Resonant Depolarization in FCC-ee

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Resonant depolarization parameters and scaling

RF flipper/depolarizer frequency: $\nu = f_{DP}/f_0$, with f_0 – revolution frequency

RF flipper/depolarizer strength – spin rotation around the longitudinal or transverse beam axis:

$$w = \begin{cases} B_{\parallel} l / 2\pi B\rho \\ \nu_0 \cdot B_{\perp} l / 2\pi B\rho \end{cases} \qquad (\nu_0 = \gamma a = 103.5 \text{ at } Z)$$

Frequency scanning rate: $\delta\nu = d\nu/dn$. Here n – the number of turns

Typical values: $w = 3\cdot 10^{-5} \div 5\cdot 10^{-4}$
$\delta\nu = 1\cdot 10^{-9} \div 1\cdot 10^{-8}$

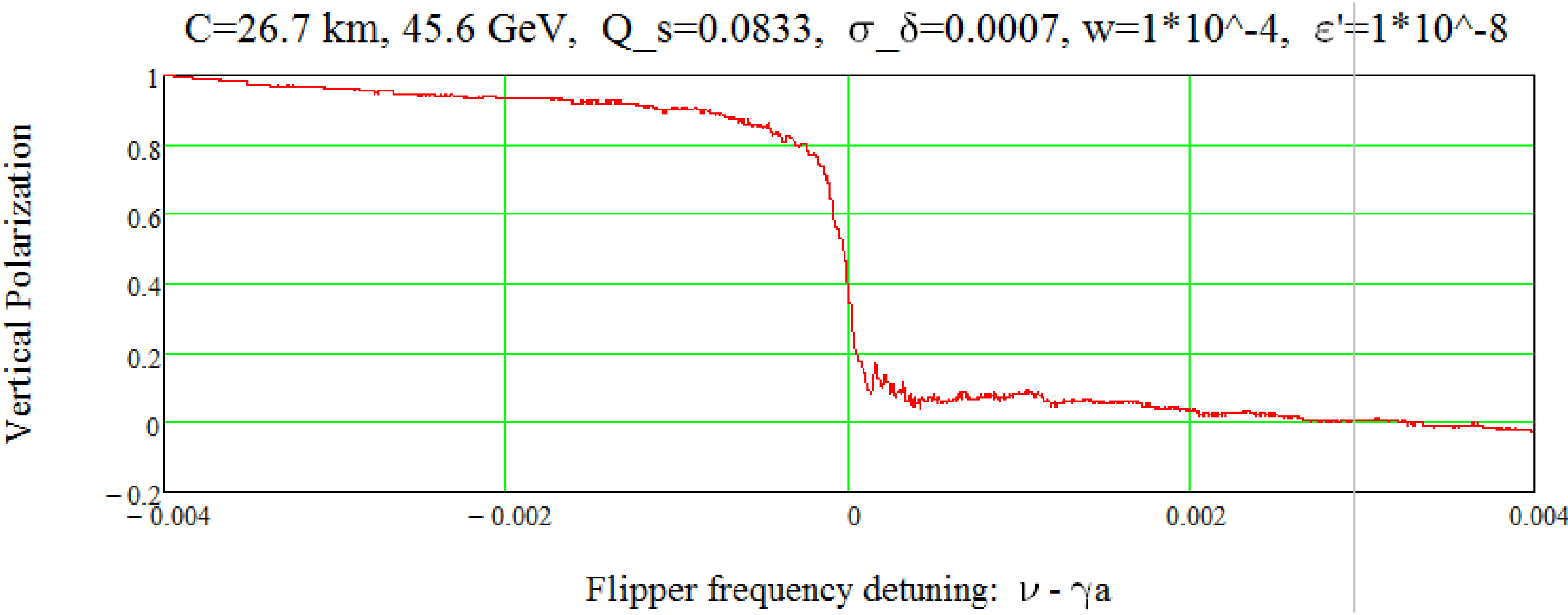
Froisart-Stora formula for reversing of polarization (dynamical depolarization!):

