# XICSRT
## RAY-TRACING CODE FOR HIGH ENERGY DENSITY PHYSICS APPLICATIONS

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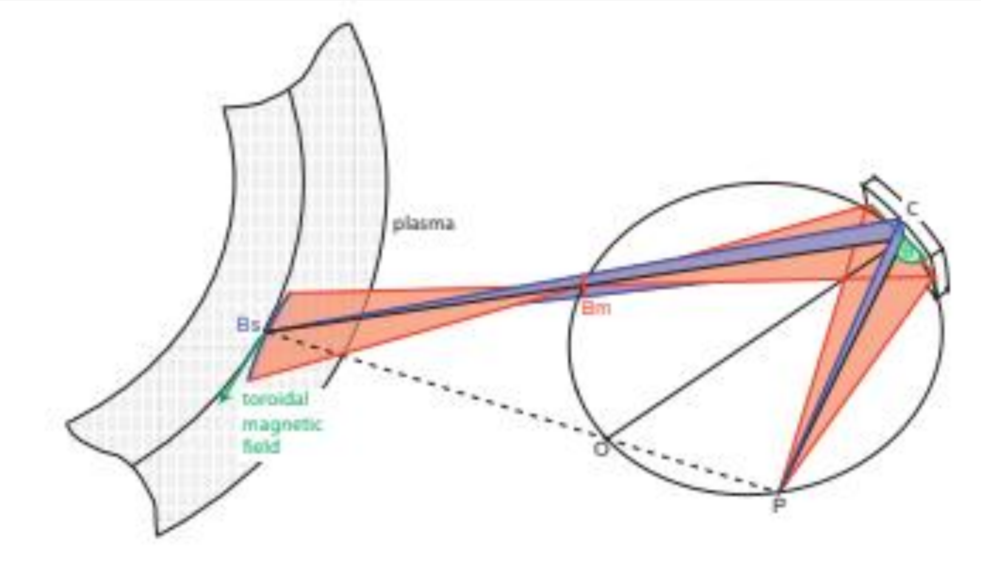
# XICS

- X-ray Imaging Crystal Spectrometer
- X-ray diagnostic for both Magnetically Confined Fusion such as stellarators and tokamaks and also for High Energy Density Physics such as NIF.
- Detects x-rays emitted by impurities in the source
- Gathers x-ray spectra which can be used to study plasma properties such as ion temperature, plasma velocity, impurity concentration etc.



