Toward a long-lifetime polarized photoelectron gun for the Ce^+BAF positron source

M. W. Bruker, J. Grames, C. Hernández-García, A. Hofler, G. Palacios-Serrano

Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

Center for Injectors and Sources

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The challenge: milliamperes of polarized beam for weeks

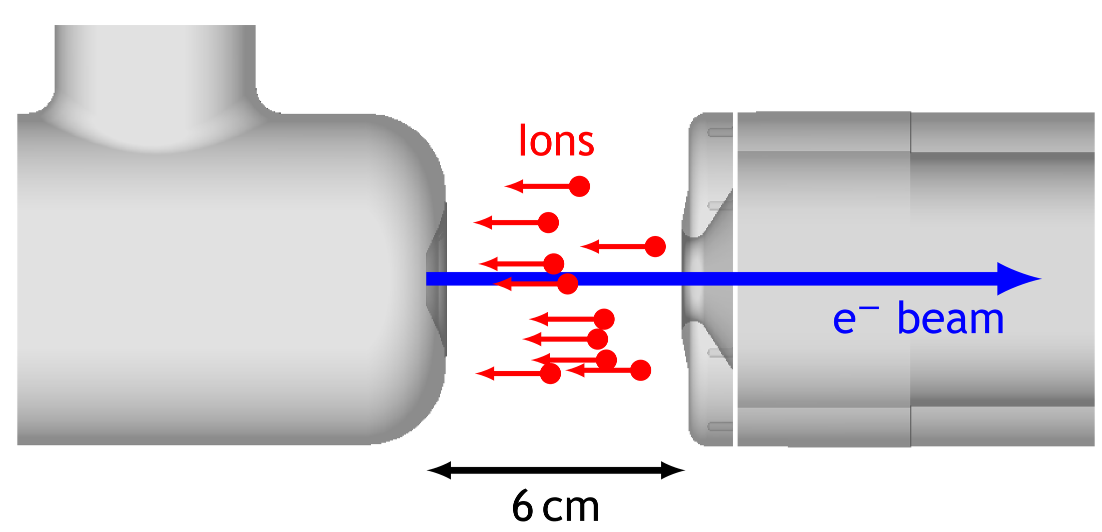
Ce+BAF: spin-polarized e^+ beam created from high-power e^- beam using pair production

- new, high-current e^- injector needed
- polarization requires DC photogun with GaAs-based photocathode
- bias voltage ≥200 kV (space charge, cryomodule acceptance)
- average current 1 to 10 mA: 4 to 40 pC at 249 MHz

Beam dynamics are likely manageable, but…

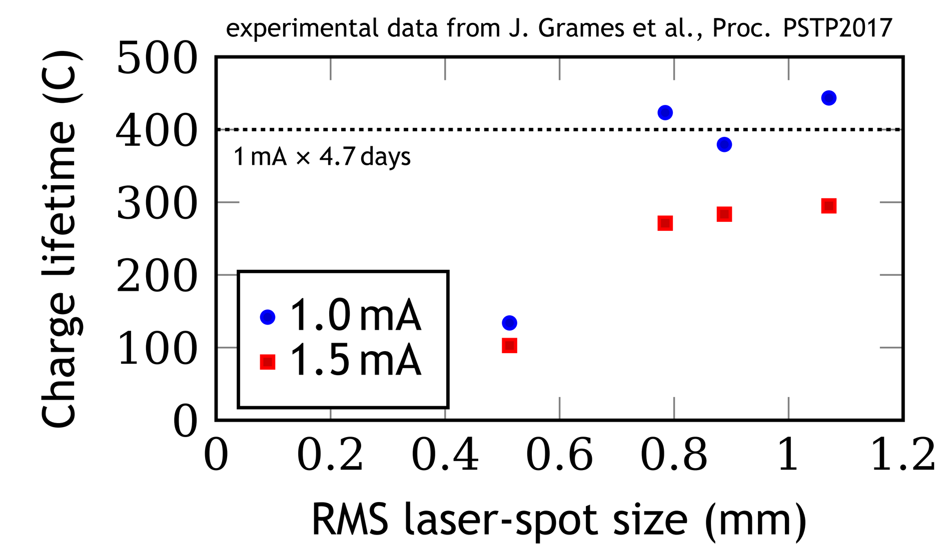
- continuous high-current operation limited by photocathode charge lifetime: 1 kC/1 mA = 11 days
- design trade-offs to increase lifetime will drive the beam parameters

