Resonant Depolarization at CEPC

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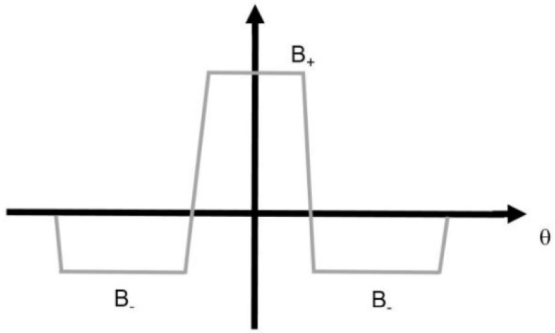
Outline

- Operation scenario 1: self-polarization
- Operation scenario 2: injection of polarized beams
- Very preliminary simulations of Resonant Depolarization

Asymmetric wigglers @ Z-pole

- 10 units of wigglers implemented into CDR lattice, the influence to spin motion was simulated, the quantum lifetime associated with the much larger energy spread not yet evaluated (K. Oide, talk on FCC Week 2022)
- Wiggler parameters have been tentatively determined, which help reduce the polarization build-up time to 20 hours.



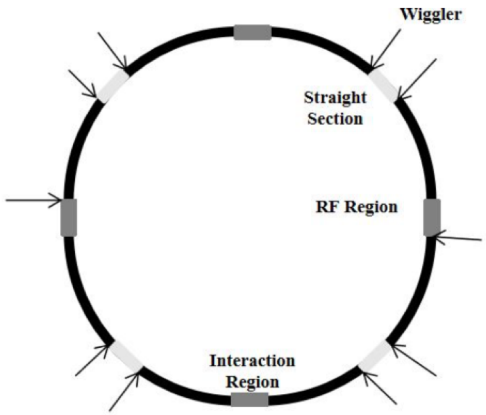
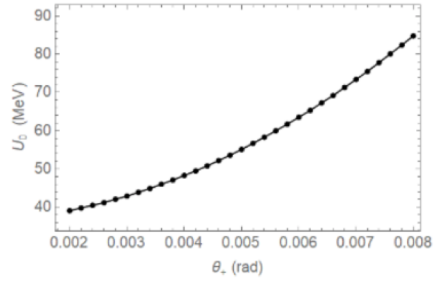


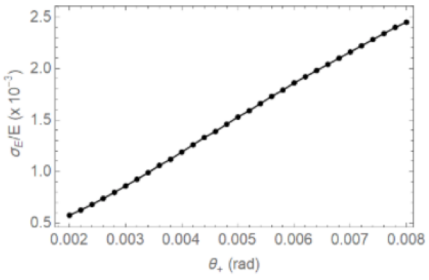
Table 1. Influence asymmetric wigglers on the CEPC-Z beam parameters.

Wigglers	B_+(T)	L_+(m)	B_-(T)	L_-(m)	U_0 (MeV)	$\sigma_E/E(\times 10^{-4})$	τ_{BKS} (h)	P_∞(%)
Off	-	-	-	-	37	4	253	92
On	0.6	1	0.15	2	49	12	20	82

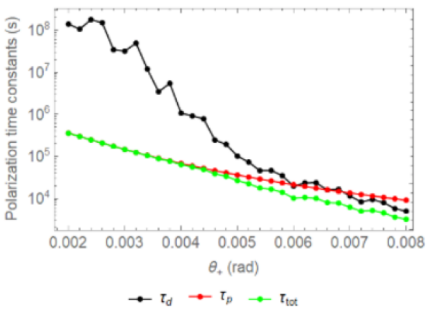
$\theta_+ = 0.0039$ rad



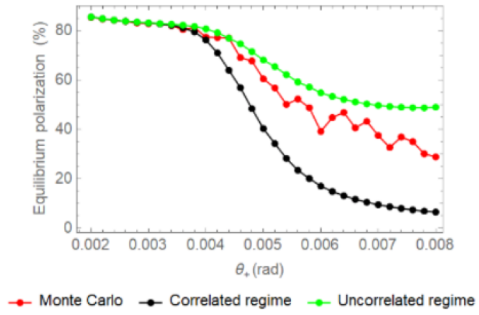
(a) U_0 vs. θ_+.



(b) σ_δ vs. θ_+.



(c) Polarization time constants vs. θ_+.



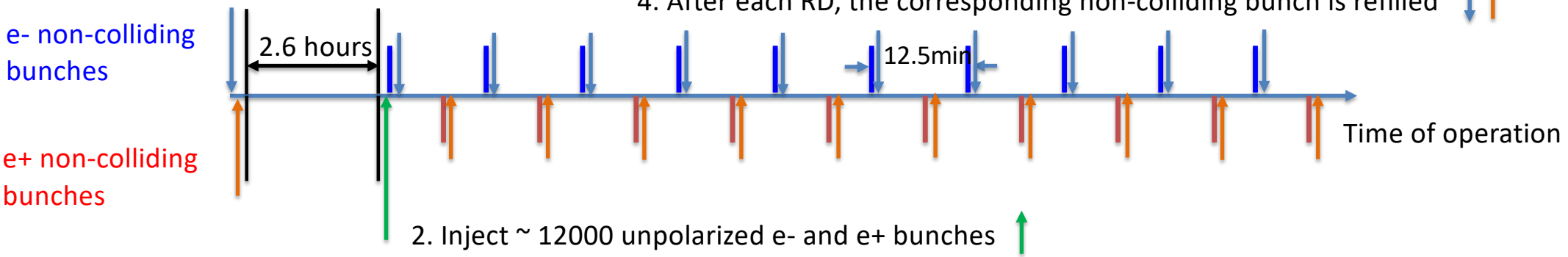
(d) P_{eq} vs. θ_+.

