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Alignment of the Mu2e Experiment

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In partnership with:

Mu2e

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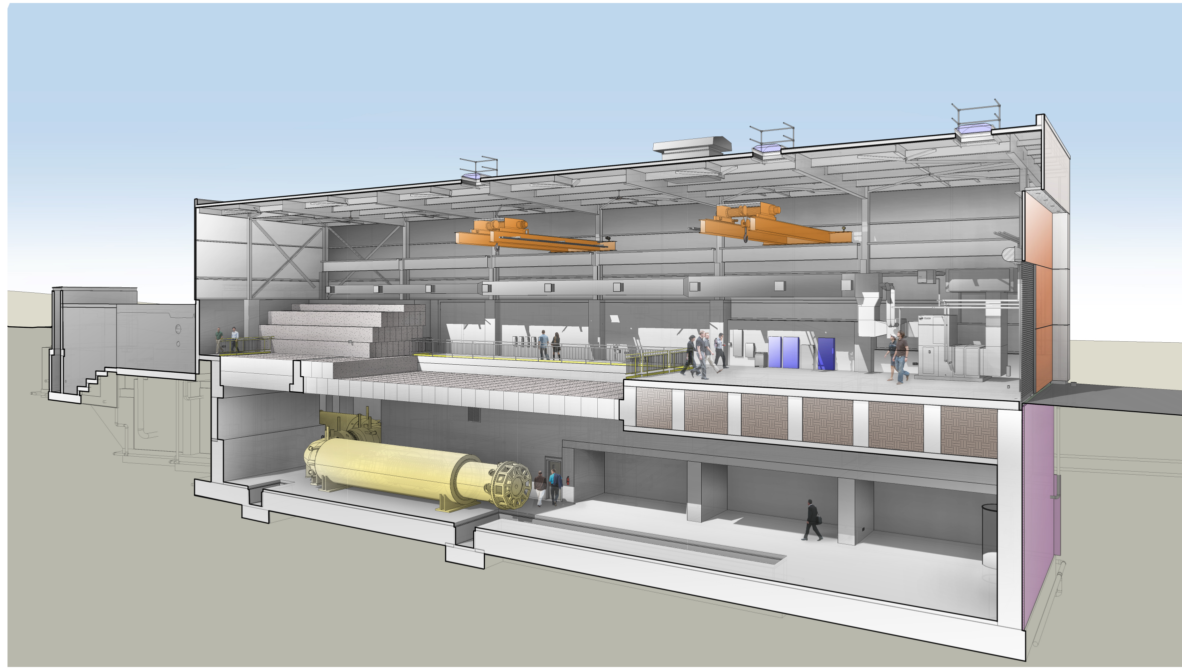
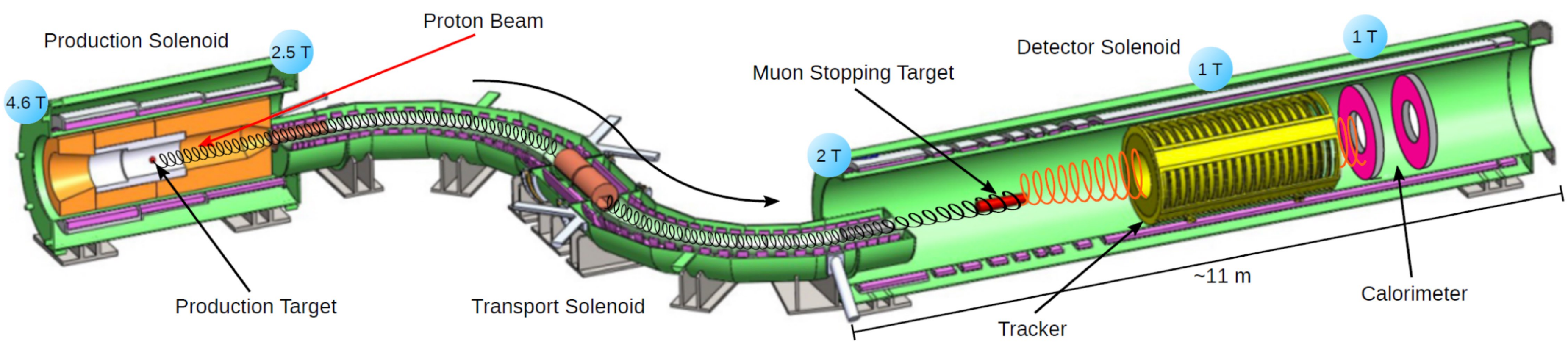
Mu2e (Muon to Electron Conversion) Experiment

- Make muons at the production target
- Collect and transport them to the stopping target
- Search for muon to electron decay without neutrinos





Mu2e Alignment Challenges

- "Guess" of the target final position based on the Solenoid QC
- After initial alignment, solenoids will be welded to steel pads imbedded in reinforced concrete slab floor.
- Measuring energized magnets (magnet field mapping…)
  - Need nonmagnetic equipment: ceramic SMRs, nonmagnetic nests, so usage limitations
  - SMRs have to be held by gravity (disadvantages in high traffic areas) or glued on (the equipment has to be carefully and completely cleaned for later reliable use)
  - Measurement crew in magnetic field
- Measurement instruments must endure magnetic fields
- Iterative alignment of the Detector Train

Mu2e Reference Network

- The building was handed over in Jan. 2017
- Reference network was designed and simulated using SA and GeoPAN
  - using an “Exclude Obscured Points and Fabricate Measurements with Lines” MP [3]
  - measured with a AT401 LT, a DNA03 Leveling instrument, and a DMT Gyromat 2000 Gyrotheodolite
- To follow the Earth curvature, the Ellipsoidal height was held on measured points during the Least Square Adjustment of the terrestrial observations

