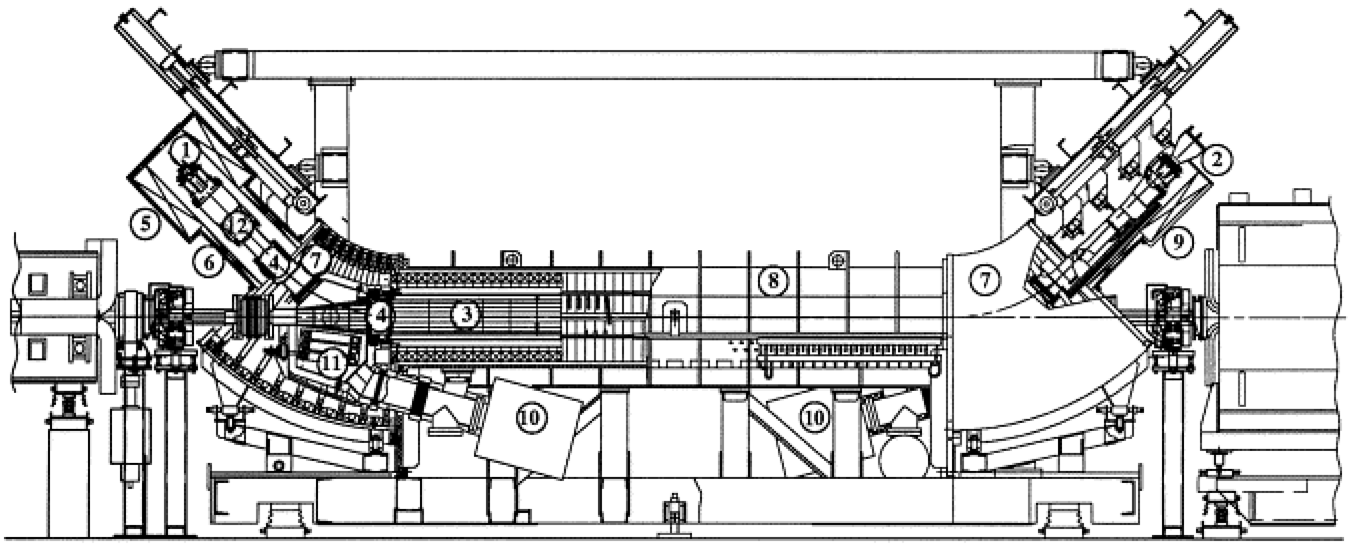
Using an Electron Cooler for Space Charge Compensation in the GSI Synchrotron SIS18

William D. Stem

Oliver Boine-Frankenheim



1. electron gun
2. electron collector
3. central drift tube
4. clearing electrodes
5. gun solenoid
6. expansion solenoid
7. toroid
8. cooling solenoid
9. collector solenoid
10. sputter ion pumps
11. NEG pumps
12. Ti sublimators

Outline

- Motivation: FAIR high-intensity upgrades
- Space-charge tune shift as an intensity-limiting factor
- Electron lens tune shift compensation
- Resonance stopband analysis
- Short comment on charge exchange
- Some preliminary experimental results
  - (taken last week!)
- Outlook

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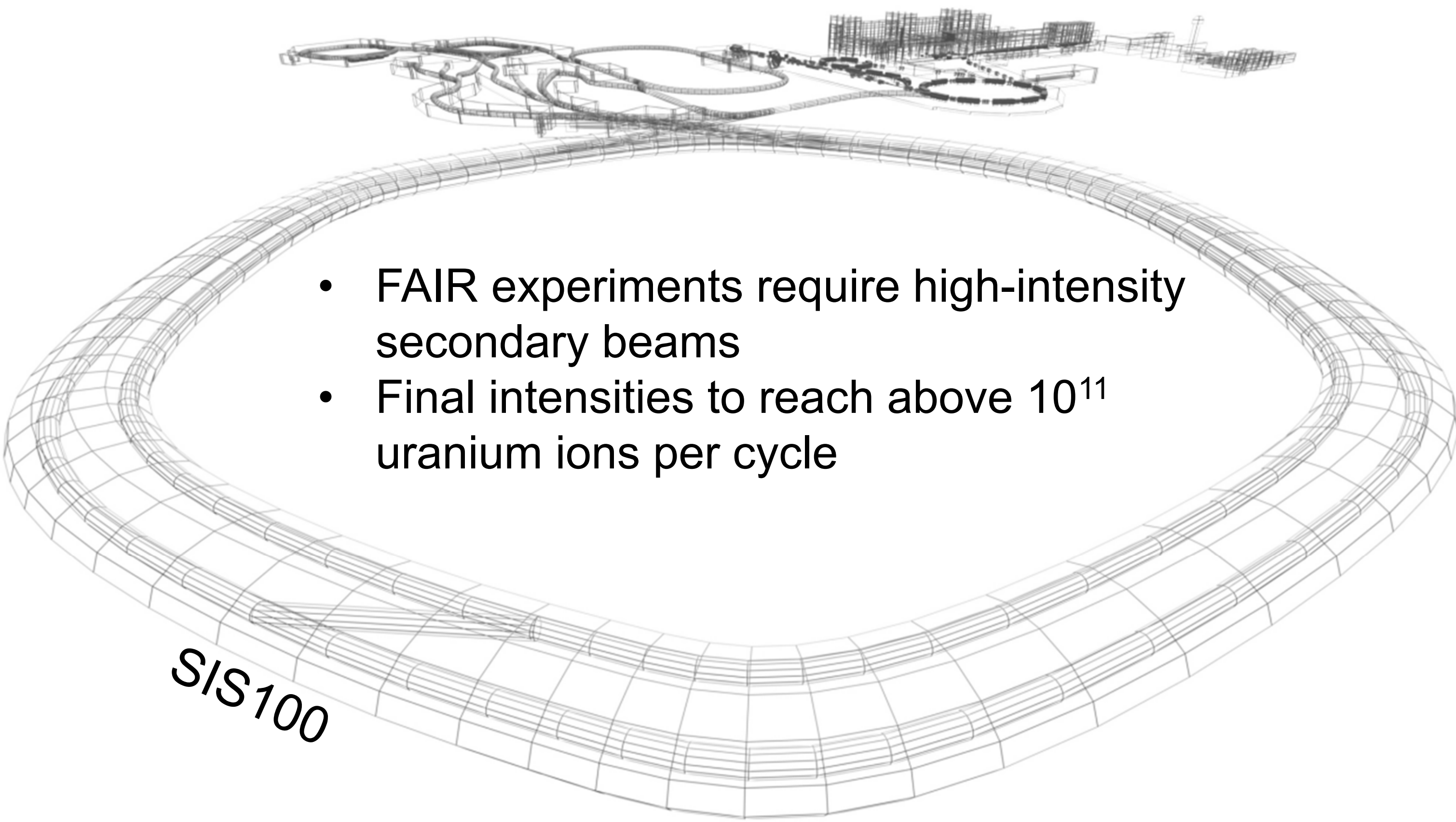
High-Intensity at FAIR

FAIR Facility for Antiproton and Ion Research



- FAIR experiments require high-intensity secondary beams
- Final intensities to reach above 10^{11} uranium ions per cycle

Space-Charge Tune Shift in FAIR Beams

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The space-charge-induced incoherent tune shift sets a restrictive intensity limit on beams.

$$\Delta Q_{SC,y} \approx \frac{NZ^2 r_p}{2\pi \epsilon_y \beta_0^2 \gamma_0^3 A B_f}$$

Tune Spread: $Q_y = Q_{0,y} + \Delta Q_{SC,y}$

GSI FAIR reference Particle: U^{28+}

E, injection	11.4 MeV/u
N	2.0e11
B_f	0.3
ϵ_x, ϵ_y	150,50 mm-mrad
$\Delta Q_x, \Delta Q_y$	0.25,0.45

$$|\Delta Q_{SC}| \leq 0.25$$

W.T. Weng, AIP Conf. Proc., 1987

$$|\Delta Q_{SC}| \approx 0.2 - 0.4$$

V.D. Shiltsev, Electron Lenses for Super-Colliders, 2016

Electron Lenses

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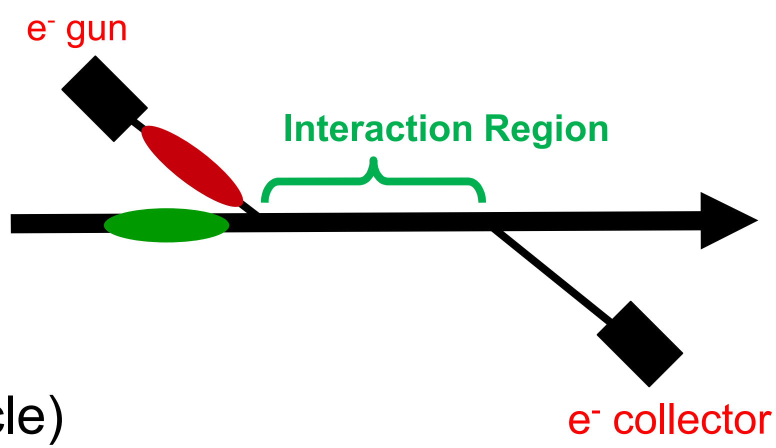
E lens tune shift (co-propagating):

$$\Delta Q^e = (1 - \beta_e \beta_0) \frac{Z}{A} \frac{L_e r_p}{2\beta_0^2 \gamma_0} \frac{I_e}{e\pi a^2 \beta_e c}$$

Items we are addressing:

- How many do we need?
- What is the percentage of tune shift each lens compensator should produce?
- Half integer resonances
- Effect on both the incoherent (single particle) and coherent (envelope) stop bands
- Ionization and capture cross sections/ beam lifetimes for heavy ions
- Pulsed electron beam for bunch compensation (future)



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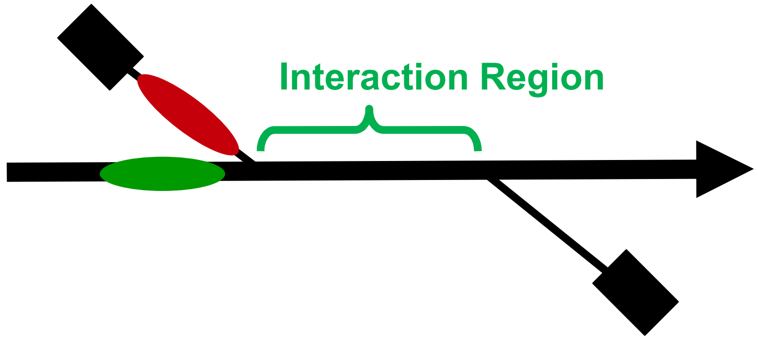

