# Cathode Studies at FLASH:

# CW and Pulsed QE measurements

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# Main Topics

## – Overview of Photocathode Production & Shipment

- Production & diagnostic at LASA/Shipment/Use in the FLASH gun
- Database
- The cathodes under investigation

## – CW QE measurements (Hg lamp)

- Experimental set-up
- Results of measurements at FLASH

## – Pulsed QE measurements

- Laser energy calibration
- Pulsed QE measurement vs. iris and accelerating field
- QE maps

## – Cathode handling issue

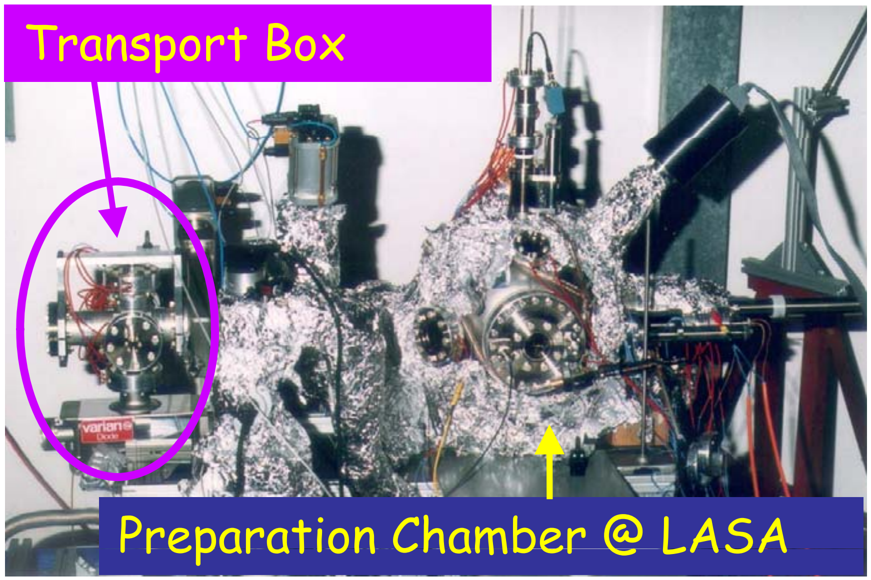
- Carrier movement
- Dark Current

## – Conclusion

# Just to remind you…

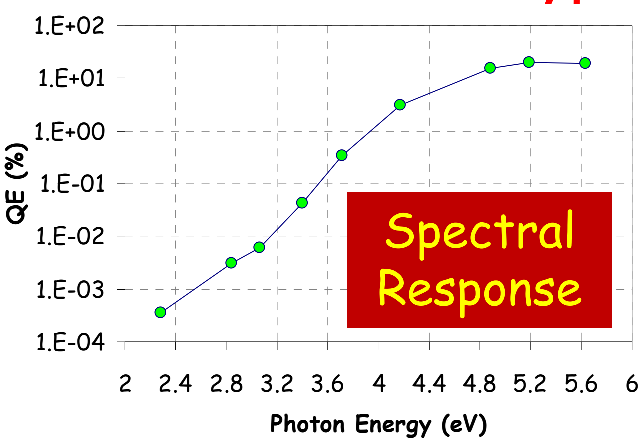
## The photocathode production and analysis at LASA

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

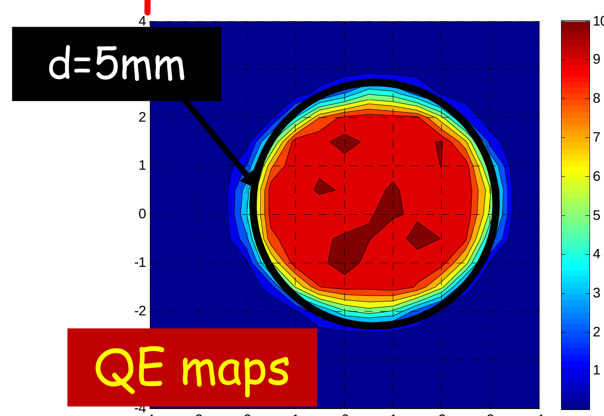



- UHV Vacuum System - base pressure $10^{-10}$ mbar
- 6 sources slot available
- Te sources out of 99.9999 % pure element
- Cs sources from SAES®
- High pressure Hg lamp and interference filter for online monitoring of QE during production
- Masking system
- 5 x UHV transport box

## And the typical diagnostic after the deposition



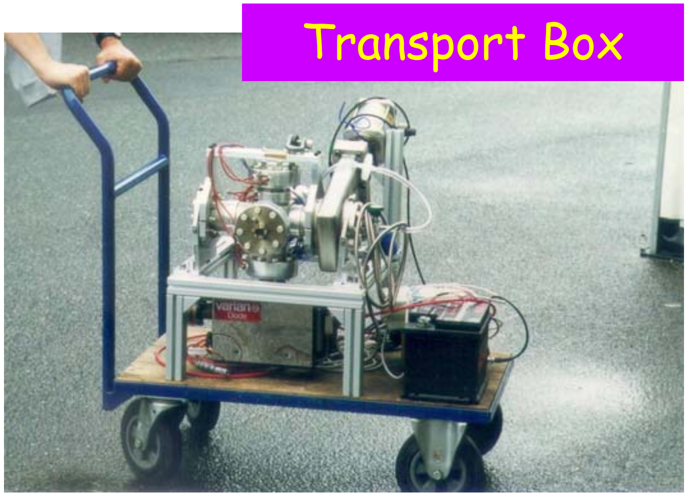




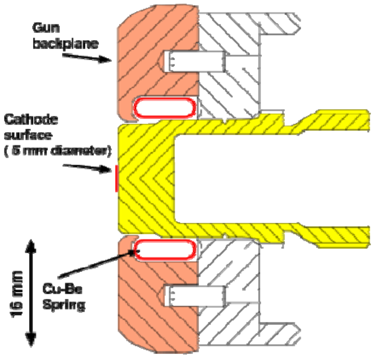
# Just to remind you...

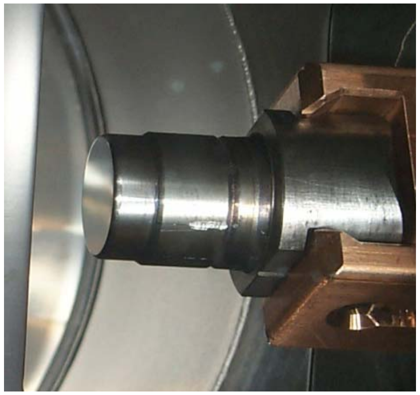
## The transport box shipment

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




## The connection to the RF gun

## and the insertion of the cathode in the gun backplane

# Just to remind you…

## Quantum Efficiency (QE)

$QE(\%) \approx 0.5 * Q(nC)/E(\mu J)$

The design asks for 72000 nC/sec

## Request for FLASH

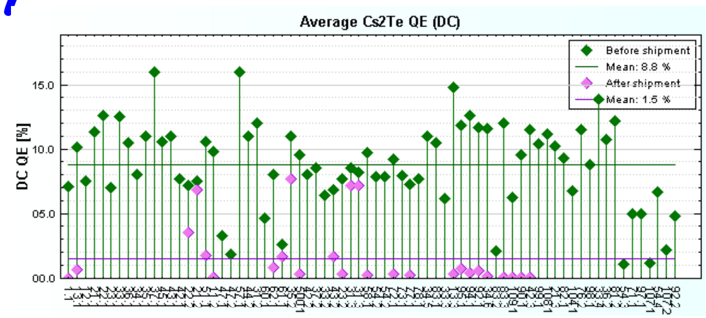
- QE required for FLASH:
  > 0.5 % to keep the laser in a reasonable limit: within an average power of ~W
- Design of present laser accounts for QE=0.5% with an overhead of a factor of 4 and has an average power of 2 W (IR)
- $Cs_2Te$ cathodes found to be the best choice

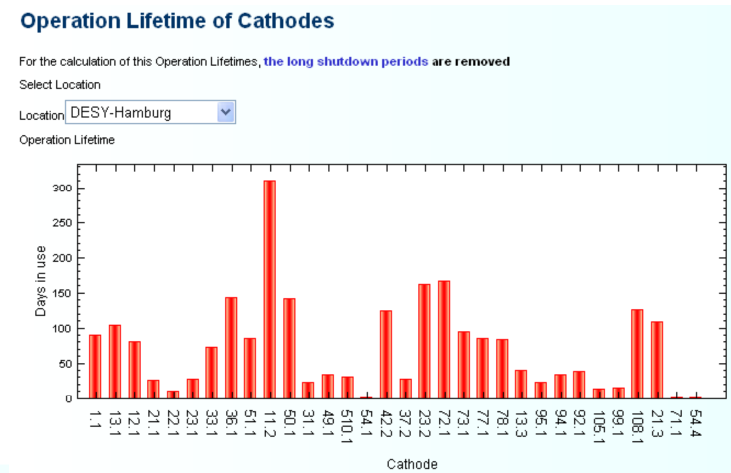
# Just to remind you…

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:

