Lifetime Measurements of GaAs Photocathodes at the Upgraded Injector Test Facility at Jefferson Lab*

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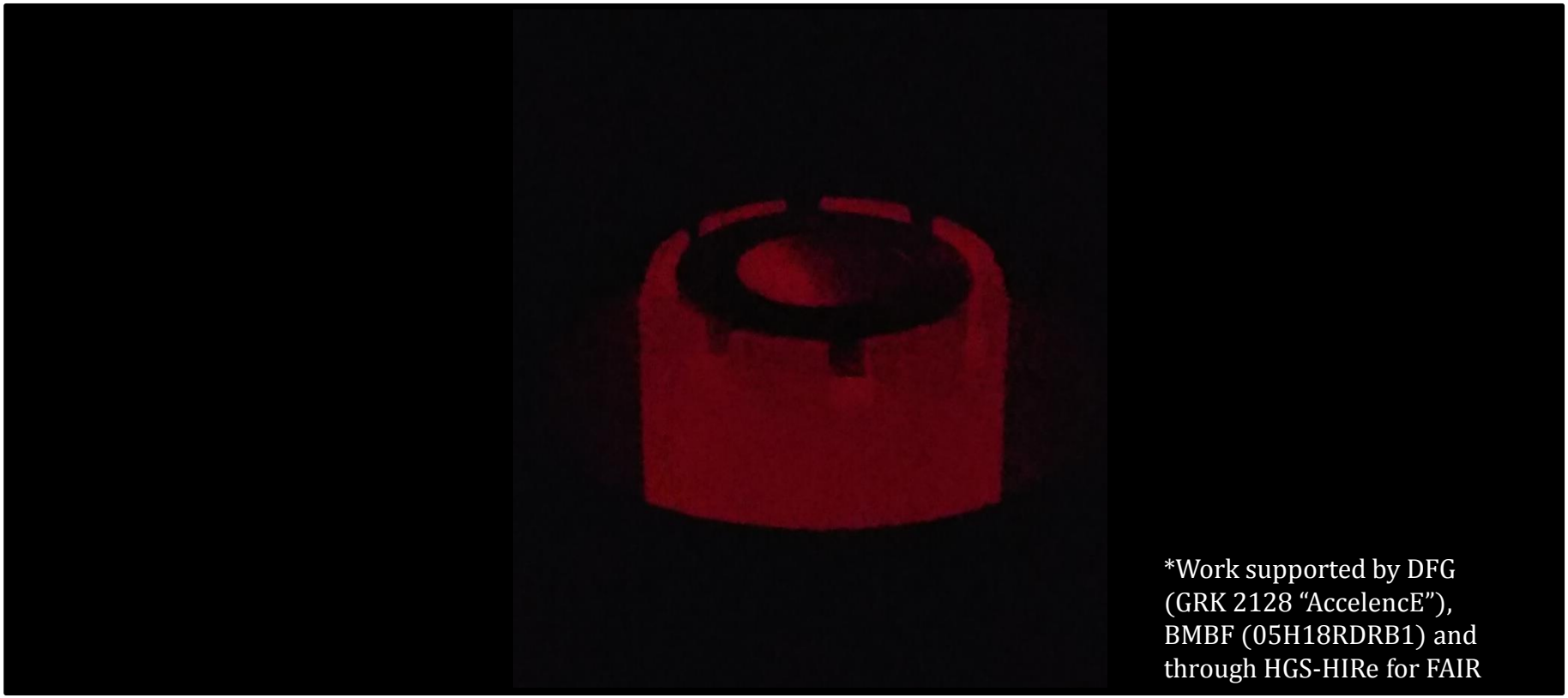
ACCELENCE



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Introduction

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- GaAs-based photocathodes used to produce spin-polarized electron beams
- Posesses negative electron affinity (NEA) when activated with specific surface layer (Cs and oxidant, e.g. O_2 or NF_3) → different methods possible
- Quantum efficiency η and lifetime τ highly depend on quality /composure of NEA layer
- η characterizes electron emission efficiency
- τ characterizes decay of NEA layer
- High η and τ desired for optimal accelarator operation

Lifetime Modeling

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$$\frac{1}{\tau} = \sum_i \frac{1}{\tau_i} = \overbrace{\frac{1}{\tau_{vac}} + \frac{1}{\tau_{fe}}}^{\text{charge-free lifetime}} + \overbrace{\frac{1}{\tau_{loss}} + \frac{1}{\tau_{ibb}}}^{\text{charge lifetime}}$$

with:

$\tau_{vac} = \tau_d$

charge lifetime $= \tau_c$

Vacuum lifetime: Vacuum conditions

Field emission: Material and Electrode design

Particle losses: Small emittance

Ion back-bombardment: H_2 vacuum conditions

$$\eta(t) = \eta_0 \times e^{\left(-\frac{t}{\tau}\right)} = \eta_0 \times e^{\left(-\frac{t}{\tau_d} - \frac{Q(t)}{k_c}\right)} \quad \text{for} \quad I \neq \text{const.} \quad \text{with} \quad Q(t) = \int_0^t I(\tilde{t})\, d\tilde{t}$$

$$= \eta_0 \times e^{-t \times \left(\frac{1}{\tau_d} + \frac{1}{\tau_c}\right)} \quad \text{for} \quad I = \text{const.} \quad \text{with} \quad \frac{1}{\tau_c} = \frac{I}{k_c}$$