$$P(t\to\infty) = P(0)\cdot(2e^{-J}-1) \qquad J = \pi^2 w^2/\delta\nu$$

My simulations will show, that to depolarize a beam we shall adjust parameters to such values, that:

$$w^2/\delta\nu \cong 1 \qquad (\text{then } J \cong 10)$$

Bench marking the code by LEP simulation at E=45.59 GeV



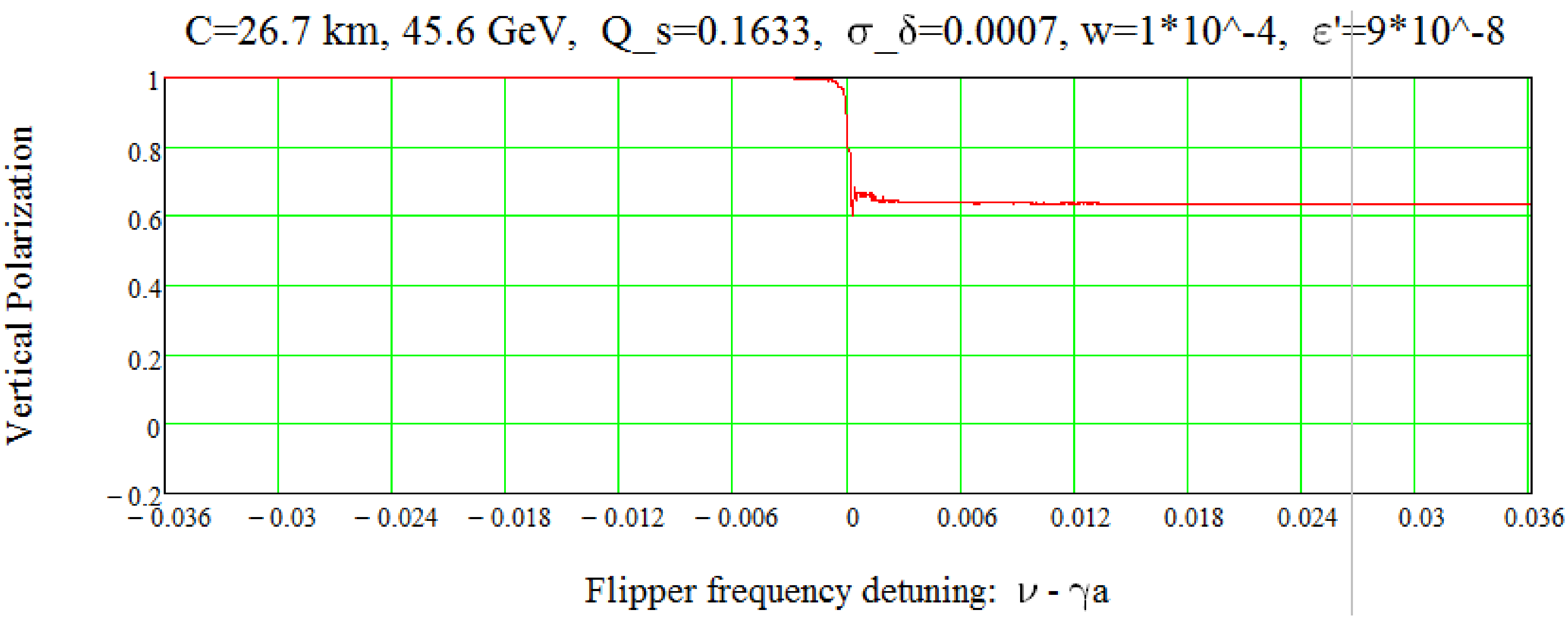
From this plot the fractional part of a spin tune can easily be determined with 0.0001 resolution. This corresponds to:

$$\Delta E/E = 10^{-6}$$

Here were tracked 50 particles, only. More particles to track will require longer simulation time. Can be done, of course!

