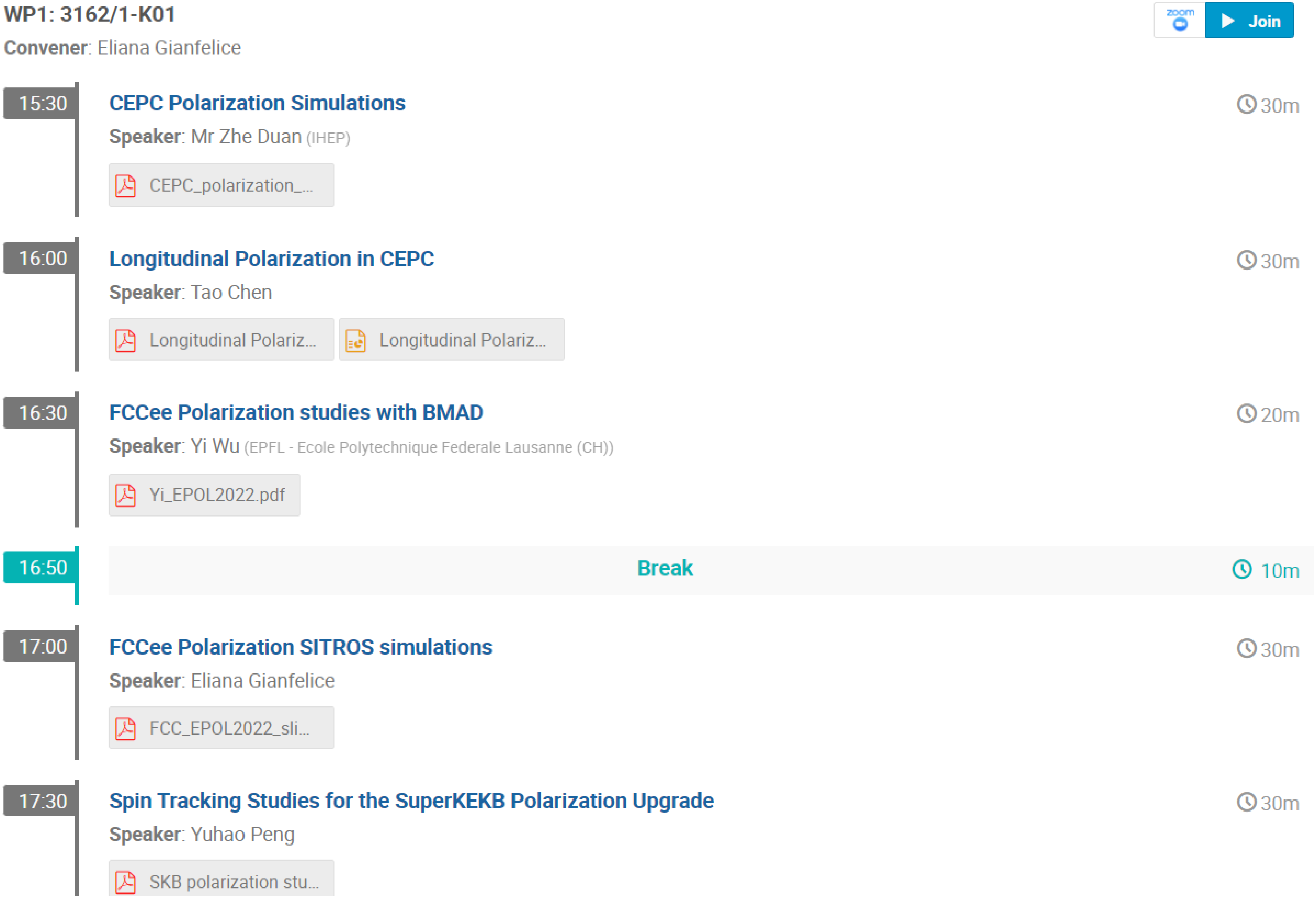
Achievements and open questions WP1

Speakers:
Eliana Gianfelice, Ivan Koop (BINP), Dr Tatiana Pieloni (EPF Lausanne)

Ivan Koop

EPOL-2022, September 23, 2022



WP1: 3162/1-K01

Convener: Eliana Gianfelice

15:30 **CEPC Polarization Simulations** — 30m

Speaker: Mr Zhe Duan (IHEP)

CEPC_polarization_...

16:00 **Longitudinal Polarization in CEPC** — 30m

Speaker: Tao Chen

Longitudinal Polariz... Longitudinal Polariz...

16:30 **FCCee Polarization studies with BMAD** — 20m

Speaker: Yi Wu (EPFL - Ecole Polytechnique Federale Lausanne (CH))

Yi_EPOL2022.pdf

16:50 **Break** — 10m

17:00 **FCCee Polarization SITROS simulations** — 30m

Speaker: Eliana Gianfelice

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17:30 **Spin Tracking Studies for the SuperKEKB Polarization Upgrade** — 30m

Speaker: Yuhao Peng

SKB polarization stu...

Zhe Duan: Overall progress in CEPC polarization studies

- Study of the radiative depolarization effects in CEPC collider rings [1] (this talk)
  - Spin tracking simulations for CEPC CDR lattice
  - Comparison between simulations with theories
- Longitudinally polarized colliding beams (Tao Chen’s talk)
  - Polarization maintenance via the “spin resonance free” feature of the CEPC booster lattice [2,3]
  - Spin rotator design at CEPC-Z energy [4]
- Resonant depolarization (Sep 29 WP1 talk)
  - The option to prepare polarized e+/e- bunches from the injector
- Compton polarimeter via scattered electron distribution [5]

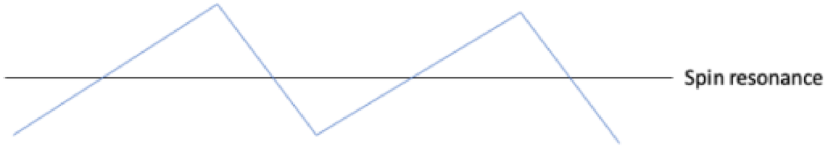
[1] W. H. Xia, Z. Duan, Y. W. Wang, B. Wang, J. Gao, arXiv:2204.12718v1 [physics.acc-ph]
[2] V. Ranjbar, et al., PRAB 21, 111003 (2018). [3] Z. Duan, presentation at eeFACT 2022.
[4] W. Xia et al., RDTM (2022) doi: 10.1007/s41605-022-00344-2
[5] S. H. Chen et al., JINST 17, P08005, (2022)

Zhe Duan:
Correlated and uncorrelated regime of spin resonance crossing

- Follow the "dynamical picture" [1] that the instantaneous spin precession rate ν_s is dependent on the instantaneous energy deviation δ, underlying spin resonances could be crossed as a result of synchrotron oscillations
- The following two regimes of spin resonance crossing were also proposed in [1]
  - Correlated regime: $\kappa = \frac{\nu_0^2 \lambda_p}{\nu_z^3} \ll 1$
    - Non-resonant spin diffusion & perturbative treatment of $\frac{\partial \hat{n}}{\partial \delta}$ applies

$$\frac{\tau_p}{\tau_d} \approx \frac{11}{18} \sum_{k=n-l}^{n+l} \sum_{m=-\infty}^{\infty} \left(\frac{\nu_0^2 \left|\tilde{\omega}_k\right|^2 e^{-\sigma^2} I_m(\sigma^2)}{\left[(\nu_0 - k - m\nu_z)^2 - \nu_z^2\right]^2} + \frac{(\nu_0 - k)^2 |\tilde{\lambda}_k|^2 e^{-\sigma^2} I_m(\sigma^2)}{\left[(\nu_0 - k - m\nu_z)^2 - \nu_z^2\right]^2} \right)$$

