SIMULATING ELECTRON CLOUD EFFECTS IN HEAVY ION ACCELERATORS*

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OUTLINE

- Distinguishing features of ecloud issues for HIF
- Our plan for self-consistent modeling
- Example with wall electron sources
- Electron effects on ions: simulations with specified electron distributions
- Preliminary results for averaged electron dynamics
- Summary

Related papers:

Molvik et al (earlier this m orning)

Stoltz et al (poster, this afternoon)

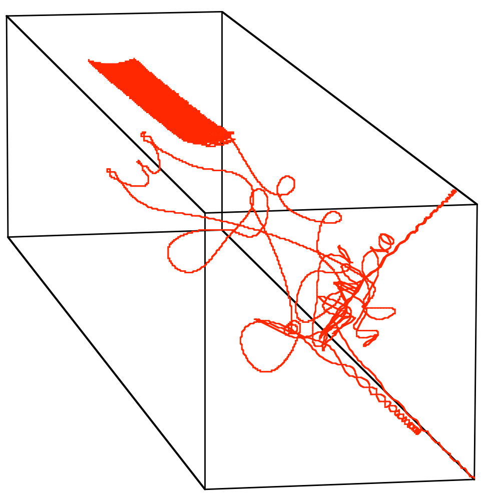
HIF accelerators have distinguishing features that impact electron cloud issues

Compared to other accelerator applications:

- Common to all: uncontrolled source of negative charge, can degrade beam
- Distinguishing aspects of HIF accelerators (U.S. main line with magnetic quadrupole focusing):
  - Linac with high line charge density
  - Economics-driven large fill factor
  - Induction accelerator -- Beam pipe only in quad magnets $\Rightarrow$ scrape-off only in quads
  - Electrostatic accelerating fields between quads
  - Large fraction of length occupied by quadrupoles (>50% at injector end)
  - Long(ish) pulses -- multi-μs at injector end

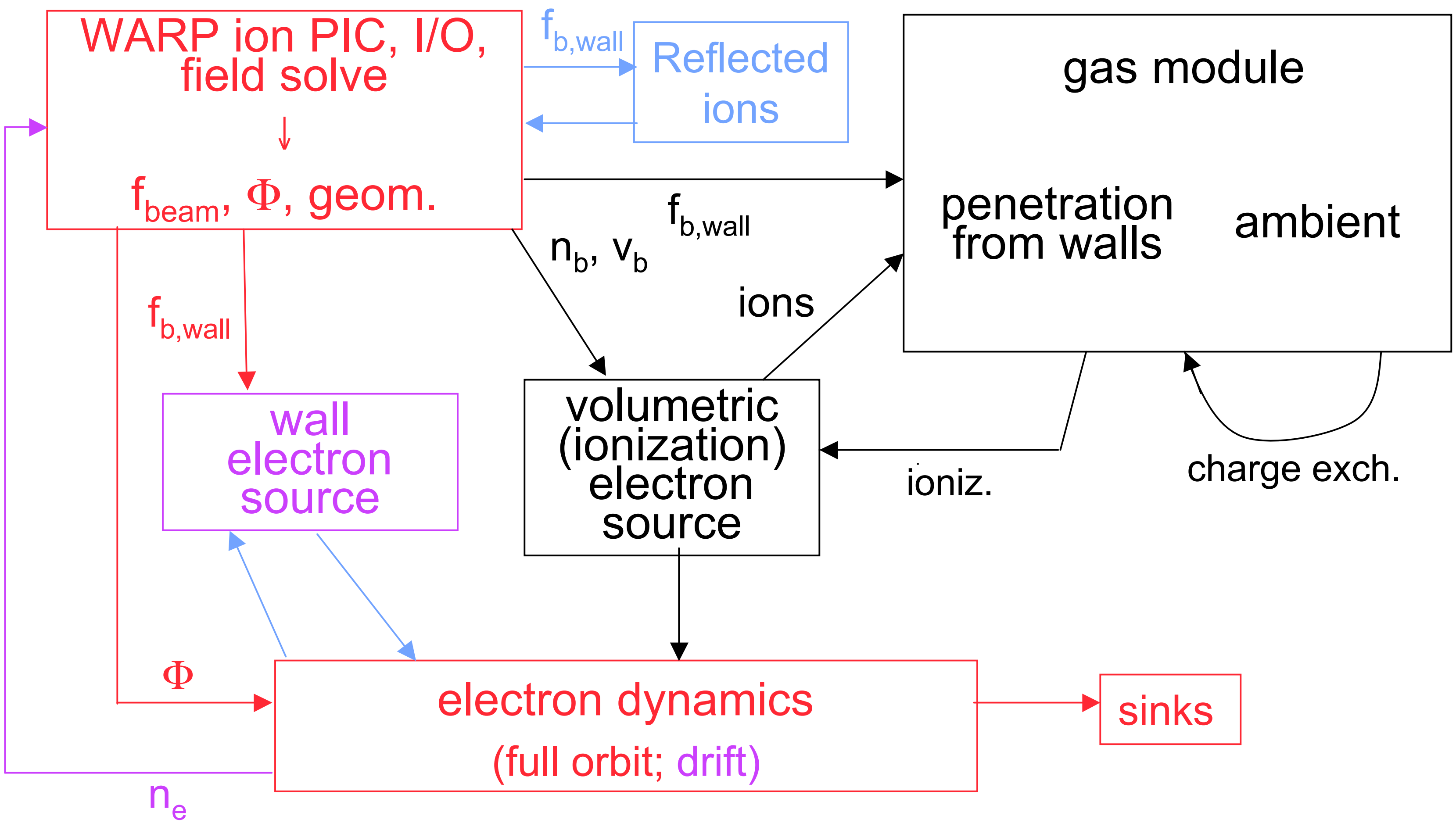
Consequences

- Dominant e^- source: desorption of gas (long pulse) and electrons (short pulse) from ion scrape-off
- Multiturn resonant multipactoring not an issue
- If accelerating gaps:
  - Electrons largely confined to the quadrupole in which they are born, and electron density smaller in gaps than in quads
  - Electrons born from ionization of neutrals deeply trapped; lifetime in a quad ~ time to drift (ExB, magnetic) out of a quad
  - Accelerating gaps enable electrons to overcome beam potential