Electron Lenses

E lens tune
(co-propaga

THPAN074 Proceedings of PAC07, Albuquerque, New Mexico, USA

SPACE-CHARGE COMPENSATION OPTIONS FOR THE LHC INJECTOR COMPLEX*

M. Aiba, M. Chanel, U. Dorda, R. Garoby, J.-P. Koutchouk, M. Martini, E. Metral, Y. Papaphilippou, W. Scandale, F. Zimmermann, CERN; V. Shiltsev, FNAL; G. Franchetti, GSI

Items we are add

- What is the perc lens compensat
- Focusing error i number of comp
- Effect on both th and coherent (e
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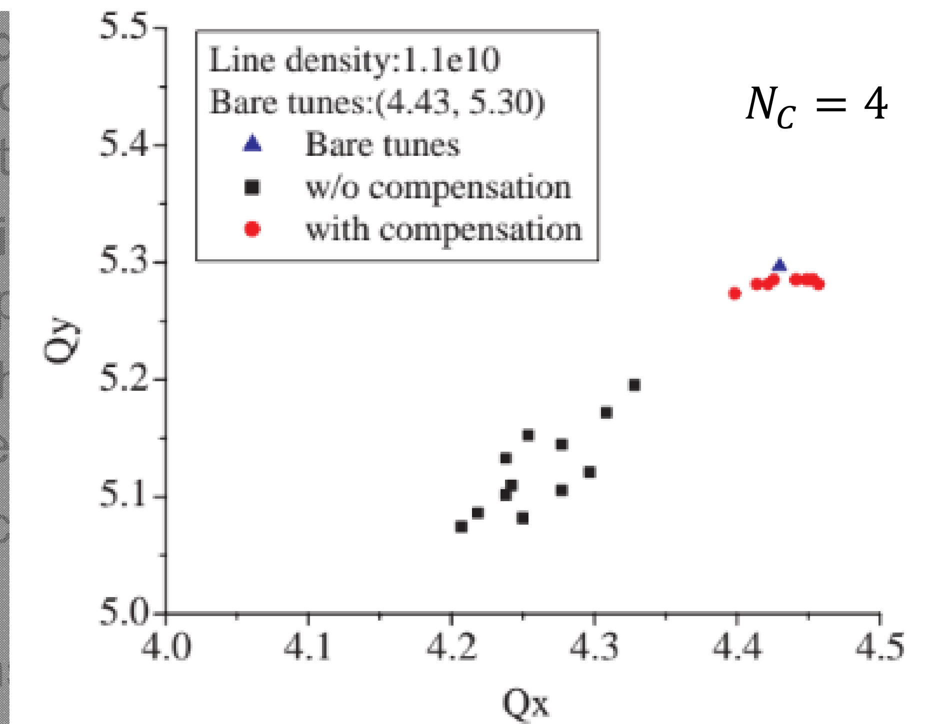
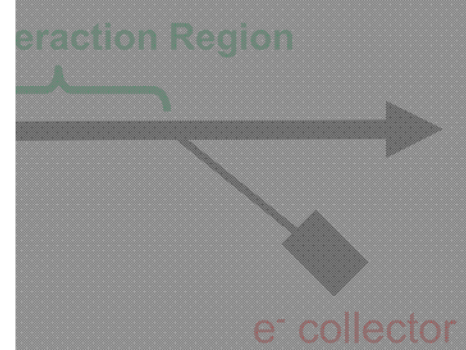
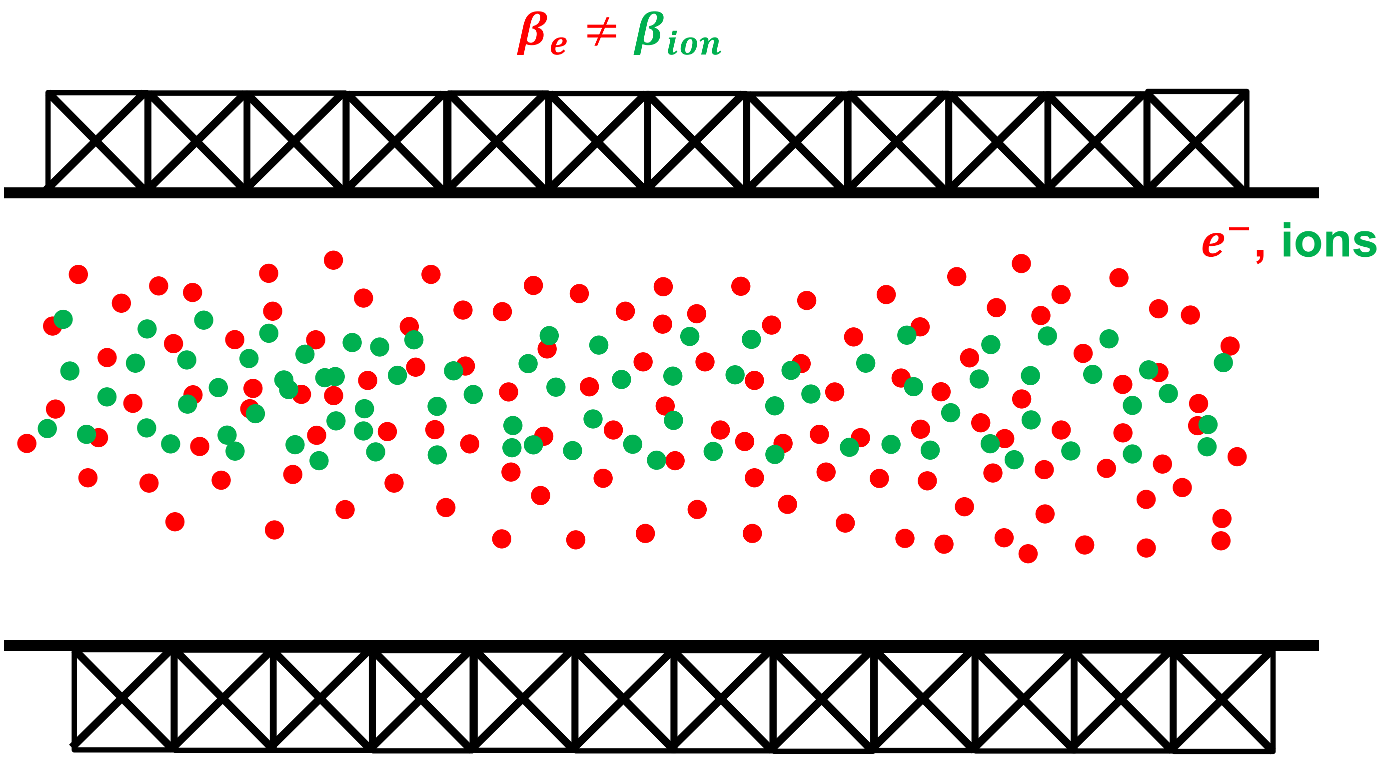
- Pulsed electron (future)





Electron Lens Concept



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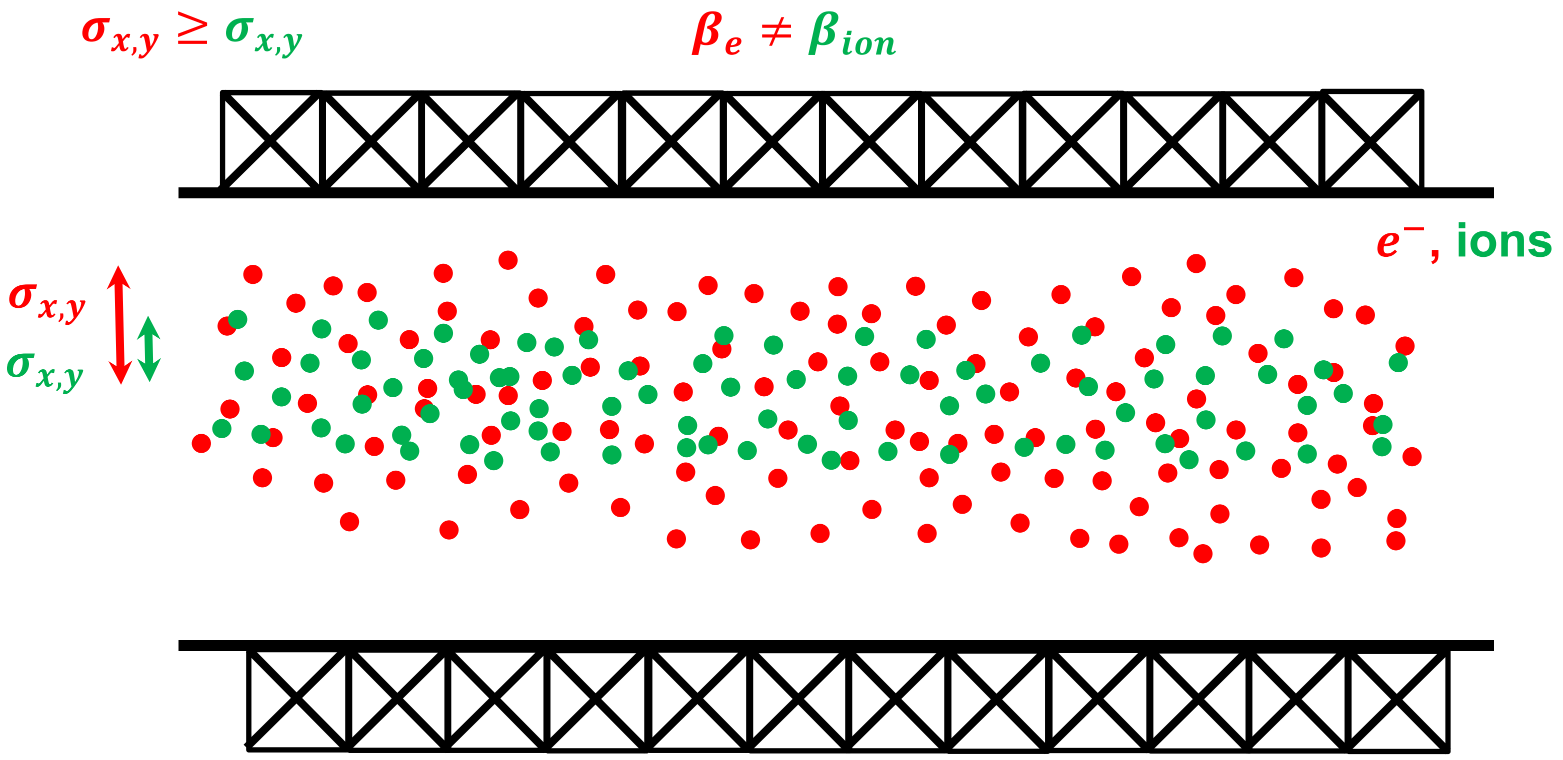

