NSF-PHY

DOE-HEP

Nonlinear Optics in UMER

Brian Beaudoin

Heidi Baumgartner, Santiago Bernal, Levon Dovlatyan, Irving Haber, Rami Kishek, Timothy Koeth, David Matthew, Eric Montgomery, Kiersten Ruisard, David Sutter

June, 6th 2017

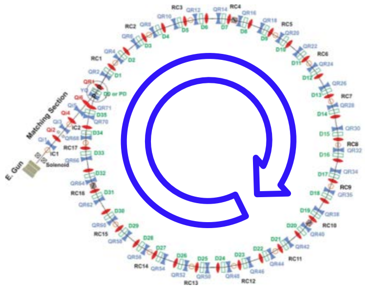
IOTA/FAST Workshop

Institute for Research in Electronics & Applied Physics

Outline

Three talks back-to-back

- Program Overview (Brian & Tim)
- Precision/Performance Upgrade (Dave)
- Experimental and Simulation Results (Kiersten)



The University of Maryland Electron Ring

A Research Machine for Advanced Beam Dynamics

Original Mission: Space charge over long path-lengths

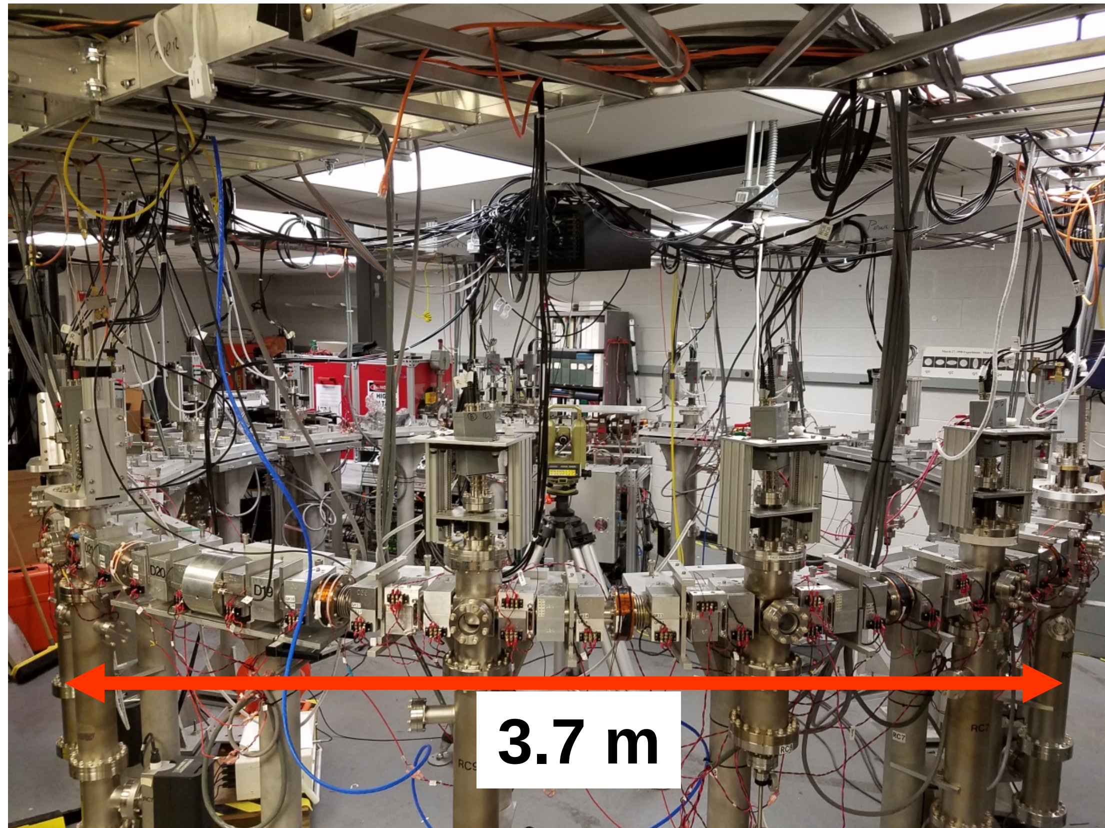
- **Low energy (10keV) electrons**
- **Currents (0.01-100 mA)**
- **Emittances (0.3-3 mm)**

Safe

Flexible Printed Circuit Magnets:

- Independently-powered quadrupoles, octupoles, dipoles
- Variable space charge
- Tune-in halo

Well bench-marked simulations



Lap time	=	197 ns, (5.08 MHz)
Pulse Length	=	15 to 145 ns,
Full-Lattice Period	=	0.32 m (std. lattice)
Vacuum Pipe radius	=	25.4 mm

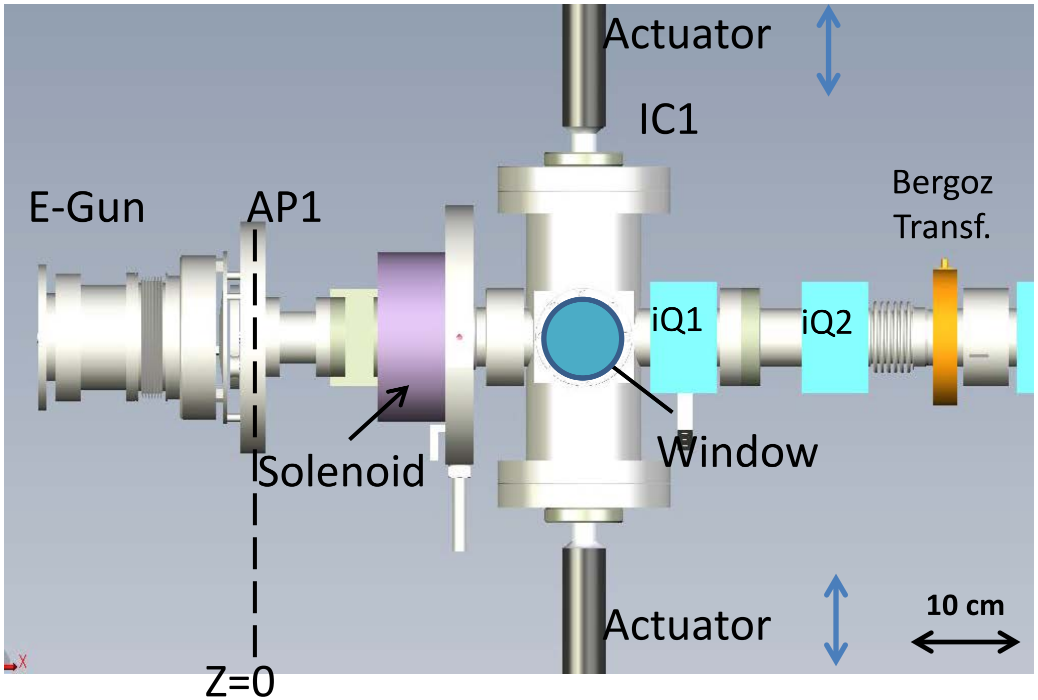
Precision/Performance Upgrade - Phase 1

Rebuilding the ring from the ground up

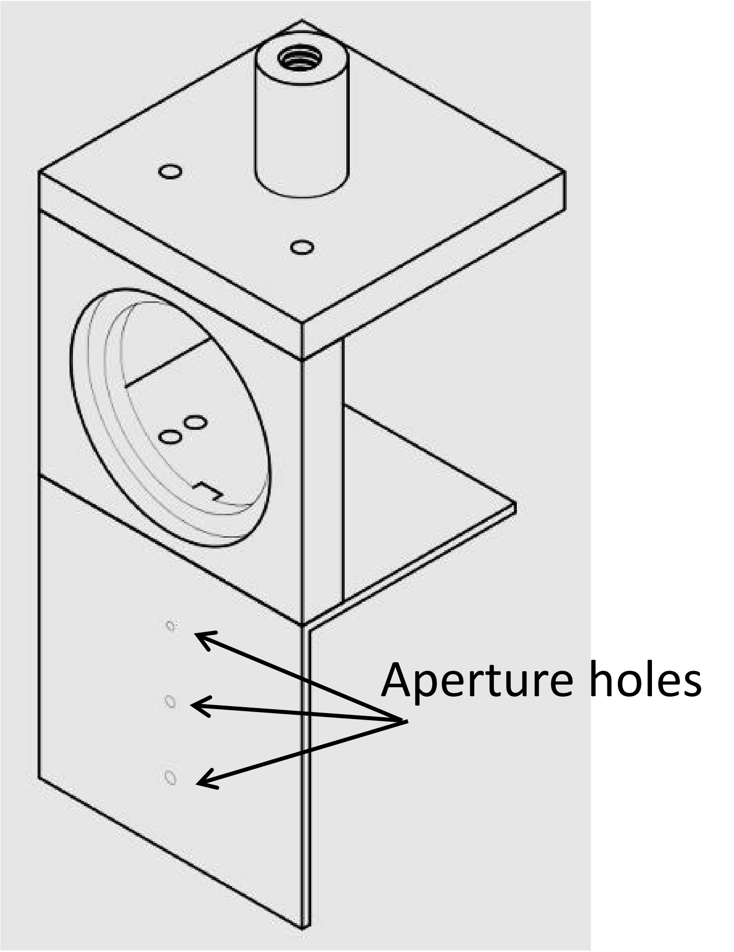
In collaboration with Fermilab IOTA project

- Reset the ring into a circle.
- Remount the ring to the floor using properly rated anchors and epoxy.
- Using Leica T3000 theodolites and laser range finders to align the ring.

Producing ultra-low current beams for pencil beam scanning - Phase 2



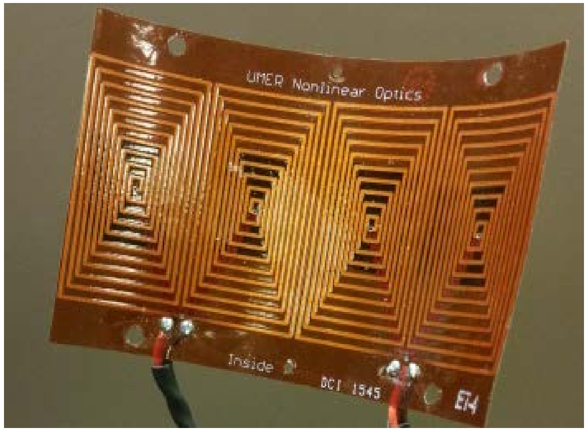
Actuating mirror cube



- The aperture would allow us to inject currents from 10 μA - 1 mA, in combination with old apertures and solenoid.
- The additional aperture would be fully retractable. To be installed soon

Constructing the Single Channel for UMER

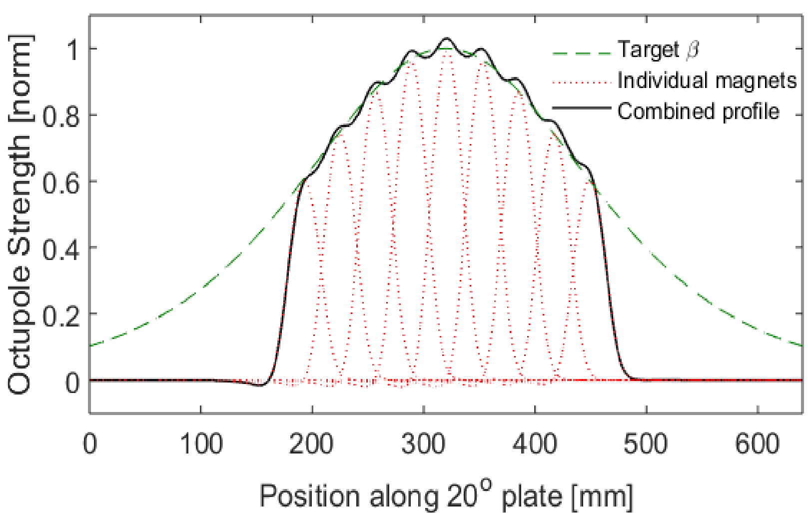
Half an Octupole

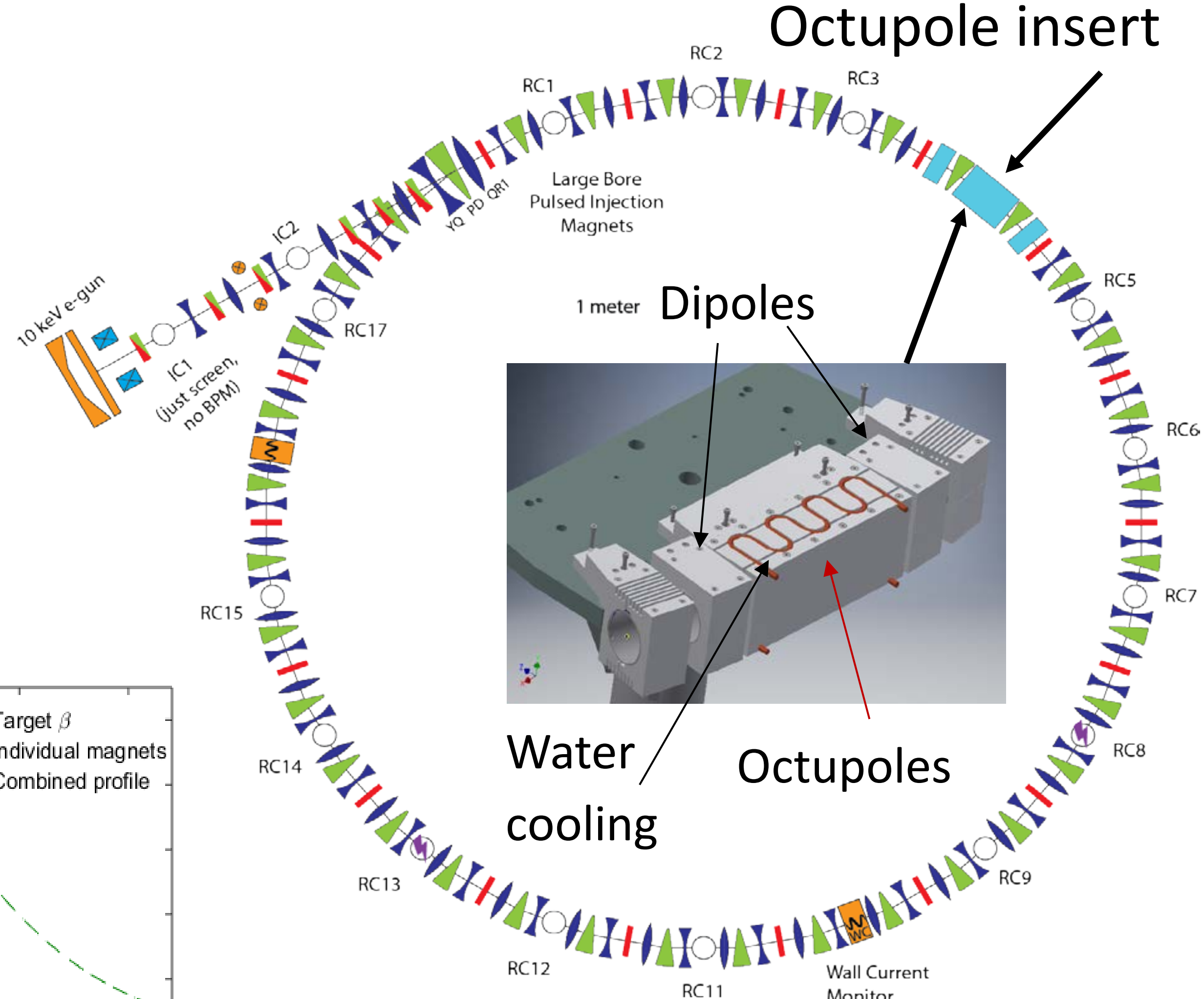


Printed Circuit Octupole

Dave Matthew, Octupole Design

Heidi Baumgartner, Octupole Characterization





Designed by Kiersten Ruisard and Heidi Baumgartner

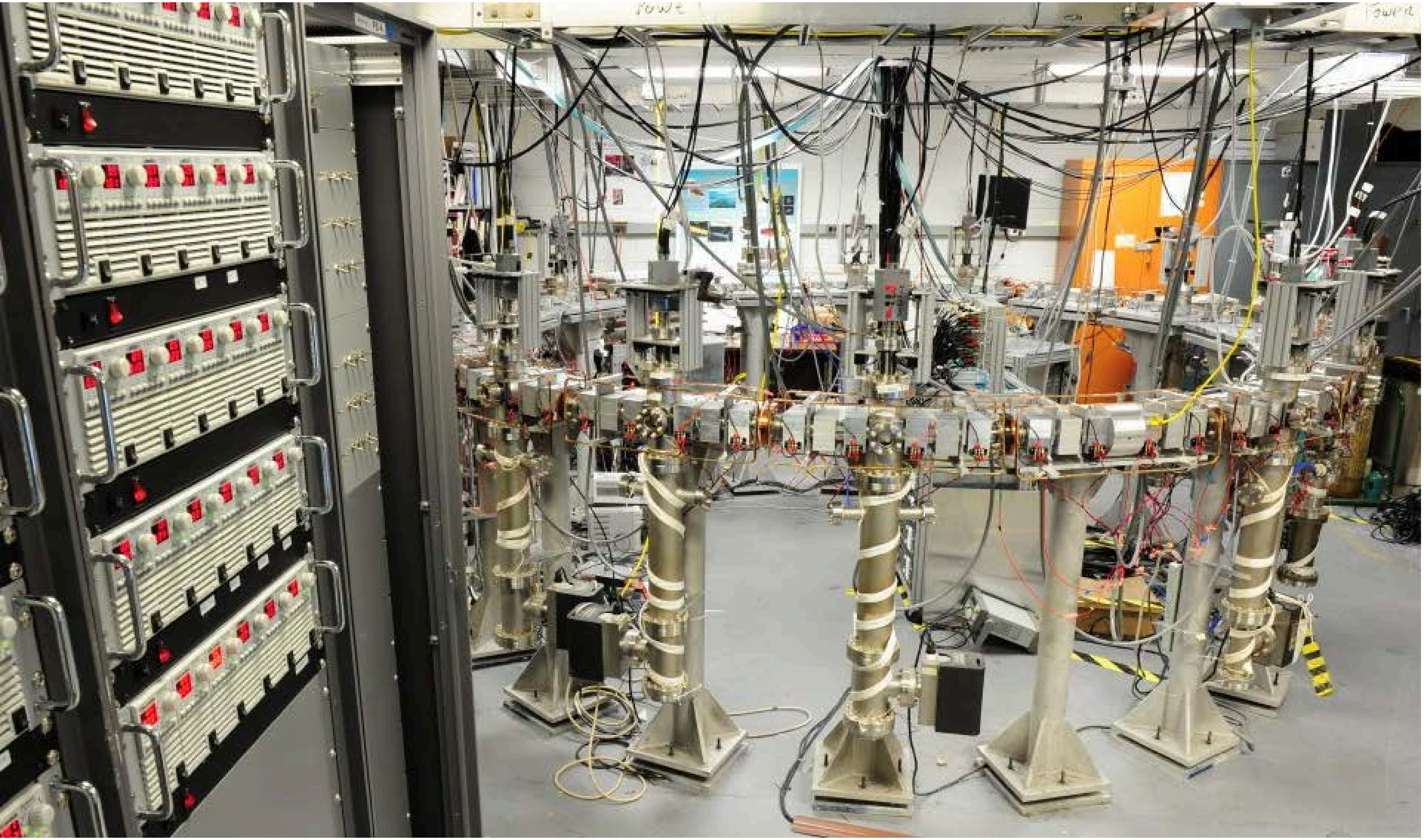
UMER:

Reconstruction and Realignment

February thru August 2016

David F. Sutter
IOTA Meeting
June 6, 2017

The U of Maryland Electron Ring

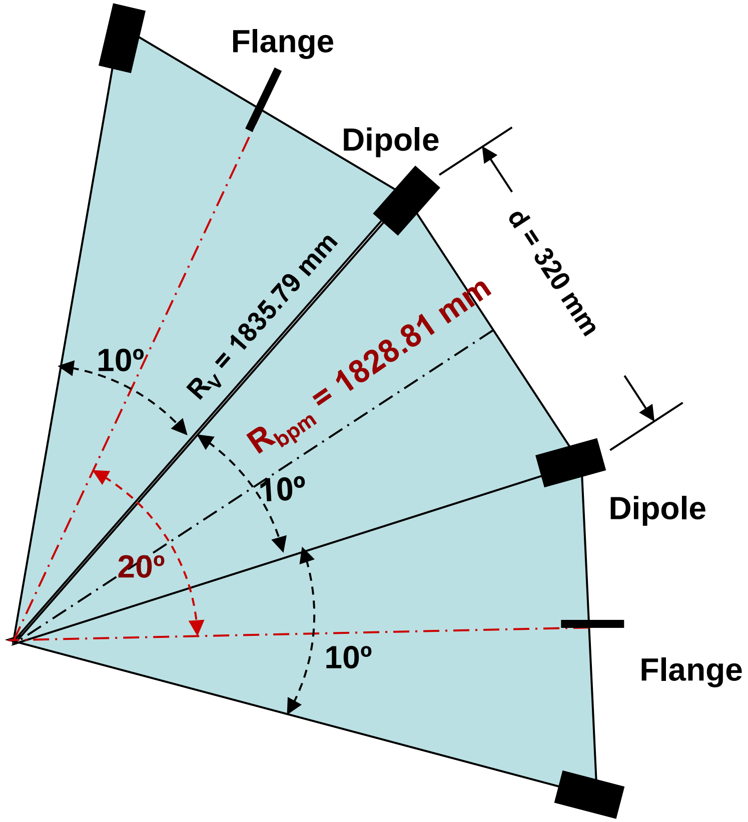


UMER Design Orbit:

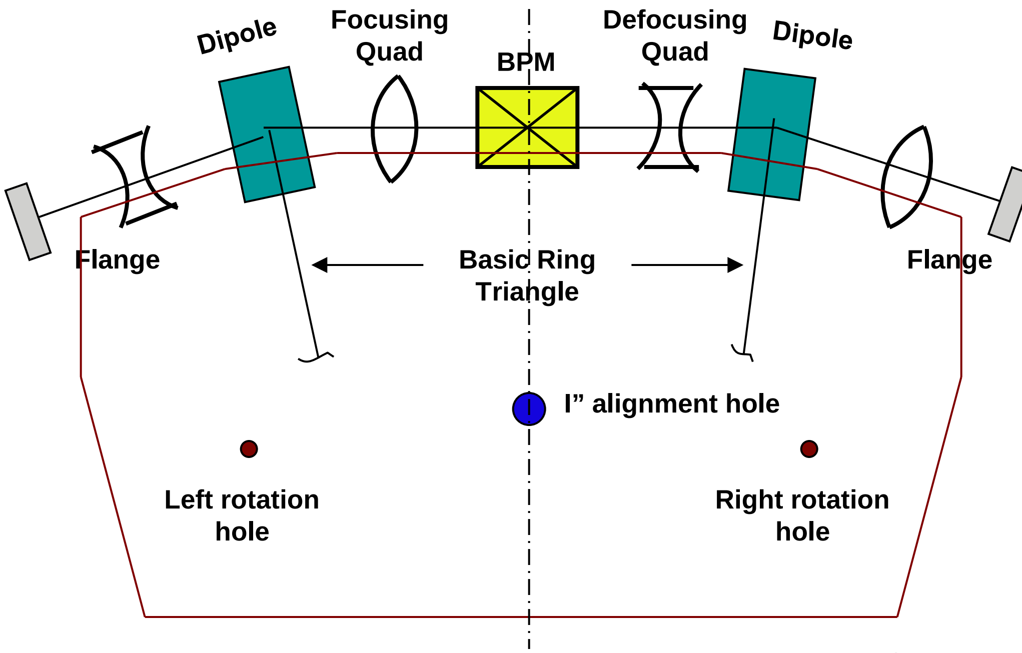
The design orbit is a 36 sided polygon with a circumference of 11520 mm.

These two specifications, and the locations of the quadrupoles on 16 cm centers, determine the Geometry of the EO, and therefore of the ring.

Standard Ring Alignment Triangles
(36 0f these make up the ring)

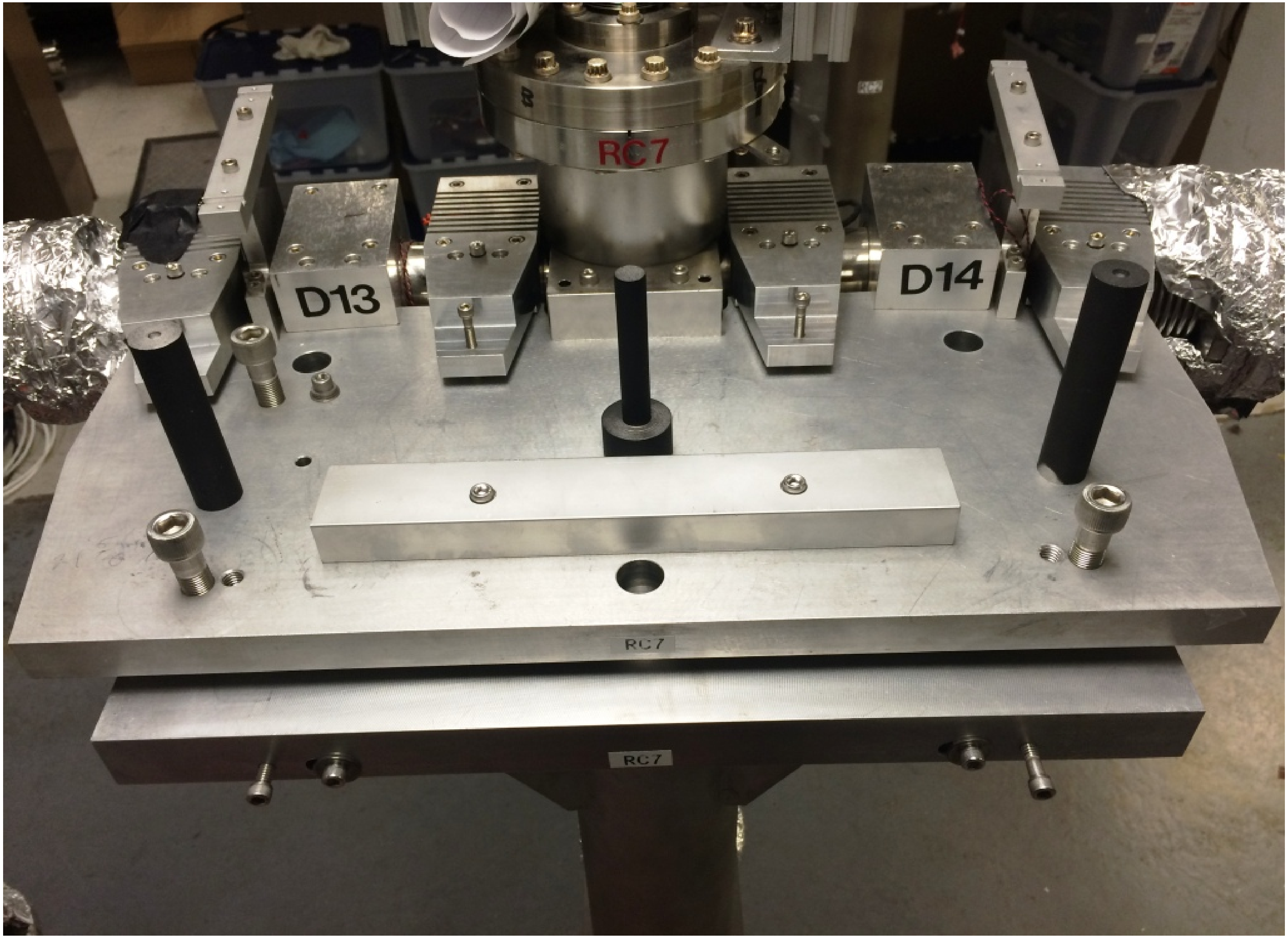


Two FODO Cells on a 20° Plate

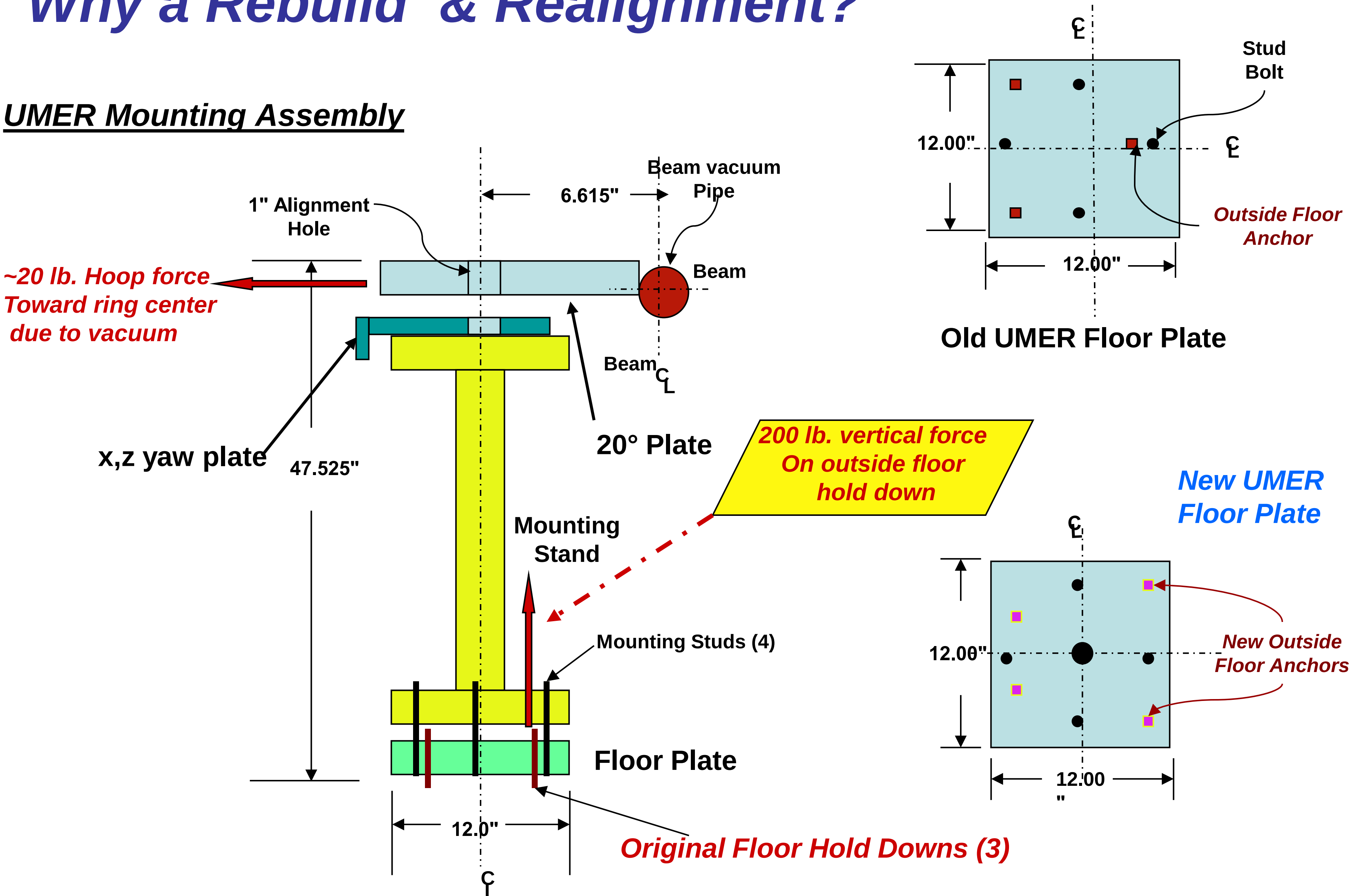


Component Mounting (20°) plate

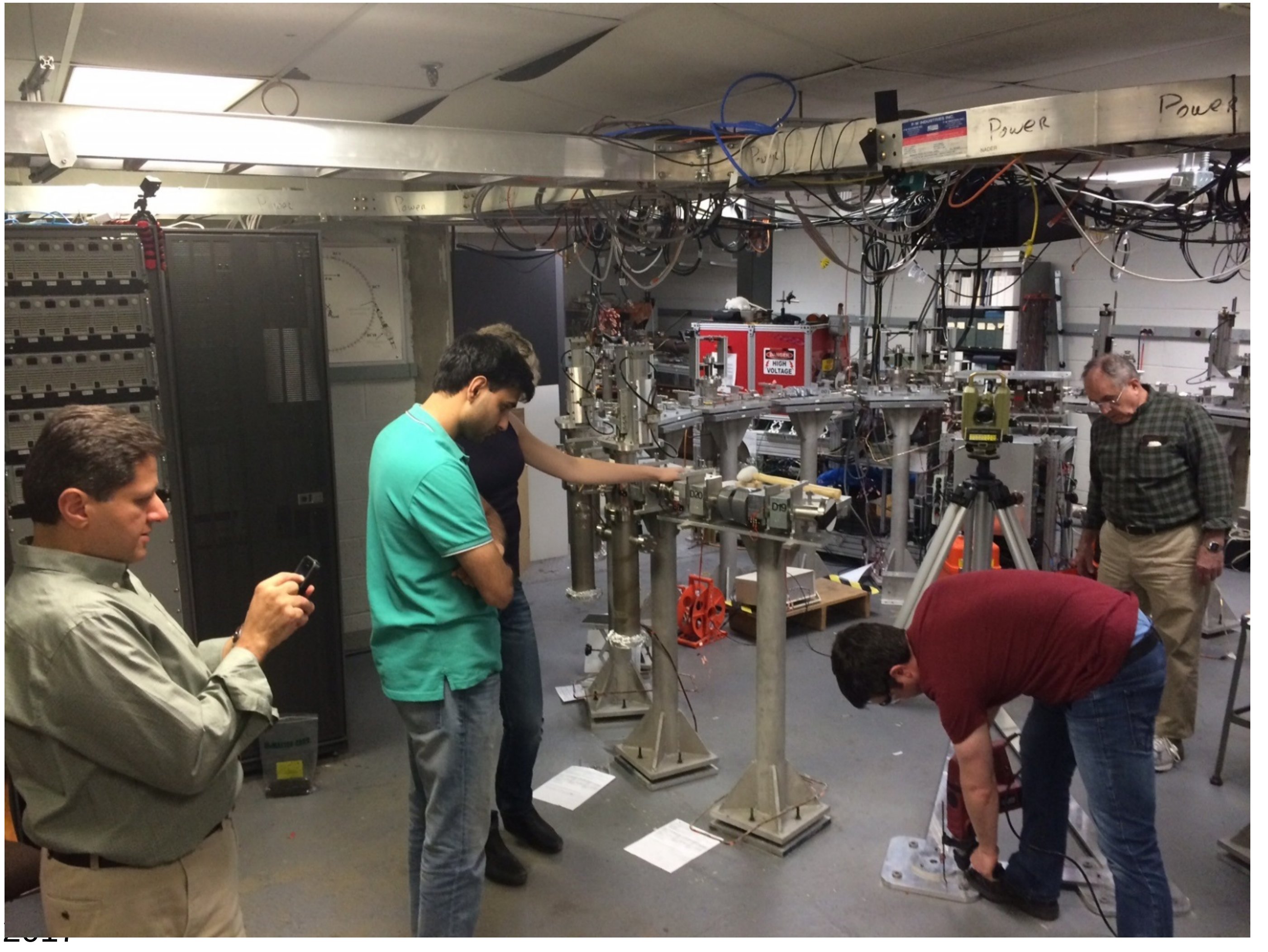
Standard UMER 20° Plate - with targets



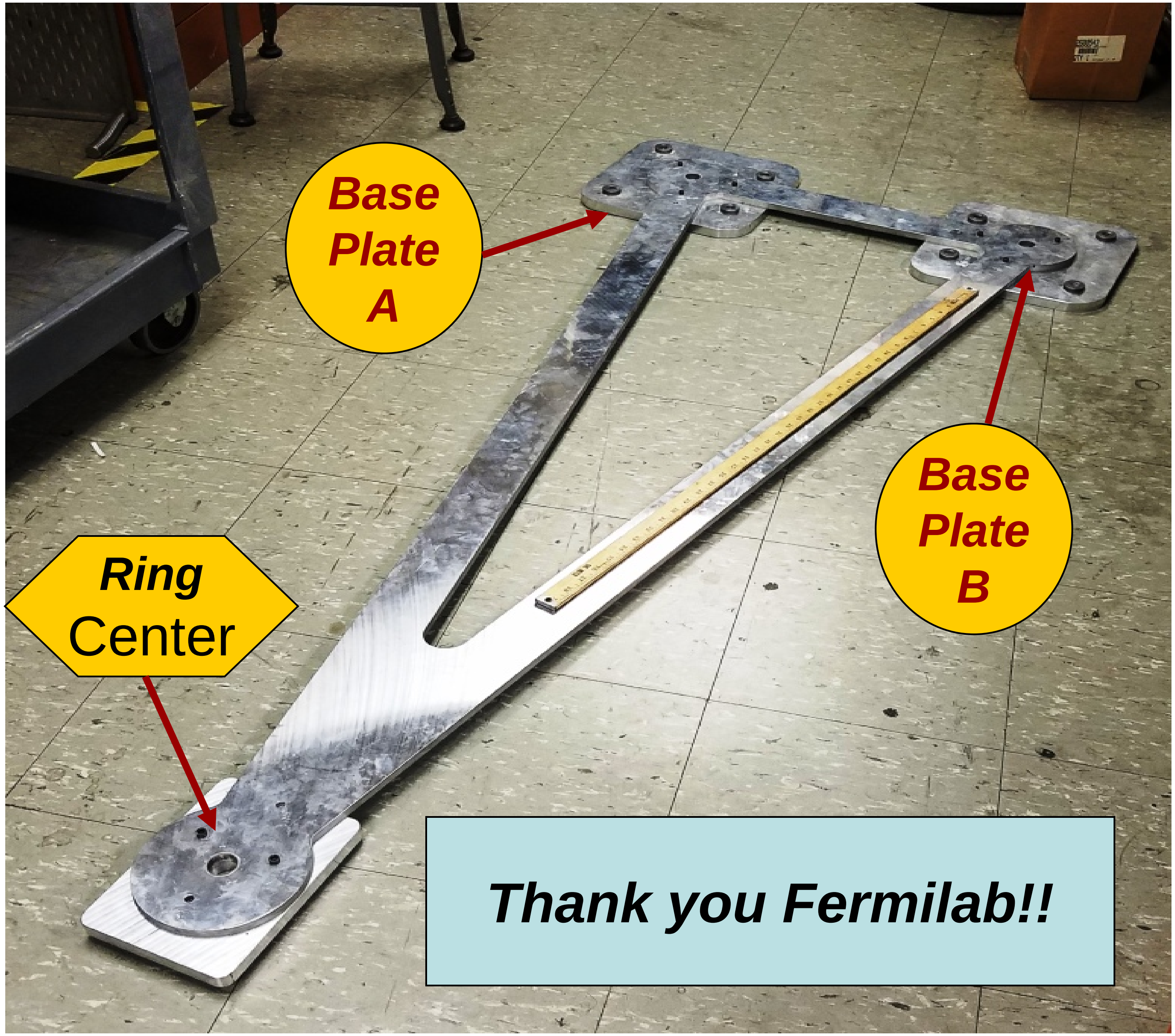
Why a Rebuild & Realignment?



