Accelerator Challenges for an MBA Machine

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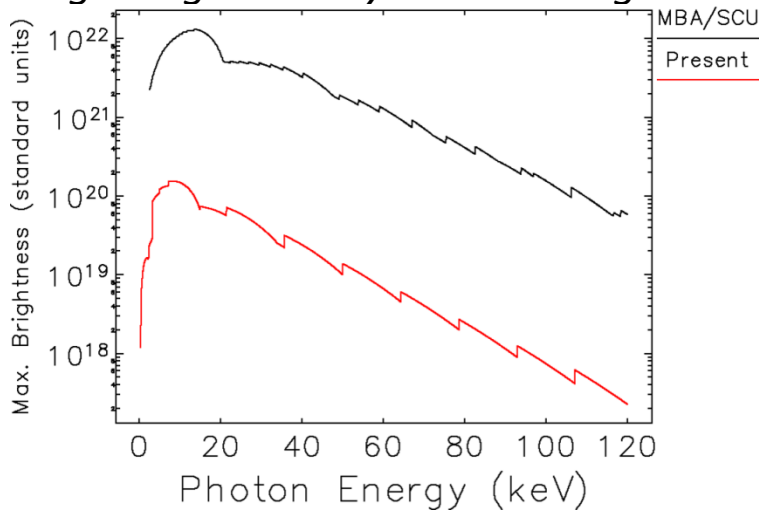
Outline

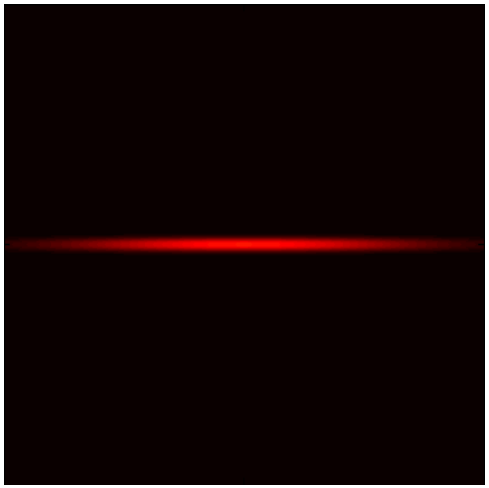
- Five things
  - Magnets / Supports / Alignment
  - Vacuum
  - Beam stability
  - Injection
  - Installation
- Summary

MBA improvement

Dramatically enhance the performance storage-ring-based synchrotron light sources



