Positron program at the Idaho Accelerator Center

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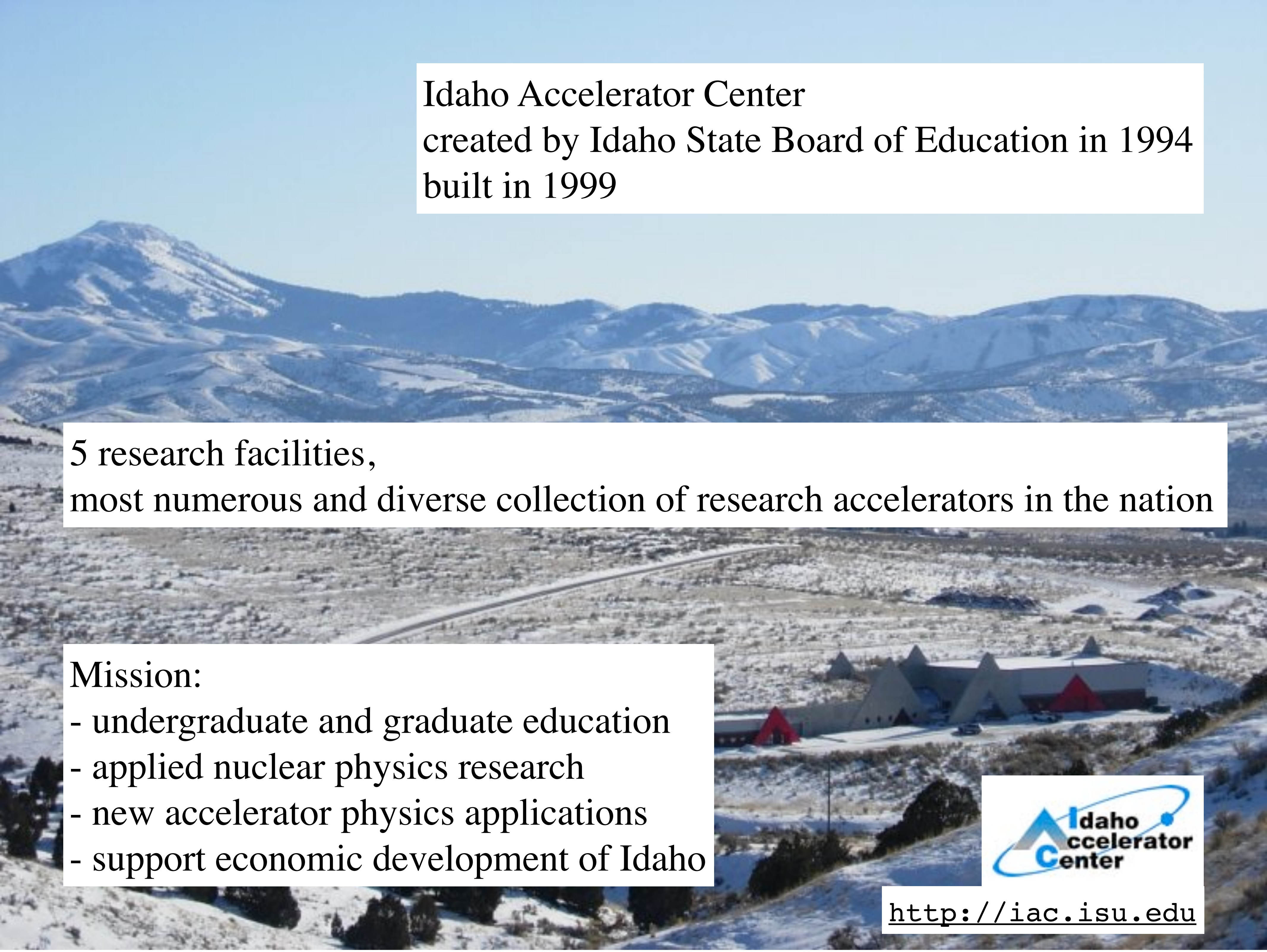
Idaho State University and Jefferson Lab

International Workshop on Positrons at Jefferson Lab
Newport News, Virginia (USA), 26 March 2009

Facilities at Idaho State University



Idaho Accelerator Center
created by Idaho State Board of Education in 1994
built in 1999

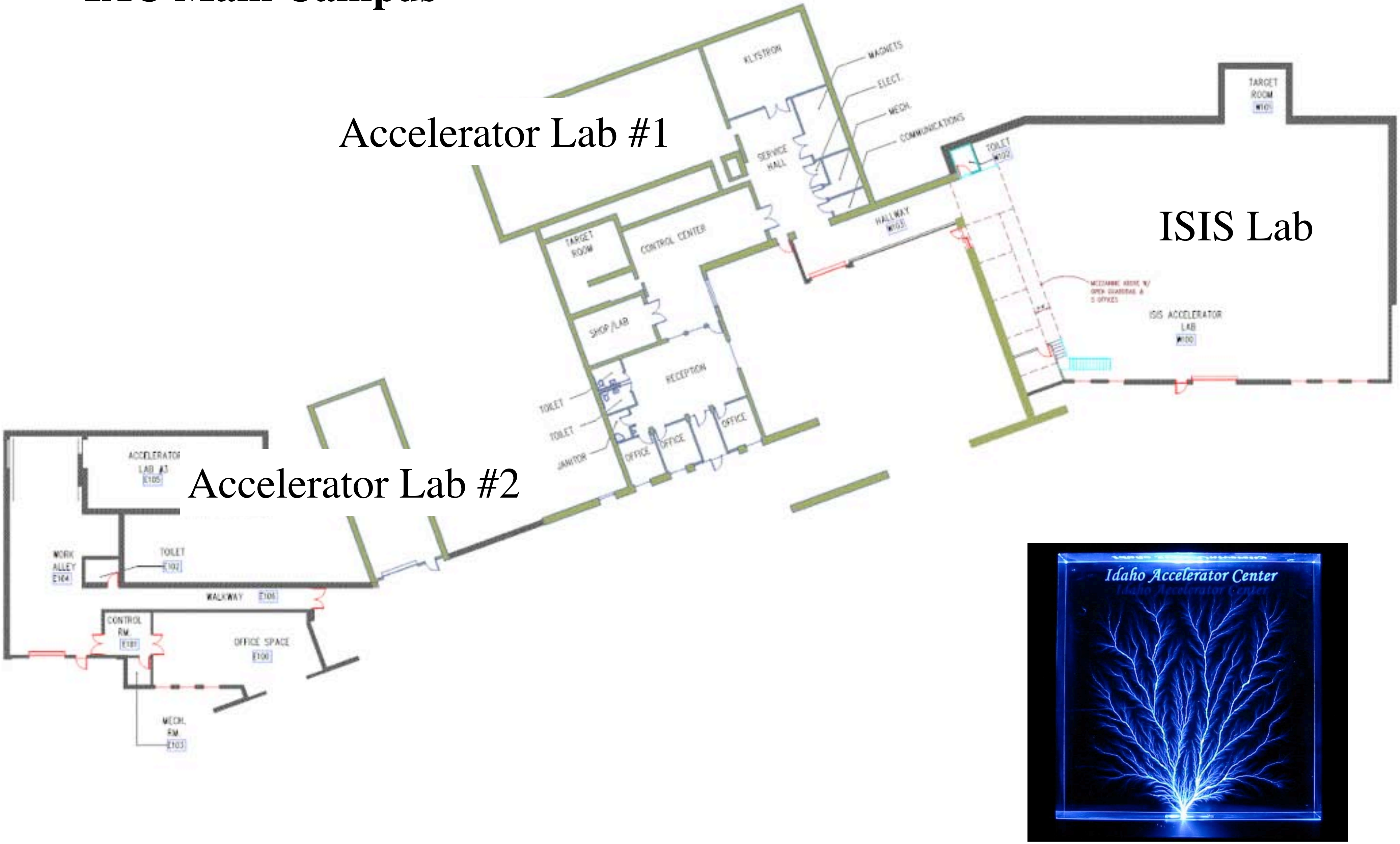
5 research facilities,
most numerous and diverse collection of research accelerators in the nation

Mission:
- undergraduate and graduate education
- applied nuclear physics research
- new accelerator physics applications
- support economic development of Idaho

