Study of the noise properties of non-destructive single-particle detector for antiproton spin flip identification

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Baryon Antibaryon Symmetry Experiment

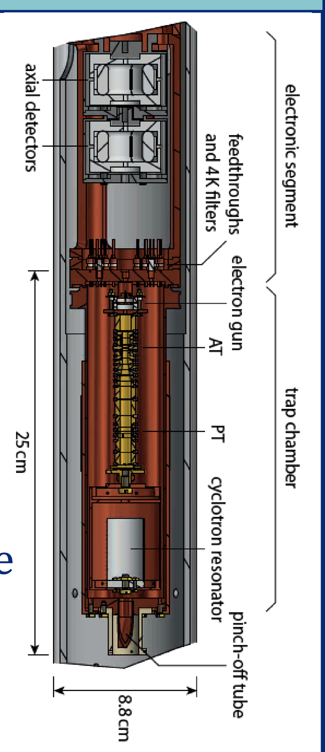
BASE

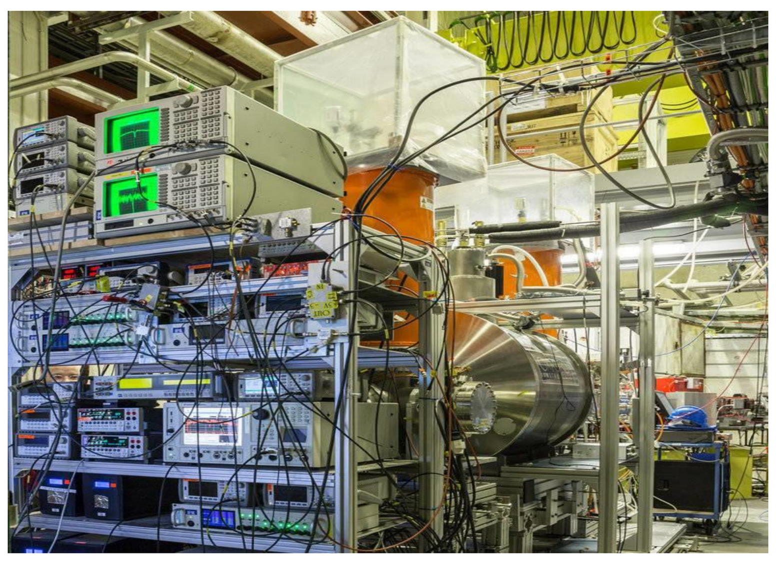
The Baryon Antibaryon Symmetry Experiment at CERN

- BASE at CERN investigates the matter-antimatter asymmetry in the universe.
- The experiment uses Penning trap techniques to produce, capture, and measure properties of antiprotons.

	Naive Expectation	Observation
Baryon/Photon Ratio	10^{-18}	0.6×10^{-9}
Baryon/Antibaryon Ratio	1	10 000

- BASE reflects the human endeavour to understand the fundamental workings of the universe and advances the field of antimatter studies.



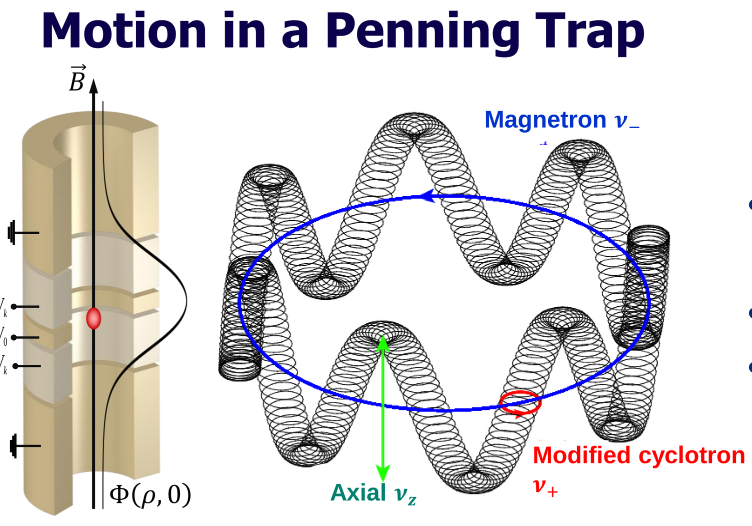


Main Achievements

- $\frac{g_{\bar{p}}}{2} = -2.7928473441(42)$ [4]
- $\frac{g_p}{2} = 2.79284734462\,(82)$ [5]
- $-\frac{(q/m)_{\bar{p}}}{(q/m)_p} = 1.000000000003(16)$ [6]

