Summary, open questions and task list for 2023, 2025 WP1

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WP1. Simulations of polarization and spin-tune to beam energy relationship.

Conveners: Ivan Koop (BINP), **Tatiana Pieloni** (EPF Lausanne), **Eliana Gianfelice** (FNAL)

- **-- simulations of spin polarization in realistic machine (also able to calculate emittances, luminosity)**
- **-- res. depolarization at Z and WW threshold**
- **-- design and integration of wigglers, RF kickers, in FCC-ee**

Presenters:

Zhe Duan (IHEP), **Taho Chen** (IHEP), **Yi Wu** (EPFL), **Yuhao Peng** (University of Victoria, CA), **Anton Bogomyagkov** (BINP), **David Sagan** (Cornell), **Gerd Kotzian** (CERN), **Jorg Wenninger** (CERN), **Sergei Nikitin** (BINP), **Jeremie Bauche** (CERN), **Michael Hofer** (CERN), **Felix Carlier** (CERN), **Francois Meot** (BNL), **Jacob Asimov** (Cornell), ...

Task 1. How misalignments and intrinsic spin resonances may affect on the attainable polarization degree and on the spin tune - energy relationship?

-- how to measure and suppress the spin resonances strengths – polarimeters quality plays most roles here!!! (**shall workout requirements for the sensitivity of 3d-polarimeters**)

-- harmonic spin matching technique by the closed orbit correction (**again, its effectiveness depends strongly on the polarimeters capabilities!**)

-- optimization of polarization wigglers operation (**Fine balance between their strengths and the maximal attainable polarization degree.**)

-- probably shall spent more than 2 hours to prepare polarized bunches with higher polarization degree? **Or relay on the acceleration of polarized beams?**

Task 2. Resonance Depolarization process - spin flip by Froissart-Stora tune scan, and alternatively – fast spin rotation and then the free spin precession observation with subsequent Fourier spectrum analysis

-- optimization of a depolarizer parameters (**strength, tune scan speed, tune scan width**)

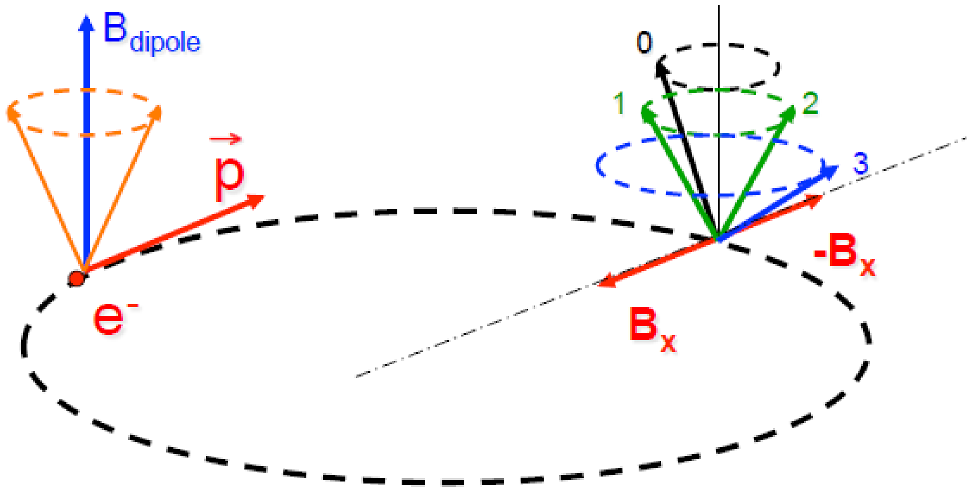
-- parameters of RF-kickers for both techniques (**optimal locations, strengths, simple single or with orbit deviation compensated pi-pairs?**)

-- optimization of the fractional part of the spin tune

-- optimization/choice of the synchrotron tune value

-- analysis of the attainable spin tune measurement accuracies, taking into account many factors (such as beam energy noise etc…) and the polarimeter statistics limitations

Resonant Depolarization by tune scan



Once the beams are polarized,
an RF kicker at the spin precession frequencv
will provoke a spin flip or complete
depolarization
Simulation of FCC-ee by I. Koop, see CDR:

spin precession (ν is the *spin tune*)

$$\delta\theta_{spin} = (g-2)/2 \;.\; E/m\, \delta\theta_{trajectory}$$
$$= \nu \,.\, \delta\theta_{trajectory}$$
$$\nu = E_{beam} / 0.4406486$$
$$= 103.5 \text{ at the Z peak}$$

