Space-Charge Simulations of UMER

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Simulation/Experiment Integration Central to UMER Program

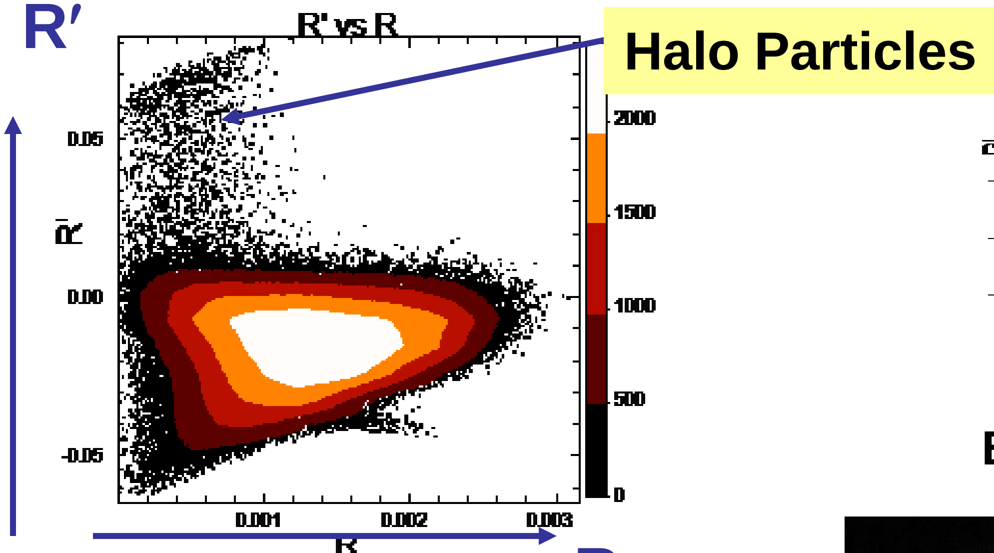
- Simulation (including space-charge when necessary) extensively used from early design, through commissioning, to current research.
- Close agreement obtained between the code (mostly WARP here) and experiment.
- Examples:
  - Halo Mitigation
  - Bunch-end interpenetration
  - Multi-Stream Instability
- Ability to achieve close agreement gives confidence both in understanding of the experiment as well as in the code fidelity.

WARP used for space-charge Simulation: Hybrid Accelerator/Plasma Code

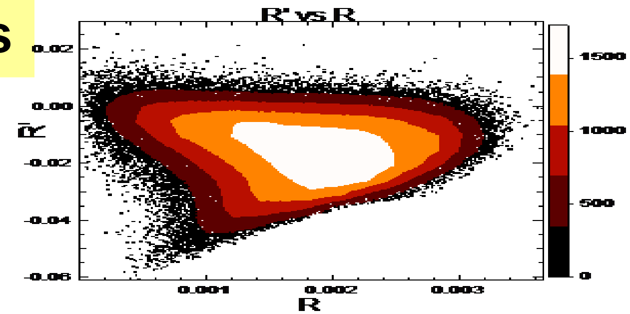
- **Geometry:** 3D (x,y,z), 2D-1/2 (x,y), (x,z) or axisym. (r,z)
- **Multiple Descriptions of Lattice Elements:**
  Hard edged, gridded, moment
- **Python and Fortran:** "steerable," input decks are programs
- **Field solvers:**
  Electrostatic - FFT, multigrid; AMR; implicit
  Magnetostatic - FFT, multigrid; AMR; implicit
  Electromagnetic - Yee, Kark, PSATD; PML; AMR
- **Parallel:** MPI (1, 2 and 3D domain decomposition)
- **Boundaries:** "cut-cell" --- no restriction to "Legos"
- **Reference frame:** lab, moving-window, Lorentz boosted
- **Surface/volume physics:** secondary e-/photo-e- emission, gas emission
- **Diagnostics:** extensive snapshots and histories

