Straight Merger Test at CBETA

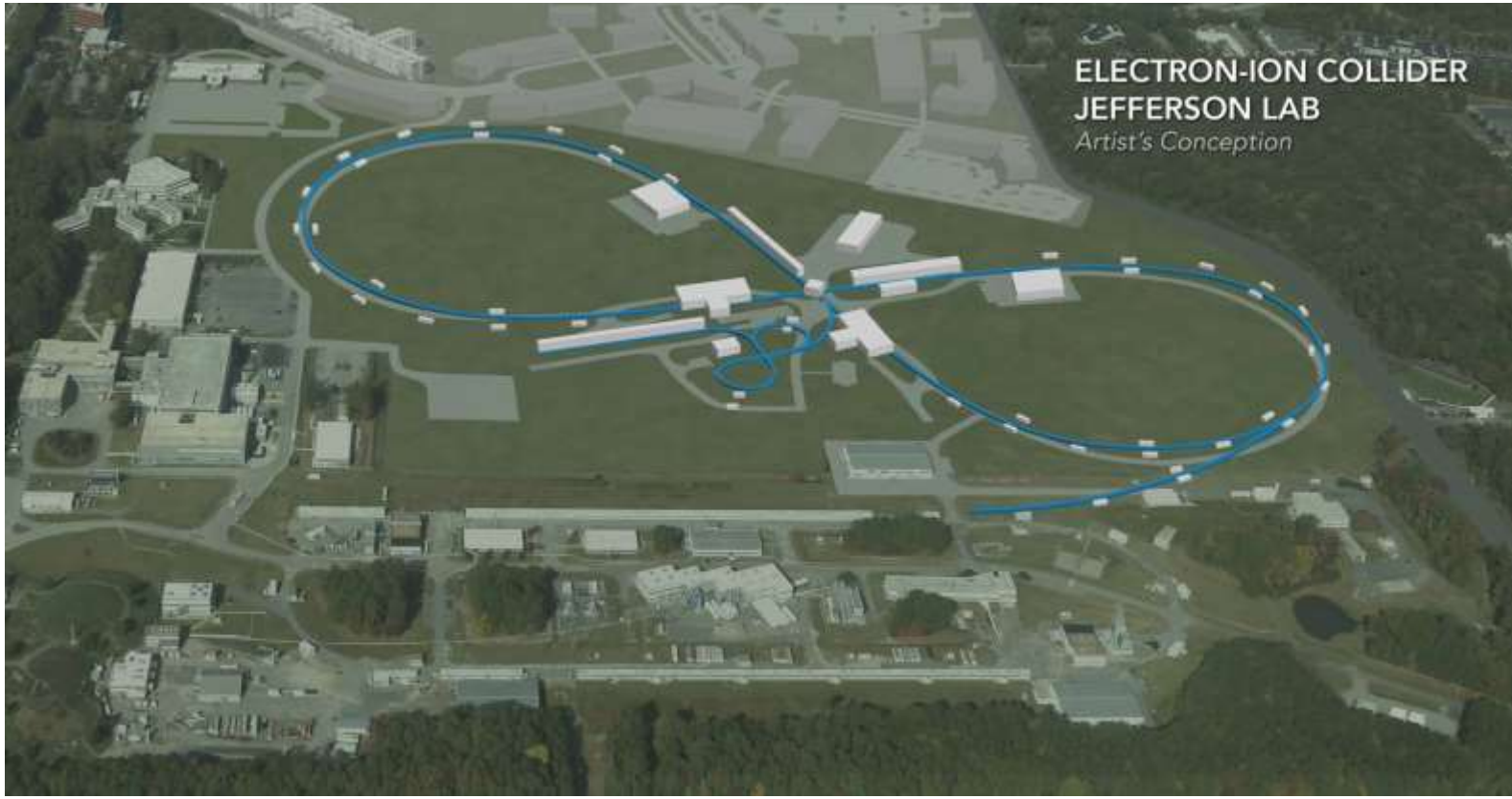
CORNELL-BNL ERL TEST ACCELERATOR

Kirsten Deitrick (*JLab*)

Collaborators:

Andrew Hutton (*JLab*)
Sarah Overstreet (*ODU*)

Adam Bartnik, Colwyn Gulliford
Karl Smolenski,
Georg Hoffstaetter
CLASSE



EIC Accelerator Collaboration Meeting

October 29 - November 1, 2018

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Outline

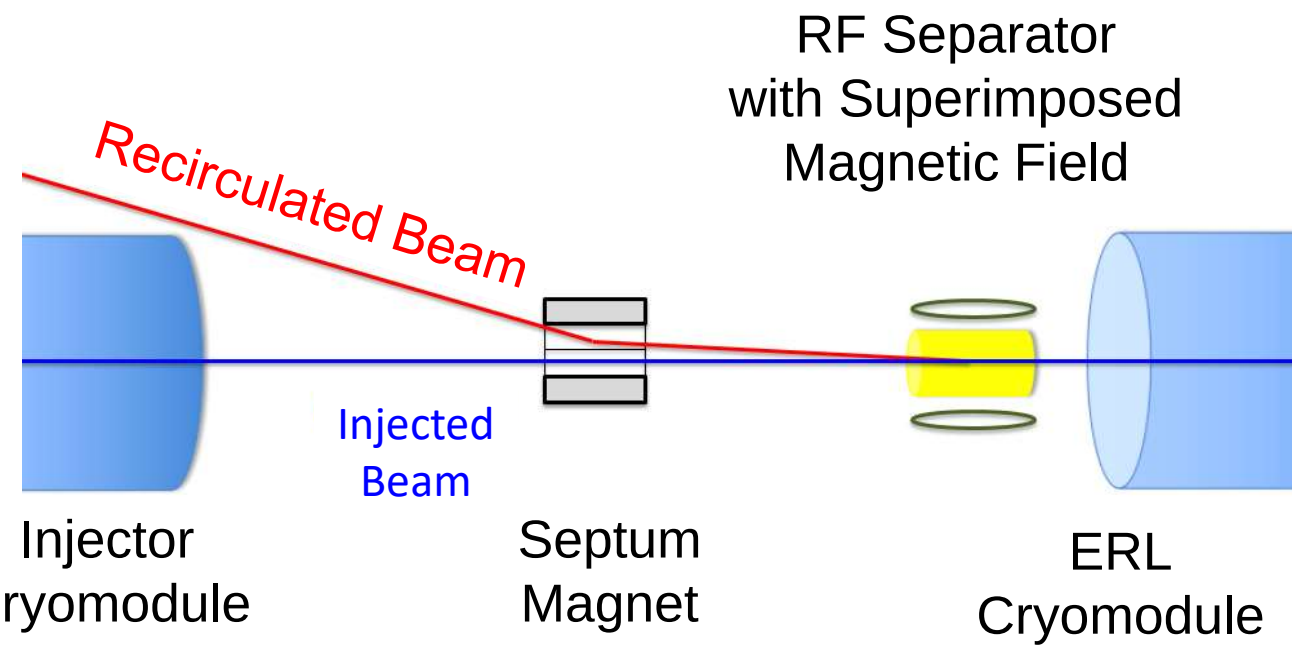
- Straight Merger
  - Motivation
  - Concept
- Experimental Layout
  - Beam parameters and measurement cases
- Evaluations of Measurements and Simulations
  - Operating point
  - As a function of phase
  - Banana effect

Includes material from previous seminars given by Virginia group

Straight Merger: Motivation

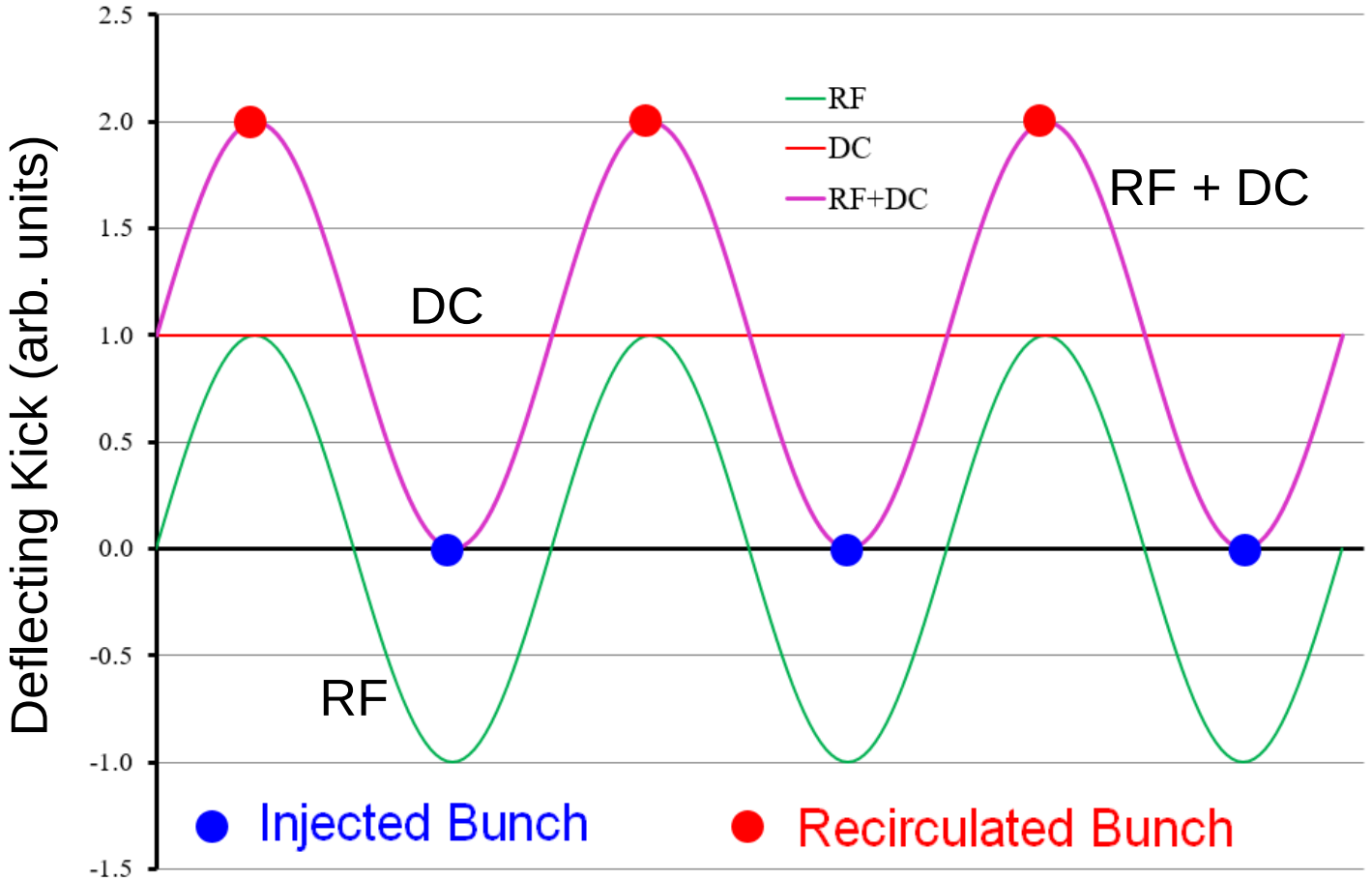
- Traditional mergers involve dipoles, exploiting energy difference between the injected and recirculated beams
  - Negatively affects rotational symmetry and quality of injected beam
- Magnetized beams are used for electron beam cooling in JLEIC
  - Sensitive to non-rotationally symmetric transport, especially at low energy and high charge
- Using traditional mergers, quality of magnetized beams significantly decreases
- For best beam quality, the goal is to merge the beams while not disturbing the injected beam → straight merger concept

Straight Merger: Concept



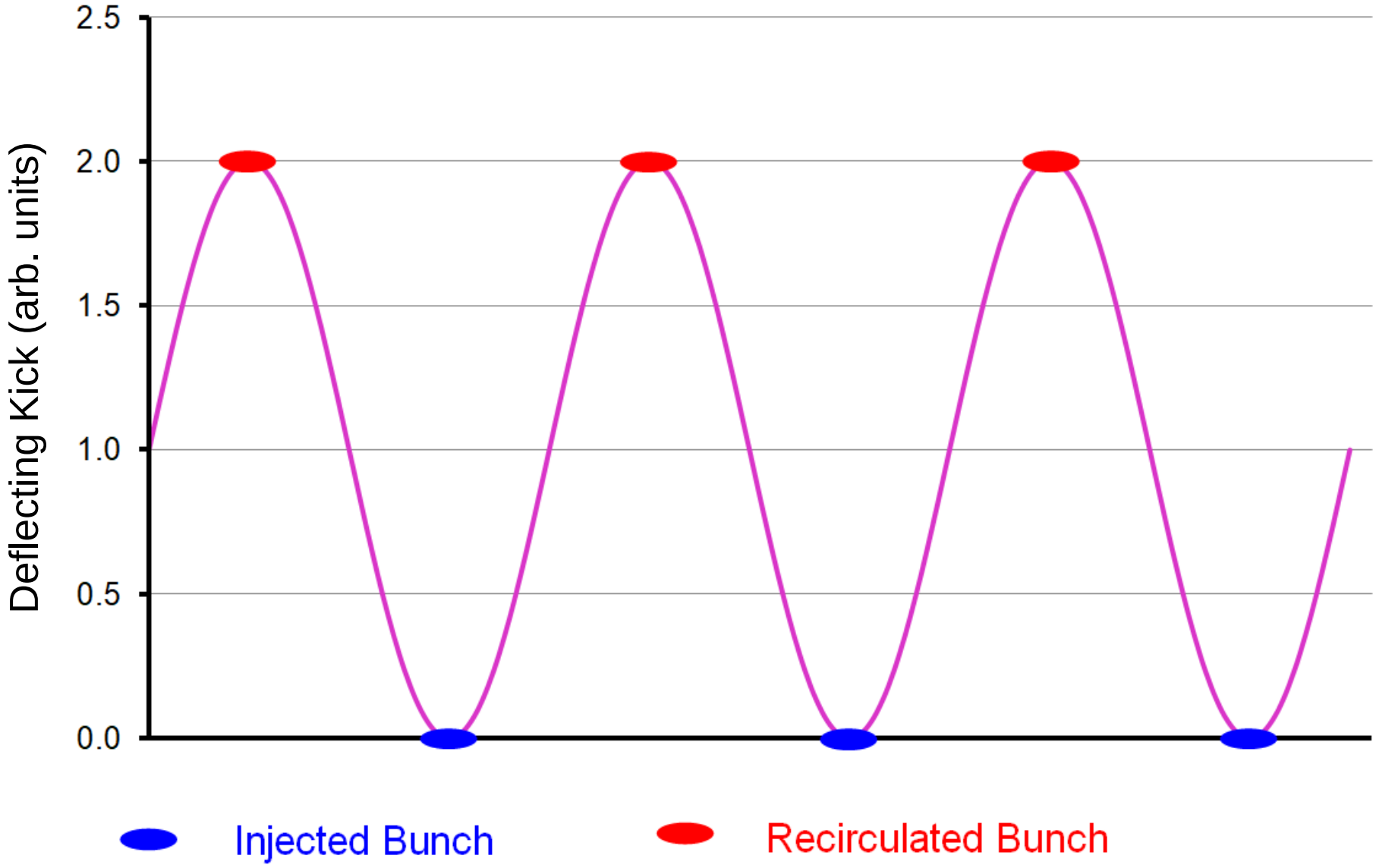
- Merger consists of septum followed by RF separator in dipole (DC) magnetic field
- Septum:
  - Injected beam sees zero field
  - Recirculated beam sees deflecting field
- RF separator and DC field:
  - Set phase and amplitudes so that injected beam is **not** deflected
  - Recirculated beam experiences twice the deflection

