



Energy recovery linacs for commercial radioisotope production

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Muons, Inc.



NIOWAVE
Accelerating Your Particles

Project Collaborators

- MuPlus/Muons, Inc. recently awarded a DOE STTR Phase I grant, with subgrants to Jefferson Lab and Niowave, Inc. to study energy recovery linear accelerators (ERLs) for radioisotope production with bremsstrahlung photons
- Concept has benefited from contributions of a number of individuals



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Motivation

- Radionuclides needed in increasing amounts for new technologies and maturing fields such as medical imaging and radionuclide therapy
- Radioisotopes produced in one of several ways:
 - 1) (n, γ) or $(n, \text{fission})$ reactions using fast or thermal neutrons from nuclear reactors
 - 2) Target bombardment with heavy ions from ion cyclotrons or ion linear accelerators (linacs)
 - 3) Target bombardment with bremsstrahlung photon beams from electron linacs
 - 4) Chemical separation from more stable parent isotopes

Motivation

- Reactor and ion accelerator methods more common, but expensive due to the limited availability of production facilities
 - For medical imaging and radionuclide therapy, procedures and treatments only available at medical centers near production facilities
- Development of low-cost method for production of short-lived, high-value, high-demand radioisotopes leads to:
 - Development of new techniques in the field of nuclear medicine
 - More widespread availability of radioisotopes of interest

Concept

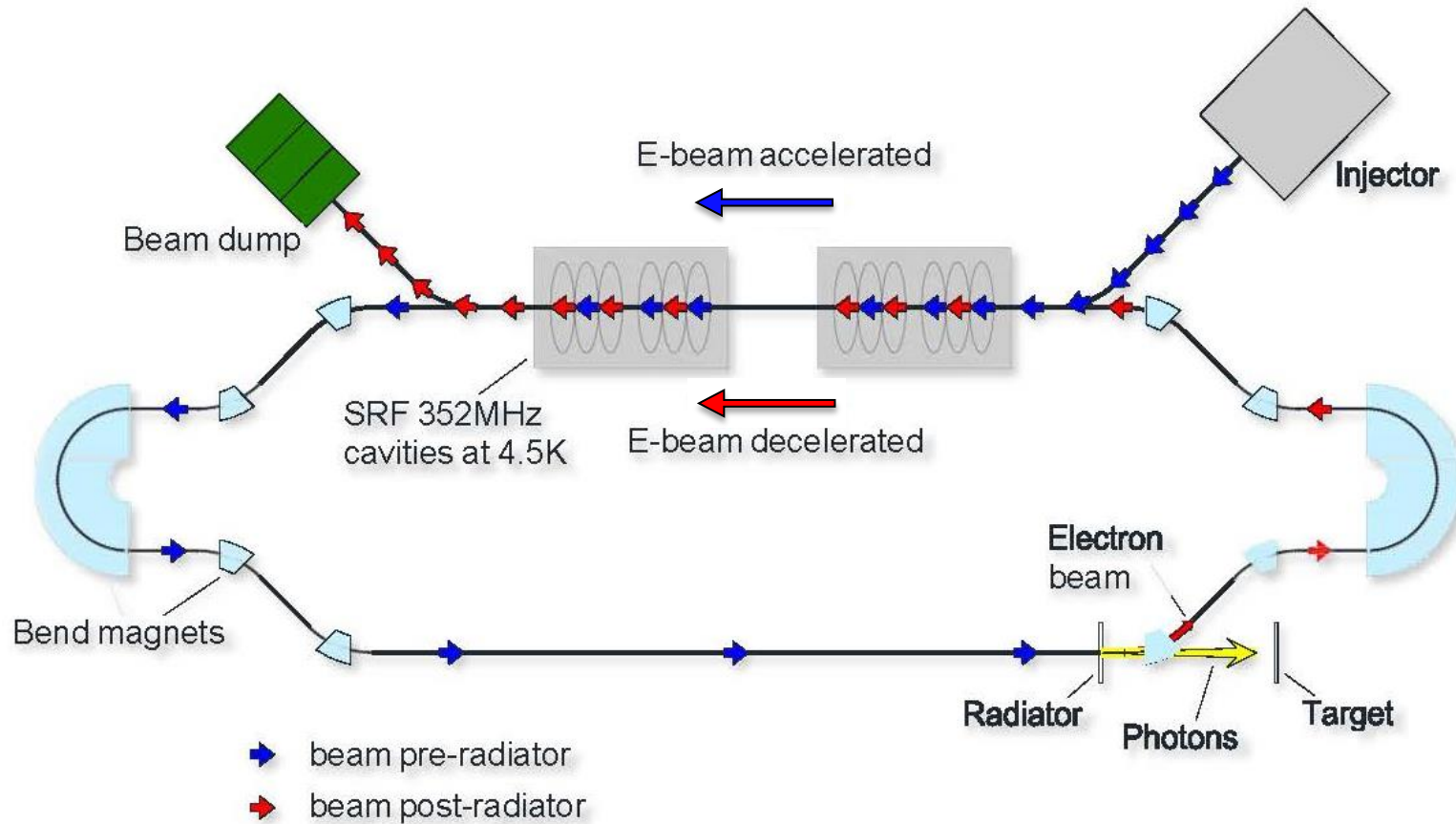
- Certain radioisotopes produced more efficiently in bremsstrahlung photon/electron linac process versus conventional reactor, ion linac methods
 - (+) Electron linacs relatively simple and inexpensive to operate and maintain
 - (+) “Isotopes on demand” and selection of desired isotope simplified compared to production from a reactor
 - (-) Specific activity of radioisotope generally low (≤ 1 Ci/g)
 - (-) Energy inefficient; majority of electron beam energy must be dumped – activation of shielding components, neutron production at beam dump

