

Study of the depolarization process, possible biases

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With many thanks to A. Blondel, D.P. Barber, A. Bondar, A. Martens,
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FCC week 2022, 02.06.2022

Content

Required accuracies from physics (CDR and A. Blondel talk at EPOL)

Baseline RD scheme at Z and W beam energies

Compton polarimeter parameters and possibilities

Coherent spin precession method – complimentary to RD

Discussion on free spin precession method and conclusion

Requirements from physics (A. Blondel talk yesterday)

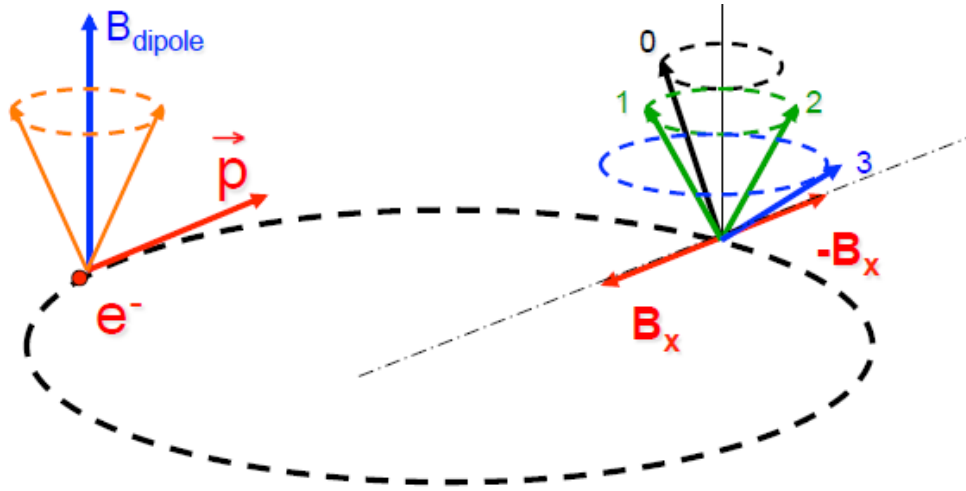
1. Center-of-mass energy determination with precision of ± 4 keV around the Z peak
2. Center-of-mass energy determination with precision of ± 250 keV at W pair threshold
3. For the Z peak-cross-section and width, require energy spread uncertainty $\Delta\sigma_E/\sigma_E = 0.2\%$

$$\nu_s = \frac{g-2}{2} \frac{E_b}{m_e} = \frac{E_b}{0.4406486(1)} \approx N + (0.5 \pm 0.1)$$

$$E_{\text{CM}} = (N + (0.5 \pm 0.1)) \times 0.8812972 \text{ GeV}$$

Required spin tune precision: $\Delta\nu = \pm 0.00001$ at Z and $\Delta\nu = \pm 0.0005$ at W

RESONANT DEPOLARIZATION



Once the beams are polarized, an RF kicker at the spin precession frequency will provoke a spin flip and complete depolarization

Simulation of FCC-ee by I. Kopp:

spin precession (ν is the *spin tune*)

$$\delta\theta_{\text{spin}} = (g-2)/2 \cdot E/m \delta\theta_{\text{trajectory}}$$

$$= \nu \cdot \delta\theta_{\text{trajectory}}$$

$$\nu = E_{\text{beam}} / 0.4406486$$

$$= 103.5 \text{ at the Z peak}$$

$C = 97.75 \text{ km}, 45.59 \text{ GeV}, Q_s = 0.025, \sigma_\delta = 0.00038, w = 10^{-4}, \epsilon' = 0.5 \times 10^{-8}$

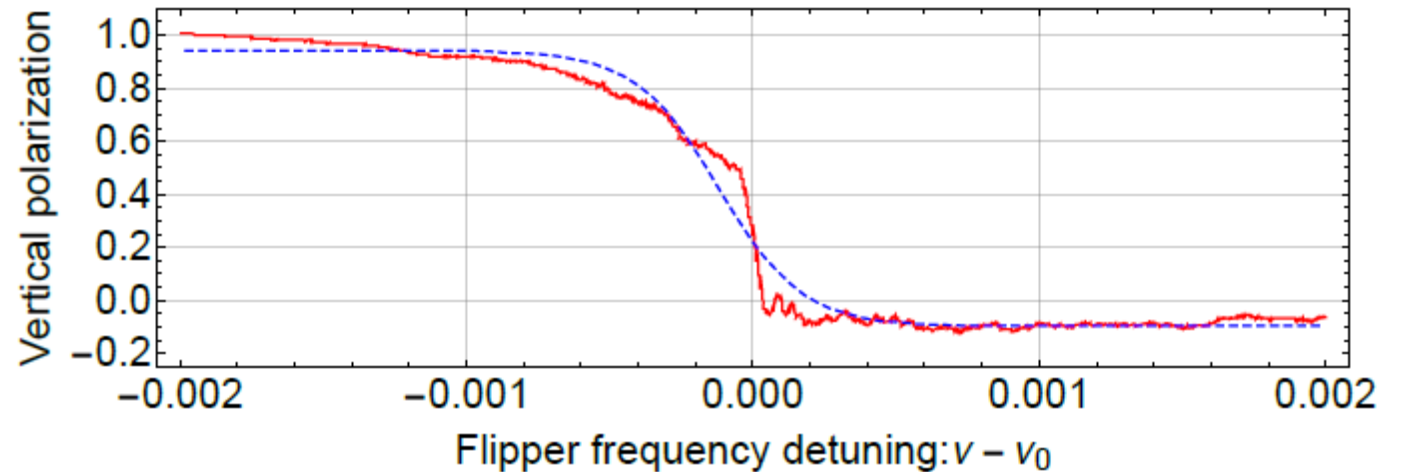
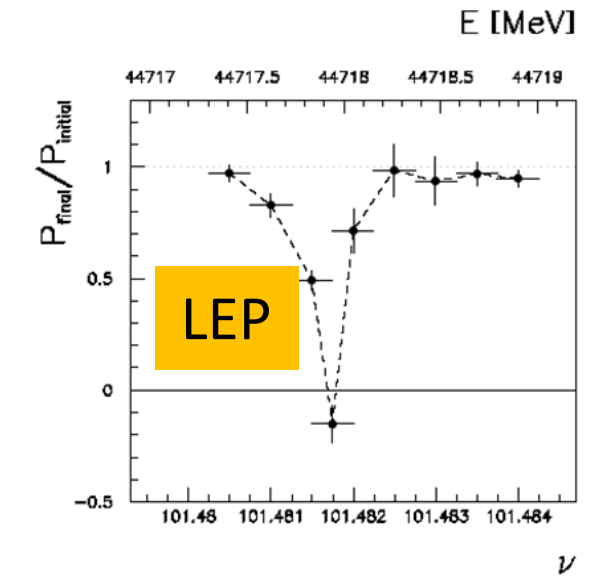
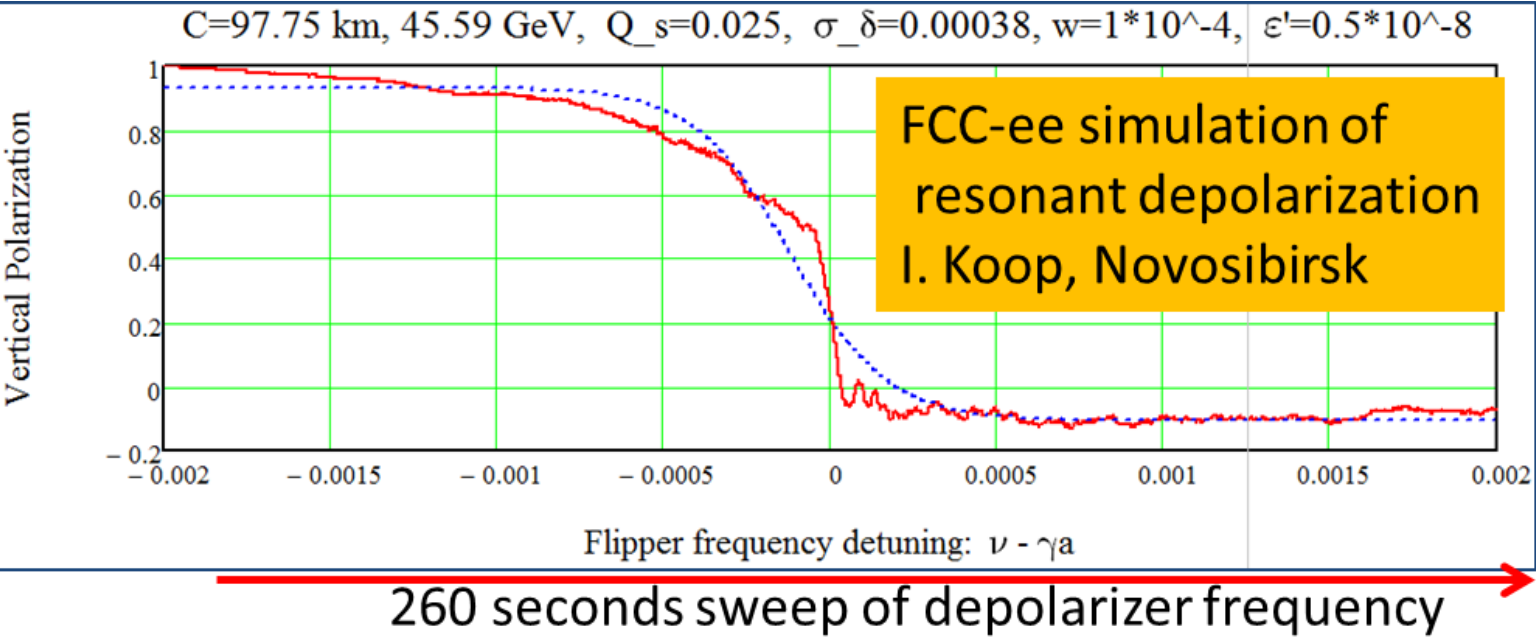
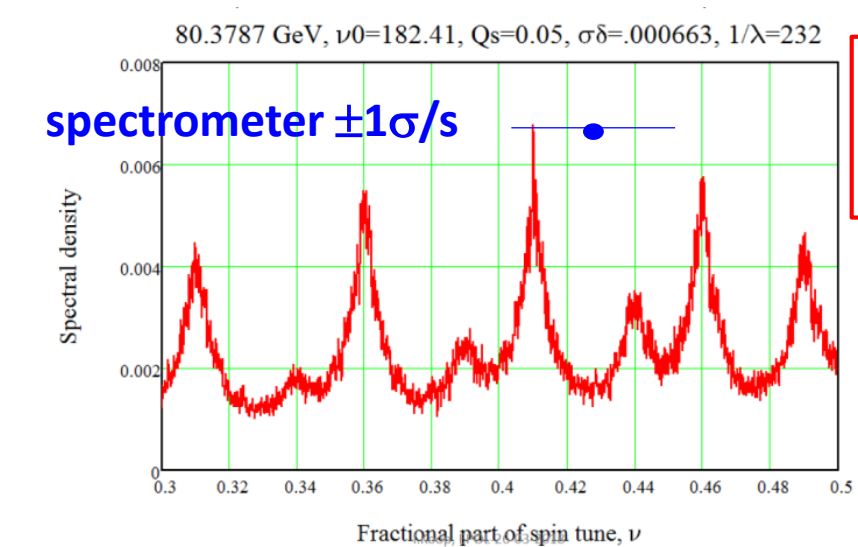


