Polarization studies for FCC-ee and CEPC

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Outline

- Polarization study approach for CEPC and FCC-ee
- Spin tracking code features
- Self-polarization degree estimations
- Resonant Depolarization problems at 80 GeV beam energy
- Conclusion.

Polarization specifics of CEPC and FCCee

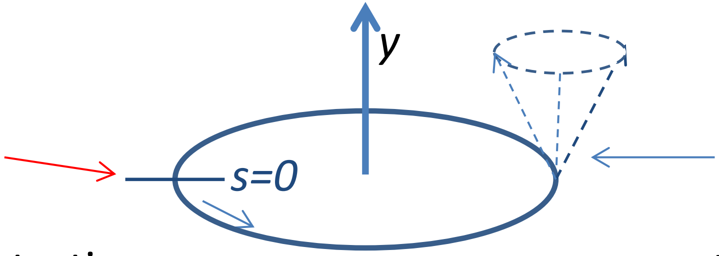
- Beam emittances in CEPC/FCCee are so small, that all resonances with the betatron frequencies are suppressed and their influence on the spin motion is negligible: $\nu_0 \cdot |\sigma_{y'}| \sim 2 \cdot 10^{-5}$ (at E=80 GeV).
- Therefore, only static vertical orbit distortions and the longitudinal magnetic fields with nonzero integrals can affect the spin motion!

- Precession frequency modulation by the synchrotron oscillations is most important! The relevant parameter is: $\xi = \nu_0\, \sigma_\delta / Q_s$. One would prefer $\xi < 1$, means Q_s as high as possible! LEP1: Q_s=0.065, $\sigma_\delta = 0.0007$, ξ =1.07 - comfortable for beam energy E=45 GeV!
- But Q_s=0.05, $\xi = 2.4$ for base line parameters of FCC-ee at 80 GeV.

Spin tracking code algorithm

Spin perturbation: $w_x(\theta_k) = w_0 + w_{DP} \cdot \cos(\nu_{DP}\theta_k)$, with θ_k=2π·k, $\phi_x(\theta_k)$ =2π·$w_x(\theta_k)$

It is localized at *s*=0.
Random jumps of relative energy deviation δ are localized also at s=0.



Spin precession around the *y*-axis with $\nu = \gamma a = \nu_0(1+\delta)$.
Radiation damping of δ is taken into account!

w_0 - sim. effects of orbit distortion

w_{DP} - simulates the Depolarizer's Impact

The code tracks a regular synchrotron and spin motion at the arc $0 < \theta < 2\pi$ as:

$$\delta'' + 2\lambda \cdot \delta' + {Q_{s0}}^2 \cdot \delta = 0 \qquad Q_s = \sqrt{{Q_{s0}}^2 - \lambda^2} \qquad \phi_y(\theta) = \int_0^\theta \nu_0 . [1 + \delta(\theta)] d\theta$$

$$\delta(\theta) = e^{-\lambda\theta} \cdot [\, \delta(0) \cdot \cos(Q_s\theta) + \mathrm{ps}(0) \cdot \sin(Q_s\theta)]$$

$$\mathrm{ps}(\theta) = e^{-\lambda\theta} \cdot [-\delta(0) \cdot \sin(Q_s\theta) + \mathrm{ps}(0) \cdot \cos(Q_s\theta)] \quad \longleftarrow \quad \mathrm{ps}(\theta) \equiv (\delta'(\theta) + \lambda\delta(\theta))/Q_s$$

$$\phi_y(\theta) = \nu_0\theta \left\{ 1 + \frac{\delta(0)[\lambda - \lambda e^{-\lambda\theta} \cdot \cos(Q_s\theta) + Q_s e^{-\lambda\theta} \cdot \sin(Q_s\theta)] + \mathrm{ps}(0)[Q_s - Q_s e^{-\lambda\theta} \cdot \cos(Q_s\theta) - \lambda e^{-\lambda\theta} \cdot \sin(Q_s\theta)]}{({Q_{s0}}^2 + \lambda^2)\theta} \right\}$$

$\nu_0 = \bar{\gamma} a = \bar{E}$(GeV)/0.44064846, ν_0=181.55 at $\bar{E} = 80$ GeV. Resonances at : $\nu_0 = n + m \cdot Q_s$

1. Equilibrium beam polarization degree simulation

The equilibrium polarization degree can be calculated as:

$$P = 92.6(\%)/(1 + \tau_{ST}/\tau_{dep})$$

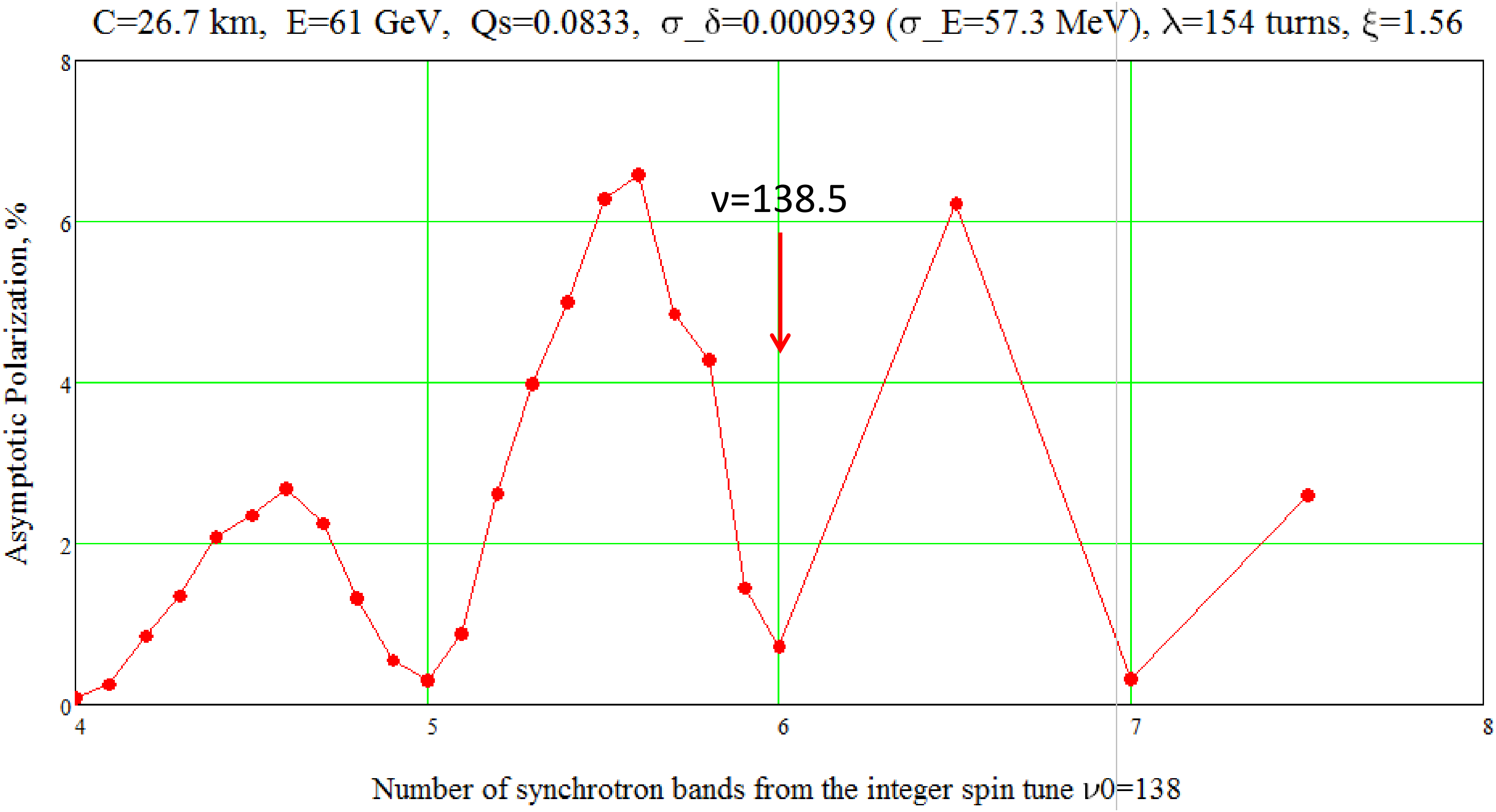
where τ_{ST} is the Sokolov-Ternov polarization time, while τ_{dep} is obtained by the spin tracking code depolarization time.

The harmonic spin matching, if applied as at LEP and HERA, can minimize the strengths of two nearby integer parent resonances. But question: how small they can be made?

We rely on data from LEP at 61 GeV, where some polarization level, say about 6%, was observed (see R.Assmann et al. , "**Spin dynamics in LEP with 40–100 GeV beams**", AIP Conference Proceedings **570**, 169 (2001); doi: 10.1063/1.1384062).

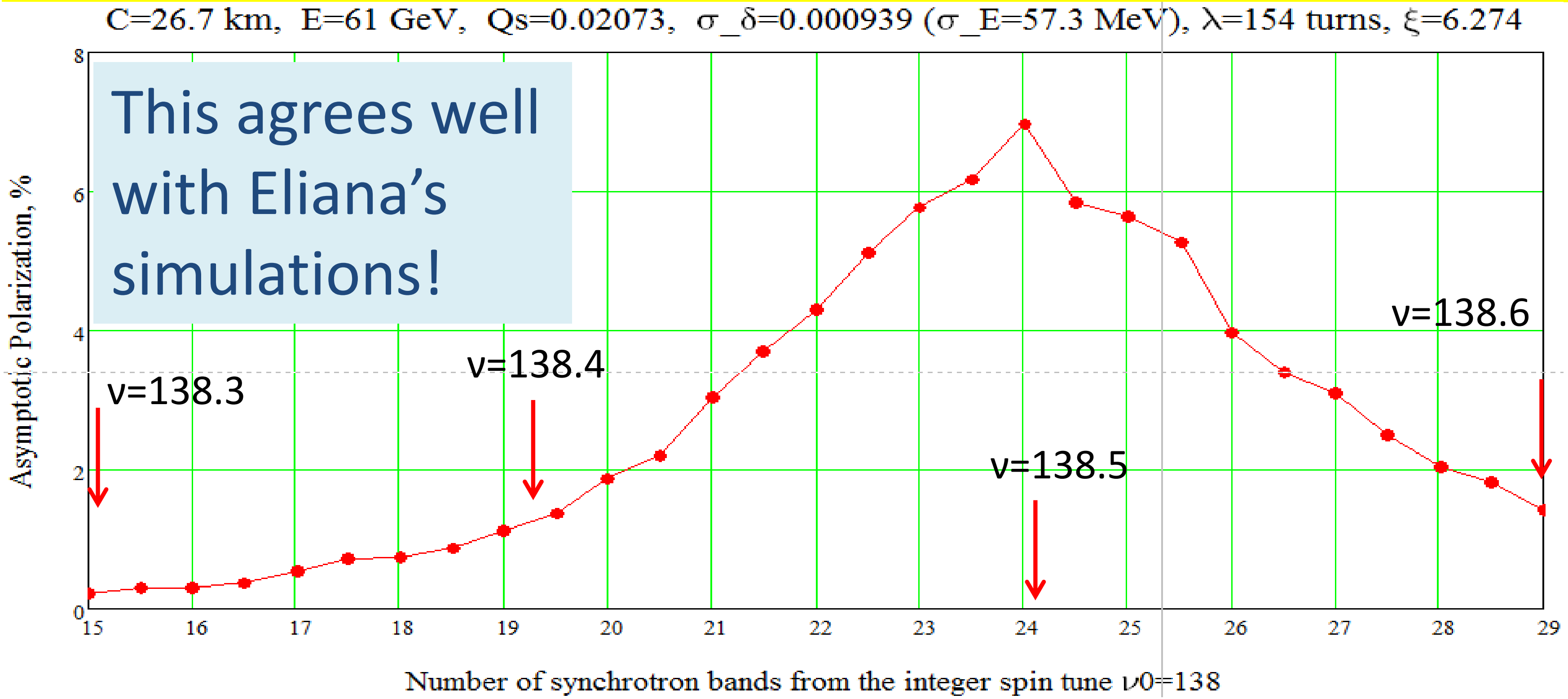
This translates to our estimation of some residual uncompensated spin perturbation: $w = 0.0015$, which we will use as a reference value.

