First electron beam operation of the LANL NCRF photoinjector

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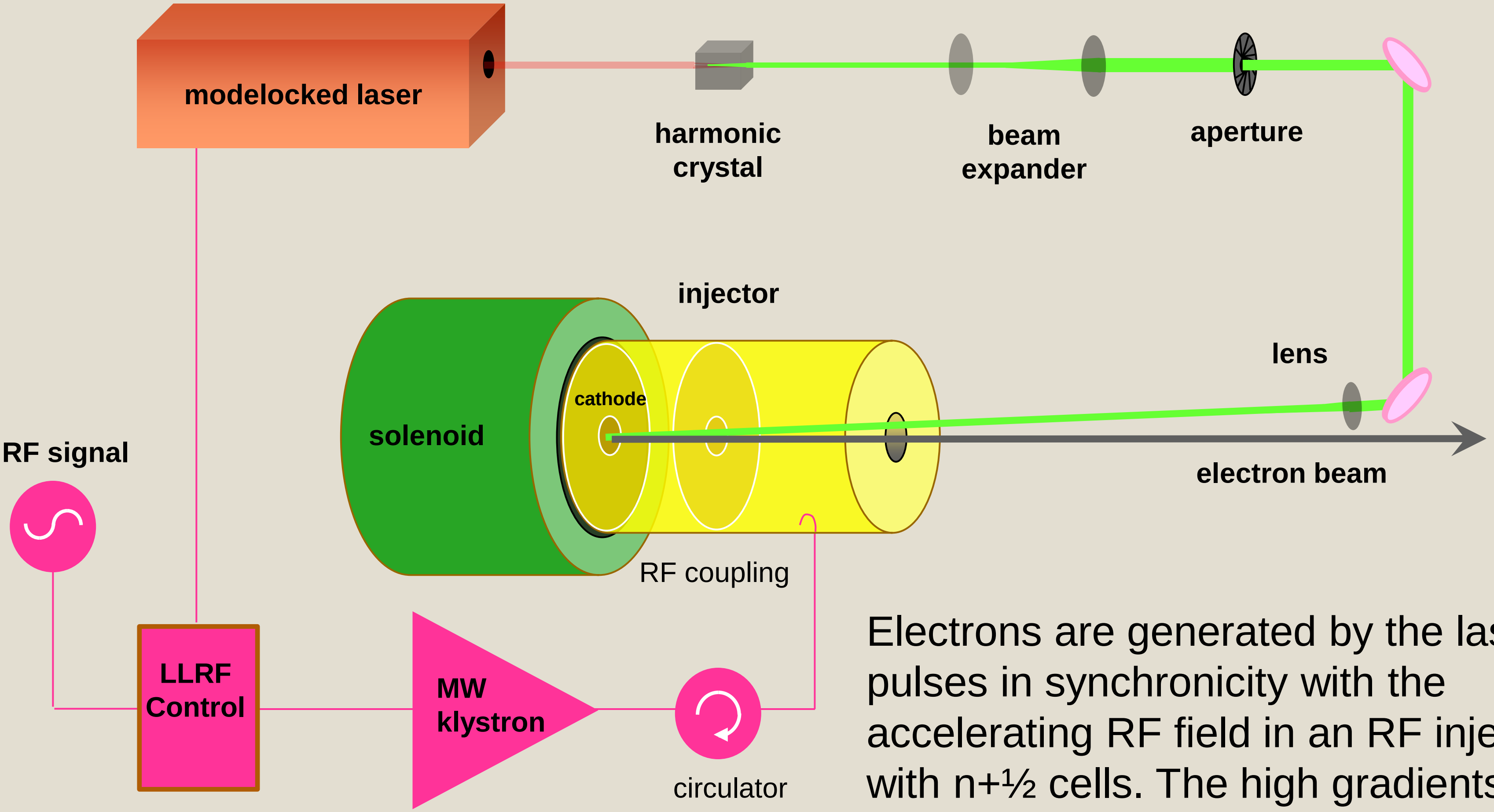
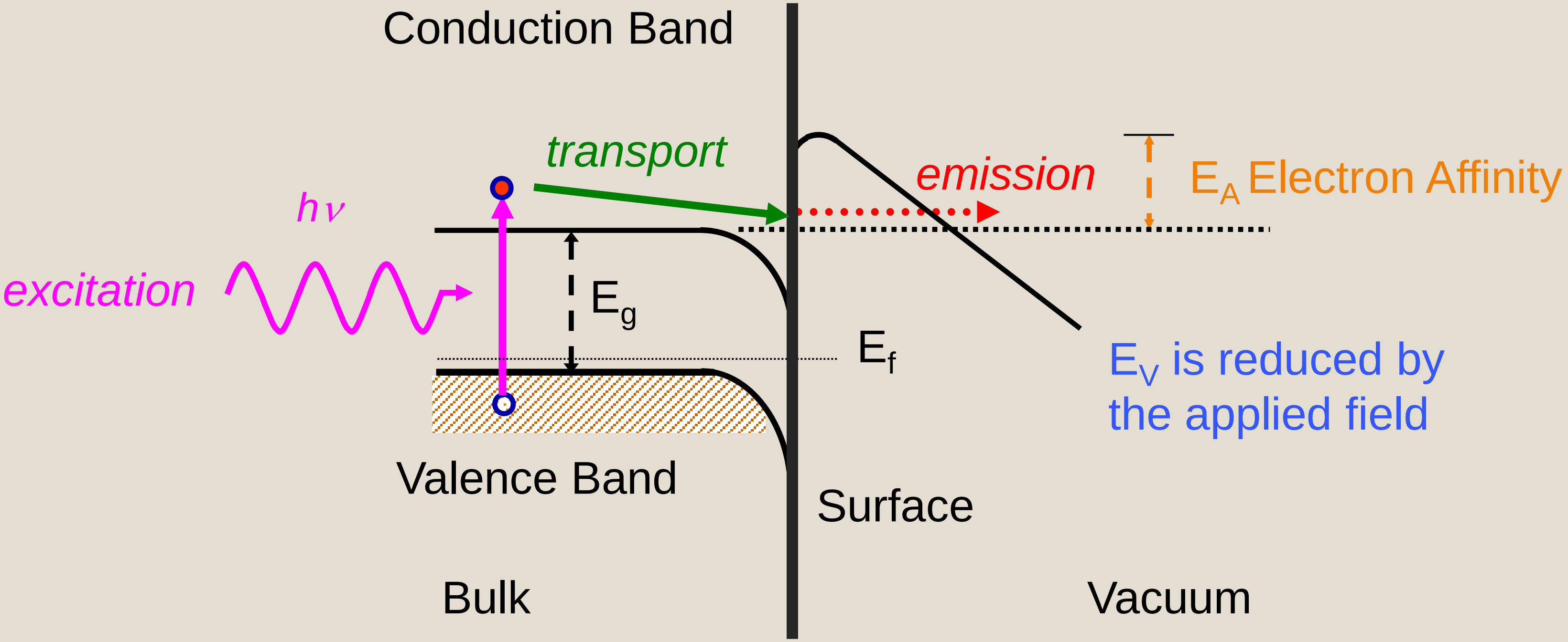
Introduction



Electrons are generated by the laser pulses in synchronicity with the accelerating RF field in an RF injector with n+½ cells. The high gradients produce electrons with relativistic energy at the injector exit.

Introduction



- Electrons are excited from the valence band to the conduction band.
- During transport they undergo electron-phonon collisions, losing energy.
- Photoemission is a tunneling process through the potential barrier at the solid-vacuum interface.
    - The barrier height is determined by the electron affinity and the barrier width is determined by the applied electric field.

Overview

- Injector
  - Dark Current Calculations
  - LLRF control
  - Fixed frequency demo
  - Beam line completion
  - Cathode lifetime test
  - Drive laser & OTS
  - Beam line diagnostics
  - First beam tests
- Cathode
  - Deposition system
  - Initial QE measurements
  - Transport system
  - Temperature control
  - Insertion tests
  - Dark current measurements
  - In-situ rejuvenation
  - Lifetime vs. RF power

Field Emission Considerations

$$J_{FN}(\theta) = \frac{A[\beta E(\theta)]^2}{\phi_w [t(y)]^2} \exp\left(\frac{-B\upsilon(y)\phi_w^{1.5}}{\beta E(\theta)} \right)$$

$$E(\theta) = E_0 \cos(\theta) \qquad I_{dark} = a_{cath} J_{FN}$$

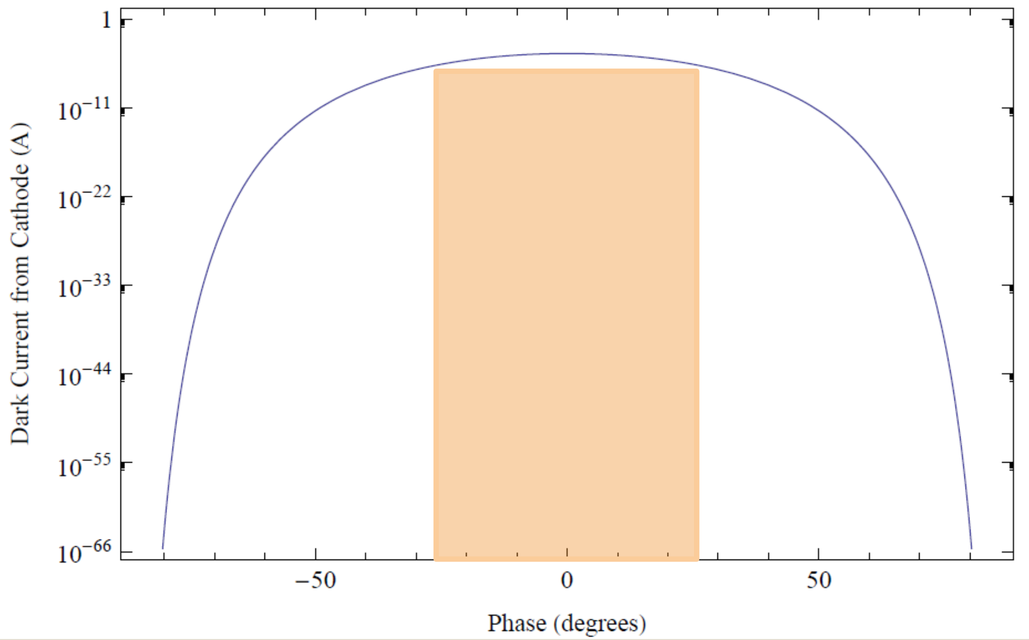
θ is phase of rf cavity

$E(\theta)$ is the field normal to cathode

ϕ_w workfunction of cathode (≥ 1.6eV)

