Development of Polarized Electron Sources in Japan

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Development of Polarized Electron Sources in Japan

Often with international collaboration and cooperation!

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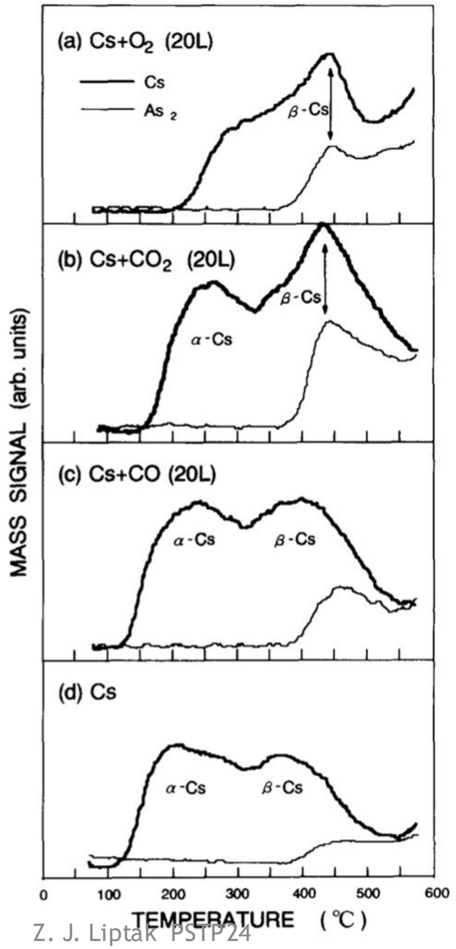
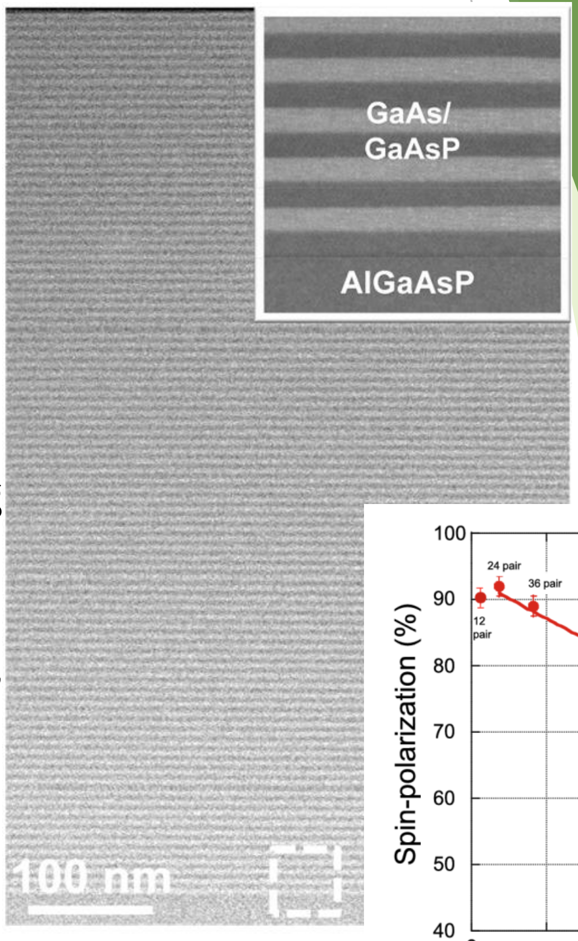
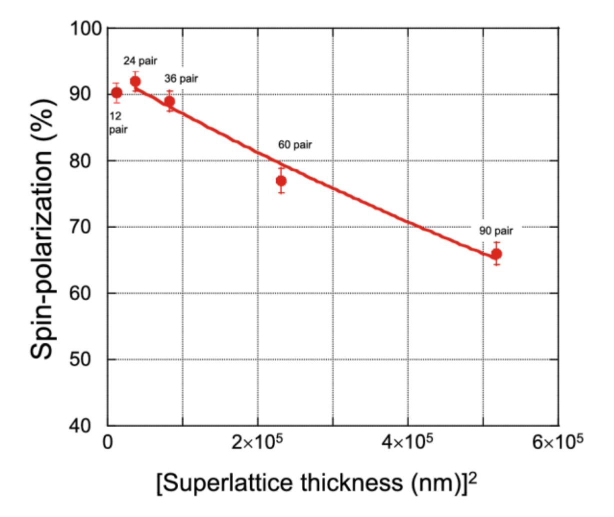
History of Polarized Source Development in Japan



Japan has a robust history of polarized source development going back decades, including development of NEA films (left), strained superlattice growth (right), etc.

