

# Diagnostic Imaging System for MAGIS-100

Simulation of Mounting Tolerance & Performance

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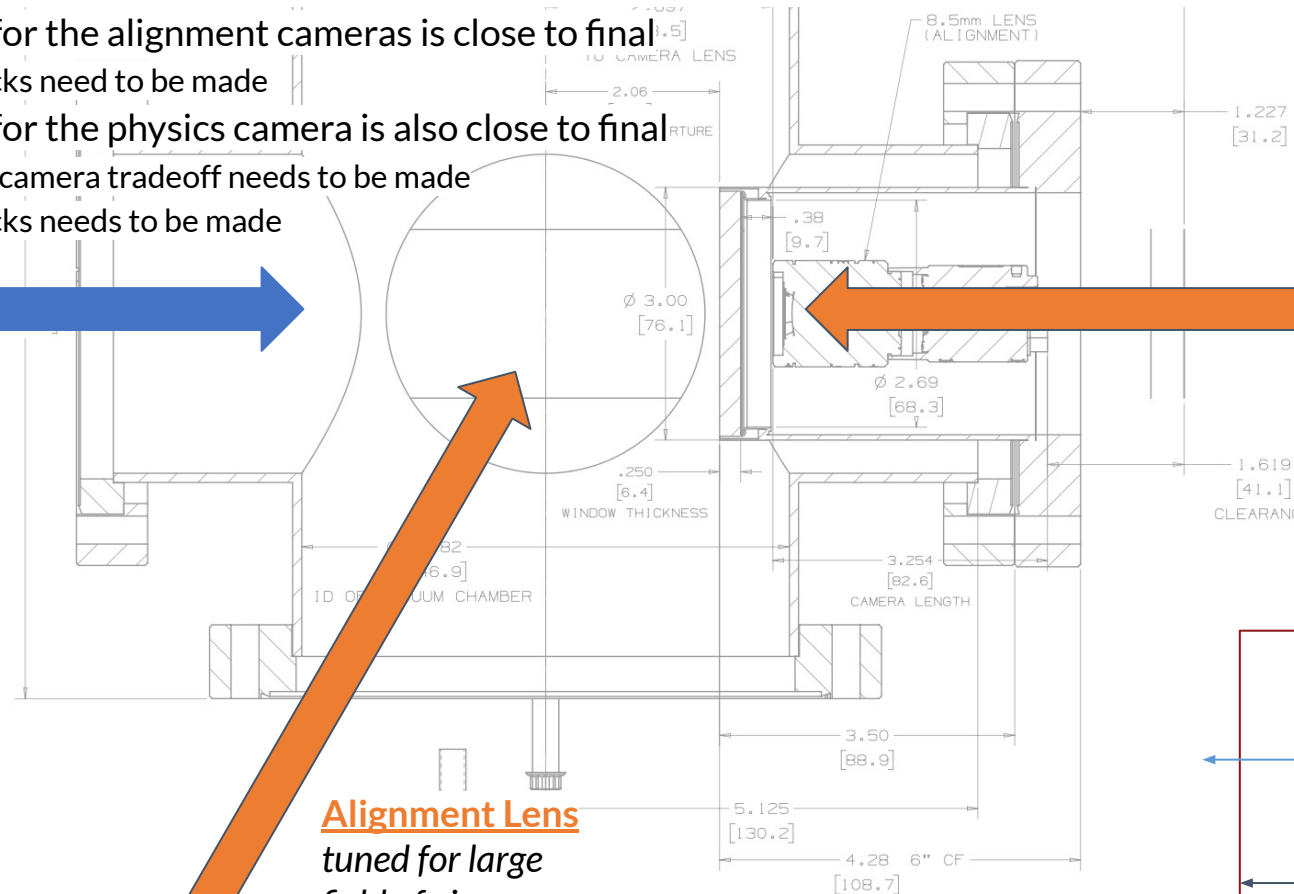
SLAC MAGIS Group Meeting  
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# Diagnostic Imaging System: Overview