Idaho Accelerator Center

http://iac.isu.edu

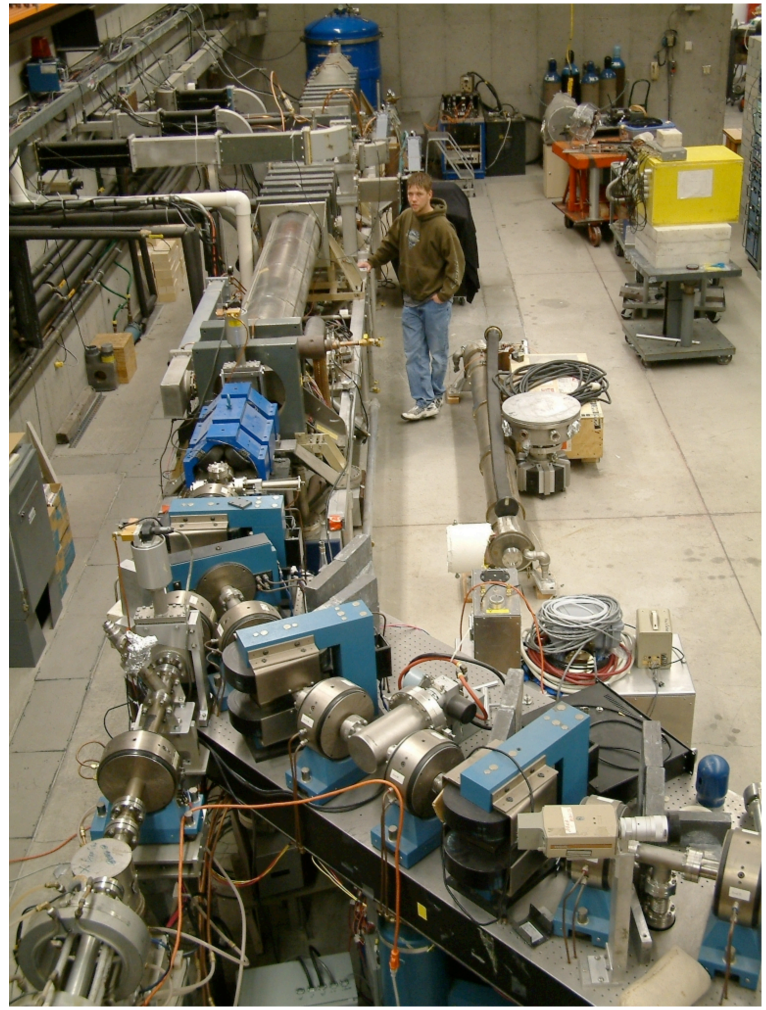
IAC Main Campus



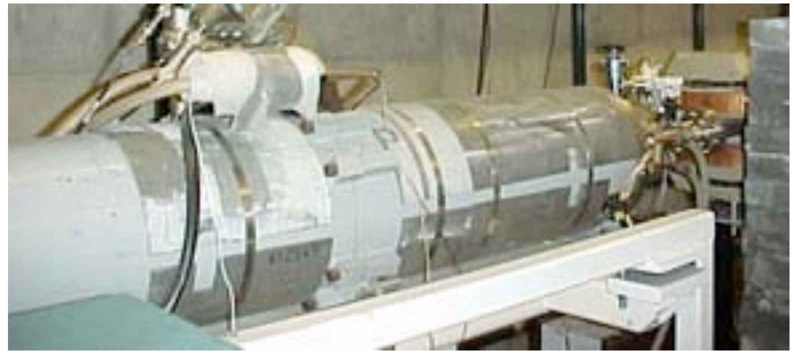
IAC Main Campus: Accelerator Lab #1

44-MeV Short Pulsed Linac
- 1.3 GHz L-band traveling-wave linac
- 50 ps to 4 μs pulse width
- 120 Hz rep rate
- 5 nC/pulse (50 ps width)
- 2 μC/pulse (4 μs width)
- 4 MeV - 44 MeV energy range
- 0.5% - 4% energy resolution

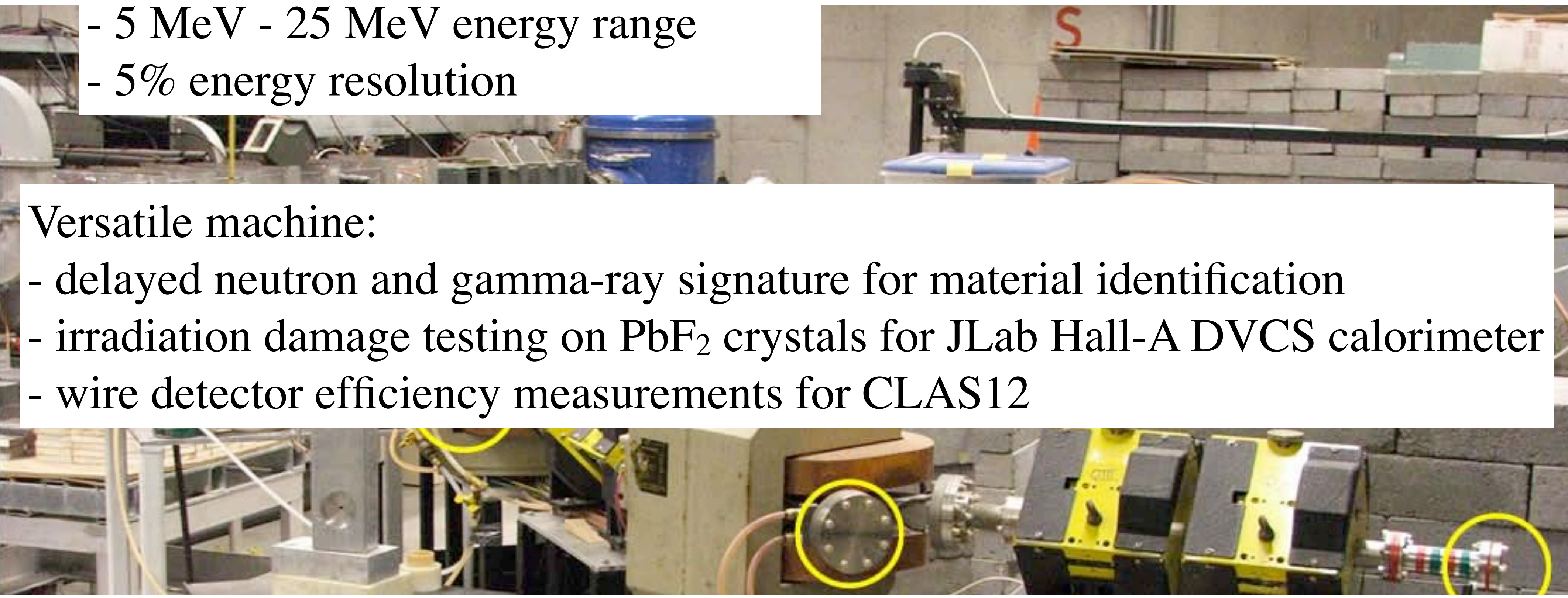
Lab workhorse:
- neutron time-of-flight spectrometry
- laser Compton scattering
- ...



IAC Main Campus: Accelerator Lab #1



25-MeV Linac
- 2.8 GHz S-band standing-wave linac
- 0.5 μs to 4 μs pulse width
- 600 Hz rep rate
- 40 nC/pulse (0.5 μs width)
- 350 nC/pulse (4 μs width)
- 5 MeV - 25 MeV energy range
- 5% energy resolution

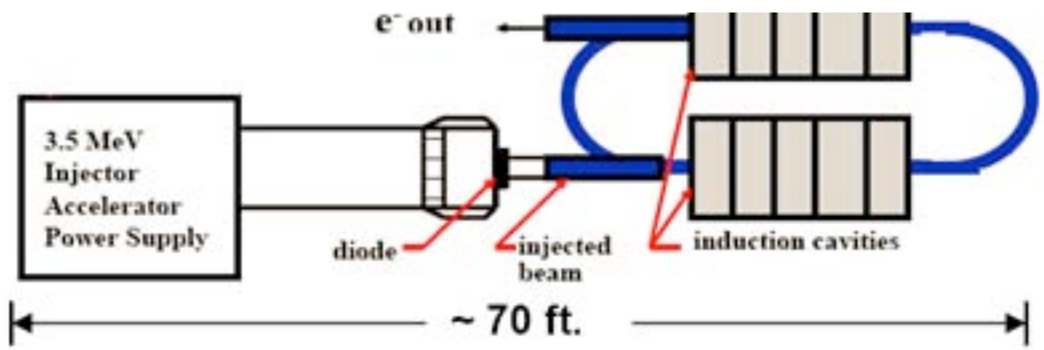


Versatile machine:
- delayed neutron and gamma-ray signature for material identification
- irradiation damage testing on PbF_2 crystals for JLab Hall-A DVCS calorimeter
- wire detector efficiency measurements for CLAS12

