# Measurements of CSR in the Jefferson Laboratory FEL Driver


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# Outline

- **Introduction**
- **The JLab FEL Driver**
- **Summary of the Experiment**
- **Results**
  - Average energy loss
  - Energy spectrum
- **Comparison to elegant Simulation**
  - Simulation of the fragmentation in the energy spectrum
  - Impact of sextupoles
- **Conclusion**

# Motivation

- Study CSR in high repetition machine.
- 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*.

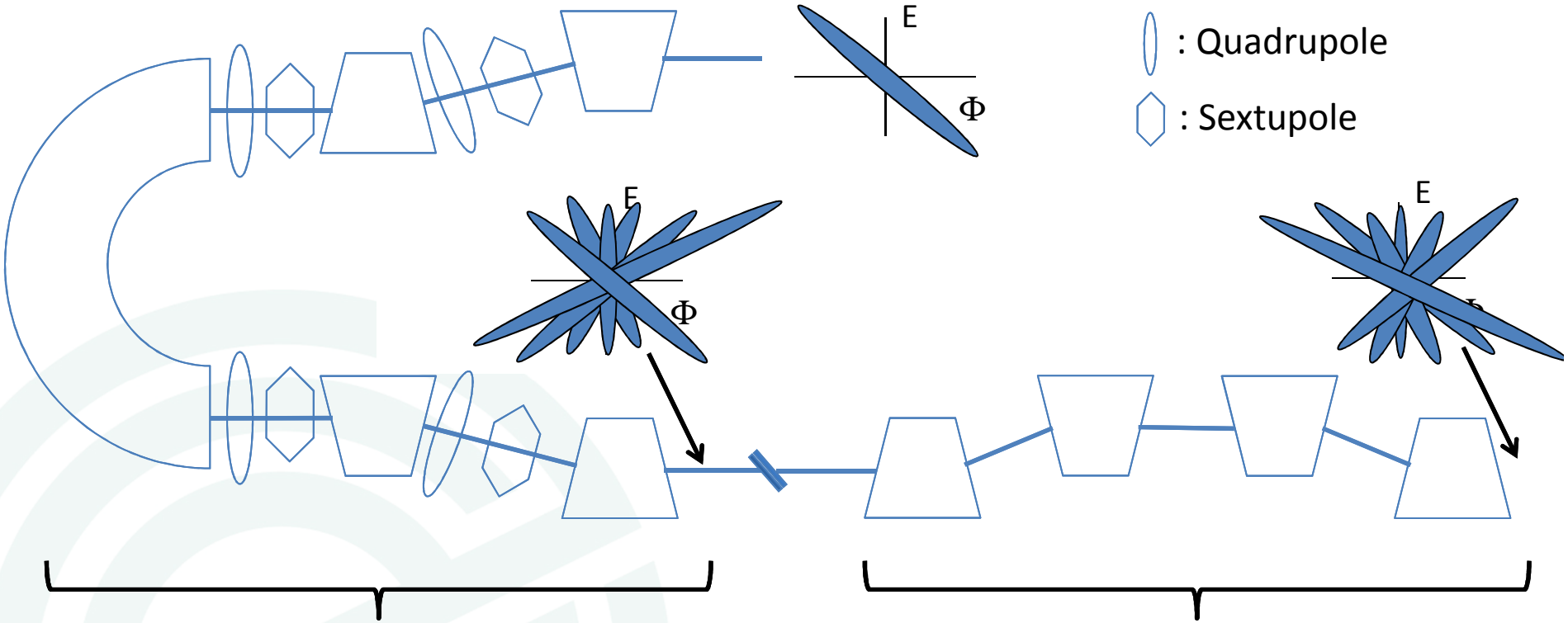
*E. Saldin, et. al, NIM A 398, 373 (1997)

# The 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 |

Can lead to 200 W/mA of CSR power!!