BASE Measurement Principles

Motion in a Penning Trap



- Trapping of Antimatter requires confinement in all directions
- Axial confinement by harmonic electrostatic potential
- Radial confinement by homogeneous magnetic field

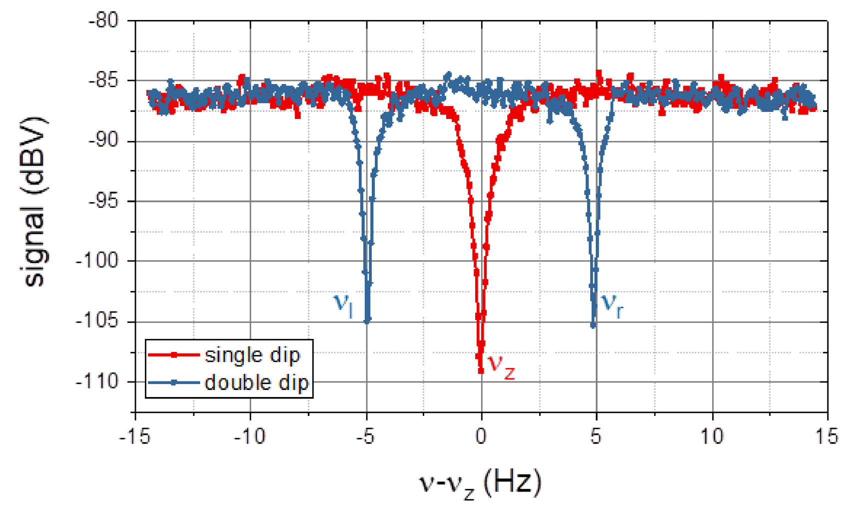
Cyclotron frequency is given by

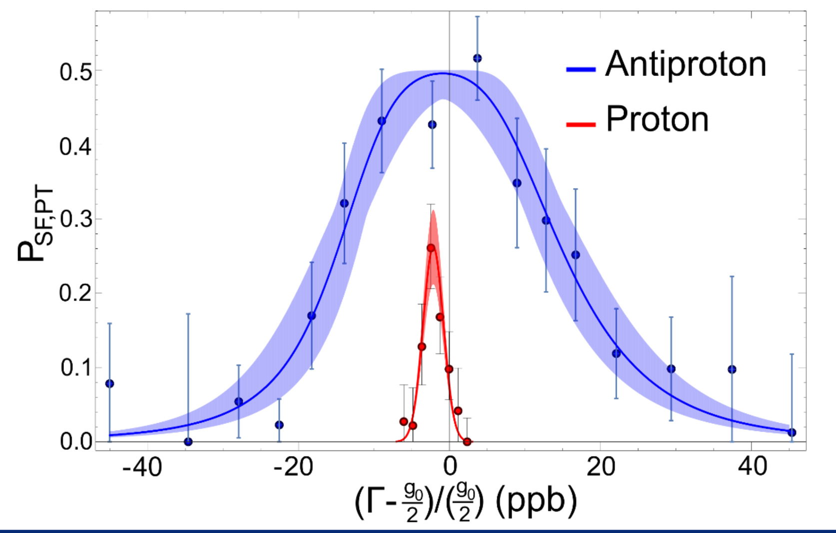
$$\nu_c = \sqrt{\nu_+^2 + \nu_-^2 + \nu_z^2} = \frac{1}{2\pi}\frac{q}{m}B$$

$$\frac{g}{2} = \frac{\nu_L}{\nu_c}$$

Larmor Frequency

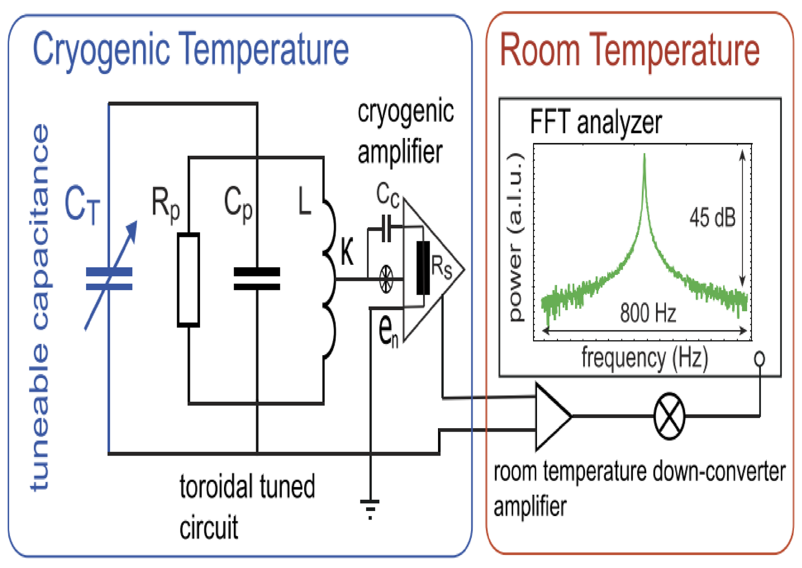
$$\nu_L = \frac{1}{2\pi} g \frac{q}{2m} B$$