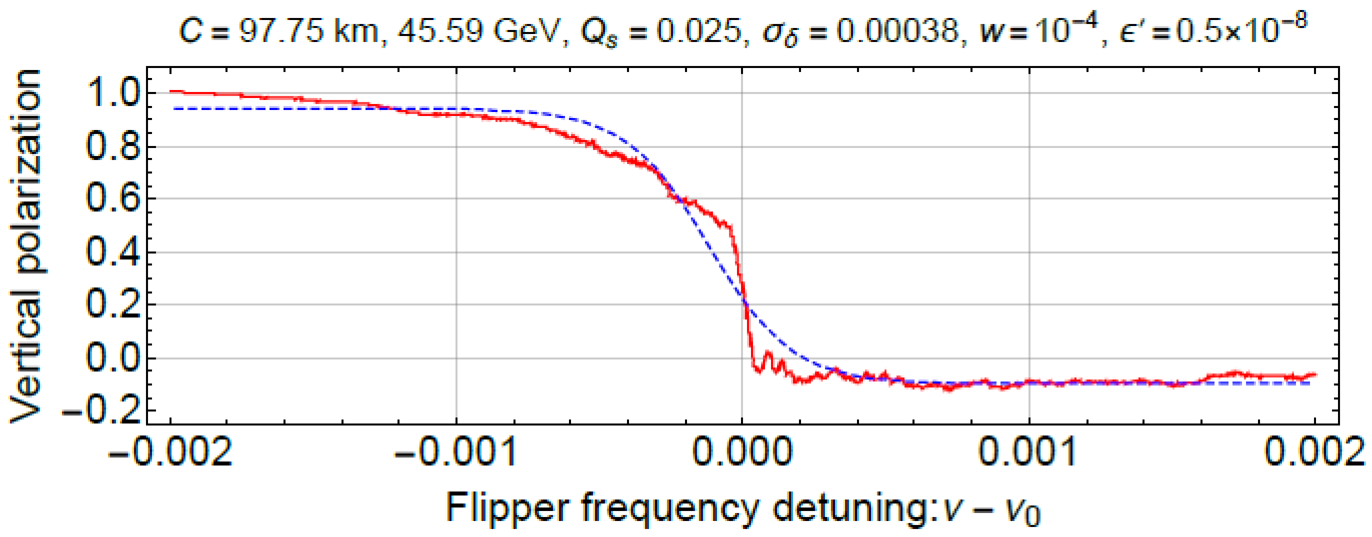
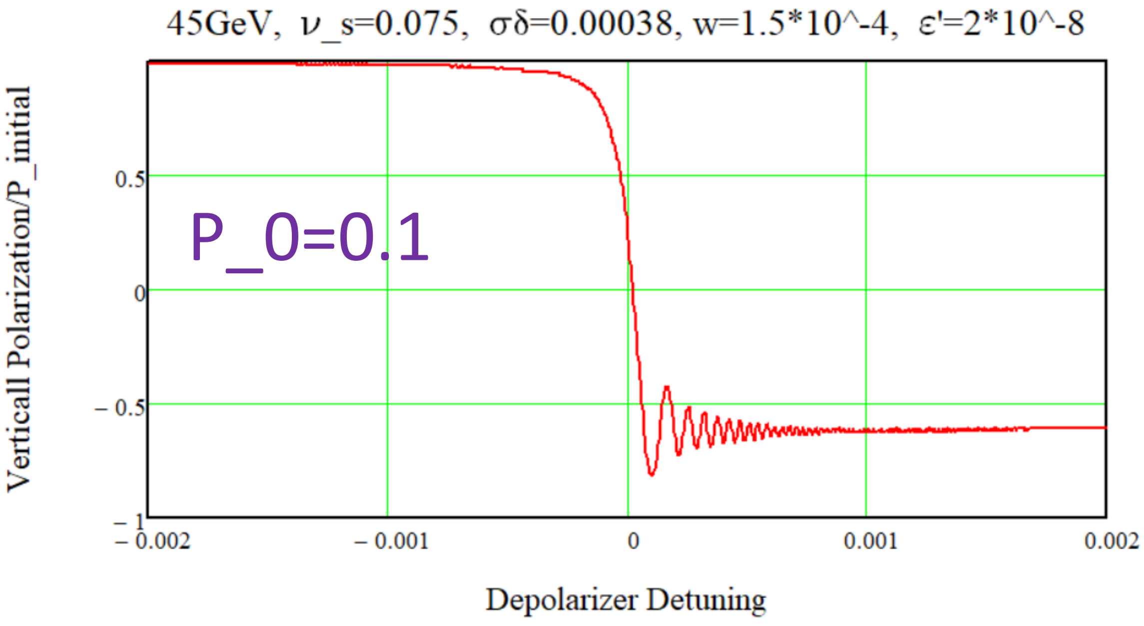
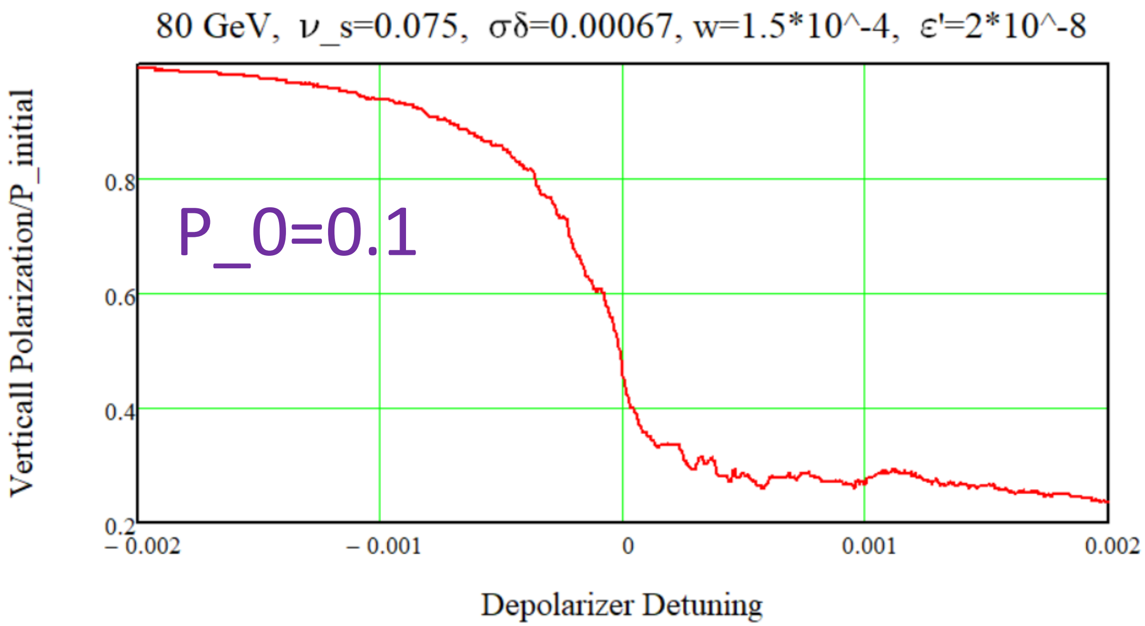
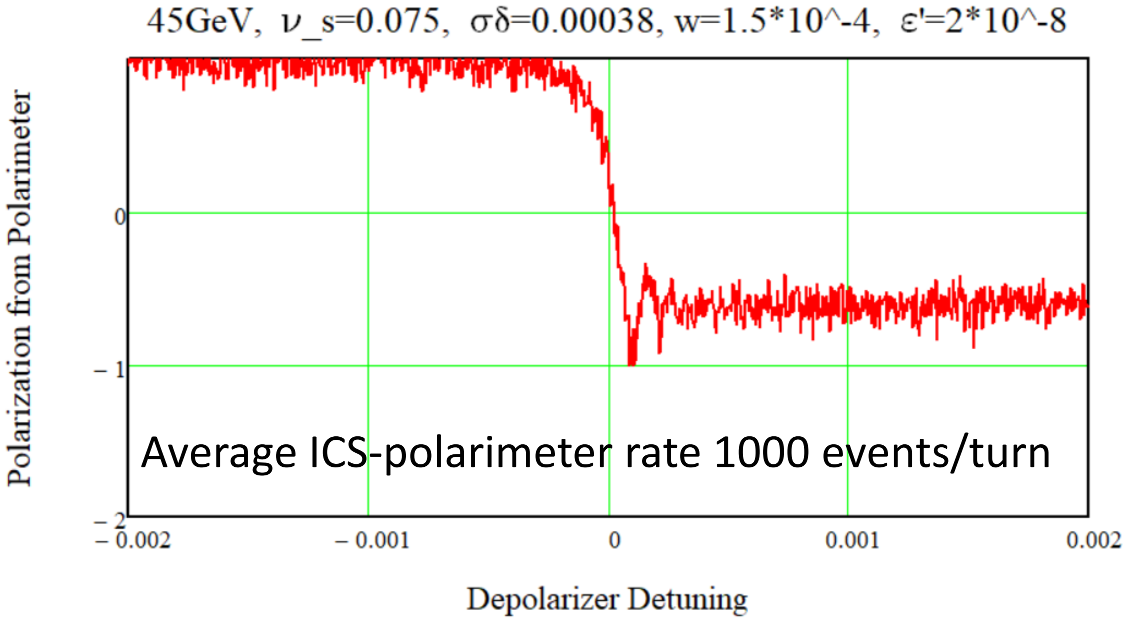


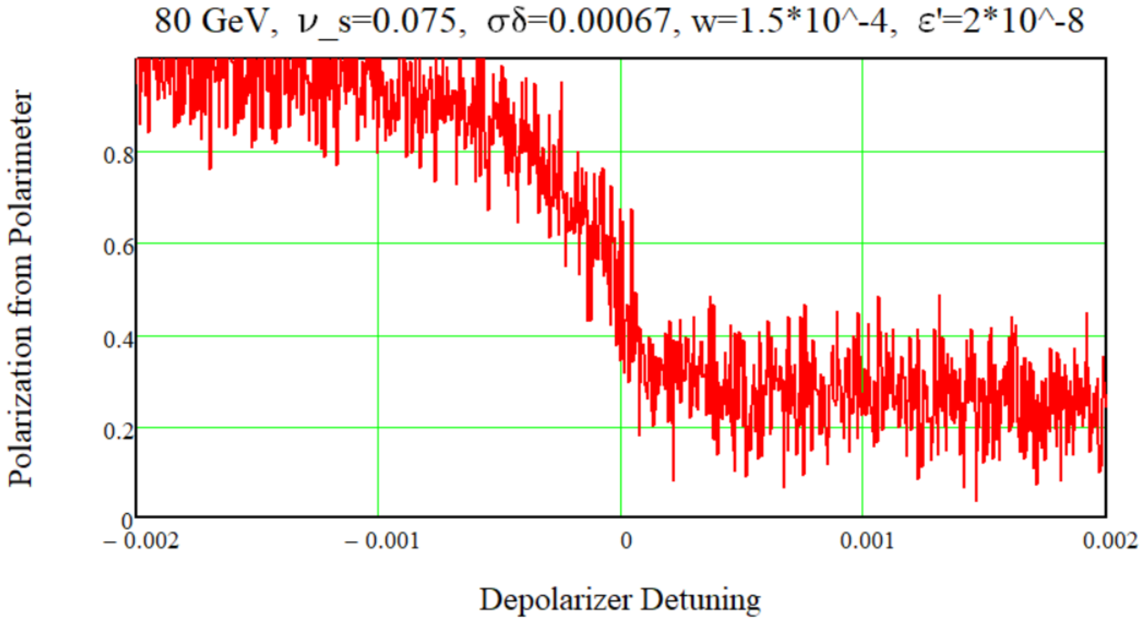
Figure 39. Simulation of a frequency sweep with the depolarizer on the Z pole showing a very sharp depolarization at the exact spin tune value.

