On the electrical parameters of a depolarizer

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Outline

Intrinsic resonances

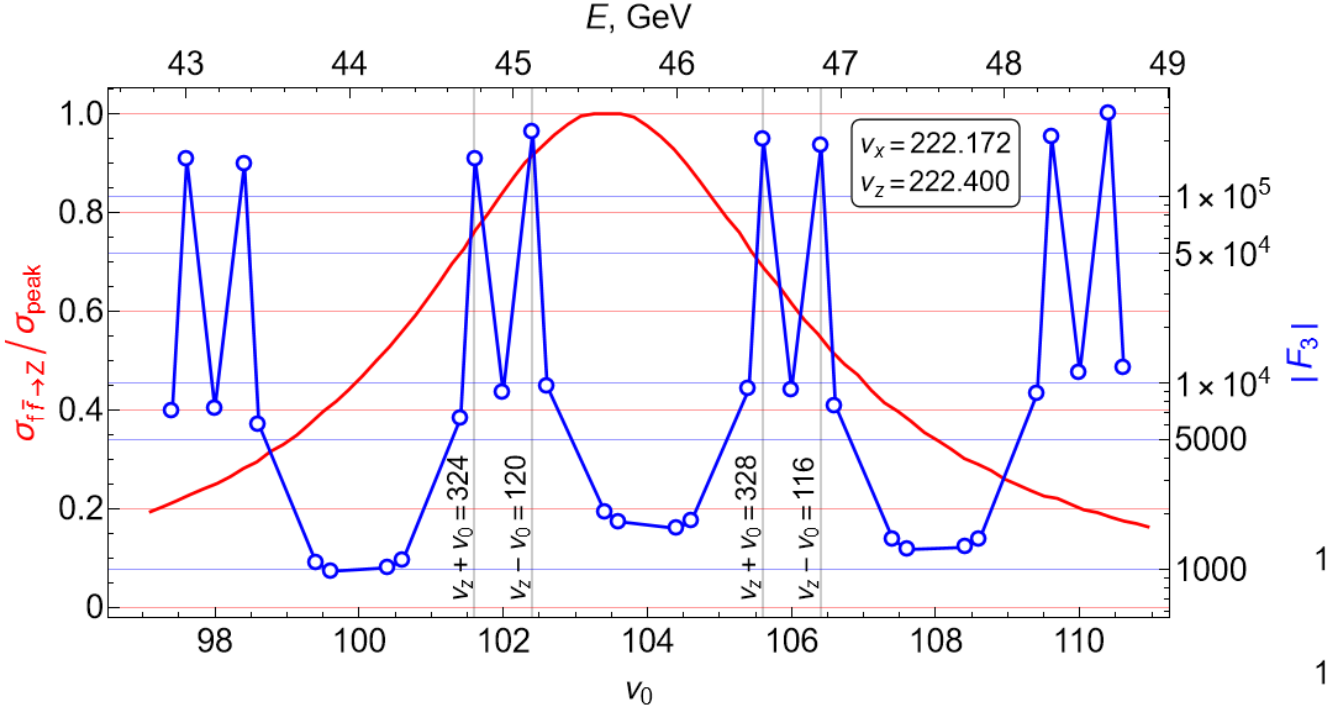
How big should be detuning from the strongest intrinsic resonances:
most strong are: $\nu_z \pm \nu_0 = 4k$ (because of 4 superperiods of a lattice!)
at Z $|\nu_z \pm \nu_0 \pm 4k| > 0.02$,
at W $|\nu_z \pm \nu_0 \pm 4k| > 0.25$

