OFF-ORBIT RAY TRACING ANALYSIS FOR THE APS-UPGRADE STORAGE RING VACUUM SYSTEM

Minimizing photon absorber heights and finding worst case local heat loads

Jason Carter, Ben Stillwell, APS-Upgrade Storage Ring Vacuum System Design Group, Argonne National Laboratory
Katherine Harkay, APS Accelerator Systems Division, Argonne National Laboratory

ABSTRACT

A MatLab program has been created to investigate off-orbit ray tracing possibilities for the APS-U storage ring vacuum system design. The goals for the program are

1. Find minimum photon absorber heights for shielding downstream components and
2. Calculate worst case heat loads due to missteering

The program computes synchrotron ray paths from discretized local phase space ellipses along bending magnet paths. The size of the ellipses are found from both multi-bend achromat lattice parameters and the limiting aperture in the future storage ring.

For height calculations, rays are projected to the locations of absorbers whose heights are then minimized while shielding downstream components. For heat loads, rays are projected until they hit a vacuum chamber wall where area and linear power densities are calculated.

MOTIVATION

- To better understand missteering possibilities[1] and their consequences
- Minimize photon absorber heights to reduce beam impedance
- Calculate worst case local heat loads so vacuum chambers and photon absorbers can be designed to survive all possible loading conditions

Maximum orbits in (x,x') or (y,y') phase space
x: spatial offset from center of orbit
x': angular offset from center of orbit
α, β, γ: Courant-Snyder parameters
a: half size of limiting aperture
β_u: beta function value at limiting aperture

$$x' = -2\alpha x \pm \frac{\sqrt{(2\alpha x)^2 - 4\beta(\gamma x^2 - A_x)}}{2\beta}$$

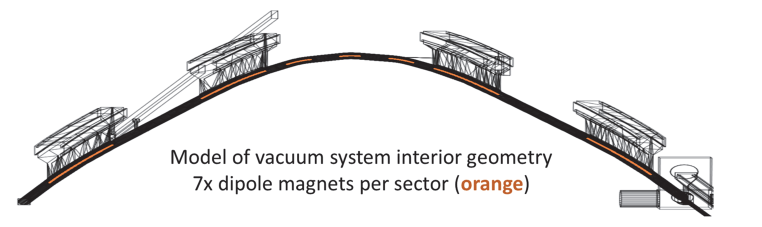
$$x_{max} = \pm\sqrt{A\beta}$$

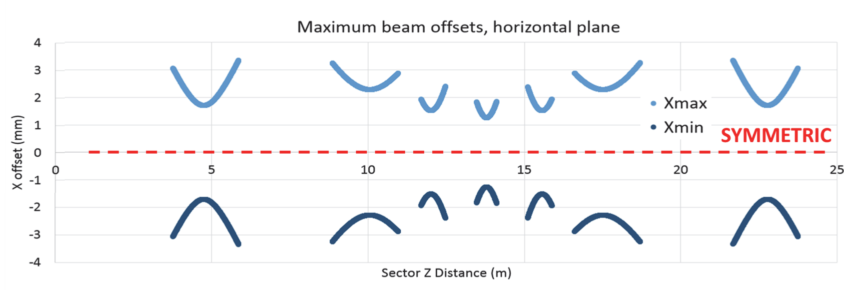
$$x'(x_{max}) = \mp\alpha\sqrt{\frac{A}{\beta}}$$

