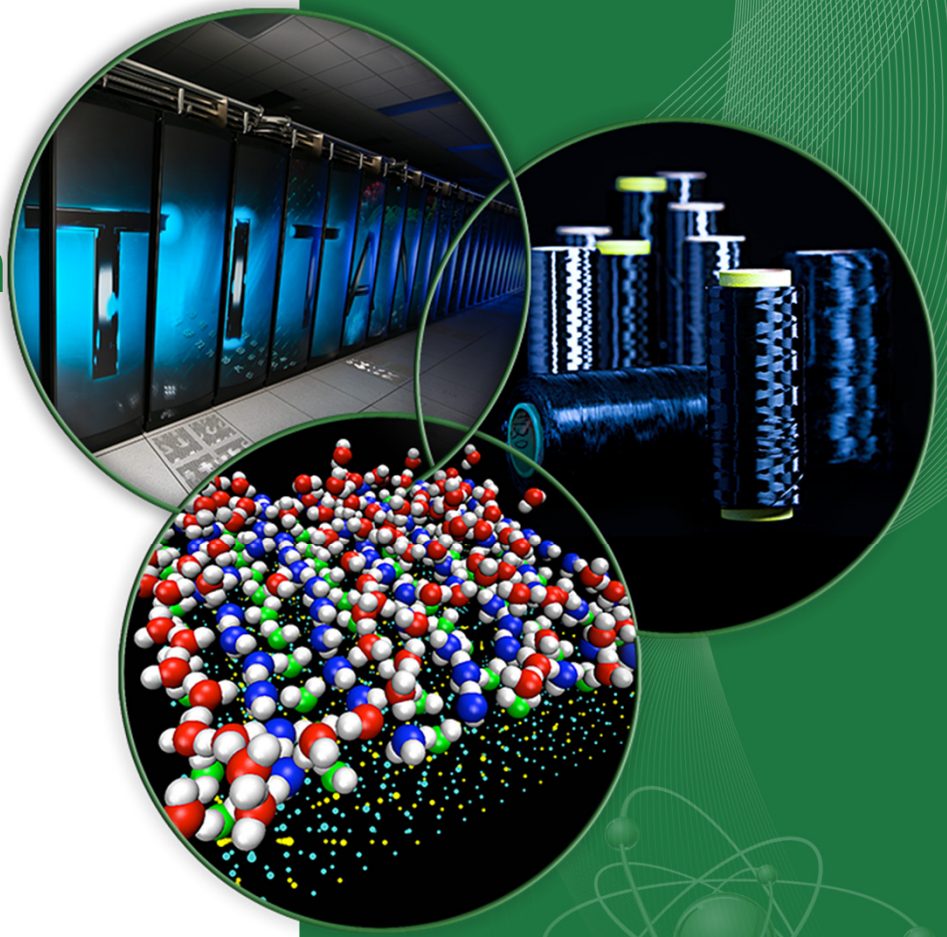
Observations of coupling during accumulation using a non-destructive Electron Scanner in the SNS



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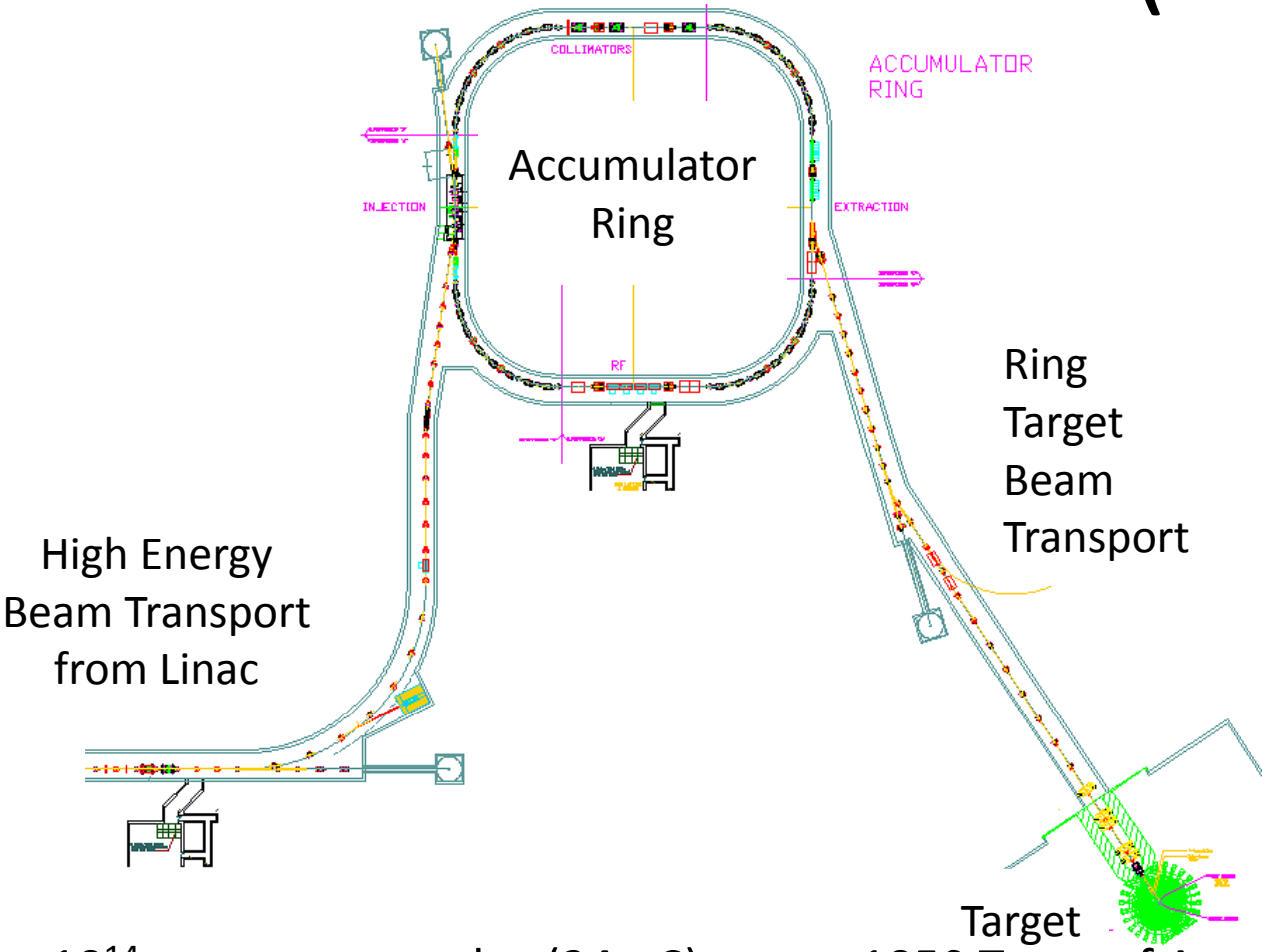
Outline

- Background
  - SNS Overview
  - Motivation
  - Electron Scanner
- Simple Accumulation Experiment
  - Effects of Tune
  - Effects of Intensity
- SNS Production-Style Experiment
  - Effects of Tune
  - Effects of Skew-Quads

Spallation Neutron Source (SNS)



Intensity: 1.5 x 10^{14} protons per pulse (24 μC)

Independent Transverse Injection Kickers

Nominal Tune: (6.2, 6.23)