Waveforms



- Without DC field, injected and recirculated beams see equal and opposite deflecting kick
- With DC field
  - Injected beam sees no deflection
  - Recirculated beam experiences twice the deflection from the RF separator alone
  - This is seen on next slide

Waveforms


2.5
2.0
1.5
1.0
0.5
0.0
Deflecting Kick (arb. units)
Injected Bunch
Recirculated Bunch

Straight Merger: Concept

- To first order: injected beam has no deflection

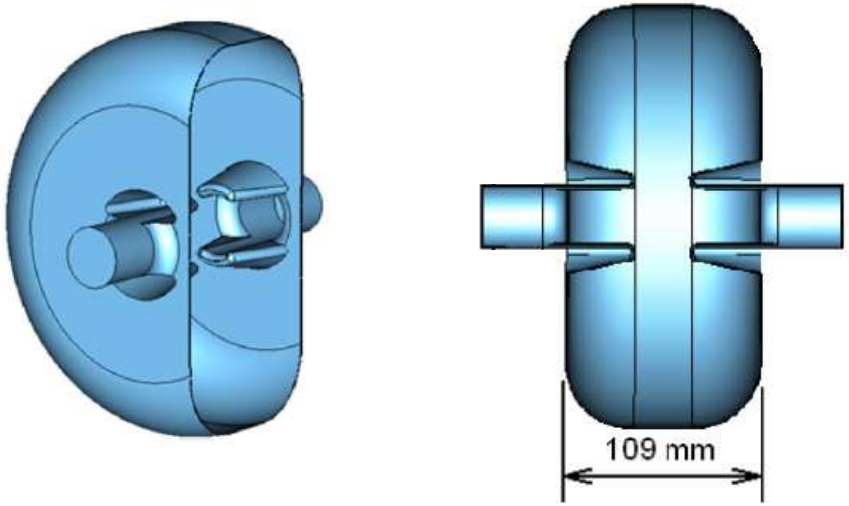
- To higher order: beam has finite length, only center has no deflection → front and back are deflected
  - We call this the “banana effect”

- Banana effect
  - Inevitable energy slew along the bunch length
  - Smaller for shorter bunch lengths and lower RF frequencies
  - Effectively removed by adding third harmonic to separator cavity

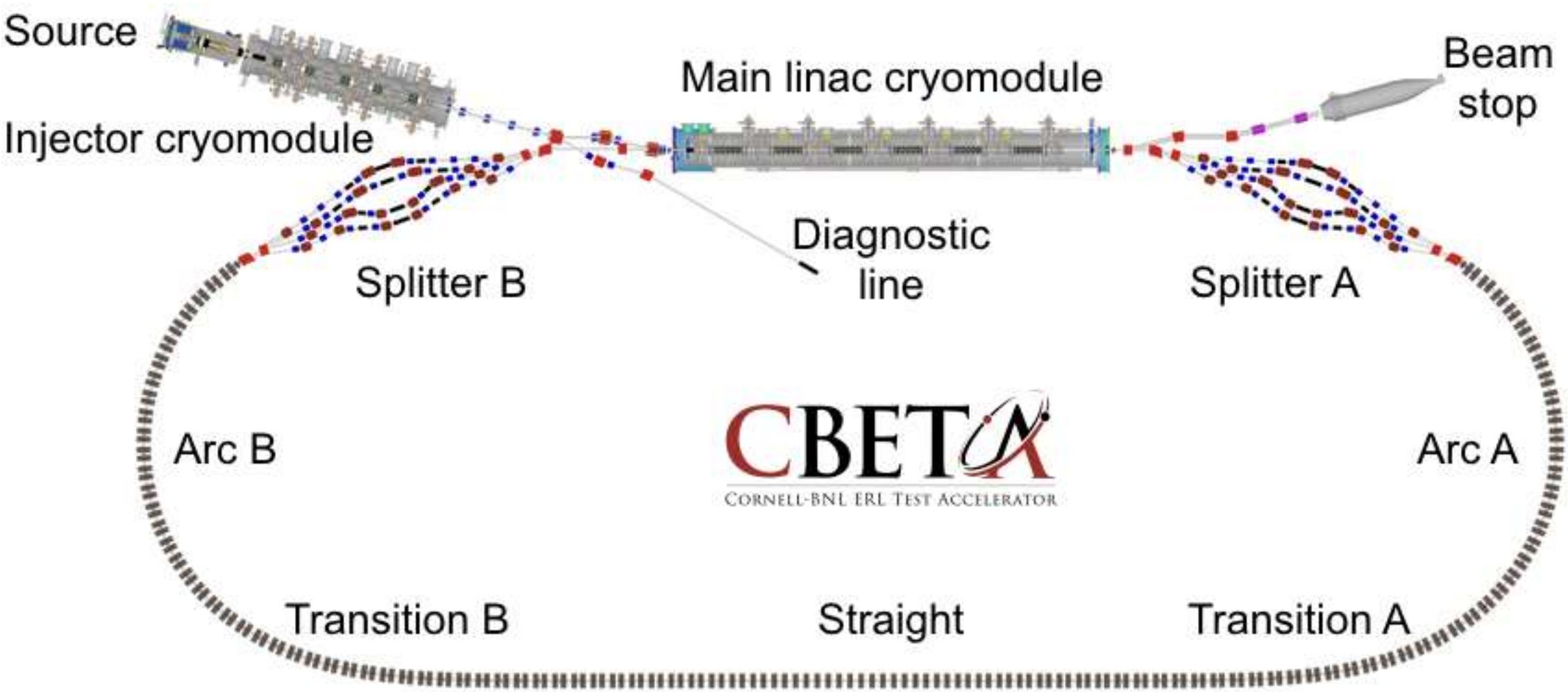
Experimental Test

- Compare simulations and measurements of beam dynamics through RF separator and DC dipole magnetic field
  - DC dipole magnetic field provided by pair of coils
  - Separator and coils referred to as “the assembly”

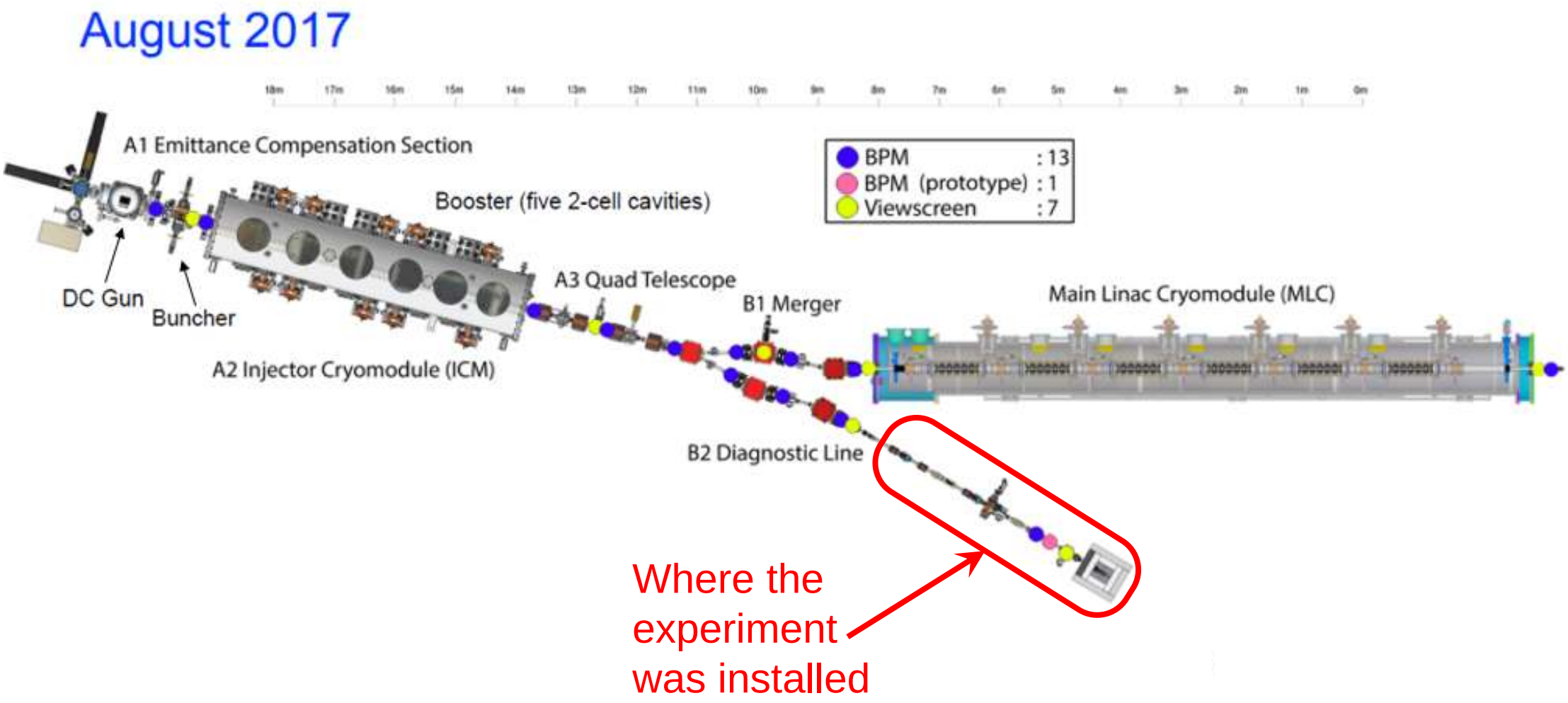
- Georg Hoffstaetter offered Virginia group beam time at CBETA
- CBETA is an excellent site for the experiment:
  - Pre-existing simulation deck of accelerator
  - RF separator already installed on beamline
  - RF separator is 1.3 GHz, high frequency to observe banana effect



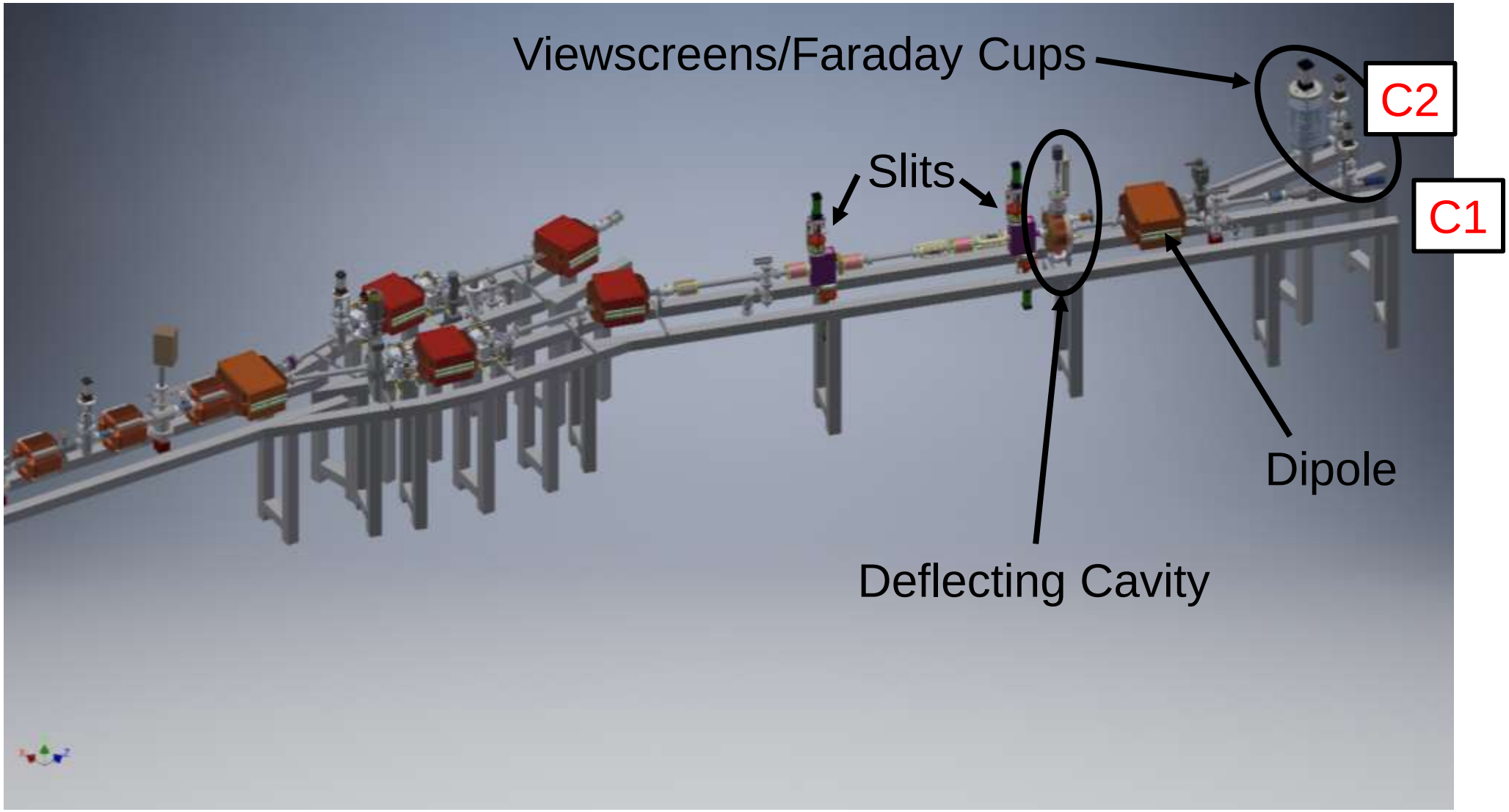
CBETA


Source
Injector cryomodule
Main linac cryomodule
Beam stop
Diagnostic line
Splitter B
Splitter A
CBETA
CORNELL-BNL ERL TEST ACCELERATOR
Arc B
Arc A
Transition B
Straight
Transition A

