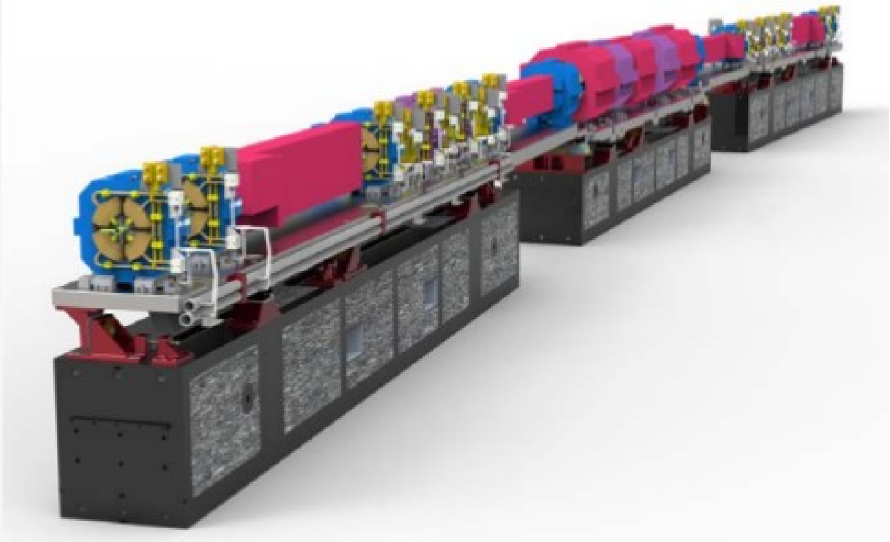
Accelerator design and simulation



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Accelerator design increasingly relies on simulation

- Design of particle accelerators is both an art and a science
- The art of accelerator design relies on experience and an intuitive appreciation of physical limits and possibilities
- The predictive capability of modern simulations has demonstrated many times, for example
  - X-ray Free Electron Lasers, e.g., SLAC's Linac Coherent Light Source
  - Storage ring light sources, e.g., ANL's Advanced Photon Source (APS)
- Both physics and engineering aspects of accelerator design have benefited from remarkable improvements in simulation capabilities
- We'll briefly highlight ANL's capabilities
  - Simulation codes developed at ANL
  - Expertise with other simulation codes
  - Computational resources

Simulations are central to the APS Upgrade

- Massively parallel multi-objective genetic optimizer to develop physics design
- Design of complex multi-function magnets using 3D codes
- Simulation of collective behavior of high-charge, multi-bunch electron beams
- Simulation of vacuum system performance in response to synchrotron radiation
- Simulation of commissioning and operational performance
- Understanding and pushing intensity limits in the injector complex
- Prediction of radiation levels and shielding requirements

