1st Topical Workshop on Laser Based Particle Sources

Photocathode for high brightness electron beams

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Beam Brightness

- ***Beam Brightness*** measures the number of generated electrons per bunch w.r.t. beam divergence

$$B = \frac{N_{part}}{A\,\Omega} \approx \frac{I}{\epsilon_x \epsilon_y}$$

  - Peak current $I = \frac{\Delta Q}{\Delta t}$ where Q is the extracted charge from the cathode in the interval t
  - The emittance term is the sum of different terms

$$\epsilon = \sqrt{\epsilon_{RF}^2 + \epsilon_{SC}^2 + \epsilon_{th}^2 + \epsilon_{rough}^2 + \cdots}$$

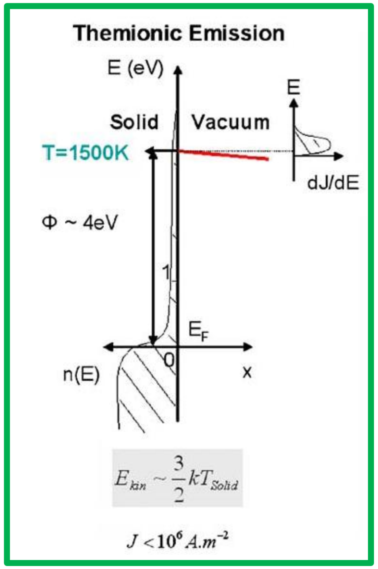
The beam brightness generated at the Injector of a linac accelerator is the ultimate value and can only be spoiled along the accelerator

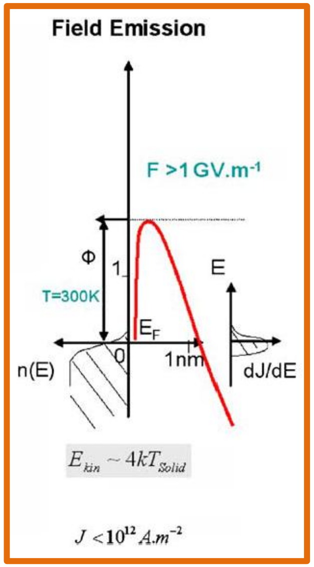
The request of small emittances is a MUST also for FEL

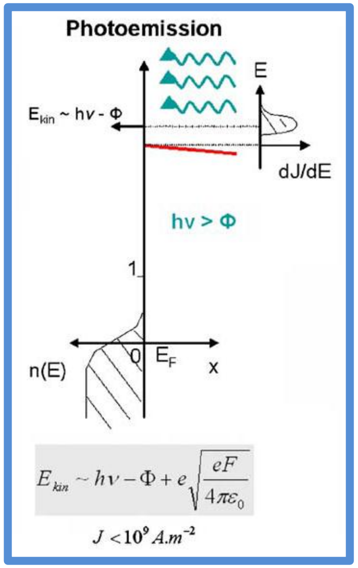
$$\frac{\epsilon_n}{\gamma} < \frac{\lambda_{FEL}}{4\,\pi}$$

Electron production effects

- Thermoionic
  - $$j_{Th}(T) = A_{RLD}\, T^2 e^{-\frac{\phi}{k_B T}}$$
    - $$A_{RLD} = \frac{(k_B^2\, e\, m)}{2\,\pi^2 \hbar^3} = 120.173 \frac{A}{cm^2 K^2}$$
- Field Emission
  - $$j_{FE}(E) = A_{FN}\, E^2 e^{-B\frac{\phi^{3/2}}{E}}$$
    - $$A_{FN} = \frac{e^3}{8\, h\, \pi\, \phi}$$
    - $$B = \frac{4\sqrt{2m}}{3\, h\, e}$$
- Photoemission (for metal)
  - $$j_{ph}(\omega) = \frac{q}{\hbar\omega}\big(1 - R(\omega)\big) F_\lambda(\omega)(\hbar\omega - \phi)^2 I_\lambda$$







Ganter et al. NIMA 565 (2006) 423

Photocathodes

- Photocathodes are materials that emit electrons when light shines on them
- Einstein postulated the Photoelctric effect in 1905 (Ann. der Phys. 17 (6) 132) and was awarded by the Nobel Prize in 1921

$$K_E = \hbar\omega - \phi_{eff}$$

- The «efficiency» of a photocathode is measured by its Quantum Efficiency

$$QE = \frac{\#\, emitted\ electron}{\#incident\ photons}$$

Quantum Efficiency

- Often, specially for calculation, an “Internal” QE is defined

$$QE_{int} = \frac{\#\ emitted\ electron}{\#absorbed\ photons} = \frac{\#emitted\ electron}{(1-R)\ \#incident\ photons}$$

- In pratical units QE is

$$QE[\%] = \frac{Q[nC]\ E_{ph}[eV]}{E_{laser}[\mu J]10}$$

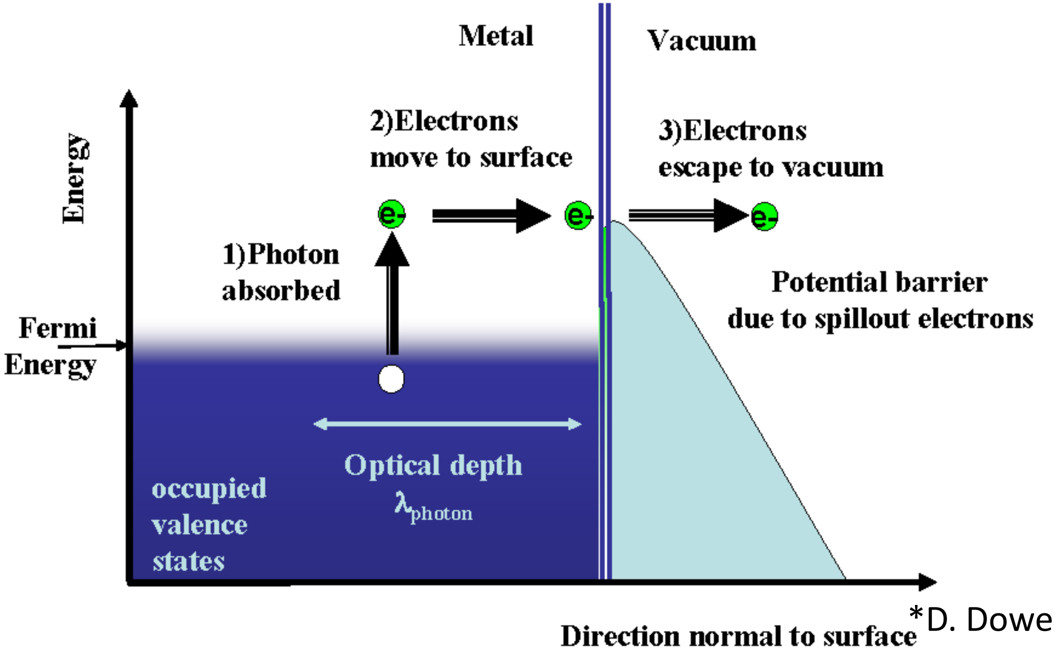
- For a typical 4th harmonic of a Nd laser (λ = 262 nm)

$$QE[\%] = \frac{Q[nC]\ 4.72}{E_{laser}[\mu J]10}$$

and hence we need 1 μJ to produce 0.472 nC having 1% QE

A deeper look in the photoemission process for metal*

- We assume a metal photocathode and use the Spicer's "Three Step Model"
  1. Light absorption and electron excitation
  2. Electron drift to the surface
  3. Electron emission



*D. Dowell et al. PRSTAB 12, 074201

QE calculation

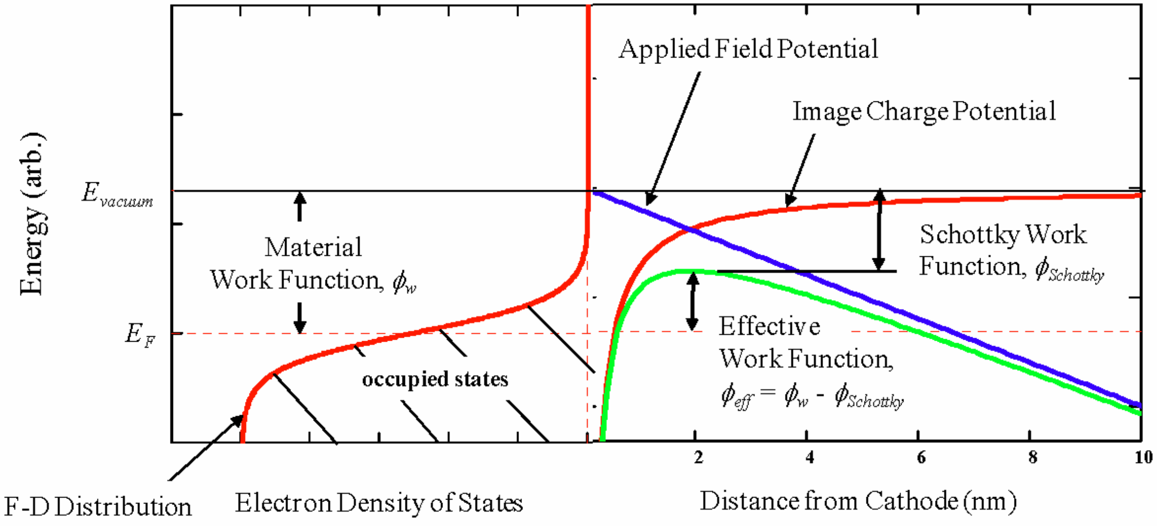
- Inside the metal electrons obey Fermi Dirac distribution

$$f_{FD} = \frac{1}{1 + e^{\frac{E-E_F}{kT}}}$$

- The potential at the surface boundary is given by

$$\phi_{eff} = \phi_w - \phi_{Schottky} = \phi_w - e\sqrt{\frac{eF}{4\,\pi\,\epsilon_0}}$$

$$\phi_{eff}[eV] = \phi_w[eV] - 0.037947\,\sqrt{F_a\,\left[\frac{MV}{m}\right]}\;[eV]$$



QE calculation

- The general expression for the QE is given by

$$QE(\omega) = \overset{\text{Optical Properties}}{\boxed{(1-R(\omega))}}\,\frac{\overbrace{\int_{E_F+\phi_{eff}-\hbar\omega}^{\infty} dE\,\left(1-f_{FD}(E+\hbar\omega)\right)f_{FD}(E)}^{\text{Absorption}}\int_{\boxed{\cos(\theta_{max}(E))}}^{1} d(\cos(\theta))\,\boxed{F_{e-e}(E,\omega,\theta)}\int_0^{2\,\pi} d\Phi}{\int_{E_F-\hbar\omega}^{\infty} dE\,\left(1-f_{FD}(E+\hbar\omega)\right)f_{FD}(E)\int_{-1}^{1} d(\cos(\theta))\int_0^{2\,\pi} d\Phi}$$

1. Absorption of photon
   - It depends on the density of states of the starting state to the ending states (JDOS). The accessible energy range is starting from $E_F + \phi_{eff} - \hbar\omega$
2. Transport to surface
   - Electrons, in their path to the surface, scatter mainly due hits with other electrons. The probability to reach the surface without collision is $F_{e\text{-}e}$. This is the case for metals.
3. Escape over barrier
   - The electron can overcome the surface barrier if the energy is above it. The criterion for escaping the barrier is

$$\frac{p_{normal}^2}{2\,m} \geq E_F + \phi_{eff}$$

QE Calculation

- The above formula can be reduced to a more manageable form

$$QE(\omega)=\frac{1-R(\omega)}{1+\frac{\lambda_{opt}(\omega)}{\lambda_{e-e}(E_m)}\frac{\hbar\omega\sqrt{\phi_{eff}}}{E_m^{\frac{3}{2}}}\left(1+\frac{\sqrt{\phi_{eff}}}{\hbar\omega}\right)}\frac{E_F+\hbar\omega}{2\,\hbar\omega}\left[1-2\sqrt{\frac{E_F+\phi_{eff}}{E_F+\hbar\omega}}\right]^2$$

  - $\lambda_{opt}(\omega)=\frac{\lambda_{laser}}{4\,\pi\,k}$ remembering that $\tilde{n}=n+ik$ is the complex index of refraction
  - λ_{e-e} is the electron scattering length

- If we expand QE as function of $\hbar\omega-\phi_{eff}$ we obtain

$$QE(\omega)=\frac{1-R(\omega)}{1+\frac{\lambda_{opt}(\omega)}{\lambda_{e-e}(\omega)}}\frac{\boxed{\left(\hbar\omega-\phi_{eff}\right)^2}}{8\,\phi_{eff}\left(E_F+\phi_{eff}\right)}$$

Cs_2Te QE @ FLASH

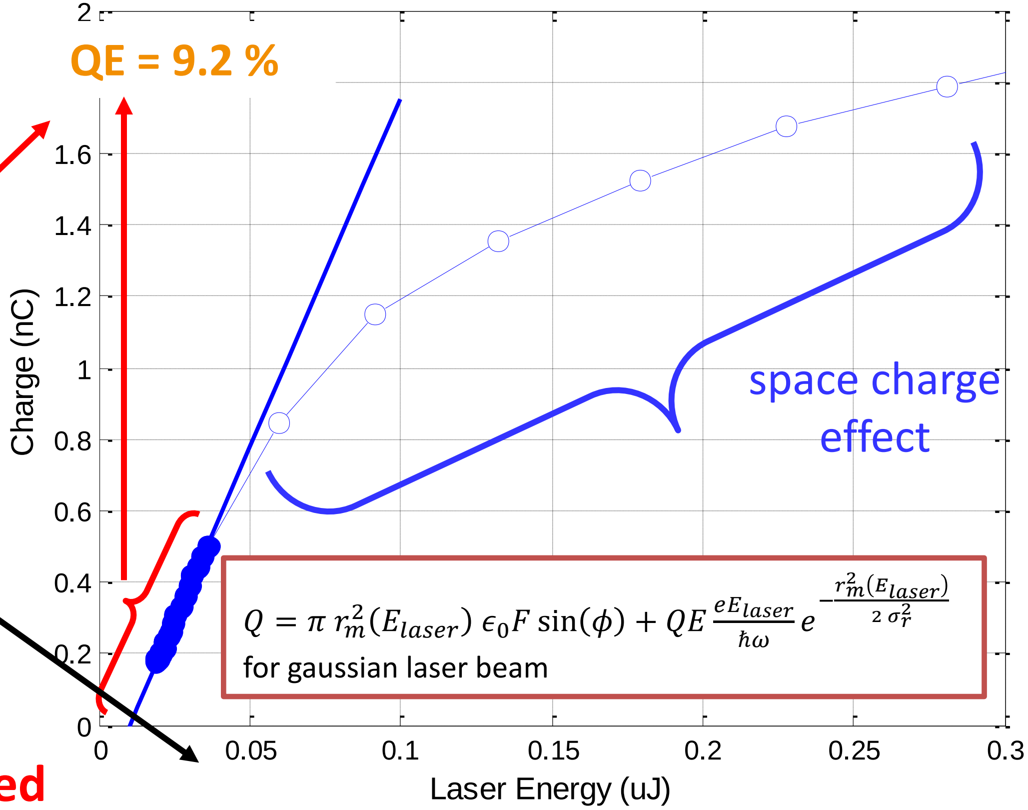
- Cs_2Te QE is routinelly measured in the FLASH RF GUN
- It is measured at nominal phase (38 deg w.r.t. zero crossing), not corresponding to maximum extracted charge

