

Polarization issues at CEPC

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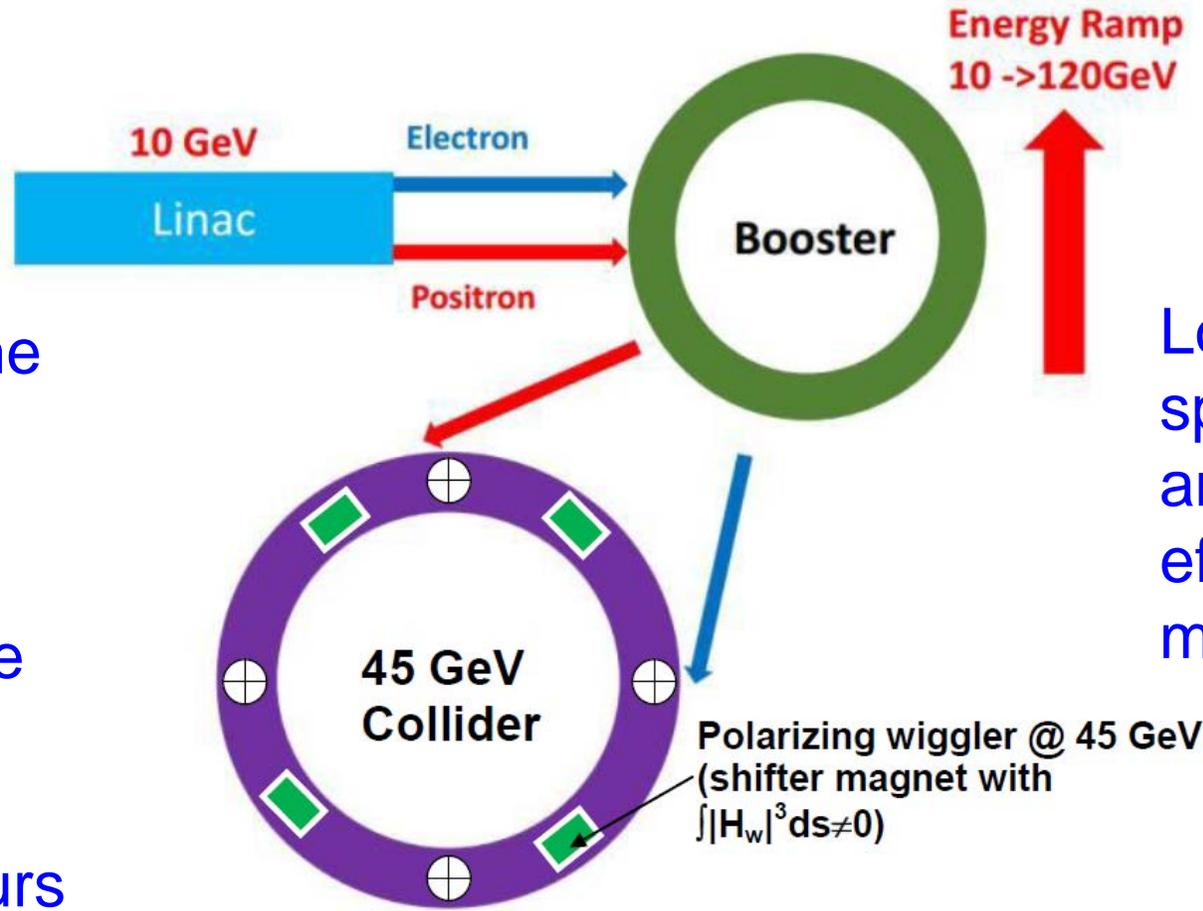
Introduction

- Prof. Jie Gao initiated discussion on CEPC polarization program in Nov. 2017
- Work is based on materials presented by author in Talk at IAS Program on High Energy Physics meeting (HK, Jan. 2018) and Talk at Circular Electron Positron Collider workshop (Rome, May 2018)
- To determine and ensure conditions under which radiative transverse self-polarization in collider rings reaches required degree within reasonable time
- To consider an alternative possibility of obtaining polarization by accelerating polarized particles in booster and then injecting them into main ring. This option can be crucial for obtaining longitudinal polarization
- To demonstrate one of possibilities to obtain longitudinal polarization with high average-in-time degree in top-on injection mode

Radiative self-polarization in CEPC

$$\tau_p = \left[\frac{5\sqrt{3}}{8} \frac{r_e \hat{\lambda}_e \gamma^5}{R^3} \langle |K|^3 \rangle \right]^{-1}$$

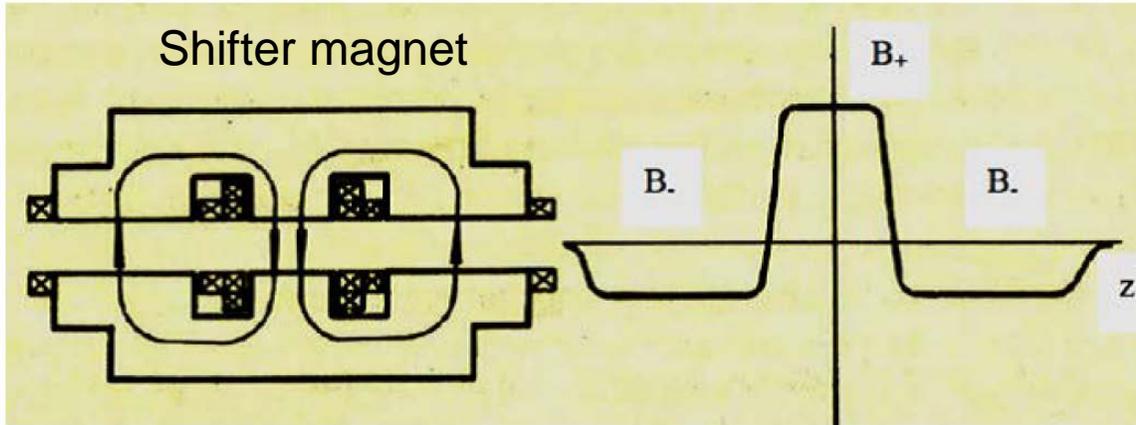
Sokolov-Ternov time of polarization in CEPC is huge: 260 hrs at 45 GeV! At 80 GeV, this time falls as $(45/80)^5$ to 15 hrs. 45 GeV LEP: 5 hours



Long-known tool: special wigglers amplify polarizing effect of storage ring magnetic field!

Similar to proposal for FCCee project

Special wigglers to speed up polarization



Requirements to fields :

$$\int B_w d\vartheta = 0, \quad \int B_w^3 d\vartheta \neq 0, \quad |B_+|^3 \gg |B_-|^3$$

Decrease of polarization time:

$$\tau_p^w = \tau_p \left[1 + N_w \frac{B_+^3 L_+ + 2 |B_-|^3 L_-}{2\pi R \langle B_0 \rangle B_0^2} \right]^{-1}$$

Fraction of radiation energy loss enhancement :

$$u = N_w \frac{B_+^2 L_+ + 2 B_-^2 L_-}{2\pi R \langle B_0 \rangle B_0}$$

Harmful effect is increase in beam energy spread:

$$\frac{\Delta E_w}{\Delta E} = \left[\frac{\tau_p}{\tau_p^w} \cdot \frac{1}{1+u} \right]^{1/2}$$

N_w	B_+ T	L_+ m	B_- T	L_- m	$\frac{\tau_p}{\tau_p^w}$	u	$\frac{\Delta E_w}{\Delta E}$
10	0.5	1	0.125	2	8.3	0.20	2.6
10	0.6	1	0.15	2	13.6	0.29	3.3

Calculated for current CEPC-Z magnetic structure

Radiative polarization in real storage ring

Depolarization factor due to field imperfections

$$G = \frac{\langle K^3 \rangle}{\langle |K|^3 \left(1 + \frac{11}{18} \bar{d}^2 \right) \rangle} \leq 1, \quad (K, \text{ orbit curvature}),$$

reduces polarization degree (P) and relaxation time of radiative polarization (τ_{rel})

$$P = G \cdot P_0, \quad P_0 = \frac{5\sqrt{3}}{8} = 0.92, \quad \tau_{rel} = G \cdot \tau_p,$$

$\bar{d} = \gamma \frac{\partial \vec{n}}{\partial \gamma}$ periodical with azimuth spin-orbit coupling function

(equilibrium axis of precession \vec{n} depends on energy)

“Shake” of precession axis due to quantum fluctuations → non-resonant spin diffusion growing nearby spin resonances, main depolarization factor in storage rings as long as spin tune spread is much less than distance to closest dangerous resonances

Depolarization factor with synchrotron modulation

Radial magnetic and vertical electric fields cause most strong depolarization effect which relates to integer spin resonances $\nu = \gamma a = k$ (ν , spin precession tune). **Kondratenko's** formula for depolarization factor takes into account spin tune modulation by synchrotron oscillations with frequency ν_γ :

$$G = P/P_0 = P/0.92 \quad G \approx \left\{ 1 + \frac{11\nu^2}{18} \sum_{k,l} \frac{|w_k|^2 I_l(\sigma_\nu^2 / \nu_\gamma^2) \exp(-\sigma_\nu^2 / \nu_\gamma^2)}{\left[(\nu - k - l\nu_\gamma)^2 - \nu_\gamma^2 \right]^2} \right\}^{-1}$$

$w_k \approx \left\langle \frac{\nu}{R} \frac{d^2 y_0}{d\vartheta^2} \exp(-ik\vartheta) \right\rangle$, resonant harmonic amplitude in case of vertical closed orbit distortions (y_0);

l , order of sideband resonance $\nu \pm l \cdot \nu_\gamma = k$;

$\sigma_\nu = \nu \sigma_\gamma$, instant spin tune spread due to energy spread σ_γ ;

$I_l(x)$, modified Bessel function.

$$\kappa = \frac{\sigma_\nu}{\nu_\gamma} \text{ is index of modulation;}$$

Equation for G is valid if $\sigma_\nu^2 \Lambda_\gamma \ll \nu_\gamma^3$; Λ_γ is the radiation decrement of synchrotron oscillations in inverse turns.

Parameter of spin phase diffusion

E=45 GeV

	σ_v	ν_γ	f_0 kHz	τ_p hr	Γ
LEP	0.061	0.083	11	5.7	<u>0.054</u>
CEPC	0.039	0.028	3	268	<u>0.103</u>
	0.128	0.028	3	19.7*	<u>1.40</u>
	0.103	0.028	3	32.3*	<u>0.860</u>

* indicates cases with wigglers
to speed up polarization

The parameter $\Gamma = \frac{11\nu^2}{18\nu_\gamma^3 \tau_p f_0} = \frac{1}{2} \frac{\sigma_v^2 \Lambda_\gamma}{\nu_\gamma^3} = \frac{1}{2} \kappa^2 \frac{\Lambda_\gamma}{\nu_\gamma}$ characterizes spin precession phase increment due to its radiative diffusion per the period of synchrotron oscillations $(\nu_\gamma f_0)^{-1}$.