Simulating polarization for LEP at 61 GeV, Qs=0.0833

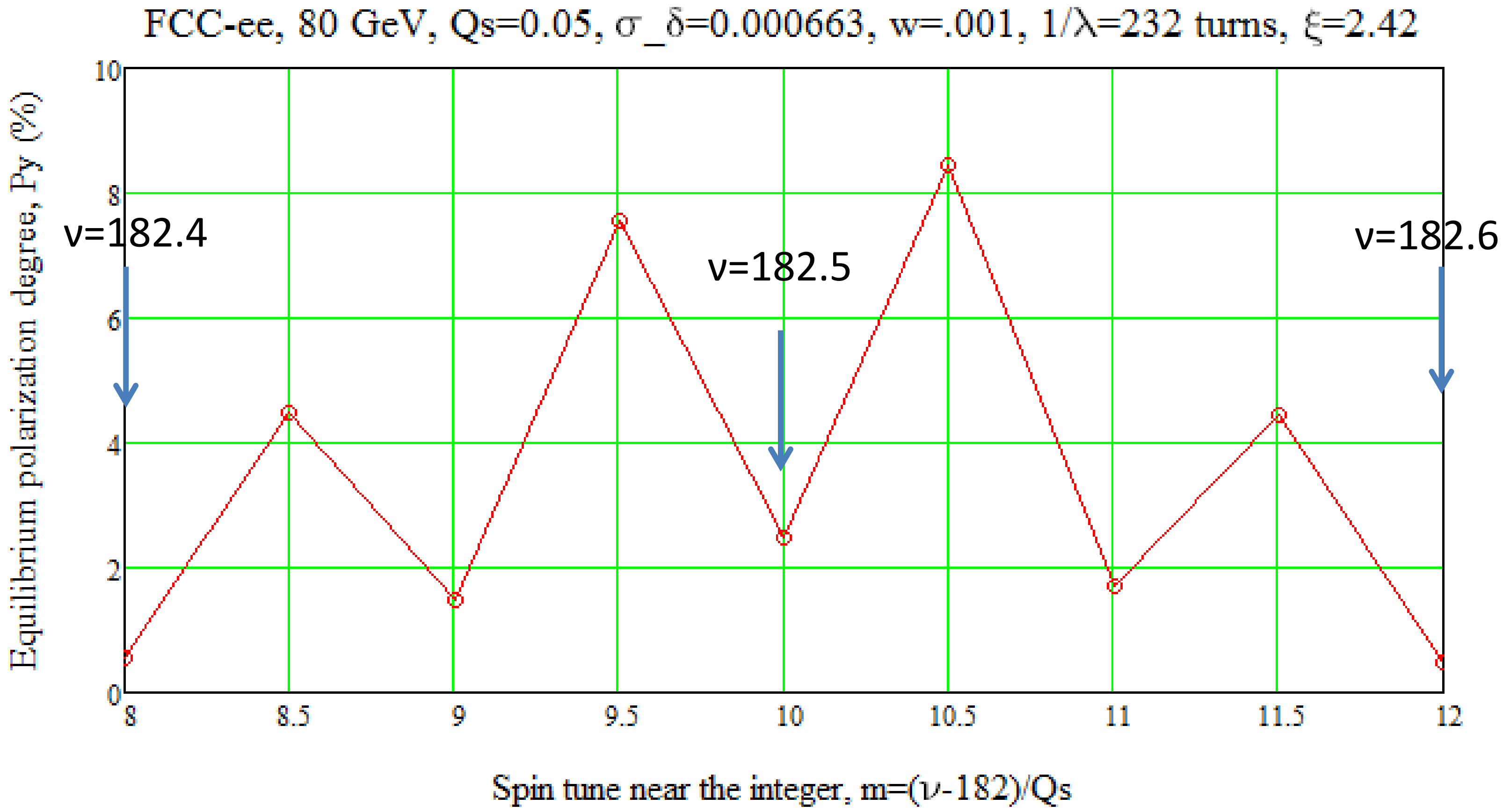


Equilibrium polarization for LEP at 61 GeV and Qs=0.02073

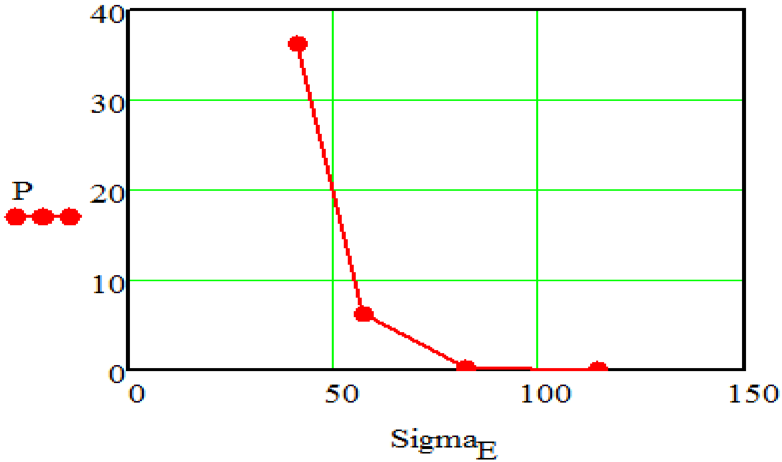
Here $w = 0.0015, Q_s = 0.02073$. Dips at high m detunings $m \cdot Q_s$ disappear! Remarkable that polarization is large near the half-integer spin tune values! Arc serves as Siberian Snake?