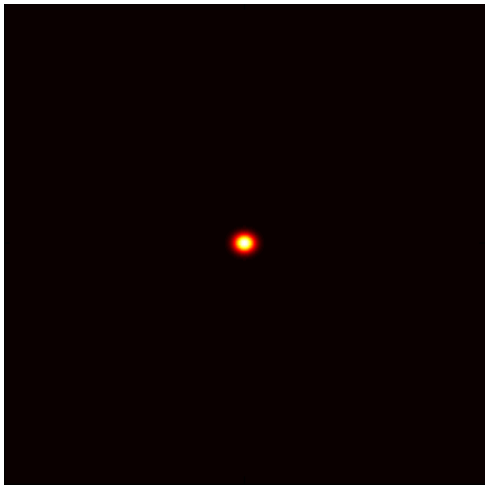
APS Now



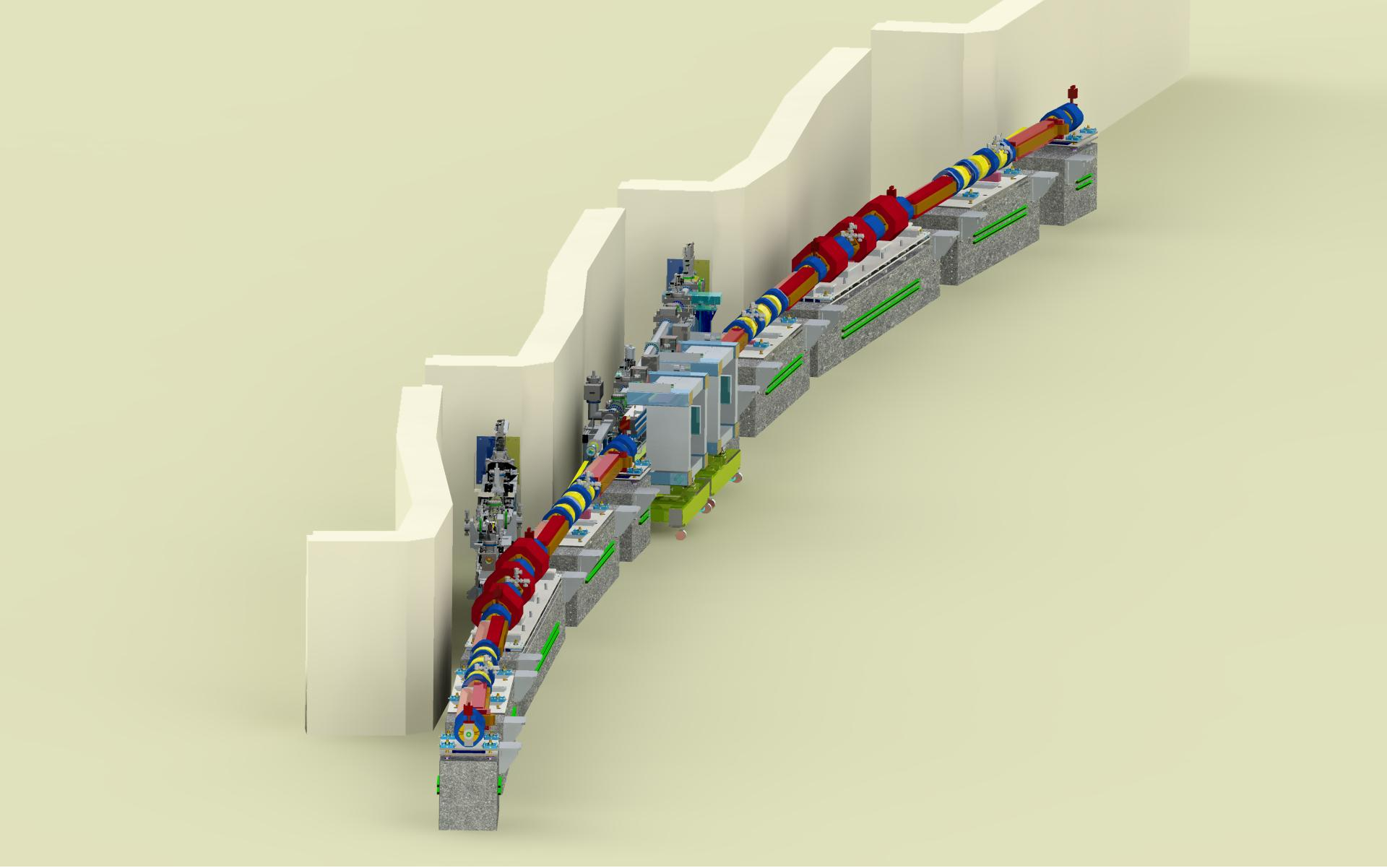
Comparison inspired by C. Steier, LBNL

Particle Beam Profiles

MBA

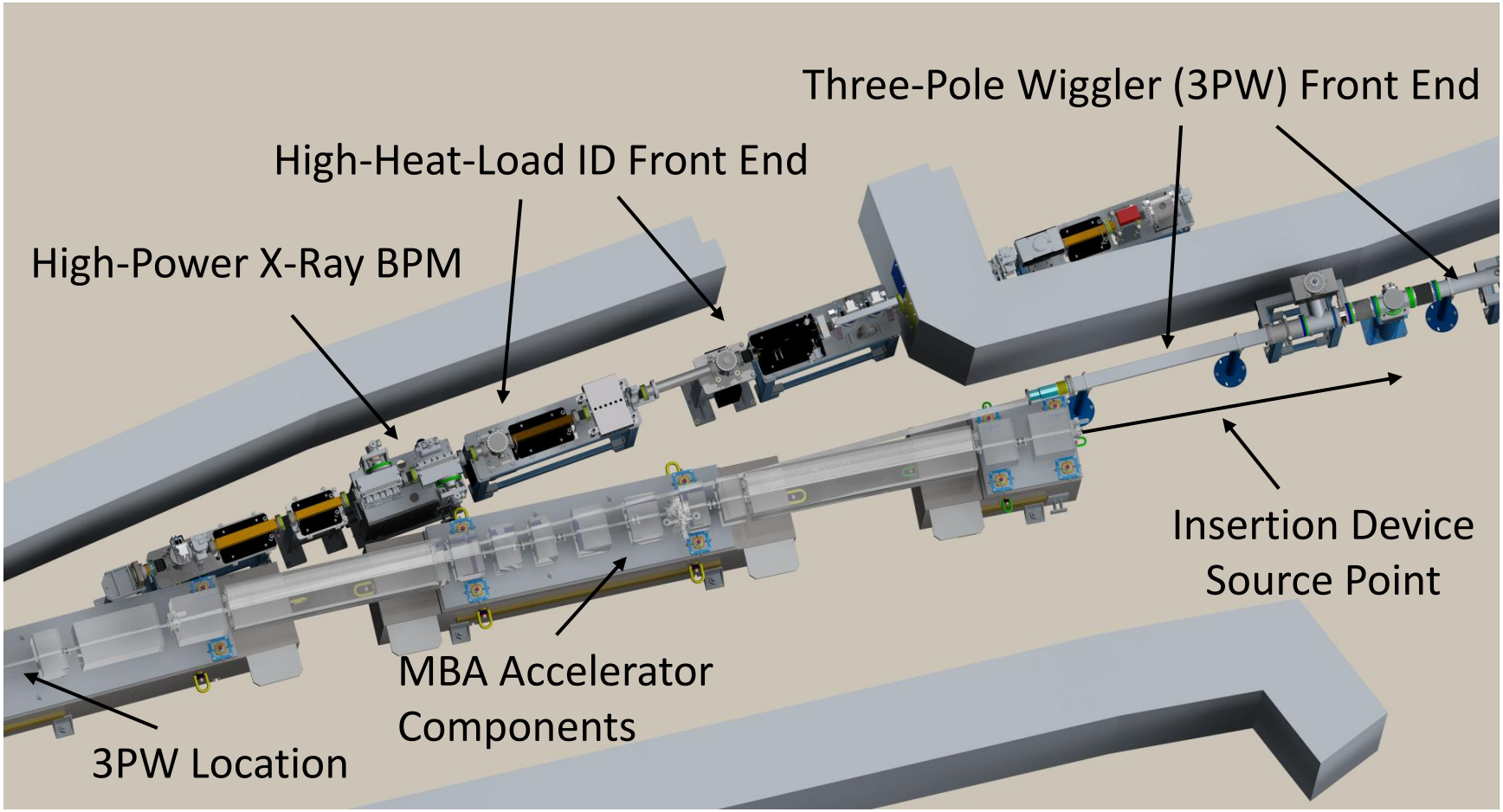


1 mm

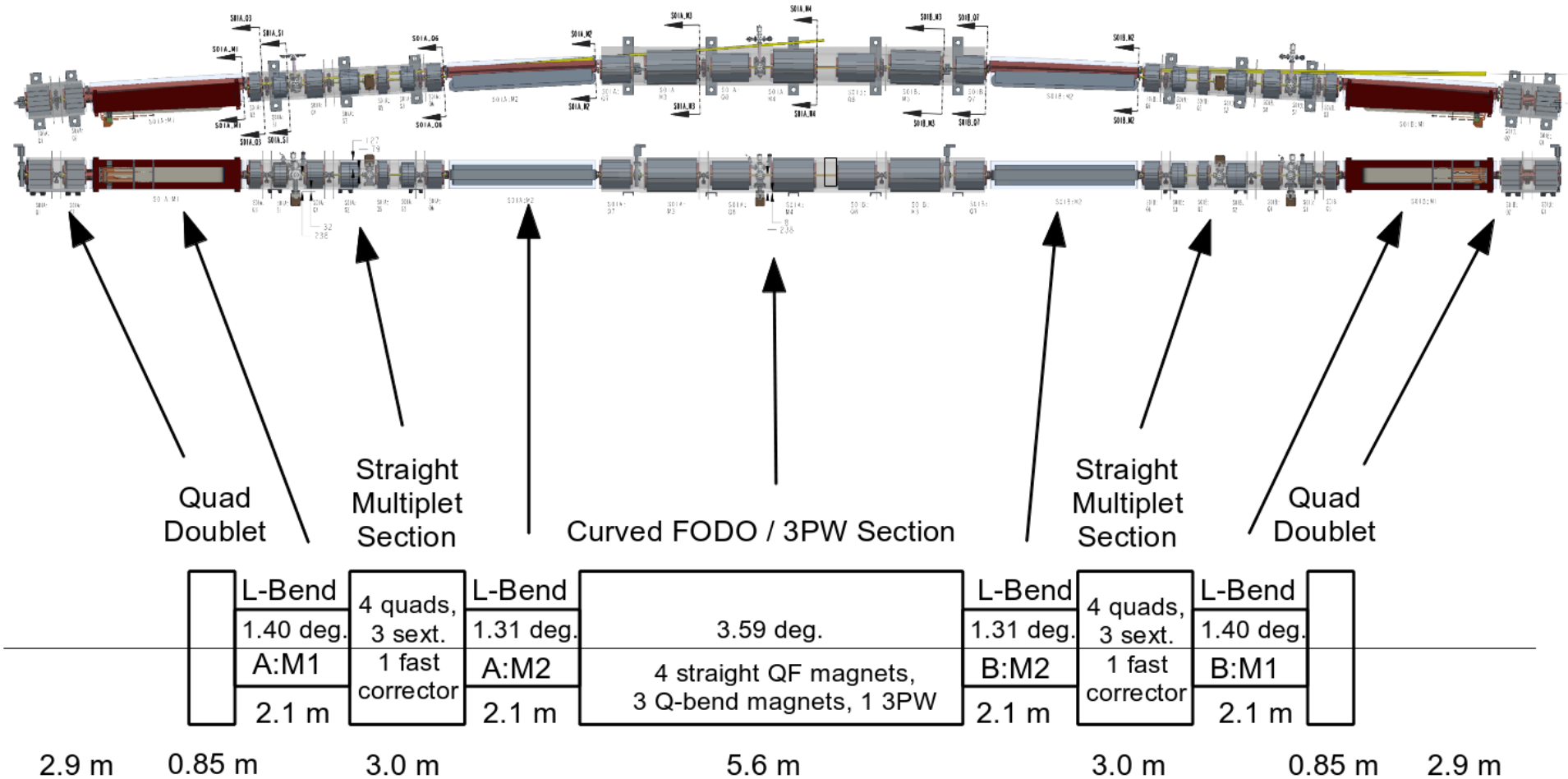


Two Sector Rendering, MBA@APS

In-Tunnel Arrangement of Components



APS H7BA Implementation



Original lattice concept from ESRF.
L. Farvacque *et al.*, Proc. IPAC13, 79 (2013).

MBA@APS Magnet Parameters*

Dipole parameters

Name	Length m	Angle deg	B_0 T	B' T/m	E_c keV	$P_{\mathrm{d,integ}}$ W/mrad	P_d $W/mrad^2$	Count
M1 (x80)								
M1.1	0.153	0.279	-0.636	-0.000	15.2	116.0	893.7	80
M1.2	0.203	0.238	-0.410	-0.000	9.8	74.7	575.9	80
M1.3	0.612	0.423	-0.241	-0.000	5.8	44.0	339.2	80
M1.4	0.744	0.314	-0.147	-0.000	3.5	26.9	207.1	80
M1.5	0.388	0.141	-0.127	-0.000	3.0	23.2	178.7	80
M2 (x80)								
M2.1	0.386	0.127	-0.115	-0.000	2.8	21.0	161.6	80
M2.2	0.345	0.133	-0.134	-0.000	3.2	24.5	188.5	80
M2.3	0.557	0.343	-0.215	-0.000	5.1	39.2	302.0	80
M2.4	0.321	0.243	-0.264	-0.000	6.3	48.2	371.2	80
M2.5	0.508	0.462	-0.318	-0.000	7.6	58.0	446.6	80
M3 (x80)								
M3.1	0.390	0.617	-0.553	45.372	13.2	100.8	777.0	80
M3.2	0.390	0.617	-0.553	45.372	13.2	100.8	777.0	80
M4 (x40)								
M4.1	0.325	0.562	-0.605	47.215	14.5	110.2	849.4	40
M4.2	0.325	0.562	-0.605	47.215	14.5	110.2	849.4	40

Bending magnet parameters for H7BA-TwoSector-nux95-nuy36-3PW-Version6

*From M. Borland, APS-ASD

Quadrupole Parameters

Element Name	Length m	K_1 $1/m^2$	B' T/m	B'L T	Count
Q1	0.238	3.601	-72.1	-17.16	80
Q2	0.238	-2.787	55.8	13.28	80
Q3	0.238	-2.256	45.1	10.75	80
Q4	0.238	3.203	-64.1	-15.26	80
Q5	0.238	1.693	-33.9	-8.07	80
Q6	0.238	-2.444	48.9	11.64	80
Q7	0.438	3.562	-71.3	-31.22	80
Q8	0.592	4.086	-81.8	-48.41	80

Quadrupole data for H7BA-TwoSector-nux95-nuy36-3PW-Version6

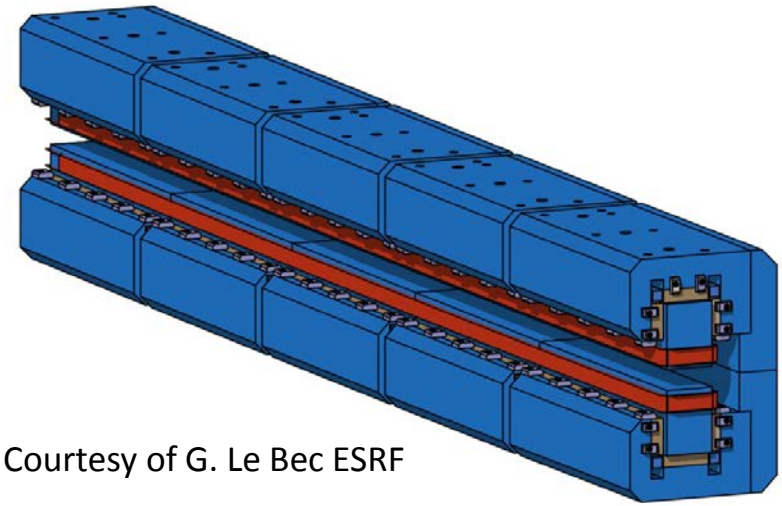
Sextupole Parameters

Element Name	Length m	K_2 $1/m^3$	B'' T/m^2	B''L T/m	Count
S01A:S1	0.256	-165.1	3305.2	847.0	20
S01A:S2	0.256	227.1	-4545.4	-1164.8	20
S01A:S3	0.256	-151.3	3028.4	776.0	20
S01B:S3	0.256	-155.9	3121.1	799.8	20
S01B:S2	0.256	230.7	-4616.7	-1183.0	20
S01B:S1	0.256	-153.0	3061.5	784.5	20
S02A:S1	0.256	-157.5	3151.3	807.5	20
S02A:S2	0.256	227.5	-4553.2	-1166.8	20
S02A:S3	0.256	-155.9	3120.5	799.6	20
S02B:S3	0.256	-152.3	3048.2	781.1	20
S02B:S2	0.256	233.1	-4665.7	-1195.6	20
S02B:S1	0.256	-157.0	3142.4	805.2	20

