

# Positron sources for CEBAF

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**Idaho State University / Jefferson Lab / INFN Ferrara**



**CLAS12 European Workshop  
Genoa, Italy  
February 26, 2009**

**Working group studying options for positrons at CEBAF:**

- **A. Freyberger, J. Grames, R. Kazimi (Jefferson Lab)**
- **J. Dumas, E. Voutier (LPSC Grenoble)**
- **S. Golge, C. Hyde (Old Dominion U.)**
- **W. J. Kossler (College of William and Mary)**
- **T. Forest, G. Stancari (Idaho State U.)**

# Scientific motivation

**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

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

**BH process well understood => clean determination of DVCS amplitude**

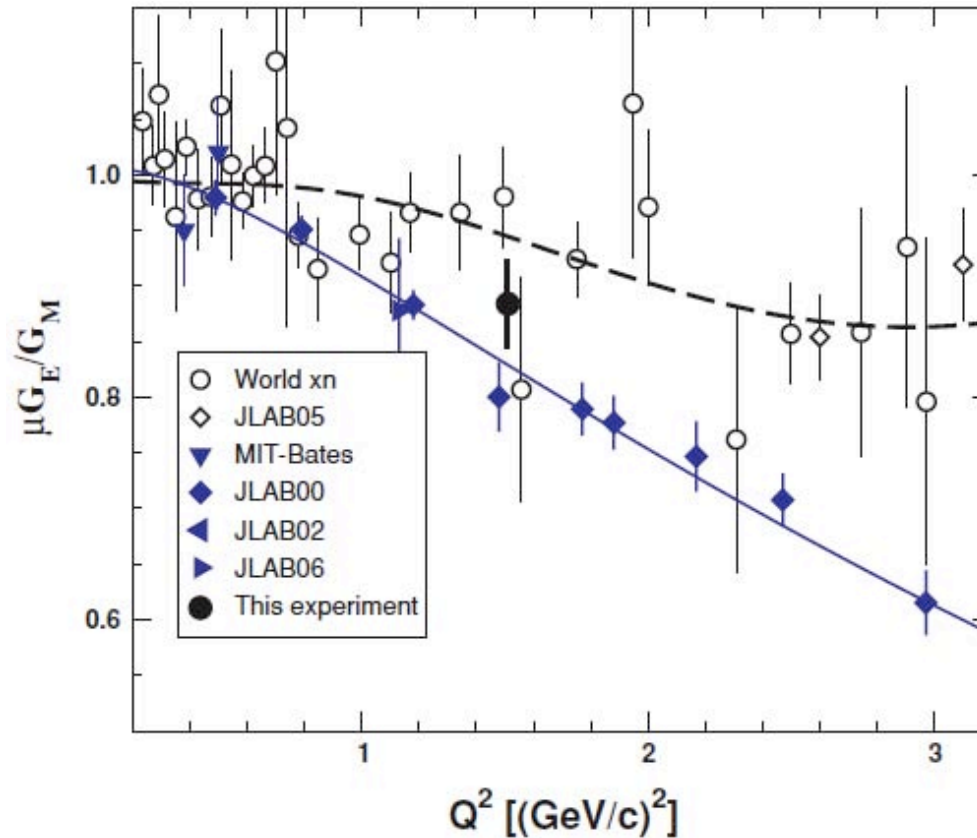
## Beam helicity asymmetry related to imaginary part of DVCS amplitude

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

**=> 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)

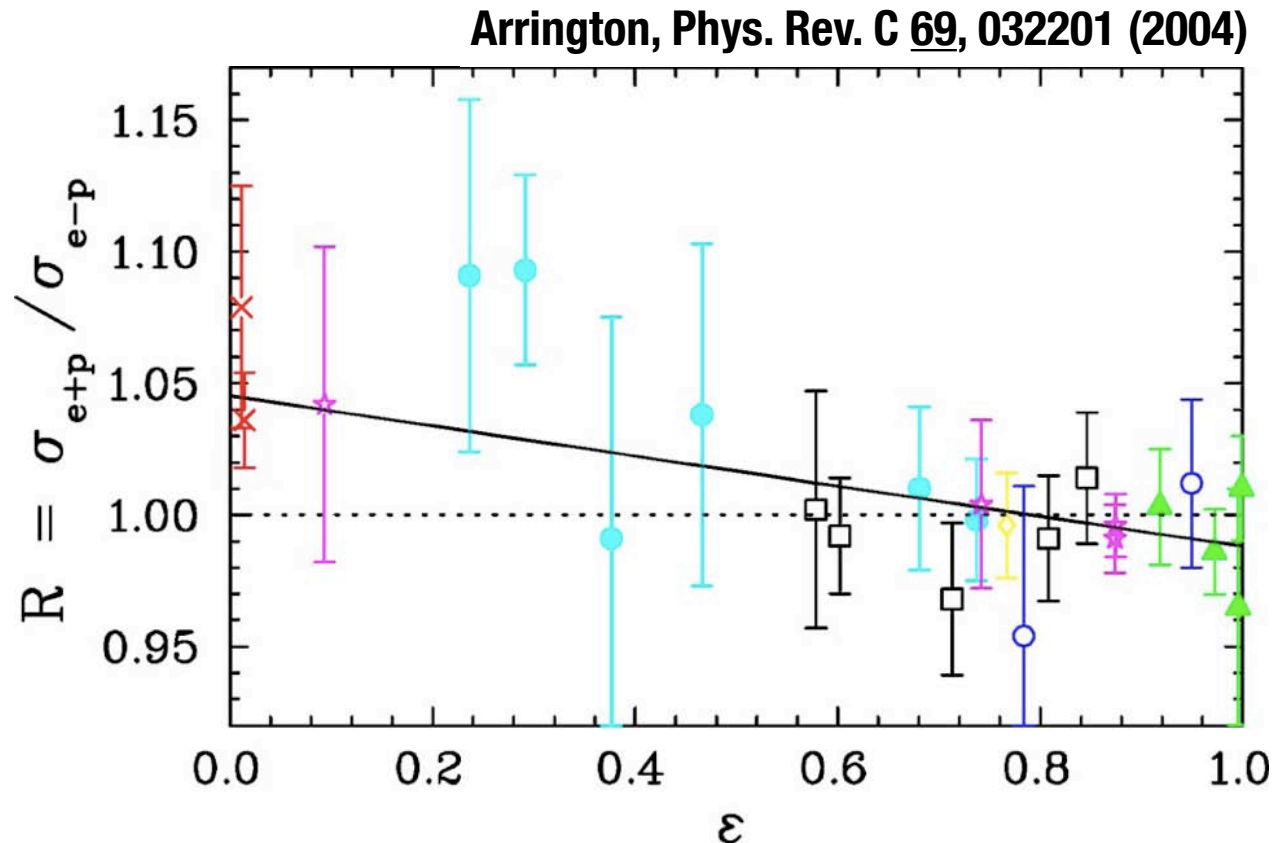


**Discrepancy between Rosenbluth separation and polarization transfer measurements probably due to two-photon processes**

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



**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](http://web.mit.edu/olympus))

# Positron production and collection



**Positron sources:**

- $\beta^+$  **radioactive decay**  
eg  $^{22}\text{Na}$ , 2.6 y half life
- pair production**  $\Leftarrow$

**More common for accelerators:**

- higher phase-space density
- controllable time structure

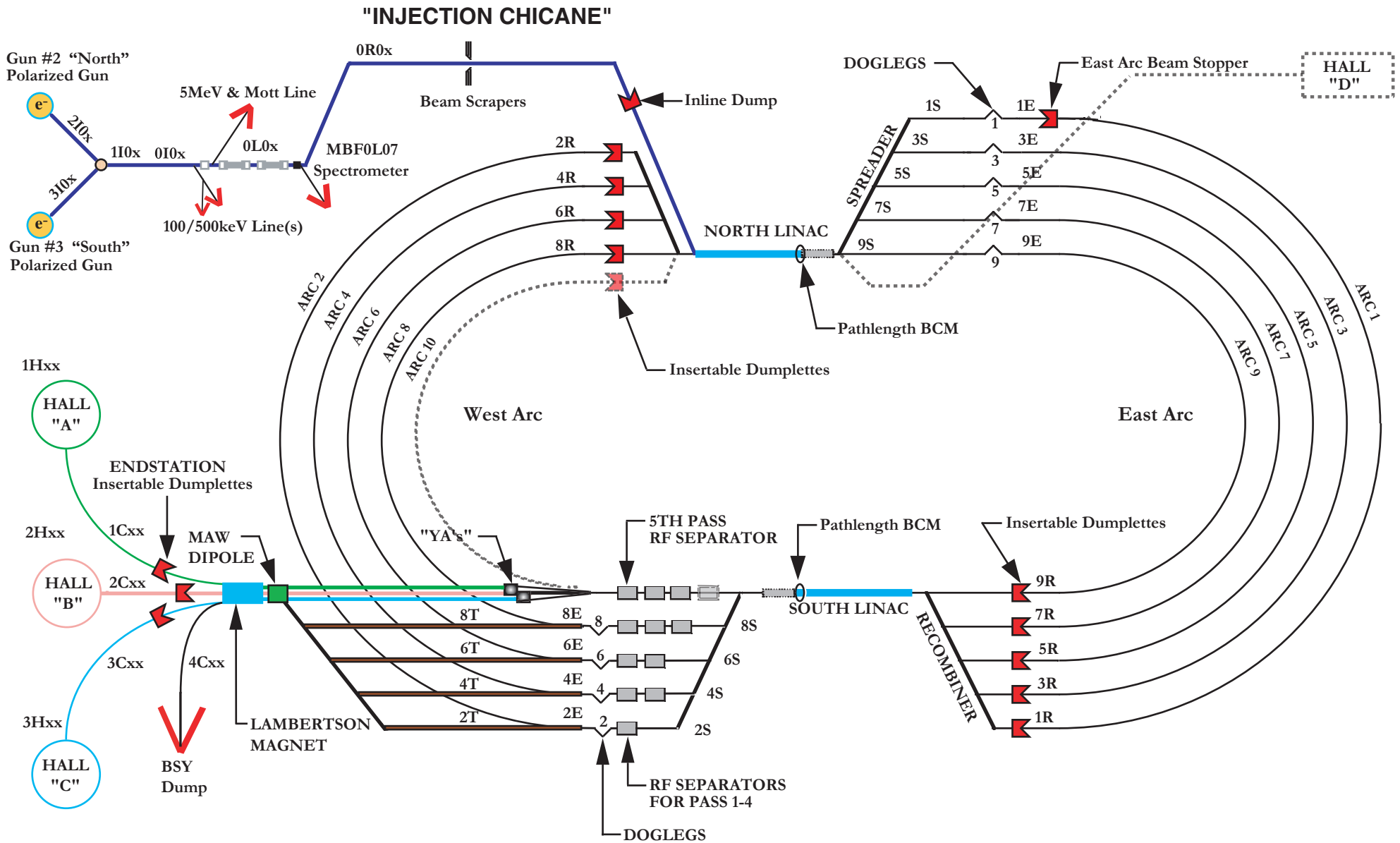
**“Conventional” sources (SLAC, KEK) and ILC designs**