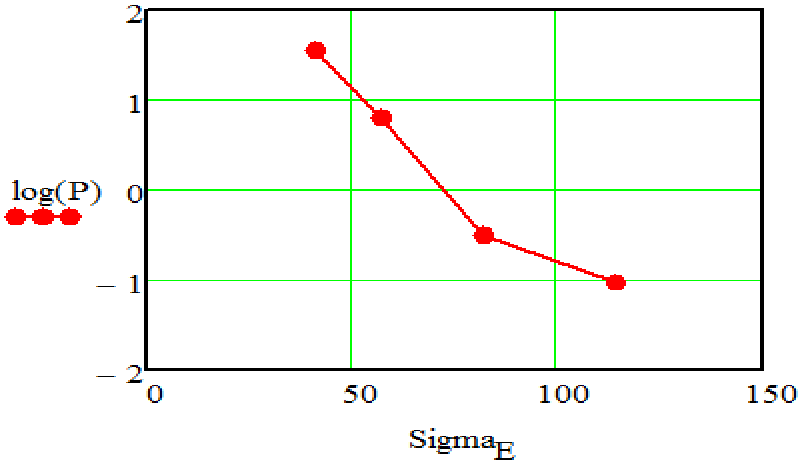


FCC-ee Equilibrium polarization degree: 80 GeV and Qs=0.05



Polarization dependence on energy diffusion rate





Lessons from this study:

1) No strong influence of Qs on the attainable polarization level!
2) Only the value of the beam energy spread is really important. Recommendation given from the LEP experience: $\sigma_E < 52\ MeV$ is confirmed by these simulations.

Spin resonance width and new nonstandard RD technique

- My spin tracking code has revealed dramatic increase of the width of the central resonance line at W threshold for chosen synchrotron tune value: Qs=0.05.

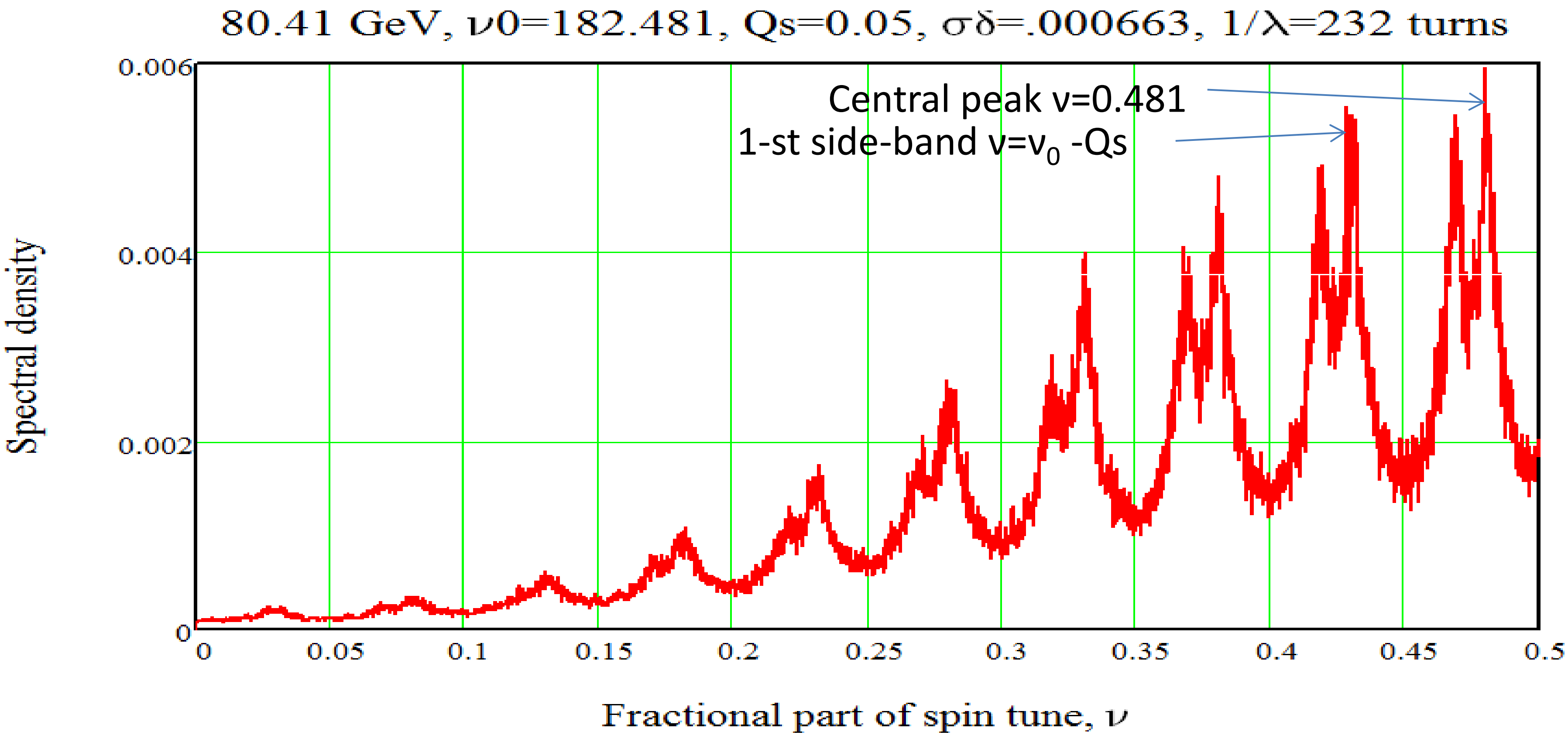
- With such low synchrotron tune and, subsequently, too high value of the synchrotron modulation index $\xi=\nu_0\sigma_\delta/Qs=2.4$ a width of the central spectrum line becomes very large: $\Delta\nu=\pm0.002$. This corresponds to $\Delta E/E=\pm0.00001$.

