Colorado State University

Study of CSR Impact on the Electron Beam in the JLab ERL

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ERL15 – Stony Brook, NY, USA

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Collaborators:
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Electrical & Computer ENGINEERING

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[2] Thomas Jefferson National Accelerator Facility
[3] Los Alamos National Laboratory

Jefferson Lab
EXPLORING THE NATURE OF MATTER

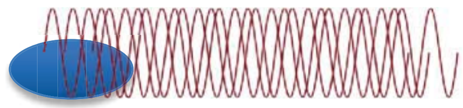
Los Alamos National Laboratory

Outline

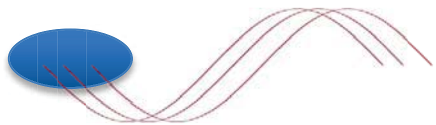
- Introduction
- Motivation
- The JLab FEL Driver
- Summary of the Experiment*
- Results/Comparison to Simulation
- Conclusion

* C.C. Hall et al., Phys. Rev. ST Accel. Beams 18, 030706 (2015).

Coherent Synchrotron Radiation Overview

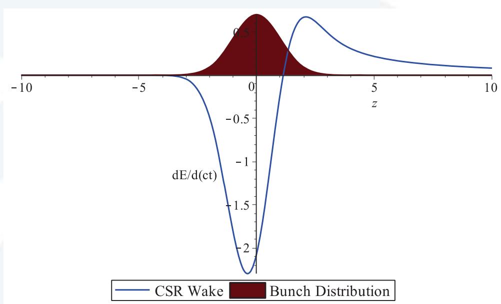


Incoherent Emission

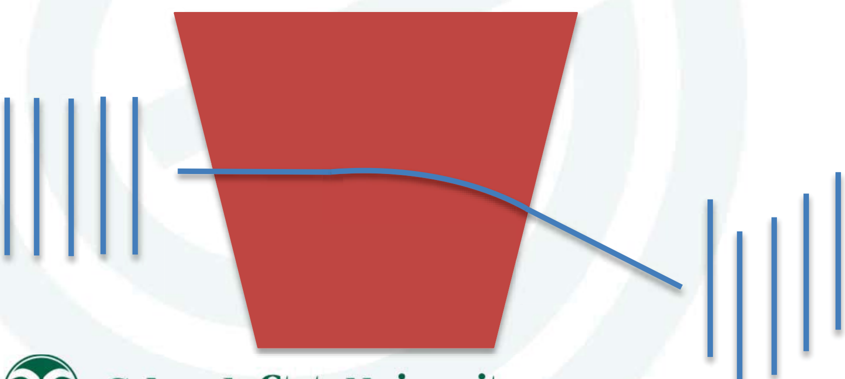


Coherent Emission

$$\lambda_{rad} > l_b \quad P \propto N_e^2$$

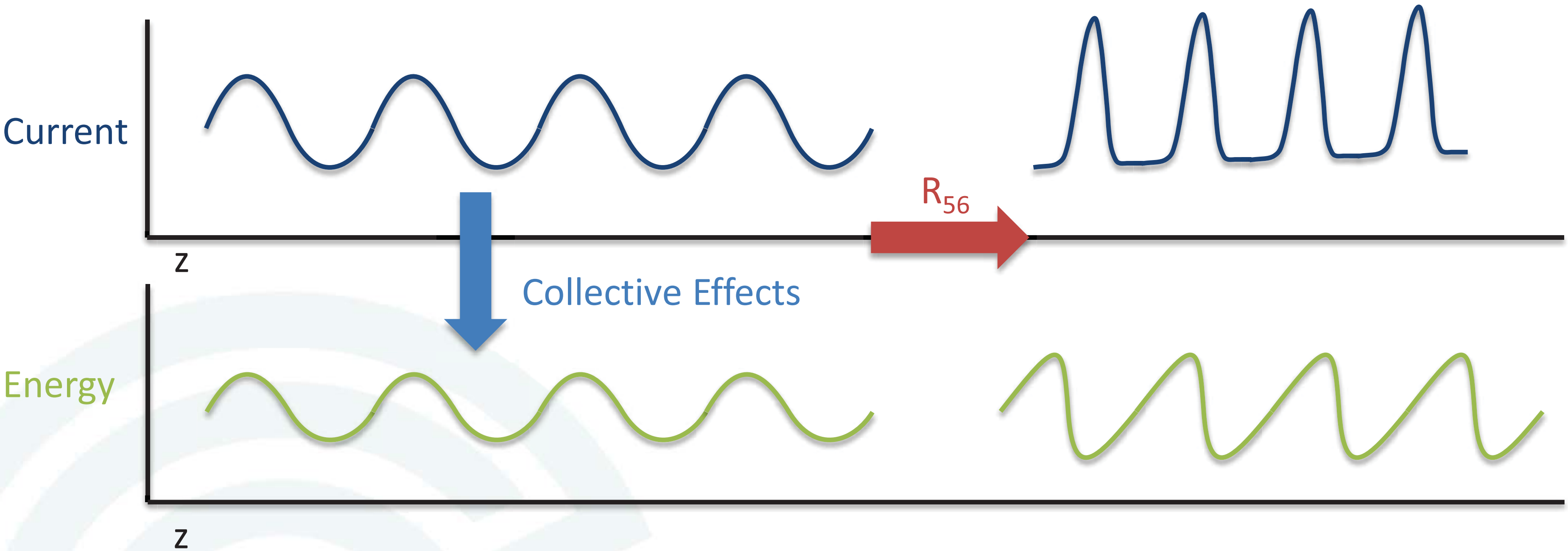


CSR leads to slice energy spread increase



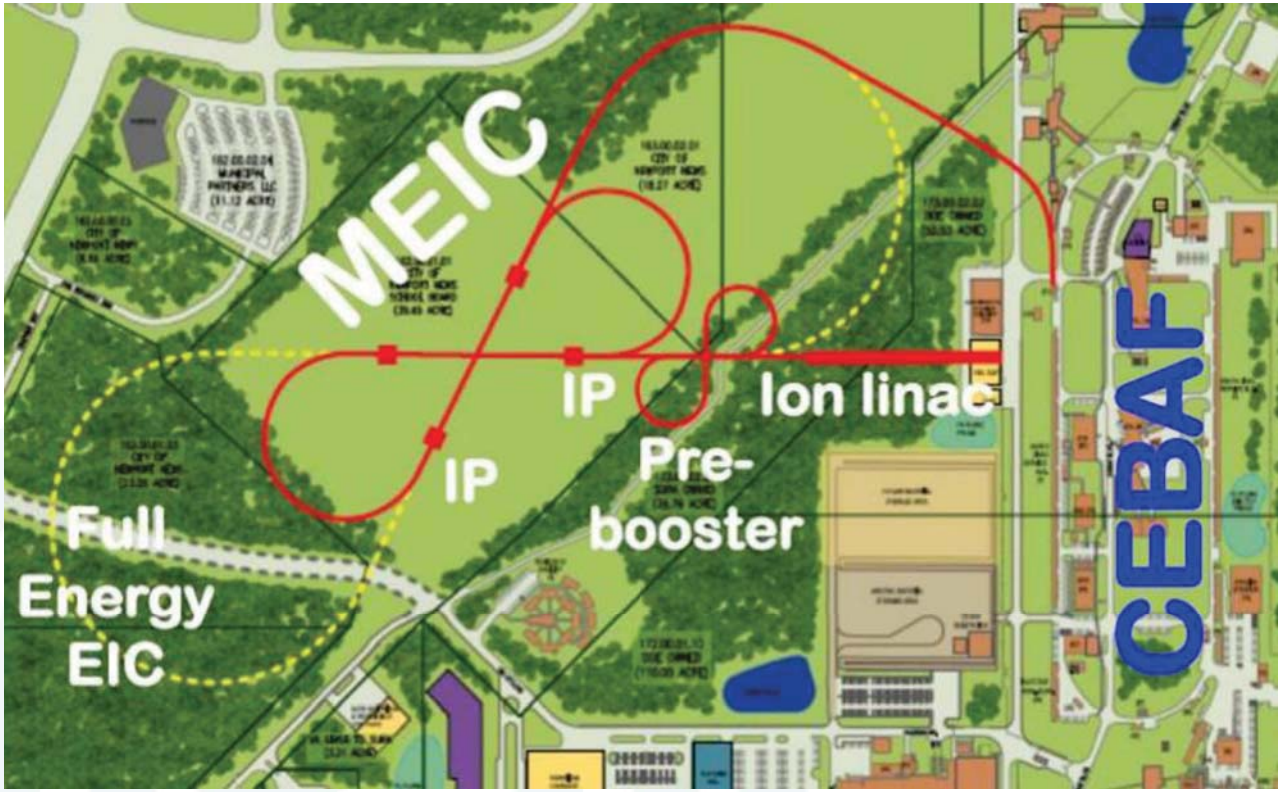
Projected emittance growth after a dipole will increase

The Microbunching Instability



- A small modulation in density leads to a modulation in energy via impedances.
- Traversing a region with time/energy correlation can increase the density modulation, under the right conditions.

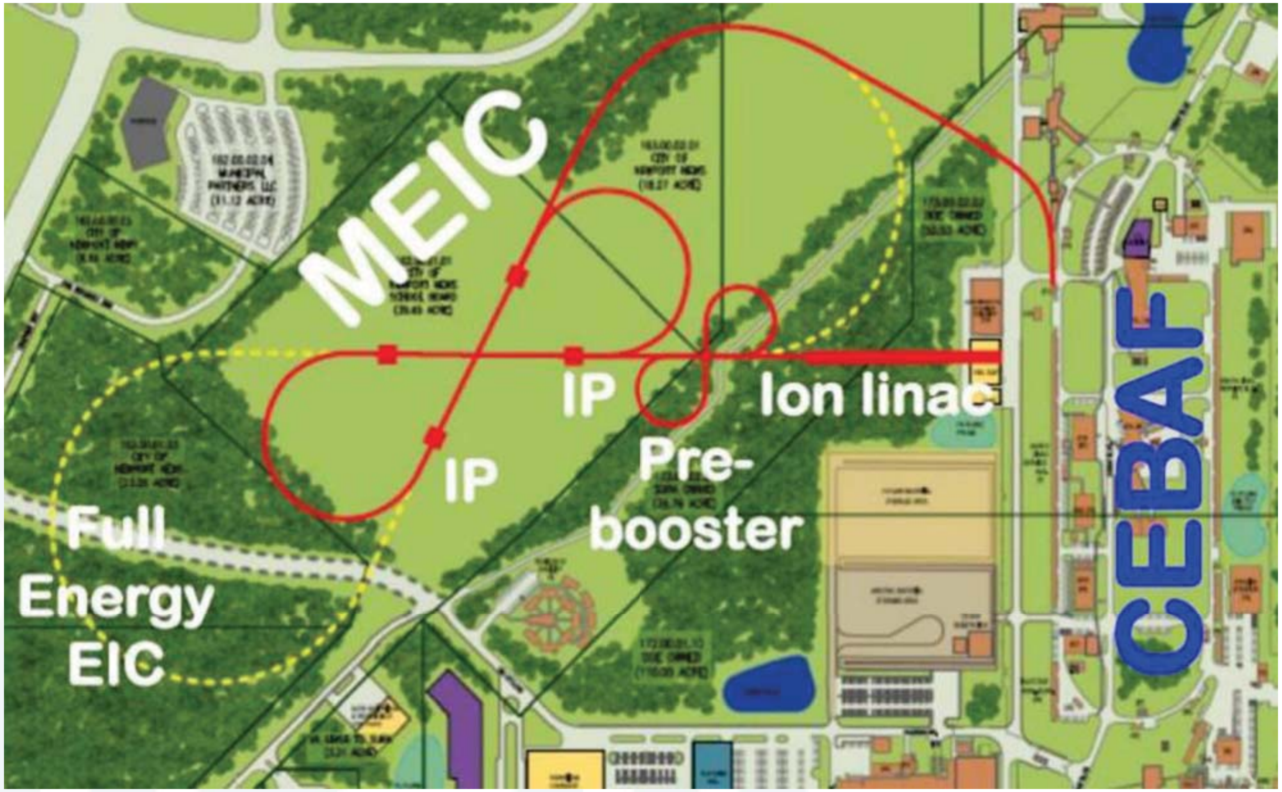
MEIC



Courtesy of D. Douglas

Medium Energy Ion-Electron Collider at Jefferson Lab

MEIC



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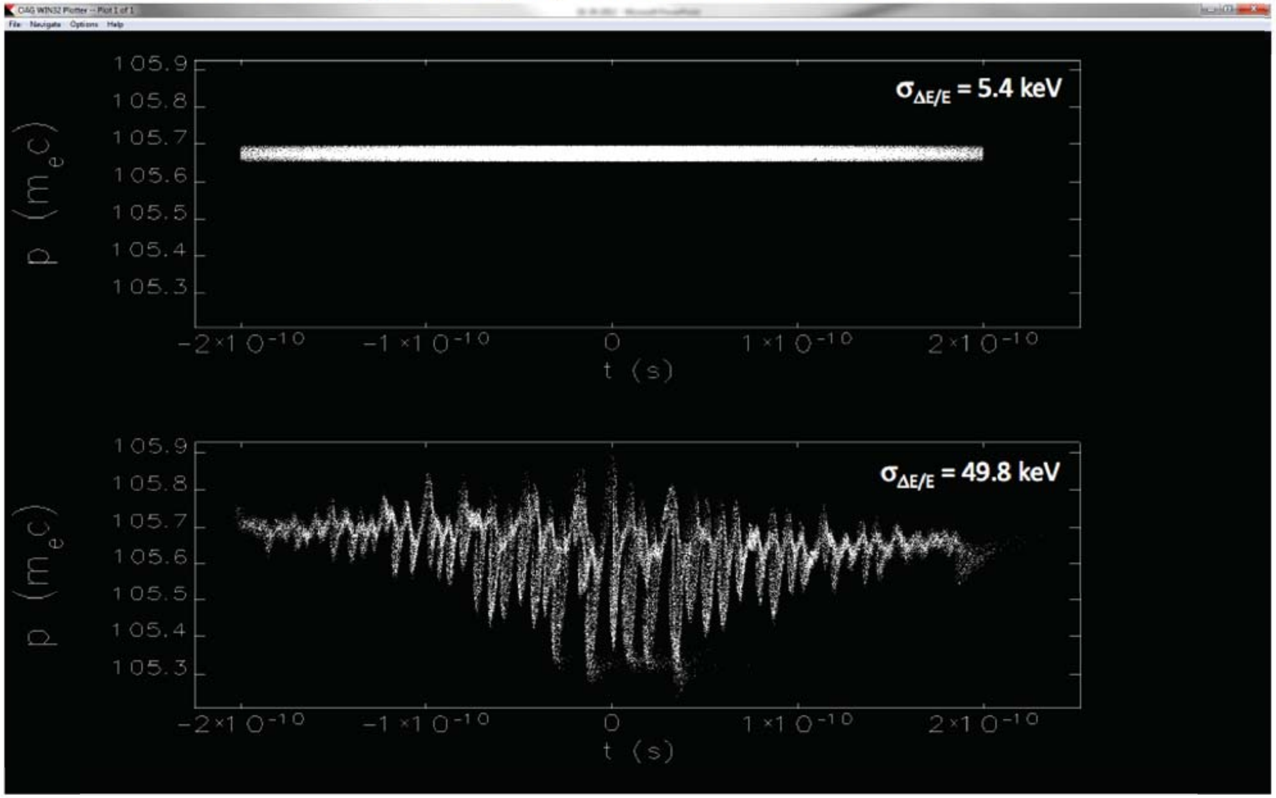
Medium Energy Ion-Electron Collider at Jefferson Lab

Simulations suggest CSR induced microbunching will need to be accounted for

MEIC

- 0.5 nC with 3 cm long bunch (rms) tracked for 100 turns with CSR



Medium Energy Ion-Electron Collider at Jefferson Lab

Simulations suggest CSR induced microbunching will need to be accounted for

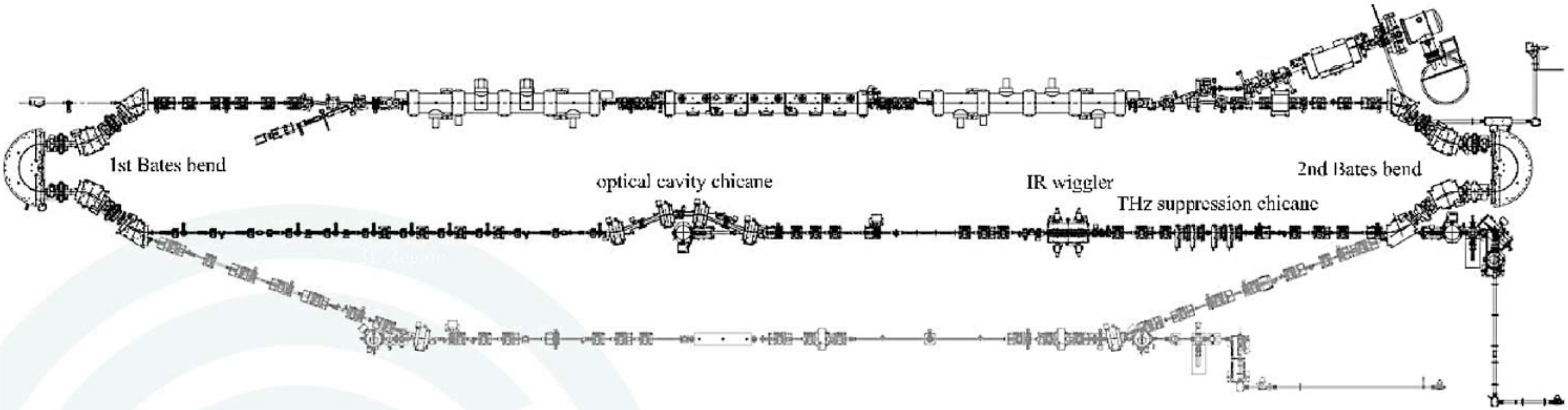
Courtesy of D. Douglas

Motivation

- **ERL are very different from other accelerators:**
  - Not at equilibrium like a ring.
  - Recirculation loops very different compared to standard linac.
- **Bates bend structures allow for novel experiment. Using quads to adjust total R_{56}.**
- **Can study CSR over wide range of compression dynamics.**
- **Verify against 1-D CSR model*.**

*E. Saldin, et. al, NIM A 398, 373 (1997)