Courtesy J.-L. Vay

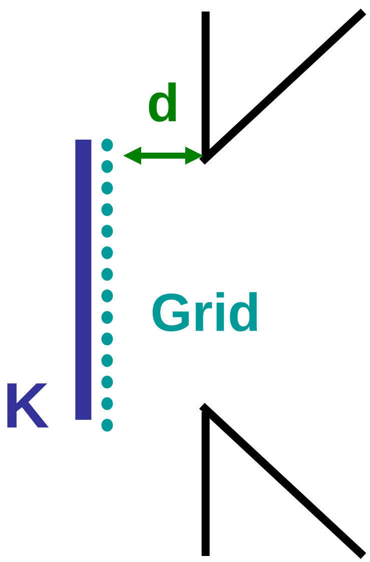
UMER: Simulations Traced Halo to Cathode

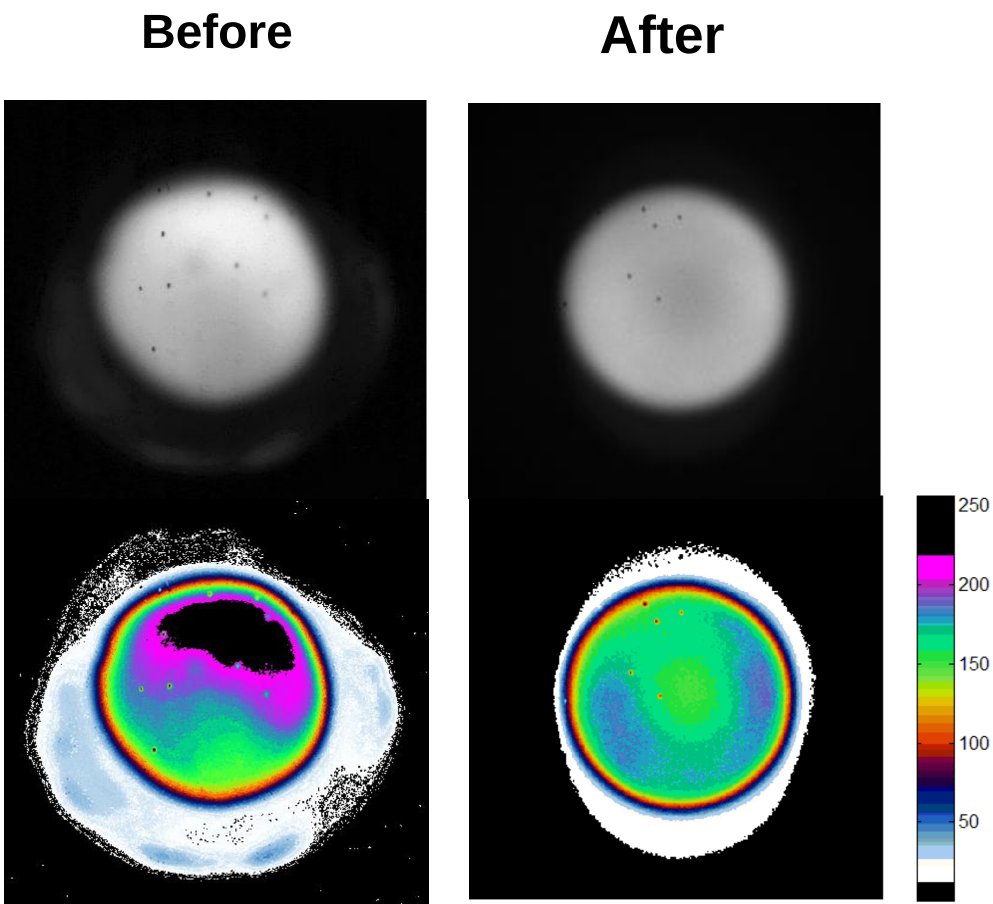


d = 0.5 mm



d = 0.1 mm

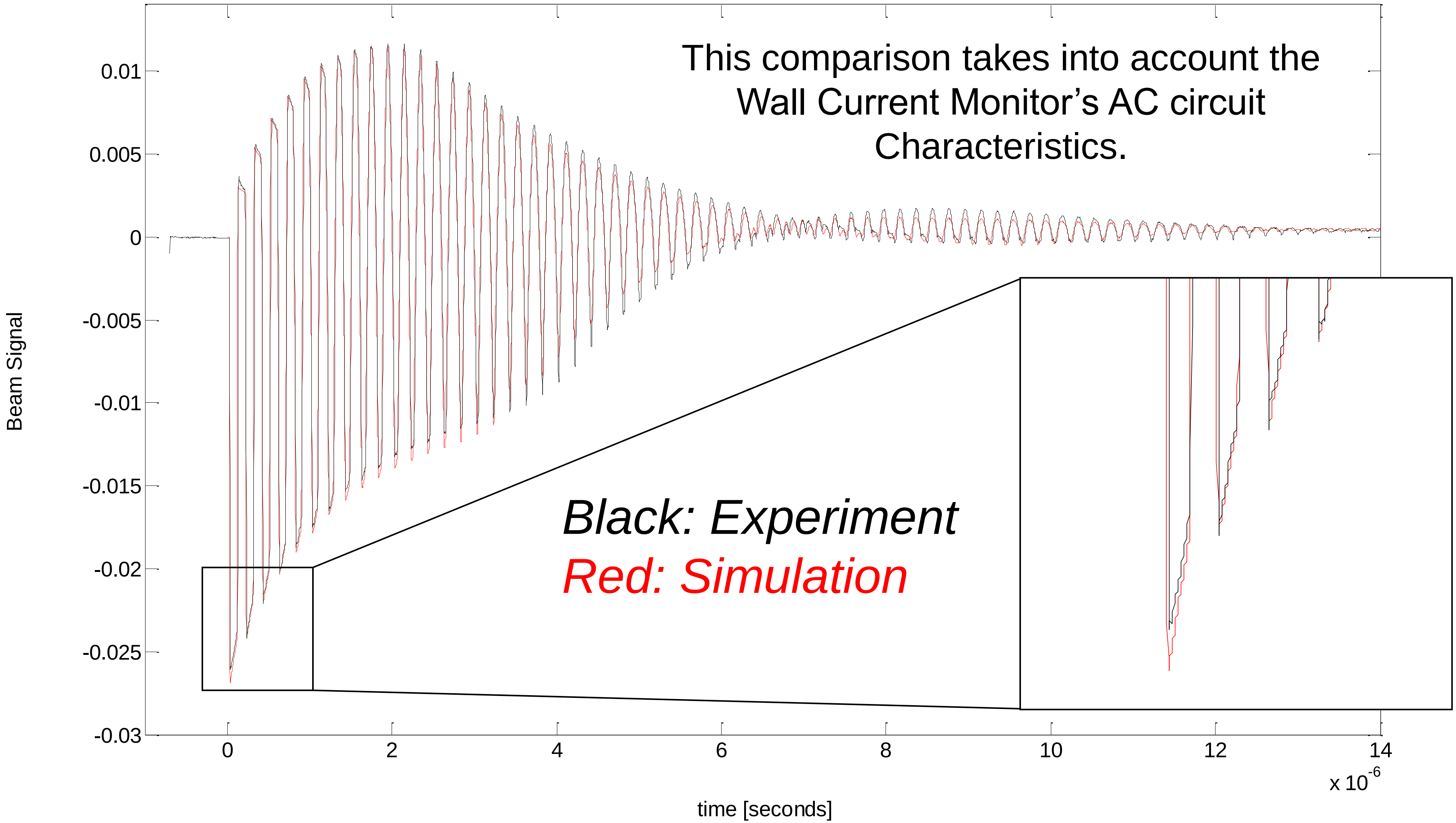




Simulation Credits: Haber
Data: Bernal/Walter/Haber/Kishek

Simulation/Code Comparison

