

# KONDRAHENKO CROSSING AND CHAO FORMALISM TESTS<sup>\*</sup>

R.S. Raymond, A.W. Chao, A.D. Krisch, M.A. Leonova,  
V.S. Morozov, D.W. Sivers, V.K. Wong

*Spin Physics Center, University of Michigan, Ann Arbor, MI 48109-1120 USA*

R. Gebel, A. Lehrach, B. Lorentz, R. Maier, D. Prasuhn, A. Schnase, H. Stockhorst  
*Forschungszentrum Jülich Institut für Kernphysik, Postfach 1913, D-52425 Jülich*

F. Hinterberger, K. Ulbrich

*Helmholtz Institut für Strahlen- und Kernphysik, Universität Bonn, Nussallee 14-16, D-53115 Bonn*

A.M. Kondratenko

*GOO Zaryad, Russkaya Str.41 Novosibirsk, 630058 Russia*

---

\* This research was supported by grants from the German BMBF Science Ministry.

## Matrix formalism for spin dynamics near a single depolarization resonance

Alexander W. Chao

*Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309, USA*

(Received 25 July 2005; published 17 October 2005)

A matrix formalism is developed to describe the spin dynamics in a synchrotron near a single depolarization resonance as the particle energy (and therefore its spin precession frequency) is varied in a prescribed pattern as a function of time such as during acceleration. This formalism is first applied to the case of crossing the resonance with a constant crossing speed and a finite total step size, and then applied also to other more involved cases when the single resonance is crossed repeatedly in a prescribed manner consisting of linear ramping segments or sudden jumps. How repeated crossings produce an interference behavior is discussed using the results obtained. For a polarized beam with finite energy spread, a spin echo experiment is suggested to explore this interference effect.

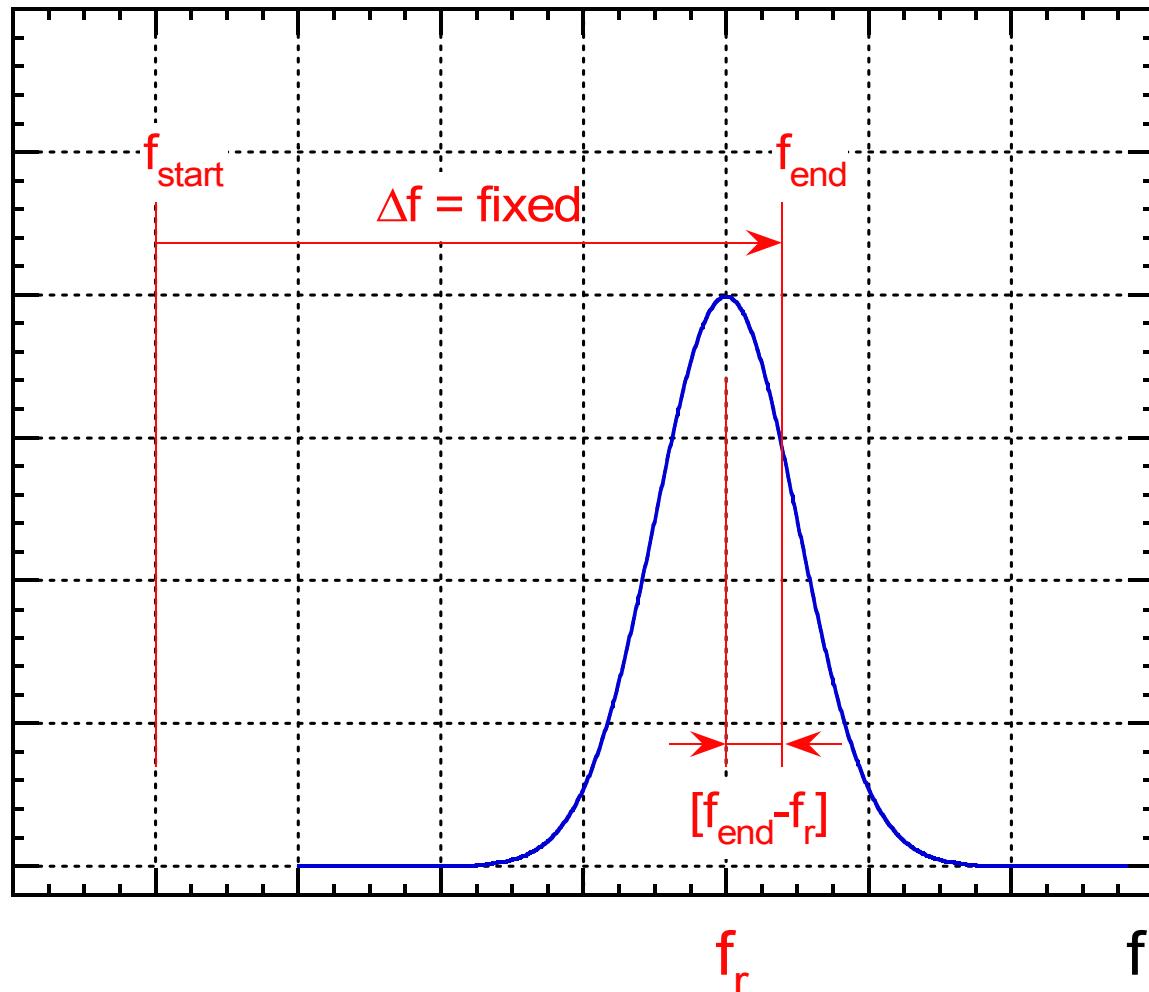
DOI: [10.1103/PhysRevSTAB.8.104001](https://doi.org/10.1103/PhysRevSTAB.8.104001)