RD of a single pilot bunch

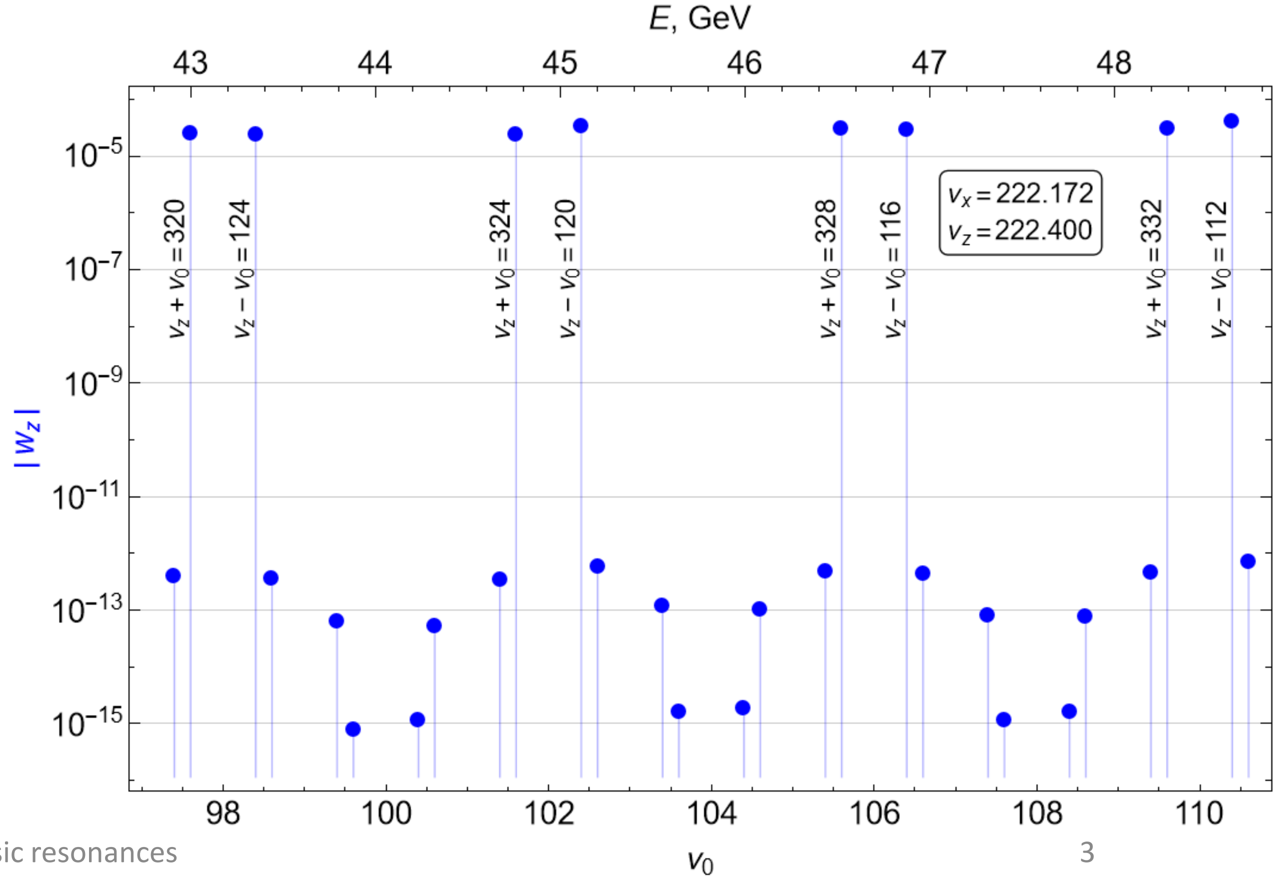
Spin half-flip for free precession

CW depolarizer operation mode for suppression of selfpolarization

Intrinsic Spin Resonances structure at Z

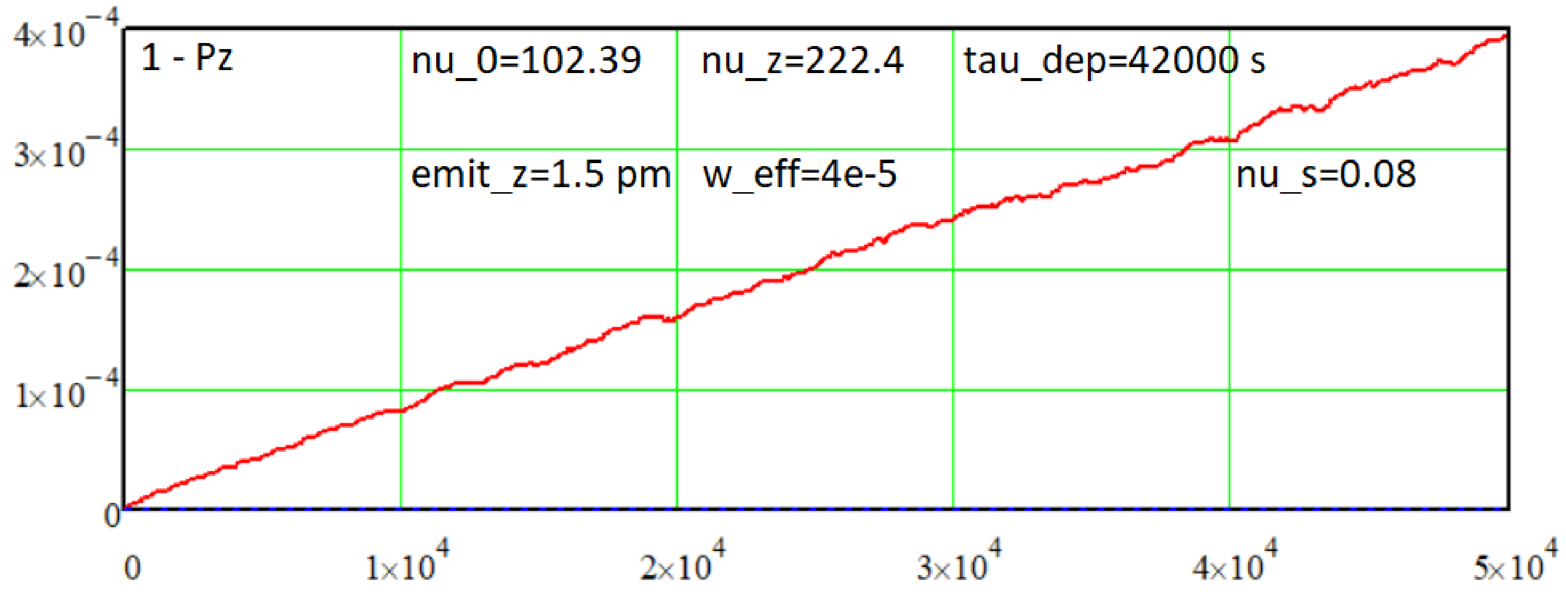


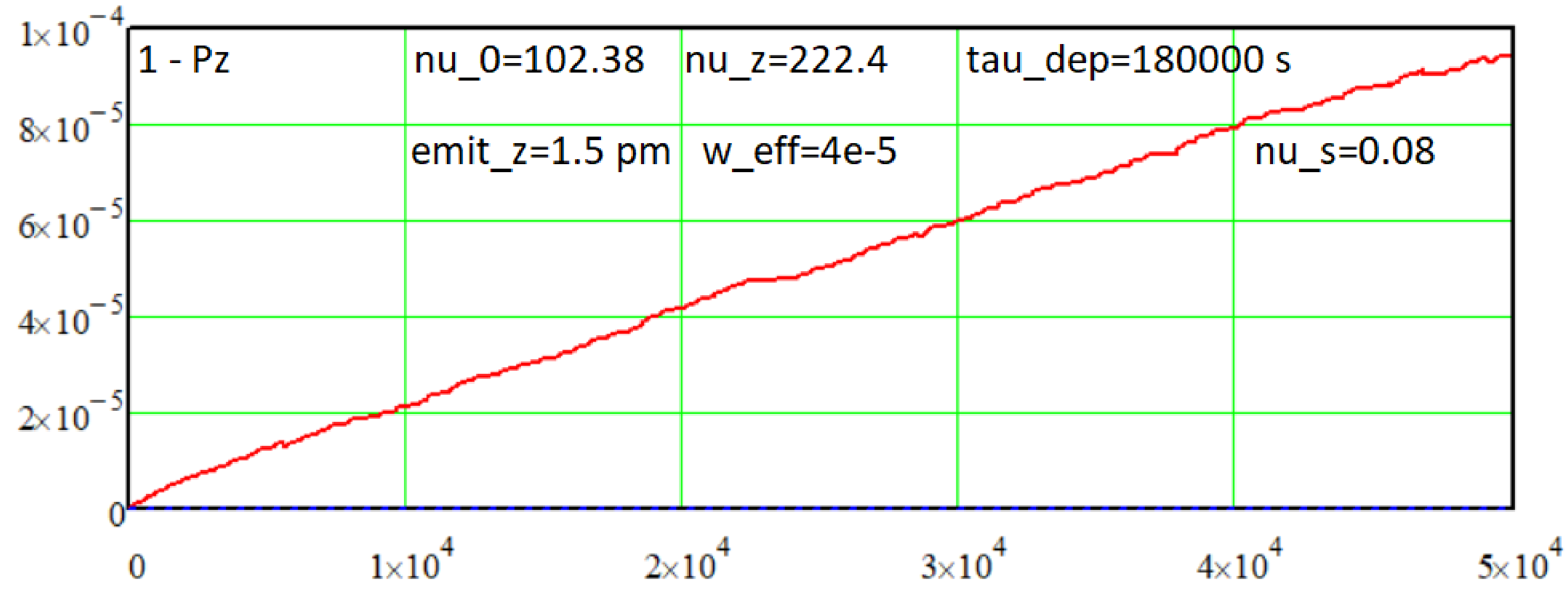
The lower plot shows the harmonic strengths of different intrinsic resonances powered by the vertical oscillations with emittance $\varepsilon_z = 1.5$ pm.