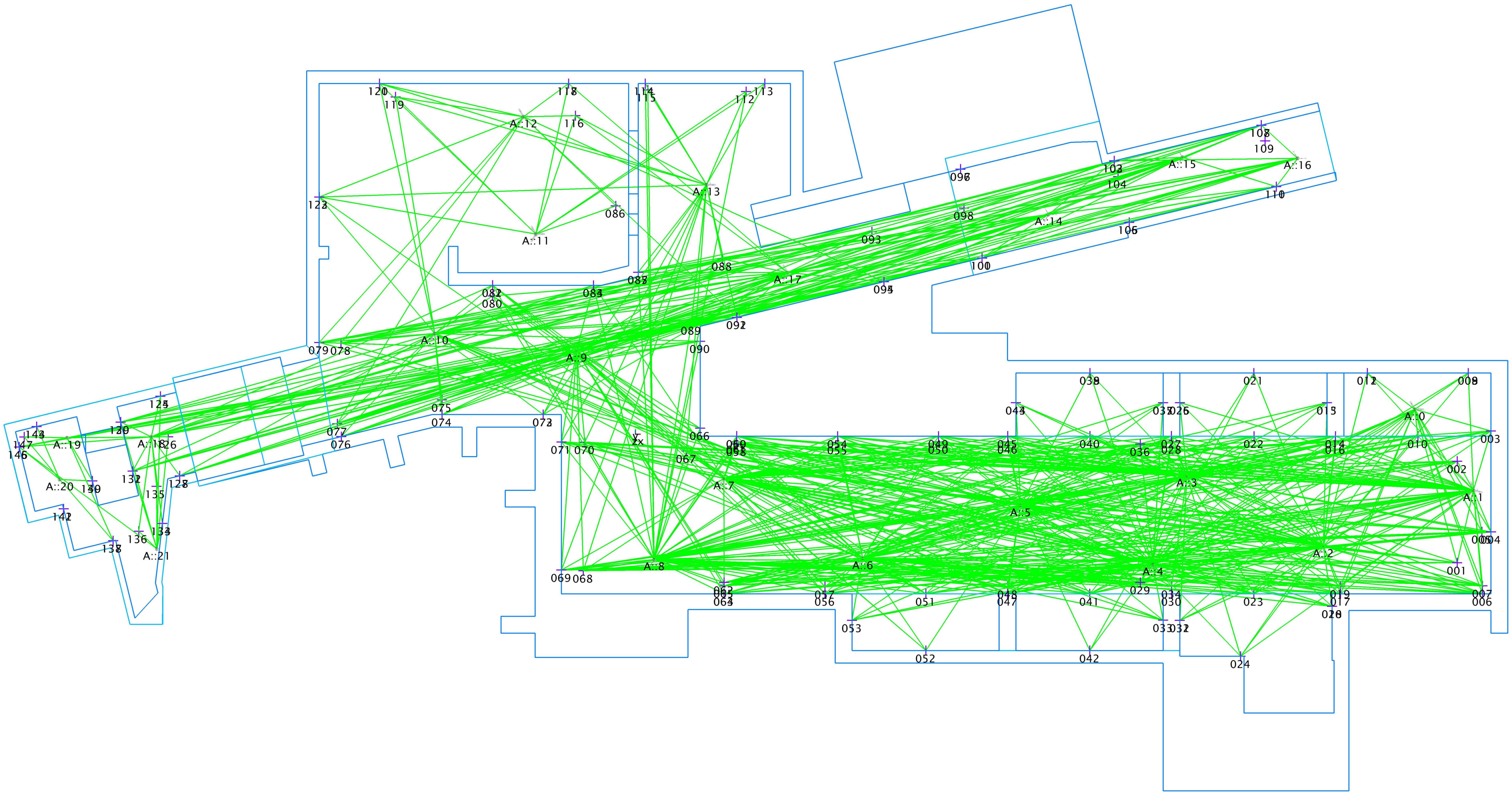
Number of observations	
Slope distance	808
Directions	806
Zenith Angles	771
Total	2385