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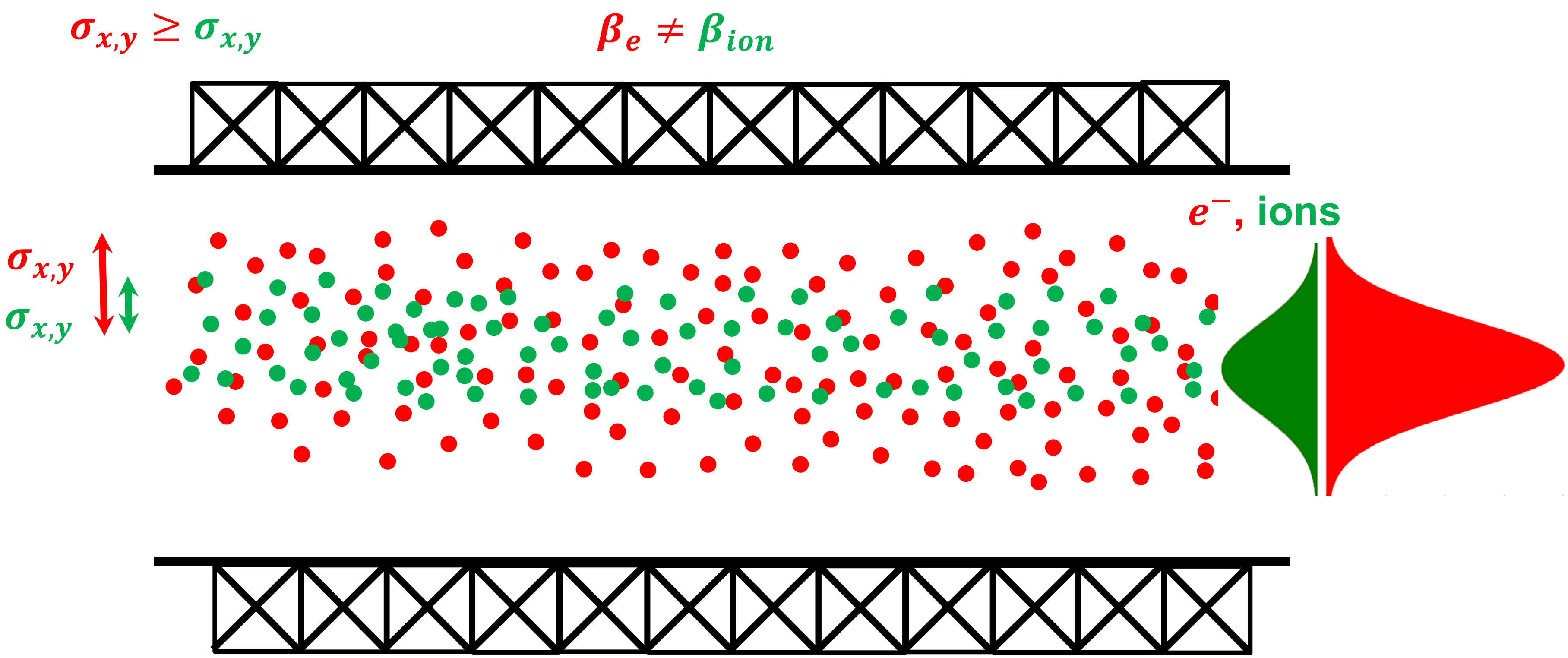
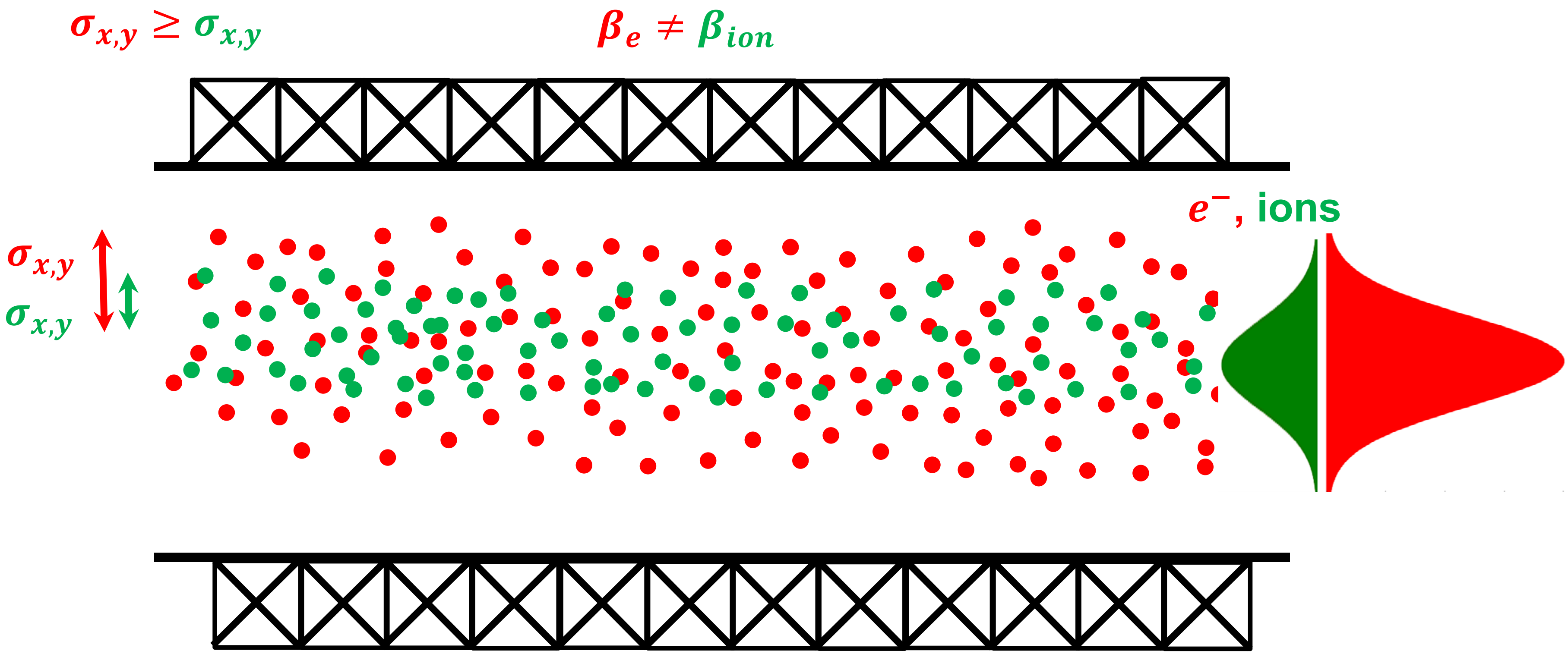


- Match transverse profiles

Electron Lens Concept



- Match transverse profiles
- Center ion beam in lens or suffer closed orbit distortion

Electron Lens Concept

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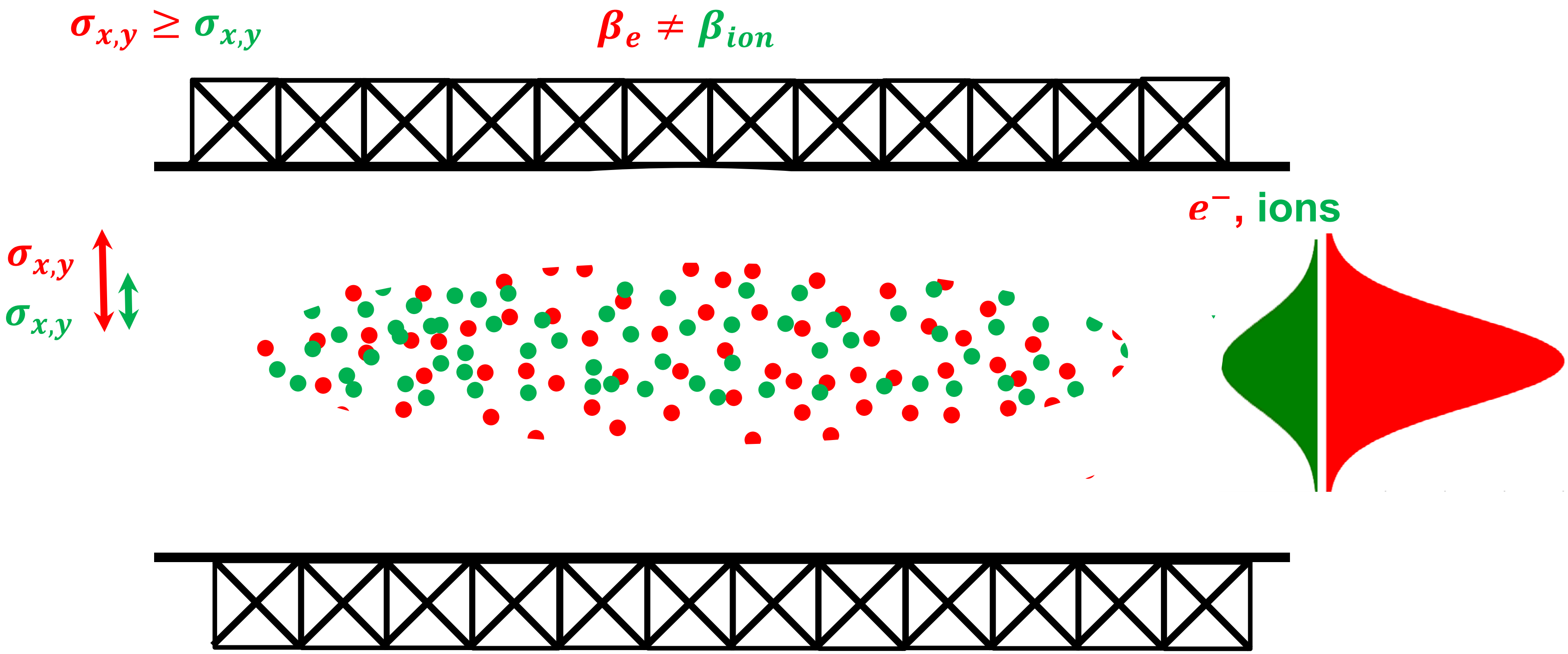