- exploit **multi-GeV** primary electron beams
- are **pulsed**

### **Positron source for CEBAF?**

- useful for JLab physics (Hall B at least)
- minimal impact on 12-GeV upgrade
- compact, low-cost

# CEBAF BEAMLINE



G. Johnston  
 22 September 2008  
 File: TBD

## Concept of “low energy” 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  $\mu\text{m}$  (geometrical) transverse
- $\pm 2\%$  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

## **Calculations and simulations** using GEANT4, G4BEAMLIN, 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**

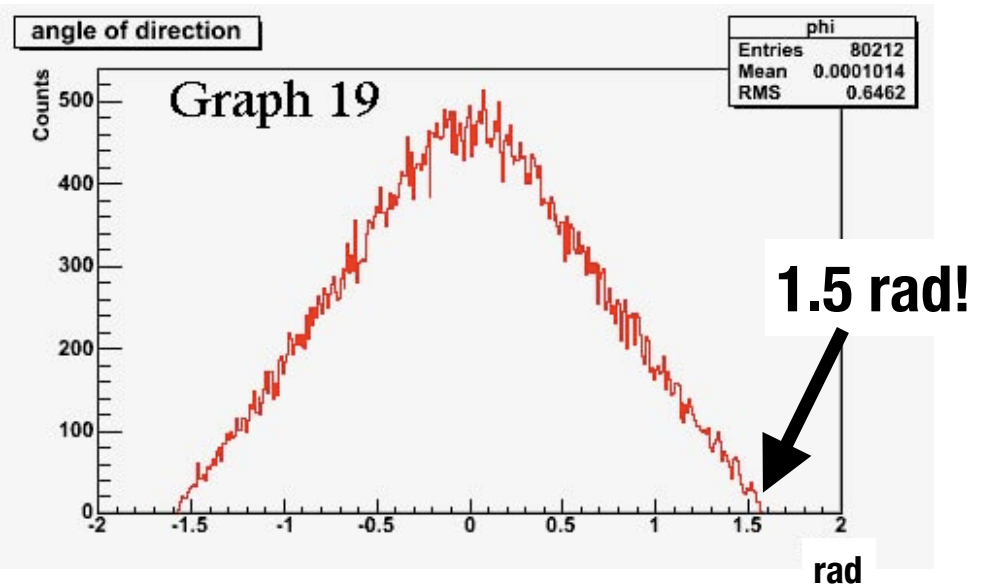
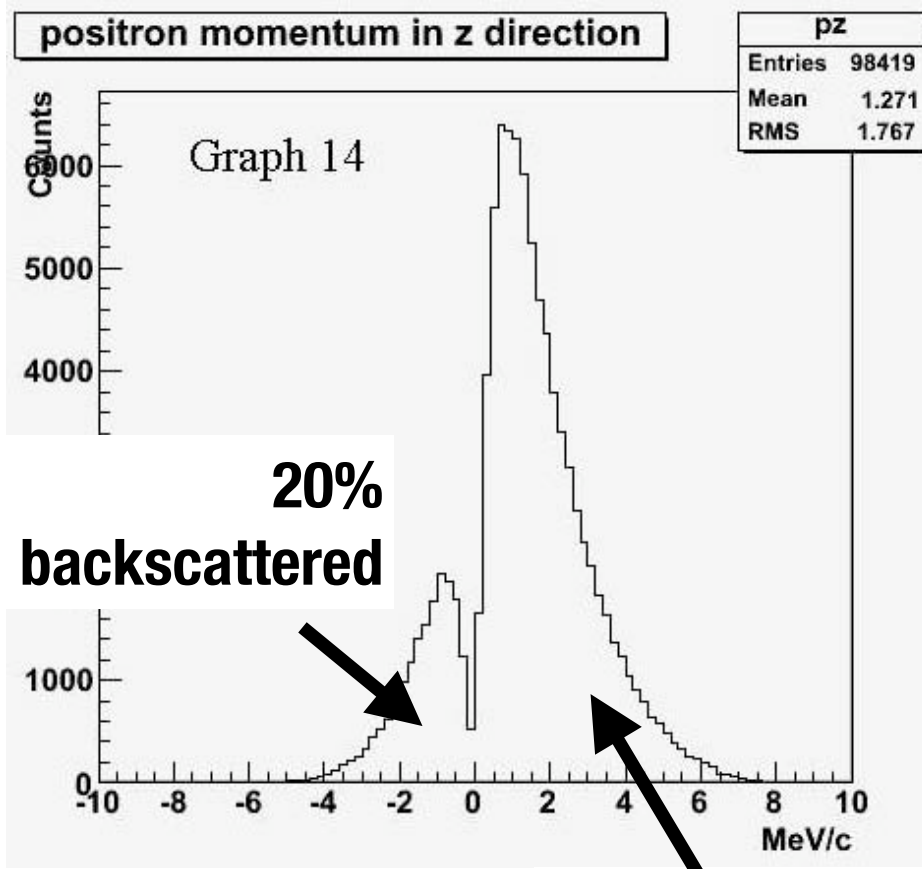
**(Golge, Dumas)**

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

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

# Positrons emerging from radiator target

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



**Large divergence**

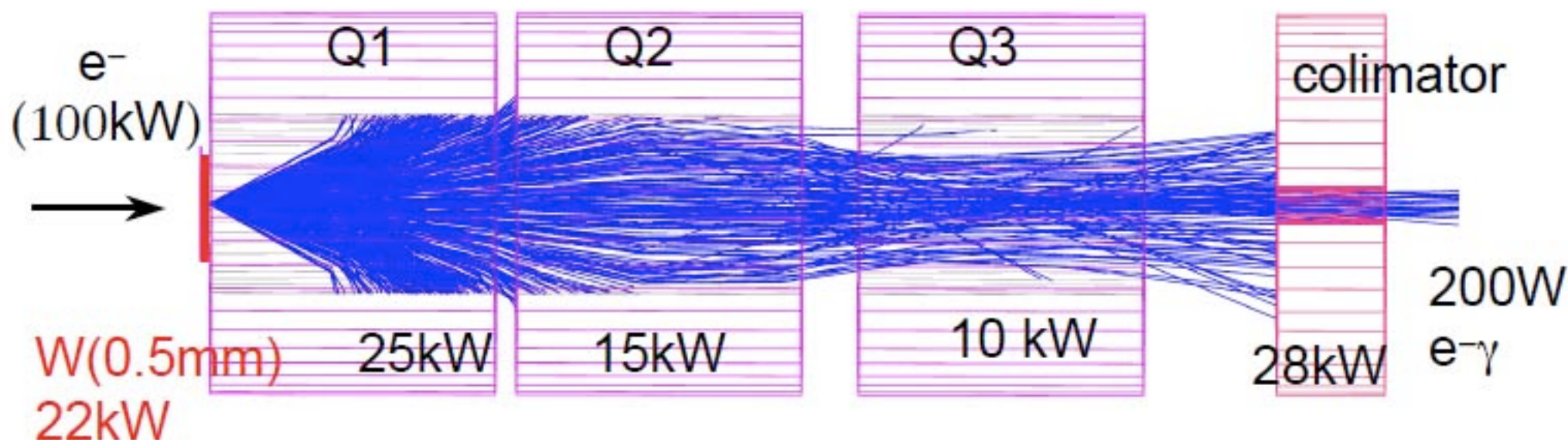
**Total forward production:  
 $8E-4 e^+/e^-$**

