A NOVEL OPTICAL METHOD FOR MEASURING BEAM PHASE AND WIDTH IN THE RUTGERS 12” CYCLOTRON

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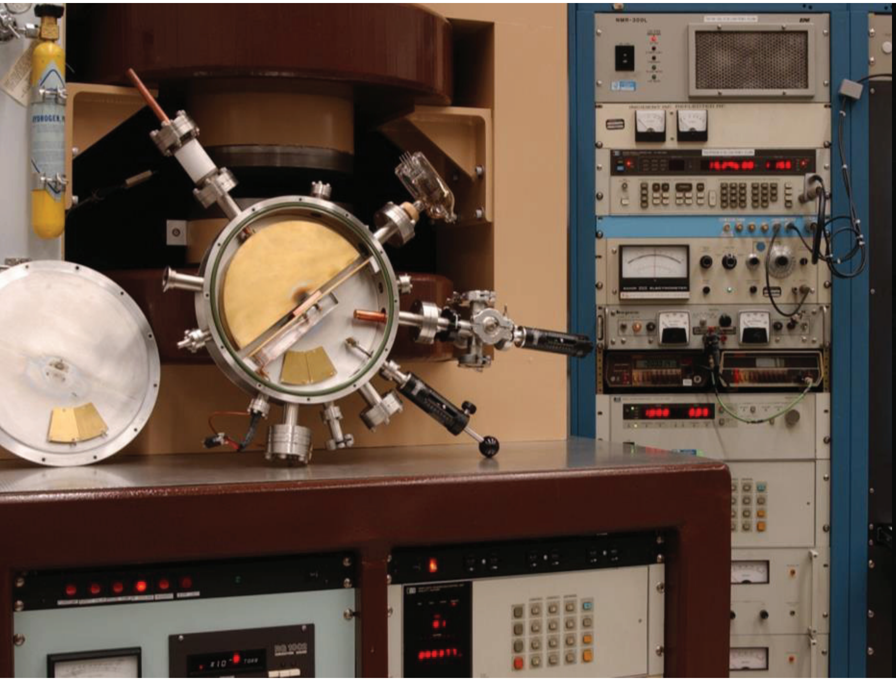
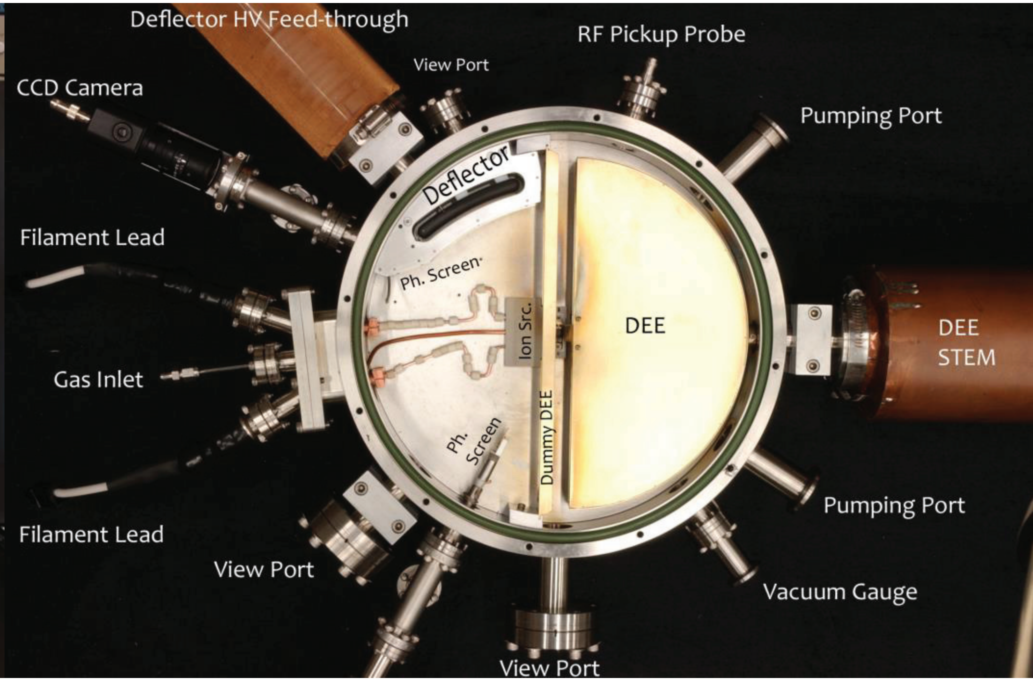
Outline

- Introduction:
  - Rutgers 12” cyclotron
  - Motivation for beam phase measurement
  - Phase slippage
- Simulation
  - Poisson Superfish
  - SIMION
- Experimental setup
- Results:
  - Data processing
  - Bunch length measurement
  - Beam phase analysis
- Improvements & conclusions

