A prototype positron source for CEBAF as part of the ISU/JLab collaboration in accelerator physics and education

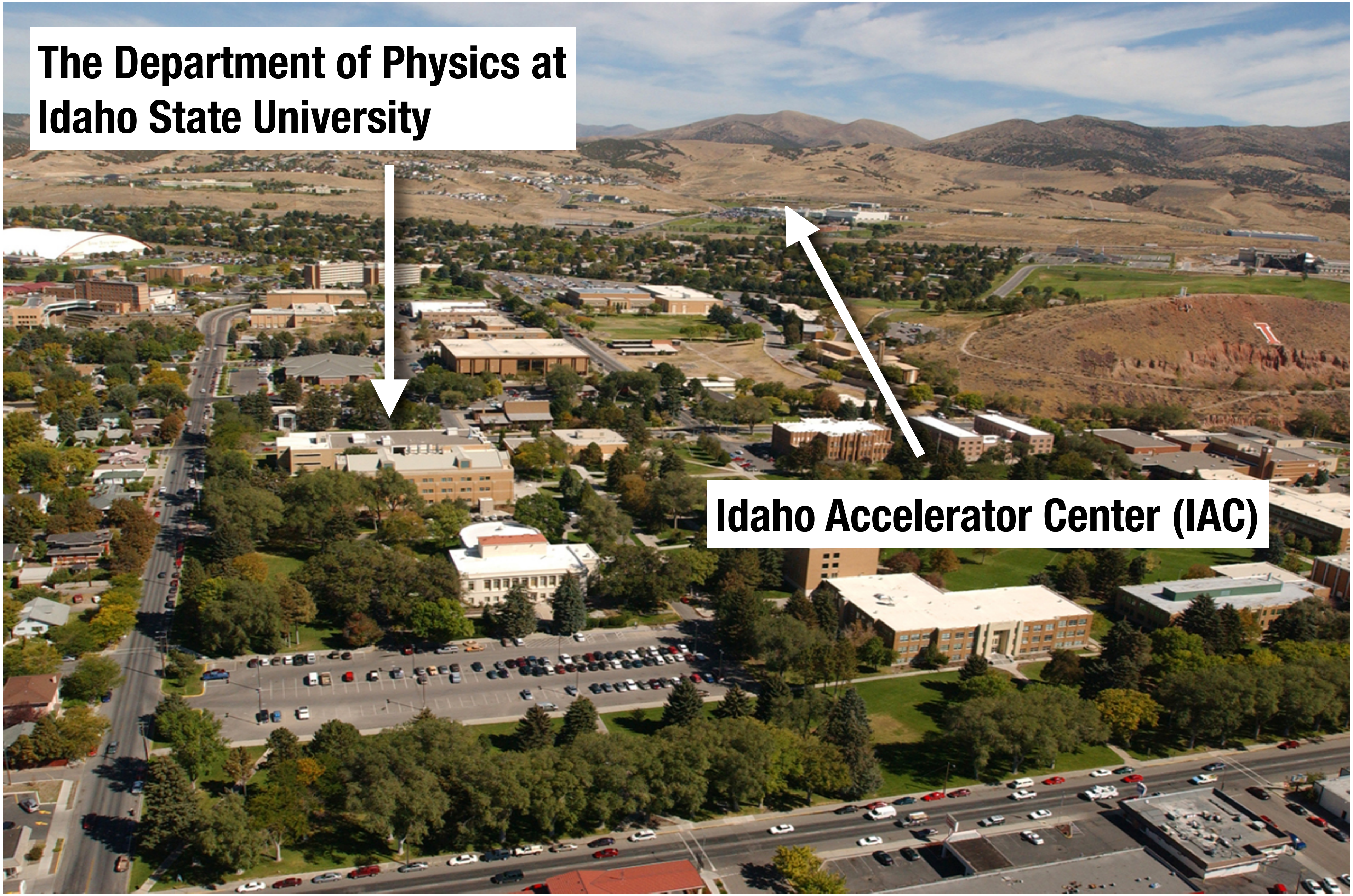
Giulio Stancari

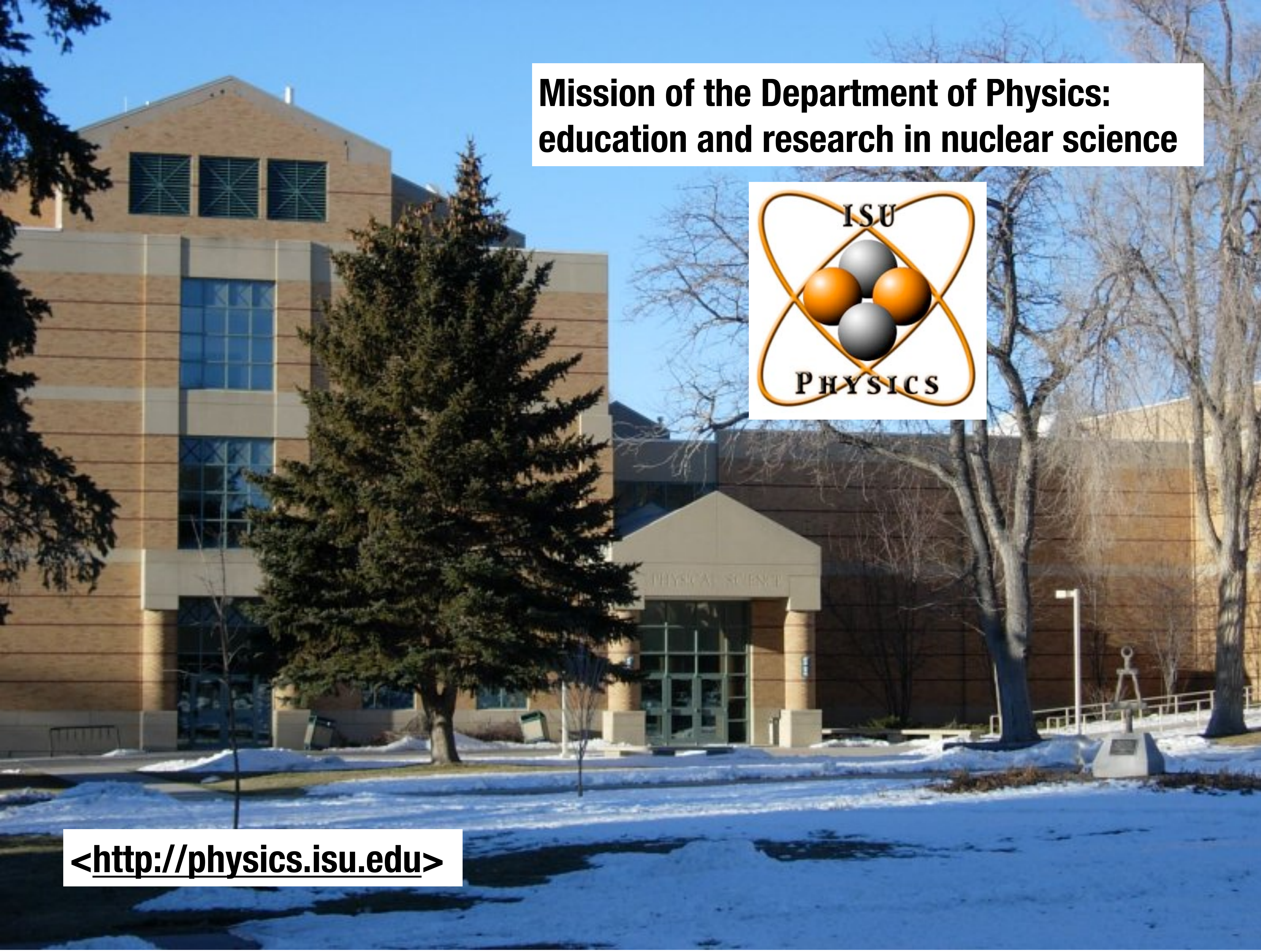
Idaho State University and Jefferson Lab

Jefferson Lab - Newport News, Virginia
February 12, 2009

Facilities at Idaho State University


Idaho State
UNIVERSITY
ISU is located in Pocatello, Idaho
About 14,000 students enrolled
Now (since Dec ’08) an Affiliate Member of the
Southeastern Universities Research Association (SURA)
<http://www.isu.edu>


The Department of Physics at
Idaho State University
Idaho Accelerator Center (IAC)


Mission of the Department of Physics:
education and research in nuclear science
<http://physics.isu.edu>

13 full-time faculty,
all involved in nuclear-related fields:

- nuclear and particle physics
- accelerator applications
- radiation effects in materials and devices
- radiobiology
- health physics

Undergraduate program, ~100 students:

- Associate Degrees for technical careers
- BA in Physics for prospective teachers and bio-science careers
- BSc in Physics or Health Physics for applied physics and graduate school

Graduate program, ~70 students:

- MNS in Physics
- MSc in Applied Physics or Health Physics
- PhD in Applied Physics

New Accelerator Physics class offered in Spring 2009 (PHYS 630):
- 3 grad students enrolled
- 2 grad students auditing

New Accelerator Technology (PHYS 631) and Particle Beam Lab (PHYS 632) classes in preparation

