Recent Results on Beam-beam Effects in Space Charge Dominated Colliding Ion Beams at RHIC

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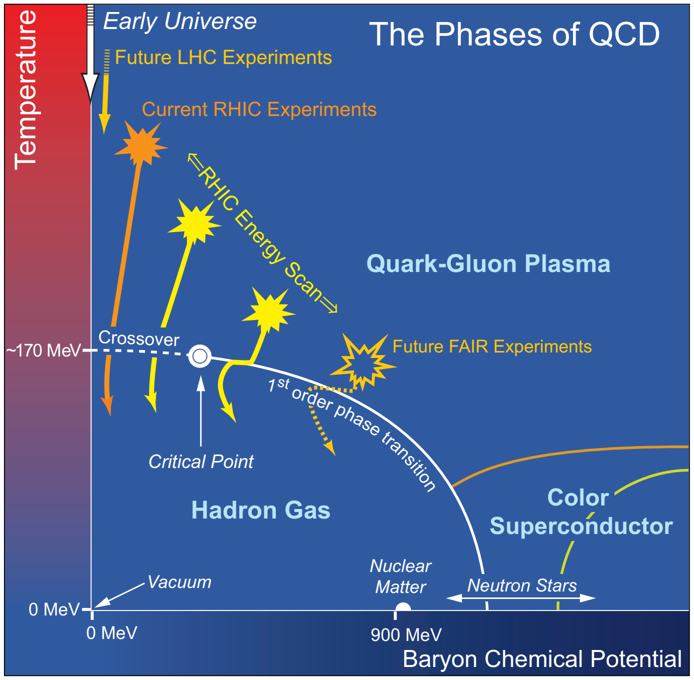
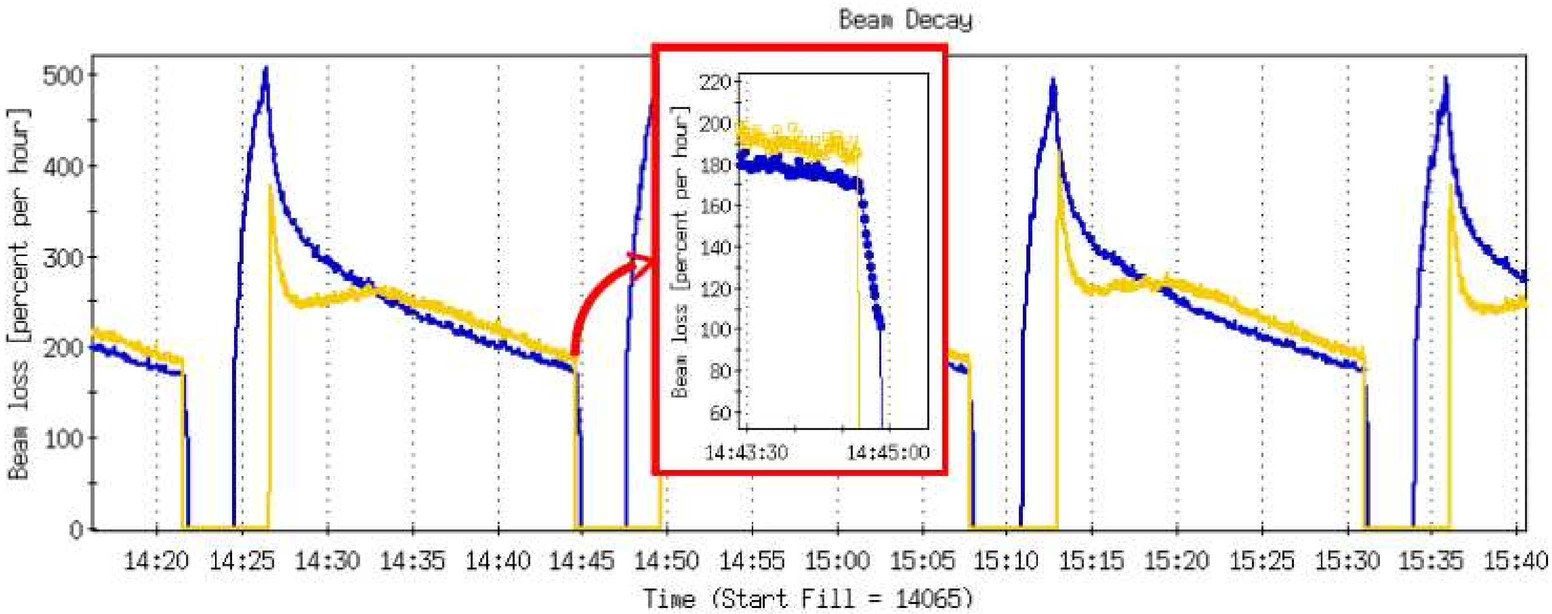
RHIC as a low energy collider