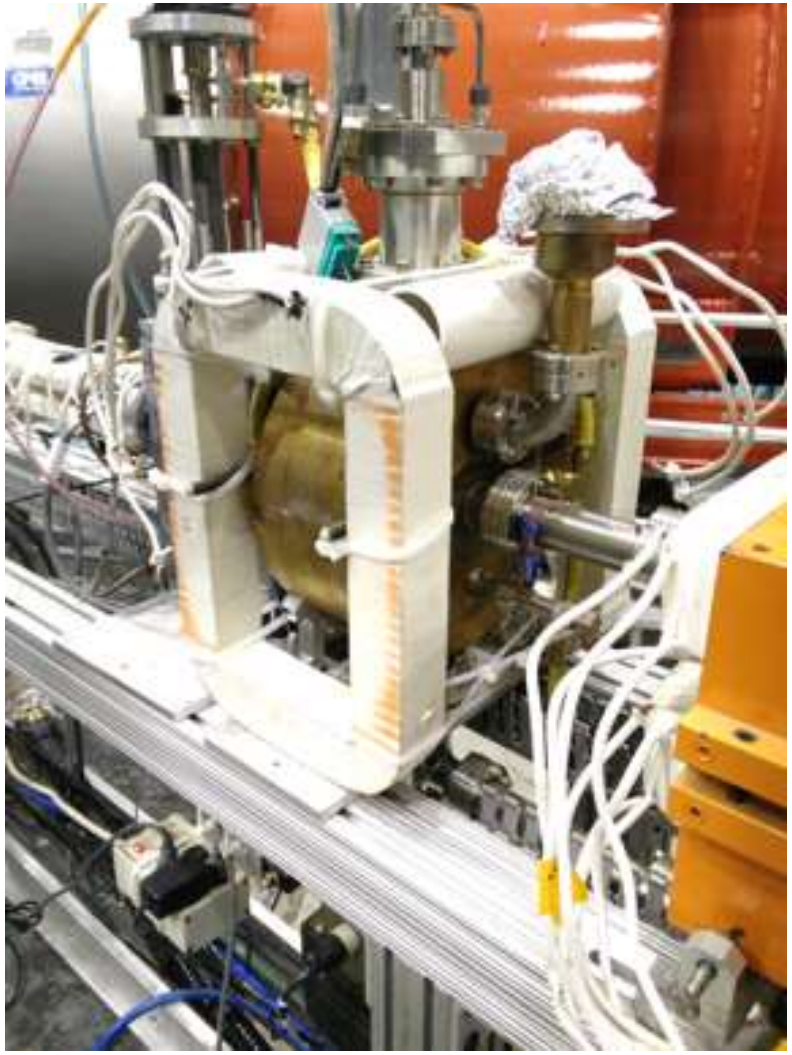
CBETA

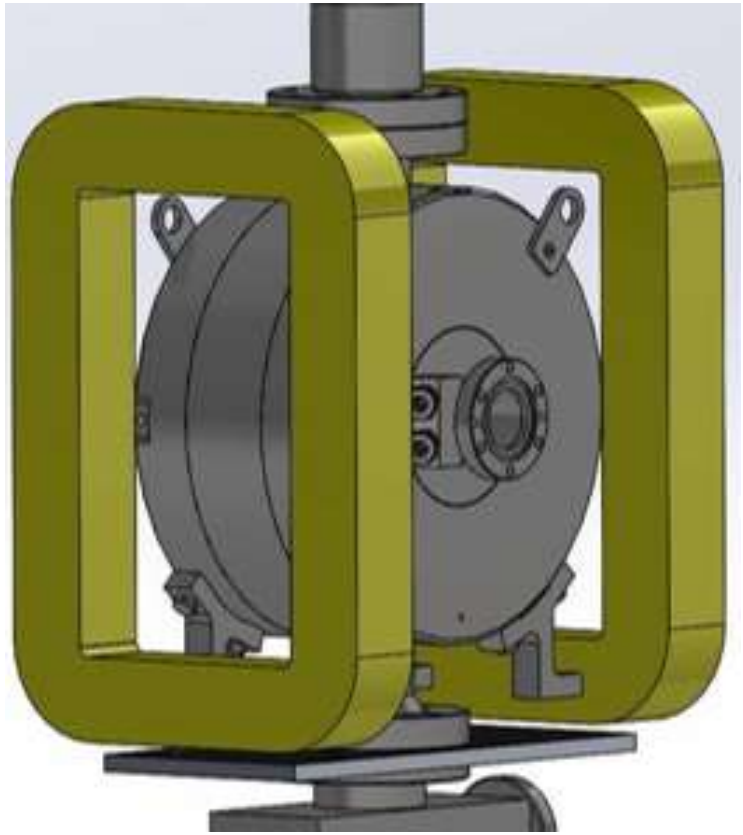

August 2017
A1 Emittance Compensation Section
Booster (five 2-cell cavities)
BPM : 13
BPM (prototype) : 1
Viewscreen : 7
DC Gun
Buncher
A3 Quad Telescope
B1 Merger
Main Linac Cryomodule (MLC)
A2 Injector Cryomodule (ICM)
B2 Diagnostic Line
Where the experiment was installed

Experimental Layout



Experimental Layout





CAD model of the cavity and coil by Joe Gubeli (JLab)

Beam Parameters and Measurement Cases

- 2.4 MeV electron beam

- 113 kV deflecting voltage
  - Conflicting calibrations

- C1 (beam spot)
- C2 (longitudinal phase space)
- 2 horizontal slits on C1 screen (spot beamlet)
- 1 vertical slit on C2 screen (longitudinal beamlet)

Undisturbed: assembly is off
Kicked: assembly is on

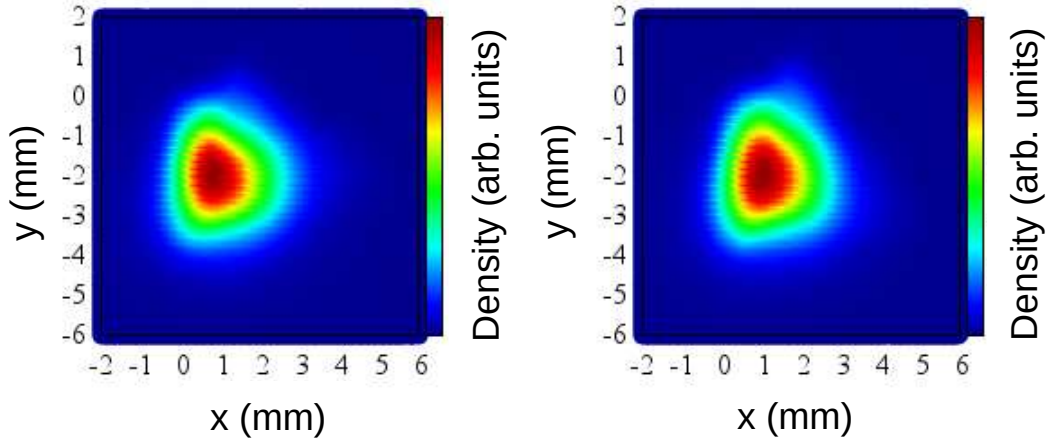
Evaluations of Measurements and Simulations

- Operating point
  - Comparison of undisturbed and kicked bunches
- As a function of phase
  - Vertical *rms* size as a function of phase (with respect to maximum deflection)
  - Coil current adjusted for no net deflection of beam
- Banana effect
  - Comparison of undisturbed and kicked beamlets
- On plots:
  - xy area is consistent for all viewscreens (simulated or measured) that share a slide
  - Density is scaled for each plot, but is NOT the same for all plots that share a slide
  - Unless otherwise specified, measurements are shown with no applied threshold
    - Sometimes appears that way due to background subtraction immediately before measurement

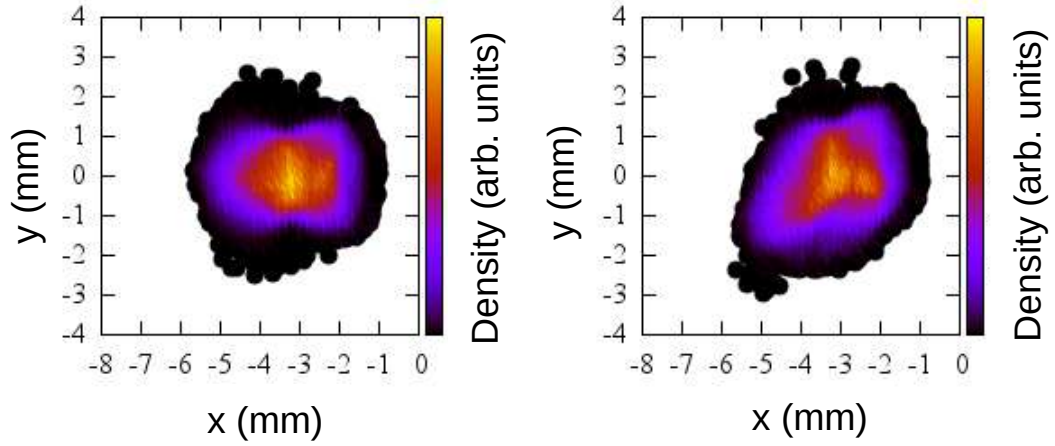
Operating Point: C1 (Beam Spot)

Undisturbed

Kicked



Measured



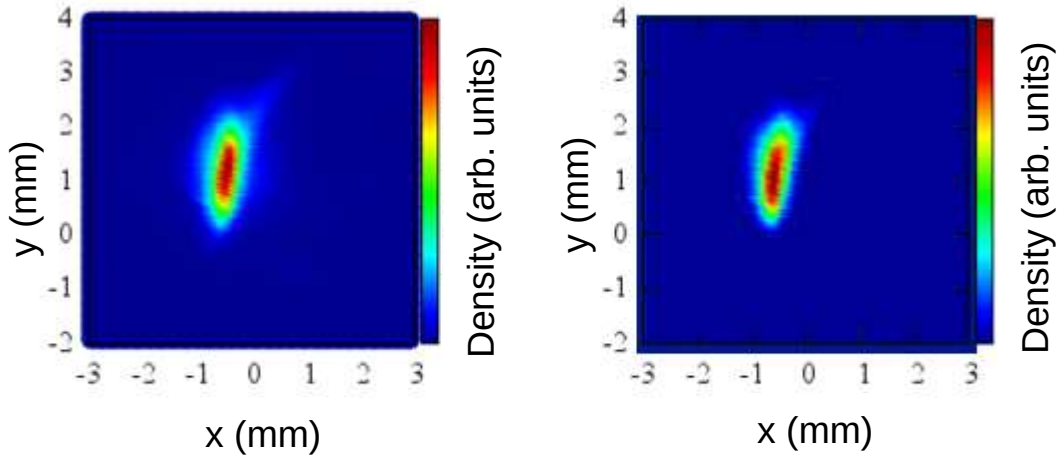
Simulated

Both simulations and measurements show minimal changed between undisturbed and kicked bunches

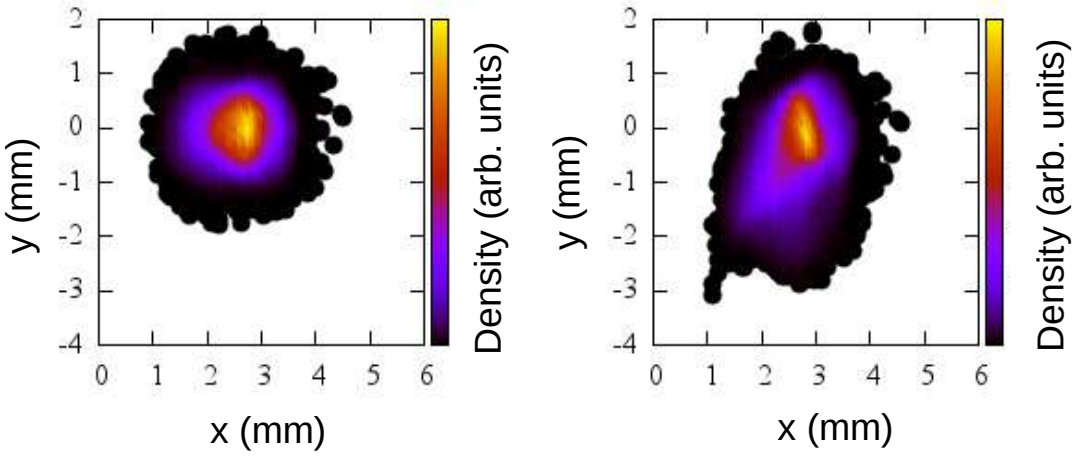
Operating Point: C2 (Longitudinal Phase Space)