Li-enhanced activation

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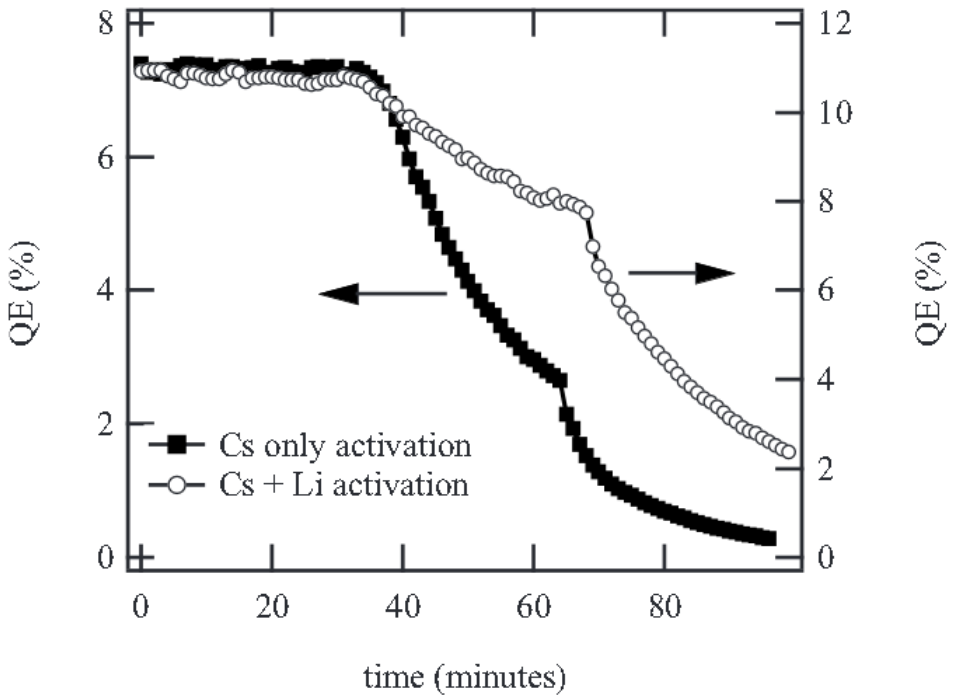
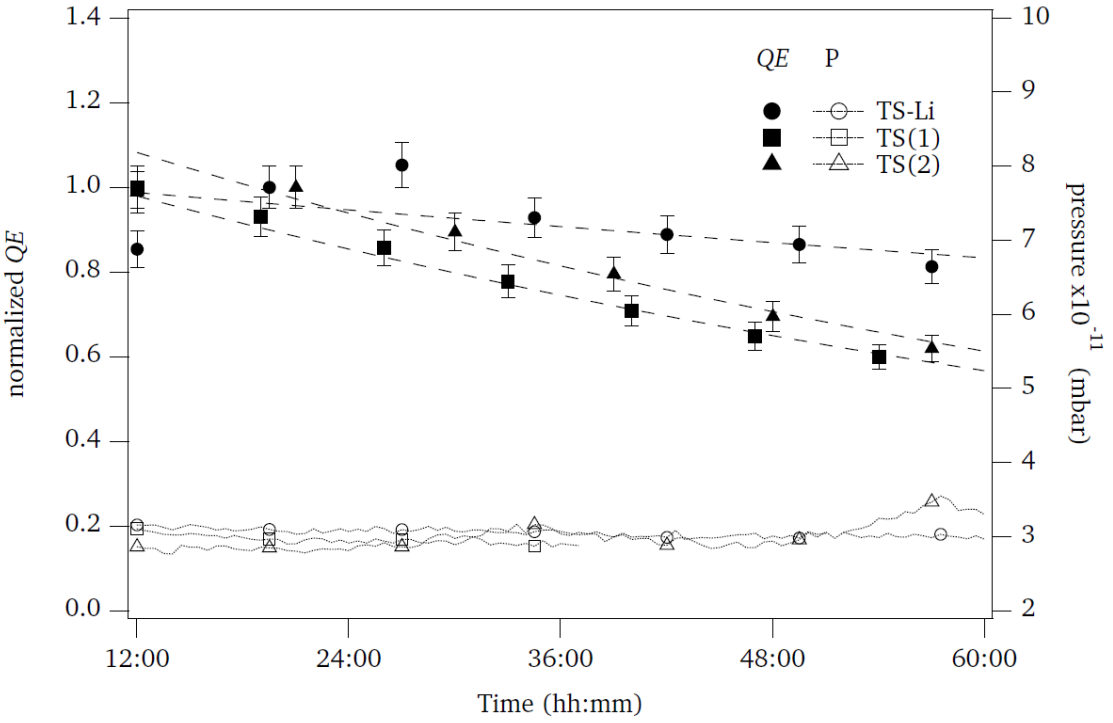
- G. A. Mulhollan and J. C. Bierman: study on Cs+Li+NF_3 activation
- Increase of η and τ_d reported @633 nm
- Further study by Y. Sun et al. (2009) on surface layer using synchrotron radiation photoemission



G. A. Mulhollan and J. C. Bierman, *Enhanced chemical immunity for negative electron affinity,* J. Vac. Sci. Technol. A, Vol. 26, No. 5 (2008)

Li-enhanced activation

- Recent study at TU Darmstadt on $Cs+Li+O_2$ activation by N. Kurichiyanil et al.
- Reduced η observed: (20±1) % vs (26±1) % @405 nm
- Increased τ_d reported: (298±35) h vs (88±1) h
- No studies on τ_c yet!



