An R&D program for milliampere spin-polarized electron beams

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Low-Energy Electron-Positron Physics at Jefferson Lab
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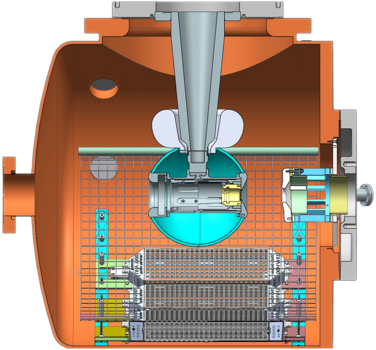

Example of a state-of-the-art polarized photogun: the 200 kV CEBAF gun (“R30”)

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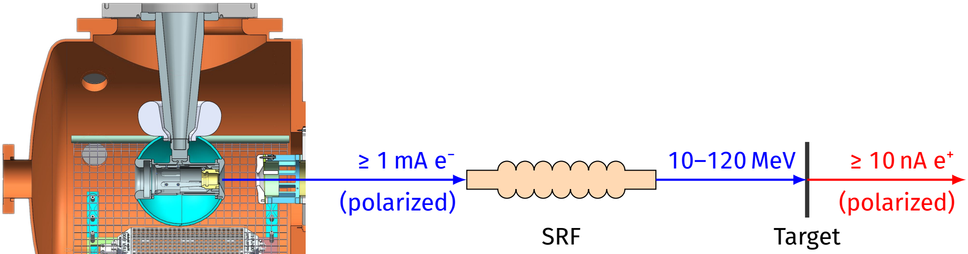
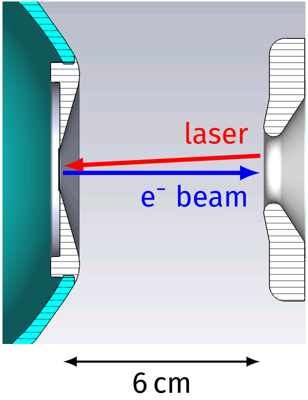
Generating a polarized electron beam for positron conversion



- High beam current determined by low conversion efficiency
- Electron beam must be polarized to make polarized positrons
- High-current capability beneficial for other purposes (e.g., CEBAF)

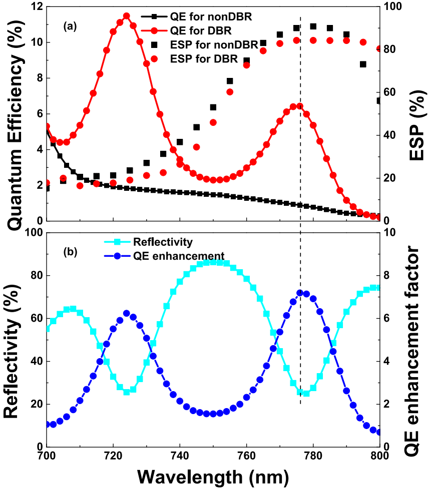
Gun requirements

- Laser-driven photogun (780 nm) with GaAs-based photocathode
- Technology is mature; design similar to CEBAF gun
- Most required parameters are not challenging:
    - bunch charge: 4 pC (1 mA at 250 MHz)
    - bias voltage: as low as possible (reliability), likely ≥ 200 kV due to subsequent RF structures
        - 200 kV routinely achieved; injector simulations promising (see Victor's talk)
    - spin polarization > 80 % is standard, not current-dependent



Photocathodes: present and future capabilities

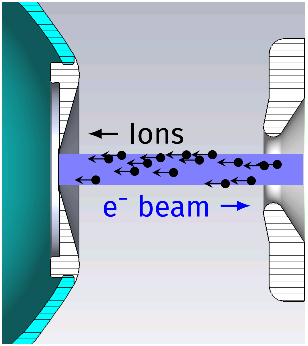
- CEBAF standard (commercial, SVT): strained superlattice GaAs/GaAsP produced by MBE; QE (quantum efficiency) ≈ 1 % and ESP (electron-spin polarization) > 85 %
- Distributed Bragg Reflector (DBR) can achieve QE ≥ 2 %, ESP ≥ 90 %
- Translates to >10 mA/W
- Ongoing collaborations (ODU, UCSB) to enhance capabilities and restore supply chain



W. Liu et al., Appl. Phys. Lett. 109, 252104 (2016)

Dominant limitation of photocathode lifetime: ion back-bombardment

- Electron beam ionizes residual gas within accelerating gap
- Ions are accelerated toward the photocathode, rate ∝ current
- Ions striking photocathode surface locally degrade its quantum efficiency (QE)
- Ce+BAF: superlattice photocathode + 780 nm light for spin polarization ⇒ very susceptible to ion damage

