Results of recent photocathode studies at FLASH

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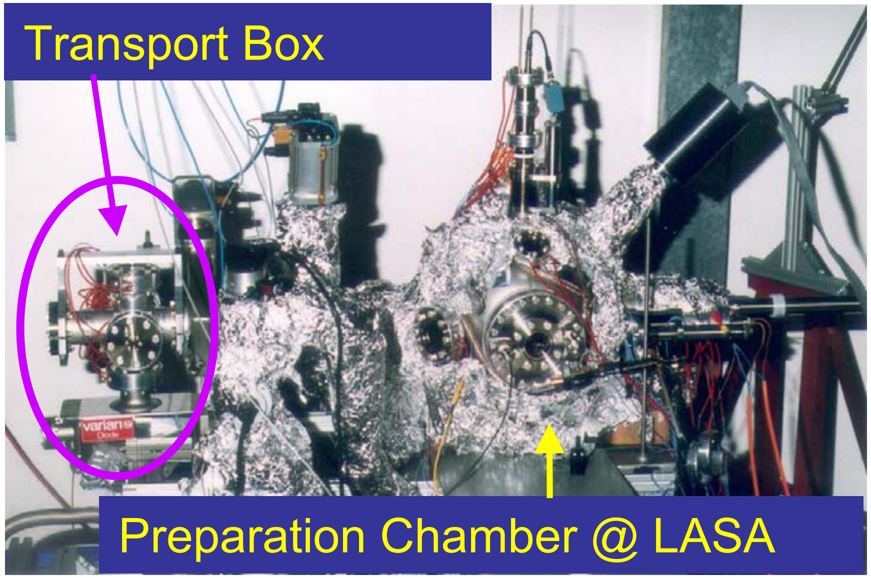
Outlook

- Cs_2Te photocathodes
- cw QE measurements
  - set-up
  - measurements
- Pulsed QE measurements
  - laser transmission
  - measurements
- Dark current problems
  - problem
  - investigation
- Summary and conclusion

Cs_2Te photocathodes

Cs_2Te photocathodes for FLASH prepared at INFN-Milano, LASA, Italy



- UHV Vacuum System - base pressure 10^{-10} mbar
- 6 sources slot available
- Te sources out of 99.9999 % pure element
- Cs sources from SAES®
- High pressure Hg lamp and interference filter for online monitoring of QE during production
- Masking system
- 5 x UHV transport box

After preparation transport to FLASH or PITZ under UHV conditions

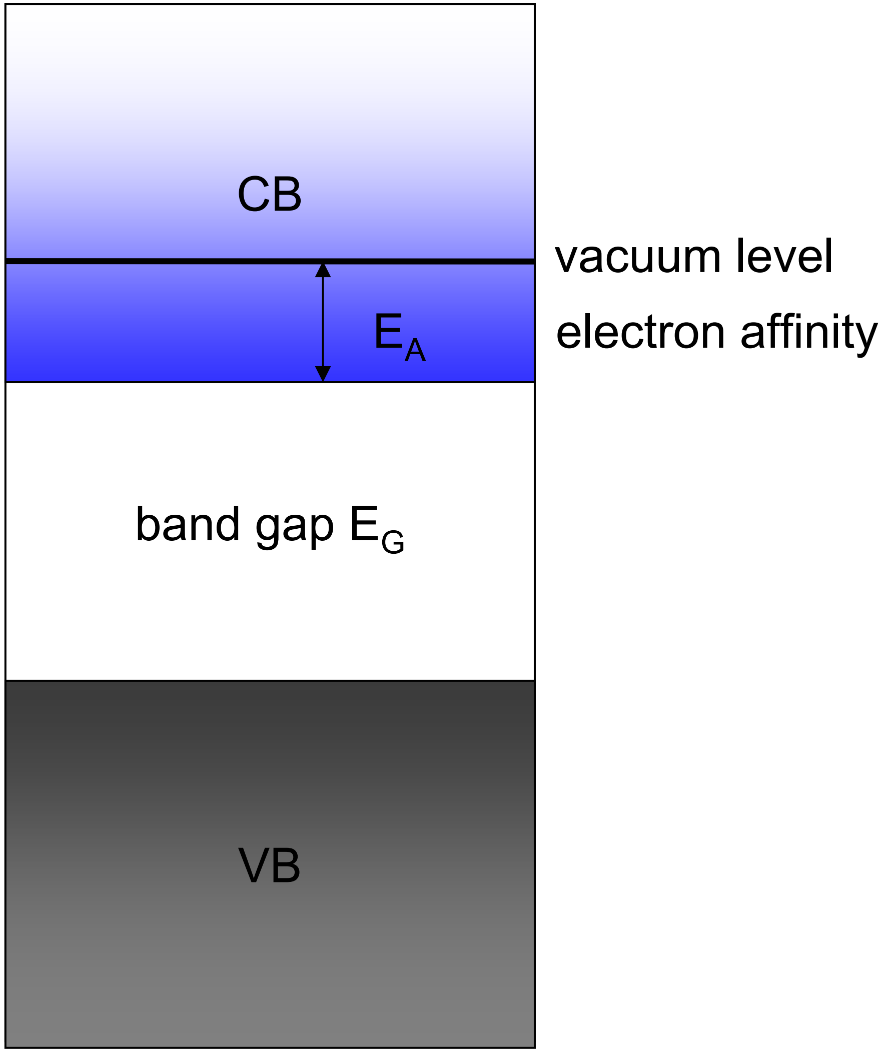
Cs_2Te photocathodes

Cs_2Te photocathodes

+ ability to release high peak current electron bunches
+ high QE

- need UHV
- UV laser needed

• semiconductor
• band gap E_G = 3.3 eV
• positive electron affinity E_A = 0.2 eV

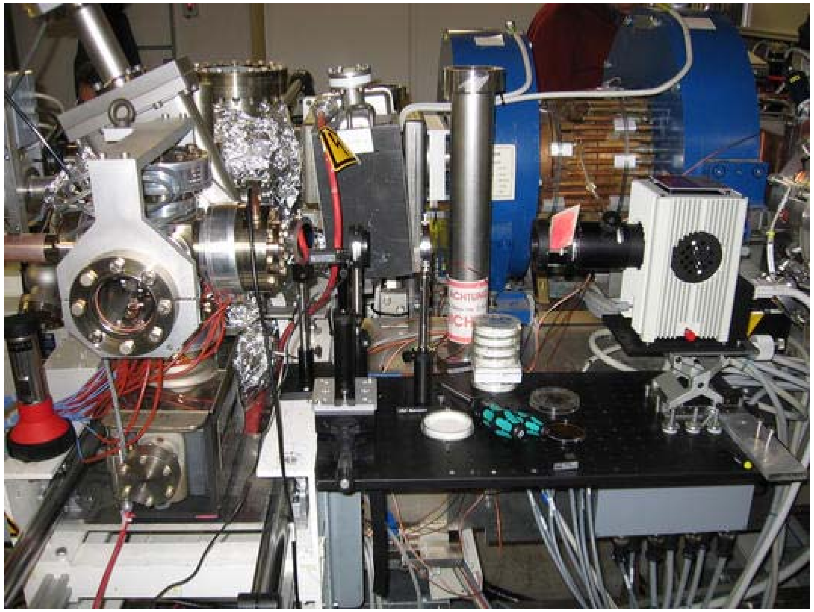


QE - cw measurements

Measurements of the spectral response of the Cs_2Te cathodes in the transport box

set-up (comparable to LASA)

- Hg lamp
- band pass filter for photon energy selection
- photodiode to determine light power
- Pico ammeter to measure current of emitted electrons
- some optics for focusing

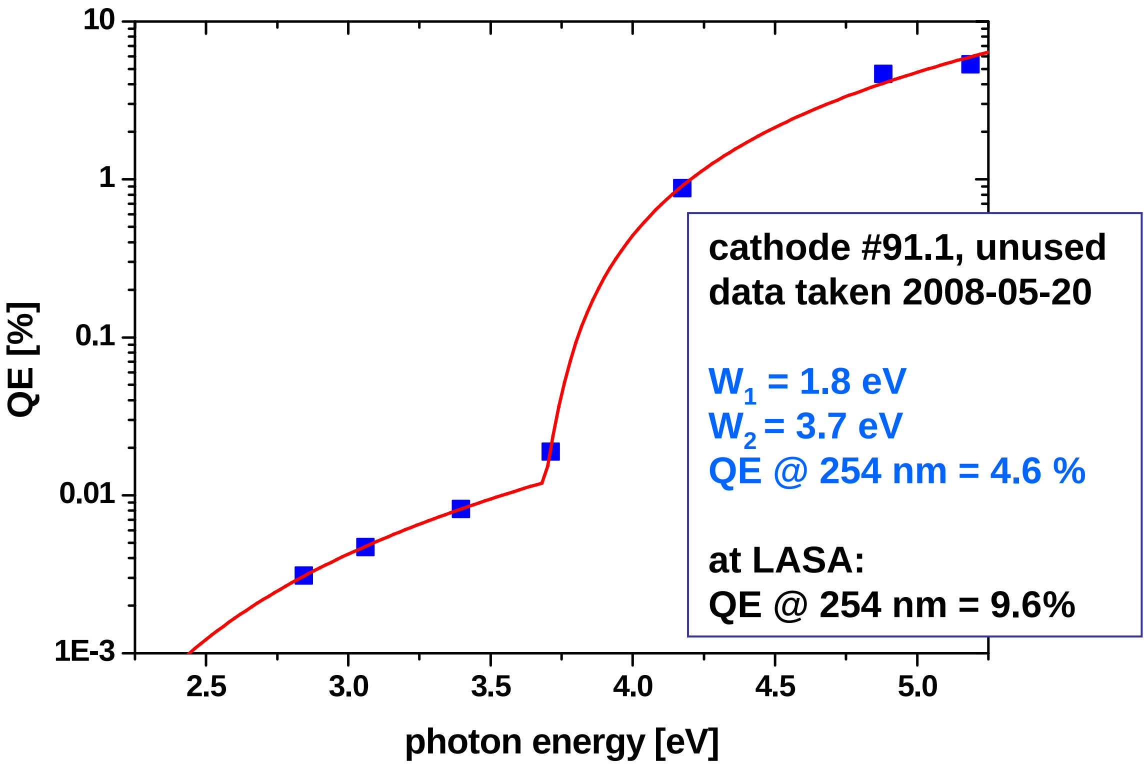


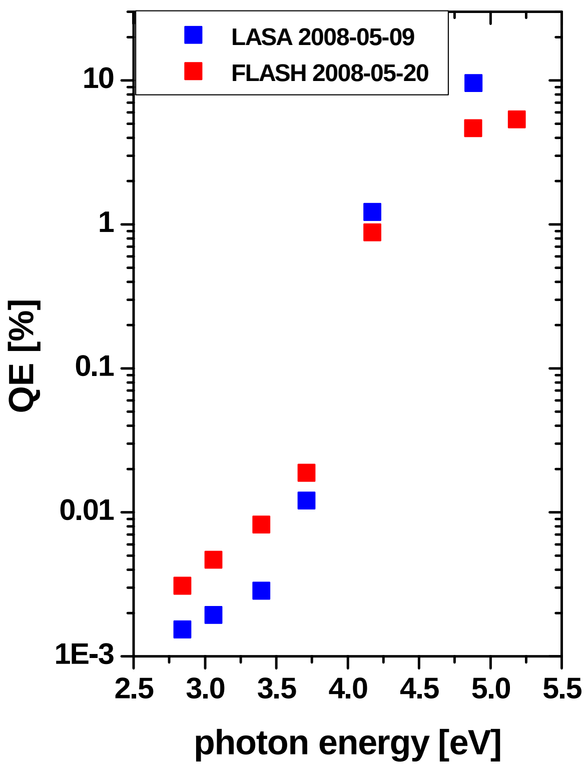
QE - cw measurements

$$QE = A_1\left(h\nu - W_1\right)^{m_1} + A_2\left(h\nu - W_2\right)^{m_2}$$

$$with \quad W_i = E_{G_i} + E_{A_i}$$

W: work function, A proportional constant, m: parameter giving some insights into the emission process





