Energy recovery linacs for commercial radioisotope production

A. Sy, G. Krafft, V. S. Morozov, R. P. Johnson, T. Roberts, C. Boulware, J. Hollister

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Muons, Inc.

NIOWAVE
Accelerating Your Particles

Jefferson Lab
Thomas Jefferson National Accelerator Facility

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

Muons, Inc.	Jefferson Lab — Thomas Jefferson National Accelerator Facility		NIOWAVE — Accelerating Your Particles
R. P. Johnson	H. Areti	R. Li	C. Boulware
T. Roberts	D. Douglas	V. Morozov	T. Grimm
	A. Hutton	A. Sy	J. Hollister
	A. Kimber		V. Starovoitova
	G. Krafft		

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, 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)

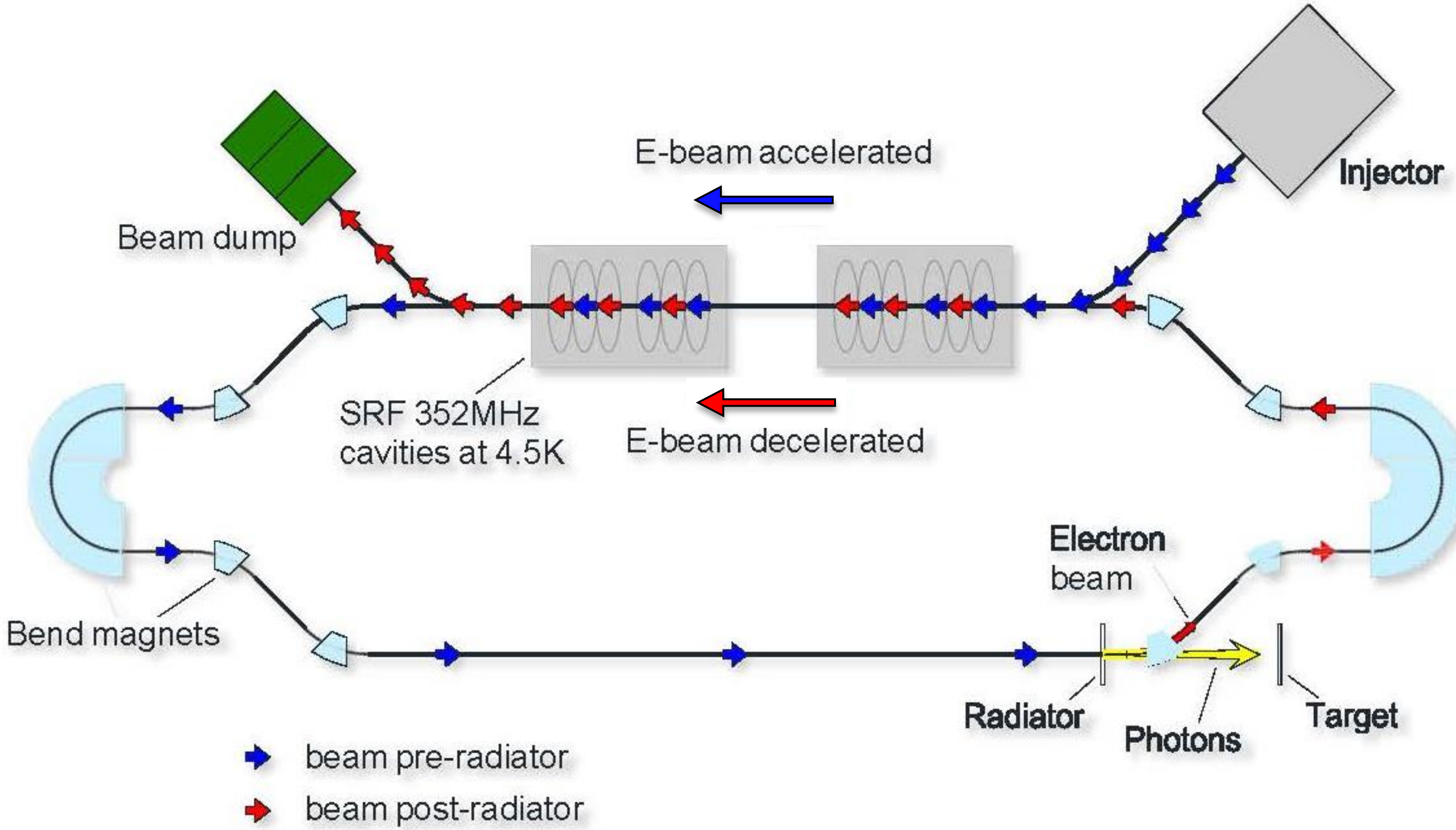
  (-) Energy inefficient; majority of electron beam energy must be dumped – activation of shielding components, neutron production at beam dump