Periodic crossing, w/ radiative diffusion



  - Uncorrelated regime:

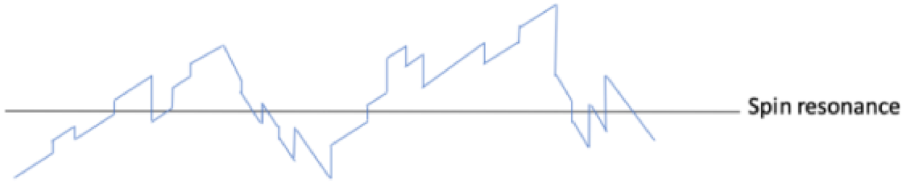
$$\kappa = \frac{\nu_0^2 \lambda_p}{\nu_z^3} \ll 1$$ is violated and $$\frac{\nu_0 \sigma_\delta}{\nu_z} \gg 1$$

    - Resonant spin diffusion

$$\lambda_d = \pi \sum_k \langle |\tilde{\epsilon}_k|^2 \delta(\nu - k) \rangle$$

$$\frac{\tau_p}{\tau_d} \approx \frac{\sqrt{\pi/2}}{\lambda_p} \sum_{k=n-l}^{n+l} \frac{|\tilde{\omega}_k|^2}{\sigma_0} \exp\left[\frac{-(\nu_0 - k)^2}{2\sigma_0^2}\right]$$

Periodic crossing, perturbed by radiative diffusion



[1] Derbenev, Kondrantenko and Skrinsky, Part. Accel. 9, 247 (1979)

Zhe Duan:

Case study: dependence on beam energy

- Increasing beam energy lead to larger σ_δ , modulation index σ and correlation index κ

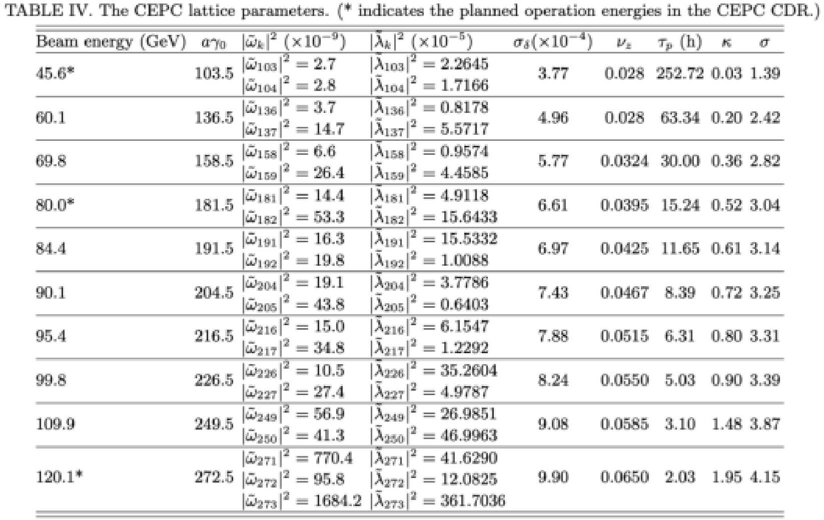
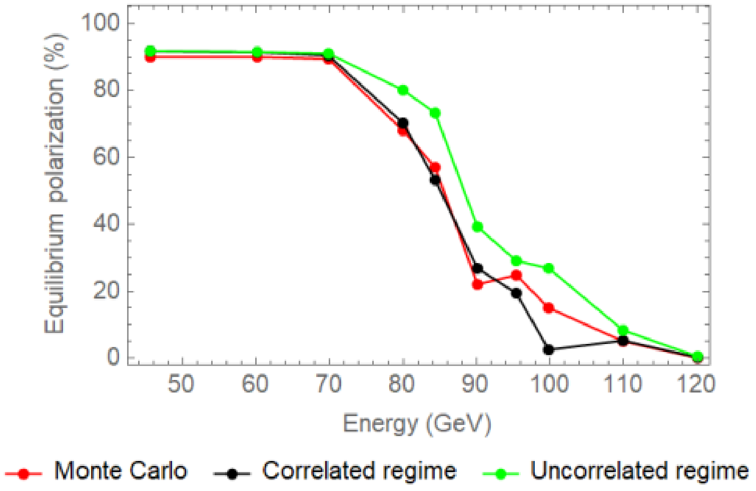
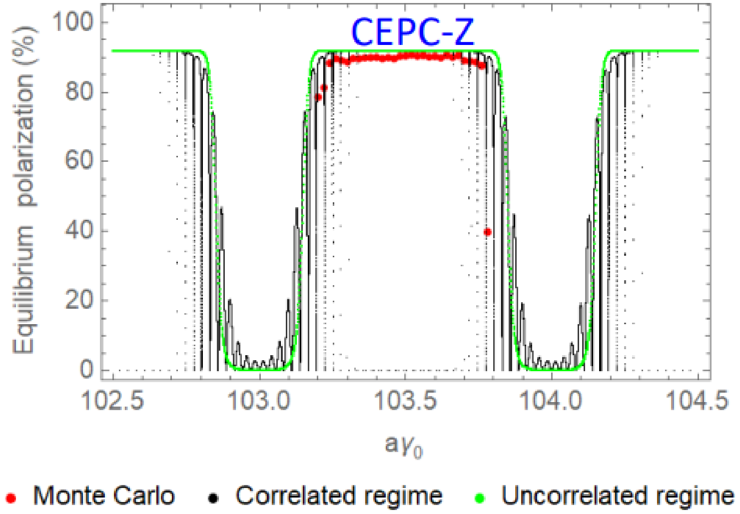
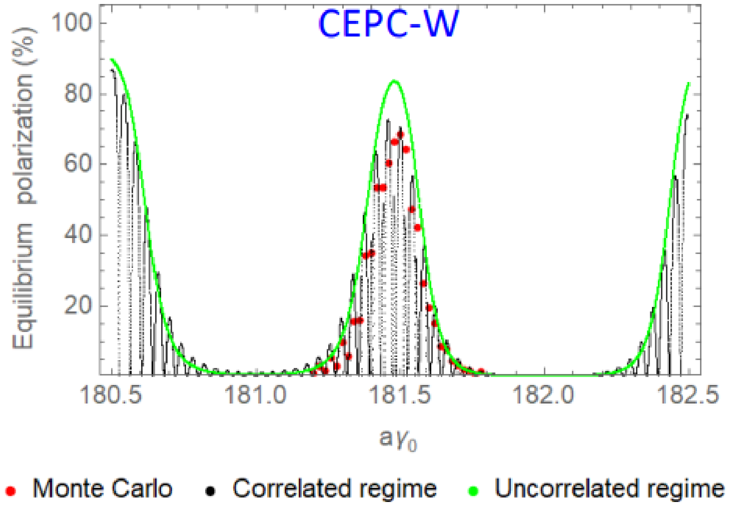


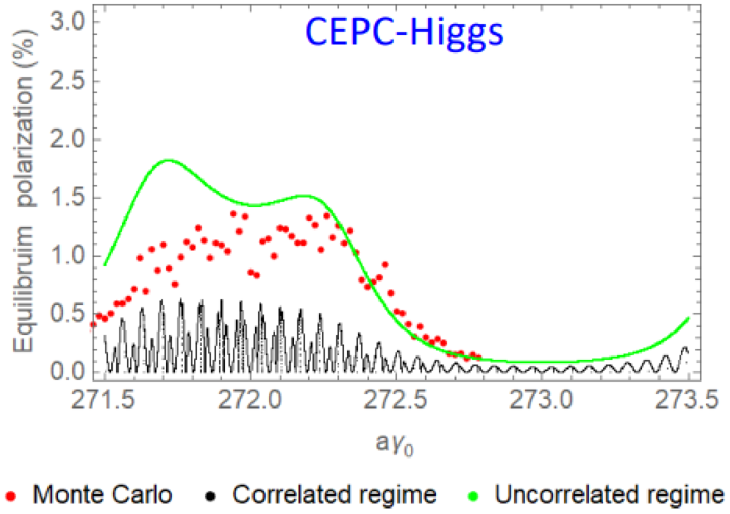
TABLE IV. The CEPC lattice parameters. (* indicates the planned operation energies in the CEPC CDR.)

