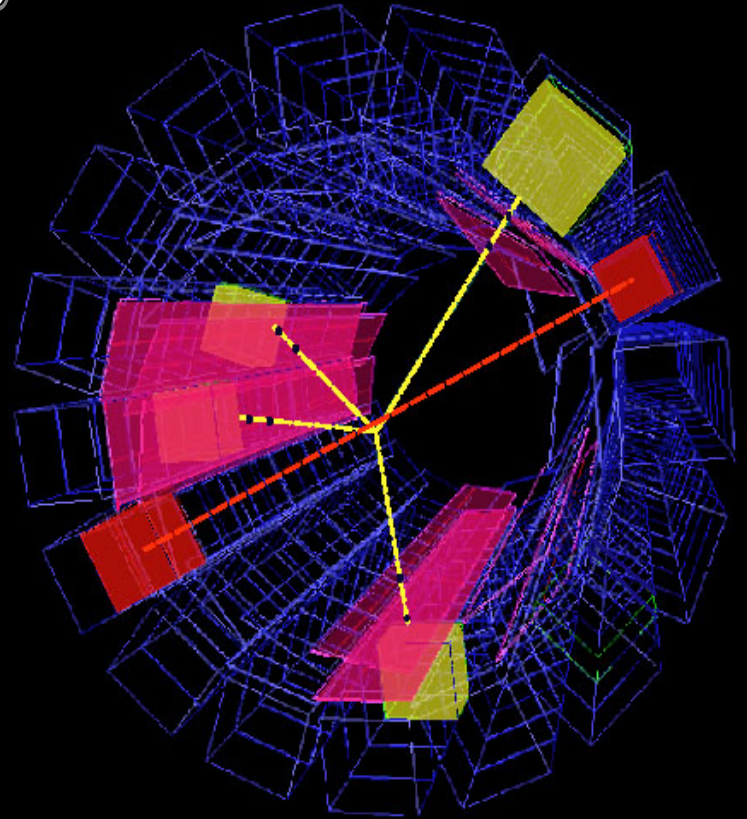




# Antihydrogen Symmetry Tests with ALPHA

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# Purpose of this presentation

- Physics case: Response to IPP Brief
- Antihydrogen in Canadian SAP context

# Project ALPHA

- Antihydrogen produced in ATHENA and ATRAP were not confined
- Trapping them will be essential next step
- ALPHA (successor to ATHENA) Initial Goal:
  - Stable trapping of cold antihydrogen atoms in a magnetic trap
  - Develop methods for antihydrogen spectroscopy

# Event History

- ALPHA was invited to submit a brief to both DNP and IPP
- IPP indicates that ALPHA will not be part of IPP vision
- We agree that this is not a standard particle physics experiment
- It is more appropriately categorized as a part of DNP's fundamental symmetries program
- Combining many disciplines, we will address some of the most fundamental questions in physics

# IPP Brief

“It is not clear if we could support:

A significant Canadian effort on the ALPHA antihydrogen project,

*as it is unclear whether the CPT tests it will make are likely to compete with those made in other subatomic physics measurements.”*

→ We wish to counter the negative impression

# CPT Symmetry

- One of the most fundamental symmetries
  - Foundation of Quantum Field Theory, on which SM and many of its extensions rest
  - CPT Theorem:
    - Lorentz invariance
    - Locality
    - Unitarity
  - Unlikely to be violated on theoretical ground?
- This is an experimental question
  - Many of fundamental symmetries in Nature are broken (parity, time reversal, chiral sym, EW, SUSY)

# CPT Violation: Theoretically possible?

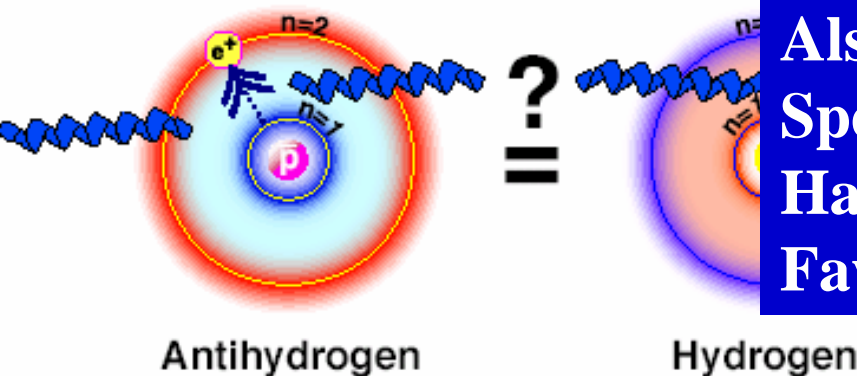
- Assumptions (Lorentz, Locality, Unitarity) could be wrong, e.g. at Planck scale ( $10^{19}$  GeV)
- Theoretical speculations do exist (Kostelecky, Ellis, Mavromatos, Pospelov ...)
- Baryogenesis via CPT violation in thermal equilibrium. (Dolgov, Zeldovich)
  - $\Delta m_t \sim 10^{-6}$  sufficient to produce  $N_B/N_\gamma \sim 10^{-10}$
- In some theory Lorentz Viol. necessary for CPTV
  - Matter expt's can rule out large parameter space, but
  - Antimatter expt's give direct measures of some param.
- Other possibilities
  - Locality: string theories may or may not violate CPT
  - Unitarity: topologically non-trivial fluctuation in space time background (Hawking, Ellis)

