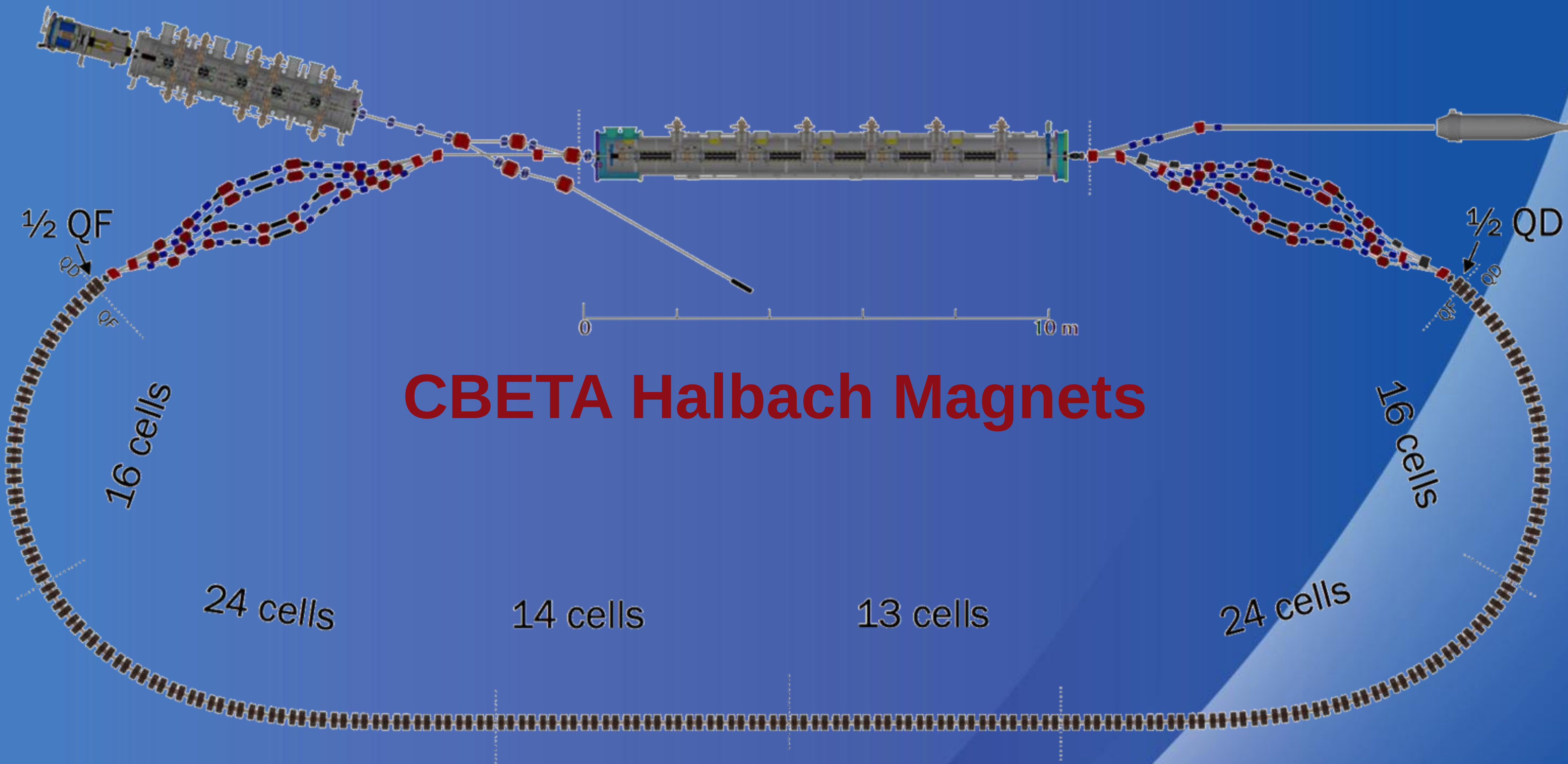
CBETA Halbach Magnets

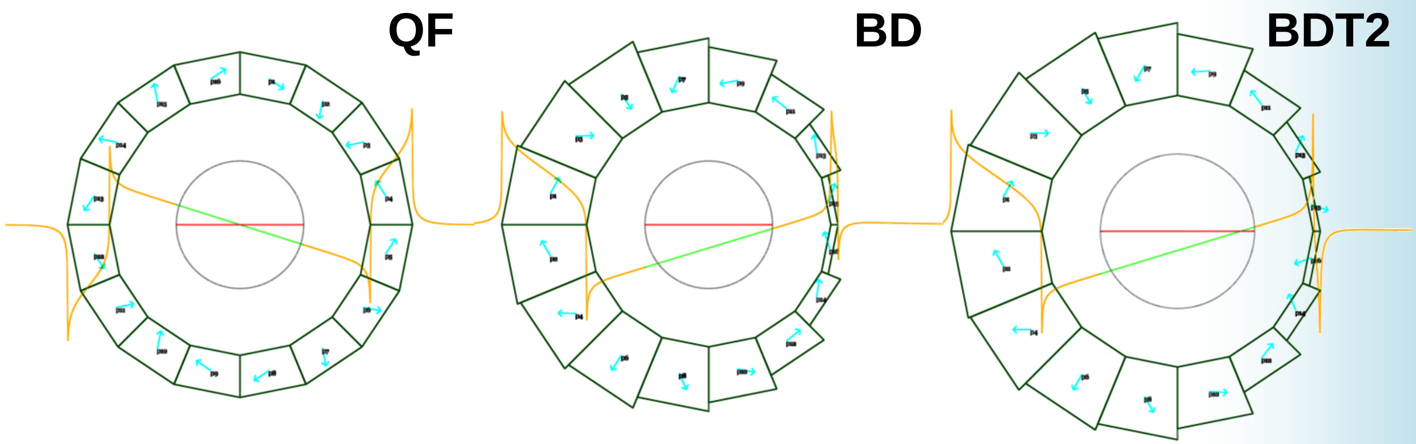


Stephen Brooks

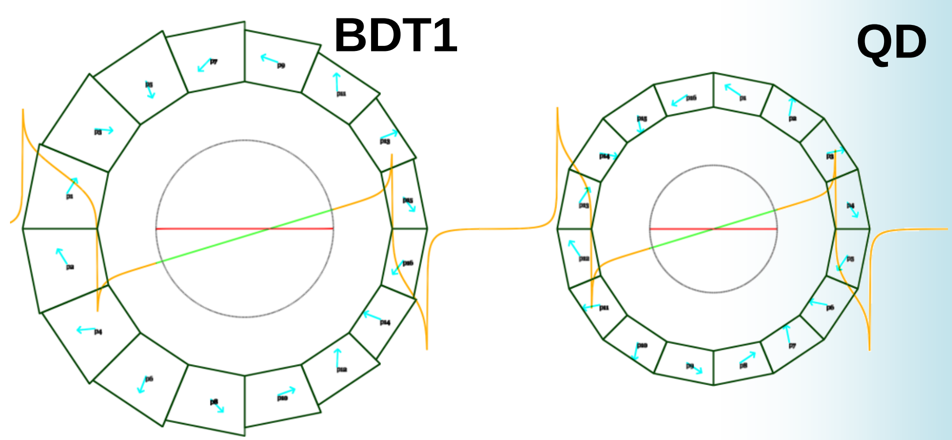
BROOKHAVEN NATIONAL LABORATORY
a passion for discovery
Office of Science
U.S. DEPARTMENT OF ENERGY