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

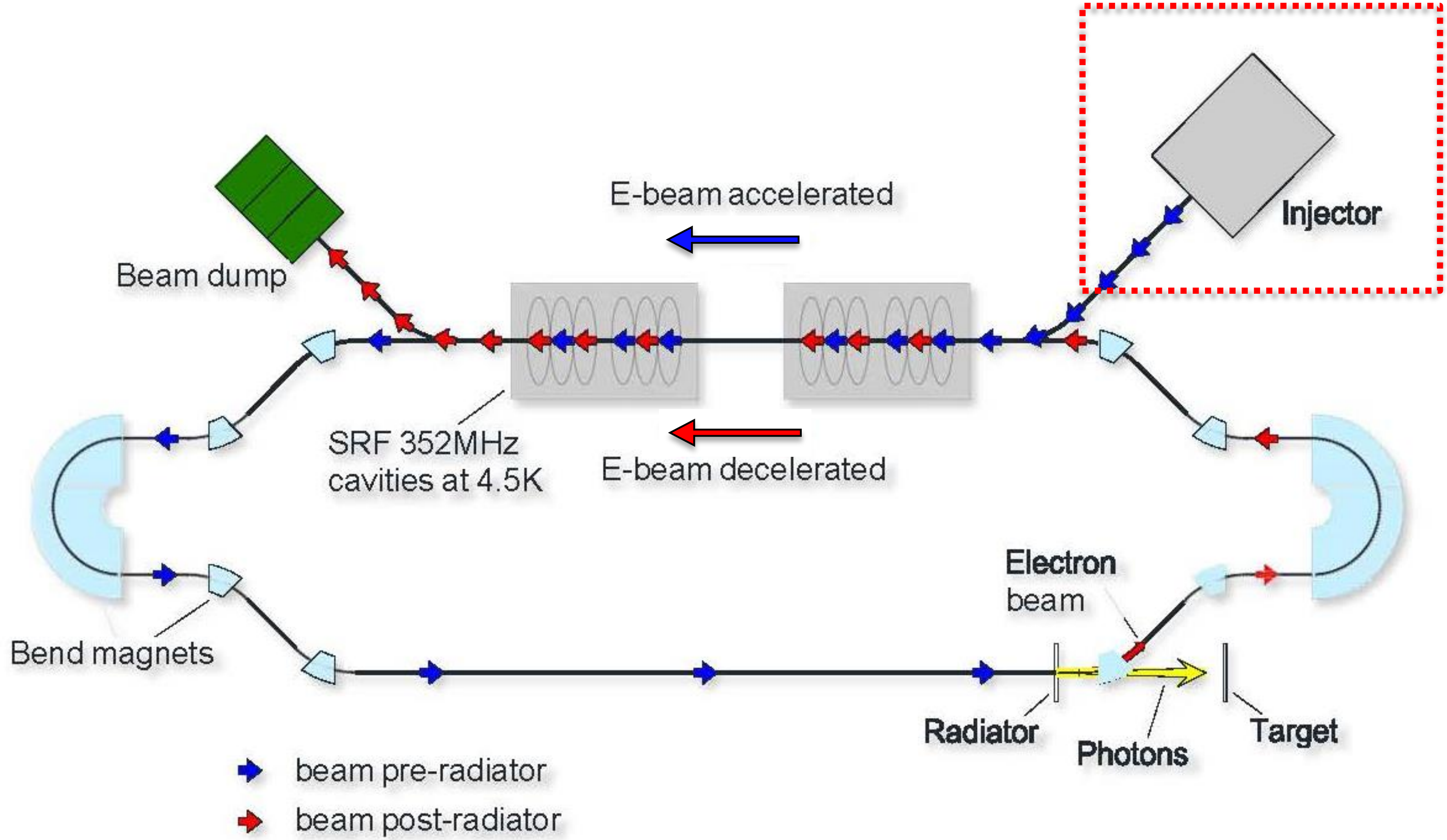
- An ERL-based radioisotope production facility utilizing bremsstrahlung photon beams for photonuclear reactions



[Adapted from A. Kimber]