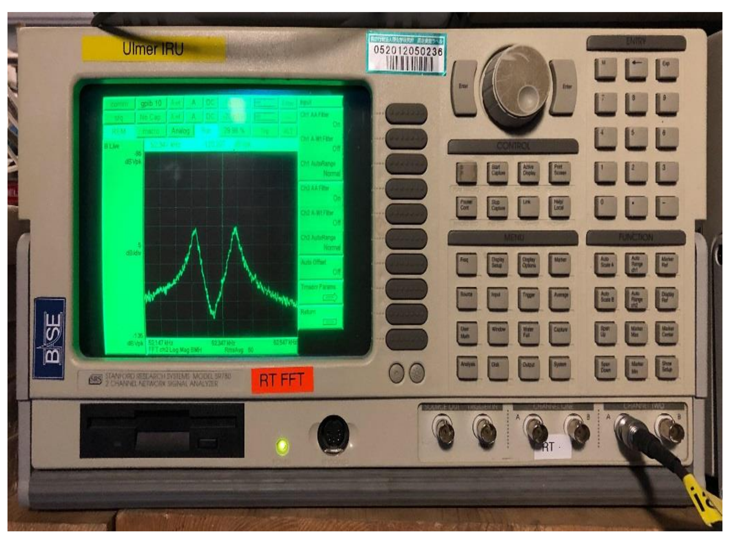




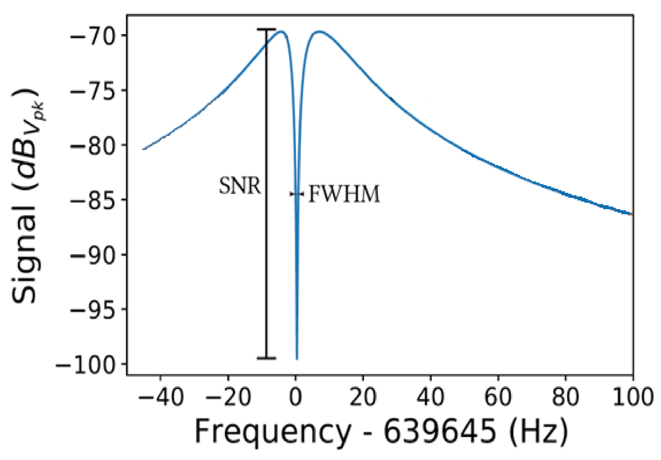
Detection System

- Particle behaves as a perfect series LC-circuit when in thermal equilibrium with a high-Q detection circuit [1].
- This particle-response situation short-circuits the resonator noise, reducing it to the level of background noise [2].



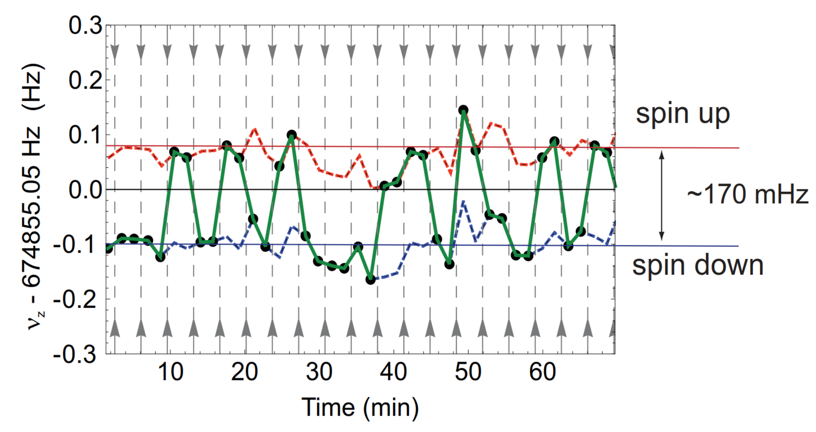


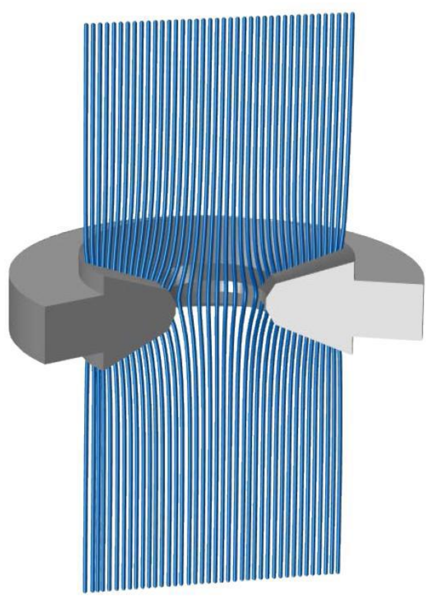
$$u_n = \sqrt{4k_B T \Delta\nu \, \mathrm{Re}[Z]}$$

