APS-U Storage Ring Vacuum System: Engineering for a Robust *and* High-Performance Design

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APS-U Forum
10 September, 2015

Robust / Reliable vs High Performance

We need a system that:

- Will work reliably from day one.
- Utilizes established designs and fabrication techniques to minimize risk of failure.
- Will be tolerant to adverse conditions.
- It difficult to “break.”
- Is easy and fast to fix if it does break.

We need a…

Robust / Reliable vs High Performance

Subaru!

Robust / Reliable vs High Performance

We need a system that:

- Provides super-low vacuum pressures to minimize gas scattering contributions to beam lifetime.
- Presents a minimal degree of potentially destabilizing impedance effects.
- Requires a minimal amount of compromise in the lattice and magnet designs.

We need a…

Robust / Reliable vs High Performance

Ferrari!

Robust / Reliable vs High Performance

Ferrarabu!

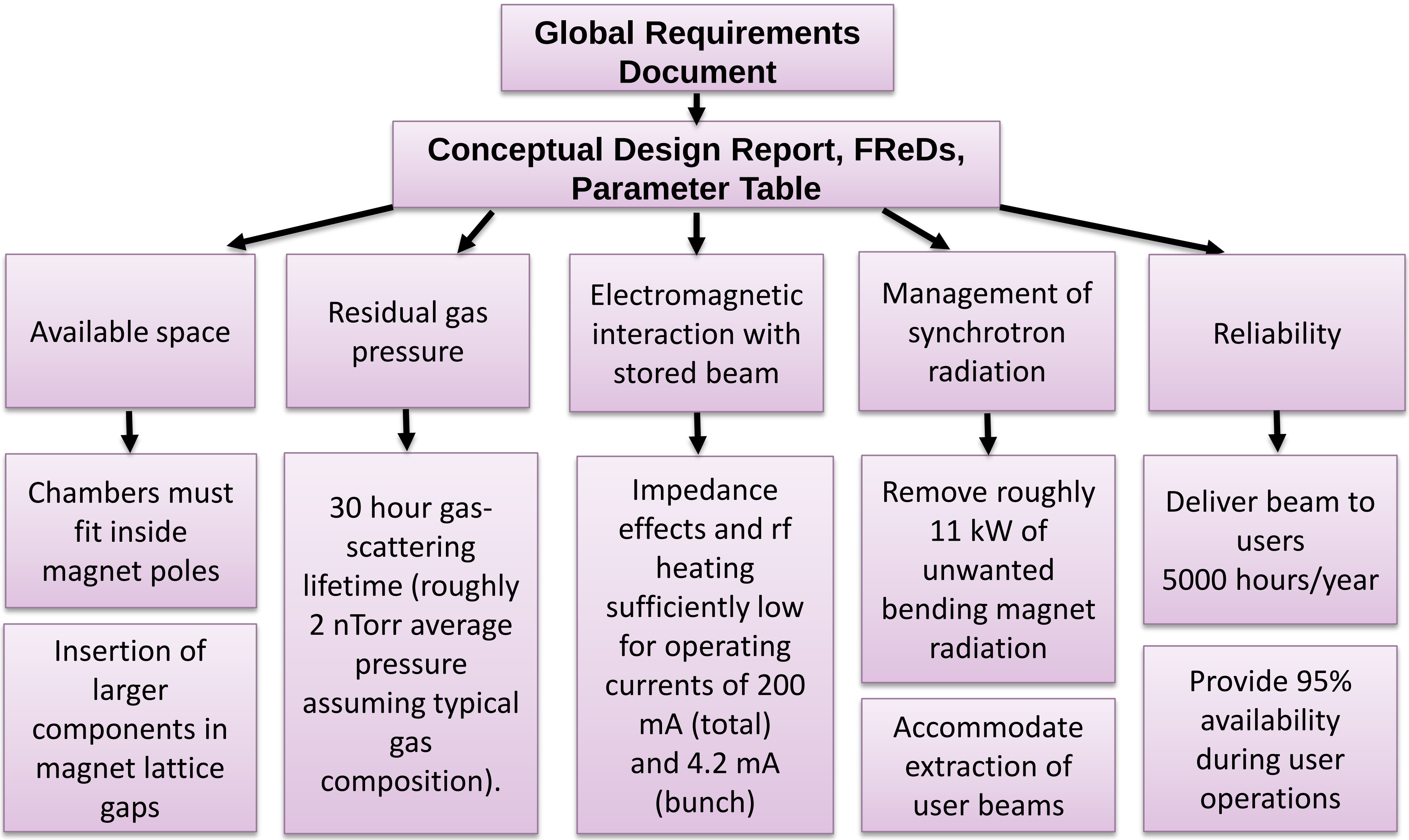
High performance modifications to an otherwise conservative design.

