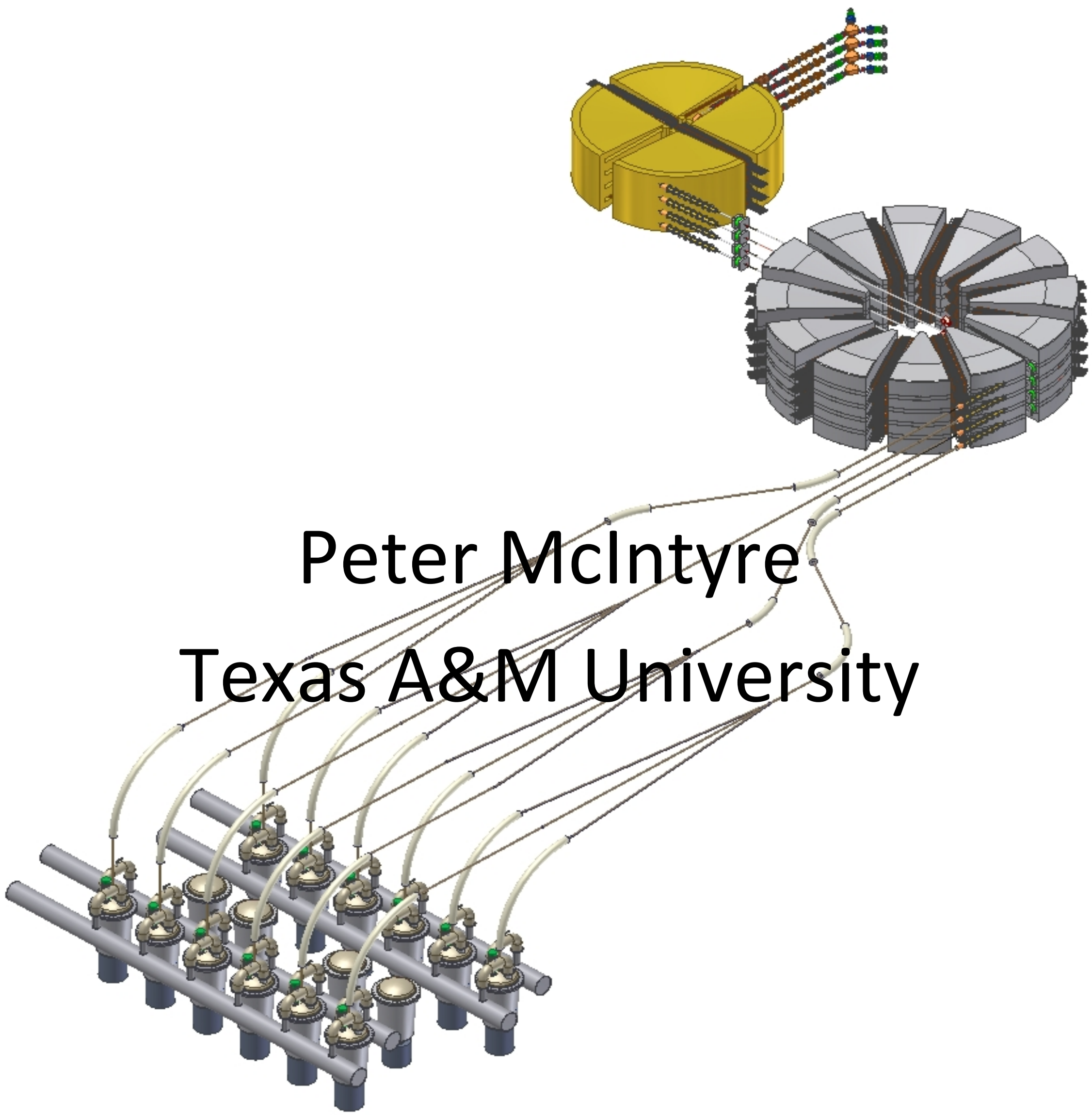
Strong-Focusing Cyclotron Optimum driver for ADS Fission