Beam energy (GeV)	$a\gamma_0$	$\lvert\tilde{\omega}_k\rvert^2$ ($\times 10^{-9}$)	$\lvert\tilde{\lambda}_k\rvert^2$ ($\times 10^{-5}$)	$\sigma_\delta(\times 10^{-4})$	ν_z	τ_p (h)	κ	σ
45.6*	103.5	$\lvert\tilde{\omega}_{103}\rvert^2 = 2.7$ $\lvert\tilde{\omega}_{104}\rvert^2 = 2.8$	$\lvert\tilde{\lambda}_{103}\rvert^2 = 2.2645$ $\lvert\tilde{\lambda}_{104}\rvert^2 = 1.7166$	3.77	0.028	252.72	0.03	1.39
60.1	136.5	$\lvert\tilde{\omega}_{136}\rvert^2 = 3.7$ $\lvert\tilde{\omega}_{137}\rvert^2 = 14.7$	$\lvert\tilde{\lambda}_{136}\rvert^2 = 0.8178$ $\lvert\tilde{\lambda}_{137}\rvert^2 = 5.5717$	4.96	0.028	63.34	0.20	2.42
69.8	158.5	$\lvert\tilde{\omega}_{158}\rvert^2 = 6.6$ $\lvert\tilde{\omega}_{159}\rvert^2 = 26.4$	$\lvert\tilde{\lambda}_{158}\rvert^2 = 0.9574$ $\lvert\tilde{\lambda}_{159}\rvert^2 = 4.4585$	5.77	0.0324	30.00	0.36	2.82
80.0*	181.5	$\lvert\tilde{\omega}_{181}\rvert^2 = 14.4$ $\lvert\tilde{\omega}_{182}\rvert^2 = 53.3$	$\lvert\tilde{\lambda}_{181}\rvert^2 = 4.9118$ $\lvert\tilde{\lambda}_{182}\rvert^2 = 15.6433$	6.61	0.0395	15.24	0.52	3.04
84.4	191.5	$\lvert\tilde{\omega}_{191}\rvert^2 = 16.3$ $\lvert\tilde{\omega}_{192}\rvert^2 = 19.8$	$\lvert\tilde{\lambda}_{191}\rvert^2 = 15.5332$ $\lvert\tilde{\lambda}_{192}\rvert^2 = 1.0088$	6.97	0.0425	11.65	0.61	3.14
90.1	204.5	$\lvert\tilde{\omega}_{204}\rvert^2 = 19.1$ $\lvert\tilde{\omega}_{205}\rvert^2 = 43.8$	$\lvert\tilde{\lambda}_{204}\rvert^2 = 3.7786$ $\lvert\tilde{\lambda}_{205}\rvert^2 = 0.6403$	7.43	0.0467	8.39	0.72	3.25
95.4	216.5	$\lvert\tilde{\omega}_{216}\rvert^2 = 15.0$ $\lvert\tilde{\omega}_{217}\rvert^2 = 34.8$	$\lvert\tilde{\lambda}_{216}\rvert^2 = 6.1547$ $\lvert\tilde{\lambda}_{217}\rvert^2 = 1.2292$	7.88	0.0515	6.31	0.80	3.31
99.8	226.5	$\lvert\tilde{\omega}_{226}\rvert^2 = 10.5$ $\lvert\tilde{\omega}_{227}\rvert^2 = 27.4$	$\lvert\tilde{\lambda}_{226}\rvert^2 = 35.2604$ $\lvert\tilde{\lambda}_{227}\rvert^2 = 4.9787$	8.24	0.0550	5.03	0.90	3.39
109.9	249.5	$\lvert\tilde{\omega}_{249}\rvert^2 = 56.9$ $\lvert\tilde{\omega}_{250}\rvert^2 = 41.3$	$\lvert\tilde{\lambda}_{249}\rvert^2 = 26.9851$ $\lvert\tilde{\lambda}_{250}\rvert^2 = 46.9963$	9.08	0.0585	3.10	1.48	3.87
120.1*	272.5	$\lvert\tilde{\omega}_{271}\rvert^2 = 770.4$ $\lvert\tilde{\omega}_{272}\rvert^2 = 95.8$ $\lvert\tilde{\omega}_{273}\rvert^2 = 1684.2$	$\lvert\tilde{\lambda}_{271}\rvert^2 = 41.6290$ $\lvert\tilde{\lambda}_{272}\rvert^2 = 12.0825$ $\lvert\tilde{\lambda}_{273}\rvert^2 = 361.7036$	9.90	0.0650	2.03	1.95	4.15









Zhe Duan:

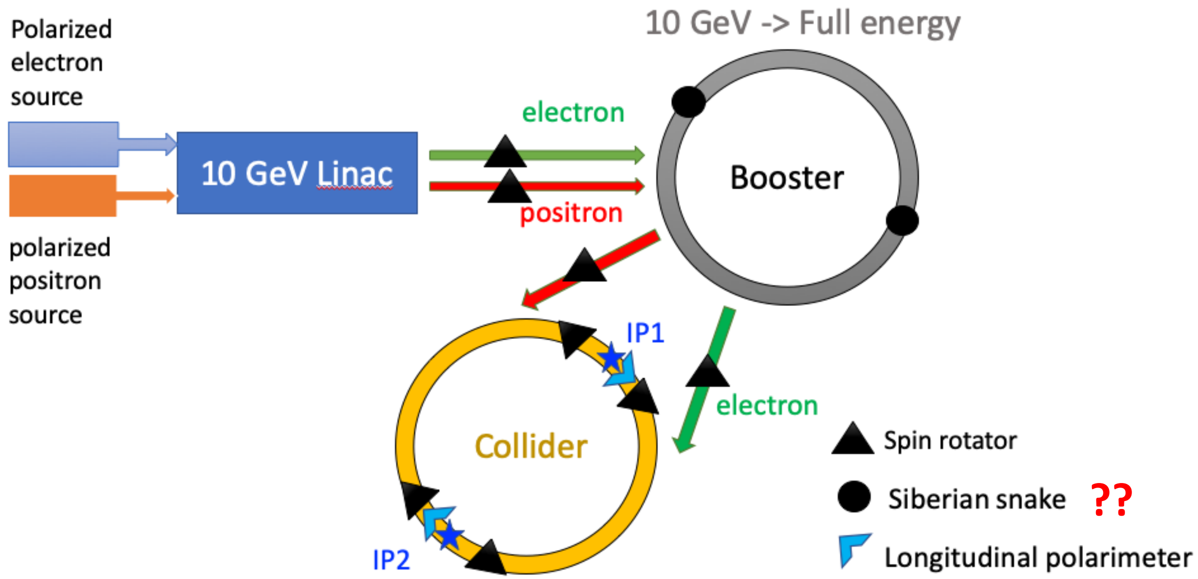
Summary

- We compared Monte-Carlo simulation of the radiative depolarization versus the two distinct theories that describe the influence of synchrotron oscillations & radiations at ultra-high beam energies.
- The comparison suggests a gradual evolution from the correlated regime to the uncorrelated regime, not clear at the moment. Work urgent is needed to clarify the theory. For example using the Bloch equation[1,2,3], that could merges into these theories at extremes.
- Generation of this study to more comprehensive lattice modeling and more error seeds is foreseen, for better understanding the radiative depolarization mechanisms and establishing correction methods to achieve a high beam polarization @ CEPC.