Start with the simplest possible solution that might work and add sophistication as it's needed.

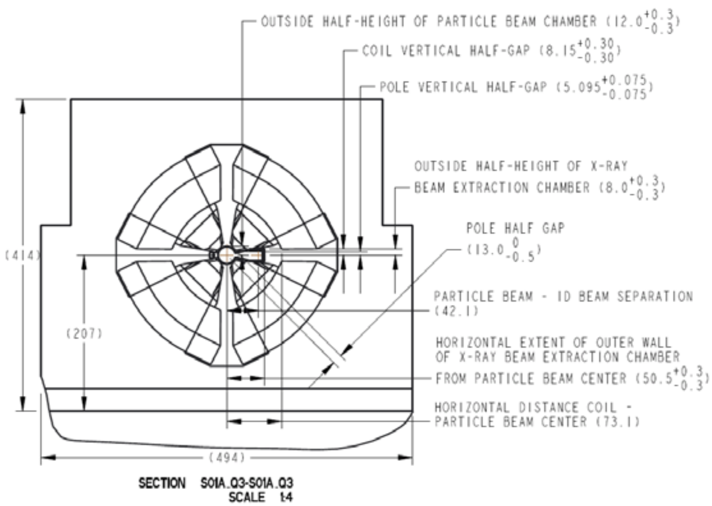
Outline

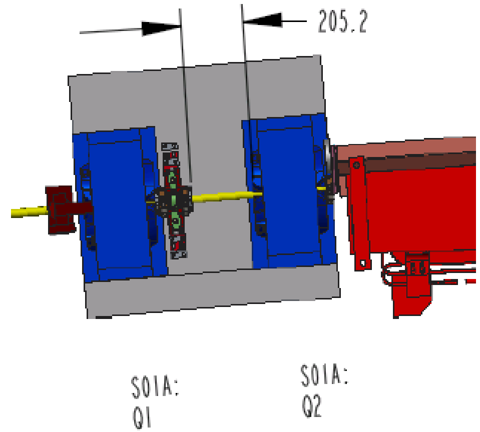
- Requirements
- Leveraging state of the art computational tools and expertise we have here at the APS
  - Parameterized CAD
  - 3D Monte Carlo simulations
  - Physicists
  - Ray tracing and finite element analysis
- Value engineering
- Conceptual design overview
- R&D
- Team

