Magnetic Measurements for the ALS-U

Erik Wallén

C. Wouters, R. Teyber, and L. Fajardo

IMMW21 International Magnetic Measurements Workshop
Grenoble, June 24-28, 2019.

Contents

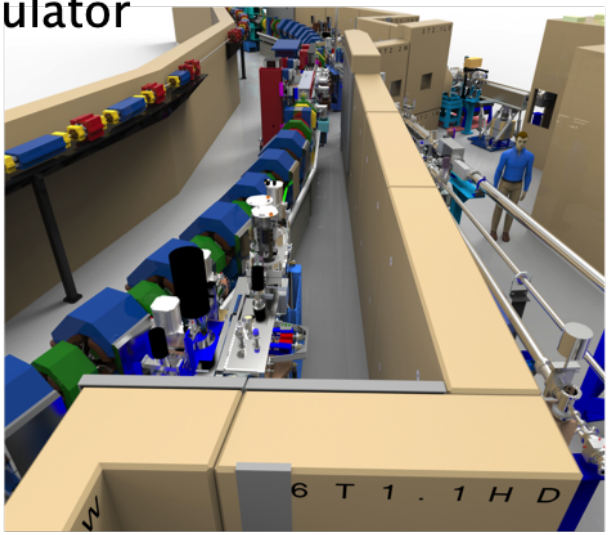
Scope of the ALS-U project

1. Replacement of the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a multi-bend achromat.
2. Addition of a low-emittance, full-energy accumulator ring in the existing storage-ring tunnel to enable on-axis, swap-out injection using fast magnets.
3. Upgrade the optics on existing beamlines and realignment and relocation of beamlines where necessary.
4. Addition of 2 new undulator beamlines and refurbishment of existing undulators or undulator vacuum chambers where needed.

Existing ALS ring

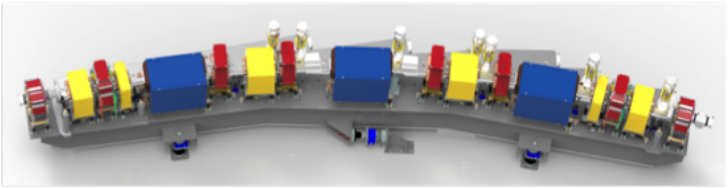
Accumulator ring

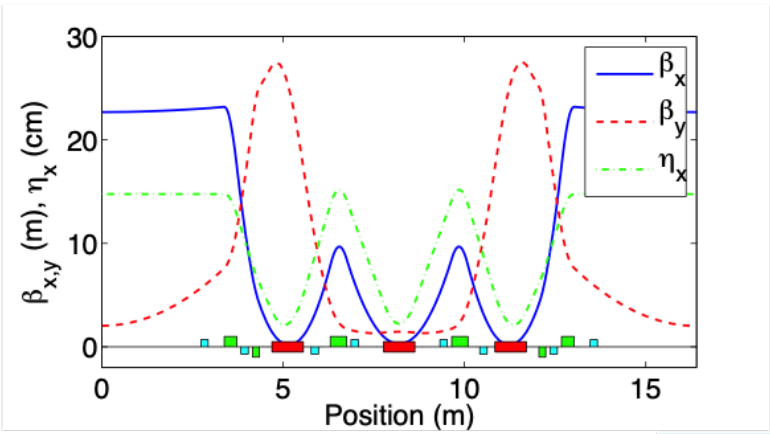
ALS-U ring



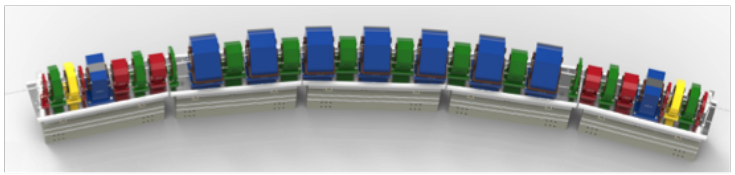
Nine-bend achromat lattice reaches the soft x-ray diffraction limit up to 1.5 keV

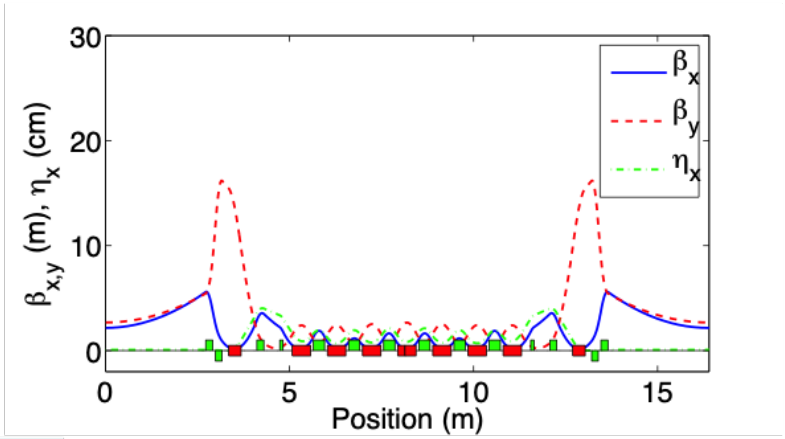
ALS today : triple-bend achromat





ALS-U: nine-bend achromat with reverse bends



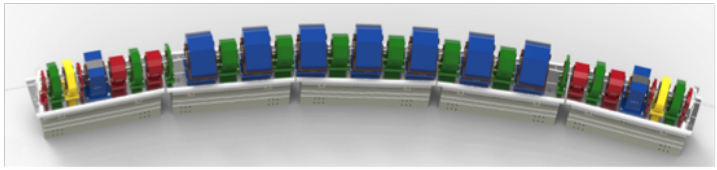


$\varepsilon_x \approx 2000$ pm rad at $1.9GeV$ $\quad \varepsilon_x \approx \sigma_x \sigma_\theta \propto \frac{E^2}{N_D^3}$ $\quad \varepsilon_x < 75$ pm rad at $2.0GeV$

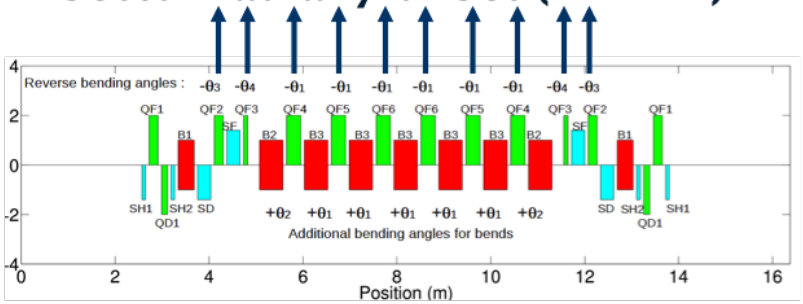
Large increase in coherent fraction due to lower emittance and smaller β-functions

Performance enhancing Lattice features: Reverse Bends / Superbends

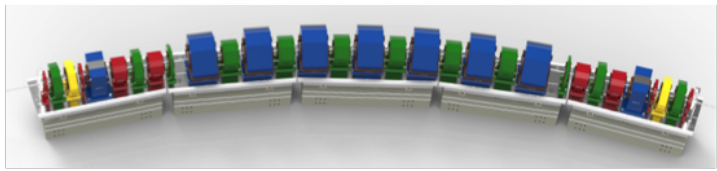
Reverse Bends

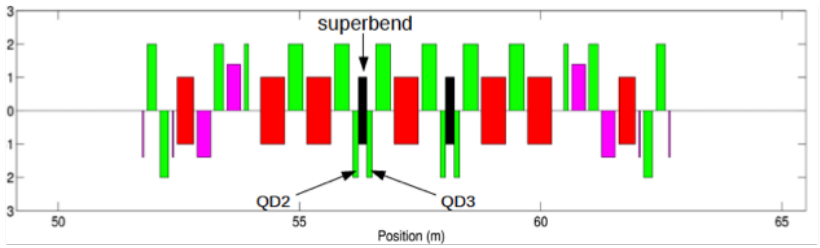


10 focusing quadrupoles per sector radially offset (~1 mm)

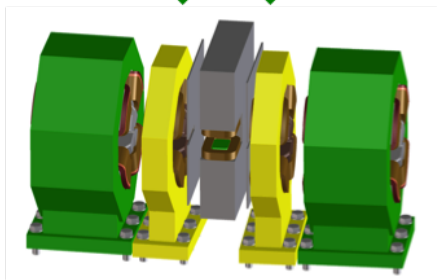


Superbends





2 magnets each



Reverse bends further reduce emittance

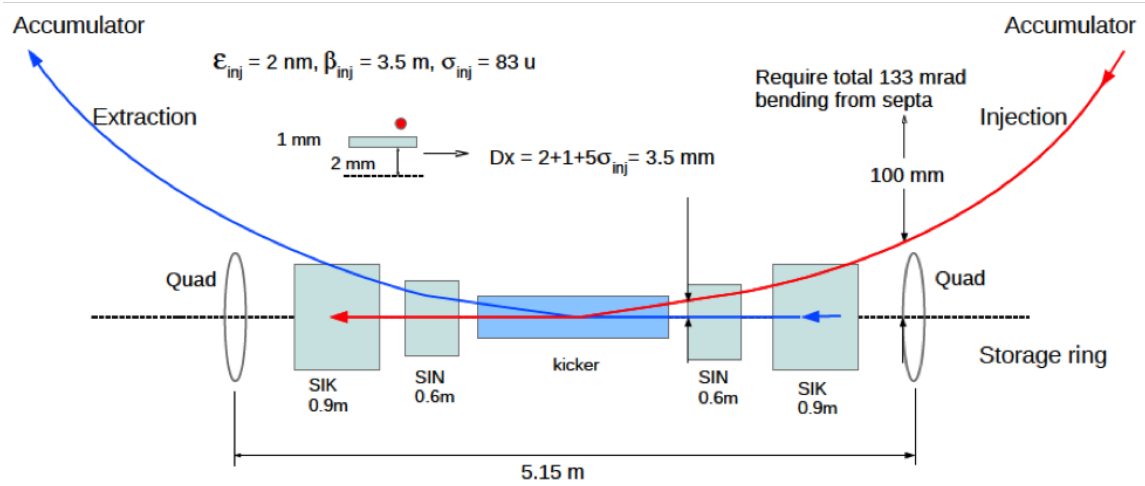
- ~1 mm offset of 10 QF per sector

Superbends allow generation of hard x-rays 5 T dipoles

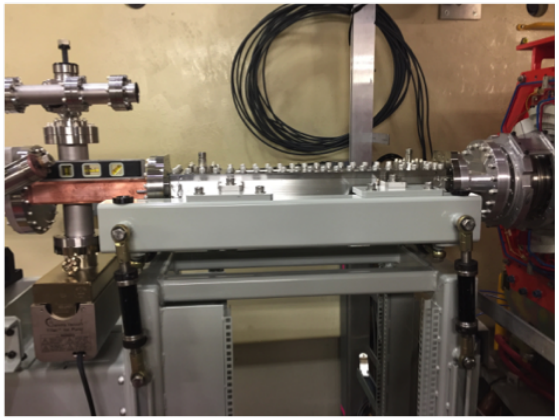
- 3.2 T permanent magnet superbend under development
- 5 T superconducting superbend has been evalueted

