Photocathodes Studies @ FLASH: Quantum Efficiency (QE)

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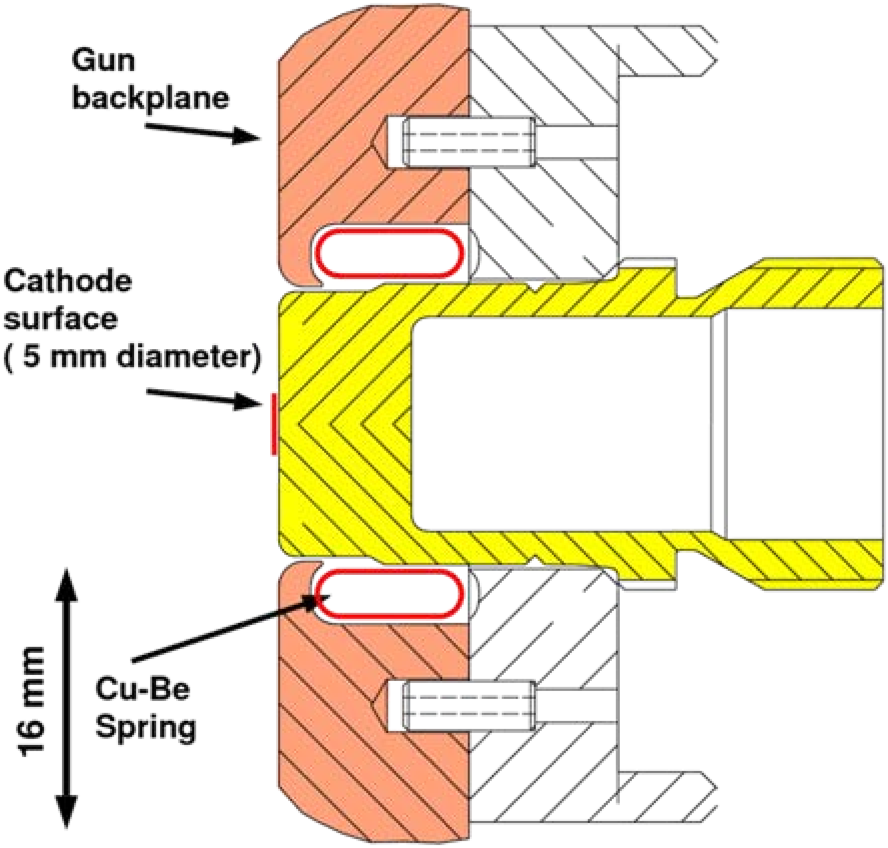
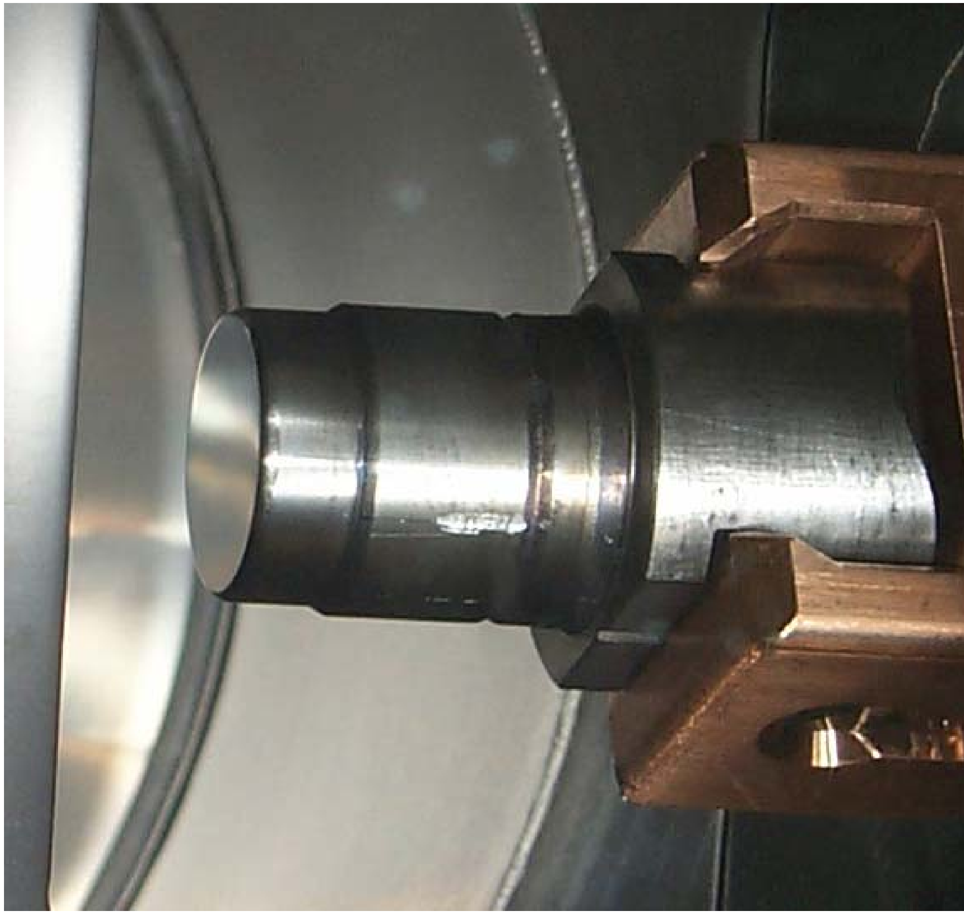
Main Topics

- Overview Photocathode Production
    - Production at LASA
    - Transportation to DESY
    - Database
- CW QE measurements (Hg lamp)
    - Experimental set-up
    - Results of measurements at FLASH
- Pulsed QE measurements
    - Laser energy calibration
    - Measurements on different cathodes
    - Results
    - QE maps
- Conclusions

Cathode in the RF Gun

- Photocathode inserted into the gun backplane





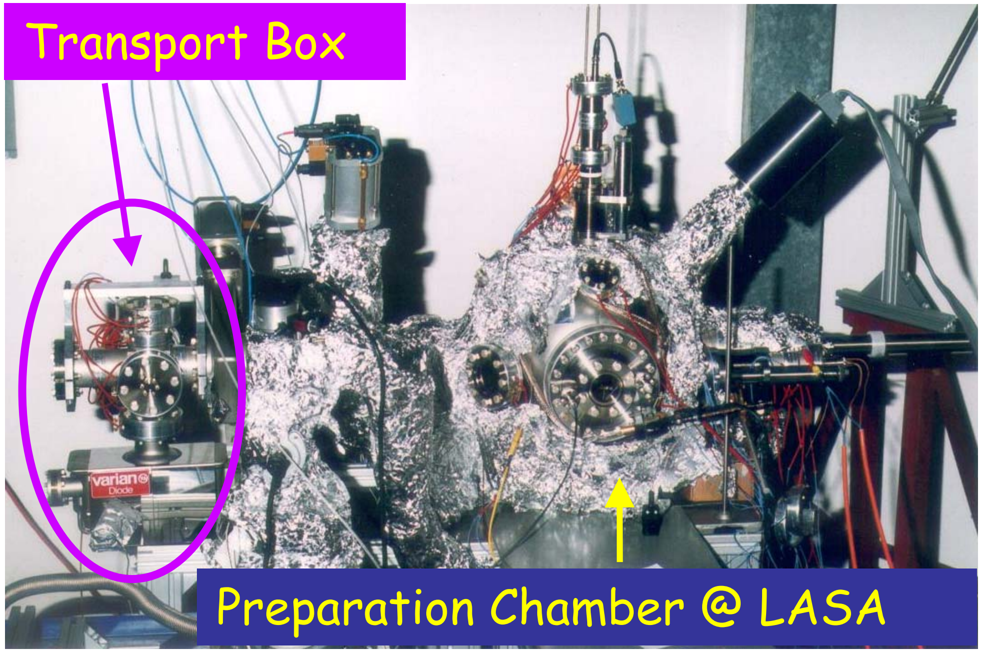
Quantum Efficiency

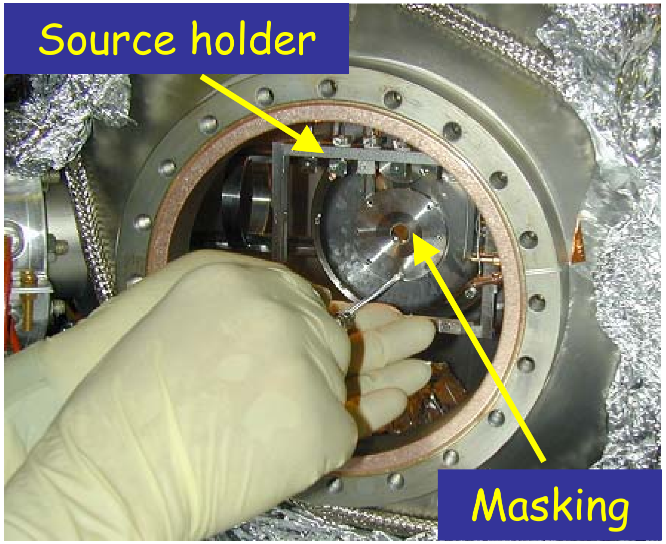
$QE(\%) \approx 0.5 * Q(nC)/E(\mu J)$
The design asks for 72000 nC/sec

- QE required for FLASH:
  > 0.5 % to keep the laser in a reasonable limit: within an average power of ~W
- Design of present laser accounts for QE=0.5% with an overhead of a factor of 4 and has an average power of 2 W (IR)
- Cs_2Te cathodes found to be the best choice

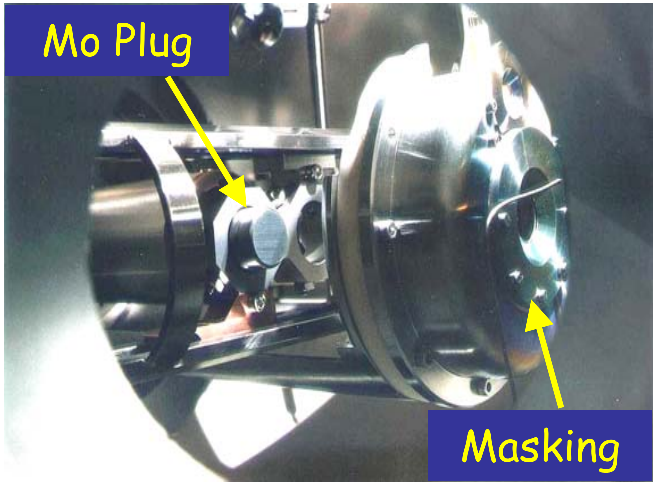
Photocathode Production: Preparation Chamber

Photocathodes are grown @ LASA on Mo plugs under UHV condition.



