Optimization of Spin Coherence Time for Electric Dipole Moment (EDM) measurements in a storage ring

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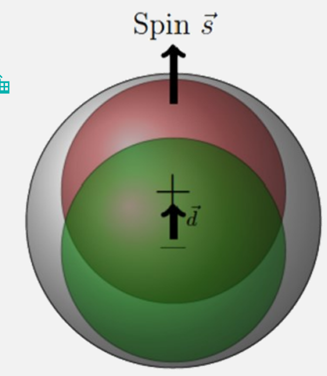
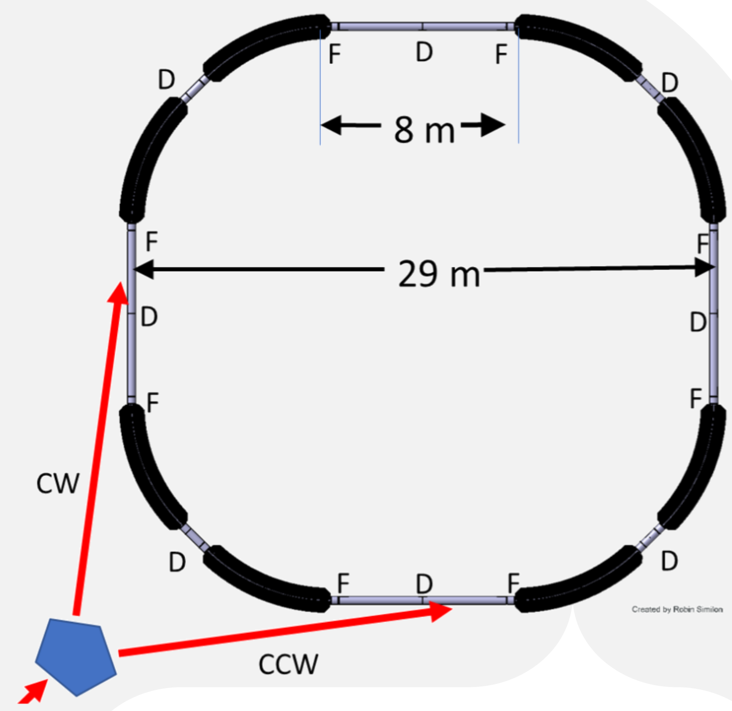
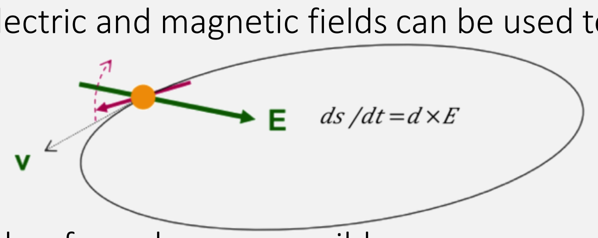
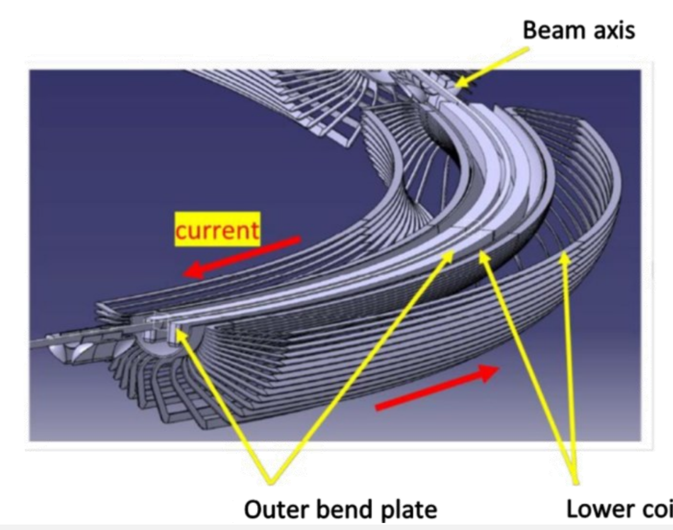




- An Electric Dipole Moment is a fundamental property of a particle:
  - → possible via CP violation
  - → closely correlated with the matter-antimatter asymmetry.
- EDM of charged particles can be measured using storage rings:
  - → Need **polarised beams**
  - → EDM can be measured via vertical precession induced using radial electric fields
- A new **Prototype** ring which uses a special combination of electric and magnetic fields can be used to "freeze" the horizontal precession of protons.
- But EDMs are expected to be very tiny:
  - → A precision experiment with **frozen spin** is needed!
  - → **Buildup of vertical polarisation** will be gradual.
  - → Particles in the bunch must remain aligned to each other for as long as possible
    - → High **Spin Coherence Time**! (time taken for the bunch polarization to fall below $^1/_e$)
- In this poster, a method to optimize the quadrupole and sextupole settings (beam optical settings) to maximize the spin coherence time is presented.