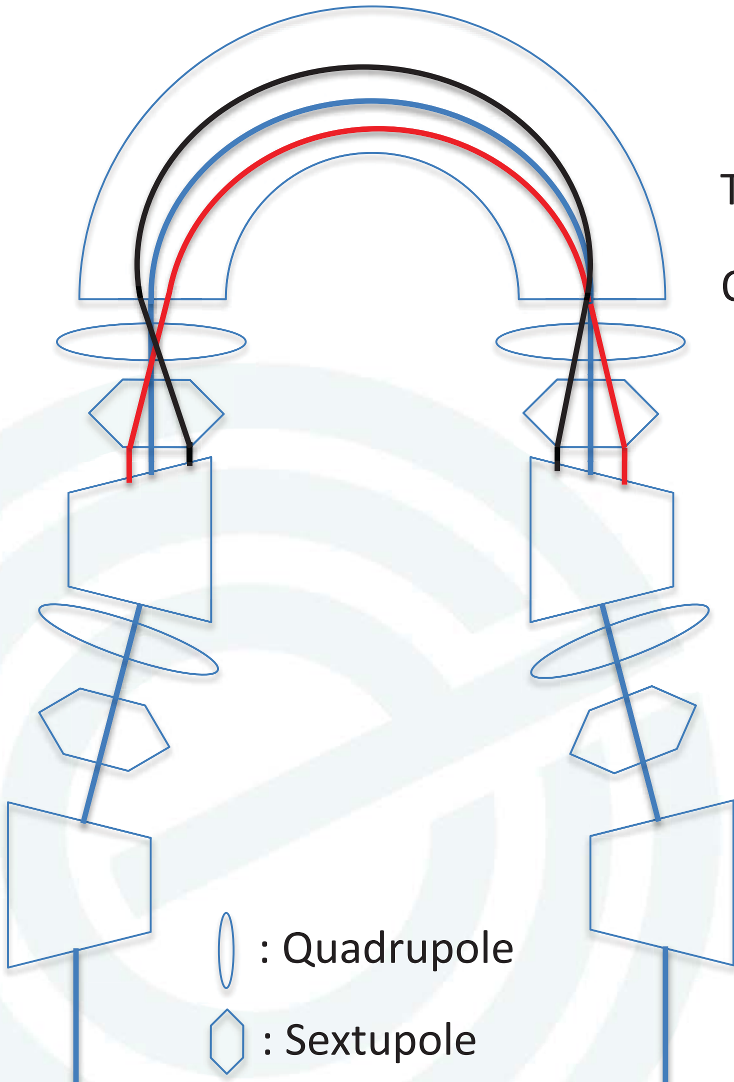
The Jefferson Lab ERL FEL



Description	Value
Max Repetition Rate [MHz]	75
Bunch Charge [pC]	135
Beam Energy [MeV]	up to 160
Max Beam Current [mA]	10
Beam Power [MW]	1.6

Observe 200 W/mA of CSR power

Controlling Momentum Compaction in the Arc



Transverse kicks given to the beam:

Quadrupole Kick $\delta x' = -Ax$

Sextupole Kick $\delta x' = -Bx^2$

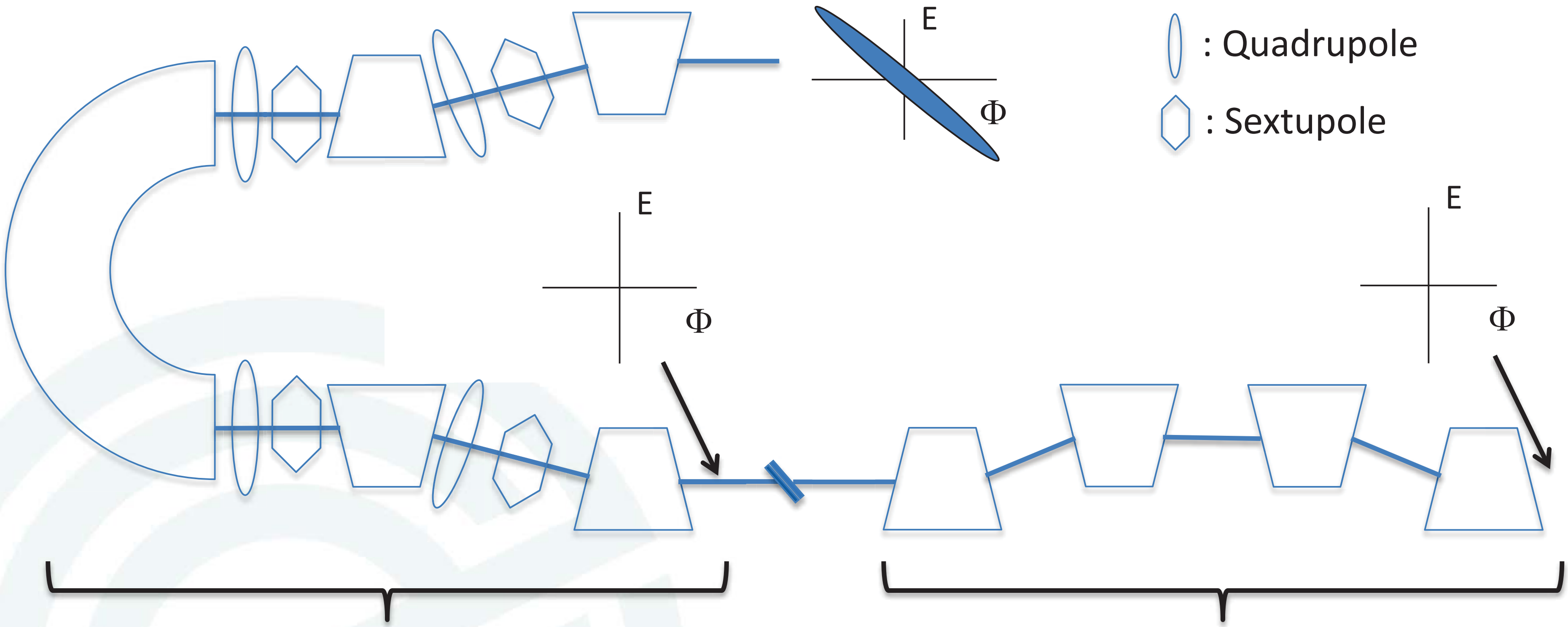
$$x \propto E$$

In the dipole:

$$R_{52} = -\rho(1 - cos\theta) \quad \text{and} \quad \theta = 180^\circ$$

Path Length Difference: $\delta z = -2\rho\delta x'$

Varying the Compression Point



R_{56} -> variable

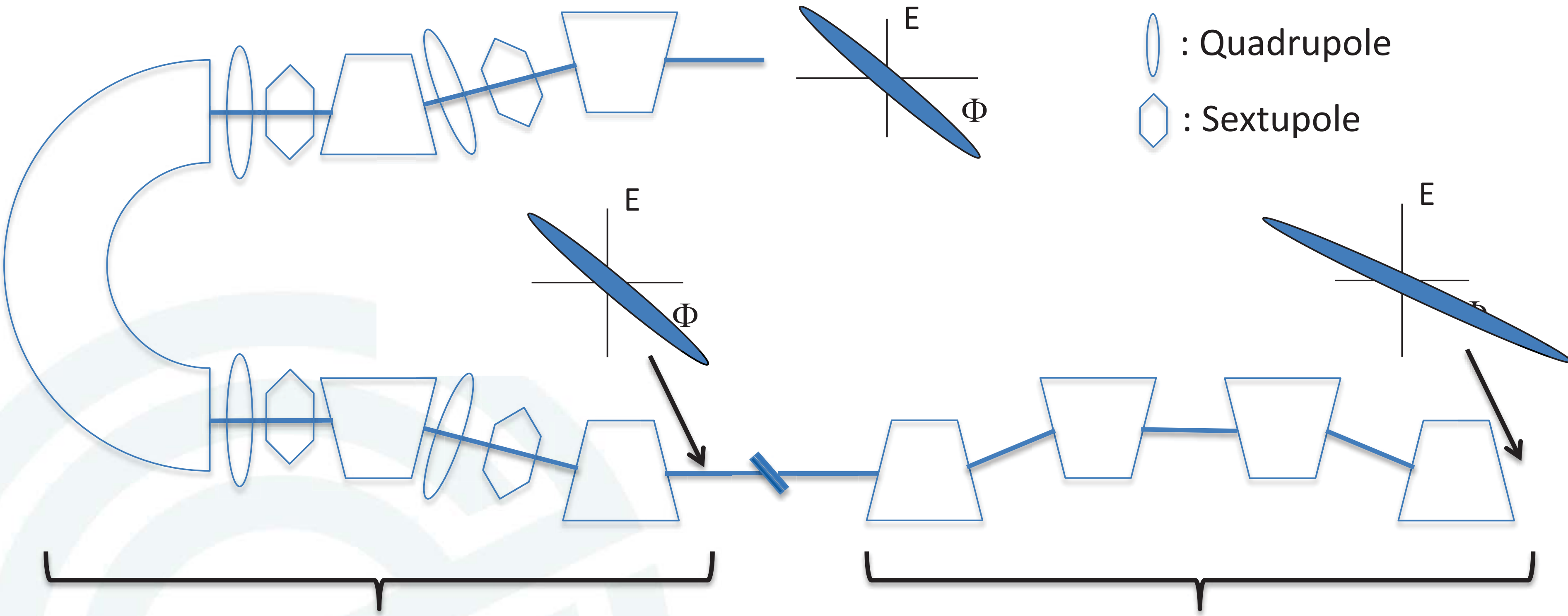
R_{56} between -0.5 to +1.0 m possible

Quadrupoles in the 1st arc can be adjusted to change R_{56} while maintaining achromatic transport.

R_{56}= - 52 cm

R_{56} for Critical Compression: +20 cm

Varying the Compression Point



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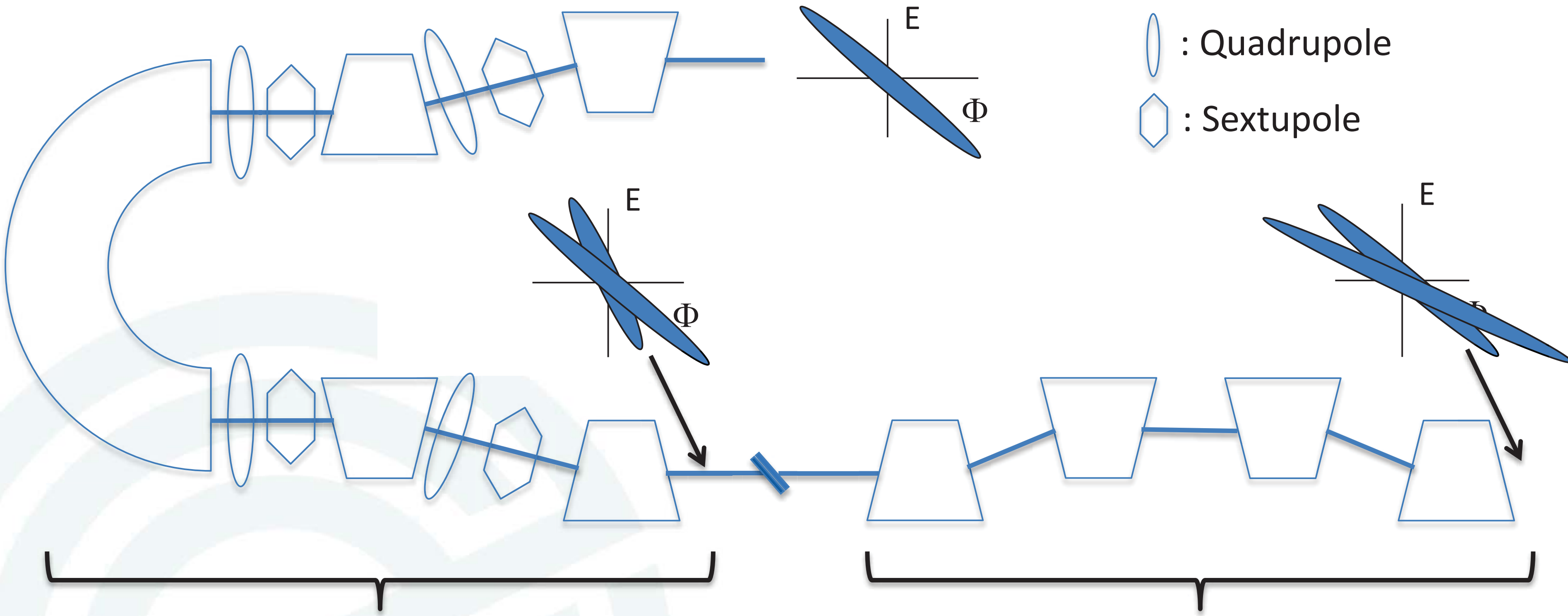

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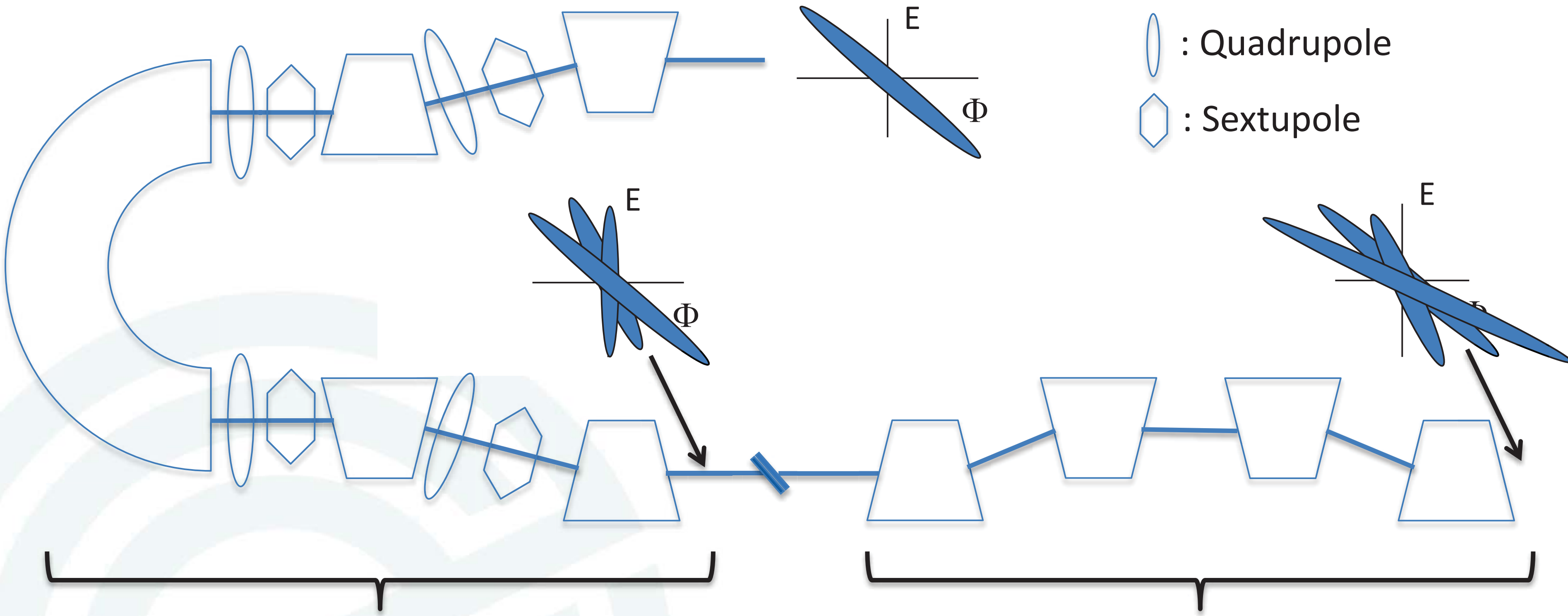

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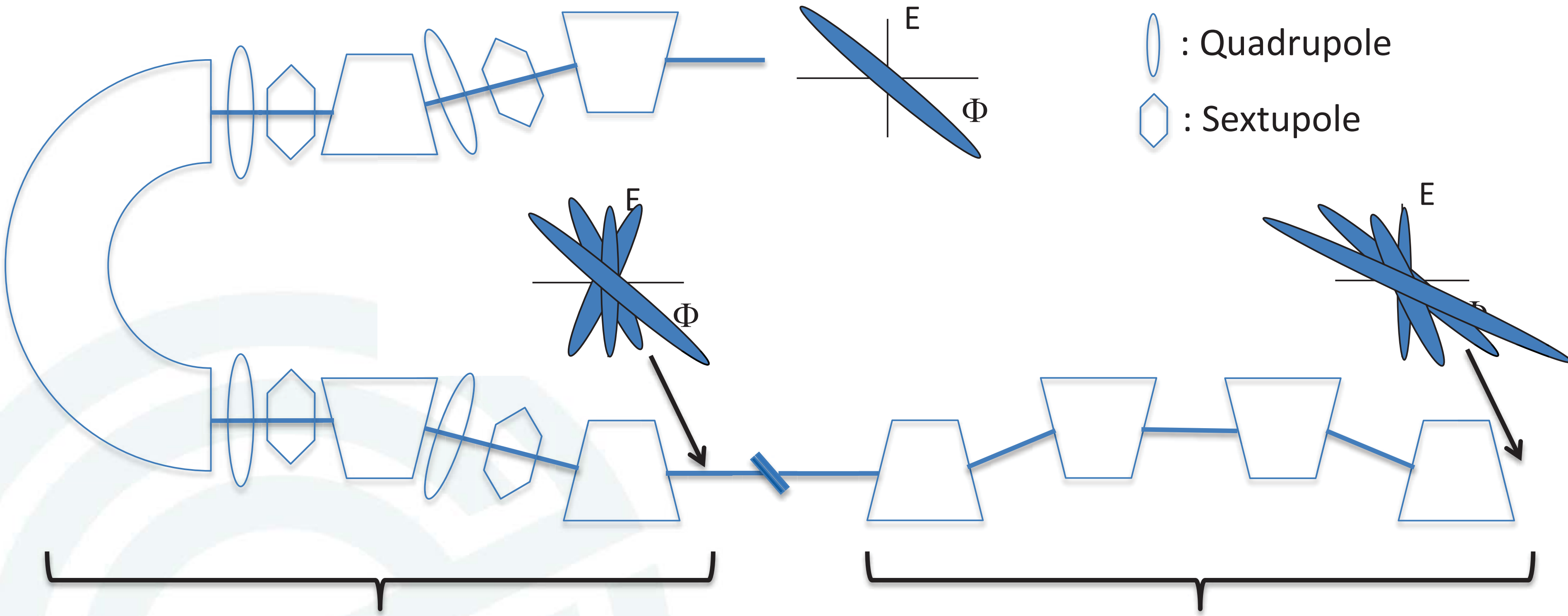