Dominant limitation of photocathode lifetime: ion back-bombardment



- beam ionizes residual gas; ions are accelerated back and hit cathode surface
- total number of ions scales with pressure and integrated charge
- $1/e$ lifetime ≲ 1 kC not demonstrated, 200 C typical

Fixed number of ions: can we spread the damage?



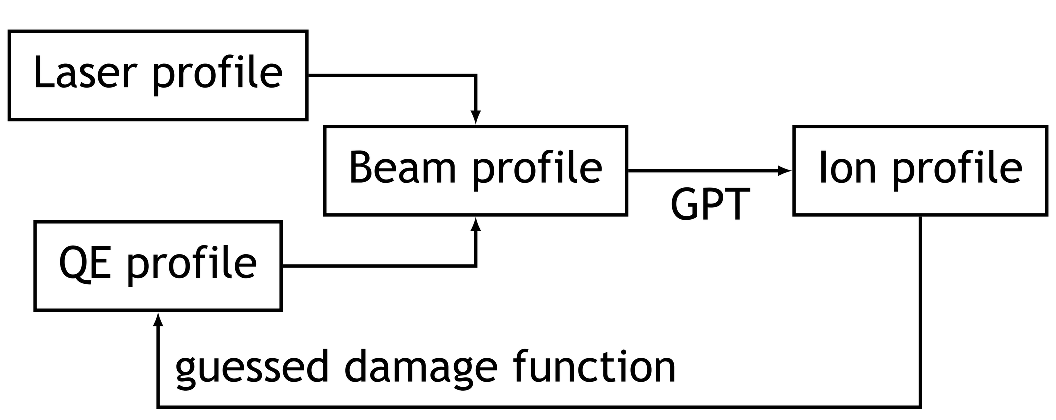
What limits the scaling?

- beam loss
- finite active area
- ion dynamics? simulate!

