Magnet Measurements of the ALS-U Magnets

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Contents

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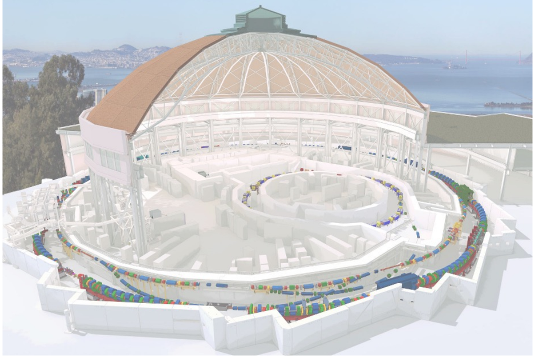
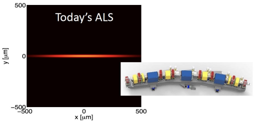
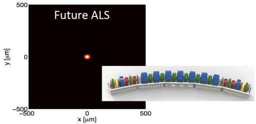
ALS-U, an upgrade of the accelerator systems at the ALS

- The accelerator systems at the Advanced Lights Source (ALS) is going through a major upgrade to become the ALS-U.
- Today's triple bend achromat will be replaced by a nine bend achromat with reversed bends from offset quadrupoles.
- The nine bend achromat storage ring (SR) uses on-axis injection from a triple bend achromat accumulator ring (AR).
- The accumulated beam in the AR is swapped with the SR beam using fast kicker magnets and a chain of transfer line electromagnets.







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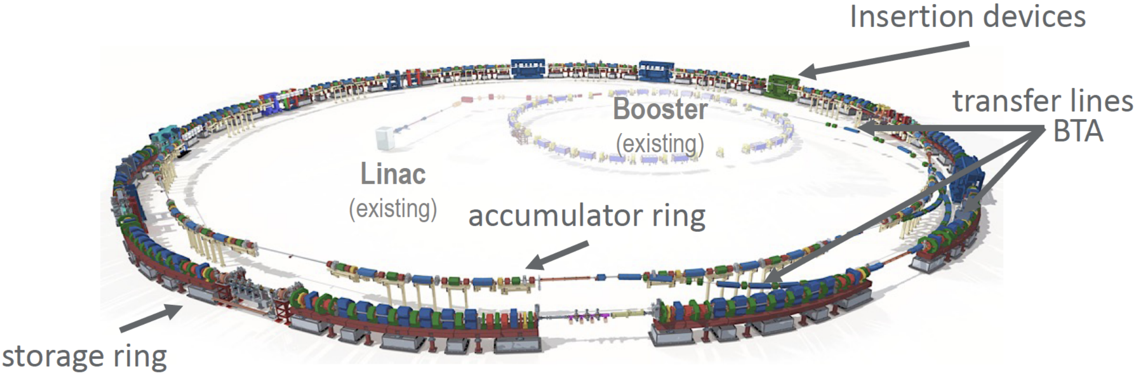
Accelerator replacements



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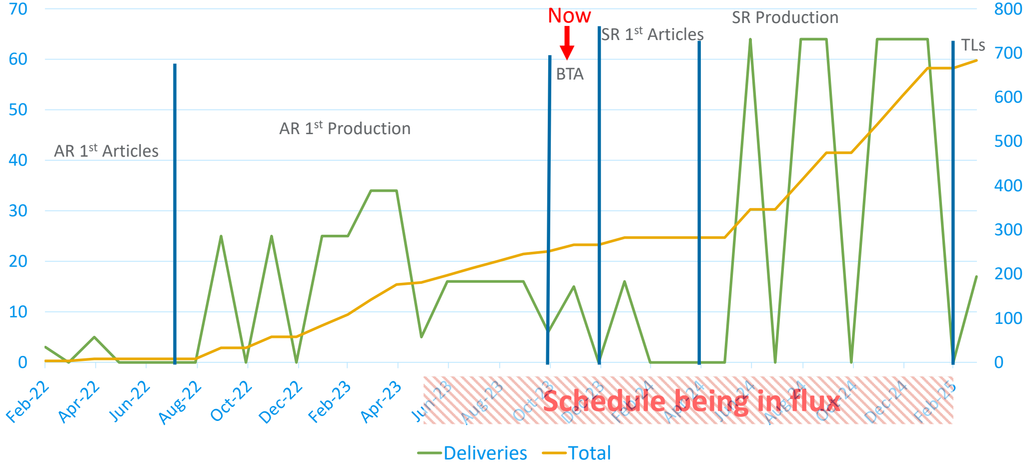
Deliveries of approximately 700 magnets over the duration of the project



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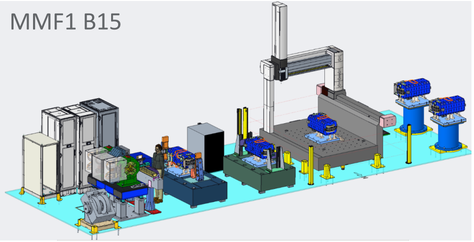
Scope of magnetic measurement work

- Develop the laboratory space and instrumentation used for the magnetic measurements needed for the ALS-U project.
- Carry out magnetic measurements of the strength (transfer function), multipole contents, magnetic axis, and fiducialization on:
  - 100% of the Accumulator Ring prototype and first article magnets. **Done**
  - 25% of the Accumulator Ring Multipole Magnets (100% measured by vendors). **Done**.
  - 100% of the Accumulator Ring ABEND dipole Magnets. **Done**
  - 100% of the Booster to Accumulator Ring (BTA) magnets. **Now**
  - 100% of the Storage Ring first article magnets.
  - 100% of the Storage Ring magnets.
  - 100% of the Accumulator To Storage Ring (ATS) and Storage Ring to Accumulator Ring (STA) transfer line magnets.