Figure 39. Simulation of a frequency sweep with the depolarizer on the Z pole showing a very sharp depolarization at the exact spin tune value.



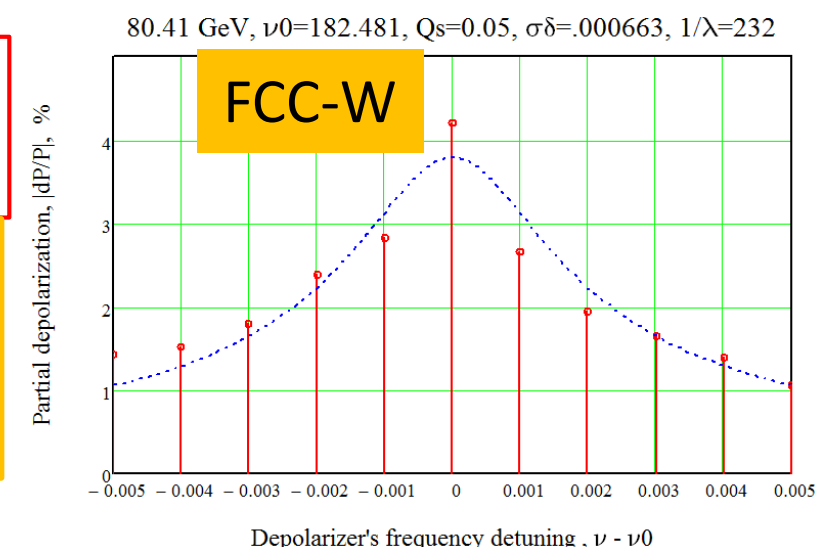
long sweep works well at the Z. Several depolarizations needed: eliminate Q_s side band and 0.5 ambiguity
 Less well at the W: the Q_s side bands are much more excited because of energy spread, need iterations with smaller and smaller sweeps – work in progress. see *I. Koop* presentations at FCC weeks.



← Fourier analysis shows the side band situation at W.

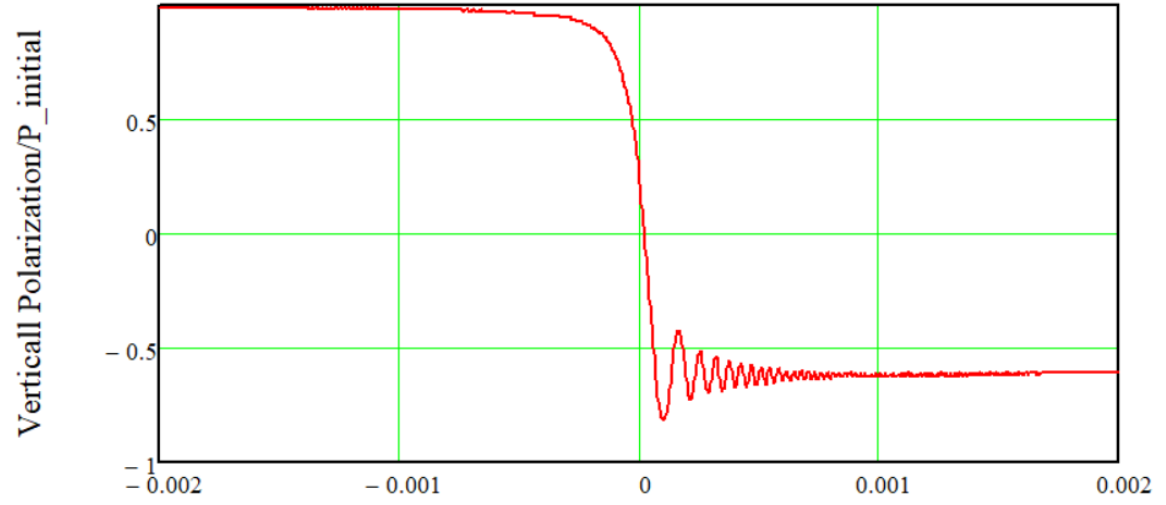
First attempt at 'LEP' multiple sweep technique →

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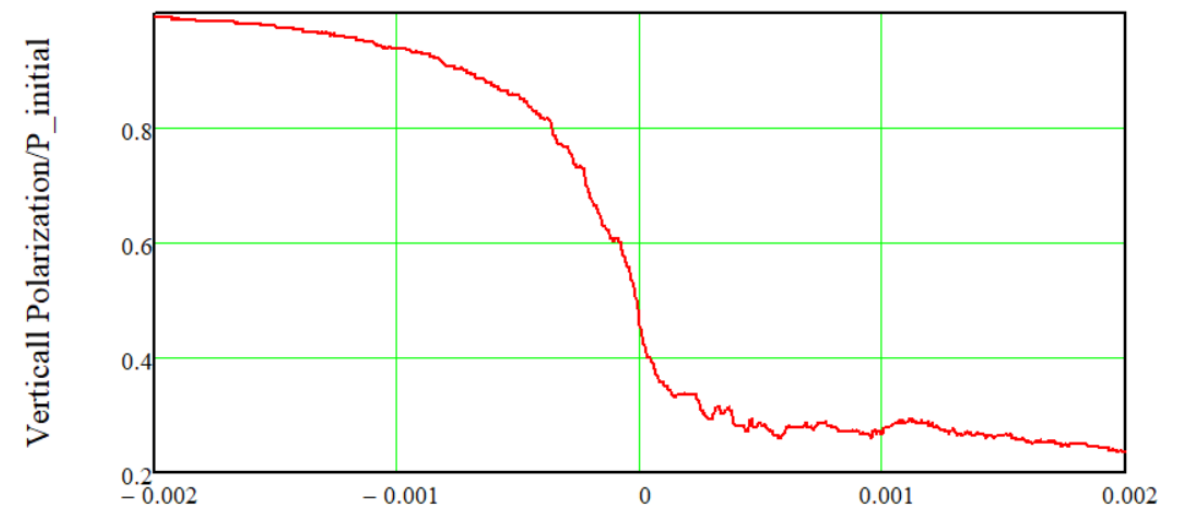
RD frequency sweeps with increased $\nu_s=0.075$

