FERMILAB-SLIDES-19-015-AD-DI

Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

A Compact Superconducting RF Accelerator for Electron Beam and X-ray Irradiation

Thomas K. Kroc

CIRMS 2018

17 April 2018

Industrial-scale electron accelerators – the Need

Energy and Environment

- Waste water and sludge
- In-situ applications
  - Sediments
  - Hydrocarbon upgrading

Industrial

- In-situ cross linking at deeper penetration
- Food and medical device sterilization without ^{60}Co
- Radiation driven chemistry

Safeguards and Security

- Non-invasive and stand-off inspection

Industrial-scale electron accelerators – the Need

EBFGT

"The most important is the high power accelerators state-of-art. The power of existing accelerators allows for construction of flue gas treatment facilities for low and medium size power generation units. On the other hand, the reliability of such big machines is still regarded as not satisfactory (over 8500 hours of operation per year is required) and the price of this apparatus is high."

Prospects and Challenges in Application of Radiation for Treating Exhaust Gases, Working Material, IAEA, Vienna, Austria, 2011

Industrial-scale electron accelerators – present status

Continuous

ILU

- 1 – 10 MeV
- 20 – 100 kW

ELV

- 0.7 – 1.5 MeV
- 20 – 400 kW

Elektron

- 5 – 10 MeV
- 15 – 150 kW

Continuous

Dynamitron

- 0.5 – 5 MeV
- 88 – 250 kW

Rhodotron

- 5 – 10 MeV
- 50 – 560 kW

Pulsed

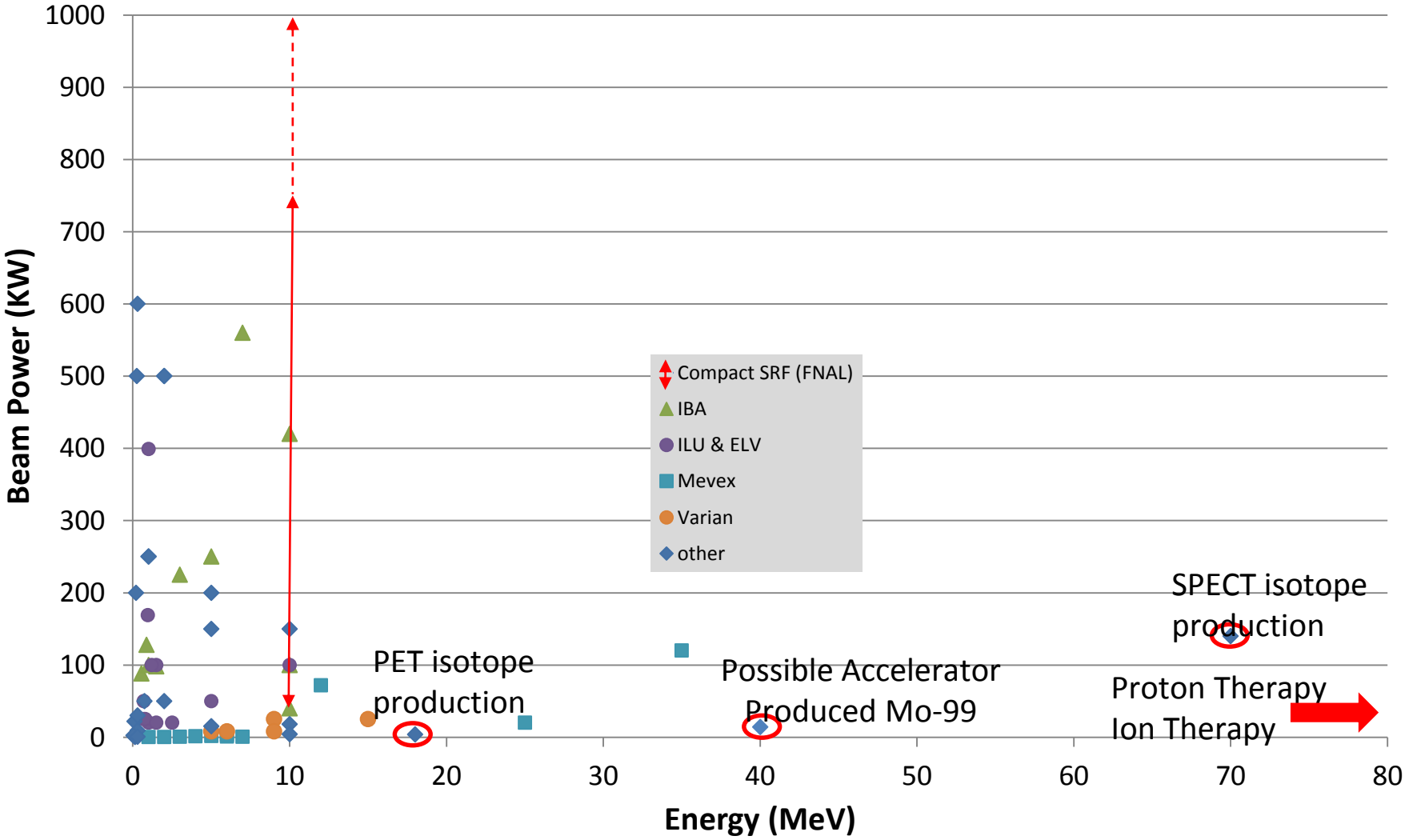
Mevex

- 5 – 25 MeV
- 250 kW – 2.5 MW
  - instantaneous

Varian

- 3 – 15 MeV
- 8 - 25 kW
  - average

Industrial-scale electron accelerators – present status



Fermilab

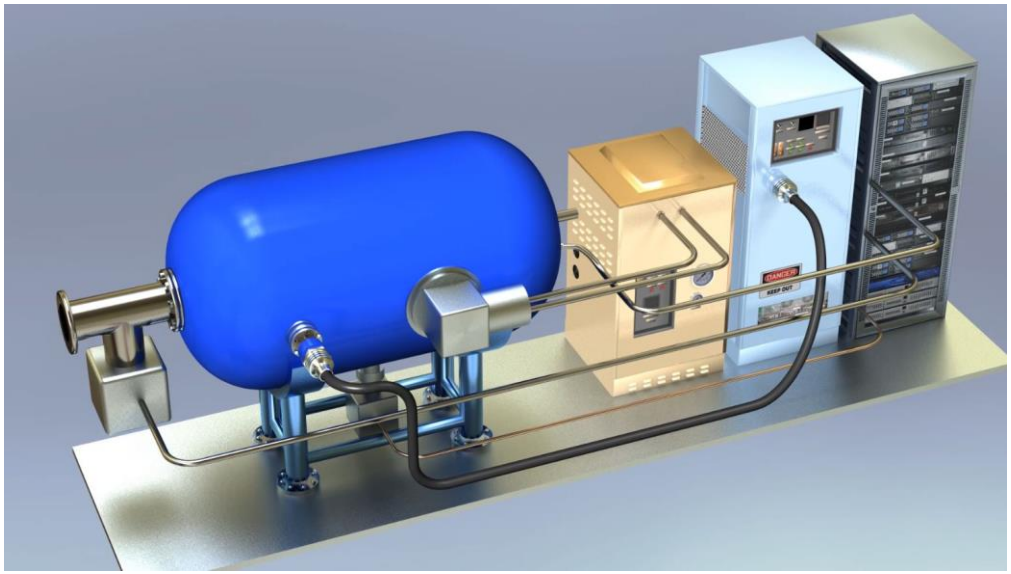
What are we doing to address this need?

- Designing an accelerator that is:
  - High Energy – 10 MeV
  - High power – 250 – 1000 kW
  - Compact
  - Reliable
  - Turn-key
  - CW (@ 650 MHz)

What we are doing

We are combining a number of state-of-the-art technological advances into a simple to operate, compact, superconducting RF accelerator.

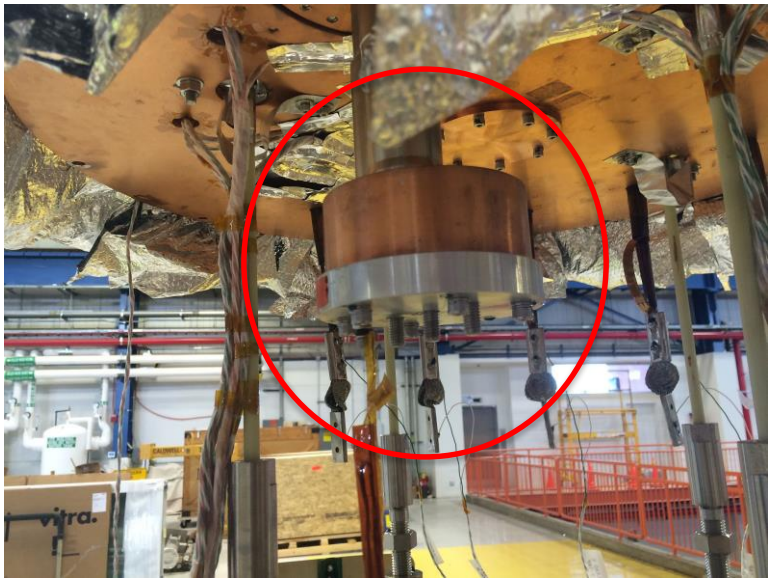
- Inexpensive (relatively)
- Efficient
  - > 80%,mains to e-beam
- Turn key operation
- High reliability
- ≤ 10 MeV
- ≤ 1000 kW
- ~ 0.7m ∅ x 1.5 m long