$A = 1.54 \times 10^{-6} \left[\mathrm{A \cdot eV/V^2} \right]$

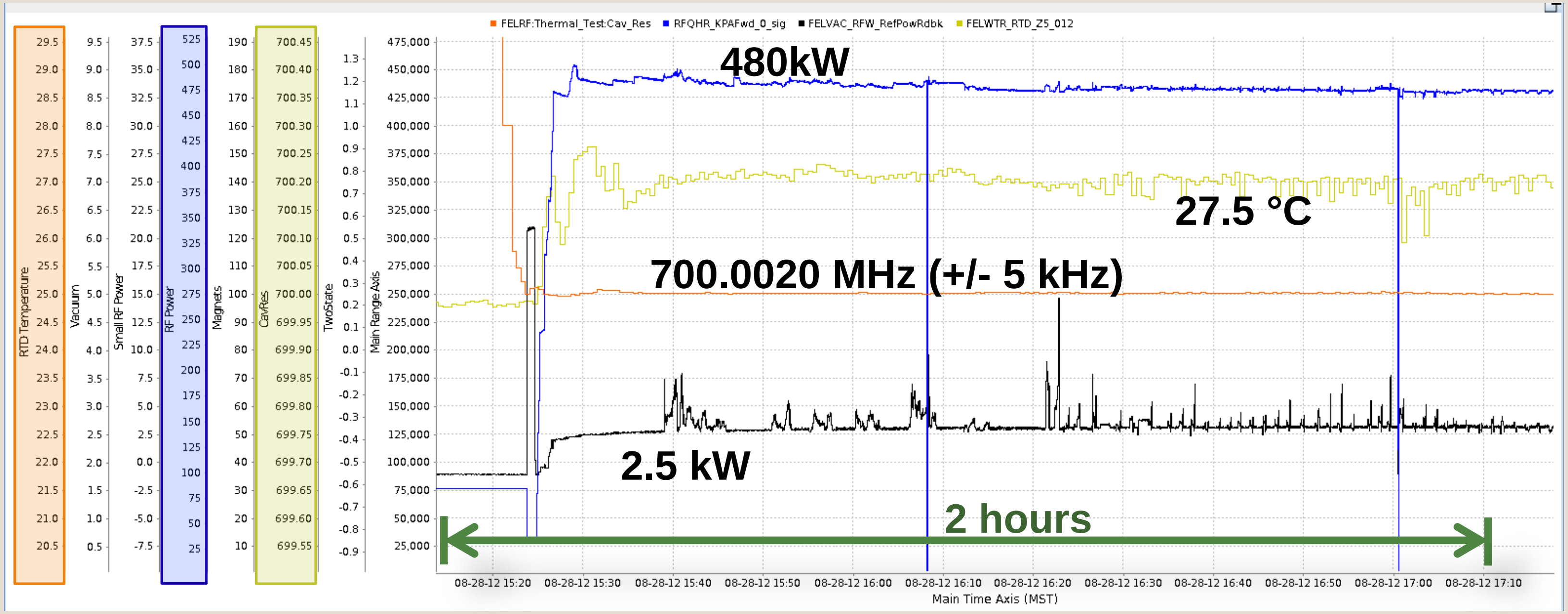
$B = 6.83 \times 10^{9} \left[\mathrm{V \cdot eV^{1.5}/m} \right]$



- Radiation measurements indicate ~60μA F. E. current
- Emission between +/- 25 degrees.
- Transit time places further restrictions on emitted electrons
- Suggests a field enhancement factor β = 64

Calculations provided by Leanne Duffy

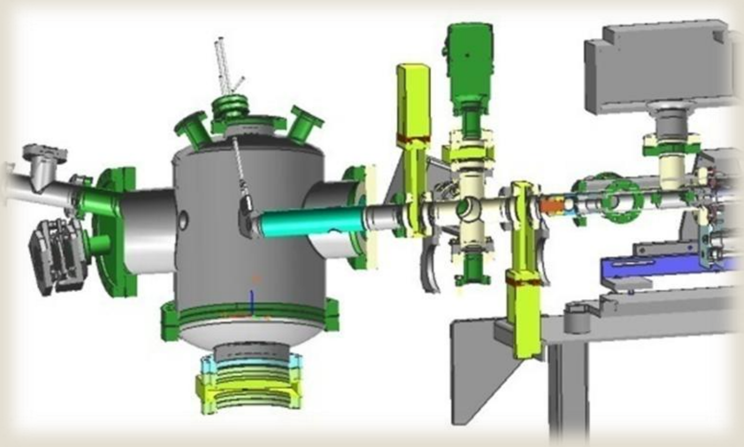
Fixed frequency drive operation

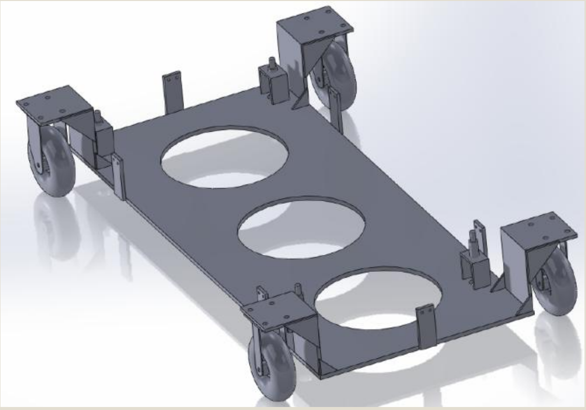


- Synthesize RF, adjust phase to target relative to slowly changing laser phase
- Thermal stability of the injector required to maintain resonance frequency
- Result: hours of continuous operation with fixed frequency and phase
    - Reflected power <1% (nominally 0.5% in fixed frequency mode)

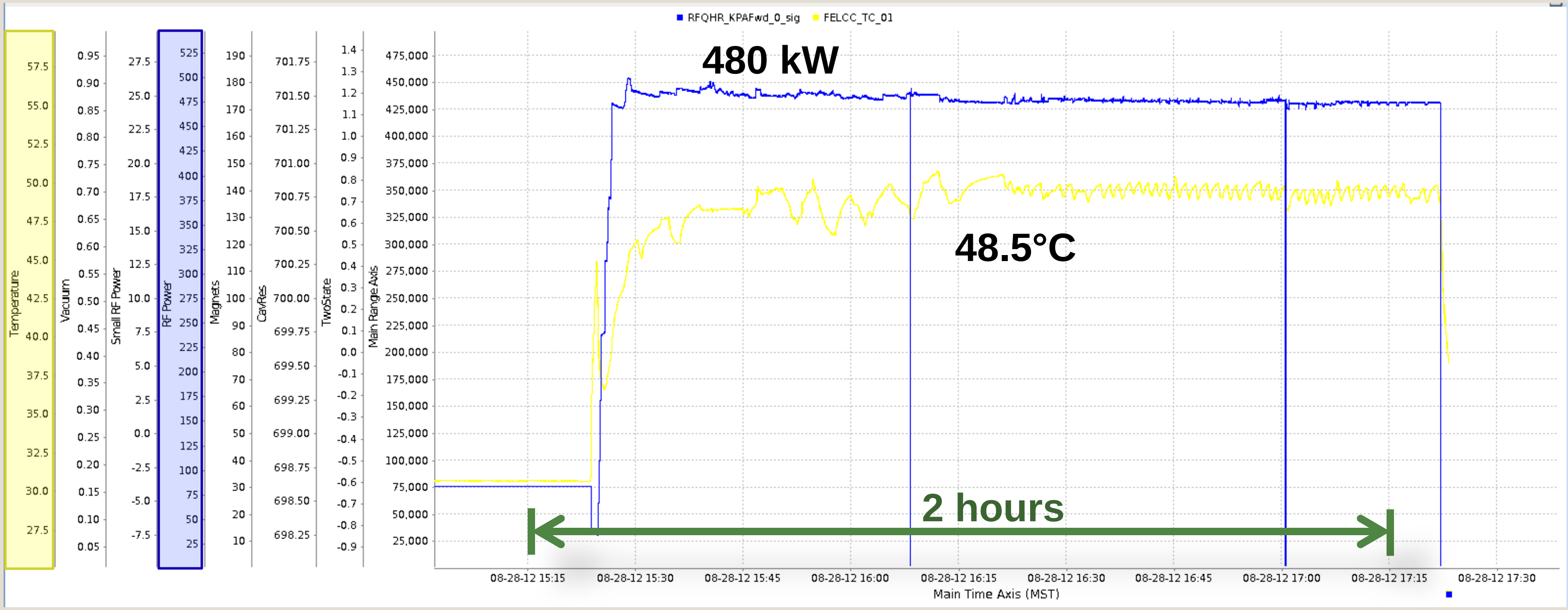
Cathode Transport

- Physical transport
  - nTorr environment
- QE measurement
- Re-cesiation capability
- Precision insertion