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Magnet Types (5 cross-sections)



Magnet	Length (mm)	Aperture Radius (mm)	Dipole (T)	Gradient (T/m)
QF	133	43.1	0	-11.562
BD	122	40.1	-0.3081	11.148
BDT2	122	44.9	-0.2543	11.148
BDT1	122	49.1	-0.1002	11.148
QD	122	40.1	0	11.143
QFH	66.5	43.1	0	-11.567
BDH	61	40.1	-0.3084	11.154
First Girder QF	133.3	39.4	0	-11.562
First Girder BD	121.7	39.4	-0.3081	11.148

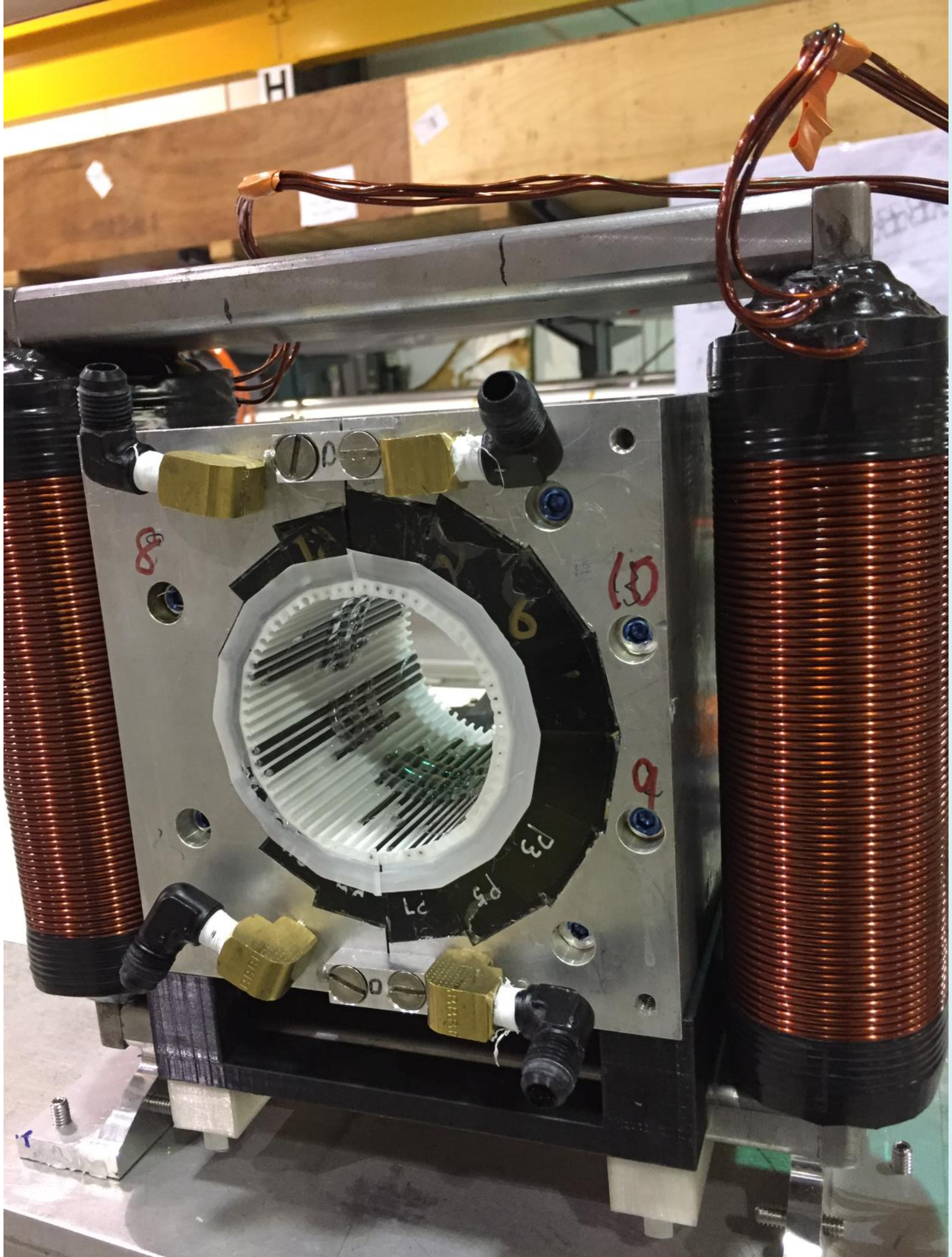


Figures of Merit

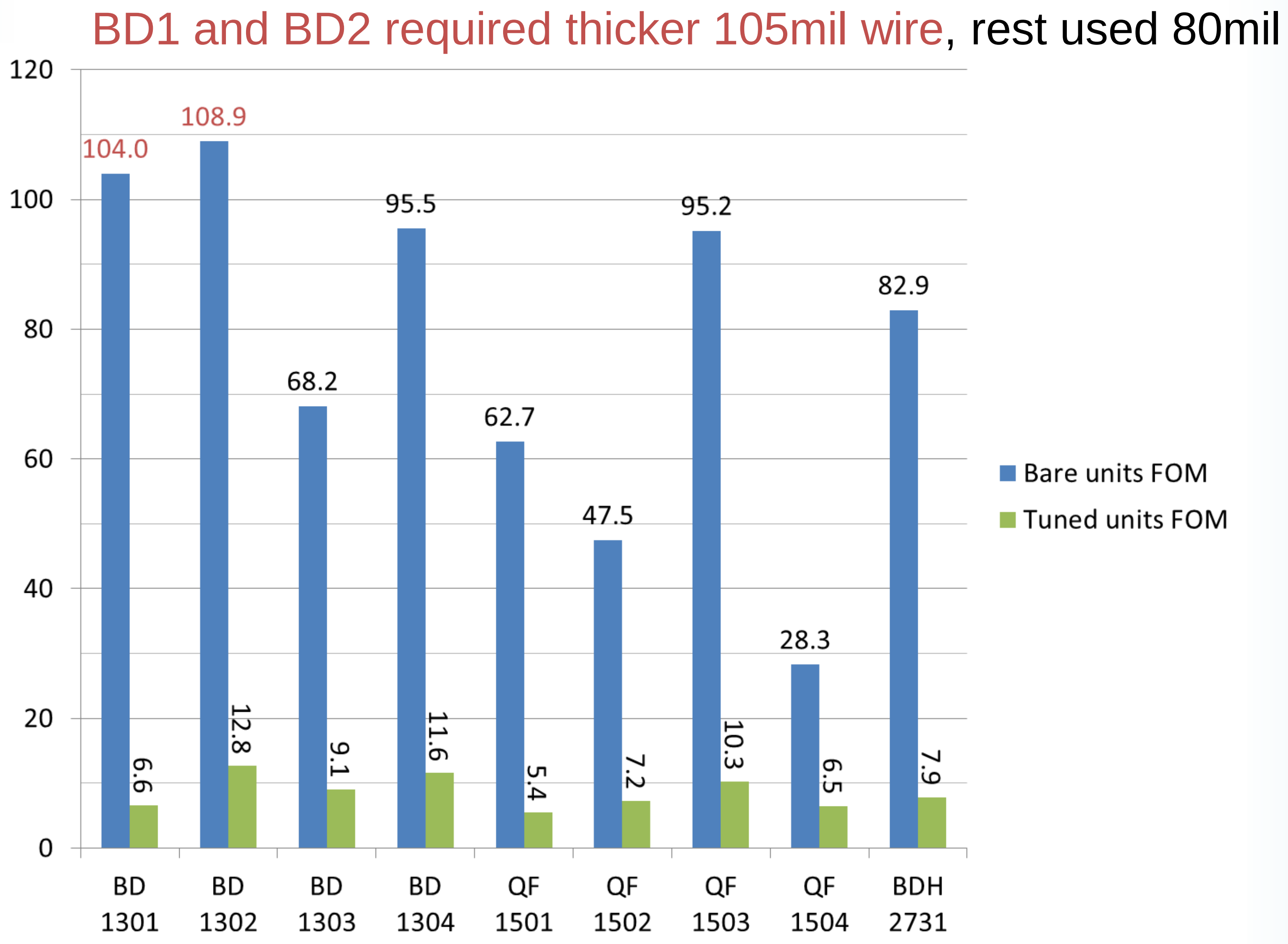
- Units FOM = sqrt(sum squares (all nonlinear multipoles at max beam radius)), 1 unit=10^{-4}
- CBETA FOM = the above with different multipoles scaled per William Lou's simulation
  - 0.75 is acceptable with misalignments but perfect BPMs, so we aim substantially lower than this
- Max field error (in Gauss) on beam midplane
  - Not on a circle, so can have different emphasis
  - 10^{-3} of max quad component is 2.8 Gauss