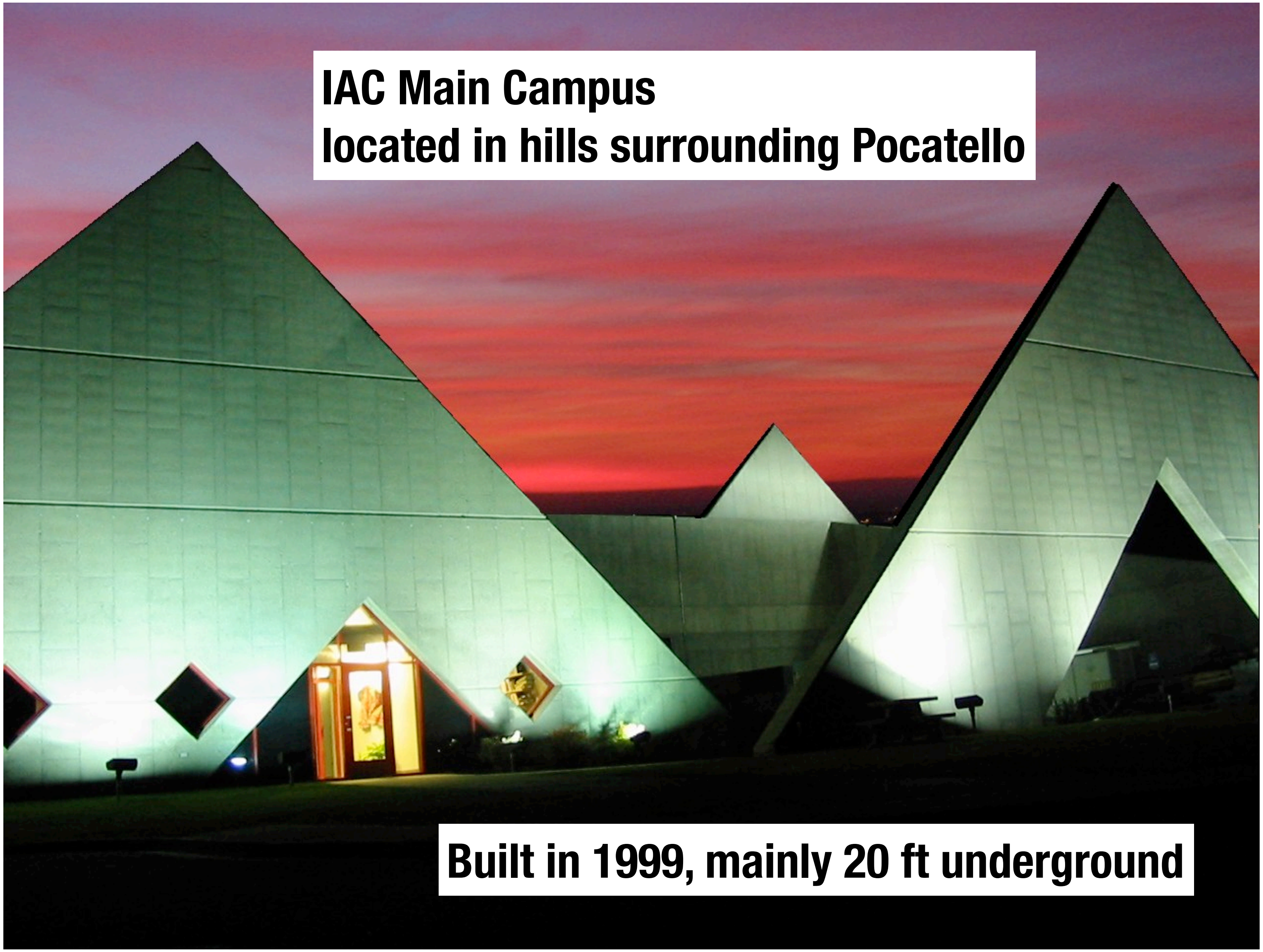
Host US Particle Accelerator School at ISU/IAC in the future?

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

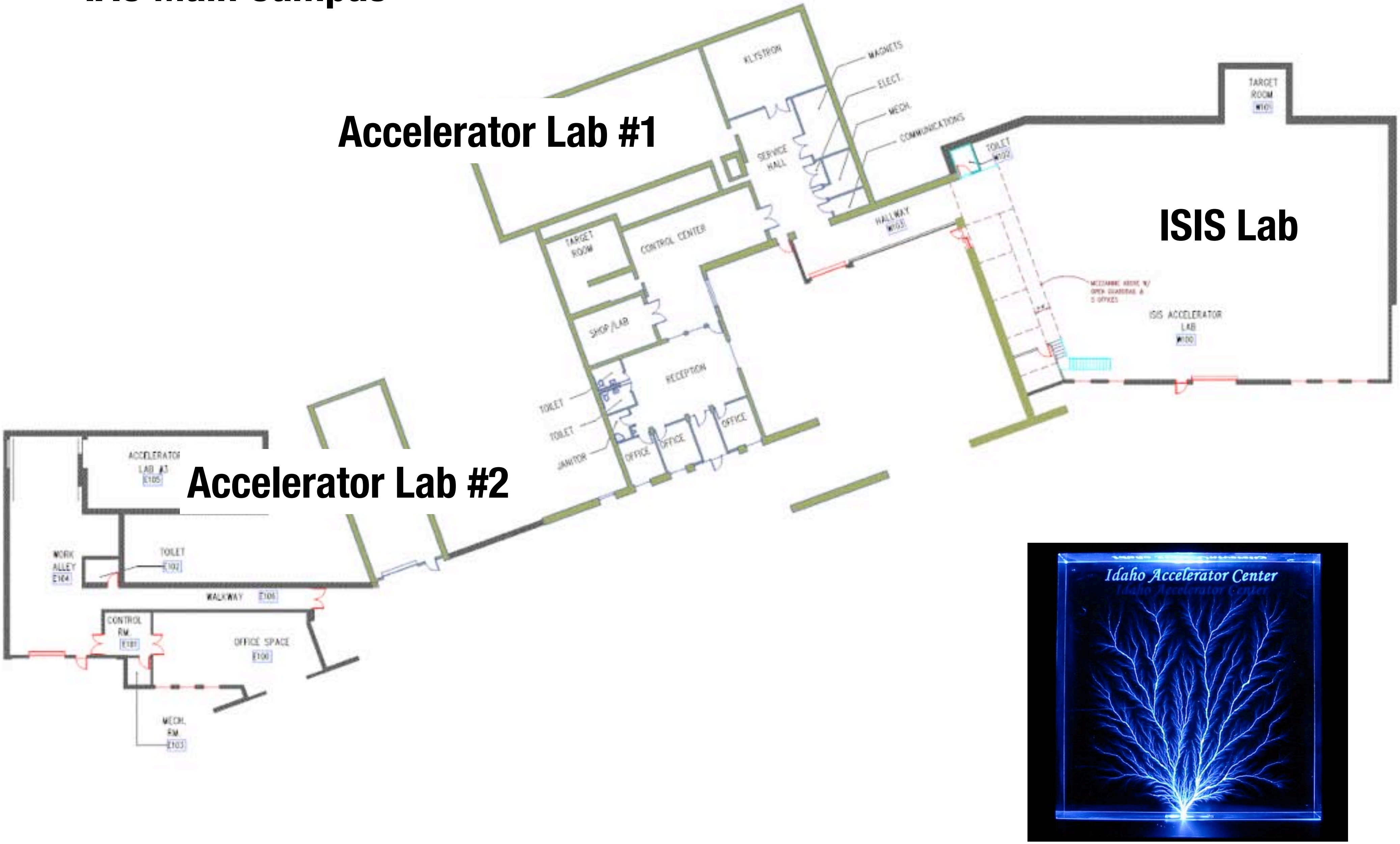
Mission:
- undergraduate and graduate education
- applied nuclear physics research
- new accelerator physics applications
- support economic development of Idaho

Idaho Accelerator Center

<http://iac.isu.edu>

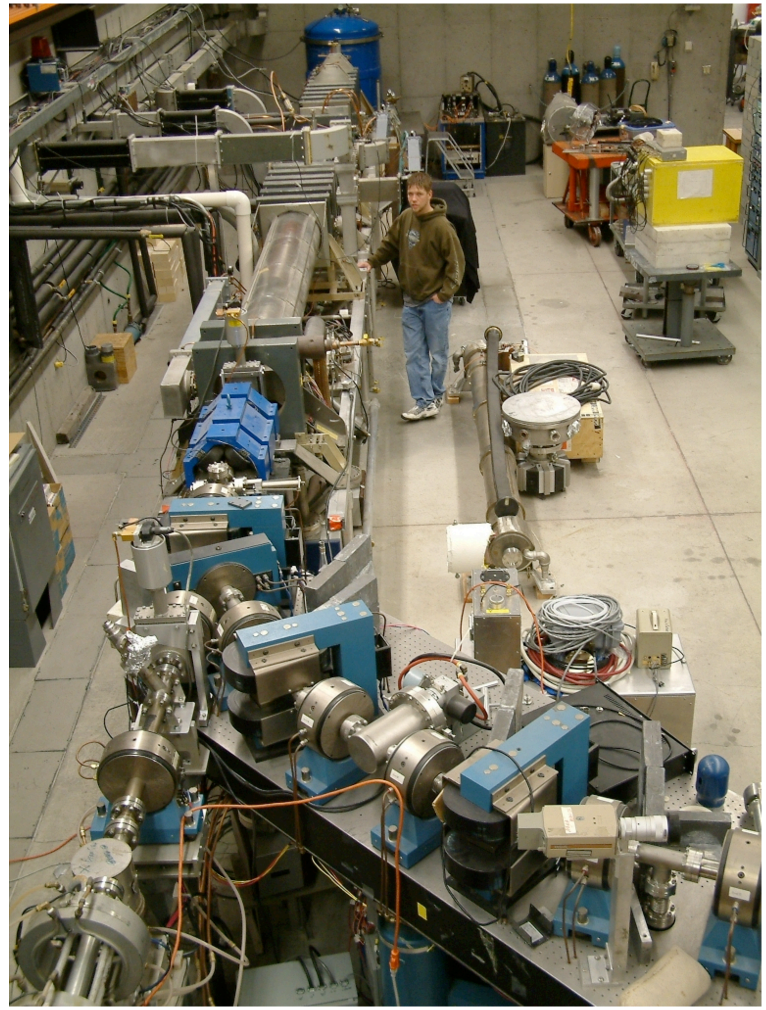

IAC Main Campus
located in hills surrounding Pocatello
Built in 1999, mainly 20 ft underground