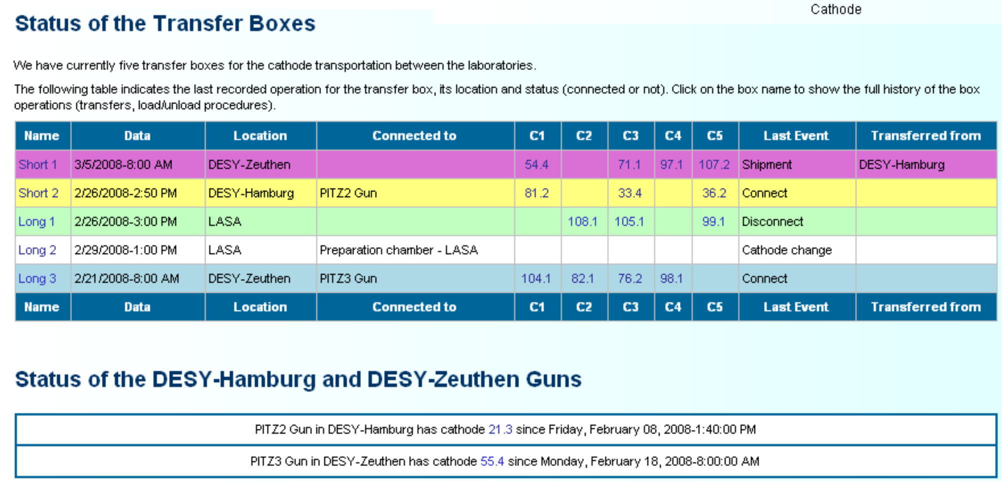
http://wwwlasa.mi.infn.it/ttfcathodes/

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







## 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 | 3/5/2008-8:00 AM | DESY-Zeuthen | | 54.4 | | 71.1 | 97.1 | 107.2 | Shipment | DESY-Hamburg |
| Short 2 | 2/26/2008-2:50 PM | DESY-Hamburg | PITZ2 Gun | 81.2 | | 33.4 | | 36.2 | Connect | |
| Long 1 | 2/26/2008-3:00 PM | LASA | | | 108.1 | 105.1 | | 99.1 | Disconnect | |
| Long 2 | 2/29/2008-1:00 PM | LASA | Preparation chamber - LASA | | | | | | Cathode change | |
| Long 3 | 2/21/2008-8:00 AM | DESY-Zeuthen | PITZ3 Gun | 104.1 | 82.1 | 76.2 | 98.1 | | Connect | |
| Name | Data | Location | Connected to | C1 | C2 | C3 | C4 | C5 | Last Event | Transferred from |

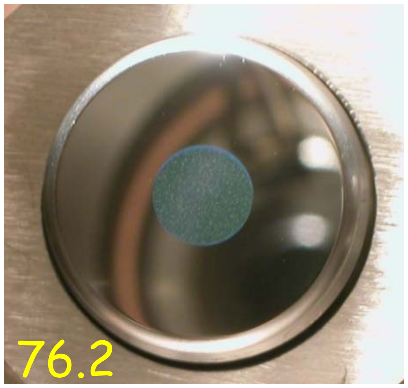
## Status of the DESY-Hamburg and DESY-Zeuthen Guns

PITZ2 Gun in DESY-Hamburg has cathode 21.3 since Friday, February 08, 2008-1:40:00 PM

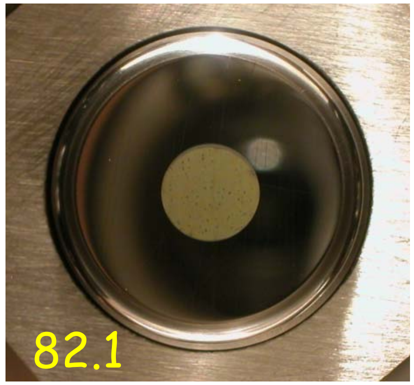
PITZ3 Gun in DESY-Zeuthen has cathode 55.4 since Monday, February 18, 2008-8:00:00 AM

# The photocathode under investigation

## Cathodes measured by Continuous (CW) QE measurements



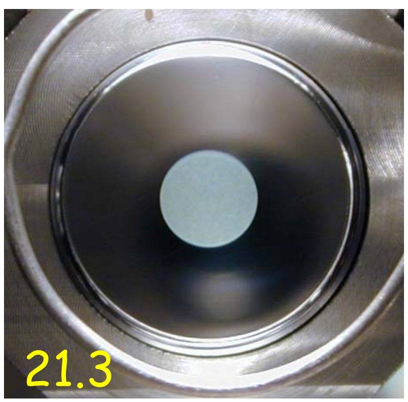

Material: Sintered
Polish. : LASA
Clean.: usual




Material: Sintered
Polish. : Zeiss
Clean.: usual


Material: Sintered
Polish. : Zeiss
Clean.: $CO_2$


Material: Arc Cast
Polish. : Zeiss
Clean.: usual

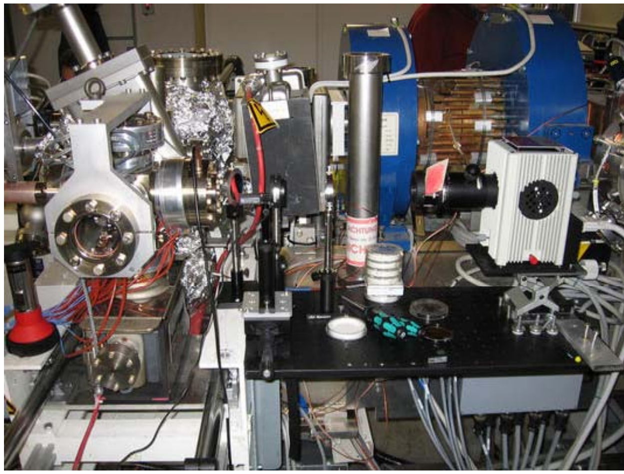



## Cathode measured by Pulsed QE measurement and QE maps:

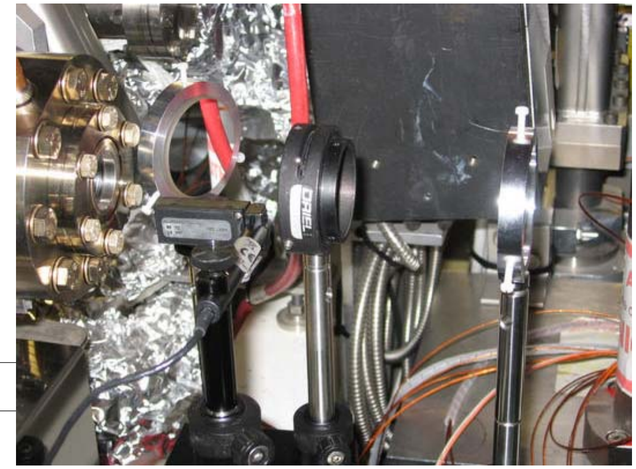
Material: Sintered
Polish. : Zeiss
Clean.: usual

This cathode has operated in the FLASH gun for about 109 days (still in use)

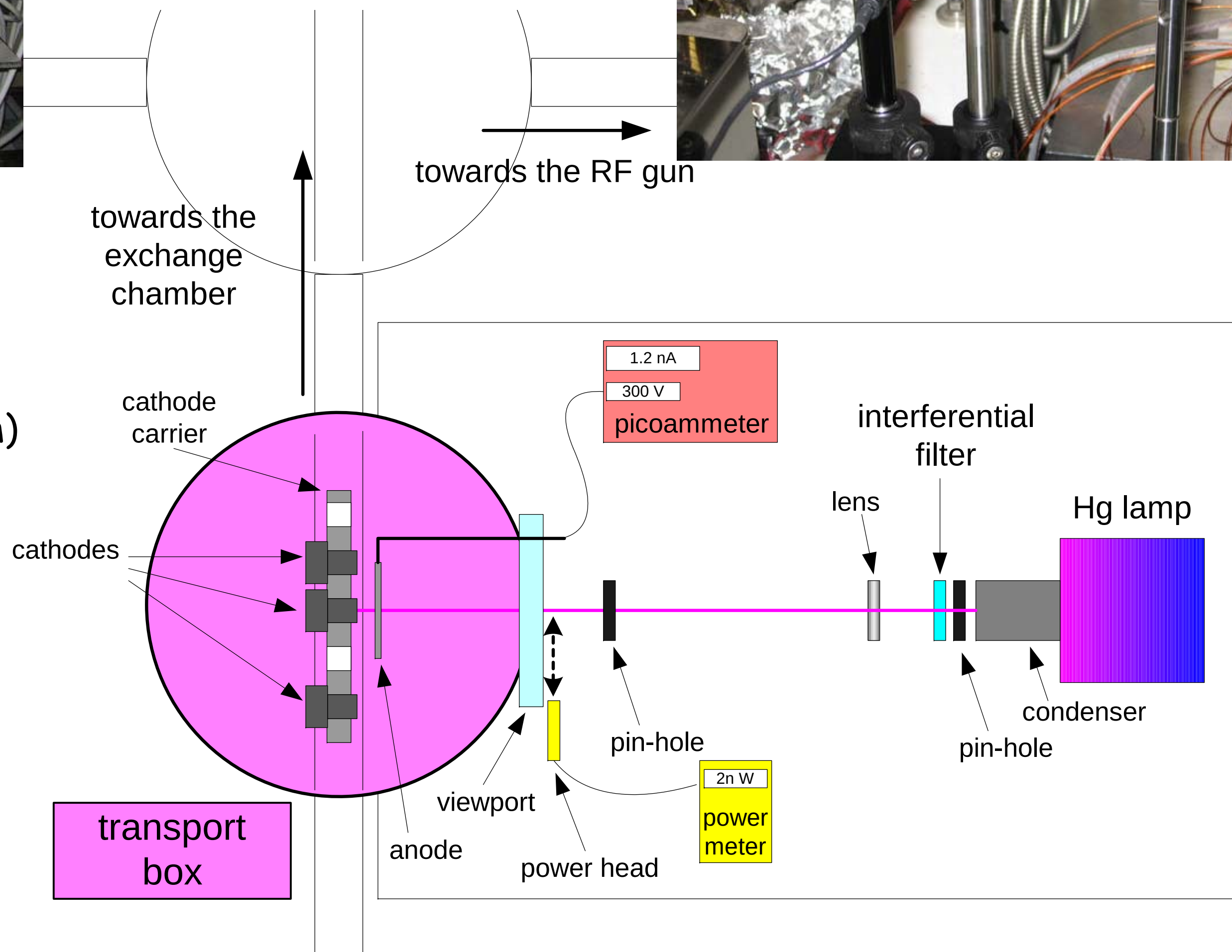
# CW QE measurements: Experimental set-up