- In such situation there is no any sense to scan the resonance monotonically – no sharp changes in the polarization degree are expected.

- More reasonable is to do probing of the depolarization efficiency in few depolarizer's frequency points around the center of a peak – then steps in polarization degree became quite visible. This idea was proposed by Alain Blondel and, seems, has been tested at LEP.

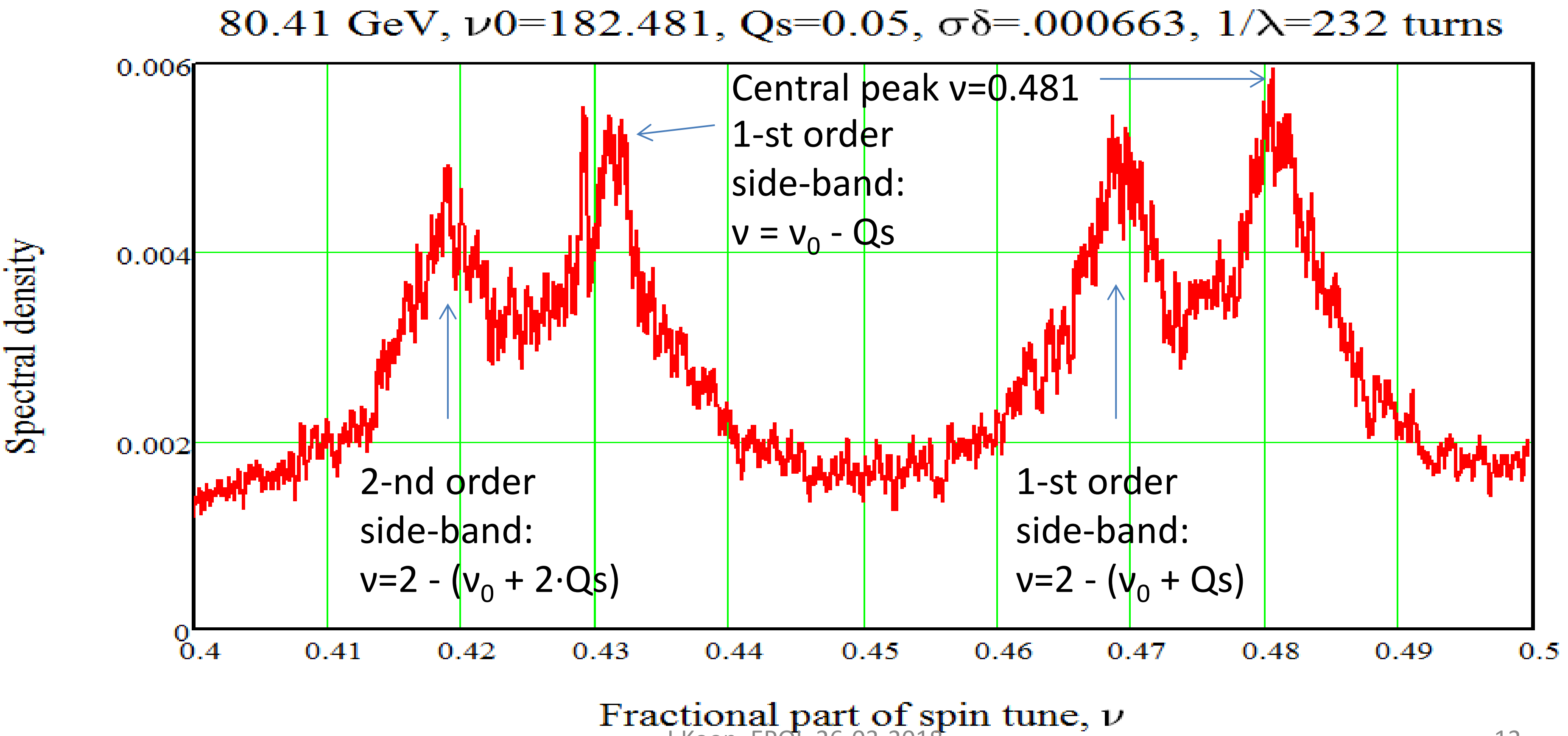
Spectrum of 80 GeV single particle spin motion

Spectrum of free spin precession of single particle during 40000 turns. Q_s=0.05.