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

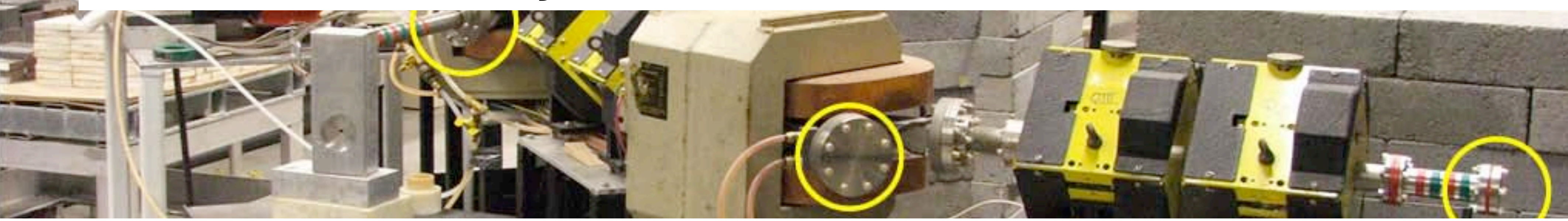


Lab workhorse:
- neutron time-of-flight spectrometry
- laser Compton scattering
- ...

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: Accelerator Lab #2

777 sq ft hall for construction and testing of accelerator components

10 ft underground

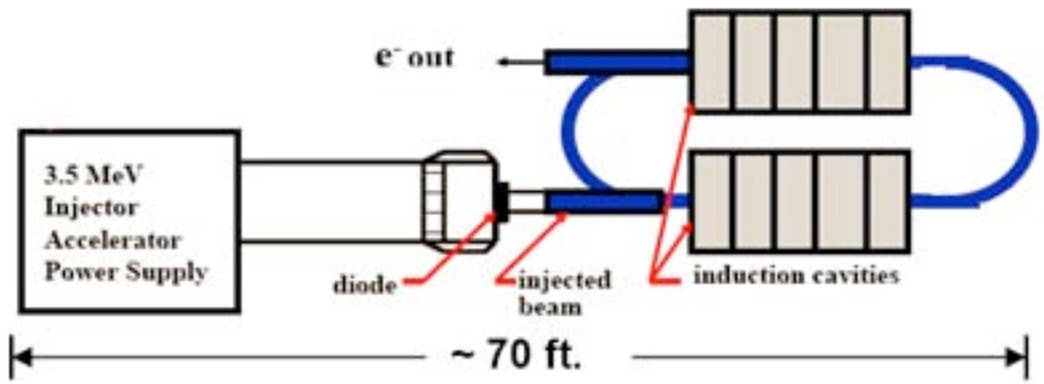
25-MeV Linac similar to the one in Lab #1
under construction

Will be dedicated to laser Compton scattering:
- source of monochromatic X-rays
- laser-based beam diagnostics

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

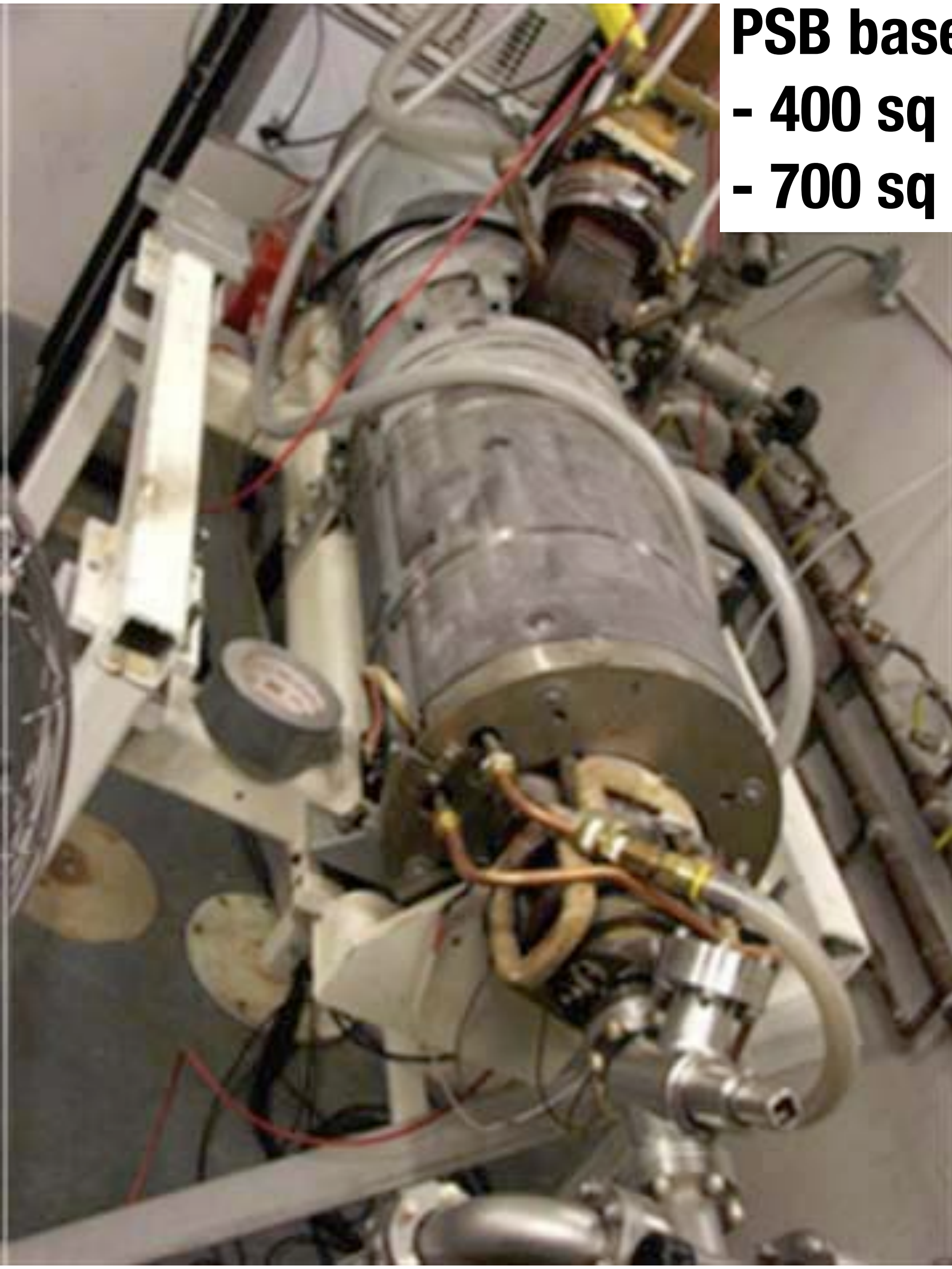
IAC Airport Facility

Located near Pocatello Regional Airport

- 20,000 sq ft high-bay space for large-scale system testing
- 15 acres of open area for field testing

- 10-MeV linac in cargo container scanning test bed
- 25-MeV electron linac for remote detection of fissionable materials

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?