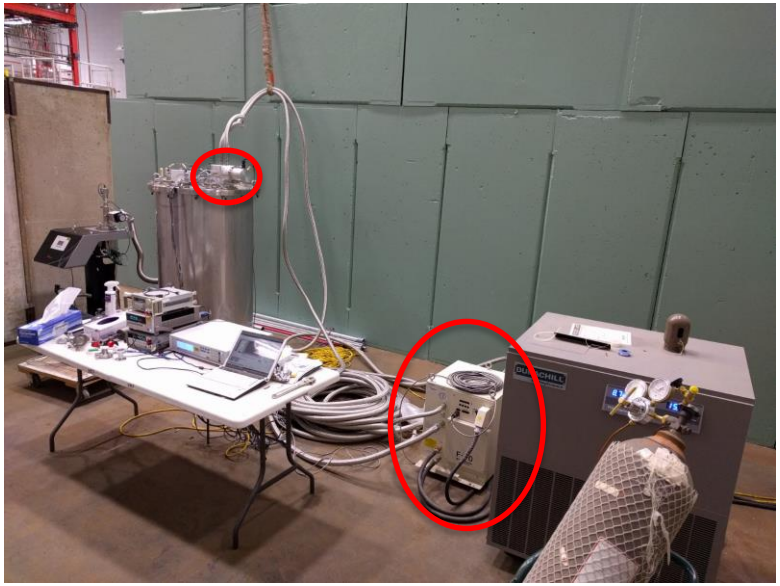


Heat – the major villian

Eliminate liquid cryogens

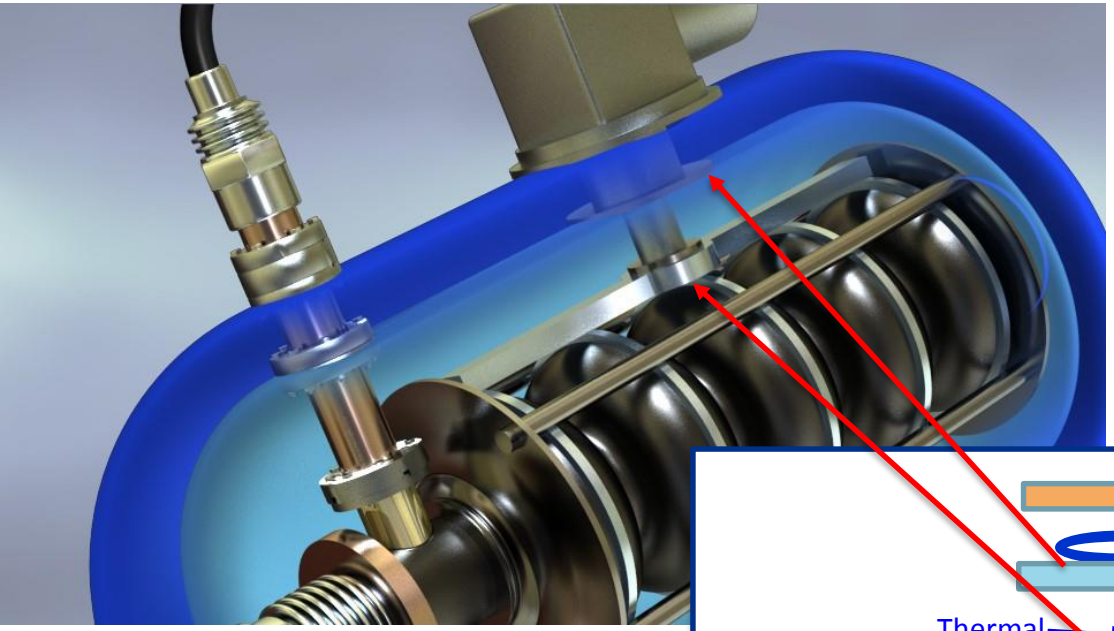
- Conduction cooling
  - No LHe
- Commercial cryocoolers
  - 2W each @ 4 K
  - 12.5 kW