Requirements



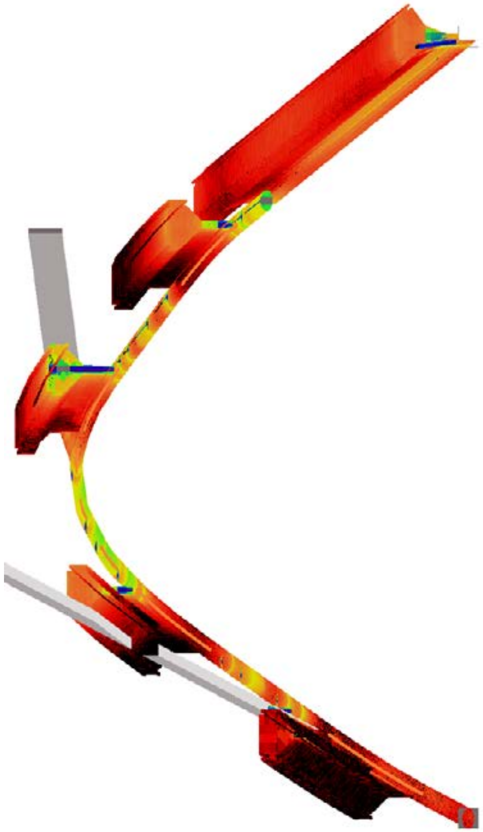
Parameterized CAD

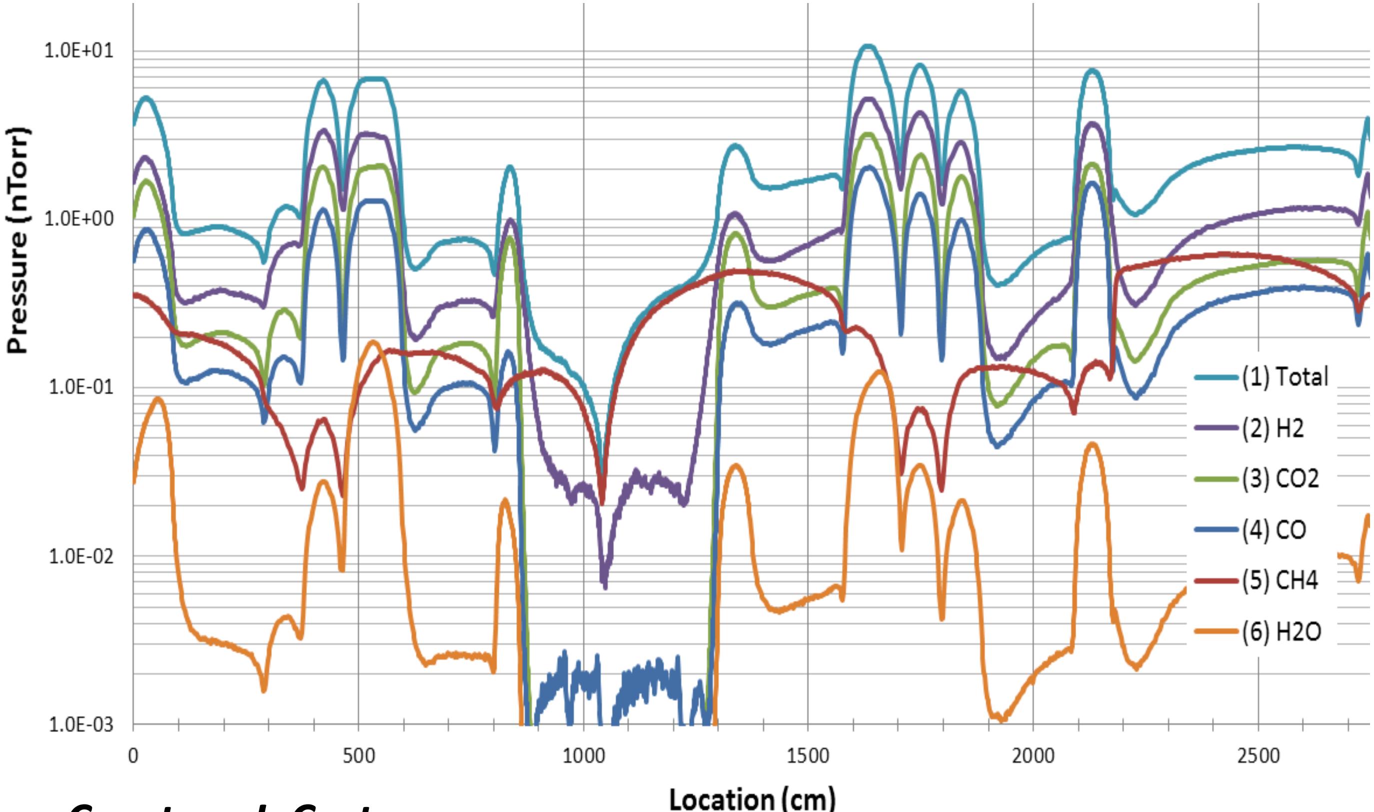




- A simplified top-level CAD model which is heavily derived from the beam trajectory and magnetic lattice.
- Detail is limited (so as not to be burdensome) but sufficient to generate accurate system layouts, track space claim, and provide geometry for other specific analyses (structural, thermal, vacuum, ray traces).
- Leveraging Parametric Computer-Aided Design for Efficient Optimization of a Storage Ring Vacuum System Design for the APS Upgrade, MEDSI 2014