RD frequency sweeps with increased v_s=0.075 looks much better!









WG1 Summary, Open Questions and further tasks

for Polarization codes

In FCCee polarization is required only for the purpose of energy calibration and the measurement is limited to pilot bunches. The measured beam energy is therefore the *average* pilot bunches energy over many turns.

For the required energy calibration precision, many subtle effects must be considered.

Those effects are of 3 different nature:

- Beam energy variation: it calls for frequent measurements.
- Breaking of the relationship $\nu_{spin} = a\gamma$.
  - Experiment solenoids: when compensated the effect is negligible. It can be measured.
  - *Vertical* closed closed orbit: second order effect, but at this level of precision may be relevant.
  - Electric fields: in general neglected because parallel to the nominal design orbit, but it may have an impact too.
- Relationship between average beam energy and CM energy.
  - Energy losse due to SR.
  - Energy losses due to machine impedances.
  - The pilot bunches betatron tunes are different from the colliding ones and their closed orbit, even if the colliding bunches are well centered, will be different.

A. Bogomyagkov gave analytical evaluations of many of these effects. It is important to

- Verify in the simulation studies the contribution of the single effects to the inaccuracy budget.
- Identify those expected to have the largest impact.
- Identify a way for *measuring* the relevant parameters: impedances, non-linear momentum compaction etc.

Some of these issues are avoided in the CEPC approach.

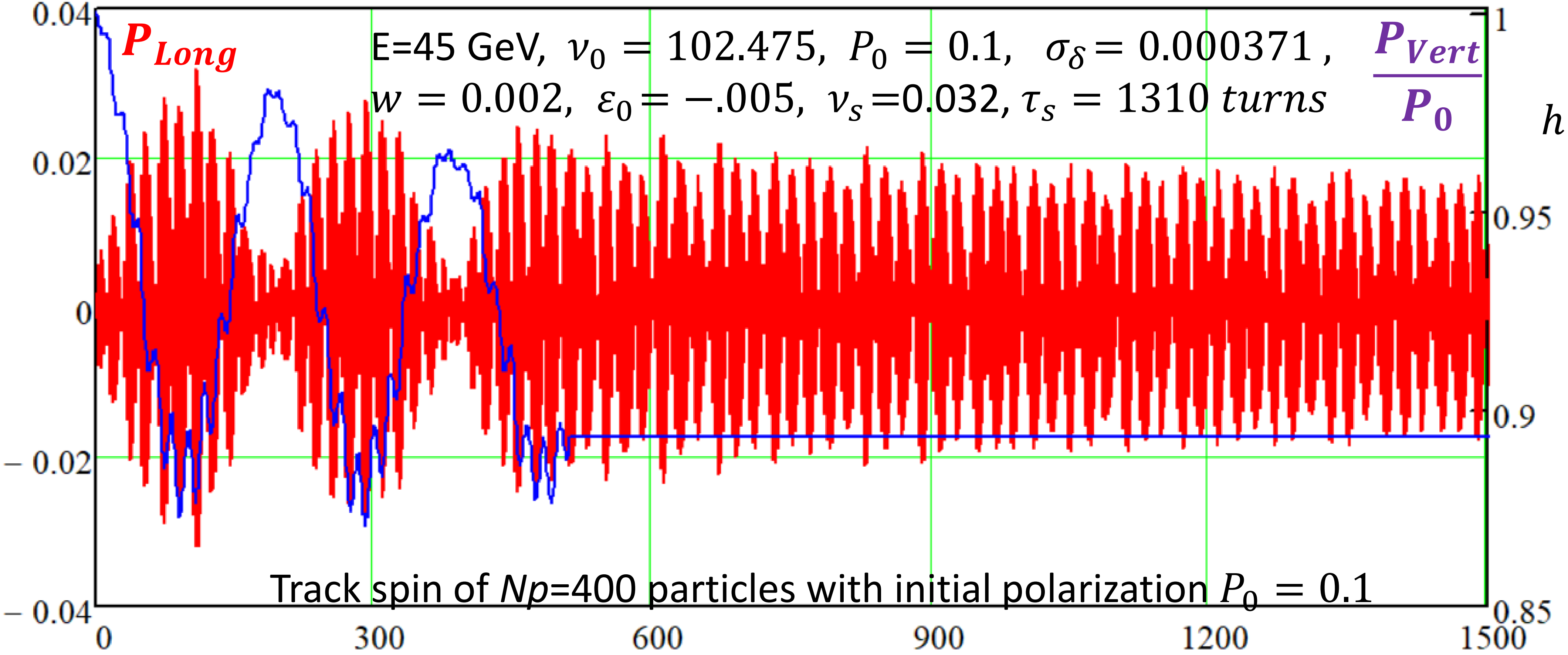
Issues and pitfalls in identifying the depolarization frequency highlighted by Ivan talk, can be studied by simulating the RF depolarization process inside polarization capable codes.

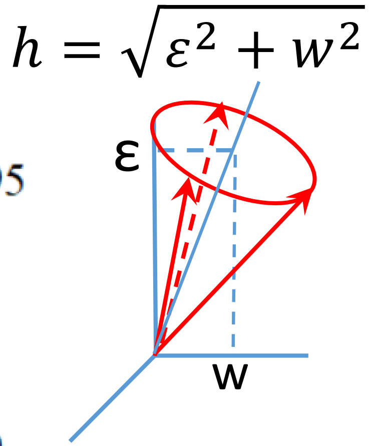
Codes attempting to evaluate Derbenev-Kondratenko expression for high energy large rings in presence of machine errors have shown either convergence problems or require extremely large computing power. Available codes for non-linear polarization calculations in presence of misalignments[a]

- (old glorious) SITROS: ring sectioning with stochastic photon emission at user chosen dipoles between sections. Fast, very large number of particles or turns seems not crucial. 2d order orbital motion, simple simulation of errors (misalignments and dipole/quadrupole errors), no multipoles, no higher harmonic cavities, simple beam-beam description in terms of an extra-lens and direct spin kicks (not much tested, for HERAe pessimistic results wrt actual observations).
- Zgouby: ensemble average substituted by time average (*ergodic* approach).
- Bmad: polarization calculation through Taylor maps, element tracking or PTC tracking. It needs sectioning as SITROS. The set up of large order maps is time consuming. It is a toolkit: "user" must have good knowledge of advanced fortran90 and knows what is doing! Many advanced features, including ramping of magnet strength: the way to go for overcoming SITROS limitations. Studies and benchmarking are going on at Cornell and CERN.
- MADX: PTC spin calculations have been now properly included. Shall we invest on it or adopt Bmad? It could become the user friendly version of Bmad: less flexible, but easier (safer) to use.

[a]presentations by Asimow, Carlier, Tao Chen, Zhe Duan, Gianfelice, Meot, Sagan, Signorelli, Yuao Peng, Yi Wu.

