High Precision Energy Calibration of the MAX II Electron Beam by Means of Resonant Spin Depolarization

(Proposal)

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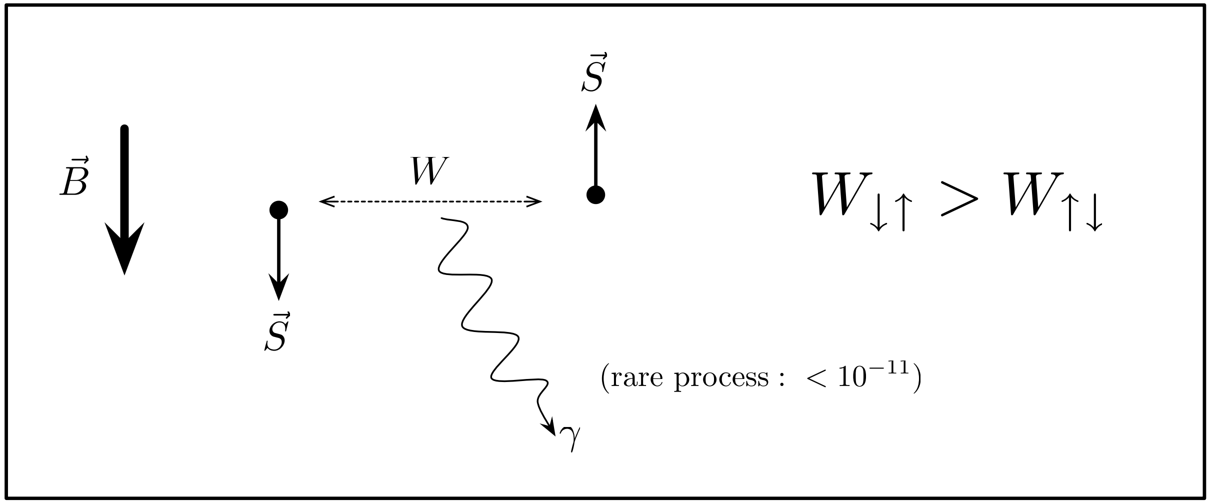
Spin-flip Radiation and Polarization Buildup



$$W_{\downarrow\uparrow,\uparrow\downarrow} = \frac{5\sqrt{3}}{16} \cdot \frac{e^2\gamma^5\hbar}{m_e{}^2c^2\rho^3} \cdot \left(1 \pm \frac{8}{5\sqrt{3}}\right)$$

Ternov, Loskutov, Korovina, Sokolov 1962-64

$$P_{\mathrm{ST}} = \frac{W_{\downarrow\uparrow} - W_{\uparrow\downarrow}}{W_{\downarrow\uparrow} + W_{\uparrow\downarrow}} = \frac{8}{5\sqrt{3}} = 92.38\%$$

Maximum polarization in a perfect (flat) machine

$$P_p(t) = P_{\mathrm{ST}}\left(1 - e^{-t/\tau_p}\right)$$

Polarization build-up

$$\tau_p = (W_{\uparrow\downarrow} + W_{\downarrow\uparrow})^{-1} \cdot \left(\frac{R}{\rho}\right) = 98.66 \cdot \frac{\rho^2 R}{E[\mathrm{GeV}]^5}$$

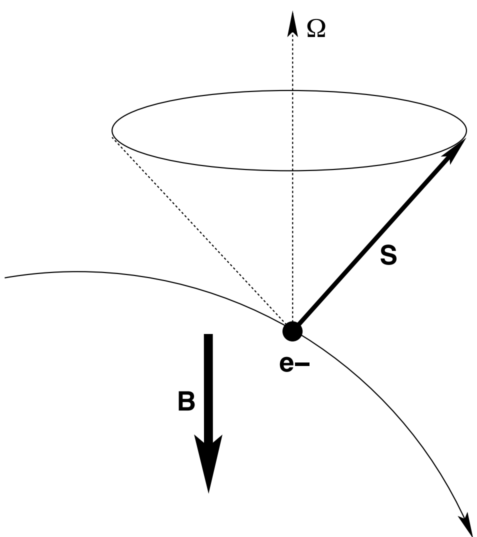
34 min in MAX II
142 min in MAX III

Spin Precession and Spin Tune

- Spins interact with em field through magnetic moment μ
- Lorenz transformation to lab frame
- Thomas-BMT equation
- Simplifies for E = E_z, B = B_{bend}
- Larmor precession