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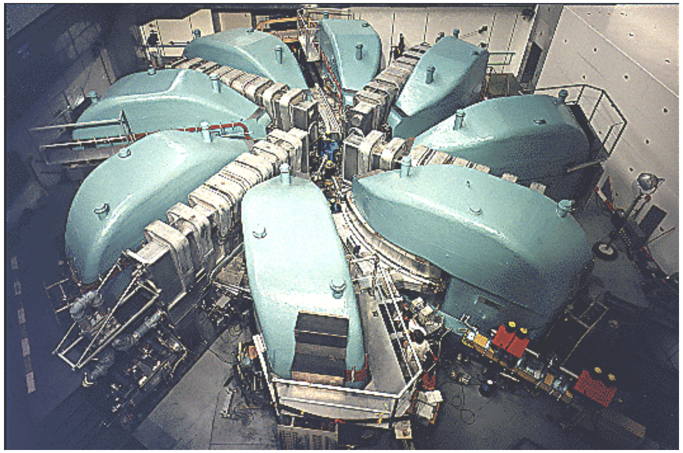
State of the Art



PSI

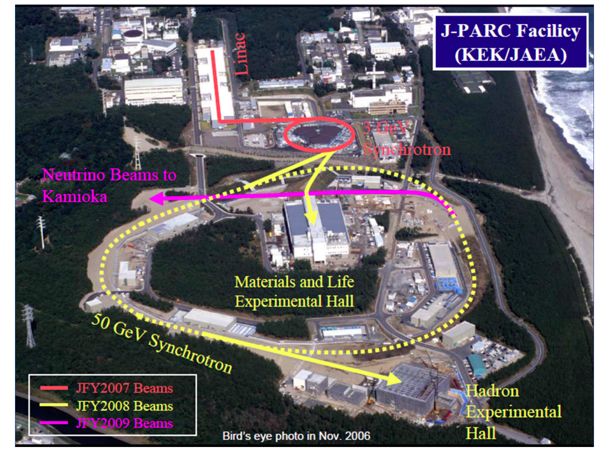
Isochronous Cyclotron

590 MeV 2.2 mA 1.3 MW

SNS

Superconducting Linac

910 MeV 1.1 mA 1.0 MW



JPARK

Rapid-cycling Synchrotron

3 GeV 0.3 mA 1 MW

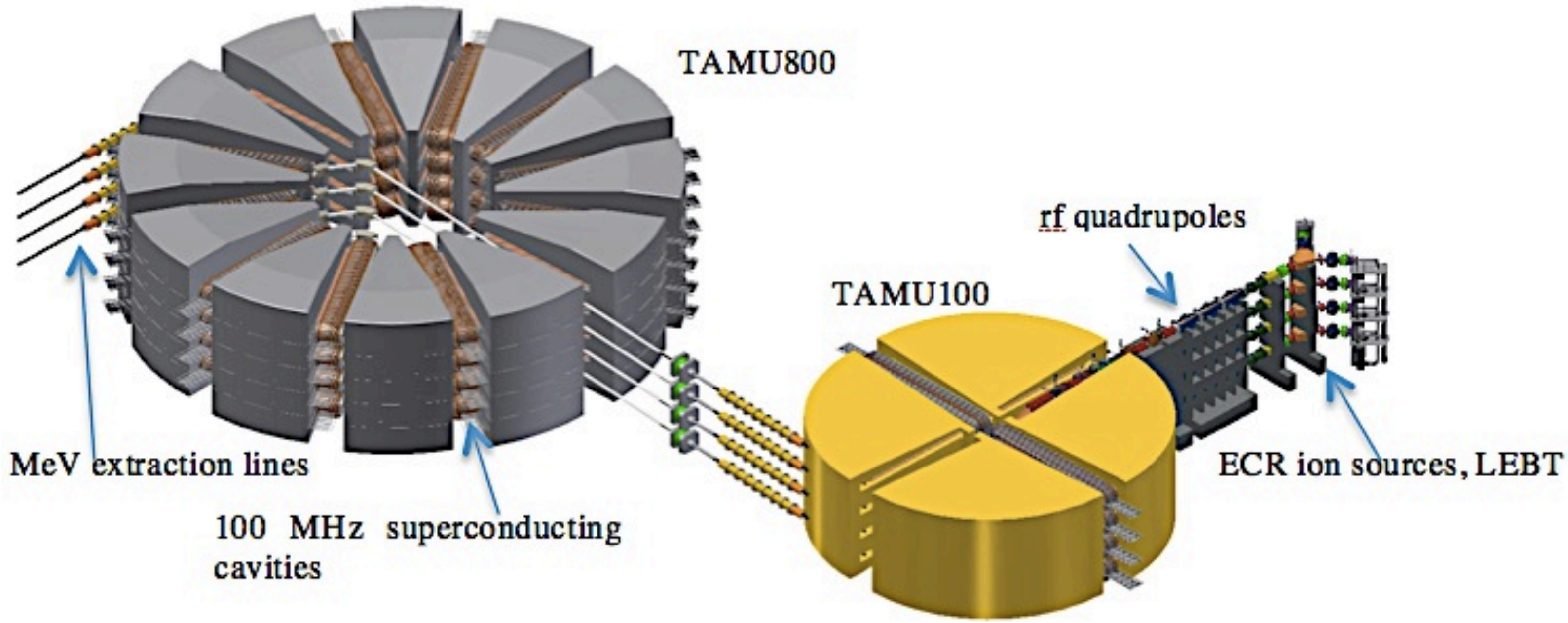
Applications for ADS fission and for spallation neutrons need ~10 mA @ 800 MeV

Beam current in an isochronous cyclotron is limited by

- bunch-bunch interactions among overlapping orbits
- variation of rf fields over the span of orbits
- matching of injected beam to the admittance
- space charge tune shift at injection
- weak focusing, crossing resonances during acceleration
- intercepted beam on the extraction septum