W. Xia et al., arXiv: 2204.12718 [physics.acc-ph]

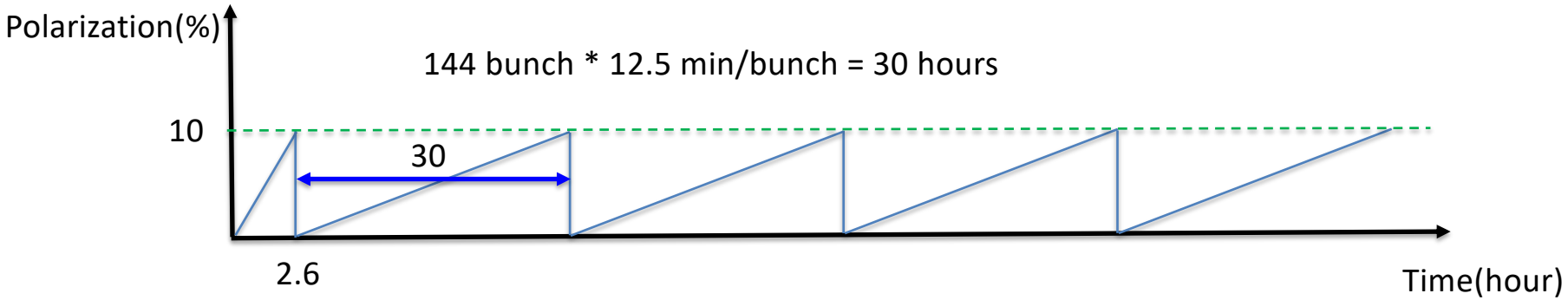
Operation scenario @ Z-pole

1. Inject 144 unpolarized non-colliding e+ and e- bunches
   - Turn-on asym. wigglers to boost self-polarization
     - Turn-off asym. wigglers

3. Resonant depolarization measurements
4. After each RD, the corresponding non-colliding bunch is refilled



2. Inject ~ 12000 unpolarized e- and e+ bunches
   - Start colliding beam experiments

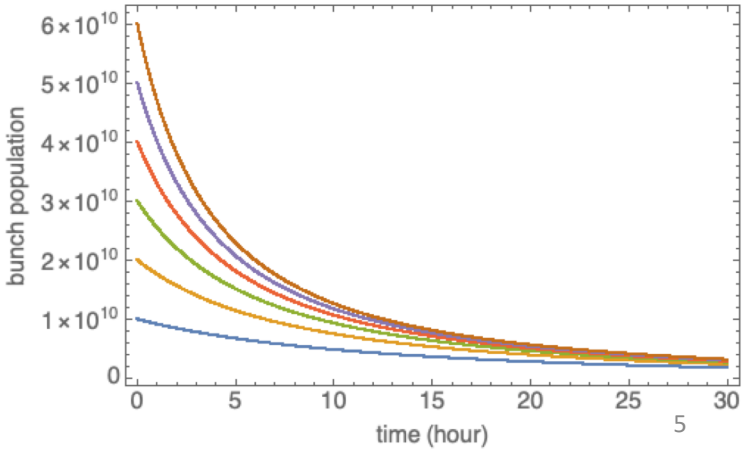


Non-colliding bunch population & lifetime when wigglers are switched off

- The Touschek lifetime for non-colliding bunches is 5.8 hours @ a bunch population of 4e10
- 30 hours after refill, the bunch population for RD measurements is on the order of 1~4e9, relevant for estimation of polarimeter statistical errors
- Tentatively, we consider a bunch population of 2e10 after refill, 1.8e10 (2.8nC) needs to be refilled after RD measurement
- The beam lifetime when wigglers are switched on will be simulated, from which we can estimate the initial bunch population to be injected.