Number of unknowns	
Orientations	33
Coordinates	692
Total	725

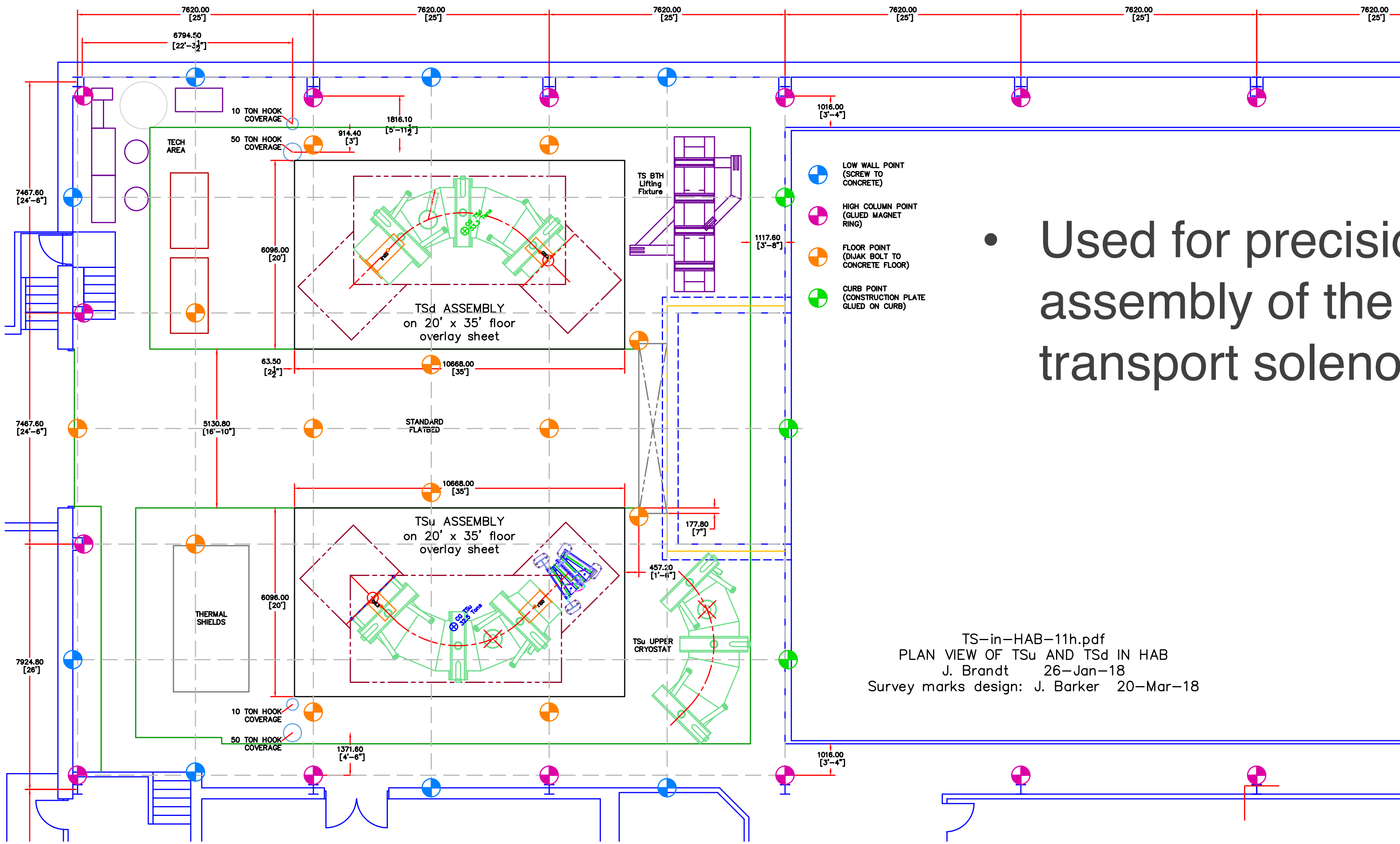
Degrees of freedom	1660

Quantity	Apriori	Aposteriori
Direction σ_φ	0.300 mgon (1″)	0.287 mgon (0.958″)
Zenith angle σ_z	0.300 mgon (1″)	0.607 mgon (2.024″)
Distance σ_d	2 ppm	2.36 ppm

Mu2e Reference Network



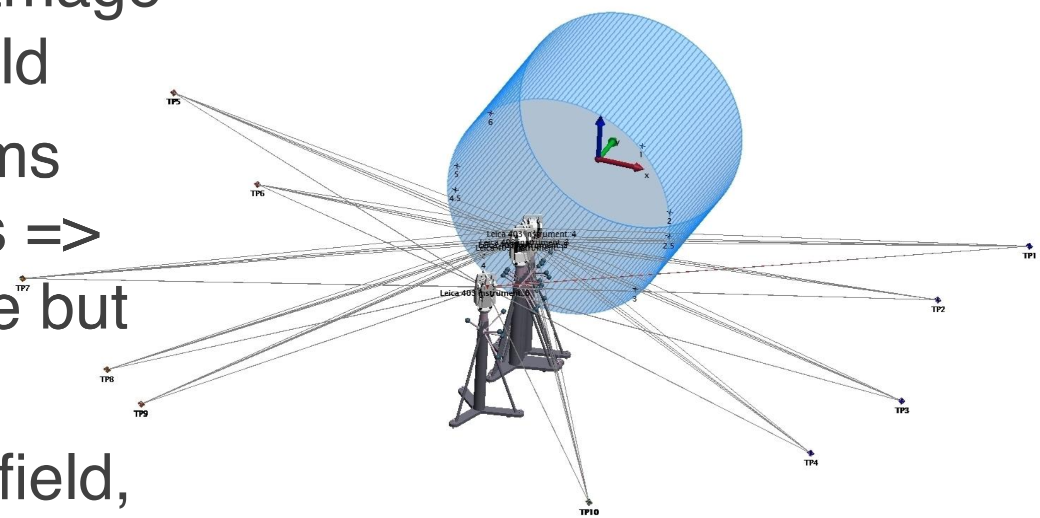
Heavy Assembly Building Reference Network



