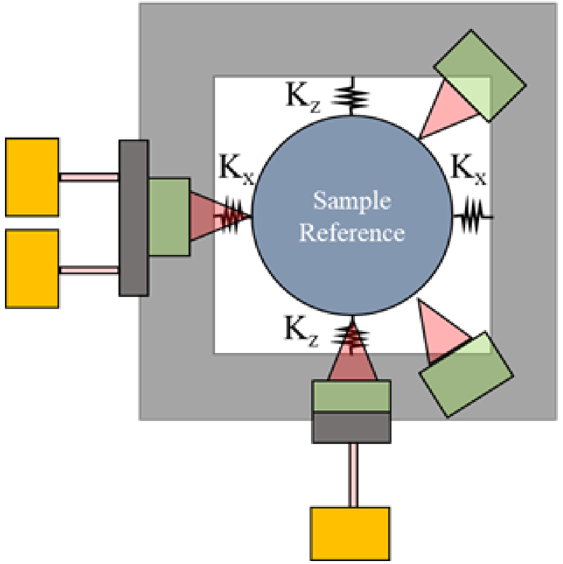
MEDSI 2020

BNP-II Traveling Metrology Configuration



SUNIL BEAN

APS/APS-U Mechanical Engineer

APS-U Instrument Coordinator/CAM

July 29, 2021

MEDSI CHICAGO 2020

2-ID BNP-II Instrument Team

Science Lead

Si Chen

Engineering & Drafting

Sunil Bean

Ben Davis

Joanna Tan

Paul Amann

Controls Development

Tim Mooney

Kevin Peterson

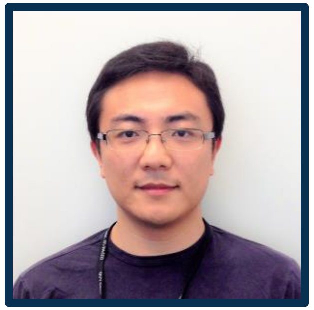
CAM

Sunil Bean

ZP Optics Dev.

Michael Wojcik

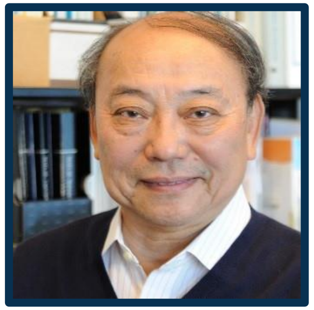
Optics Simulation



Xianbo Shi

Technical Advisory

Barry Lai



Deming Shu

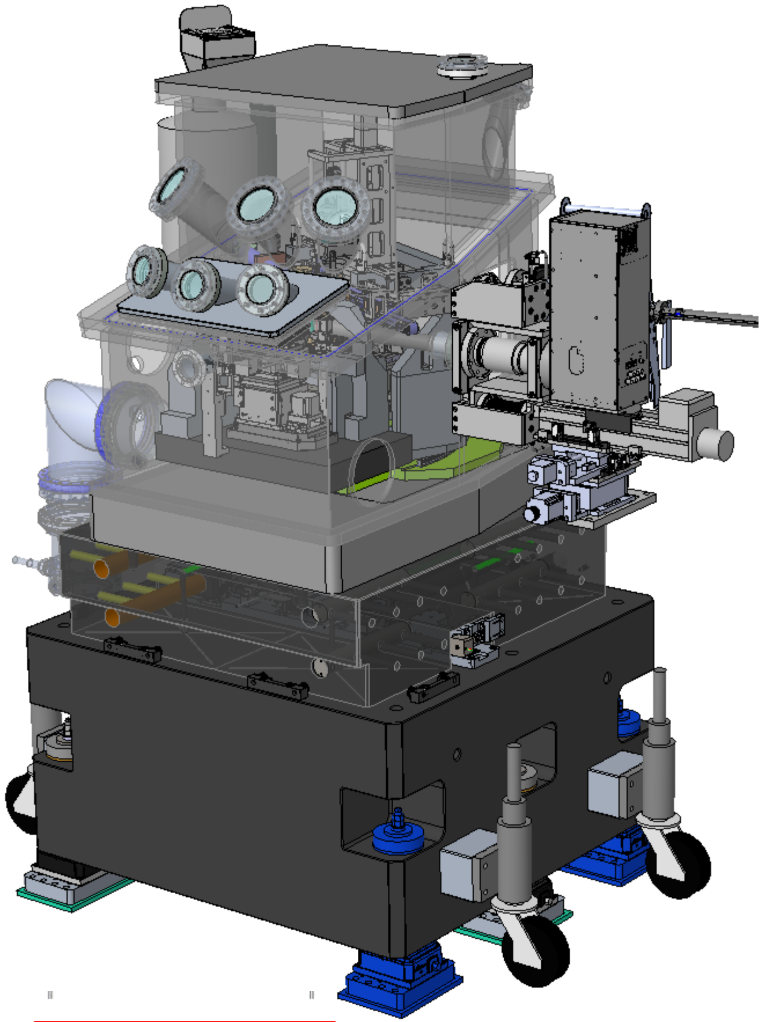
Chris Jacobsen

Beamline Specialist

Evan Maxey

2-ID-D MIC Bionanoprobe 2

BNP-II

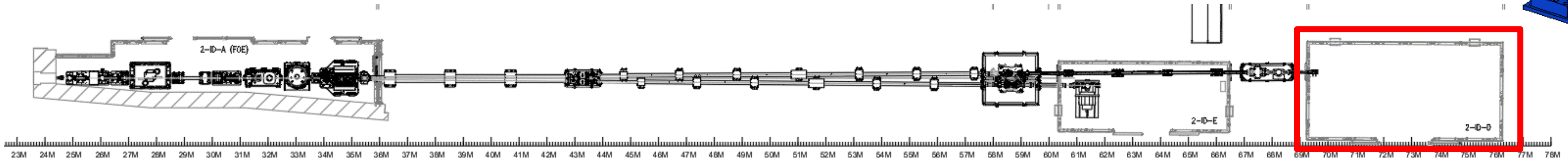


Scientific Scope:

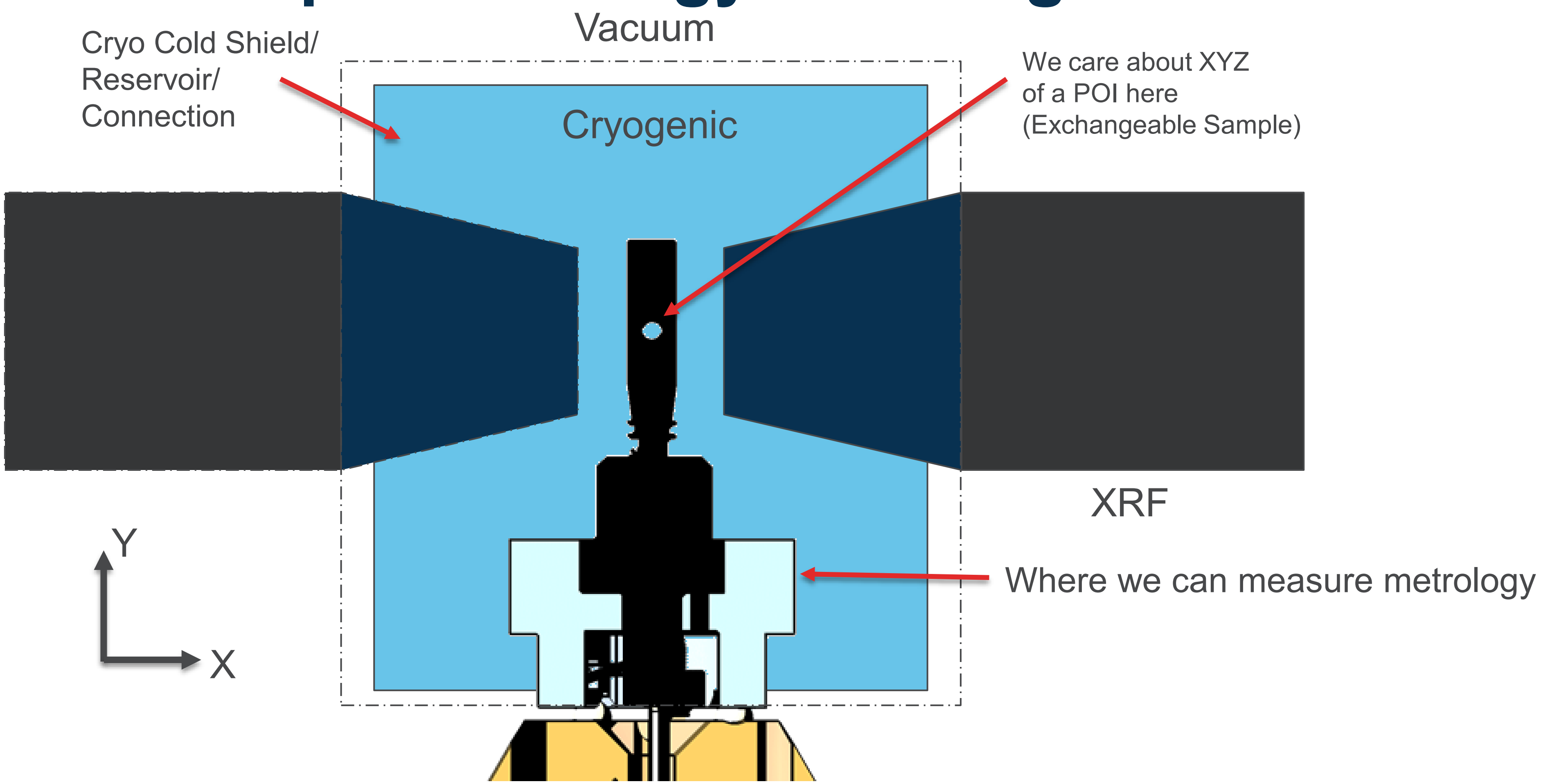
- The BNP-II will be used to quantitatively study trace element distribution and ultrastructure of a sample with <10 nm resolution and a-few-atom sensitivity in both two and three dimensions for life, environmental and materials sciences.

Metrology:

- The metrology configuration for this instrument is the heart of meeting the spatial resolution. <u>It is the focus of this presentation.</u>
- The metrology and scanning system is still being designed.



Sample Metrology Challenge



How to measure a rotating and translating cryogenic sample?
How to configure metrology with respect to the positioning and scanning strategy.?