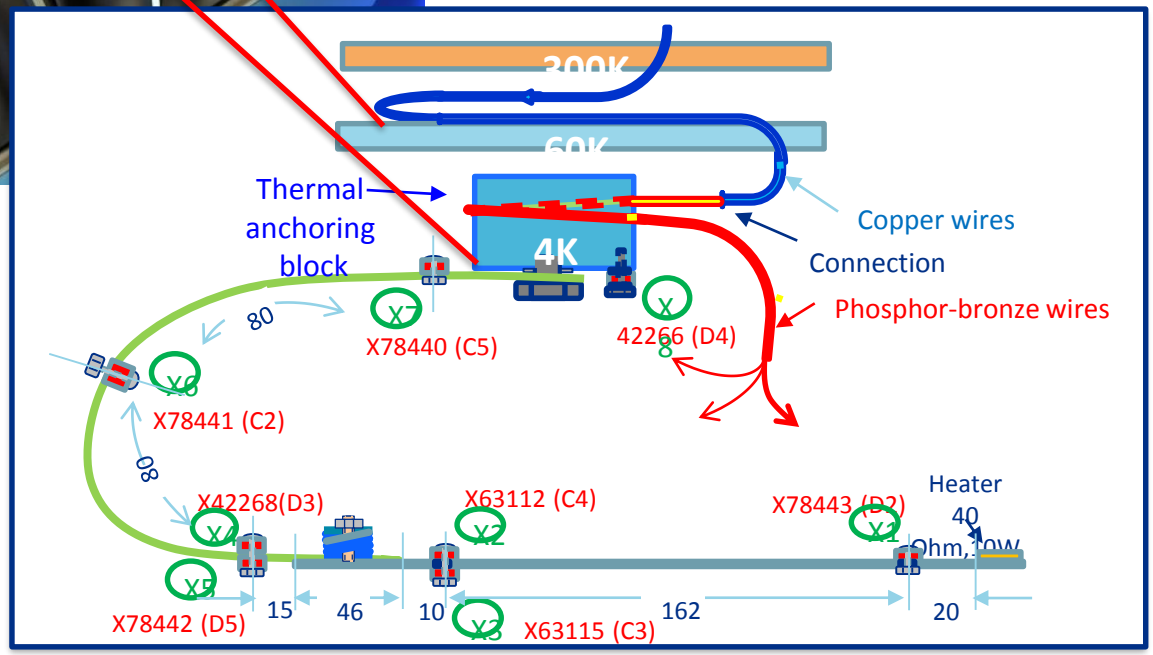




Conduction Cooling

Cold head(s) of the cryocooler(s) connected to cavities by high purity aluminum





Heat Budget

4 – 6 W

US patent applications

#15/280,107

#14/689,695

Fermilab

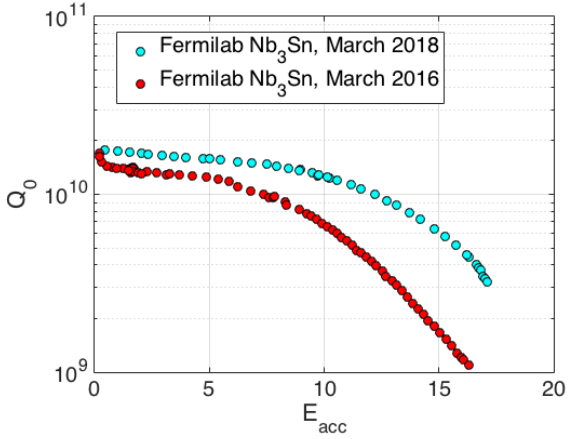
How do we accommodate the heat budget?

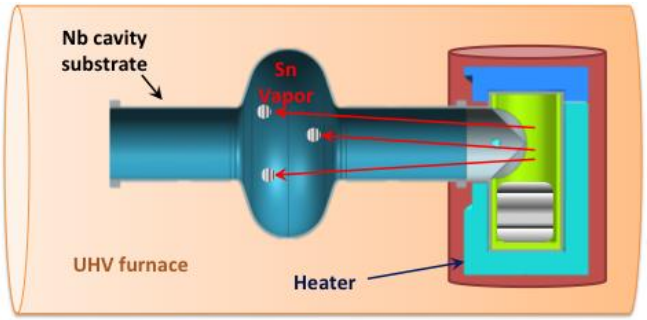
- Higher temperature superconductor
  - Very high quality factors
  - < 2.5 W @ 4K
- Low loss RF power couplers
  - 10 kW with < 0.7 W @ 4K
- Integrated electron gun
  - < 0.1 W @ 4K

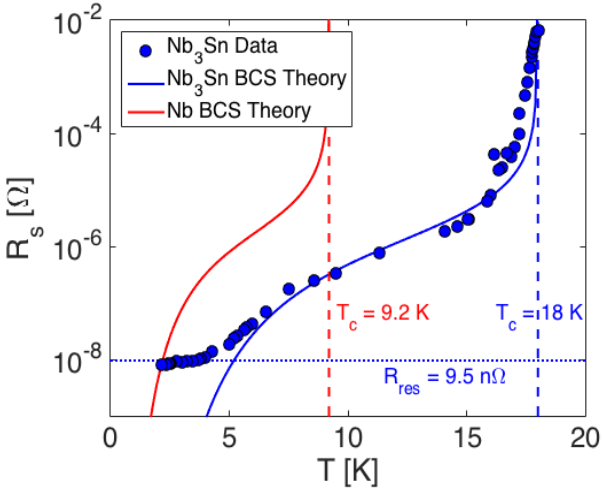
Higher temperature SRF cavities

Nb_3Sn Coated SRF Cavities

- 1.3 GHz, 14 MV/m, Q=2x10^{10} @ 4K
- At 650 MHz, we predict < 2.5 W @ 4K
- Sam Posen
  - $2.5M DOE Early Career Award
- First article @ FNAL within factor of 3 of Cornell performance



