Polarization studies for FCCee

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Outline

- FCCee demands for precise energy calibration.
- Two alternative/complimentary polarization scenarios: use of self-polarization in the collider; or, alternatively, measure a free precession spin frequency of beams injected from a booster.
- Self-polarization scenario in FCCee. Asymmetric field wigglers. Resonant depolarization (RD). Simulation results for RD.
- Acceleration of polarized e± beams in a booster ring. Siberian Snakes. Low energy polarizing damping rings.
- Free precession approach. Advantages as against to RD.
- Conclusion

Introduction

- FCCee is a 100 km circular e+e- collider with the luminosity exceeding 10^{36} $cm^{-2}s^{-1}$ at Z-peak energy.

- FCCee and CEPC need 50 keV beam energy resolution at Z and about 100-200 keV at W, separately in both rings.

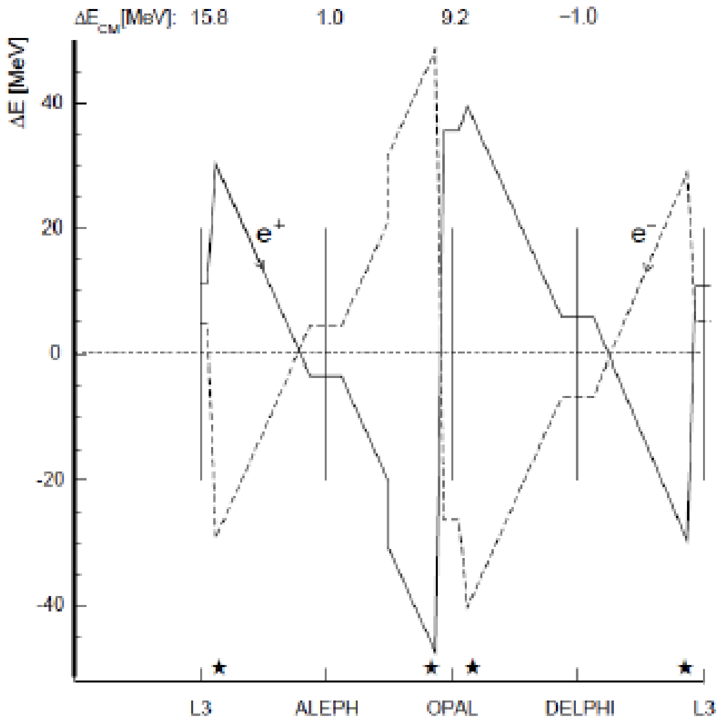
- Only the Resonant Depolarization (RD) can provide such extreme absolute accuracy: $\Delta E/E \sim 1 \cdot 10^{-6}$. Still RD measures the averaged over the circumference energy! But a local energy differs from the average one according to saw-tooth phenomena (SR losses + energy gains from RF). SR losses per turn: 30 MeV at Z and 330 MeV at W.

- Longitudinal impedance also contributes to saw-tooth picture, but could be accounted via extrapolation of energy measurements to zero beam current.

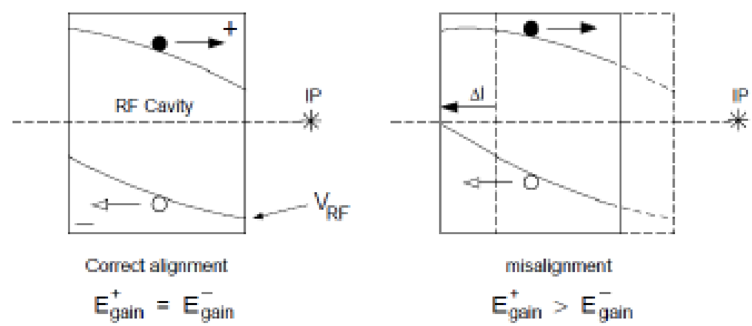
Introduction, cont.

- So, in principle, we shall pay efforts to develop the local energy monitors, almost as sensitive as RD.
- These monitors (magnetic spectrometers) will be calibrated (absolutely) via RD at low energies, say at 20 - 30 GeV, where SR is low (ΔE_{turn}= 1.1 - 5.7 MeV, respectively) and be used for saw-tooth energy distribution control.
- To extend their calibration to higher energies we shall rely on precise field mapping studies in a lab.
- Magnetic spectrometers shall provide beam energy calibration at energies beyond the limit for RD technique: say above 100 GeV per beam.

RF corrections



Errors arise due to cavity misalignments primarily:



- At LEP cavity misalignment was assumed to be 1.4mm in 1995

Work is needed to reduce this error. For LEP the error was of the order of 500keV (leading to an error of 400/200keV for the mass/width of the Z. Need to reduce this error by (more than) a factor of 10!

This might be the dominant error at FCC-ee

M. Koratzinos, Washington, 25/3/2015

Two polarization scenarios for FCCee.

Two main scenarios are currently under discussion:

1) Start operation with injection of about 250 non-colliding bunches. Switch on asymmetric wigglers making the ST polarization time at Z-pole τ≈12-25 hours and polarize beam to 10% polarization level (during 1 hour). Switch off wigglers and start normal run. Depolarize every 6 min one bunch.

2) Alternative: continuously prepare polarized bunches at 1 GeV damping ring (70-90% polarization level) using strong asymmetric wigglers to decrease polarization time to few minutes. Then accelerate beams top up in a sequence of synchrotrons preserving polarization by the use of Siberian Snakes. Inject beams with polarization rotated into the horizontal plane. Measure a free spin precession frequency using the longitudinal Compton polarimeter.

Resonant Depolarization scenario.

- Well established technique since 70-th (ϕ, ω, K-meson masses at VEPP-2M; J/ψ, ψ′, D, ϒ at VEPP-4 and VEPP-4M; Z at LEP).
- Still large energy spread $\sigma_\delta > 0.001$ will limit the self-polarization approach at energies above 80 GeV, when $\sigma_\delta \cdot \nu_0 \geq 0.2$ ($\nu_0 = \gamma a = 180$).
- Also the self-polarization time is too large, exceeding 250 h at Z pole. Therefore shall think on use of polarization wigglers.
- Polarization wigglers, like used at LEP, switched on for 1-2 hours, to polarize few hundreds of bunches to 5%-10% polarization level, may solve a problem for Z and W, but not for full energy range.
- Then, the local energy monitors shall be calibrated by RD and will be used for continuous energy monitoring, as is requested by physics.

Sokolov-Ternov build-up rates (E. Gianfelice talk, Washington)

- High precision beam energy measurement ($\ll 100$ keV) is needed for Z pole physics at 90 GeV CM energy and W physics at 160 CM energy. RF depolarization widely used at LEP it can provide a $\sim 10^{-6}$ accuracy.
- Z pole physics would profit from longitudinal beam polarization.

Sokolov-Ternov polarization build-up rate

$$\tau_p^{-1} = \frac{5\sqrt{3}}{8} \frac{r_e \gamma^5 \hbar}{m_0 C} \oint \frac{ds}{|\rho|^3}$$

for FCC-ee with $\rho \simeq 10424$ m

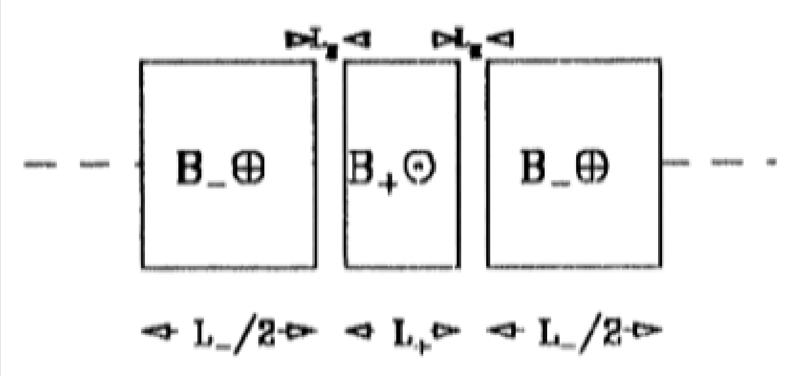
E (GeV)	U_0 (MeV)	$\Delta E/E$ (%)	τ_{pol} (h)
45	35	0.038	256
80	349	0.067	14

Asymmetric field wiggler (E. Gianfelice talk)

For decreasing the polarization time keeping the polarization level high wigglers are introduced in the lattice. Constraints:

- $x' = 0$ outside the wiggler $\Rightarrow \int_{wig} ds\, B_w = 0$ (vanishing field integral)
- $x = 0$ outside the wiggler $\Rightarrow \int_{wig} ds\, sB_w = 0$ (true for symmetric field)
- P large $\Rightarrow \int_{wig} ds\, B_w^3$ must be large

LEP polarization wiggler



$$\int_{wig} ds \frac{1}{\rho_w^3} = \frac{L_+}{\rho_+^3}\left(1 - \frac{1}{N^2}\right) \qquad N \equiv L_-/L_+ = B_+/B_-$$

N should be large for keeping polarization high!

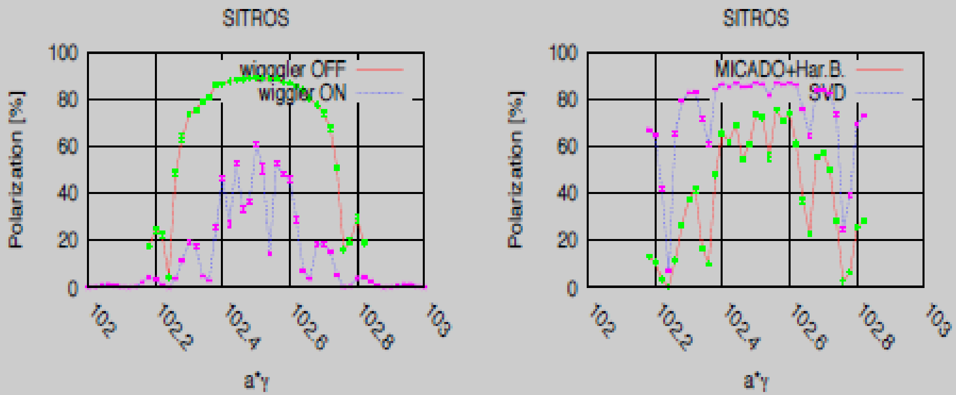
Spin resonances compensation (from E. Gianfelice talk)

1 wiggler with B_{+}=1.35 T for reaching 10% polarization (enough for energy calibration) after 140'.

"toy" ring

- 200 μm quadrupole misalignment
- 1 corrector + 1 BPM close to each vertical focusing quad
- correction
  - MICADO like correction + *harmonic bumps*

    or
  - use of all BPMs and correctors through SVD analysis



Beam parameters scaling with a wiggler field value

Assuming E=45 GeV, ρ_0 =10.4 km and l_1=1.3 m, $l_2=6\cdot l_1$=7.8 m				
B (T)	τ_p *(hours)*	*P (%)*	$(\sigma_\delta)_{SR}/\sigma_E$ *(MeV)*	U_0 *(MeV)*
0	256	92.4	0.000378 / 17	34.9
1.1	25.4	87.9	0.001125/ 50.6	39.6
1.3	16	87.7	0.001384 / 62	41.4
2.6	2.1	87.4	0.003134 / 141	61.1

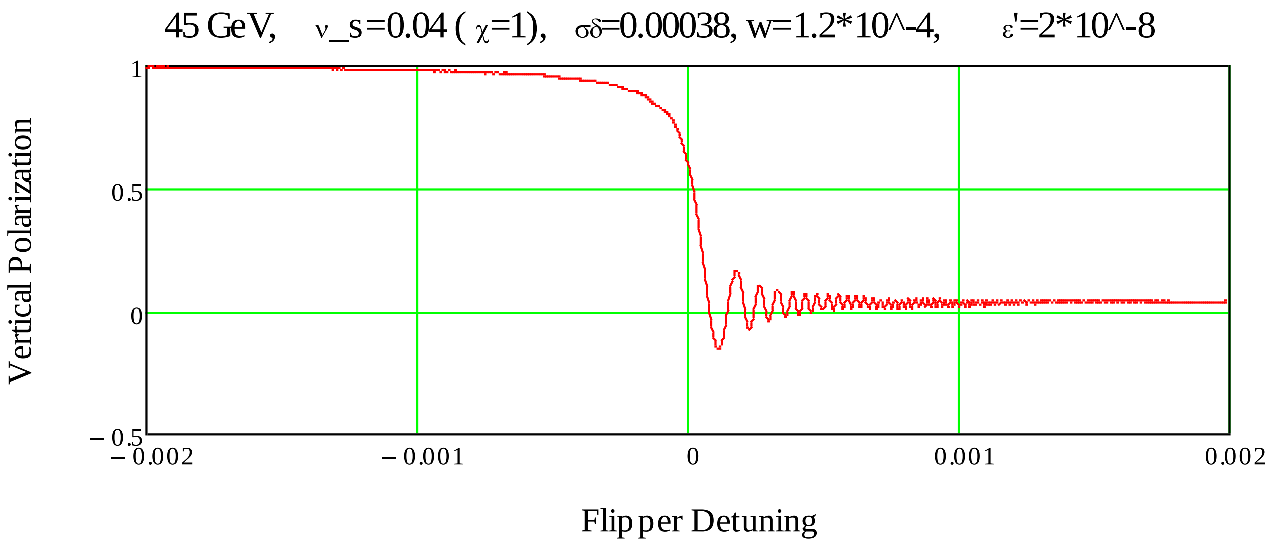
$$\tau_p^{-1} = \frac{5\sqrt{3}}{8} \lambda\!\!\!^{-}_e r_e c \gamma^5 \left\langle \frac{1}{|\rho|^3} \right\rangle = \tau_0^{-1} \frac{|B_0|^3 l_0 + |B_1|^3 l_1 + |B_2|^3 l_2}{B_0^3 l_0}$$