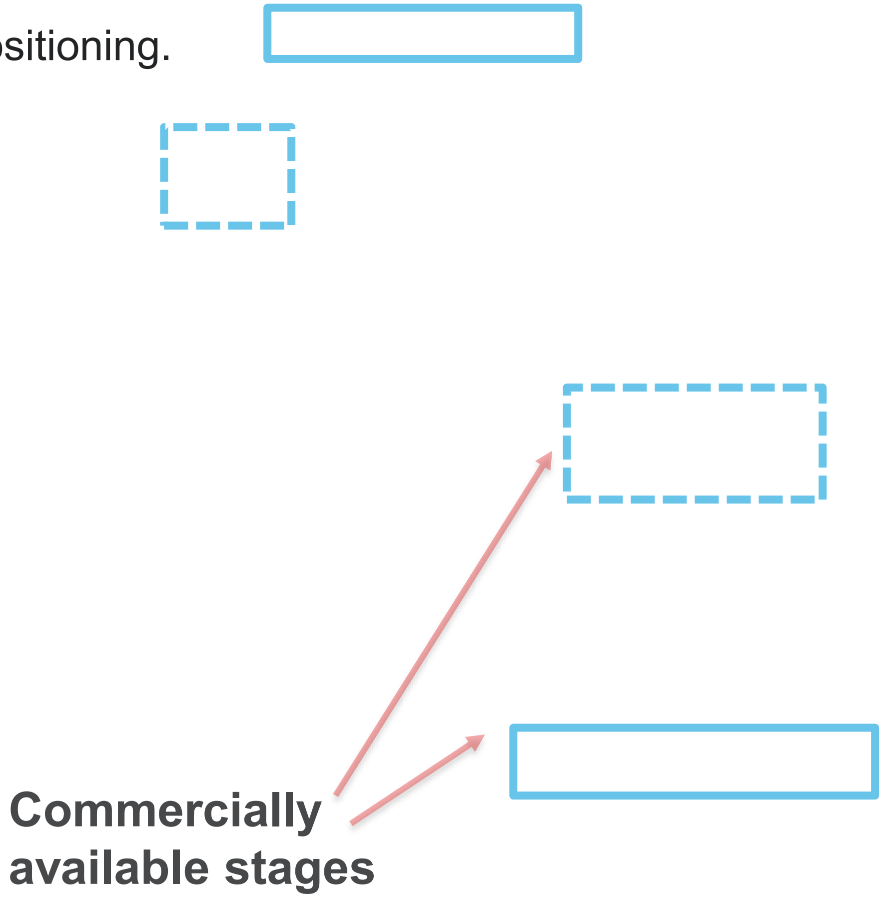
BNP-II Scan and Metrology Requirements

1. 2D Fly scanning required (100x100 μm), with fast scanning axis >10 Hz to avoid sample damage given the APS-U new source. Slow direction can be on the order of nm/s per second.
2. Move to rotation position , position sample in beam, then scan a 2D slice of the sample.
3. The metrology system must discern information < 2 nm in order to achieve a 10 nm fluorescence resolution **(to bin correctly).**
4. The metrology scheme must be able to measure re-positioning the sample through translations (mm's) and one main vertical rotation axis (<360 deg).
5. The sample metrology reference optic and the sample should be intimately coupled (cryogenic).
6. The metrology must incorporate relative measurement between the optic and sample positions for both positioning and scanning.
7. The cryogenic sample will be fly scanned while the optics are stationary during measurement.
8. The metrology should be non-intrusive to the nearby XZ (horizontal) plane of the sample to allow for fluorescence, beam conditioning optics, radiative shielding, and diffraction coverage.

- The combination of constraints are challenging. 2 stage measurement strategies for rotating instruments from ESRF (ID16A) and SLS (LamNI & flOMNI) were considered.
- The unique requirements for a cryogenic sample environment, positioning requirements, fast scanning, the constraints of the instrument configuration, and the desire to measure as close to the sample as possible (cryogenic reference) led to looking for a new solution.

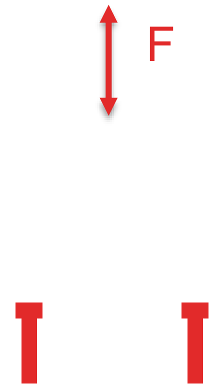
Proposed Sample Traveling Interferometry Configuration

- Below are schematics of the top view (left) and front view of the proposed 2 step metrology configuration for the sample.
  - Green – Traveling interferometer.
  - Gold – Stationary global interferometer.
  - Scanners are outlined. Other DOF are used for positioning.



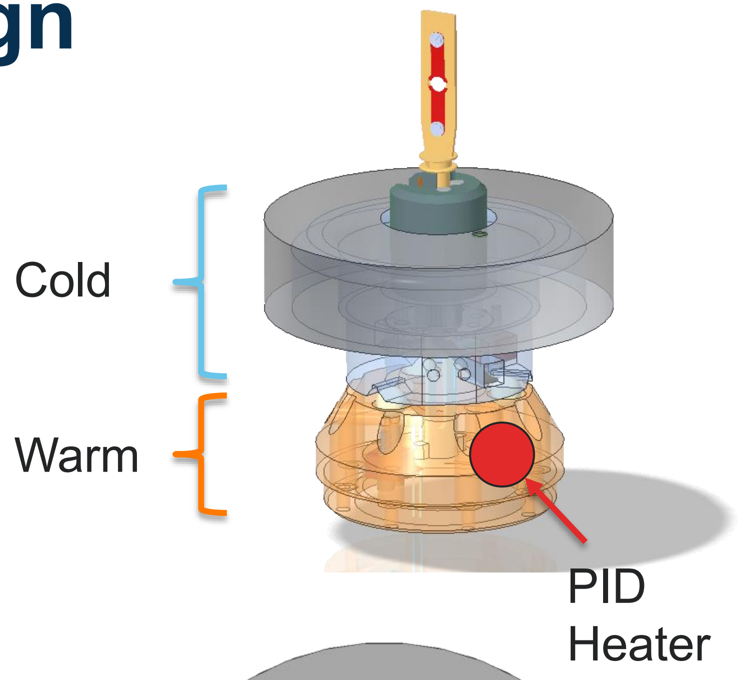
Why this scanning configuration?