45GeV, $\nu_s=0.075$, $\sigma\delta=0.00038$, $w=1.5 \cdot 10^{-4}$, $\epsilon'=2 \cdot 10^{-8}$



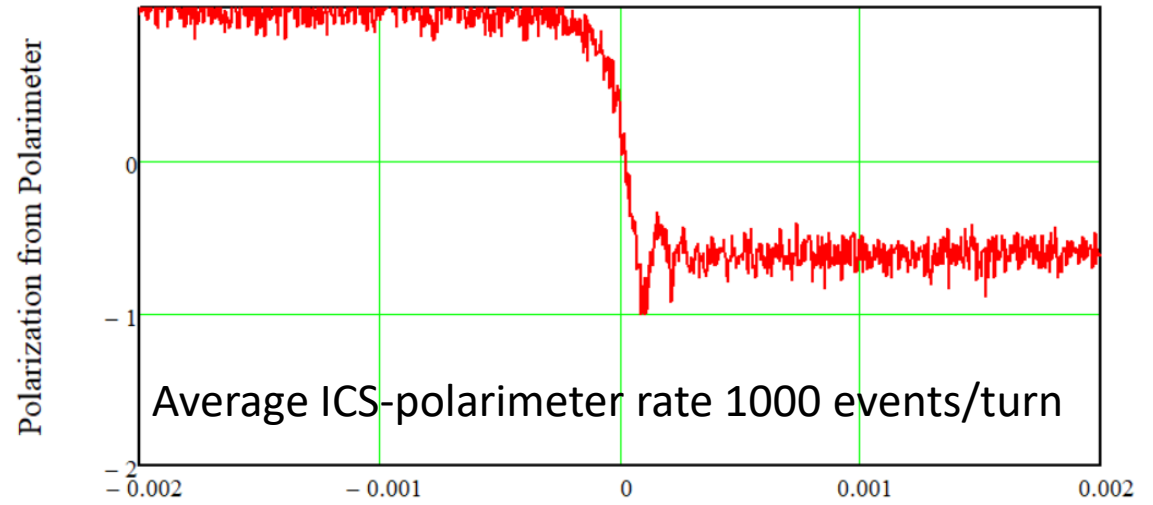
Depolarizer Detuning

80 GeV, $\nu_s=0.075$, $\sigma\delta=0.00067$, $w=1.5 \cdot 10^{-4}$, $\epsilon'=2 \cdot 10^{-8}$



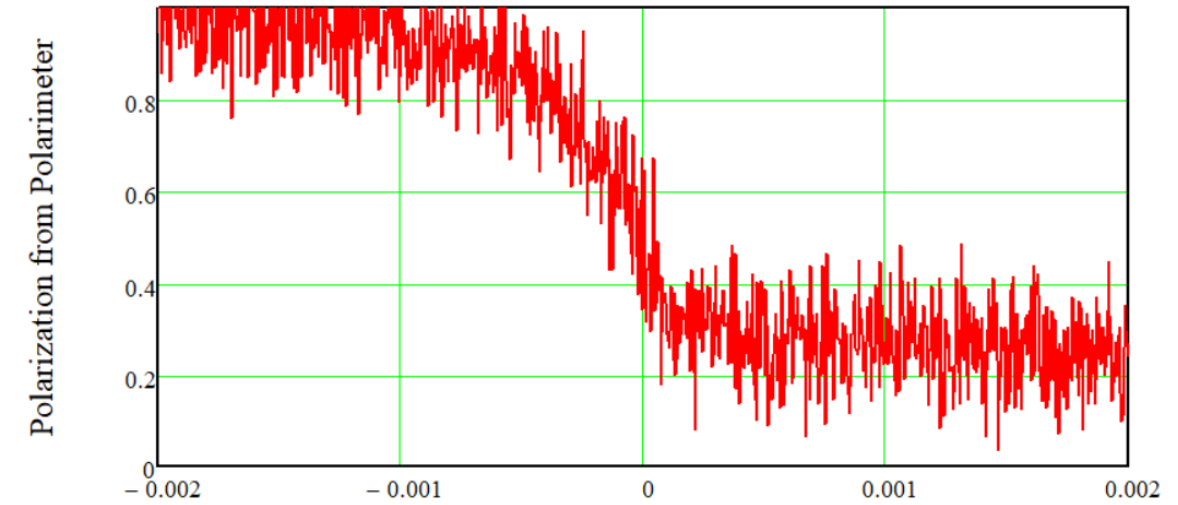
Depolarizer Detuning

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Depolarizer Detuning

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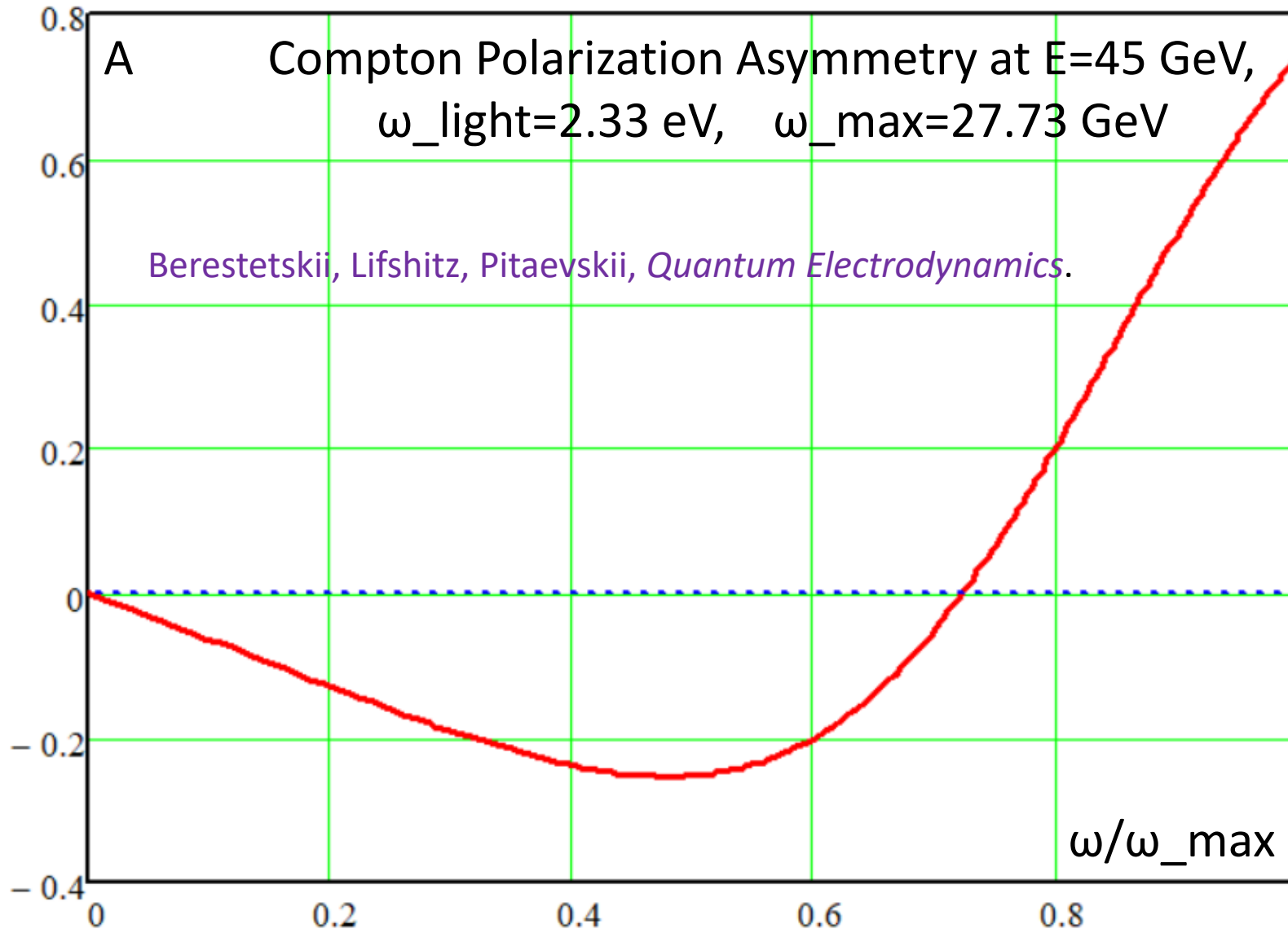
Depolarizer Detuning