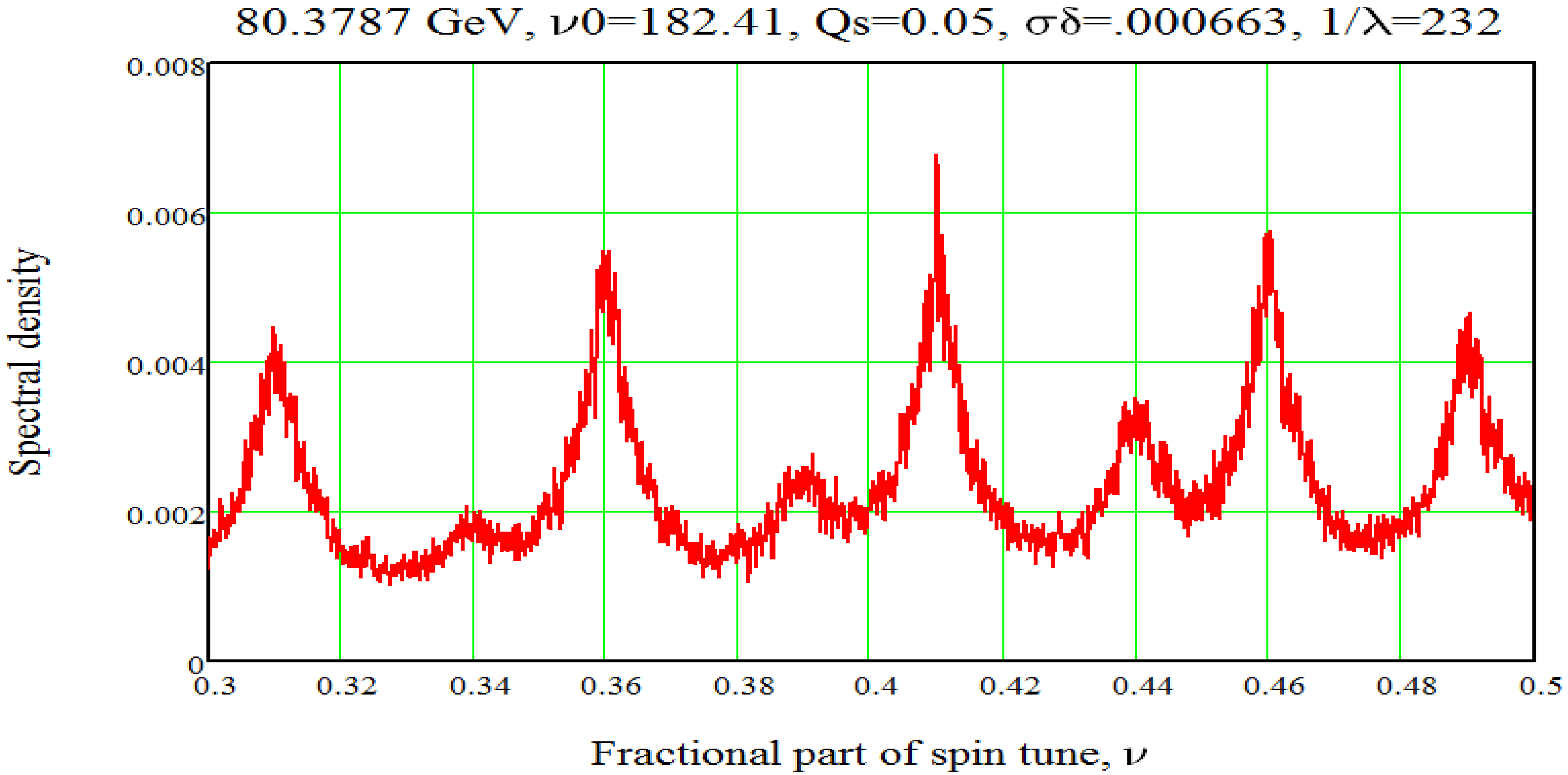
Zoom of spectrum of single particle spin motion

Spectrum of free spin precession of single particle during 40000 turns. Q_s=0.05.



Spectrum for slightly shifted spin tune $\{\nu_0\}$=0.41

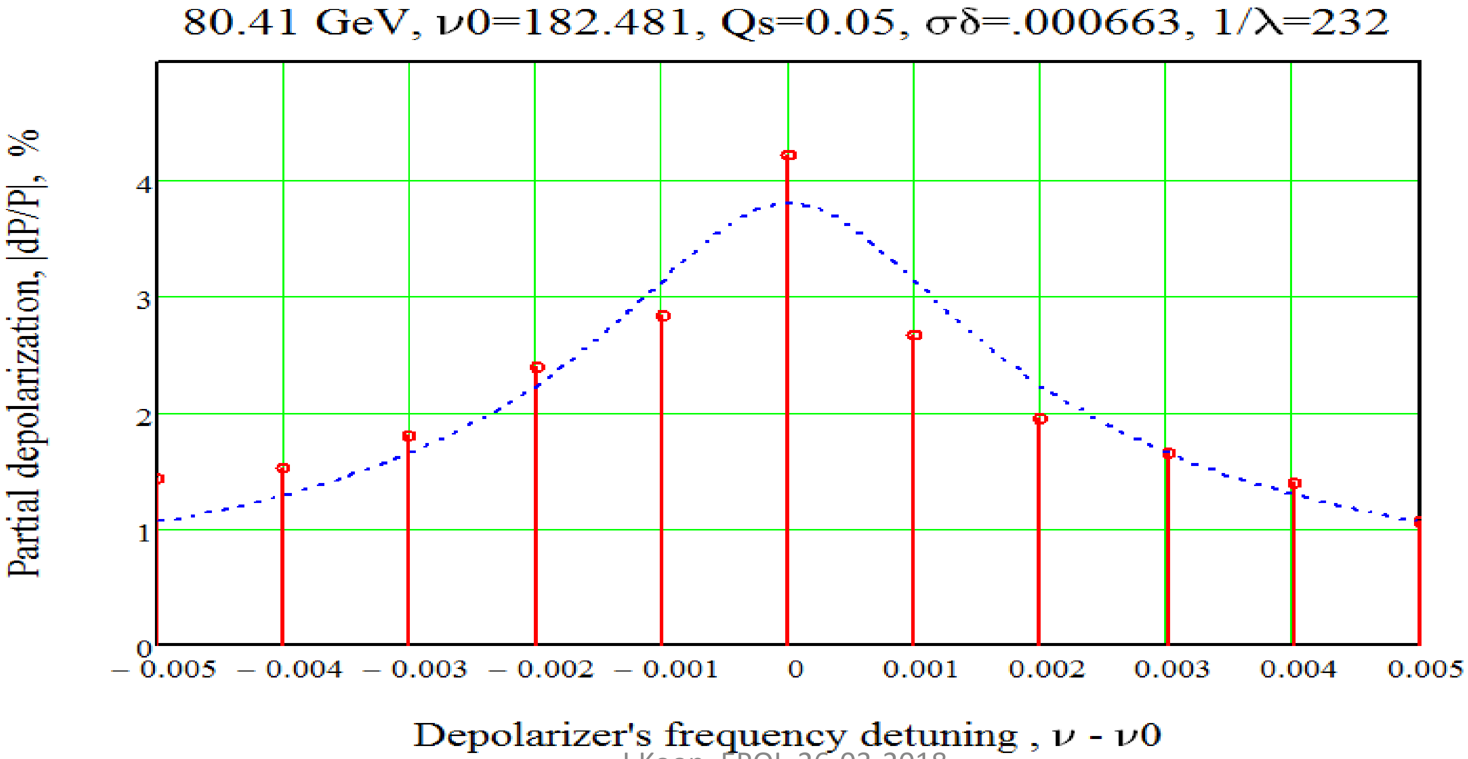
Mirror symmetric the left and the right wings of the central line with this choice of $\{\nu_0\}$. It is better to reduce a possible error in determination of the center of a peak!