- Used for precision assembly of the transport solenoid

Testing of the Leica AT403 in Magnetic Field

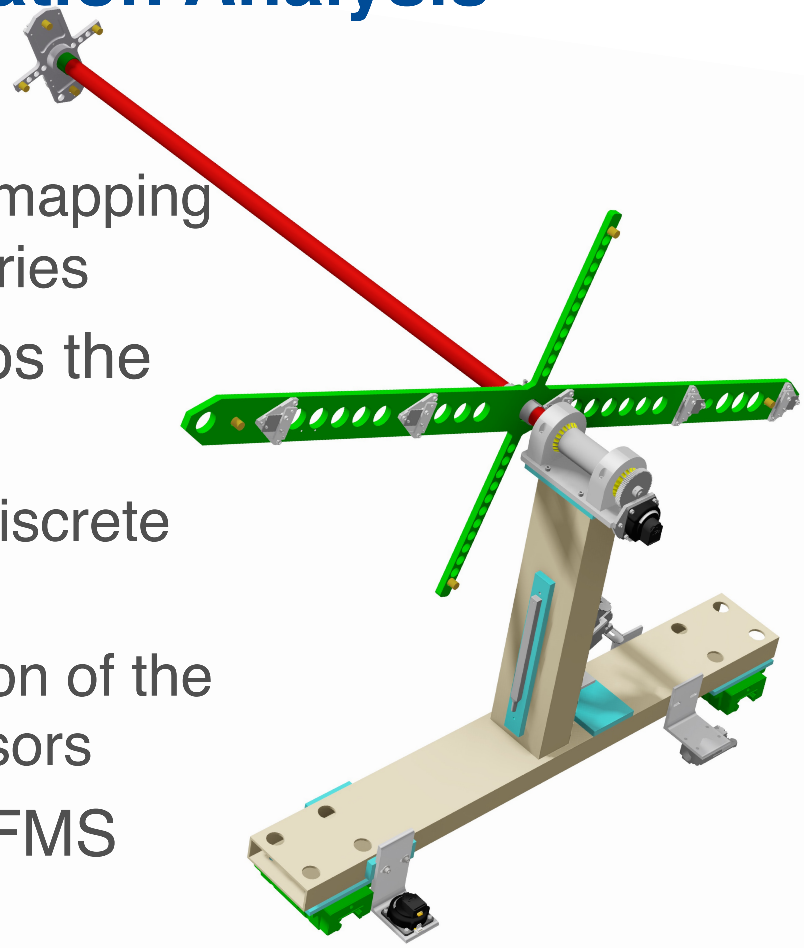
- No long-term effect or damage caused by 500 Gauss field
- That field causes problems with aiming at the targets => longer measurement time but possible
- After leaving 500 Gauss field, instrument came back to normal accuracy



Best-Fit Transformation (30_Gauss - 500_Gauss_1) (Details) Leica AT 403::500_Gauss_1 to Leica AT 403::30_Gauss 10/24/2017 2:35:51 PM											
Name	On	Nom X	Nom Y	Nom Z	Wt X	Wt Y	Wt Z	dX	dY	dZ	dMag
TP1	X	4341.0019	817.9182	-372.6448	1.000	1.000	1.000	0.0754	-0.1467	-0.0041	0.1650
TP3	X	4355.5871	-2823.0821	-377.2413	1.000	1.000	1.000	-0.0777	-0.0241	0.0114	0.0821
TP4	X	3411.3308	-2804.1966	-1201.8453	1.000	1.000	1.000	-0.0575	0.0174	0.0176	0.0626
TP5	X	-4589.7051	117.6239	-374.8057	1.000	1.000	1.000	-0.0351	0.0539	-0.0142	0.0659
TP6	X	-3644.9923	111.1576	-1195.2581	1.000	1.000	1.000	-0.0618	0.0242	-0.0078	0.0668
TP7	X	-4547.6548	-4260.2160	-369.7543	1.000	1.000	1.000	-0.0053	0.0002	-0.0154	0.0163
TP8	X	-3604.2259	-4241.7972	-1196.5774	1.000	1.000	1.000	-0.0220	-0.0123	0.0375	0.0452
TP9	X	-2520.6798	-6232.1800	-375.2802	1.000	1.000	1.000	0.1035	-0.0366	-0.0111	0.1104
TP10	X	2287.9707	-6221.1918	-376.9193	1.000	1.000	1.000	0.0804	0.1239	-0.0140	0.1484

Field Mapping System – Vibration Analysis

- Motivation:
  - Needs precise 3D magnetic field mapping to model charged particle trajectories
- Field Mapping System (FMS) maps the magnetic field of the solenoids.
  - Discrete translation on rails and discrete rotation of the propellers
  - Need to precisely know the location of the location of the magnetic field sensors
- Rigid mechanical coupling of the FMS needed to be proved
- Measured with three API LTs and used SA with UDP



FMS Assembly

Image credit: DFSM Design Group, ANL

Data processing in Python

Start: Text data files in

Same Sampling Frequency?

