ESRF | The European Synchrotron

ENERGY MEASUREMENT USING SPIN DEPOLARISATION AT THE ESRF

Attempts, Experiences, Simulations

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- *Several attempts have been made over the years to measure the absolute electron beam energy at the ESRF using the depolarisation method (2001, 2012-2014, 2022)*
- *Polarisation time is well in agreement with predictions*
- *However, the precise determination of the spin tune frequency (and therefore energy) fails. Depolarisation occurs in a very large region (several kHz) around the presumed resonance frequency despite many attempts to optimize the excitation parameters.*
- *In 2014/2015 simulations were performed which indicate that the fruitless measurements have a real origin in the lattice configuration of the pre-EBS ESRF (and the EBS-ESRF !)*
- *Until now, no indication of a sharp depolarization resonance for the EBS-ESRF*
- *Note: all data shown in these slides were taken or simulated for the pre-EBS ESRF storage ring lattice!*

POLARISATION TIME – MEASUREMENT AND FIT

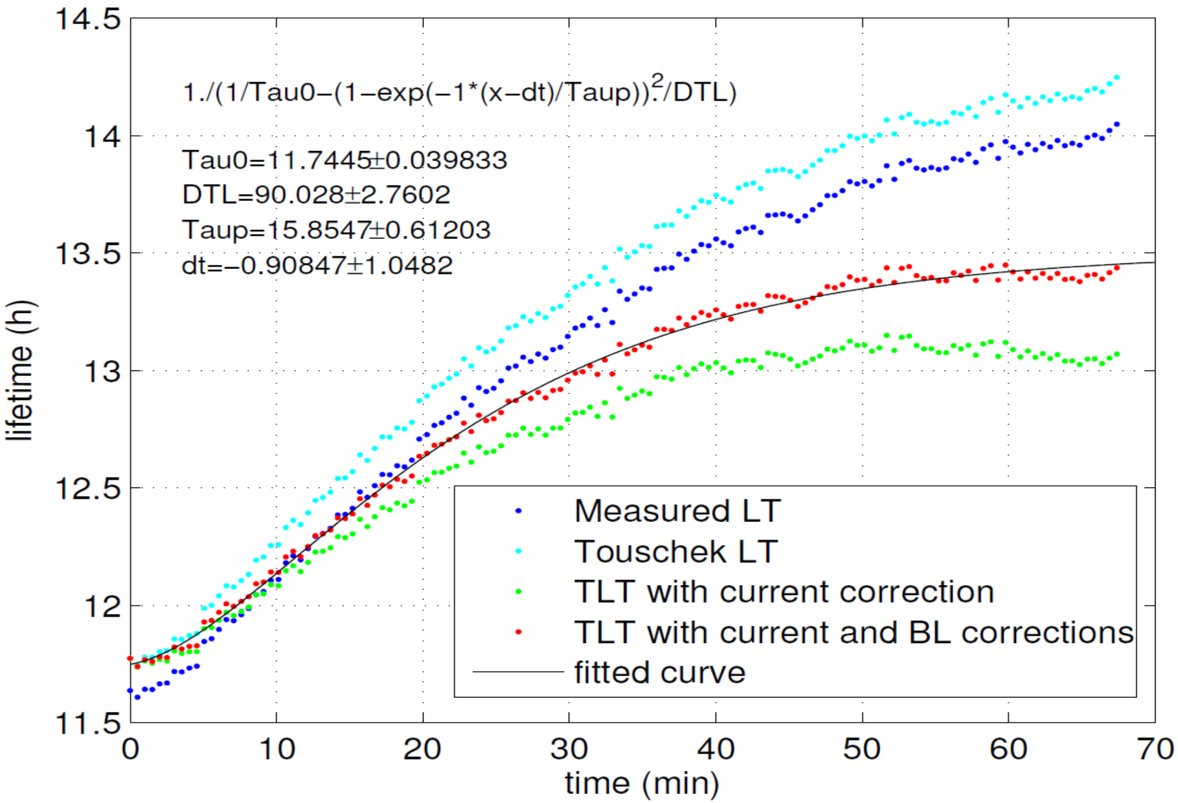
$\tau_T\,(t) = \;[\,1/\tau_T\,(0) + const. \cdot (1\text{-}exp(\text{-}t/\tau_0))\,]^{-1}$