Undisturbed

Kicked



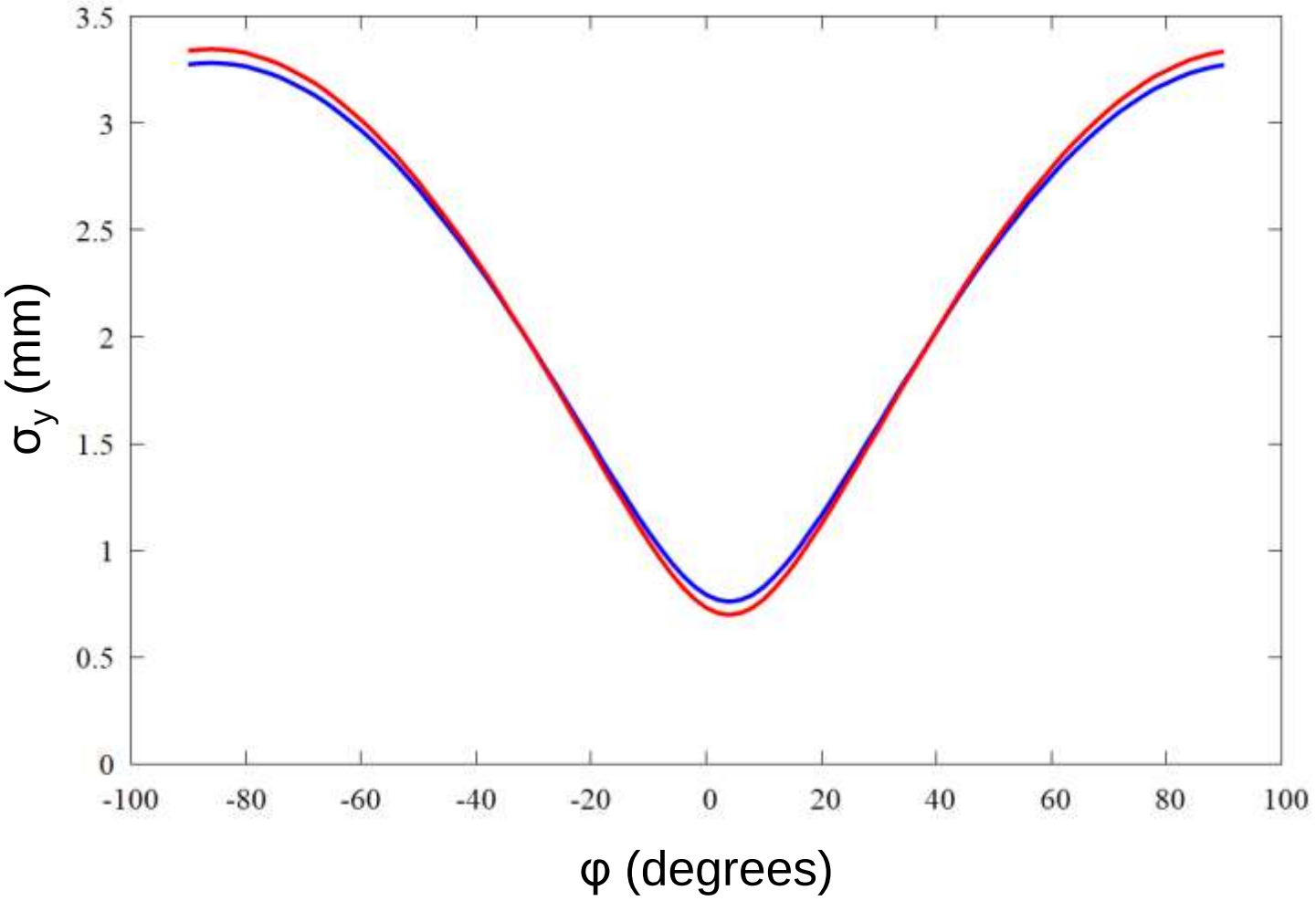
Measured



Simulated

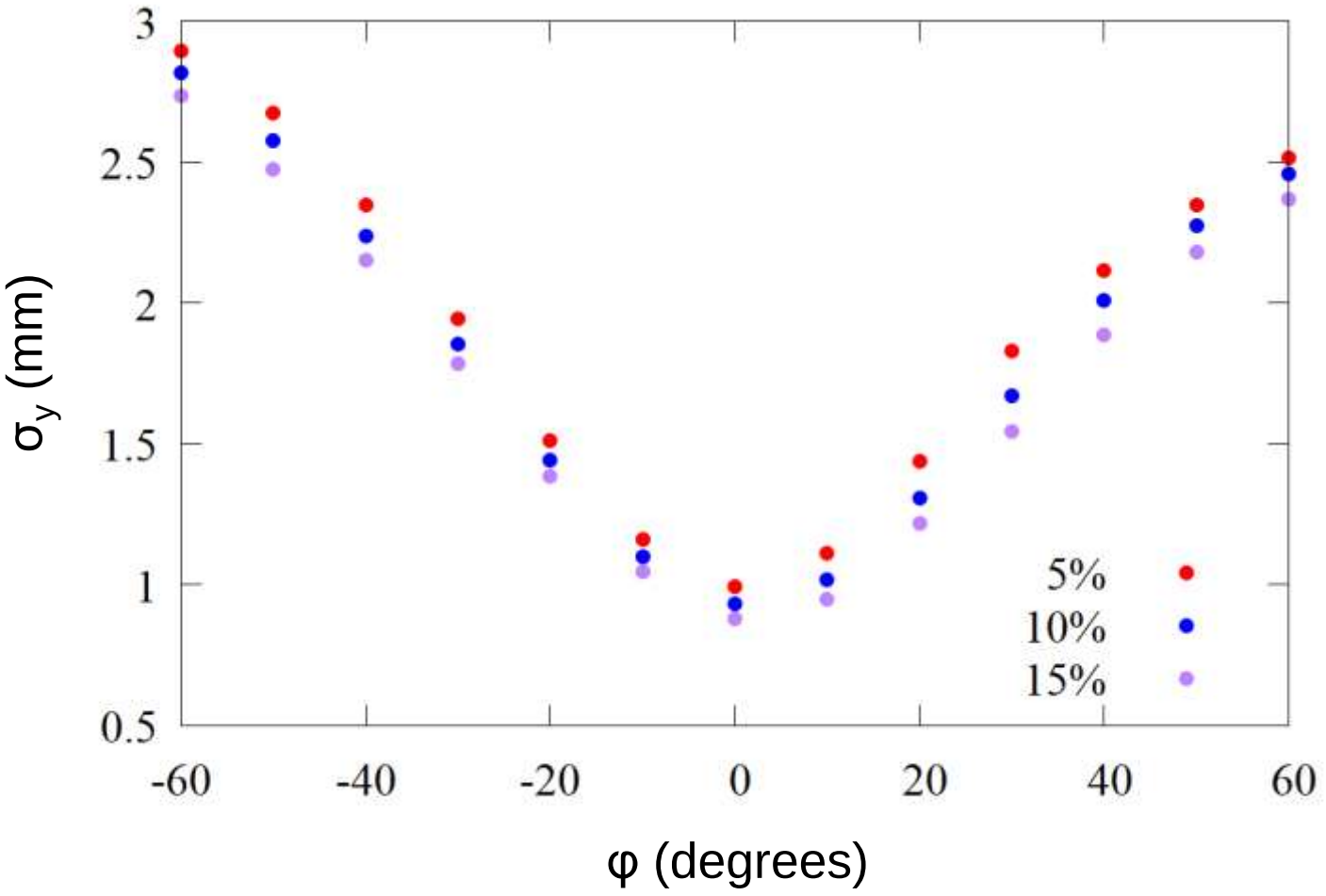
Both simulations and measurements show minimal changed between undisturbed and kicked bunches

As a Function of Phase: Simulation



Simulated vertical *rms* size of the beam for C1 (blue) and C2 (red)

As a Function of Phase: C1 (Beam Spot)

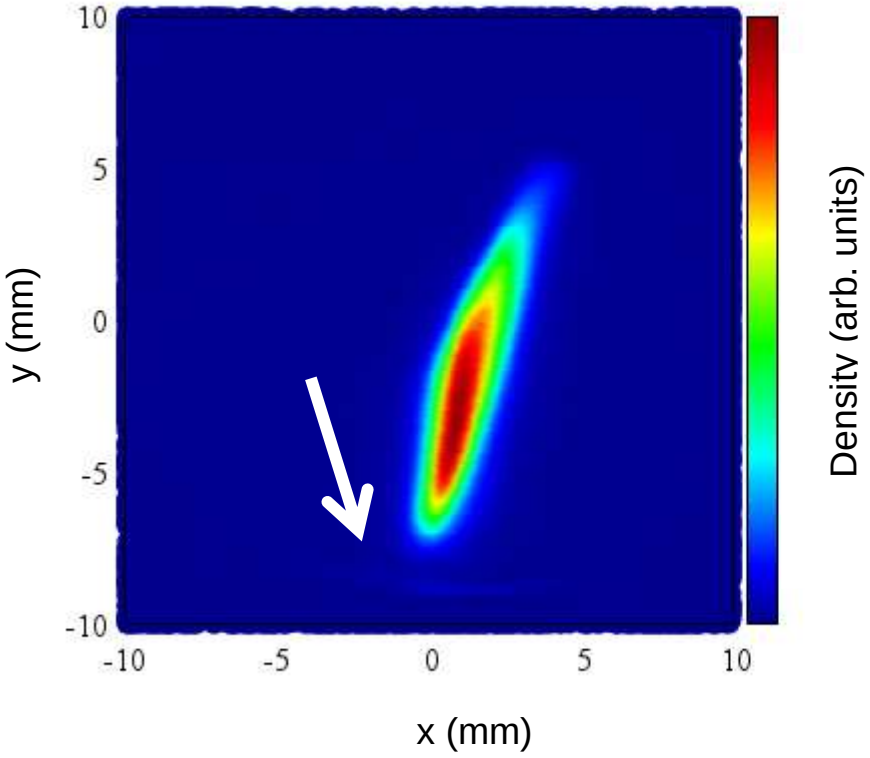


Measured *rms* vertical size on the beam spot screen plotted as a function of degrees off-crest for different thresholds

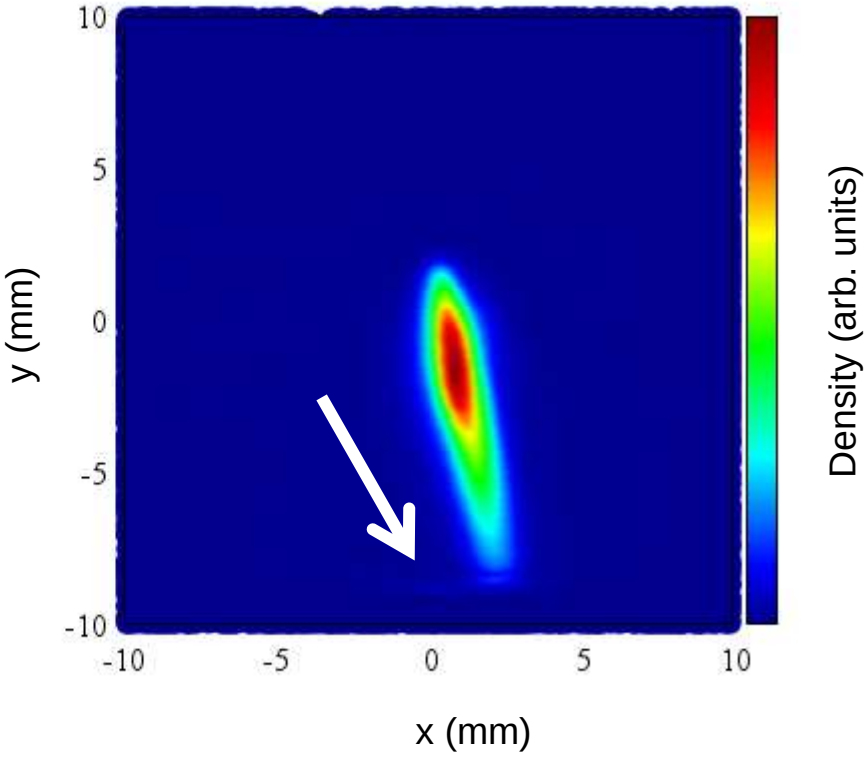
Notice how symmetry is broken at larger positive phase

As a Function of Phase: C1 (Beam Spot)