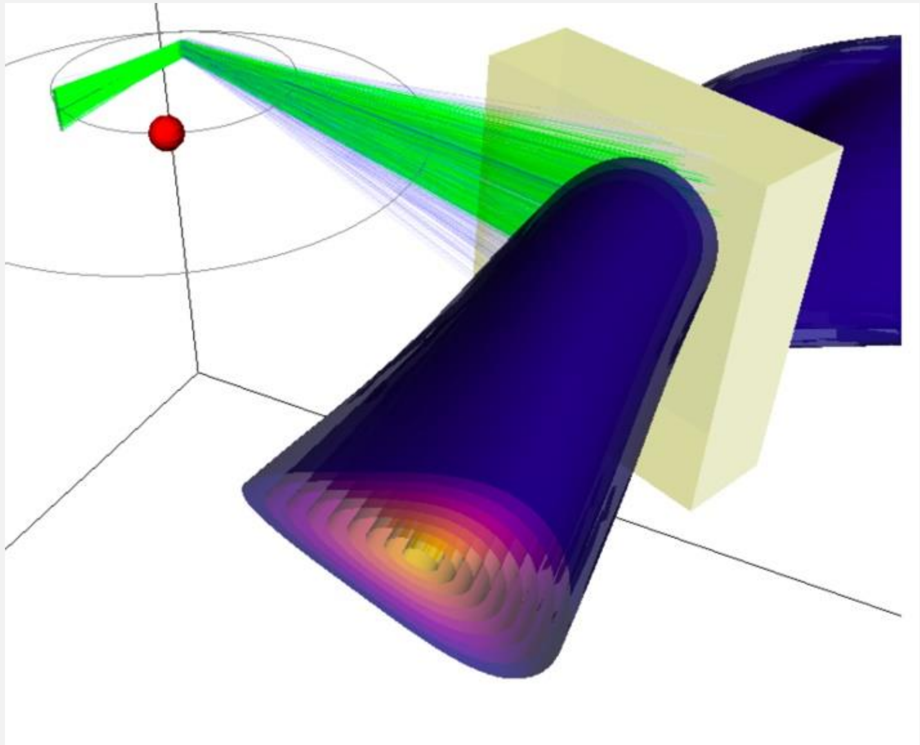

Generic setup of XICS system for tokamaks and stellarators

# XICSRT CODE

- Object-oriented ray-tracing code
- Simulates x-ray source, crystal and detector of XICS
- Very useful for simulating XICS systems on a number of different reactors
- Can be used to test new XICS setups as well as new optics or plasma sources within an existing XICS setup

# HOW XICSRT WORKS

- Simulates emission of x-rays, reflection of rays at the crystal, and detection of rays on the detector
- Only rays that are incident on the crystal and satisfy the Bragg condition are diffracted to the detector
- Creates output dictionary of rays and their points of incidence on the crystal and detector
- Can produce images of rays, crystal and detector



A visualization of a ray-trace run performed in XICSRT

# ALTERNATE CRYSTAL GEOMETRIES

# PURPOSE

- Multiple new crystal geometries featuring variable radii of curvature across the crystal surface have been proposed
- Expected to greatly improve wavelength resolution and total throughput.
- Will also allow for crystals of arbitrary size to be used with little to no degradation in focusing/wavelength resolution
- Multi-Cone, Modified Toroid, and Sinusoidal Spiral

# MULTI-CONE CRYSTAL

- Proposed as a replacement for Hall's conical spectrograph (a single-cone crystal) at NIF and other high powered laser facilities
- With Hall's geometry, rays with the same Bragg angle incident at different points on the crystal will be reflected to different points on the detector
- The multi-cone geometry arranges the crystal points on many (ideally, an infinite number of) cone surfaces
- Perfect images of the point source are produced for each wavelength

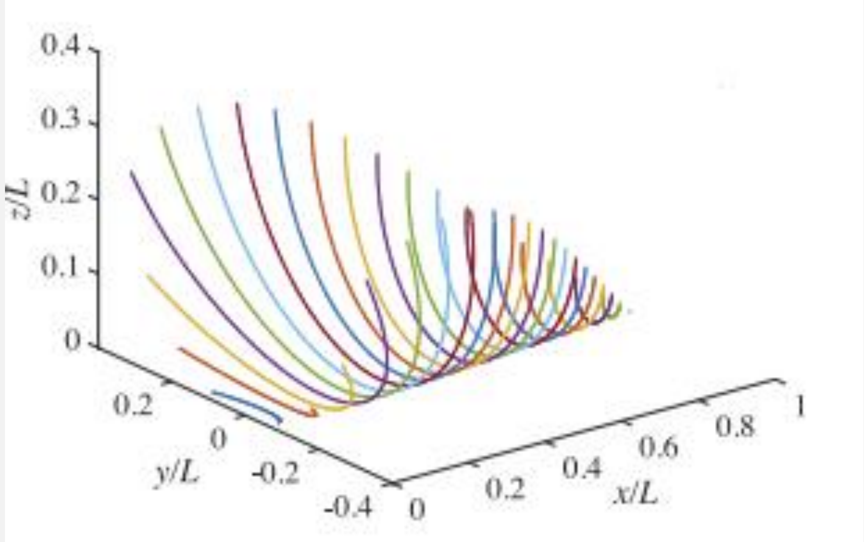
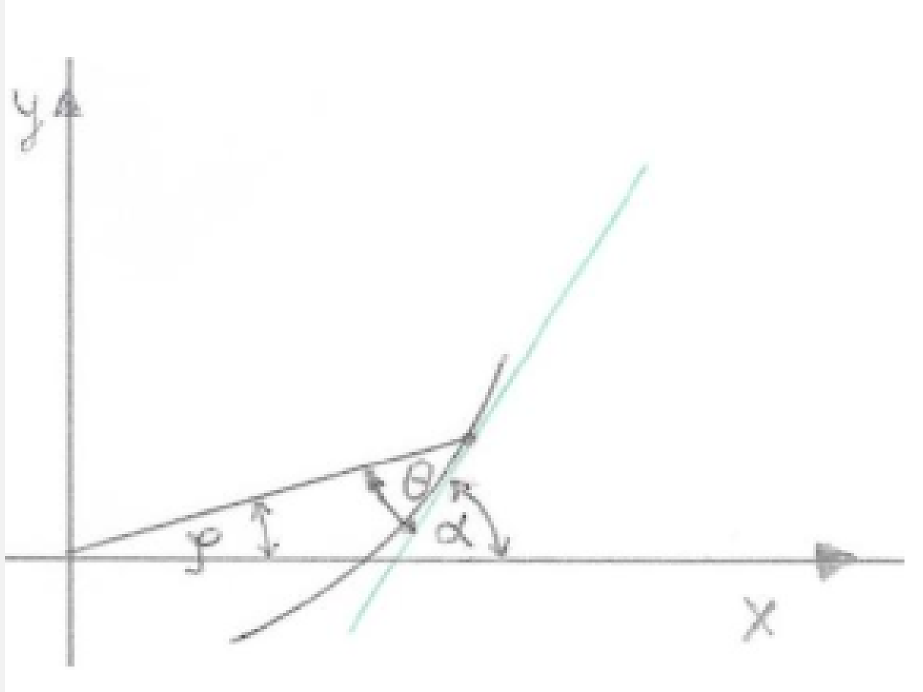