Bunch-lengthening without Longitudinal Focusing

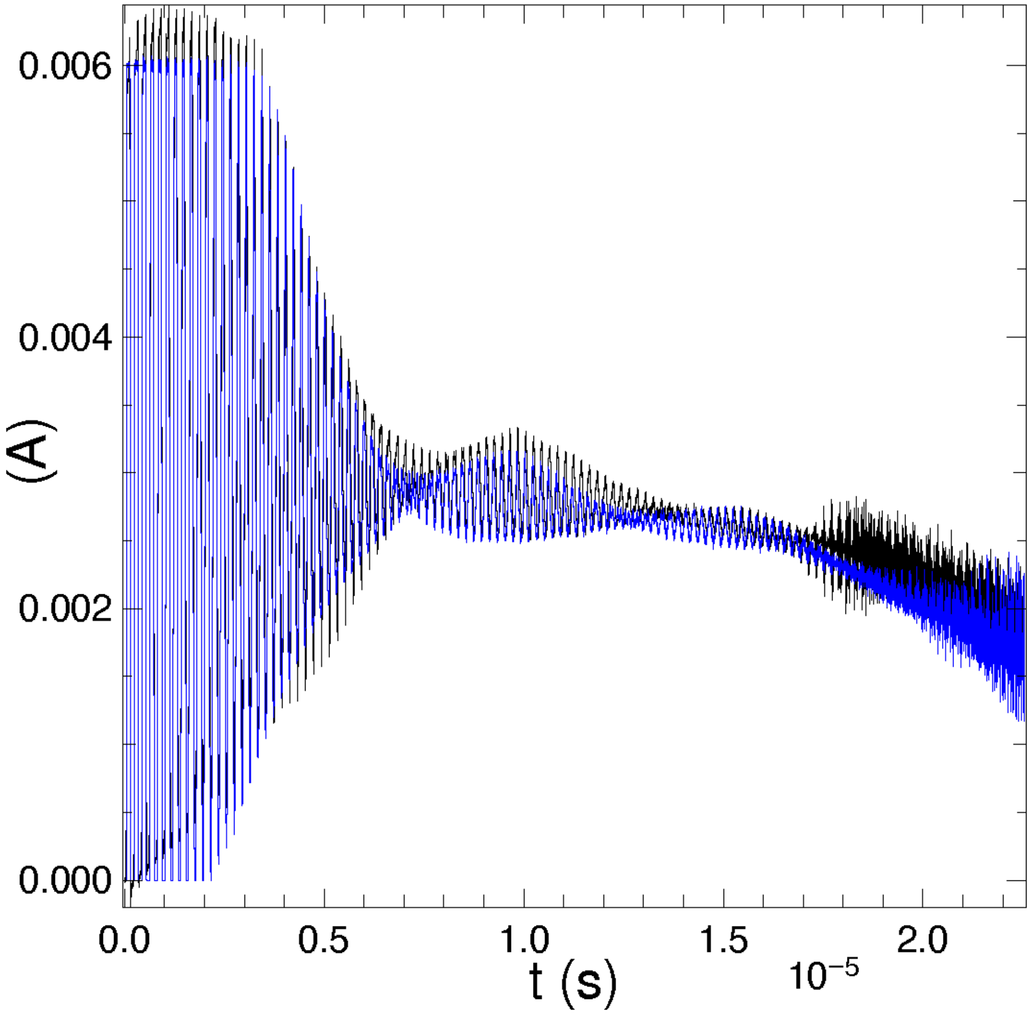


Koeth, Haber, et al., PAC 2011.

Multi-Stream Instability Observed and Simulated

- Overtaking and interpenetration eventually create multiple streams.
- Successive streams are closer in velocity.
  - As the stream velocity separations near the wave-propagation velocity the beam become unstable.
  - The unstable wavelength is of order of several pipe diameters.
  - This instability is in addition to the normal plasma two-steam mode which occurs at a shorter wavelength and saturates at a low level.
- The unstable behavior is seen both in simulation and experiment.