Vacuum lifetime:
$\tau_v \approx 600$ *h*

Theory:
$\tau_p = 15.75$ *min*
$\Delta\tau_T\,/\,\tau_T = 15.1$ *%*

Measurement:
$\tau_p = 15.9 \pm 0.6$ *min*
$\Delta\tau_T\,/\,\tau_T = 15 \pm 0.005$ *%*

BL … bunch length
TLT … Touschek lifetime



RESONANT DEPOLARIZATION (MEASUREMENTS @ PRE-EBS ESRF, 2012 – 2014)

Beam Energy: $E = 6.04$ GeV

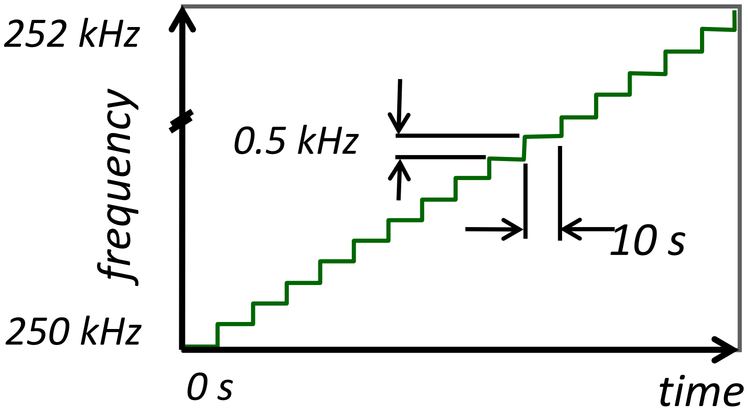
Spin tune: $\nu = a \cdot \mathbf{E}/m_e = 13.707$ — *a … anomalous magnetic moment of the electron*

Resonant depolarisation frequency $f_{dep} = 251$ kHz

Filling pattern: 16 bunch with 2 mA/bunch, $\varepsilon_z = 5$pm

Touschek lifetime $\tau_T = 12$ h

Vacuum lifetime $\tau_v = 600$ h → *Lifetime is Touschek dominated*



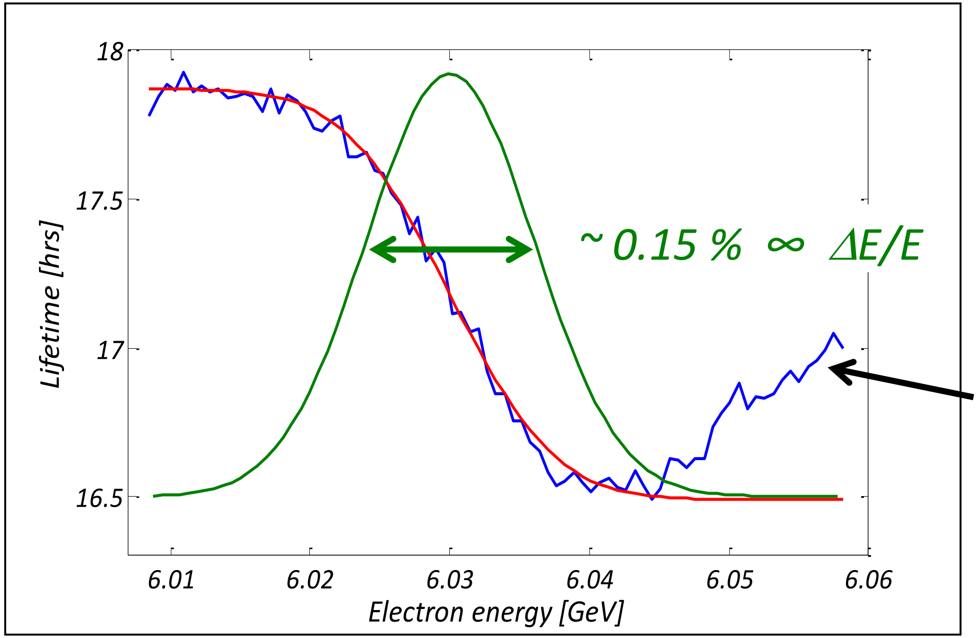
Typical parameters:

- *Single frequency excitation*
- *Over a frequency range of a few kHz around* f_{res}
- *0.5 kHz steps*
- *10s excitation per step*
- *Excitation qith vertical shaker* $B_x \cdot L \approx 2\ \mu T\ m$

Measurement of lifetime after each step

EXAMPLE OF MEASUREMENT

Excitation B_h L = 2 μT m
10 s sweeps of Δf = 0.5 kHz



Fit with error function
→ Center energy: 6.03 GeV

polarisation sets in again

- *Why the depolarisation "resonance" is so wide ?*
- *The energy is lower than we expect (6.03 instead of 6.04 GeV)*

WHAT IF WE EXCITE THE BEAM FAR AWAY FROM THE RESONANCE ?

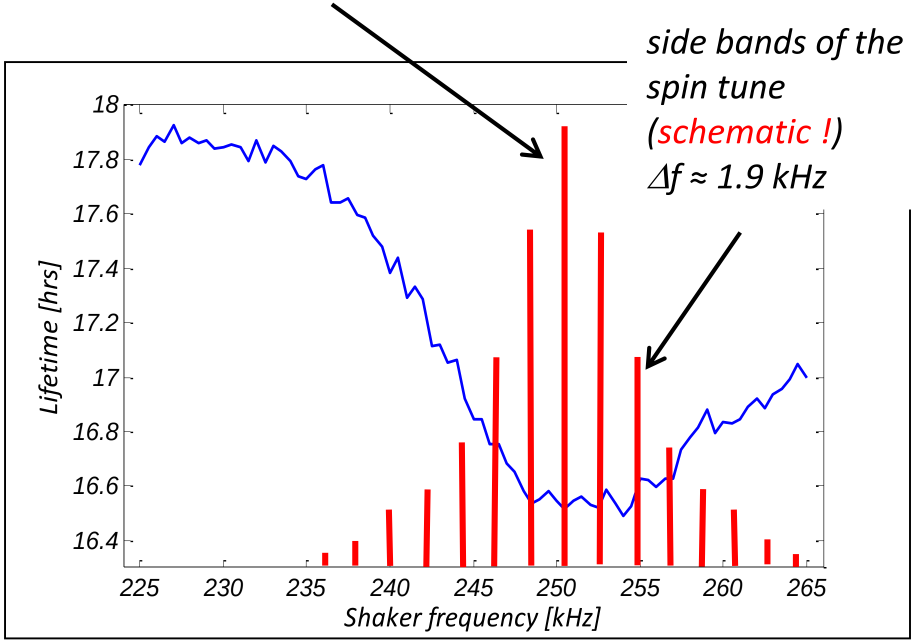
→ Depolarisation at any single frequency excitation
even if far from the theoretical resonance (as far as ~ 5 kHz) !!

Why don't we see narrow resonances at the synchrotron tune and its side bands ?

What may be wrong about our understanding / simulation of the resonance width ?
(should be very narrow at the use excitation strengths)

Synchrotron resonance lines would have to be broadened?
Or depolarization resonance widths are much wider than what we estimate?