$$\frac{d\vec{S}}{ds} = \vec{\Omega}_{\rm sp} \times \vec{S} \quad \rightarrow \quad \vec{\Omega}_{\rm sp} = \underbrace{\frac{e\vec{B}_\perp}{m_e c\gamma}}_{\vec{\omega_0}} \cdot \underbrace{a\gamma}_{\nu_{ST}}$$

$$\nu_{st} = a\gamma \qquad a = \frac{g-2}{2} = 0.00115965218$$



f_{sp}	$3 \cdot f_0$ $= 10$ MHz	$3.5 \cdot f_0$ $= 11.667$ MHz	$4 \cdot f_0$ $= 13.333$ MHz
$\nu_{\rm st}$	3	3.5	4
γ	2587	3018	3449
E	1.321 GeV	1.542 GeV	1.762 GeV

1.5 GeV

$\gamma = 2936.4$

$\nu_{\rm ST} = 3.40522$

Depolarizing Effects and Equilibrium Polarization

Real machines are not flat

- errors
- misalignments
- kickers
- or any other hor. B-field component

$$P_d(t) = P_{\mathrm{ST}}\ e^{-t/\tau_d}$$

Depolarizing effects

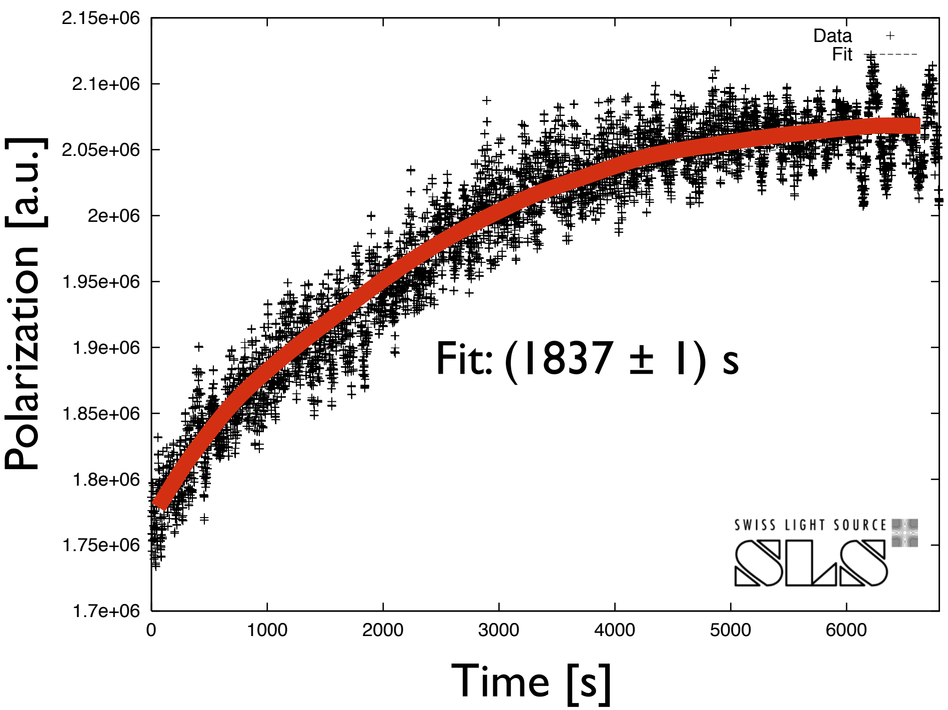
$$P(t) = P_{\mathrm{eff}} \left(1 - e^{-t/\tau_{\mathrm{eff}}}\right)$$

$$\frac{1}{\tau_{\mathrm{eff}}} = \frac{1}{\tau_p} + \frac{1}{\tau_d}$$

τ_{eff}: from fit; τ_p: known; τ_d: → calculate!

$$P_{\mathrm{eff}} = P_{\mathrm{ST}} \frac{\tau_d}{\tau_p + \tau_d}$$

theory



SLS (2.4 GeV)

- calculated build-up time: 31 min
- flat, well corrected, and ‘quiet’ machine
- observed up to 90% polarization!