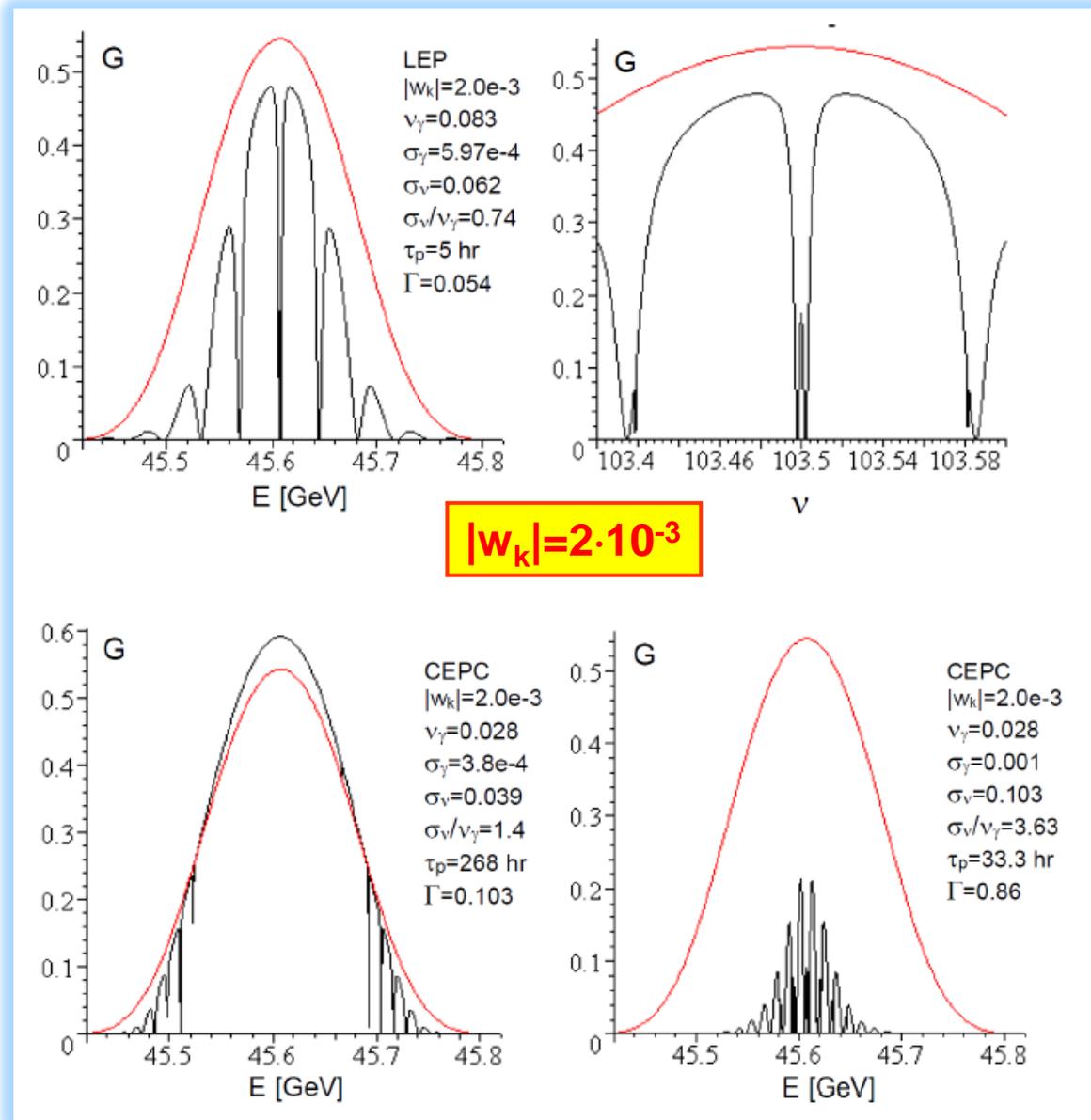
- Strictly linear spectrum of synchrotron modulation:

$$\Gamma \ll 1 \rightarrow w_k \exp\left(-i \frac{\Delta}{\nu_\gamma} \sin \psi_\gamma\right) = w_k \sum_{l=-\infty}^{l=\infty} J_l\left(\frac{\Delta}{\nu_\gamma}\right) \exp(-il\psi_\gamma) \text{ is valid!}$$

- $\Gamma \geq 1 \rightarrow$ The spectrum of spin perturbations becomes blurry!
The modulation resonances with the synchrotron tune are not isolated!
Hence, the used approximation for G is of an evaluative nature.

Decrease of modulation index κ by increasing synchrotron tune is desirable in viewpoint of efficiency of resonant depolarization technique (see I.Koop's Talk)
In our interpretation, this is recommendation to move Γ from range $\Gamma \geq 1$ to range $\Gamma \ll 1$

Comparison of polarizations at CEPC and LEP



Equilibrium polarization degree $G=P/P_0$ for LEP and CEPC at the same spin harmonic amplitude $|w_k|=2 \cdot 10^{-3}$

LEP: no special wigglers were used



red curves: “no synchrotron modulation”

$$G \approx \left[1 + \frac{11v^2}{18} \sum_k \frac{|w_k|^2}{(v-k)^4} \right]^{-1}, \quad |v-k| \gg \max(\sigma_v, v_\gamma)$$

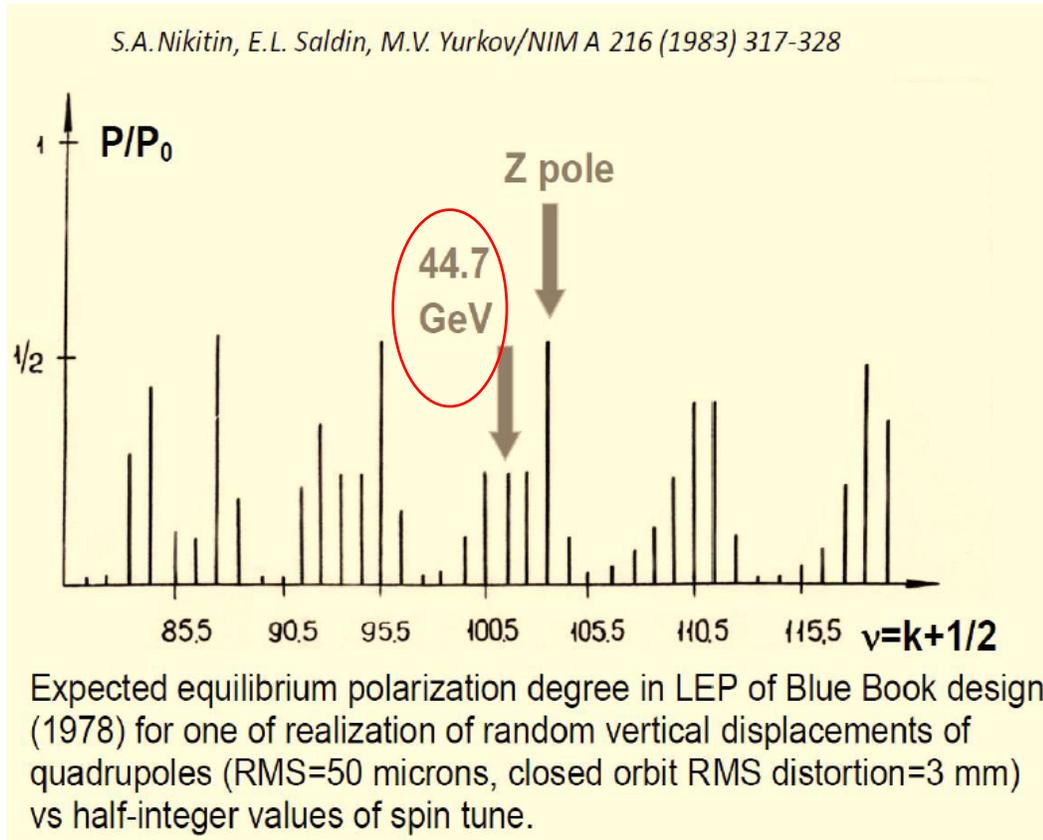
CEPC at left: good conditions for conservation of polarization in luminosity mode of magnetic structure (wigglers are turned off)



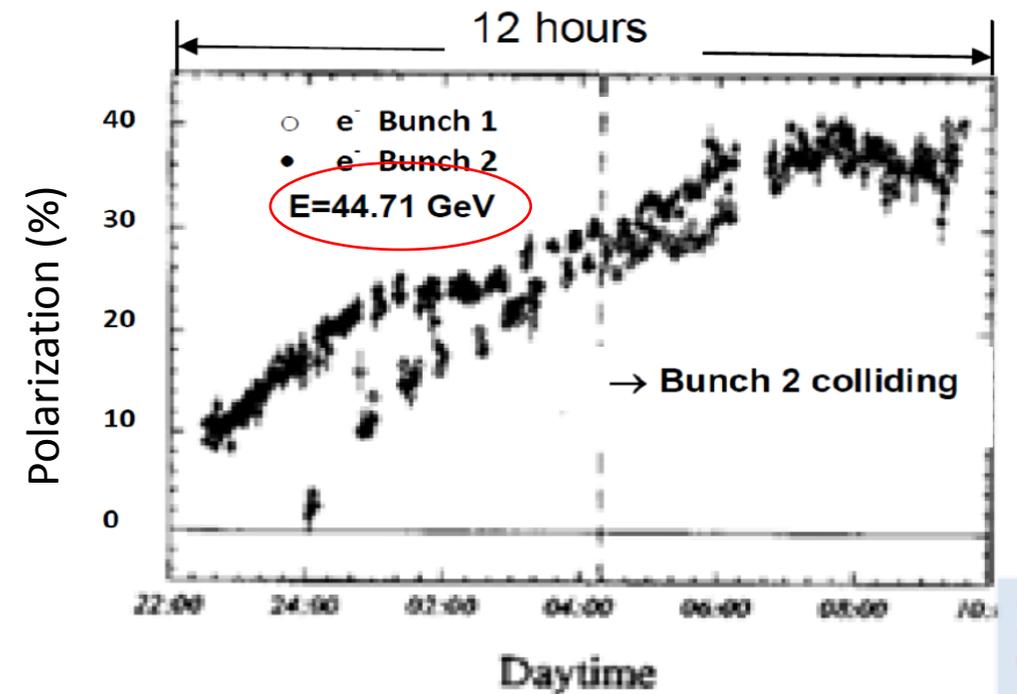
CEPC at right: in wiggler mode, equilibrium degree of polarization noticeably decreases