N. Kurichiyanil *et al., A test system for optimizing quantum efficiency and dark lifetime of GaAs photocathodes,* Journal of Instrumentation 14 P08025 (2019)

UITF at JLab

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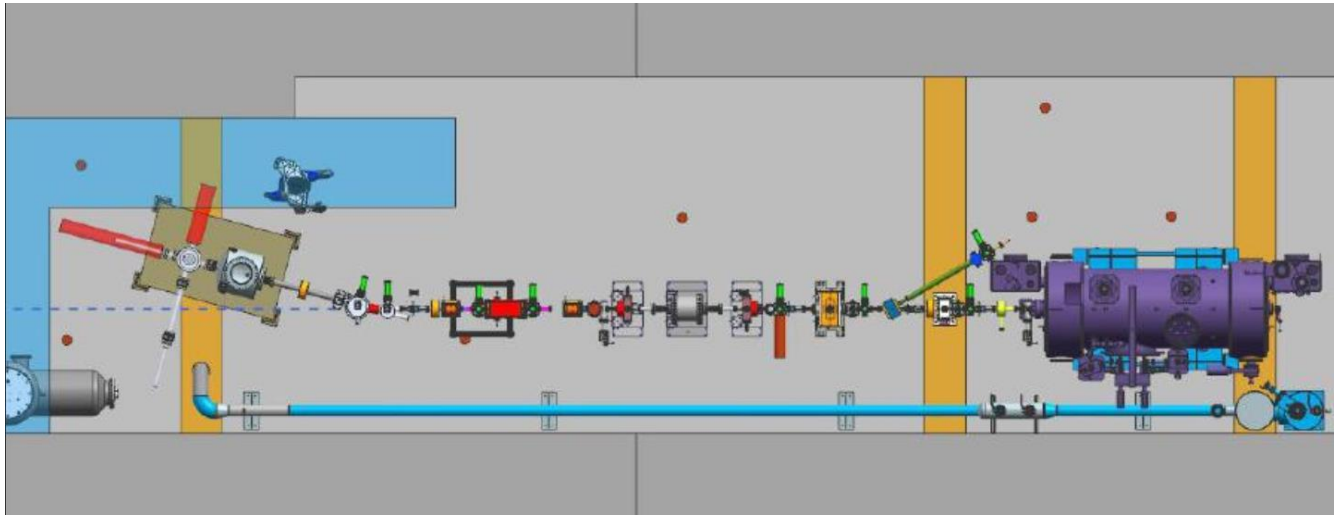
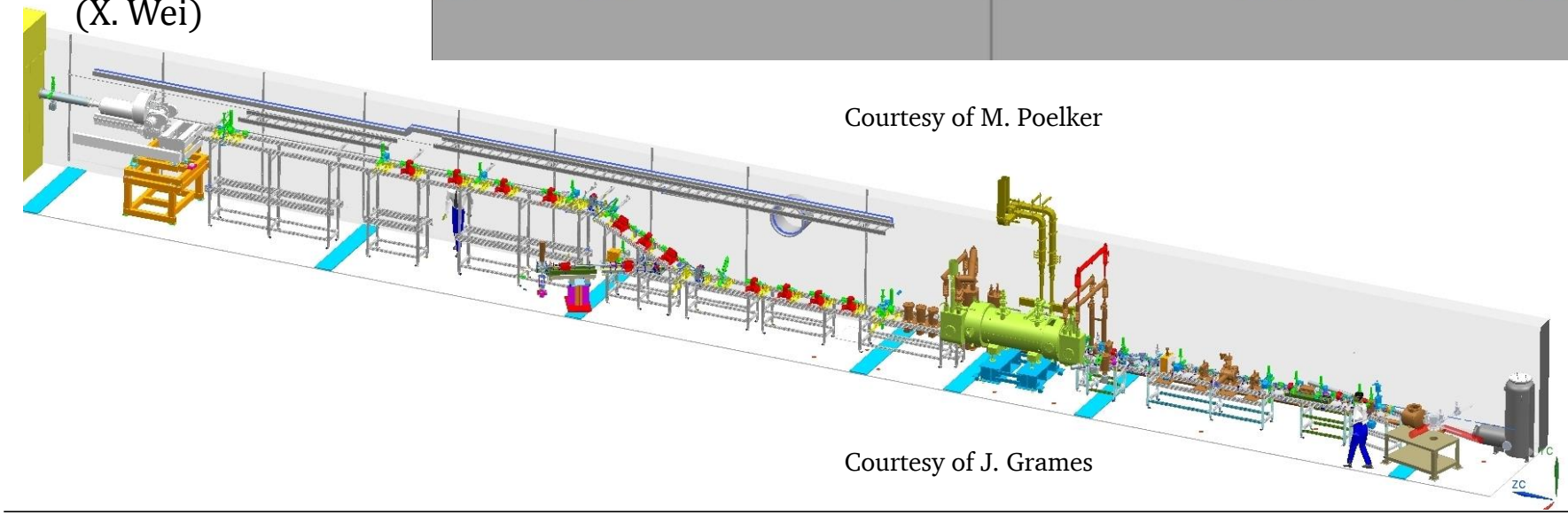
- Research and development facility for CEBAF at JLab
- 10 MeV beamline for experiments (HDice)