Resonant Depolarization

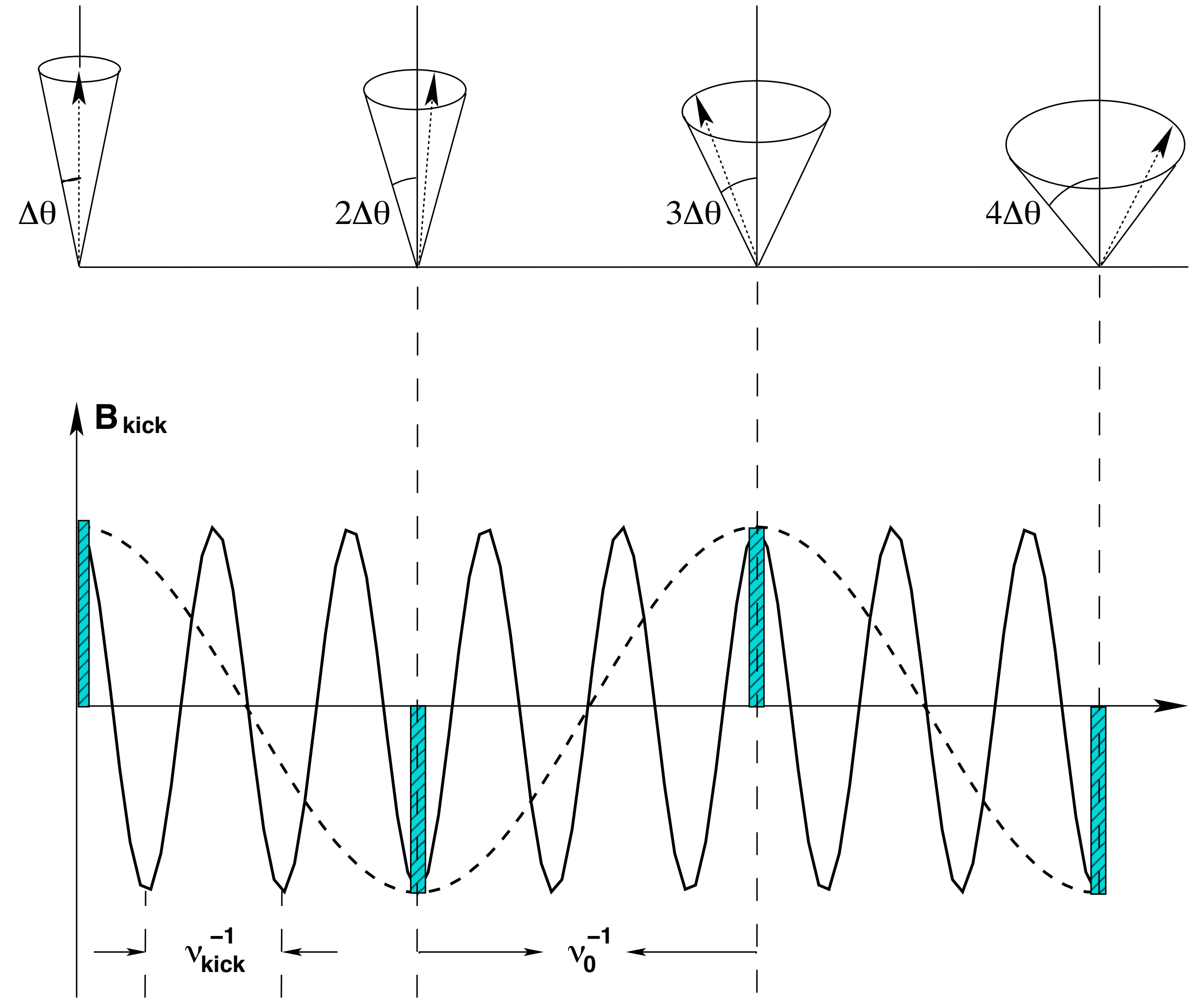
Once high degree of equilibrium polarization has been verified... → depolarize!