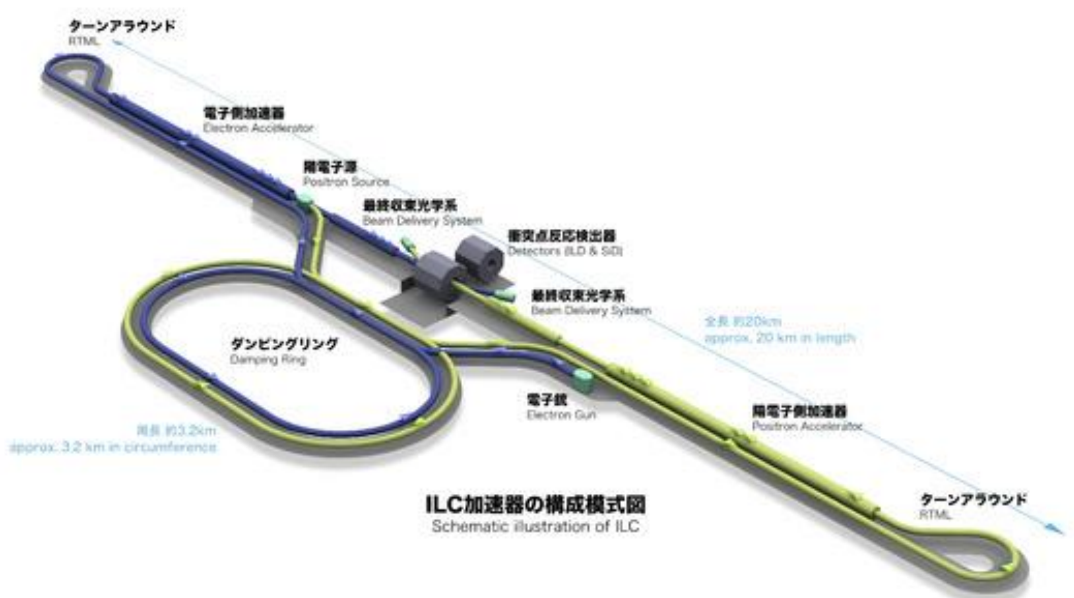


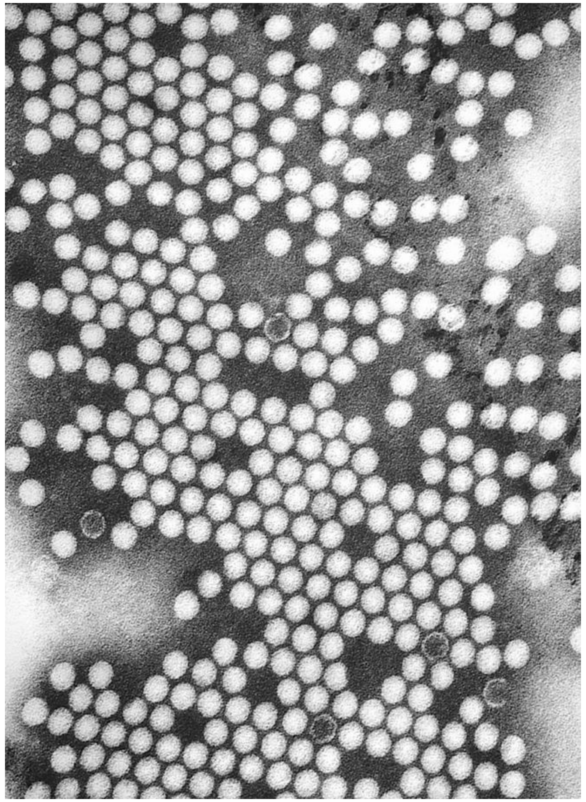


J. Sakai et al. Surf. Sci. 283 (1993) 217-220

X. Jin *et al. Appl. Phys. Lett. 105* (2014)

Applications





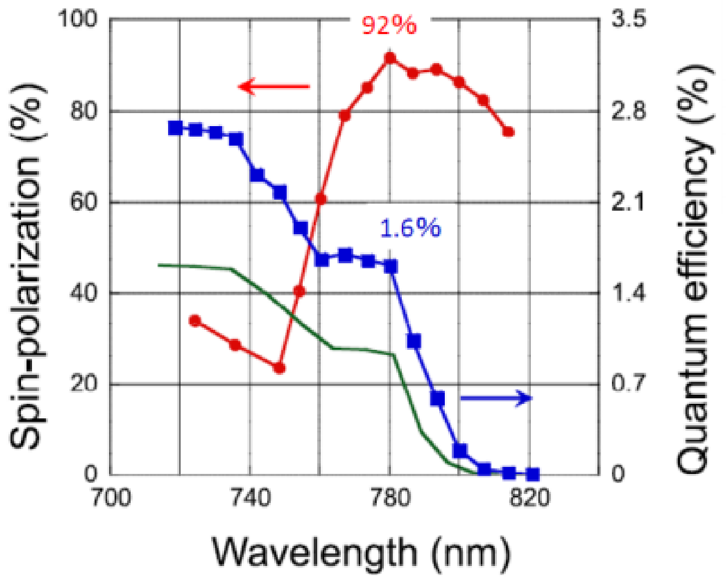
Accelerator-based Research

Polarized Electron Microscopy

Source Requirements drive material choice

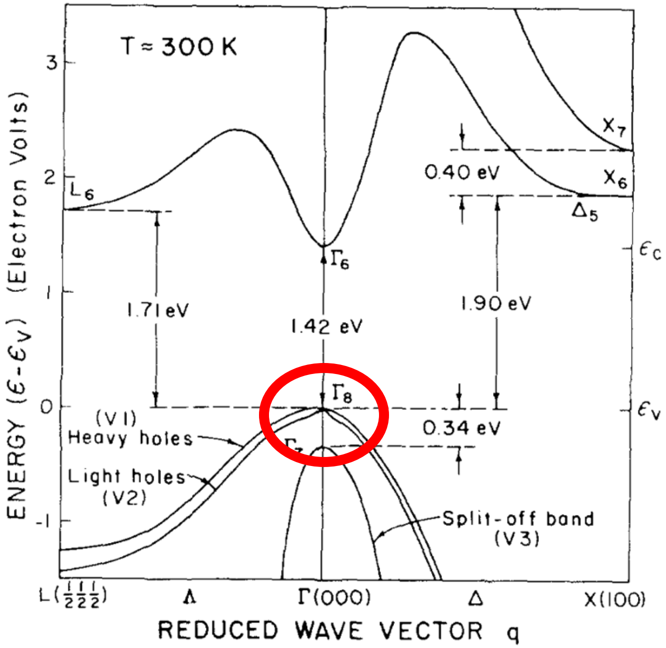
Parameter	Symbol	Value	Units
Electrons per bunch (at gun exit)	N_-	3×10^{10}	
Electrons per bunch (at DR injection)	N_-	2×10^{10}	
Number of bunches	n_b	1312	
Bunch repetition rate	f_b	1.8	MHz
Bunch-train repetition rate	f_{rep}	5	Hz
FW Bunch length at source	Δt	1	ns
Peak current in bunch at source	I_{avg}	3.2	A
Energy stability	σ_E/E	<5	% rms
Polarisation	P_e	80 (min)	%
Photocathode Quantum Efficiency	QE	0.5	%
Drive laser wavelength	λ	790 ± 20 (tunable)	nm
Single-bunch laser energy	u_b	5	μJ

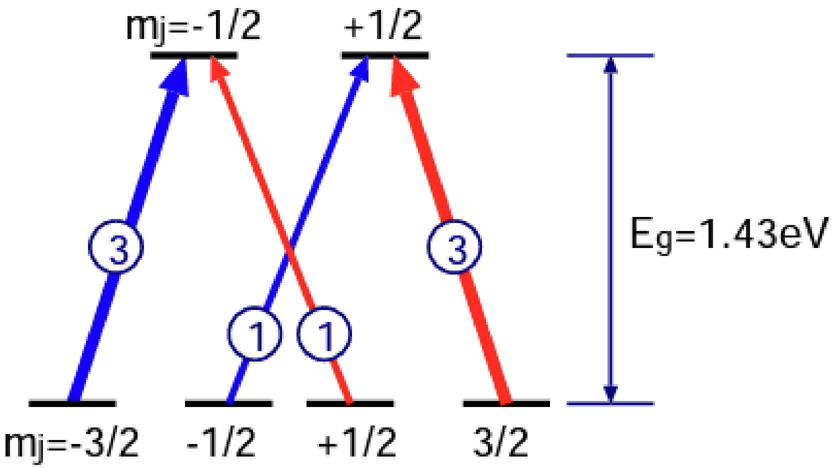
(ILC TDR)



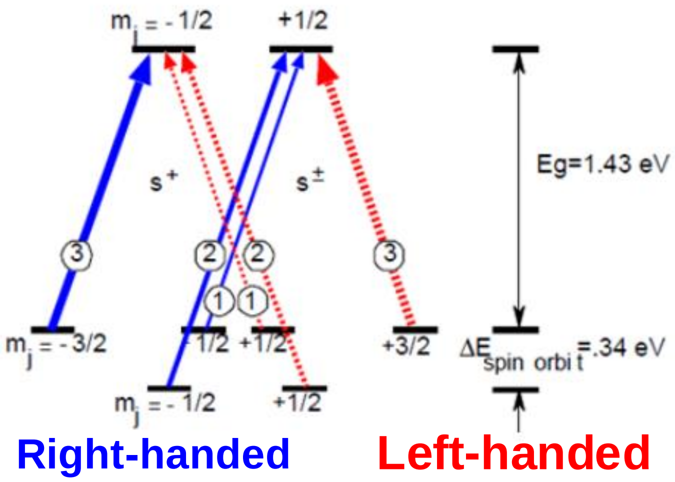
- GaAs can meet polarization/QE requirements:
  - >90% polarization possible at >1% QE
  - Surface charge should be manageable