Search for the critical point in the QCD phase diagram requires colliding Au beams with energies between 2.5 and 10 GeV/nucleon

Beam decay rates during RHIC low energy run in 2010



With tunes set to $(Q_x, Q_y) = (.13, .12)$, Blue beam decay recovers immediately as soon as Yellow beam is dumped

Strong beam-beam effect, though space charge tune shift is much larger ($\Delta Q_{\text{sc}} \approx -0.05$, $\xi_{\text{bb}} \approx -0.003$)

The tracking "toy" model

- 11 FODO cells - 10 are identical, quad strengths in 11th cell are scaled up by 3 percent to break the periodicity

- Dipoles are modeled as drifts for simplicity; thin-lens approximation for quads

- No nonlinear elements such as sextupoles

- Space charge kicks are applied at equidistant locations; based on self-consistent RMS beam size at each location

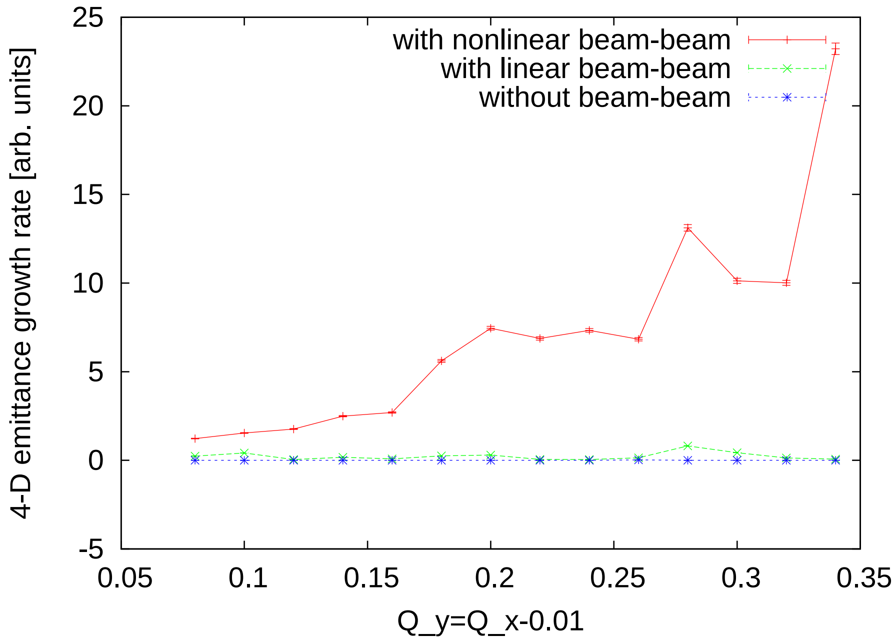
- One beam-beam kick per revolution; strong beam has self-consistent size as well

- All tracking done on-energy, no longitudinal motion

- With beam-beam: $\Delta Q_{\text{spacecharge}} = -0.05, \xi_{\text{beam}-\text{beam}} = -0.003$

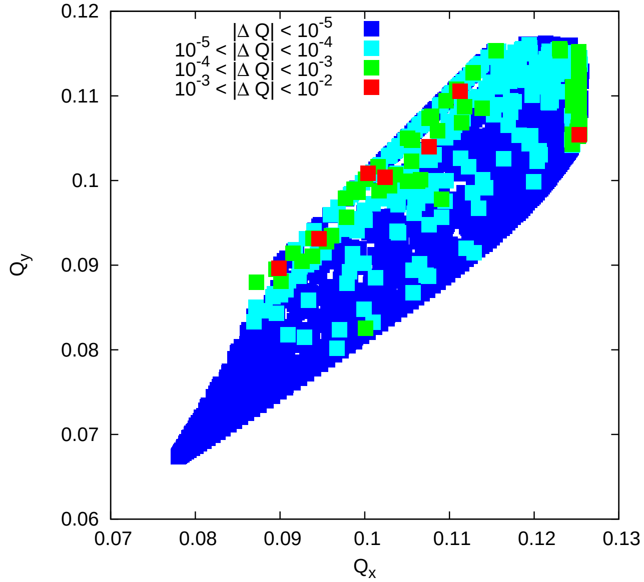
- Without beam-beam: $\Delta Q_{\text{spacecharge}} = -0.053$, keeping total tune shift constant for both cases

