Alkali Cathode Testing for LCLS-II at APEX

Houjun Qian, LBNL
on behalf of APEX team

FEL 2015, Korea, April 24, 2015

APeX @ Berkeley Lab

The APEX Team!

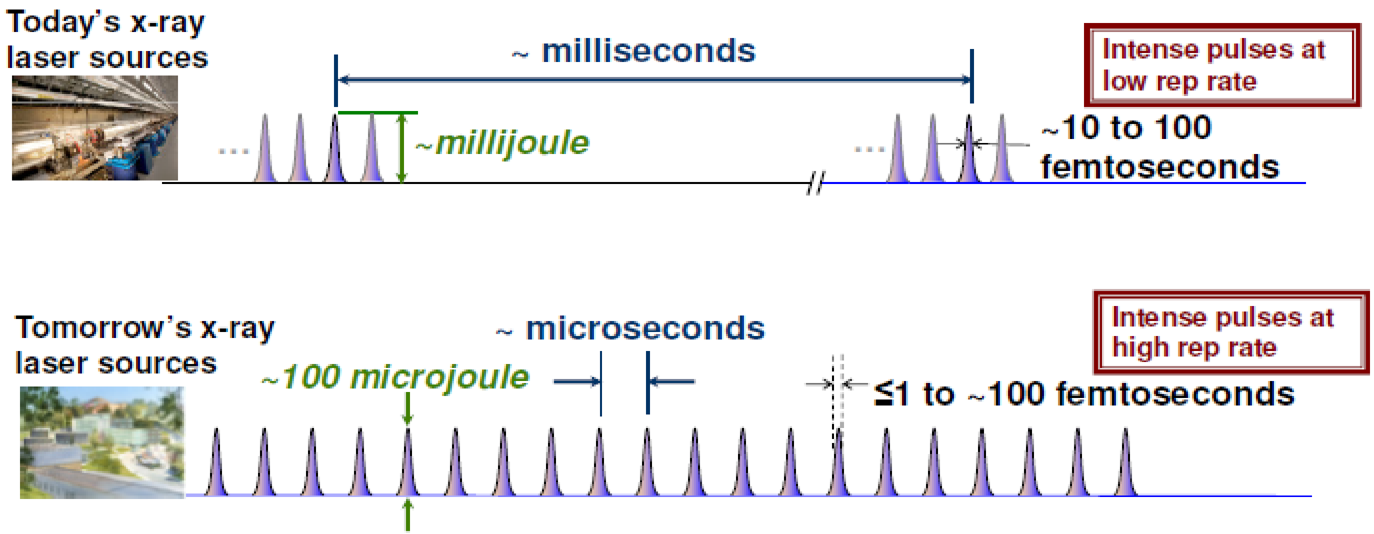
K. Baptiste, M. Chin, J. Corlett, C. Cork, S. De Santis, M. Dickinson, L. Doolittle, J. Doyle, J. Feng, D. Filippetto, G. Harris, G. Huang, H. Huang, R. Huang, M. Johnson, T. Kramasz, S. Kwiatkowski, D. Leitner, R. Lellinger, V. Moroz, W. E. Norum, H. Padmore, G. Portmann, H. Qian, F. Sannibale, J. Staples, M. Vinco, S. Virostek, W. Wan, R. Wells, M. Zolotorev, … .

Outline

- Introduction to APEX systems
- Photocathodes test at APEX
  - – Cs_2Te cathode testing results
  - – Gun improvements benefit cathode operation
  - – Preliminary Alkali antimonide cathodes testing
- Summary

Science asks for higher flux

- Next-gen XFEL facility: 100 Hz → MHz
  - More coherent X-ray photon flux per sec
  - More stable machine with wider control BW
  - More FEL beamlines, more users



~mJ
~100 Hz

~mJ
~1 MHz

Electron source requirements

- Typical specs on electron source for MHz XFEL

Parameter	Value and Unit
Bunch Repetition rate	Up to 1 MHz
Charge per bunch	10 – 300 pC
Normalized emittance	0.2 – 0.6 mm
Beam energy at the gun exit	> 500 keV
Cathode electric field at photoemission	>10 MV/m
Bunch length and shape control	5 - 60 ps
Magnetic field at cathode	< 2 G
Dark current at nominal gun energy	< 400 nA
Operational vacuum pressure	$< 2\ 10^{-9}$ Torr
Loadlock cathode vacuum system	

Typical gun requests:

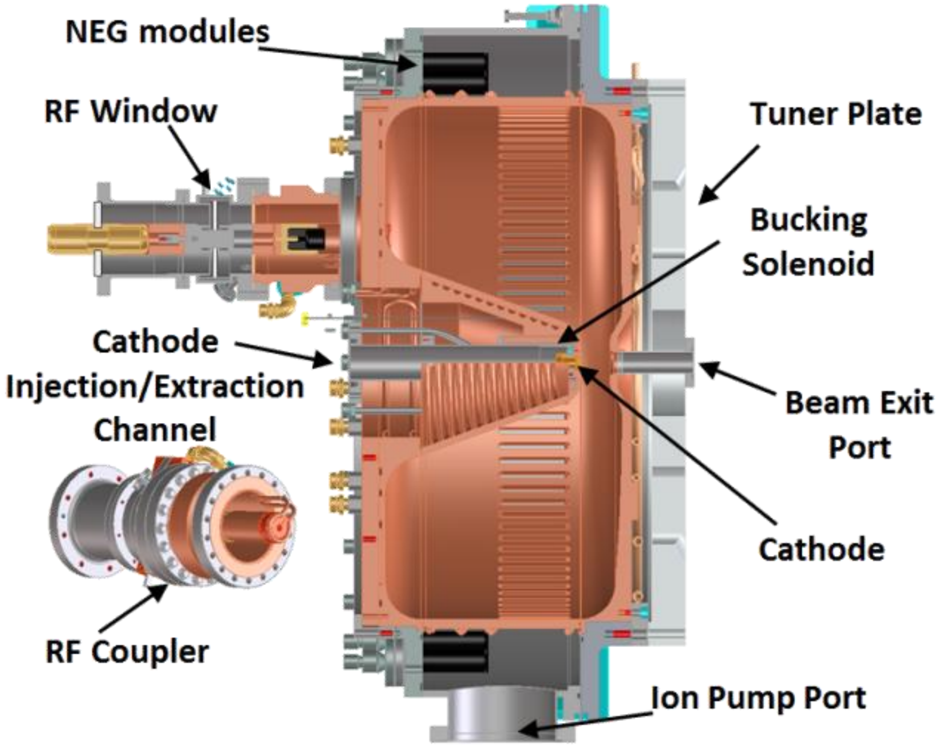
- High duty cycle - CW
- High gradient
- High gun voltage
- Low dark current
- UHV vacuum w/ loadlock
- …

Typical photocathode requests:

- High QE (>1%)
- Low thermal emittance (< 1 mm.mrad/mm)
- Long life time (>1 week)

F. Sannibale, D. Filippetto, C. Papadopoulos, JMO **58**, 1419 (2011)

Normal Conducting VHF gun demonstrated



Frequency	185.7 MHz
Operation mode	CW
Gap voltage	> 750 kV
Field at the cathode	20 MV/m
Q0 (measured at R.T.)	30050
Shunt impedance	5.8 MΩ
RF Power @ Q_0	99 kW
Stored energy	2.4 J
Peak surface field	24.4 MV/m
Peak wall power density	25.0 W/cm^2
Accelerating gap	4 cm
Diameter/Length	69.4/35.0 cm
Operating pressure	~3 x 10^{-10} Torr
Transported dark current	< 0.1 nA

F. Sannibale et al., Phys. Rev. ST Accel. Beams **15**, 103501 (2012).

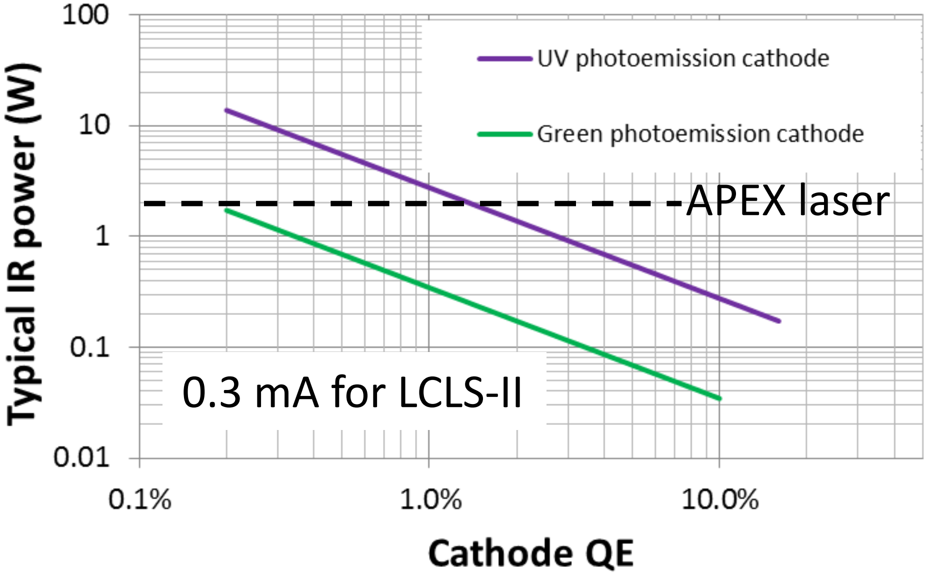
Photocathodes under test at APEX

- Alkali cathodes
  - Cesium Telluride Cs_2Te (UV)
  - Multi-Alkali Antimonides CsK_2Sb, $CsSb_3$... (Green)

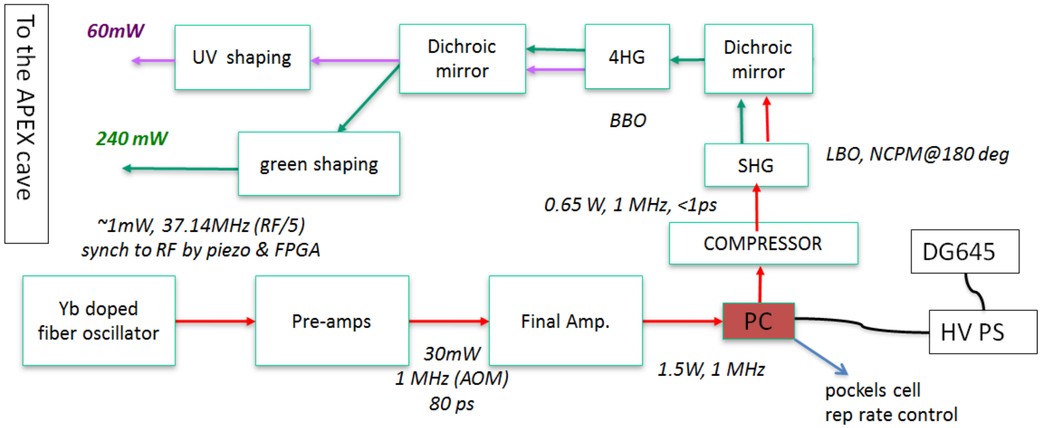
Reported typical cathode performance in other guns

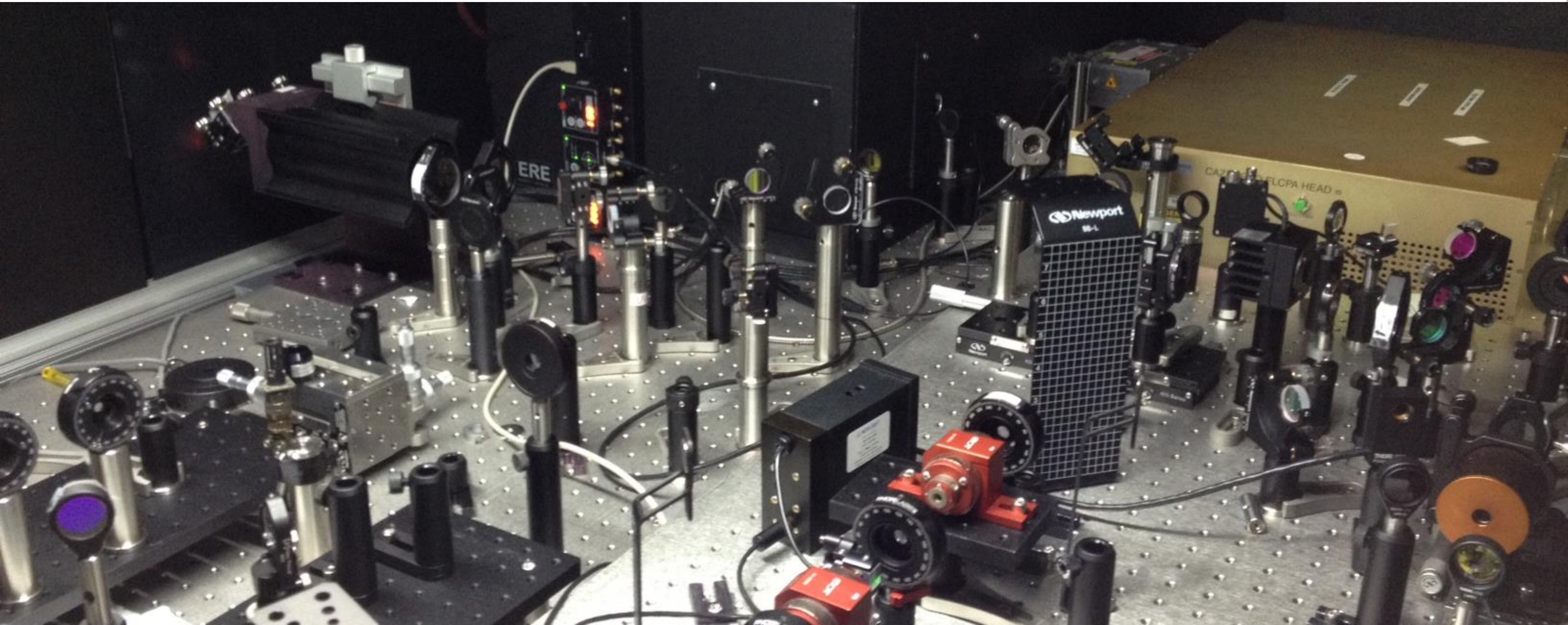
	Cs2Te	Anotimonide
Laser	UV	Green
Response	~ps	~ps
Vac	Low 10^{-9} torr	Low 10^{-10} torr
QE	~10%	~5%

