Energy calibration in FCC-ee based on polarization

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Outline

- Energy calibration concept
- Longitudinal Compton Backscattering Polarimeter
- Free precession frequency measurement approach
- Spin precession de-phasing rates
- Spin tracking results for various FCC-ee beam parameters
- Discussion
- Conclusion

Energy calibration concept

1. Production of polarized electrons from a laser photocathode.

2. Production of polarized positrons in a small energy damping ring (1-2 GeV), with polarization time in the order of 10 min (wigglers).

3. Acceleration of polarized beams via linac, SPS (?) and finally in the booster storage ring (100 km) using Siberian Snakes.

4. Injection of polarized bunches into the collider rings with the horizontal spin orientation and measuring turn by turn free precession frequency using the longitudinal Compton polarimeter.

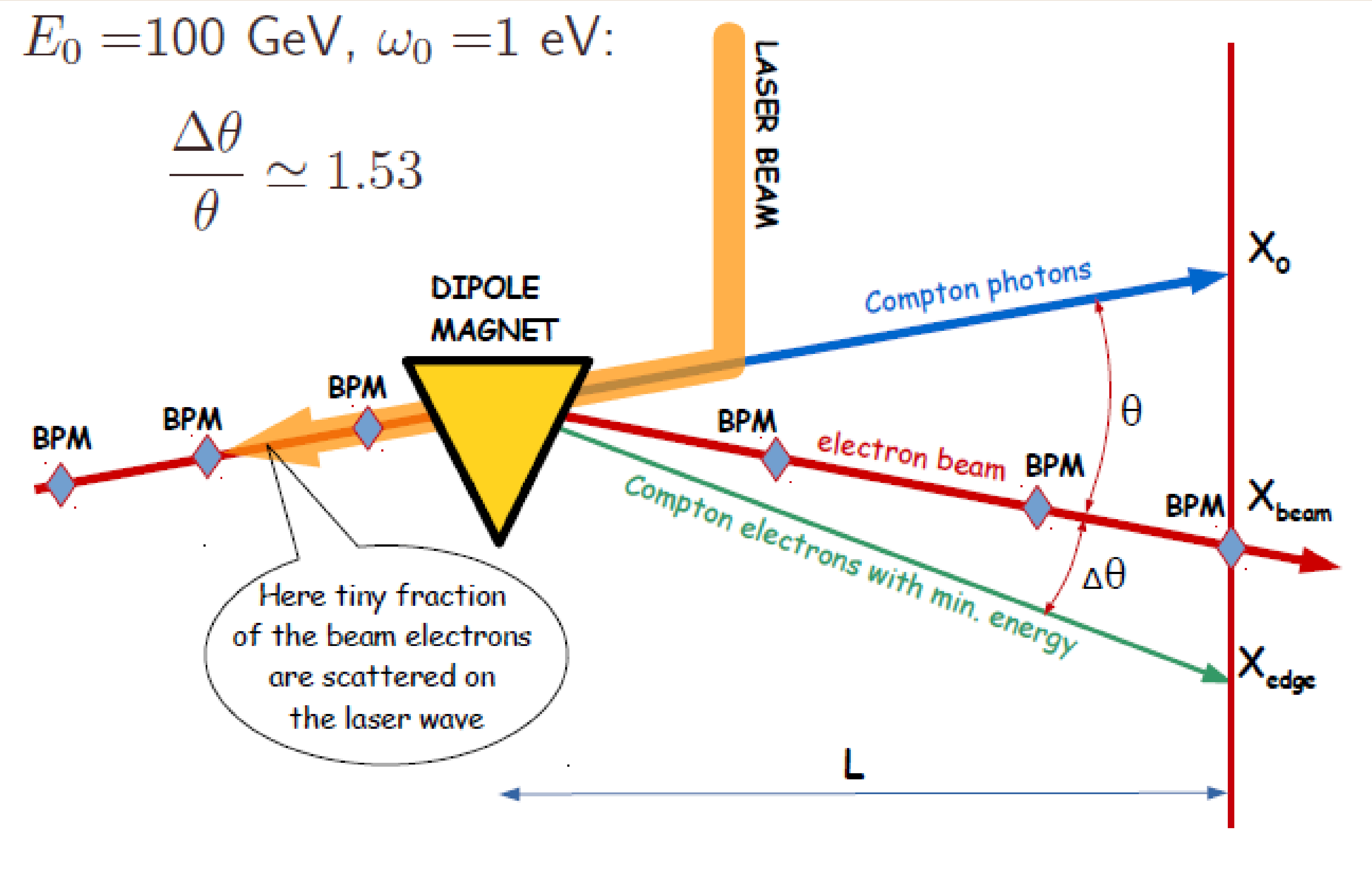
5. Number of polarimeters should be large (4-12). Then one can measure the spin precession phase advances per every arc. This paves a way to validate the saw-tooth energy distribution model, constructed on the full data set, such as RF-voltage/ RF-phases, plus orbit data from BPMs, plus geodesy data, plus many other.

Energy calibration concept, cont.

6. Measuring the beam energy in several points (about 4-12), using the magnetic spectrometer, based on Compton scattering of a laser light on an electron beam (N. Muchnoi proposal).
7. Absolute calibration of such spectrometric system will be done by measurement of the spin precession phases per arc segments.