Strong-Focusing Cyclotron

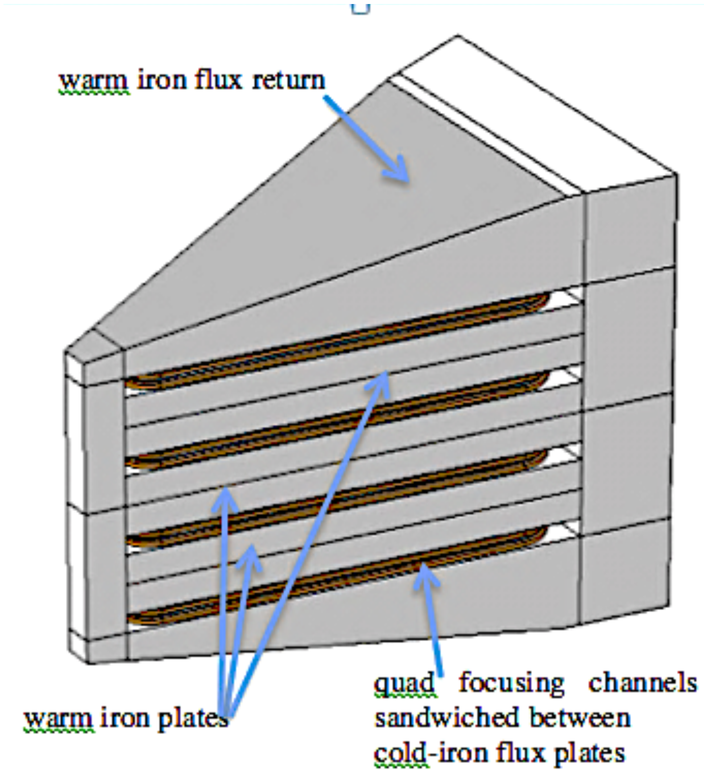
800 MeV   10 mA CW   4 beams   32 MW

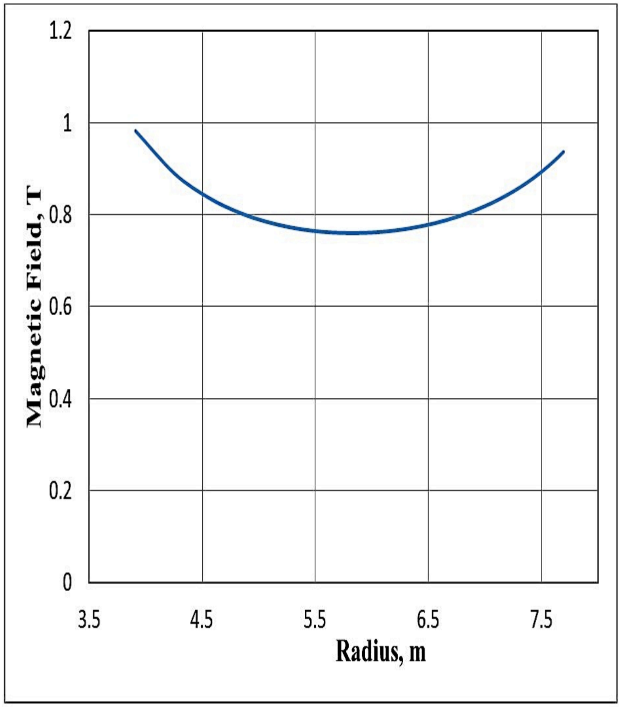


The SFC incorporates innovations that address those limitations:

- Superconducting rf cavities provide >20 MV/turn energy gain
  - Orbits are fully separated throughout acceleration
  - Parasitic modes are suppressed, flatten rf gain profile
- Quadrupole focusing channels give strong-focusing transport
  - Local matching at injection and extraction
  - Lock betatron tunes to a favorable operating point
- Dipole windings on QFCs enable strong septum at injection, extraction
- Flux-coupled stack of 4 SFCs in one footprint
- Superconducting rf, magnetics gives >50% energy efficiency

