Photoinjector Guns at AWA

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ANL Theory Institute on
Production of Bright Electron Beams
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Advanced Accelerator R&D and Future HEP Accelerators

- AWA Group is developing technologies and studying physics related issues on:
  - Developing electron beam driven acceleration methods. Operating a unique facility to study high current electron beam generation and propagation for an efficient beam driven scheme.
  - Studying and inventing advanced accelerating structures (particularly dielectric based).
  - AWA facility is also being sought by external users (scheduled):
    - Dielectric Power Extractors for CLIC, DULY
    - Laboratory Astrophysics/UHECR detection, Hawaii/UCLA
    - High transformer ratio experiment, Euclid Concepts
    - In the works…(IIT, APS, R. Fiorito)
- Because: HEP community needs a visible path to achieve higher energy ($> \sim 5$ TeV) linear colliders.
  - New type energy source (RF, beam or laser).
  - New structure/medium to support high gradients (metal, dielectrics or plasmas)

HEP Accelerator R&D Group (AWA)

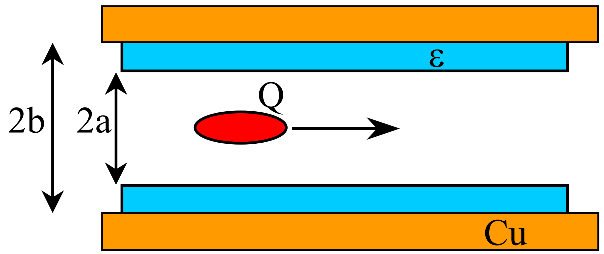
- Staff:
  W. Gai (group leader), M. Conde, R. Konecny, J. Power and Z. Yusof.

- Visiting Scientist
  Prof. W. Liu

- *Current Students:*
  C. Jing (IIT), H. Wang (IIT), G. Beztel (NIU NICADD)

- Part time/Consultants:
  J. Simpson, P. Schoessow, G. Cox

Wakefield in Dielectric Structures



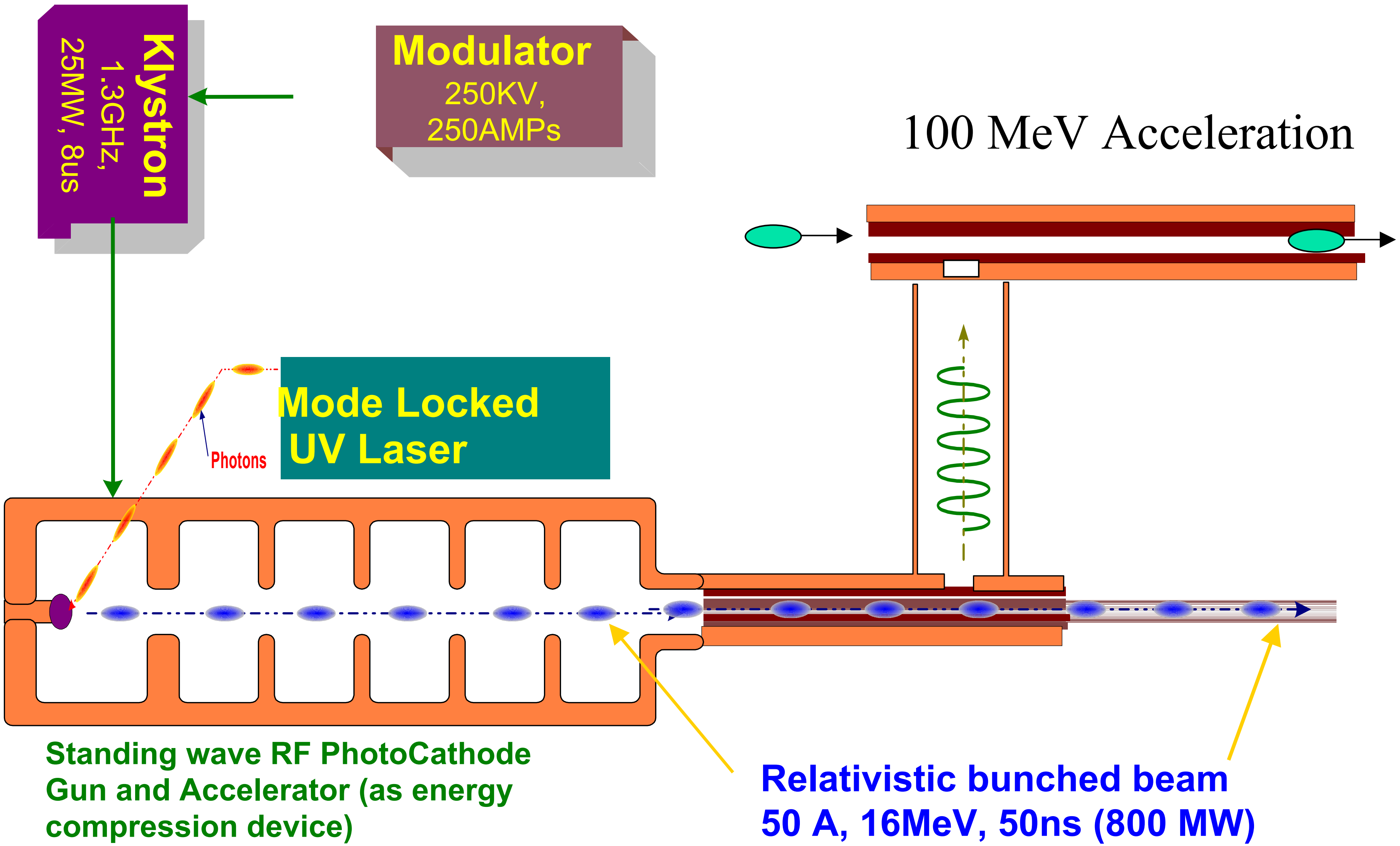
$$W_Z \approx \frac{Q}{a^{3/2}} \exp\left[-2\left(\frac{\pi\,\sigma_z}{\lambda_n}\right)^2\right]$$

$$\sigma_r = \left(\frac{\varepsilon_N}{\gamma}\beta\right)^{1/2}$$

Example:

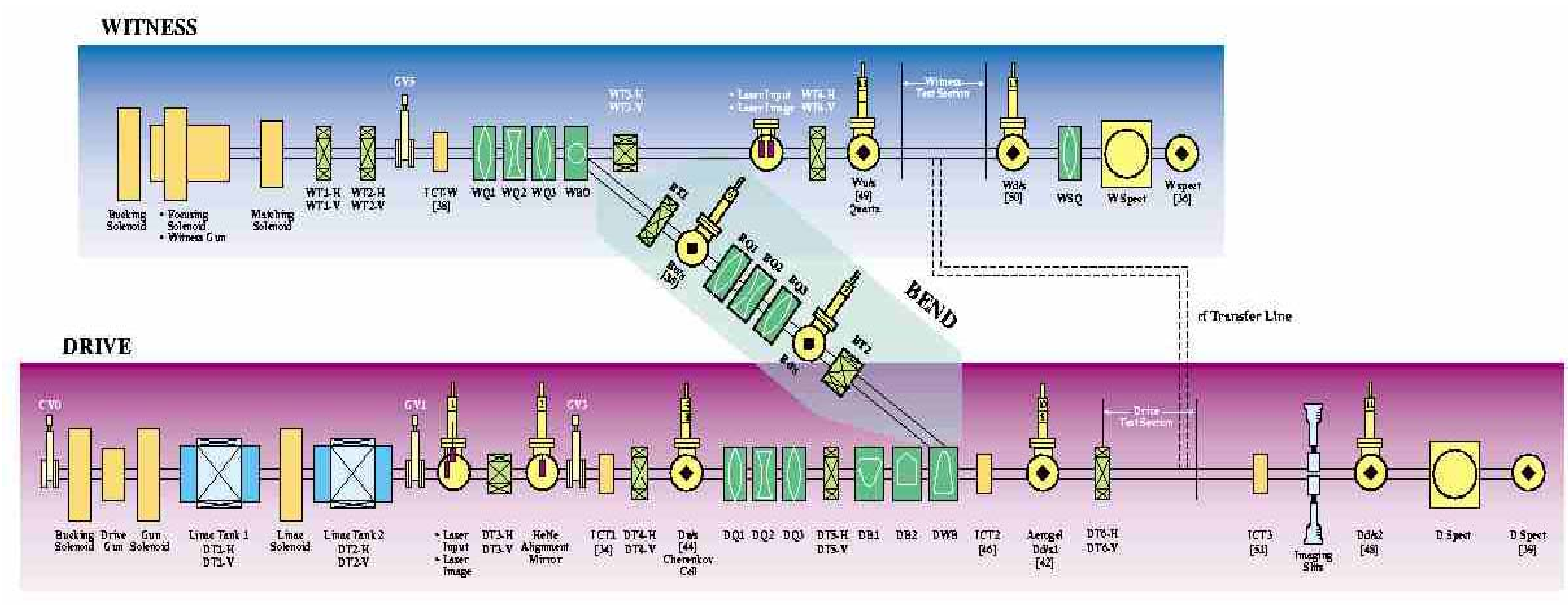
- Direct wakefield acceleration:
  - Dielectric parameters: 2a = 6 mm, 2b = 10 mm, ε = 4.6
  - Electron bunch: σ_z = 1 mm, Q = 100 nC, RF power: 400 MW, yielding 92 MV/m at 19 GHz
  - Field superposition from bunch train: four bunches of 100 nC or eight bunches of 50 nC generate over 300 MV/m
- Two beam wakefield acceleration
  - Drive beam: 64 bunches of 50 nC, each separated by one RF period, generating a 50 ns long RF pulse.
  - Stage I (23 cm long): 2a=11 mm, 2b=22 mm, ε = 4.6, 45 MV/m deceleration field, generating 500 MW (flat top).
  - Stage II (85 cm long): 2a= 6mm, 2b= 11 mm, ε = 20, 112 MV/m acceleration field, yielding a total acceleration of 95 MeV.