Exciting Polarized Electrons in GaAs





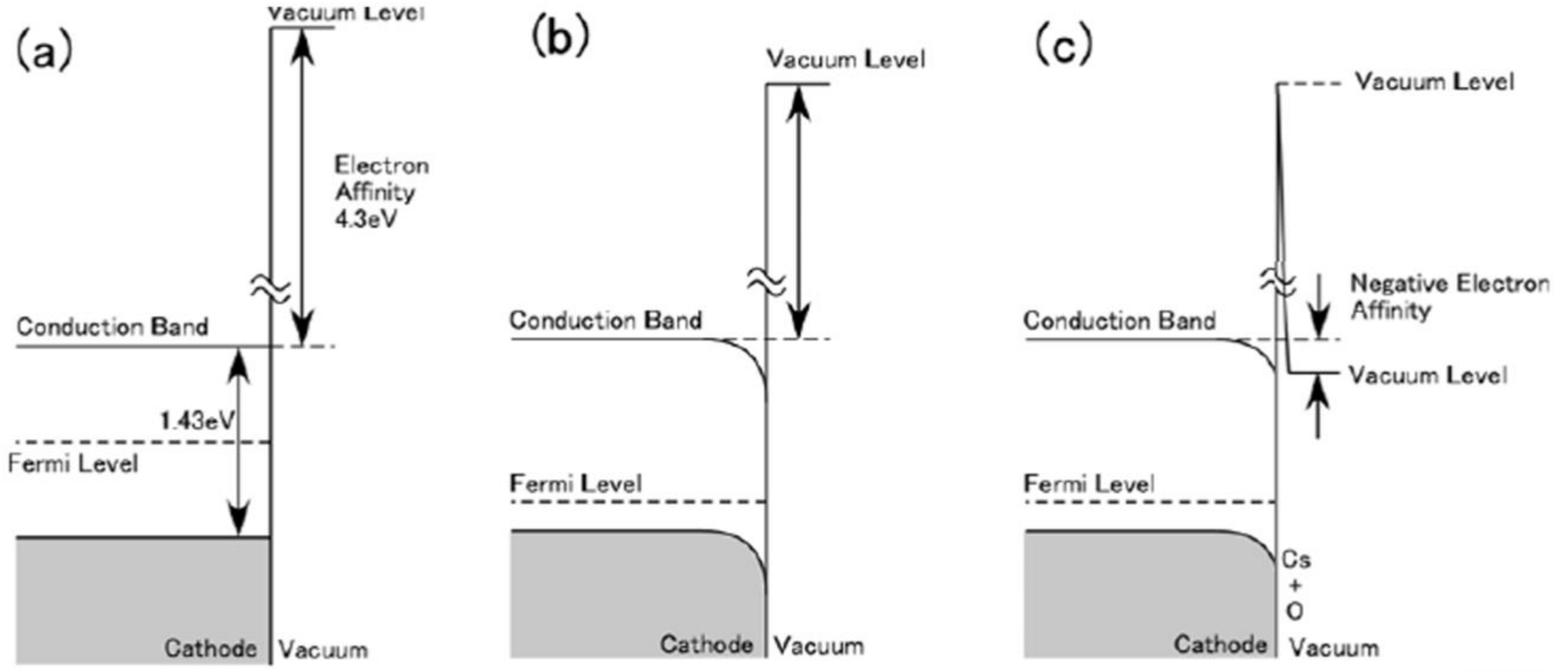
Strain to break degeneracy



J. S. Blakemore, J. App. Phys. **53**, R123-R181 (1982)

We can use a circularly polarized laser to take advantage excite polarized electrons preferentially once we break the degeneracy at the Γ point.

NEA mechanism



Bulk GaAs P-doping NEA surface

NEA surface makes it possible to bring electrons out of the bulk by lowering the effective vacuum potential and work function.

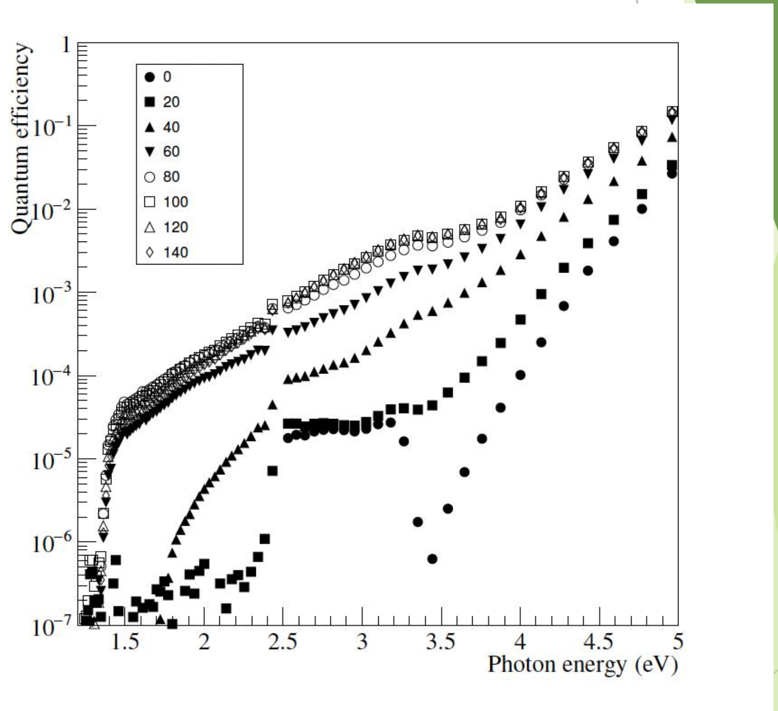
Improving NEA Lifetimes

- The traditional Cs-O NEA films are chemically active and are susceptible to ion back bombardment, thermal desorption, and chemical poisoning.
  - QE degrades rapidly → time loss for changing cathodes, degrading beam delivery, &c.
- Sugiyama (2011) proposed modifying the thin-film to use Te instead of O to improve cathode lifetimes, and subsequent experiments verified longer lifetimes for cathodes made with such surfaces.
  - Other semiconductors can also be used, e.g. Sb.