No

Interpolate finer data stream to match sampling frequency

Yes

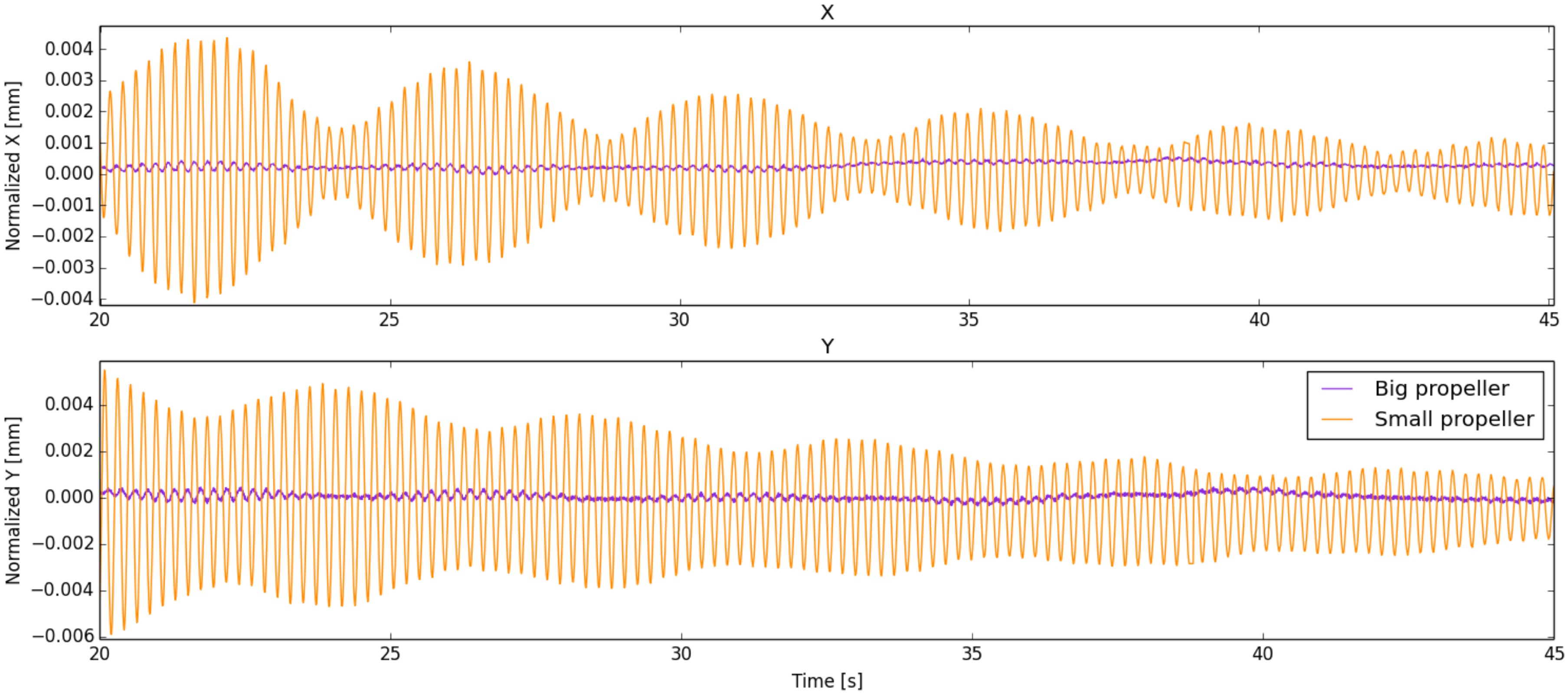
Find course offset:
Min χ^2 from shifting by discreet number of samples

Find fine offset:
Min χ^2 from shifting (-1,1) sampling periods,
Between-sample interpolation

Δt

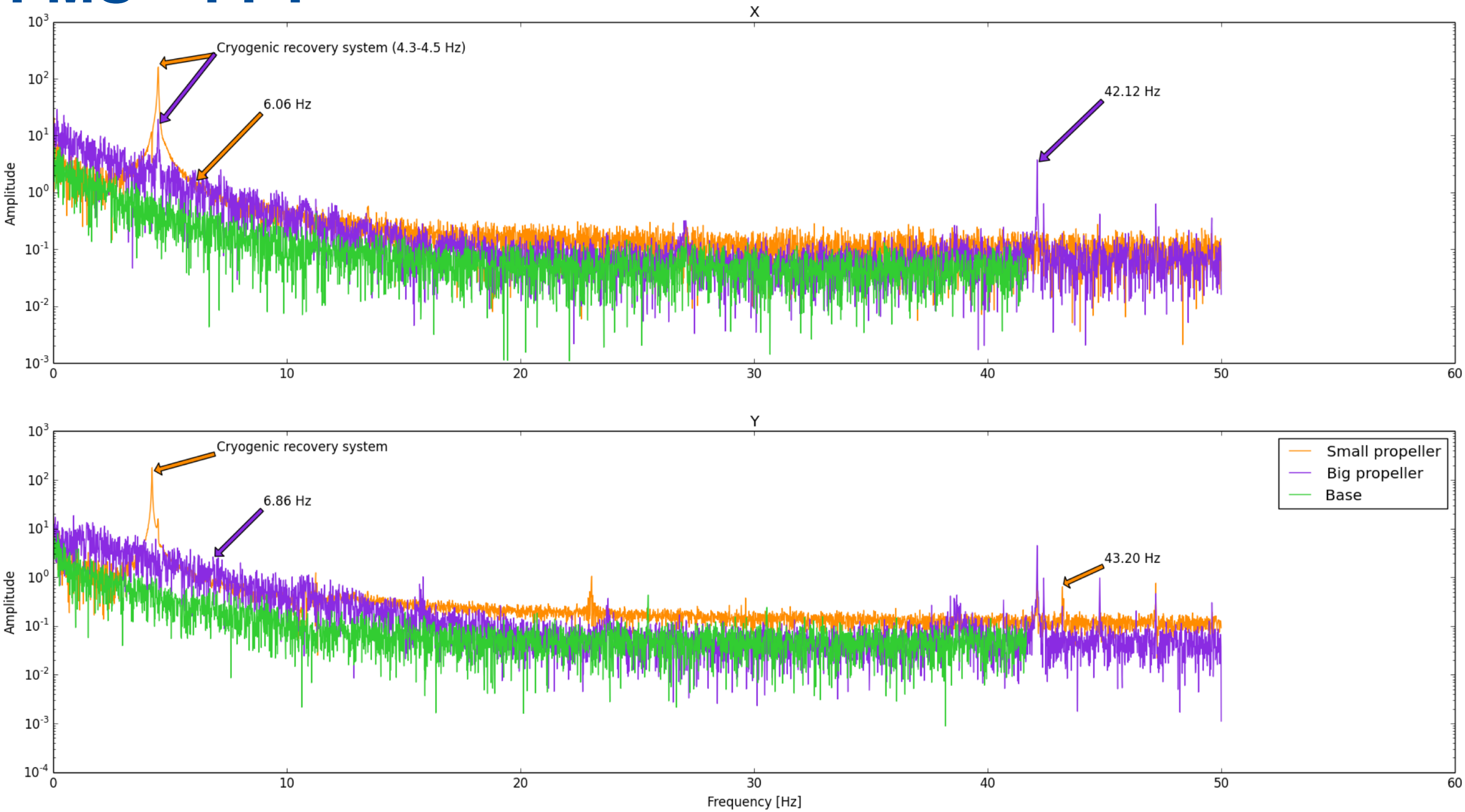
Done, Δt found to 0.1 to 0.5 sampling periods