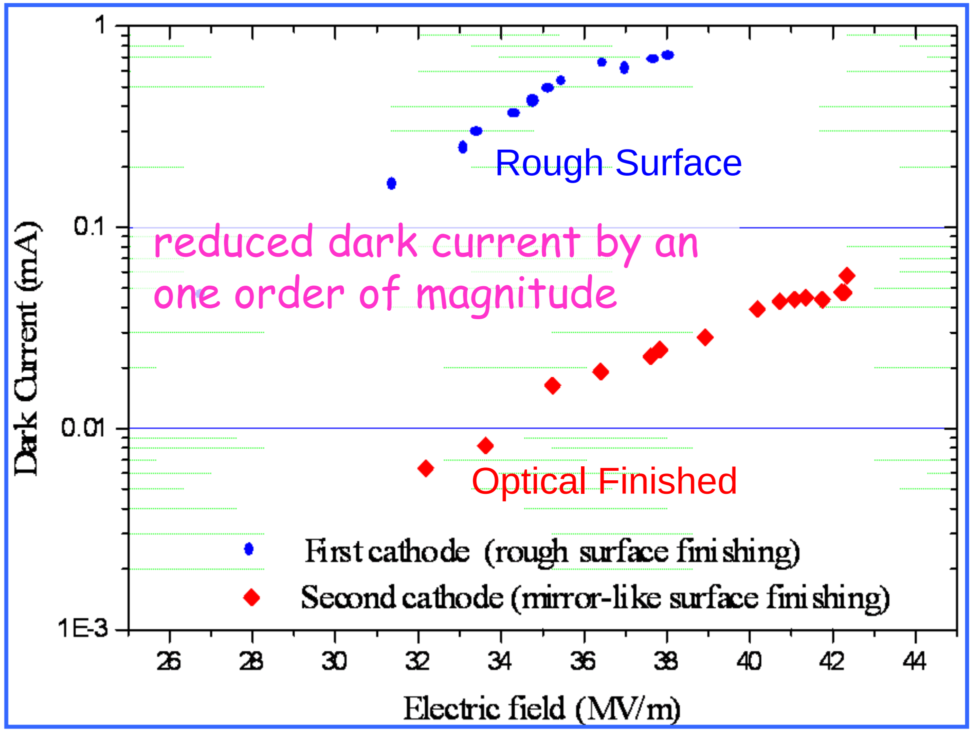


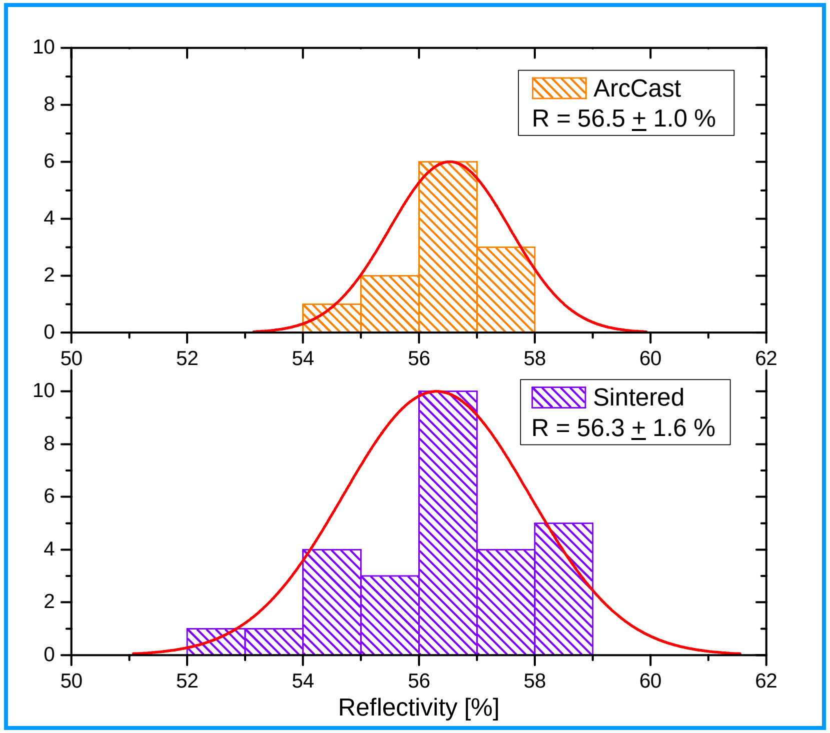
- UHV Vacuum System - base pressure 10^{-10} mbar
- 6 sources slot available
- Te sources out of 99.9999 % pure element
- Cs sources from SAES®
- High pressure Hg lamp and interference filter for online monitoring of QE during production
- Masking system
- 5 x UHV transport box



Production: from Mo plugs...

1. Milling and/or lathing of the plug from the rod (arc cast / sintered)
2. Buffer Chemical Polishing (BCP)
3. Polished to optical finishing (roughness about 10 nm)
4. Reflectivity measurement to check optical polishing

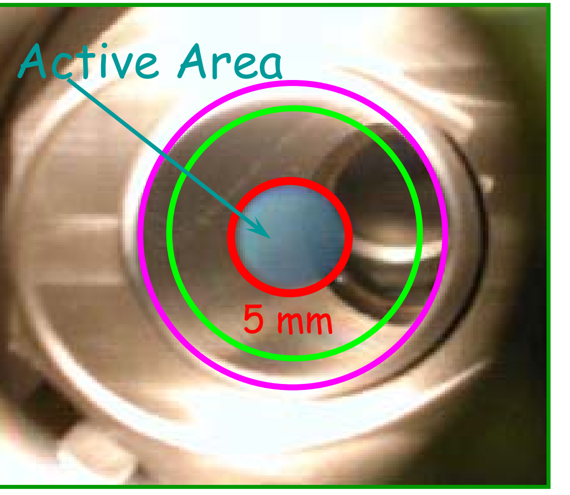


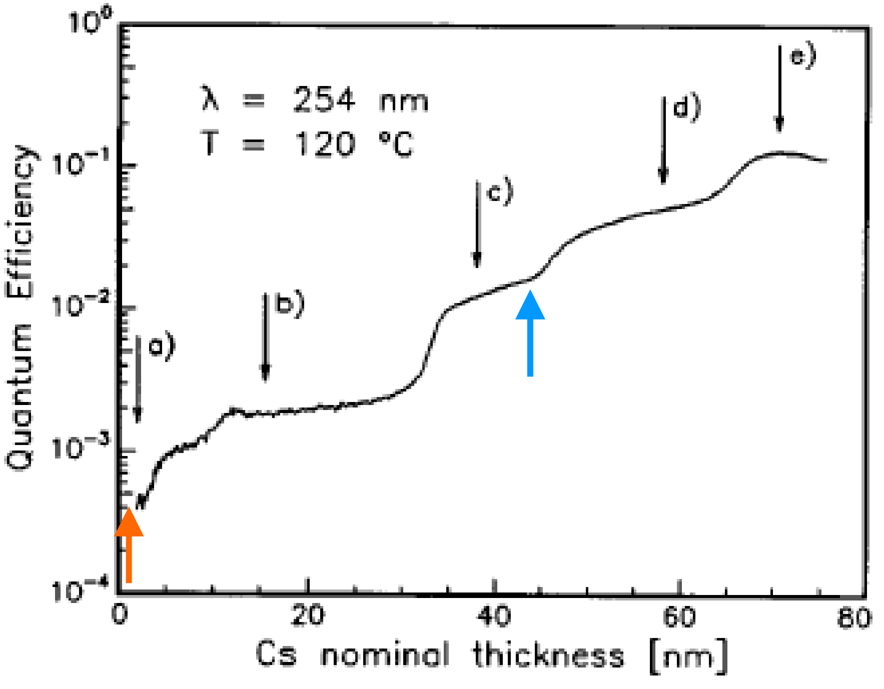


Production:…to photocathodes growth

Cs_2Te photocathode receipe:

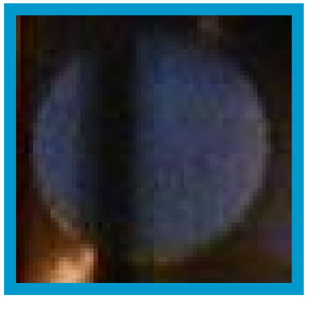
- during the evaporation, the plug is heated to 120°C.
- The dimension of the film is determined by a circular masking (the actual one is 5mm diameter)
- first, a thin layer of 10nm of Te is produced
- then Cs is evaporated at a rate of 1nm/min
- during the deposition, the film is illuminated with UV (λ=254 nm) of a Hg-lamp to monitor the quantum efficiency.
- the evaporation is stopped, when the QE is at maximum.





Different stoichiometric compounds form during Cs deposition till the "correct" Cs/Te ratio is reached corresponding to the QE maximum

After 10min of Te deposition



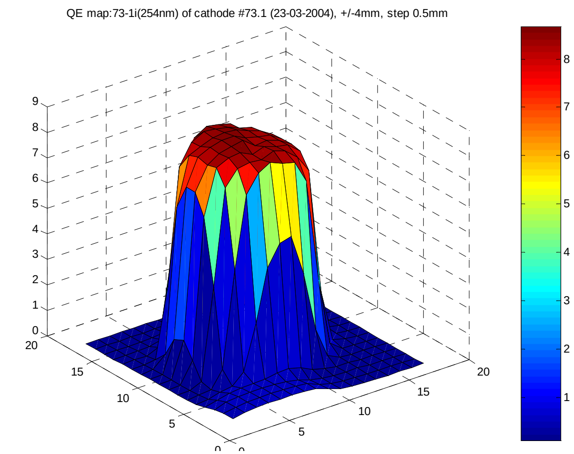
After 45 min of Cs deposition

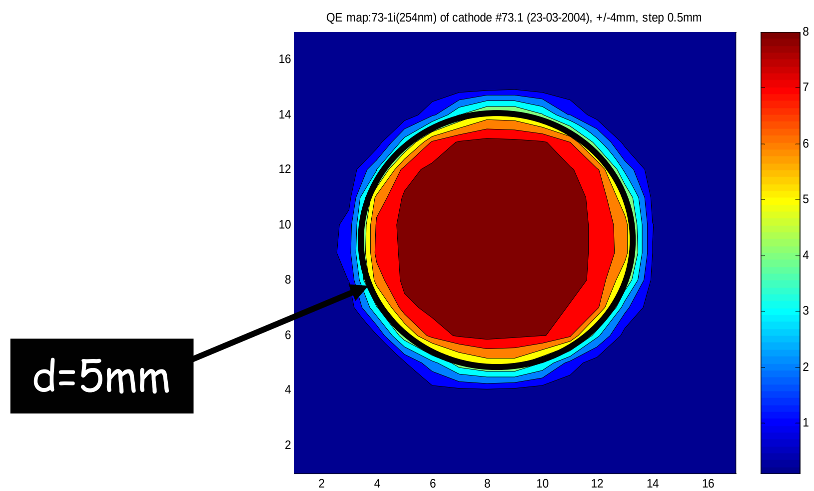
Production: diagnostic on photocathodes

The photoemissive properties of produced cathodes are checked performing spectral response measurements and QE maps (also at different wavelengths).

- QE map @ 254nm

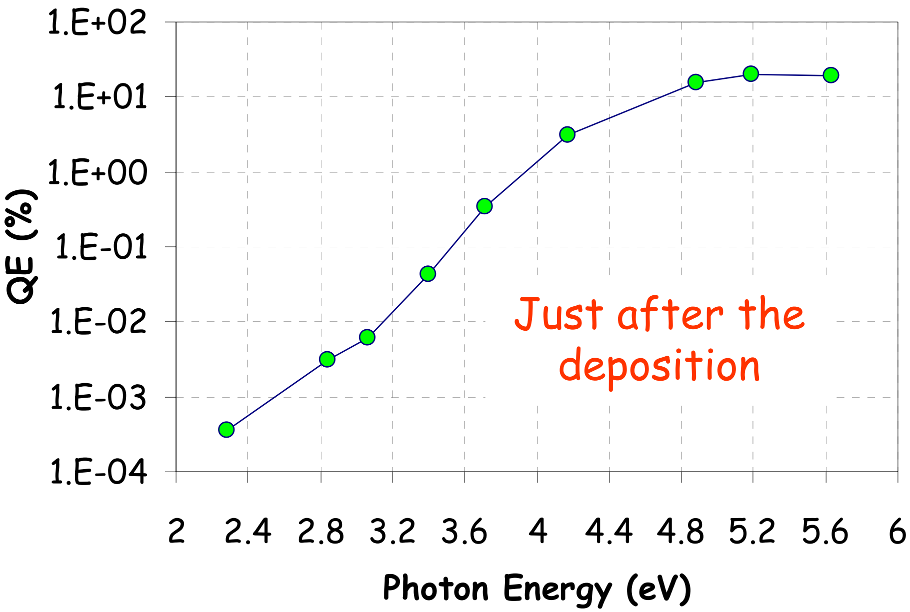
(Hg lamp, interferential filter, 1mm spot diameter)



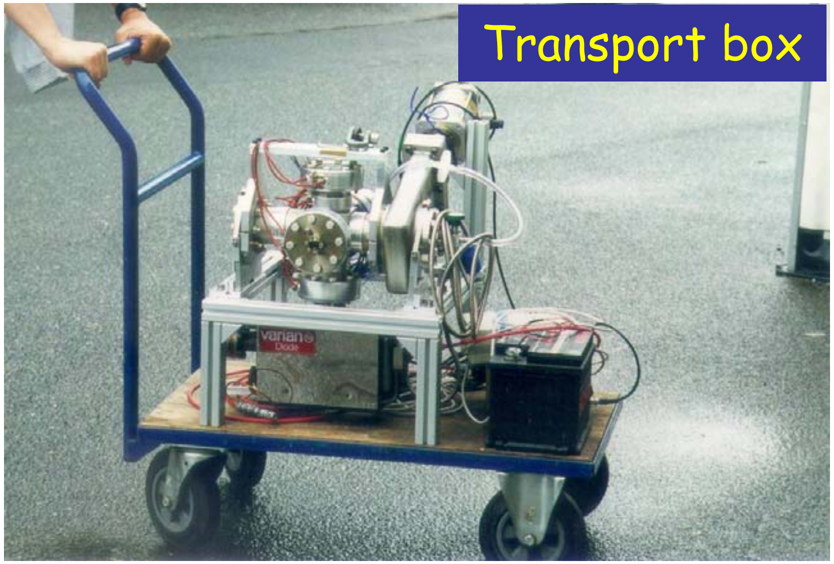


- Spectral response

(Hg lamp, interferential filters, 3mm spot diameter)



Production: from LASA to FLASH and PITZ



Transport box

Produced cathodes, are loaded in the transport box and shipped to FLASH or PITZ keeping the UHV condition.

