Swiss Accelerator Research and Technology

CHART Project: FCC-ee SPIN POL

FCC-ee spin tracking and polarization studies

Team:

W. Yi, F. Carlier, T. Pieloni, M. Seidel (EPFL-LPAP) and A. Blondel, J. Keintzel, (CERN), E. Gianfelice (FNAL).

1 Introduction

High precision measurements in the FCC-ee will allow the observation of new physics and a leap in the understanding of the Higgs bosons. The precise center-of-mass energy calibration in the FCC-ee at Z and W energies can be achieved by using resonant depolarization, for which a minimum of 10% transverse polarization level at equilibrium should be guaranteed under various possible lattice conditions, and the impact of lattice perturbations on polarization should be investigated.

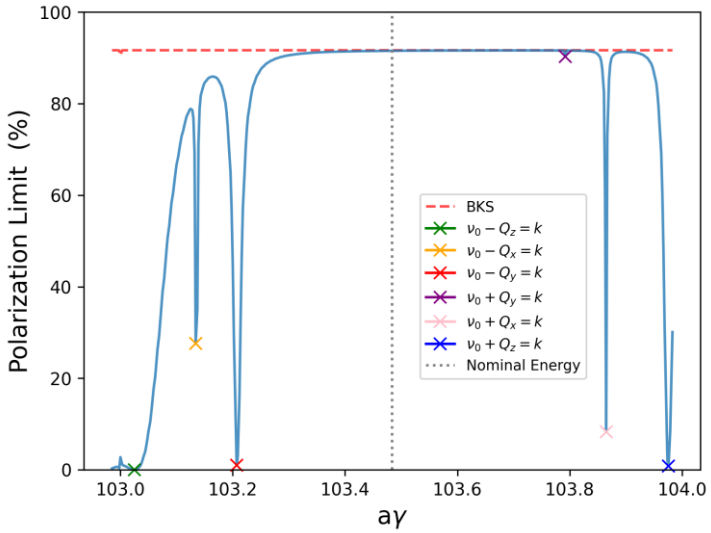

Figure 1 Energy scan using error seed with 43.7 µm rms vertical orbit distortion

2. Preliminary investigations and results

The influences of orbit distortions on equilibrium polarization in linear regime have been investigated via energy scans using the Tao module in Bmad. Figure 1 shows the polarization levels at different energies using one error seed generated to simulate the realistic orbits after lattice corrections. With the rms vertical orbit distortion of 43.7 µm at the nominal energy, an equilibrium polarization level of 91.56% can be achieved at 45.6 GeV. A significant decrease of polarization can be observed when the machine operates near the first-order spin-orbit

CHART Project: FCC-ee SPIN POL

resonances. The resonances are stronger near odd integer spin tunes due to the periodic lattice structure and machine imperfections. The energy scans of linear equilibrium spin polarization offer an illustration of the basic spin dynamics theory to first order, revealing the sensitivity of polarization curves to the orbits.

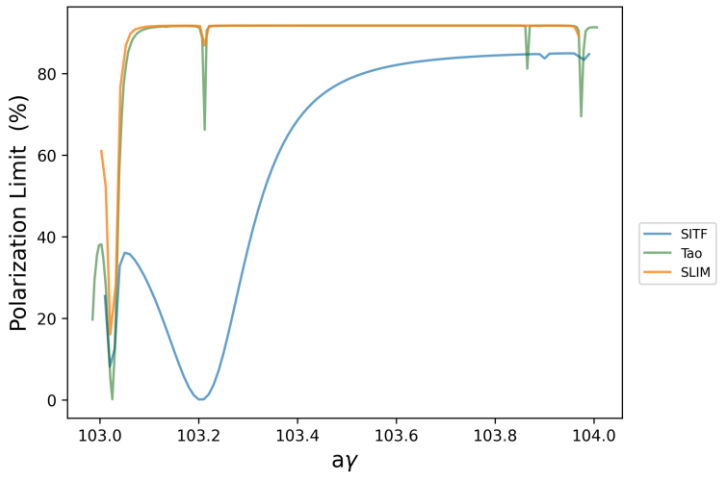

Figure 2 Energy scan of linear polarizations by SITF, Tao and SLIM

Benchmarking studies between SITF (SITROS) and Tao (Bmad) have been performed. Large discrepancies are observed between SITF and Tao at vertical spin resonances as shown in Figure 2, where SITF shows broader vertical resonance peaks than Tao and SLIM. The different damping settings of the transfer matrices in two codes are responsible for the discrepancy. Further investigations are in progress.

Linear spin simulations help to estimate the influence of first-order resonances. Higher order spin resonances could be prominent at high energies and jeopardize the achievable polarization level. Nonlinear spin tracking simulations are therefore critical to evaluate the full impact of lattice imperfections on spins. The Long-Term Tracking module in Bmad has been used for Monte-Carlo spin tracking. A preliminary nonlinear spin tracking simulation has been conducted at several energies using 1000 particles tracked for 7000 turns via PTC Bmad. As shown in Figure 3, the nonlinear polarization is in good agreement with linear results. The first-order vertical resonances can be observed in both linear and nonlinear simulations, while higher order resonances can only be reflected in nonlinear spin tracking simulations. The equilibrium polarization near nominal energy remains sufficient for the energy calibration of the FCC-ee case. However, a more realist set of orbital errors and a full simulation set needs further investigations. The simulations of multiparticle tracking have shown a clear limit in terms of computational time for which a technical solution needs to be found (i.e. parallelization of particle computations, GPU based computations). This will be an important step toward the development of a stable simulation framework also for the polarization

CHART Project: FCC-ee SPIN POL

studies in strong collaboration with the FCC-ee Software Framework CHART project of our group.

