New Experiments with Antiprotons

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http://capp.iit.edu/hep/pbar/

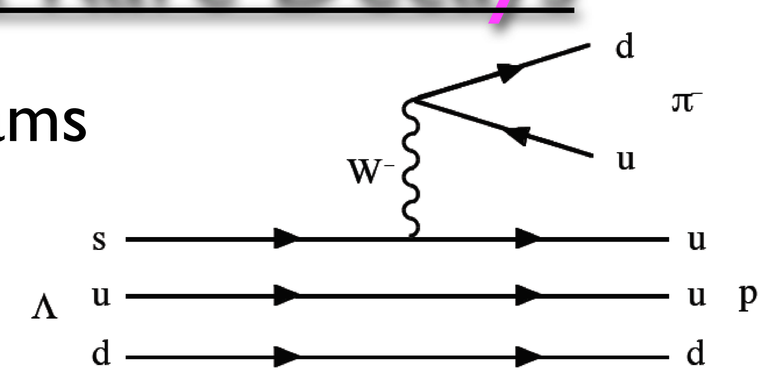
Abstract

Fermilab operates the world's most intense source of antiprotons. Experiments have been proposed that can use those antiprotons either parasitically during Tevatron Collider running or after the Tevatron Collider finishes in about 2011. We summarize the physics goals and potential of the proposed experiments.

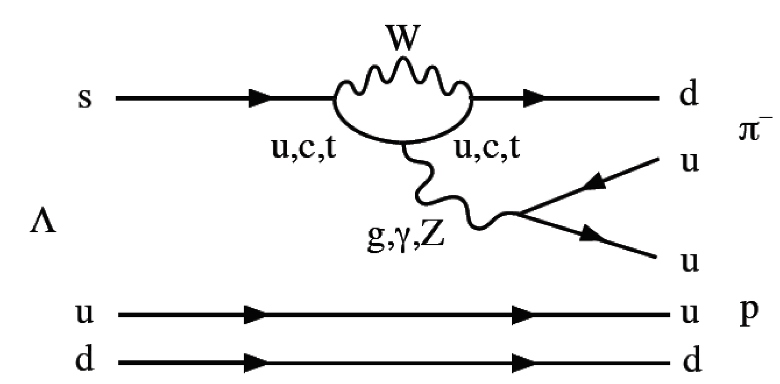
Hyperon CPV & Rare Decays

- Example Feynman diagrams (Standard Model):

tree:



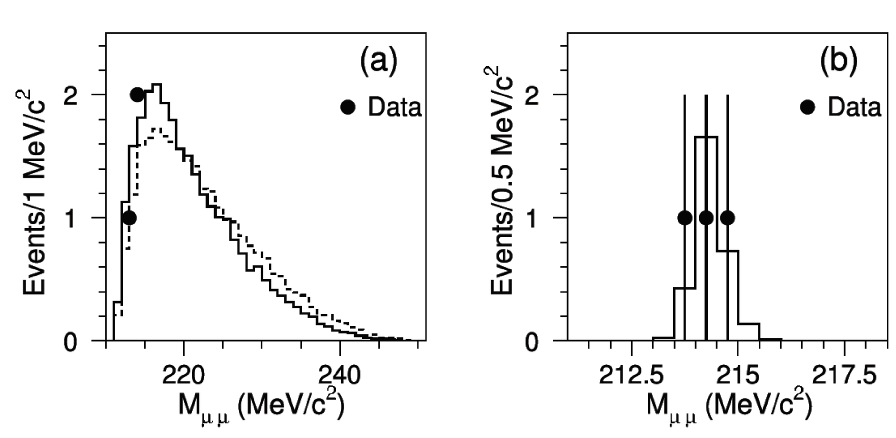
penguin:



- New physics can contribute too!