The Rutgers 12” Cyclotron

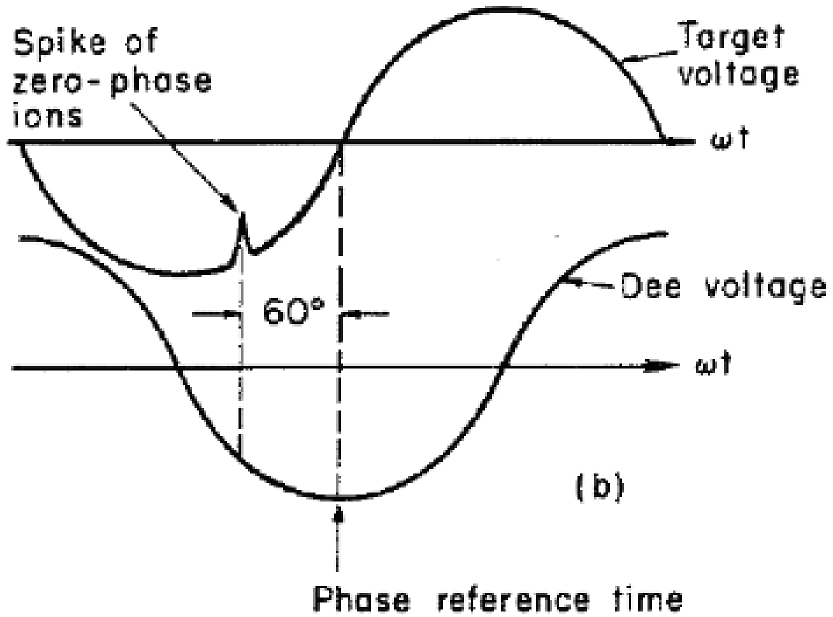




- Weak focusing (radially tapering) pole tips
- Operating conditions:
  - Beam pulse frequency: 20 Hz
  - RF frequency: 7.8 MHz
  - RF power: 1.25 kW

Motivation

- Goal: develop technique to measure cyclotron isochronicity via beam phase assessment
- Development of technique with a weak focusing field, for use on other pole tips (i.e. spiral AVF)
- In accelerating gap, RF fields induce voltages that are orders of magnitude higher than beam signal
- Direct optical measurements circumvent such fields

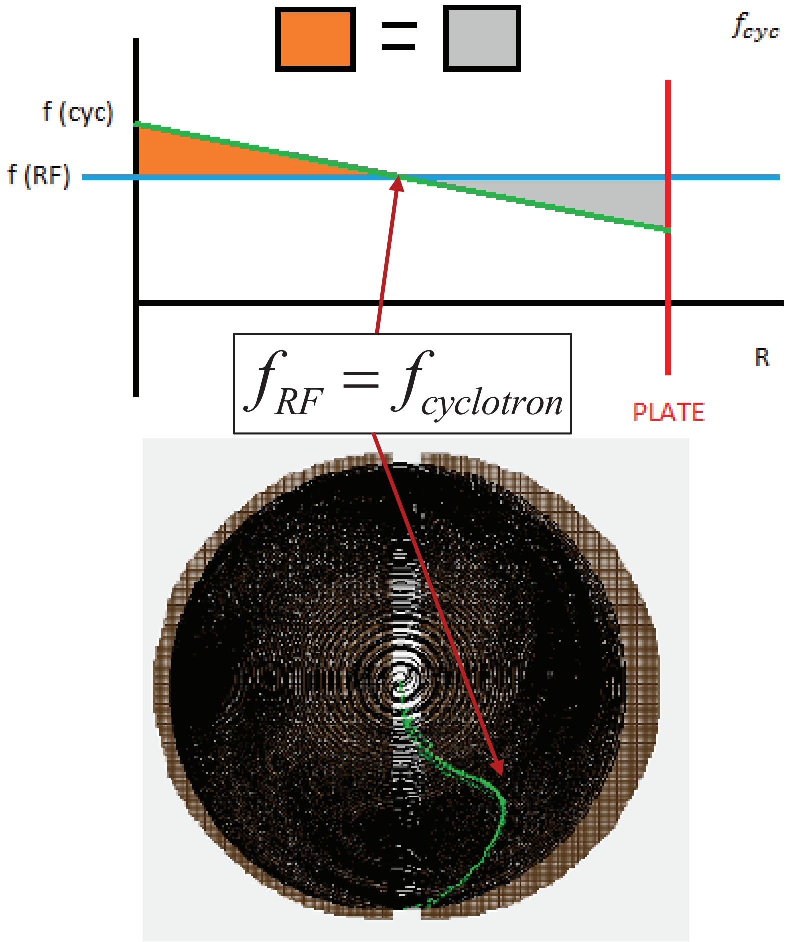


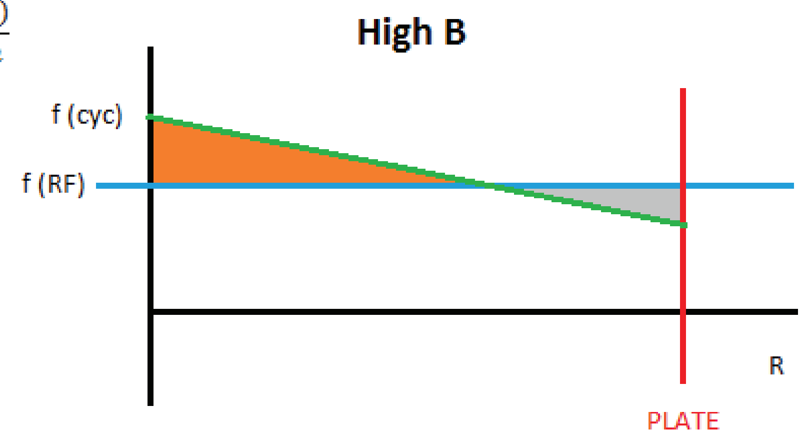
C.G. Dols. “Measurement of Beam Phase of the Berkeley 88-inch Cyclotron”. 1962.

