ATRAP: Future and ELENA

G. Gabrielse,[1,*] W. S. Kolthammer,[1] R. McConnell,[1] P. Richerme,[1] R. Kalra,[1] E. Novitski,[1] D. Grzonka,[2] W. Oelert,[1] T. Sefzick,[2] M. Zielinski,[2] D. Fitzakerley,[3] M. C. George,[3] E. A. Hessels,[3] C. H. Storry,[3] M. Weel,[3] A. Müllers,[4] and J. Walz[4]

(ATRAP Collaboration)

[1]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
[2]IKP, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany
[3]Department of Physics and Astronomy, York University, Toronto, Ontario M3J 1P3, Canada
[4]Institut für Physik, Johannes Gutenberg Universität and Helmholtz Institut Mainz, D-55099 Mainz, Germany

Antihydrogen and the Antiproton Magnetic Moment

Gerald Gabrielse
Spokesperson for TRAP and ATRAP at CERN
Leverett Professor of Physics, Harvard University

ATRAP Program

1. Comparison of Antihydrogen and Hydrogen Structure (laser spectroscopy in a trap)
   - Trap useful number of antihydrogen atoms
   - Laser cool antihydrogen atoms with Lyman alpha laser
   - Lyman alpha spectroscopy
   - Near resonant two photon spectroscopy
   - 1s-2s two photon spectroscopy

2. Comparison of Magnetic Moments of Antiproton and Proton
   - Finish developing spin flip methods with a proton
   - Compare magnetic moments at first experimental port

Not the Usual CERN Experiment

High Energy Experiments:

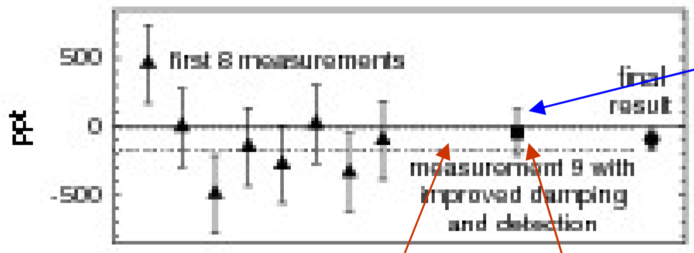
Given luminosity → Gives rise to a predictable signal in well-understood detectors

Low Energy, High Precision Experiments

- Always looking for new ways to detect tiny signals
- Spend the time inventing rather than counting
- Limited by systematic uncertainties and statistics
- Too many branch points to make a realistic chart

(more art than industry)

e.g. Last TRAP Measurement of Antiproton Q/M



done with
a single antiproton

improved
apparatus
and technique

Low Energy Antiproton Ring
(LEAR) shut down

In the end we used only one single antiproton, as promised,
But it took a lot of antiprotons to develop the techniques

Could do significantly better!

Why More Antiprotons are Crucial?

1. More antiprotons would speed up the antihydrogen progress

   ATRAP and ALPHA, per 100 second AD cycle
   accumulate ~ 100 million positrons
   accumulate ~ 1 million antiprotons (10 million takes too long)

   30 times more antiprotons → 30 times more antihydrogen

2. More antiprotons → more antihydrogen → more measurement precision

3. More antiprotons are needed to accommodate 4 collaborations approved to do antihydrogen experiments

4. Simultaneous operation of all experiments

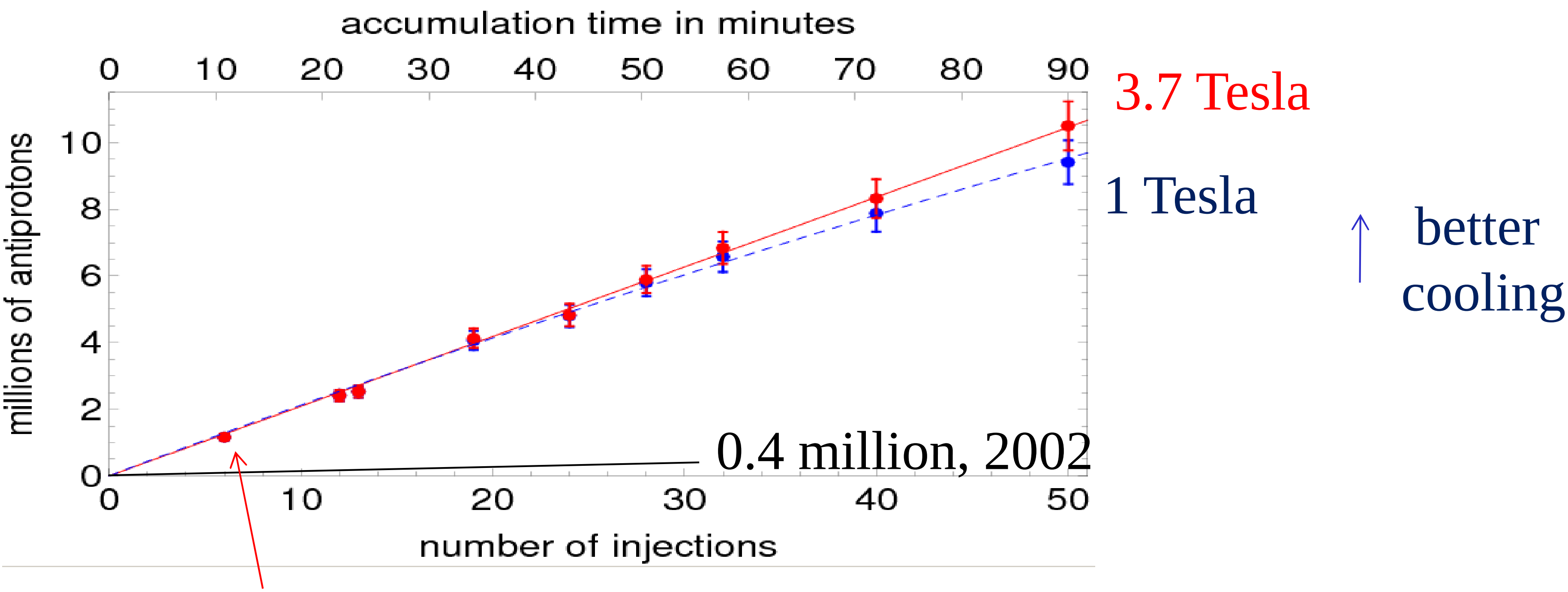
extremely important

Currently Takes Much Too Long to Accumulate 10 Million Antiprotons

ATRAP

0.4 million → 10 million
(5.4 Tesla) (1 Tesla)