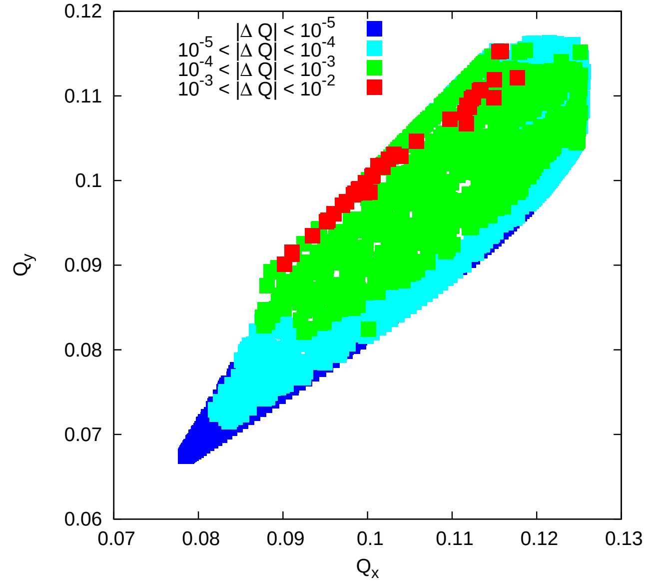
4-D emittance growth rates in the “toy” model



- Growth rates with beam-beam increase the further the tunes are from the integer
- Linear beam-beam lens shows no growth - effect is not just due to broken periodicity
- No growth without beam-beam

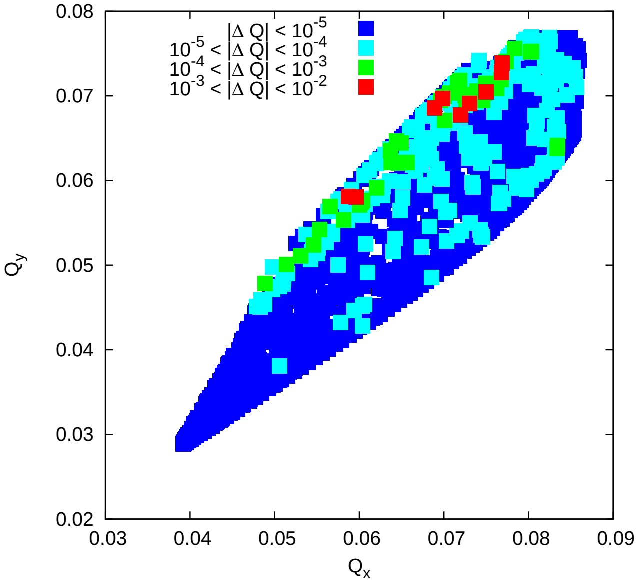
Tune footprints at 2010 working point (.13,.12)

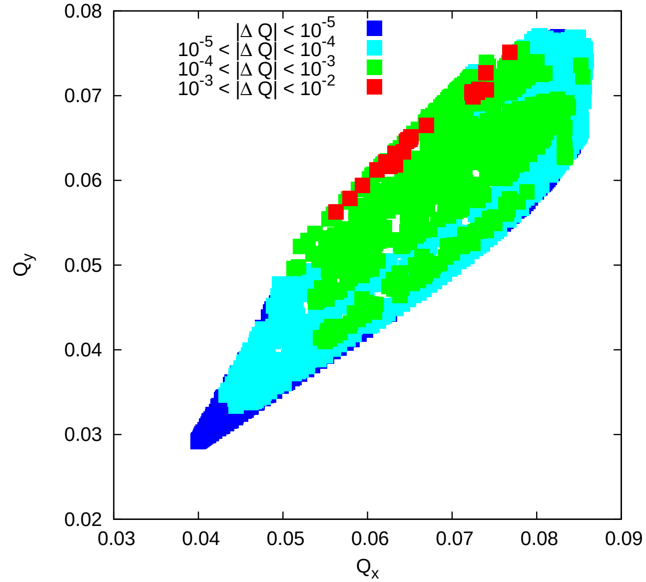




- Beam-beam interaction enhances tune diffusion almost everywhere
- No distinct resonances appear besides linear coupling resonance $Q_x = Q_y$