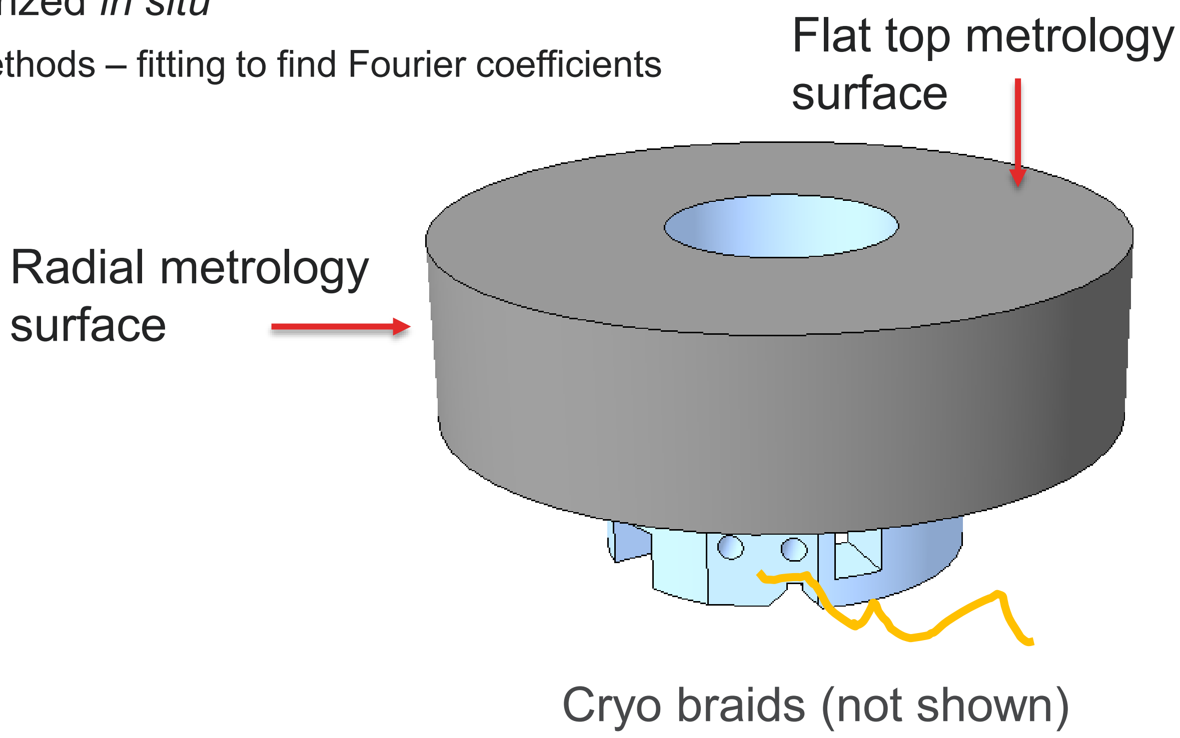
- Longer working distance contactless measurement.
- Nominally there are small displacements measured by the traveling interferometers.
  - ð Rigid body positioning/scanning errors.
  - ð Flexible mode vibration response.
  - ð Thermal variation.
- Thermally symmetric coupling of traveler.
- Fast scanning forces (F) don't react directly through the follower (⊥).
  - ð However, Flexible modes + damping = crosstalk in the XZ. This is the direction being tracked by the traveler.
- Slow scanning axis does not support the weight load of the traveling platform.
  - ð Some flexibility in choosing how to design the traveling platform.
  - ð Some flexibility in choosing the slow scanning axis (can be 5DOF).
  - ð However, platform mass cannot be chosen arbitrarily (mentioned later).

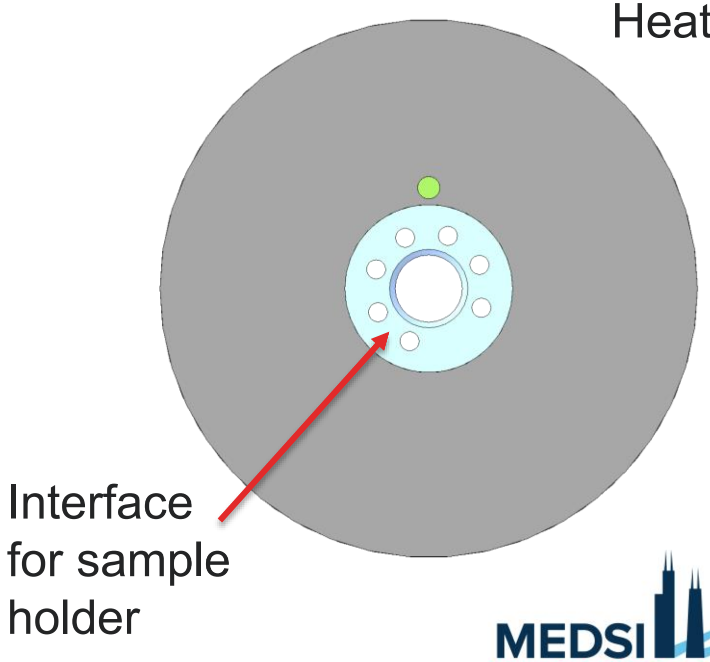


Cryogenic Reference Design

- Currently Ø45 mm in design
- Aluminum being considered (good thermal diffusivity)
- Cryo braids attach 2 places
  - ð Below reference surfaces.
  - ð Limits rotation +/- 180 degrees.
- Fast scanning mass ~ 70 grams
- Form to be characterized *in situ*
  - ð Error separation methods – fitting to find Fourier coefficients