# Direct CPTV: Low Energy Tests

- No underlying theory
  - No reliable figures of merit
  - No single gold-plated measurement
  - Each particle sector *complimentary*
- Where to look?
  - Highest energies (c.f. UHE cosmic rays,  $\gamma$  rays)
  - Highest precisions
    - Compare matter-antimatter in best measured observables
  - Lowest absolute energies
    - At low energies, CPTV could be Planck-suppressed  
e.g.  $m_p^2/M_{\text{planck}} \sim 10^{-19}$  GeV

# Hydrogen-Antihydrogen comparisons

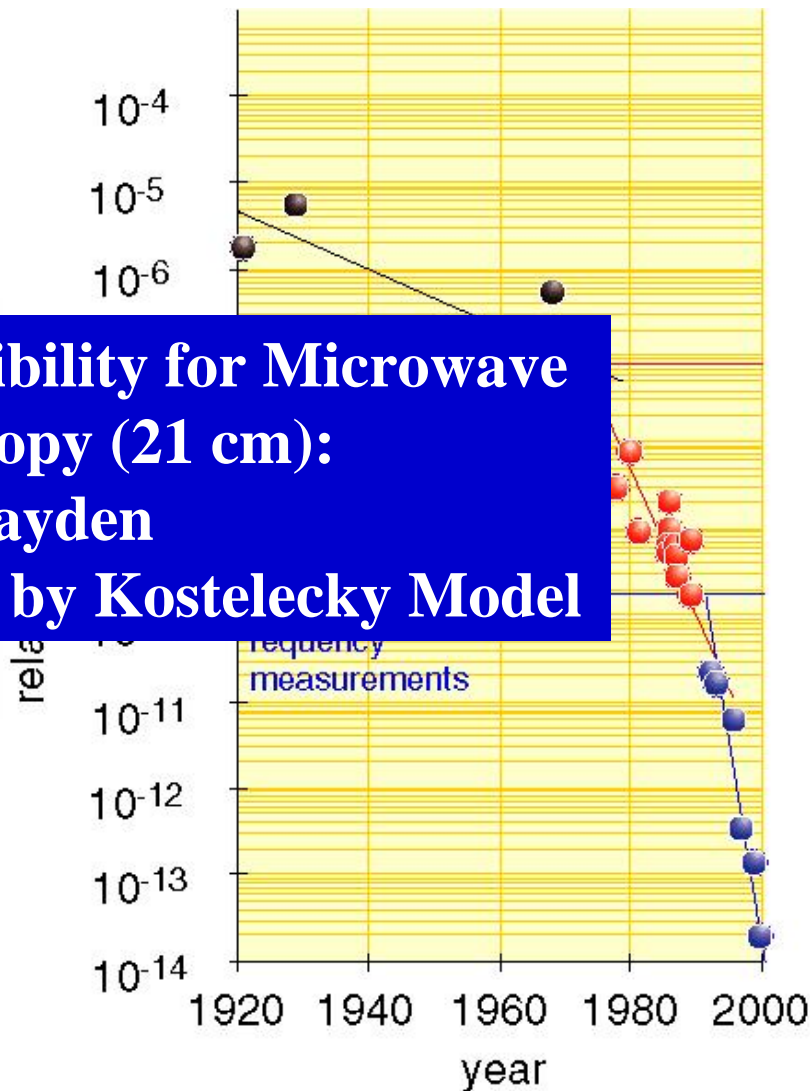
Hydrogen energy levels:  
Some of the best measured  
quantities in all of physics