$$\nu_0 = 103.461158$$
$$w^2/\varepsilon' = 1$$
$$\nu_0 \sigma_\delta / Q_s = 0.87$$
Scan time: T= 71.2 s

LEP at E=45.59 GeV: weak depolarizer case



$\nu_0 = 103.461158$

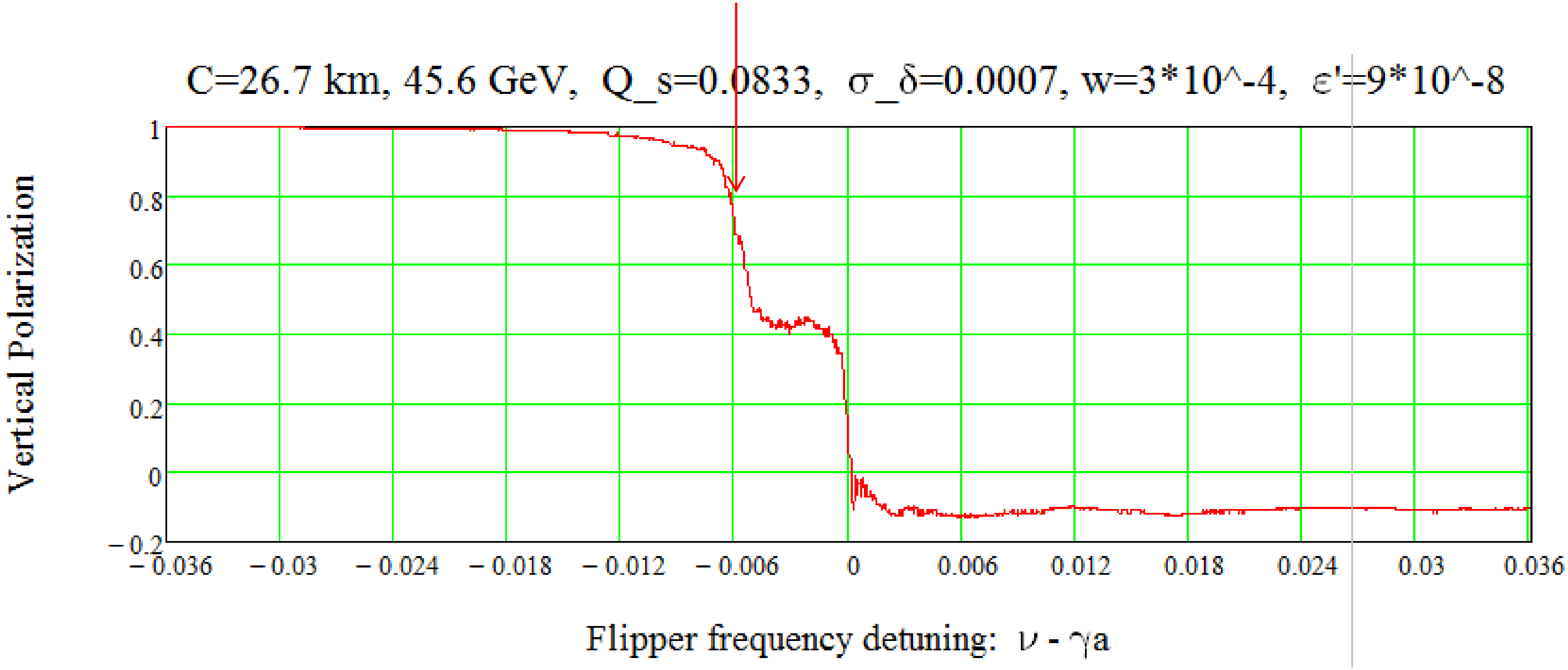
$w^2/\varepsilon' = 0.111$

$\nu_0 \sigma_\delta / Q_s = 0.435$

Scan time: T= 71.2 s

LEP at E=45.59 GeV. Wider frequency scan range.