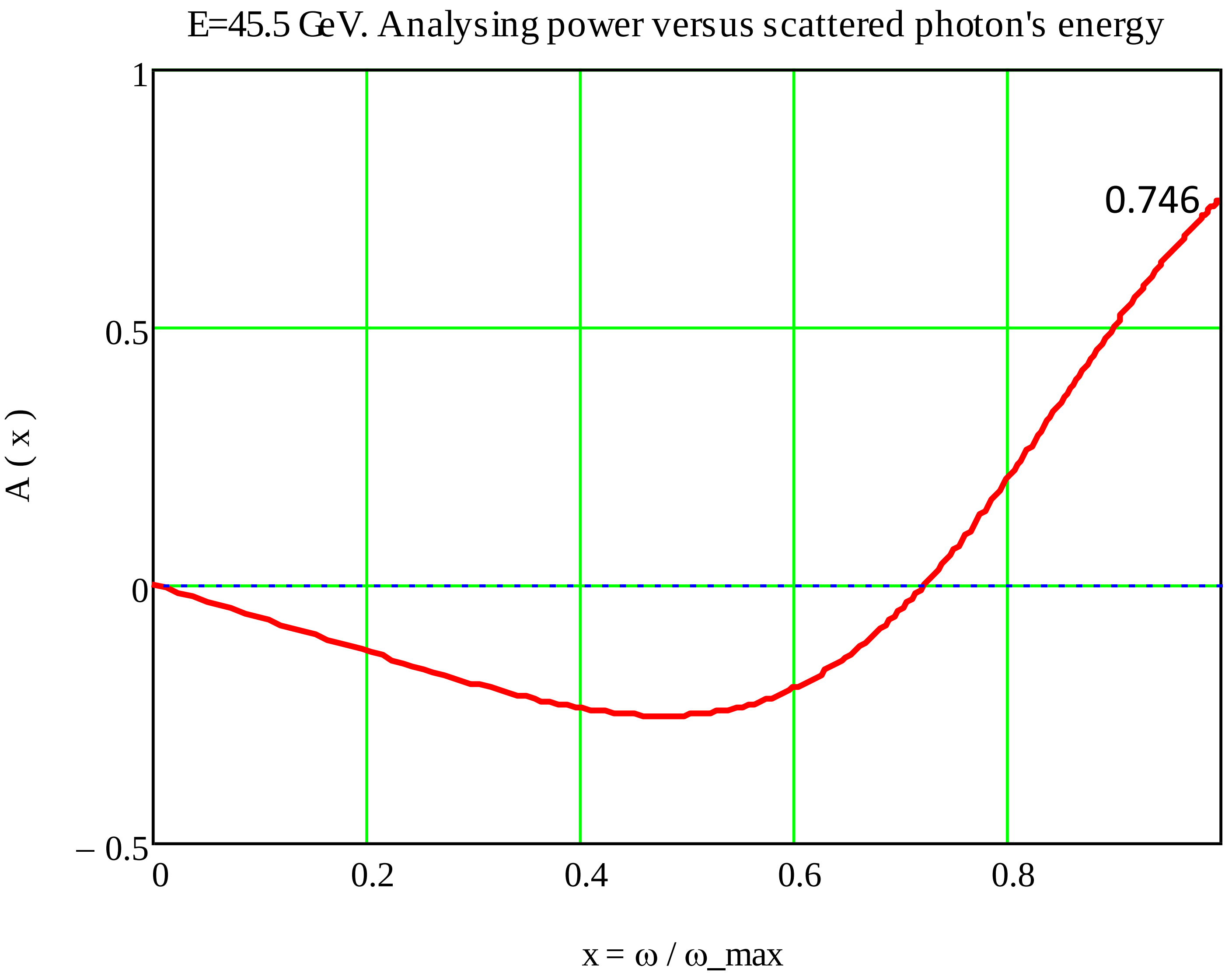
8. Spin coherence time depends strongly on the value of synchrotron modulation index: $\chi = \sigma_\delta \nu_0/\nu_s$ ($\nu_0=\gamma a$). It should be chosen not too large: acceptable is $\chi < 1.8$ ($\nu_s \approx 0.1\text{-}0.2$ is required). Examples will be shown at several slides.
9. Resonance depolarization is not excluded, but did not work near integer resonances. In contrast, the free precession method works everywhere!
10. Shall measure, suppress and account spin resonances in a broad energy interval. Only after that can claim true energy value!

Spectrometer with laser calibration (suggestion)



Access to the beam energy: $E_0 = \frac{\Delta\theta}{\theta} \times \frac{m^2}{4\omega_0}$

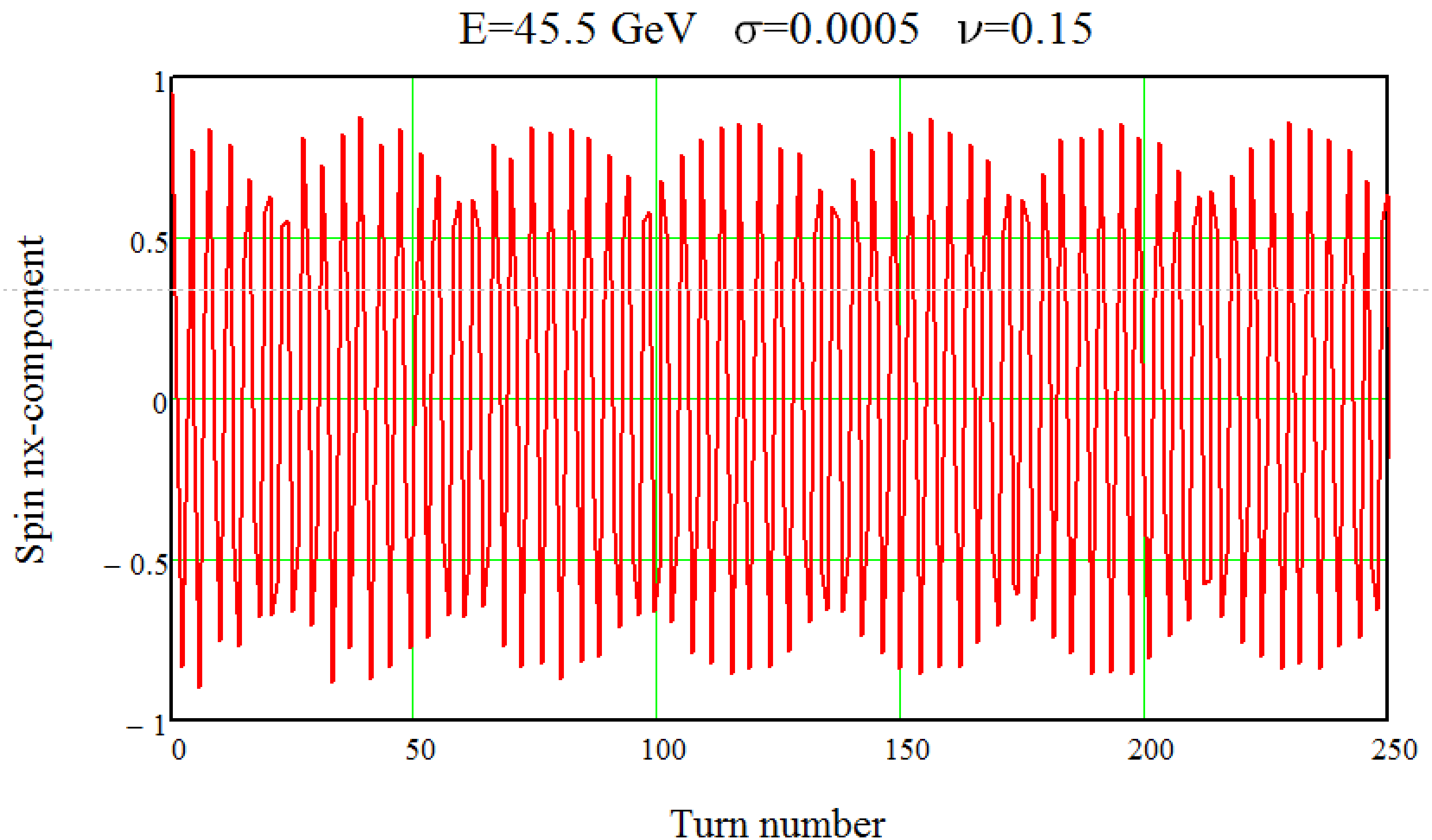
Compton scattering of a laser light



Detection of the scattered electrons instead of photons provides selection of events with maximal momentum loss!