fundamental spin tune resonance

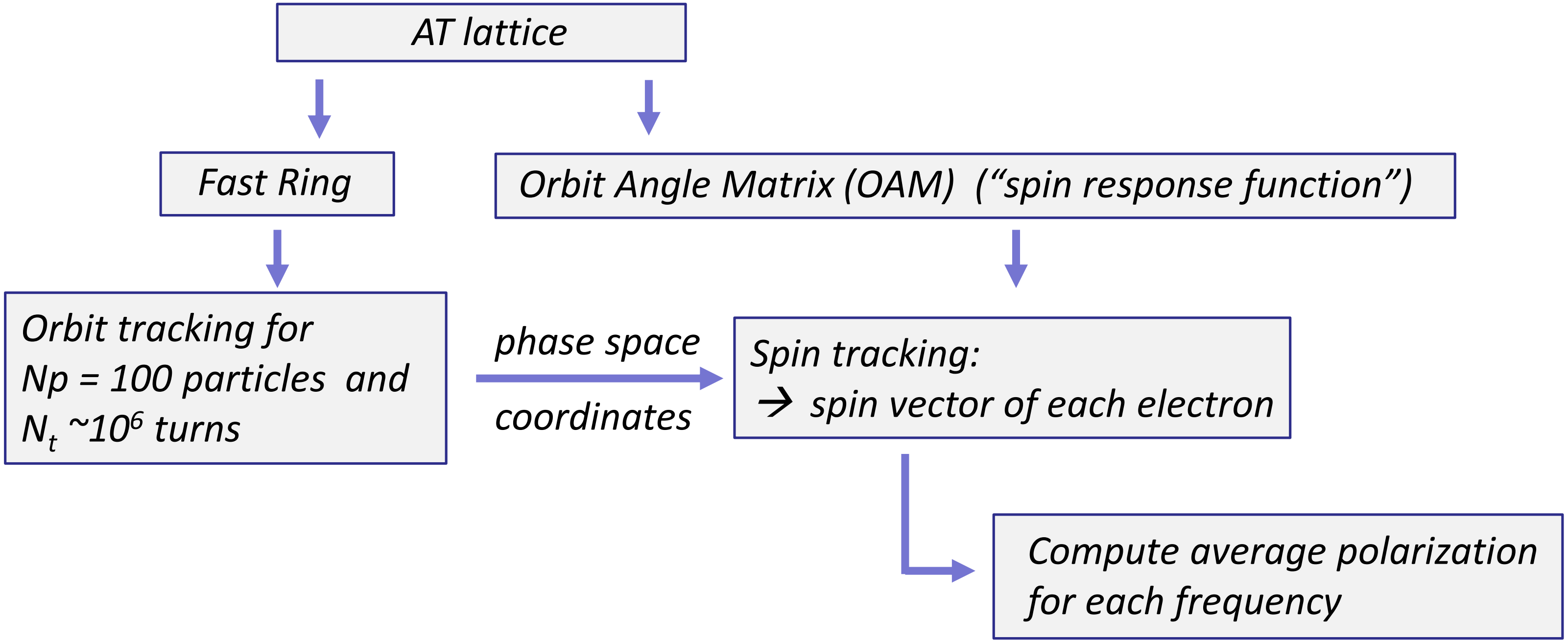


side bands of the spin tune (schematic !)
$\Delta f \approx 1.9$ kHz

WHICH EFFECTS INFLUENCE THE SPIN MOTION AND RESONANCE BW?

→ *Development of a spin tracking code **F**ast **E**lectron **S**pin **T**racking based on **A**T ("FESTA") by B. Nash + N. Carmignani*

N. Carmignani et al. "Modeling and Measurements of Spin Depolarsiation", IPAC 2015, MOPWA013.



AT lattice

Fast Ring

Orbit Angle Matrix (OAM) ("spin response function")

Orbit tracking for
Np = 100 particles and
N_t ~10^6 turns

phase space coordinates

Spin tracking:
→ spin vector of each electron

Compute average polarization for each frequency

WHICH EFFECTS INFLUENCE THE SPIN MOTION AND RESONANCE BW?

0. *All electrons have the same energy and precess about the vertical axis at $\nu_{sp,0} = a\,\gamma_0 = 13.707$*

→ *Very narrow depolarisation resonance*

→ *Depolarisation will occur, when kicker imparts a total angle of $\pi/2$*

→ *leads to a depolarisation in N_{d0} turns:*

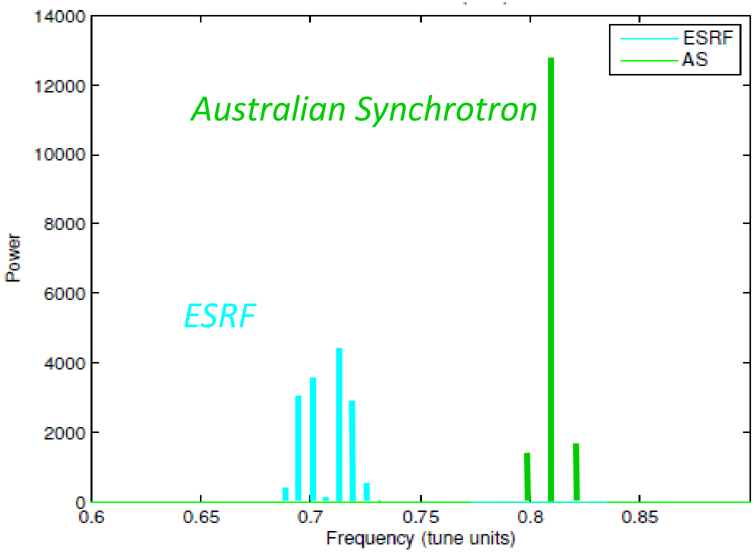
$$N_{d0} = \frac{\pi^2}{4\theta_k \nu_{sp}}$$ *= 180 000 turns (= 0.5 s @ ESRF) for $\theta_k = 1\ \mu$rad kick strength*