Toward a self-consistent model of electron effects

- Plan for self-consistent electron physics modules for WARP



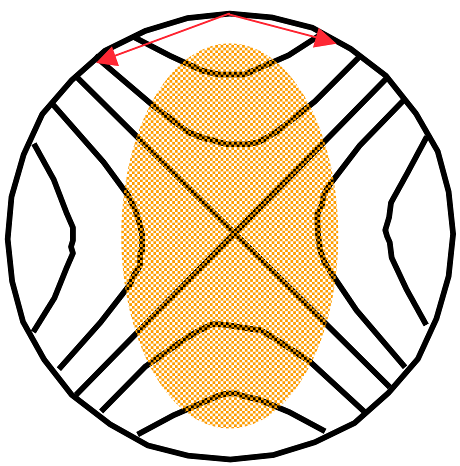
- Key: operational; implemented, testing; partially implemented; offline development

Example of current capability: wall-born electrons from primary and secondary ion bombardment

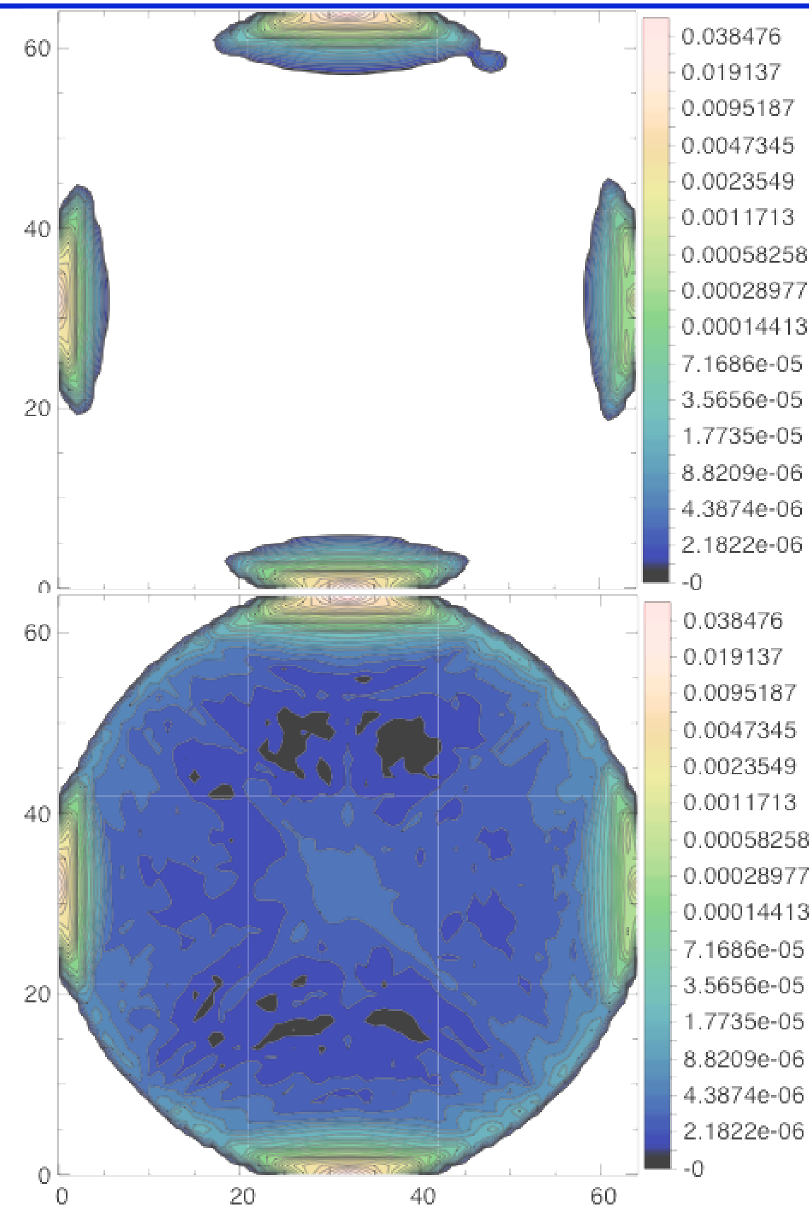
- WARP ion slice simulation
  - 100 lattice-period transport system (no acceleration)
  - Slightly misaligned magnets to exaggerate beam scrapeoff
- Gather data for ions impacting wall and calculate:
  - Electrons produced (from simple fit to Molvik et al data)
  - Scattered ion population, from TRIM Monte-Carlo code
- Follow scattered ions in WARP until they next impact wall.
- Calculate electrons produced by those ions
- Follow dynamics of electrons produced by primary and scattered ion impacts with WARP; accumulate electron charge density

Calculation of n_e from wall-born electrons shows importance of following scattered ions

- Full-orbit calculations of electrons born near wall from impact of lost beam ions
  - Based on initial ion-wall impacts: cloud confined to wall near beam ellipse tips