→ see talk on Friday (X. Wei)



Courtesy of M. Poelker



Courtesy of J. Grames

UITF Source Section

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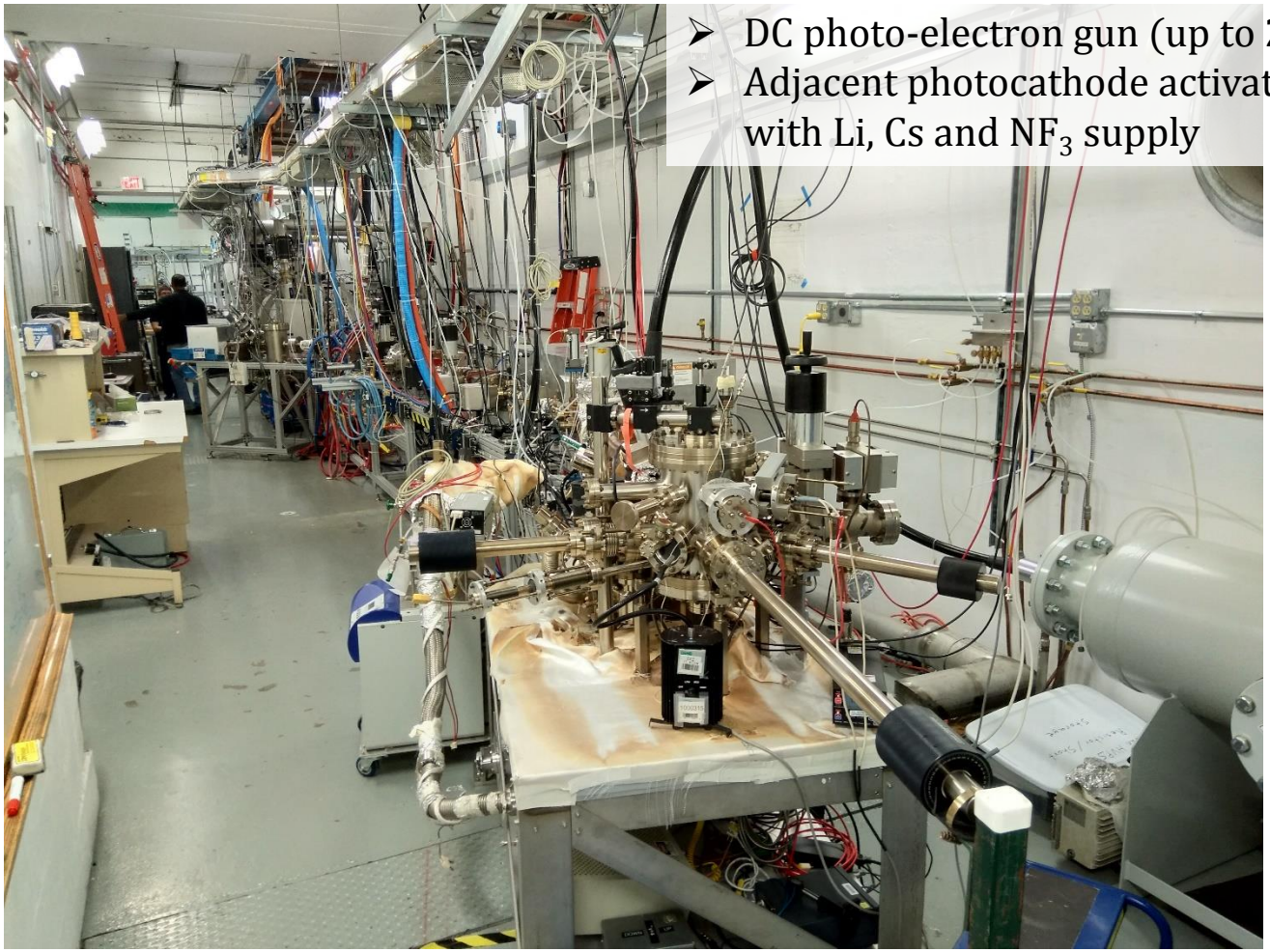
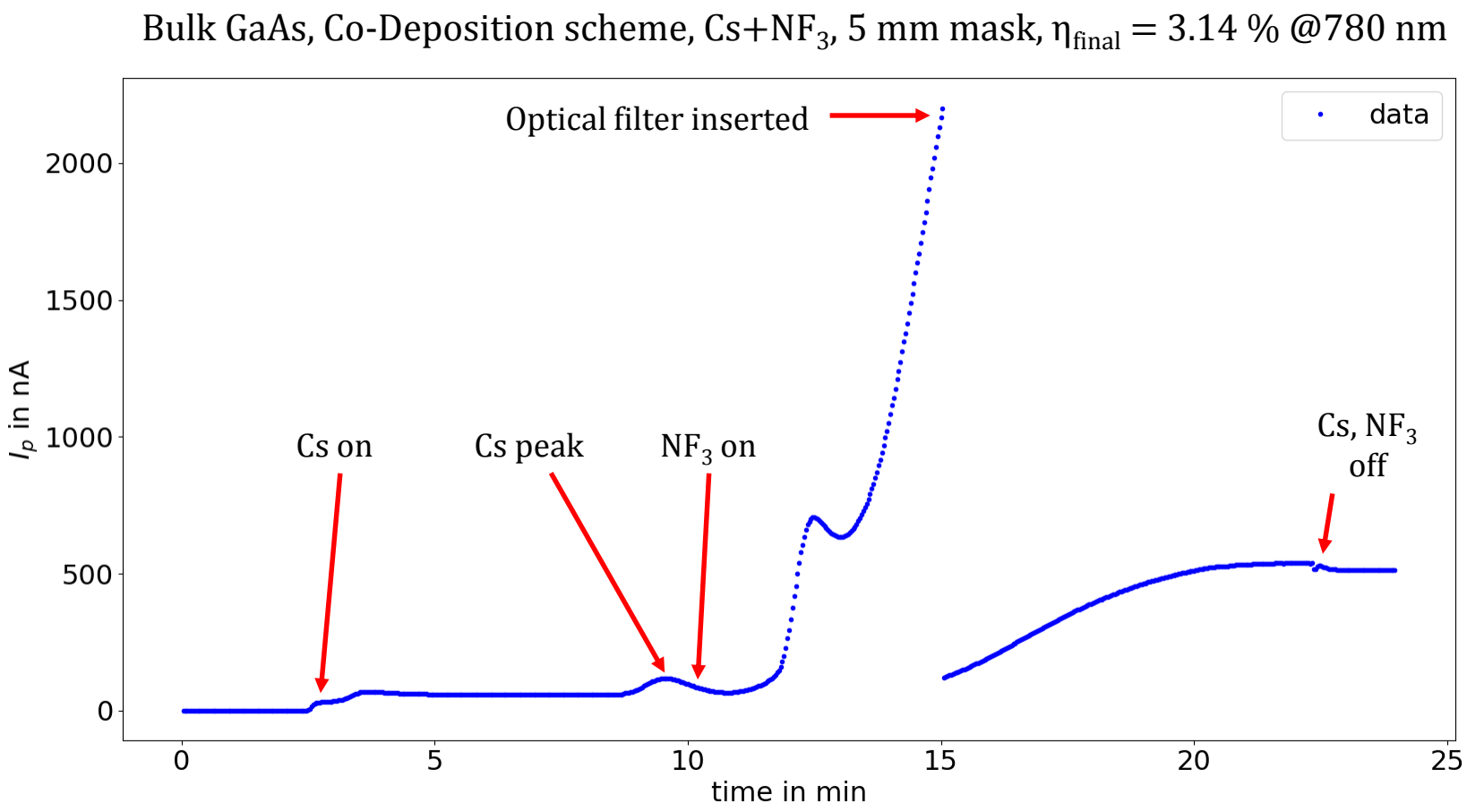