Image of the varying radii of curvature of the multi-cone crystal. (M. Bitter et all.)

# MODIFIED CRYSTAL TOROID

- Features constant major radius ‘R’ and variable minor radius ‘r’
- Minor radius ‘r’ differs in magnitude and direction with respect to ‘R’ for each wavelength
- Allows larger crystal to be used to increase throughput without losing spectral resolution

# SINUSOIDAL SPIRAL CRYSTAL SPECTROMETER




Example geometry of a logarithmic curve representing a curved crystal. The angle (theta) represents the Bragg angle, and is constant for a ray emitted from any direction (phi). (Courtesy of Dr. M. Bitter)

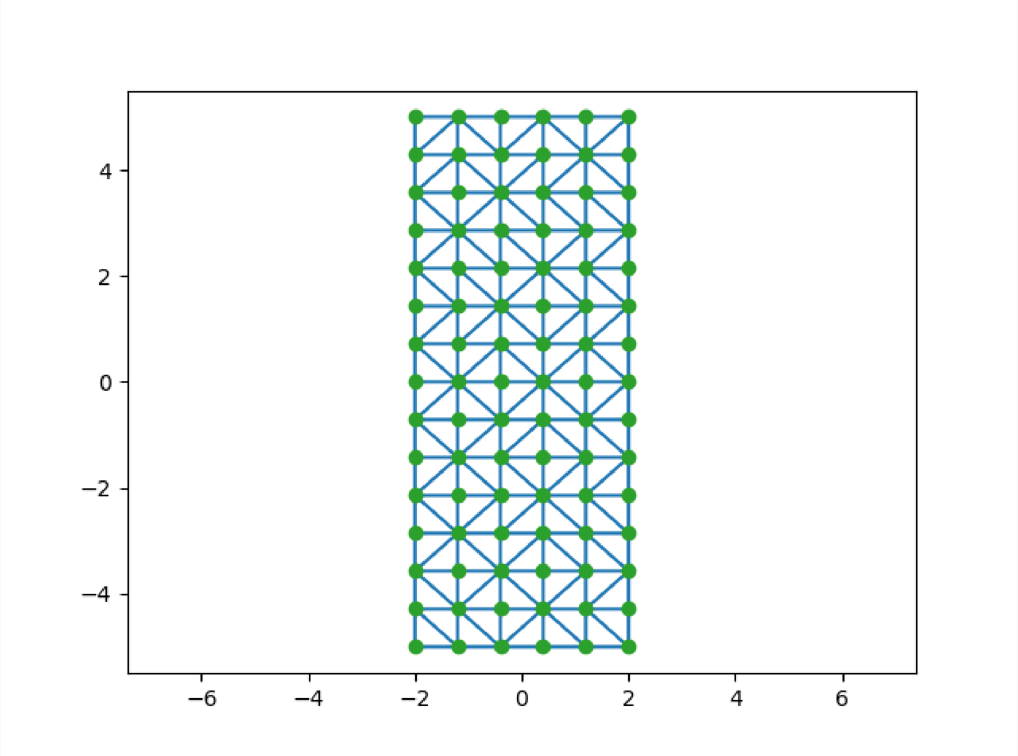
- A crystal whose major radius varies and is defined by a sinusoidal spiral
- Bragg angle and wavelength of reflected rays are constant across the crystal surface
- Allows an arbitrarily large crystal to be used for the observation of a specific wavelength to maximize throughput