QE - cw measurements

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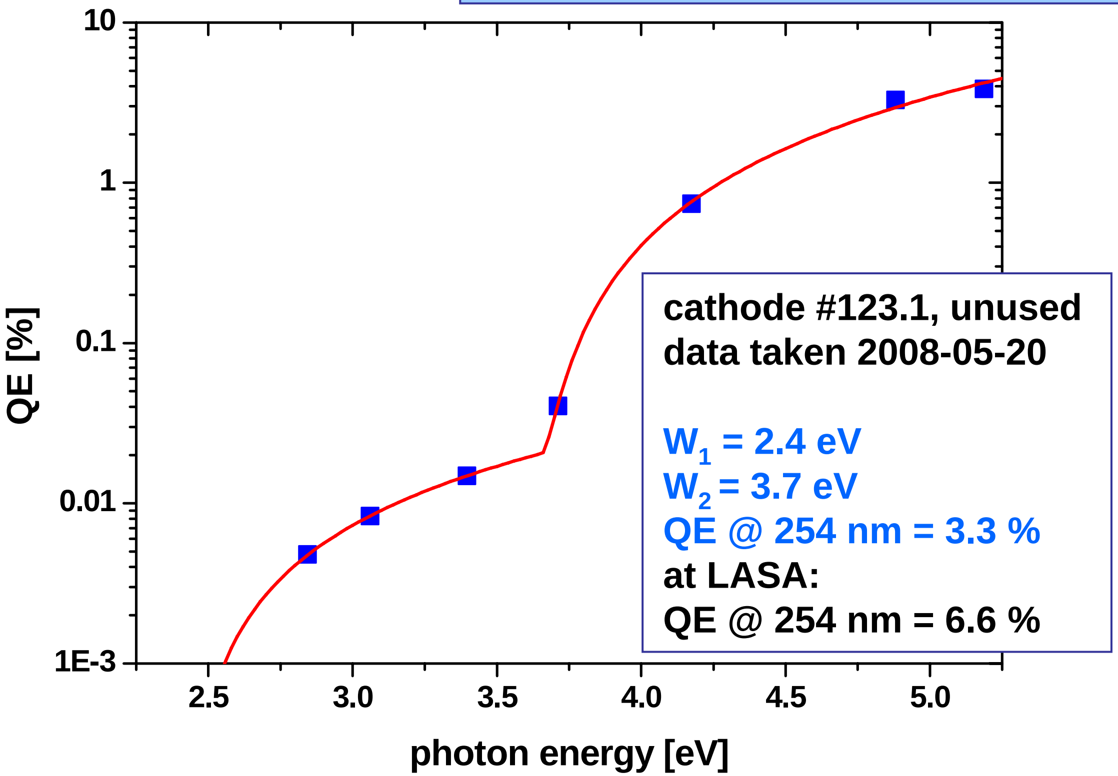
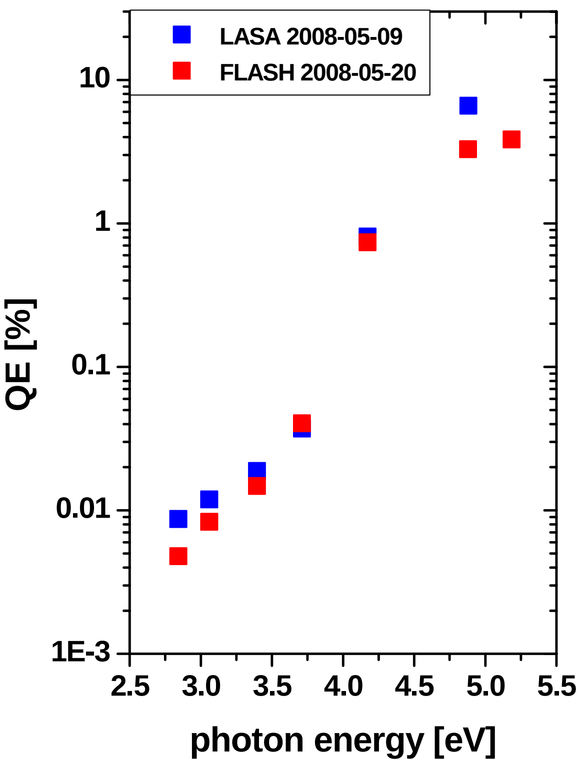


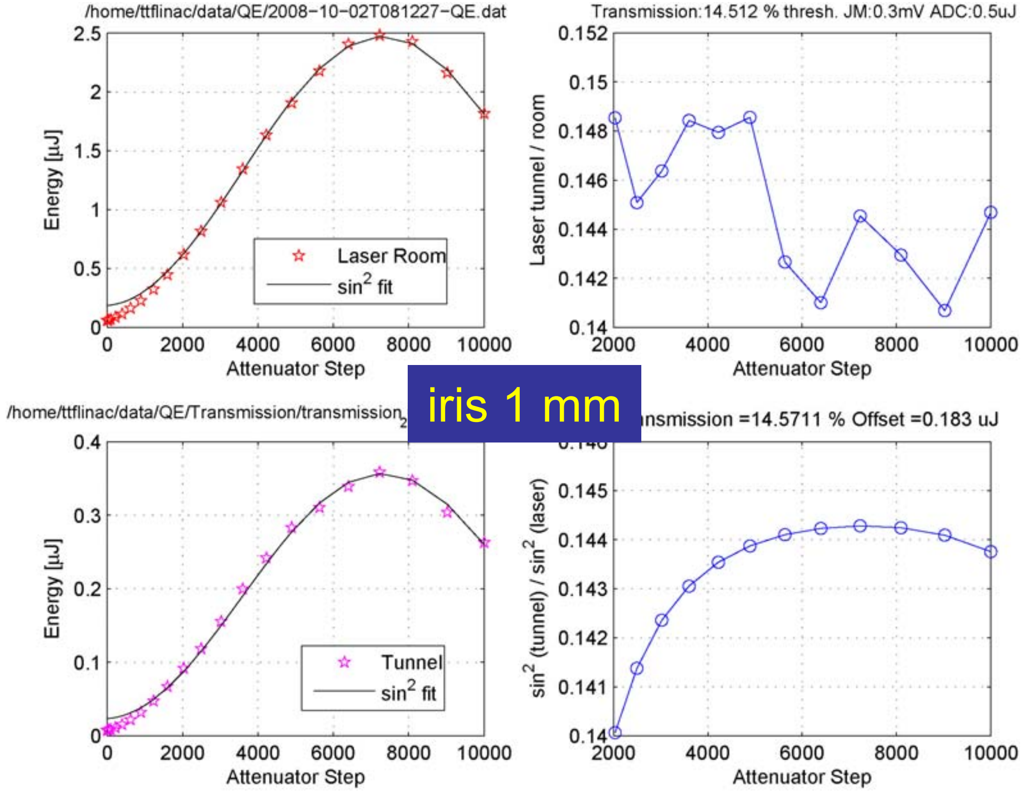


Usually the QE is constant over month if the cathodes stay in the transport box (*Laura Monaco, FLASH seminar 2008-04-08*). The drop for the two shown cathodes we relate to the operation under bad vacuum conditions (10^{-8} mbar).

QE - pulsed measurements

For the pulsed QE measurements the laser energy at the cathode has to be determined

- **laser energy measured with joulemeter (Molectron J-5)**
- **laser energy measured on laser table and in laser hut as function of the attenuator**
- **transmission of view port (92 %) taken into account**
- **reflectivity of vacuum mirror (90 %) accounted for**
- **fitted by sin² to evaluate transmission (half-wave plate/polarizer attenuator)**



iris	date	transmission
1mm	2008-01-09	**2.3 %**
2 mm	2008-01-09	**4.9 %**
3 mm	2008-01-09	**9.7 %**
1 mm	2008-07-30	**14.5 %**
2 mm	2008-07-30	**34.5 %**
3 mm	2008-07-30	**46.1 %**
1 mm	2008-10-02	**14.5 %**
2 mm	2008-10-02	**31.9 %**
3 mm	2008-10-02	**45.2 %**

QE - pulsed measurements

QE measurement

- **charge measured with toroid T1**
- **laser energy measured in laser hut**
- **automated procedure for measuring charge vs. laser energy dependence**