The box is then connected to the RF gun.

RF gun and FLASH linac

Since 1998, we have shipped to TTF phase I, FLASH and PITZ:

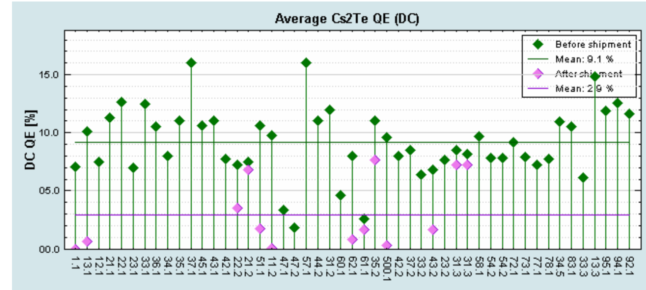
- 49 x Cs_2Te
- 2 x KCsTe
- 25 x Mo
- Total transfers from LASA: 25

Production: The Photocathode Database

Many of the data relative to photocathodes (production, operation, lifetimes) and transport box are stored in the "photocathode database" whose WEB-interface is available at:

http://wwwlasa.mi.infn.it/ttfcathodes/

The database keeps track of the photocathodes in the different transport boxes and in the different labs (TTF, PITZ and LASA).



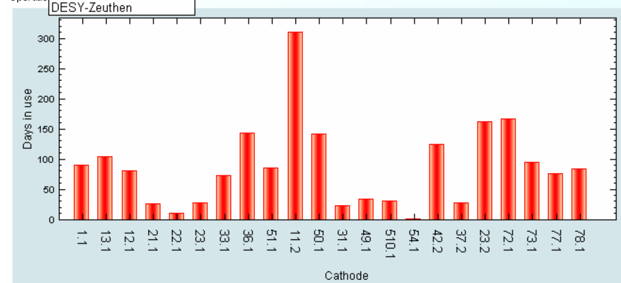
Operation Lifetime of Cathodes

For the calculation of this Operation Lifetimes, the long shutdown periods are removed

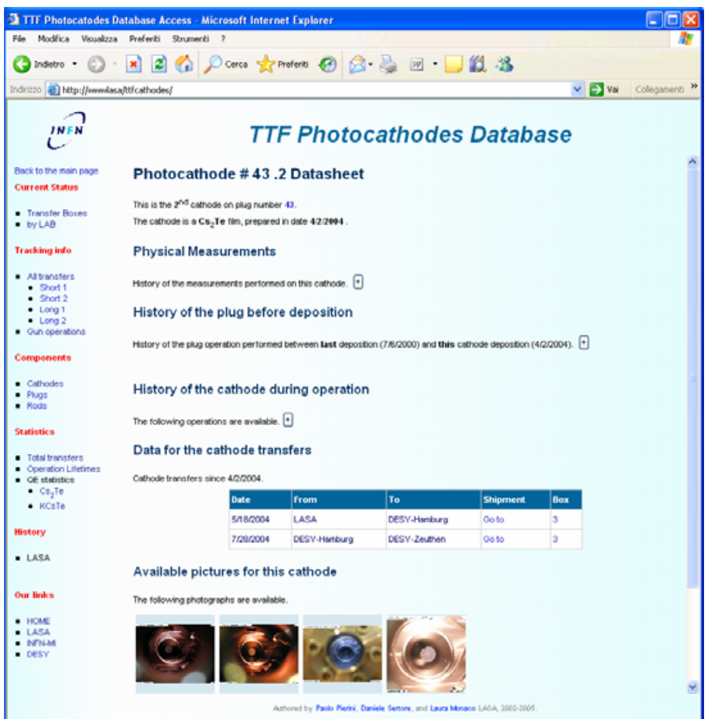
Select Location

Location DESY-Hamburg

DESY-Hamburg
DESY-Zeuthen



77.1 76 days of operation



Status of the Transfer Boxes

We have currently five transfer boxes for the cathode transportation between the laboratories.

The following table indicates the last recorded operation for the transfer box, its location and status (connected or not). Click on the box name to show the full history of the box operations (transfers, load/unload procedures).

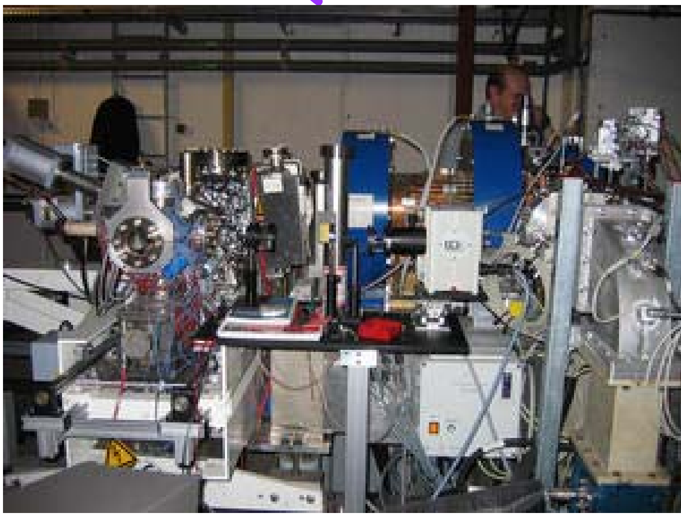
Name	Data	Location	Connected to	C1	C2	C3	C4	C5	Last Event	Transferred from
Short 1	9/26/2006-8:50 AM	DESY-Hamburg		95.1	13.3		94.1	92.1	Shipment	LASA
Short 2	9/25/2006-10:30 AM	LASA		81.1		23.2	72.1		Shipment	DESY-Zeuthen
Long 1	7/11/2006-3:01 PM	DESY-Hamburg	PITZ2 Gun	76.1			78.1	73.1	Cathode change	
Long 2	8/30/2006-9:00 AM	DESY-Hamburg		33.3			54.2	56.2	Shipment	LASA
Long 3	8/15/2006-12:05 AM	DESY-Zeuthen	PITZ3 Gun	35.3		53.1		75.1	Cathode change	
Name	Data	Location	Connected to	C1	C2	C3	C4	C5	Last Event	Transferred from

Status of the DESY-Hamburg and DESY-Zeuthen Guns

PITZ2 Gun in DESY-Hamburg has cathode 77.1 since Tuesday, July 11, 2006-3:01:00 PM

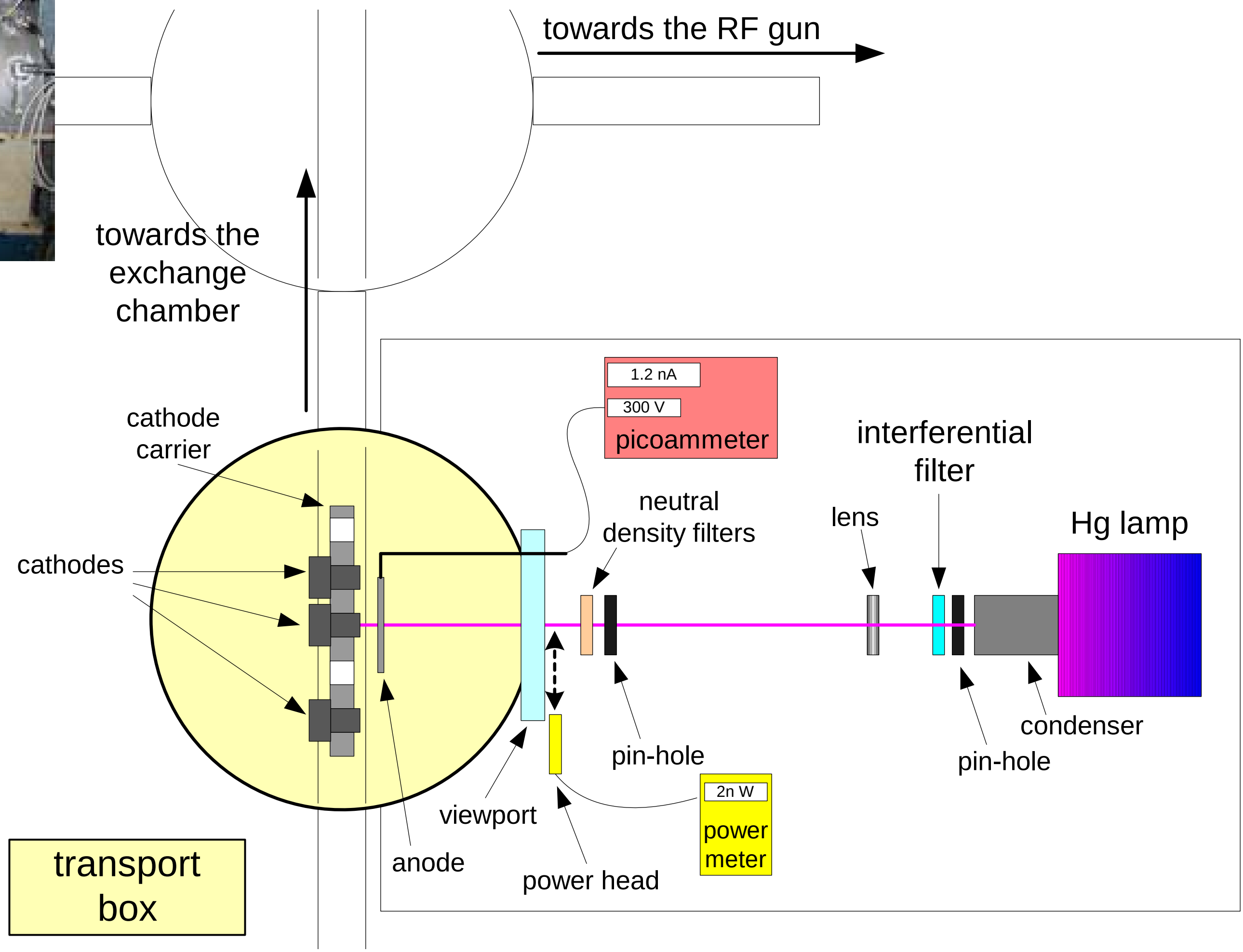
PITZ3 Gun in DESY-Zeuthen has cathode 58.1 since Tuesday, August 15, 2006-12:05:00 AM

CW QE measurements: Experimental set-up



The experimental set-up for the CW QE measurements is mainly composed by:

- ✓ a high pressure Hg lamp
- ✓ Interferential filters (239nm, 254nm, 297nm, 334nm)
- ✓ Pico-Amperemeter
- ✓ Power energy meter
- ✓ Neutral density filters
- ✓ Optical components (1 lens, 1 mirror, 2 pin-holes)