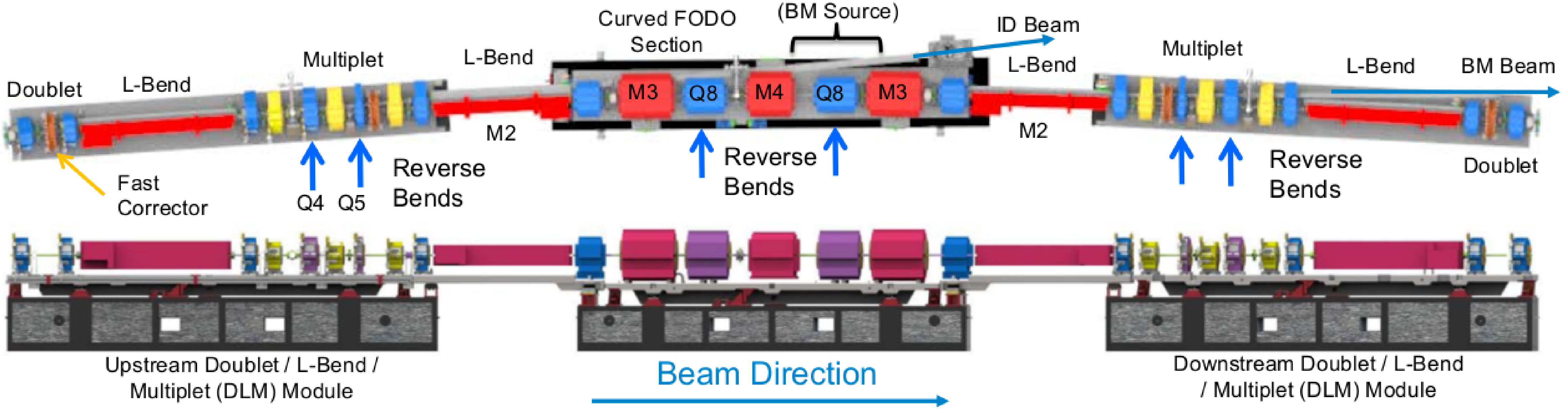
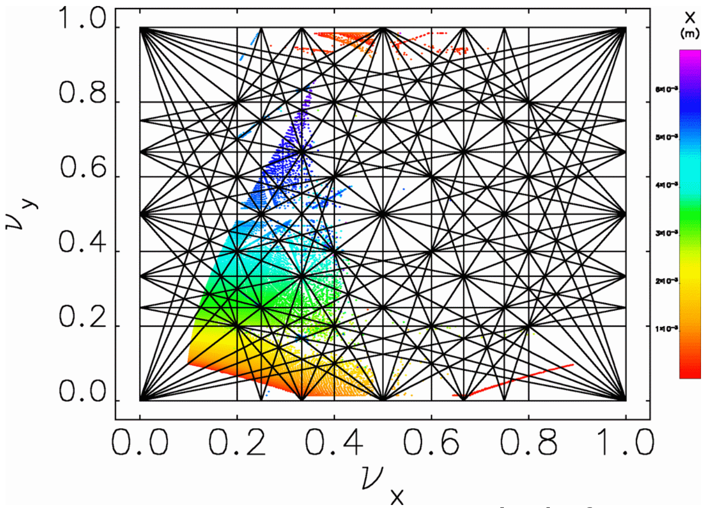


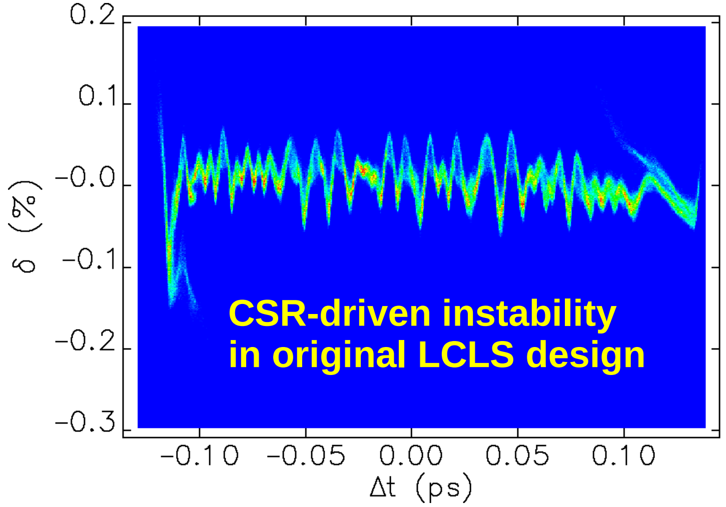
Image courtesy G. Decker, APS-U

Accelerator design can be elegant

- `elegant` –- general-purpose code (ANL) for linacs, transport lines, rings
  - Widely used code with about 90 citations per year
  - Runs on leadership-class facilities, desktops, laptops
  - Optimization of linear otpics, nonlinear properties, radiation integrals, tracking-derived properties
  - Simulation of errors and correction methods
  - 6D tracking (matrices, symplectic integration, ...)
  - Synchrotron radiation, gas scattering, Touschek scattering
  - Collective effects (wakes, cavity modes, beamloading, ions, CSR)
  - Feedback (rf cavities, bunch-by-bunch)
  - Easily extensible and in constant development
  - User forum for getting/giving help