FMS – Synchronized Data



Close-up of the vibrations of the system in X and Y axes (right-left and up-down) – third set of measurements

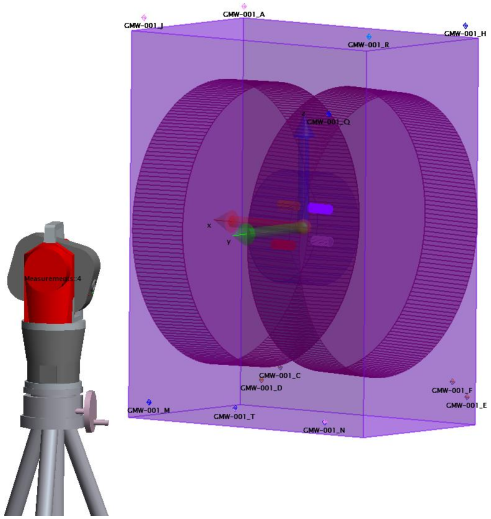
FMS – FFT



- Fast Fourier Transform was performed for identification of the vibration sources

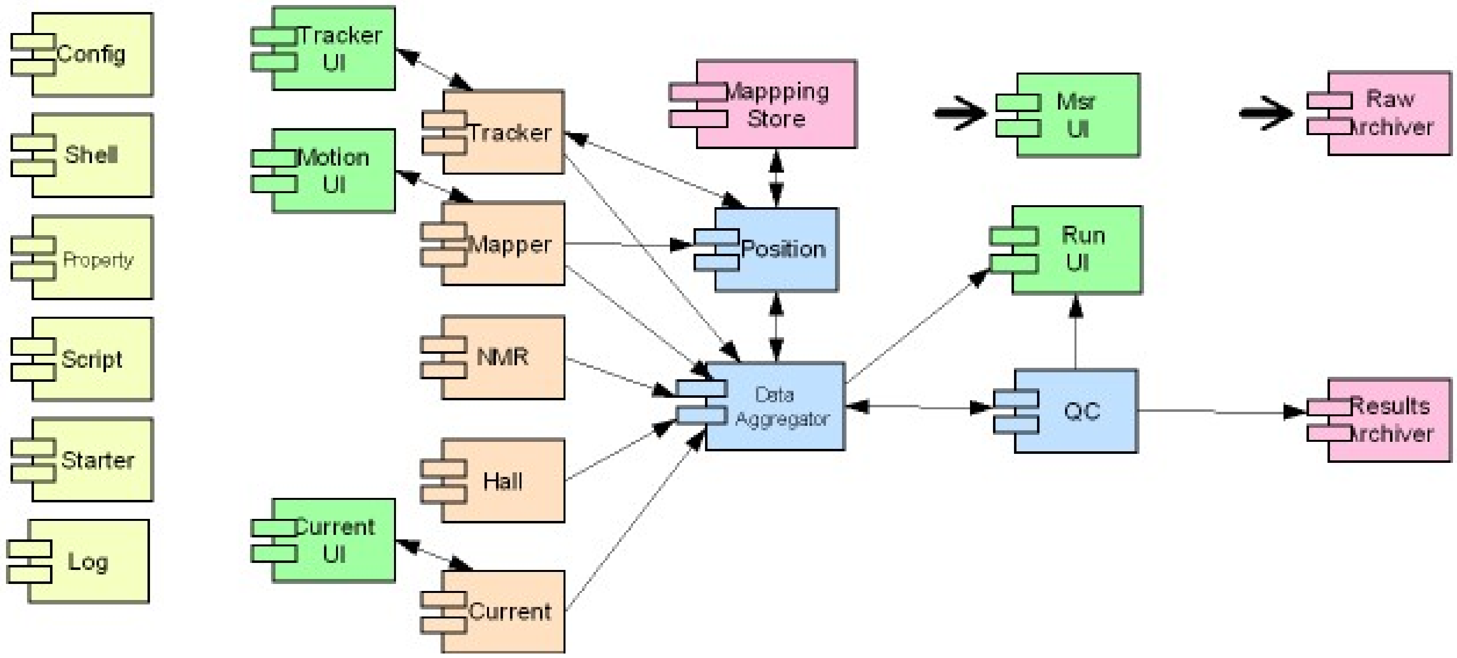
FMS – Calibration Magnet

- Hall probes (magnetic sensors) need calibration in known field
- Magnet is mapped mechanically and compared to magnetic measurements (NMR probes)
- Magnet poles will be mapped using interferometer measurements (LT in IFM mode), used to find bisecting plane