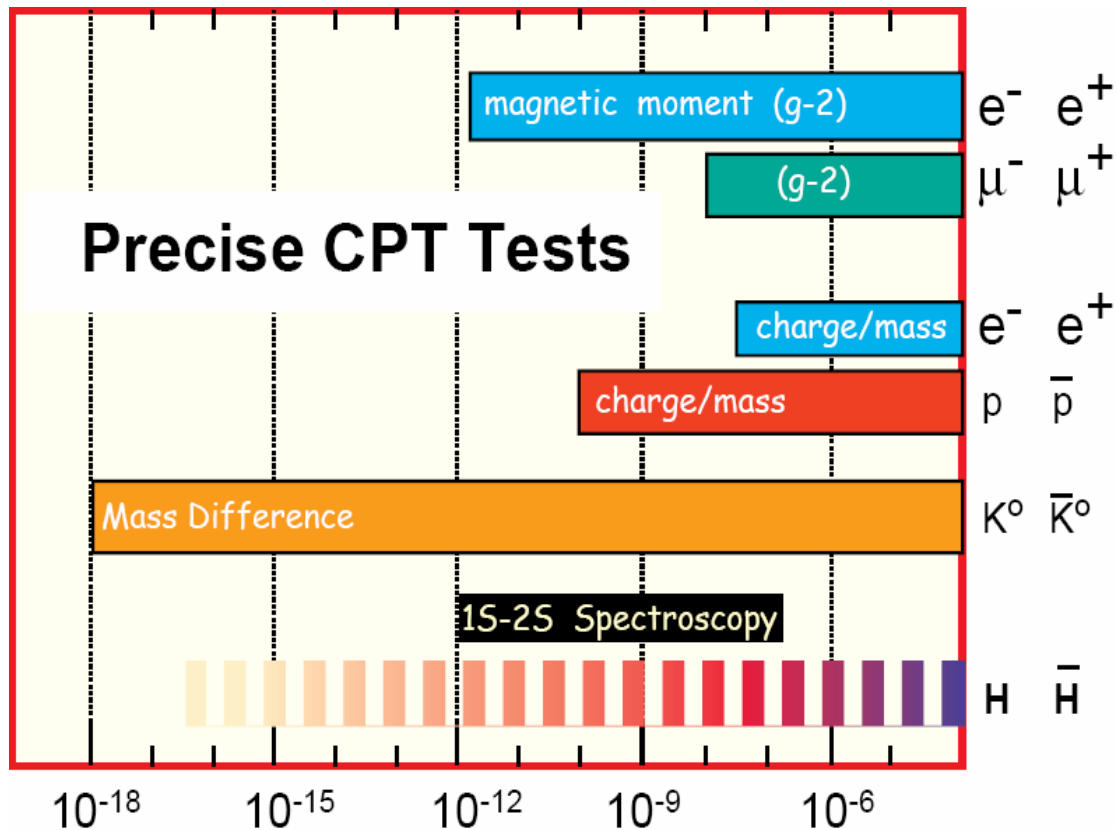
Also Possibility for Microwave  
Spectroscopy (21 cm):  
Hardy, Hayden  
Favoured by Kostelecky Model

- 1s-2s laser spectroscopy
- Doppler effect cancels

“Hänsch Plot”