Concept

- What if we can recover the electron beam energy? Increase energy efficiency of the machine by recycling waste beam energy with energy recovery linac (ERL)
 - (+) Reduced power at beam dump; less neutron production/activation of shielding
 - (+) Simplified decommissioning
 - (+) High yields obtainable with high electron current
 - (+) Improved overall energy efficiency of the electron linac complex

Concept

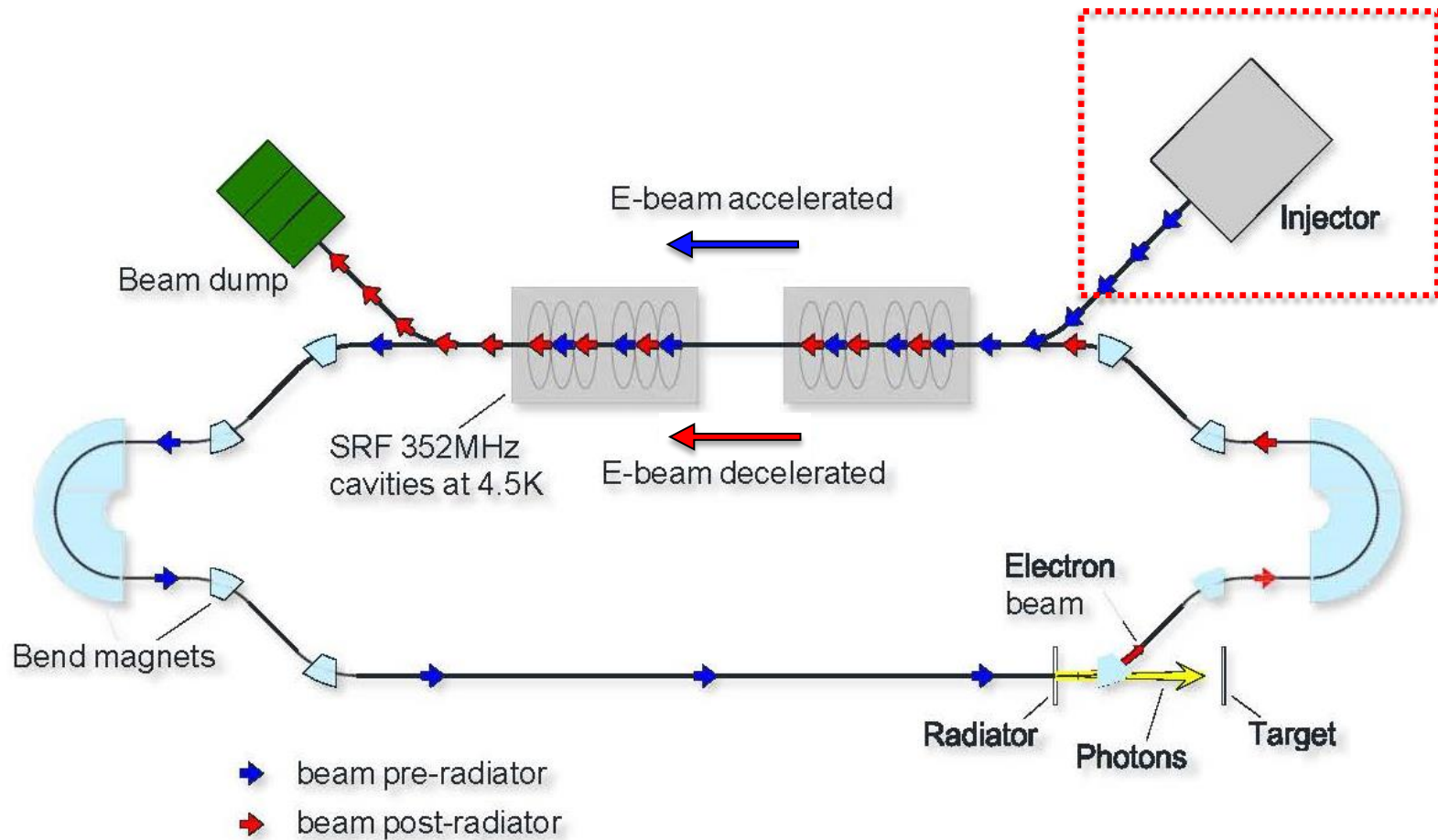
- An ERL-based radioisotope production facility utilizing bremsstrahlung photon beams for photonuclear reactions



[Adapted from A. Kimber]