AC + DC Current vs. TIme

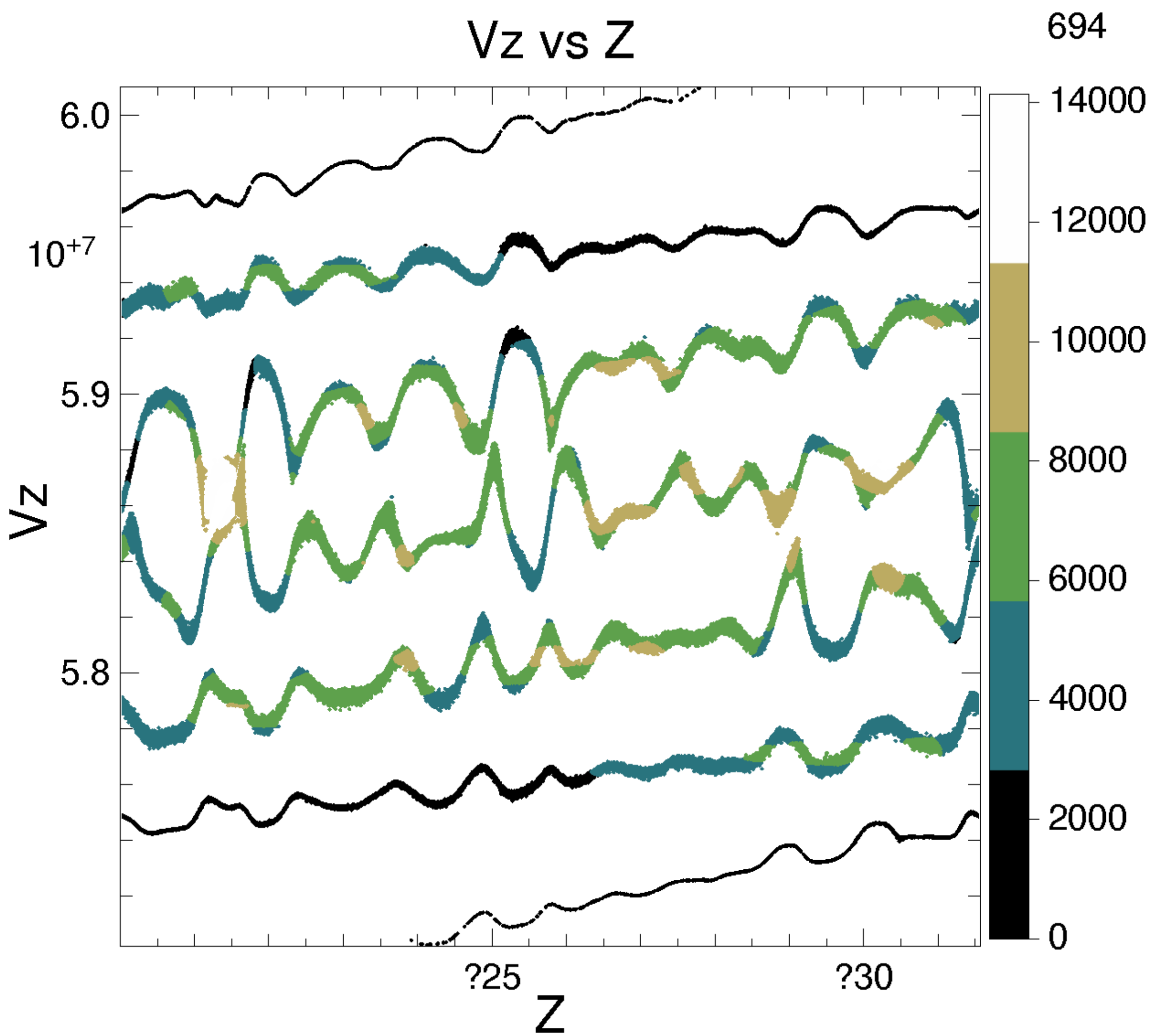


Comparison of current from experiment (black) and simulation (blue). Onset of instability in experiment is observed earlier than in simulation. (Ongoing)

Conclusion

- The simulations work.