Emittance (Phase Space Area): Up to 240 π mm mrad

1050 Turns of Accumulation

Energy: 1 GeV

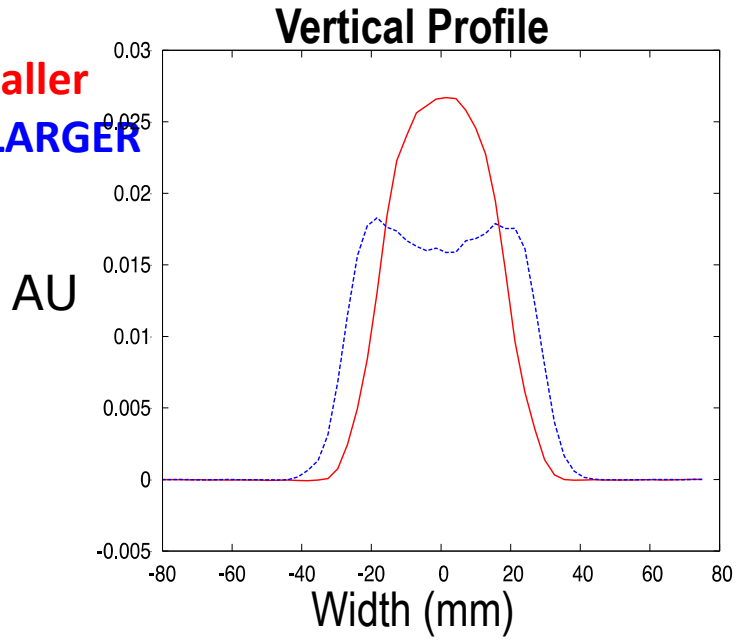
Typical Space Tune Shift: ≈0.15

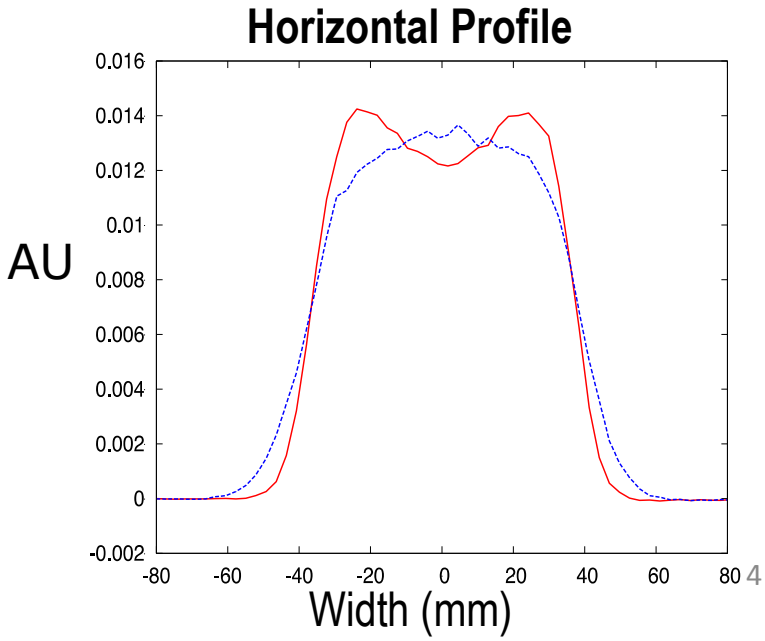
Coupling at SNS

- SNS target requires independent control of transverse profiles – peak density & size – Shape Matters!
- For certain configurations, a lack of independent control has been observed
  - Change in one painting shows up as change in the alternate plane
  - Occurs at small tune split

Change in vertical profile produces unexpected change in horizontal profile

vertical smaller
VERTICAL LARGER



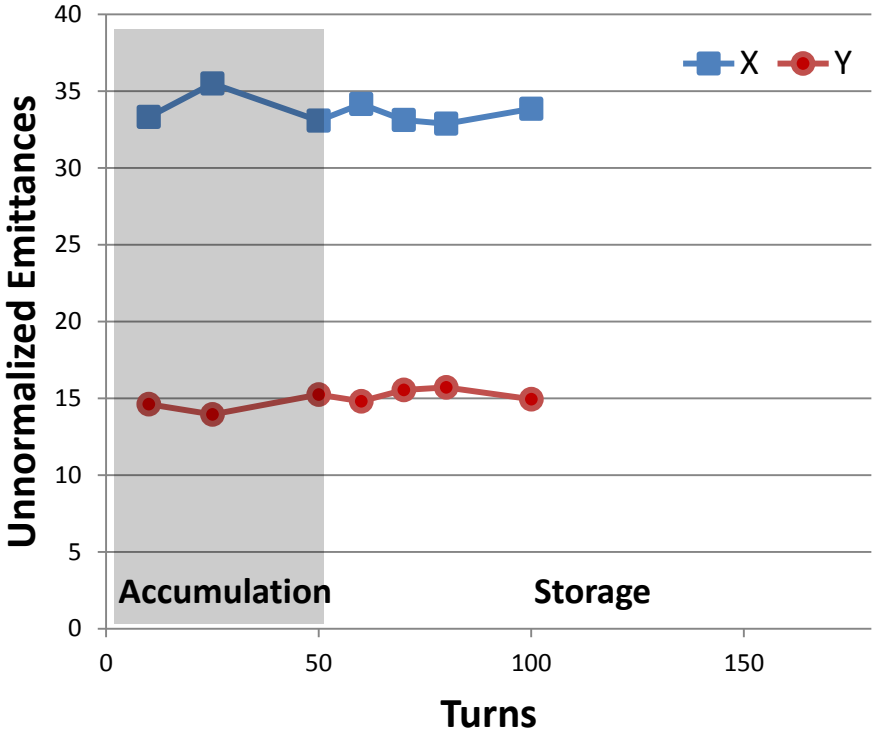


Exploration with Wire Scanners

- WS measurements in RTBT show emittance exchange

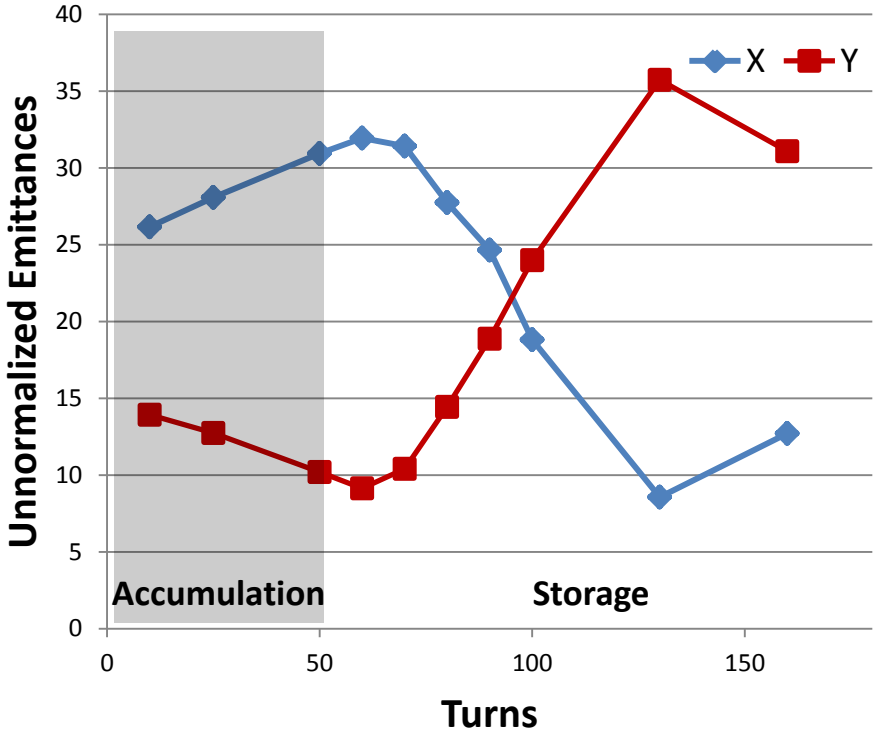
Unequal Tune Beam (ΔQ = 0.03)

Q = (6.170, 6.199)



Equal Tune Beam (ΔQ = 0)