Only harmonics $k=103$ and $k+1=104$ are “turned on” with assumption $|w_k|=|w_{k+1}|$

Calculation vs observation: LEP experience



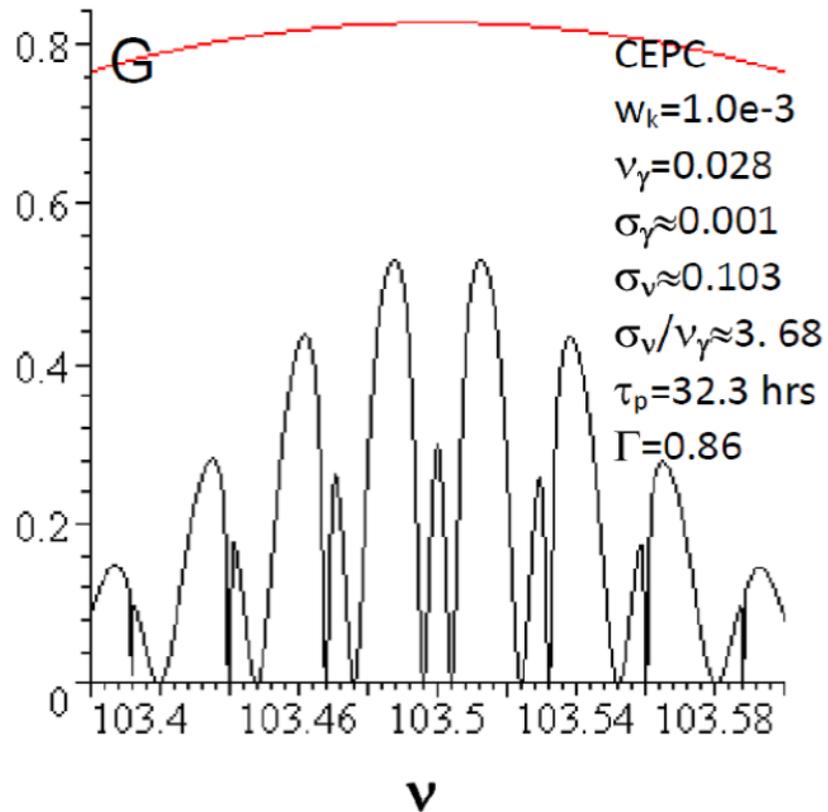
EXPERIMENTS ON BEAM-BEAM DEPOLARIZATION AT LEP
 R.Assmann et al. PAC 1995
 With the beam colliding at one point, a polarization level of 40% was achieved ...



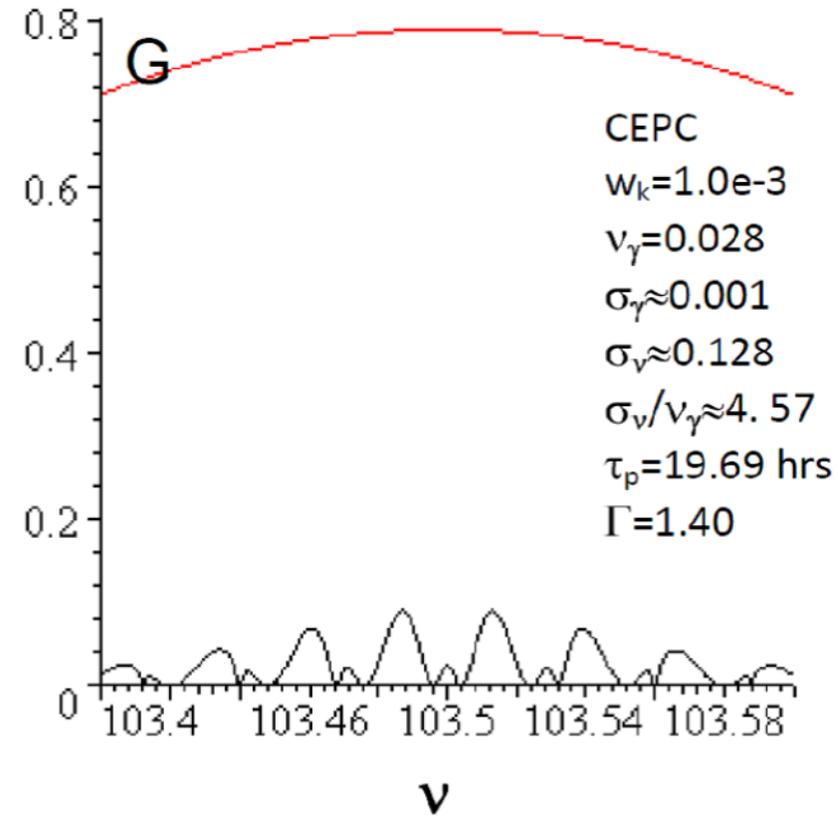
It is important to reduce the resonant harmonic amplitudes in orbit distortions down to level $|w_k| \leq 10^{-3}$ using special orbit bumps or global correction. There was positive experience of LEP team: polarization was improved to more than 35 % with average around 50% using Harmonic Spin Matching technique (R. Assmann , A.Blondel et.al., CERN SL/94-62 (AP))

Effect of energy spread increase at CEPC

Equilibrium polarization degree in region of Z-pole vs spin tune in two cases of wiggler mode



$B_+=0.5$ T
energy spread $\sigma_\gamma=9.9e-4$
spin tune spread $\sigma_\nu=0.103$



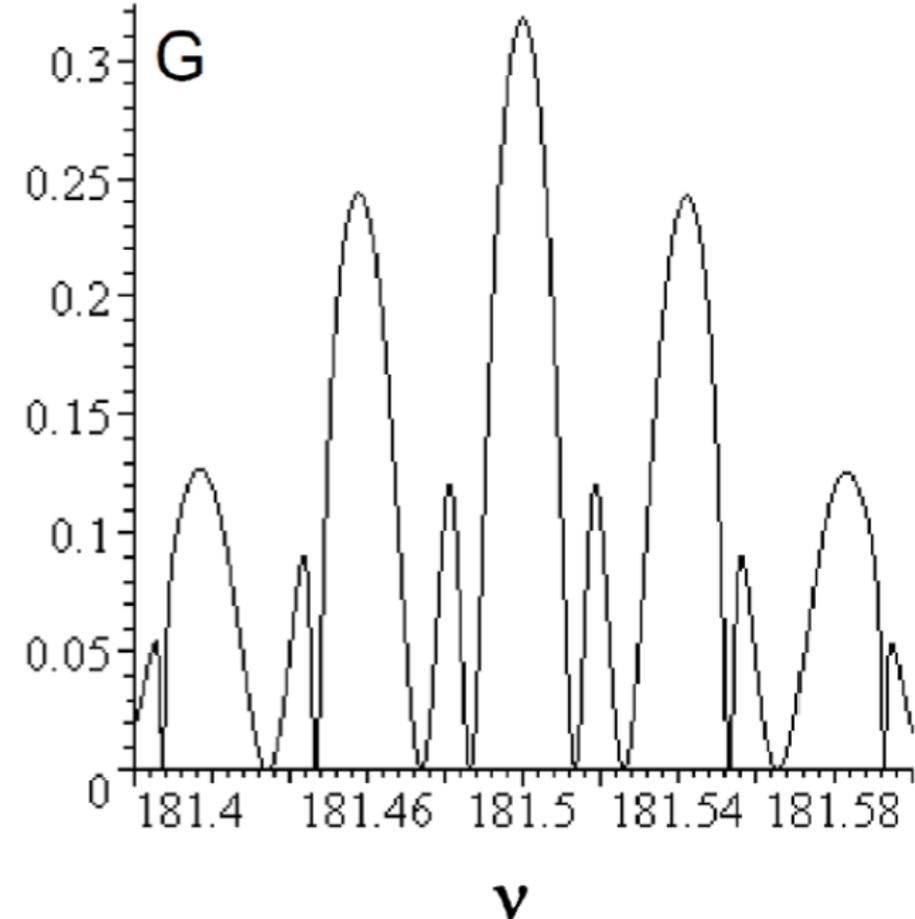
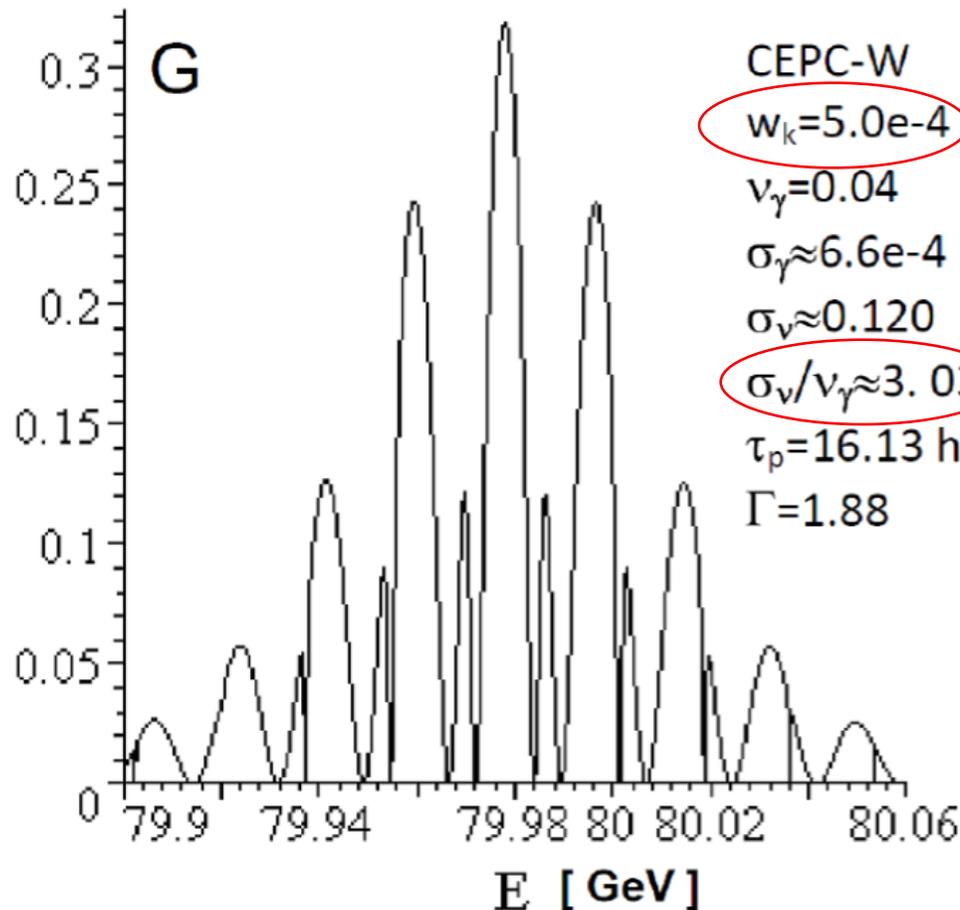
$B_+=0.6$ T
energy spread $\sigma_\gamma=1.25e-3$
spin tune spread $\sigma_\nu=0.128$

$|w_k|=10^{-3}$

CEPC polarization at 80 GeV

No special wigglers needed!

$$|w_k|=5 \cdot 10^{-4}$$



In comparison with Z-pole case, this one is some harder. Spin harmonic amplitude in vertical closed orbit perturbations should be corrected to level $\leq 5 \times 10^{-4}$.