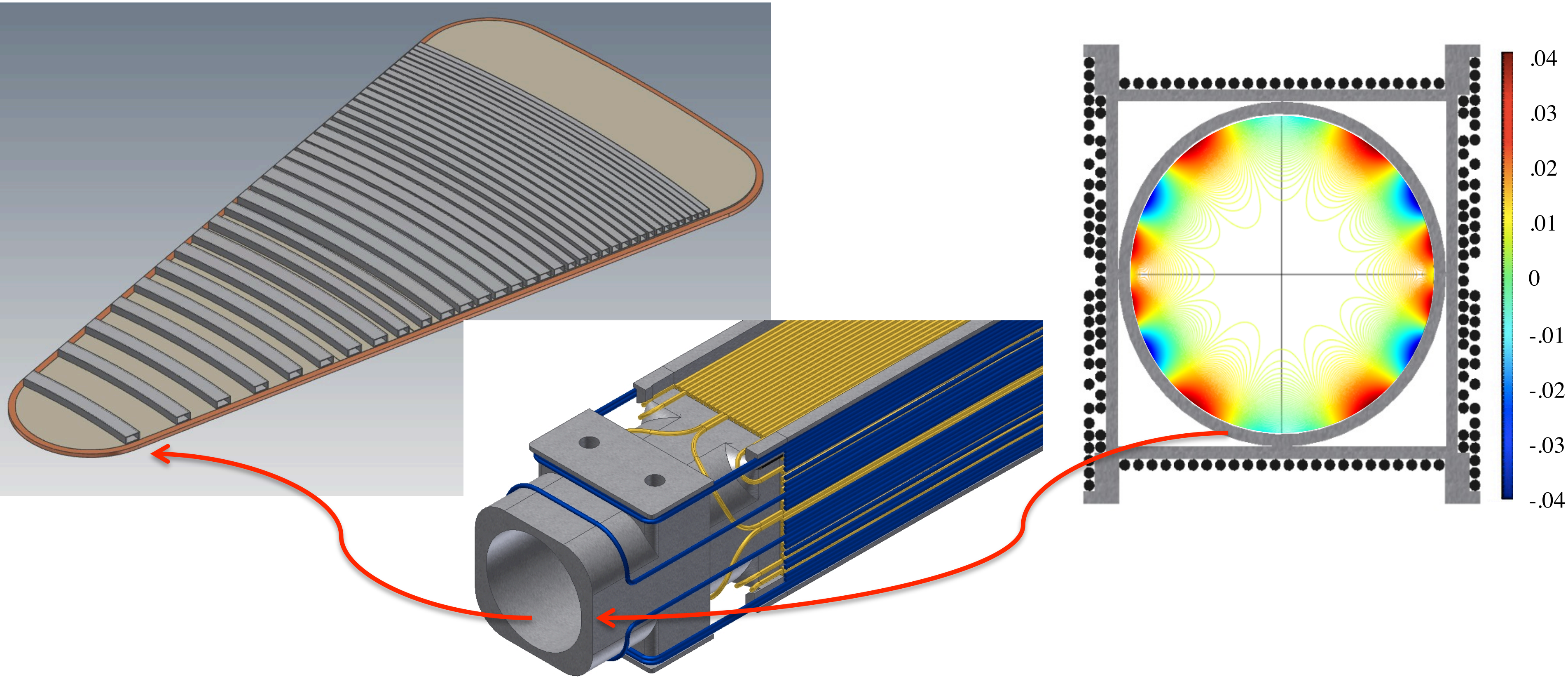
Magnetics





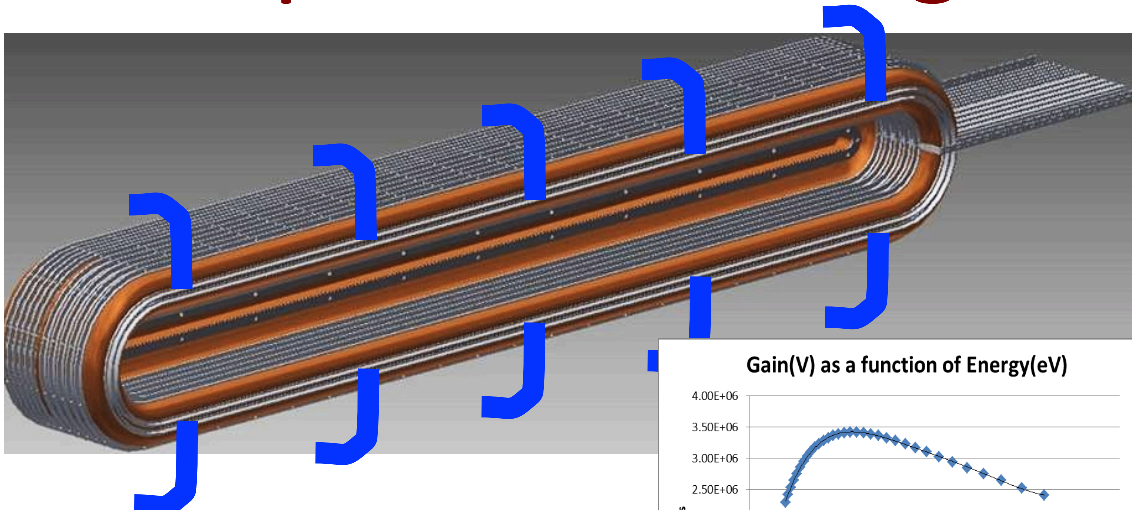
- Flux-coupled stack of cyclotron apertures, ~1 Tesla dipole field.
- Lorentz forces are cancelled on each pair of flux plates (inspired by RIKEN)
- Sectors are simple wedges (no spiralicity needed for vertical focusing)
- All windings (Main dipole, QFC windings) utilize MgB_2, operating at 15-20 K refrigeration