The upper plot shows the resonance structure of $|F_3|$ and the Z-lineshape. Each resonance peak is narrow. We stay detuned off peaks by $\Delta\nu = 0.01$. Exactly on a resonance the spin response becomes infinite.

Beam depolarization by the intrinsic spin resonance at Z





With $\Delta\nu_0 = -0.01$ from a resonance tune value $\nu_0 = 102.4$ the depolarization is 4 times faster than with $\Delta\nu_0 = -0.02$ (lower plot).

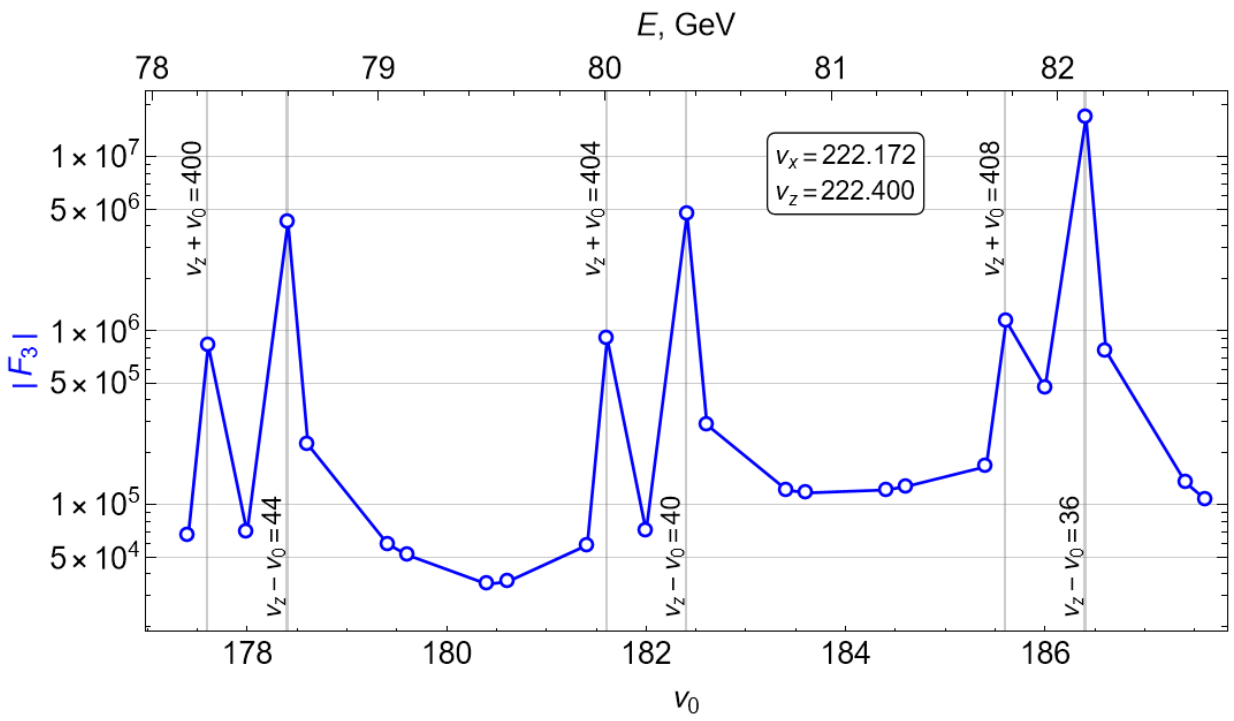
Many other parameters enter into play. By spin tracking we find the following scaling:

$$\tau_{dep} \sim \left(\frac{\nu_0 - \nu_z}{w}\right)^2 \sqrt{\frac{\nu_s}{\sigma_\delta}}$$

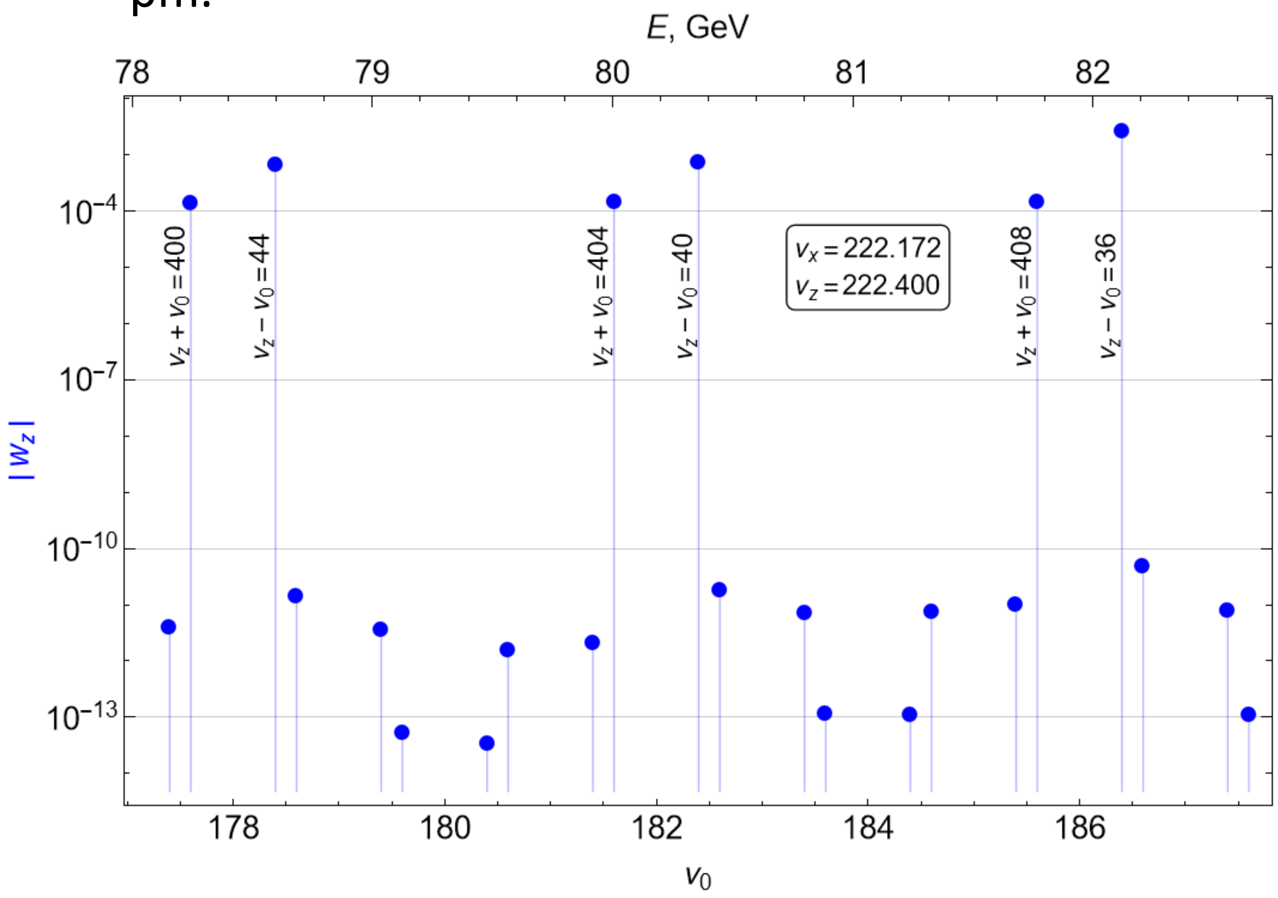
where σ_δ is the energy spread, ν_s - is the synchrotron tune, w - is the effective resonance harmonic value. Note that $w^2 \sim \varepsilon_z$.

Conclusion: a gap between the spin tune ν_0 and the vertical betatron tune ν_z could be chosen at Z as small as: $\nu_0 - \nu_z + k = \pm 0.02$.