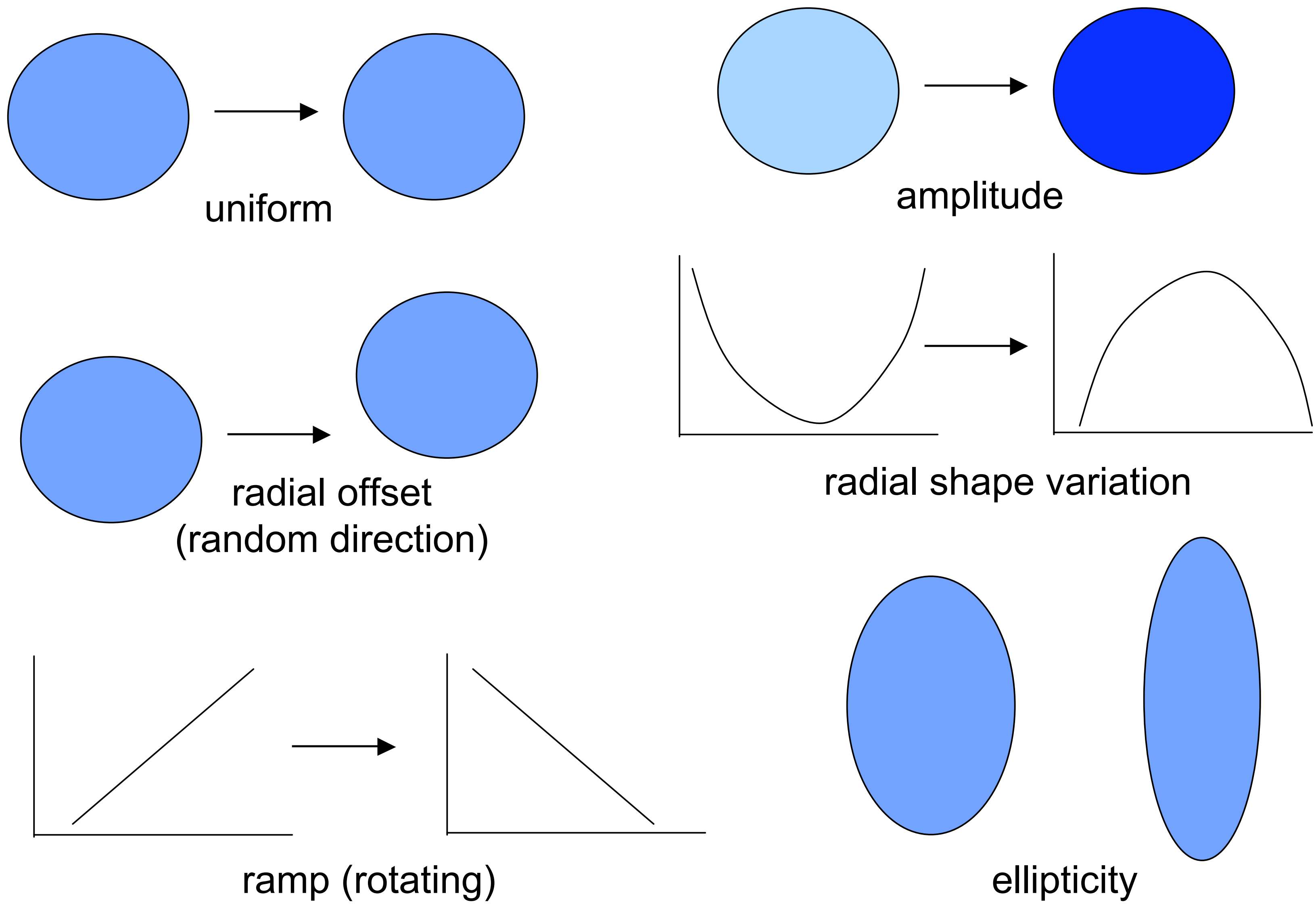
  - Dramatic difference if we follow scattered ions and add in the electrons THEY produce



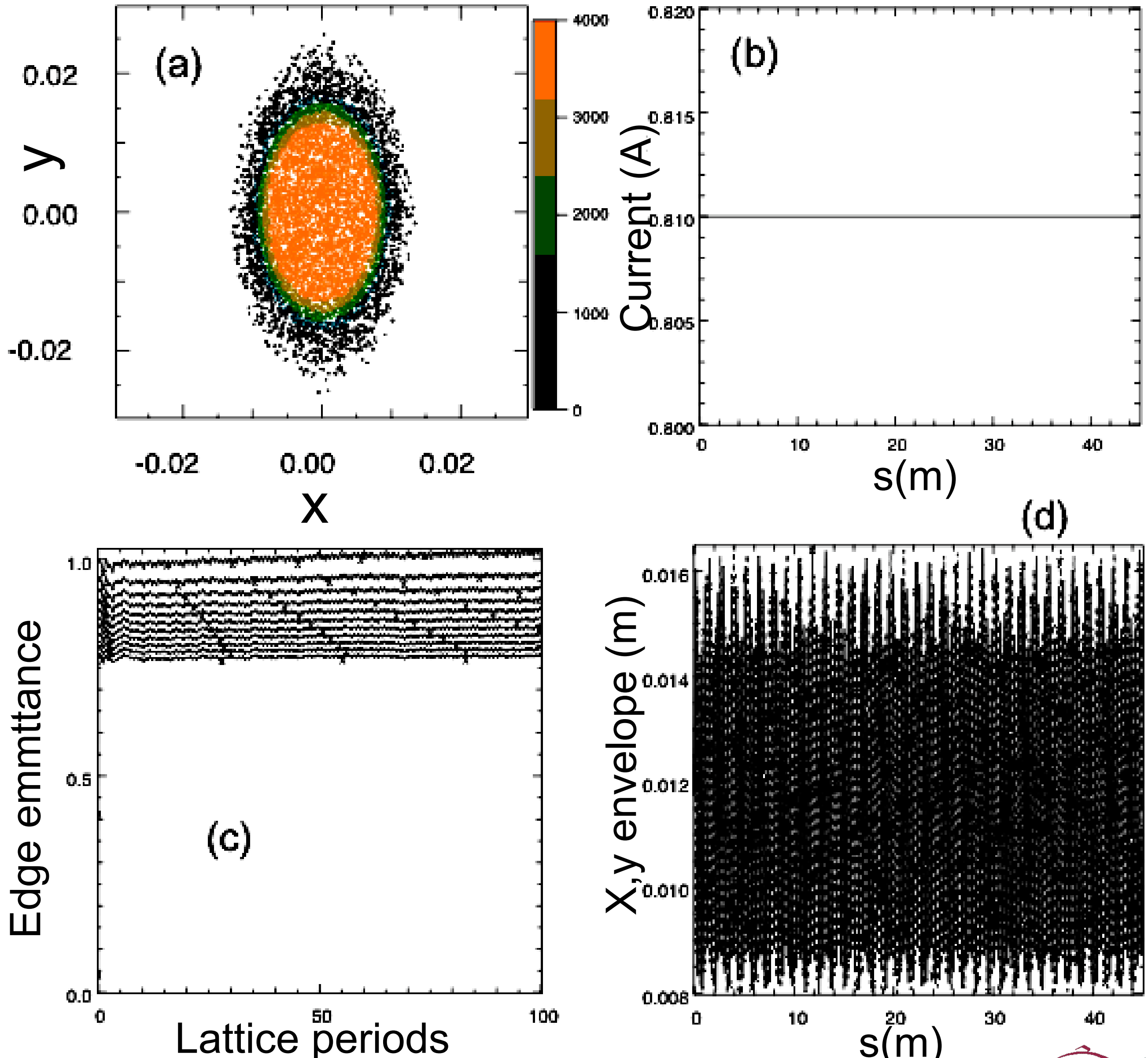
Ion simulations with legislated electron clouds show level of acceptable density and highlight areas for concern