BNP-II Interferometry Configuration

- Below is a schematic view of the entire instrument metrology configuration (right) and a corresponding table (left) that identifies which DOF are measured.
  - ð Green – Traveling interferometer
  - ð Gold – Stationary global interferometer

Measured Degrees of Freedom of Interferometers			
Interferometer/s	Measured (Or Calculated*) Degrees of Freedom	Measurement From	Metrology Head Type
I1 & I3	Coarse Optic X, θ_Y	Reference Frame	Collimated
I2 & I4	Coarse Optic Y, θ_X	Reference Frame	Collimated
I5	High Res. Optic X	Reference Frame	Collimated
I6	High Res. Optic Y	Reference Frame	Collimated
I7 & I8	Sample Follower X, θ_Y	Reference Frame	Collimated
I9	Sample Follower Z	Reference Frame	Collimated
I10 & I11 & I12	Sample Y, $\theta_{X,}$ θ_Z	Reference Frame	Collimated
I13	Sample Z	Sample Follower	Focused
I14	Sample X	Sample Follower	Focused
I15 & I16*	N/A, For Form Characterization	Sample Follower	Focused

Argonne NATIONAL LABORATORY

MEDSI CHICAGO 2020

Geometric Rigid Body Scanning Errors

- Use geometric relationships from the metrology configuration to try to discern what is important.
- Look at the error motions of the reference and traveling platform (both intended to move when scanning)

Simplified Geometric Errors

- The following geometric error relationships can be derived
  - ð What if fast scanning (optic reference) is not performing pure cyclic vertical motion?
  - ð What if slow scanning follower is not ideally following slow scanning motion.

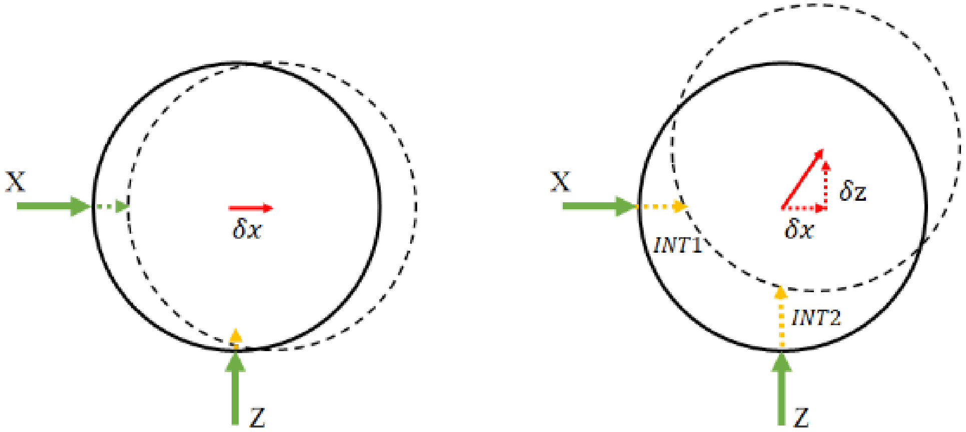
Conclusions from Geometric Errors

- The traveling X and Z measurements are coupled (green)
- The traveling X & Z interferometers don't discern actual sample displacements U_X and U_Z **caused** by angular errors of the reference.
  - Must be calculated from global Y interferometers (red)
- Angular errors of the follower does result in measurement errors (next slide)
  - Helps determine follower guiding and contribution to error budget.