# Varying the Compression Point



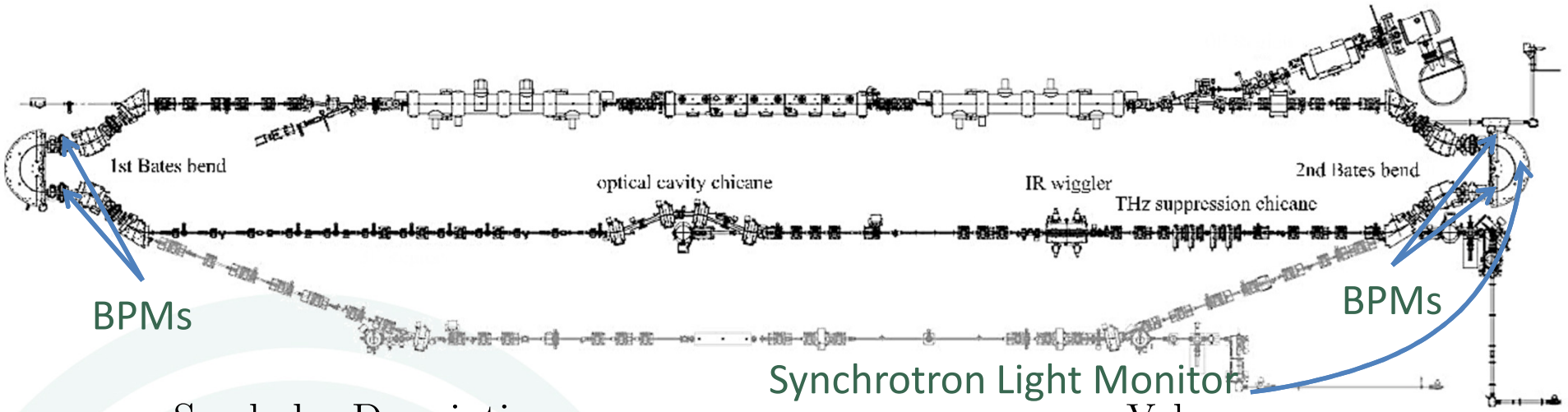

$R_{56}$ -> variable

$R_{56}$= - 52 cm

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

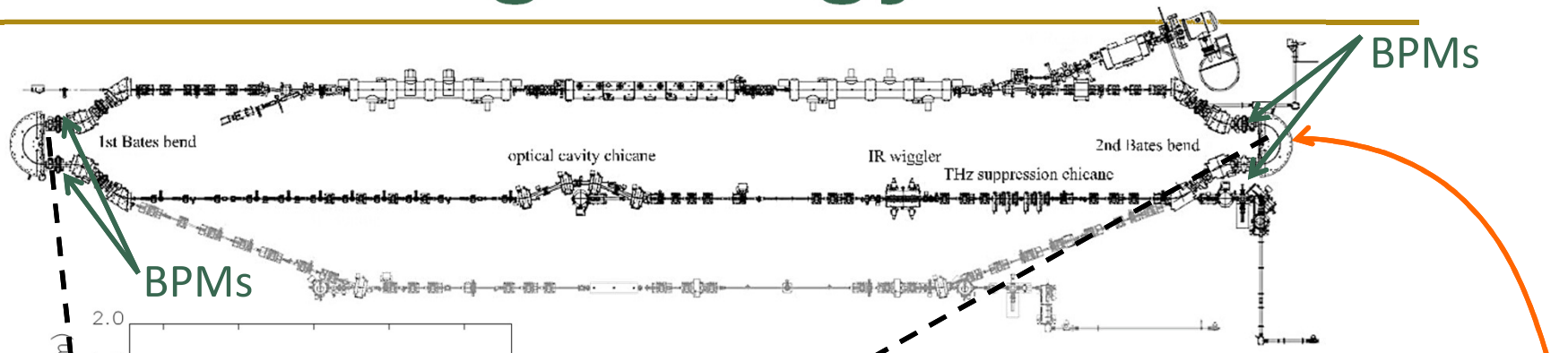
$R_{56}$ for Critical Compression: +20 cm

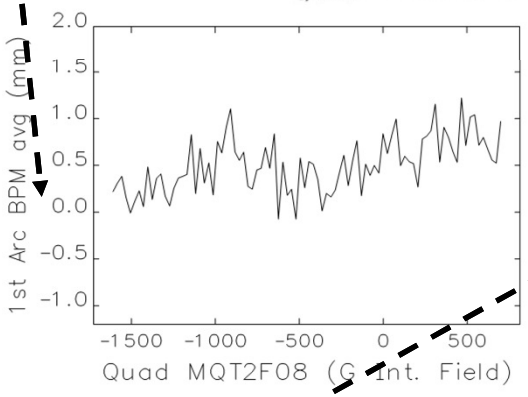
# Experiment Machine Parameters

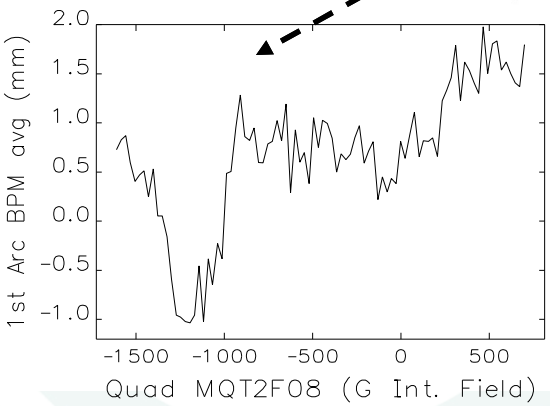



| Symbol | Description | Value |
|---|---|---|
| $E_0$ | Injection energy [MeV] | 9 |
| $E_f$ | Final energy [MeV] | 135 |
| - | Charge per bunch [pC] | 135 |
| $\sigma_0$ | Bunch length after injector [ps] | 3 |
| $\sigma_f$ | Bunch length at max compression [fs] | 150 |
| h | Energy-position correlation (chirp) $[m^{-1}]$ | $\mp 5$ |
| - | RF phase [degrees] | $\pm 10$ |
| - | 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