[1] Heinemann, et al., IJMP A 34, 1942032, (2019). [2] Bosnosov Ph. D Thesis, University of New Mexico (2020). [3] Heinemann, et al., IJMP A 34, 2041003 (2020).

Tao Chen: Longitudinal polarization @ CEPC

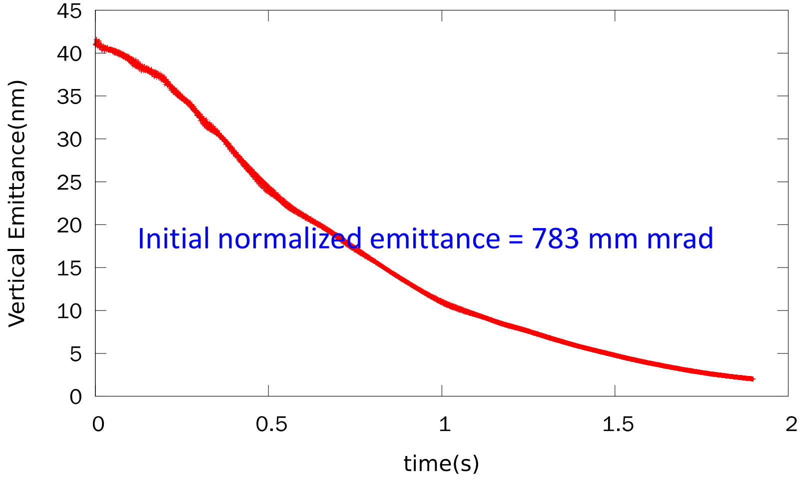
- In the injector: preparation and maintenance of highly polarized e- (e+) beam(s).
  - Polarized source: polarized e- gun (specs defined), polarized e+ source (preliminary study)
  - Booster: polarization maintenance (underway)
  - Transfer lines: ensure the matching of polarization directions (to be studied)
- In the collider ring:
  - spin rotators - > longitudinal polarization[1] (don
  - ensure $\tau_{DK} \gg \tau_b$, then $P_{\text{avg}} \approx P_{\text{inj}}$
  - Compton polarimeter[2] (under way)



[1] W. H. Xia et al., RDTM (2022) doi: 10.1007/s41605-022-00344-2
[2] S. H. Chen et al., JINST 17, P08005, (2022)

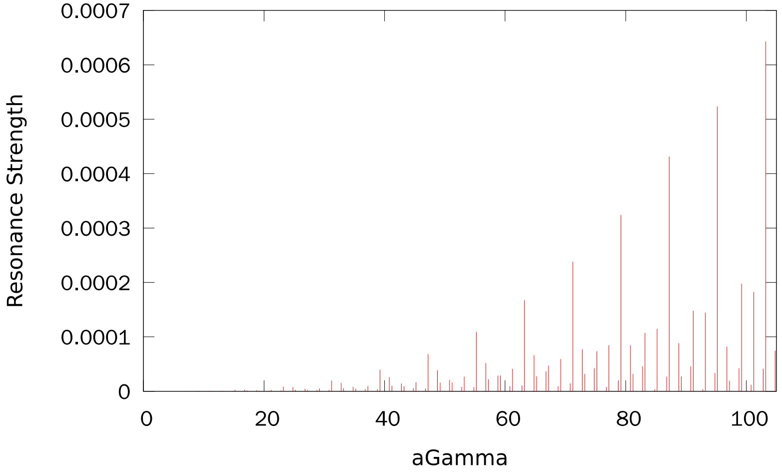
Tao Chen: Simulation of polarization transmission to 45.6 GeV

Evolution of vertical rms emittance

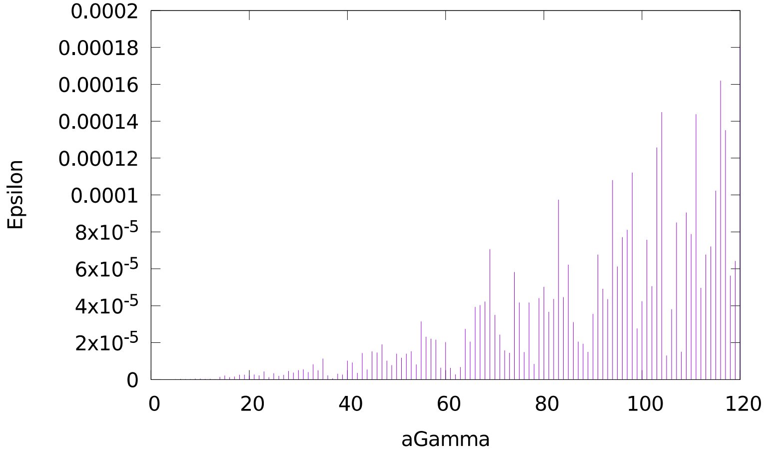


Initial normalized emittance = 783 mm mrad

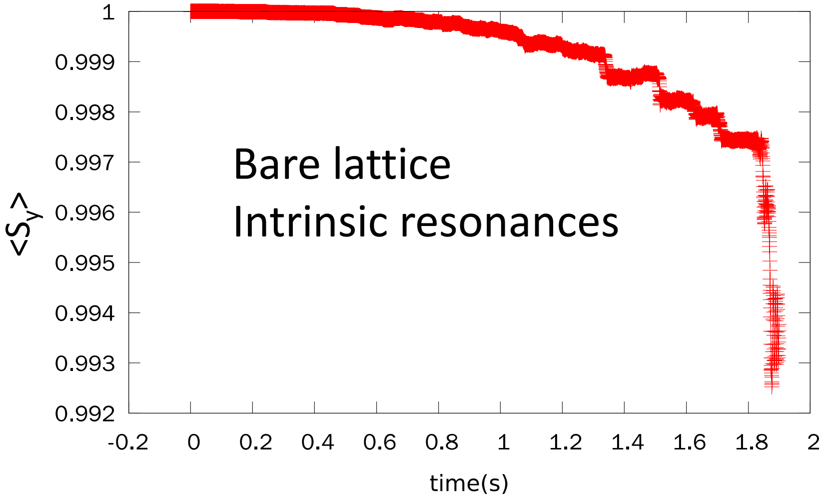
Intrinsic resonance strength scaled with emittance