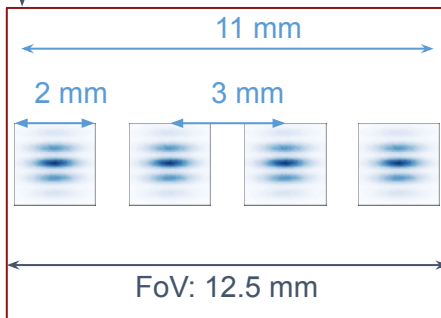
## Triple Camera Node Configuration

- Camera and Lens choice for the alignment cameras is close to final
  - Final dimensional checks need to be made
- Camera and Lens choice for the physics camera is also close to final
  - Decision on lens size / camera tradeoff needs to be made
  - Final dimensional checks needs to be made



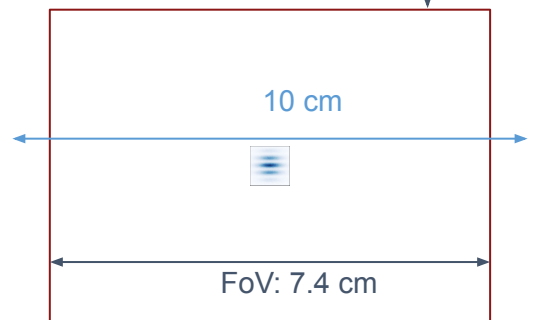
**Physics Lens**  
tuned for higher magnifications  
 $m = 0.6$

w/ Remotely adjustable  
base for focus



**Alignment Lens**  
tuned for large field of view  
 $m = 0.1$

w/ Fixed mount



**Alignment Lens**  
tuned for large field of view  
 $m = 0.1$

# DIS: Alignment Camera Summary

Specs relevant for today's studies

- Two alignment cameras / node
- 8.5mm lens
- Nominal mag. = 0.1
- Working distance = 93.5mm
- Field of view: 49.8mm × 74mm
- Depth of field: 10mm for 5lpmm, 40mm for 1lpmm

Other details:

- 2.4 $\mu$ m pixel size
- 3072 × 2048 pixels
- Exposure time: 25 $\mu$ s - 30s



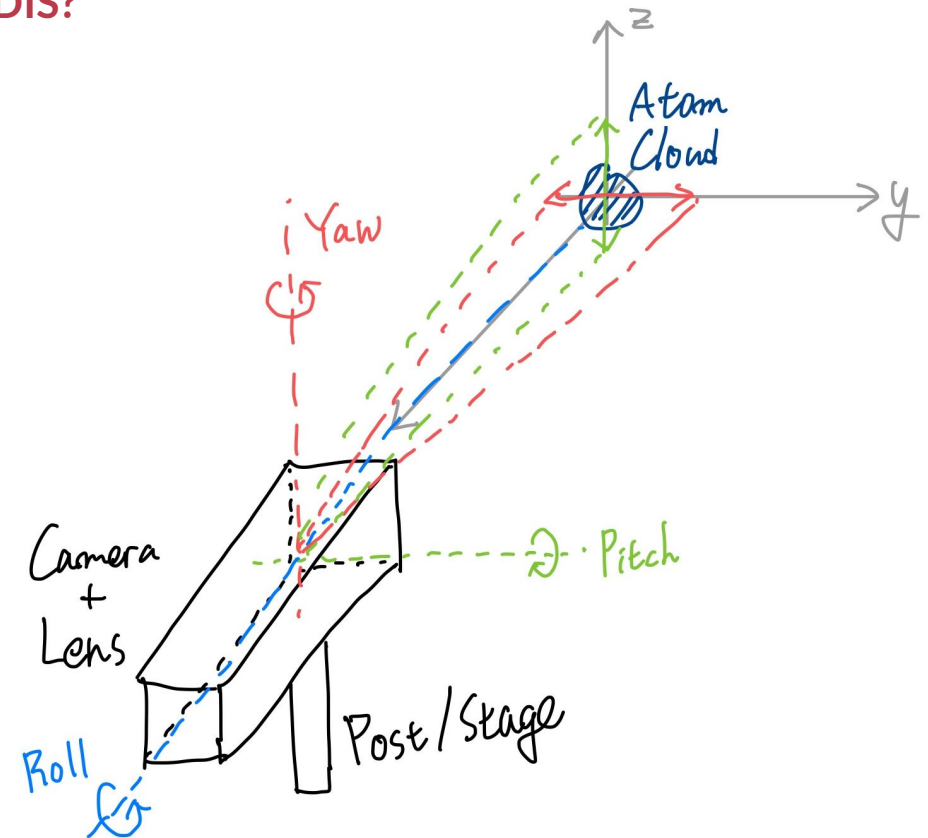
# Camera Mounting Tolerance

From discussions with Fermilab engineers (Dirk Hurd, Noah Curfman)