Asymm.	Mode	SM	NP
A_Λ	$\Lambda \to p\pi$	$\lesssim 10^{-5}$	$\lesssim 6\times10^{-4}$
$A_{\Xi\Lambda}$	$\Xi^\mp \to \Lambda\pi,\ \Lambda \to p\pi$	$\lesssim 0.5\times10^{-4}$	$\leq 1.9\times10^{-3}$
$A_{\Omega\Lambda}$	$\Omega \to \Lambda K,\ \Lambda \to p\pi$	$\leq 4\times10^{-5}$	$\leq 8\times10^{-3}$
$\Delta_{\Xi\pi}$	$\Omega \to \Xi^0\pi$	2×10^{-5}	$\leq 2\times10^{-4}$ *
$\Delta_{\Lambda K}$	$\Omega \to \Lambda K$	$\leq 1\times10^{-5}$	$\leq 1\times10^{-3}$

- Rare decays:
  - HyperCP observed 3 $\Sigma^+ \to p\mu^+\mu^-$ events
  - Consistent with new low-mass $X^0 \to \mu^+\mu^-$



- Aim to start with $\bar{p}p \to \Omega^- \bar{\Omega}^+$
- Sensitive to B ~10^{-6}, CP asymm ~ 10^{-4}
- Probe both parity-conserving and violating interactions ⇒ complementary to K & B studies

Antihydrogen Measurements

- $\bar{H}$-in-flight CPT test feasible:

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Measuring the antihydrogen Lamb shift with a relativistic antihydrogen beam

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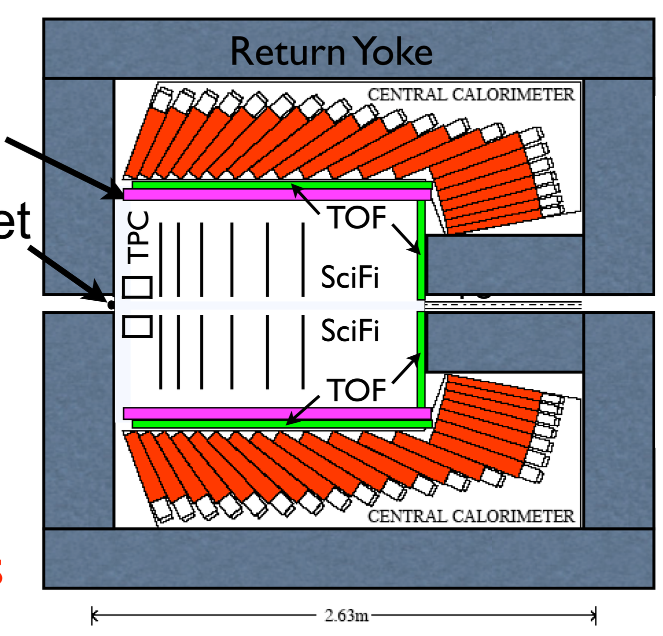
We propose an experiment to measure the Lamb shift and fine structure (the intervals $2s_{1/2}-2p_{1/2}$ and $2p_{1/2}-2p_{3/2}$) in antihydrogen. A sample of 10 000 antihydrogen atoms at a momentum of 8.85 GeV/c suffices to measure the Lamb shift to 5% and the fine structure to 1%. Atomic collisions excite antihydrogen atoms to states with $n=2$; field ionization in a Lorentz-transformed laboratory magnetic field then prepares a particular $n=2$ state, and is used again to analyze that state after it is allowed to oscillate in a region of zero field. This experiment is feasible at Fermilab. [S0556-2821(98)04711-0]

- Interferometric $\bar{H}$ gravity test: ∄ direct limit
  - simple solution to missing antimatter & dark energy:
    ⟶ could matter & antimatter repel gravitationally?
  - more generally, quantum gravity can have scalar & vector terms as well as tensor
    ⇒ $\bar{g}/g = 1 \pm \varepsilon$
  - measurement feasible with proven technology (trapping, atomic interferometer)
  - goal: determine ε first to 10^{-4} (gratings), then 10^{-9} (lasers)
- ▸ First test of Equivalence Principle for antimatter

Proposed Exp'tal Approaches

- FNAL Antiproton Source is world's most intense – even after FAIR@Darmstadt turns on (~2018)
- Opportunity for small, simple experiments soon after Tevatron finishes
- Medium-Energy experiment: "upgraded E835" with magnetic spectrometry:

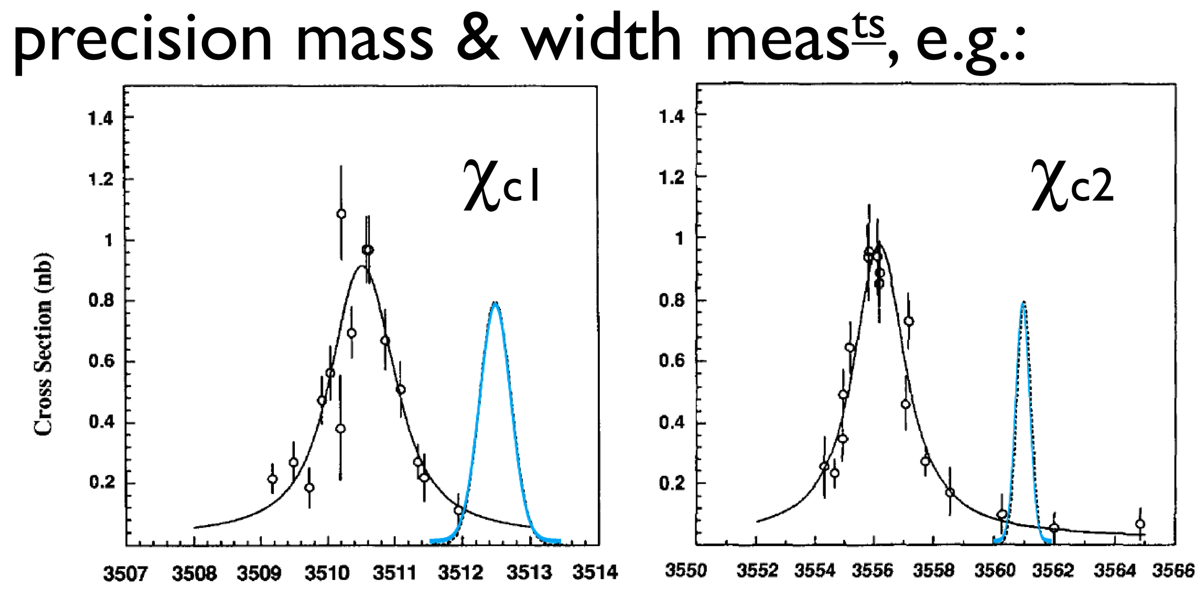


  - ▸ use existing E760 calorimeter, BESS solenoid, & DØ VLPC photodetectors & DAQ boards
- $\mathcal{L}$ ~10^{32} feasible ⇒ ~10^8 $\bar{p}p \to \Omega^- \bar{\Omega}^+$ events/year
- Slow-$\bar{H}$ expts: decelerate in MI & degrade into trap
- Possible future upgrade: add small decelerator ring

Charmonium & XYZ States

- $\bar{p}p$ can directly form states of all non-exotic J^{PC}
- $\bar{p}p$ capable of precision mass & width meas^{ts}, e.g.:

FNAL E760
σ_m (beam) = 0.5 MeV



- Directly study singlet states: η_c, h_c, $\eta_c(2S)$ & other non-1^{--} states (e.g., χ_c's)

- ▸ Are XYZ states charmonium or hybrids or...?

XYZ States

State	J^{PC}	Mass	Decay Modes
X(3872)	1^{++}	3871.2±0.5	$J/\psi\,\pi^+\pi^-$, $J/\psi\,\pi^+\pi^-\pi^0$, $J/\psi\,\gamma$
X(3872)	$?^{??}$	3875.5±0.7	$D^0 D^0 \pi^0$
Z(3930)	2^{++}	3929±6	$D^0 D^0$, $D^+ D^-$
Y(3940)	$?^{++}$	3943±17	$J/\psi\,\omega$
X(3940)	$?^{?+}$	3942±9	$D D^*$
Y(4008)	1^{--}	4008±65	$J/\psi\,\pi^+\pi^-$
X(4160)	$?^{?+}$	4156±27	$D^* D^*$
Y(4260)	1^{--}	4259,4284,4247	$J/\psi\,\pi^+\pi^-$, $J/\psi\,\pi^0\pi^0$, $J/\psi\,K^+K^-$
Y(4350)	1^{--}	4324, 4361	$\psi(2S)\,\pi^+\pi^-$
Z^+(4430)	$?^?$	4433±5	$\psi(2S)\,\pi^+$
Y(4620)	1^{--}	4464±13	$\psi(2S)\,\pi^+\pi^-$

Charm CPV

- $\sigma(\bar{p}p \to D^*\bar{D})$ ~ 1 μb?
  ⇒ >10^{10} events produced
  – charm mixing: new physics?
- ▸ Potential world's-most-sensitive measurement

D*D cross-section estimate (after E. Braaten, Phys. Rev. D 77, 034019 (2008))