Studies on positrons for CEBAF

Scientific motivation: inner structure of the proton

Nucleon structure described by Generalized Parton Distributions (GPDs)

GPDs accessible by measuring amplitude of deeply virtual Compton scattering (DVCS) in the process $e\,p \rightarrow e\,p\,\gamma$

DVCS amplitude small compared to Bethe-Heitler amplitude, i.e., real photon radiated by incoming or scattered electron

Guichon, Prog. Part. Nucl. Phys. 41, 125 (1998)

Ji, Ann. Rev. Nucl. Part. Sci. 54, 413 (2004)

Beam charge asymmetry related to real part of DVCS amplitude

$$\frac{d^5\sigma^+}{d\Omega^5} - \frac{d^5\sigma^-}{d\Omega^5} = 4\, A_{\mathrm{BH}}\, \Re(A_{\mathrm{DVCS}})$$

BH process well understood => clean determination of DVCS amplitude

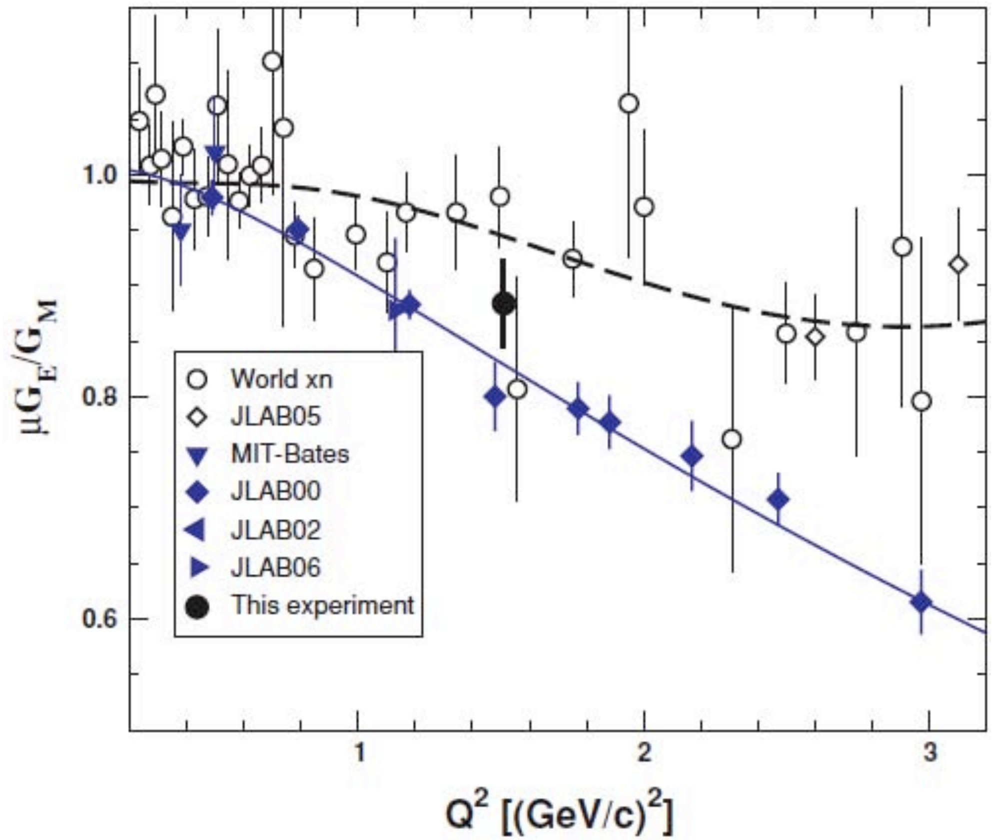
Beam helicity asymmetry related to imaginary part of DVCS amplitude

$$\frac{d^5\ \overrightarrow{\sigma}}{d\Omega^5} - \frac{d^5\ \overleftarrow{\sigma}}{d\Omega^5} = 2\, A_{\mathrm{BH}}\, \Im(A_{\mathrm{DVCS}}) + \underbrace{2\, \Re(A_{\mathrm{DVCS}})\, \Im(A_{\mathrm{DVCS}})}_{\textbf{(small)}}.$$

=> Strong case for polarized positron beams (Dumas, Grames, Voutier) to control systematics in charge-asymmetry data

Scientific motivation: role of two-photon amplitudes in nucleon form factors

Jones et al., Phys. Rev. C 74, 032201 (2006)



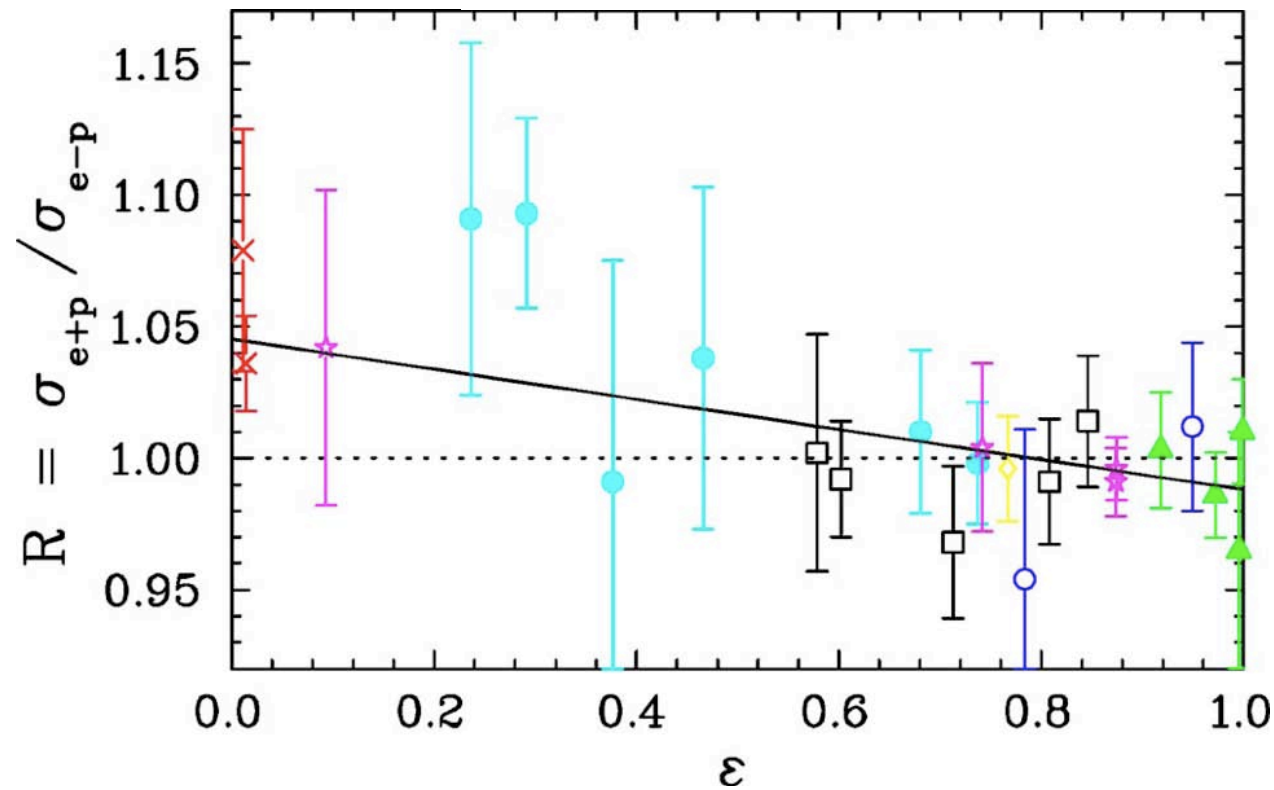
Discrepancy between Rosenbluth separation and polarization transfer measurements probably due to two-photon processes

Hyde-Wright and de Jager, Ann. Rev. Nucl. Part. Sci. 54, 217 (2004)

Carlson and Vanderhaeghen, Ann. Rev. Nucl. Part. Sci. 57, 171 (2007)

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

Arrington, Phys. Rev. C 69, 032201 (2004)



Three proposed experiments:

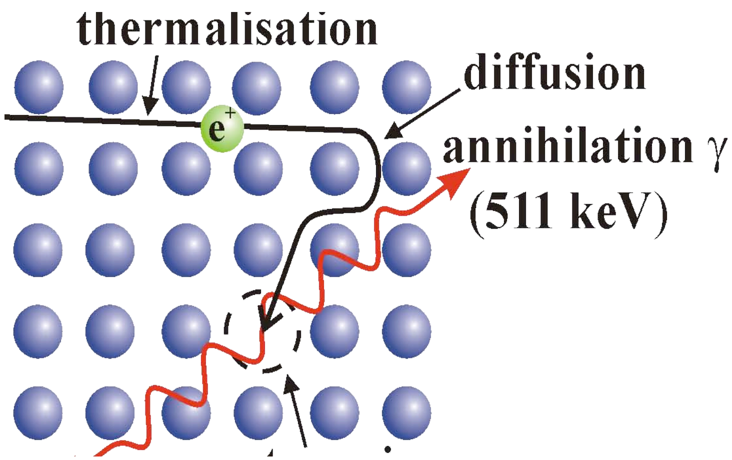
- at VEPP-3 in Novosibirsk (arXiv:nucl-ex/0408020)