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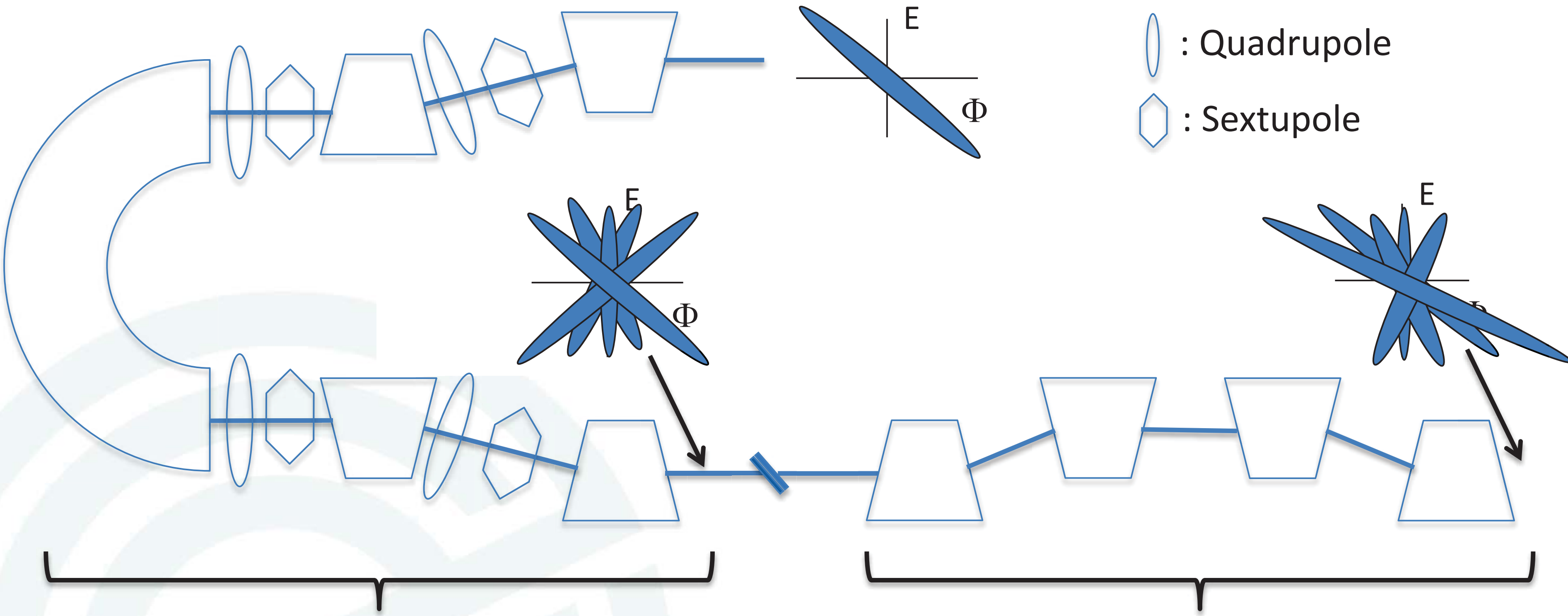

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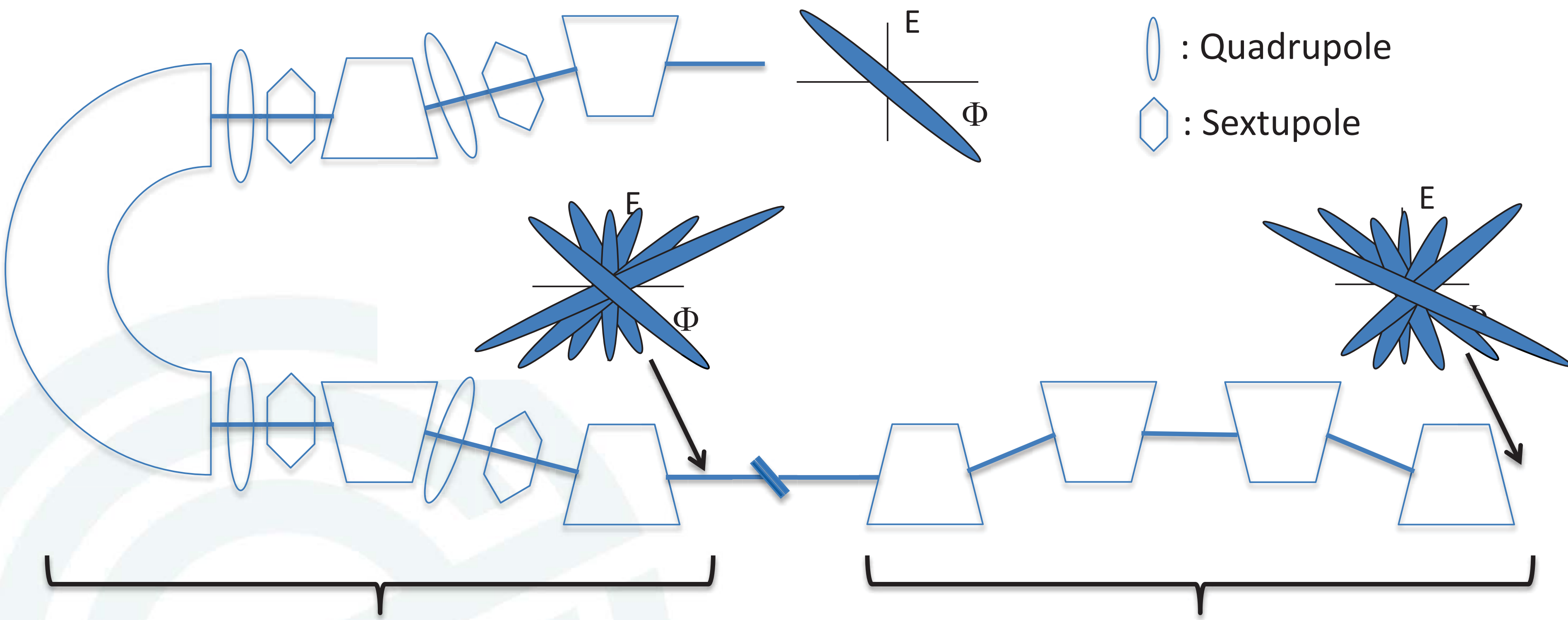

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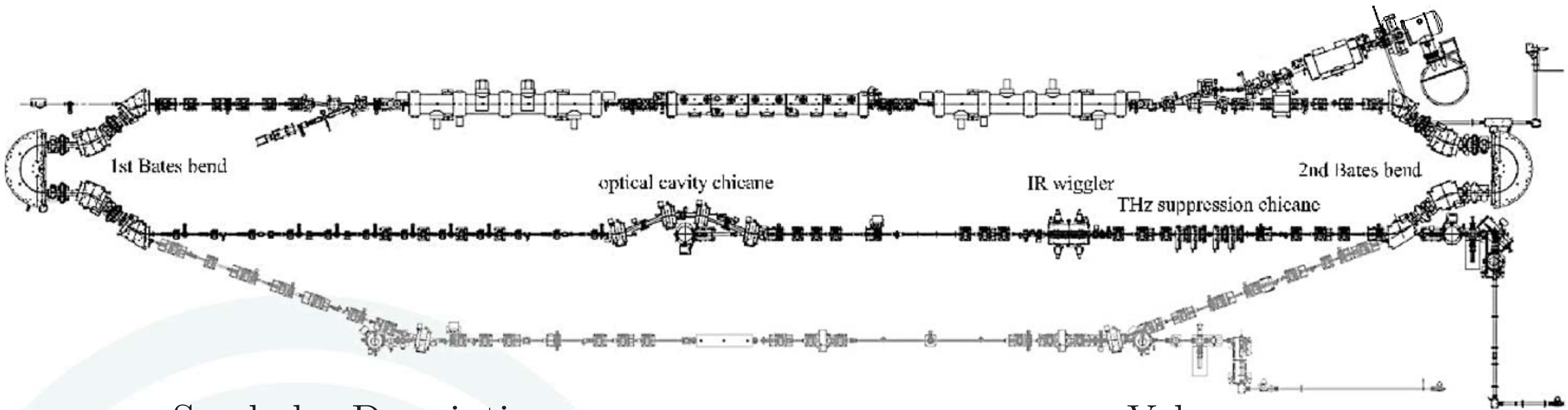
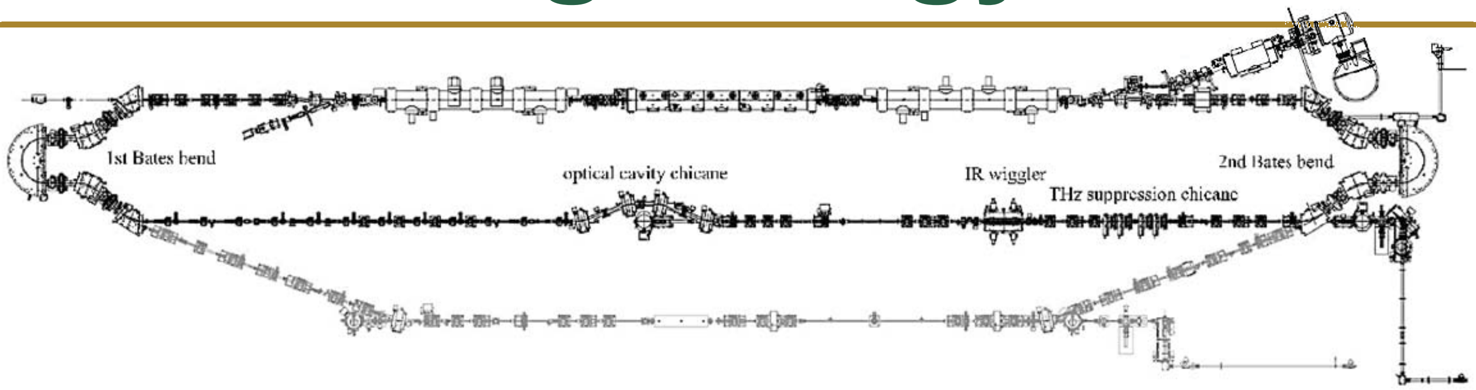
Experiment Machine Parameters



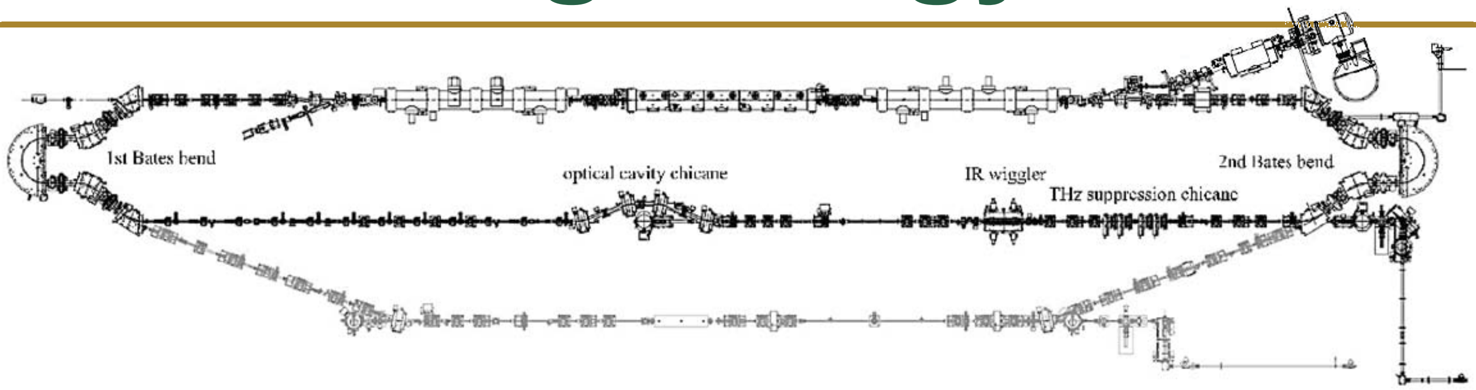
Symbol	Description	Value
E_0	Injection energy [MeV]	9
E_f	Final energy [MeV]	135
-	Charge per bunch [pC]	135
σ_0	Bunch length after injector [ps]	3
σ_f	Bunch length at max compression [fs]	150
h	Energy-position correlation (chirp) $[m^{-1}]$	∓ 5
-	RF phase [degrees]	± 10
-	RF frequency [GHz]	1.497
R_{56}^{bc}	Optical cavity chicane R_{56} [cm]	-52
R_{56}^{bb}	THz suppression chicane R_{56} [cm]	-4.6
R_{56}^{thz}	Bates arcs R_{56} [cm]	variable

Measuring Energy Loss



Measuring Energy Loss

BPMs



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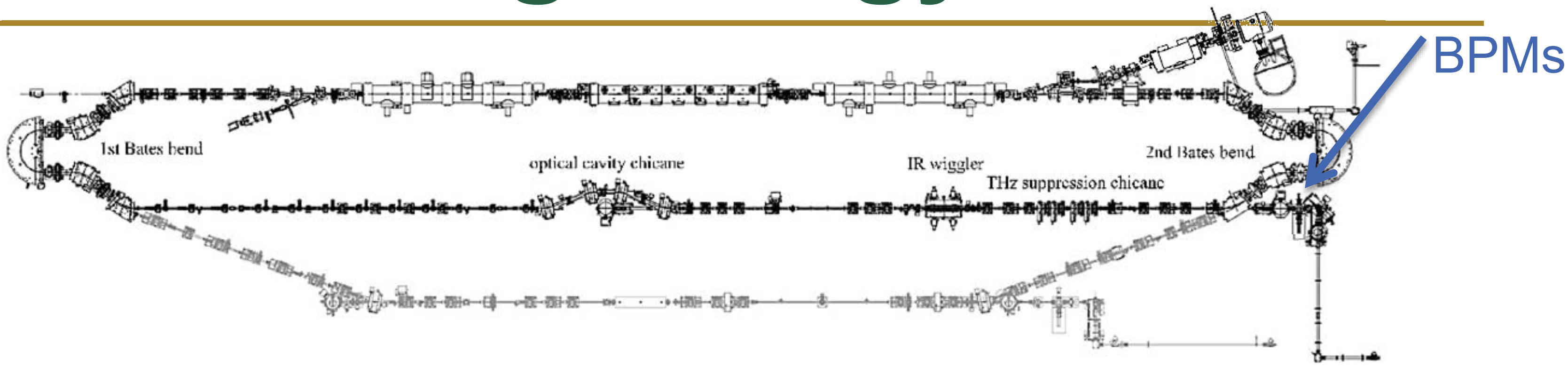

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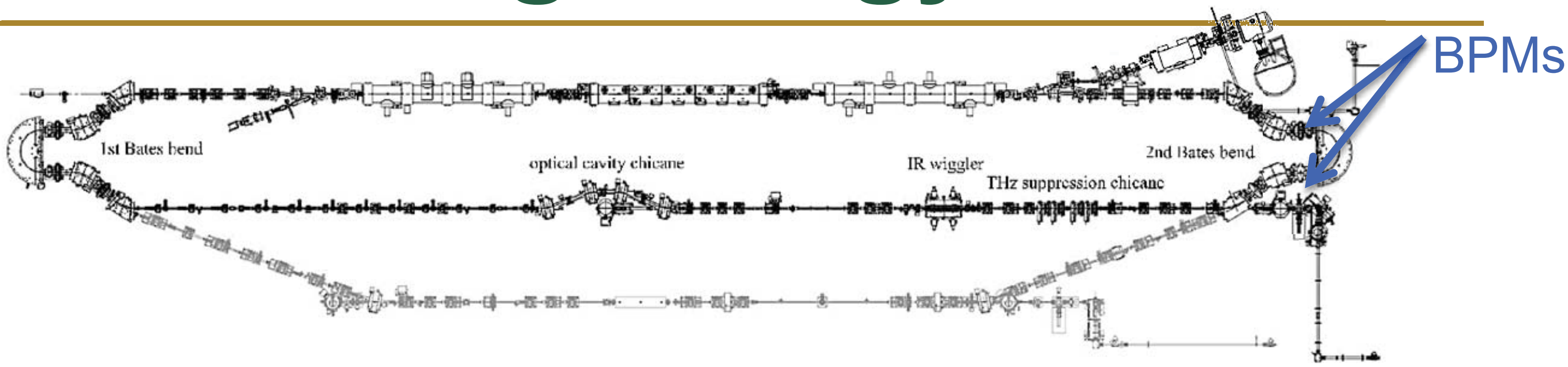

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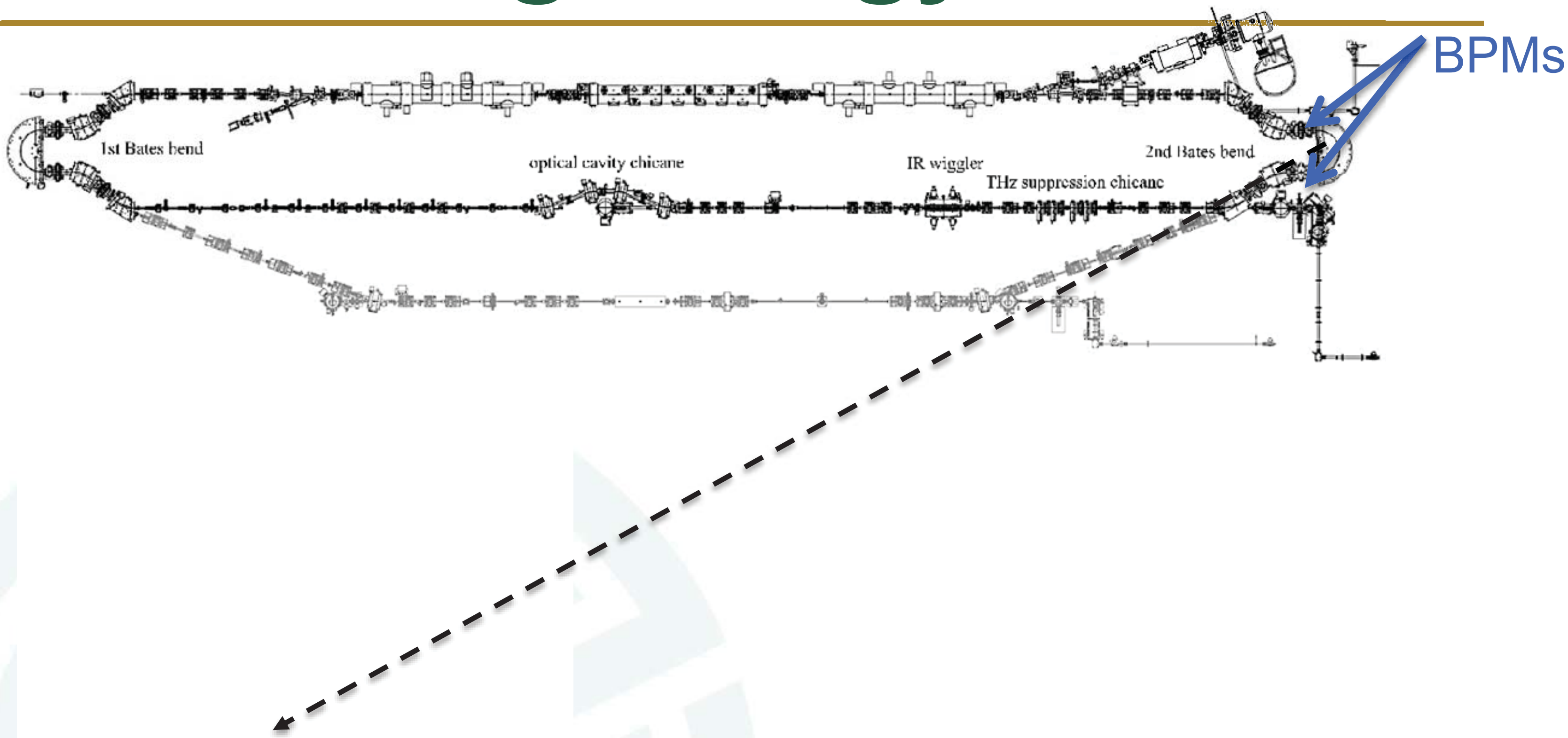

