JENAS-2022
2nd Joint ECFA-NuPECC-APPEC Symposium

Optimization of Spin Coherence Time for Electric Dipole Moment measurements in a Storage Ring

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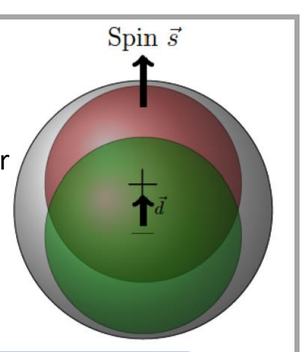
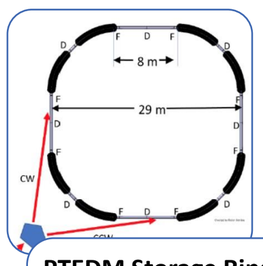
On behalf of the JEDI collaboration.

Motivation

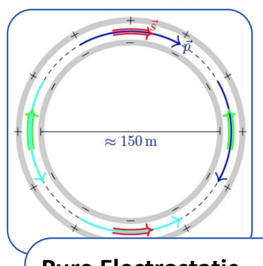
- Electric Dipole Moment is a permanent separation of the positive and negative charge in a fundamental particle → possible via CP violation.
- EDM magnitude closely correlated with matter-antimatter asymmetry in the universe.
- JEDI aims to measure the EDM of charged particles using storage rings in a three-stage experiment. Current work focusses on second stage.



COSY Storage Ring
- Uses only magnetic fields to confine ions
- Spin Precession w.r.t ion momentum
- RF Wien filter to increment planar angle proportional to EDM



PTEDM Storage Ring
- Combines electrostatic and magnetic confinement
- "Frozen" spin through fine-tuning of E and B fields
- Natural increment via E field

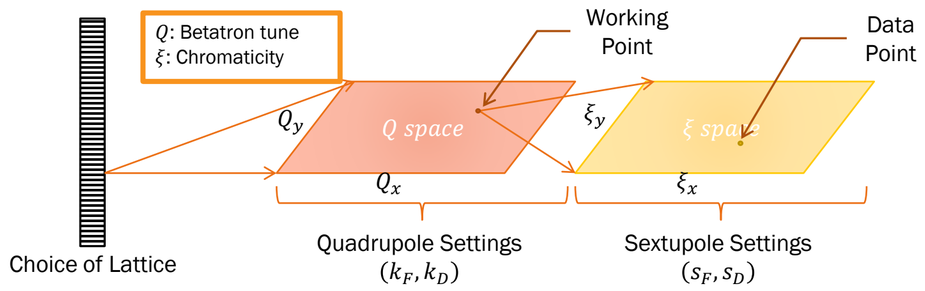


Pure Electrostatic Ring
- Uses only Electrostatic confinement
- "Frozen" spin through fine-tuning of E field, momentum and radius.
- Natural increment via E field

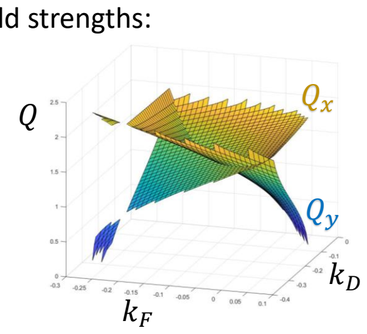
- BMAD library used to simulate spin decoherence in PTEDM ring model with two families of quadrupoles and sextupoles.
- Spin Coherence Time (τ): time taken for resultant spin vector to reduce to $\frac{1}{e}$ times its initial value.
- Maximum SCT indicates precision of the EDM measurement at lattice running optimized field parameters.