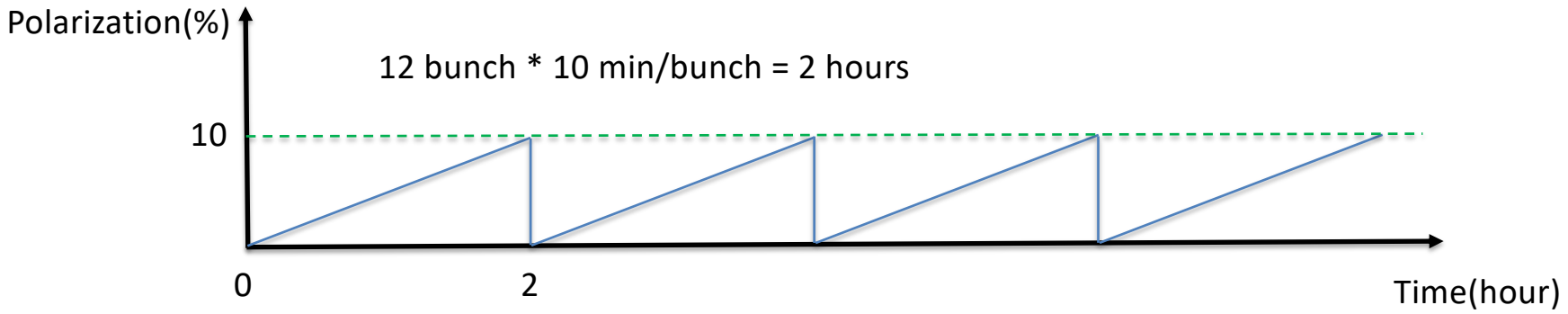
Parameter	Value
Energy (GeV)	45.6
Bunch population	4e10
Emittances (pm)	271.5 / 1.4
Rms energy spread	3.845e-4
Bunch length(mm)	4.2
Touschek lifetime(hour)	5.8

Simulated bunch population evolution



Operation scenaro @ W

- CEPC-W, τ_{BKS} ~ 15 hour， 2 hours to generate 10% polarization
- asymmetric wigglers not needed
- Assume 12 non-colliding bunches (colliding bunches ~1200) per beam
- Conduct RD every 10 minutes,
- Beam lifetime ~ 75 hour (CDR) for the bunch charge of colliding bunches
- Refill one bunch every 2 hours, 3% of bunch charge is needed



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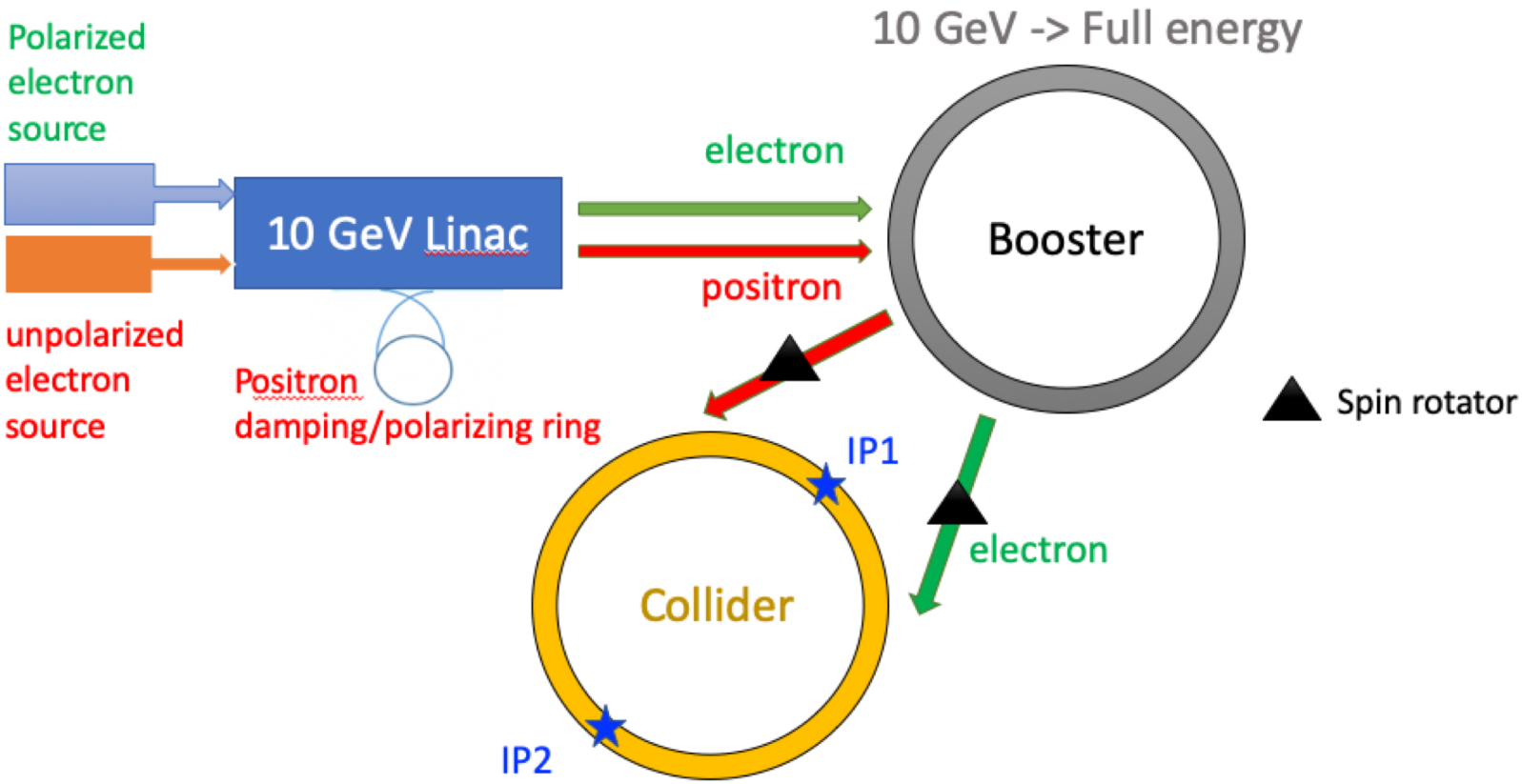
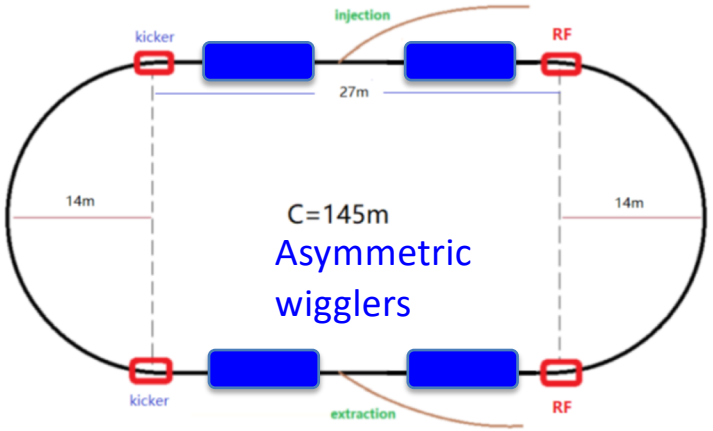
Basic setup of the injector chain

