Novel Magnetic Field Mapping Technology for Small and Closed Aperture Undulators

Erik Wallen and Hyun-Wook Kim

06.06.2017

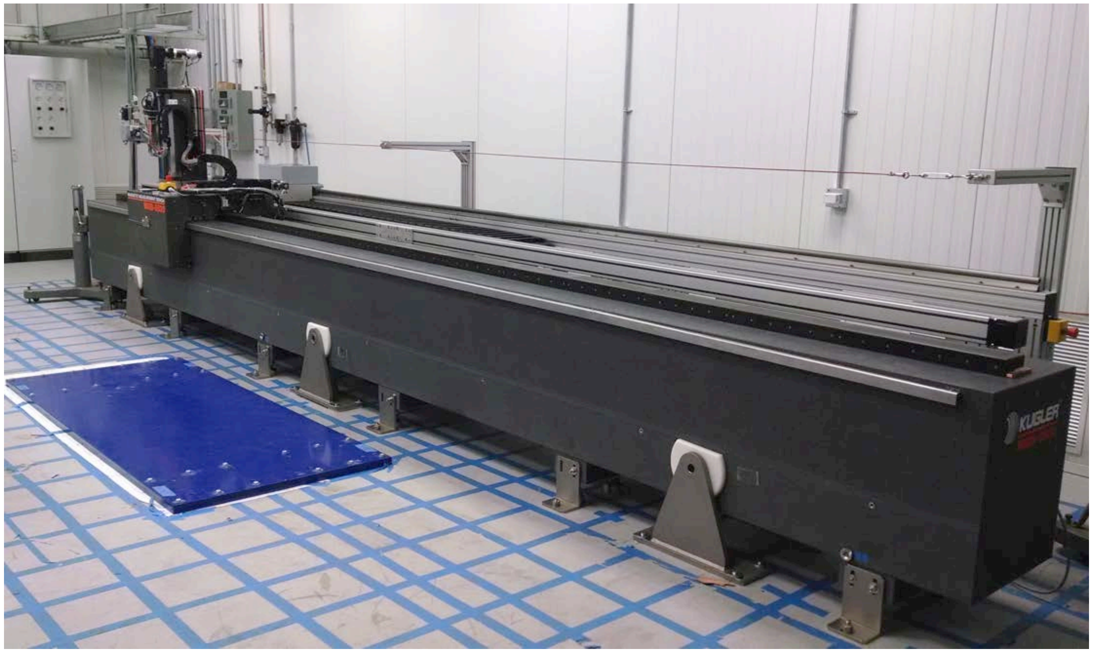
Outline

- Introduction
  - Measurement systems at LBNL
  - Activities at LBNL
  - Need for new field mapping system
- System setup
  - Laser system
  - Compact sensor package
  - Sensor transport system
  - Control software
- Test measurement
  - Sensor calibration
  - Position measurement
  - Magnetic field measurement
- Summary

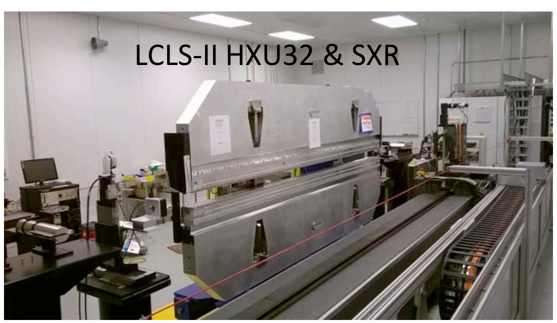
Introduction

UMF Undulator Measurement Facility

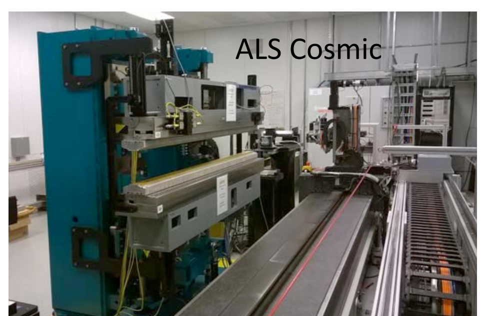
Temperature controlled (20±0.1°C) room with 1.2 m thick concrete floor.



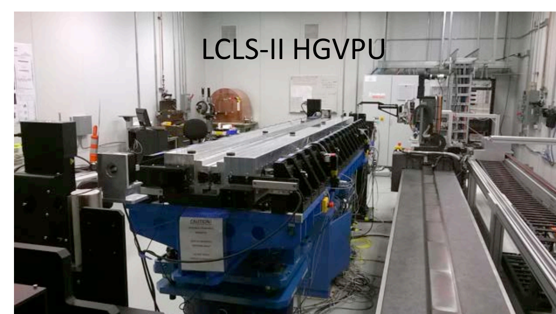
- 6.5 m long Hall probe bench
- Flip coil system at bench
- Automated measurements using batch scripts
- Mobile flip coil system
- Pulsed wire system
- Helmholtz coil system
- NMR probes
- Alignment magnets
- Rotating coils
- Small bore Hall probe system under development



LCLS-II HXU32 & SXR



ALS Cosmic



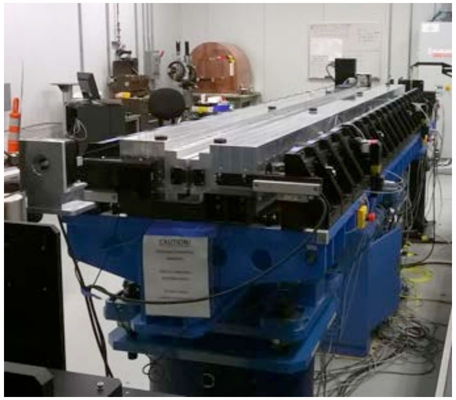
LCLS-II HGVPU

Undulators for the LCLS-II

- Collaboration LBNL, ANL, and SLAC
- Extensive use of industrial suppliers

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

The HGVPU was developed at ANL. LBNL has modified the magnet structure and arranged the production.



23 SXR undulators and 33 HGVPU undulator are in production.

23 HGVPU undulators will be tuned at LBNL.

BERKELEY LAB

Cosmic EPU - assembled and tuned in house year 2016

Main parameters

Period Length	38	mm
Gap	10	mm
Length	2106.39	mm
Number of full size poles	109	
Beam Energy	1.9	GeV

Geometry

Width of magnets	30	mm
Height of magnets	25	mm
Thickness of magnets	9.35	mm
Coating thickness	6	μm
Gap between rows	1	mm

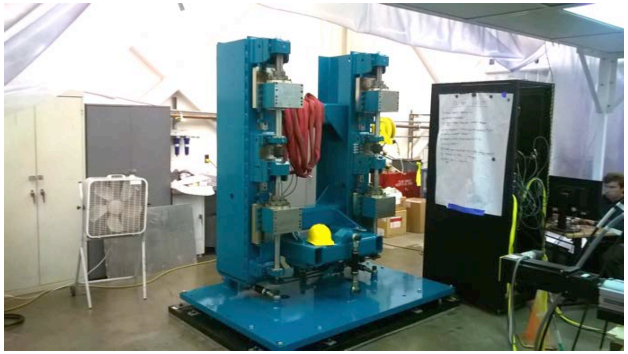
Calculated

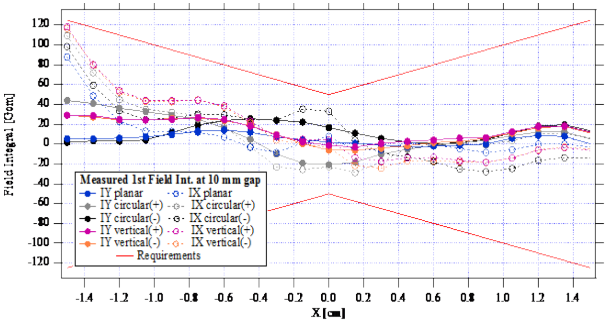
Mode	Phase [mm]	Effective vertical field [T]	Effective horizontal field [T]	*K*-value	Photon energy [eV]	Radiated power [kW]
Planar	0	0.896	0	3.18	149.1	1.93
Circular	11.236	0.535	0.535	2.69	195.7	1.38
Vertical	19	0	0.669	2.38	236.2	1.08
45° Incl	10.376	0.382	0.382	1.92	317.5	0.70

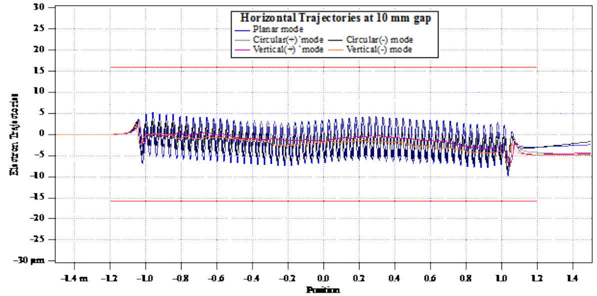
Measured

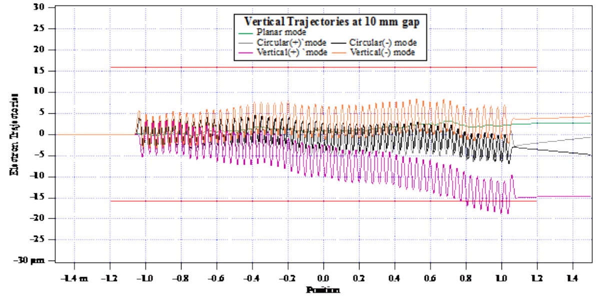
Gap mm	Mode	I1X Gcm	I1Y Gcm	I2X Gcm^2	I2Y Gcm^2	Ph.Er. °RMS	B_{eff} T	Ph.En. eV
10	Planar	-4	14	-1753	-1523	4.45	0.892	150.0
10	Vertical (+)	-5	9	9206	-2772	4.32	0.669	236.4
10	Vertical (-)	-9	4	-2667	-2957	4.50	0.669	236.4
10	Circular (+)	-29	-13	410	-3127		0.759	194.8
10	Circular (-)	25	30	3022	-1067		0.754	196.8
10	Inclined (+)	39	4	6386	320	38.26	0.551	309.9
10	Inclined (-)	-36	21	-2161	-2784	6.32	0.552	308.9

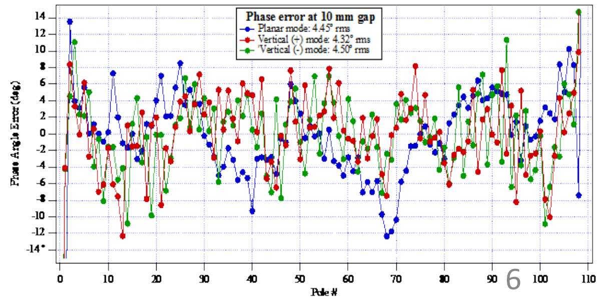
Magnet blocks are mounted in pairs on keepers to minimize twisting of magnet blocks of during phase shifts.







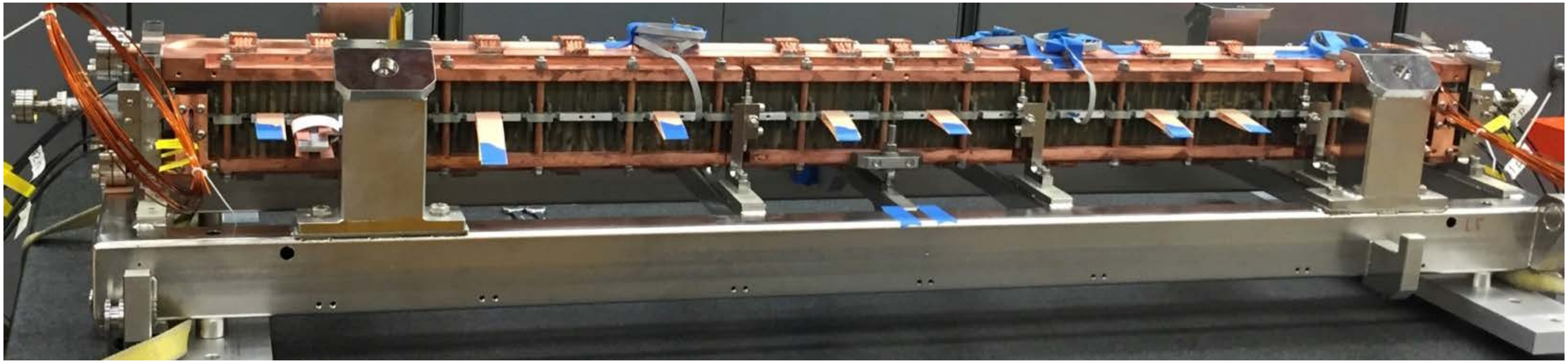




BERKELEY LAB

Superconducting undulators using NbSn coils

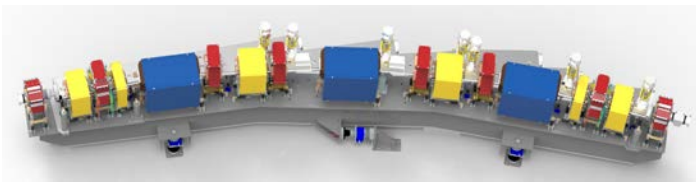
- A 2015-2016 SLAC/ANL/LBNL collaboration with the following LBNL deliverables:
  - Fabrication of a 1.5 m long Nb_3Sn undulator
  - Development and fabrication of field correction scheme
  - Development and transfer of pulsed wire setup for magnetic measurements (complementary to ANL measurement system)
- Final magnetic measurements performed in ANL cryostat