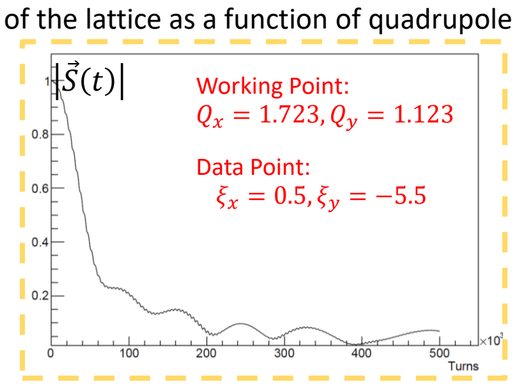
Optical Properties and Decoherence

- This set of optical parameters are optimized to find maximum SCT:



- A plot of all accessible betatron tunes of the lattice as a function of quadrupole field strengths:



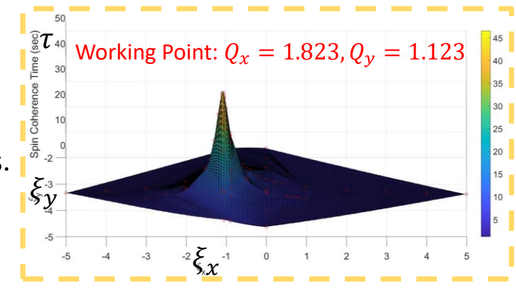


- SCT is measured from the time development of

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

of a bunch of 1000 simulated particles. SCT is τ when

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



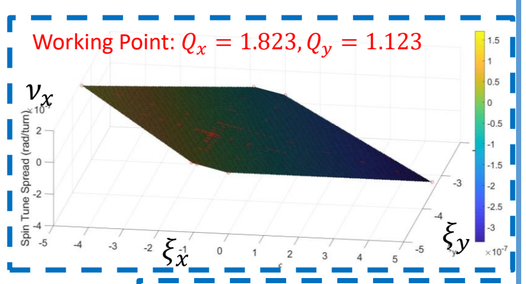
- Scan of decoherence of multiple data points at a single working point → local SCT maxima. Scan of local maxima over all accessible working points → global SCT maxima.

Using STS zero-line and fitting functions to optimize SCT

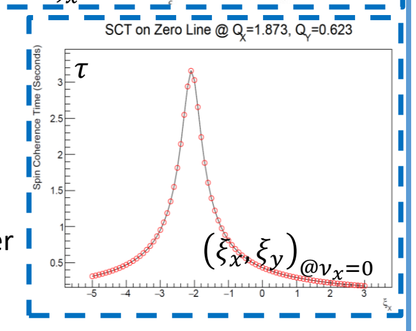
- Maximum spin-coherence time is likely to coincide with minimum spin tune spread (ν_x).

$$\nu_x = \frac{d}{dt}\left[\sin^{-1}\left(\frac{\vec{S}(t).\hat{\imath}}{|\vec{S}(t)|}\right)\right]$$

- ν_x varies linearly with chromaticity in both transverse directions ⟹ there is a straight line of vanishing ν_x on the ξ-space.



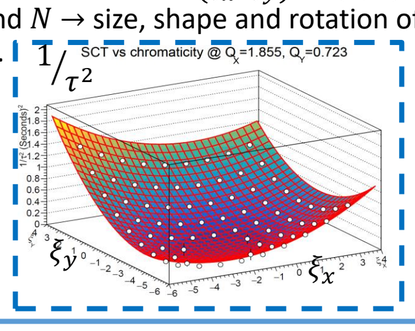
- ∴ optimized data point can be found from a search along the "zero-line".
- Maximum SCT in good agreement with earlier brute force searches.

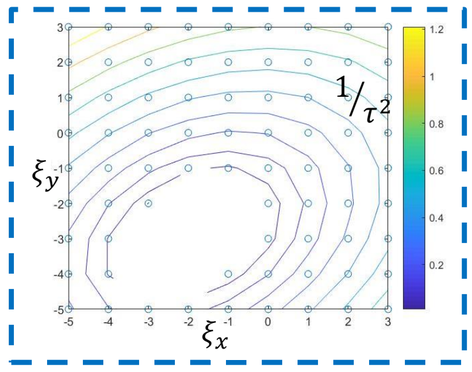


- Contour lines of SCT form concentric ellipses over the ξ-space, regularly scaled at $1/\tau^2$.
- Thus, SCT shown to vary with chromaticity as:

$$\frac{1}{\tau^2} = \frac{1}{{\tau_0}^2} + L(\xi_x - h)^2 + M(\xi_y - k)^2 + N(\xi_x - h)(\xi_y - k)$$

Free parameters:
Maximum SCT → τ_0
location of maxima → $(\xi_x, \xi_y) = (h, k)$
L, M and N → size, shape and rotation of ellipse.