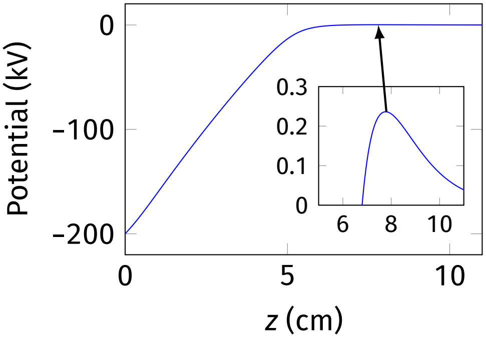


Requirement for unprecedented lifetime of high-polarization photocathodes (1/e lifetime > 1000 C would give ≈ 23 days uptime at 1 mA)

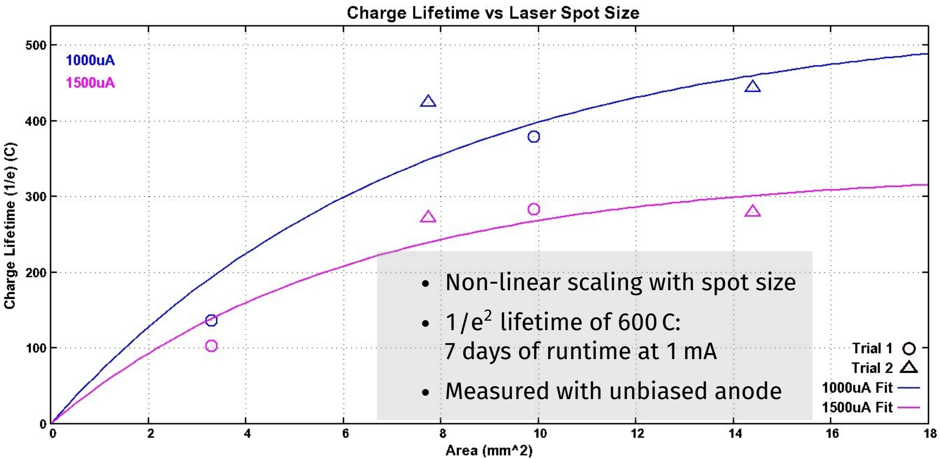
How to increase the charge lifetime

- Improve vacuum: already close to extreme high vacuum, < 10^{-11} mbar
- Increase voltage (ionization cross-section): unclear trade-off
- Make the photocathode less sensitive: being worked on independently
- If we have to accept the remaining ions, can we displace/dilute the damage?
  - Use as much photocathode area as possible for emission
  - Deflect electrons and/or ions to displace damage area

- Apply positive bias to anode for a potential barrier to reflect ions from downstream: already standard



CEBAF measurement of lifetime vs. laser-spot size (2017)



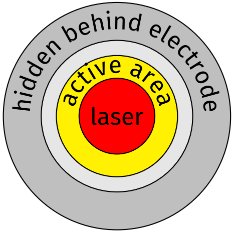
J. Grames et al., “Milliampere Beam Studies using High Polarization Photocathodes at the CEBAF Photoinjector,” Proceedings of XVII International Workshop on Polarized Sources, Targets & Polarimetry — PoS(PSTP2017), vol. 324, 2018, p. 014

R30-5: a low-aberration photogun with shifted anode

Design criteria:

1. mechanical compatibility with existing JLab lock-load guns (CEBAF, GTS, UITF)
   - 12.7 mm exposed photocathode diameter
2. uniform emission from maximum area
   - dilutes low-energy ion damage
   - helps with space charge
   - but this means the emission area is centered
3. deflect ions away from emission area
   - vertical electric field created by shifted anode

   O. Rahman et al., “Increasing charge lifetime in dc polarized electron guns by offsetting the anode”, Phys. Rev. Accel. Beams, vol. 22, p. 083401, 2019