Compton Polarimeter: Rates

- Laser wavelength $\lambda = 532$ nm.
- Waist size $\sigma_0 = 0.250$ mm. Rayleigh length $z_R = 148$ cm.
- Far field divergence $\theta = 0.169$ mrad
- Interaction angle $\alpha = 1.000$ mrad
- Compton cross section correction 0.5
- Pulse energy: $E_L = 1$ [mJ]; $\tau_L = 5$ [ns] (sigma)
- Pulse power: $P_L = 80$ [kW]
- Ratio of angles $R_a = 5.905249$
- Ratio of lengths $R_l = 0.984208$
- $P_L/P_c = 1.1 \cdot 10^{-6}$
- “efficiency” = 0.13
- Scattering probability $W \simeq 7 \cdot 10^{-8}$

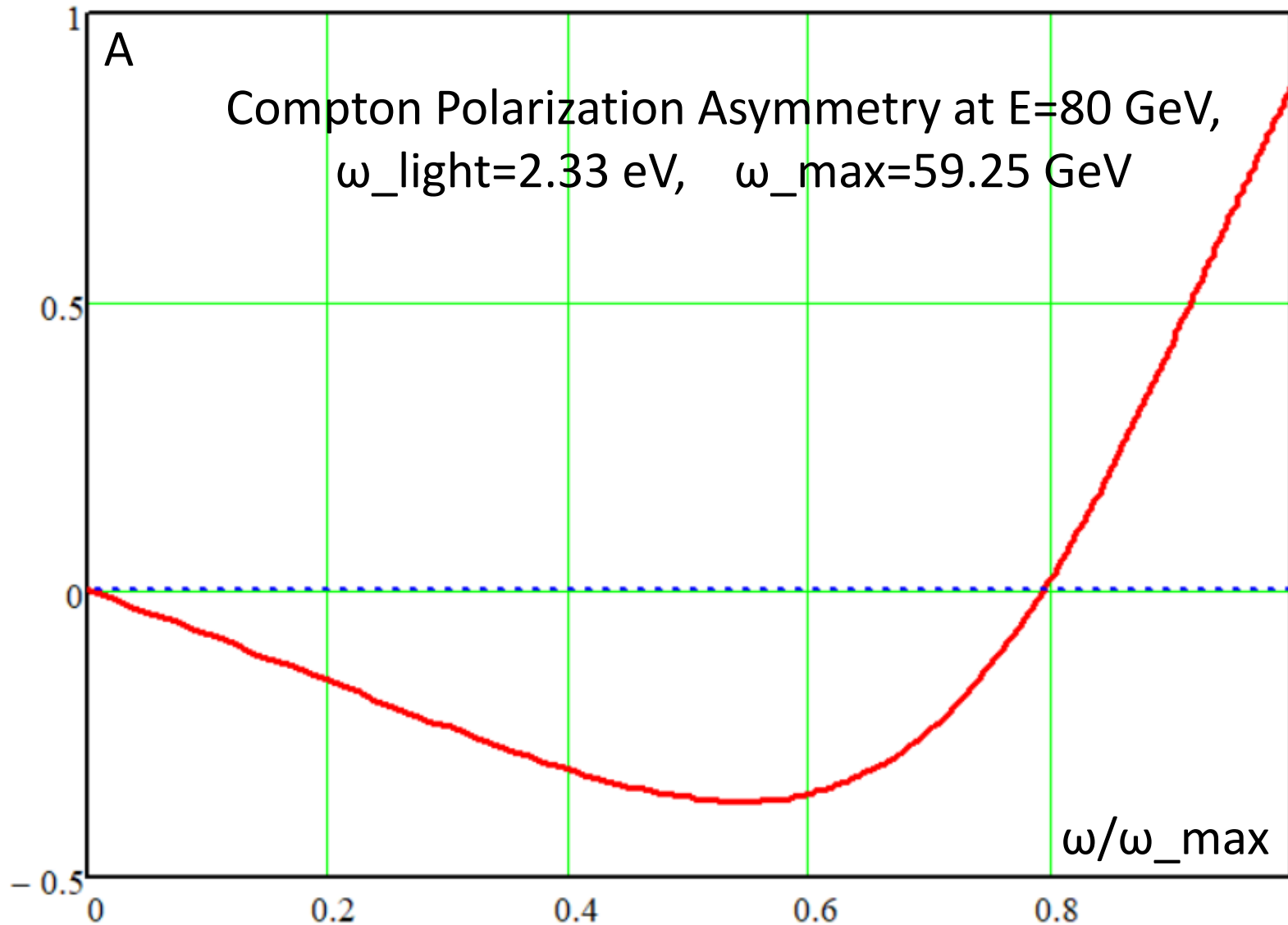
- With 10^{10} electrons and 3 kHz rep. rate: $\dot{N}_\gamma \simeq 2 \cdot 10^6$

Compton polarimeter asymmetry to longitudinal polarization at Z



In case of **coherent spin precession** we can explore large asymmetry A to the longitudinal spin component of the ICS cross-section, selecting events from two regions: $\omega/\omega_{\text{max}} > 0.8$ (N1) and $0.3 < \omega/\omega_{\text{max}} < 0.6$ (N2). Then do FFT analysis of a signal: $(N1-N2)/(N1+N2)$, modulated by spin turn to turn.

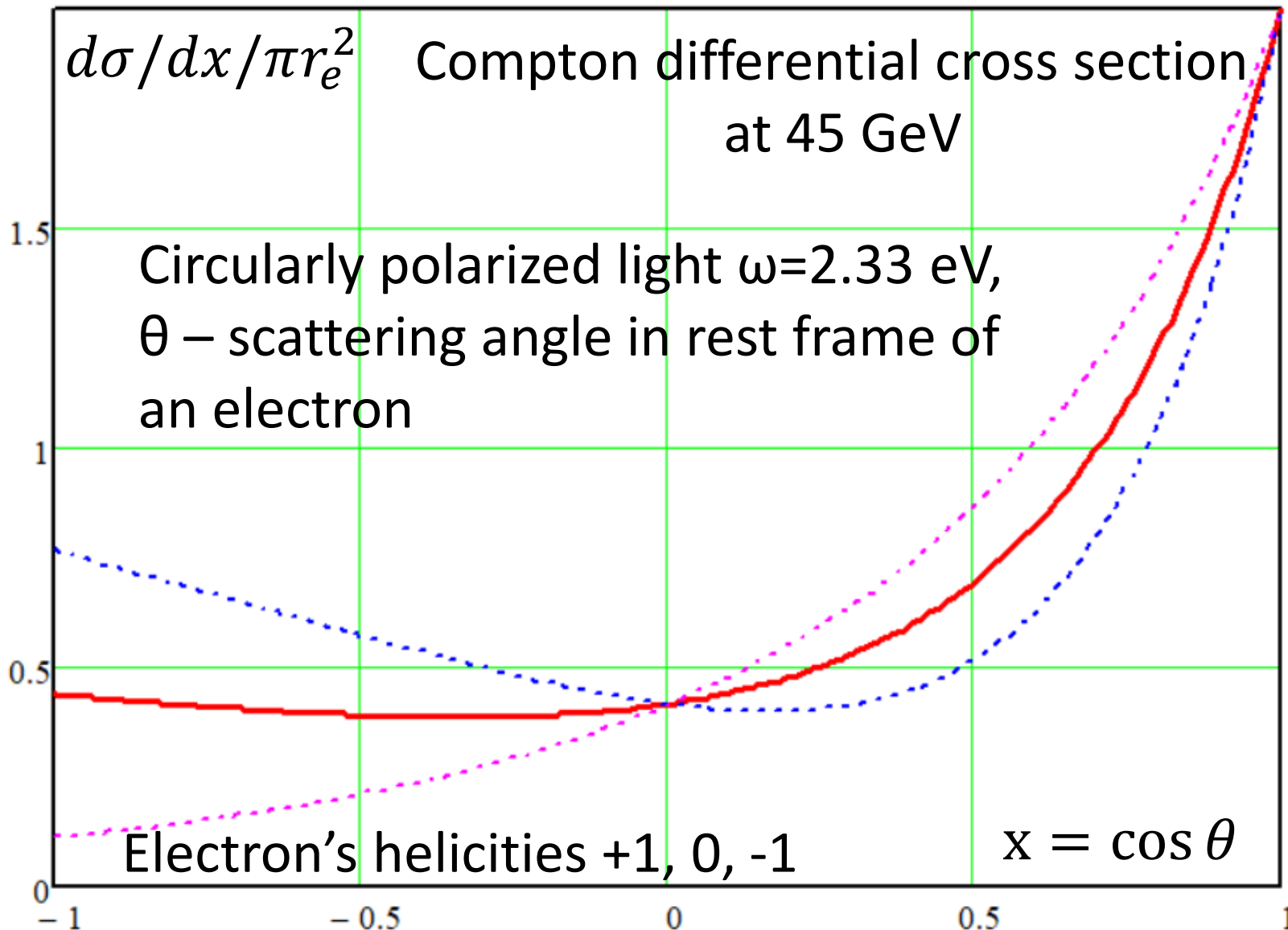
Compton polarimeter asymmetry to longitudinal polarization at W