3D Monte Carlo simulations

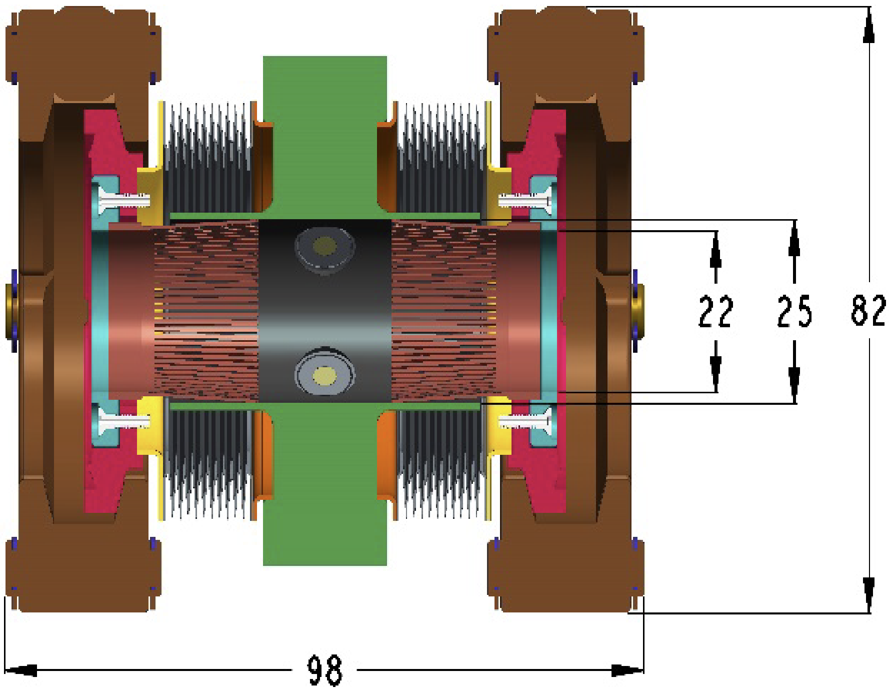




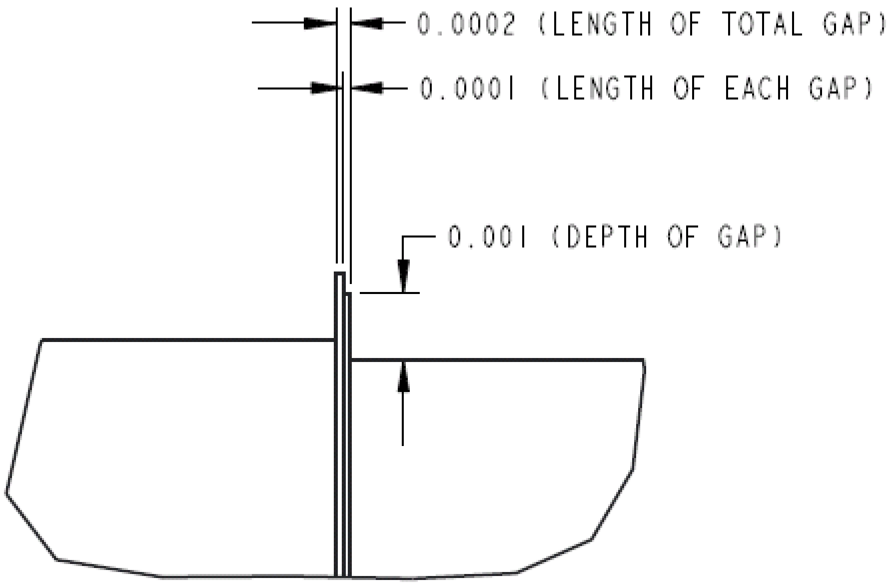
Courtesy J. Carter

- Using SynRad+/MolFlow+ developed at CERN which perform Monte Carlo simulations of photons and gas molecules.
- CDR reported 2.3 nTorr (effective gas scattering lifetime 25.8 h) after 1000 A-hrs of conditioning However, recent refinement of inputs suggests average pressures will be ***half*** *that*.

Working closely with physicists.

