic Background

- One fake signal to worry about : cosmic rays!



- Standard (2010/11) : 1.4/1000 cosmic "fakes" / experiments

Phys. Lett. B **695**, 95 (2011)

Mirror Trapping

New J. Phys. **14**, 015010 (2012)

Mirror Trapping

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- To avoid these we apply clearing fields before the trap is turned off.

New J. Phys. **14**, 015010 (2012)

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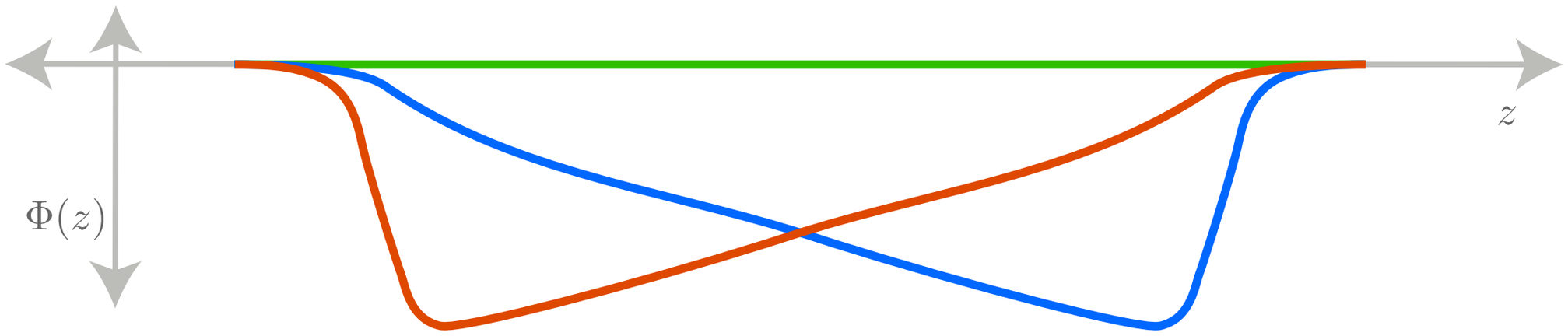
- We distinguished charged particles from neutral using a bias-field (during quench) which does not influence the neutrals!



Trapping Results

- 335 cold e^+ cycles: Each: 30000 $\bar{p}$, 2×10^6 e^+, 5000 $\bar{H}$
- 0.46±0.01 mis-identified cosmics expected

Experiment	Number of attempts	Annihilation events
No bias	137	15
Left bias	101	11
Right bias	97	12
No bias, heated e^+	132	1
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38 annihilation events

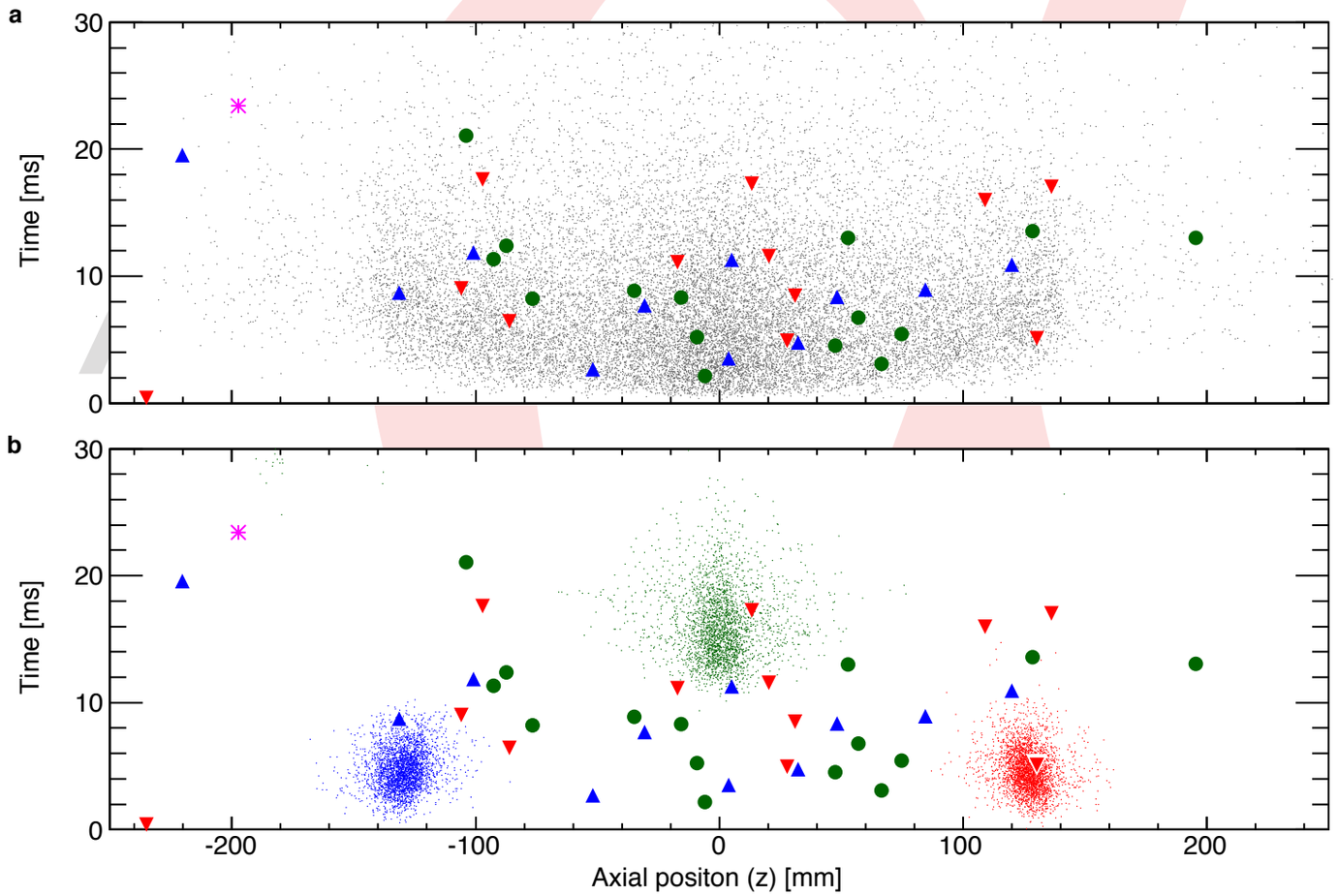
1 "hot" event

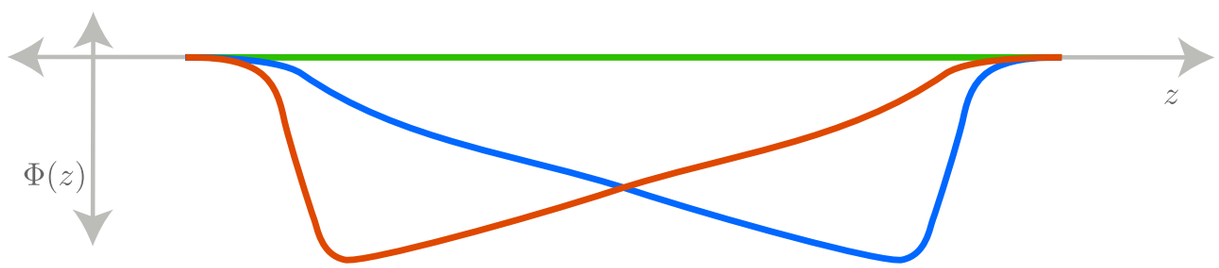
Trapping Results

- No spatial bias in signal; Heating 'turns off' signal

Simulation: Antihydrogen

Simulation: Antiprotons





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Nature **468**, 673 (2010)

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38 Antihydrogen atoms trapped! Background 1.4±1.4