PACS numbers: 29.27.Hj, 41.75.-i

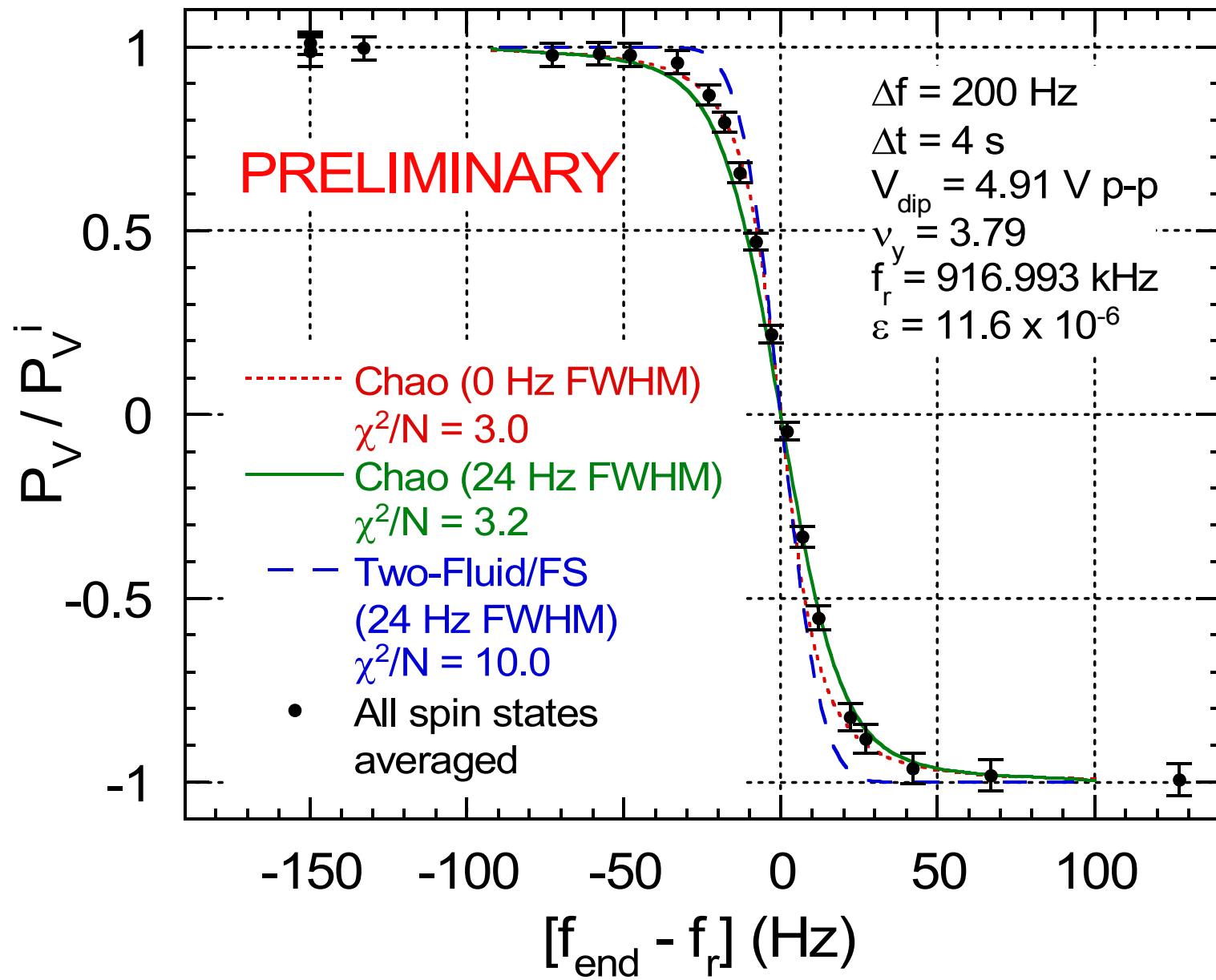
- The spinor equation of motion near an isolated spin resonance was solved analytically for:
  - constant distance between the spin tune and spin resonance.
  - linearly changing distance between the spin tune and spin resonance.
- In each case the spinor evolution is described by a time-dependent matrix.
- For a piece-wise linear crossing pattern, the linear segments' matrices are multiplied sequentially to obtain the final spinor state.
- The spinor state determines the polarization.