$$QE = \frac{n_{el}}{n_{ph}}$$

$$QE[\%] = 100\,\frac{Q[C]E_{ph}[eV]}{E_{cath}[J]}$$

$$QE[\%] \approx 0.47\,\frac{Q[nC]}{E_{cath}[\mu J]}$$

@ 262 nm



$$Q = \pi\, r_m^2(E_{laser})\, \epsilon_0 F \sin(\phi) + QE\,\frac{eE_{laser}}{\hbar\omega}\, e^{-\frac{r_m^2(E_{laser})}{2\,\sigma_r^2}}$$

for gaussian laser beam

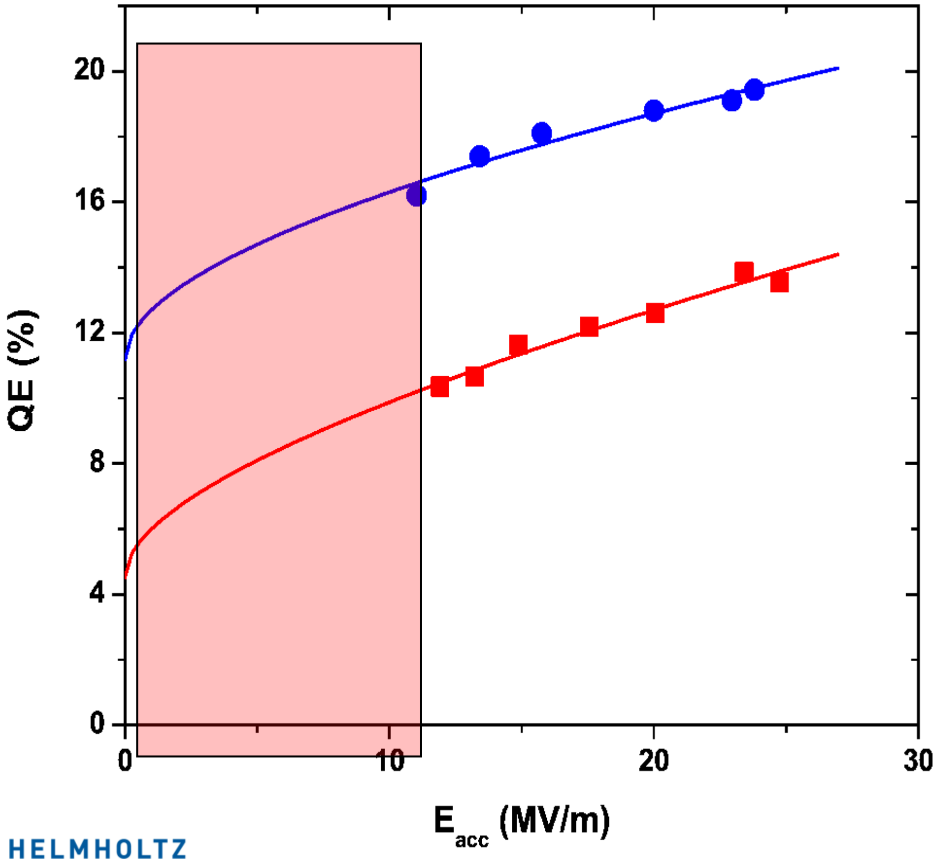
charge trend at low charge fitted

Graph from S.Lederer PPP 2012 Workshop

Cs_2Te QE vs Field @ FLASH

$$QE = A \cdot \left[h\nu - (E_G + E_A) + q_e \cdot \sqrt{\frac{q_e \cdot \beta \cdot F \cdot \sin(\phi)}{4 \cdot \pi \cdot \varepsilon_0}} \right]^m$$

Generalized formula
for semiconductor



QE @ zero gradient = 11.2 %
W = E_G+E_A = 3.5 eV
β = 4.7

56 days of operation
@ FLASH

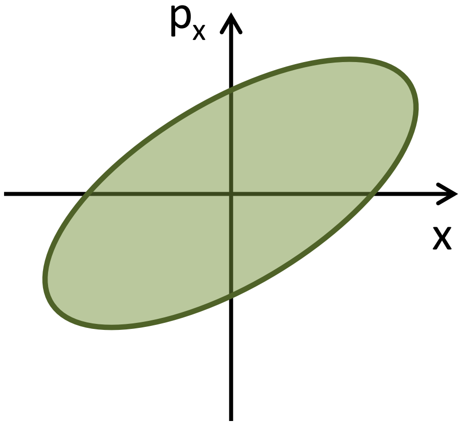
QE @ zero gradient = 4.5 %
W = E_G+E_A = 3.8 eV
β= 12.7

→ **QE decreased**
→ **E_G+E_A increased**
→ **field enhancement increased**

Thermal Emittance

- The emittance is the area occupied by the electron beam in the phase space

$$\epsilon_x = \frac{1}{\beta\gamma mc}\sqrt{\langle x^2\rangle\langle p_x^2\rangle - \langle x\, p_x\rangle^2}$$



- If we assume no correlation between position and momentum the second term under the square root vanishes and we get for the normalized emittance

$$\epsilon_n = \beta\gamma\epsilon_x = \sigma_x \frac{\sqrt{\langle p_x^2\rangle}}{mc}$$

- If we now define $\sigma_{p_x} \equiv \frac{\sqrt{\langle p_x^2\rangle}}{mc}$
- In term of rms quantity we can express emittance as

$$\boxed{\epsilon_n = \sigma_x\sigma_{p_x}}$$

- We have then to calculate the variance of the electron momentum to have the normalized emittance

Thermal emittance derivation

- To derive thermal (electron distribution related) emittance, we calculate the variance of electron momentum

$$\sigma_{p_x}^2 = \frac{\int_{E_f+\phi_{eff}-\hbar\omega}^{\infty} dE\,\big(1-f_{FD}(E+\hbar\omega)\big)f_{FD}(E)\int_{\cos(\theta_{max}(E))}^{1} d(\cos(\theta))\int_0^{2\,\pi} d\Phi\ \ p_x^2}{(mc)^2\int_{E_f-\hbar\omega}^{\infty} dE\,\big(1-f_{FD}(E+\hbar\omega)\big)f_{FD}(E)\int_{\cos(\theta_{max}(E))}^{1} d(\cos(\theta))\int_0^{2\,\pi} d\Phi}$$

- As for the QE derivation, the *maximum emission angle* θ_{max} is given by the energy in the direction normal to the barrier to be larger that barrier itself

$$\frac{p_z^2}{2\,m} \geq E_f + \phi_{eff}$$

- No dependence from the electron-electron scattering probability
- After some math we get

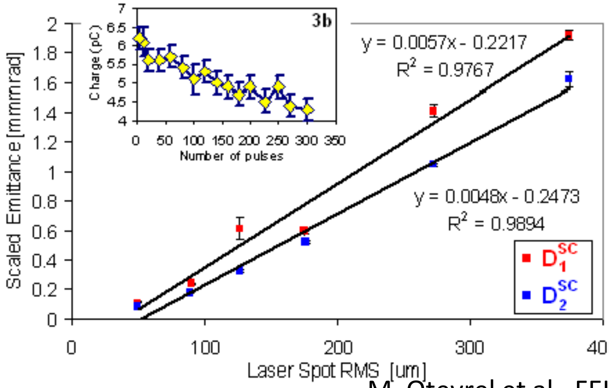
$$\sigma_{p_x} = \sqrt{\frac{\hbar\omega-\phi_{eff}}{3\,m\,c^2}}$$

- The thermal emittance is then given by

$$\boxed{\epsilon_{th} = \sigma_x\sqrt{\frac{\hbar\omega\ -\ \phi_{eff}}{3\,m\,c^2}}}$$

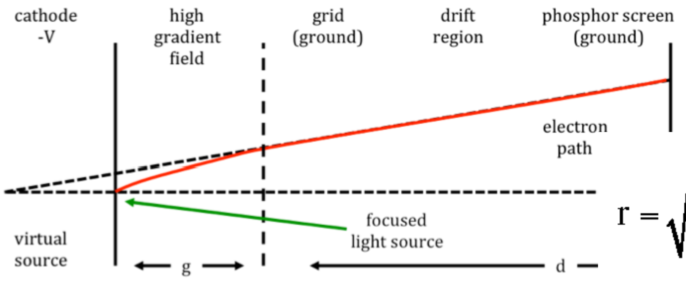
Thermal Emittance Measurement

- RF Gun Approach
  - Minimize all contributions to emittance and scan emittance versus laser spot size



M. Otevrel et al., FEL 2011

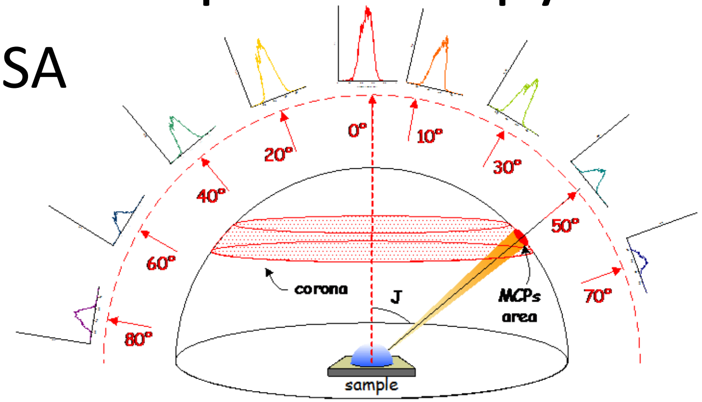
- Momentron
  - Correlate position and momentum
    (T. Vecchione et al. FEL2011)



$$r = \sqrt{\frac{mc^2}{2eV}}\,(2g+d)\left[\frac{p_x}{mc}\right]$$

- Angular Resolved Photo Emission Spectroscopy
  - Time of Flight-INFN Milano LASA

$$\varepsilon_x = \frac{1}{2\cdot c}\cdot\sqrt{\left\langle r^2\right\rangle\cdot\left\langle \frac{2\cdot E_{Kin}}{m_0}\cdot\cos^2(\theta)\right\rangle}$$

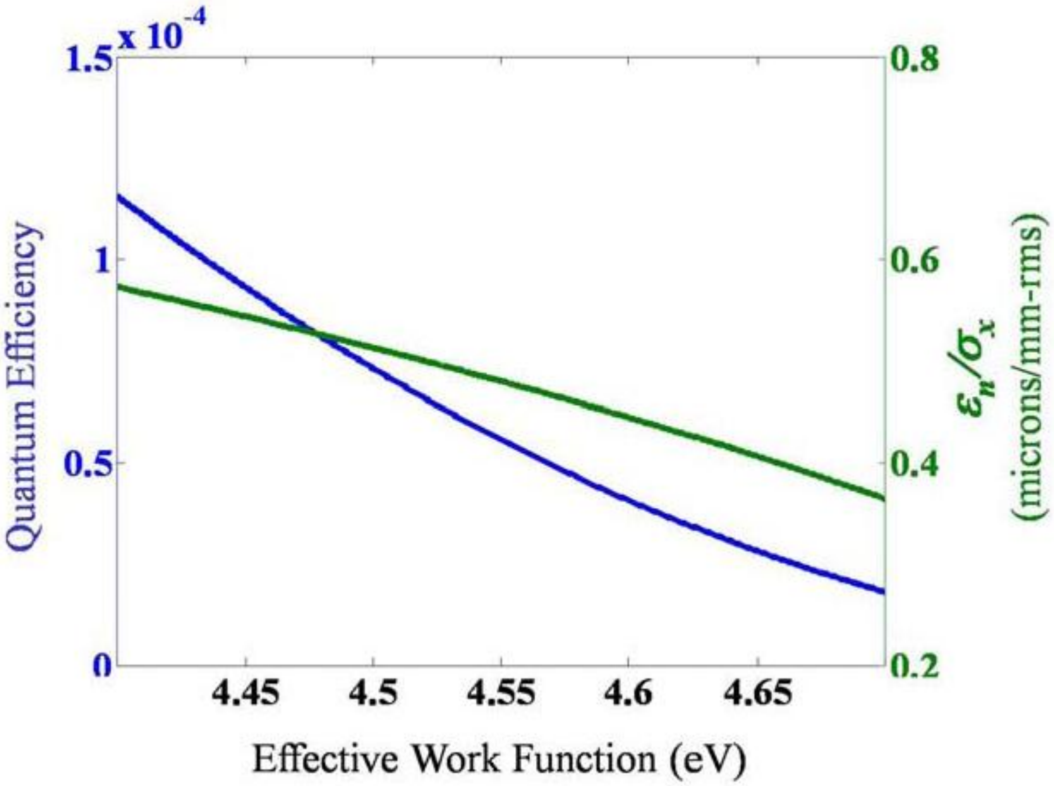


QE vs thermal emittance

$$\phi_{eff} = \phi_W - e\sqrt{\frac{eF}{4\,\pi\,\epsilon_0}}$$

$$QE(\omega) = \frac{1 - R(\omega)}{1 + \frac{\lambda_{opt}(\omega)}{\lambda_{e-e}(\omega)}} \frac{\left(\hbar\omega - \phi_{eff}\right)^2}{8\,\phi_{eff}\left(E_F + \phi_{eff}\right)}$$

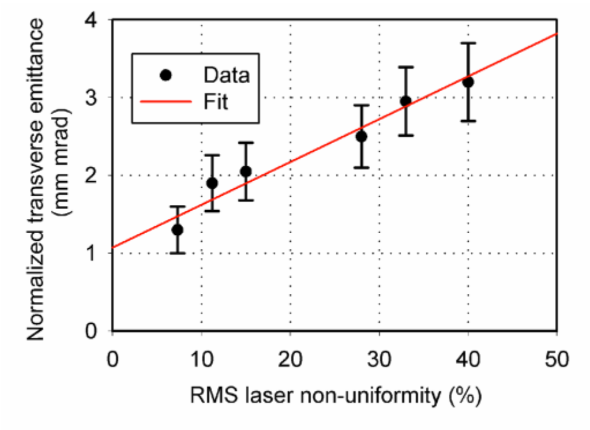
$$\epsilon_{th} = \sigma_x \sqrt{\frac{\hbar\omega - \phi_{eff}}{3\,m\,c^2}}$$

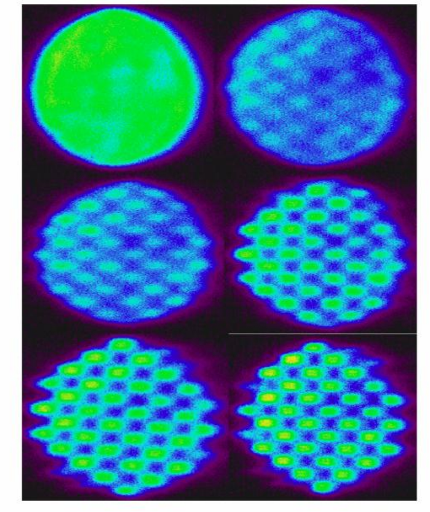


- QE and emittance have the same dependency on photon energy.
- We can reduce emittance at the expense of very low QE.
- Free knobs are the **optical properties** and **scattering parameters** inside the material!!!