A Real BD Magnet including Tuning Wires

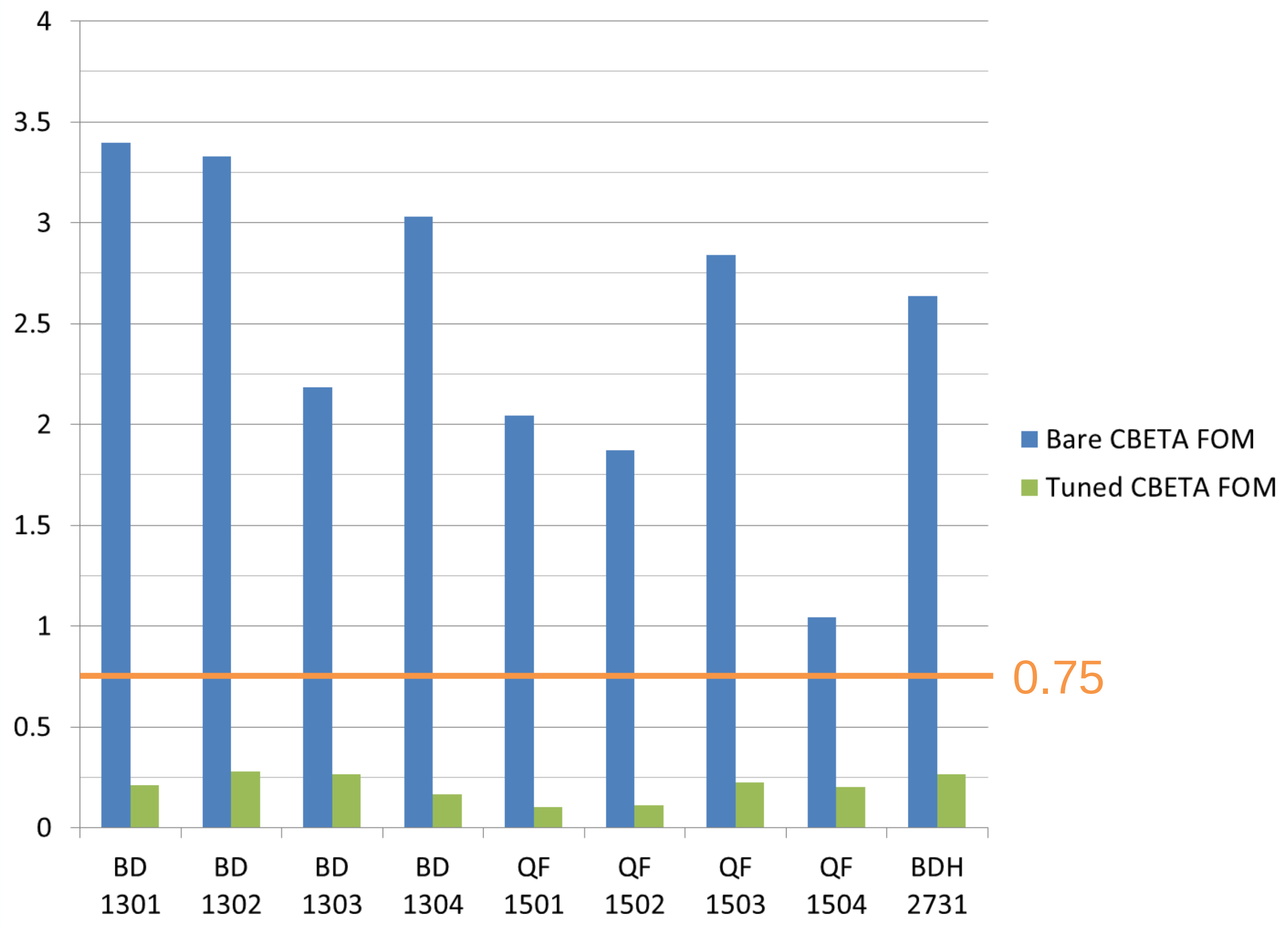
The CBETA "First Girder" consists of 4 BD magnets, 4 QF magnets and one BDH magnet