Cathode Thermal Management Results



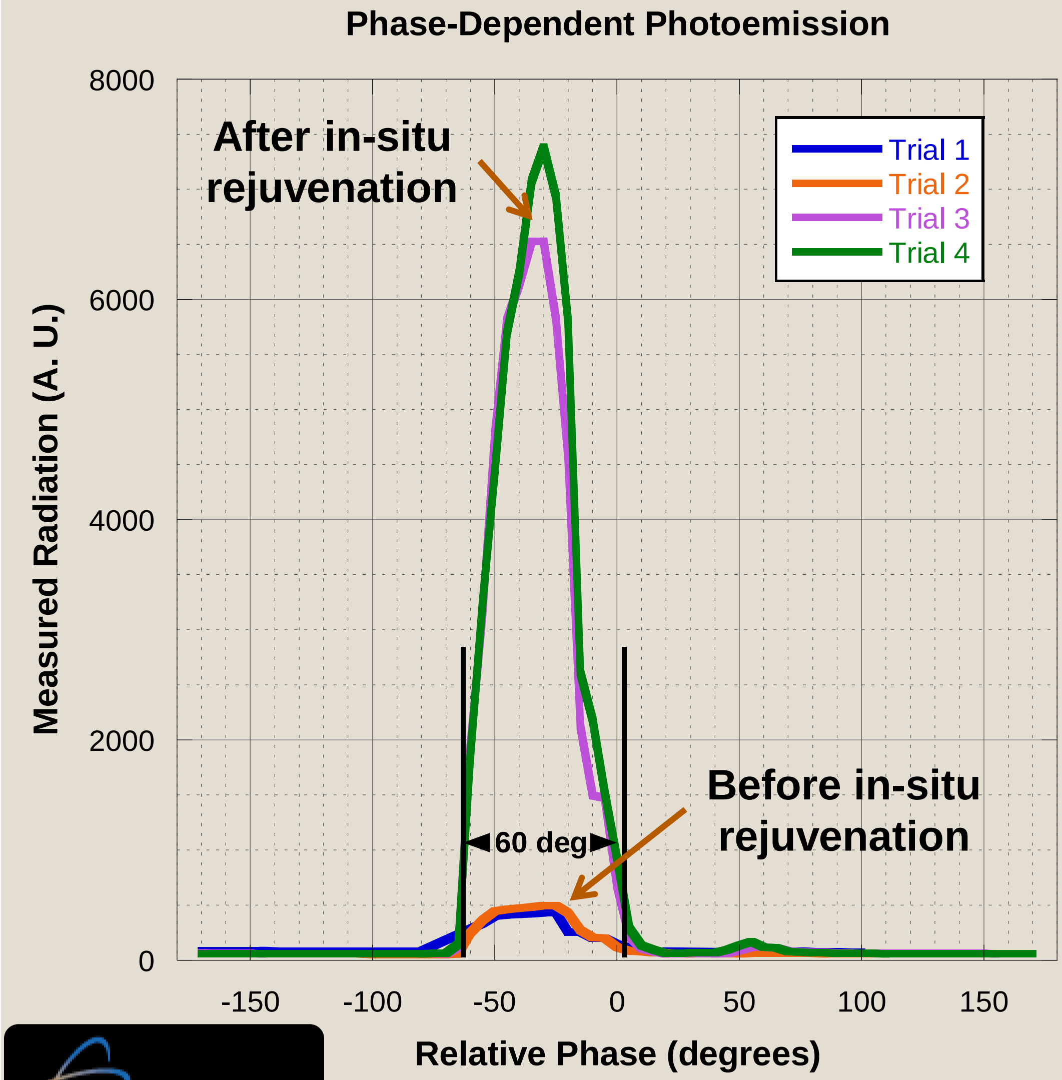
- At 480kW cavity power, cathode temperature stabilized to 48.5 °C
- Copper cathode substrate includes in-situ heater and passivation layer
- 50-100°C temperatures are not detrimental to K2CsSb3 cathodes
- Thermal model accurately predicted (approximate) temperature

Cathode Maintenance Results

- Re-cesiation capability on cart restores majority of QE each run cycle
- Low QE is tolerable at early stages because of beam spill during magnet tuning
- Upon fabrication, QE = 0.5%. Combination of empirical techniques allowed for extended operation with 0.1-0.3% QE
- $T_{1/2} \approx 2.4$ hours, as measured with low laser power
- Potential to 'rejuvenate' in-situ
  - Laser "on" plus frequency tracking yields restored QE
  - Hypothesis is electron bombardment cleaning
  - Possibility of automating this process for convenience
- The same cathode has been used for 20 runs spread out from June to August 2012

Thanks to Howard Padmore (LBNL) for helpful discussions regarding cathode fabrication technique

Phase-dependent photoemission results



- Low average current beam (0.1mA)
- Radiation monitor located directly behind artificial dump
- Phase scan serves as confirmation of photocurrent
- All trials show emission window of about 60 degrees, as expected
- In-situ rejuvenation effects are clear (more than order-of-magnitude improvement)
- $R \propto E(\theta)^{3.5} I(\theta, QE)$

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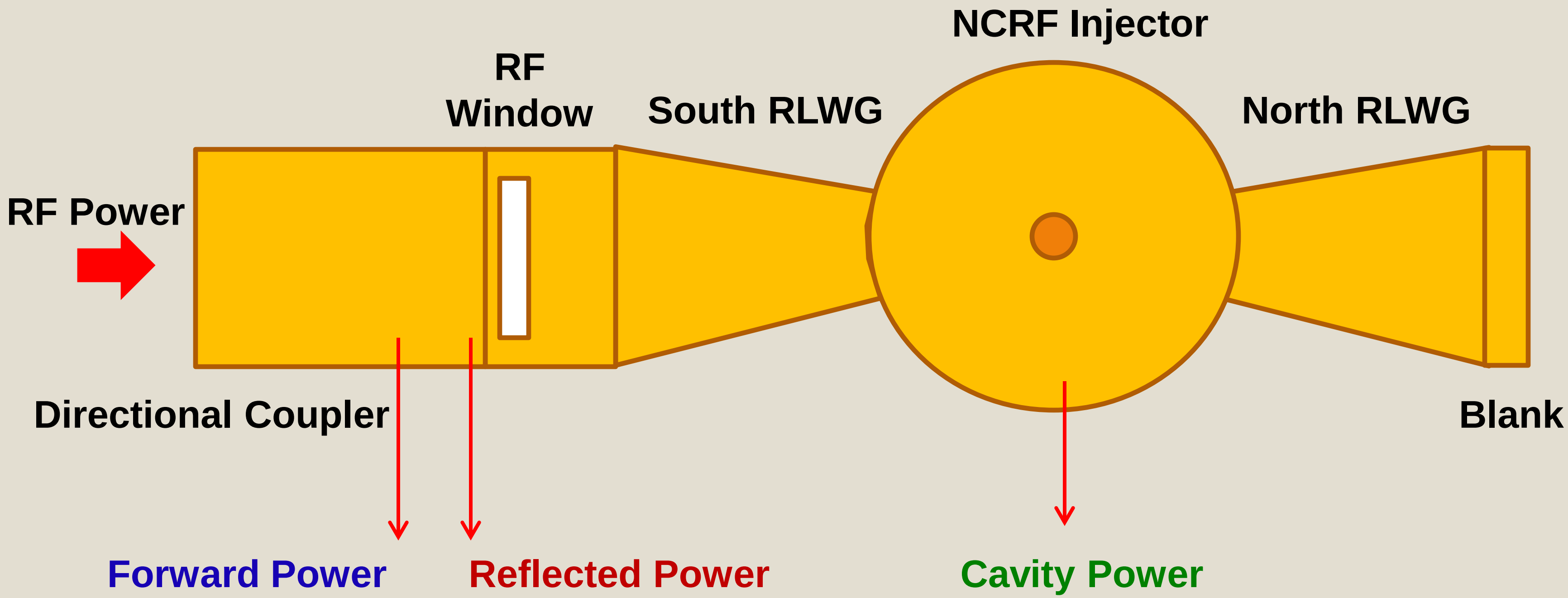
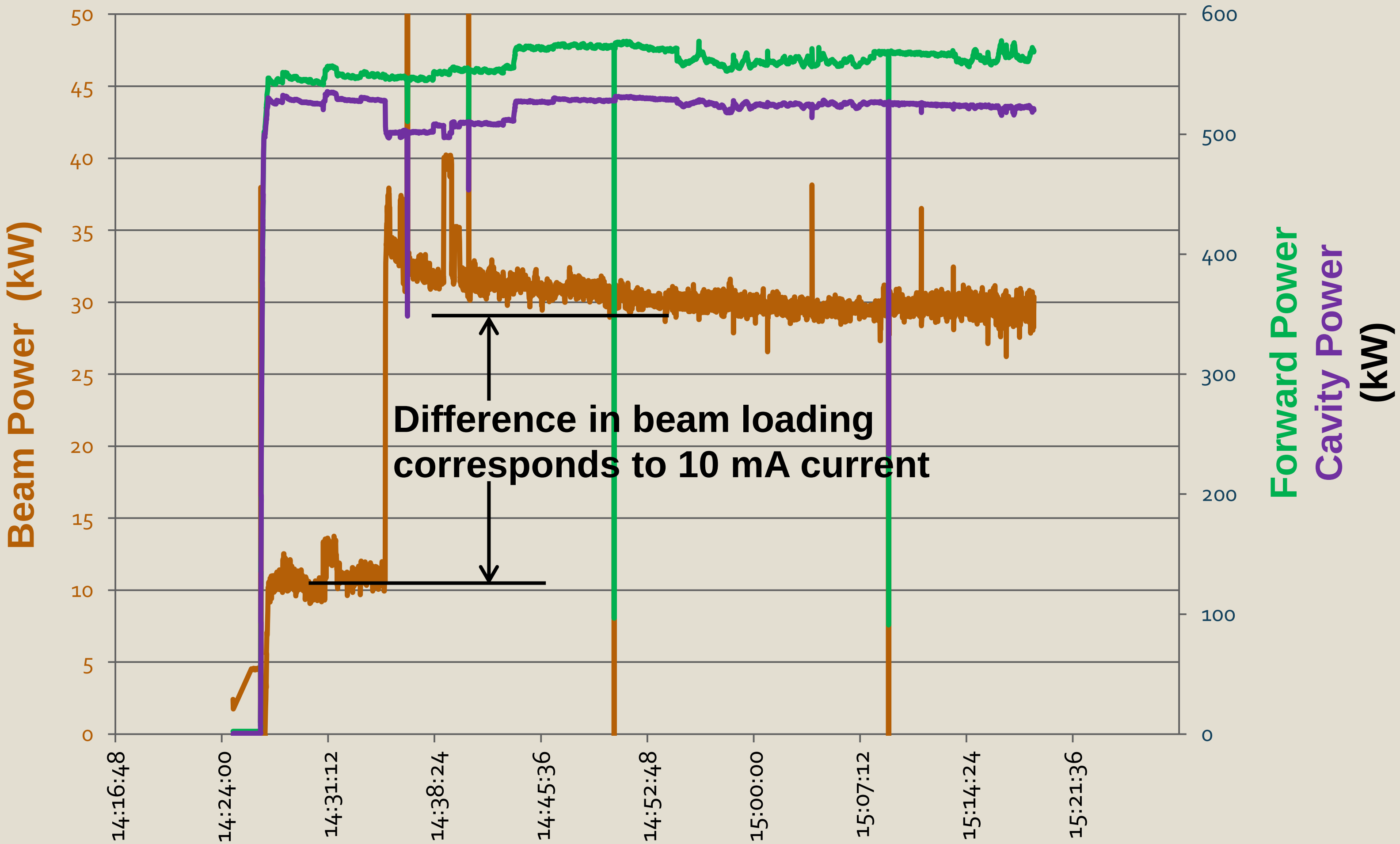
RF Power Measurements



