A Brief Overview of the R&D Efforts towards High Quantum Efficiency and High Polarization Photocathodes

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Photocathode Physics for Photoinjectors (P3) 2016

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Outline

- Motivation
- Polarized Photocathode R&D, highlights
- Summary & Future development

Motivation Behind Intense Polari. e⁻ Sources

- Research subjects require polar. e^-

Spin observables ⇨ unique insights in studying

- fundamental symmetries/interactions
- particle properties & hadron structure

Spin experiments ⇨ understanding of

- nuclear reaction dynamics
- structure of hadron-nucleon many body systems

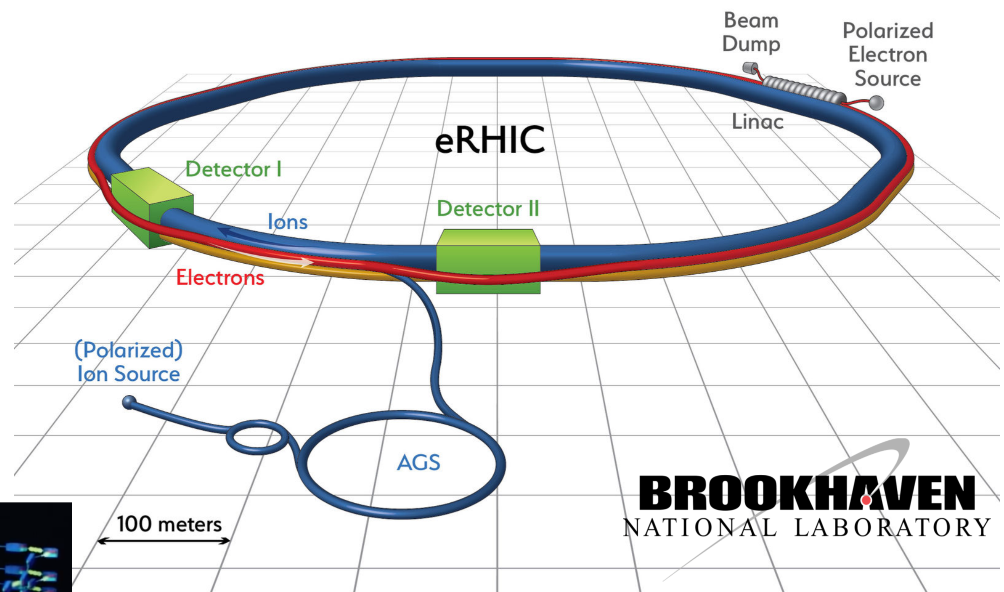
High Polar. e^- beams at mA level will enable new capabilities & new physics experiments!

High Current Pol. e^- /e^+ Accelerators

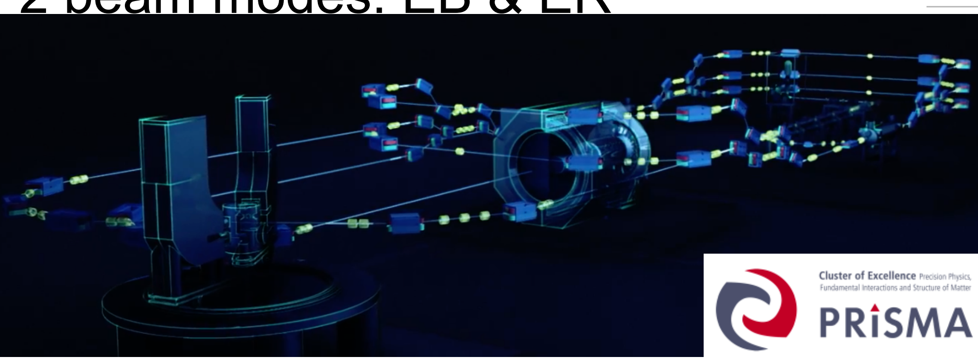
CEBAF CW beam/250 MHz

e: Ave = 1-10 mA,4-40 pc

e^+: Ave = 100 nA - 1 μA



MESA: CW beam **1mA (80% pol.)**, 10mA (un-pol.), 100~150MeV, 2 beam modes: EB & ER



BNL eRHIC: CW beam *50~250mA* (80% pol.)/18GeV 5.3C/bunch

https://www.youtube.com/watch?v=RrfiGatx9_4&list=PLB22EC2B38A982F06

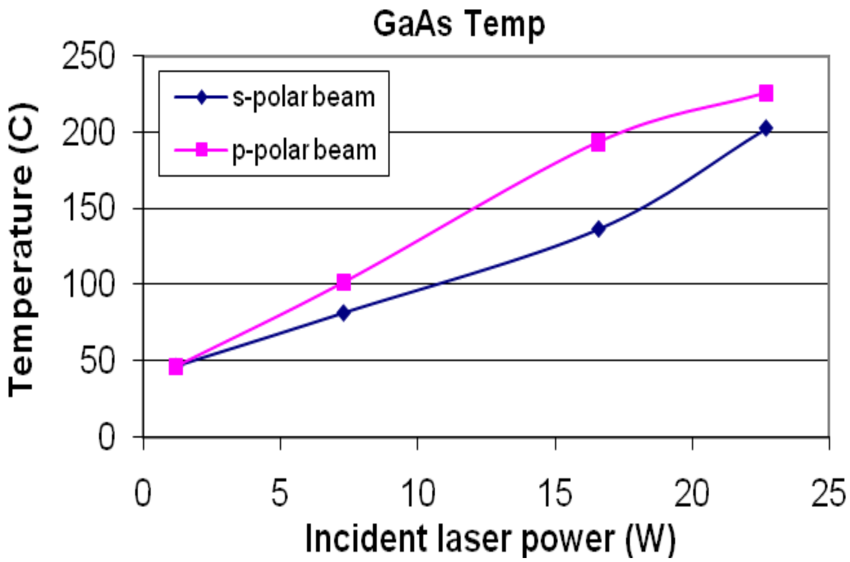
Existing Polarized Photocathodes

- High Pol. Satisfies most physics experiment
- But low QE only supporting ~ uA sustained beam delivery

Material / Structure	P (%)	QE (%)
Bulk GaAs	35	10
GaAsSb/AlGaAsP	75	0.3
GaAs/GaAsP	92	1.2
GaAs/GaAsP	92	1.6
InGaAs/AlGaAs	77	0.7
AlInGaAs/GaAs	91	0.5
AlInGaAs/AlGaAs (with DBR)	92	0.85
AlInGaAs/GaAsP (with DBR)	92	0.6

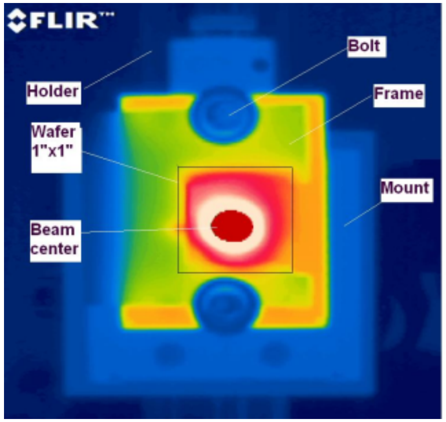
QE Really Matters

- Enough laser power?
  limitation: dissipation & heating., Cs evaporation, vacuum deterioration,….