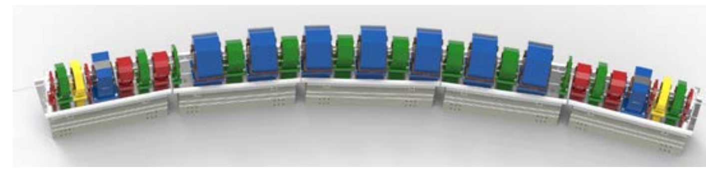


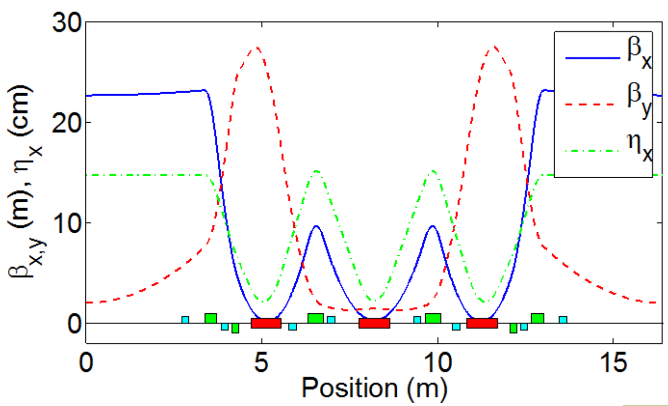
ALS-U, upgrade of the ALS with a multi-bend achromat lattice reaches the soft x-ray diffraction limit up to 2 keV

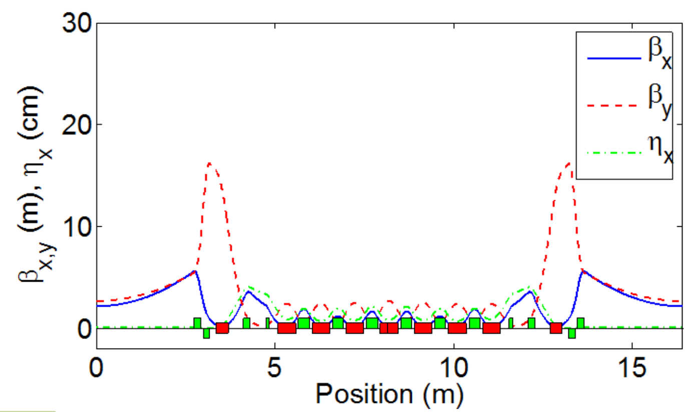
ALS today : triple-bend achromat

ALS-U: multi-bend achromat









$\varepsilon_x \approx 2000$ pm-rad at $1.9 GeV$

$$\varepsilon_x \approx \sigma_x \sigma_\theta \propto \frac{E^2}{N_D^3}$$

$\varepsilon_x \sim 50$ pm-rad at $2.0 GeV$

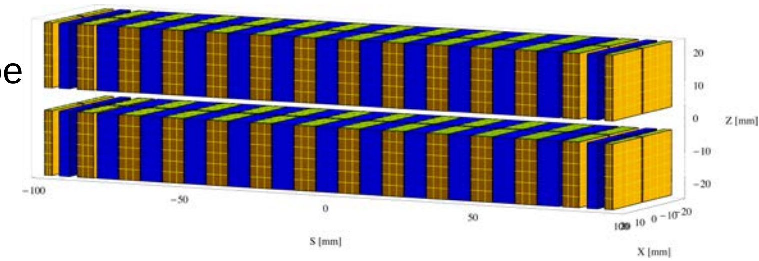
Large increase in coherent fraction due to lower emittance and smaller β-functions

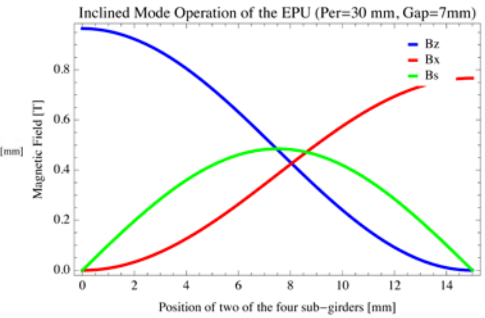
Insertion devices can have down to 4 mm diameter vacuum aprture

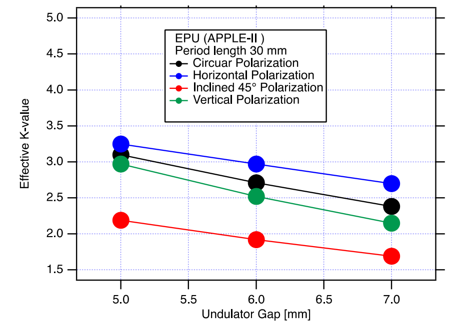
Parameter studies for the ALS-U, examples

Radia is used for magnet calculations [O. Chubar, P. Elleaume and J. Chavanne,. Journal of Synchrotron Radiation, 5:481-484, 1998.]

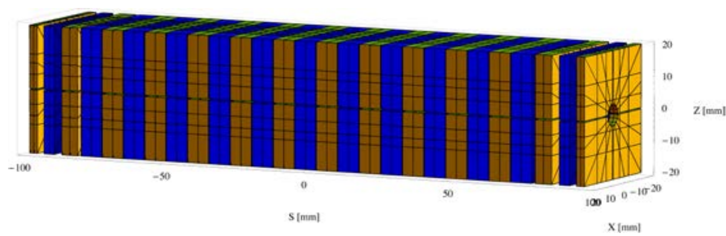
EPU of type APPLE-II

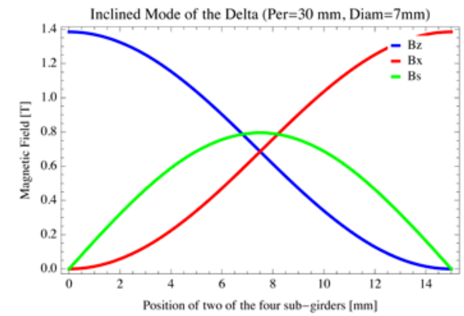


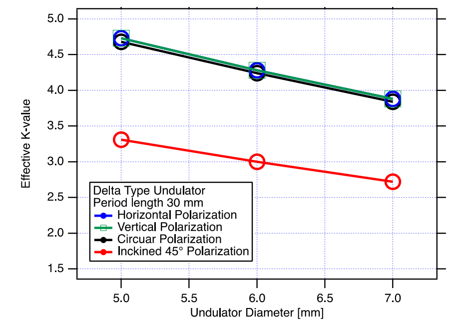




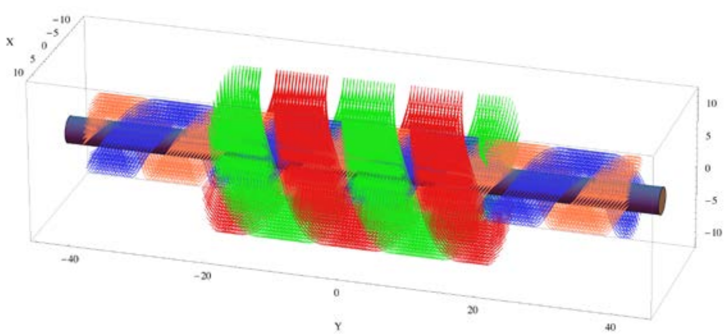
Delta type undulator



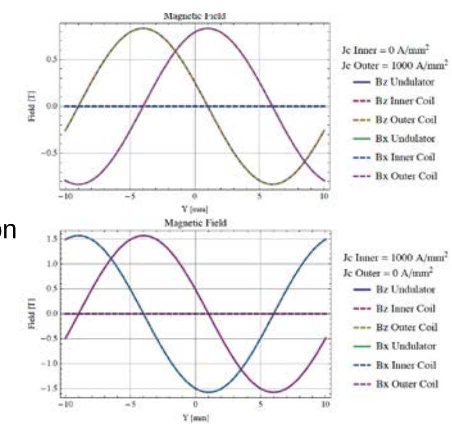




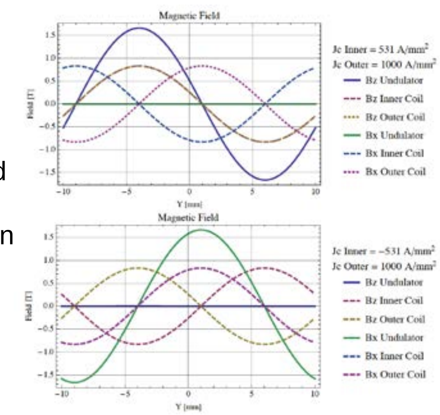
Superconducting double helical undulator