The key swap-out injection technology has been demonstrated on ALS

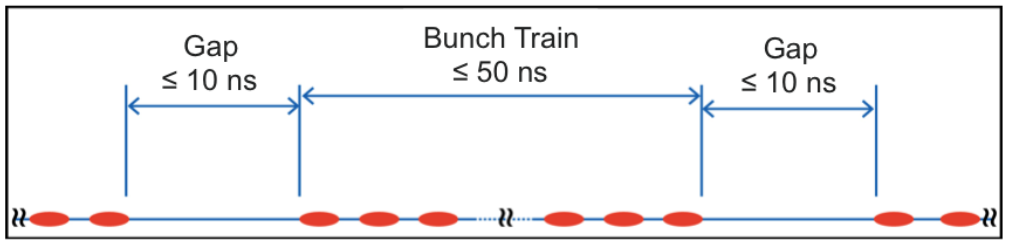
Injection swap-out concept

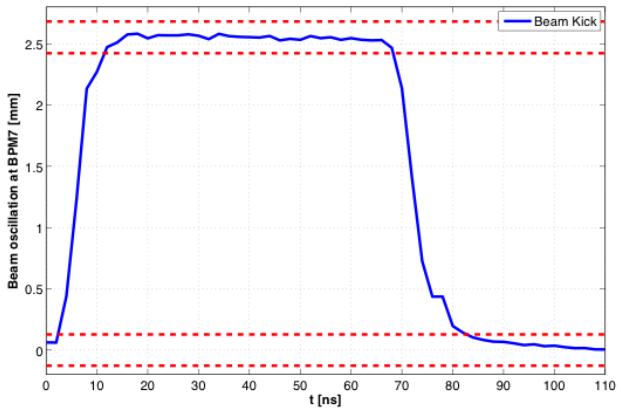


Fast kicker installed

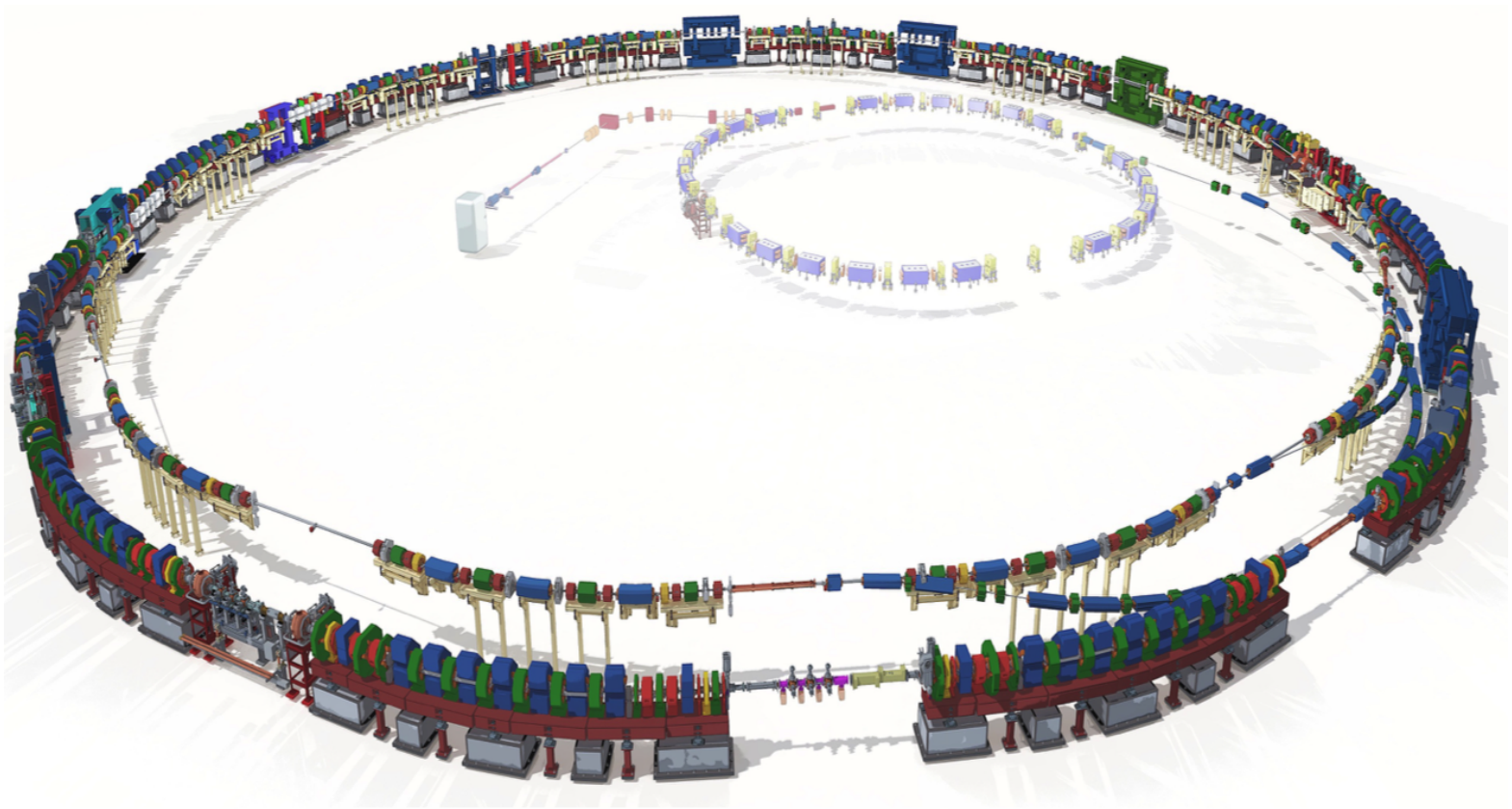


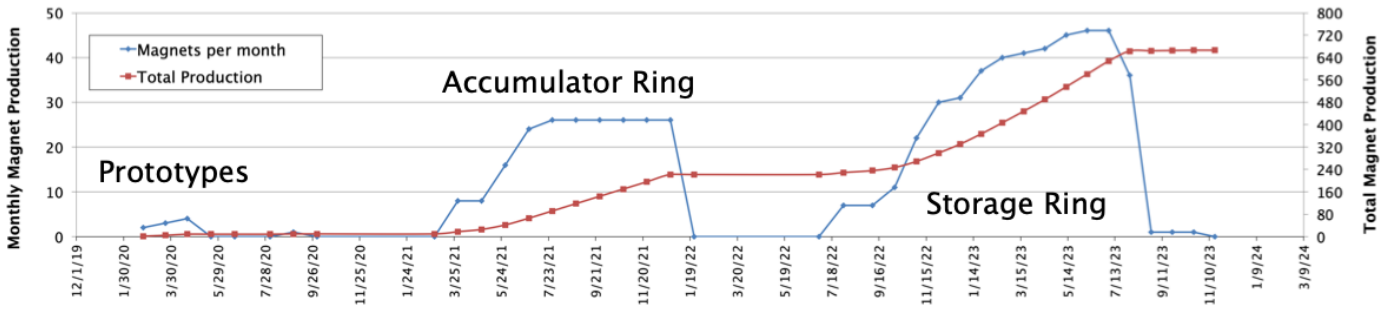
Swapping out a bunch train





The ALS-U will have 670 new magnets. 100% will be measured and fiducialized.





Stability and alignment requirements on the ALS-U magnets

Storage Ring

DOF	Stability (>10 Hz)	Alignment Accuracy	Adjustment Resolution
X	±20 nm	±20 μm	10 μm
Y	±20 nm	±20 μm	10 μm
Z	±200 nm	±200 μm	10 μm
R_X	±400 μrad	±400 μrad	100 μrad
R_Y	±400 μrad	±400 μrad	100 μrad
R_Z	±40 μrad	±40 μrad	20 μrad

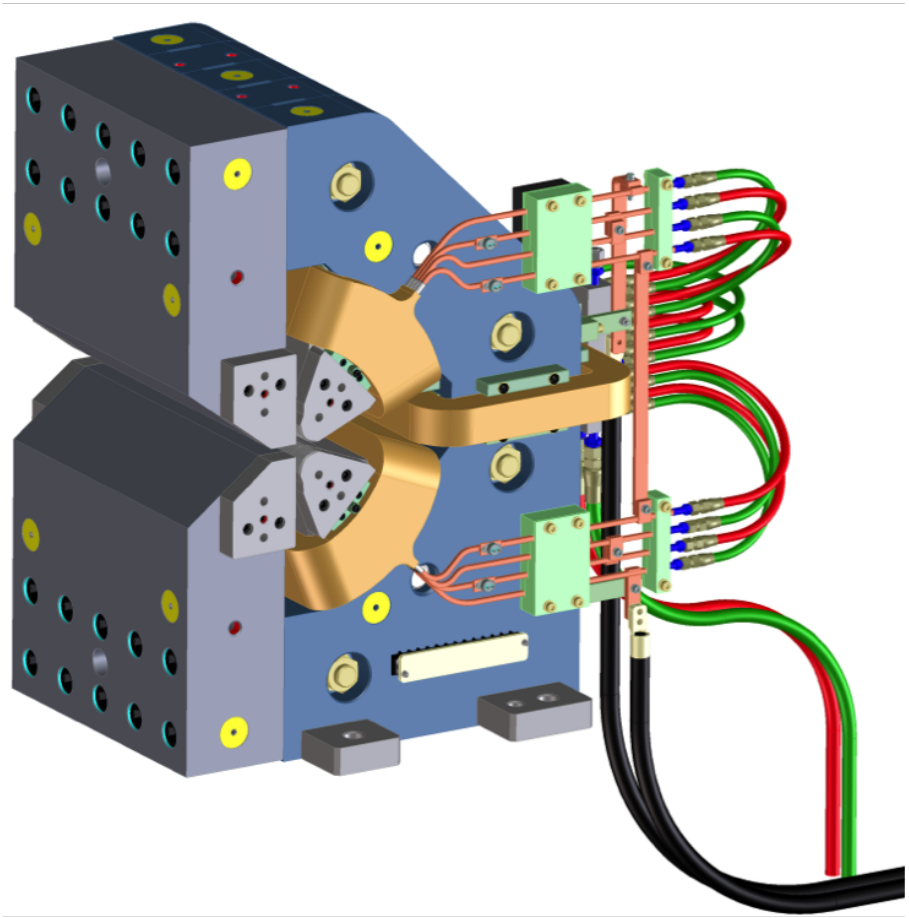
- 400 SR Magnets in total mounted on 94 rafts
- 96 Magnets are swept gradient dipole magnets which require Hall probe scanning
- All other magnets are straight magnets which can be measured with rotating coils and wire methods.
- Alignment and rotation is important while multipole contents is not critical since beam dimensions are small

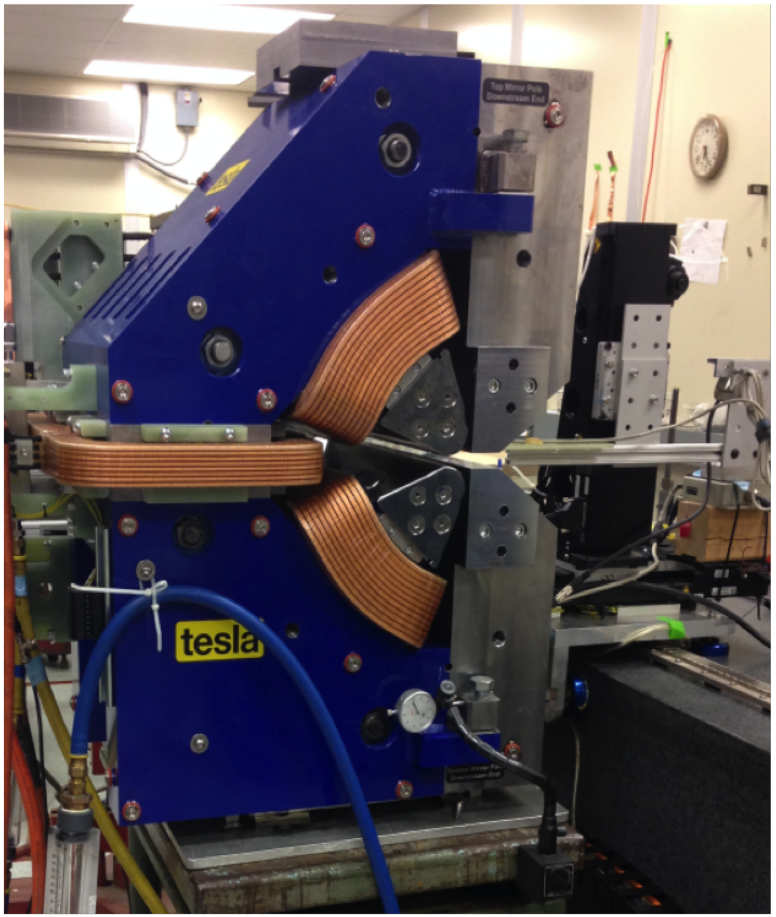
Accumulator Ring/Transfer Lines

DOF	Stability (>10 Hz)	Alignment Accuracy	Adjustment Resolution
X	±1000 nm	±50 μm	25 μm
Y	±200 nm	±50 μm	25 μm
Z	±1000 nm	±500 μm	25 μm
R_X	±10 mrad	±1 mrad	200 μrad
R_Y	±10 mrad	±1 mrad	200 μrad
R_Z	±1 mrad	±400 μrad	100 μrad