High power generation using a beam from RF Photo cathode gun and accelerator



Block Diagram of the Argonne Wakefield Accelerator Beamlines

4 MeV, 0.1 nC Witness Beam



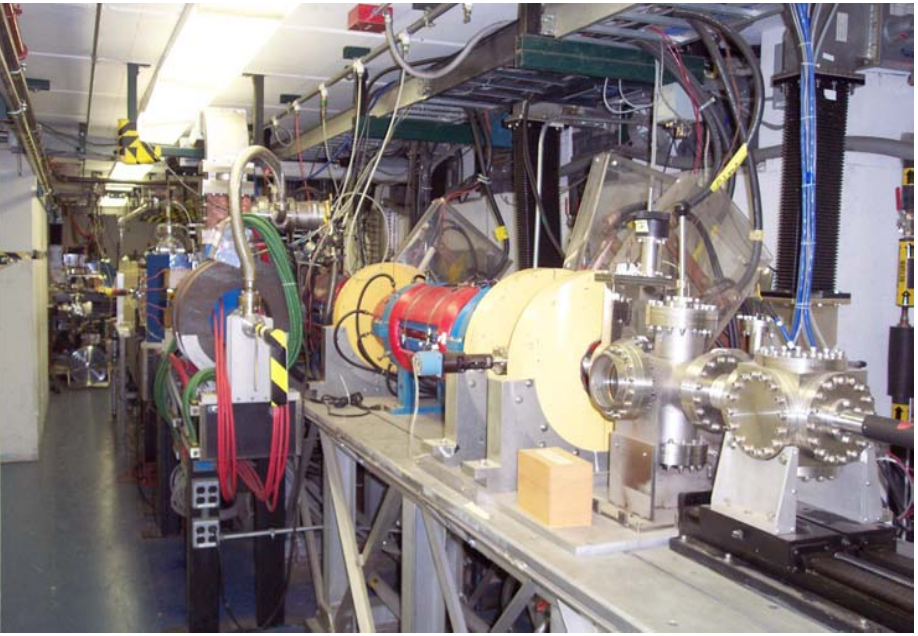
15 MeV, 20 – 100 nC Drive beam

The Upgraded Facility and Its Parameters

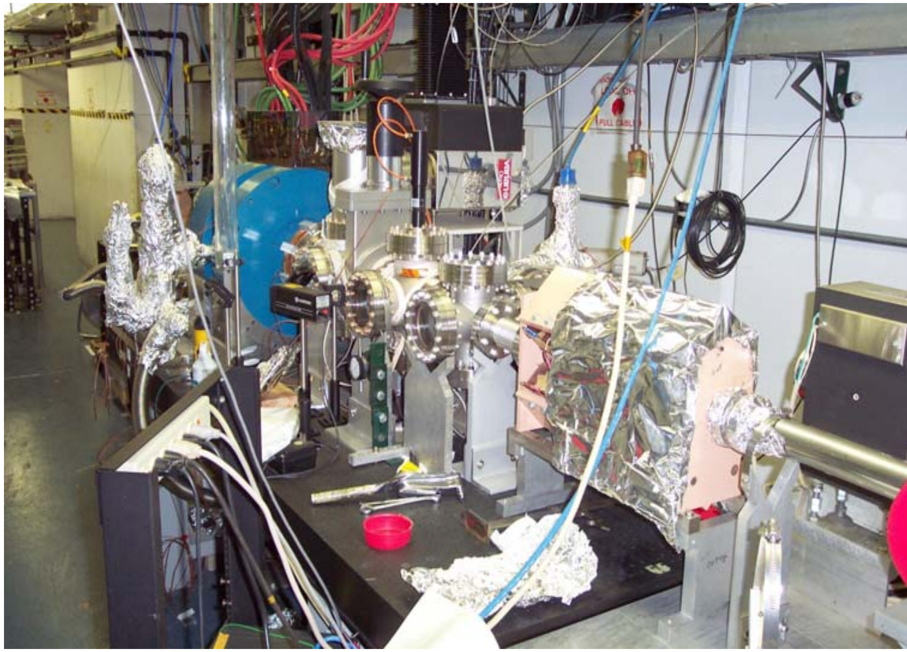
- The new gun upgrade:
  - A new 1 1/2 cell RF photocathode gun with capabilities 20 - 100 nC/pulse, 2 - 4 ps rms pulse length and 40 - 200 mm mrad rms emittance. Pulse train operation (as high as 64 pulses).
  - Q_0 = 26000 (calculated), ~21000 (measured), 13 MW yielding 80 MV/m on cathode surface. Base pressure 4×10^{-10} Torr.
  - This gun has potential to generate very high brightness beam at ~ 1 nC. Our simulation results show it can achieve < 1mm –mrad emittance @ 1 nC. Experiment to be done very soon.
- RF upgrade
  - Extended RF pulse from 4 to 5.5 μs, soon to be 7 μs.
- Laser upgrade
  - A new all solid state laser with ~ 2 mJ UV.
- Others
  - Control system, data acquisition, diagnostics and etc.
  - Laser room climate control.