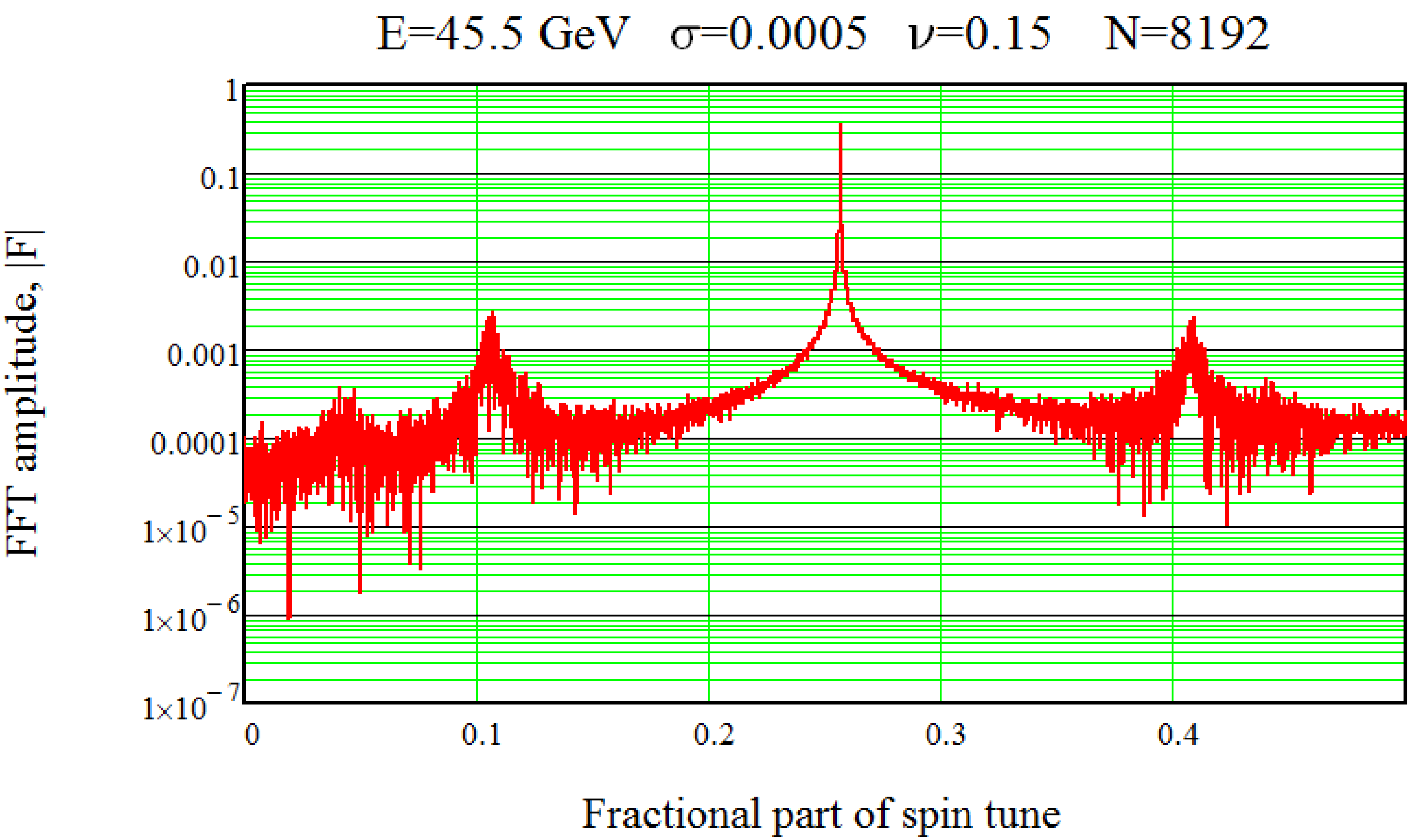
Let's utilize the highest value of the analysing power!

Spin tracking oscillogram. 125 test-particles.
E=45.5 GeV, σ_δ=0.0005, ν_s =0.15, τ_s =1320 turns



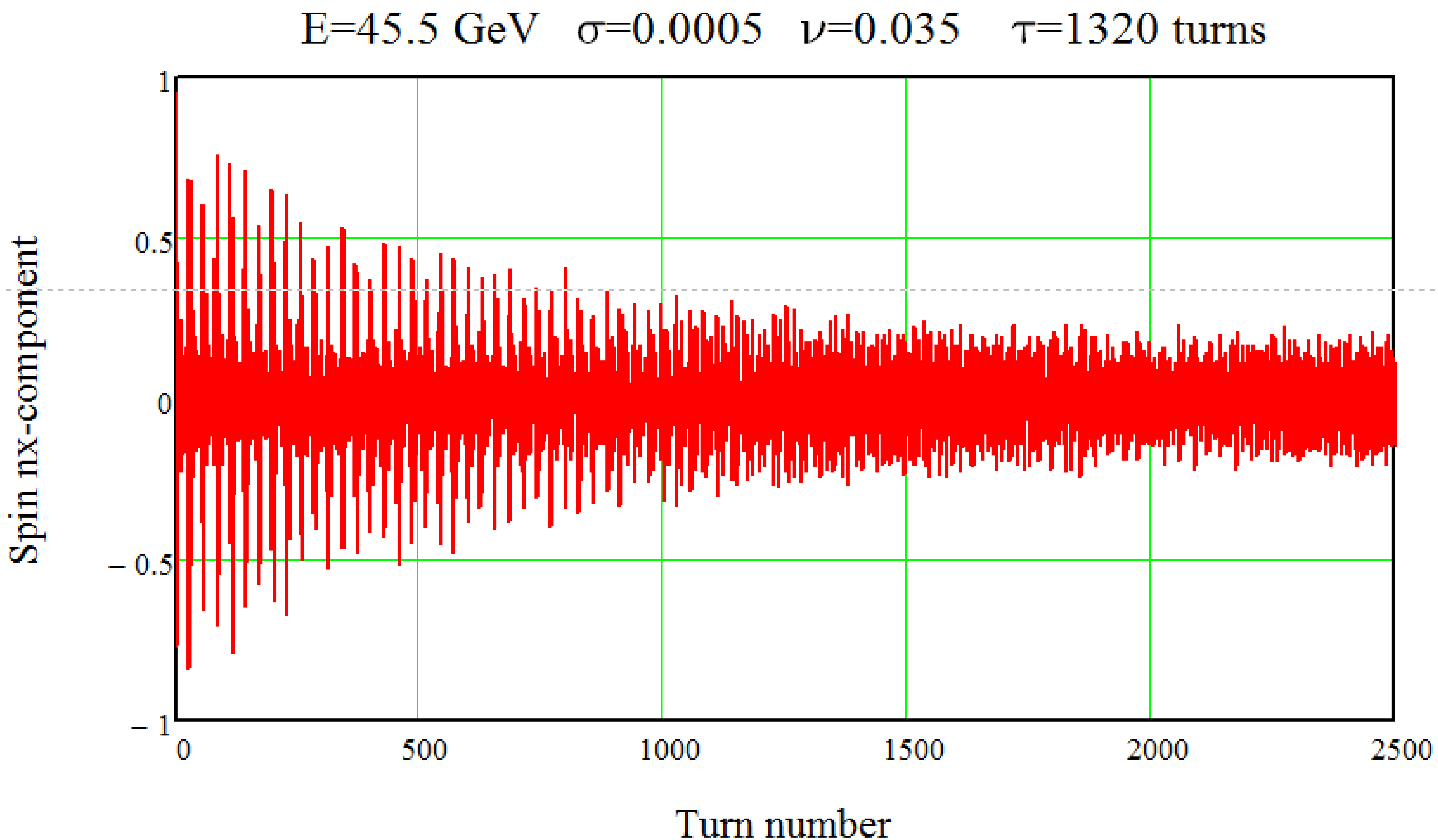
Loss of polarization degree due to de-phasing is small thanks to high enough ν_s.