Imperfection resonance strength

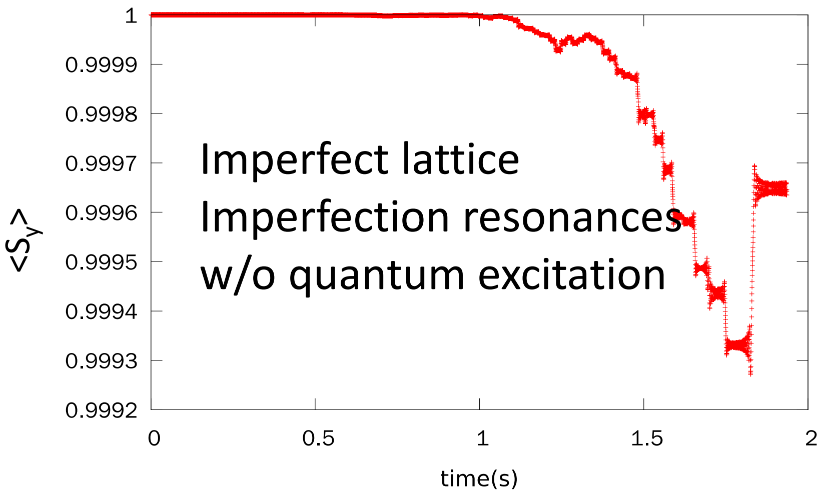


200 particles ,initial vertical emittance 40nm



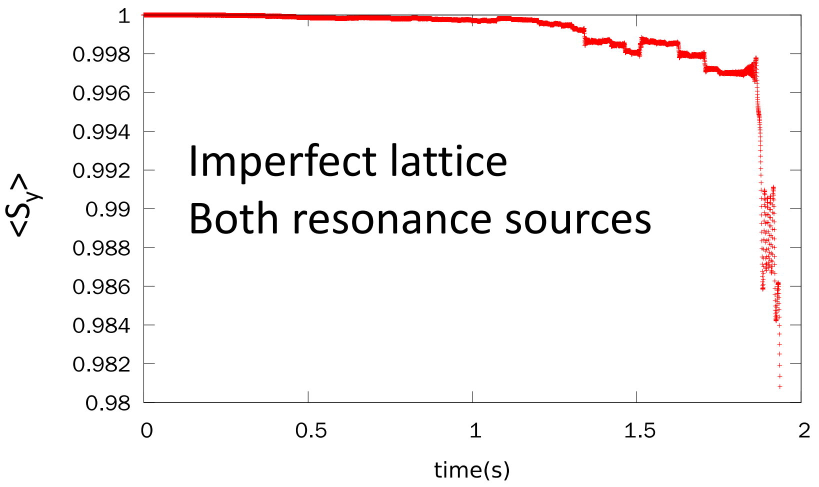
Bare lattice
Intrinsic resonances

On the closed orbit



Imperfect lattice
Imperfection resonances
w/o quantum excitation

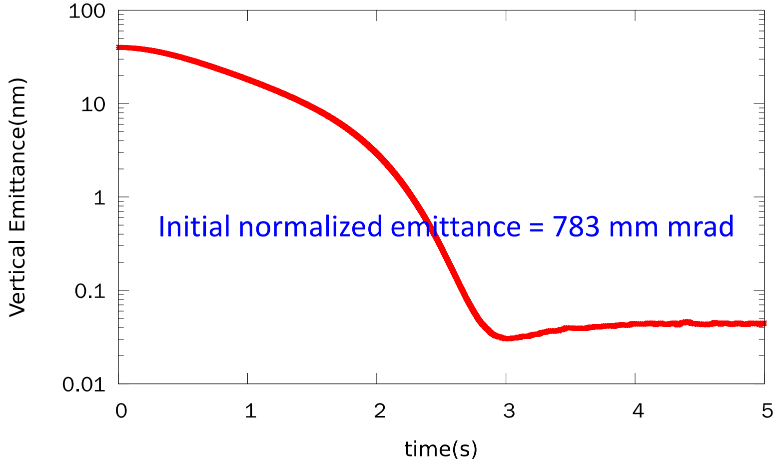
200 particles ,initial vertical emittance 40nm



Imperfect lattice
Both resonance sources

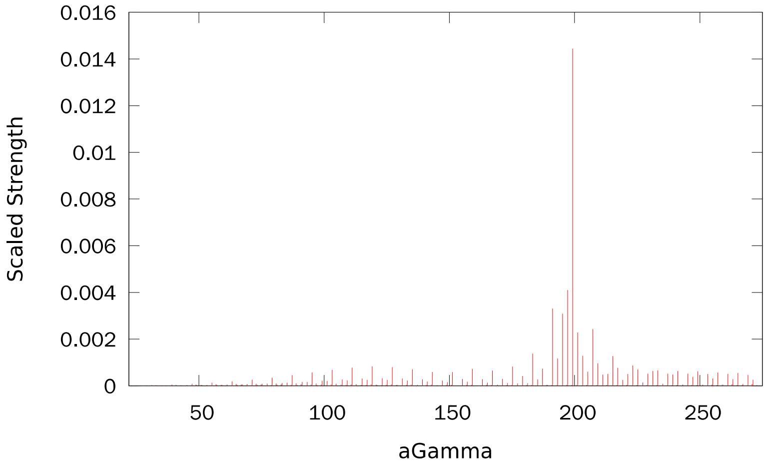
Tao Chen: Simulation of polarization transmission to 120 GeV

Evolution of vertical rms emittance

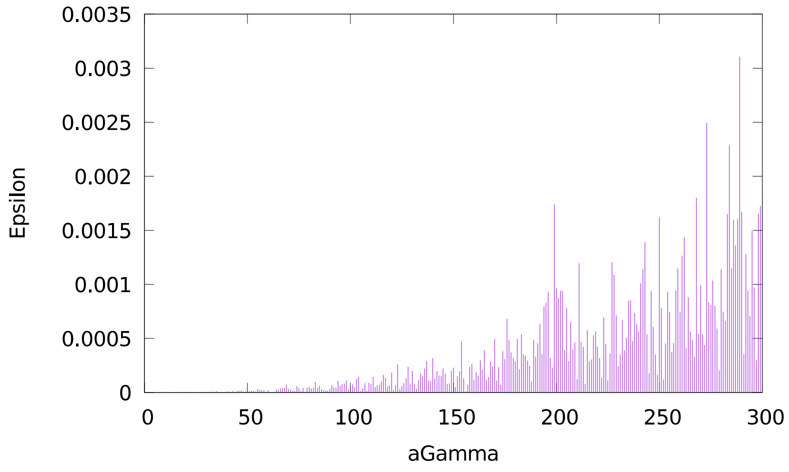


Initial normalized emittance = 783 mm mrad

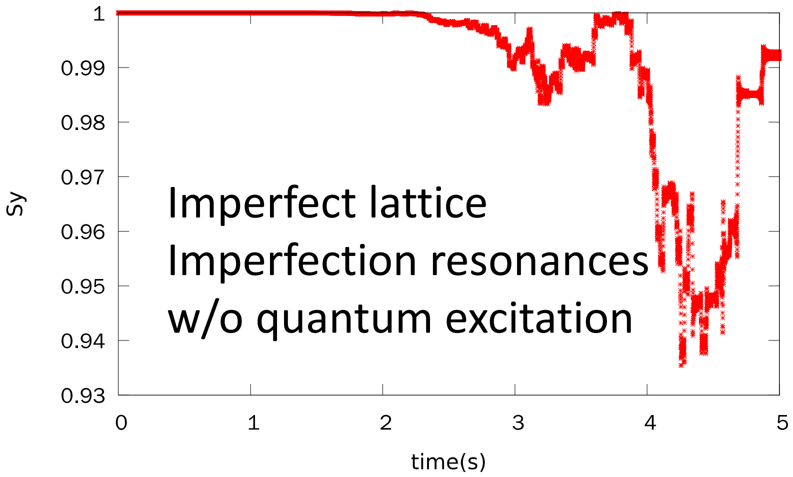
Intrinsic resonance strength scaled with emittance