- DC photo-electron gun (up to 200 kV)
- Adjacent photocathode activation chamber with Li, Cs and NF_3 supply

Photocathode activation



Photocathode activation

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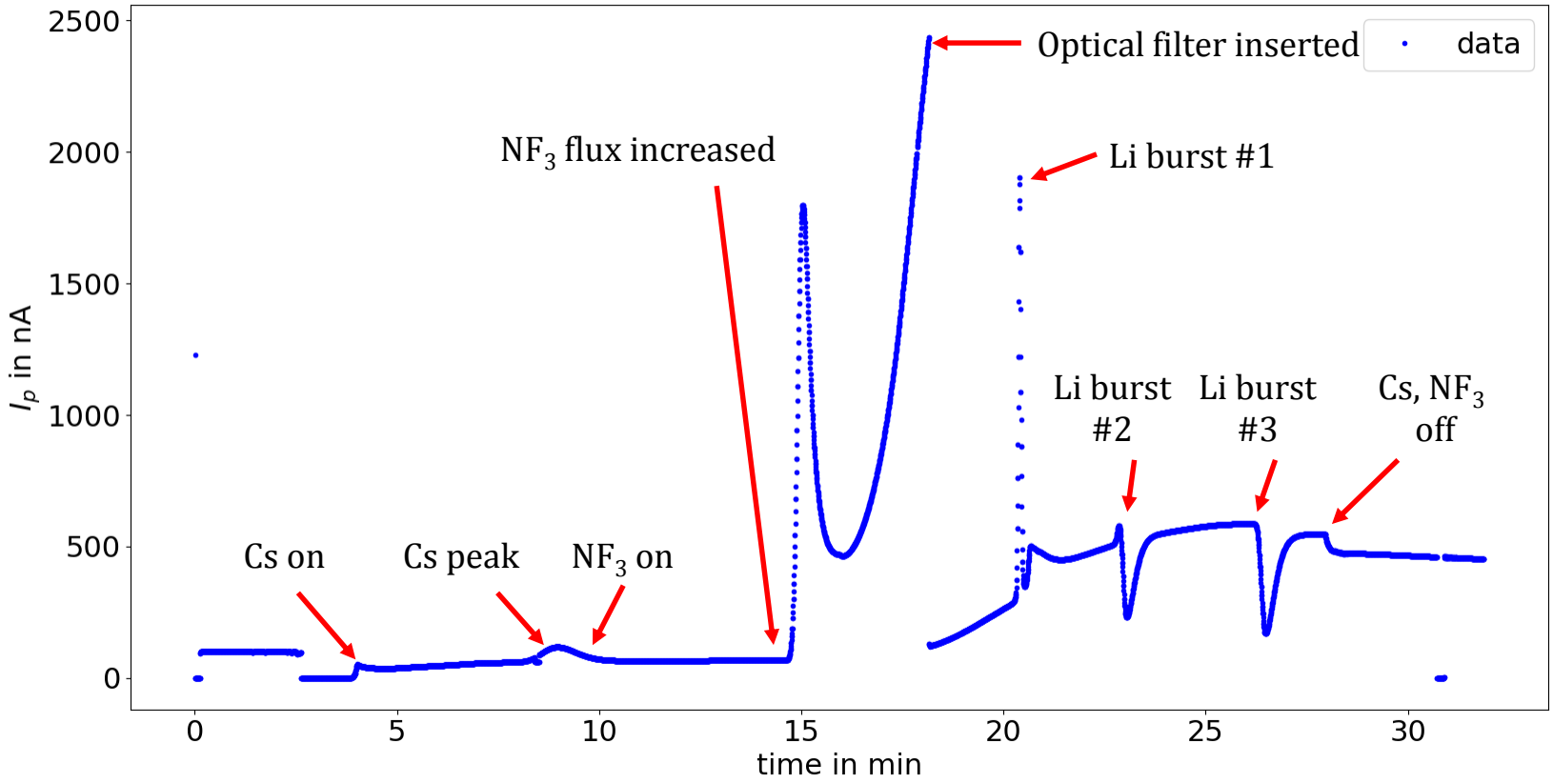
Bulk GaAs, Co-Deposition scheme, Cs+Li+NF_3, 5 mm mask, η_{final} = 2.75 % @780 nm