Spin precession spectrum. Number of turns 8192. E=45.5 GeV, ν_0=103.25, σ_δ=0.0005, ν_s =0.15, χ=0.35

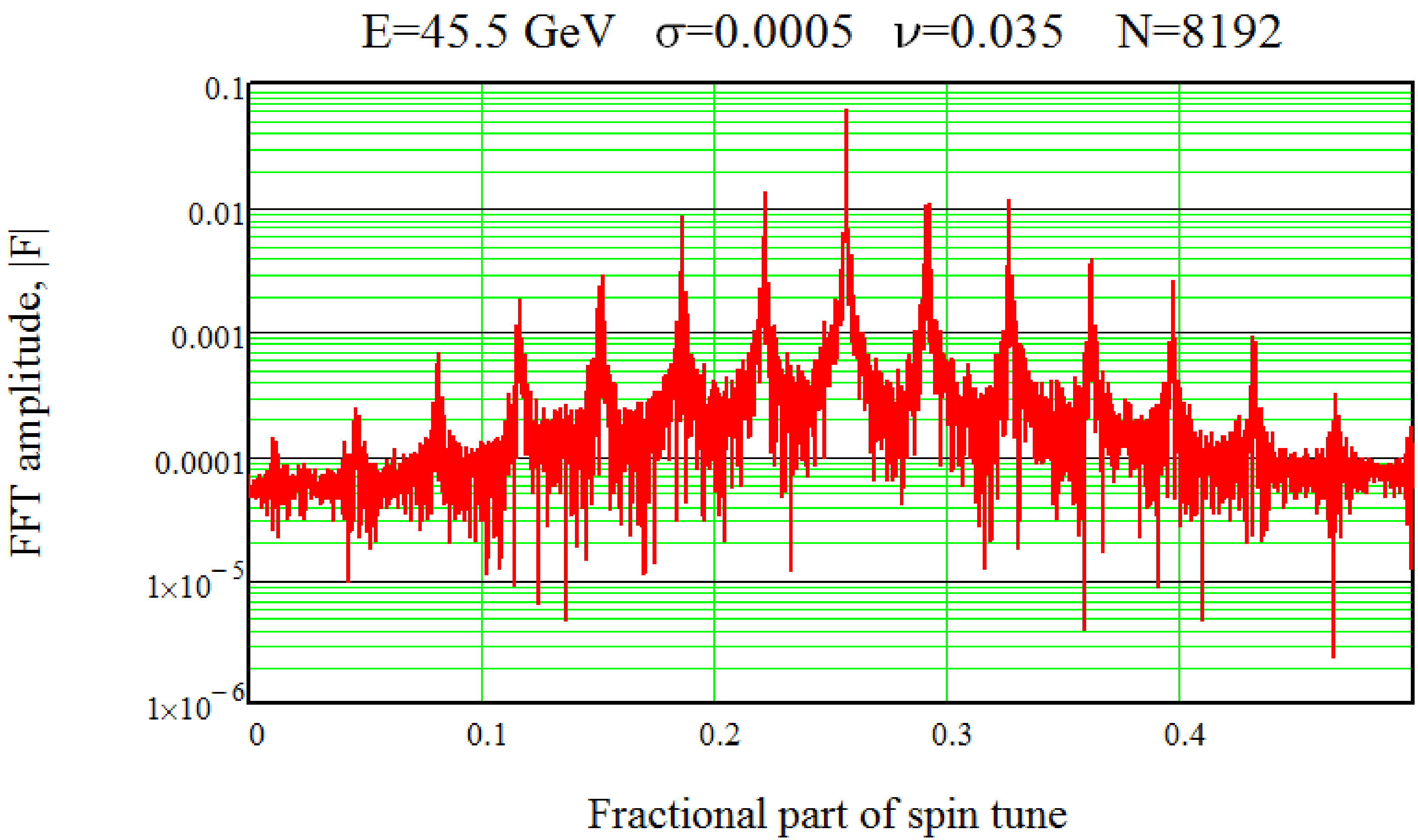


$\chi = \sigma_\delta \nu_0 / \nu_s = 0.35$ – synchrotron modulation index.

