Positron program at
the Idaho Accelerator Center

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International Workshop on Positrons at Jefferson Lab
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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

http://iac.isu.edu
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
- ...

25-MeV Linac
- 2.8 GHz S-band standing-wave linac
- 0.5 $\mu$s to 4 $\mu$s pulse width
- 600 Hz rep rate
- 40 nC/pulse (0.5 $\mu$s width)
- 350 nC/pulse (4 $\mu$s 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 $\gamma$ 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 $^{22}\text{Na}$ 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 $(\gamma,n)$ reaction yields $\beta^+$ emitter

Sample remains activated

**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)

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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 $\beta^+$ emitter from ($\gamma$,n)
  - sample is activated

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

- $^{22}$Na source
  - cheap
  - low intensity
  - low energy (surface maps)
  - low backgrounds
  - proposed in the past
  - potential synergy with prototype $e^+$ source for CEBAF

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

\[ \beta^+ \text{ radioactive decay} \]  
\[ \text{e.g., } ^{22}\text{Na, 2.6 y half life} \]  

- More common for accelerators:  
  - higher phase-space density  
  - controllable time structure  

**pair production** <=  
- "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)

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

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

Large divergence

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


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

\[(\text{beam energy}) \times (\# \text{ electrons in 100 ns})\]

\[(\text{beam cross section})\]
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/cm². 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)
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
- $\gamma$ 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

19 T/m, 1” quads

45°, “Kiwi” dipoles
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.