- Perform ion simulations with legislated negative charge distributions to mock up electrons from gas ionization
- All choices have constant parameters within a quad, but variable from quad to quad:
  - Const n_e
  - Random cloud variations
  - Sinusoidal cloud variations, with period chosen to match the relevant beam natural mode
    - Breathing
    - Centroid oscillations (dipole mode)
    - Elliptical distortion oscillations (quadrupole mode)
  - Types of electron cloud variations studied:

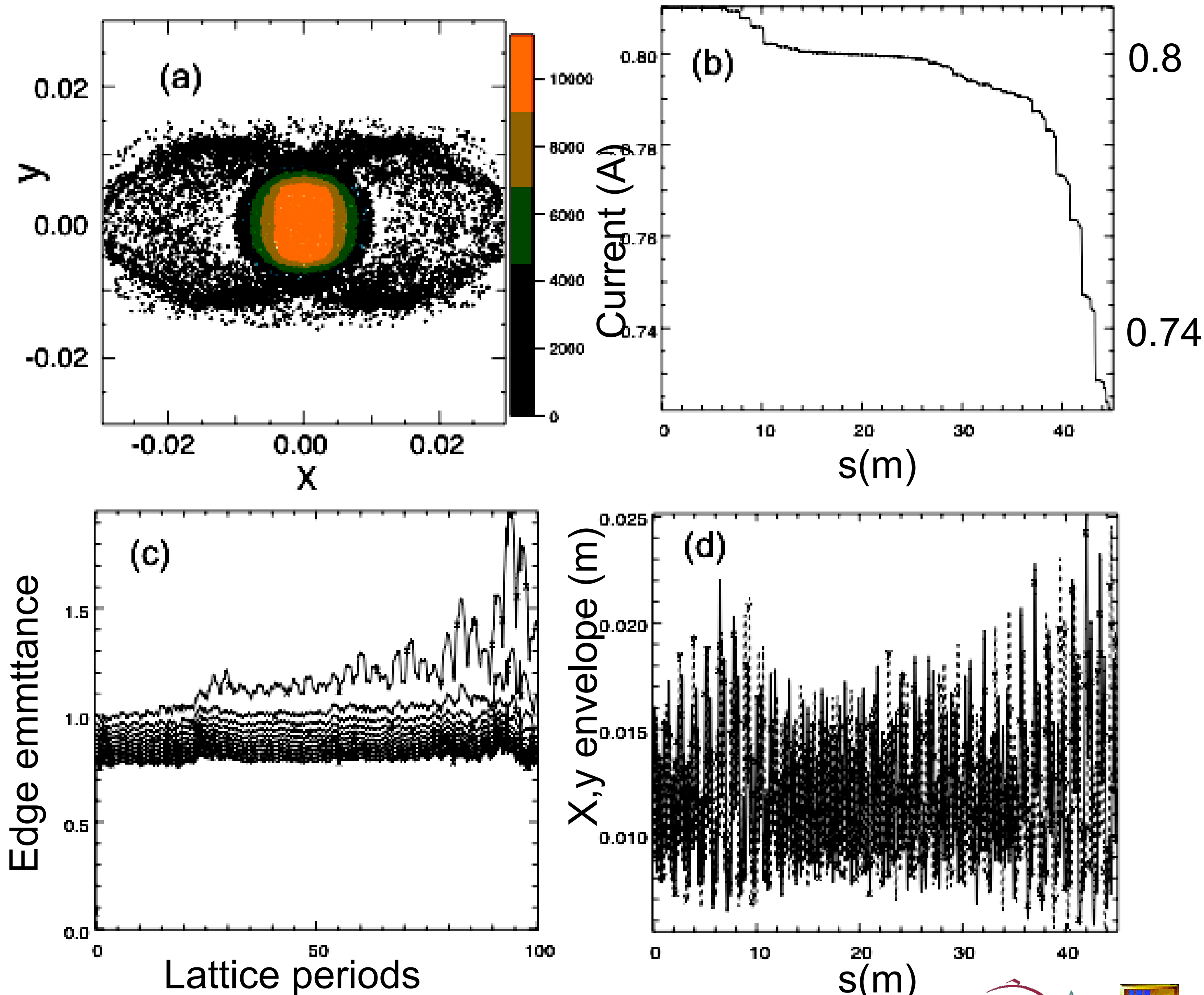
Types of electron cloud perturbations specified