Heterojunctions for Improved Robustness

NEA Material	Lifetime (10^{-3} Pa · s)
Cs-O	0.29 ± 0.03 [21]
Cs-O	0.40 ± 0.02 [22]
Cs-K-Te	6.50 ± 0.01

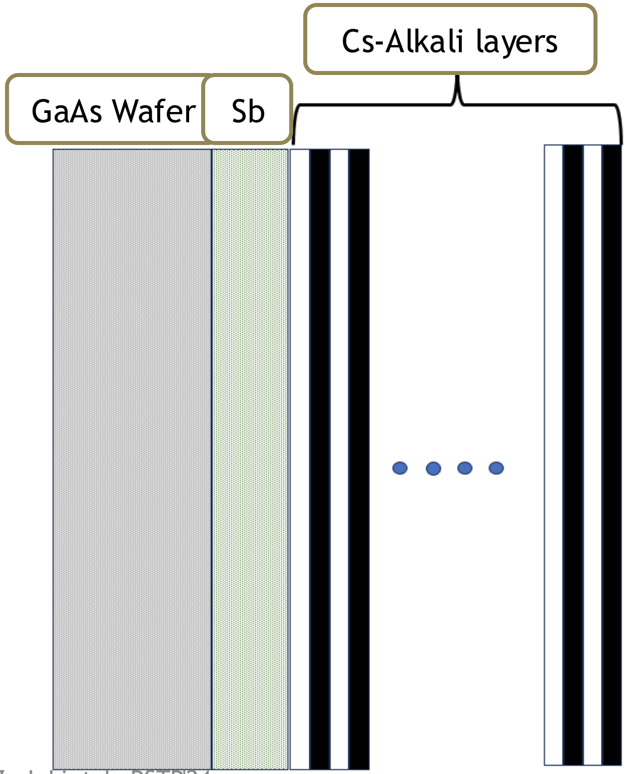
Lifetime results for heterojunction NEA films, reported by Kuriki (2019)



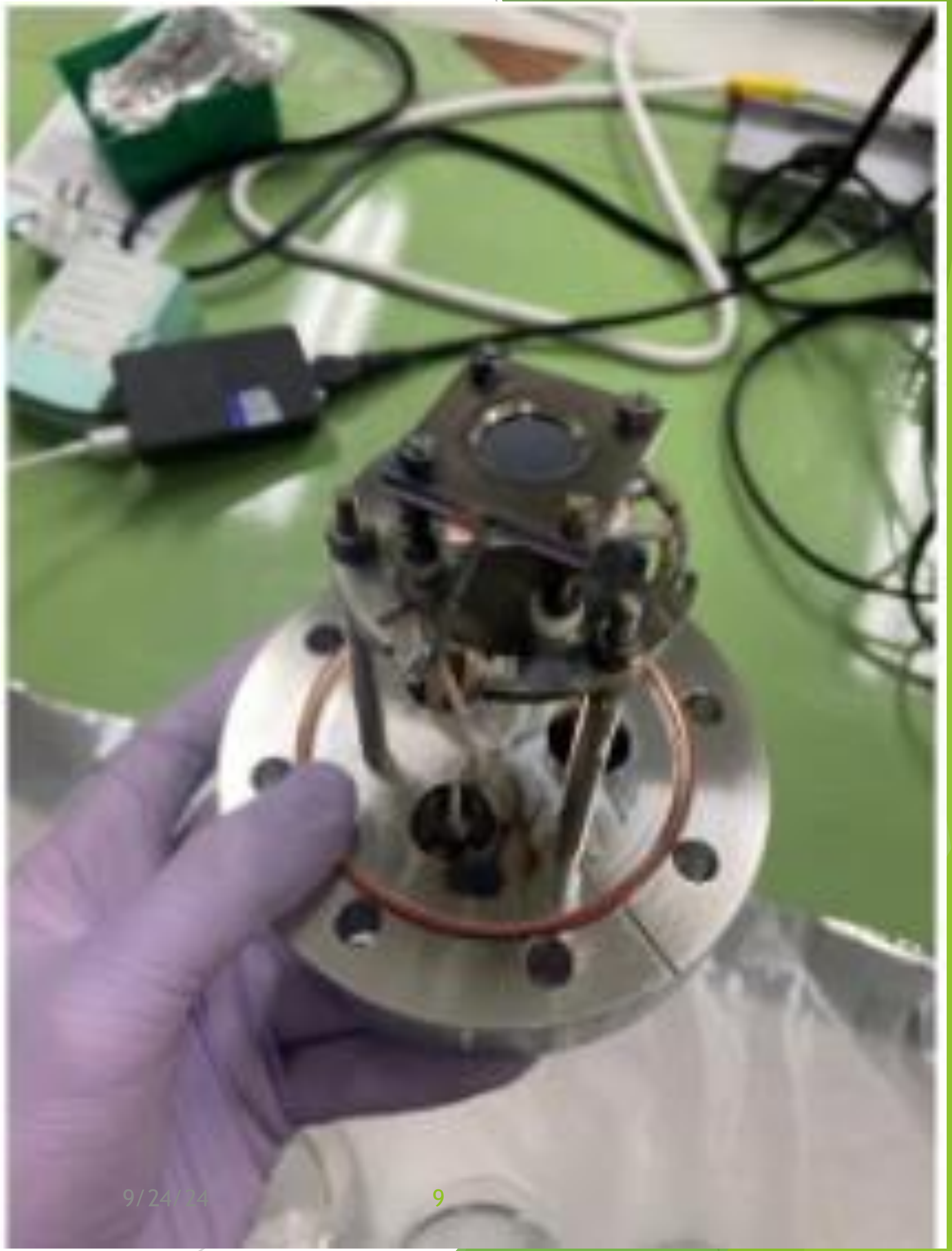
Measured QE vs. photon energy for varying thicknesses of NEA film

NEA Cathode Production

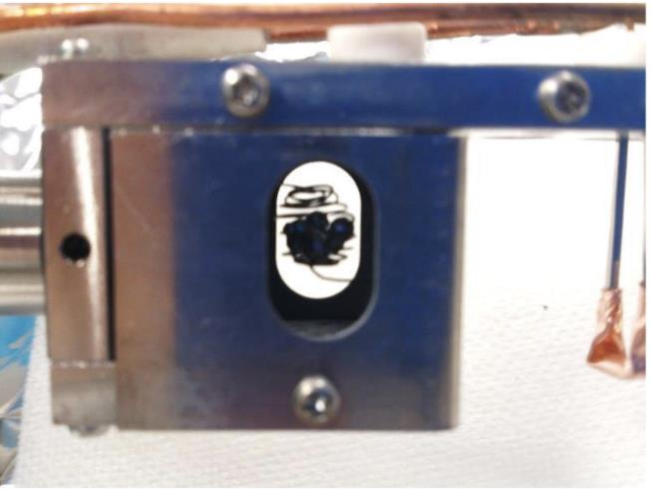
- There is much room left for improvement! We are continuing to optimize materials and recipes for cathode production.
- Thickness and deposition order can play a large role in determining the cathode QE