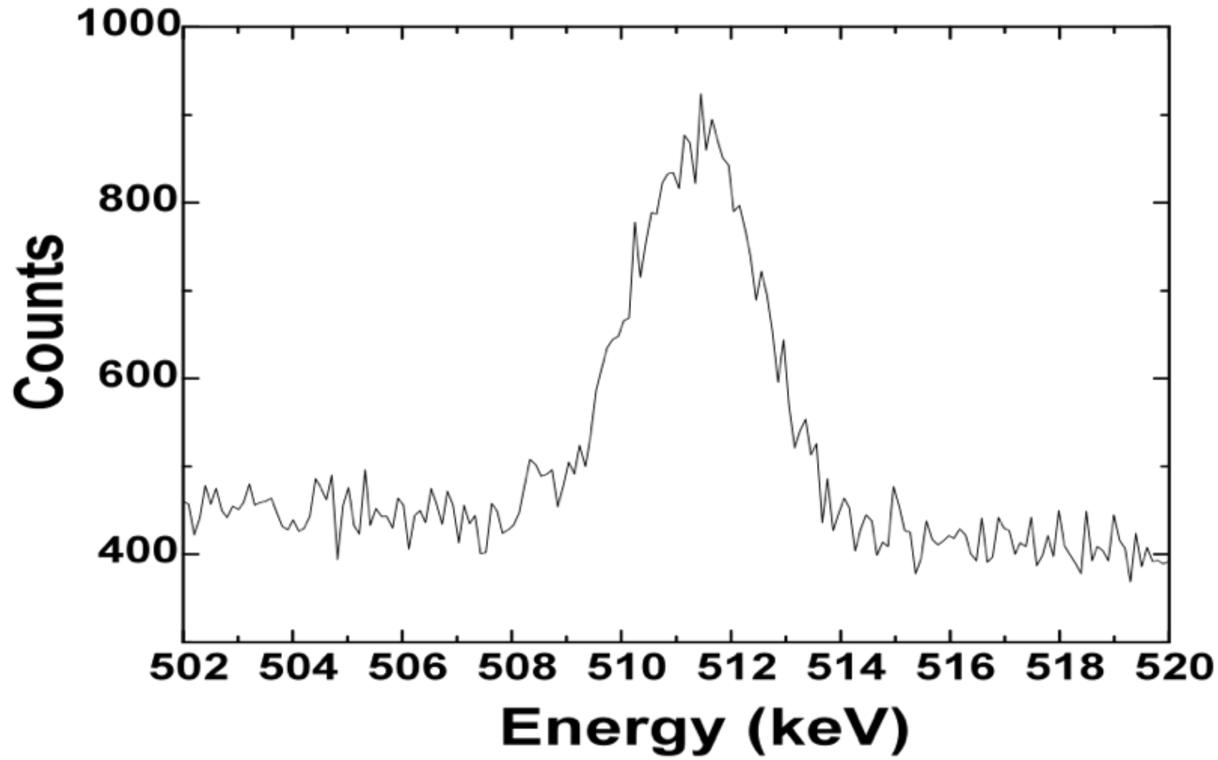
- at JLab with CLAS (proposal to PAC31, Dec '06)

- at DESY, with BLAST detector in DORIS ring (web.mit.edu/olympus)

IAC research program would benefit from intense source of positrons

Example: positron annihilation spectroscopy to detect material defects in bulk

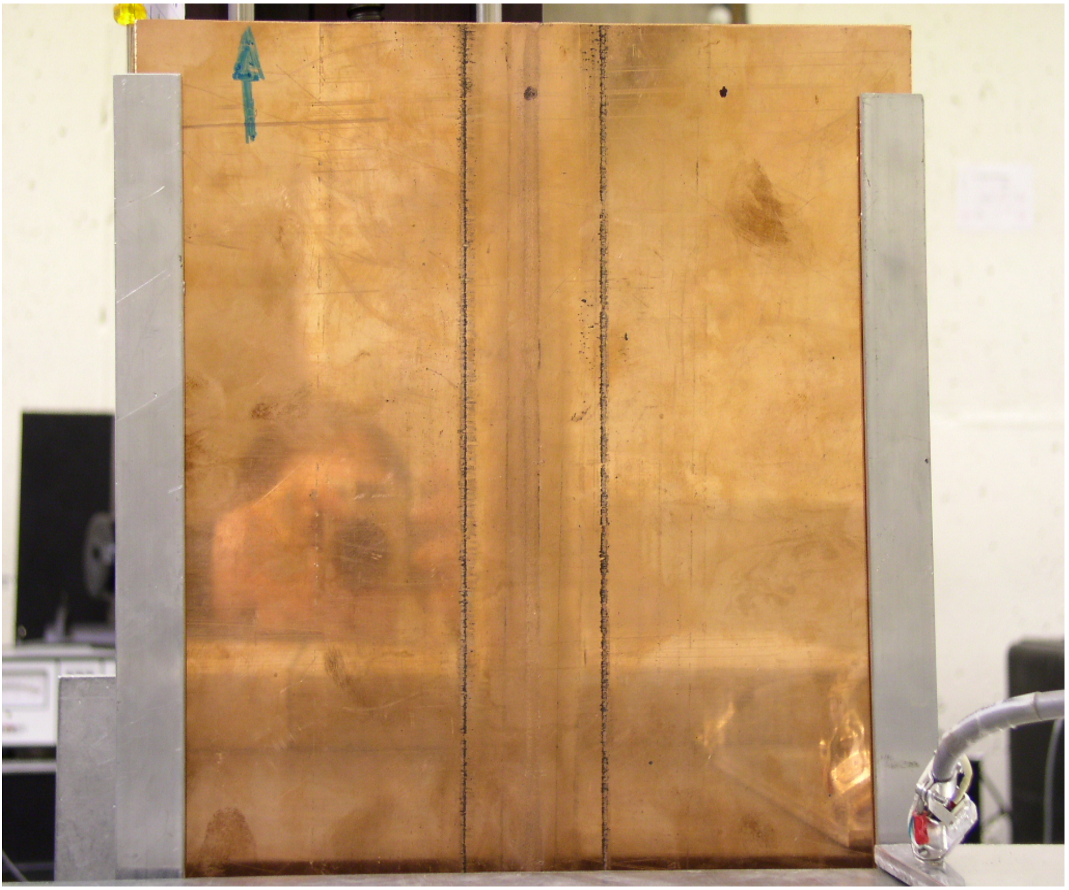


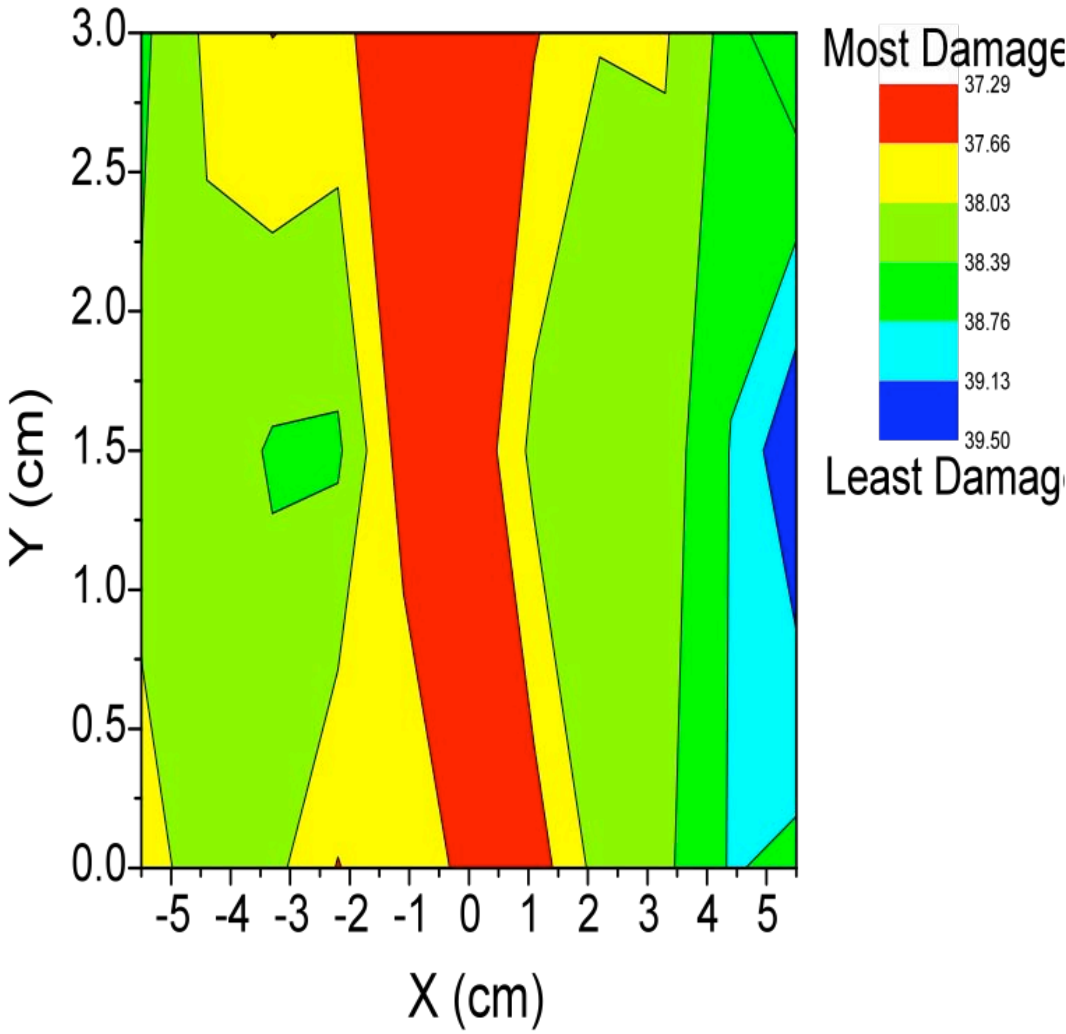


Width of annihilation spectrum is related to microscopic structure

DeBenedetti et al., Phys. Rev. 76, 440 (1949)
Asoka-Kumar et al., J. Appl. Phys. 76, 4935 (1994)

World's first 2-D defect density map in thick material obtained at IAC





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

β^+ radioactive decay
eg ^{22}Na, 2.6 y half life

Positron sources:

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

"Conventional" sources (SLAC, KEK) and ILC designs exploit multi-GeV primary electron beams

Several people working on positron source for CEBAF:
- A. Freyberger, J. Grames, R. Kazimi (JLab)
- E. Voutier, J. Dumas (LPSC Grenoble)
- C. Hyde, S. Golge (ODU)
- T. Forest, G. Stancari (ISU)
- ...