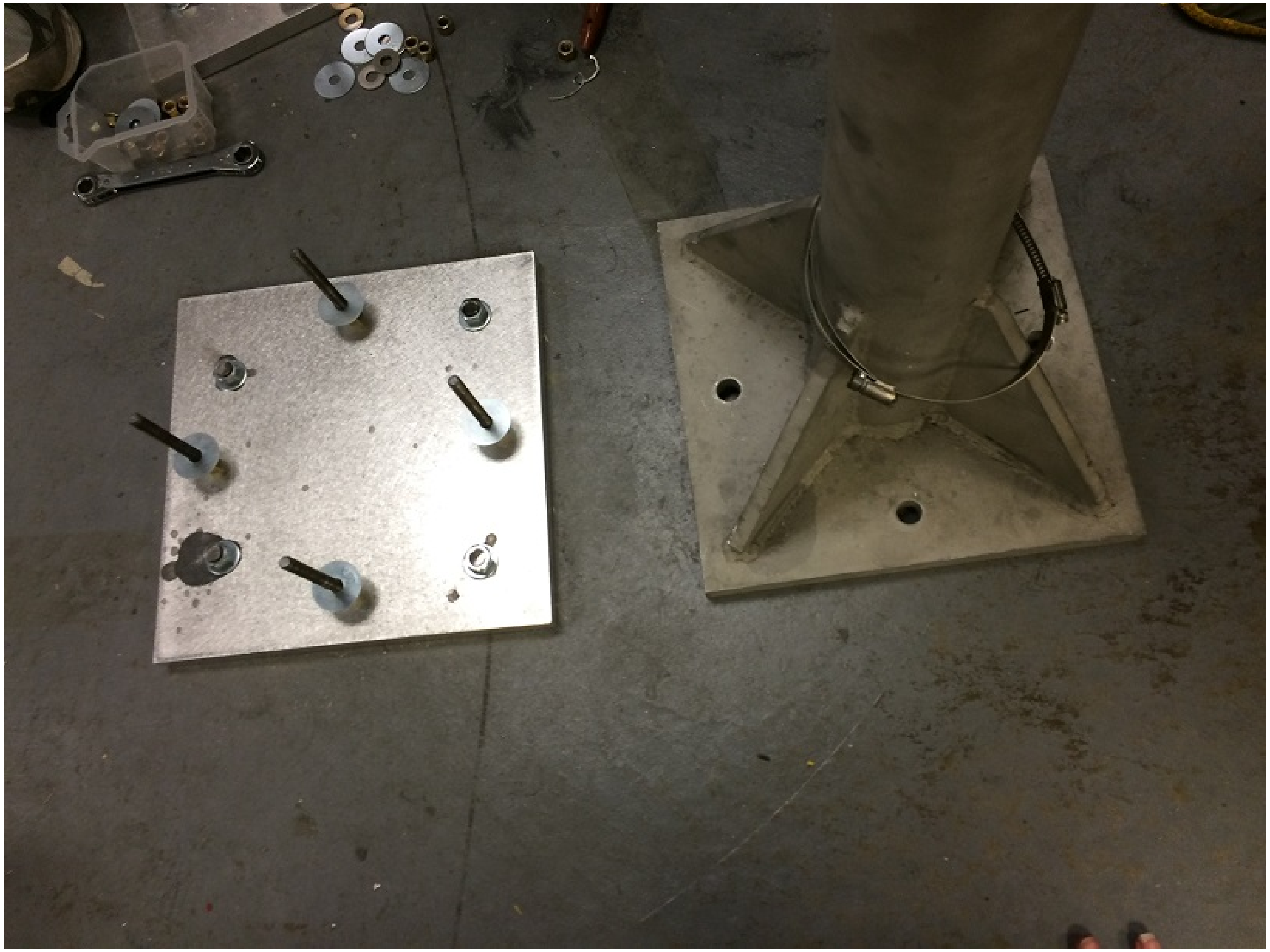
Fasteners – Before and After


Power
Power
HIGH VOLTAGE

The Essential Floor Template

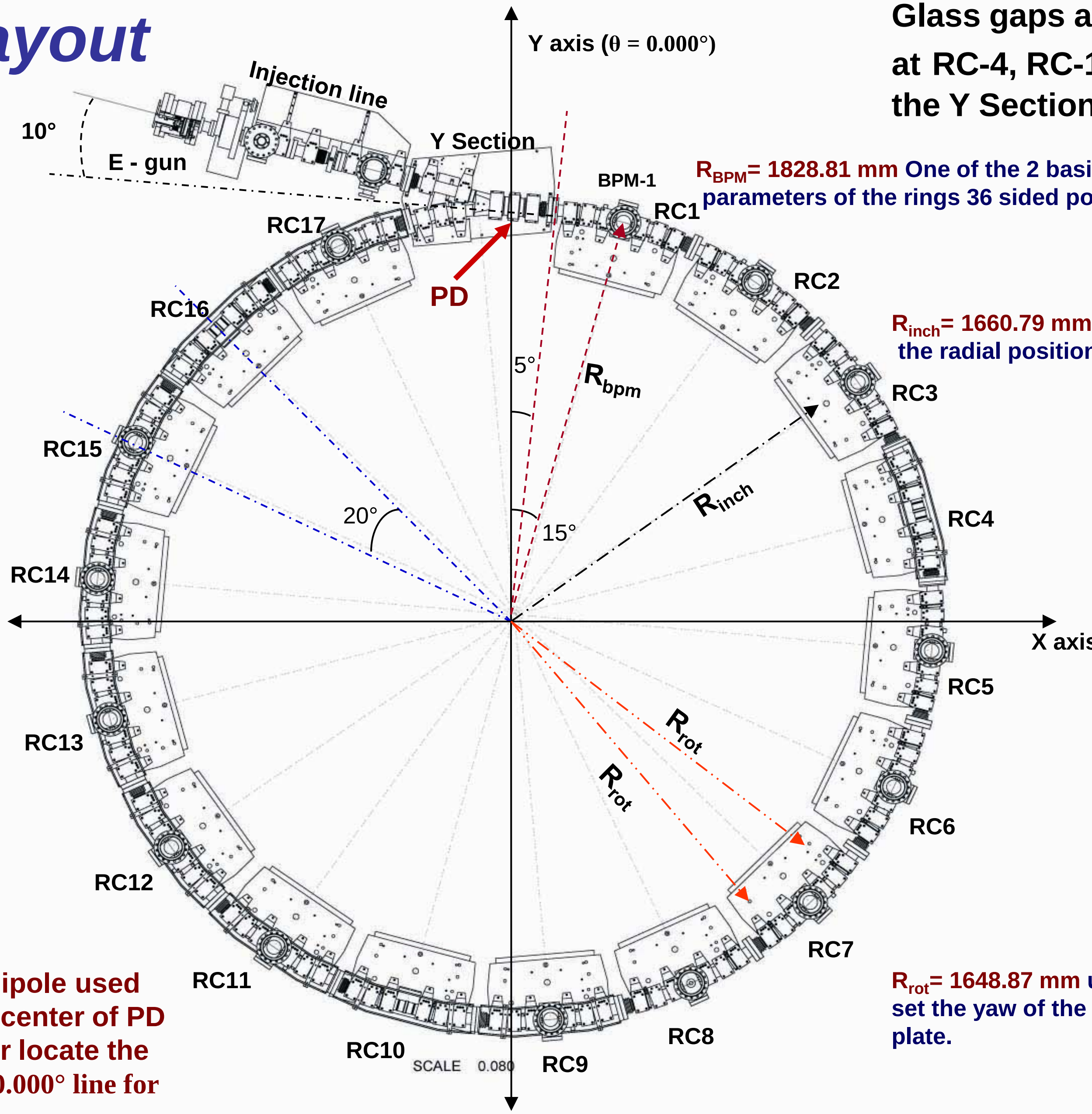


New Floor Plate Ready for Stand



Ring Layout

Glass gaps are installed at RC-4, RC-10, RC-16 and the Y Section.



R_{BPM}= 1828.81 mm One of the 2 basic design parameters of the rings 36 sided polygon

R_{inch}= 1660.79 mm used to set the radial position of the top plate.

R_{rot}= 1648.87 mm used to set the yaw of the top plate.

PD is the pulsed dipole used for injection. The center of PD and the ring center locate the Y axis and the θ =0.000° line for polar coordinates.

150804, D. F. Sutter

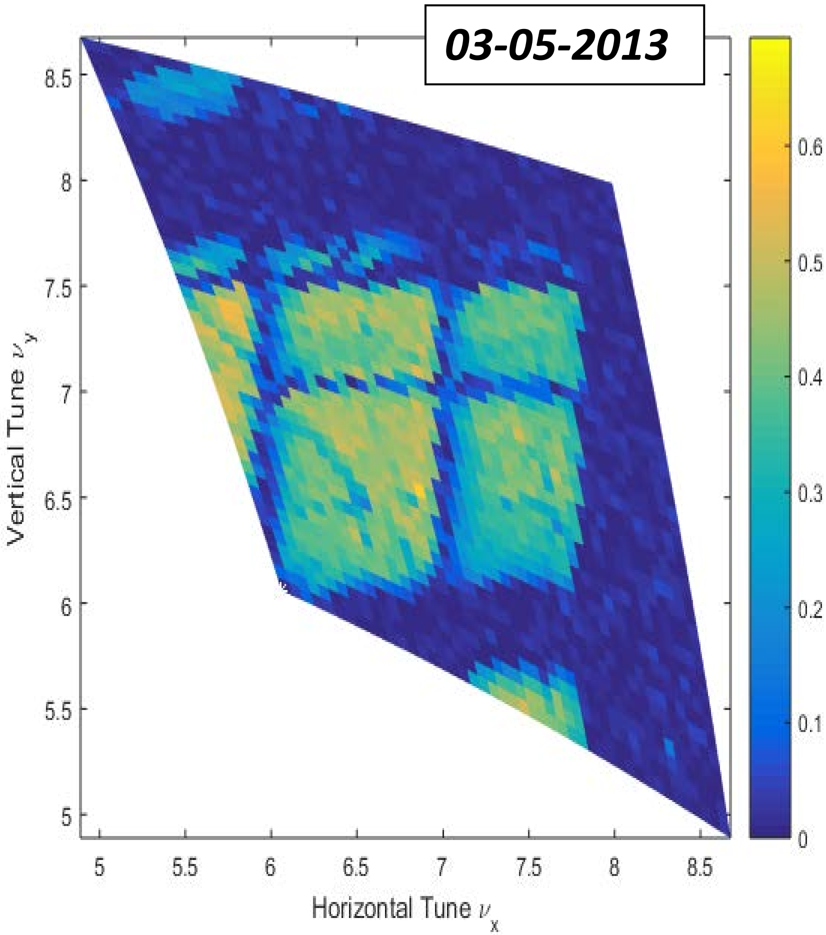
UMER Design Tolerances

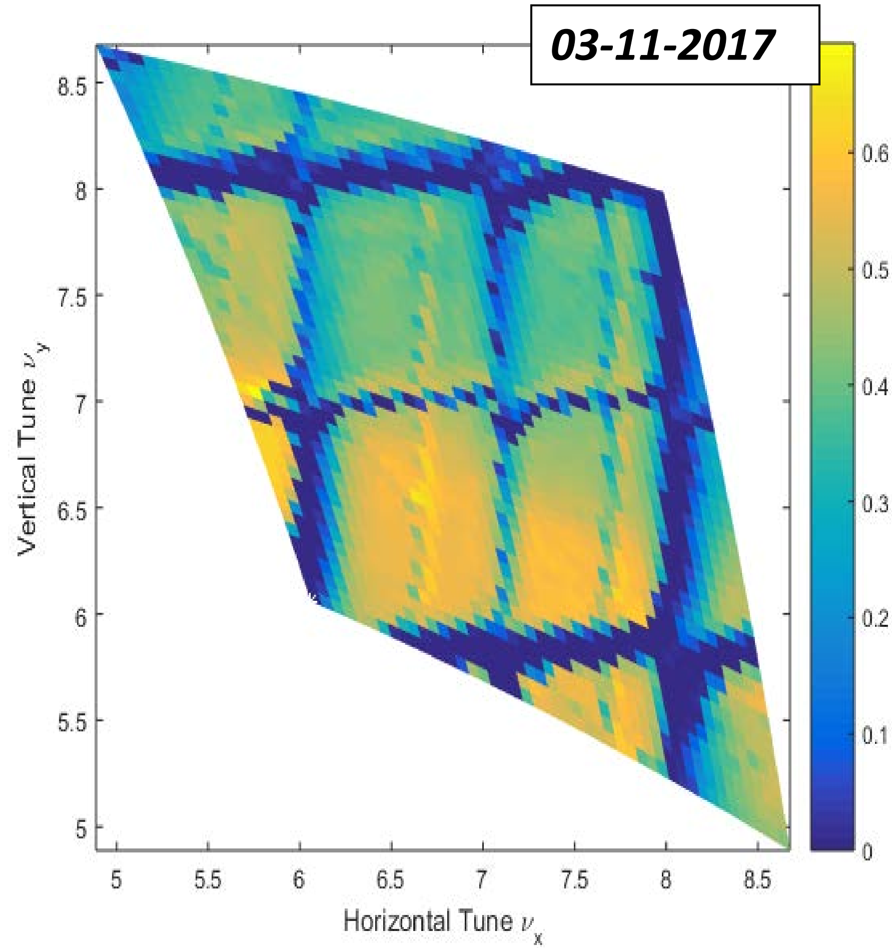
An ELEGANT simulation suggests that transverse rms position errors of 125 microns will give a 2 mm rms amplitude variation in the equilibrium orbit – this is acceptable for operation.

Type of Error	Simulation Tol.	Control Tol.
Quadrupoles		
Translation (x)	0.100 mm	0.05 mm
Translation (y)	0.100 mm	0.05 mm
Translation (z)	1.0 mm	0.50 mm
Rotation (about z)	2.0 mrad	1.0 mrad
Rotation (about x)	~ 2.0 mrad	1.0 mrad
Rotation (about y)	~ 2.0 mrad	1.0 mrad
Strength	0.10 %	0.05 %
Dipoles		
Translation	1.0 mm	0.05 mm
Rotation (about z)	~ 2 mrad	1 mrad
Strength	0.40 %	0.20 %
BPM		
Aggregate Res.	---	0.25 mm
X, Y Position	---	0.1 mm
Rotation Angle	10 mrad	5 mrad

Tune scan, comparison: pre- and post- upgrade

Comparison of current in 6 mA beam on 20th turn across a range of operating points normalized to maximum current in first turn.