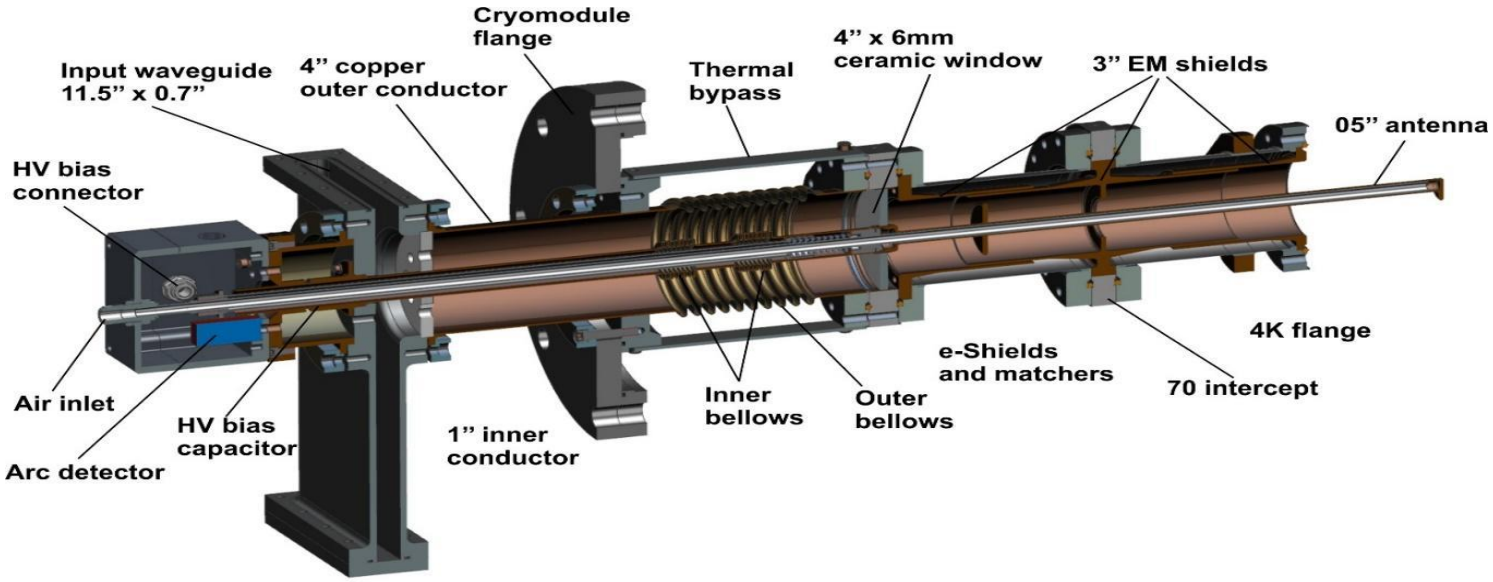




Low loss RF power couplers

FNAL and Euclid TechLabs

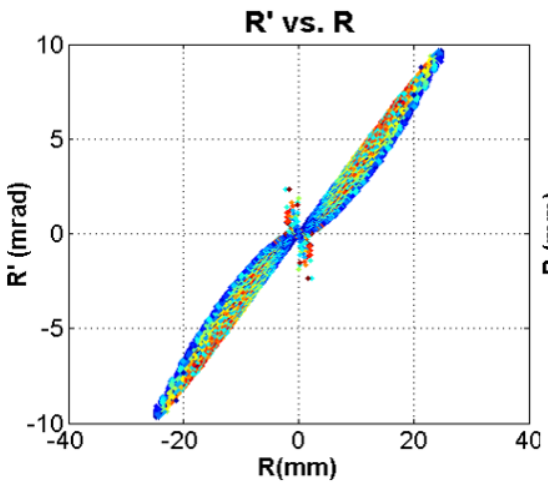
- Patent application # 15/278,299
- DOE OHEP grant to fund fabrication of two 1.3 GHz prototypes
- Testing this year
- Eliminates copper plating

