Spin Resonance Free Booster For Future 100~km-scale Circular e+ e-Colliders

CEPC Workshop 2022

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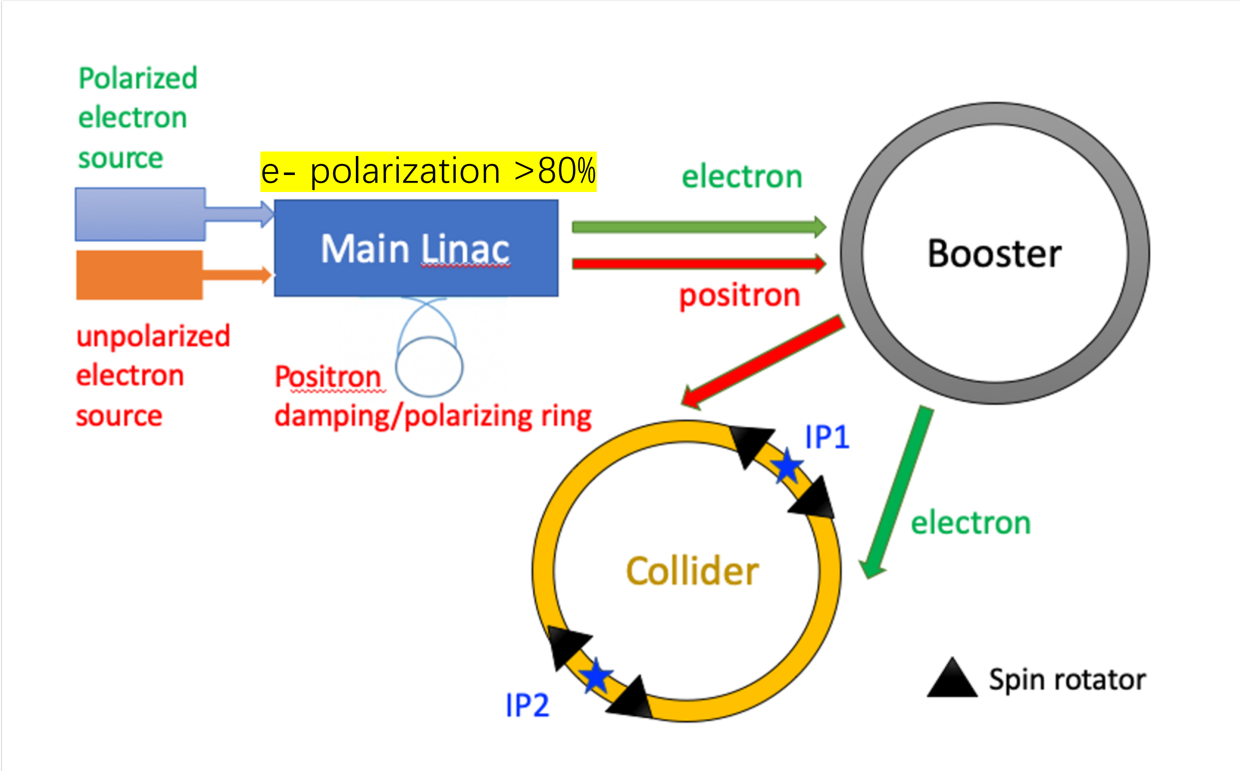
Preparation and injection of polarized beams

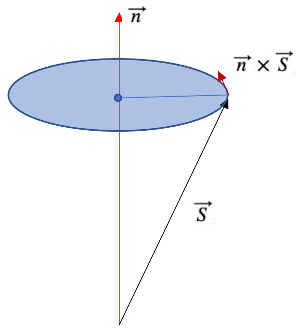


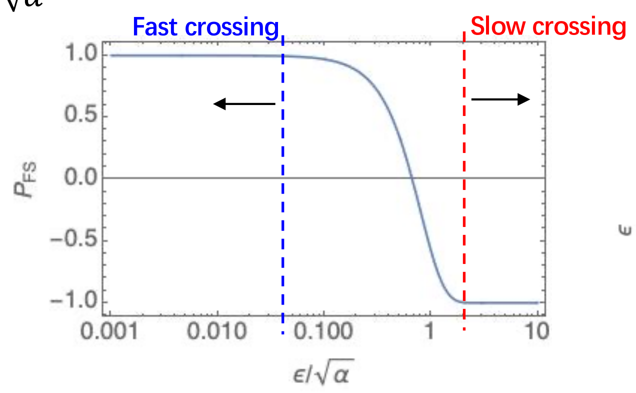
Key issues:

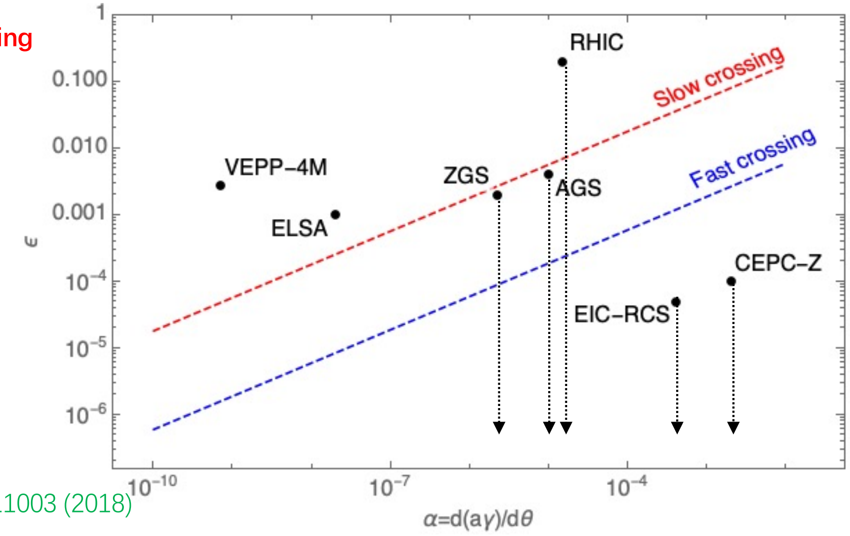
- **Depolarization in the booster: how serious, possible mitigation?**
- For resonant depolarization (RD): how to generate polarized e+ beam?
- For longitudinally polarized colliding beams(LP): how to design spin rotators in the collider rings?

Polarization maintenance in synchrotron/booster

- $J_s = \vec{S} \cdot \vec{n}$ is an adiabatic invariant
- $\nu_0 \approx a\gamma_0$ and $\vec{n}_0$ changes during acceleration. When crossing a spin resonance, $|J_s|$ could vary due to non-adiabaticity, leading to depolarization described by Froissart-Stora formula[1]:
  - Two factors: spin resonance strength ε and acceleration rate $\alpha \sim 10^{-6} \frac{dE}{dt}[\mathrm{GeV}/s]C[\mathrm{km}]$
  - Polarization is maintained (ΔP < 1%) if
    - Fast crossing: $\frac{\epsilon}{\sqrt{\alpha}} \ll 0.06$
    - Slow crossing: $\frac{\epsilon}{\sqrt{\alpha}} \gg 1.82$, spin flip







[1] Froissart and Stora, NIM 7, 297 (1960) [2] A. K. Barladyan, et al., PRAB 22, 112804, (2019)
[3] S. Nakamura, et al., NIM A 411, 93 (1998) [4] T. Khoe et al., Part. Accel. 6, 213 (1975)
[5] Configuration Manual: Polarized Proton Collider at RHIC, 2006 [6] V. Ranjbar, et al., PRAB 21, 111003 (2018)

Spin resonance structure

Parameter of CEPC CDR Booster	Value
P: number of periodicities	8
M: number of unit cells in each arc region (per period)	99
ν_y: total betatron phase advance/(2π)	261.2
ν_B: total betatron phase advance in arc regions/(2π)	198