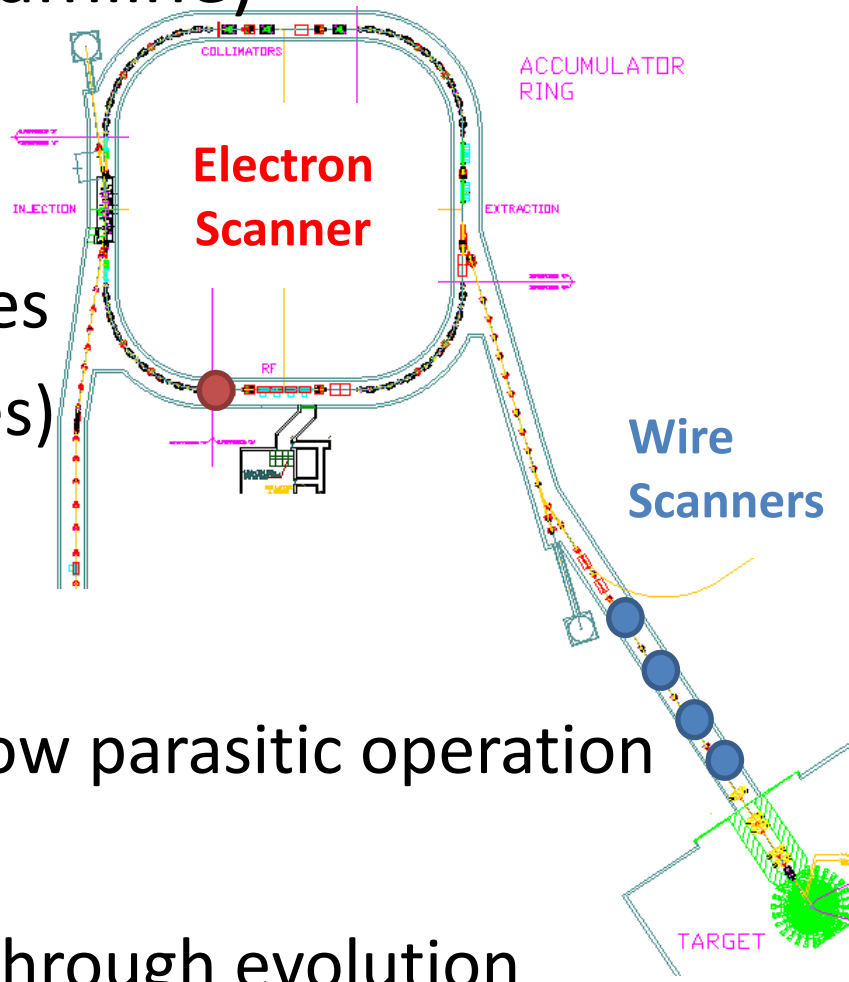
Q = (6.200, 6.199)



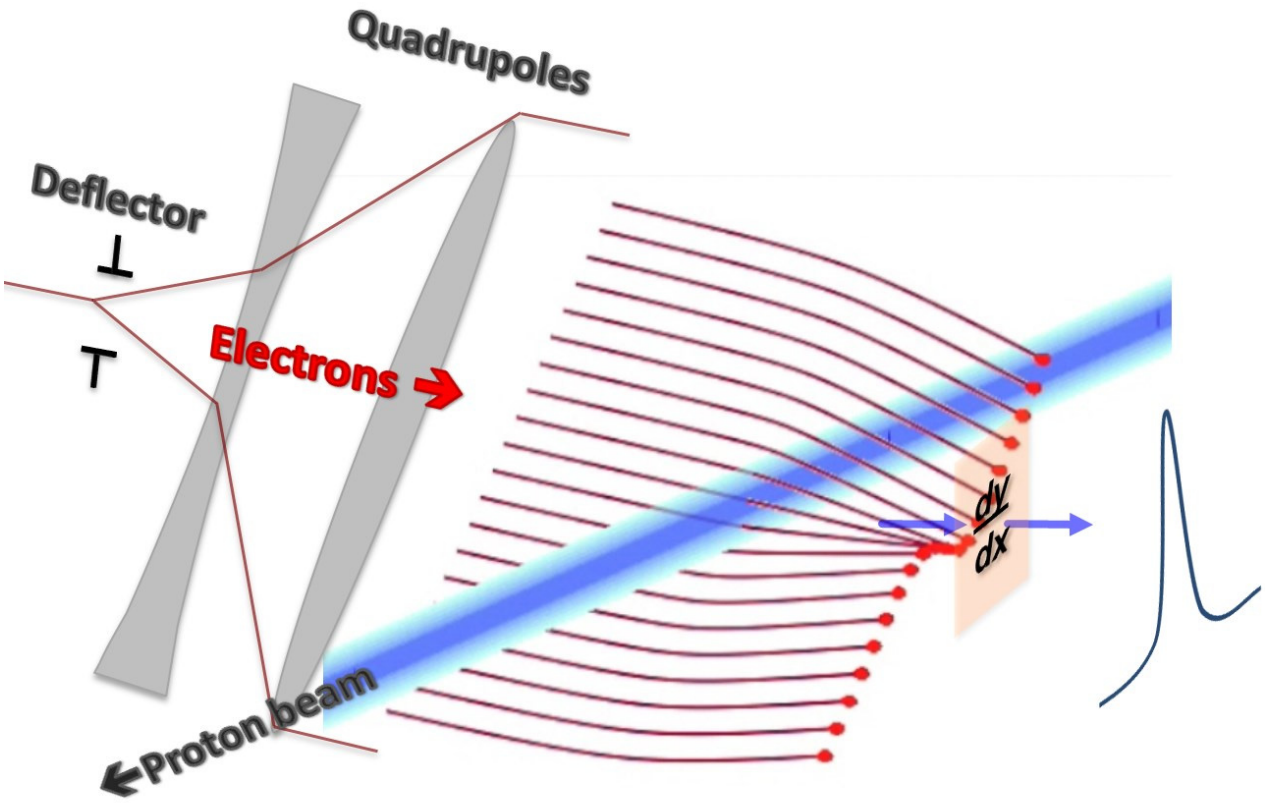
- Data collection for these two beam configurations took +68 minutes of shift time.
- **Time Consuming!** Needed alternative method of probing the effect.

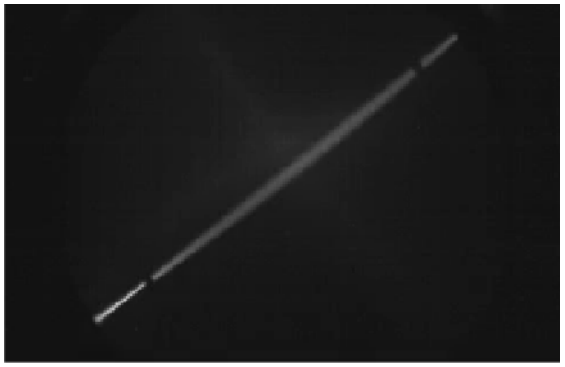
Comparison of Wire Scanner and Electron Scanner

- WS (Located along final beamline)
  - + Detailed profiles (H, V, D)
  - + Emittance station
  - – Summed longitudinal profiles
  - – Time consuming (4+ minutes)
- ES (Located in the ring)
  - + Fast profiles (H, V) (@ 1 Hz)
  - + Non-destructive profiles allow parasitic operation
  - + 20ns long resolution
  - + Customizable scan pattern through evolution
  - ★**First Major Physics Study**