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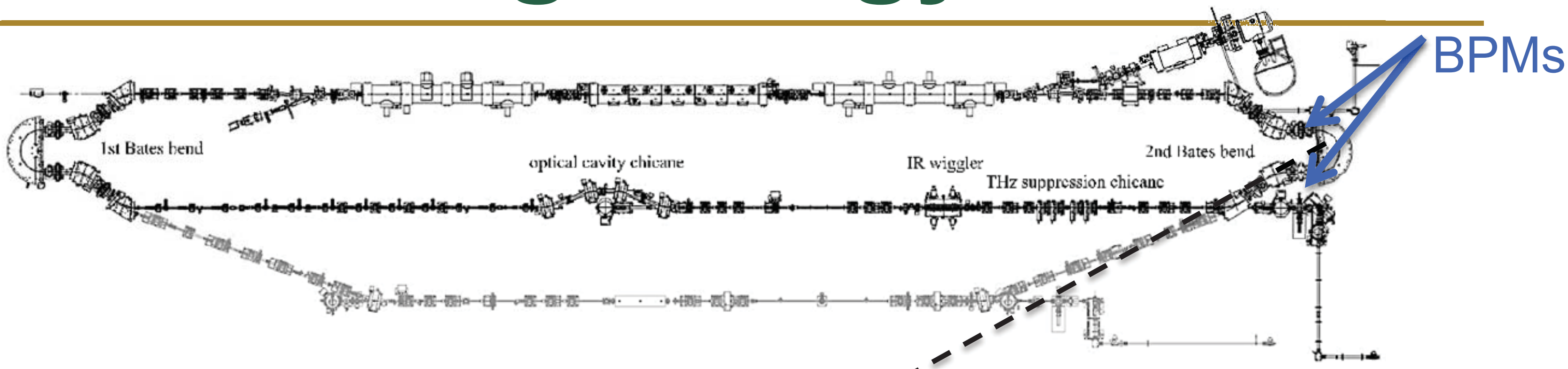

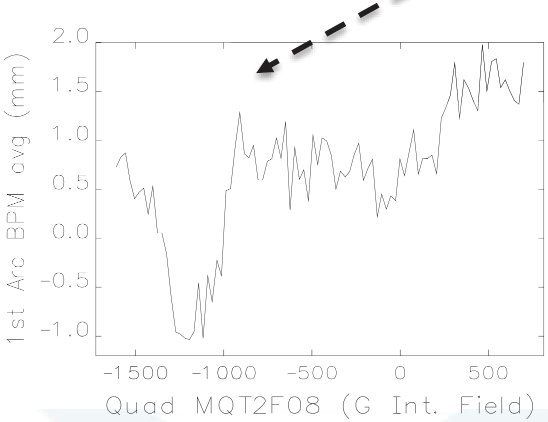

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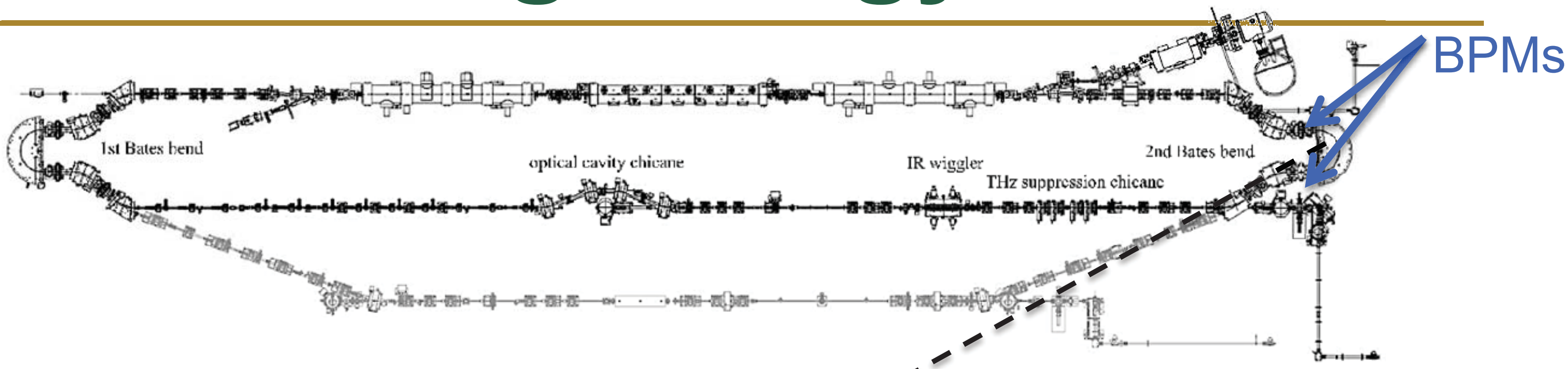

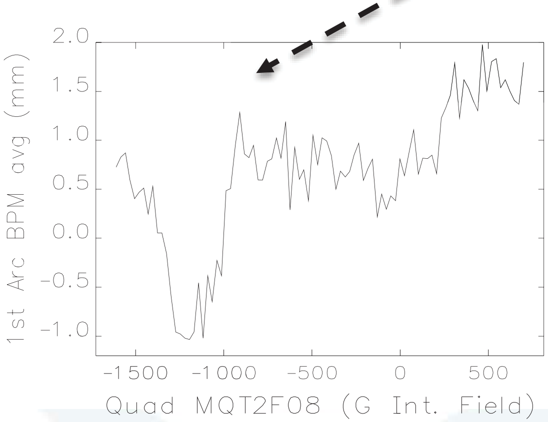

BPM readings from each side of 180° bend average to remove any betatron offset

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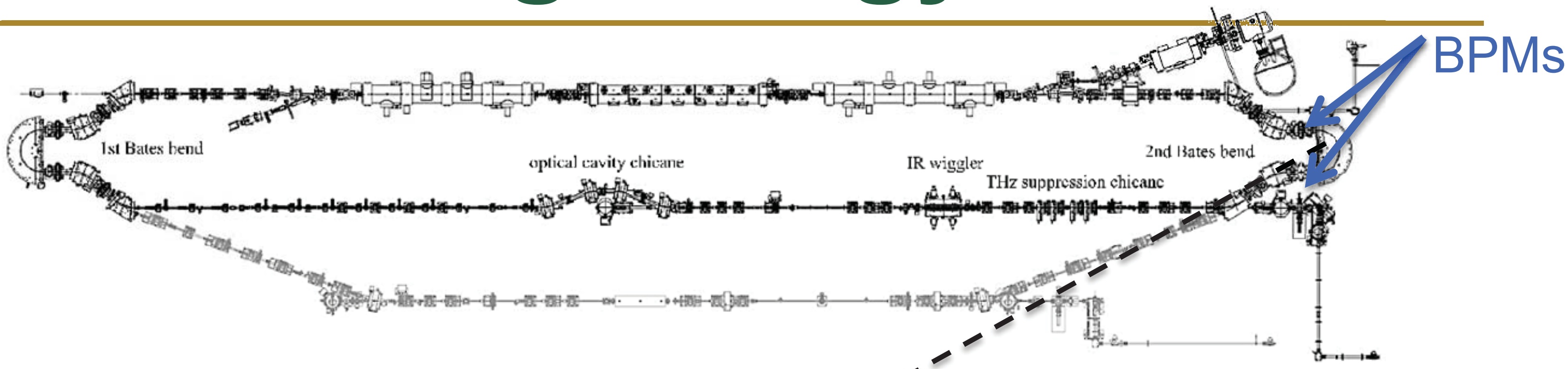

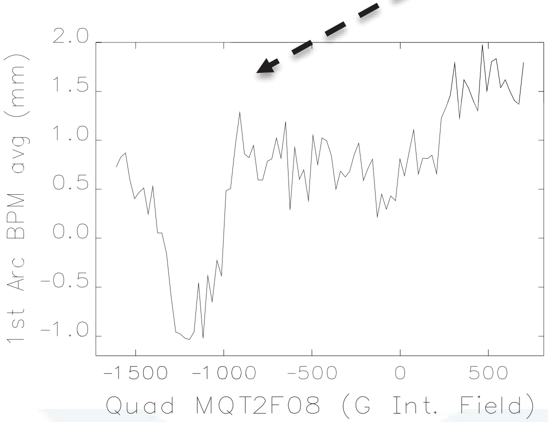

BPM readings from each side of 180° bend average to remove any betatron offset

Averaged reading taken in 1st and 2nd arc. Common jitter is removed by subtracting out the measurement from arc 1.

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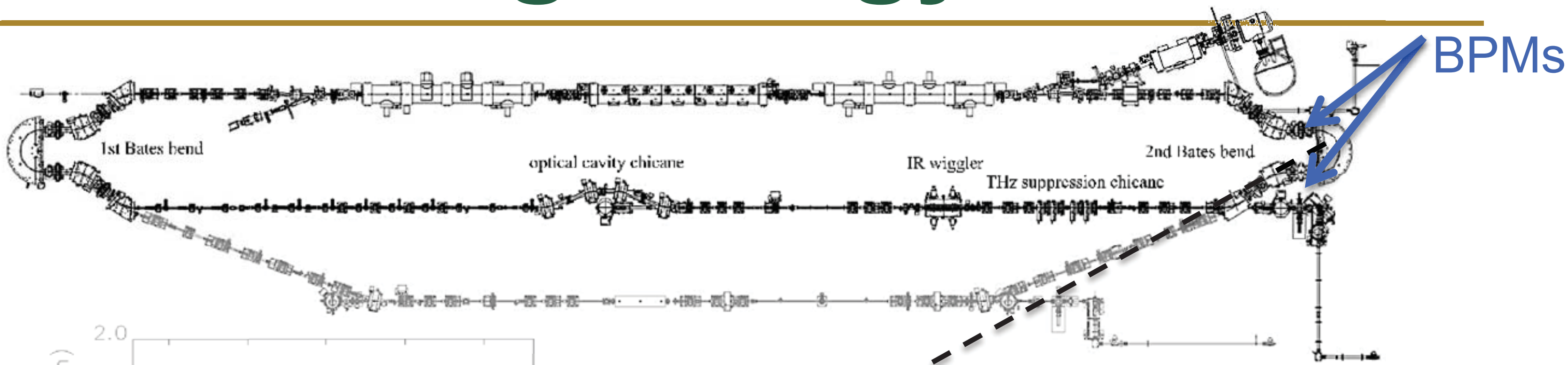

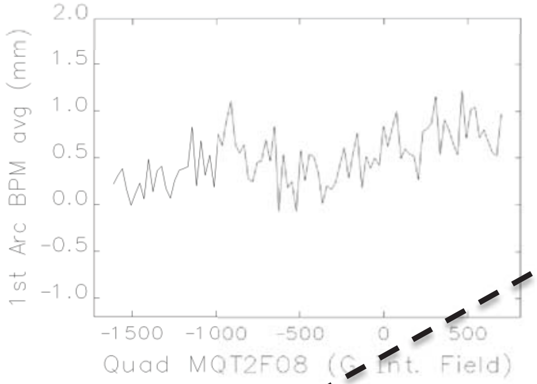

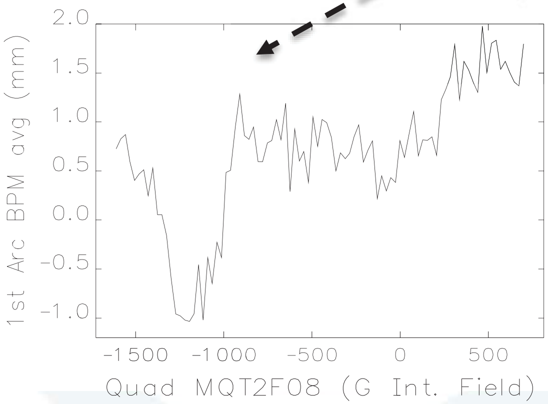

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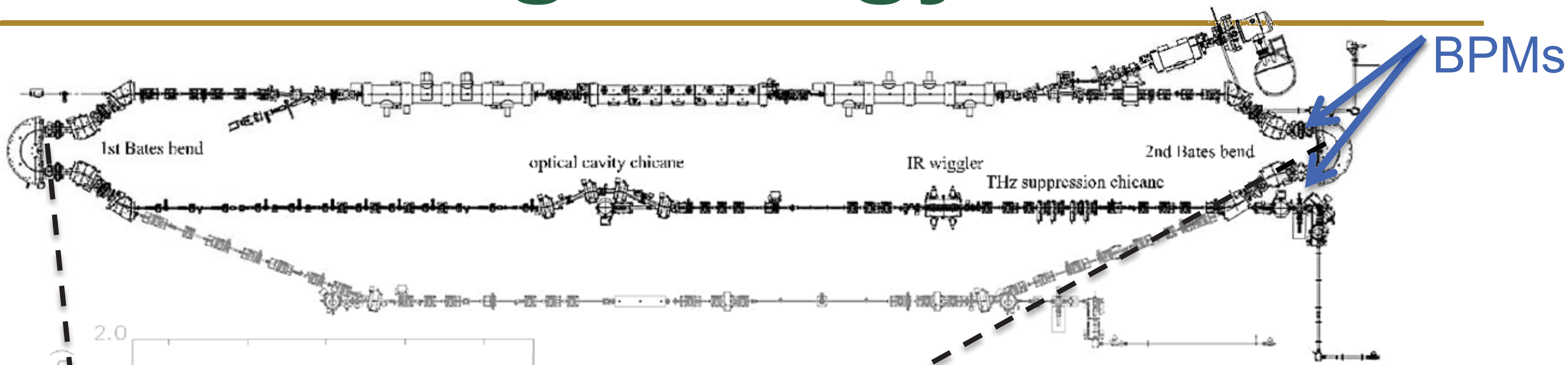

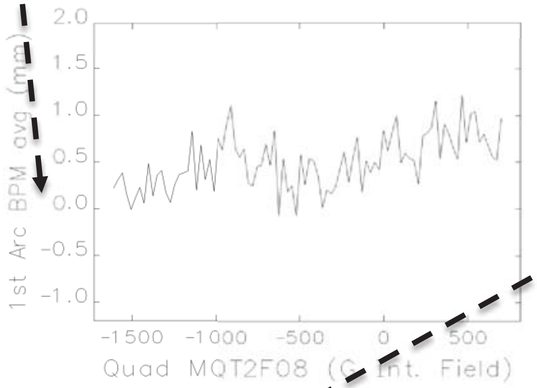

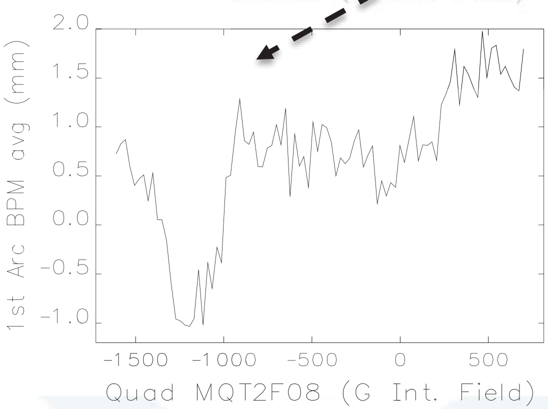

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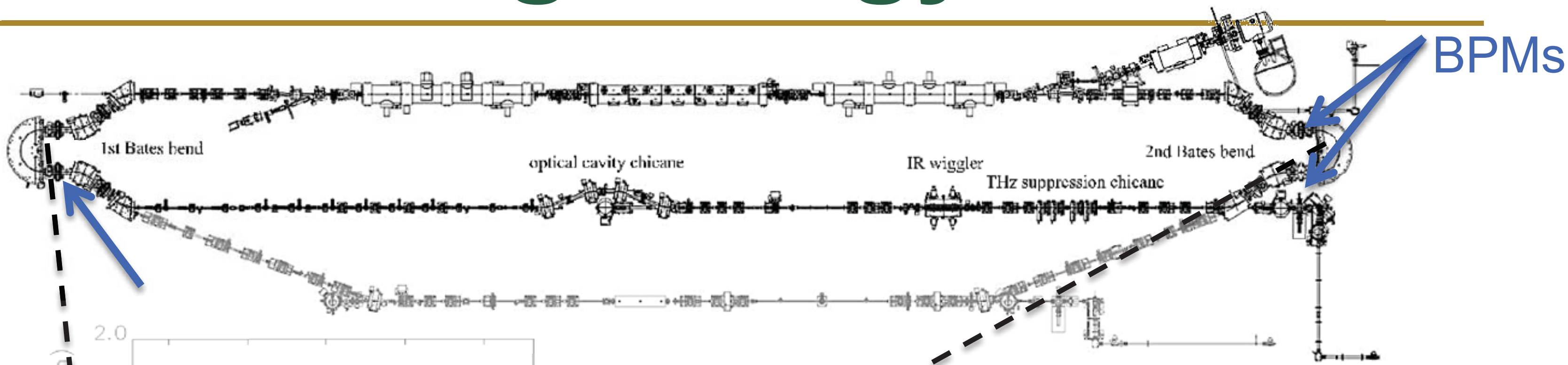

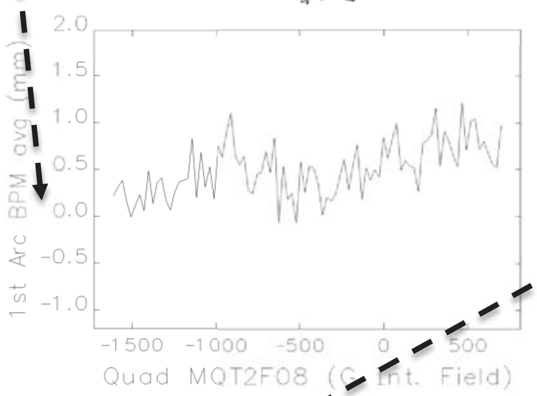

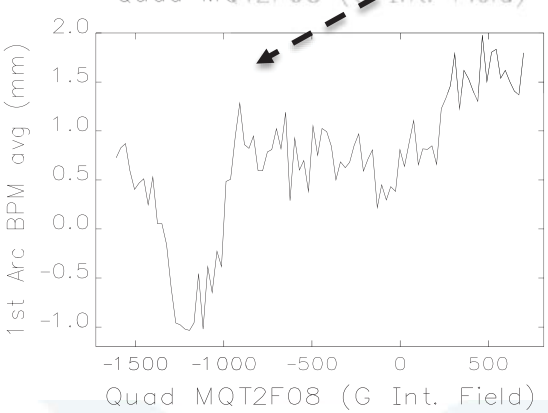

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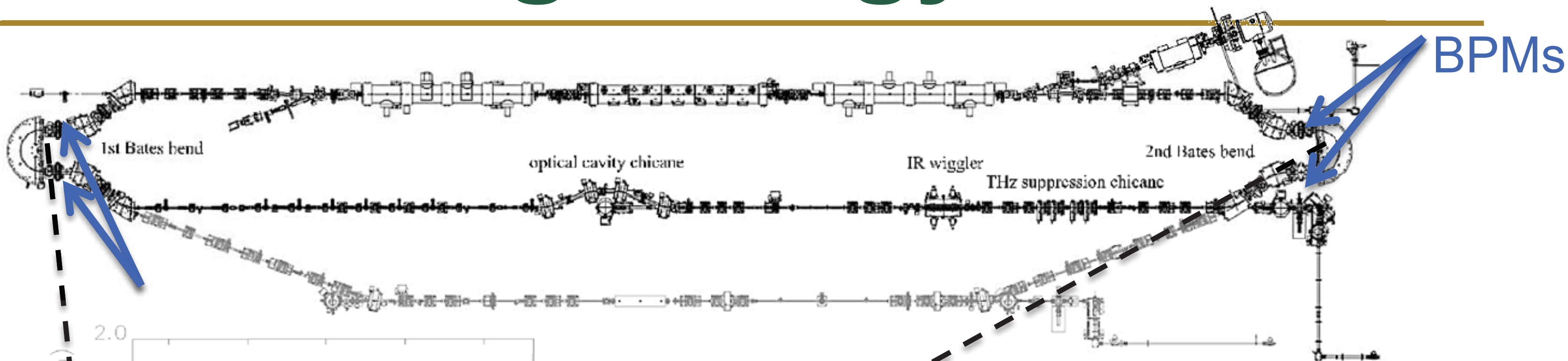
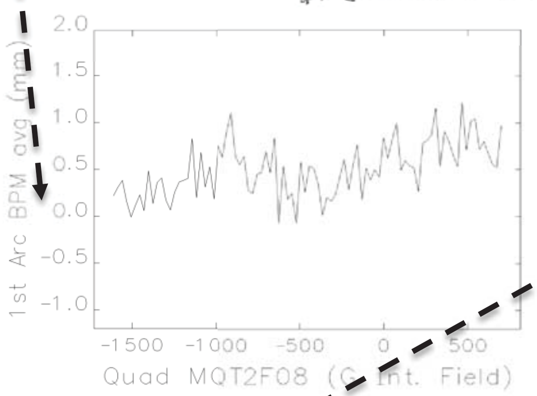
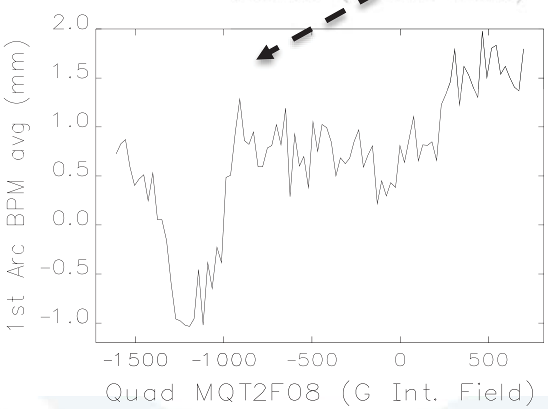
Measuring Energy Loss