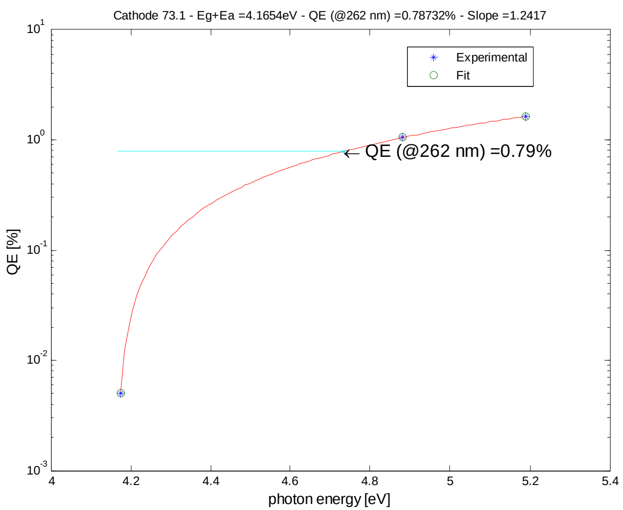
CW QE measurements: Results

Measured @ DESY on March 31 2006

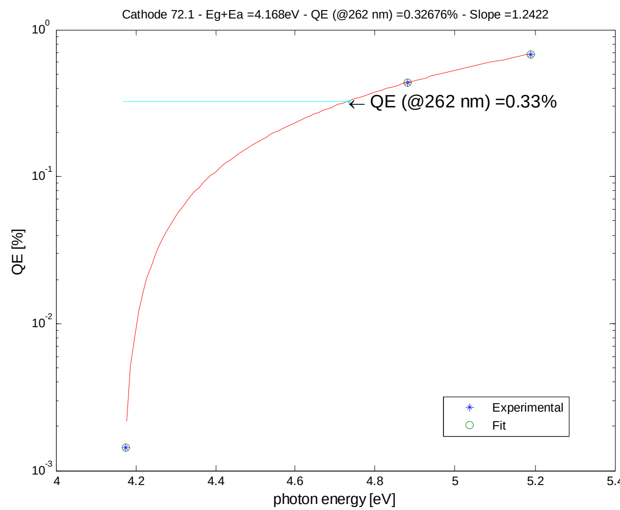
Data have been fitted to evaluate: the QE @ 262nm and Eg+Ea

Cathode	Dep. data	QE@254nm (LASA)	Operation lifetimes	QE@254nm (DESY)	QE@262nm (DESY)	Eg+Ea (eV)
73.1	23-Mar-05	7.9%	86	1.64%	0.79%	4.165
72.1	22-Mar-05	9.2%	166	0.44%	0.33%	4.168
23.2	16-Sep-04	7.2%	161	0.22%	0.15%	4.157

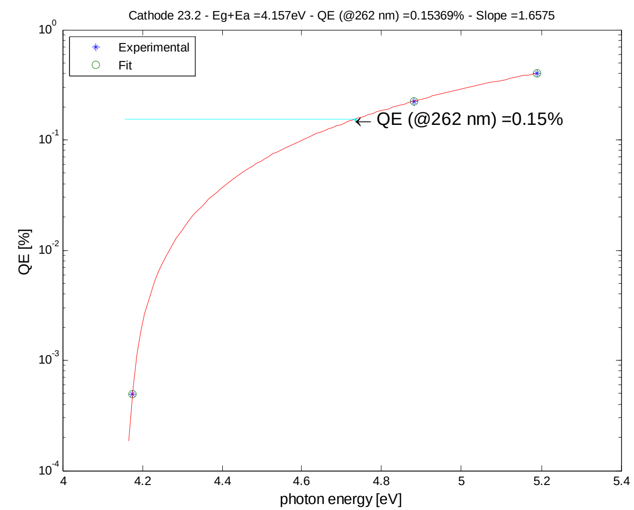
Cathode 73.1



Cathode 72.1



Cathode 23.2

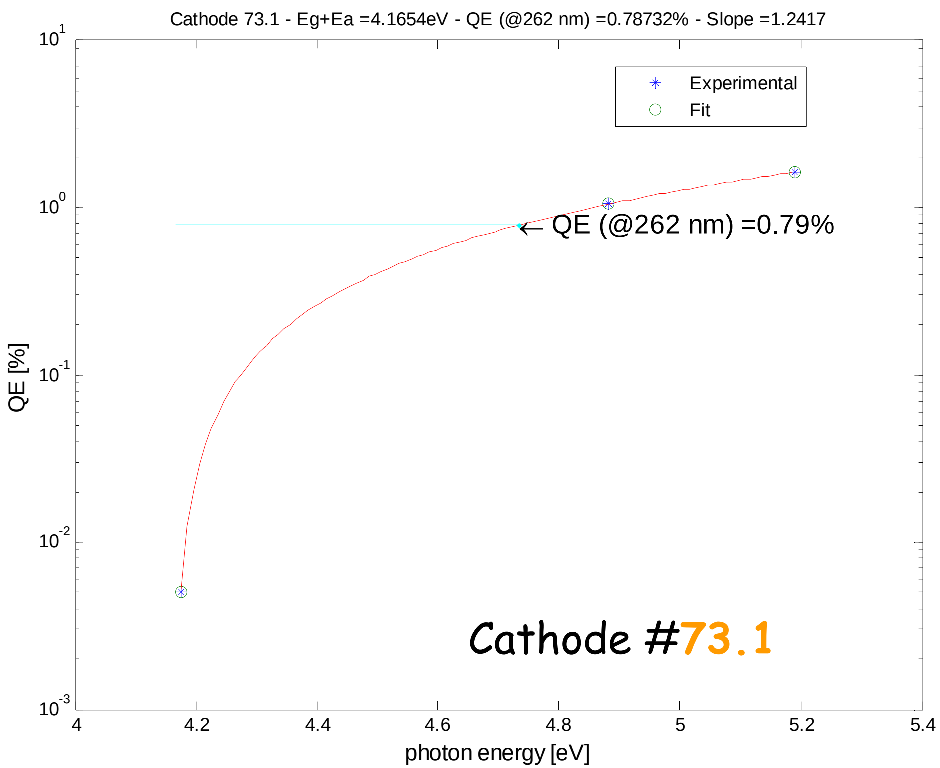


CW QE measurements: Data Analysis

- CW data analysis
  - Fitting of the spectral response

$$QE = A \cdot \left[h\nu - \left(E_G + E_A\right)\right]^m$$

where A is a constant, E_G and E_A are energy gap and electron affinity.



An example is given for the analysis of the CW QE data for cathode 73.1.
In this case:

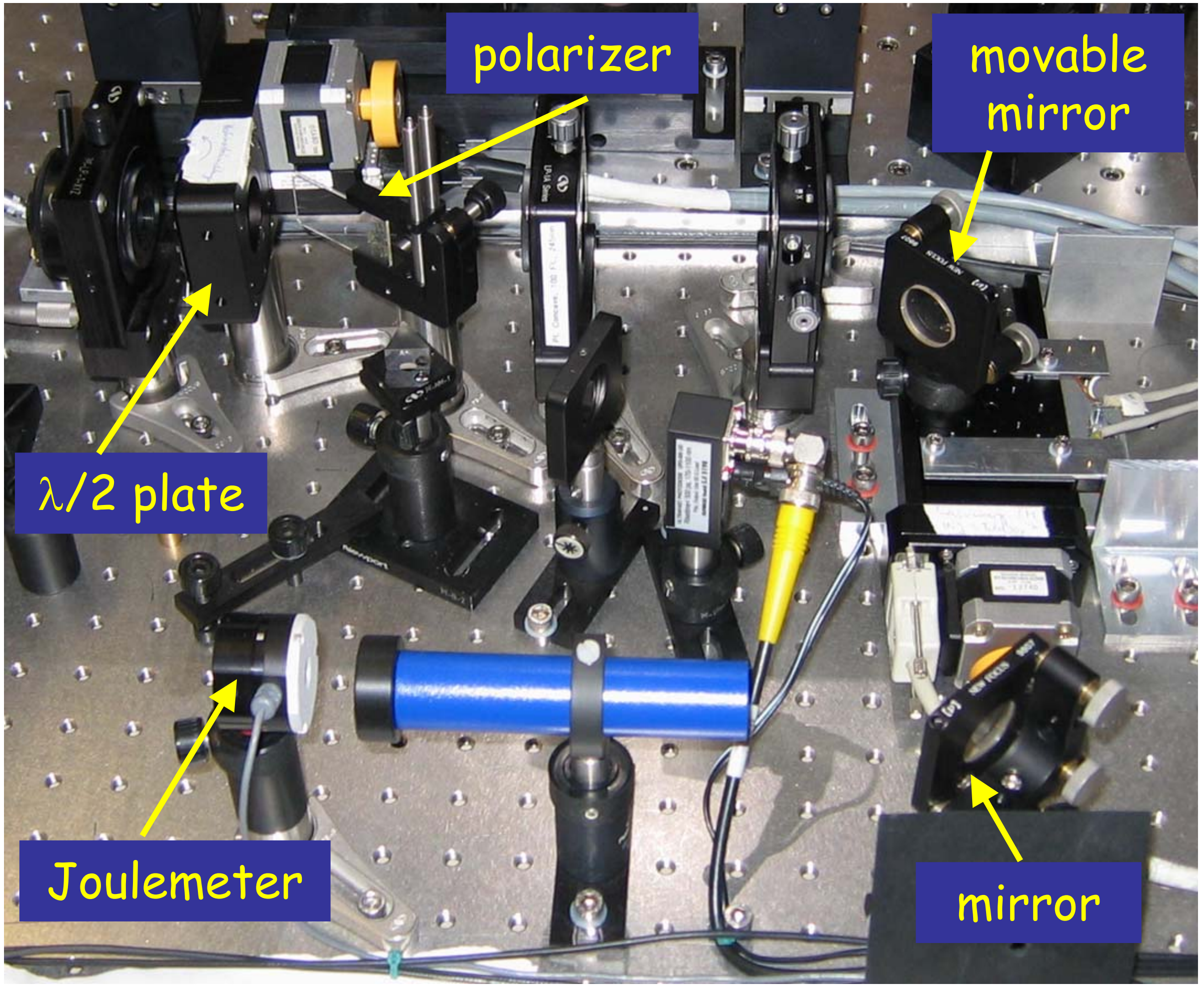
- Eg+Ea = 4.165 eV
- m = 1.24

(for a “fresh” Cs_2Te cathode we tipically have Eg+Ea = 3.5eV)

Pulsed QE measurements: laser energy calibration experimental set-up

The laser energy transmission (from the laser hut to the tunnel) has been evaluated for different iris diameters (3.5mm, 2.0mm and 0.16mm) and different energies.

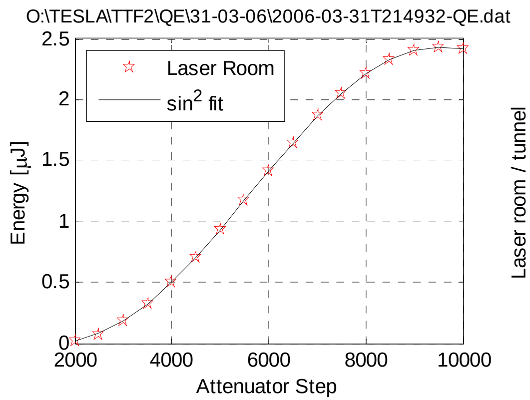
The laser energy has been measured using a Pyroelectric gauge (Joulemeter), varying the laser energy using the variable attenuator ($\lambda/2$ wave plate + polarizer).