- Match transverse profiles
- Center ion beam in lens or suffer closed orbit distortion
- Match longitudinal bunch profiles (pulsed electron beam)

Outline

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Coherent Stopbands, Envelope Equations

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Start Somewhere:
Simple Studies

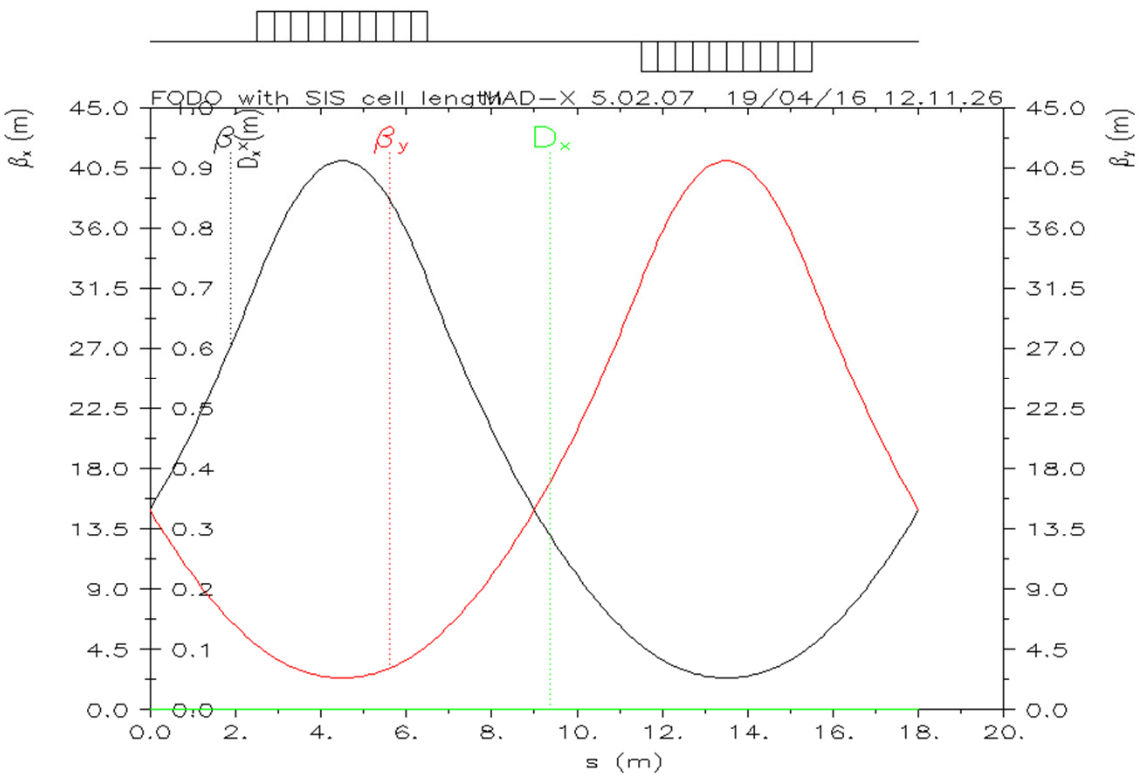
$$X'' + \kappa_x(s)X - \frac{2K}{X+Y} - \frac{{\epsilon_x}^2}{X^3} = 0$$

$$Y'' + \kappa_y(s)Y - \frac{2K}{X+Y} - \frac{{\epsilon_y}^2}{Y^3} = 0$$

$$X(s) = \sqrt{\epsilon_x \beta_x(s)}$$

$$\mathrm{Y}(s) = \sqrt{\epsilon_y \beta_y(s)}.$$

SIS18, FODO



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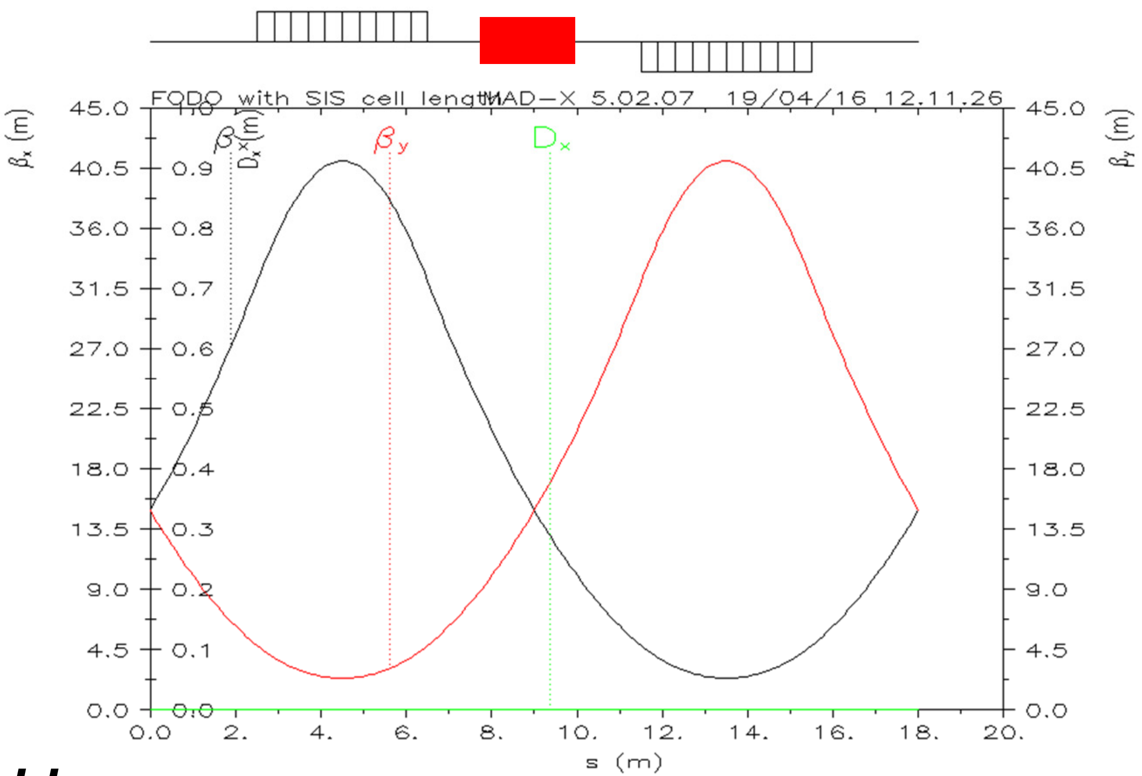

What happens when we add an electron lens every cell?

Coherent Stopbands, Envelope Equations

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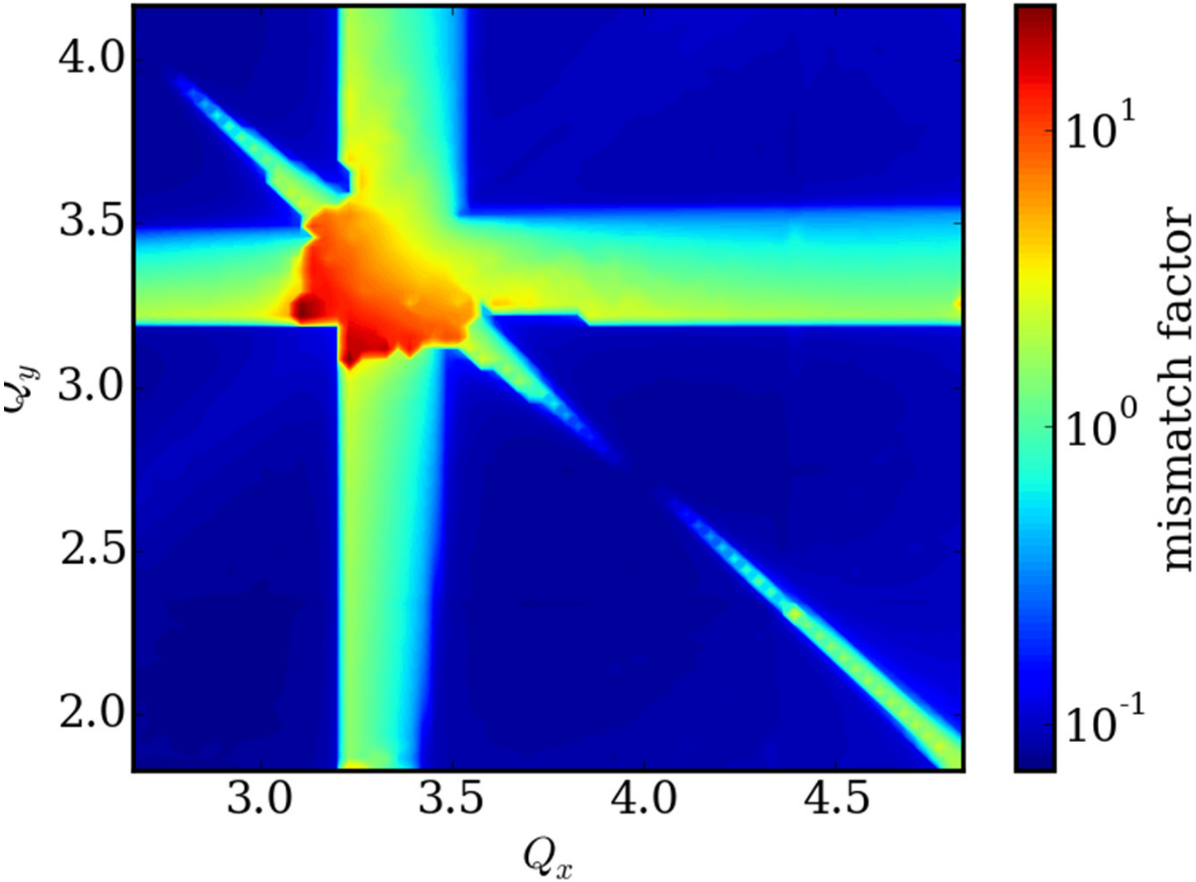
No Compensation