Electron Scanner Methodology





Multiple scans through one bunch

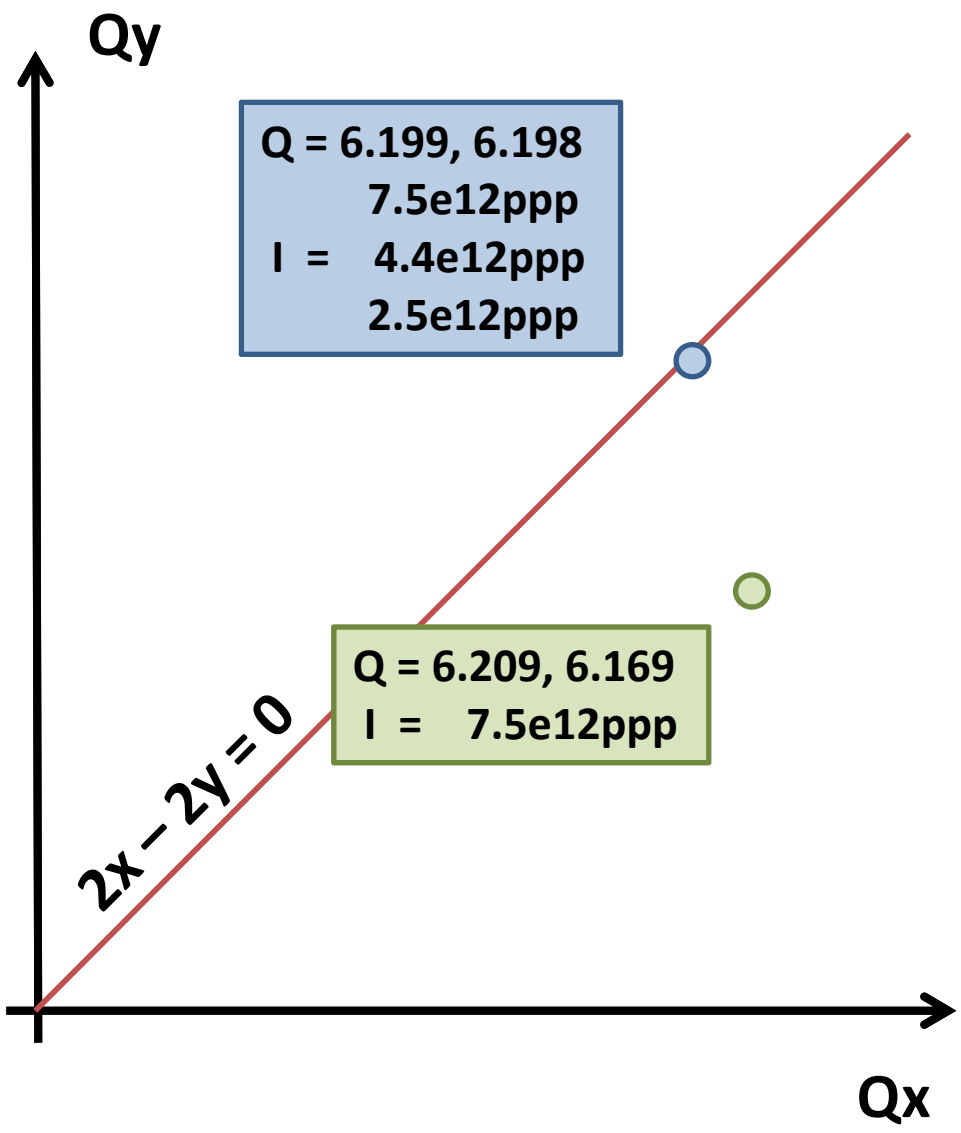
$$\frac{d\theta_0(x)}{dx} = \int_L \frac{e}{mv^2} \frac{\delta(x,y)}{\varepsilon_0} dy$$

θ - Electron Deflection

δ - Proton Density Function

- Examine the projection of a tilted sheet of electrons
- To get the profile, we take the derivative with respect to position of the deflected beam minus the undeflected beam

Simplified Accumulation Experimental Settings



Motivation

Set up a simple experiment to explore coupling versus ΔQ & I

- No injection painting
- No ring RF
- Zero chromaticity to isolate space charge tune shift
- 100 turns of accumulation; 300 turns of storage

I = 7.5e12ppp
(1.2 μC)

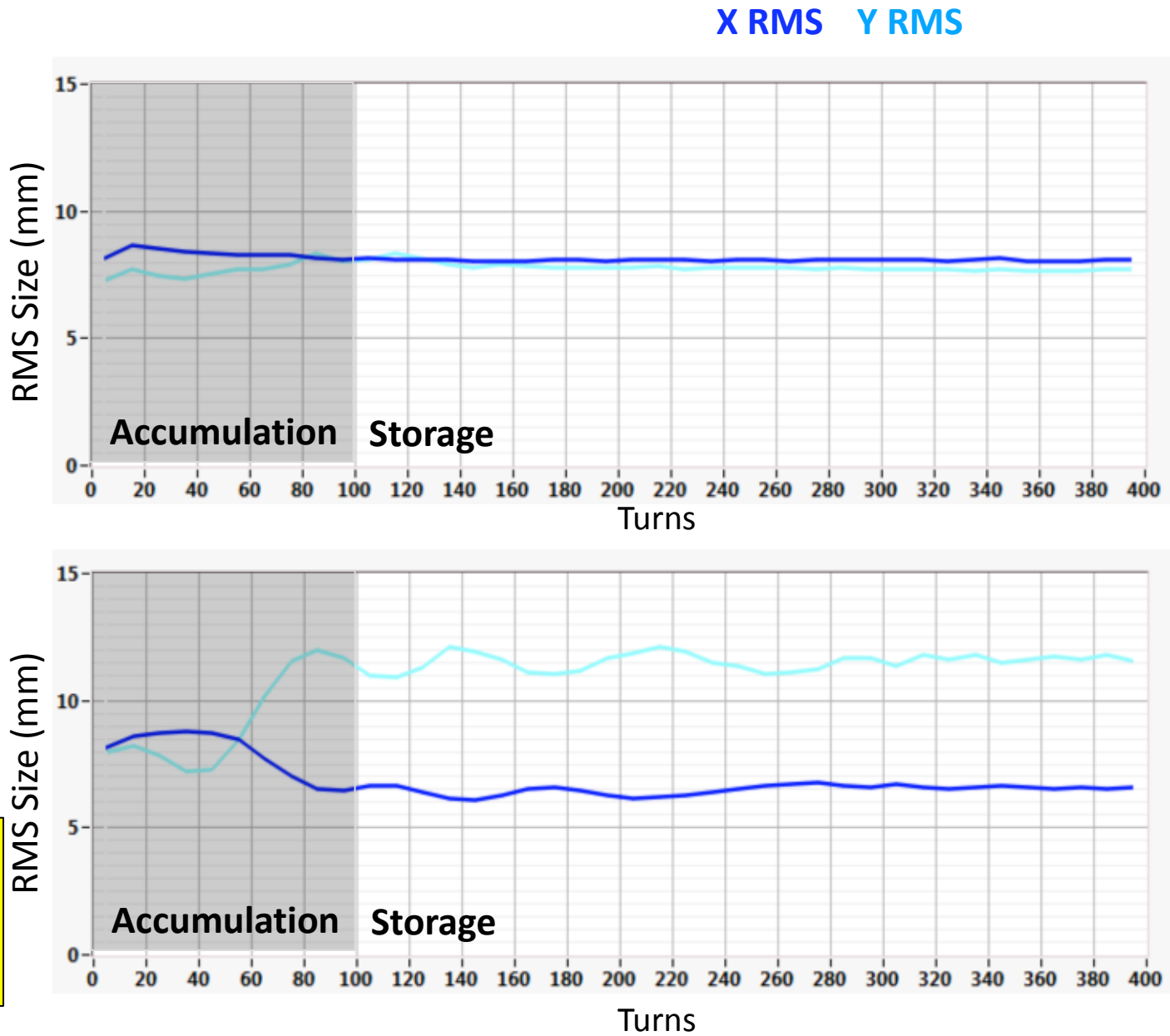
Effect of Tune

Split Tune
Q = 6.209, 6.169
(ΔQ = 0.04)

All other beam parameters remain unchanged

Equal Tune
Q = 6.199, 6.198
(ΔQ = 0.001)

Evolution is as expected for a beam with large tune split but coupled for a beam with equal tunes



I = 7.5e12ppp
(1.2 μC)

Effect of Tune

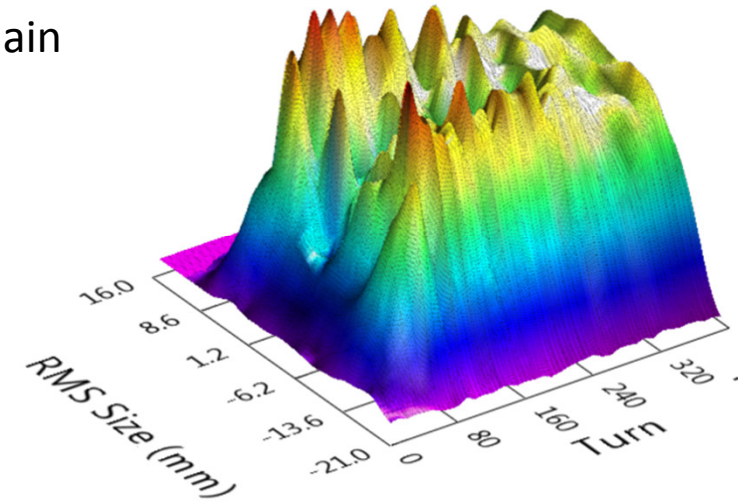
All other beam parameters remain unchanged

