Depolarizer for the FCC-ee

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Outline

Three different tasks for use of the depolarizers: RDP of pilot polarized bunches, free precession approach, continuous colliding bunches depolarization to keep $P < 10^{-5}$

Local bump depolarizers by two identical transverse AC-field kickers

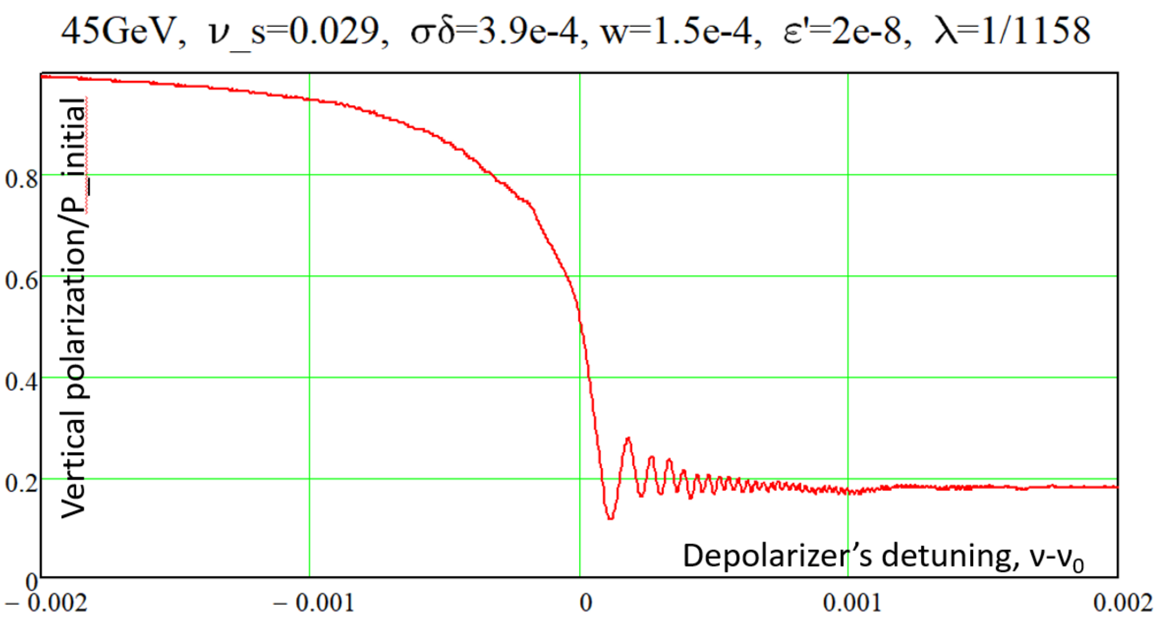
Harmonic strength evaluation at Z and at W beam energies

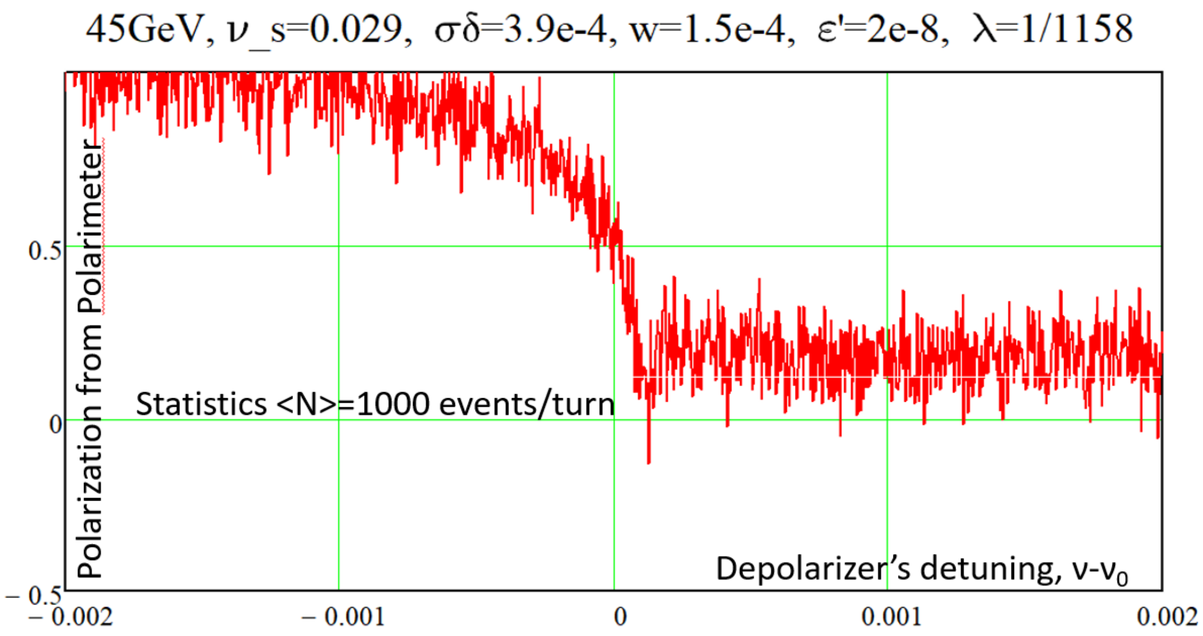
Discussion of results

Three scenarios for using of depolarizers. Regular RDP procedure.