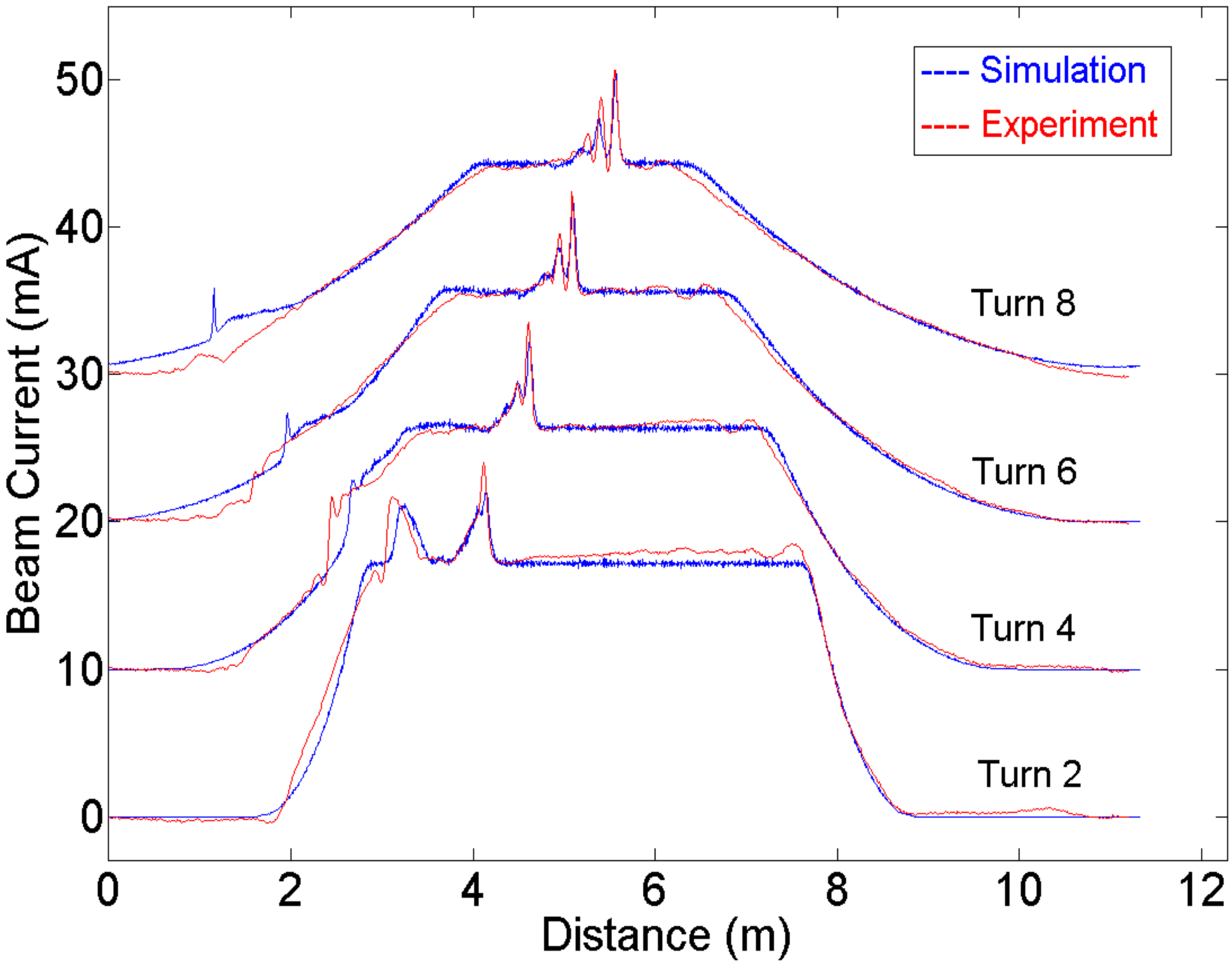
Extras



z-Vz phase space from the simulation after the instability is well developed. Unstable wavelength is ~1m, compared to ~0.05m pipe diameter.

Soliton Train Formation from Large Initial Perturbation

- Laser illumination used to initiate a short-pulse large-amplitude current perturbation.
- After several turns initial pulse evolves into a soliton train.
- Tests used to verify soliton characteristics
  - Shape preserved after collisions
  - Product width^2*amplitude is constant
- Simulation/experiment agreement achieved
  - Agreement requires some adjustment of initial pulse width from what is expected.