1. *Energy spread σ_δ is added*

→ *spread in spin tune $\sigma_{\nu,sp} = \nu_{sp}\sigma_\delta$*

WHICH EFFECTS INFLUENCE THE SPIN MOTION AND RESONANCE BW?

2. Effect of synchrotron oscillations



- → *Longitudinal component of the spin modulated by synchrotron oscillations*
- → *Narrow resonance width with synchrotron sidebands*
- → *sideband spacing is determined by ratio between spin tune and synchrotron tune*
- → *sideband amplitudes are modulated with the Bessel function $J_n(B)$*
- → *With* $B = \frac{\nu_{sp}\sigma_\delta}{\nu_s}$ *also known as spin tune modulation index [*] and can be interpreted as the number of sidebands inside the spin tune spread.*

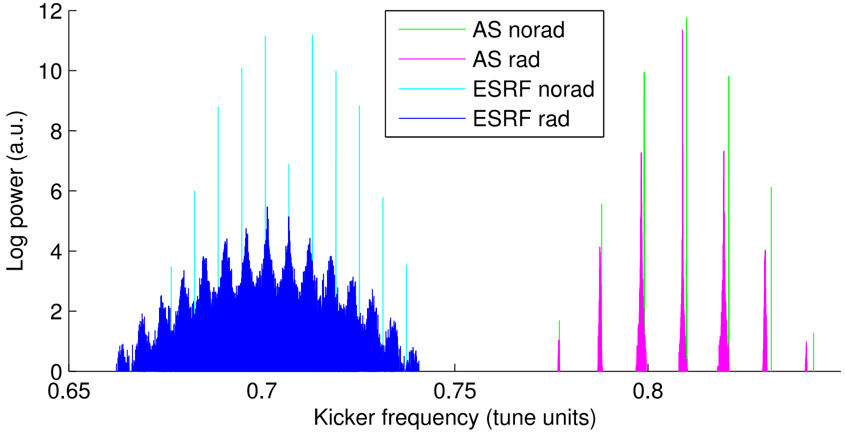
[*] J. Buon, "A stochastic model of Depolarisation Enhancement due to Large Energy Spread in Electron Storage Rings", LAL-RT 88-13 (1988)

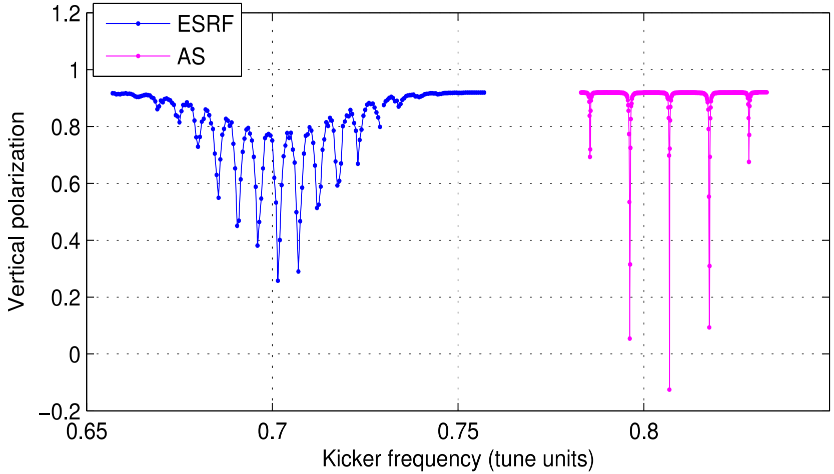
WHICH EFFECTS INFLUENCE THE SPIN MOTION AND RESONANCE BW?