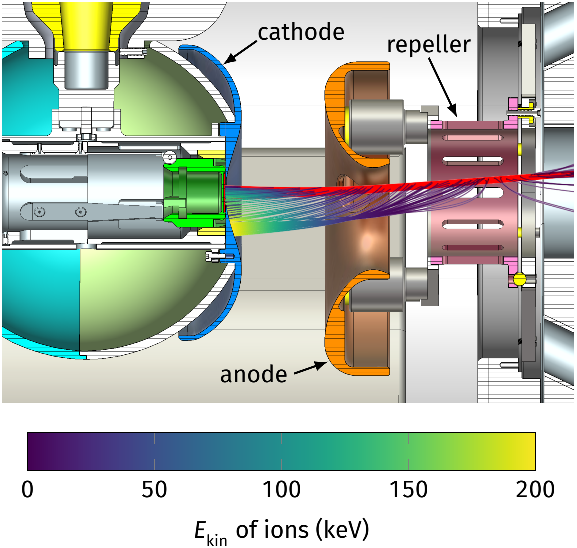


How to get the large beam (and all halo!) through the shifted anode hole?

- low-aberration geometry with arbitrary hole size

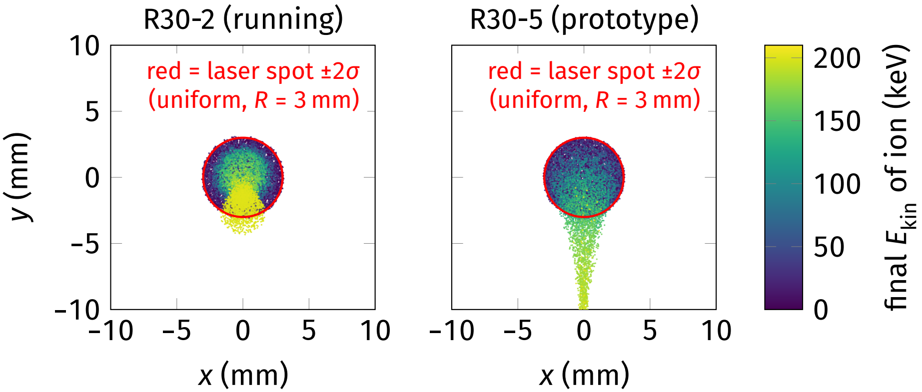
  W. Peter and M. E. Jones, “Theory of high-brightness electron-beam production from photocathodes”, Particle Accelerators 24, pp. 231–243 (1989)

R30-5 gun: cross-section view with beam (red) and ion trajectories



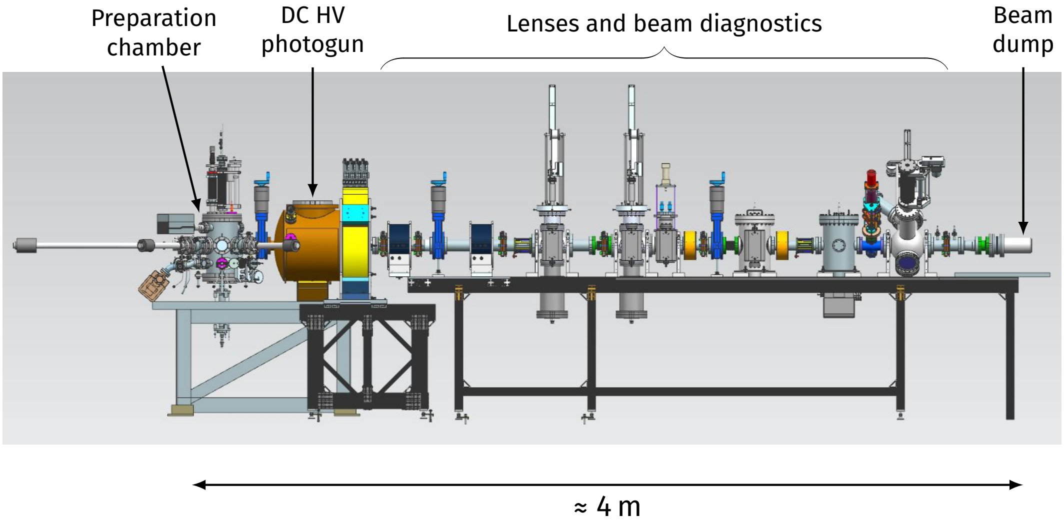
- GPT (+ IONATOR) tracking simulation
  - $V_{cathode}$ = −200 kV
  - $V_{repeller}$ = 0.5 kV
  - radially uniform emission profile, R = 3 mm
  - Gaussian temporal profile, σ_t = 20 ps
  - q_{bunch} = 4 pC
- top 25 % of ion spectrum is filtered out
- could filter more with extra magnetic field

Simulated ion distributions at photocathode surface (200 kV, biased repeller)



- Large spot size dilutes density of low-energy ions
- But overlap with high-energy ions increases with spot size
- Maximize both spot size and deflection