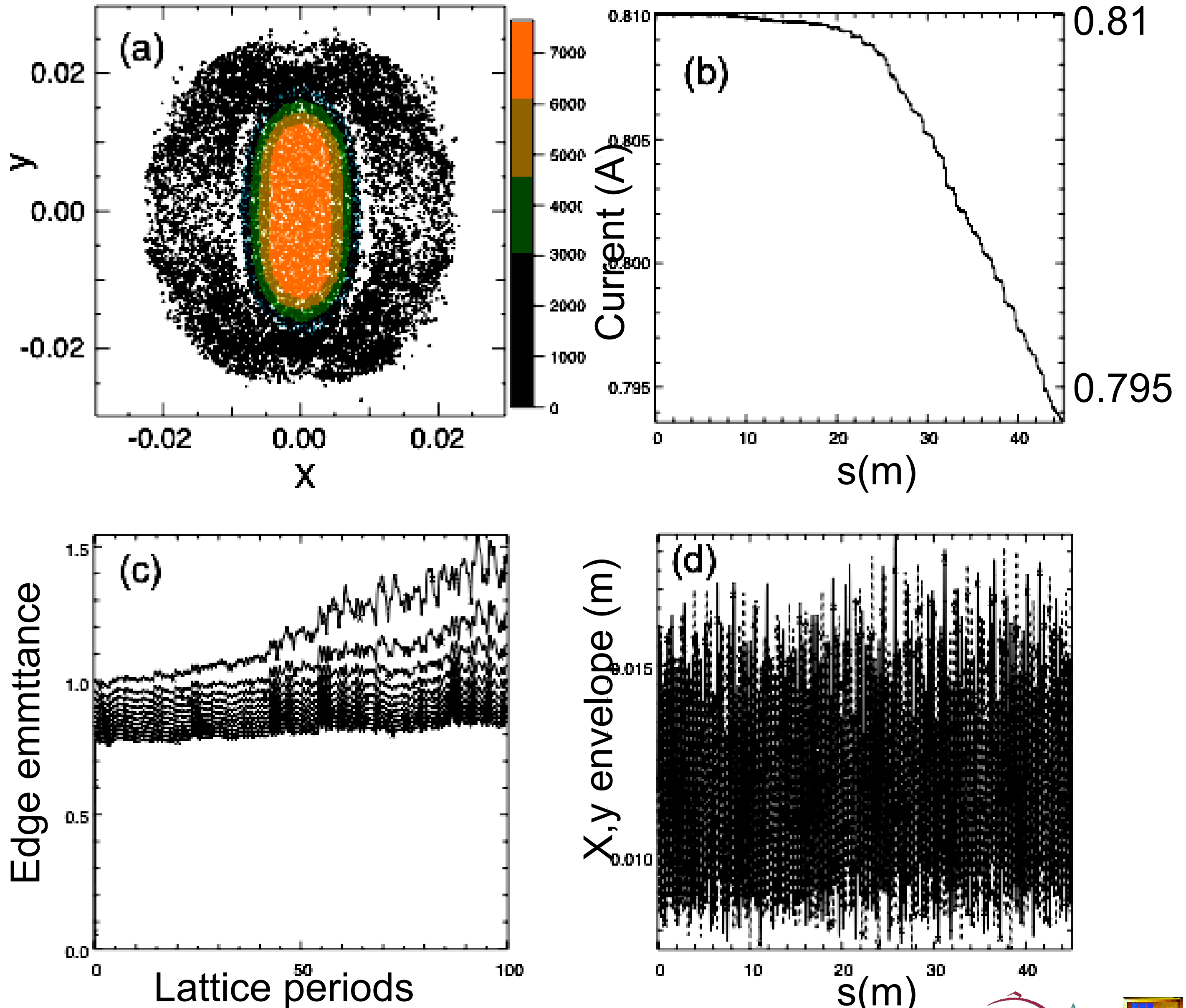
20% constant n_e has little effect



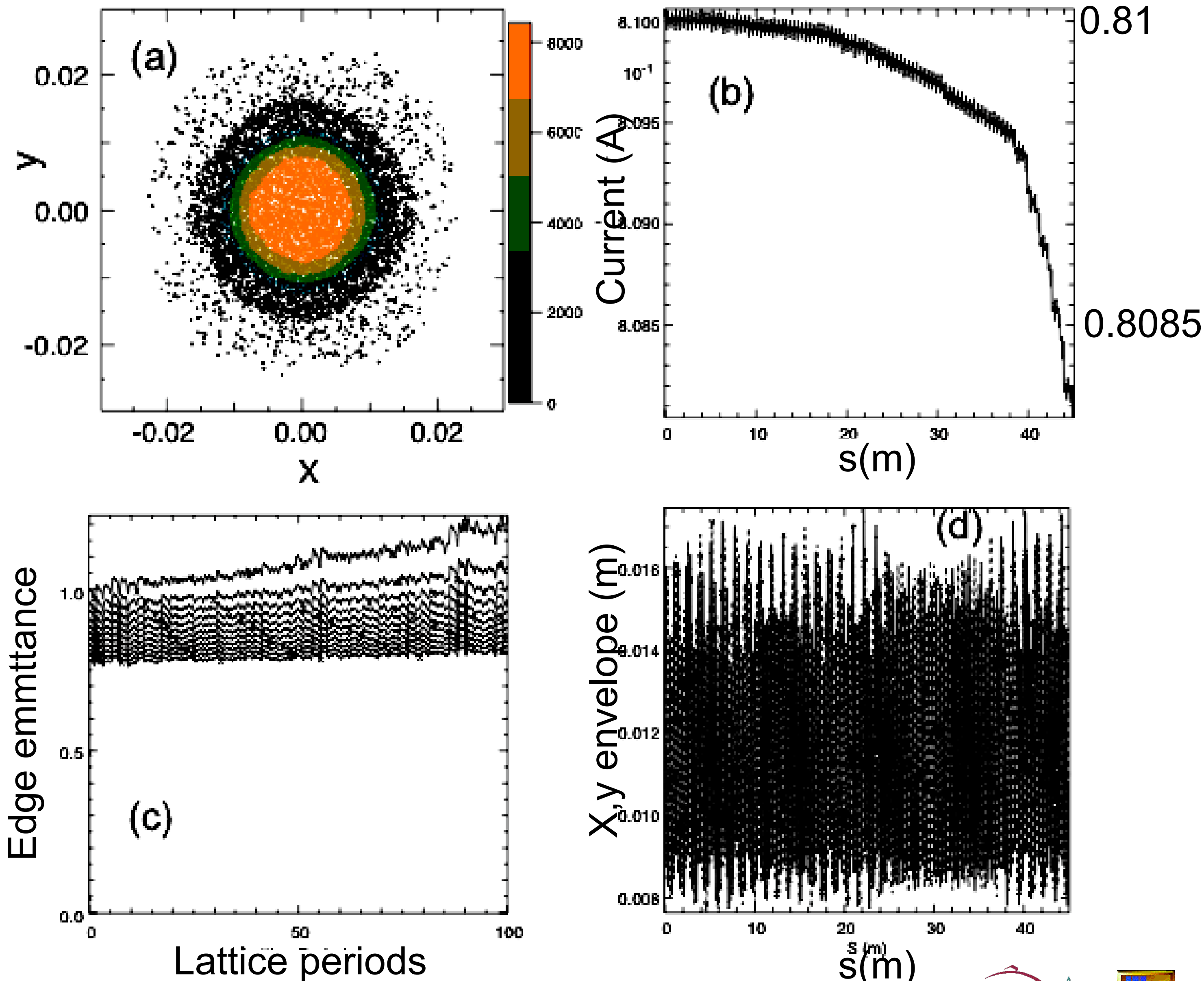
20% mean, 0-40% random n_e produces significant beam loss, envelope growth, halo