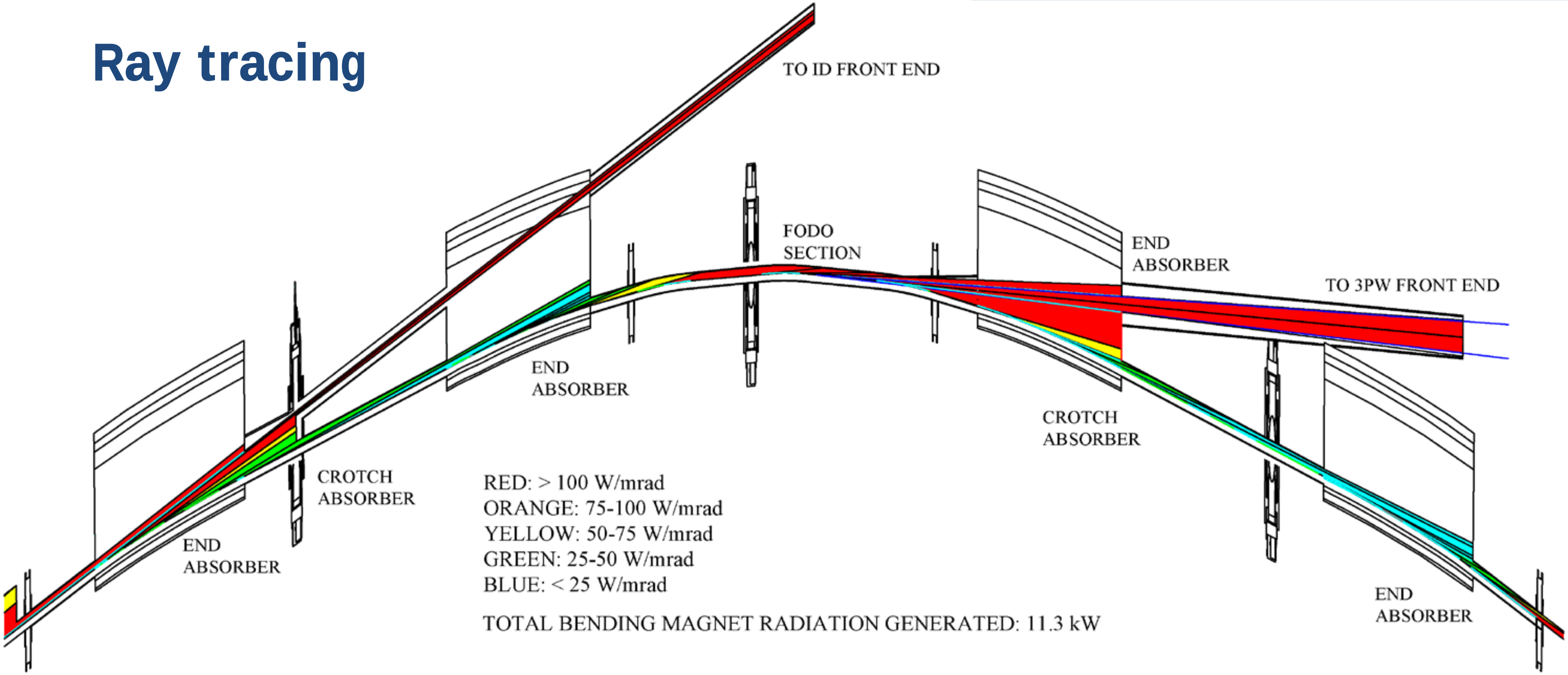


Impedance / rf heating of integrated BPM/bellows assembly (See B. Stillwell et al., Conceptual Design and Analysis of a Storage Ring Vacuum Beam Position Monitor…, Proc. IPAC'15.)