Quantum Efficiency Scans

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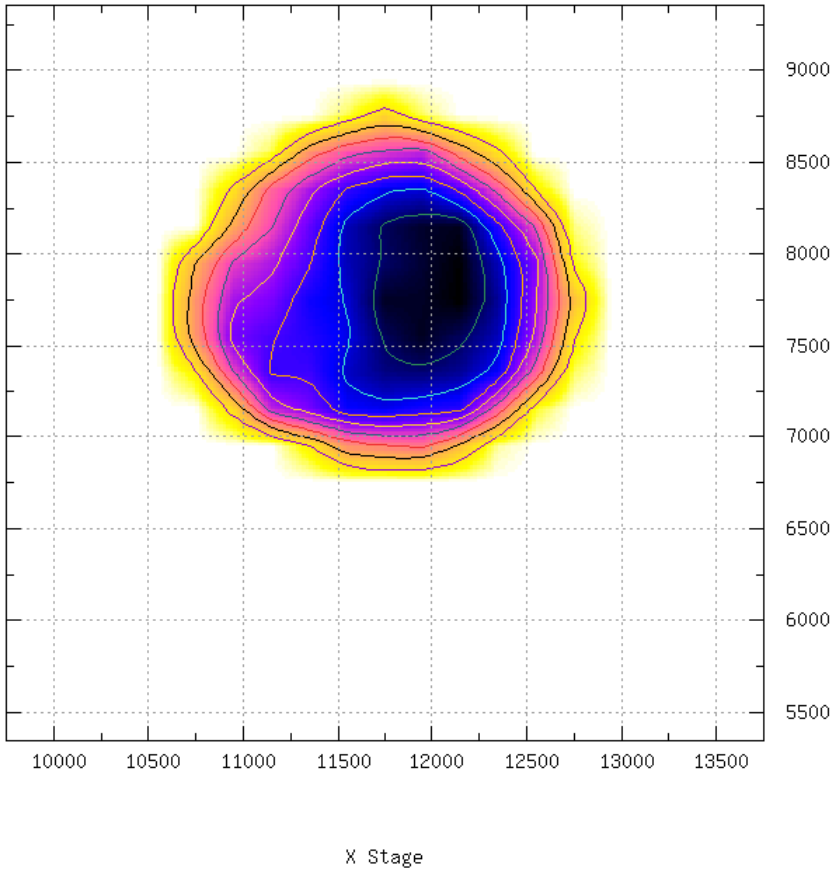
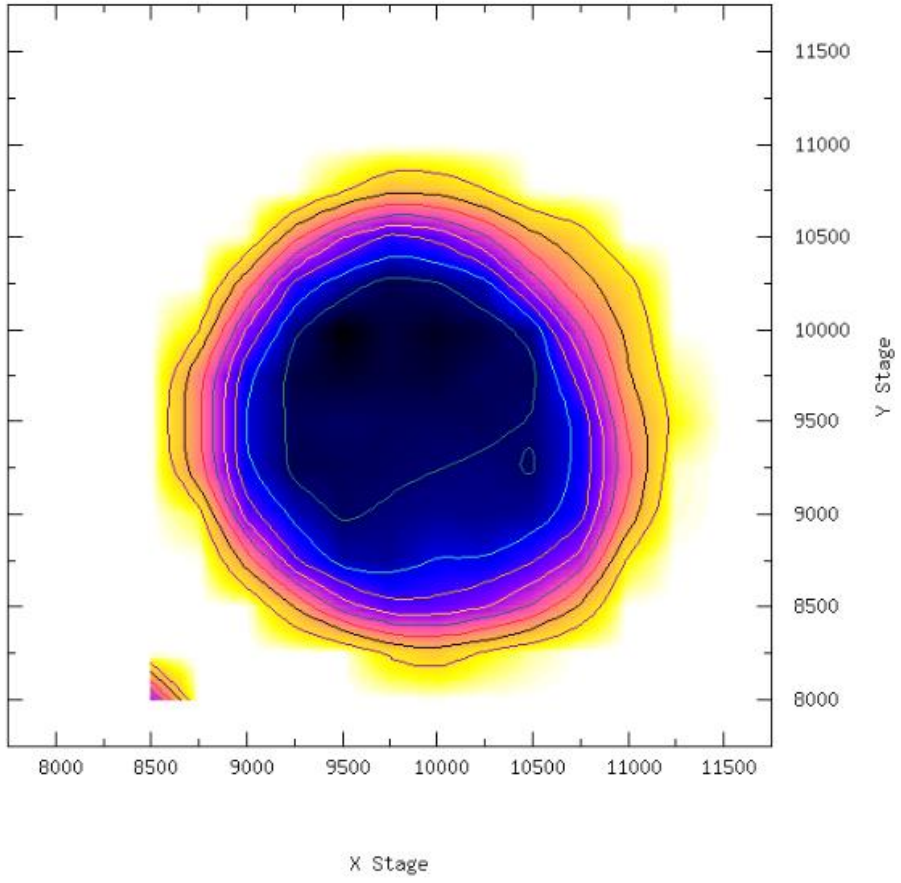
$Cs+NF_3$
$\eta_{max} = 3.45\ \%$ @780 nm



$Cs+Li+NF_3$
$\eta_{max} = 4.84\ \%$ @780 nm