Expected counting rate is about 1000 events/turn. **Photon calorimeter** suits well to measure a vertical spin component (up/down asymmetry), while **lost energy scattered electrons**, intercepted by some granular counter after a bend, could serve as the horizontal spin component polarimeter.

(more details at EPOL, N. Muchnoi)

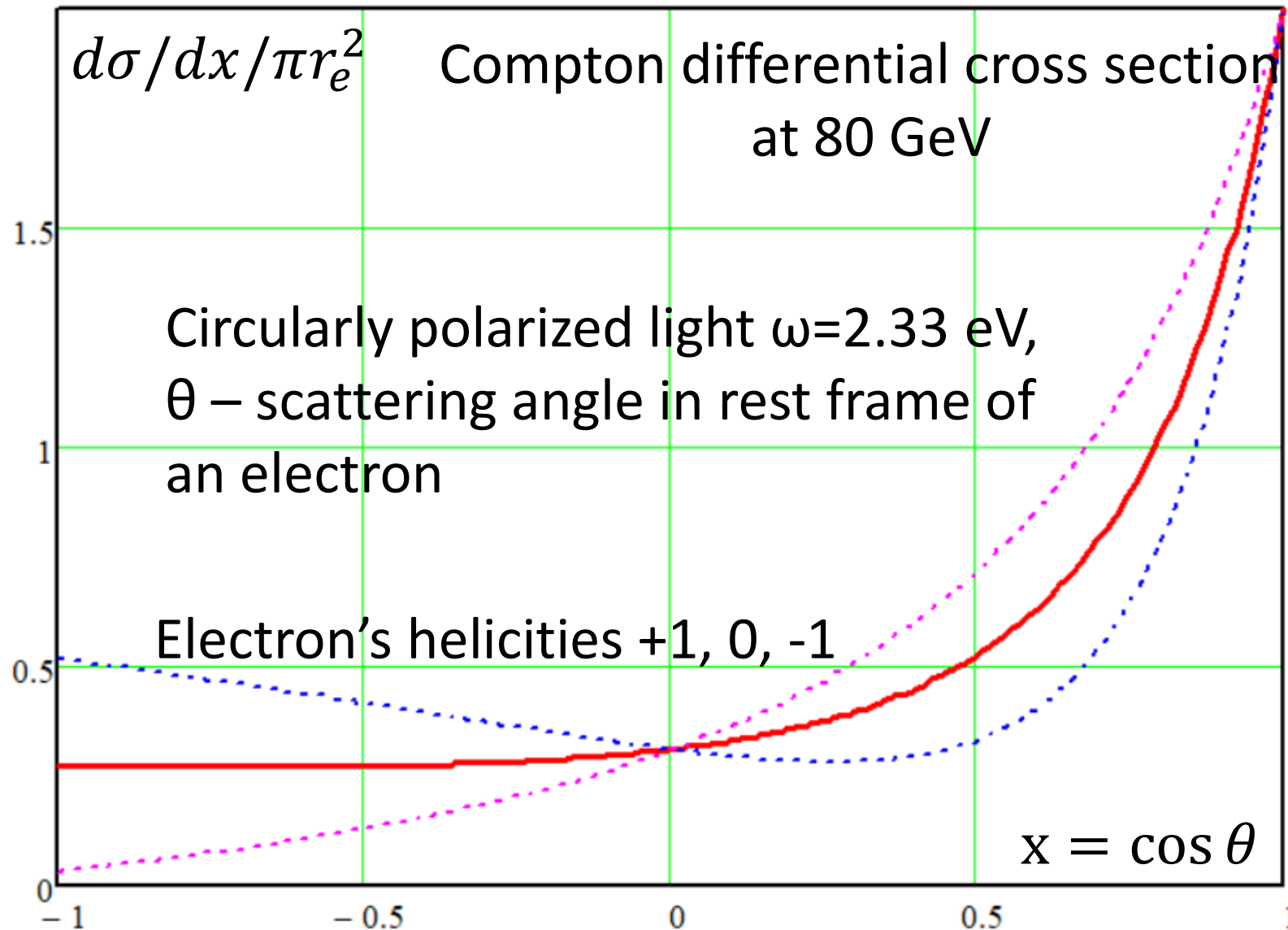
Compton scattering differential cross section at 45 GeV



Back scattering ($\cos \theta = -1$) of the laser photons shows the largest sensitivity to the longitudinal spin component.

Precess spin may significantly modulate the counting rate of that events.

Compton scattering differential cross section at 80 GeV



Free spin precession: some preceding works

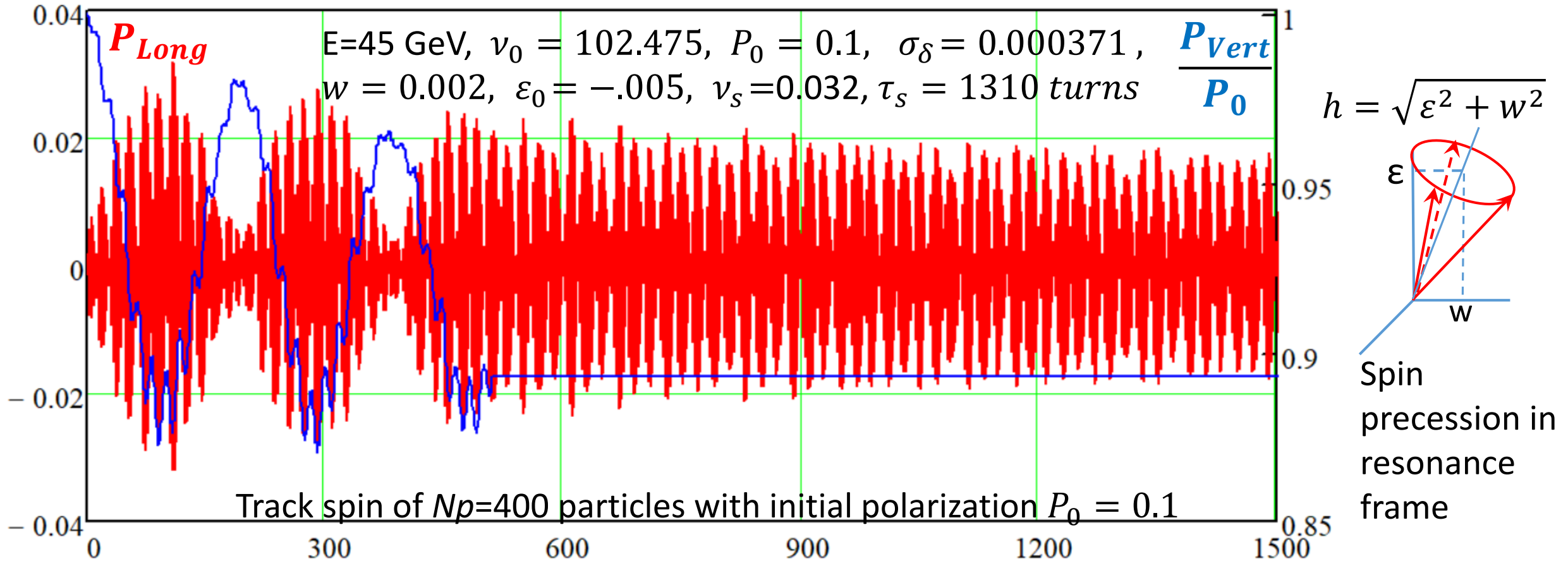
I.B. VASSERMAN et al., “**COMPARISON OF THE ELECTRON AND POSITRON ANOMALOUS MAGNETIC MOMENTS: EXPERIMENT 1987**”, Physics Letters B, Volume 198, number 2, November 1987.