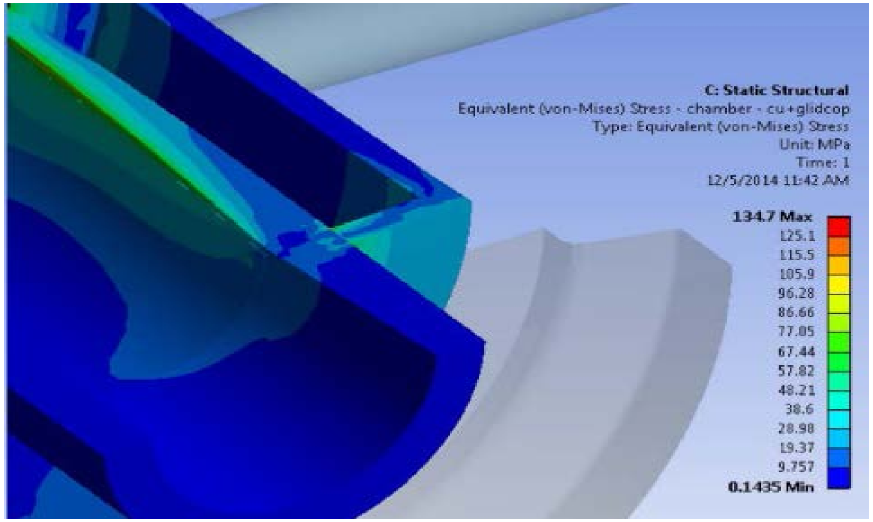
Impedance / rf heating of flange gaps

Ray tracing

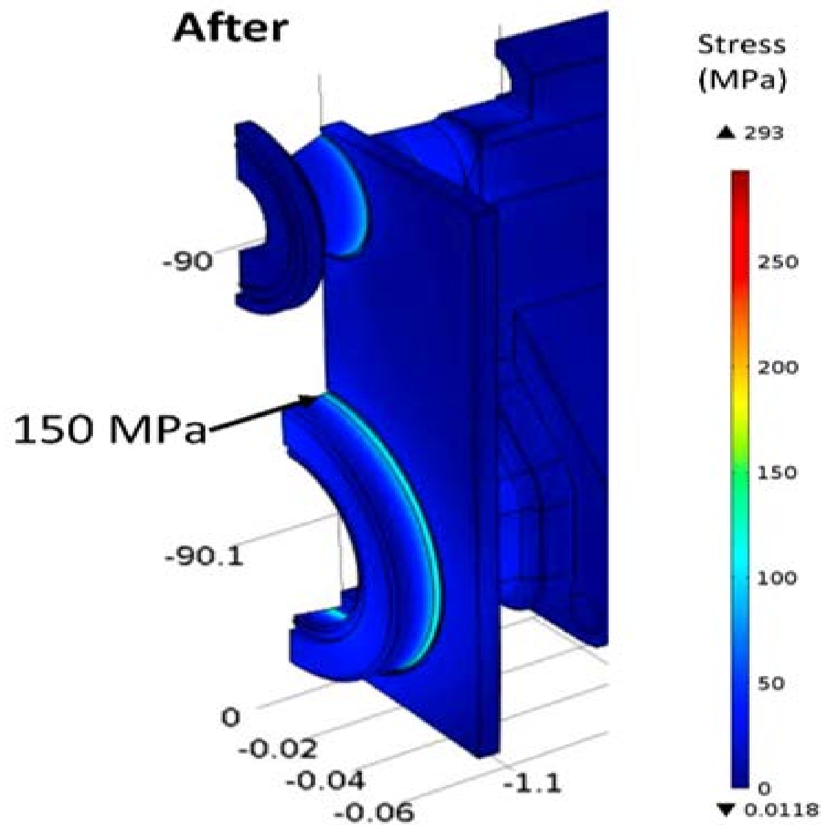


- Uses parameterized CAD model: beam trajectory defines radiation fans and system design shows where there intercept chambers and absorbers.
- Total managed power ~ 11.3 kW but is not uniformly distributed:
  - FODO section must manage ~1 kW/ m
  - Straight multiplet sections only have to deal with ~100 W/m