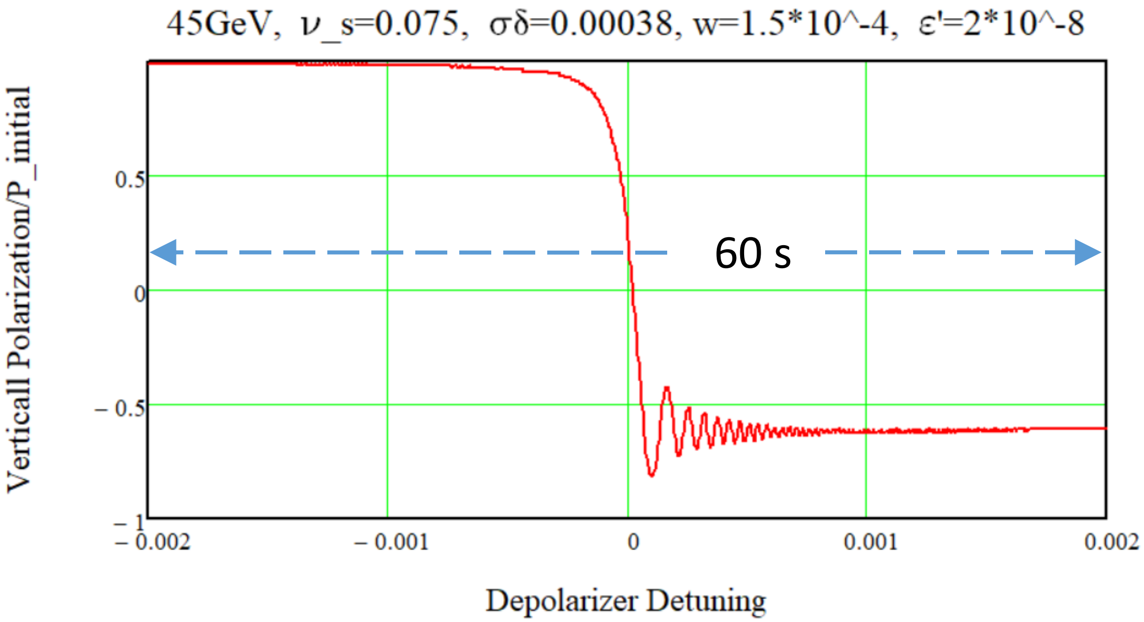
The Resonance Depolarization (RDP) by scanning of some narrow region of frequencies. Relevant parameters: spin tune $\nu_0 = E(GeV)/0.4406486$, the depolarizer's tune $\nu = (f + kf_0)/f_0$, detuning from a resonance by $\varepsilon = \nu - \nu_0$, tune scan rate $\varepsilon' = d\nu/dn$, the strength of a depolarizer (harmonic value) $w = \varphi/2\pi$ - spin rotation by its transverse field in one pass through a string of installed AC-dipoles – the whole depolarizer.

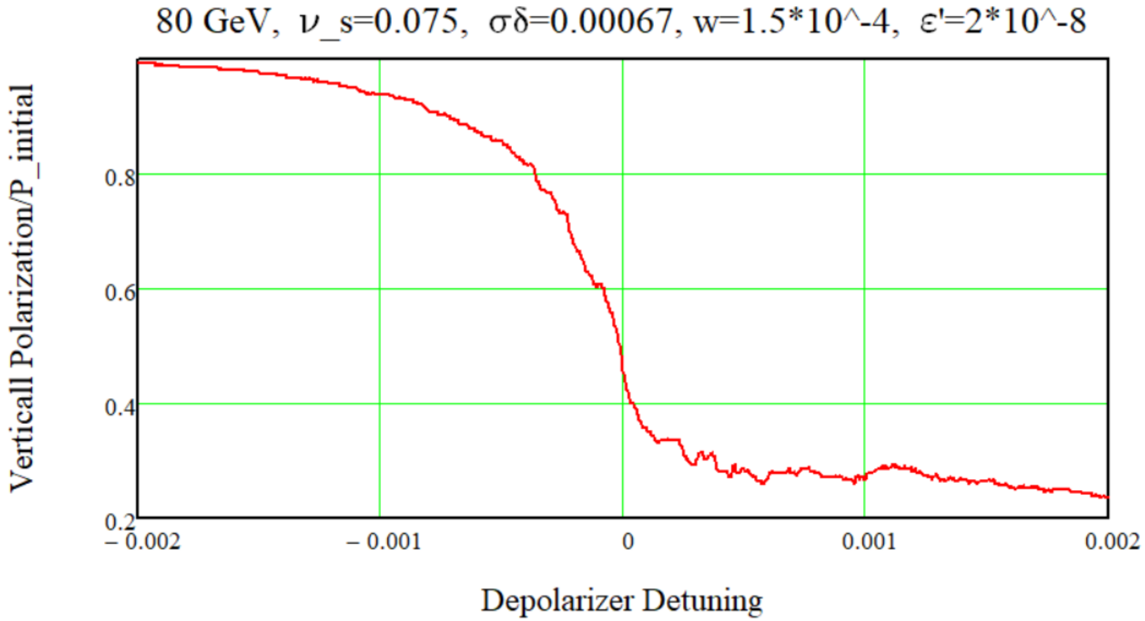
As an example see simulated RDP for 45 GeV actual beam parameters: reduced ν_s =0.029