Concept

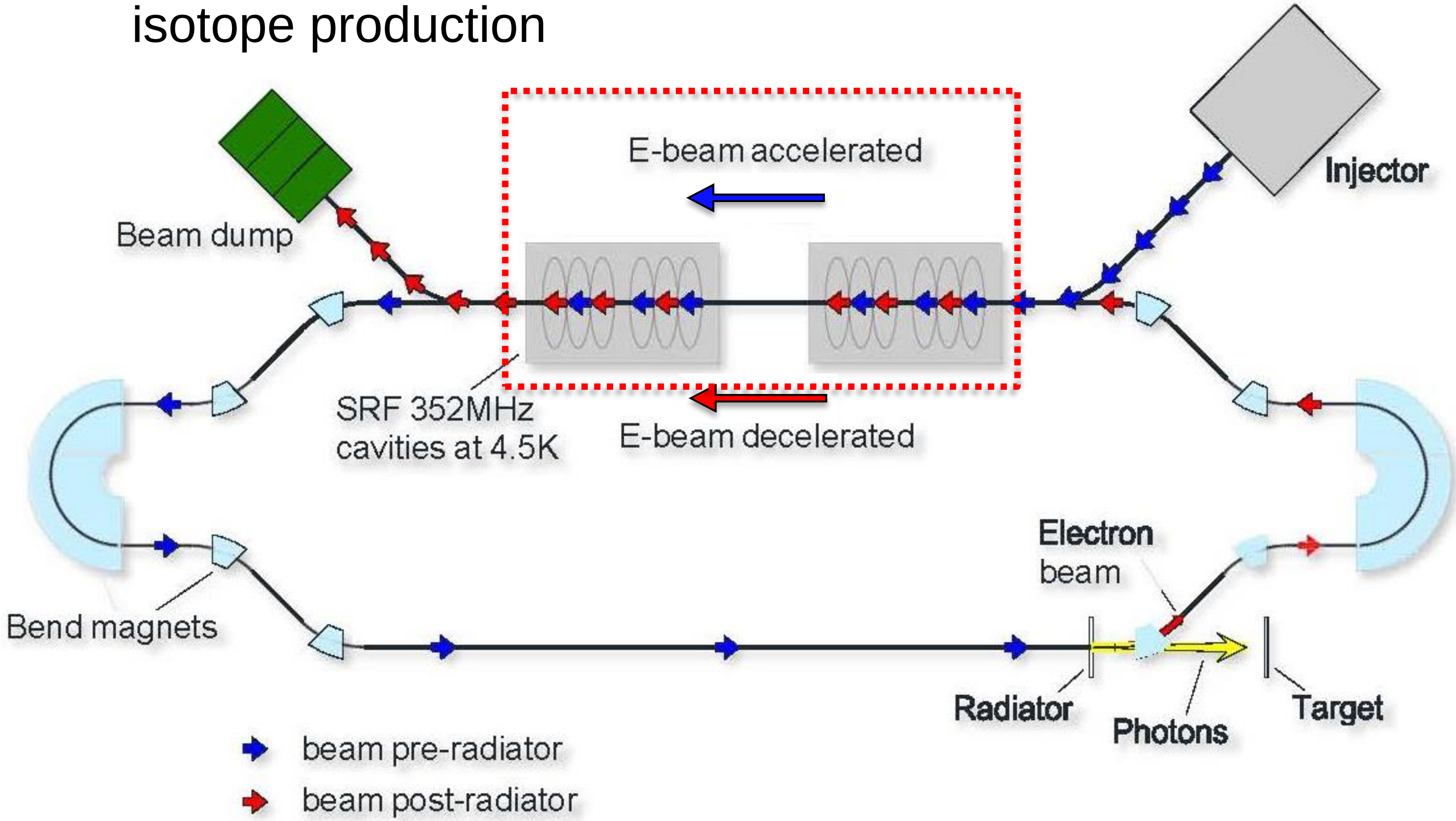
- Electrons from injector are injected into accelerating beamline



[Adapted from A. Kimber]