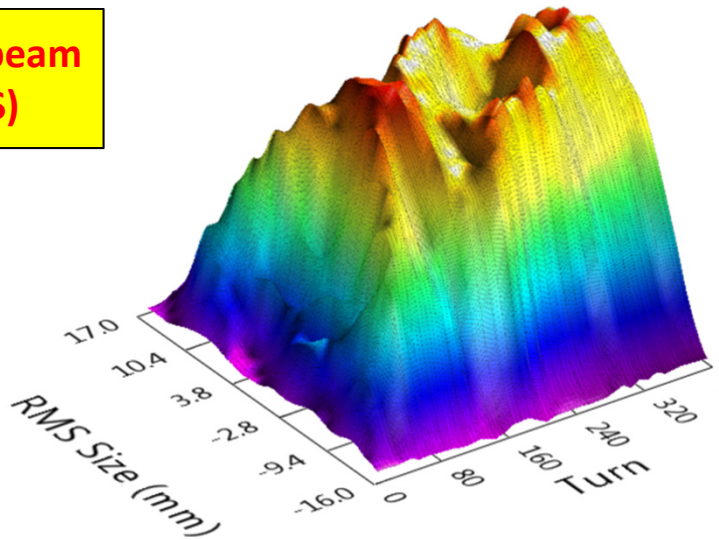
Split Tune
Q = 6.209, 6.169
(ΔQ = 0.04)

Coupled oscillation of beam shape (not just RMS)

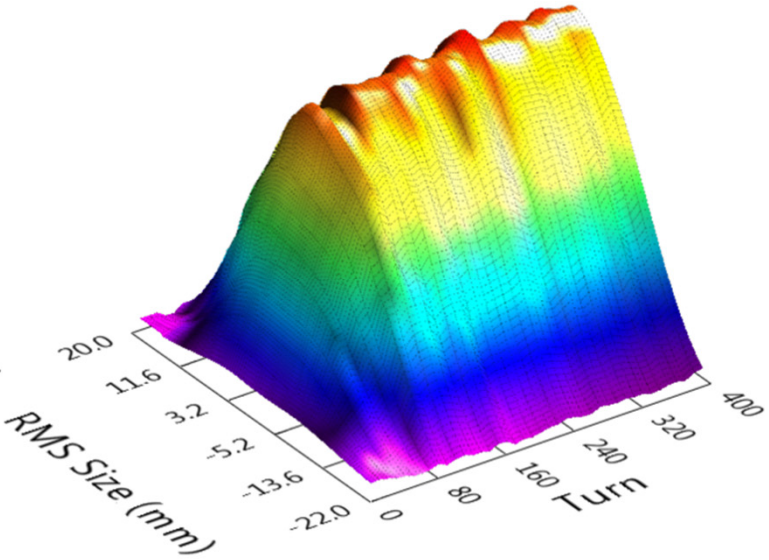
Equal Tune
Q = 6.199, 6.198
(ΔQ = 0.001)

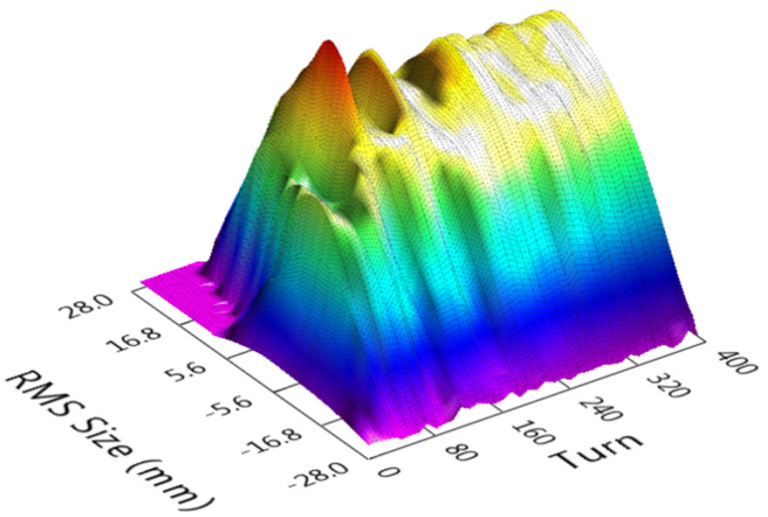
Horizontal





Vertical



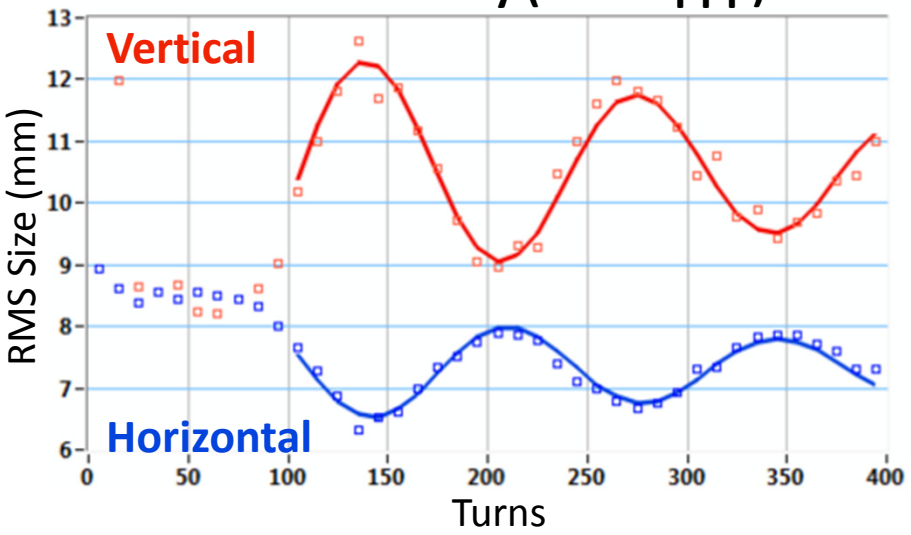


Effect of Intensity

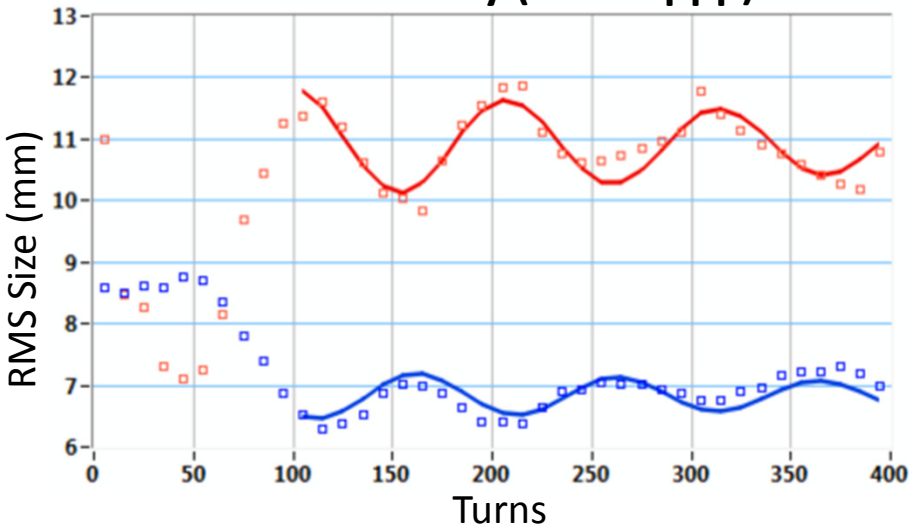
Fitting Function
A Exp(-K*x) Sin(B*x + C) + D
Fit Only During Storage

Equal Tune
Q = 6.199, 6.198
(ΔQ = 0.001)