Req for Cathode QE & laser power



APEX Photo-Cathode Laser





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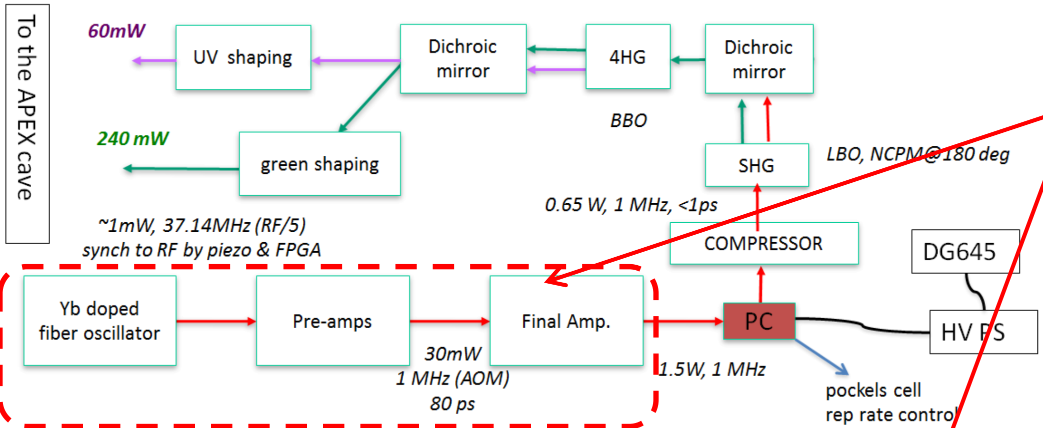
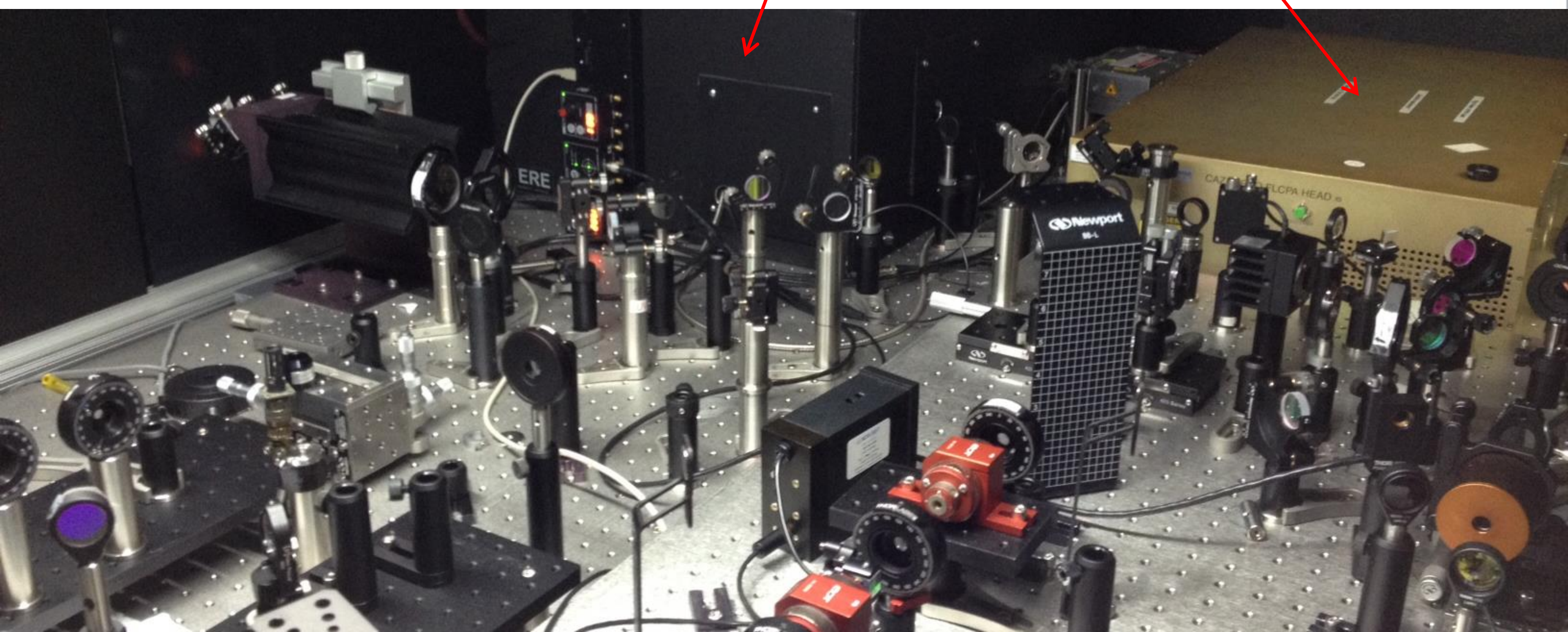


LASER 1: 1 MHz reprate Yb fiber laser from a LLNL/UCB/LBNL collaboration, 0.7 W at ~1064 nm

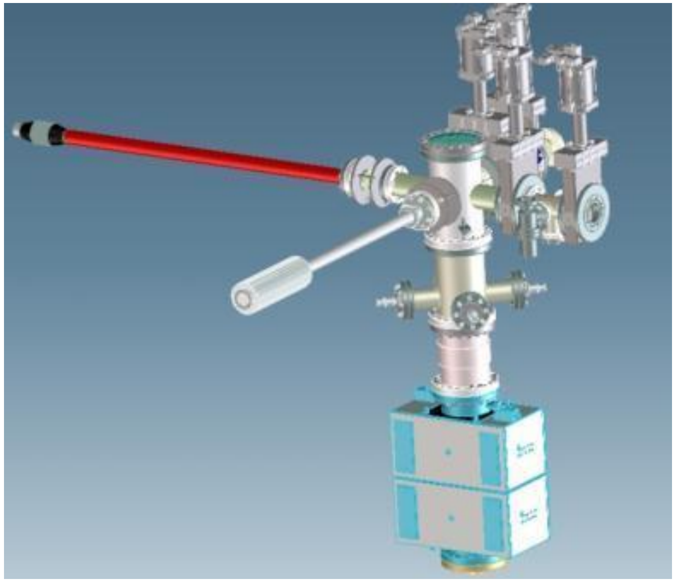
LASER 2: Commercial 1 MHz 2 W @ 1052 nm (presently used).



Loadlock for high QE cathodes

- APEX loadlock system

Collaboration with INFN – LASA, adapted version of the INFN/PITZ/FLASH load-lock system.



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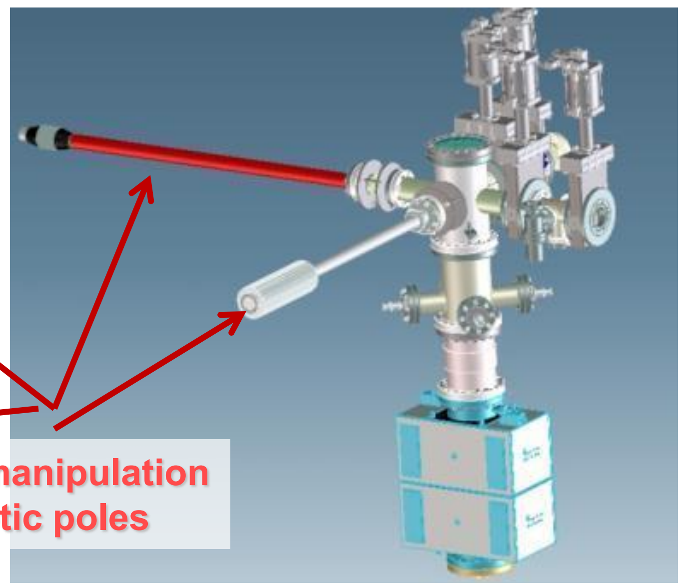

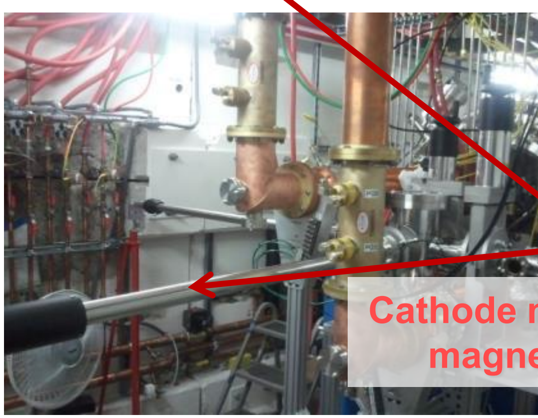

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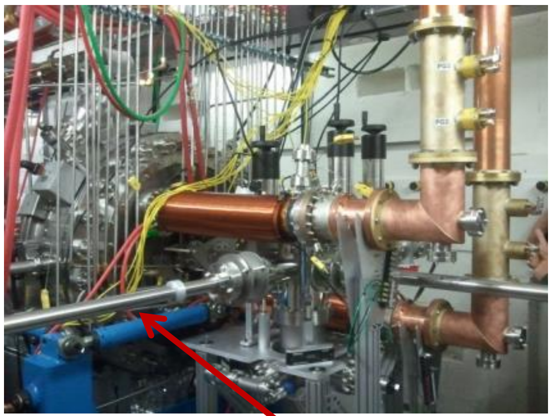

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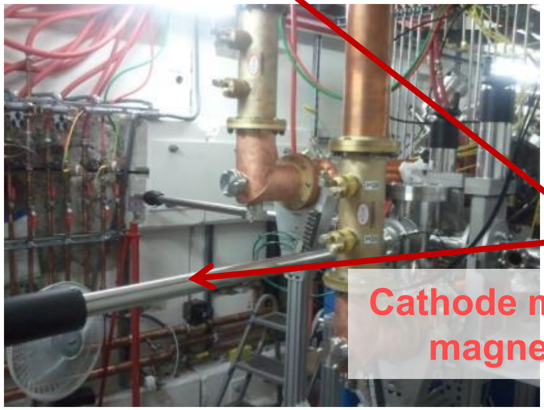

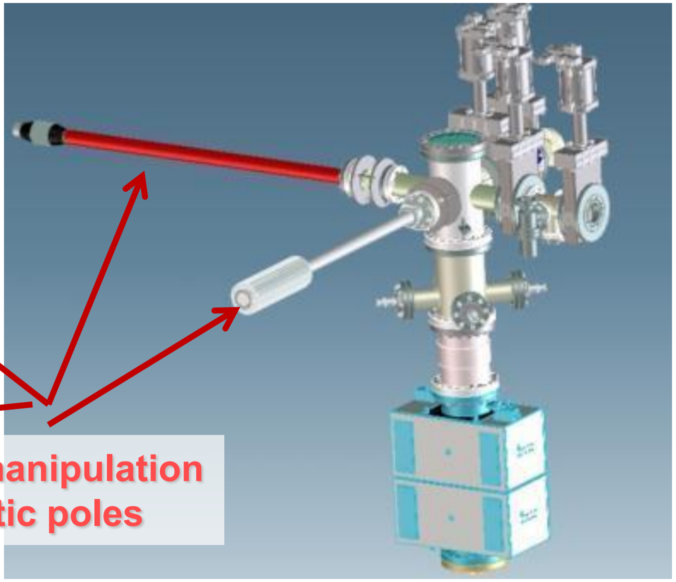

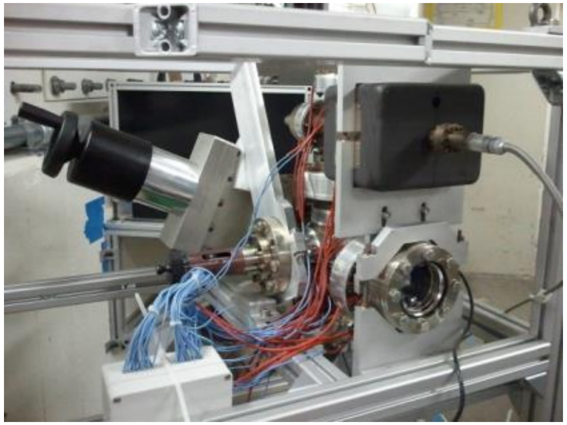

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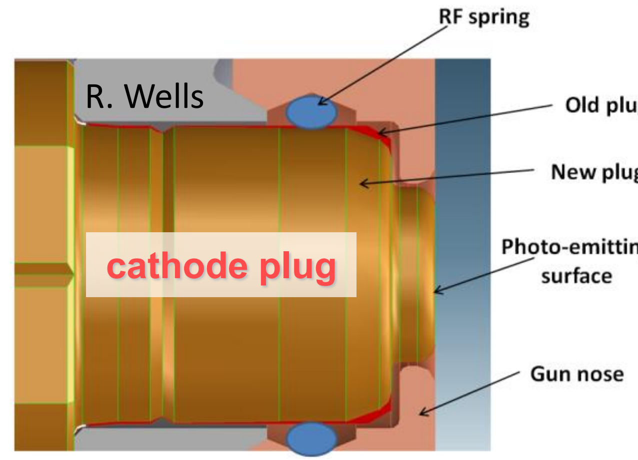