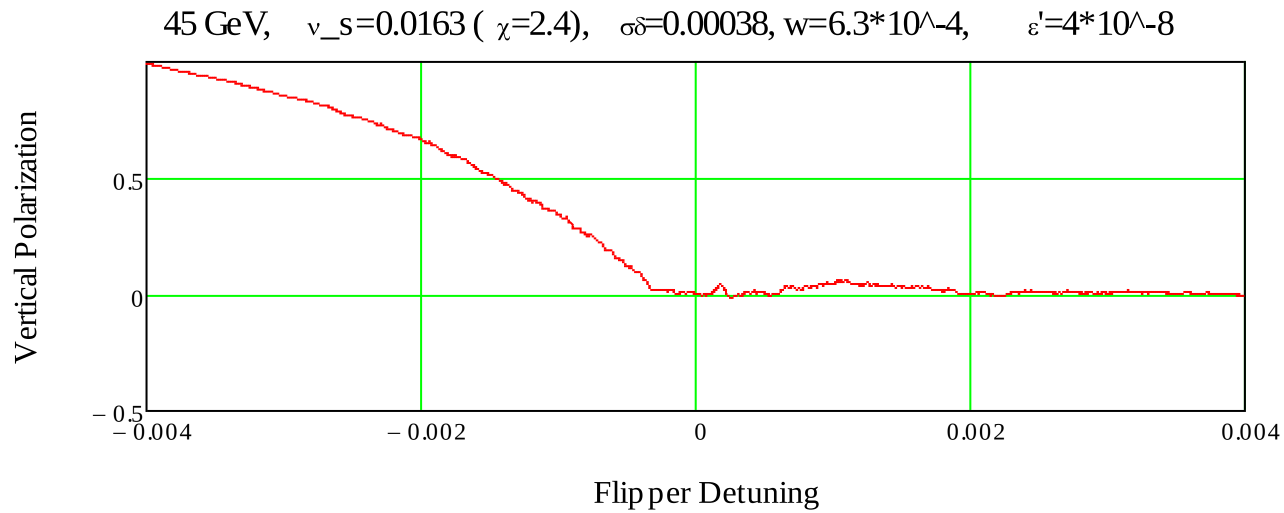
$$(\sigma_\delta)^2_{SR} = \frac{55\sqrt{3}}{192} \frac{\lambda\!\!\!^{-}_e}{B\rho} \gamma^2 \frac{|B_0|^3 l_0 + |B_1|^3 l_1 + |B_2|^3 l_2}{B_0^2 l_0 + B_1^2 l_1 + B_2^2 l_2} \qquad U_0 = \frac{2}{3} mc^2 r_e \gamma^4 \frac{B_0^2 l_0 + B_1^2 l_1 + B_2^2 l_2}{(B\rho)^2}$$

Development of RD spin tracking code

- The code is based on a simple and fast algorithm for simulation of spin dynamics in the process of RD.
- Main features: only synchrotron oscillations and energy diffusion due to quantum fluctuations of SR are included into consideration. The betatron oscillations are neglected (extremely small emittances).
- Energy of all particles jump randomly in the end of each turn. Radiation damping is included in the one turn map.
- Single spin motion perturbation can be switched on, if needed.
- Such approach provides the quantitative analysis of the role of synchrotron oscillation parameters on the depolarization rate during the frequency scan of the depolarizer.

Simulation of RD with different synchrotron tunes





Full depolarization happens before or after crossing the resonance, depending on the value of synchrotron modulation index χ and w - strength of a depolarizer.

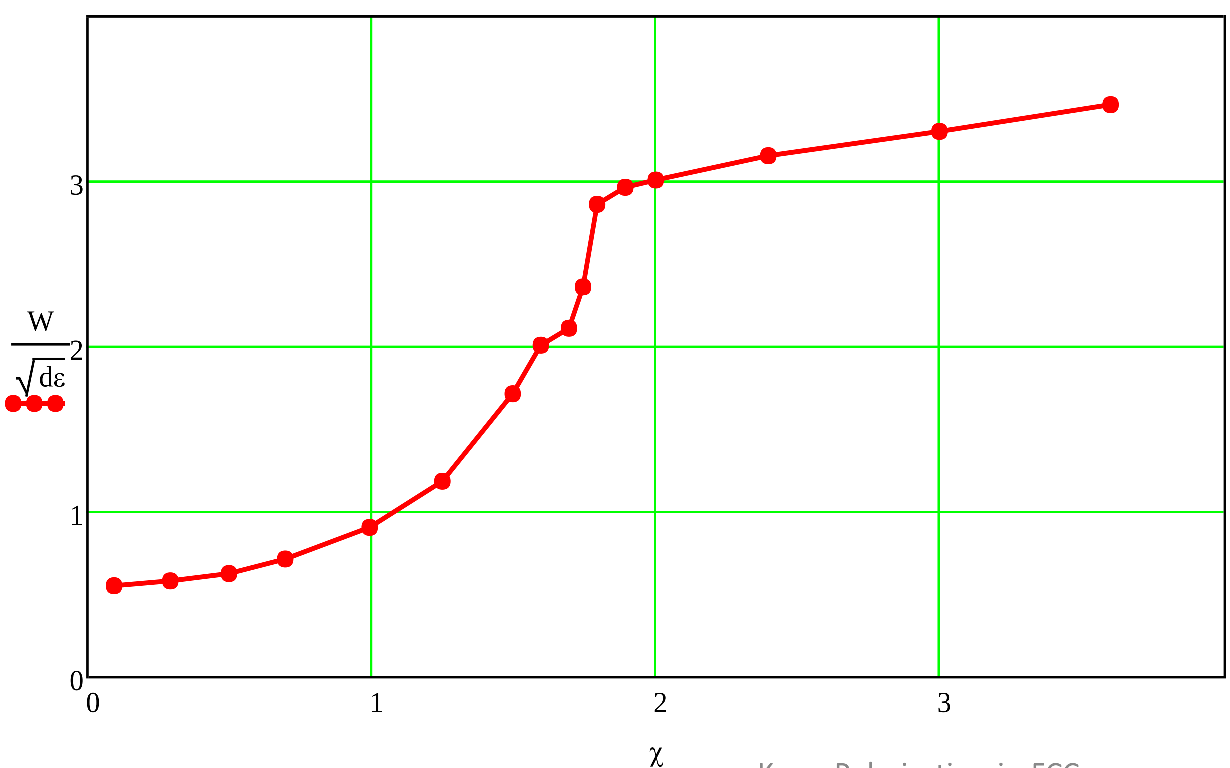
Therefore for precise determination of the resonance frequency one should made scans in two opposite directions! (Depolarizing two bunches almost simultaneously in opposite directions of the frequency scan.)

The needed strength W of a depolarizer dependence on the synchrotron modulation index χ value

Froissart-Stora prediction: $P_{\varepsilon\to\infty} = -1 + 2\exp(-\pi^2 W^2 / \varepsilon'), \quad \varepsilon' \equiv d\varepsilon/dN \equiv d\varepsilon$,

Therefore the needed W to depolarize a beam is proportional to $\sqrt{d\varepsilon}$, where $d\varepsilon$ is the detuning step per turn.

E=45.5 GeV, dε=4*10^-8, σ=0.00038, λ=1/1320



Nominal for:

$E = 45.5$ GeV

$\nu_0 = 103.256$

$\sigma_\delta = 0.00038$

$\nu_s = 0.0163$

$$\chi = \frac{\nu_0 \sigma_\delta}{\nu_s} = 2.4$$

- too high!

Shall increase ν_s, twice at least!

Discussion of the results for RD simulation

- To be sensitive to $\Delta E/E \sim 1\cdot10^{-6}$ one should have the resolution in the determination of fractional part of the spin tune in the order of $\Delta\nu \sim 1\cdot10^{-4}$ (because $\nu_0=100$).

- Therefore the depolarizer strength W should not exceed too much the level $1\cdot10^{-4}$. But then the detuning step dε should be made too much small. For $W=3\cdot10^{-4}$ and $\chi=2.4$ one finds from the plot at previous slide that $d\varepsilon < 1\cdot10^{-8}$ to have W/sqrt(dε) > 3.

- Let's assume that before playing with RD we can predict a beam energy with the accuracy $\Delta E/E \sim 1\cdot10^{-4}$, then we shall start sweeping at a distance $\varepsilon_{in} = \pm\, 10^{-2}$ from the resonance value. Then the full scan will take $N=2\cdot10^6$ turns - roughly 666 seconds.

- This looks too long, because the expected energy stability time at a level $\Delta E/E \sim 1\cdot10^{-6}$ is estimated to be 100 seconds or even less (ground motion due to aircrafts, trains, etc.).

- Therefore the local energy monitors (magnetic spectrometers), being calibrated once using RD data, shall be used for the fast energy monitoring and its stabilization.

- To validate of the energy measurements one can use a sharp dependence of the Z-production cross-section on the sum of two beam energies at the slope of Z-curve.

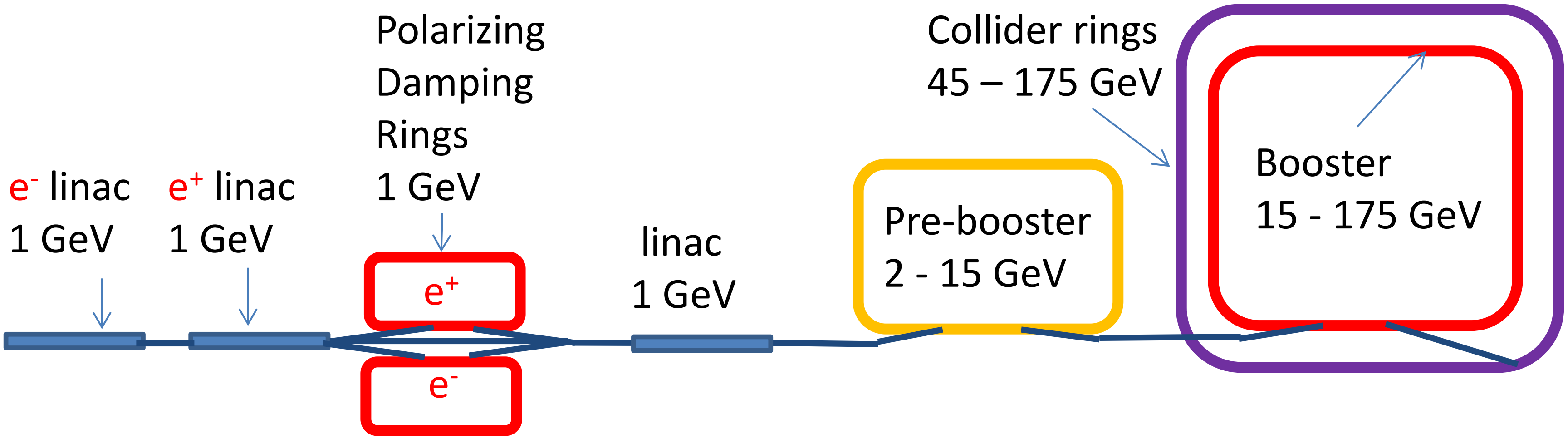
Free precession concept – advanced scenario