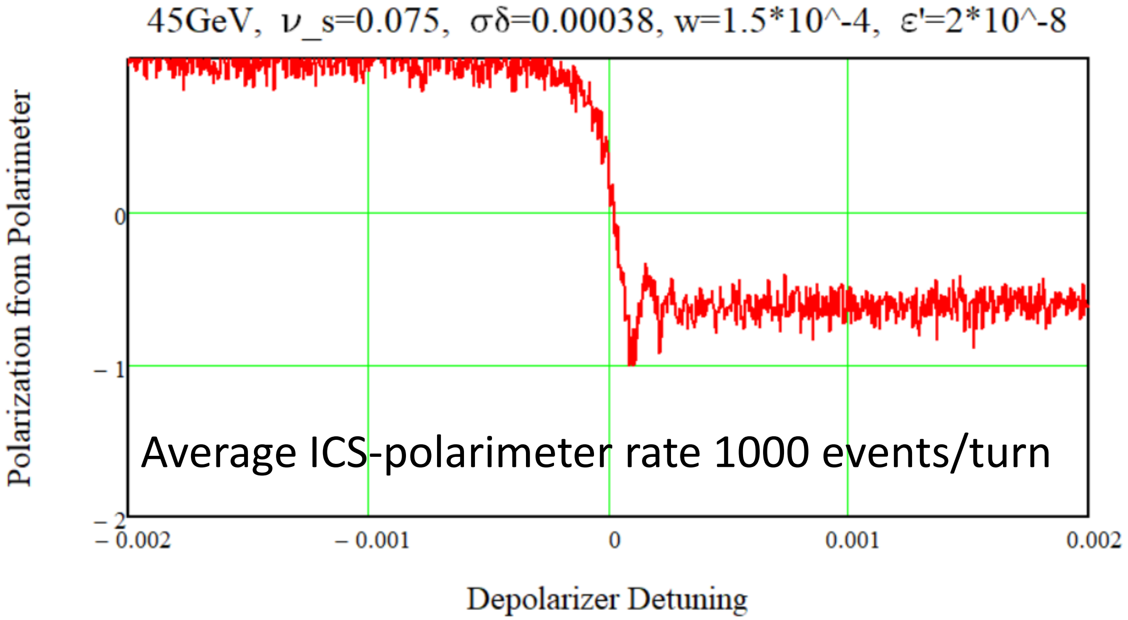


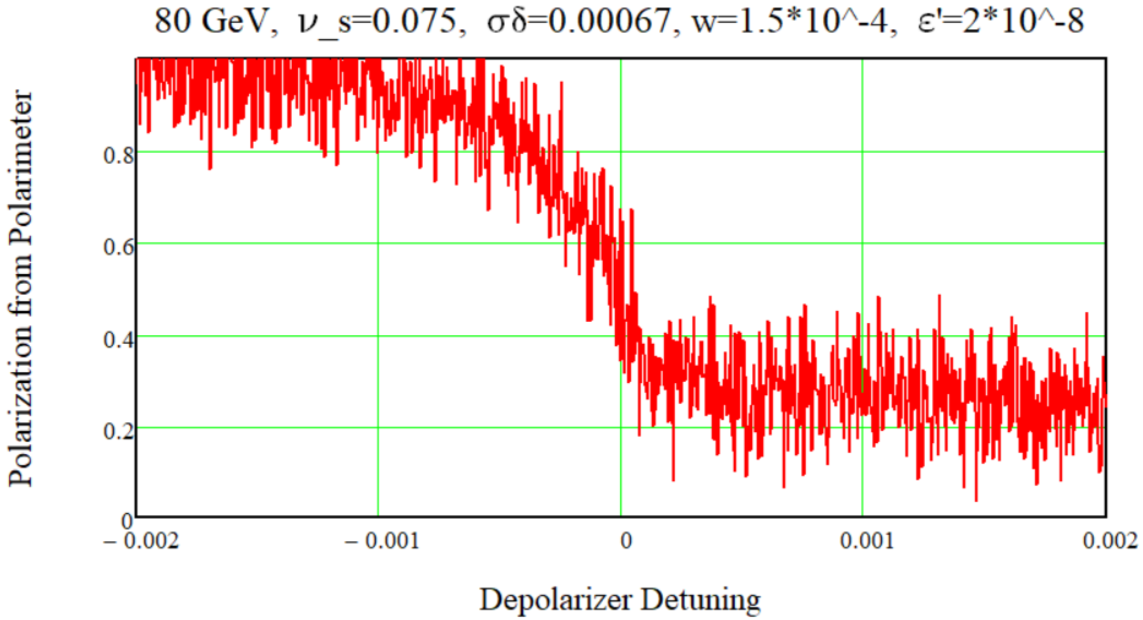


RD frequency sweeps with increased ν_s=0.075









Regular RDP procedure: the required depolarizer's strength

At all beam energies the required dimensionless depolarizer's strength is in a range:

$$w = \varphi/2\pi = 10^{-6} \div 10^{-4}$$

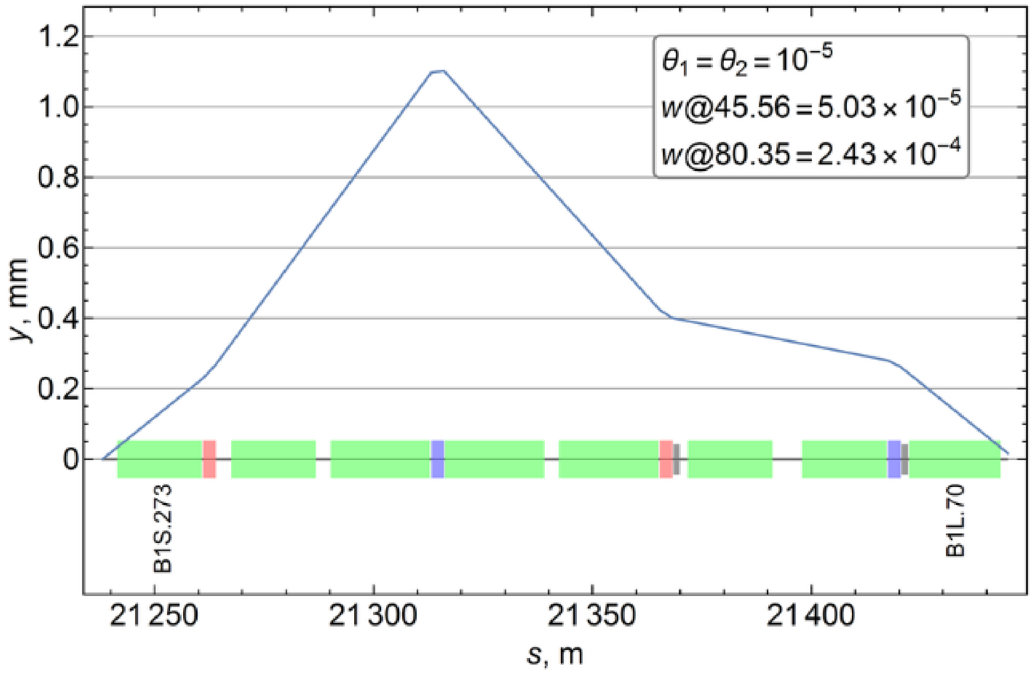
depending on how accurately can we predict the beam energy and then can start a scan closer to the unknown spin tune. We remind: each depolarization in everyday life should be carried out in less than 5-10 minutes. This limits the scanning speed from below.