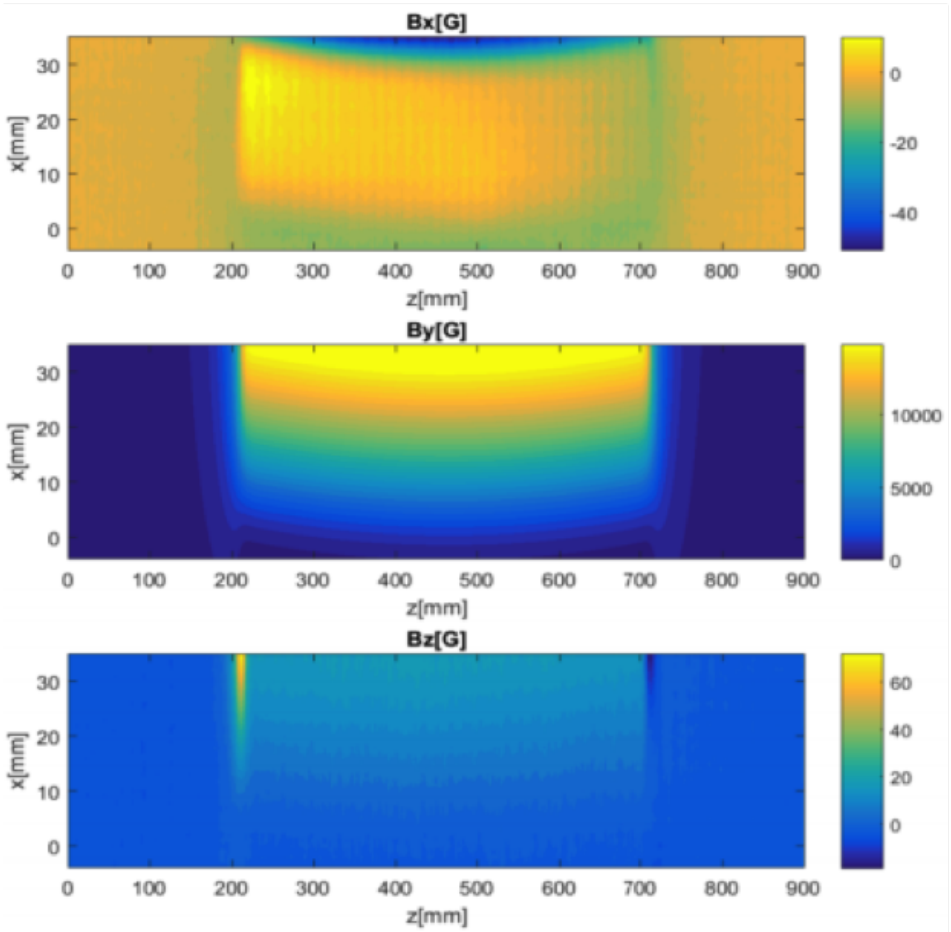
- 260 Magnets in total mounted on walls of tunnel and supports to the floor
- All AR magnets are straight magnets which can be measured with rotating coils and wire methods.
- Multipole contents is critical since beam dimensions are large
- Alignment and rotation requirements are standard values for accelerators

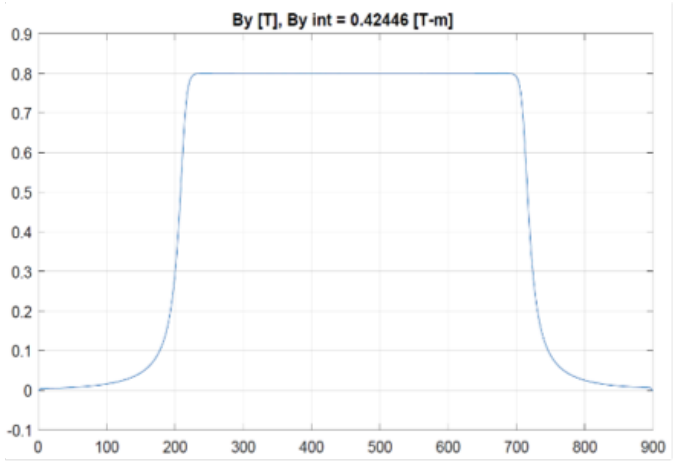
A prototype swept combined quadrupole and bend magnet has been built

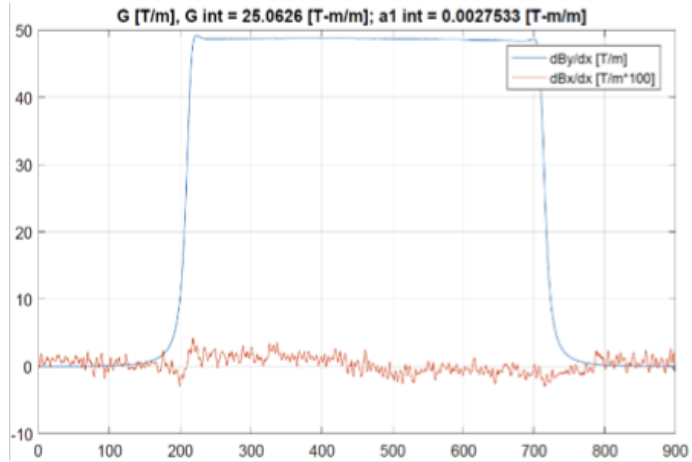




The prototype magnet was measured at CHESS (A. Temnykh) in March 2019

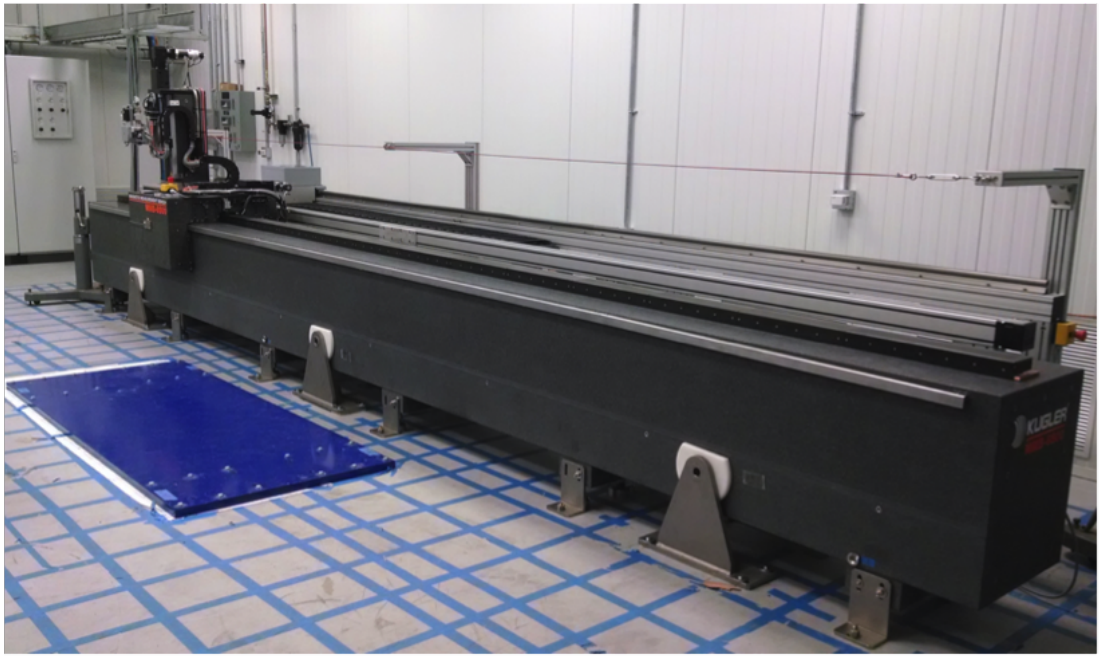




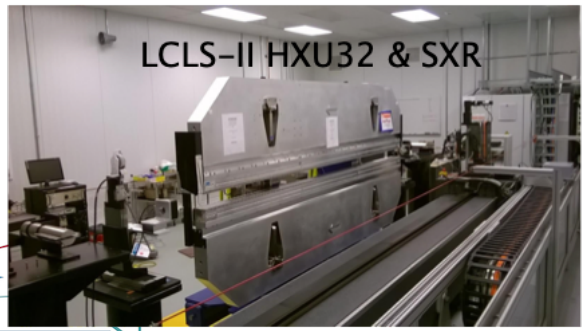


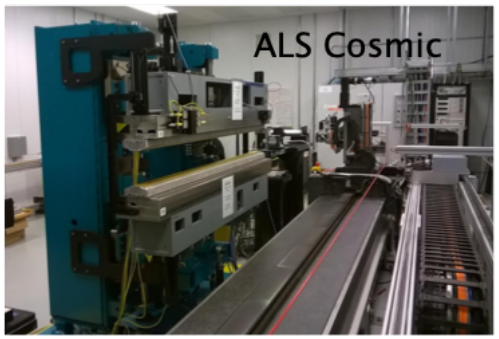
The Undulator Measurement Facility UMF

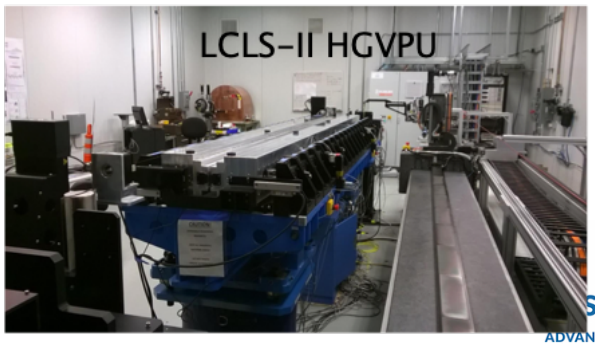
Temperature controlled (20±0.1°C) room with 1.2 m thick concrete floor.