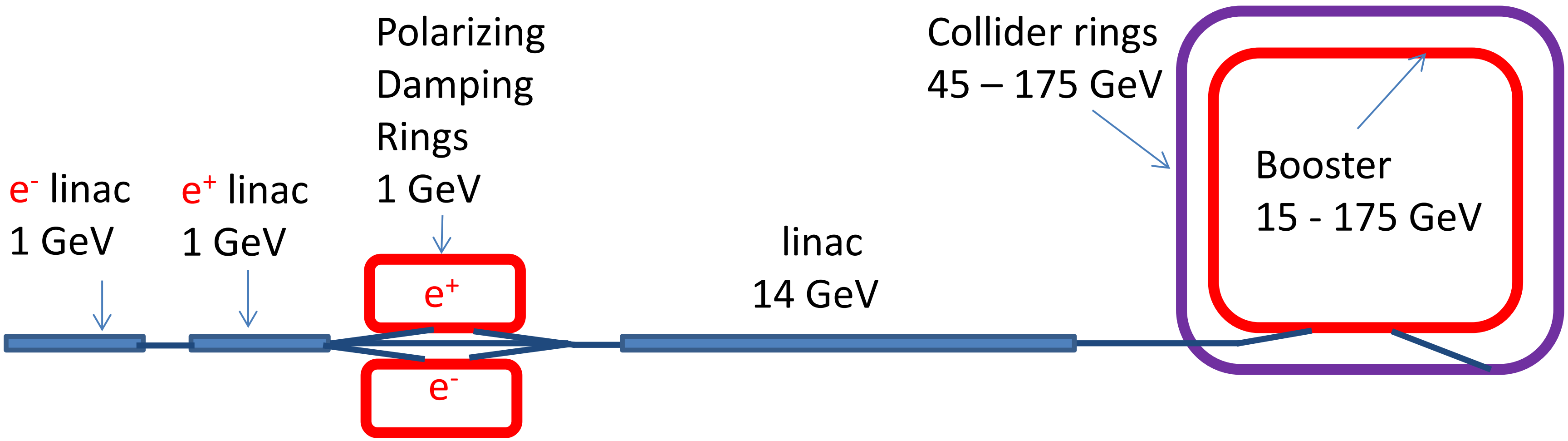
1. Production of polarized e+ in damping ring at 1 GeV, achieving polarization time 2 - 5 min (by use of high field bends or wigglers).
2. Production of polarized e- from a laser photocathode, or in a damping ring for the energy calibration only, like e+.
3. Acceleration of polarized beams via linac and finally in the 100 km booster storage ring, preserving polarization there by the help of Siberian Snakes (solenoid-type spin rotators).
4. Injection of polarized bunches into the collider rings with the horizontal spin orientation and measuring turn by turn the free precession frequency using the longitudinal Compton polarimeter.
5. The number of polarimeters should be large (≥4?). Then one can measure the spin precession phase advances per every arc sector. This paves a way to validate the saw-tooth energy distribution model, constructed on the full data set, such as RF-voltage and RF-phases, plus orbit data from BPMs, plus geodesy data, plus many other data.

Free precession concept, cont.

6. Also shall measure beam energy by the magnetic spectrometers or other type local energy monitors in few points along the ring (≥4?).
7. Absolute calibration of any spectrometric system will be done by a measurement of the spin precession frequency at low energy, say about 20 - 30 GeV, where SR is weak and can be accounted with very good accuracy. Measurement of the spin precession phase advances shall provide a cross-check of this calibration.
8. Dephasing of spins in coherent precession depends strongly on the synchrotron modulation index: $\chi = \sigma_\delta \nu_0/\nu_s$ ($\nu_0=\gamma a$). It should be chosen not too large: acceptable is $\chi < 1.7$ (means $\nu_s > 0.023$).
9. Resonance depolarization method is not excluded, but did not work near integer resonances and above 80-100 GeV. In contrast, the free precession method works everywhere!
10. Shall measure, suppress and account spin resonances in some energy interval near the energy of interest, because the spin resonances can modify the spin tune in their vicinity.

Acceleration scheme for FCC-ee: two options





Proposed polarizing ring parameters

Energy, E	1	GeV
Circumference, C	22	m
Average radius, R	3.5	m
Bending radius, ρ	0.6	m
Bending field, B	5.5	T
Energy loss / turn, U_0	145	keV
Momentum spread, σ_p	0.00155	
Number of e± per bunch, N	10^{10}	
Number of bunches, N_b	16	
Total beam current, I	350	mA
SR power	50	kW
Polarization time (Sokolov-Ternov), τ_{ST}	127	s
Polarization degree	70	%
Injection/Ejection time periodicity, T_0	10	s

Here we assume that every bunch spends in a ring $T_0 \cdot N_{b=}$=160 s before extraction.

So, the polarization degree is high enough, in the order of 70%!

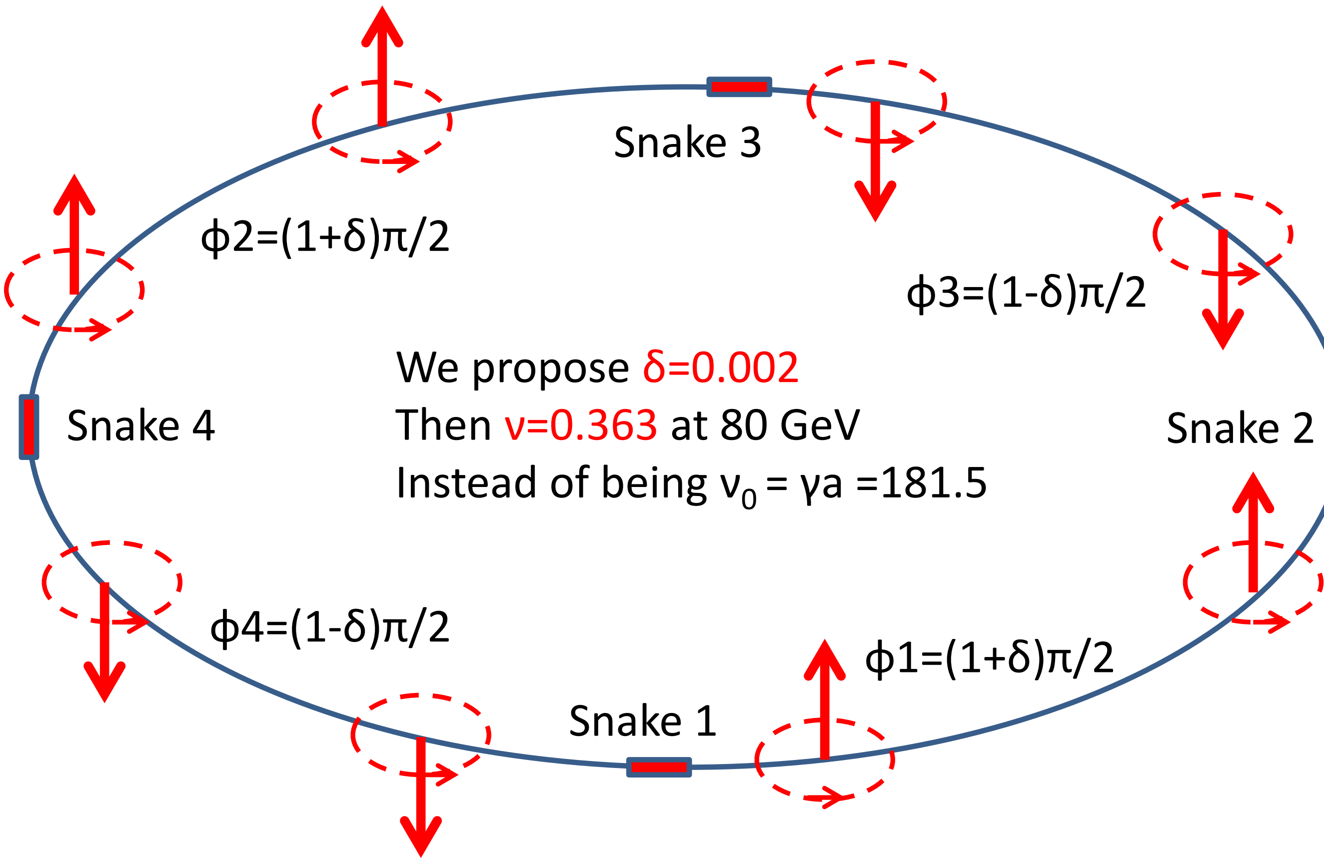
Every 10 s one bunch is assumed to be extracted for the energy calibration purposes only.

Use of high bending field is energetically beneficial to obtain certain polarization degree.

High energy booster synchrotron demands

- Fast acceleration from 15 GeV up to 175 GeV train of unpolarized e± bunches to keep the collider luminosity constant within ±5% or better.
- Preserve during acceleration the polarization of one or few polarized bunches, which are extracted from the polarizing damping ring and be added to the train of unpolarized bunches.
- The Resonant Depolarization technique can work only below 80-100 GeV (extrapolation from LEP studies). Therefore, the operational limit for Siberian Snakes in a booster could be set to 100 GeV, only.
- Energy measurement above 80-100 GeV shall be provided by the magnetic spectrometers, which will be studied and calibrated by RD below that threshold.

Closed spin orbit in a ring with 4 snakes

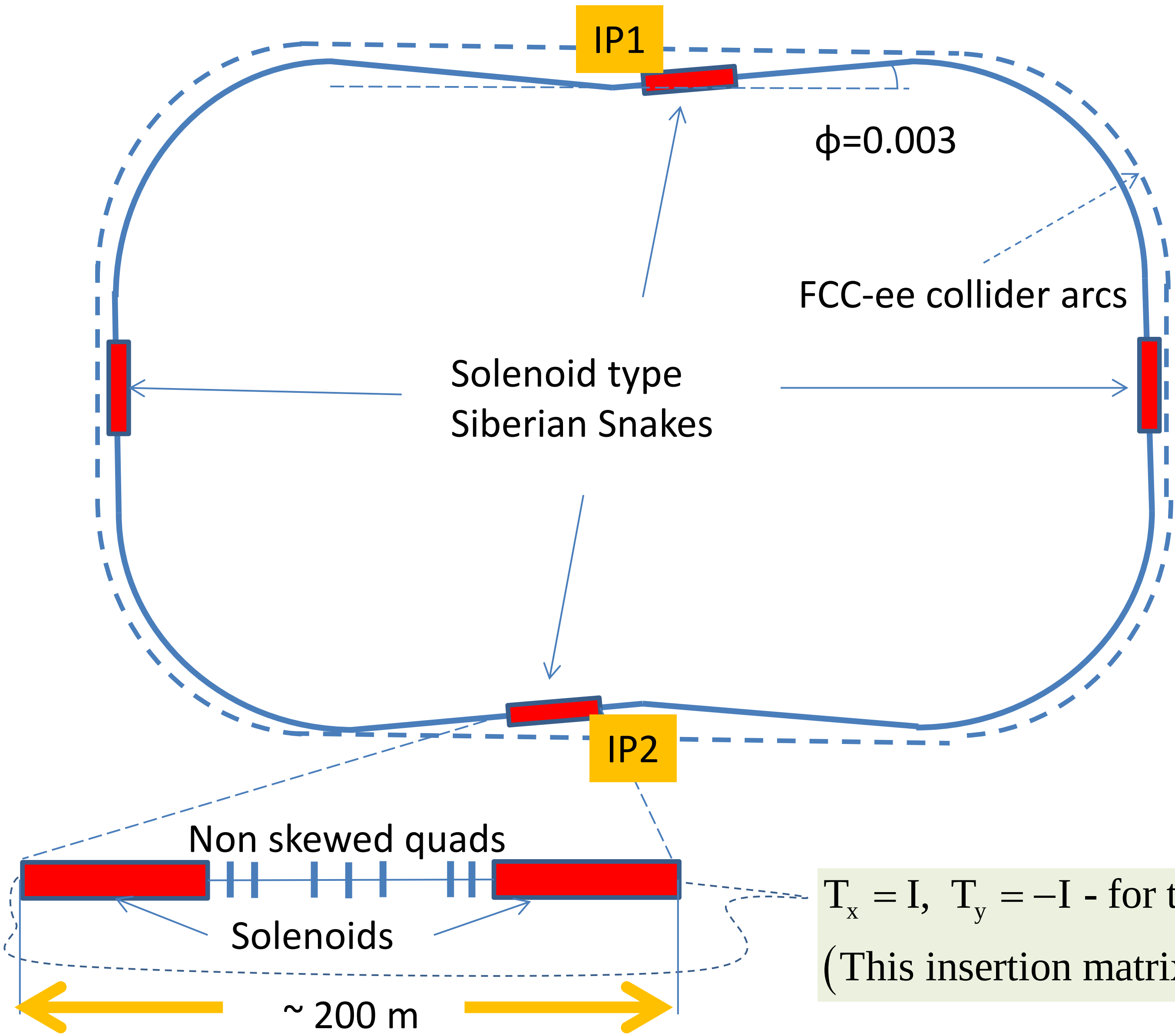


We propose $\delta=0.002$
Then $\nu=0.363$ at 80 GeV
Instead of being $\nu_0 = \gamma a = 181.5$

In 70-th such approach was considered by A.Kondratenko, for FCC discussed by S.R. Mane In arXiv:1406.0561v1 physics.acc-ph 3 Jun 2014.