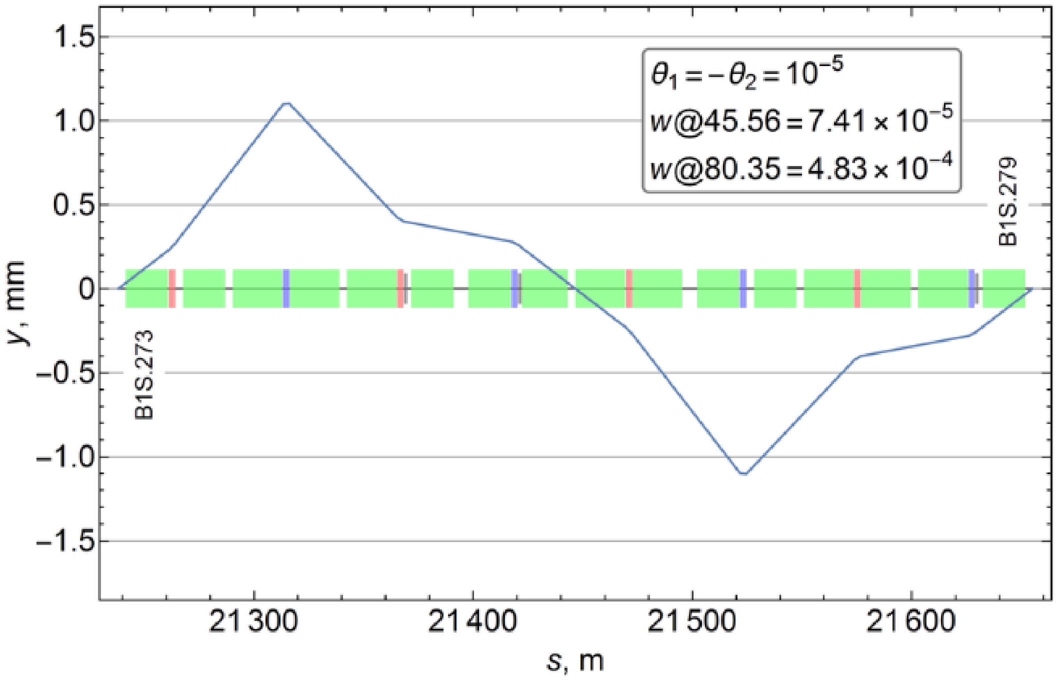
For safety we shall keep a possibility to have a large depolarizer's harmonic: $w \geq 10^{-4}$. The most accurate measurements of the spin tune will be performed at much lower power.

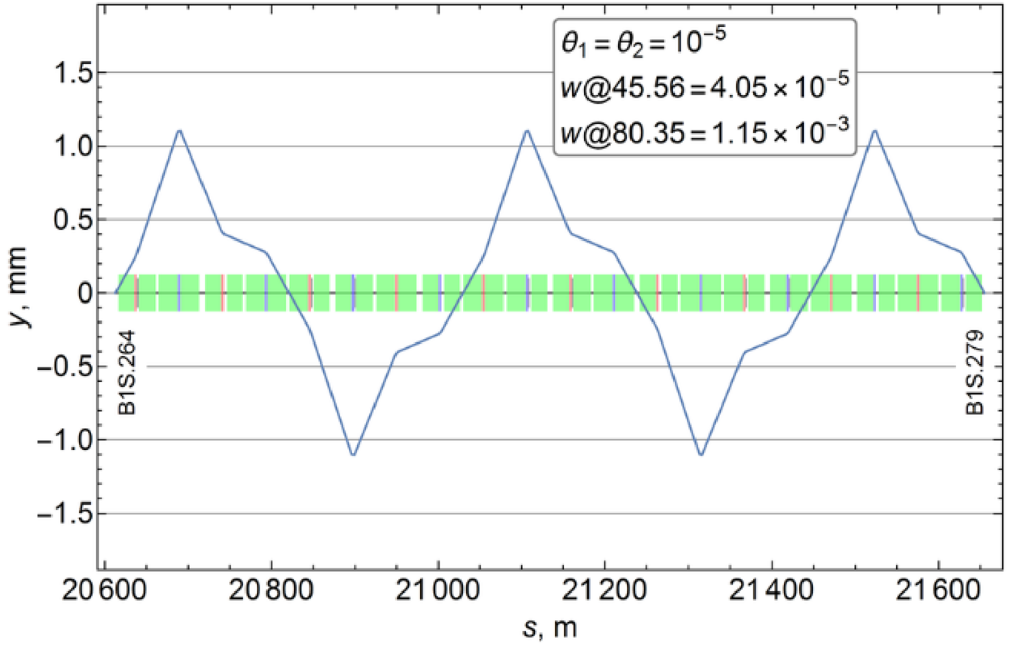
The depolarizer shakes the beam in the vertical direction. It is undesirable to have any oscillations of the beams at the place of their collision. This requirement can satisfied only by the local orbit bump, organized by two synchronized AC-magnets/beam shakers.