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

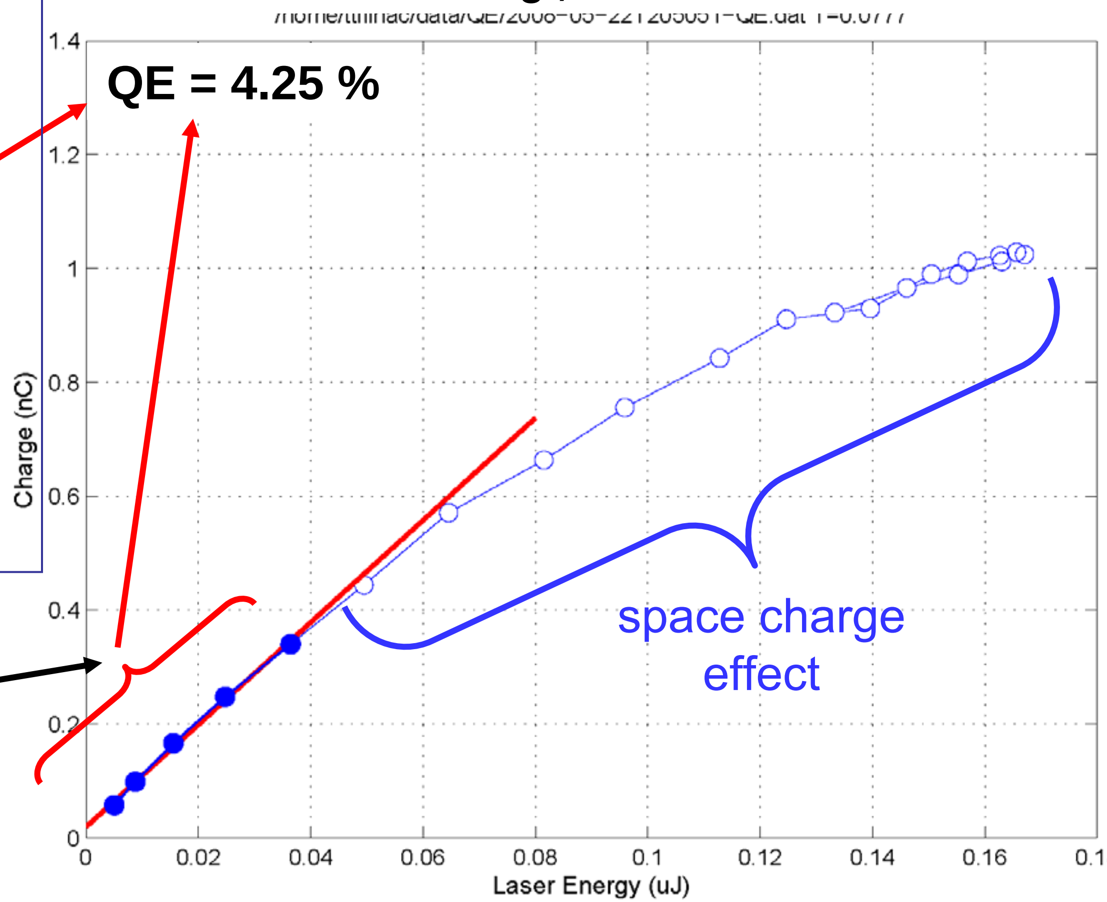
$$QE[\%] = 100\frac{Q[C]E_{ph}[eV]}{E_{cath}[J]}$$

$$QE[\%] \approx 0.5\frac{Q[nC]}{E_{cath}[\mu J]}$$

@ 262 nm

example of QE measurement at FLASH cathode #123.1 2008-05-22

P_{for} = 3.3 MW phase 38 deg w.r.t. zero crossing , iris = 3 mm



charge trend at low charge fitted

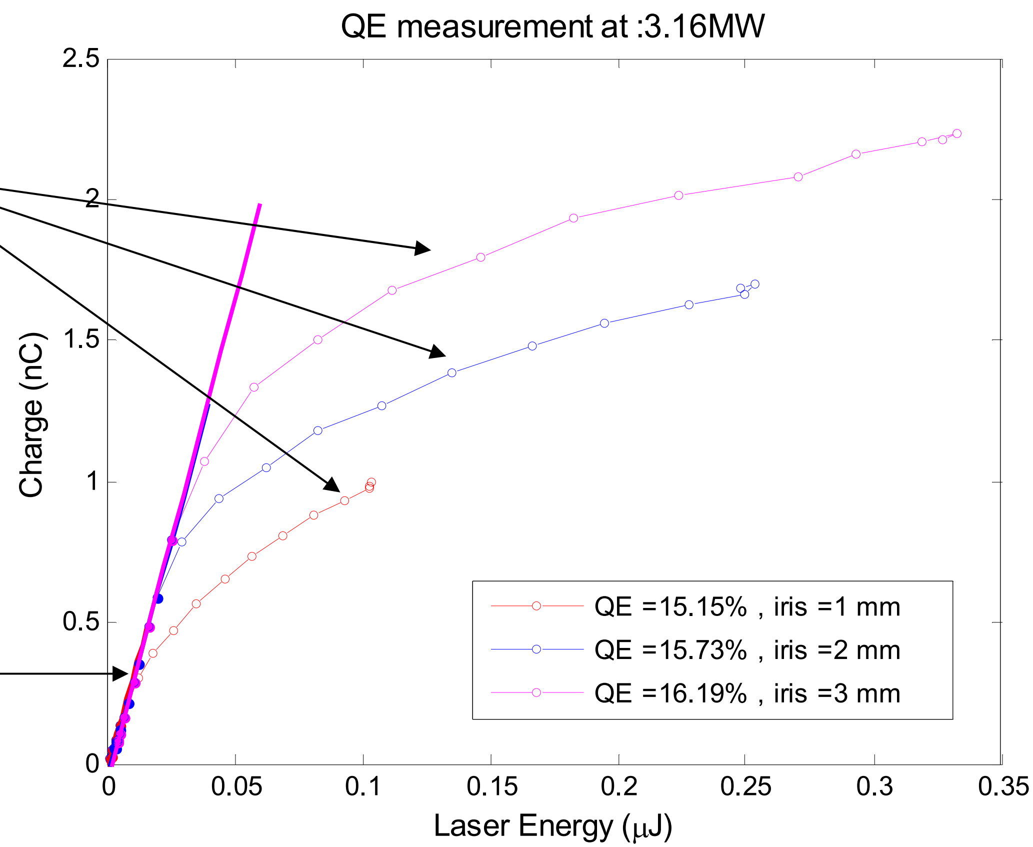
S. Lederer, DESY

QE - pulsed measurements

Charge versus laser energy obtained for different laser diameters at the cathode, accelerating field constant.

In the space charge affected regime the extracted charge depends on the laser spot size.

The slope of the linear part in the low energy region is independent from the spot size since here the emission is not effected by space charge.



QE – vs. field

RF data analysis – QE enhancement

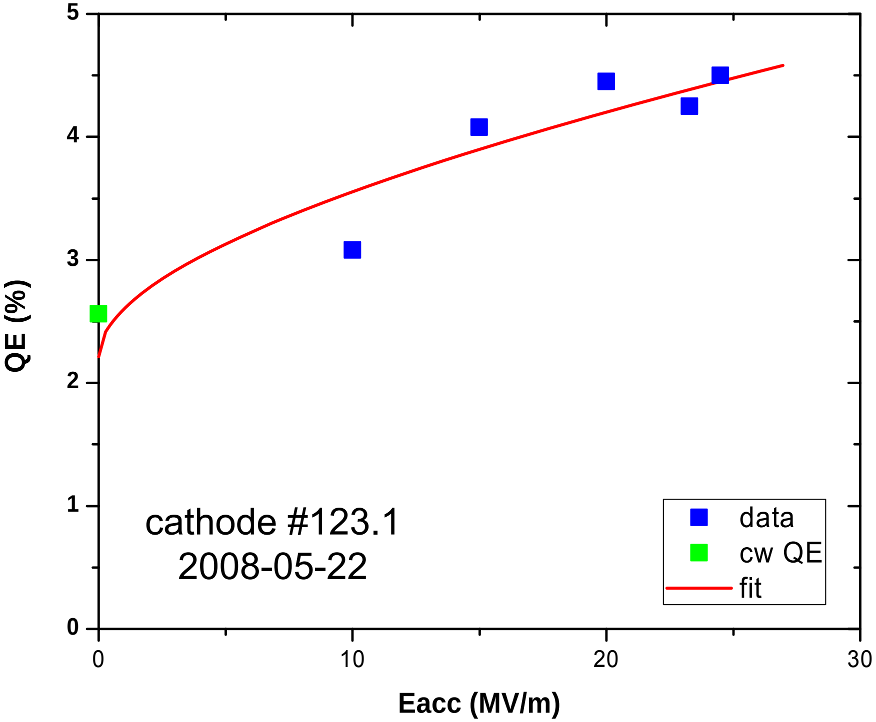
- **QE @ given acc. gradient E and phase ϕ**
- **with a given laser energy without space charge**

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

where E is the accelerating field, ϕ is the phase RF/laser, β is the geometric enhancing factor

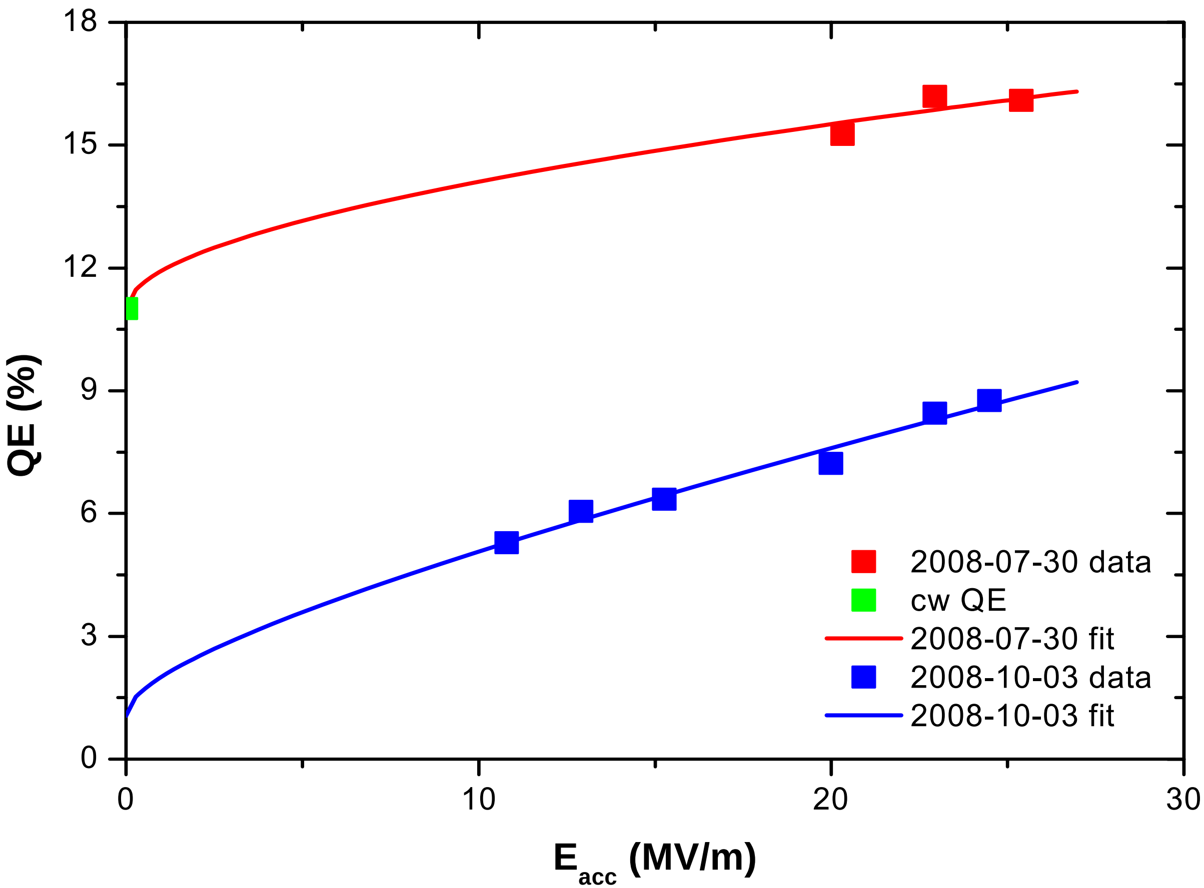
From the fit of QE versus electric field at the cathode one gets information about the work function and the geometric enhancement factor.