Update on Simulations and Experiments at UMER

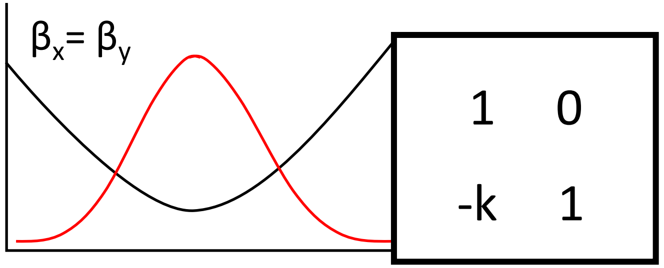
Kiersten Ruisard

Heidi Baumgartner, David Matthew, Irving Haber, Santiago Bernal, Brian Beaudoin, Timothy Koeth

June 6, 2017
IOTA/FAST Collaboration Meeting

Nonlinear (octupole) lattice at UMER

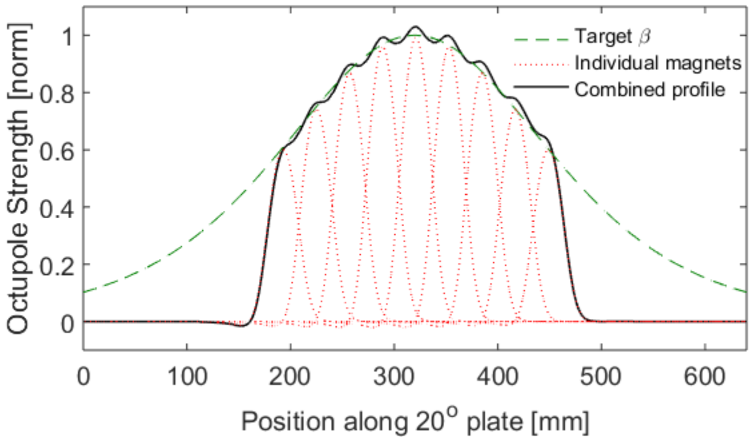
Octupoles scale with $\beta(s)^{-3}$ → quasi-integrable Hamiltonian conserved

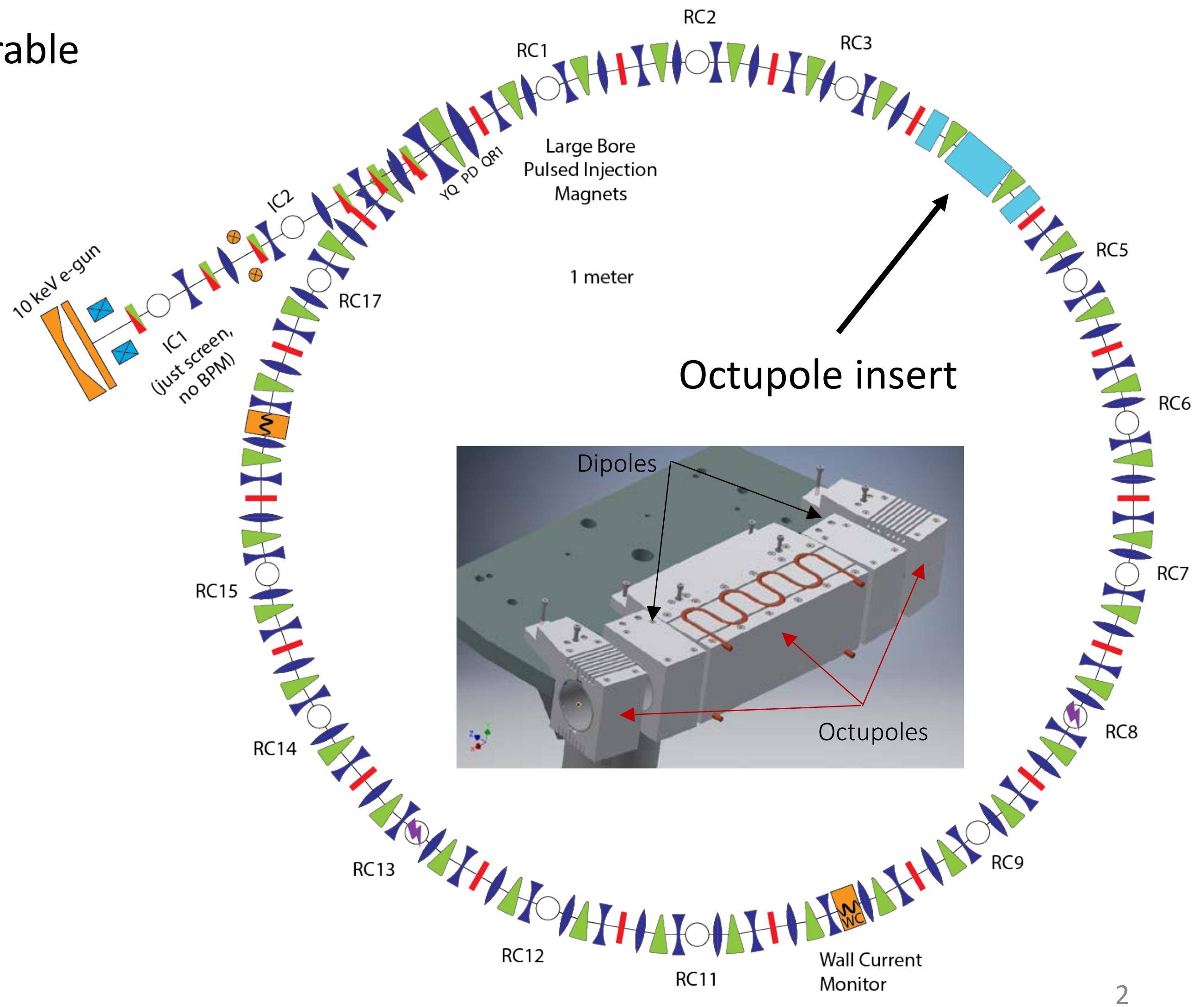


Octupole strength

T-insert

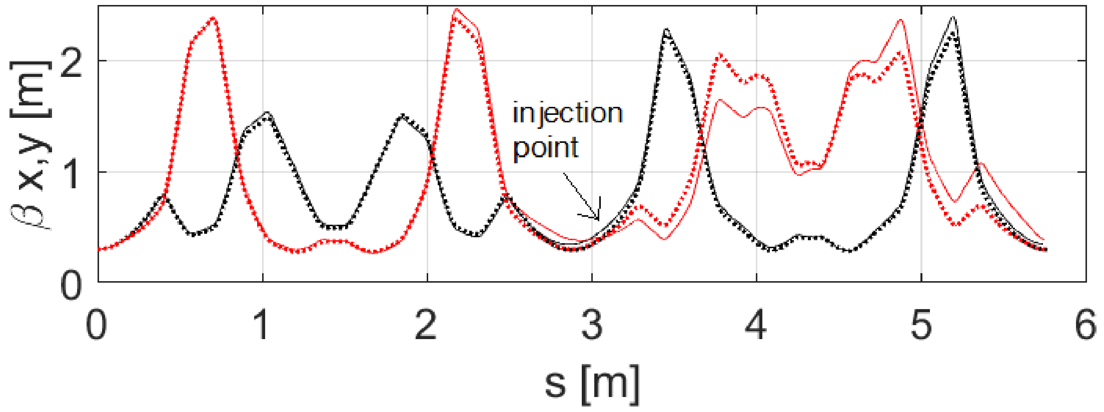
Diagram of the lattice structure for Nonlinear UMER

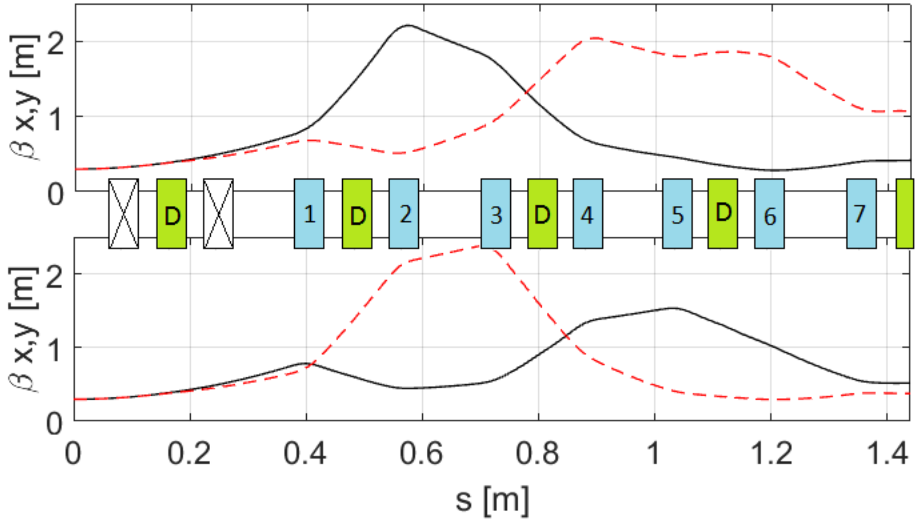


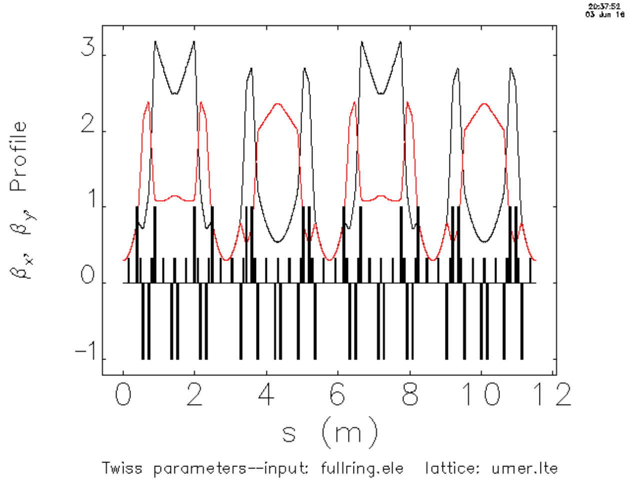


Lattice Design

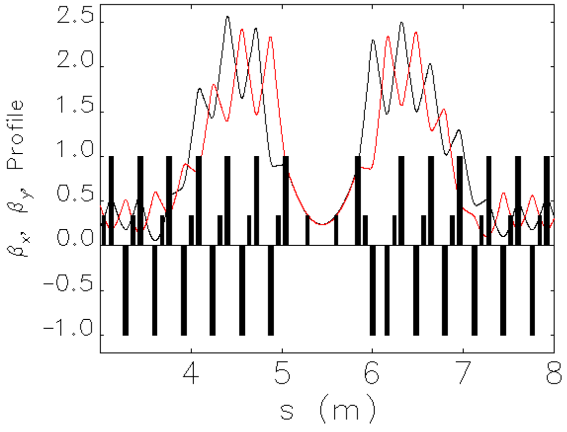
Half of ring, in non-FODO lattice:







$\Delta\Psi_{channel} = 0.23 * 2\pi$

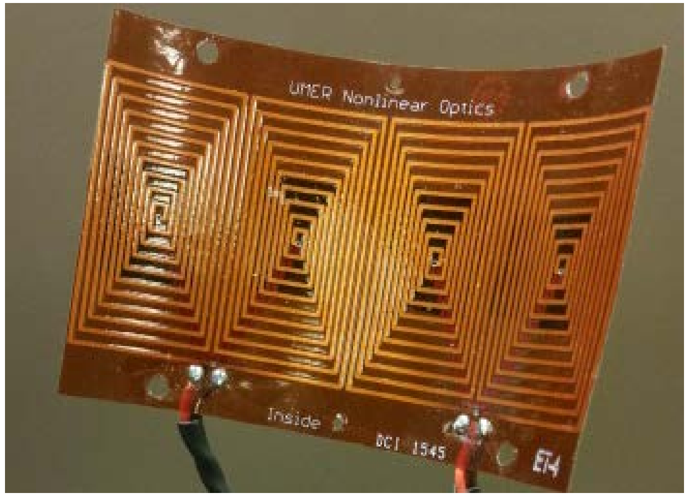


$\Delta\Psi_{oct} = 0.28 * 2\pi$

- $\beta_x = \beta_y$ in nonlinear insert
- Equivalent to thin lens kick
- Phase advance π
- Achromatic

Printed Circuit Octupole Magnets

Heidi Baumgartner, Dave Matthew

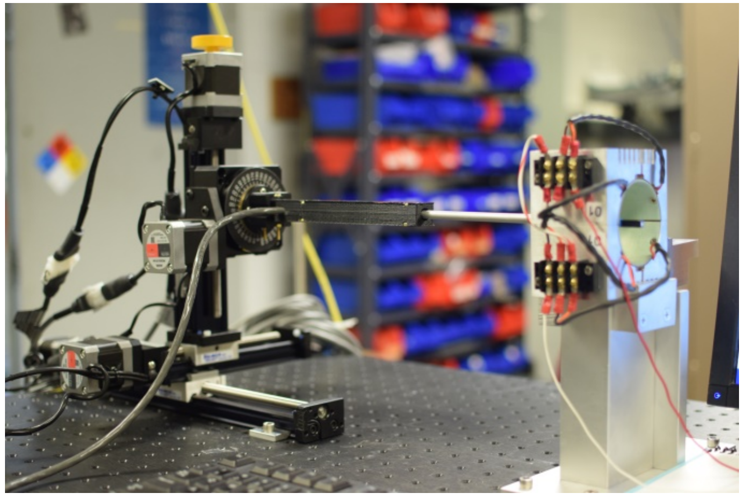


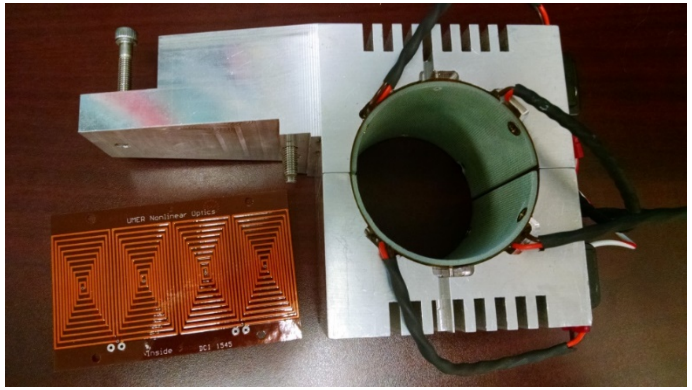
Measured: 51.6 ± 1.5 $T/m^3/A$

Predicted: 74 $T/m^3/A$

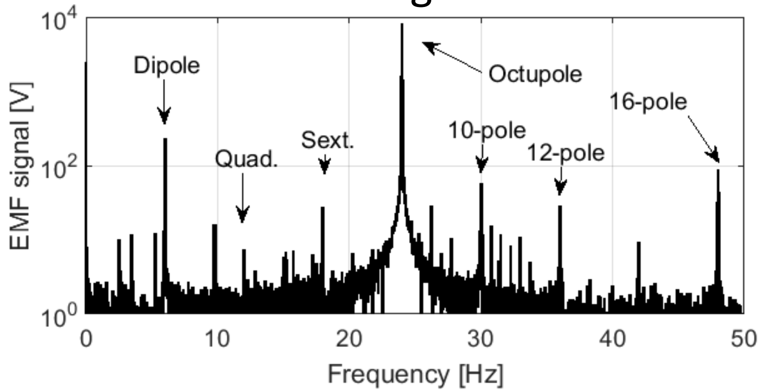
Higher order multipoles suppressed by 10^{-2}

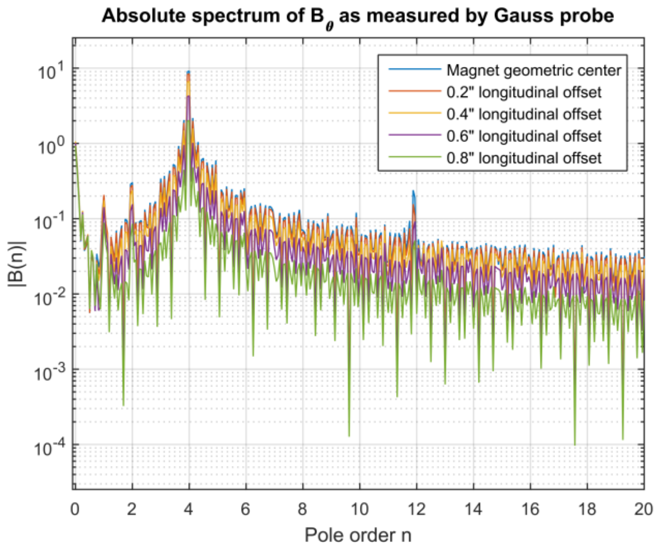
Quadrupole/sextupole components unexpected





Rotating coil data



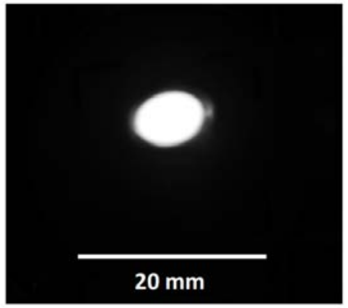


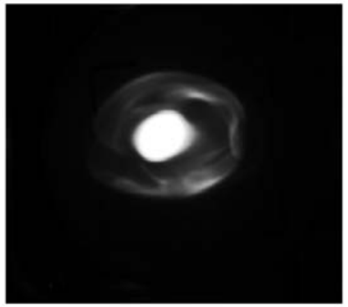
Experimental Plans

- Tune/ lattice function measurement
- Tune scan around integrable condition
- Halo damping

Starting with low current (~60 μA)

Need large number of turns





Dialed-in Halo

How many turns can we expect?

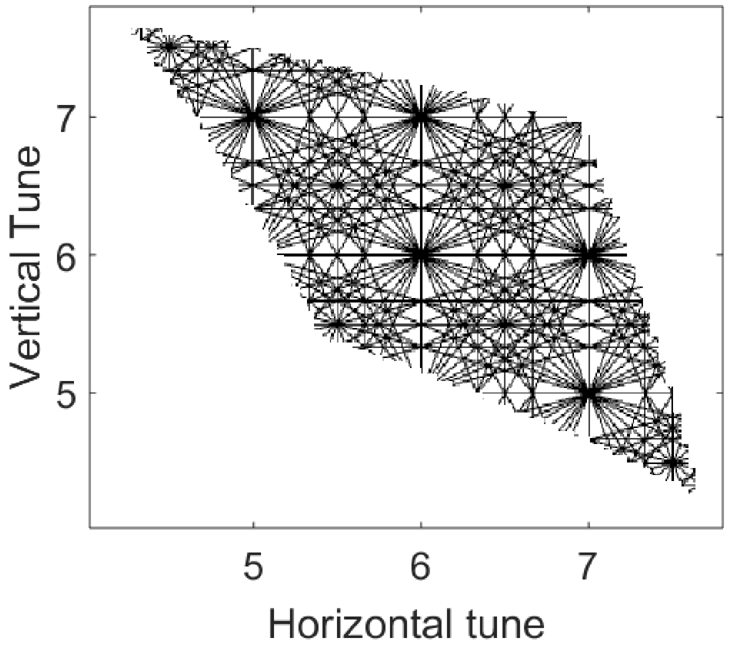
Is dominant loss mechanism due to transverse or longitudinal losses?

What is our sensitivity to transverse resonances?