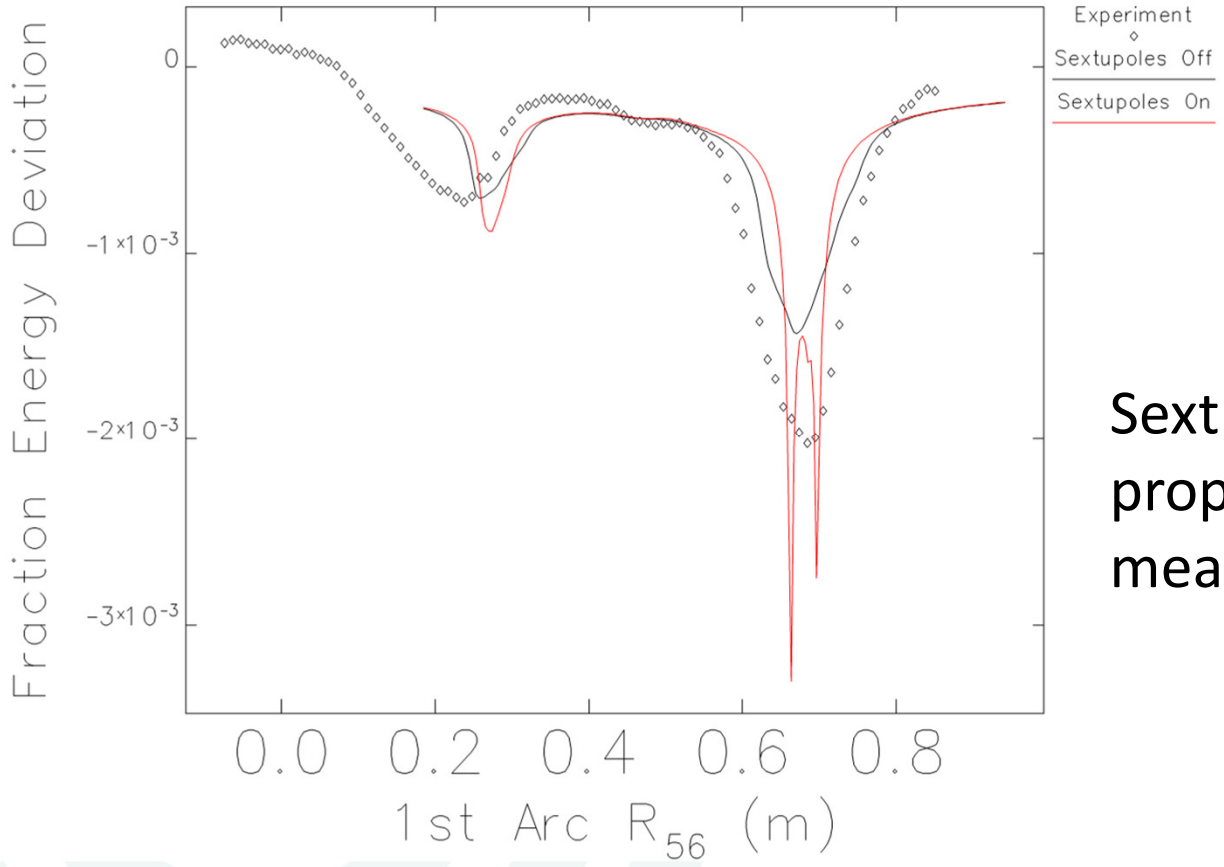




BPM readings from each side of 180 deg bend average to remove any betatron offset

