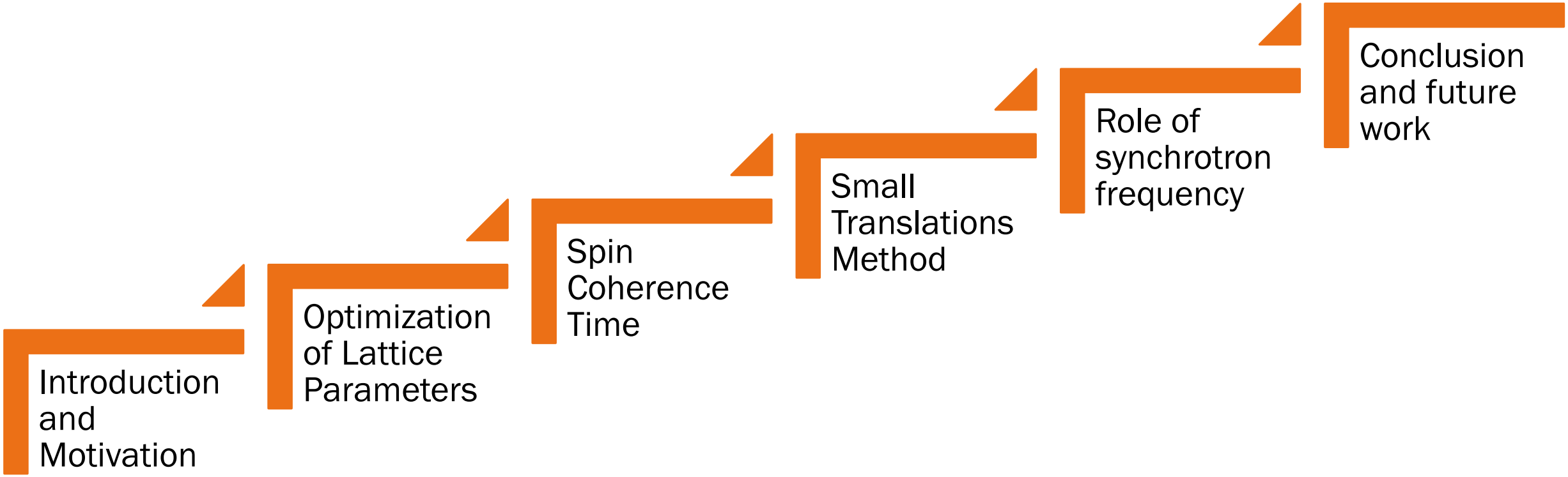
Optimization of Spin Coherence at a Prototype Storage Ring for Electric Dipole Moment Measurements

Rahul Shankar (UniFe and INFN)

Maximillian Vitz (RWTH Aachen)

Paolo Lenisa (UniFe and INFN)

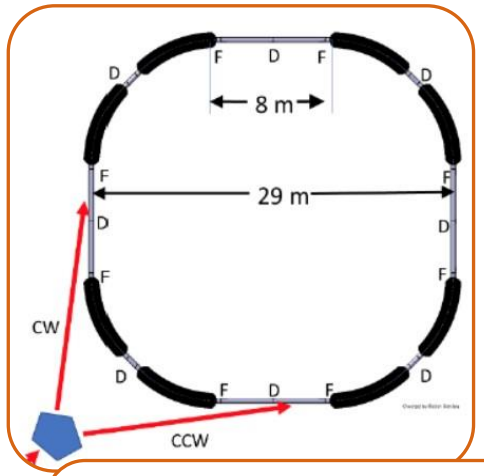
What's in here…



Stages of the Experiment [2]

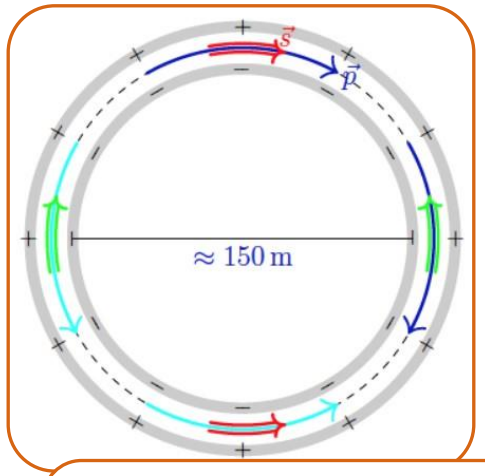
COSY Storage Ring

- 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

Strategy for EDM Measurement in PTEDM ring

The presence of intrinsic particle properties introduces precession.

∴ for particles in the storage ring:

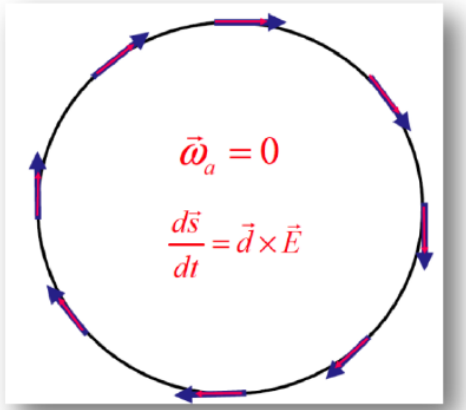
Magnetic Dipole Moment ⟹
Horizontal Polarization

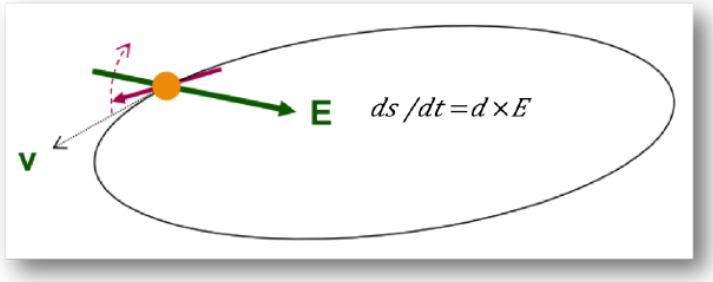
Electric Dipole Moment ⟹
Vertical Polarization
(in the presence of a radial E field)

[1]

Measurement concept

1. Inject particles in storage ring
2. Align spin along momentum (→ freeze horiz. spin-precession)
3. Search for time development of vertical polarization