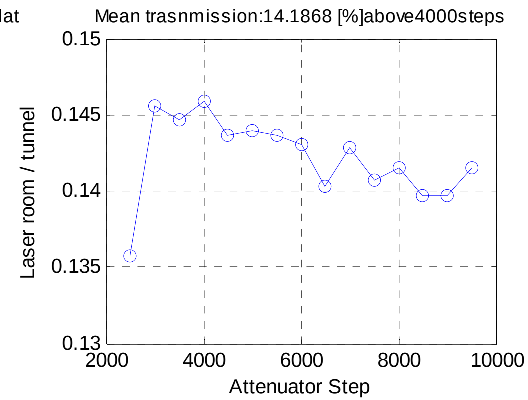


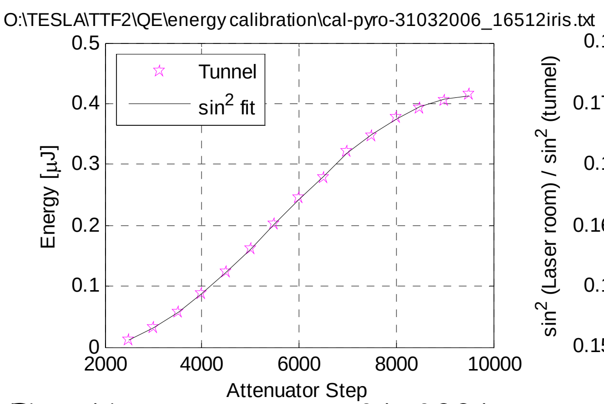
Pulsed QE measurements: laser beamline transmission analysis

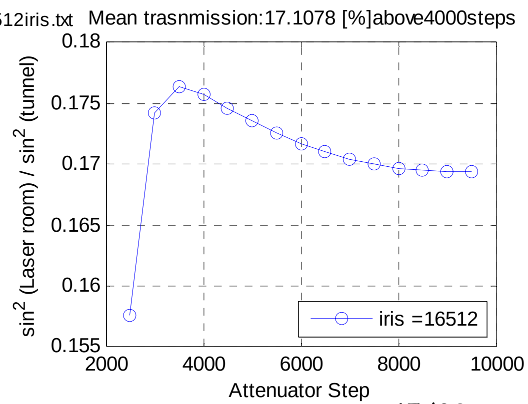
- The QE measurement procedure uses the laser energy measured on the laser table
- Transmission to the vacuum window is regularly measured
- Transmission of the vacuum window (92 %) and reflectivity of the vacuum laser mirror (90 %) are accounted for

iris = 3.5 mm as an example:

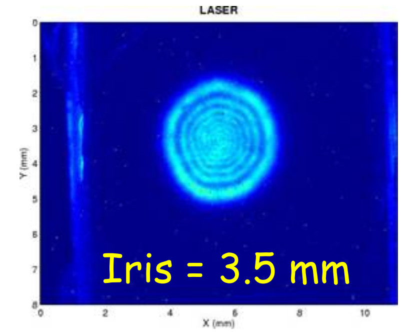


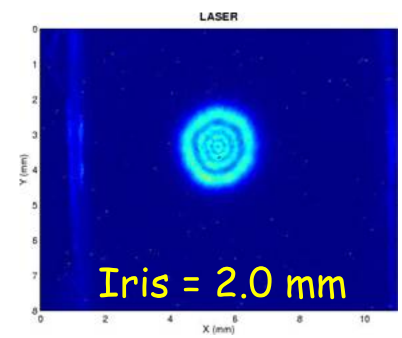


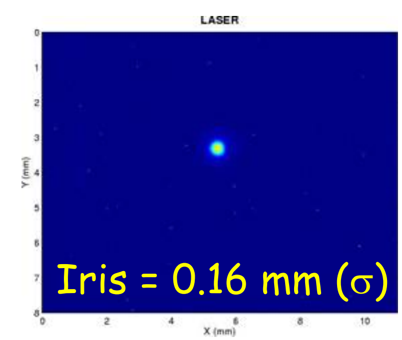




- Laser energy is measured as a function of the variable attenuator setting
- fitted by $\sin^2$ to evaluate the transmission







Pulsed QE measurements: laser beam line transmission measurements

The laser beamline transmission has been evaluated four times (from March to August 2006) to take care of changes in the optical transmission path.

Iris Φ (mm)	Iris (step)	Date (tunnel file)	Date (laser room file)	Transmission	Used
3.5	16512	12-Mar-06	12-Mar-06	13.21 %	From 12 March to 31 March
2.0	17280	12-Mar-06	12-Mar-06	6.64 %	
0.16	18208	not done	not done	-	
3.5	16512	31-Mar-06	31-Mar-06	17.1 %	From 31 March to 6 June
2.0	17280	31-Mar-06	31-Mar-06	8.75 %	
0.16	18208	31-Mar-06	31-Mar-06	0.85%	
3.5	16512	not done	not done	-	From 6 June to 7 Aug
2.0	17280	6-June-06	6-June-06	7.18 %	
0.16	18208	not done	not done	-	
3.5	16512	not done	not done	-	From 7 August till now
2.0	17280	7-Aug-06	7-Aug-06	4.49 %	
0.16	18208	not done	not done	-	

Pulsed QE measurements: measurement analysis

The QE measurement is done following this procedure:

1. Measurement of the charge (toroid T1, Q[C])
2. Measurement of the laser energy (laser hut) E
3. Calculation of the energy on the cathode E_{cath} [J] using transmission (considering the losses due to the vacuum window and mirror)

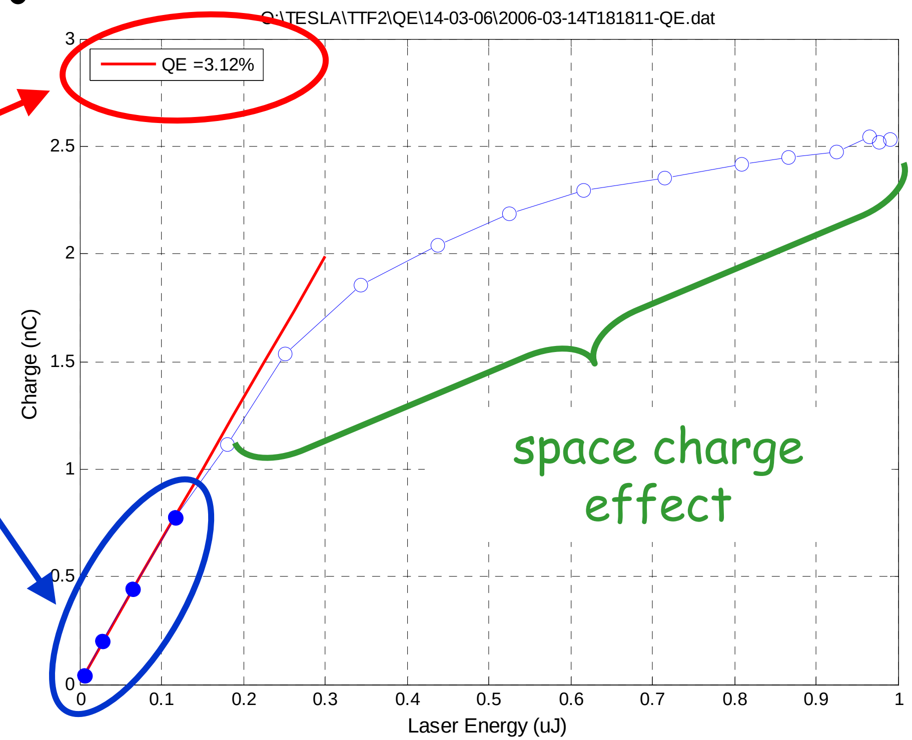
$$QE[\%] = \frac{nel}{nph} \cdot 100 = \frac{Q[C] \cdot E_{ph}[eV]}{E_{cath}[J]} \cdot 100$$

262 nm: QE(%) ≈ 0.5*Q(nC)/E(μJ)

The QE value is then obtained

fitting the charge trend @ low charge

to be sure not to be affected by the space charge



✓ The relative and systematic error are in the order of 20 %.

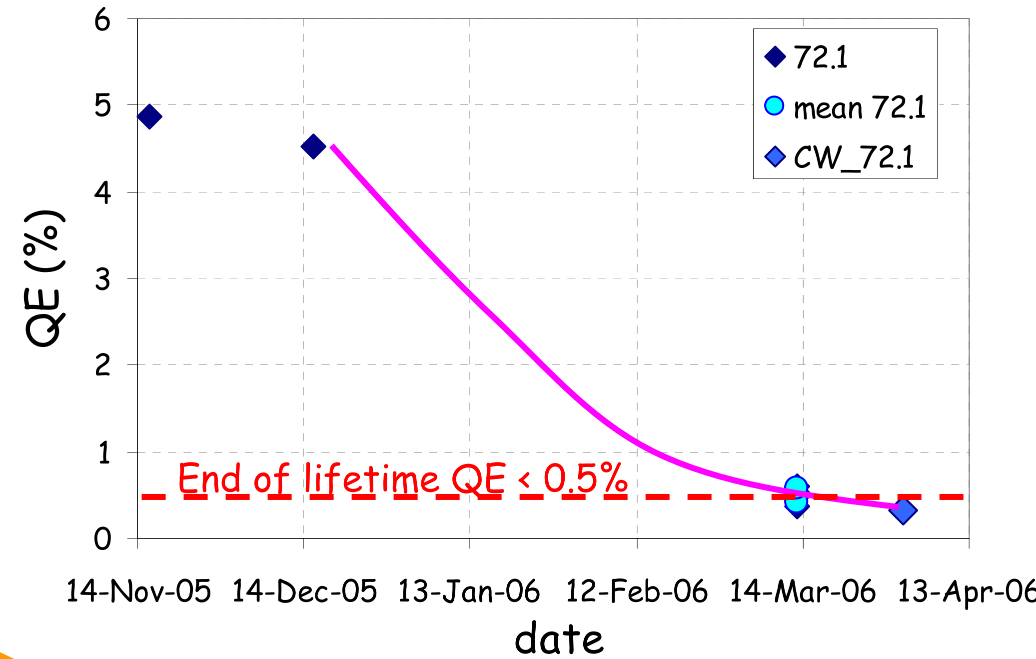
✓ The systematic error is mainly due to the uncertainty of identifying the linear part for the fit and due to the transmission measurement uncertainty

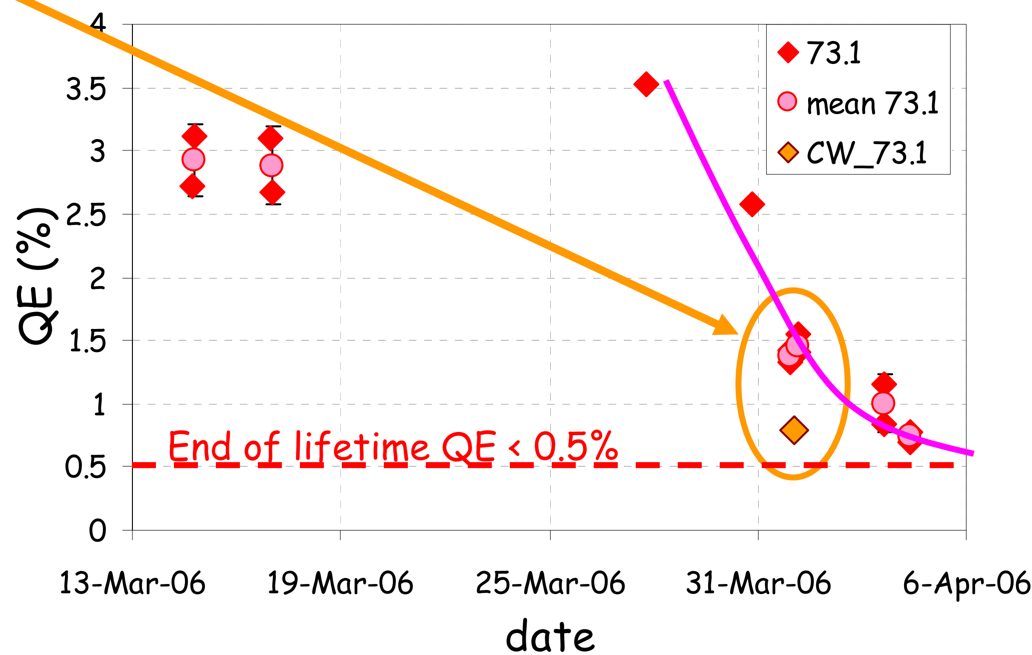
Pulsed QE measurements: cathode lifetime

QE of cathodes are measured frequently within months.