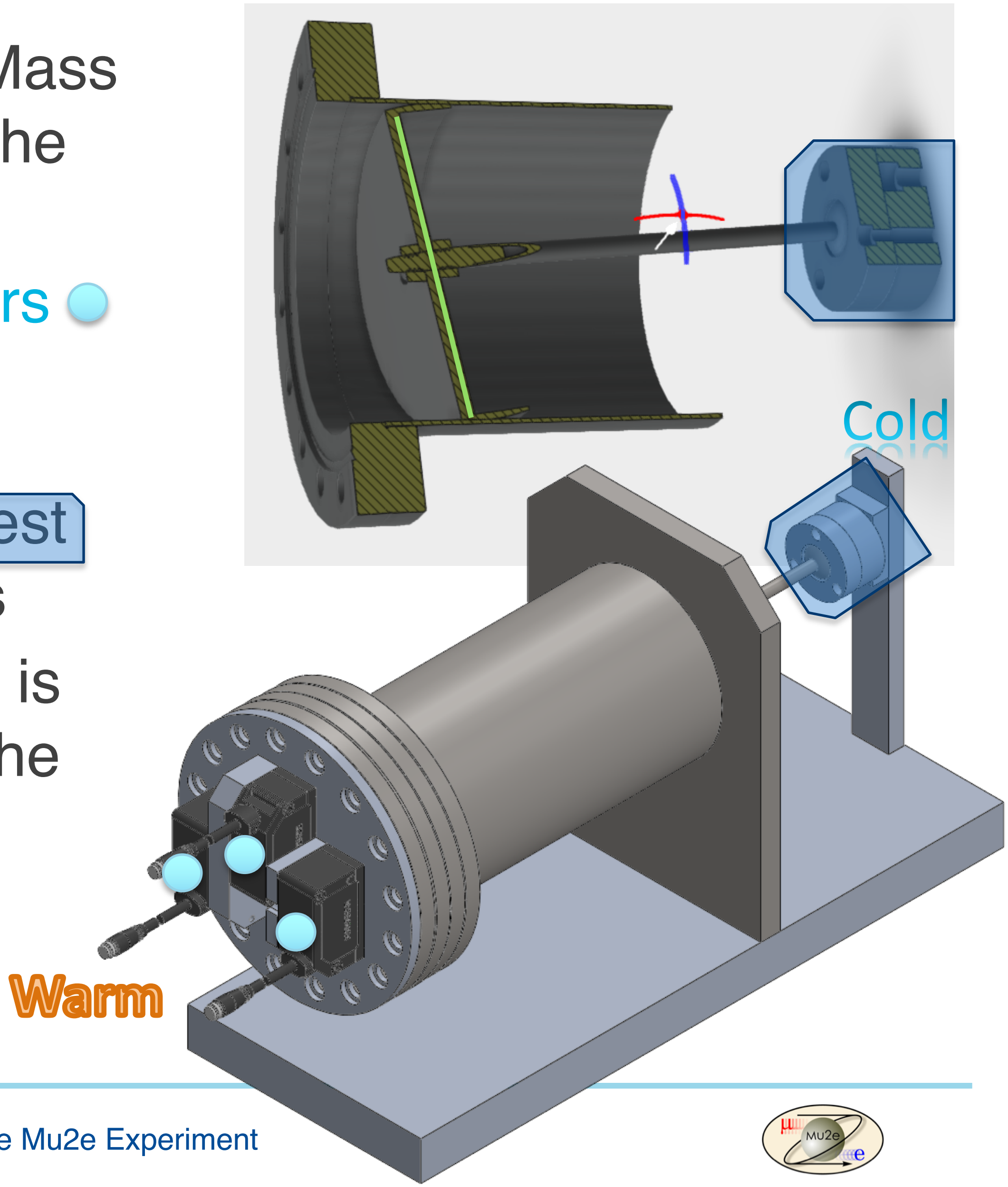
FMS – EMMA

- Complex Field Mapping System's software includes LT interface and calculations
- Cooperating with a software developing team on the correct approach, calculations, and interpretation of gathered data



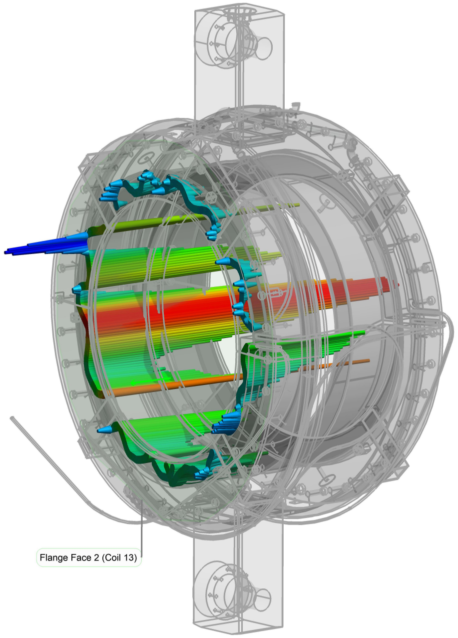
Cold Mass Positioning System

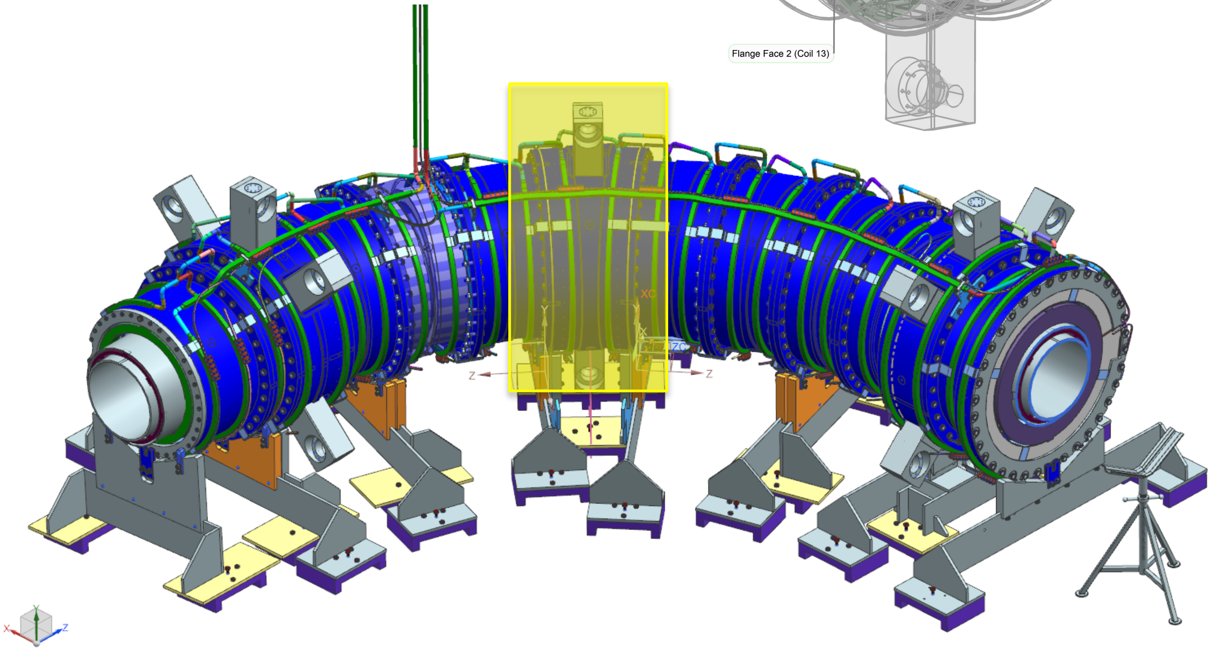
- Communicates the Cold Mass position to the outside of the cryogenic vessel
- Three interferometric lasers on the flange monitor the position of the piston disc connected to the piston nest position on the Cold Mass
- Main metrology challenge is referencing the lasers to the fiducials