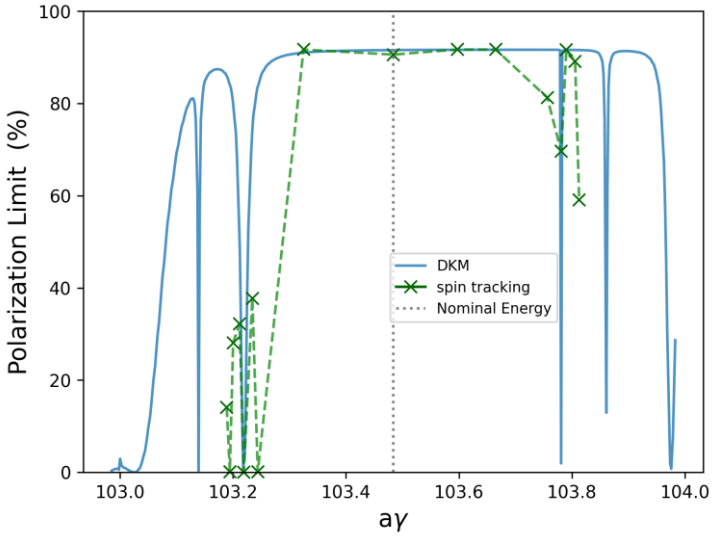

Figure 3 Polarization levels from linear and nonlinear spin simulations

The harmonic spin matching is being explored in the FCC-ee to reduce the loss of polarization due to spin diffusion. By making additional orbit corrections using vertical correction magnets, the rms tilt of the stable spin direction on the closed orbit can be reduced by minimizing the critical harmonics. This technique has been used in the past at LEP and HERA colliders. For the FCC-ee case four closed vertical bumps have been installed in the lattice to cancel harmonics 0 and 1, and to optimize the polarization near spin tune 104. Figure 4 shows the polarization curve after the installation of four bumps, which brings a significant improvement to the polarization near spin tune 104. More complicated harmonic spin matching scheme for the FCC-ee is under study and will be the focus of the next 6-months period.

CHART Project: FCC-ee SPIN POL

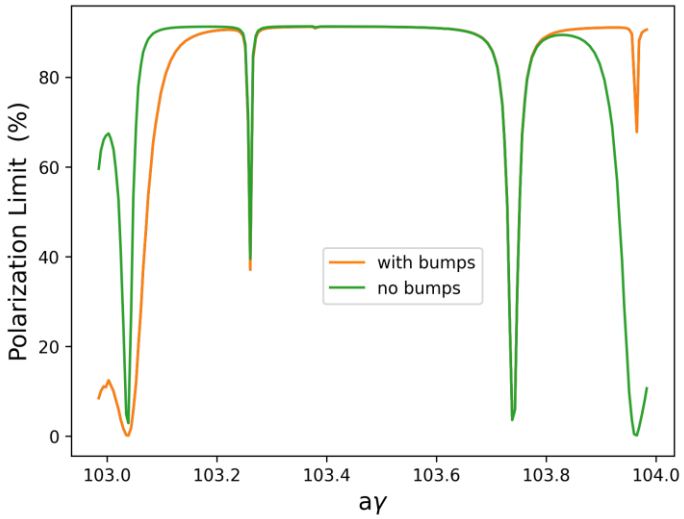

Figure 4 Polarization curves using 4 bumps optimized at 45.82 GeV

3. **Presentations and reports:**

1. FCC Week 2022, "Simulations of the Spin Polarization for the Future Circular Collider e+e- using Bmad"

   https://indico.cern.ch/event/1064327/contributions/4893334/attachments/2454010/4207092/FCCweek_Yi.pdf

2. Annual meeting of the Swiss Physical Society 2022, "First Exploration of Spin Polarization Simulations in the Future Circular Collider e+e- using Bmad", https://indico.cern.ch/event/1119258/contributions/4868422/attachments/2469663/4237021/SPS_Yi.pdf

3. 65th ICFA Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders (eeFACT2022), "Spin Polarization Simulations for the Future Circular Collider e+e- using Bmad", https://agenda.infn.it/event/21199/contributions/173705/attachments/96356/132688/Yi_eeFACT2022.pdf

4. 2nd FCC Polarization Workshop, "FCCee Polarization studies with BMAD", https://indico.cern.ch/event/1181966/contributions/5051868/attachments/2514025/4321752/Yi_EPOL2022.pdf

5. FCC-FS EPOL group and FCCIS WP2.5 meeting 5, "Exploration of spin polarization simulations in the FCC-ee using Bmad"

https://indico.cern.ch/event/1119730/contributions/4701839/attachments/2380319/4176854/EPOL_pre_Yi.pdf

6. FCC-FS EPOL group and FCCIS WP2.5 meeting 16, “Updates on spin polarization study”, https://indico.cern.ch/event/1223987/contributions/5149147/attachments/2568348/4428399/EPOL_Dec.pdf

7. EPFL Master thesis, “Simulations of the Spin Polarization for the Future Circular Collider e+e- using Bmad”