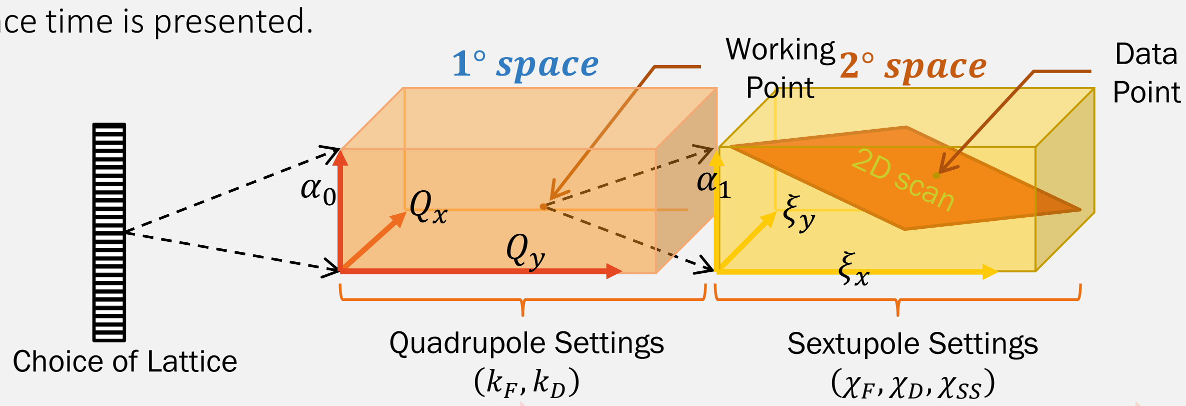


Combined E and B fields



Simulations using BMAD:

A Software toolkit for charged particle and X-ray simulations



Preliminary Scans
- Scans of available working points
- Scan of phase slip factor and natural chromaticities
- Define the Observables of interest

Investigations into Decoherence
- Track polarisation vector magnitude and spin tune spread over time
- Extrapolate and measure the spin coherence time (τ) and average spin tune $\langle \Delta\nu_s \rangle$.

Grid Tests
- Track the variation of spin coherence time and average spin tune over the "space" of 2° optics.
- Devise the optimization strategy from data analysis

Lattice-wide Optimization Survey
- Optimized turns and grid resolution to maximize accuracy.
- 12 working points systematically optimized (optimized grid tests)

$$\vec{P}(t) = \frac{1}{n}\sum_{i=0}^{n}\frac{\vec{s}_i}{|\vec{s}_i|}$$

$$|\vec{P}(\tau)| = \frac{1}{e}|\vec{P}(0)|$$

Polarization vector

Individual particle spin

Number of particles in the bunch

Spin Coherence Time

$$\theta_x(t) = \tan^{-1}\left(\frac{P_x(t)}{P_z(t)}\right)$$

$$\langle \Delta\nu_s \rangle = \left\langle \frac{d}{dt}\theta_x(t) \right\rangle$$

$$\left\langle \frac{\Delta L}{L} \right\rangle = \alpha_1\delta_0^2 - \frac{\pi}{L}\epsilon_x\xi_x - \frac{\pi}{L}\epsilon_y\xi_y$$

Spin tune spread

Average spin tune of the bunch

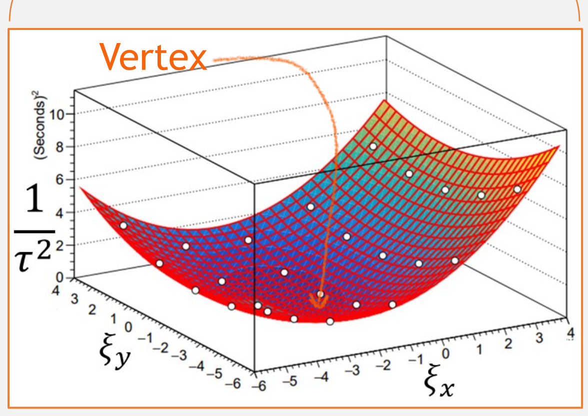
Average increase in path length per turn