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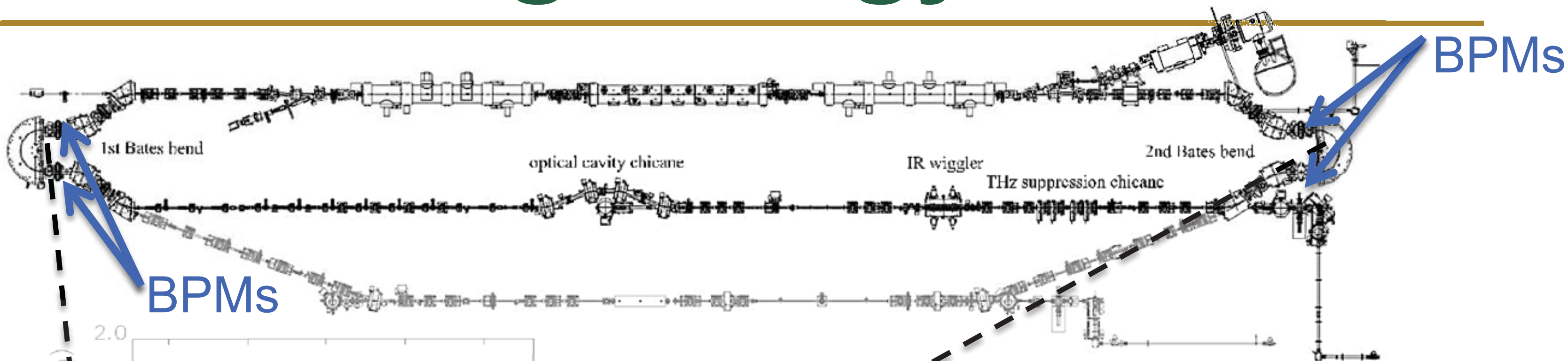

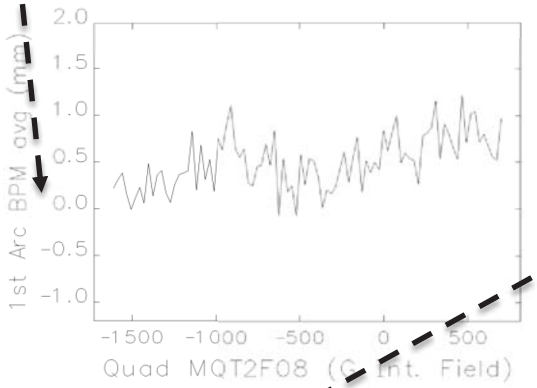

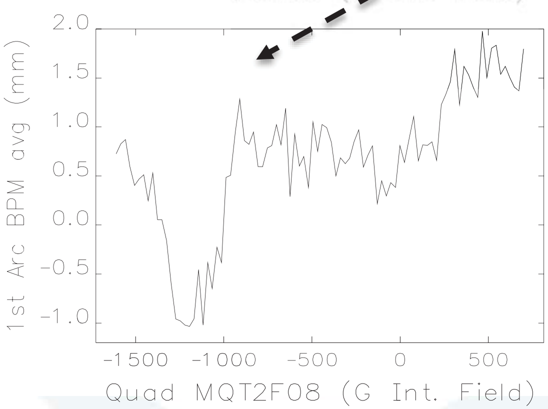

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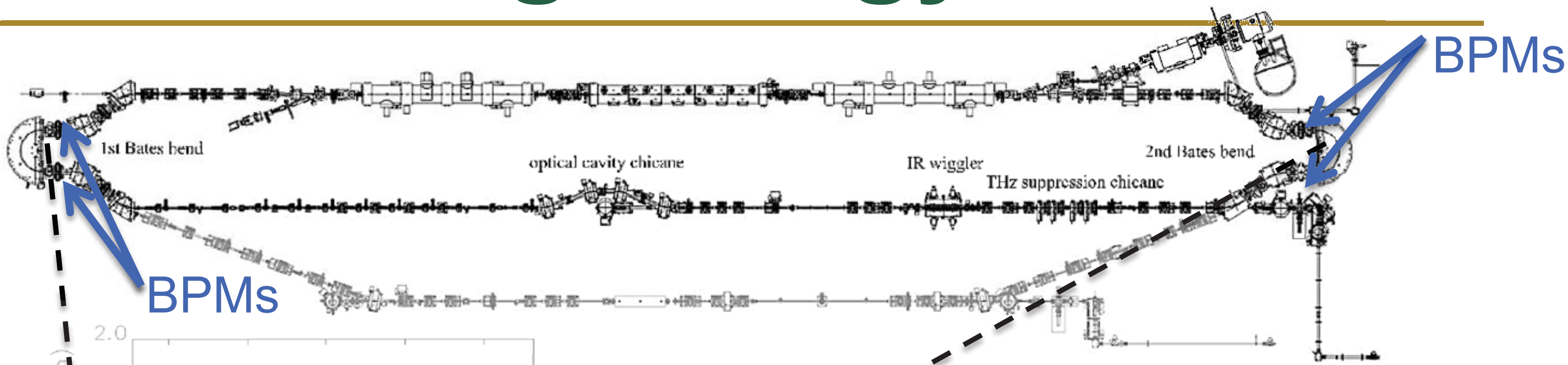

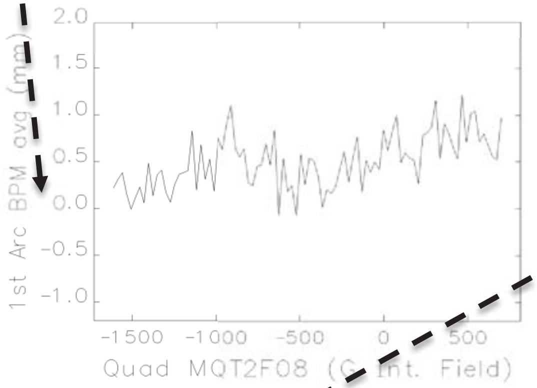

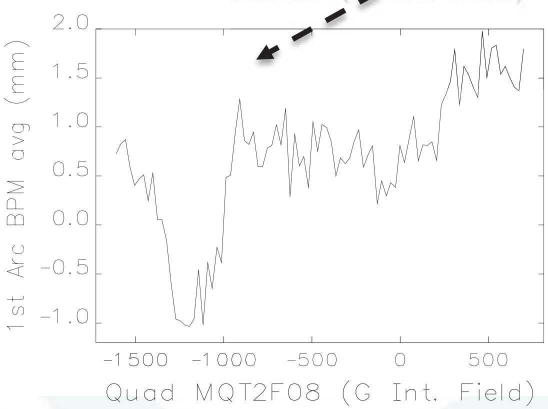

Synchrotron Light Monitor

BPM readings from each side of 180° bend average to remove any betatron offset

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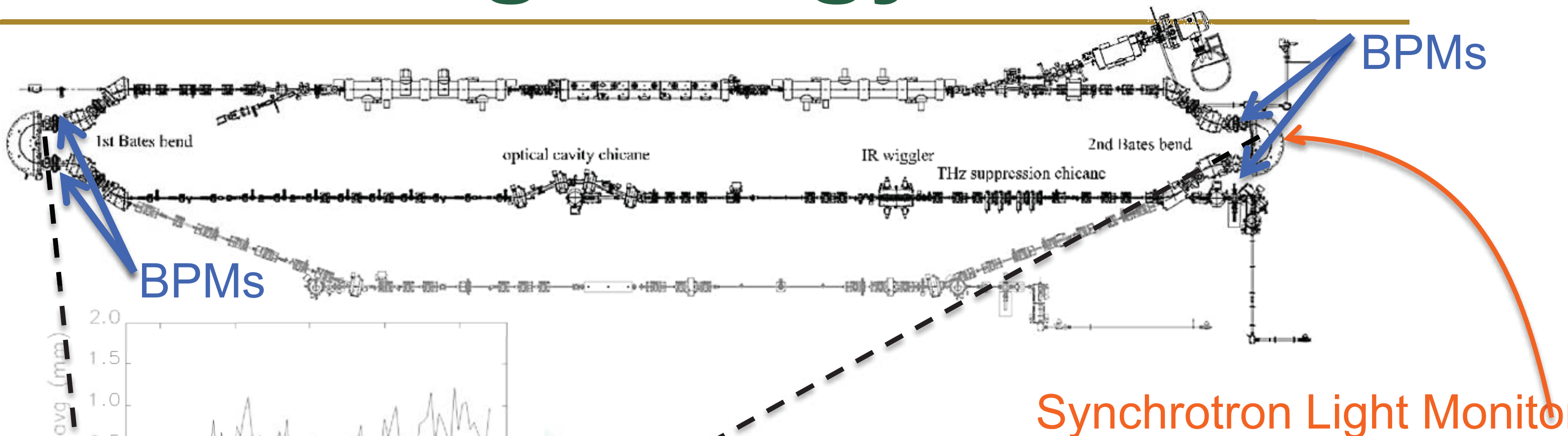
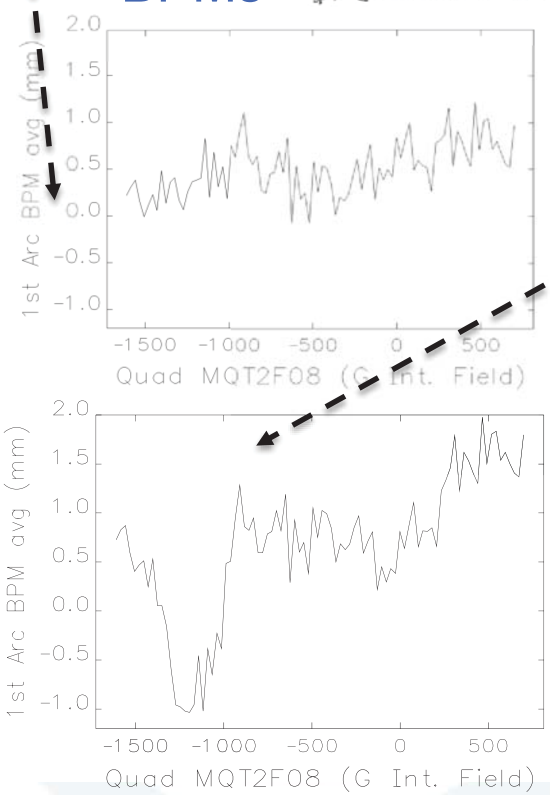
Measuring Energy Loss





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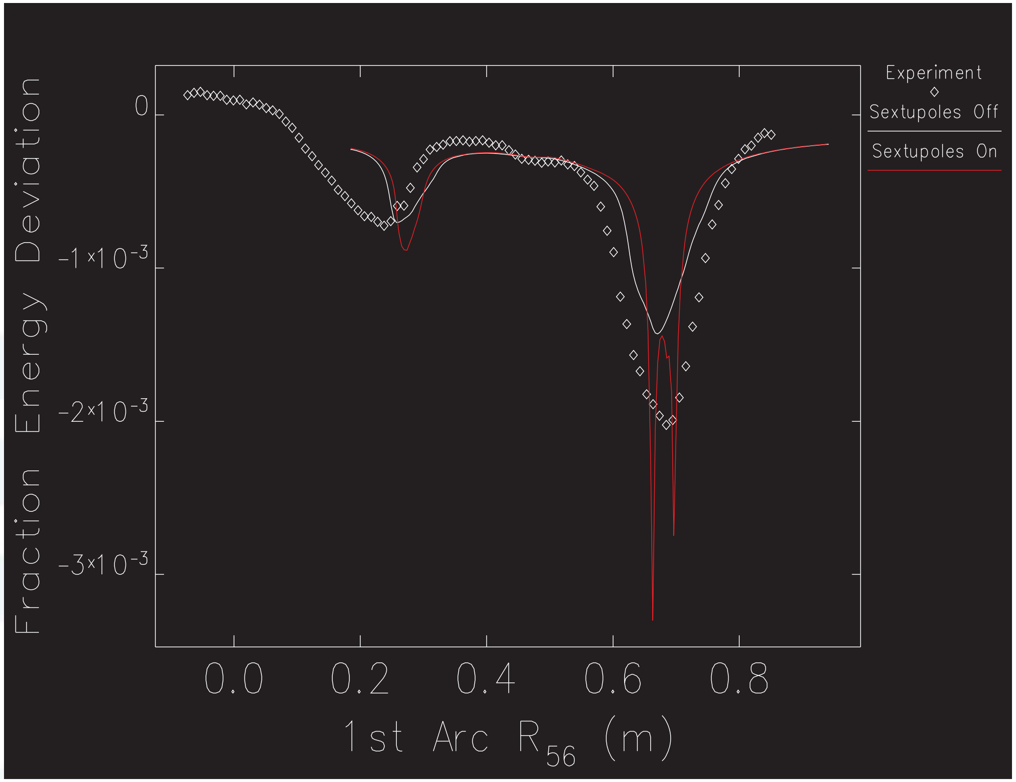
Falling RF Measurement



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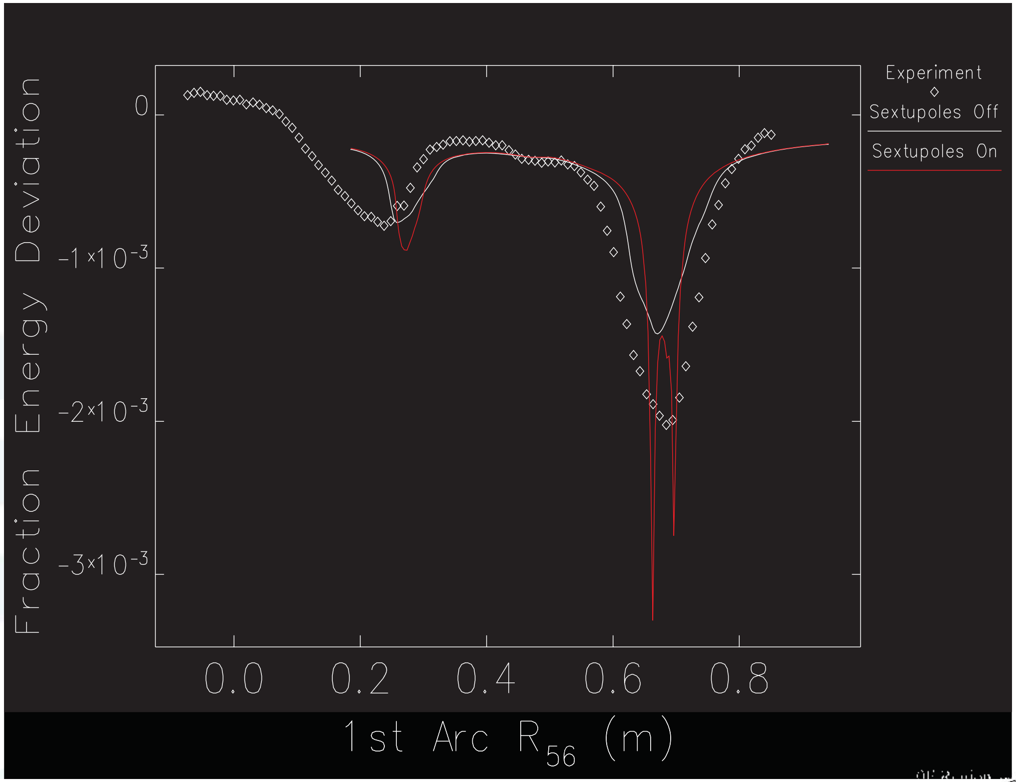