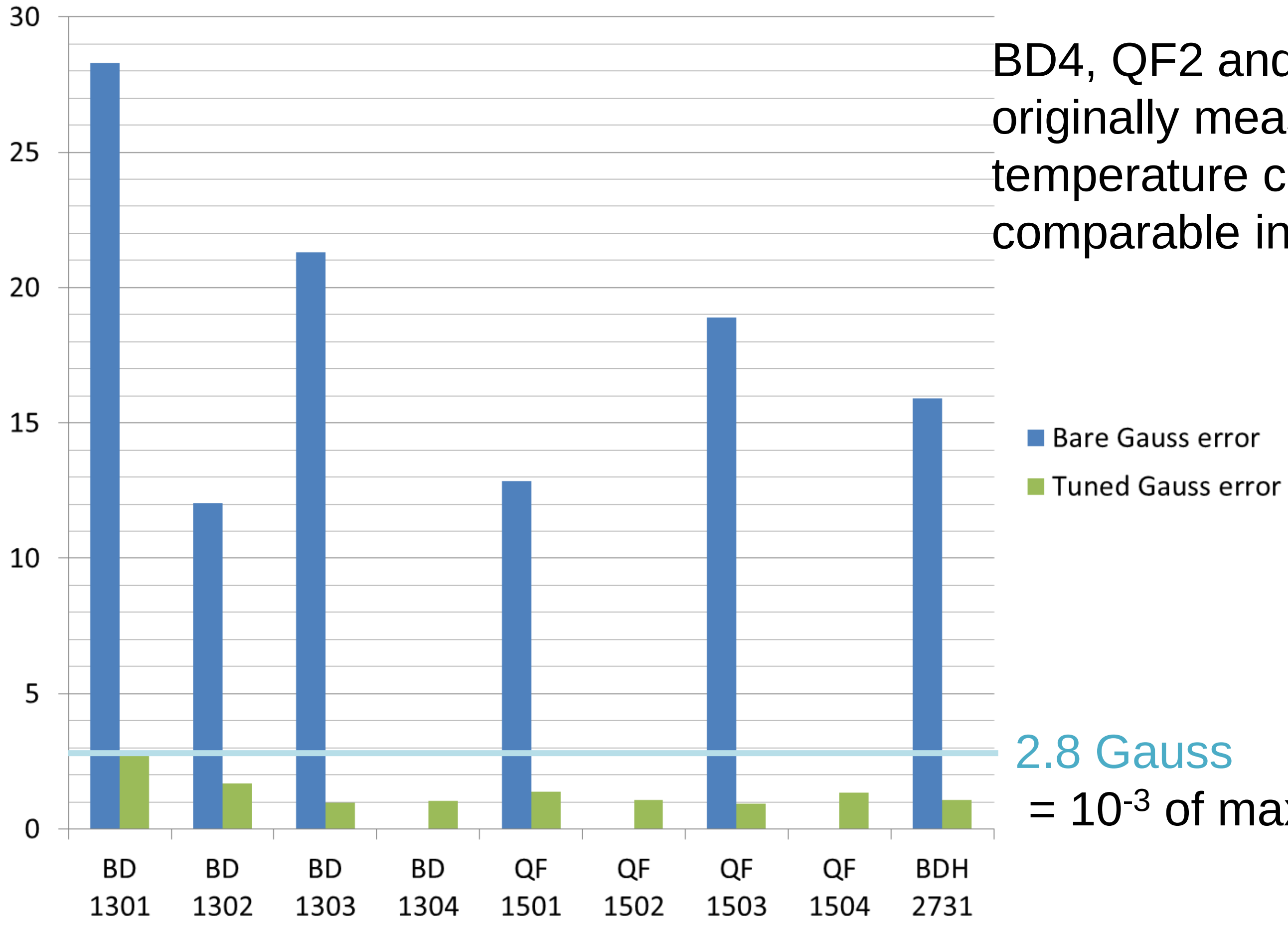
First Girder Results



First Girder Results



First Girder Results



BD4, QF2 and QF4 were originally measured without temperature control, so no comparable initial data

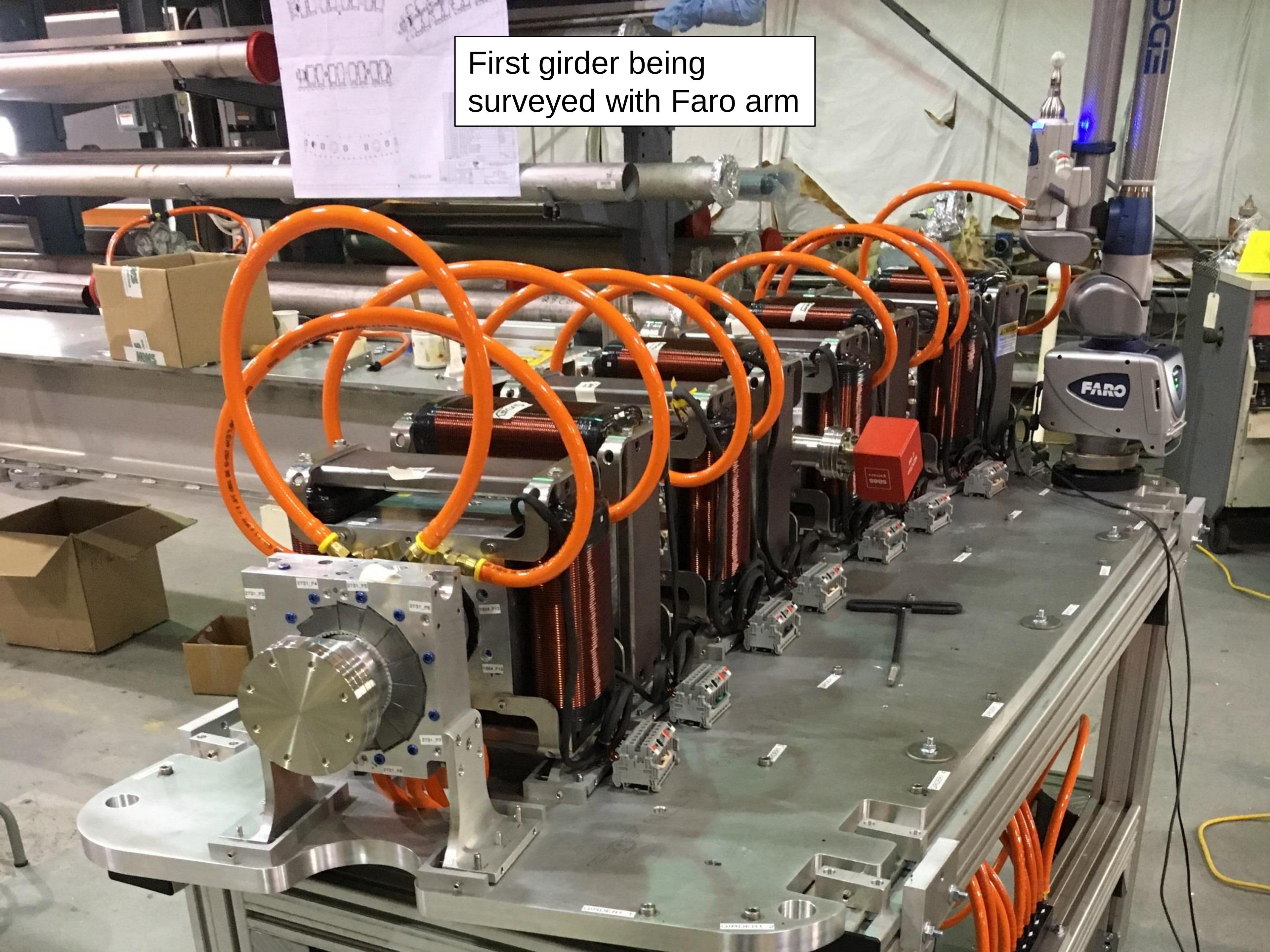
2.8 Gauss

= 10^{-3} of max quad

First Girder Results

- Example harmonics tables
- BD1 before/after
- Quad is normalised to 10000 units