- 6.5 m long Kugler Hall probe bench
- Flip coil system at bench
- Automated measurements using batch scripts
- Mobile flip coil system
- Pulsed wire system
- Helmholtz coil system
- NMR probes
- Alignment magnets
- Rotating coils

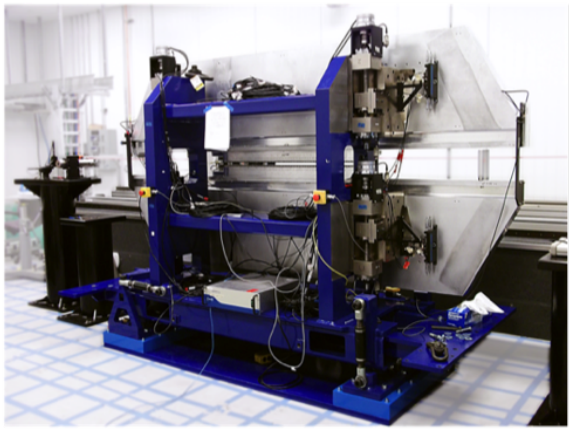
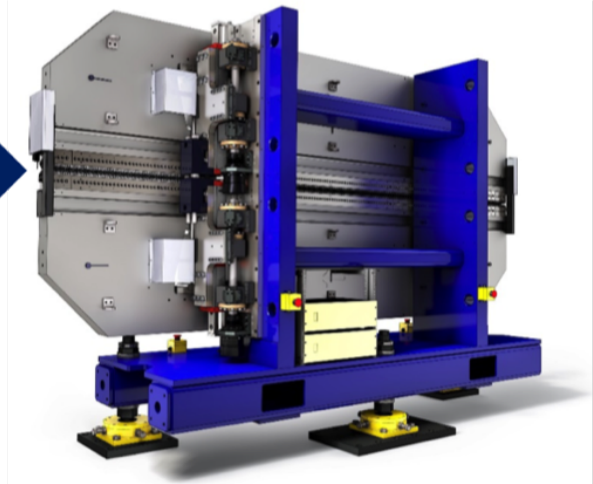






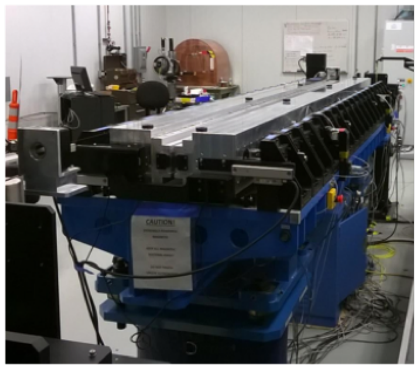
The UMF is used for LCLS-II undulator tuning. Work finished autumn of 2019.

Collaboration LBL, ANL, and SLAC with extensive use of industrial suppliers

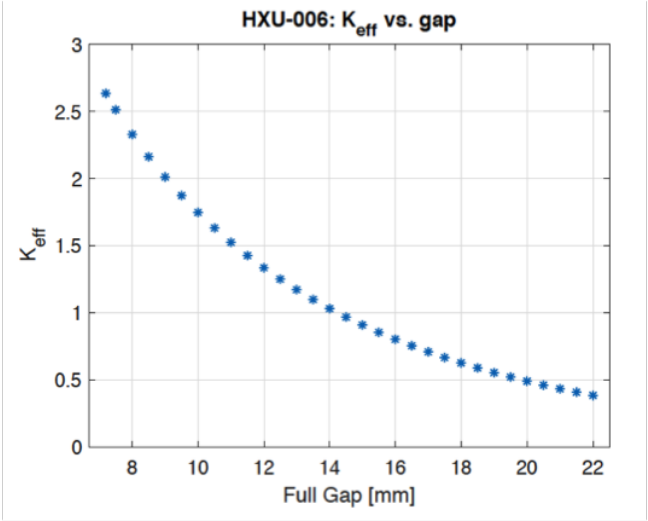
Small-Scale Prototype	Undulator Prototype ("HXU-32")	SXR Pre-Production
2013	2014	2015

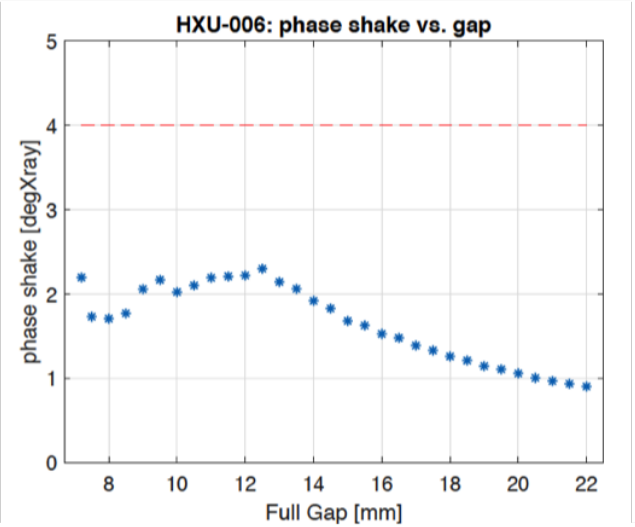
The HGVPU was developed at ANL. LBL has modified the magnet structure, improved the mechanical system, and arranged the production.

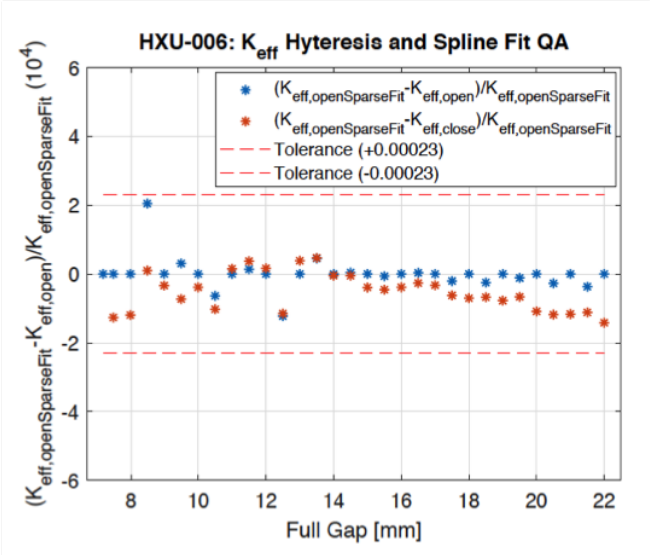


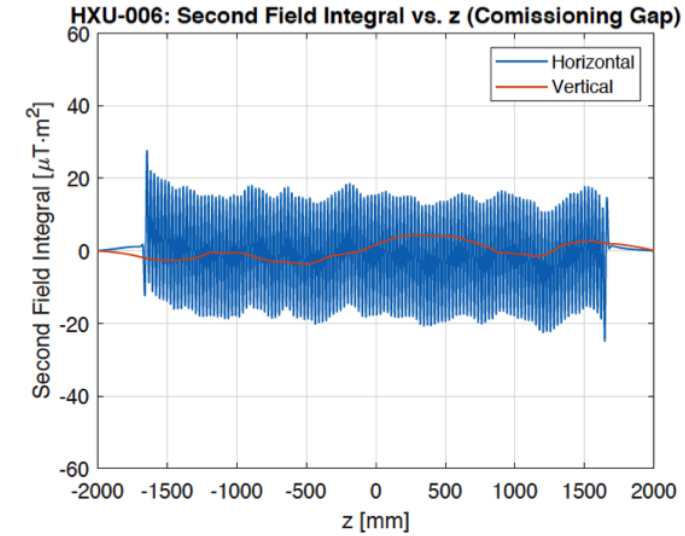
- 33 HGVPU undulator are in production and most of them (>23) are tuned at LBL.
- The 23 SXR undulators are tuned by SLAC.