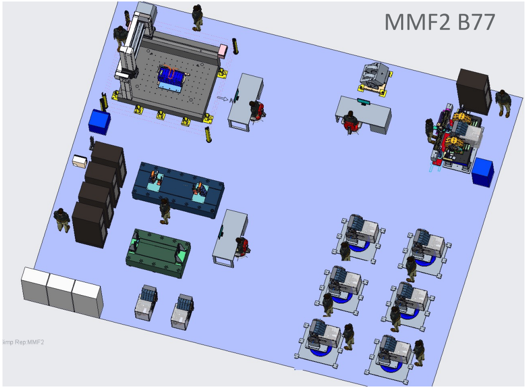
Magnetic Measurement Facility

- It has been challenging to find a sufficiently large and suitable area at LBNL for the Magnetic Measurement Facility (MMF).
- In addition to the magnetic measurements, QA inspections, CMM measurements, and mechanical reassembly tests will be carried out in the same laboratory space.
- The MMF was in building 15 high bay (MMF1) during the first half of project for prototype and AR magnet measurements.
- The MMF is now moved to building 77 room 161 (MMF2) for the measurements on BTA, SR, and ATS and STA magnets.
- The move between two locations is bringing its own challenges, especially in California where seismic anchoring is mandatory.

Magnetic Measurement Facility moved to building 77 in year 2024



Move
2024



Equipment in MMF2:

- 2 stretched wire systems
- Rotating coil system
- 2 Hall probe mappers (0.6 and 1.2 m travel length)
- CMM with integrated Hall probe functionality
- Hall probe calibration magnet

Magnetic measurement methods used

- Stretched wire
  - Magnet strength (transfer function)
  - Multipole contents
  - Magnetic axis and roll
  - Magnetic length measurements of quadrupoles and sextupoles (hard edge approximation)
  - Fiducialization of magnets
- Rotating coils
  - Fast and accurate measurement of multipole contents
  - Used for the AR multipole magnets
- Hall probes
  - Detailed mapping of magnets for problem solving
  - Magnetic length measurements in addition to multipole contents
  - Baseline method for, multipole, magnetic axis, and fiducialization measurements of the swept SR dipole magnets. We plan to replace this by stretched wire measurements.

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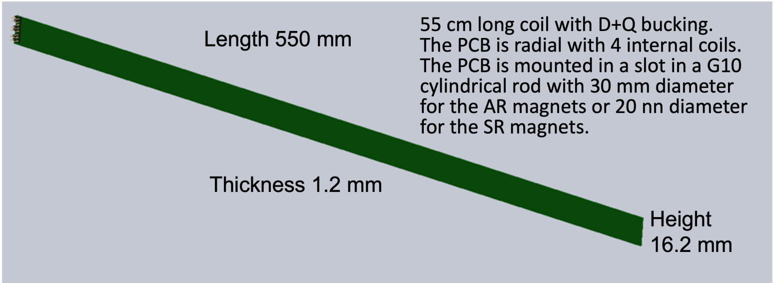
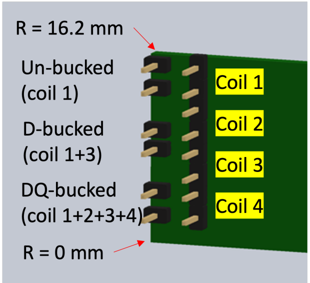
Printed Circuit Board (PCB) coils for the AR magnets





- Three different vendors of PCB coils have been used.
- The PCBs are individuals with bucking ratios starting at around 100 going up to several 1000 for some individuals.
- Ordering a surplus of PCBs and testing is needed for good bucking ratios.

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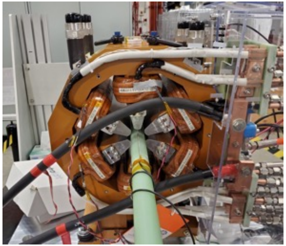
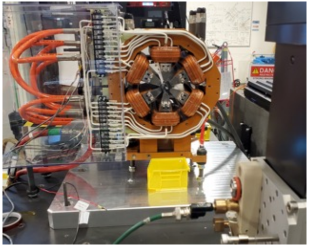
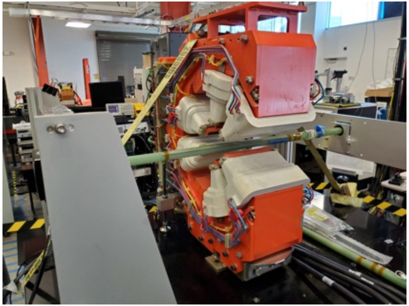
Calibration of rotating coils

The rotating coils were calibrated using comparisons to stretched wire data and using magnets that have been measured at other laboratories.