Sextupole data for H7BA-TwoSector-nux95-nuy36-3PW-Version6

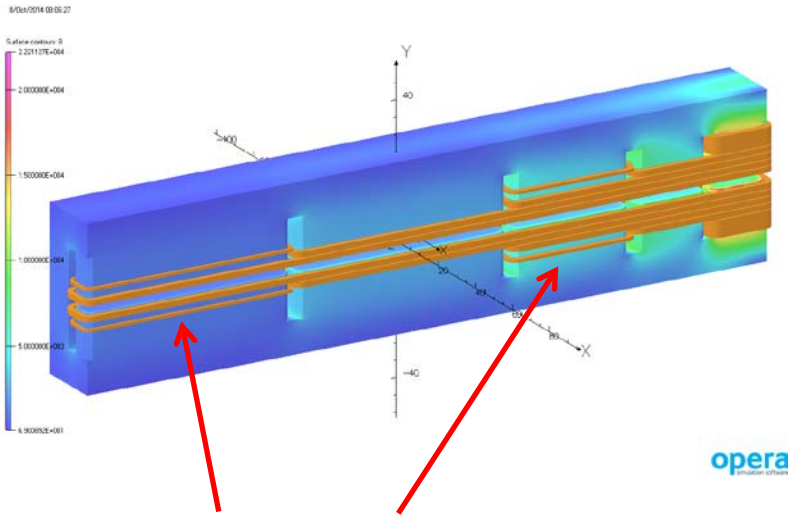
Longitudinal-Gradient Dipoles

Permanent Magnet Design
0.17 T -> 0.53 T, 1.85 m long



Courtesy of G. Le Bec ESRF

Electromagnet Design
0.17 T -> 0.53 T, 1.85 m long



2nd integral trim coils (optional)

Courtesy M. Jaski APS-AES

- Longitudinal alignment relatively tight – hundreds of microns.
- Both first and second field integrals matter

Requirements – Alignment and Vibration*

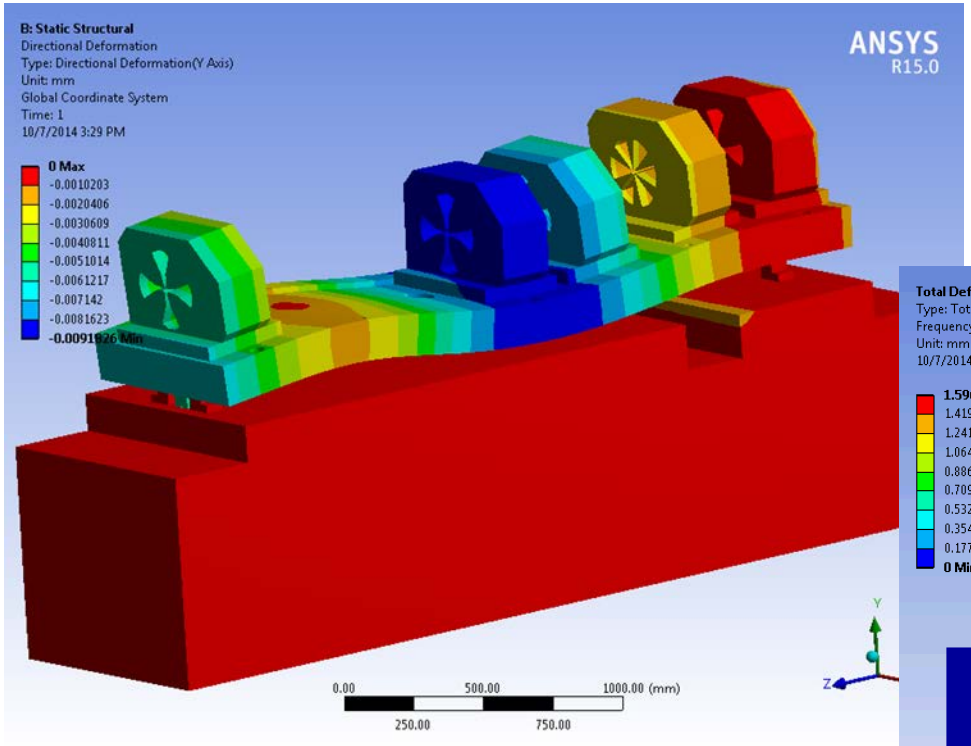
	Radial (x) μm	Vertical (y) μm	Roll (θ) μrad
Girder alignment			
Longitudinal gradient dipole (L-bend)	100	100	200
Multiplet and FODO girders	100	100	200
Doublet girders	100	100	200
On-girder component alignment			
Quadrupoles (including Q-bend)	30	30	200
Sextupoles	30	30	200
BPMs relative to adjacent sextupole or quadrupole	200	200	10 mrad

Vibration	APS MBA		NSLS-II	
	ΔX(nm)	ΔY(nm)	ΔX(nm)	ΔY(nm)
Magnets				
Magnet to magnet (same girder)	<130	<37	<150	<25
Girder to girder	<340	<250	<600	<70
BPMs (w.r.t. adjacent quadrupole)	<70	<70	<100	<100

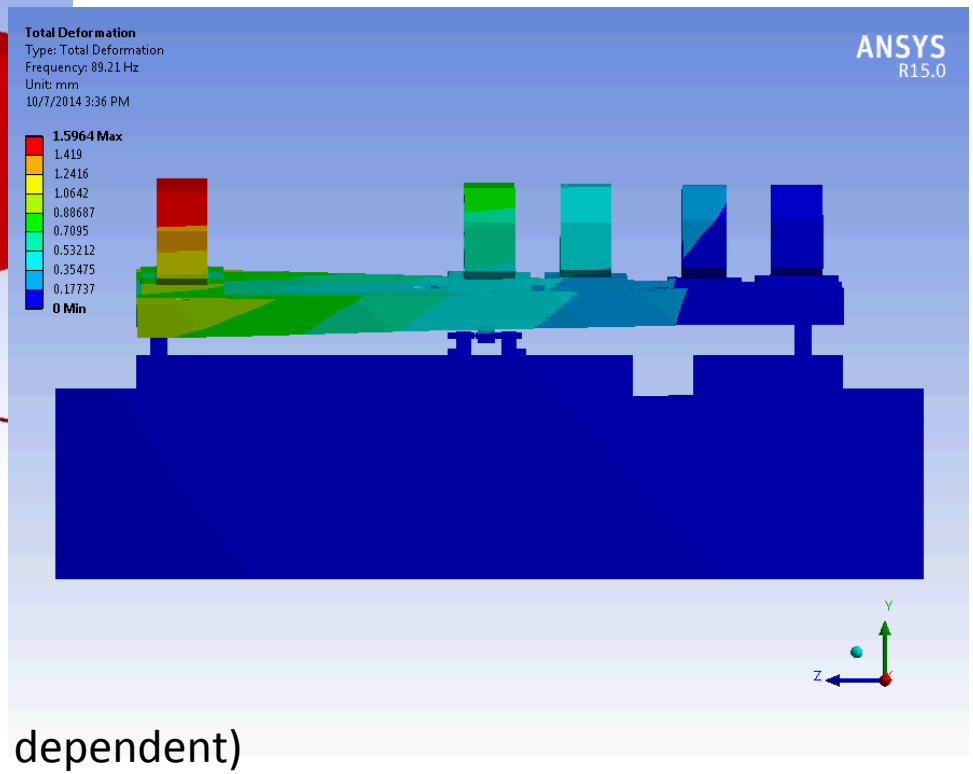
* Preliminary rms values, APS c. 2014

Magnet Alignment, Stability

Static Deflection



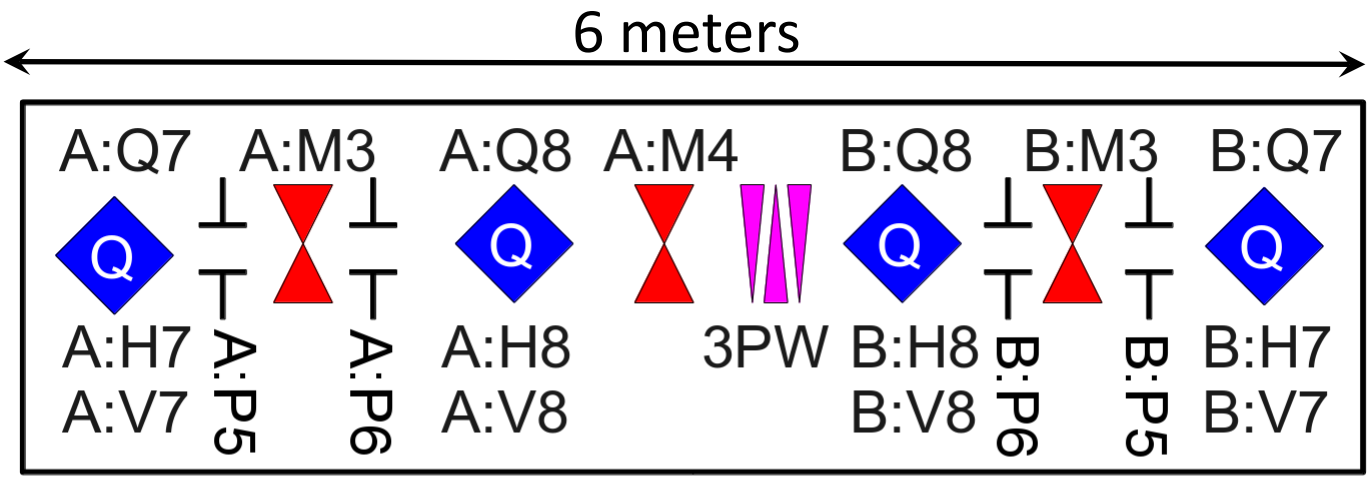
Lowest mode Deformation



- Three-point support, short base
- Deflection: 9 μm (need to review)
- First mode: 89 Hz (boundary condition dependent)