• Apply horizontal magnetic field to kick S out of the vertical

$$\Delta\theta = \frac{e\,a}{m_e c} \cdot \int_{\text{kicker}} B\; ds$$

• If kicks are applied in resonance with the spin precession frequency f_{sp}, S can be knocked into horizontal plane → P = 0

$$P = \left\langle \frac{S_z}{|\vec{S}|} \right\rangle_{\text{beam}}$$



Energy Calibration Measurement

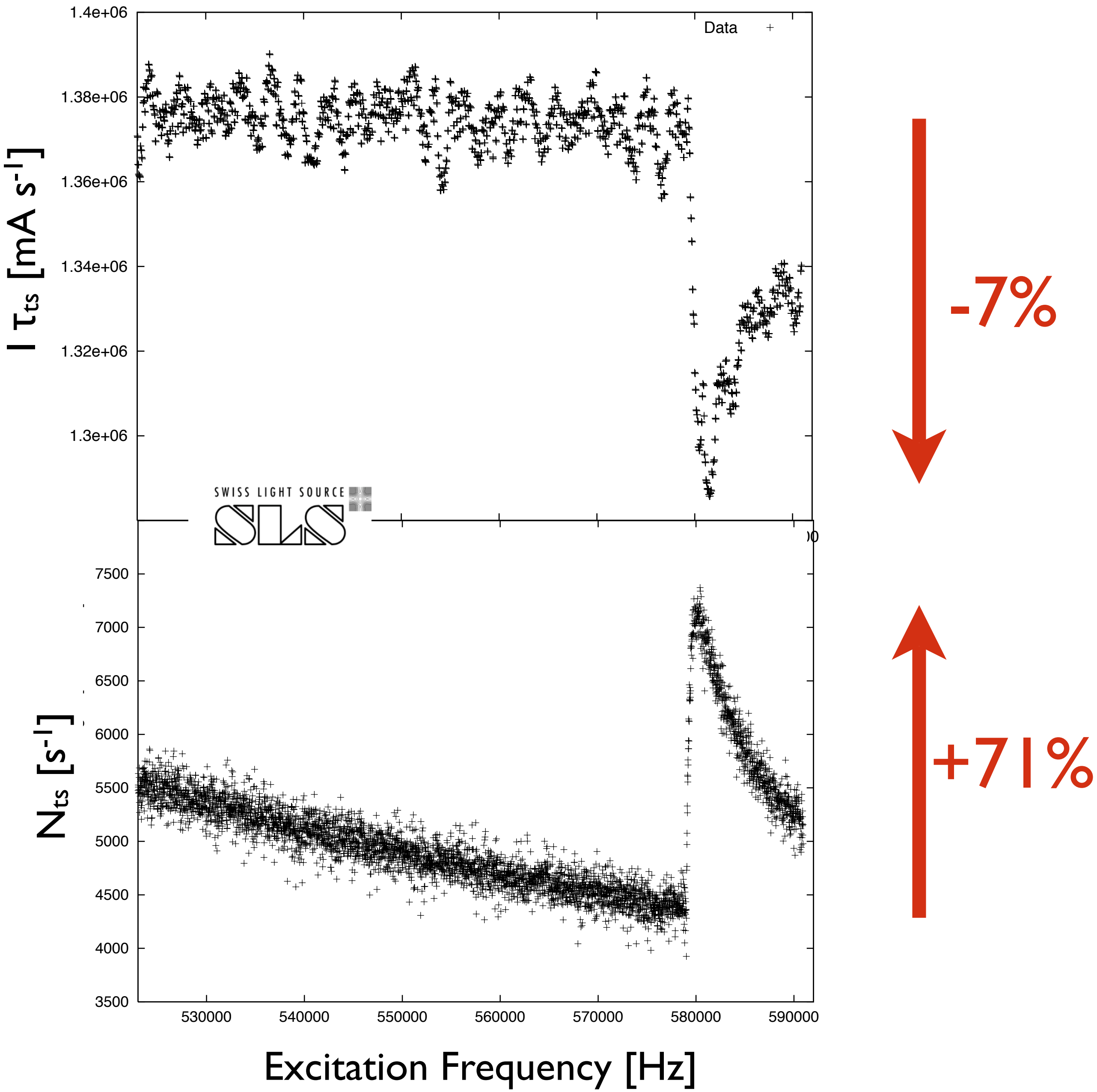
- Setup: sine generator → amplifier → fast vertical kicker magnet
- Sweep frequency of sine wave; when resonance is hit, beam depolarizes; this frequency f_d is directly linked to the beam energy