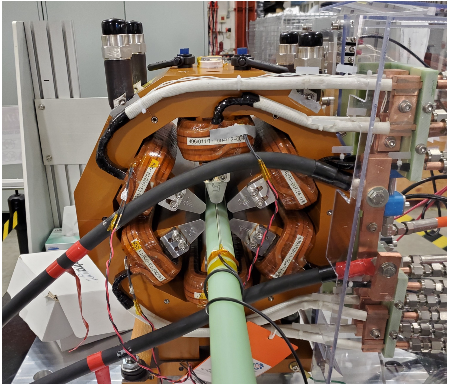




Gcm	ASD-01 SLAC RC July 29, 2022				ASD-01 LBL SW June 16, 2022				ASD-01 LBL RC2 June 13, 2022			
Rr=15	SLAC	SLAC	SLAC	SLAC	LBL	LBL	LBL	LBL	LBL	LBL	LBL	LBL
n	An	sigAn	Bn	sigBn	An	sigAn	Bn	sigBn	An	sigAn	Bn	sigBn
1	12.21	0.11	-43.65	0.11	8.37	2.17	-24.47	3.33	-24.55	0.55	-18.14	0.73
2	87.14	0.08	-50.35	0.08	3.99	2.19	5.72	2.19	341.26	1.19	-278.52	0.31
3	333.65	0.42	17698.69	0.42	-85.05	1.18	17733.00	1.08	0.00	1.03	17733.10	1.55
4	5.72	0.19	9.08	0.19	1.11	1.31	14.79	1.38	-3.78	1.84	11.49	0.96
5	2.83	0.33	3.20	0.33	-5.72	1.11	7.60	1.61	-3.05	0.35	7.19	0.66
6	2.62	0.40	2.63	0.40	-3.30	1.16	2.17	0.97	-3.05	0.35	3.26	0.20
7	-2.66	0.68	8.02	0.68	3.00	1.32	5.45	1.39	2.59	0.13	0.72	0.24
8	-0.31	0.71	0.29	0.71	-1.54	1.49	1.79	1.41	-3.65	0.17	4.27	0.10
9	-1.80	0.31	-54.61	0.31	0.06	1.67	-53.50	1.60	2.50	0.08	-54.18	0.14
10	-3.34	0.65	-0.70	0.65	-2.23	1.22	6.08	0.79	-1.07	0.11	-0.24	0.07

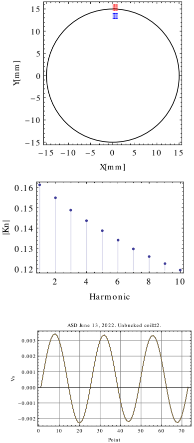
Gcm	SINAP 96A RC2 2022		SINAP 96A RC1 2022		SINAP 96A 2022		SINAP 96A SW 2022		SINAP 96A 2012	
Rr=15	RC2	RC2	RC1	RC1	SW	SW	SW	SW	RC?	RC?
n	An	Bn	An	Bn	An	Bn	An	Bn	An	Bn
1	-34.97	101.37	-33.85	102.03	-20.73	75.13	-23.15	76.73	-64.17	120.27
2	14.26	-210.33	18.98	-182.58	19.25	-210.00	-2.39	-1.23	3.26	-6.09
3	-2.04	-4334.72	-1.46	-4334.59	0.00	-4343.87	0.59	-4337.90	0.00	-4334.00
4	0.57	-0.69	1.01	-3.05	-0.58	-0.79	-0.75	-1.01	-1.69	-0.75
5	-0.06	-0.33	-0.04	-0.19	-0.24	-0.65	-0.03	-0.91	0.08	0.29
6	0.08	-3.44	0.09	-3.43	-0.11	-3.18	-0.42	-3.56	-0.05	-3.59
7	0.05	0.00	0.04	0.01	0.08	-0.26	0.17	-0.16	0.03	-0.02
8	-0.01	0.07	-0.02	0.06	-0.10	0.29	0.10	-0.38	0.00	-0.01
9	-0.05	0.48	-0.01	0.45	-0.01	0.44	-0.21	0.28	0.01	0.49
10	0.00	0.01	-0.02	0.00	-0.08	0.29	0.05	-0.10	0.00	0.00

Measurement on sextupole magnet

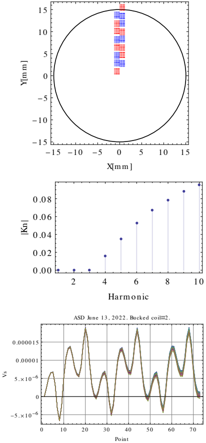


ASD Magnet at the rotating coil stand
Bucking ratio is 533 for the sextupole component

Unbucked



Bucked



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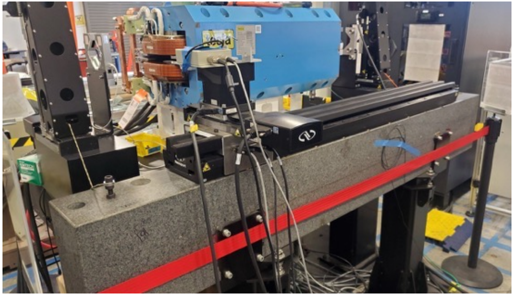
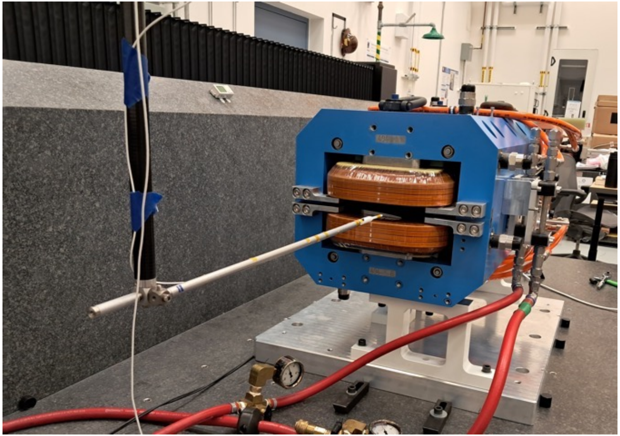
Hall probe scanning capabilities





Hall probe scanning:

- 1.2 m travel scanner based on Newport equipment (above).
- 0.6 m travel scanner based on Newport equipment.
- Zeiss CMM with integrated Hall probe functionality with 0.6 m long rod for Hall probe holder, 11 mm diameter (right).