Excitation of the coherent spin precession at Z by Flipper

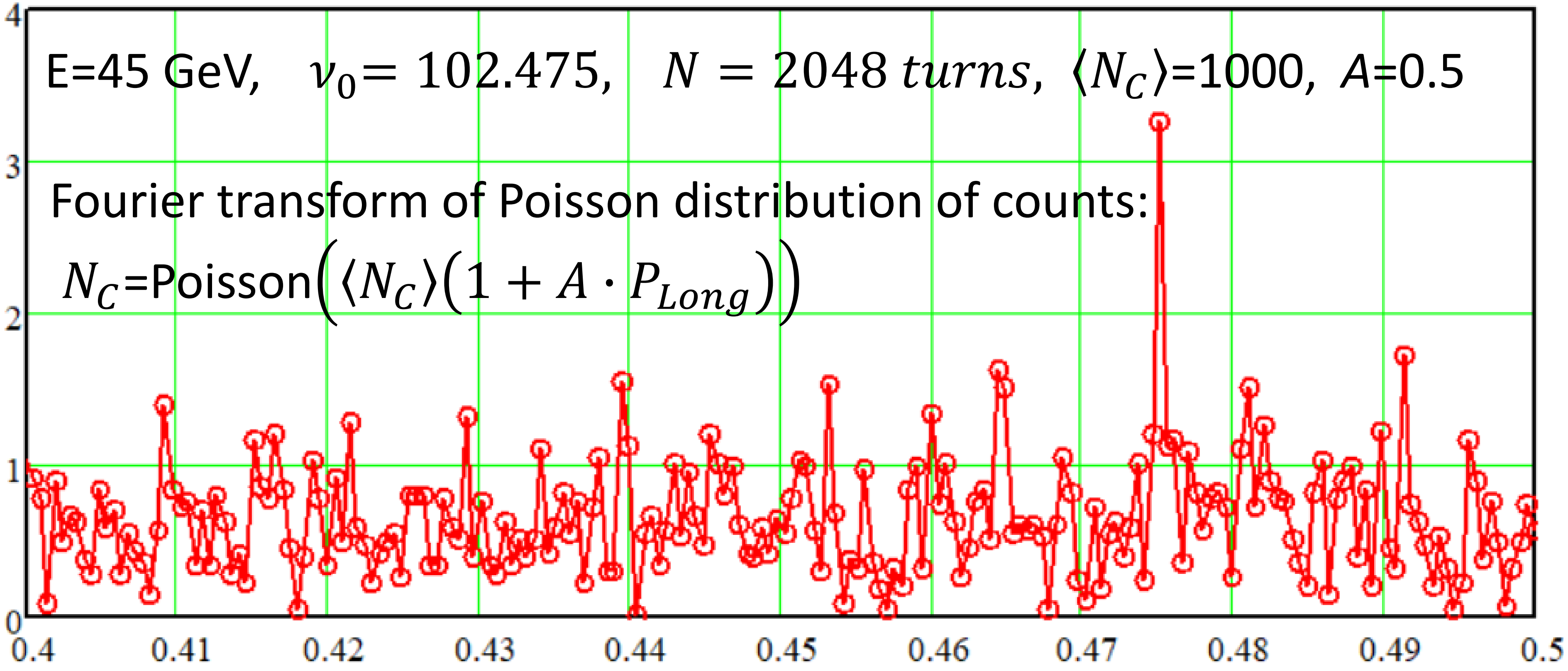




Spin precession in resonance frame

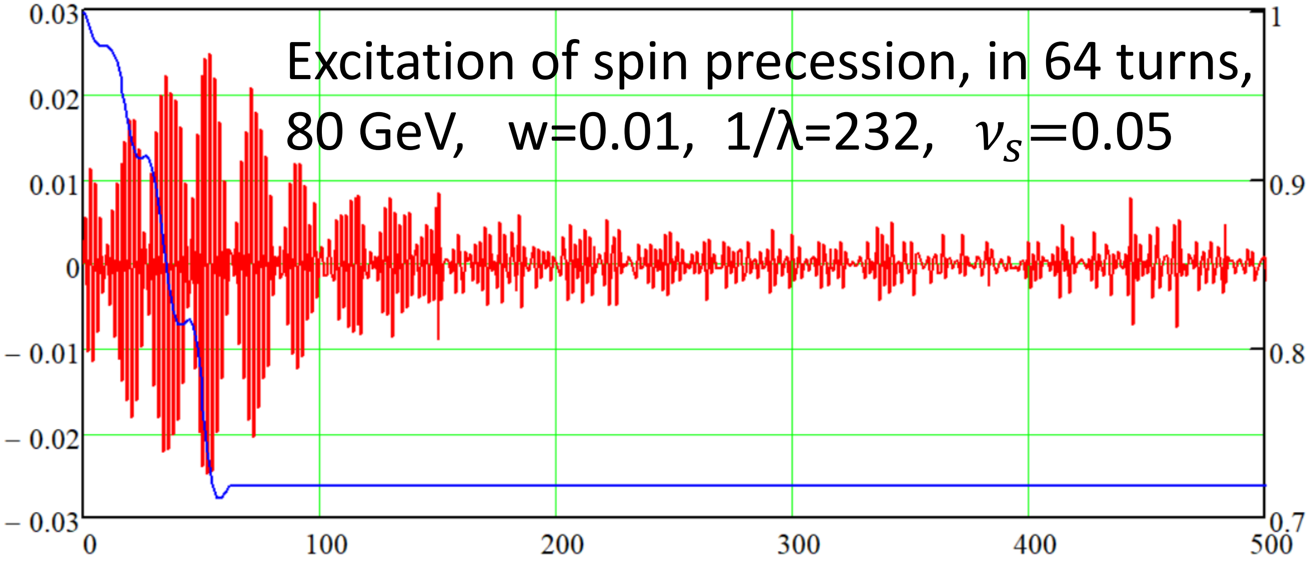
Coherent rotation of the total spin ensemble is done by powerfull Flipper device: w=0.002. Its frequency is shifted from the resonance by small detuning factor: $\varepsilon_0 = -.005$. Flipper is on 512 turns. After that we observe free spin precession during 2048 turns. Polarization loss is only 10%. In principle, Flipper kicks effectively spin only first 100 turns, or so!

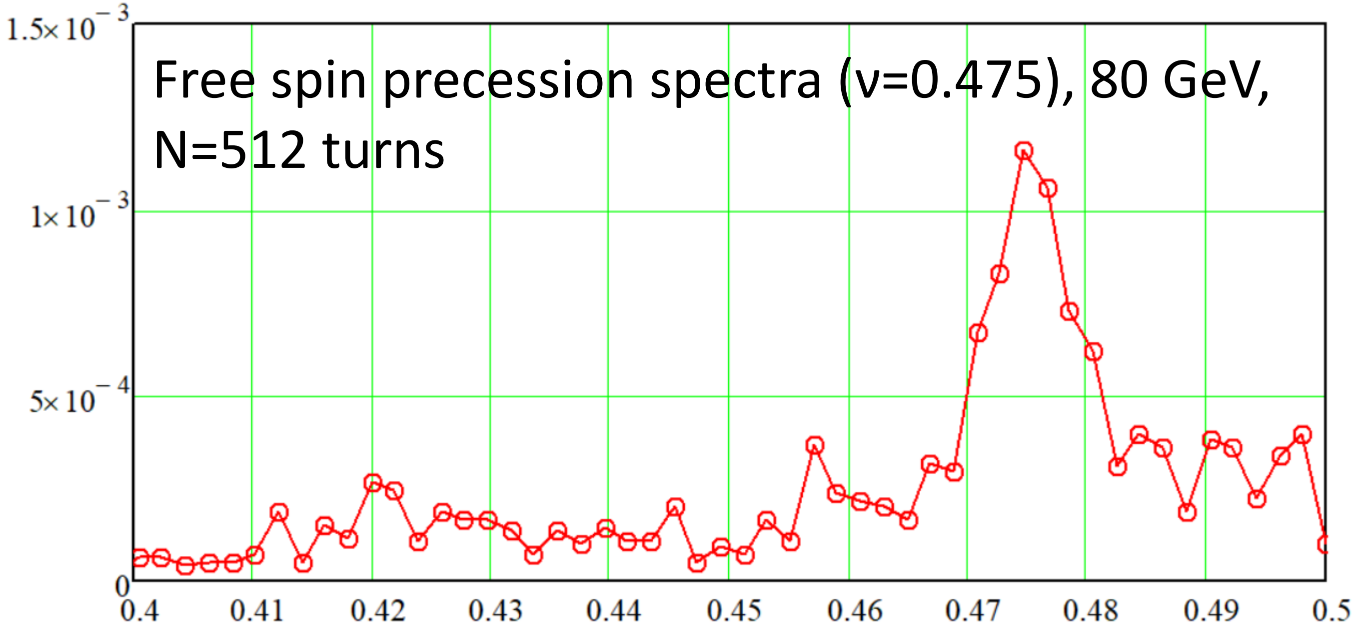
Fourier transform of the counted electrons with high energy loss (at Z)



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 ν=0.475 is well above the statistical noise.