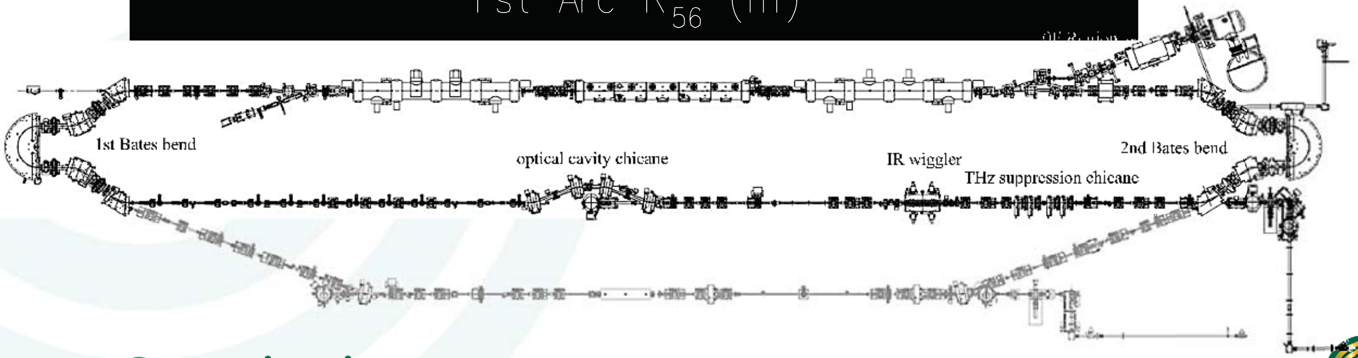

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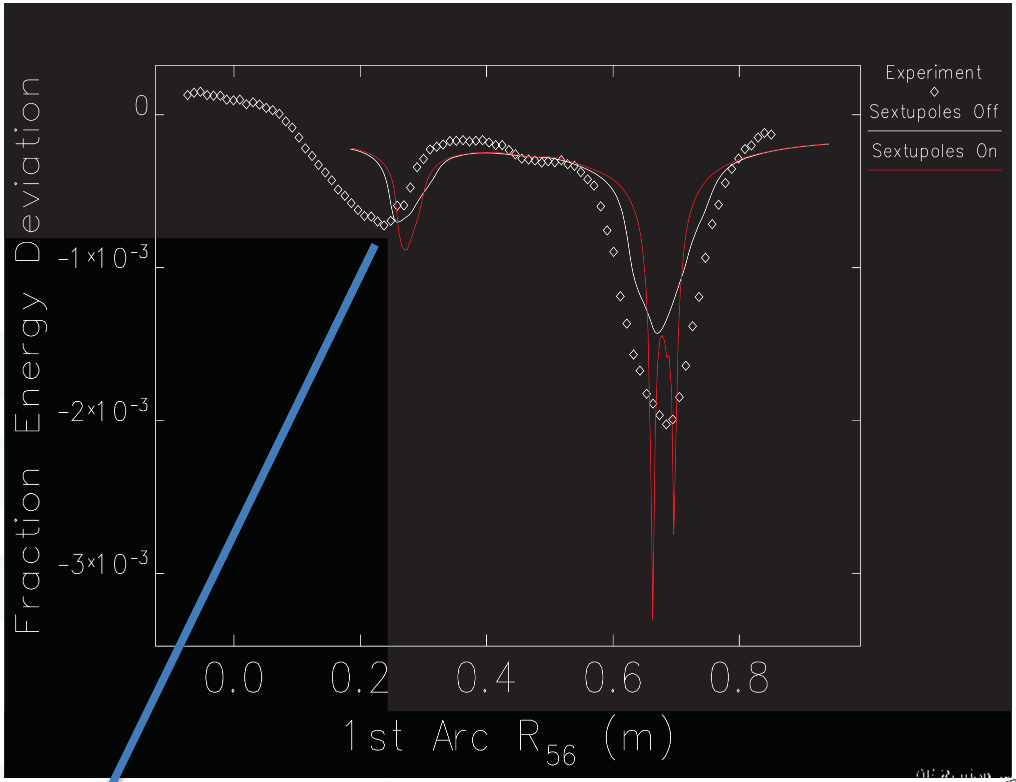

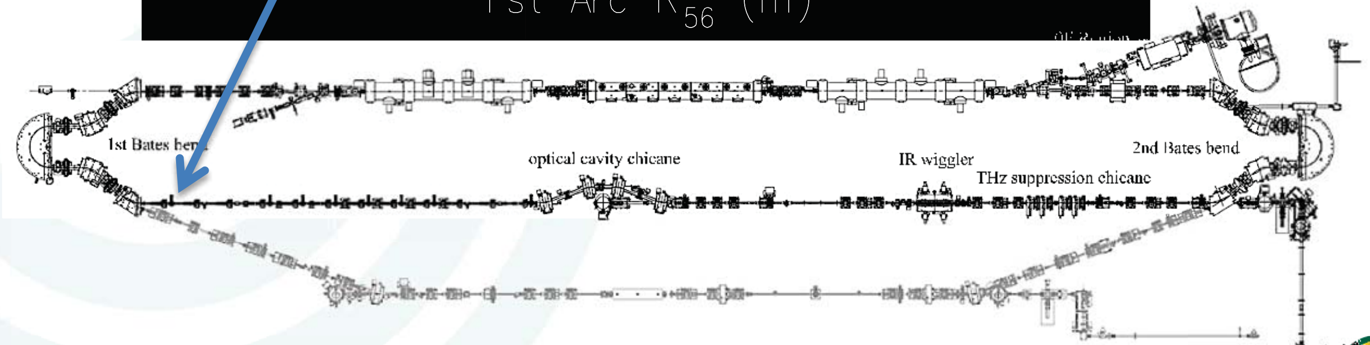

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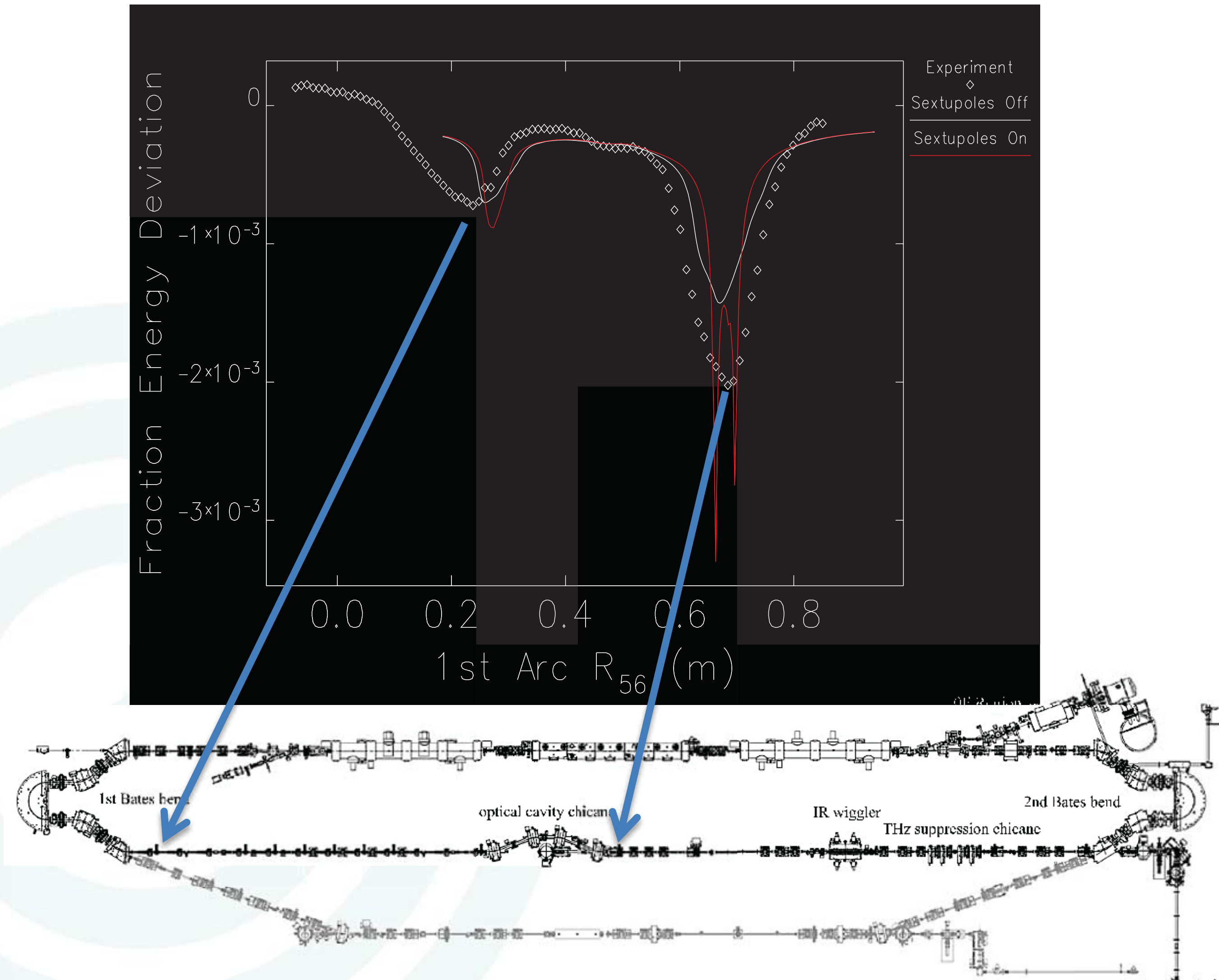

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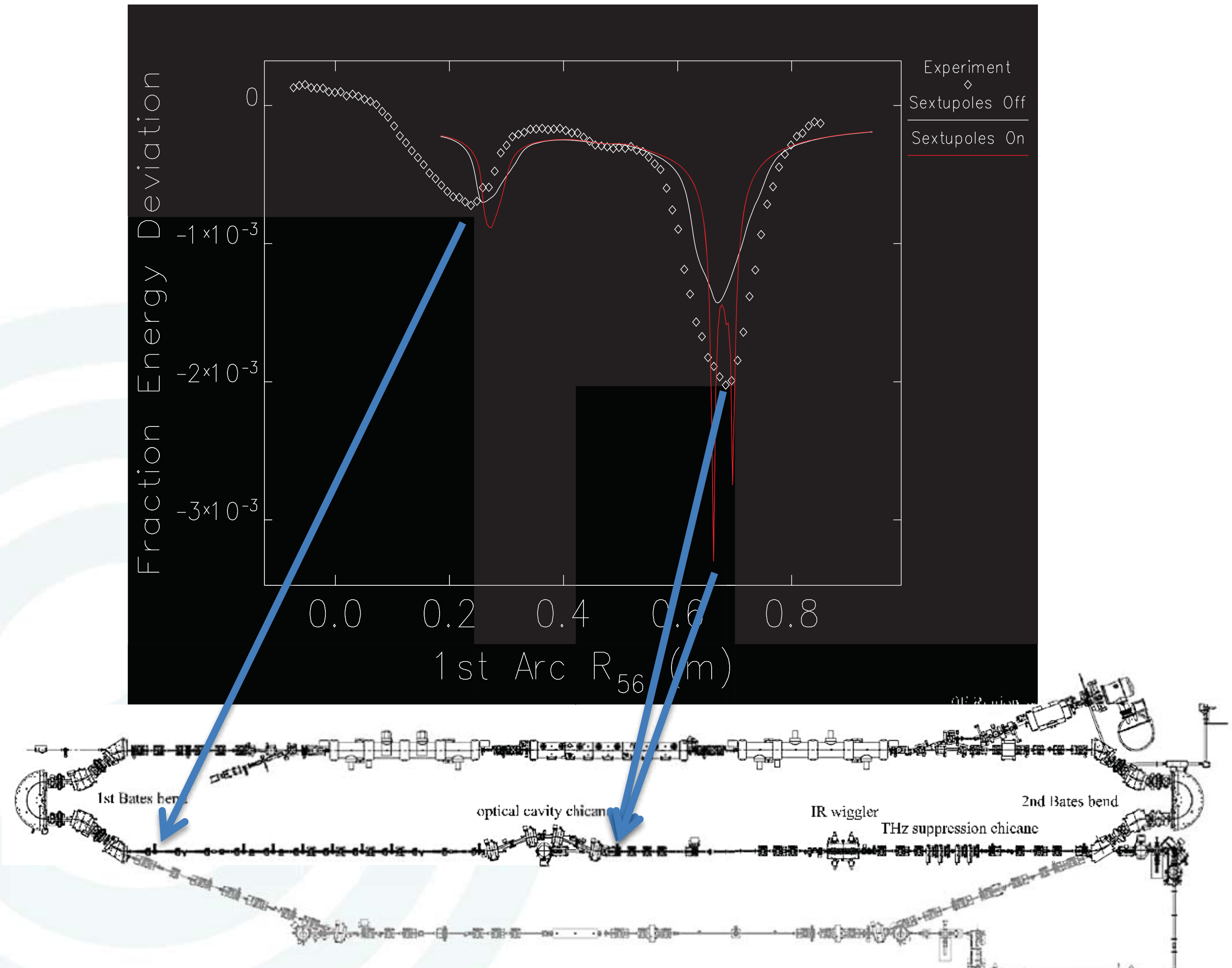

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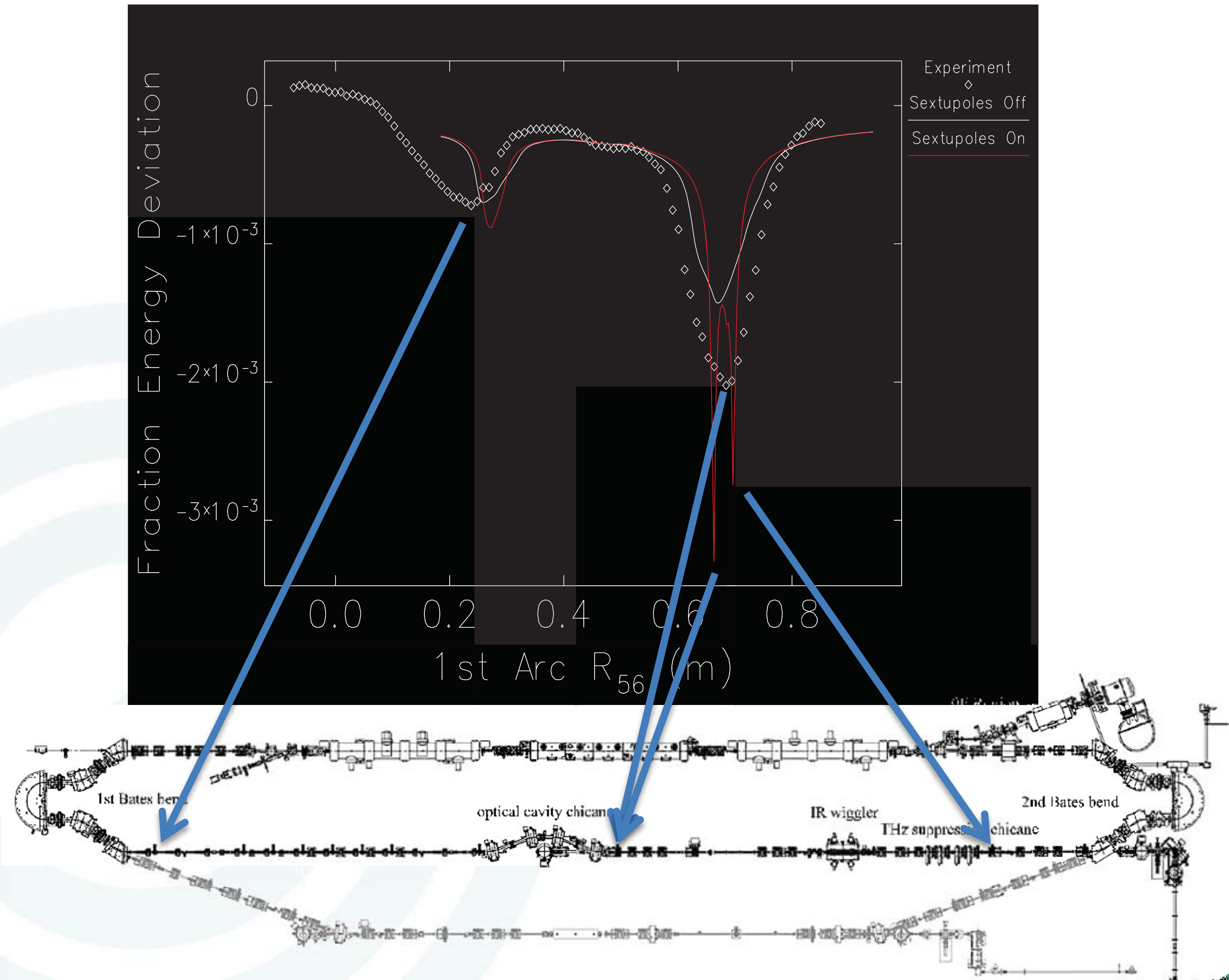
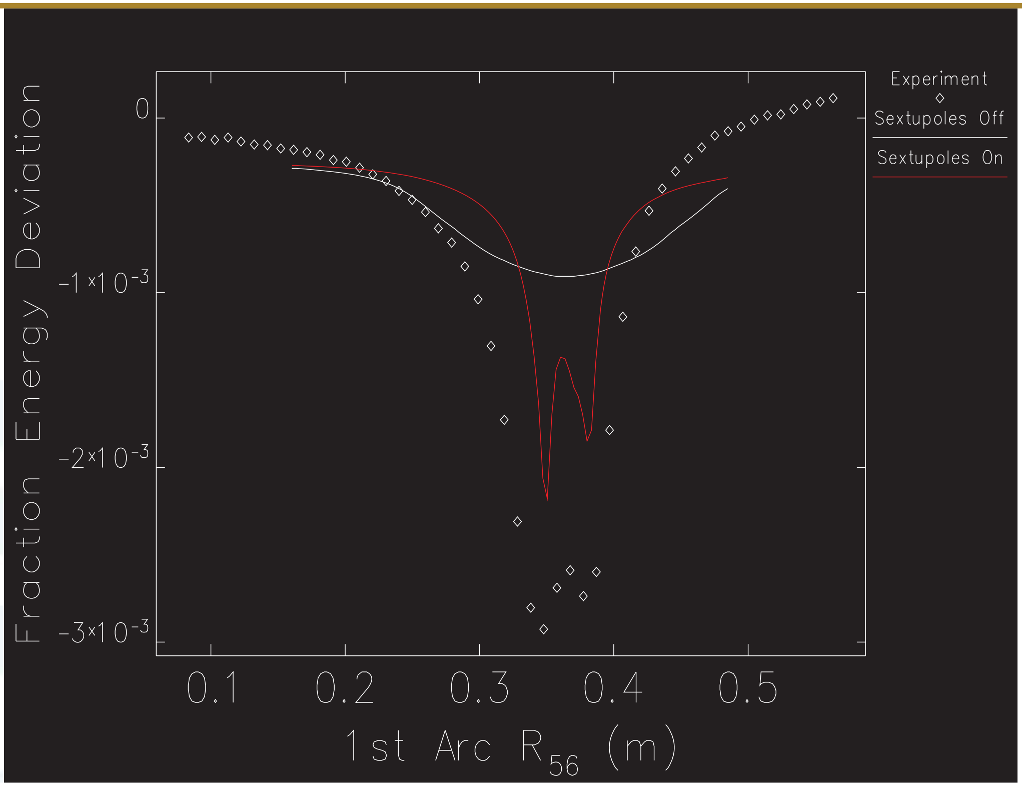


Rising RF Measurement

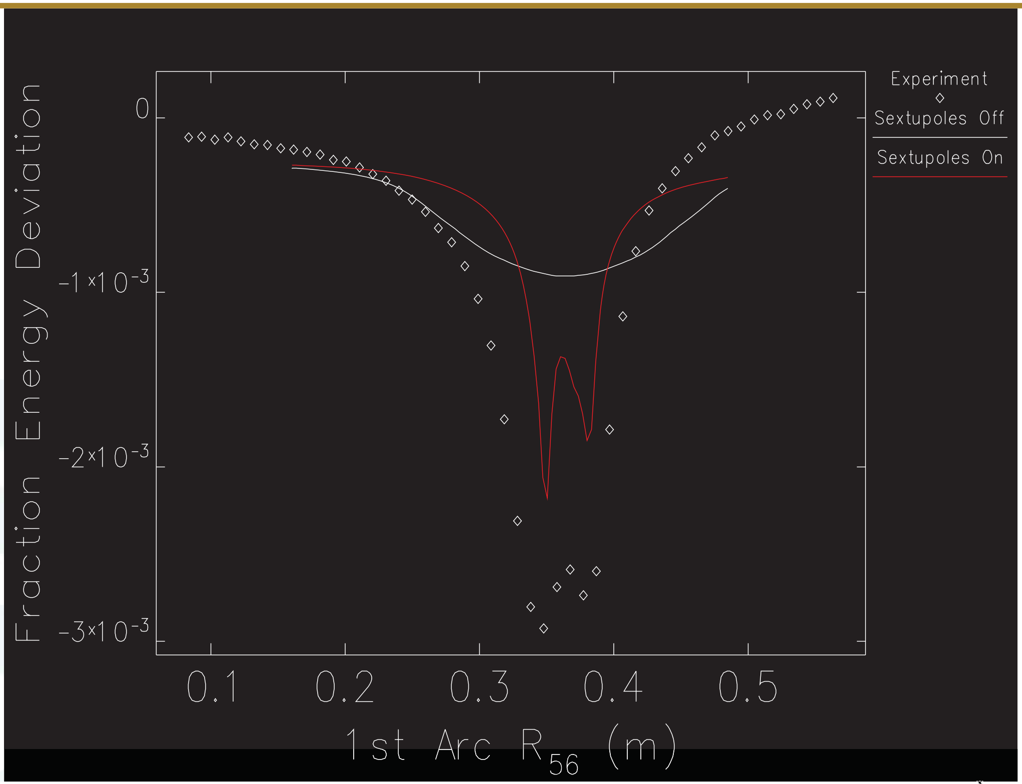
Did not sweep far enough to see full compression in the 1st arc