Courtesy C. Preissner, Z. Liu, J. Nudell, APS-AES

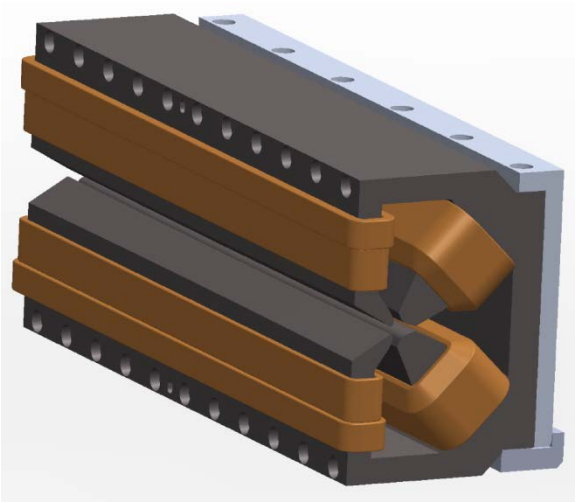
Curved FODO Section

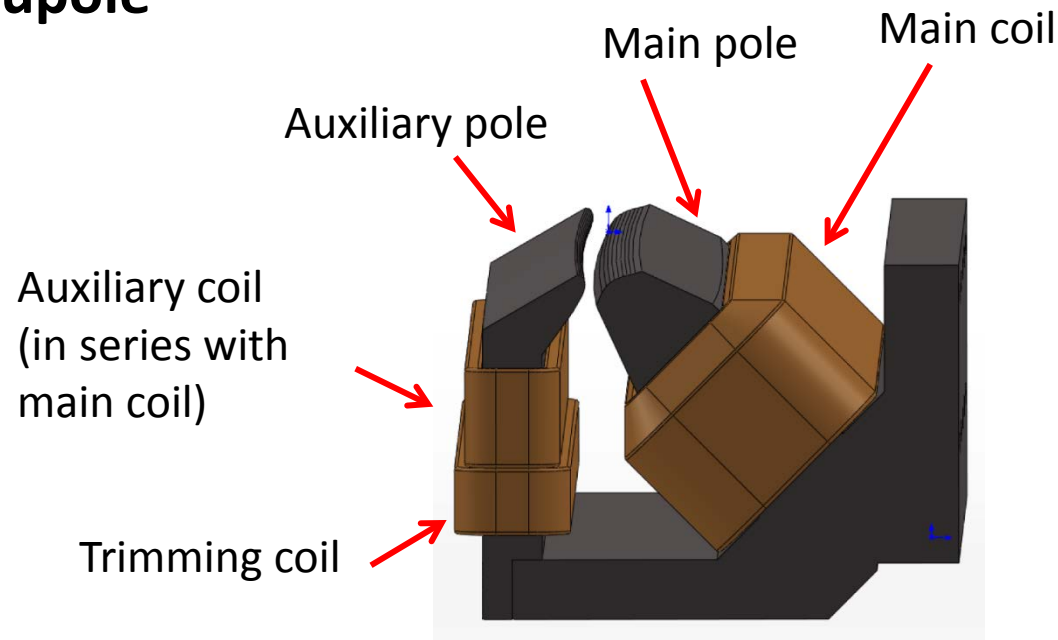


Q7, Q8 Strongly-focusing quads
H7, H8 Dipole windings inside quads
M3, M4 Defocusing transverse-gradient dipoles
P5, P6 Beam position monitors

Transverse-Gradient Dipole

Single sided dipole – quadrupole

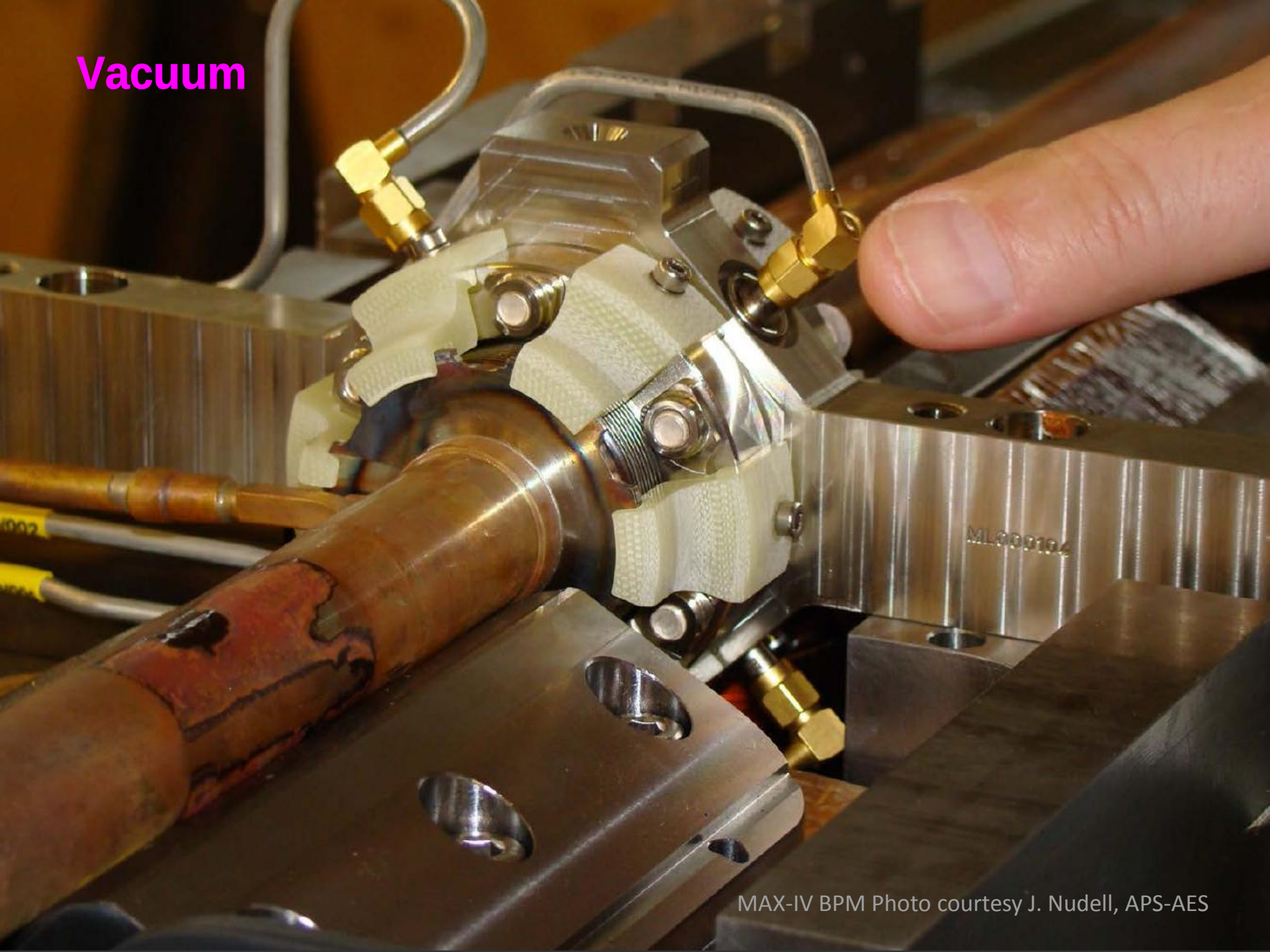




- A “3-pole” design (2 poles + 2 “half” poles)
- 0.54 T field, 34 T/m gradient
- Iron length: 1.1 m
- Magnet mass ~ 1 ton
- Power consumption: 1.7 kW