IAC Main Campus: ISIS Lab

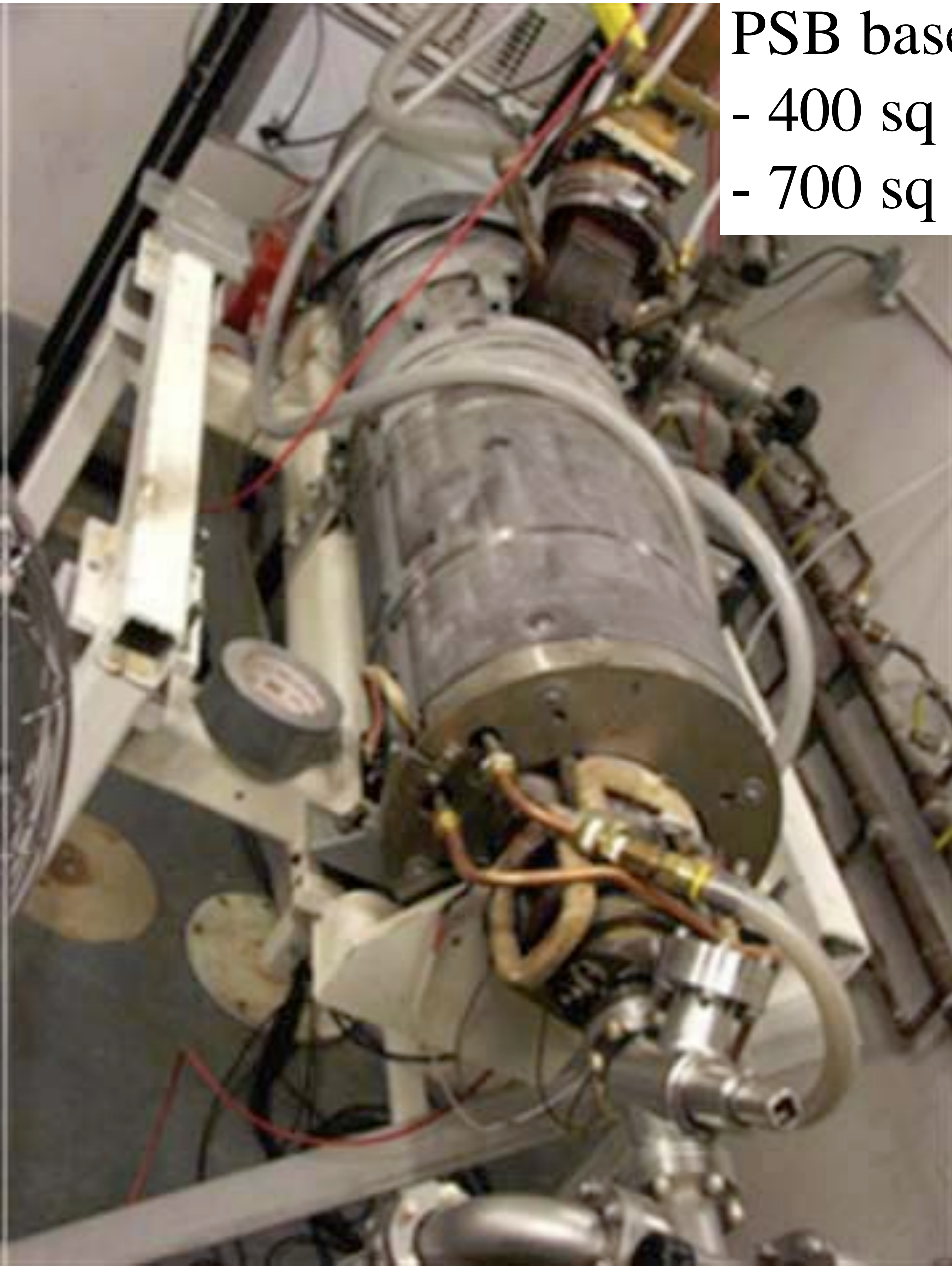
Idaho State Induction accelerator System (ISIS)
- high-intensity, pulsed-power machine
- 3-MeV electron injector
- 10-cell, spiral-shaped induction accelerator
- 9.5-MeV 10-kA 35-ns pulse every 2 min
- 0.1 TW instantaneous power!

7700 sq ft high-bay lab



- radiation effects in electronic and biological systems
- single-pulse detection of fissionable material

Physical Sciences Building: HRRL Lab



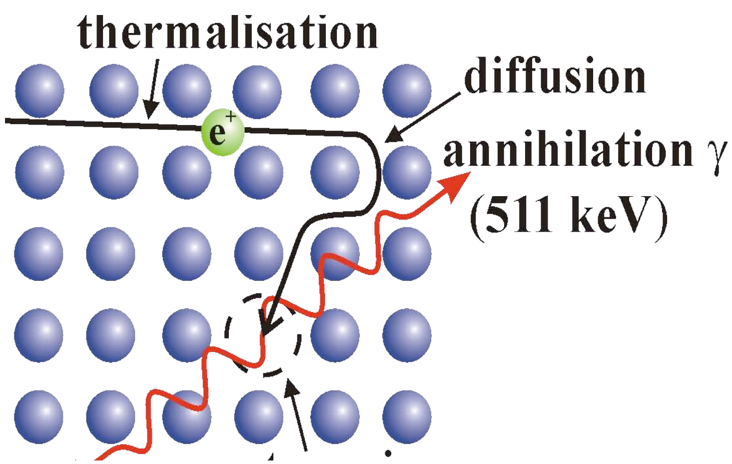
PSB basement:
- 400 sq ft accelerator hall
- 700 sq ft shielded experimental area

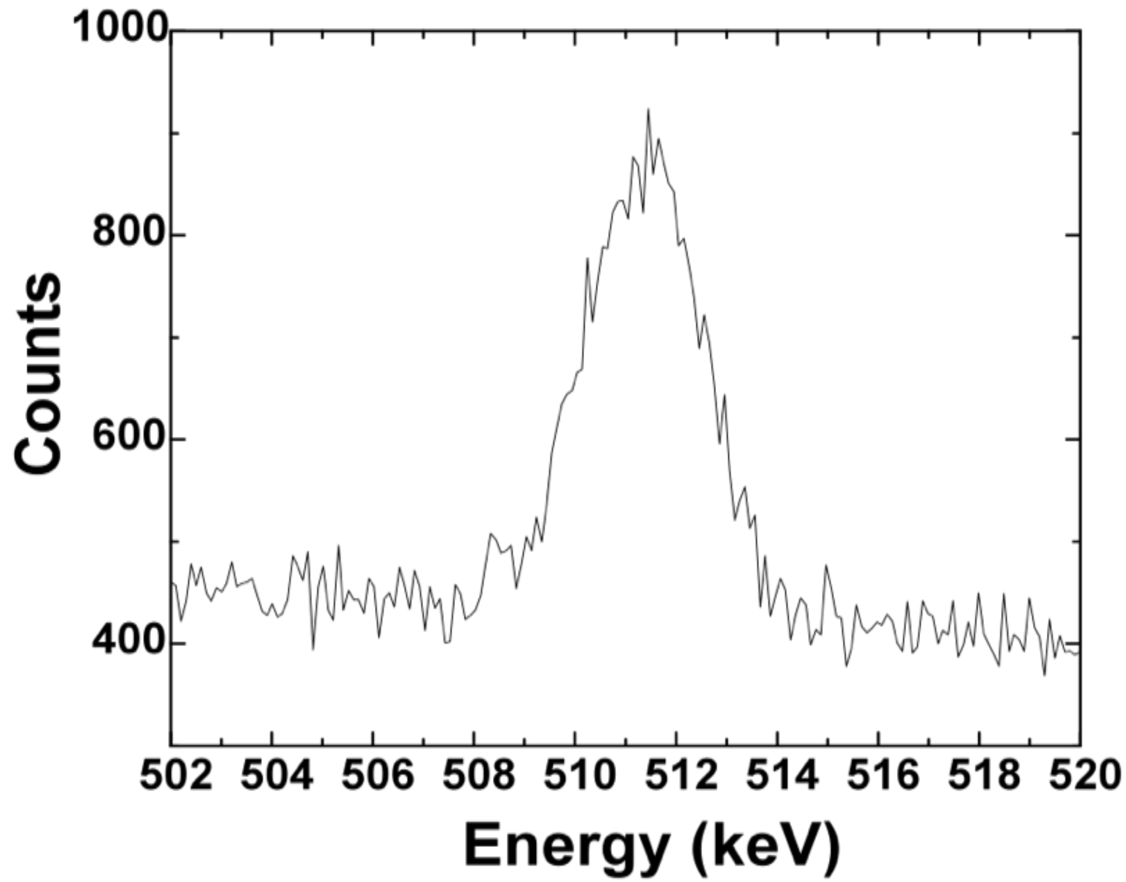
High Repetition Rate Linac (HRRL)
- 2.8 GHz S-band standing-wave linac
- 70 ns pulse width
- 1.2 kHz rep rate
- 8.4 nC/pulse
- 3 MeV - 16 MeV energy range
- 8% energy resolution

- role of γ polarization in photofission
- calibration of CLAS12 wire chambers
- tests of positron production for CEBAF?