# IMPLEMENTING A MESH OPTIC IN W7-X XICSRT

# INTRODUCTION OF MESH OPTICS

- New crystal geometries make it difficult to analytically calculate the ray interaction and surface normal
- The use of crystals modeled with a mesh grid has been proposed to speed up model development.

# WHAT IS A MESH OPTIC




A 2-D visualization of the surface of the spherical mesh crystal

- Crystal designed with a surface comprised of a grid of many triangular faces
- Simplifies calculation of normal vectors for variable radii geometries
- Makes implementing new geometries easier within XICSRT

# VALIDATION OF MESH OPTICS

- In order to validate the use of these mesh-surfaced crystal geometries, a mesh version of an existing crystal was created
- A spherical crystal with a mesh grid surface was created with the same dimensions as the spherical crystal used in the W7-X XICSRT setup
- Ray tracing results were collected from each crystal and compared.

# VALIDATION CONT'D

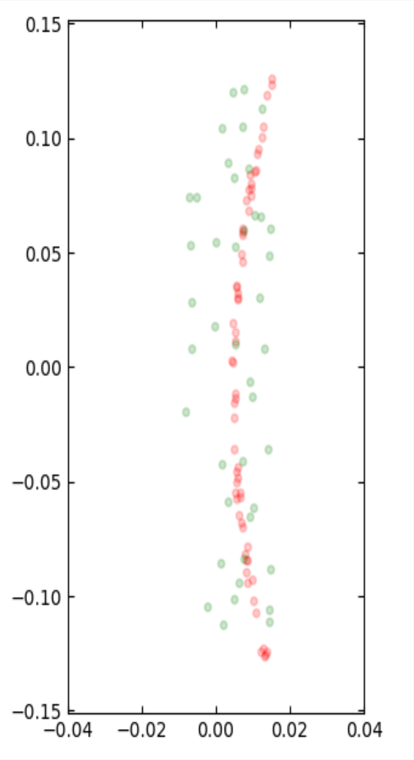
- Six mesh crystals were tested in total, each with varying mesh-grid density, to show the effect of surface quality on spectral resolution
- The results from each of these mesh crystals was compared to one ray-trace run with the analytical spherical crystal
- The ray tracer was set up identically for both the spherical and mesh crystals
- The same number of rays were produced for every run