Tune footprints at near integer working point (.09,.08)



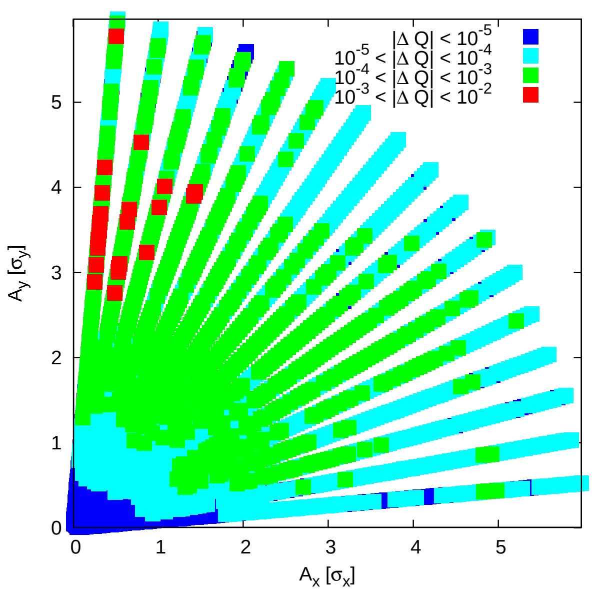


- Beam-beam interaction enhances tune diffusion almost everywhere
- No distinct resonances appear besides linear coupling resonance $Q_x = Q_y$

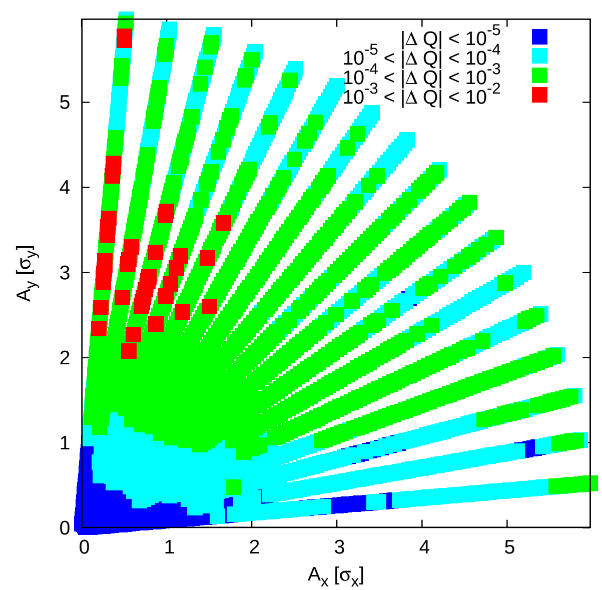
Very similar to 2010 working point

Tune diffusion in amplitude space

(.09, .08) :



(.13, .12) :



- Tune diffusion at near integer working point appears larger than at 2010 working point
- Disagreement with emittance growth results

MADX-SC tracking in the RHIC lattice

beam energy [GeV]	5.86
bunch intensity	$4 \cdot 10^{10}$
transverse rms emittance [mm mrad]	0.16
β^* [m]	10
σ_{IP} [mm]	1.3
RMS bunch length [m]	3.0
space charge tune shift	-0.065
beam-beam tuneshift per IP	-0.005

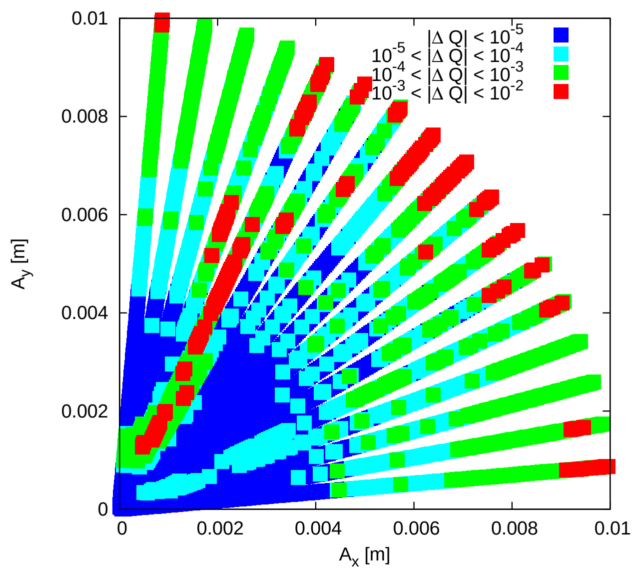
Off-momentum dynamic aperture in collision:

5.5σ at $(28.095, 30.085)$, 4.5σ at $(28.013, 30.012)$

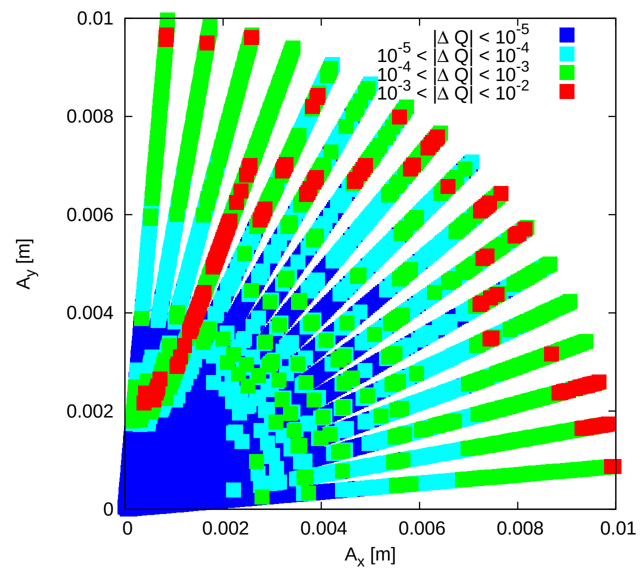
Larger dynamic aperture at near-integer working point

Tune diffusion in the RHIC lattice

$(.095, .085)$:



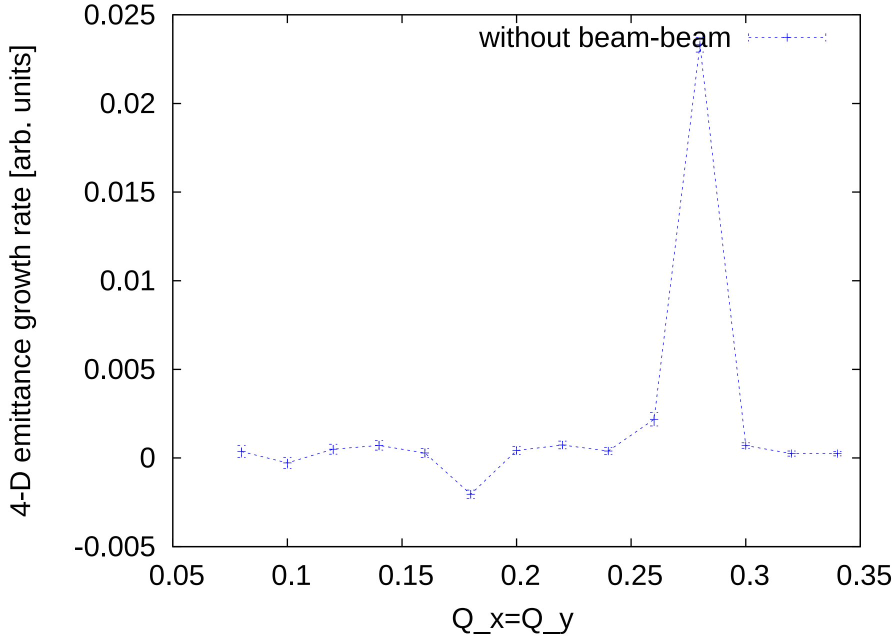
$(.13, .12)$:



- Tune diffusion at near integer working point larger than at 2010 working point - contradicts dynamic aperture results
- Dominated by linear coupling resonance ($Q_x = Q_y$)

Is frequency map analysis the right tool?