The Argonne Wakefield Accelerator

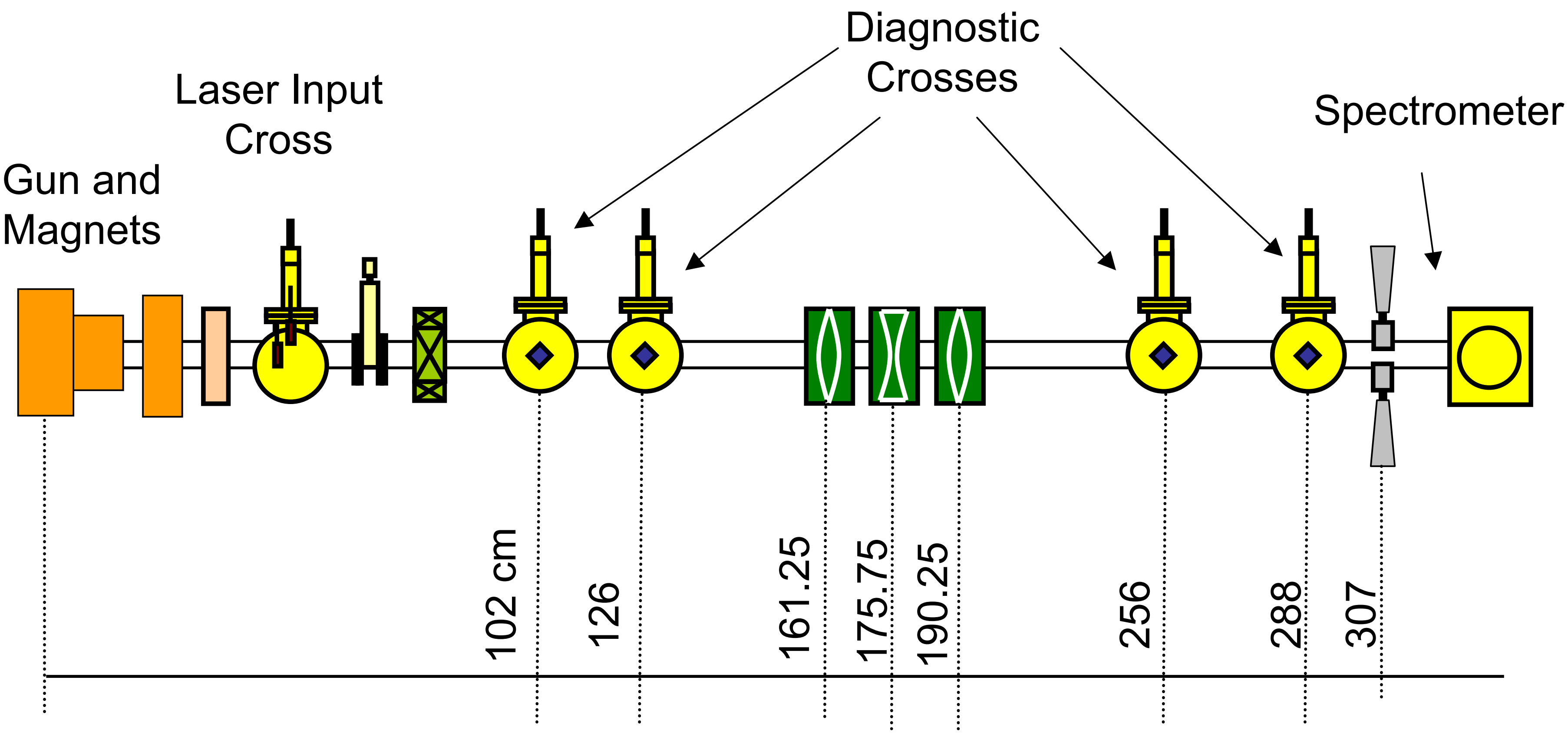
Existing AWA Facility



New AWA Gun Test Stand

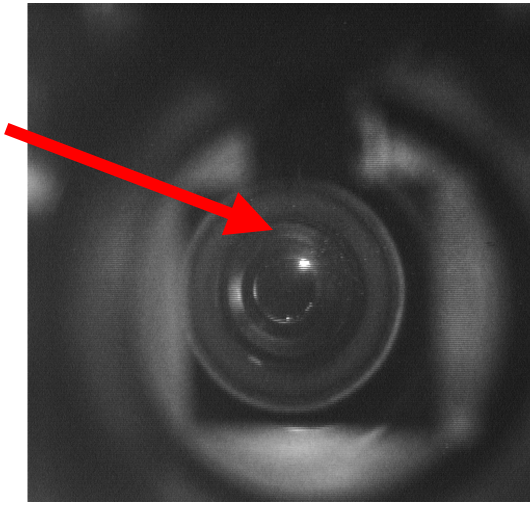


AWA Teststand Beamline

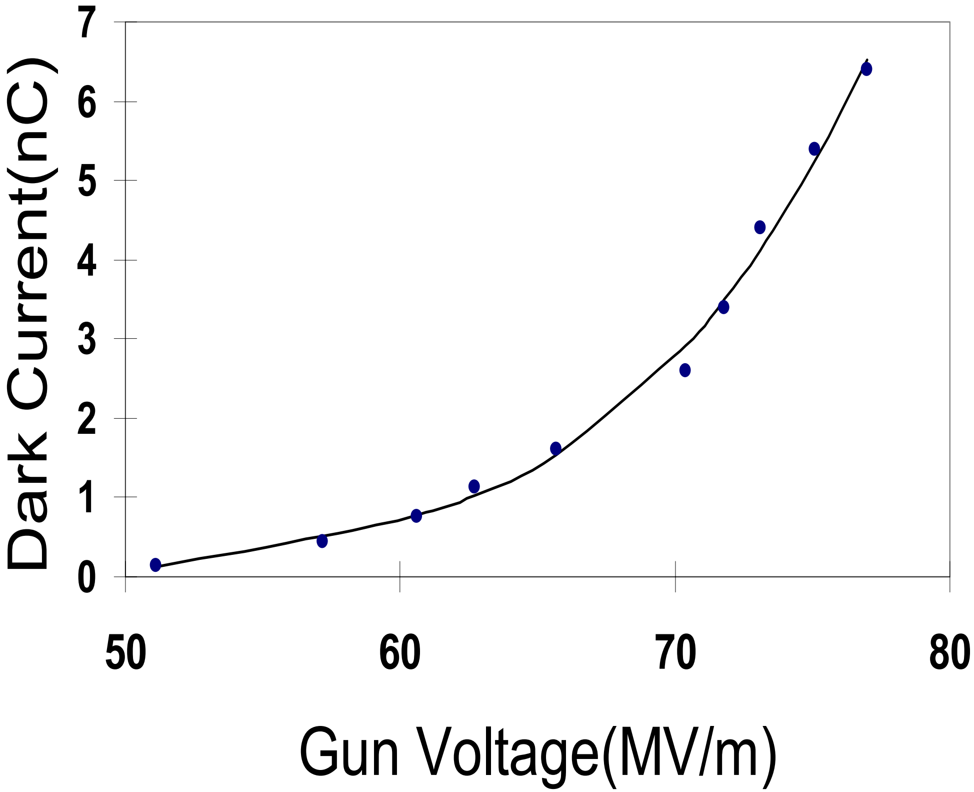


Electron Gun Conditioning and Dark Current Measurement Data

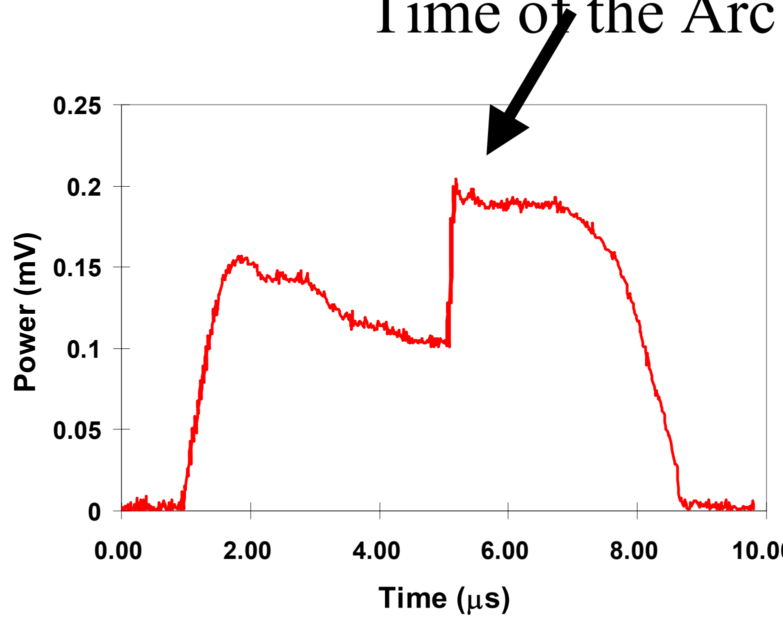
Arcing spot



Measured Dark Current Per Pulse

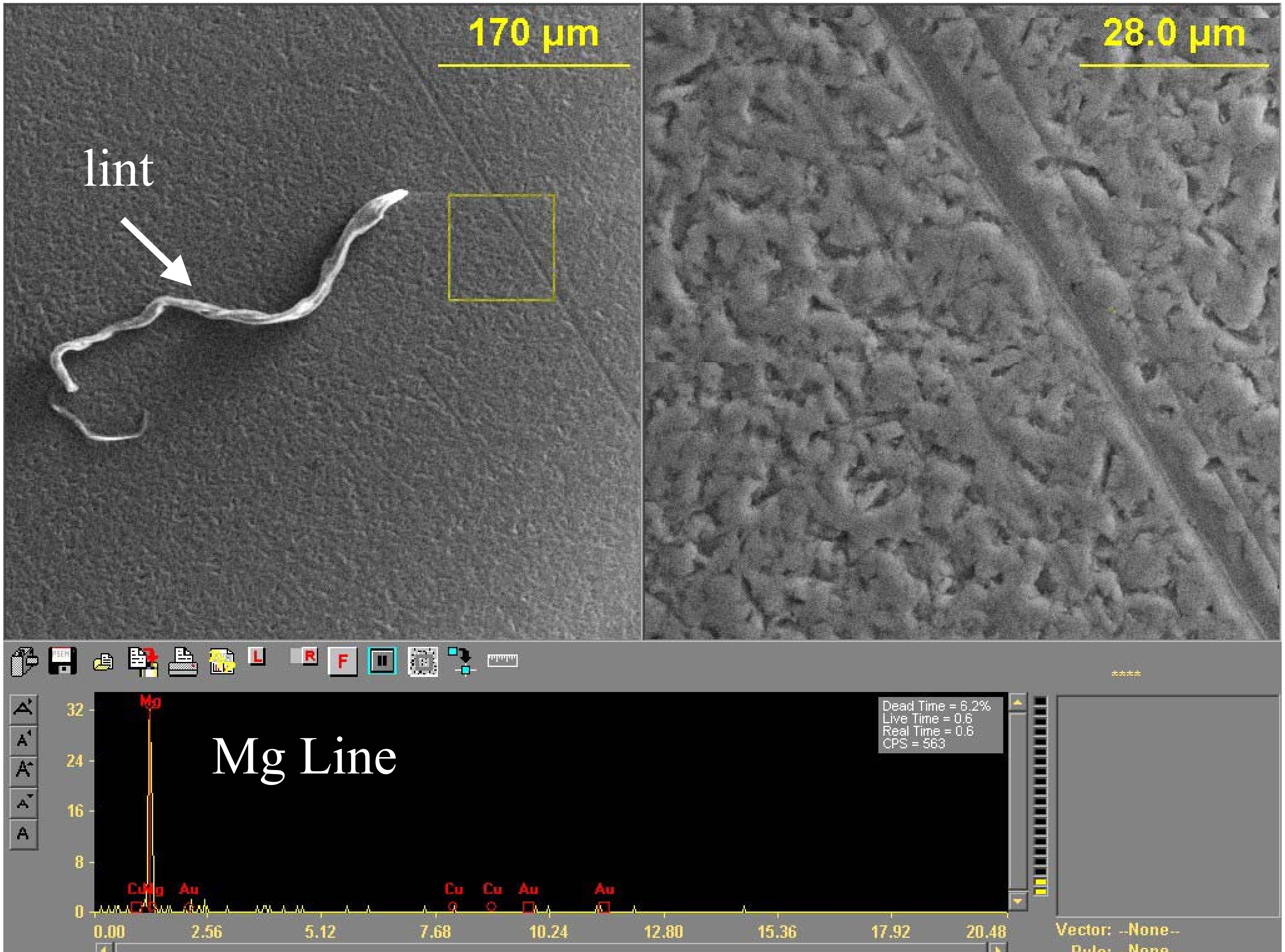


Time of the Arc



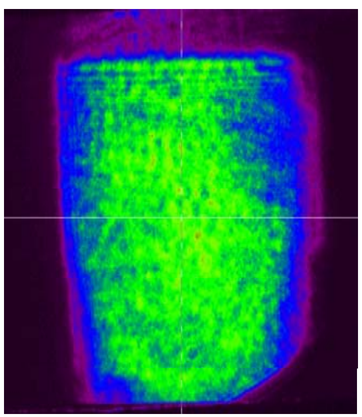
Reflected RF Pulse During Gun Arc

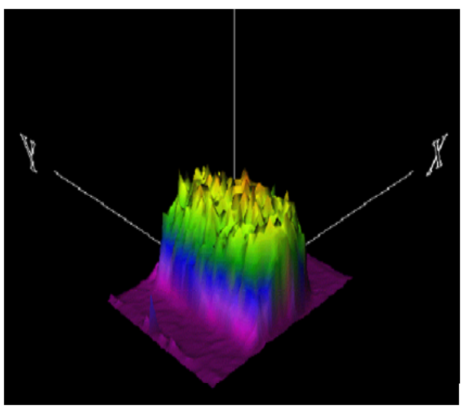
Mg Cathode, SEM Study



AWA Facility Upgrade:
New Laser System

- Spectra Physics Tsunami oscillator, Spitfire Regenerative Amplifier, and two Ti:Sapphire Amplifiers (TSA 50), Excimer, 1.5 – 15 mJ at 248 nm, 6 - 8 ps FWHM,
- Improved stabilities:
  - Timing (< 1ps rms), Amplitude (± 3% rms) high energy, and ±1% at the lower energy. Transverse Beam (good uniformity).
  - Improved Environment:
    - New Air Conditioner, New HEPA Filters



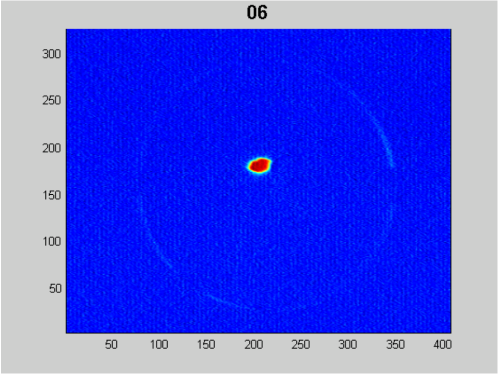


X-Y Profile   X-Y-Intensity

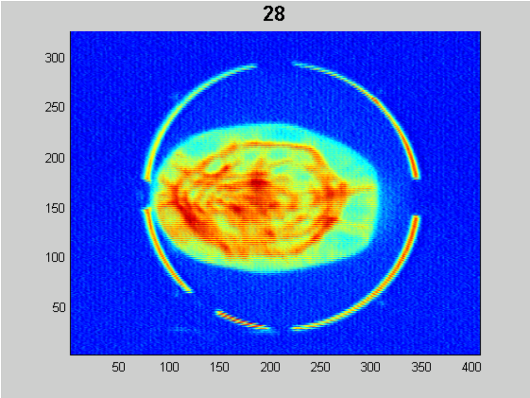
Measurement shows only +-5% Fluctuations.

Photo Electron Beam Produced From the New AWA RF Photocathode Gun

- **Photo-electron beam generated using both the old and the new AWA laser. Beam profiles are monitored using fluorescent YAG screen and optical transition radiation mirror.**
- **Charge produced ~ 20 - 25 nC using Cu cathode. ~ 100 nC single pulse measurement using Mg cathode.**
- **Detailed beam properties are being measured.**



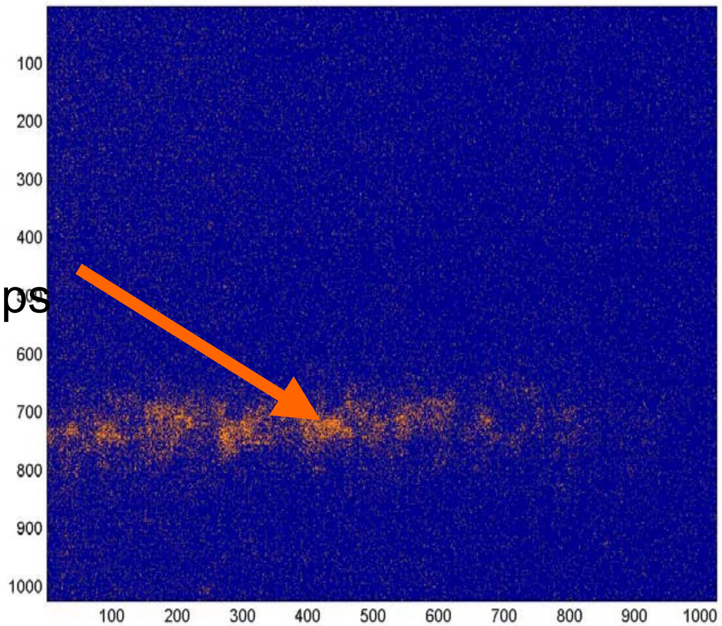
Electron beam can be focused easily to ~ mm spot using a solenoid a meter away