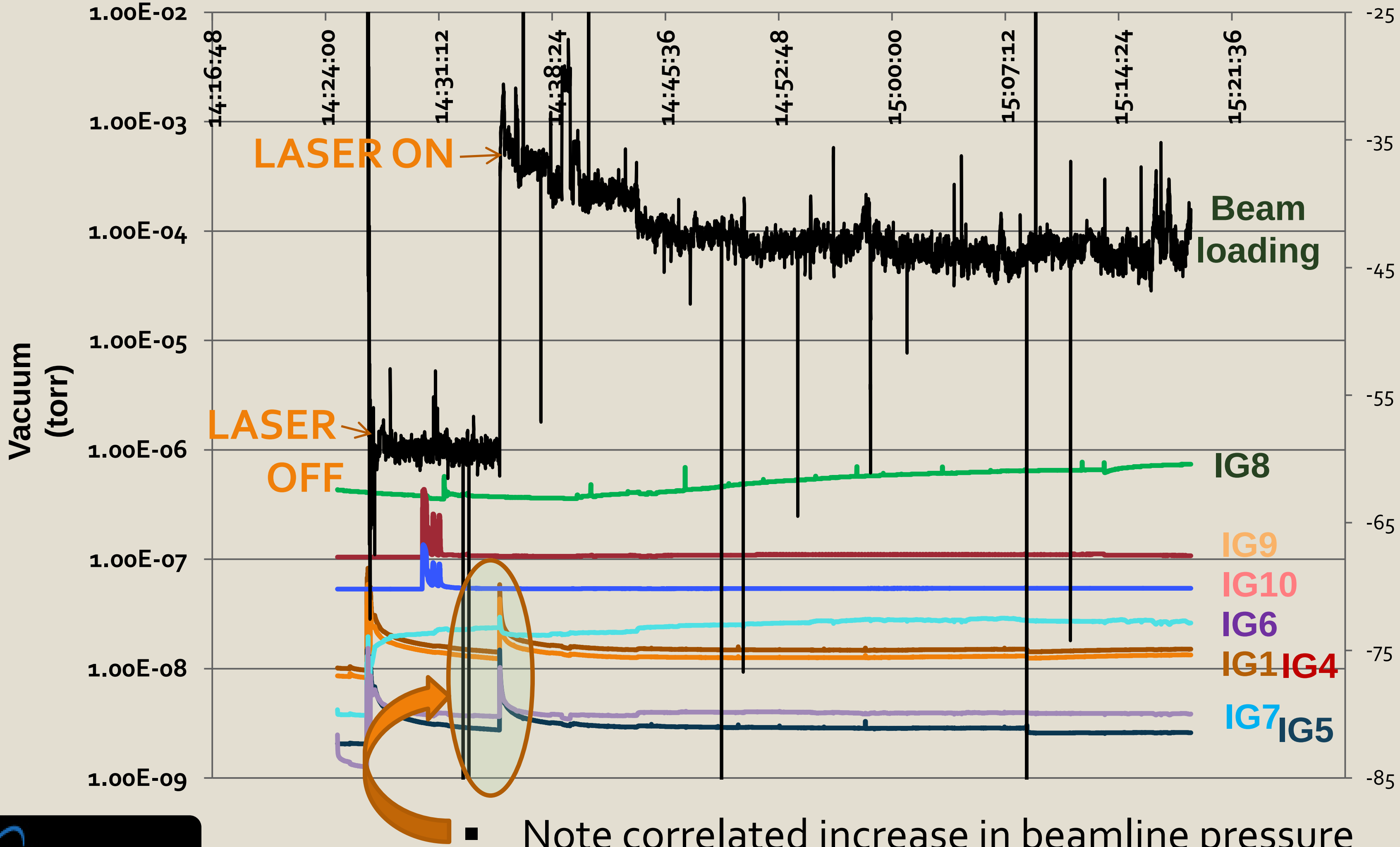
Beam Power = Forward Power – Cavity Power – Reflected Power

First Beam Test Results



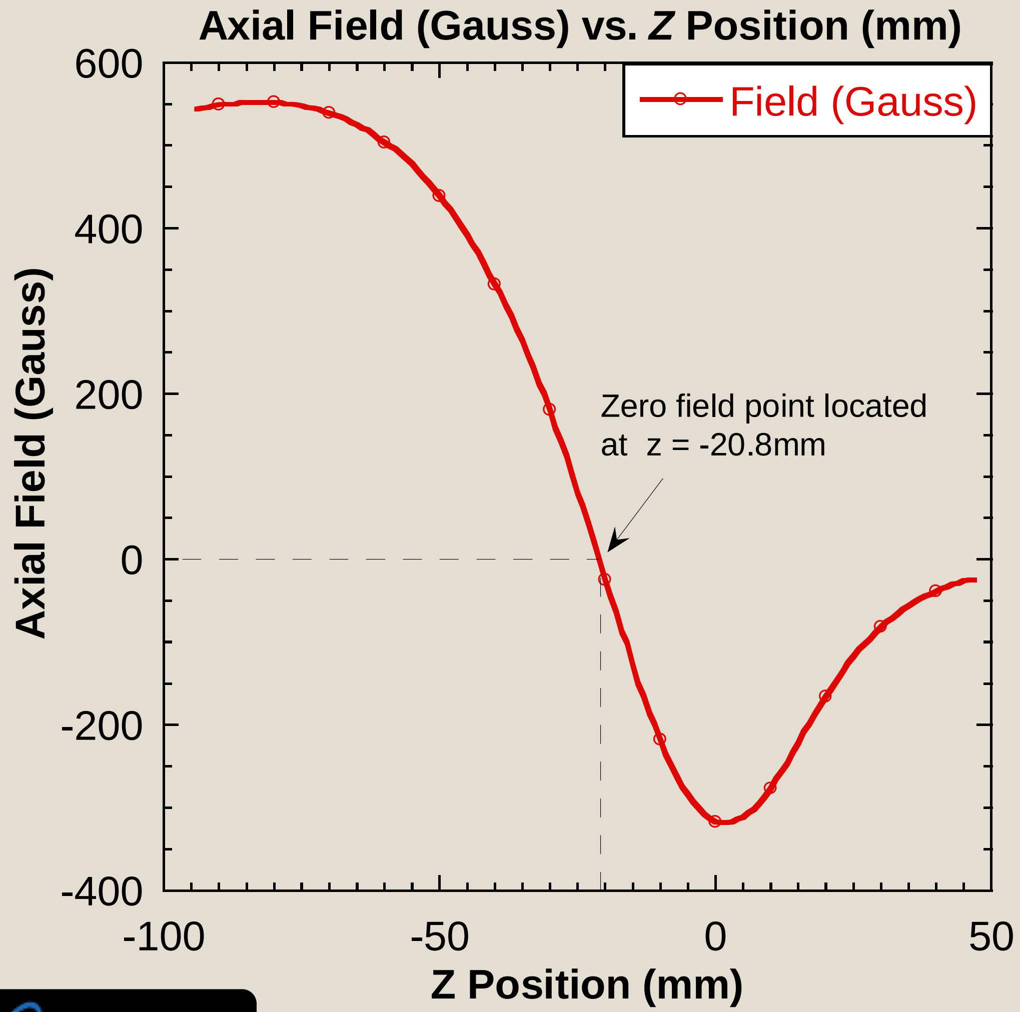
Difference in beam loading corresponds to 10 mA current