Coherent Stopbands, Envelope Equations

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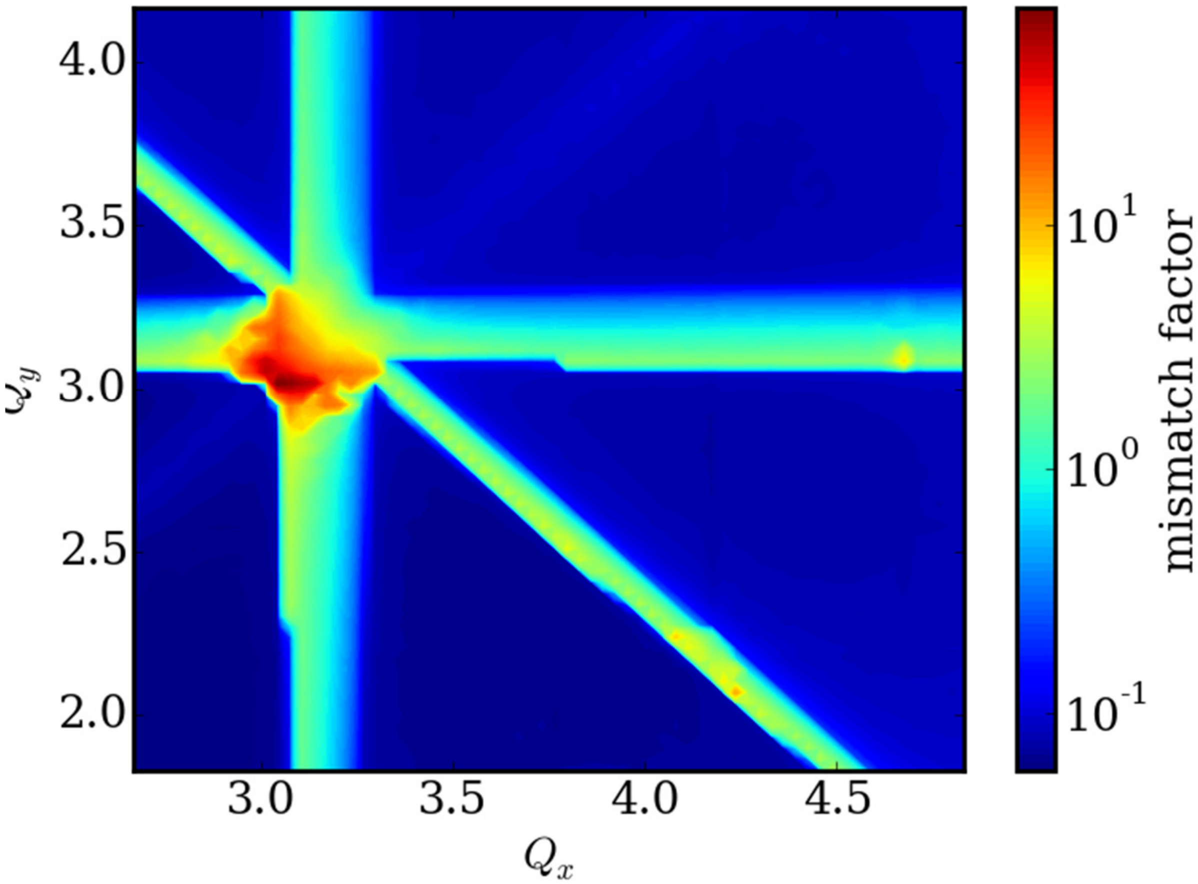
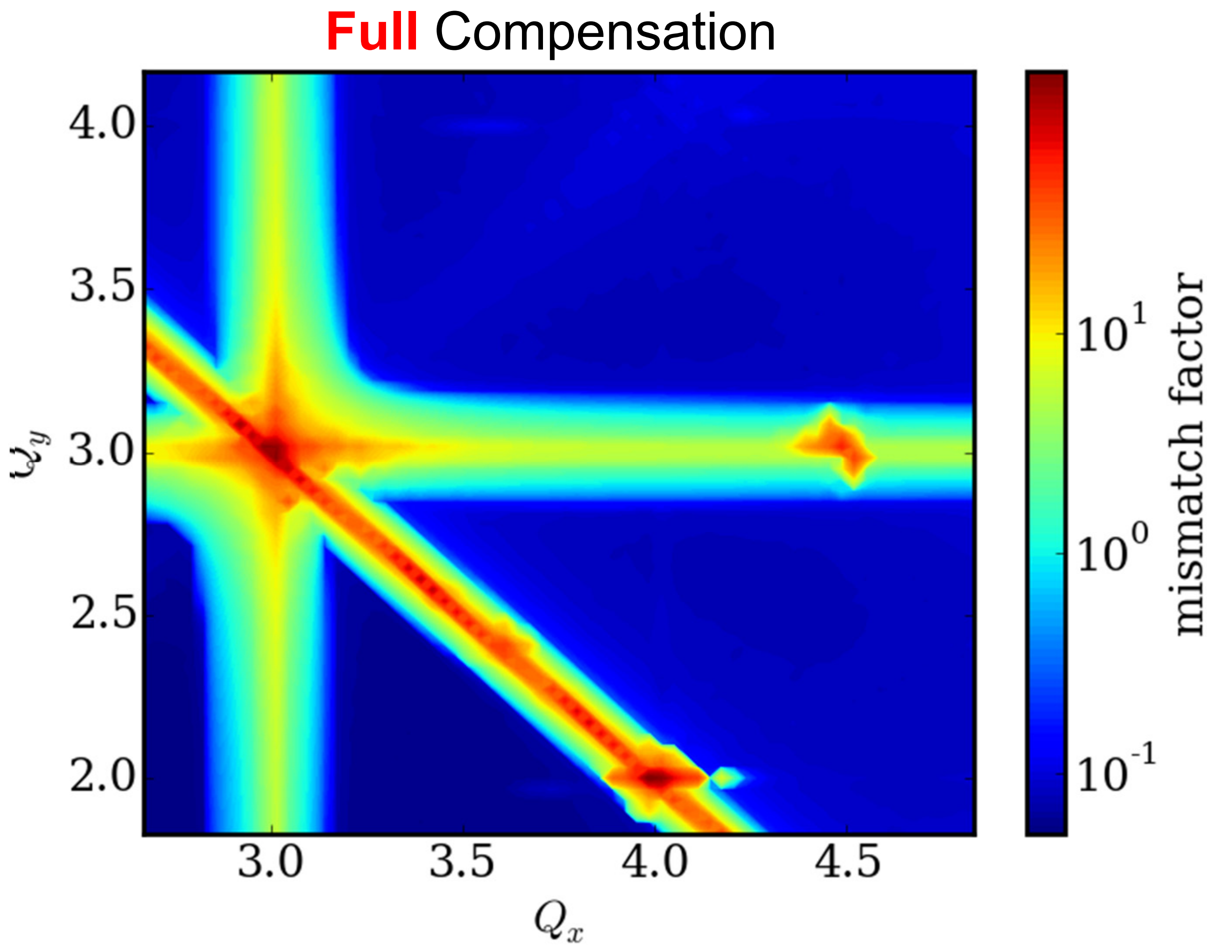
Half Compensation



Coherent Stopbands, Envelope Equations



Single Particle Resonance Stopbands (Orbit Instabilities)

Number of compensators needed depends on the stability criterion:

$$|Tr(Ring\ Transfer\ Matrix)| < 1$$

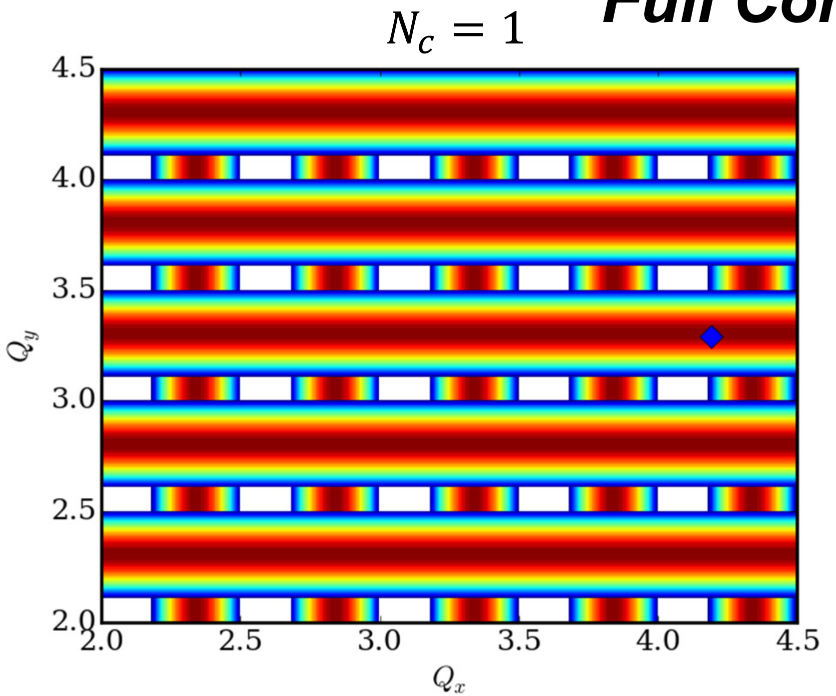
$$|\cos\varphi_0 - 2\pi\Delta Q \sin\varphi_0| < 1$$