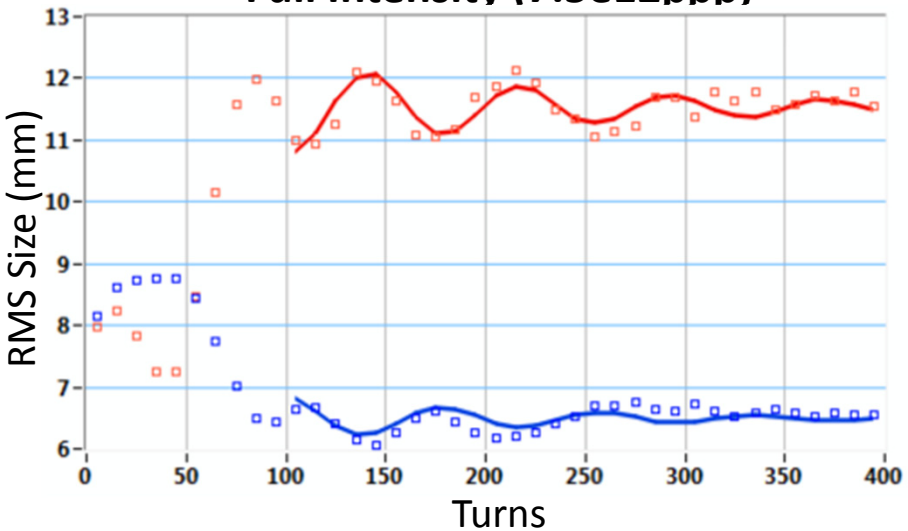
Low Intensity (2.5e12ppp)



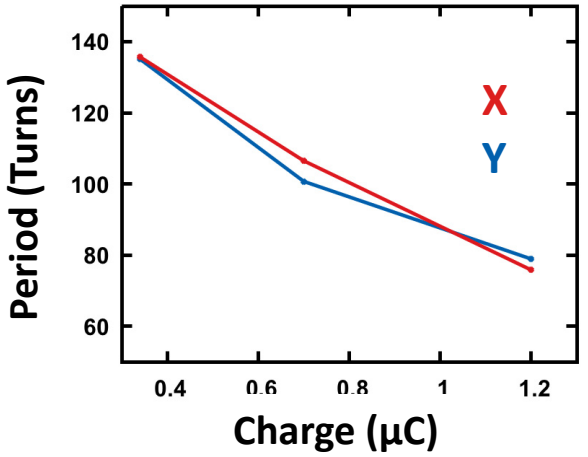
Mid Intensity (4.4e12ppp)



Full Intensity (7.5e12ppp)



Oscillation Period



Increasing beam intensity dampens oscillations

Equal Tune
Q = 6.199, 6.198
(ΔQ = 0.001)

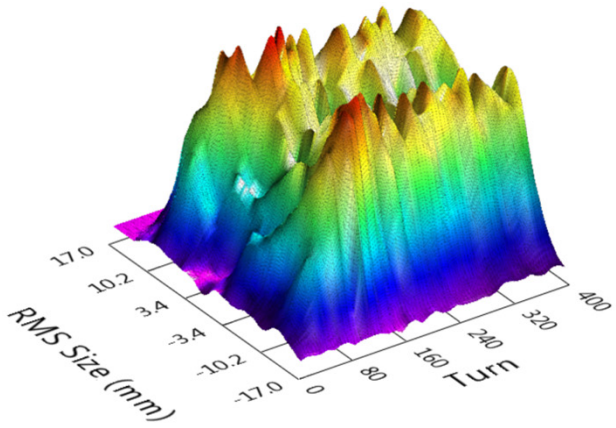
Effect of Intensity

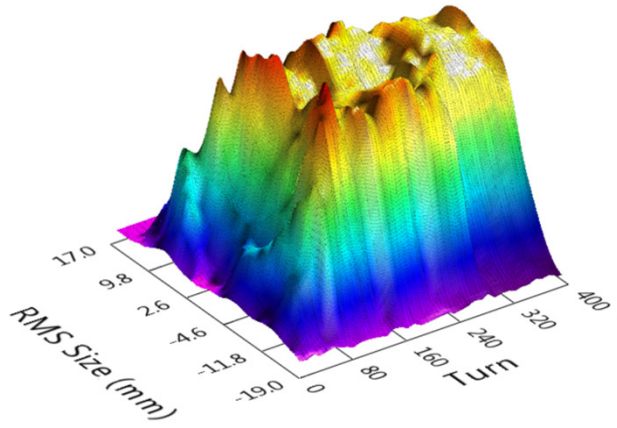
Low Intensity
(2.5e12ppp)

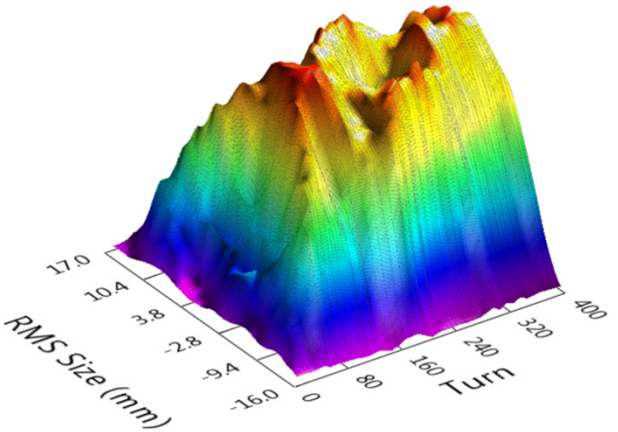
Mid Intensity
(4.4e12ppp)

Full Intensity
(7.5e12ppp)

