Spin Dynamics in the JLEIC Alternative Pre-Booster Ring

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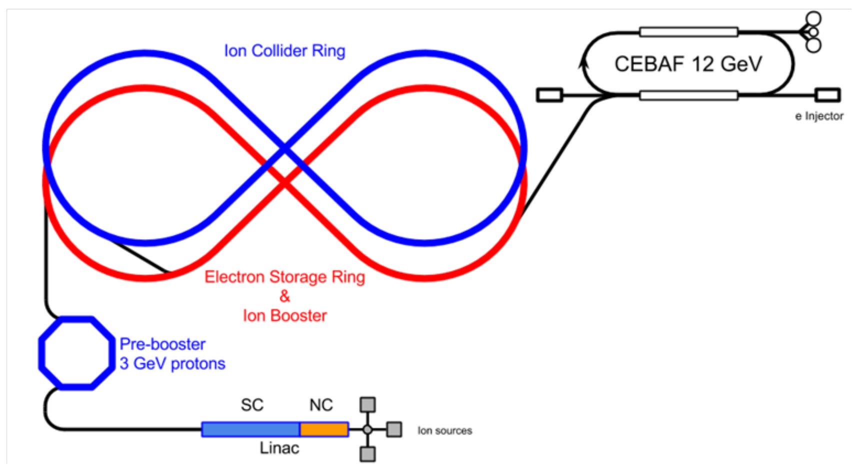
Abstract

In order to reduce the foot-print of the **JLEIC ion complex**, we have designed a more compact and cost-effective octagonal 3 GeV ring about half the size of the original design. However, this new design does not preserve ion polarization, so it is necessary to study the **spin dynamics** to find the best solution for spin correction. Different codes, **Zgoubi** and COSY, are used to model and simulate the spin dynamics in the **octagonal 3 GeV ring**, including the spin correction with Siberian snakes.

2. Alternative Design

Layout for the Alternative Design.

- At least ~**70% polarization required.**
- **Figure-8 preserves spin.**
- **Spin Dynamics** needed in the **Pre-Booster**.



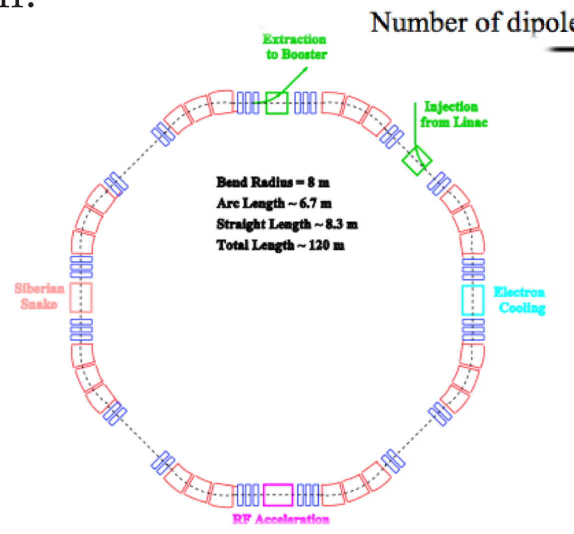
3. Pre-Booster

A compact Pre-Booster. Energy Range: :

- **Proton**: 130 MeV/u - 3 GeV/u
- **Deuteron**: 75 MeV/u - 1.91 GeV/u

Parameter	Octagonal
Circumference, m	120
Maximum β_x, m	15.3
Maximum β_y, m	21
β_x at injection, m	6.0
Maximum dispersion, m	4.2
Normalized dispersion at injection	1.7
Tune in X	3.01
Tune in Y	1.18
Transition γ	4.7
Momentum compaction factor	0.045
Number of Quadrupoles	40
Number of dipoles	24

A non-dispersive section about **4.11 m** is reserved for a Siberian Snake or other device needed to correct depolarization.