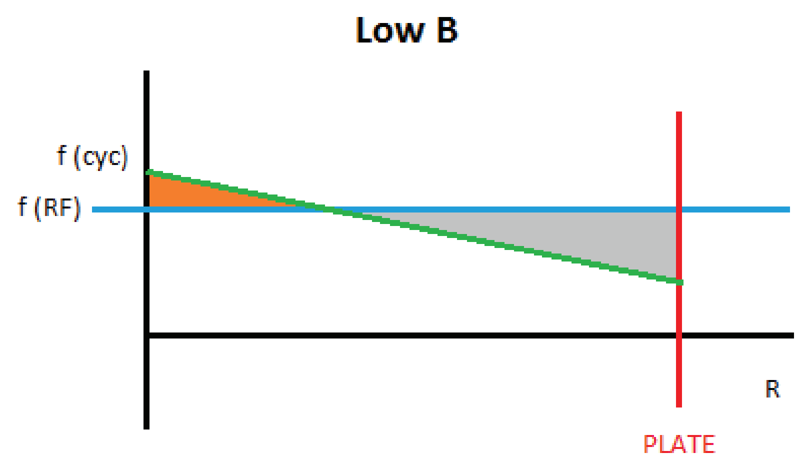
Phase Slippage

- Weak focusing cyclotron: phase slippage during ion flight
- Cyclotron condition met at one radial location

$$f_{cyc} = \frac{qB(r)}{2\pi m}$$





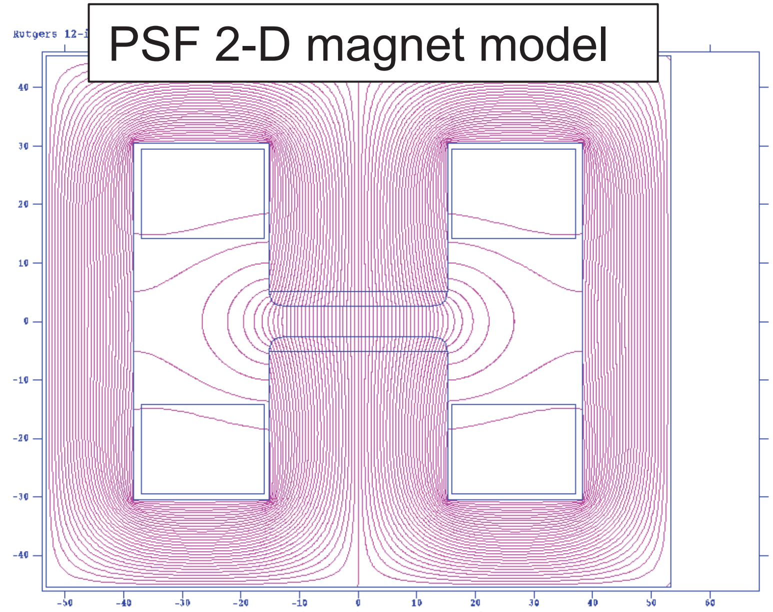


Simulation

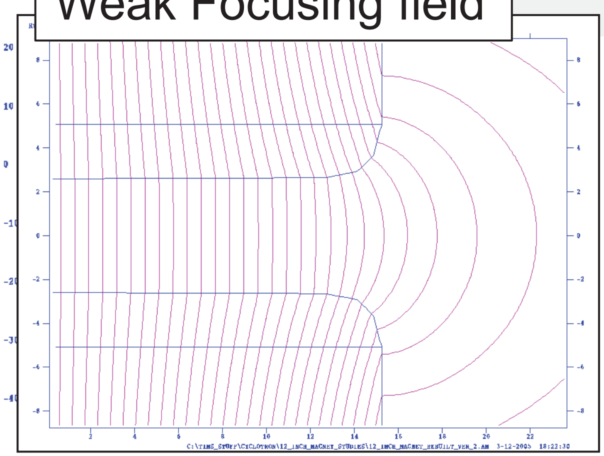
- Magnetic field was modeled using Poisson Superfish (PSF)
- SIMION was used to simulate the trajectory of protons in the cyclotron