W = 3.6 eV
β = 7
QE @ zero field =2.2 %



QE – vs. field

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



cathode #13.4 2008-07-30
QE @ zero gradient = 11 %
$W = E_G + E_A = 3.5$ eV
$\beta = 2$

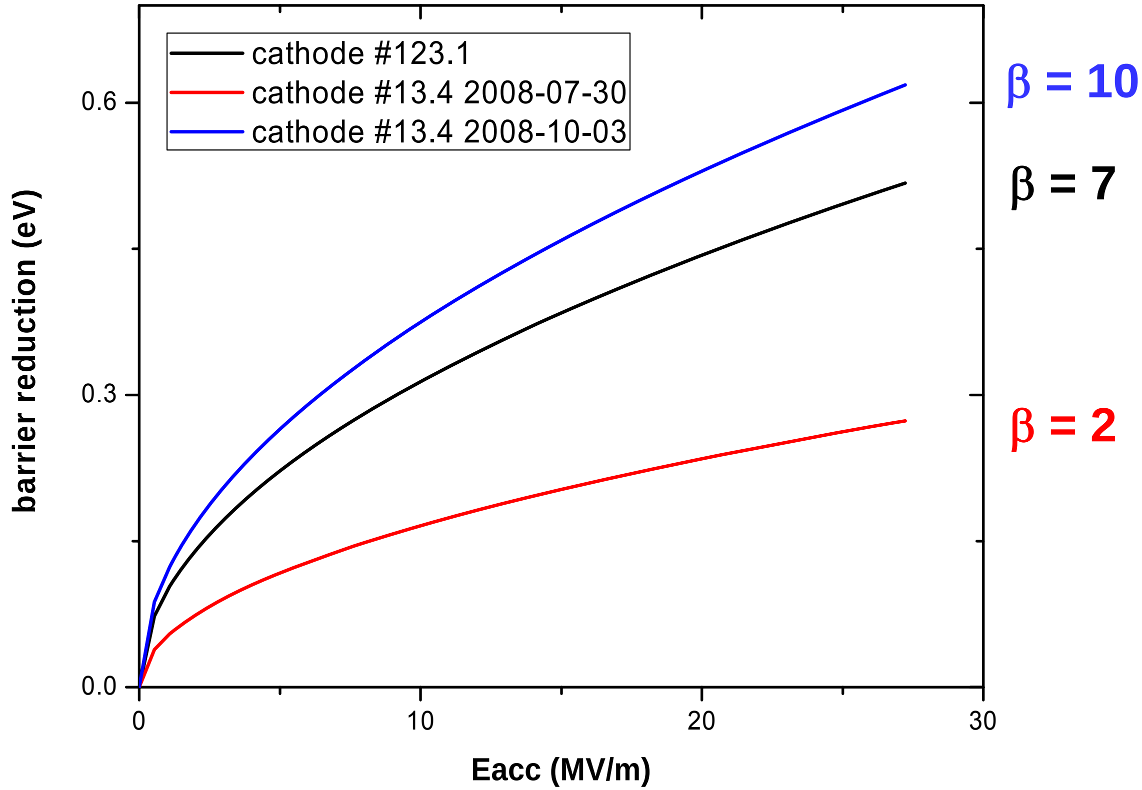
2 month of operation

cathode #13.4 2008-10-03
QE @ zero gradient = 1.1 %
$W = E_G + E_A = 4.4$ eV
$\beta = 10$

→ QE decreased
→ W increased
→ field enhancement increased

QE – vs. field

effective lowering of the work function obtained from pulsed QE measurements

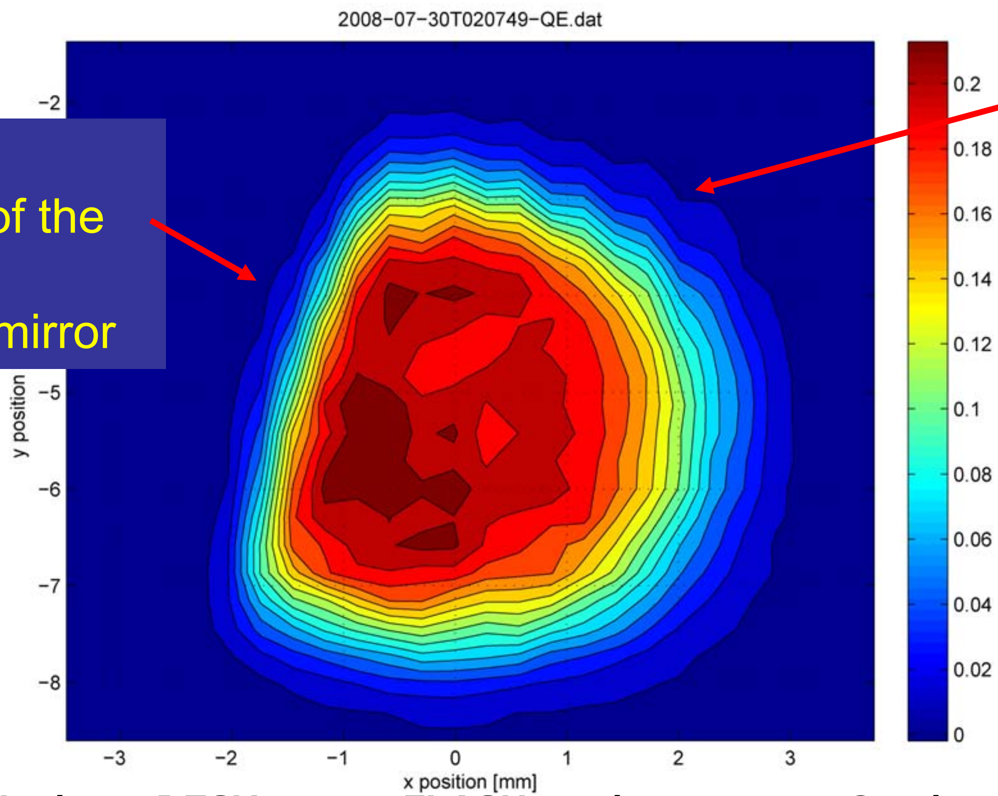


The theoretical electron affinity of the cathodes is 0.2 eV. The obtained lowering of the work function is higher than expected, but the uncertainty of this parameter is rather high.

QE maps

Laser with smallest possible spot size (0.26 mm) is moved over the cathode and the extracted charge is measured with the toroid T1. The aim of this studies is to get an idea of how homogeneously the charge is extracted from the cathode.

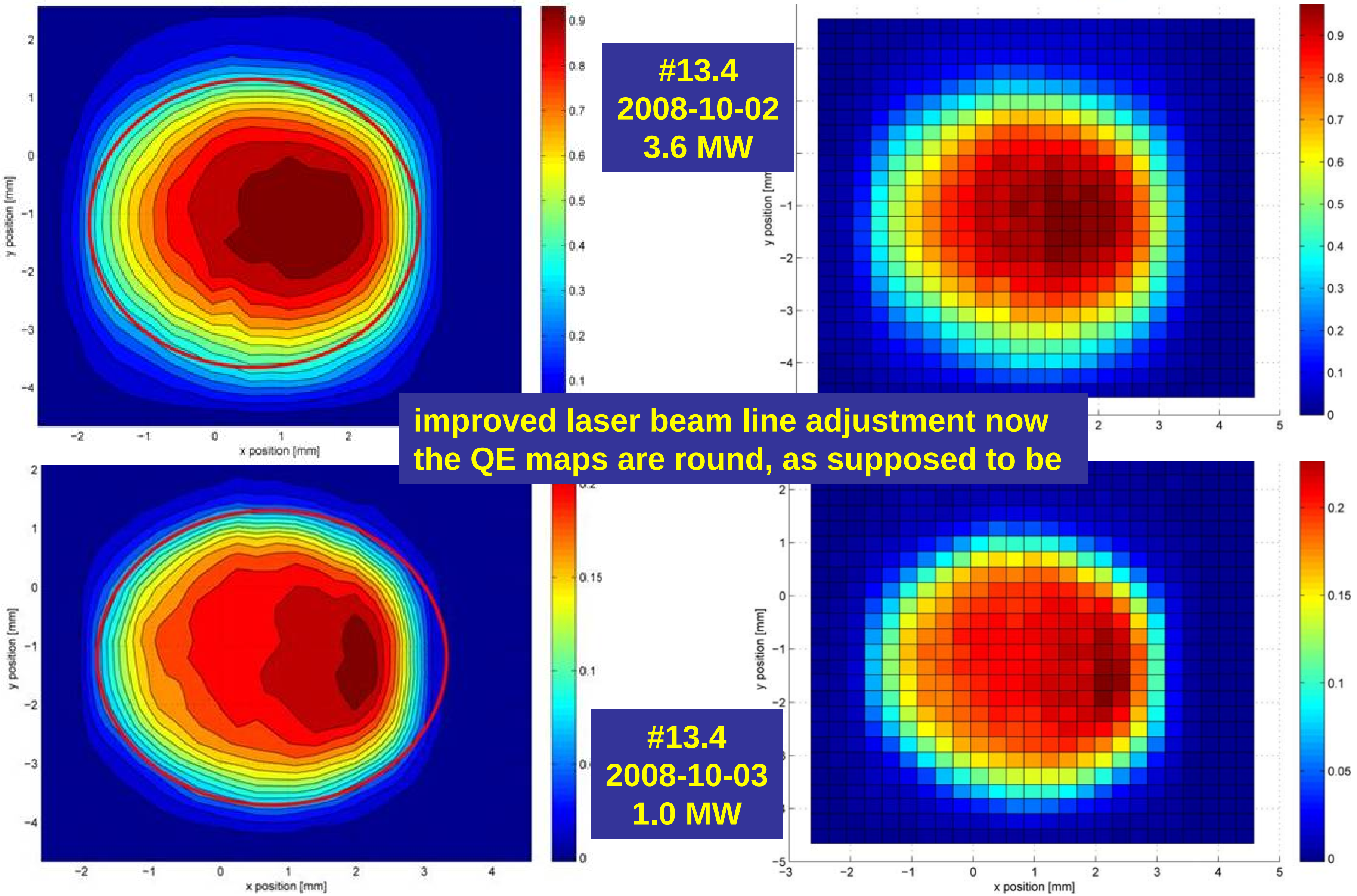
QE map of cathode 13.4 measured 2008-07-30