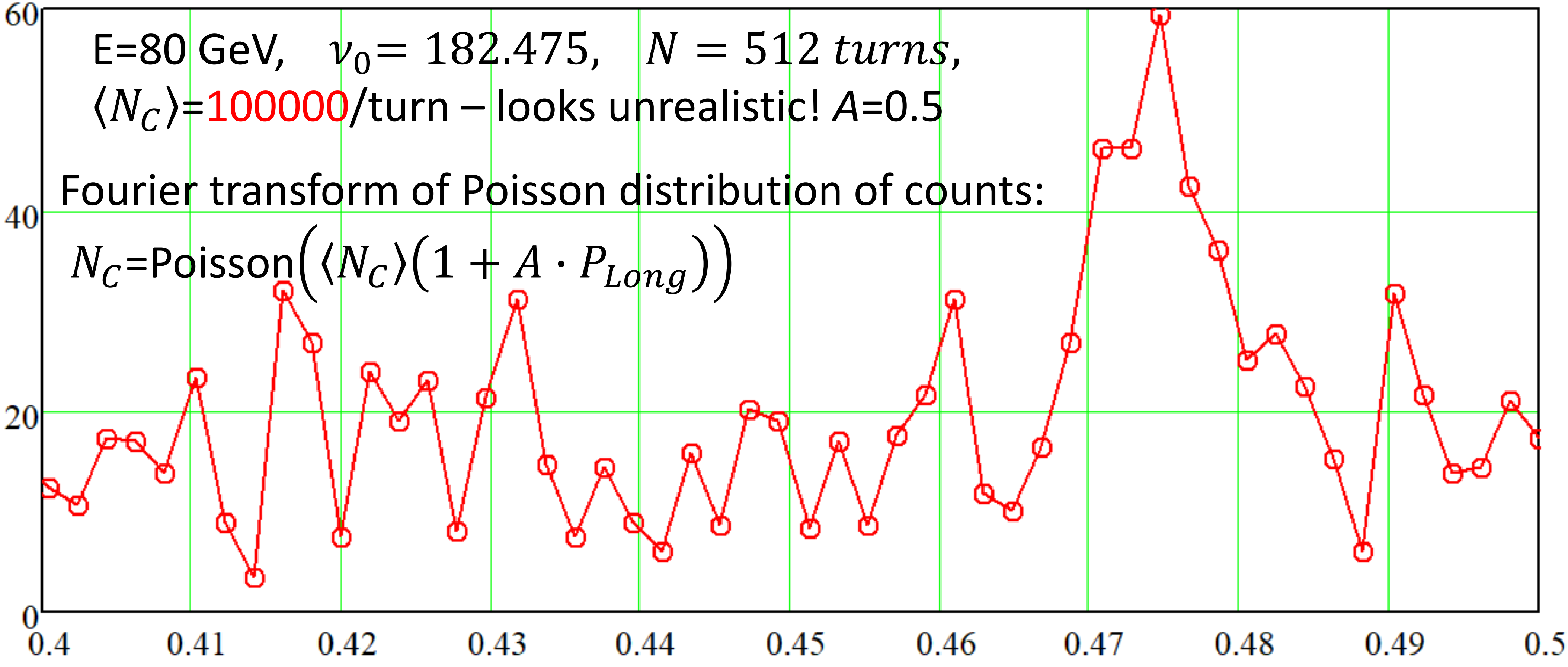
Excitation of the coherent spin precession at W by Flipper





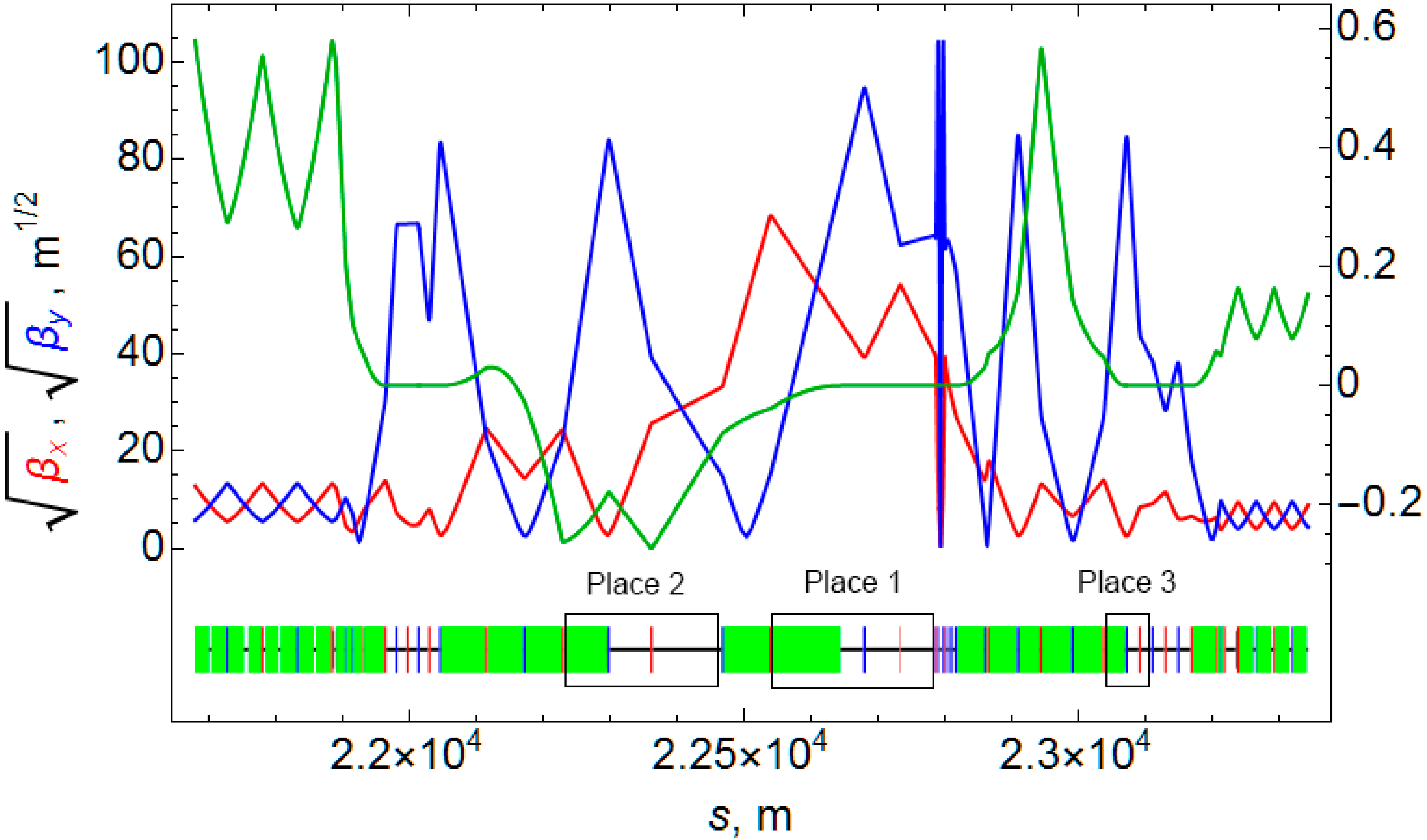
Track spins of *Np*=400 particles with initial polarization $P_0 = 0.1$