Other cathode contributions to intrinsic emittance

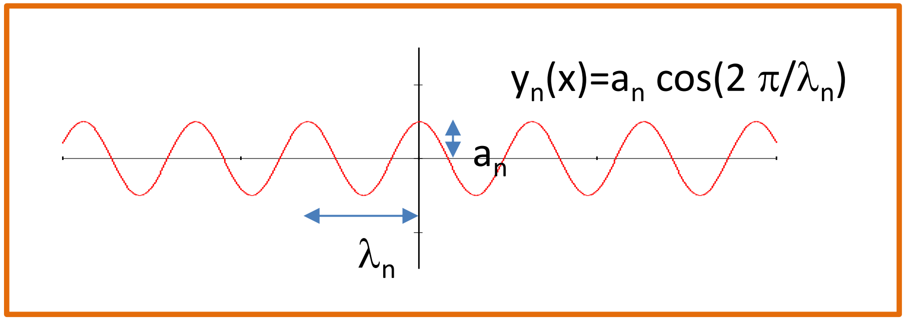
- Cathode “not” uniformity (F. Zhou et al., PRSTAB 5, 094203)





- Cathode roughness (D. Xiang et al., PAC07)

$$\epsilon_{ns} = \sigma\sqrt{\frac{e\pi^2 a_n E_{RF}\sin(\theta_{RF})}{2\,m\,c^2\lambda_n}}$$

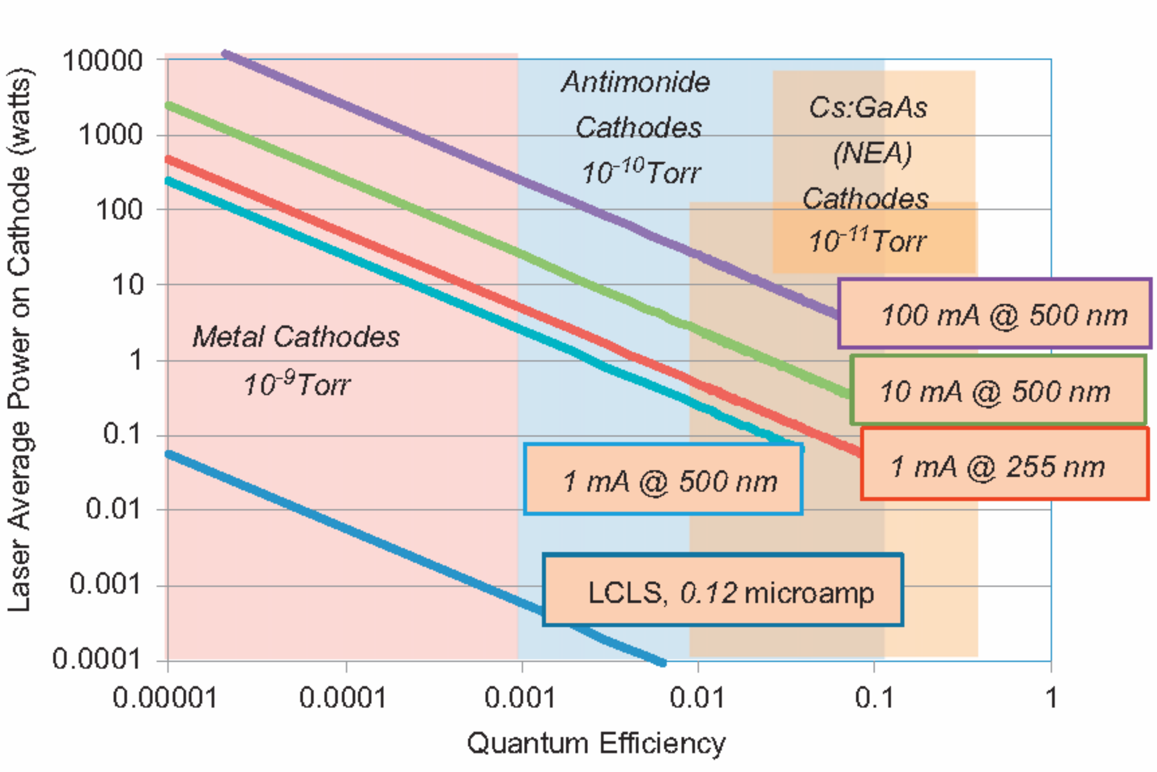


Photocathode Request

- **Quantum Efficiency**
  - Highest at longest wavelengths
  - Fast response time (< 100’s fs)
  - Uniform emission (space charge effects)
  - Constant charge along the train
  - Low dark current
- **Intrinsic Emittance**
  - As low as possible
  - Eventually tunable (see conflict with QE)
- **Operation**
  - Operational lifetime > months
    - UHV required
  - Possible cleaning and/or rejuvenation
  - Reliable installation and replacement

Photocathodes

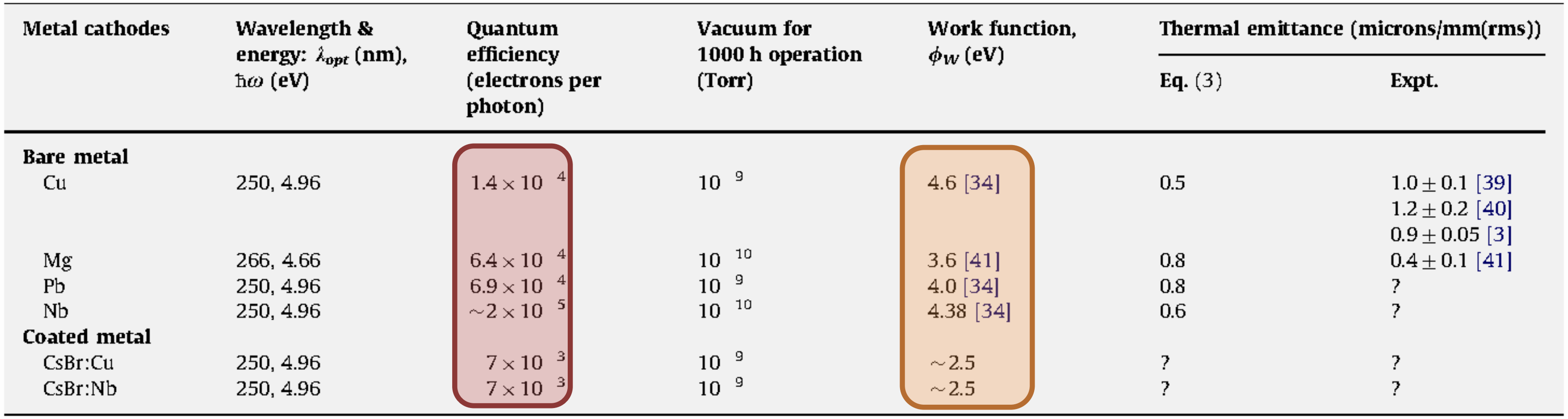
- Metal
  - Cu
  - Mg
  - Superconductor
    - Nb
    - Pb
- Semiconductor
  - PEA
    - Cs_2Te
    - K_2CsSb
    - Cs_3Sb
  - NEA
    - GaAs and strained



- Here after I made a «very» personal selection of some of the materials and labs

D. Dowell et al., NIM A 622(2010) 685

Metal Photocathode



Metal cathodes	Wavelength & energy: λ_{opt} (nm), $\hbar\omega$ (eV)	Quantum efficiency (electrons per photon)	Vacuum for 1000 h operation (Torr)	Work function, ϕ_W (eV)	Thermal emittance (microns/mm(rms))	
					Eq. (3)	Expt.
Bare metal						
Cu	250, 4.96	1.4×10^{4}	10^{9}	4.6 [34]	0.5	1.0 ± 0.1 [39] 1.2 ± 0.2 [40] 0.9 ± 0.05 [3]
Mg	266, 4.66	6.4×10^{4}	10^{10}	3.6 [41]	0.8	0.4 ± 0.1 [41]
Pb	250, 4.96	6.9×10^{4}	10^{9}	4.0 [34]	0.8	?
Nb	250, 4.96	$\sim 2 \times 10^{5}$	10^{10}	4.38 [34]	0.6	?
Coated metal						
CsBr:Cu	250, 4.96	7×10^{3}	10^{9}	~2.5	?	?
CsBr:Nb	250, 4.96	7×10^{3}	10^{9}	~2.5	?	?

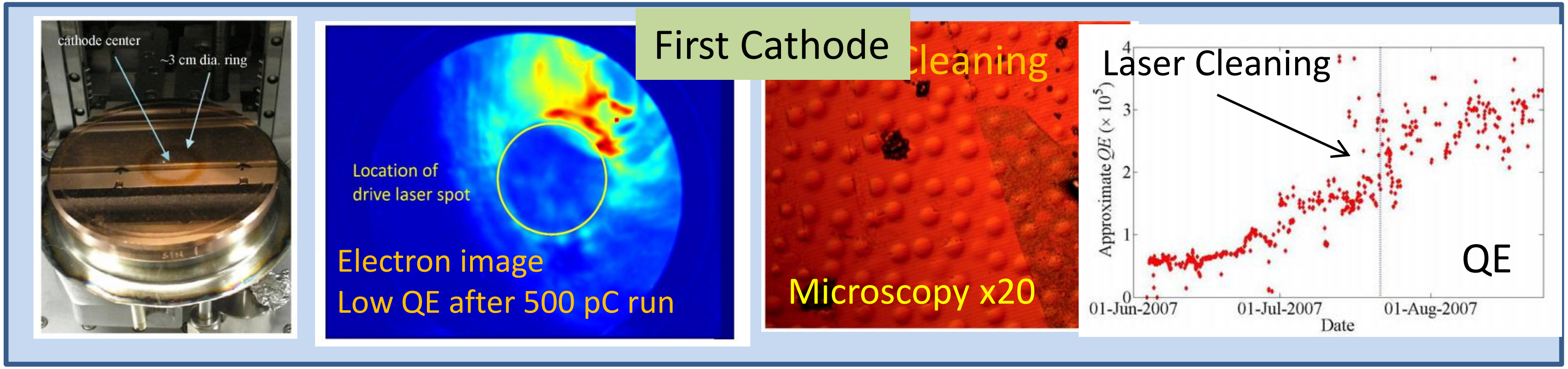
- These are the cathode used in normal conducting low repetition rate micro bunch RF gun.
- Pros
  - Unlimited lifetime
  - Low sensitivity to vacuum condition
  - Very fast response time
  - Low field emission
- Cons
  - High work function → UV light
  - Low QEs
  - No polarization possible

D. Dowell et al., NIM A 622(2010) 685

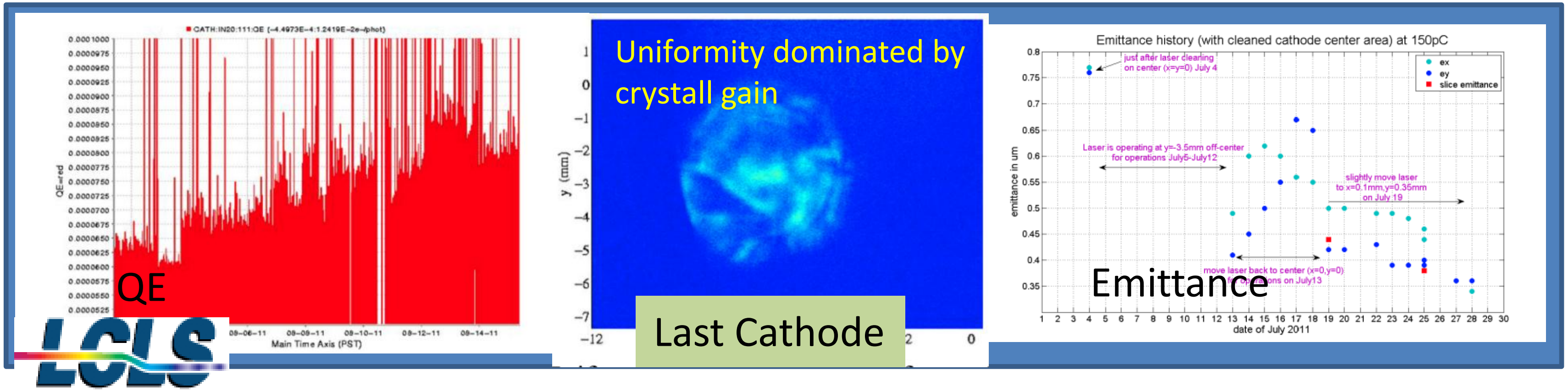
Cu cathode @ LCLS

Parameter	Value
Laser wavelength [nm]	253
Spot on cathode [mm]	1.2
QE minimum	$5\ 10^{-5}$
Bunch Charge [pC]	250
Emittance [μm]	< 0.5

- From 2007 to 2011, three cathodes have been used.
- The Cu cathode surface is prepare by optical quality diamond turning.
- Laser Cleaning has been necessary to allow operation of the machine, due to decrease of QE at high repetition rates.



First Cathode

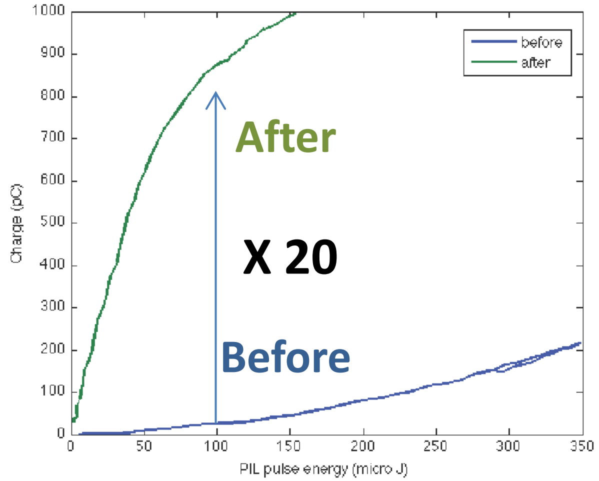


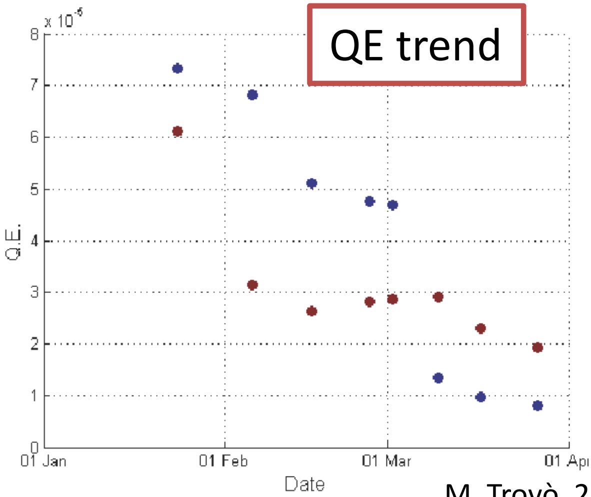
Last Cathode

Uniformity dominated by crystall gain

Metal Photocathodes

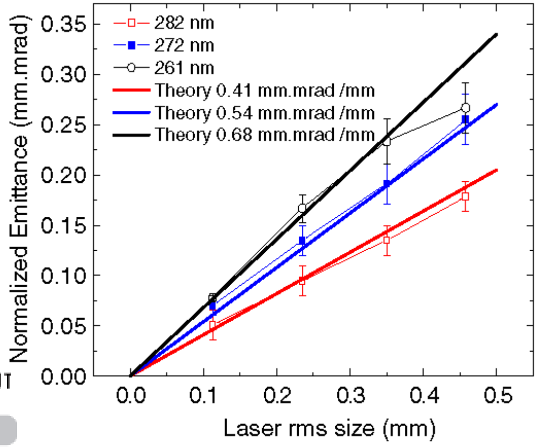
- Ozone cleaning technique for Cu at FERMI