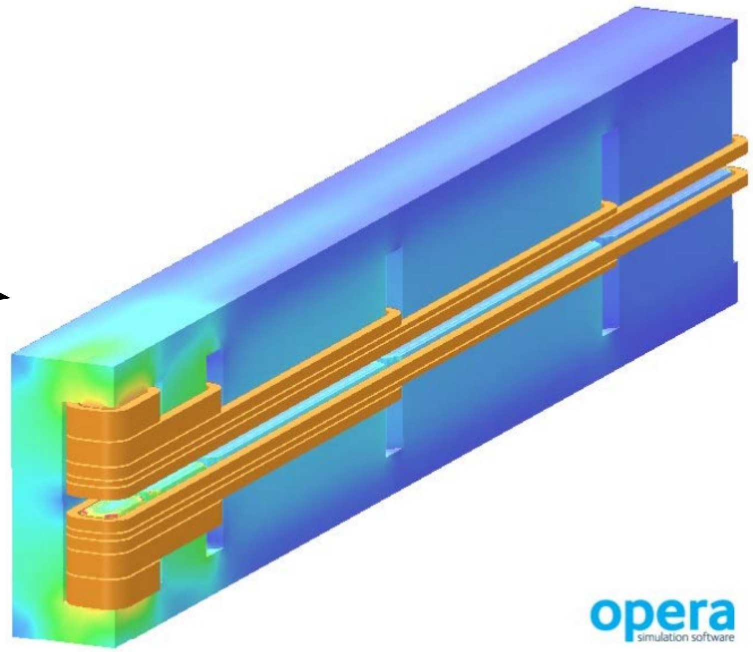


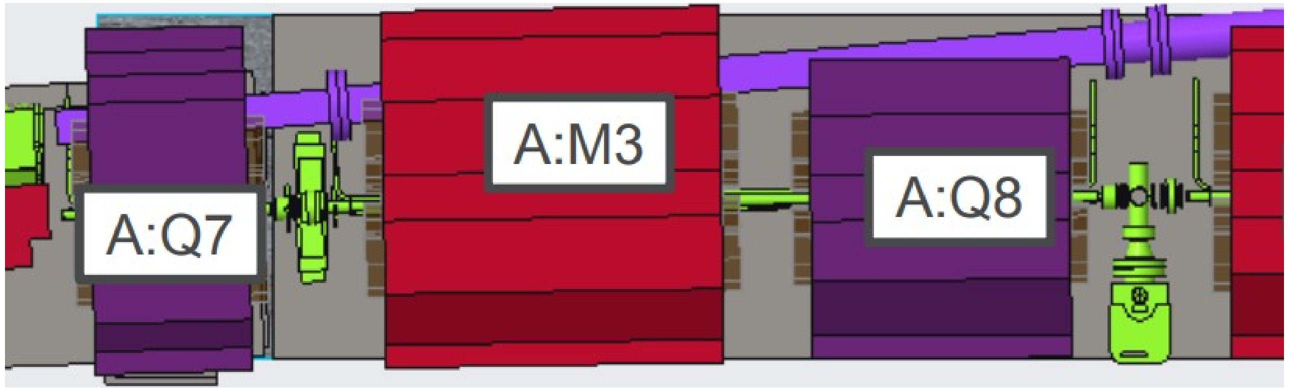
Frequency map analysis for APS-U final design lattice



Complex electromagnets must be designed in 3D

- Next-generation storage rings (APS-U) require high-strength electromagnets
  - Combined bending and focusing magnets (~100 T/m)
  - Sextupoles with steering correction capability
  - Fast steering magnets supporting feedback at ~1kHz
  - Five-segment longitudinal gradient dipoles
- Magnet designs must be integrated with vacuum system design to allow extraction of x-rays
- We “close the loop” by taking data from OPERA back into `elegant` to verify field distribution, quality