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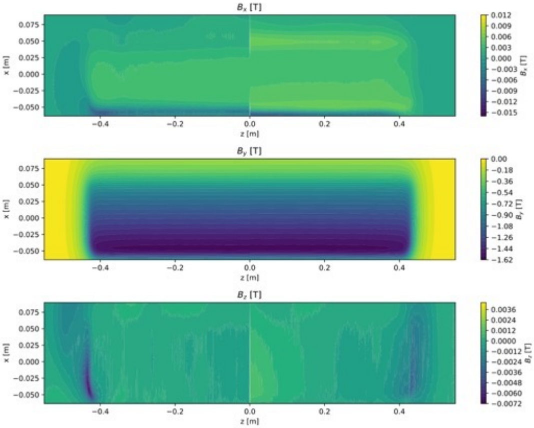
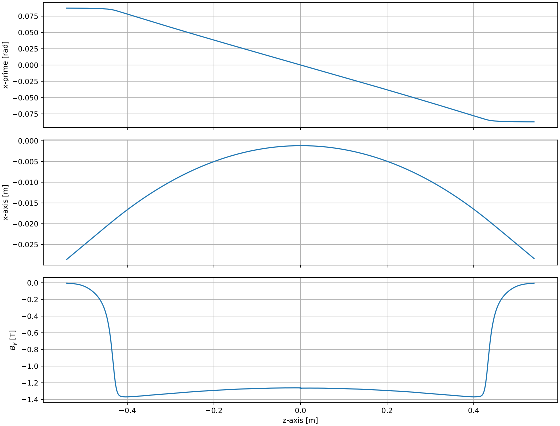
Hall probe scanning of ABEND-35 with the CMM



ABEND-34 Measured Field with CMM



ABEND-34 Calculated Field Trajectory

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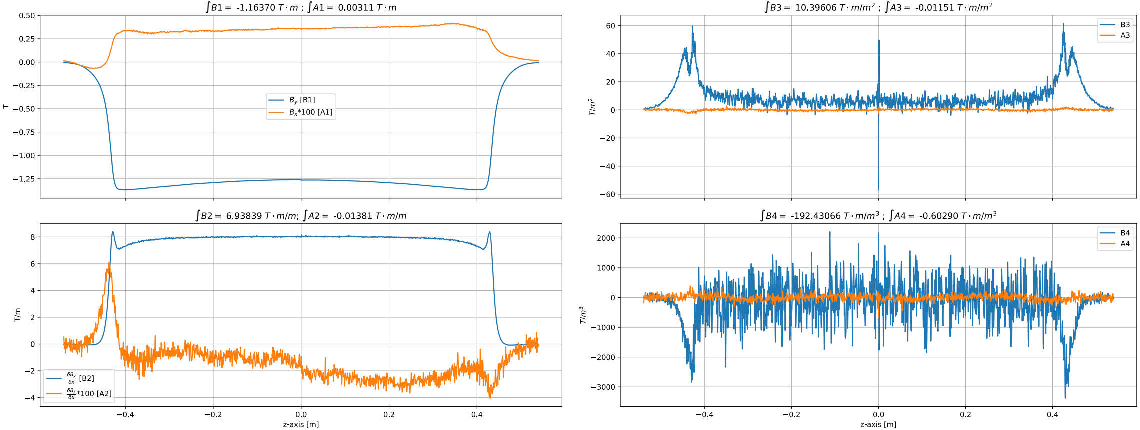
Multipoles along trajectory in ABEND-35 from Hall probe scanning



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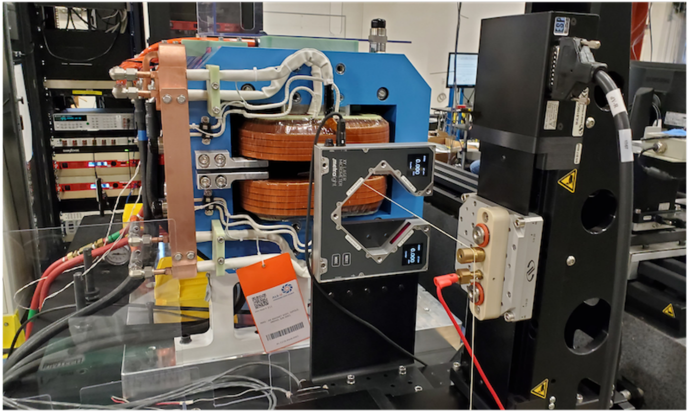
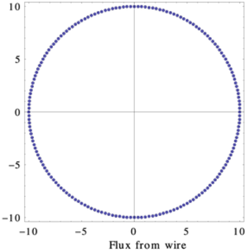
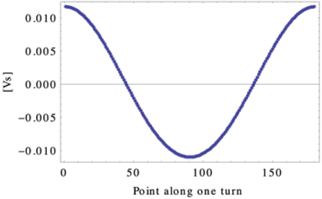
Stretched wire measurement setup in building 15





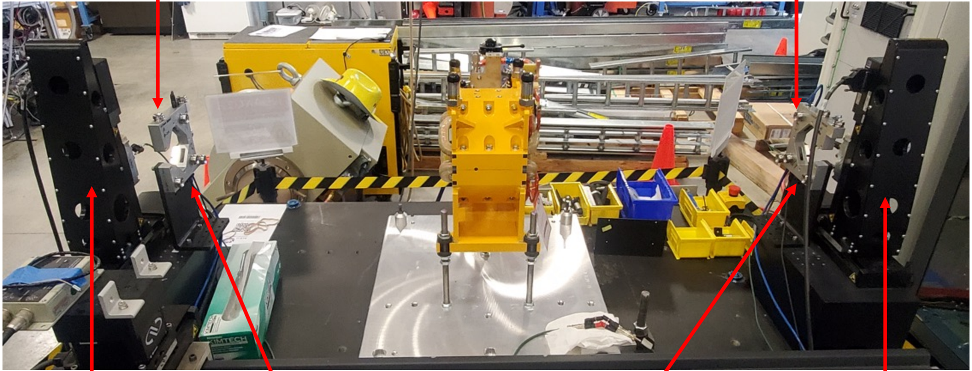


Stretched wire system setup

Upstream S&A Geo
USGeoX, USGeoY (and USGeoZ)

Magnet
MagX, MagY, (and MagZ)

Downstream S&A Geo
DSGeoX, DSGeoY (and DSGeoZ)