Example: cathode 72.1 and 73.1.

- We define the end of lifetime when the QE reaches 0.5 %
- The CW QE ◇ of cathode 73.1 is compared with the pulsed QE ◆ measured the same day.
- The difference may be explained considering the increase of the charge due to the field enhancement.

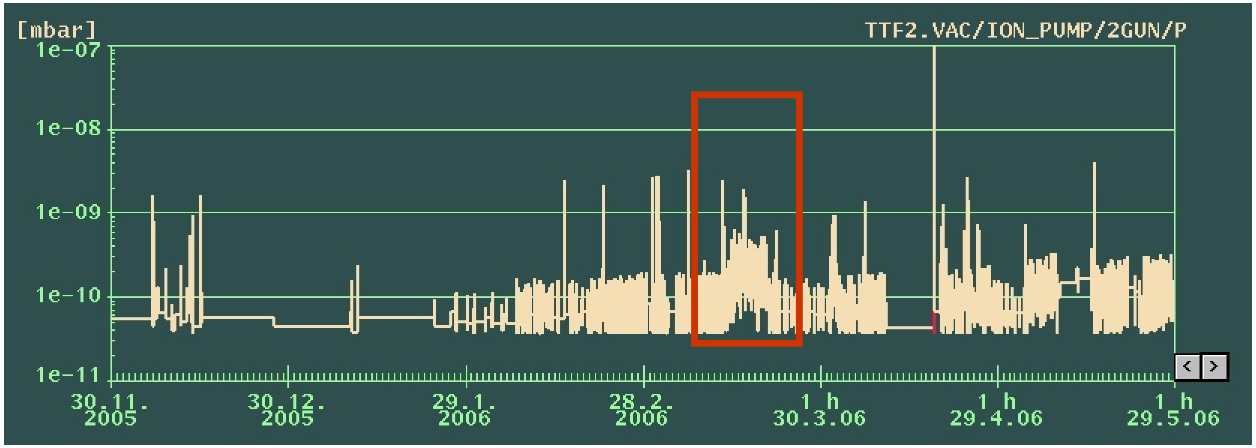




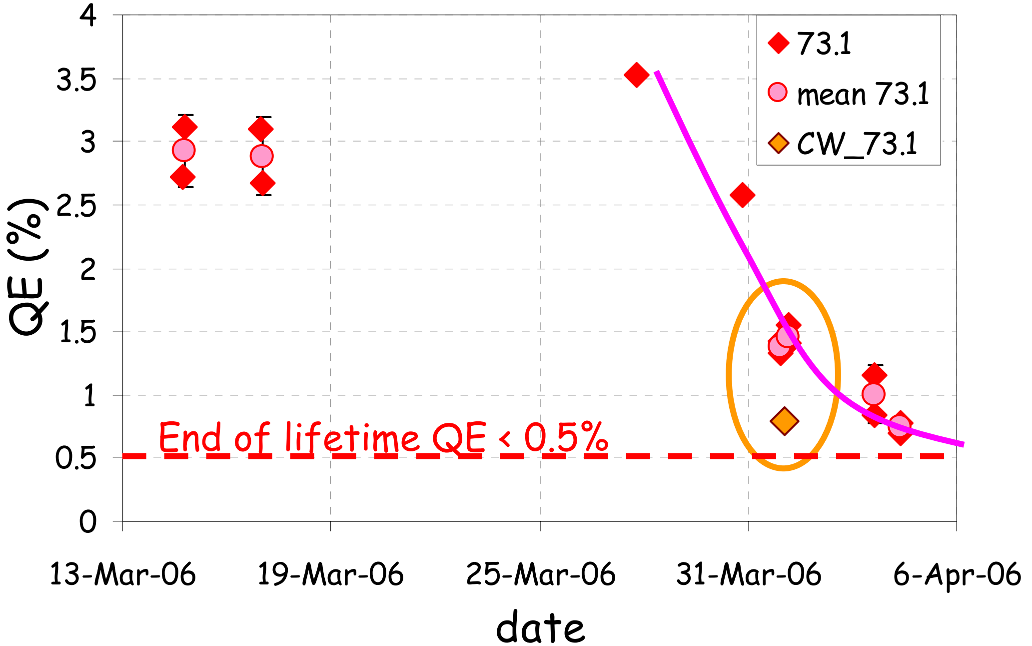
- All cathodes show a drop of the QE over time, with different characteristics.

Pulsed QE measurements: drop of QE with time

We can relate the drop of QE with the vacuum condition in the RF gun.



- As an example, early 2006, the RF gun has been operated with 300 μs long RF pulses.
- Up to this, the pulse length was restricted to 70 μs.
- During the long pulse operation period, the pressure increased from $5 \div 7 \cdot 10^{-11}$ mbar to $2 \cdot 10^{-10}$ mbar.
- This coincides with the drop of QE of cathode 73.1.

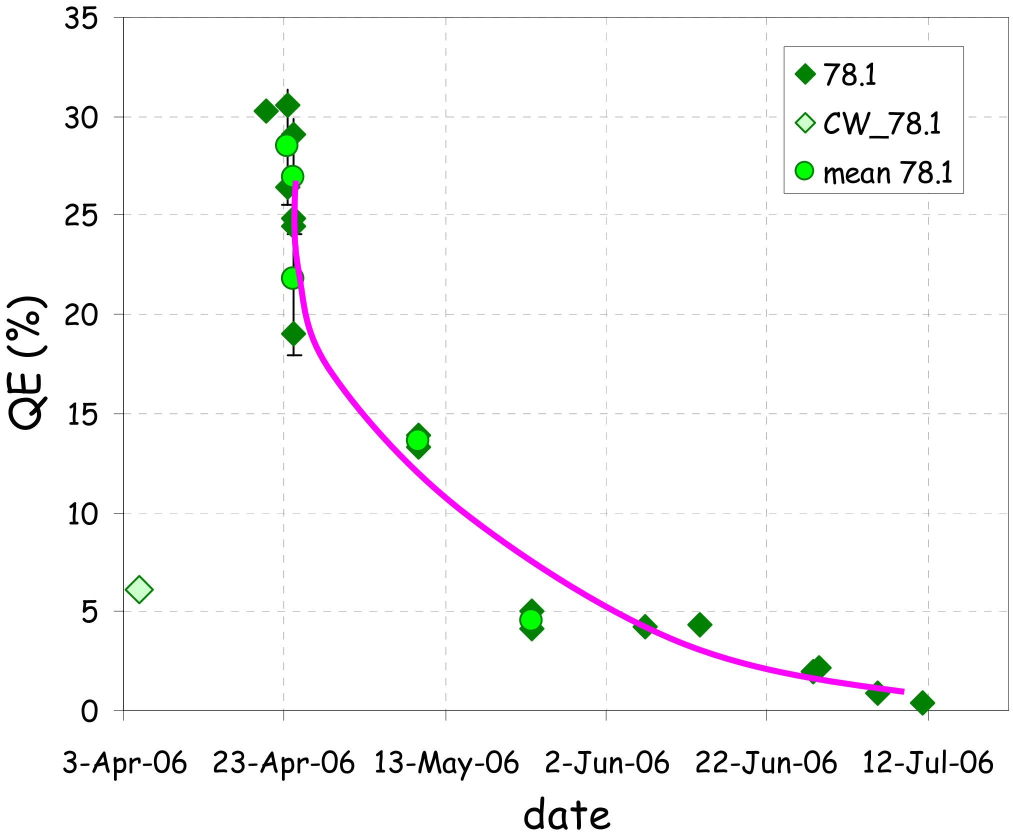


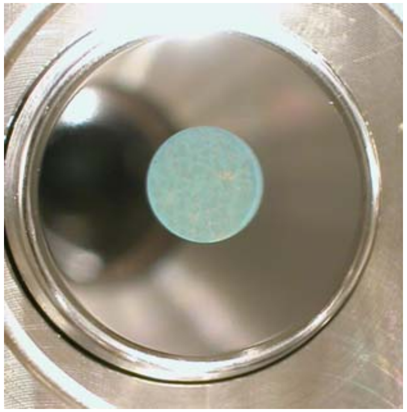
Pulsed QE measurements: cathode 78.1

Referring to cathode **78.1**, several measurements have been done during about 3 months (period: April, 19 to July, 11).

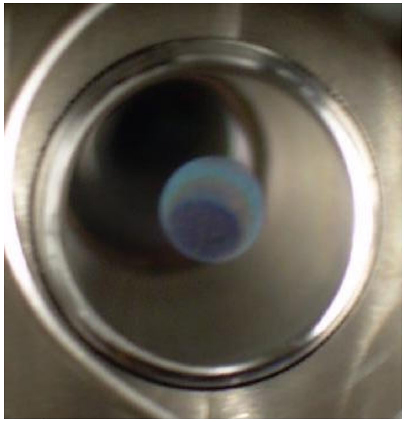
Also this cathode shows a drop of the QE vs. time.

- long pulse operation (increase of vacuum)
- different growth of the cathode during deposition
- damaging due to dark current coming from ACC1