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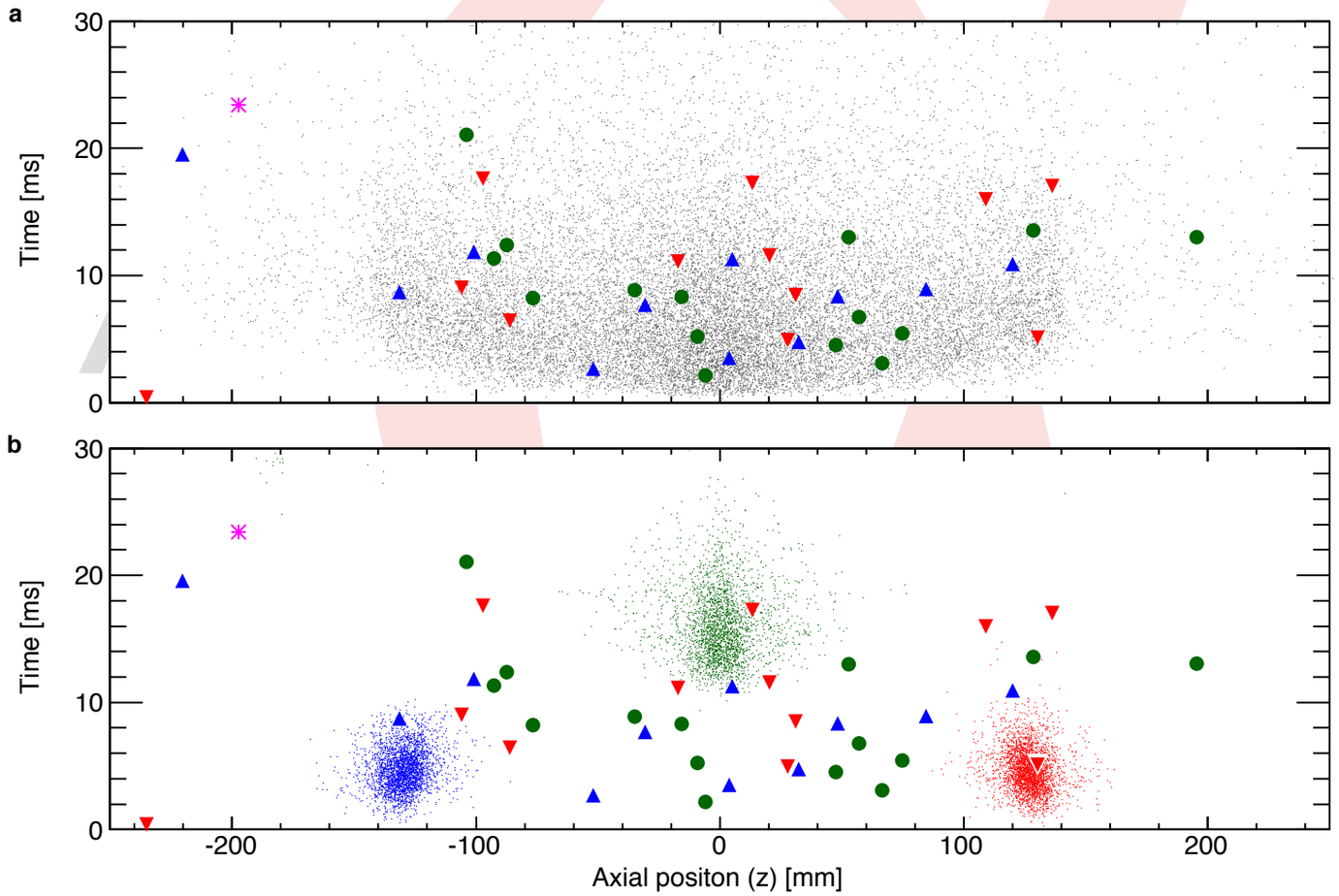

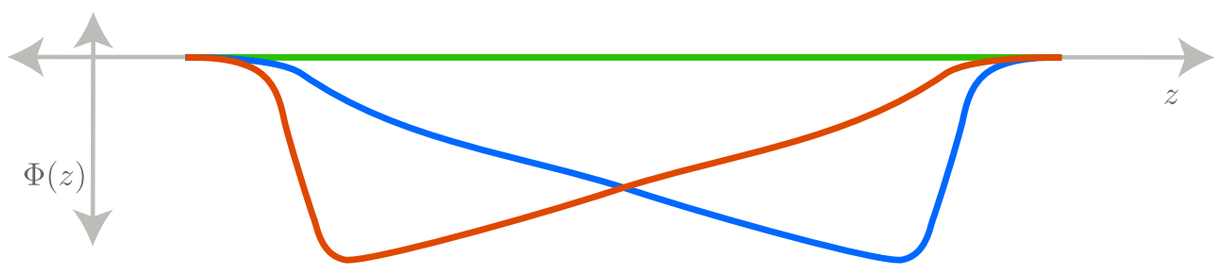

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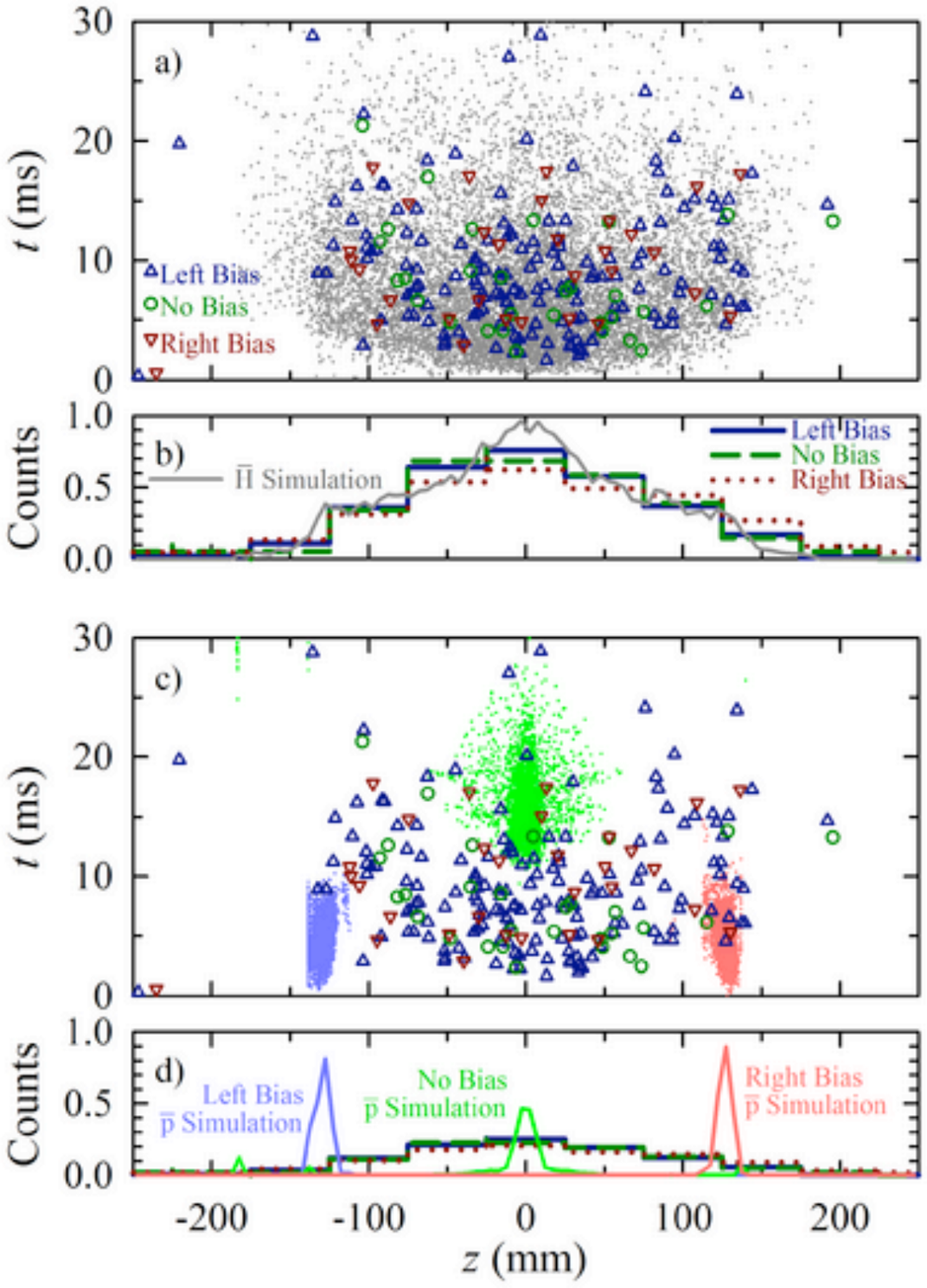
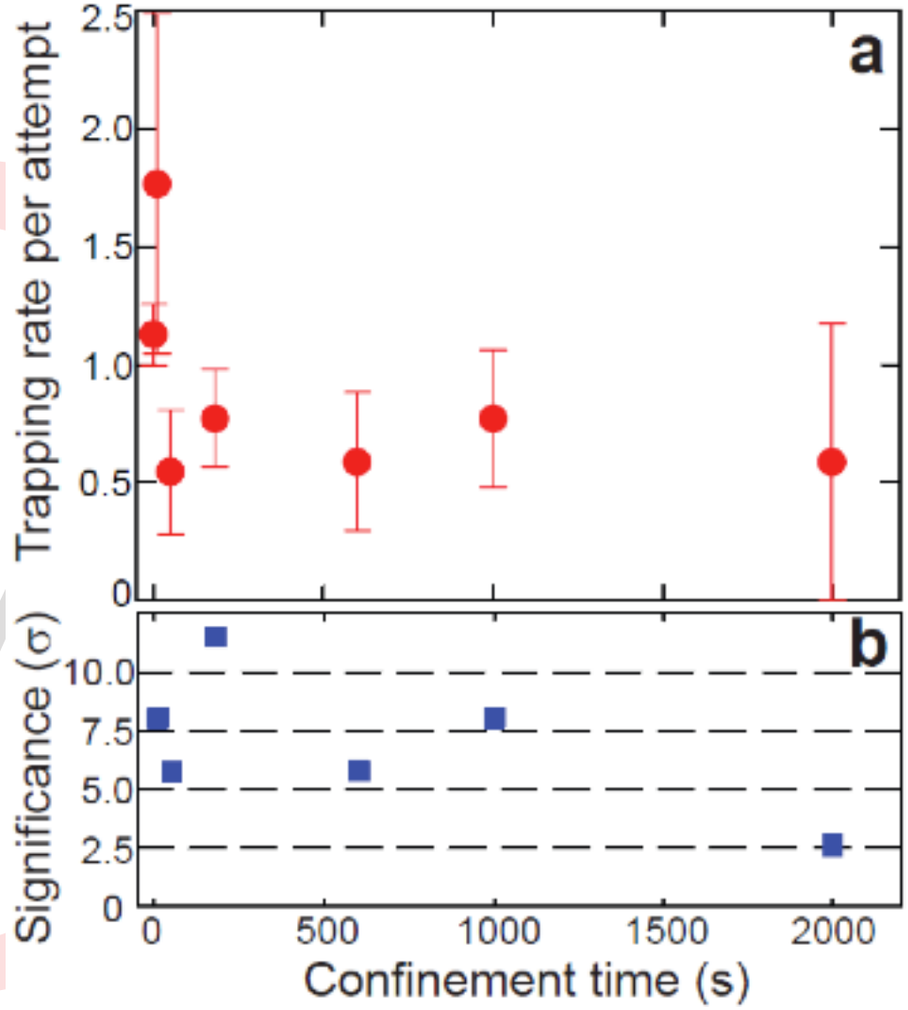
Nature **468**, 673 (2010)

Long time confinement





>300 events!
stored for a 1000s!
1 trapped/experiment!