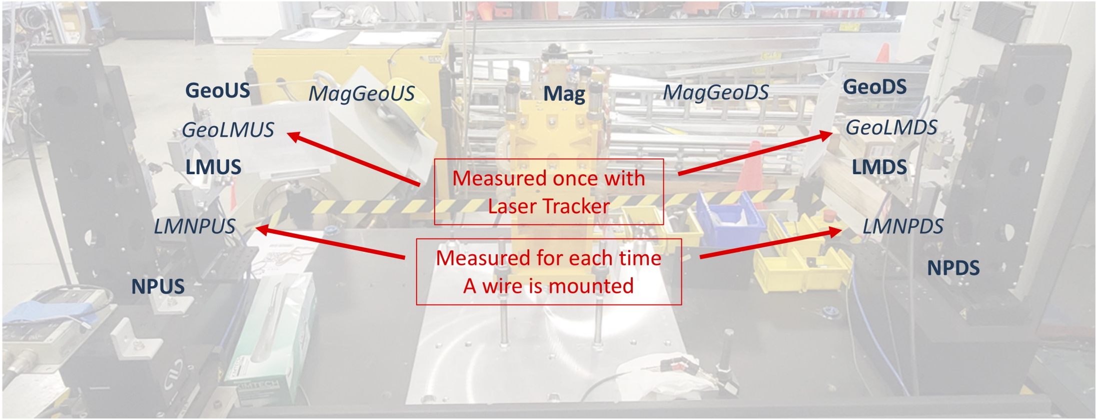
Upstream Linear Stages
R_X.X and R_Y.Y

Upstream Laser Micrometer
LMUSX and LMUSY

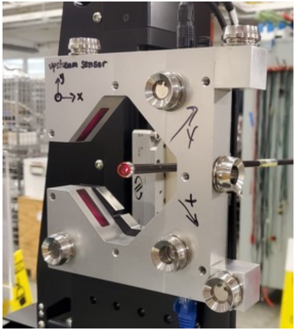
Downstream Laser Micrometer
LMDSX and LMDSY

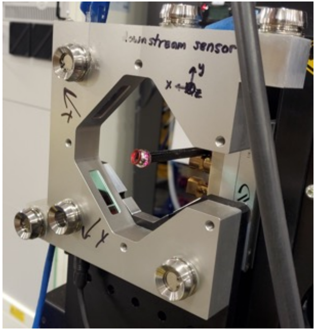
Downstream Linear Stages
L_XY.X and L_XY.Y

Stretched wire system coordinate systems and transformations

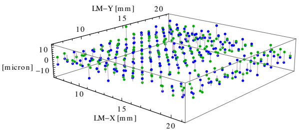


Direct measurement of the transformations GeoLMUS and GeoLMDS

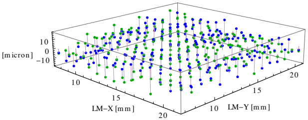


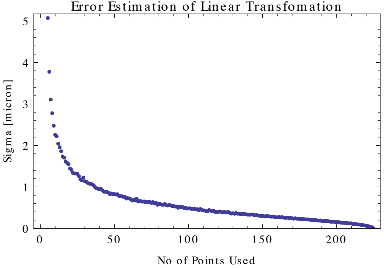


Upstream Difference to Linear Transformation



Downstream Difference to Linear Transformation





A large number of points gives an accurate translation between the coordinate systems.

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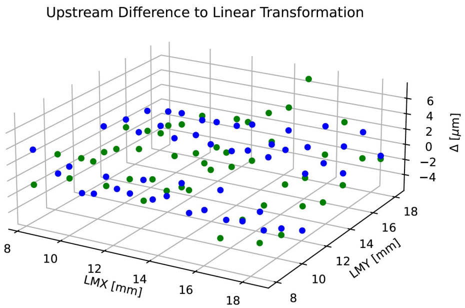
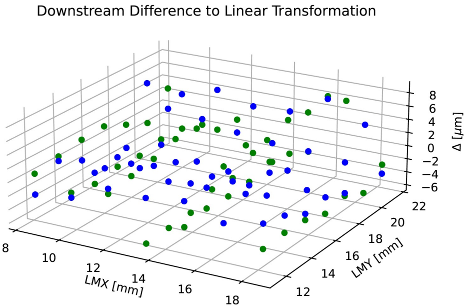
The transformation wire position to Laser Micrometer is measured at each wire setup (2 min)





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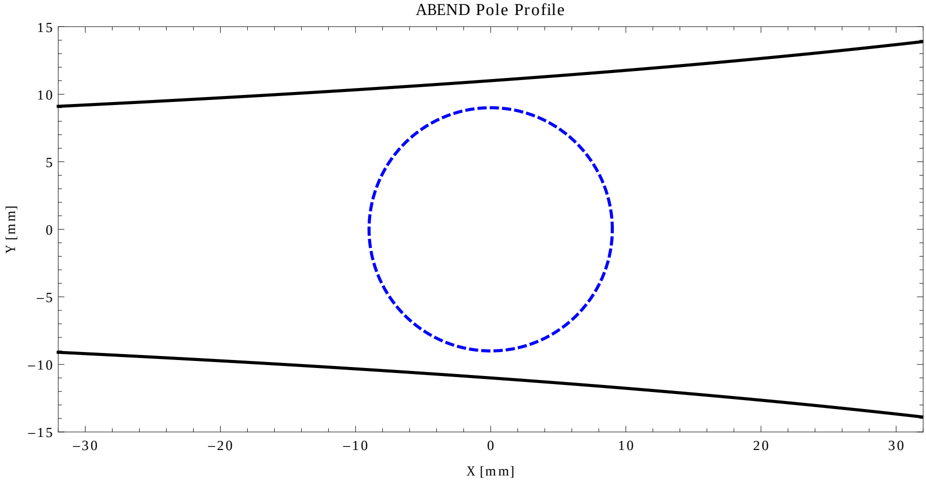
Standard circle measurement on an ABEND takes about 1 min/scan, and 10 min for 12 scans.