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

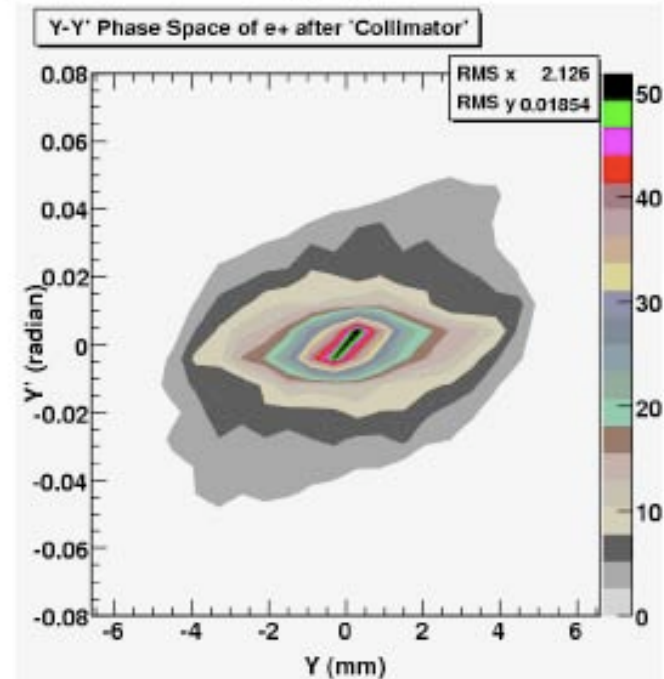
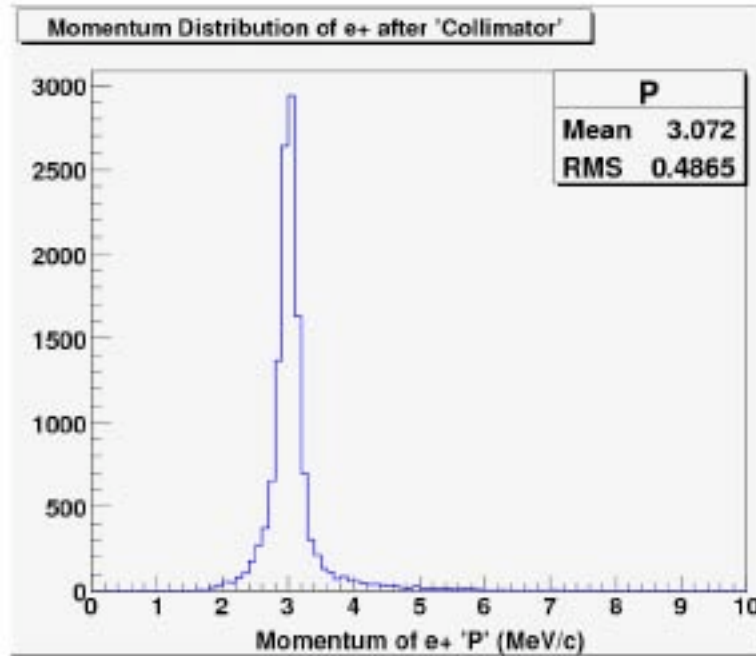
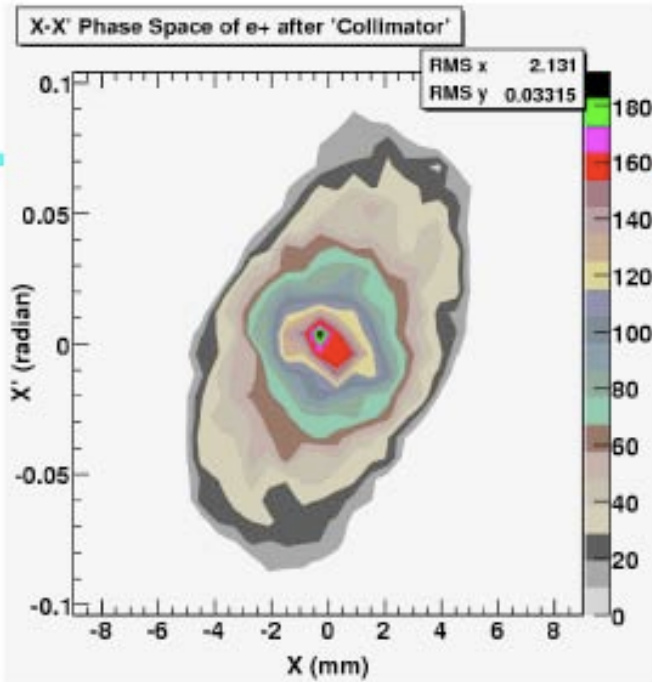
Sarma, J. Phys. D 36, 1896 (2003)



- water-cooled rotating tungsten wheel?
- liquid metal target?