Can we verify quasi-integrable condition is met? (Including accurate tune prediction and measurement)

UMER Beams

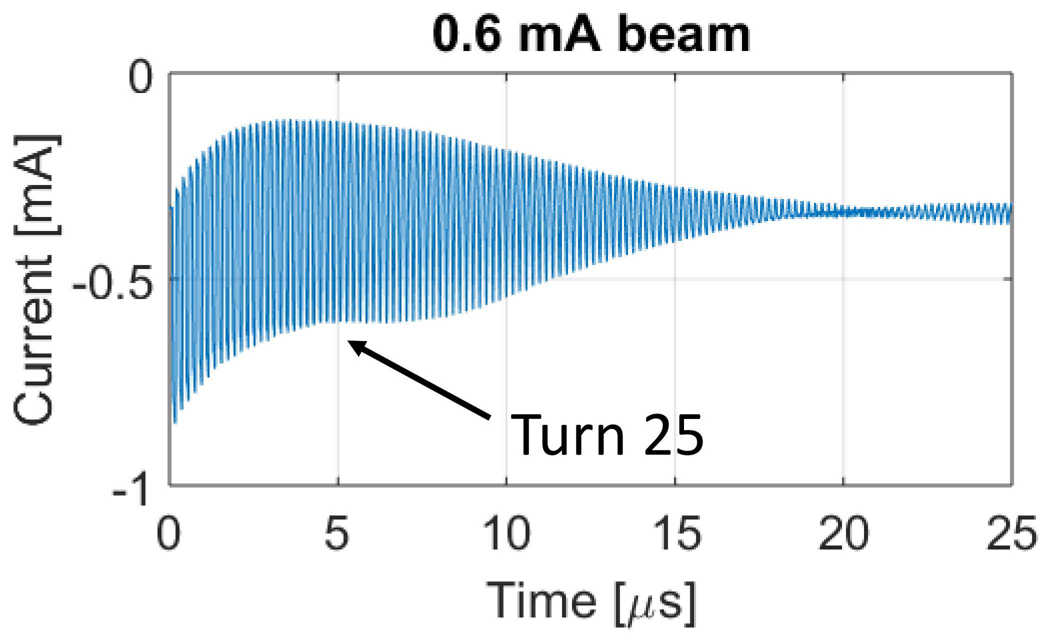
Current [mA]	Initial rms ε [μm]	Avg. Radius [mm]	v/v_o	Coherent tune shift	Incoherent tune shift
0.6	0.4	1.6	0.85	-0.005	0.94
6.0	1.3	3.4	0.62	−0.05	2.4
21	1.5	5.2	0.31	−0.17	4.5

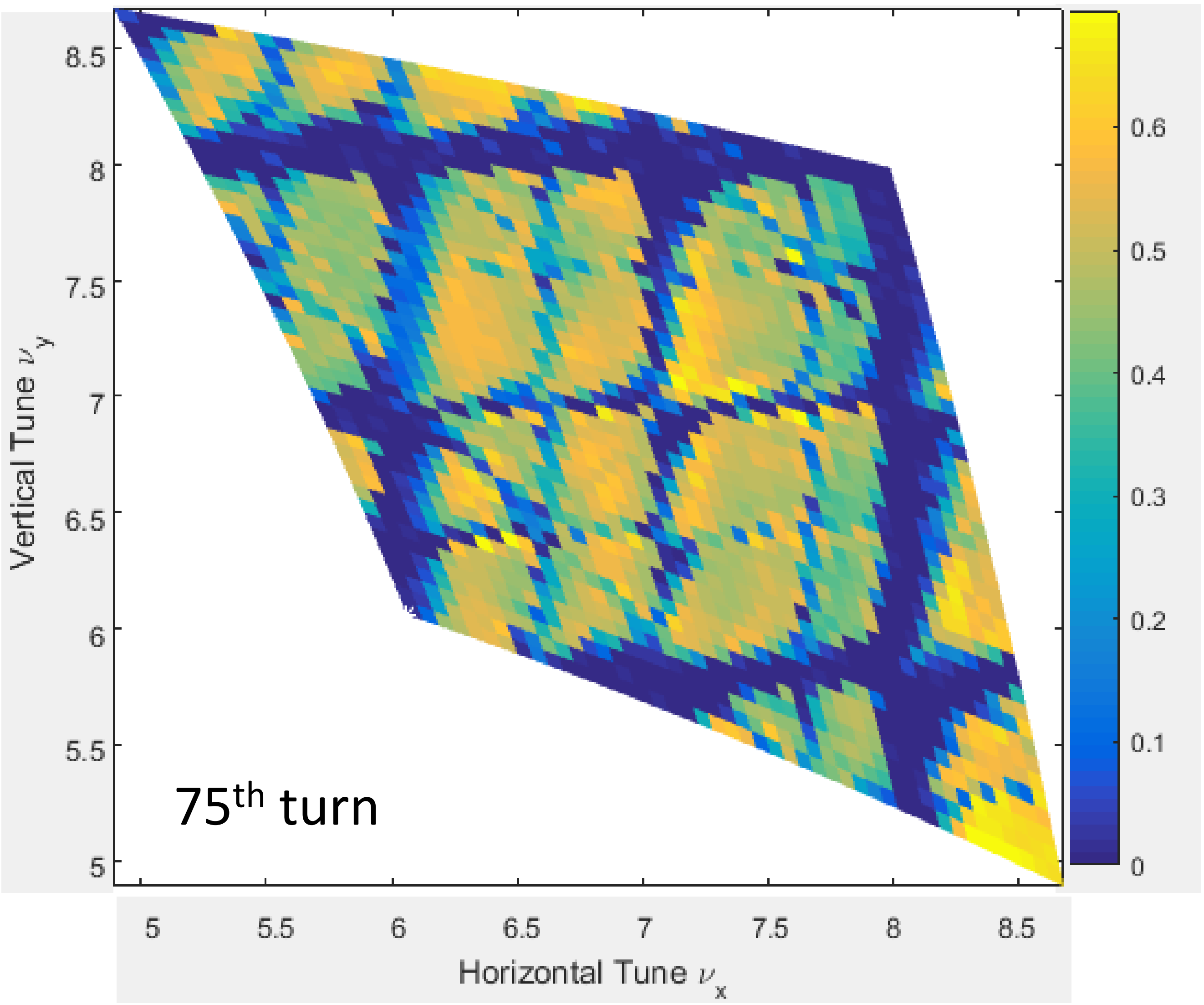


Beam Current	Approx. # Turns to Debunch	Approx. # Turns with Long. Focusing
60 μA	72	
600 μA	25	1,000
6.0 mA	9	100
21 mA	6	
104 mA	3	

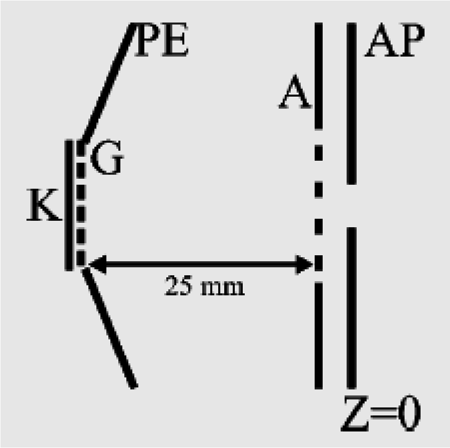
0.6 mA (Pencil Beam)

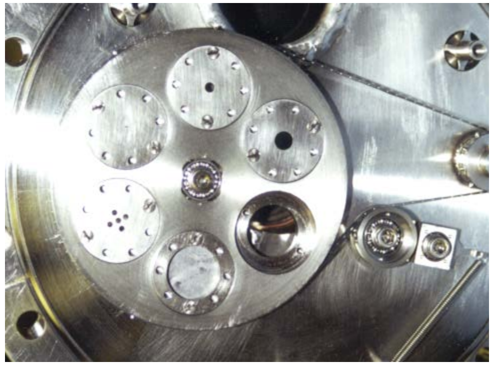
Current	Initial rms ε	Avg. Radius	v/v_o	Coherent tune shift	Incoherent tune shift
0.6 mA	0.4 μm	1.6 mm	0.85	−0.005	0.94





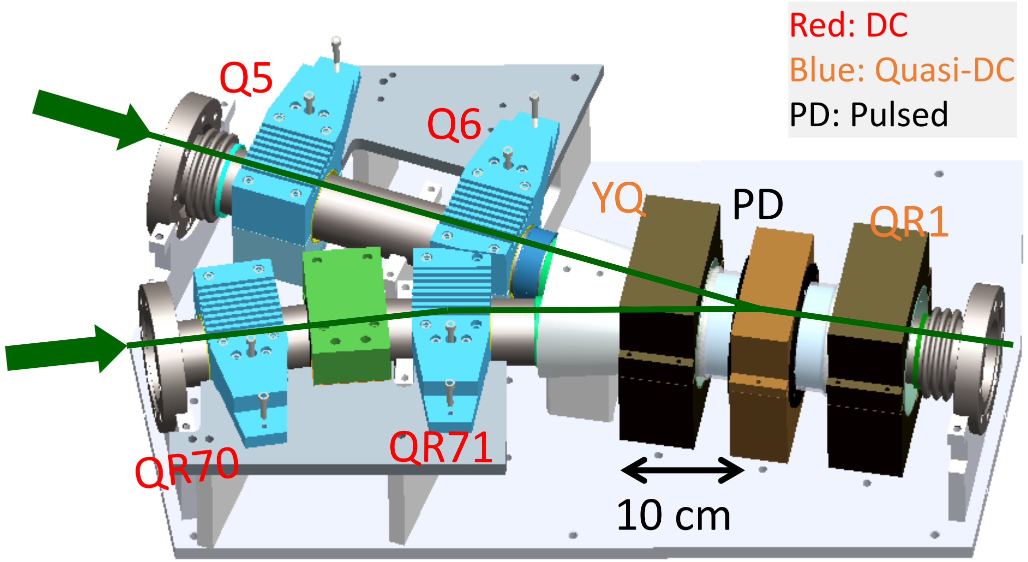
Low-current "DC-beam"

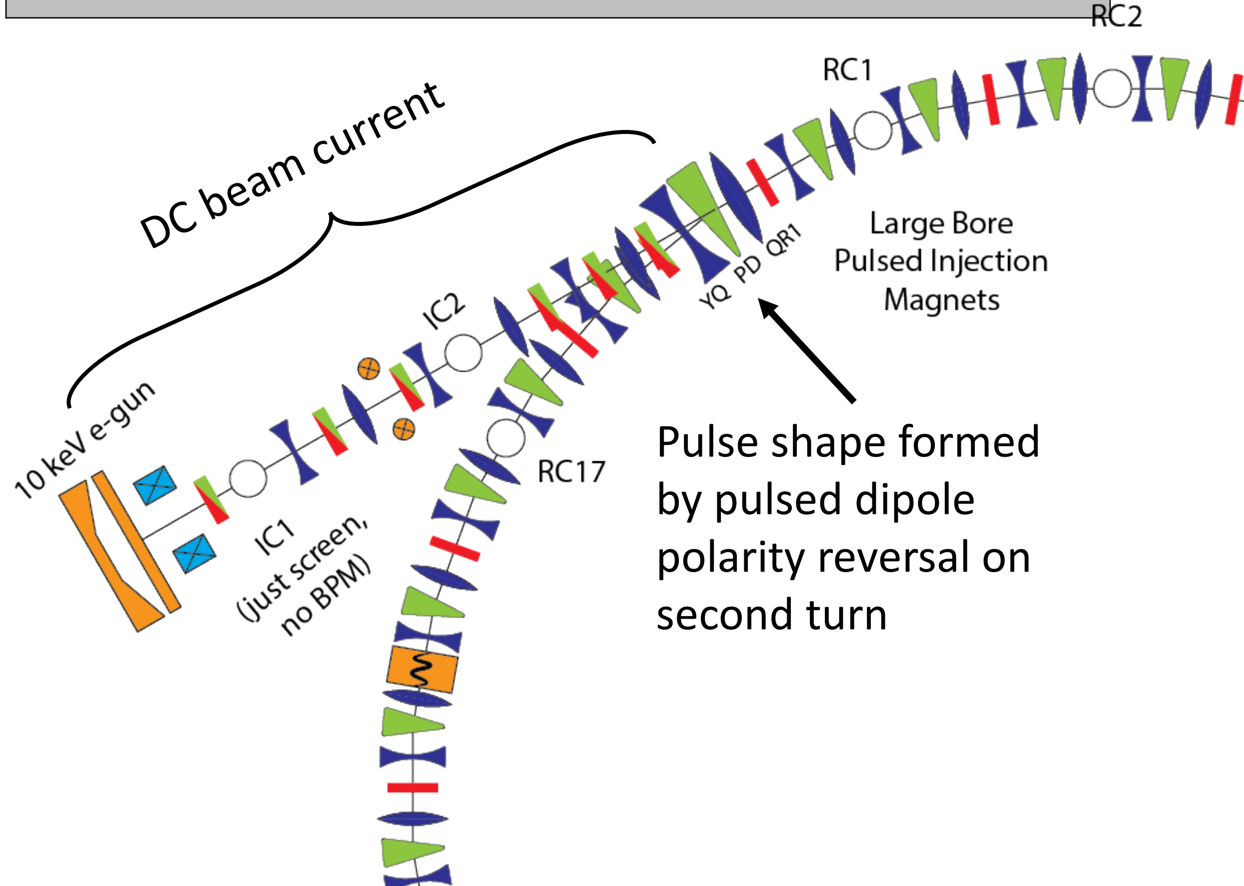




APERTURE PLATE

METHOD	BEAM CURRENT, PULSE LENGTH	MEASUREMENT
DC Electron Gun	10 –100mA, 100 ns	40mA, $\varepsilon_{x,y} \cong 300{,}100\mu m$

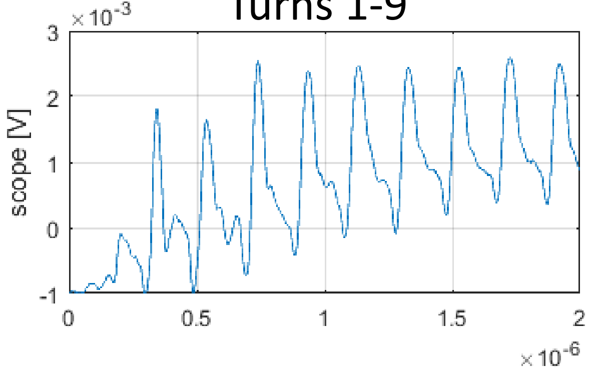




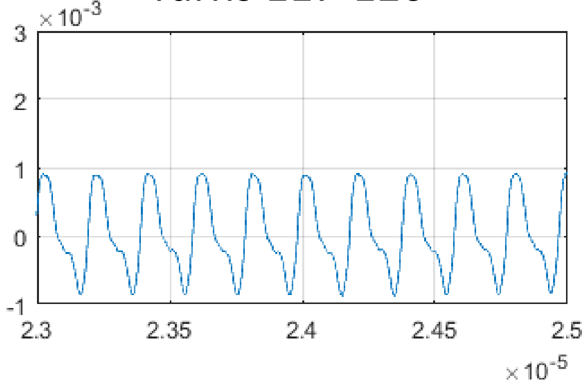
60 μA "DC-beam"

Current	Initial rms ε	Avg. Radius	v/v_o
60 μA	300 μm,100 μm	?	?

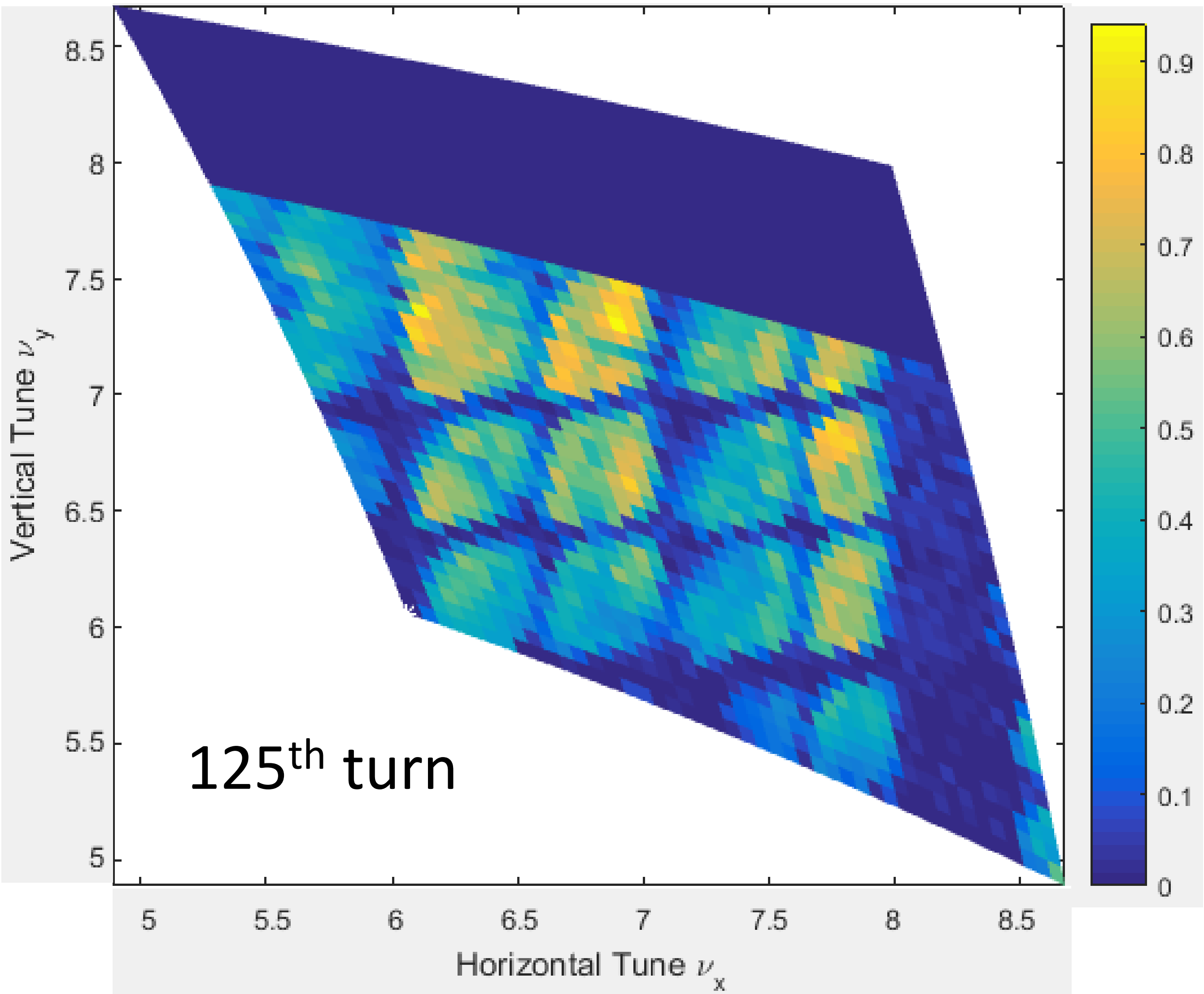
Turns 1-9



Turns 117-126



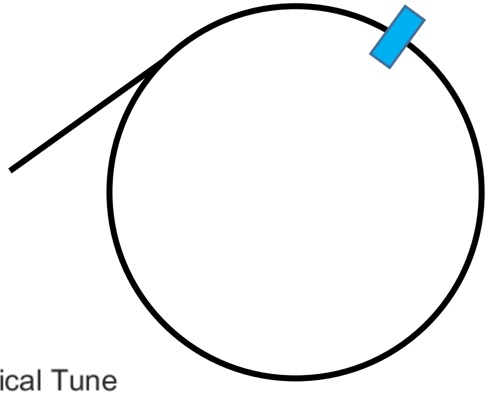
Virtually no end erosion or other losses beyond first 10 turns (out to 125)!