Concept

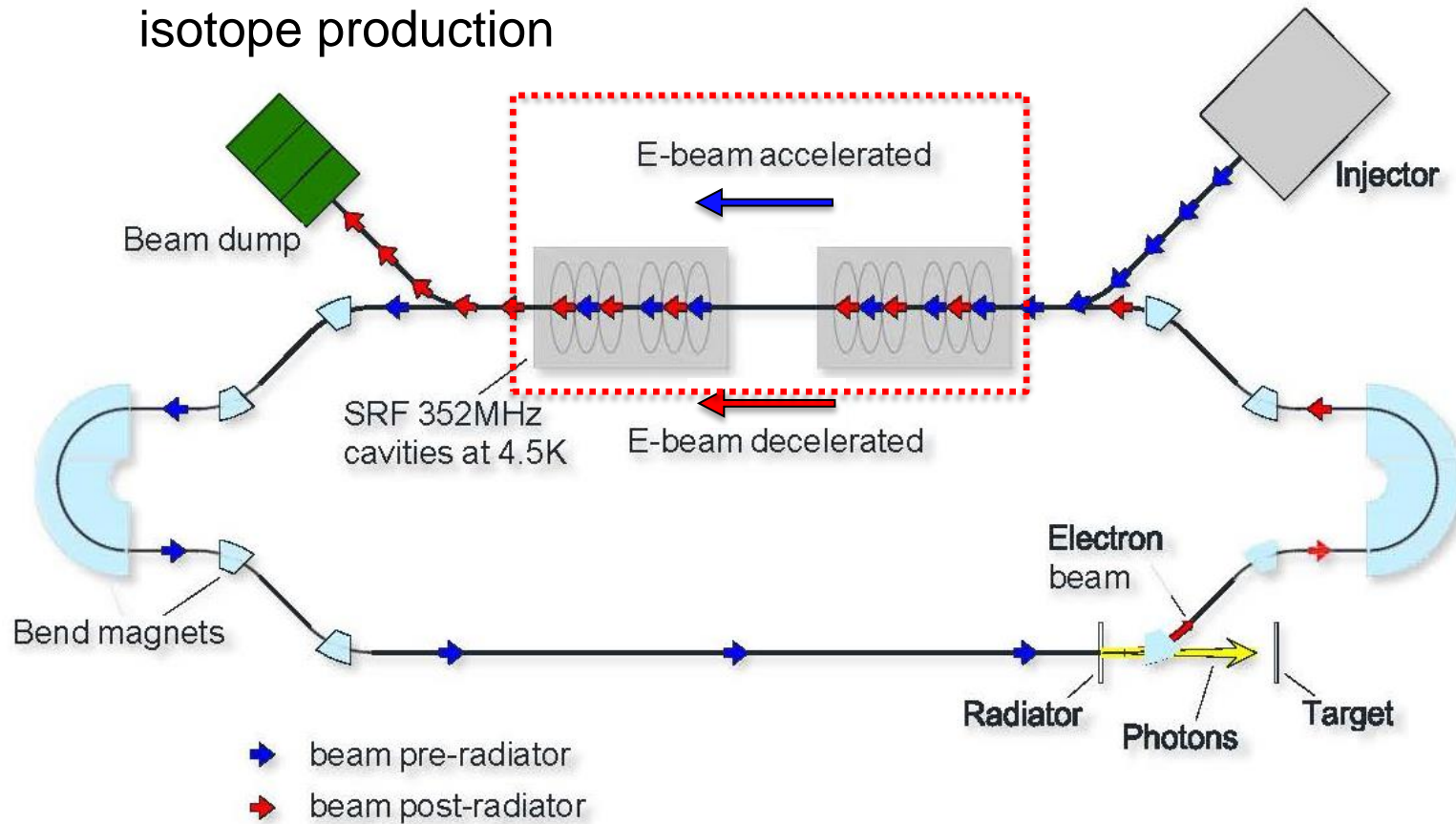
- Electrons from injector are injected into accelerating beamline



[Adapted from A. Kimber]