Nature Physics **7**, 558 (2011)

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- Many techniques developed to reduce energy.
- BUT : Even 1 atom can be interrogated!

Quantum Transitions

Nature, March 7th (2012)

Quantum Transitions

- Trapped atom(s) in the ground state - even if there's only one it is a platform for starting to compare antihydrogen and hydrogen.

Nature, March 7th (2012)

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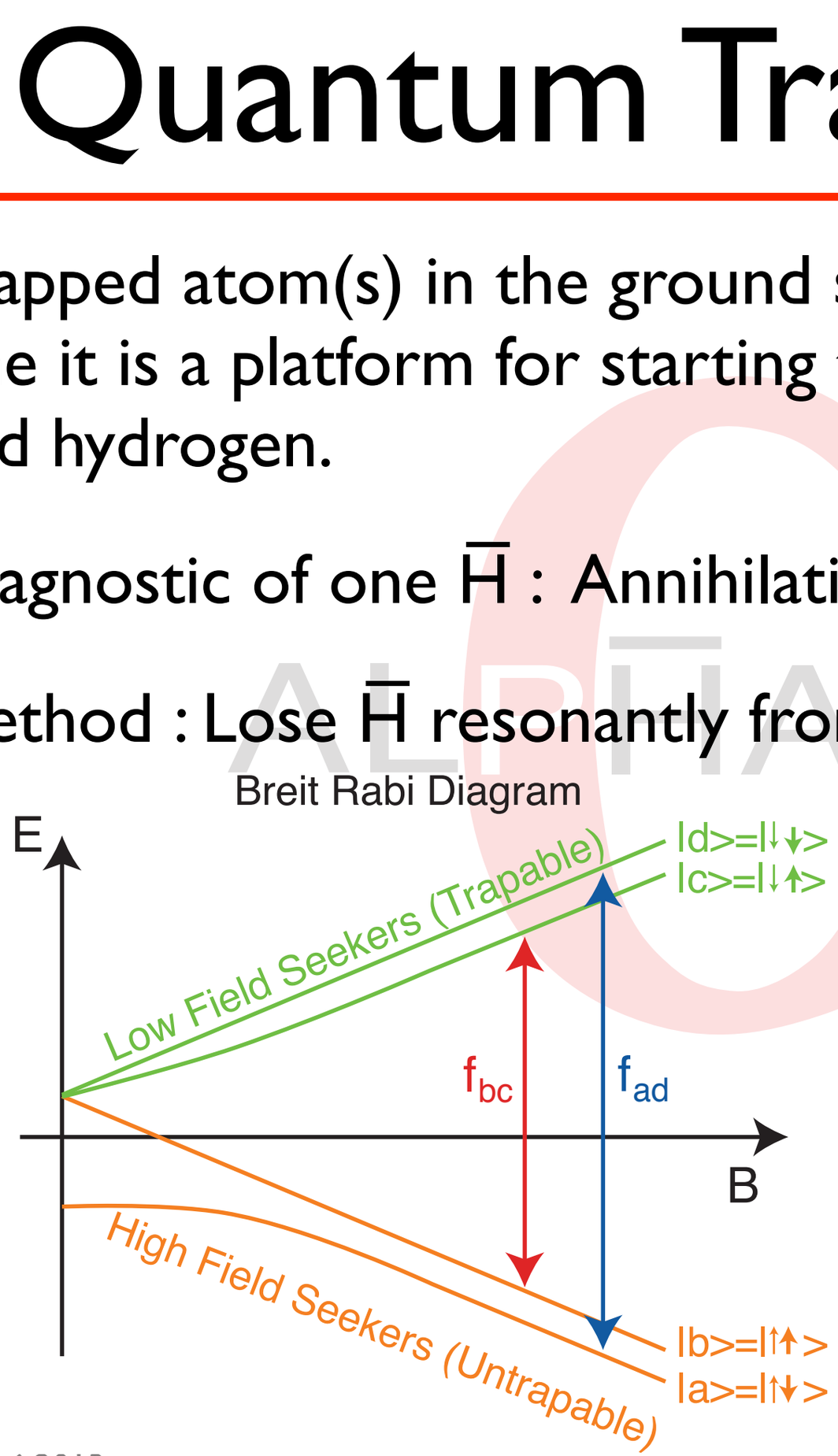
Nature, March 7th (2012)

Quantum Transitions

- Trapped atom(s) in the ground state - even if there's only one it is a platform for starting to compare antihydrogen and hydrogen.
- Diagnostic of one $\bar{H}$: Annihilation detection
- Method : Lose $\bar{H}$ resonantly from trap - spin flip.



Details : Prof. M. Hayden, Monday 11h00

Nature, March 7th (2012)

Microwave Spectroscopy

microwave
spectroscopy

Disappearance Summary

- Clear decrease observed in on-resonance relative to off-resonance

	Attempts	Antihydrogen left	Rate
ON resonance	103	2	0.02±0.01
OFF resonance	110	23	0.21±0.04
NO μ-waves	100	40	0.40±0.06

$p = 1.0 \times 10^{-5}$

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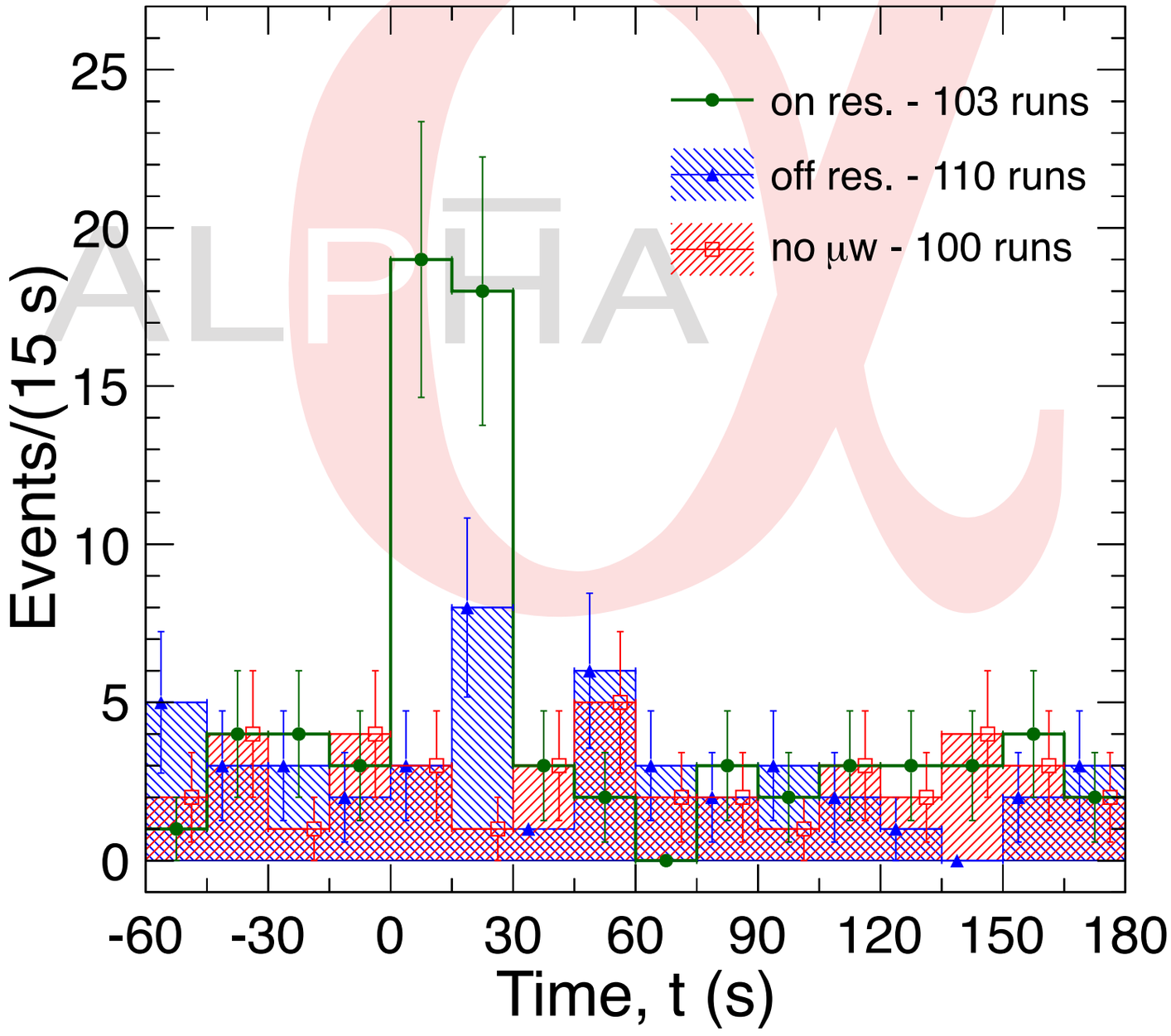
313 attempts 20min each - 104h - 2w (no hickups)