Spin tracking oscillogram. 125 test-particles.
E=45.5 GeV, σ_δ=0.0005, ν_s =0.035, τ_s =1320 turns

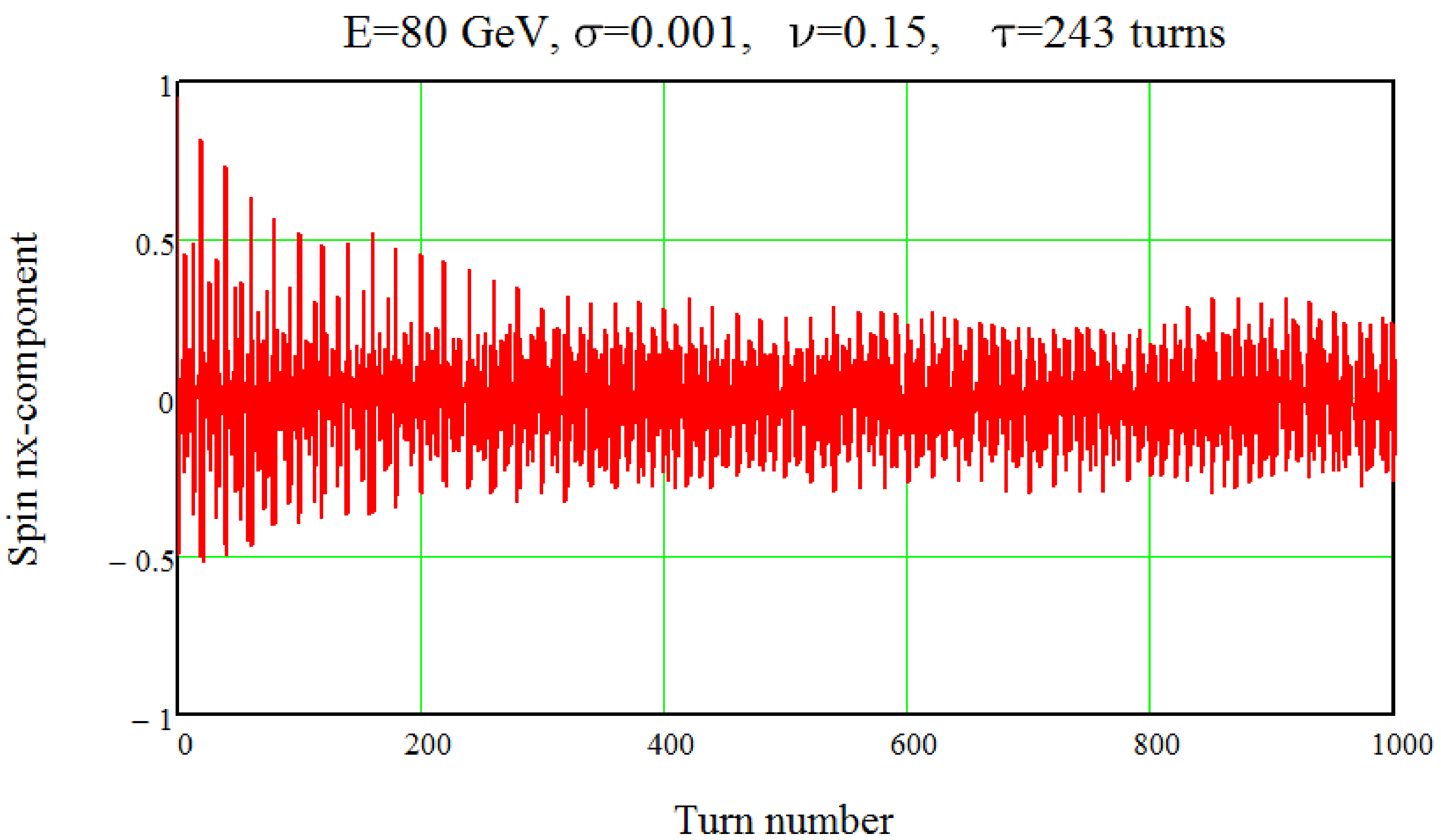


Spin precession spectrum. Number of turns 8192.
E=45.5 GeV, ν_0=103.25, σ_δ=0.0005, ν_s =0.035, χ=1.48

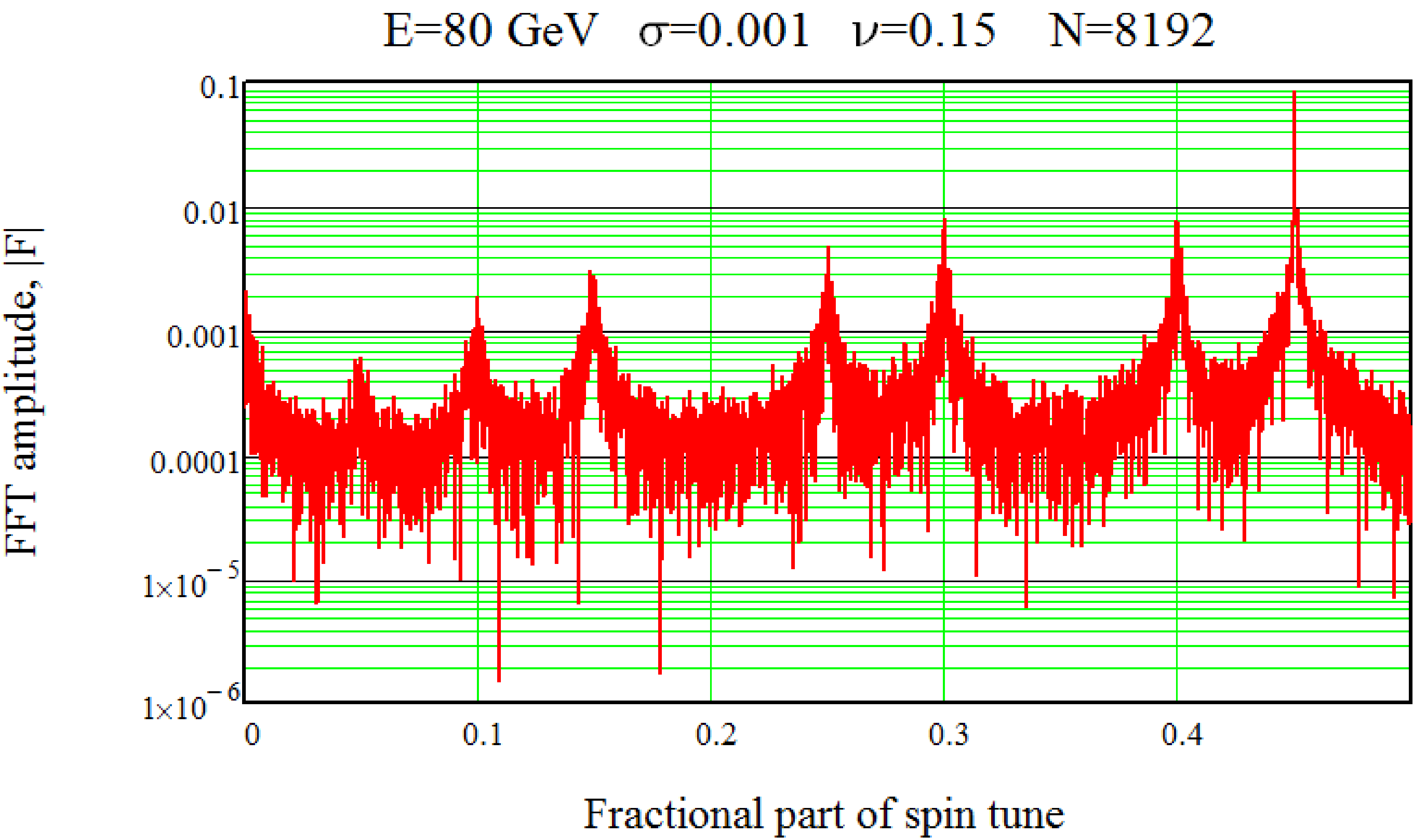


We want: χ < 1.7. With χ > 1.7 peaks will disappear!