) . 4ρ #ȯ 'Y √'Y· #◗˥
) . 4ς #◗ 'Y √'Y· #●˥

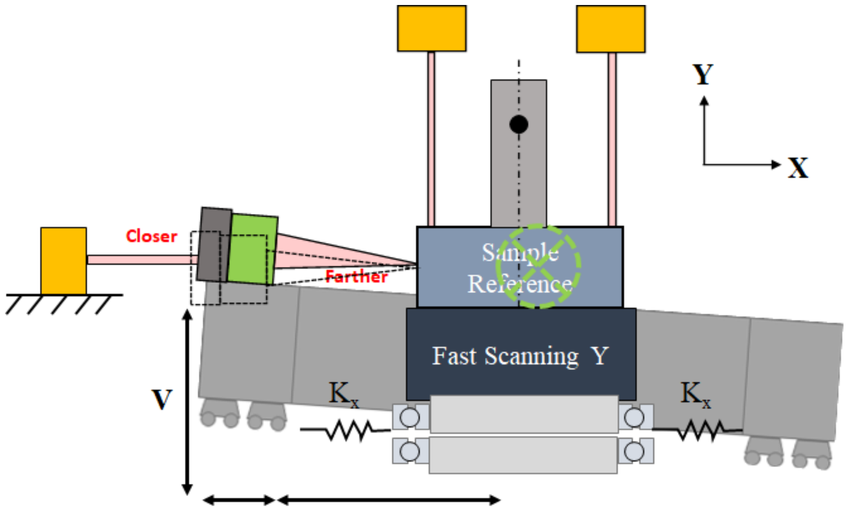
R dominates the non-linear term

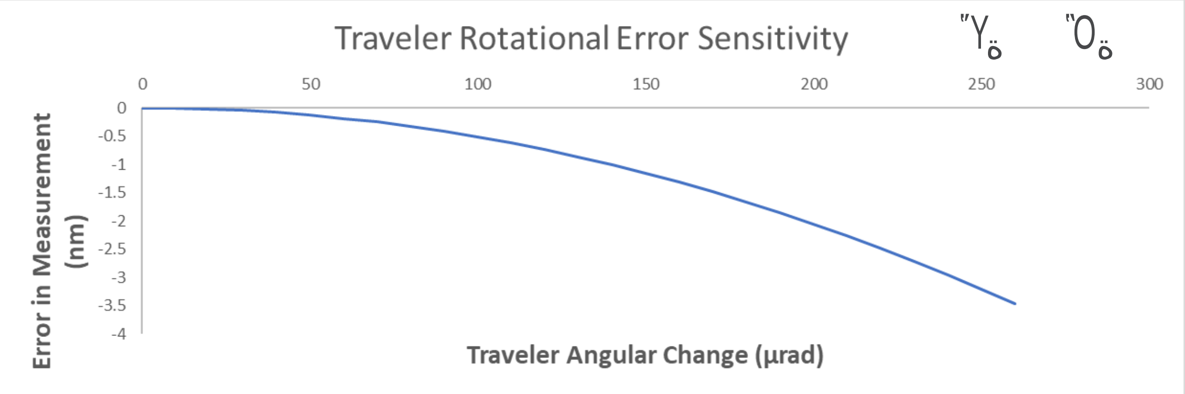
) . 4ρ #ȯ
) . 4ς #◗

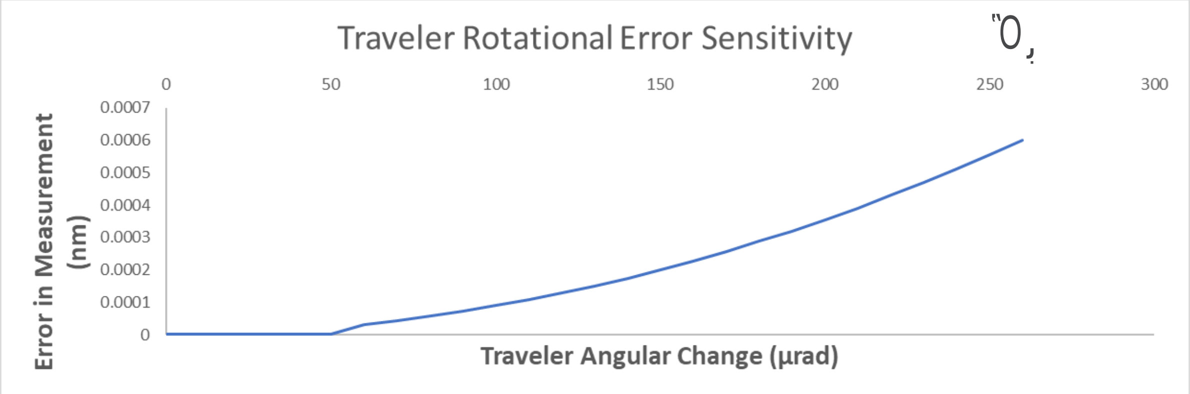


Conclusions from Geometric Errors

- Traveler platform angular change, resultant error measurement.
- Shows promise that the traveler XZ guide can be something like opposed cross roller bearings.







Conclusions from Geometric Errors

- Global measurement of sample ╤╨, Ᵽ╧, Ᵽ╨
  - Calculations from 3 points on a plane
- 2 step global + local measurement of optic XZ
  - Add interferometer signals
- Calculation of sample ╤╧, ╤╨ from –¸ , –ӧ and 2 step information
  - Add optic XZ to additional calculated XZ caused by rotations of the reference

Traveler Resonant Considerations

- When considering the travelers vibrational modes, assuming the follower planar stiffnesses are much lower than typical stage bearings of the sample stack, the twice repeated eigenvalue for two directions of is given as