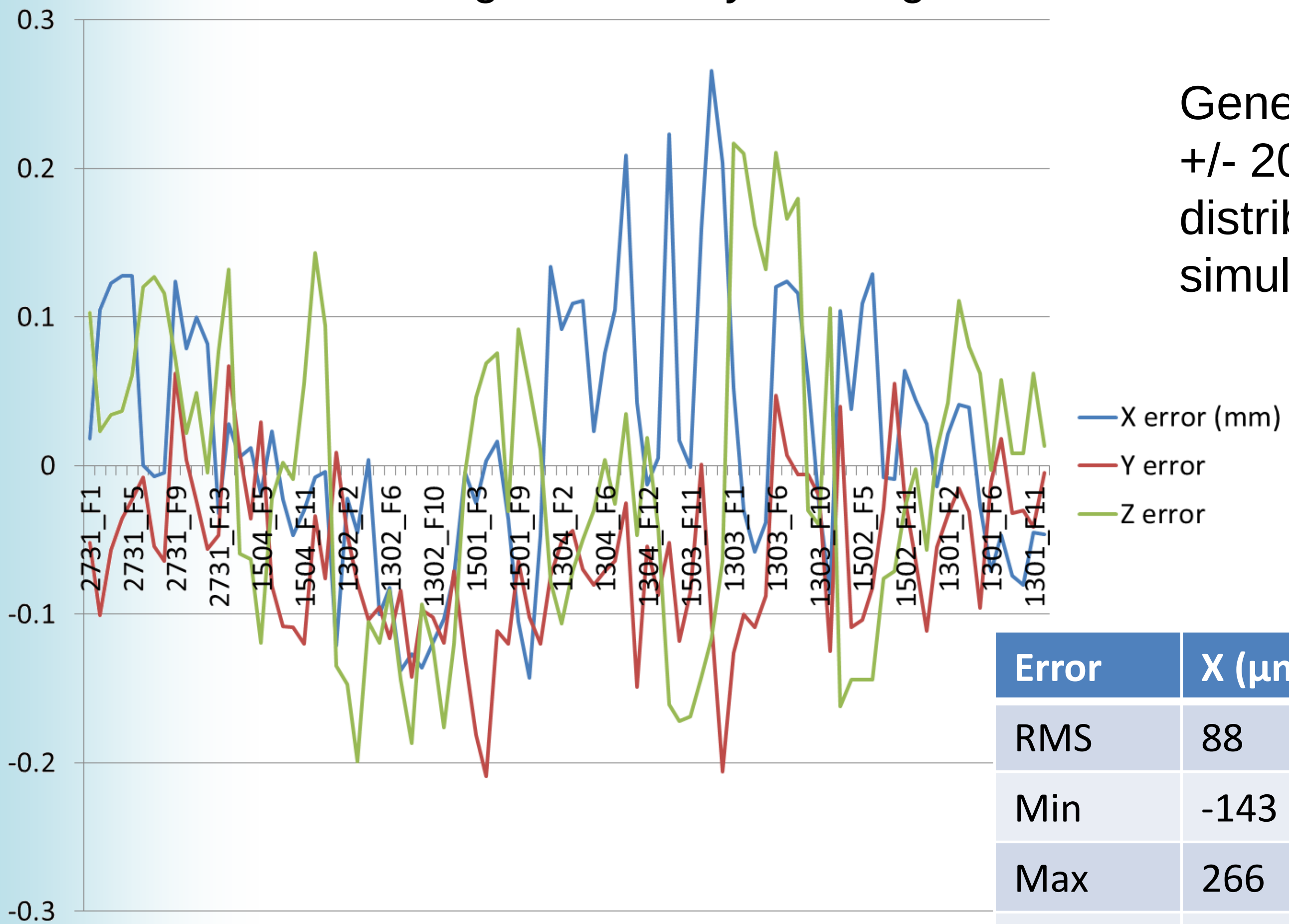
Integrated quad (T)	BD1 before		BD1 after	
	1.355455		1.358539	
	Normal	Skew	Normal	Skew
Dipole	-11092.96	0.00	-11067.78	0.00
Quad	10000.00	0.00	10000.00	0.00
Sext	-21.17	3.49	1.74	0.80
Oct	-101.50	-9.81	-4.67	2.54
Deca	-0.35	-12.37	-2.00	0.03
Dodeca	2.90	5.08	1.89	1.03
14-pole	-0.37	-2.01	0.77	-1.01
16-pole	-0.38	-1.65	0.68	0.13
18-pole	-1.53	-0.36	-0.13	0.63
20-pole	0.12	-0.42	-0.11	0.16
22-pole	-0.40	-0.16	0.44	-0.55
24-pole	-0.20	-0.33	-0.11	0.12
26-pole	0.42	-0.02	0.05	0.14
28-pole	0.14	0.06	0.07	-0.06
30-pole	0.13	-0.04	-0.03	-0.07
32-pole	0.06	0.00	0.07	-0.04
34-pole	-0.09	0.01	0.07	0.01
36-pole	0.21	-0.02	0.02	-0.01
38-pole	0.02	0.03	0.00	-0.06
40-pole	0.01	0.00	0.00	-0.03



First girder being surveyed with Faro arm

Q. from 2017: Survey Accuracy

Errors in the first girder survey, all magnet fiducials

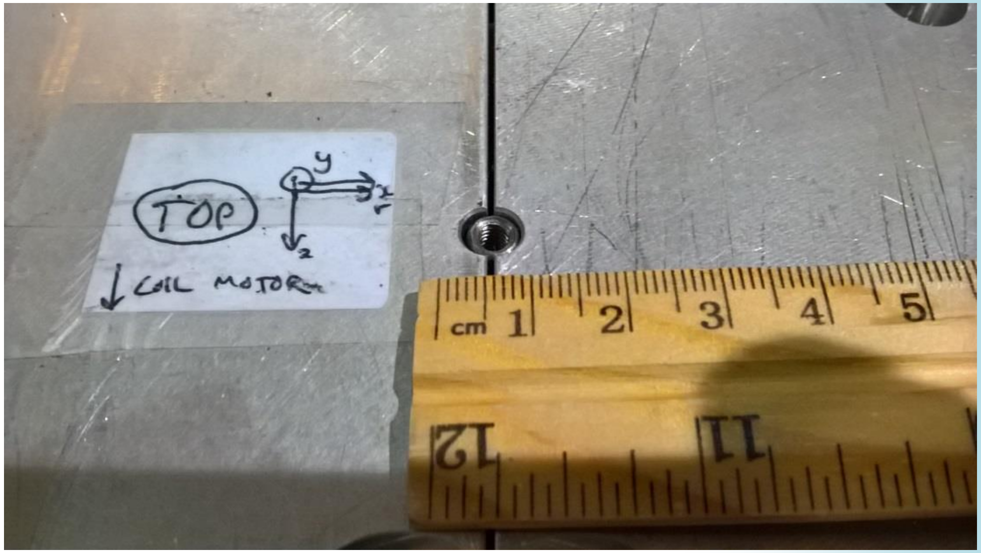


Generally consistent with +/- 200 micron uniform distribution assumed in simulations, baseline

Error	X (µm)	Y	Z	Distance
RMS	88	83	103	159
Min	-143	-209	-199	48
Max	266	67	217	309
Average	17	-62	-7	147