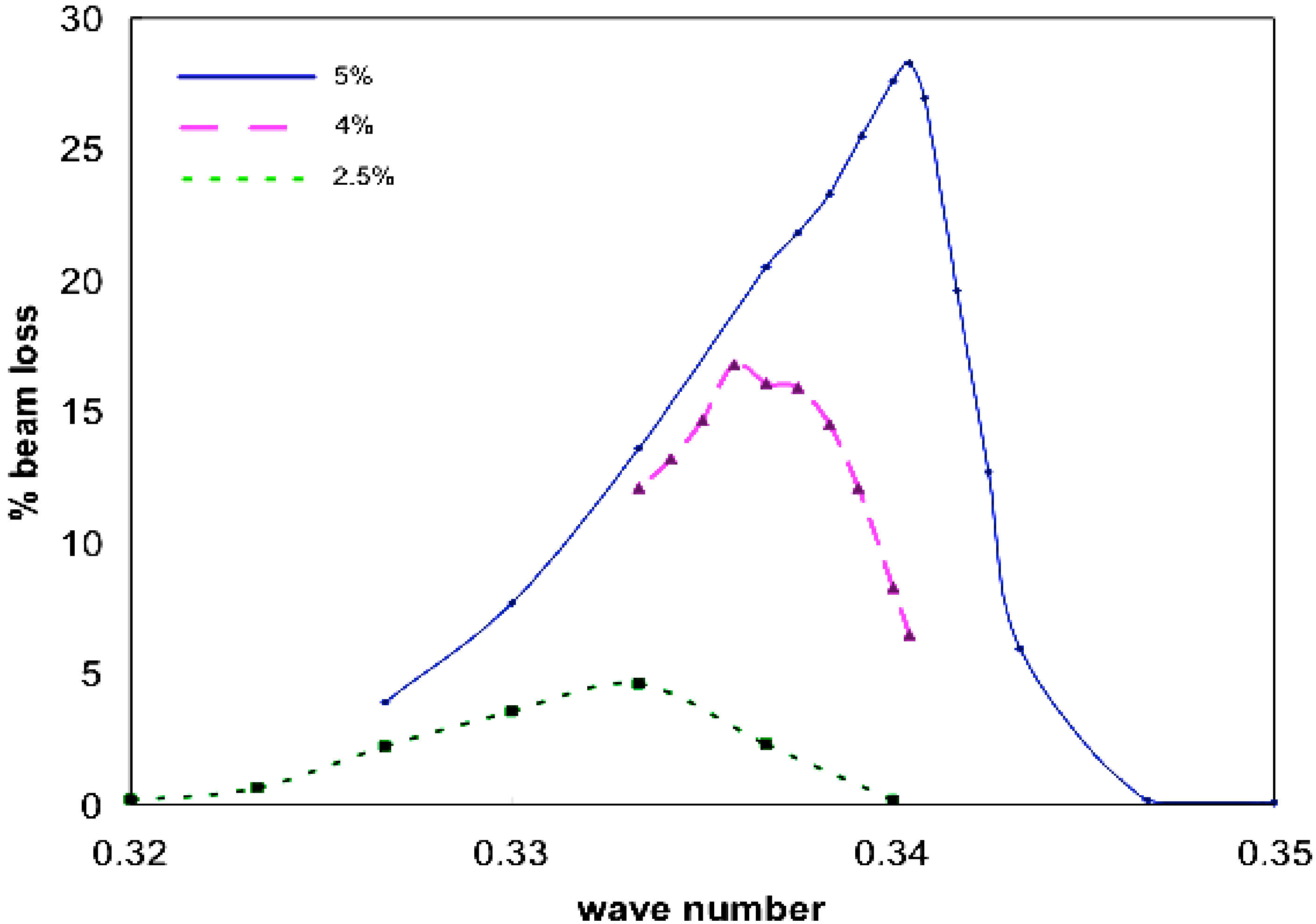
20% n_e with random transverse offsets produces less beam loss, halo, emittance growth



20% n_e with random radial shape variation produces still-less degradation



RESONANT perturbations are more damaging: 0-10% sinusoidally varying n_e resonant with breathing mode