- Cooling? complicated with HV

High polar. & ~ 10%QE desired:
simplify gun design, reduce laser power, prolong operating lifetime



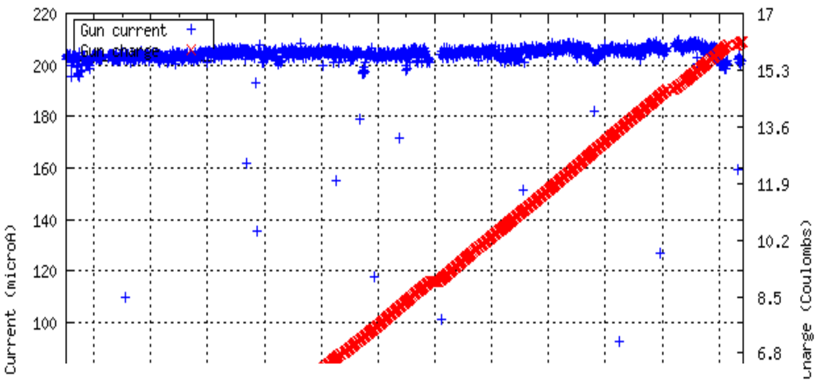
A solution: Distributed Bragg Reflector

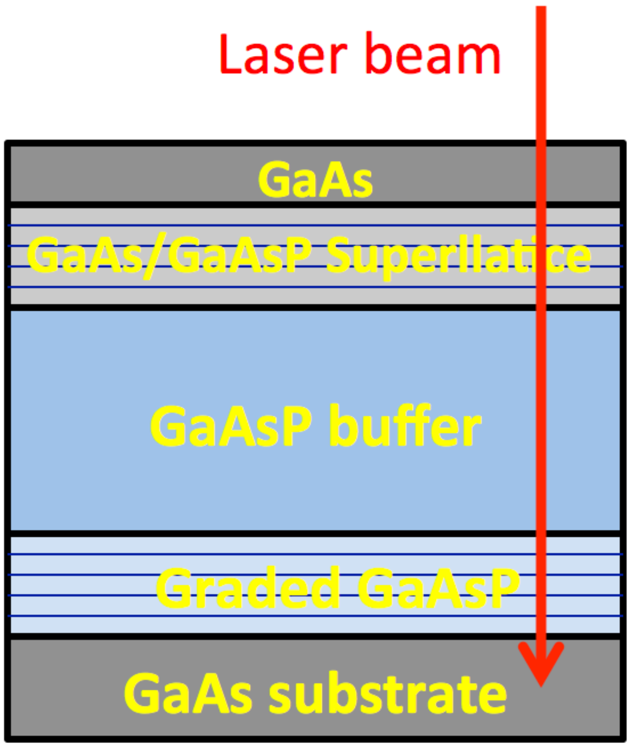
S. ZHANG, NIMA631, 22 (2011)

Supertlattice Photocathodes

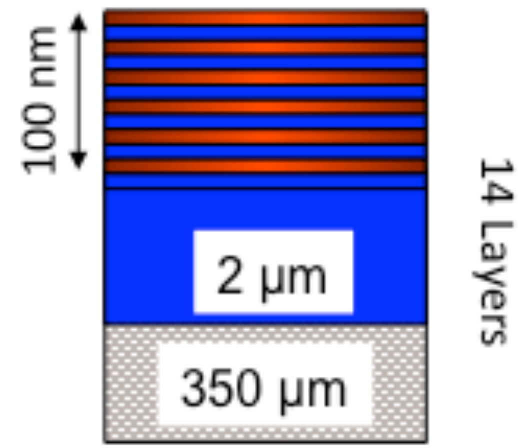
- non-DBR Photocathode :
  Absorpt. in GaAs/GaAsP SL < 5%

  Most light deposited
  ⇨ unwanted heat





Superlattice GaAs:
Layers of GaAs on GaAsP



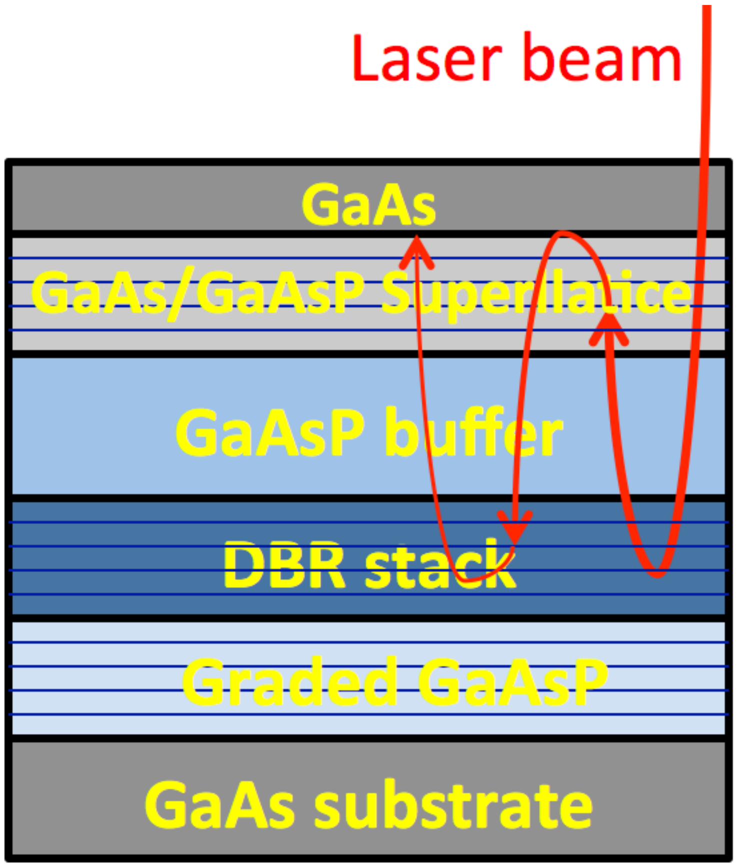
No strain relaxation
QE ~ 1%, 6 µA/mW
Pol ~ 85% @ 780 nm (1.59 eV)