Spin Resonances structure at W energy range

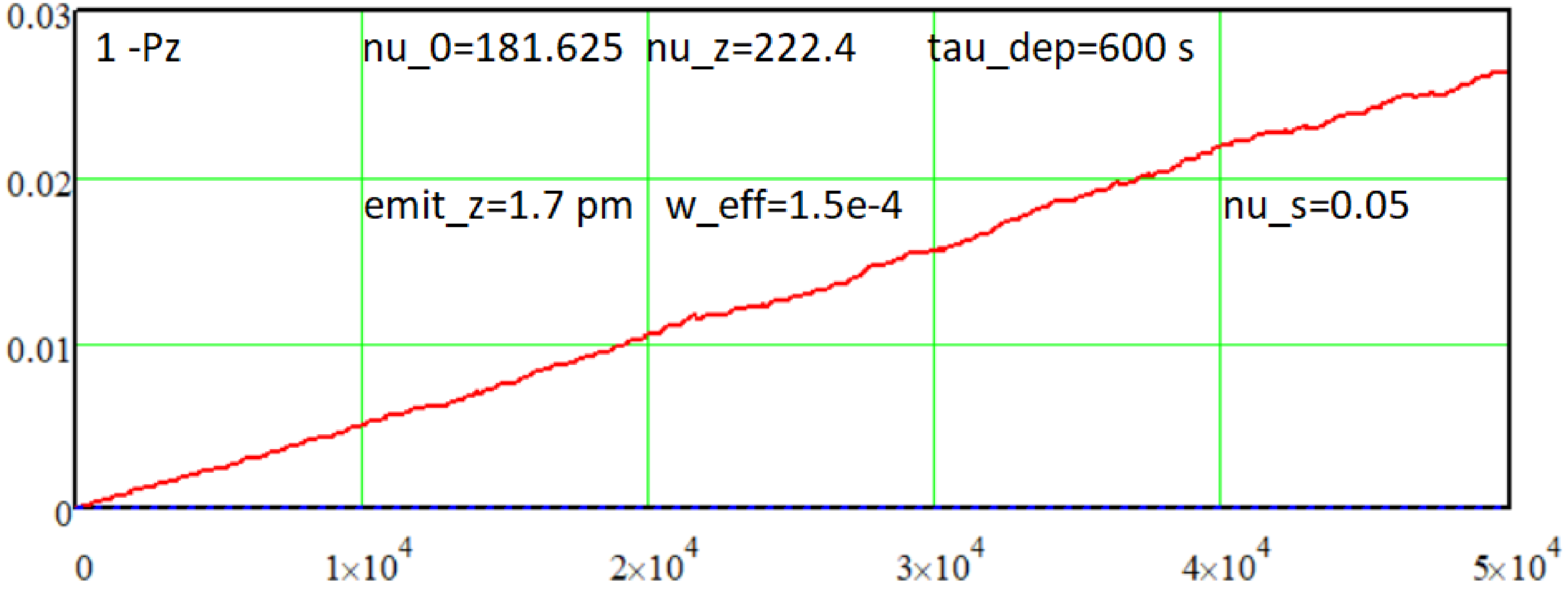


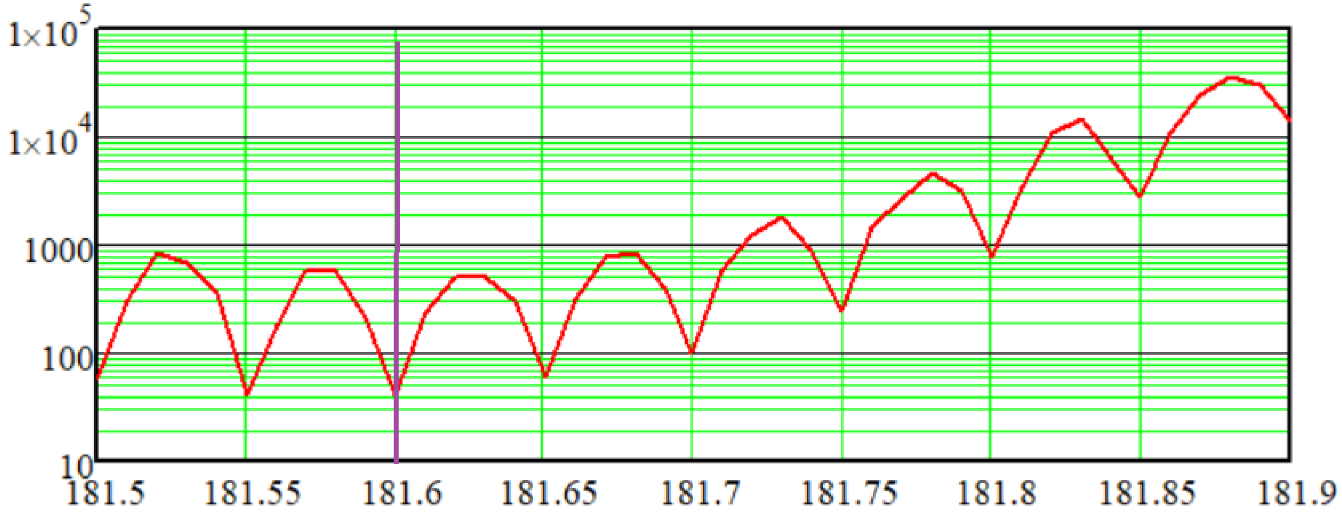
The lower plot shows the harmonic strengths of different intrinsic resonances powered by the vertical oscillations with the emittance $\varepsilon_z = 1.7$ pm.