The equilibrium spin direction is upright or down in arcs.
Snakes rotate spin by 180^0 around the longitudinal direction.
The spin precession frequency will be zero in case of equally spaced snakes.
To make the spin motion stable a small asymmetry of "positive" and "negative" arcs has to be foreseen: $\phi=(1\pm\delta)\pi/2$. Then the spin tune became reduced to $\nu=\delta\cdot\nu_0$. Here $\nu_0=\gamma a$ – unperturbed spin tune, with a=0.001159652187… - the anomalous magnetic moment.

Booster ring for FCC-ee top up injection



Four snakes spaced by the azimuthal angle $\pi/2 \pm \phi$ from each other reduce the spin precession tune by a factor $2\phi/\pi$

With ϕ=0.003
ν=0.36 at E=80 GeV
instead of be ν_0=181.5
without snakes

$T_x = I,\ T_y = -I$ - for the spin transparency!

(This insertion matrix includes solenoid edges!)

Depolarization in presence of snakes

Derbenev-Kondratenko formula:

$$\tau_p^{-1} = \frac{5\sqrt{3}}{8}\lambda_e r_e c\gamma^5 \left\langle \left|K^3\right| \left(1 - \frac{2}{9}(\vec{n}\vec{v})^2 + \frac{11}{18}\vec{d}^2\right) \right\rangle \approx \tau_{ST}^{-1} \frac{11}{18}\left\langle \vec{d}^2 \right\rangle$$

$K = \rho^{-1}, \quad |\vec{v}| = 1, \quad \vec{d} \equiv \gamma\left(\partial\vec{n}/\partial\gamma\right)$ - spin-orbit coupling vector

Spin transparency cancels the betatron contribution: $\vec{d} = \vec{d}_\gamma + \cancel{\vec{d}_\beta}$

For m pairs of snakes $\left\langle \vec{d}^2 \right\rangle = \nu_0^2 w^2 / m^2$, Here $\nu_0 = \gamma a$,

w - spin perturbation (due to orbit distortions, or other field errors)

Tracking simulations, ASPIRRIN code, analytic results, all give:

For E=80 GeV , m=2, w=0.1 we find $\left\langle \vec{d}^2 \right\rangle = 4000 \quad \rightarrow \quad \tau_d \approx 18$ s

That ensures small polarization loss if $t_{ramp} \leq 12$ s

Tolerances on the orbit distortions

Tolerances on the vertical orbit distortion y(s):

Spin rotation angle kick produced by a single quad: $\varphi_1 = \nu_0 \cdot \Delta y_1'$

Number of quads in a ring: N~2500

Statistically indepent N kicks will produce the total spin rotation:

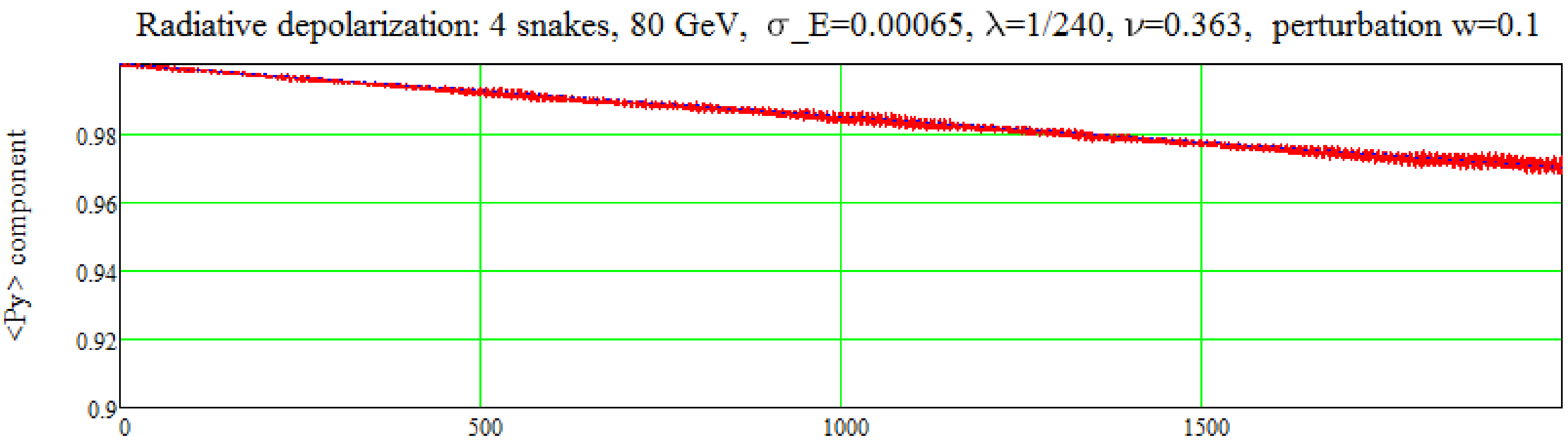
$\varphi_\Sigma = \nu_0 \cdot \Delta y_1' \cdot \sqrt{N}$ Now we want: $\varphi_\Sigma \le w \cdot 2\pi,$

Here w - single equivalent by strengh the spin perturbation tune

Spin tracking shows that w=0.1 is tolerable for booster at 80 GeV

Thus we get: $\Delta y_1' \le \dfrac{w \cdot 2\pi}{\nu_0 \cdot \sqrt{N}} = 6 \cdot 10^{-5} \quad \rightarrow \quad y_{rms} = \Delta y_1' \cdot \beta_y = 6\ \text{mm}$

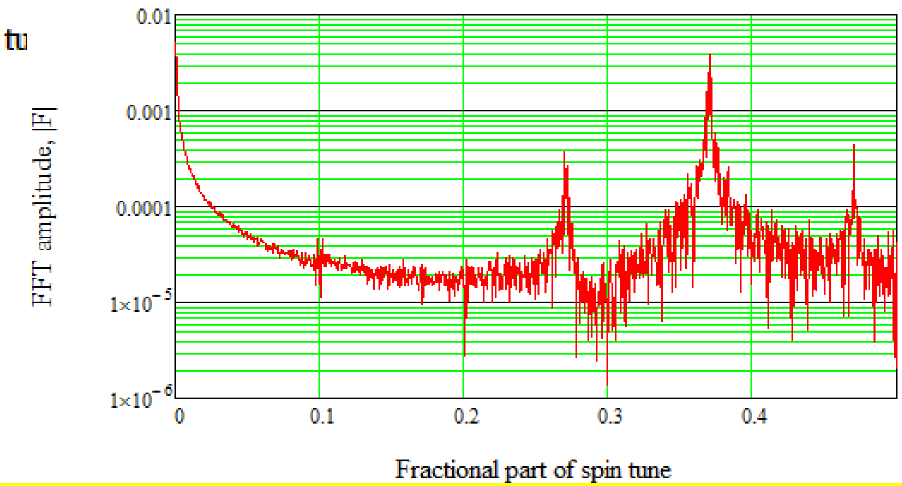
Spin tracking of the depolarization process in a booster



Spin tracking of 1000 particles, over 2000 turns in a ring with the spin perturbation w=0.1.

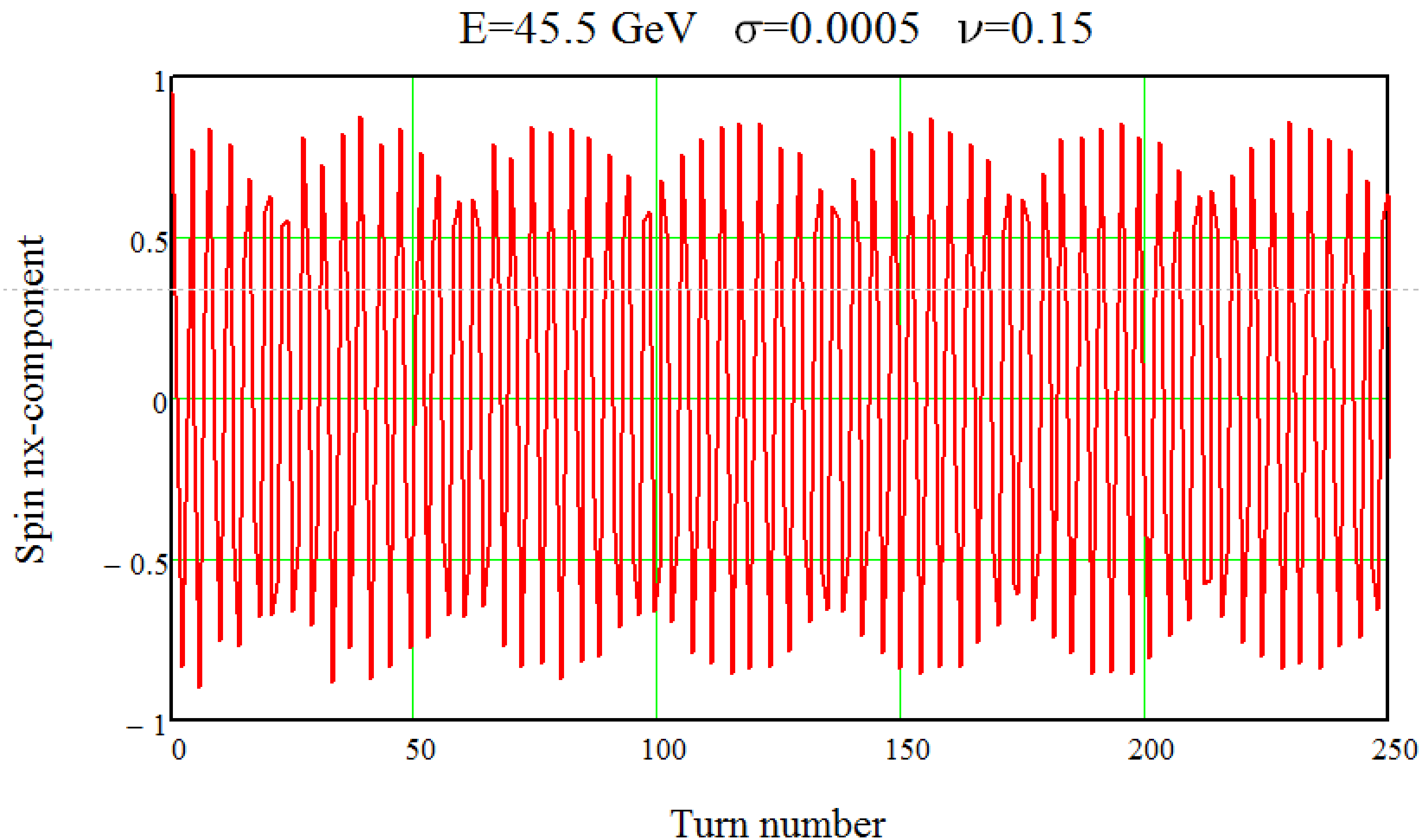
The observed depolarization time 18 s is large enough for acceleration of a beam from 15 GeV to 80 GeV in 10 s.

Due to perturbation (w=0.1) the spin precession frequency became shifted to 0.3702 from the ideal 0.3631 value.



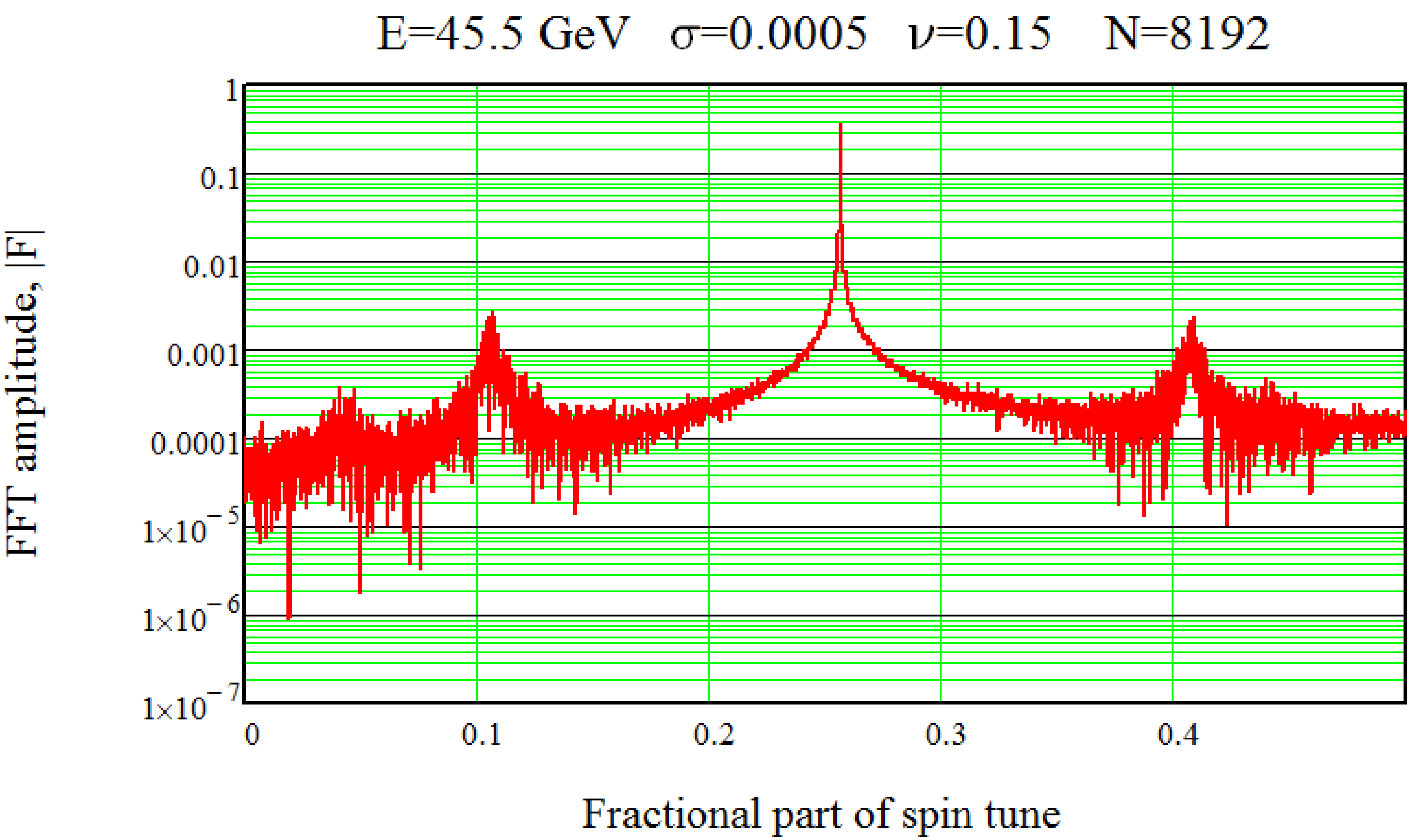
Spectrum of the transversal polarization component. Side bands are spaced by synchrotron tune v_s=0.1