# VALIDATION RESULTS

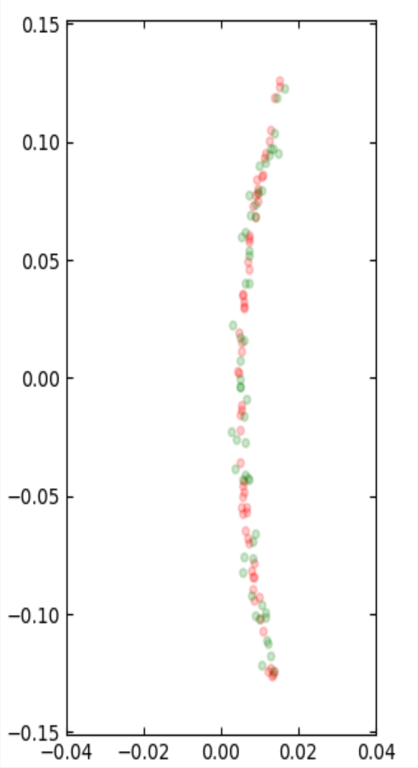
● :Spherical Crystal

● :Mesh Crystal

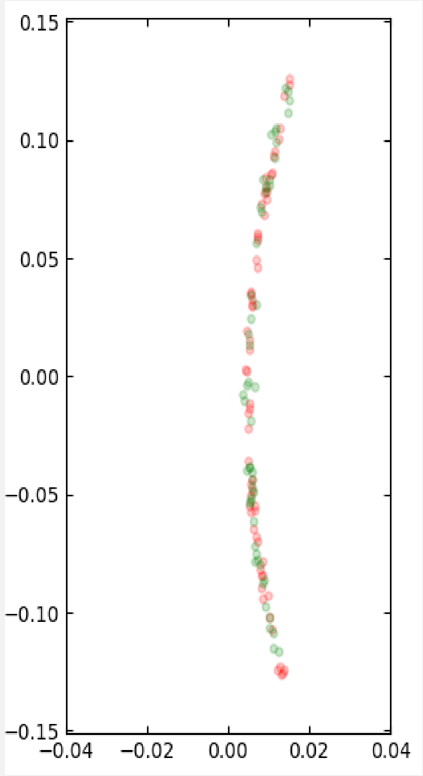
Mesh Density: 0.2 faces per square cm; 10 mesh points




Mesh Density: 6.65 faces per square cm; 160 mesh points



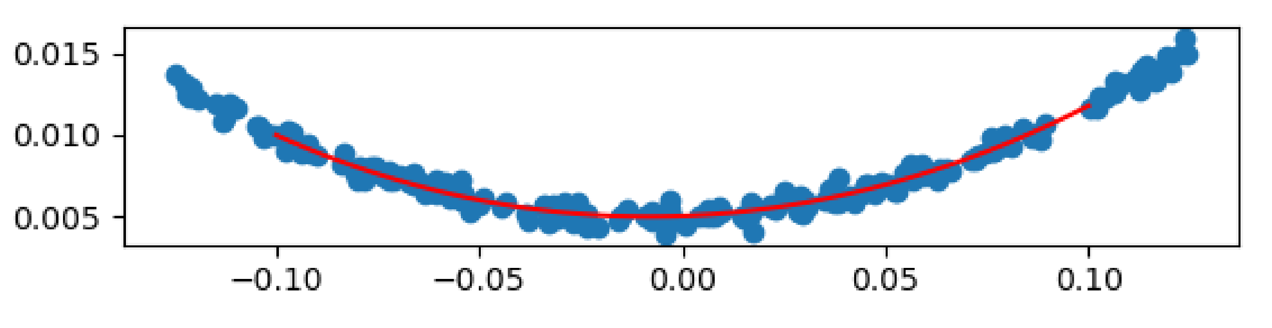

Mesh Density: 46.55 faces per square cm; 1,000 mesh points




Images of the detector for 3 separate runs with rays from mesh crystal in green and spherical crystal in red.