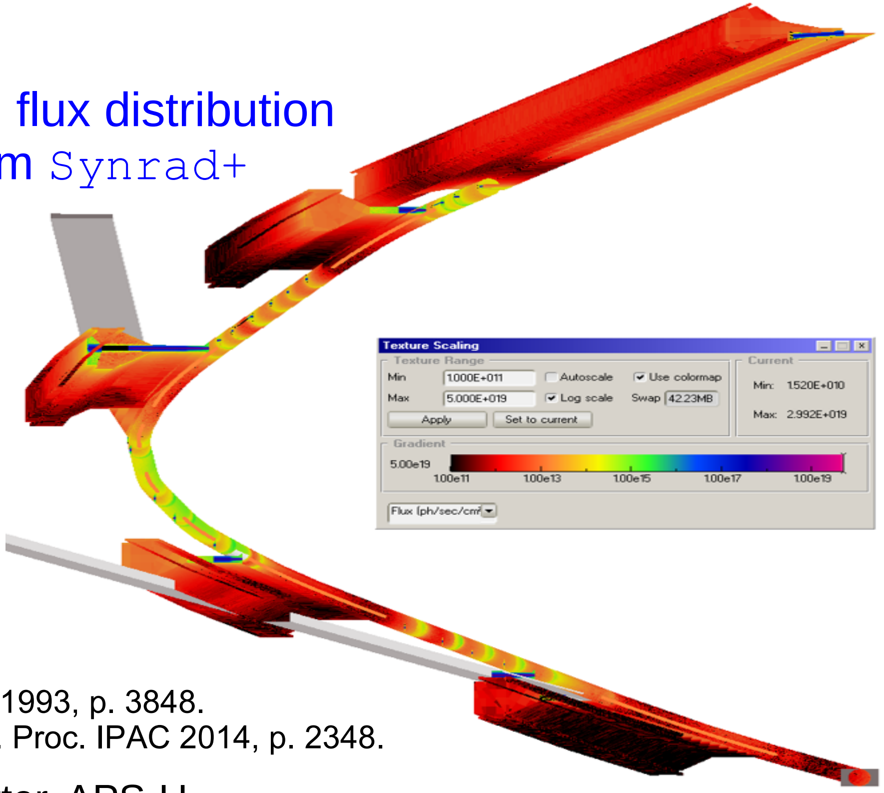


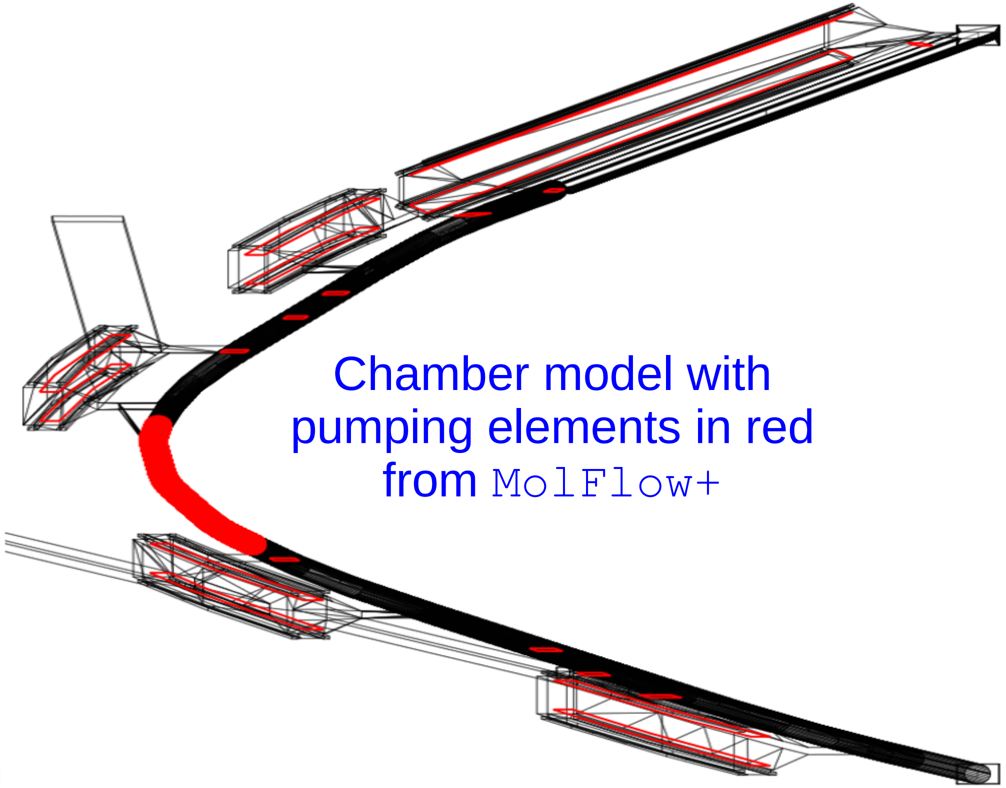
Images courtesy M. Jaski

Large-scale vacuum systems can be accurately modeled

- Electron beams in the APS-U storage ring can be lost or disrupted by residual gas
- Gas is produced by photon-stimulated desorption from metal surfaces and pumped out by NEG and ion pumps
- This is modeled by the CERN codes `SynRad+`[10] and `MolFlow+`[11]

Photon flux distribution from `Synrad+`





Chamber model with pumping elements in red from `MolFlow+`

[10] R. Kersevan. Proc. PAC 1993, p. 3848.
[11] M. Ady and R. Kersevan. Proc. IPAC 2014, p. 2348.