First Beam Test Results

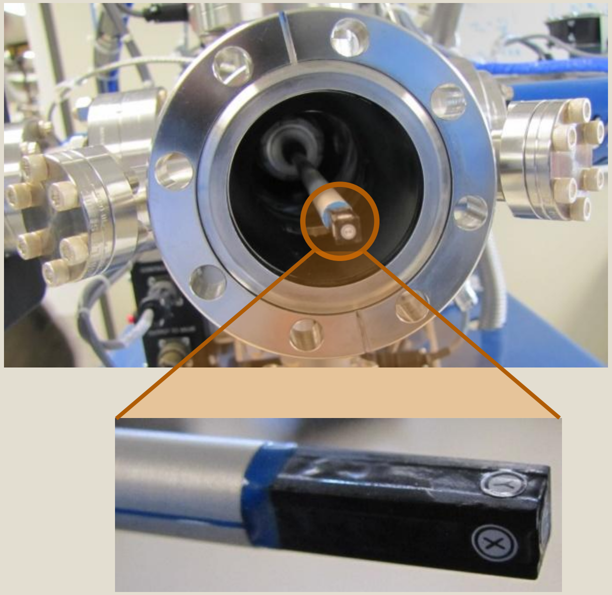


- Note correlated increase in beamline pressure

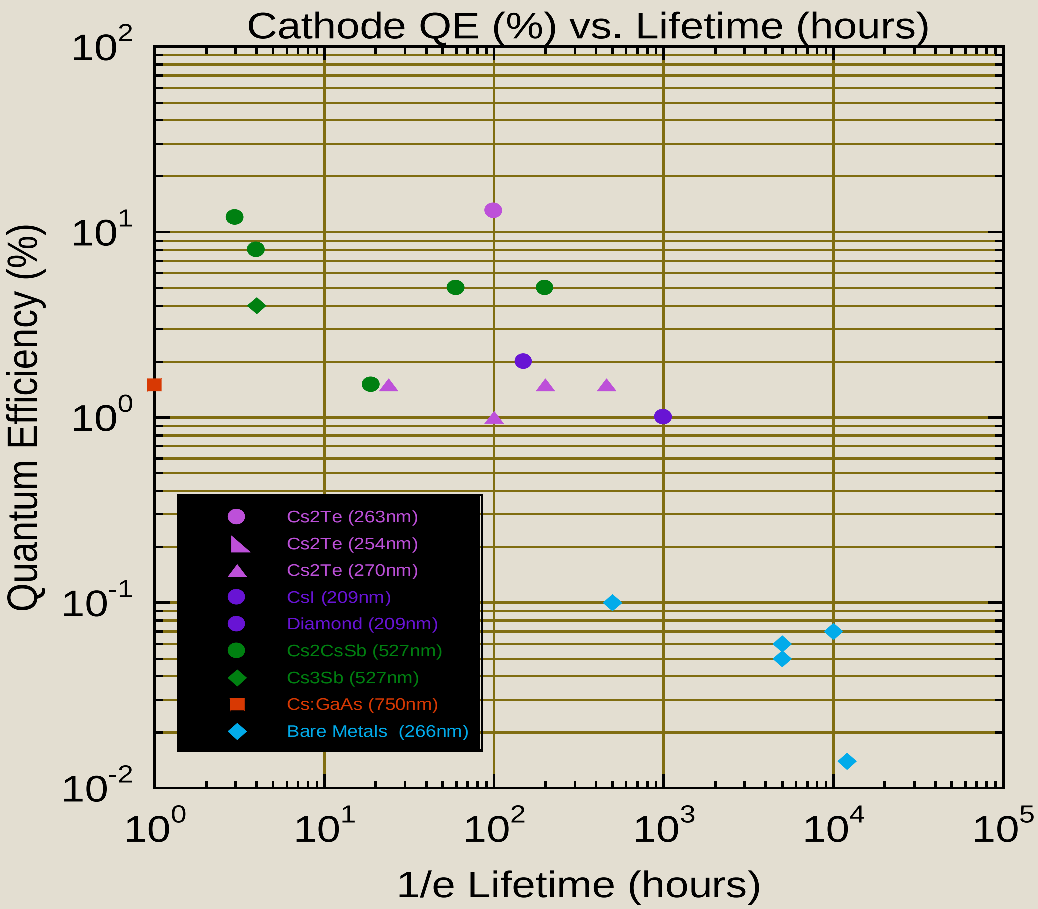
Solenoid field mapping and adjustment



- In-situ field mapping
- Changes w.r.t. bench testing on the order of 10 Gauss.
- Focusing magnet polarity was reversed.



Parameters for high average current



	532 nm
QE	100 mA
1%	23 W
4%	5.9 W
8%	2.9 W

	355 nm
QE	100 mA
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7%	5 W

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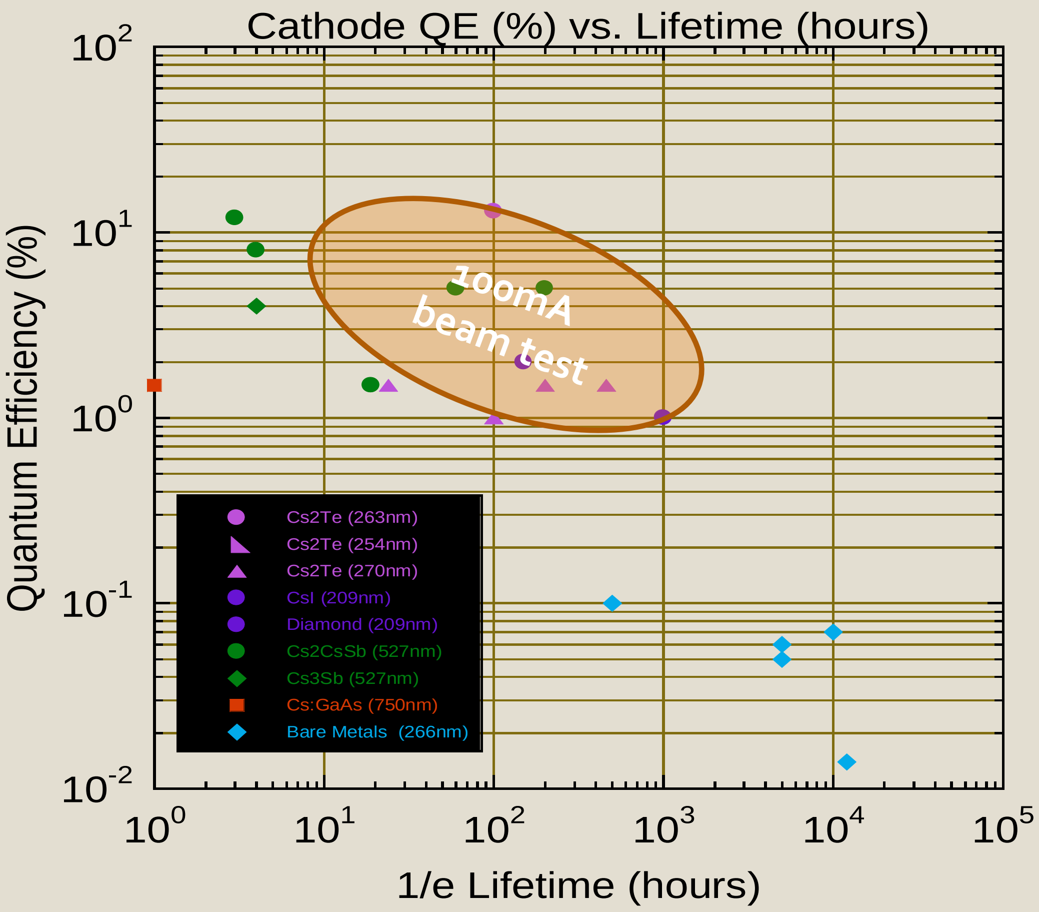

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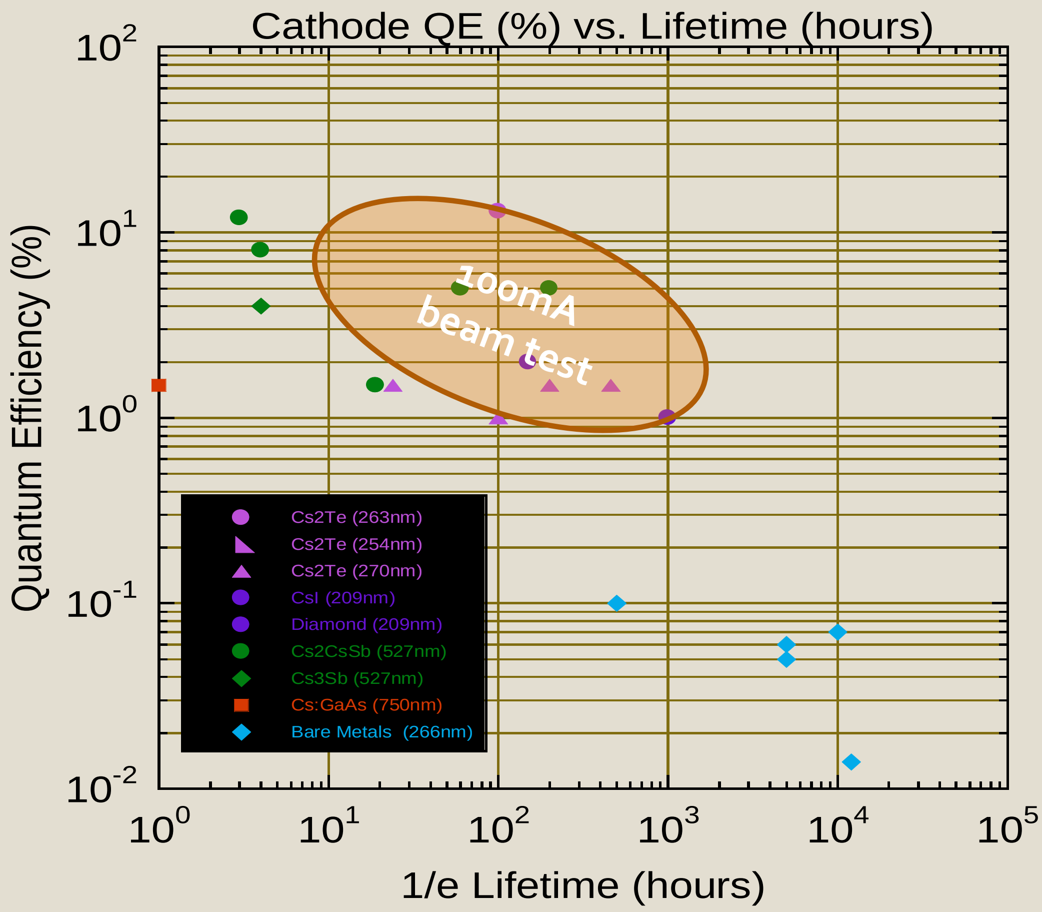