SIMION Rutgers cyclotron model

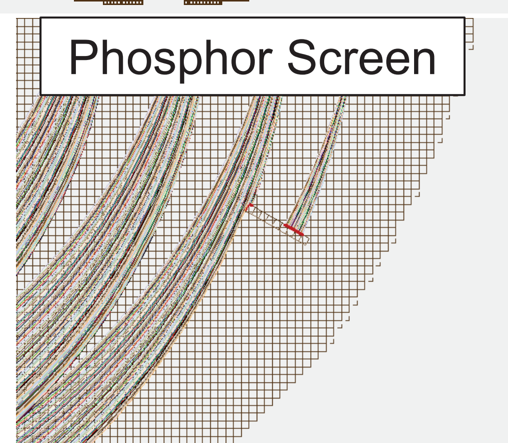
PSF 2-D magnet model



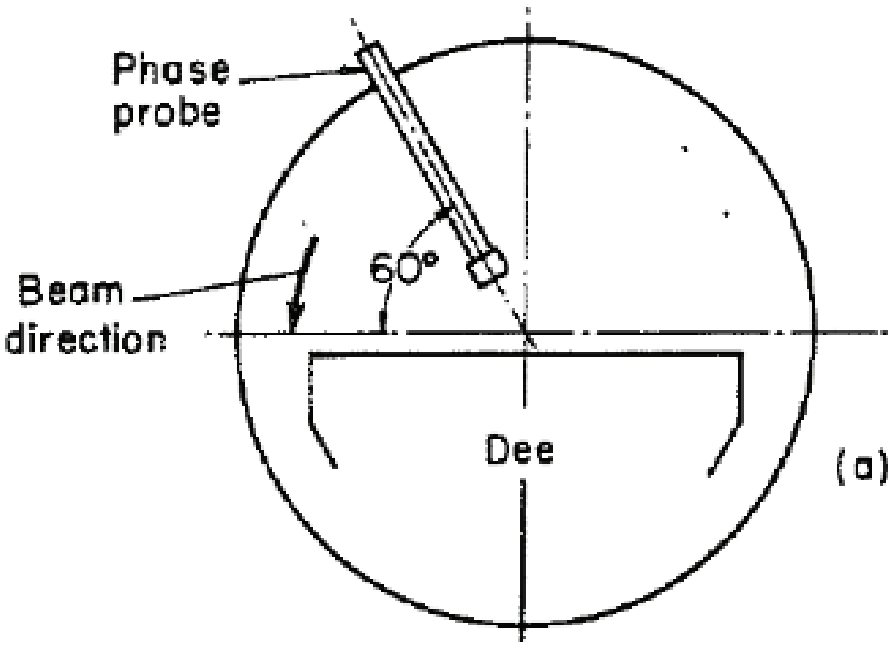
Weak Focusing field

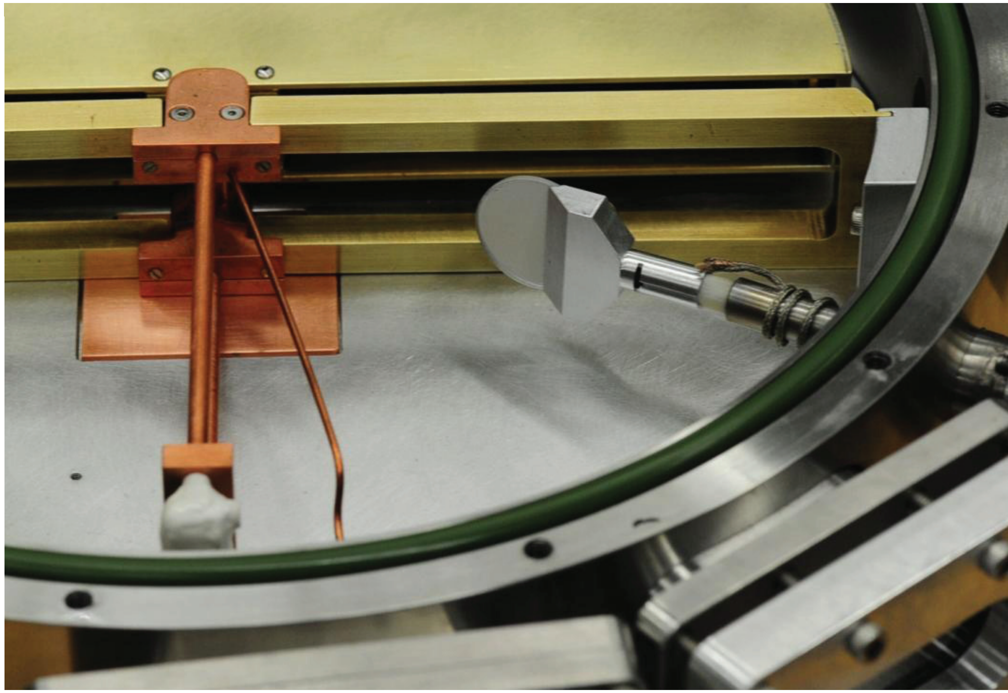


Phosphor Screen



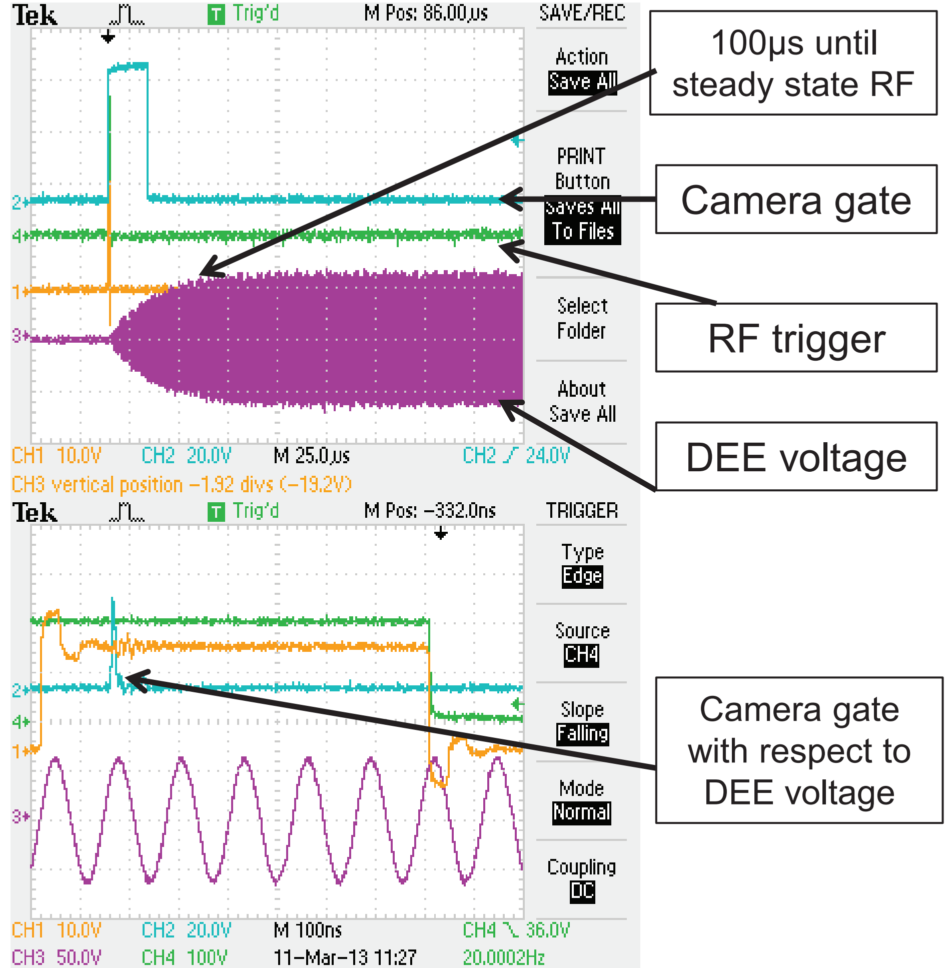
Fast Phosphor Screen





- Phosphor Screen:
  - 0.944-inch diameter ZnO:Ga doped “fast” phosphor deposit
  - 3ns 1/e relaxation time
  - Back illuminated: quartz is last layer that ions pass through