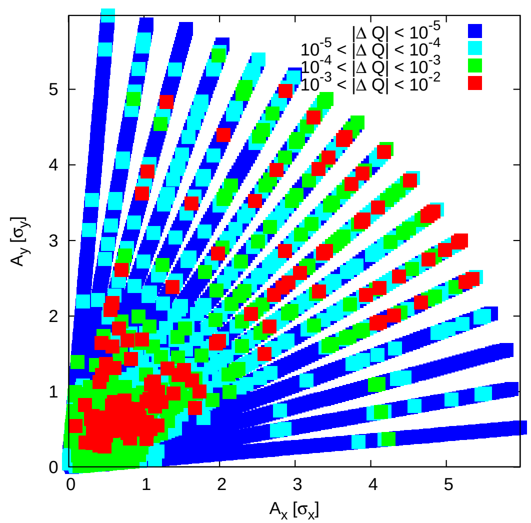
Emittance growth on the coupling resonance ($Q_x = Q_y$)



Within error bars, no emittance growth without beam-beam

Tune diffusion on the coupling resonance

$(Q_x, Q_y) = (.08, .08)$:



Large tune diffusion due to coupling resonance even at very small amplitudes

Tune diffusion does not indicate amplitude diffusion

Amplitude diffusion in "Toy Model"

- For each action (J_x, J_y), launch 100 particles in phase space

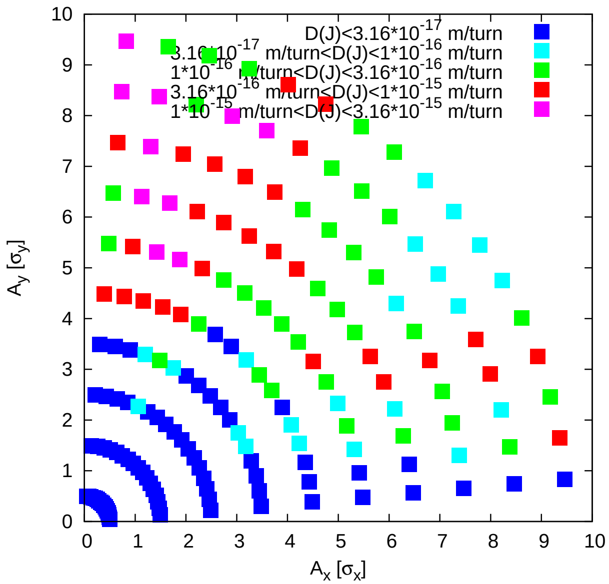
- Track for 10000 turns

- At each turn, calculate RMS action spread $J^2_{\mathrm{RMS}} = \langle (J_x - \langle J_x \rangle)^2 + (J_y - \langle J_y \rangle)^2 \rangle$, with the average taken over the 100 particles

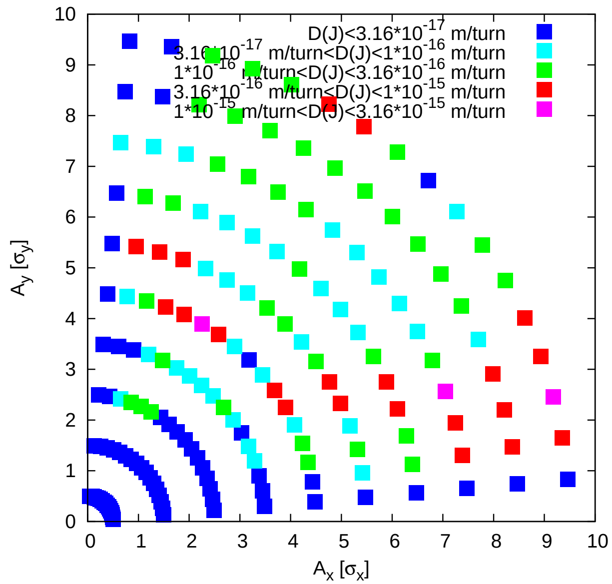
- Fit a straight line J_{RMS} vs. turn number; slope equals diffusion coefficient $D(J)$

Amplitude diffusion results

(.09, .08) :