Transport Solenoid Test Unit 01

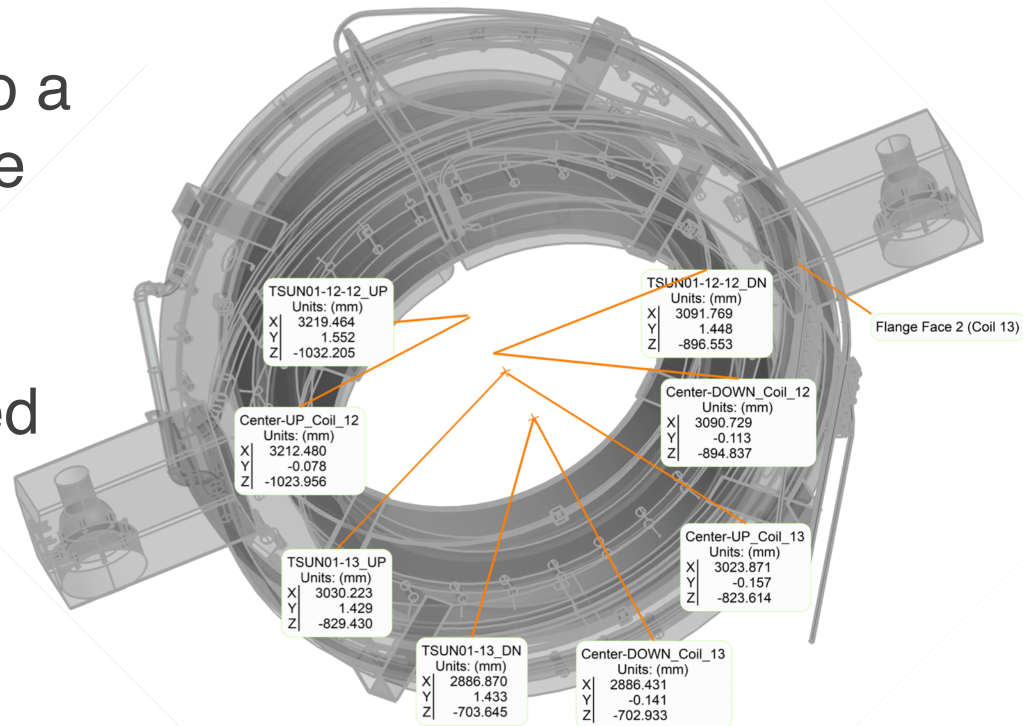
- TSUN01 is unit consisting of 2 solenoid coils
- It's the center part of TSU (The TS is made up of the TSU and TSD)





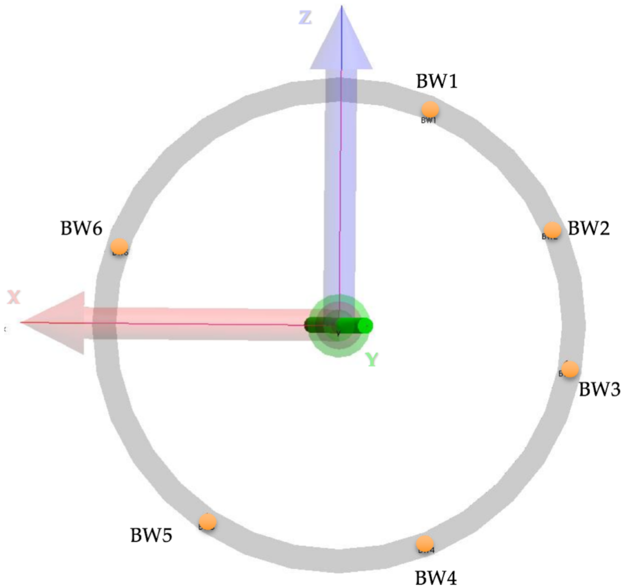
Transport Solenoid Test Unit 01 Measurements

- Quality Control and Referencing measurements were performed
- Mechanical and magnetic axes were measured and compared to the original CAD model
- Measurements are fitted to a CAD model which uses the Mu2e coordinate system
- Results, such as the magnetic axis, are the used to recalculate the final position within the experiment



Production Target Measurements

- Developed new fiducial type: fitting into an 80/20 groove
- Production Target held by 6 spring loaded spokes
- Measured adjustability
- Repeatability of placing tested



https://youtu.be/SCl_jyeUels

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Thank you for your attention

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[8]