- PM = 792, arc sections take up > 80% circumference
- About k * 2π betatron phase advance in each straight section & arc section

	Super strong	Less strong	Regular
Imperfection resonance	$\nu_0 = nPM \pm [\nu_B]$	$\nu_0 = nP \pm [\nu_y]$	ν_0 = n
Intrinsic resonance	$\nu_0 = nP \pm \nu_y$ near $nPM \pm [\nu_B]$	$\nu_0 = nP \pm \nu_y$	$\nu_0 = n \pm \nu_y$

ε_{RING} = Enhancement Factor * $\varepsilon_{arc\ cell}$ + $\varepsilon_{straight\ sections}$

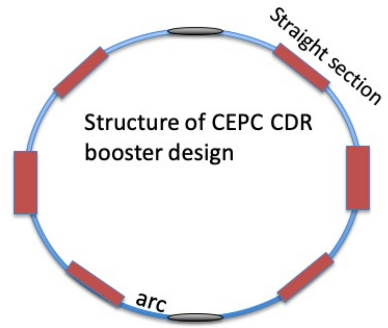
- Enhancement Factor : $\zeta_M(x) = \frac{\sin M\pi x}{\sin \pi x}$, when x = integer , $\zeta_M(x) = M$

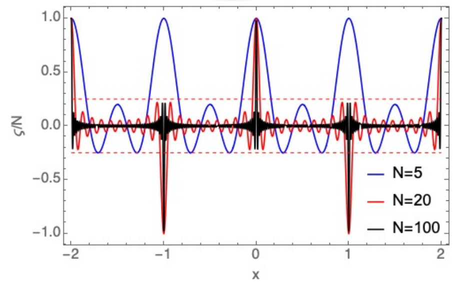
For intrinsic resonances

One FODO

$$\varepsilon_K \approx \frac{1+G\gamma}{2\pi}\sqrt{\frac{\varepsilon_N}{\pi\gamma}}\left\{E_P^+\left[E_M^+\left(g_F\sqrt{\beta_F} - g_D\sqrt{\beta_D}e^{i\frac{K+\nu_B}{MP}}\right) + X_{ins}\right] + E_P^-\left[E_M^-\left(g_F\sqrt{\beta_F} - g_D\sqrt{\beta_D}e^{i\frac{K-\nu_B}{MP}}\right) + X_{ins}\right]\right\}$$

- Enhancement factor: $E_P^{\pm} \approx \zeta_P(\frac{K\pm\nu_z}{P})$; $E_M^{\pm} \approx \zeta_M(\frac{K\pm\nu_B}{PM})$





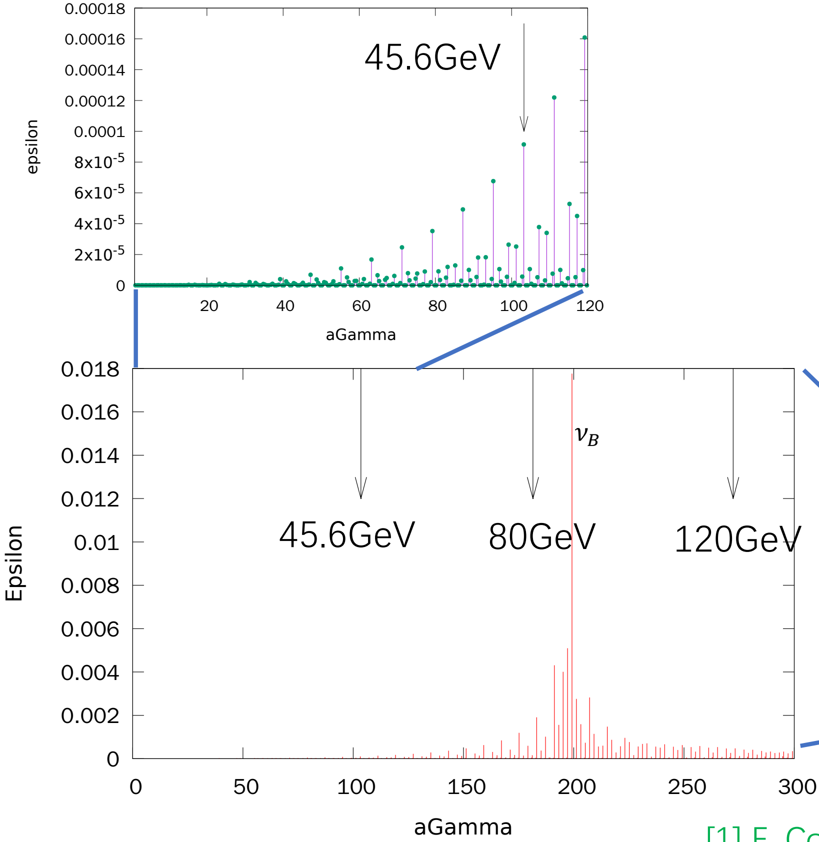
$g_{F/D} = \frac{1}{f}$, For FODO cells with same phase shift: $\sin\frac{\phi}{2} = \frac{L}{2f}$