The difference between the resonances strengths of resonances 4*k with all others is about 8 orders of magnitude!

Beam depolarization by the intrinsic spin resonance at W





At W the intrinsic resonances are much stronger than at Z : $w_k \approx 1.5 \cdot 10^{-4}$.

With $\Delta\nu_0 = -0.025$ from a resonance tune value $\nu_0 = 181.6$ the depolarization is too fast, approximately $\tau_{dep} = 600\ \mathrm{s}$.

Detuning should be as large as $\Delta\nu_0 = \pm 0.25$, but there the synchrotron side bands from the nearest integer parent resonance may depolarize a beam.

Conclusion for W energy region: a gap between the spin tune ν_0 and the vertical betatron tune ν_z needs to be chosen as large as:

$\nu_0 - \nu_z + k = \pm 0.25$.

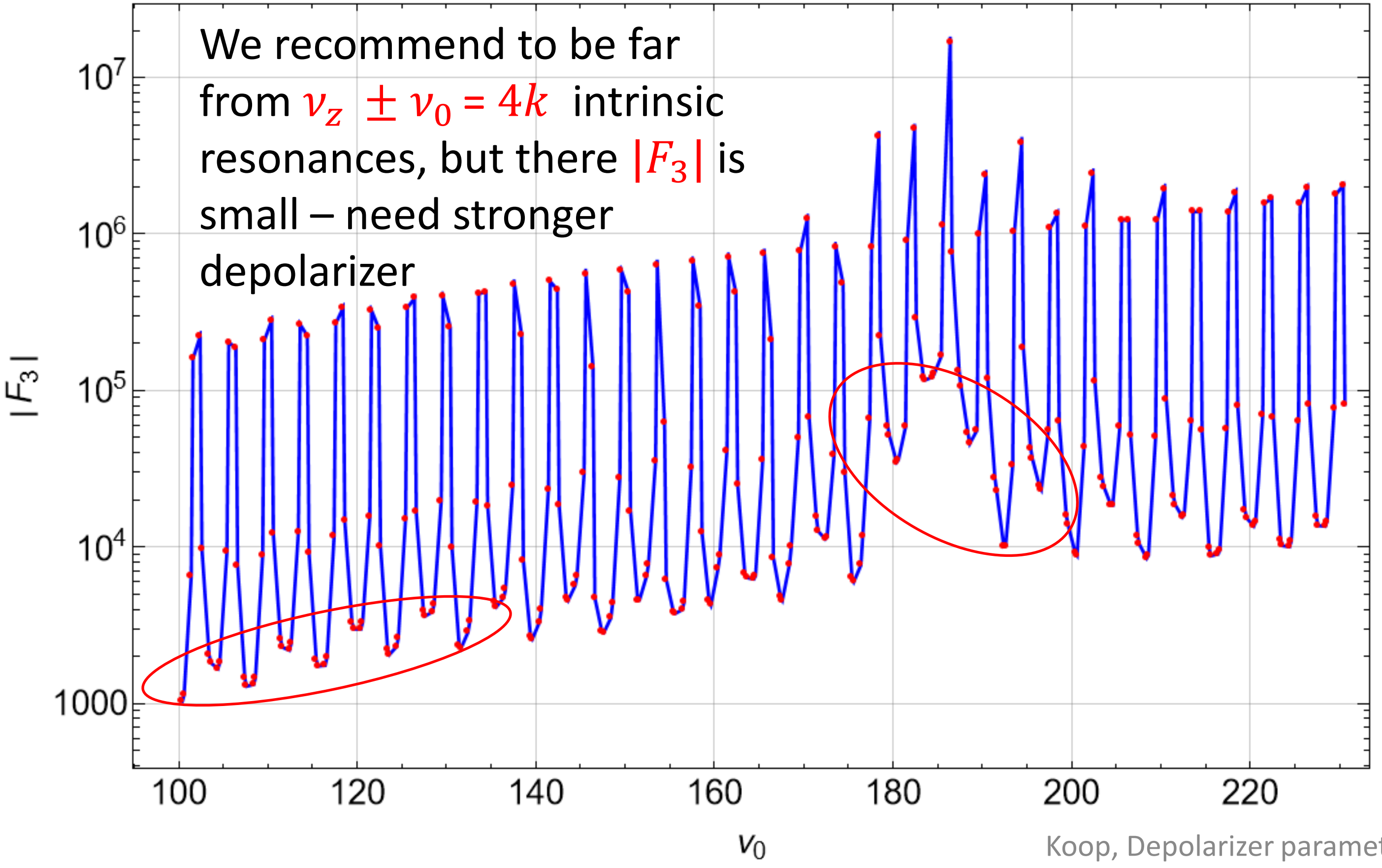
Input/Output parameters for RD of a single bunch

Depolarizer's harmonic wanted value $w = 1.4 \cdot 10^{-4}$. Spin-orbit response function $F_3 = 1 \cdot 10^3$ at Z-energy, near FF doublet. $\theta_{kick} = 2\pi w/|F_3| = 1 \cdot 10^{-6}$ - kick angle of a depolarizer.