Lifetime measurements at the Gun Test Stand (GTS) in the LERF building



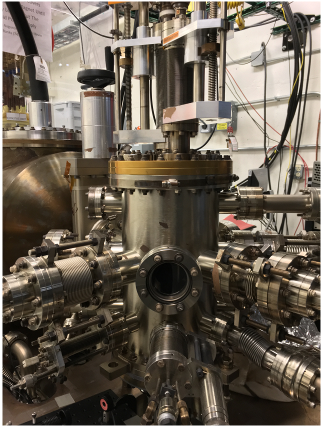
GTS status and perspective

- Deposition chamber modified from KCsSb to Cs/NF_3 deposition for NEA GaAs
- 780 nm laser installed (1 W, σ_t = 20 ps at 374 MHz), commissioned with beam

This year:

- Upgrade deposition chamber with loading chamber port and large activation mask
- Assemble and install R30-5 gun
- Improve beam-line vacuum
- Measure lifetime vs. spot size, verify scaling predictions

Visit the GTS during the LEEPP tour!



Outlook

- Lifetime scaling studies at GTS about to begin; new gun prototype to make first beam this summer
- Vision: design future guns with predictable lifetime exceeding 1000 C
- R30-5 potential candidate for LERF program

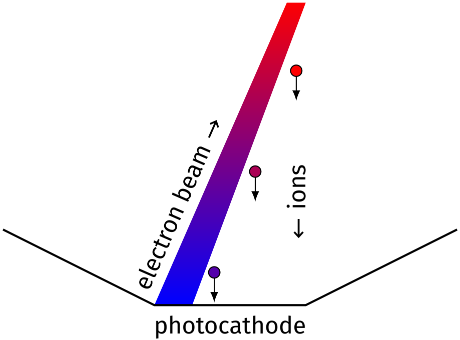
Discussion:

- Is there any interest in > 1 mA polarized electron beams for other purposes (at what energy)?

machined R30-5 cathode
(before polishing)

BACKUP: A closer look at the dynamics

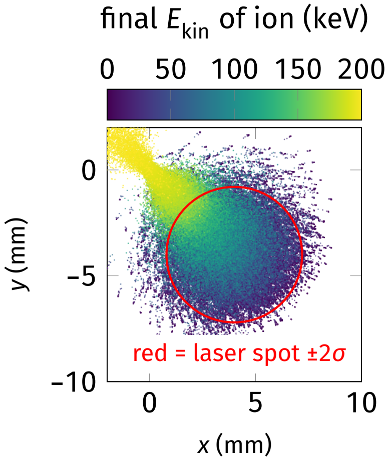
- Electron beam envelope determines starting position of ions
- Low energy: close to photocathode, damage area ≈ emission area
- High energy: far away from photocathode, damage area depends on optics…
  - Deflect electron beam away from emission area ⇒ shift ion origin
  - Ions close to the anode are also subject to its focusing field
- Simulate in detail



Beam trajectory in gap determines energy distribution of ions incident on emission area

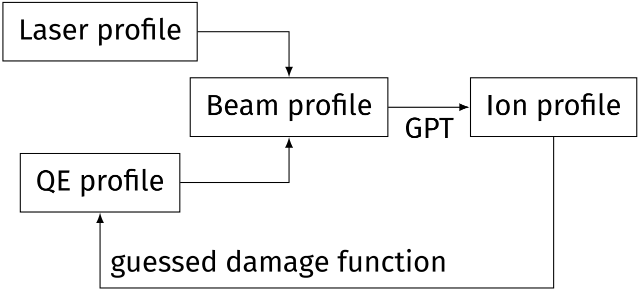
BACKUP: Simulating ion damage in photoguns

- Need electrostatic field map (CST)
- Ions are created inside electron beam depending on envelope and energy
  ⇒ simulate electron dynamics with General Particle Tracer (GPT)
- Extend GPT with IONATOR to get ions and track to photocathode in the same model
- Problem: QE degradation depends on ion energy in an unknown way
  (likely: more energy ≈ worse)

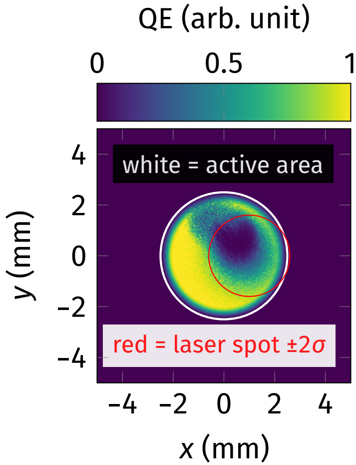


Simulated ion distribution hitting the photocathode (example gun)