Concept

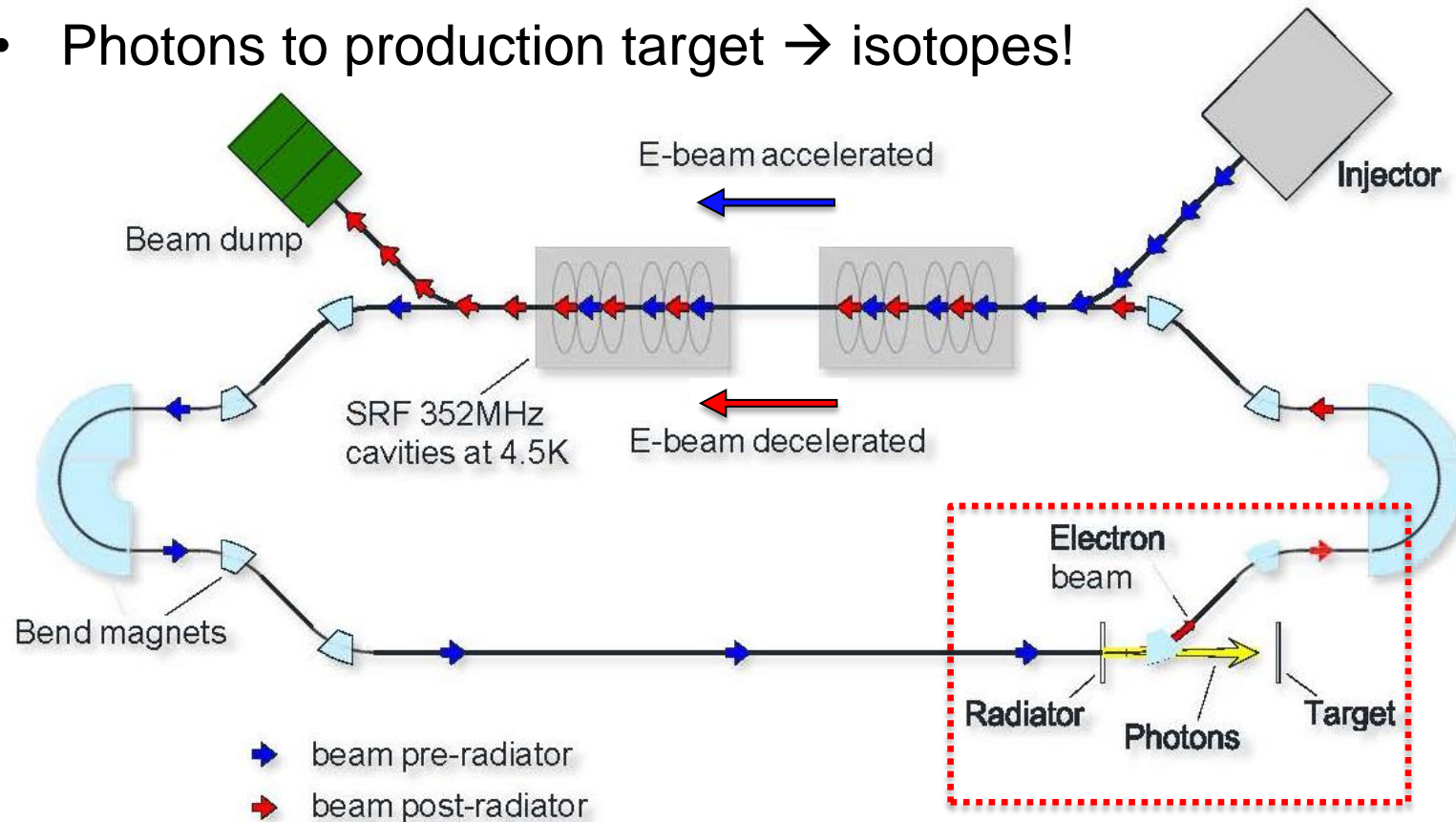
- Acceleration in SRF cavities with gradients 10-15 MV/m
 - Electron beam energies of 20-100 MeV of particular interest for isotope production



[Adapted from A. Kimber]

Concept

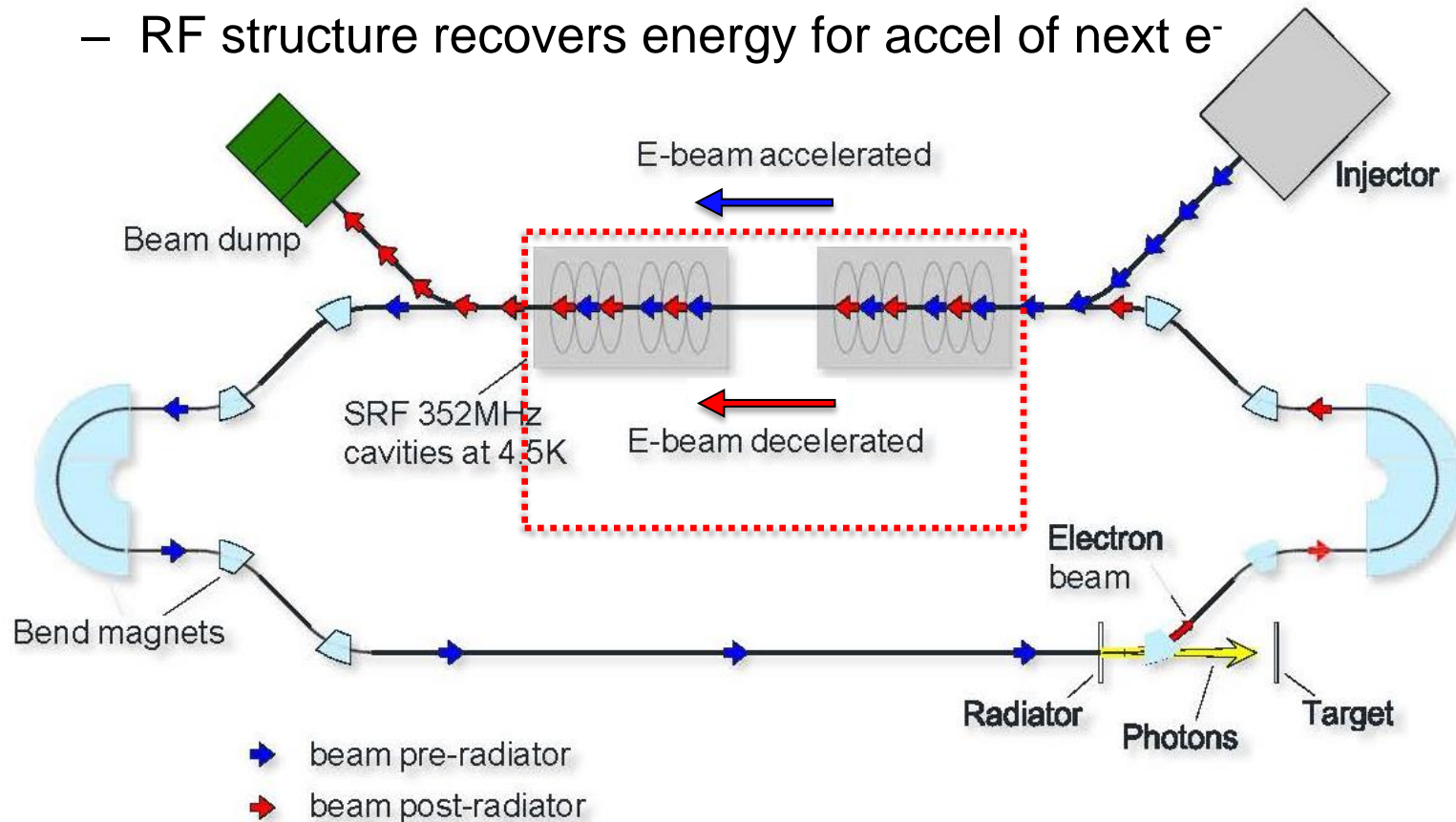
- Full-energy electrons pass through thin photon radiator
 - ~99% of e^- pass through as “waste” beam; ~1% generate photons
- Photons to production target \rightarrow isotopes!