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

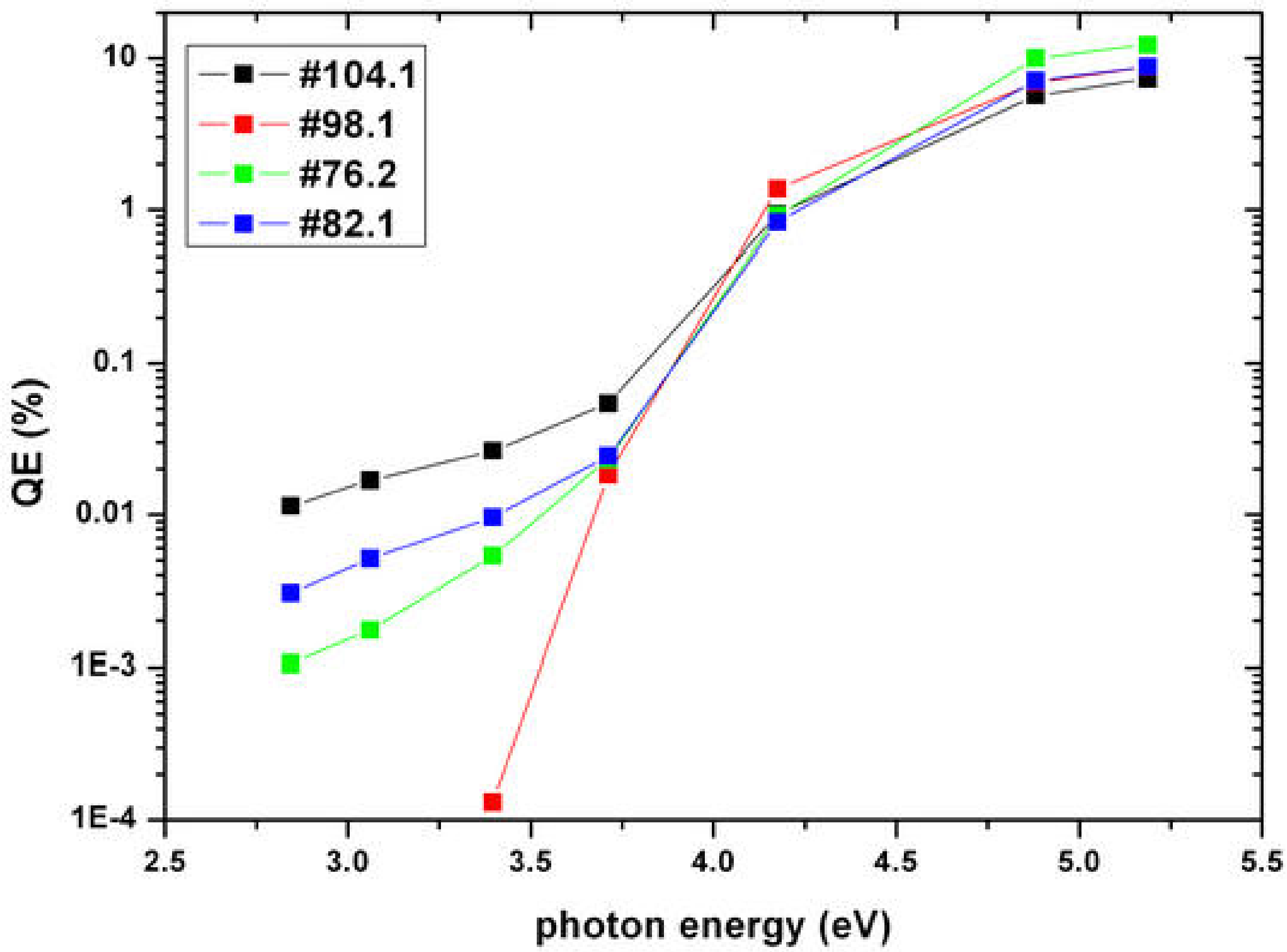


- ✓ A high pressure Hg lamp
- ✓ Interferential filters (239nm, 254nm, 297nm, 334nm, 365nm, 405nm, 436nm)
- ✓ Picoammeter
- ✓ Power energy meter (calibrated photodiode)
- ✓ Optical components (1 lens f=500mm, 1 mirror, 2 pin-holes)



# CW QE measurements

The CW QE measurement have been done on 4 cathodes.
This cathodes have never been used in the FLASH RF gun.



# CW QE measurements: data analysis (1)

- CW data analysis with the
  - Fitting of the spectral response

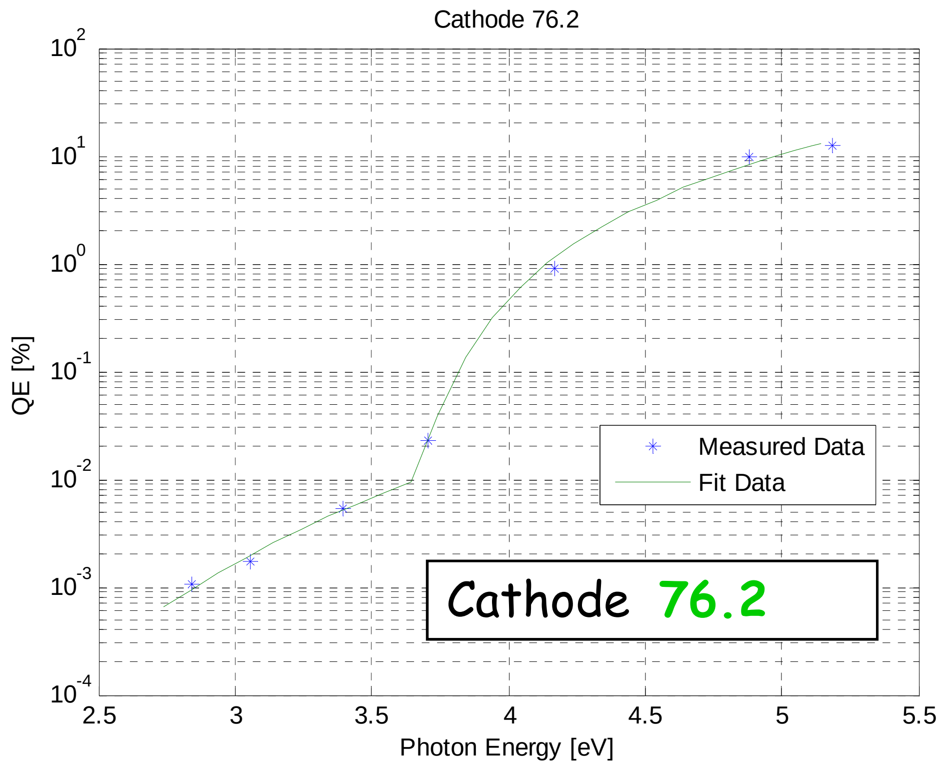
$$QE = A\cdot\left[h\nu-\left(E_G+E_A\right)\right]^m + A_1\cdot\left[h\nu-\left(E_{G1}+E_{A1}\right)\right]^{m1}$$

where A and $A_1$ are constants, m and m1 are related to the transition in the material, $E_G$ and $E_A$ ($E_{G1}$ and $E_{A1}$) are respectively the energy gap and electron affinity of the low and the high energy thresholds.

An example is given for the analysis of the CW QE data for cathode **76.2** measured at FLASH.
In this case:

- $E_G+E_A$ = 1.3 eV
- $E_{G1}+E_{A1}$ = 3.6 eV

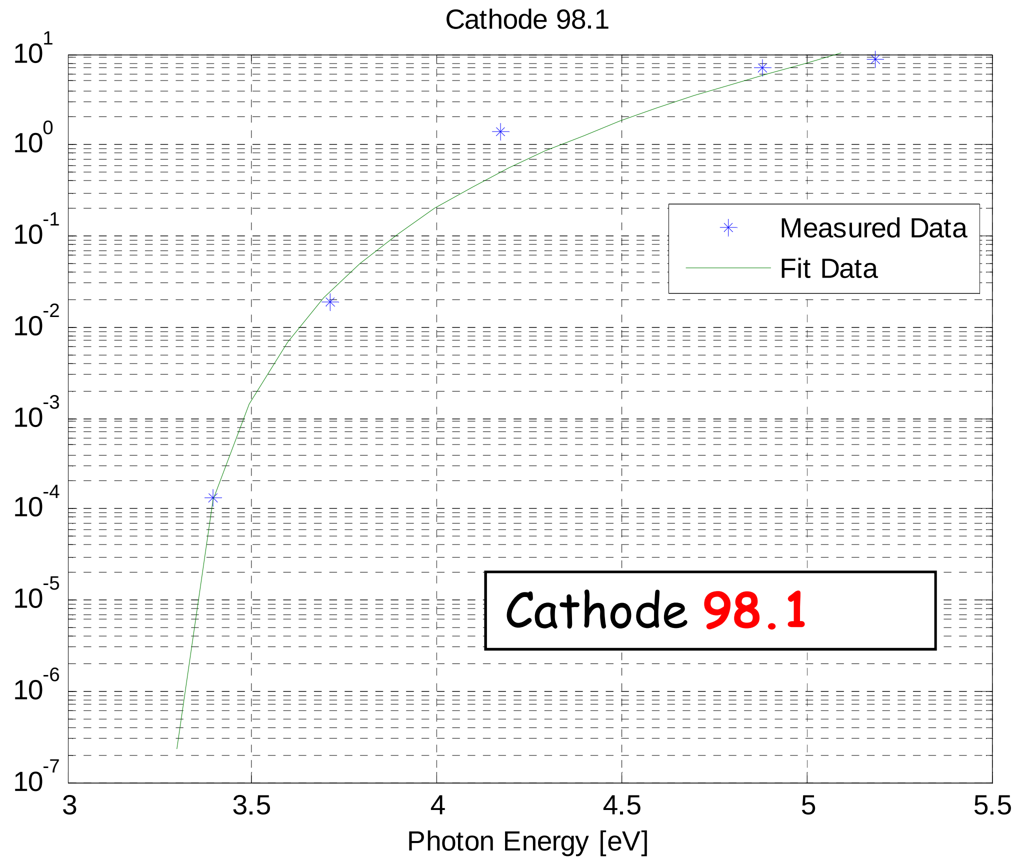
QE@262 nm = 6.2%



# CW QE measurements: data analysis (2)

- CW data analysis of cathode **98.1** has been done fitting only the high energy threshold (due to the different spectral response shape!) using:

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




where $A$ is a constant, m is related to the transition in the material, $E_G$ and $E_A$ are energy gap and electron affinity.

# CW QE measurements: Results

The measurements have been done to measure the QE of cathodes, to evaluate the robustness of films and to validate the box storing efficiencies.

These cathodes have never been used and stays in the box for about 5 months.