Positron annihilation spectroscopy at the IAC

Positron annihilation spectroscopy is a powerful technique to detect defects in materials

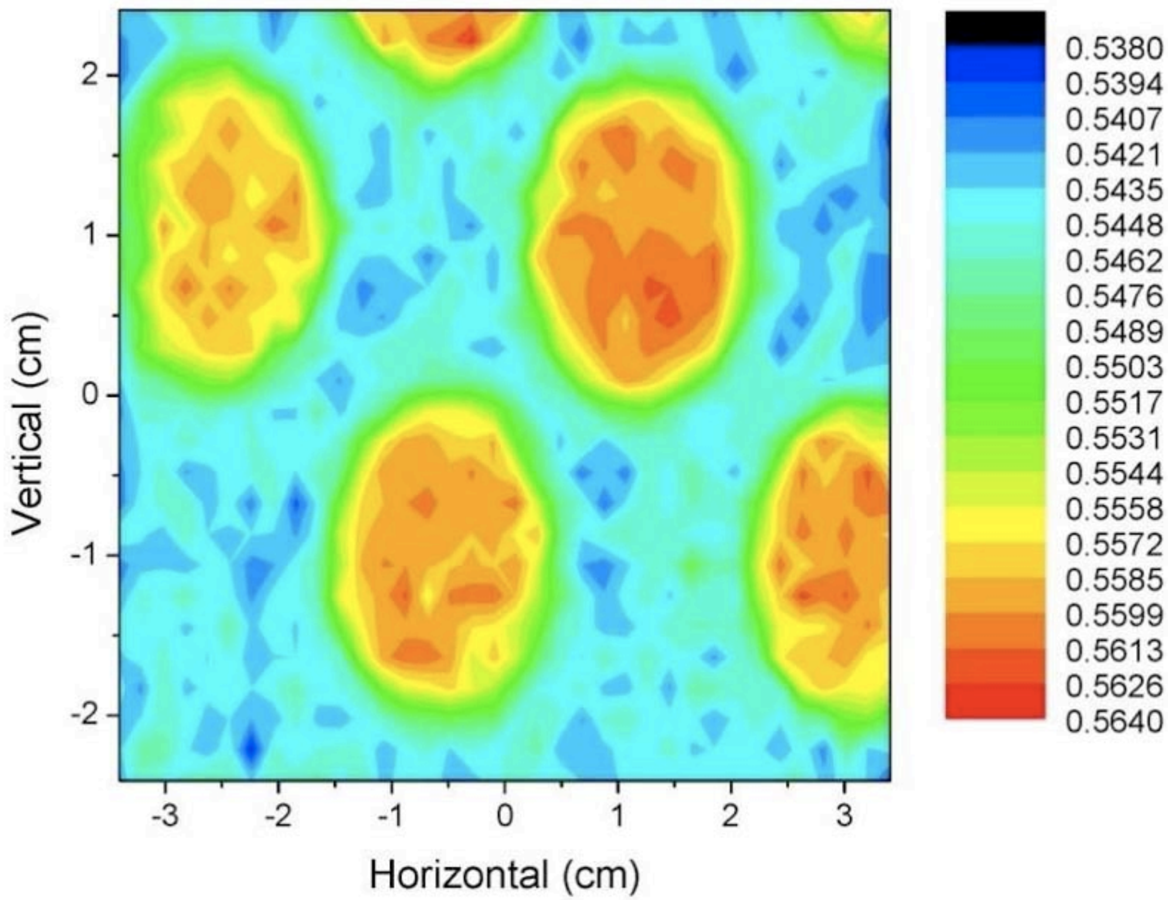




Annihilation time and shape of Doppler-broadened 511-keV peak are sensitive to local structure of materials

Positrons from ^{22}**Na source** can probe surface effects

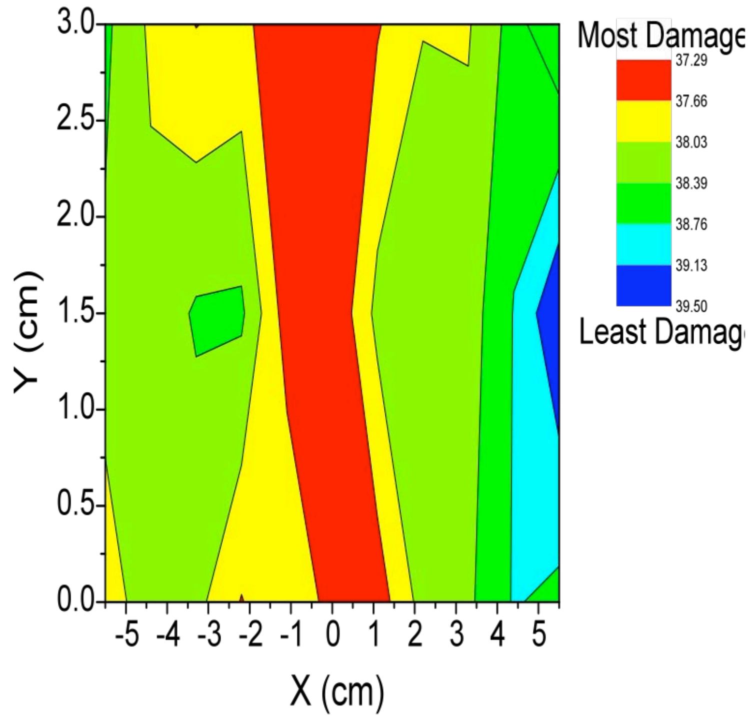
Surface map of defect density obtained for copper samples shot-peened at different intensities



Gagliardi and Hunt, CAARI 08, AIP Conf. Proc. 1099, 857 (2009)

Photo-activation with bremsstrahlung beams from ~20 MeV electron linacs allows one to map large-area samples and probe greater depths (~cm).

Technique successfully commercialized (Positron Systems, Inc.)