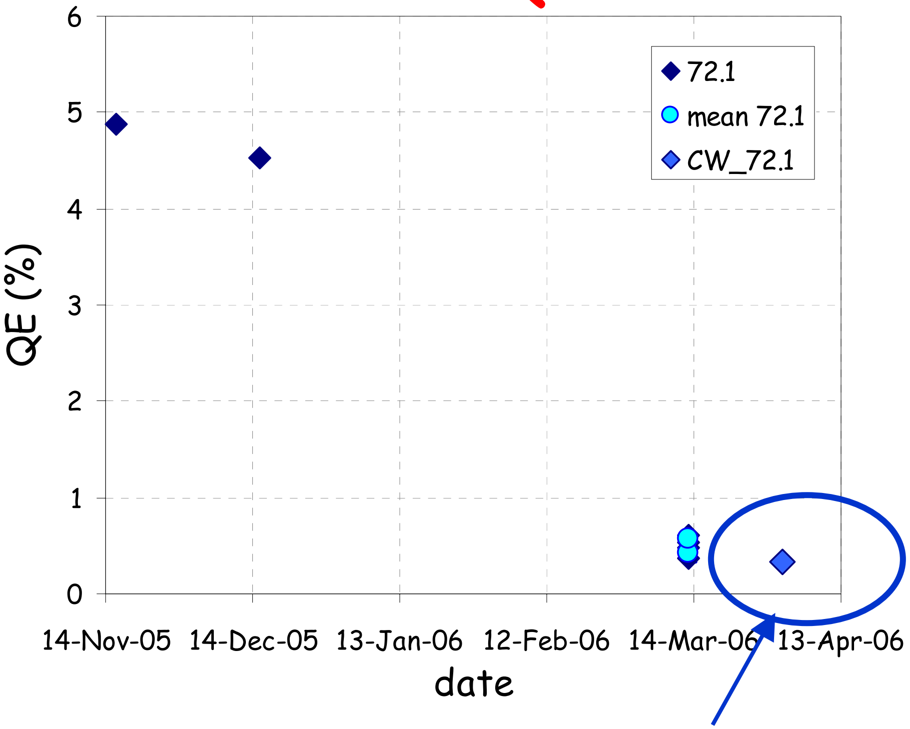


- **78.1** just after the deposition

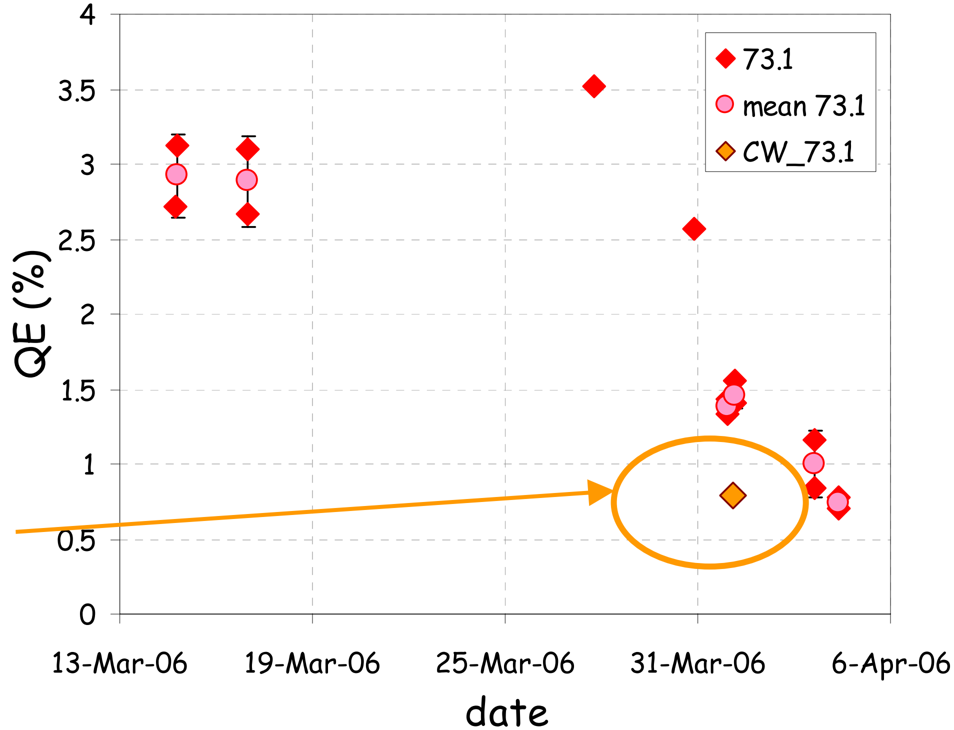


- **78.1** during operation

Comparison between: Pulsed QE and CW QE measurements



The pulsed QE measurements of cathode 72.1 and 73.1 have been compared with the CW QE value @ λ = 262nm, evaluated from the spectral response.



CW QE @ 262nm

The CW QE respect to the pulsed QE value is lower:

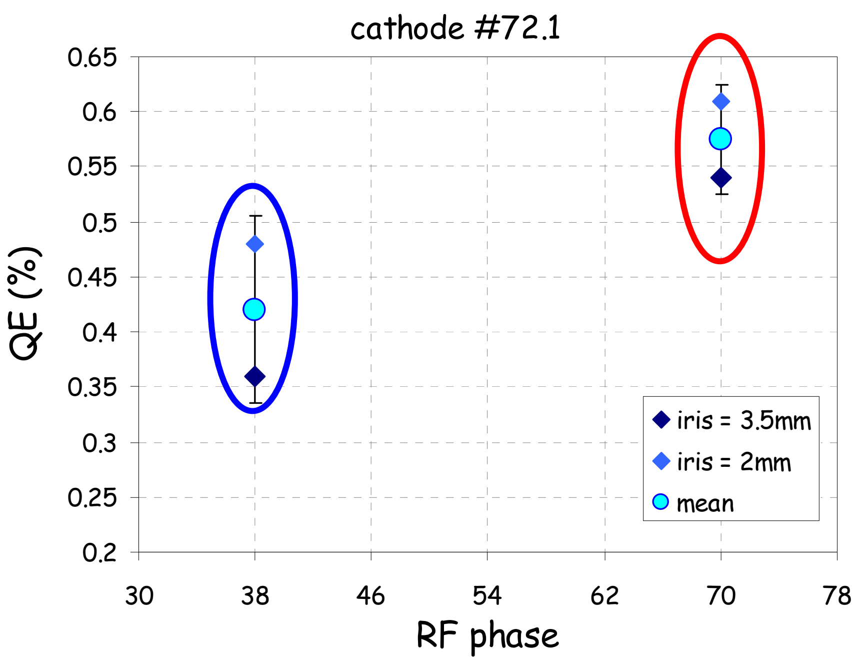
- this can be due to the high accelerating field on the cathode in pulsed QE measurements.

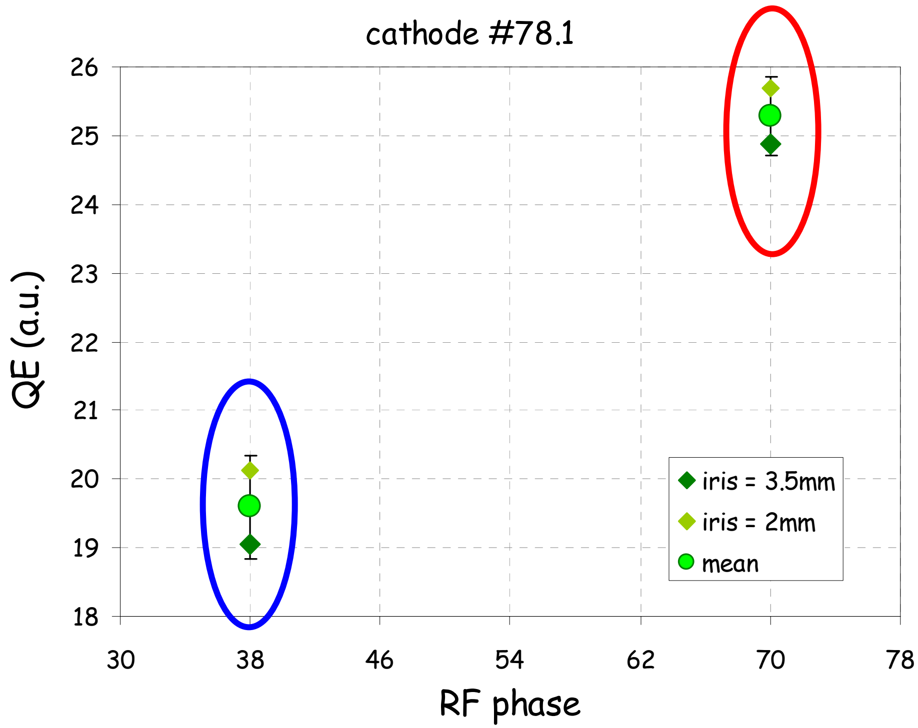
Pulsed QE measurements: QE vs. phase laser/RF gun

- Measurements have been performed on two cathodes varying the laser/RF gun phase.

For cathodes **72.1** and **78.1**,

the measured QE @ 70 deg is higher respect to the one measured @ 38 deg.





Pulsed QE measurements: analysis (1)

- RF data analysis – QE enhancement
  - QE @ given acc. gradient E_{acc} and phase ϕ
  - with a given laser energy without space charge

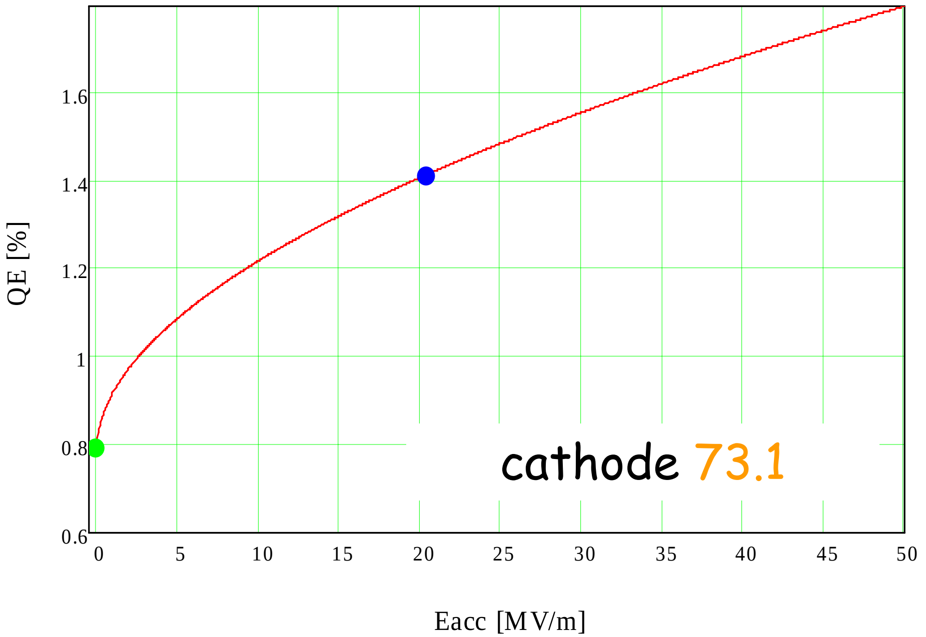
$$QE = A \cdot \left[h\nu - (E_G + E_A) + q_e \cdot \sqrt{\frac{q_e \cdot \beta \cdot E_{acc} \cdot \sin(\phi)}{4 \cdot \pi \cdot \varepsilon_0}} \right]^m$$

where E_{acc} is the accelerating field, ϕ is the phase RF/laser, β is geometric enhancing factor

Using the values calculated before for A, E_G+E_A and m, the geometric enhancing factor results:

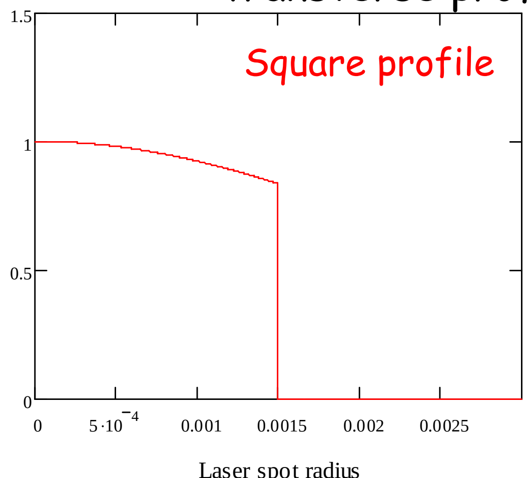
$\beta = 10$

with E_{acc} = 40.9 MV/m and the phase ϕ = 38° from the experimental measurement.

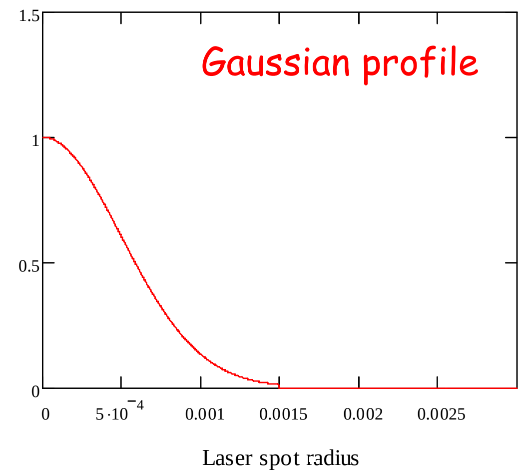


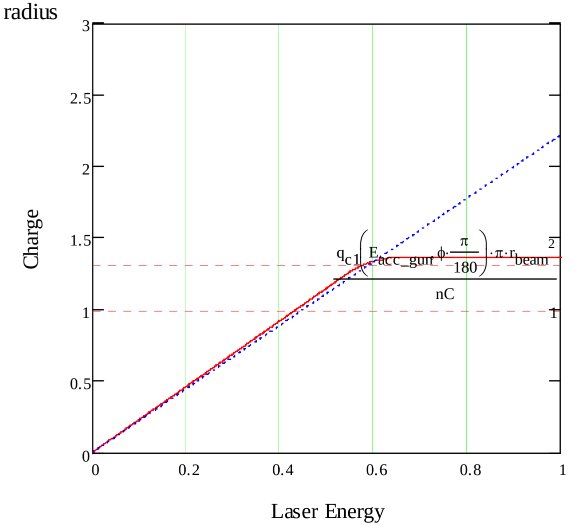
Pulsed QE measurements: analysis (2)

- RF data analysis – Laser spot profile influence
  - QE @ given E_{acc} and ϕ, at different laser energies
    - Space charge forces have to be taken into account and depends on the laser transverse profile.