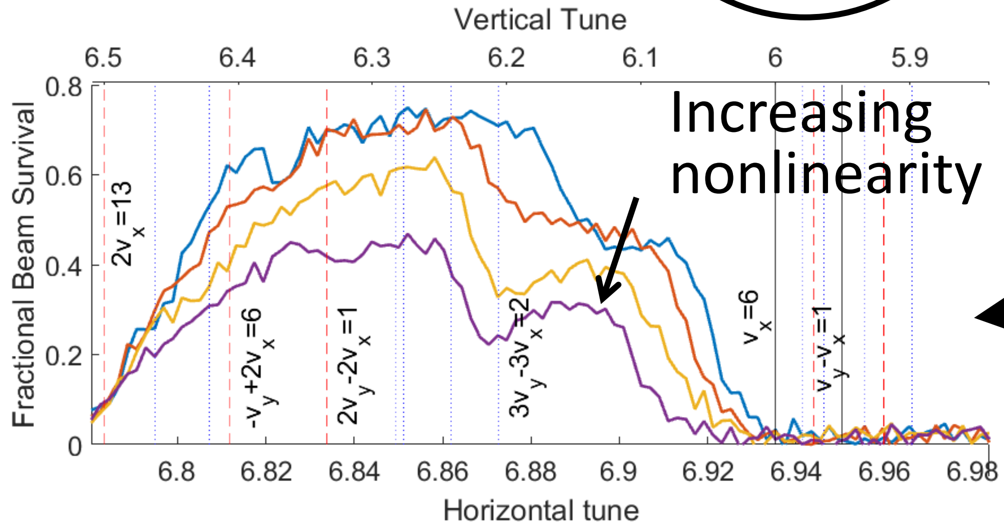


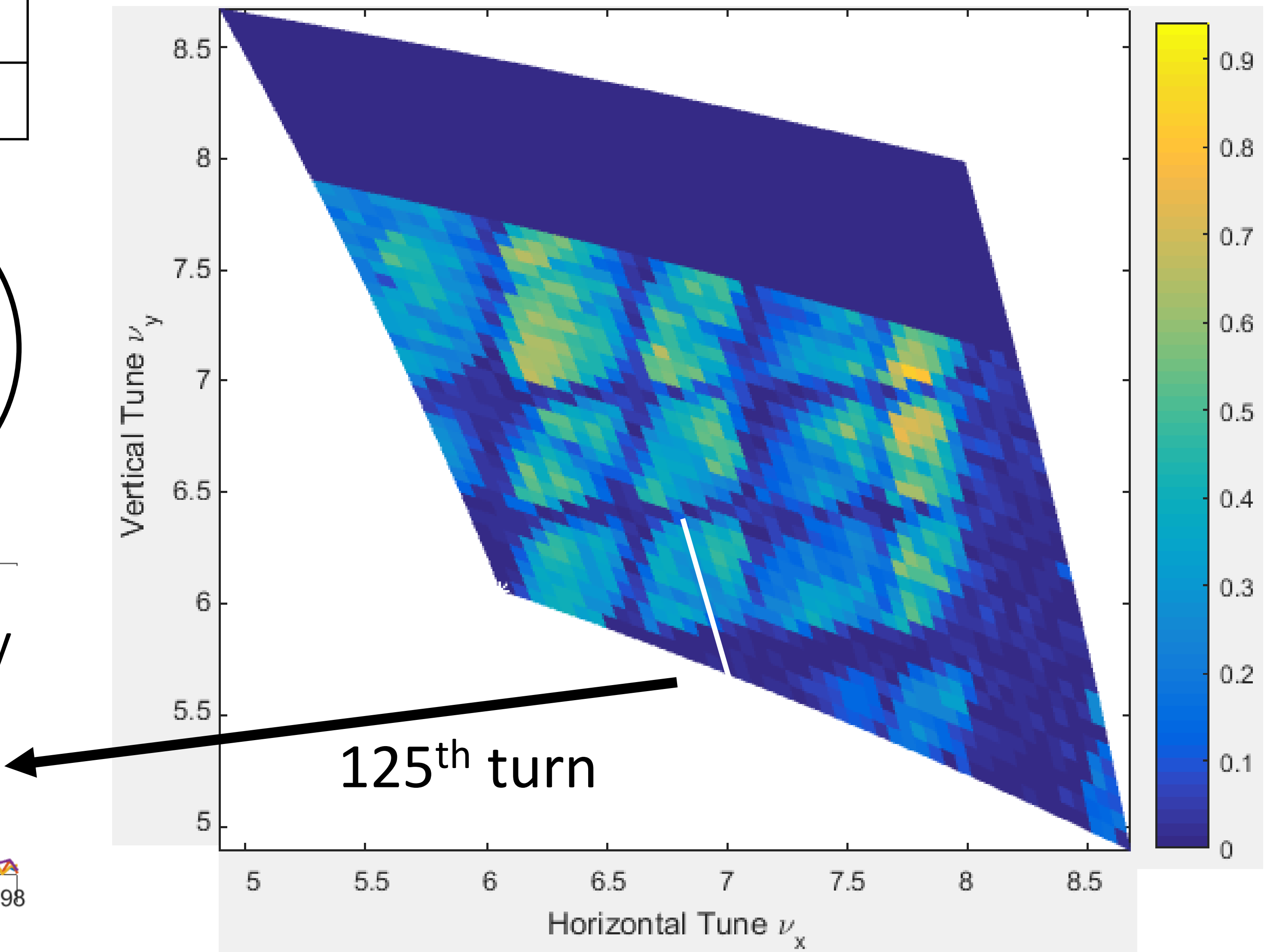
60 µA “DC-beam”

Current	Initial rms ε	Avg. Radius	v/v_o
60 µA	300 µm,100 µm	?	?

single octupole powered at 3 A, 155 T/m^3

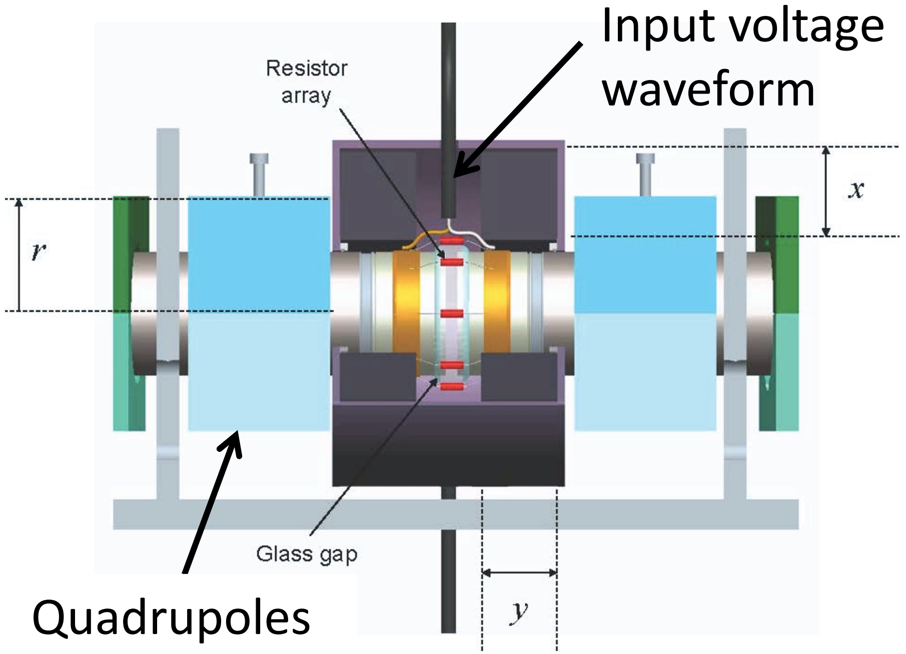


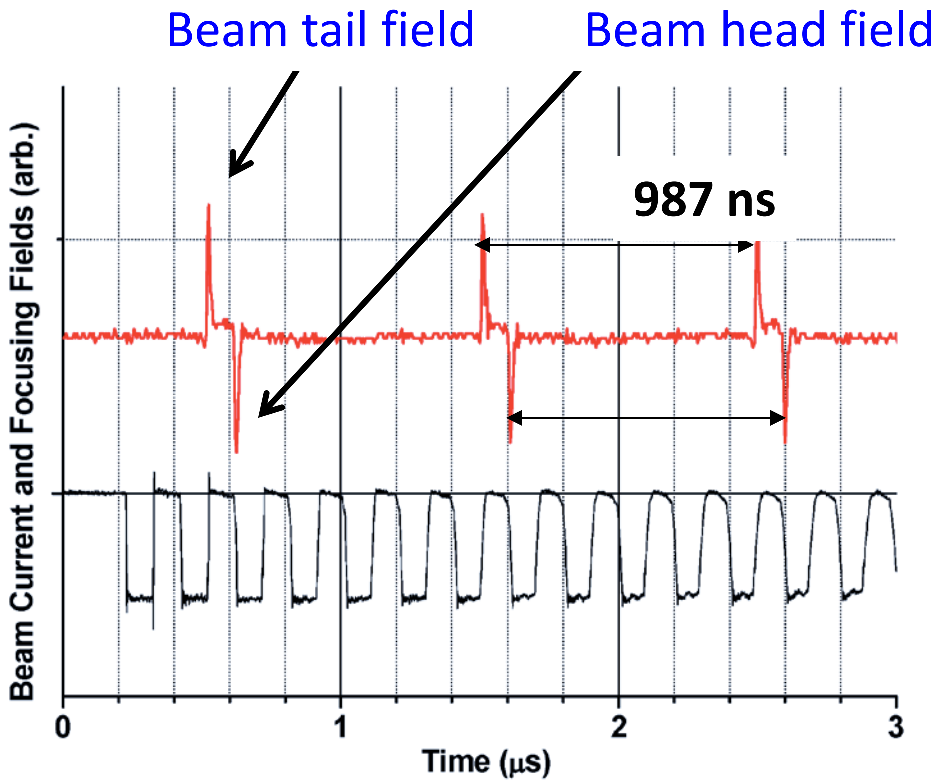




Longitudinal Confinement

Induction Cell in between Quadrupoles

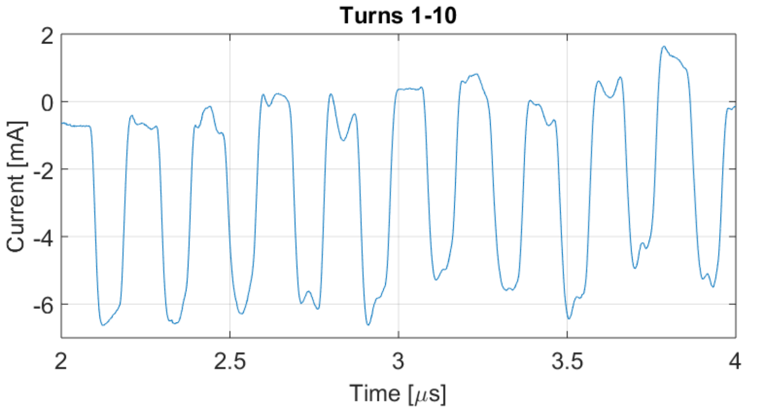


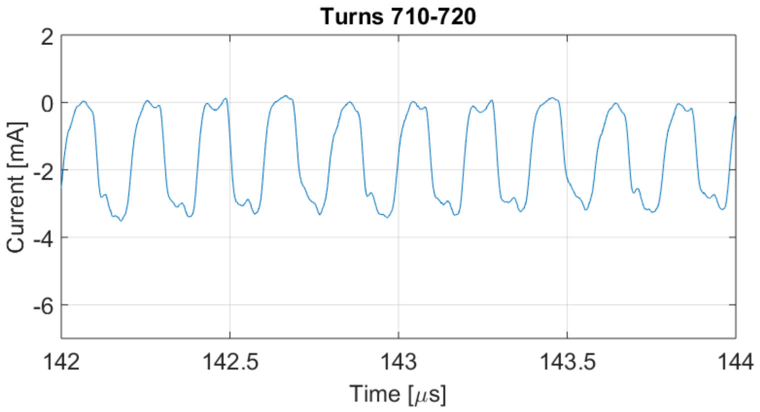


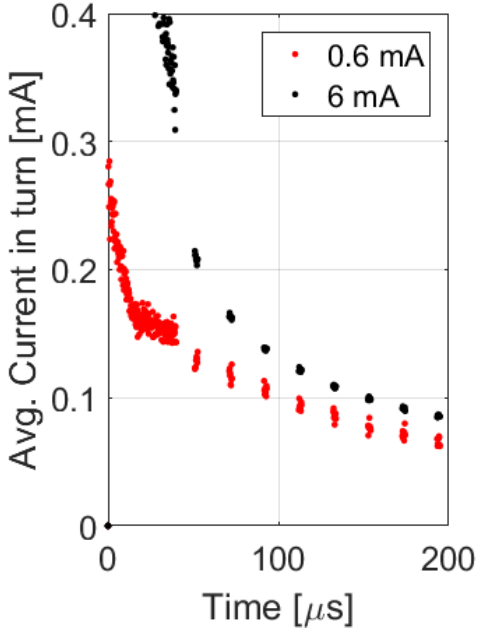
Pencil beam with confinement

Use RF induction cell to extend beam lifetime.

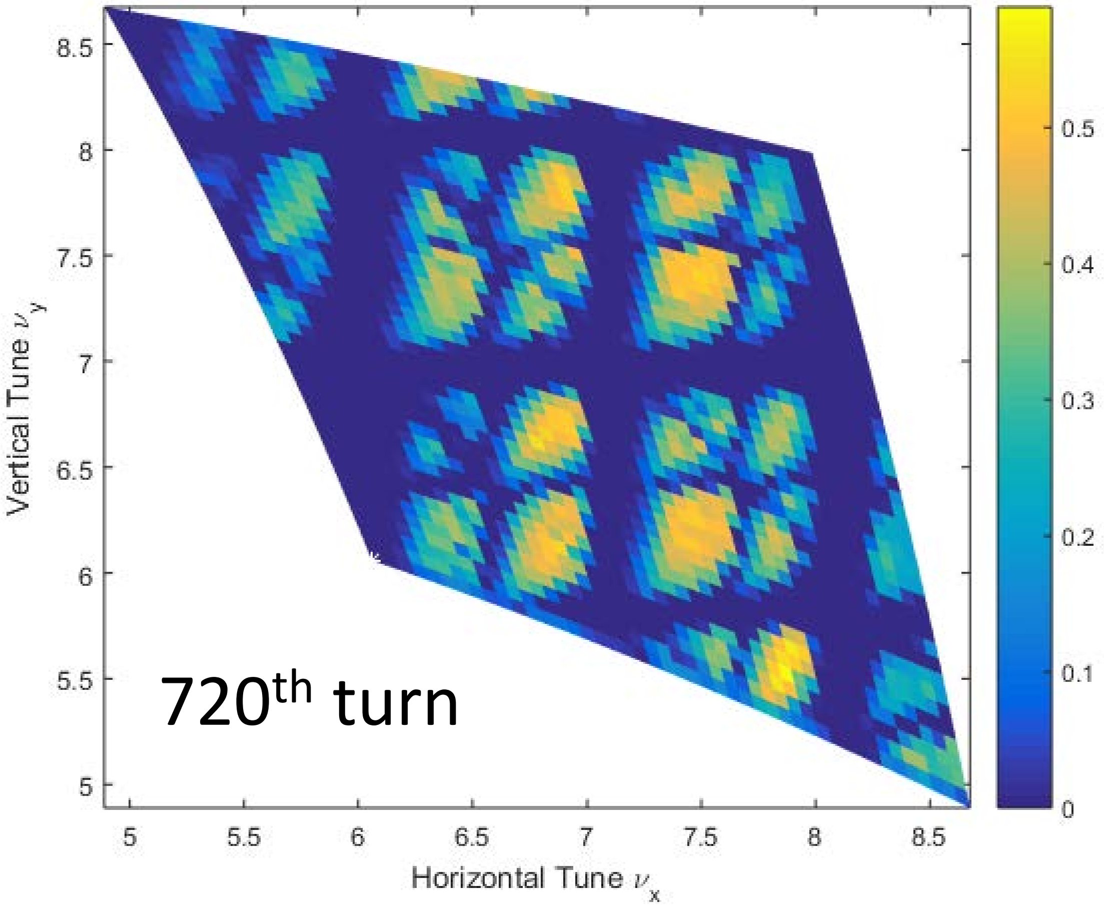
Pencil beam scan with 30% loss after 720 turns