Circular right/left polarization

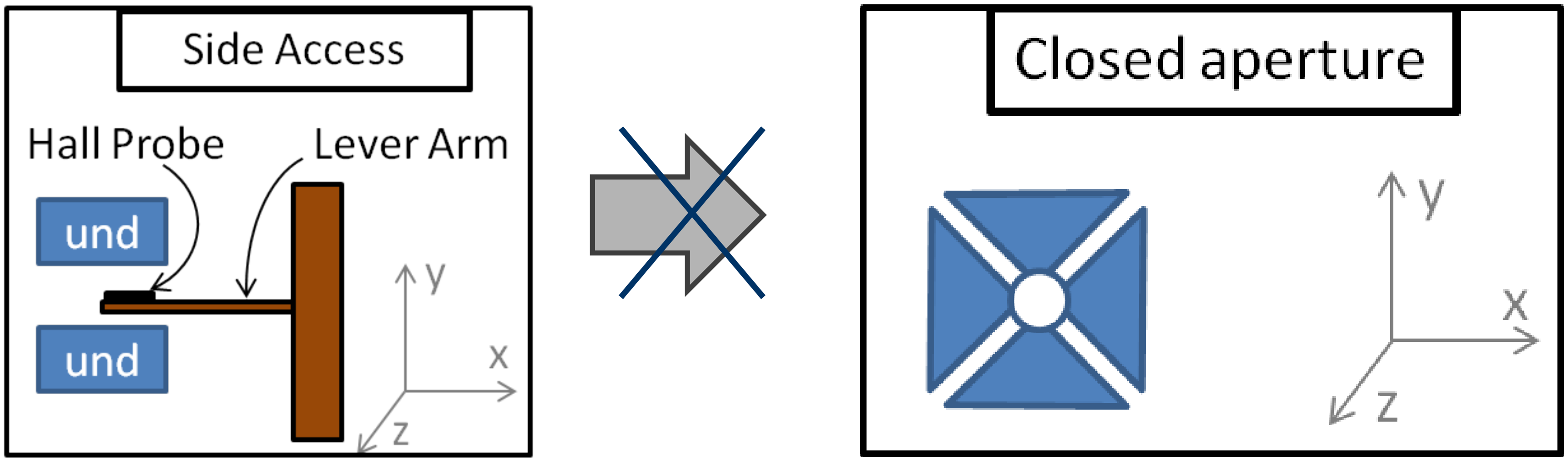


Planar and vertical polarization



BERKELEY LAB

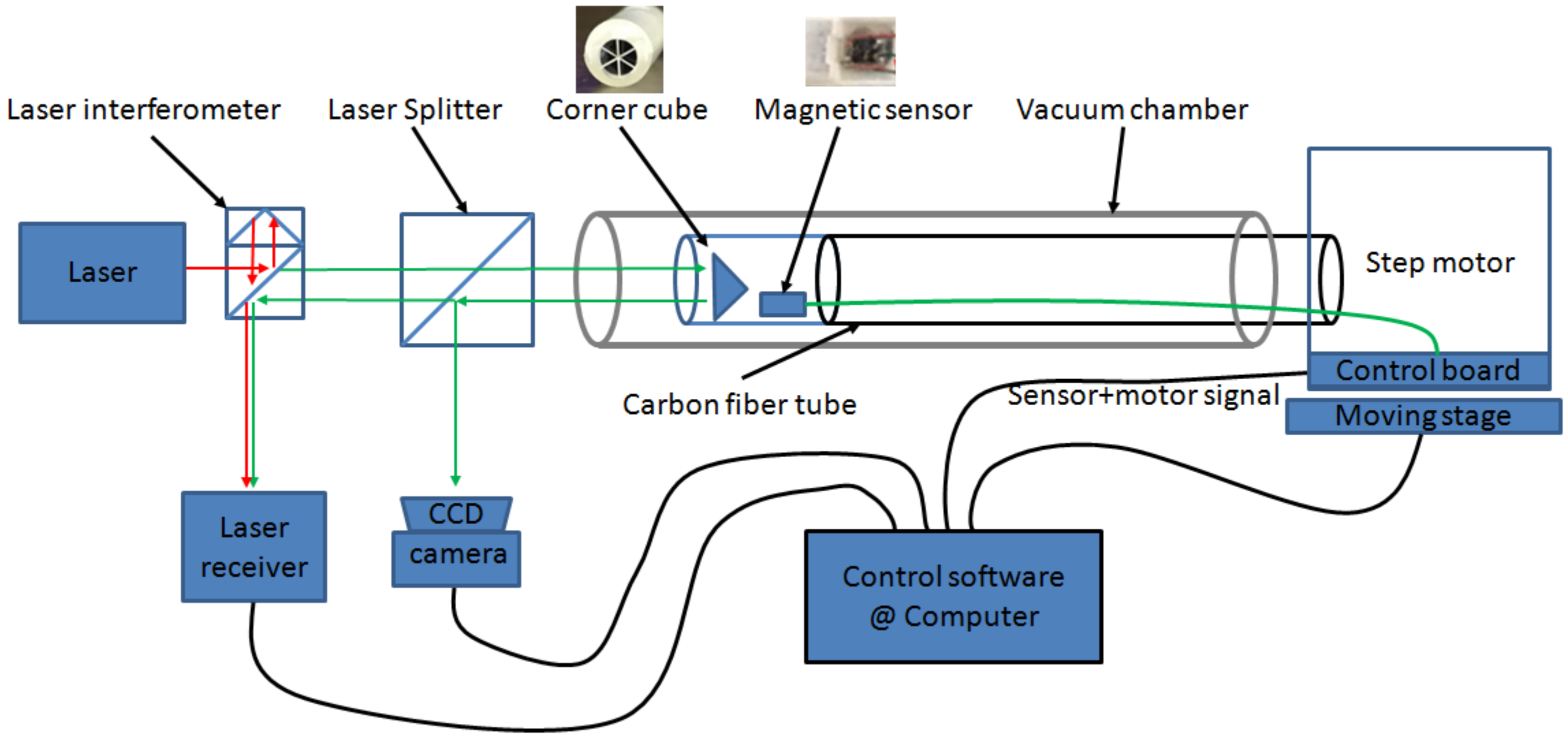
- Closed aperture insertion devices in the ALS-U and FELs
  - ~5 mm diameter vacuum chamber
  - Delta, Delta-X, and Superconducting bifilar helical undulators



- Need for field mapping in closed aperture undulators
  - LDRD funding for small bore measurement project obtained
  - First prototype is completed

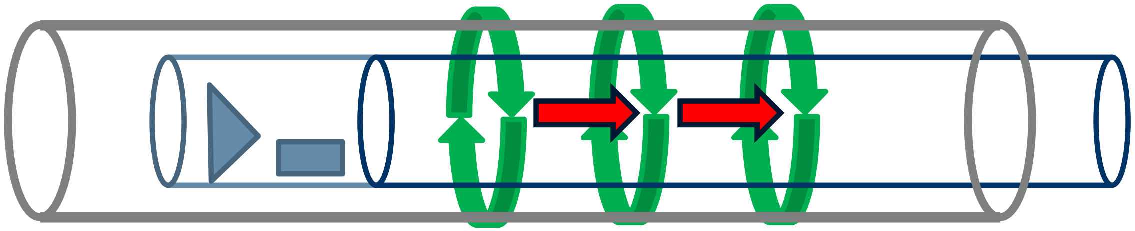
- Concept for the closed aperture measurement system

  - Develop a novel ultra-compact magnetic field mapping sensor
  - 3D position measurement with laser interferometry and CCD camera
  - Rotation motion in transverse plane and longitudinal transportation
  - Allowing simultaneous position and magnetic measurement

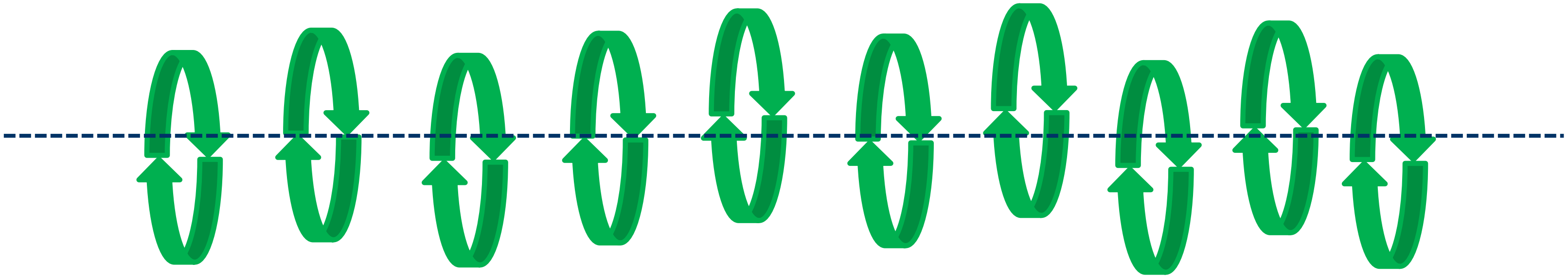


Measurement concept

Measure the radial field on circles with radial hall probe
The position of the circle given by laser system
The complete field inside the circle is known



The circles will not be on a straight line since tube is not straight



The field on the undulator axis is calculated from the circles

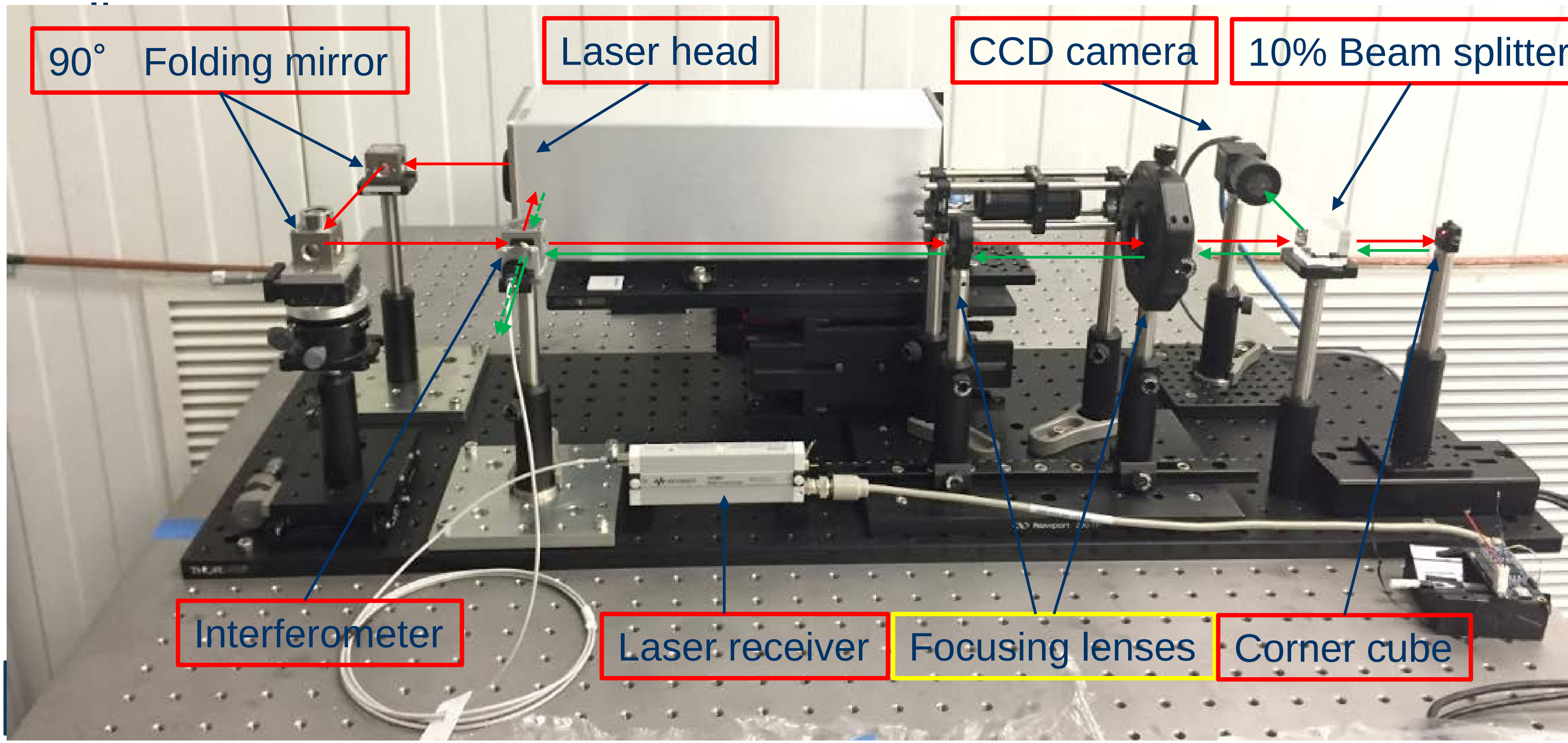
BERKELEY LAB

System setup

Laser system

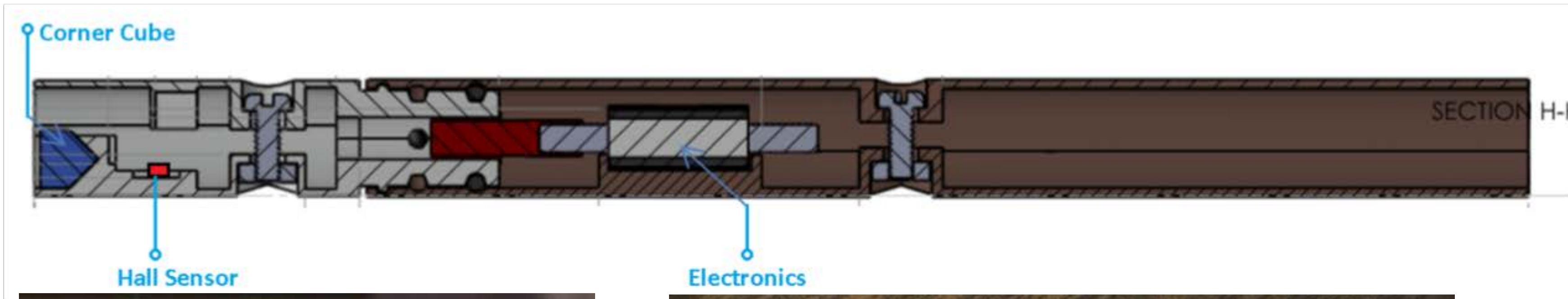
- Laser system set up

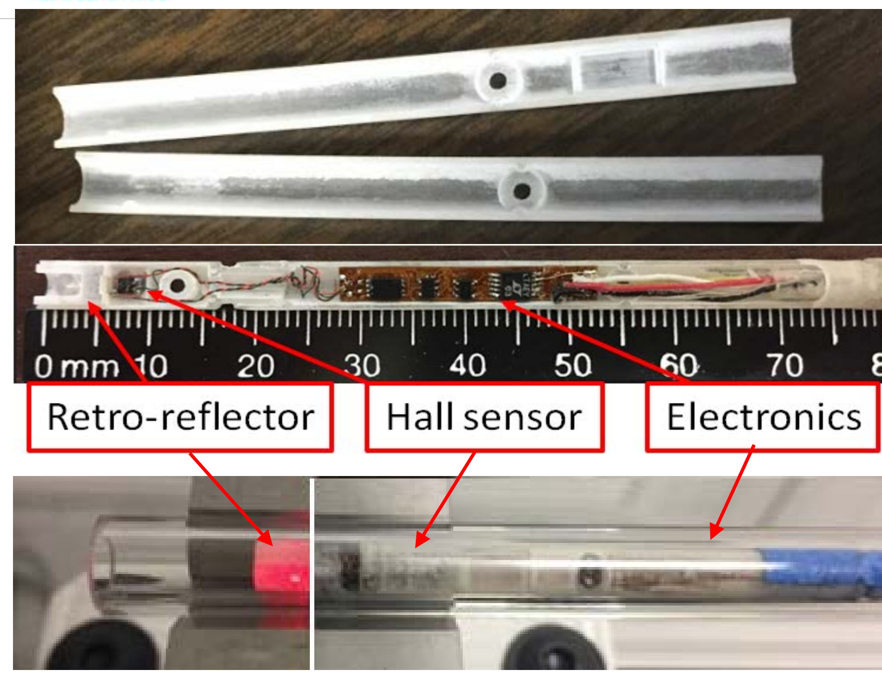
- Put all parts on a single plate -> compact & easy to align