Concept

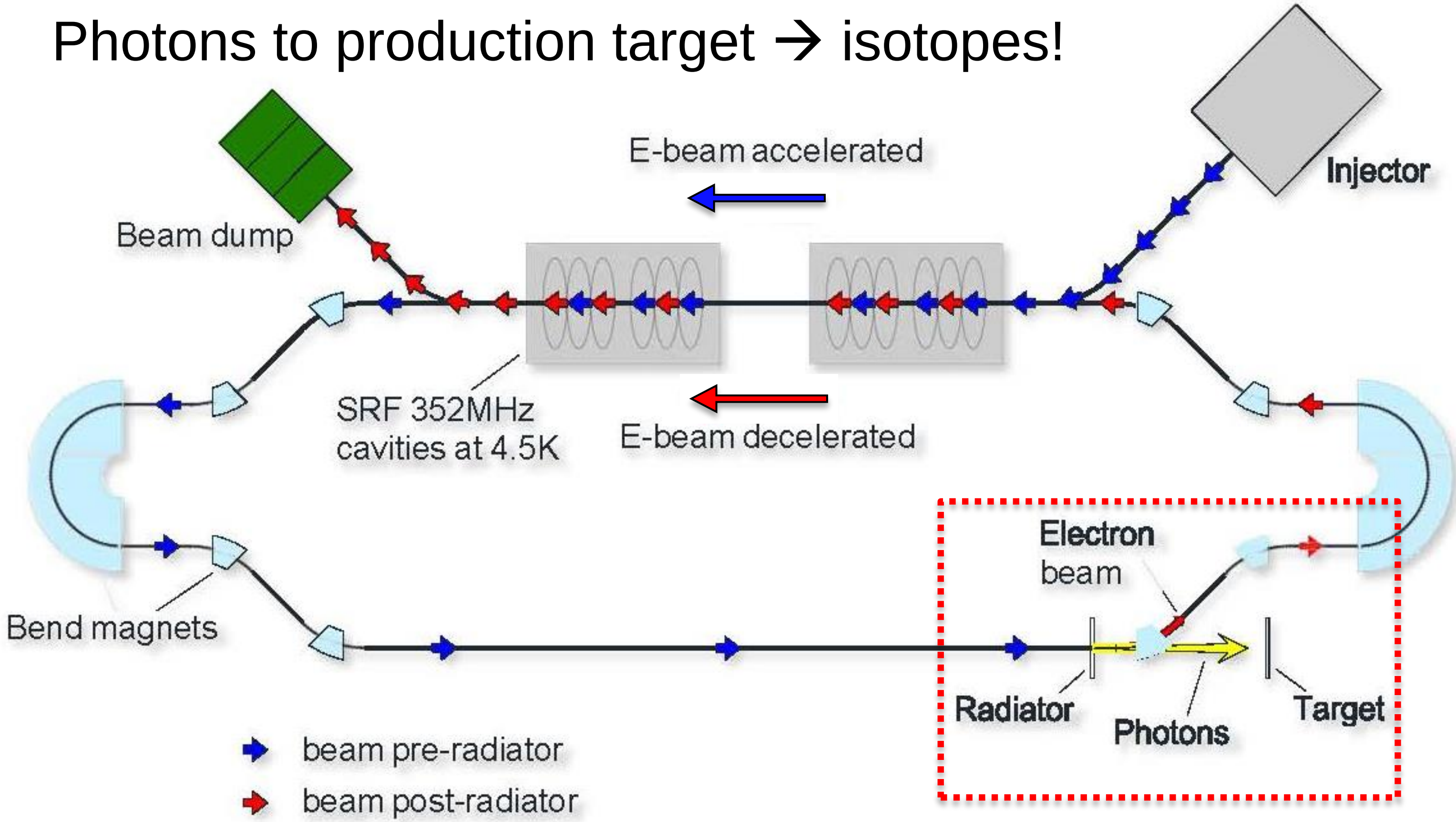
- Acceleration in SRF cavities with gradients 10-15 MV/m
  - Electron beam energies of 20-100 MeV of particular interest for isotope production



[Adapted from A. Kimber]

Concept

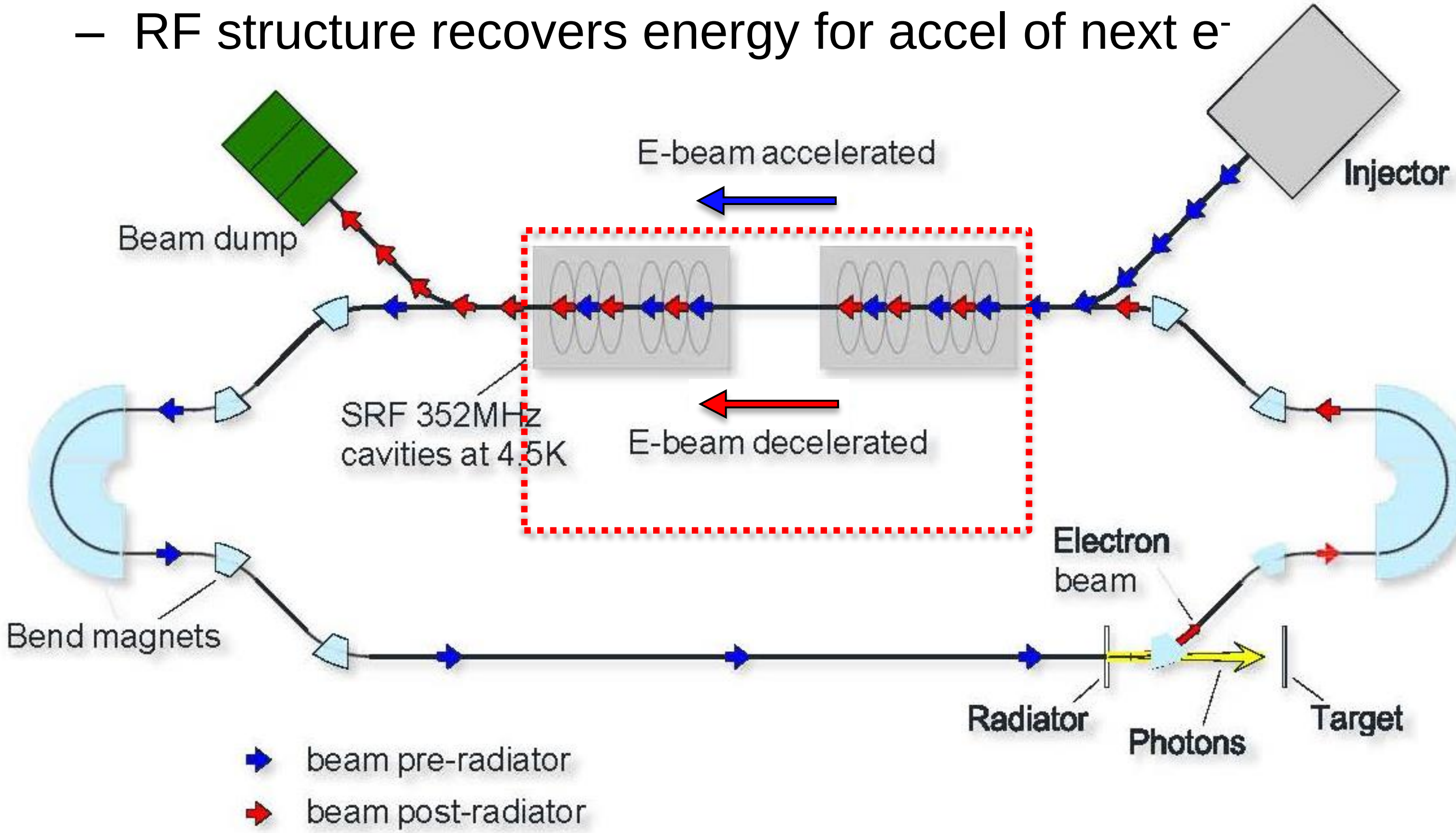
- Full-energy electrons pass through thin photon radiator
  - ~99% of e^- pass through as "waste" beam; ~1% generate photons
- Photons to production target → isotopes!