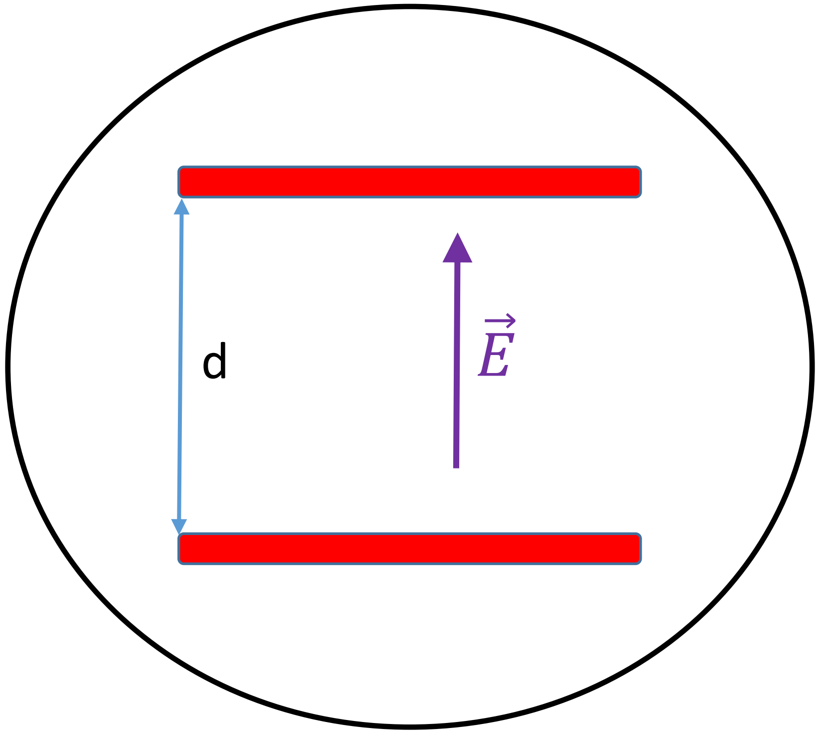
$$BR = 45/0.3 = 150\ T \cdot m \quad \rightarrow \quad El = Bl = 0.5 \cdot \theta_{kick} BR = 0.75 \cdot 10^{-4}\ T \cdot m$$

$$l = 1\ m, \quad d = 4\ cm, \quad B = 0.75 \cdot 10^{-4}\ T, \quad E = 225\ V/cm, \quad U = 0.5 \cdot E \cdot d = 450\ V$$

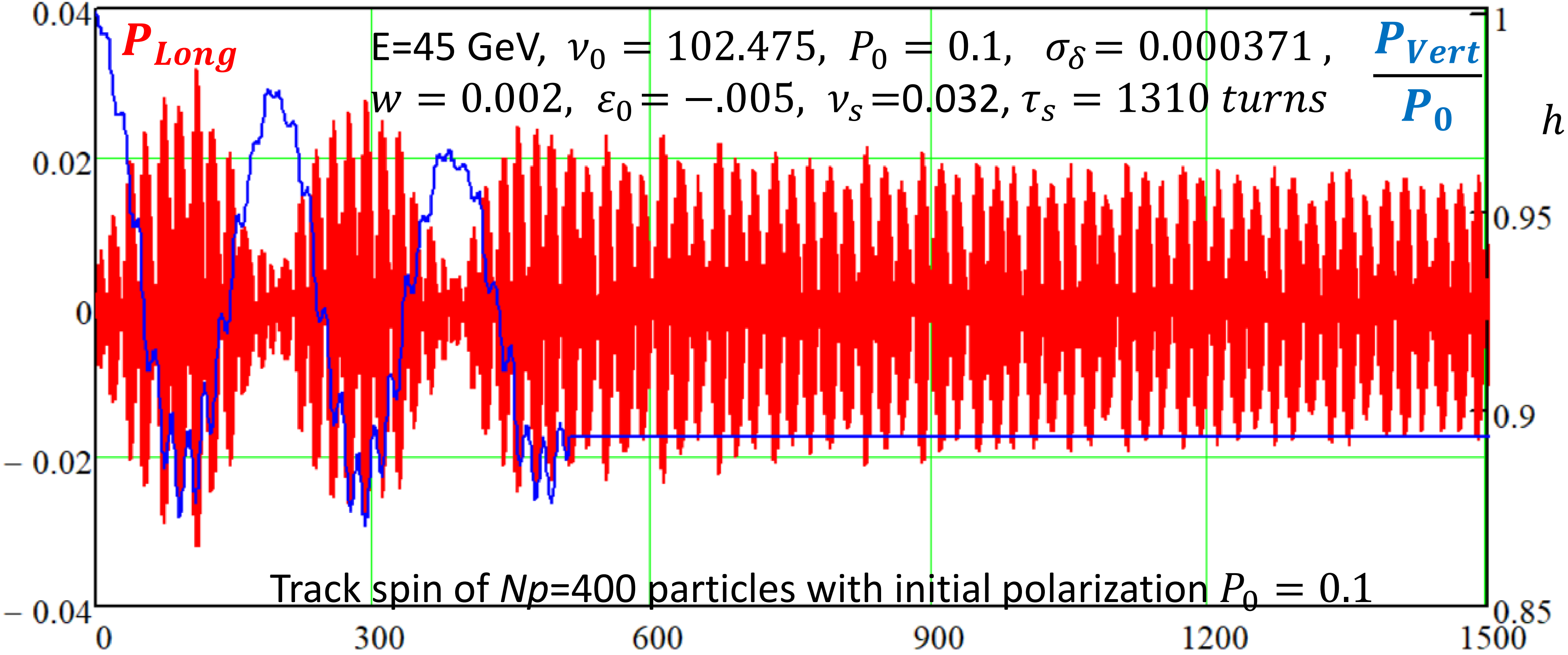
$$P_{pulse} = 0.5 \cdot U^2/Z_{Line} = 2000\ W, \quad \langle P \rangle = P_{pulse} \cdot \Delta t/T = 2000 \cdot 10\ ns/320\ mks = 63\ mW$$