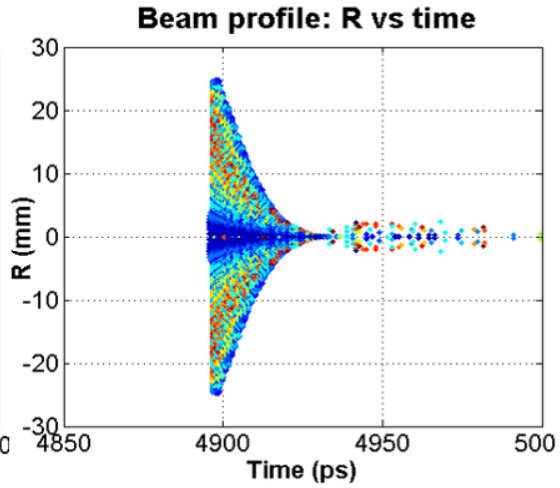


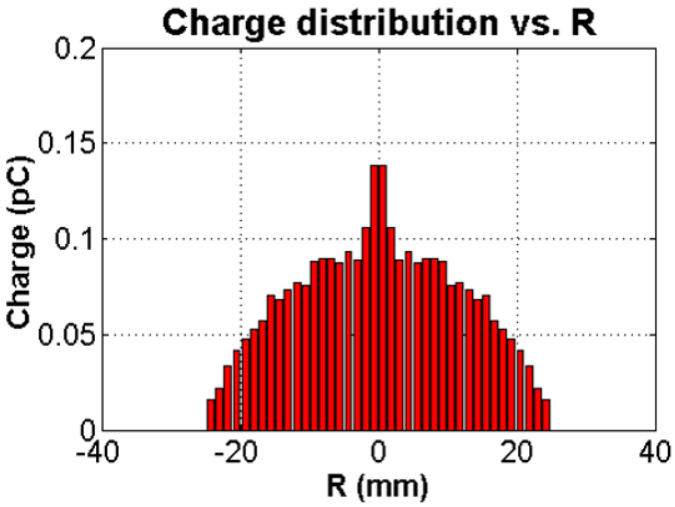
Fermilab

Integrated Electron Gun

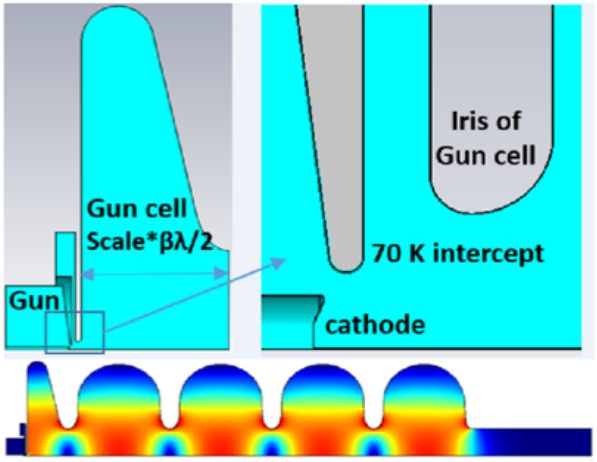
Reduces size and complexity







	Value
Electron energy	9 MeV±5%
Current modulation range	0.1 μA - 1 mA
Beam loss at 4K	<0.5 W
Cathode backward bombardment	<1 W
Cathode blackbody radiation	< 200 mW