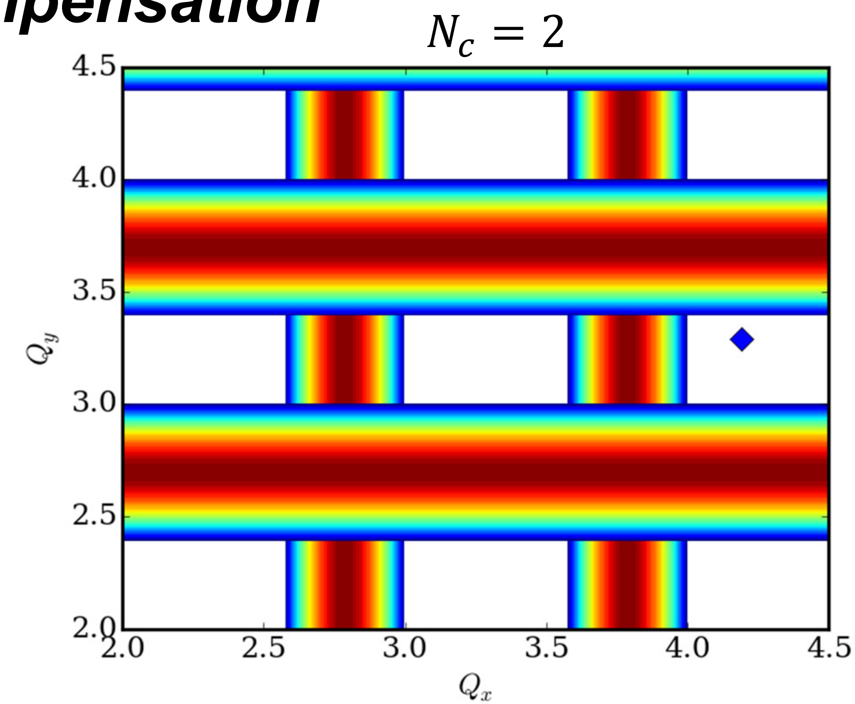
$$\varphi_0 \equiv 2\pi Q_0/N_c$$

Edwards & Syphers

SIS18, U^{28+}

Full Compensation

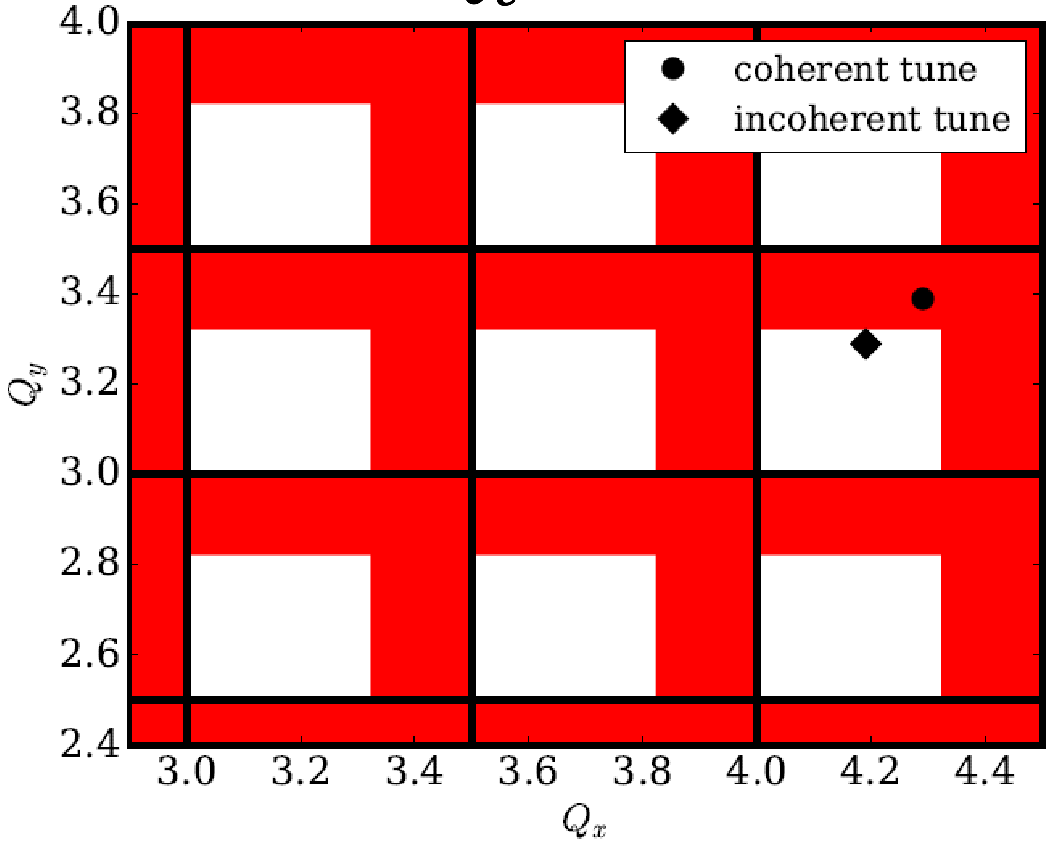




Single Particle Resonance Stopbands (Orbit Instabilities)

SIS18, U^{28+}

$\Delta Q_e = 0.1$



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Cross Sections and Beam Lifetimes

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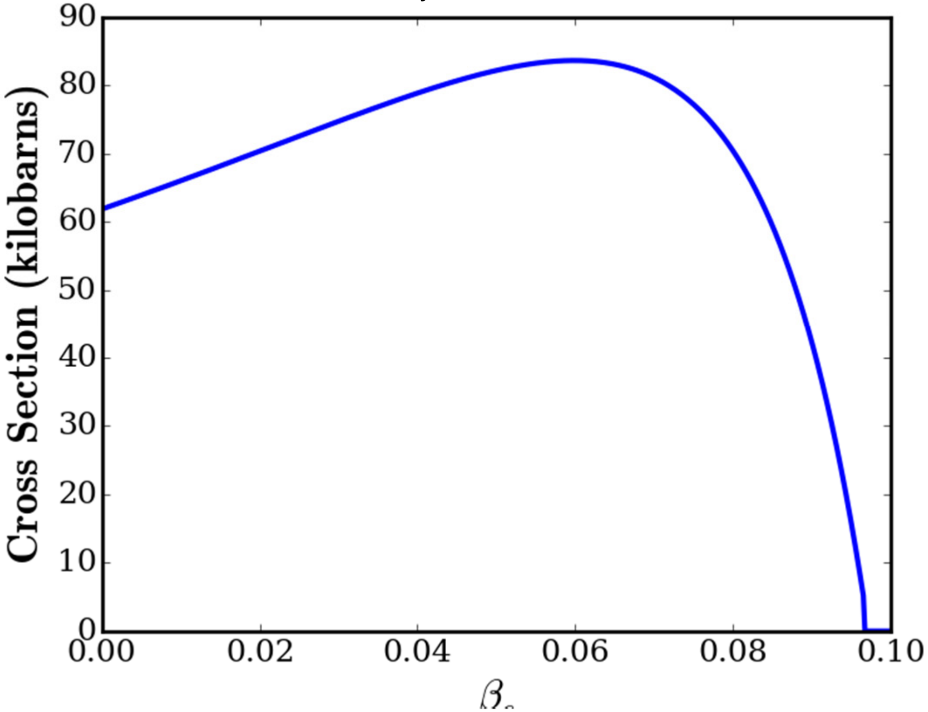
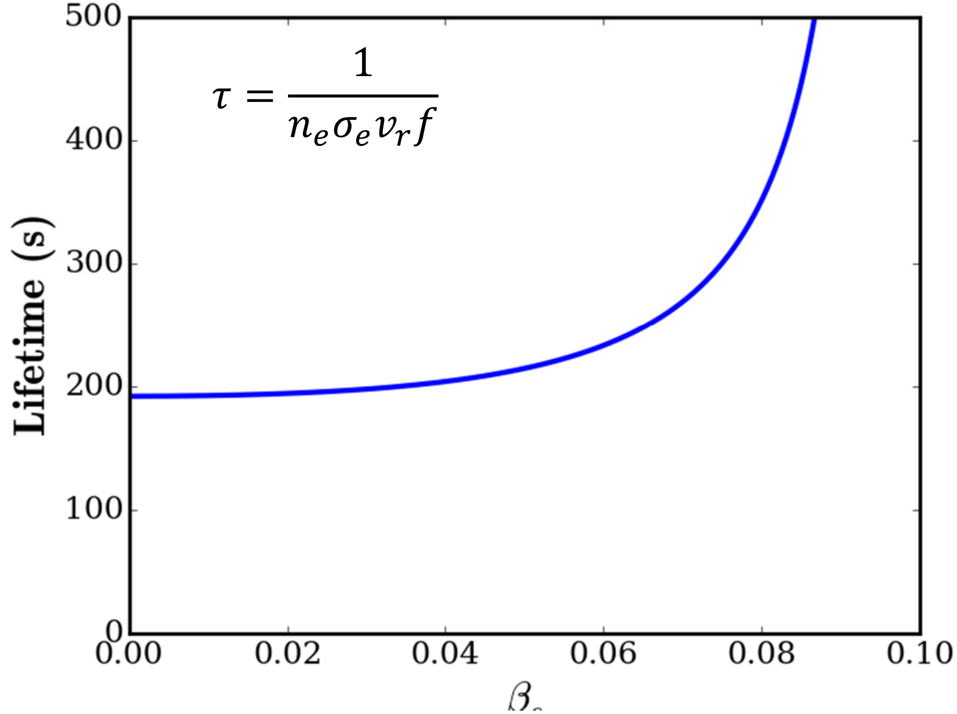
Ion: U^{28+} Mechanism: Ionization from free electrons

T. Peter and J. Meyer-ter-Vehn, PRA, 1991





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Benchmarking Experiments in the SIS-18

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- **Goals:**
  - Measure coherent tune shift as a function of electron density and compare with experiment
  - Measure the effect of the beam offset on the closed orbit
  - Measure beta beat onset as a function of electron density in the cooler

Benchmarking Experiments in the SIS-18

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Benchmarking Experiments

Electron Cooler Parameters

U_{kin}	6.6 keV
β_e	0.16
f_{exp}	2,3
$\beta_{x,y}$	8.0,15.0 m
L_e	3.4 m
I_e	0-0.6 A

June 27, 2016

Xe^{43+}

U_{kin}	6.75 MeV/u
β_0	0.12
ϵ_x	36.1 mm-mrad
ϵ_y	40.2 mm-mrad
$Q_{x,y}$	4.32,3.25

July 2, 2016

C^{3+}

U_{kin}	6.78 MeV/u
β_0	0.12
ϵ_x	15.5 mm-mrad
ϵ_y	20.1 mm-mrad
$Q_{x,y}$	4.32,3.25