Response of field perturbations in spin motion

Equation of particle motion in vertical plane

$$z'' + g_z z = h(\theta, x, x', z, z'),$$

perturbation h is “switched on” at $\theta = -\infty$.

Small disturbance of spin vector at given azimuth,

transverse to vertical, accumulated over large number

of turns is

$$|\delta S_{\perp}| \approx \left| \int_{-\infty}^{\theta} \nu \cdot h \cdot F^{\nu} \exp(-i\nu\theta') d\theta' \right|.$$

Here, $F^{\nu}(\theta)$ is factor accounting depolarizing effect of

vertical oscillations caused by h -fields

Spin response function by Derbenev-Kondratenko ($\nu \gg 1$):

$$F^{\nu} \approx \frac{\nu \cdot e^{i\nu\theta}}{2} \left\{ \left[1 - e^{\frac{i2\pi}{m}(\nu+\nu_z)} \right]^{-1} \cdot f_z \int_{\theta-\frac{2\pi}{m}}^{\theta} K f_z^* e^{-i\nu\Phi} d\theta' - \left[1 - e^{\frac{i2\pi}{m}(\nu-\nu_z)} \right]^{-1} \cdot f_z^* \int_{\theta-\frac{2\pi}{m}}^{\theta} K f_z e^{-i\nu\Phi} d\theta' \right\}$$

$f_z \exp(-i\nu_z\theta)$ is Floquet function, “z” stands for “y”; K is orbit curvature; $\Phi = \int K d\theta$; m is number of super-periods; $\nu = \gamma a$; ν_z is vertical betatron tune).

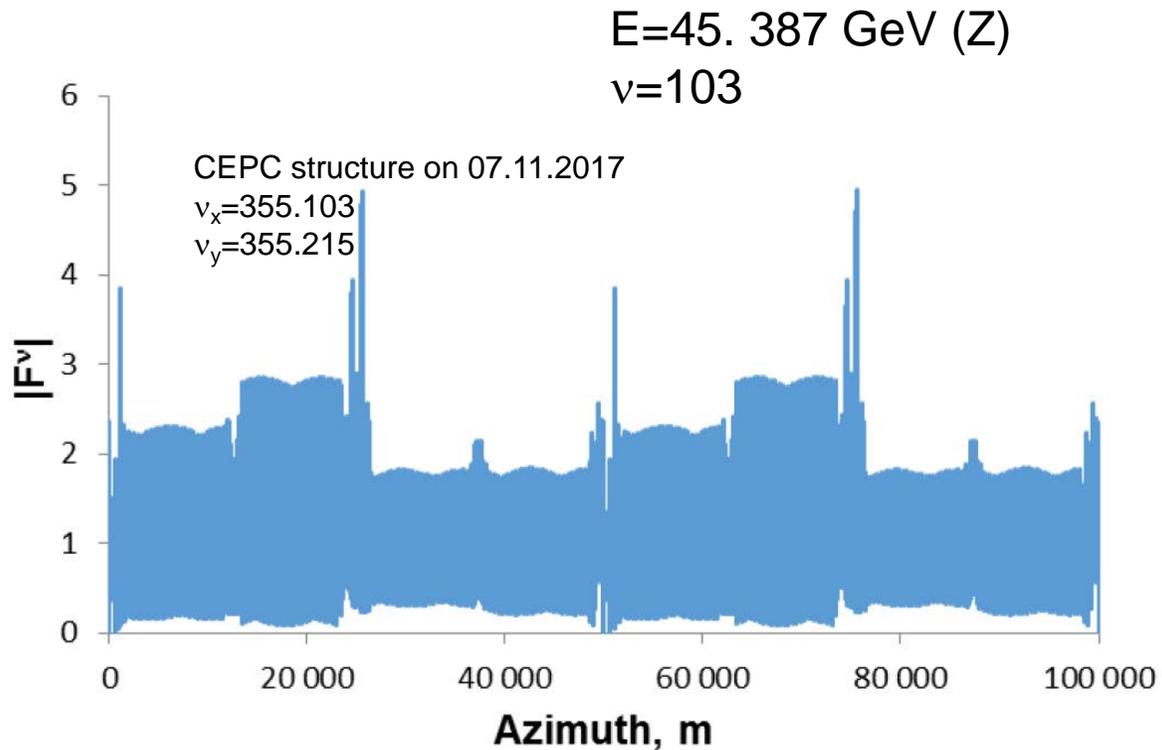
- It is “passport” characteristic like beta-function
- Periodical with machine super-period
- Non-monotonic with energy
- Resonant at $\nu \pm \nu_z = m \cdot l$, $l=0, \pm 1, \pm 2, \dots$

CEPC: m=2

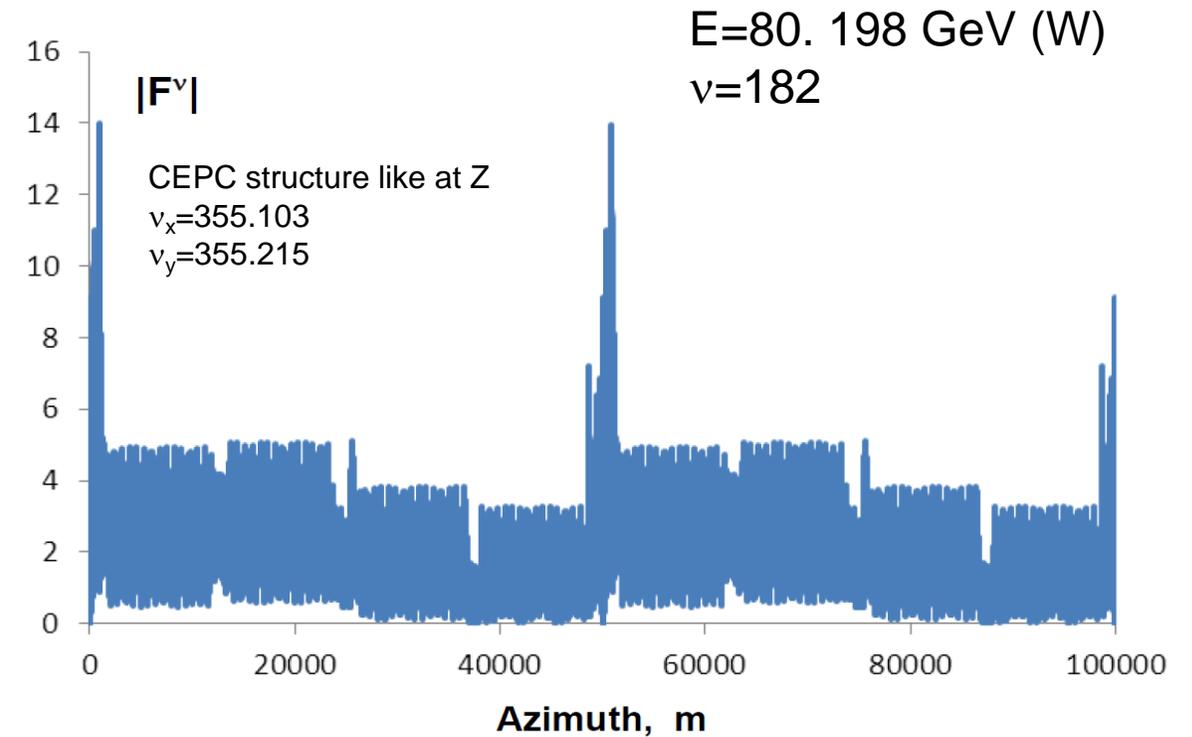
Properties of this function were studied and confirmed in experiments at VEPP-4 and VEPP-4M

Spin response function at two CEPC energies

Analytic formula-based calculation



Z-pole region: Spin Response Function module is quite moderate.



At energy of W pair production threshold, $|F^\nu|$ is noticeably larger. It makes requirements to field imperfections harder.

Tracking-based method to calculate F^v

Initial conditions of probe particle at certain azimuth:

$$(x, x', z, z') = (0, 0, 0, h), \quad h \ll 1, \quad \text{vertical kick};$$

$$\vec{S} = (0, 0, 1), \quad \text{spin vector.}$$

Equations for spin motion of probe particle:

$$\frac{d\vec{S}}{dt} = \vec{w} \times \vec{S}$$

Attention!

“z” stands for vertical

$$w_x = (1 + \nu)z''$$

$$w_y = (1 + a)K'z + (a - \nu)Kz'$$

$$w_z = \nu K - (1 + \nu)x''$$

Perturbed spinor matrix at m -th element of magnetic structure:

$$M_m = M_m^0 + \delta M_m$$

Its contribution to matrix of full turn (N elements):

$$M_N^0 \cdot M_{N-1}^0 \cdot \dots \cdot M_{m+2}^0 \cdot M_{m+1}^0 \cdot \delta M_m \cdot M_{m-1}^0 \cdot M_{m-2}^0 \cdot \dots \cdot M_2^0 \cdot M_1^0.$$

Multi-turn matrix at k -th turn associated with initial kick is determined.