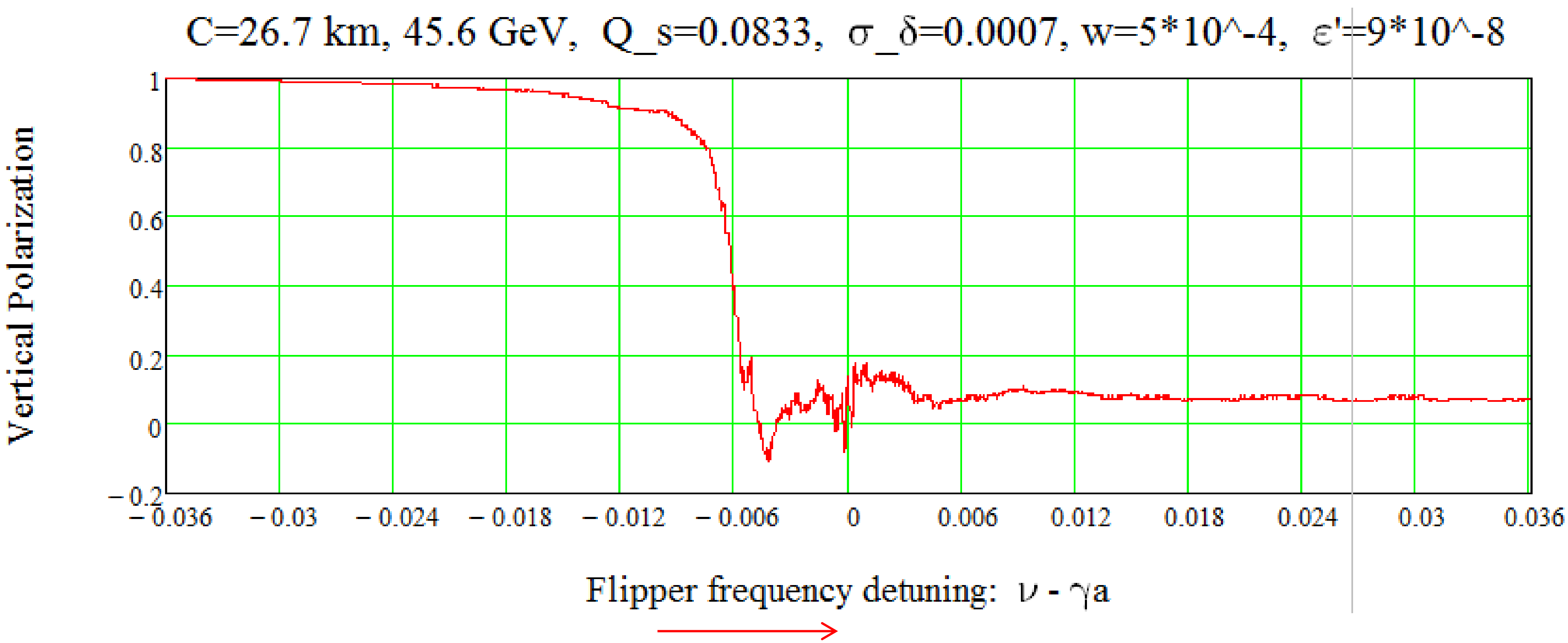
Synchrotron side band from the mirror symmetric fractional tune!
$1 - 2 \cdot 0.461158$ - 0.0833 = - 0.0057



This example shows of how important is to distinguish between different types of resonances. The synchrotron side bands can be met during the scan.

$$\nu_0 = 103.461158$$
$$w^2/\varepsilon' = 1$$
$$\nu_0 \sigma_\delta / Q_s = 0.87$$
Scan time: T= 71.2 s