Imperfection resonance strength

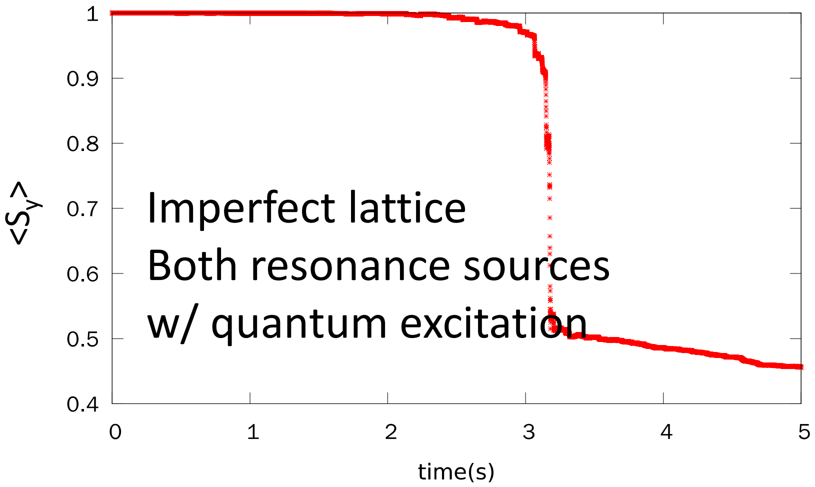


On the closed orbit

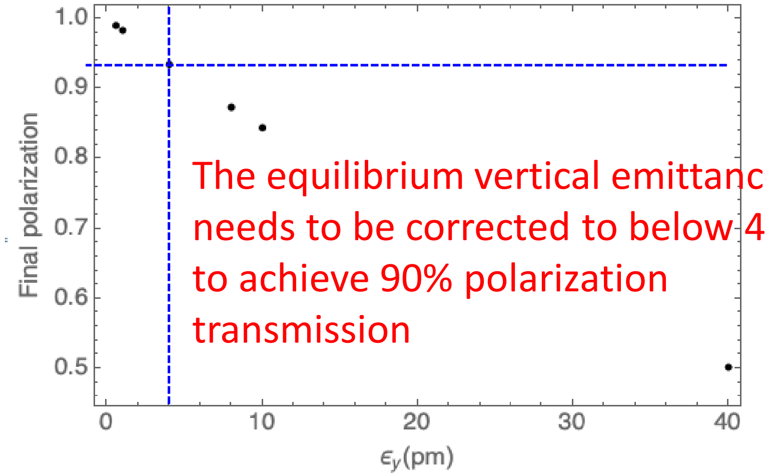


Imperfect lattice
Imperfection resonances
w/o quantum excitation

5000 particles, initial vertical emittance 40nm



Imperfect lattice
Both resonance sources
w/ quantum excitation



The equilibrium vertical emittance needs to be corrected to below 4 pm, to achieve 90% polarization transmission

Tao Chen: Short summary on polarization maintenance in booster

Findings:

- A large ramping rate of spin precession frequency α, due to the large circumference
- Spin resonances are generally weak, due to the high periodicity & cancellation
- Depolarization is negligible, in the fast crossing regime $\frac{\epsilon}{\sqrt{\alpha}} \ll 0.1$, up to 45.6 GeV
- The strong intrinsic resonance at ~ 87 GeV leads to large depolarization, and hurts the polarization transmission up to 120 GeV, potential mitigations:
  - A new lattice with the first strong intrinsic resonance larger than 120 GeV
    - The above study used the lattice of CDR， In the new design of TDR the condition is satisfied.
  - Control the vertical equilibrium beam emittance to below ~ 4 pm (coupling ~ 0.1%)
- Further research is needed on the tolerance of the highly efficient polarization transmission to the corrected closed-orbit amplitude

Ideas for longitudinal polarization at the Z/W/H/top factory

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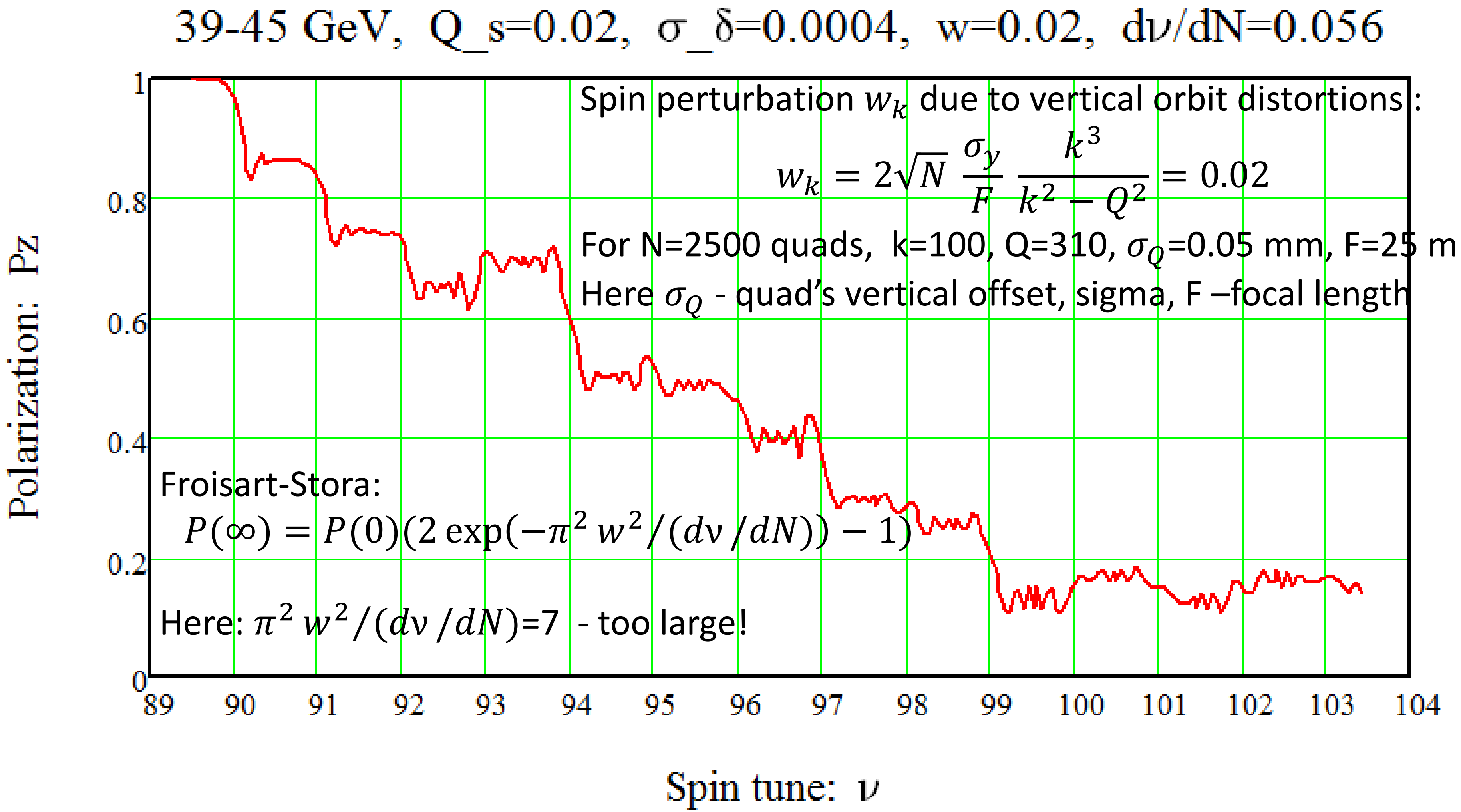
62nd ICFA Advanced Beam Dynamics Workshop
on High Luminosity Circular e^+e^- Colliders
(eeFACT2018)