Nature, March 7th (2012)

Appearance Measurement

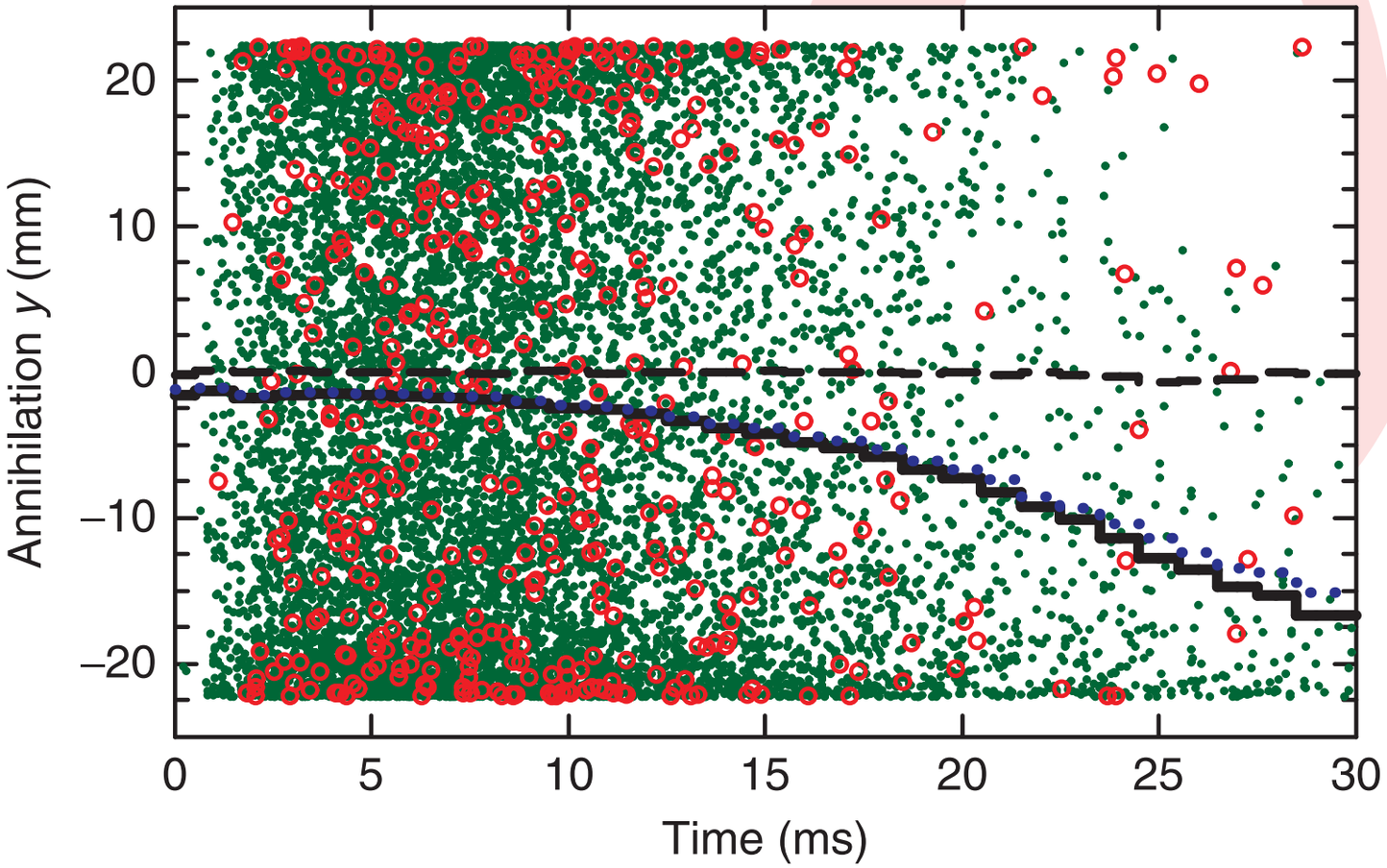
- Significant excess in first 2 sweeps in the 0-15s + 15-30s windows



Nature, March 7th (2012)

First "stab" at Gravity

- Using the position sensitivity of our detector and the "long" shutdown time we're sensitive to some deviations from standard gravity...



Simulation for $M_{gravity}/M_{inertial}=100$

- Details: Friday morning 9h30, Prof. J. Fajans

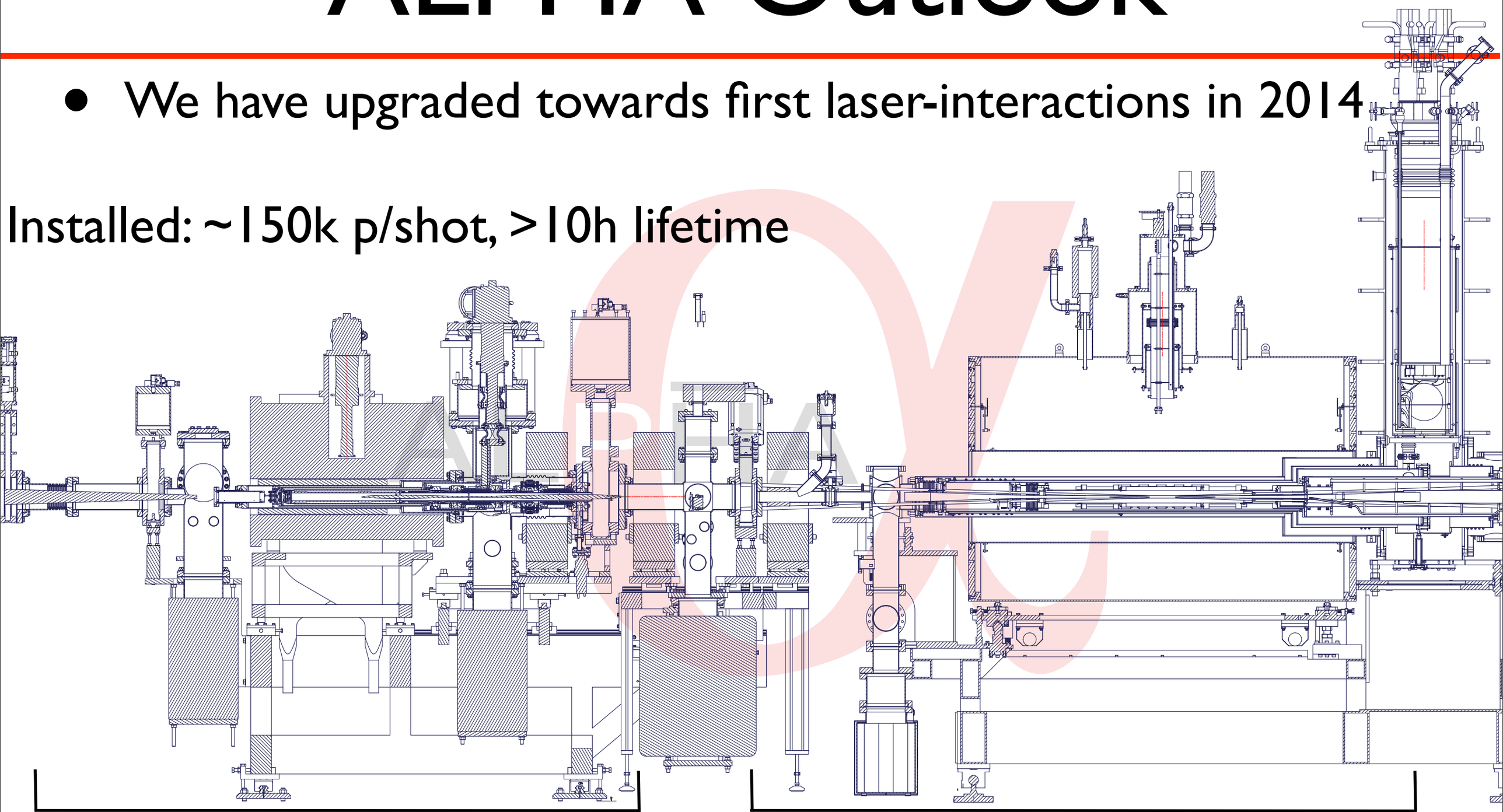
Nat. Comm., **4**,1785 (2013)