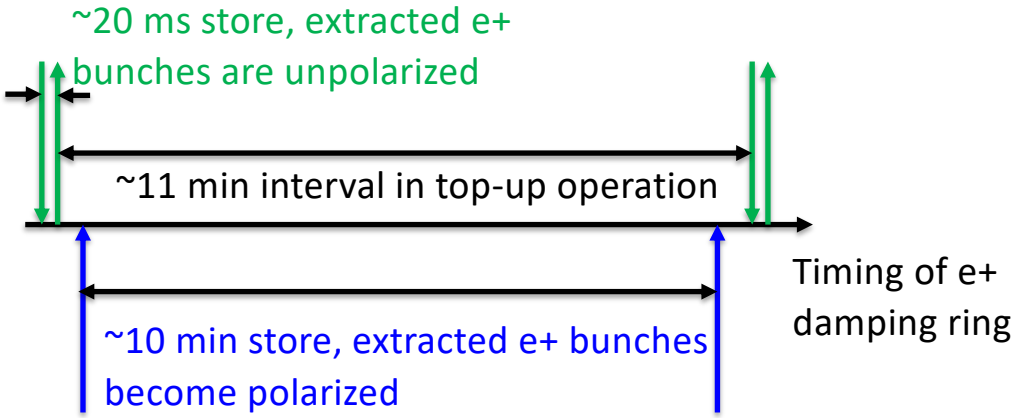


Addition of spin rotators in the collider ring would enable longitudinal polarized colliding beam experiments (see Tao Chen's talk on Sep 22 in this EPOL Workshop)

Polarized beam sources

- Polarized e- gun can supply > 80% polarization e- beams
- e+ damping/polarizing ring w/ asymmetric wigglers could deliver > 20% polarization in 10 min
  - 3-pole wiggler with a higher B+ part in the middle, two lower B- parts on both sides
  - Polarization level is sufficient for RD
  - Lattice design is under way





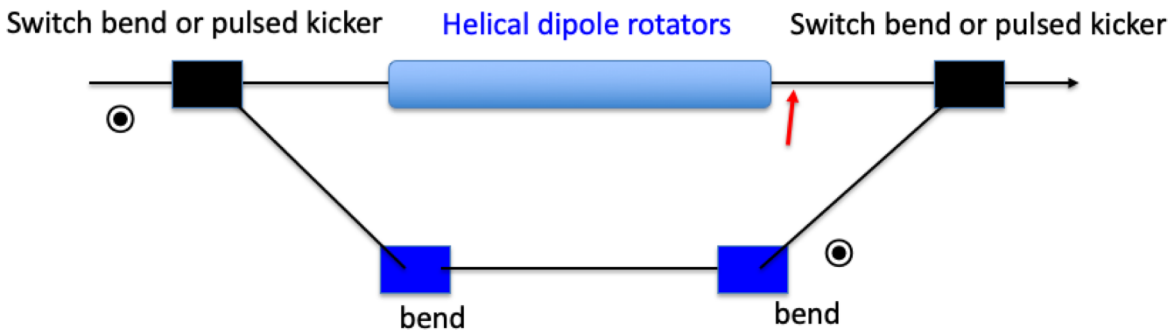
Parameter		Value
Beam energy, $a\gamma_0$		1.542 GeV, 3.5
Circumference		145m
Asymmetric wiggler	B+ / B-	3.3 T / 0.66 T
	Total length	6 m
P_∞ in the presence of wigglers		90%
Polarization build-up time τ_{BKS}	w/o wigglers	52 min
	w/ wigglers	34 min
Storage time		10 min
Polarization of extracted beam		22%