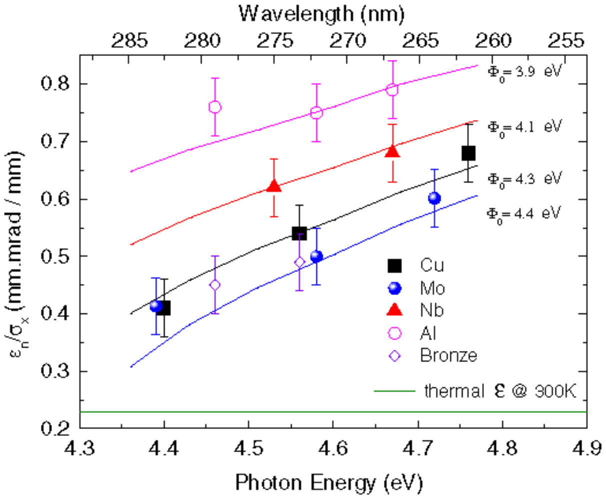




M. Trovò, 2011 EUROFel Workshop

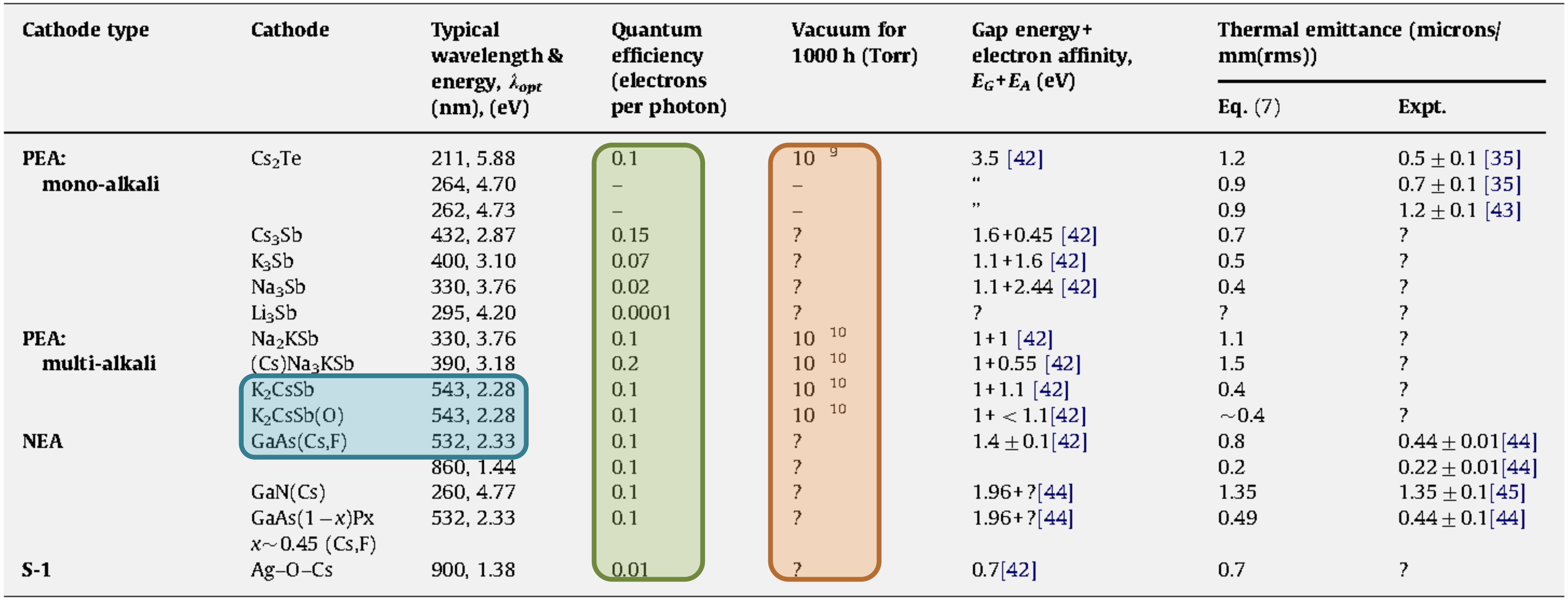
- PSI has a dedicated facility for intrinsic emittance measurements





C. Hauri et al., PRL 104, 234802(2010)

Semiconductor photocathode

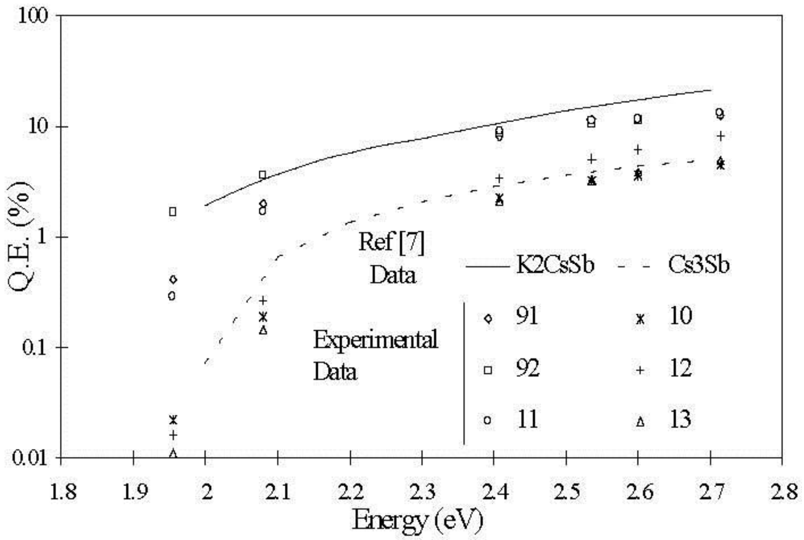


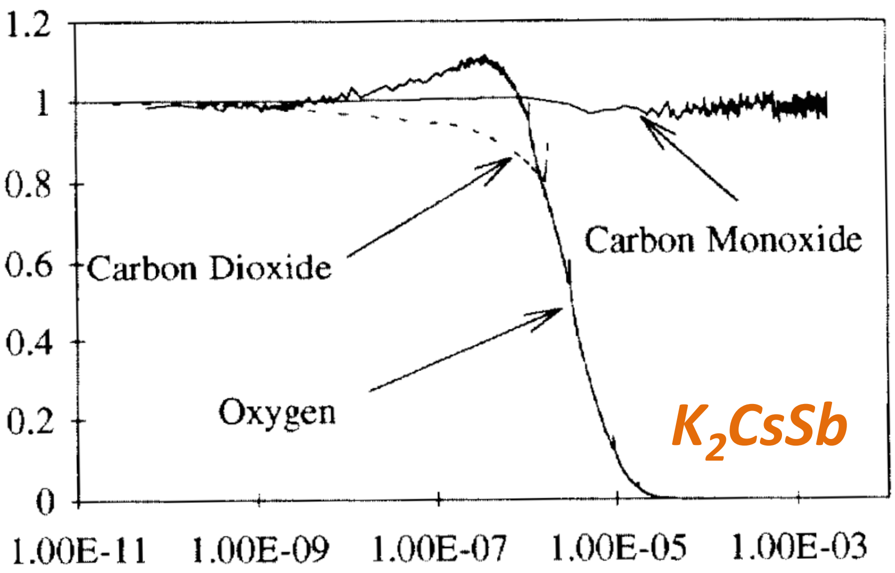
Cathode type	Cathode	Typical wavelength & energy, λ_{opt} (nm), (eV)	Quantum efficiency (electrons per photon)	Vacuum for 1000 h (Torr)	Gap energy+ electron affinity, E_G+E_A (eV)	Thermal emittance (microns/ mm(rms))	
						Eq. (7)	Expt.
PEA: mono-alkali	Cs_2Te	211, 5.88	0.1	10^{9}	3.5 [42]	1.2	0.5 ± 0.1 [35]
		264, 4.70	–	–	“	0.9	0.7 ± 0.1 [35]
		262, 4.73	–	–	”	0.9	1.2 ± 0.1 [43]
	Cs_3Sb	432, 2.87	0.15	?	1.6+0.45 [42]	0.7	?
	K_3Sb	400, 3.10	0.07	?	1.1+1.6 [42]	0.5	?
	Na_3Sb	330, 3.76	0.02	?	1.1+2.44 [42]	0.4	?
	Li_3Sb	295, 4.20	0.0001	?	?	?	?
PEA: multi-alkali	Na_2KSb	330, 3.76	0.1	10^{10}	1+1 [42]	1.1	?
	$(Cs)Na_3KSb$	390, 3.18	0.2	10^{10}	1+0.55 [42]	1.5	?
	K_2CsSb	543, 2.28	0.1	10^{10}	1+1.1 [42]	0.4	?
	$K_2CsSb(O)$	543, 2.28	0.1	10^{10}	$1+<1.1$[42]	~0.4	?
NEA	GaAs(Cs,F)	532, 2.33	0.1	?	1.4 ± 0.1[42]	0.8	0.44 ± 0.01[44]
		860, 1.44	0.1	?		0.2	0.22 ± 0.01[44]
	GaN(Cs)	260, 4.77	0.1	?	1.96+?[44]	1.35	1.35 ± 0.1[45]
	$GaAs(1-x)Px$ $x\sim0.45$ (Cs,F)	532, 2.33	0.1	?	1.96+?[44]	0.49	0.44 ± 0.1[44]
S-1	Ag–O–Cs	900, 1.38	0.01	?	0.7[42]	0.7	?

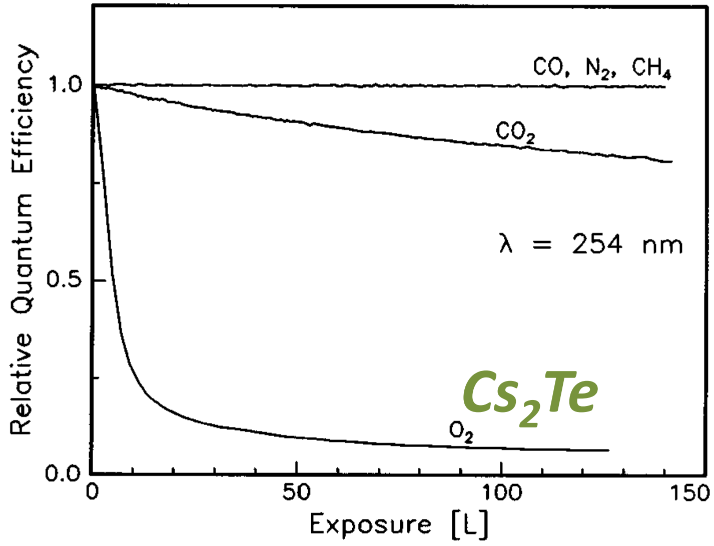
- Pros
  - High QE. Suitable for high charge, long pulses and high repetition rate machine given the average laser power of some tens of Watts. For example **FLASH** or European **XFEL** require to produce thousands to ten-thousands of bunches per second, each of nearly 1 nC.
  - Some work in the visible range
  - Possible polarized source
- Cons
  - Require very good vacuum
  - «Slow» response time (< ps?)
  - Complex handling