typical feature,
not a real effect of the cathode,
caused by laser mirror

typical feature,
caused by laser mirror

QE maps

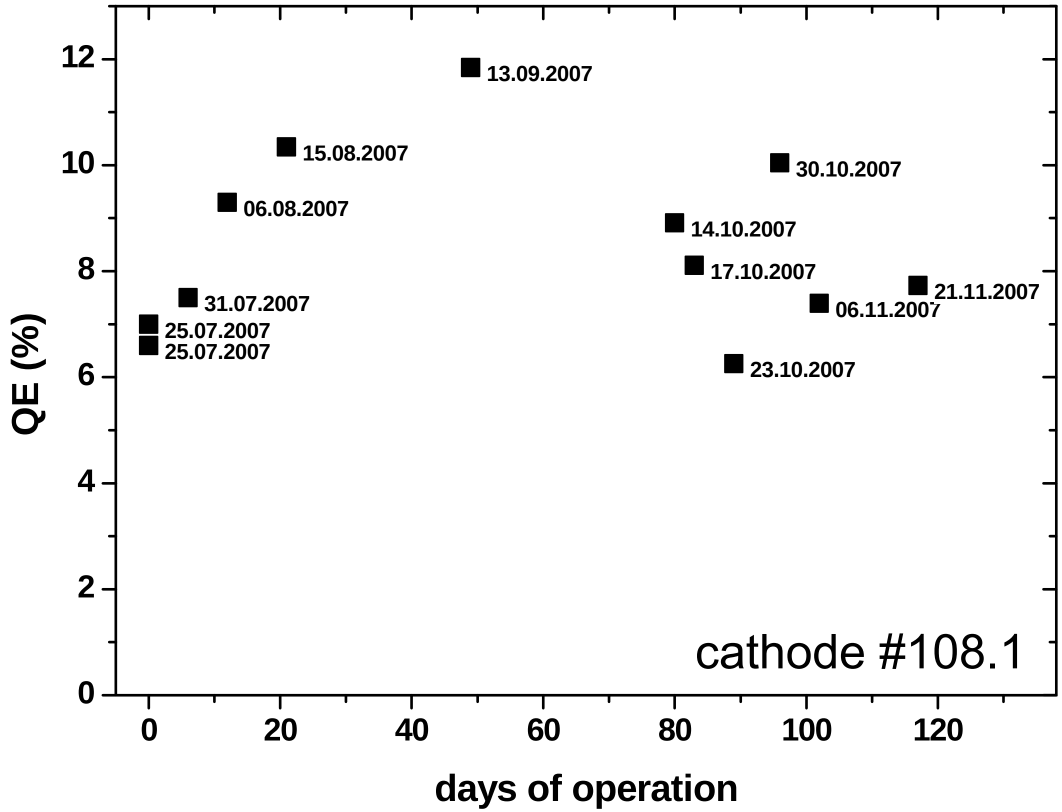


#13.4
2008-10-02
3.6 MW

improved laser beam line adjustment now the QE maps are round, as supposed to be

#13.4
2008-10-03
1.0 MW

QE – cathode lifetime



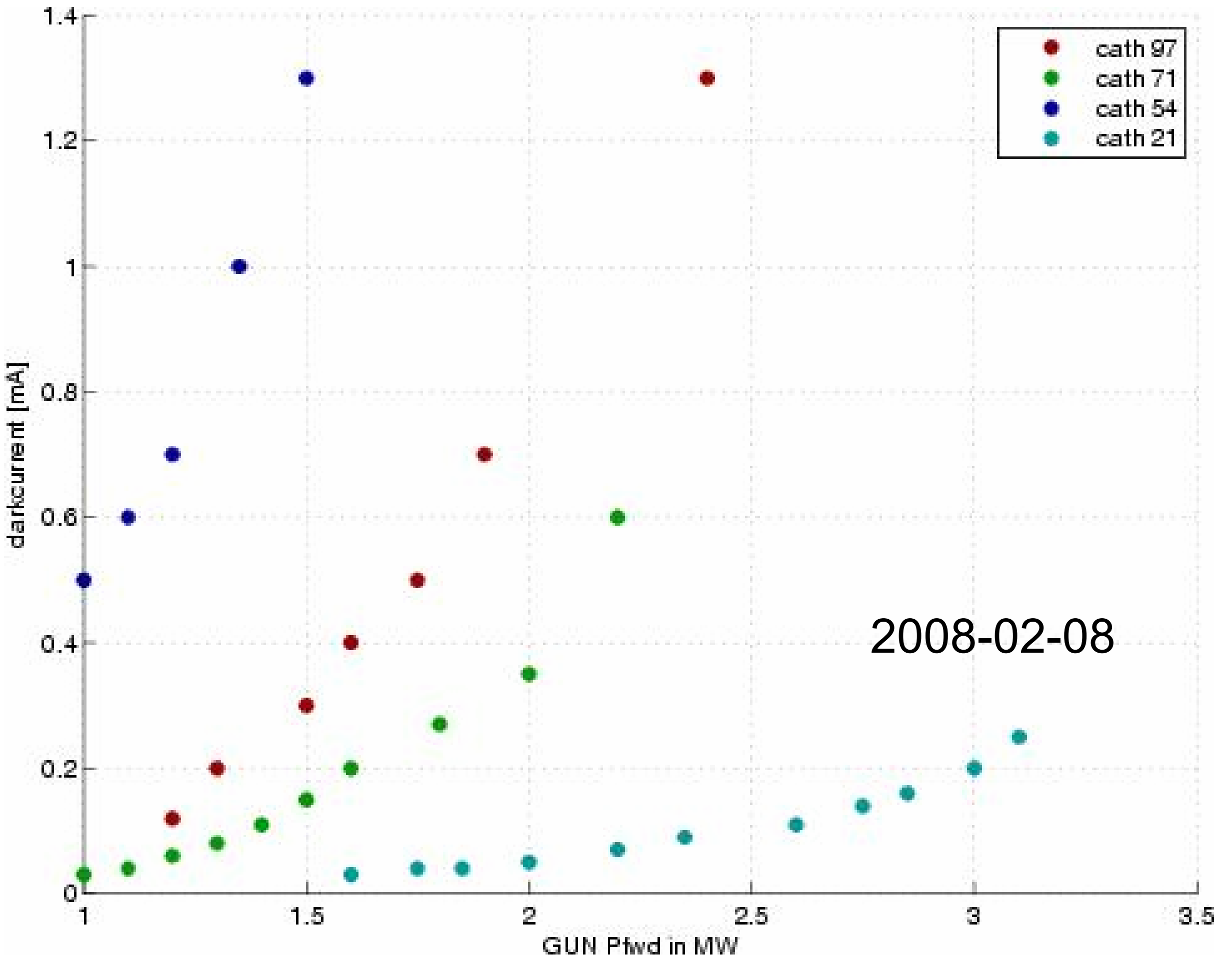
Since shut down works 2007 in the gun region (improved vacuum, removed teflon washers) an increased lifetime is observed.

Cathode #108.1 was operated for 126 days, #21.3 for 129 days, and cathode #91.1 for 68 days.

In addition cathode changes were not motivated by a low QE.

Dark current problems

In winter 2007 and spring 2008 several cathodes exhibited an enormous dark current, up to 1.8 mA. With these cathodes no operation was possible!!

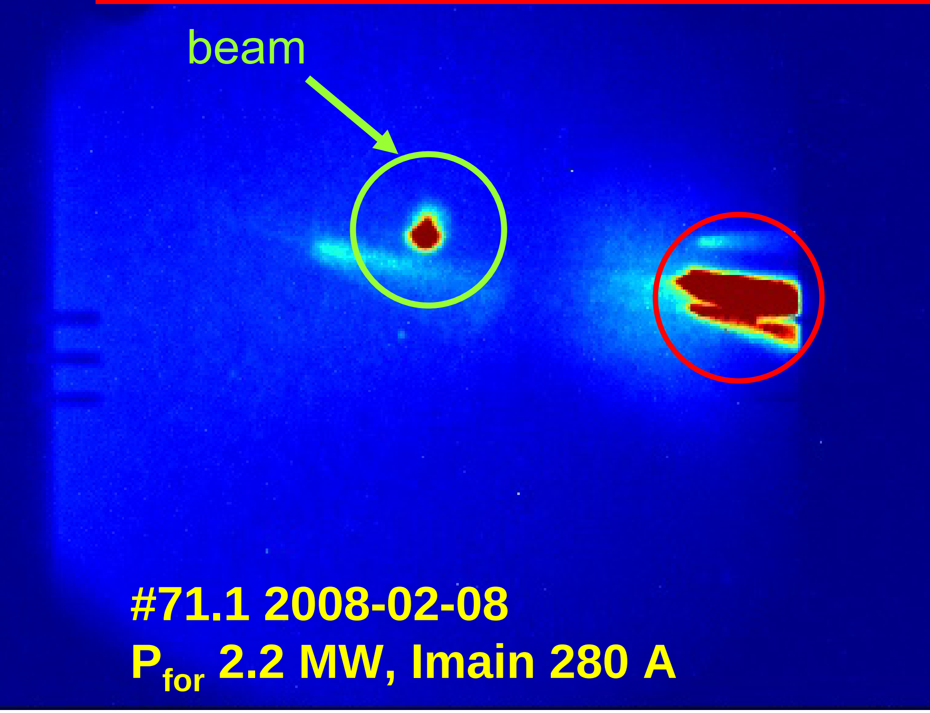


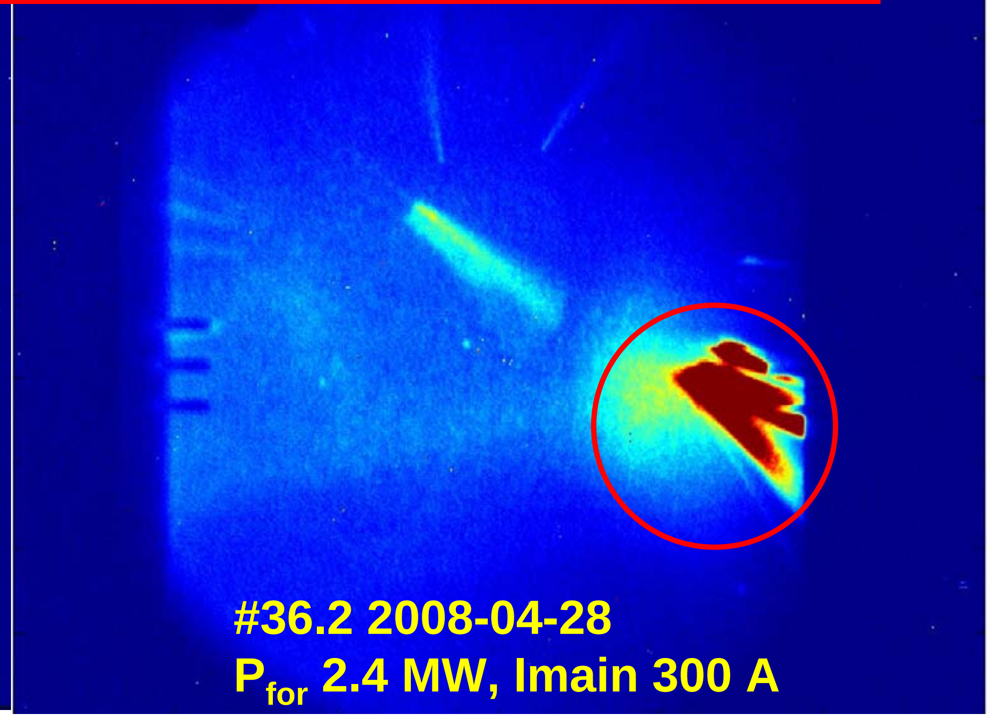
dark current for several cathodes of box short1