HKUST, Hongkong, 24-27 September, 2018

Koop: option-2: Fast acceleration in a booster ring



39-45 GeV, Q_s=0.02, σ_δ=0.0004, w=0.02, dν/dN=0.056

Spin perturbation w_k due to vertical orbit distortions :

$$w_k = 2\sqrt{N}\,\frac{\sigma_y}{F}\,\frac{k^3}{k^2 - Q^2} = 0.02$$

For N=2500 quads, k=100, Q=310, σ_Q=0.05 mm, F=25 m

Here σ_Q - quad's vertical offset, sigma, F –focal length

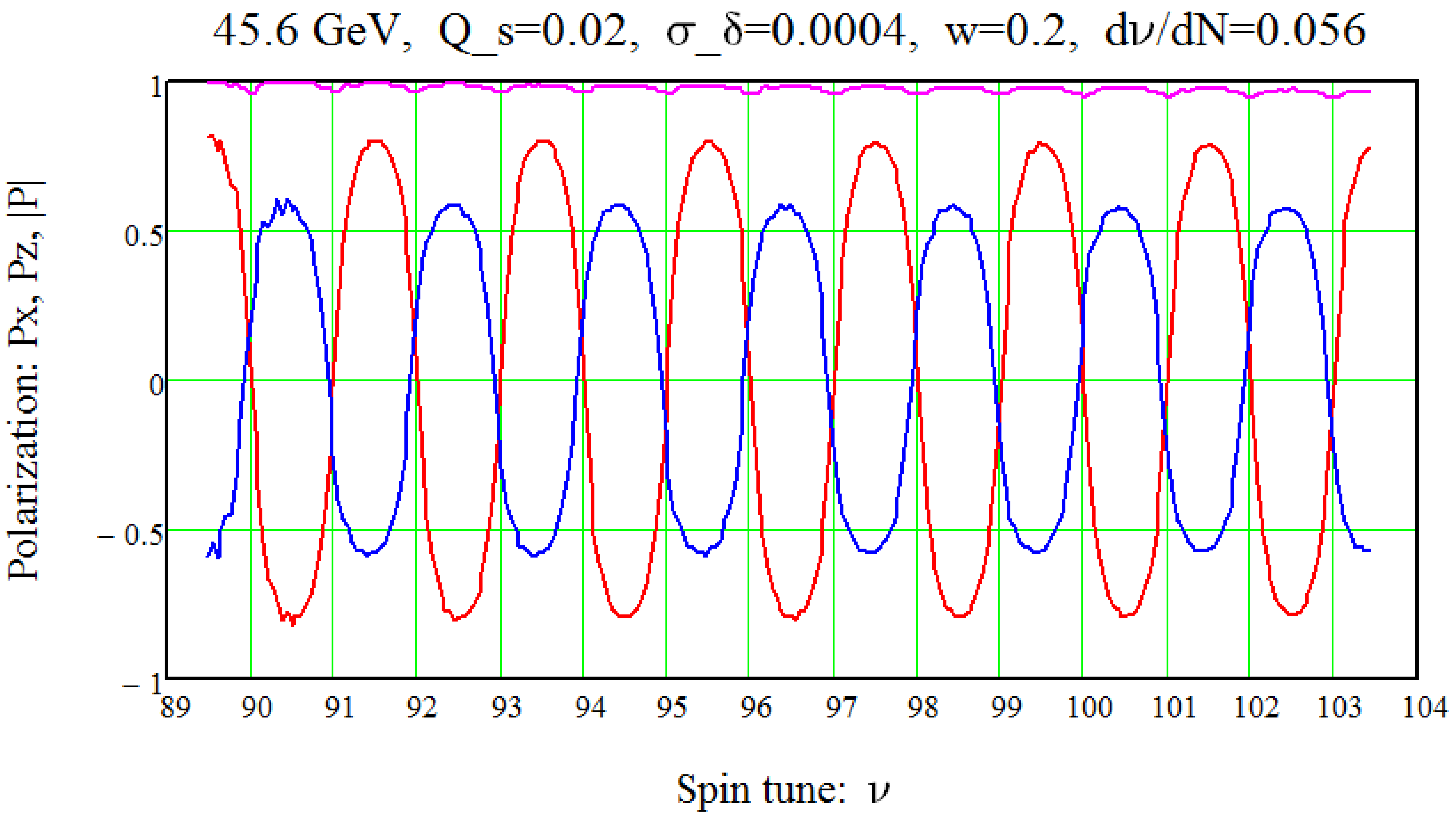
Froisart-Stora:

$$P(\infty) = P(0)\left(2\exp\left(-\pi^2 w^2/(d\nu/dN)\right) - 1\right)$$

Here: $\pi^2 w^2/(d\nu/dN)$=7 - too large!

As one can see, the presented here simulation shows very strong depolarization in the FCC-ee booster synchrotron during acceleration with the nominal ramp rate: 25 GeV/ 0.32 s. Besides, we can expect up to 3 times stronger harmonics due to statistical fluctuations.

Koop: option 3: Adiabatic crossing of integers near Z



Beam polarization is well preserved with the use of single Partial Snake for the acceleration in the FCC-ee booster ring. Polarization loss is only 3%, energy ramp rate 25 GeV/0.32 s.
Can use static solenoid with field integral BL=200 T·m. Then, at 20 GeV we will have w=0.5 (full snake!) and w=0.22 at 45.6 GeV. Quads of spin-rotator will ramp to keep $Q_{x,y} = const$.

Koop:

I schould check – how closed orbit distortion amplitudes used in my simulations in a toy ring are relevant to a real situation in the fast ramping booster synchrotron…

That strongly affects the parameters of a needed partial snake for adiabatic crossing of integer resonances.

And, probably, fast crossing can work without any problems? That is a simplest solution! EIC and CEPC rely on such approach!

Spin Polarization Simulations for the Future Circular Collider e+e- using BMAD

Yi Wu[1], Félix Carlier[2], Tatiana Pieloni[1]

[1] École Polytechnique Fédérale de Lausanne (EPFL)
[2] The European Organization for Nuclear Research (CERN)

Acknowledgments to Alain Blondel, Desmond Barber, David Sagan, Eliana Gianfelice-Wendt, Tessa Charles, Werner Herr, Léon Van Riesen-Haupt and all colleagues

Swiss Accelerator Research and Technology

Benchmark between Tao (BMAD) and SITF

- SITF, the linear spin simulation module in SITROS
- Underlying differences between two codes exist → check step by step

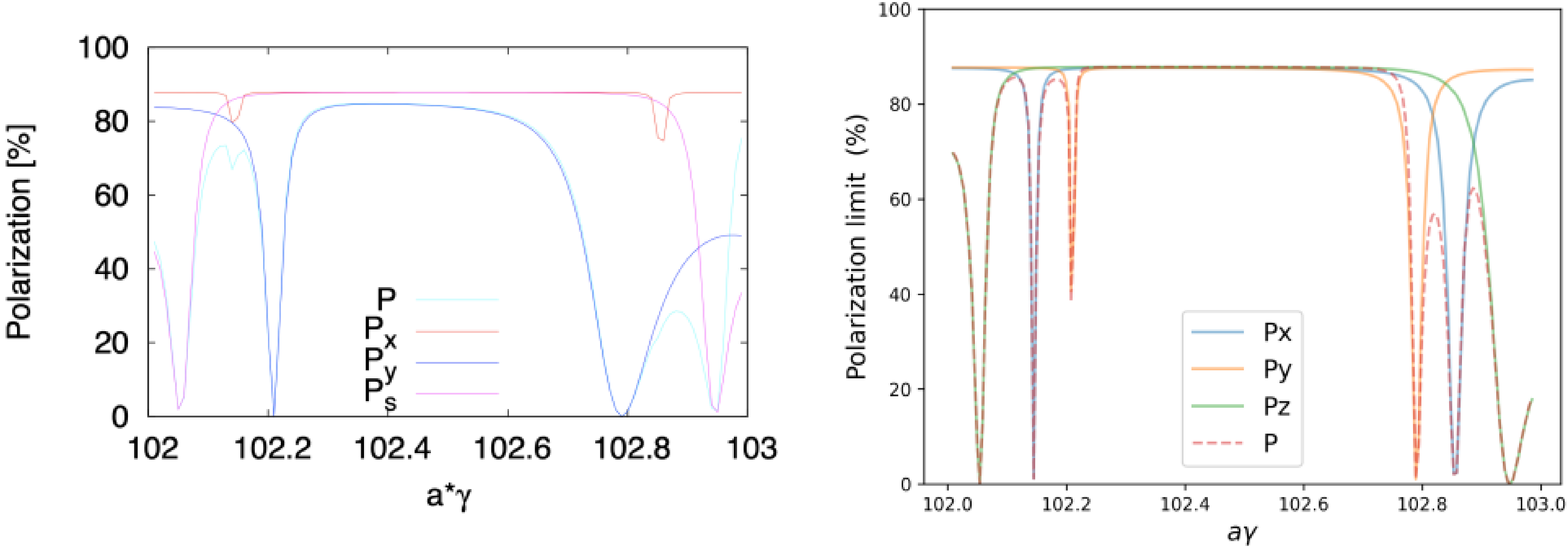


Figure: Energy scan using sequence version 213 seed 13 in SITF (left) and Tao (right)