For large ring lake CEPC ,L is larger so $g_{F/D}$ and resonance strength is smaller.

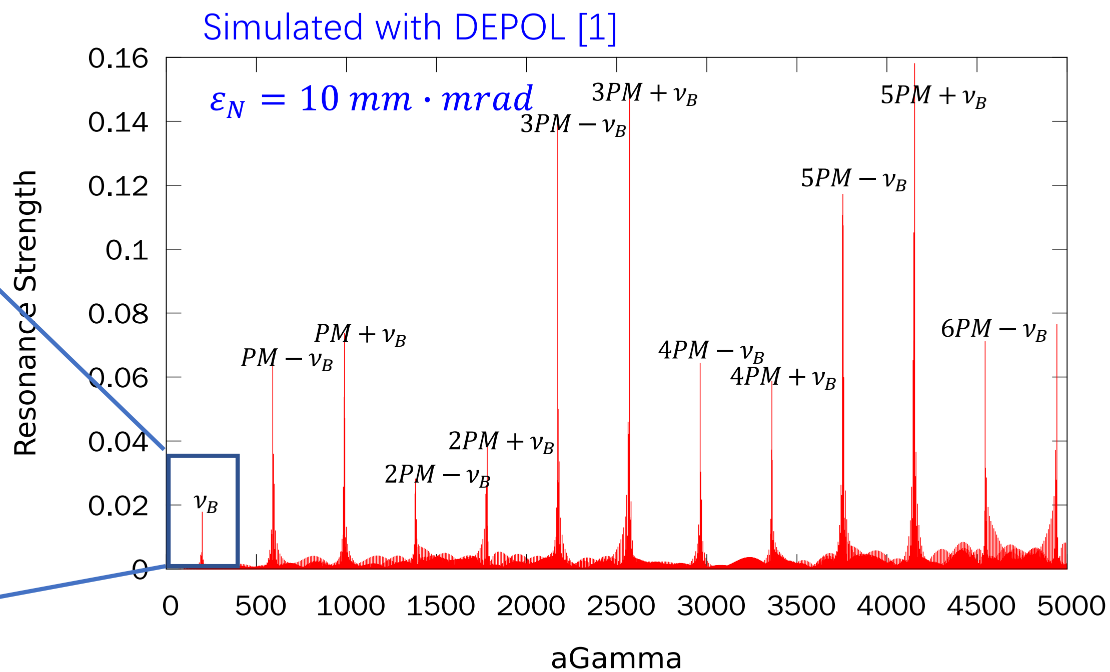
[1] S. Y. Lee, Spin Dynamics and snakes in synchrotrons, World Scientific, 1997, [2] V. Ranjbar, et al., PRAB 21, 111003 (2018)