- Backing:
  - 0.050 inch thick quartz substrate
  - 1000 Å aluminium coating

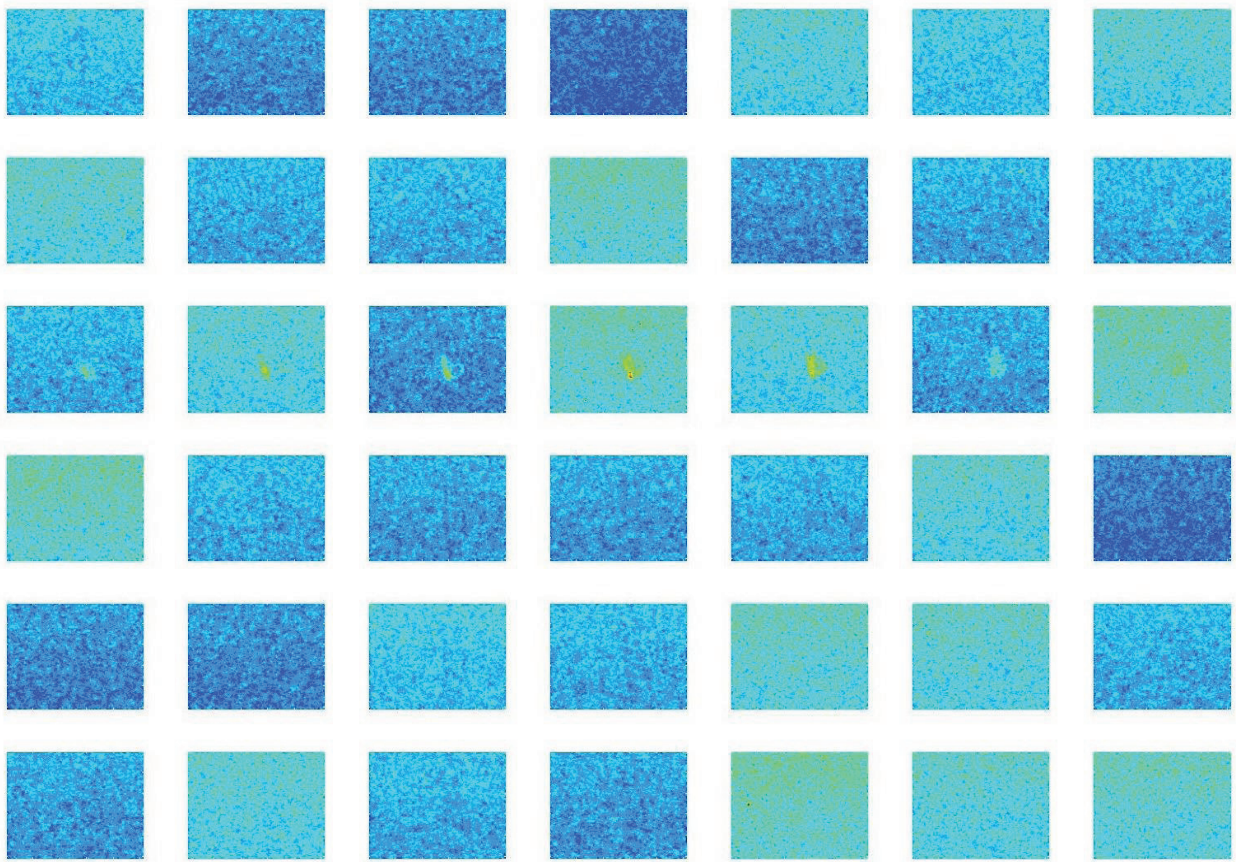
Gated Camera Setup



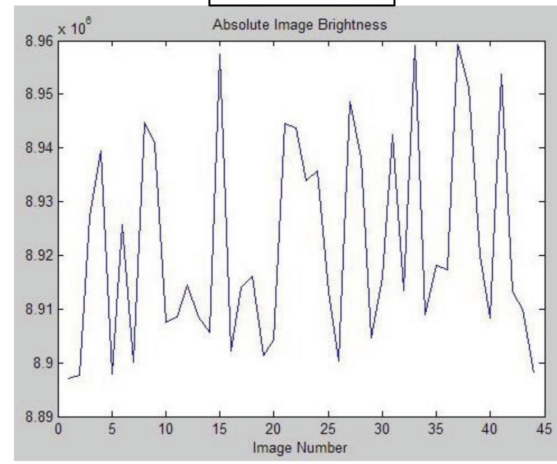
- Princeton Instruments PI-MAX 2 ICCD gated camera: 3ns shutter time, 16 bit image production
- Trigger synchronized to RF trigger using SRS DG535 digital delay generator
- Dataset: 44 3ns time steps to cover one RF period (128 ns), 900 integrations per time step