I.A. Koop, Yu.M. Shatunov, “**The spin precession tune spread in the storage ring**”, EPAC1988_0738, 1988.

D.P. Barber, M. Boege, K. Heinemann, H. Mais and G. Ripken, “**Spin Decoherence in Electron Storage Rings**”, Spin94 (Bloomington).

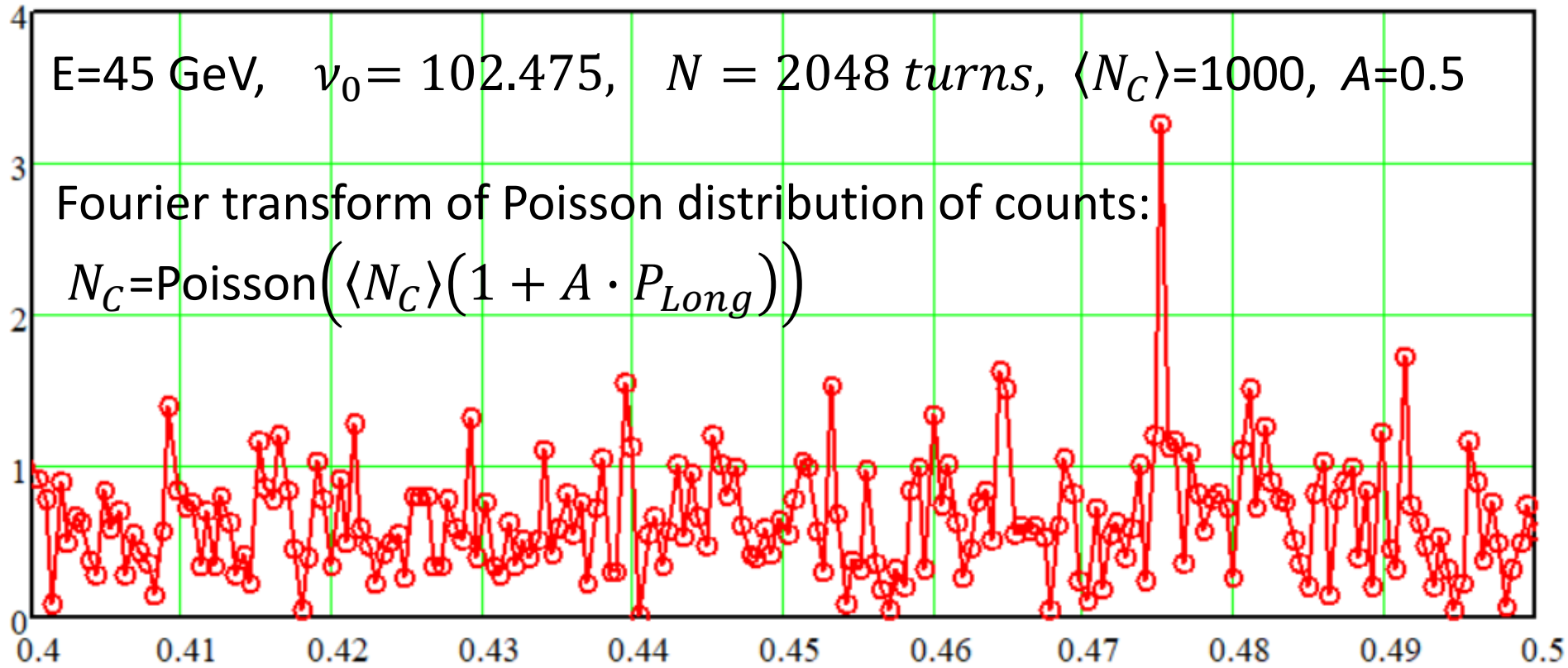
K. Heinemann, “**Some models of spin coherence and decoherence in storage rings**”, Report number DESY-97-166, 1997,
<https://arxiv.org/abs/physics/9709025> .

Excitation of the coherent spin precession at Z by Flipper



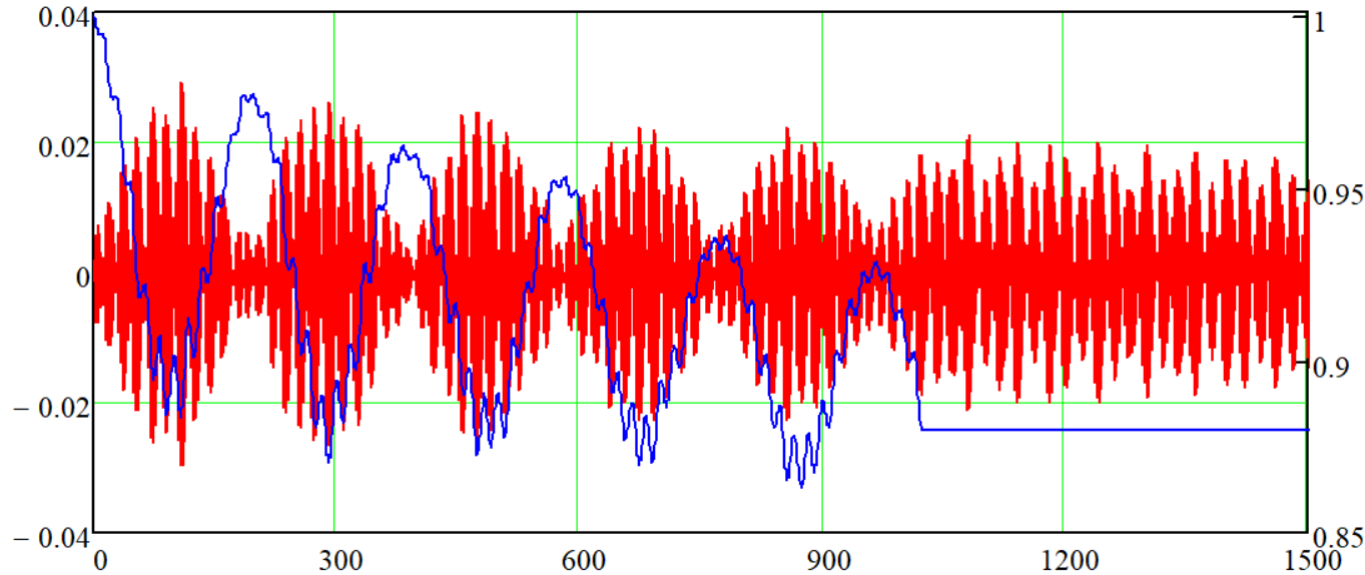
Coherent rotation of the total spin ensemble is done by powerful Flipper device: $w=0.002$. Its frequency is shifted from the resonance by small detuning factor: $\varepsilon_0 = -0.005$. Flipper is on 512 turns. After that we observe free spin precession during 2048 turns. Polarization loss is only 10%. In principle, Flipper kicks effectively spin only first 100 turns, or so!