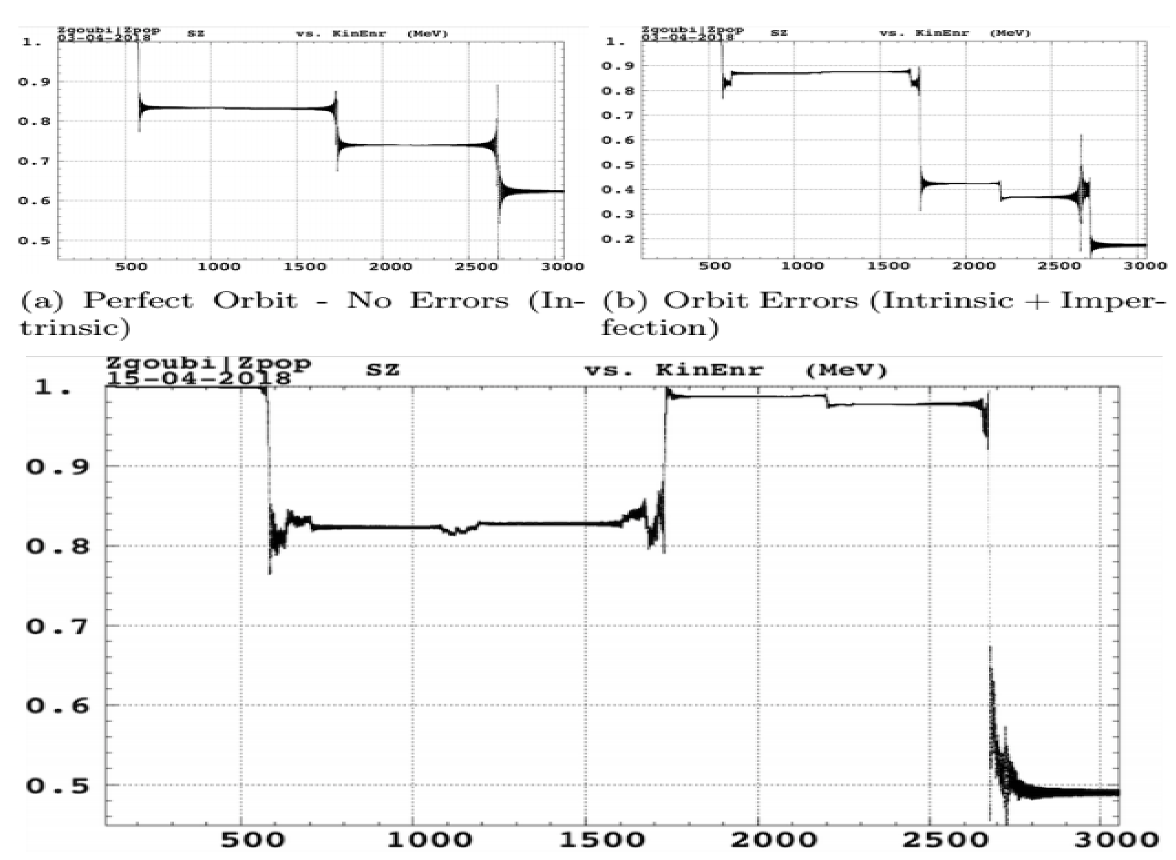


4. Spin Resonances

The **spin tune** is the number of spin precession per turn in a conventional ring: $v_s = G\gamma$ where G is the anomalous g-factor. For protons, $G \approx 1.793$ and for deuterons $G \approx -0.143$. A **spin resonance** occurs whenever the spin precession becomes synchronized with the frequency of spin perturbing fields.

1. **Intrinsic resonances** due to betatron oscillations: $v_s = n \pm v_z$.
2. **Imperfection resonances** due to alignment and field errors: $v_s = n$.
3. Coupling and higher-order resonances: $v_s = n \pm l v_x \pm m v_z \pm k v_{syn}$.

where n, l, m, k are integers, v_x, v_z the horizontal and vertical betatron tunes and v_{syn} the synchroton tune.



(a) Perfect Orbit - No Errors (Intrinsic) (b) Orbit Errors (Intrinsic + Imperfection)

(c) Orbit Errors + Sextupole Component (Intrinsic + Imperfection)

Figure 1
Pre-Booster Ring. Zgoubi. ($\epsilon_{rmsz} = 20\pi mm.mrad.$).

Table 2
Imperfection Resonances. Proton Beam.

		$G\gamma$	K (MeV)
Regular	k	3	632
Very Strong	kP	4	1155
Regular	k	5	1678
Regular	k	6	2202
Super Strong	~ kPM - v_z	7	2725

Table 1
Intrinsic Resonances. Proton Beam.

		$G\gamma$	K (MeV)
Intrinsic	nP - vz	4 - vz = 2.82	538
Strong Intrinsic	nP + vz	4 + vz = 5.18	1773
Very Strong Intrinsic	nPM - vz	8 - vz = 6.82	2631

Table 3
Total Number of Spin Resonances.