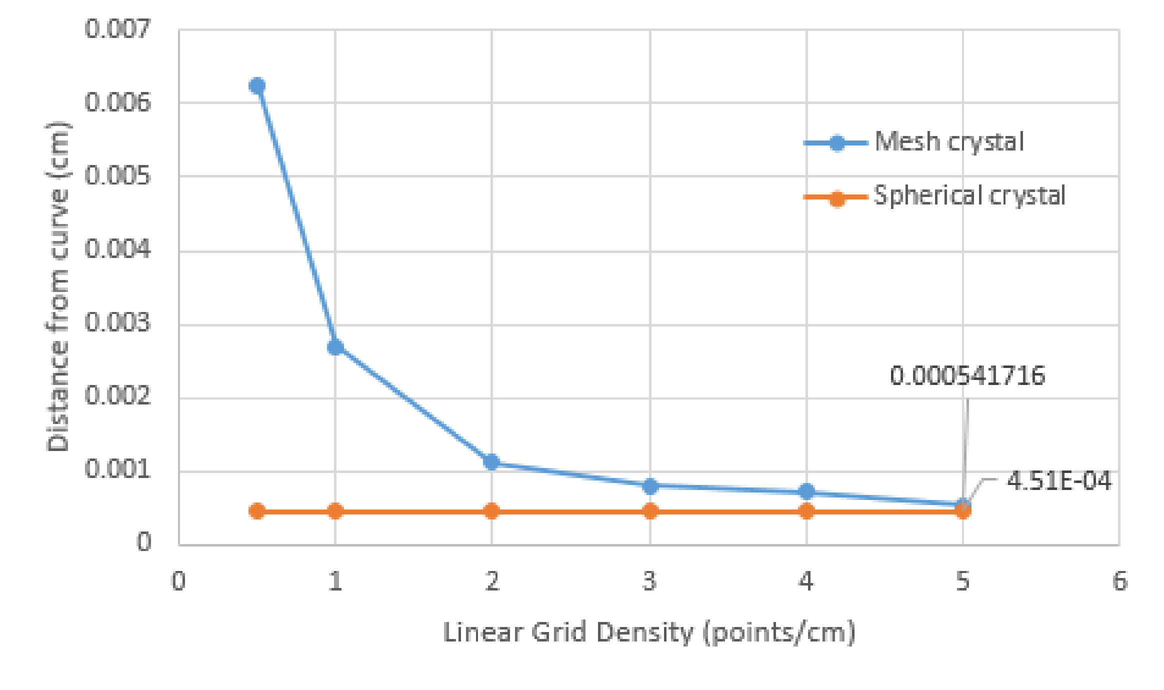
# RESULTS

- As the mesh density of the mesh crystal was increased the spectral resolution in the detector plane also increased
- A curve was fit to the set of points collected from the spherical crystal for reference
- The distance (in the spectral direction) between each point from the mesh crystal and the curve was calculated