[Adapted from A. Kimber]

Concept

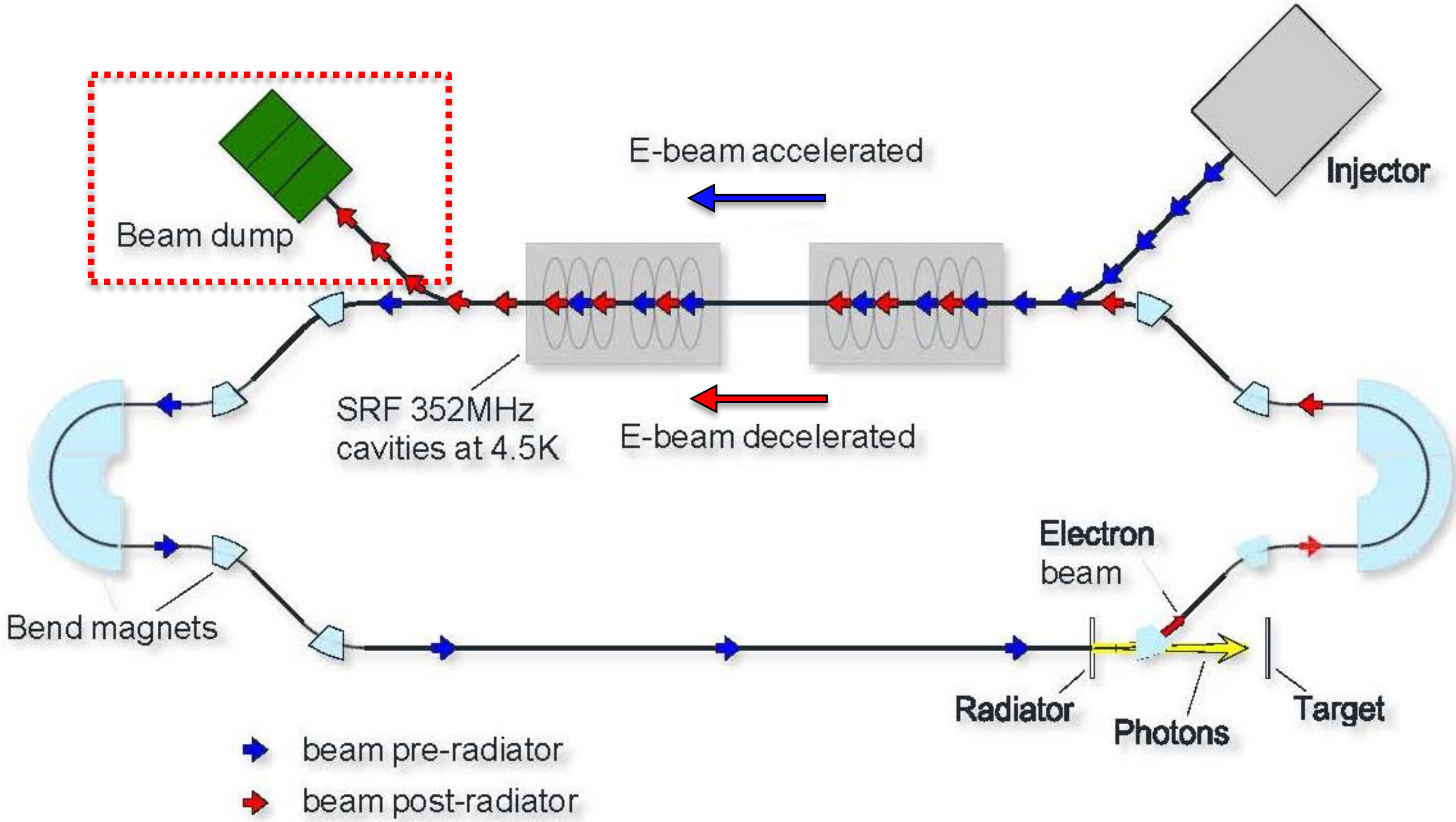
- “Waste” electrons redirected through complex back into SRF cavities, where RF is now 180º out of phase and decelerates
  - RF structure recovers energy for accel of next e^-