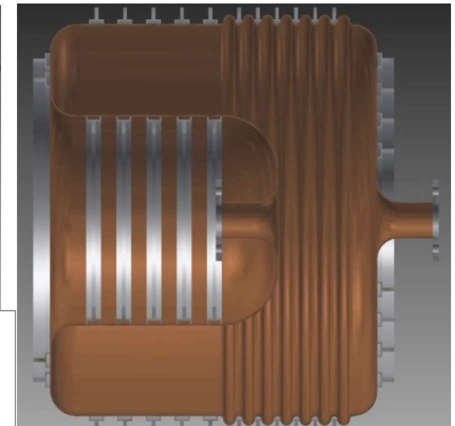
Quadrupole Focusing Channels



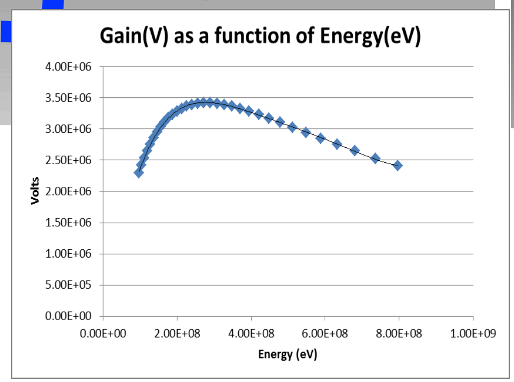
- Single-layer Panofsky quadrupole, window-frame dipole windings on a square SS form
- Each QFC is configured as an F/D lens pair
- 100 A/mm^2 in wire yields 3.5 T/m in quad, .09 T in dipole
- Cryogenics integrated between coil form and beam tube
- Wire placement optimized for gradient homogeneity

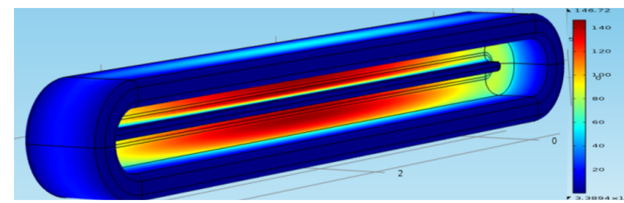
Superconducting ¼ wave cavity





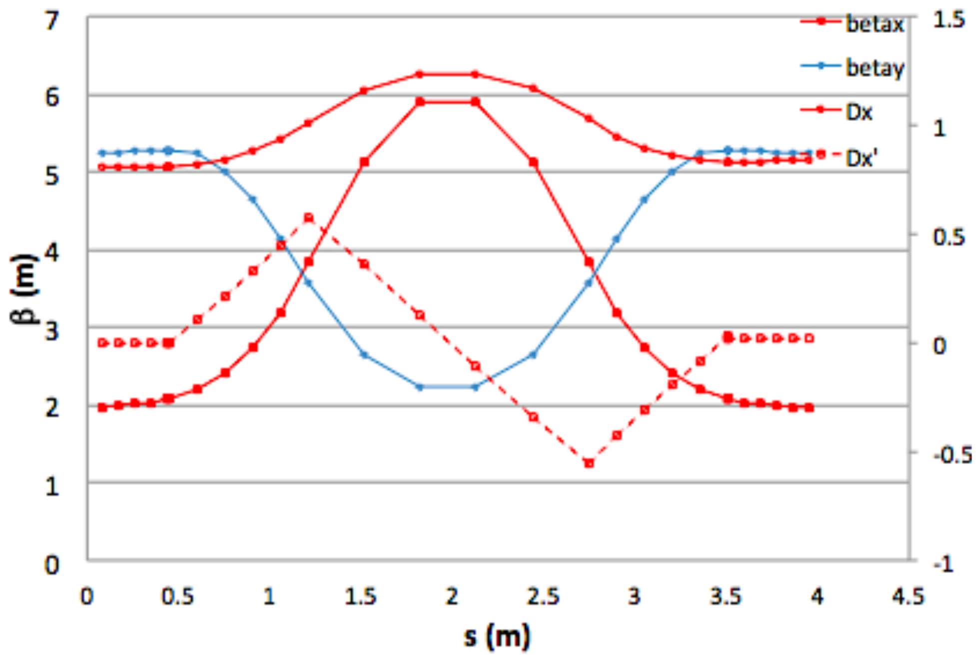
Q = 3.3×10^9
Dynamic heat load: 66 W @ 4.2 K
Stored energy: 340 J.