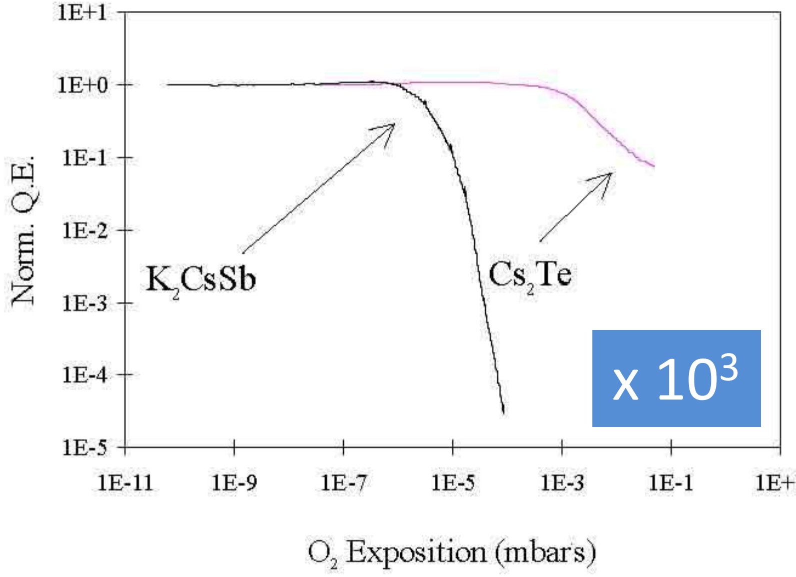
D. Dowell et al., NIM A 622(2010) 685

PEAs Vacuum Sensitivity





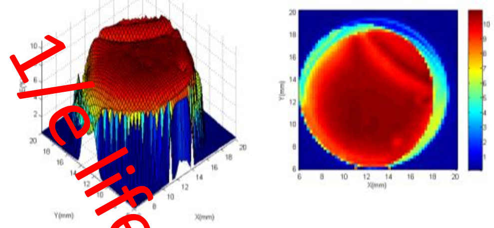




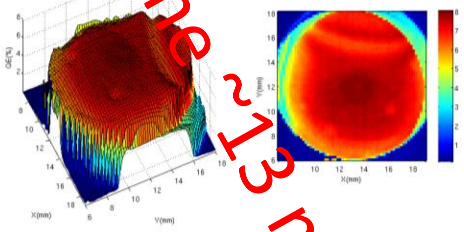
KCsSb @ Cornell ERL

Low average current operation in DC Gun

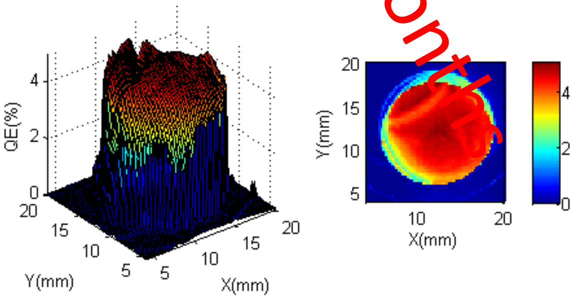
1/e lifetime ~13 months



QE map on 03 Feb 2012 QE~10%

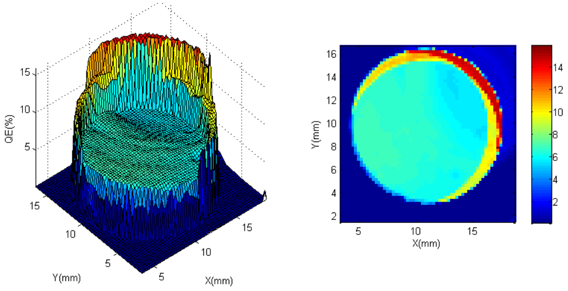


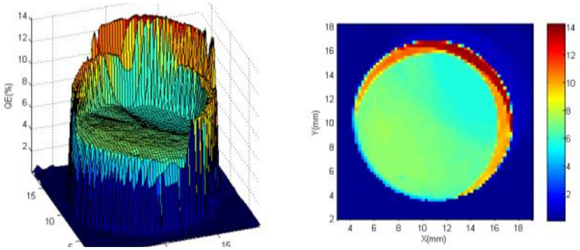
QE map on 03 Apr 2012 QE~8%



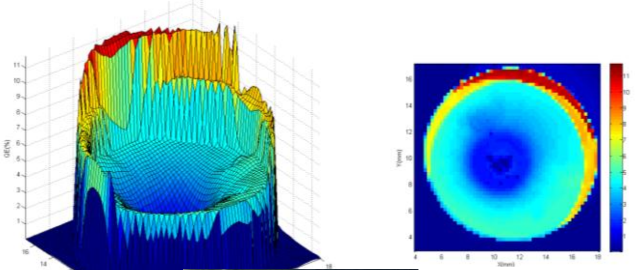
QE map on 02 Oct 2012 QE~5%

High average current operation in DC Gun





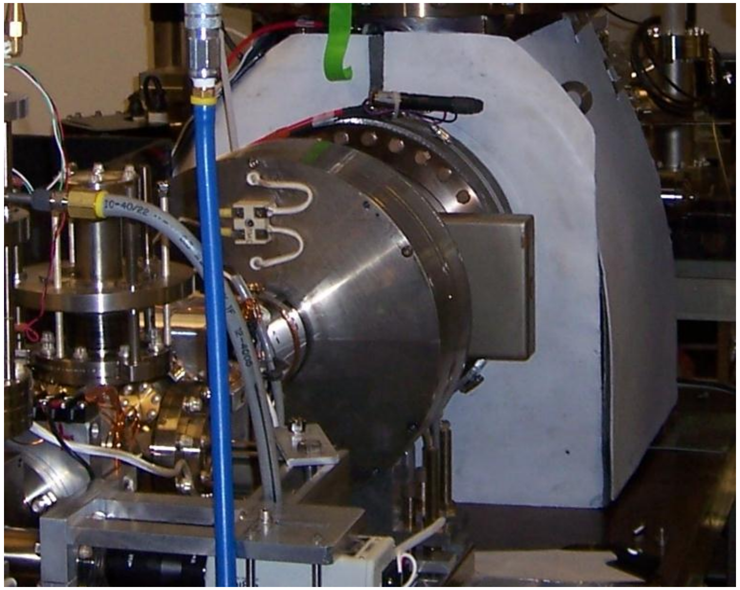
~10 mA
2 hours
No RF trips



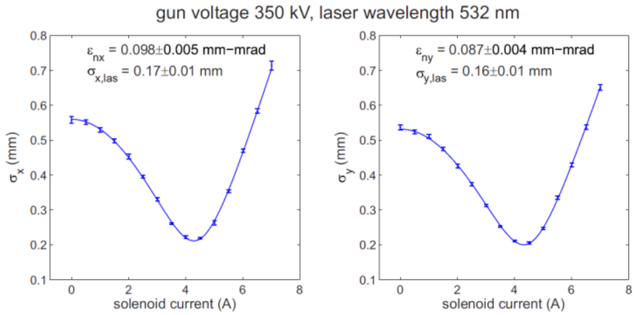
~20 mA
2 hours
many RF trips

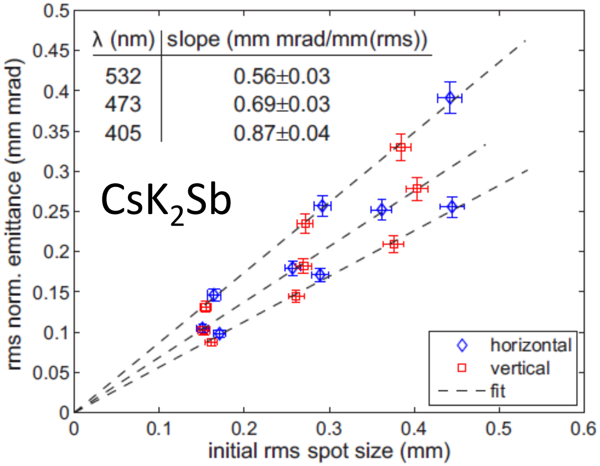
Central damaged area

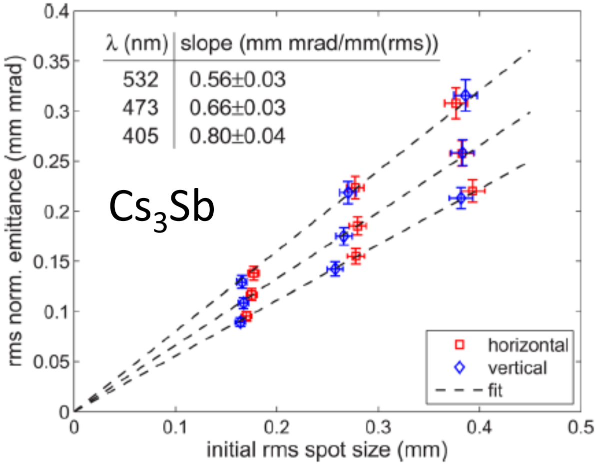
KCsSb @ Cornell ERL
Thermal Emittance Measurement



Measured in HV DC gun using solenoid scan



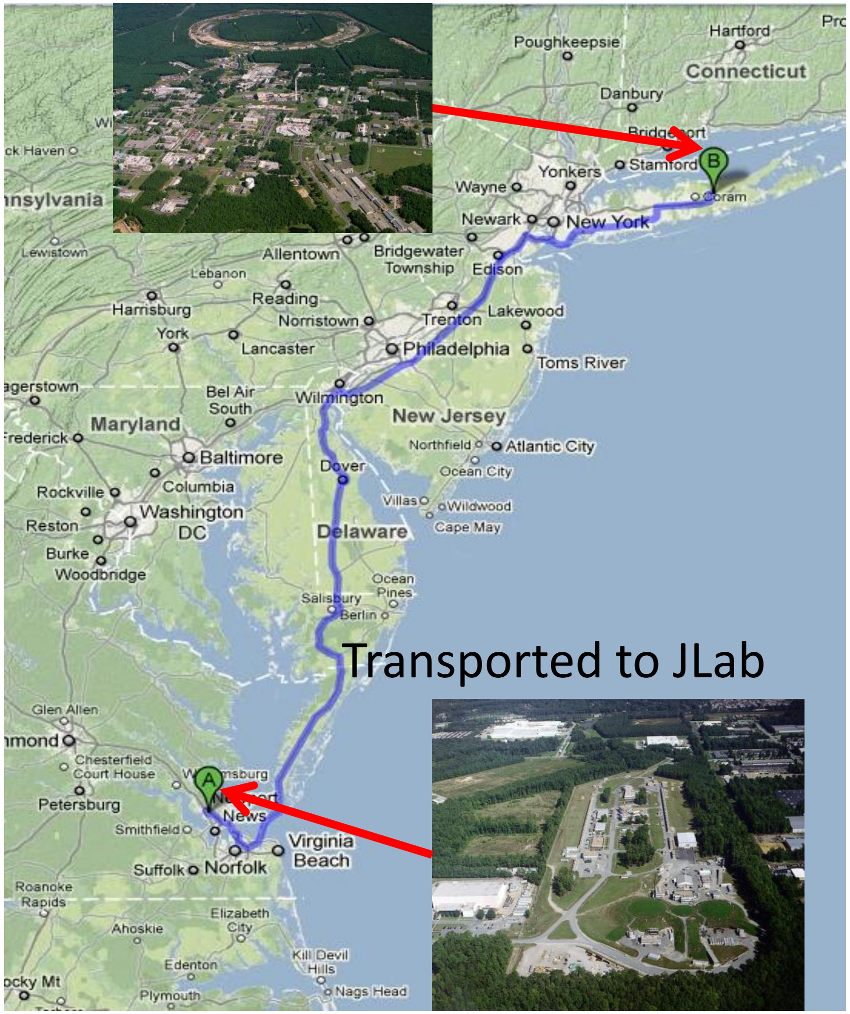




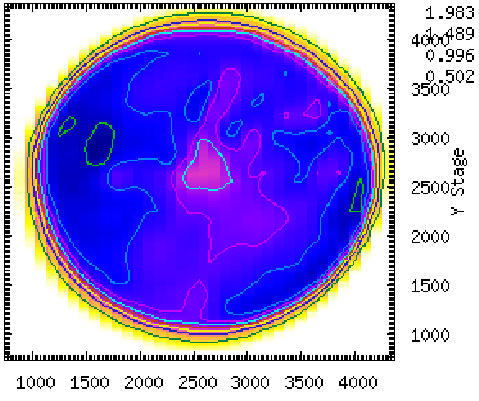
L. Cultrera et al., Appl. Phys. Lett. **99** (2011) 152110
I. Bazarov et al., Appl. Phys. Lett. **98** (2011) 224101

KCsSb @ BNL/JLAB coll.

Photocathode made at BNL

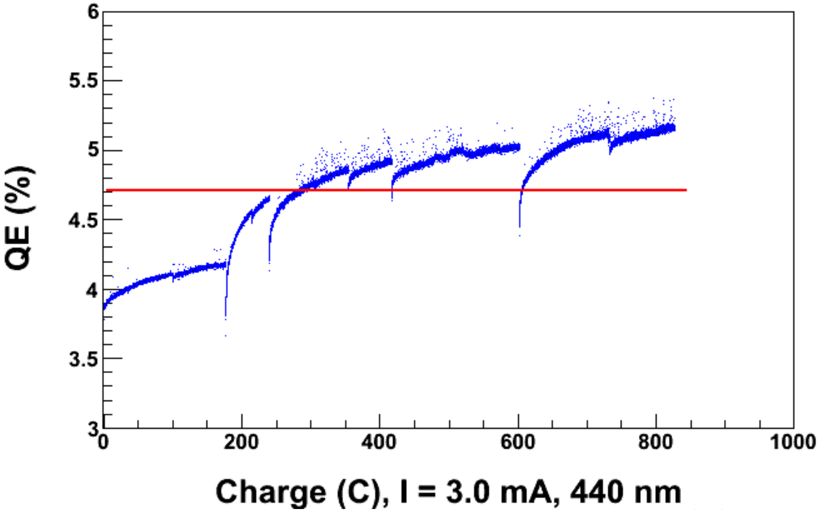


Transported to JLab



QE scan after several runs

No QE decrease in any of the runs; actually, the QE seems to increase



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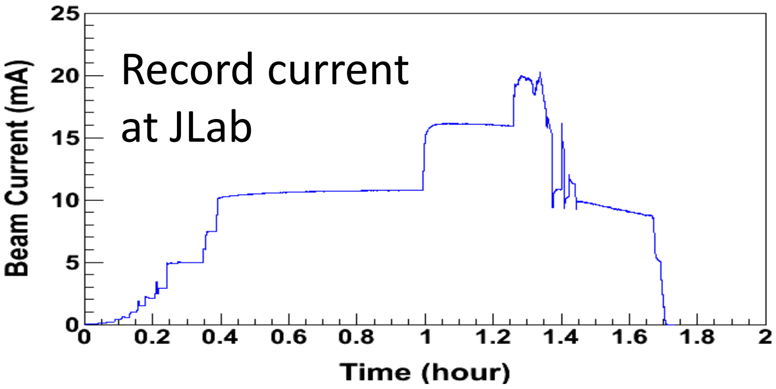
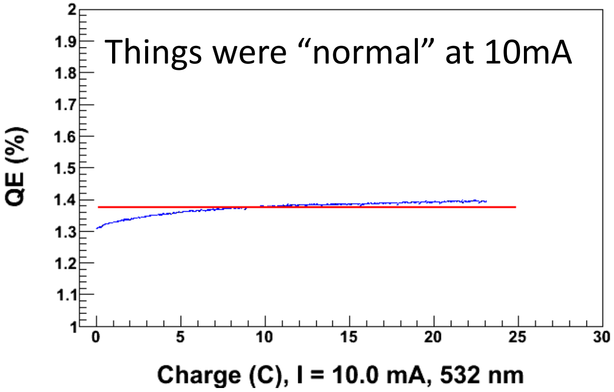
KCsSb @ BNL/JLAB coll.

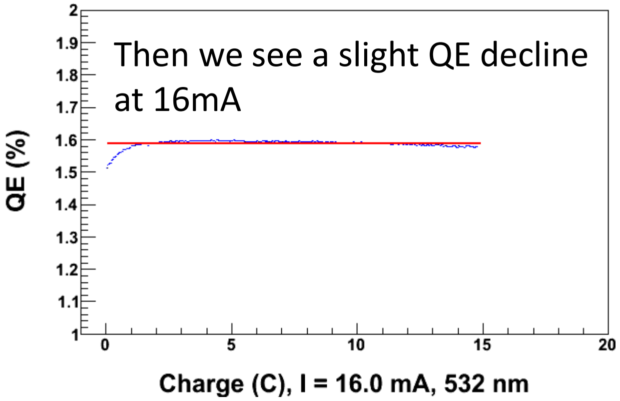
20 mA, DC Gun 100 kV, 532 nm, 500 µm spot



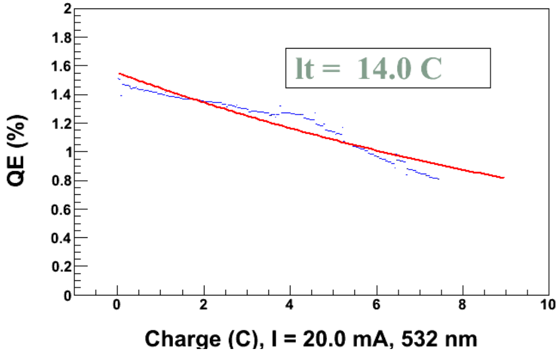
Record current at JLab



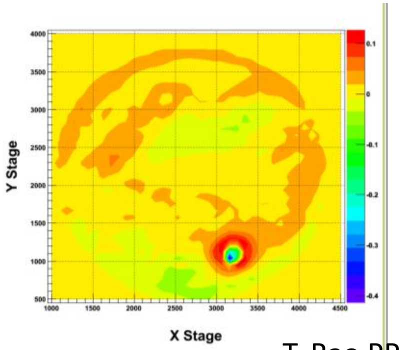
Things were “normal” at 10mA



Then we see a slight QE decline at 16mA



QE change plot shows QE decline at center of the laser spot



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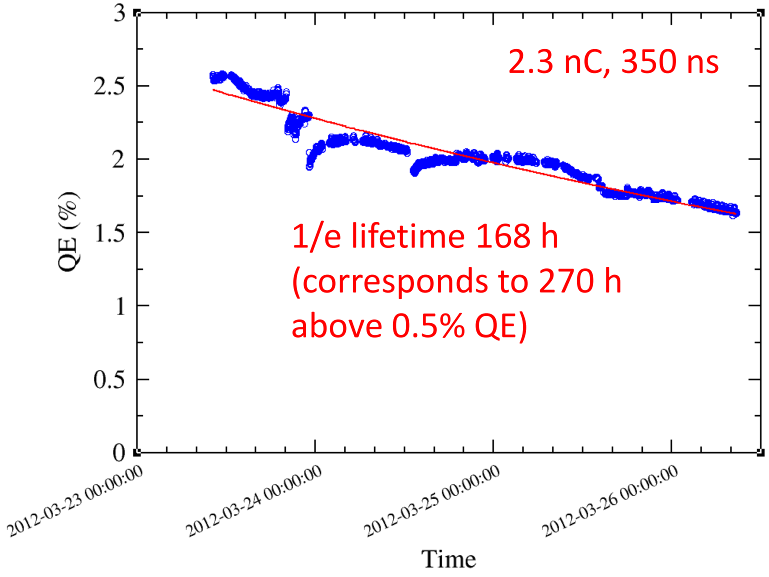
Cs_3Sb & Cs_2Te in RF Gun @ CERN

- Lifetimes are similar and within CLIC specifications.
- For Cs_3Sb a factor 6 less of QE is needed as for Cs_2Te cathodes, due to the different wavelength and the absence of 4th harmonics conversion stage

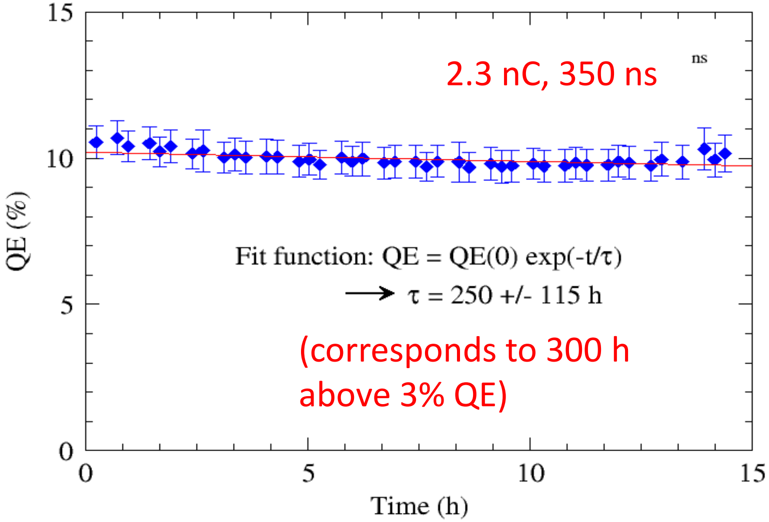
Cathode #189 (Cs_3Sb)