LEP at E=45.59 GeV: too strong depolarizer



$\nu_0 = 103.461158$

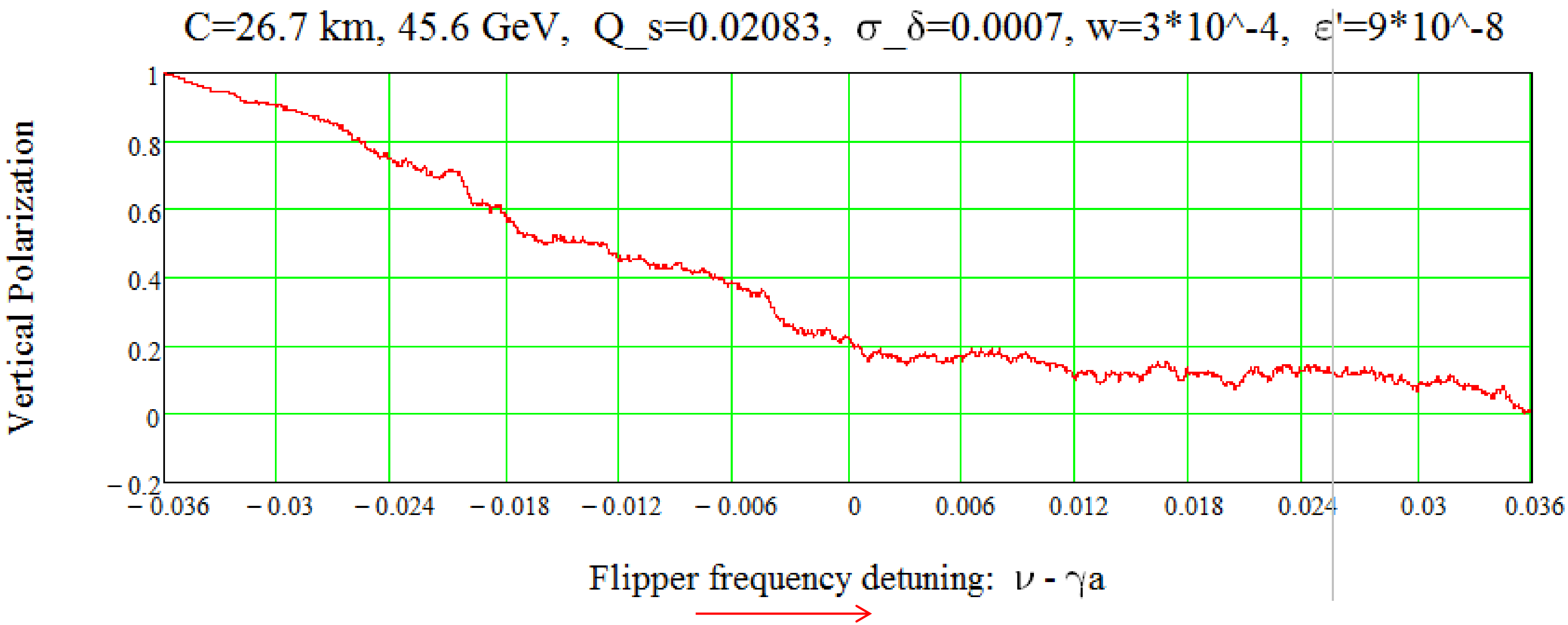
$w^2/\varepsilon' = 2.78$

$\nu_0 \sigma_\delta / Q_s = 0.435$

Scan time: T= 71.2 s

Attention: beam became fully depolarized at the synchrotron side band!

LEP at E=45.59 GeV: normal depolarizer and low Q_s.



This example shows of how important is to have a large enough Q_s, correspondingly, a small value of the synchrotron modulation index. Here Q_s is too small.