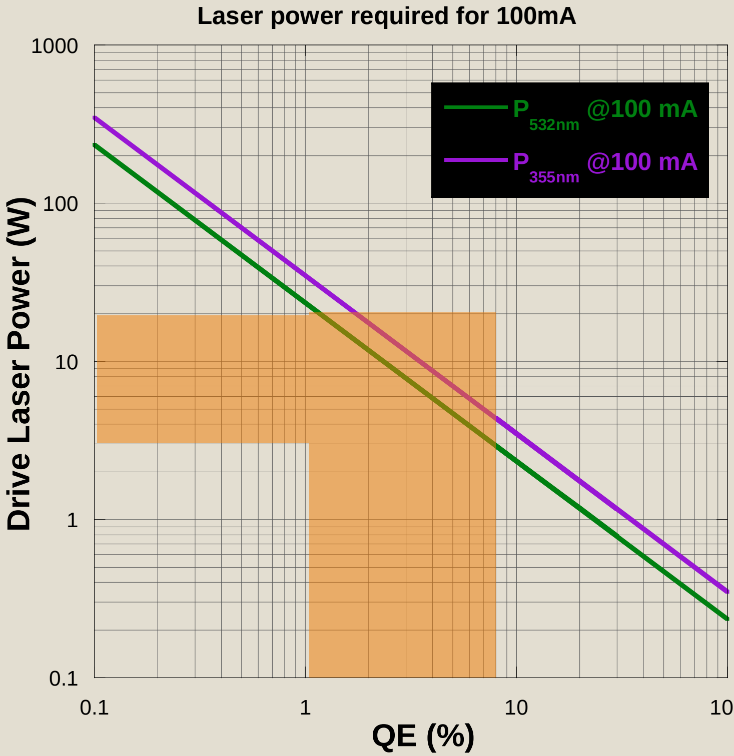

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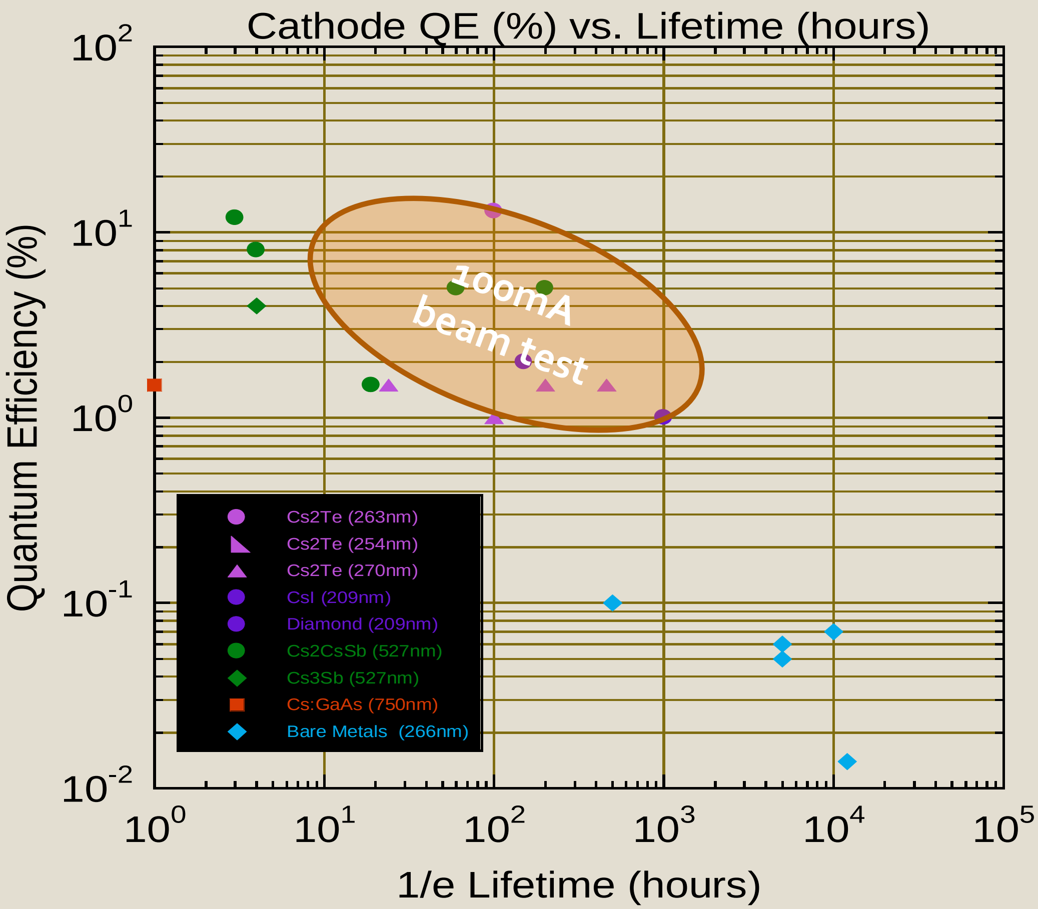

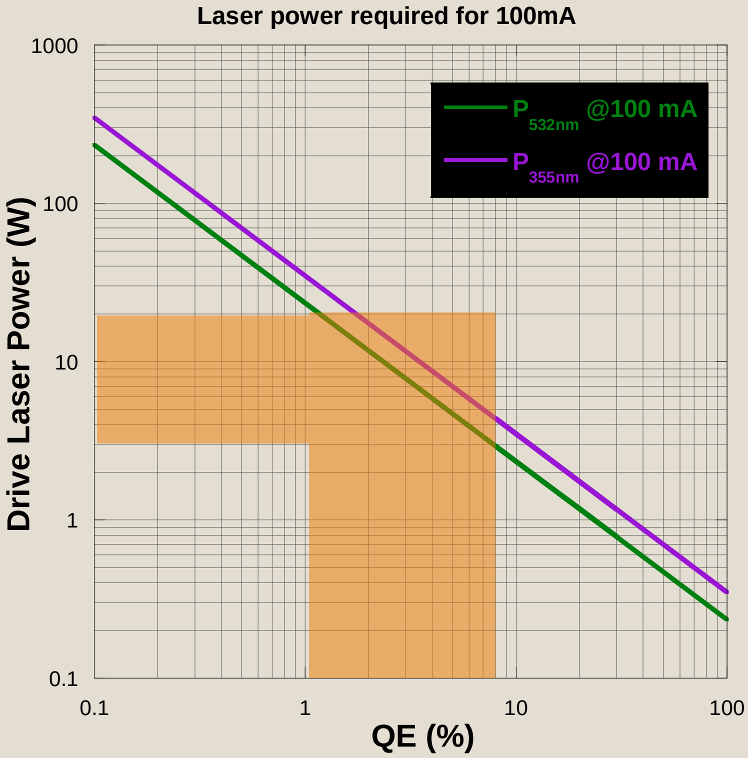

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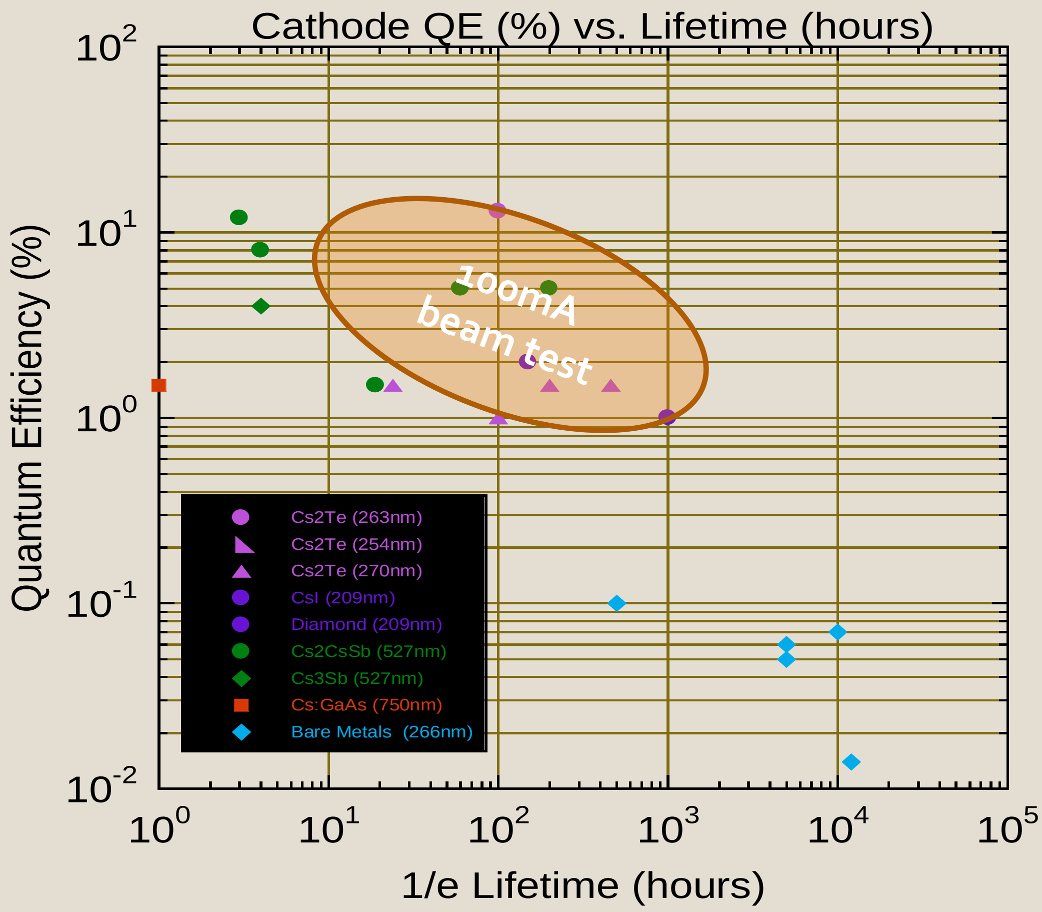