Compact sensor package

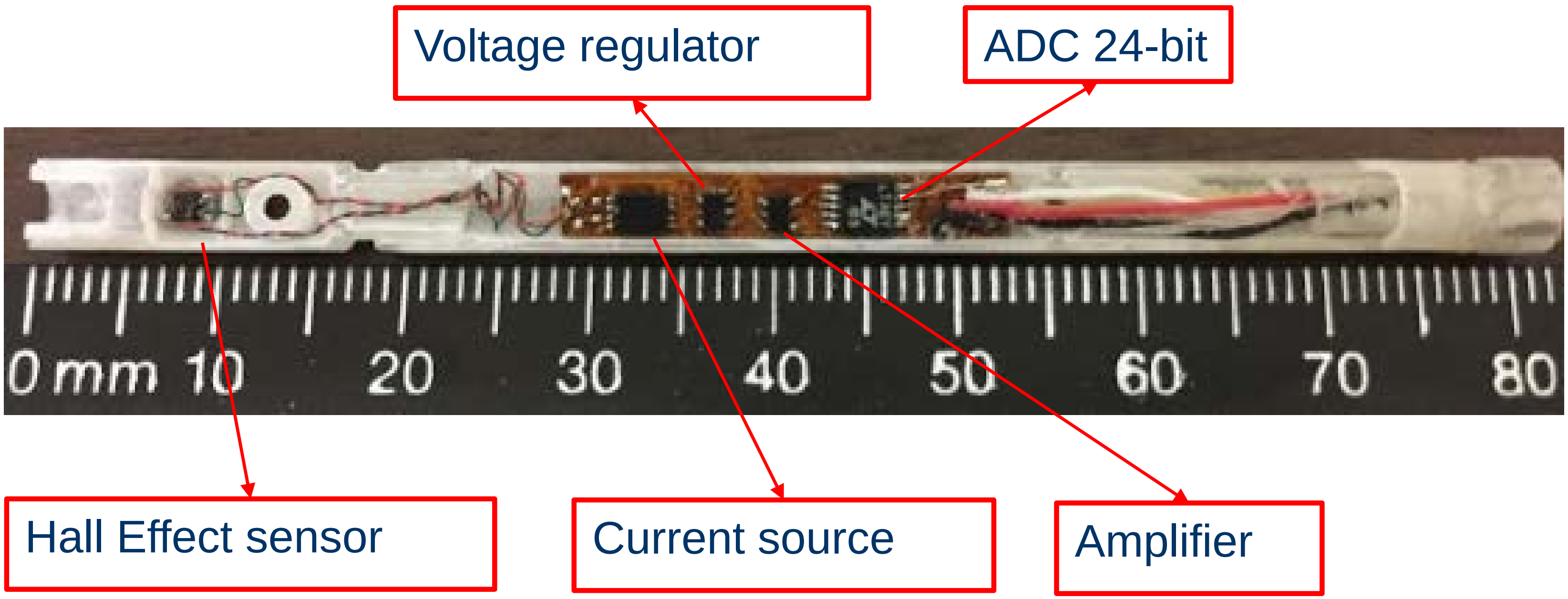
- 3D printing parts & electronics





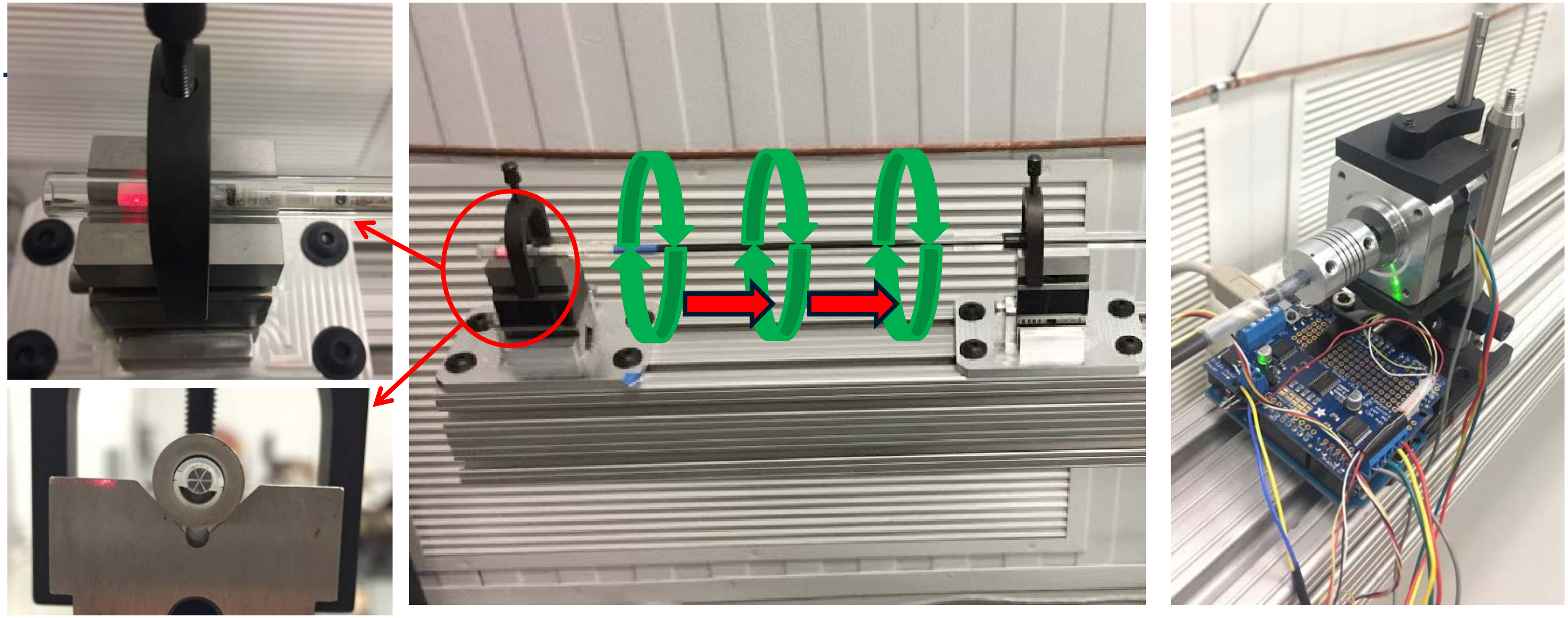
Compact sensor package

- 3D printing parts & electronics
  - Current source, Voltage regulator, Amplifier and ADC
  - High density interconnect flexible circuit



Transport system

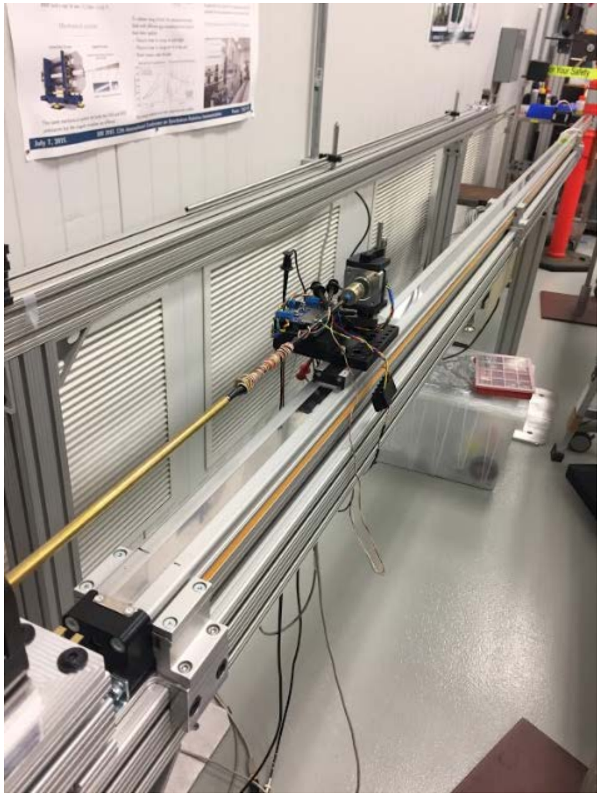
- Rotation motion by stepping motor gives Movement on a circle in transverse plane

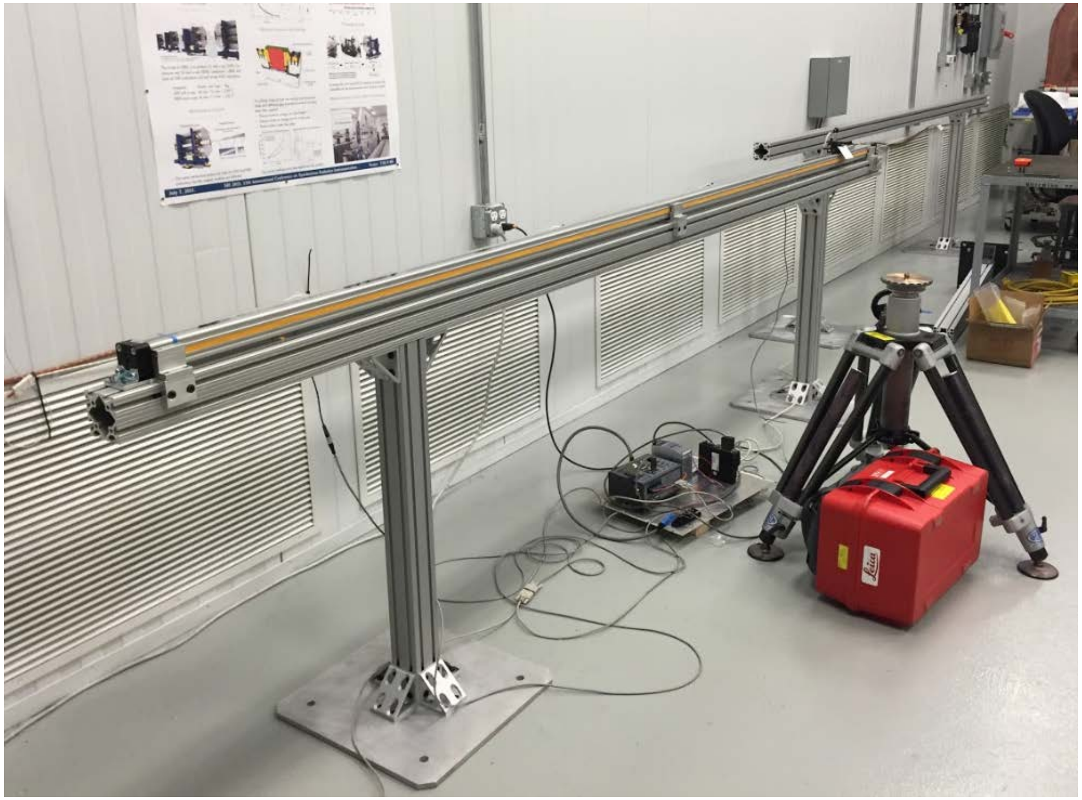


Transport system

- Longitudinal movement by linear drive

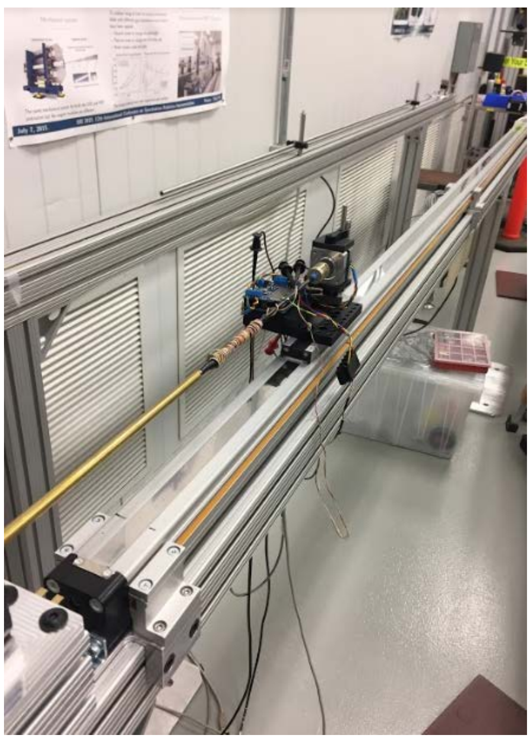
- Max. 3m movement along longitudinal direction