Fourier transform of the counted electrons with high energy loss (at Z)

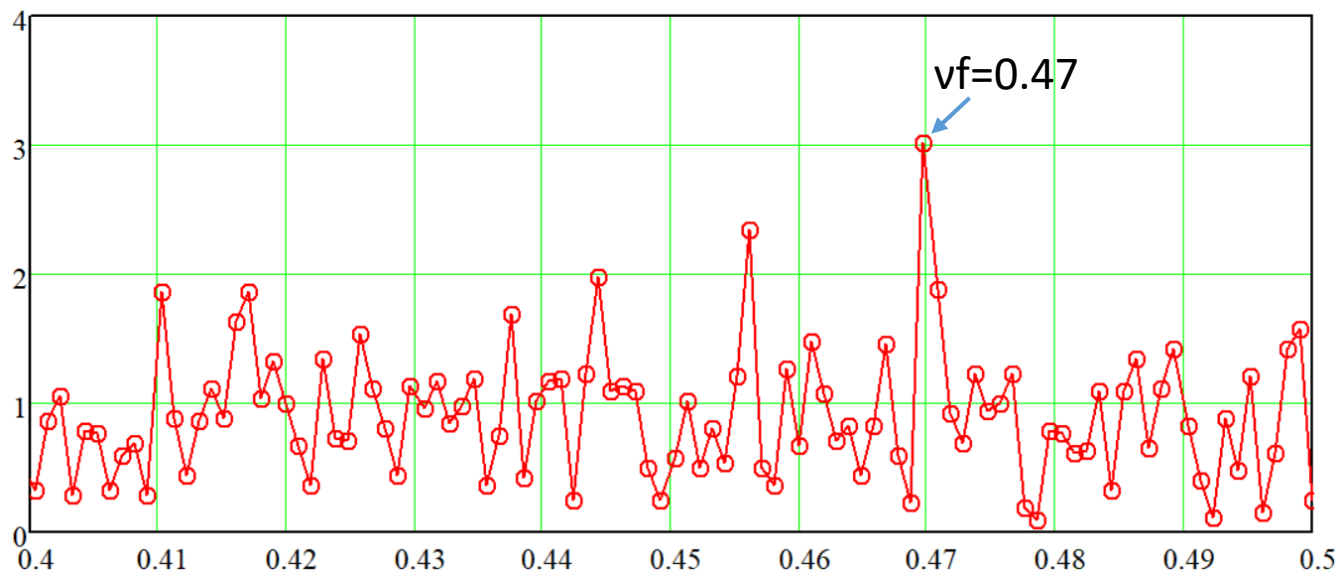
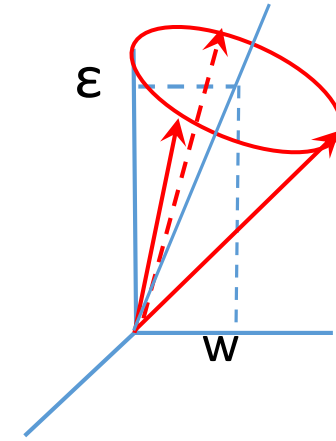


At Z polarization asymmetry of the Compton cross section relative to the longitudinal spin component could easily exceed $A > 0.5$ and the free precession peak at $\nu = 0.475$ is well above the statistical noise.

Spectrum of the forced spin precession at Z

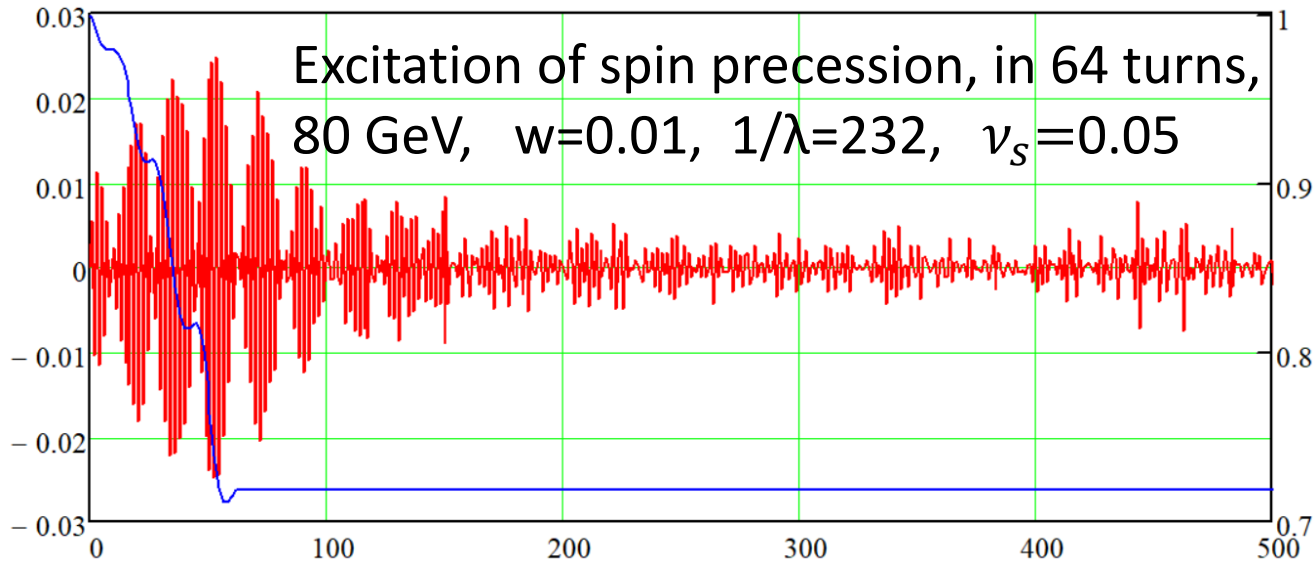


$$h = \sqrt{\varepsilon^2 + w^2}$$

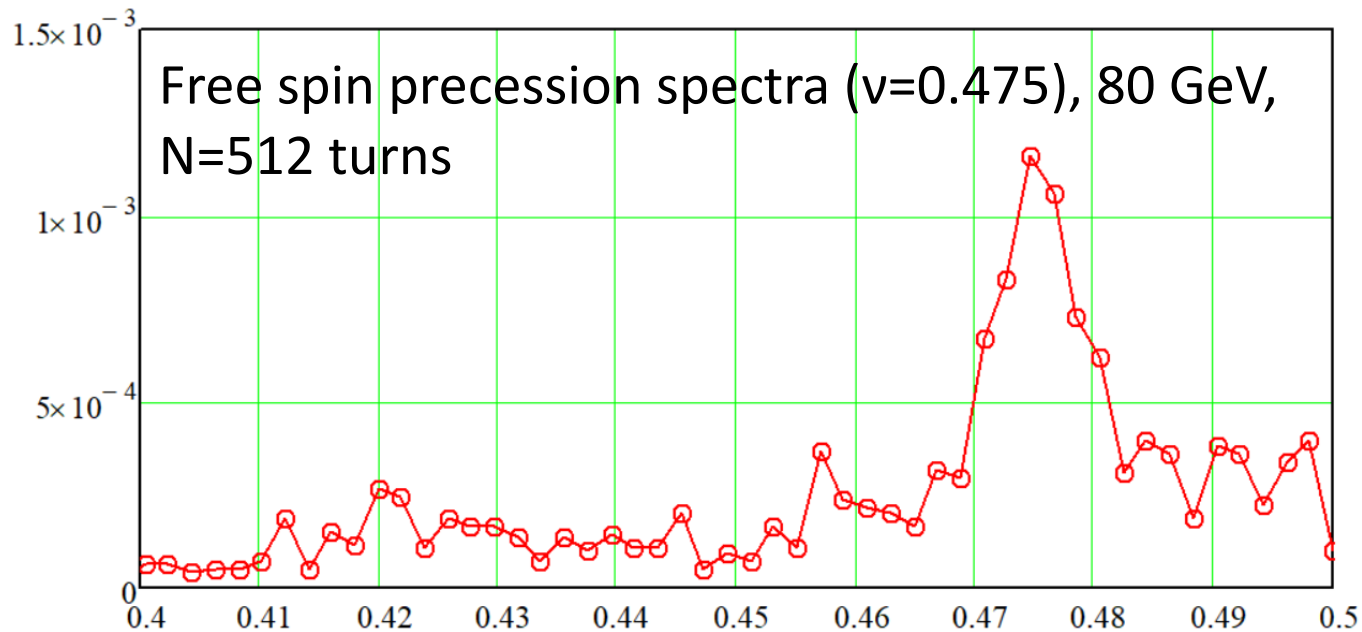


Track spins of $N_p=400$ particles with initial vertical polarization $P_0 = 0.1$. Flipper frequency $\nu f=0.47$ does not coincide with free precession frequency $\nu = 0.475$! Flipper peak is visible at 1024 turns sample.