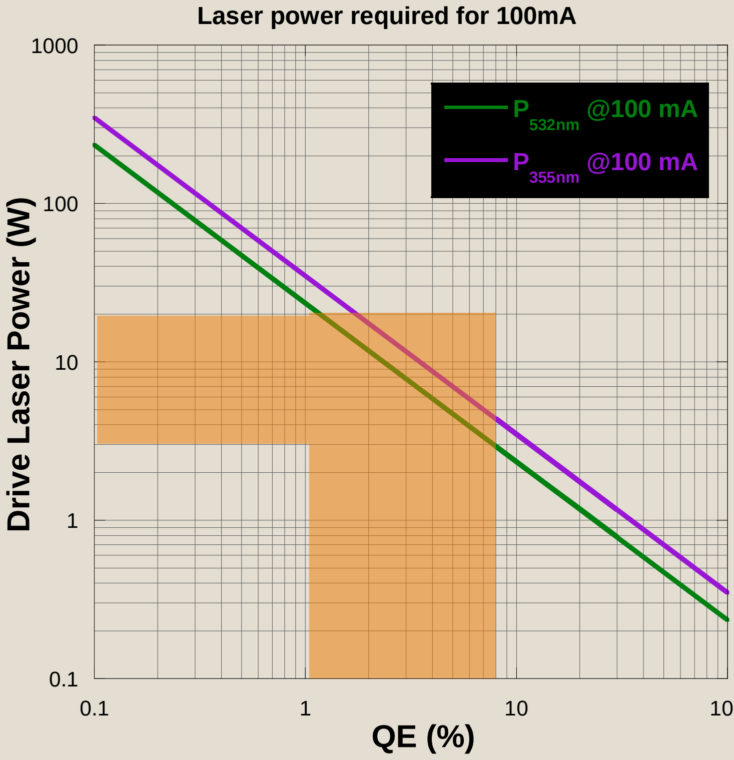

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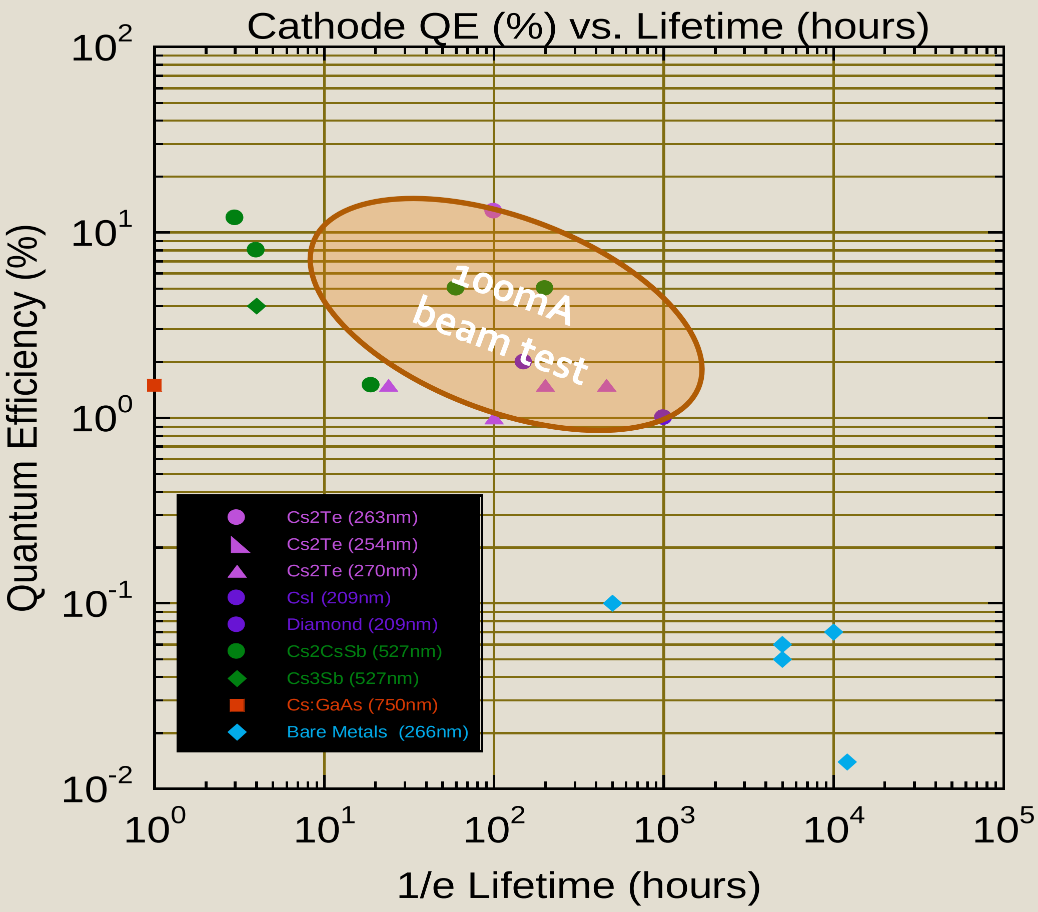

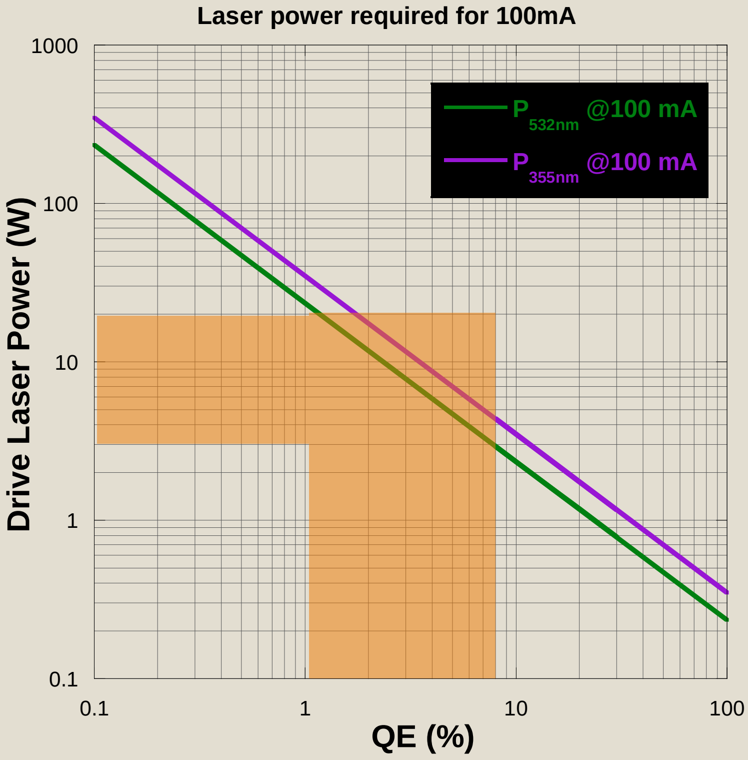

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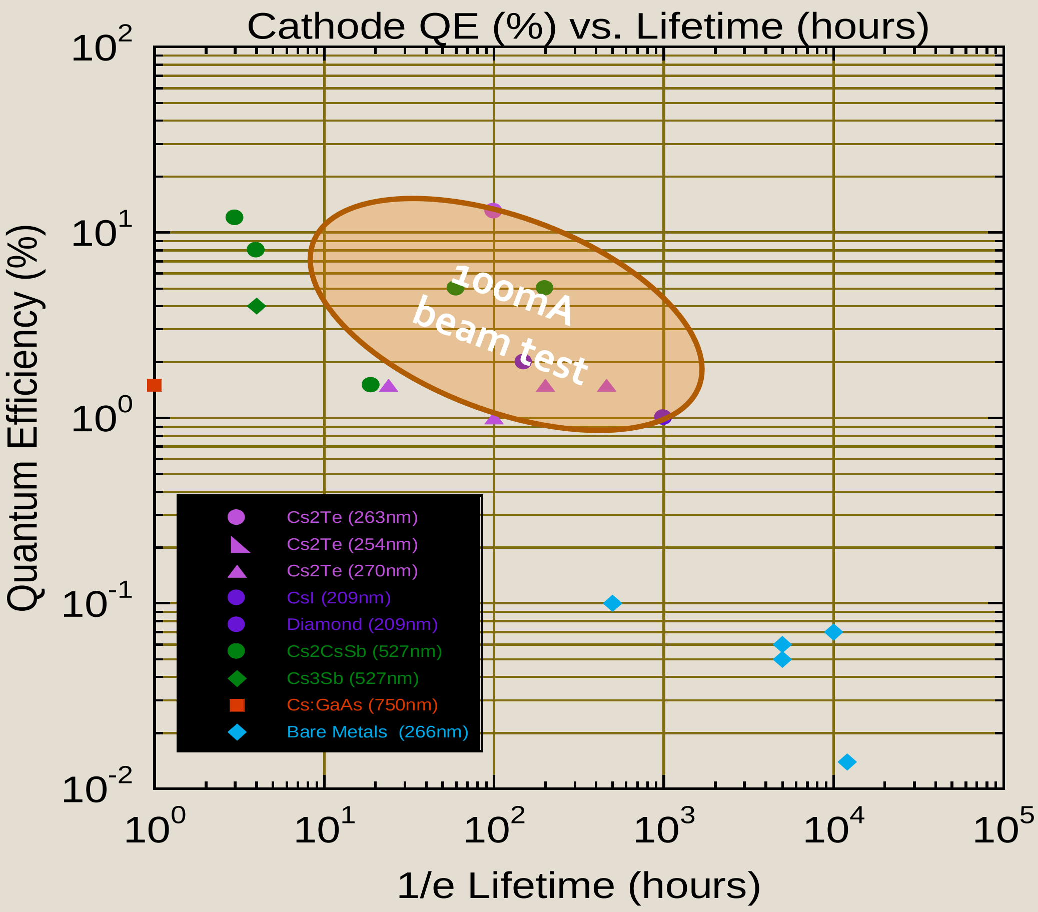