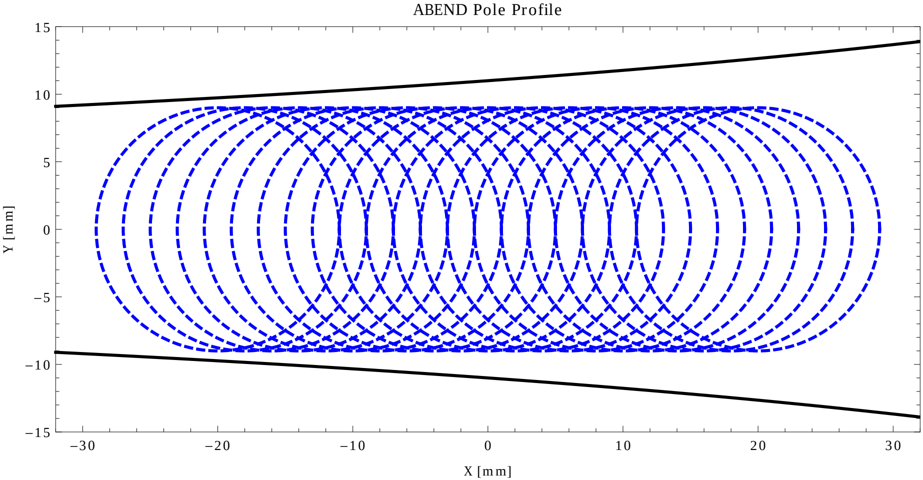


Standard circle measurement on an ABEND takes about 1 min/scan, and 10 min for 12 scans.

ABEND-01

Multipoles at Rr = 9 mm in Gcm			1 scan, 1 min		12 scans, 8 min	
n	Anaver	Bnaver	Anstd	Bnstd	Anstderr	Bnstderr
1	71.56	-1219085.91	7.18	7.93	2.27	2.51
2	-0.11	60114.62	14.15	17.34	4.48	5.48
3	24.73	929.29	16.79	12.55	5.31	3.97
4	-8.02	-338.87	15.41	27.61	4.87	8.73
5	-39.64	121.69	36.88	23.93	11.66	7.57
6	-8.21	87.18	18.97	20.59	6.00	6.51
7	51.36	-139.03	27.77	29.65	8.78	9.38
8	-7.66	515.84	37.23	34.86	11.77	11.02
9	-8.54	-472.84	33.60	46.16	10.62	14.60
10	22.30	-38.81	33.21	68.25	10.50	21.58

There is an interest in off axis multipoles for ABEND. With 12 scans/point it takes 2 h.



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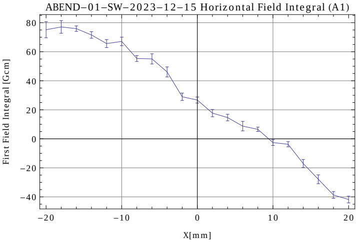
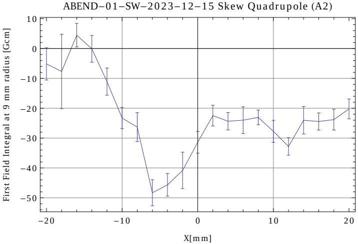
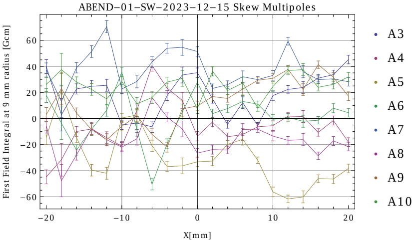
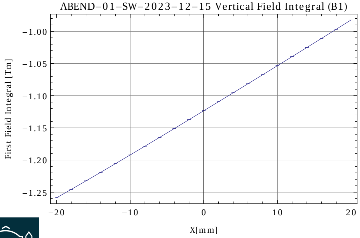
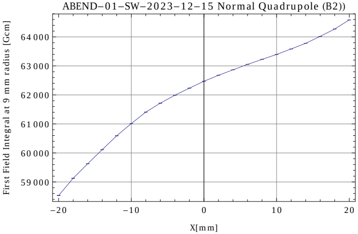
Off axis multipoles for ABEND-01, using circular scans, 12 scans/point, which takes 2 h.