- **main solenoid current fixed to 300 A**
- **cathode #21.3 was in the gun before cathode exchange**

Dark current problems

For nearly all cathodes with dark current problems the images look very similar



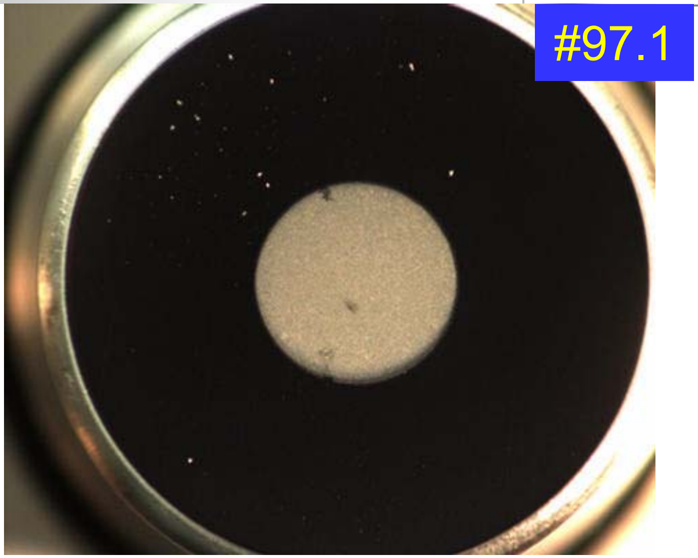


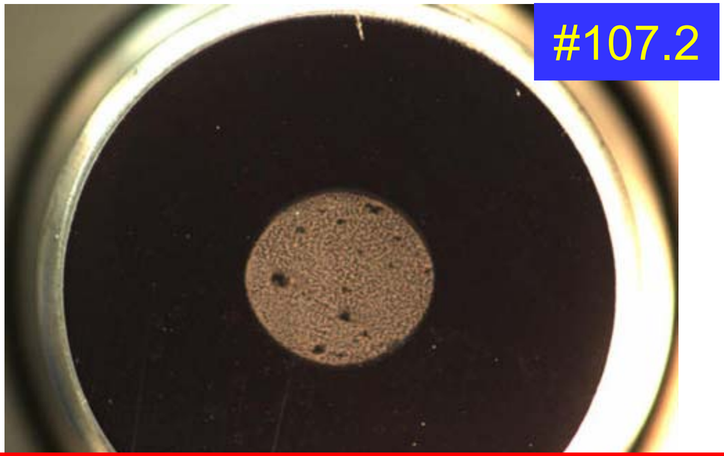
On this cathode lots of dust particles could be found. The reason was accidentally missing N_2 flushing of the cathode before insertion into the box.

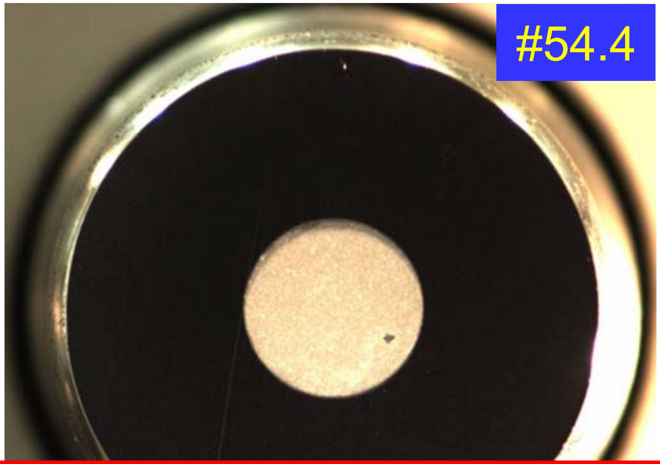
For this cathode the N_2 flushing was done.

=> Dust can affect the total amount of dark current but seems not to be the main source.

Dark current problems- analysis of box short 1



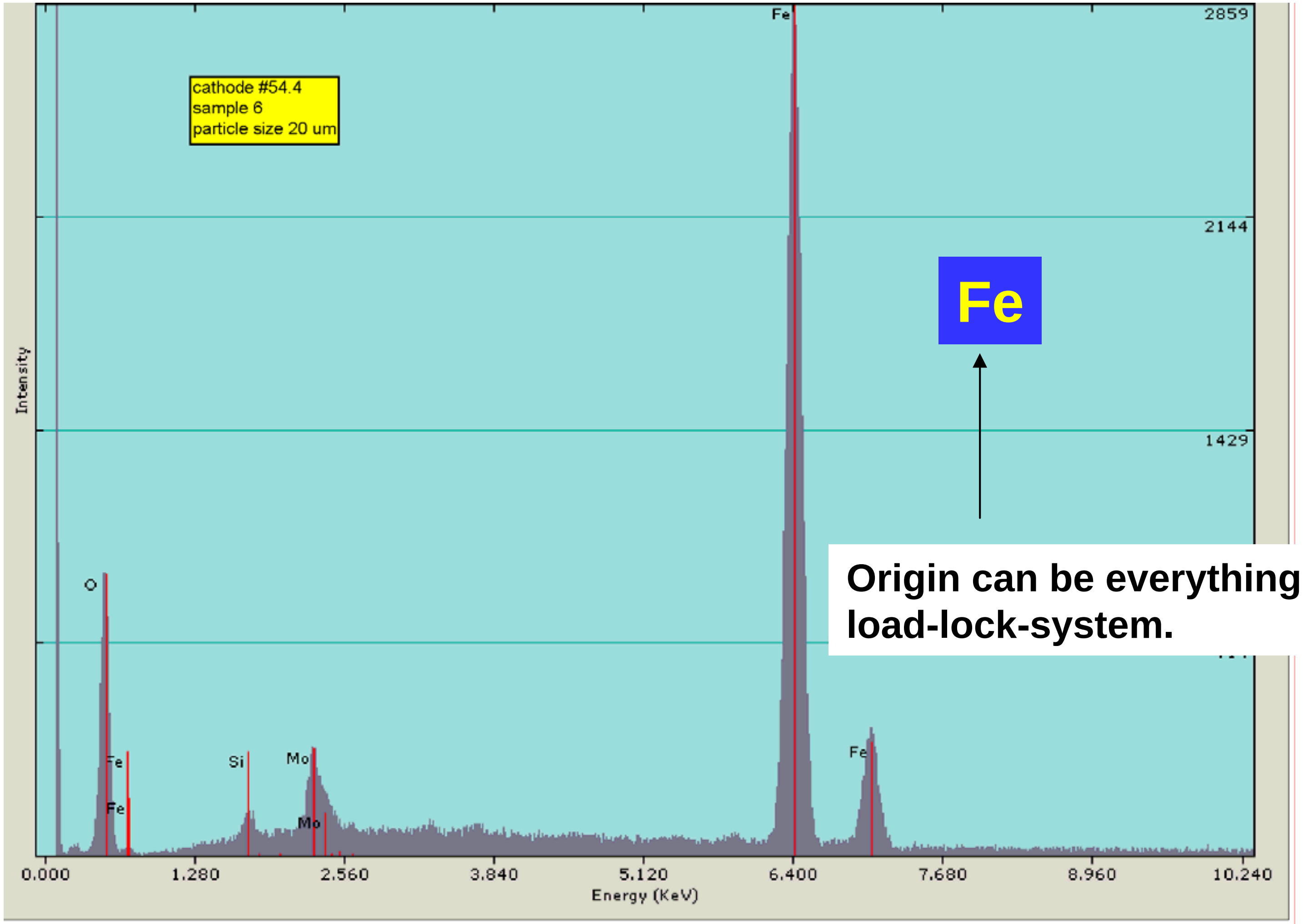




most of particles already at LASA – reason for this known: missing N2 flushing before insertion into the cathode box (appeared for the first time)
reason of scratch at 12 o'clock known, and present since 2004 (but not the dark current problem) – maintenance at LASA in September 2008 fixed this problem

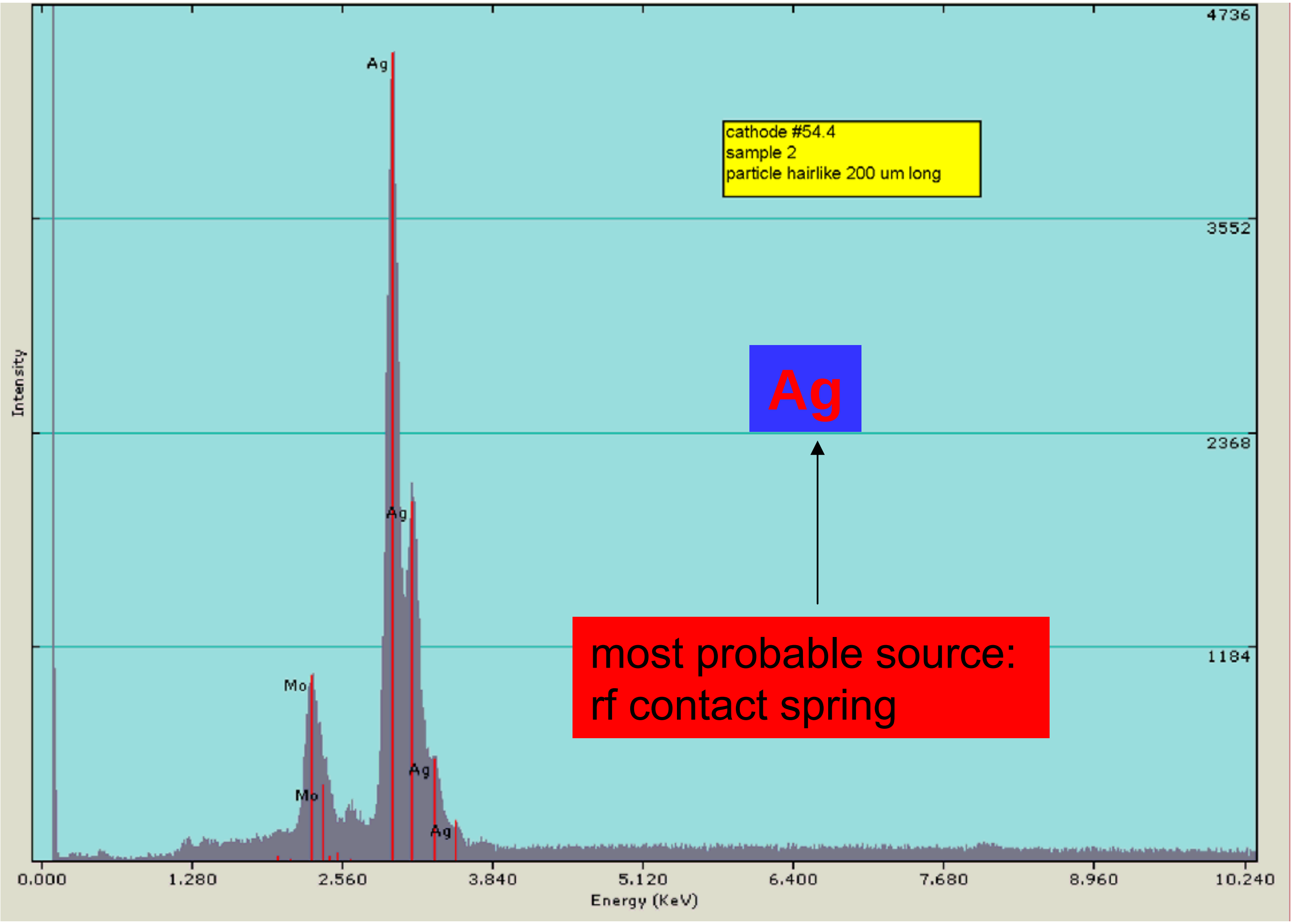
Dark current problems- analysis of box short 1

EDX measurements at University of Hamburg, to identify particles and their origin. Therefore the box was opened - under clean room conditions.