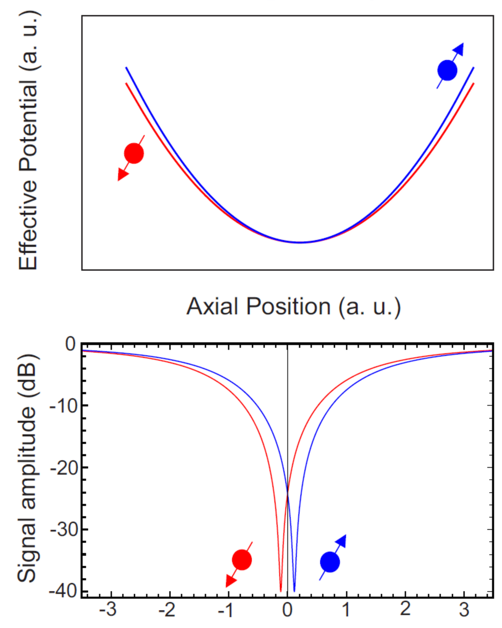


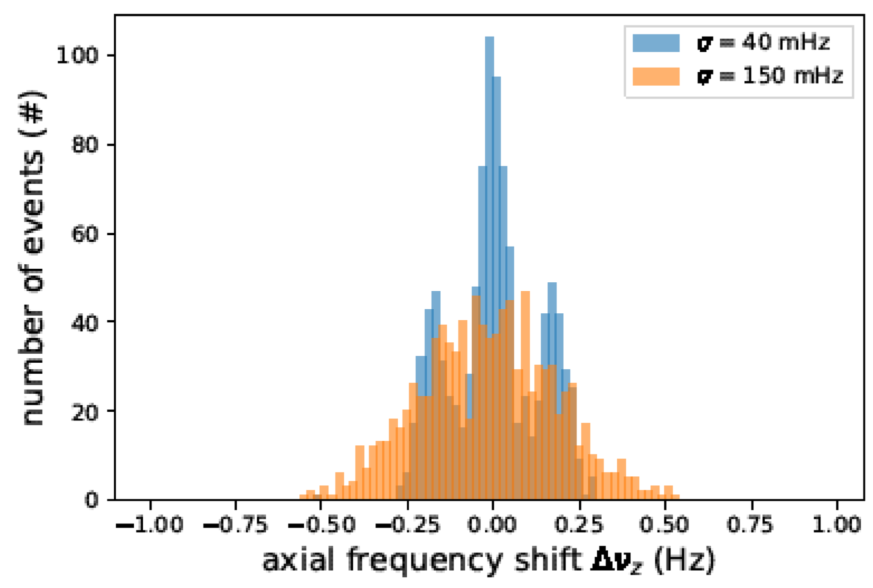
Single Spin Flip Detection

- Continuous Stern Gerlach Effect: Superimpose magnetic bottle to couple axial frequency to spin state, B2=300 000 T/m^2.
- Spin flip changes axial frequency by 173(4) mHz
- Ability to detect spin flips depends on the background scatter of the axial frequency