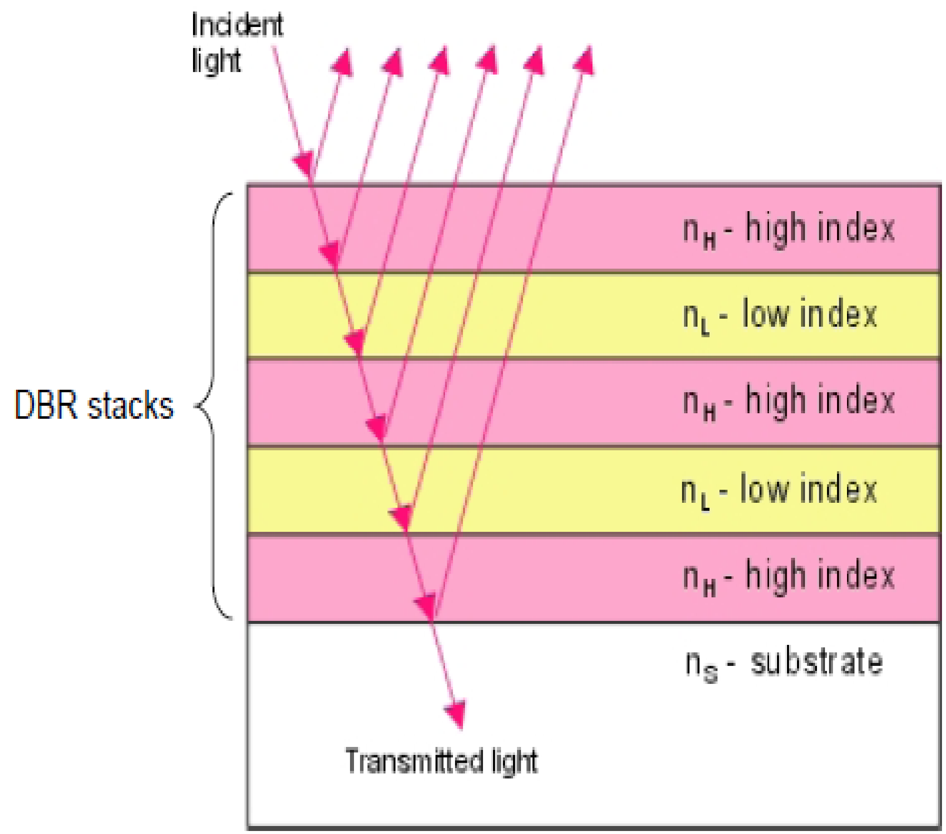
Benefits of DBR

- DBR photocathode : absorpt. in GaAs/GaAsP SL >20%

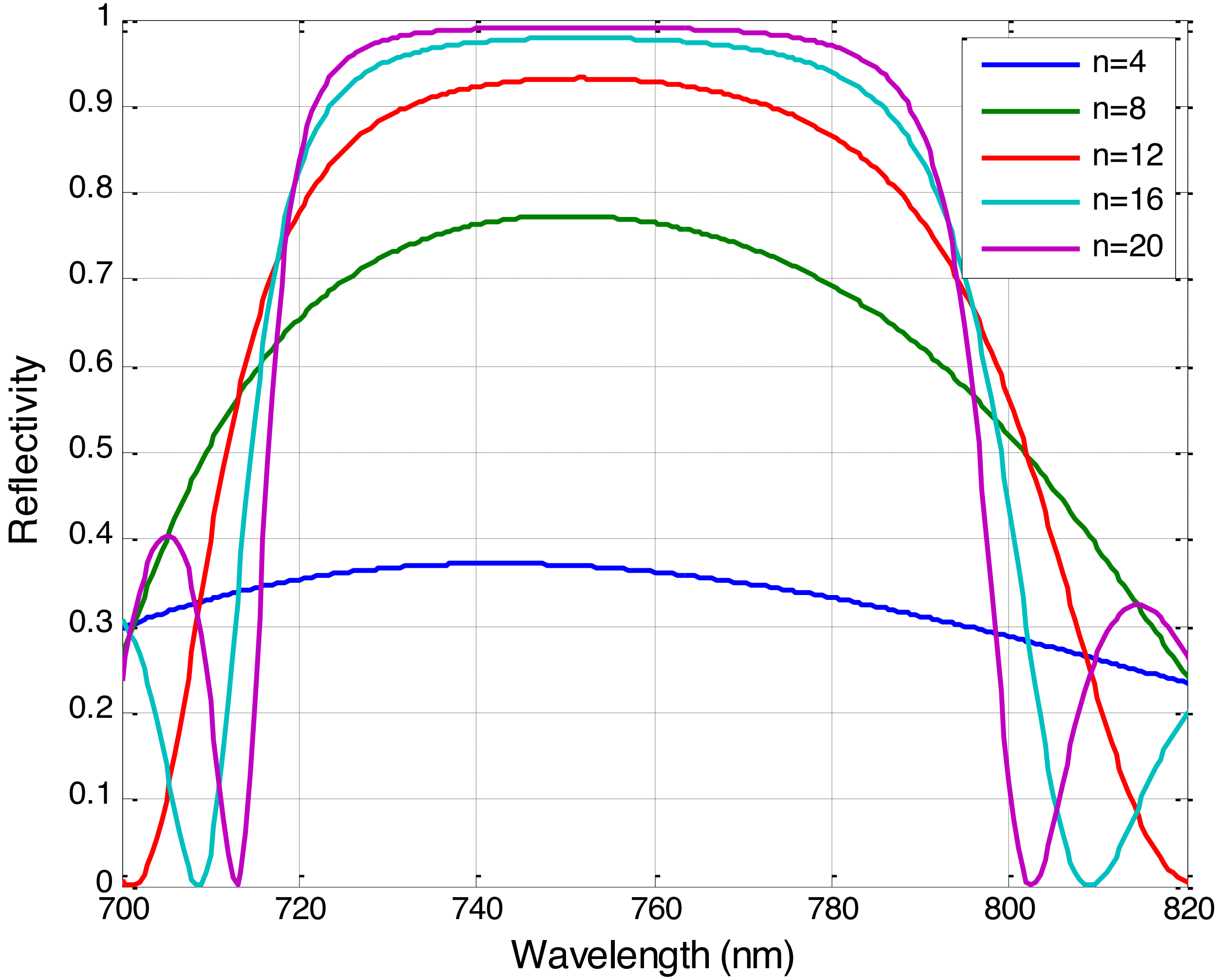
  Less light needed ⇨ less heat deposited