- “What kind of mounting mechanism/precision do you need for DIS?”

This study:

- “Assuming some reasonable tolerance  $T$ , what kind of location precision can we get from DIS?”
- Assumed mounting tolerances:
  - $\pm 1\text{mm}$  uniform error in  $x, y, z$  positions
  - $\pm 0.5^\circ$  uniform error in pitch & yaw angles
    - At 93.5mm, this causes  $\pm 0.8\text{mm}$  effect
  - Small roll doesn't affect our measurement



# Simulation Set-up

## Simplifying assumptions

- Everything is in focus; no de-focusing information
- No other ray-tracing things

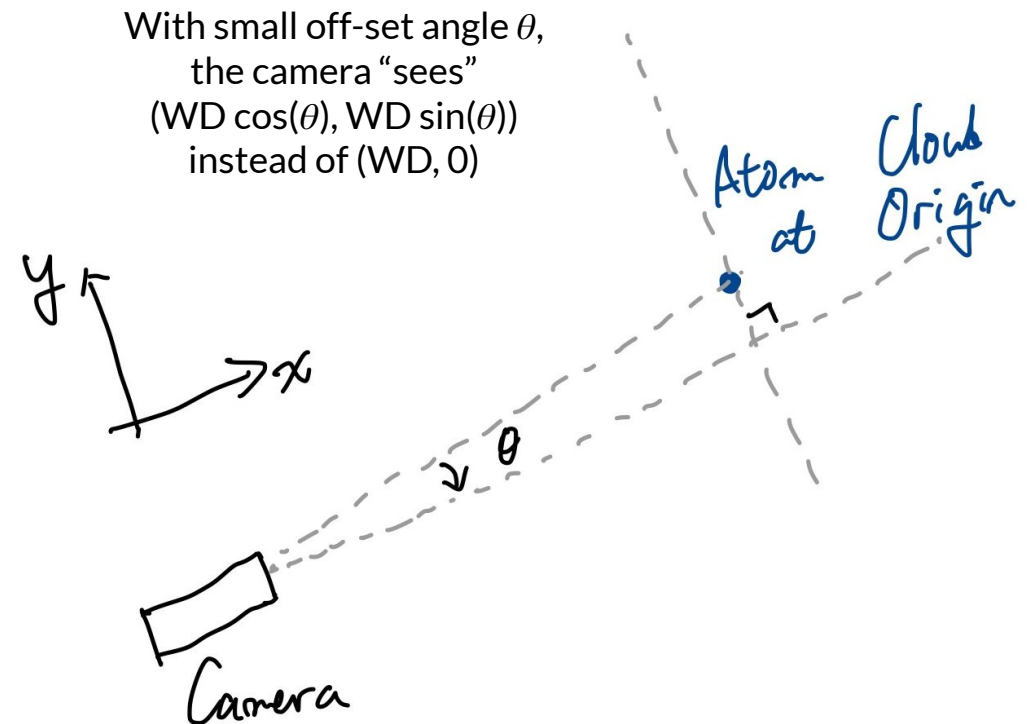
`DIS` class has following variables:

- Focal length
- Working distance (internal)
- Nominal position and some offset
- Nominal orientation and some offset

and following functions:

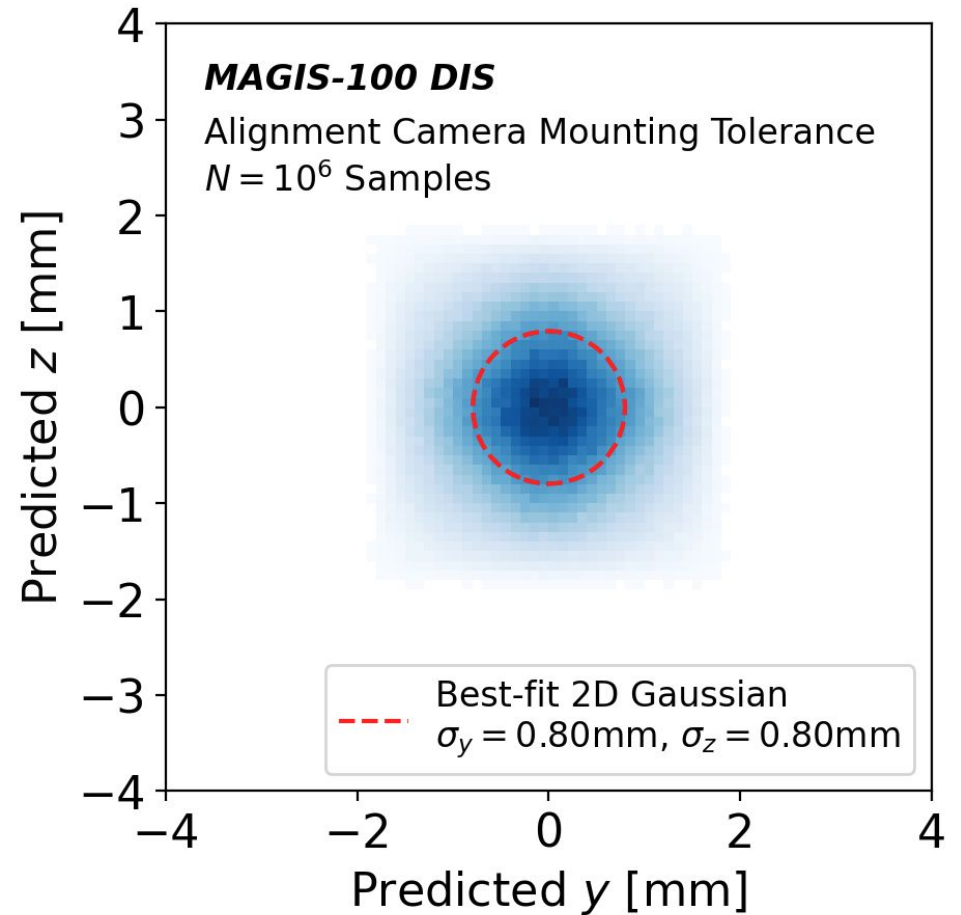
- View image from object
  - Relative object coordinate  $\times$  real magnification
- **Infer object position from image**
  - **Transverse: image coordinates / internal mag.**
  - **Axial: internal working distance**

Everything is implemented differentiably, in PyTorch



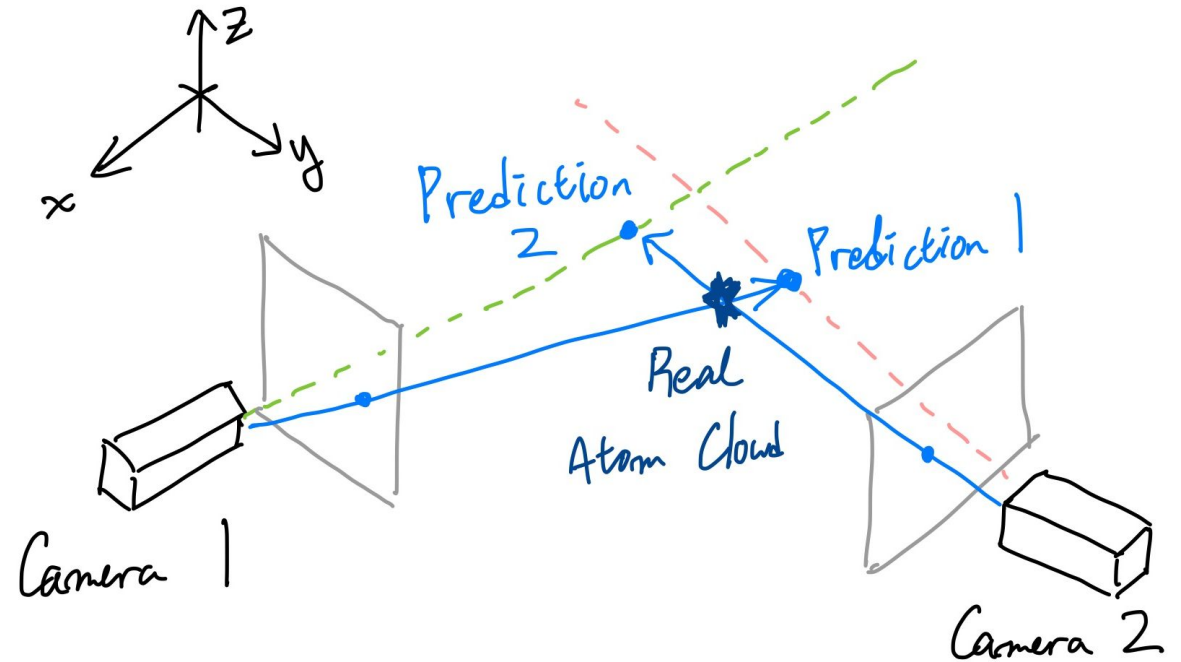
# Verifying Simulation & Basic Tolerance Check