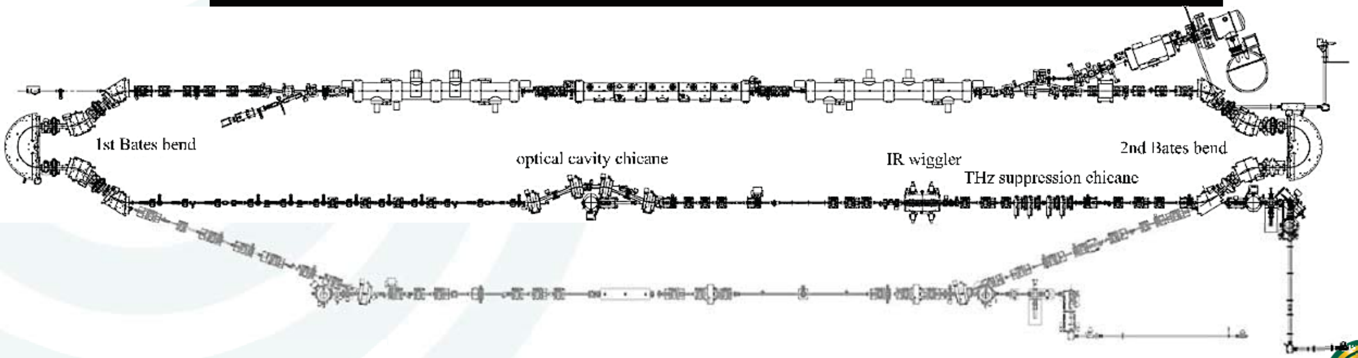
Impact of sextupoles shown in this measurement

Rising RF Measurement

Did not sweep far enough to see full compression in the 1st arc



Impact of sextupoles shown in this measurement

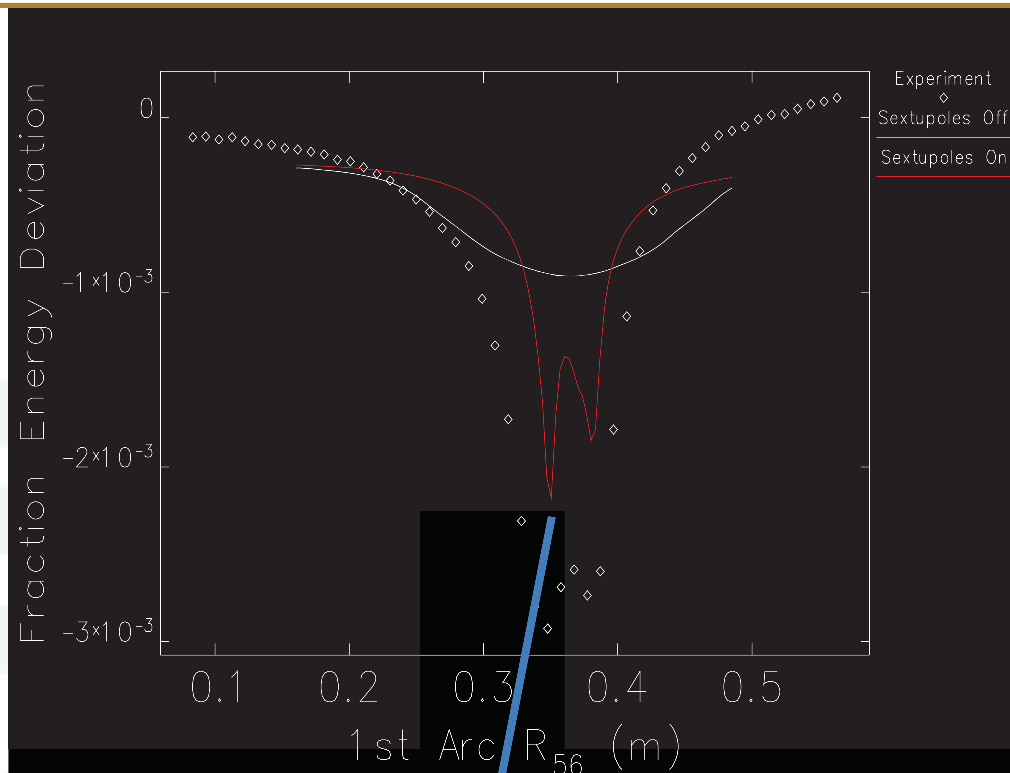


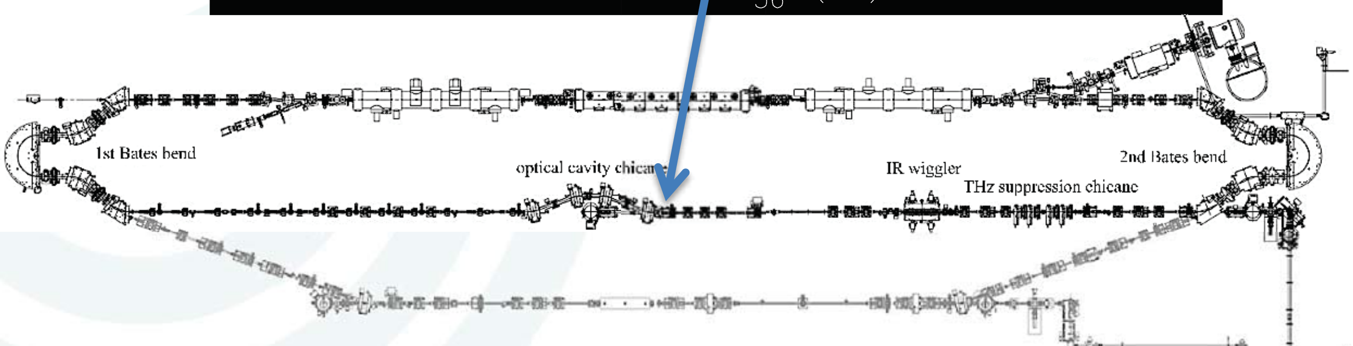
Colorado State University

Electrical & Computer ENGINEERING

Rising RF Measurement

Did not sweep far enough to see full compression in the 1st arc

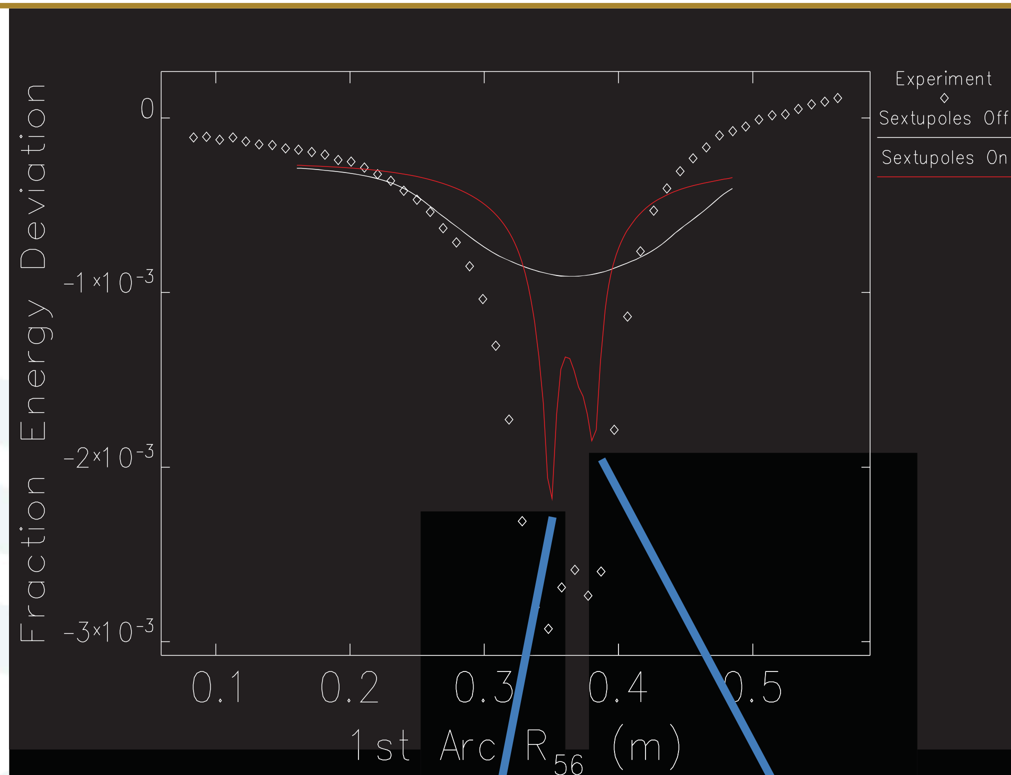




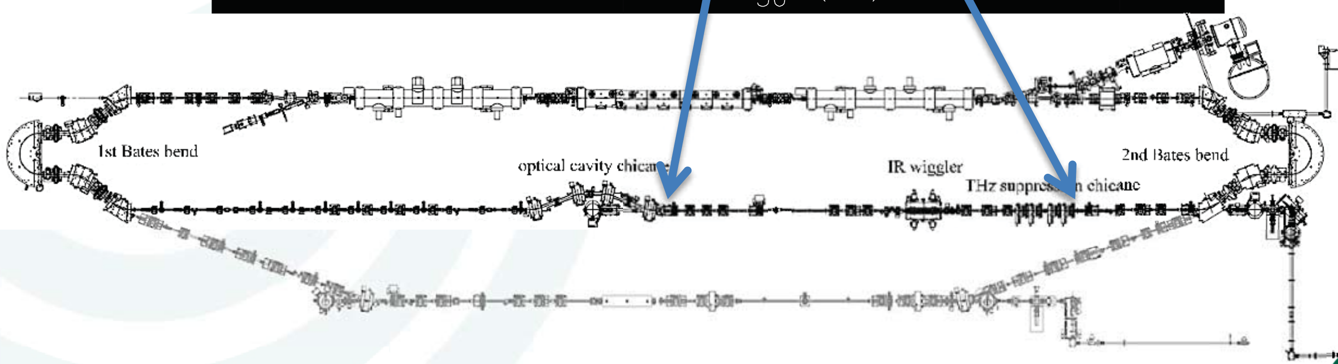
Impact of sextupoles shown in this measurement

Rising RF Measurement

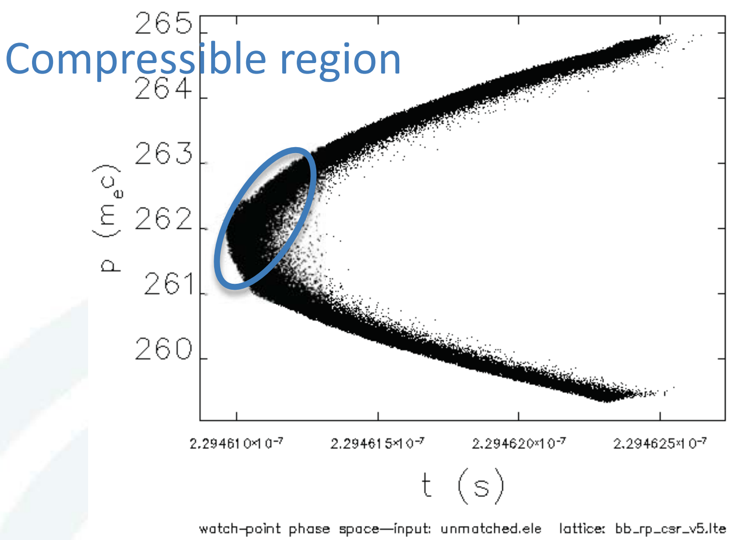
Did not sweep far enough to see full compression in the 1st arc



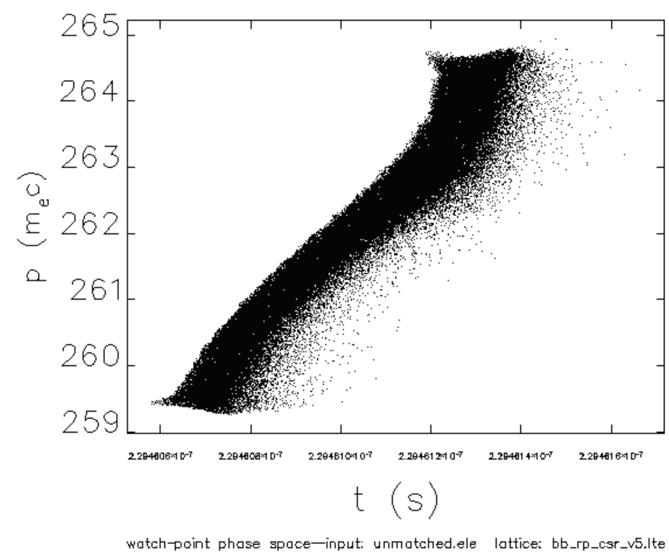
Impact of sextupoles shown in this measurement