Experimental Procedure

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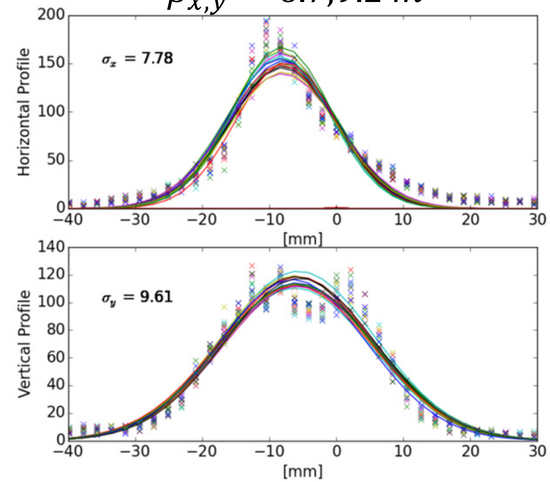
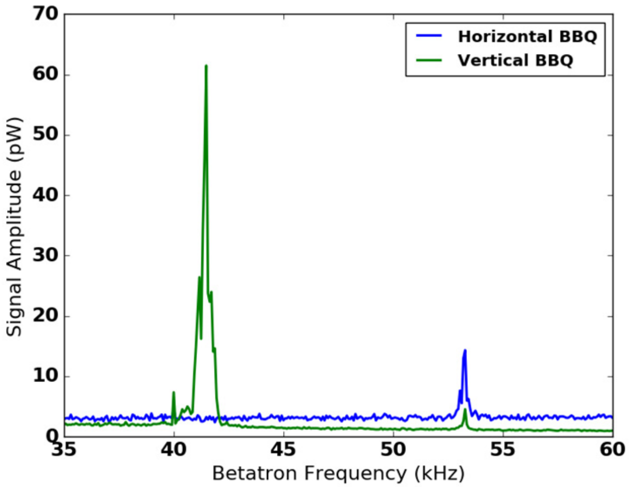
- Low intensity beam at injection energy (<5 turn stacking)
- Measure ion current to approximate SC tune shift (should be negligible!)
- Measure beam profiles with Residual Gas Monitor (RGM) to get emittances
- Measure tune as a function of electron density
  - Used Schottky and Base Band Tune (BBQ) measurement

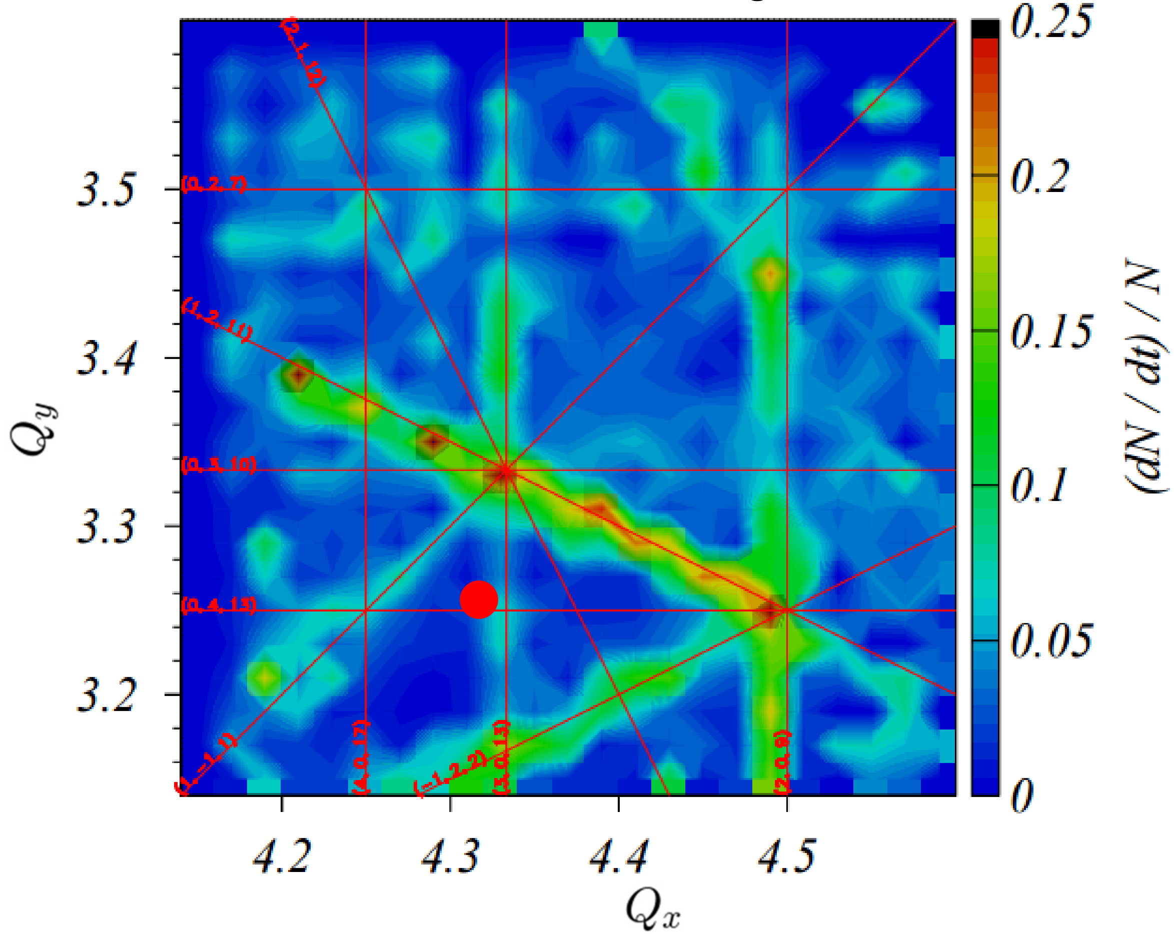
$\beta_{x,y} = 6.7, 9.2\ m$





Tune Space

Franchetti, HB Proceedings 2008



Tune Space

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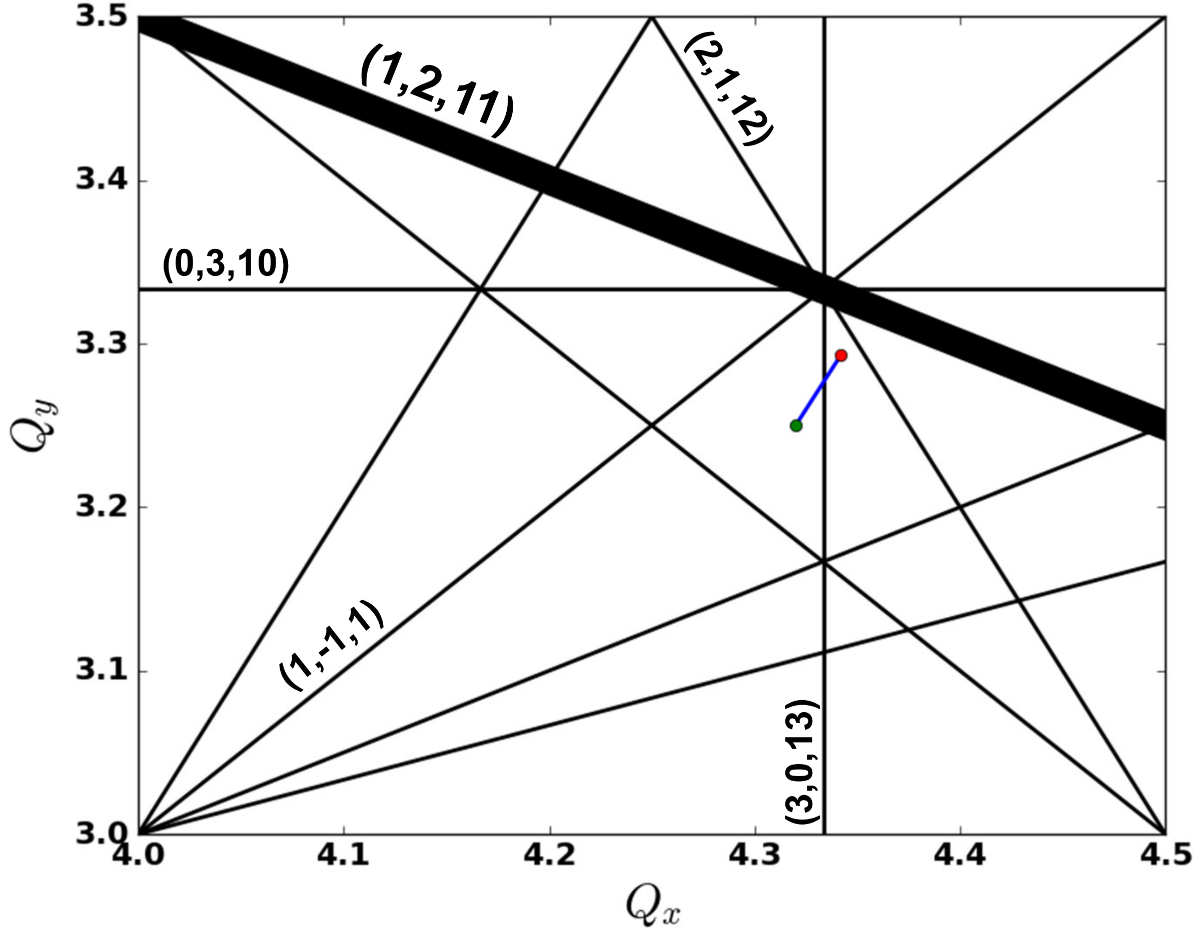
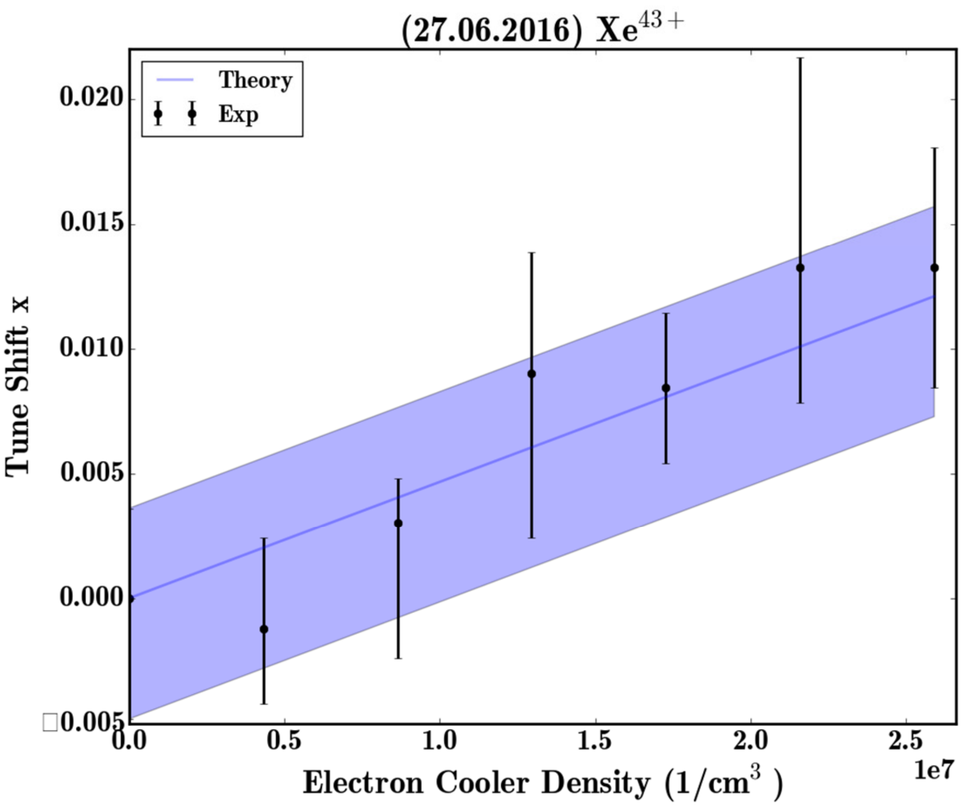
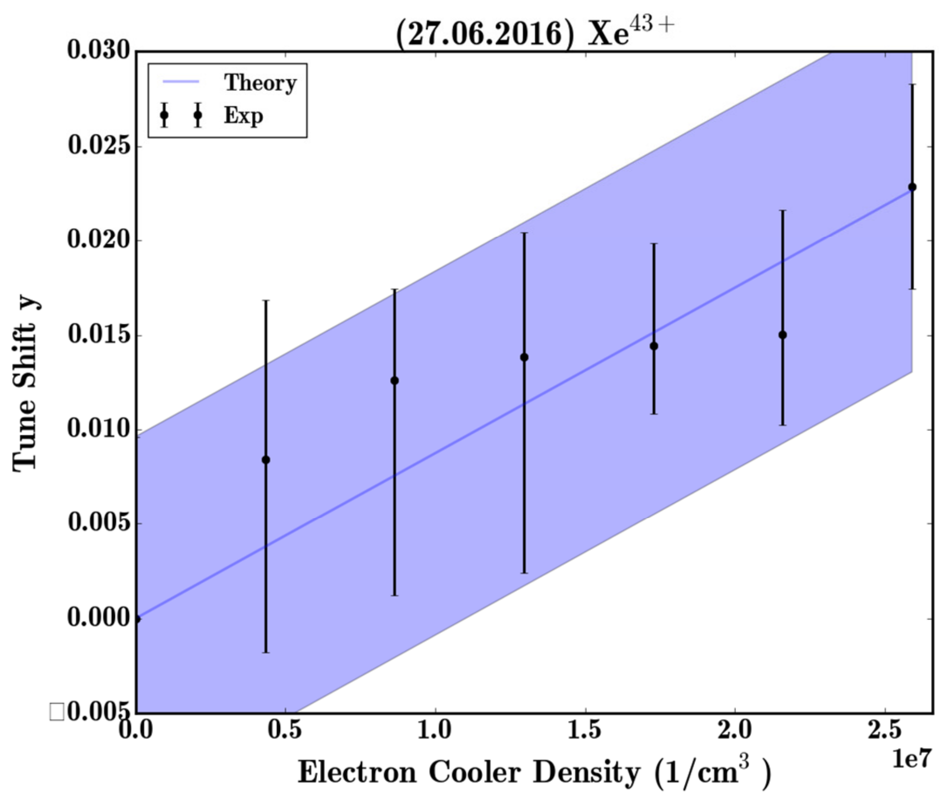