# Various Direct CPT tests

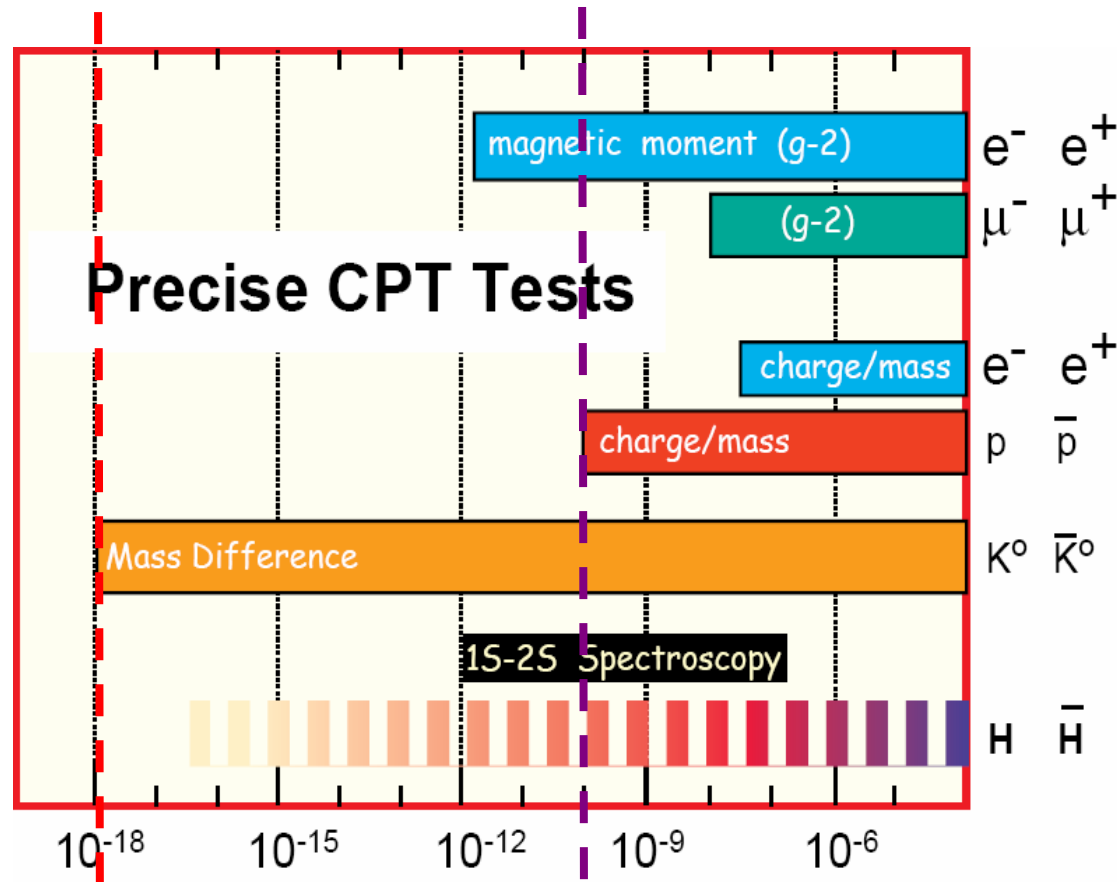


■ How meaningful is relative “precision” ?

■ Interpretation of Kaon result controversial

- Kobayashi&Sanda, Bigi
- 1% or  $10^{-5}$  test of CPT violating interaction

# Possible ALPHA sensitivities



**“Initial” measurements already comparable with  $K^0$  ( $10^{-18}$  GeV)  
 Nearly Planck Scale sensitivity!**

## 1s-2s (laser):

- $10^{-18}$  theoretical limit (by 2s life time)
- If trapped, 0.1ppb should be initially possible without laser cooling
- Improve  $e^+$  mass, charge
- Absolute energy scale:  $10^{-18}$  GeV ( $\rightarrow 10^{-22}$  GeV)

## Hyperfine ( $\mu$ -wave):

- $<10^{-12}$  current H limit (lifetime infinite)
- 100 ppm should be possible (cf muonium 0.1ppm)
- Improve  $\mu$ (pbar)
- Absolute energy scale:  $10^{-18}$  GeV ( $\rightarrow 10^{-27}$  GeV)

# Gravity: Long Term

- Gravitational acceleration of antimatter never measured
- Weak Equiv. Principle
- Various theoretical and indirect arguments exist against any differences
- Experimental question!
- Trapped neutral antimatter essential

# CERN Committee Reviews

- CERN Long Range Planning Review
  - Strong endorsement of AD program inc. ALPHA
- Experiment scientifically endorsed by CERN PAC
- Approved for running 2006 by CERN Research Board
- CERN Research Director J. Engelen on antihydrogen program: “every effort will be made to ensure successful running [Research Board Minutes (draft), 23 Sep 2005].”
- 3 complimentary antihydrogen experiments at AD

# ALPHA International Funding



The following entities are providing financial support for antihydrogen research:



[The Engineering and Physical Sciences Research Council \(EPSRC\) \(United Kingdom\)](#)



[The Danish Natural Science Research Council \(SNF\) \(Denmark\)](#)



[\(USA\)](#)

[National Science Foundation \(NSF\)](#)



[\(Japan\)](#)

[Ministry of Education, Culture, Sports, Science and Technology \(MEXT\)](#)



[\(Brazil\)](#)

[Conselho Nacional de Desenvolvimento Científico e Tecnológico \(CNPq\)](#)



[\(Brazil\)](#)

[Financiadora de Estudos e Projetos, Ministério da Ciência e Tecnologia \(FINEP\)](#)



[Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro \(FAPERJ\) \(Brazil\)](#)

- UK EPSRC just funded 1.8 M pounds
- GSC19 “physics is exciting, build group”

# ALPHA-Canada prospective

- Interdisciplinary team ~15 Canadian Researchers (7 institute) + 1 stdnt: importance recognized by Canadian scientists from other fields → Good for SAP
- SAP techniques essential
  - Belle-like Si vertex detector (faster KIPIO ADCs)
  - Westgrid expertise, new detectors (HPD, KOPIO scint + Si PM?)
- Canadians playing leading roles (5 founding members)
  - Detector coordinator, Si readout, software
  - Several trap and spectroscopy new initiatives
- Not expensive
  - Whole ALPHA \$1.6M /5 year (~\$50k/group/year + salaries & travels)
  - Other groups well funded: providing us funds
- Excellent for HQP training
  - From precision lasers, trapped plasmas, Si tracking detector to grid computing
  - Competitive but rewarding environment

# Summary

- Physics case very strong
  - Fundamental physics with Planck scale sensitivity
- Ground breaking experiment, opening up new field of science
- Interests, impact far reaching outside of SAP
- ALPHA will strengthen the case for SAP Long Range Plan



# Project ALPHA Collaboration

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L. Kurchaninov, K. Olchanski, A. Olin (+Professional Support)

York University: S. Menary