3. Radiation effects

→ *Add radiation damping and diffusion (from AT tracking)*

→ *Resonances are broadened*





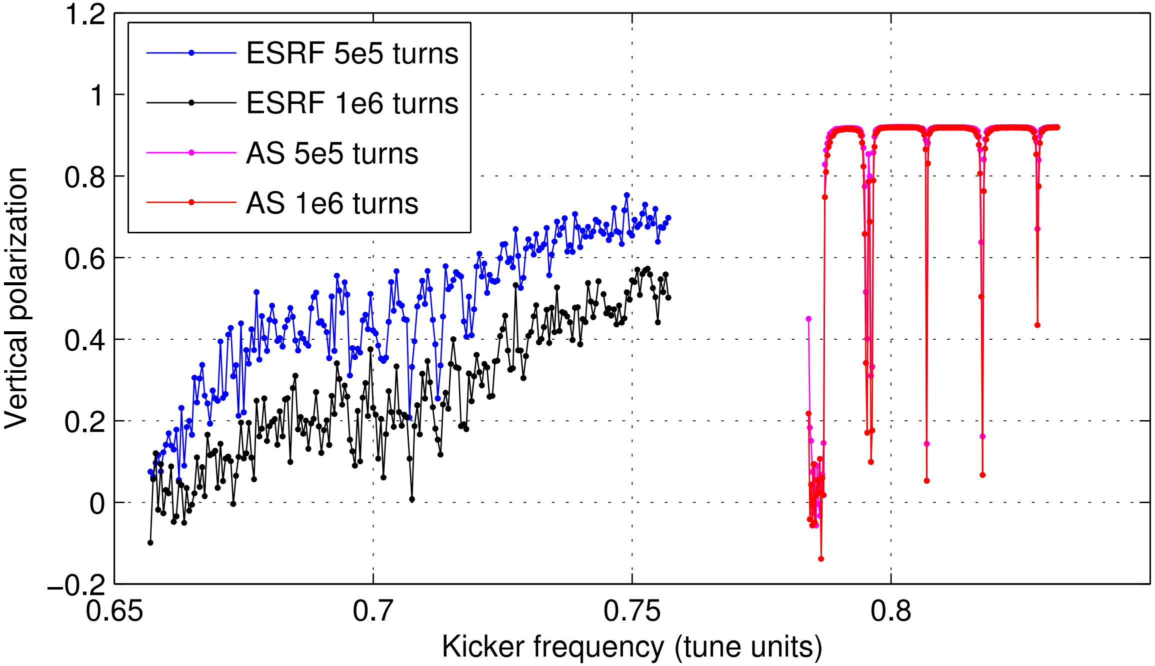
kicker strength = 25 mrad

100 particles tracked for 10^6 turns

WHICH EFFECTS INFLUENCE THE SPIN MOTION AND RESONANCE BW?

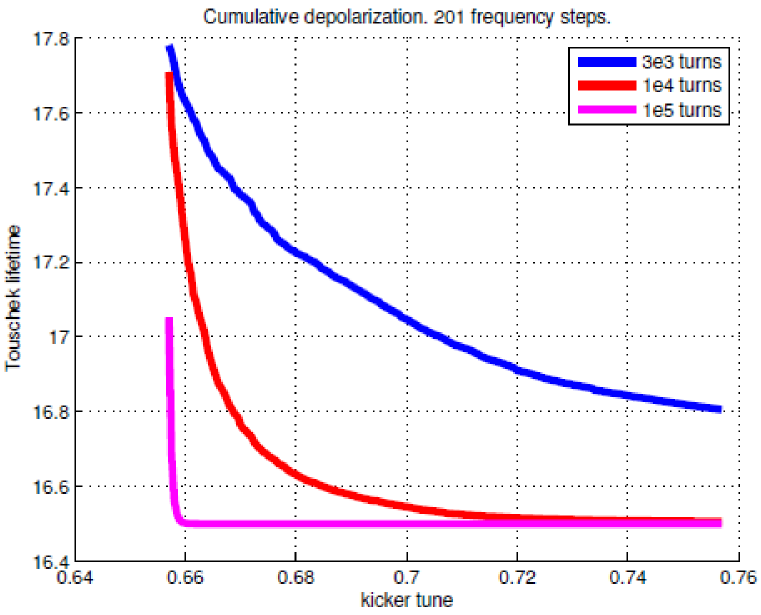
4. Effects of quadrupoles

- → *Need to consider the effect of orbital offsets in the quadrupoles*
- → *additional spin rotation*
- → *Resonances are broadened and effect of kicker strength is amplified.*
- → *Vertical betatron tune also amplifies the resonances.*