Intrinsic spin resonance structure in CDR

CEPC CDR Booster： $P = 8; M = 99; \nu_B = 198$



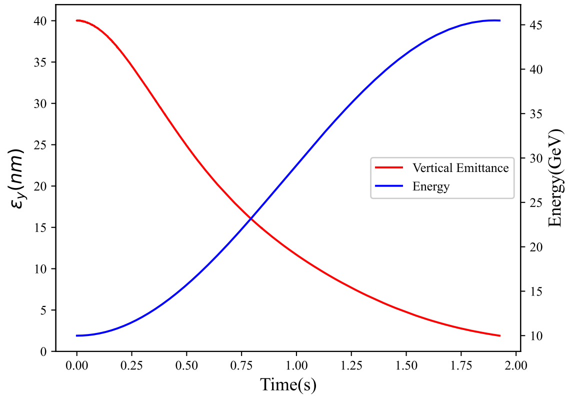
$\epsilon_{\mathrm{K,intrinsic}} \sim \gamma\sqrt{\varepsilon_{\mathrm{rms}}}$

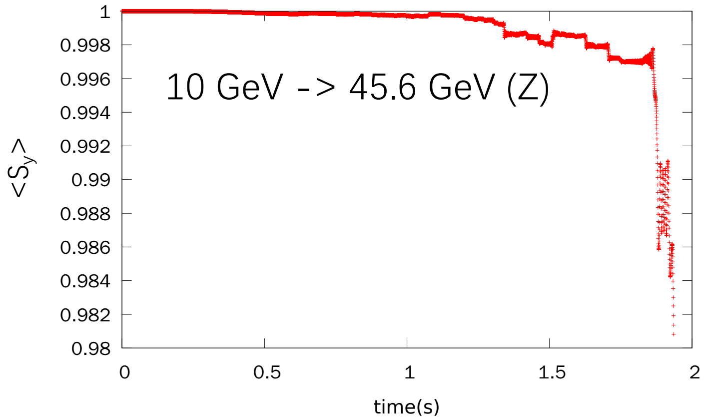


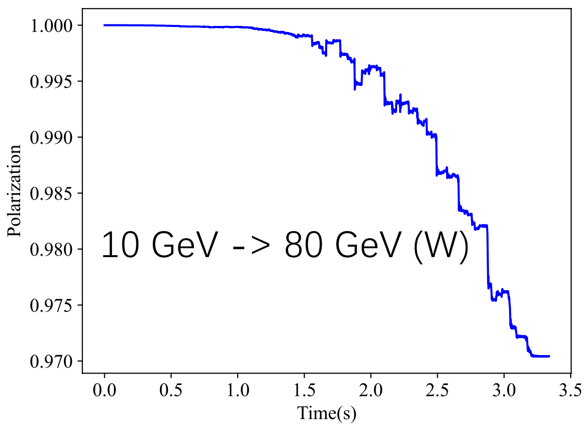
[1] E. Courant and R. Ruth, BNL-52170, 1980

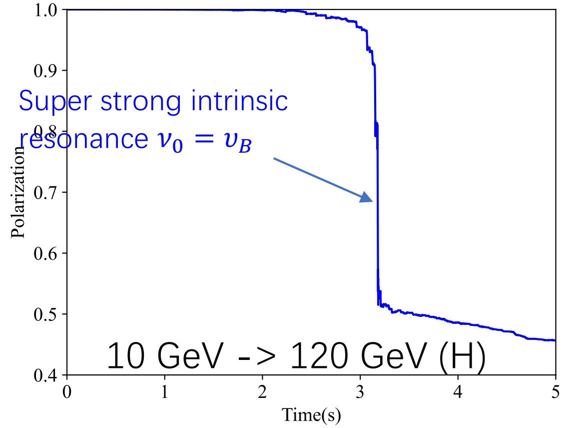
Simulation of polarization transmission

Ramping curve:

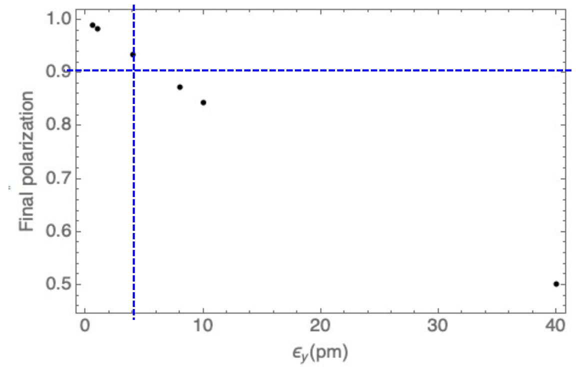








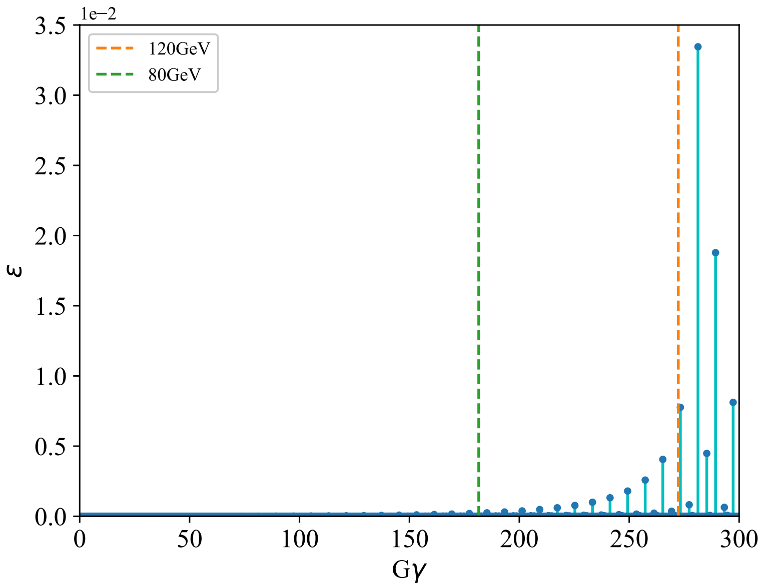
The equilibrium vertical emittance needs to be corrected to below 4 pm, to achieve 90% polarization transmission in H mode



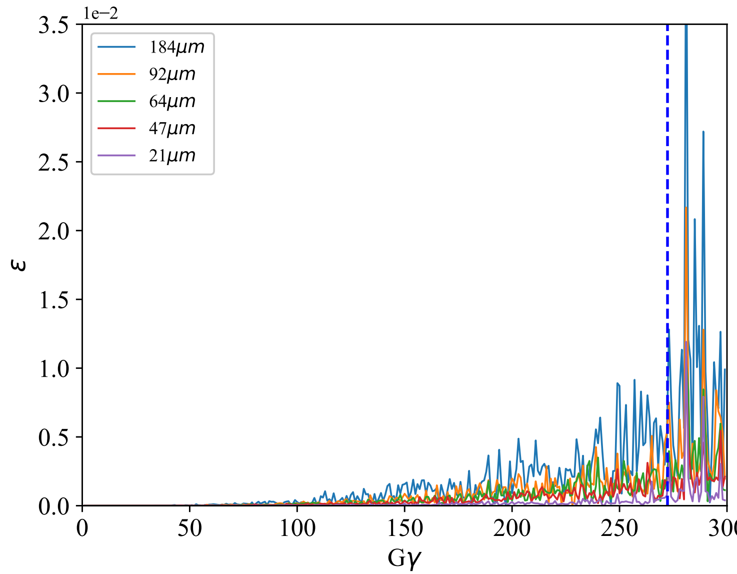
New lattice

- To improve the polarization behavior in 120GeV acceleration, we use a new lattice with $\nu_y = 352.28, \nu_B = 281$
  - First strong resonance is after 120GeV

Intrinsic resonance



Imperfection resonance



Polarization performance-newlattice

- Using $P_{final} = \prod_K \frac{P_f}{P_i}(K)$, we can estimate the polarization loss due to imperfection resonances and intrinsic resonances, respectively.
- In the new lattice, the strongest resonances are all in high-energy area, thus a cos ramping curve will cause more polarization loss