Free precession spin tracking. 125 test-particles. E=45.5 GeV, σ_δ=0.0005, ν_s =0.15, τ_s =1320 turns



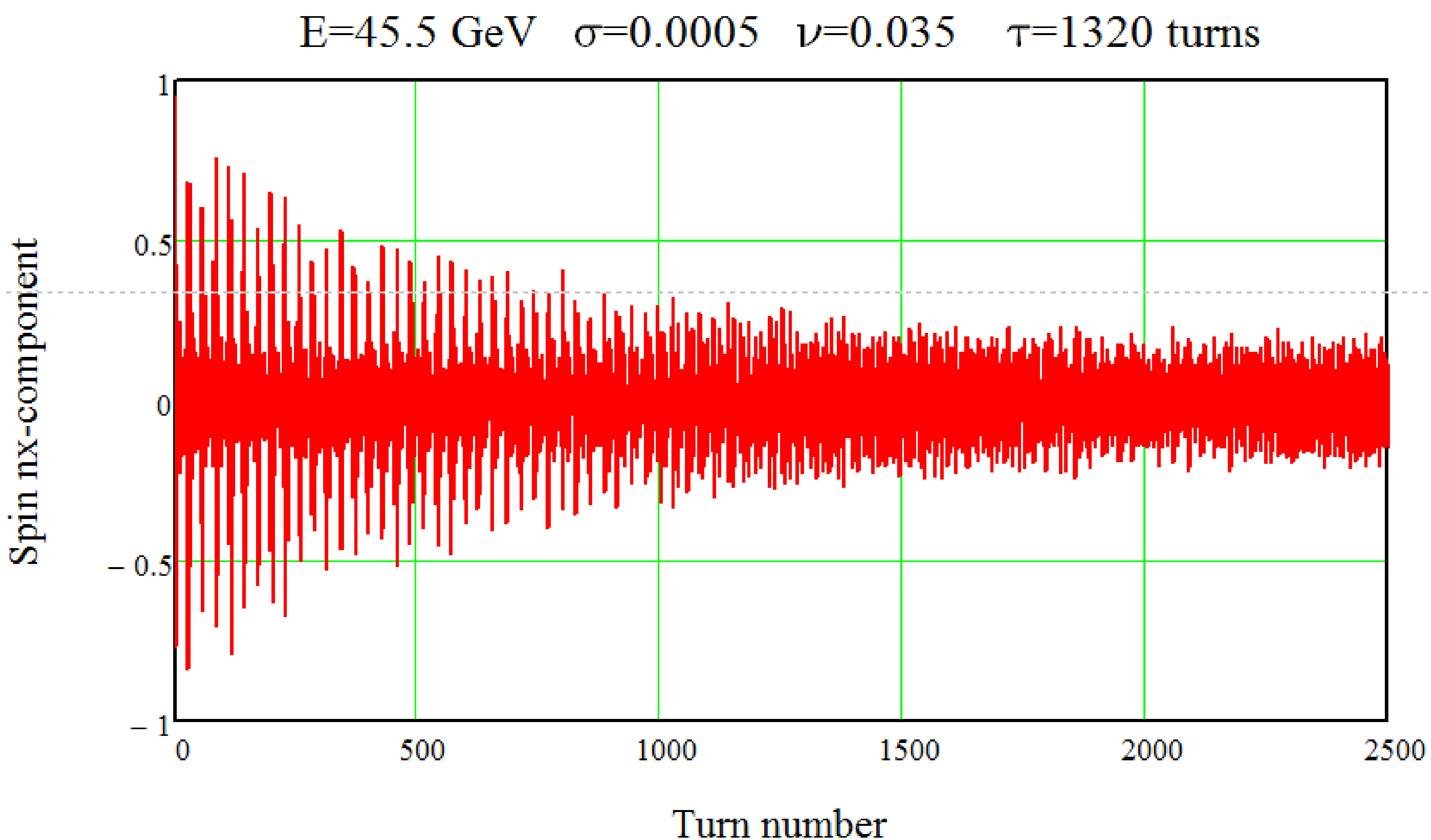
Loss of polarization degree due to de-phasing is small thanks to high enough ν_s.
Spin echo at synchrotron frequency are clearly visible!

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

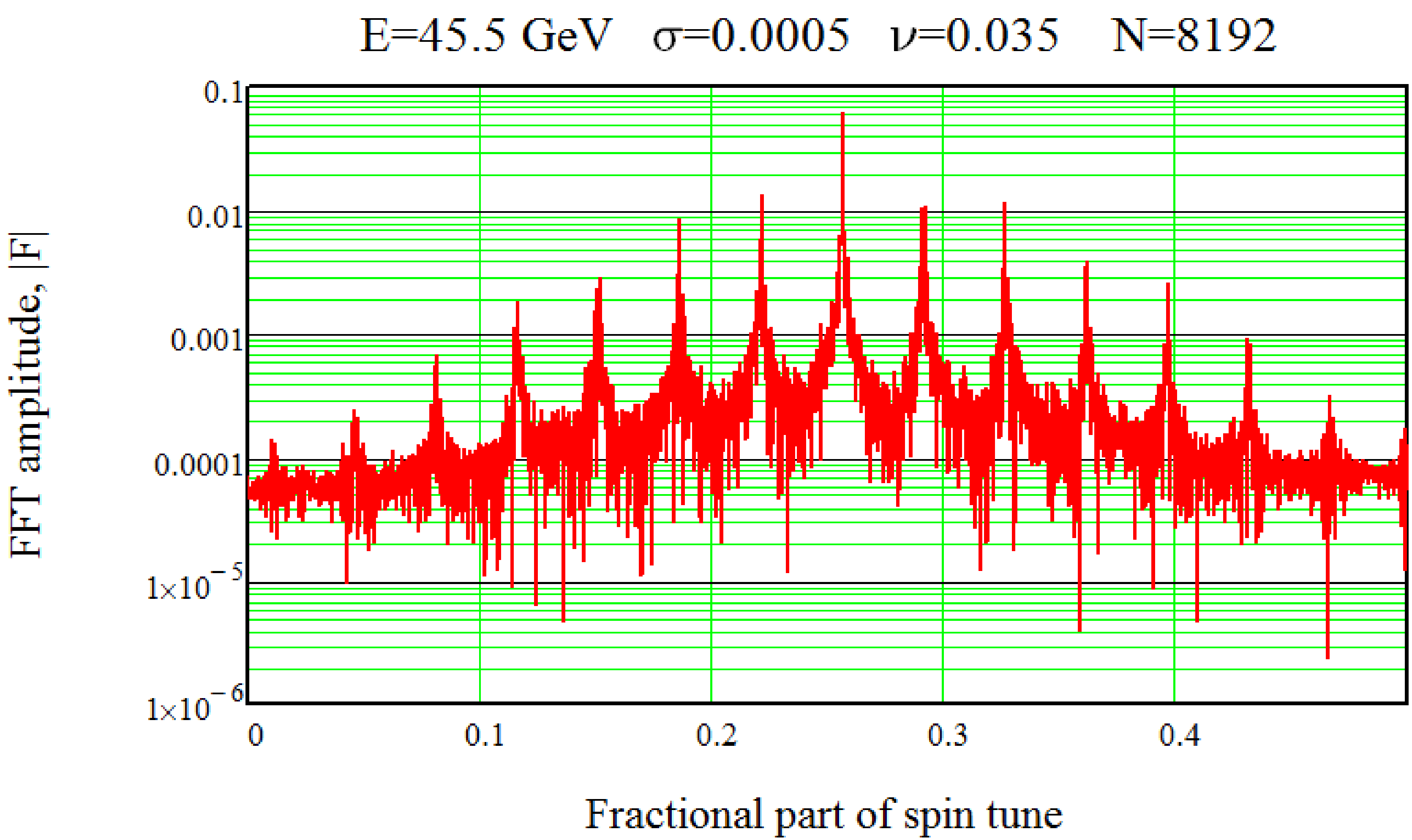


$\chi = \sigma_\delta \nu_0 / \nu_s = 0.35$ – synchrotron modulation index.

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

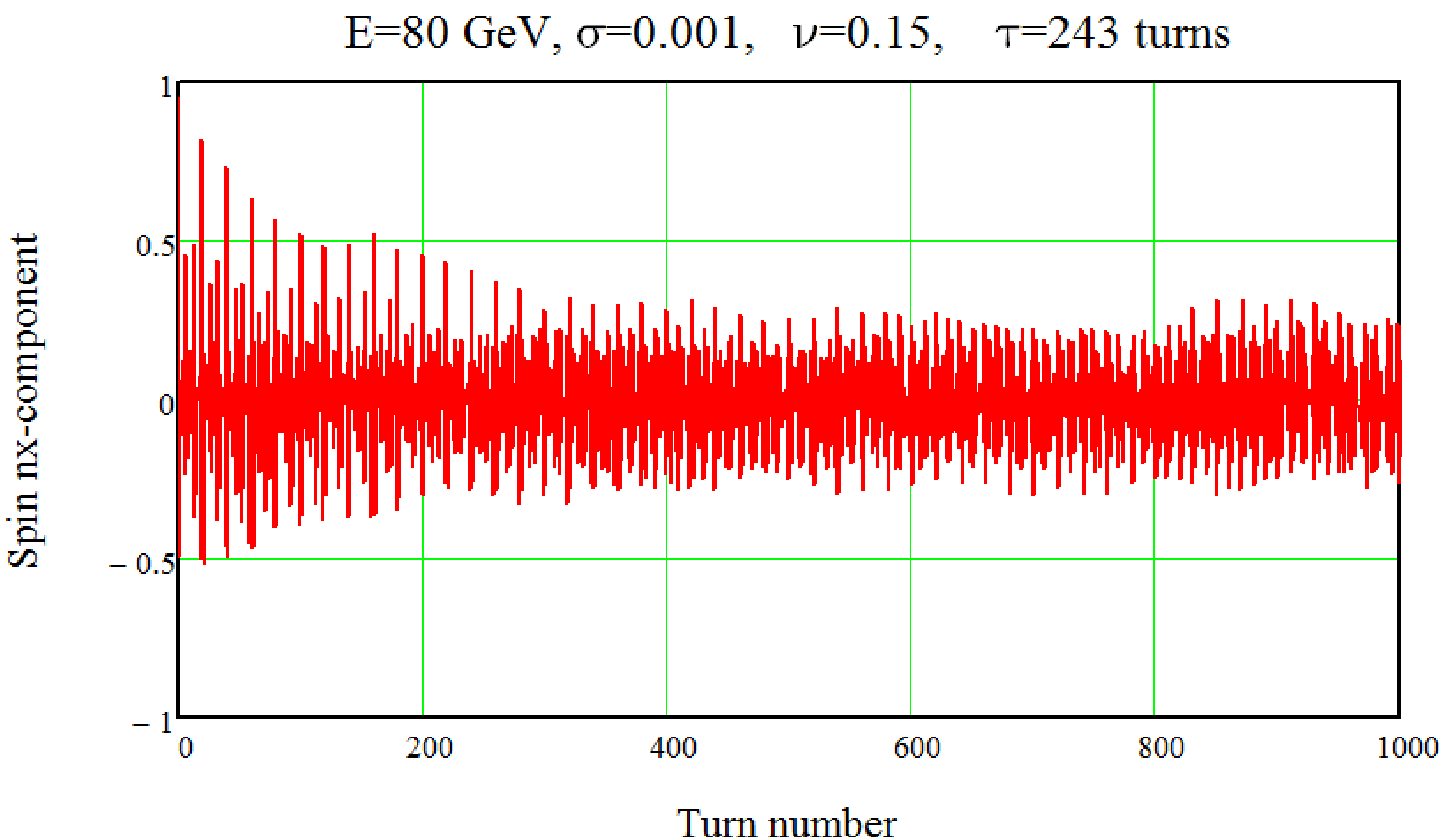


Spin precession spectrum. Number of turns 8192.
E=45.5 GeV, ν_0=103.25, σ_δ=0.0005, ν_s =0.035, χ=1.48