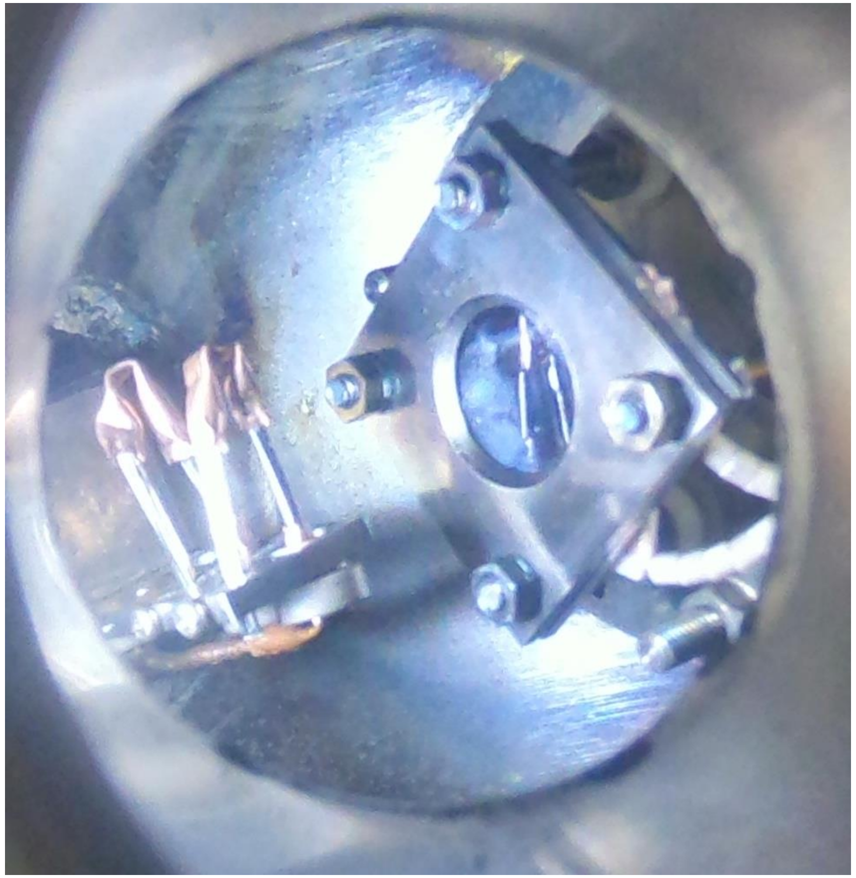
Example deposition recipe with Cs-Alkali deposited atop a Sb base