Finite element analysis

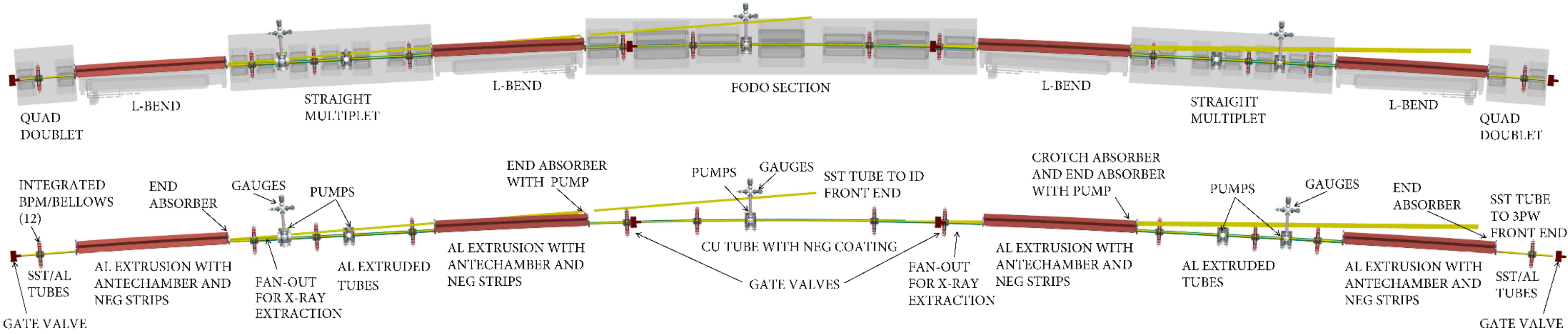


Results from ANSYS Mechanical simulation of FODO chamber end absorber thermal behavior. FODO chambers are expected to see up to 20 W/mm^2 on walls and 50-60 W/mm^2 on "in-line" absorbers needed to protect BPM/bellows and pump liners. ***Courtesy B. Brajuskovic***



Results from a COMSOL simulation an explosion bonded end plate planned for L-bend vacuum chambers. During bake-out deformation and stresses emerge in the plate as a consequence of the differential CTE between the aluminum and stainless steel materials. ***Courtesy K. Suthar***

Conceptual design overview



- Built of 9 separate “strings” to accommodate installation of integrated magnet + vacuum + plinth “modules”
- Hybrid conventional / NEG-coated system
  - FODO Section: NEG-coated copper vacuum chambers with efficient water-cooling and GlidCop “in-line” photon absorbers.
  - L-bend Sections: Aluminum chambers with antechambers, NEG strips, and discrete photon absorbers.
  - Doublet/Multiplet Sections: Aluminum tubular chambers (SST at fast-corrector locations) with aluminum “in-line” absorbers built into explosion-bonded flanges.

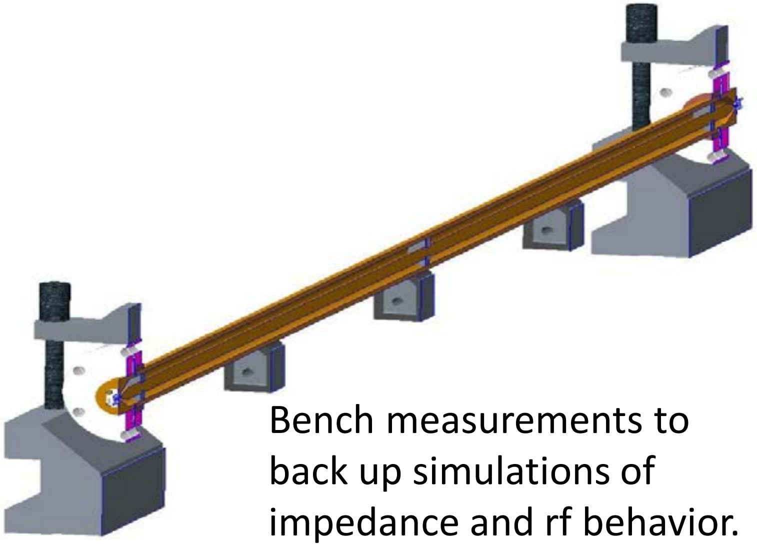
See B. Stillwell et al., Conceptual Design of a Storage Ring Vacuum System…, Proc. IPAC’14.

Value Engineering

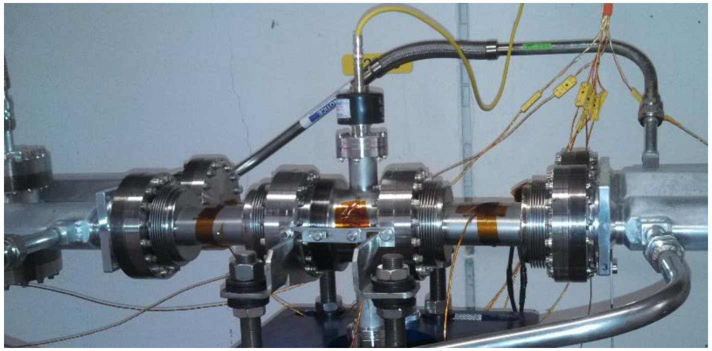
	All NEG-coated copper	Conventional chambers with antechambers	Hybrid
Vacuum performance	✓✓✓	✓✓✓	✓✓
Minimum compromises to magnet design	✓✓✓	✓	✓✓
Impedance effects	✓✓✓	✓	✓✓✓
Risk	✓	✓✓✓	✓✓
Installation time	✓	✓✓✓	✓✓
Reliability/maintenance time	✓	✓✓✓	✓✓
Cost	✓	✓✓✓	✓✓