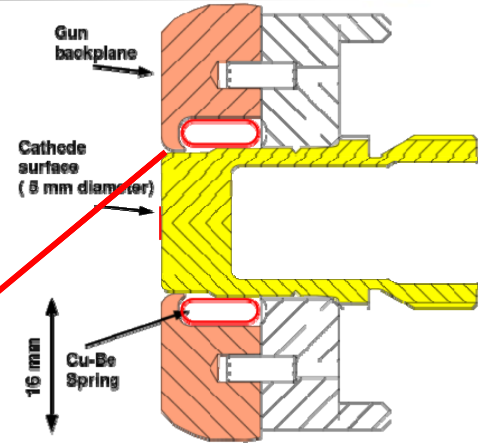
Origin can be everything in the load-lock-system.

Dark current problems- analysis of box short 1



Dark current problems

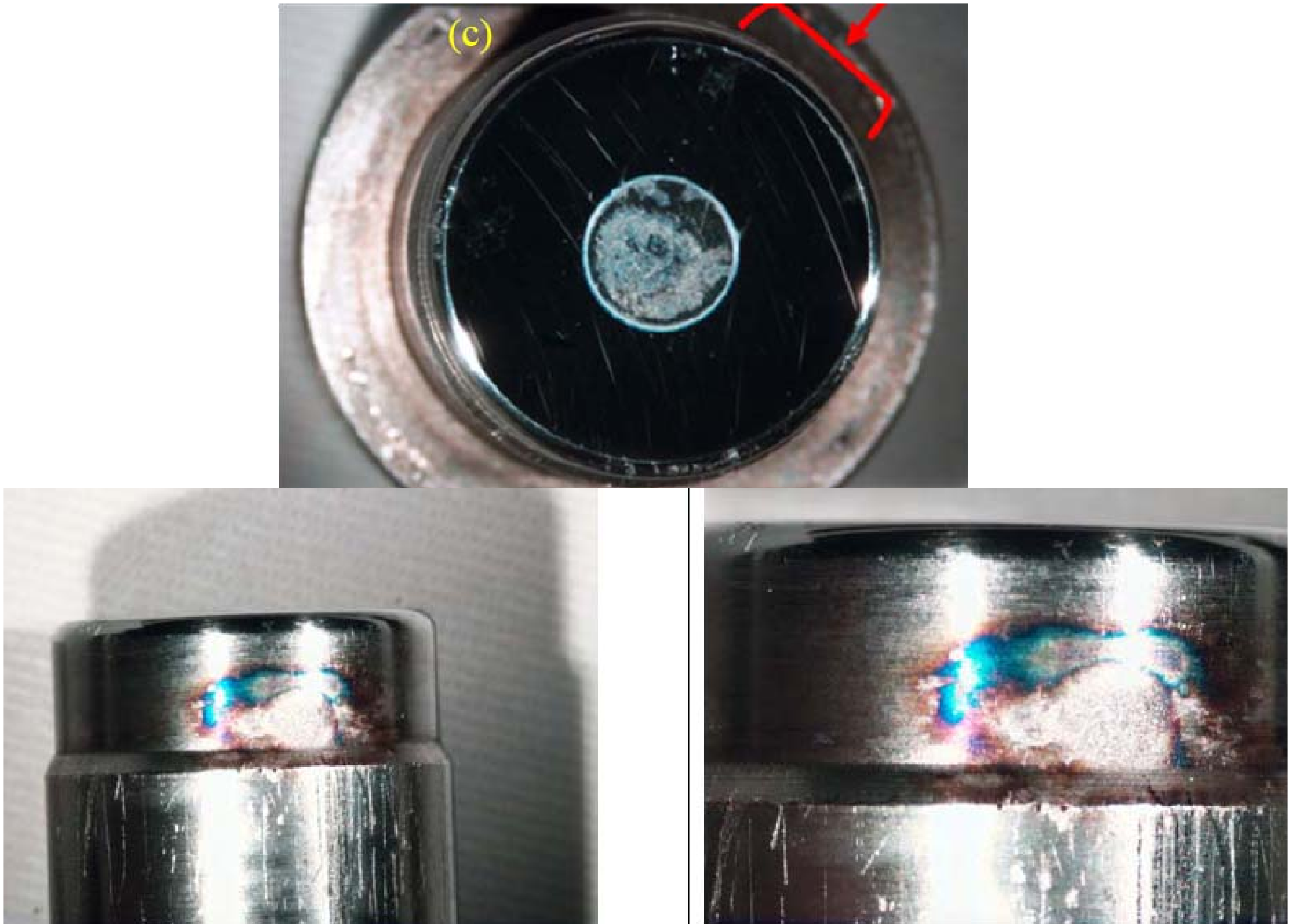
- **work during shutdown, week 18 - 20**
  - gun was opened
  - inspection of cathode region
  - spring removed
  - spring exchanged
  - Cathode box with CO_2 cleaned Mo plugs



inspection of cathode region with endoscope 2008-05-06

Dark current problems

Optical inspection of cathode #21.3 after usage clearly shows damages on the side of the plug caused by the rf spring

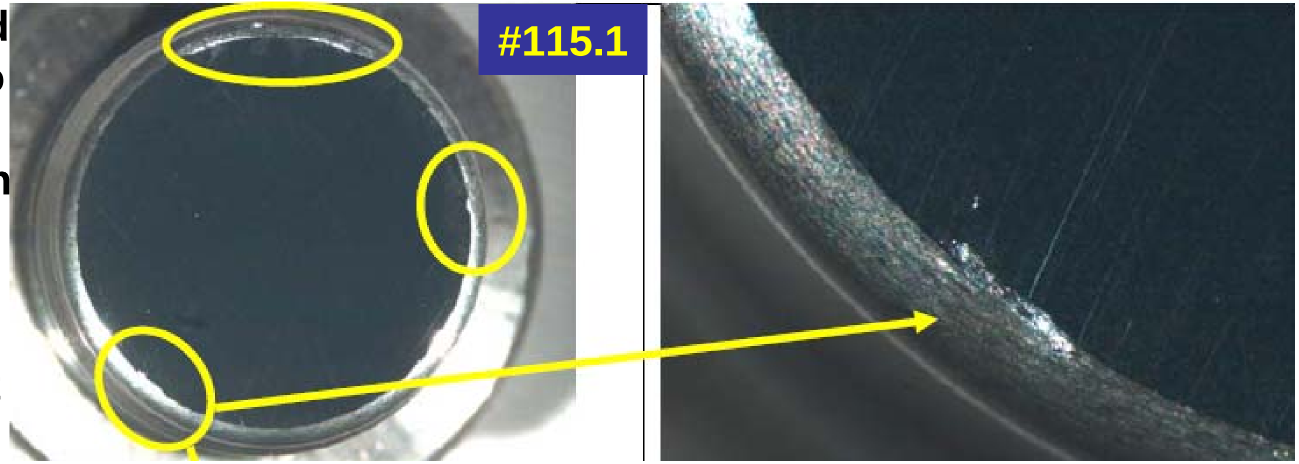


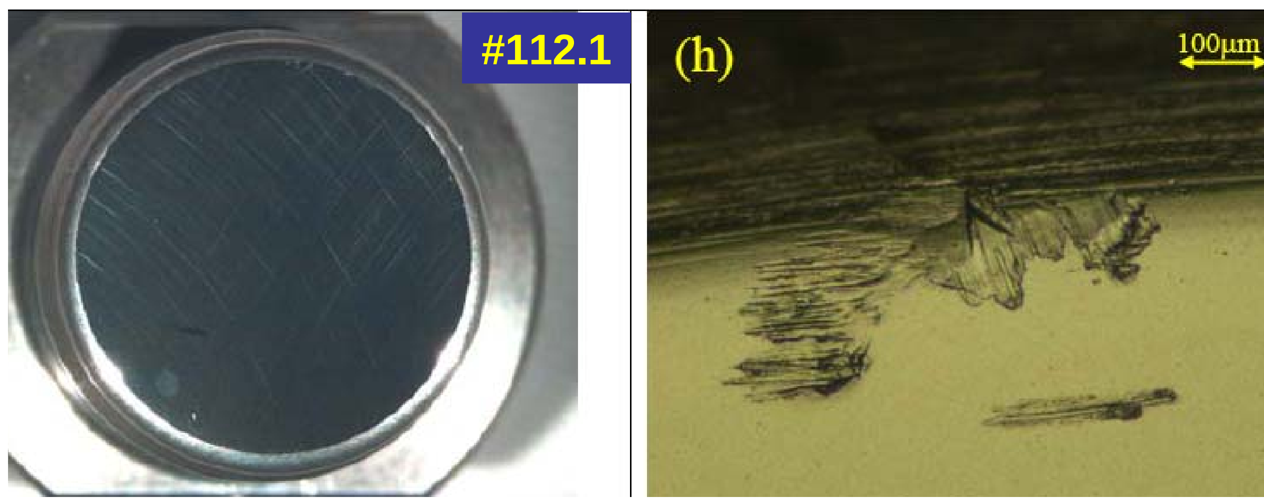
Dark current problems

Mo-plus #115.1 and #112.1, operated after rf contact spring exchange

Both cathodes were polished and cleaned at LASA, sent to DESY, CO_2 cleaned and inserted at DESY under clean room conditions in the transport box.