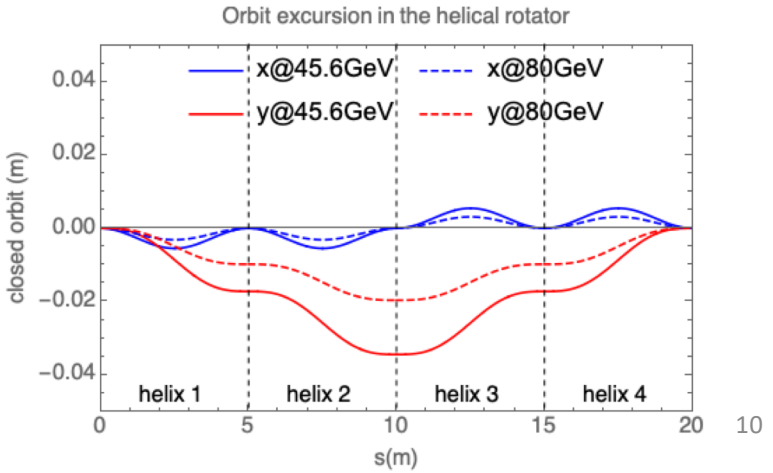
Polarized beam transmission in the injector

- "Resonance free" due to the ultra-high lattice periodicity & cancellation in CEPC booster, beam polarization is expected to be largely maintained (see Tao Chen's talk in Sep 22)

- Spin rotator in the booster-to-ring transport line
  - Vertical polarization at ring injection point in ordinary conditions
  - Horizontal polarization at ring injection point, for "free spin precession" measurement
  - Helical dipole as a potential candidate

Parameter		Value
Magnetic field (T)		0.658
Total length (m)		20
Relative SR energy loss U_0/E_b	45.6 GeV	5e-4
	80 GeV	8.8e-4





What we can gain from injected polarized beams?

- Higher level of beam polarization for pilot bunches
  - No initial 1~2 hours dead time for physics
  - No need of asymmetric wigglers in the rings
  - Beneficial for the “free spin precession” method?
  - More frequent beam energy measurements, at least for e- beam
- This could enable high level of beam polarization for specific colliding e+/e- bunches
  - Can we do RD measurements on colliding bunches?
    - Beam energy spread increase due to beamstrahlung
  - This might help crosscheck the difference versus pilot bunches (see K. Oide’s talk on Sep 19 this EPOL Workshop)

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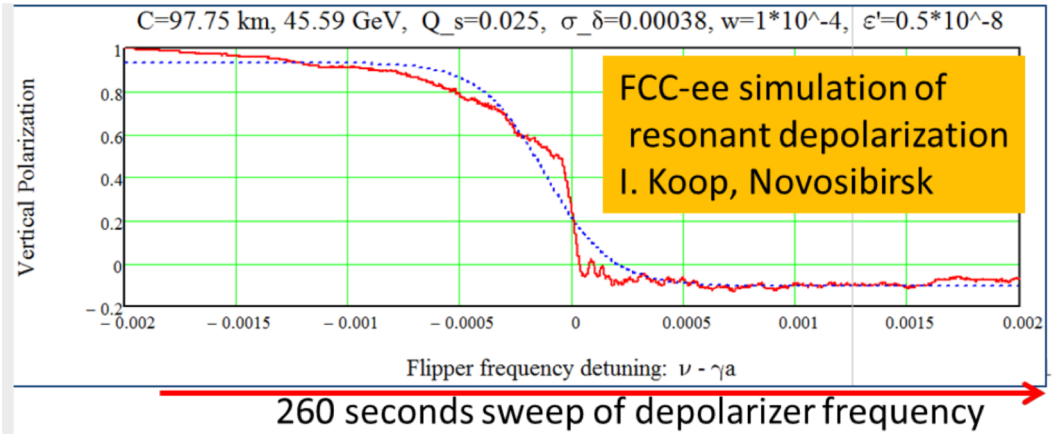
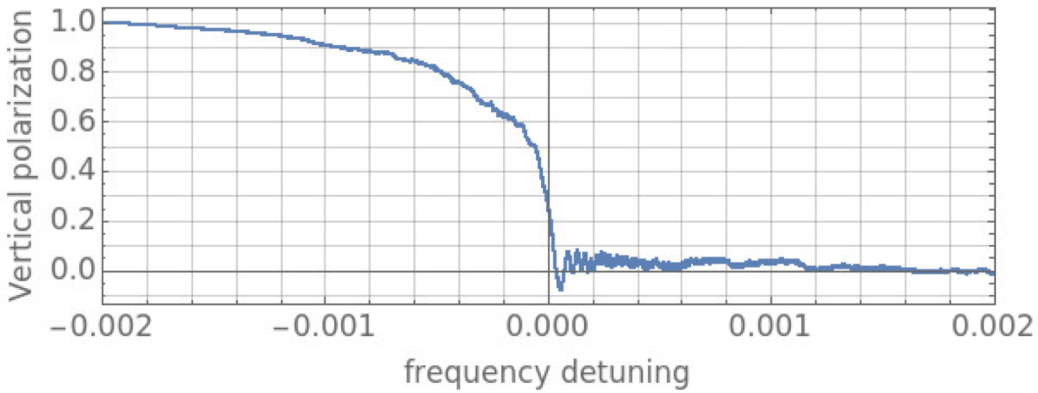
Simulation method and benchmark