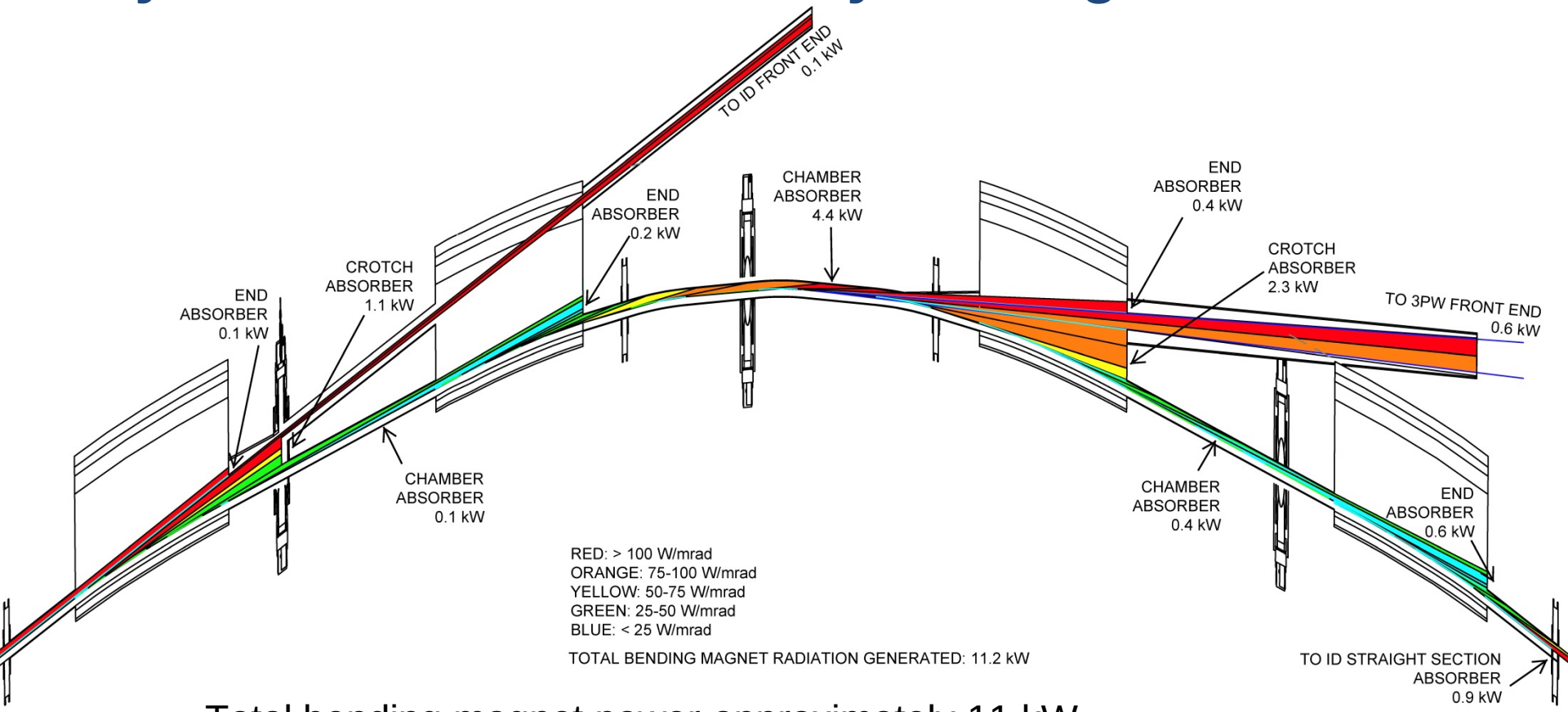
Courtesy of G. Le Bec ESRF

Vacuum

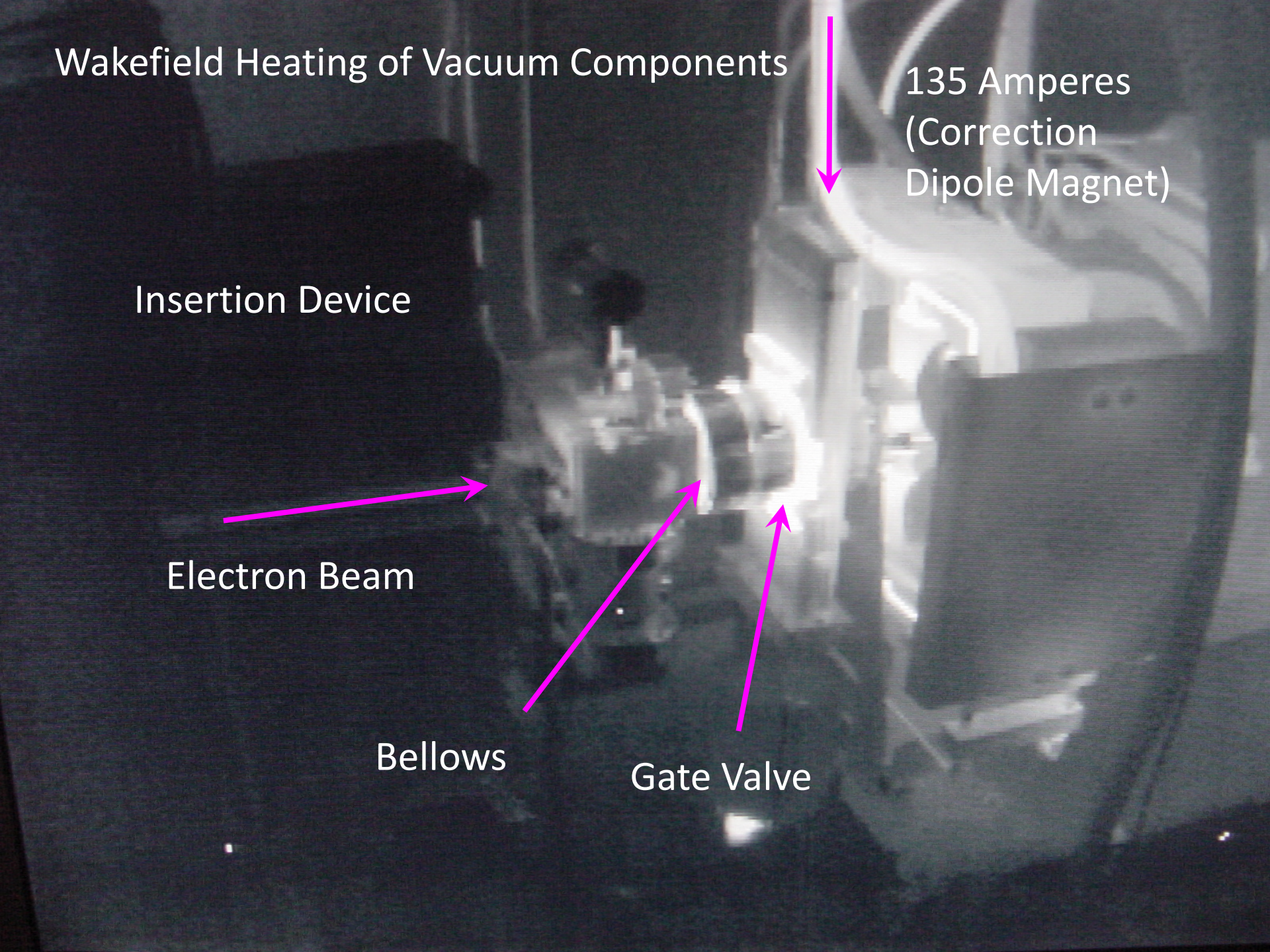


MAX-IV BPM Photo courtesy J. Nudell, APS-AES

Synchrotron Radiation Ray Tracing



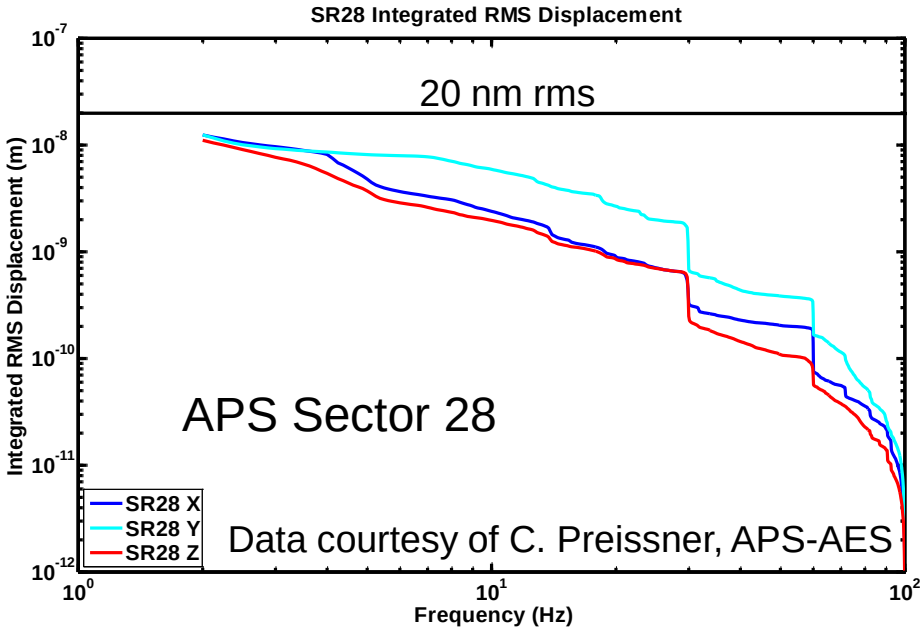
- Total bending magnet power approximately 11 kW.
- High power bending magnet radiation generated primarily in central section and at outer ends (near ID straight section).
- NEG coated FODO chambers receive slightly less than half of the total power. Power densities there 10-15 W/mm^2


Wakefield Heating of Vacuum Components
135 Amperes (Correction Dipole Magnet)
Insertion Device
Electron Beam
Bellows
Gate Valve

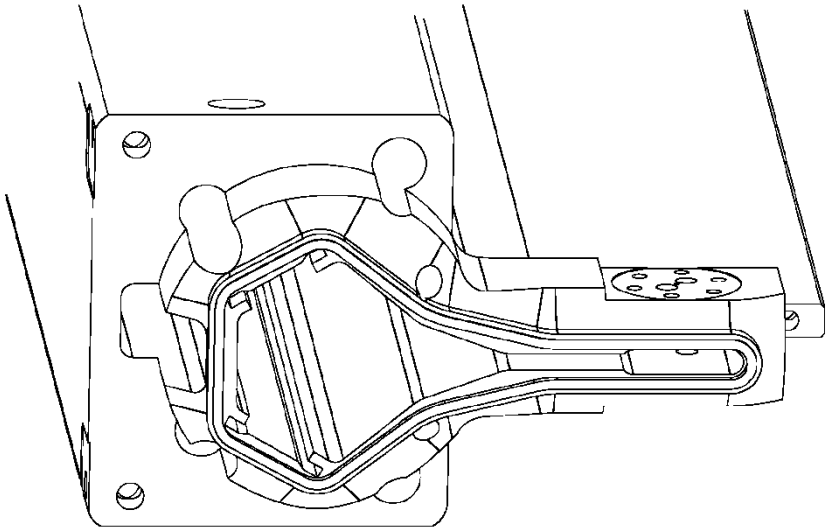
Beam Stability Goals

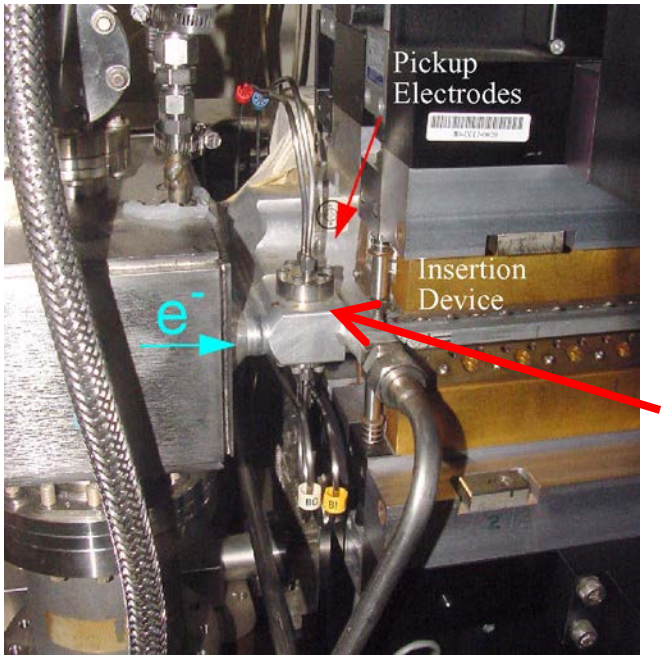
	AC rms (0.01–1000kHz)	Drift (period of 1 wk)
Horizontal beam size at ID	1.7 μm	1 μm
Horizontal divergence at ID	0.25 μrad	0.6 μrad
Vertical beam size at ID	0.39 μm	1 μm
Vertical divergence at ID	0.18 μrad	0.5 μrad

- Accelerator support structures must keep component vibration comparable to ground motion.
- Power supply noise, ripple must be minimized.
- Line harmonics from RF systems contribute.
- Fast orbit feedback necessary to clean up the residual.