Lifetime Measurements

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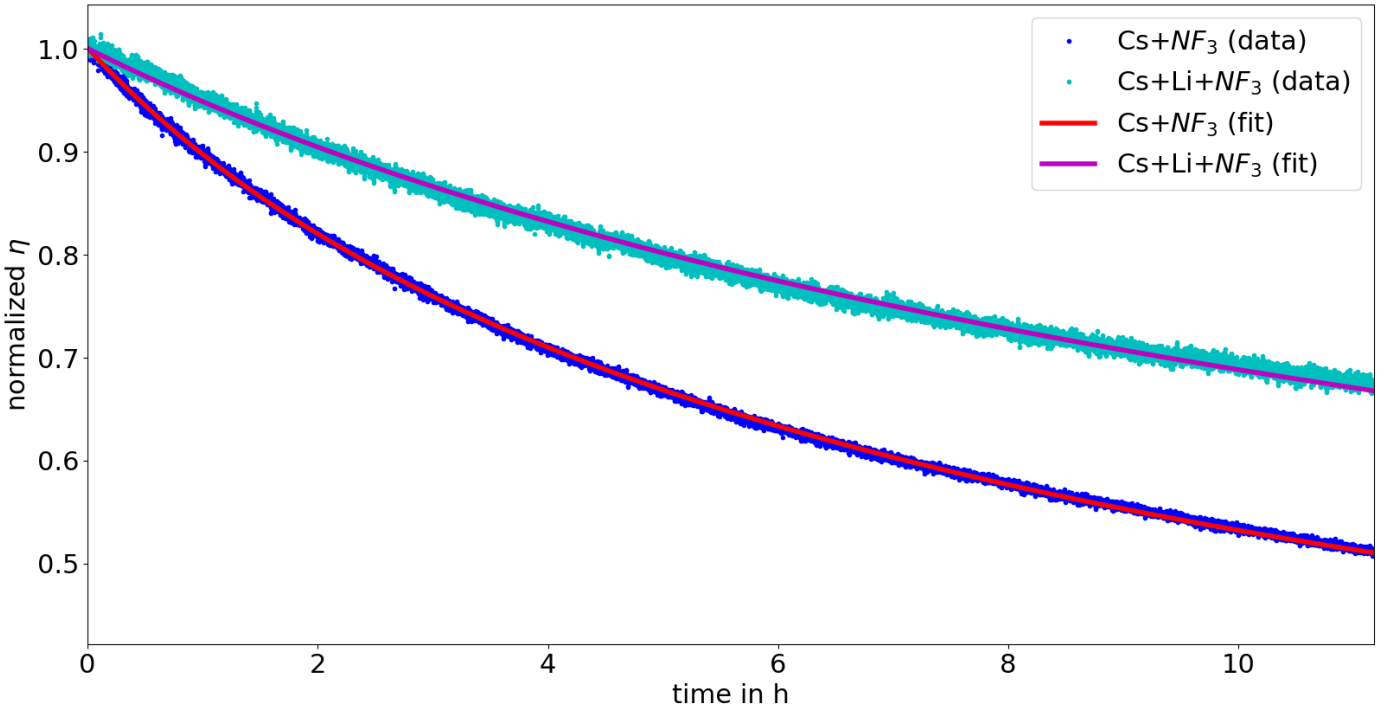
	U_{Gun} in kV	λ in nm	η_0 in %	τ_d in h	k_c in C
$Cs+NF_3$	150	780	4.59 ± 0.05	79 ± 6	3.32 ± 0.03
$Cs+Li+NF_3$	150	780	5.18 ± 0.04	905 ± 9	5.81 ± 0.01