- Atom cloud fixed at origin
- One alignment camera at (-93.5mm, 0, 0) with some tolerance
  - $\pm 1\text{mm}$  uniform error in x, y, z positions
  - $\pm 0.5^\circ$  uniform error in pitch & yaw angles
    - At 93.5mm, this causes  $\pm 0.8\text{mm}$  effect
- **This camera can predict transverse position with  $\pm 2\text{mm}$  range,  $\pm 0.80\text{mm}$  Gaussian resolution**
- Rough sanity check:
  - $\pm 1\text{mm}$  uniform error in y, z positions
    - $\Rightarrow \text{Var}(y) = \frac{1}{12}(2\text{mm})^2$
  - $\pm 0.5^\circ$  uniform error in pitch & yaw angles
    - $\Rightarrow \text{Var}(y) = \frac{1}{12}(1.6\text{mm})^2$
  - These add up to  $\pm 0.75\text{mm}$  stdev.



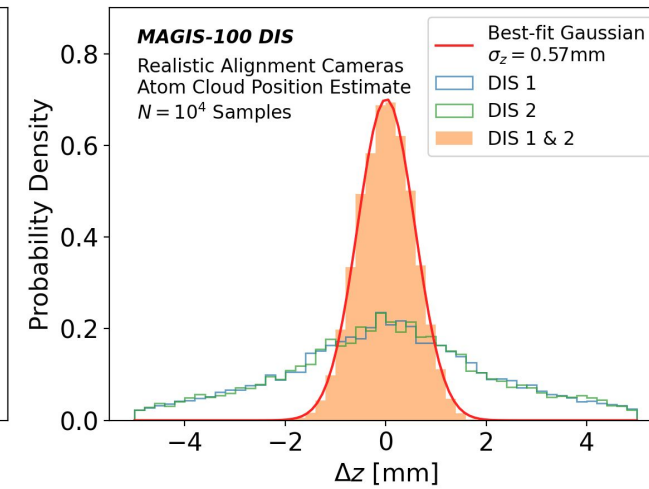
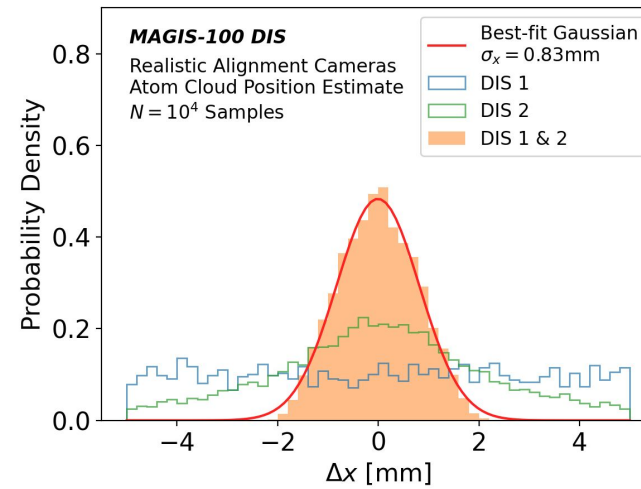
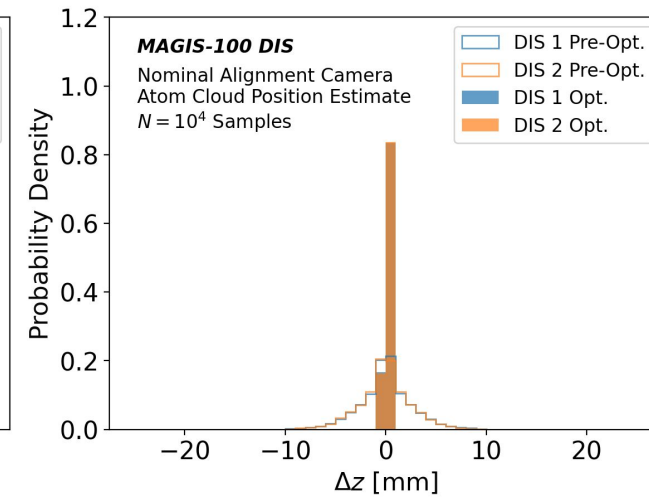
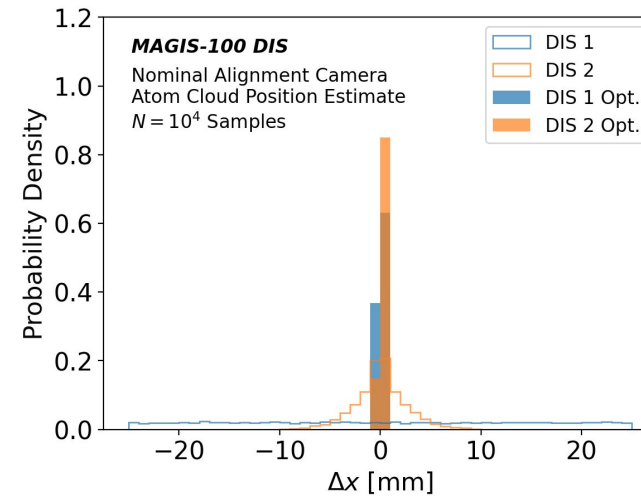
# Combining Two Alignment Cameras

- One alignment camera cannot predict depth / axial distance
  - De-focus is small (high DOF)
  - Depth is hard to predict from a simple image
- We have two cameras mounted perpendicularly along x and y axes
- How to combine information from two cameras?
  - Each camera predict 3D coordinate
    - Transverse based on image
    - Depth just as its “internal WD”