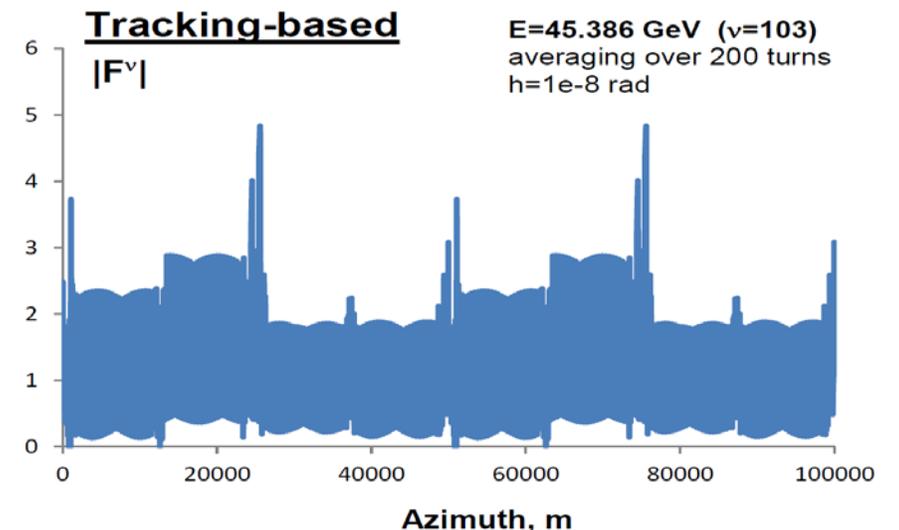
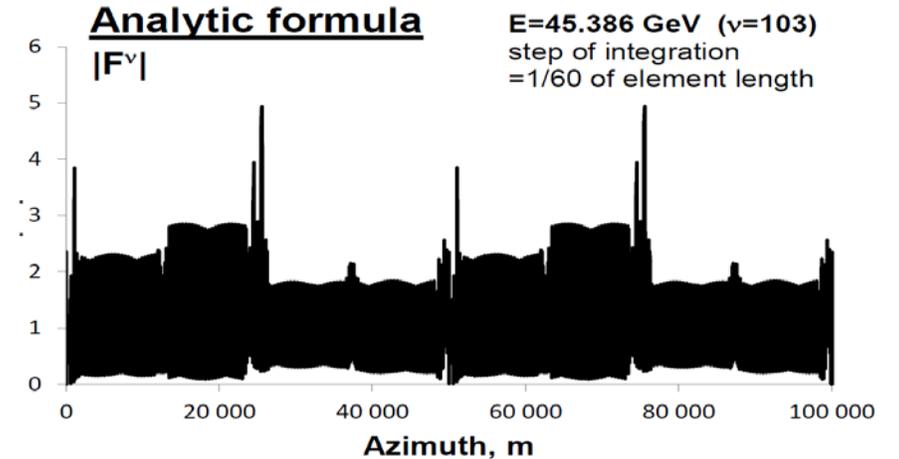
Increment of spin vector, transverse to vertical, is $\delta\vec{S}_\perp^{(k)} = \delta\vec{S}_x^{(k)} + i\delta\vec{S}_y^{(k)}$.

Spin Response Function is calculated by formula

$$F^v(\text{azimuth of kick}) = \left\langle -\frac{i \cdot e^{-i2\pi\nu k}}{\nu \cdot h} \cdot \delta\vec{S}_\perp^{(k)} \right\rangle - 1$$

S.A. Nikitin. Talk at 20th Intern. Spin Physics Symposium (SPIN 2012), 17-22 Sept. 2012, Dubna, Russia

Compare these two graphs!



Self-Test OK!

Estimate of spin harmonics at 45 GeV

Contributions of various perturbations to strength of integer spin resonance $\nu_k = k$:

Vertical offset of orbit in N_q quads with spread $\overline{(\delta z)^2}$

$$|w_k^{(1)}|^2 = \overline{(\delta z)^2} \left(\frac{\nu}{2\pi}\right)^2 \sum_{i=1}^{N_q} \left(\frac{\partial H_i}{\partial x} \cdot \frac{l_i}{HR}\right)^2 |F_i^k|^2$$

Tilts of N_b bending magnets with spread of $\overline{(\delta\phi)^2}$

$$|w_k^{(2)}|^2 = \overline{(\delta\phi)^2} \left(\frac{\nu}{2\pi}\right)^2 \sum_{i=1}^{N_b} \left(\frac{H_i l_i}{HR}\right)^2 |F_i^k|^2 \approx \frac{\nu^2}{N_b} \overline{|F^k|^2} \cdot \overline{(\delta\phi)^2}$$

Tilts of quads with spread of $\overline{(\delta\phi)^2}$ (η_x is dispersion function)

$$|w_k^{(3)}|^2 = \overline{(\delta\phi)^2} \left(\frac{\nu}{\pi}\right)^2 \sum_{i=1}^{N_q} \eta_{x,i}^2 \left(\frac{\partial H_i}{\partial x} \cdot \frac{l_i}{HR}\right)^2 |F_i^k|^2$$

Totally

$$|w_k|^2 = |w_k^{(1)}|^2 + |w_k^{(2)}|^2 + |w_k^{(3)}|^2 \cdot (k-\nu)^2,$$

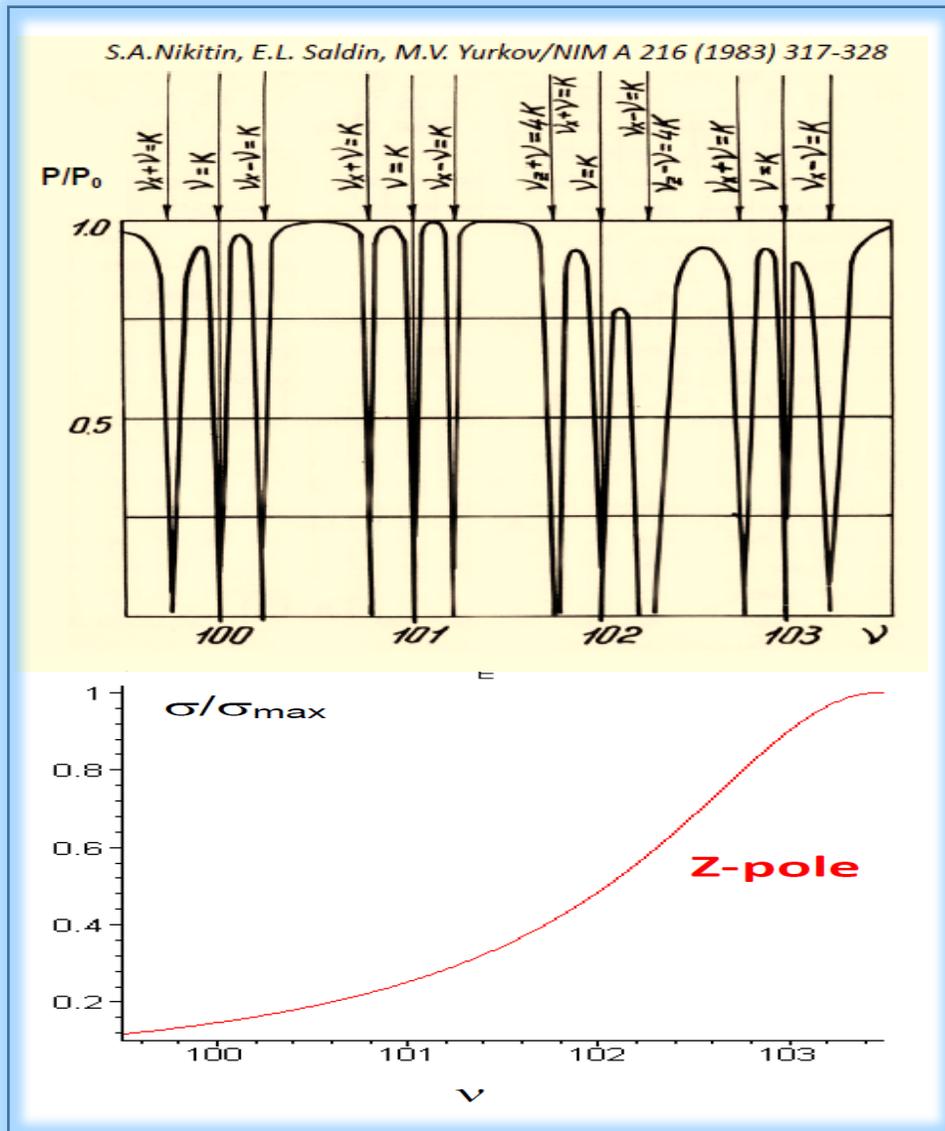
$(\nu-k)$ is resonance detuning

N_q	N_b	δz [μm]	$\delta\phi$ [rad]	$ \nu - k $
5368	2458	50	3×10^{-4}	0.5

45387 MeV < $E_{Z \text{ pole}} = 45594$ MeV < 45828 MeV
 $k=103$ $k=104$

k	103	104
$ w_k^{(1)} $	2.7×10^{-3}	1.2×10^{-3}
$ w_k^{(2)} $	7.4×10^{-4}	4.1×10^{-4}
$ w_k^{(3)} $	2.8×10^{-3}	1.6×10^{-3}
$ w_k $	2.9×10^{-3}	1.5×10^{-3}

Effect of quad tilts ($\delta\phi=5e-4$ rad) at LEP

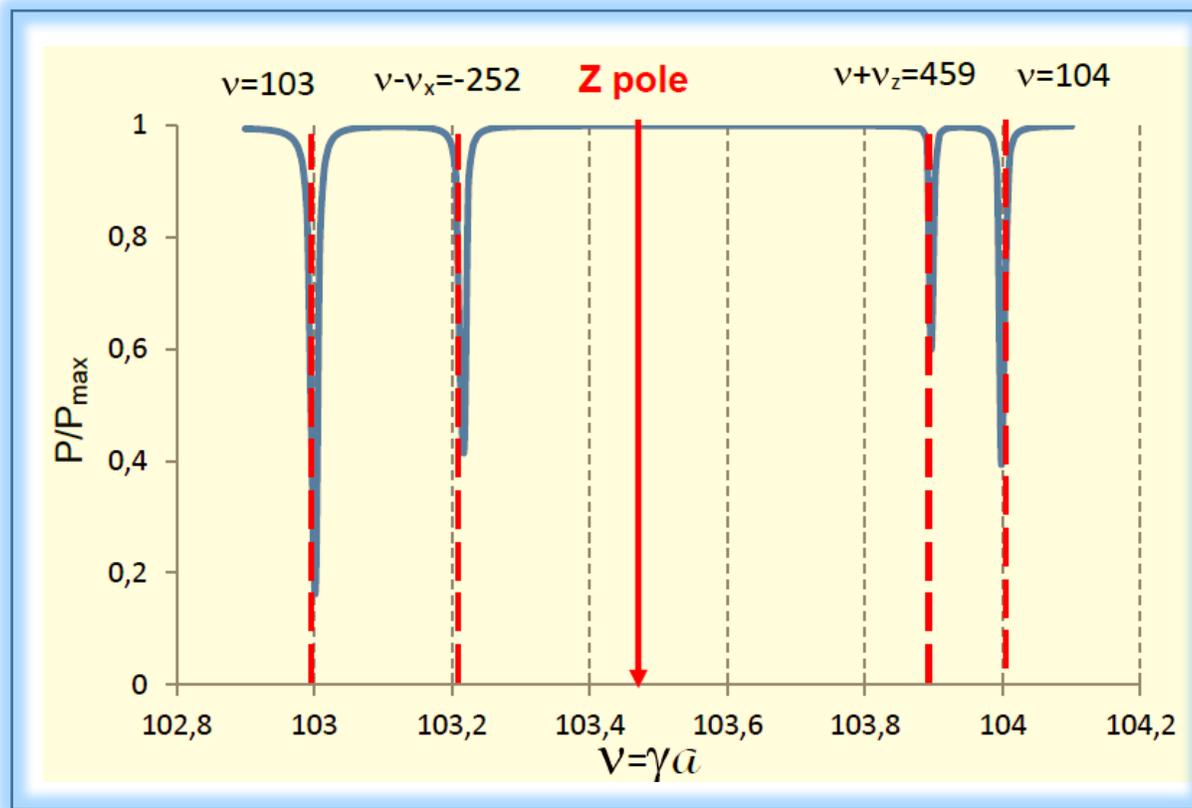


- Equilibrium degree of radiative polarization vs beam energy in units of spin tune at LEP (Blue Book design 1978) with 5×10^{-4} rad spread of quadrupole tilt angles. Dips correspond to integer $\nu=k$ and intrinsic spin resonances $\nu \pm \nu_x = k$ and $\nu \pm \nu_y = 4 \cdot k$. Their partial width achieves 50 MeV.
- Below, cross section of Z-boson ($\Gamma_{tot} = 2.5$ GeV) is plotted on the same energy scale.
- Working point (ν_x, ν_z) of LEP occupies intermediate position between integer and half-integer values. It is compatible with necessity to have energy of experiment close to half integer values of spin tune because of strong depolarizing effect of vertical orbit distortions. A similar situation seems to be the case with FCCee and CEPC.