Resonance	Proton	Deuteron
Intrinsic	3	0
Weak intrinsic	8	0
Imperfection	5	0

- **No resonances** for **deuteron** due to the anomalous g-factor G and the energy range.

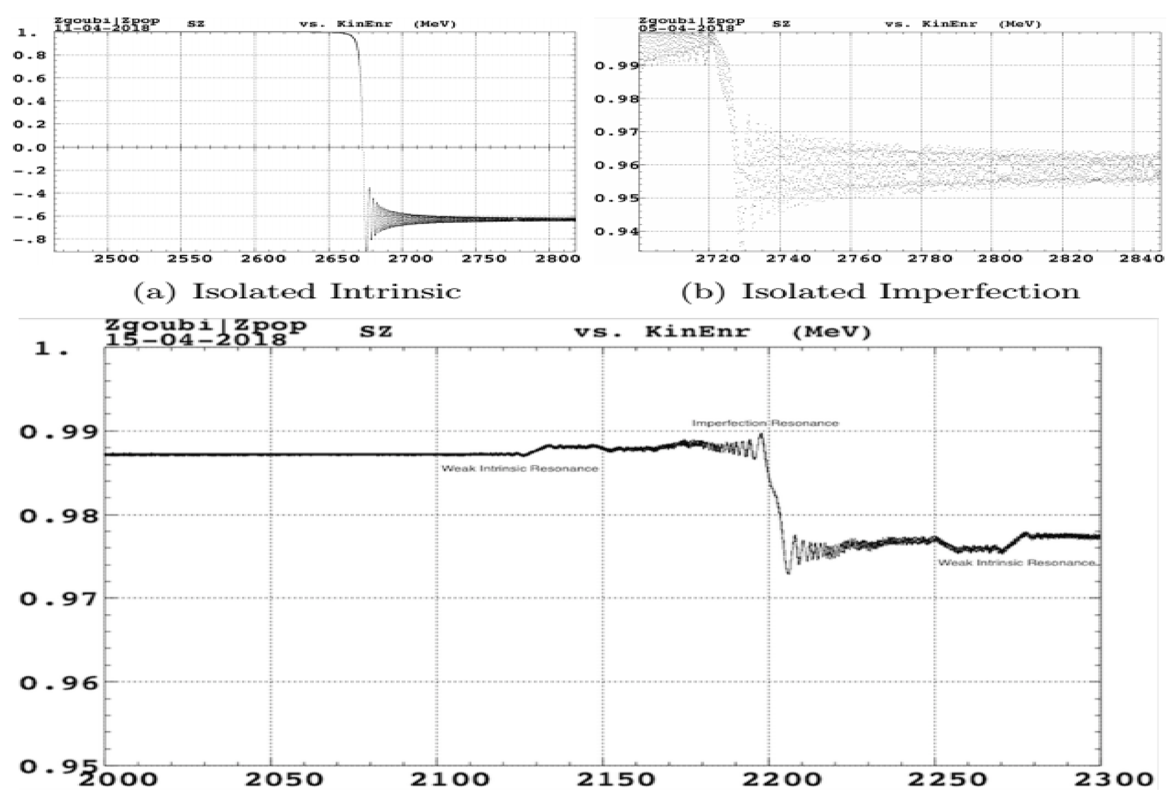
5. Strength of Spin Resonances

It is possible to get the strength of the spin resonances isolating them and using *Froissart-Stora* formula.
$\frac{P_{final}}{P_{initial}} = 2exp(-\frac{\pi}{2}\frac{|\epsilon|^2}{\alpha}) - 1$ being $\alpha = G\frac{d\gamma}{d\theta} = G\frac{1}{2\pi}\frac{\Delta E}{M_0}$

1. The **weak resonances** localized in $n \pm v_z$ are **negligible** (<1% of polarization loss).
2. The majority of **resonances** found are **not too strong**. Three cases of intrinsic resonances may cause a considerable polarization.

Table 4
Strength of Intrinsic Resonances. Proton Beam.