Where are we now

ALPHA Outlook

- We have upgraded towards first laser-interactions in 2014

Installed: ~150k p/shot, >10h lifetime



$\bar{p}$ catch and accumulation

$\bar{H}$ formation, trap and spectroscopy

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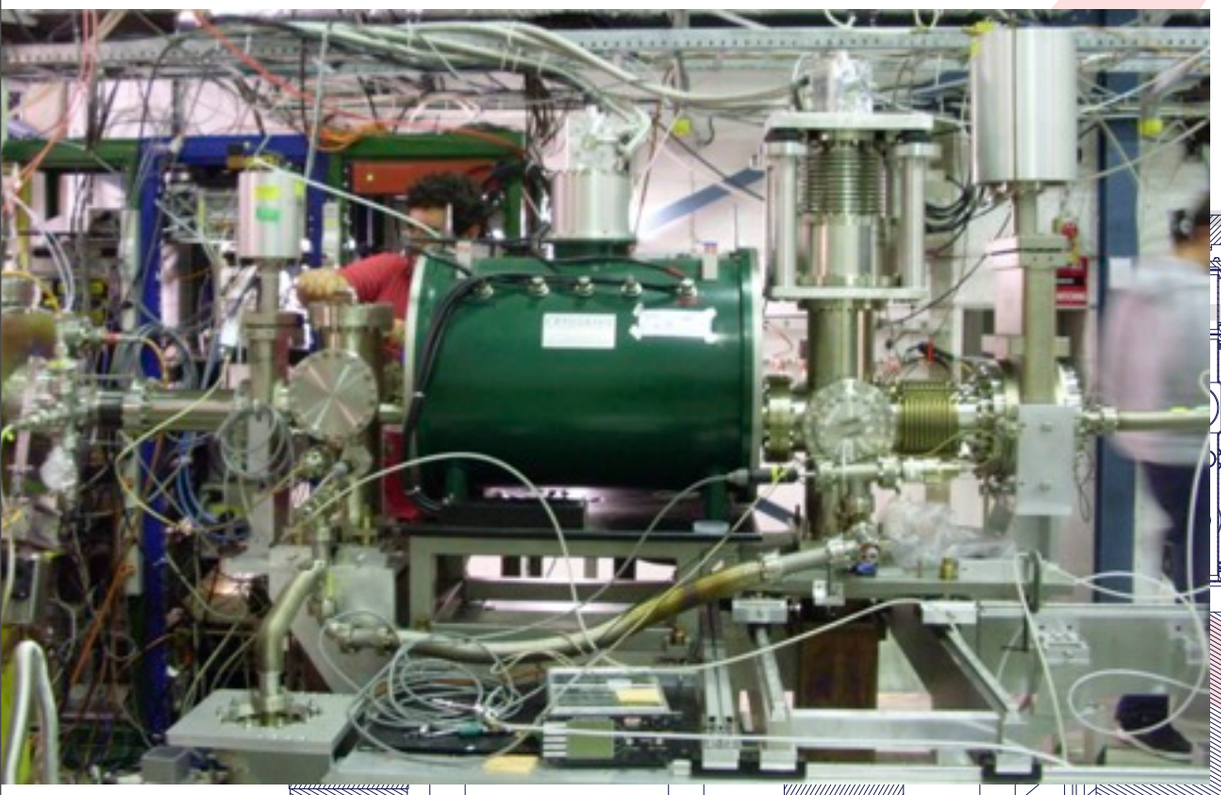

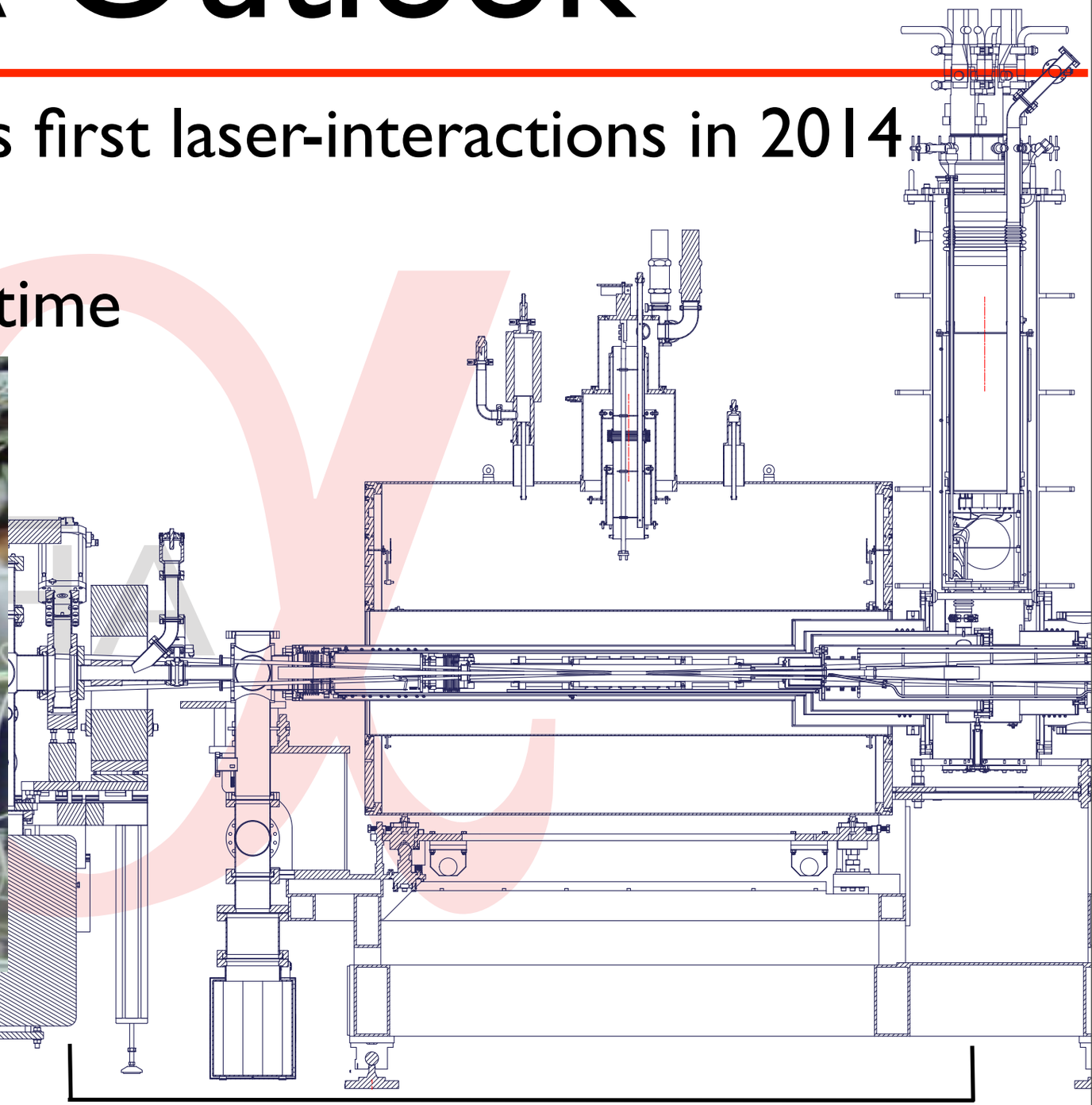

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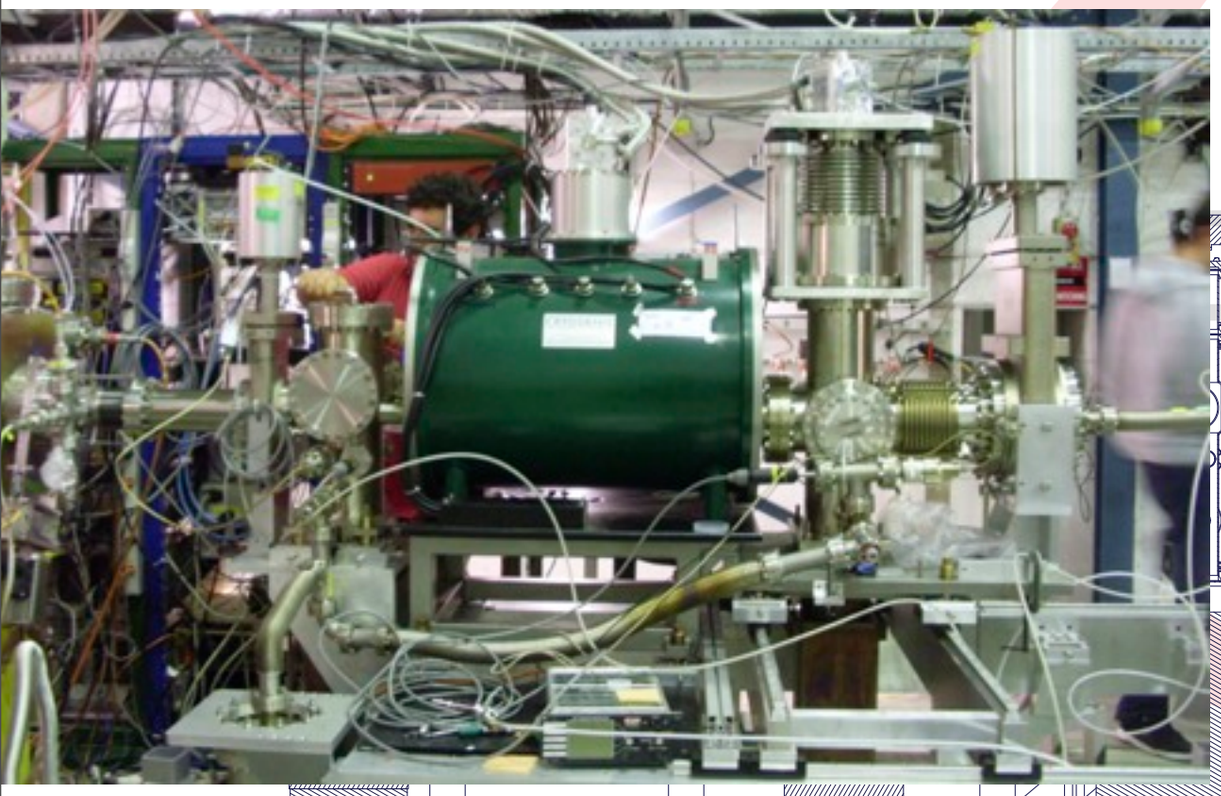