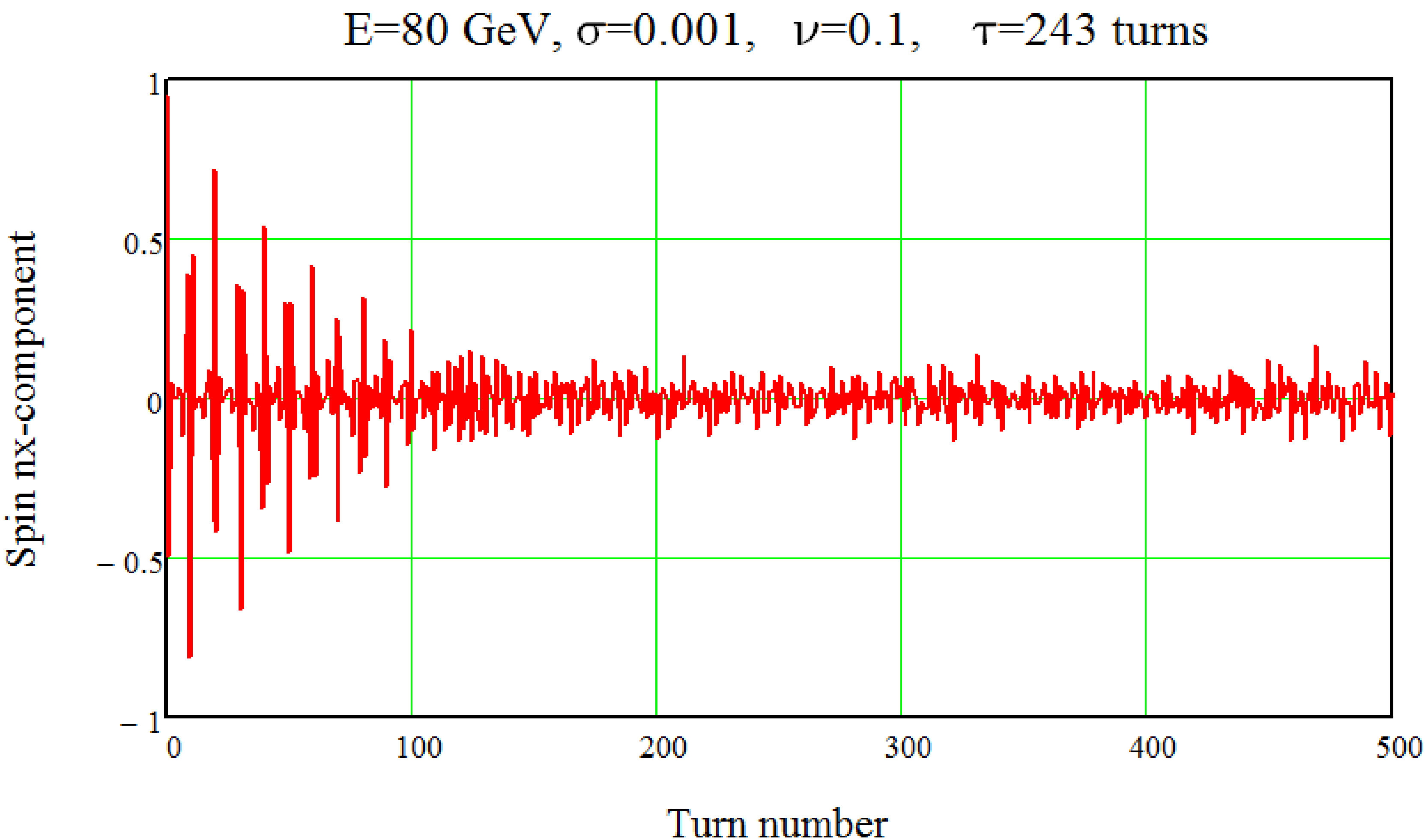
Spin tracking oscillogram. 125 test-particles.
E=80 GeV, σ_δ=0.001, ν_s =0.15, τ_s =243 turns



Spin precession spectrum. Number of turns 8192. E=80 GeV, ν_0=181.55, σ_δ=0.001, ν_s =0.15, χ=1.21