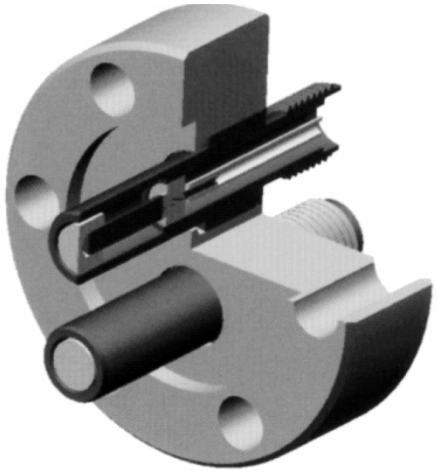


BPM Pickup Electrodes

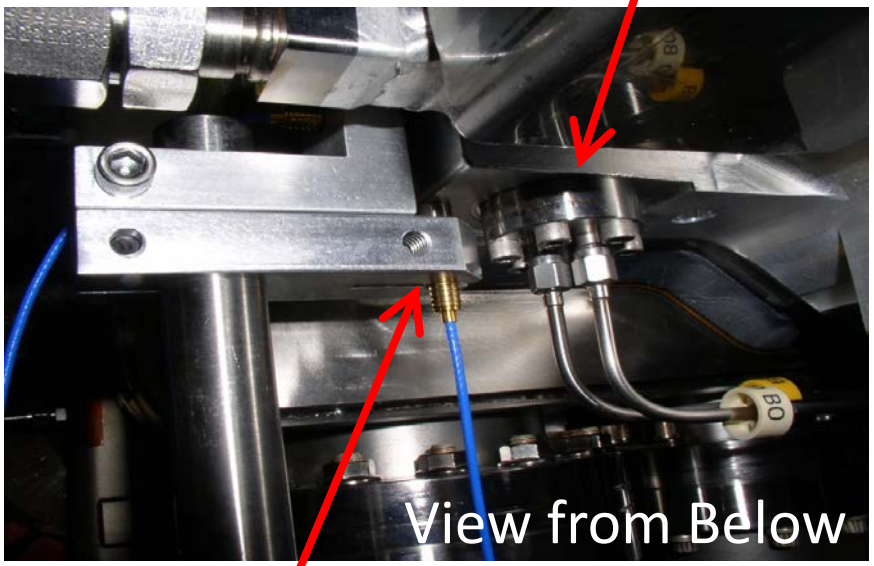




Beam
Pickup
Electrodes



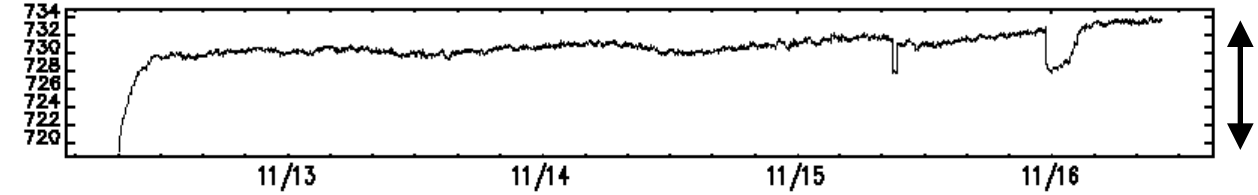
4 mm Diameter Capacitive buttons



Capacitive Proximity Sensor – APS Sector 27

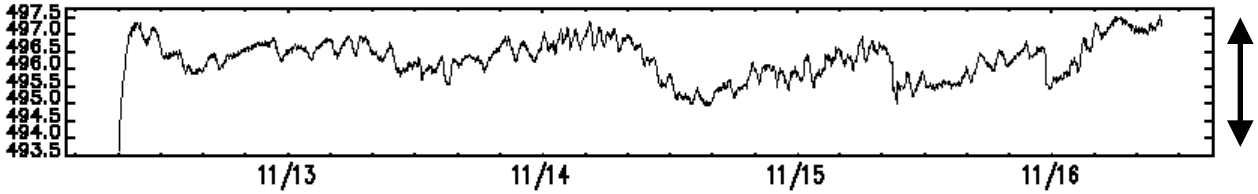
Mechanical Stability – 24 bunch, 2-minute Top-up

Horizontal BPM Displacement (microns)



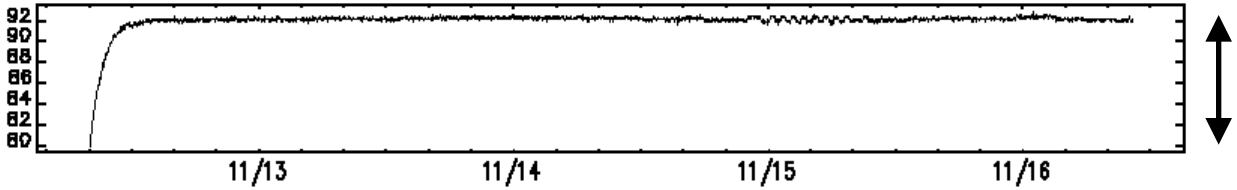
14 microns

Vertical BPM Displacement (microns)



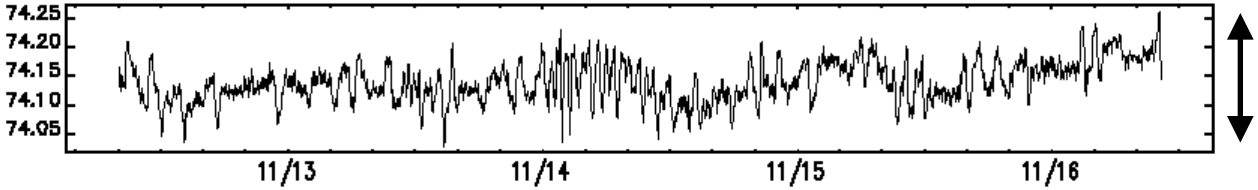
4 microns

BPM Chamber Temperature (F)



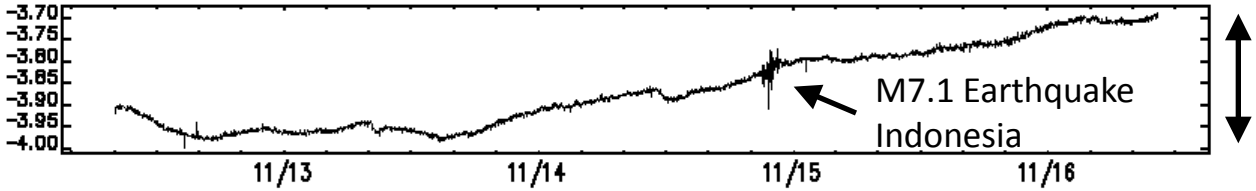
12 Deg. F

Air Temperature (F)



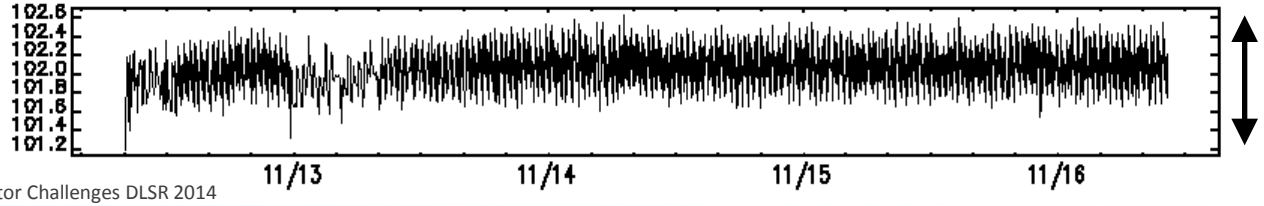
0.2 Deg. F

Floor Tilt (microradians)



300 nanorad.