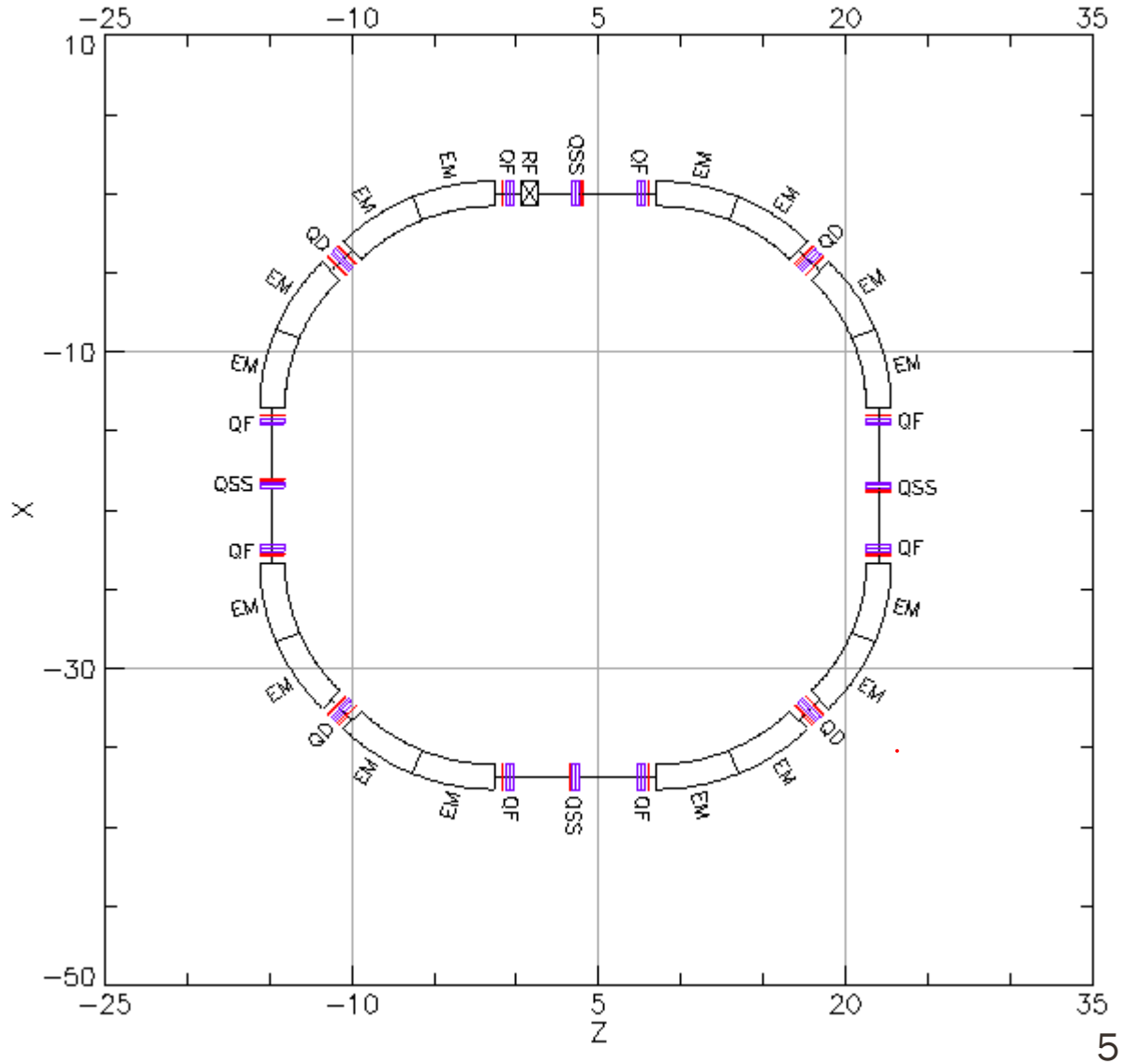




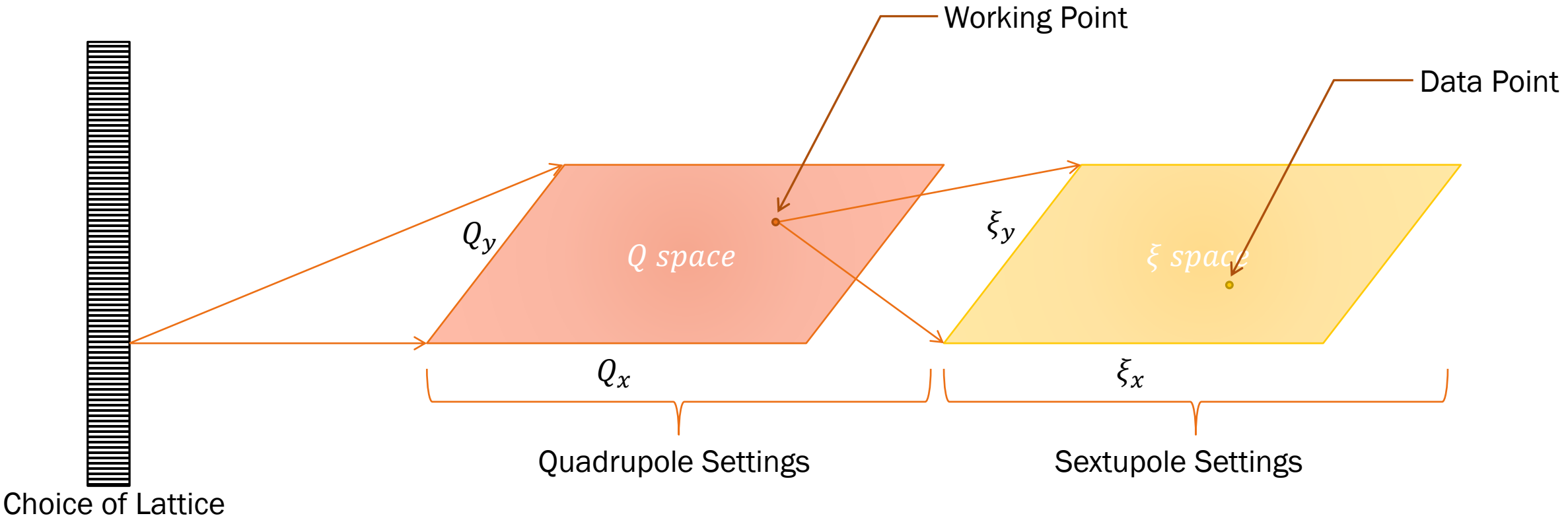
The Prototype EDM Ring Lattice

BMAD Prototype lattice ver 3.0

[3]



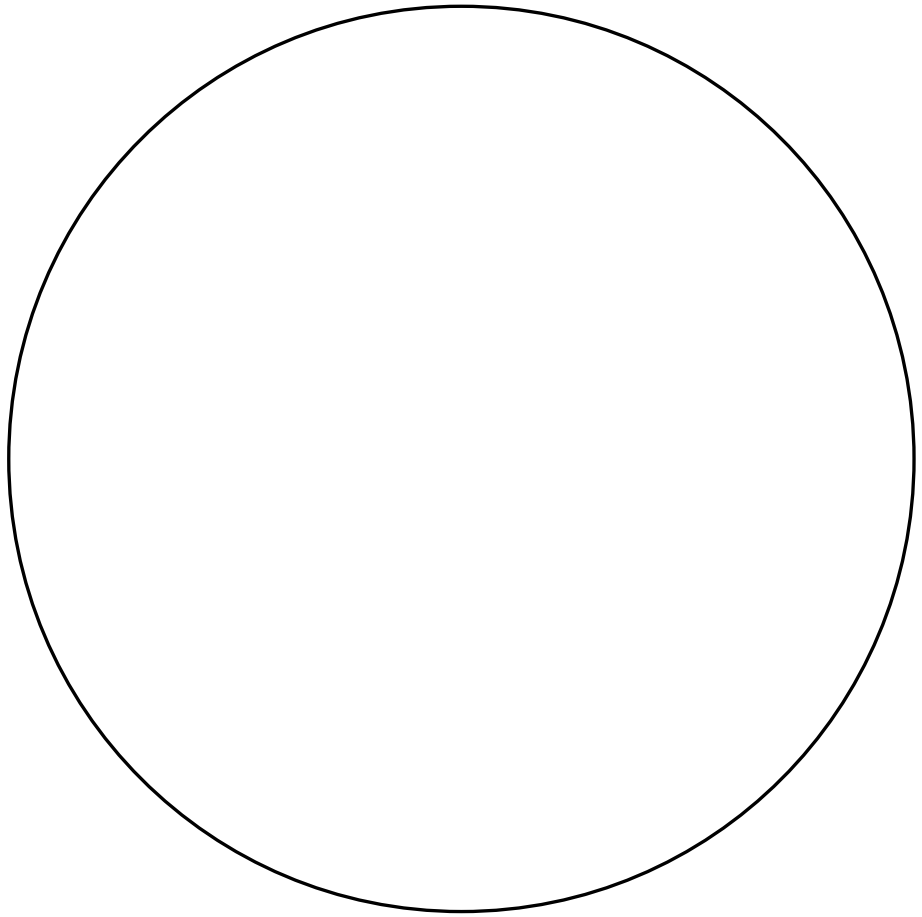
Scanning the Parameter Space [4]



Spin Coherence Time

Time taken for the resultant spin vector of all the particles in a bunch to reduce to $1/e$ of its initial value due to decoherence.

For the desired accuracy of EDM measurements at the prototype ring, it is desirable to have a SCT of above $1000\ s$. [2]



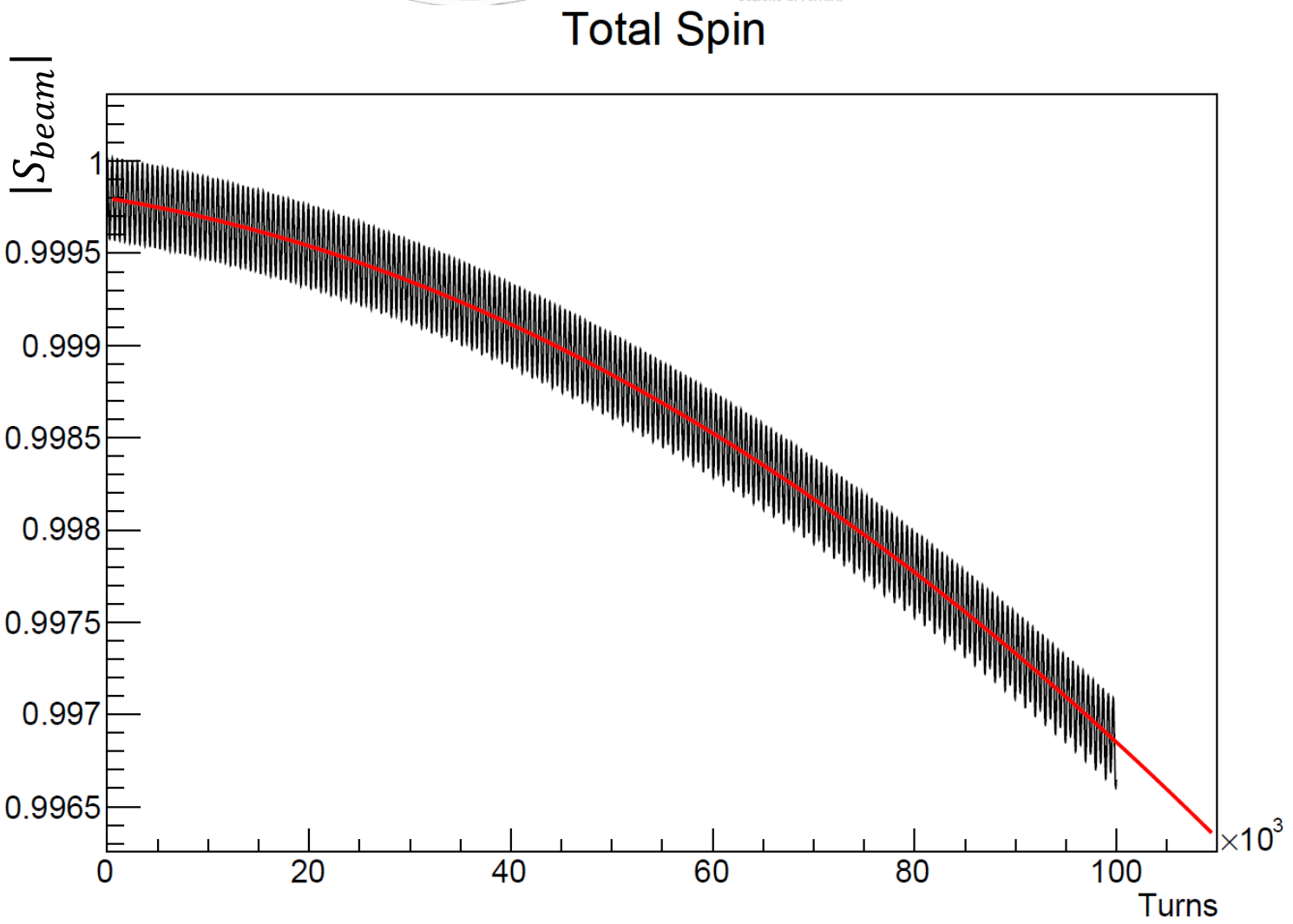
Scanning the Parameter Space

Working Point:

$$Q_x = 1.823, Q_y = 1.123$$

Data Point:

$$\xi_x = 2.0, \xi_y = -3.5$$



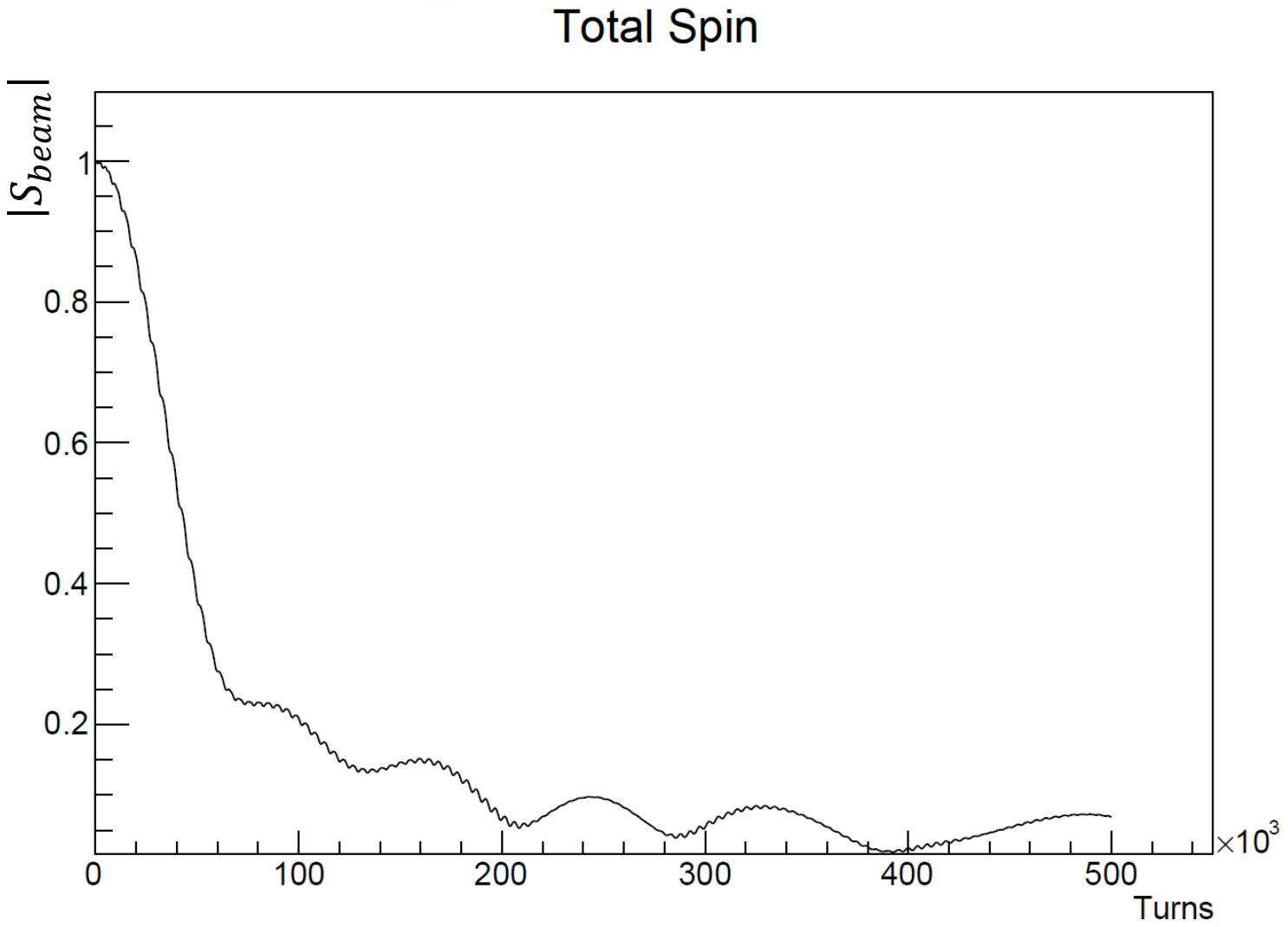
Scanning the Parameter Space

Working Point:

$$Q_x = 1.723, Q_y = 1.123$$

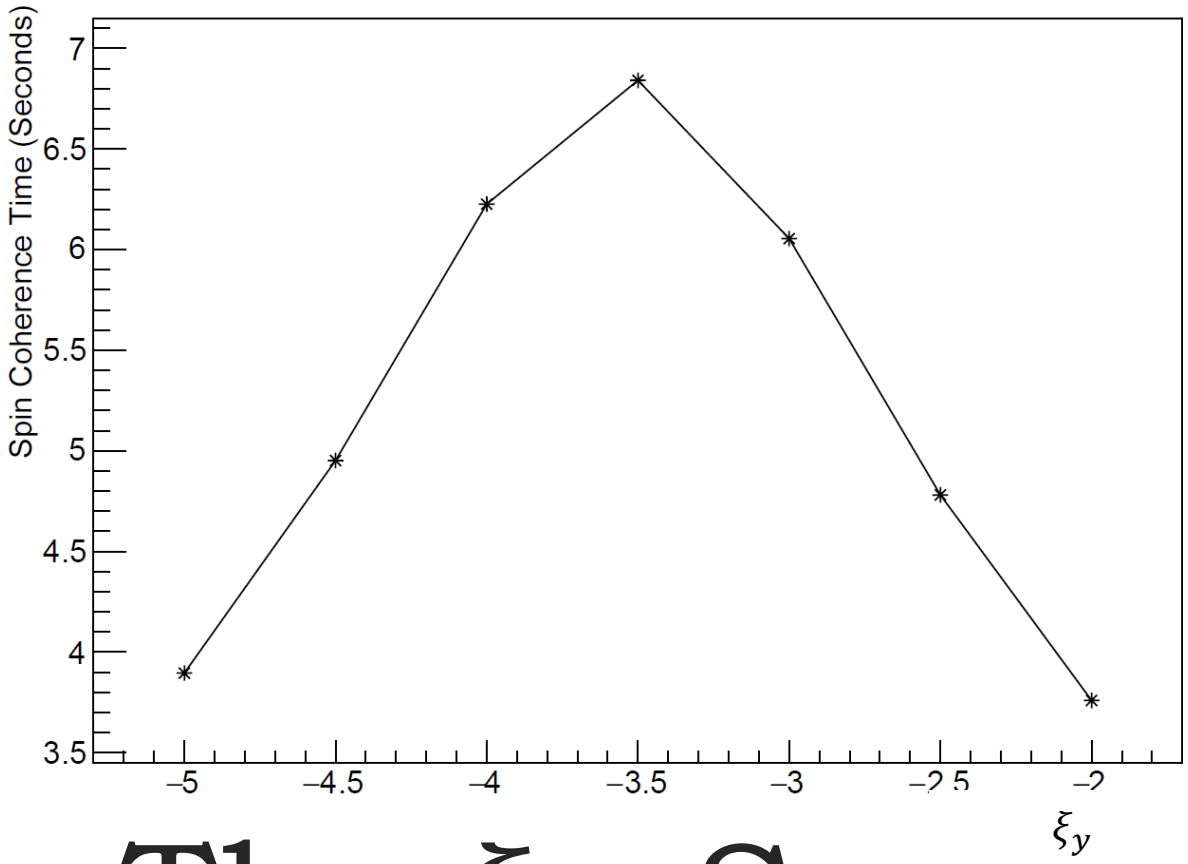
Data Point:

$$\xi_x = 0.5, \xi_y = -5.5$$

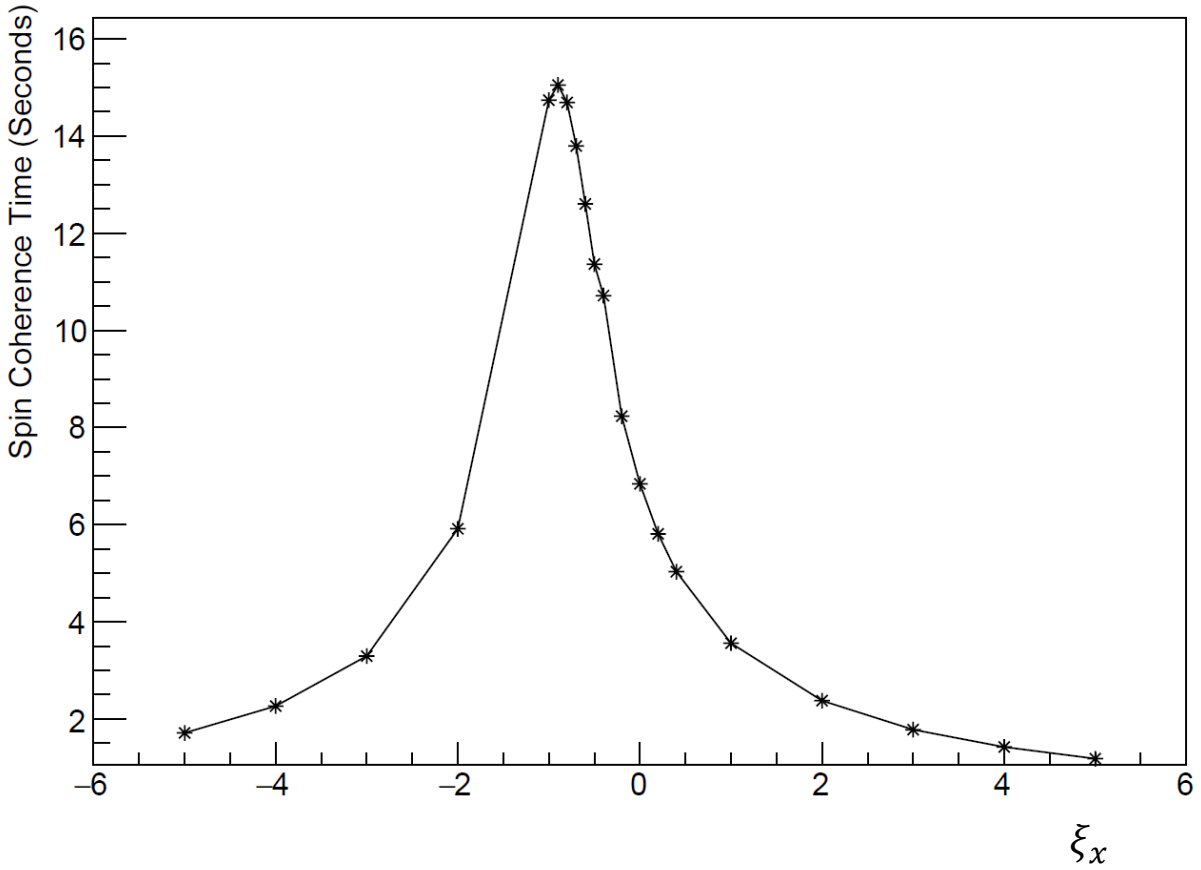


Working Point: $Q_x = 1.823, Q_y = 1.123$

SCT vs chromaticity $@\ \xi_x = 0$

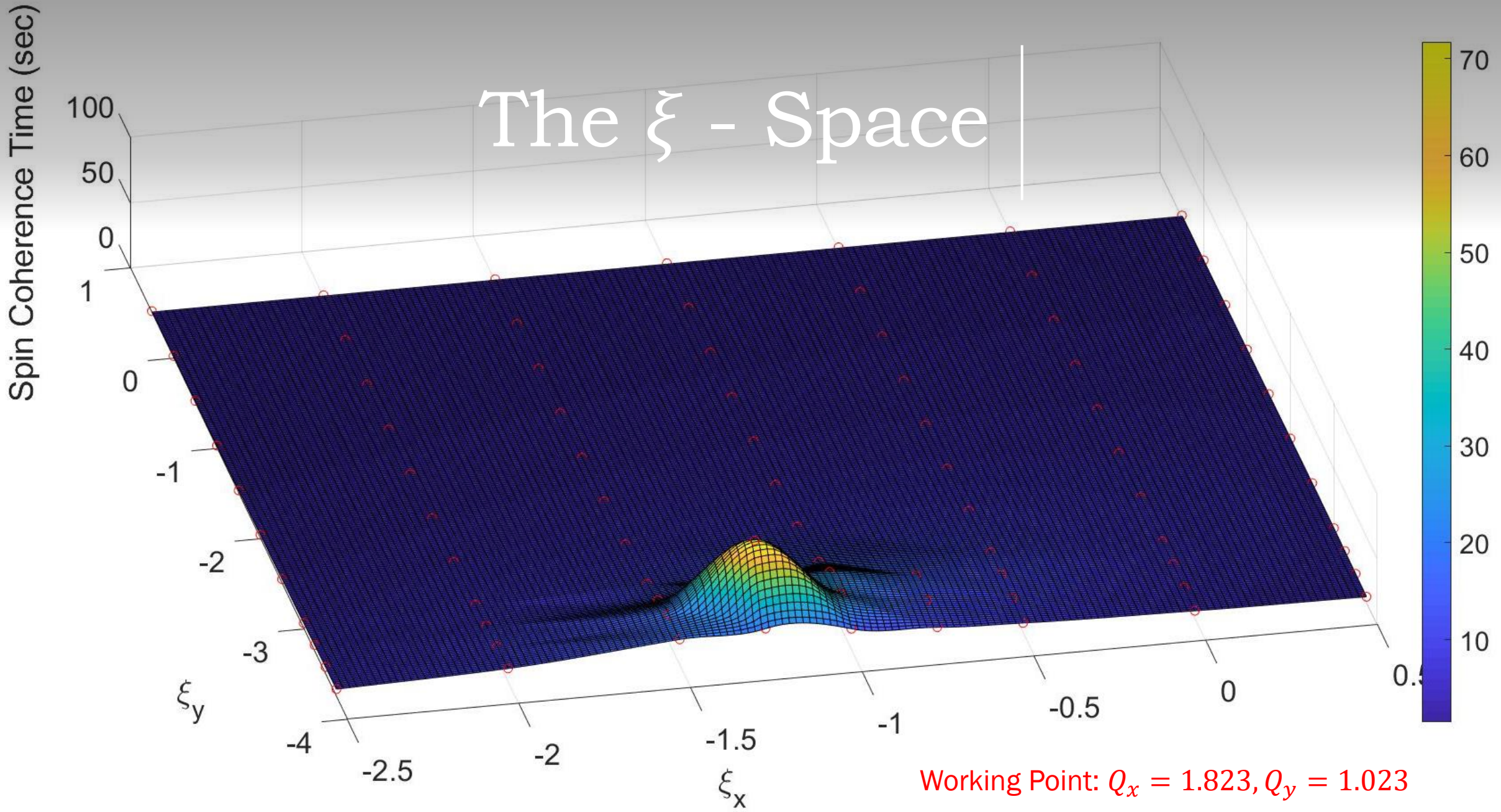


SCT vs chromaticity $@\ \xi_y = -3.5$



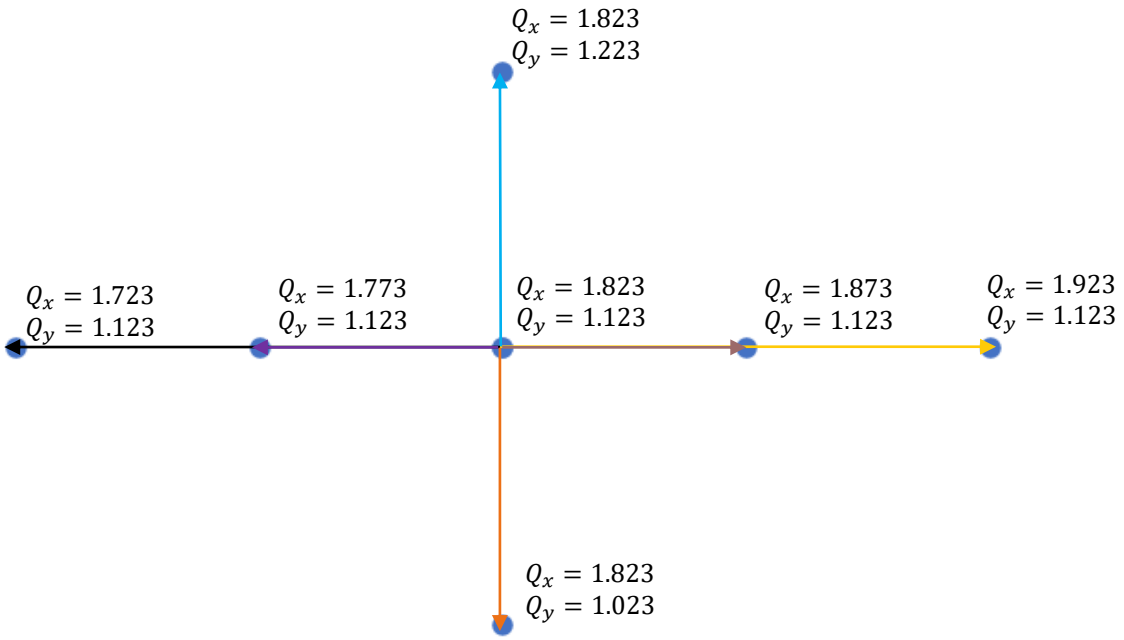
The ξ - Space

The ξ - Space

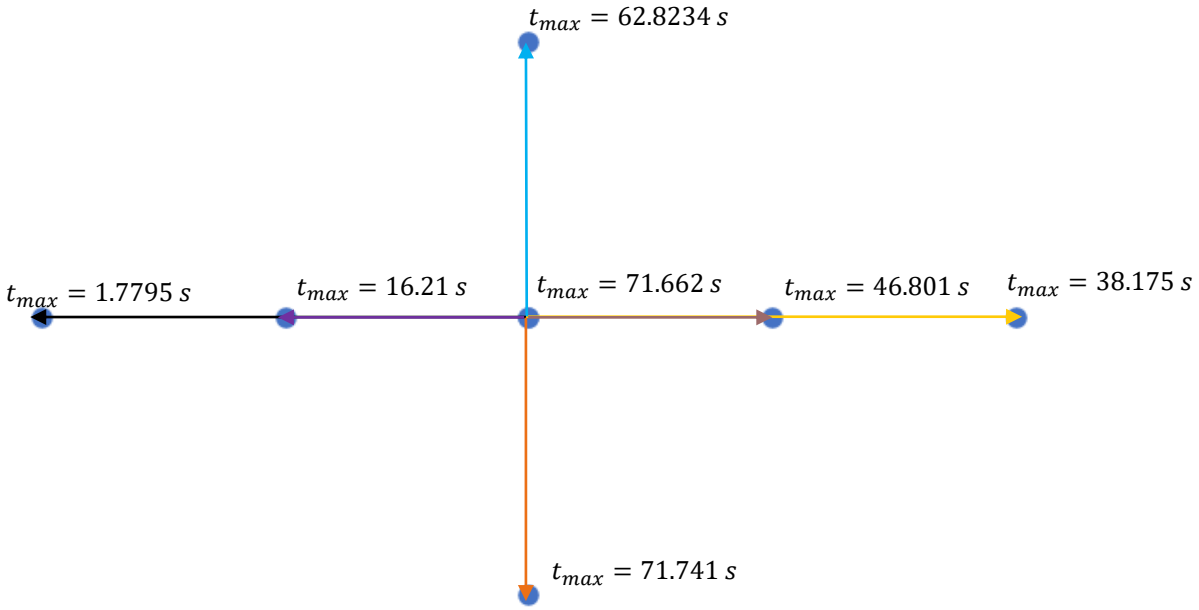


Working Point: $Q_x = 1.823, Q_y = 1.023$

Small Translations[4]