Image Processing

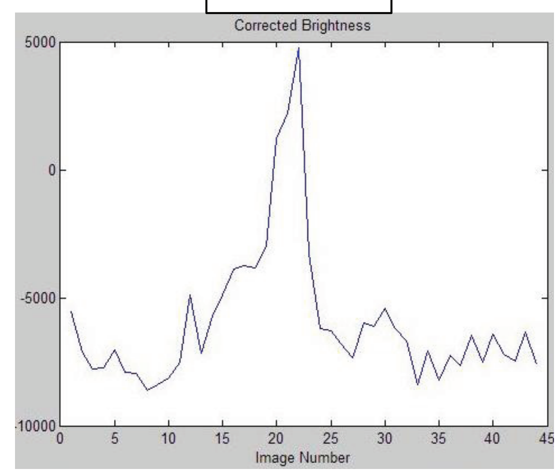
- Average intensity over entire image was subtracted from user-specified image area (beam spot) to pull the signal from the noise



Before

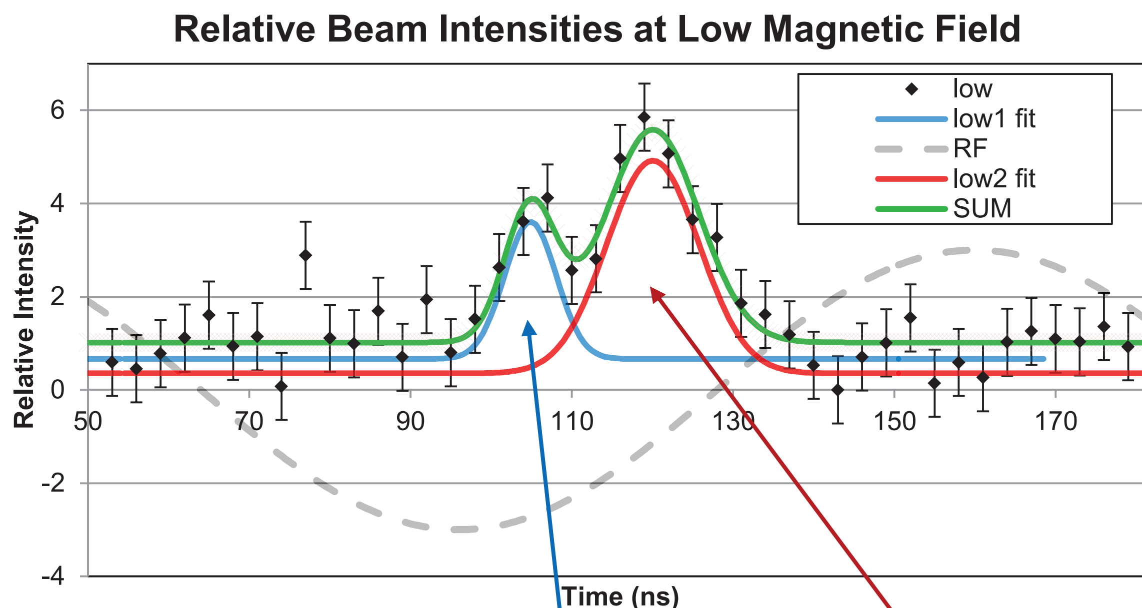


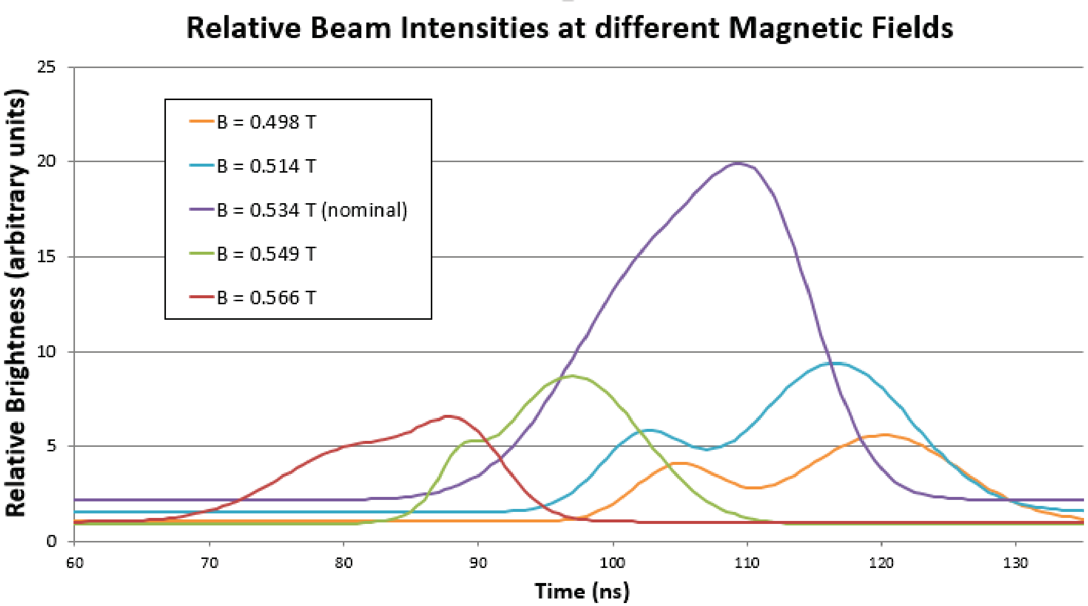
After

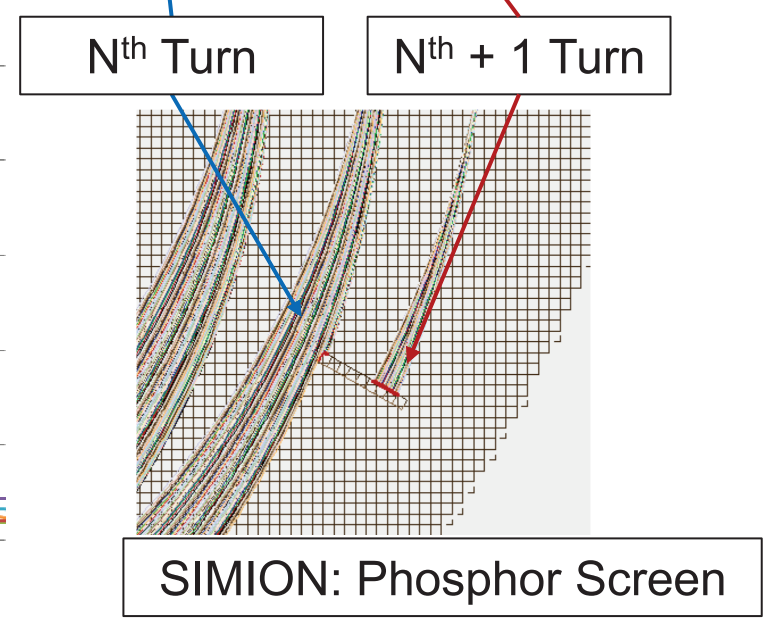


Analysis

- Two peaks in intensity during the same RF phase, providing a direct measurement of turn-to-turn phase slippage
- Verified in SIMION simulation