- F-P can be formed btw top layer & DBR





Surface Reflection of DBR



GaAsP/AlAsP

12 paired layers: highest reflection ~93.2%

More layers, higher reflection, but more challenging

DBR Surface reflection vs. numbers of paired layers (n)

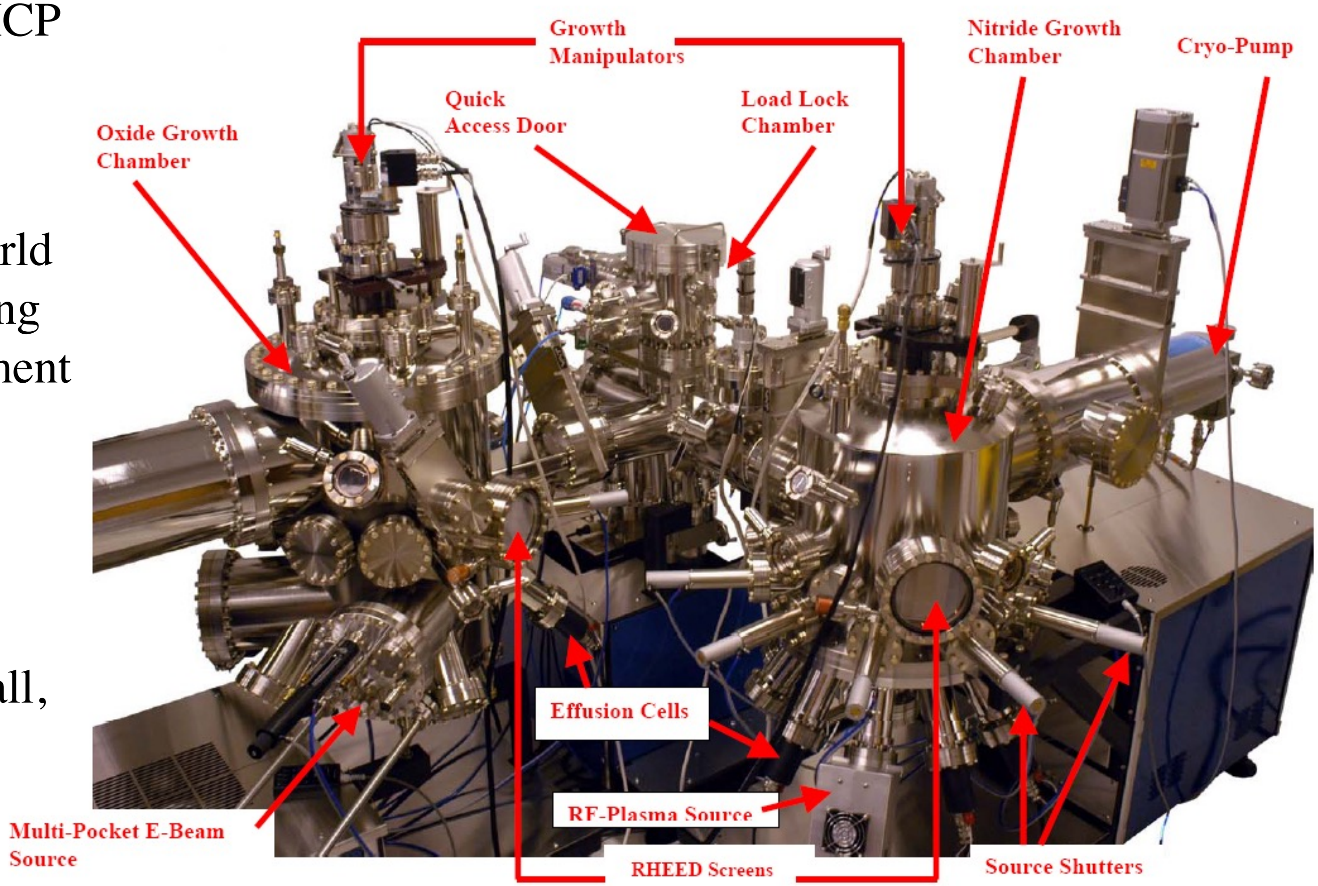
Fabrication of Photocathodes

- Material deposition systems: MBE PLD, ALD, PECVD, ICP

Established know-how:
8 Applications Laboratory MBE systems producing world class epitaxial growth, feeding requirements back to equipment designers

- Complete semiconductor material characterization facility: HR-XRD, FTIR, Hall, Low-temp probe station, Semiconductor parameter analyzer, ellipsometer.

- Device Fabrication



Dual Oxide - Nitride MBE

SVT Associates, Inc.

Structure of Photocathodes

GaAs	5 nm	p=5E19 cm^{-3}
GaAs/GaAsP SL	(3.8/2.8 nm) ×14	p=5E17 cm^{-3}
$GaAsP_{0.35}$	2750 nm	p=5E18 cm^{-3}
Graded $GaAsP_x$ ($x = 0 \sim 0.35$)	5000 nm	p=5E18 cm^{-3}
GaAs buffer	200 nm	p=2E18 cm^{-3}
p-GaAs substrate (p>1E18 cm^{-3})		