Previous work by W. J. Kossler, A. J. Greer, and L. D. Hulett

Kossler et al., Nucl. Instrum. Meth. B 79, 345 (1993)

Concept of “low energy” positron source:

- 10-mA 10-MeV CW electron beam (JLab FEL injector)
- tungsten radiator target
- collection and energy selection with quadrupole triplets
- maximize yield in CEBAF admittance
  200 π mm mrad (rms, normalized) transverse
  ± 2% longitudinal

Advantages:

- below neutron activation threshold
- energy spread of positron limited by primary electron energy
- compact in size
- unique continuous source

Disadvantages:

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

Calculations and simulations using GEANT4, G4BEAMLINE, DIMAD

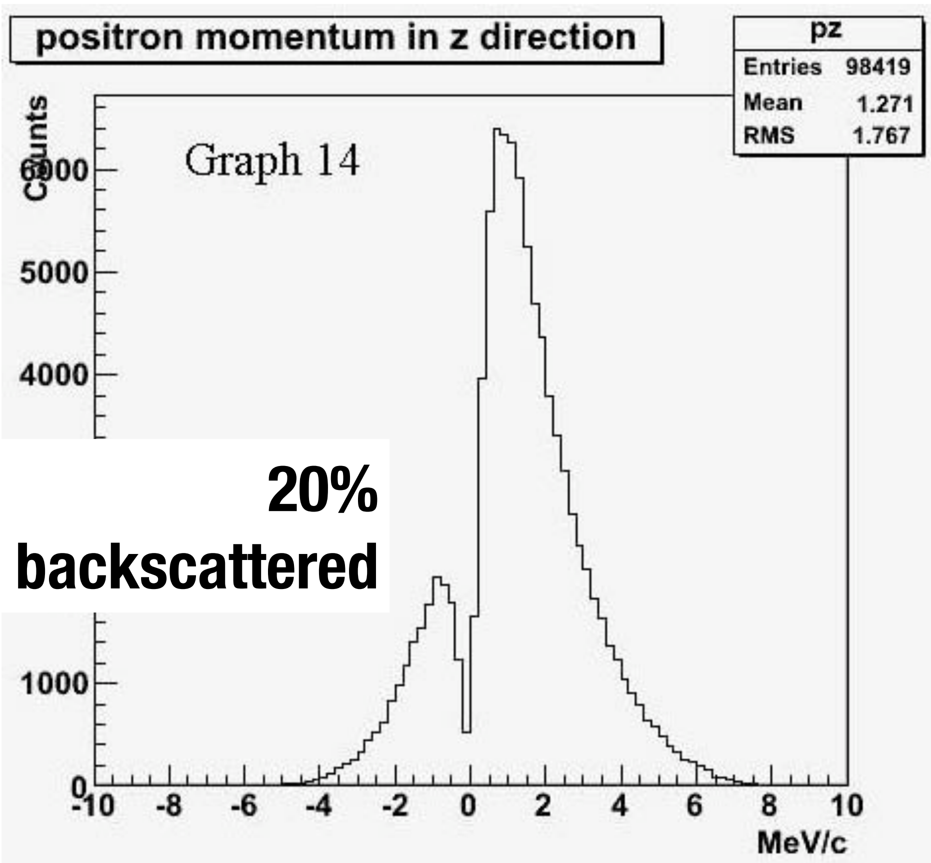
Goal is to optimize yields and heat loads as a function of:

- **electron beam energy**
- **target material and thickness**
- **beam incidence angle**
- **collection system**

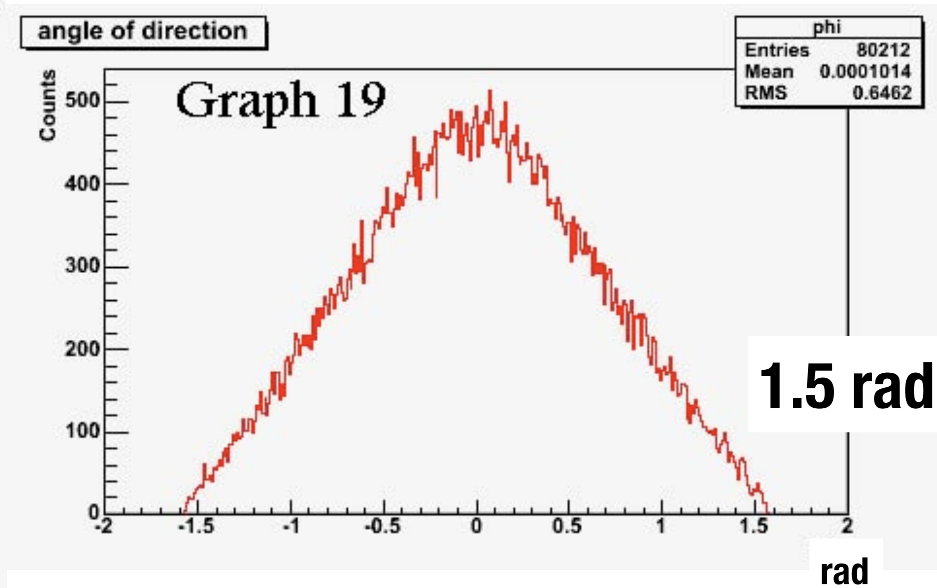
(Golge, Dumas)

Positrons emerging from radiator target

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



20% backscattered



1.5 rad!

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

Dumas, Internship Report, LPSC Grenoble, June 2007

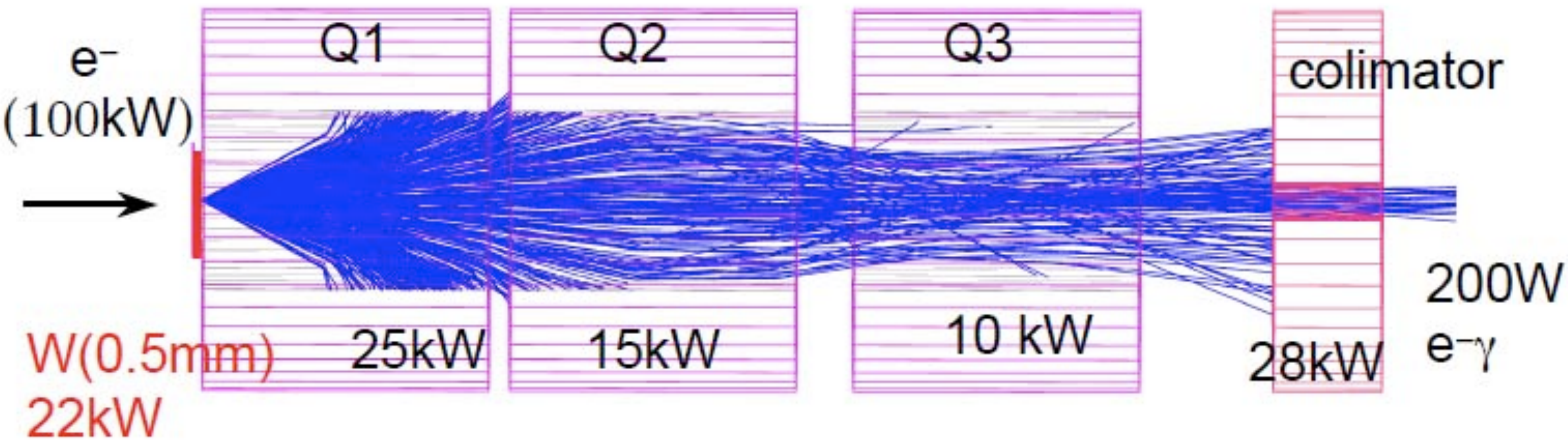
Emerging paradigm:

- 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)