Sample results of tuning for the HGVPU called HXU-006

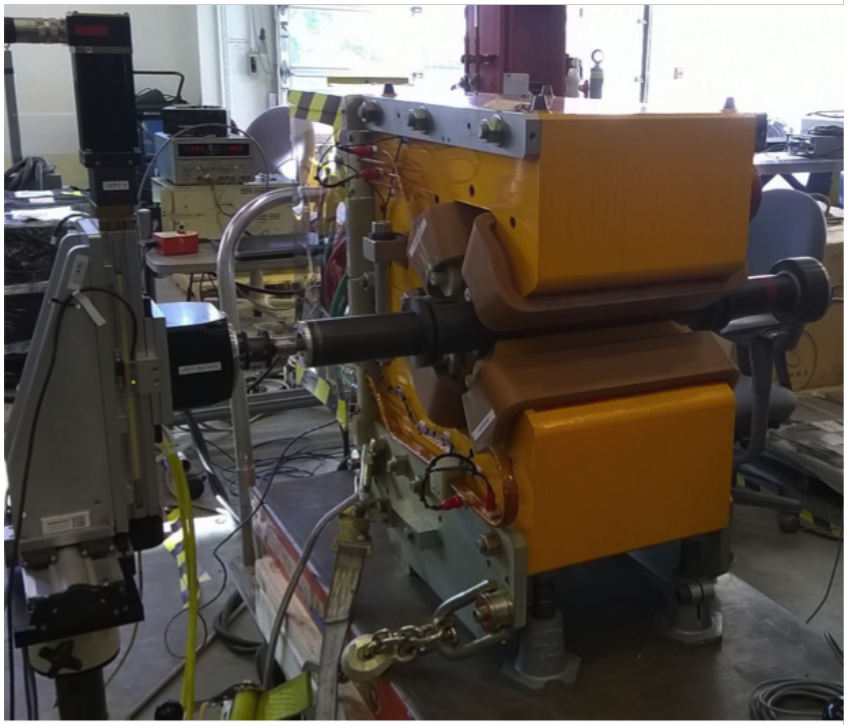


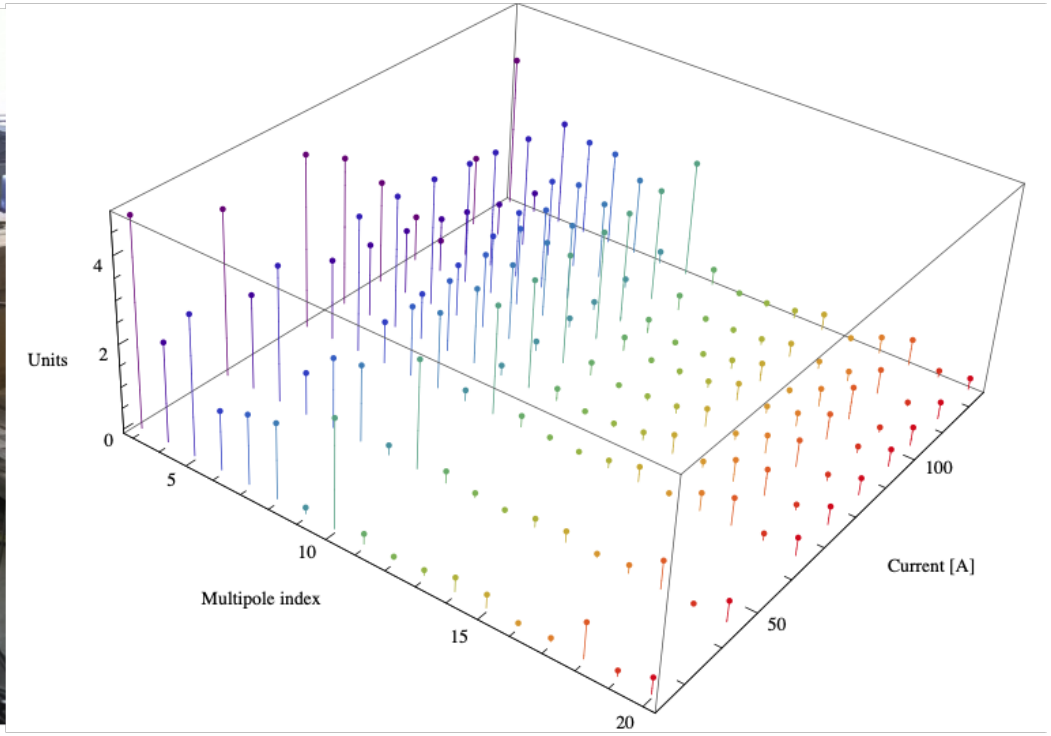




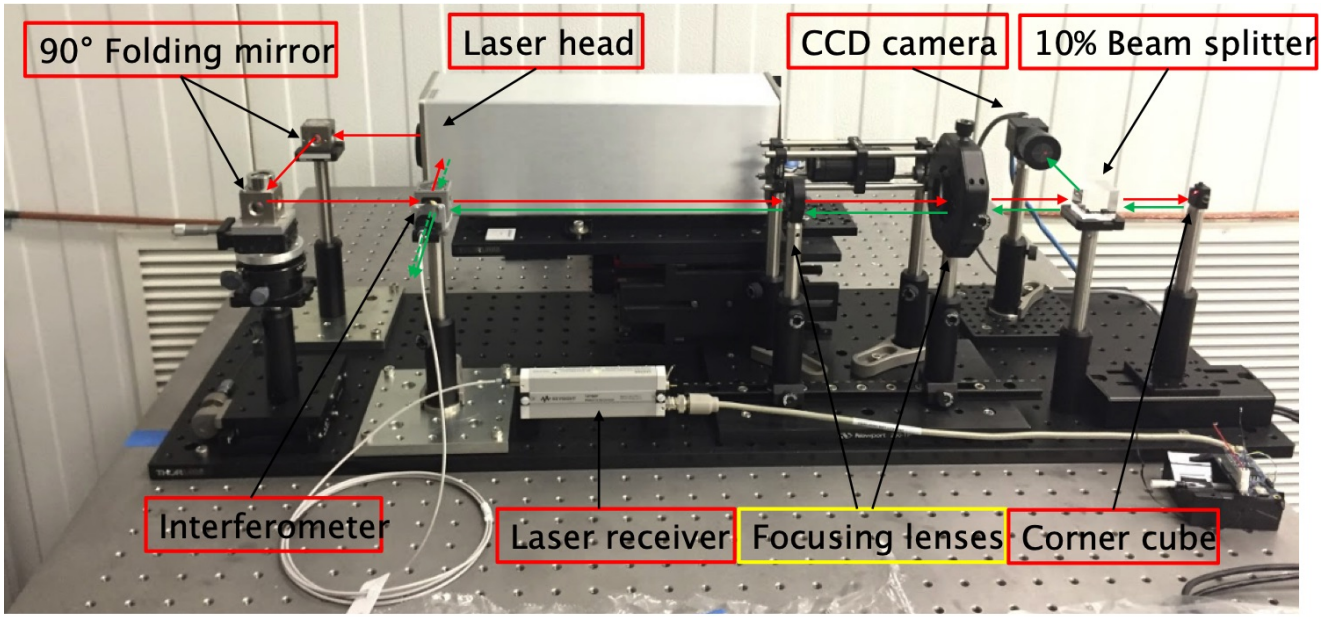


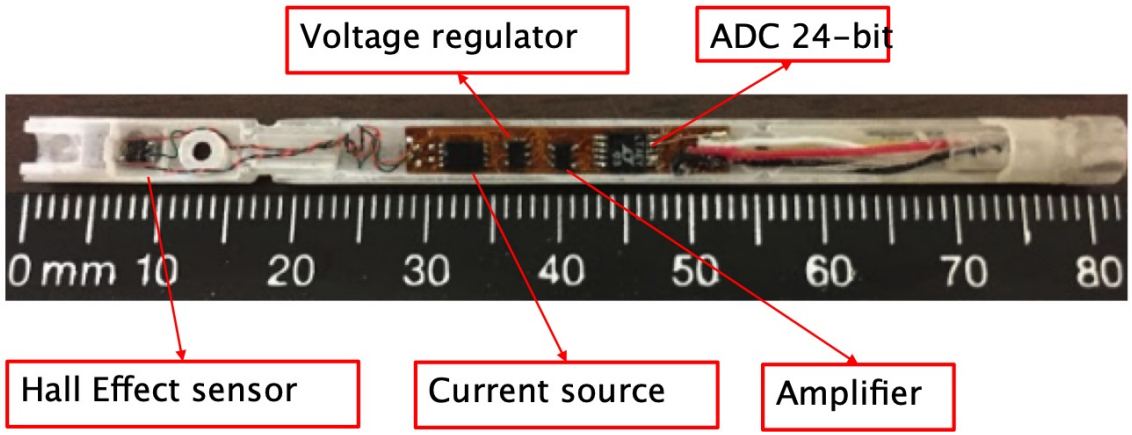
The original ALS rotating coils used in 2017 to measure on ALS quadrupoles





A first version of a small bore Hall probe measurement system has been built





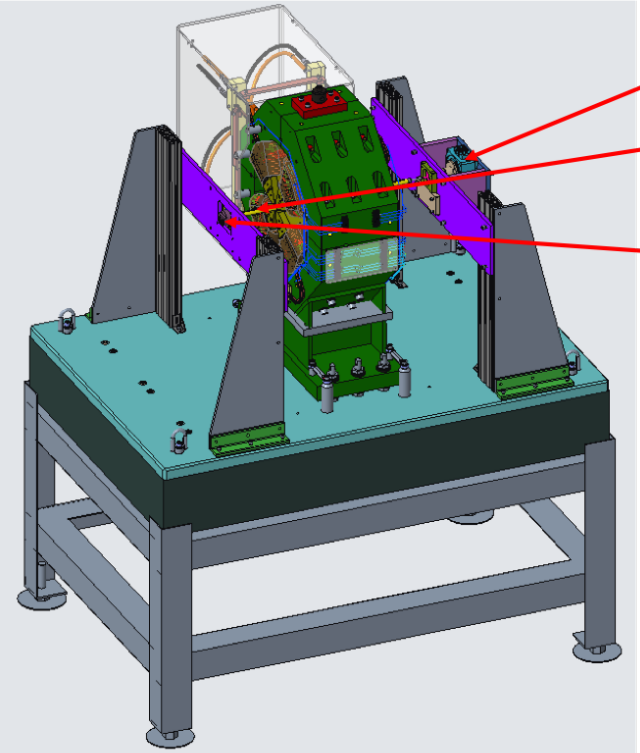
Magnet measurement systems for the ALS-U

For the accelerator magnet measurements:

- 2 rotating coil systems. One system on a bench and one system that can be brought to the magnets.
- 2 stretched wire systems with integrated vibrating wire function.
- A small 1.2 m travel length Hall probe bench for measurements on swept dipoles
- A CMM with Hall probe mapping capacity
- The search for a proper magnet measurement area with temperature stability, crane, cooling water, and sufficient floor area is in progress.

The work with developing a small bore Hall probe system for Delta and X-type undulators is continuing.

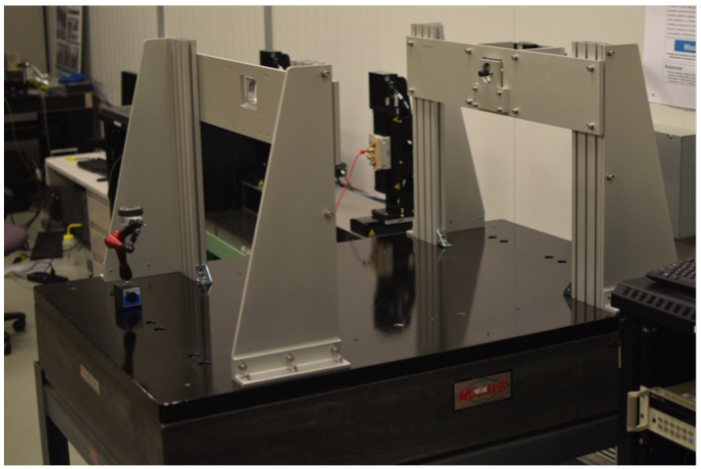
Rotating coil system being assembled in the UMF



Rotary stage Newport RGV100

Removable G10 rod with the PCB coils inside

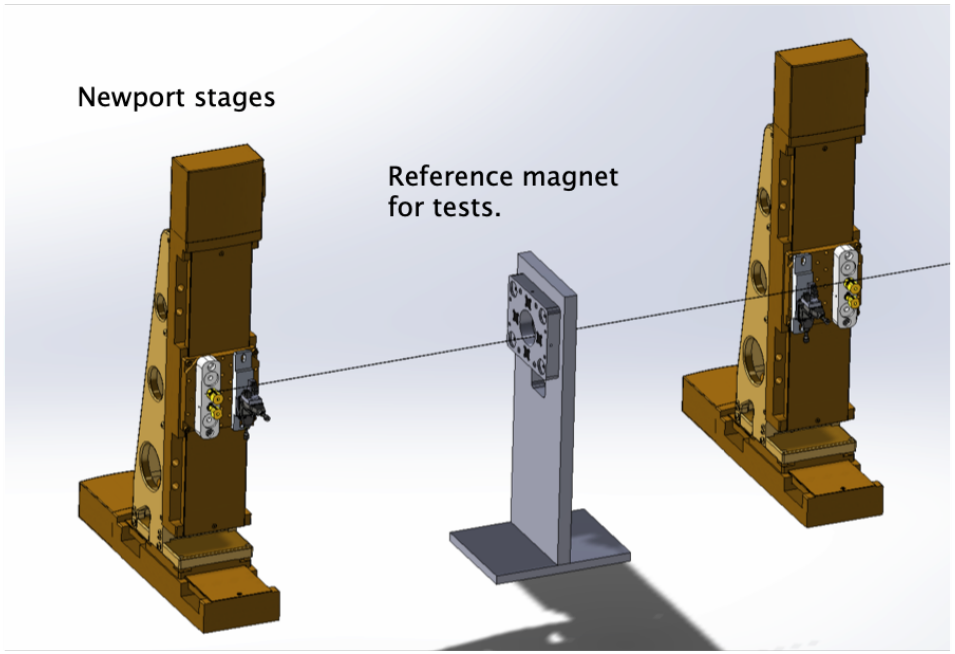
Bearings fixed to the plate



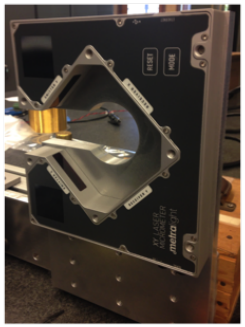
- The PCB coils are done by industry and several versions, radial, tangential, and bucked D+Q, have been bought.
- Assembly and test of the system is in progress.
- A second system with magnet-supported exterior tube will also be built.

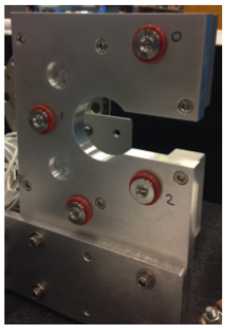
Stretched wire system

Stretched wire systems give flexibility to measure on different magnet types to find strength, multipoles, and magnetic axis.



Laser micrometers to track the position of the wire in space are being purchased.

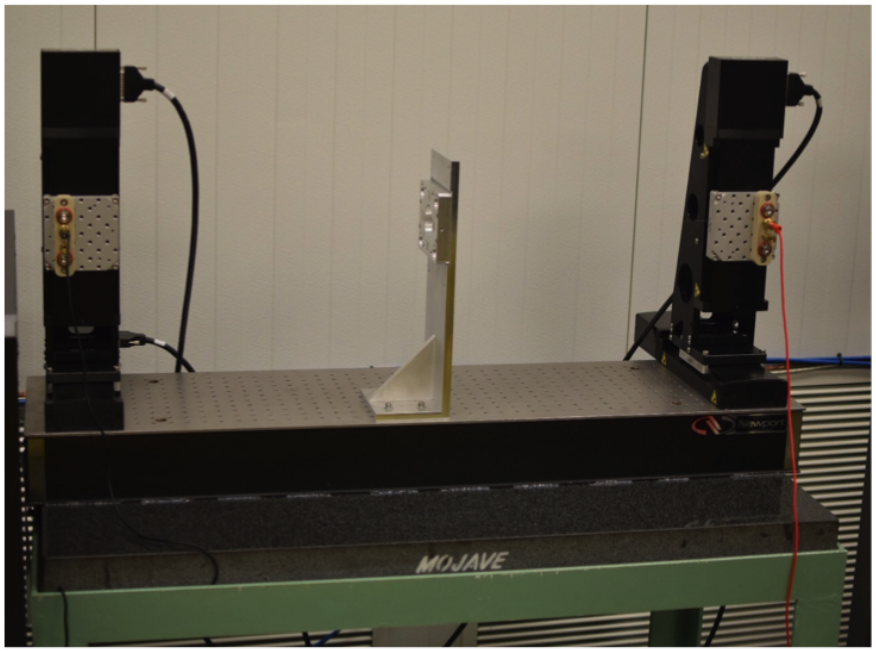


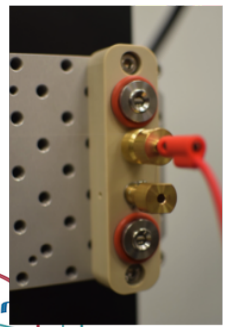


The vibrating wire function give possibility to accurately measure the magnetic axis and can be used for fiducialization.
Different options for the voltage readings are tested, including Keysight 3485A, Keithley 2701, Keithley Nanovoltmeter, and Metrolab integrators.