$$\nu_0 = 103.461158$$

$$w^2/\varepsilon' = 1$$

$$\nu_0 \sigma_\delta / Q_s = 1.74$$

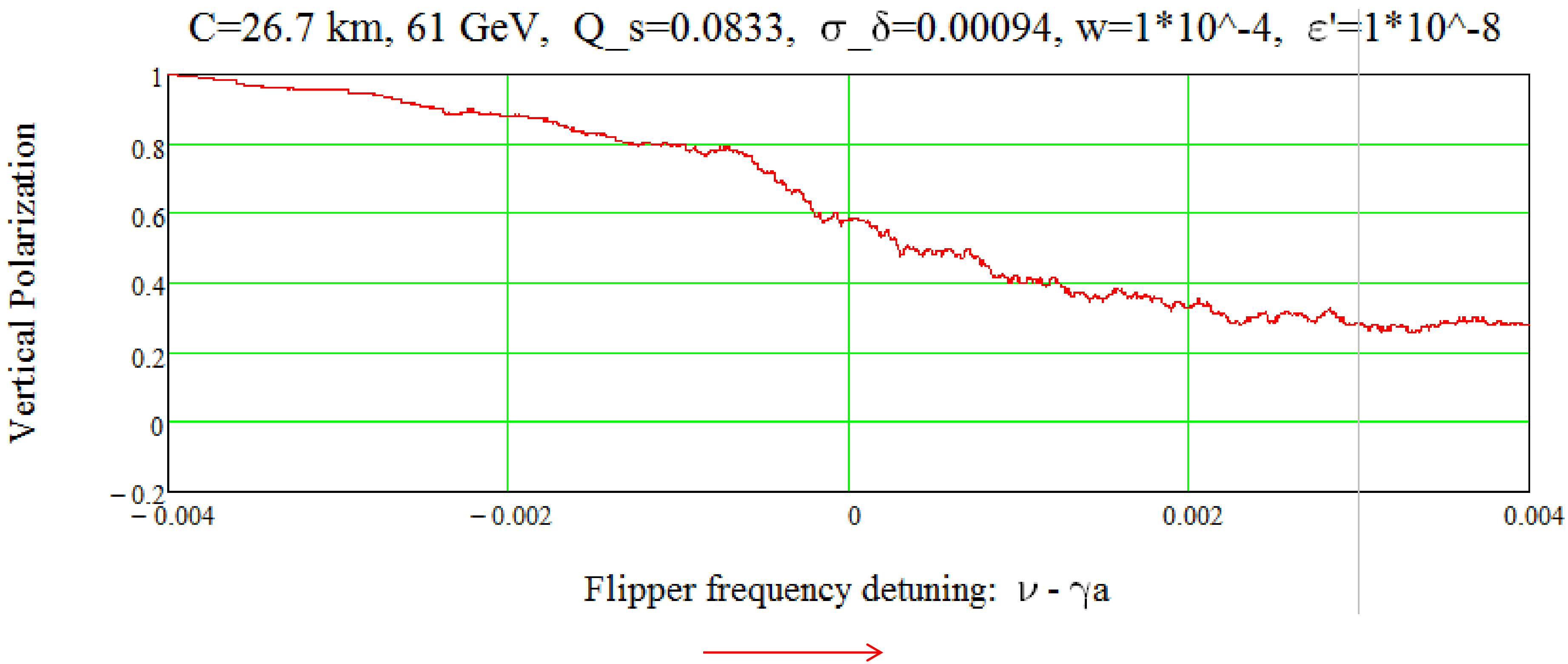
Scan time: T= 71.2 s

Beam starts depolarize immediately after switching on a depolarizer! So, the spin ensemble does not resonate! Consequently, the beam energy can not be determined with the wanted accuracy!

Now few scans for LEP at 61 GeV.
Equivalently FCC-ee at 80 GeV.

(same absolute value of beam energy spread: RMS= 57 MeV)

LEP at E=61 GeV with Q_s=0.0833



Not sharp depolarization picture!

The synchrotron modulation index of a spin tune is too high!