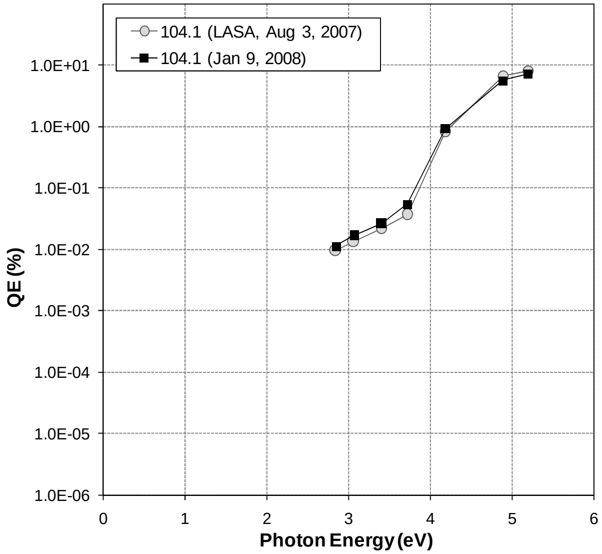
Data have been fitted to evaluate: the QE @ 262nm and $E_G+E_A$ at the two energies

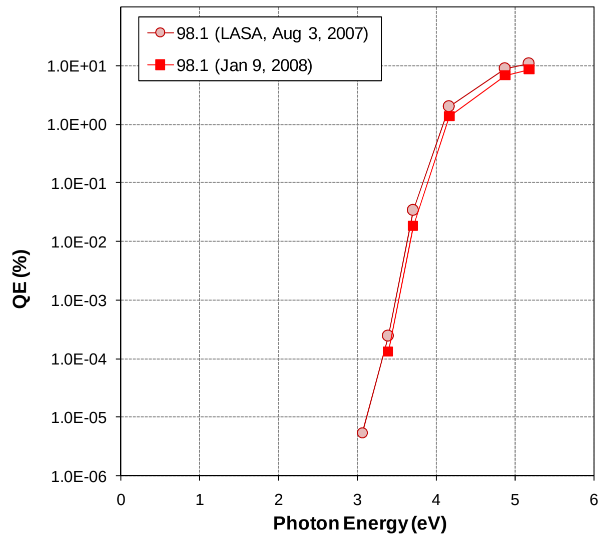
| | Cathode | Dep. date | QE@254nm | QE@262nm | $E_G+E_A$ (eV) (low) | $E_G+E_A$ (eV) (high) |
|---|---|---|---|---|---|---|
| LASA | 104.1 | July 31, '07 | 6.75% | 4.3% | 1.2 | 3.7 |
| | 82.1 | August 1, '07 | 9.3% | 5.9% | 1.3 | 3.6 |
| | 76.2 | August 2, '07 | 11.5% | 6.8% | 0.8 | 3.6 |
| | 98.1 | August 3, '07 | 8.82% | 6.1% | - | 3.7 |

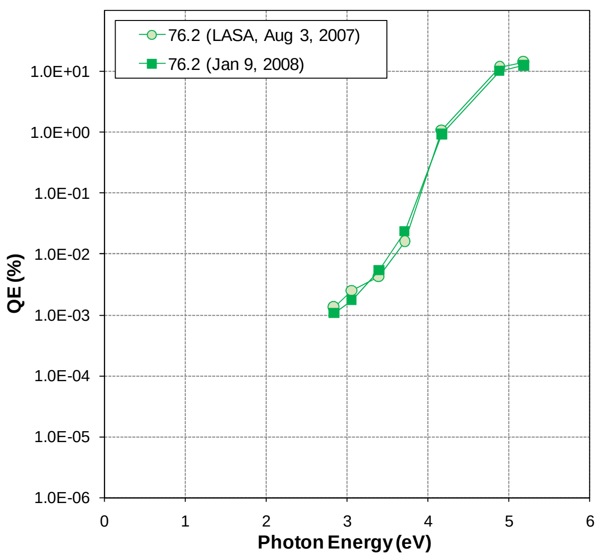
| | Cathode | CW meas. | QE@254nm | QE@262nm | $E_G+E_A$ (eV) (low) | $E_G+E_A$ (eV) (high) |
|---|---|---|---|---|---|---|
| FLASH | 104.1 | January 9, '08 | 5.7% | 3.9% | 2.1 | 3.6 |
| | 82.1 | January 9, '08 | 7.1% | 4.5% | 1.8 | 3.6 |
| | 76.2 | January 9, '08 | 10% | 6.2% | 1.3 | 3.6 |
| | 98.1 | January 9, '08 | 6.92% | 5.1% | - | 3.7 |

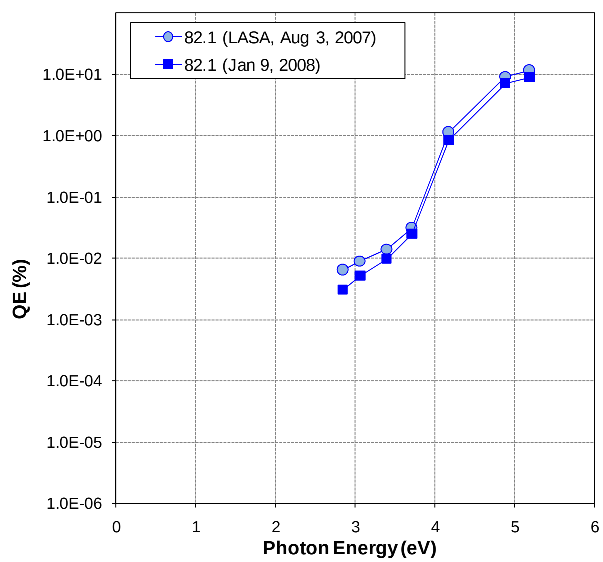
# CW QE measurements: Results

Comparison between the spectral responses at LASA and the one measured at FLASH



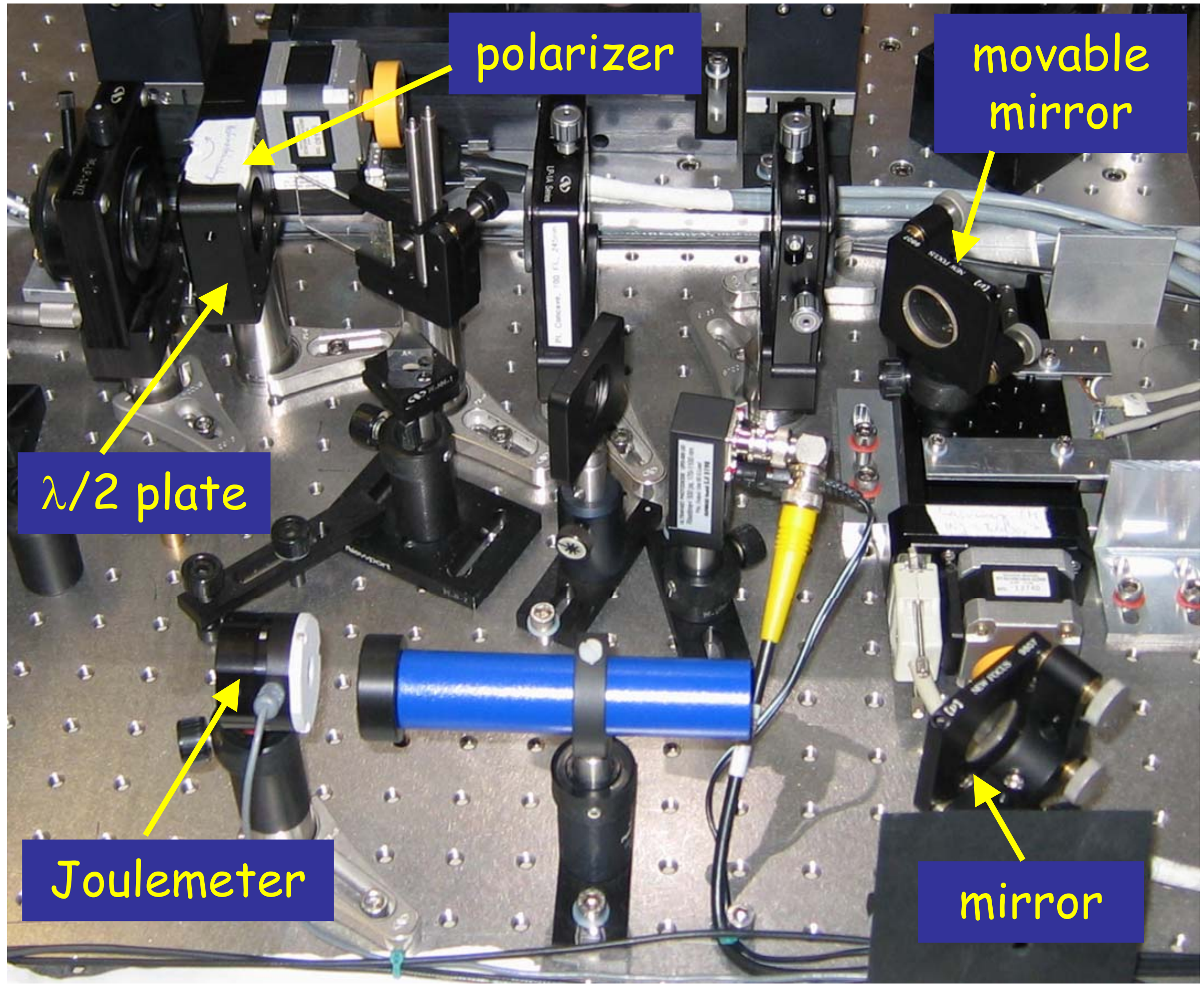



# Pulsed QE measurements: laser energy calibration experimental set-up

The laser energy transmission (from the laser hut to the tunnel) has been evaluated for different iris diameters (3.0mm, 2.0mm and 1.0mm) and different energies.