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GaAs/GaAsP SL	(3.8/2.8 nm) ×14	p=5E17 cm^{-3}
$GaAsP_{0.35}$ spacer	750 nm	p=5E18 cm^{-3}
$GaAsP_{0.35}$/ $AlAsP_{0.4}$ DBR	(54/64 nm) ×12	p=5E18 cm^{-3}
$GaAsP_{0.35}$	2000 nm	p=5E18 cm^{-3}
Graded $GaAsP_x$ ($x = 0 \sim 0.35$)	5000 nm	p=5E18 cm^{-3}
GaAs buffer	200 nm	p=2E18 cm^{-3}
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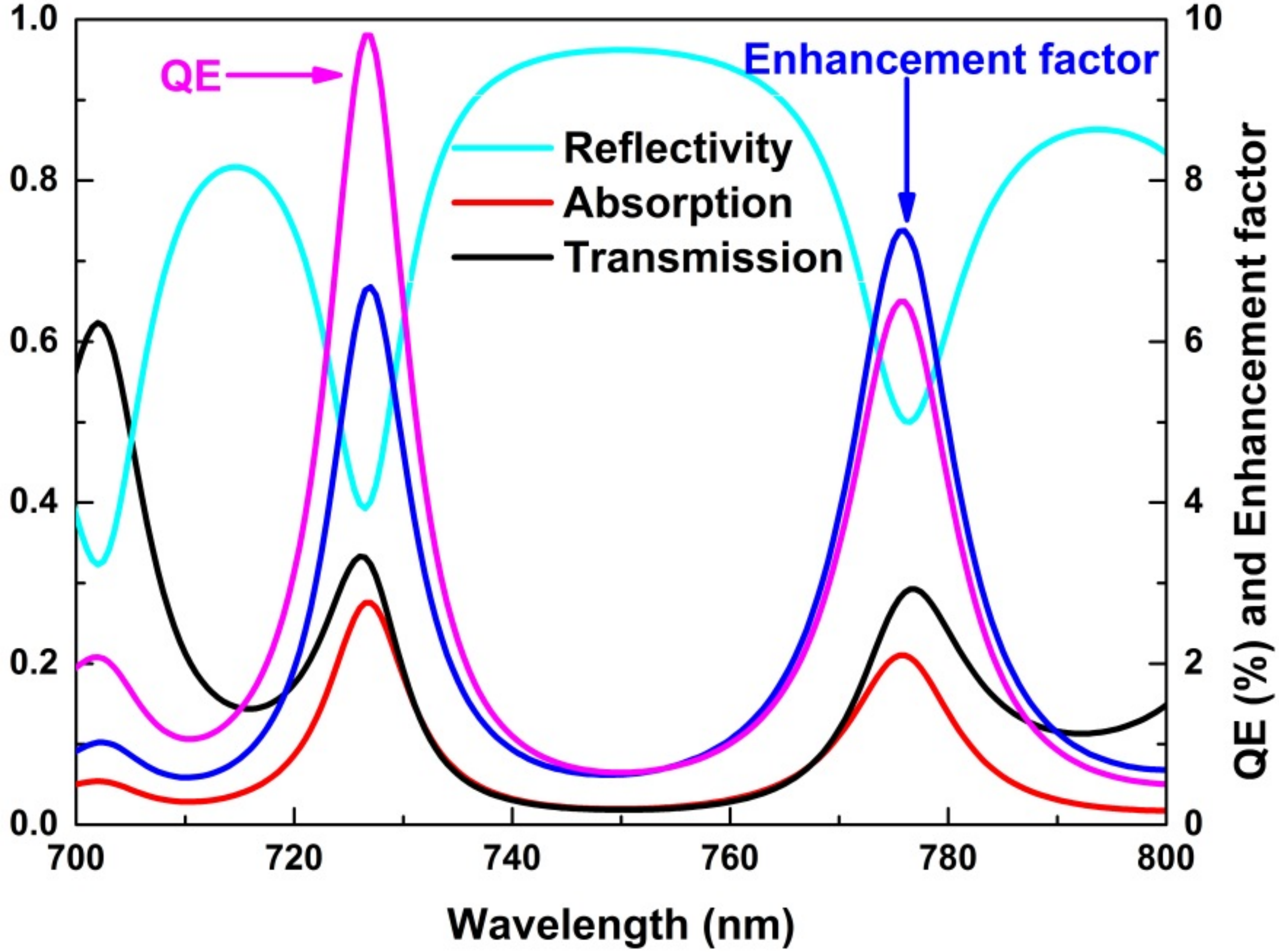
Key design consideration: **Optical path length**

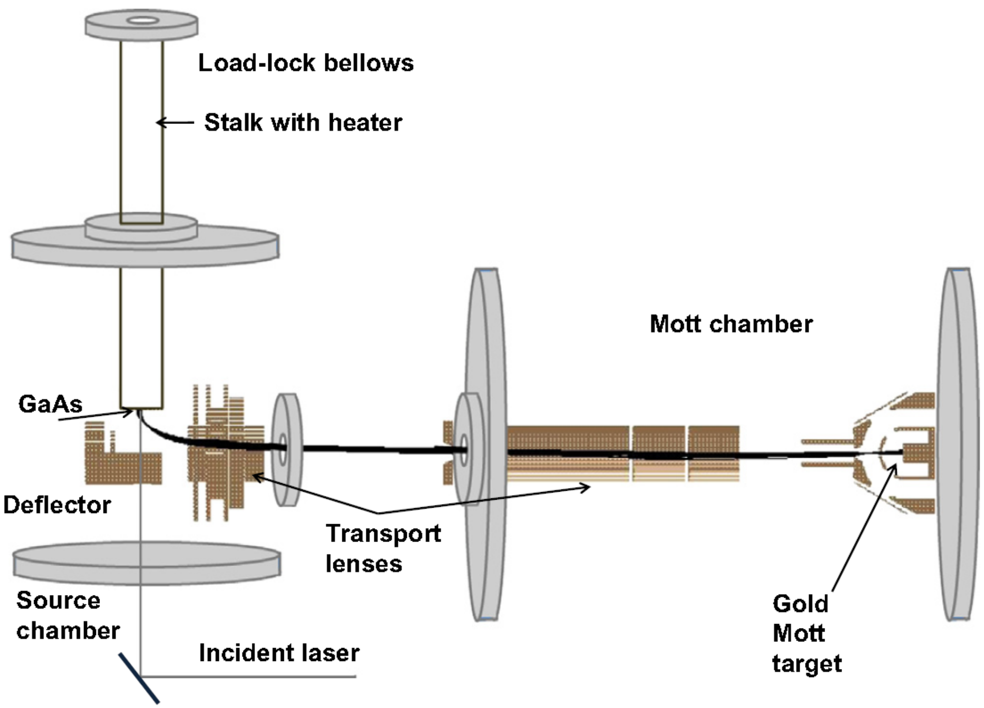
- Layer thickness, and
- Refractive index/Phosphorus content