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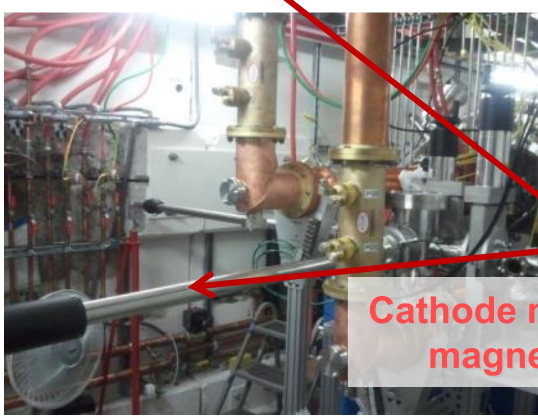
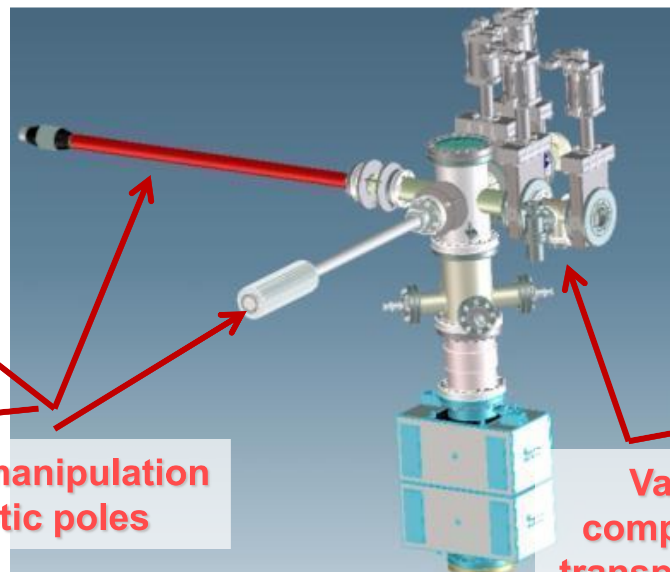
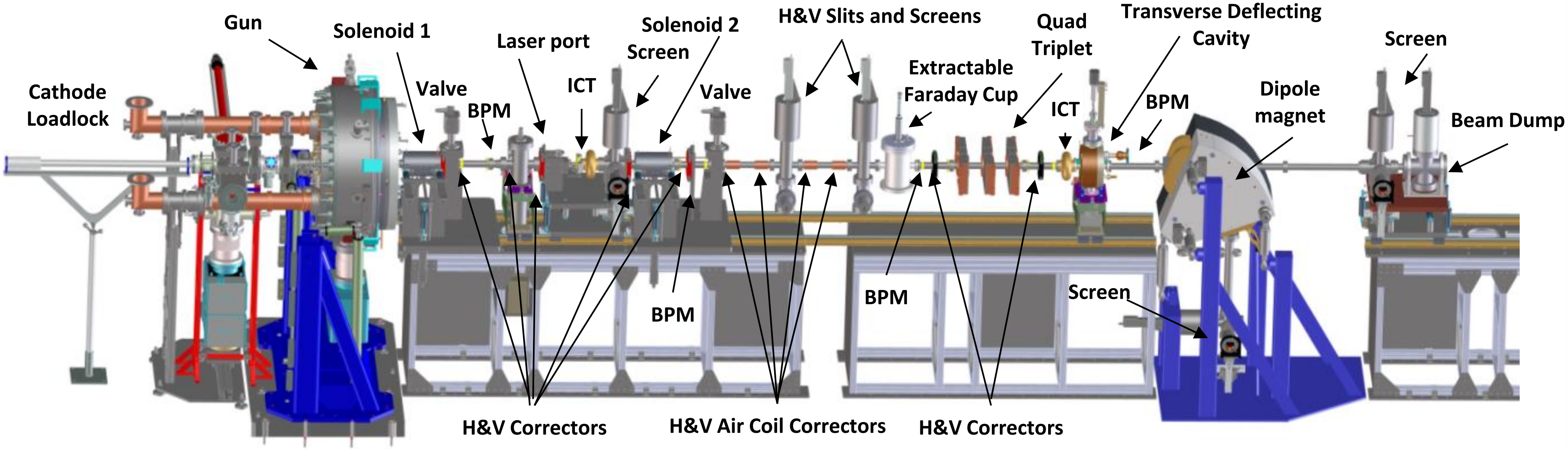




Cathode manipulation magnetic poles

Vacuum “suitcase” compatible with airplane transportation (NEG pump)

- APEX Phase-I beamline for cathode testing



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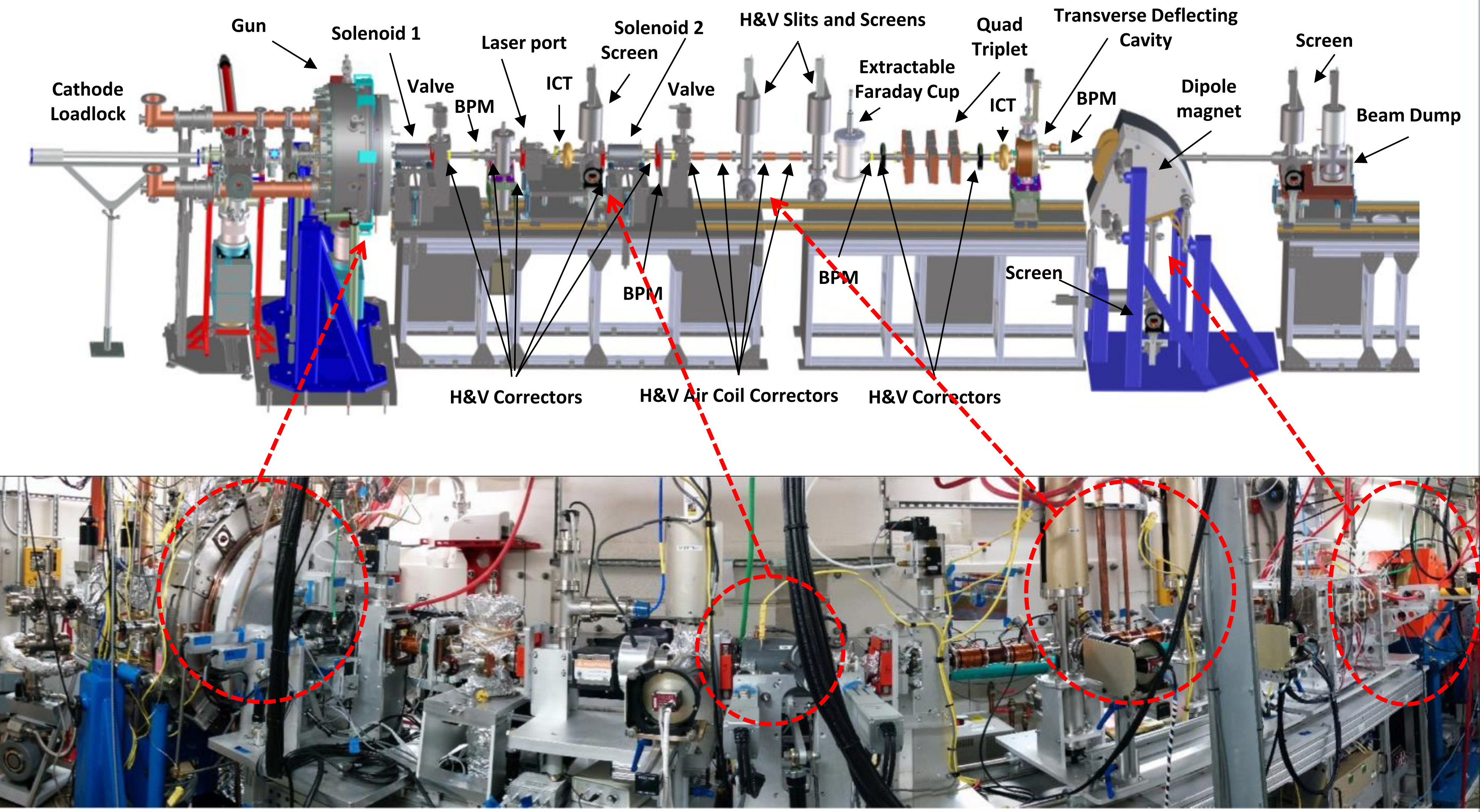


Cs_2Te cathode testing

- Cs_2Te cathodes prepared by INFN/LASA
  - 2010/2011, 3 cathodes prepared by INFN
  - 2012.10, tested in vacuum suite, QE ~ 13% (#409.1)

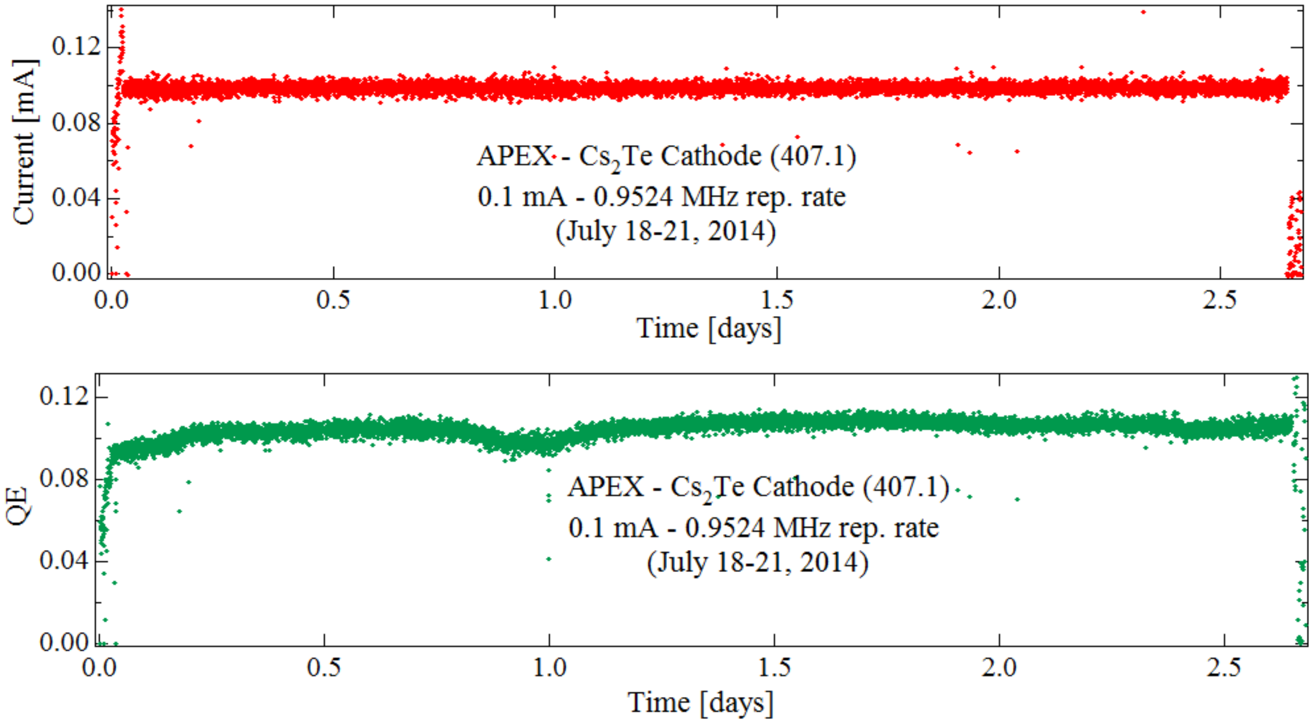
Almost two years in the vacuum suitcase with no apparent QE degradation!