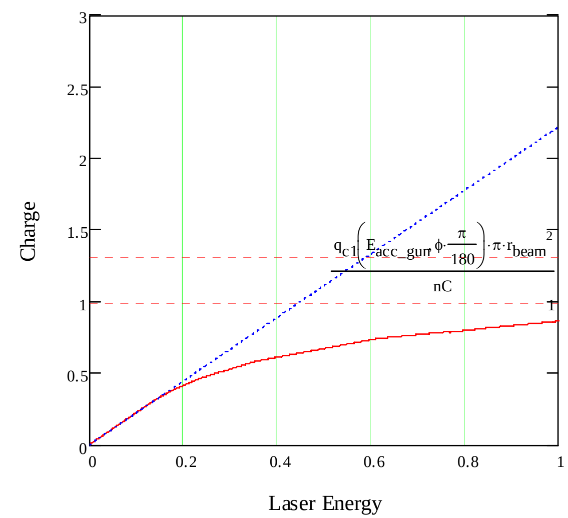


Laser Beam Transverse Profile





Extracted Charge vs. Laser Energy



Pulsed QE measurements: Comments to the analysis

- The influence of the laser spot profile mainly affects the shape of the charge vs. laser energy curves.
- With this "simple" model, we can explain the shape of the curve and some of the asymptotic values.
- It would be very helpful to have CW QE and pulsed QE measurements in the same day (QE constant) to further study the model.

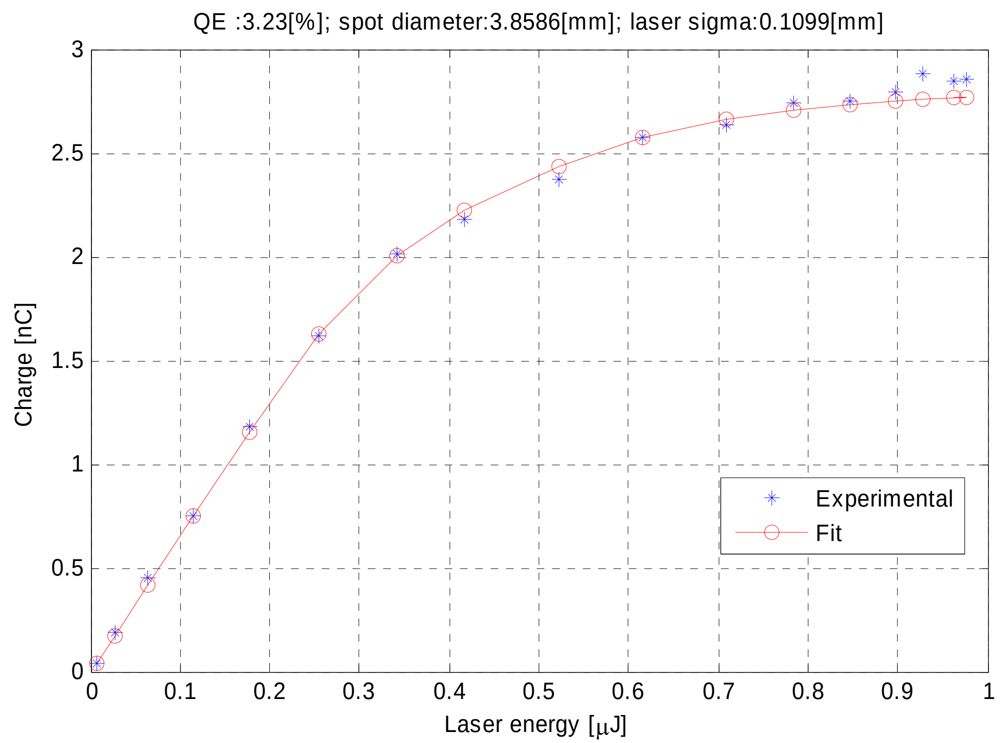
Example for cathode **73.1**

•Laser spot/iris diameter = 3.5mm.

•Extrapolated spot size = 3.8mm.

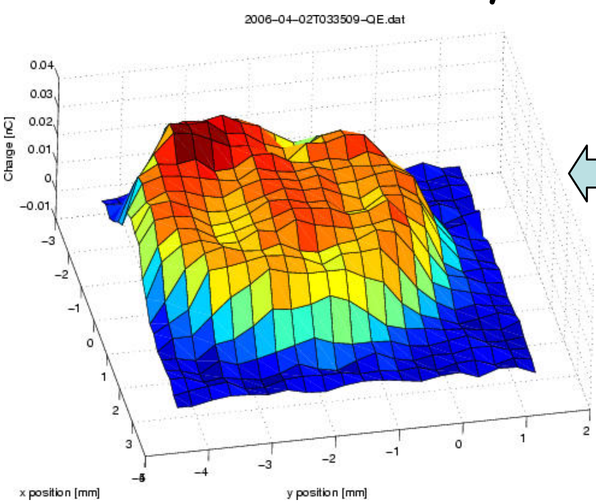
•QE from the linear fit = 3.1%

•QE from this analysis = 3.23%

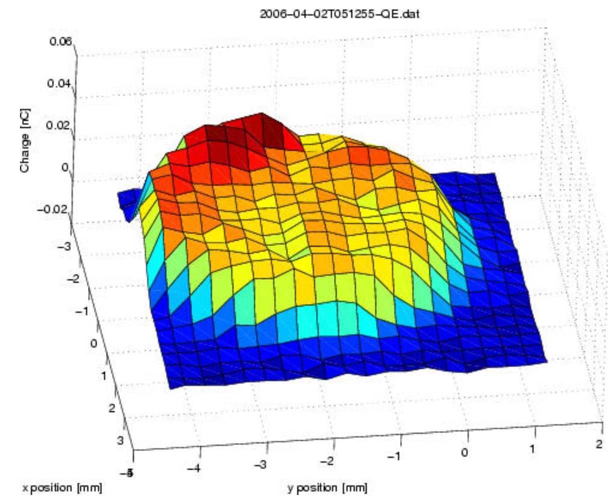


Pulsed QE measurements: QE map (1)

QE maps by scanning a small laser spot over the cathode
tiny iris = 0.16mm (σ), step size 0.3 mm.



Map of the charge emitted from the cathode moving the iris only.

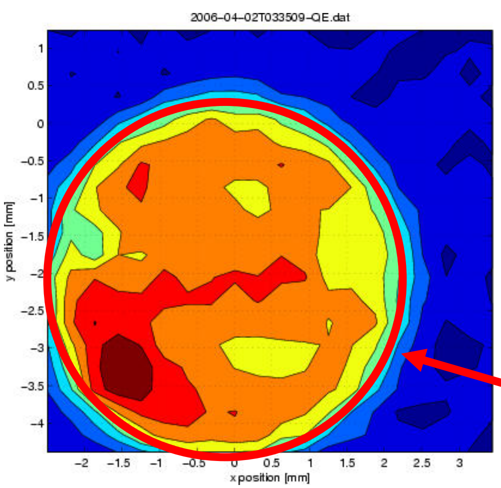


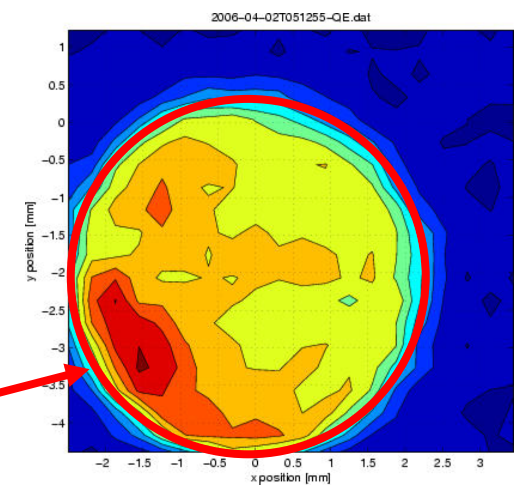
cathode 73.1

Map of charge emitted from the cathode moving iris and mirror together.

The photoemissive layer is 5 mm in diameter.

Well reproduced, center position: (-0.2,-2.2) mm.



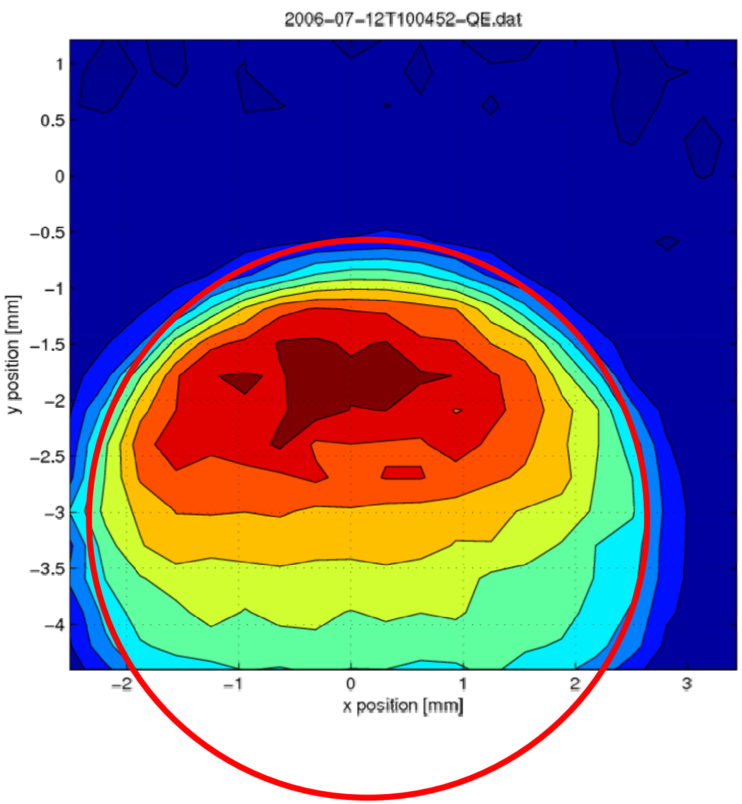


5mm diameter of the photoemissive layer

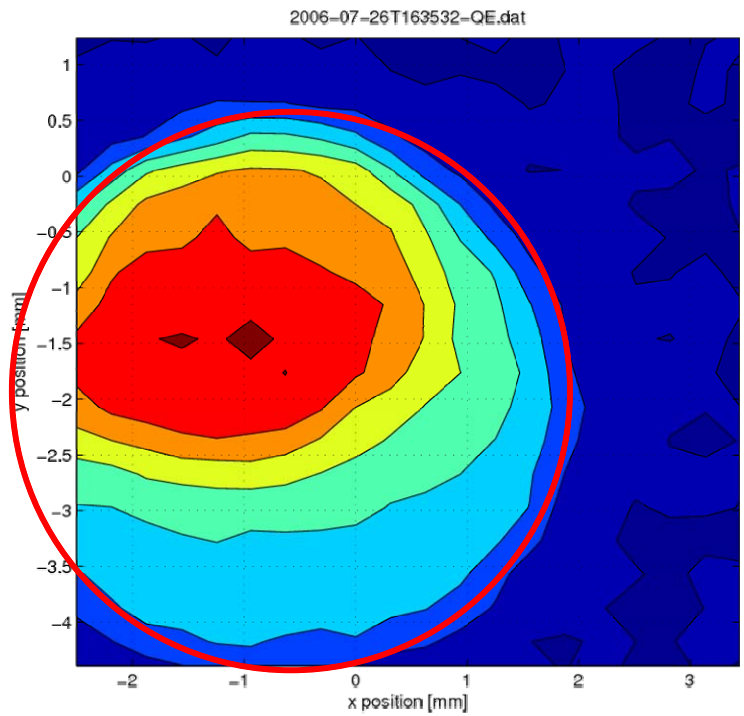
Pulsed QE measurements: QE map (2)

QE maps cathode 77.1, used to center the laser beam on the cathode.

QE maps before alignment



QE map of cathode 77.1 after centering of the laser beam



Conclusion

- CW QE measurements:
  - Experimental set-up in the tunnel
  - The CW QE of 3 cathodes has been measured @ FLASH
- Pulsed QE measurements:
  - Laser beamline transmission calibration
  - QE vs. time and vs. RF phases
  - Analysis of the pulsed QE measurements:
    - E_{acc}, RF phase, etc.
- QE maps
  - Tool to check the centering between the laser spot and the photoemissive film
- For the future
  - On-line measurements of the laser beamline transmission