Such oscillating orbit bumps could be realized in a regular arc lattice, where we have a phase advance of 90^0/FODO-cell. Bumps can have both an odd and an even number of half-waves between two AC-dipoles.

Local vertical orbit bumps (spin rotators) in FCC-ee arc







At 45 GeV a full-wave spin rotator is about 50% more efficient (w=0.000074) than a half-wave spin rotator (w=0.000050).

At 80 GeV, with the same kick angles $\theta_{1,2}$, a half-wave spin rotator is about 45 times more effective than at 45 GeV. This is thanks to about 2 times larger spin rotation by the RF-kicks itself, as well as larger rotation angles due to horizontal bends.

The forced oscillation amplitude for $\theta_{1,2} = \pm 10^{-5}$ is about 1 mm inside the local orbit bump region and is kept zero outside. Shall prove the DA!

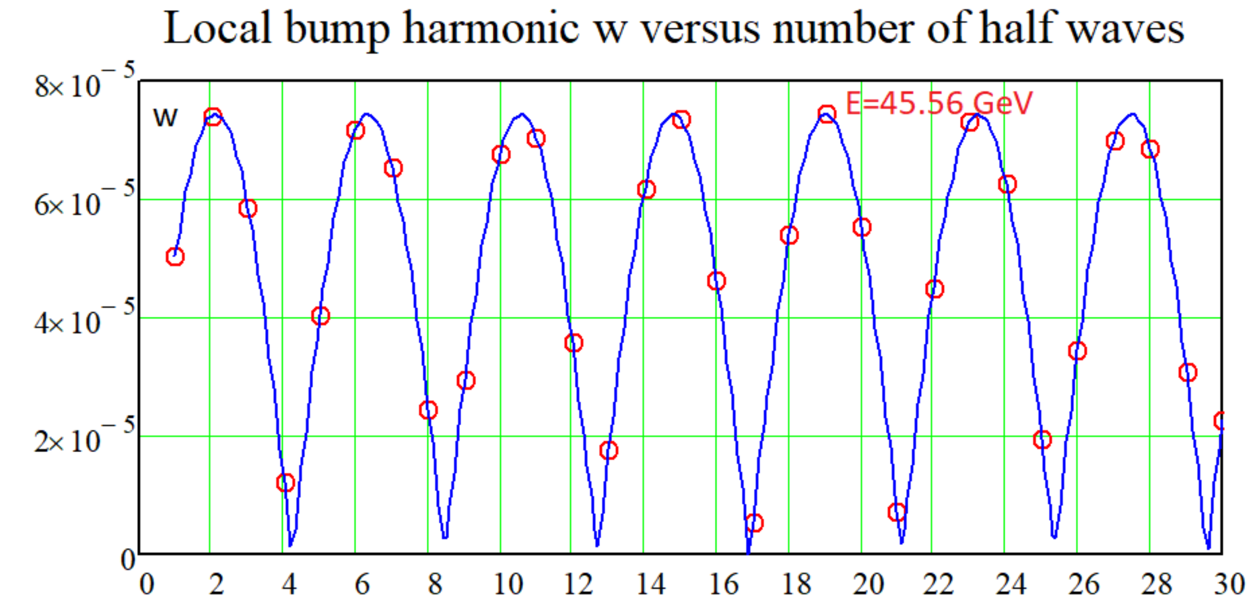
Algorithm to calculate w for the local vertical orbit bumps

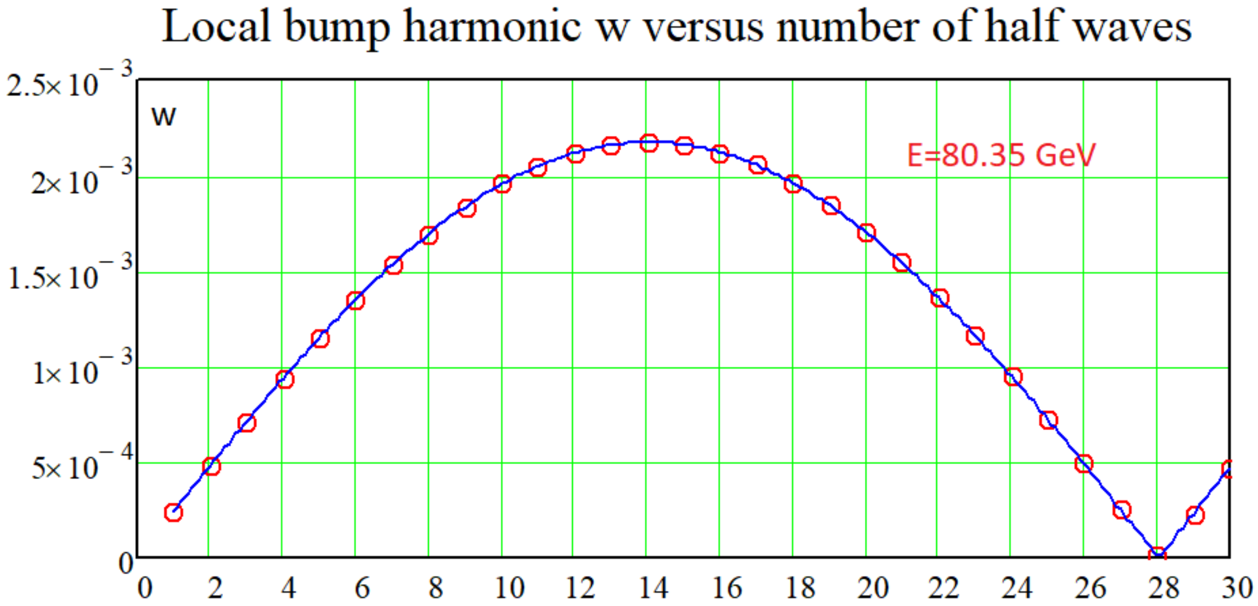
The effective harmonic value *w* of a local bump spin rotator is just a sum of $\nu_0\alpha_m$ - spin rotations by the *M* kickers or quads around the *x*-axis. Each kick is included in the final sum with a weighting factor $\eta_m = e^{i\nu_0\varphi_m}$:

$$w = \frac{1}{4\pi}\sum_{m=1}^{M} \nu_0\alpha_m \cdot \eta_m$$

Where ν_0 is a spin tune, and φ_m is the total horizontal bend angle starting from the first kick.

Harmonic value at Z and at W versus the number of half waves





A half-wave bump is the shortest. Longer spin rotators consisting of N π-bumps could provide a greater value of the harmonic of the depolarizer. Their strength can be calculated exponentially :

$$w_N = w_1 \left| \frac{1 - (-e^{i\nu\varphi_M})^N}{1 + e^{i\nu\varphi_M}} \right|$$

At *Z* the spin phase advance $\nu\varphi_M = 1.655$ per one half-wave bump is small and increase of *N* is not too much efficient.

On the contrary, at *W* the spin phase advance $\nu\varphi_M = 2.918$ per one half-wave arc section is close to its optimal value π, and w grows almost linearly with increasing *N*. Its optimal value would be N=14. Then $w = 2.2 \cdot 10^{-3}$ for kick angles $\theta_{1,2} = \pm 10^{-5}$.

Depolarizer parameters for RDP of a single bunch

The desired harmonic of the depolarizer $w = 1.4 \cdot 10^{-4}$.
Two local bumps (each full-wave) are required to limit the beam deflection by +- 1 mm.

Then at Z-energy $\theta_{kick} = 1 \cdot 10^{-5}$ - kick angle provided by each AC-dipole.

$BR = 150\ T \cdot m$, $El = Bl = 0.5 \cdot \theta_{kick} \cdot BR = 7.5 \cdot 10^{-4}\ T \cdot m$

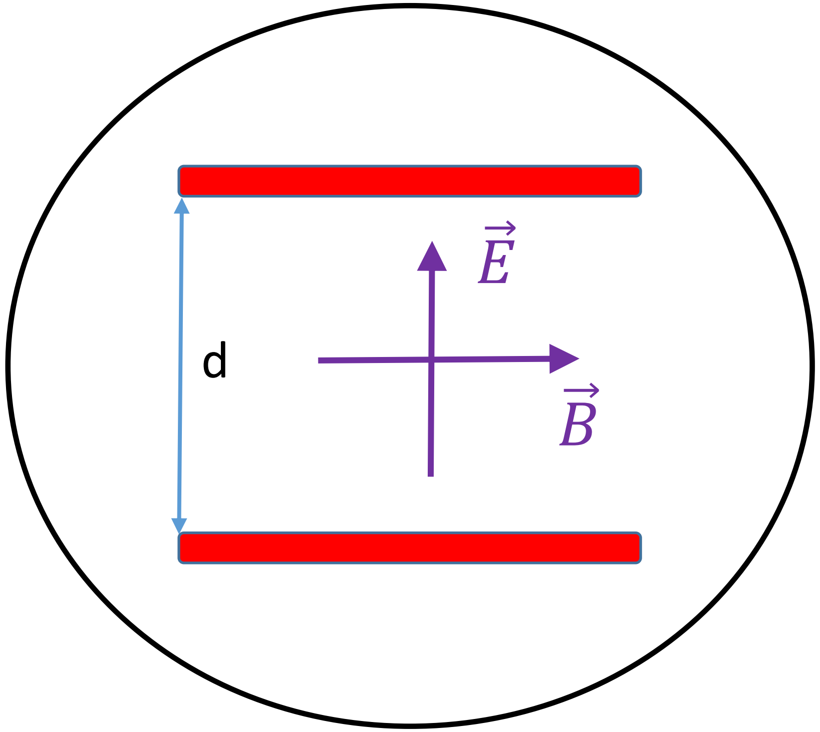
$l = 2.5\ m$, $d = 2\ cm$, $B = 3\ Gs$, $E = 900\ V/cm$,

$U = 0.5 \cdot E \cdot d = 900\ V$, $P_{pulse} = 0.5 \cdot U^2/Z_{Line} = 8100\ W$,

$\langle P \rangle = P_{pulse} \cdot \Delta t/T = 8100 \cdot 10\ ns/320\ mks = 250\ mW$ - during a pulse.

Technically looks feasible? Only too high peak voltage present some problem.