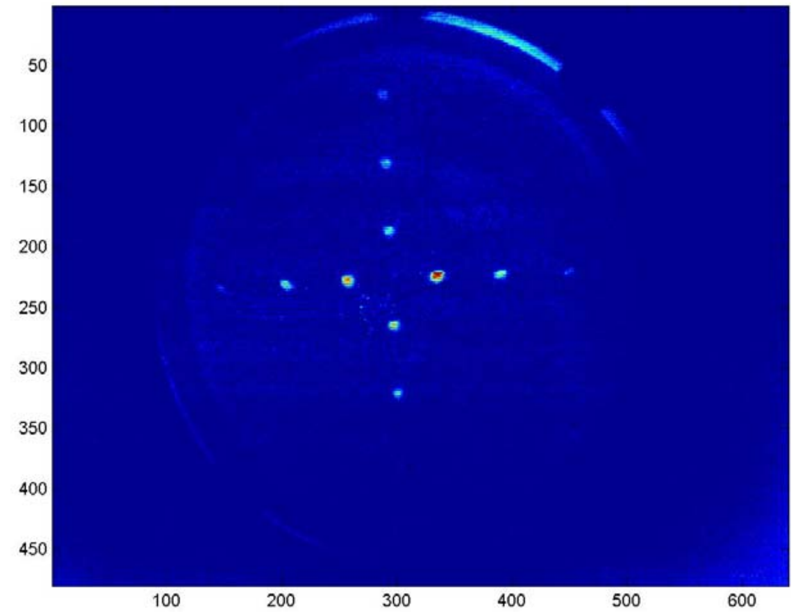
Measured larger electron beam image from screen has the same image as input laser beam.

Pulse length and emittance measurement of 20 nC beam

~10 ps



Pulse length measured for 20 nC beam

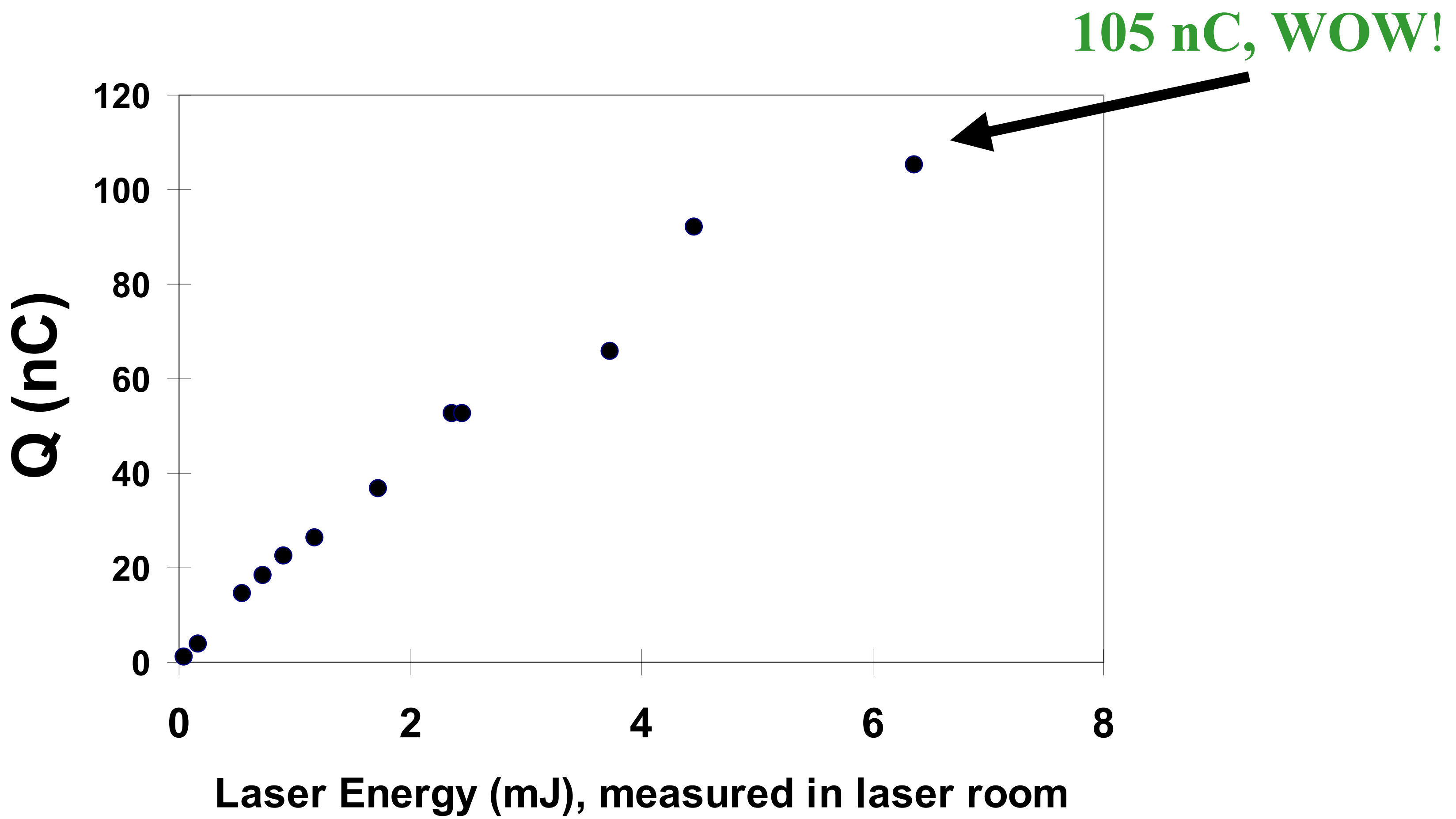


Estimated Norm. Emittance
~ 40 mm mrad

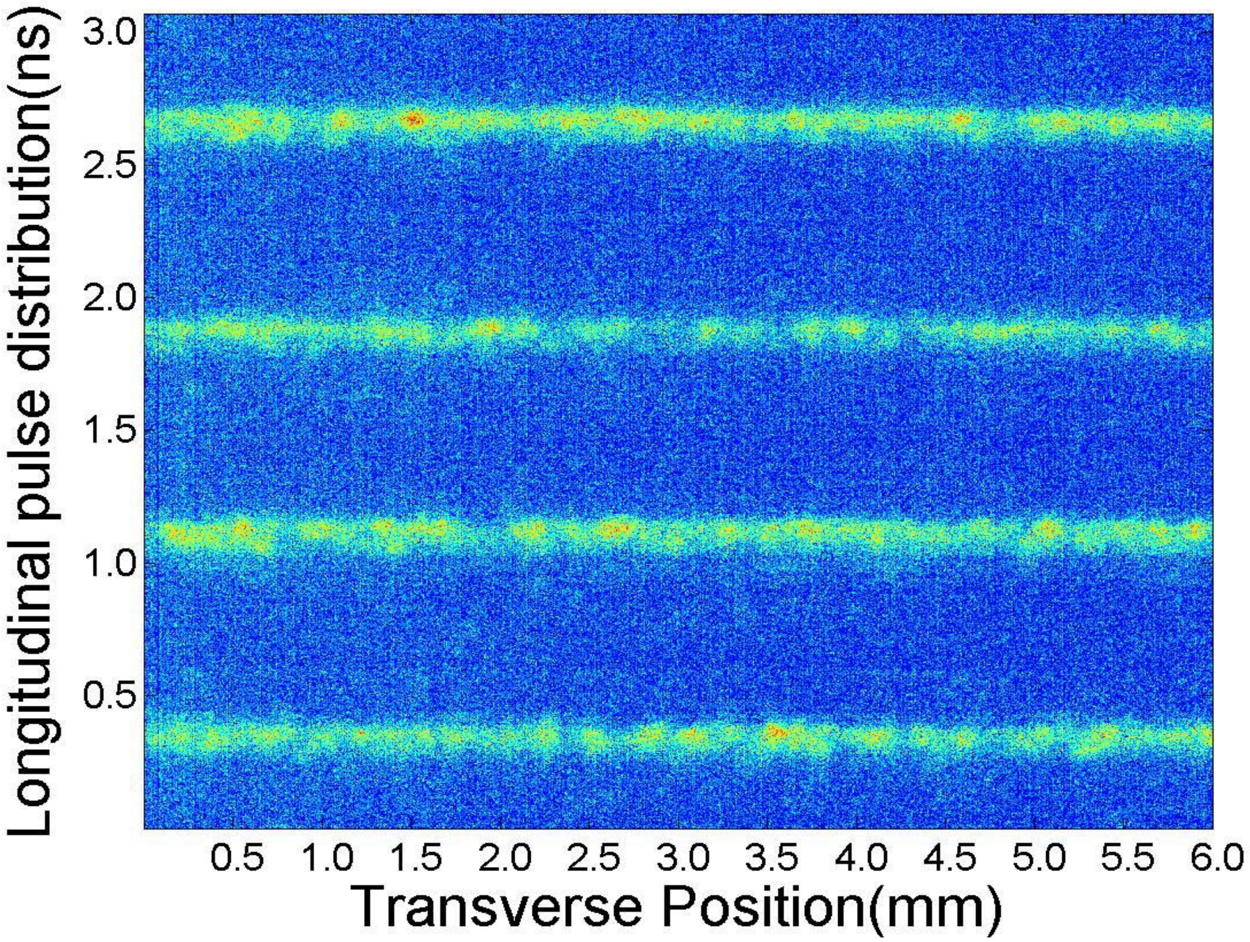
Preliminary data:

FWHM: 13 ~ 17 ps for beam < 70 nC.
Energy spread: 5% (rms) @ 20 nC

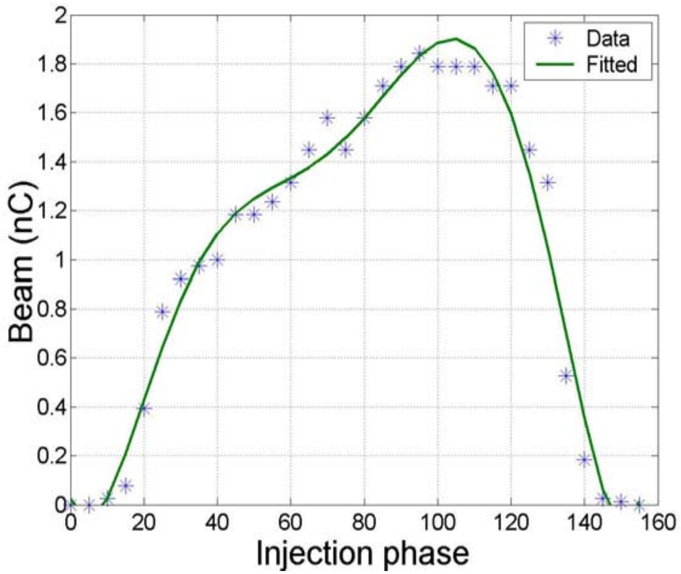
Electron Beam Generated vs Laser Intensity

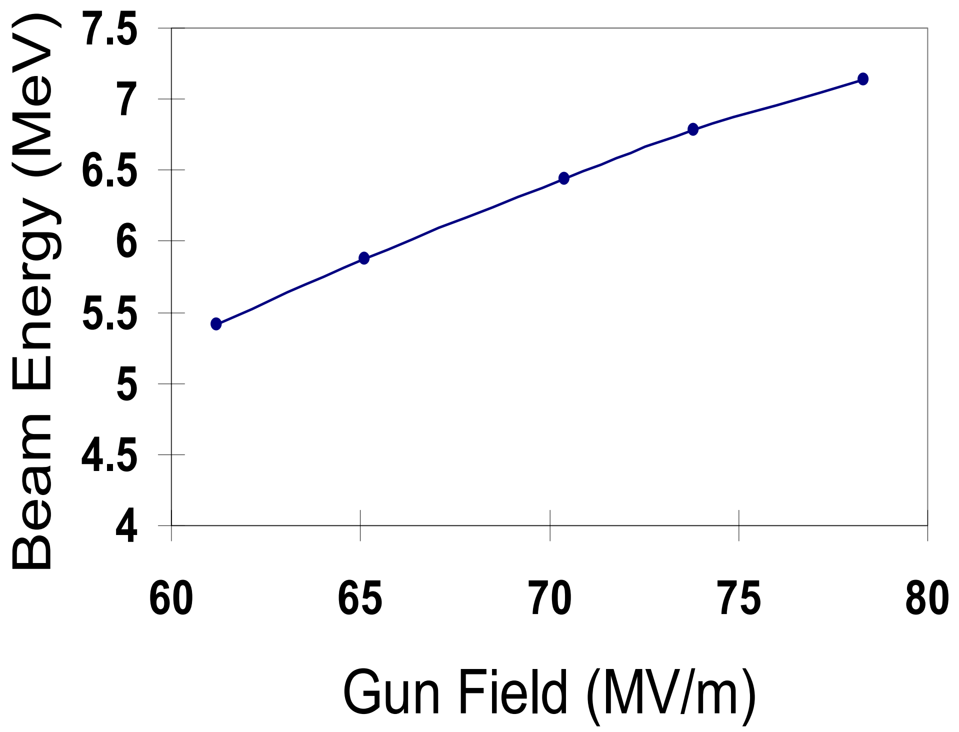


4 Laser Pulses Generated



Study of Low Charge Beam (2 nC) vs Injection Phase and Beam Energy vs Gun Field





Preliminary Simulation Results

- Input (idealized) conditions: 2 mm R (flat), 4° (flat) phase (~10 ps)
- σz and ε vs Ez

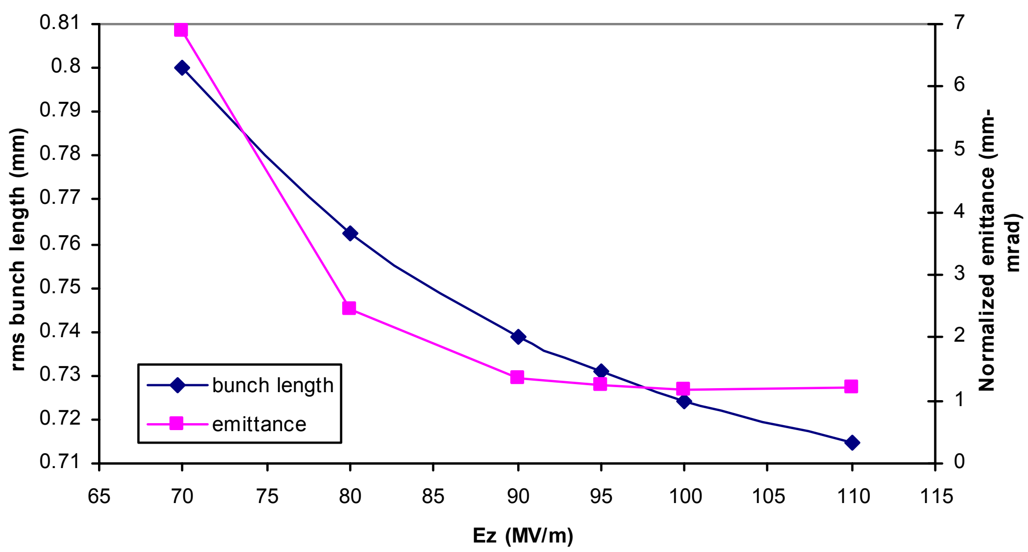


Fig. 1. Simulations of the electron bunch length and emittance (90%) dependent on the peak electric field on the photocathode.