Demonstration for LCLS-II at AEPX

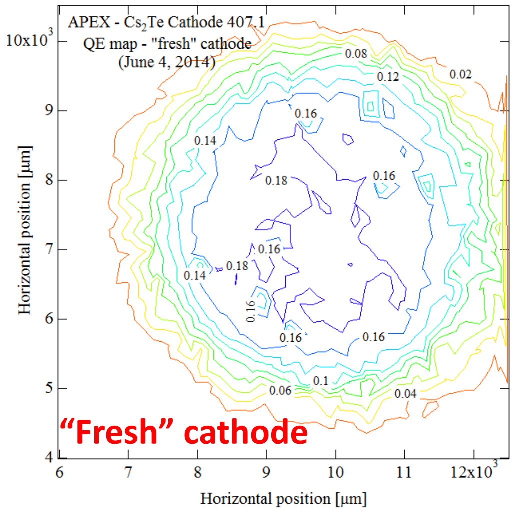
0.3 mA - 0.02 mA LCLS-II modes

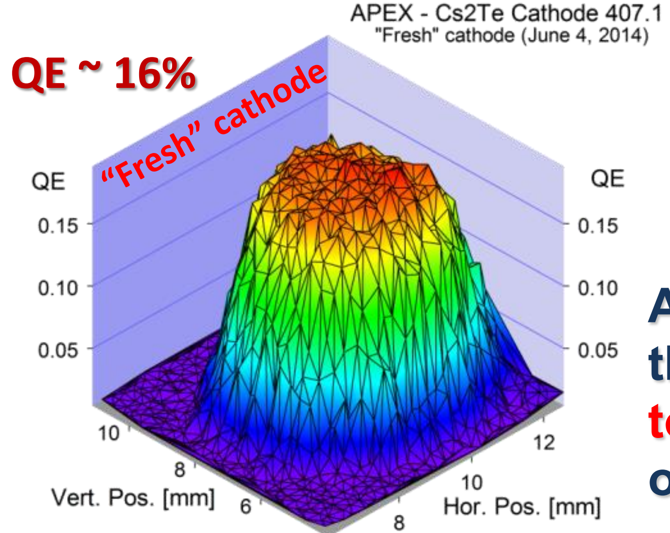
demonstrated with Cs_2Te at APEX.

~0.1 mA, ~2.6 days, ~23 C, cathode #407.1

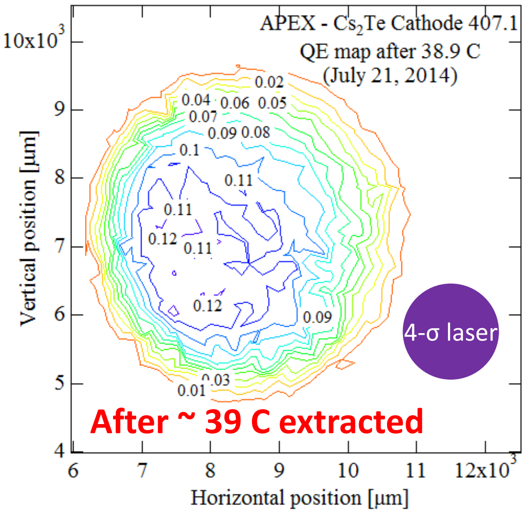


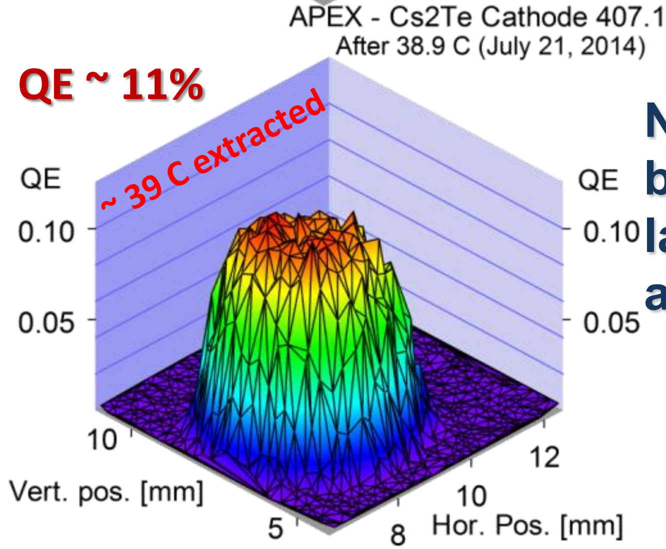
QE & lifetime satisfy LCLS-II with margin





After the extraction of ~39 C the QE degraded from ~16% to ~11%. (integrated ~ 5 days of continuous operation).



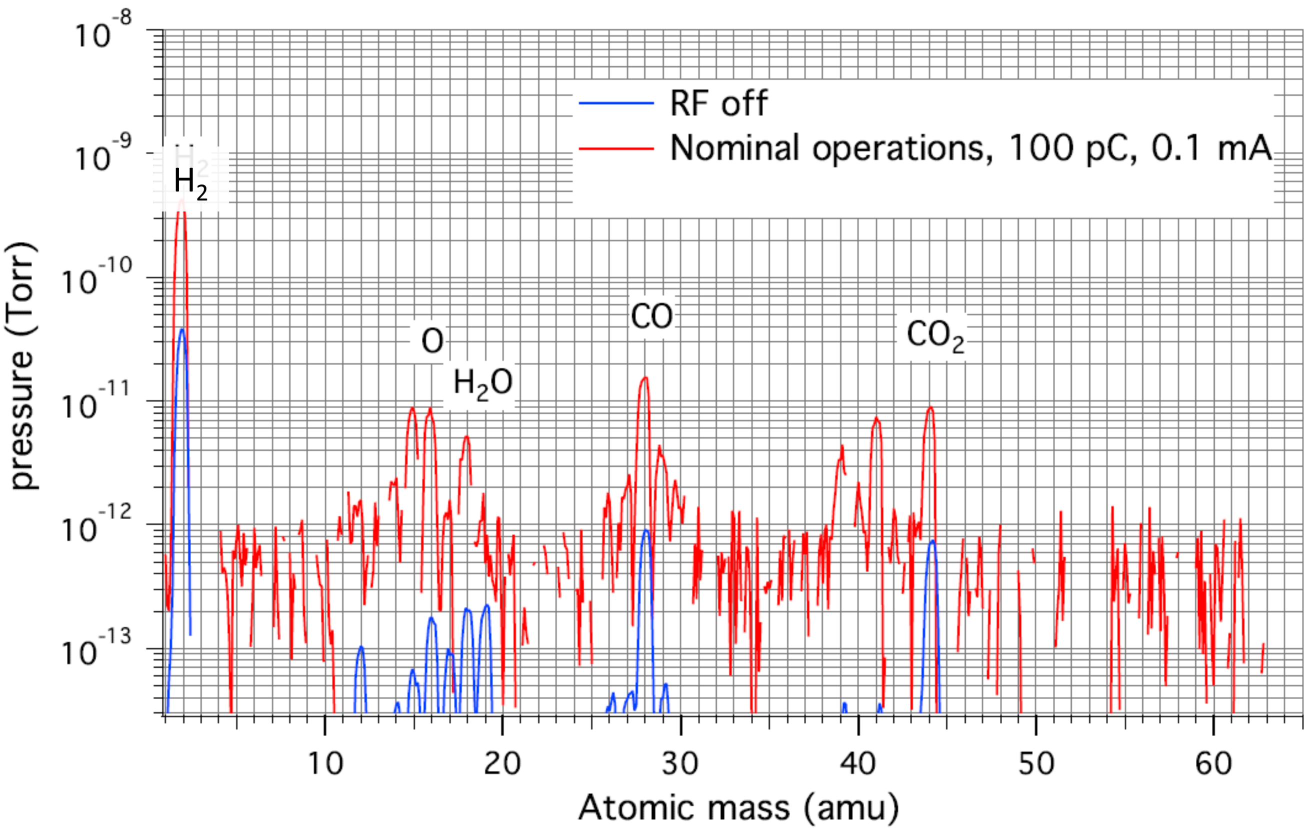


No signs of ion back-bombardment or of laser induced QE depletion at cathode center.

Cs_2Te (#407.1) lifetime analysis

Absolute pressure goes from low 10^{-11} (RF off) to high 10^{-10} Torr (RF on).

Oxygen line increases by almost two orders of magnitude achieving a partial pressure of ~8 x 10^{-12} Torr.



Previous work* demonstrated that the major QE degradation mechanism for Cs_2Te is oxidation

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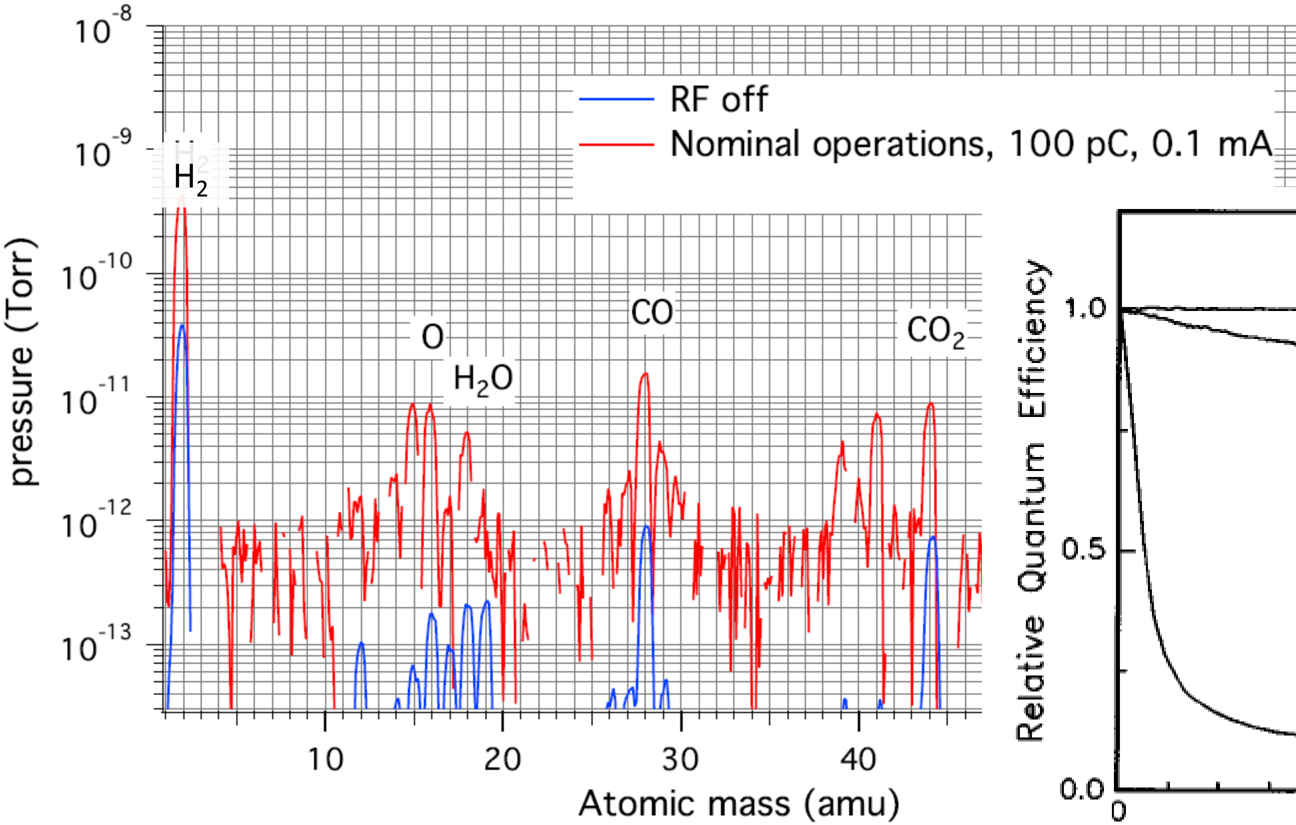

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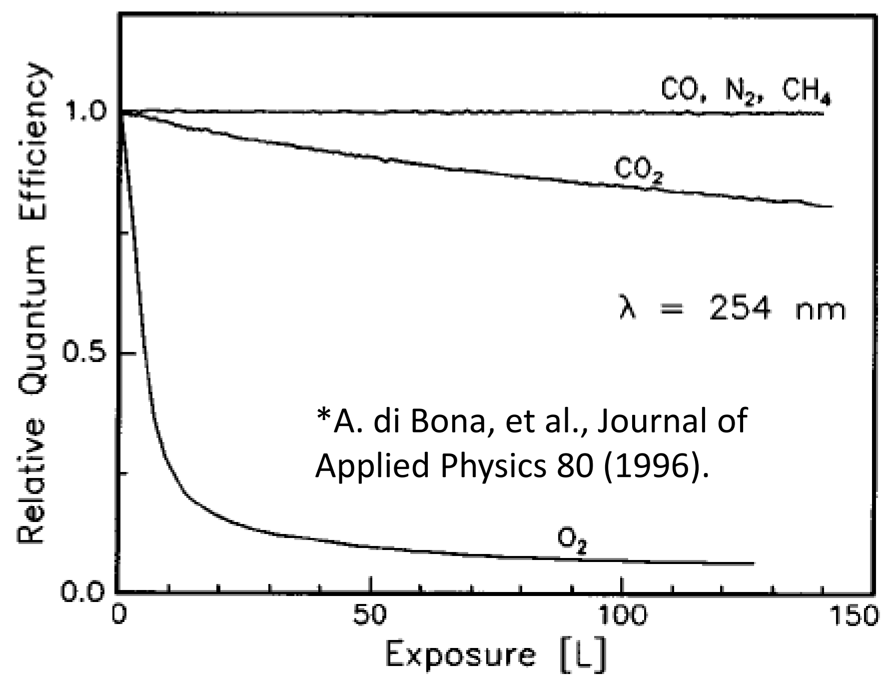

*A. di Bona, et al., Journal of Applied Physics 80 (1996).