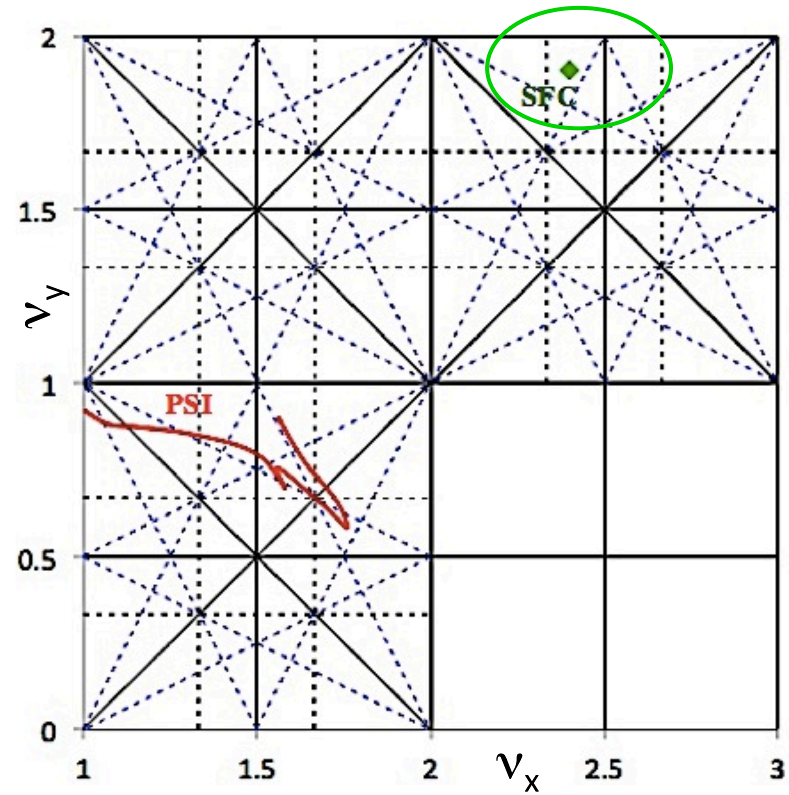




- ➢ The Nb cavity is a folded-geometry ¼-wave structure, in which the top and bottom lobes are coupled at the ends.
- ➢ Each lobe is driven by a linear array of 10 loop couplers, each coupler is driven by a solid-state power source (80% efficient).
- ➢ End coupling stabilizes the accelerating mode, flattens the gradient across the wide beam slot.
- ➢ Coupler drives can be independently modulated to match drive to beam loading during startup, operation, turn-off.

Beam transport in the SFC





We can lock tune to any desired value in a unit of tune.