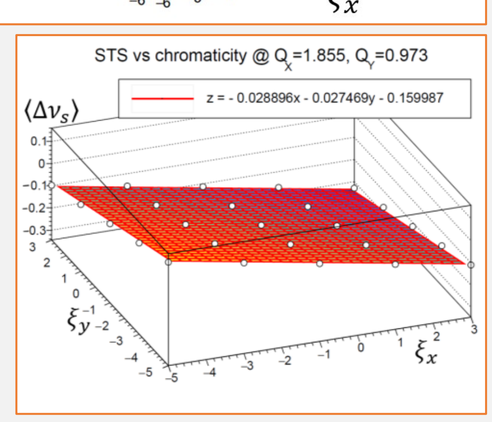
Square of initial momentum offset

Transverse Emittances

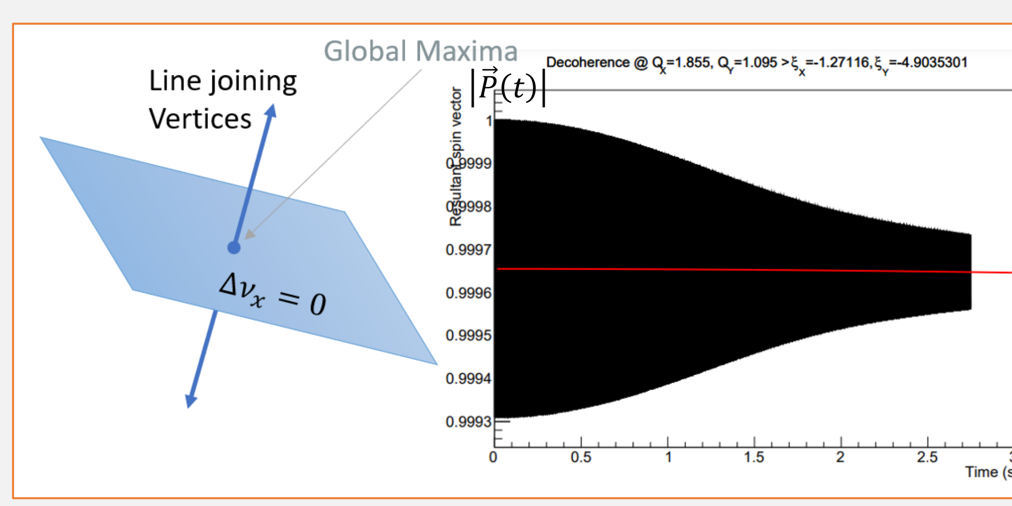
Chromaticities

second order momentum Compaction factor





Q_x	Q_y	κ_F	κ_D	ξ_x^o	ξ_y^o	α_1^o	τ_{model}	τ_{low}	Δ_{1000}^{ξ}
1.855	1.095	0.077	-0.242	-1.271	-4.904	-0.0756	1473	1472	0.020
1.855	1.123	0.077	-0.247	-1.253	-5.036	-0.156	877	1614	0.016
1.855	1.223	0.079	-0.264	-1.167	-5.626	-0.211	3721	3237	0.013
1.823	0.723	0.036	-0.140	-1.483	-1.353	0.0543	677	676	
1.823	0.823	0.055	-0.177	-1.465	-2.389	0.0132	6105	4154	0.016
1.823	0.923	0.062	-0.201	-1.337	-2.983	-0.0573	5647	3870	0.019



❖ **Conclusions:**

- ✓ Variation of SCT with 2° optical parameters follows definite pattern, influenced by the change in path length due to chromaticity and second order momentum compaction factor.
- ✓ **Decoherence virtually non-existent at optimized point.**
- ✓ **Average spin tune $\langle \Delta\nu_s \rangle = 0$, when path lenghtening effects exactly compensate the longitudinal phase-shift due to the distribution of momentum offset.**
- ✓ Optimized point occurs at the point where the line joining the local maxima crosses the plane of zero spin tune spread.
- ✓ **Global maximum SCT is sensitive to the optimized setting (more so at some working points than others).**

References

1. CPEDM Collaboration, "Storage ring to search for electric dipole moments for charged particles: Feasibility study," CERN Yellow Reports: Monographs, Geneva, 2021.

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