Cathode Operation at FLASH

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Overview FLASH

Cathode System

Operational Issues

Summary

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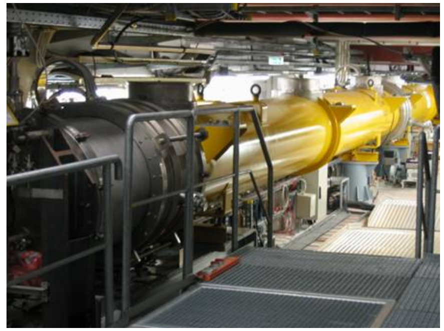
High QE Photocathodes for RF Guns

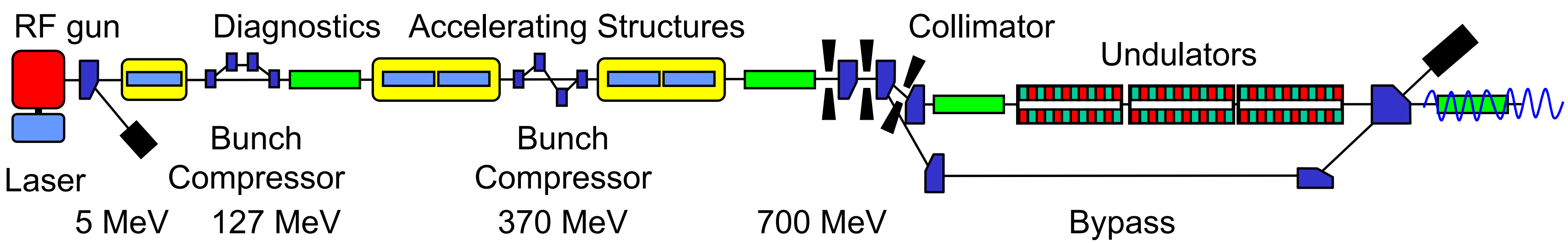
The TTF/VUV-FEL has a new name

- Stimulated by the users of the VUV-FEL and the first exciting results obtained, the suggestion was made to find a compact name for the facility which is more attractive and easier to pronounce in different languages
- On 6th April 2006 the DESY directorate decided for the new name FLASH instead of VUV-FEL