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

# Falling RF Measurement

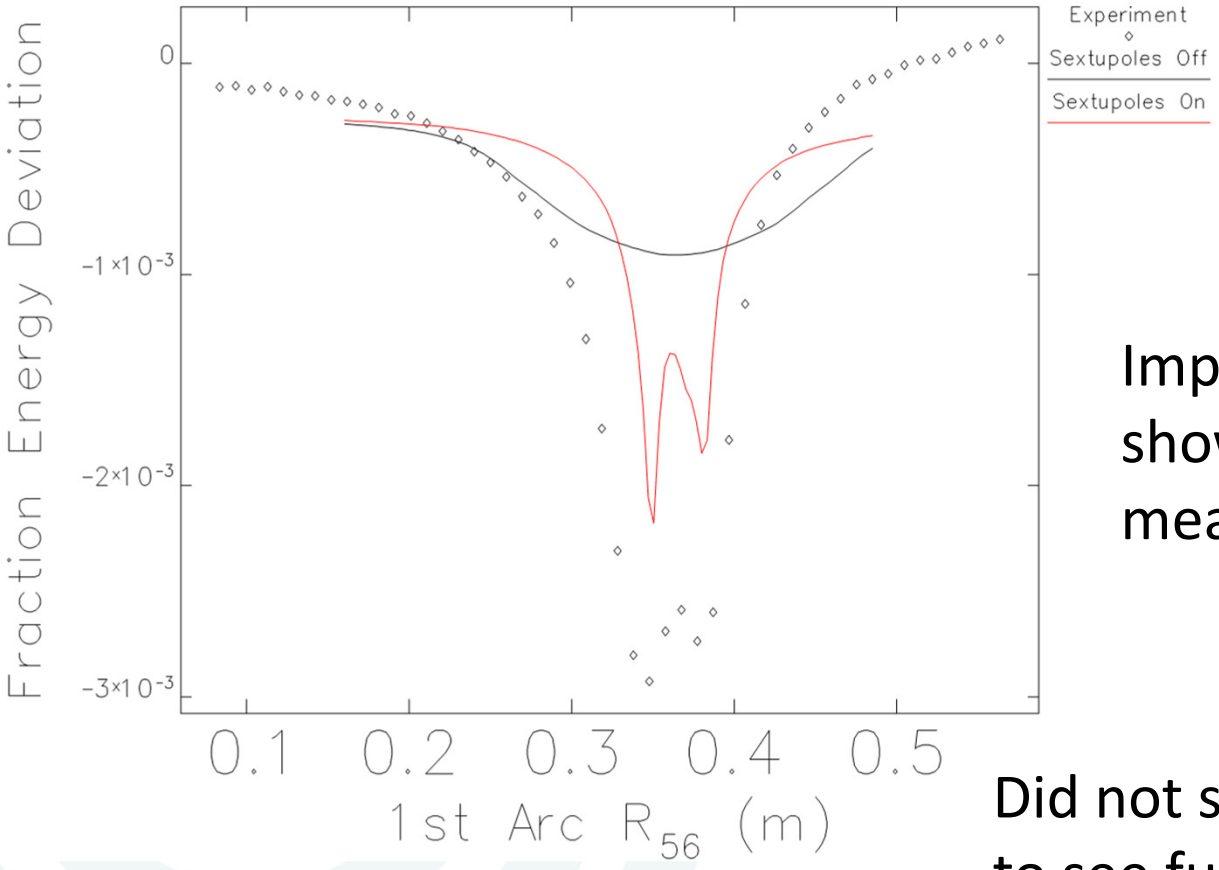
Energy loss from CSR as a function of compression point.




Sextupoles not set properly during measurement

# Rising RF Measurement

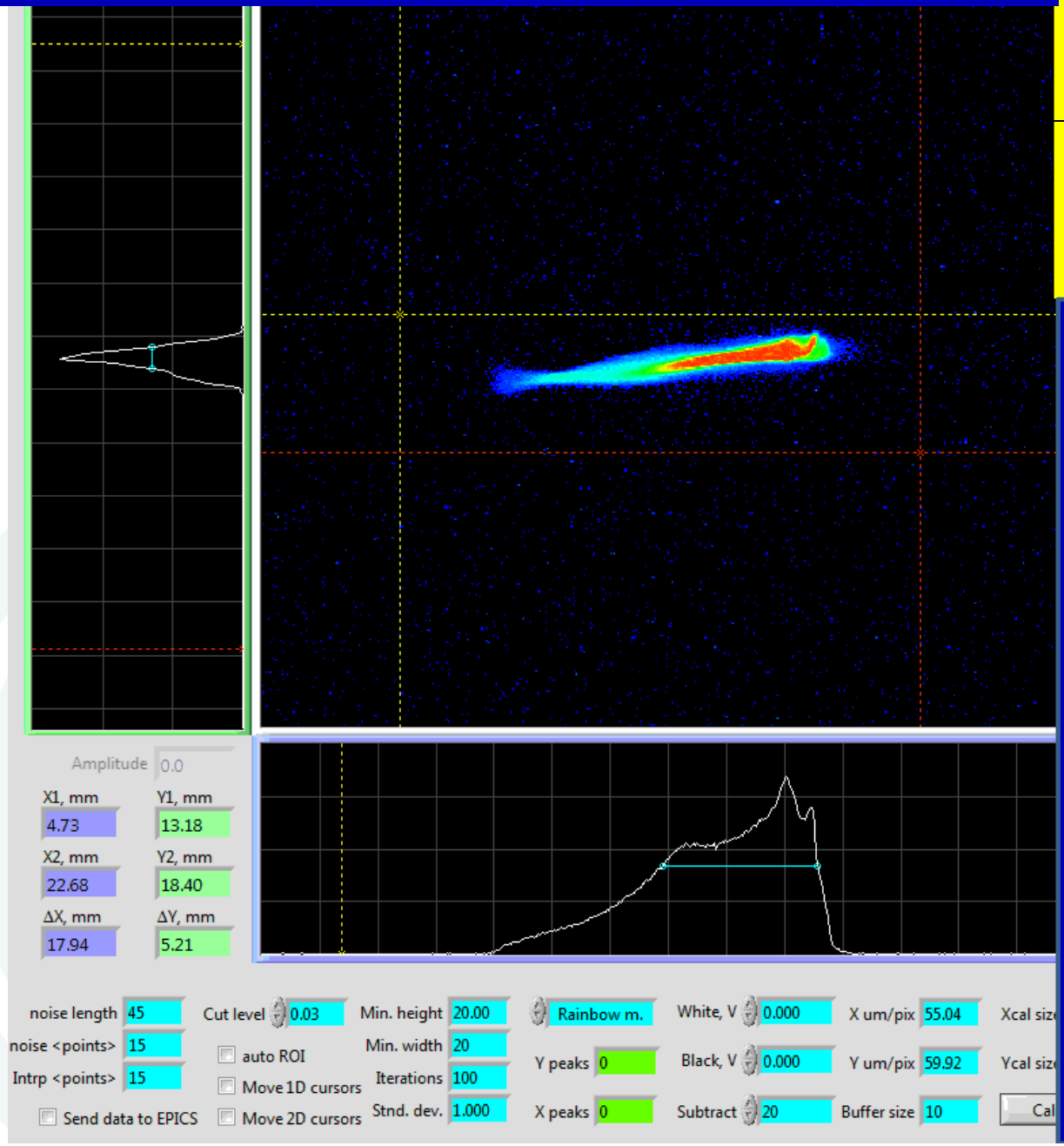
Energy loss from CSR as a function of compression point.