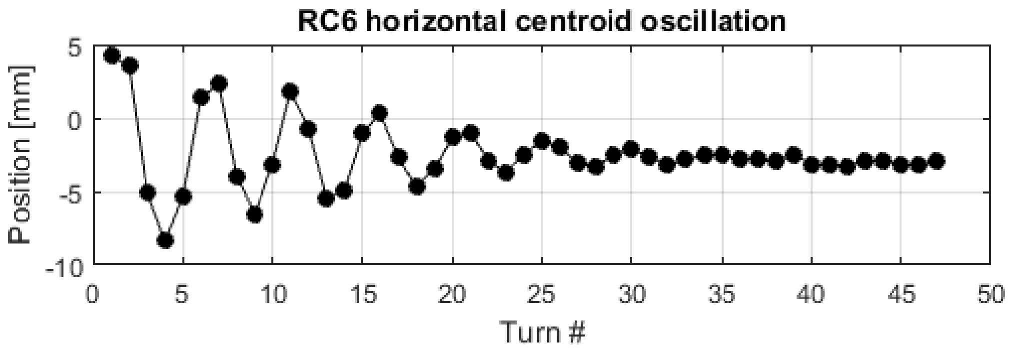


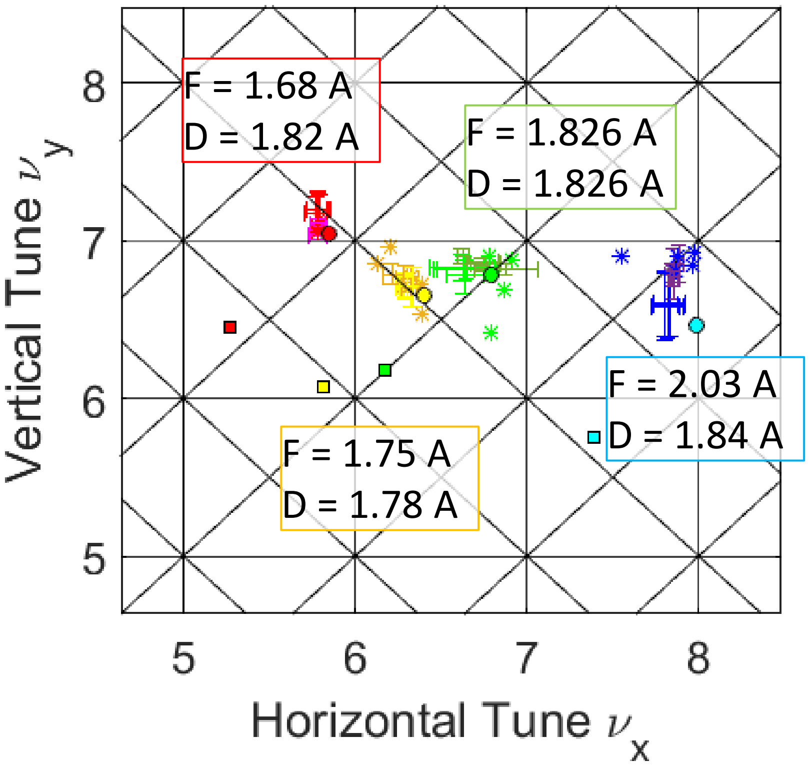


Loss curve measurement without confinement, 1000 turns



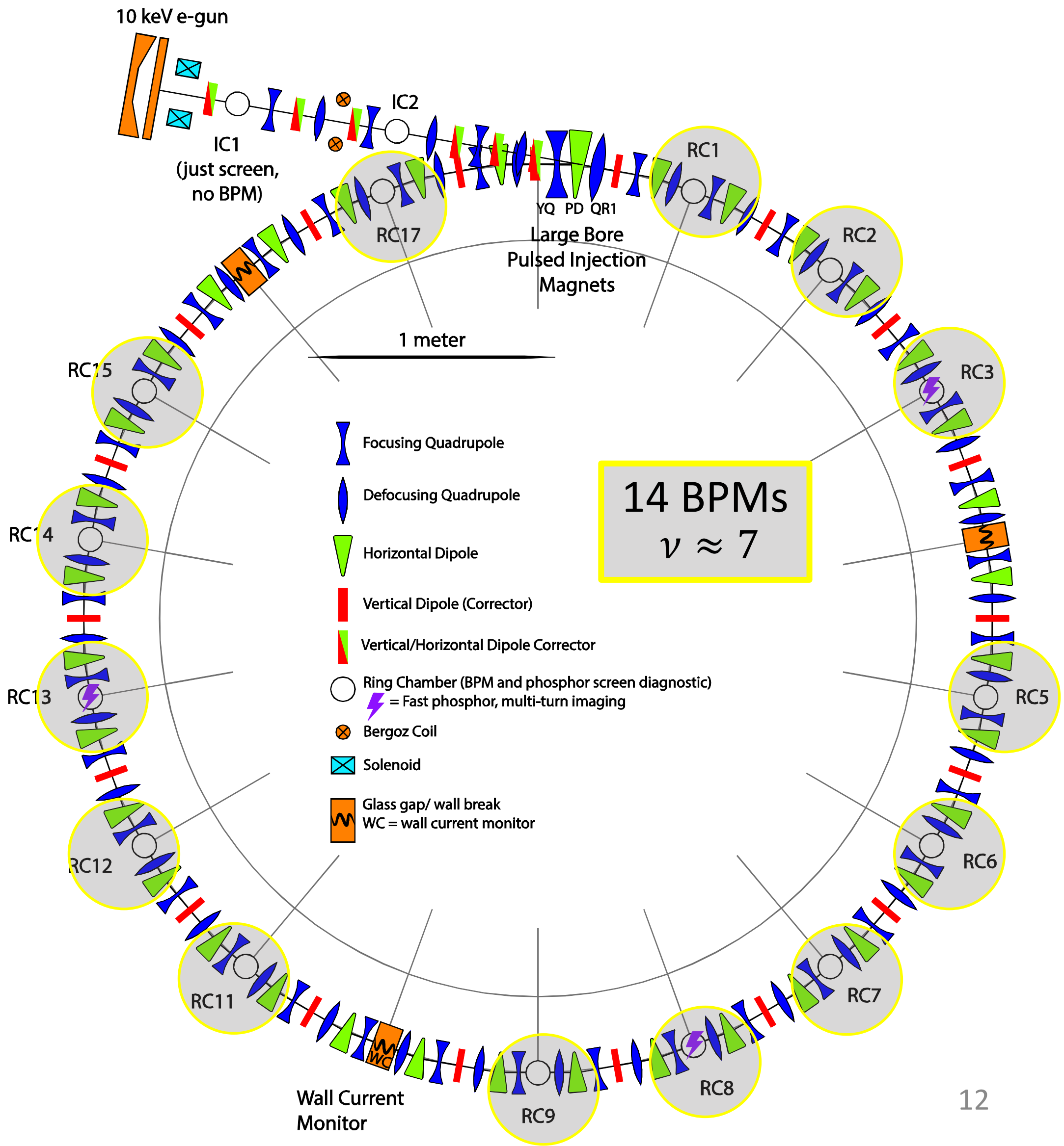
Measuring bare tune





Experimental tune measurement

□ WARP envelope model
○ Smooth approximation
* Sine wave fit
┼ fft/4 turn formula



Last year’s to-do list

Recommissioning of the beam — Experimental run with re-aligned beam

Simulation program to catch up to experimental — Working out kinks with magnet models. Experimental study for beam-based survey of magnets (Levon Dovlatyan)

- Quantify conservation of Hamiltonian/ tune spread

Characterization of octupoles — See NAPAC ’16 proceedings, Heidi Baumgartner

Mechanical framework for single-channel experiment on 20-degree section — In-progress

Distributed octupole lattice tests at improved operating point — On hold for now, in favor of experimental studies to support planned octupole lattice experiments

Ongoing work

Simulation effort

- Correction for edge-focusing effect on matching (aided by beam-based survey of dipoles)
- Lattice design with less sensitivity to errors

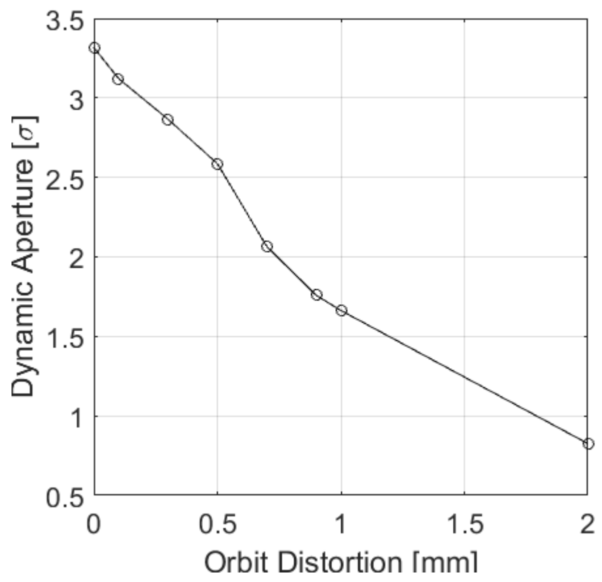
Experimental Effort

- Characterizing resonances/loss rates of low-current DC beam beyond 125 turns
- Longitudinal confinement for assisting many-turn studies – addressing noise and shock-wave effect on measurement of transverse losses.
- Verifying models against tune measurement
- Beam injection to non-FODO lattice

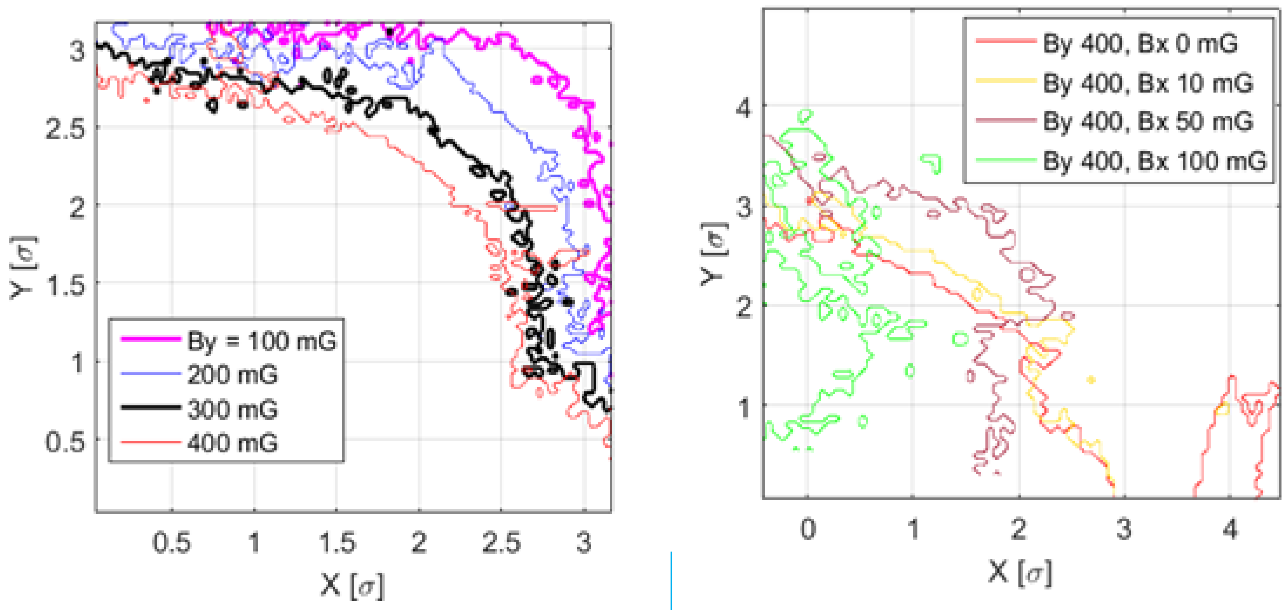
Ring improvements

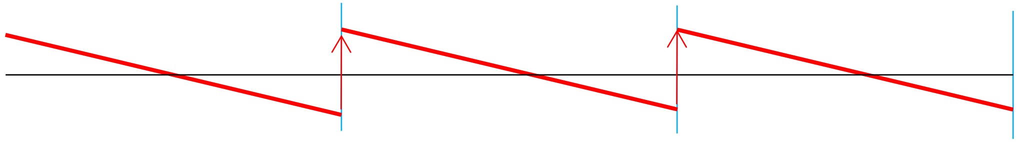
- Full implementation of vertical steering upgrade
- Long octupole channel in-progress
- Installation and characterization of new apertures

Steering Tolerances

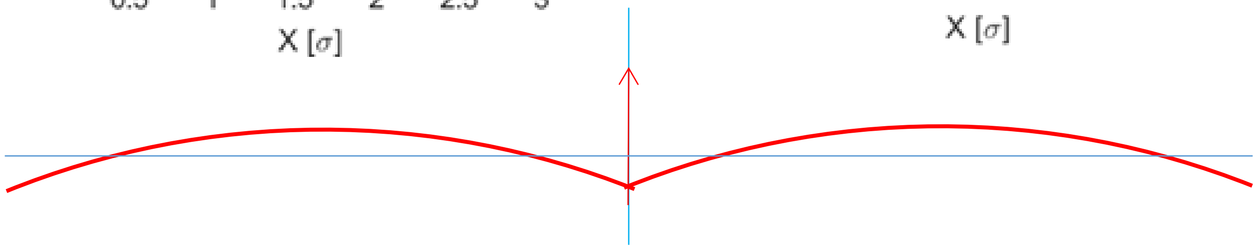


"Toy model" WARP simulations with steering error;
Left: dependence on orbit distortion
Right: immersed in background field





Modeling of orbit distortion

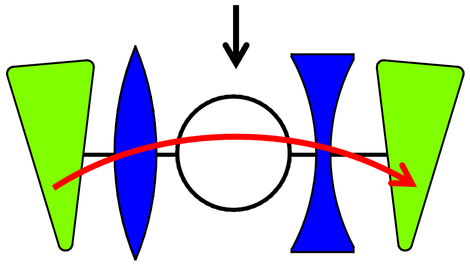


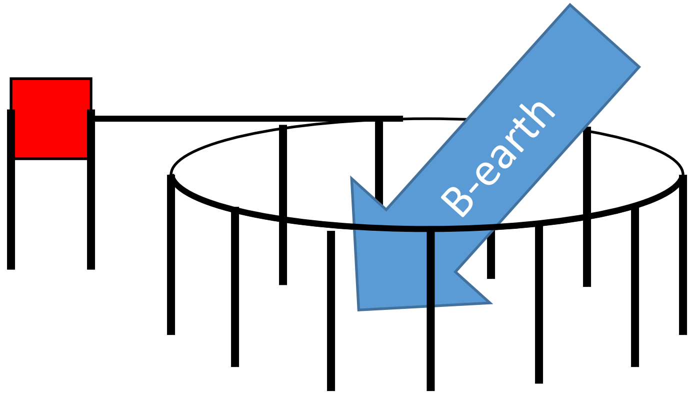
Modeling of beam immersed in background field

Steering tolerances

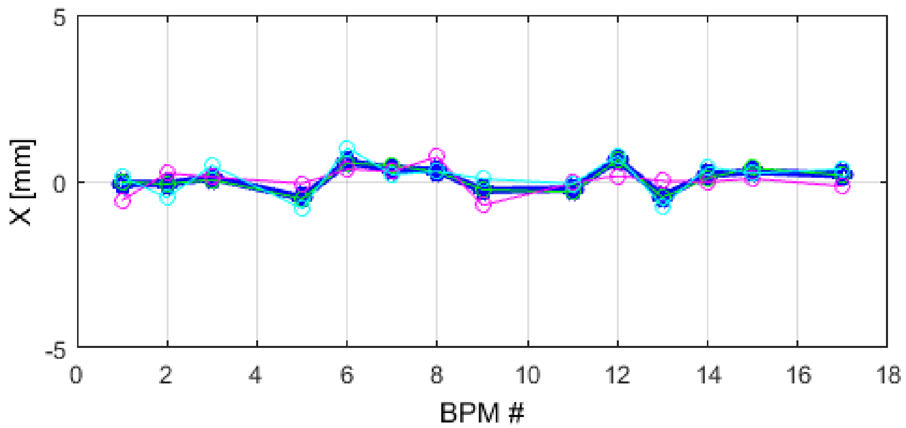
1st turn orbit control; deviation from quadrupole center			
	2017	2016	2013
X RMS [mm]	0.4	1.2	3.4
X Maximum [mm]	1	4.1	> 20
Y RMS [mm]	3.2 (0.6)	3.2	7.4
Y Maximum [mm]	10.8 (3.6)	10.8	> 20
Multi-turn control < 1.2 mm			