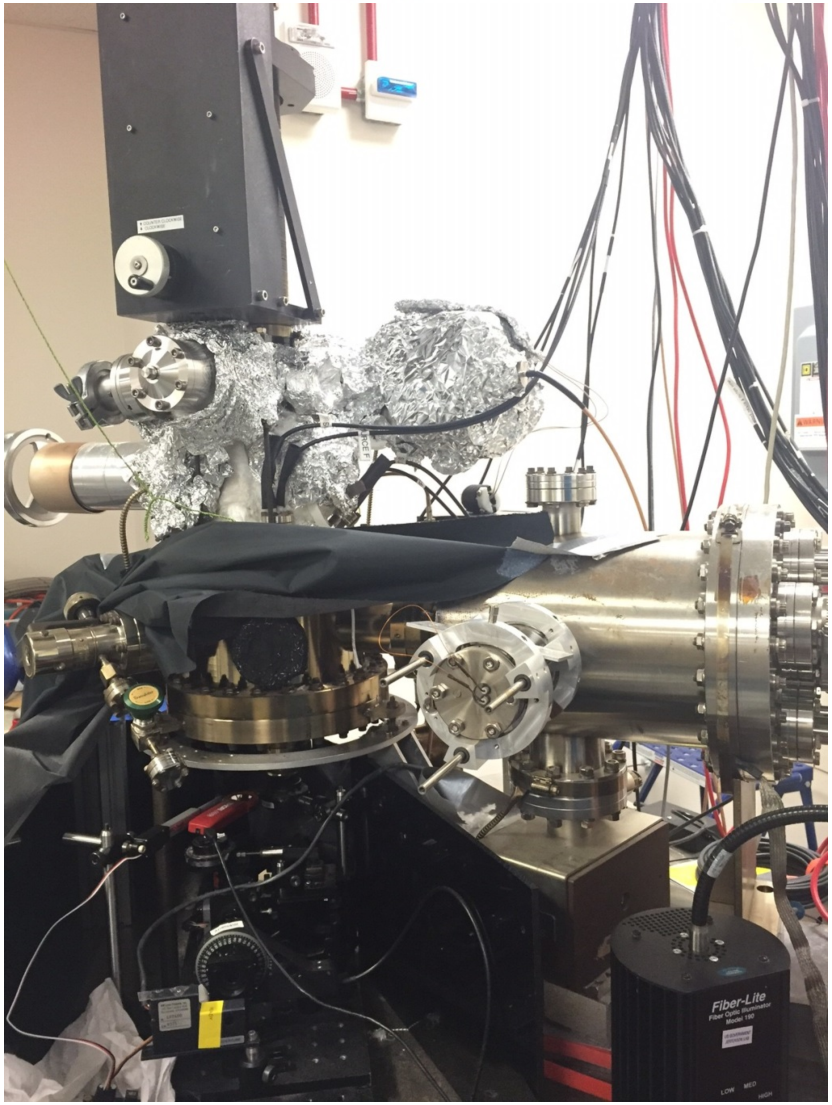
Calculation/Prediction

Absorpt: 21.03% QE~ 6.4%, Enhancement ~7.4 @ 776 nm



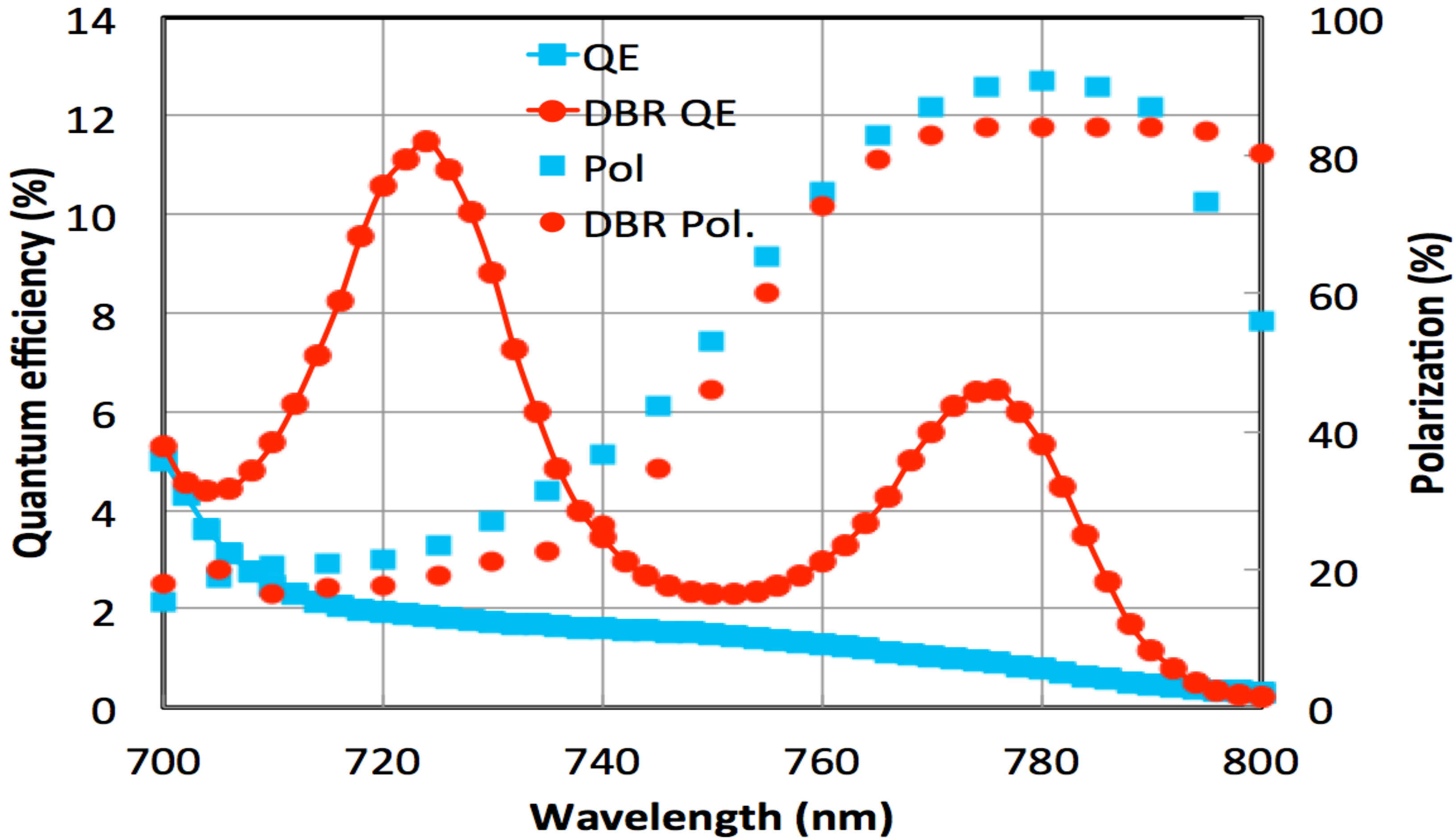
Experimental Apparatus-Mott





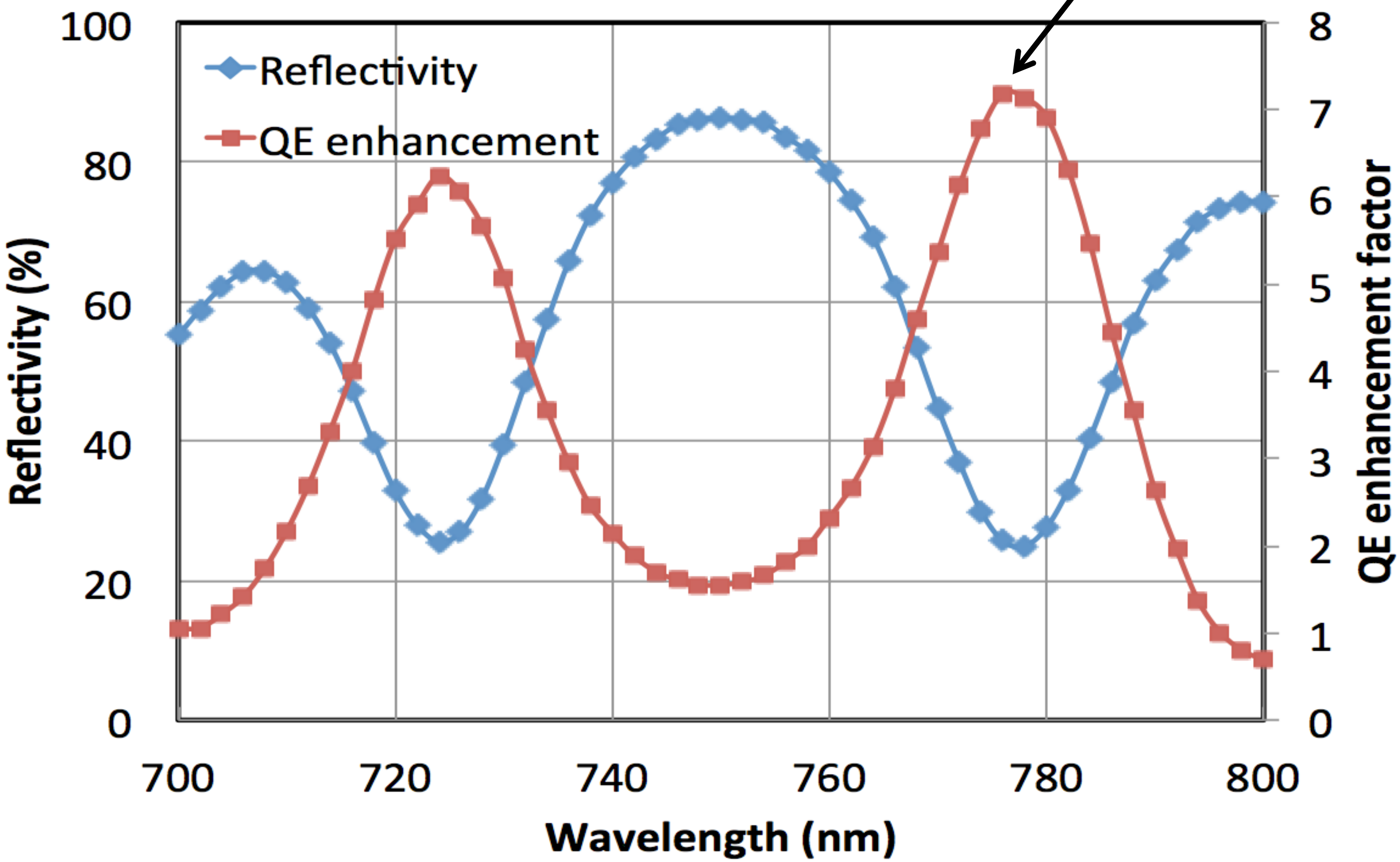
Experimental Results

- non-DBR: QE ~ 0.89%, Pol ~ 92% @ 776 nm:
  - DBR: Pol. ~ 84%, QE ~ 6.4%, Enhancement: ~7.2



Experimental Results

QE Enhancement: 7.2 @776 nm:



Performance of Photocathodes

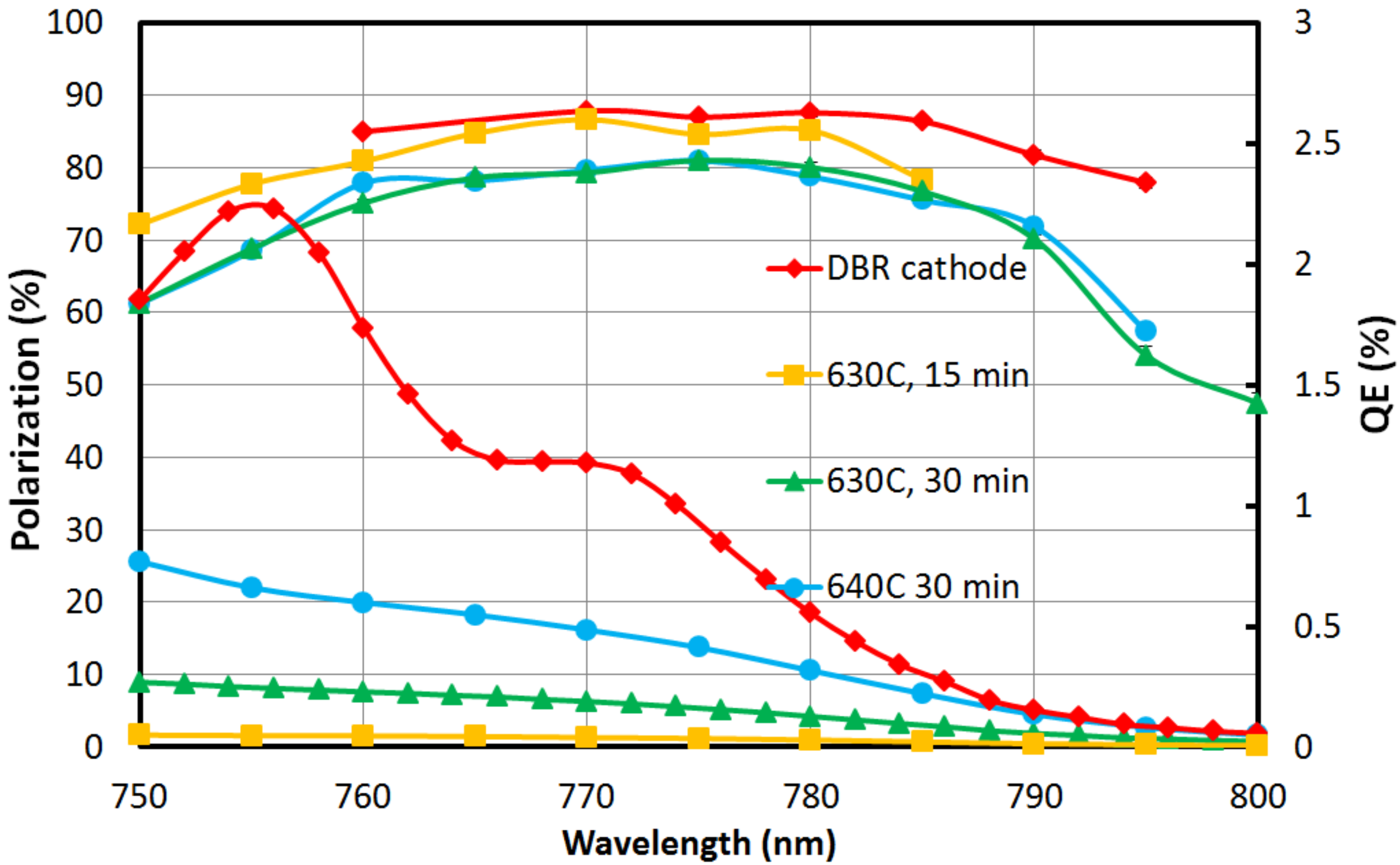
- Accurate modeling helps
- Precise control over many layers - the real challenge!