$$x(x'_{max}) = \mp\alpha\sqrt{\frac{A}{\gamma}}$$

$$x'_{max} = \pm\sqrt{A\gamma}$$

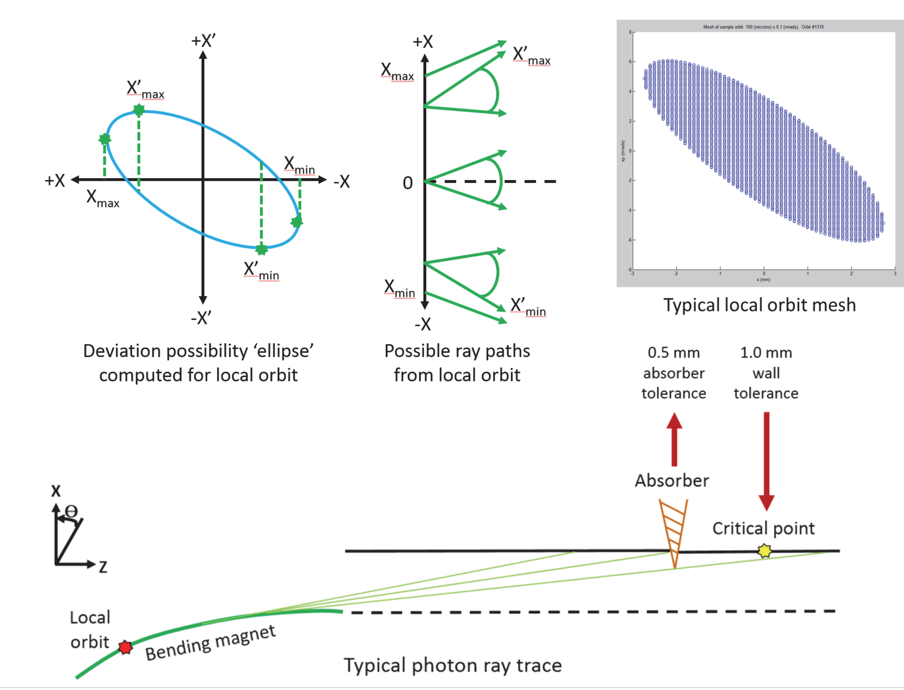
$$A_x = \frac{a^2}{\beta_u}$$





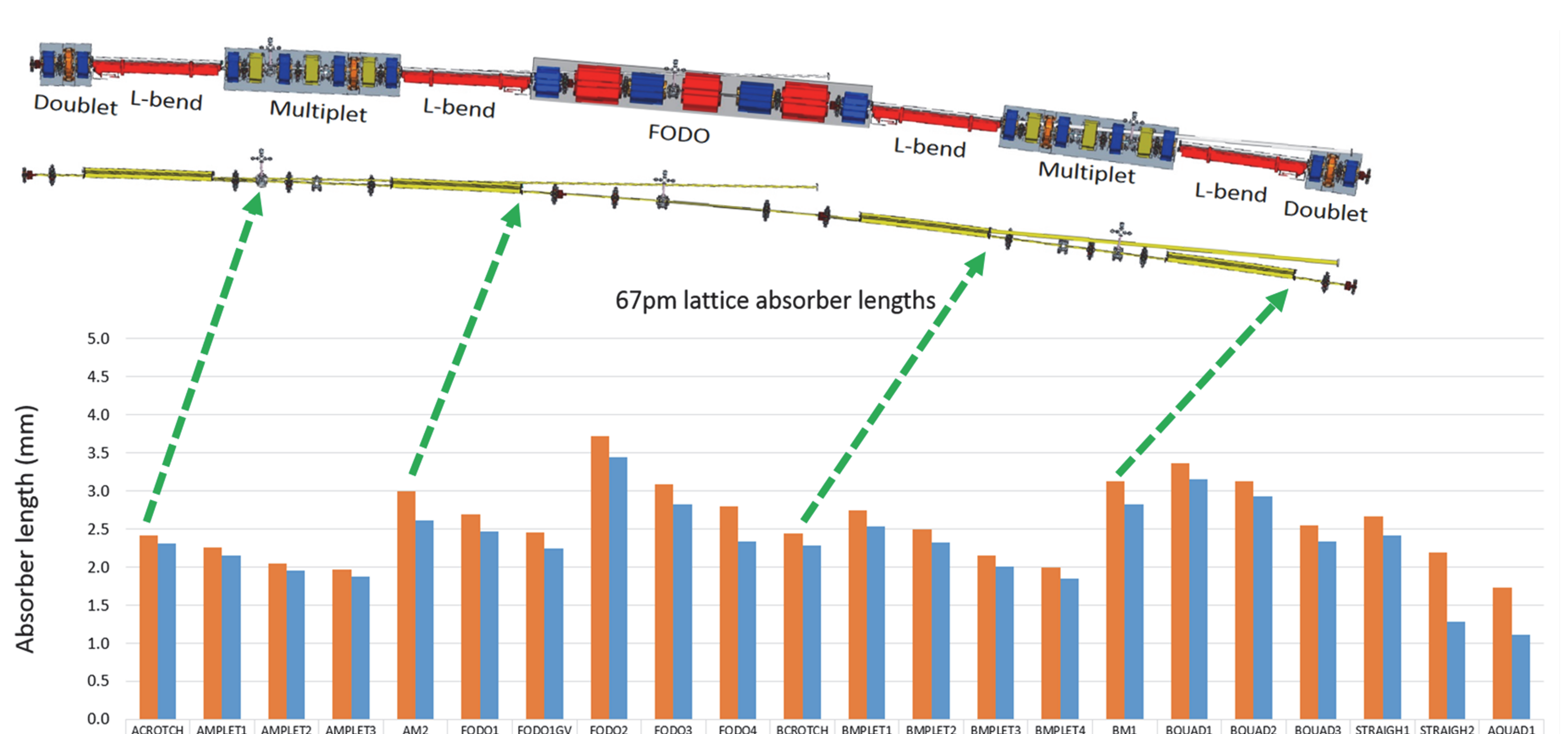
METHODS

- Compute discretized local phase space ellipses along finely segmented points of bending magnet paths
- Define global locations of absorbers including worst case alignment tolerances
- Project rays from ellipses towards targets: either photon absorber or vacuum chamber wall
- Evaluate shielding or compute thermal loads