φ = -50°



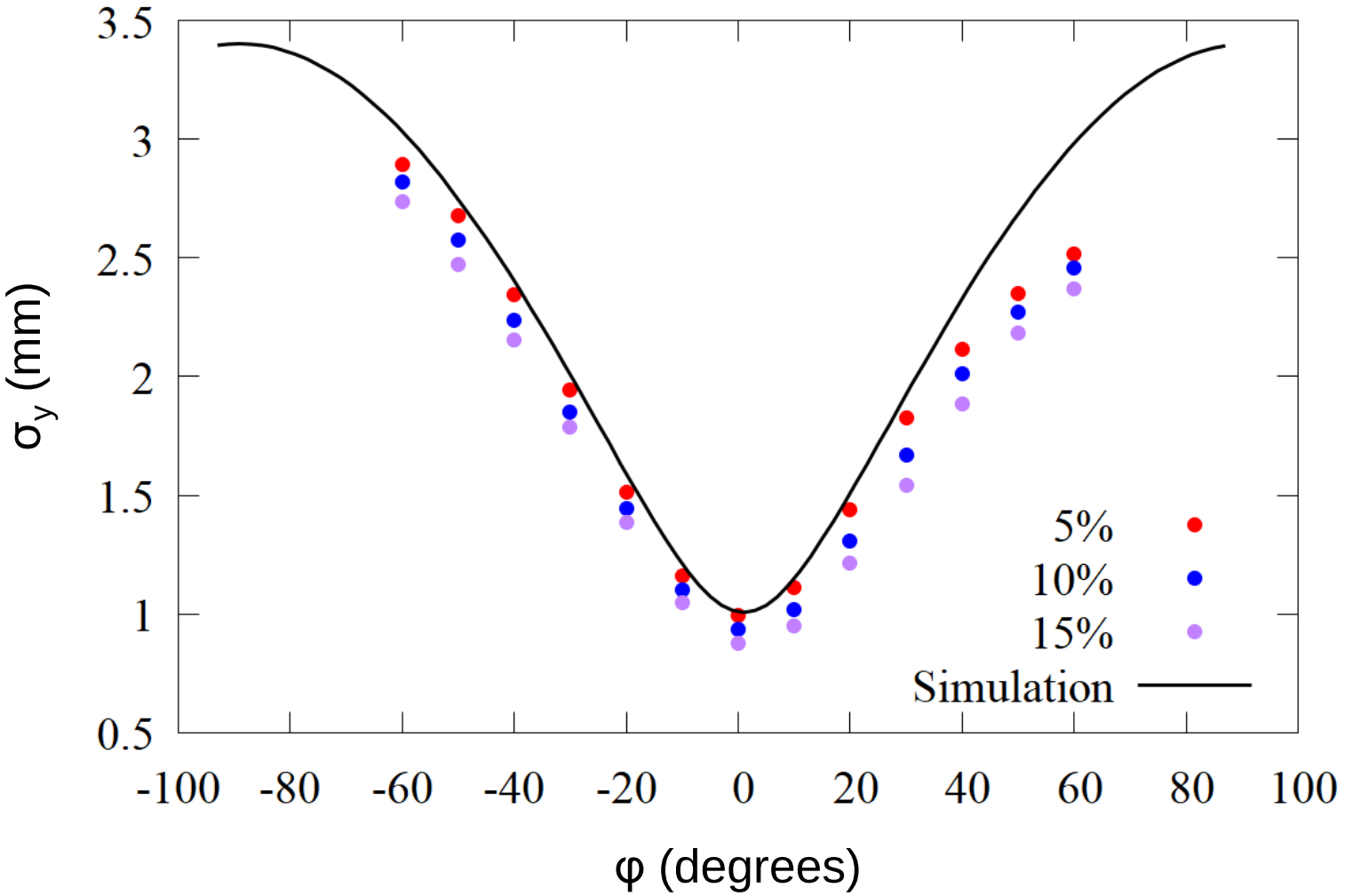
φ = 50°



Edge of screen is seen in both plots, but beam is only clipped in positive phase

Consequently, bunch size is reduced for large positive phase

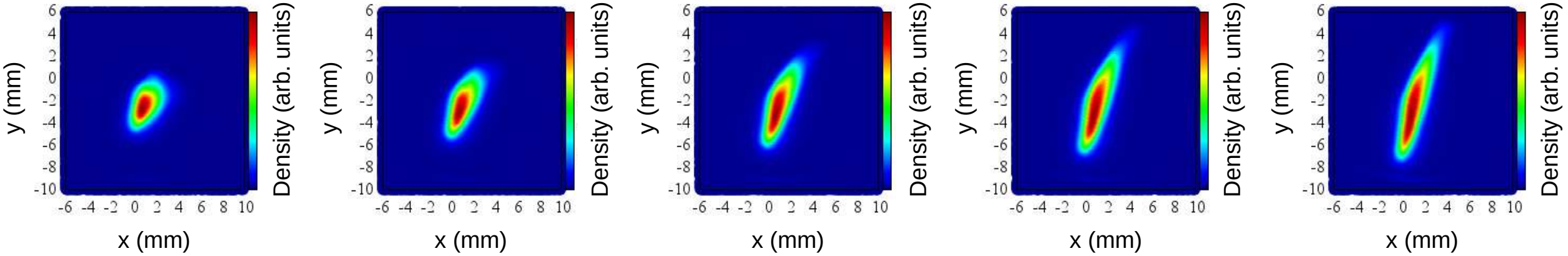
As a Function of Phase: C1 (Beam Spot)



Beam spot measurements plotted with the simulated curve, with no alterations

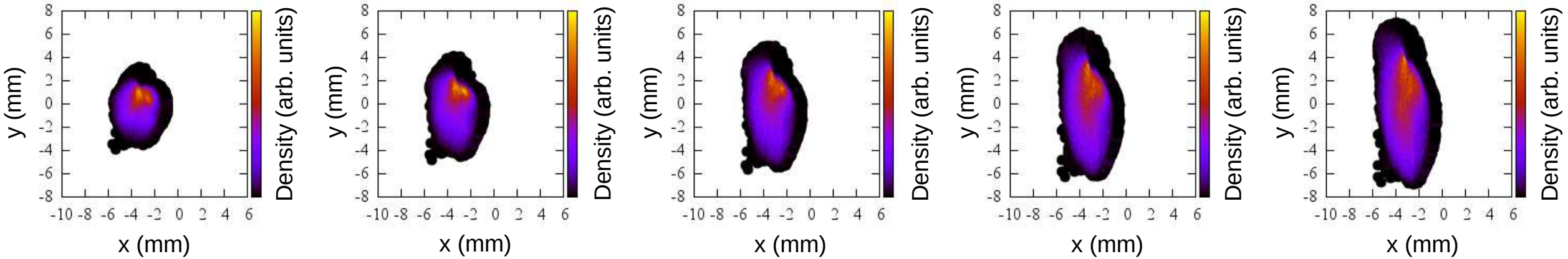
As a Function of Phase: C1 (Beam Spot)

Measured

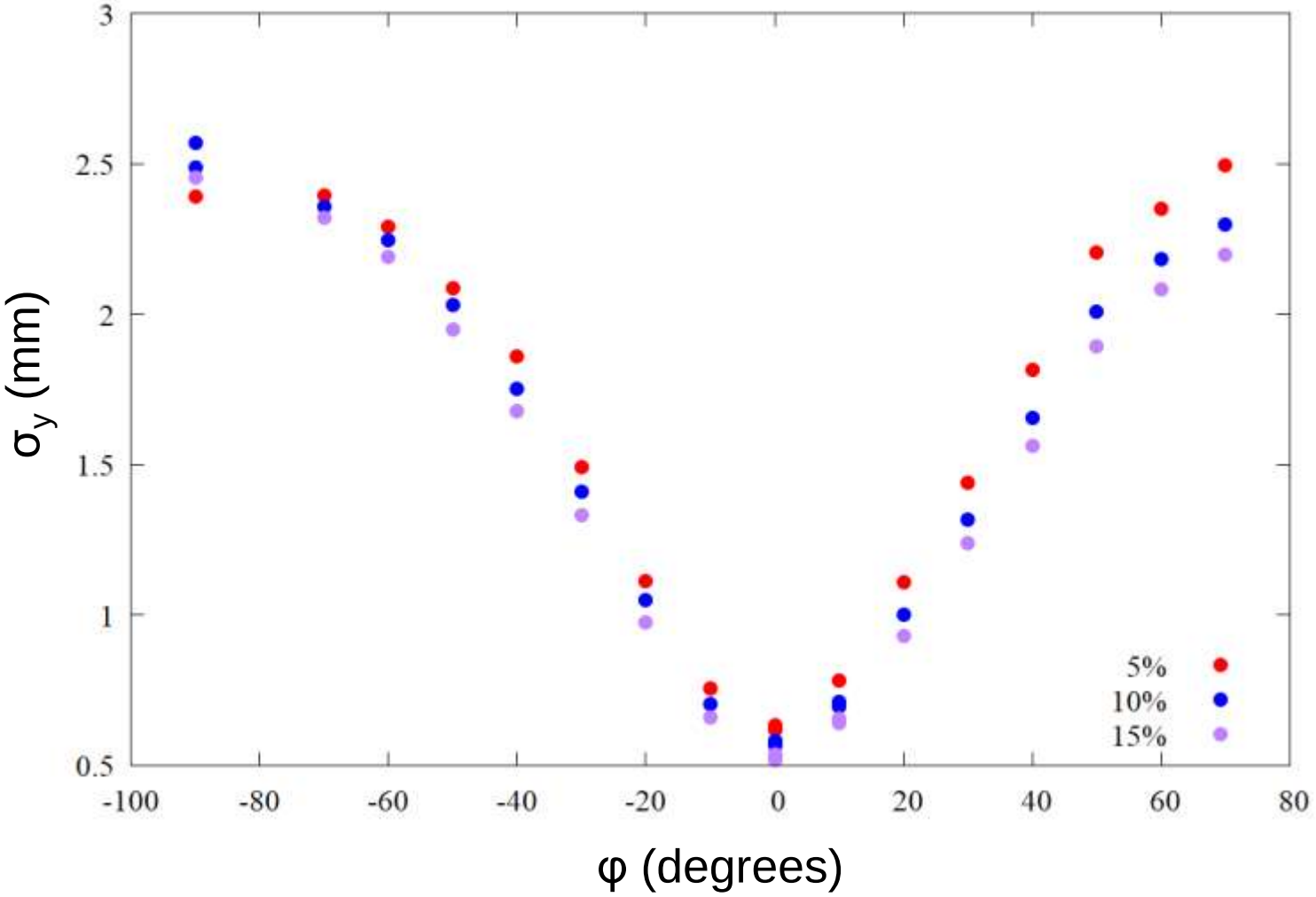


φ = -10° φ = -20° φ = -30° φ = -40° φ = -50°

Simulated

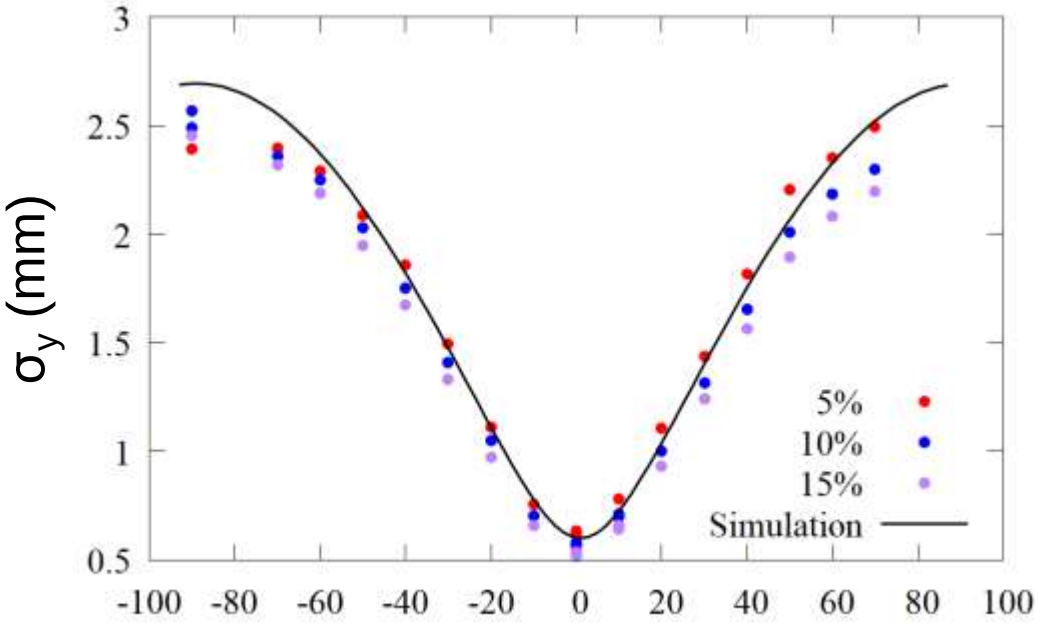


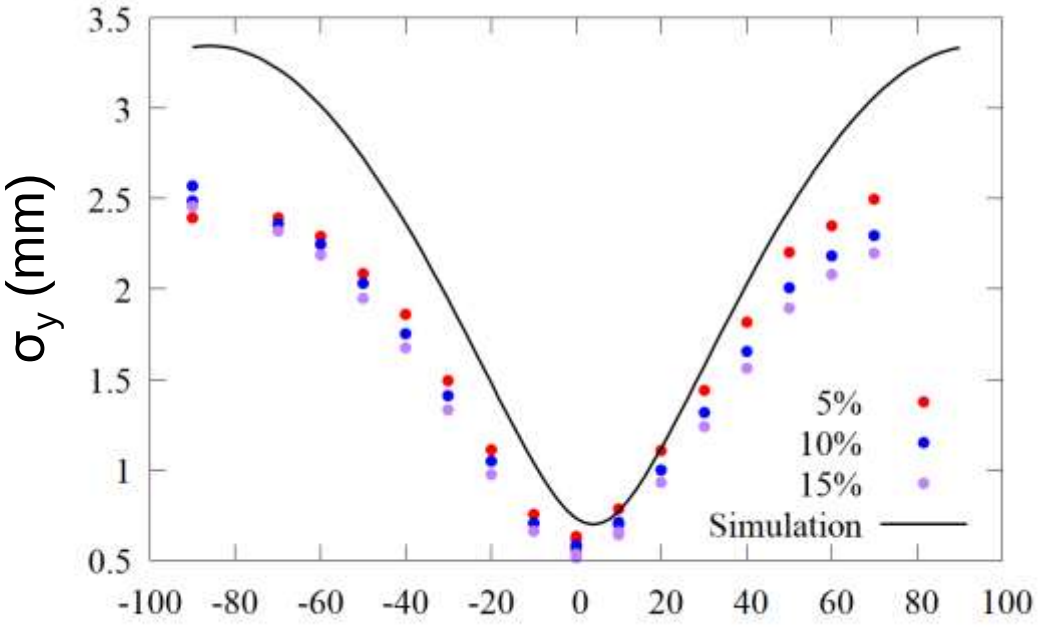
As a Function of Phase: C2 (Longitudinal Phase Space)



Measured *rms* vertical size on the longitudinal screen plotted as a function of degrees off-crest for different thresholds

As a Function of Phase: C2 (Longitudinal Phase Space)