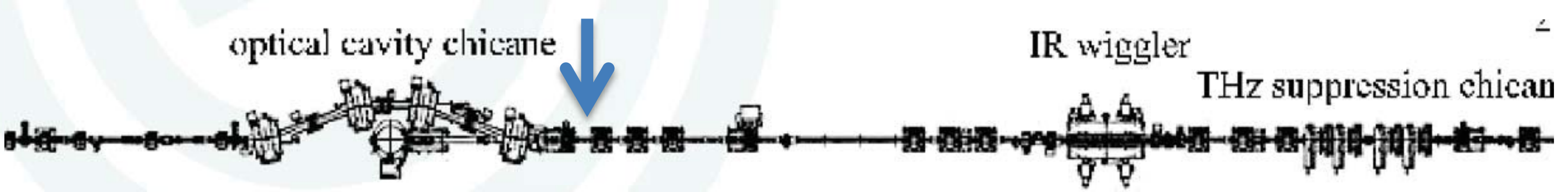
Linearization



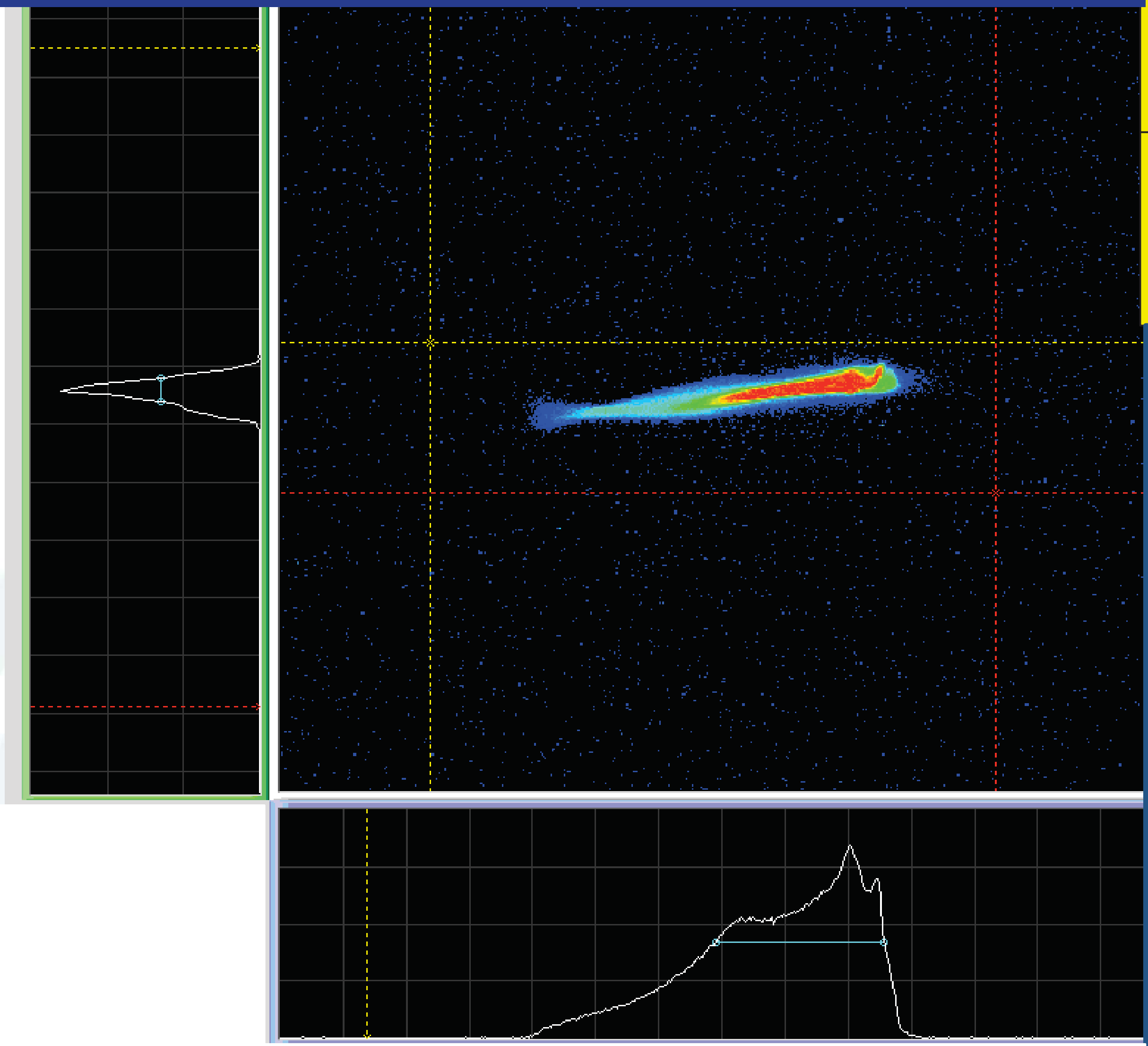
Sextupoles Off

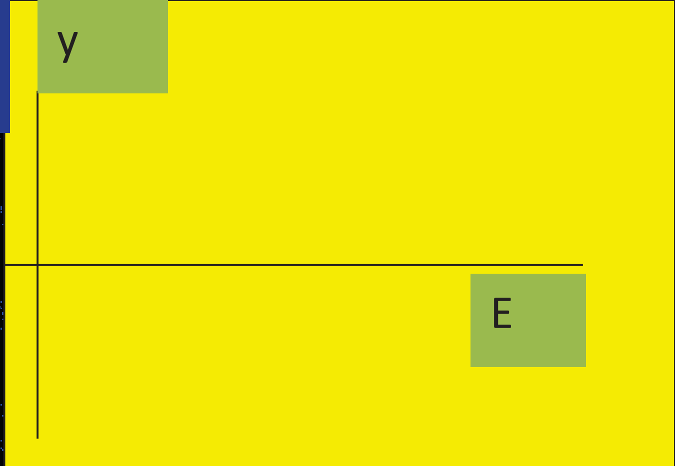


Sextupoles On - Linearized Bunch

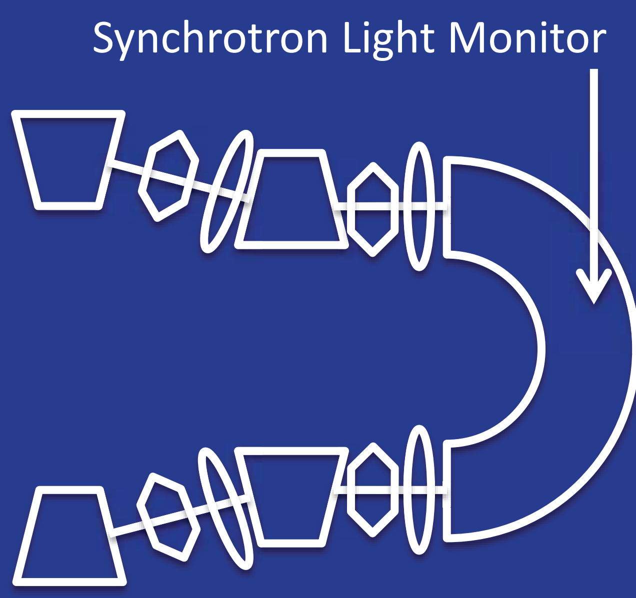


CSR effects as Observed in second arc



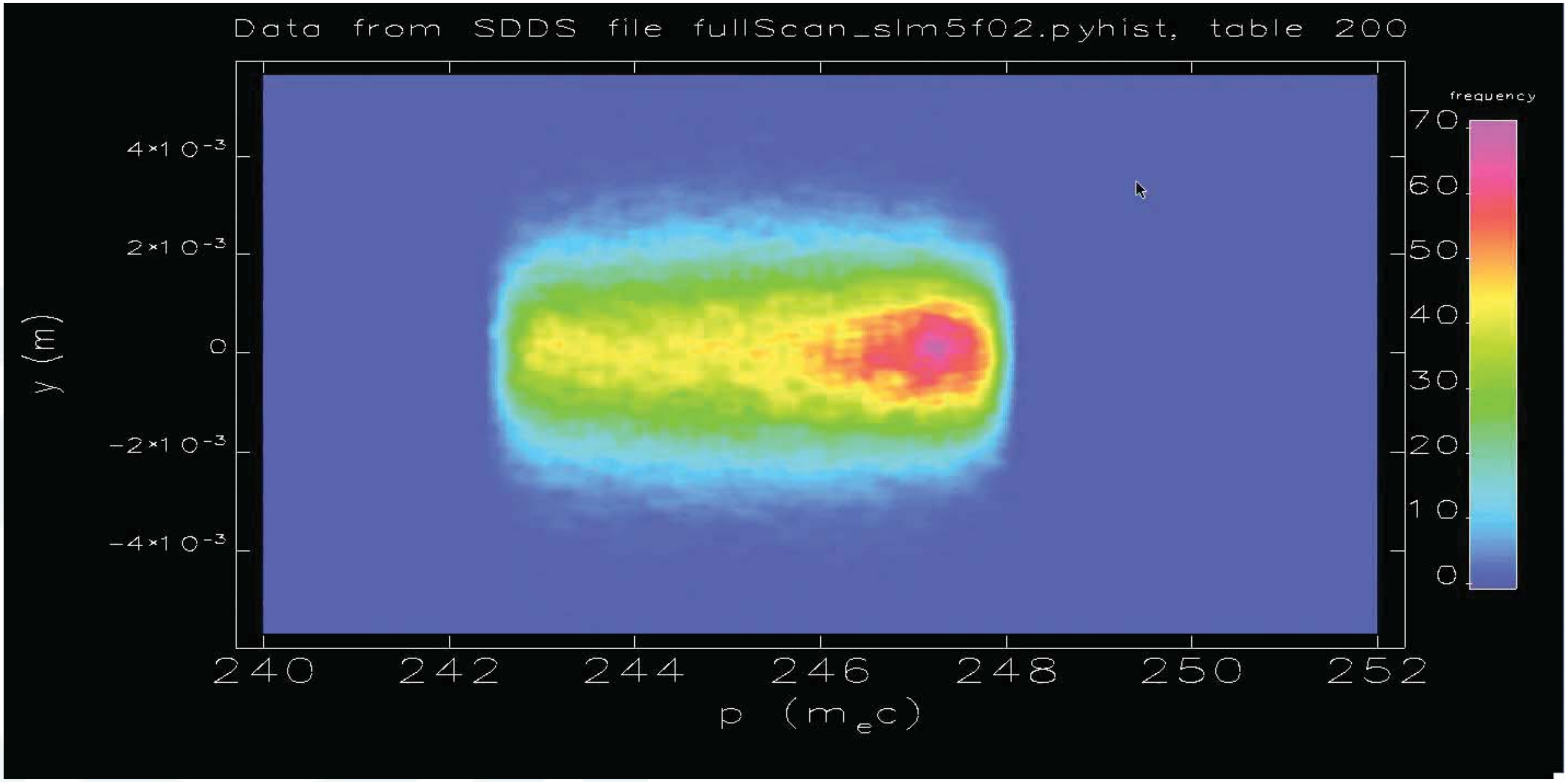


When bunch is compressed energy redistribution from CSR/LSC is observed. This redistribution is dependent on the degree of compression.

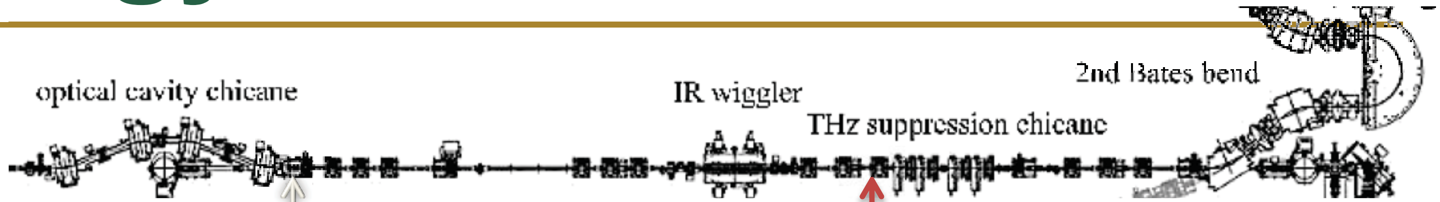


Energy Distribution Simulation

Energy Distribution Simulation



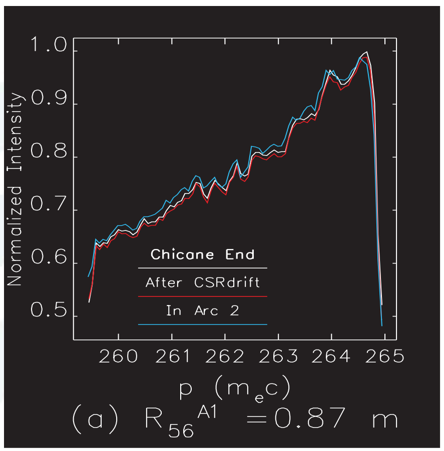
Energy Distribution Simulations



In Arc 2

Chicane End

After CSRdrift*



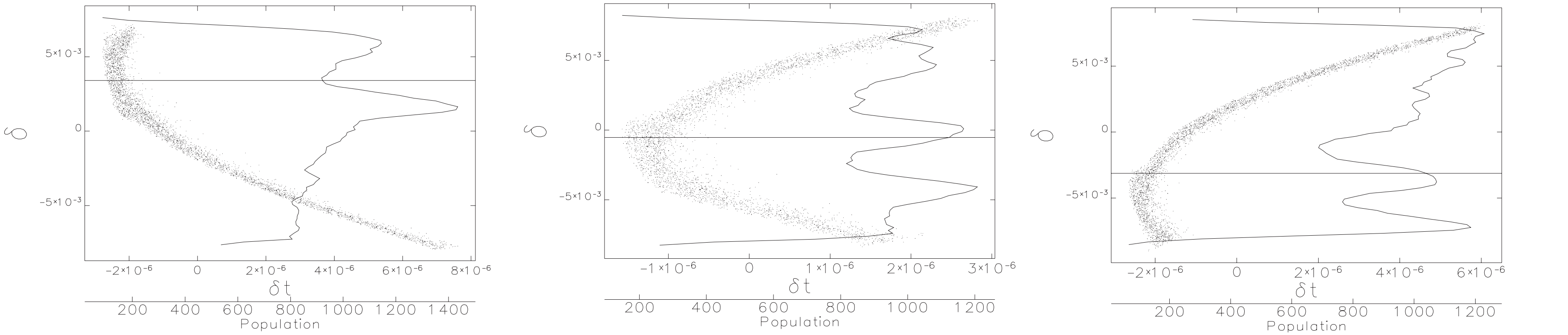
*G. Stupakov and P. Emma, SLAC Technical Report No. LCLSTN-01-12, 2001

Longitudinal Phase Space Picture

Can fit a parabola to the longitudinal phase space:

$$\delta(z;h) = -\frac{(\frac{1}{h} + R_{56})}{2T_{566}} \pm \frac{1}{2T_{566}}\sqrt{(\frac{1}{h} + R_{56})^2 + 4T_{566}z}$$

Average energy of the head of the bunch will shift as compression is changed



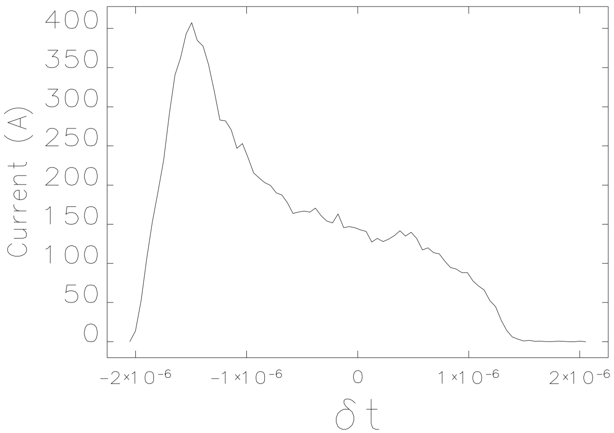
CSR wake strongest at head of the bunch. Causes fragmentation of the energy spectrum dependent on compression.

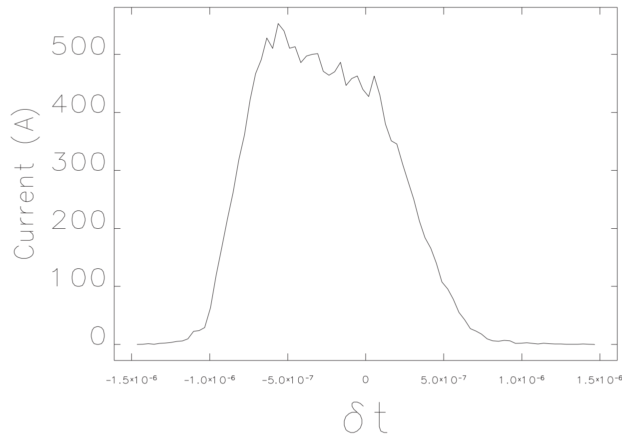
Impact of Sextupoles

Sextupoles Off

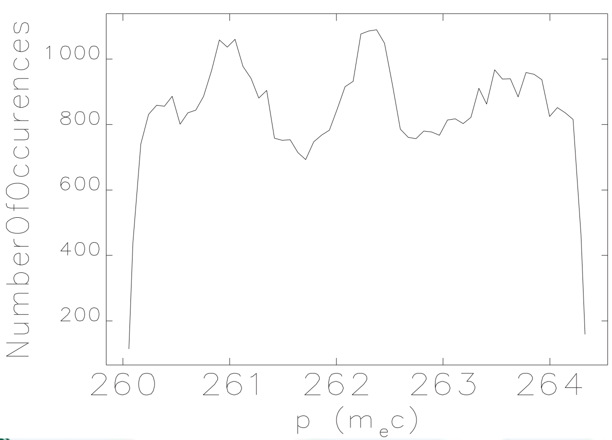
Sextupoles On

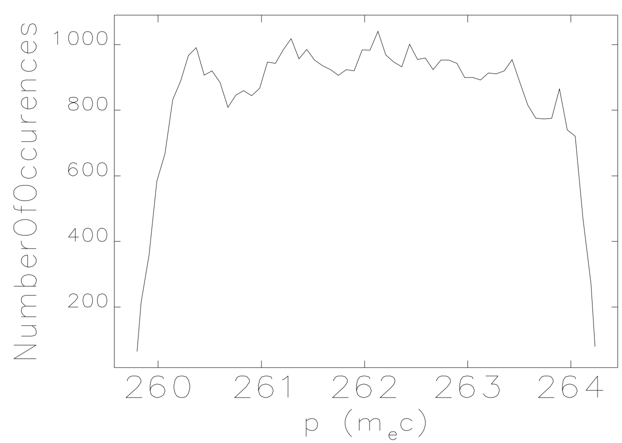
Charge Distribution



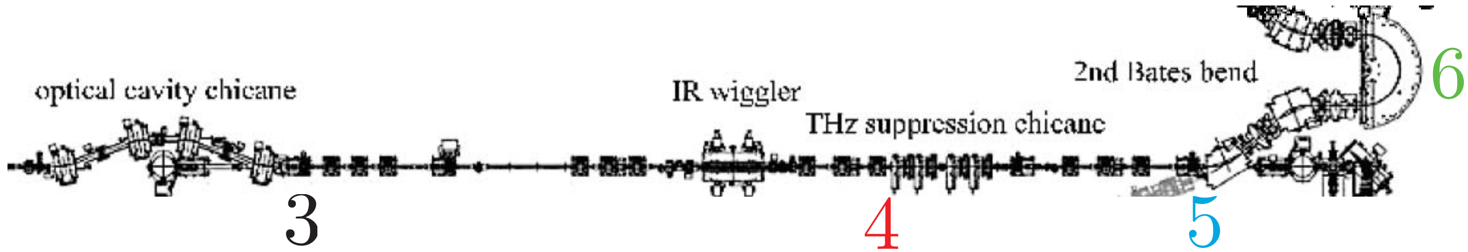


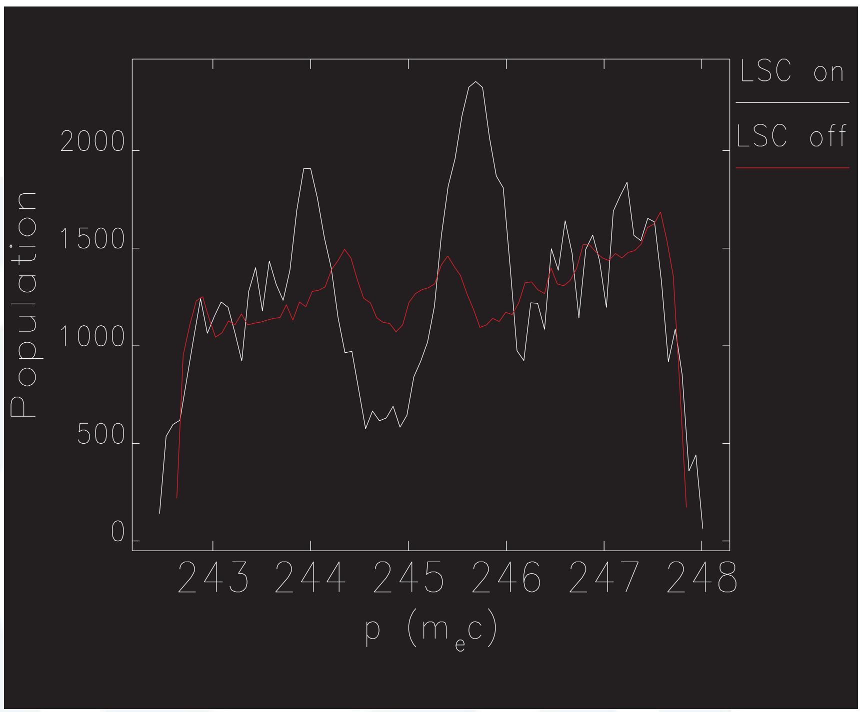
Energy Distribution

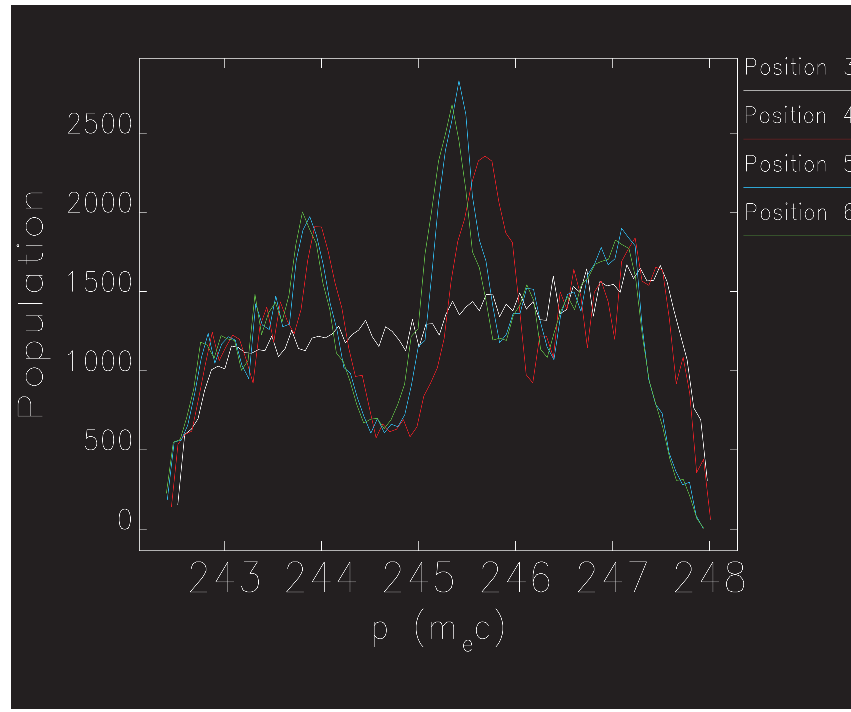




Energy Spectrum Simulations with LSC







Fragmentation in the energy spectrum is enhanced by longitudinal space charge

Conclusions

- Better understanding of CSR will be critical for the success of many upcoming accelerators.
- Measurements show good qualitative agreement to 1-D CSR model.
- CSR in drifts after a bunch compressor can have a large impact on the energy distribution.
- Important to control longitudinal curvature to keep energy distribution uniform.
  - Leads to greater energy loss overall due to better compression.

Further Work

- Perform a better analysis of simulations for microbunching.
- Include longitudinal space charge in simulation.
  - Underway currently
  - Leads to large enhancement of fragmentation in energy spectrum
- Further experiments?
  - Better test sextupole impact
  - Measure emittance

THANK YOU!