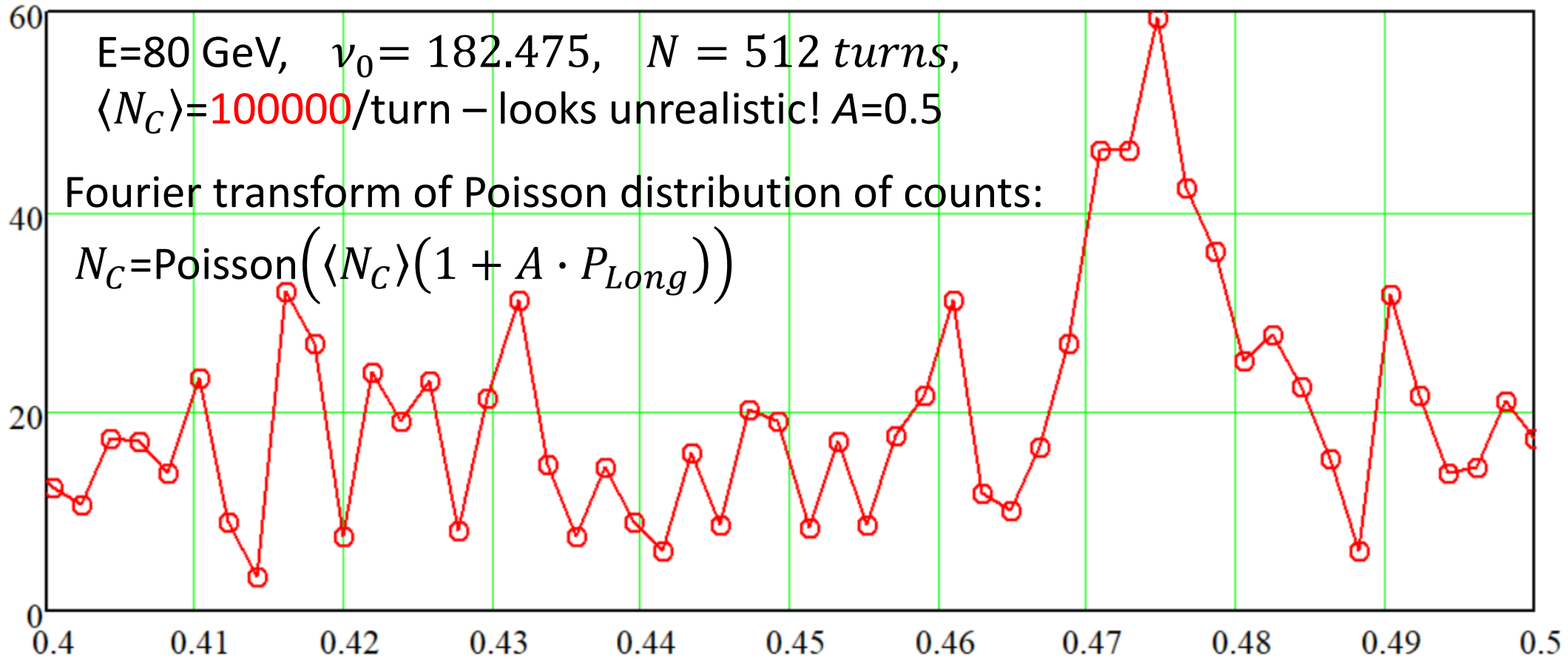
Excitation of the coherent spin precession at W by Flipper



Track spins of $N_p=400$ particles
with initial polarization $P_0 = 0.1$



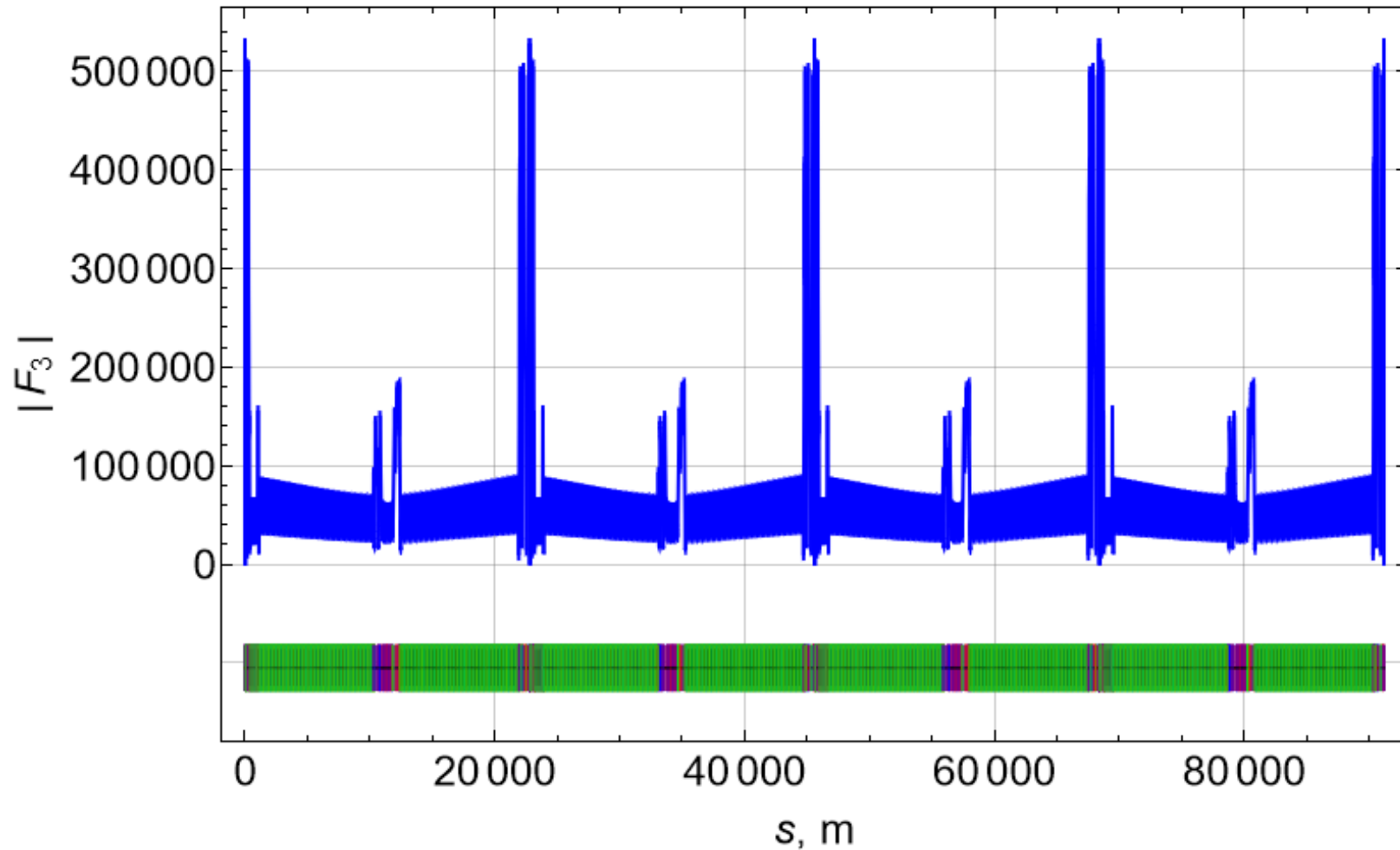
Fourier transform of the counted electrons with high energy loss (at W)



At W polarization asymmetry is very high (here we assume only $A=0.5$). Still free precession peak at $\nu=0.475$ is visible only with very high statistics level: $\langle N_C \rangle = 100000$ /turn.

Spin response function to the vertical oscillations excitation

FCCee, $E = 80.4029$ GeV, $\nu_0 = 182.5$



A flipper harmonic value $w = \theta \cdot F_3$, where θ is an amplitude of the orbit kick.

$|F_3|$ is very large near the Final Focus lenses. Optimal location for placing there of a weak depolarizer. The strong one will excite too large vertical oscillations, beyond of the DA.

Discussion on free spin precession method and conclusion

Compton polarimeter statistics (~ 1000 events/turn) is sufficient to detect the resonance frequency from measurement of the free spin precession, at least for Z beam energy. Short pulse flipper is capable to deflect spins from their natural vertical orientation to a large enough θ -angle to organize a free spin precession around the vertical axis.

At W the decoherence of spins precession is much faster and makes difficult to play the same game! Could help an increase of the synchrotron tune to a level of 0.075 or so!

Flipper strength is limited by the small DA in the vertical plane, therefore we can not explore large spin response to the vertical orbit excitation by a single depolarizer! Compensated π or 2π standard FODO cell can be used instead with a pair of pulsed spin kickers at the ends. This idea is now under investigation.

The polarimeter statistics can be used more effectively, if we will count almost all scattered electrons. Longitudinal polarization asymmetry is high enough not only at the edge of the spectrum, but also below the half distance from it, where the asymmetry changes a sign.