[Adapted from A. Kimber]

Concept

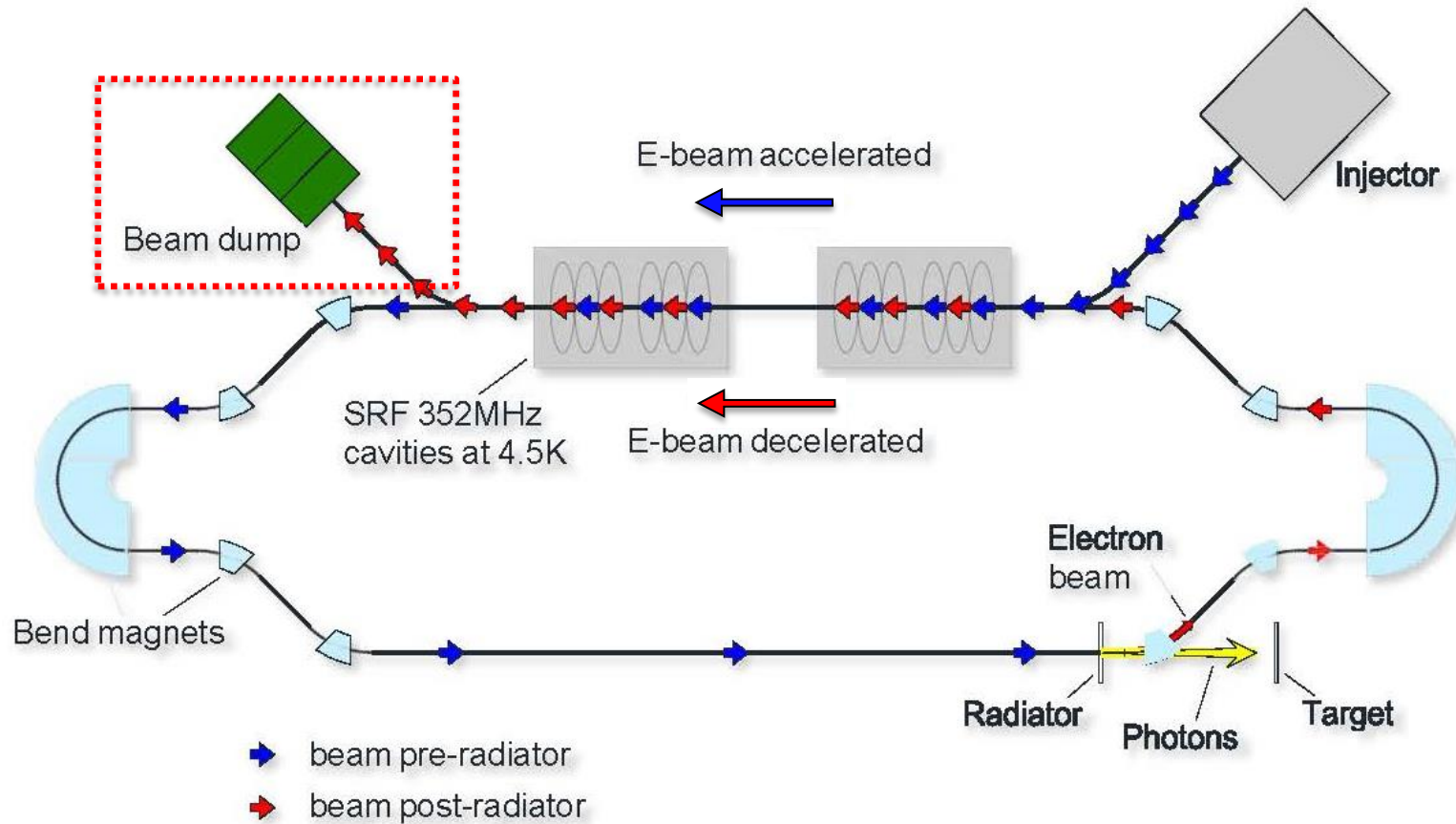
- “Waste” electrons redirected through complex back into SRF cavities, where RF is now 180° out of phase and decelerates
 - RF structure recovers energy for accel of next e^-