Partial depolarizations by 11 steps in depolarizers frequency

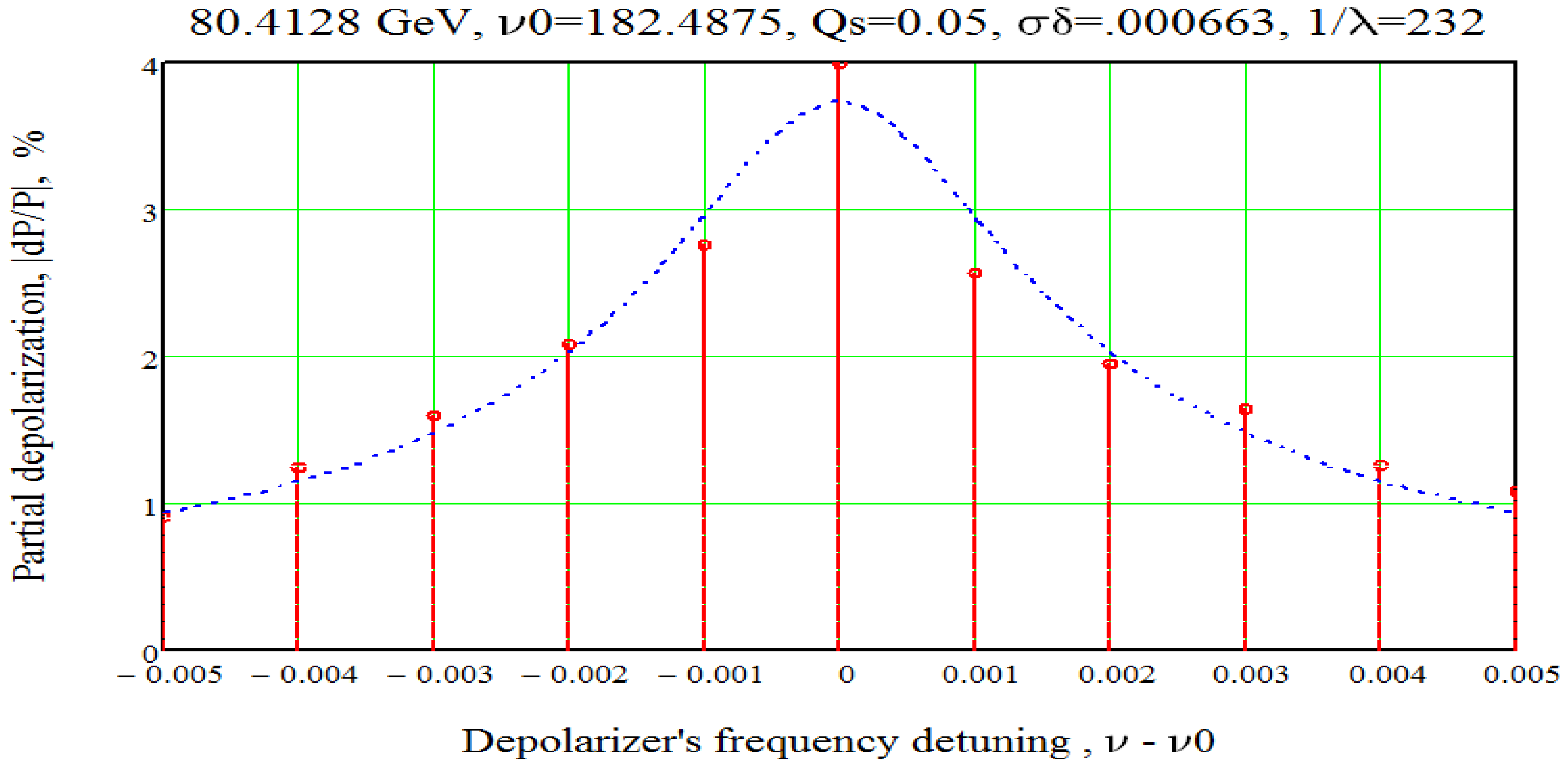
The left and the right wings of the central line are asymmetric due to too close proximity of 1-st order synchrotron side-band. This should be accounted when fitting to a model.

The presented here fit is symmetric – hence not fully correct – could be modified.