R&D

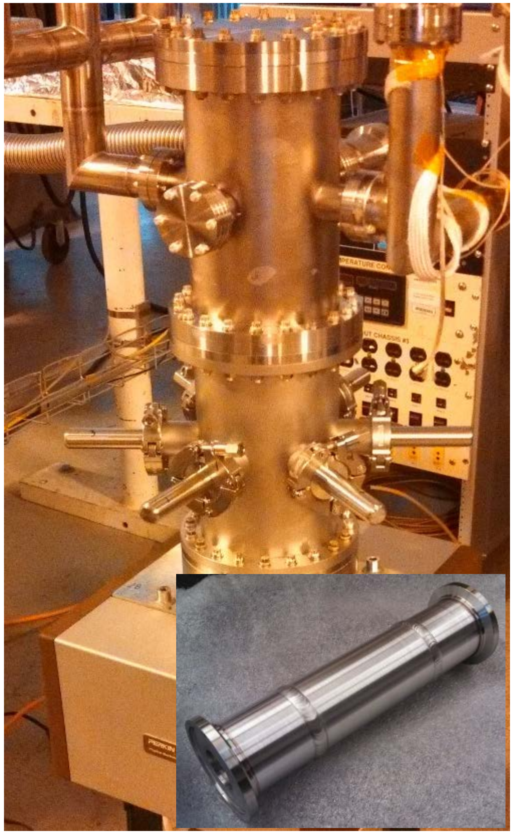
Sector mock-up to evaluate design feasibility, inform improvements needed for mechanical stability, and develop procedures.



Bench measurements to back up simulations of impedance and rf behavior.



“In-ring” testing of BPMs to better predict rf heating and impedance effects.



Flange/metallic joint test stand to ensure adequate robustness and reliability.

Plus, were building relationships (NSLS-II, MAX-IV, SIRIUS, CERN) to share our learning experiences.

The pit crew

Mechanical design / analysis:

- Ben Stillwell
- Branislav Brajuskovic
- Greg Wiemerslage
- Kamlesh Suthar
- Jason Carter
- John Noonan

Mechanical operations:

- John Zientek

Design / drafting:

- Maria O'Neil
- Dave Fallin
- Ed Kirkus

Summary

Technical requirements have been established which provide a clear metric for system performance.

State of the art computational tools and techniques are being used to ensure that the design will meet its performance objectives.

A “hybrid” conventional/NEG-coated system design has been developed which appears to strike a balance between performance objectives, reliability, and cost.

R&D is underway to build confidence in the design and analysis by building and measuring real components.

Back-up Slides

Accelerator Vacuum System
Value Engineering / Alternatives

- All NEG-coated copper chambers (MAX-IV, Sirius)
  - Excellent performance due to ubiquitous distributed pumping
  - High risk associated with NEG-coating entire ring (adhesion, limited vendor options, beam impedance implications not completely understood).
  - Longer installation and intervention times likely (depending on activation method)
  - Limited number of venting cycles (10 - 20 cycles for 1-2 micron thick coating)
  - High cost associated with electron-beam welding and NEG coating ~ $17.5k/m
- All-conventional system with antechambers (ESRF Upgrade, Spring 8-II)
  - Excellent performance due to ubiquitous distributed pumping
  - Requires compromises in multipole magnet design to accommodate antechambers large enough to house NEG strips.
  - Requires larger gaps between magnets in lattice to accommodate photon absorbers and local pumping.
  - Moderate cost ~ $10.6k/m

Accelerator Vacuum System
Value Engineering / Alternatives

- Hybrid chamber approach
  - No compromises to multipole magnet geometry or lattice required.
  - Various risks associated with NEG-coated chambers are reduced.
  - The additional installation time associated with in-situ activation can be avoided if gate valves are used to isolate the FODO section and FODO section is installed in a pre-activated state.
  - Number of activation cycles needed for NEG-coated chambers can be reduced if these gate valves are used.
  - Pressure bumps in areas with no distributed pumping mean that performance margin is small. However, state-of-the-art simulation tools may be leveraged to ensure adequate performance and optimize design.
  - Cost is only slightly higher than conventional/antechamber approach ~$12.8k/m