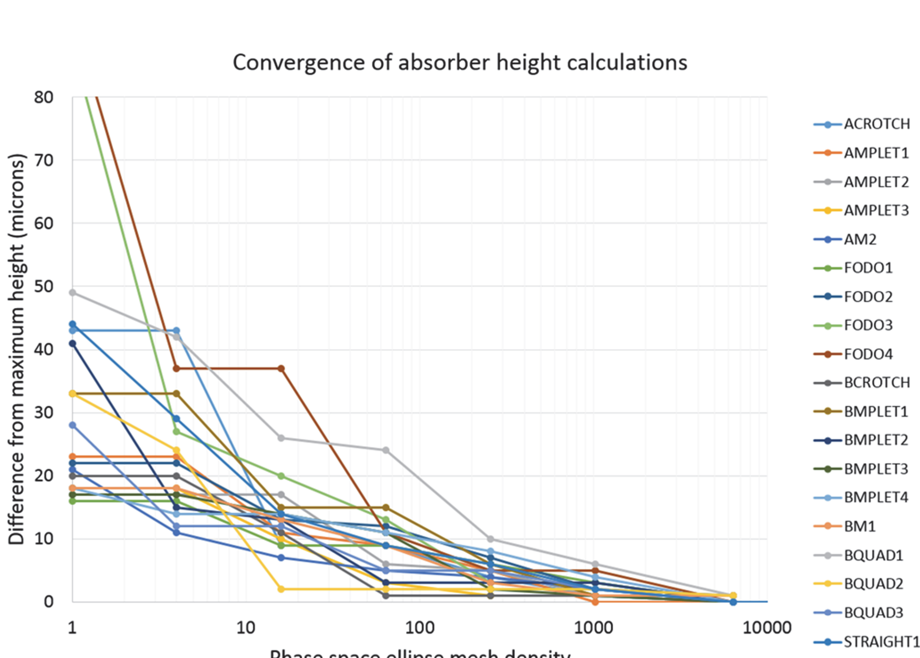


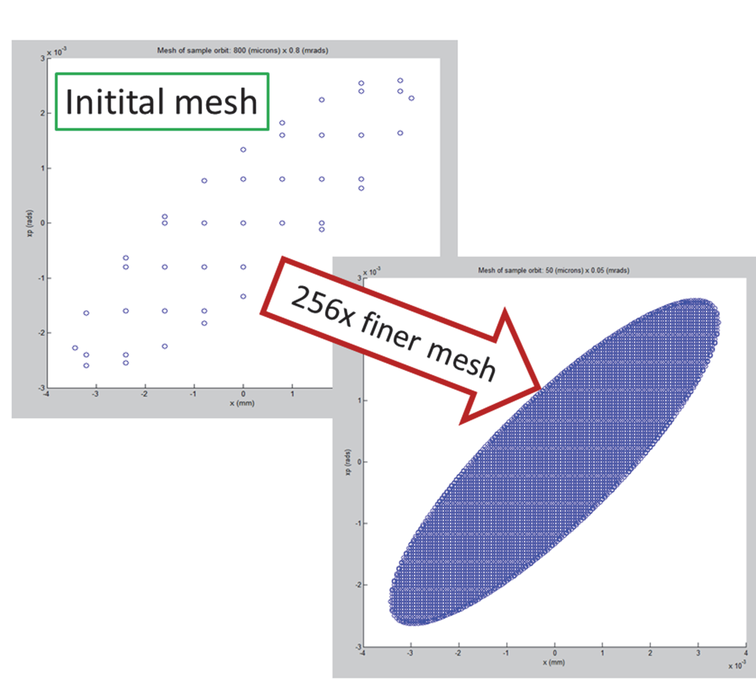
MINIMUM PHOTON ABSORBER HEIGHTS

- Absorber heights (top) calculated as minimum length required to shield full length of downstream components such as bellows and BPMs
- Calculations converge (bottom) with increased mesh density



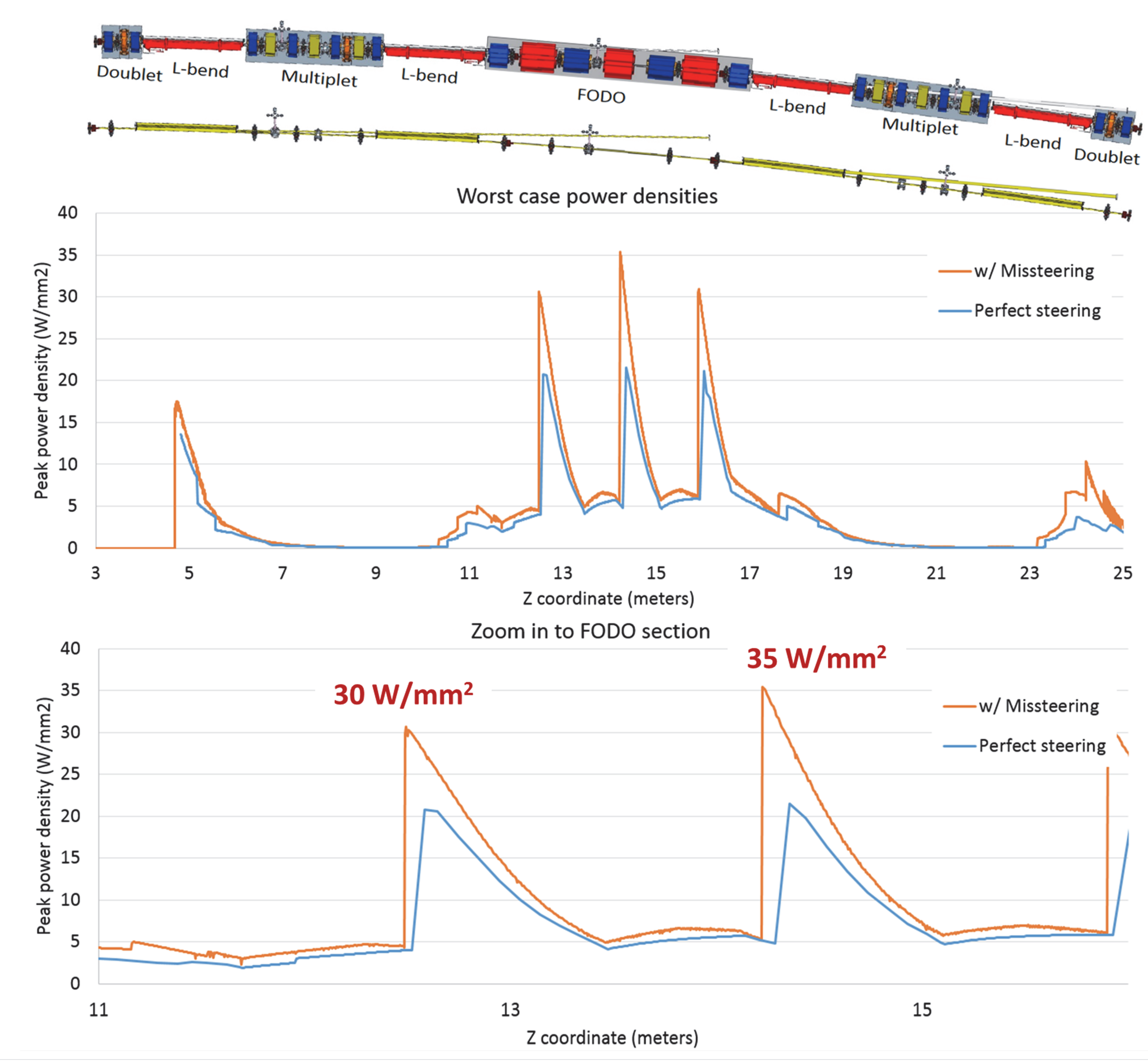
	ACROTCH	AMPLET1	AMPLET2	AMPLET3	AM2	FODO1	FODO1GV	FODO2	FODO3	FODO4	BCROTCH	BMPLET1	BMPLET2	BMPLET3	BMPLET4	BM1	BQUAD1	BQUAD2	BQUAD3	STRAIGHT1	STRAIGHT2	AQUAD1
with Missteering	2.42	2.26	2.05	1.97	3.00	2.69	2.46	3.72	3.09	2.80	2.44	2.74	2.50	2.16	1.99	3.13	3.36	3.13	2.55	2.67	2.19	1.73
Perfect Steering	2.31	2.15	1.96	1.88	2.62	2.47	2.25	3.45	2.82	2.34	2.28	2.54	2.32	2.01	1.85	2.82	3.16	2.93	2.34	2.42	1.29	1.11