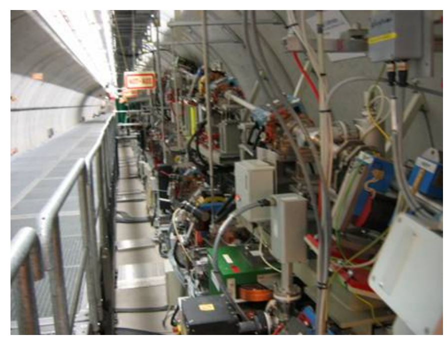
FLASH

FLASH Overview

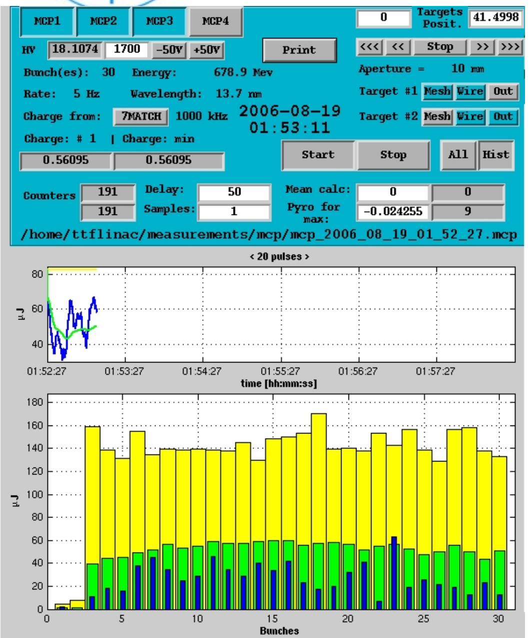


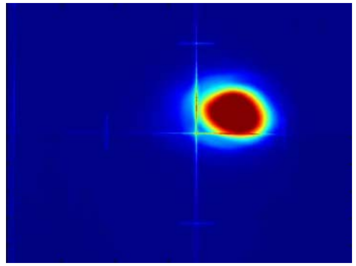





250 m

Best SASE Performance so far





Multibunch SASE signal (μJ) recorded with MCP detector

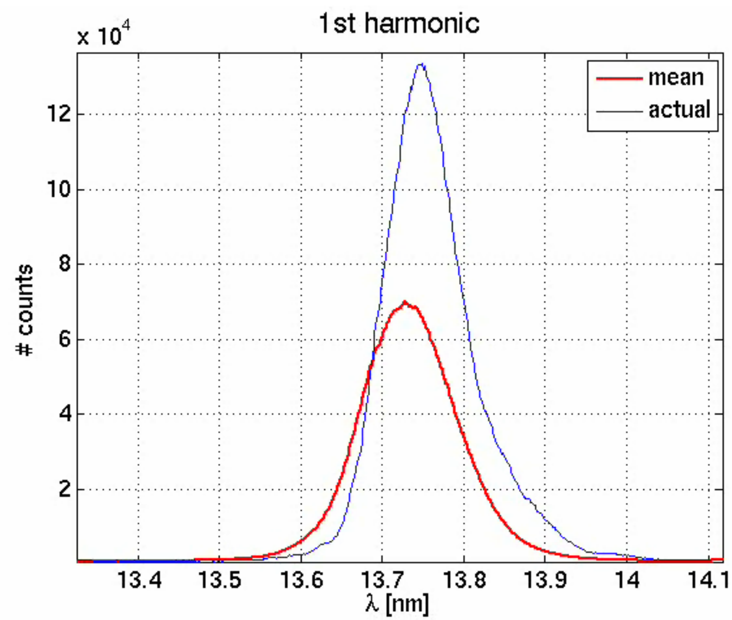
max

single

average

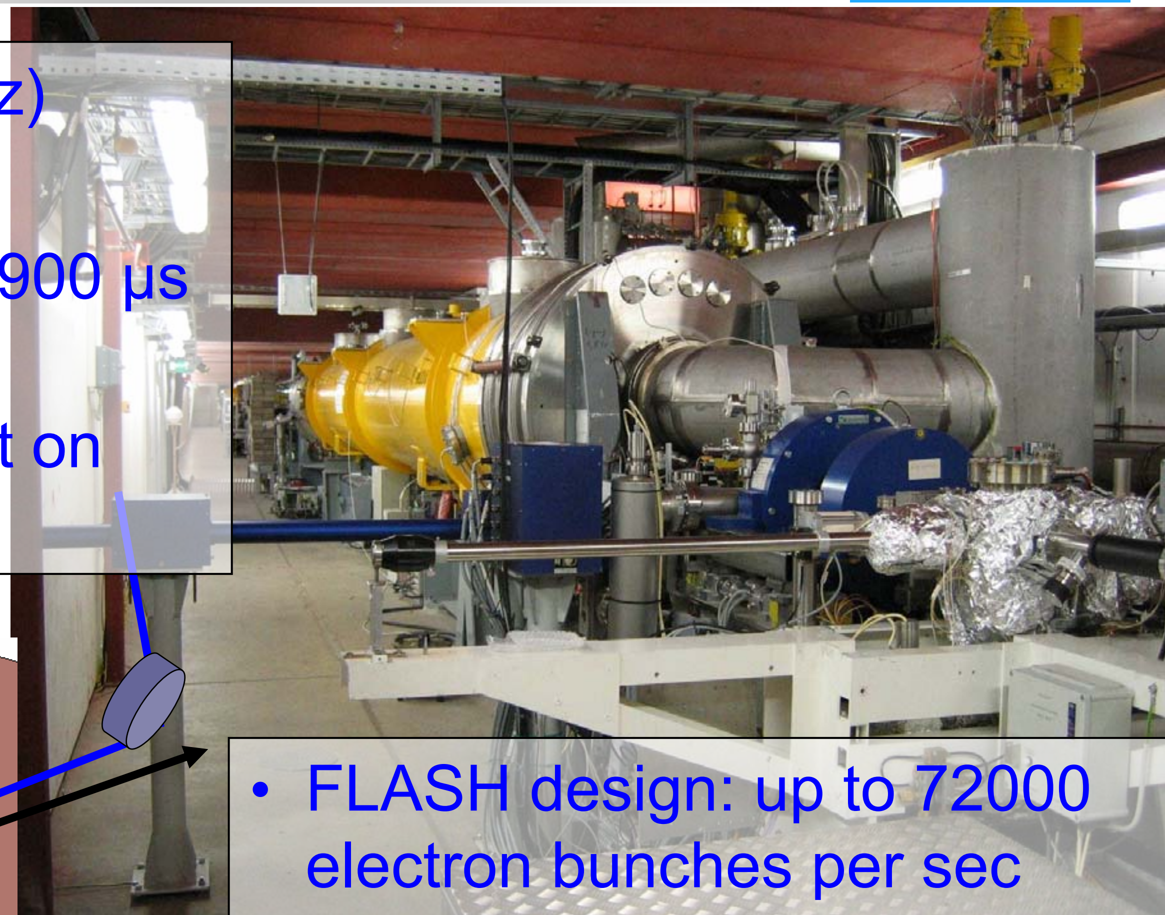
- Averaged at 13.7 nm exceeds 70 μJ
- Peak radiation energy ~170 μJ,
- Pulse duration estimate around 10 fs.
- Peak power well exceeds 5 GW
- *SSY: "This is nearly ultimate performance for the present machine configuration in both aspects, minimum wavelength and maximum radiation energy."*