# TEST OF THE CHAO EQUATION

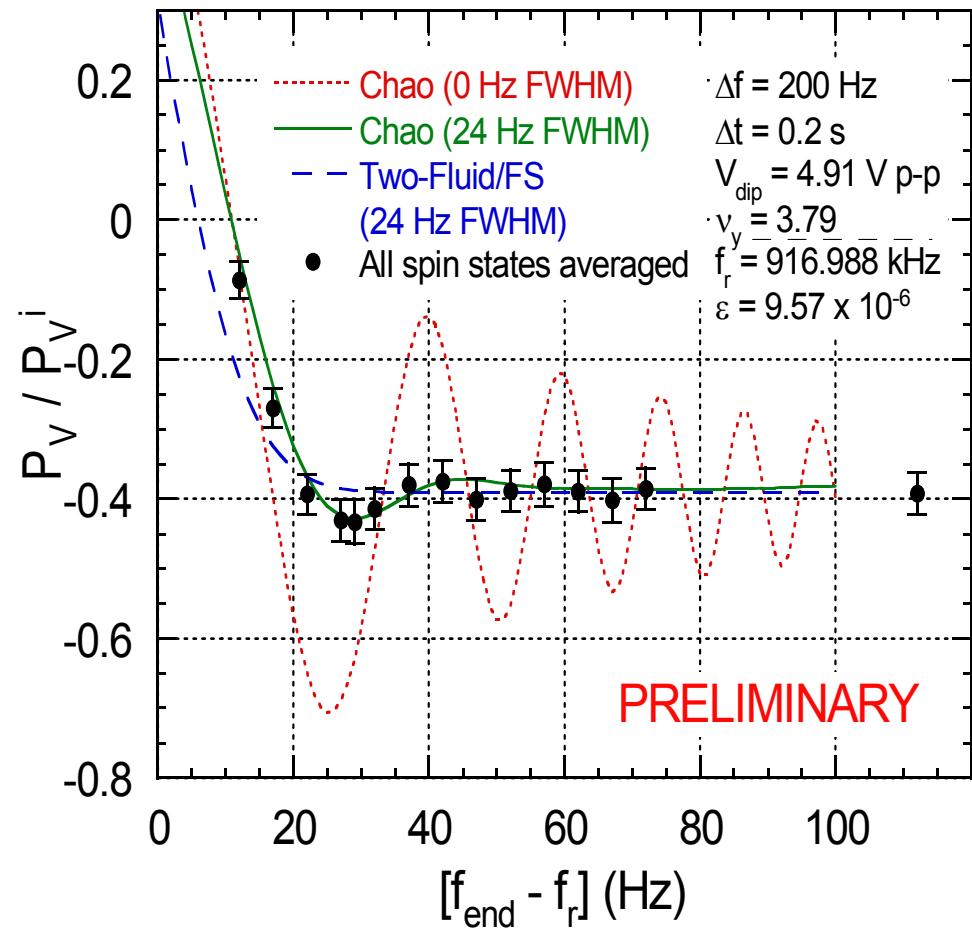
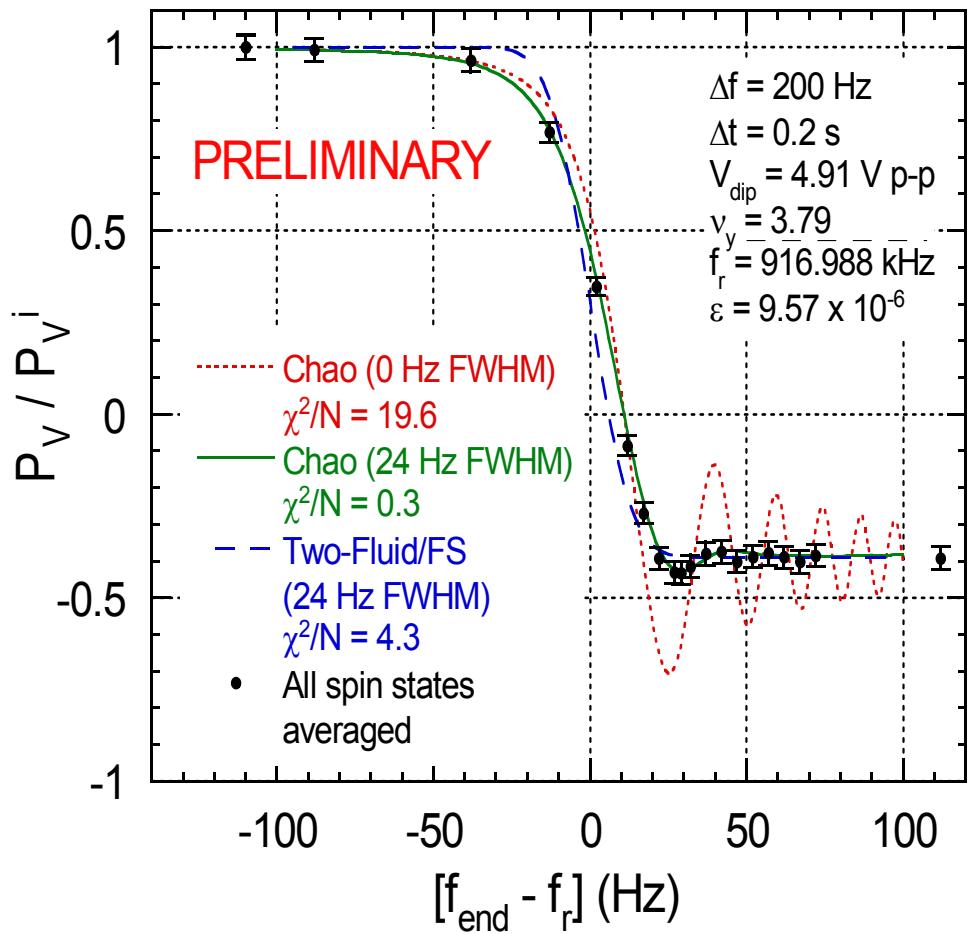
- Deuteron beam stored in COSY at 1.85 GeV/c
- D<sup>-</sup> ion source cycled through four polarization states
- EDDA detector as a polarimeter
- Ferrite rf dipole with  $\int B_{\text{rms}} \cdot dl = 0.6 \text{ T} \cdot \text{mm}$  at  $\sim 0.9 \text{ MHz}$