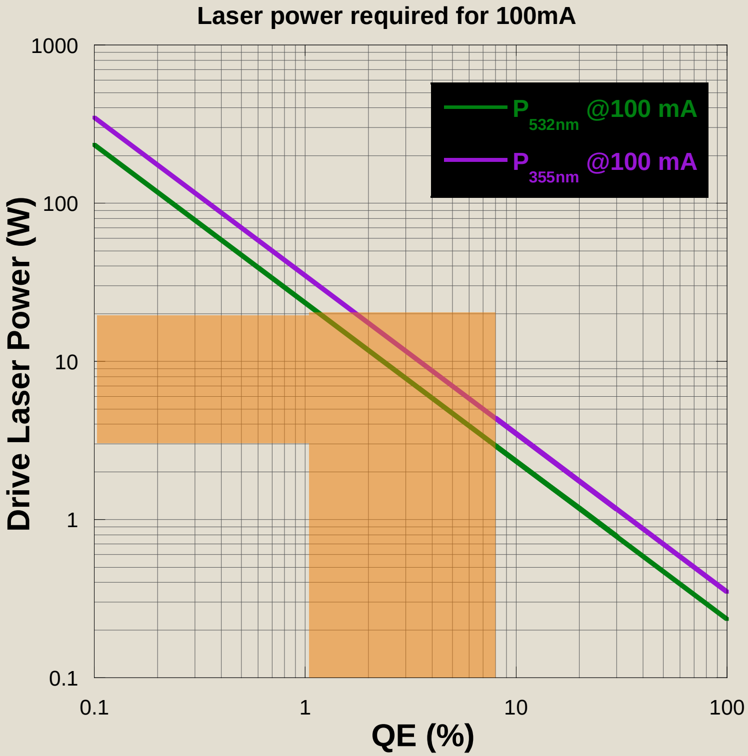

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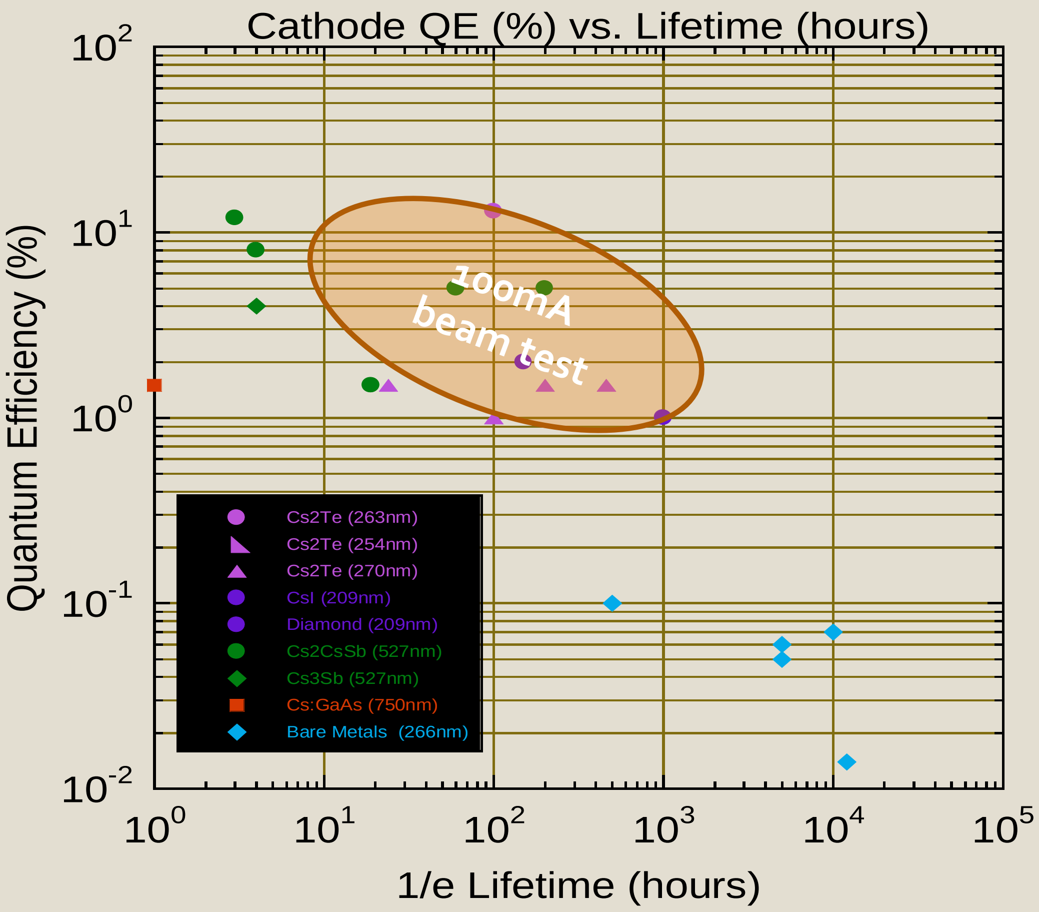

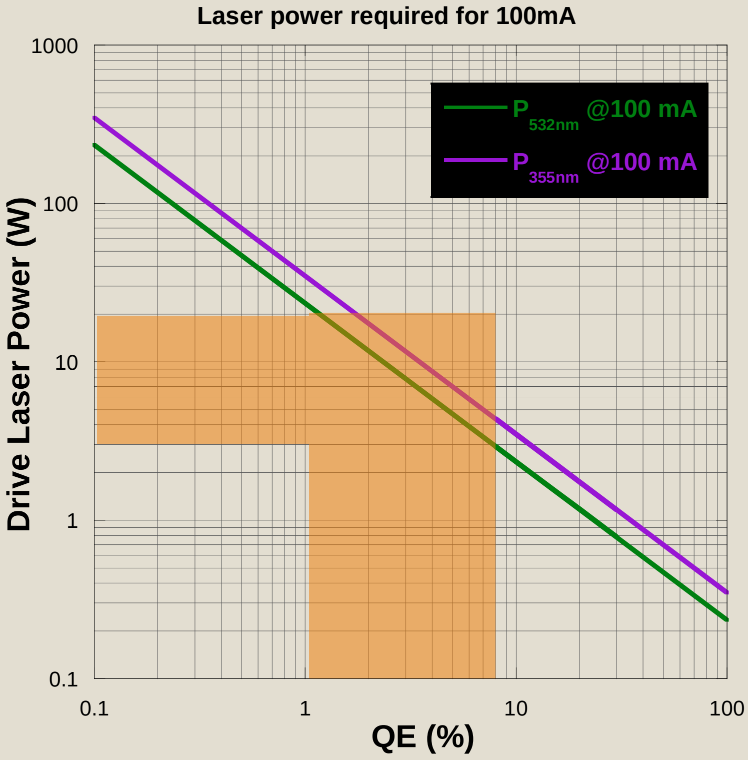

Routine

Low risk →

High risk →

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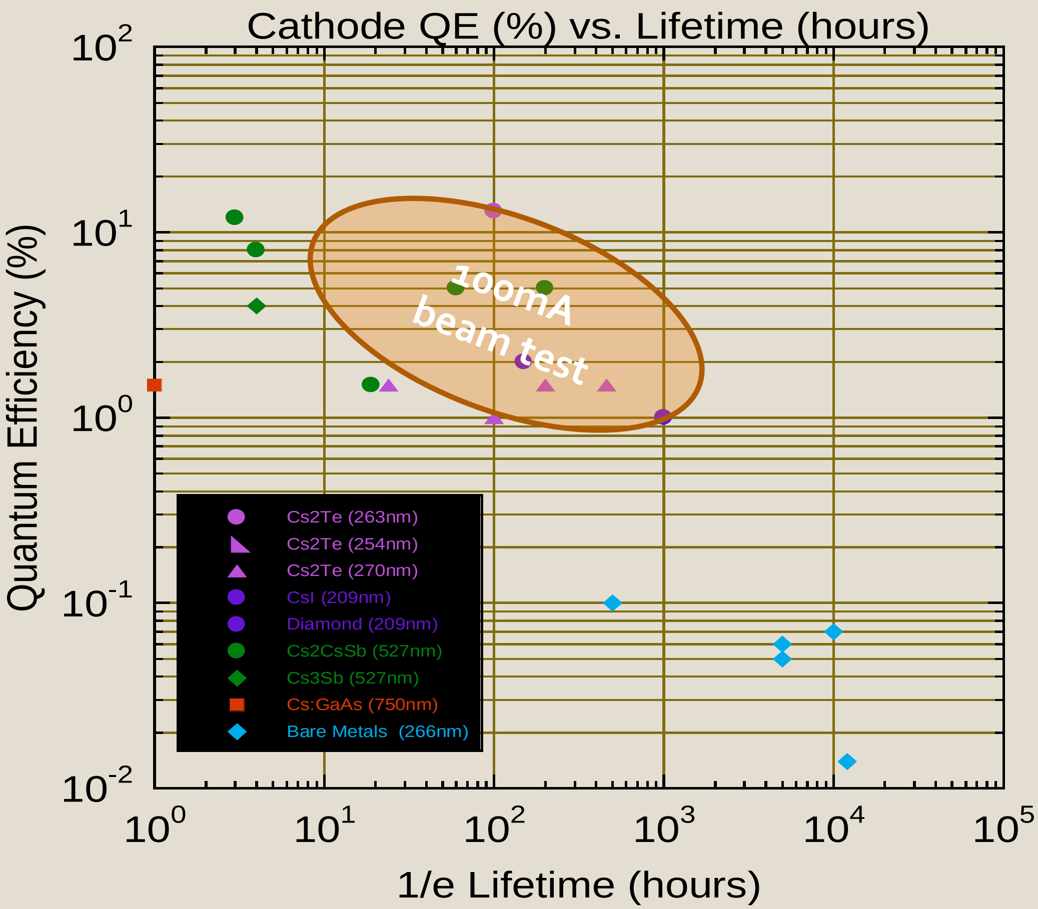

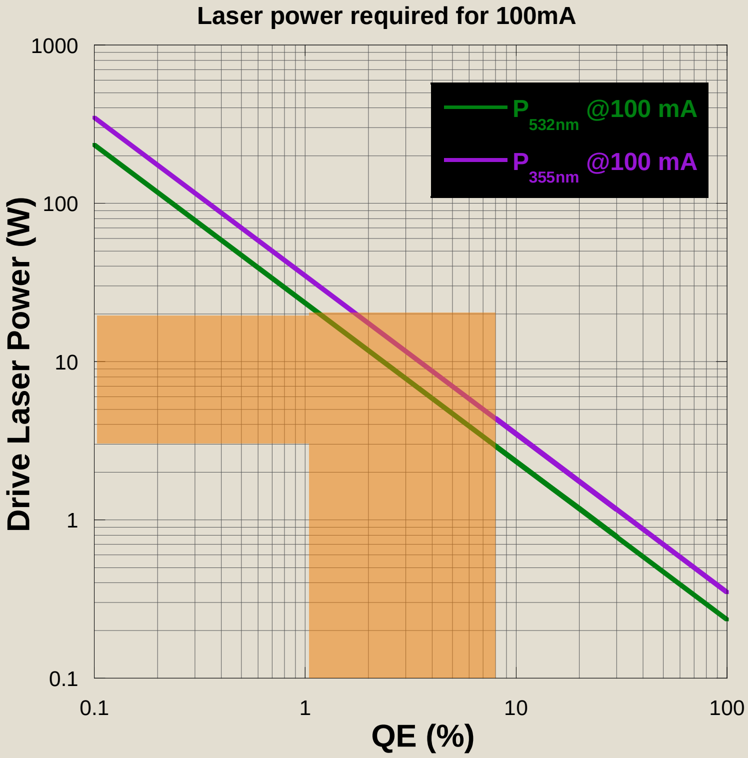

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Conclusions

- 700 MHz NCRF injector
  - Thermal test and conditioning completed
  - K_2CsSb use appears feasible
  - Transport of cathodes demonstrated
  - 1-10 mA demonstration using 7W @ 532nm
  - Cathode maintenance techniques identified

Thermal Testing

Field Emission

LLRF Control

532nm Beam Test

Cathode Maintenance

- Next steps
  - Understanding cathode improvement
  - Beam characterization
  - 100mA demonstration using 20W 355nm