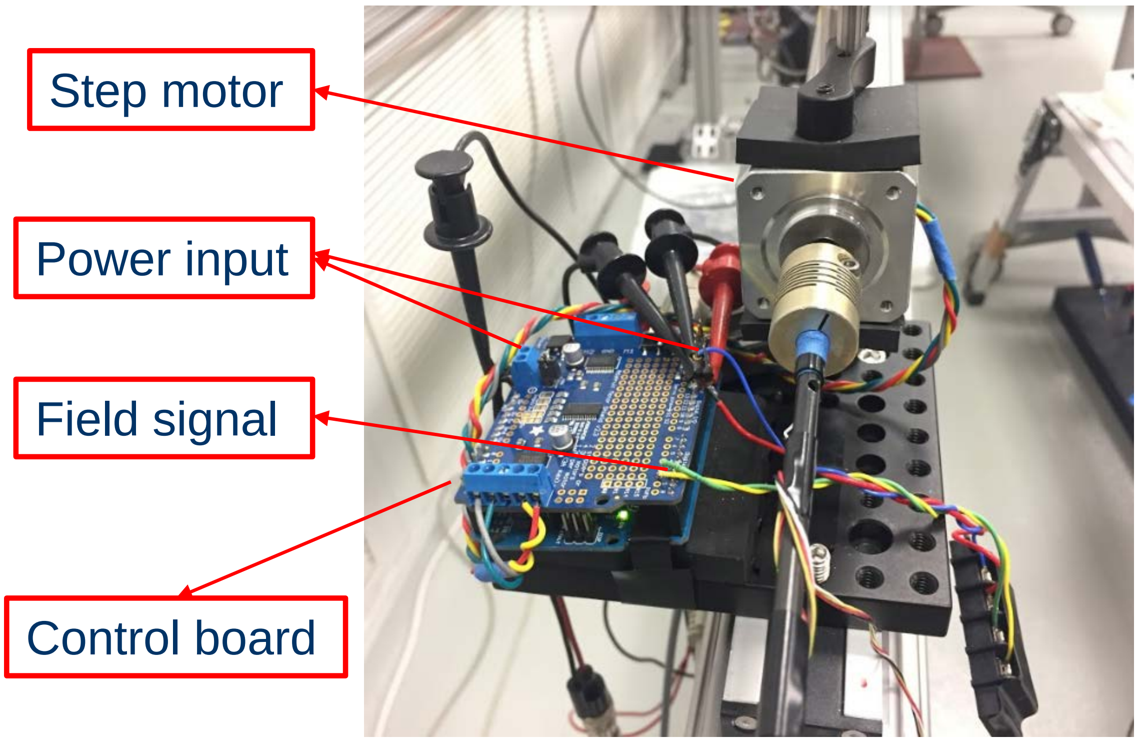




Moving stage

- Control board and step motor

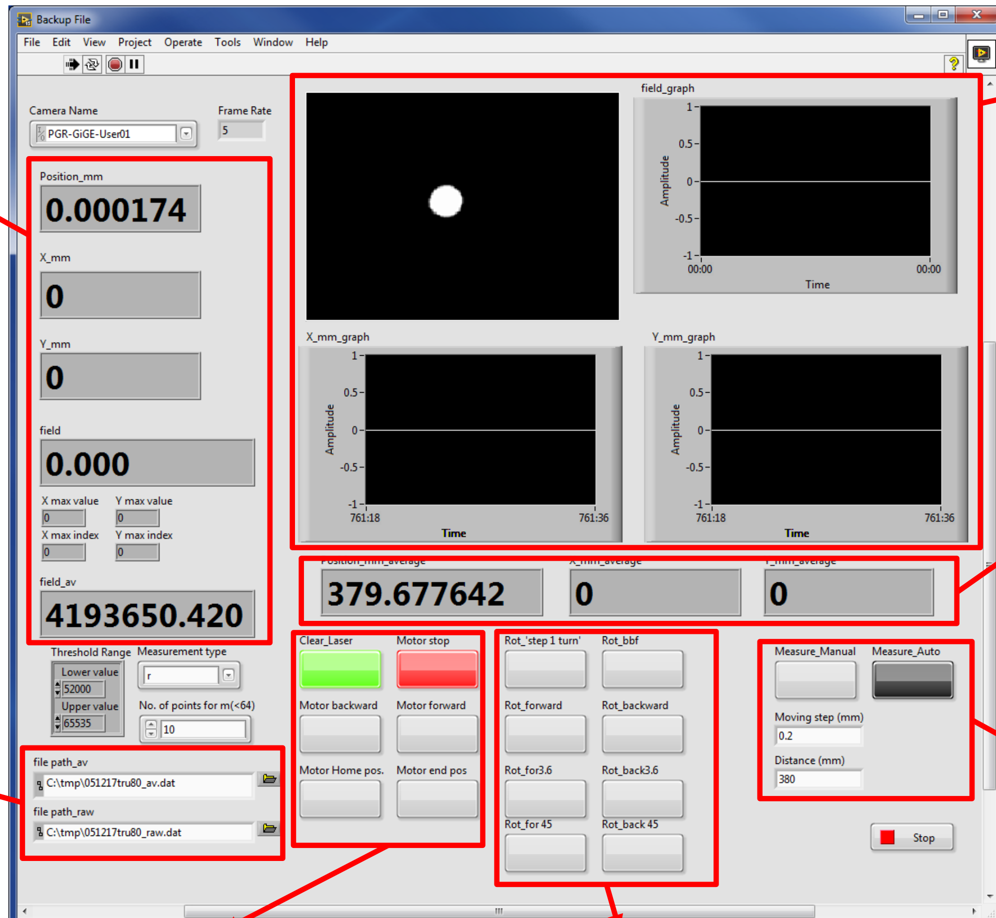




Control software

- Control software made with Labview

Real time data
Laser position
& field



Laser position data
& field data graph

Averaged data
Laser position

Data logging
file paths

Measurement
control

Longitudinal motion control

Transverse rotation control

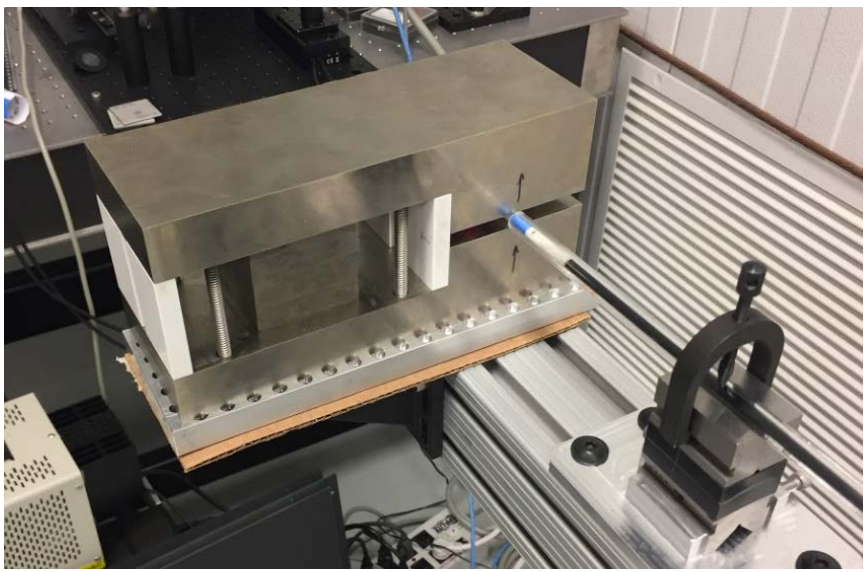
BERKELEY LAB

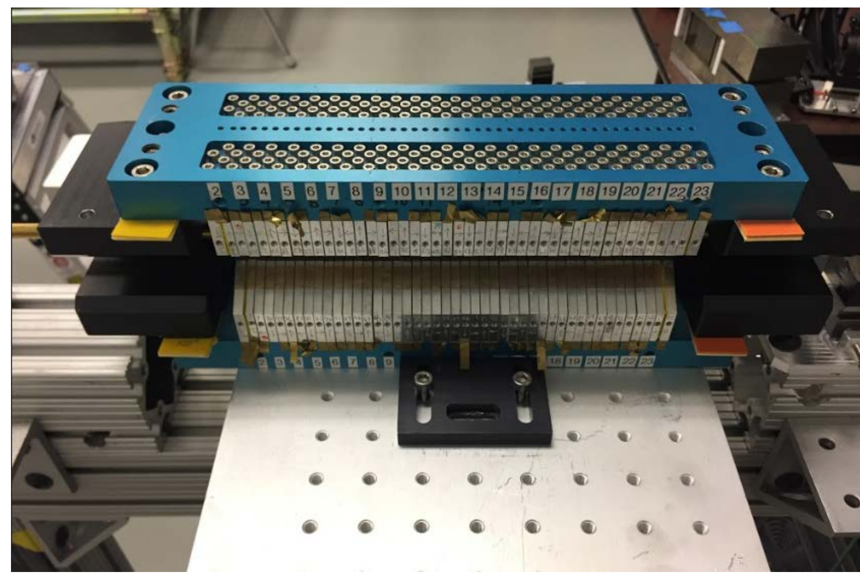
Test measurement

Magnets for test

- Reference dipole magnet
  - Max. 0.2425 T @ gap center
  - For the sensor calibration
  - Noise level test

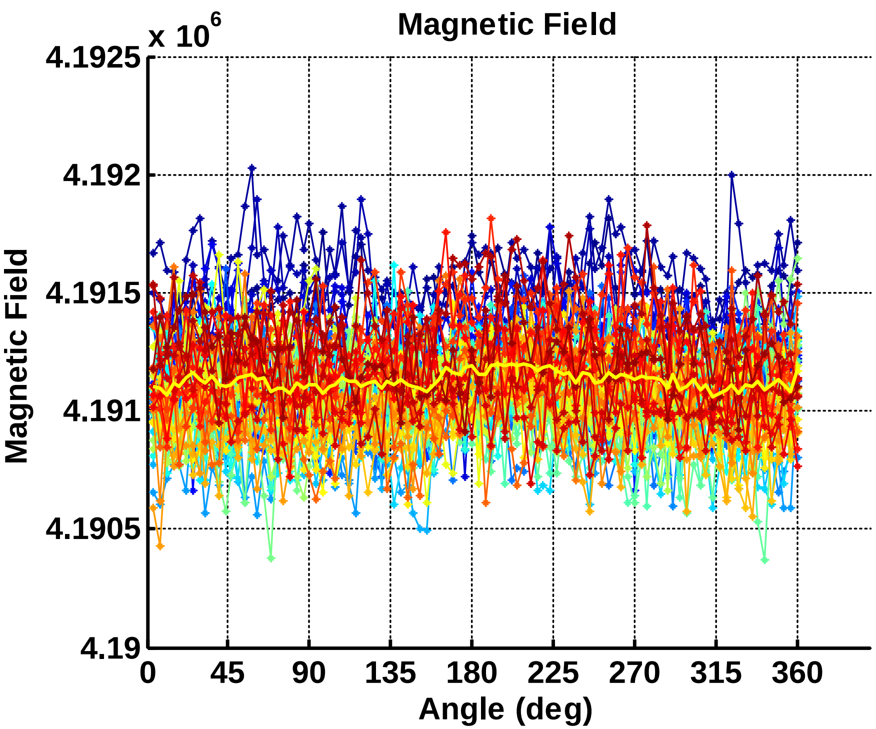
- 10 periods undulator
  - Max. 0.3958 T peak @ gap center
  - Measurement test

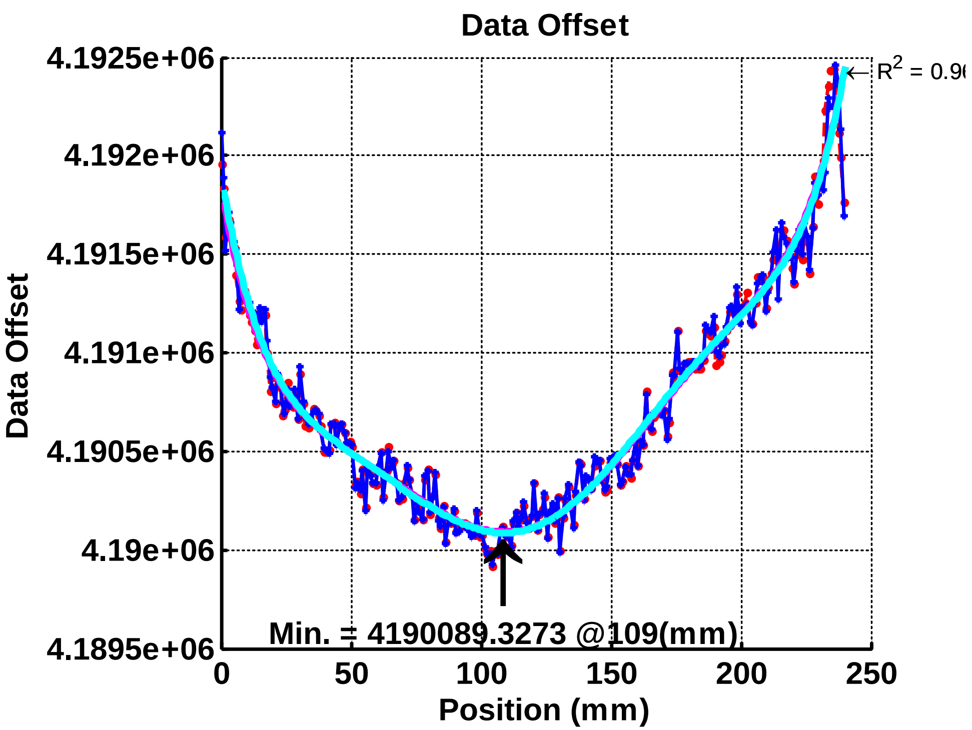




Offset measurement in Zero Gauss Chamber

- Rotation measurement @ Z=120 mm in zero gauss cham
- Rotation measurement along z-axis in a zero gauss chamber