$$f_{sp} = f_0 \cdot a\gamma = \underbrace{f_0 \cdot \mathrm{int}(a\gamma)}_{\text{integer multiple of } f_0} + \underbrace{f_0 \cdot \mathrm{frac}(a\gamma)}_{\text{depolarizing excitation } f_d}$$

But how do we measure polarization break-down?

- MAX II is Touschek-limited machine $\frac{1}{\tau} = \frac{1}{\tau_{ts}} + \frac{1}{\tau_{el}} + \frac{1}{\tau_{bs}} = (23.8\ \mathrm{h})^{-1}$
- Touschek scattering is polarization dependent $\sigma_{ts} = f_1(\beta, \Theta) - P^2 \cdot f_2(\beta, \Theta, \Phi)$
- Upon resonance crossing Touschek scattering increases dramatically
  - ➡ Touschek lifetime drops: $I\tau_{\mathrm{ts}} \downarrow$
  - ➡ Increase of loss rates $\dot{N}_{\mathrm{ts}}/I^2 \uparrow$
    - ➡ Scintillators in coincidence downstream of dispersive section (BESSY, SPEAR) or at location of global aperture limitation (ALS, SLS)

Examples from SLS



- Measured I and τ
  $\rightarrow$ τ_{ts} calculated from τ

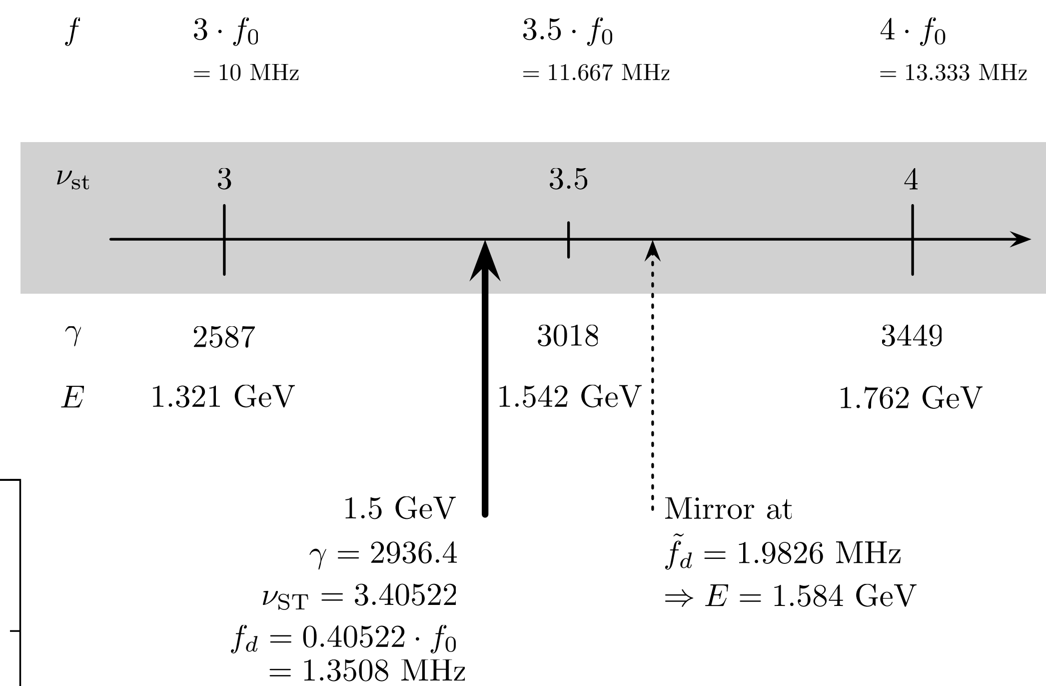
- Touschek losses: two scintillators in coincidence downstream of the mini-gap in-vacuum undulator U19