No synchrotron modulation taken into account.

Appropriate sideband resonances could be noticeably narrower than in case of vertical orbit distortions

Effect of quad tilts ($\delta\phi=6e-4$ rad) at CEPC



- Expansion with respect to resonant harmonics related to $\partial H_x / \partial x$ perturbations is used
- Harmonics are estimated from spread of tilt angles and design parameters of magnetic structure
- Required azimuthal distribution of spin response F^v is calculated at each point in energy

Emittance of 45 GeV CEPC (0.17 nm) is an order of magnitude smaller than that of LEP . In both cases, influence of betatron oscillations on polarization in working energy region, where spin tune is close to half integer values, can be neglected

Time to reach $\eta\%$ polarization in CEPC

While using laser polarimeter for RD technique it is enough to ensure polarization degree about of 10%

E GeV	$ w_k $	G_{max}	ν_γ	τ_{rel} hr	η %	t_η hr
45.602	10^{-3}	0.53	0.028	17.1*	10	3.93
45.602	10^{-3}	0.09	0.028	1.8**	6	2.28
79.978	.0005	0.32	0.040	4.8	10	2.14

Relaxation time of polarization

$$\tau_{rel} = G \cdot \tau_p \text{ or } \tau_{rel} = G \cdot \tau_p^w$$

Polarization-time law

$$P(t) = G \cdot P_0 [1 - \exp(-t / \tau_{rel})]$$

For $P = \eta \%$

$$t_\eta = -\tau_{rel} \ln \left(1 - \frac{\eta}{92G} \right)$$

*) $B_+ = 0.5 \text{ T}$

***) $B_+ = 0.6 \text{ T}$

Polarization scenario at 45 GeV

(qualitatively similar to FCCee concept)

- About 100 pilot bunches of relatively small total current I_p are stored to be polarized up to 10% using wigglers in a few of hrs
- 3 kW SR power from each of 0.6 T wigglers at total current of pilot bunch train of $I_p = 2$ mA ($\sim 1\%$ of the main train)
- When the polarization process ends the wigglers turn off
- Then the main bunch train is stored
- Pilot bunches are not in collision. Their lifetime is about 10^5 s due to scattering on thermal radiation photons (like at LEP). The bunches are used one by another for RD calibration of beam energy every 15 min.
- So, the polarized bunch train is spent as a whole per day while taking data in detector occurs

More issues ...

- Depolarizing influence of SR in interaction area where beams intersect 3T detector solenoid axis at angle ~ 15 mrad (“no spin transparency” contributes to spin-orbit coupling)
- Resonance diffusion at large spin tune spread ($\sigma_v \sim 0.1$ in wiggler mode) in framework of model basing on radiative excitation and damping. For particle falling into tail of distribution function, amplitude of spin tune modulation by synchrotron oscillations can sporadically overlap distance to closest spin resonances ($\varepsilon_k \approx 0.5$). As result, there are accidentally recurring fast crossings of that resonance... (consideration is in progress)
- ...

Partial Siberian Snake in booster

Maintaining of polarization in Booster using Partial Siberian Snake

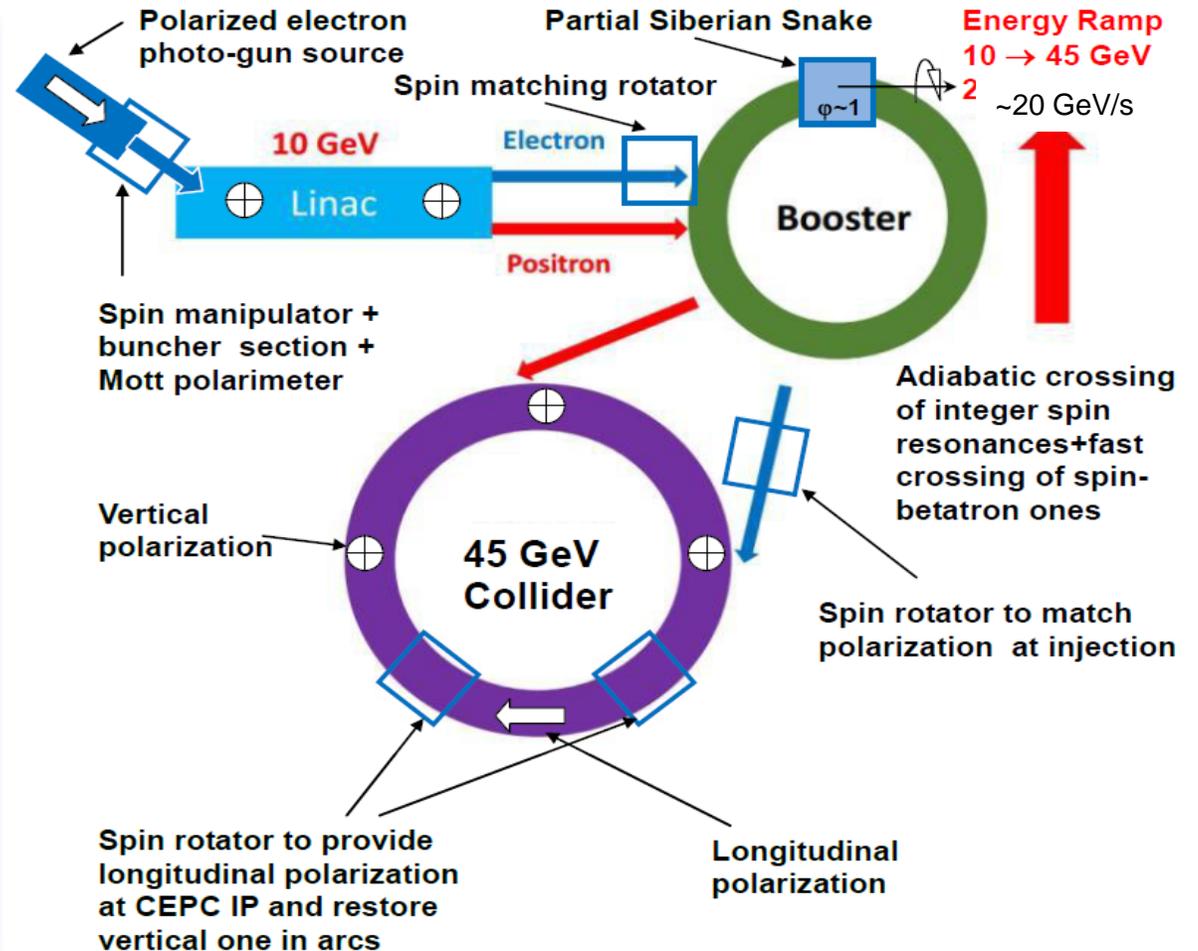
Adiabatic crossing of energy values corresponding to integer spin resonances:

$\varphi^2 \gg 4\pi^2 \varepsilon'$ $\rightarrow \varphi \sim 1$, spin rotation angle around velocity, at $\varepsilon' \approx 2 \cdot 10^{-3}$, rate of detuning change. In presence of such perturbation equilibrium polarization vector is not vertical and changes with energy. By this reason, it is required to match polarization vectors at injection as well as at ejection.

Adiabatic mode is needed to keep particle polarization oriented along that vector.

Owing to snake, detuning from integer resonances does not become zero anywhere.

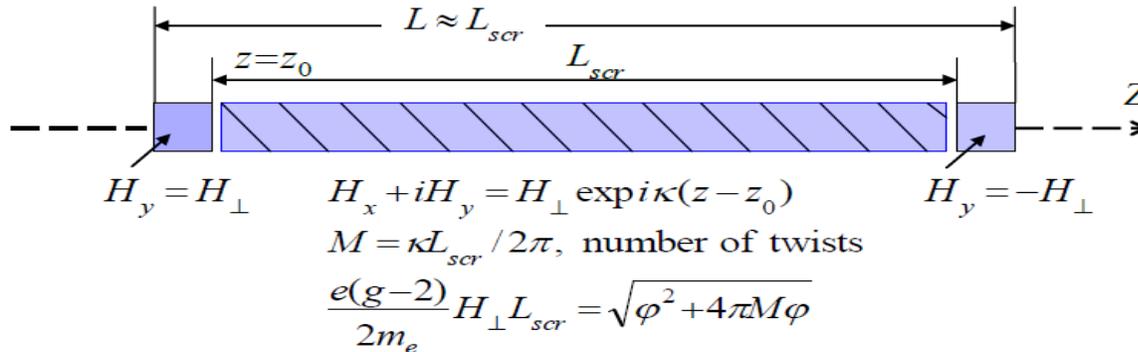
Worth to be considered!



High energy ramping rate and large machine size \rightarrow huge rate of change of detuning are base of proposal!