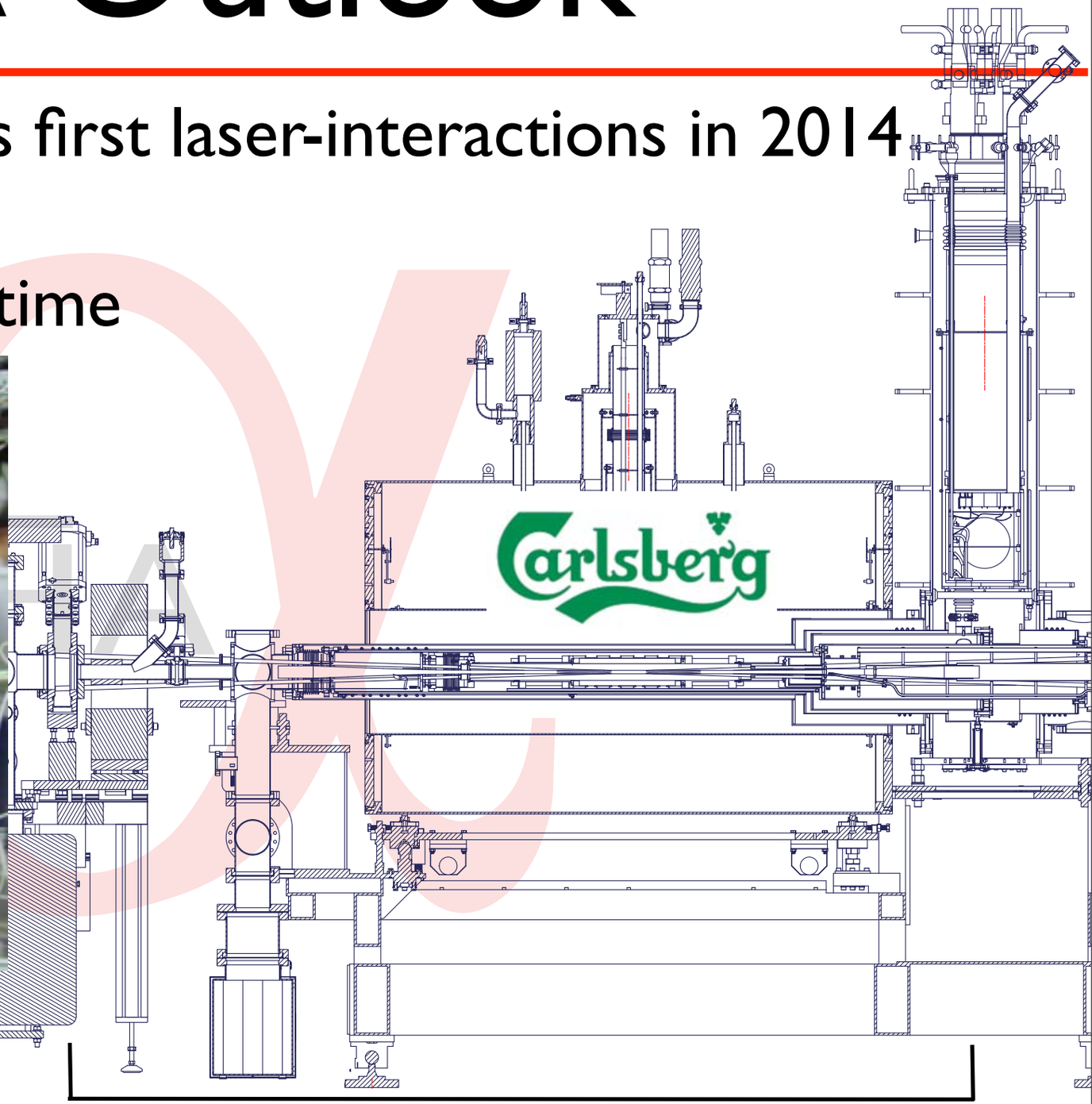

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