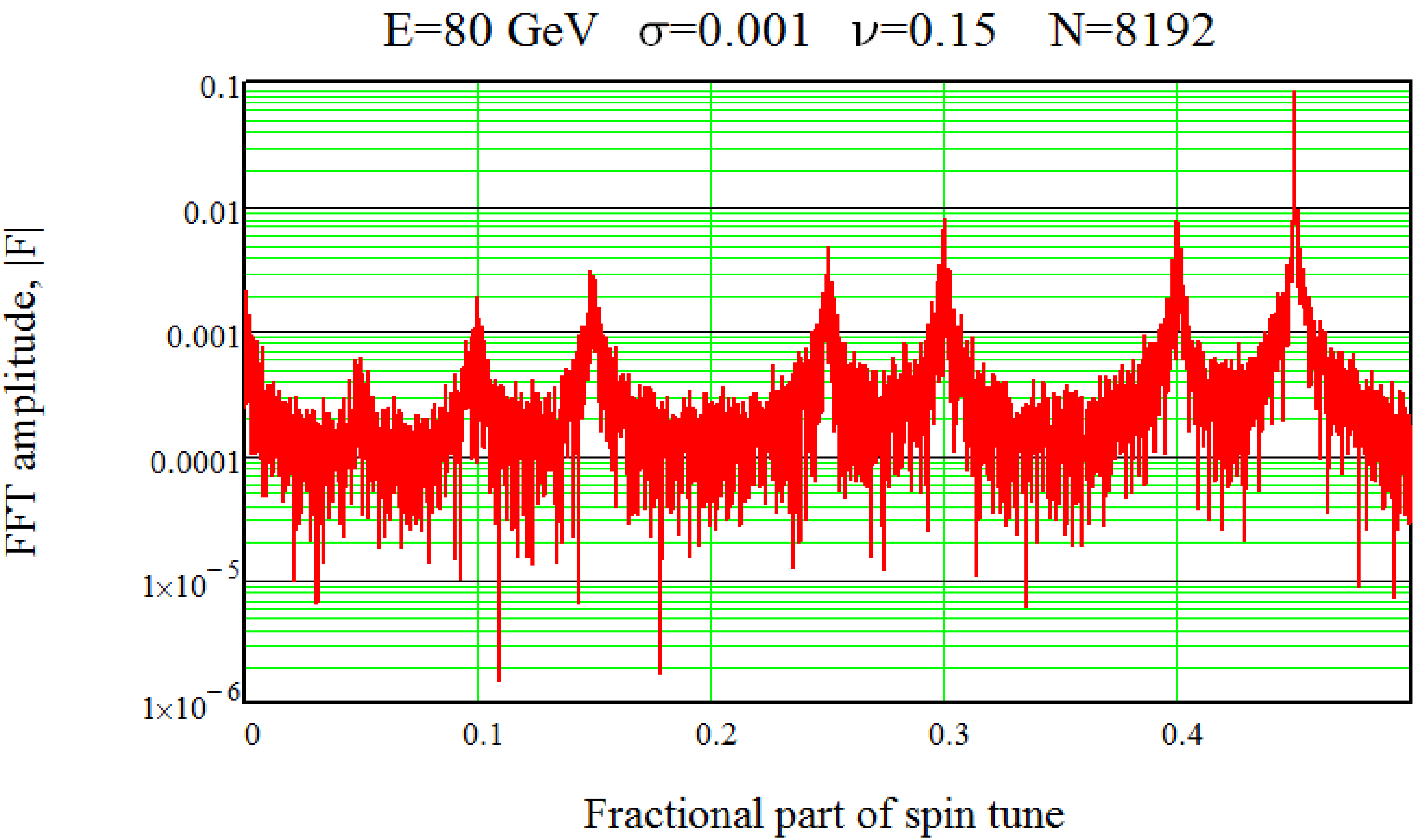


We want: χ < 1.7. With χ > 1.7 peaks disappear!

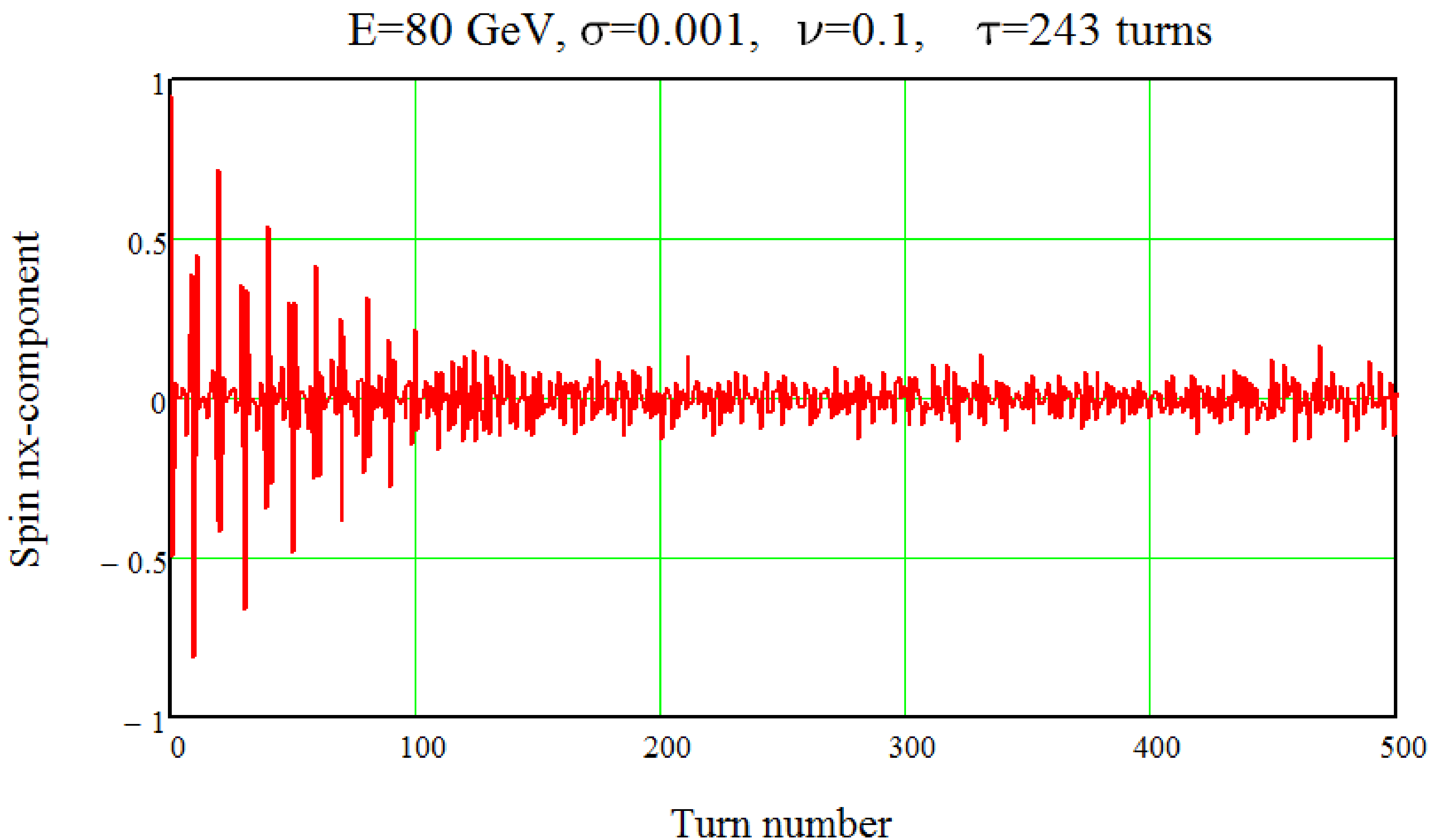
Spin tracking oscillogram. 125 test-particles.
E=80 GeV, σ_δ=0.001, ν_s =0.15, τ_s =243 turns



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

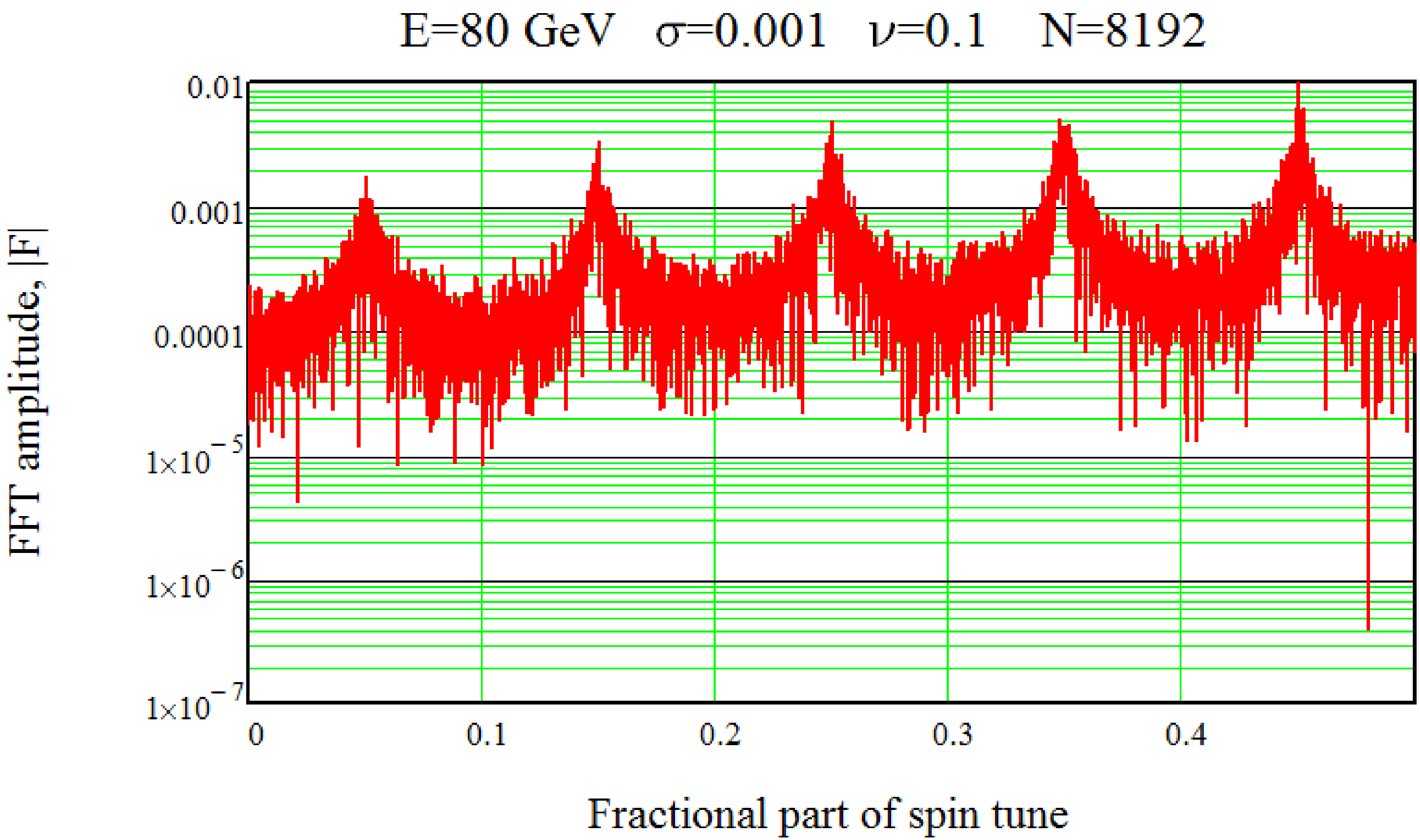


Spin tracking oscillogram. 125 test-particles.
E=80 GeV, σ_δ=0.001, ν_s =0.10, τ_s =243 turns