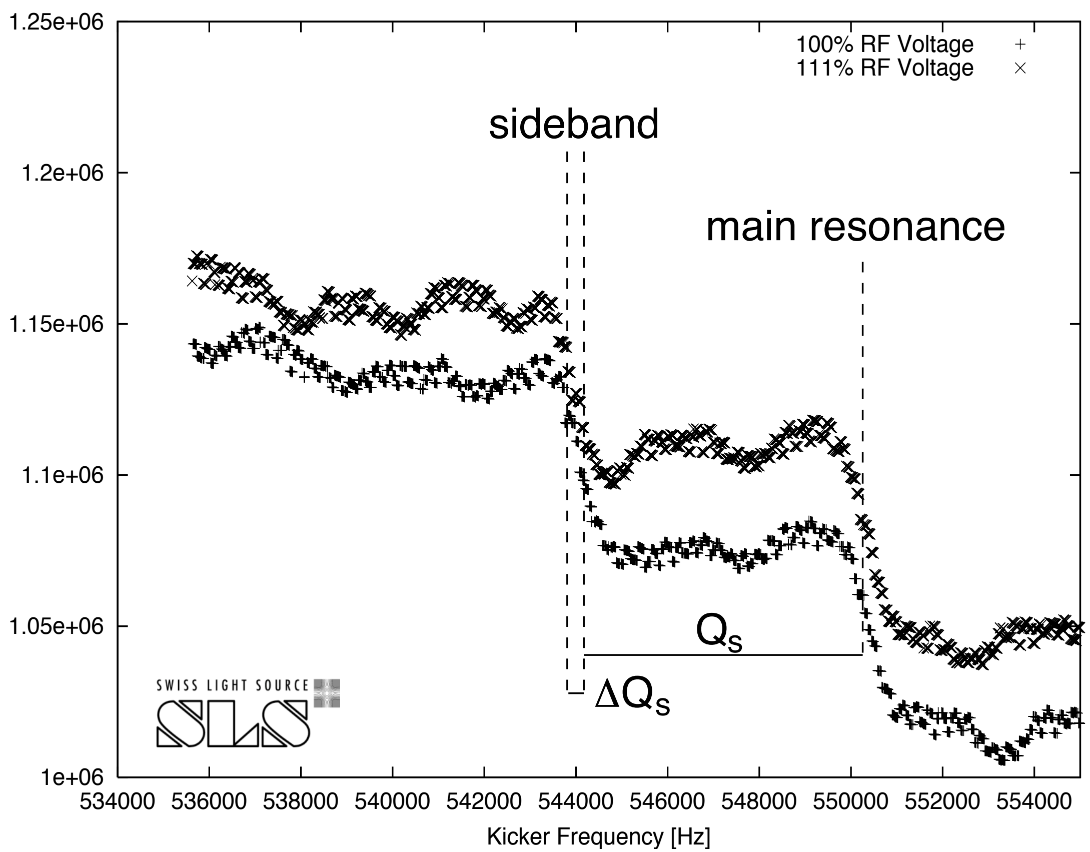
- During the sweep, sine generator writes its current frequency to a channel (EPICS control system)

There are some obstacles though...