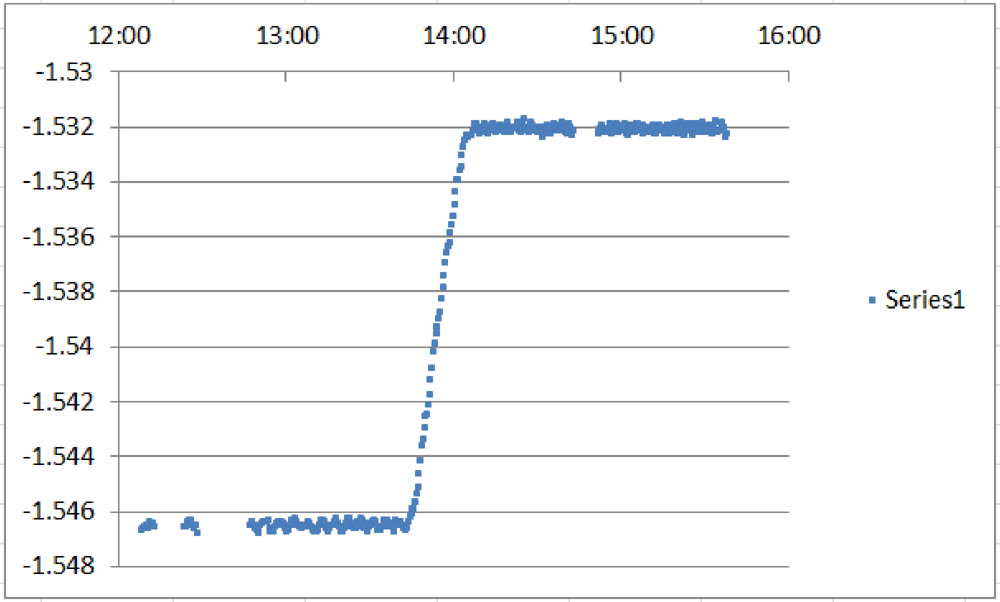
Q. from 2017: Reassembly Quality

- BNL magnet with loose pin went from 2.1 → 21.2 units error when reassembled (bad)
- We rebuilt the magnets with loose pinning
- Magnet with aluminium halves flush went from and 3.4 → 4.8 units error (good)



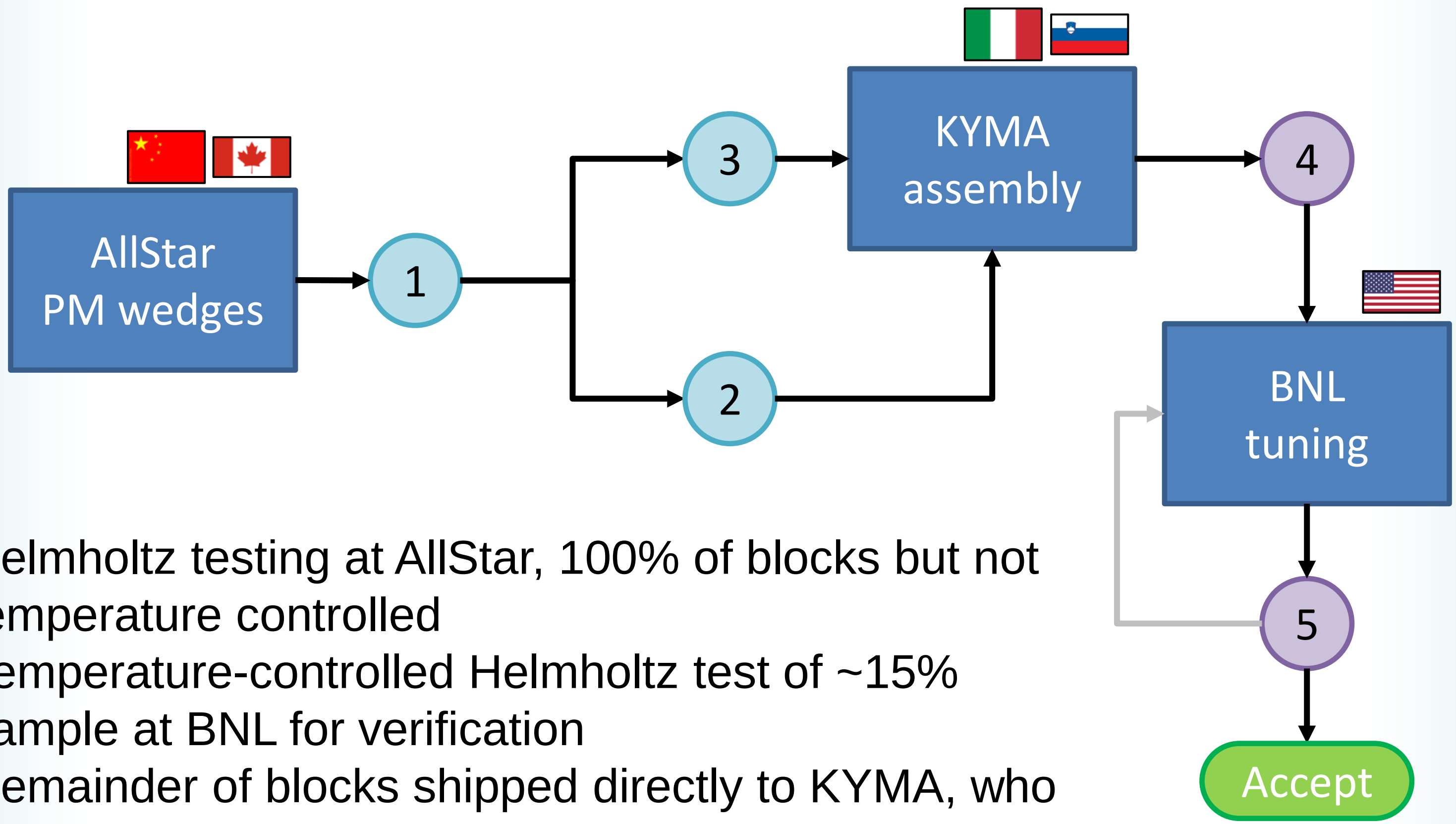
KYMA checks for no protruding blocks when manufacturing

Water Cooling Stability



QF3 (nice reassembly reassembled)							
goal integrated field							
-1.5279	(T/m).m						
average run 17 (equilibrium)				min	max	midpoint	+/- relative
-1.53208	(T/m).m			-1.53236	-1.53179	-1.53207	1.87E-04
relative error (non-thermal wire iter 2) at 85F							
0.274%							