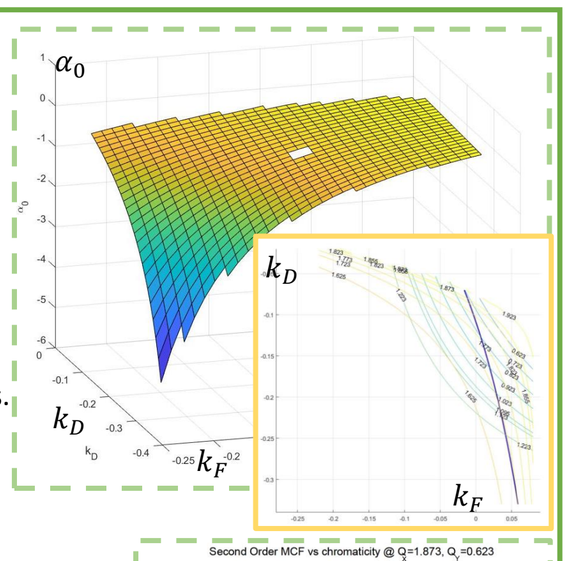


Results

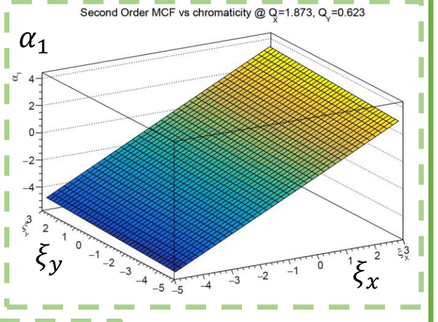
- Negative values of first order momentum compaction factor (α_0) indicate the inaccessibility of the working points at the current phase ($\cos\varphi_s = -0.5$) of the RF cavity (synchrotron frequency becomes imaginary):

$$f_s = f_{rf}\sqrt{-\frac{\alpha_0 e U_0}{2\pi\beta_0 E_0 h}\cos\varphi_s}$$

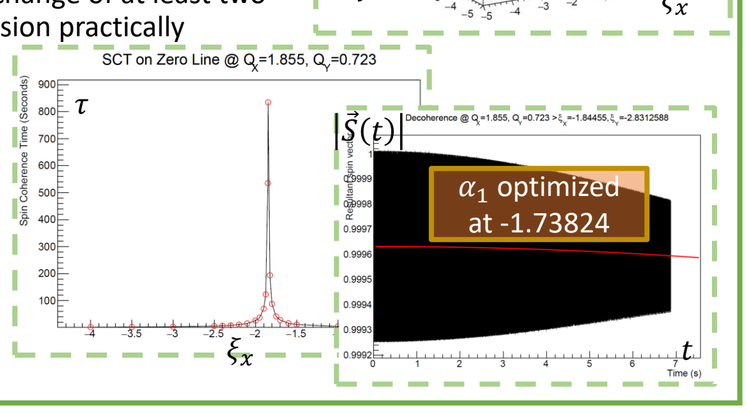
limiting the search to positive points.



- Second order momentum compaction factor (α_1) varies linearly with chromaticities.
- Global SCT maxima, upwards of 1000s, was found for optimized second order optics ($\xi_x = -1.845, \xi_y = -2.831, \alpha_1 = -1.735$) at working point $Q_x = 1.855, Q_y = 0.723$.



- SCT highly sensitive to chromaticity possibly due to simultaneous change of at least two parameters → Is precision practically achievable?
- Sharpness of such peaks may reduce with additional family of sextupoles.



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