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

# Positrons after collimator



**Yield after collimator:  
20 nA e<sup>+</sup> (2E-6 e<sup>+</sup>/e<sup>-</sup>) at 3 MeV/c**

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

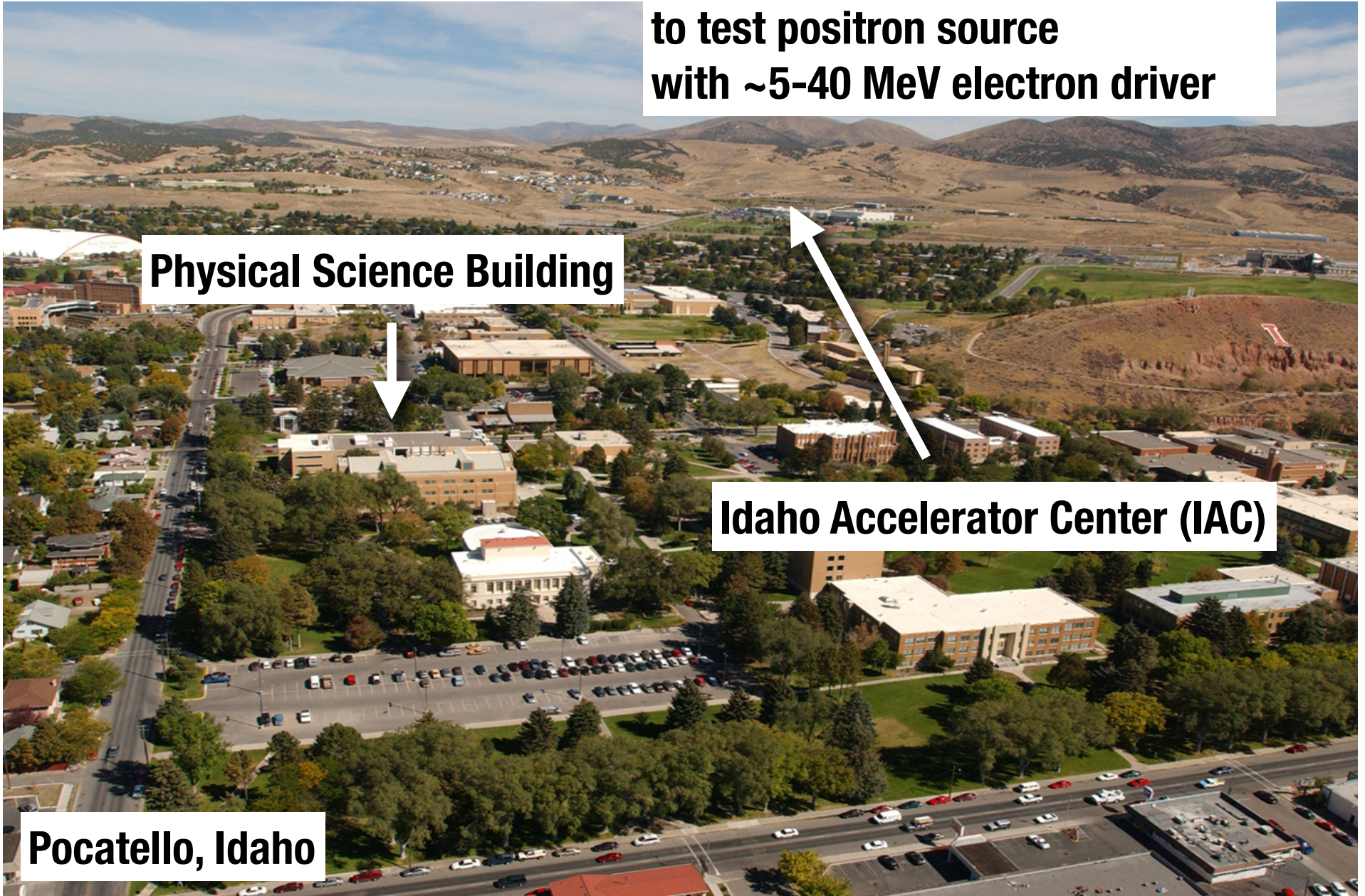


**Facilities at Idaho State University  
to test positron source  
with ~5-40 MeV electron driver**

**Physical Science Building**

**Idaho Accelerator Center (IAC)**

**Pocatello, Idaho**





# Idaho Accelerator Center

Physical Science Building

IAC Main Campus:  
Accelerator Lab #1  
Accelerator Lab #2  
ISIS Lab



IAC Airport Facility

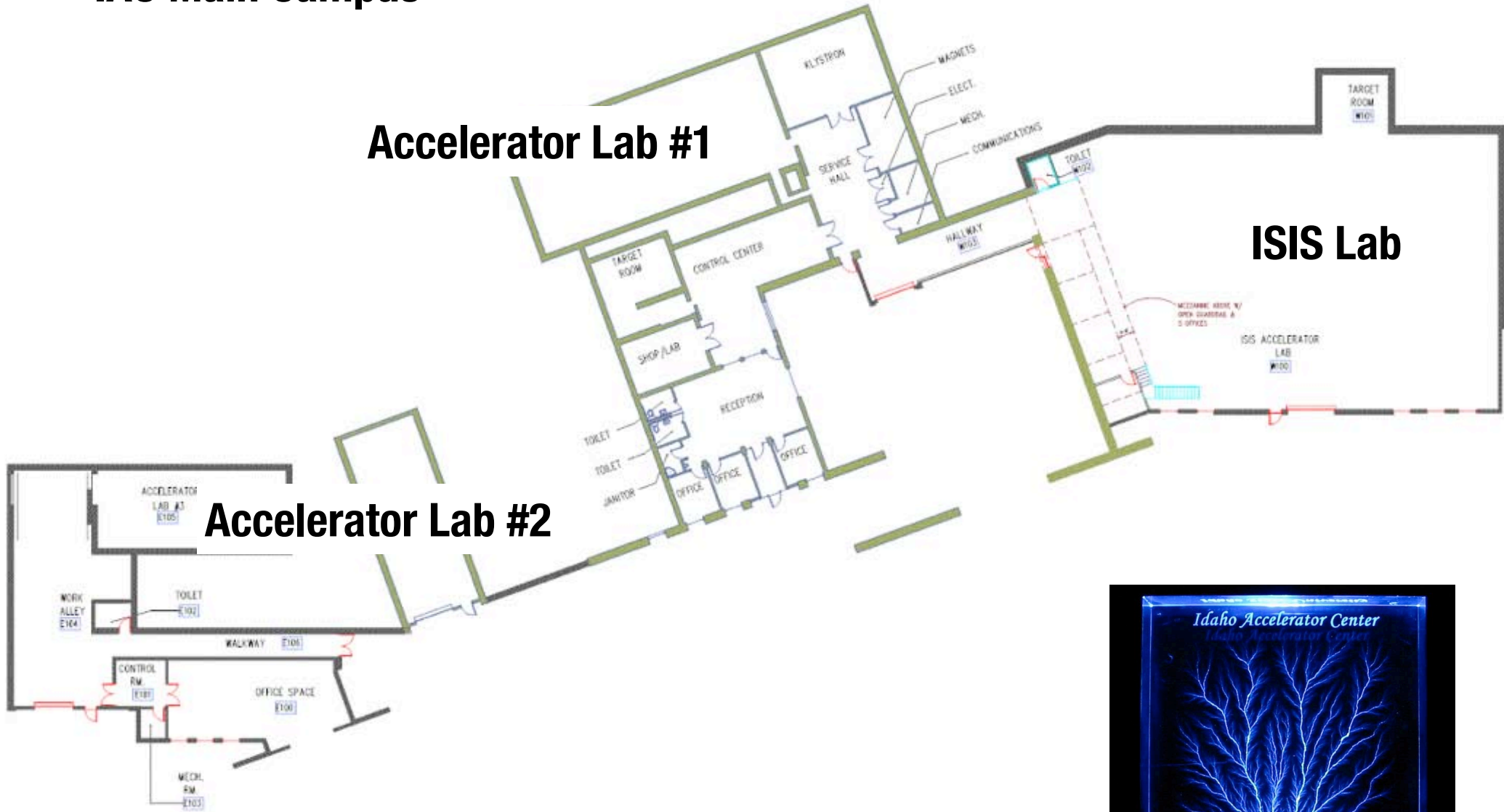
<http://iac.isu.edu>

# IAC Main Campus

## Accelerator Lab #1

## Accelerator Lab #2

## ISIS Lab





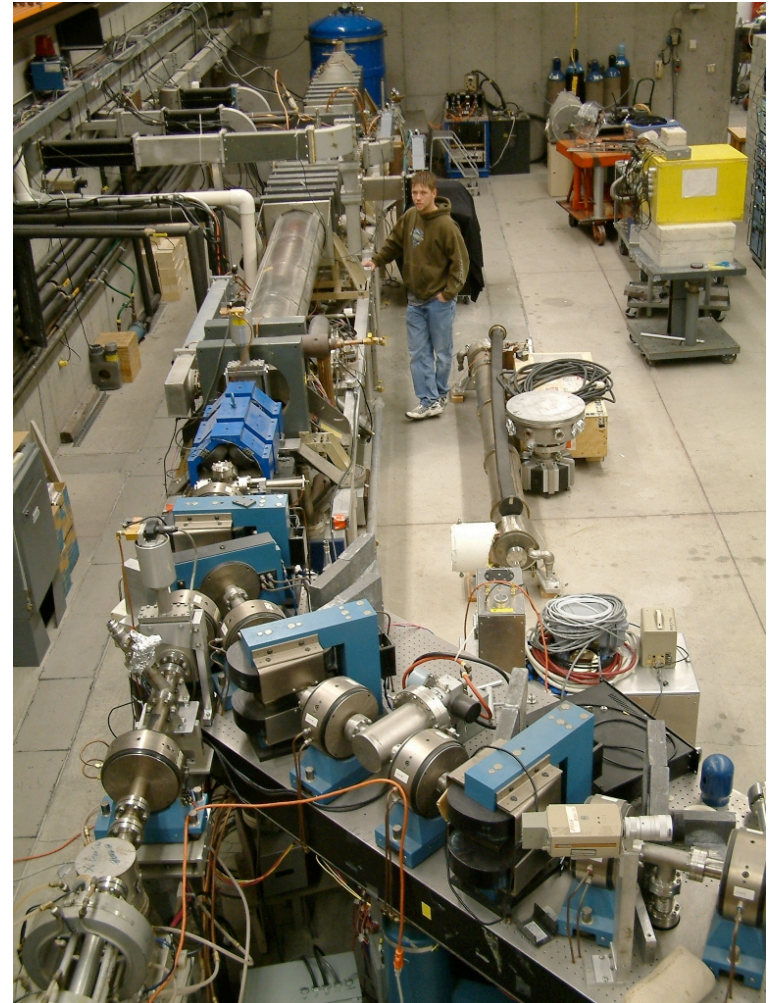
# IAC Main Campus: Accelerator Lab #1

## 44-MeV Short Pulsed Linac

- 1.3 GHz L-band traveling-wave linac
- 50 ps to 4  $\mu$ s pulse width
- 120 Hz rep rate
- 5 nC/pulse (50 ps width)
- 2  $\mu$ C/pulse (4  $\mu$ s width)
- 4 MeV - 44 MeV energy range
- 0.5% - 4% energy resolution

## Lab workhorse:

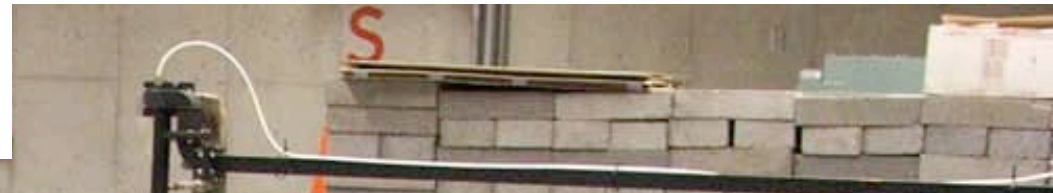
- neutron time-of-flight spectrometry
- laser Compton scattering
- ...



# IAC Main Campus: Accelerator Lab #1

## 25-MeV Linac

- 2.8 GHz S-band standing-wave linac
- 0.5  $\mu$ 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