Needs material for which (γ,n) reaction yields β^+ emitter

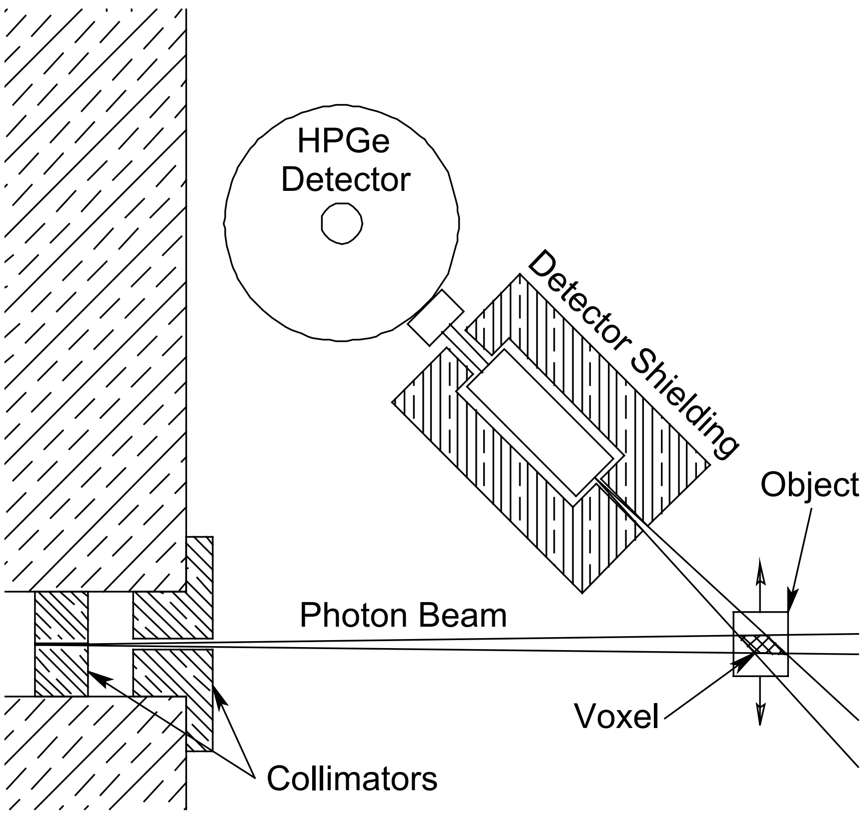
Sample remains activated

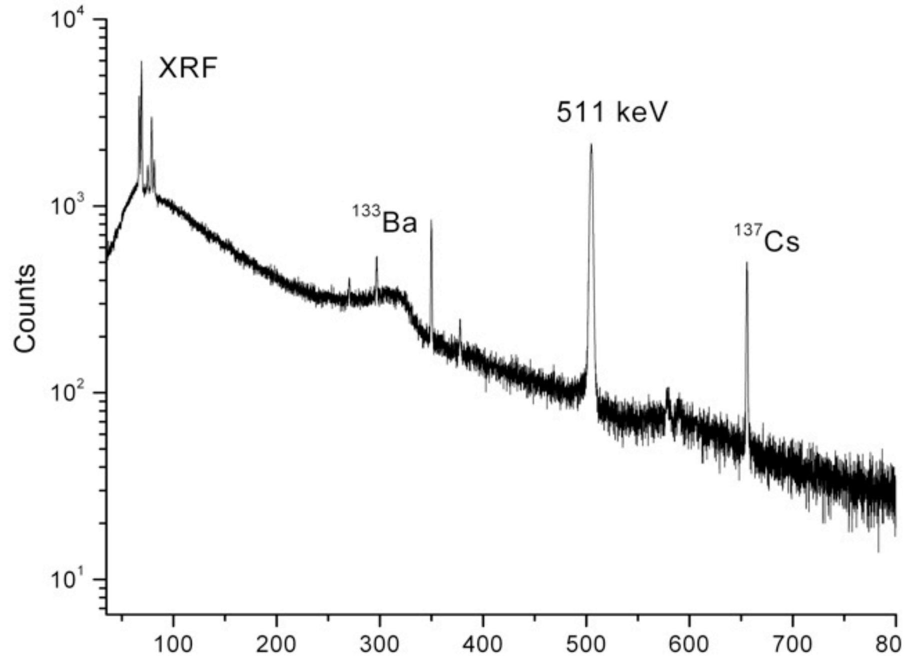
Hunt et al., Nucl. Instr. Meth. B **241**, 262 (2005)

Photon-induced pair production from ~10-MeV bremsstrahlung beam also used to probe large-area samples up to ~cm depths

Better for high-*Z* material, but demonstrated down to Al (*Z=13*)

No material activation (below neutron emission threshold)





Higher γ background

Makarashvili et al., CAARI 08, AIP Conf. Proc. 1099, 900 (2009)

Facilities for material defect analysis with positron annihilation spectroscopy at the IAC

✔ Photo-activation
- 20-MeV e^- beam
- large samples, ~cm depths
- needs β^+ emitter from (γ,n)
- sample is activated

✔ Photon-induced pair production
- 10-MeV e^- beam
- large samples, ~cm depths
- better for high-Z
- higher γ background

✔ ^{22}Na source
- cheap
- low intensity
- low energy (surface maps)
- low backgrounds

☐ eV to MeV positron beam
- ~kW e^- linac
- converter + moderator + transport
- sample size limited by vacuum chamber volume
- high intensity
- controllable depth
- low backgrounds

- *proposed in the past*
- *potential synergy with prototype e^+ source for CEBAF*

A prototype positron source for CEBAF

Scientific motivation

(1) inner structure of the proton

Generalized Parton Distributions of the nucleon accessible by measuring amplitude of deeply virtual Compton scattering in the process

$$e\,p \rightarrow e\,p\,\gamma$$

Beam charge asymmetry related to real part of DVCS amplitude; beam helicity asymmetry related to imaginary part

(2) role of two-photon amplitudes in nucleon form factors

Discrepancy between Rosenbluth separation and polarization transfer measurements probably due to two-photon processes

Deviation from unity of **ratio between elastic $e^+ p$ and $e^- p$** scattering would be direct evidence of multiple photon exchange

Three proposed experiments:
- VEPP-3 (arXiv:nucl-ex/0408020)
- JLab/CLAS (PAC31, 12/06)
- DESY/OLYMPUS

Positron sources:

/ β^+ radioactive decay
e.g., ^{22}Na, 2.6 y half life

\ **pair production** <= More common for accelerators:
- higher phase-space density
- controllable time structure

"Conventional" sources (SLAC, KEK, VEPP-5, Frascati, ...) and ILC designs
- exploit **multi-GeV** primary electron beams
- are **pulsed**

Positron source for CEBAF?
- useful for JLab physics
- minimal impact on 12-GeV upgrade
- compact, low-cost

Concept of **"low energy" continuous positron source**:
- 10-mA, 5 to 120 MeV CW electron beam
- ~0.5-mm tungsten radiator target
- collection and energy selection with quadrupole triplets

Goal: maximize yield into CEBAF admittance

1 μm (geometrical) transverse

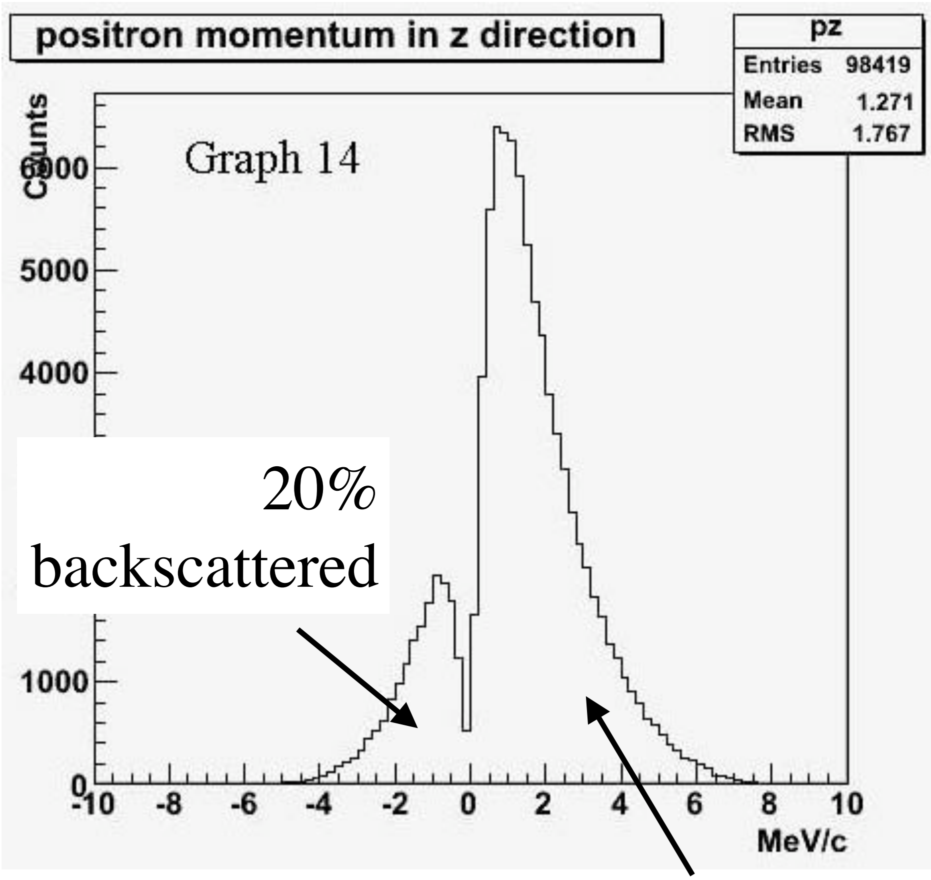
± 2% longitudinal

Advantages :)
- compact, low-cost primary beam, similar to CEBAF or FEL injectors
- below neutron activation threshold
- energy spread of positron limited by primary electron energy
- unique continuous source