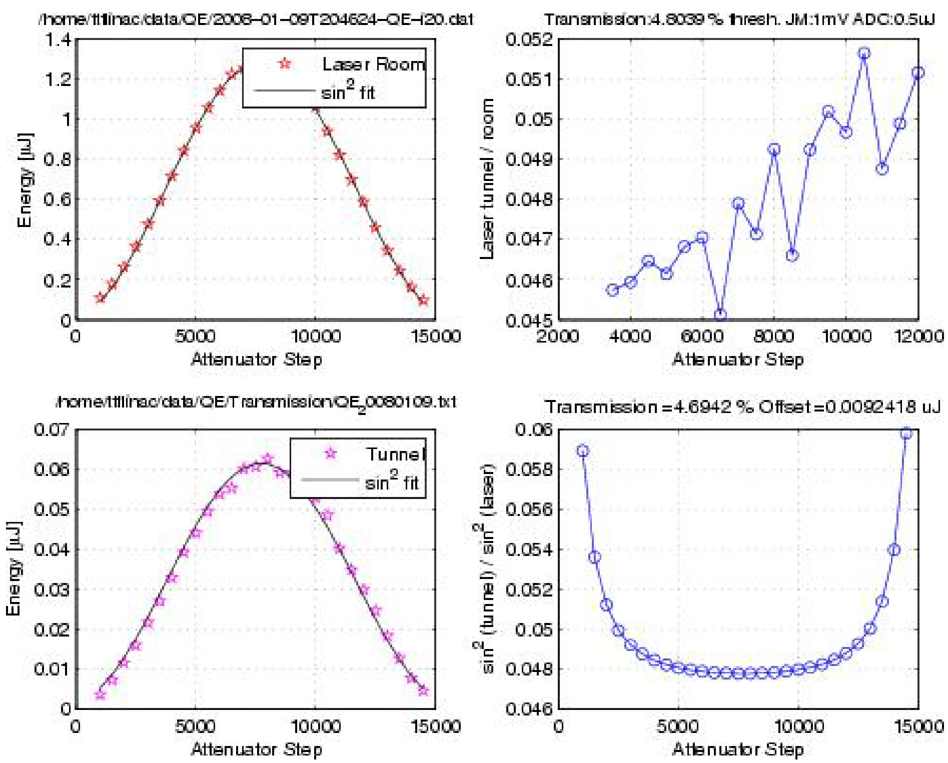
The laser energy has been measured using a Pyroelectric gauge (Joulemeter), varying the laser energy using the variable attenuator ($\lambda/2$ wave plate + polarizer).



# Pulsed QE measurements: laser beamline transmission results

| Iris Φ (mm) | Iris (step) | Transmission | Used |
|---|---|---|---|
| 3.0 | 16768 | 9.7 % | From 9 January till now |
| 2.0 | 17280 | 4.9 % | |
| 1.0 | 17776 | 2.3 % | |

## Transmission analysis for iris = 2.0mm




- 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

•Laser energy is measured as a function of the variable attenuator setting

•fitted by $\sin^2$
to evaluate the transmission

# 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)

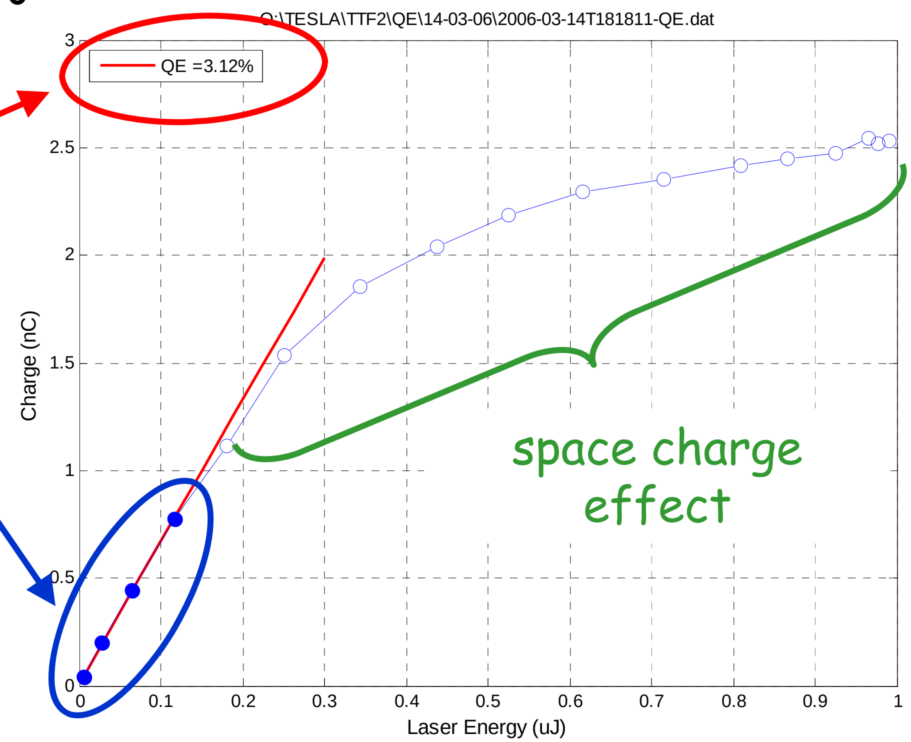
$$QE[\%] = \frac{nel}{nph} \cdot 100 = \frac{Q[C] \cdot E_{ph}[eV]}{E_{cath}[J]} \cdot 100$$

262 nm: QE(%) ≈ 0.5*Q(nC)/E(μJ)

The QE value is then obtained

fitting the charge trend @ low charge

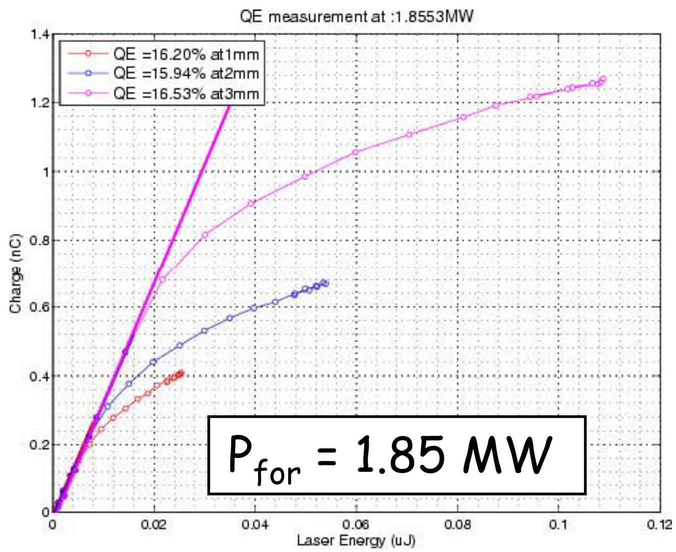
to be sure not to be affected by the space charge

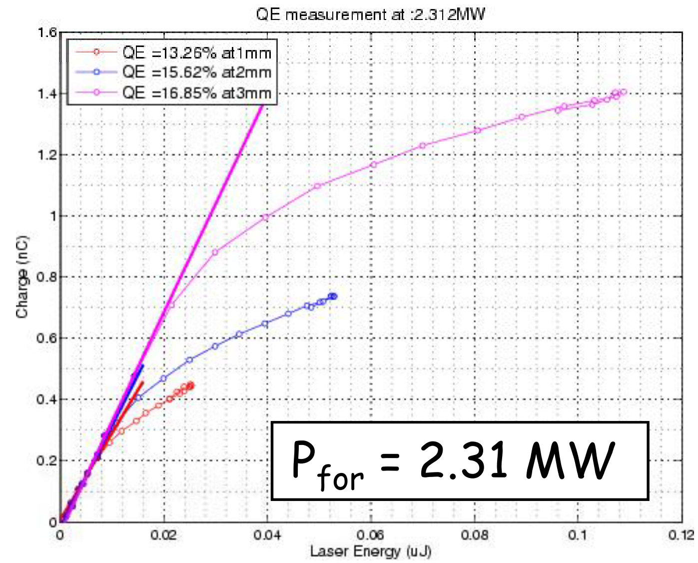



✓ The relative and systematic error are in the order of 20 %.

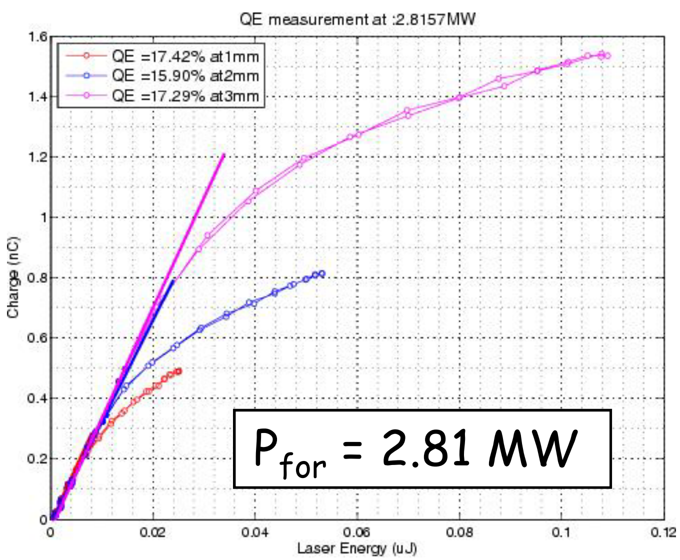
✓ The systematic error is mainly due to the uncertainty of identifying the linear part for the fit and due to the transmission measurement uncertainty

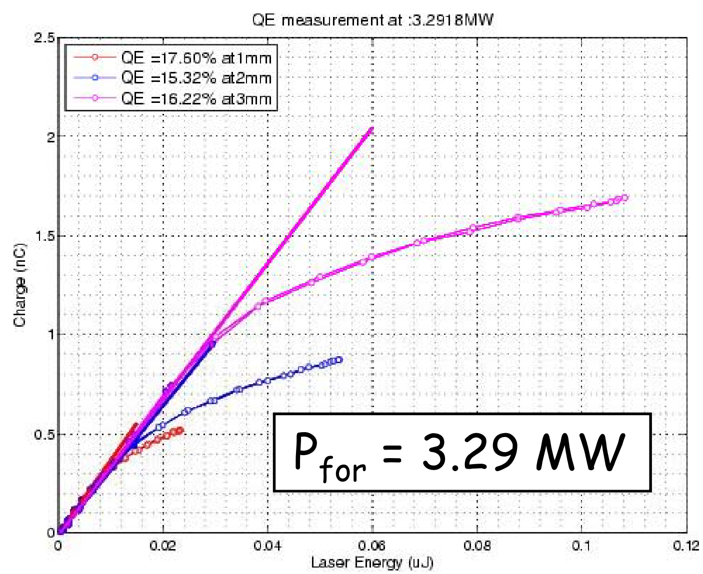
# Pulsed QE measurements: different irises (1)