Energy and Energy Spread

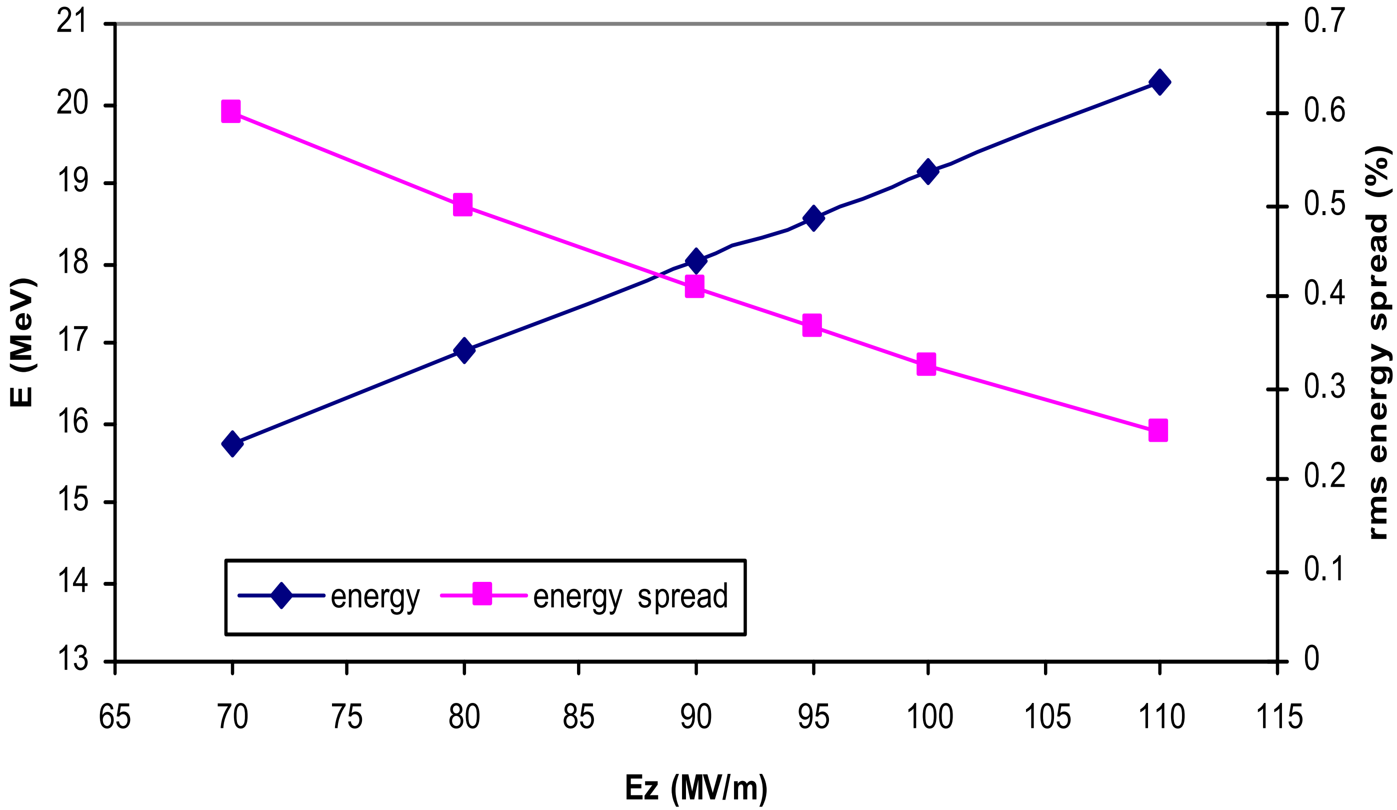


Fig. 2. Energy and energy spread of a 1 nC beam at the end of Linac. It shows the trend that higher field on the cathode not only improves the bunch length and emittance, but also reduces the energy spread.

Spot size optimizations

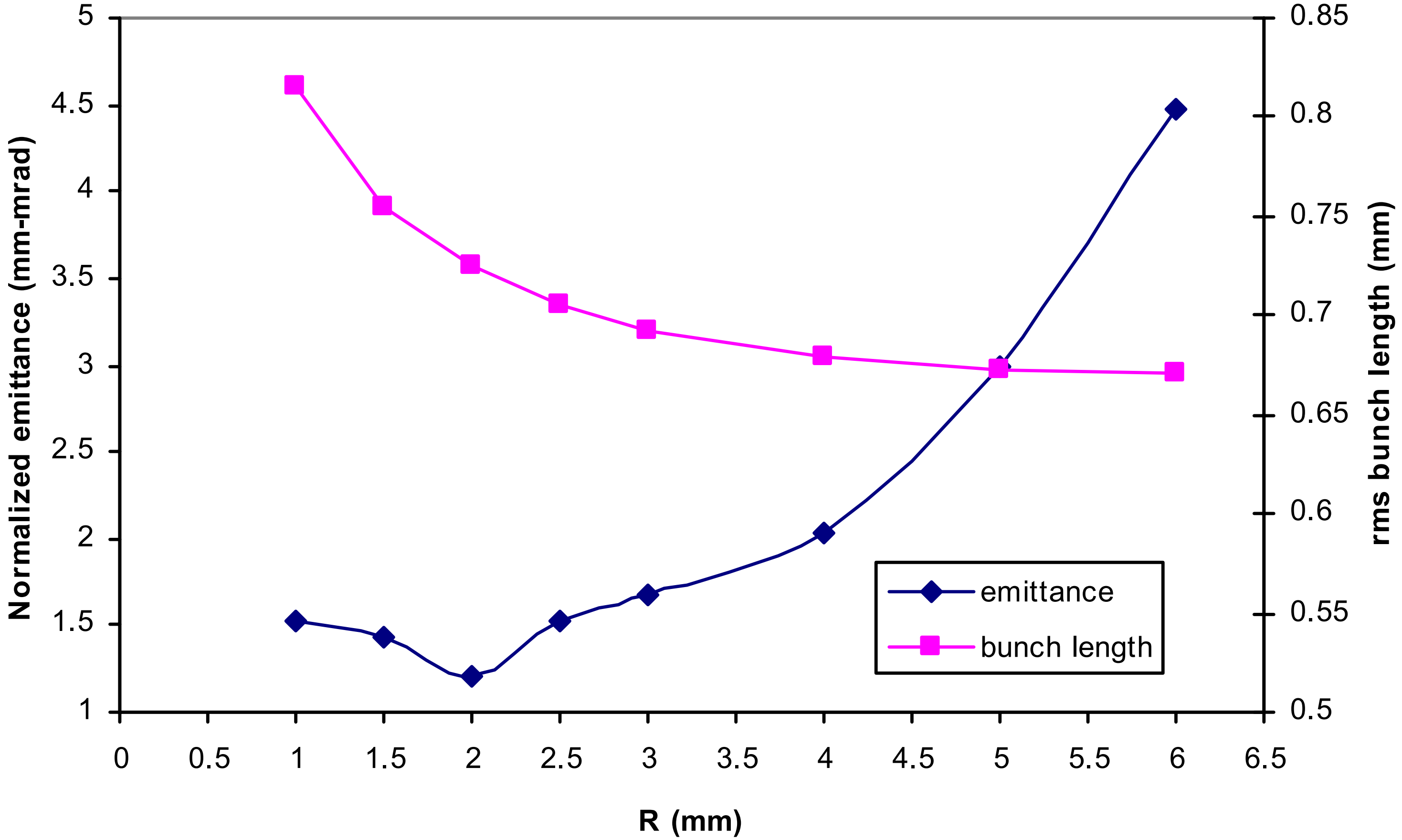


Fig. 3. The electron bunch length and emittance dependence on the radius of spot on the photocathode. The simulation uses 1 nC charge and 100 MV/m peak electric field on the photocathode.

AWA Gun + Linac + Long Drift

- Input (idealized) conditions:

  R (flat) = 1.87 mm, Phase (flat) = 2° (~4ps), Ez = 100 MV/m.

- Results:

  Minimum emittance (100%) = 1.12 mm-mrad,

  Minimum emittance (90%) = 0.56 mm-mrad,

  Bunch length = 0.452 mm,

  Average energy = 19.14 MeV.

AWA Gun + Linac + Long Drift (continued)

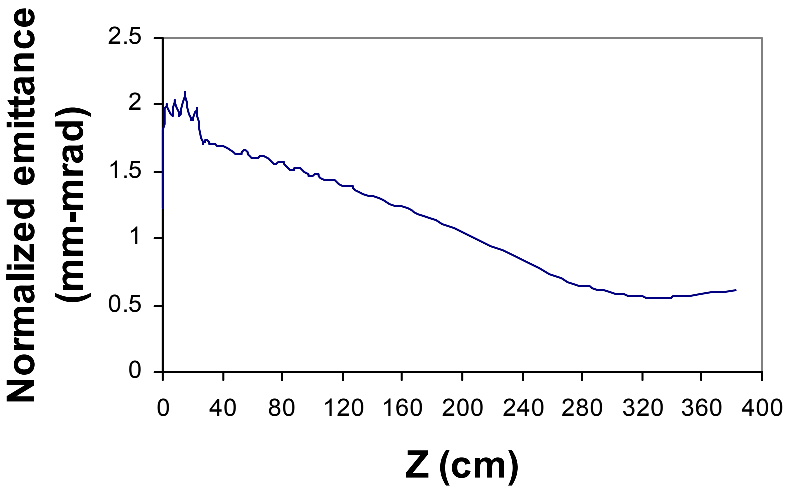


Fig. 8. Evolution of the normalized transverse emittance (90%) for the 1 nC beam along the z-axis with the configuration (gun + linac + long drift).