(Preliminary) Experimental Results!





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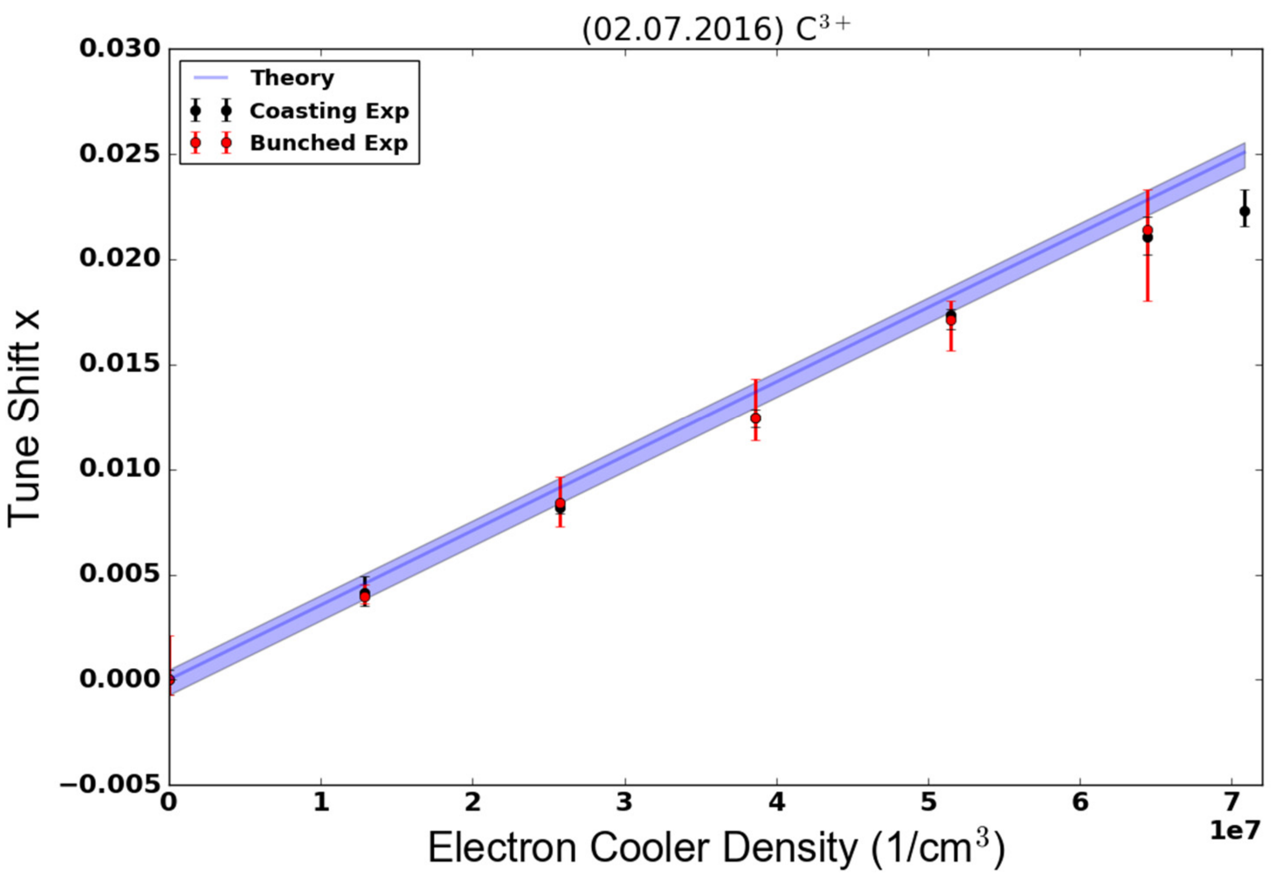

Conclusions and Outlook

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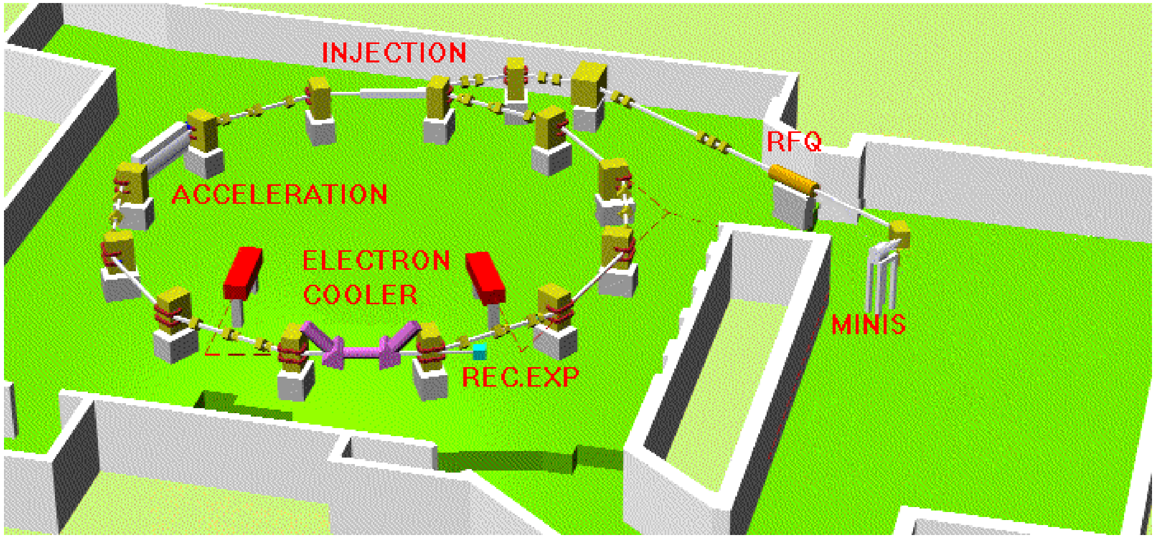
- **Conclusions:**
  - We are using the SIS-18 in concert with simulation tools to determine the number of electron lenses for high-intensity space charge compensation
  - Instabilities/resonances uncovered in the incoherent and coherent stopbands need to be prevented for electron lens commissioning
  - One compensator could only (very) partially compensate for space charge. The study will indicate the number needed for full compensation
  - Ionization in the SIS18 electron cooler doesn‘t seem to play a major role in beam lifetime for the ionization-dominated reference particle U^{28+}

- **Future Goals:**
  - Beta beat and closed orbit analysis of data taken Saturday, July 2nd (5 days ago!), Collaboration with V. Chetvertkova and G. Franchetti
  - Study of the incoherent beam physics with pyORBIT PIC simulations. Compare results to experiment to determine how many electron lenses are needed for compensation
  - Pulsed electron lens beam to match longitudinal beam profile
  - CRYRING experiments for future space-charge compensation experiments and benchmarking

CRYRING



Acknowledgements and References

▪Experiment Team

Oliver Boine-Frankenheim, Rahul Singh, Christina Dimopoulou, Markus Steck, Sabrina Appel, Ivan Karpov

▪References

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