Resonance Strength	$G\gamma$	$\frac{P_f}{P_i}$	ϵ_k
Medium	3 - v_z = 2.82	0.6865	0.001104
Strong	4 + v_z = 5.18	0.171	0.001956
Very Strong	8 - v_z = 6.82	-0.636	0.003489



(a) Isolated Intrinsic (b) Isolated Imperfection

(c) Weak resonance. Zoom to Fig. 4, c)

Figure 2
Strength of resonances. Pre-Booster. Zgoubi. ($\epsilon_{rmsz} = 20\pi mm.mrad.$)

6. Options for Spin Correction

Table 6
Overcoming the Pre-Booster Depolarizing Resonances for Proton Beam.

Option	~ 5 Imperfection	~ 2 Strong Intrinsic	~ 1 Intrinsic	~ 8 Weak Intrinsic
A	Orbit Corrections	rf Dipole	rf Dipole	Nothing/Pulsed Quads
B	5% Siberian Snake	rf Dipole	rf Dipole	Nothing/Pulsed Quads
C	Orbit Corrections	Pulsed Quads	Pulsed Quads	Nothing/Pulsed Quads
D	5% Siberian Snake	Pulsed Quads	Pulsed Quads	Nothing/Pulsed Quads
E	42% Siberian Snake	42% Siberian Snake	42% Siberian Snake	42% Siberian Snake

- Several ways to avoid depolarization have been proposed.
- It is better to **avoid Pulsed Quads** for intrinsic resonances because of beam emittance growth.

7. Siberian Snake

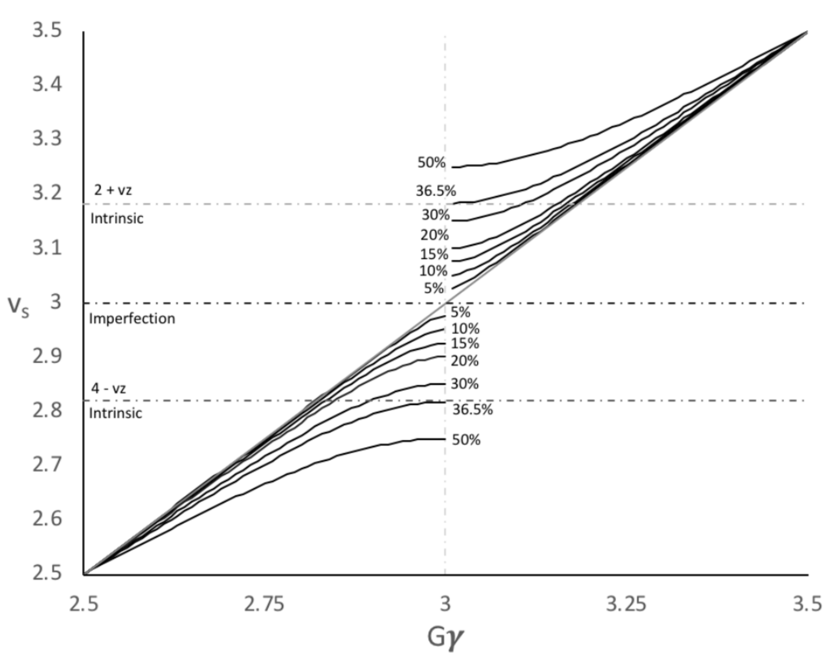


Figure 3
Spin tune gap.

- **5% Solenoid** for imperfection resonances: $\int B_{\|} dl = \frac{\pi}{1+G}B\rho = \frac{10.479}{1+G}p[GeV/c] = 4.6898[Tm]$ with a field of 1.5 T, it will need **less than 3.5 m** long.
- **42% Modified Steffen Snake** for all resonances: To minimize the maximum orbit displacement **more than 4.5 m** long is needed.

Table 5
Strength of Imperfection Resonances. Proton Beam.

Resonance Strength	$G\gamma$	$\frac{P_f}{P_i}$	ϵ_k
Negligible	3	0.9940	0.000147
Negligible	4	0.9999	0.000160
Negligible	5	0.9930	0.000158
Negligible	6	0.9932	0.000138
Weak	7	0.9585	0.000387

8. Conclusions

- Siberian Snake would be the best option to avoid depolarization if space is available. In our case, neither a full Siberian Snake or a 42% snake can be used due to lack of space. There is enough room for a 5% Steffen snake or a **5% solenoid** to correct imperfection resonances. A **helical snake** can be a solution for all resonances because it is more compact but will require 3D modelling.
- Using **rf Dipole** could be enough to avoid the strong intrinsic resonances and minimize depolarization.