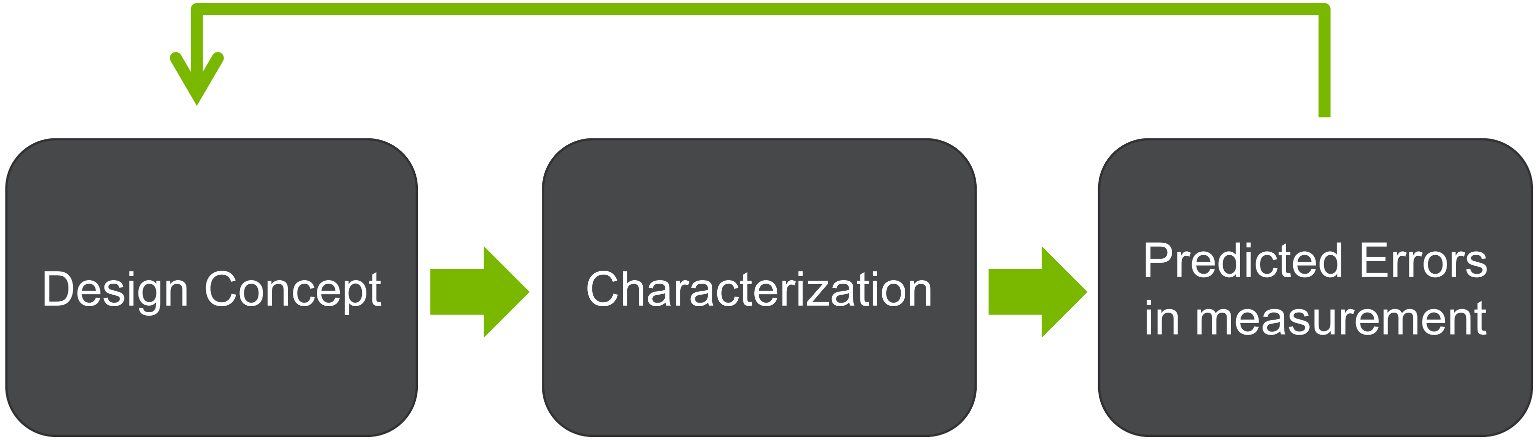
ɔ √(ςὑ / ά)ȟ ὑ ὑ ὑ

- m is the mass of the following platform. To avoid resonance of the follower from excitations of the sample stack scanning, its mass must be chosen appropriately with respect to the stiffness coupling in the XZ plane.

Currently working on FEA to quantify stiffness / flexible modes / resonant frequencies of the following mechanics design concept.

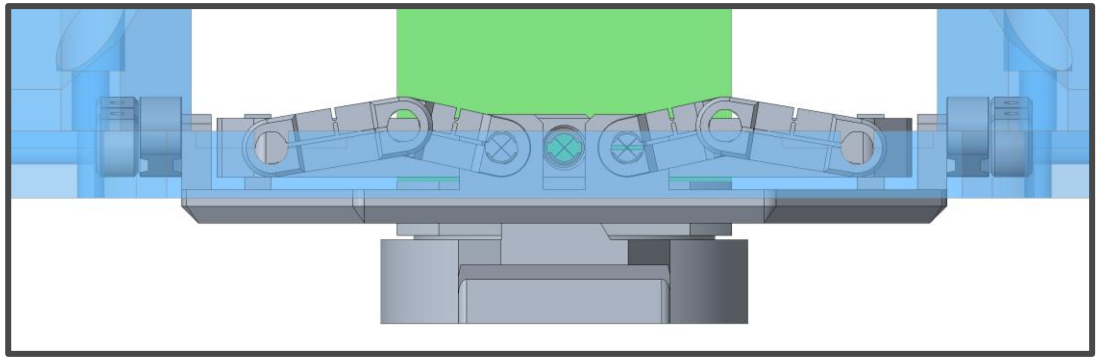
Next Steps in the Metrology Design Process

- Mature design feasible design mechanics that facilitate the traveler interferometer decoupling.
- Better understand how flexible modes influence the accuracy of the measurement.
  - Modal analysis → Plant based modeling.
  - Challenge in that characterization of commercial stages and mechanics may not be available. May