# CHAO TEST WITH A SLOW CROSSING RATE



# CHAO TEST WITH A FAST CROSSING RATE



# Compensation for Particle-Beam Depolarization of Spin Resonance Intersection at Accelerators

A. M. Kondratenko, M. A. Kondratenko, and Yu. N. Filatov

*Urban Public Organization “Zaryad,” Novosibirsk, Russia*

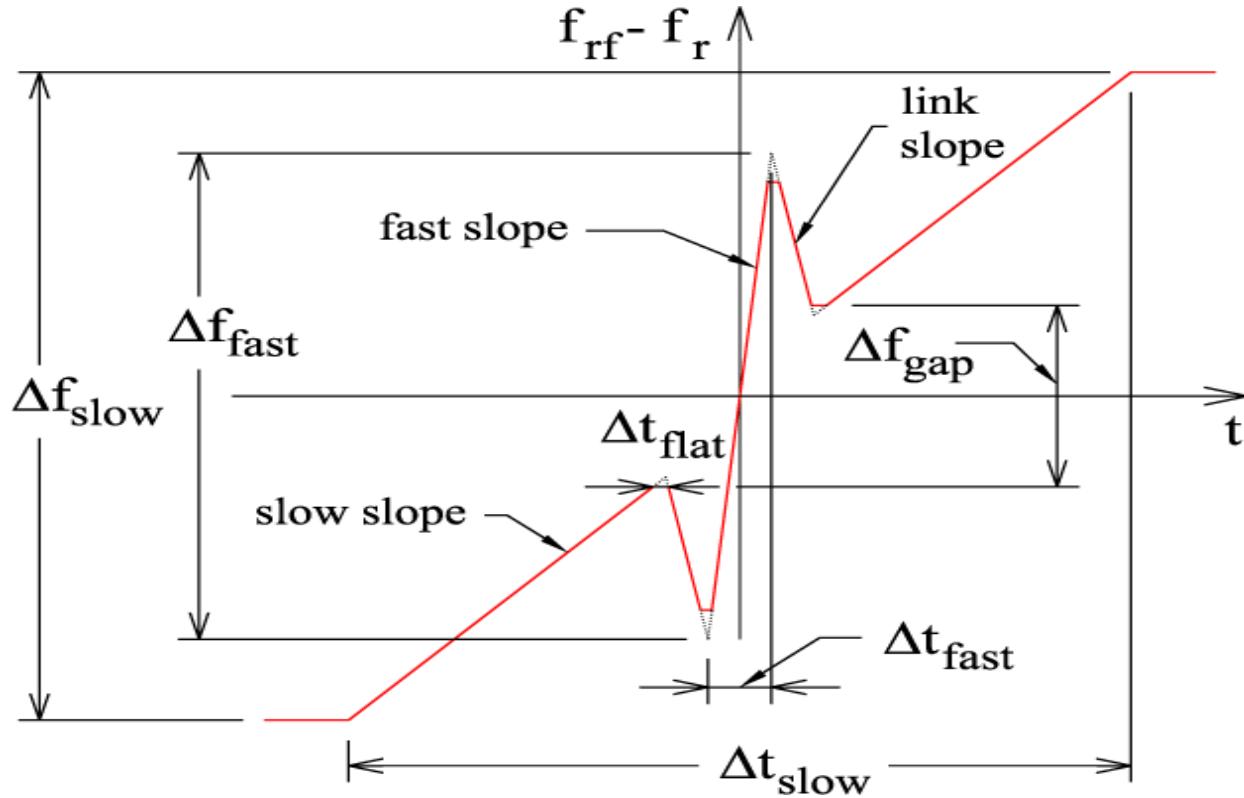
Received January 26, 2004

**Abstract**—A method for preserving the beam polarization while intersection a spin resonance in a cyclic accelerator is suggested. The results could be important for production of intensive polarized beams of high-energy particles. Numerical examples are given.

- During acceleration, a polarized beam may encounter spin resonances, which may cause depolarization.
- One of the most commonly used methods to overcome weak and medium strength resonances is to cross them quickly to reduce their depolarizing effect.
  - This results in a greatly reduced but finite polarization loss.
- Recently A.M. Kondratenko proposed a new resonance crossing technique, which, in theory, should allow one to completely preserve the polarization even when using moderate crossing speeds.

## KONDRAHENKO CROSSING SHAPE

The shape is defined by the parameters  $\Delta t_{\text{slow}}$ ,  $\Delta f_{\text{slow}}$ ,  $\Delta t_{\text{fast}}$ ,  $\Delta f_{\text{fast}}$ , and fast slope / link slope ratio.