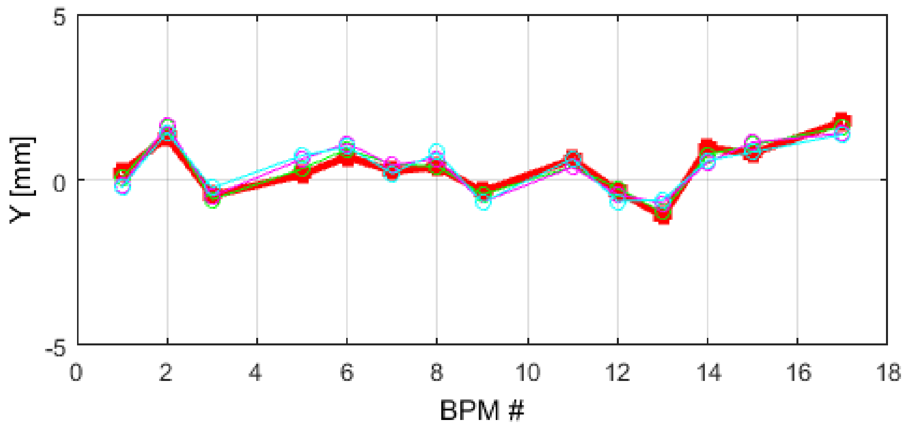
BPM location





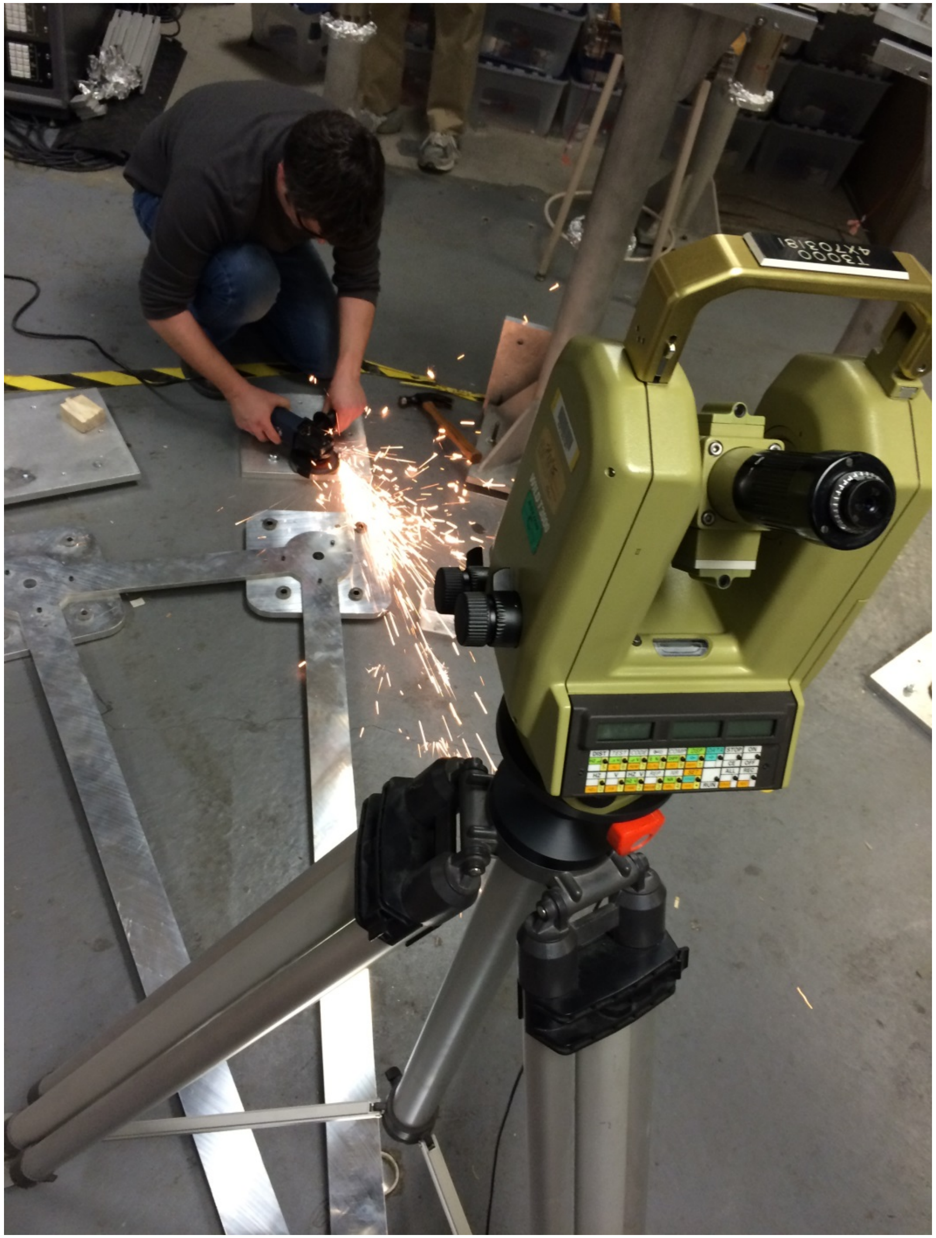
BPM Data



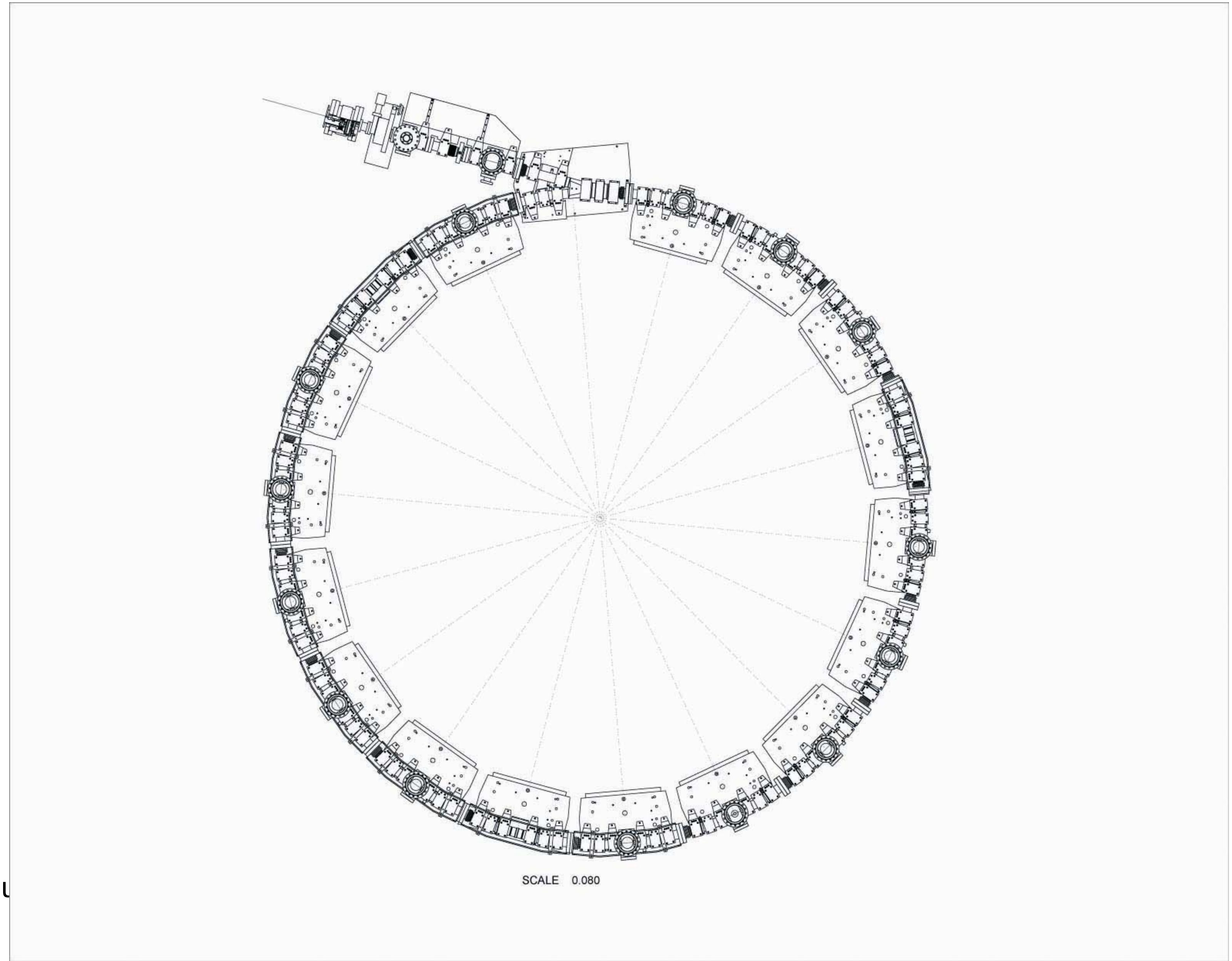


Back Up Slides

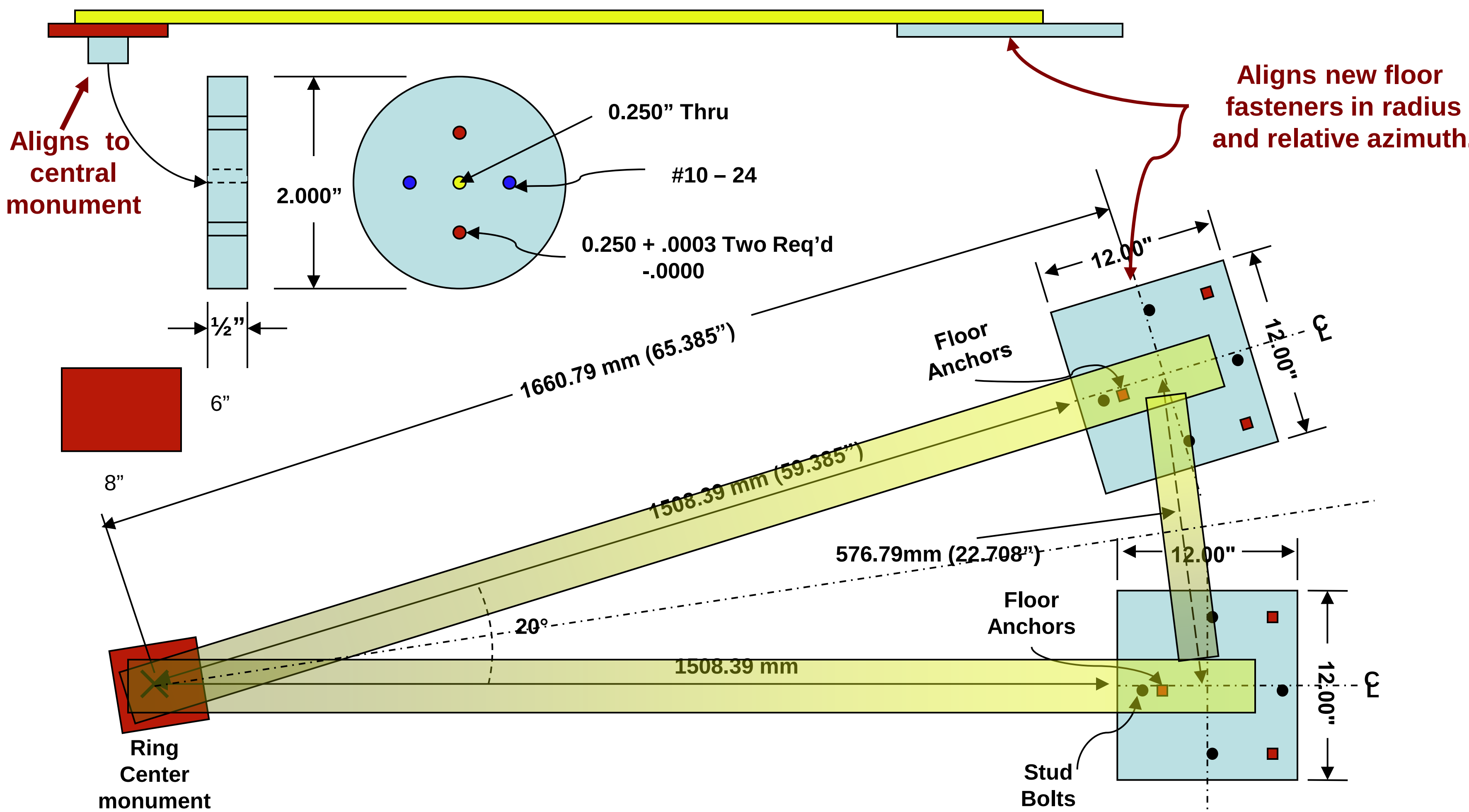
Installing a Base Plate

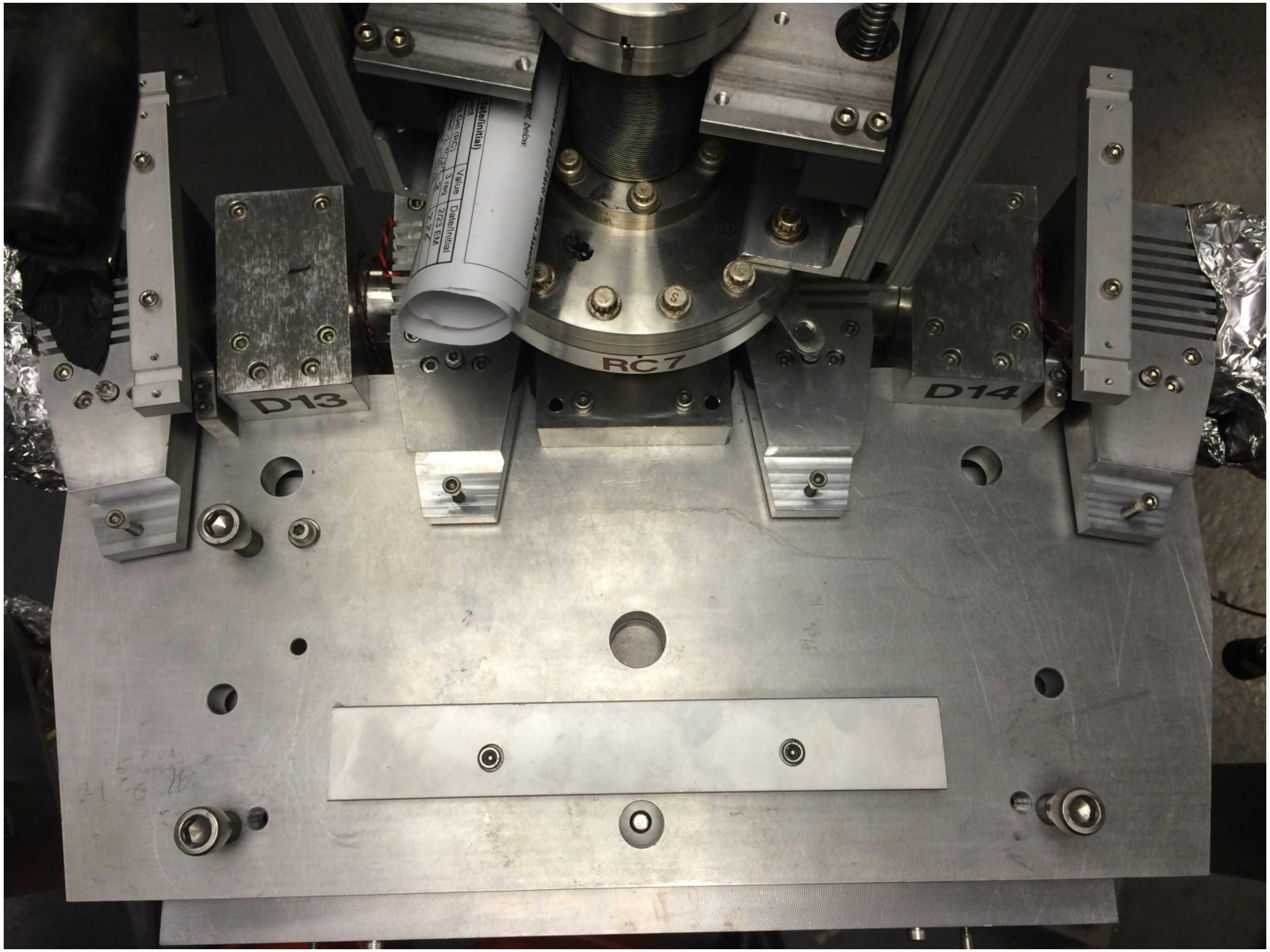


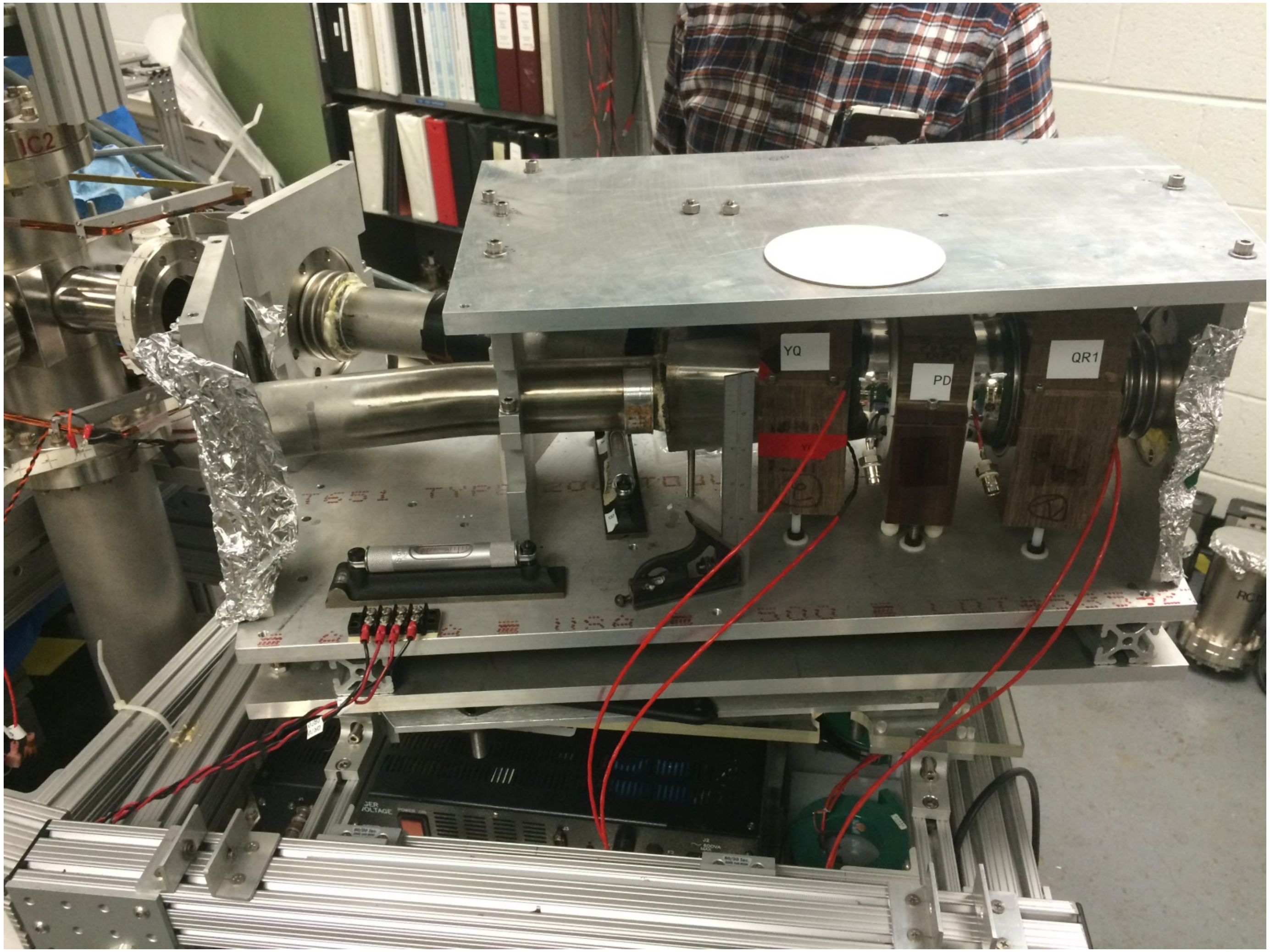
Mechanical Layout



Refastening Template

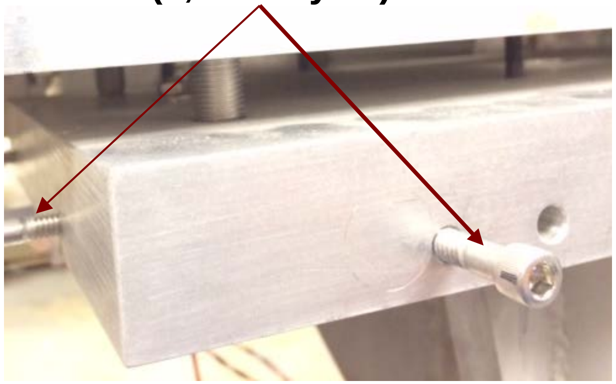


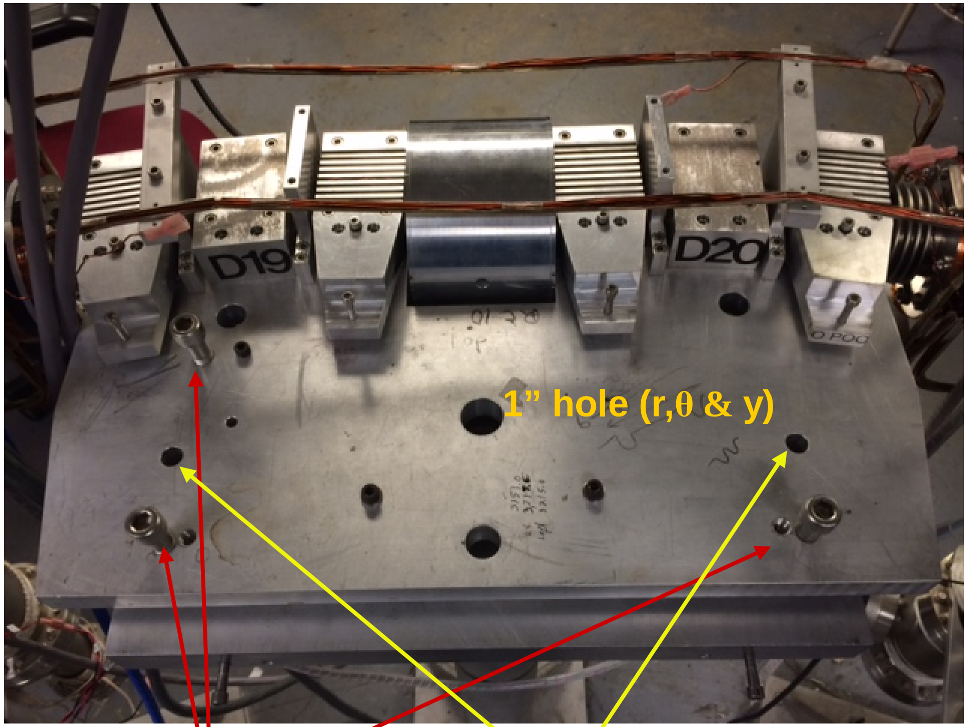

D13
RC7
D14


YQ
PD
QR1

Mechanical Alignment (cont.)

x, z plate position adjustment screws (x, z and yaw)





20° plate vertical adjustment screws (roll, pitch,y)

Left & Right rotation holes (r, and yaw)