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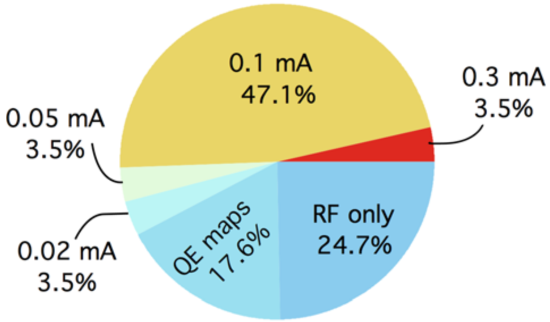
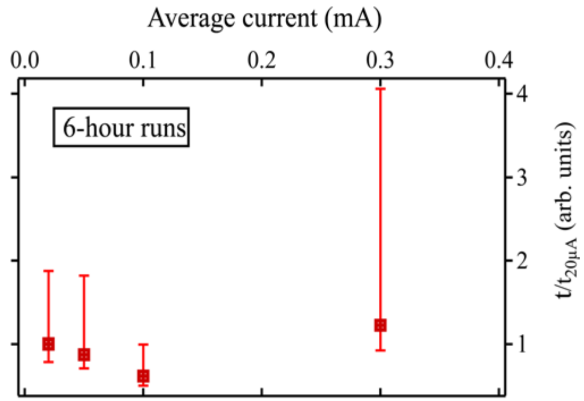
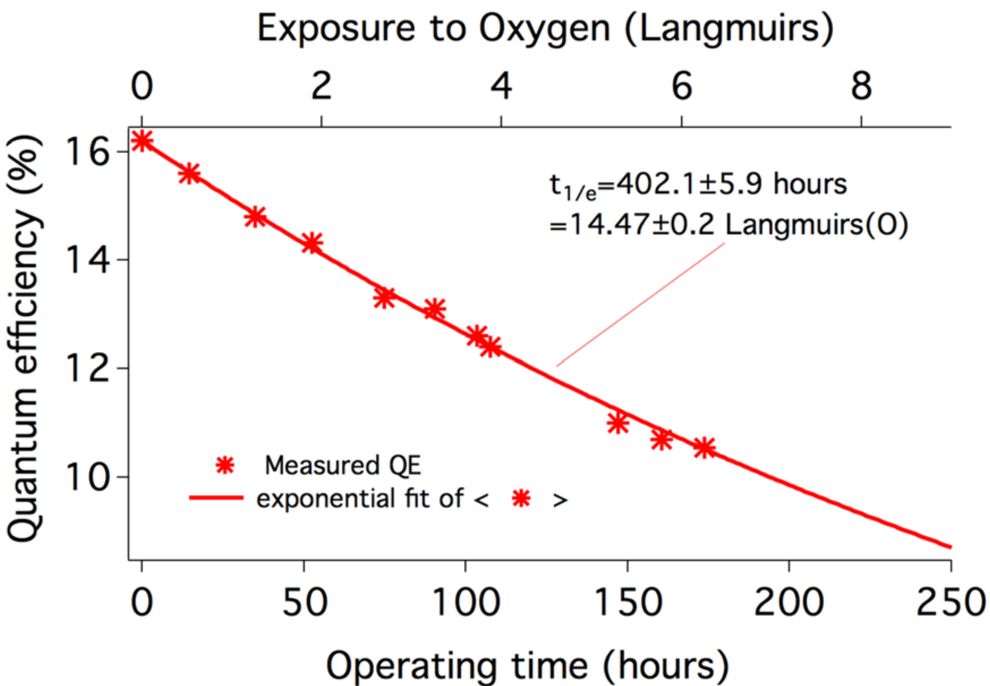




No QE lifetime correlation with current.

Consistent with previous findings*, lifetime can support LCLS-II operation.



D. Filippetto et al., Applied Physics Letters 107, 042104 (2015).

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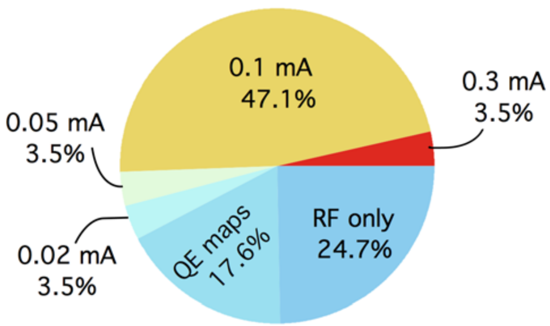

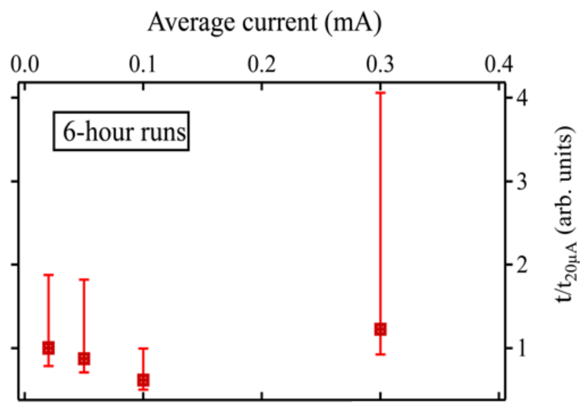

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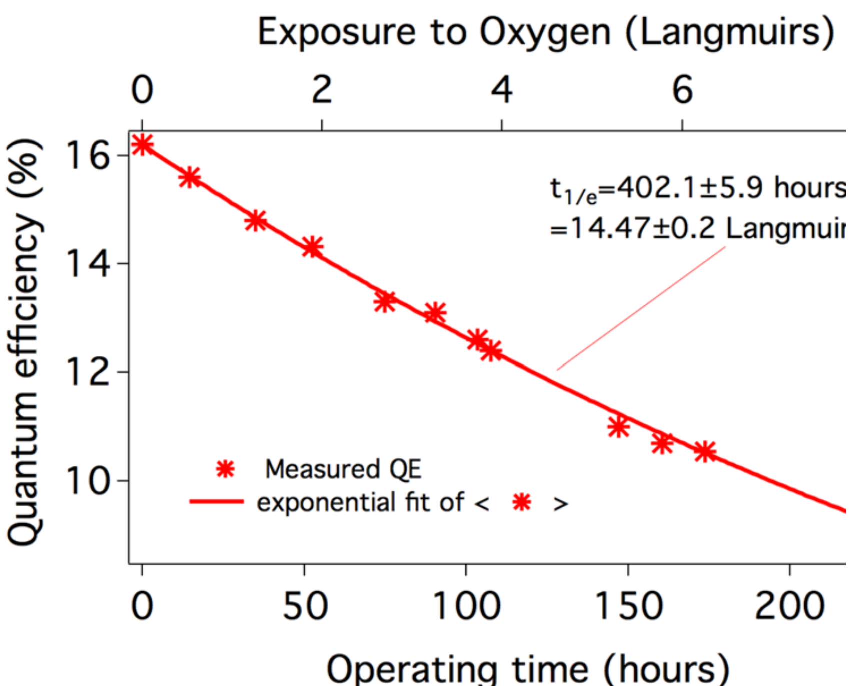

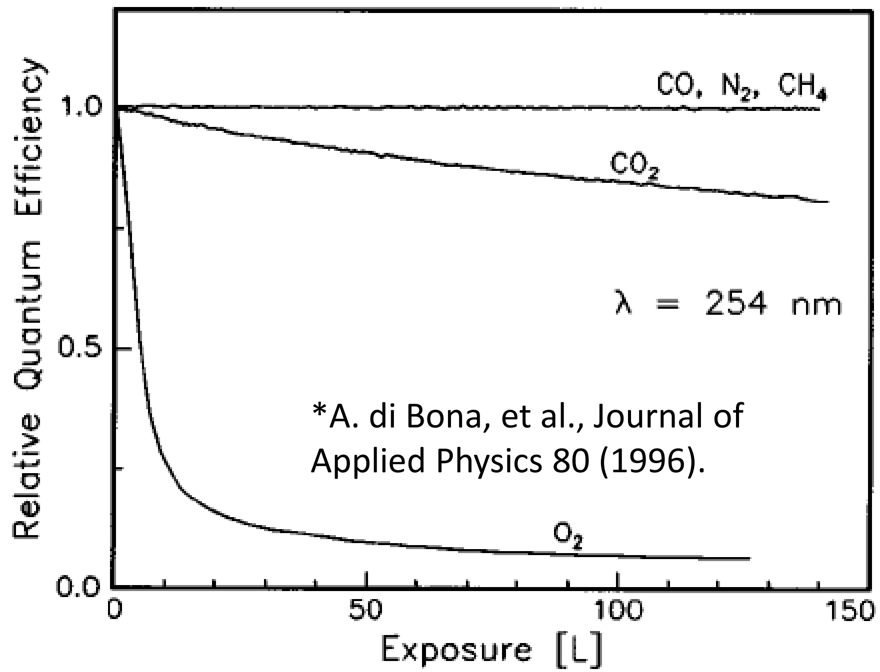

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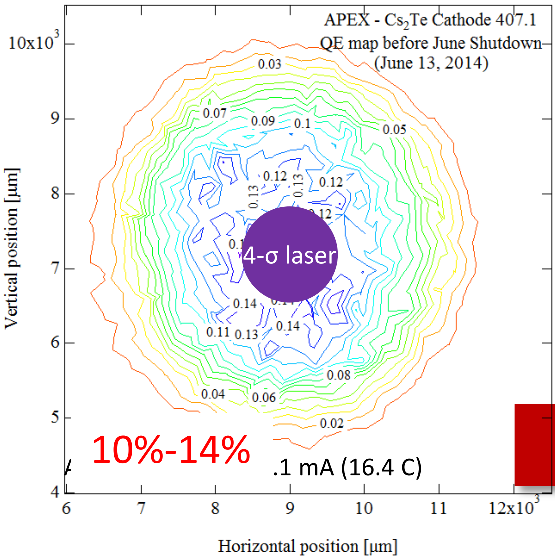
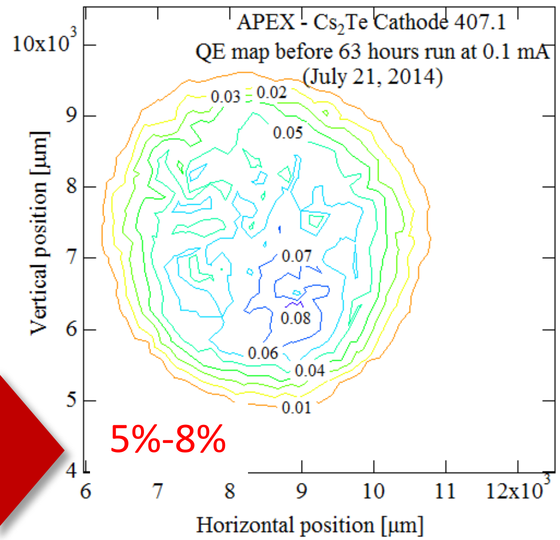
RF assisted QE rejuvenation