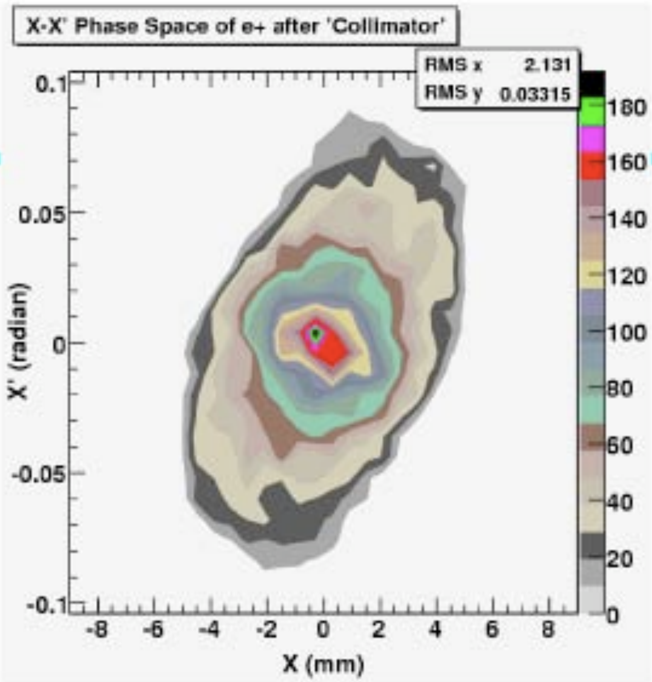


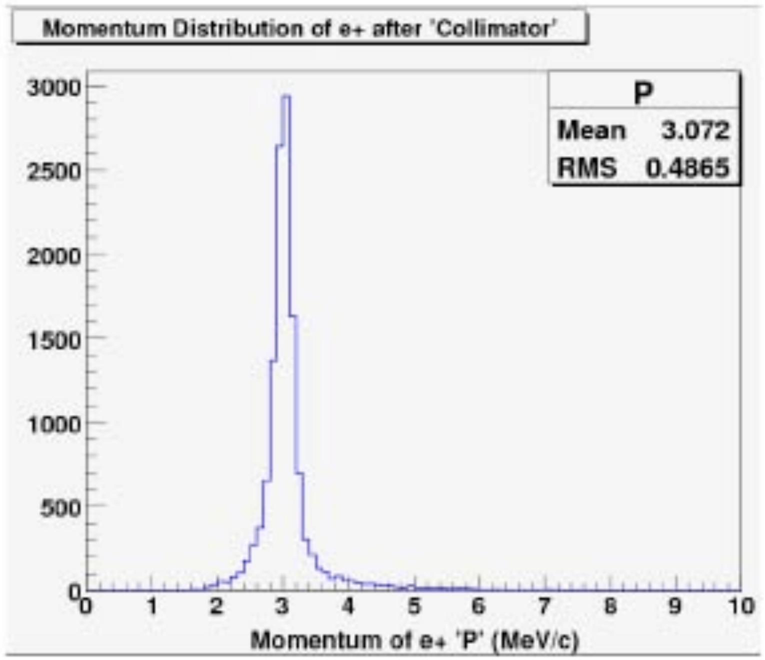
- water-cooled rotating tungsten wheel?

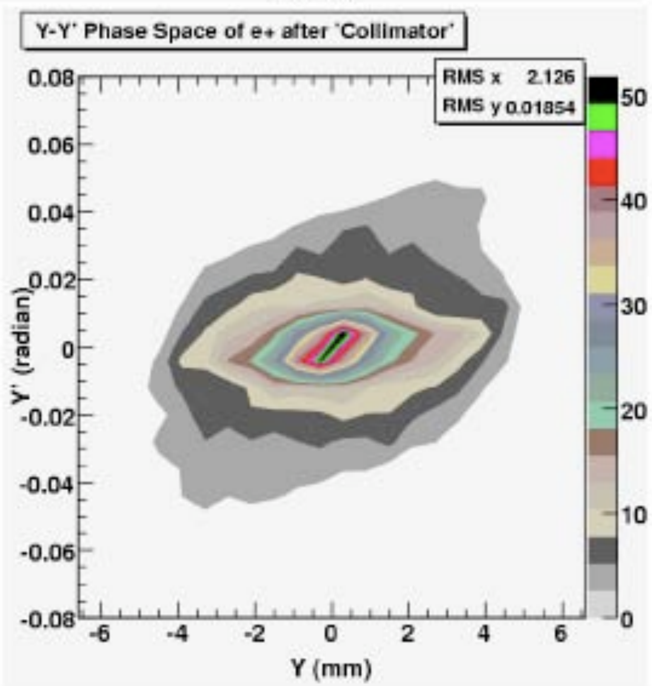
- liquid metal target?

Golge et al., Proc. of PAC07, p. 3133

Positrons after collimator



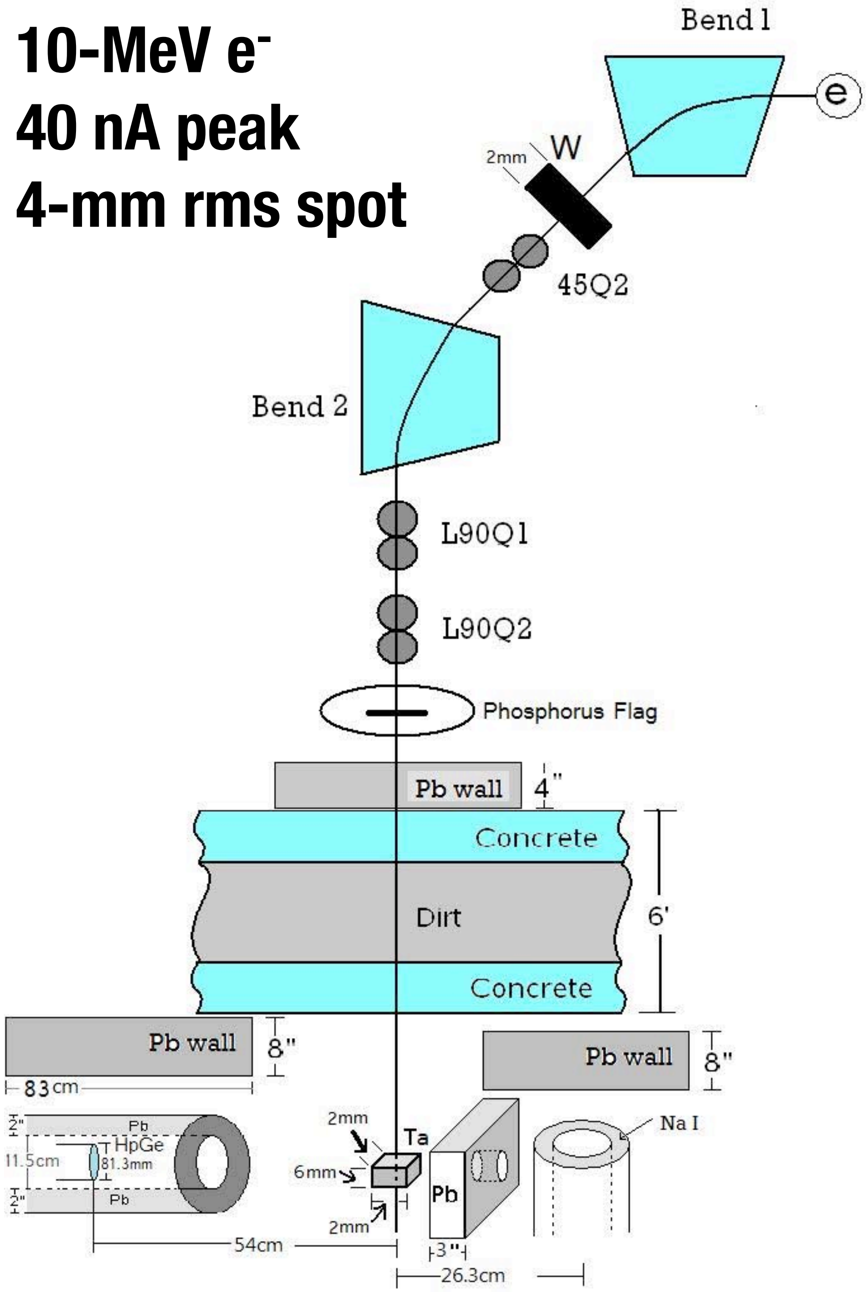




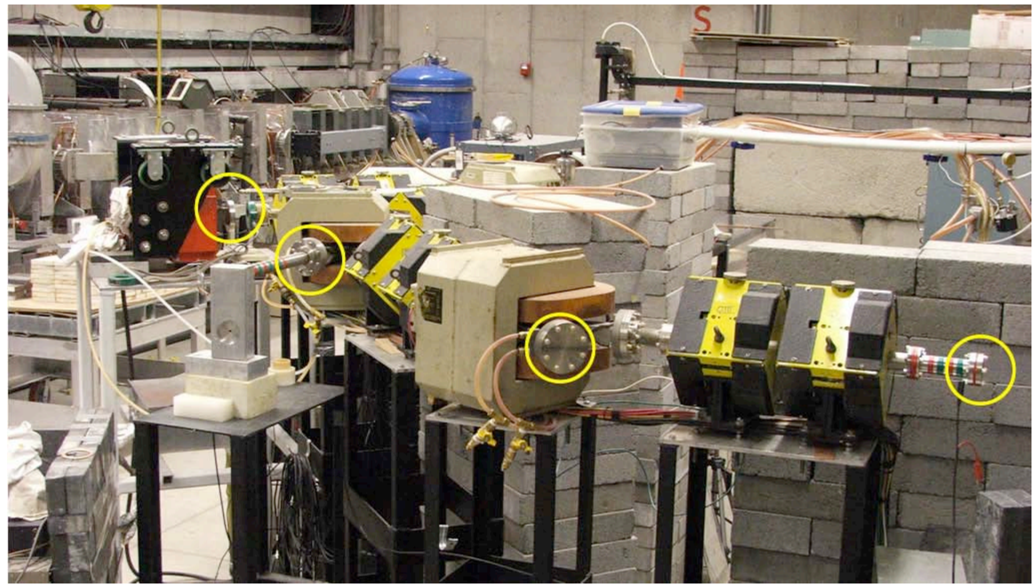
Yield into CEBAF:
20 nA e^+ (2E-6 e^+/e^-) at 3 MeV/c