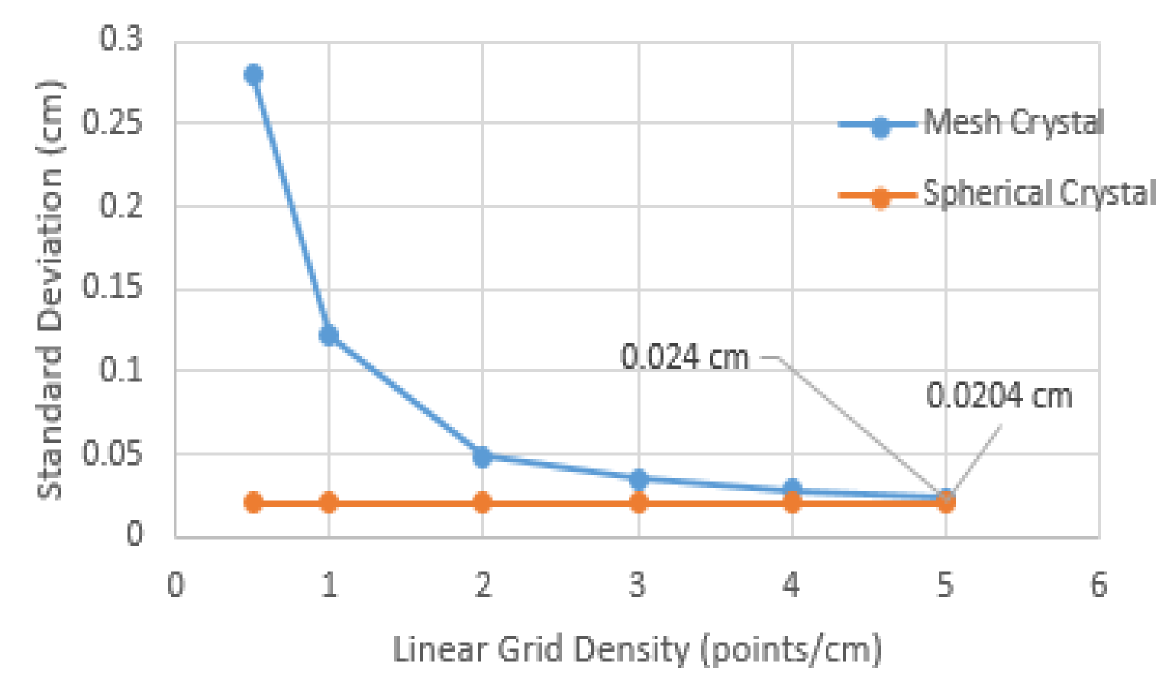



Curve fit to the set of points from spherical crystal. The curve is a fourth order polynomial with coefficients; $13.78\ x^4 + 0.02884\ x^3 + 0.3953\ x^2 + 0.0101\ x + 0.005241$

# RESULTS




Graph of mean distance of points from curve




Graph of standard deviation in distance of each point from curve

# RAY MATCHING

- Due to the Bragg check condition, rays from the spherical and mesh crystals were not able to be matched one-to-one
- Another set of ray-tracing runs was performed without the Bragg check
- This allowed rays on the detector from each crystal to be matched and compared.

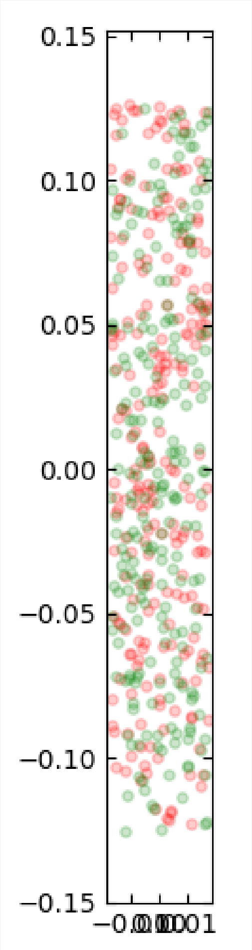
# RESULTS WITH RAY MATCHING

- Images of the detector were produced for the lowest mesh density (left) and highest mesh density (right) crystals
- Points from mesh crystal in green and spherical crystal in red
- No discernable curve because the Bragg check is off
- Notice in the second image, most of the rays overlap each other