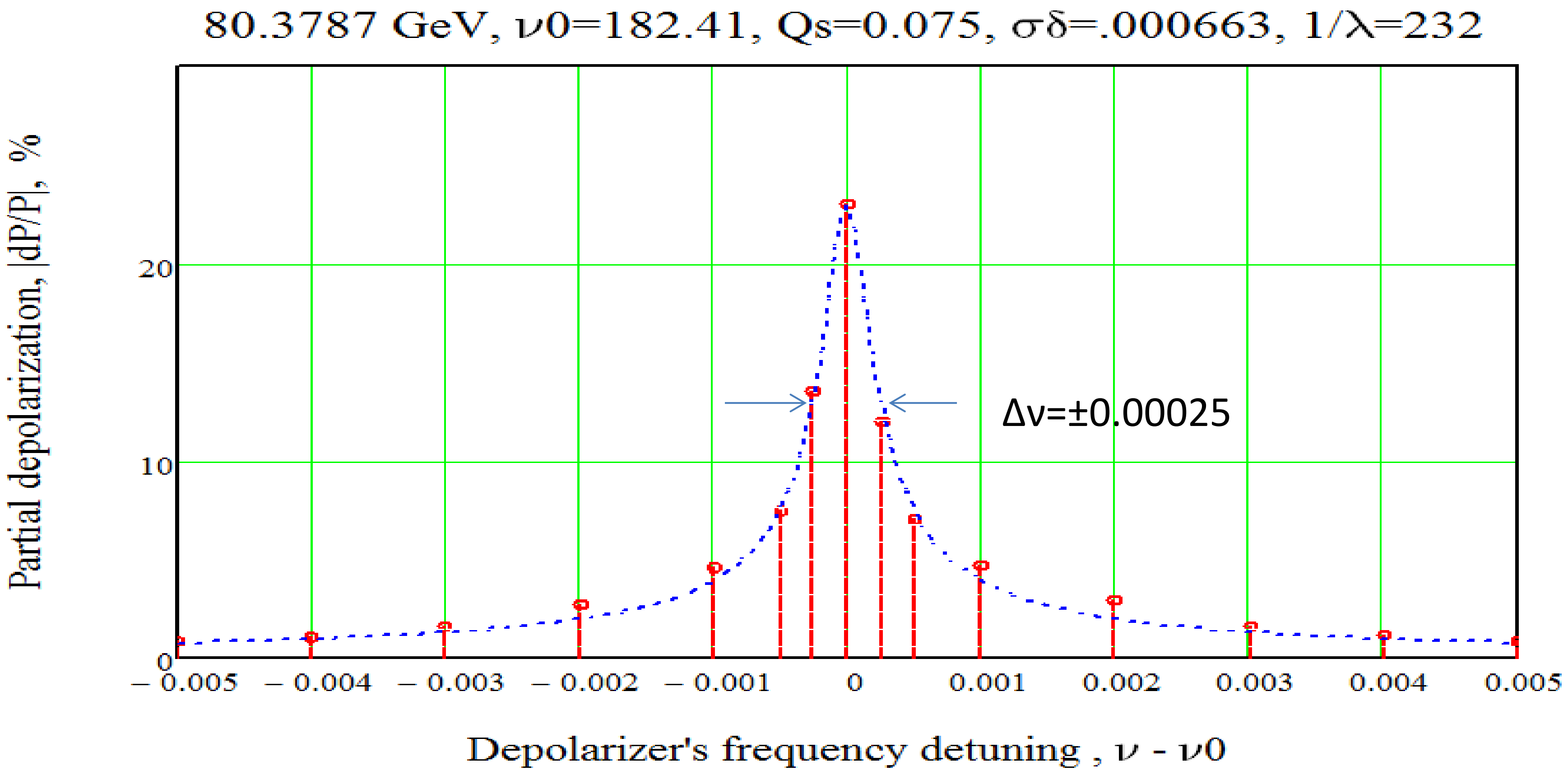
Partial depolarizations by steps when $\{\nu_0\}$=0.4875

The left and the right wings became symmetric with this choice of fractional part of ν_0.



Partial depolarizations by steps with Qs=0.075, $\{\nu_0\}$=0.41

The RD response with Qs=0.075 is 8 times more narrow in comparison with the case Qs=0.05



Spectrum line width scaling law

Line shape fitting function: $f(\nu)=A\frac{\Delta}{\sqrt{\Delta^2+(\nu-\nu 0)^2}}$ with parameters: A, Δ, ν0

Fit found by the tracking of the line width dependence on the synchrotron motion and beam parameters:

$$\Delta = 0.0035 \cdot \frac{\lambda}{0.000686} \cdot \left(\frac{\nu 0 \cdot \sigma_\delta}{182.425 * 0.000663}\right)^{2.5} \cdot \left(\frac{0.05}{Q_s}\right)^3$$

$\Delta = 0.0035$ at E=80 GeV

For given accelerator without wigglers the energy dependence is very strong:

$\Delta \sim E^8$ because $\lambda \sim E^3$, $\nu 0 \sim$ E, $\sigma_\delta \sim$ E

Therefore, this effect plays important role only at W threshold and not at Z!

Conclusion

- Spin tracking of a motion of a single particle reveals the dependence of the spectrum line width from the synchrotron tune and other beam parameters.

- This width becomes very large for chosen synchrotron tune Qs=0.05 and standard RD procedure becomes not applicable.

- The discussed above new RD procedure (by steps) works well even in cases when a width of the spin resonance became very large. That is just a case with Qs=0.05.

- Still the accuracy of a method needs to be studied further.

- Second order terms in orbital motion also contribute to the line width (I.Koop, Yu.Shatunov, in proc. EPAC 1988, Rome, p.738-739). Will be evaluated later on.

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