Cathode	Ref.	P(%)	QE (%)	FOM*
$GaAs/GaAsP_{0.36}$ (non-DBR)	SLAC/SVT	86	1.2	0.89
$GaAs/GaAsP_{0.38}$ (non-DBR)	Nagoya	92	1.6	1.35
$Al_{0.19}In_{0.2}GaAs/Al_{0.4}GaAs$ (DBR)	St. Peterburg	92	0.85	0.72
$GaAs/GaAsP_{0.35}$ (DBR)	JLab/SVT	84	6.4	4.52

* Figures of Merit=P^2*QE

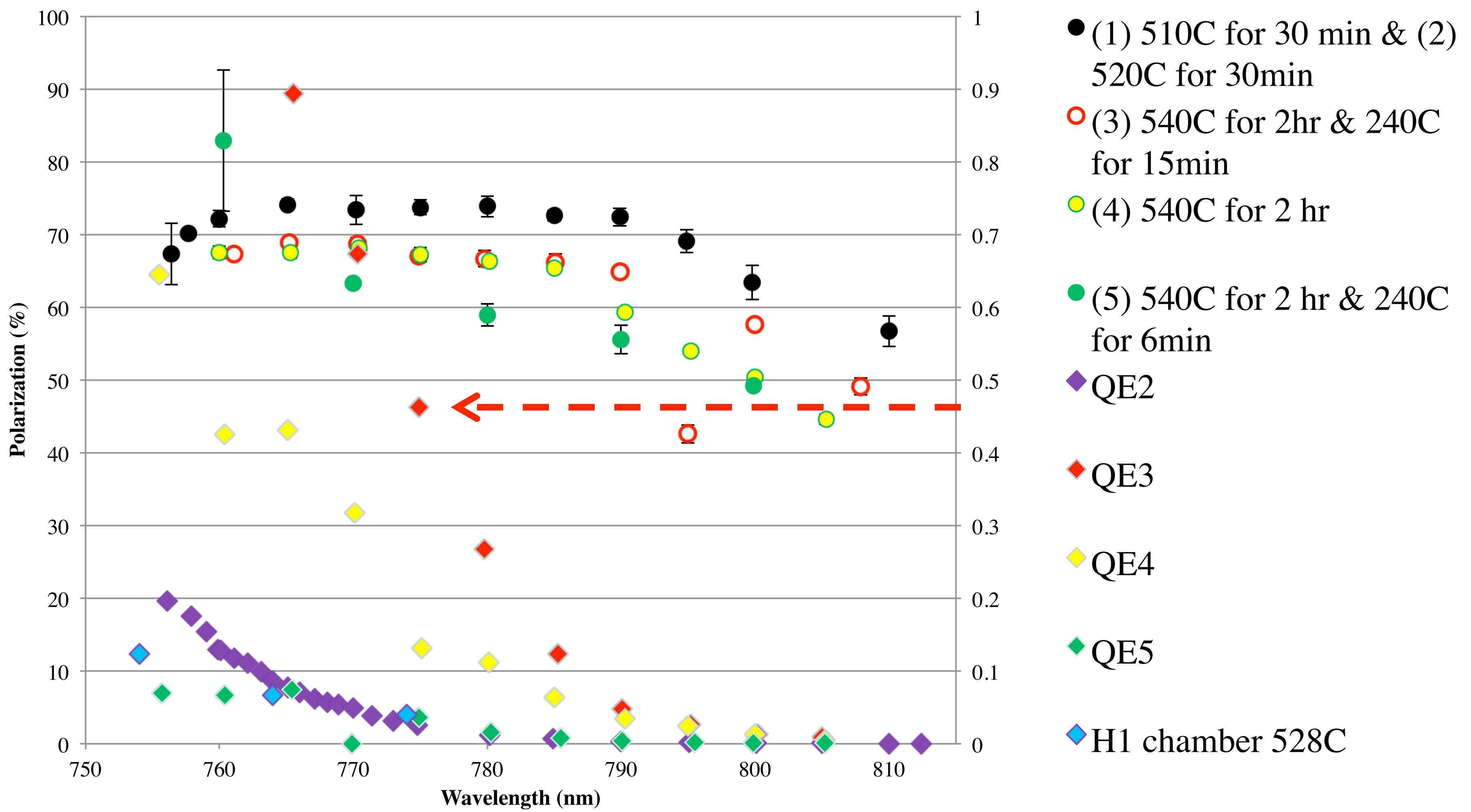
Results back in 2015

- Significant improvement in QE achieved!



GaAs/GaAsP:Sb Photocathode

- Different exp. conditions explored, relatively low QE & Polar.



Summary

- Dramatic QE enhancement ~ 7x, polarization ~ 84% achieved with Strained DBR GaAs/GaAsP SL photocathodes
- DBR photocathodes will be used to produce high current polarized electron beams in UITF/CEBAF
- Further effort to tune the wavelength and increase QE peak is underway.
- Simulation and new polarized photocathode R&D have been proposed

Also like to hear ideas from you!