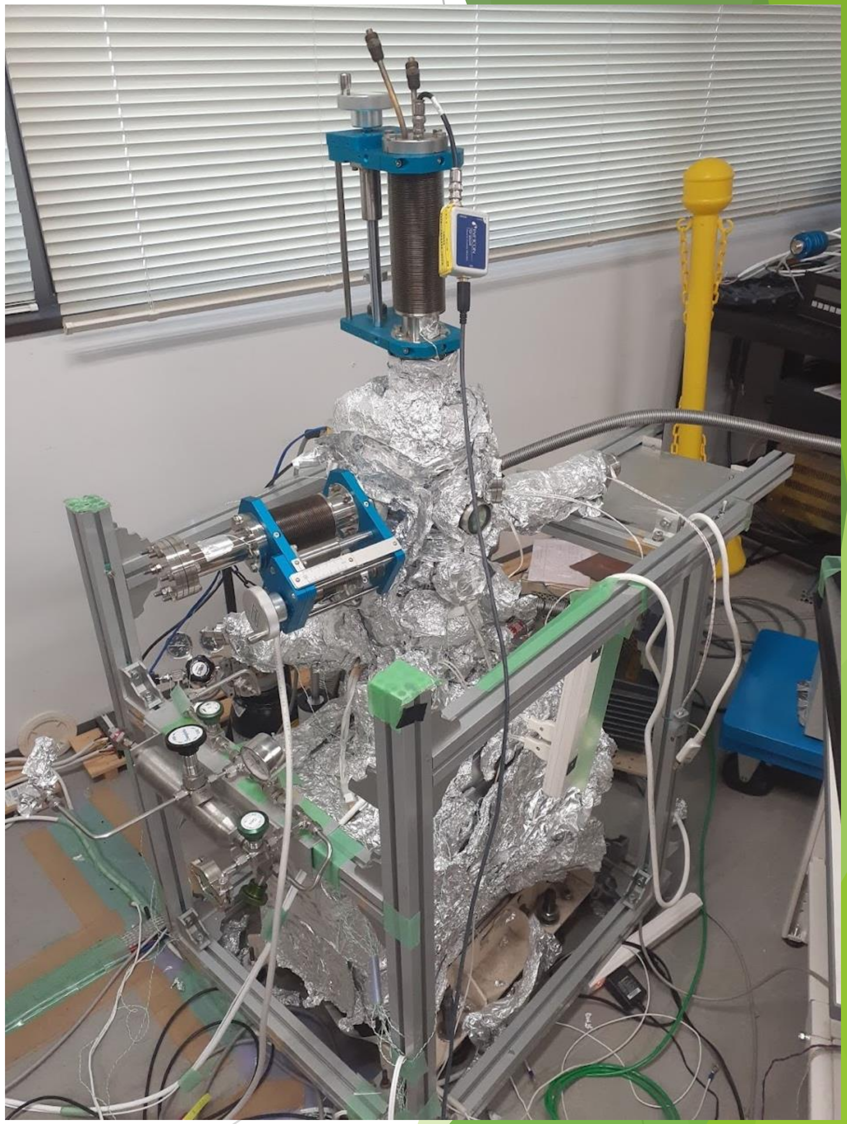
NEA Cathode Production



Sb/Te dispenser head

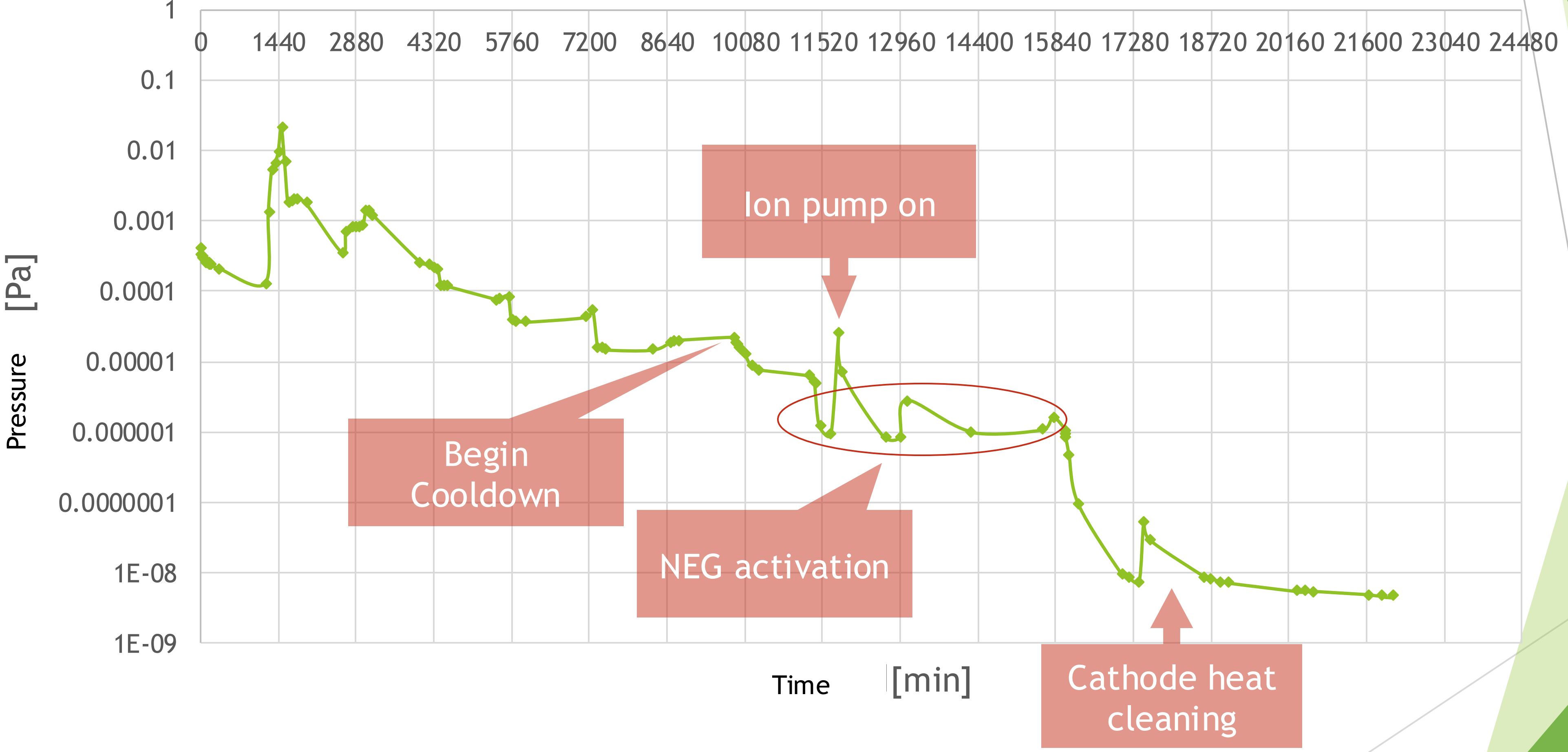


View of cathode and NEA material dispensers in vacuum. Thickness monitor not pictured.



Vacuum chamber setup

Chamber baking

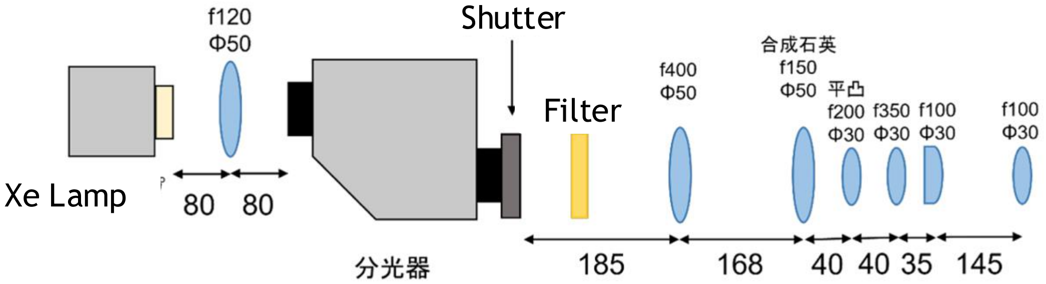


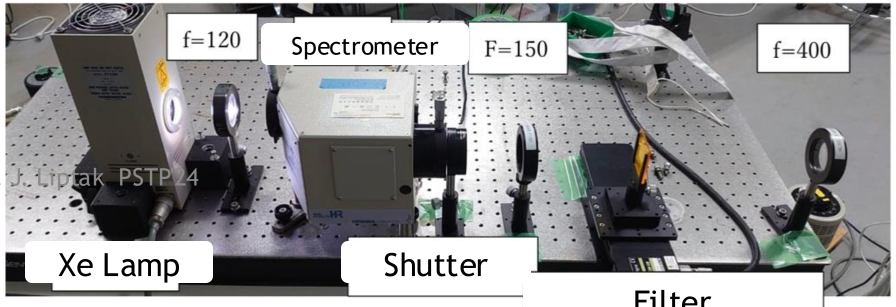
Baking at ~400C followed by cathode heat cleaning has shown to give vacuum at the level of 10^{-9} Pa. We are also actively optimizing the cathode cleaning procedure to get better thin-film formation.

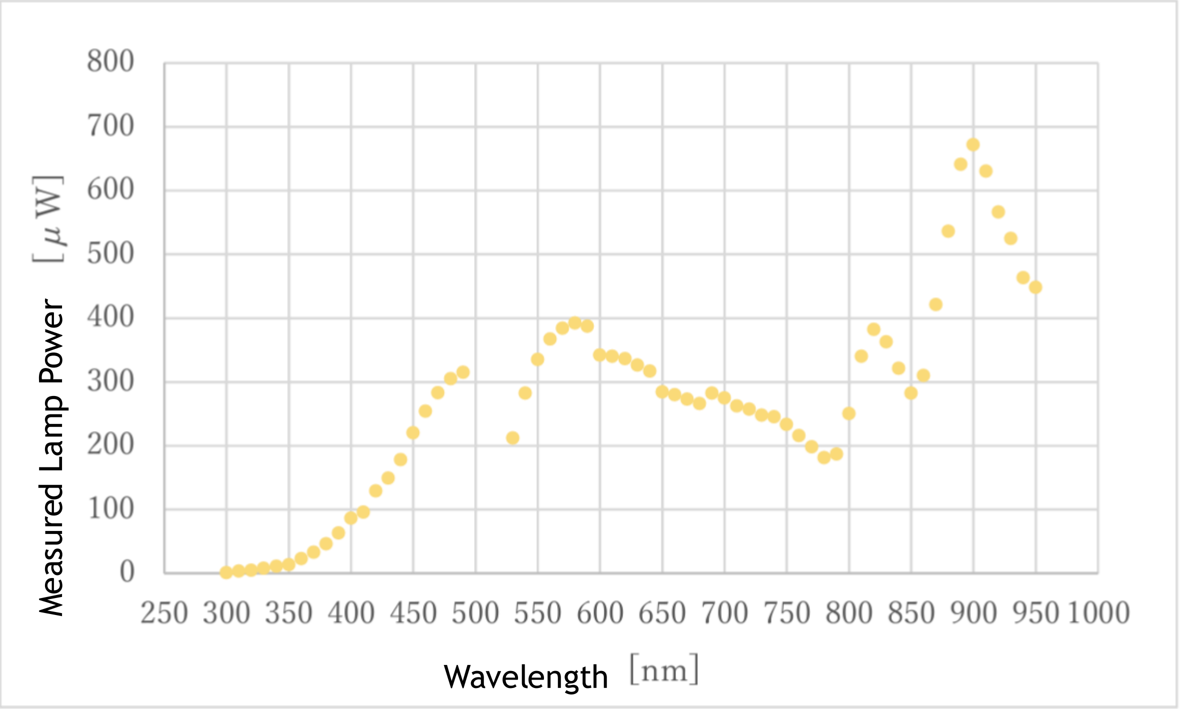
Cathode Illumination and measurement

Two modes of illumination:

- Xe lamp with spectrometer to measure response across spectrum from UV to IR
  - Full spectrum available, but difficult to focus and control
- Laser fixed to viewport
  - Easier to control and consistent power, but only for discrete wavelengths







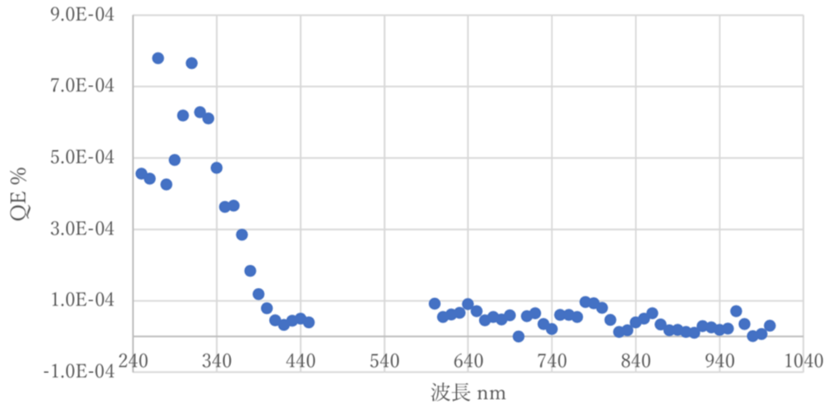
Kishi (2021)

Heterojunction Experiments

Several generations of masters/undergrad students have been trying recipes for cathode production.

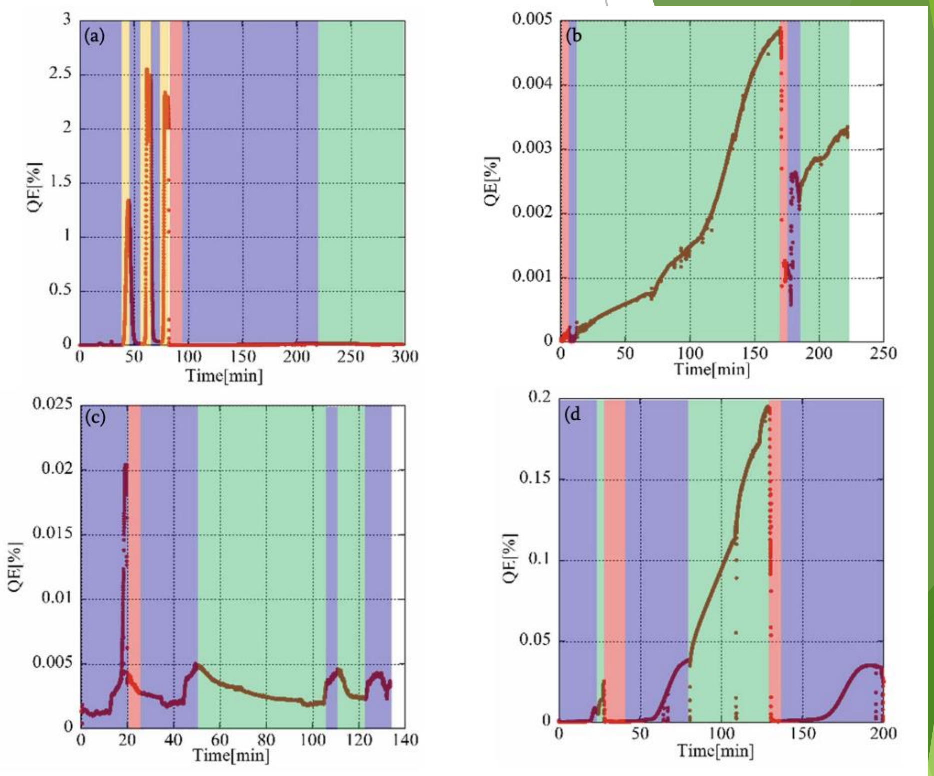
波長[nm]/エネルギー[eV]	量子効率[%]	誤差[%]
910/1.36	1.3×10^{-7}	$\pm2.7\times10^{-7}$
890/1.39	3.5×10^{-7}	$\pm3.3\times10^{-7}$
870/1.43	-2.4×10^{-7}	$\pm3.0\times10^{-7}$
830/1.49	-2.4×10^{-7}	$\pm3.4\times10^{-7}$
780/1.59	3.9×10^{-7}	$\pm1.1\times10^{-6}$
730/1.70	3.2×10^{-7}	$\pm7.5\times10^{-7}$
620/2.00	3.4×10^{-7}	$\pm7.4\times10^{-7}$
410/3.03	4.3×10^{-6}	$\pm4.5\times10^{-6}$
350/3.54	1.3×10^{-5}	$\pm3.1\times10^{-5}$

M. Kishi, 2021 (Thesis)
CsK_2Sb



S. Obora, 2020 (Thesis)
CsK_2Sb

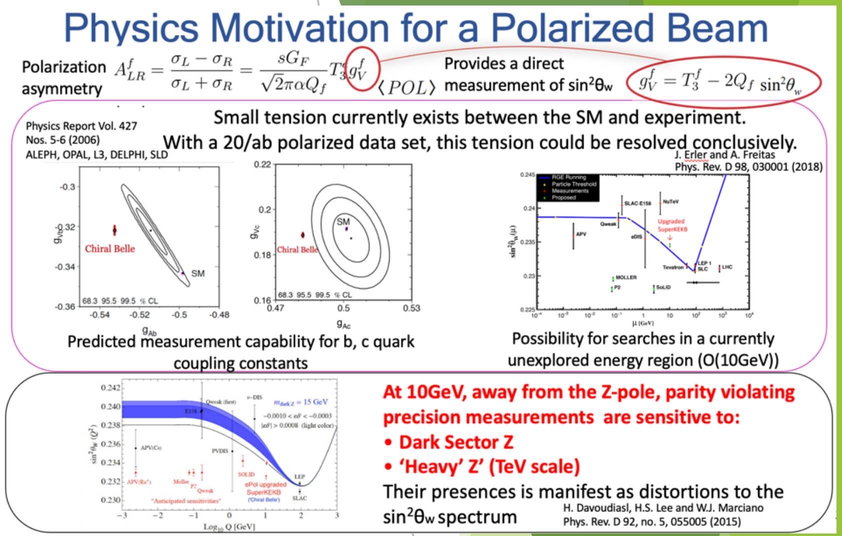
L. Guo, Y. Wakita, M. Kuriki (2024)
IPAC’24 WEPC62
Cs-Sb-O