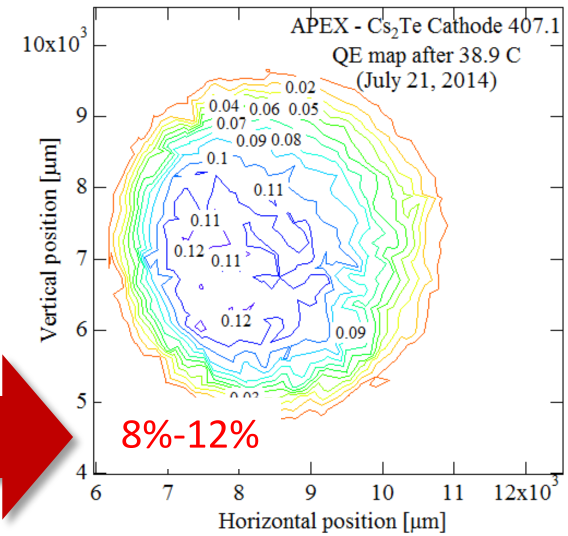
Before 4-week gun shutdown



After 4-week gun shutdown

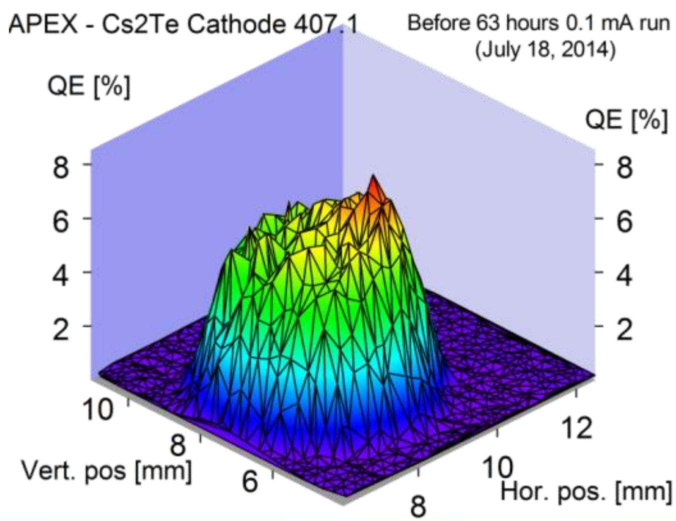


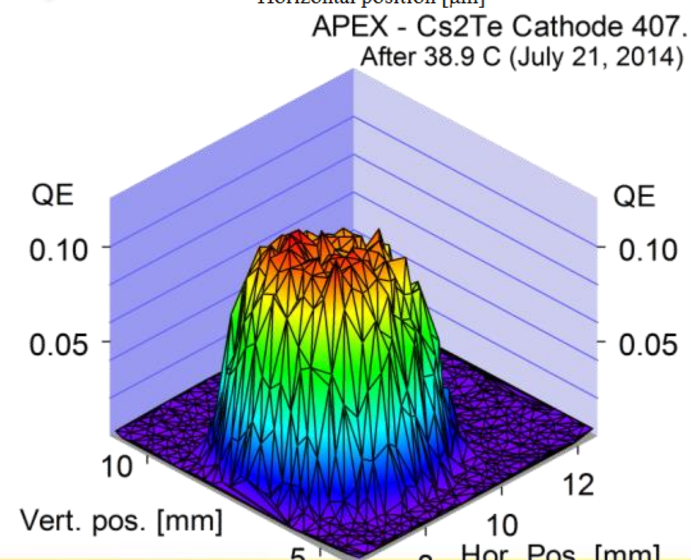
Few hours after gun restart



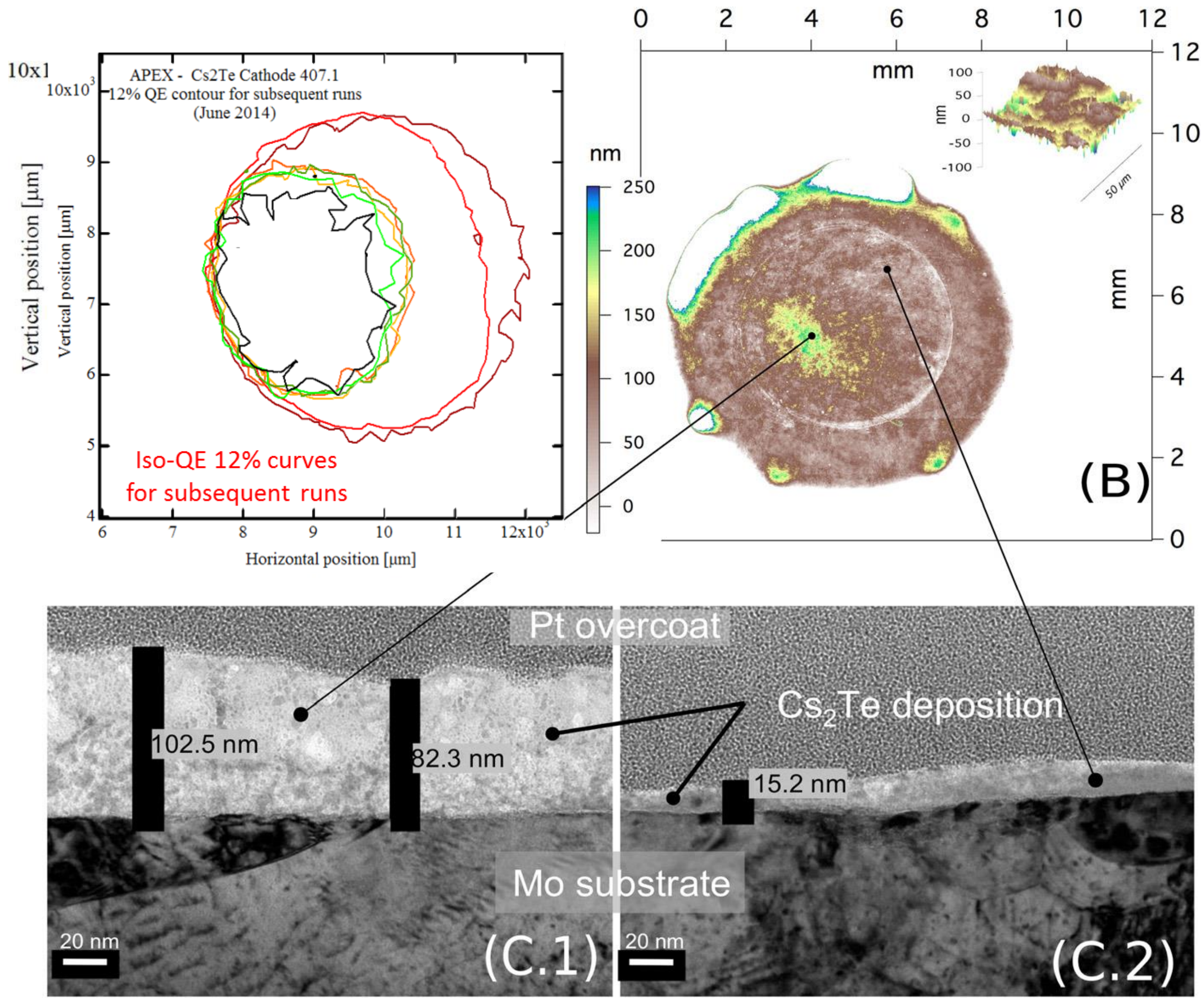
Routinely observed during gun restart after long shutdowns.

High RF gradient breaks Van der walls like weak bonds.





Cs_2Te surface analysis



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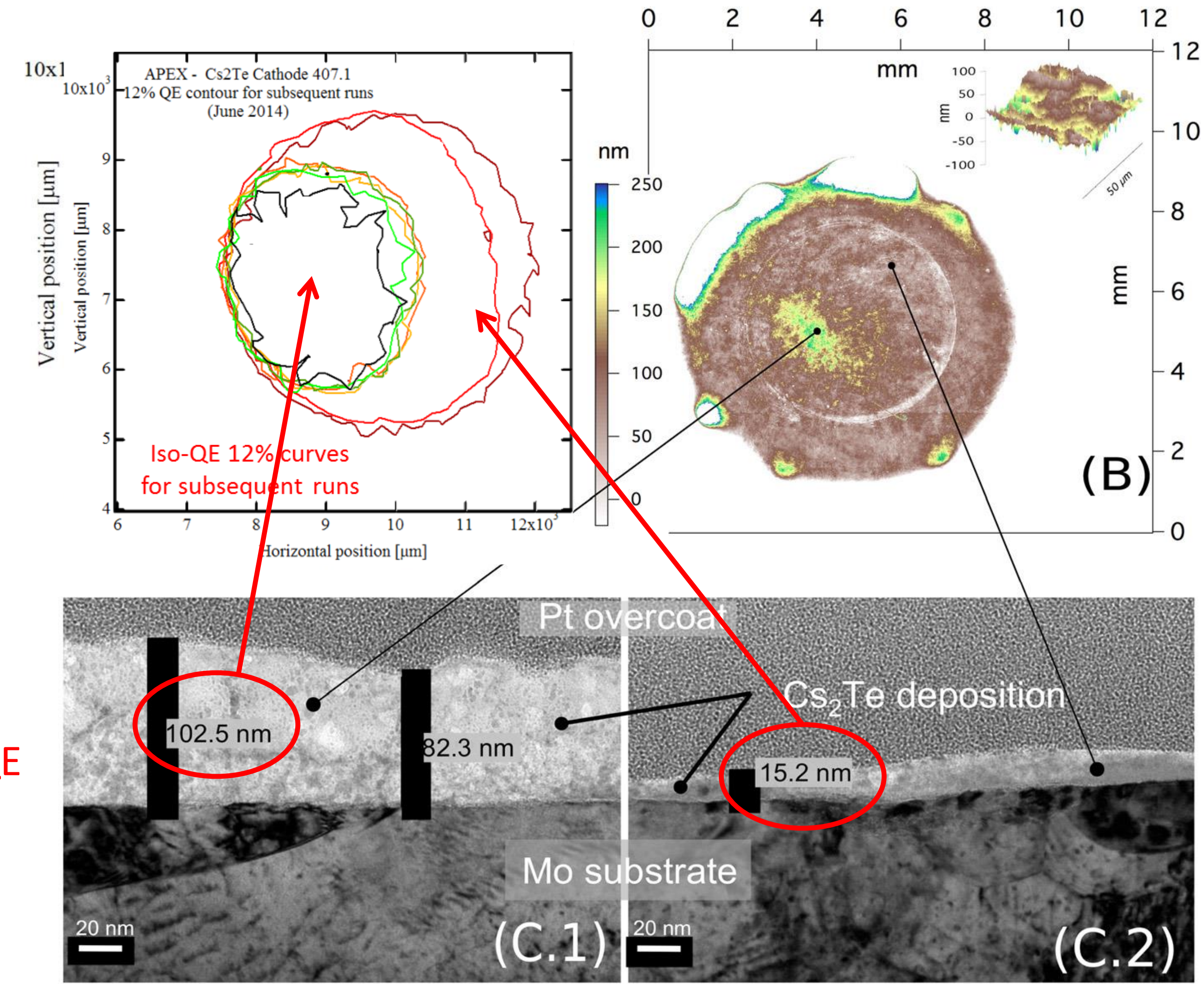
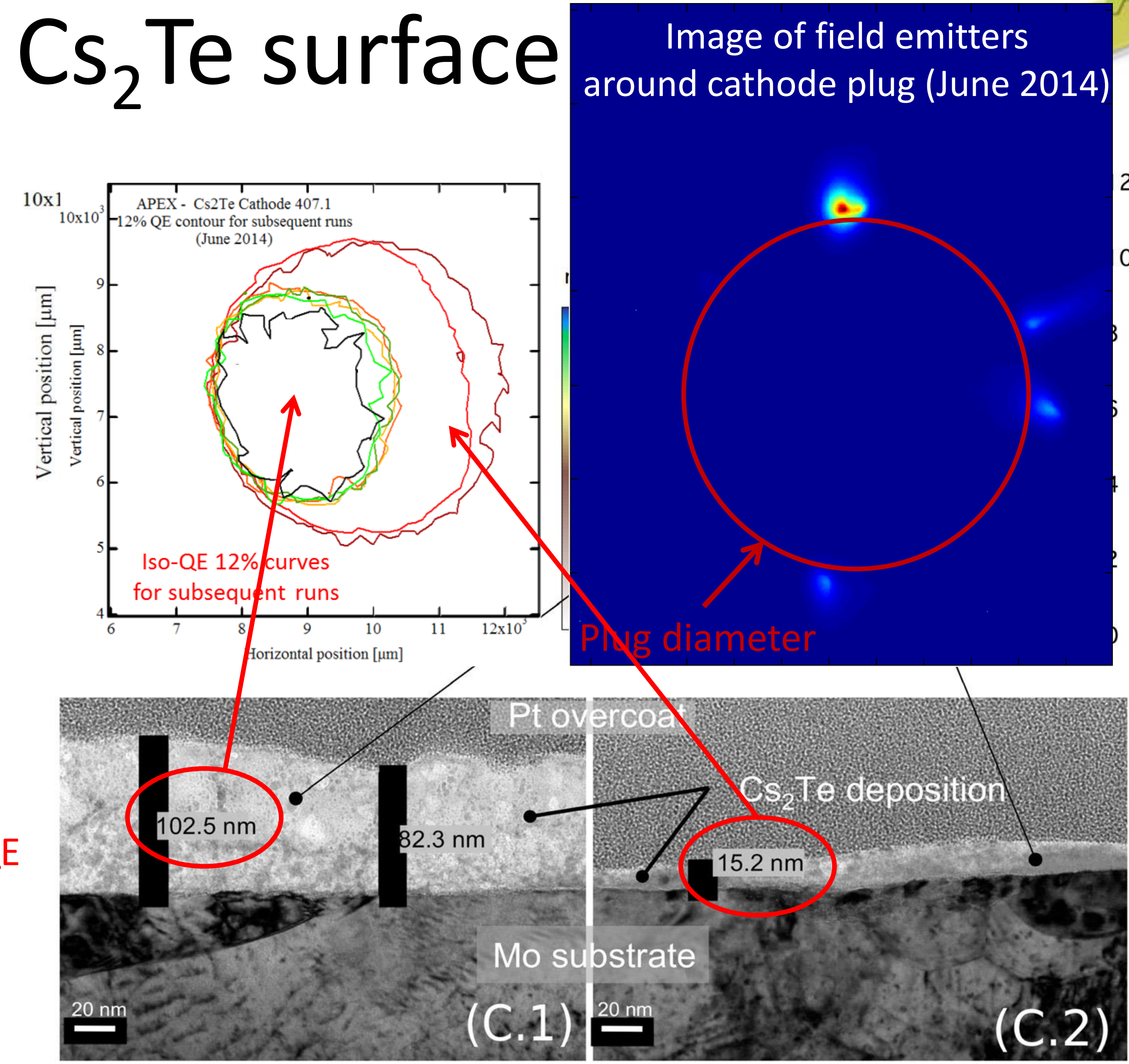