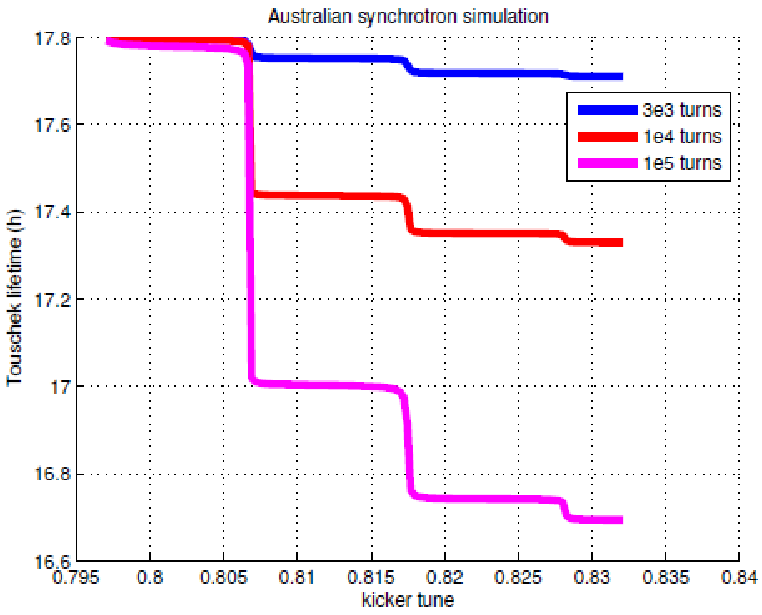
SIMULATED TOUSCHEK-LIFETIME DURING EXCITATION WITH KICKER

ESRF



1 μrad kicker strength

Australian Synchrotron



10 μrad kicker strength

Each point starts with the maximum possible polarisation (92%) (which is not the case in the real experiments! so no exact quantitative comparison of these plots with the data possible)

CONCLUSIONS – NO SHARP DEPOLARIZATION RESONANCE FOUND AT THE ESRF

Three effects seem to influence the quality and detectability of the depolarisation resonance:

1. *Synchrotron oscillations*
   -> B-factor determines the spin tune sideband densities and amplitudes

$$B = \frac{\nu_{sp}\sigma_\delta}{\nu_s}$$

	ESRF	**SPRING8**	**APS**	**Diamond**	**Bessy**	**LEP**	**SPEAR3**	**ALBA**	**SLS**	**AS**	**ANKA**	**ESRF S28**
spin tune	*13.707*	*18.276*	*15.992*	*6.842*	*3.860*	*130.000*	*6.810*	*6.810*	*5.450*	*6.810*	*5.673*	*13.707*
energy spread	*1.06E-03*	*1.00E-03*	*1.01E-03*	*9.62E-04*	*6.60E-04*	*1.20E-03*	*1.20E-03*	*1.01E-03*	*8.60E-04*	*1.00E-03*	*1.00E-03*	*1.01E-03*
synchrotron tune	*5.43E-03*	*7.78E-03*	*7.20E-03*	*3.37E-03*	*1.50E-03*	*1.20E-01*	*8.00E-03*	*8.51E-03*	*6.25E-03*	*1.04E-02*	*9.94E-03*	*3.45E-03*
B	**2.68**	**2.35**	**2.24**	**1.95**	**1.70**	**1.30**	**1.02**	**0.81**	**0.75**	**0.65**	**0.57**	**4.01**

2. *Radiation effects -> lead to line broadening and amplitude reduction*

3. *Orbital offsets in the quadrupoles -> further line broadening.*

see also: N. Carmignani et al. “Modeling and Measurements of Spin Depolarsiation”, IPAC 2015, MOPWA013.