  - **Minimize the difference between two predictions only by tuning working distance**



# Two-Camera Performance Results

- Atom cloud displaced uniformly over  $(5\text{cm})^3$  volume
- Two cameras mounted perfectly:
  - ⇒ this method finds the atom cloud perfectly in 3D
- With realistic mounting tolerances:
  - ⇒  $(\pm 2\text{mm})^3$  volume range or  $\pm 0.83\text{mm}$  (x and y) and  $\pm 0.57\text{mm}$  (z) Gaussian resolution
- Performance seems good!



# Summary

- Differentiable, geometric simulation for DIS alignment algorithm
- **Performance seems good with  $\pm 1\text{mm}$  &  $\pm 0.5^\circ$  tolerances**
- Effects not considered:
  - Finite pixel size at the sensor
    - $2.4\mu\text{m}$  pixel corresponds to  $24\mu\text{m}$  at nominal WD
  - Atom cloud is not a point; we need image  $\rightarrow$  centroid finding
    - This is probably easy (unless there is noisy, bright bkg.)
  - Both these effects can be added to the current set-up and studied, but probably won't change the conclusion
- Plots sent to Jason (DOE Review for MAGIS this week)
- Next steps
  - **Repeat studies with a few other tolerance levels**
  - **Respond to Fermilab engineers with tolerance numbers**
  - Add missing effects mentioned above