Impact of sextupoles shown in this measurement.

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

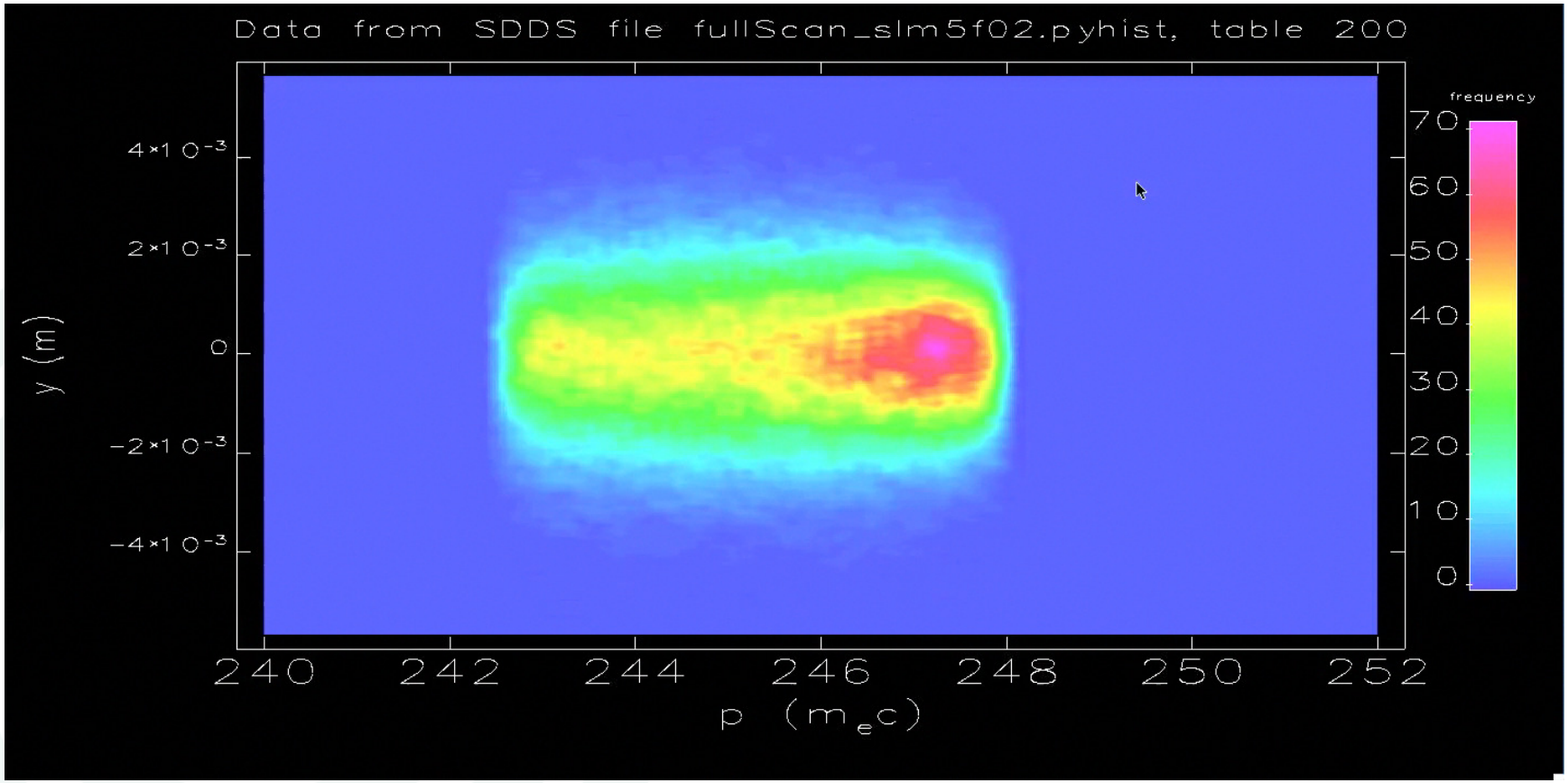
# CSR effects as Observed in second arc



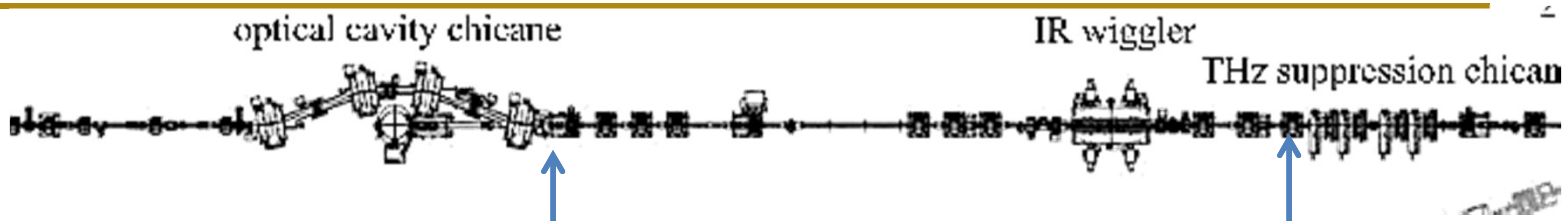


When bunch is compressed energy redistribution from CSR/LSC is observed. This redistribution is dependent on the degree of compression.