Max $\Delta I \sim (n_e/n_b)^p$, p ~ 2.3 - 2.6

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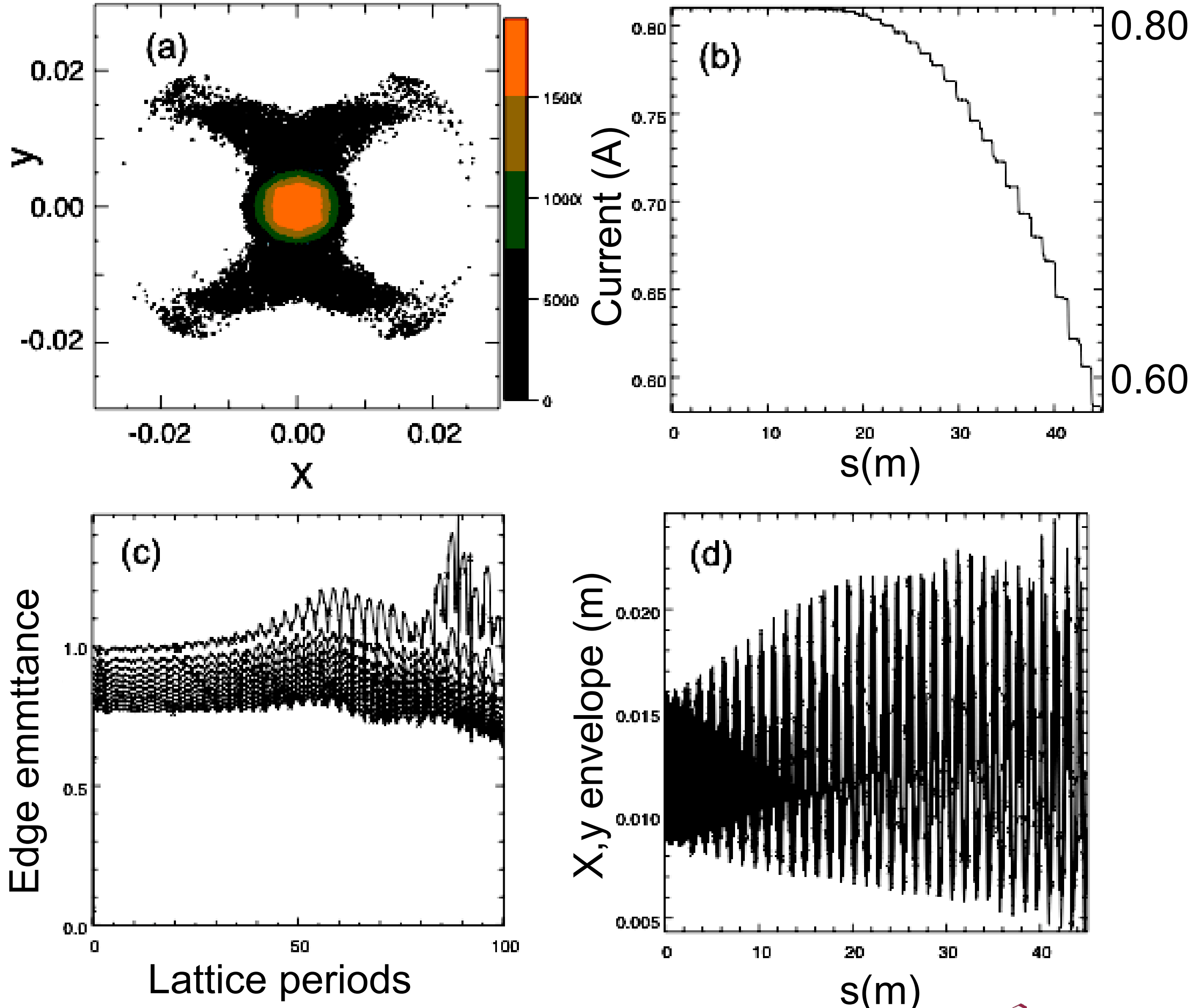
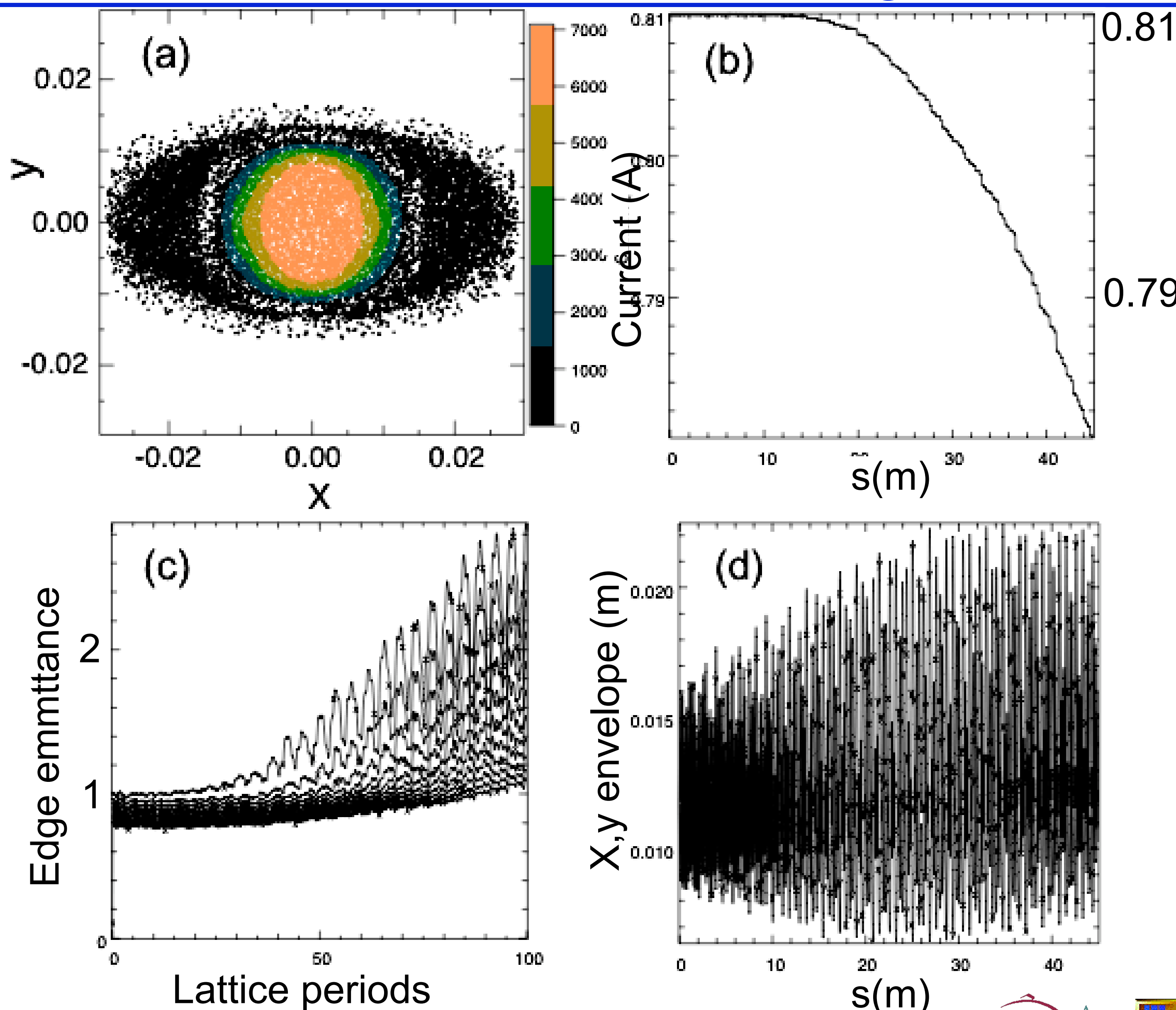
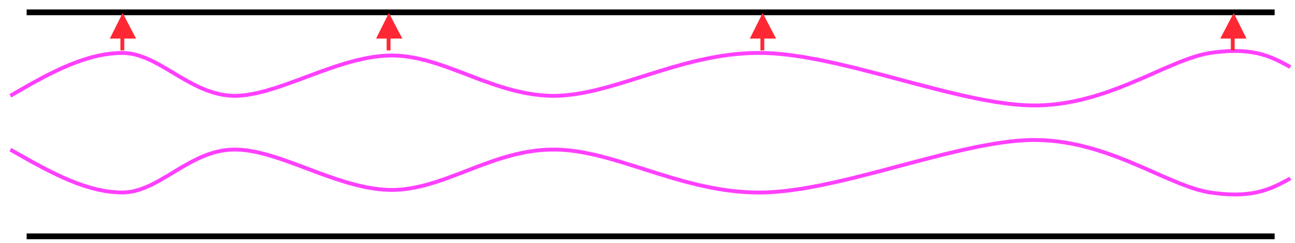