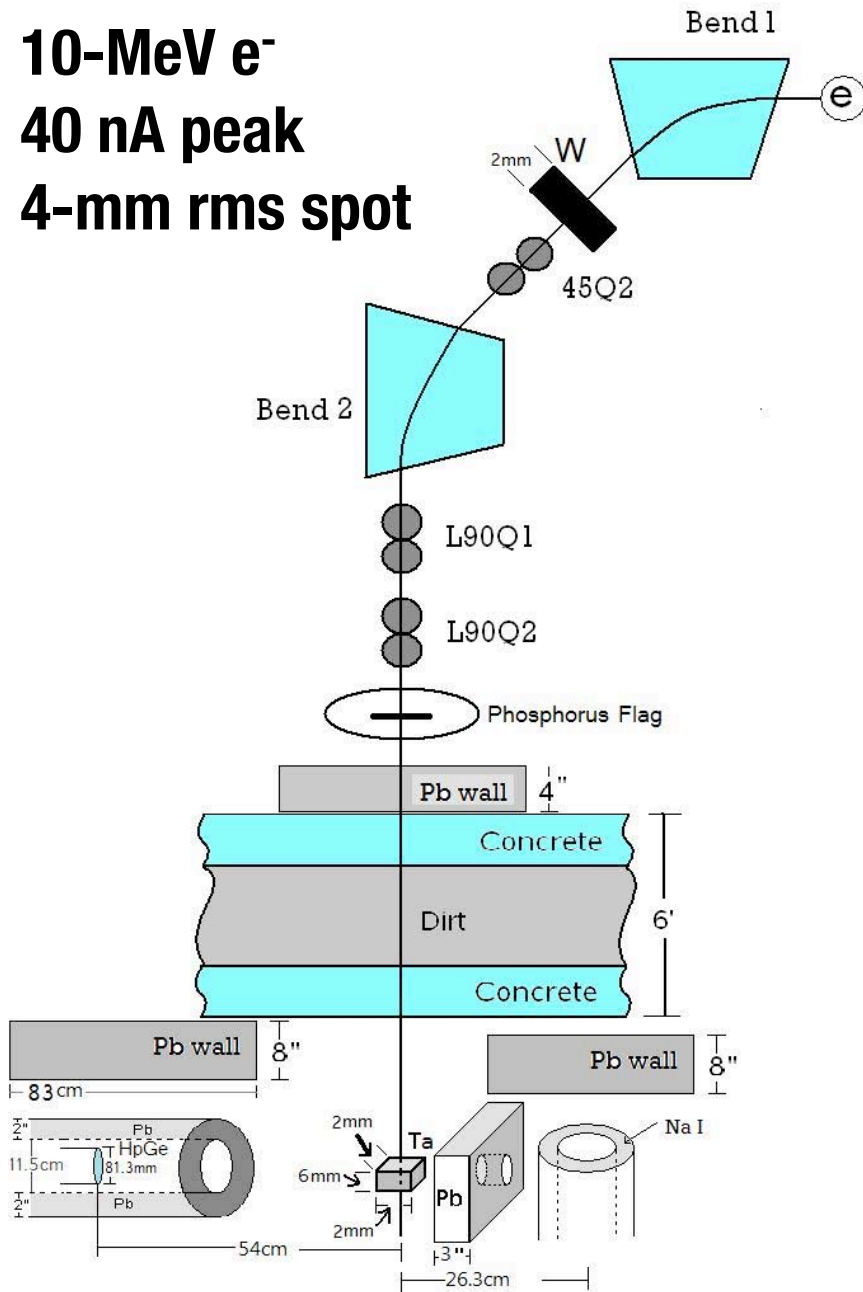
## Versatile machine:

- delayed neutron and gamma-ray signature for material identification
- irradiation damage testing on PbF<sub>2</sub> crystals for JLab Hall-A DVCS calorimeter
- wire detector efficiency measurements for CLAS12

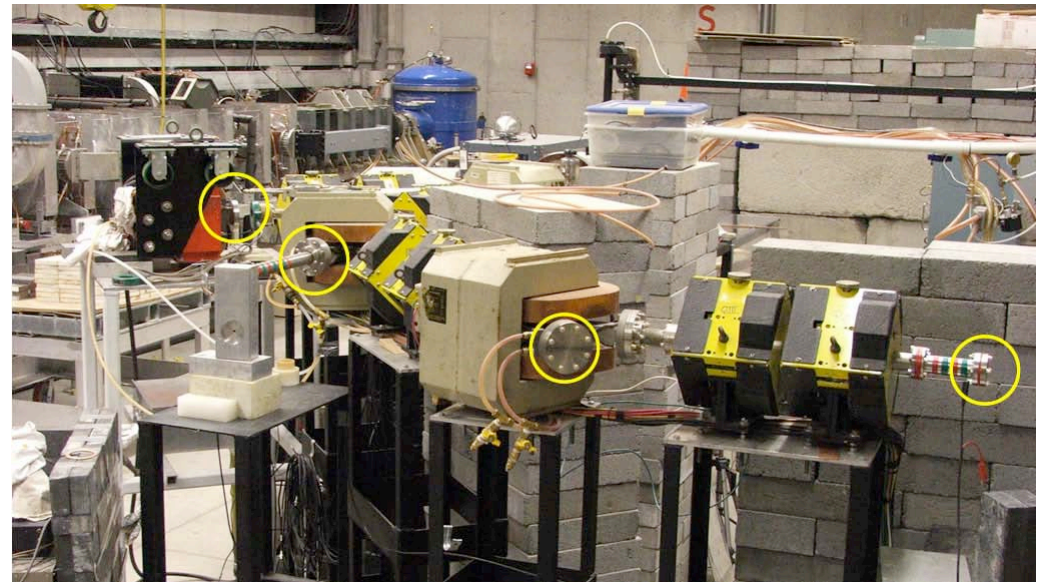




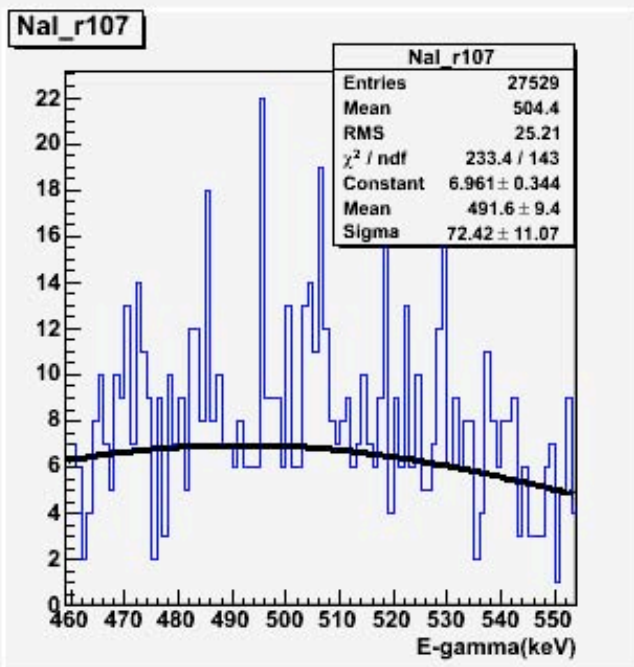
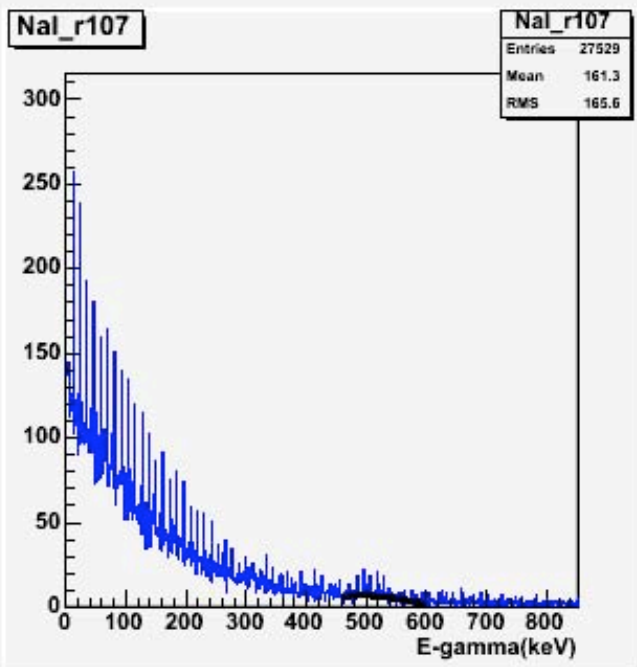
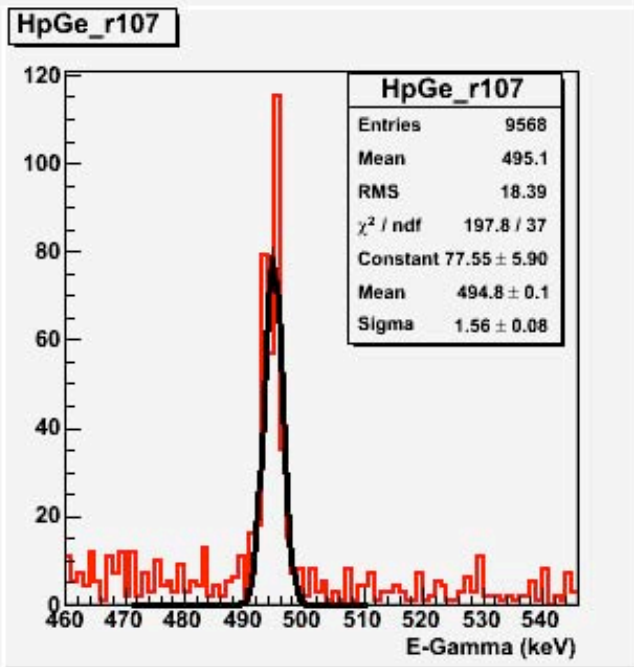
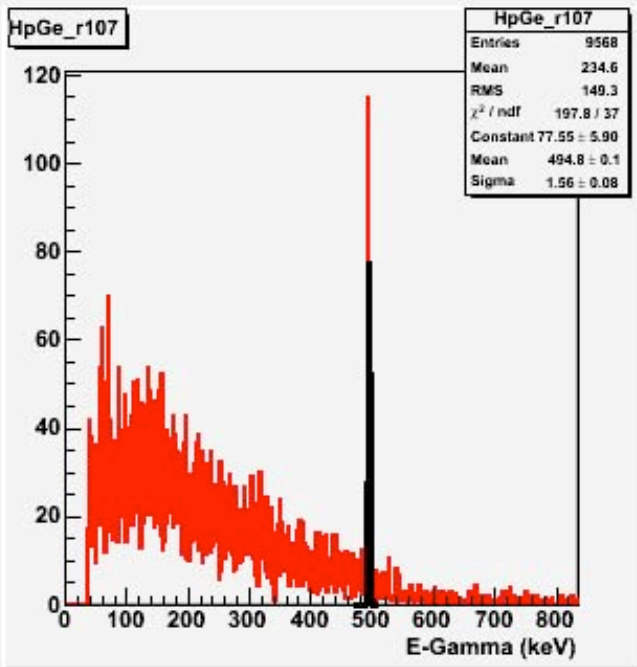
10-MeV e<sup>-</sup>  
 40 nA peak  
 4-mm rms spot