- The resonant depolarization could take ~min in the real world (~100k turns at Z-pole), very time consuming using element-by-element spin tracking
- I. Koop's simplified model [1] is implemented in Mathematica, tracking 120 particles with a 120-core cluster cost a few minutes
  - One-turn map of synchrotron motion, lumped photon emission per turn
  - Spin precession
    - One-turn spin precession around vertical direction, machine imperfections not yet included
    - Spin precession around radial direction in the depolarizer



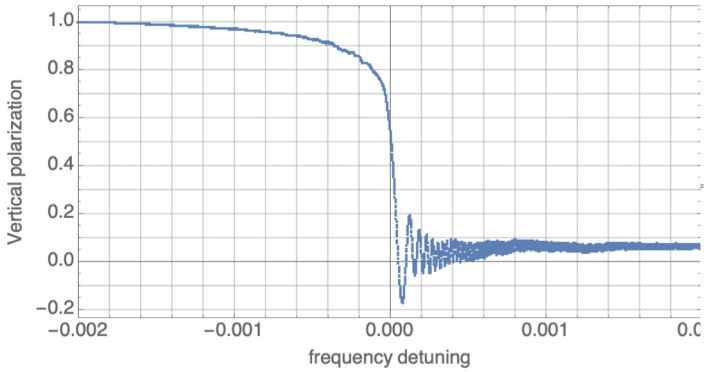


[1] I. Koop, EPOL Workshop 2017, eeFACT 2018, HKIAS mini workshop 2020, FCC Week 2022

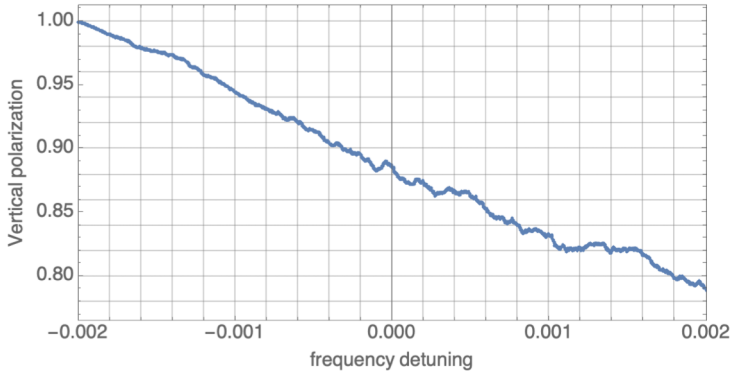
Simulations for CEPC parameters: long sweep

Cases	CEPC-Z pilot bunch	CEPC-Z colliding bunch	CEPC-W pilot bunch
$a\gamma_0$	103.4921	103.4921	181.5123
σ_δ	3.847e-4	1.3e-3	6.79e-4
ν_z	0.03448	0.03448	0.062
Modulation index	1.15	3.9	2.0
Resonance strength ω_K (Koop's definition)	1e-4	1e-4	1.5e-4
Scan rate $\varepsilon'=d\nu/dn$	1e-8	1e-8	2e-8
ω_K^2/ε'	1	1.	1.125
Scan time (s)	130	130	65