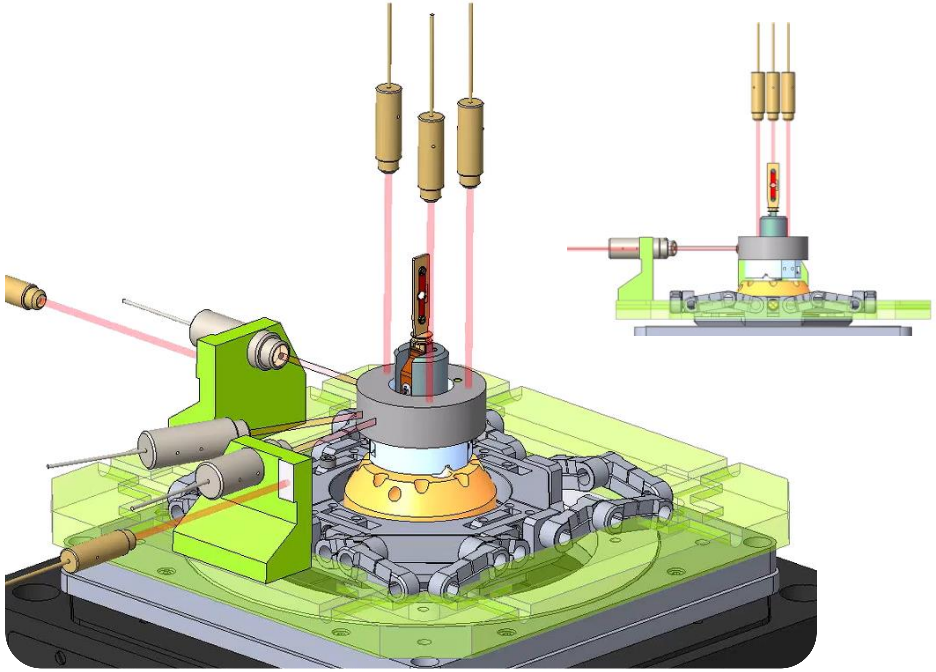


Error budget, < 2 nm measurement error

Proposed Traveler Coupling Design Concept



OLD DESIGN CONCEPT



Proposed Design Concept

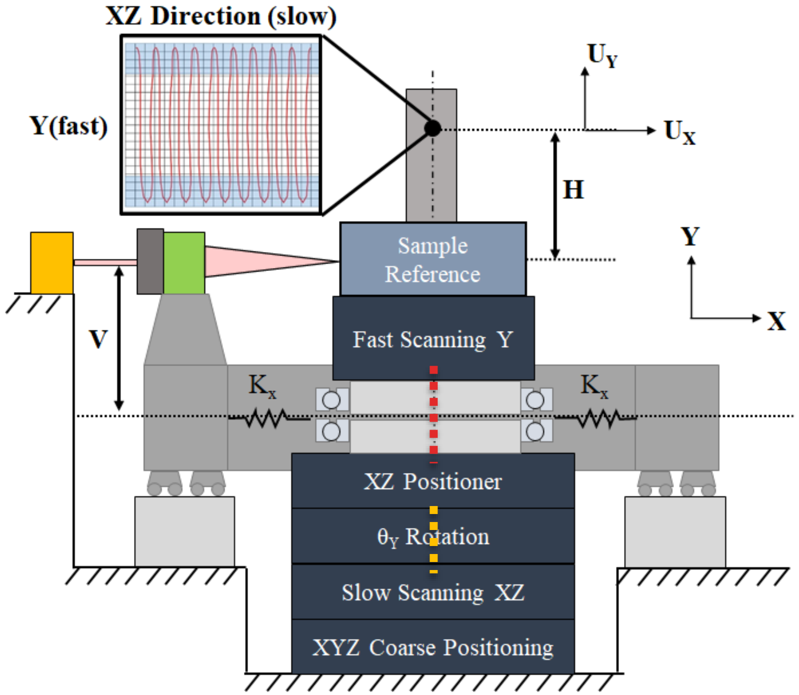
Exploded View

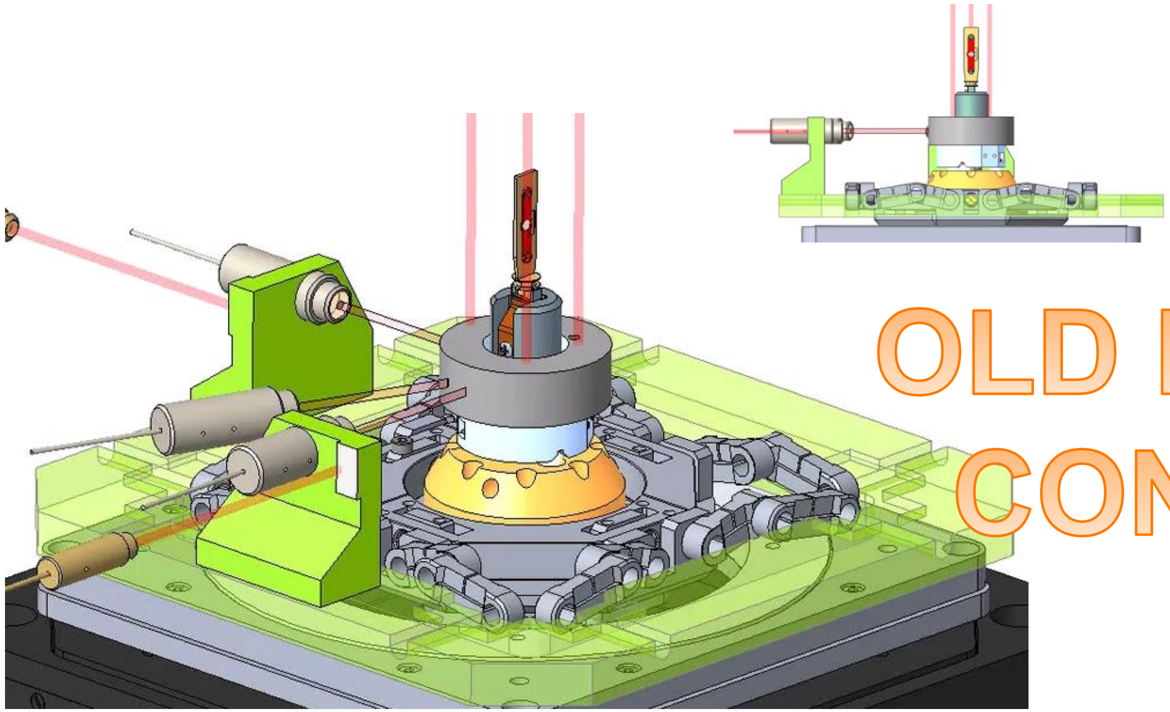
1. Focused probe interferometer
2. Traveling platform (2 tiered)
3. Vertical flexure links
4. Tip tilt mechanism
5. Radial bearing set (preloaded)
6. Preload plate and scanner interface
7. Fast scanning stage
8. Sample mount (warm)
9. Cryogenic reference and sample receiver
10. Sample Holder

(10)
(9)
(8)
(7)
(6)
(1)
(4)
(5)
(2)
(3)

Positioning walk during positioning

- Happens when follower bearing (red) axis is not co-aligned with – rotation axis (orange). Pretty much always the case
- This positioning walk must be accounted for in the controls strategy





OLD DESIGN CONCEPT

Thank you!

- We are excited to finish this design and produce a test bench soon.
- I welcome any further questions, discussion, ideas or collaboration.