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

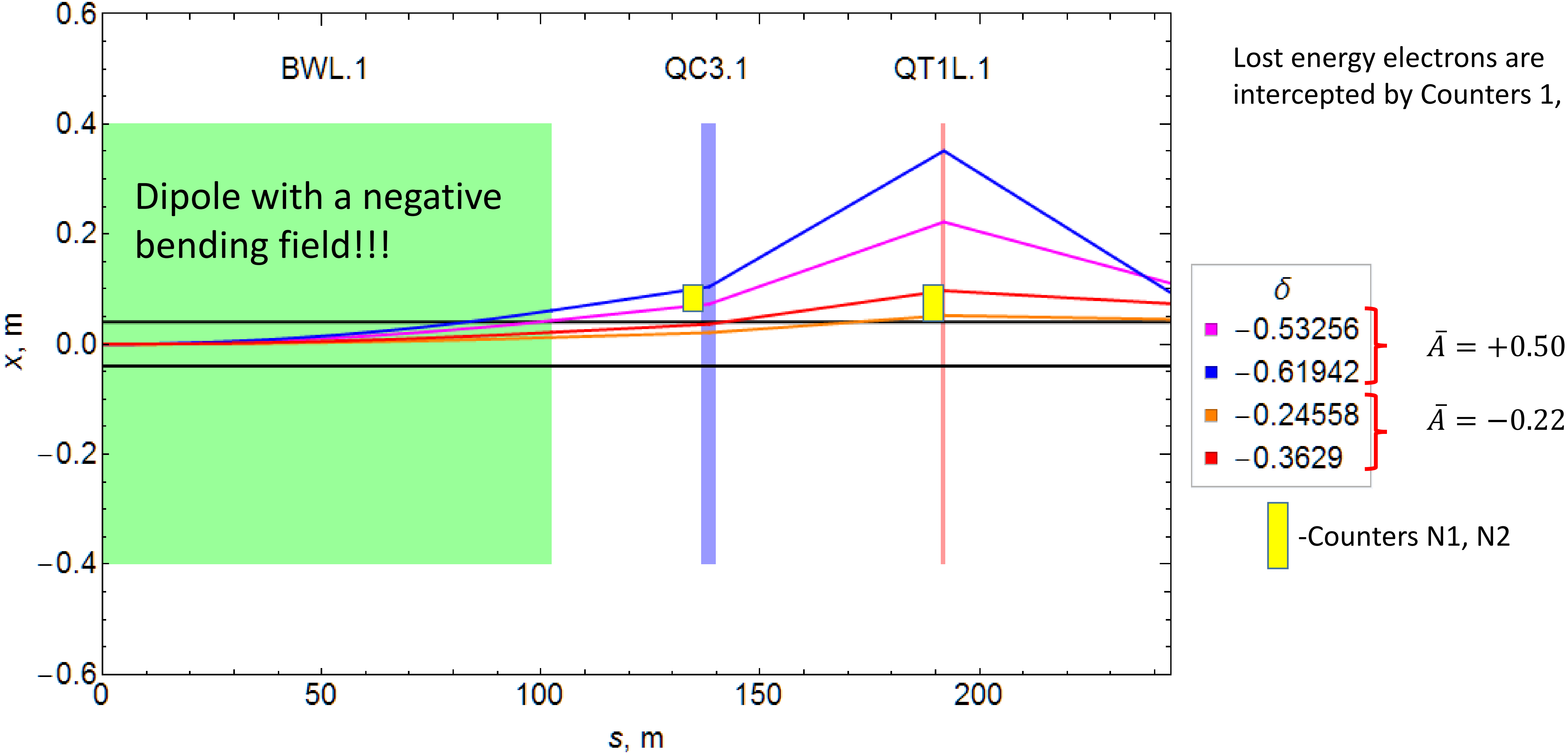


At W polarization asymmetry is very high (here we assume only A=0.5). Still free precession peak at ν=0.475 is visible only with very high statistics level: $\langle N_C \rangle$=100000/turn.

Possible longitudinal polarimeter locations in FCC-ee

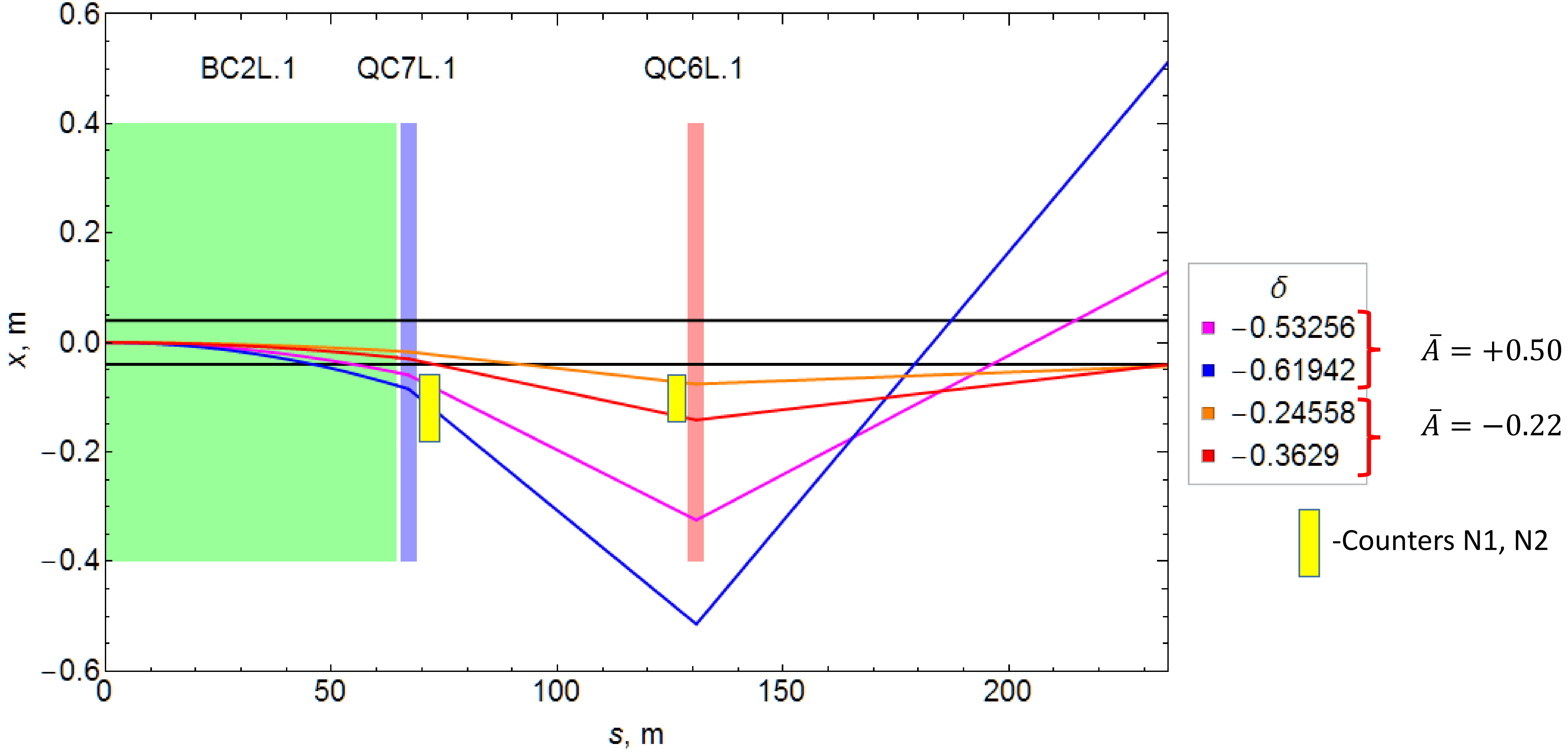


Trajectories with different energy losses at E=45.6 GeV, place1:

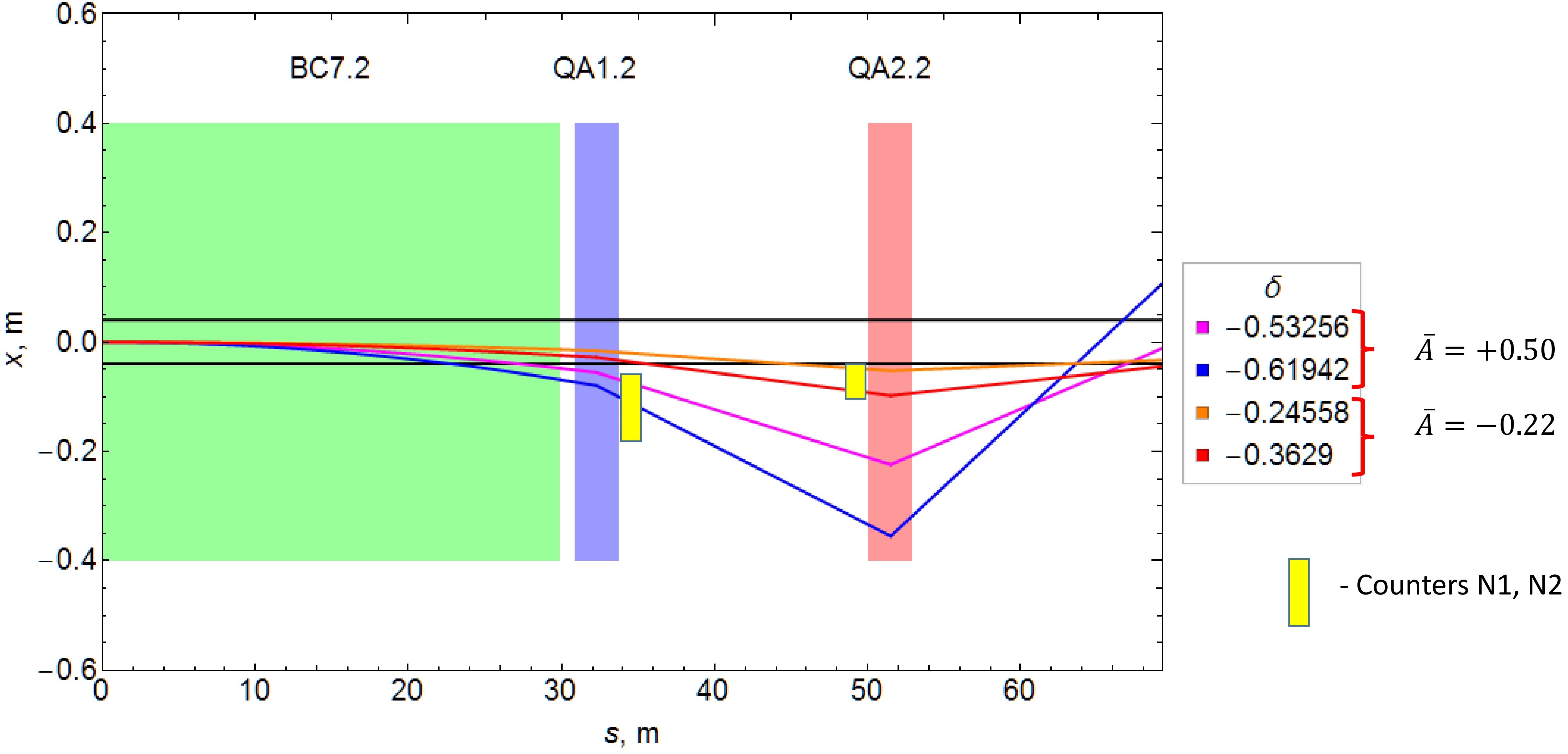


Lost energy electrons are intercepted by Counters 1, 2

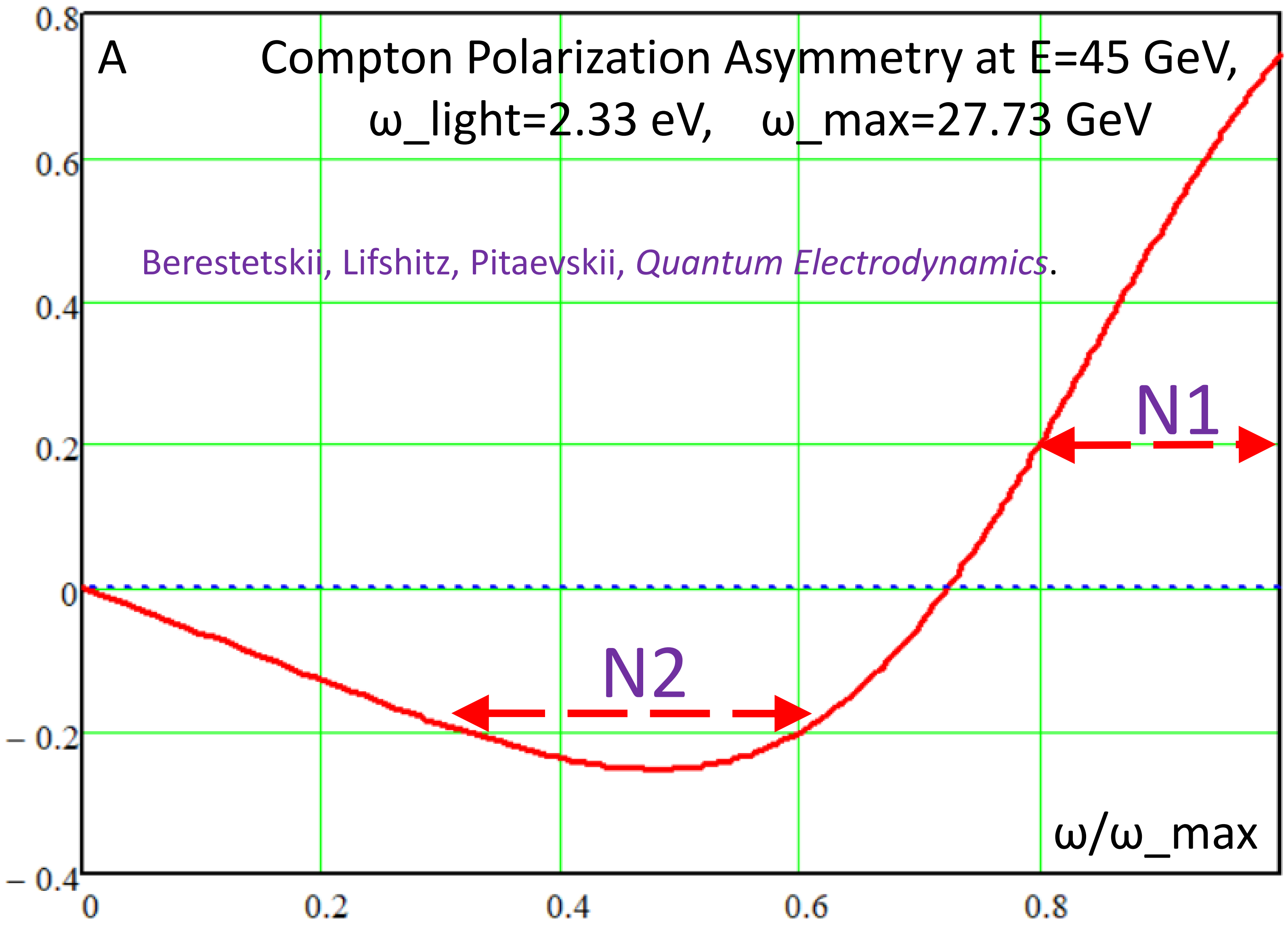
Trajectories with different energy losses at E=45.6 GeV, place 2:



Trajectories with different energy losses at E=45.6 GeV, place 3:



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: $\omega/\omega\_max > 0.8$ (N1) and $0.3 < \omega/\omega\_max < 0.6$ (N2). Then do FFT analysis of a signal: (N1-N2)/(N1+N2), modulated by spin precession.

Task 3. Analysis of different sources of systematics. Corrections for them.