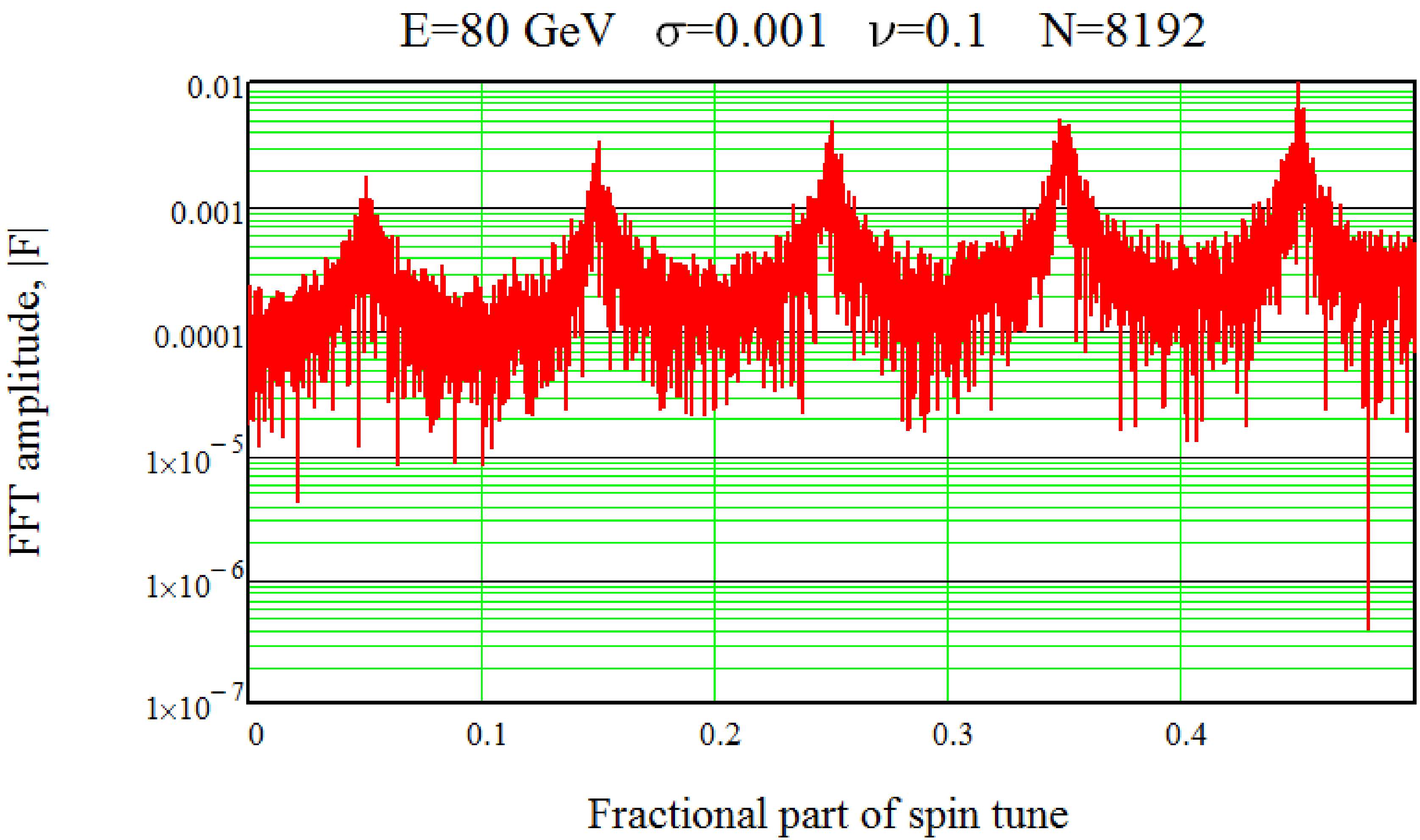


Spin tracking oscillogram. 125 test-particles.
E=80 GeV, σ_δ=0.001, ν_s =0.10, τ_s =243 turns



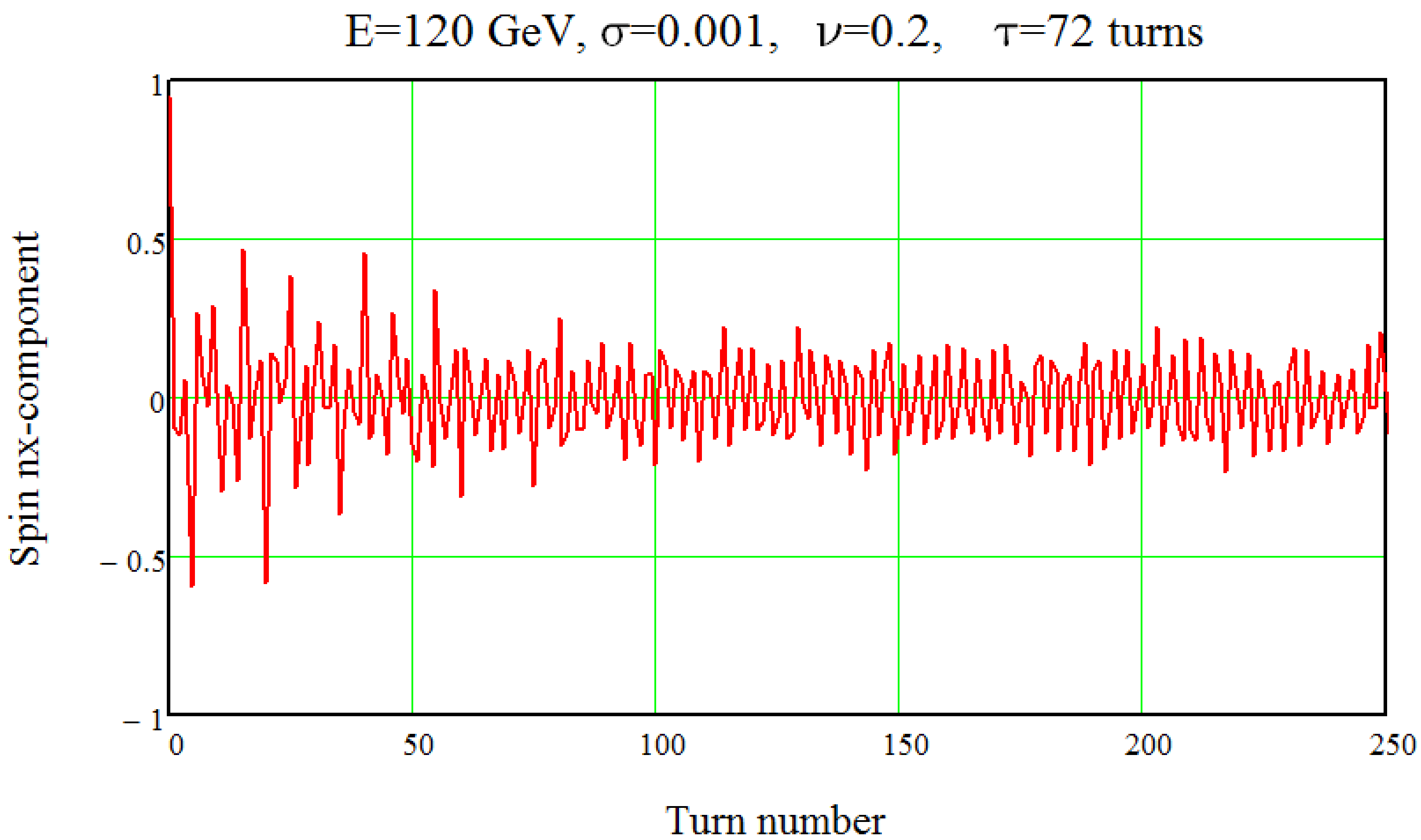
Fast de-phasing due to slow synchrotron motion!

Spin precession spectrum. Number of turns 8192. E=80 GeV, ν_0=181.55, σ_δ=0.001, ν_s =0.10, χ=1.82