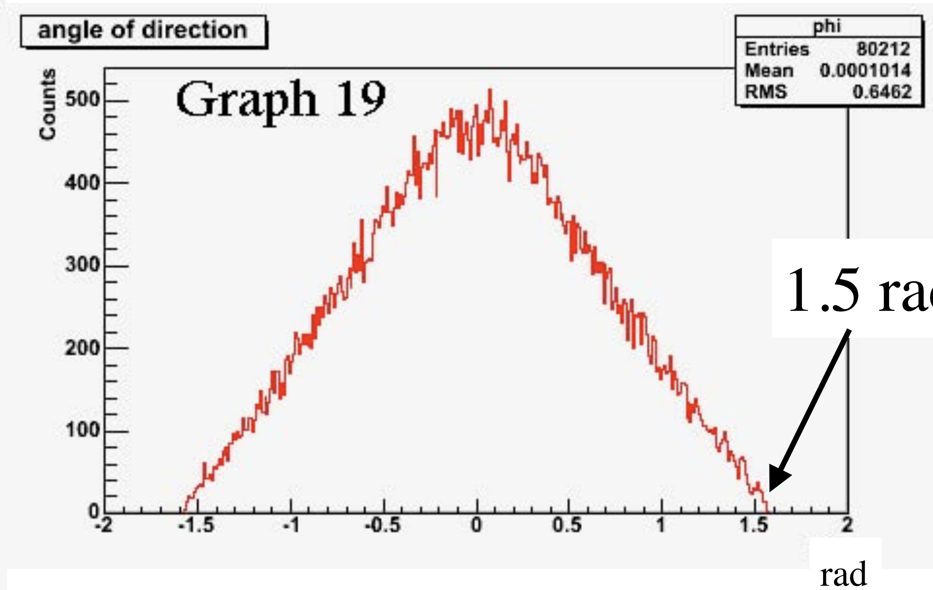
Disadvantages :(
- lower pair-production cross section
- large divergence of positron beam
- heat load on target

Positrons emerging from radiator target (GEANT4 calculation)

e^-: 10 MeV, 0.5 mm rms
W: 0.5 mm



20% backscattered



1.5 rad!

Large divergence

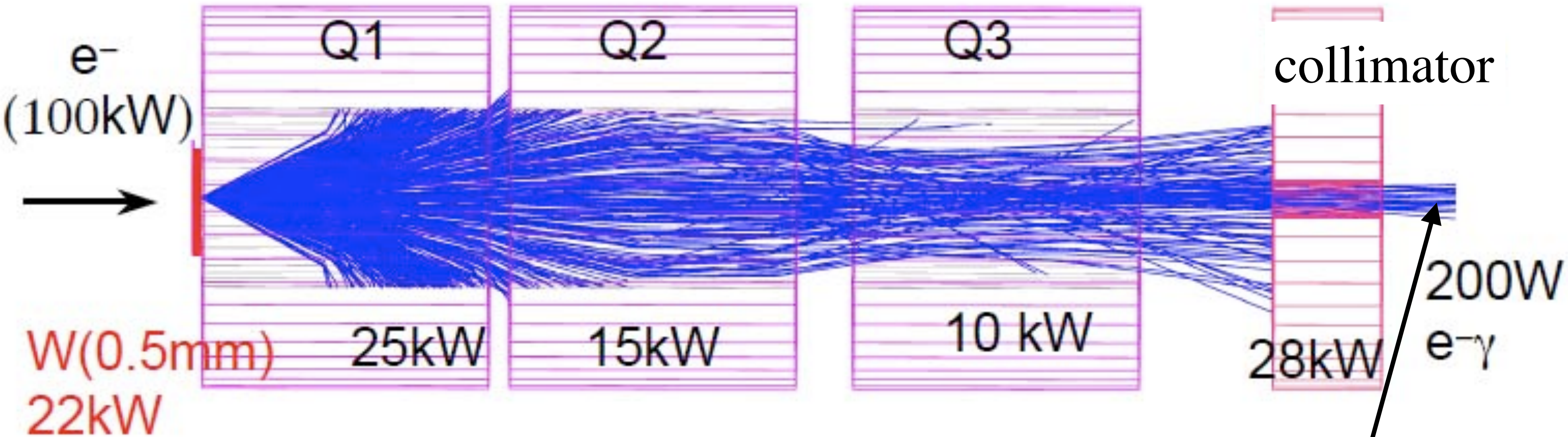
Total forward production:
8E-4 e^+/e^-

Dumas, Internship Report, LPSC Grenoble, June 2007

Paradigm emerging after optimization:

- 10-mA 10-MeV primary electron beam, 0.5 mm rms transverse size
- 0.5 mm tungsten radiator target
- collection and momentum selection with quadrupole triplets

Sarma, J. Phys. D 36, 1896 (2003)

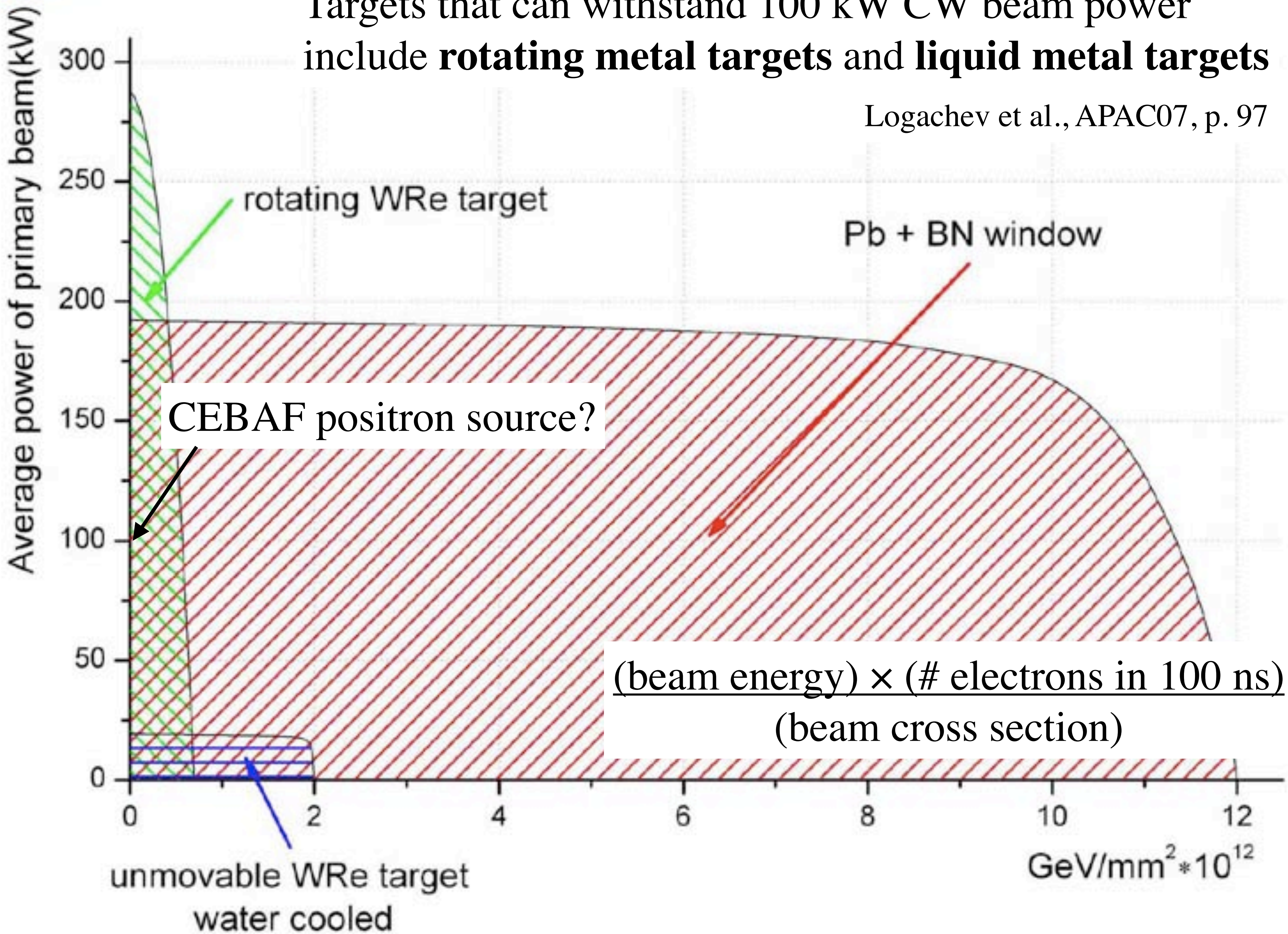


Yield after collimator
(G4BEAMLINE calculation)
20 nA e^+ (2E-6 e^+/e^-) at 3 MeV/c