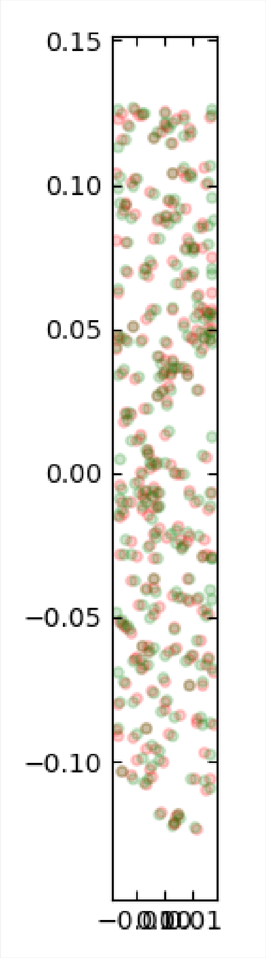
:Spherical Crystal

:Mesh Crystal

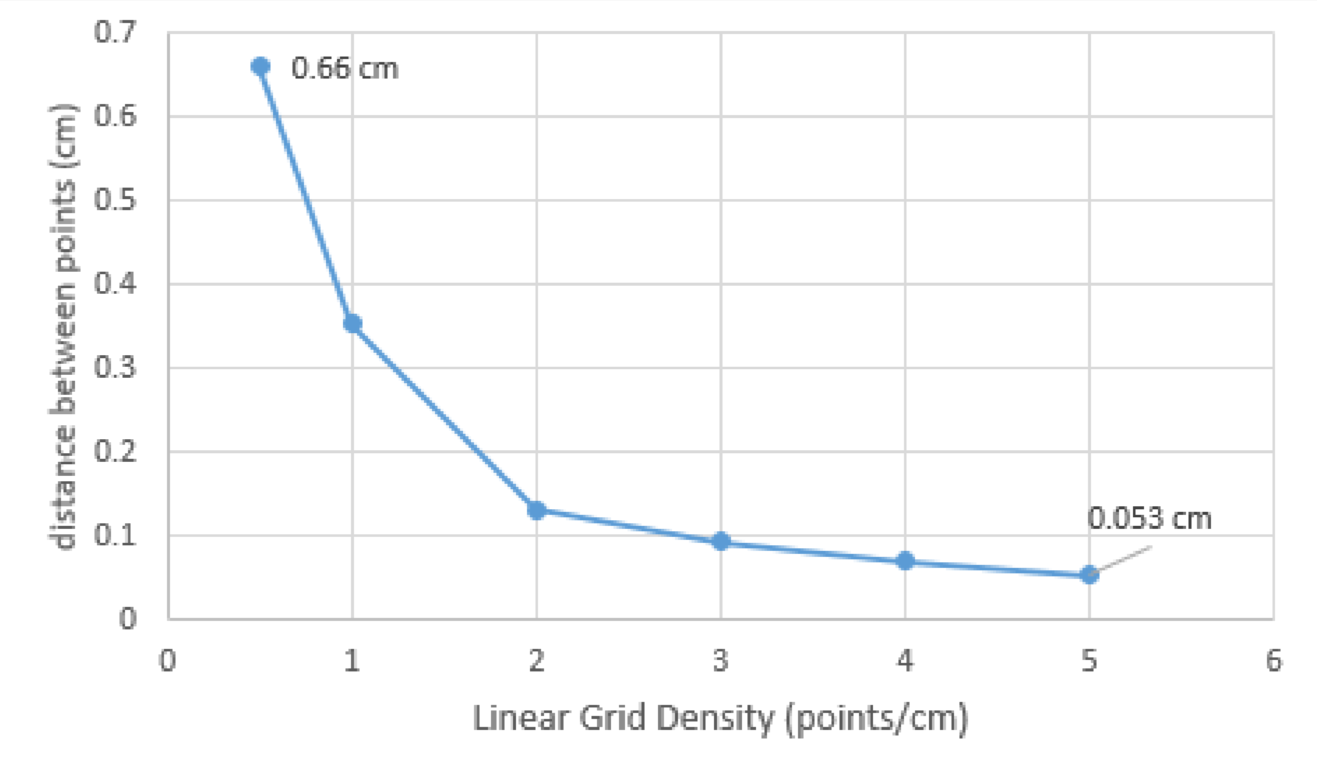
Mesh Density: 0.2 faces per square cm




Mesh Density: 46.55 faces per square cm



# RESULTS WITH RAY MATCHING




Graph of the mean distance between each point from the spherical crystal and mesh crystal. Note: this is the total distance, not just the distance in the spectral direction as before

- Distance between each mesh point and its respective spherical crystal point was calculated
- Similar trend to runs with Bragg check

# MESH OPTIC CONCLUSIONS

- Use of mesh optics was validated within XICSRT code using a spherical mesh crystal
- High mesh density crystals produced results very similar to those produced by the generic spherical optic
- Note: computational time increases as the square of the number of mesh points the mesh crystal has.
- Optimization of code could allow much higher mesh densities to be used

# CONCLUSIONS

- The use of optics with mesh-grid surface geometries was validated within the XICSRT code.
- These mesh-surfaced crystals are useful in the implementation of new geometries proposed for XICSRT
- Optimization of the XICSRT mesh-grid code could lead to drastic reductions in computational time, allowing much higher grid densities to be utilized
- Newly proposed crystal geometries (Multi-Cone, Modified Crystal Toroid, and Sinusoidal Spiral Crystal Spectrometer) should be created and validated within the XICSRT code