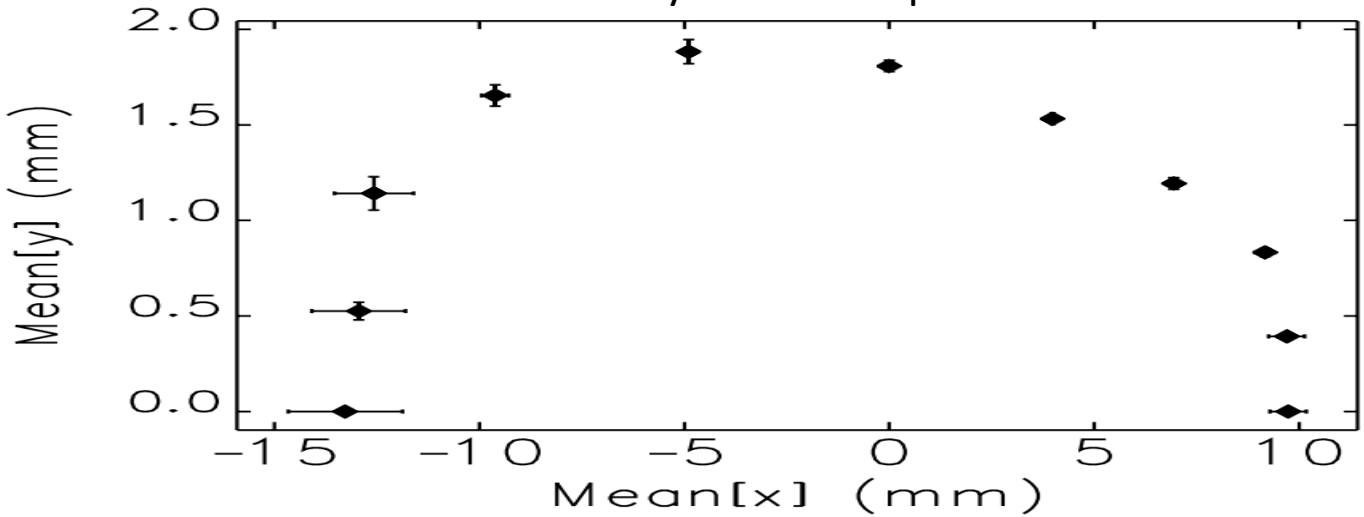
Stored Beam Current (mA)



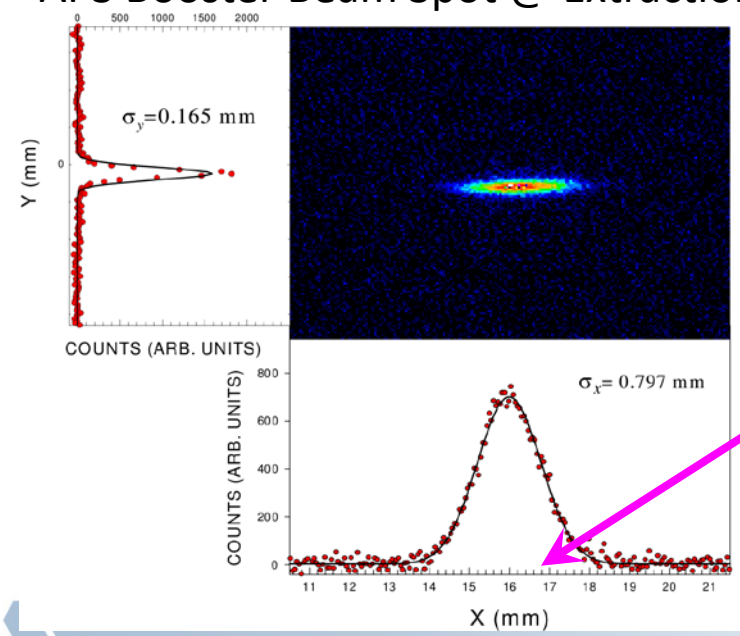
1.4 mA

Injection

Present APS Dynamic Acceptance*

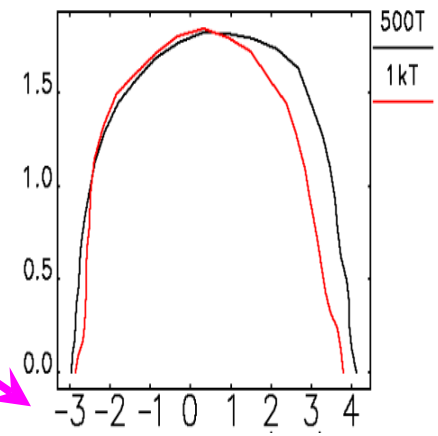


APS Booster Beam Spot @ Extraction**



Horizontal axes roughly to scale

APS MBA Dynamic Acceptance*

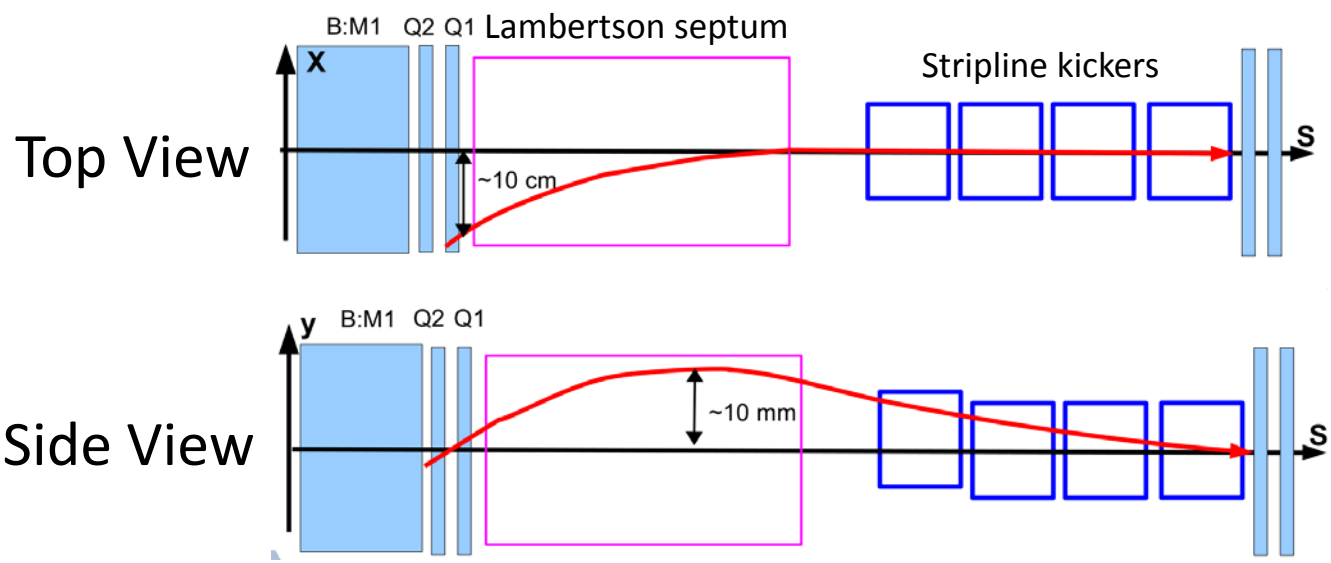


*Courtesy of M. Borland

**Courtesy of B.X. Yang

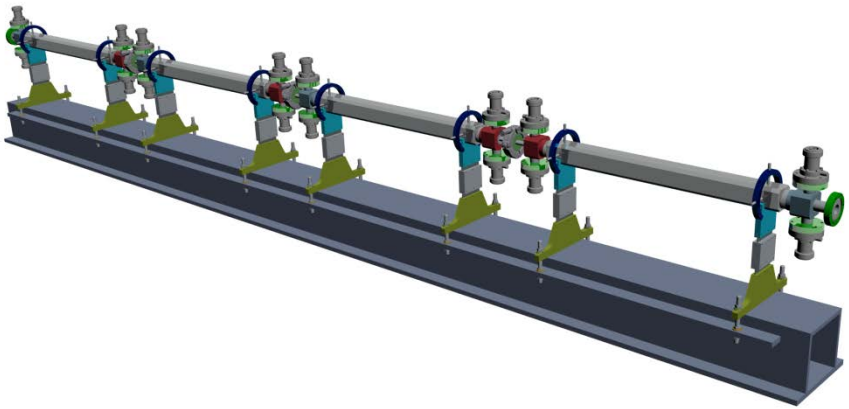
Swap-out Injection

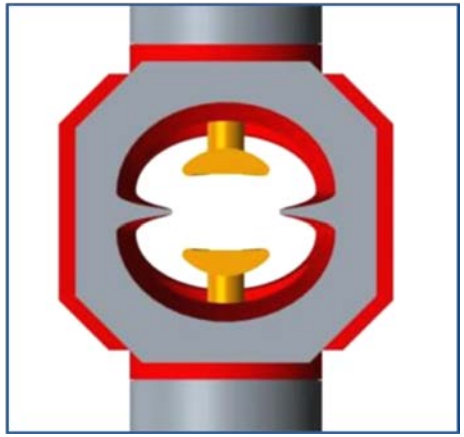
- On-axis “swap-out” injection allows more extreme charged-particle optics with higher overall brightness, albeit with lower beam lifetime.
- Involves periodic replacement of individual bunches (several to tens of seconds, depending on beam lifetime).
- Fast injection kickers (< 20 ns) required for 324 bunch mode (11.4 ns bunch spacing).
- High-charge (4 mA / bunch) injector operation required for 48-bunch timing mode.
- Insertion device apertures can be small in both horizontal and vertical planes.