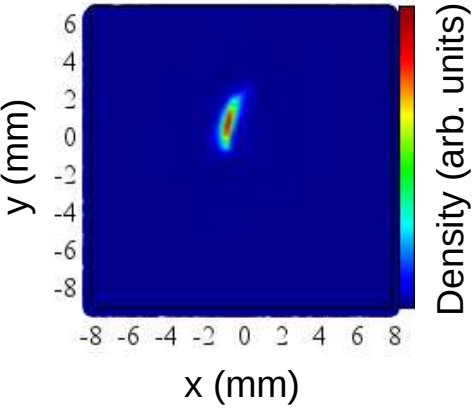




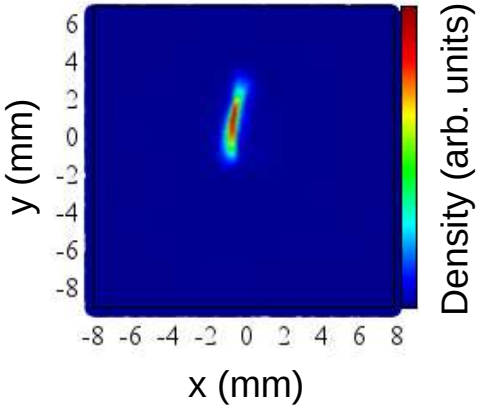
Longitudinal measurements plotted with the simulated curve, which has (left) and has not (right) been shifted and scaled for best agreement

As a Function of Phase: C2 (Longitudinal Phase Space)

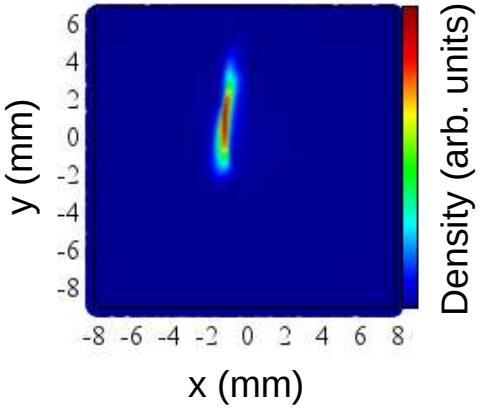
Measured



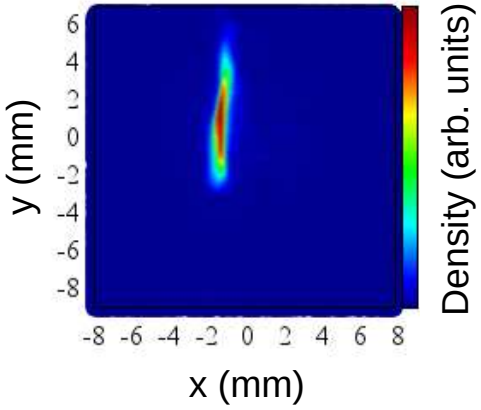
φ = -10°



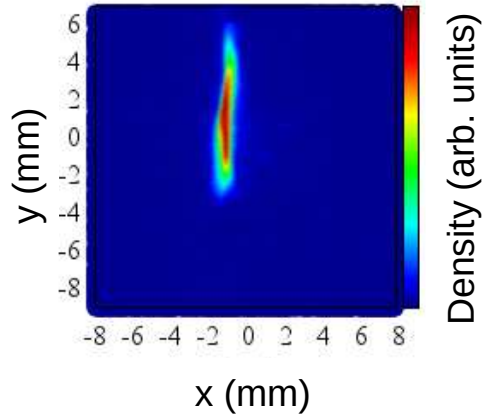
φ = -20°



φ = -30°

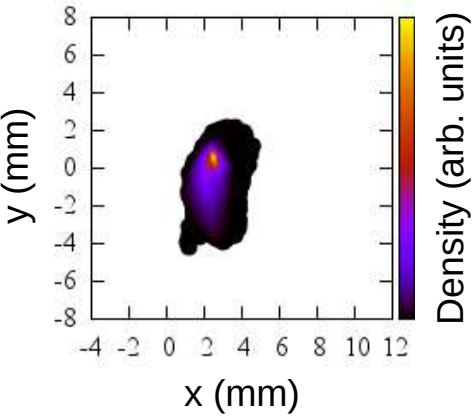


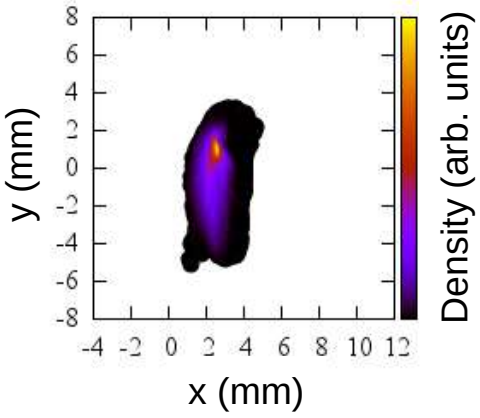
φ = -40°

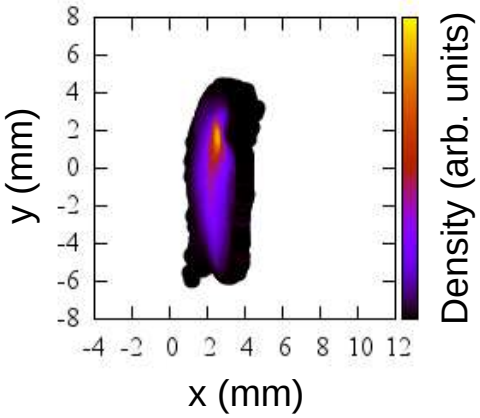


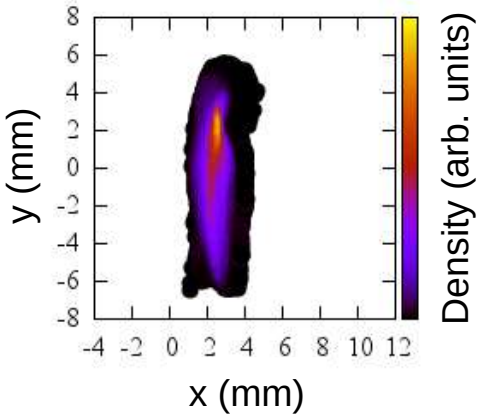
φ = -50°

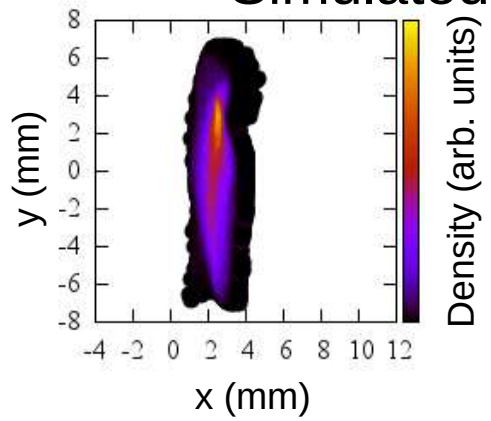
Simulated



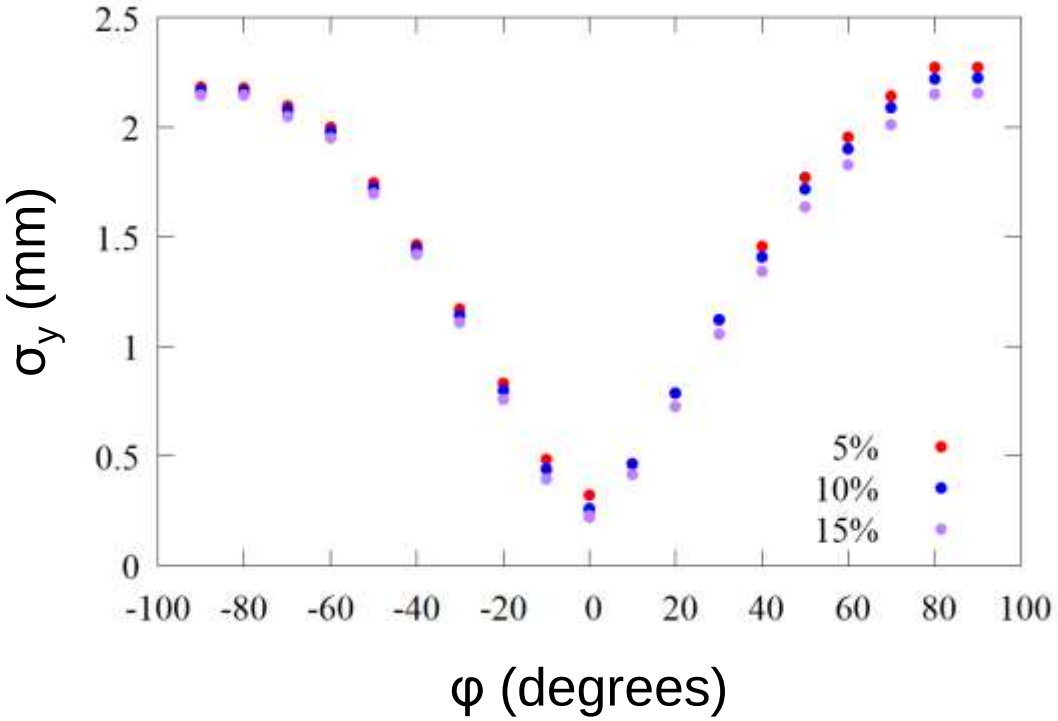


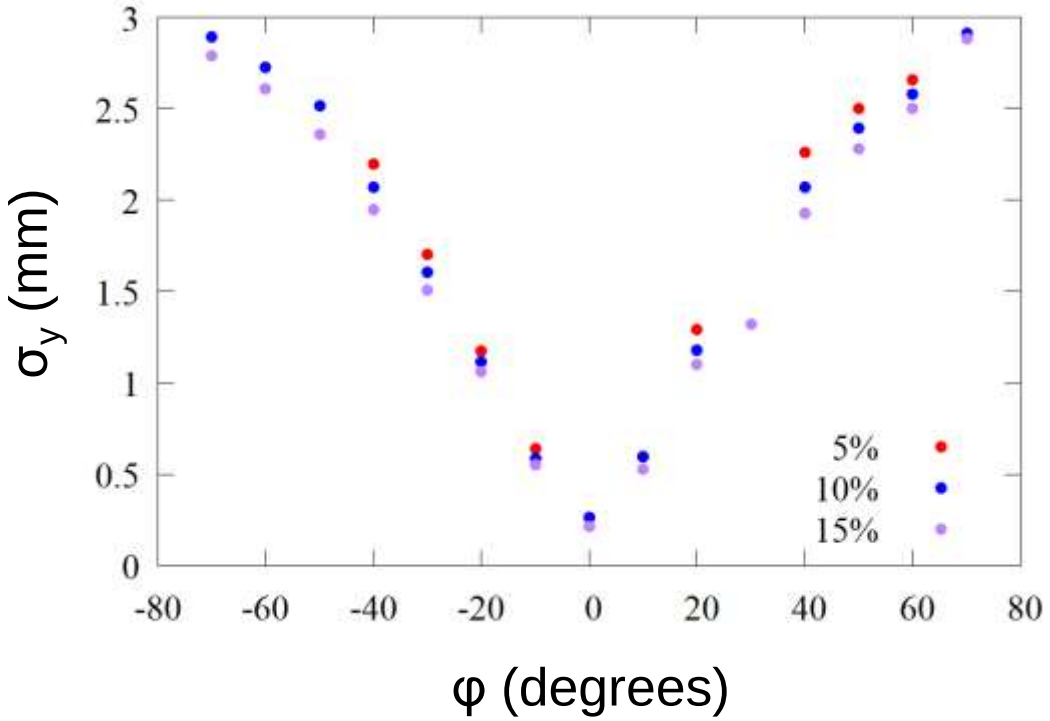






As a Function of Phase: Slits





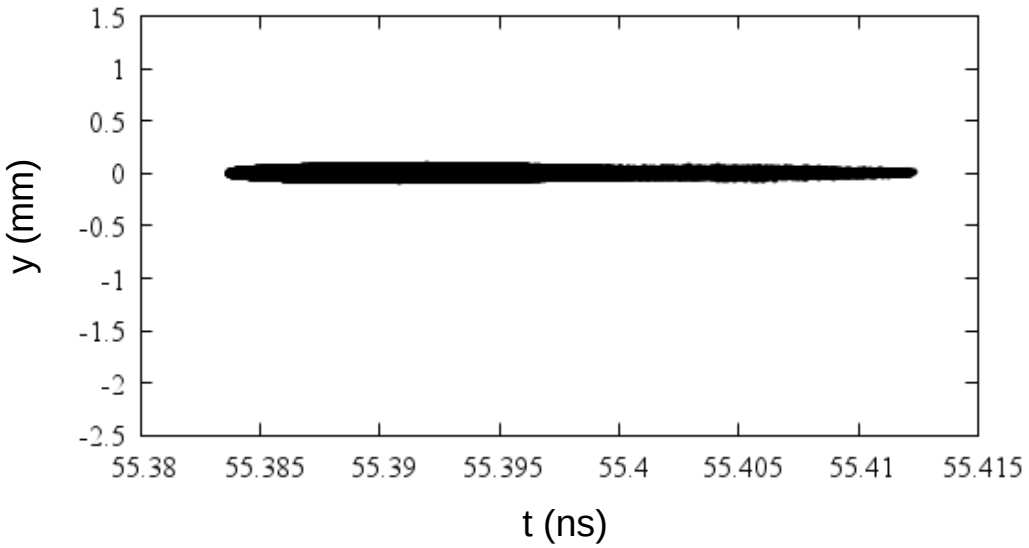
Measured *rms* vertical size on the longitudinal beamlet (1 vertical slit, left) and spot beamlet (2 horizontal slits, right) plotted as a function of degrees off-crest for different thresholds

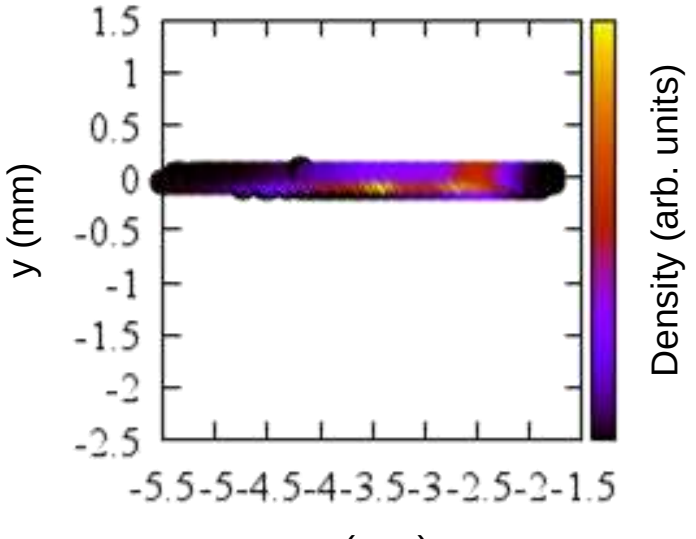
Banana Effect: In General

- Operating point for beamlets
  - Measurement using horizontal slits to examine increased vertical size because of deflection at front and back of the bunch
  - Measurement using vertical slit to examine energy slew and spread across bunch length because of deflection