Strip Line sketch:

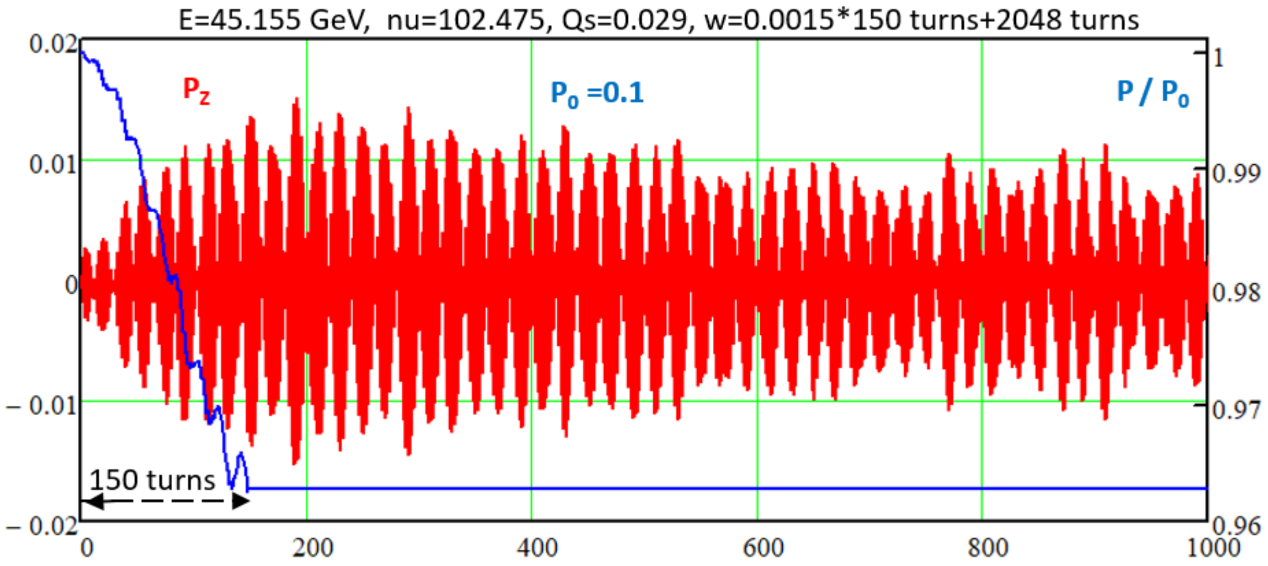


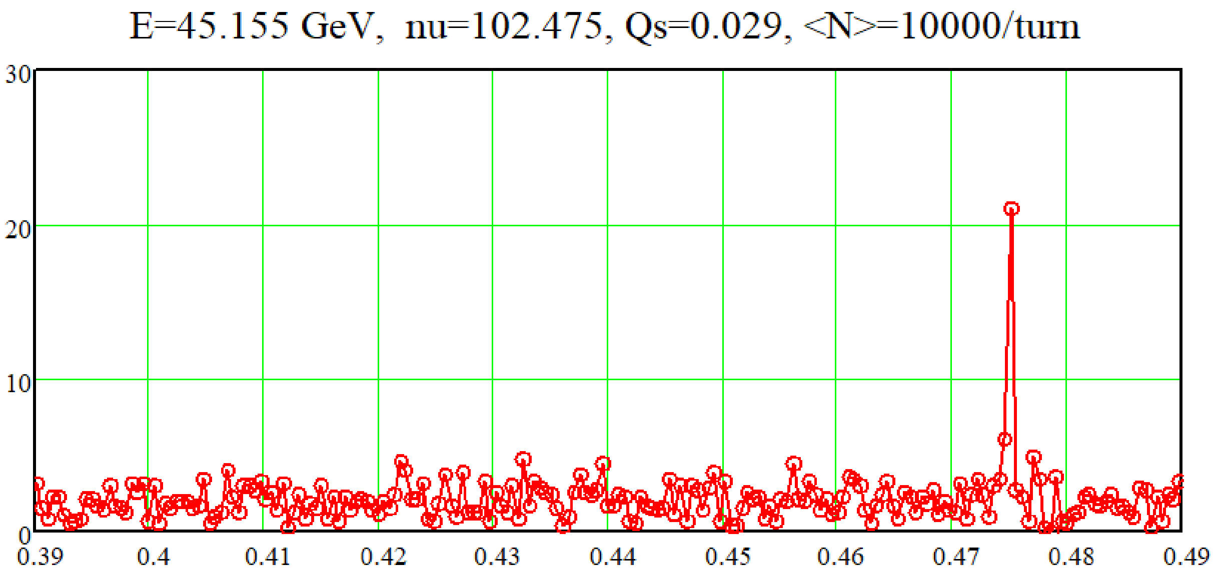
Depolarizer parameters for free precession mode

For free precession the desired harmonic of the depolarizer should be increased up to $w = 0.0015$ at 45 GeV (10 times as higher compared with RDP) and about up to $w = 0.003$ at 80 GeV .
Too low a value of $\nu_s = 0.0288$ with the last RF-parameters leads to too large modulation index of the synchrotron tune:

$$\xi = \nu_0 \sigma_\delta / \nu_s = 1.85$$

This makes problematic spin rotation by a flipper. Only small fraction (few percent) of spins became deflected from a vertical direction and began make precession around the vertical axis.
The required number of local bumps should be increased to 5-20, depending on the actual limitations of DA.