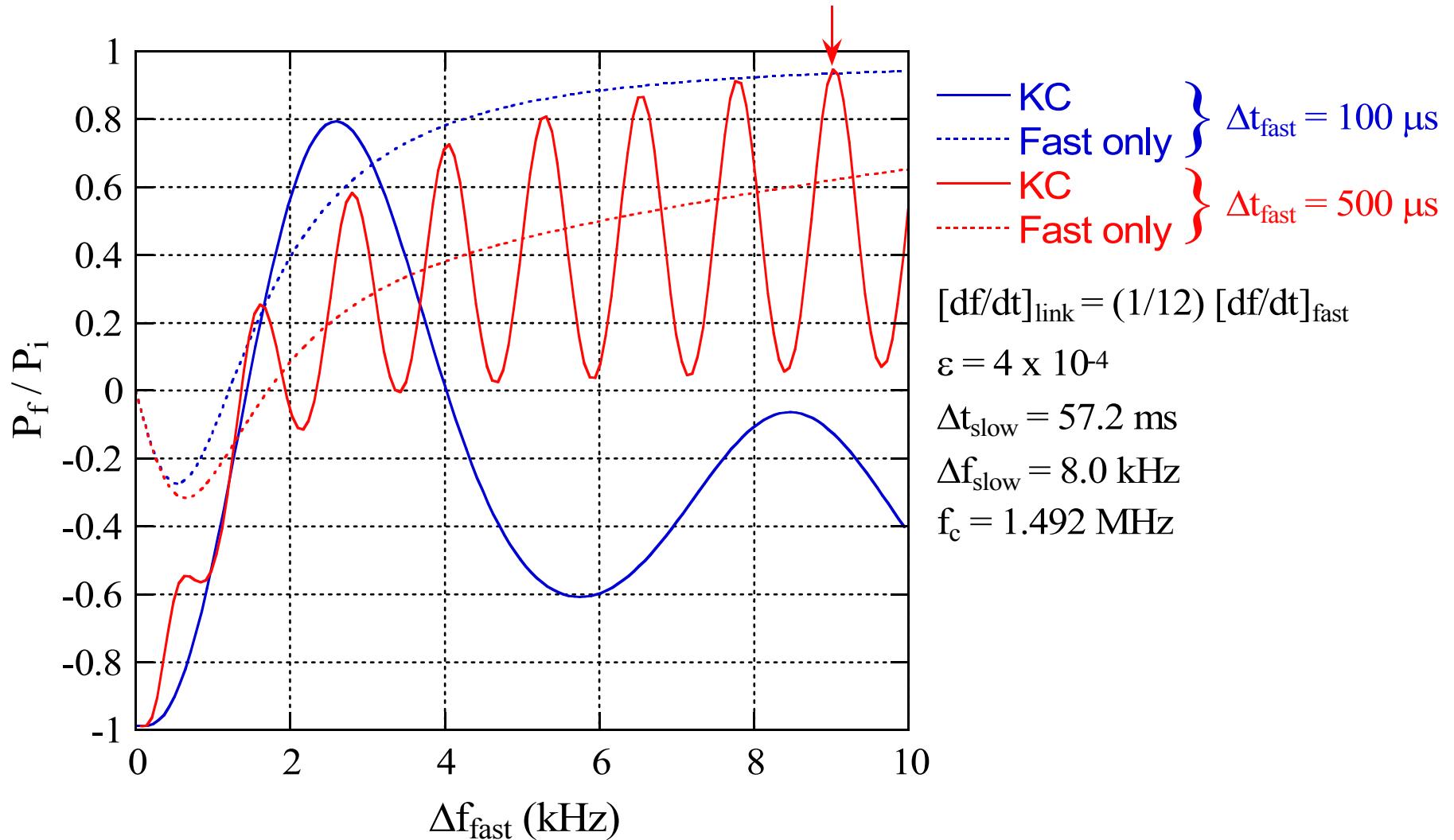
Parameters of Kondratenko paper using Chao notation:

$$\theta = 2\pi f_c t; \quad \alpha(\theta) = \frac{f_{rf} - f_r}{f_c}; \quad \Gamma = \frac{d\alpha}{d\theta} = \frac{1}{2\pi f_c^2} \frac{\Delta f}{\Delta t}; \quad \theta \sqrt{\Gamma} = t \sqrt{2\pi \frac{\Delta f}{\Delta t}};$$