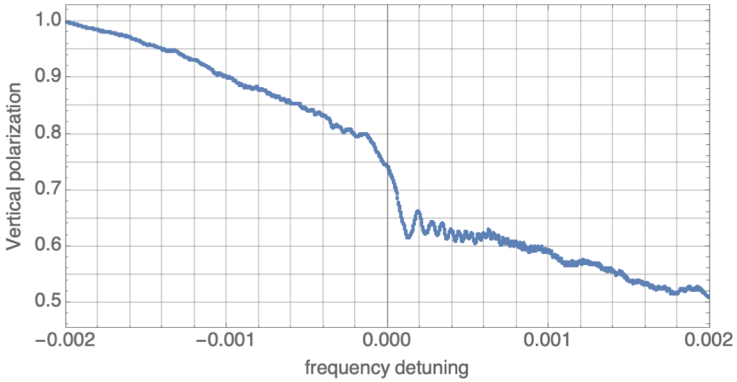
CEPC-Z pilot bunch



CEPC-Z colliding bunch



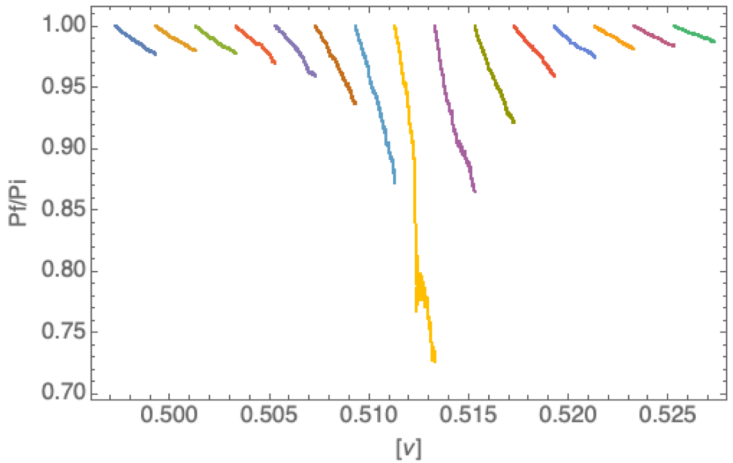
CEPC-W pilot bunch

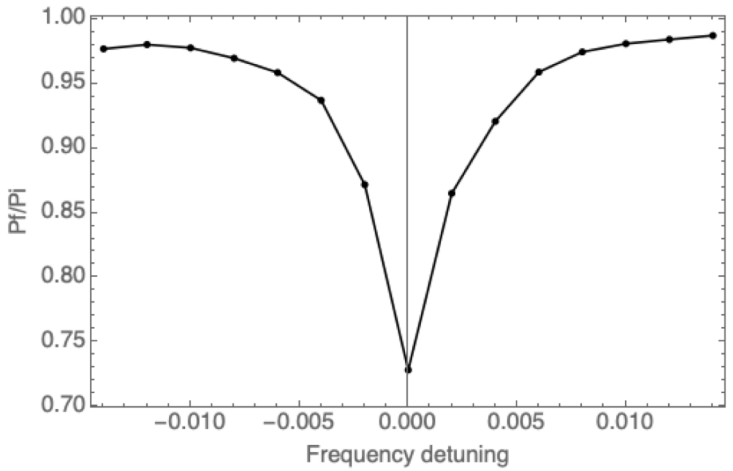


Simulations for CEPC parameters: LEP “multiple sweep” technique

- A few sweeps of depolarizer frequency, observe when most depolarization occurs.
- Question: can multiple sweep be used to measure the beam energy of colliding bunches at Z-pole, at what accuracy?
- More refined simulation of this procedure is needed.

CEPC-W pilot bunch



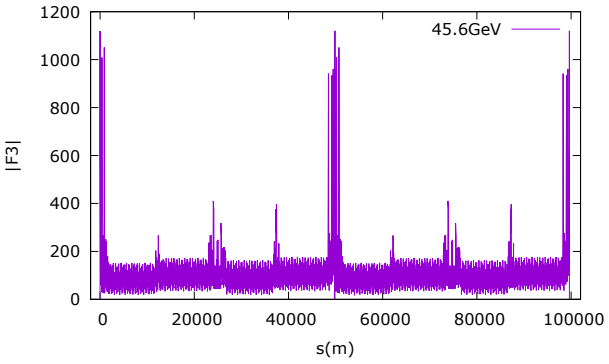


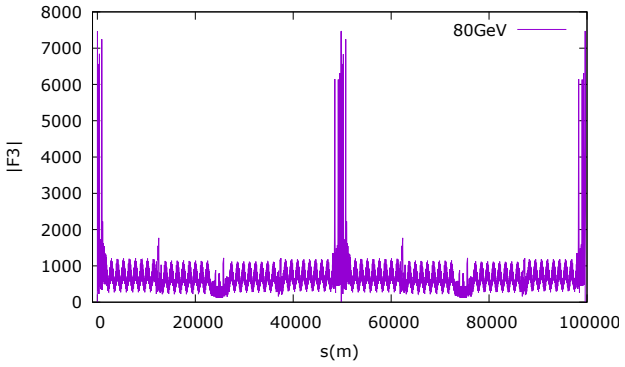
RF depolarizer parameters

- The amplitude of the force spin resonance $\epsilon_{\mathrm{dp}} = 0.5\omega_{\mathrm{K}} = \frac{1}{4\pi}|F_3|\theta_{orb}$
- Spin response function $|F_3|$ of CEPC TDR lattice w/ Bmad/PTC [1]
  - First order spin normal form to obtain $\frac{\partial \vec{n}}{\partial p_y}$

$$F_{3r} = \frac{\partial \mathbf{n}}{\partial p_y} \cdot \boldsymbol{\eta}_2 - (1+\nu_0)\eta_{1x}$$
$$F_{3i} = -\frac{\partial \mathbf{n}}{\partial p_y} \cdot \boldsymbol{\eta}_1 - (1+\nu_0)\eta_{2x}$$

- Assume the specs of bunch-by-bunch feedback kicker (Y. F. Sui), $\theta_{orb} = \sqrt{2PR}/(E_0/e)$





Parameter		Value
Kicker shunt impedance R(Ω)		155e3
Amplifier power (W)		2000
Maximum orbital deflection (μrad)	45.6 GeV	0.55
	80 GeV	0.31
ϵ_{dp}	45.6 GeV	4.3e-5
	80 GeV	1.7e-4

[1] S. R. Mane, PTC spin: benchmark tests for analytically solvable models, KEK Report 2009-8

Summary

- Two operation scenarios of RD measurements have been studied for CEPC. Injection of polarized e+/e- beams, if achieved, could provide some additional benefits.
- Very preliminary simulations of the RD process for CEPC are presented, a careful study of the multiple sweep technique and its accuracy is planned.

Thank you for your attention!