Still high dark current (about 0.5 mA, measured on May 17 and 18)

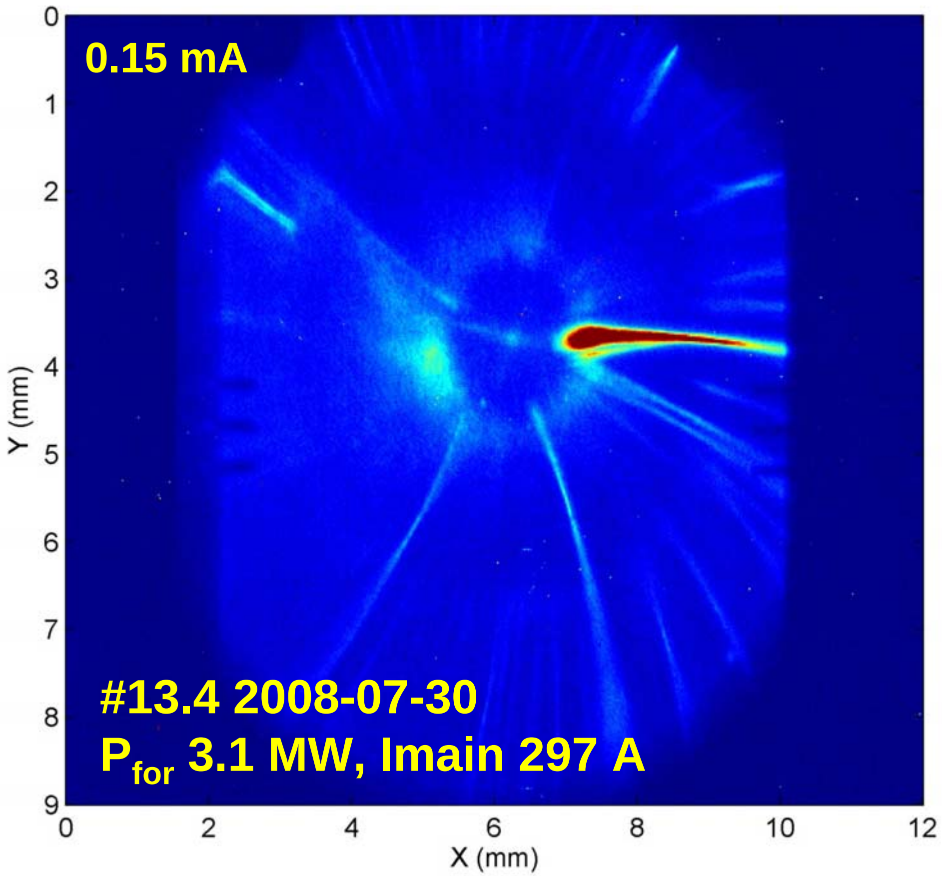


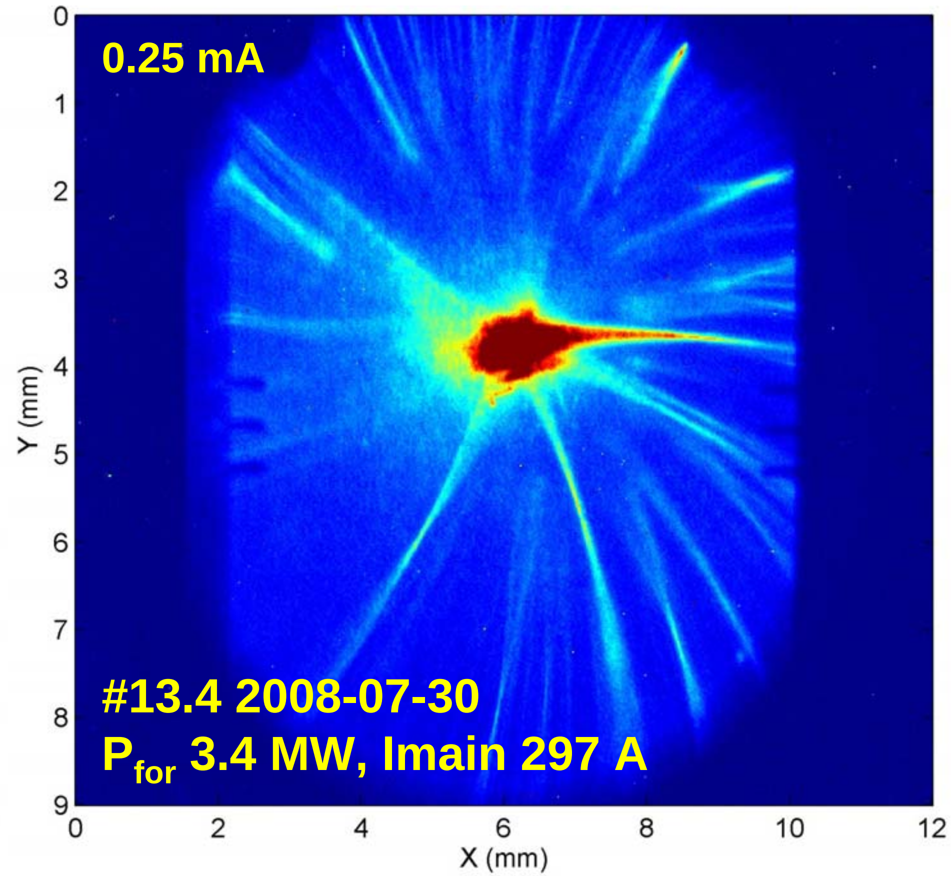


=> After the rf spring exchange we still have problems.

=> high dark current from Mo cathodes inserted in the clean room indicates that the dust and the coating procedure are not the main causes of the dark current issue

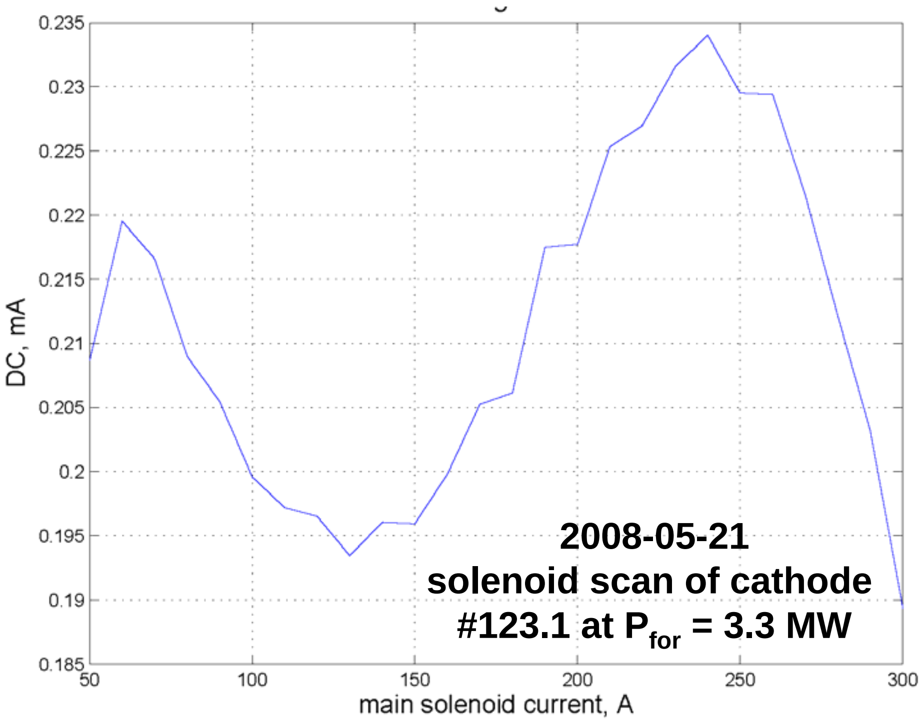
Dark current problems- after shut down activities

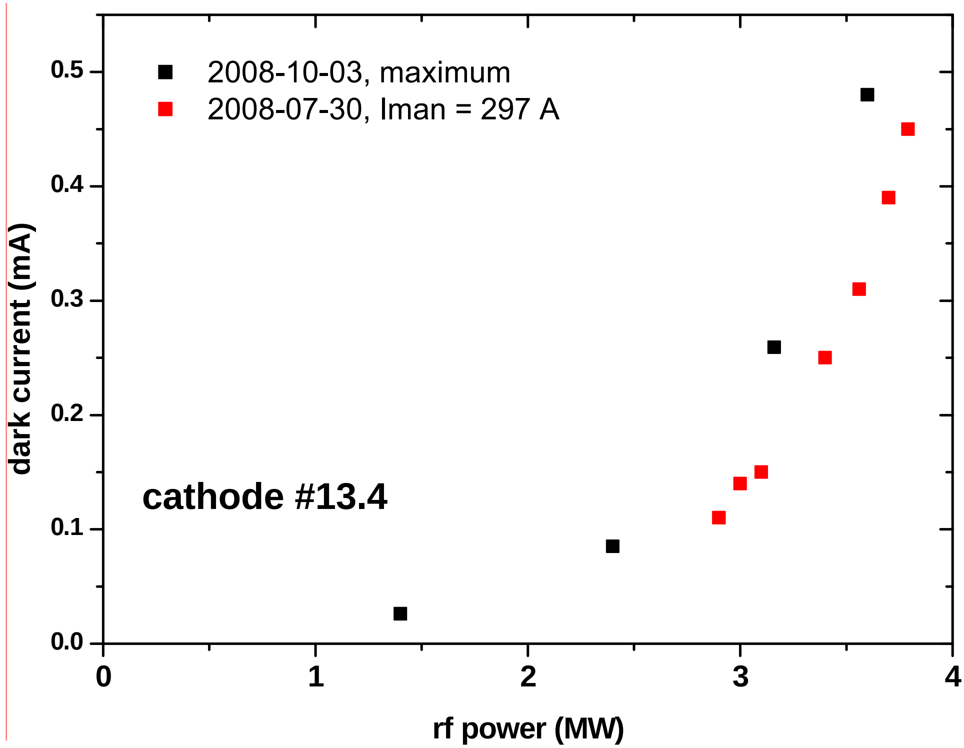




Still dark current emitter visible but not so many, and less intense

Dark current problems- after shut down activities





cathode #91.1: 0.6 mA dark current at 3.6 MW and solenoid current 230 A

dark current still high but on acceptable level

Dark current problems

In 2008 (until May) three unusable cathode boxes

- **long 3 with 4 Cs_2Te cathodes – carrier not movable**
- **short 2 with 3 Cs_2Te cathodes – too high dark current**
- **short 1 with 4 Cs_2Te cathodes – too high dark current**

cathode #21.3 was operated the whole time

Each cathode box requires lots of time, manpower, and money!

Actual situation

- **dark current acceptable**
- **but the gun produces lots of dc and the cathodes add up**
- **therefore any cathode exchange can lead to unacceptable dc**

GUN EXCHANGE BEST WAY TO IMPROVE SITUATION

Summary and Conclusion

- Results from two beam times presented
  - cw QE
    - Measurements and analysis
    - caused by time issues only in one beam time
  - Laser beam line transmission (from January until now)
  - pulsed QE
    - Measurements and analysis
    - Evolution over time
    - Life time
  - More studies needed for further understanding the QE behaviour under influence of rf field

- Dark current issues
  - Problem at FLASH
  - Investigation on cathodes
  - Changes in the gun
  - Exchange of the gun strongly recommended