-- see Anton’s, Sergei’s and Dmitry’s talks!

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Task 4. Transition from the measured average beam energy to the local energy at IP – common issue with WP2.

-- how to constrain a saw tooth curve (energy loss integrals between IPs)?

-- could the free spin precession phase measurements (by few longitudinal polarimeters placed near IPs) help us to solve this problem?

-- could we disentangle the coherent losses from the SR and beamstrahlung losses? Ivan presented his speculations on this matter in talk on Sept.29.

-- could we use energy boosts information from the detectors to derive the energy loss integrals between 4 IPs?

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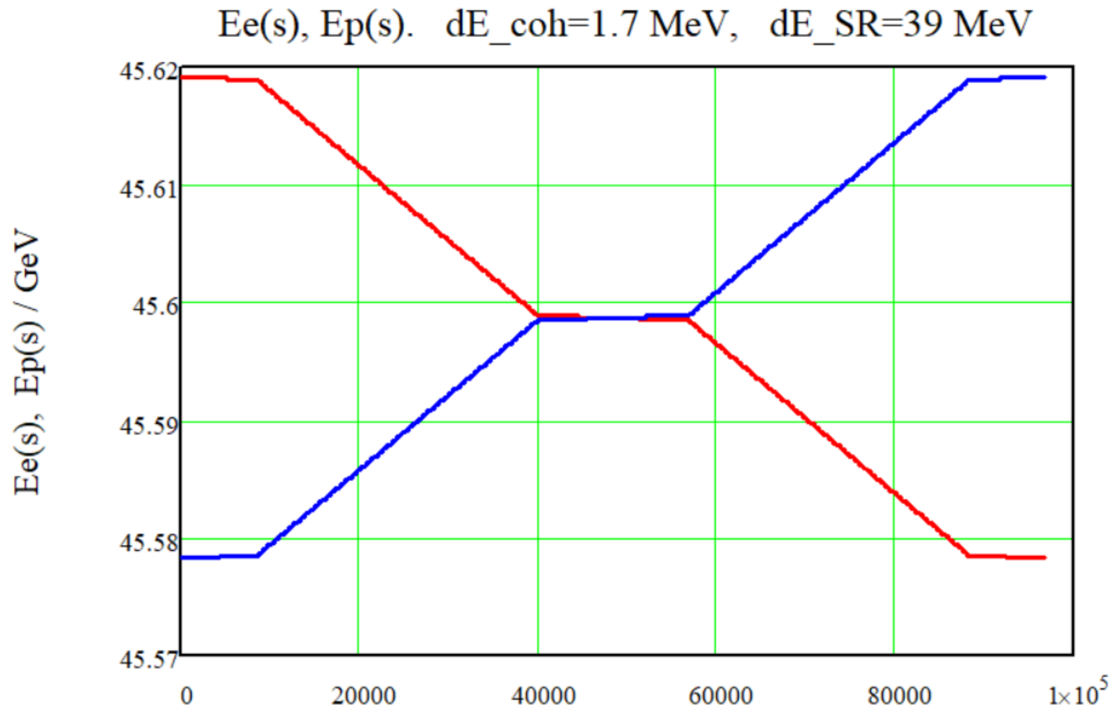
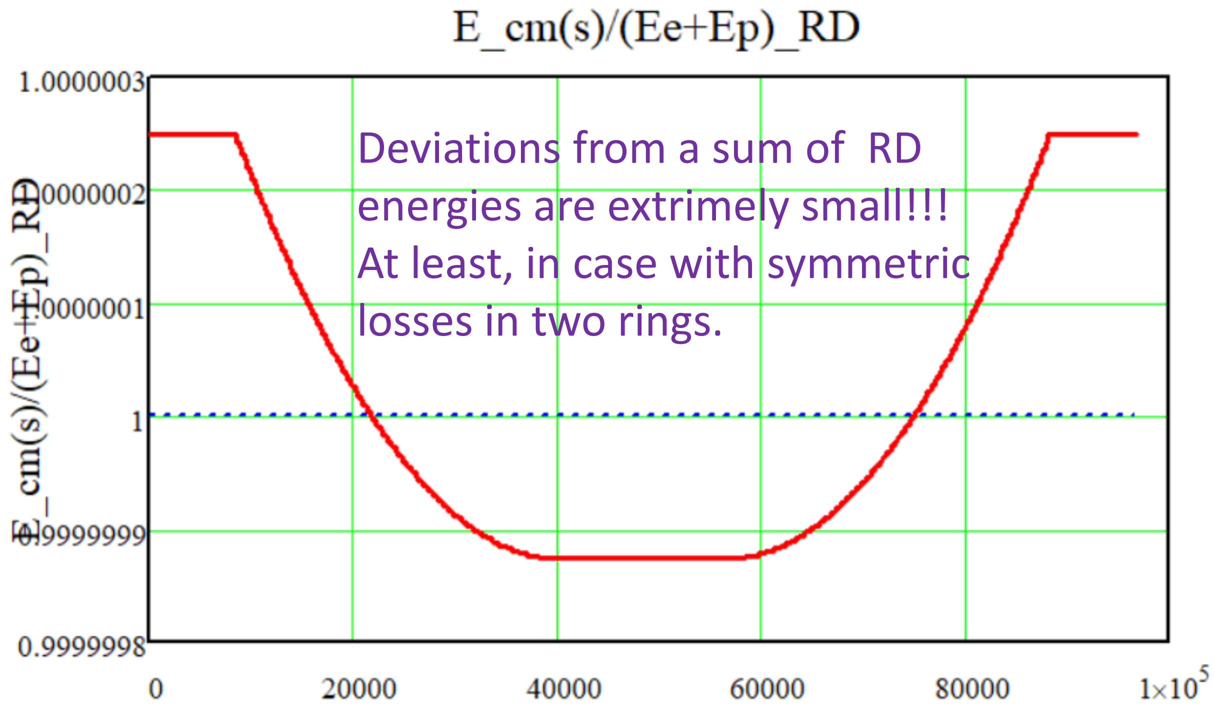
Disentangling the coherent and SR losses





Toy-ring with a head-on collision: 2 straights and 2 half-turn arcs. Coherent loss 1.7 MeV/turn, SR 39 MeV/turn.

Equation1: $\Delta E_{boost} = Ee_{RD} + Ue_{coh} \cdot Ie + \Delta Ee_{SR} \cdot (Ee_{RD}/E0)^4 - Ep_{RD} - Up_{coh} \cdot Ip - \Delta Ep_{SR} \cdot (Ep_{RD}/E0)^4$

Equations $2-4$ with different set of measured 5 input parameters: $\Delta E_{boost}, Ee_{RD}, Ep_{RD}, Ie, Ip$

Solve Linear System of Equations, $finding\ of\ 4\ unknowns$: $Ue_{coh}, Up_{coh}, \Delta Ee_{SR}, \Delta Ep_{SR}$

Now can find: $E_{cm} = Ee_{RD} + Ue_{coh} \cdot Ie + \Delta Ee_{SR} \cdot (Ee_{RD}/E0)^4 + Ep_{RD} + Up_{coh} \cdot Ip + \Delta Ep_{SR} \cdot (Ep_{RD}/E0)^4$

Important: not expand relative to a reference energy, or a current! Use a model dependence of losses from an energy and a current – then no unknown constant terms appear! A model could be refined for better fit to the measurements.

Accuracy of the reconstruction of Ecm. Conclusion.

With 4 sets of input parameters: Ie=1, 2, 0.5, 1.5; Ip=1, 2.5, 0.5, 1.5;
Ee_RD=45.6·(1, 0.97, 1.02, 0.99); Ep_RD=45.6·(1, 1.015, 1.025, 0.975);
and the calculated corresponding boosts.
I find Ecm with some systematic shift from the known simulated values by $2.9 \cdot 10^{-7}$.
Needs to be understood.

Conclusion:
Algorithm works in principle! Futher studies will be done in near future.
Other ideas welcome!

Let's continue our work!