# Energy Distribution Simulation

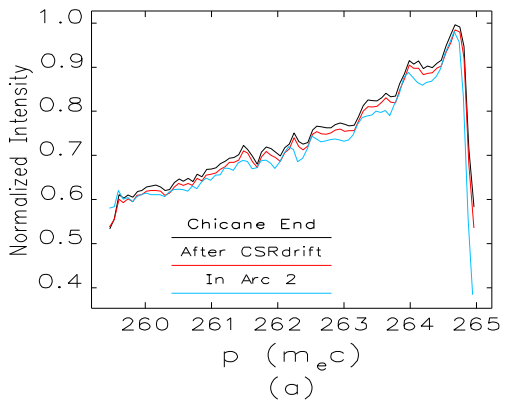


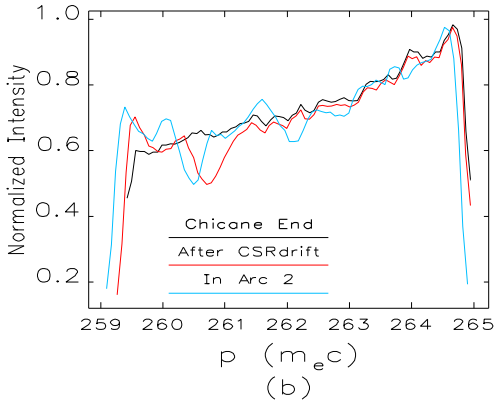
# Energy Distribution Simulations

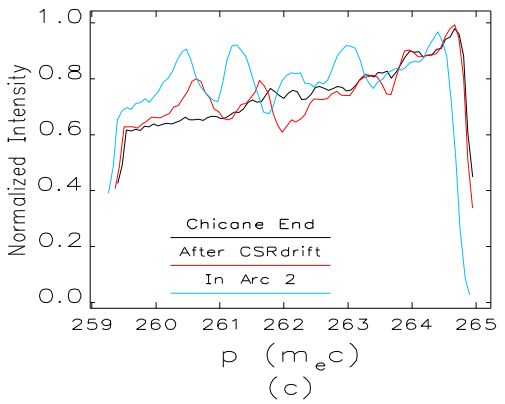


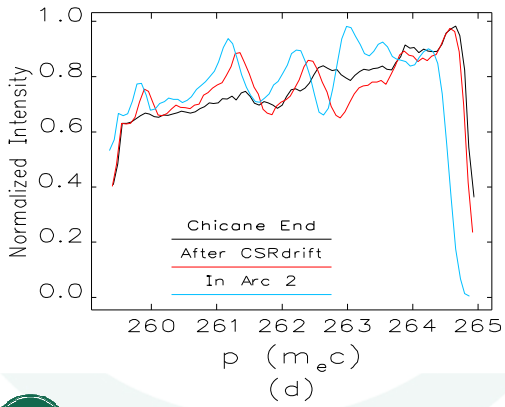

Chicane End

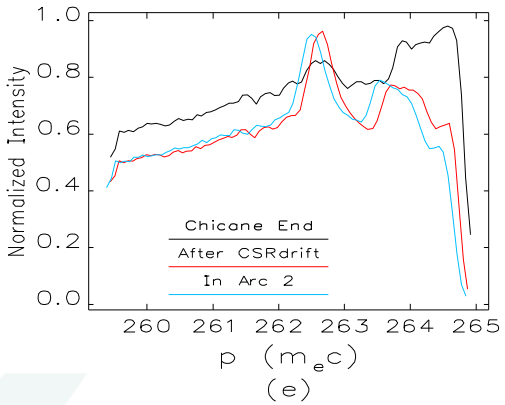
After CSRdrift

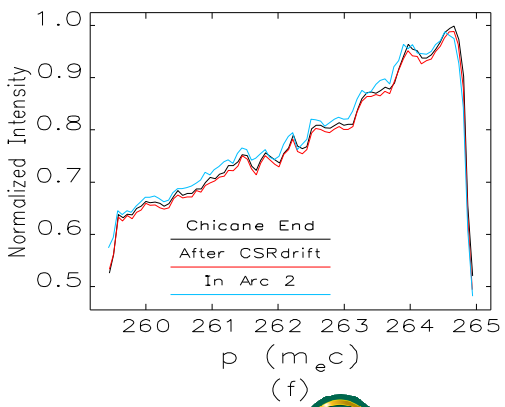