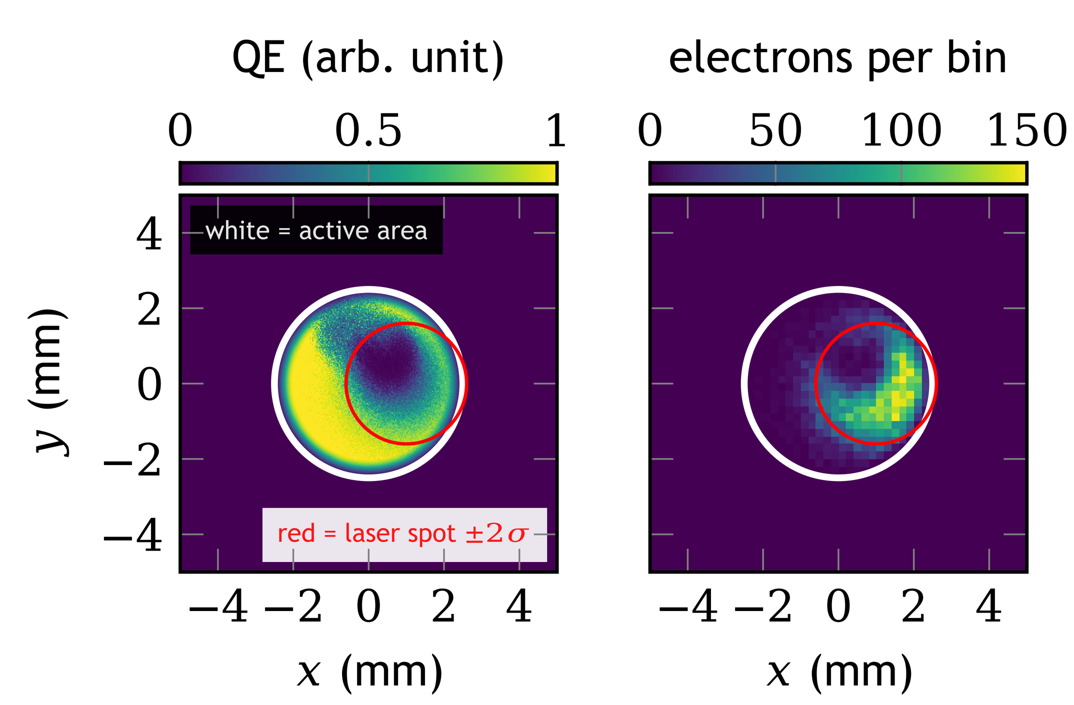
Iterative model for QE degradation

To make the problem accessible to simulation:

- Given an initial beam distribution, particle dynamics are computable with GPT
- $I_{beam}(x, y) = P_{laser}(x, y) \times QE(x, y)$
- Beam creates ions using the IONATOR module; ions are tracked through gun field
- Damage mechanism unknown, but assume each ion degrades the QE in some way (e.g., $\propto E_{kin}$)
- Iteration gives lifetime (in units of time steps)

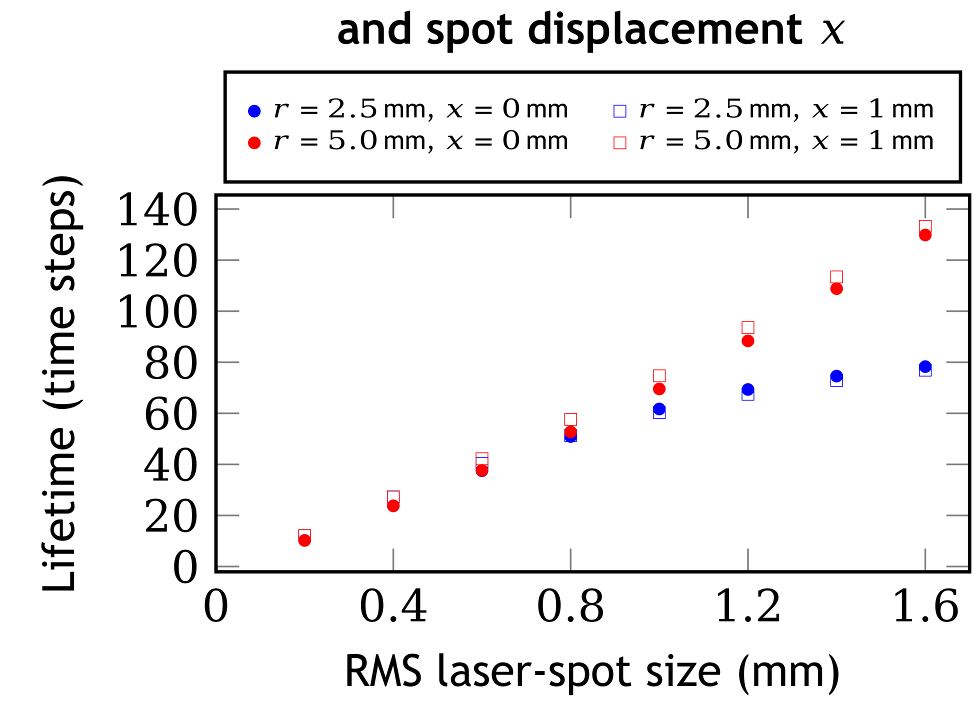


QE and beam shape after 50 time steps
(Gaussian profile, $\sigma = 0.8$ mm, $x = 1$ mm)



- homogeneous damage from low-energy ions (coincident with spot)
- displaced damage from high-energy ions

Lifetime vs. active area radius r and spot displacement x



- lifetime should naively be $\propto \sigma^2$, but larger spot samples more of the displaced damage
- radius of active area limits potential benefits of spot displacement and size

Strategy for long-lifetime gun development

What gets in the way of scaling up the spot?