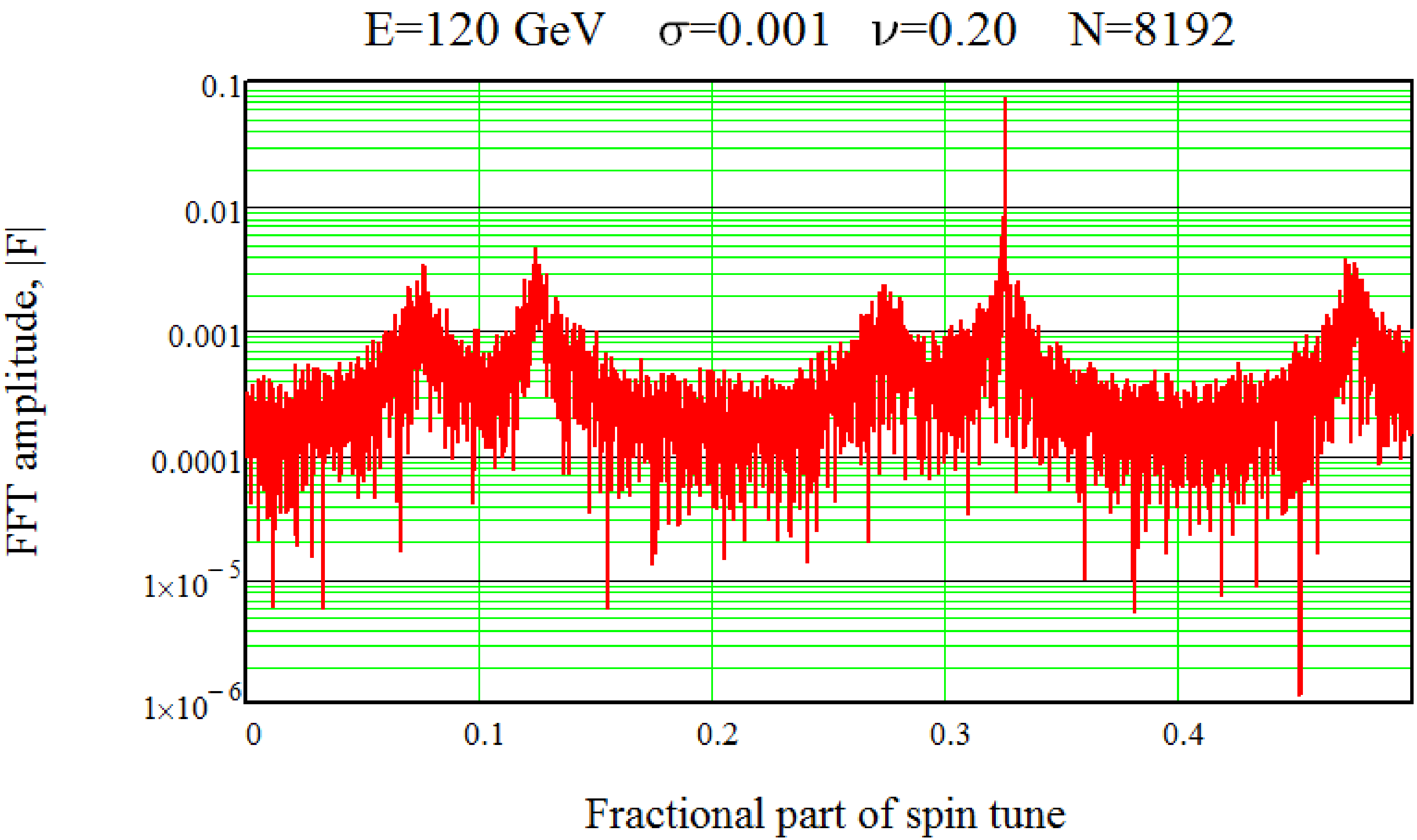
Same results one gets with doubled both: energy spread and synchrotron tune.

Spin tracking oscillogram. 125 test-particles.
E=120 GeV, σ_δ=0.001, ν_s =0.20, τ_s =72 turns



Fast de-phasing! Synchrotron modulation index is too high: χ=1.36.

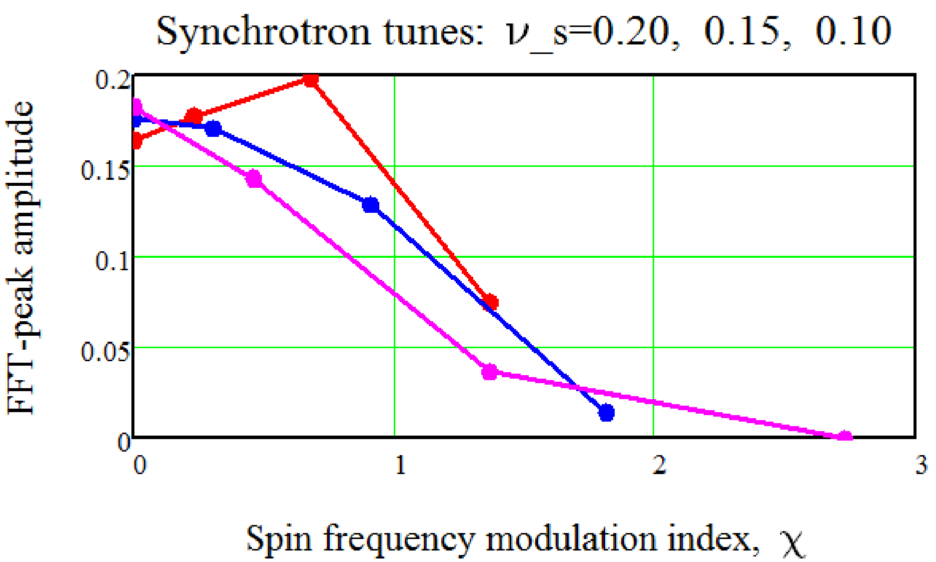
Spin precession spectrum. Number of turns 8192. E=120 GeV, ν_0=272.325, σ_δ=0.001, ν_s =0.20, χ=1.36



Same results one gets with scaled both: energy spread and synchrotron tune.

Discussion

- Spin dephasing rate is governed by the synchrotron frequency modulation index χ. It should be low enough: $\chi < 1.7$ at least. Collision with the half-intensity bunch will reduce σ_δ, may help? Special polarization runs with high ν_s, to calibrate the Compton based spectrometers!?
- VEPP-4 team performs just now the experiment "Pulsar" which, hope, will validate free spin precession technique.



Conclusion

- Free precession approach provides extremely fast method of spin frequency measurement.

- It is limited only by the energy spread averaging rate, provided by the synchrotron oscillations. This is expressed via synchrotron modulation index. It should not exceed a factor $x < 1.7$ or lower. This, in general, leads to choice of high synchrotron tunes.

- FCCee-CW parameters do not satisfy this requirement: $\nu_s \approx 0.015\text{-}0.05$. So, special calibration runs with high ν_s are needed from time to time, then calibrated Compton magnetic spectrometers shall continuously monitor beam energy during normal runs.

Plans for future work

- Incorporate into the ring the 90^0 spin rotator insertions for experiments with longitudinally polarized beams at *Z*-peak. Required additional space could be shared with RF.
- Make numerical simulations of the saw-tooth energy model reconstruction code.
- Develop/understand the acceleration chain for polarized beams.
- Simulate tools for suppression of spin resonances.
- Consider technical aspects of Compton polarimeter and Compton magnetic spectrometer. Combine them in one?
- Think on resonance depolarization technique, as an alternative to free spin precession method.
- There are more experts at BINP for these tasks! Polarization is our specialty since 70-th!