Production and Testing Flow

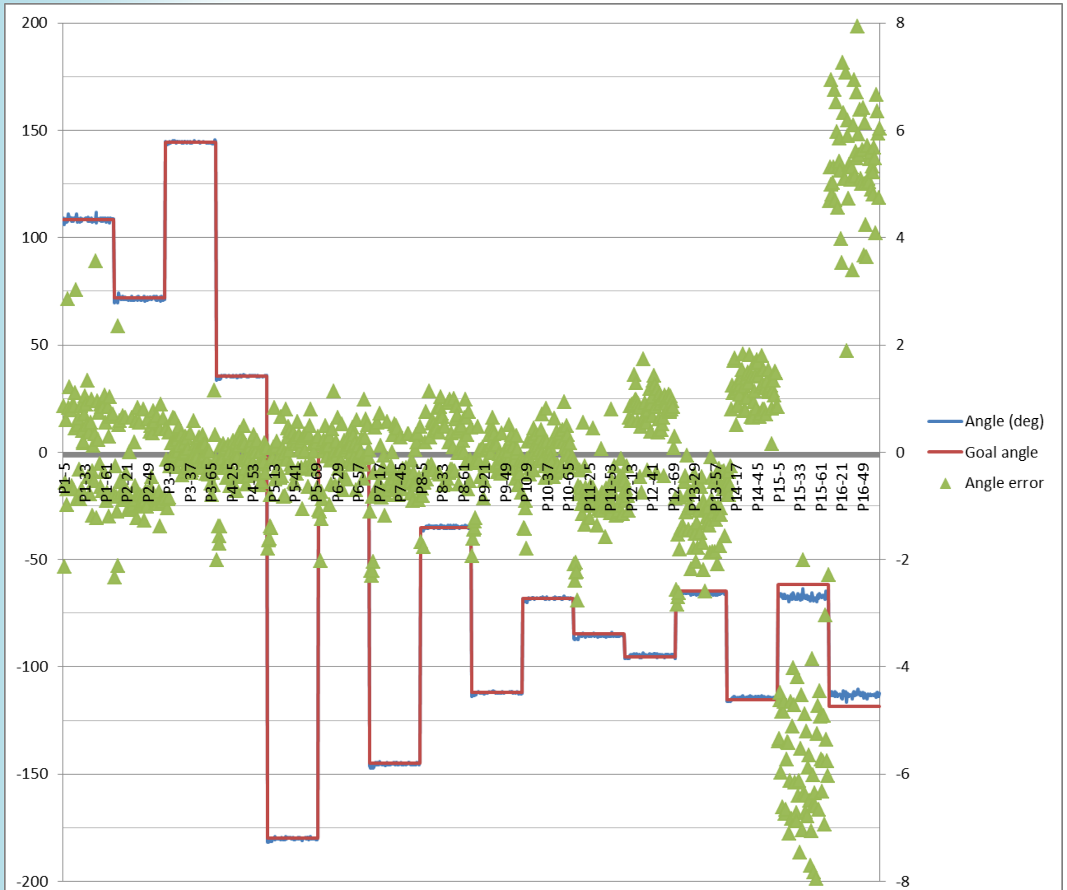


1. Helmholtz testing at AllStar, 100% of blocks but not temperature controlled
2. Temperature-controlled Helmholtz test of ~15% sample at BNL for verification
3. Remainder of blocks shipped directly to KYMA, who also re-test ~10% sample
4. Rotating coil measurement of bare magnet at BNL
5. Rotating coil measurement of tuned magnet at BNL

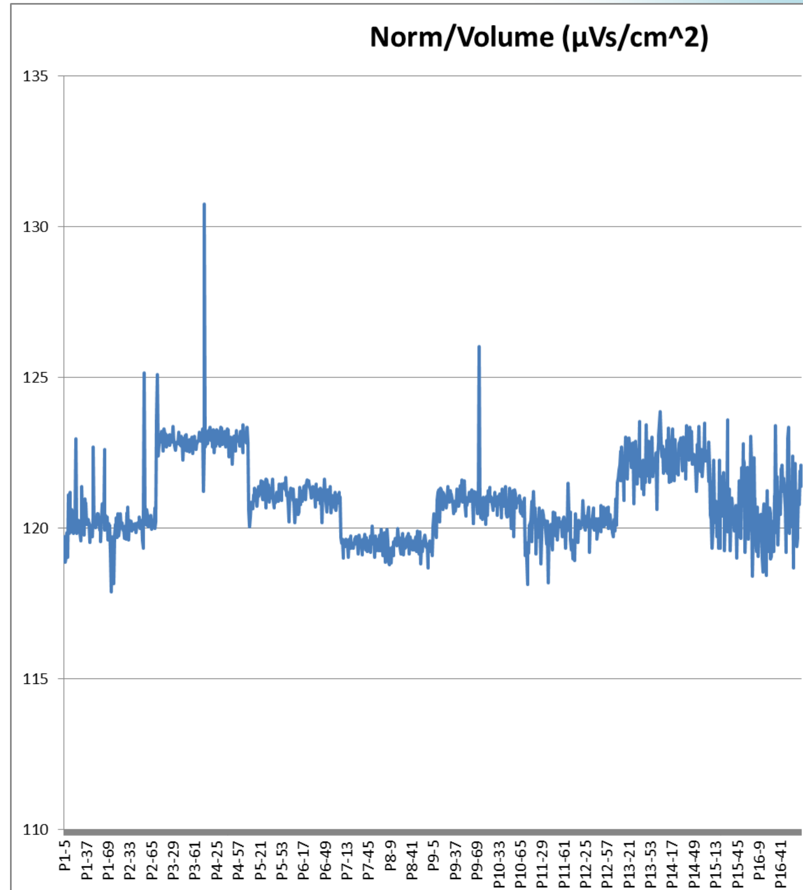
Helmholtz Measurements

Example: AllStar data for wedge types P1 through P16 (BD magnet)