Cathode 23.1

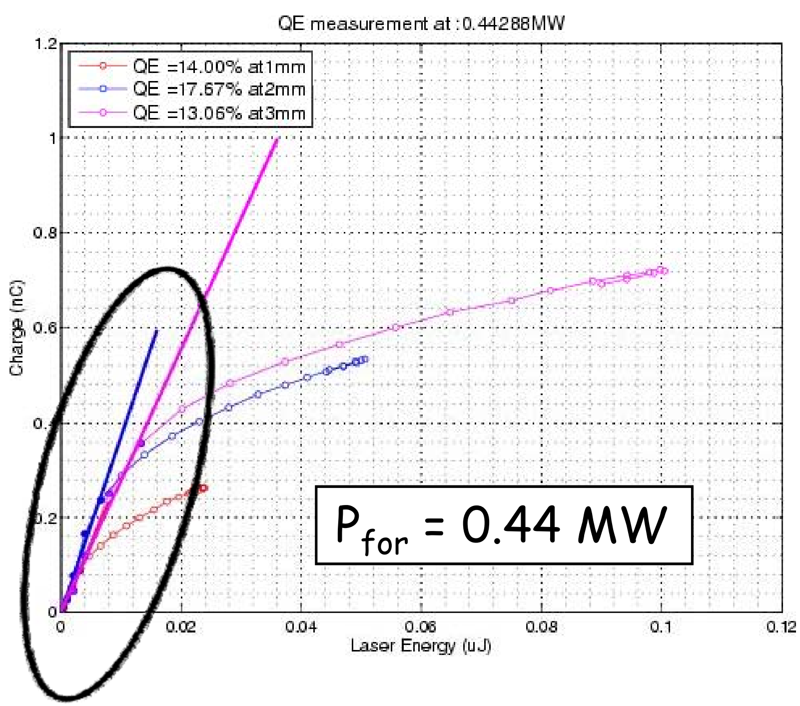


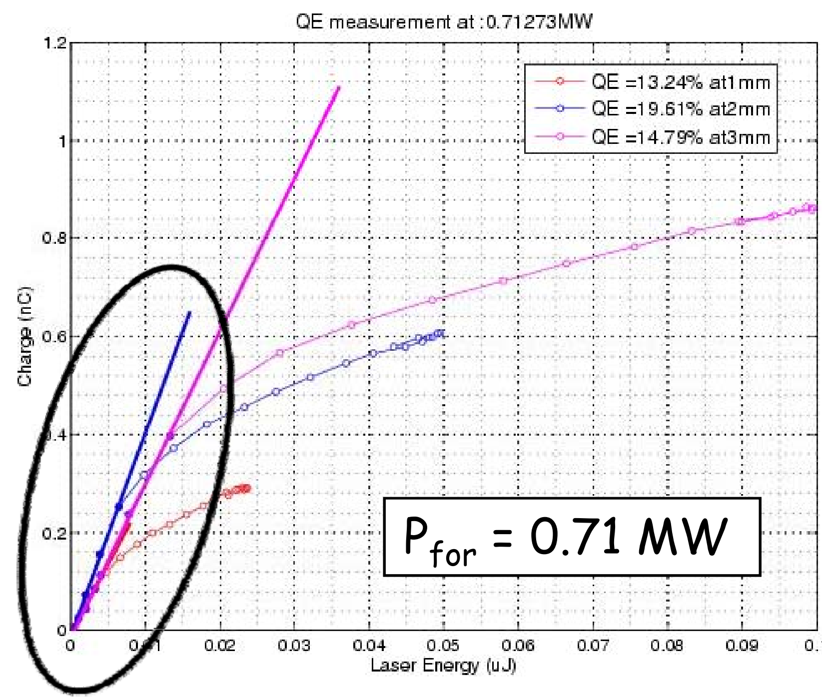

We have performed QE pulsed measurements for the 3 irises, fixing the accelerating voltage.

# Pulsed QE measurements: different irises (2)

Nevertheless we observed a strange behavior for the 2 mm iris case




At lower accelarating fields.
This effect it is not yet understood!



# Pulsed QE measurements: analysis

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

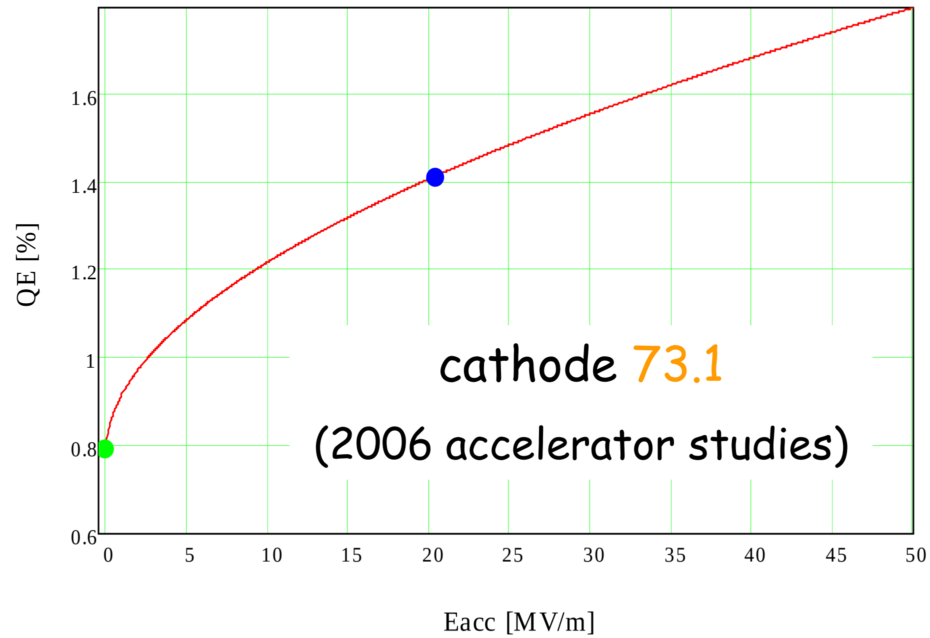
$$QE = A_1 \cdot \left[ h\nu - \left(E_{G1} + E_{A1}\right) + q_e \cdot \sqrt{\frac{q_e \cdot \beta \cdot \varepsilon \cdot E_{acc} \cdot \sin(\phi)}{4 \cdot \pi \cdot \varepsilon_0}} \right]^{m1}$$

where $E_{acc}$ is the accelerating field, $\phi$ is the phase RF/laser, $\beta$ is geometric enhancing factor

Using the values obtained with the fit for $A_1$, $E_{G1}+E_{A1}$ and m1, the geometric enhancing factor results:

**$\beta \cdot \varepsilon = 10$**

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

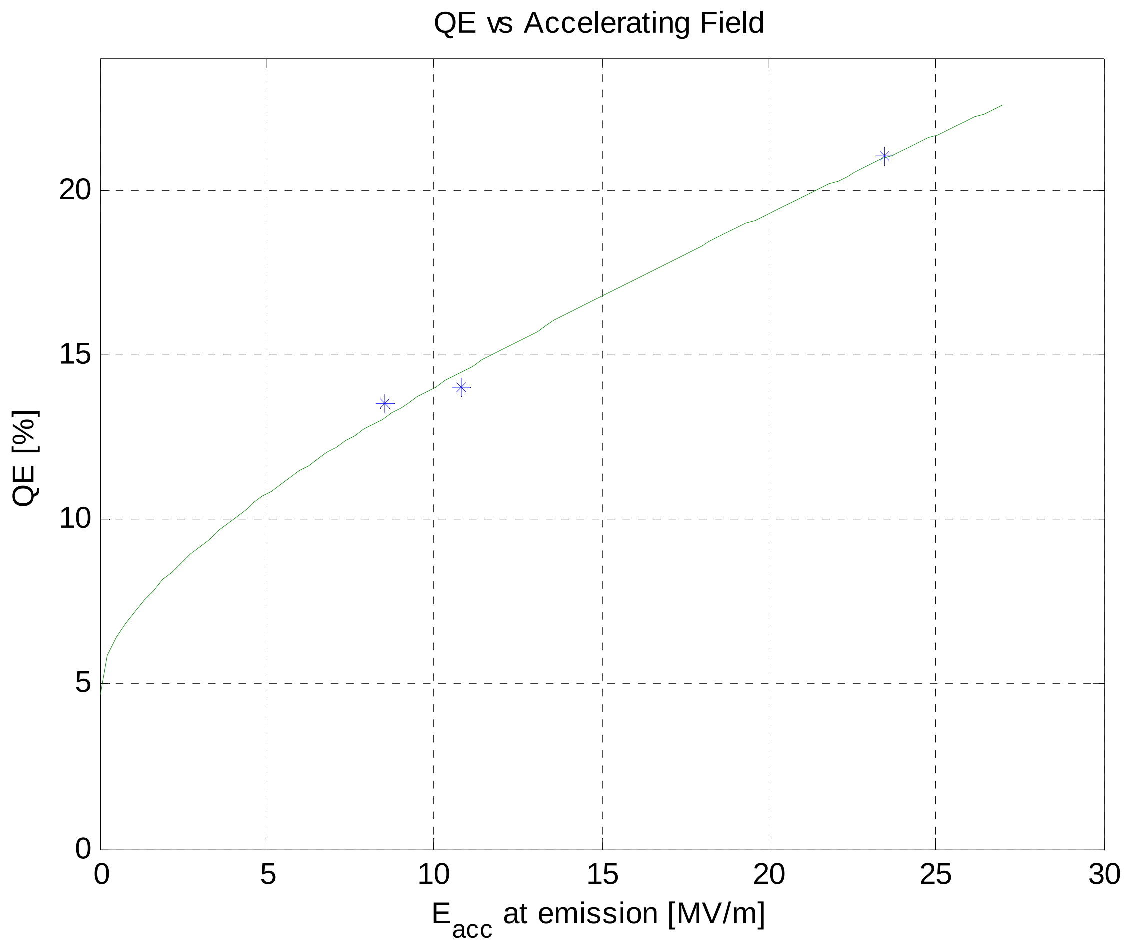


# Pulsed QE measurements: different accelerating field

QE @ zero field= 4.7 %

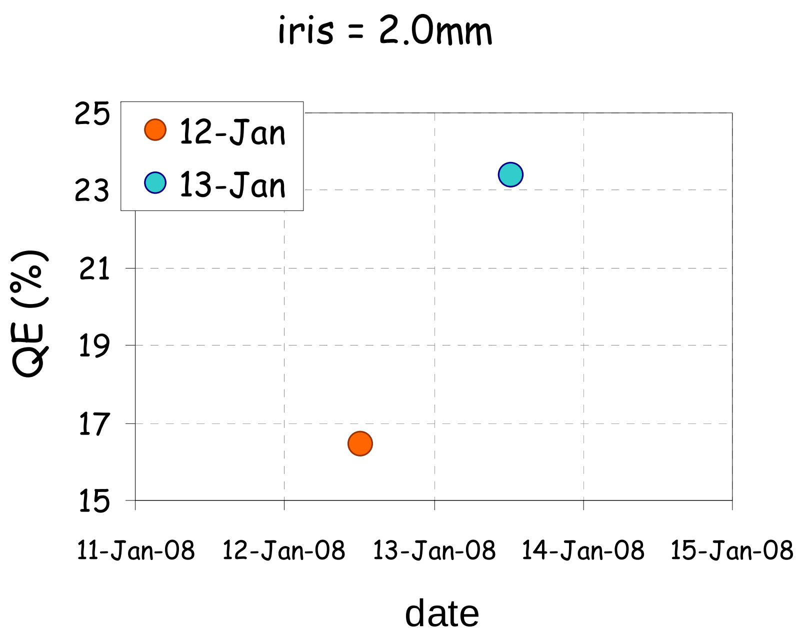
$E_{G1}+E_{A1}$ = 3.8 eV

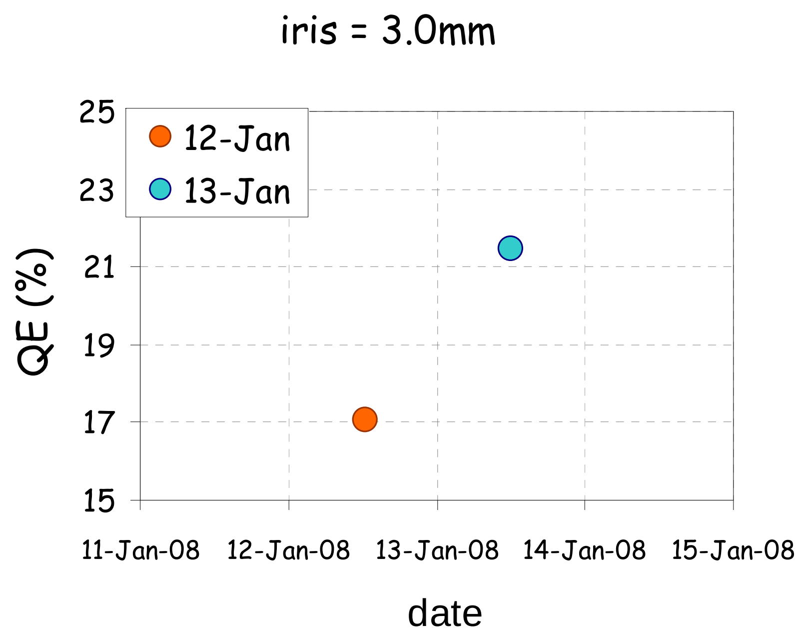
$\beta.\varepsilon$ = **27**



# Pulsed QE measurements
# QE increases in time !?

We observed an increase of the QE from 12 to 13 January !!

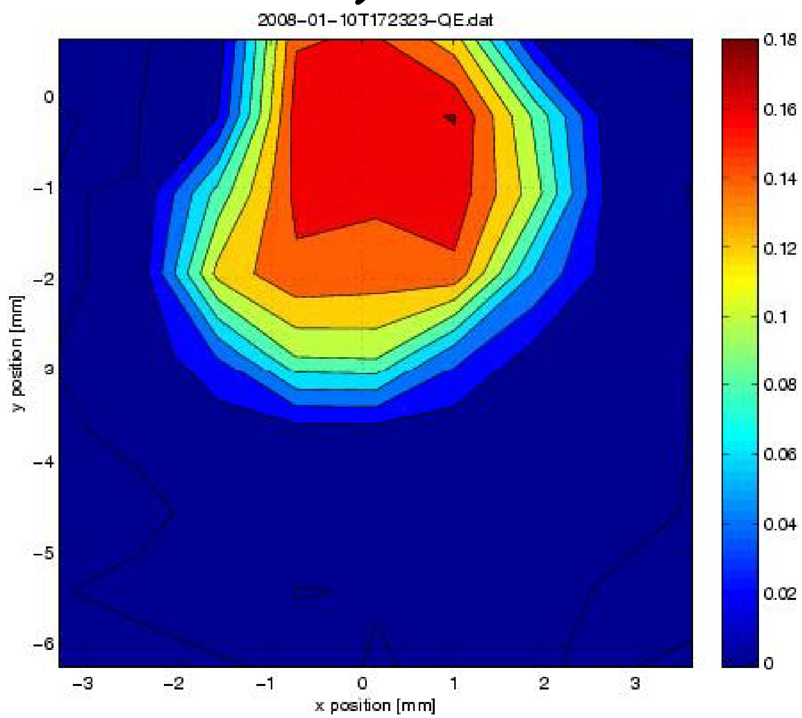


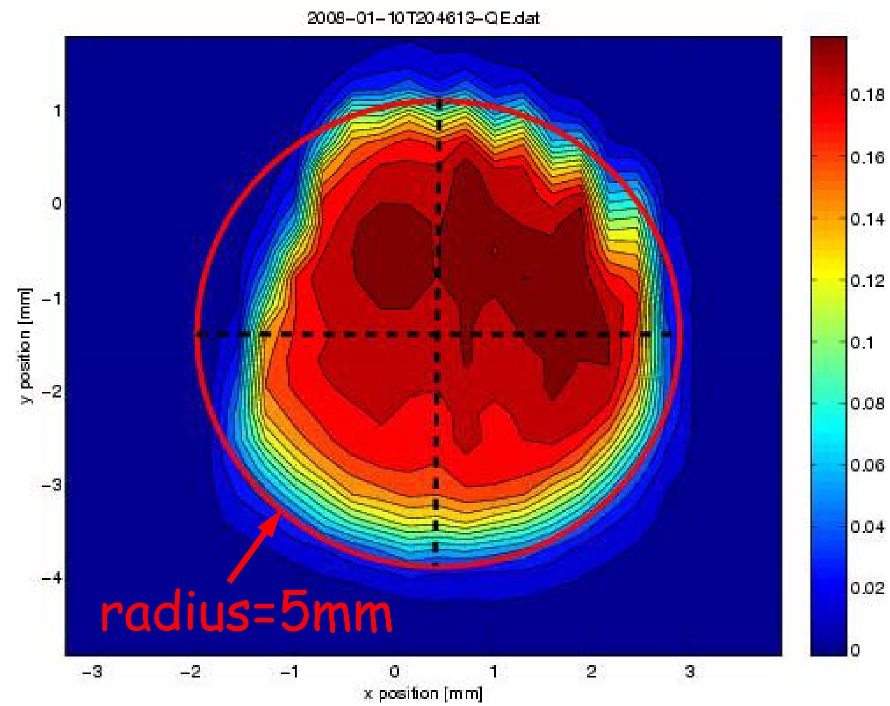

The two measurements have been done in the same condition (accelerating field at the emission of 26.4 MV/m) using irises 2.0mm and 3.0mm.

# QE maps: a tool for laser beam centering

- Nearly a shift dedicated to have the laser beam center on the cathode and able to scan the full 5 mm photocathode spot area (to be ready for the fresh cathodes).



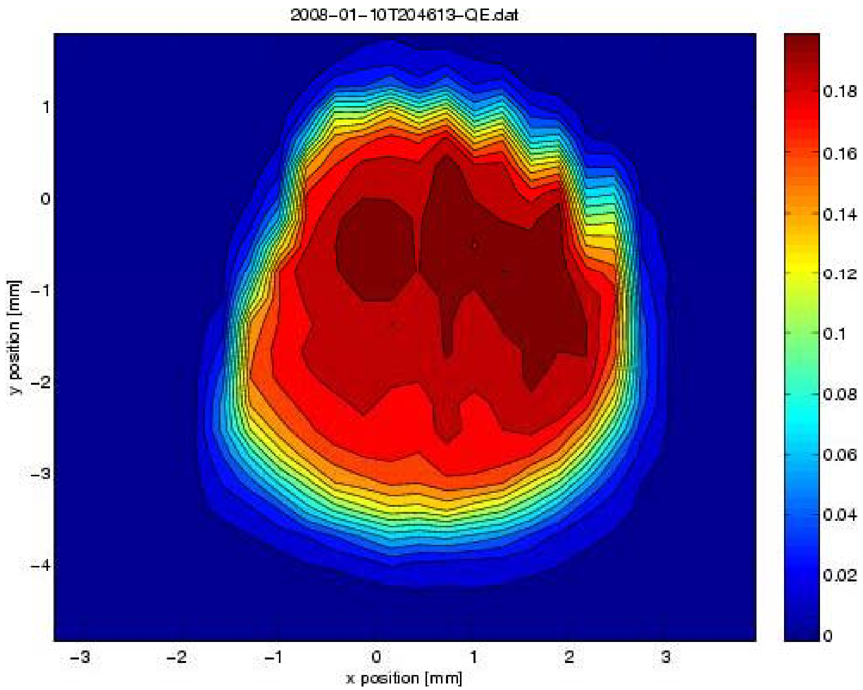

At the beginning of the alignment procedure



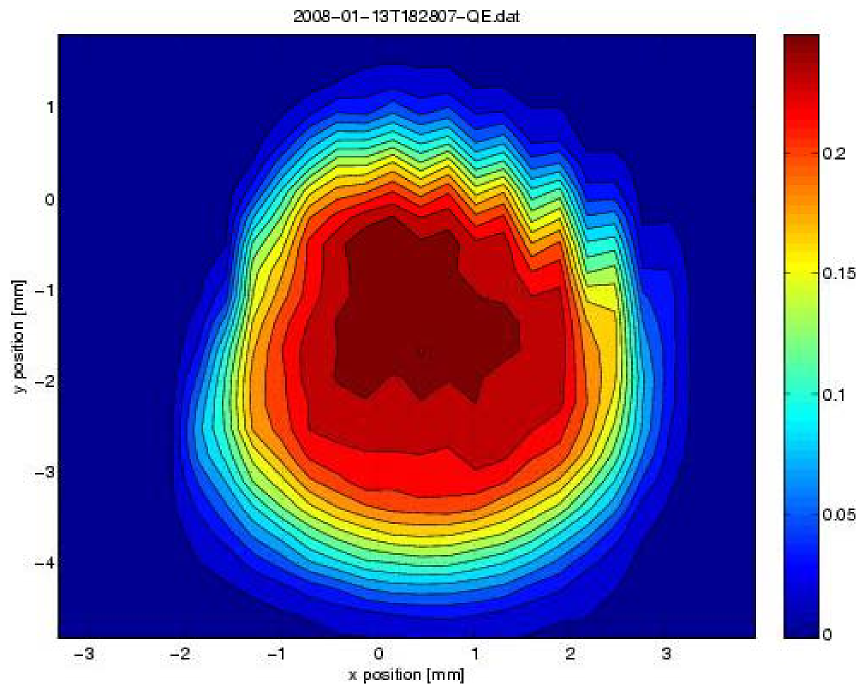

After the alignment procedure

# QE maps: the cathode uniformity

- QE maps at different accelerating fields show a similar uniformity.