Non-colliding bunch population & lifetime when wigglers are switched off

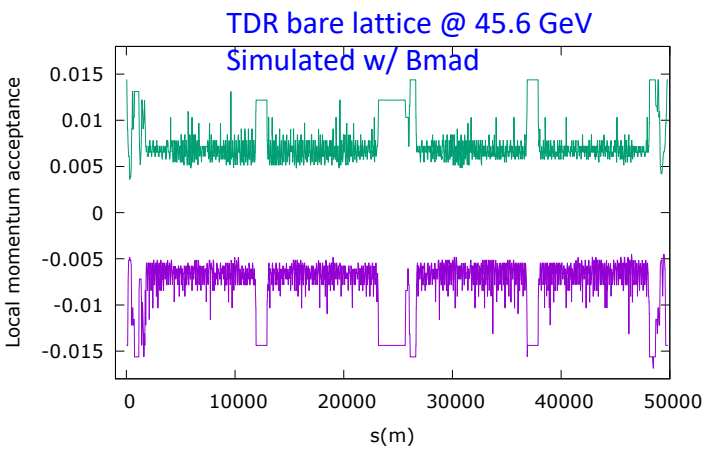
- Beam lifetime contributions
  - Touschek lifetime τ_t : 5.8 hour @ bunch population N = 4e10, τ_t scales with σ_z/N , bunch length σ_z [mm] = $2.55+0.64(N/10^{10})^{2/3}$
  - Beam-gas bremsstrahlung: 57 hours [1]
  - Beam-thermal photon scattering: 70 hours [1]

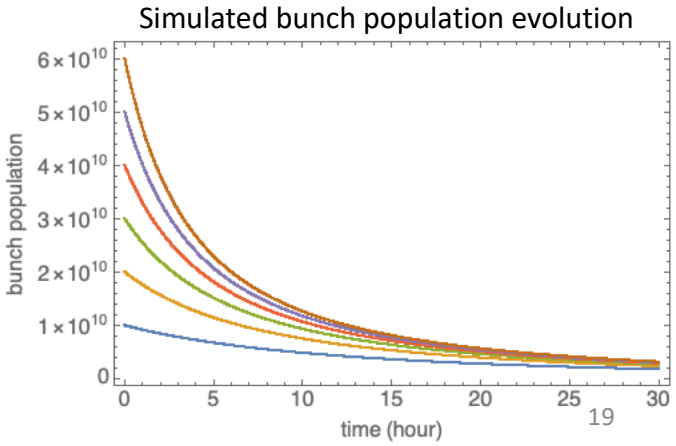
Potential well distortion, by Na Wang

- 30 hours after refill, the bunch population for RD measurements is on the order of 1~4e9, relevant for estimation of polarimeter statistical errors
- Tentatively, we consider a bunch population of 2e10 after refill, 1.8e10 (2.8nC) needs to be refilled after RD measurement
- We will determine the bunch charge for initial injection, according to the beam lifetime when wigglers are switched on

Parameter	Value
Energy (GeV)	45.6
Bunch population	4e10
Emittances (pm)	271.5 / 1.4
Rms energy spread	3.845e-4
Bunch length(mm)	4.2
Touschek lifetime(hour)	5.8

[1] S. Bai, IPAC'2019, MOPRB024

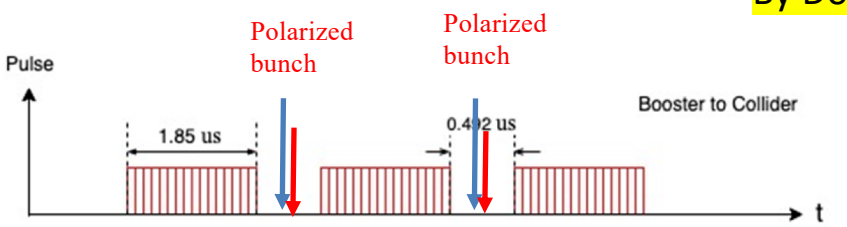




Injection for non-colliding bunches

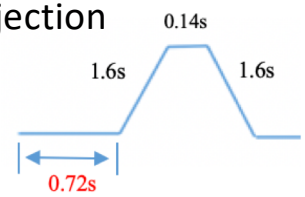
- Filling pattern (one option)
  - Between colliding-bunch trains
  - Kicker rise/fall time < 0.246 μs
- Bunch charge from linac = 1.17 nC (7.3e9)
- Initial injection
  - Inject 144 bunches together
- Refill
  - Every ~6 min for injector
  - Injection for one non-colliding bunch will take 9.6s

By Dou Wang



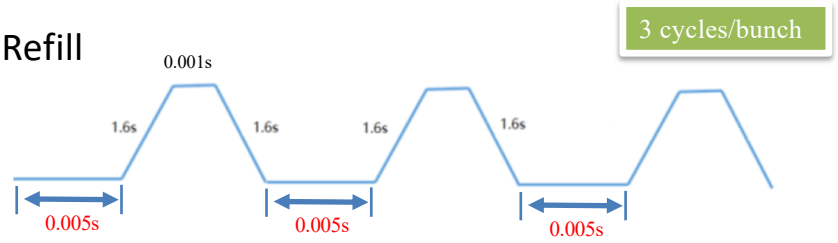
Stagger 7.6ns for e+ polarized bunch and e- polarized bunch

Initial injection



(0.72s+1.6s+0.14s+1.6s)=4.06s

Refill



(0.005s+1.6s+0.001s+1.6s)*3=9.6s