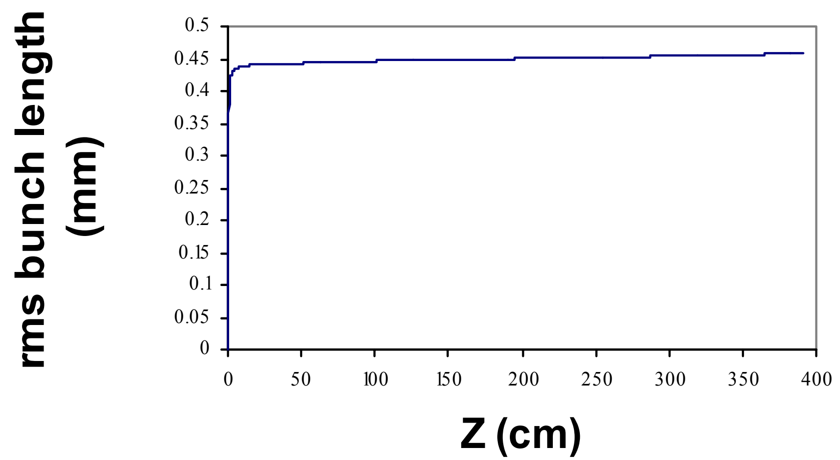


Fig. 9. Evolution of the r.m.s. bunch length for the 1 nC beam along the z-axis with the configuration (gun + linac + long drift).

AWA Gun + Linac + Long Drift (continued)

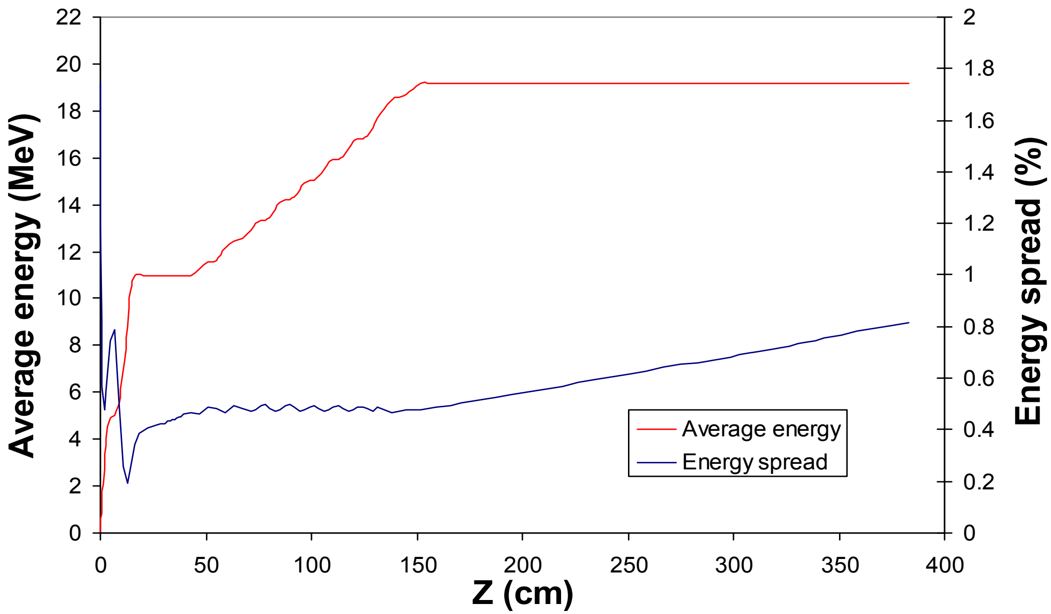


Fig. 10. Evolution of the Average energy and energy spread for the 1 nC beam along the z-axis with the configuration (gun + linac + long drift).

AWA Gun + Linac + Long Drift (continued)

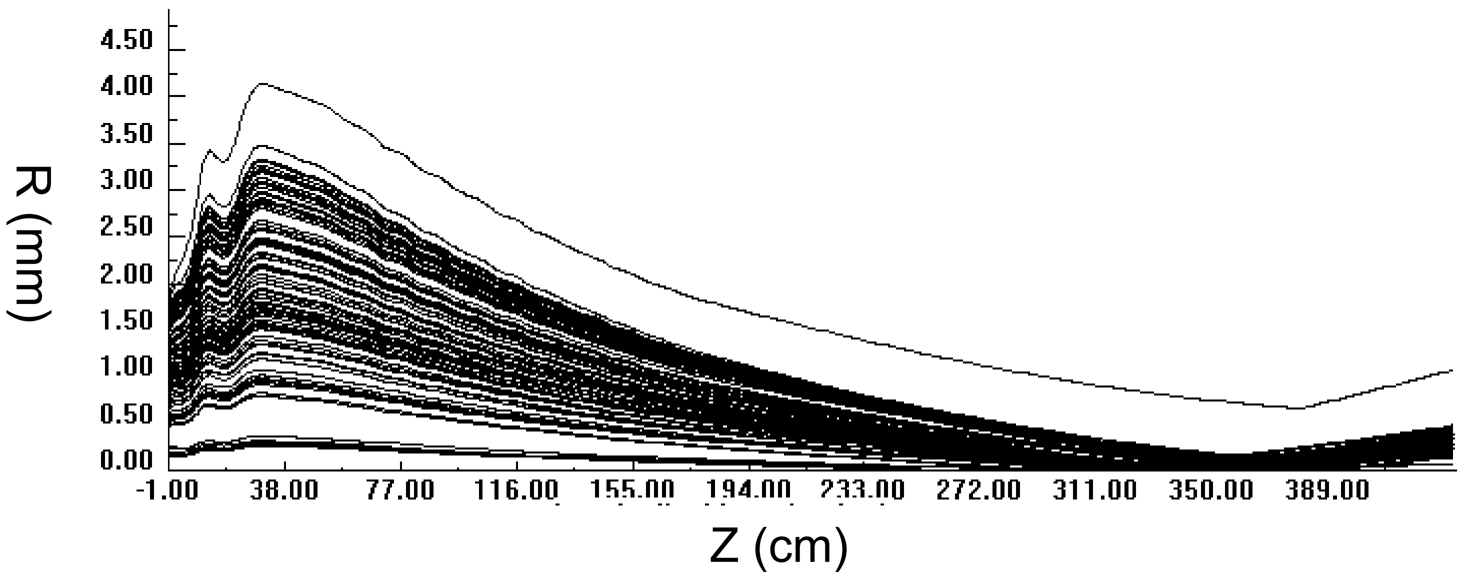


Fig. 11. r – z traces of selected macro-particles for the 1 nC beam with the configuration (gun + linac + long drift).

Next Steps for the AWA facility:

- Near Term:
  - Characterize the electron beam properties, at low bunch charges (~ 1 nC) and high bunch charges (30 – 60 nC), for single bunches and bunch trains.
  - High gradient testing of a short dielectric structure (1 – 4 pulses).
  - Increase drive beam energy from 7.5 to 18 MeV by adding a linac tank in the beamline
  - Implement high QE cathode. Characterize the electron beam properties, single and bunch train.
- Long Term (2 ~ 3 years):
  - Integrate the new gun into the AWA facility.
  - Demonstrate high current electron pulse and RF generation at 7.8 GHz; Demonstrate high power RF generation ~ 30 - 100 GHz, power ~ 100 MW - GW range with pulse length of ~ 10 ns. (Critical for future linear colliders development.)
  - Demonstrate high gradient and sustained acceleration. Dielectric breakdown test and accelerate a 1 nC beam to 100 MeV.