Golge et al., Proc. of PAC07, p. 3133

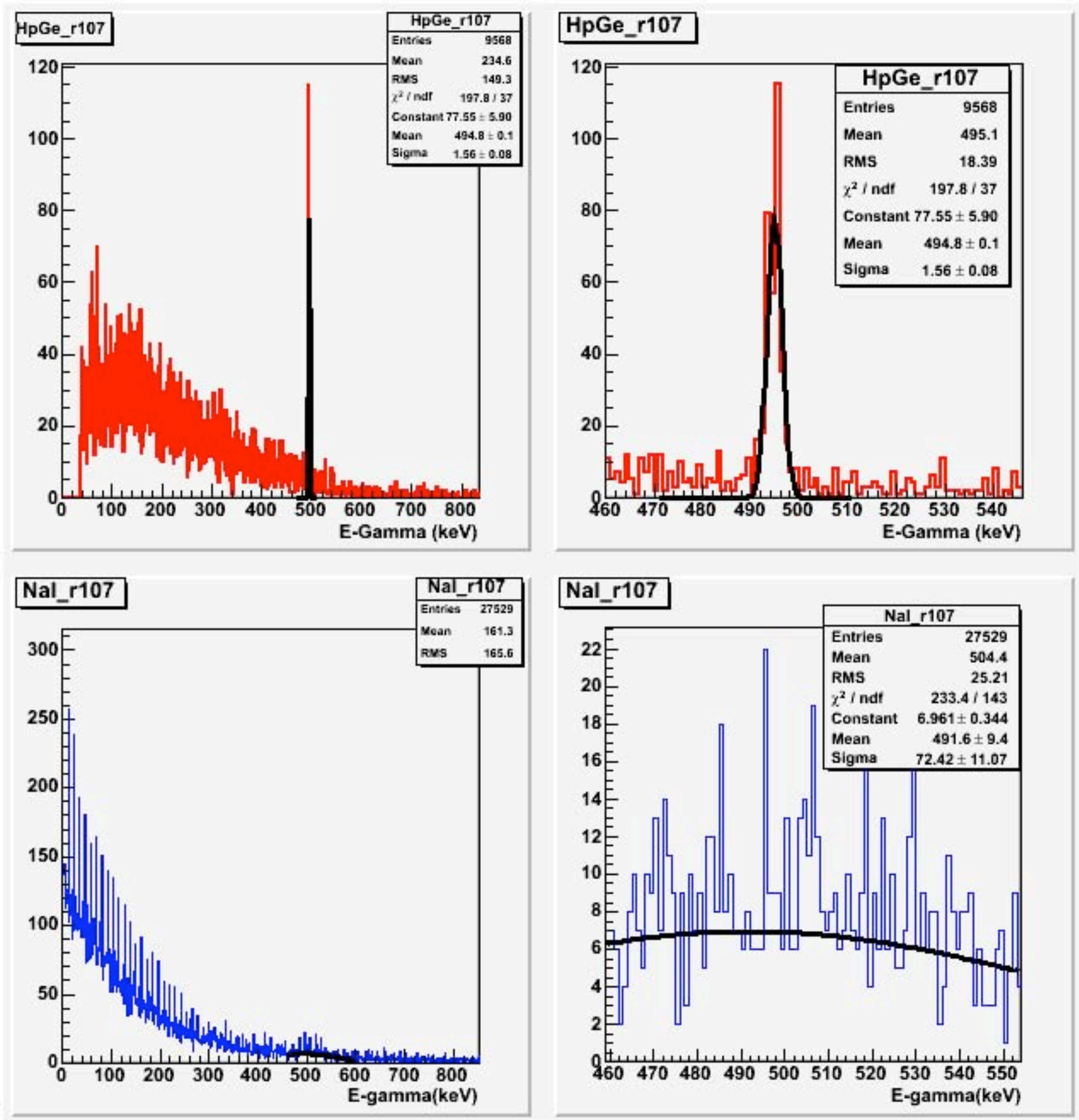
10-MeV e^-
40 nA peak
4-mm rms spot



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



Feb ’08 and May ’08
(Forest, Freyberger, Golge)

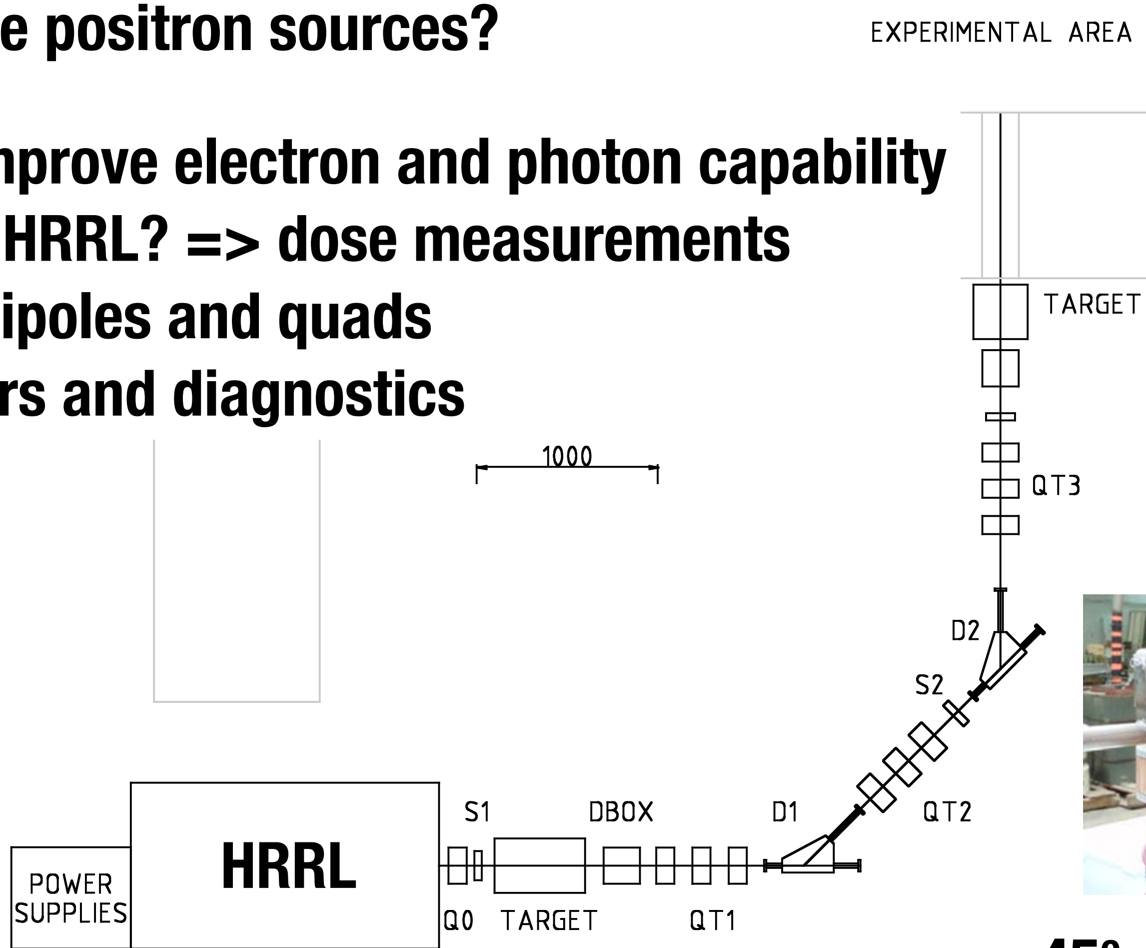


Seen positron signal

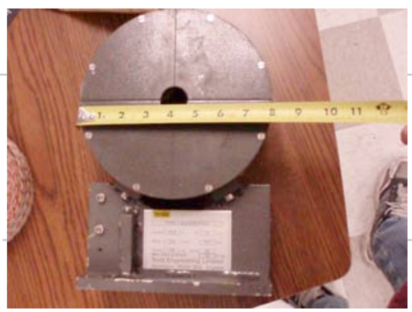
Need to improve control and diagnostics

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



45°, “Kiwi” dipoles



19 T/m, 1” quads


INTERNATIONAL WORKSHOP ON
POSITRONS
AT JEFFERSON LAB
March 25-27, 2009
JEFFERSON LAB
TOPICS:
• Positron-proton elastic scattering
• Deeply virtual Compton scattering
• New 12 GeV experiments with positrons
• Technology of positron sources
• Polarized positrons
• Electron/photon drivers
• Positron & electron polarimetry
• Applied physics with positrons
International Advisory Committee:
• X. Artru (IPN Lyon)
• L. Cardman (JLab)
• P. Cole (Idaho State U.)
• A. Freyberger (JLab)
• P. Guichon (CEA Saclay)
• R. Holt (ANL)
• A. Hunt (Idaho Accelerator Center)
• C. Hyde (LPC Clermont Ferrand)
• M. Klein (U. Liverpool)
• K. Kumar (U. Massachusetts)
• M. Poelker (JLab)
• J. Sheppard (SLAC)
• A. Variola (LAL Orsay)
Local organizing committee:
• L. Elouadrhiri (JLab)
• T. Forest (Idaho State U.)
• J. Grames (JLab)
• W. Melnitchouk (JLab)
• E. Voutier (LPSC, Grenoble)
e+
e-
email: jpos09_admin@jlab.org
conferences.jlab.org/JPOS09
Jefferson Lab
Idaho Accelerator Center
LPSC Grenoble

Conclusions

Long and very successful collaboration between JLab and ISU in detector development for JLab experiments

Started collaboration in accelerator physics and education:
- ISU/IAC great place to recruit and train students
- first JLab bridge faculty position in accelerator physics
- positron source project
- ...

Developing prototype positron source at ISU:
- exchange information on optimal parameters and diagnostics
- looking forward to next measurements

Thank you for your attention!