Mirror resonance
(Nyquist theorem)

➡ Change f_{rf} and observe direction of resonance shift





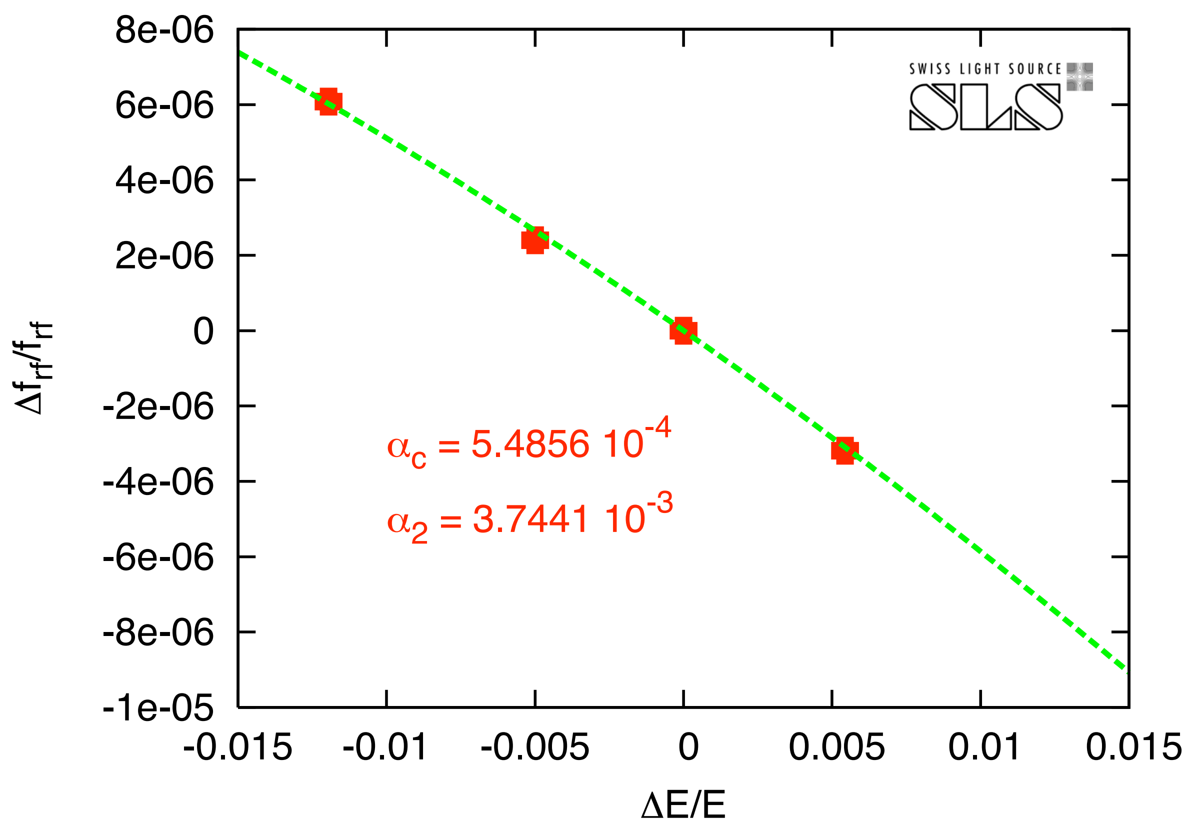
Sidebands
(synchrotron motion → Q_s sidebands)

➡ Change V_{rf} → Q_s shifted → find unshifted resonance candidate

Applications and Benefits for MAX II

- Better understanding of MAX II storage ring
- Not fast, but very high precision (~10^{-5}) → long-term studies (energy stability, slab settlement, temperature stability, seasonal variations, etc.)
- High precision allows measurement of nonlinear momentum compaction

$$-\frac{\Delta f_{\mathrm{rf}}}{f_{\mathrm{rf}}} = \alpha_c \frac{\Delta E}{E} + \alpha_2 \left(\frac{\Delta E}{E}\right)^2$$



Requirements for Implementation at MAX II

- Real-time logging of beam current and beam lifetime with a time stamp (sampling > 1 Hz)
- Sine generator for the frequency sweeps (adjustable range, step size, and dwell) (ideally with time-stamped output)
- Fast and sufficiently strong vertical kicker magnet with the sine generator as source
- Pair of scintillators in coincidence installed at the MAX II storage ring; signal readout with time stamp