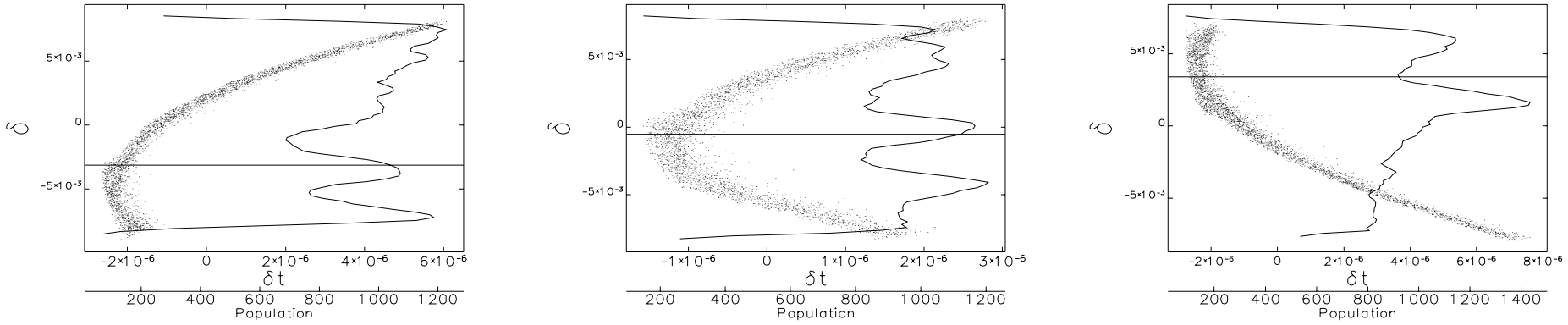



# LPS Picture

Can fit a parabola to the longitudinal phase space:

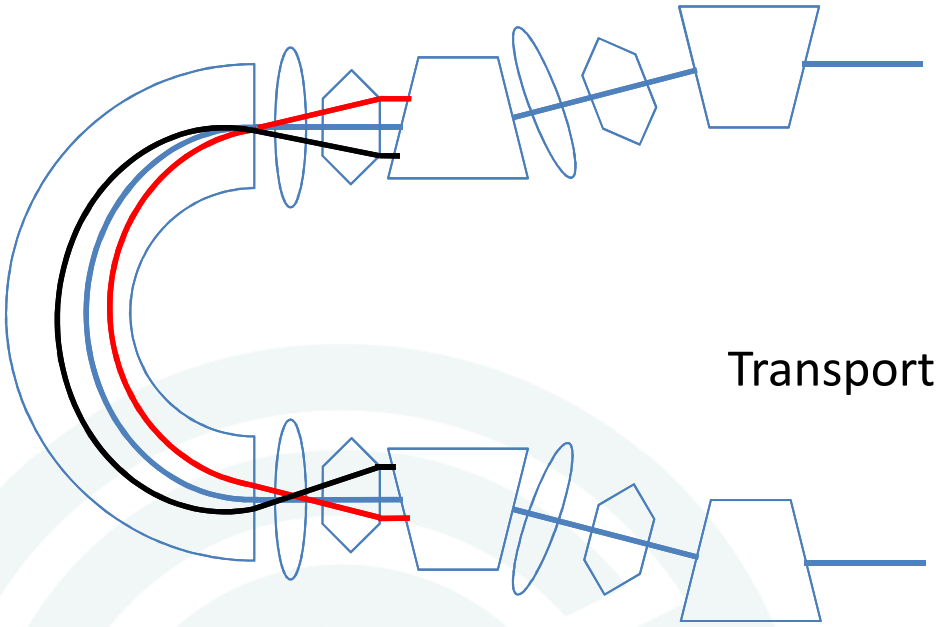
$$\delta(z;h) = -\frac{(\frac{1}{h} + R_{56})}{2T_{566}} \pm \frac{1}{2T_{566}}\sqrt{(\frac{1}{h} + R_{56})^2 + 4T_{566}z}$$

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.