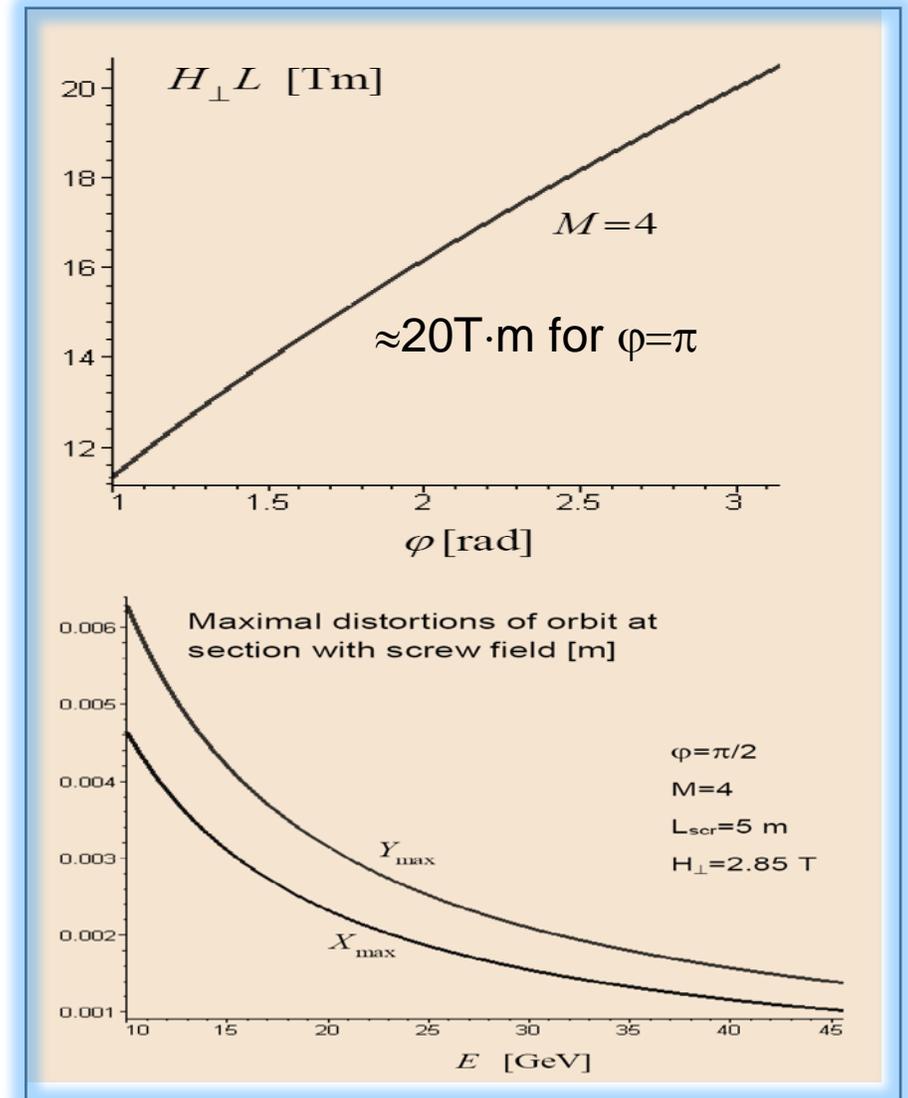
Helix snake

Y.S. Derbenev, A.M. Kondratenko, AIP Conf. Proc. 51,292 (AIP, NY, 1979);
A.M.Kondratenko, Doctoral thesis, Novosibirsk, 1982



- Orbit makes transverse excursions and restores at exit
- Snake doesn't excite perturbations of dispersion outside
- One dipole magnet at left end and the same but inverse in sign at right end provide optical transparency
- Almost exactly longitudinal spin rotation axis
- Necessary field integral doesn't depend on energy ($\varphi = \text{const}$)
- Continuous screw field can be replaced by a screw-like system of piecewise-constant magnets
- Need to ensure some optical matching (edge focusing in magnets of snake)

Advantage of Helix Snake is compact arrangement.
Solenoid-based full Siberian Snake:
104 T·m @ 10 GeV;
474 T·m at 45.6 GeV.



Weak helix snake

Full Snake $\varphi = \pi$: all resonances excluded

CEPCB:

Mid Snake $\pi/2 < \varphi < \pi$: integer + intrinsic resonances excluded

Weak Snake $\varphi < \pi/2$: integer resonances excluded

Helix Snake increases radiation losses.

In particular, $H=1.78$ T and $L=8.6$ m ($\varphi = \pi/2$),

$$\int_{\text{snake}} H^2 dl / \int_{\text{ring}} H^2 dl \sim 25 \text{ at } 10 \text{ GeV}; \quad \int_{\text{snake}} H^2 dl / \int_{\text{ring}} H^2 dl \sim 0.5 \text{ at } 120 \text{ GeV}.$$

In CEPCB, Helix Snake should not be very strong, which limits spin rotation angle φ .

For instance, let $\varphi = 0.4$ rad, then detuning from any integer spin resonance under acceleration is $\varepsilon \approx \varphi / 2\pi \approx 0.06$ (about 26 MeV in energy units). So, integer spin resonances are excluded.

At the same time, main spin-betatron resonances are intersected

since $\left| \cos \frac{\varphi}{2} \right| > \left| \cos \pi \nu_{x,y} \right|$. Resonance crossing rate

$$\varepsilon'_0 = \frac{d}{d\theta} \varepsilon_0 = \frac{\sqrt{\cos^2 \frac{\varphi}{2} - \cos^2 \pi \nu_{x,y}}}{\sin \pi \nu_{x,y}} \cdot \varepsilon'_1 \approx \varepsilon'_1 \approx 2 \cdot 10^{-3}$$

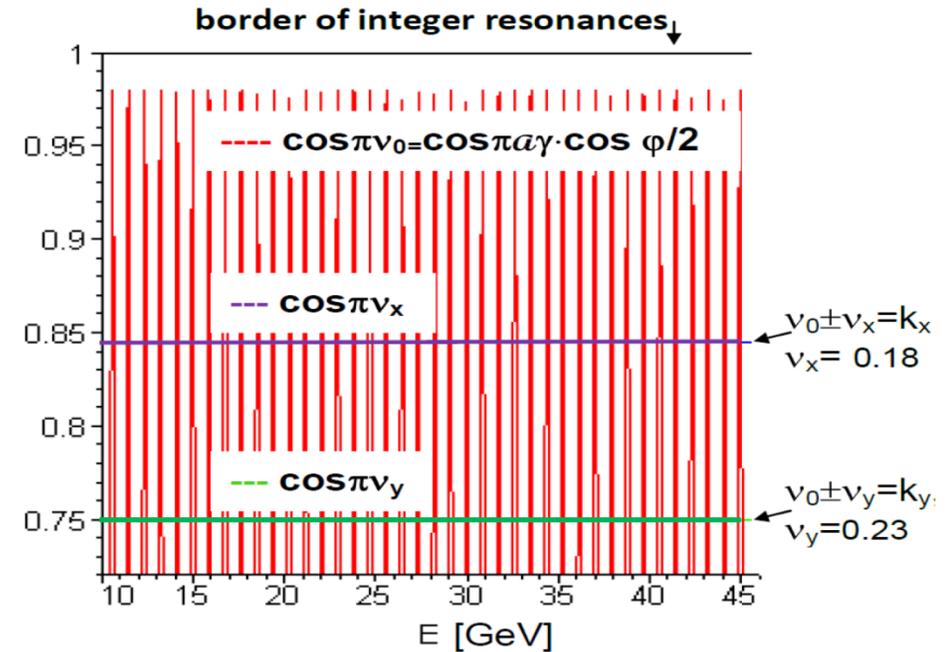
if $\varphi \ll 1$ and $\nu_{x,y} \rightarrow$ half integers.

Low depolarization: $\varepsilon'_0 \gg \pi N_{s-b} |w_{s-b}|^2 \rightarrow |w_{s-b}| \ll 0.003$

($N_{s-b} = 320$, number of resonances in range 10-45 GeV).

This condition on characteristic harmonic seems feasible.

Thus, weak snake allows you to bypass integer resonances while maintaining the ability to intersect spin-betatron resonances in fast crossing mode



Comparison of two Helix Snakes

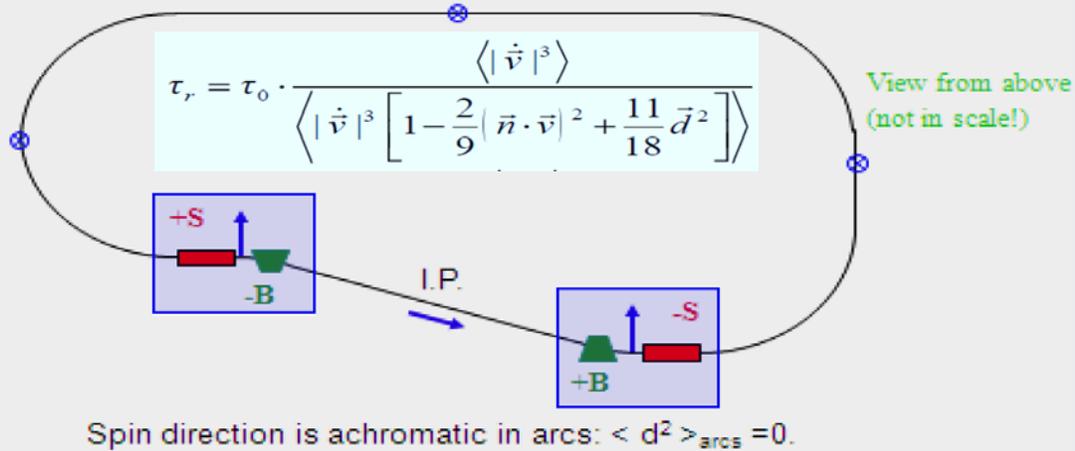
φ rad	H_{\perp} T	L_{tot} m	M twist number	α mrad	E GeV	Y_{max} mm	X_{max} mm
0.4	0.89	8.6	4	4.7	10 45.6	5 1.1	3.7 0.8
1.57	1.78	8.6	4	1.2	10 45.6	10 2.2	7.4 1.6

LP scheme with minimization of spin-orbit coupling

One of LP options for SuperB

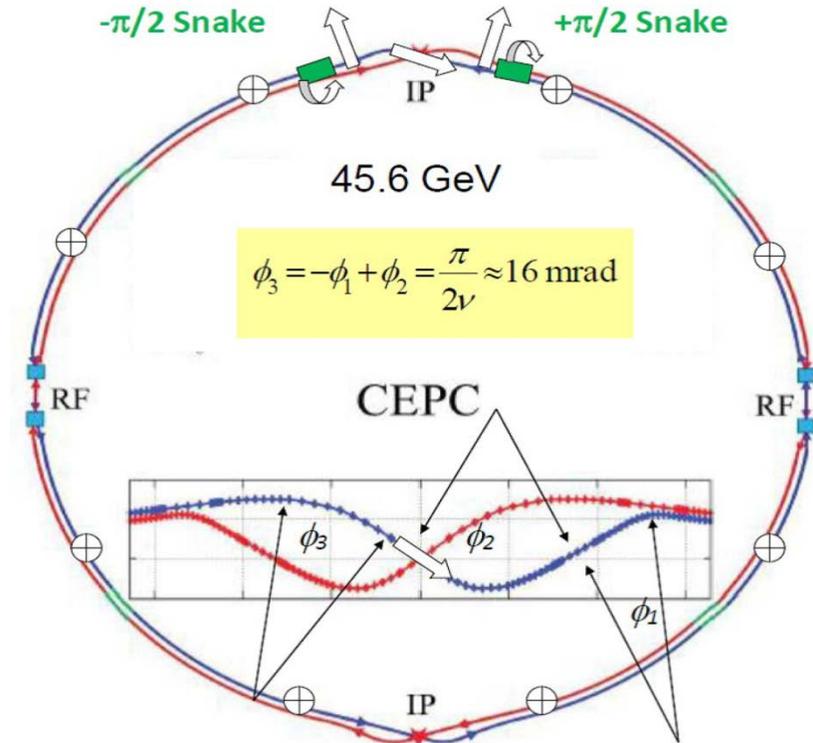
Different-in-sign 90° solenoids and anti-symmetric bend in between.