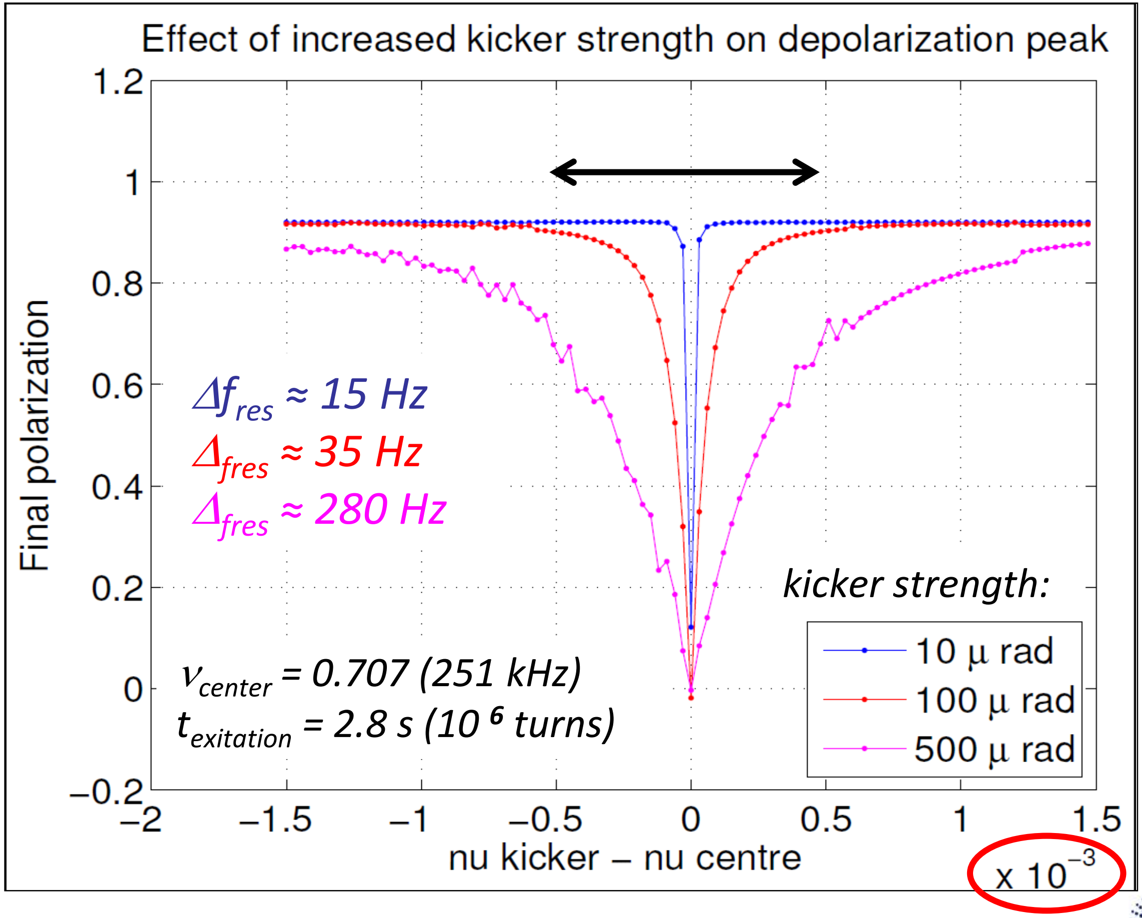
https://indico.cells.es/event/22/contributions/436/attachments/364/493/DEELS2015_Ewald_Spin.pdf

Resonance width computed with a simple spin track code, with varying kicker strengths.

We observe clear depolarisation at $B_x L \approx 2\ \mu Tm$

An integrated field of 2 μTm *corresponds to an angular kick strength of ~ 0.1* μrad.

→ *simulated resonance width only a fraction of Hz !!*



$\Delta f_{res} \approx 15\ Hz$

$\Delta_{fres} \approx 35\ Hz$

$\Delta_{fres} \approx 280\ Hz$

kicker strength:

$\nu_{center} = 0.707\ (251\ kHz)$

$t_{exitation} = 2.8\ s\ (10^6\ turns)$