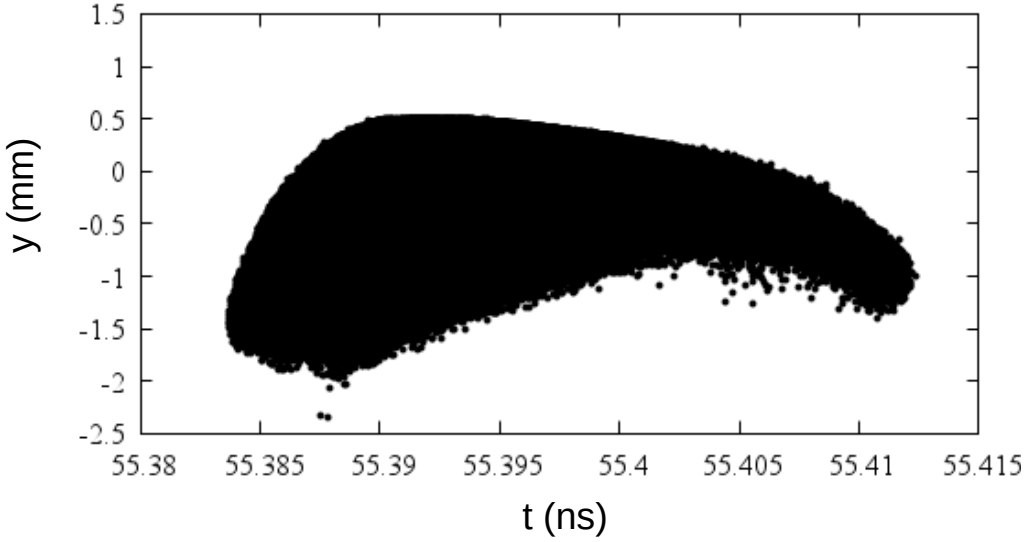
Banana Effect: Horizontal Slits

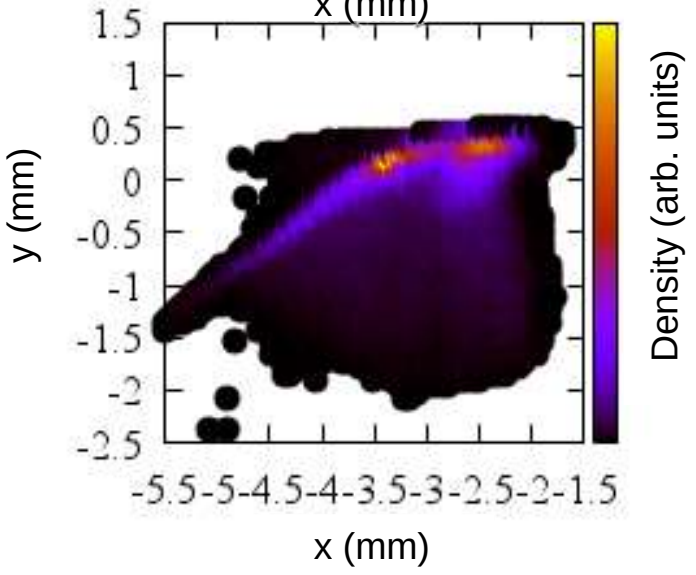
Undisturbed





Kicked

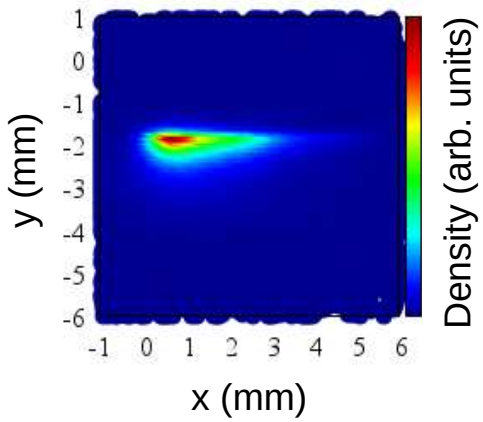


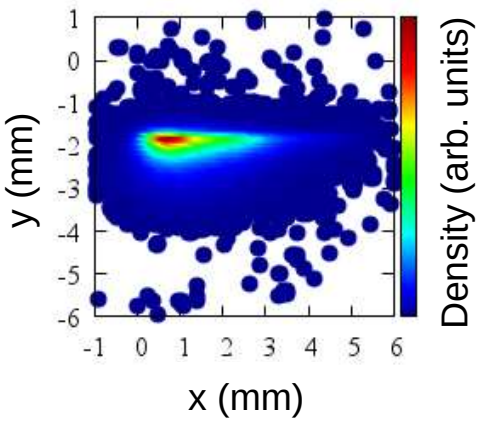


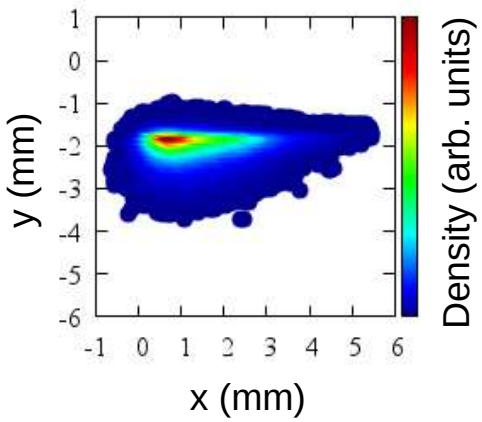
- y vs t plots are not density plots
- Simulation of fake beamlet – no vertical motion after passing through slits
- Spread of curve in y vs t plot correlates with horizontal distance off-axis

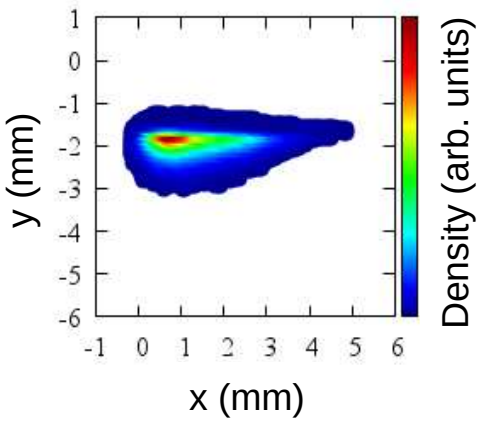
Banana Effect: Horizontal Slits

Undisturbed



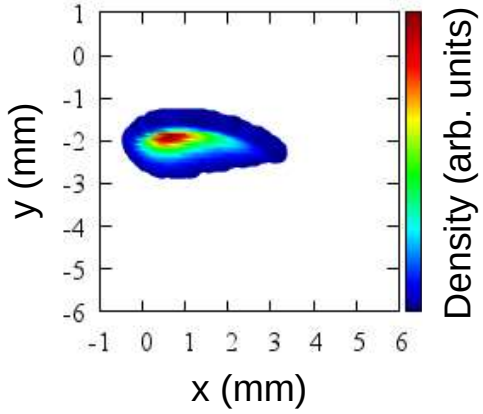




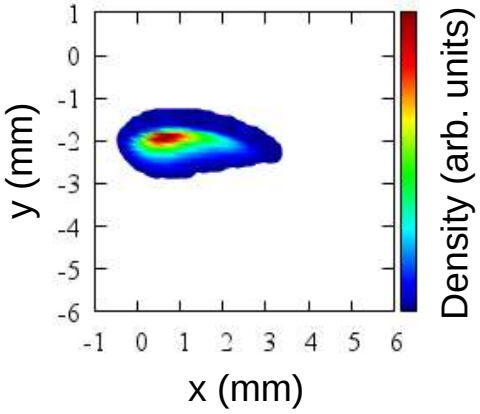


Kicked

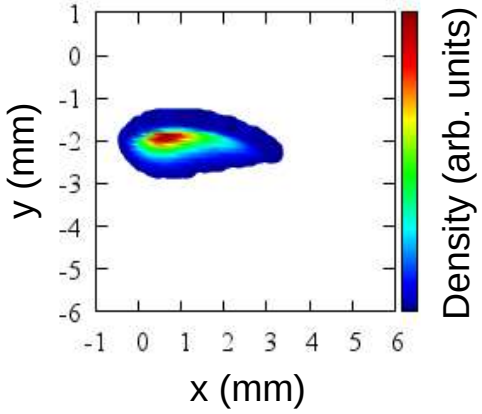
0%



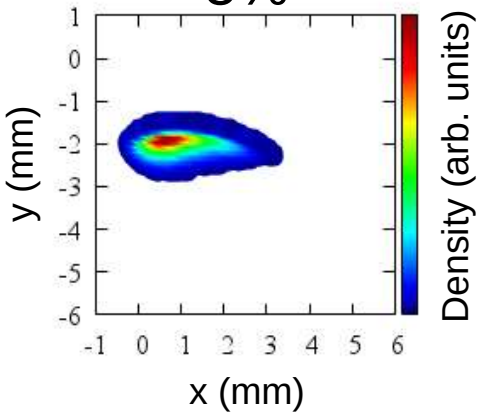
1%



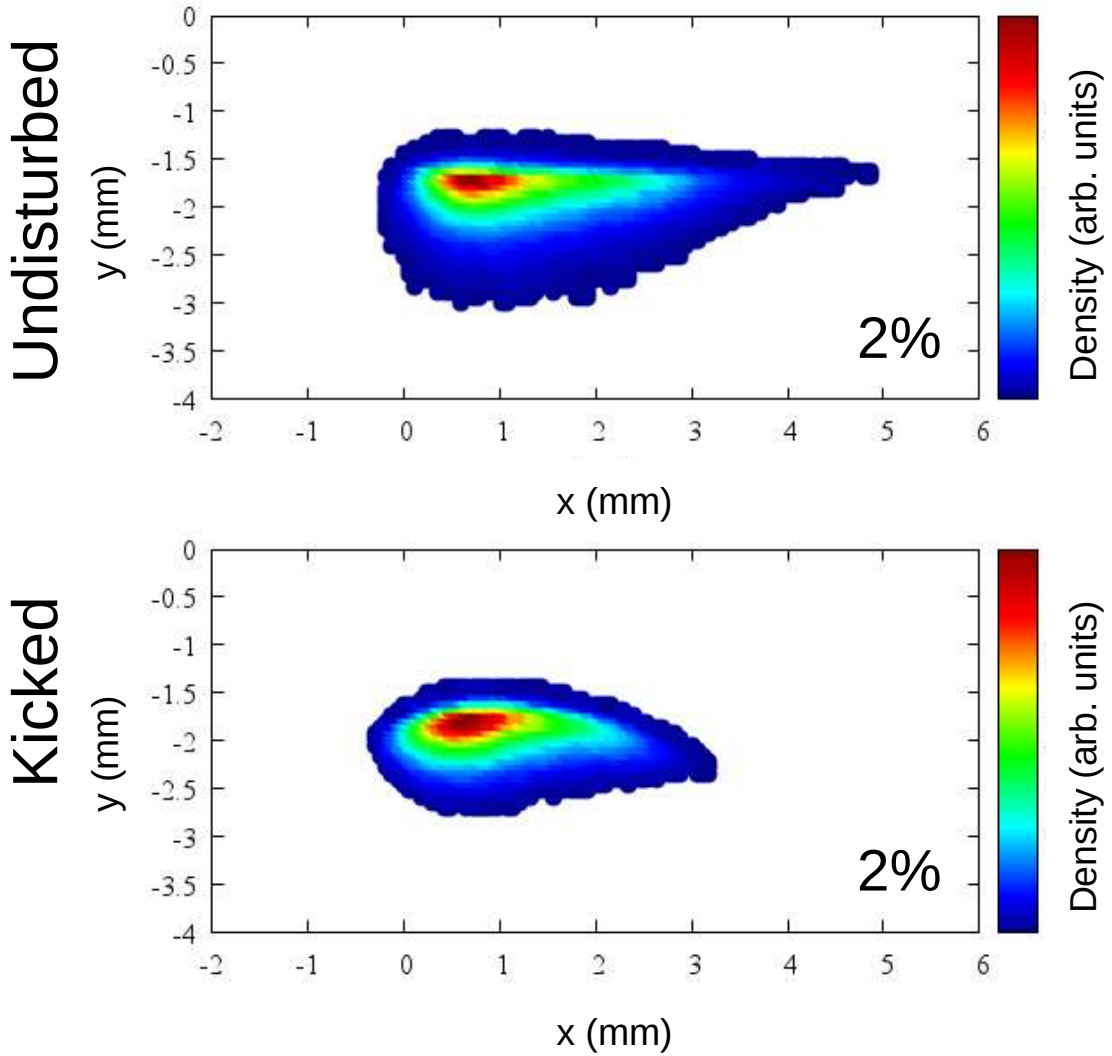
2%



5%



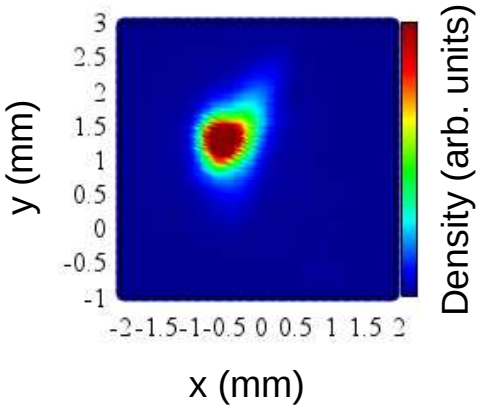
Banana Effect: Horizontal Slits

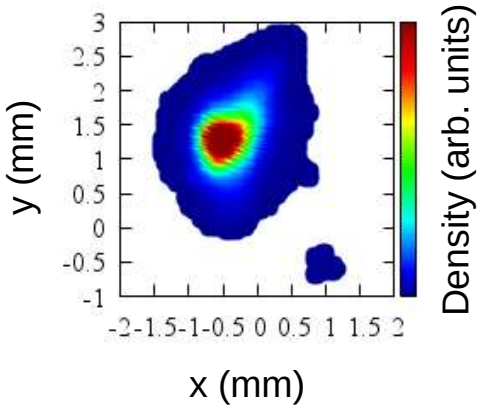


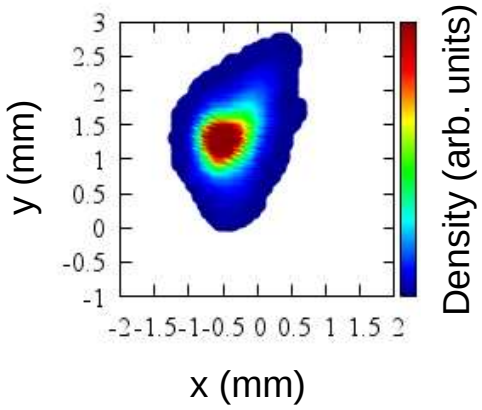
- Kicked beamlet does not appear to have a larger vertical size, unless you consider the core section of the beamlet
- Droop seen in kicked spot beamlet is because the off-axis fields of the RF separator and the off-axis fields of the coils do not cancel
  - This is a transverse effect
  - The banana effect is longitudinal, just seen in the transverse