BACKUP: Simulating lifetime

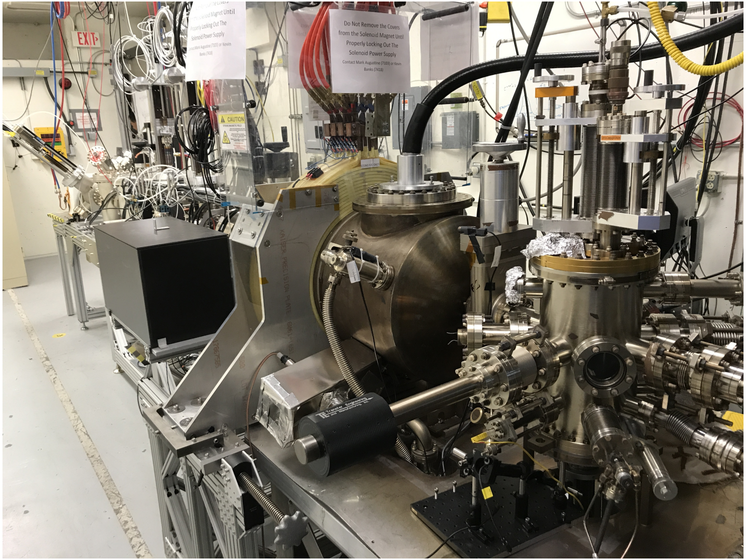


- Most of the dynamics can be simulated from first principles
- Reasonable guess of damage function should allow for qualitative comparisons



Example simulation, after 50 time steps

BACKUP: GTS photo



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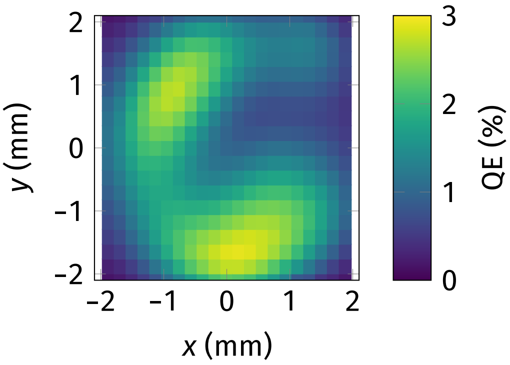
BACKUP: QE damage measurements

- No direct way to measure the ion distribution on the photocathode
- QE can be measured as a function of position
  - Caveat: convolution with laser profile ⇒ minimize spot size for measurement
- Extract a known amount of charge with a given laser-spot size, then compare measured and simulated QE distribution to calibrate simulation model
- Systematic studies at GTS to happen this year



Example of a QE scan from UITF, showing ion damage on bulk GaAs

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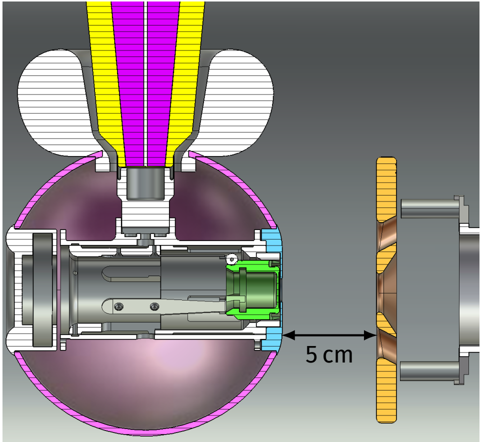
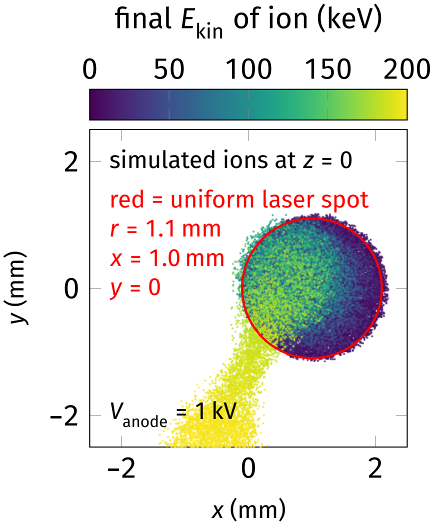
BACKUP: Status of GTS simulations with the as-built gun



CST model by G. Palacios-Serrano



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