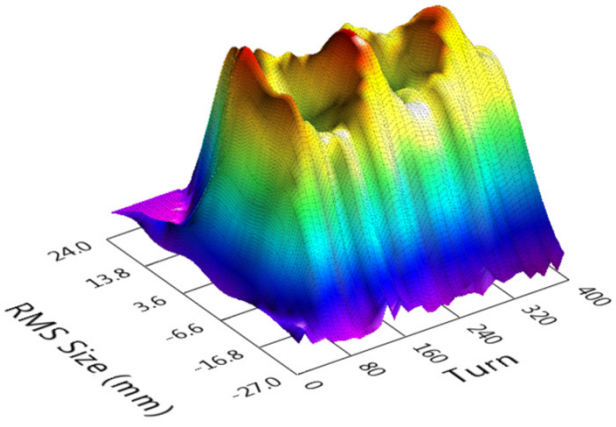
Horizontal

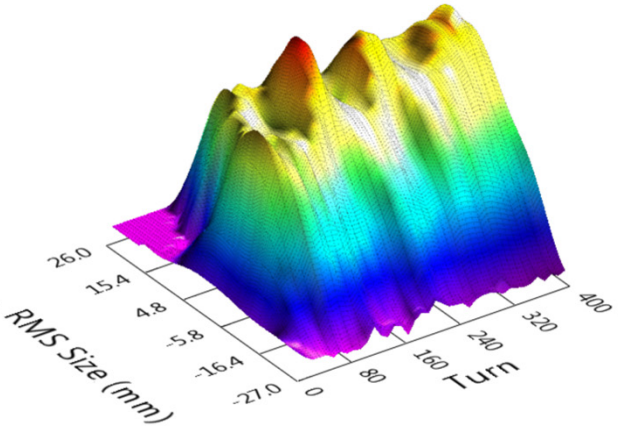


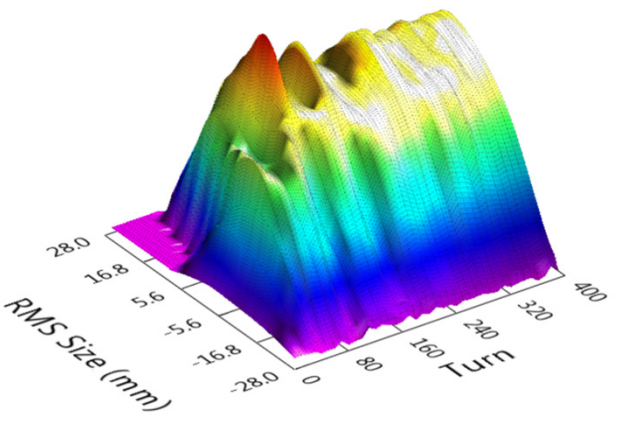




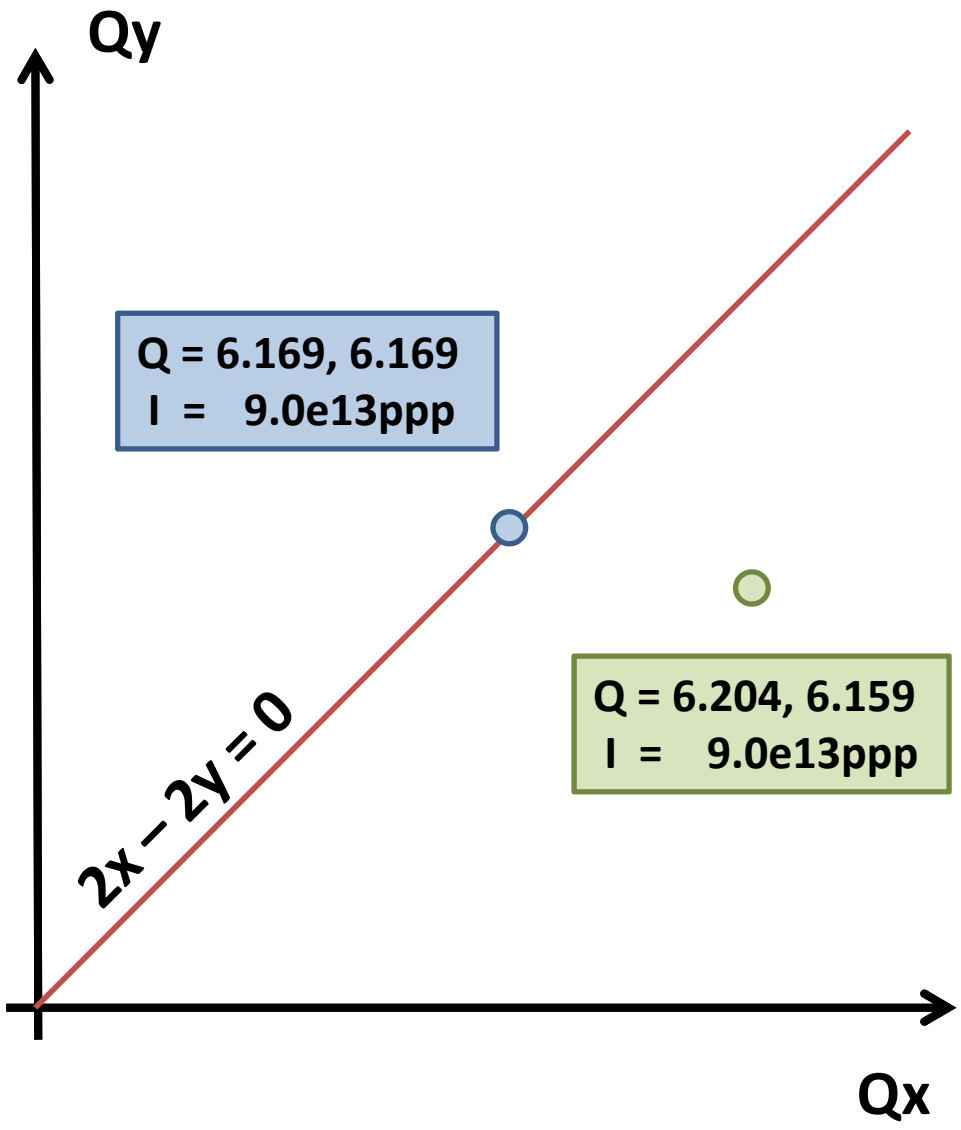
Vertical







SNS Production-Style Beam Study



Motivation

How does our production configuration look for ΔQ = 0 compared to ΔQ = 0.04

- Nominal dual-plane injection painting
- Dual harmonic ring RF
- Natural chromaticity
- Accumulation only (no storage)

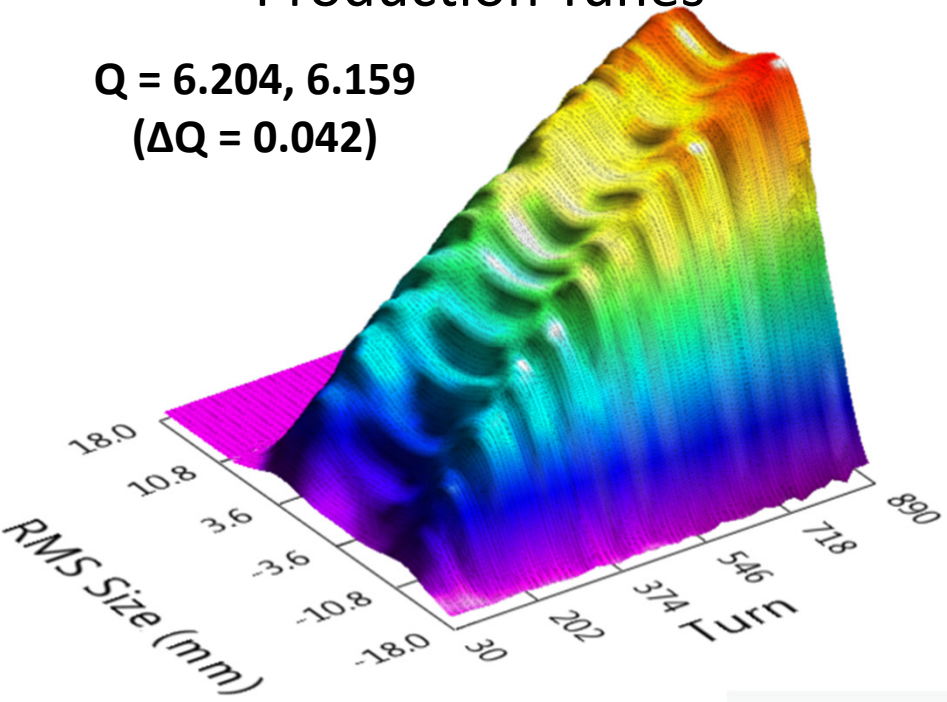
Effects of Tune

I = 9.0e13ppp
(14.4 μC)

Horizontal Profiles Shown

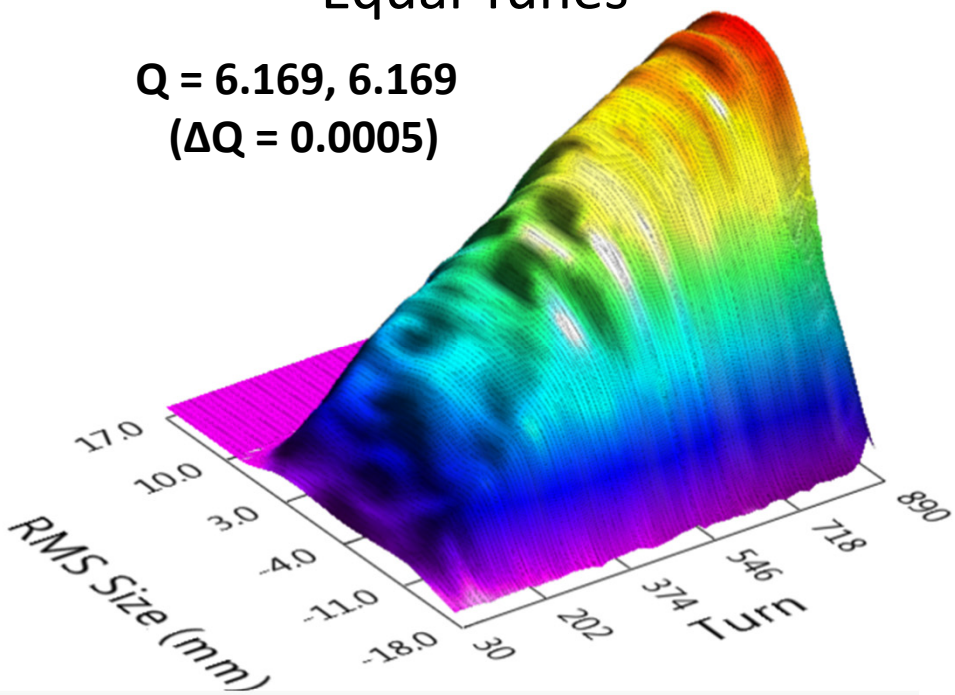
Production Tunes

Q = 6.204, 6.159
(ΔQ = 0.042)