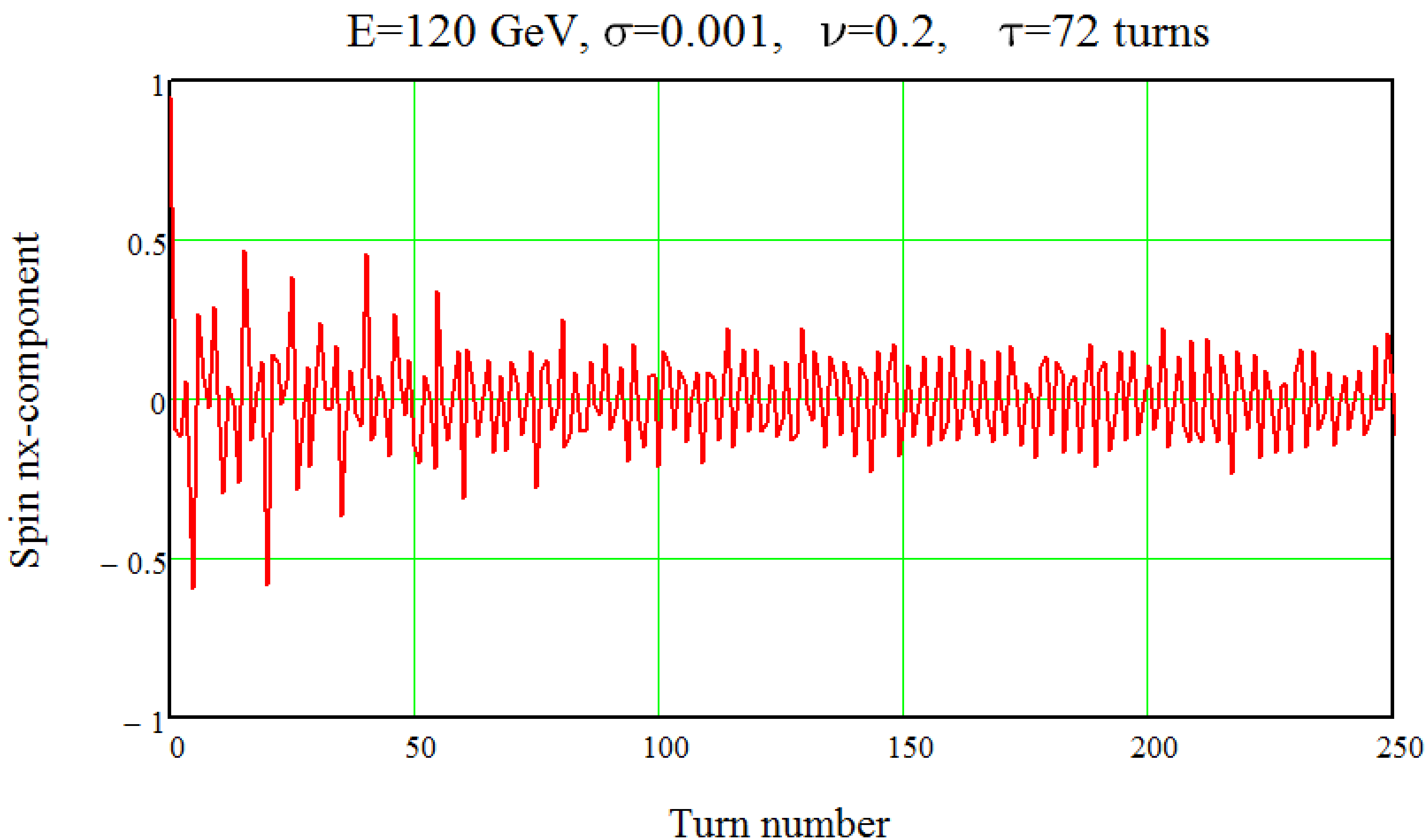
Fast de-phasing due to slow synchrotron motion!

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.

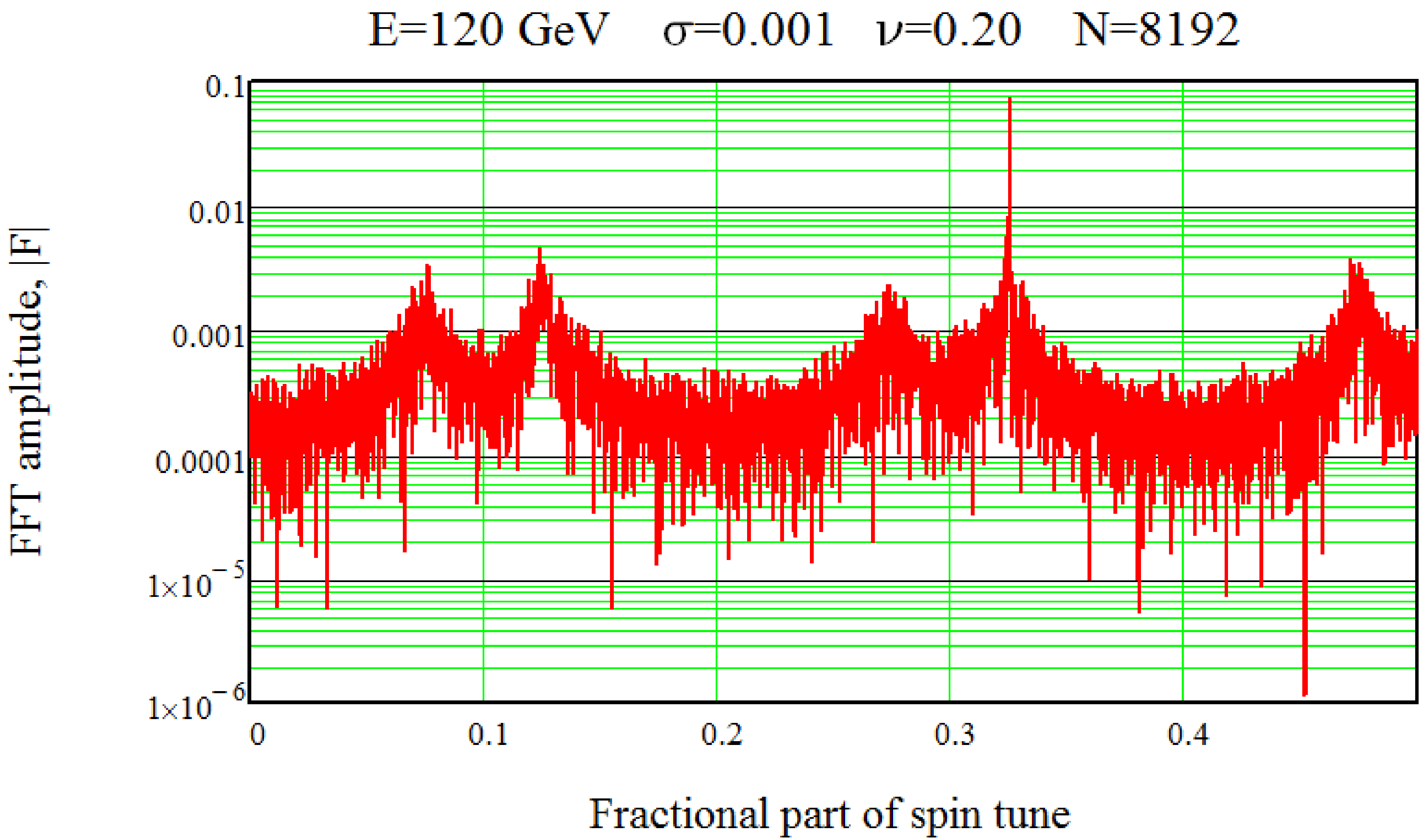
Spin tracking oscillogram. 125 test-particles. E=120 GeV, σ_δ=0.001, ν_s =0.20, τ_s =72 turns



Fast dephasing! Synchrotron modulation index is too high: χ=1.36.

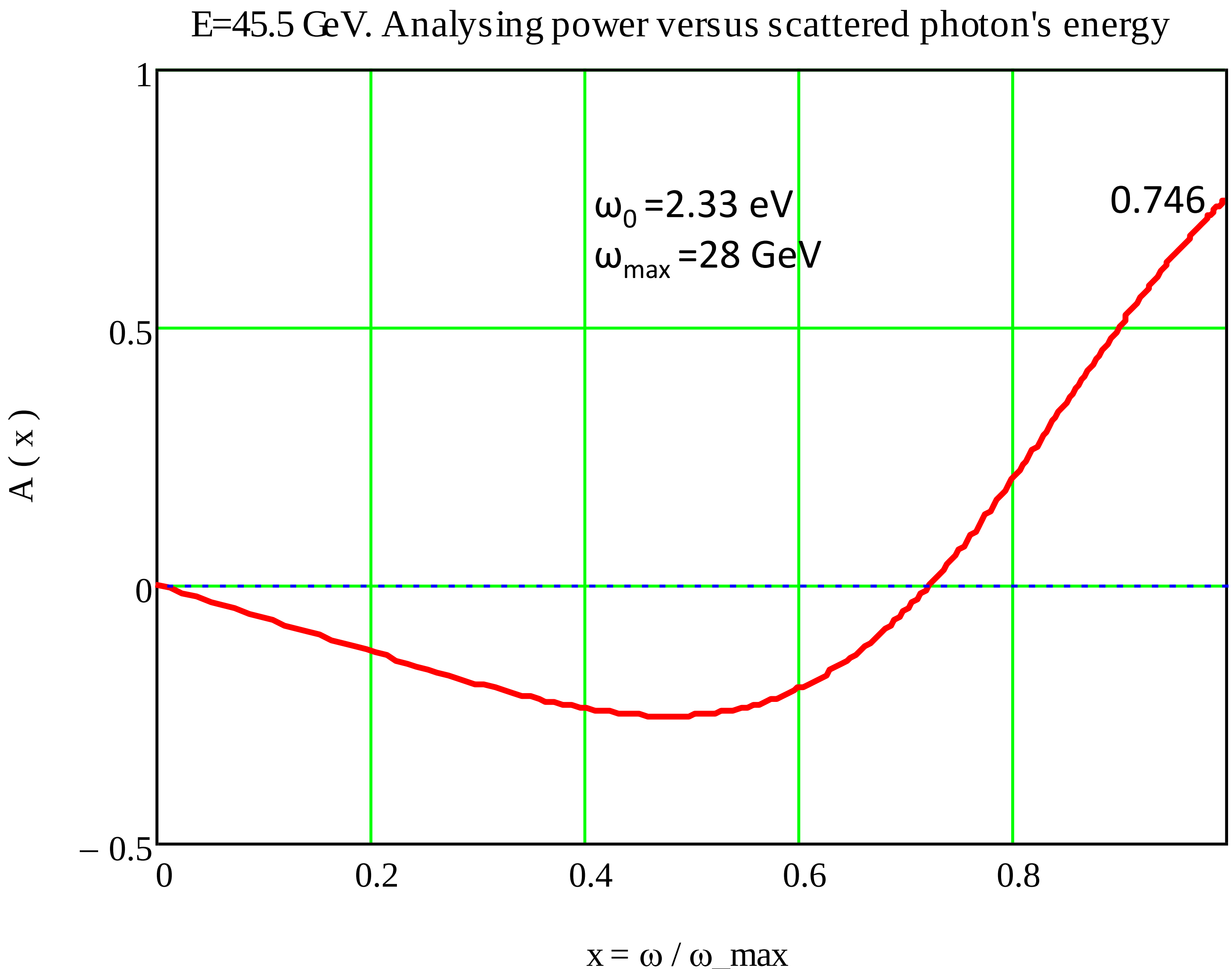
Spin precession spectrum. Number of turns 8192.

E=120 GeV, ν_0=272.325, σ_δ=0.001, ν_s =0.20, χ=1.36



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

Longitudinal polarimeter based on Compton scattering of a laser light



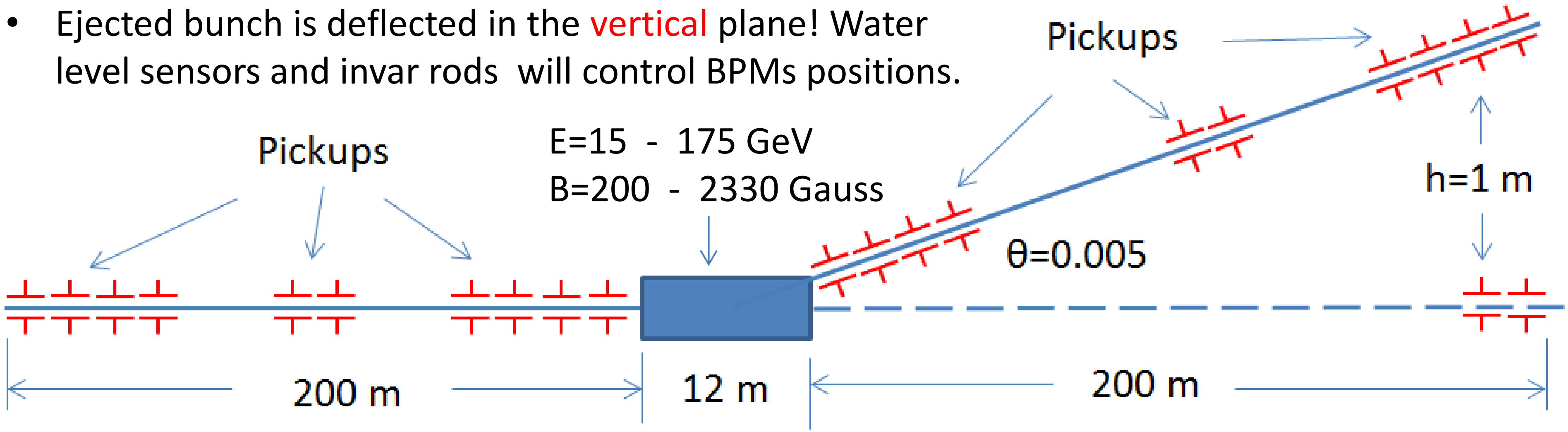
Detection of the scattered electrons instead of photons provides selection of events with maximal momentum loss!