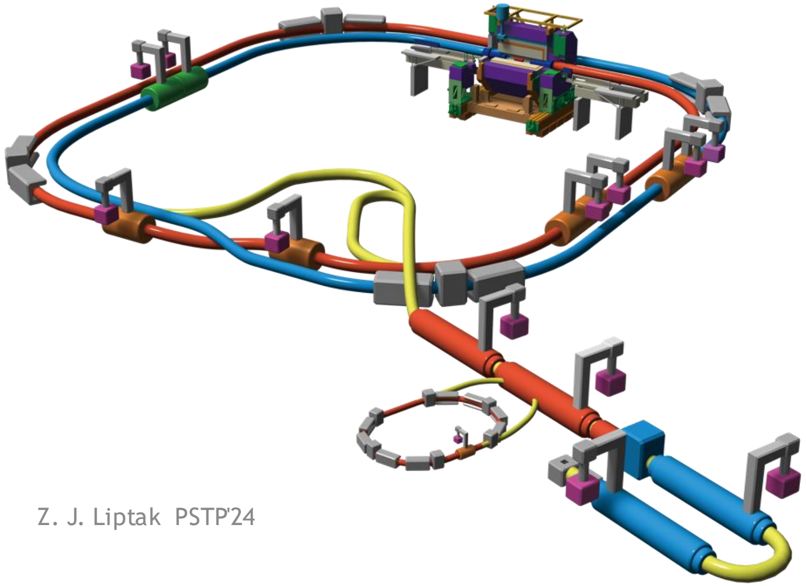
Optimizing the deposition recipe and thicknesses is important and leaves us lots of room to improve!

Other novel improvements under investigation, e.g. graphene protective layer (see L. Guo, IPAC’23 TUPA013)

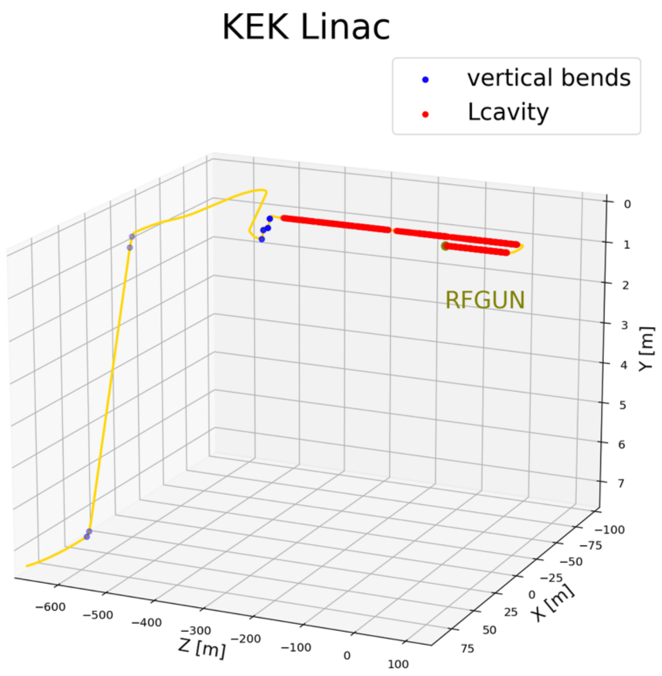
Potential Near-Term Application: Chiral Belle

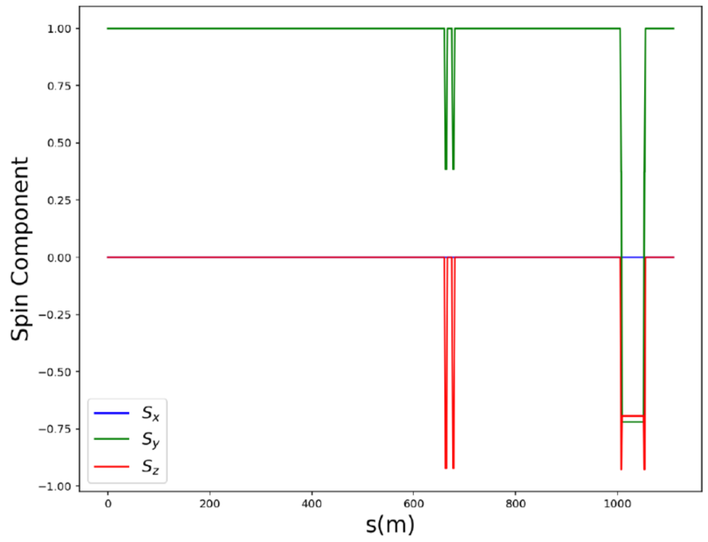


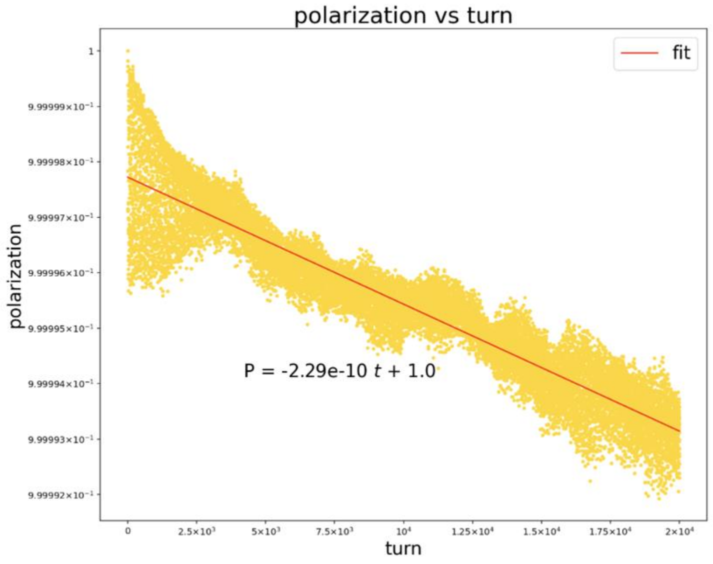
- Extend physics program and lifetime of SuperKEKB/Belle II
- Gain experience with polarized e^- beam in real-world situation
  - Avoid future pitfalls at ILC and preserve institutional knowledge



- Minimal version of Chiral Belle proposed with only electron source and necessary beam elements (Wien filters, &c)
- Assembled a team w/ KEK accelerator group, HU, BNL, Louisville, Victoria
- Can use Touschek lifetime to confirm presence of polarization at IP
  - Touschek lifetime measurements well established by Belle II background group (A. Natochii *et al.*, NIM A Volume 1055, October 2023, 168550; Z. Liptak *et al.*







Images courtesy of Y. Peng

Spin Preservation Simulations

0^{th} order simulations indicate that spin can be preserved through the SKB J-arc and vertical beam transport lines. More work remains to introduce misalignments, errors, &c.

Summary and Future Plans

- Japan has a history of developing polarized cathodes and looks to continue this work for ongoing and future projects.
- Heterojunction cathodes have improved cathode lifetimes while maintaining QE, but their lifetimes need to be improved.
  - Produced samples also need to be tested for polarization rates – Mott polarimeter test bench setup and use under investigation now
- Work is ongoing to optimize production recipes to maximize cathode robustness and meet the needs of current and future facilities.
  - Need to be on the lookout for other novel solutions
- Future projects will need expertise and institutional knowledge and international collaboration and cooperation developed and carried out now.