WORST CASE HEAT LOADS

- Composite plot of worst case local power densities (top) along APS-U vacuum chamber walls and zoom in to two notable peaks in FODO section region
  - Plot does not include absorbers
  - Perfect steering values verified to 2D CAD ray trace
- Up to 67% increase in local power densities due to missteering
  - Photon rays find shorter paths and higher striking angles along wall leading to higher power densities

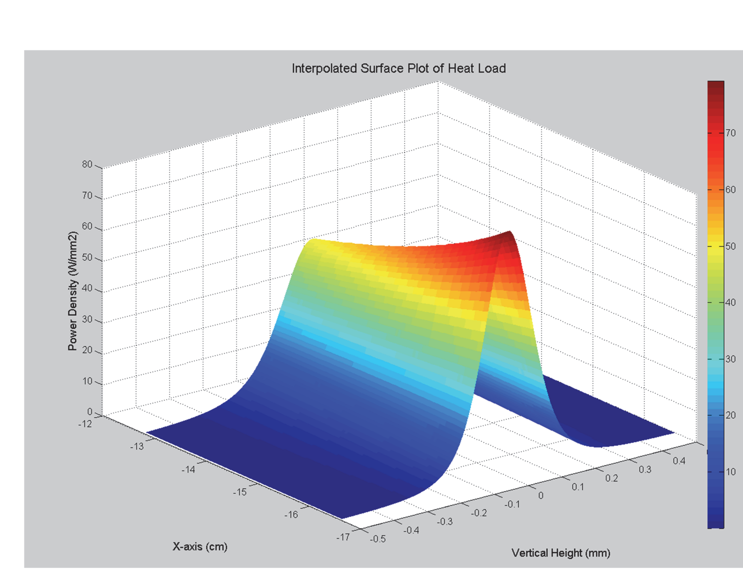


CONCLUSIONS

- New program allows for quicker iterations on vacuum system design, informs negotiations between engineering and physics
- Most challenging components to shield positioned close to upstream bending magnets
- Heat load plot reveals critical hot spots in vacuum system
- Finer meshing leads to converging solutions

NEXT STEPS

- Post process power densities into input data for ANSYS or COMSOL thermal/ structural analysis (right)
- Thermal/Structural analysis will determine if vacuum chamber design can withstand heat loads
- Add complex 3D model geometries: cylindrical tubes, angled absorber faces, chambers with beam extraction



Example photon power density distribution mapped onto a surface

REFERENCES

- [1] V. Sajaev, private communication (2016)
- [2] R. Dejus, private communication (2016)

ACKNOWLEDGEMENTS

Argonne National Laboratory's work was supported by the U.S. Department of Energy, Office of Science under contract DE-AC02-06CH11357