Maximum Spin Coherence Times



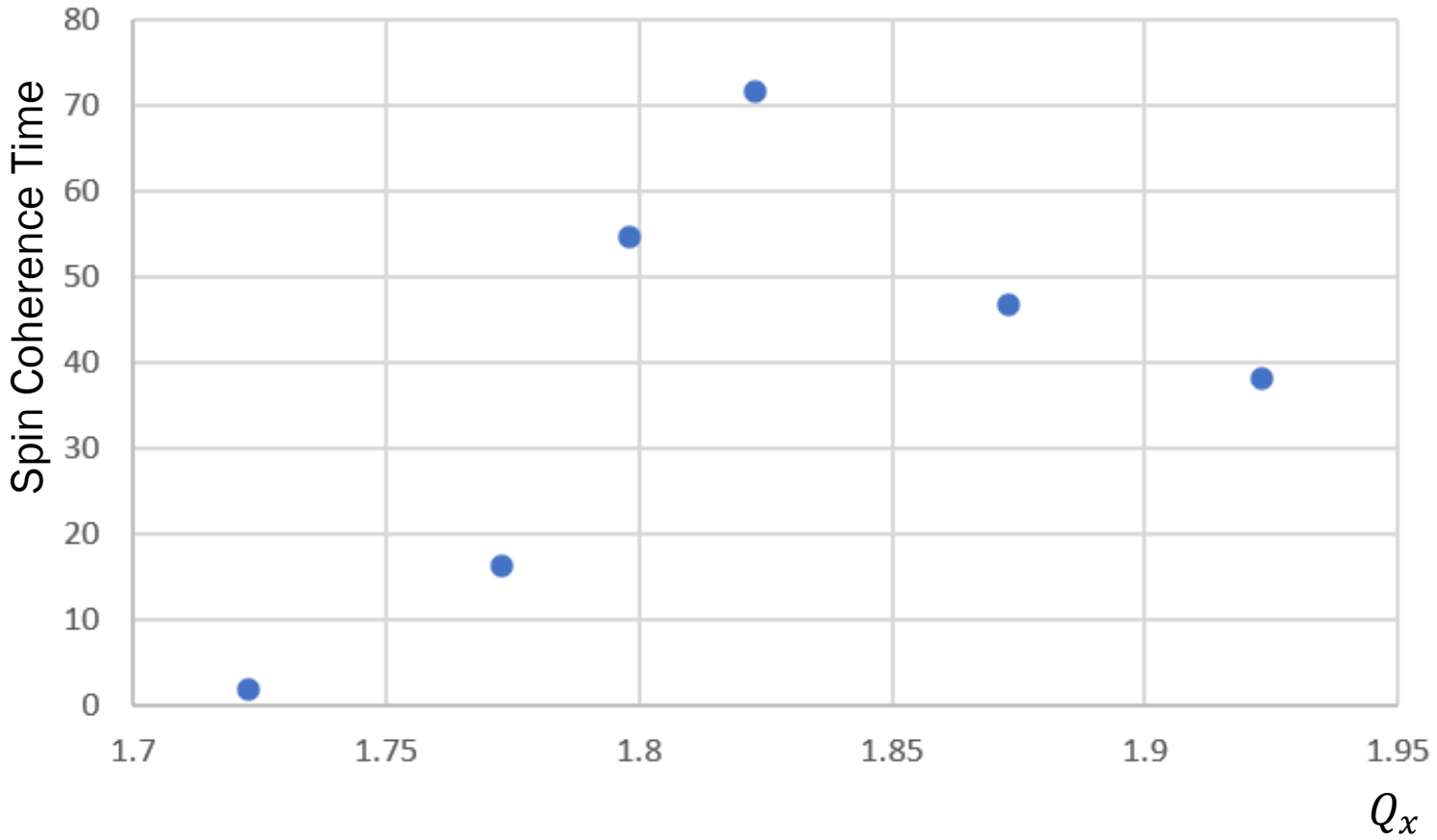
Maximum Spin Coherence Times

Working Point:

$$Q_y = 1.123$$

Data Point:

$$\xi_x, \xi_y \; @ \; t_{max}$$



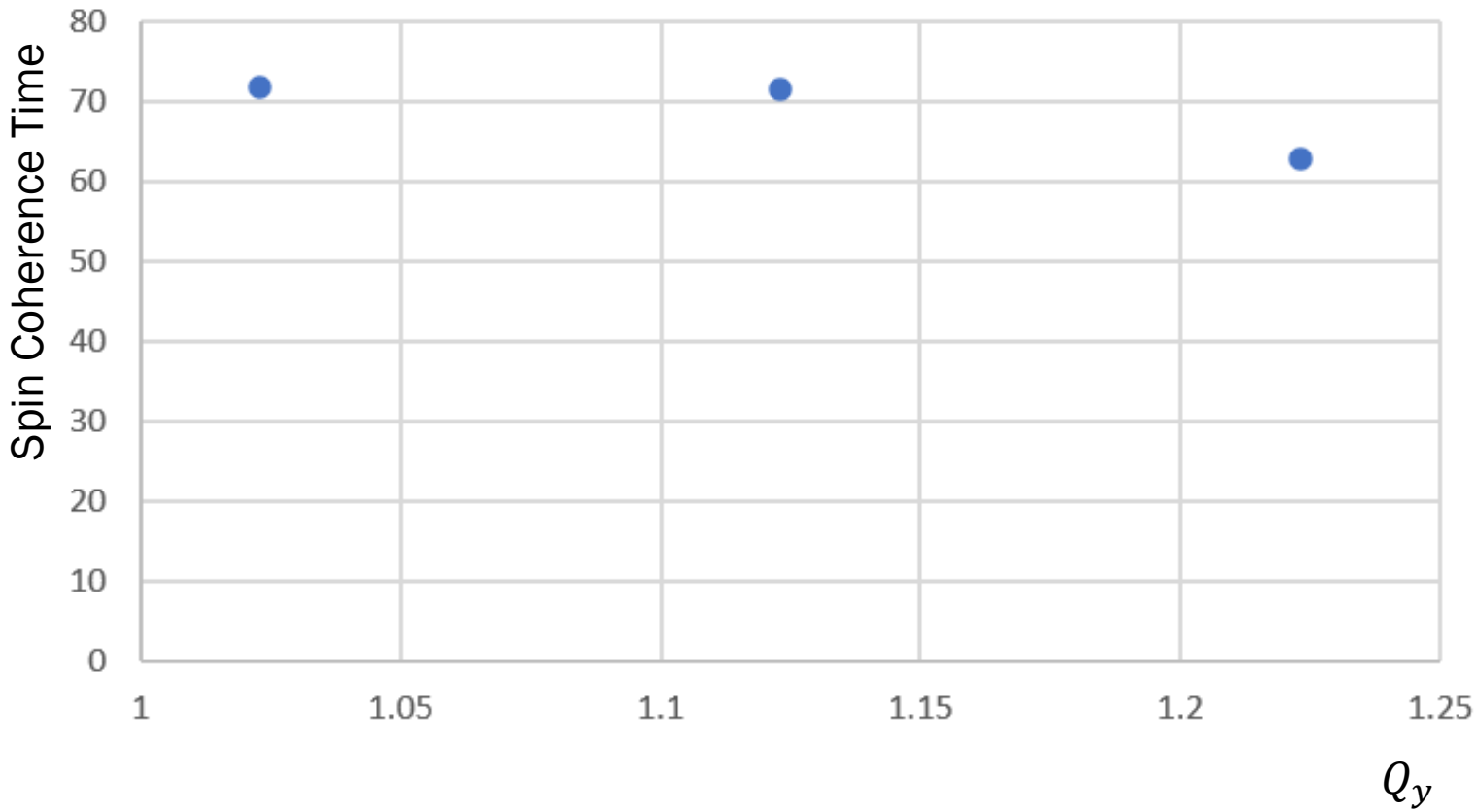
Maximum Spin Coherence Times

Working Point:

$$Q_x = 1.823$$

Data Point:

$$\xi_x, \xi_y \; @ \; t_{max}$$



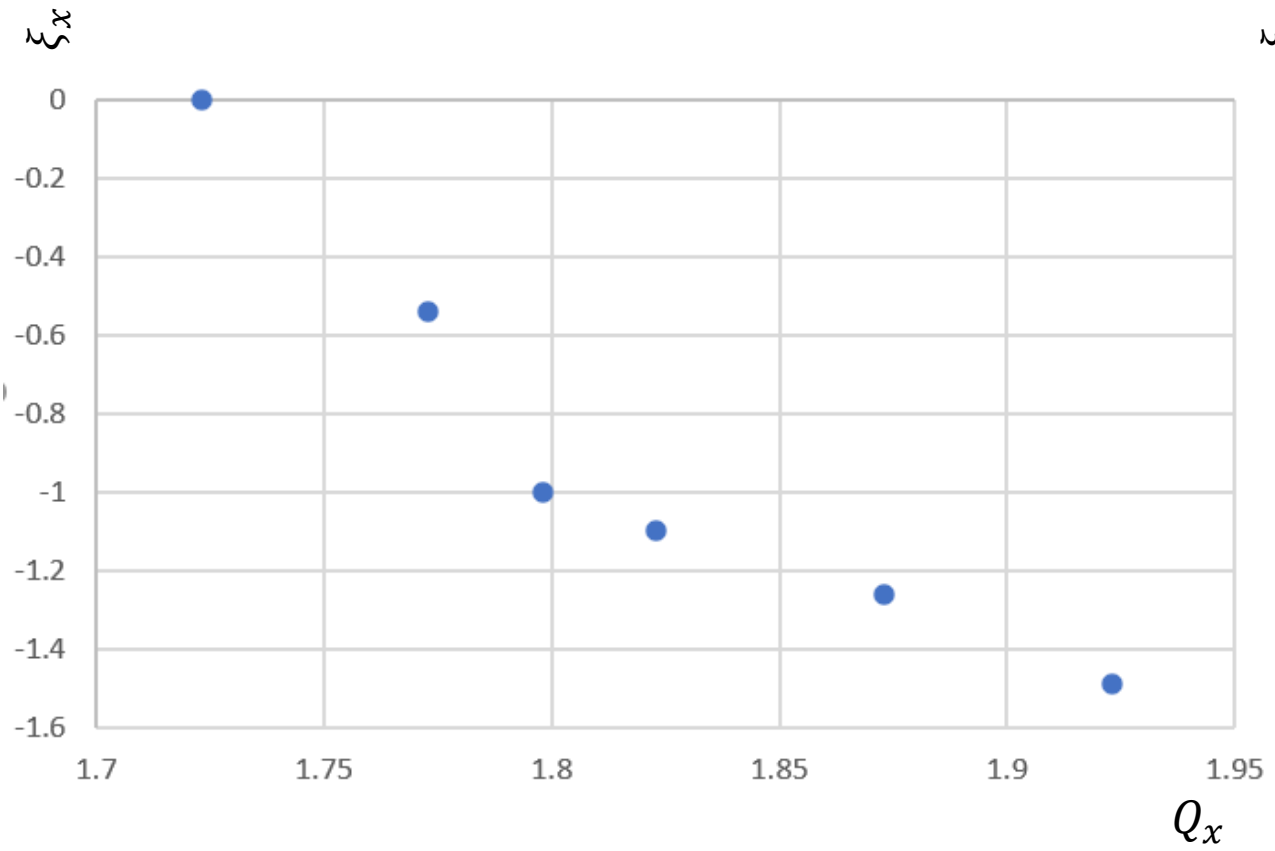
Transformations from Q to ξ - Space

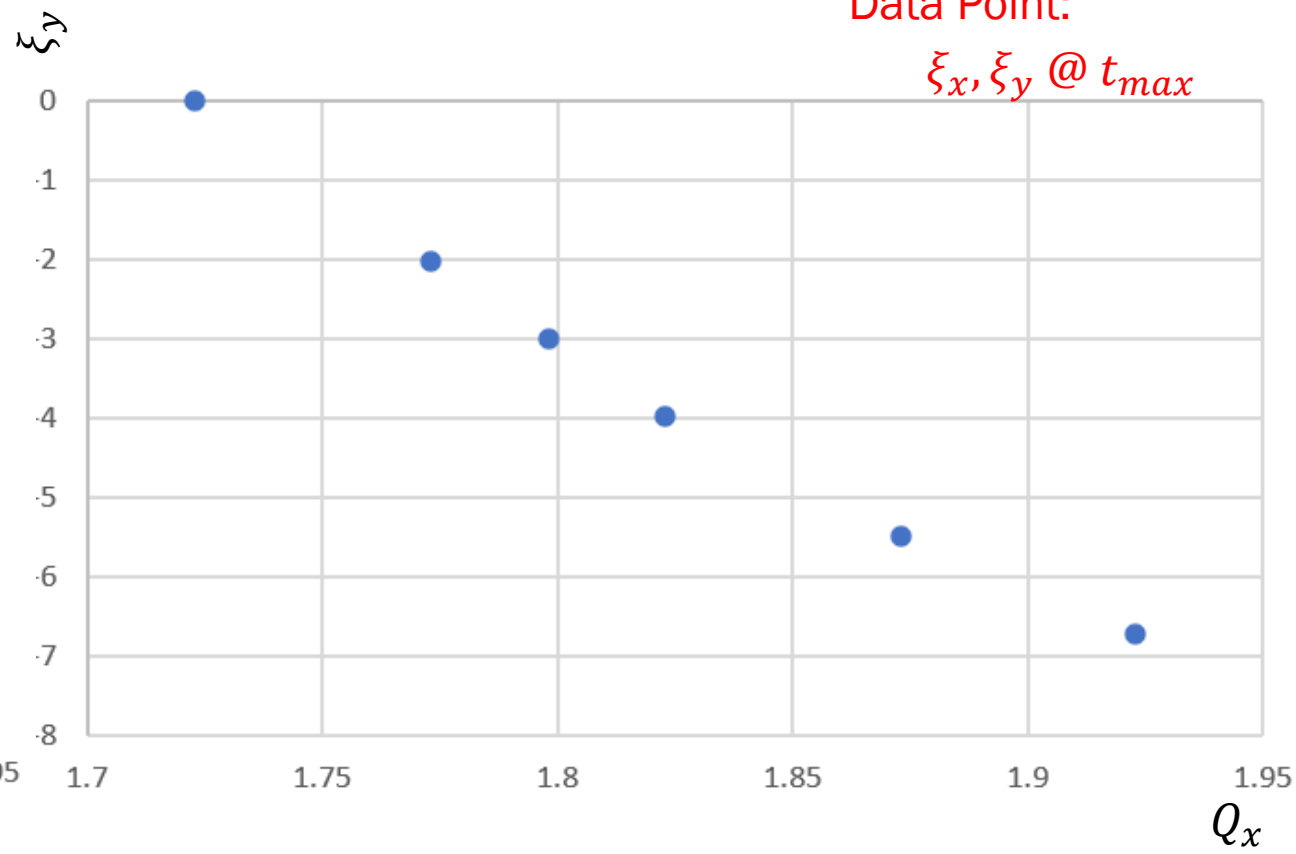
Working Point:

$Q_y = 1.123$

Data Point:

ξ_x, ξ_y @ t_{max}





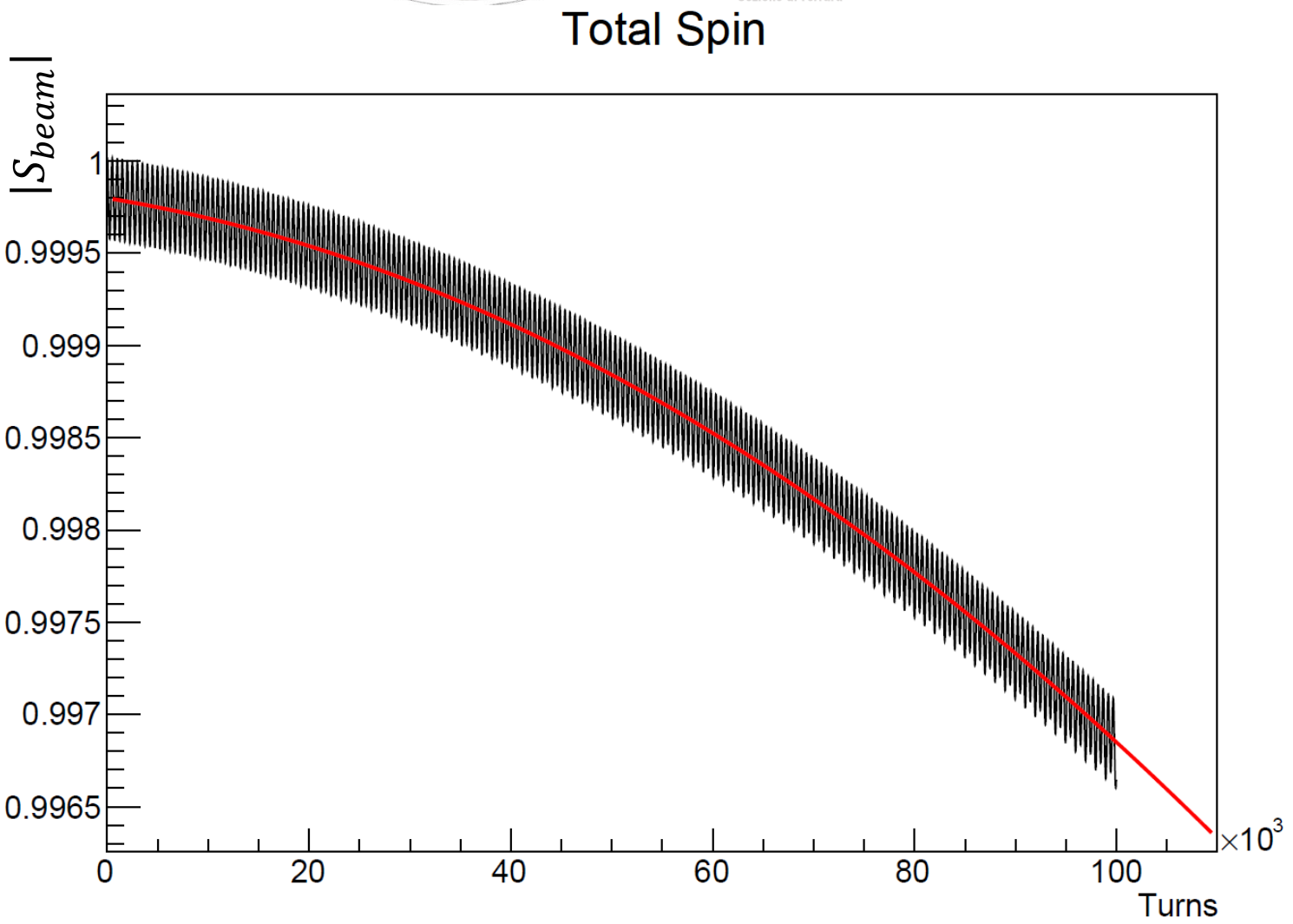
Role of Synchrotron Frequency

Working Point:

$$Q_x = 1.823, Q_y = 1.123$$

Data Point:

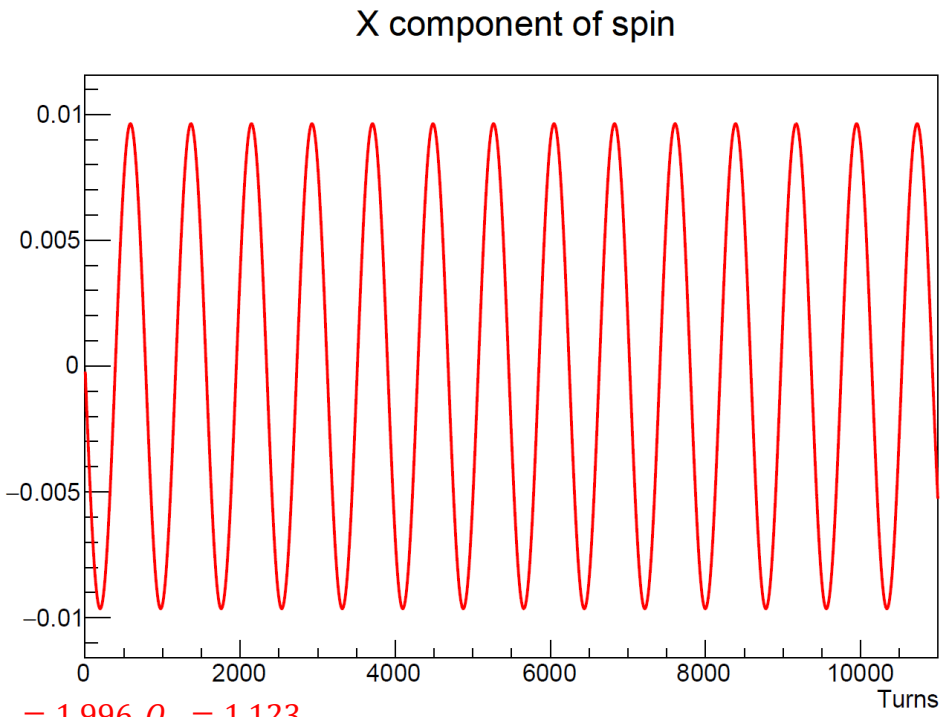
$$\xi_x = 2.0, \xi_y = -3.5$$

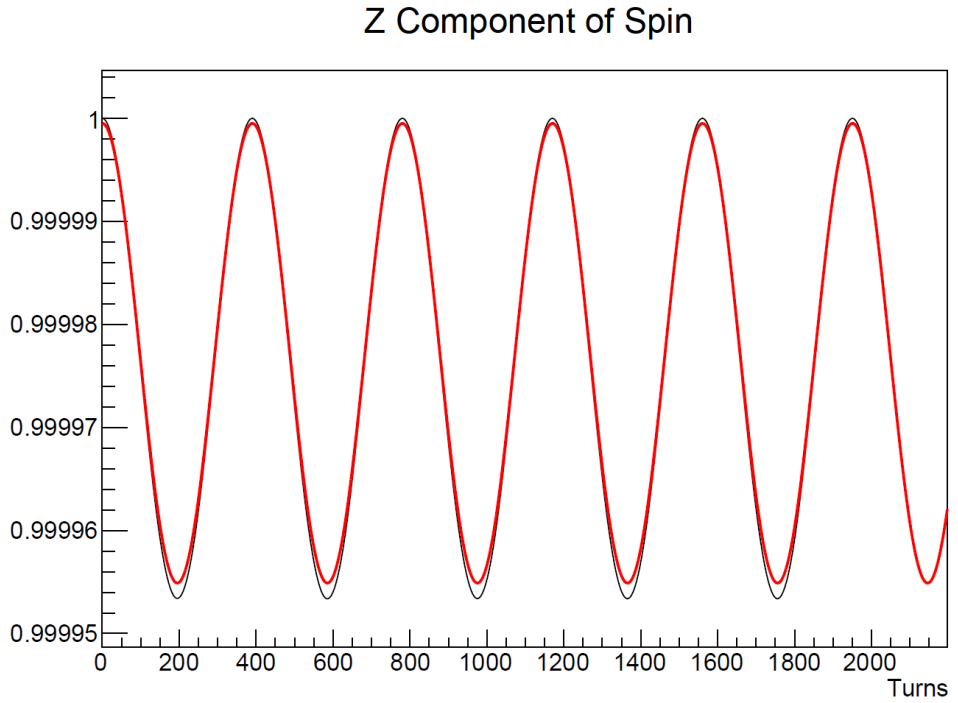


Role of Synchrotron Frequency

- Idealized single particle tracking
- Introduce small momentum offset in z direction
- Measure frequency of longitudinal particle motion
- Compare with oscillation of total spin of a bunch

Role of Synchrotron Frequency





Working Point:

$Q_x = 1.996, Q_y = 1.123$

Data Point:

$\xi_x = 0.0, \xi_y = 0.0$

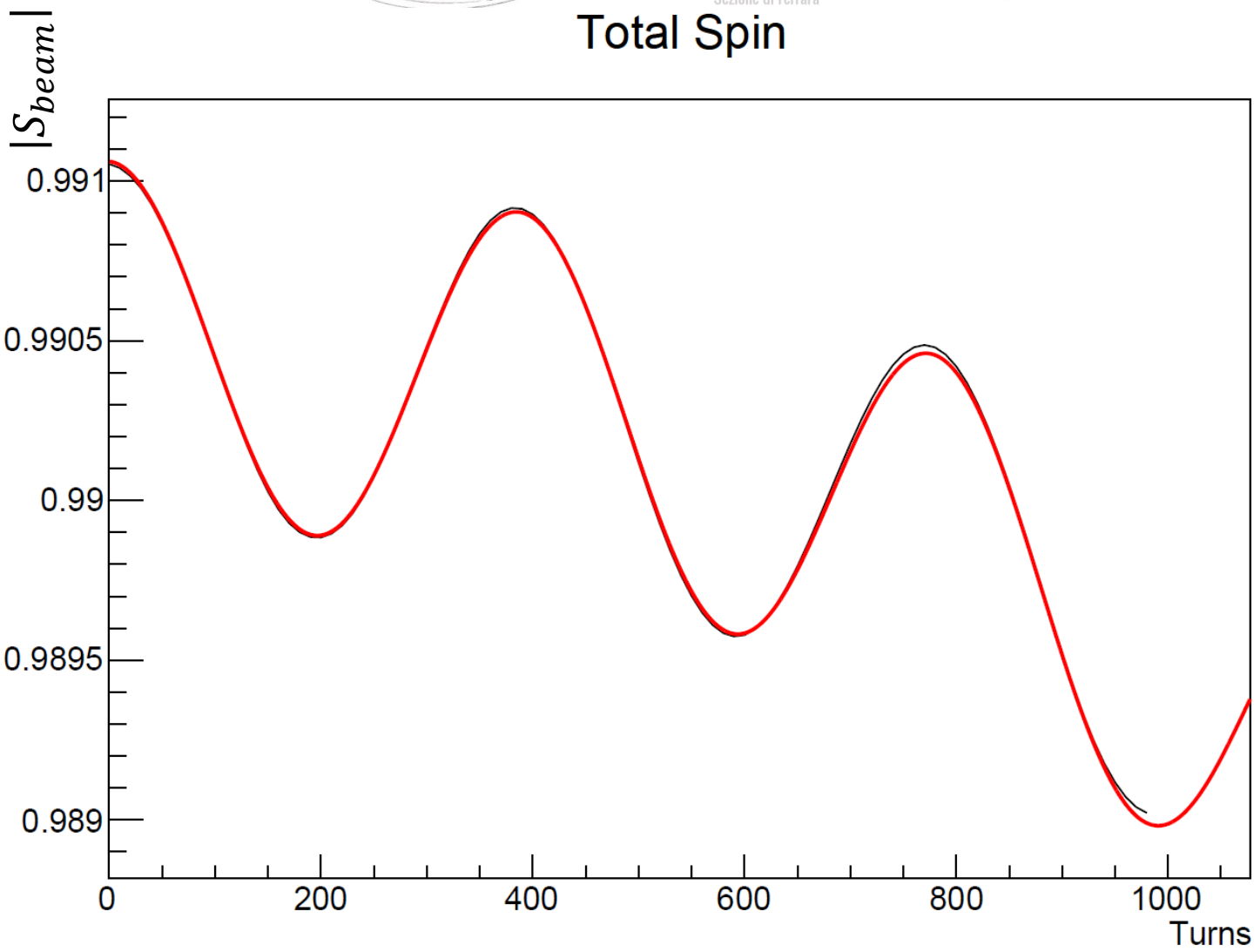
Role of Synchrotron Frequency

Working Point:

$$Q_x = 1.996, Q_y = 1.123$$

Data Point:

$$\xi_x = 0.0, \xi_y = 0.0$$



Role of Synchrotron Frequency

Working Point:
$Q_y = 1.123$

Data Point:
ξ_x, ξ_y @ t_{max}

Working Point		Frequency of				Ratio of
Q_x	Q_y	S_z	S_x	z	$\lvert S_{beam}\rvert$	$\lvert S_{beam}\rvert / z$
1.723	1.123	311.706	156.166	156.159	312.181	1.999123
1.773	1.123	1111.34	557.396	557.402	1097.65	1.969225
1.823	1.123	1453.81	729.568	729.567	1452.58	1.991017
1.873	1.123	1664.41	834.267	834.26	1667.84	1.999185
1.923	1.123	1794.94	897.222	897.219	1792.04	1.997327
1.996	1.123	1863.92	932.123	932.14	1855.62	1.99071
		Single Particle Tracking			Bunch Tracking	

Role of Synchrotron Frequency

Working Point:

$Q_x = 1.823$

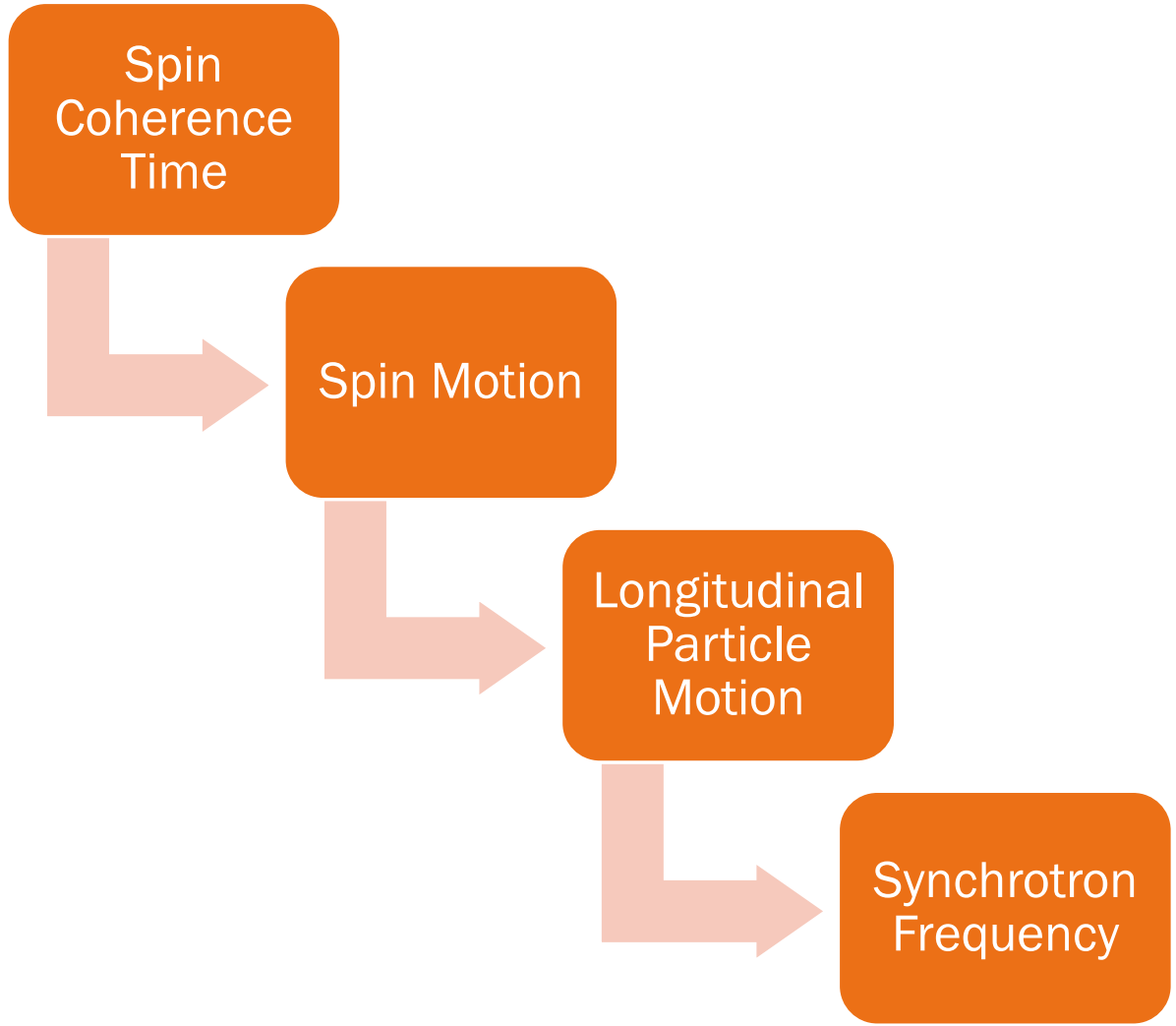
Data Point:

ξ_x, ξ_y @ t_{max}

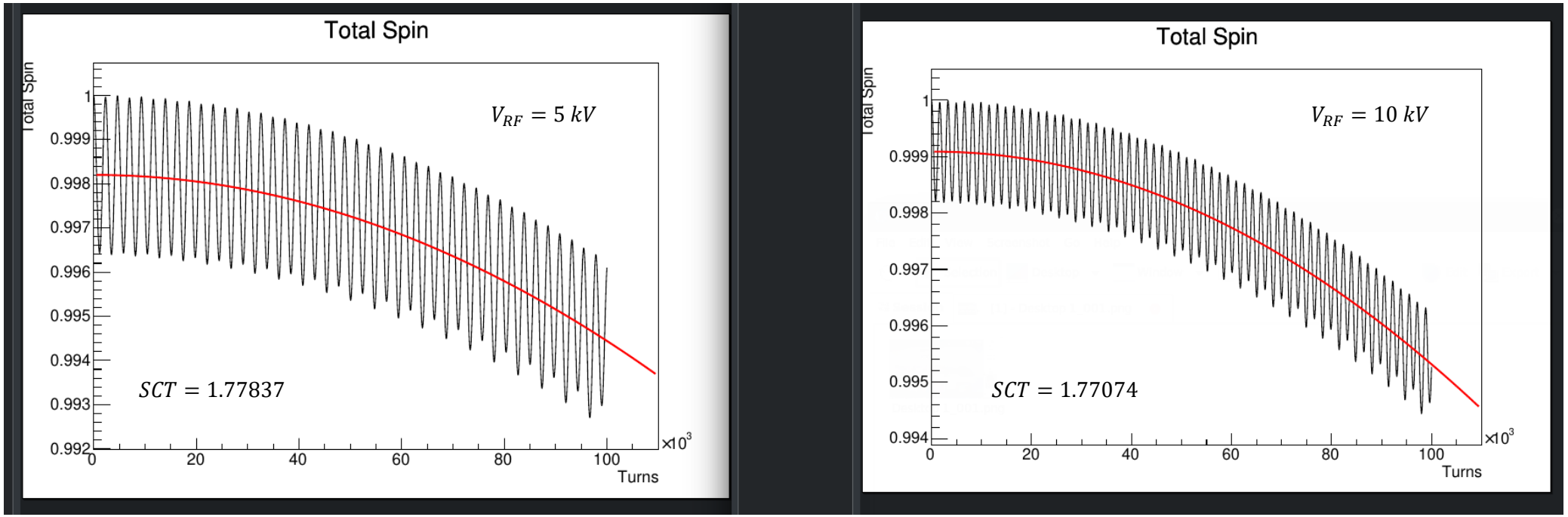
Working Point		Frequency of				Ratio of
Q_x	$\boldsymbol{Q_y}$	S_z	S_x	z	$\lvert S_{beam}\rvert$	$\lvert S_{beam}\rvert/z$
1.823	**1.023**	1471.02	737.38	737.29	1477	2.003282
1.823	**1.123**	1453.81	729.568	729.567	1452.58	1.991017
1.823	**1.223**	1416.42	713.916	714.035	1424.5	1.995

So…

What if we could change the synchrotron frequency?



But…



Working Point:

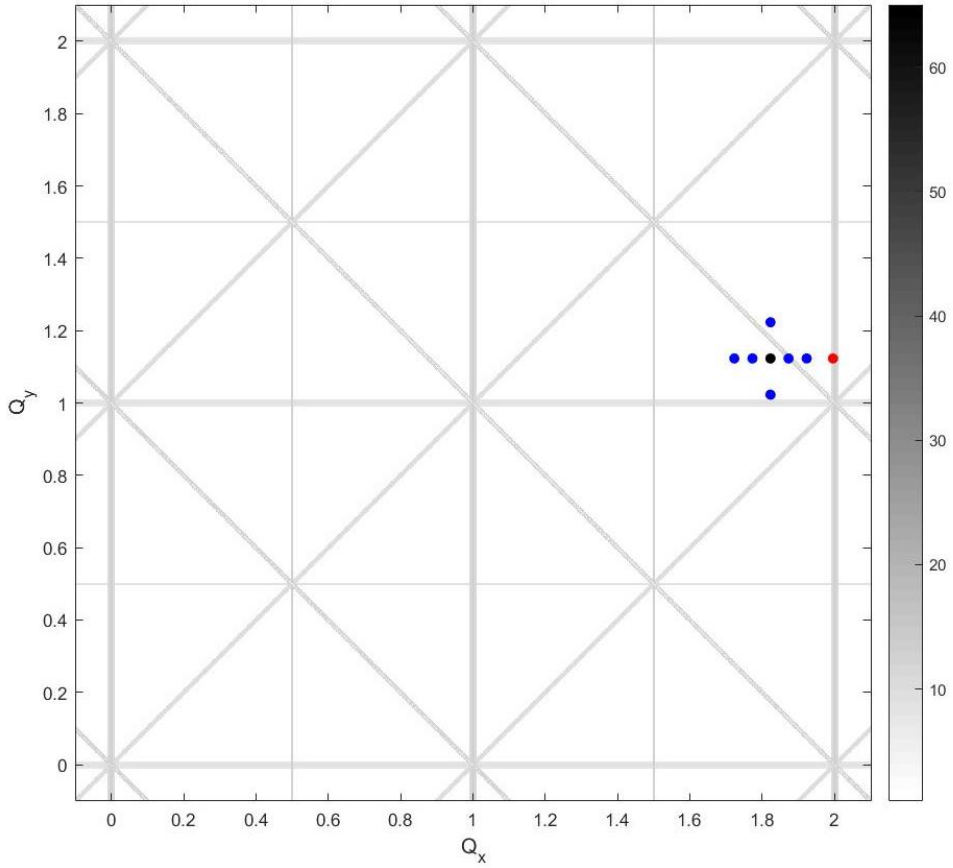
$Q_x = 1.723, Q_y = 1.123$

Data Point:

$\xi_x = 0.0, \xi_y = 0.0$

Results so far…

- The maximum value of SCT in each working point seems to depend on some variables:
  - Q_x
  - Q_y (not so much?)
  - ξ_x and ξ_y (not zero?)
  - Resonances (Horizontal only?)
  - Gamma transitions



Future work

- To explore other working points in this lattice…
- To explore other improved Lattices…
- To develop a theoretical understanding of the relationship of SCT with parameters…
- To use data from COSY precursor run to validate hypotheses and draw new inference on relationships.
- Suggestions?

References

1. Paolo Lenisa, *Storage Rings for the Search of Charged Particle Electric Dipole Moments*, Talk presented at 107th Plenary ECFA meeting (November 2020).
2. CPEDM Collaboration, *Storage Ring to Search for Electric Dipole Moments of Charged Particles: Feasibility Study*, CERN-PBC-REPORT (December 2019)
3. A. Lehrach, S. Martin and R. Talman, *Design of a Prototype EDM Storage Ring*, Proceedings of Science, PoS SPIN2018, 144, 2018.
4. Max Vitz, *Simulation and optimization of the spin coherence time of protons in a prototype EDM ring*, Master thesis submitted to RWTH Aachen University (October 2020).

Thank you…!

Contact: shankar@fe.infn.it