Angle errors

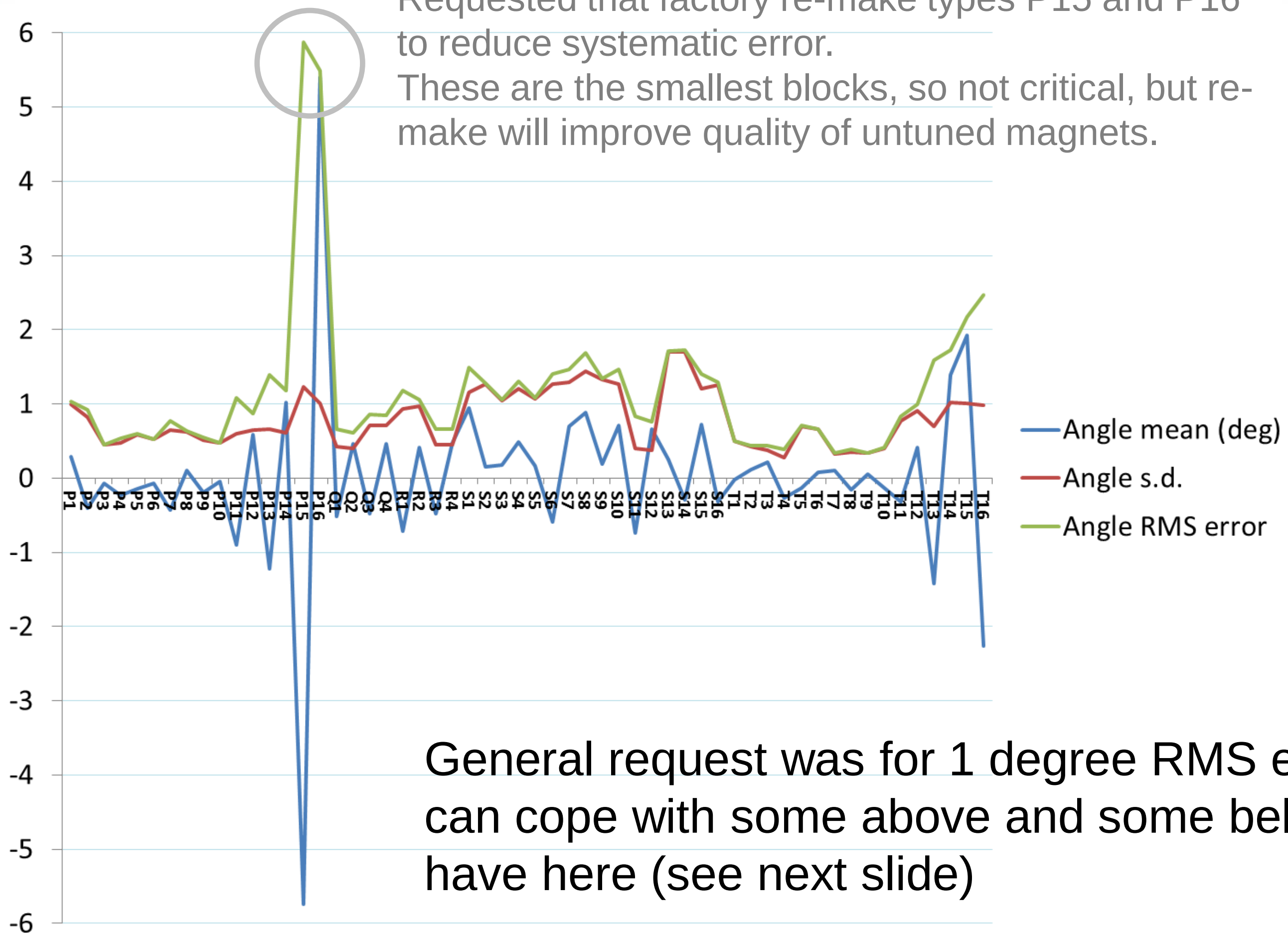


Strength variation



Magnetisation Angle Distributions

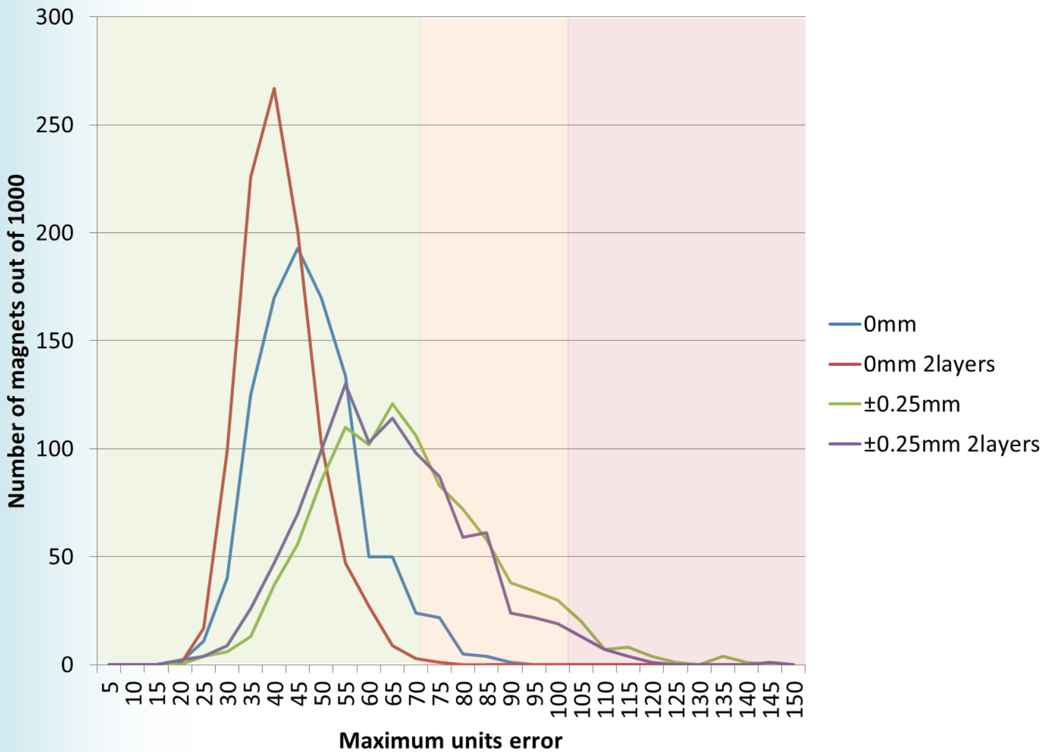
Requested that factory re-make types P15 and P16 to reduce systematic error.
These are the smallest blocks, so not critical, but re-make will improve quality of untuned magnets.



General request was for 1 degree RMS error, but can cope with some above and some below as we have here (see next slide)

Magnet Error Model

- Both the strength and angle error distribution can be put back into the field simulation



Example: BD magnet using AllStar's data set.

1000 magnets were generated, some with position errors. Histogram is binned by the "units FOM".

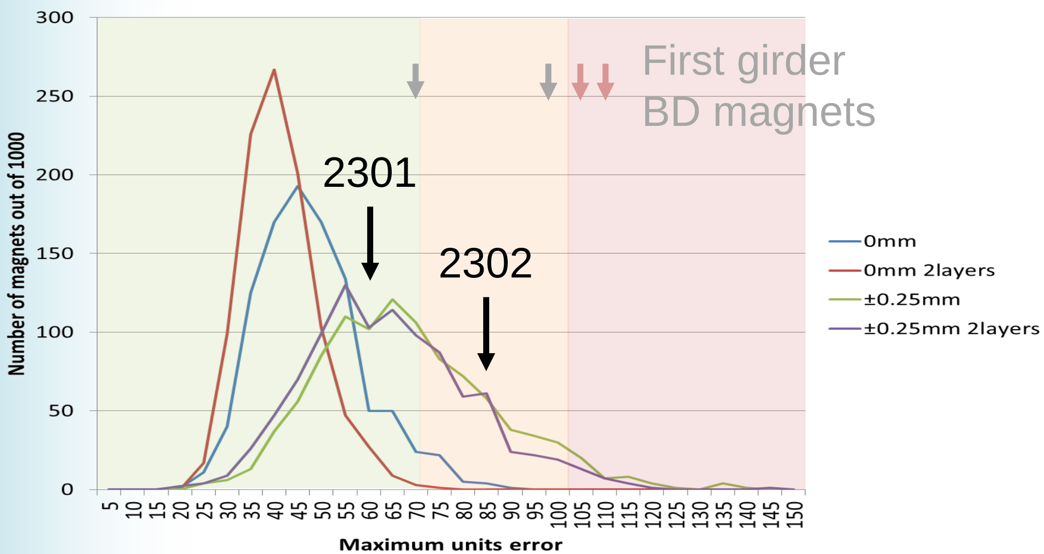
Green = easy to tune
Red = possible problems
Based on first girder experience.

BD First Articles from KYMA

BD First Articles from KYMA

- Measurements of bare magnets (last week):

Magnet type, identifier #	Units FOM	CBETA FOM	Midplane error (Gauss)	Gradient error at x=0
BD 2301	58.72	1.746	10.13	-0.091%
BD 2302	83.41	2.498	15.64	-0.065%



First two BD magnets are consistent with simulated distribution including expected position errors.

Tuning works in simulation, testing in practice this week.

Three more will be tested before full BD production run approved.

Conclusion / Next Steps

- We've tuned 9 magnets to suitable field quality (21 if you include FFAG line at ATF)
- Production magnets are coming in as expected
- Next, will test and tune first articles of the other types, then go to production
- Tuning wire holders are being 3D printed at Cornell
- Wire cutting machine will be used for wires