Golge et al., PAC07, p. 3133

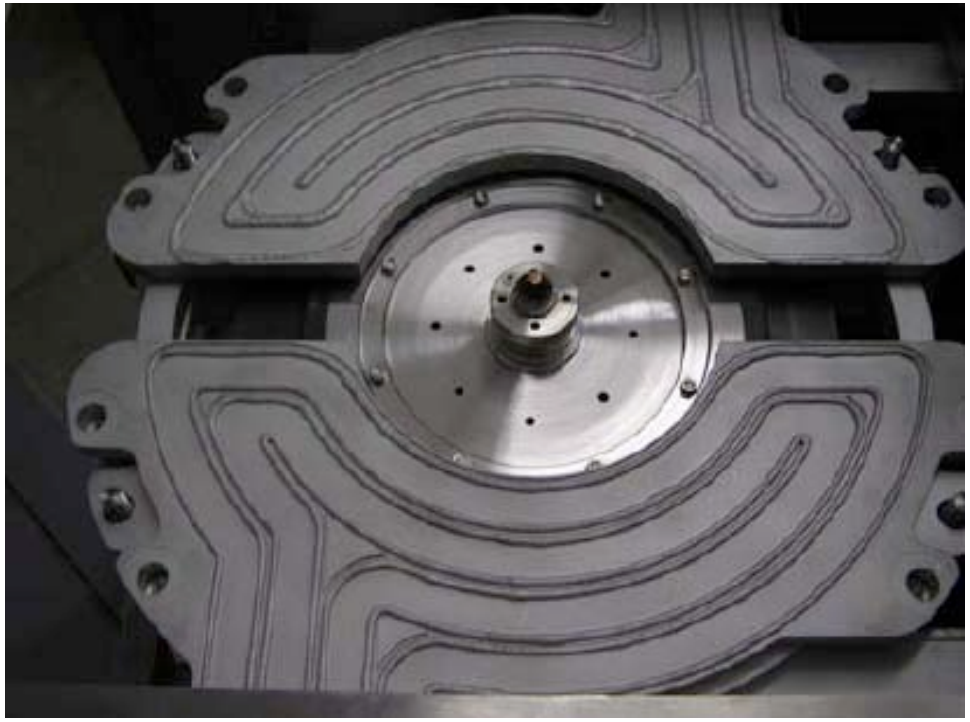
Targets that can withstand 100 kW CW beam power include **rotating metal targets** and **liquid metal targets**

Logachev et al., APAC07, p. 97



Radiation-cooled rotating steel wheels supporting graphite targets for radioactive ion beam production have been shown to withstand electron beam average power densities of 70 kW/cm^2

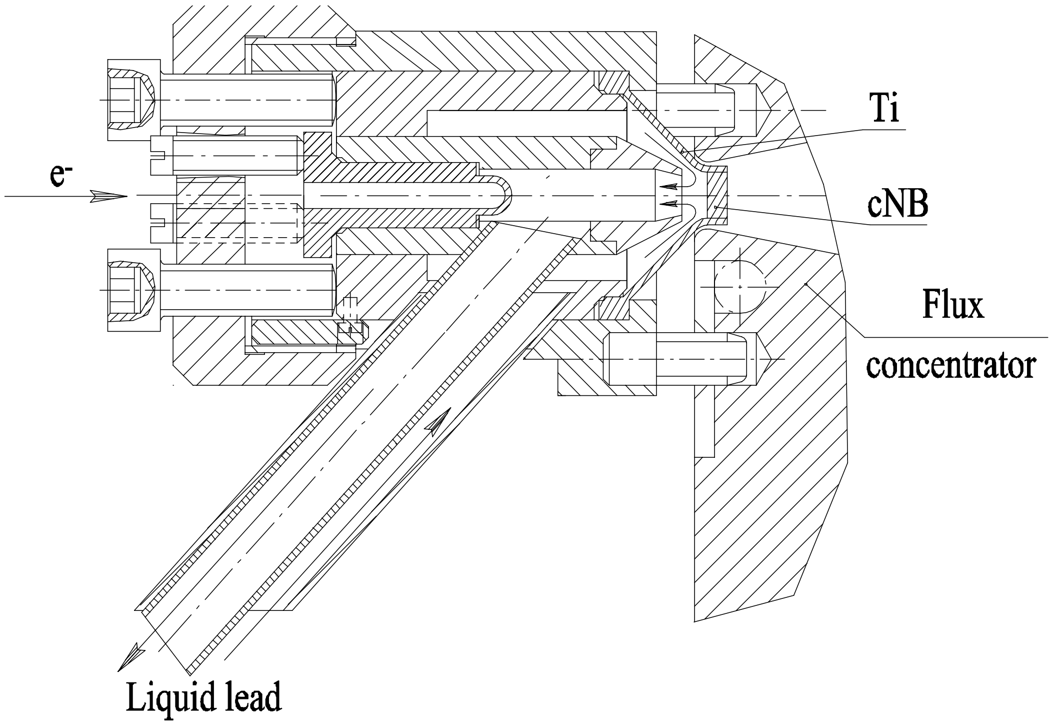
340-mm diameter, operate at 1200-3000 rpm, 2200 K



Alyakrinskiy et al., NIM A 578, 357 (2007)

Liquid lead-tin targets for pulsed ILC beams are being developed by the same group at BINP Novosibirsk

Demonstrated pumping of Pb-Sn alloy at 600 K with cogwheels for 15000 h



Tests of prototype planned at KEKB

Belov et al., PAC01, p. 1505 Logachev et al., APAC07, p. 97

Can the concept of a low-energy (~MeV) positron source for CEBAF be tested at the IAC?

Goals:

- measure yields and phase-space distributions

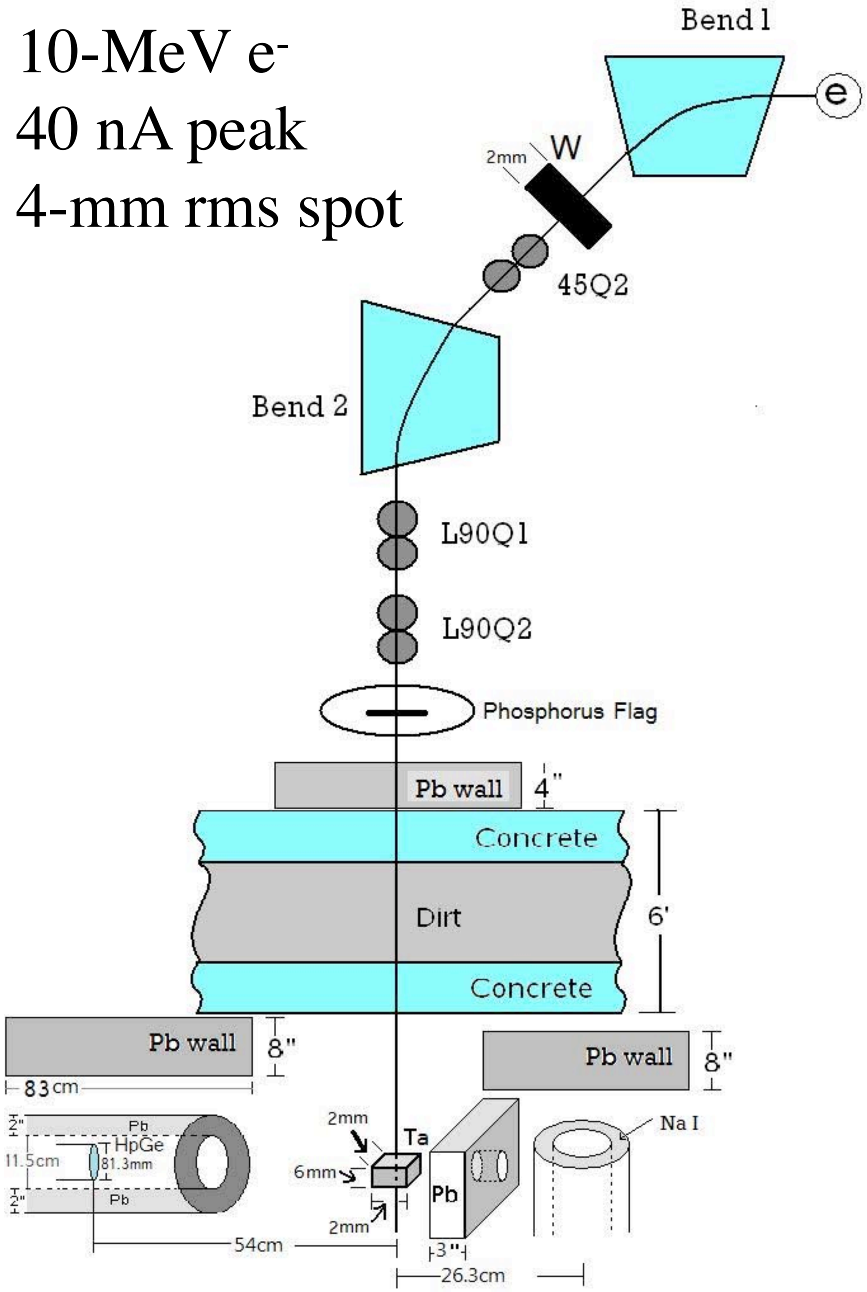
- implement collection optics

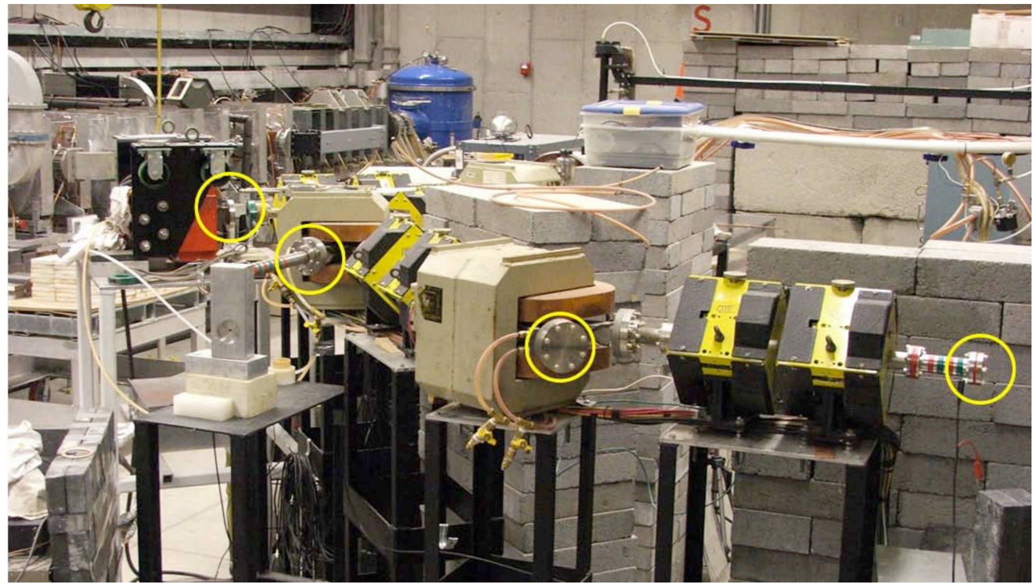
- test target designs (max. avg. beam power at IAC is ~10 kW)

10-MeV e-
40 nA peak
4-mm rms spot

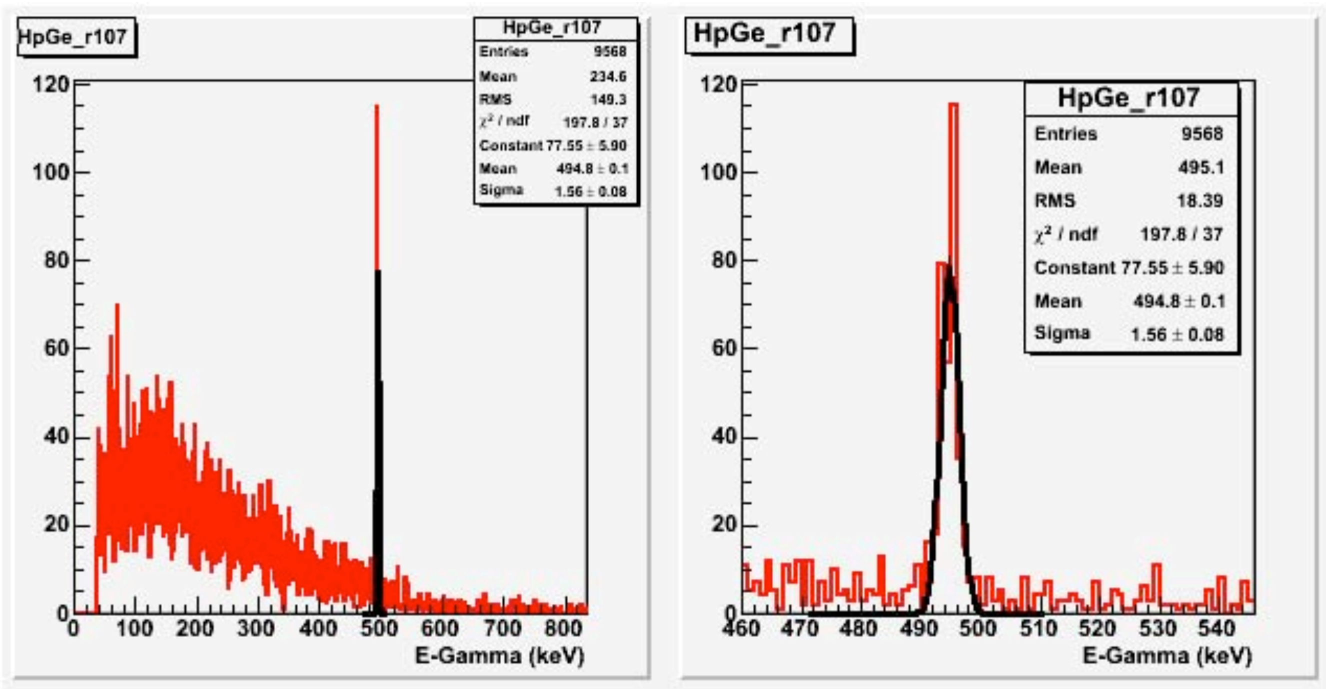
First tests of positron production at IAC 25-MeV linac in Accelerator Lab #1

February and May 2008





Positron signal observed with HPGe detectors

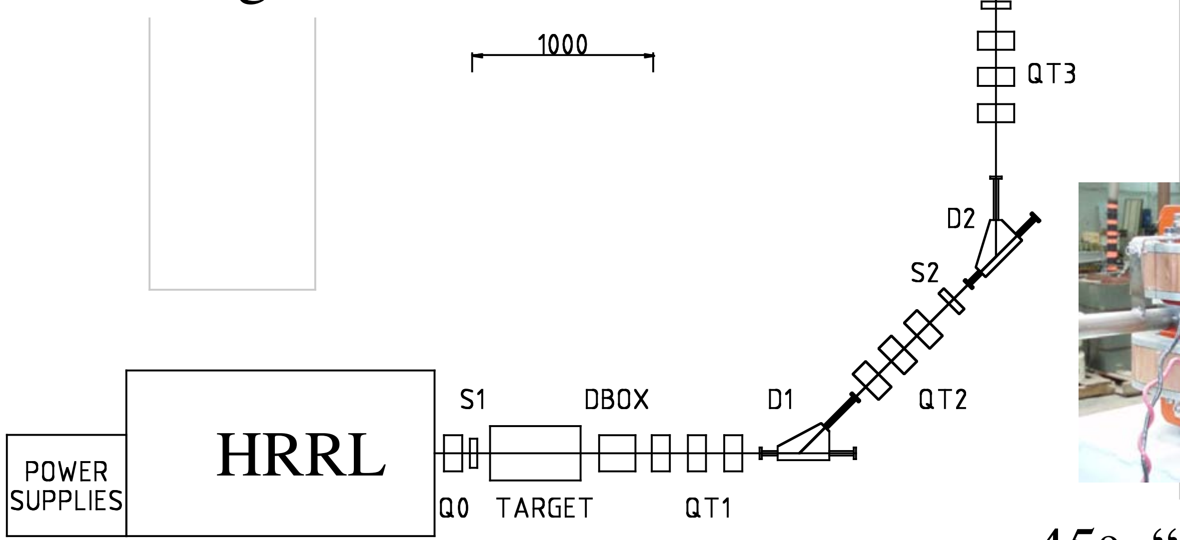


Need to improve:
- beam control
- beam optics
- diagnostics
- γ background

More permanent setup desirable

HRRL Lab at PSB
to test prototype positron sources?

- maintain or improve electron and photon capability
- need to move HRRL? => dose measurements
- use existing dipoles and quads
- need correctors and diagnostics



45o, “Kiwi” dipoles

19 T/m, 1” quads

Conclusions

The Idaho Accelerator Center is a unique research facility.

Positron annihilation spectroscopy successfully used to probe local material defects; positrons produced by radioactive sources, photo-activation, and photon-induced pair production.

Currently investigating possibility to build prototype of a continuous positron source for CEBAF.

Thank you for your attention!