[Adapted from A. Kimber]

Concept

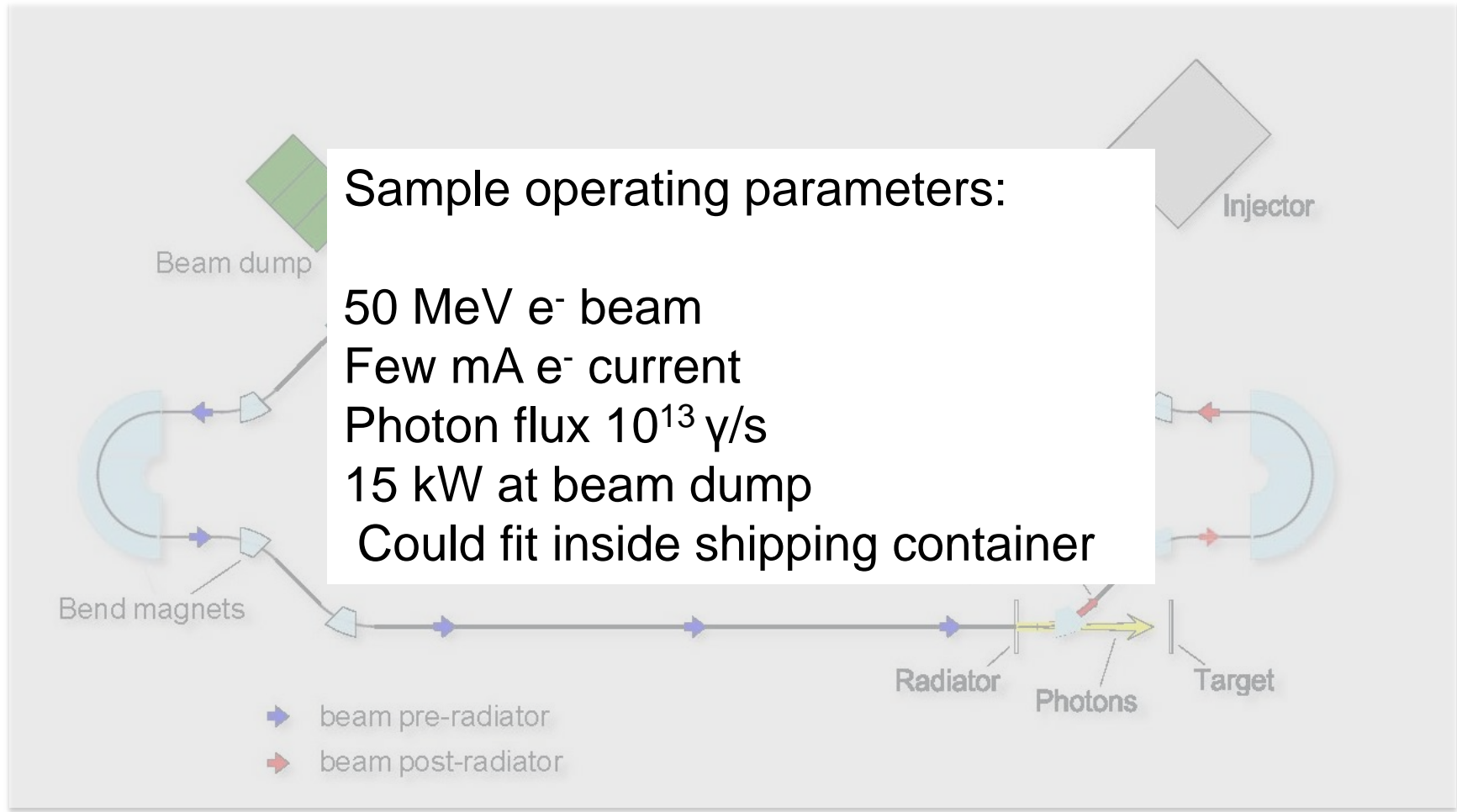
- Decelerated electrons redirected to beam dump
 - Energy below threshold for neutron production



[Adapted from A. Kimber]

Concept

- Overall facility can be compact, inexpensive to operate



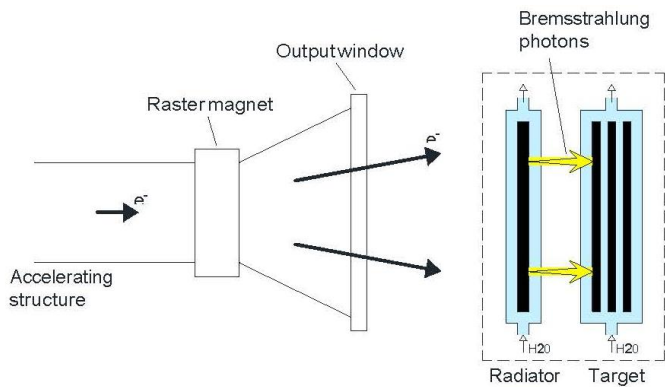
[Adapted from A. Kimber]