[Adapted from A. Kimber]

Concept

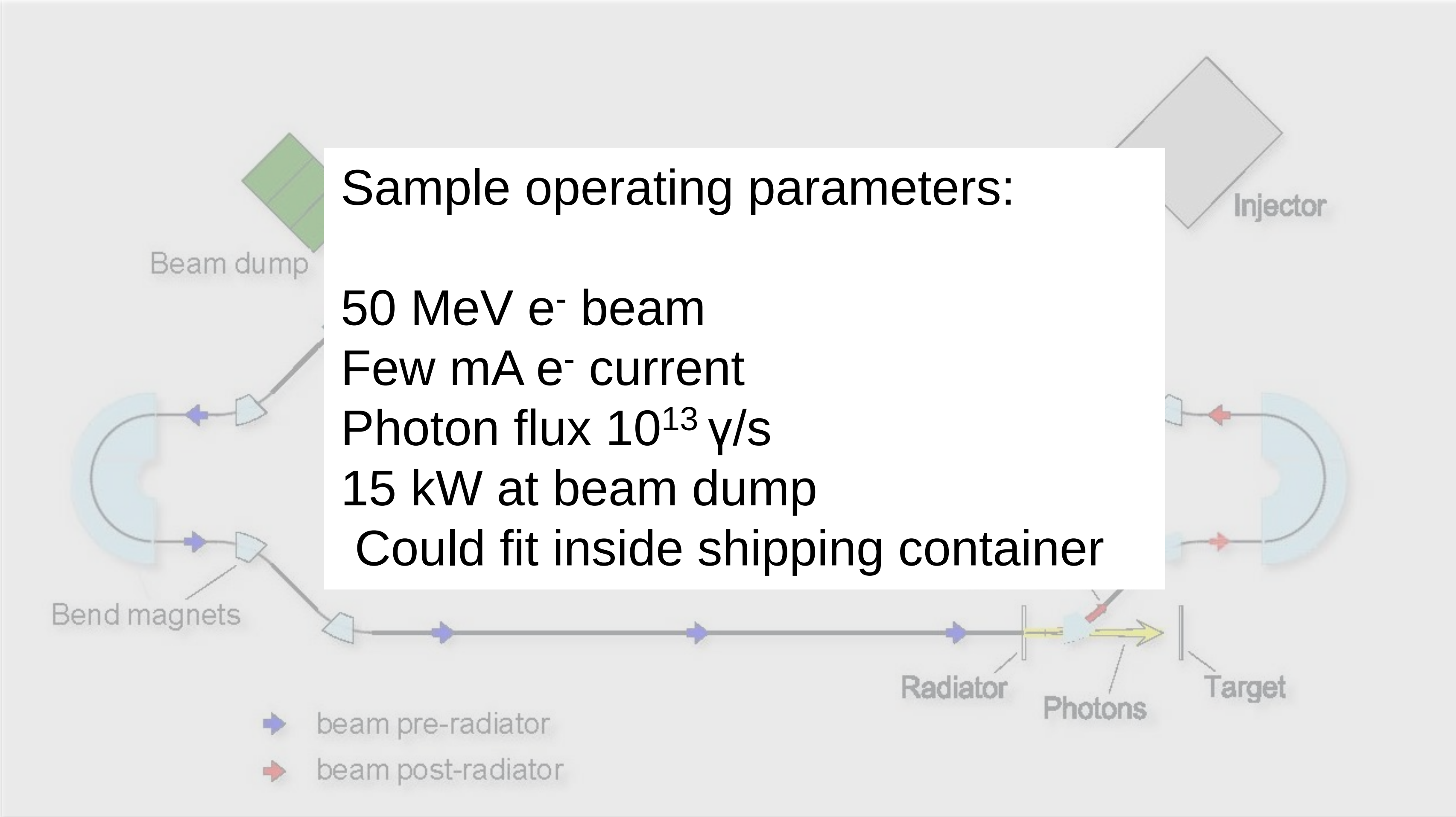
- Decelerated electrons redirected to beam dump
  - Energy below threshold for neutron production