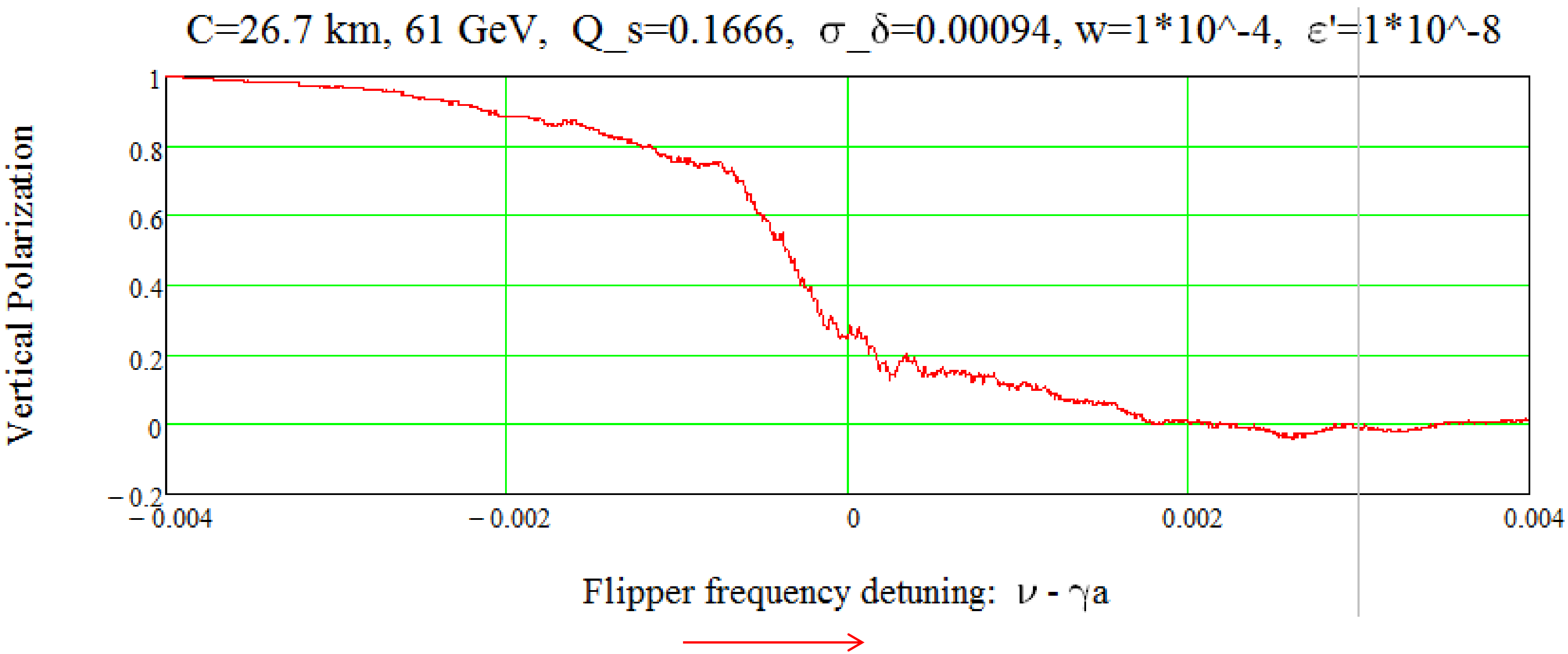
$\nu_0 = 138.432346$

$w^2/\varepsilon' = 1$

$\nu_0 \sigma_\delta / Q_s = 1.56$

Scan time: T= 71.2 s

LEP at E=61 GeV with Q_s=0.1666



Crossing the resonance became here more pronounced.
Depolarization frequency can be determined well.

The synchrotron modulation index of a spin tune now is small.

$\nu_0 = 138.432346$

$w^2/\varepsilon' = 1$

$\nu_0 \sigma_\delta / Q_s = 0.78$

Scan time: *T*= 71.2 s

Conclusion

- In spite of selfpolarization can be obtained with small synchrotron tune, we can not make use the resonant depolarization at W threshold in FCC-ee, if Q_s is smaller than 0.15.

- The synchrotron tune in FCC-ee shall be increased to the values:

$Q_s=0.05$ at $E=45.6$ GeV and $Q_s=0.15$ at $E=80$ GeV

- The only way to do so is to increase the momentum compaction value.