Approach

- An ERL-based radioisotope production facility utilizing bremsstrahlung photon beams for photonuclear reactions requires optimization of:
 - Photon and electron beam parameters: energy, current, size
 - Beam-radiator interactions: induced energy spread, gamma flux
 - Methods for control of electrons scattered in radiator
 - Radiator parameters: material, thickness
 - Thermal distributions and power handling in radiator, target, beam dump
 - Isotope production target cooling
 - Energy spread and angular acceptance for recirculation arc
 - Overall isotope production versus energy recovery requirements
- These studies will inform a choice of isotope production target

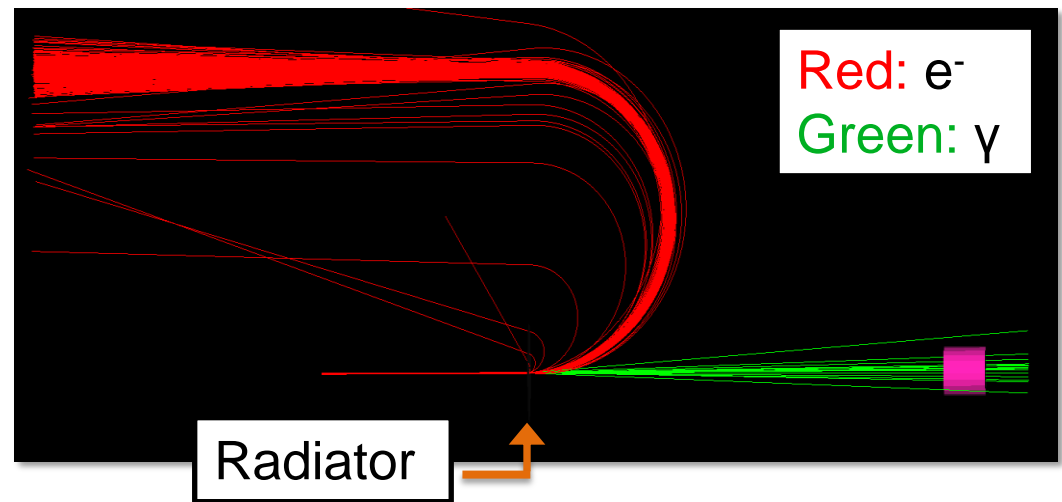
Beam-radiator interactions

- Full-energy e^- beam interacts with thin photon radiator
 - Nearly all e^- pass through with minimal energy loss and gain energy spread – also secondary e^- generation
 - Fraction of e^- generates bremsstrahlung photon beam



[Adapted from A. Kimber]

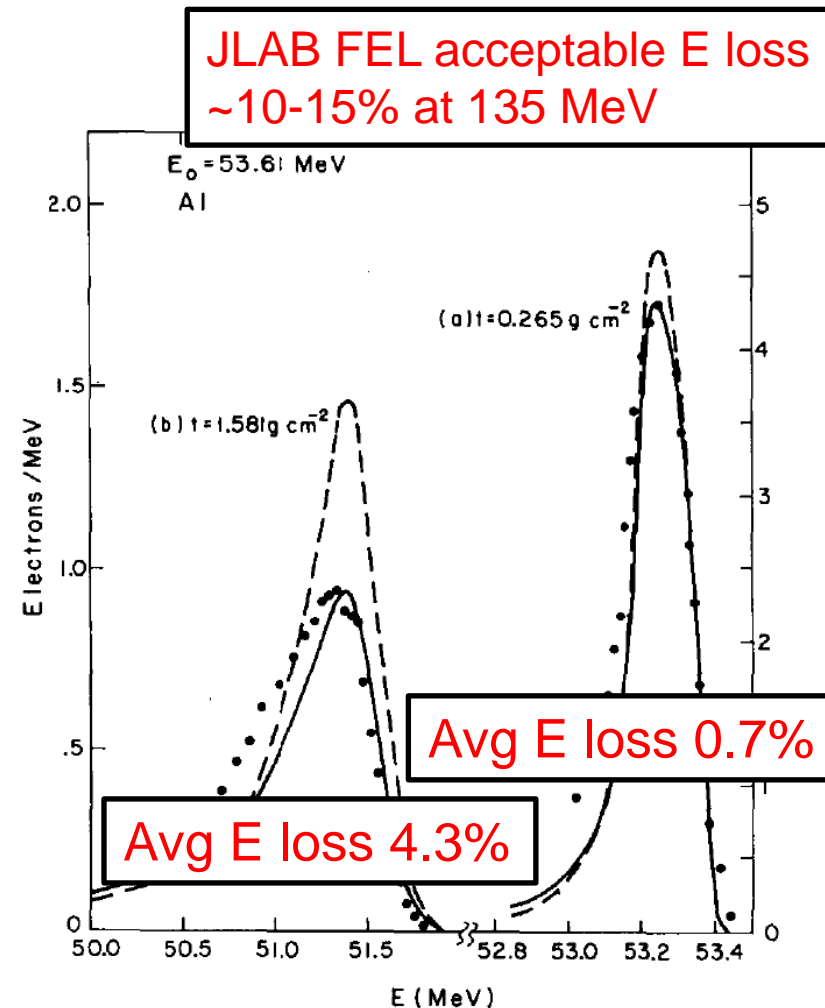
[S. Golge G4Beamline simulations]



- B field after radiator bends e^- away from production target
- Forward-directed photons interact in target

ERL energy acceptance

- Electron energy spread after passing through radiator is critical to energy recovery in ERL
 - ERL design has specific energy, angular acceptances that dictate radiator properties
 - Energy loss distribution, γ production rate key to radiator selection
- Control of beam size after passing through radiator necessary for ALL electrons after radiator interaction
 - Collimation, phase space exchange, etc.