2.3 nC, 350 ns

1/e lifetime 168 h
(corresponds to 270 h
above 0.5% QE)

Cathode #185 (Cs_2Te)



2.3 nC, 350 ns

Fit function: QE = QE(0) exp(-t/τ)
→ τ = 250 +/- 115 h

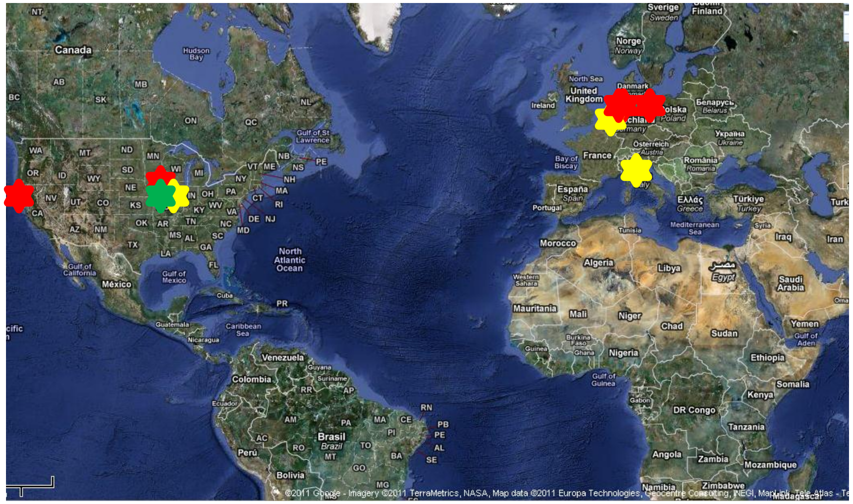
(corresponds to 300 h
above 3% QE)

C. Hessler PPP 2012 Workshop

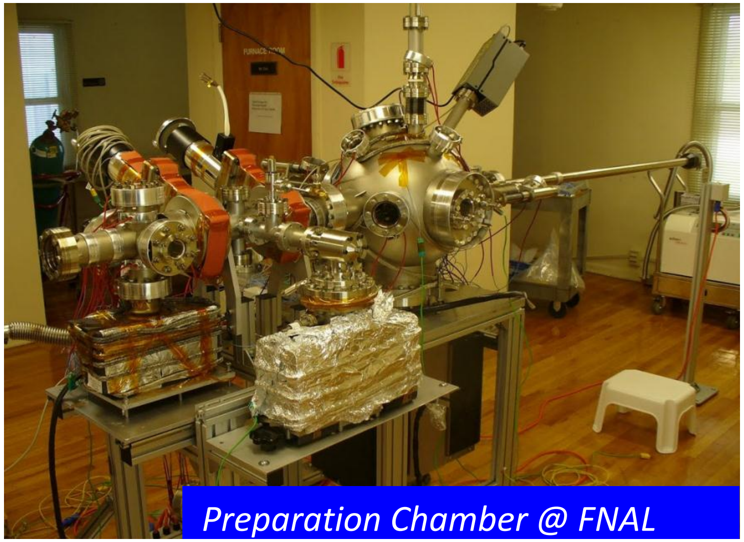
Cs_2Te @ INFN Milano

- Cs_2Te are used in many laboratories around the world and support the FLASH user facility at DESY.
- INFN Milano photocathodes and systems around the world

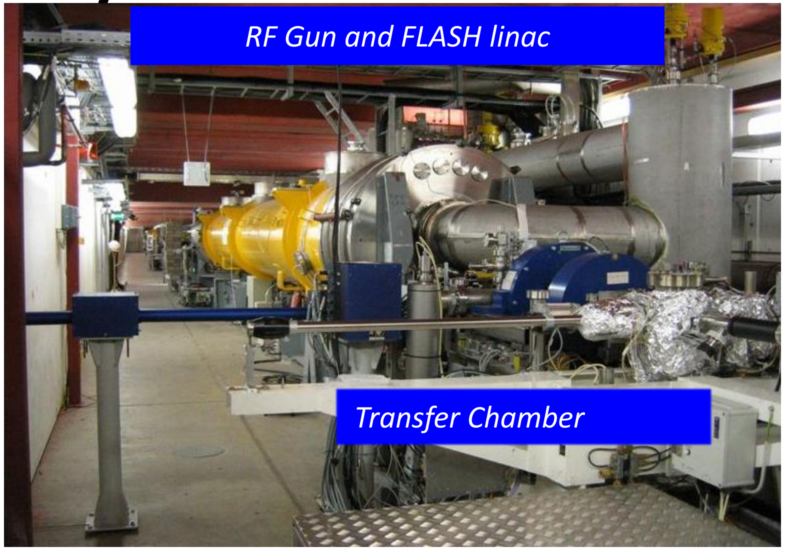
Preparation Systems	**Transfer System**
INFN Milano – LASA	***DESY - FLASH***
DESY – HH	***DESY - PITZ***
Fermilab – Lab7	***DESY - REGAE***
Fermilab-A0	***Fermilab –NML***
HZB (XPS)	***LBNL***



Cathode systems

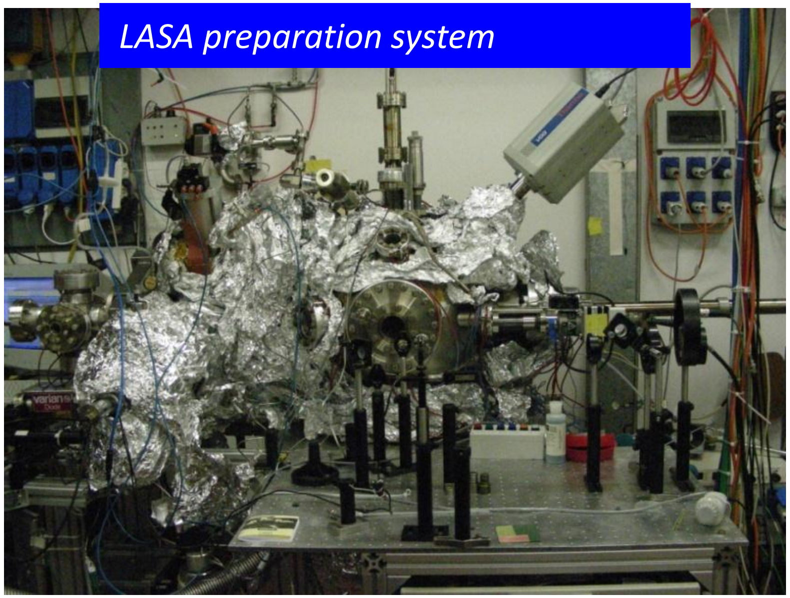


Preparation Chamber @ FNAL

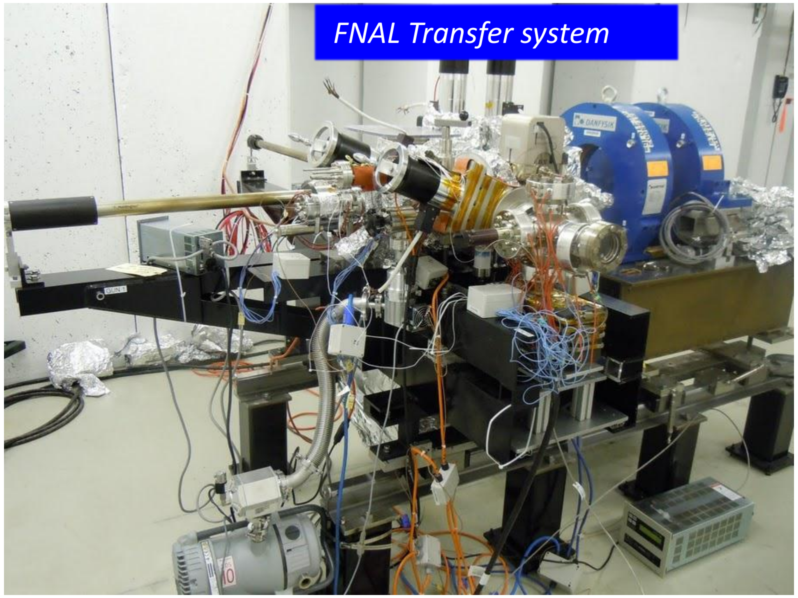


RF Gun and FLASH linac

Transfer Chamber



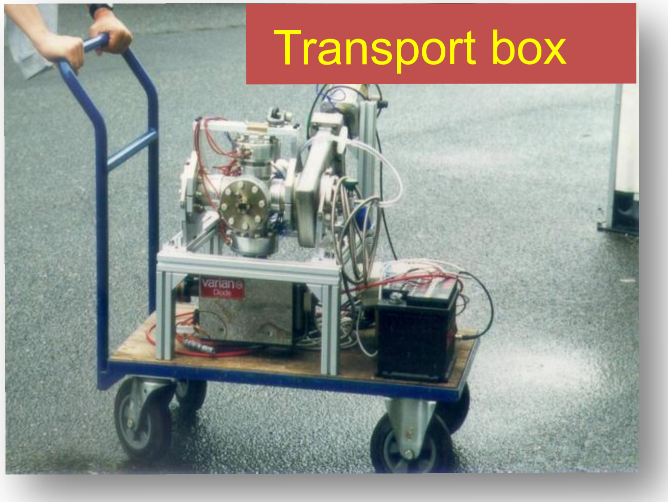
LASA preparation system



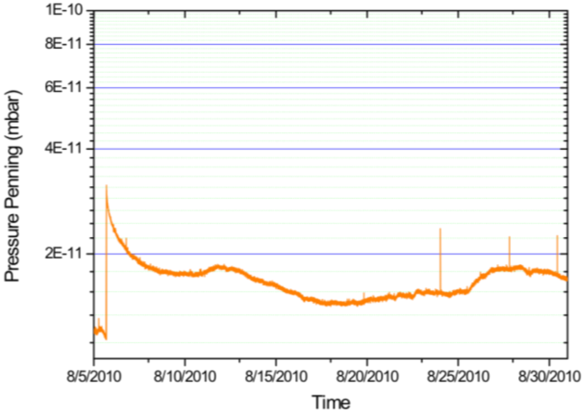
FNAL Transfer system

Transport System

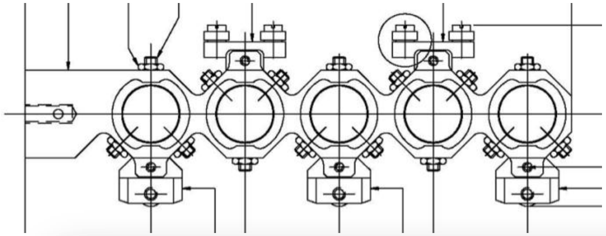
- Cathodes are transported under UHV condition from INFN Milano to the Labs since 1997.



No power supply needed.
OK for airplane



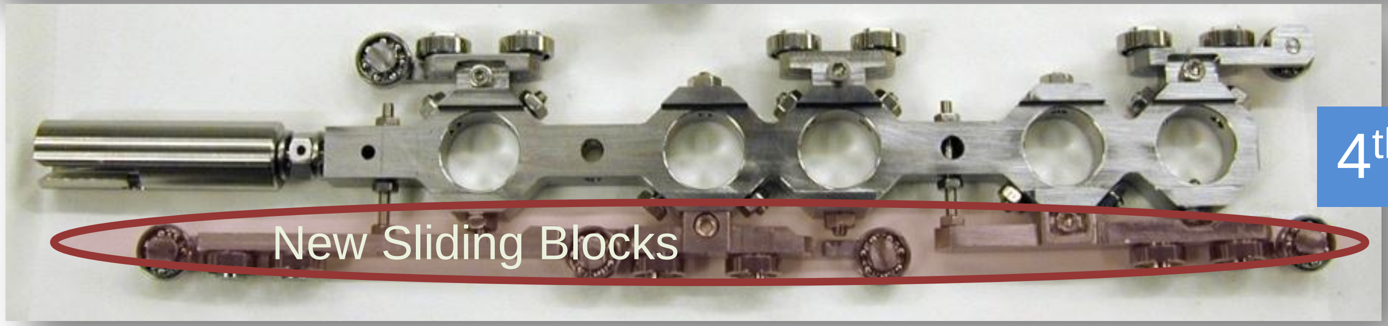
Carriage Evolution



A0 Carrier

2nd gen.

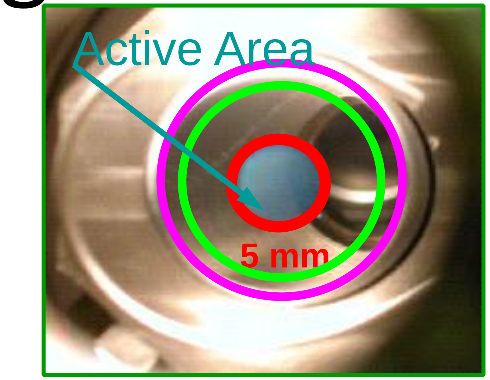
3rd gen.

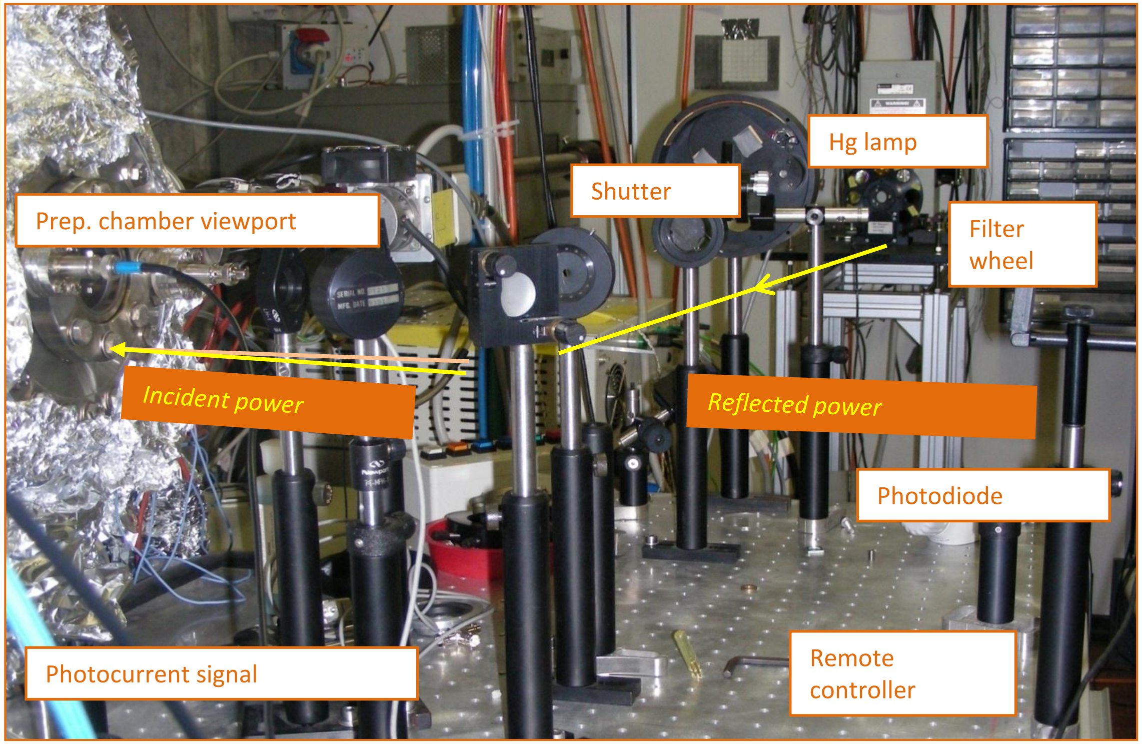


4th gen.