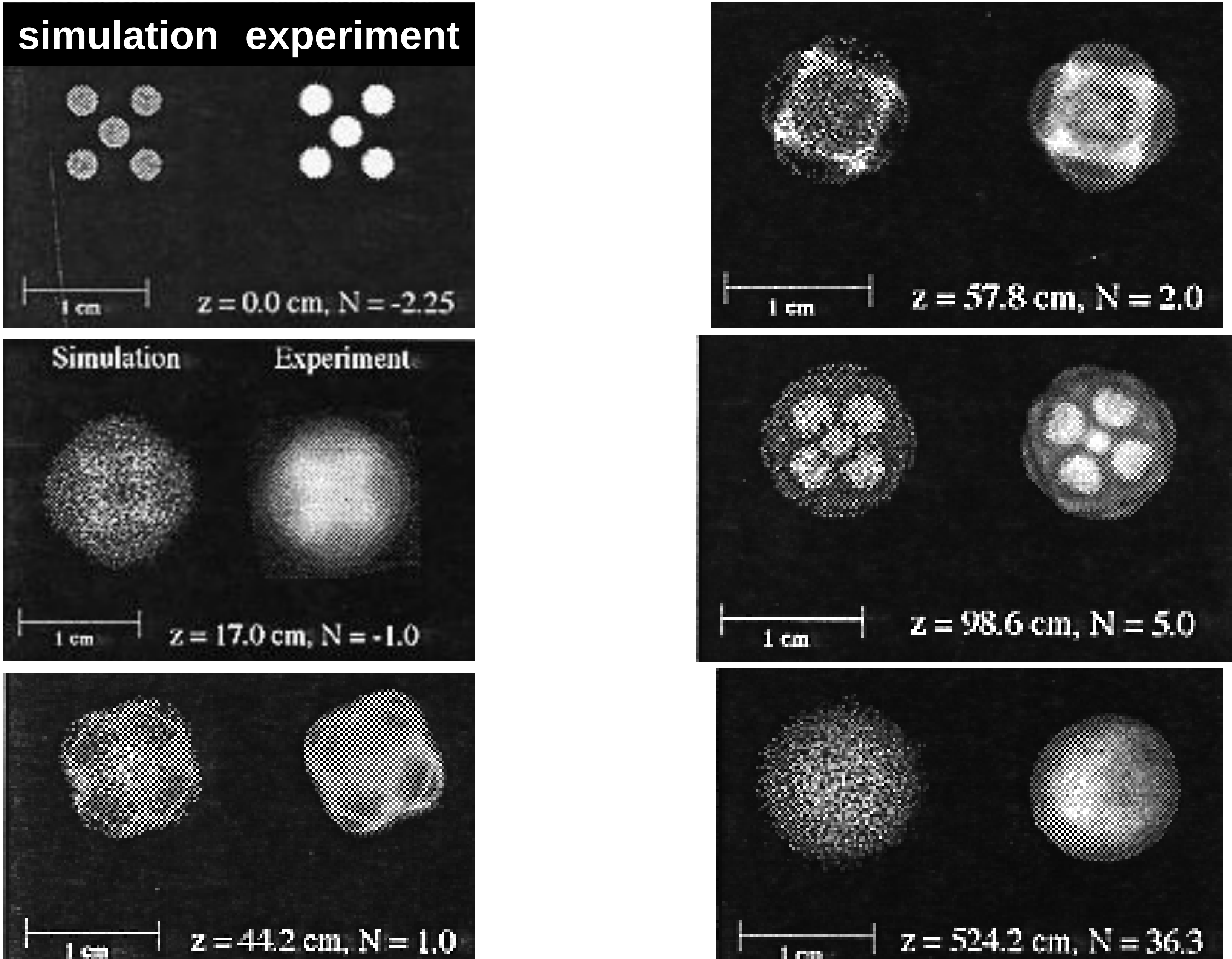


---- Simulation
---- Experiment
Turn 8
Turn 6
Turn 4
Turn 2
Beam Current (mA)
Distance (m)
0
10
20
30
40
50
0
2
4
6
8
10
12