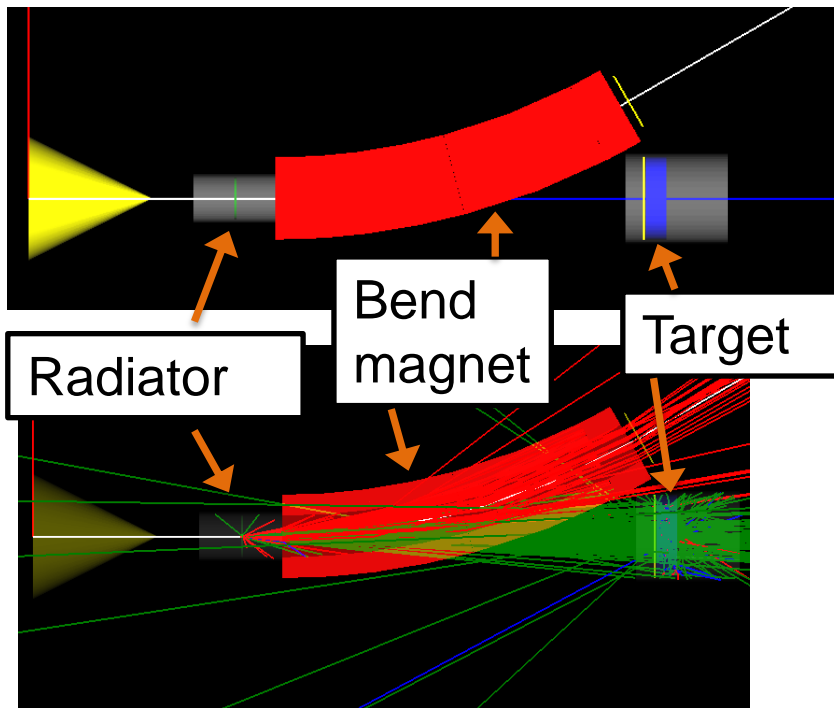
[J. L. Mathews, et al., NIMS 180, 573-579 (1981)]

Tools

- Project encompasses variety of processes, must be simulated to establish feasibility of production facility
- Interfacing between separate simulation codes is inconvenient
- Muons, Inc. has developed MuSim, simulation tool that provides a graphical user interface to several independent simulation codes spanning a variety of physical processes
 - Provides centralized access to data and plots
- MuSim will be used to interface to:
 - G4Beamline/GEANT4
 - MCNP6
 - Other codes as necessary

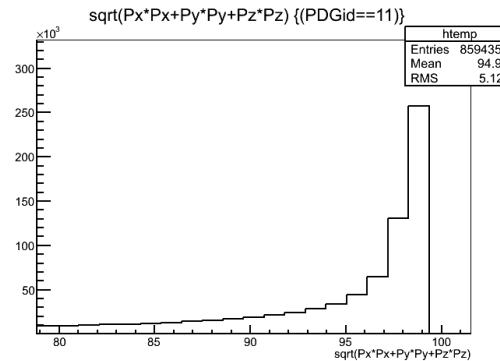
Sample of MuSim capabilities

- MuSim sample isotope production simulation with 100 MeV e^- beam on Pb radiator and LEU target for production of Tc99m

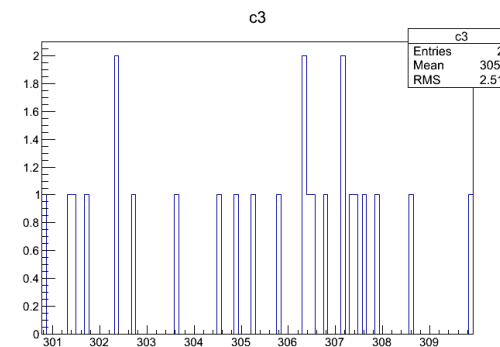


[T. Roberts simulation]

Red: e^-
Green: γ



G4Beamline output; e^- total momentum after radiator



MCNP6 output; Mo99 distribution in target along z

Summary

- ERL-based radioisotope production facility utilizing bremsstrahlung photon beams for photonuclear reactions represents a novel approach to production of short-lived, high-value radioisotopes for medical and other applications
- Simulation studies using G4Beamline and MCNP6 through MuSim, other programs, will quantify parameters related to
 - Electron and photon beams
 - Electron beam acceptance into the recirculation arc for energy recovery
 - Photon interaction rates within isotope production target
 - ...
- Simulations will inform a choice of isotope production target for possible future studies and physical experiments

Thank you for your attention!