High QE area

Low QE area

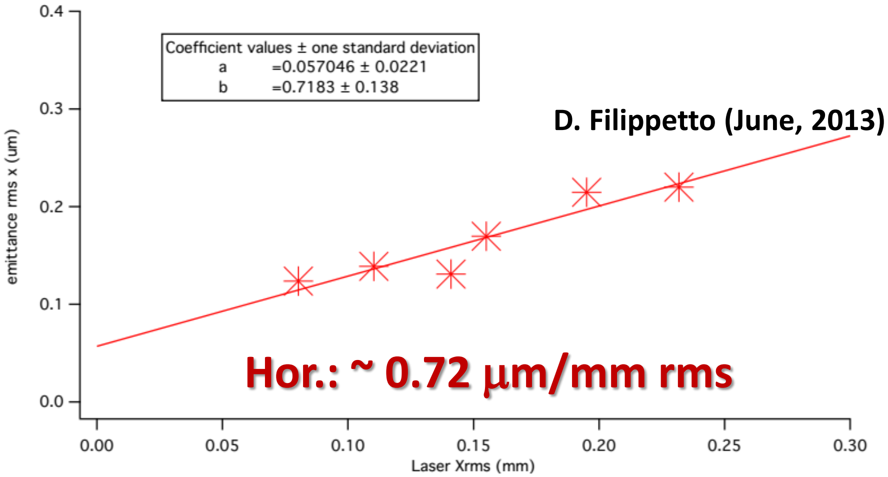
Cs_2Te surface

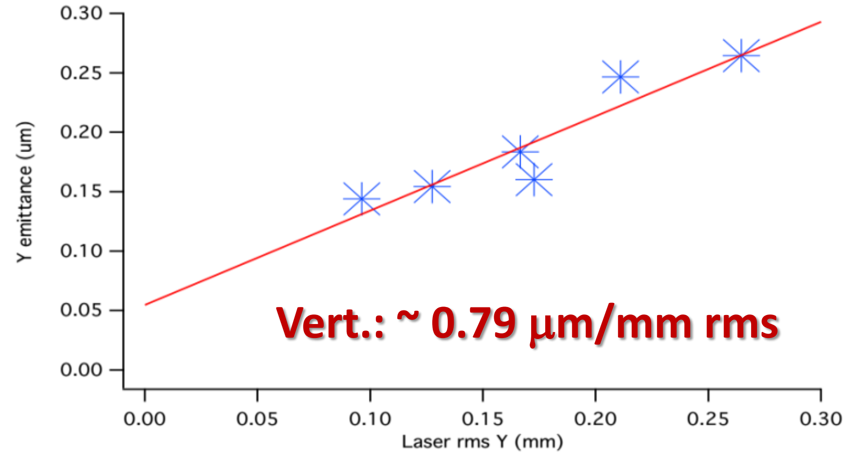


High QE area

Low QE area

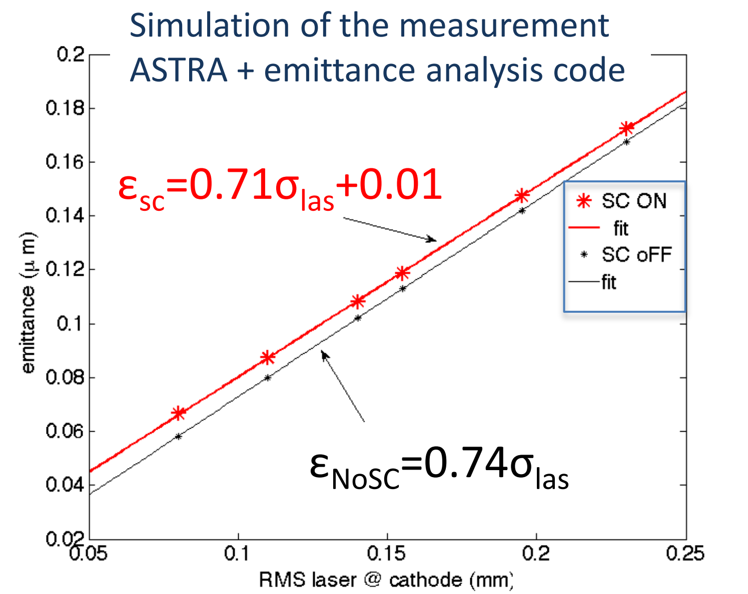
Cs_2Te thermal emittance





- Solenoid scan
  Fixed charge: 0.5 pC bunch charge, 56 ps, 780 keV beam energy

- Values in line with previous measurements.
  D. Sertore et al., Proc. EPAC 2004
- **Meets LCLS-II requirement of 1 μm/mm rms**



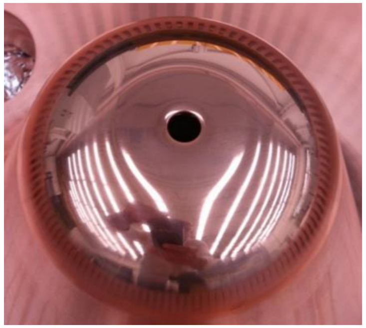
Gun improvement for cathode operation

- **Better machining of the contact parts between the anode and cathode halves of the cavity, improved the flatness of the parts and hence the contact, and a damaged RF spring was replaced with one that has thicker gold coating.**

Nominal energy (750 keV) achieved with~ 15% less RF power, which benefits gun vacuum.

Combination of dry-ice cleaning and mirror-like polishing of the cathode/anode areas.

Dark current @ the nominal energy (750 keV) dropped from 350 nA to ~ 0.1 nA!

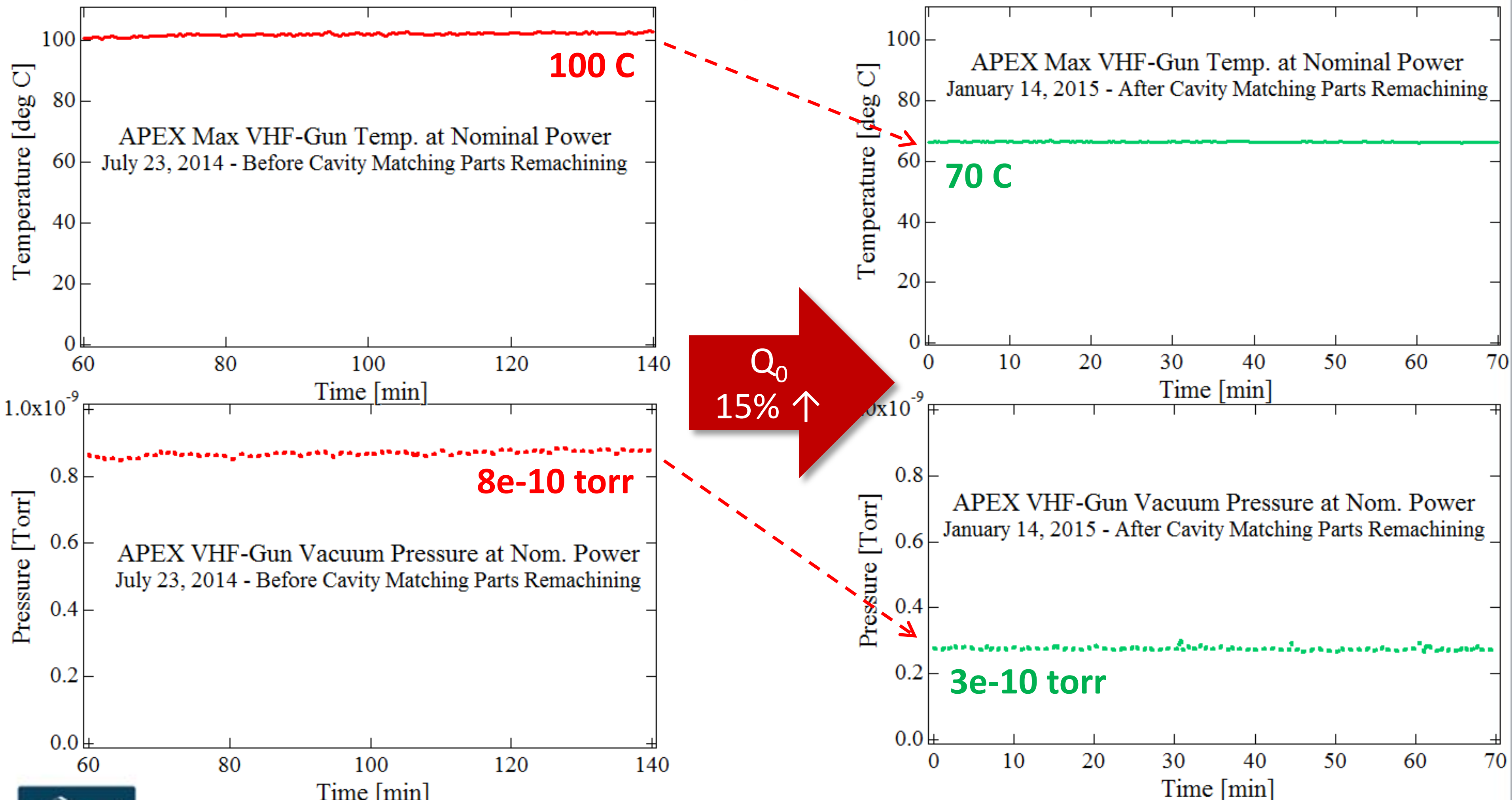


Both are very important improvements for LCLS-II

- **Cathode life time**
- **Collimation system**

Gun improvement for cathode operation

Impact of the Improved Cavity Quality Factor



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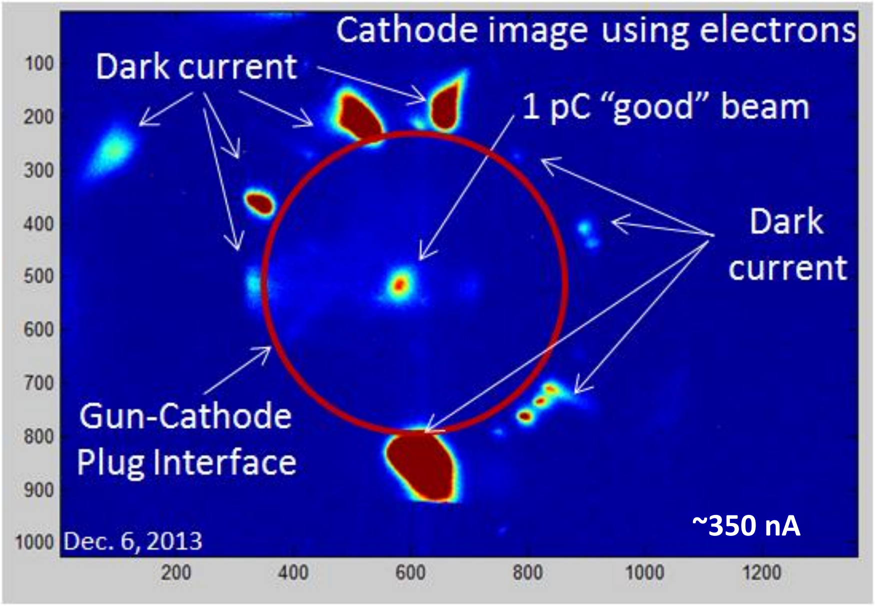
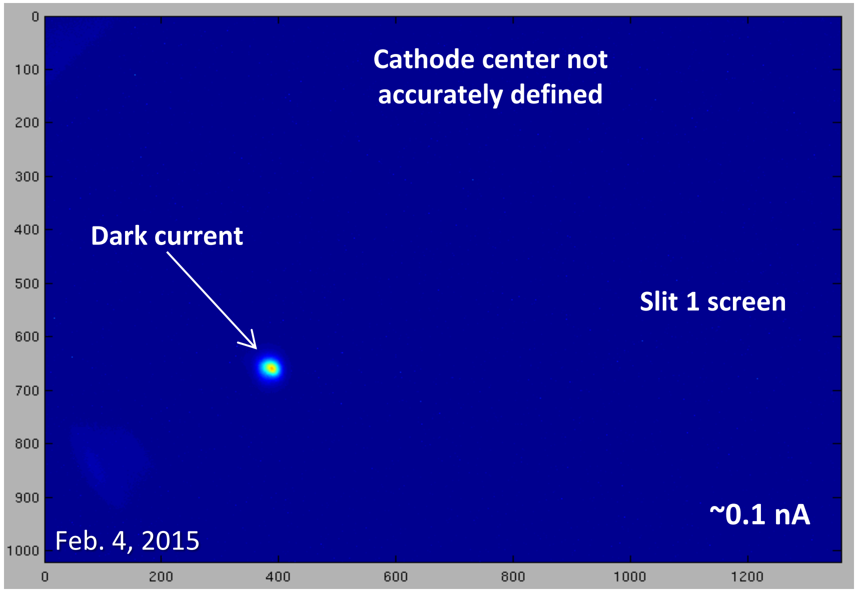