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

ω_0 =2.33 eV

Magnetic spectrometer layout & features

- Ejected bunch is deflected in the vertical plane! Water level sensors and invar rods will control BPMs positions.



- Spectrometer measures the energy of the extracted bunches. Advantage: much larger bending field can be applied to deflect a beam compared to the regular arc magnets.

- To get the required energy resolution in the order of 10^{-6}, the sensitivity of pickups should be in the order of 1 micron, if a beam is deflected by h=1 m (in the end of a channel).

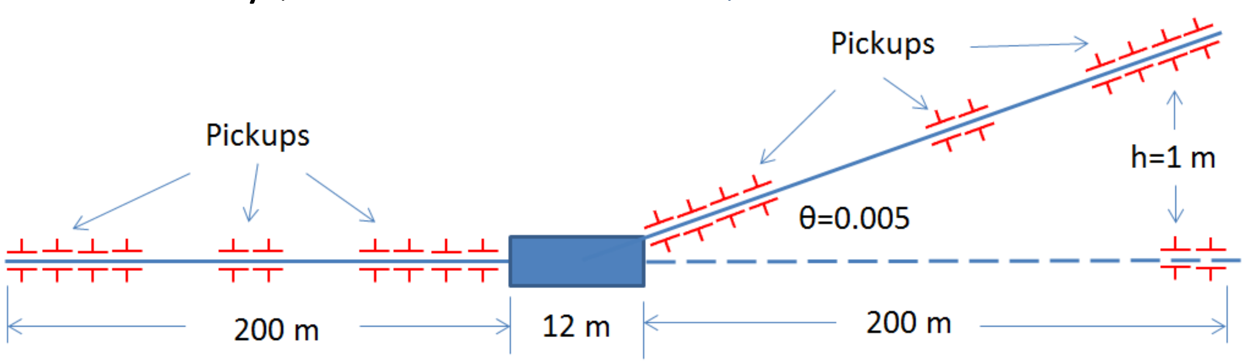
- The integral of the bending field should be controlled at the same level: 10^{-6}. Stray fields and the Earths field should be screened at same level along the entire channel .

- Absolute coordinates of all pickups should be measured and tracked in time with 1 micron accuracy in the transverse direction and about 200 microns along the beam path.

How to reach the required accuracies and sensitivities?

The energy resolution of the spectrometer is : $E \sim Bl/h,\ \dfrac{\Delta E}{E} = \dfrac{\Delta(Bl)}{Bl} - \dfrac{\Delta h}{h} \approx 10^{-6}$

- To get the required Δh=1 mkm sensitivity, the pickups with the aperture about 1 cm shall have the electronics with 10^{-4} relative resolution.
- All pickups are grouped in families 5-10 m long, 3-5 units each, to monitor their relative displacements. This will provide the cross-check between the family members (how stable are BPM's electric centers) and also will increase statistics of trajectory measurement.
- Beam deflection shall be made in the vertical direction. Advantage: one can use the well established technique of hydrostatic sensors, which have demonstrated the submicron sensitivity (FERMILAB-PUB-11-452-AD-APC-E).



- NMR probes shall monitor the magnetic field in many points along the magnet.
- Permalloy tubes, equipped by the demagnetization coils, shall protect the whole beam path from the Earths field.

- The longitudinal dimensions can be monitored by the invar tape.
- The dipole shall be made from the solid iron (more stable in dimensions).
- Coils will paste-in into iron, forming a solid block.
- The dipole edges should have neutral pole to be more stable in length.

Discussion of magnetic spectrometer problems

The proposed above technical solution for the magnetic spectrometer, which bends the extracted bunch in the vertical plane, has many principal advantages. These are:

- We are not so limited in the length of dipoles and their field values, as it will be for the case of in-ring solution.
- Fields in all energy range are high enough to be suitable for NMR technique.
- This special beam line is not subjected to SR. Therefore its temperature stability will be much higher, again compared to in-ring approach.

Disadvantage is only one: pickups shall measure single bunch wake, like in ILC.

- Few spectrometers shall be installed around a ring to control the saw-tooth model.
- The absolute calibration of these local spectrometers and study of different correlations of their output results with the changes of many environmental parameters (like temperatures and so on) should be done with the help of RD at some sufficiently small energy: E=20-30 GeV, where SR losses can easily be accounted with the required accuracy.

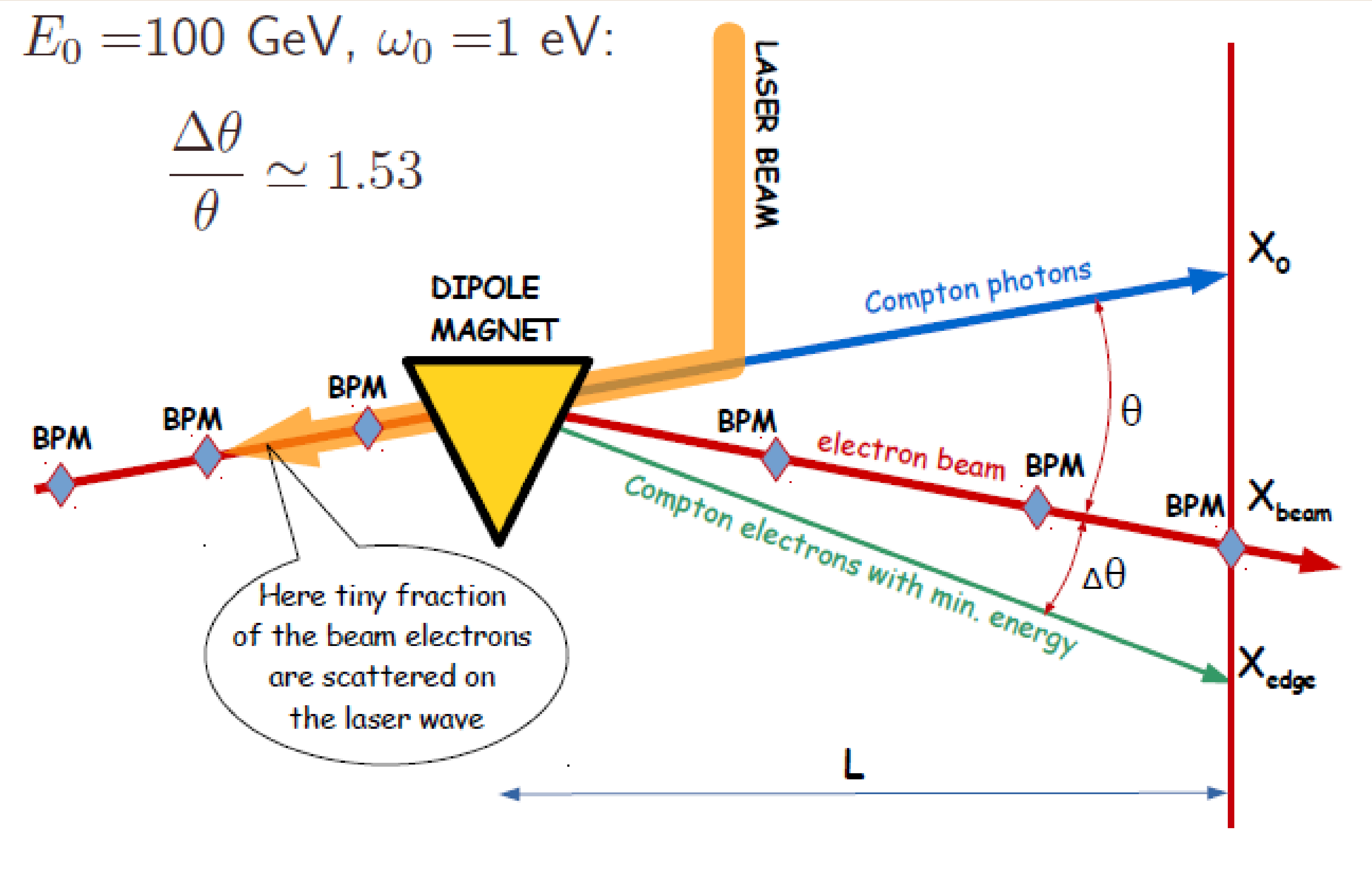
Conclusion

- No show stoppers are found to produce and explore polarization for beam energy measurements in both rings of FCCee collider.

- A simple and very useful spin tracking code was developed for the quantitative and qualitative evaluation of the depolarization rates and spin resonances studies.

- Still a lot of work to validate the discussed above approaches shall be done in the near future.

Spectrometer with laser calibration (suggestion)



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

Rough accuracy estimation

- Assume 10 μm accuracy for $[X_{beam} - X_0]$ and $[X_{edge} - X_{beam}]$.
- For $\Delta E/E \simeq 10^{-5}$: $[X_{beam} - X_0] \simeq [X_{edge} - X_{beam}] \simeq 1$ m.
- For example, this is $\theta \simeq 10$ mrad and $L \simeq 100$ m.

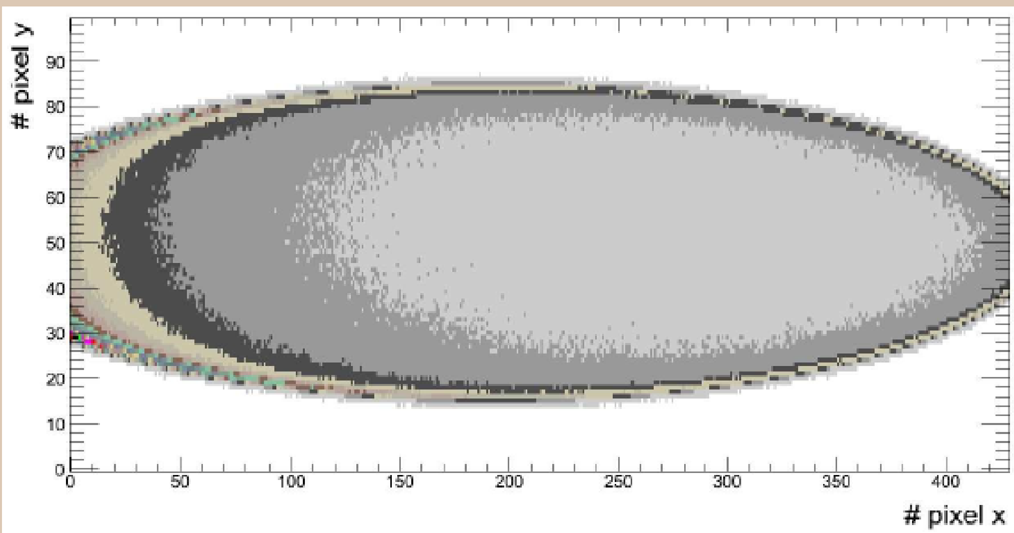
Compton backscattering polarimeter (N. Muchnoi)

ILC note: LC-M-2012-001

A Transverse Polarimeter for a Linear Collider of 250 GeV e Beam Energy

Itai Ben Mordechai and Gideon Alexander

"... For the detection of the scattered electrons we consider only a position measurement using a Silicon pixel detector placed at a distance of 37.95 m from the Compton IP. The active dimension of the detector is 2×200 mm^2. The size of the pixels cell taken is 50×400 μm^2 similar to the one used in the ATLAS detector [9]. This scheme yields an approximate two dimensional resolution of 14.4×115.5 μm^2 [10] with a data read-out rate of ..."



Nickolai Muchnoi | BINP experimental seminar | March 20, 2015 | 8 / 29

Measuring (fitting) the shape of that elliptical 2d-plot , we can determine position of the center of the ellipse and thus the maximal scattered angle Δθ.

Without invoking of the pickups data !

Still, the bend angle θ one gets from the pickups data only.

Both, the transverse and the longitudinal polarizations can be extracted from such 2d-pattern. Up/down or left/right asymmetries are spin dependent!