Stretched wire systems being assembled in the UMF

System 1 for method development



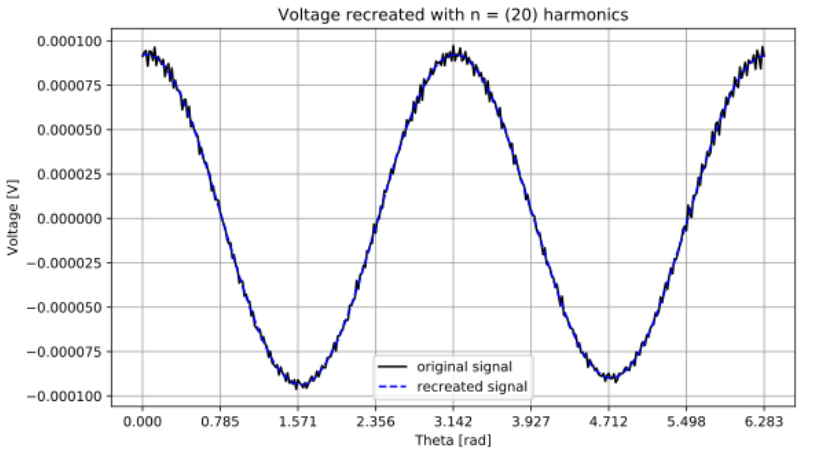


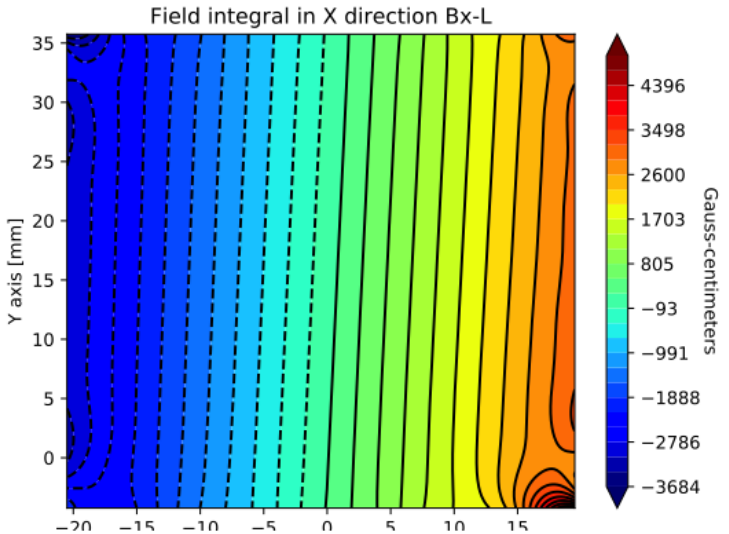
The motion control and data analysis is done with Python scripts.

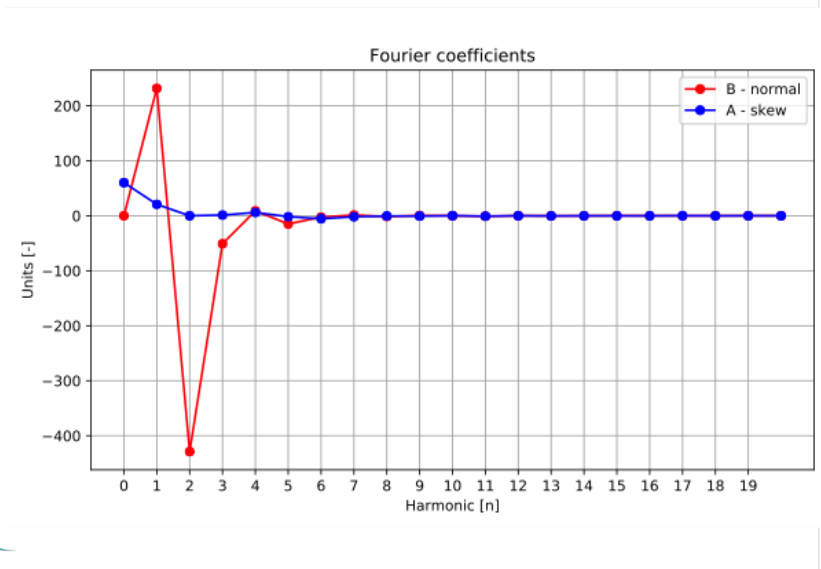
System 2 with granite bench

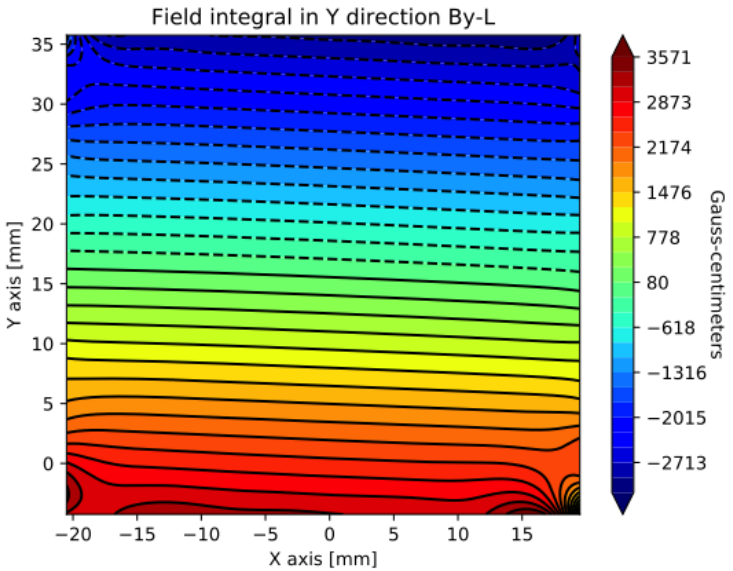
Stretched wire measurements on reference magnet