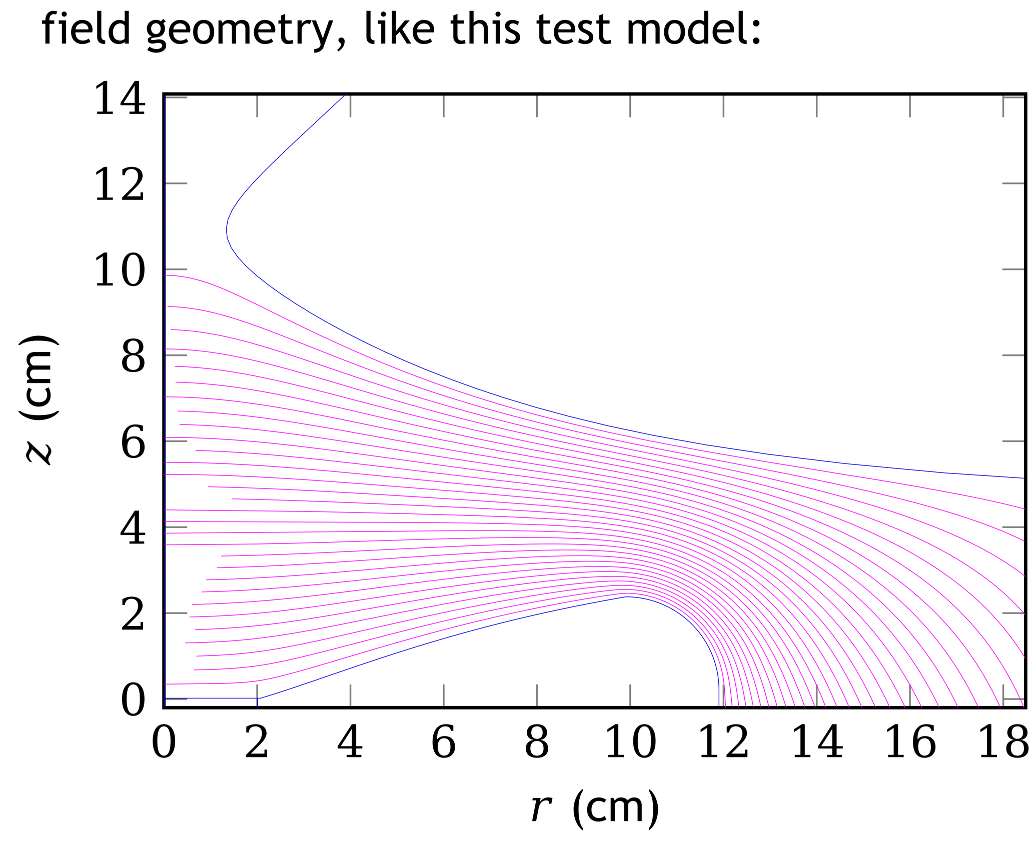
- thermal emittance
- emittance from field aberrations
- stray beam from large active area