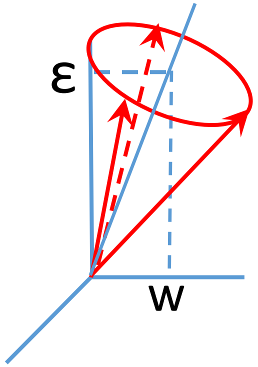
Strip Line sketch:



Excitation of the coherent spin precession at Z by Flipper



$h = \sqrt{\varepsilon^2 + w^2}$



Spin precession in resonance frame

Coherent rotation of the total spin ensemble is done by powerfull Flipper device: w=0.002. Its frequency is shifted from the resonance by small detuning factor: $\varepsilon_0 = -.005$. Flipper is on 512 turns. After that we observe free spin precession during 2048 turns. Polarization loss is only 10%. In principle, Flipper kicks effectively spin only first 100 turns, or so!

Parameters for spin flip of a single bunch

For spin flip at Z the required effective depolarizer strength is about w=0.002 with a pulse duration 100 turns (coherent spin rotation by *0.2turn=72*^{0}, see previous slide).

This is about 14 times stronger than for the frequency sweep method, but about 1000 times shorter in time.

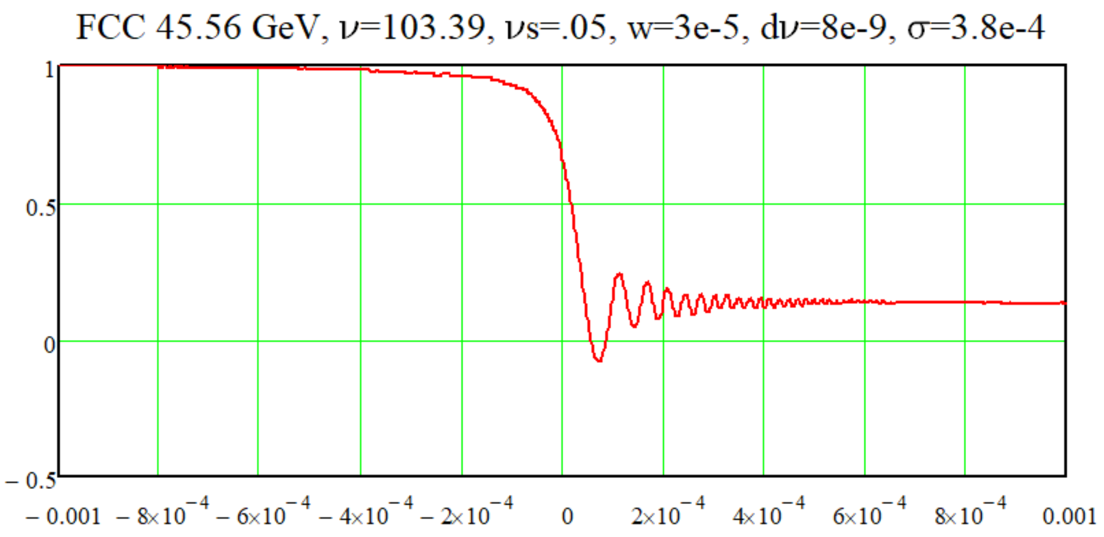
Conclude: $P_{pulse} = 400\ kW, \quad \langle P \rangle = P_{pulse} \cdot \Delta t/T = 400000 \cdot 10\ ns/320\ mks = 125\ W, \quad t = 33\ ms$

CW regime to depolarize colliding bunches

We will be able to predict a beam energy with the accuracy of about 10^{-5}. Taking into account that $\nu_0 \approx 100$, this means that depolarizer's tune is shifted from a resonance value not more than by $\varepsilon = 0.001$.
Our fit for the depolarization time:

$$\tau_{dep} \approx \tau_\delta \cdot 0.024 \left(\frac{\varepsilon}{w}\right)^2 \frac{\nu_s^{1.5}}{\nu_0^2 \sigma_\delta^{2.5}}$$

Polarization degree $P = 10^{-4}$ will appear in 85 s due to Sokolov-Ternov mechanism. To get such depolarization time with constant detuning $\varepsilon = 0.001$ from a resonance will require $w = 5 \cdot 10^{-4}$ - too large harmonic value for CW regime! More economic would be to use $w = 3 \cdot 10^{-5}$ in a frequency scan mode, span in 85 s.



$E = 48\ V/cm, \quad U = 96\ \mathrm{V}, \quad \langle P \rangle = 92\ W$

Conclusion

- There are many uncertainties due to strong dependence of spin response function F3 from the betatron and spin tunes. F3 varies by many orders of magnitude when spin tune changes its integer part.
- Most safe is to operate far from the strong intrinsic resonances: integer multiples of 4. Our calculations show that the needed depolarizer power is in the order of 100 W. It is sufficient to depolarize a beam in all modes of operation.
- Selectivity also is important ingredient of a system. Needs to be developed.