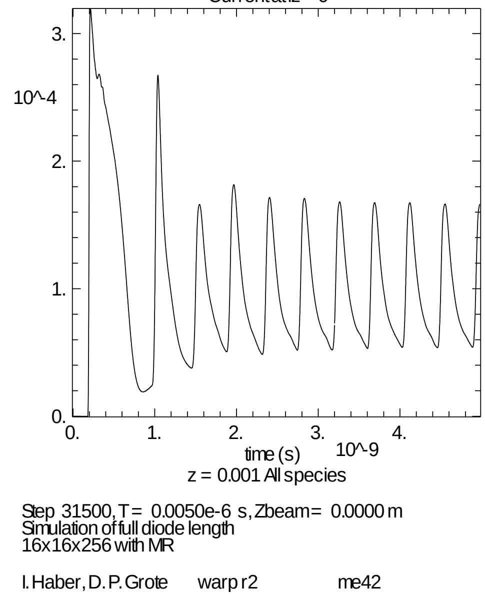
WARP Success at UMD

- Transverse
  - Five-Beamlet Evolution (Haber, et al, Phys. Rev. A15, 44, 5194 (Oct. 15, 1991).
  - Identification of Source-generated halo I. Haber, et. al.NIM-A **606**, 64-68 (2009).
- Longitudinal (r-z geometry)
  - Bunch-end interpenetration (Koeth, PAC)
  - Soliton Formation (Charles Thesis)
  - Multi-Stream Instability
- Three-Dimensional
  - Prediction of virtual cathode oscillations in UMER gun I. Haber, et. al. NIM-A **577**, 157-160 (2007).

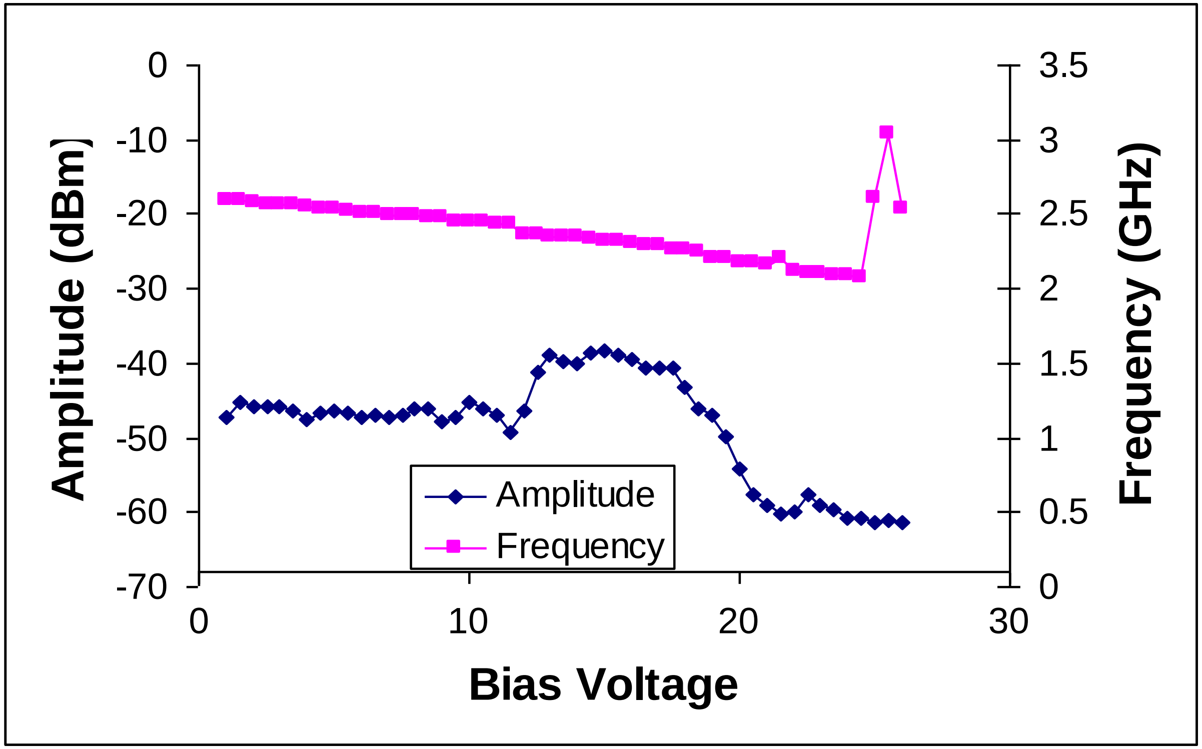
RMS Matched Beam ~1989



Virtual cathode oscillations predicted by simulation were measured by spectrum analyzer near predicted frequency.



Simulated current waveform



Peak of measured spectrum