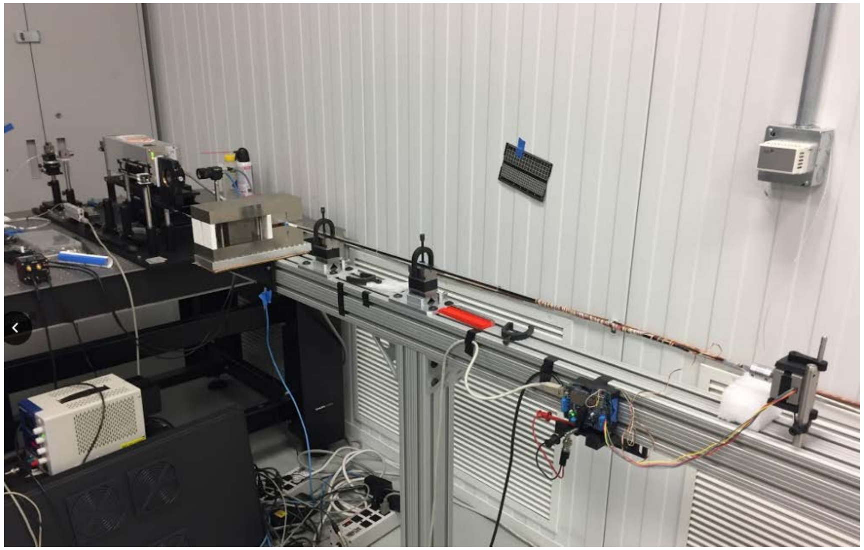


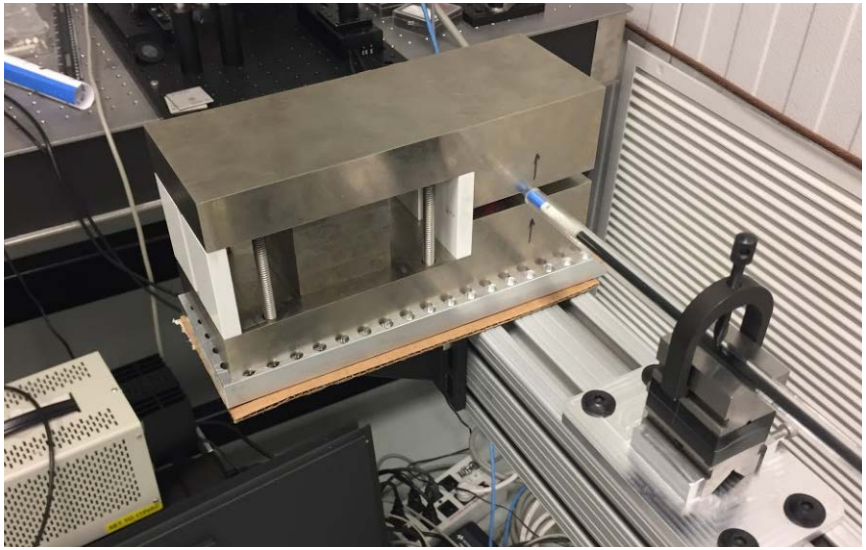


Sensor Calibration

- Reference dipole magnet max. 0.2425 T
- Rotate sensor on central position of the magnet gap
- 200 point / turn (1.8 deg step), 100 turns averaged

– Using Linear polynomial curve fitting and extrapolation

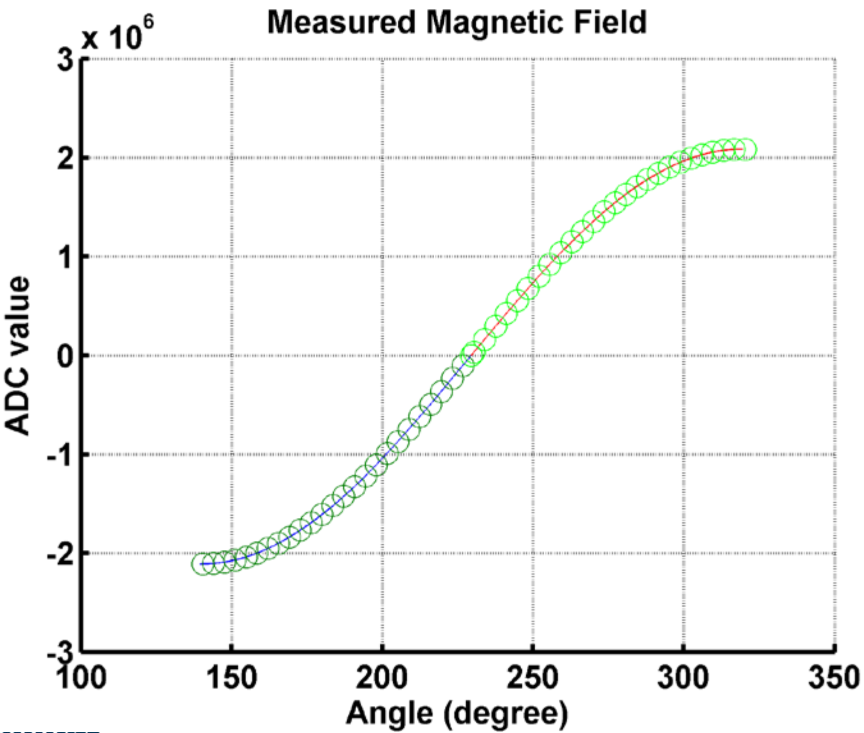


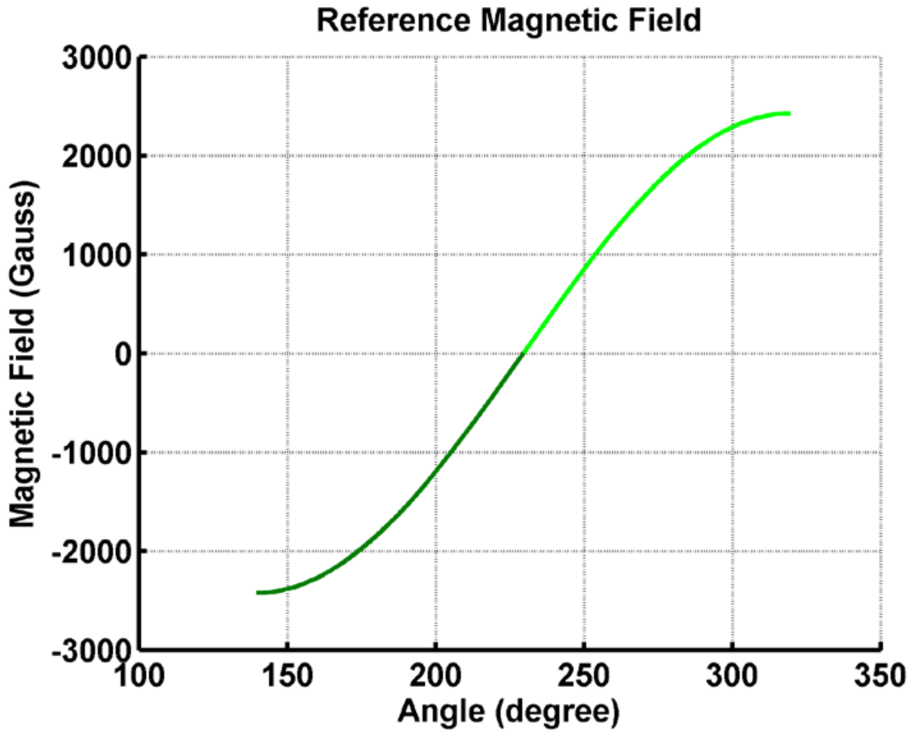


BERKELEY LAB

Sensor Calibration

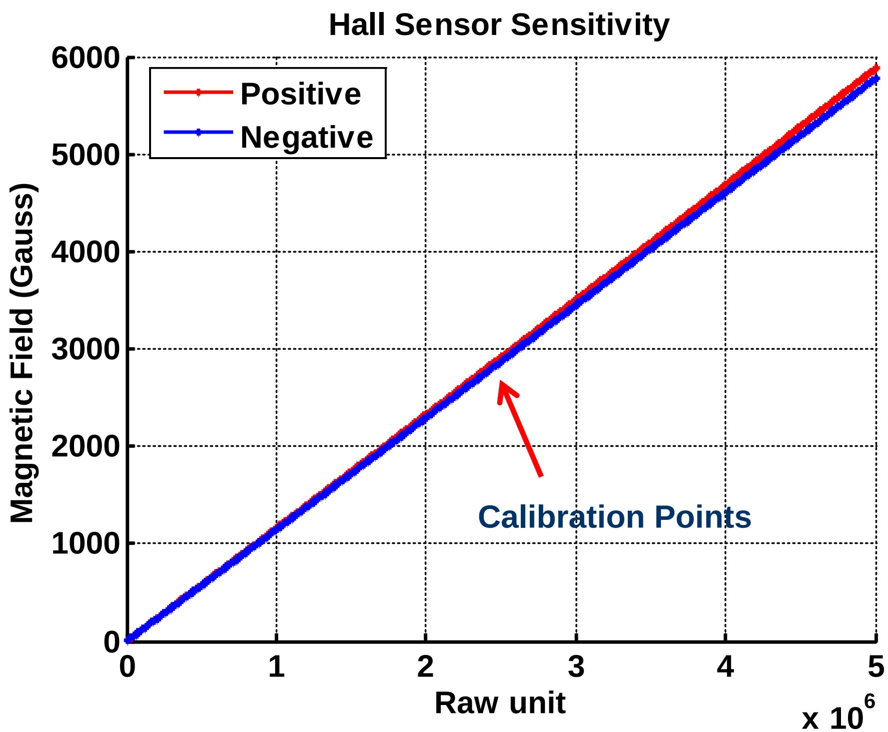
- Linear fitting with reference curve
  - Reference field : 0.2425 T peak sine curve
  - Set different sensitivity for negative and positive field





Sensor Calibration

- Measured field sensitivity
  – Extrapolated after 0.2425 T for converting a stronger magnetic field

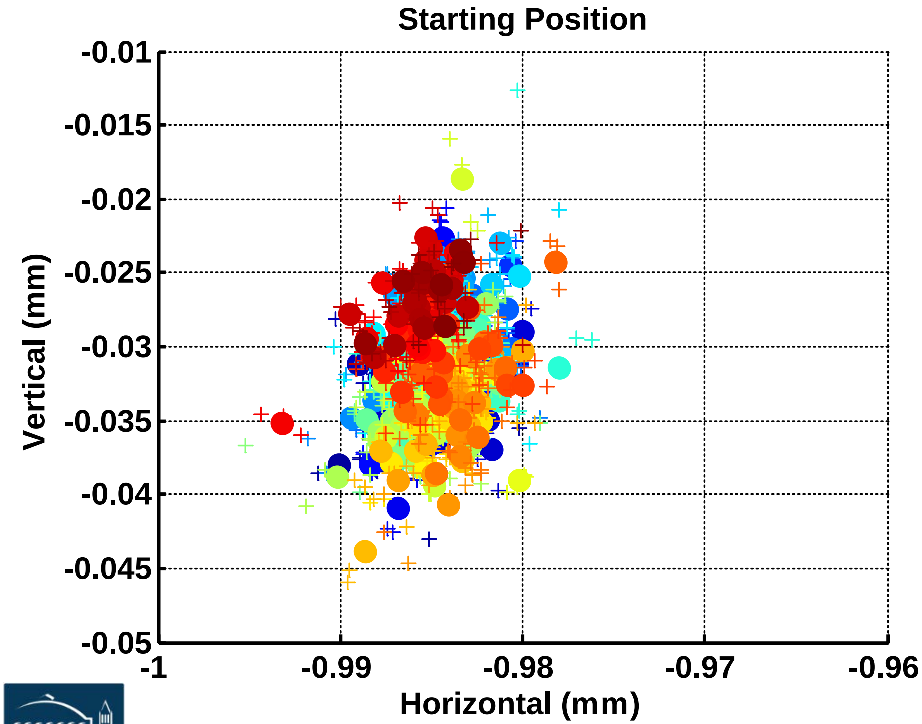


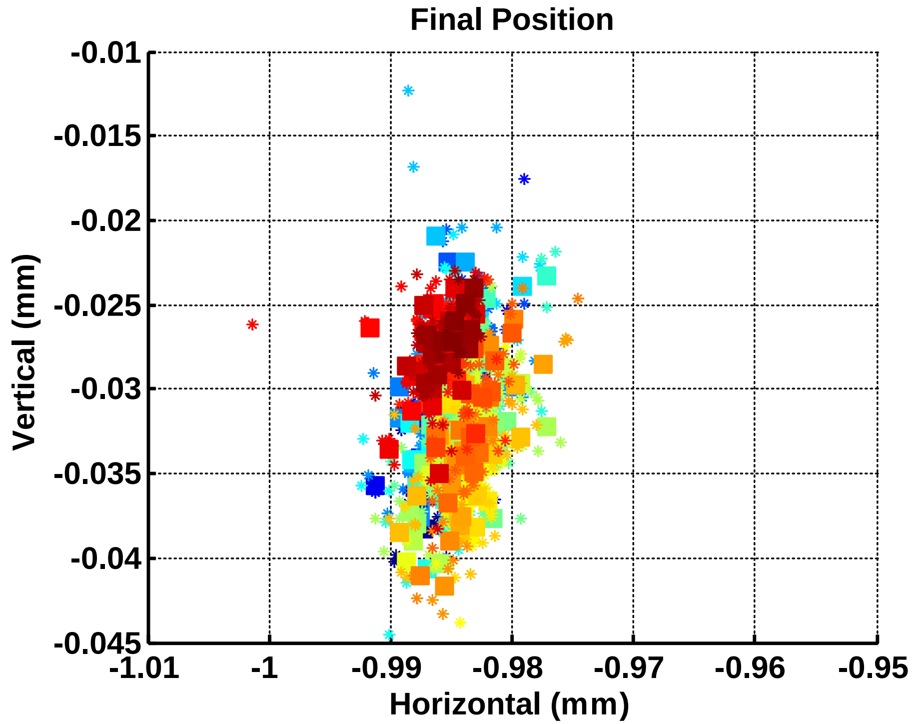
●電気的特性(測定温度 25℃) Electrical Characteristics(Ta=25℃)