Images courtesy J. Carter, APS-U

Vacuum system model helps predict beam lifetime and stability

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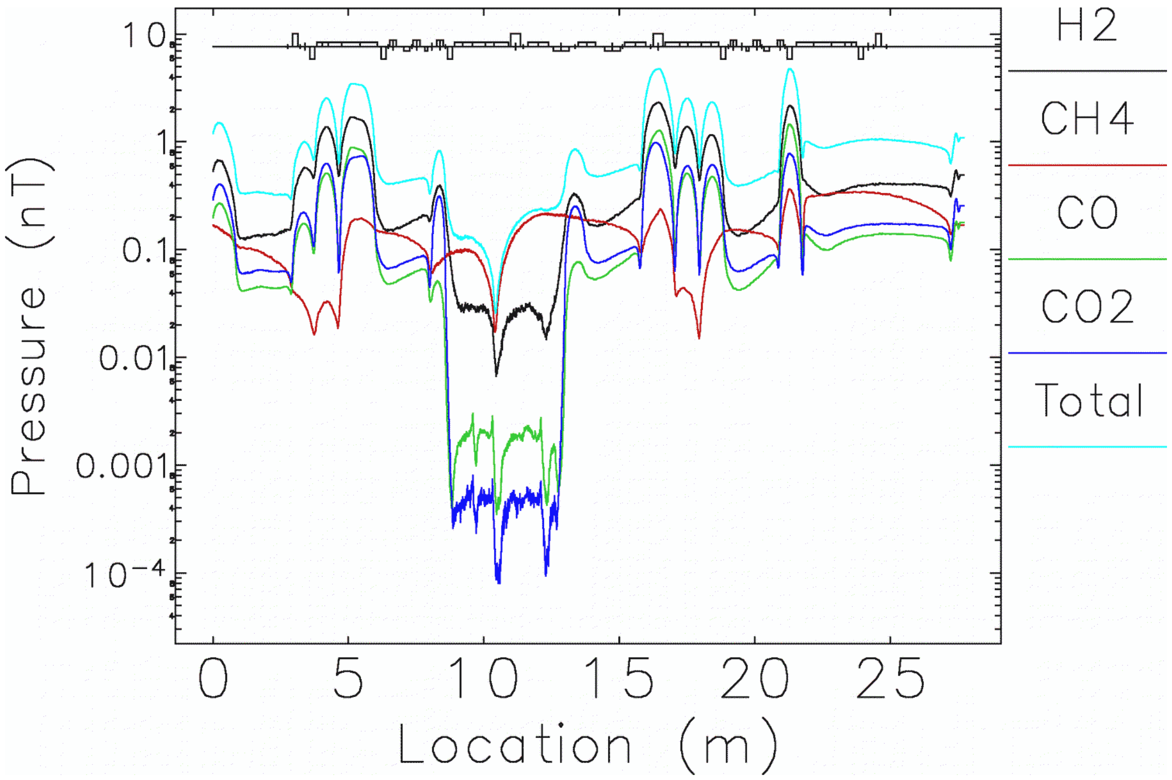
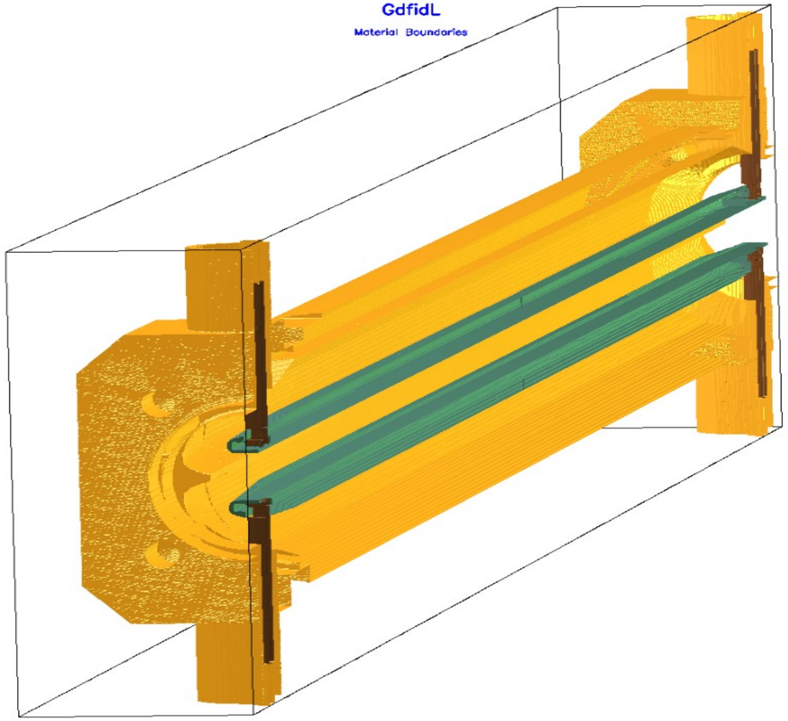
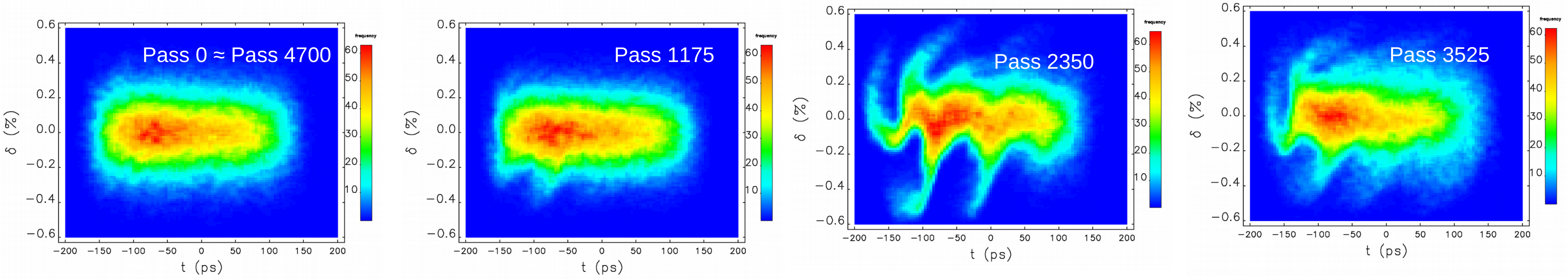