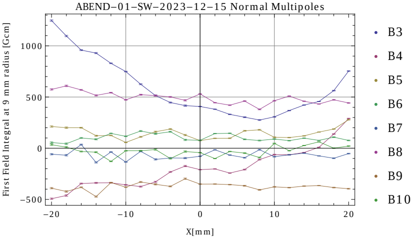












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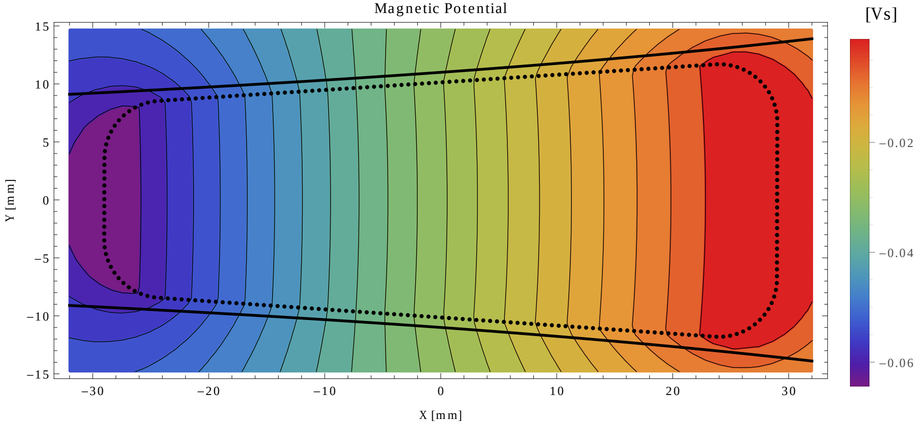
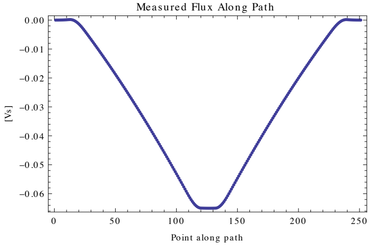
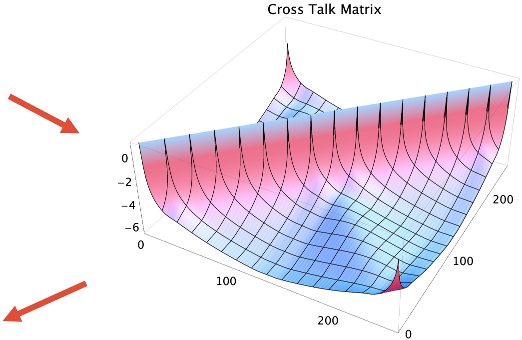
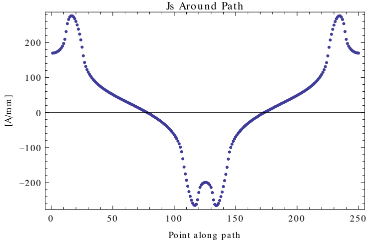
Instead, we can scan along the pole profile and calculate the potential, which takes 20 s.



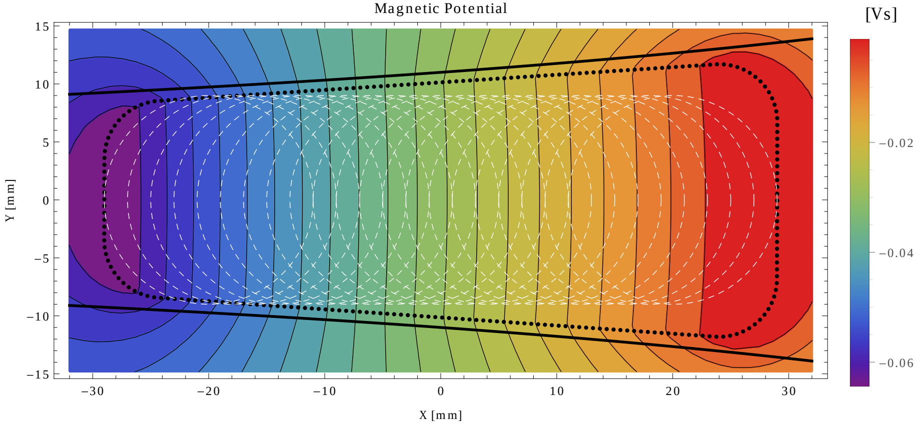
The potential method, or Cauchy method, was developed at the ESRF [ref. Chavanne, et. al] .







The potential methods gives us the off axis information we are looking for (in 20 s).



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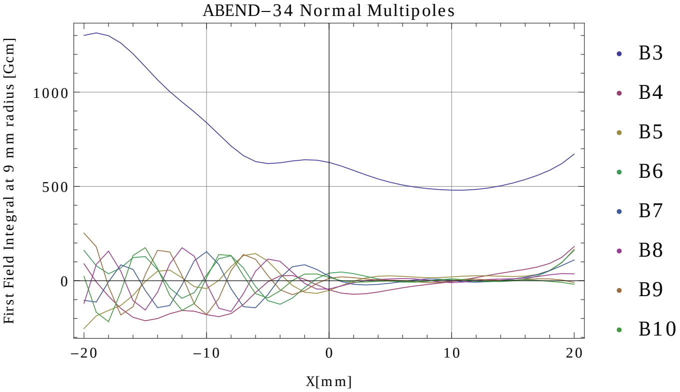

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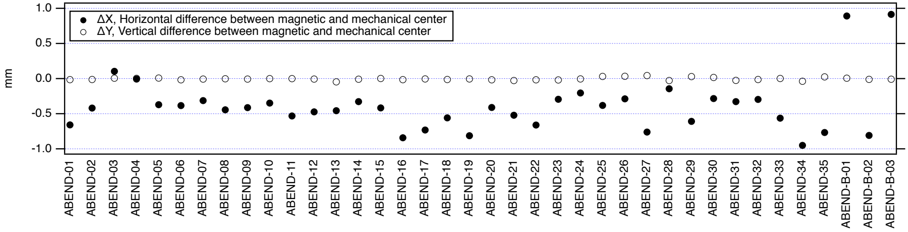
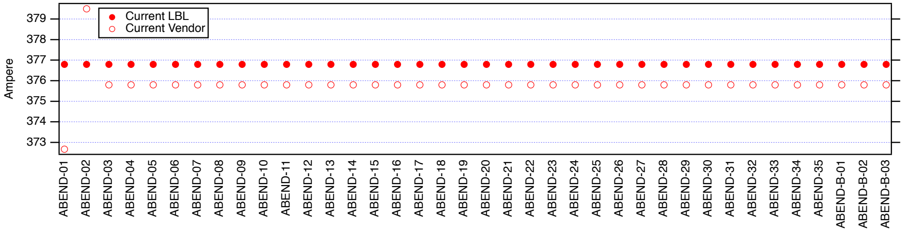
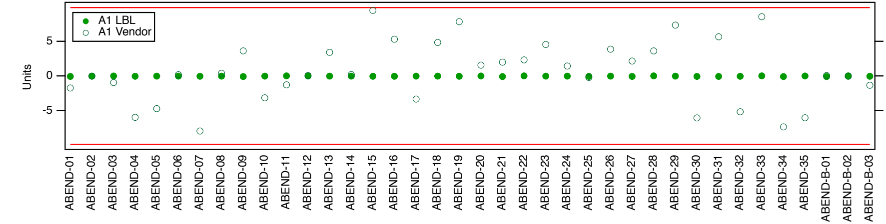
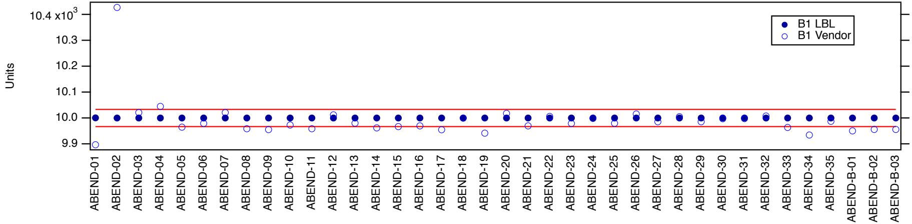
Summary of ABEND measurements