Pfwd = 0.44 MW, iris = 17798



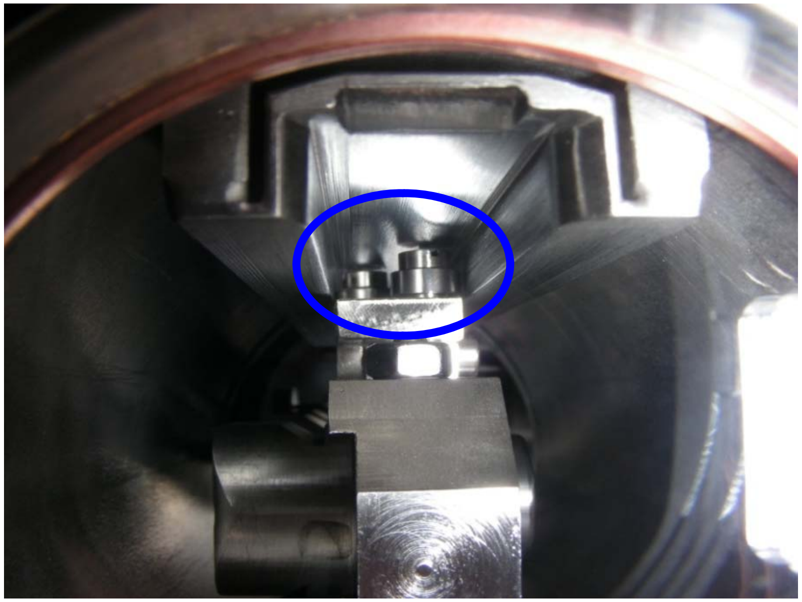

Pfwd = 3 MW, iris = 18032

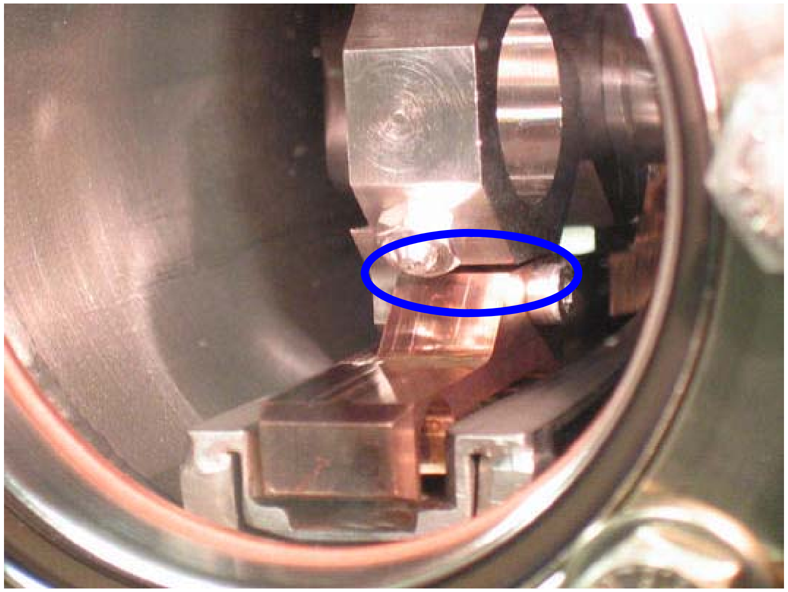
The QE value cannot be compared due to the different dimension of the laser spot size used and missing beam line calibration for tiny spot size

# Carrier movement issue (1)

After the CW QE measurements of the four cathodes stored in the transport box the movement of the carrier into the transfer chamber was not possible.

From the visual inspection from outside the reason might be a lower sliding block misalignment.





In the past, this carrier was used many times at PITZ without problem.

Now it is at PITZ and it moves with some noise (friction).

On the contrary, no problem in the preparation chamber at LASA.

Is it due to different tollerances between the 3 systems?

Problem during the transportation (it would be the first time)?

# Another issue… the dark current (2)

High dark current of fresh cathodes produced for FLASH (February '08).

Analysis (photos) done at PITZ shows that the reason could be the presence of dust particles on the cathode surface.

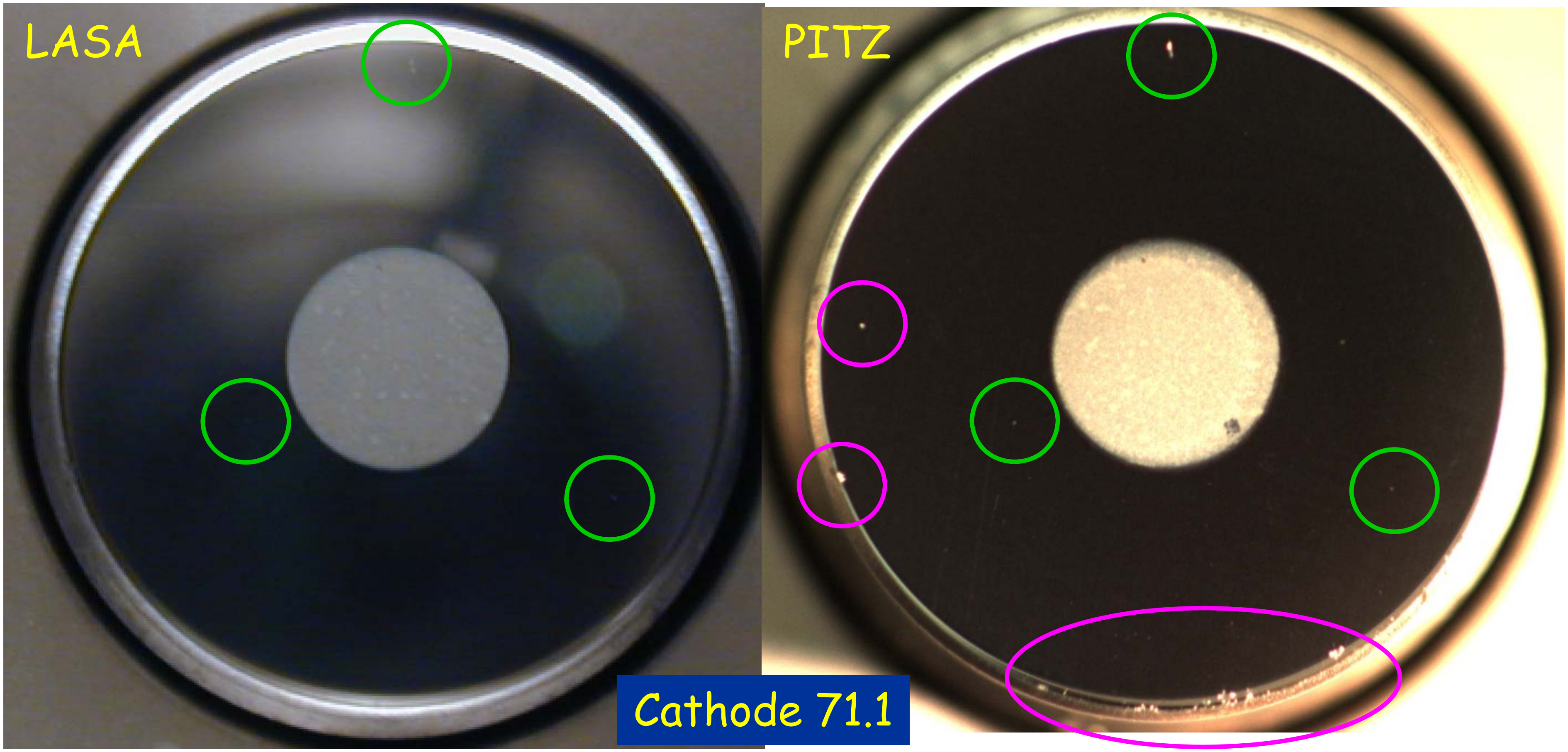
Dust particle sources:

- LASA (missed $N_2$ flushing of the plug before the loading in the carrier, dust in the system?)
- DESY (from the transfer system at FLASH or from the GUN?)

We are comparing the photos of cathodes just after the cathode production ad LASA and the ones taken at PITZ.

It would be useful to know the dust particle nature to understand their origin.

# Another issue… the dark current (3)




after the deposition at LASA after the usage in FLASH gun

Green circles: the dust coming from LASA (no $N_2$ flushing, system?)
Pink circles: the dust coming from FLASH (gun? transfer system?)

# Conclusion

- CW QE measurements:
  - Experimental set-up in the tunnel
  - The CW QE of 4 cathodes has been measured @ FLASH
  - QE stable in time: validation of the transport box environment
- Pulsed QE measurements:
  - Laser beamline transmission calibration at 3 irises
  - QE vs. irises and accelerating field
  - Analysis of the pulsed QE measurements:
    - $E_{acc}$, RF phase, etc.
  - Still to be completed with comparison with simulation
  - QE maps used to check the centering between the laser spot and the photoemissive film. It is also used to control the uniformity at different accelerating field.
- Carrier movement issue & dark current
  - Analysis of the sliding system
  - Sources of dust
- For the future
  - We need to further study the influence of the field on the QE measurements and understand the behavior at low fields (2 mm iris case).
  - Error analysis