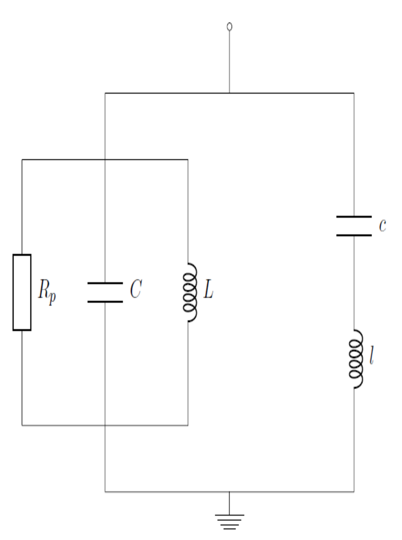






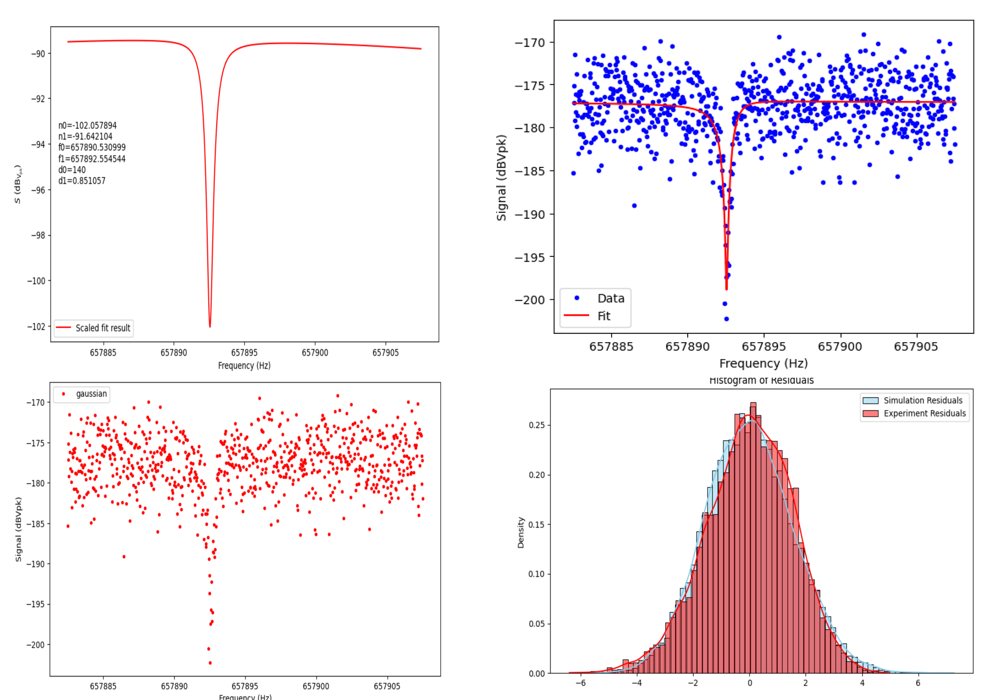


Noised Signal Simulation Process



$$\frac{1}{Z} = \frac{1}{R_p} + \frac{1}{i\omega L} + i\omega C + \frac{1}{i\omega l + \frac{1}{i\omega c}}$$

$$S(\nu) = \sqrt{\frac{n_1^2}{1 + \left[\frac{\frac{Q}{\nu_0}(\nu_0^2-\nu_p^2)(\nu^2-\nu_p^2) + \frac{\gamma}{2\pi}\nu^2}{\nu(\nu^2-\nu_p^2)}\right]^2} + n_0^2}$$

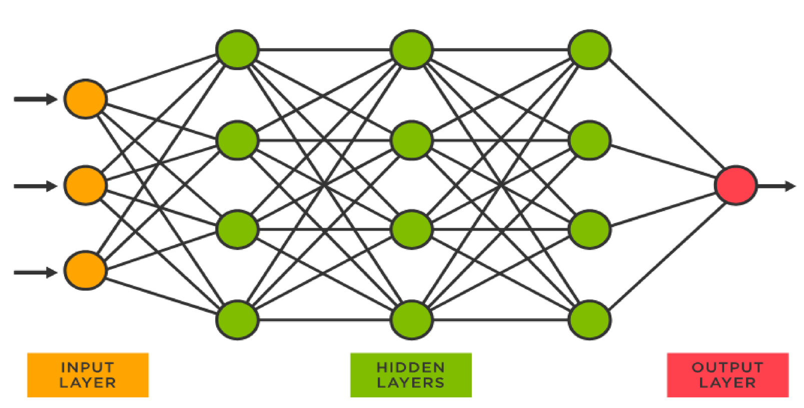


- **Rayleigh Distribution:**
- Derived from a two-dimensional Gaussian distribution.
- PDF formula: $f(x;\sigma) = \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}}, \quad x \geq 0$
- It is the square of the sum of two independent Gaussian distributed **random variables.**

- **Gaussian Distribution:**
- Also known as Normal. Z distribution.
- PDF formula: $f(x;\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$
- Defined by a mean μ and a variance σ^2.

Outlook

- Investigating the applicability of Artificial Neural Networks: How can artificial neural networks be integrated to improve various aspects of our work?



- Design of Room-Temperature Amplifiers: Developing a room-temperature amplifier design to acquire signals with low noise levels.
- Conversion of Voltage Signals to FFT: Examining different methods that can be used to transform voltage signals in the time domain into FFT signals in the frequency domain.

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