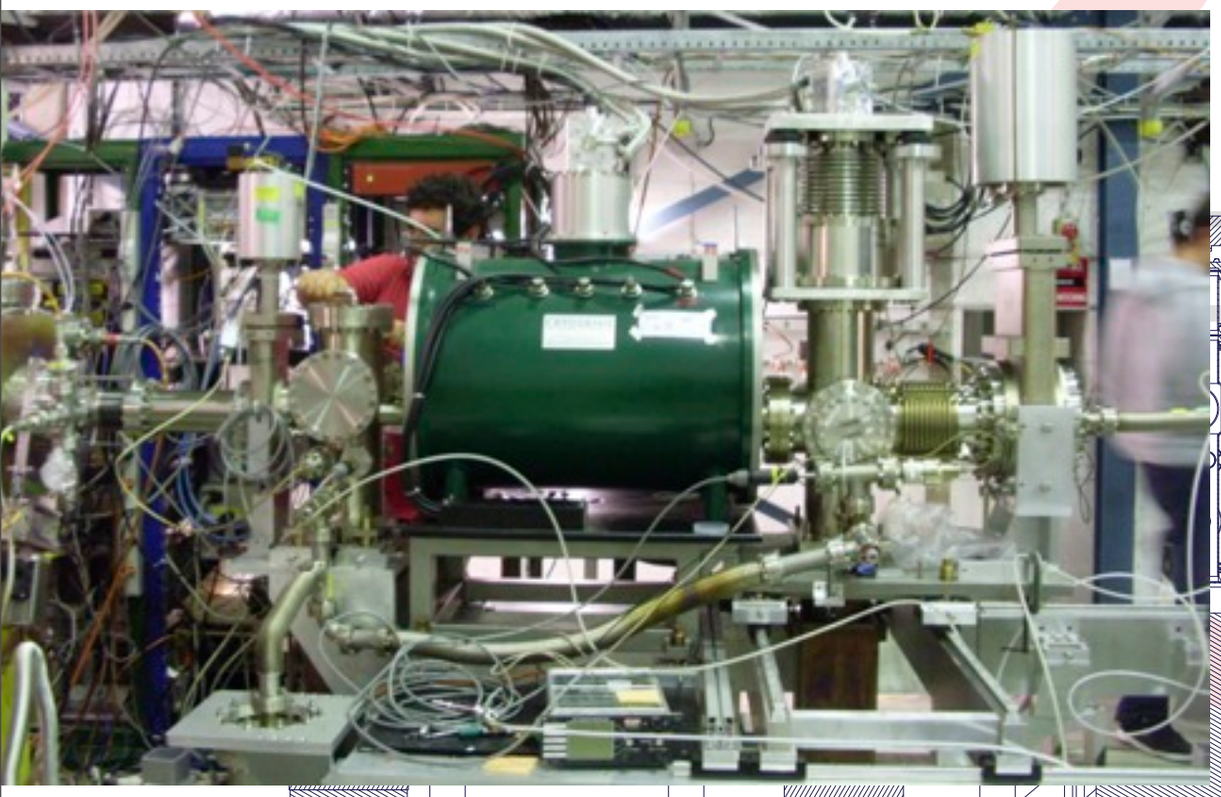
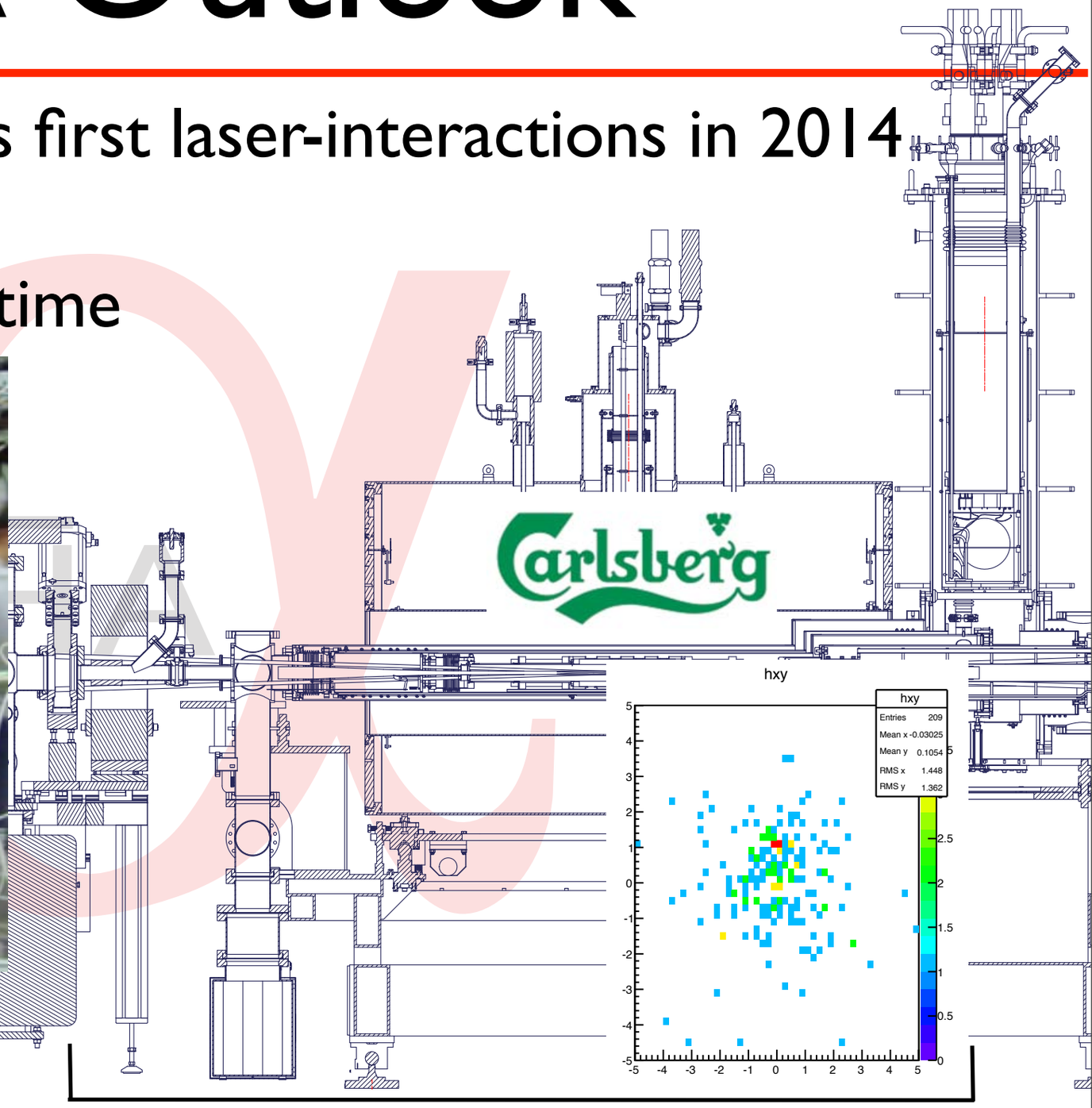
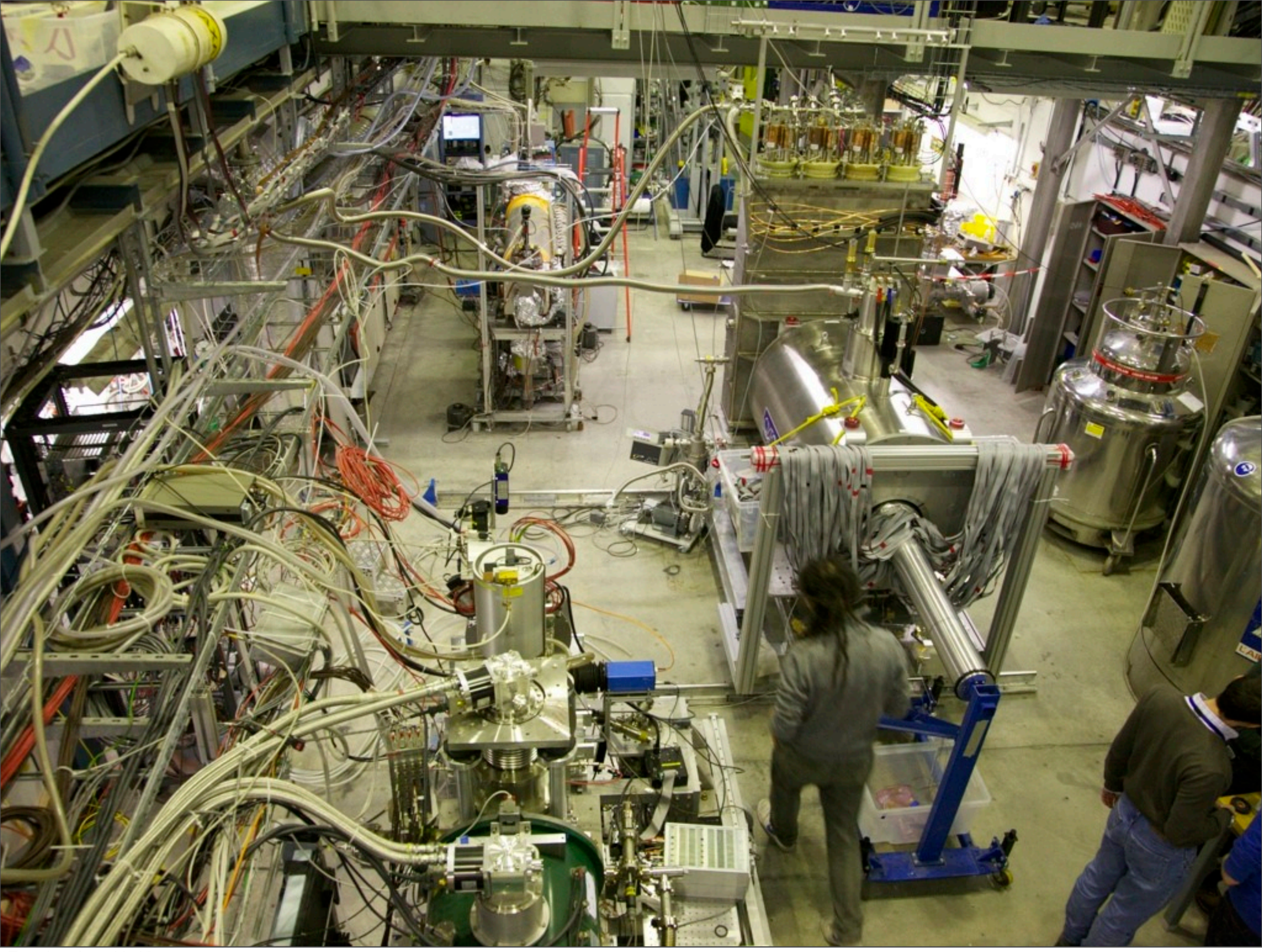