FCCee Polarization simulations with SITROS

Content:

- Introduction
- Polarization wigglers
- Simulations at 45 and 80 GeV
- The importance of damping in the 8x8 matrix
- Summary

Eliana GIANFELICE (Fermilab)
EPOL2022, September 22, 2022

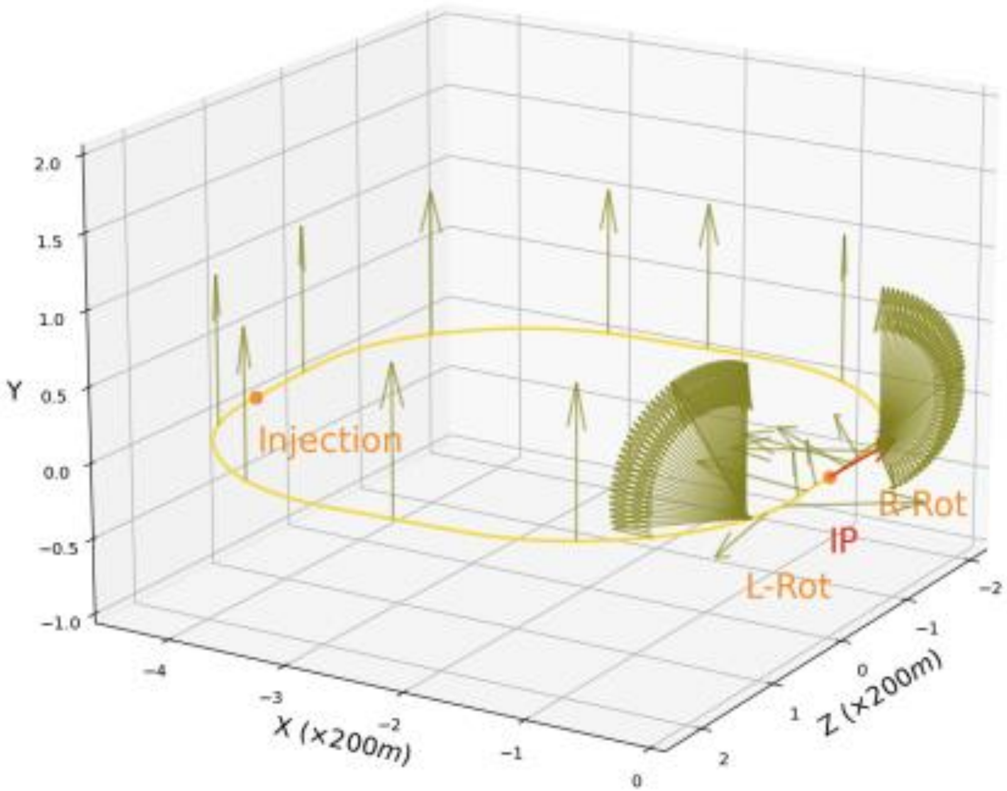
Eliana's **Summary**

Due to the demanding IR optics design and the machine size, establishing a closed orbit and keeping a stable machine look challenging.

- Beam polarization is obtained "for free" through Sokolov-Ternov effect.
  - At 45 GeV wigglers are required to get $\tau_{10\%} \approx$ 2-3 h.
    They do not harm polarization.
- P_∞ depends on how well is the machine aligned/corrected, requirements becoming stricter at high energy.
  - Extremely well corrected orbit/optics is required for a large chromatic machine with β_y^*=0.8 - 1 mm as FCC-ee to work and meet required performance.
    - ∗ This benefits also polarization.
- The puzzling small P_y, in particular at 80 GeV, has been likely understood.

Thanks!

Spin Studies with BMAD for a SuperKEKB Polarization Upgrade



Yuhao Peng

University of Victoria

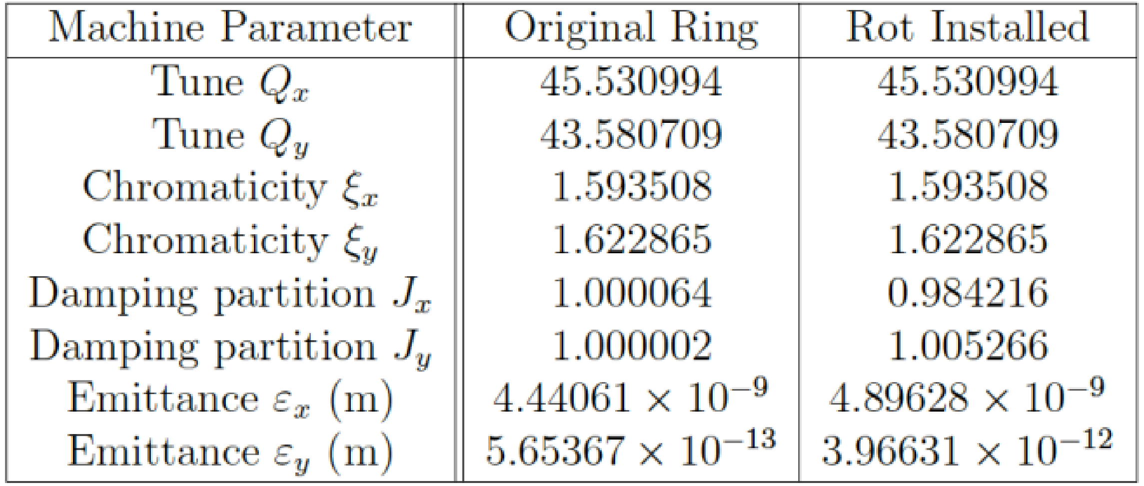
2022.09.22

- Sextupole pairs locates at the Rotator tuning area are turned off because the phase difference between these identical pairs is no longer π (the condition to cancel out the non-linear effects)

- Adjust sextuples in 4 arc section (45 pairs) shown in the picture above to match the original Chromaticity

University of Victoria

Ring Parameters Comparison after performing the closed-geometry optimization



Machine Parameter	Original Ring	Rot Installed
Tune Q_x	45.530994	45.530994
Tune Q_y	43.580709	43.580709
Chromaticity ξ_x	1.593508	1.593508
Chromaticity ξ_y	1.622865	1.622865
Damping partition J_x	1.000064	0.984216
Damping partition J_y	1.000002	1.005266
Emittance ε_x (m)	4.44061×10^{-9}	4.89628×10^{-9}
Emittance ε_y (m)	5.65367×10^{-13}	3.96631×10^{-12}

Tune and Chromaticity are matched to the original

Conclusion

Acceleration of polarized beams (both – e+ and e-) in a booster – most challenging and most attractive solution. Shall study seriously!

Simulation codes are developing, but need to be faster and become more friendly for users, as MADx and other accelerator codes.