Remarks on the Antiproton Source and Possible Experiments

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The FNAL Antiproton Source is a unique and valuable resource

- The number of antiprotons accumulated per unit time is unmatched by any other existing or planned facility.
- Stochastic cooling (and the absence of synchrotron radiation) provides a very small beam energy spread.
- The beam energy can be precisely calculated using the measured revolution frequency and the orbit length calculated using beam position monitor measurements and the Accumulator lattice model.
- These features were exploited (most recently in 2000) by the charmonium experiments E760 and E835.
The E760/E835 Technique

• Charmonium states can be formed by complete antiproton-proton annihilation.
  – E760/E835 used a hydrogen “gas-jet” target in the Antiproton Accumulator at AP50.

• E760/E835 concentrated on final states including $J/\psi \rightarrow e^+e^-$
  – Electrons identified by Pb-glass and gas Cherenkov detectors
  – Photons measured by Pb-glass
  – Charged tracks measured (but no magnetic field)
  – Beam energy scanned in small steps; yield in specific final state measured as a function of beam energy.
    • World’s most precise measurements of charmonium masses and widths.
**Comparison $e^+e^-$ versus $p\bar{p}$**

**$e^+e^-$ interactions:**  
only $1^-$ states formed  
other states populated in secondary decays  
(moderate mass resolution)

**$p\bar{p}$ reactions:**  
all states directly formed  
(very good mass resolution)

**Production of $\chi_{1,2}$**  
$e^+e^- \rightarrow \psi'$  
$\gamma \chi_{1,2}$  
$\gamma \gamma J/\psi$  
$\gamma e^+e^-$

**Formation of $\chi_{1,2}$**  
$p\bar{p} \rightarrow \chi_{1,2}$  
$\gamma J/\psi$  
$\gamma e^+e^-$

**E 760 (Fermilab)**  
$\sigma_m (\text{beam}) = 0.5 \text{ MeV}$
Physics drivers for the design of a new charmonium experiment

• Most obvious goal = mass and width of the singlet charmonium states.
  – Not directly accessible in e+e-.
  – E760/E835 attempted measurements using decays to ηc --> γγ (small branching fraction/problematic backgrounds).
  – New experiment should use ηc --> ΦΦ --> 2K+2K- (Magnetic spectrometer required).

• “New” states such as X(3872) are probably best measured (as in previous experiments) using decays to J/ψ --> e+e-
  – Experiment must retain very good electron & photon measurement capability.
CPT test using relativistic antihydrogen

- Antihydrogen is produced in the gas-jet target - exits the Accumulator in the ground state.
  - 99 antihydrogen atoms were observed by E862 with 0 background.
- The atoms enter a 7kG magnet and a large fraction are excited to N=2 long-lived Stark state by laser light.
- Atoms exit magnet & pass through a field-free region, then enter a second magnet with field 6-8 kG. The mixture of N=2 Stark states in the second magnet depends on the time spent in the field-free region, the fine structure, and the Lamb shift.
- Distribution of field ionization in the second magnet reflects probability of being in each of the three N=2 Stark states.
- Monte Carlo —> an experiment in which 100 atoms exit the first magnet in N=2,L will yield a 1% measurement of the fine structure and a 5% measurement of the Lamb shift. Assuming that only the 2S level is shifted by a CPT violating force, the $1\sigma$ sensitivity is 50 parts per billion of the 2S binding energy.