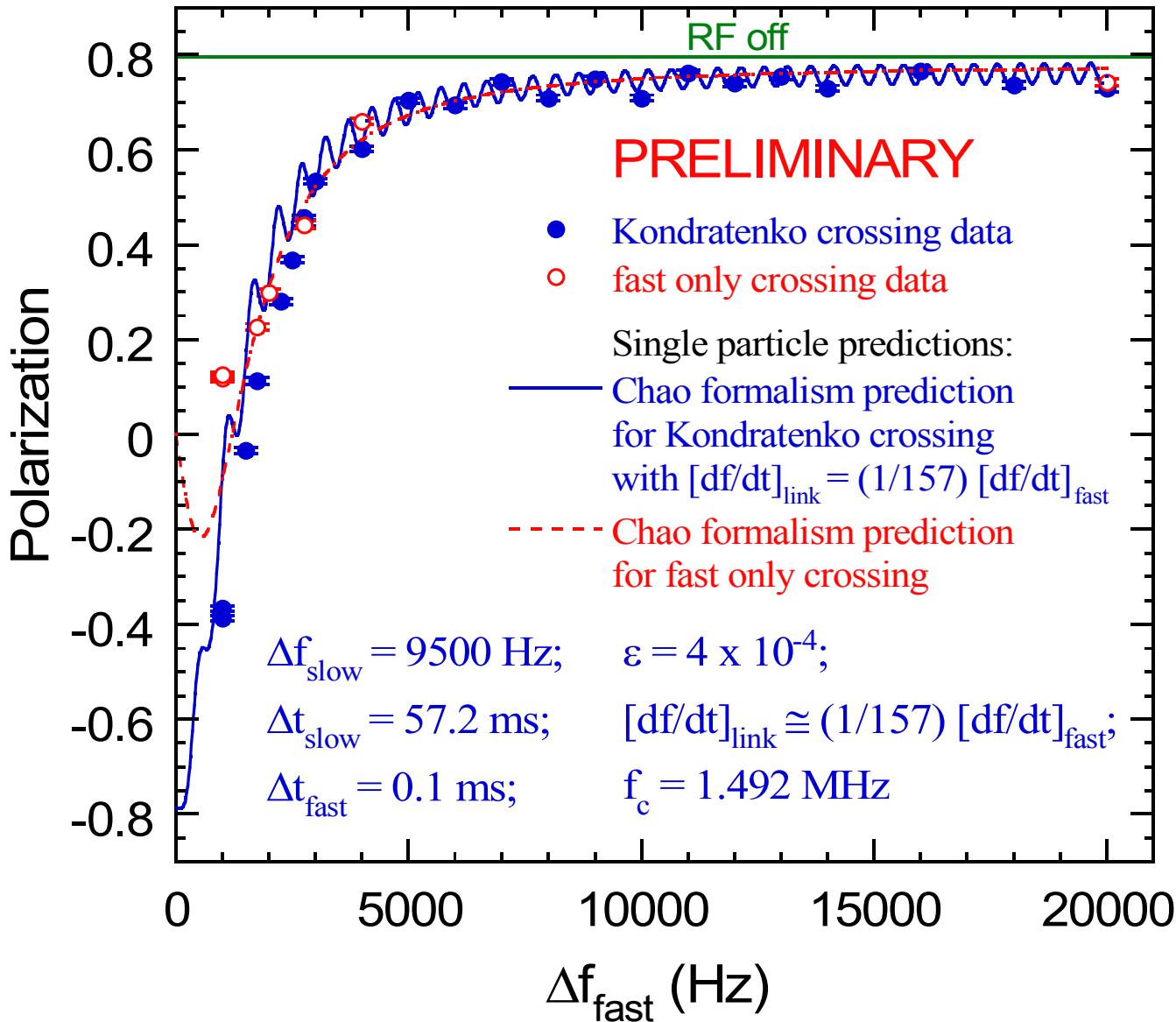
$$\frac{\alpha(\theta)}{\sqrt{\Gamma}} = (f_{rf} - f_r) \sqrt{2\pi \frac{\Delta t}{\Delta f}}; \quad A = \frac{\Delta f / 2}{f_c}; \quad \frac{A}{\sqrt{\Gamma}} = \sqrt{\frac{\pi}{2} \Delta f \Delta t}.$$

## SINGLE PARTICLE PREDICTION VIA CHAO FORMALISM

- Valid for both protons and deuterons with  $f_c = 1.492 \text{ MHz}$ .
- $P_f$  depends sensitively on parameters such as  $\Delta f_{\text{fast}}$  and  $\Delta t_{\text{fast}}$ .
- The arrow shows  $\Delta f_{\text{fast}}$  where the polarization is almost fully preserved.



# KONDRAHENKO CROSSING WITH PROTONS



$\Delta p/p$  of  $\sim 10^{-3}$  caused spin resonance frequency spread of  $\sim 5$  kHz.

# KONDRAKENKO CROSSING PREDICTION WITH DEUTERONS

Dashed line: Froissart-Stora prediction for simple fast crossing.

Solid line: Chao single-particle prediction for Kondratenko Crossing.

Red circles: Chao prediction including beam's  $\Delta f_r = 40$  Hz FWHM.