I.Koop . FACTORIES '08. 14-16 Apr. 2008,



Antisymmetric rotator insert system:
 solenoids S_{\pm} rotate spin by $\pm\pi/2$
 Bends $B_{\pm} = \pm\pi/2\nu$ rotate by $\pm\pi/2$ (bends to left and to right of IP, between solenoids)
 S-shaped twist of orbit at CEPC helps to design it. Contributions to spin chromaticity from left and right parts of rotator system cancel each other.
 Depolarization effect of SR in arcs is suppressed.

e.g. $H_{\parallel} L \approx 8T \times 30 \text{ m}$ solenoid-based snake



Radiative relaxation time τ_r of polarization in order of magnitude can be comparable with S-T time $\tau_p = 260 \text{ hrs}$! This provides average polarization degree close to that of injected beam

S.Nikitin, Talk at IAS Program on HEP, Jan. 2018, Hong Kong

Summary

- Depolarization effect of quantum fluctuations in presence of vertical closed orbit distortions at CEPC has been estimated taking into account modulation of spin tune by synchrotron oscillations. Resonance harmonic amplitude is input parameter
- Spin harmonic amplitude of vertical closed orbit distortion sources at Z-pole should be corrected to level $\leq 10^{-3}$ to ensure 50% equilibrium polarization degree
- If this is done and role of other factors (e. g. resonance diffusion) is not notable, it is possible to reach polarization in range (6-10)% in 45 GeV CEPC in time of (2-4) hours using e.g. ten shifter magnets with moderate characteristics
- Spin Response Function has been calculated for CEPC at 45 and 80 GeV (in two ways for self-cross-checking). It allows us to determine critical level of machine field errors with respect to depolarization process.

- At 45 GeV, expected harmonic amplitude of closest integer spin resonance (quad offset of 50 μm , tilts of b. magnets and quads of $3 \cdot 10^{-4}\text{rad}$) is about 3 times larger than desirable one. Correction of resonance harmonics ($k= 103$ and $k= 104$) is needed as it was done at LEP in past
- As can be seen from results of calculation of depolarizing influence of random tilts of quads, betatron contribution to spin-orbit coupling can be neglected in working range of energy
- It is shown that there is alternative possibility of obtaining polarization by accelerating polarized particles in CEPC booster and then injecting them into main ring. It's worth to study it, for instance, with regard to usage of weak helix snake. This option saves time spent on the polarization process, and can also be crucial for obtaining longitudinal polarization
- In top-on injection mode, because of twisted orbit in interaction area, there is principal possibility to provide high average degree of longitudinal polarization using known kinematic scheme which minimizes spin-orbit coupling in arcs

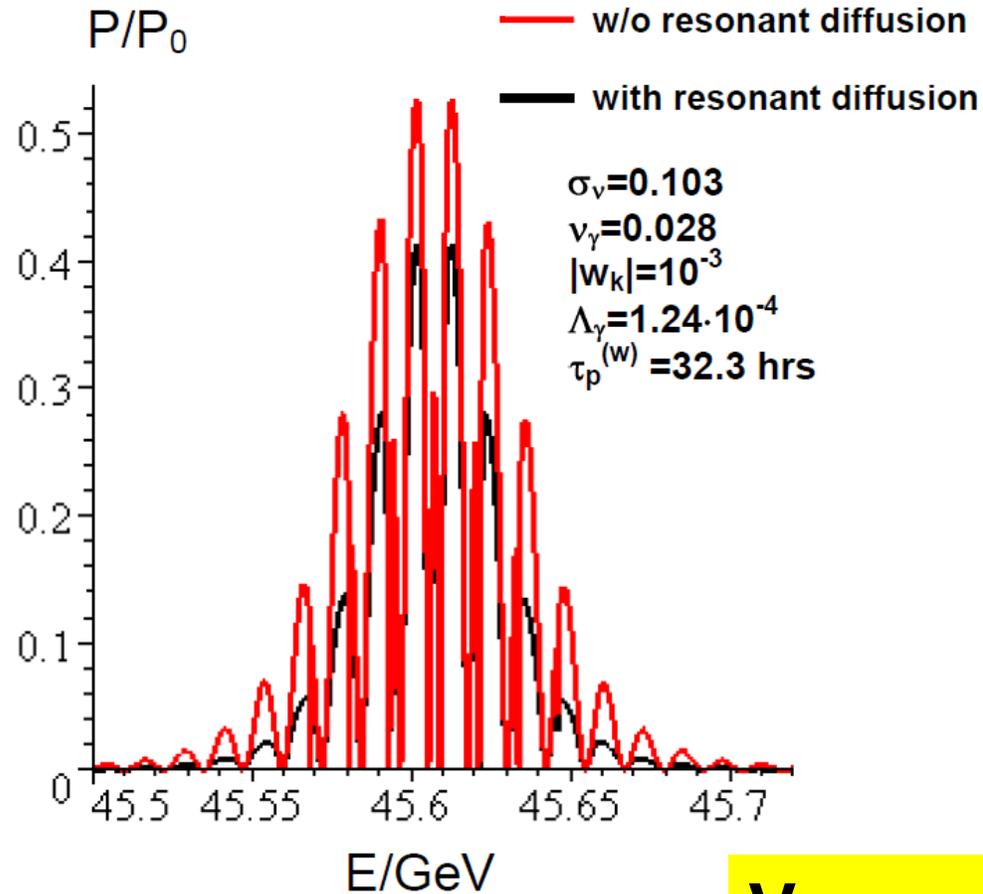
I am grateful to Prof. Jie Gao for initiation of this discussion. I thank Anatoly Kondratenko for conversations on spin dynamics; Evgeni Levichev, Ivan Koop, Dmitry Shatilov and Sergei Sinyatkin for useful discussions on FCCee project; Dou Wang and Yiwei Wang for technical help

THANK YOU FOR ATTENTION!

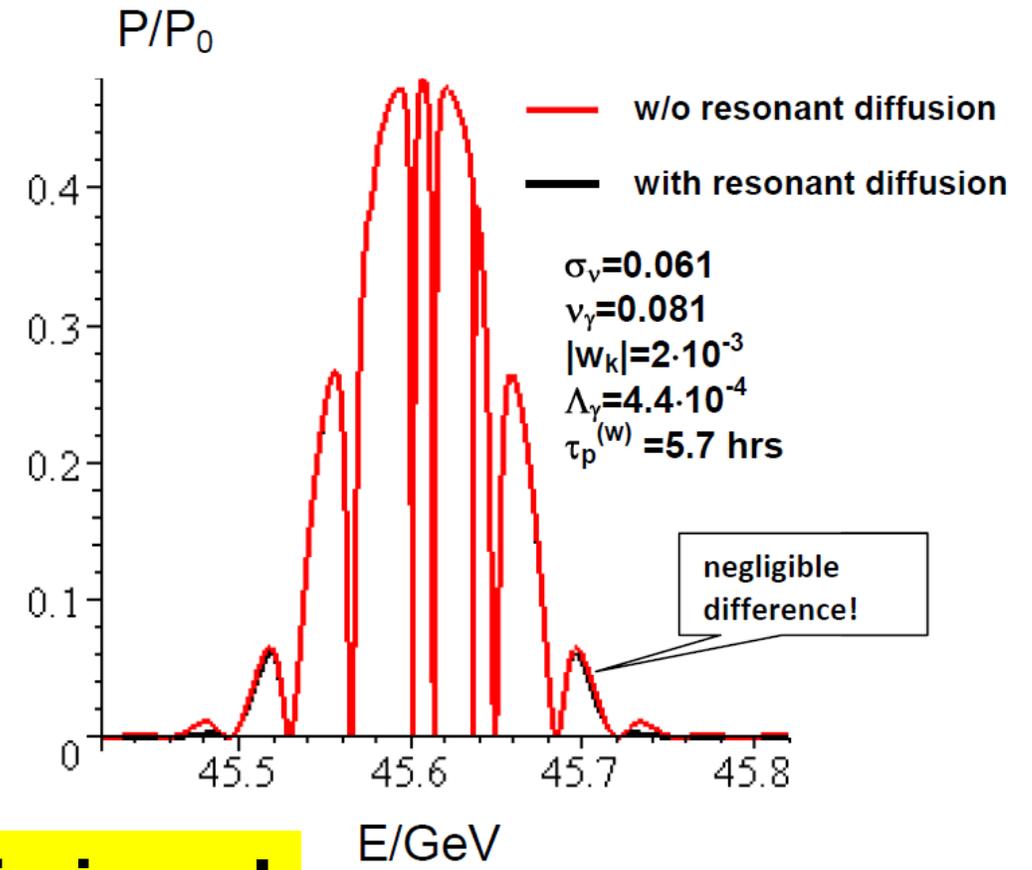
Resonant diffusion due to large spin tune spread

Intersections of integer resonances $k=103$ and $k=104$ are taken into account

CEPC



LEP



Very preliminary!

Spin response in resonant depolarization technique

Rate of depolarization is $\tau_d^{-1} \propto \varphi_{\perp}^2 |F^v|^2$. One passage spin rotation angle is φ_{\perp} . Spin Response Function F^v takes into account a depolarization effect of vertical betatron oscillations excited by the depolarizer kick.

In different cases $|F^v|^2$ may be < 1 or achieves $\sim 10^2$ and more

- Efficiency of RF transverse field depolarizer depends on Spin Response Function module at azimuth of depolarizer placement as well as on rate of frequency scanning
- Basing on knowledge of $|F^v|$ magnitude, depolarizer is tuned to can depolarize at main spin resonance but to be not enough in strength for that at sideband (more weaker) ones. Important to exclude false depolarization events under scanning depolarizer frequency!