[Adapted from A. Kimber]

Concept

- Overall facility can be compact, inexpensive to operate



Sample operating parameters:

50 MeV e^- beam
Few mA e^- current
Photon flux 10^{13} γ/s
15 kW at beam dump
Could fit inside shipping container

[Adapted from A. Kimber]

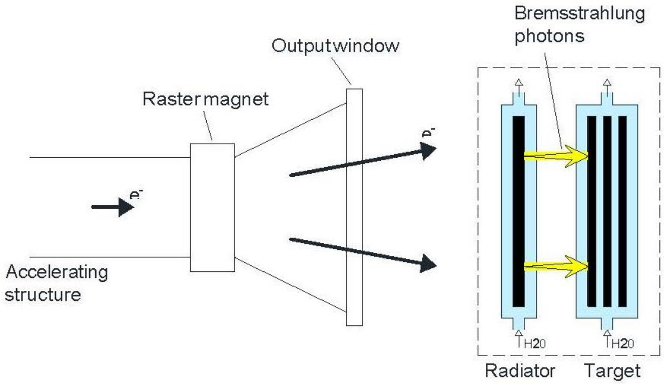
Approach

- 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

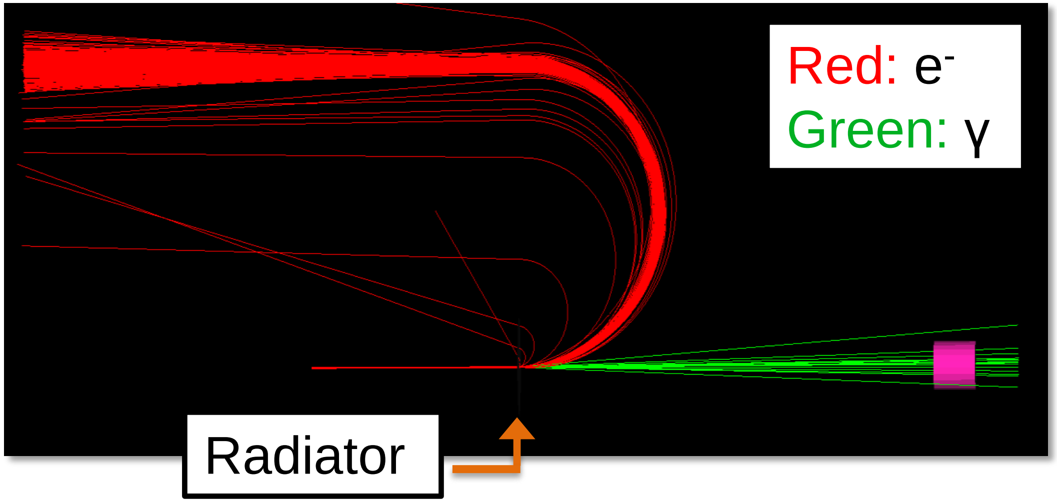
Beam-radiator interactions

- 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]



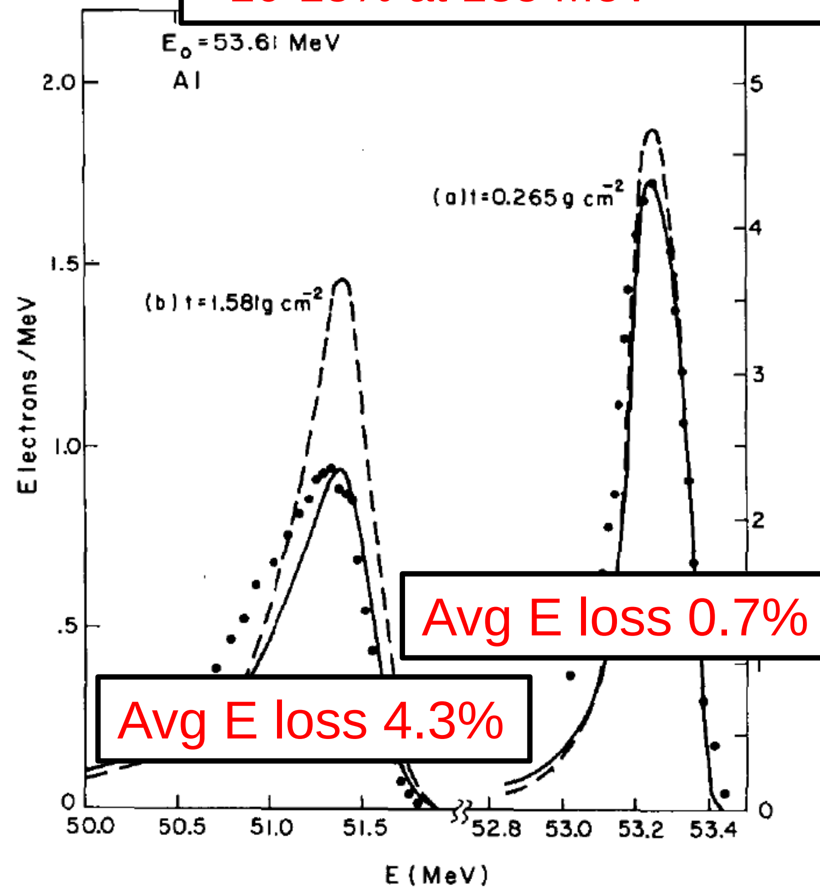
- B field after radiator bends e^- away from production target
- Forward-directed photons interact in target