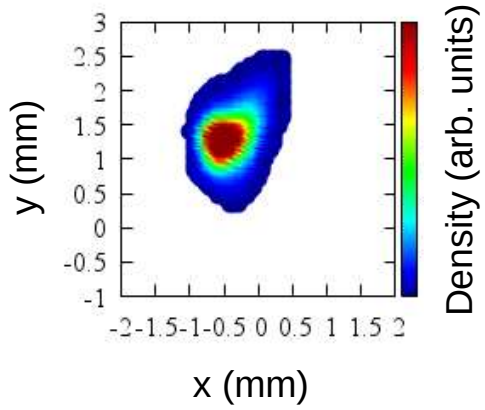
Banana Effect: Vertical Slits

Undisturbed



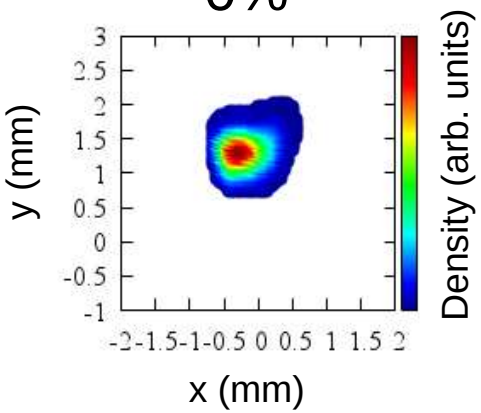




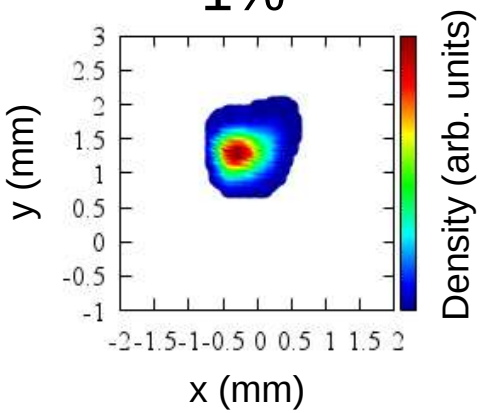


Kicked

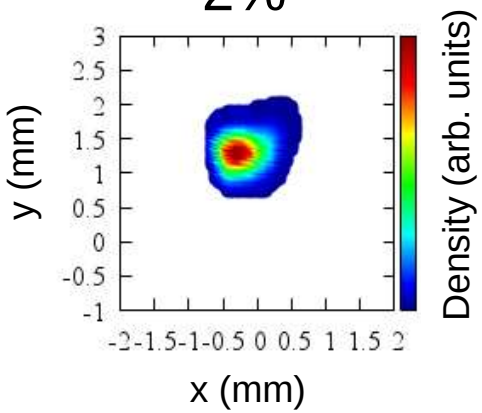
0%



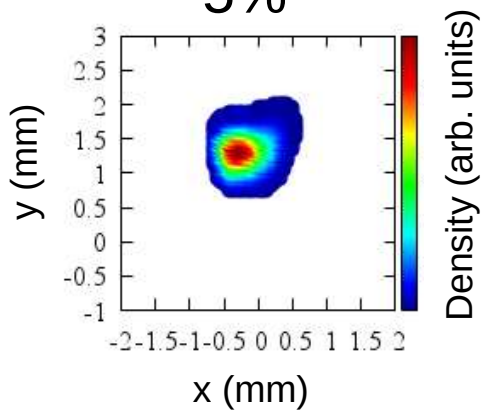
1%



2%

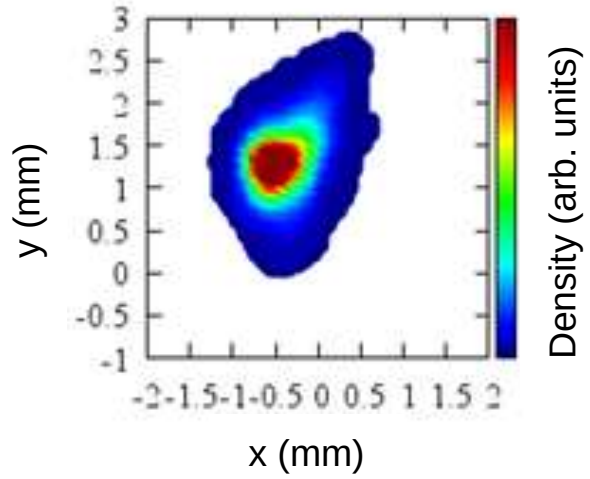


5%



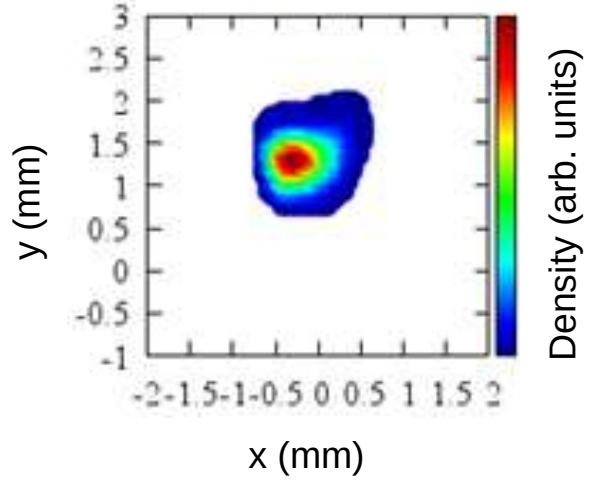
Banana Effect: Vertical Slits

Undisturbed



2%

Kicked



- Kicked beamlet appears to experience minor energy loss
- Energy along bunch length does not increase
  → but it *does* change
- Simulations suggests that energy spread of incoming is bunch is significantly larger than any change from assembly

Conclusion

- Overall, a good agreement between the qualitative behavior of the beam measurements and the simulations

- Deeply appreciate CBETA for the opportunity to perform this experiment

- A good first step towards demonstrating the potential of the straight merger system

- Follow up experiment would require at least one of the following:
  - Higher bunch charge
  - Higher deflector voltage
  - Magnetized beam

  With field clamps

Thank you for your attention!

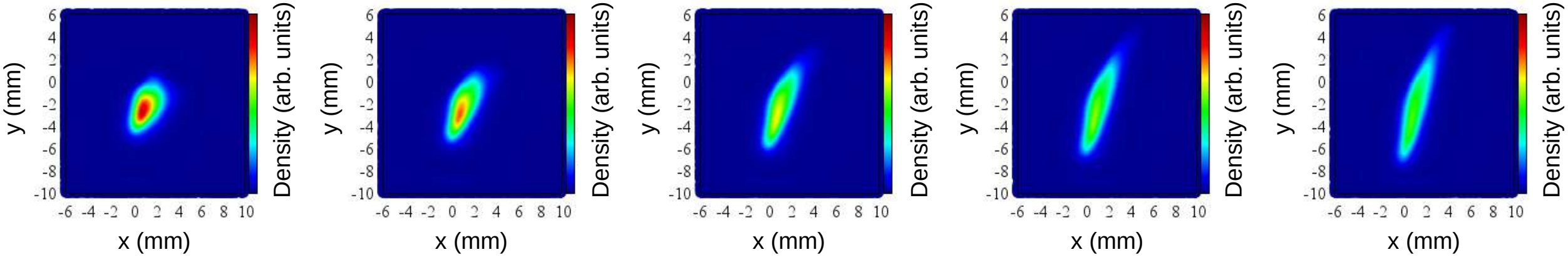
New email: kd324@cornell.edu

Or kirsten.deitrick@cornell.edu

As a Function of Phase: C1 (Beam Spot)

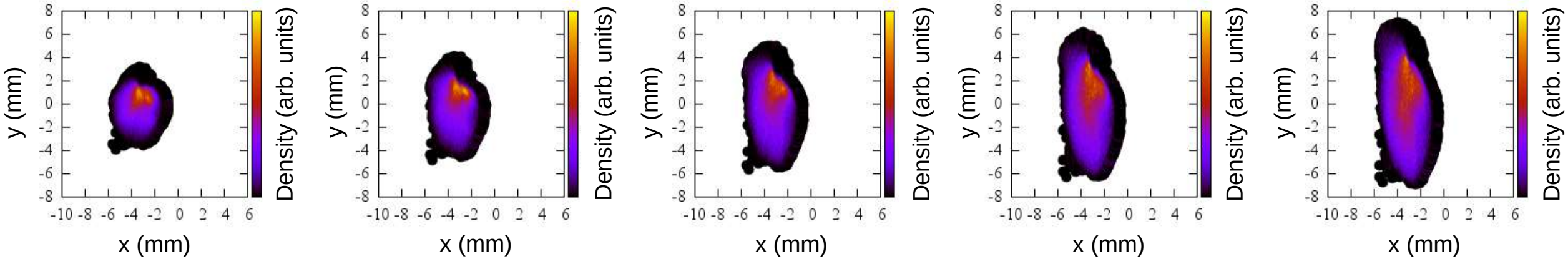
Fixed density scale across measurements

Measured



φ = -10° φ = -20° φ = -30° φ = -40° φ = -50°

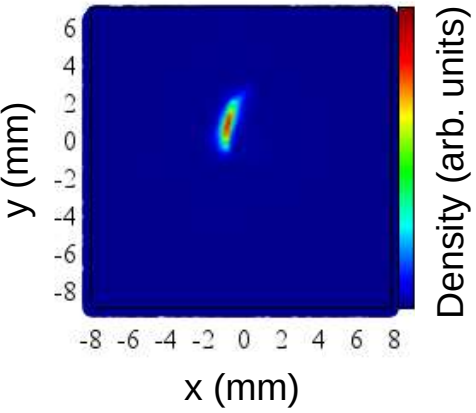
Simulated



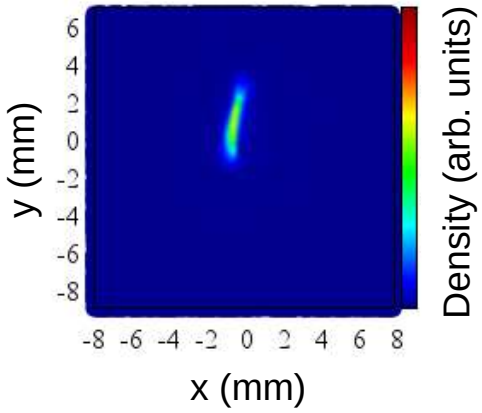
As a Function of Phase: C2 (Longitudinal Phase Space)

Fixed density scale across measurements

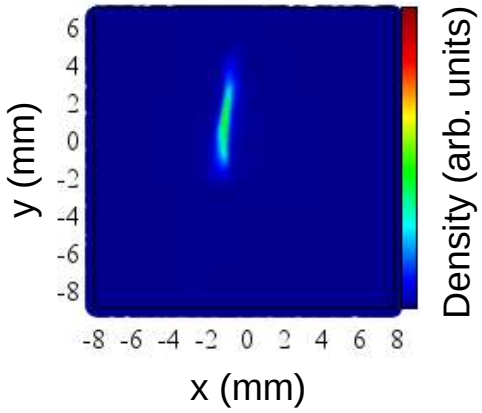
Measured



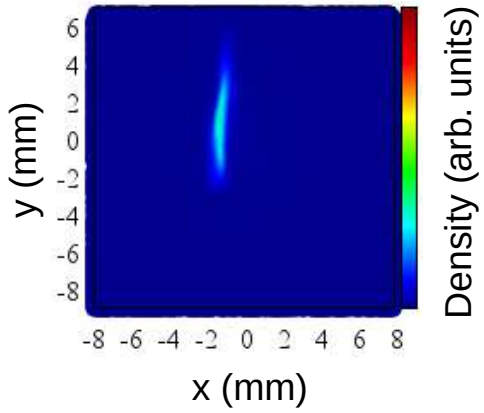
φ = -10°



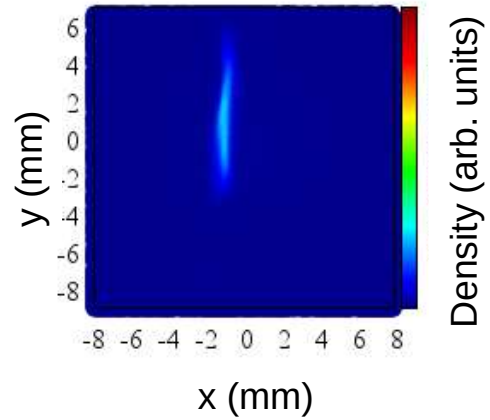
φ = -20°



φ = -30°



φ = -40°



φ = -50°

Simulated