# Compensating Non-Linear Compression



Dispersive Region

Curvature Induced by RF:

$$z_1 = z_0$$

$$\delta_1 = \delta_0 + R_{65} z_0 + T_{655} z_0^2$$

Transport through a longitudinally dispersive region:

$$z_2 = z_1 + R_{56}\delta_1 + T_{566}\delta_1^2$$

$$\delta_2 = \delta_1$$

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

Quadrupole Kick $\delta x' = Ax$

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

Can remove curvature by correctly setting $T_{566}$ in the first arc with the sextupoles:

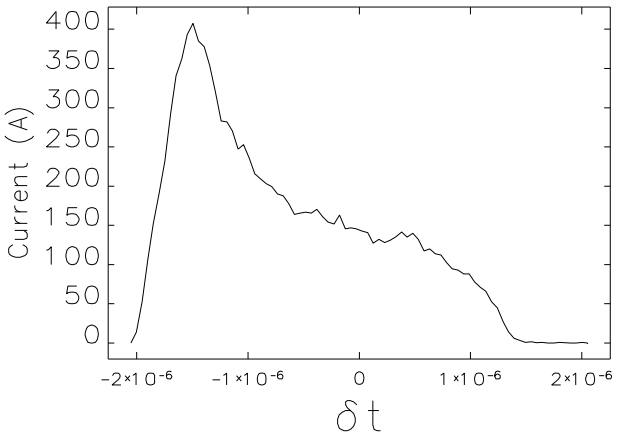
$$R_{56}T_{655} + T_{566}R_{65}^2 = 0$$

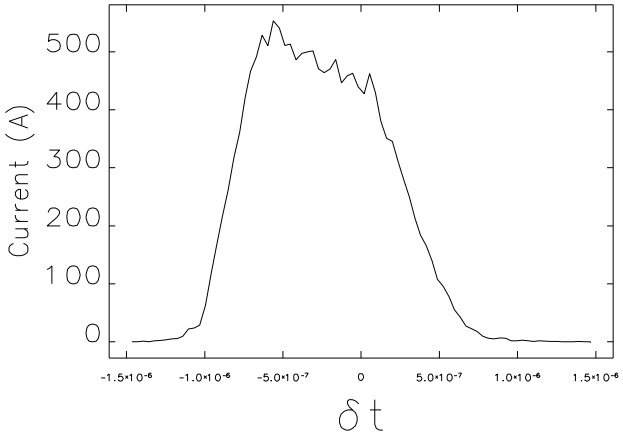
# Impact of Sextupoles

Sextupoles Off

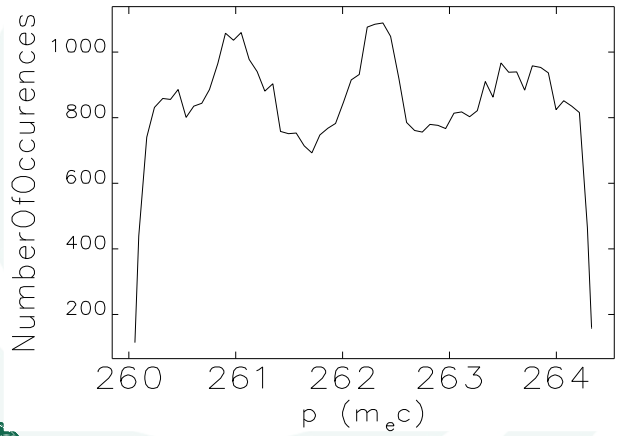
Sextupoles On

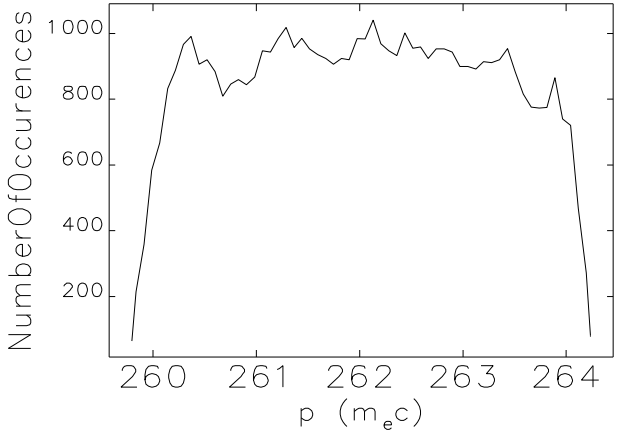
Charge Distribution




Energy Distribution



# Conclusions

- **Measurements show excellent 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?? Test sextupole impact maybe?**


# THANK YOU
# QUESTIONS?

# Backup: LPS Linearization