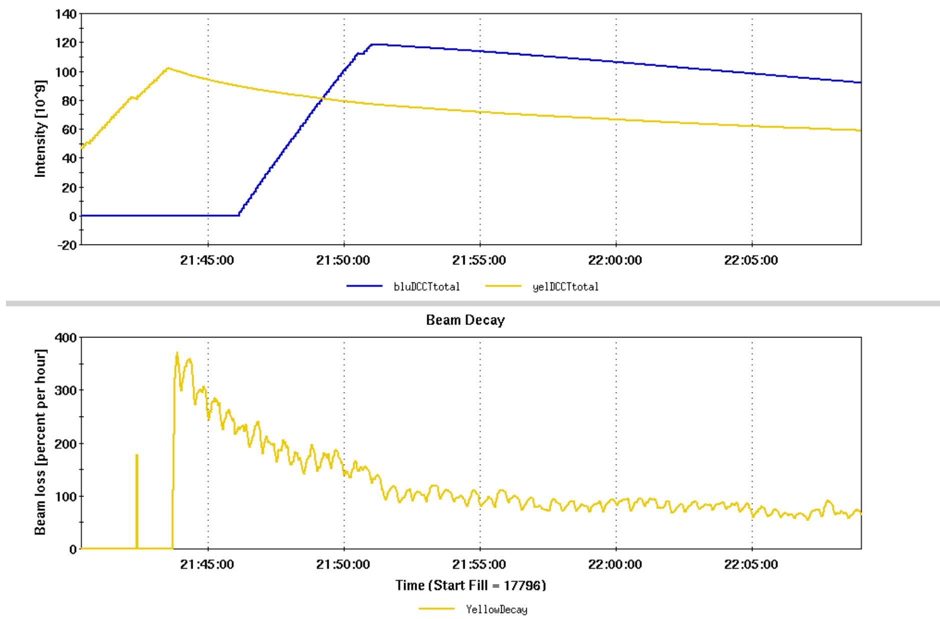
(.13, .12) :



- 2010 working point shows larger amplitude diffusion at amplitudes up to 4σ than near-integer working point
- Consistent with emittance growth results

Yellow beam decay during Blue beam injection

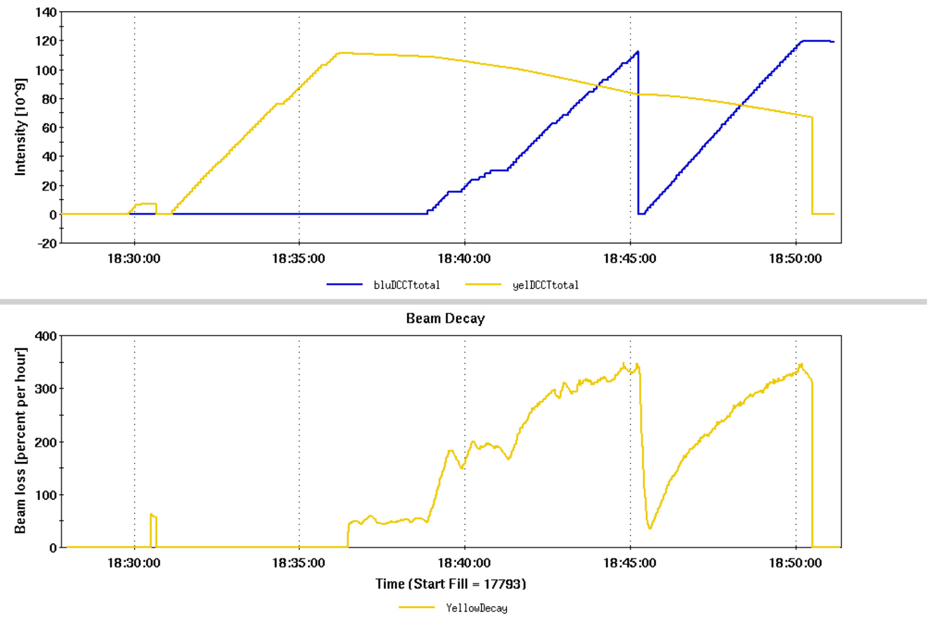
Near-integer working point (.095, .085) :



- Yellow beam decay continues to improve during Blue injection
- No significant beam-beam effect

Yellow beam decay during Blue beam injection

2010 working point (.13, .12) :



• Yellow beam decay rises sharply during Blue beam injection

• Strong beam-beam effect

Conclusion

- Tracking with the simple model reproduces observed beam-beam effect qualitatively well

- Near-integer tunes are preferred

- Frequency map analysis shows tune diffusion even when there is no emittance growth

- Amplitude diffusion simulations show tune dependence in agreement with emittance growth data

- Significant improvement in RHIC performance with near-integer tunes during FY2014

Thanks to:

F. Schmidt, V. Kapin, M. Blaskiewicz, and many others