Injection Region Swapout Components (A. Xiao APS-ASD)

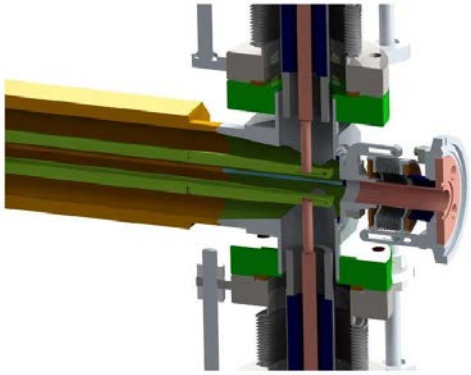
Stripline Kickers





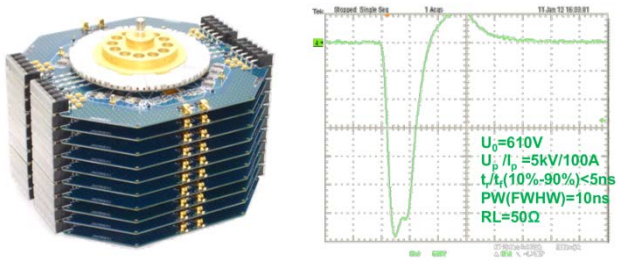
"D" Shaped stripline blade

- Pulse width 10's of ns
- Required voltage 10 – 25 kV
- Small aperture (approx. 1 cm)
- Careful impedance matching



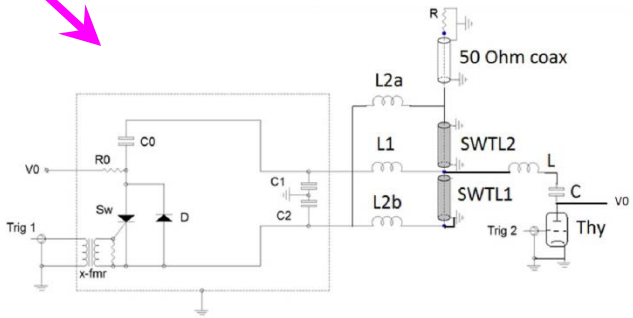
Fast High-Voltage Pulsers

- Commercial fast pulsers
  - FID Technologies, Germany, t_r < 5ns, > 20kV
- MOSFET based inductive adders
  - Many organizations worked on this technology, LLNL, SLAC, LBNL, IHEP, KEK, DTI, and many others
  - ~ 1ns/kV rise time
- Shock wave transmission line with ferrite medium to improve rise / fall time.
- Other technologies, e.g., Thyratron, Drift Step Recovery Diode (DSRD), Transmission line transformers (TLT)



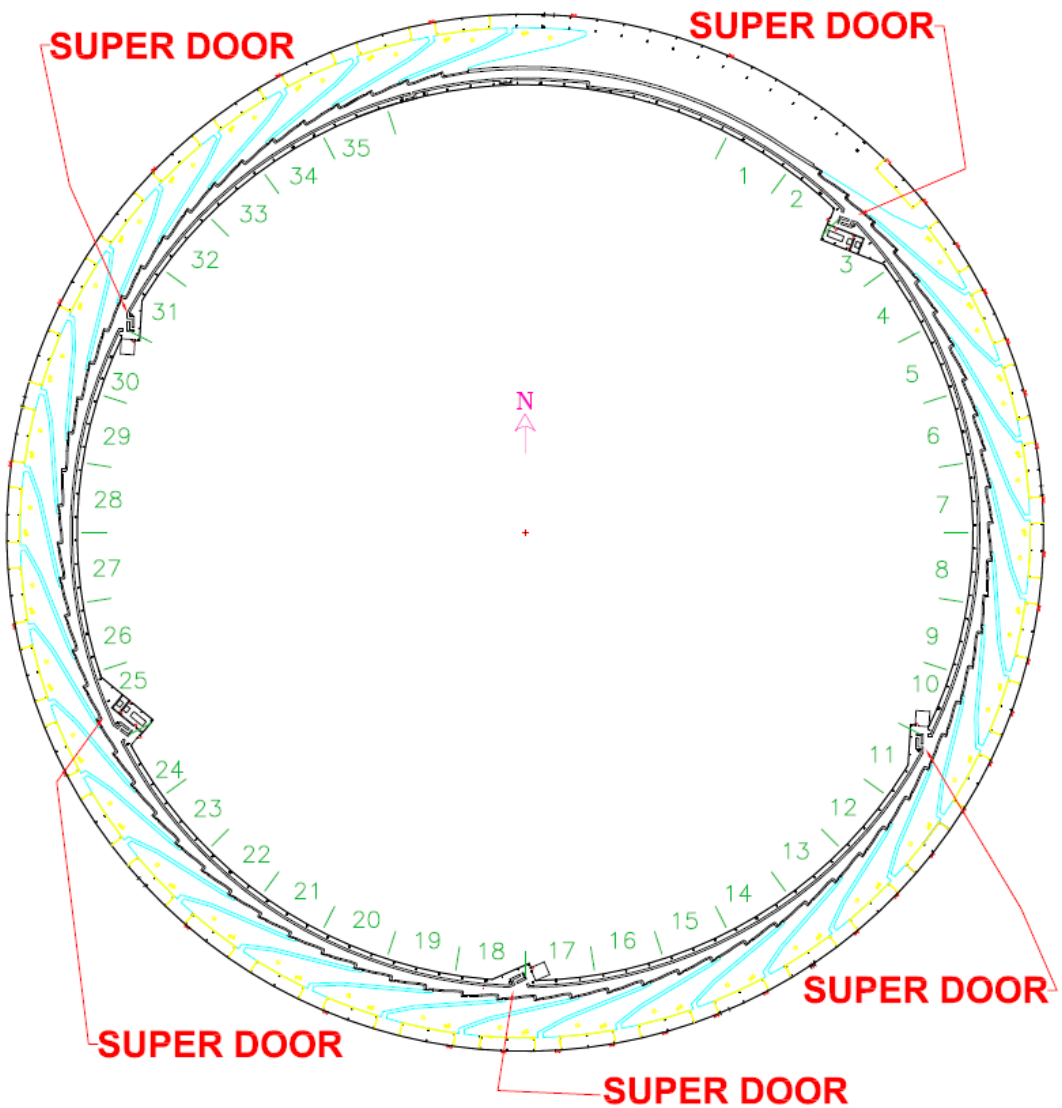
10-stage inductive adder assembly and test result

Courtesy Qing Qin, IHEP



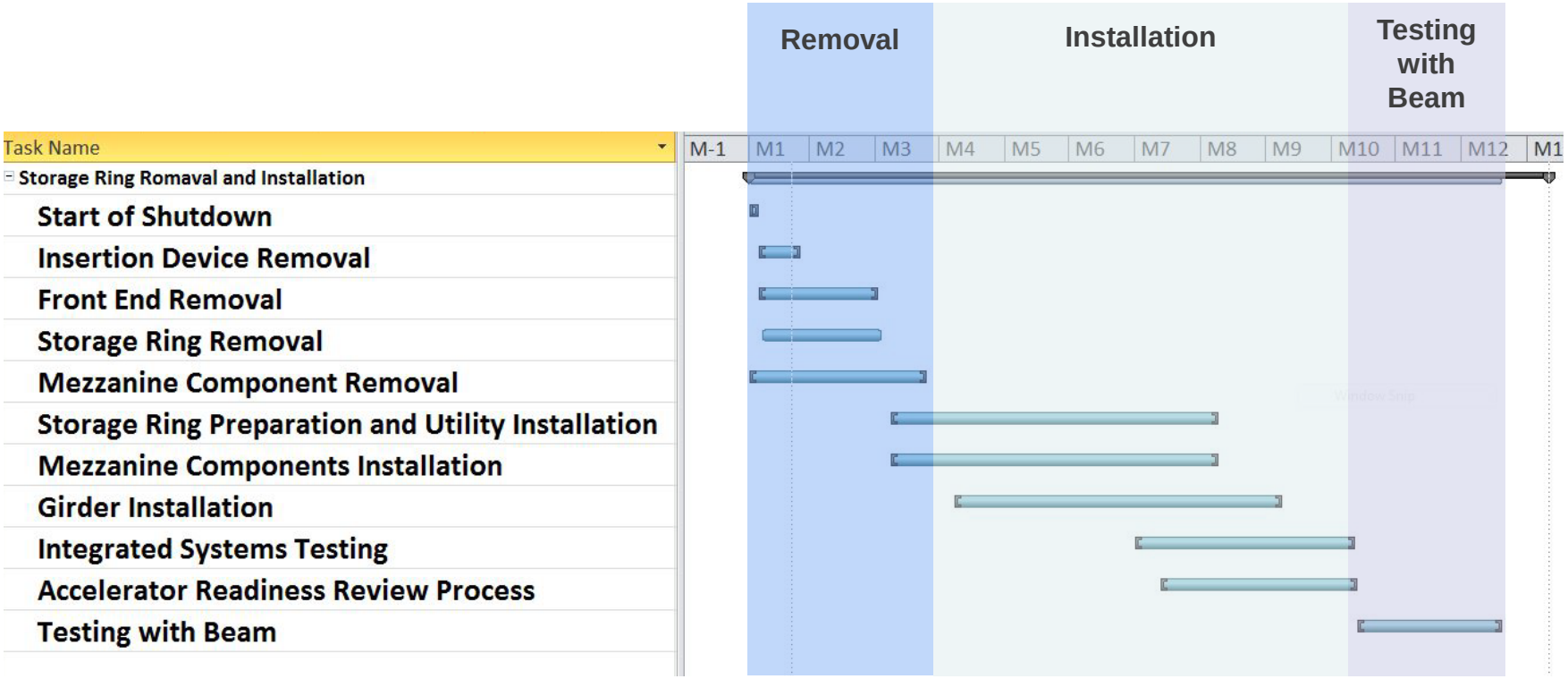
Courtesy Anatoly Krasnykh, SLAC

Installation – Impact on Operating Facilities



- Interruption of x-ray beamline operation must be minimized.
- Duration of removal, installation, and startup period is a key deliverable.
- Has a profound impact on accelerator design:
  - modular components
  - integrated testing
  - staging, storage, QA
  - commissioning tools

Accelerator Removal, Installation and Startup Schedule



Items not discussed

- Accelerator physics
- Insertion Devices
- Harmonic Cavities
- Power supplies
  - 10 ppm achievable
  - for thousands of supplies simultaneously…
- Controls
- Diagnostics
  - How to measure emittances below 100 pm-rad
  - Multibunch feedback
  - Electron and x-ray beam position monitors, electronics
- Injector complex
  - High charge, shot-to-shot reproducibility, low emittance optics, reliability
- Shape dissimilarity
  - A 40-sided polygon with the same circumference as a 280-sided polygon implies 4 cm lateral displacement of insertion device source points

Summary

- Development is needed in many areas
  - Magnets / Supports / Alignment
  - Vacuum
  - Beam stability
  - Injection
  - Installation
  - Everything else
- This workshop is an important contribution to this effort