Deposition and Diagnostic

- During cathode deposition a circular masking system shapes the photoemissive layer and center it. The actual masking diameter is 5 mm



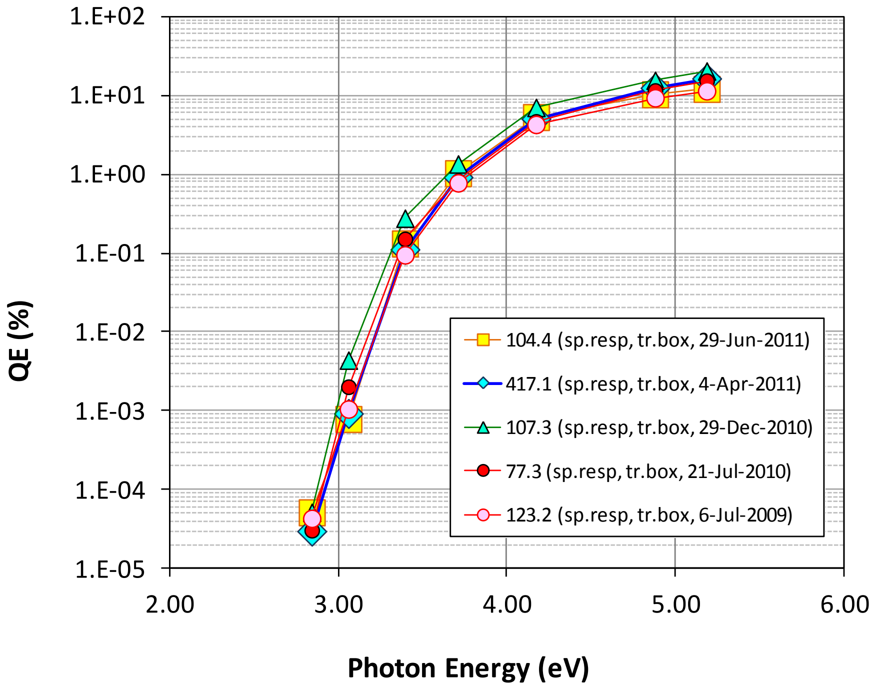


•***Calibrated photodiode*** for reflected light power from the film

•*A* ***motorized*** and remotely controlled ***filter wheel*** with interference filters (239 nm, 254 nm, 334 nm, 365 nm, 405 nm, 436 nm)

•***Picoammeter*** for photocurrent measurement

Spectral response reproducibility



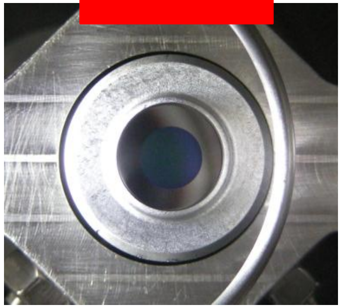
The on-line diagnostic allows better control of the cathode growing.

The reproducibility of produced cathode spectral responses is largely improved.

The Cs excess is under control. No more low energy shoulder.

104.4

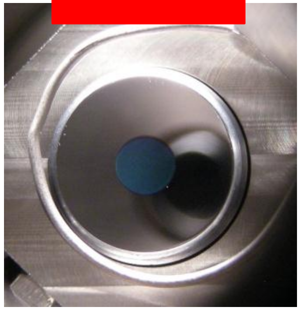
417.1



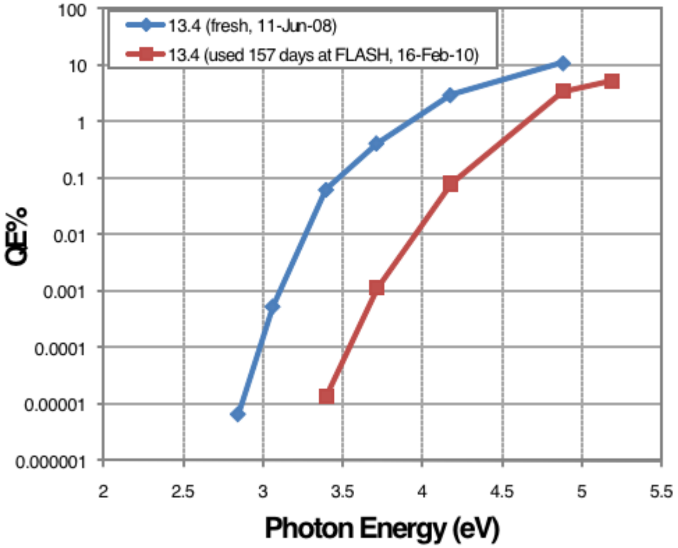
107.3

77.3

123.2



Post Usage Diagnostic



Cathode 13.4 – 157 days of operation

Measurement done at LASA

QE @ 254 nm = ***3.5%***

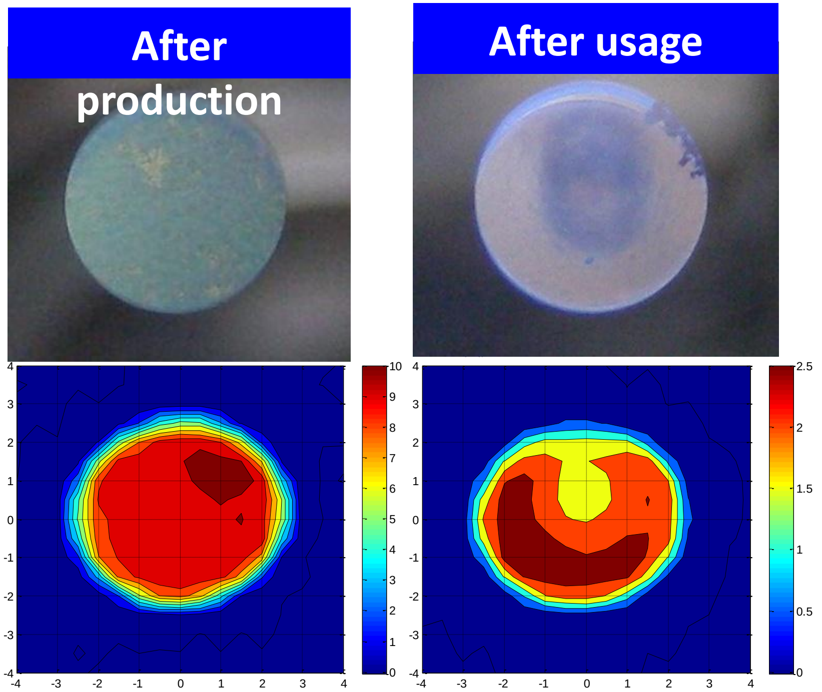
Initial QE was 11%.

Decrease of the low energy threshold as expected

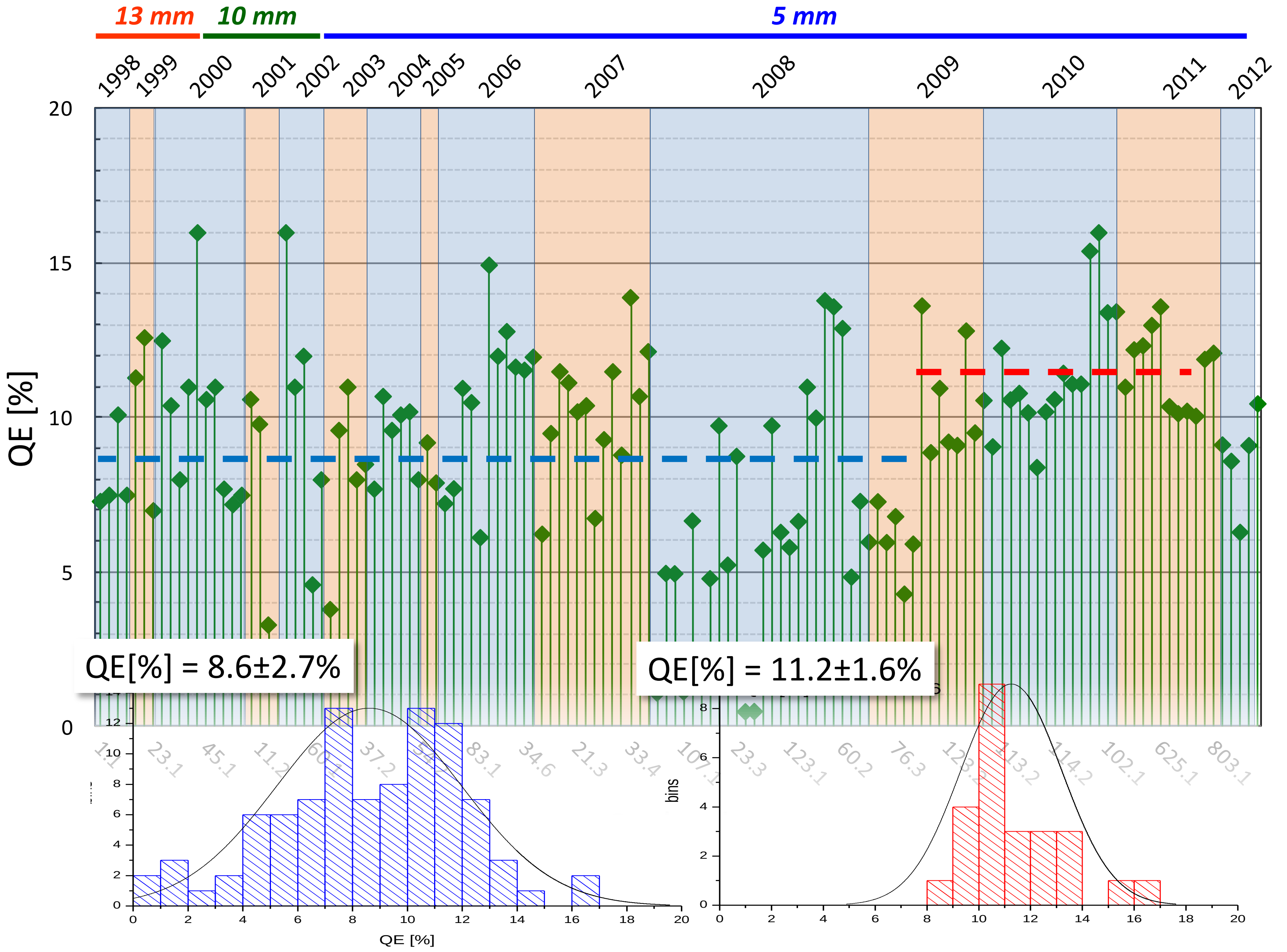
Cathode 77.2 – 176 days of operation

- After usage, central part of the cathode has a clear darker area

- Lack of coating on the right upper film area



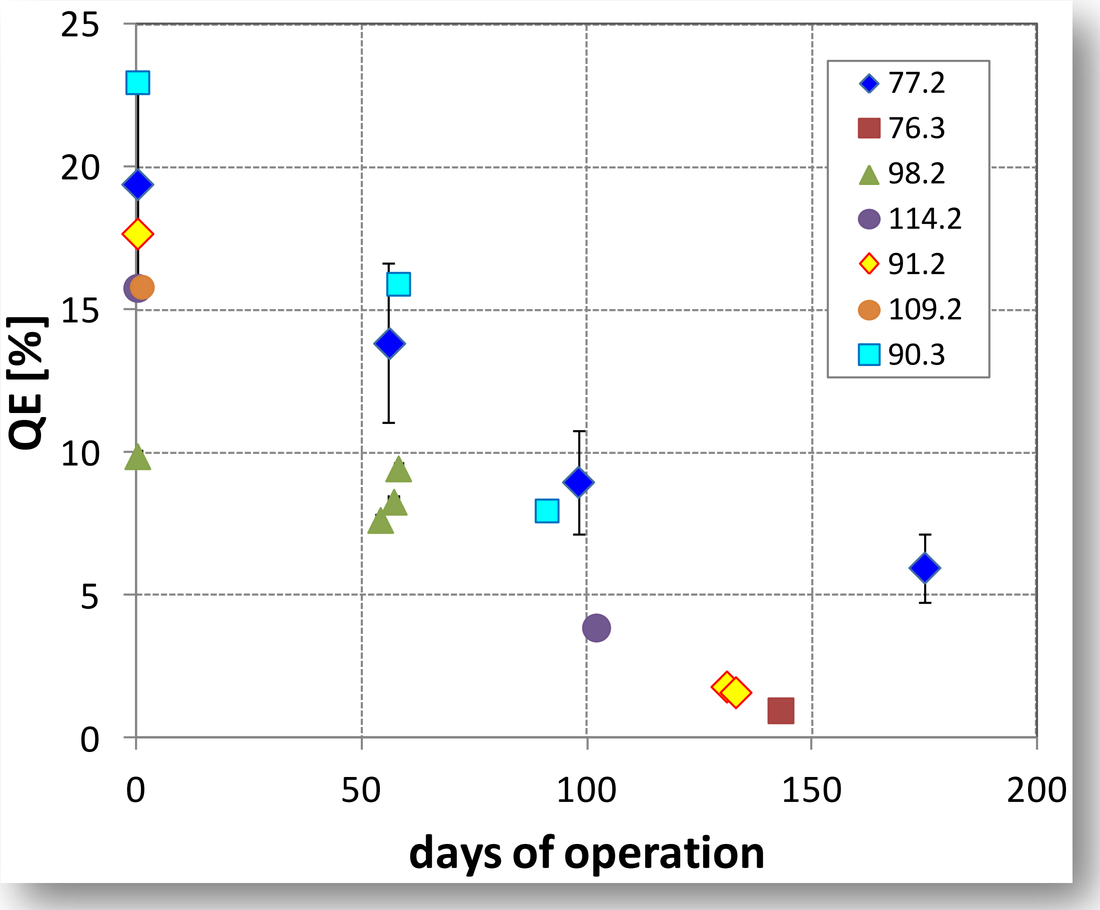
Cs_2Te QE after production



QE[%] = 8.6±2.7%

QE[%] = 11.2±1.6%

QE during operation

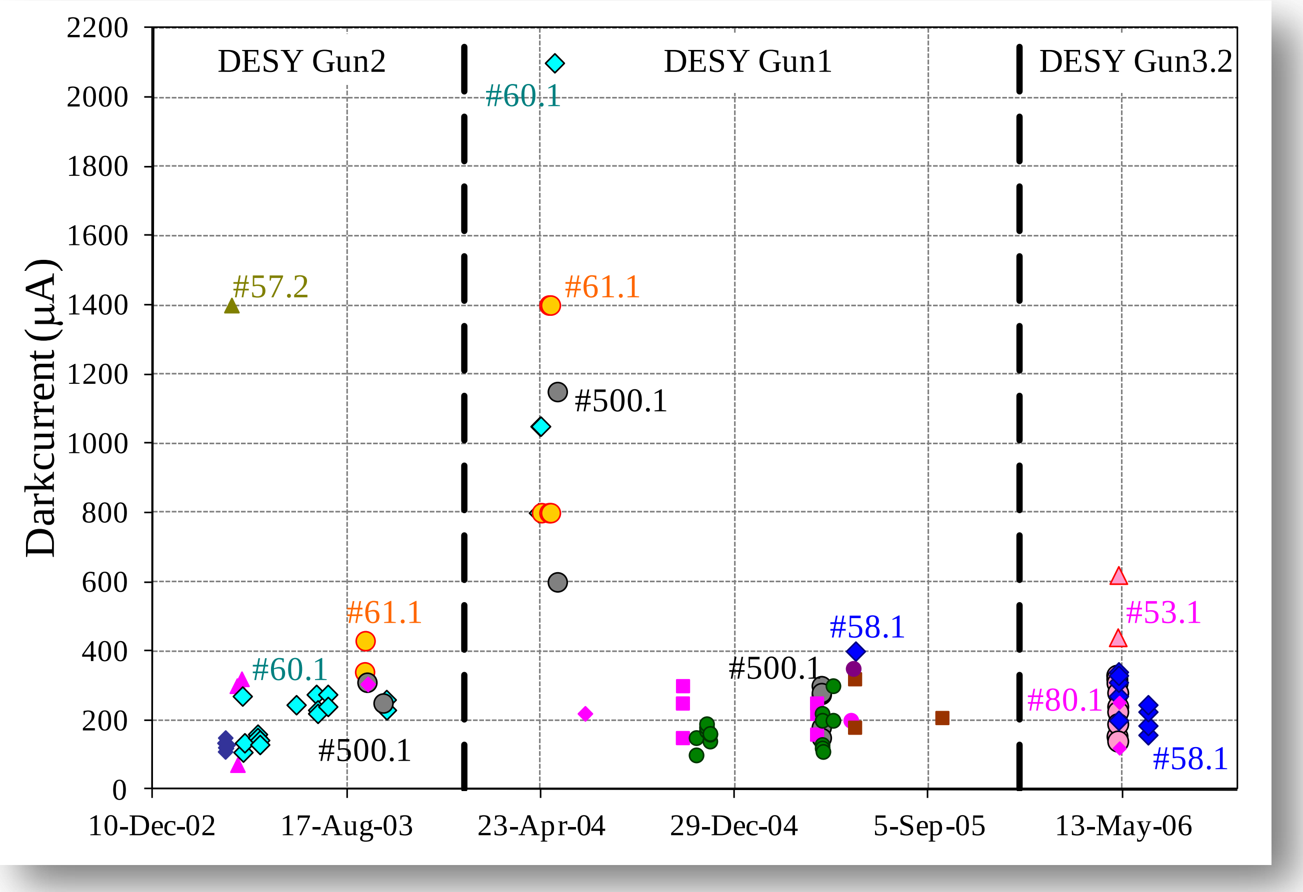


QE during operation.
The operation last for more than 100 days of continuous operation.