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.

JLAB FEL acceptable E loss ~10-15% at 135 MeV



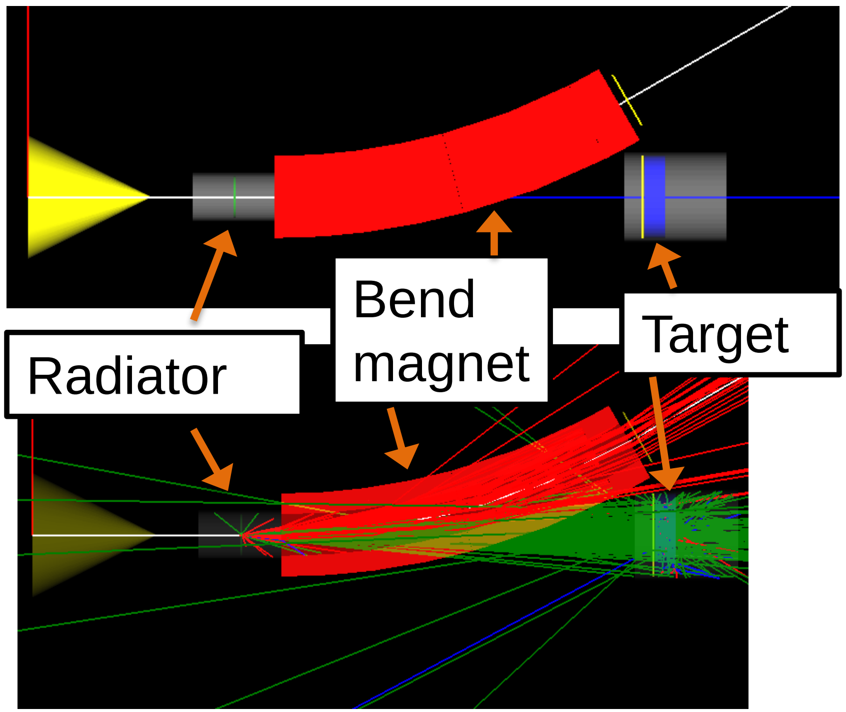
[J. L. Mathews, et al., NIMS 180, 573-579 (1981)]

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

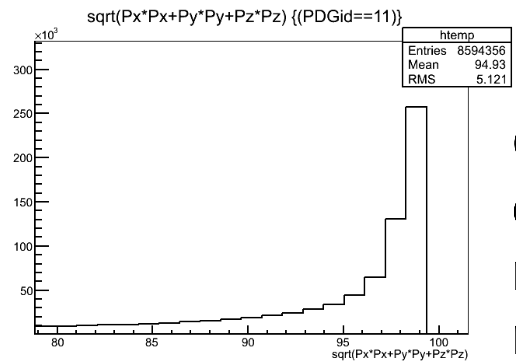
Sample of MuSim capabilities

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

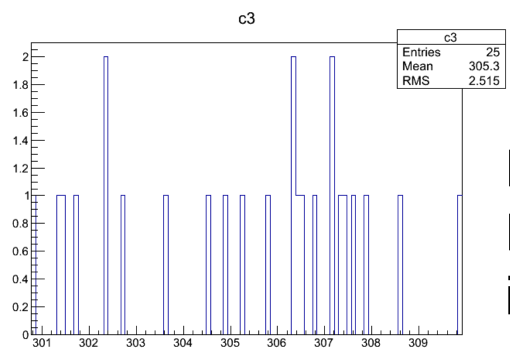


Red: e^-
Green: γ

[T. Roberts simulation]



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!