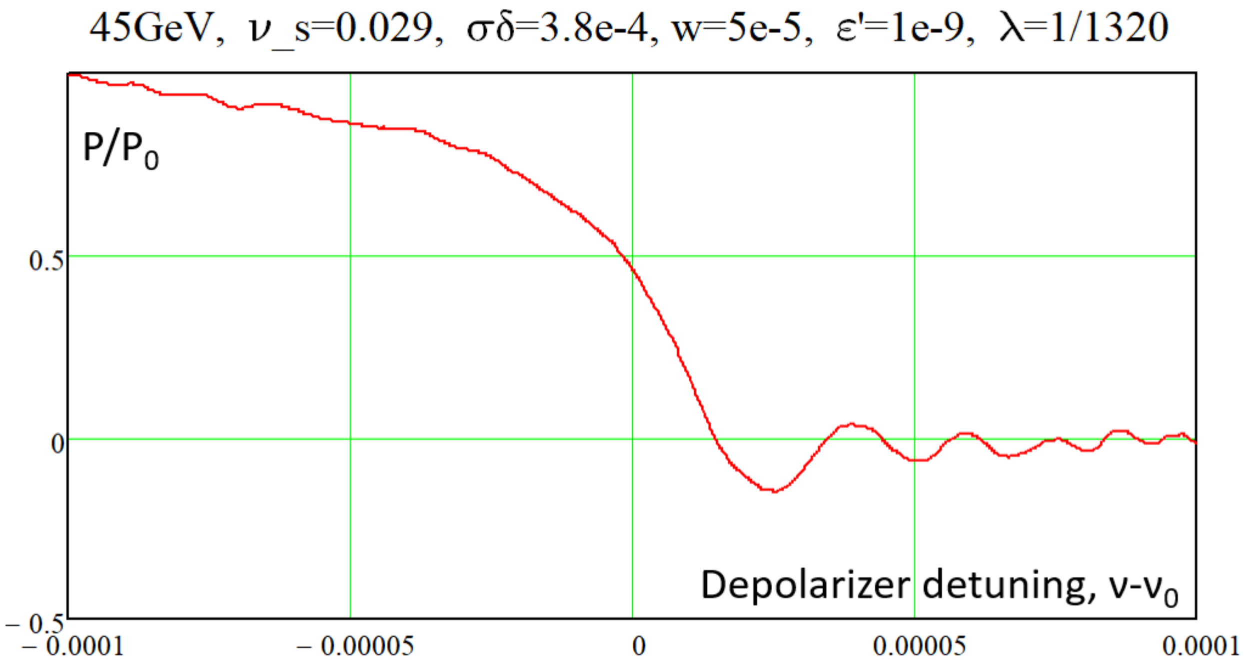


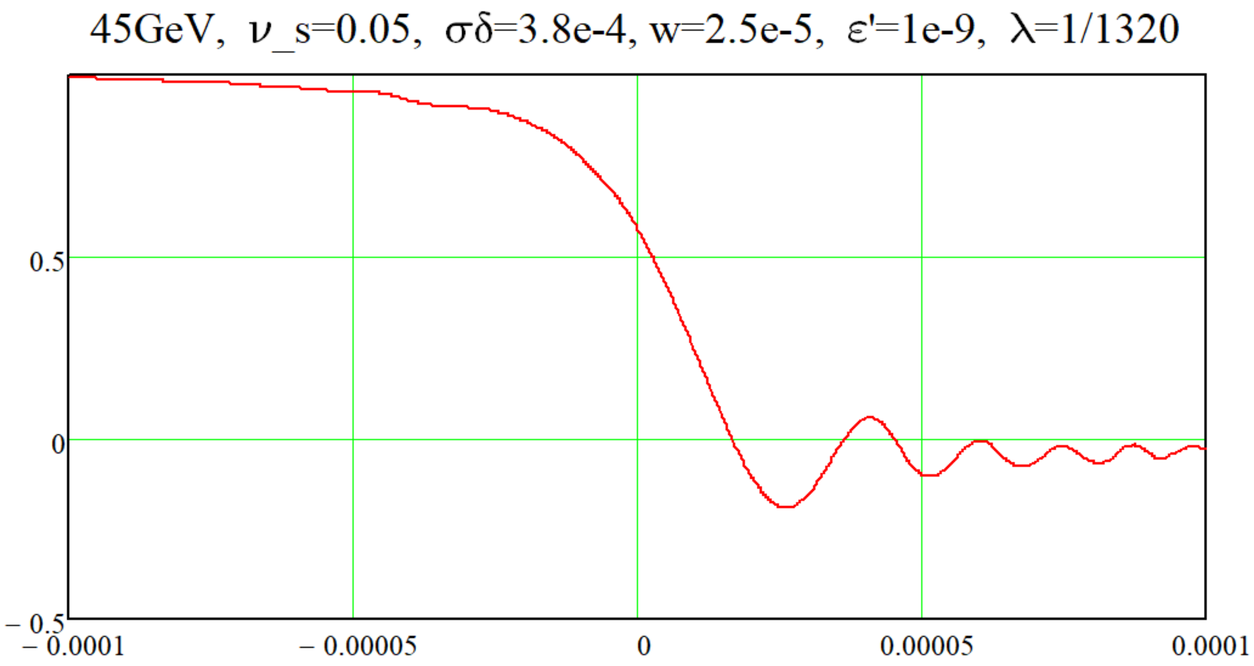


Parameters for continuous depolarization of the colliding bunches

For continuous beam depolarization the strength of a depolarizer could be decreased down to $w = 0.00005$ at 45 GeV. At the same time, it is assumed that we know the position of the resonance well by frequency and slowly scan the resonance zone, passing it in about 80 seconds. An examples of such a scan is shown below. For larger synchrotron tune we can use weaker depolarizer.

Due to the continuous mode, the power dissipation in the strip lines increases dramatically. Some cooling of the strip line plates should be provided.





Discussion of results

The concept of a local bump depolarizer looks feasible.

For beam energy of 45 GeV, the optimal length of such a device is the full-wave part of the arc section.

The depolarizer itself consists of two AC-magnets (strip lines) 2.5 meters long. The gap between the plates is about 2 cm.

The generator of the depolarizer should produce a sequence of short pulses of variable amplitude, lasting about 20 ns, spaced by one revolution period or by the time distance between the bunches. For continuous operation, the generator signal could be just a sine wave.

The electrical circuit of the depolarizer must be developed.