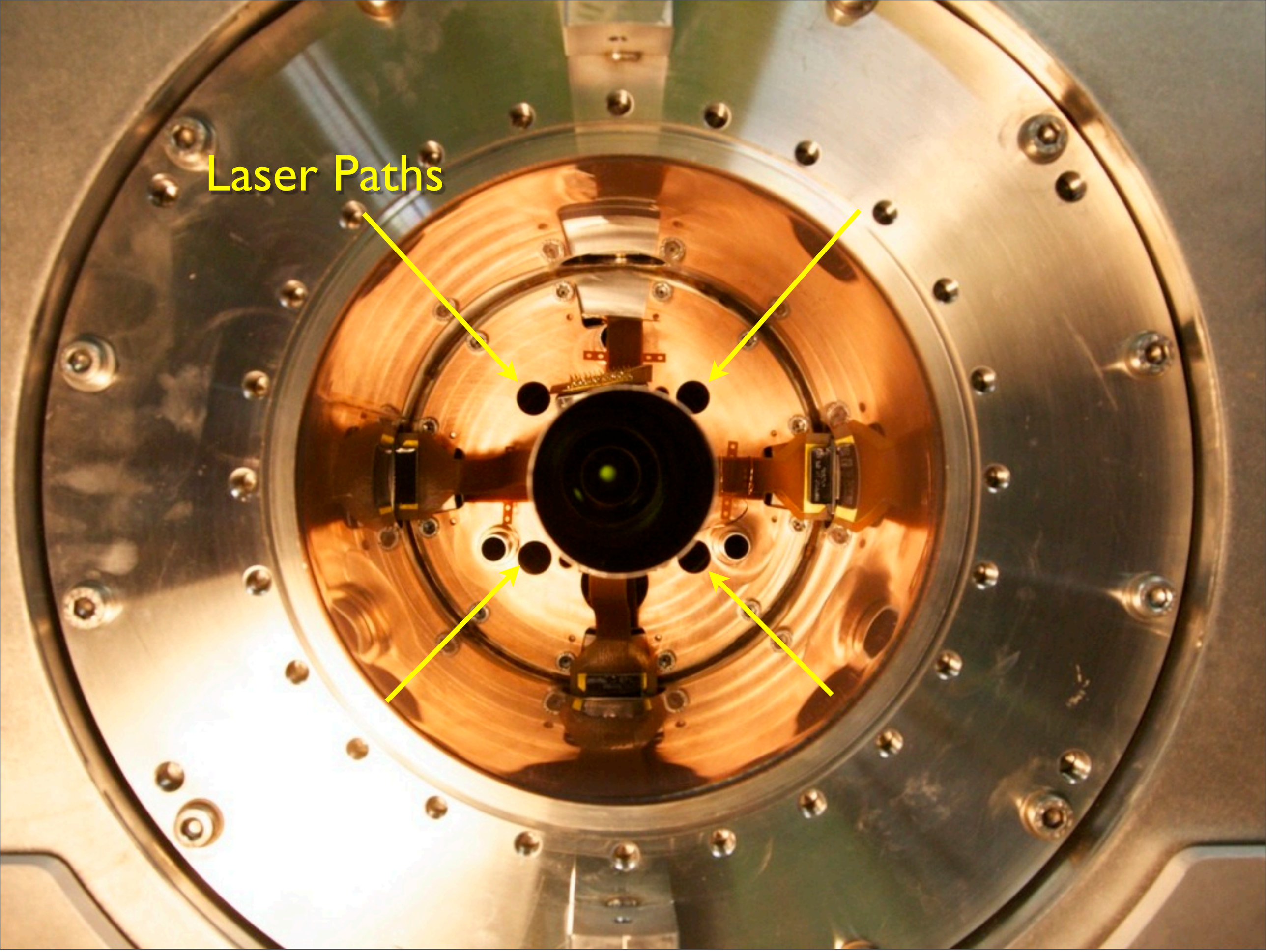


$\bar{p}$ catch and accumulation

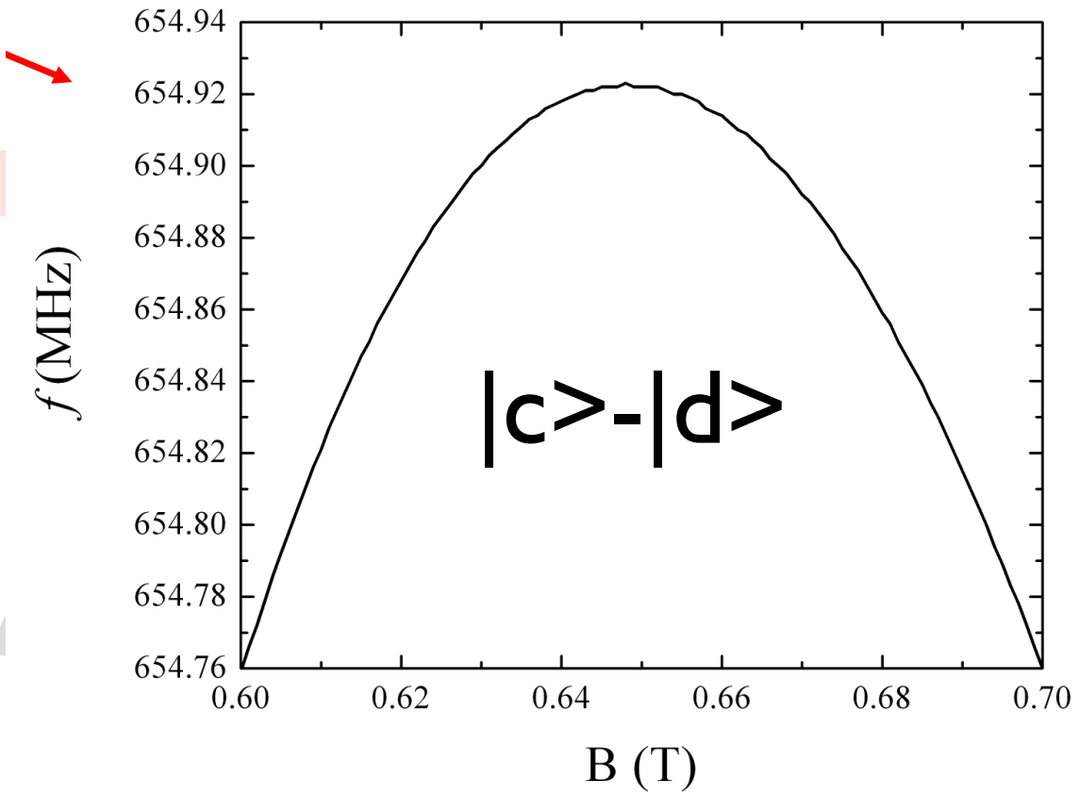
$\bar{H}$ formation, trap and spectroscopy

Modular approach - ELENA & "$\bar{g}$" ready



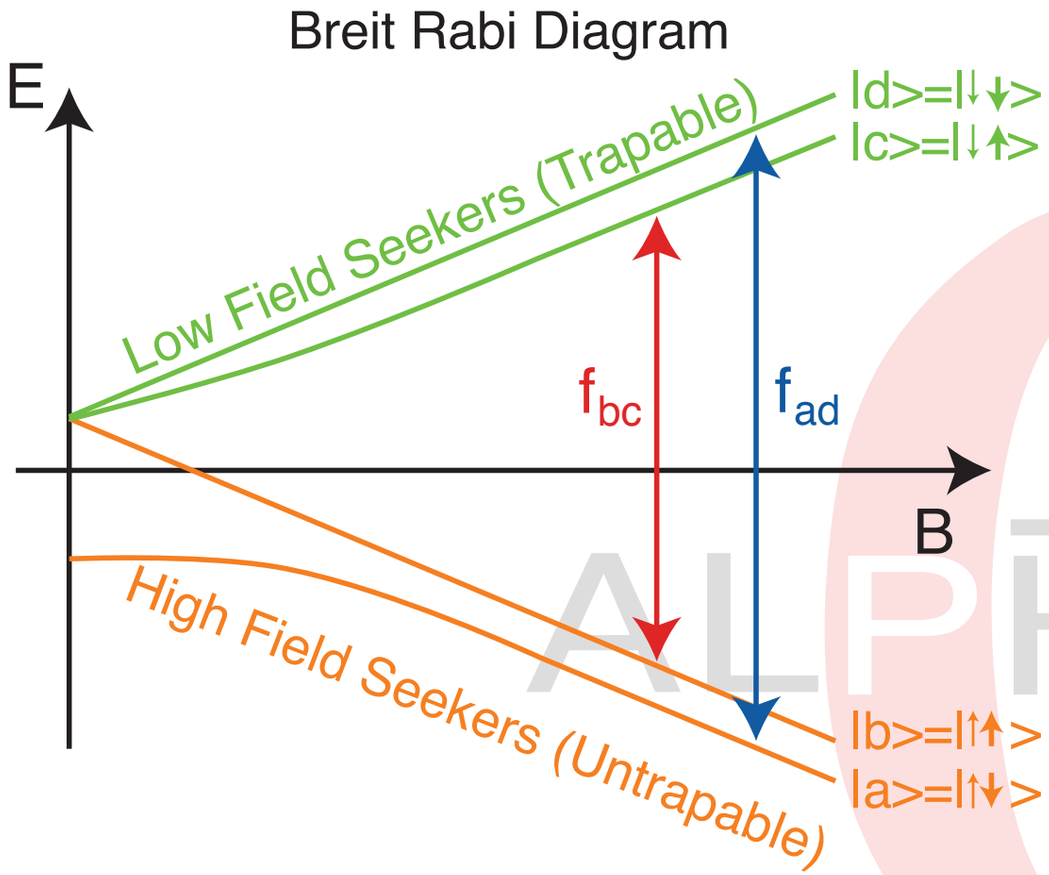

Laser Paths

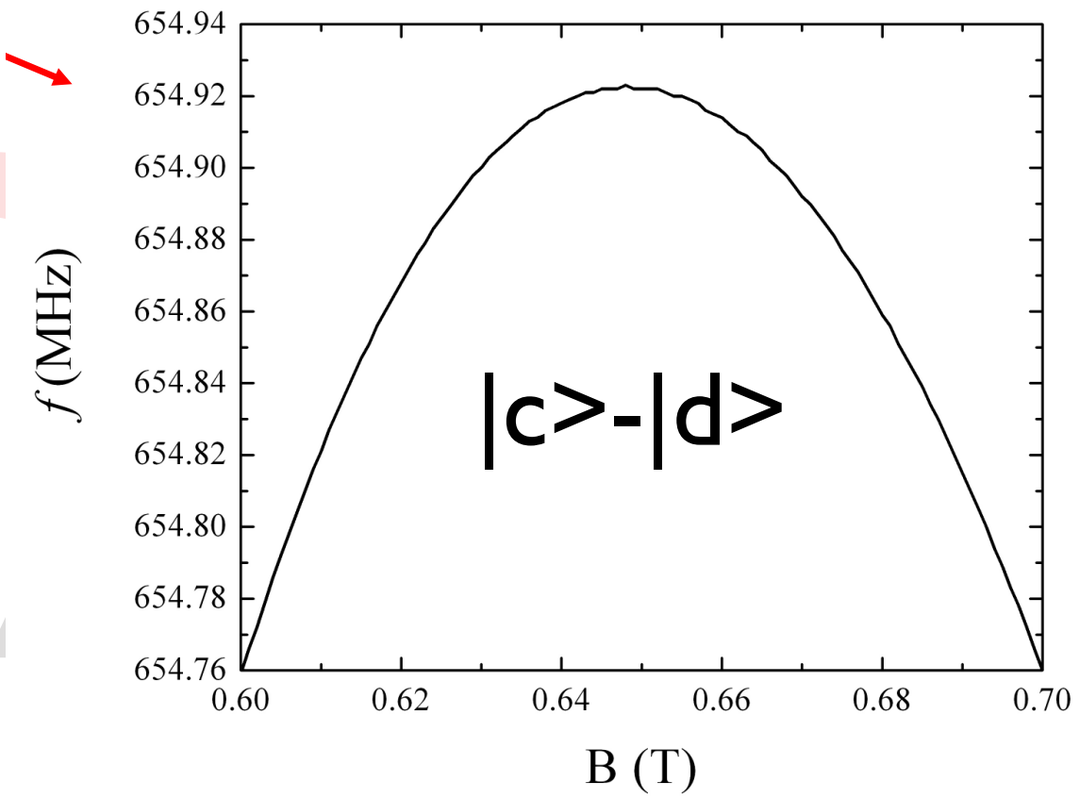
μ-waves continued



- NB: Antiproton μ - known only to ~ 10^{-3}
- We can also measure the Hyperfine splitting (f_{ad}-f_{bc}) which is independent of B !
- Upgrade includes μ-waves! 10^{-6} -> 10^{-8} potential!

μ-waves continued





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Pre-requisite... and preps...

- While micro-wave and gravity measurements have been demonstrated with ~1 atom trapped/experiment (every ~15 min) and laser experiments are pending return of $\overline{p}$s - it's not ideal and will pose a limit to the ultimate precision.
- We seem limited by the plasma (in particular e^+) temperatures...
- Upgrade and other initiatives are aimed at making the e^+ colder for increased trapping rates.
- Successful commissioning of the ALPHA-upgrade cryostat + ~1y to tune all our "guns" = steady progress towards first laser-interaction with $\overline{H}$ in the fall of 2014...


nature physics
Thank you for listening.