Takes much too long



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Compare Antiprotons Accumulate Per AD Cycle Without and With a Decelerator

	million pbars / AD cycle
No decelerator:	0.1
RFQ decelerator: (10 million pbars decelerated)	1
ELENA decelerator:	3 ??

(design report 10 million pbars at 100 keV)

- much larger acceptance (robust for regular use)
- electron cooling
  - → narrower energy distribution
  - → more trapped antiprotons

ELENA → 30 times more pbars trapped (perhaps more)

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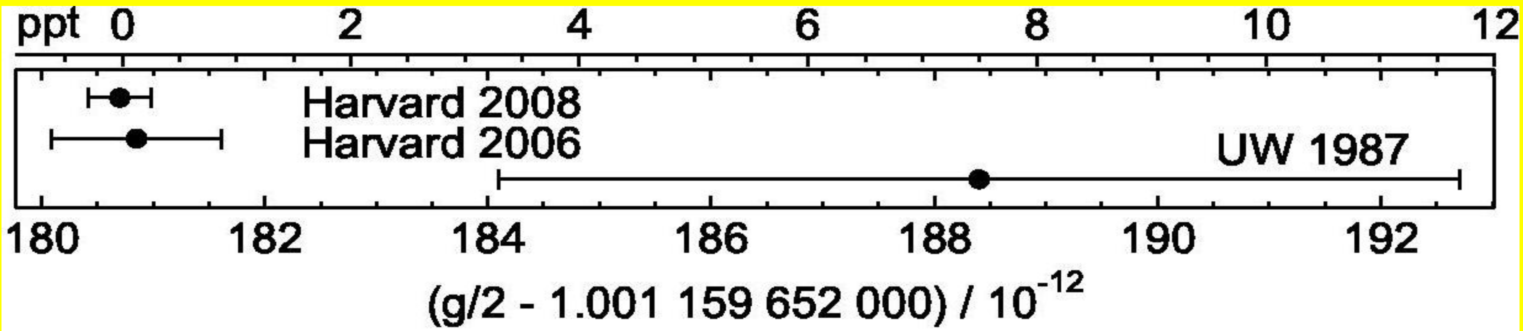
How We Do High Precision Measurements at Low Energy

100 mK

e.g. most accurate measurement of the properties of an elementary particle (and the fine structure constant, and QED test)

2.8×10^{-13}



electron magnetic moment in Bohr magnetons

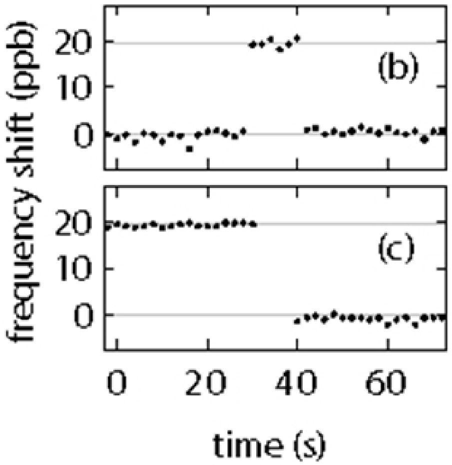
D. Hanneke, S. Fogwell, G. Gabrielse, PRL (2008), PRA (2011)

- First improved measurements (2006, 2008) since 1987
- 15 times smaller uncertainty
- 1.7 standard deviation shift
- 2500 times smaller uncertainty than muon g

Dehmelt, Van Dyck, Schwinberg

Resolve the Lowest Quantum Transitions of a One-Electron Cyclotron

QND observations of one-quantum transitions



one quantum cyclotron excitation

spin flip

How we did these measurements:

During the workday → tune apparatus and develop methods

During evening and night → computer takes data

Experiment runs 24 hours with a very small crew

Compare to How AD Will Work

How we did the high precision electron experiments

During the workday → tune apparatus and develop methods

During evening and night → computer takes data

Experiment runs 24 hours with a very small crew

How the AD will work before ELENA

ATRAP will get a 6 hour shift per day (on average)

At most 6 antihydrogen data points per day

AD plus ELENA upgrade

ATRAP can run in the same mode as at Harvard

(as can all other experiments)

Experiments Can Take Antiprotons Every AD Cycles (or almost every cycle)

Stable electrostatic beam lines to be developed and built as part of ELENA upgrade

- requires accelerator expertise
- operation of the AD/ELANA required uniform implementation and common control of the beam lines
- need reliable switching between experiments during or between 100 s AD cycle
- beam line diagnostics should make it possible to correct beam trajectory after a single pbar ejection from the AD

Challenge: large fringe fields of superconducting magnets interferes with beam transport

Conclusion

Thanks to CERN for committing to the Elena upgrade to the AD

More antiprotons → more antihydrogen → more precise spectroscopy

Continuous operation and progress
→ Much more efficient use of CERN's unique low energy pbars

Challenges that must be carefully dealt with

- Stable and reliable switching between experiments
- Magnetic fringing fields