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



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



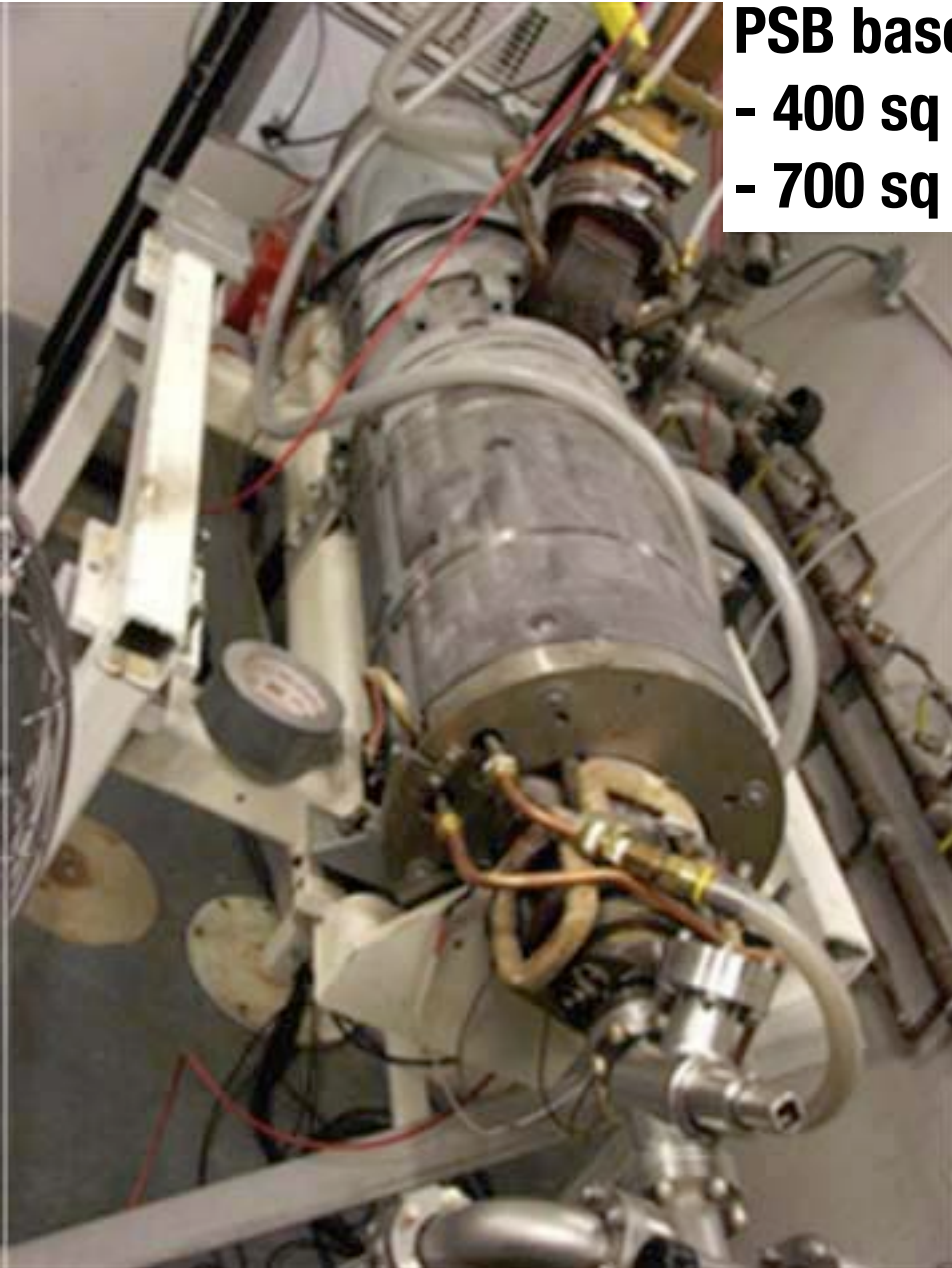
**Positron signal observed**

**Need to improve:**

- beam control
- beam optics
- diagnostics
- photon background

**More permanent setup desirable**

## Physical Science Building: HRRL Lab



### PSB basement:

- 400 sq ft accelerator hall
- 700 sq ft shielded experimental area

### High Repetition Rate Linac (HRRL)

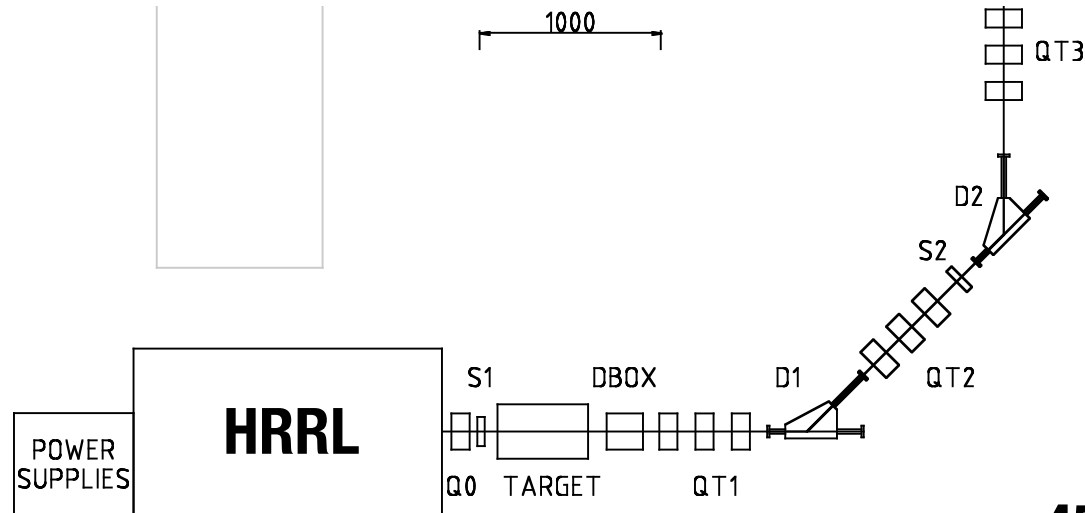
- 2.8 GHz S-band standing-wave linac
  - 70 ns pulse width
  - 1.2 kHz rep rate
  - 8.4 nC/pulse
  - 3 MeV - 16 MeV energy range
  - 8% energy resolution
- 
- role of  $\gamma$  polarization in photofission
  - calibration of CLAS12 wire chambers
  - tests of positron production for CEBAF?



# HRRL Lab at ISU Physical Science Building to test prototype positron sources?

EXPERIMENTAL AREA

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



45°, “Kiwi” dipoles

19 T/m, 1” quads

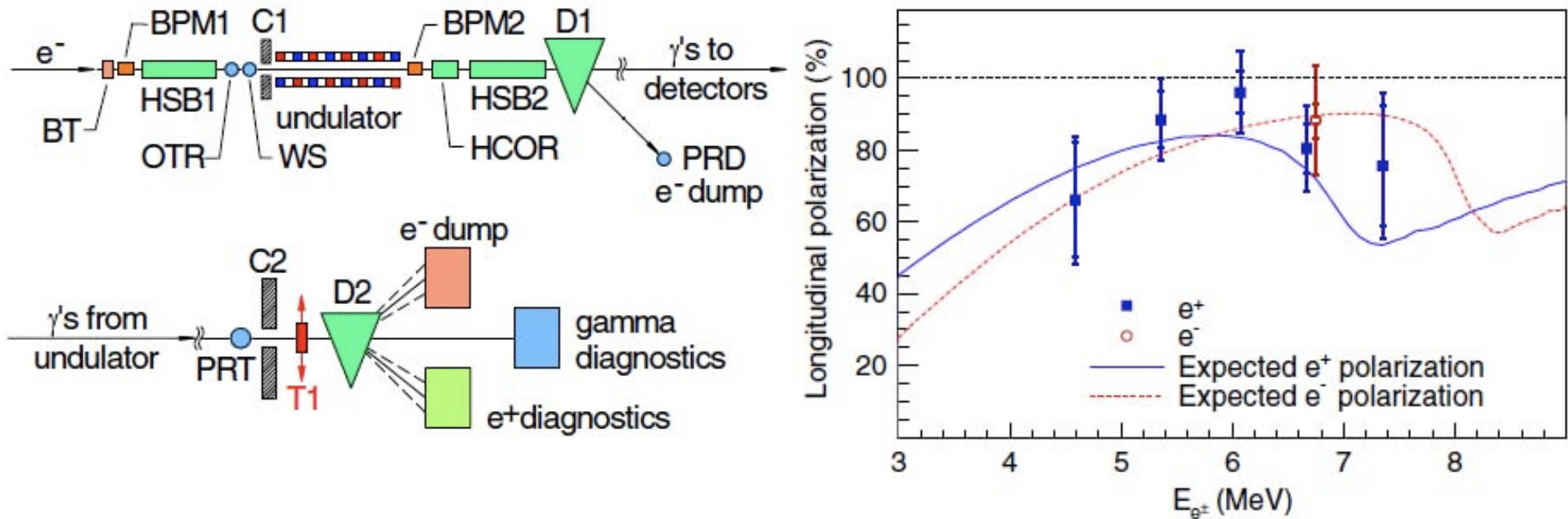




# Polarized positrons

# Production of polarized positrons recently demonstrated by SLAC-E166

47-GeV unpolarized electrons in helical undulator produce 8-MeV circularly polarized photons