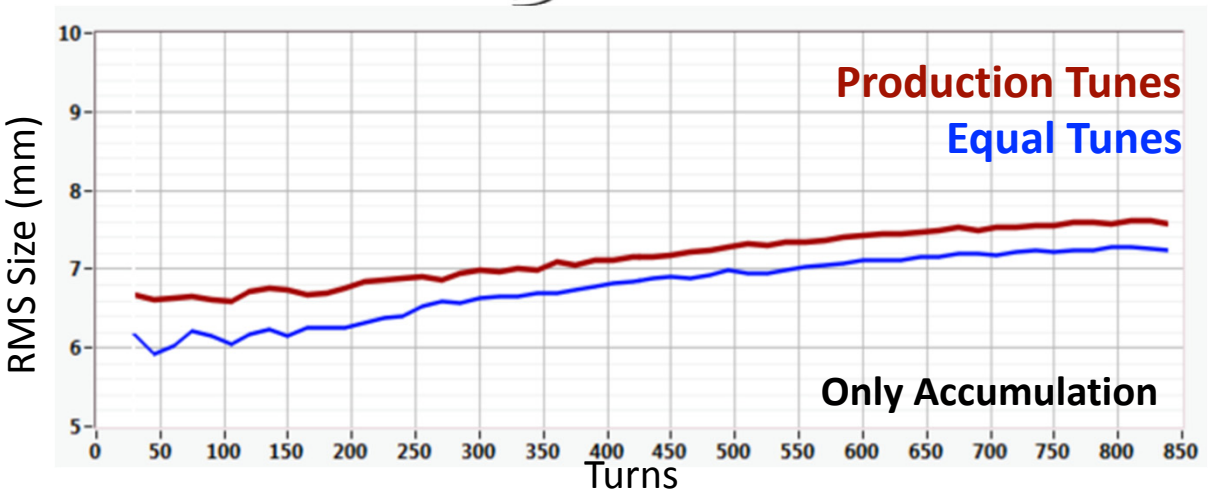


Equal Tunes

Q = 6.169, 6.169
(ΔQ = 0.0005)



- Although coupling is not visible as oscillations, the equal tune beam dilutes much faster



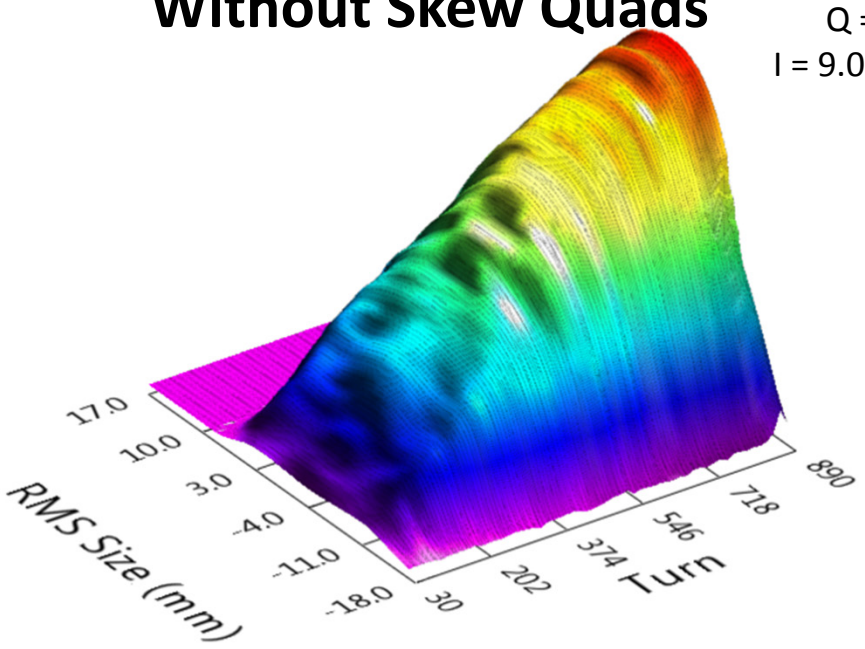
Effects of Skew-Quadrupoles

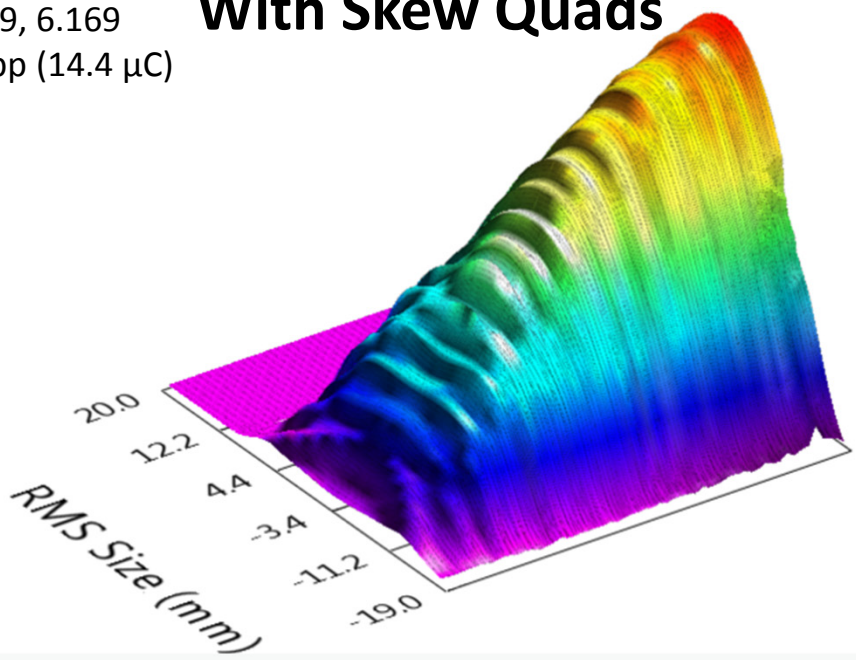
- **Skew-quads are normally used to correct linear coupling**

Without Skew Quads

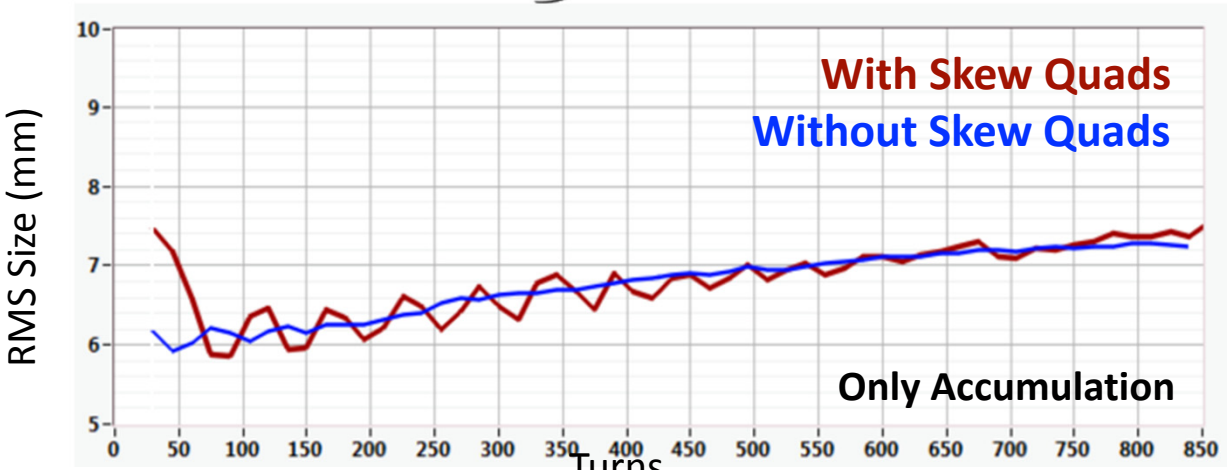
Horizontal Profiles Shown
Q = 6.169, 6.169
I = 9.0e13ppp (14.4 µC)

With Skew Quads





- Using our skew quadrupoles, we can agitate the coupling and produce an oscillation visible through most of the evolution



Conclusions

- Demonstrated
  - Equal tunes produces coupling in beam shape
    - Not just coupling of RMS sizes
  - Increased beam intensity dampens oscillations
    - It does not amplify it as we expected
  - Skew-Quads have been used to amplify the coupling
    - Expected the effect to be to reduce the coupling

Originally, we thought this was a Montague Resonance however these results imply an alternative source

Thank you!