項目 Item	記号 Symbol	測定条件 Conditions	最小 Min.	標準 Typ.	最大 Max.	単位 Unit
ホール出力電圧 Output Hall Voltage	V_H ※	B=50mT, Vc=6V	55		75	mV
入力抵抗 Input Resistance	Rin	B=0mT, Ic=0.1mA	650		850	Ω
出力抵抗 Output Resistance	Rout	B=0mT, Ic=0.1mA	650		850	Ω
不平衡電圧 Offset Voltage	Vos(Vu)	B=0mT, Vc=6V	−11		+11	mV
出力電圧の温度係数 Temp. Coefficient of V_H	αV_H ※	B=50mT, Ic=5mA Ta=25~125℃			−0.06	%/℃
入力抵抗の温度係数 Temp. Coefficient of Rin	αRin ※	B=0mT, Ic=0.1mA Ta=25~125℃			0.3	%/℃
ホール電圧直線性 Linearity	ΔK ※	B=0.1/0.5T, Ic=5mA			2	%

Rotation motion test

- Track the starting and final position of laser spot
  - Compare start position and final position
  - All measured positions stay in ±15 μm range

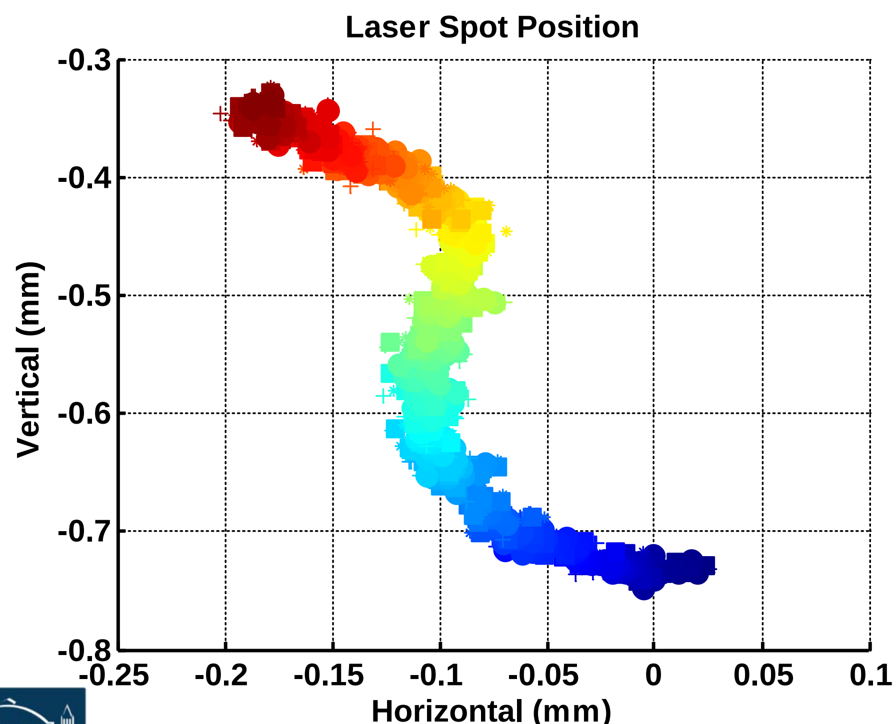


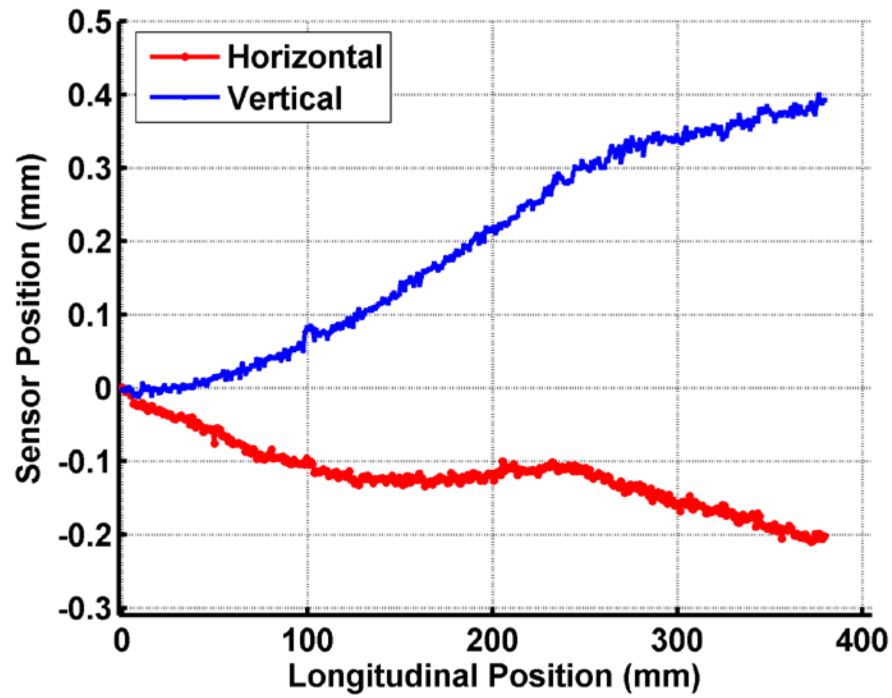


BERKELEY LAB

Longitudinal motion test

- Track the laser spot along longitudinal position
  - Laser interferometry has submicron range resolution
  - 0 to 380 mm range measured for 10 periods undulator

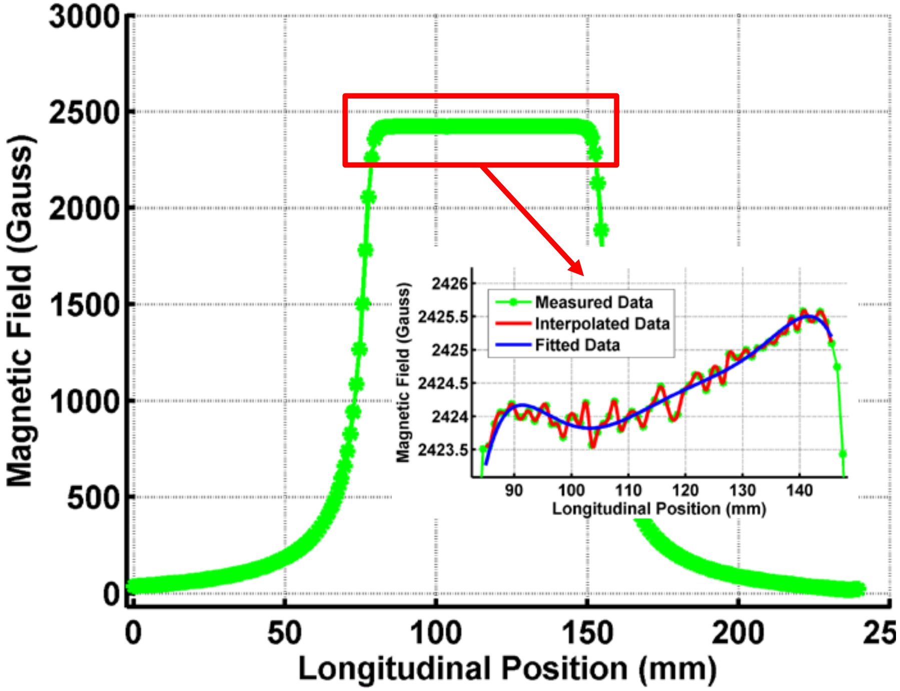


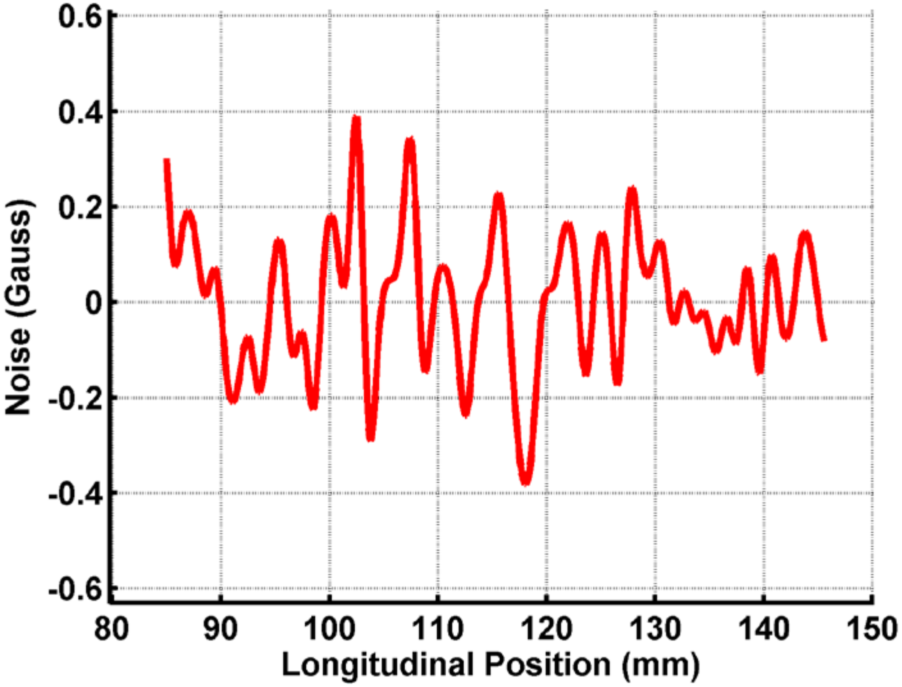


BERKELEY LAB

Magnetic field measurement

- Dipole magnet measurement result
  - Measurement result of the dipole magnet by scanning mode
  - Observed noise level of ±0.5 G at a peak field region