The wire is moving on a circular trajectory



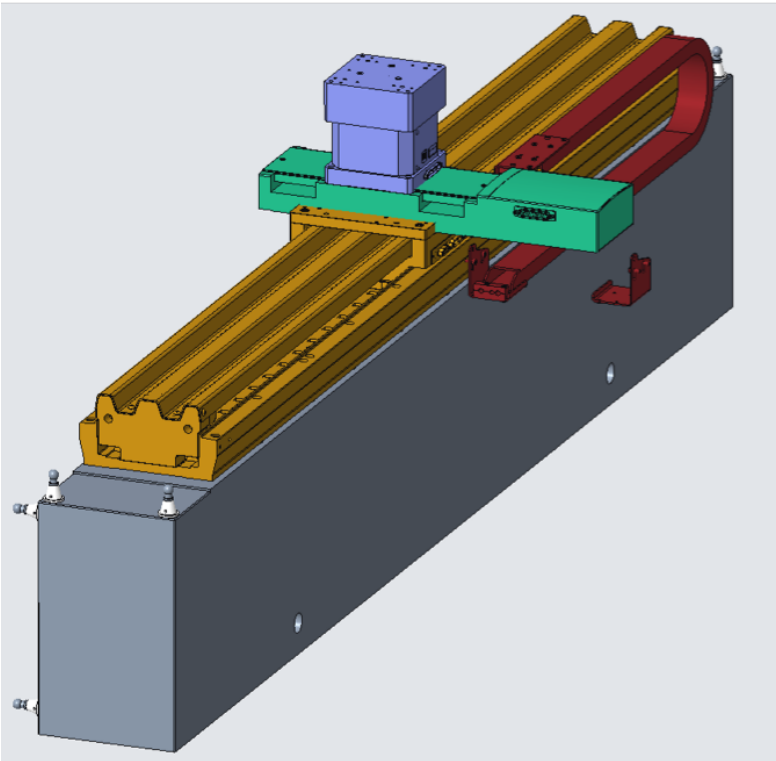




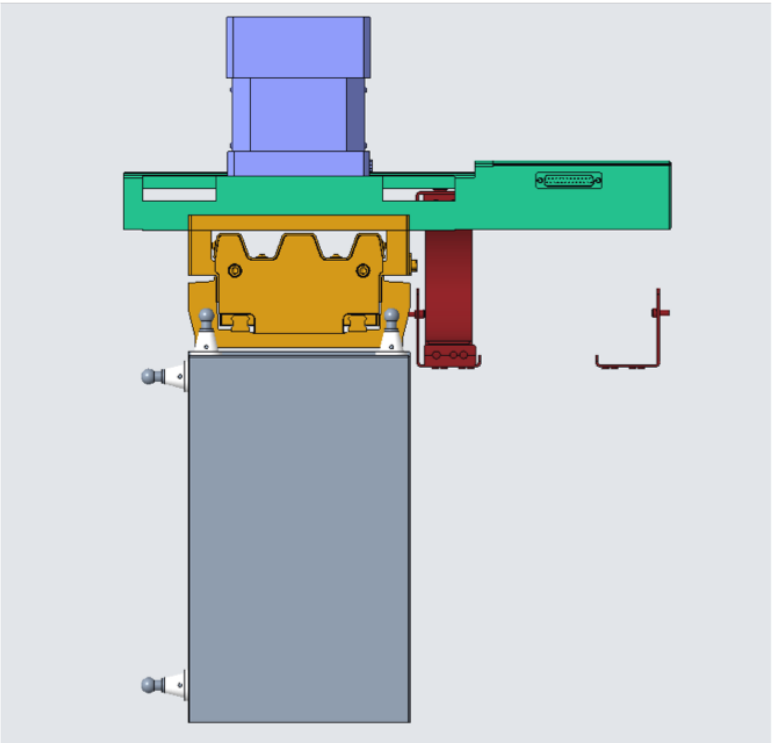


Construction of small Hall probe scanner dedicated for accelerator magnet scans

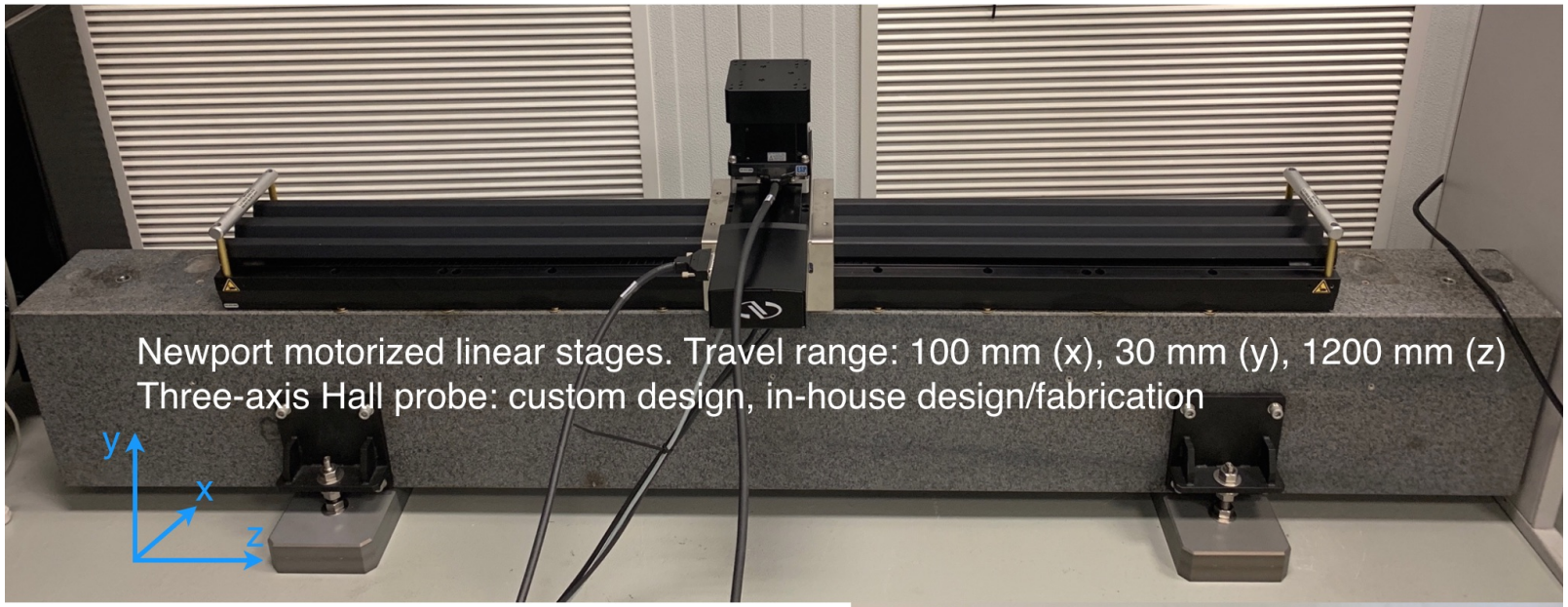
Travel length 1200 mm
Scan volume {X,Y,Z}={100,30,1200}
Maximum scan speed 1000 mm/s



Made from standard parts
Granite beam with fiducials
Parts costs ~$60K



Present status of small Hall probe scanner with ADC electronics and Hall probes

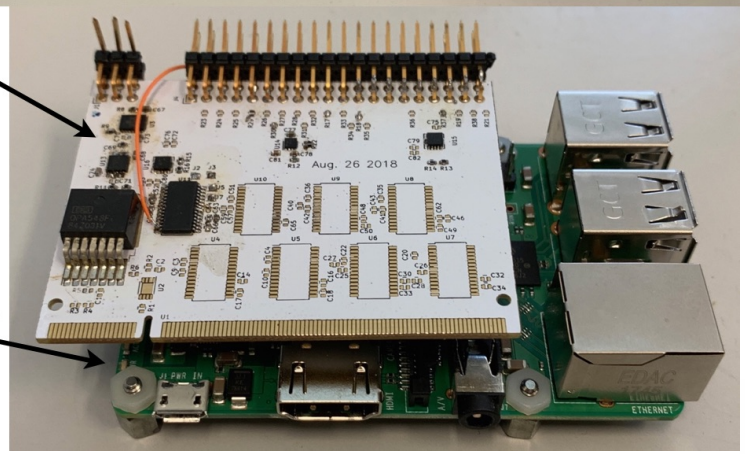


Data acquisition:

Newport XPS-D controller (trigger)

2 x 32-bit ADC
(ADS1263: 38kSPS, 11 channel)

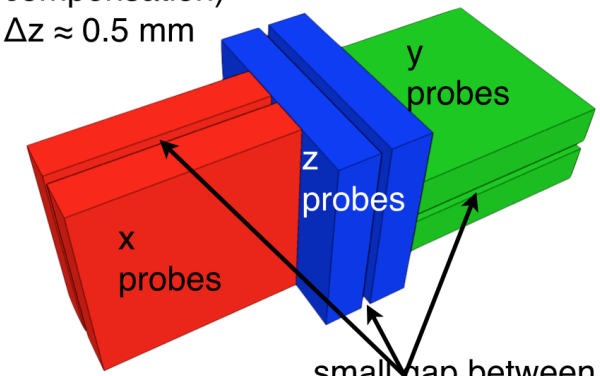
C-code using SPI interface between
ADC and Raspberry Pi (Linux)



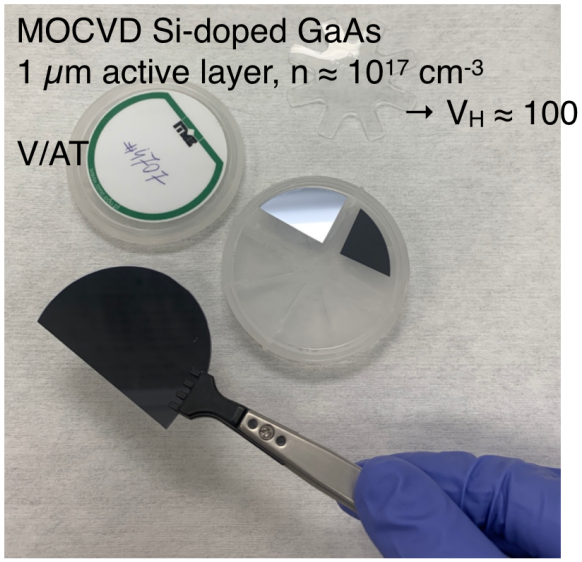
Hall probes made GaAs starting with bare wafers

Hall sensor design

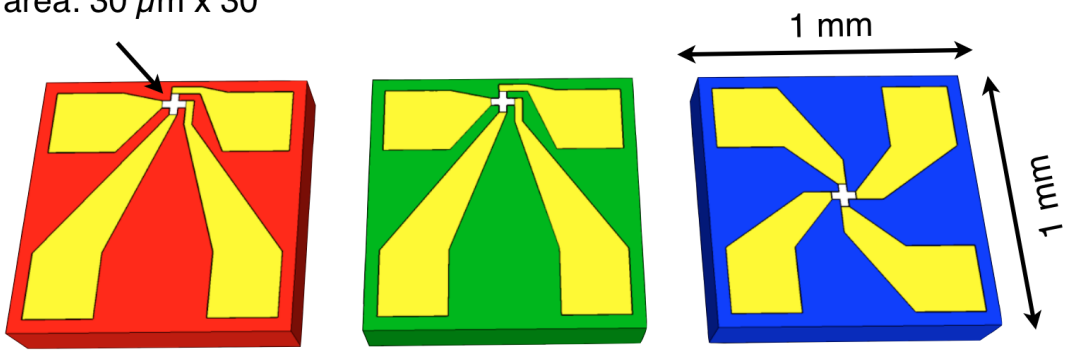
pairs of Hall probes (PHE compensation)
$\Delta z \approx 0.5$ mm



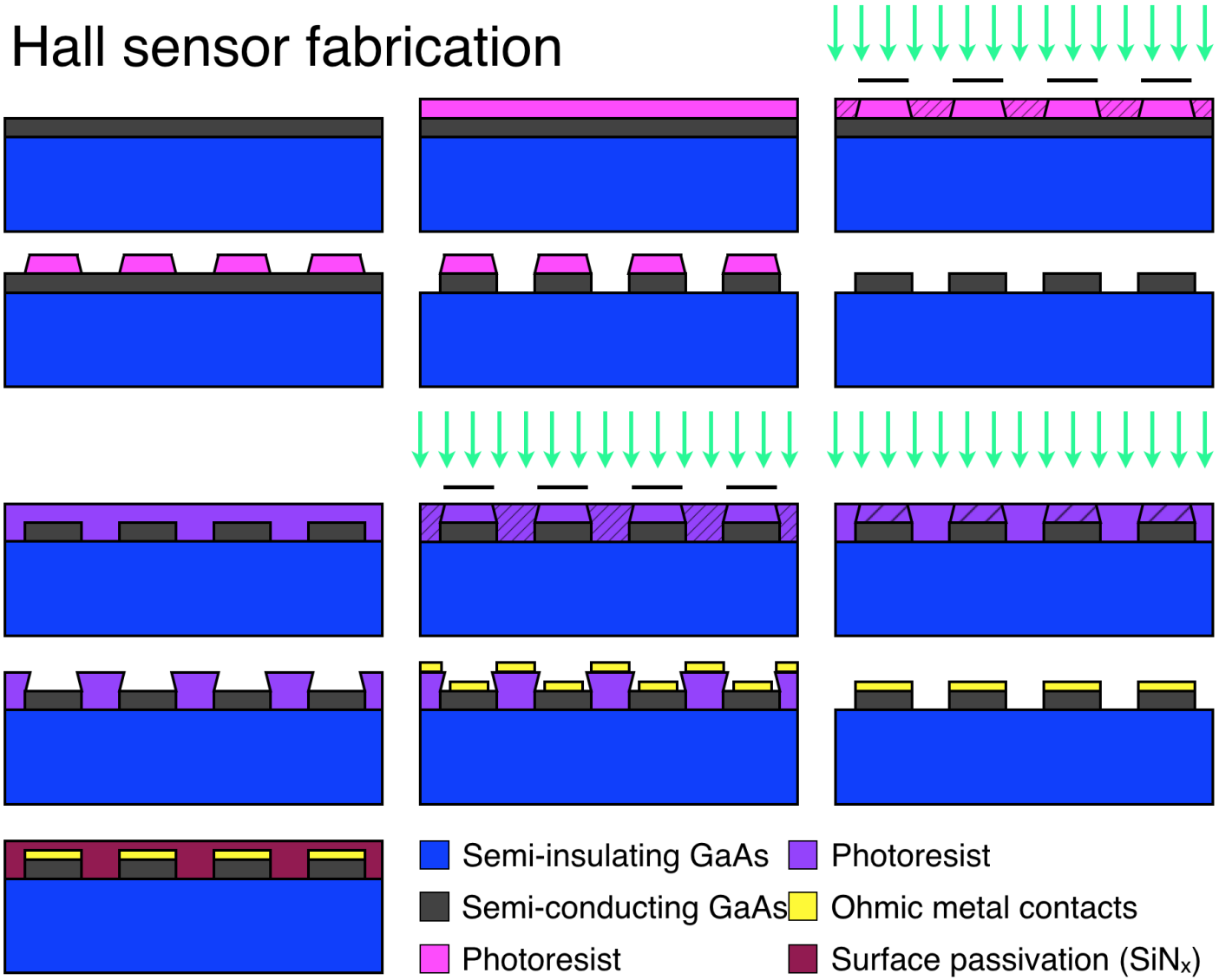
small gap between pairs:
flex-pcb (25 μm)
solder ball (surface mount)



cruciform Hall probe
active area: 30 μm x 30 μm



The process consist of many steps carried out in the UC Nanolab



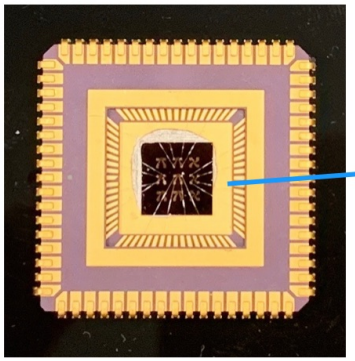
First tests with one of the new Hall sensors indicate a stable output signal

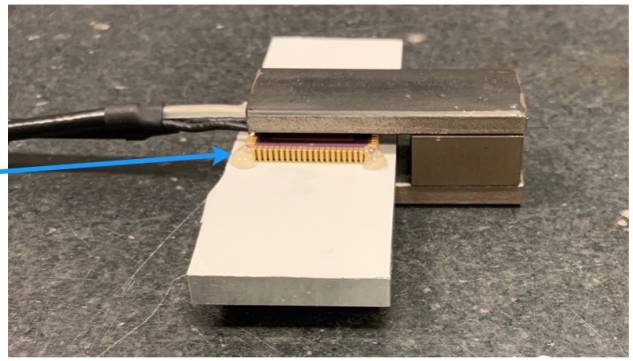
Data acquisition:

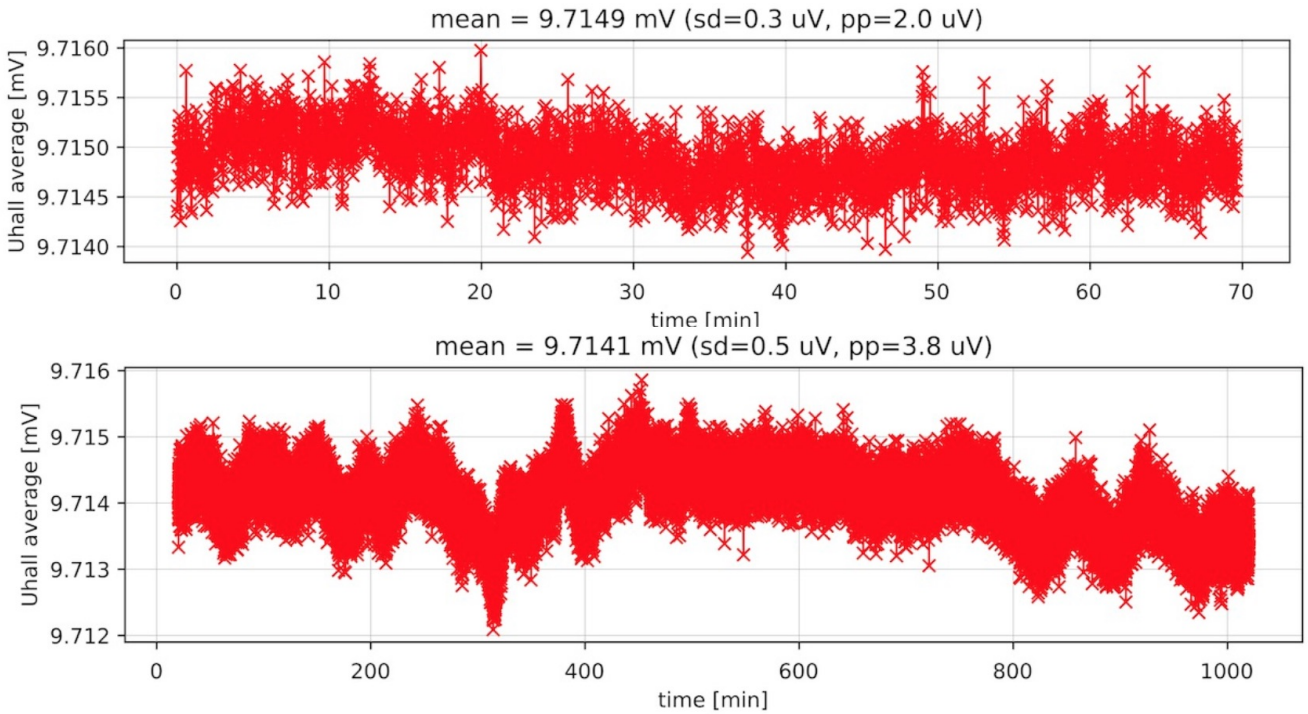
Keithley 6221 CCS:
I_H = 1 mA

Keysight 3458A DVM

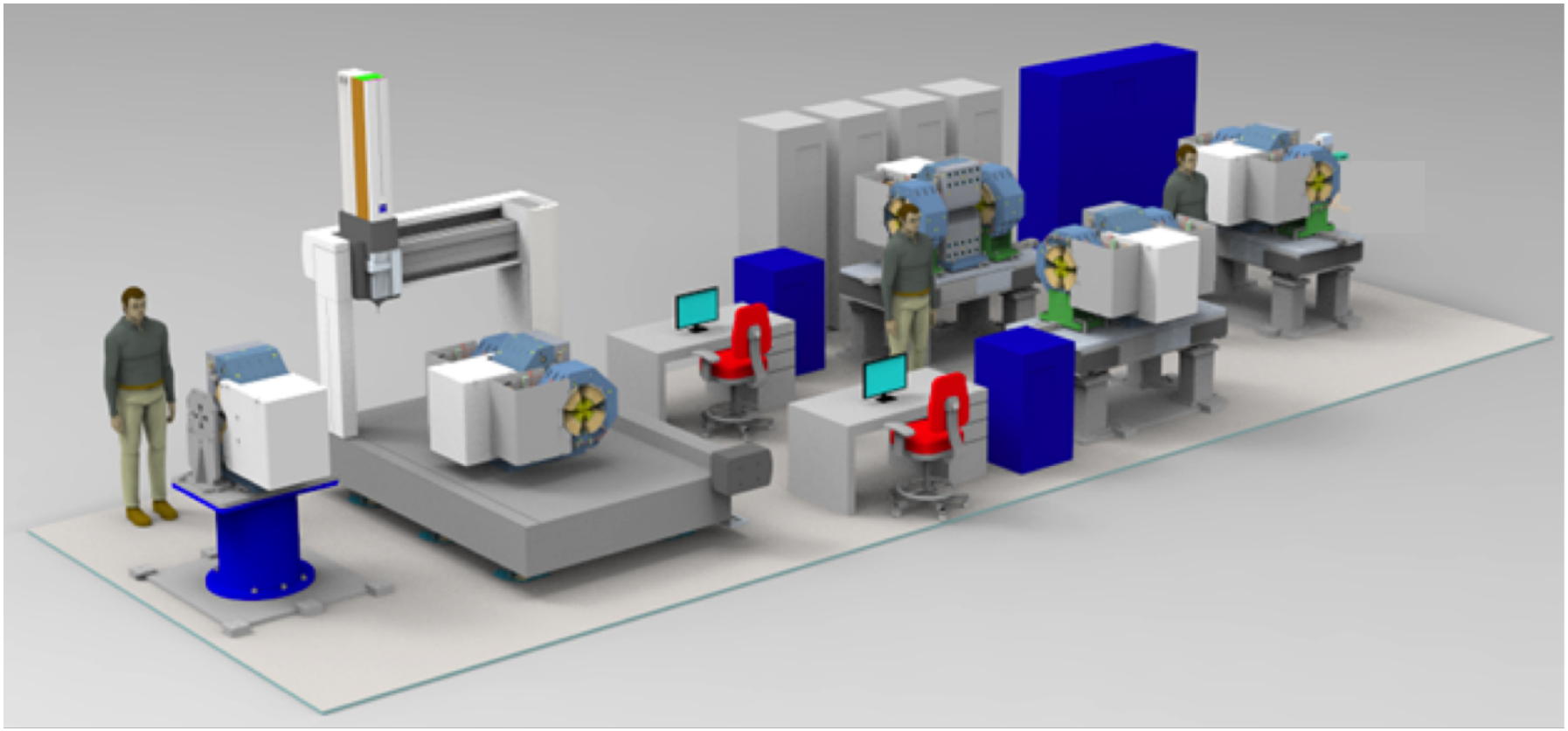
T = 20 ± 0.1 ˚C



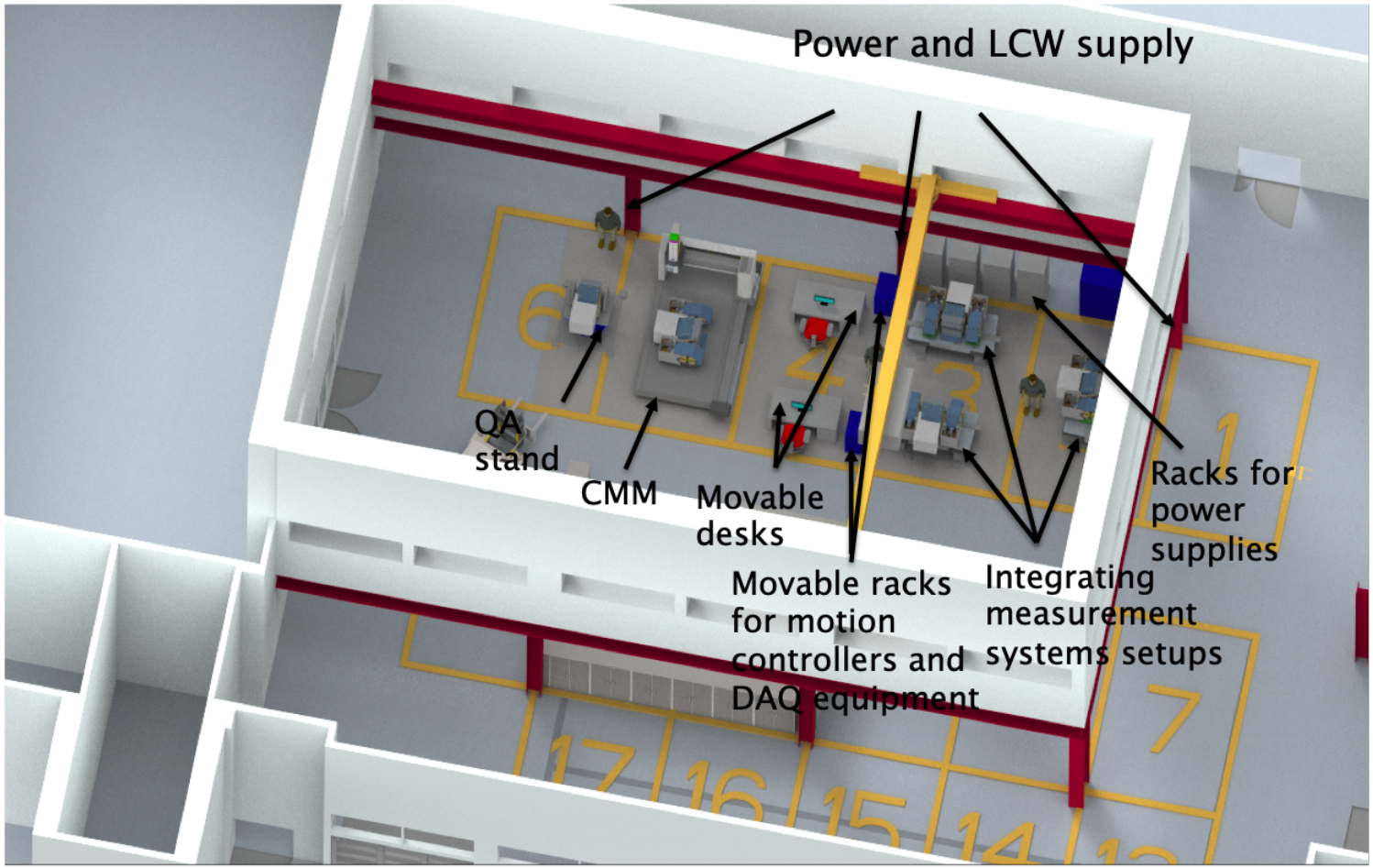




Finding space for accelerator magnet measurements at LBL is not trivial



Lab space with LCW, temperature control, and elecricity exist in building 15.



Summary

- The ALS-U project includes the replacement the existing triple bend achromat lattice with a 9 bend achromats and an accumulator ring.
- 700 magnets will be produced for the ALS-U project.
- The 400 magnets for the ALS-U storage ring have unusually tight tolerances on alignment and roll.
- The 96 swept combined function dipole-quadrupole magnets for the ALS-U storage ring will be measured with Hall probe scans.
- The main work horse for measurements on straight magnets is the stretched wire method combined with the vibrating wire method.
- Magnet measurement systems, including rotating coil, stretched wire, vibrating wire, and a small Hall probe, are being assembled, tested and commissioned at LBL.

Acknowledgments and references

- The material is presented on behalf of the groups working with ALS-U, ALS, and LCLS-II at Lawrence Berkeley National Laboratory.
- The help and advice from the accelerator community is highly appreciated.
- Special thanks to A. Temnykh, J. DiMarco, G. LeBec, and A. Jain for detailed advice on magnetic measurements.