Decay Modeling

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- "Standard" exponential decay does not match data
- Other options (J. Navas *et al., Int. J. Energy Res.* 2012; **36**:193-203):
  - Bi-exponential function:

$$I(t) = I_r + I_0 \left[\alpha \exp\left(-\frac{t}{\tau_1}\right) + (1-\alpha)\exp\left(-\frac{t}{\tau_2}\right) \right]$$

  - Bequerel function:

$$I(t) = I_r + I_0 \frac{1}{\left(1+\alpha\frac{t}{\tau_0}\right)^{\frac{1}{\alpha}}} \quad \text{with } 0 \le \alpha \le 1$$

→ modified Bequerel function:

$$\eta(t) = \eta_0/(1 + \frac{t}{\tau_d} + \frac{Q(t)}{k_c})$$

➔ very good match to data…but why?

Conclusion

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- First operational study of GaAs cathode with Li-enhanced NEA layer
- First lifetime measurement at UITF
  - → Li-enhanced activation yielded highest η achieved at UITF so far!
- Increase in η and τ observed:
  - η increased by factor of ~1.1
  - τ_d increased by factor of ~11.5 (previously reported: 3.4)
  - k_c increased by factor of ~1.75
- Exponential decay model does not match
  - → further investigation required
- Further studies planned at JLab ($Cs+Li+NF_3$) and TU Darmstadt ($Cs+Li+O_2$)

Thank you for your attention!

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Quantum Efficiency Scans

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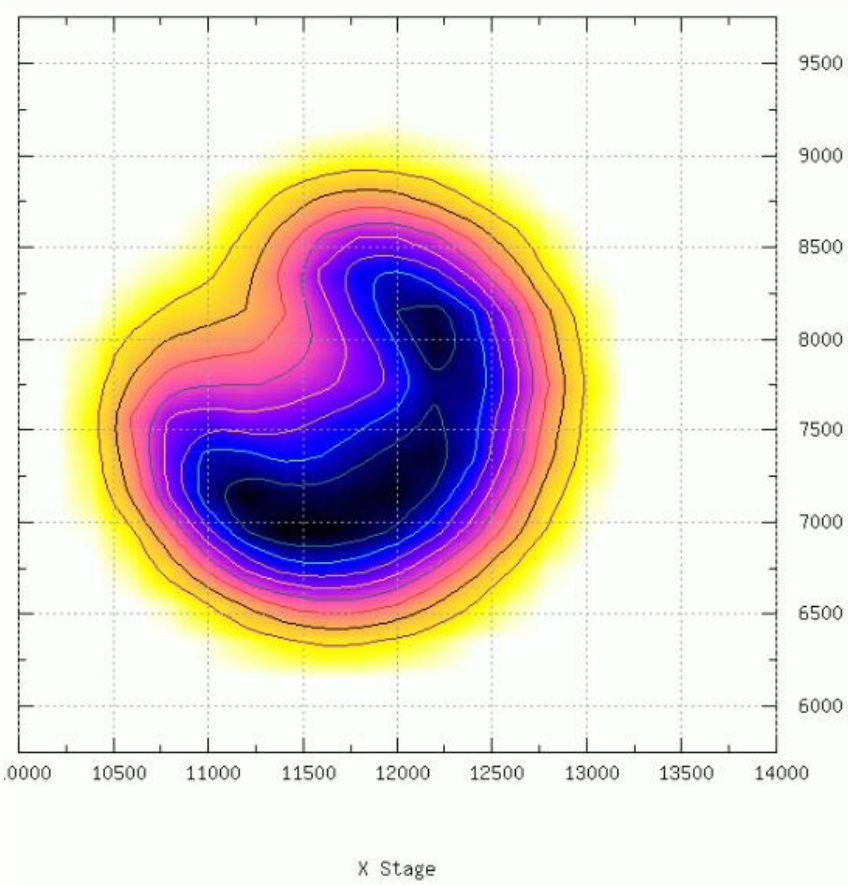
$Cs+NF_3$



$Cs+Li+NF_3$