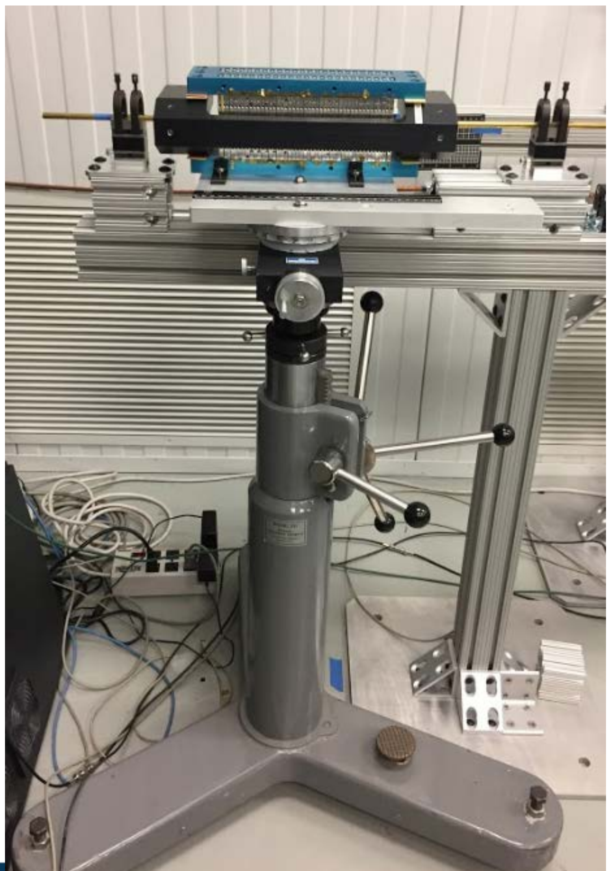




BERKELEY LAB

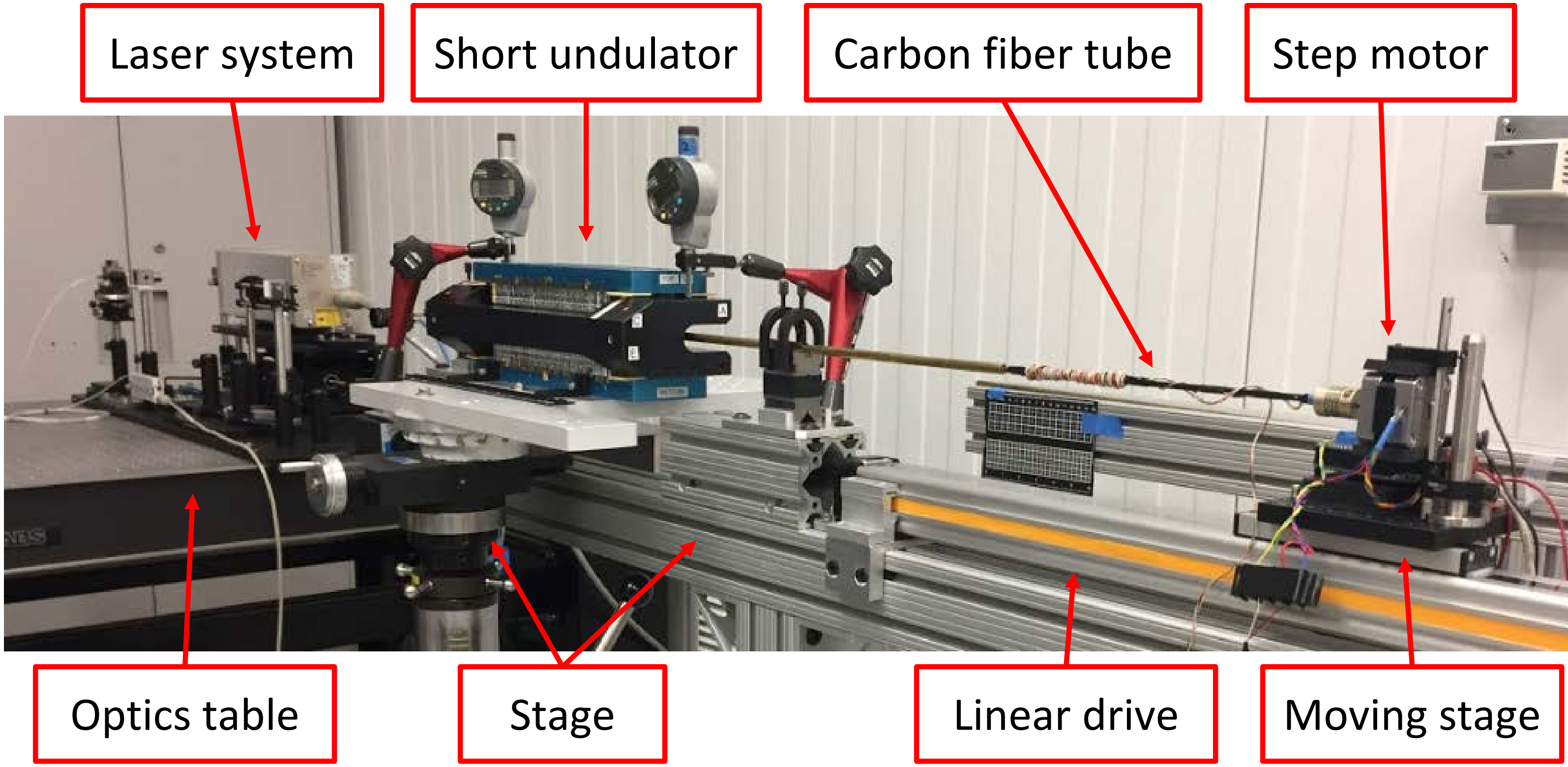
Magnetic field measurement

- Setup - short undulator



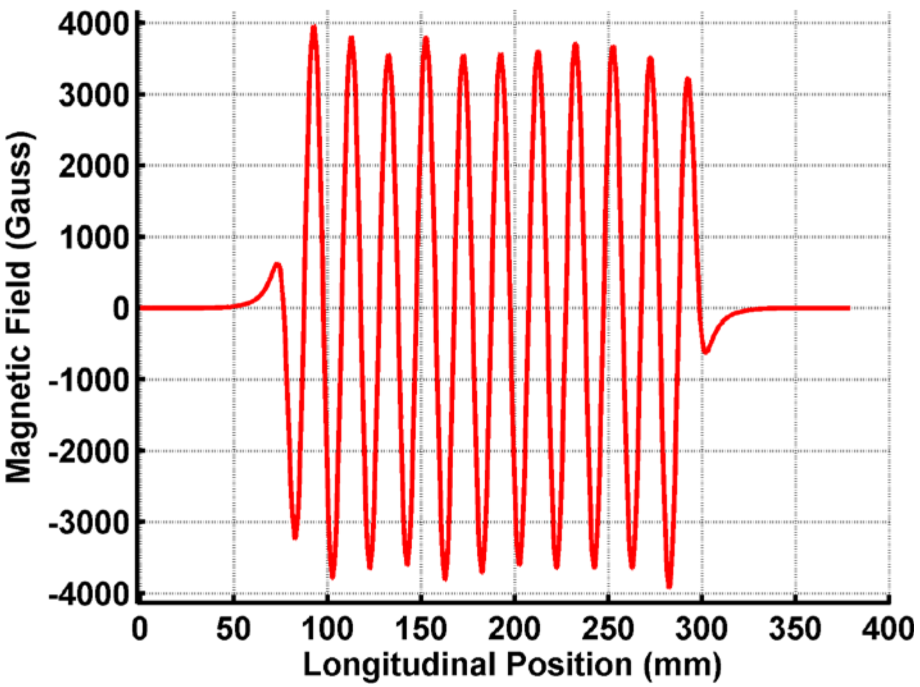
Magnetic field measurement

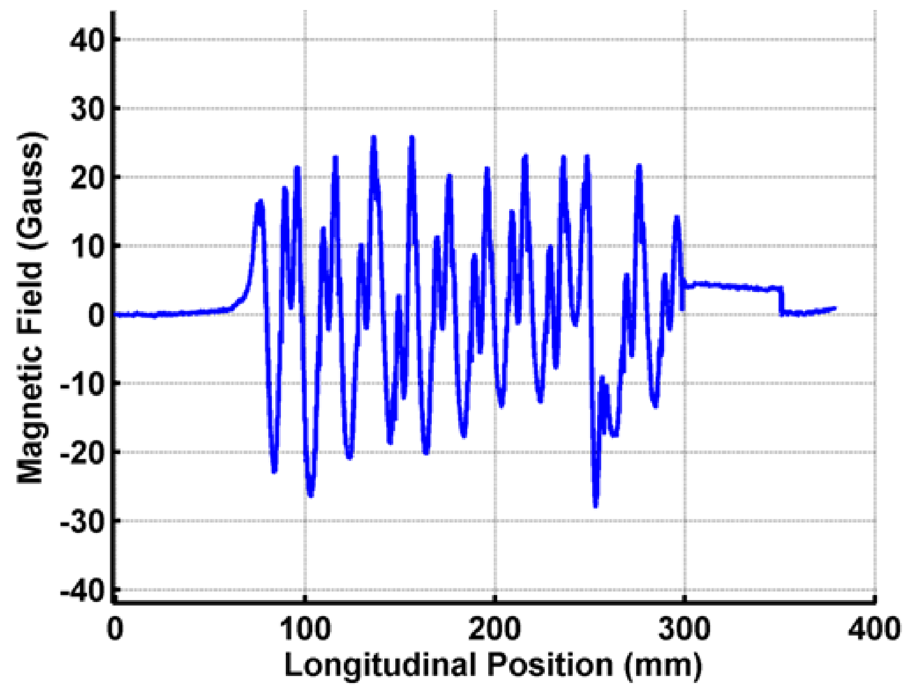
- Setup - short undulator, complete system



Magnetic field measurement

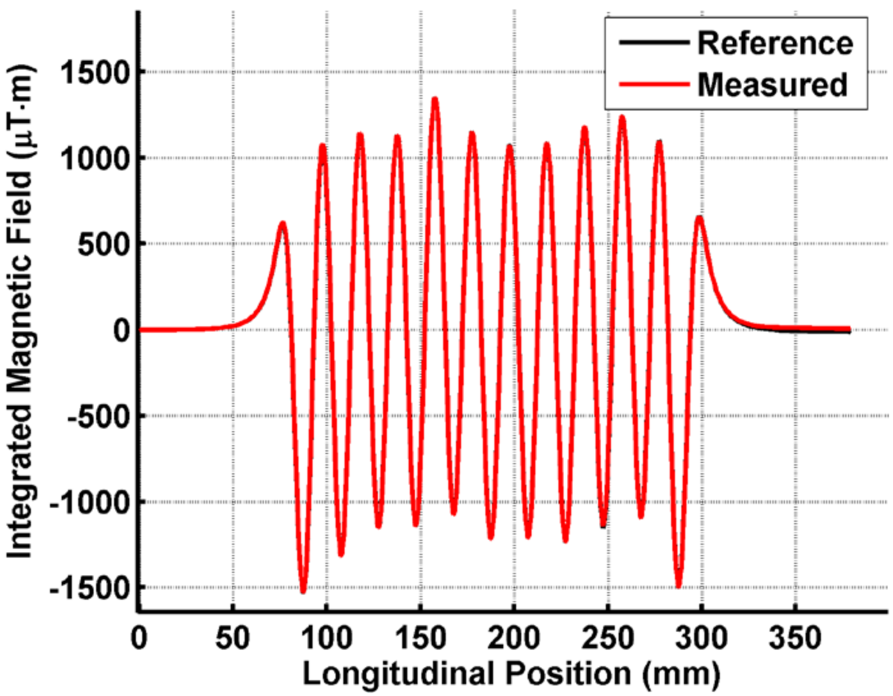
- Undulator measurement result
  - Measurement result by scanning mode
  - Compared with reference measurement data

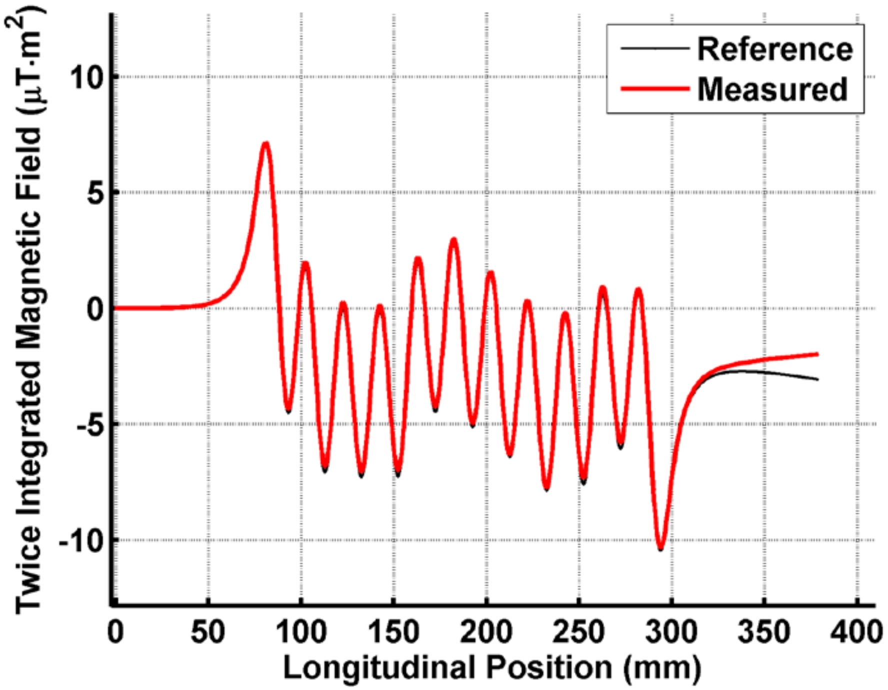




Magnetic field measurement

- Undulator measurement result
  - Integrated and twice integrated magnetic field





Summary

- A prototype of a magnetic measurement technique for closed aperture undulators has been developed
- An ultra-compact magnetic field sensor package and a 3D position acquisition system using a laser were combined with a magnetic sensor transport system
- Test measurements with a 0.2425 T dipole magnet and a short 10-period undulator were carried out
- Further improvements of the Hall probe sensor and 3D positioning system will be carried out
- The concept with measuring on circles gave valuable experience but will not be used in next generation of the closed aperture measurement system
- The closed aperture measurement system is a critical component for future work with novel undulators and the work will be continued.

BERKELEY LAB

Open Postdoctoral Position

Lawrence Berkeley National Laboratory

- **Magnetic field measurements on accelerator magnets and undulators**
- **Development of measurement methods and instrumentation**
- **Hardware development of sensors and electronics**
- **Development of laser interferometer systems for 3D positioning**

If you are interested please contact Erik Wallén <ejwallen@lbl.gov>

Erik Wallén, Dr.
Lawrence Berkeley National Laboratory
1 Cyclotron Road Mail Stop 15R0217
Berkeley, CA 94720

E: ejwallen@lbl.gov
T1: +1-510-486-4970
T2: +1-510-486-6456
F: +1-510-495-2030