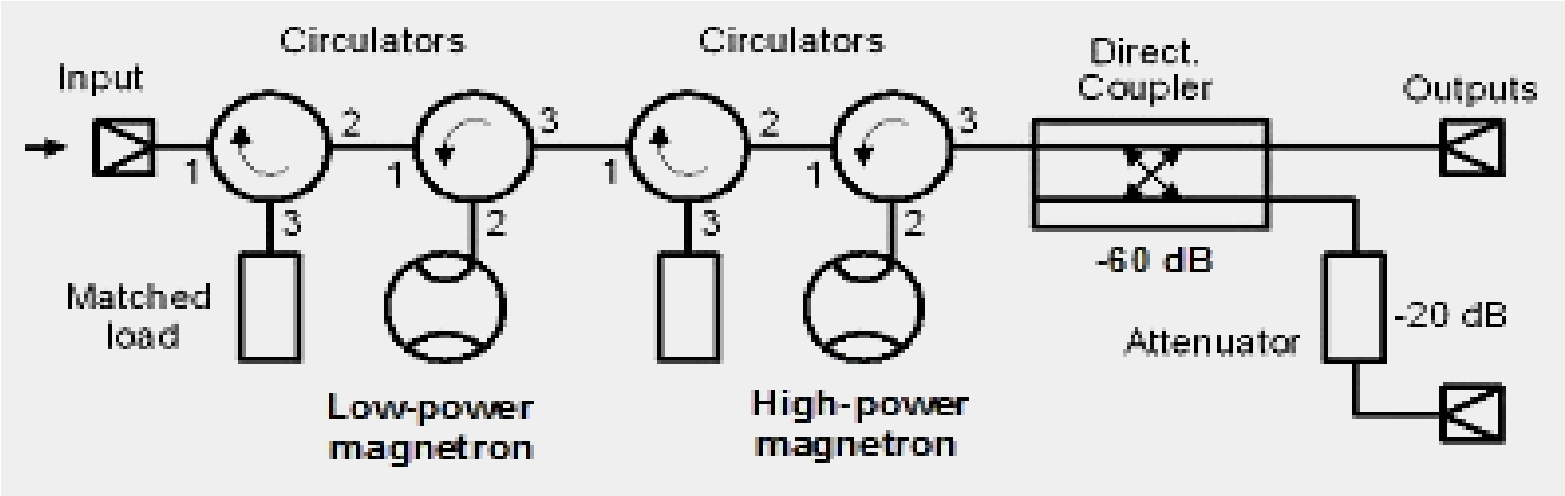


Fermilab

Reduce cost

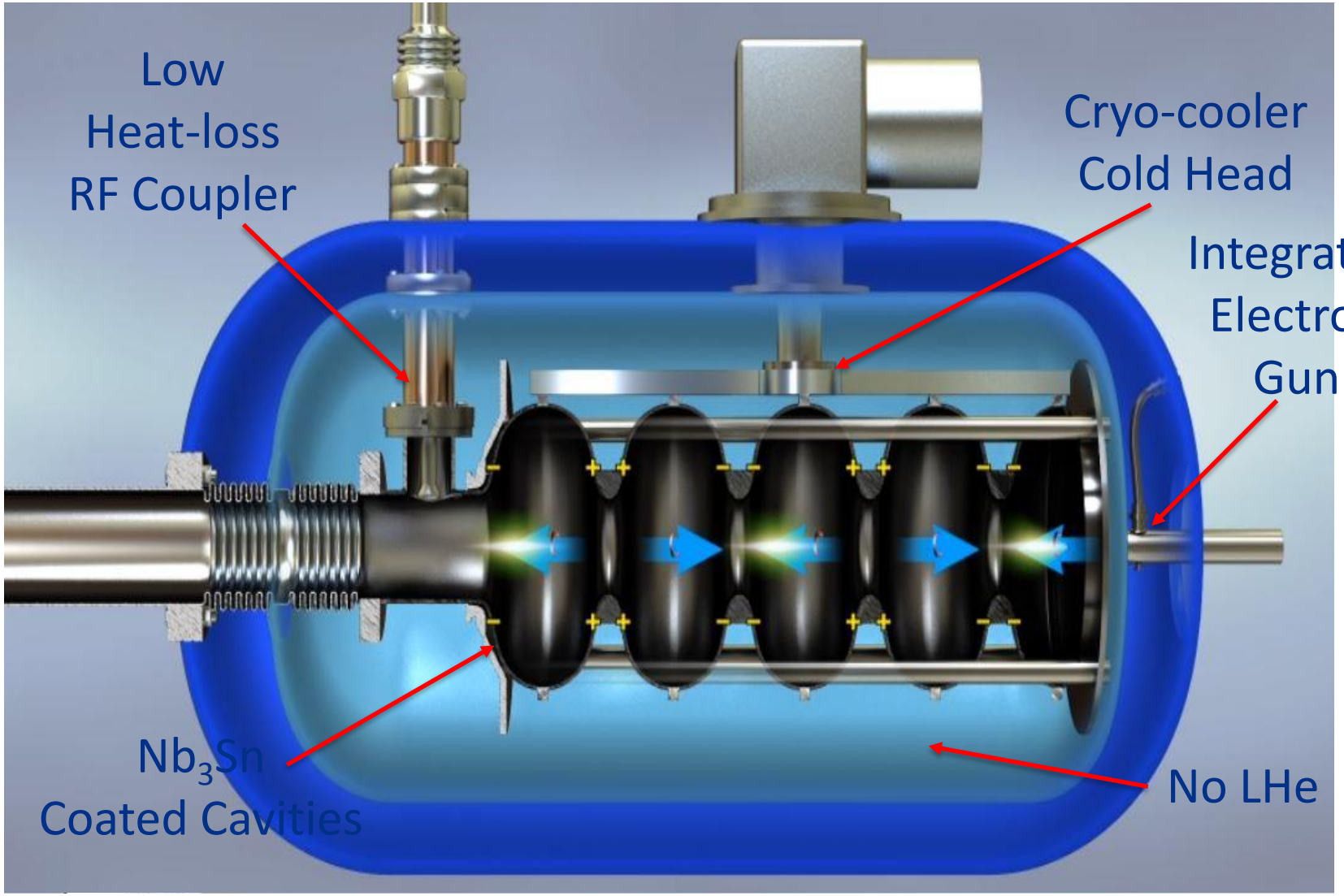
Injection locked magnetron (PCT/US2014/058750)