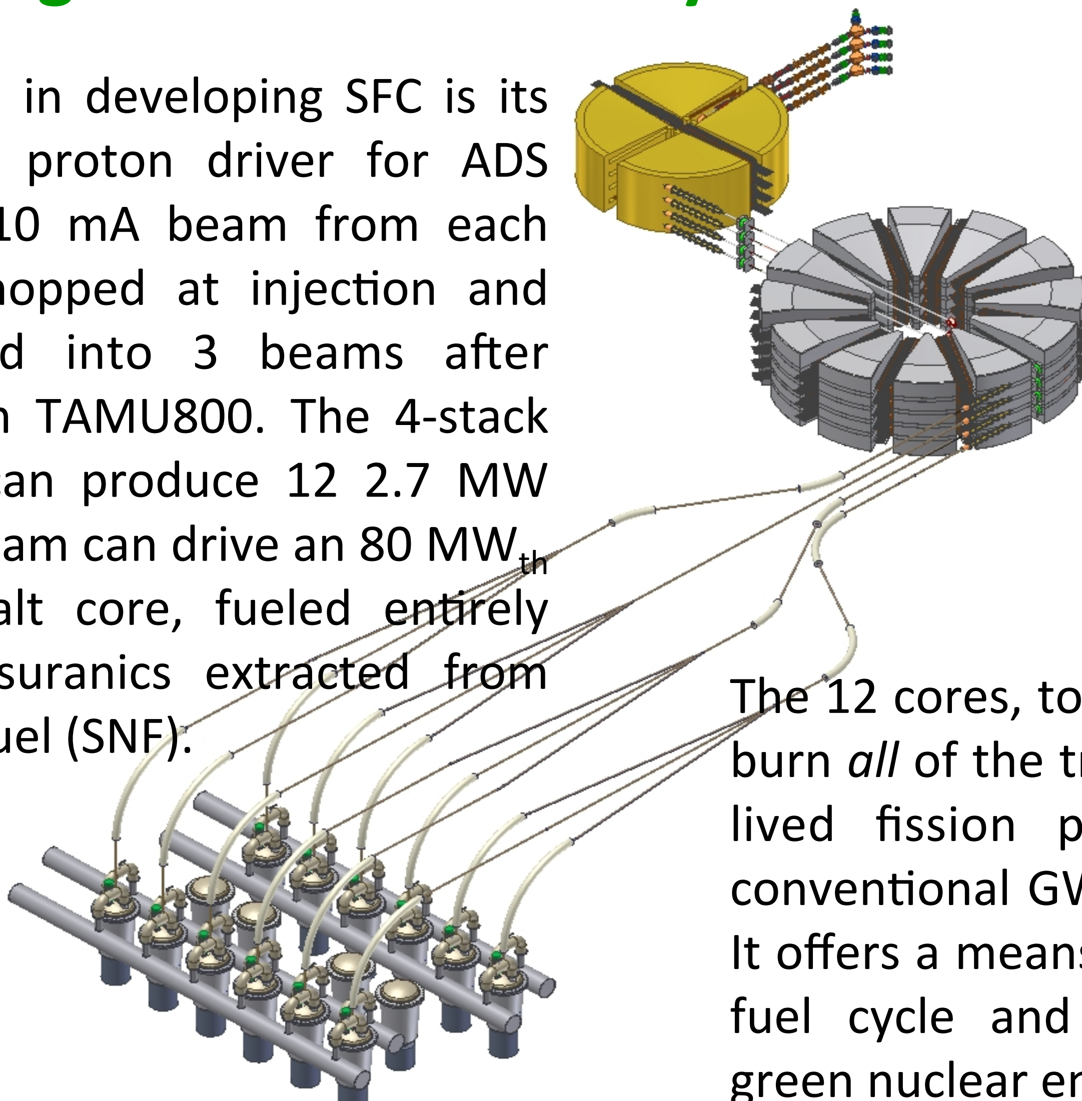
We can match at injection, extraction phase space.

Dipole windings on the QFCs enable us to maintain isochronicity, and to open the orbits at injection and extraction for zero-loss transfers.

Accelerator-Driven Subcritical Fission in a Molten Salt Core

Closing the Nuclear Fuel Cycle for Green Fission

Our motivation in developing SFC is its potential as a proton driver for ADS fission. The 10 mA beam from each cyclotron is chopped at injection and then separated into 3 beams after extraction from TAMU800. The 4-stack of cyclotrons can produce 12 2.7 MW beams. Each beam can drive an 80 MW_{th} ADS molten salt core, fueled entirely from the transuranics extracted from spent nuclear fuel (SNF).



The 12 cores, totalling 1 GW_{th}, would burn *all* of the transuranics and long-lived fission products in from a conventional GW_e power reactor [1]. It offers a means to close the nuclear fuel cycle and provide a path to green nuclear energy.