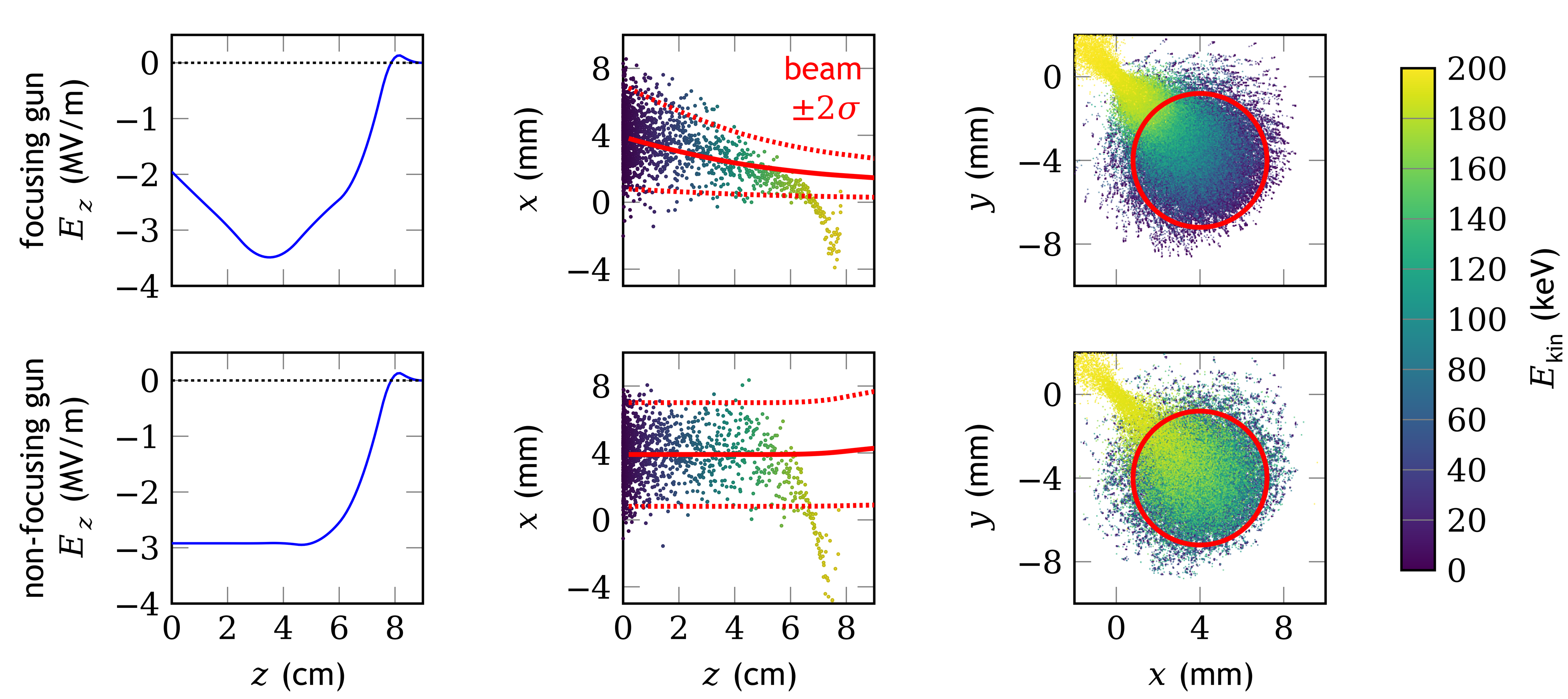
These are solvable, but…

- keep high-energy ions away from the emission area!
- focusing and/or deflecting field helps

Implications for gun geometry:

- large photocathode with large, displaced active area
- expect to need large electrodes and low-aberration field geometry, like this test model:





Simple 1-d models…

- cathode at −200 kV
- potential barrier at anode ($z \approx 8$ cm)
- $E_r(r, z) = -\frac{r}{2}\frac{\partial E_z}{\partial z}$
- arbitrary spot size without aberrations or clipping at cathode/anode

Ion trajectories vs. point of origin in z

- x refers to where ions hit the cathode
- low-energy ions: only the beam envelope matters
- high-energy ions are focused by the anode

Ion distribution on cathode

- focusing field displaces damage from high-energy ions away from laser spot
- spot displacement needs to be commensurate with spot diameter to be effective

Jefferson Lab

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