Ellipticity resonant with q-pole oscillation (10% n_e) produces small beam loss but more bulk emittance growth



Pertubation-induced loss + desorption potentially a source of instability

- Mechanism:
  - Electron density variations produce enhanced envelope osc.
  - Envelope peaks reaching wall desorb gas



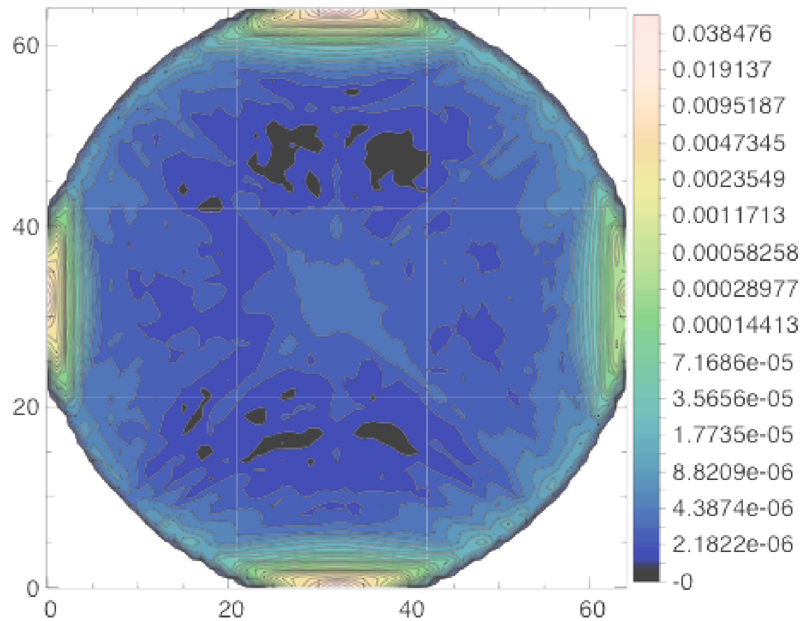
  - Gas ionizes, producing more electrons
  - Electrons ~ immobile in beam direction due to quadrupoles
  - Perturbation will grow or not depending on spatial phase relations
  - Wouldn't require const wavenumber (acceleration allowed)
- Very crude estimate of growth rate ~ 1 μs for parameters of simulation
- Better calculation in progress

Self-consistent e-i simulation requires technique to bridge timescales

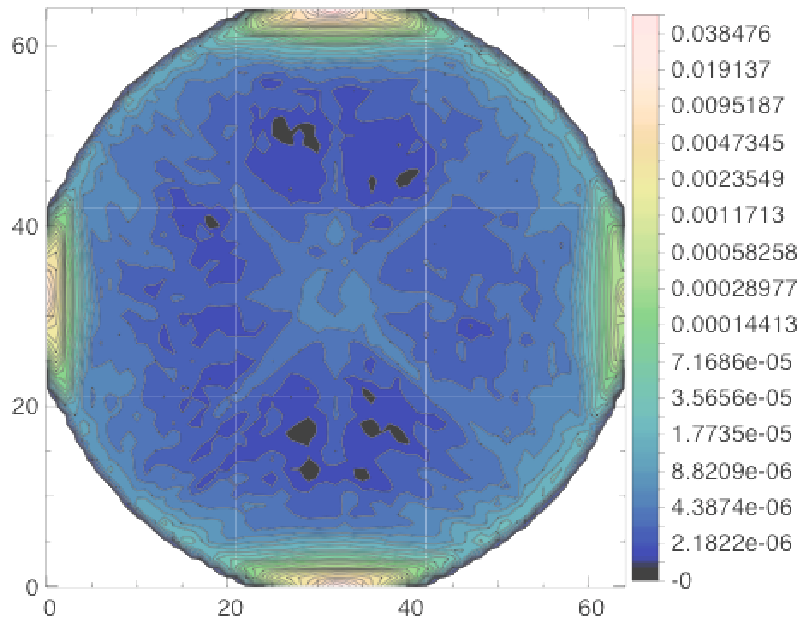
- Need to follow electrons through strongly magnetized and unmagnetized regions ⇒ need to deal with electron cyclotron timescale, ~ 10^{-11} sec.
- Ion timescales > 10^{-8} sec.
- Algorithm to bridge: interpolation between full-electron dynamics (Boris mover) and drift kinetics (motion along B plus drifts).
- Properly chosen interpolation allows stepping electrons on bounce timescale (~10^{-9} sec) yet preserves:
  - Drift velocity
  - Parallel dynamics
  - Physical gyroradius

Interpolated model reproduces the e-cloud calculation in < 1/25 time

- Compare full-orbit model, $\Delta t = .25/f_{ce}$, with interpolated model with Δt 25 times longer



Full-orbit



Large-timestep interpolated

Summary/conclusions

- High current, fill factor, pulse length, unclean walls of HIF induction accelerators $\Rightarrow$ dominant electron source is ionization of neutrals released from walls
  - except ion-impact-produced wall-born electrons for short pulse expts or after drift compression
- Developing self-consistent modeling capability for e-cloud formation, dynamics, effects on ions
- Simulation of dynamics of wall-born electrons from ion impacts shows importance of keeping scattered ions
- Simulation of ion evolution with various model electron distributions shows:
  - effect of random amplitude variations > random offsets > const n_e
  - Resonant sinusoidal perturbations more potent, especially amplitude resonant with breathing mode.
  - Ion beams surprisingly robust: 20% const n_e little effect; several percent resonant perturbation needed for significant impact
  - Possible instability associated with resonant perturbations.