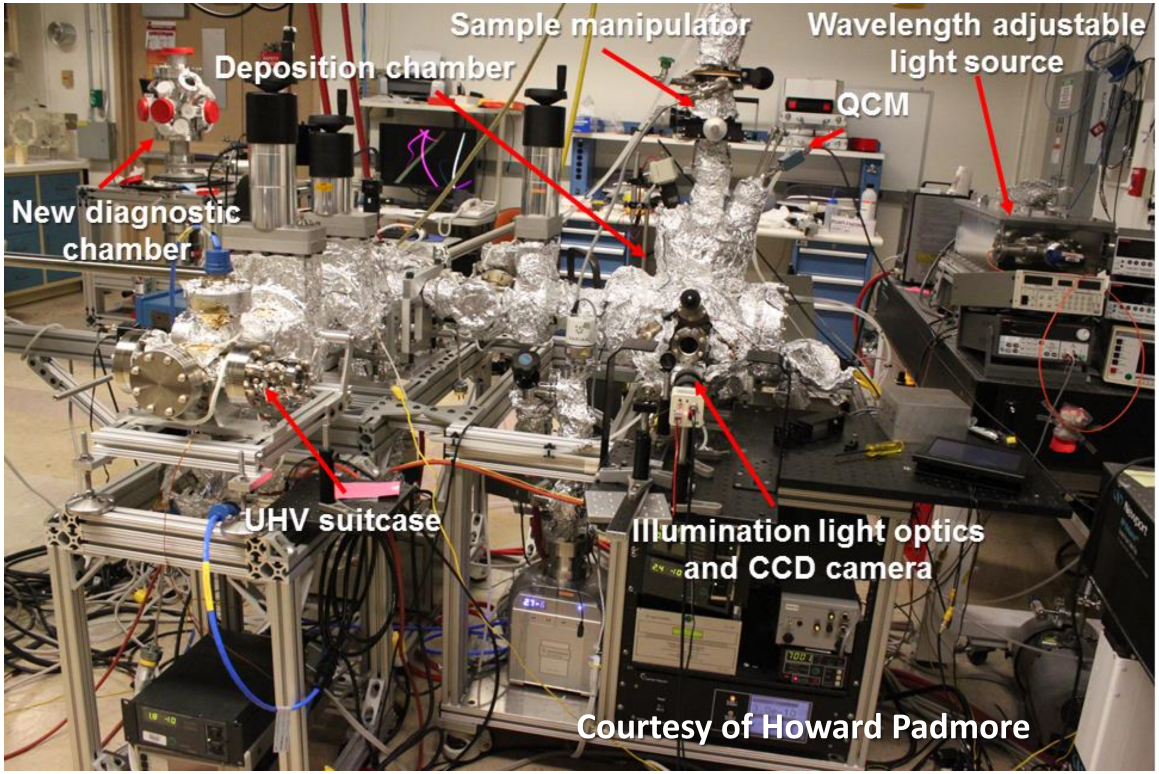


BEFORE
polishing & dry ice cleaning

NOW (w/ higher CCD gain)

Alkali antimonide

- Locally fabricated at LBNL (CsK_2Sb, $CsSb_3$…)



APEX gun provides practical test environment for antimonide cathode preparation recipe optimization for QE/lifetime/thermal emittance:

- Deposition sequence
- Deposition thickness
- Deposition speed
- Surface roughness
- …

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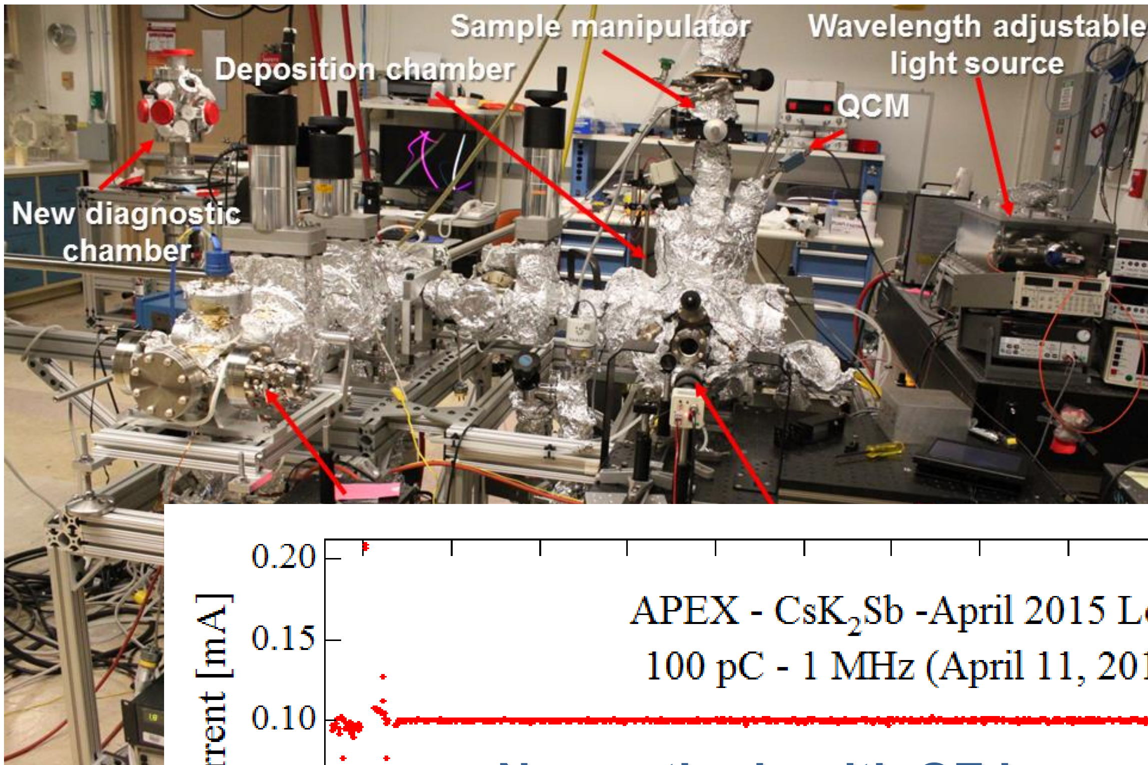

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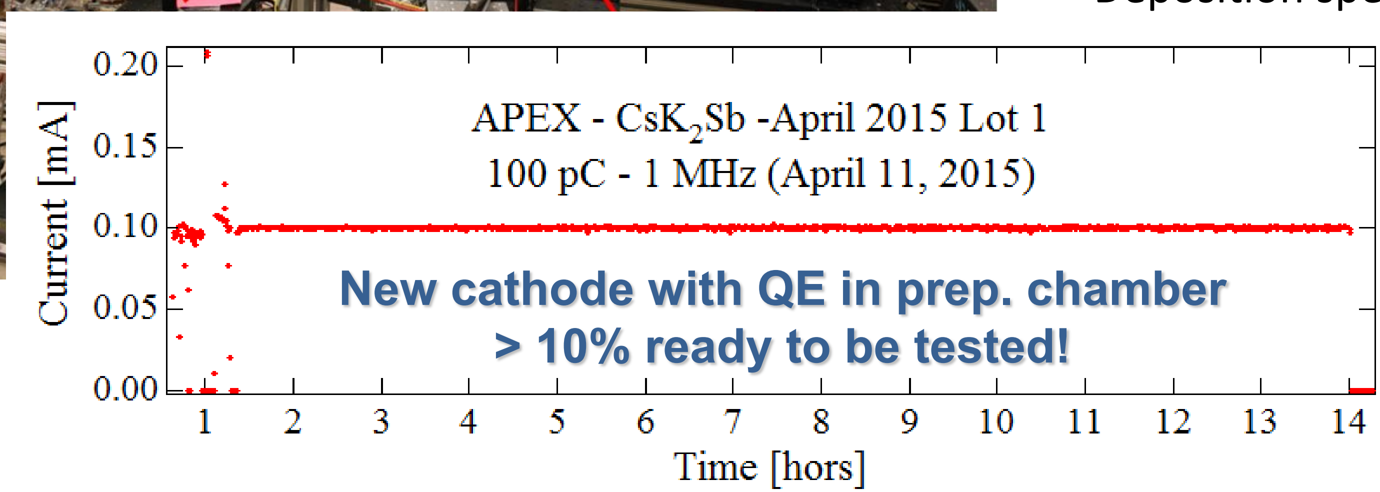
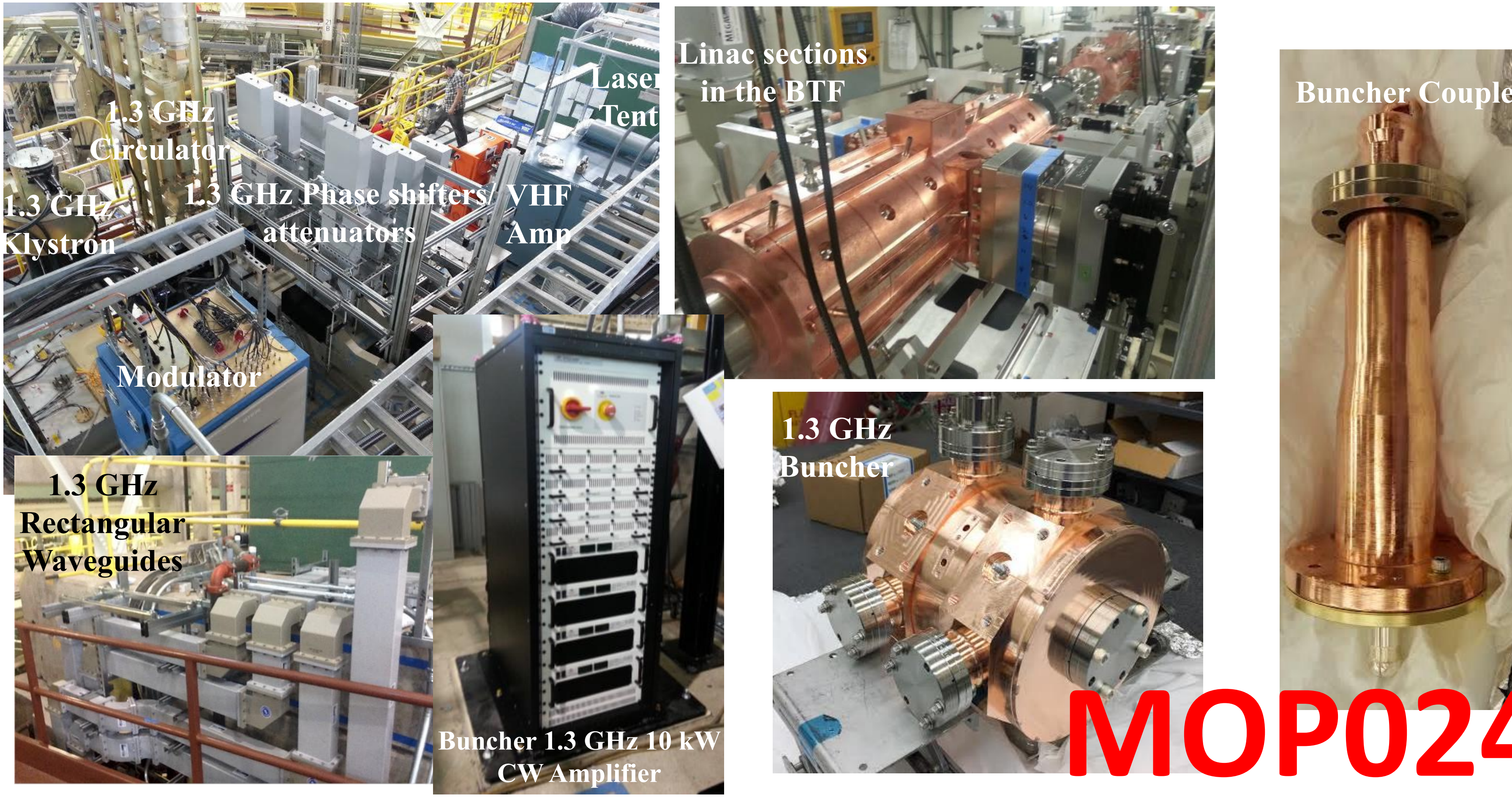


APEX Phase-II installations



MOP024

APEX phase II commissioning starts soon!

Conclusion

- A first campaign of measurements demonstrated that Cs_2Te cathode from INFN/LASA satisfies all requirements for LCLS-II.
- Initial tests with CsK_2Sb have not yet demonstrated the required performance but are showing a promising trend with improved cathode recipe.
- APEX gun is an ideal test bed for characterizing high QE reactive photocathode performance in practical environment.

Recent APEX publications:

F. Sannibale, et al., PRST-AB 15, 103501 (2012)

R. Huang, et al., PRST-AB 18, 013401 (2015)

D. Filippetto, H. Qian, F. Sannibale, Appl. Phys. Letters 107, 042104 (2015).