Photons are converted in 0.7-mm tungsten target to 6-MeV positrons with 80% polarization

Yield is  $\sim 10^{-5} e^+ / e^-$

Alexander et al., PRL 100, 210801 (2008)

## **New concept** for JLab polarized positron source

**Existing electron source:**

- **strained superlattice GaAs/GaAsP photocathode**
- **100-keV DC electron gun**
- **1497-MHz rf cavity**

**produces**

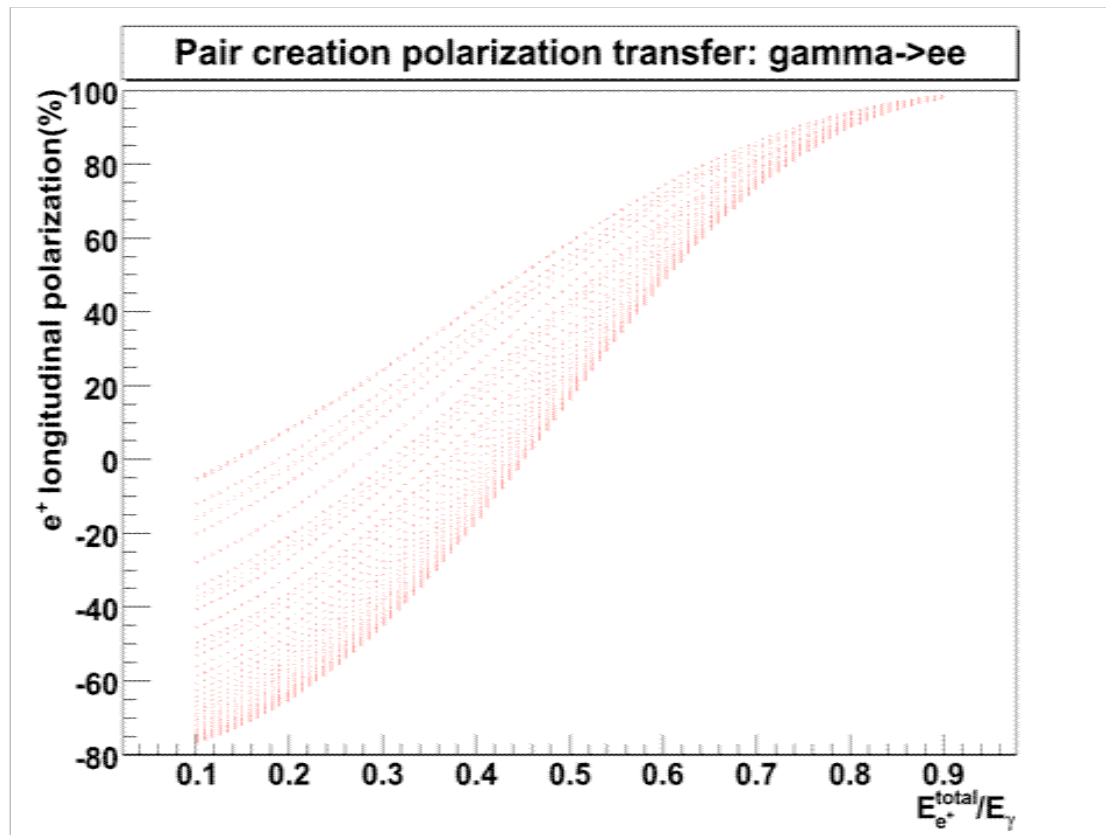
- **5-MeV, 1-mA, high-brightness ( $\epsilon_{n,rms} < 1 \mu\text{m}$ ,  $\Delta E/E < 2 \times 10^{-5}$ ), highly-polarized (>80%) electron driver beam**

**Polarization transfer** to bremsstrahlung photon and pair-produced positrons (and electrons) in 0.25-mm tungsten target

**Positron polarization depends on driver beam energy and polarization**

## GEANT4 simulations

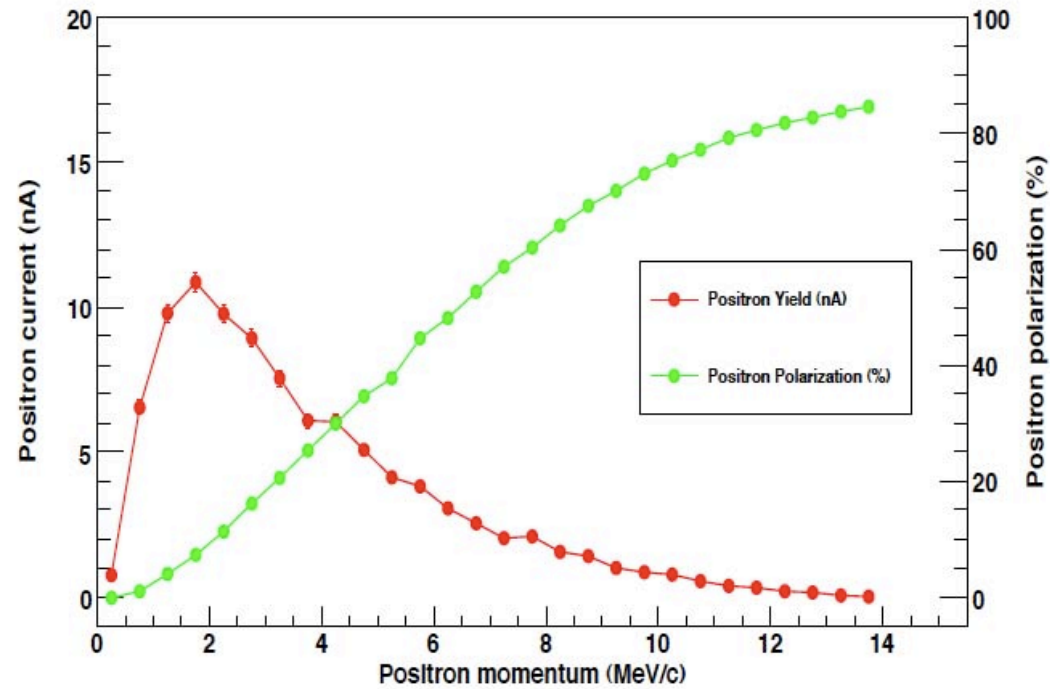
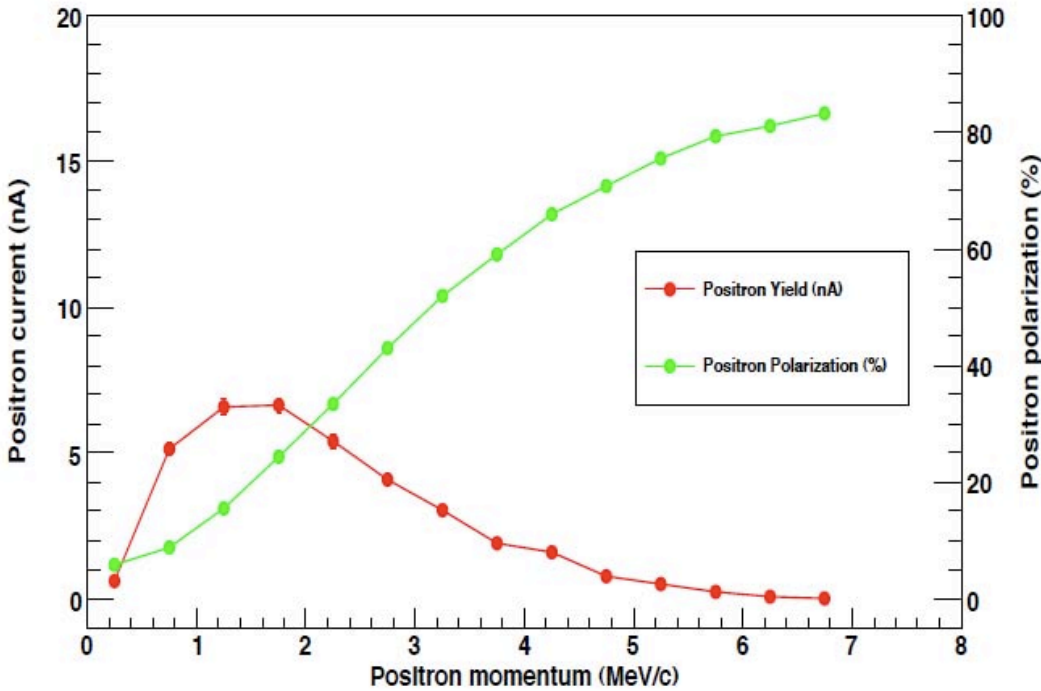
**Polarization transfer in bremsstrahlung and pair-production implemented in GEANT4 based upon Olsen and Maximon, Phys. Rev. 114, 887 (1959)**