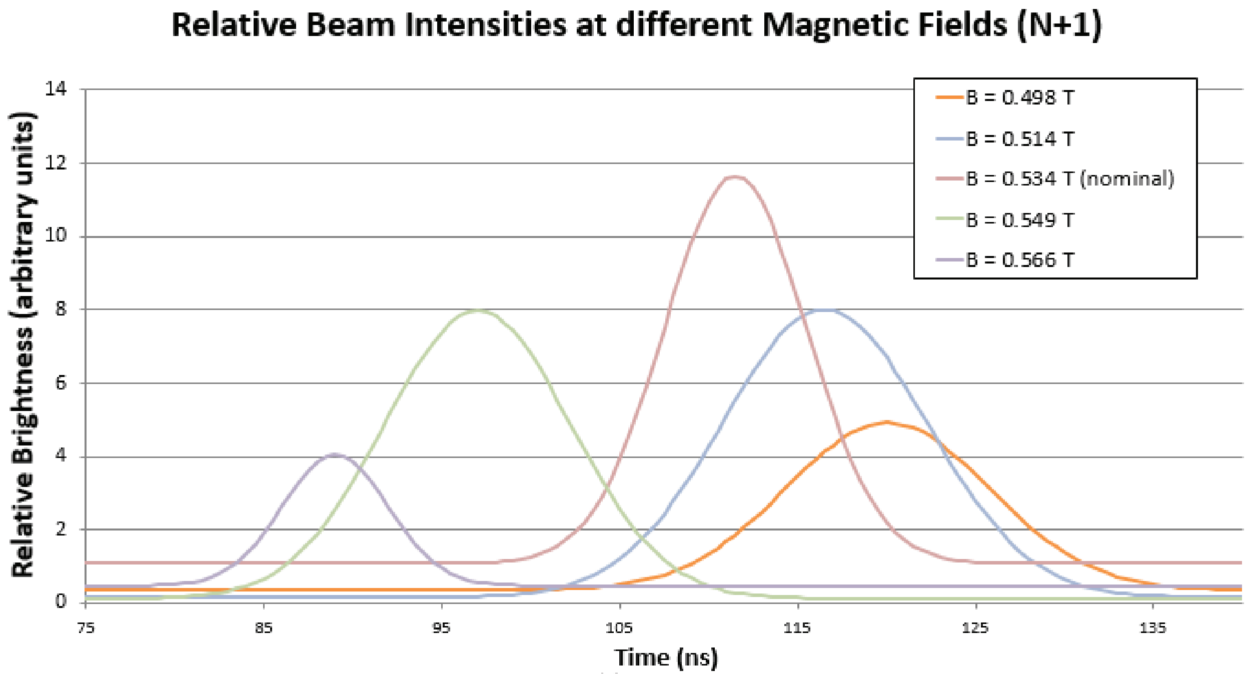


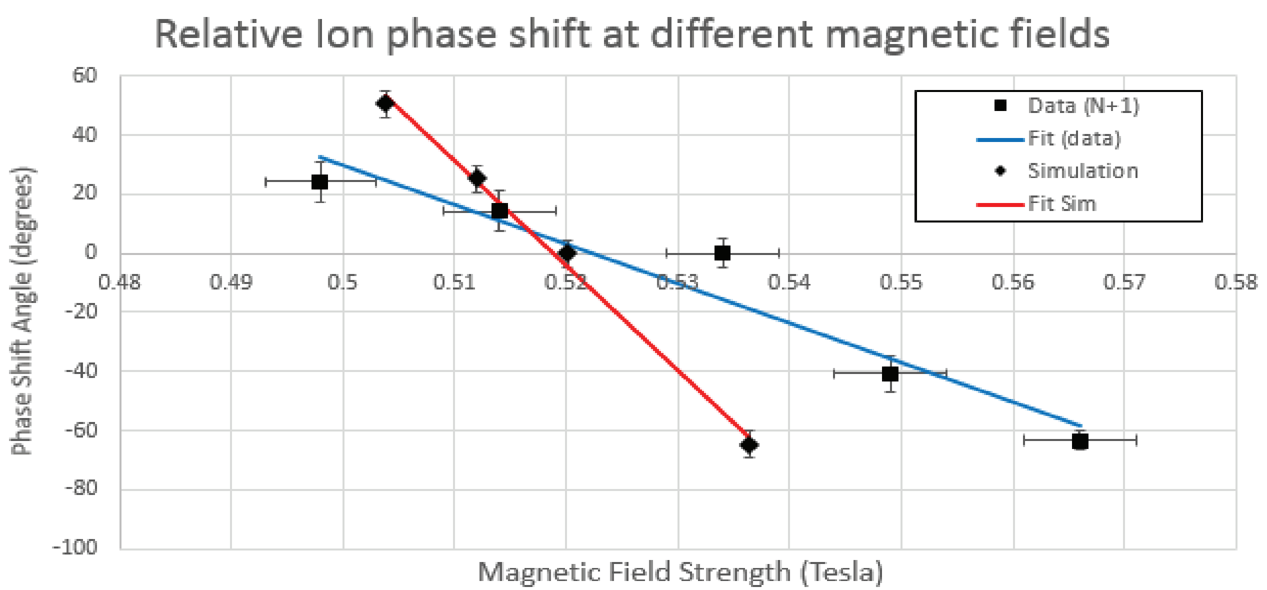




Phase Shift

- Isolated the $N^{th}+1$ turn peaks
- Compared data to simulation
- Qualitative agreement is good, but absolute agreement will require further studies



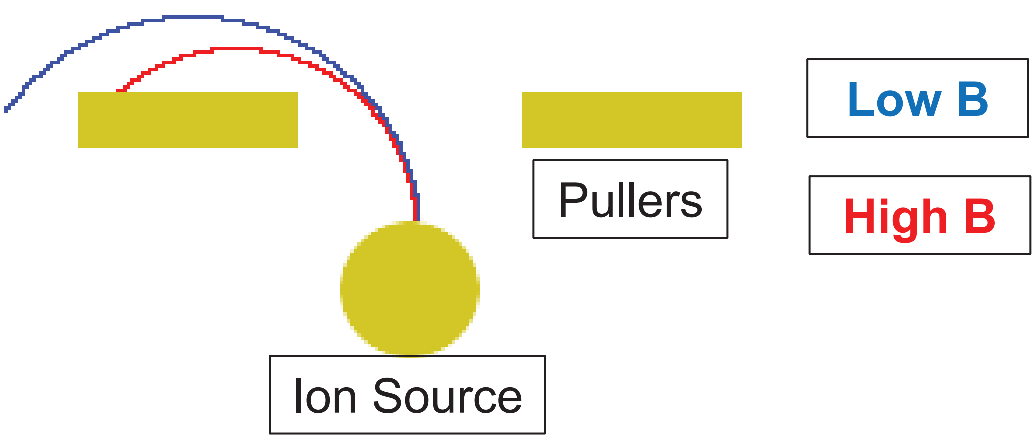


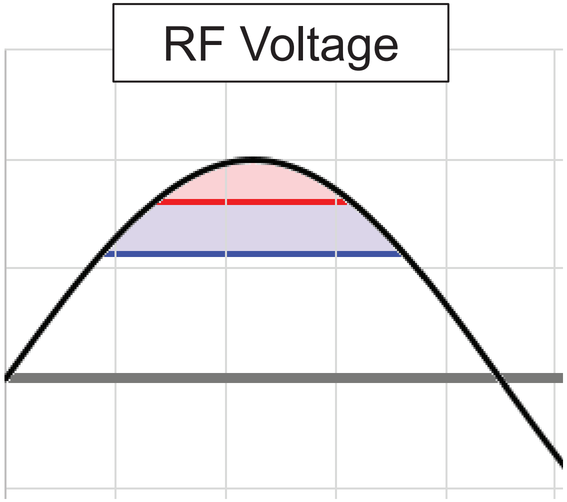
Bunch Length

- Bunch length was taken to be the full width half maximum of the Gaussian fits
- Tended to decrease with increasing magnetic field

Magnetic Field [T]	Bunch Length [degrees]
0.498 ± 0.005	38 ± 4.5
0.534 ± 0.005	26 ± 4.5
0.566 ± 0.005	20 ± 4.5

- Decreasing the B field decreases the radius of curvature. This increases the "first-turn acceptance" for ions.





Improvements

- Make a rectangular “fast” phosphor screen that spans vertical beam height
- Make a screen with a thinner backing
- Place the camera closer to the view port (limited by magnetic field effect on gated camera cooling fan & lens)
- Improve RF cooling to enable operation in continuous wave (CW) mode

Conclusion

- Successful optical measurement of relative phase shift and bunch length
- Insensitive to DEE gap voltage
- Method is applicable to all cyclotrons
- Qualitative agreement with SIMION simulation (absolute agreement expected)