The cathode is changed if:

- QE < 0.5 %
- dark current is limiting LINAC operation

Dark current and Guns

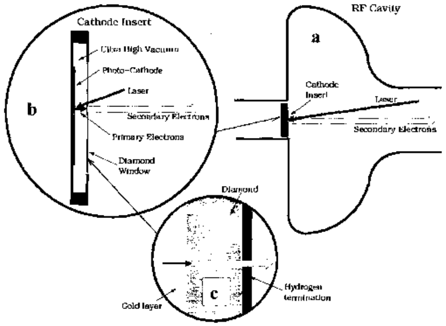


Trend of dark current for different guns.

To be notice DC decrease during operation of the gun.

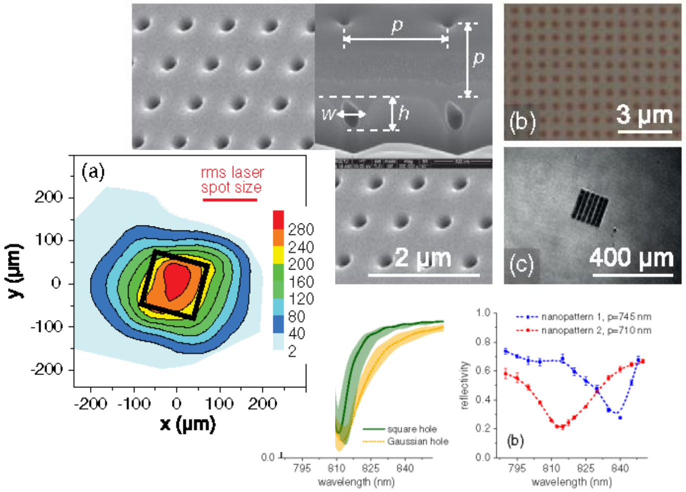
New trends and ideas

- Diamond Amplifier
  - An high QE photocathode sits behind a diamond thin barrier that acts as an electron multiplier. The electrons are then accelerated by the RF field

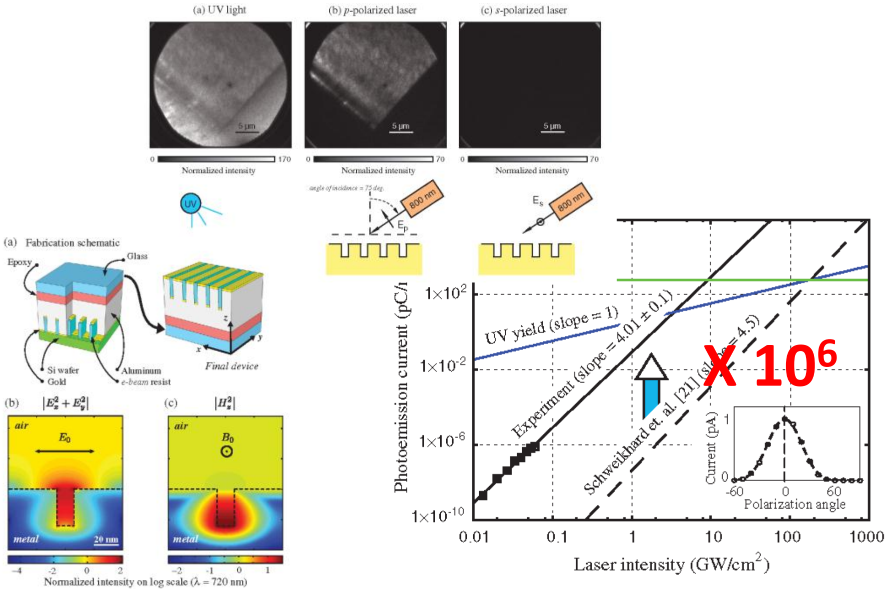


T. Rao, BNL-73169-2004-CP

- Plasmonic –Enhanced Photoemission
  - With nanostructure engineered structured interface, it is possible to have strong coupling between light and metal electron oscillation or surface plasmon



R. Li et al. PRL 100, 074801 (2013)



A. Polyakov et al. PRL 100, 076802 (2013)

Final Cathode Overview

Cathodes for Electron sources

	Macro-pulse repetition rate	Macro-pulse length	Max bunches per macro-pulse	single pulse energy	Wave-length	Cathode Type	Charge per second	QE
FLASH	10 Hz	800 µs	800 @ 1 MHz	100 µJ IR 10 µJ UV	1047→ 262 nm	Cs_2Te	8 µC	10 %
European XFEL	10 Hz	650 µs	2900 @ 4.5 MHz	100 µJ IR 10 µJ UV	1047→ 262 nm	Cs_2Te	450 W	10 %
LCLS	120 Hz	--	--	20 mJ	800 → 255 nm	Cu	--	<0.01 %
Fermi@ Elettra	10 Hz 50 Hz	--	--	20 mJ	800 → 255 nm	Cu	--	< 0.01 %
BerlinPro ERL	1.3 GHz	--	--	1 µJ	550 nm	CsK_2Sb	--	10 %
Cornell ERL	1 MHz 1.3 GHz	--	--	10 µJ 1 µJ	800 nm	GaAs (?)	--	>10 %

S. Schreiber 2011 Eurofel Photocathode Workshop

Final Laser Overview

Lasers for Electron sources

	Macro-pulse repetition rate	Macro-pulse length	Max bunches per macro-pulse	single pulse energy	Wave-length	Laser Pulse length	Power in burst	Average power
FLASH	10 Hz	800 µs	800 @ 1 MHz	100 µJ IR 10 µJ UV	1047→ 262 nm	10 ps rms	100 W	0.8 W
European XFEL	10 Hz	650 µs	2900 @ 4.5 MHz	100 µJ IR 10 µJ UV	1047→ 262 nm	20 ps flat hat	450 W	3 W
LCLS	120 Hz	--	--	20 mJ	800 → 255 nm	10 ps flat hat	--	2.4 W
Fermi@ Elettra	10 Hz 50 Hz	--	--	20 mJ	800 → 255 nm	10 ps flat hat	--	1 W
BerlinPro ERL	1.3 GHz	--	--	1 µJ	550 nm	10 ps	--	1.3 kW
Cornell ERL	1 MHz 1.3 GHz	--	--	10 µJ 1 µJ	800 nm	?	--	10 W 1.3 kW

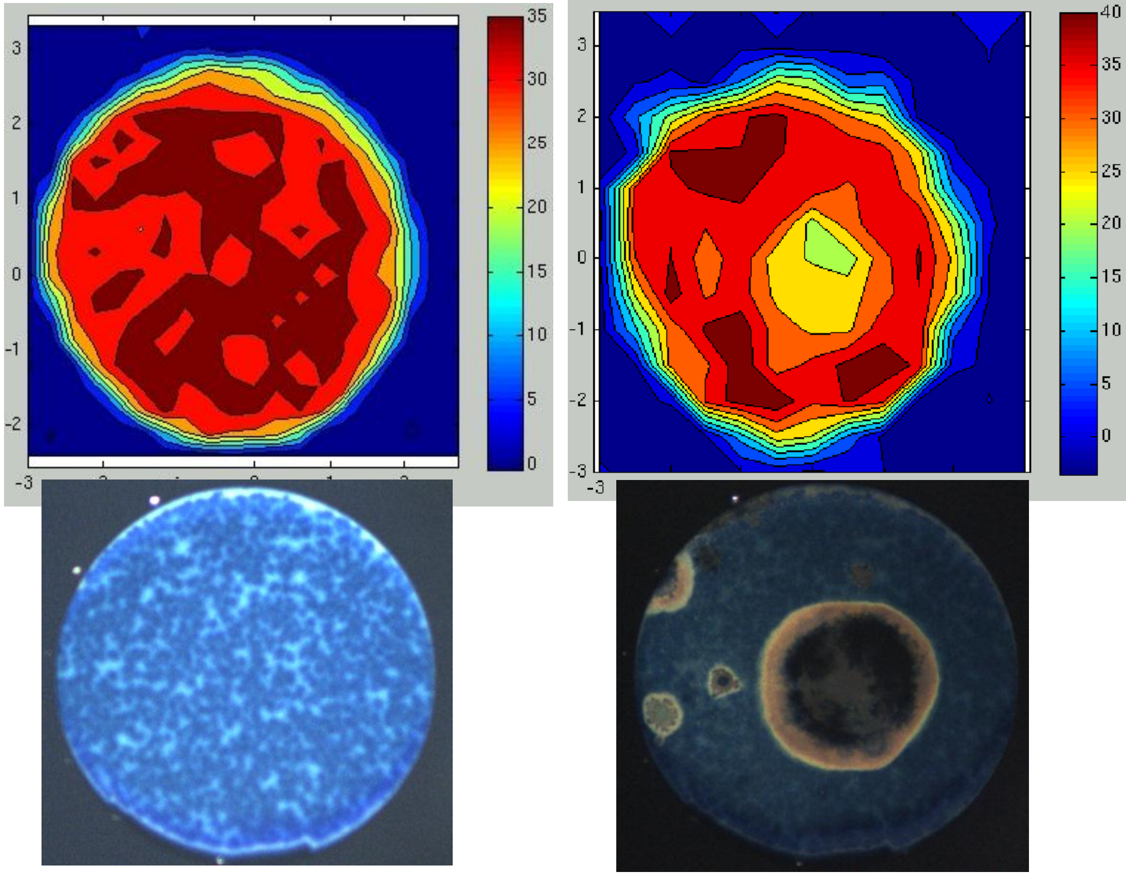
S. Schreiber 2011 Eurofel Photocathode Workshop

References

- P3 Workshop series
- 2011 Eurofel Photocathode Workshop
- Cs_2Te Photocathode Database
  - http://wwwlasa.mi.infn.it/ttfcathodes
- Photocathodes Wiki
  - http://photocathodes.chess.cornell.edu/wiki/Main_Page
- CERN Photoemission Laboratory
  - http://photoinjector.web.cern.ch/photoinjector/default.htm
- ....
- and many others

Standard Cathode analysis: QE-maps

- Investigations on homogeneity of electron emission



#613.1 operated at PITZ 60 MV/m, 600 bunches approx. 1 nC, 10 Hz – less than a week – possible life time problem!!

Standard Cathode analysis: cw mode

- Quantum Efficiency (QE) measurements in cw mode
  - QE after preparation / after usage
  - QE versus photon energy

$$QE(E_{ph}) = A_1(E_{ph} - W_1)^{m_1} + A_2(E_{ph} - W_2)^{m_2}$$

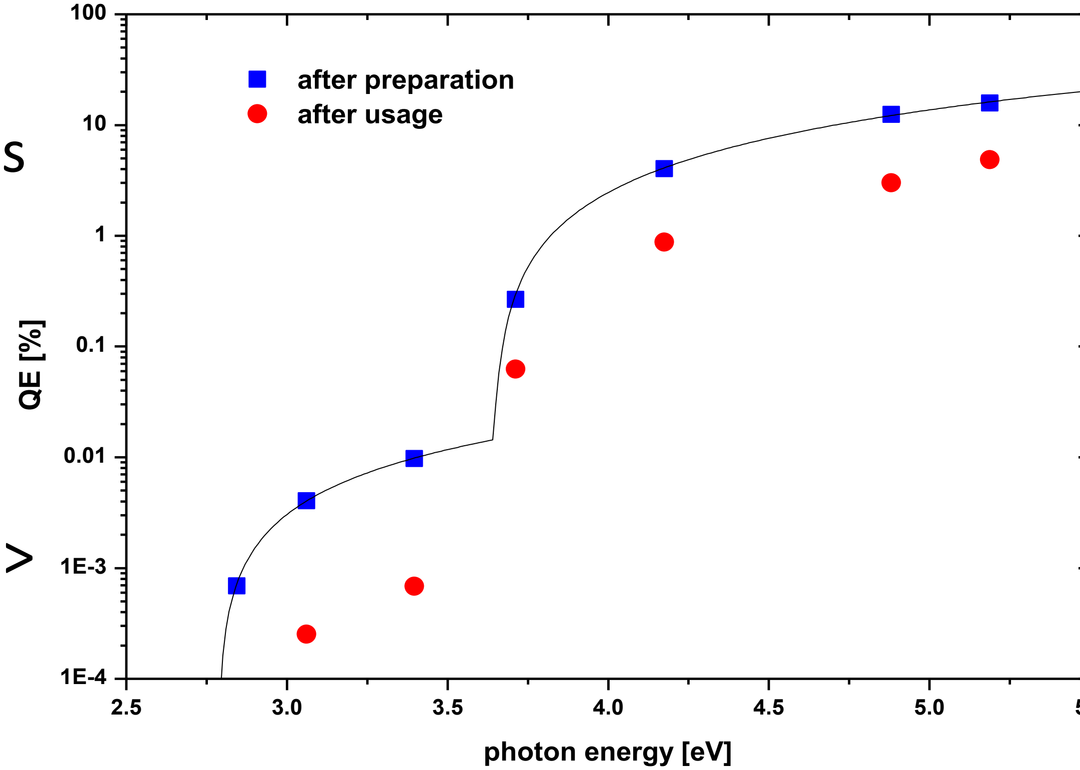
$$W_i = E_{g_i} + E_{a_i}$$

- Preparation recipe results in

  W_2 = 3.5 - 3.6 eV

  Theory [1]: 3.5 eV

- New preparation technique from LASA no low energy part =>



[1] R. Powel et al., Phys. Rev. B **8** (1973), 3987.