**(Screening corrections known only in ultra-relativistic, small-angle regime. Implementation at low energy in progress.)**

Electrons: 8 MeV/c, 1 mA | W target: 100  $\mu\text{m}$

Electrons: 15.5 MeV/c, 1 mA | W target: 100  $\mu\text{m}$



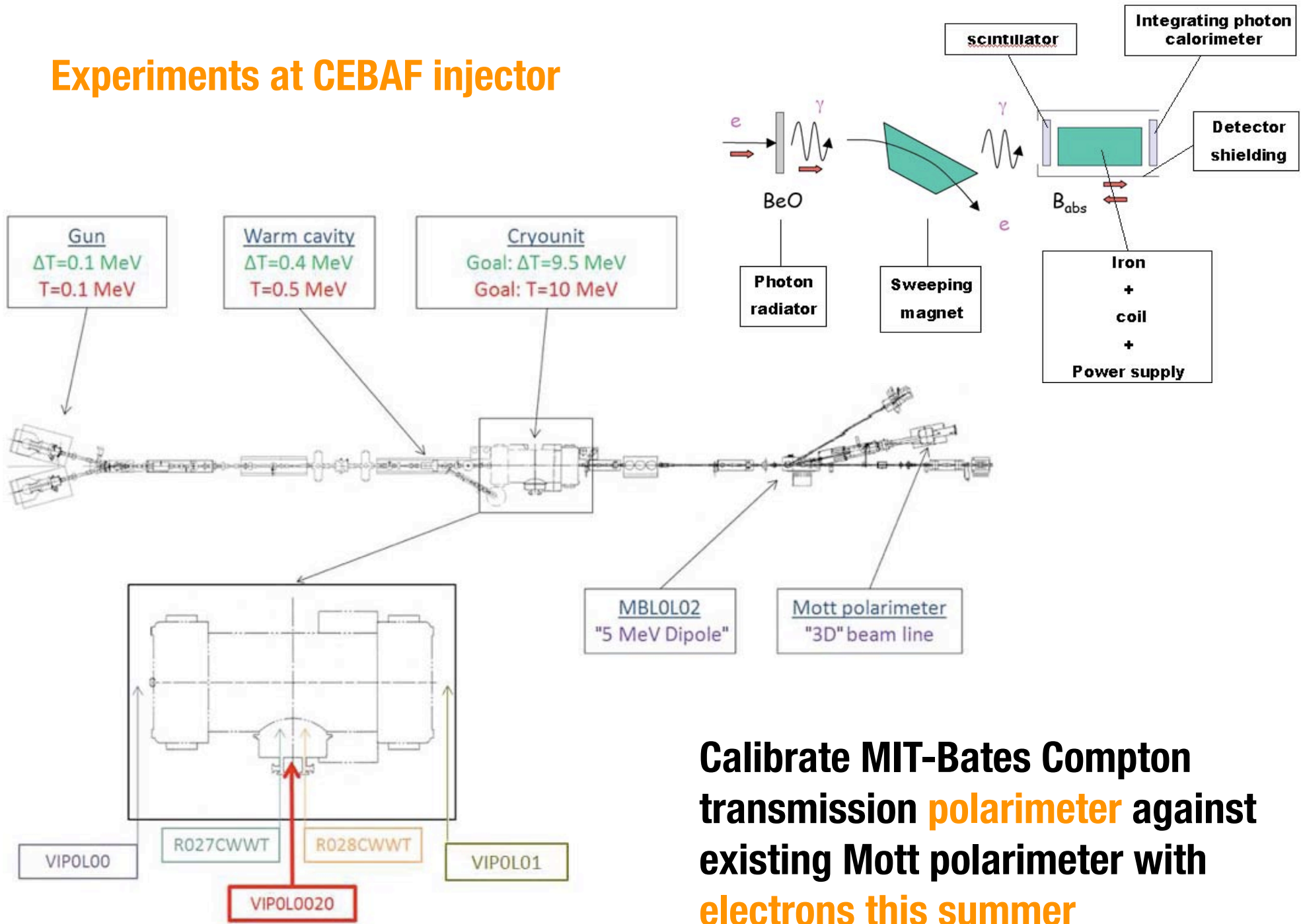
**Optimization of figure of merit: (intensity) x (polarization)<sup>2</sup> in CEBAF acceptance**

**Results are promising: ~1 nA at 40% polarization**

**Need experimental verification**

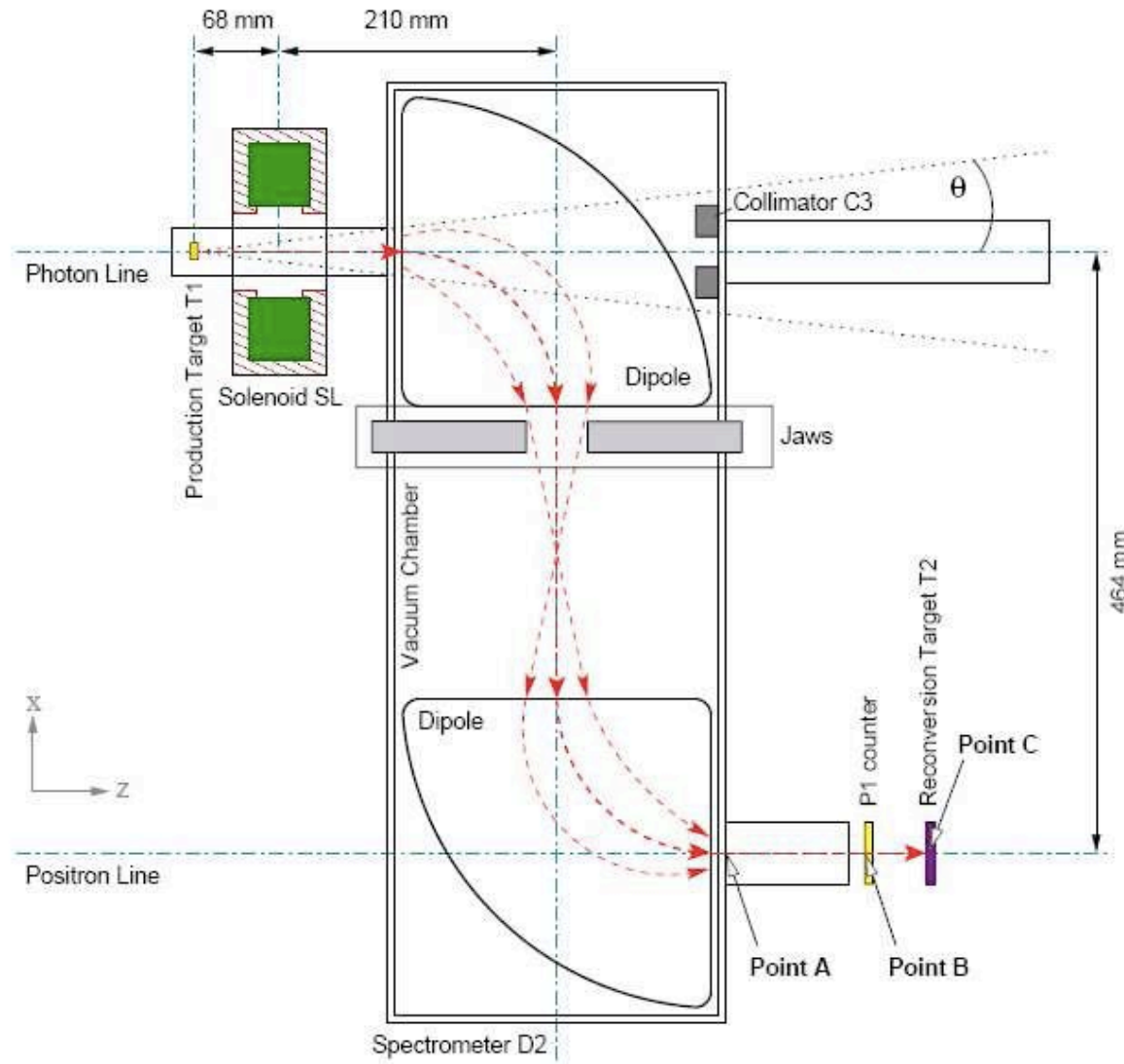
**(J. Dumas)**

# Experiments at CEBAF injector



**Calibrate MIT-Bates Compton transmission polarimeter against existing Mott polarimeter with electrons this summer**

Later, install **W foil** after first cryomodule and use **SLAC-E166 chicane/collimators** for  $e^+$  separation



# Conclusions

Working group is **studying options for positrons at CEBAF:**

- design optimization
- experimental tests

First **results are promising**

**Experiments at JLab and ISU/IAC are planned**

- to validate calculations of yields and polarizations
- to test schemes for collection optics
- to study heat deposition on target

International **Workshop on Positrons** at Jefferson Lab

March 25-27, 2009

*Thank you for your attention!*



# 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. Meitner (JLab)
- E. Voutier (LPSC, Grenoble)

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[conferences.jlab.org/JPOS09](http://conferences.jlab.org/JPOS09)

Jefferson Lab