- These results are used for follow-on simulations
  - Gas scattering lifetime and distribution of lost particles
  - Ion instabilities and suppression with bunch-train gaps
- Lost-particle distributions are fed into simulations of radiation levels outside the shield wall

Vacuum chamber interacts electromagnetically with beam

- Particle beams can suffer instabilities via EM interaction with vacuum chamber
  - Discontinuities in the chamber cross section are particularly troublesome
- Interaction can be characterized as a wake function using programs like GdfidL[1] and MWS[2]
- Wake functions can be used in particle tracking (e.g., elegant) to model beam stability
  - Predictions provide thresholds for instability, assessment of impact on operation



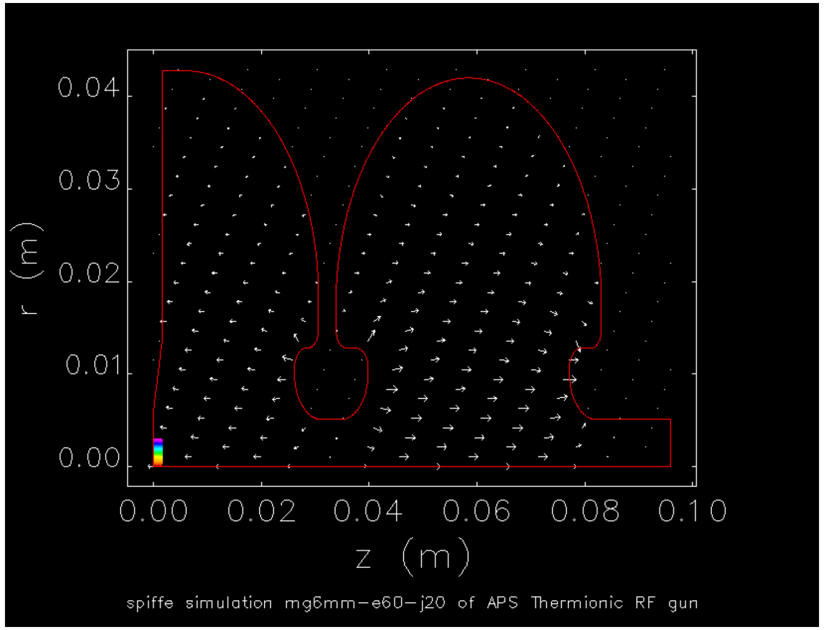


1: www.gdfidl.de
2: www.cst.com/products/cstmws

Images courtesy R. Lindberg

Other ANL resources and expertise

- Modeling of electron guns, including thermionic and photocathode guns
  - Codes include ASTRA[1], GPT[2], and spiffe[3]
- Modeling of low-energy linear accelerators with space charge effects
  - Codes include ASTRA and TRACK[4]
- Radiation safety
  - Codes include MARS[5] and MCPN[6]
- Computing clusters
  - "Blues" cluster available for industrial users[7]



1: www.desy.de/~mpyflo
2: www.pulsar.nl/gpt
3: www.aps.anl.gov/Accelerator-Operations-Physics/Software
4: V. N. Aseev et al., Proc. PAC 2005, p 2053.
5: mars.fnal.gov
6: mcnp.lanl.gov
7: www.lcrc.anl.gov.

ANL codes permit rapid development of physics designs

- An idea (J. Byrd) for a new application of storage rings was a figure-eight ring to provide two-view hard x-ray imaging
- Concept explored from linear optics to basic collective effects in a few weeks