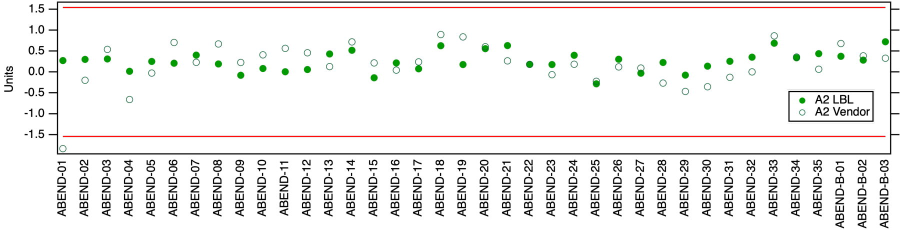


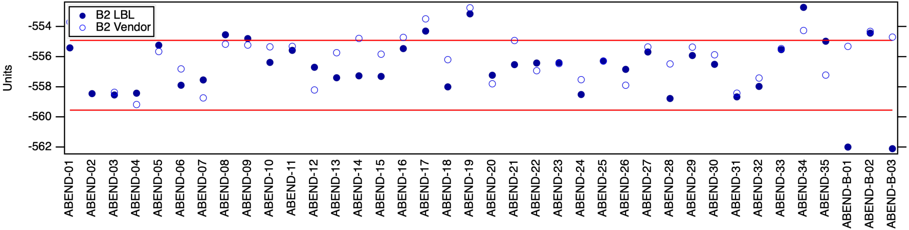
Summary of ABEND measurements





Summary of ABEND measurements





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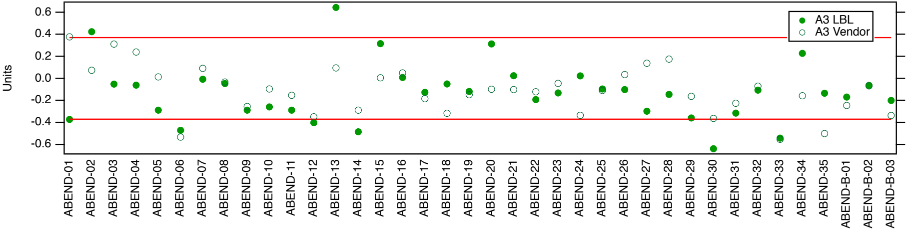
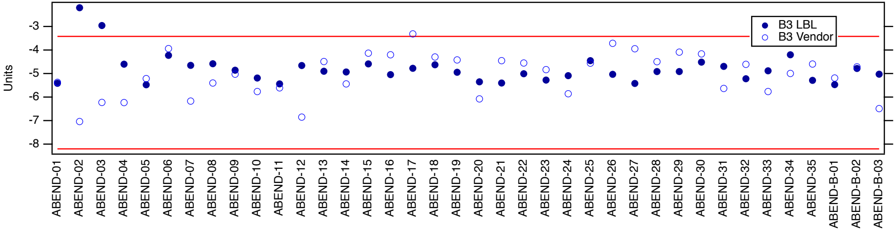
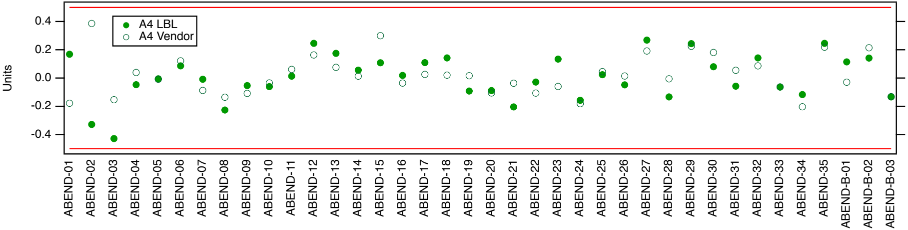
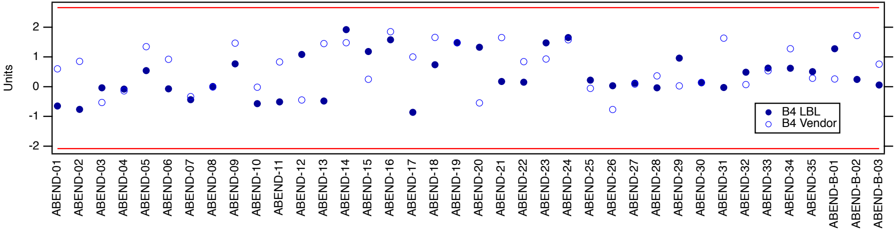
Summary of ABEND measurements





Summary of ABEND measurements





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Summary

- The ALS-U project requires the procurement and quality control of about 700 magnets.
- Magnetic measurement systems have been set up and used for measuring approximately 200 magnets.
- The measurement campaign on the AR magnets is complete.
- The measurement equipment has been moved to a new location during 2024.
- The methods used are still under development to reduce the measurement time and increase accuracy and precision.
- The coming two years will be busy finishing the quality control of approximately 500 magnets.

Thank you for listening

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