- Reduce cost/watt by factor of 5 over IOT and solid state
- Efficiency > 80%
- Excellent phase and amplitude control



Conceptual scheme of a single 2-cascade magnetron transmitter allowing dynamic phase and power control

The Compact SRF Accelerator

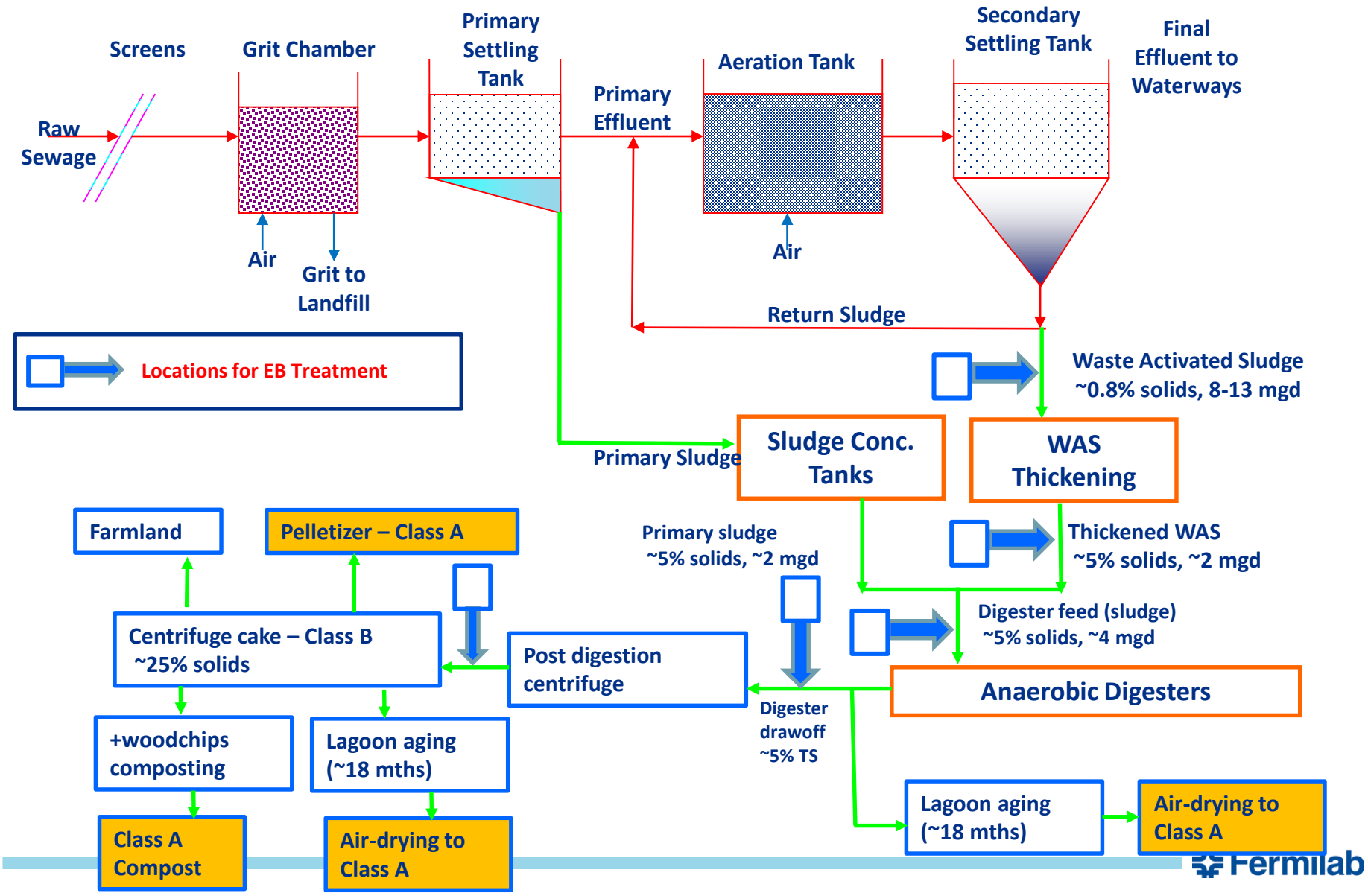


Biomass pretreatment

- Electron range
  - Hardwood (maple) - 6.4 cm
  - Switchgrass - 45 cm
- Dose required for wood
  - 750 kGy (?)
  - 1.2 tonne/hr @ 250 kW

Pictures curtesy of M. Driscoll, SUNY

Schematic of MWRD Stickney WRP Treatment Process



Thank you