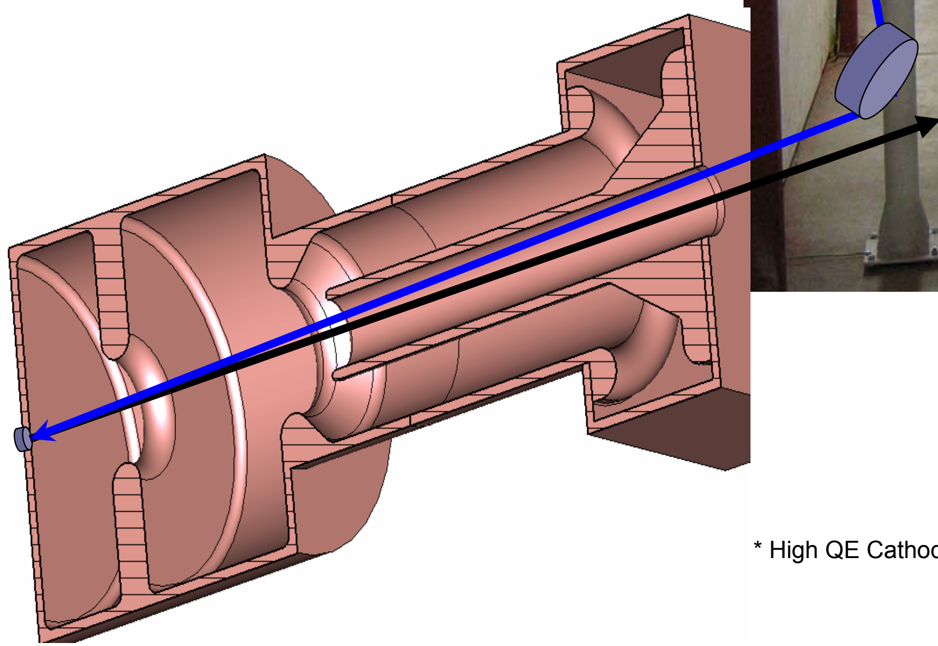
- Wavelength range (fundamental): 13-47 nm
- Pulse energy average: 100 μJ
- Pulse energy peak: 200 μJ
- Peak power: ~ 5 GW
- Average power: > 100 mW
- Pulse duration (FWHM): 10-50 fs
- Spectral width (FWHM): 0.5-1 %
- Peak brilliance: $10^{29} - 10^{30}$ B



RF gun section

- L-band rf gun (1.3 GHz)
- Pulsed 5 or 10 Hz
- RF pulse length up to 900 µs
- RF power 3.2 MW or 42 MV/m max gradient on cathode



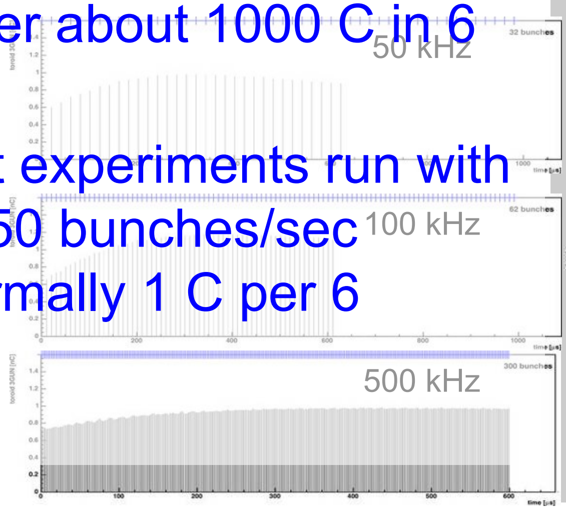


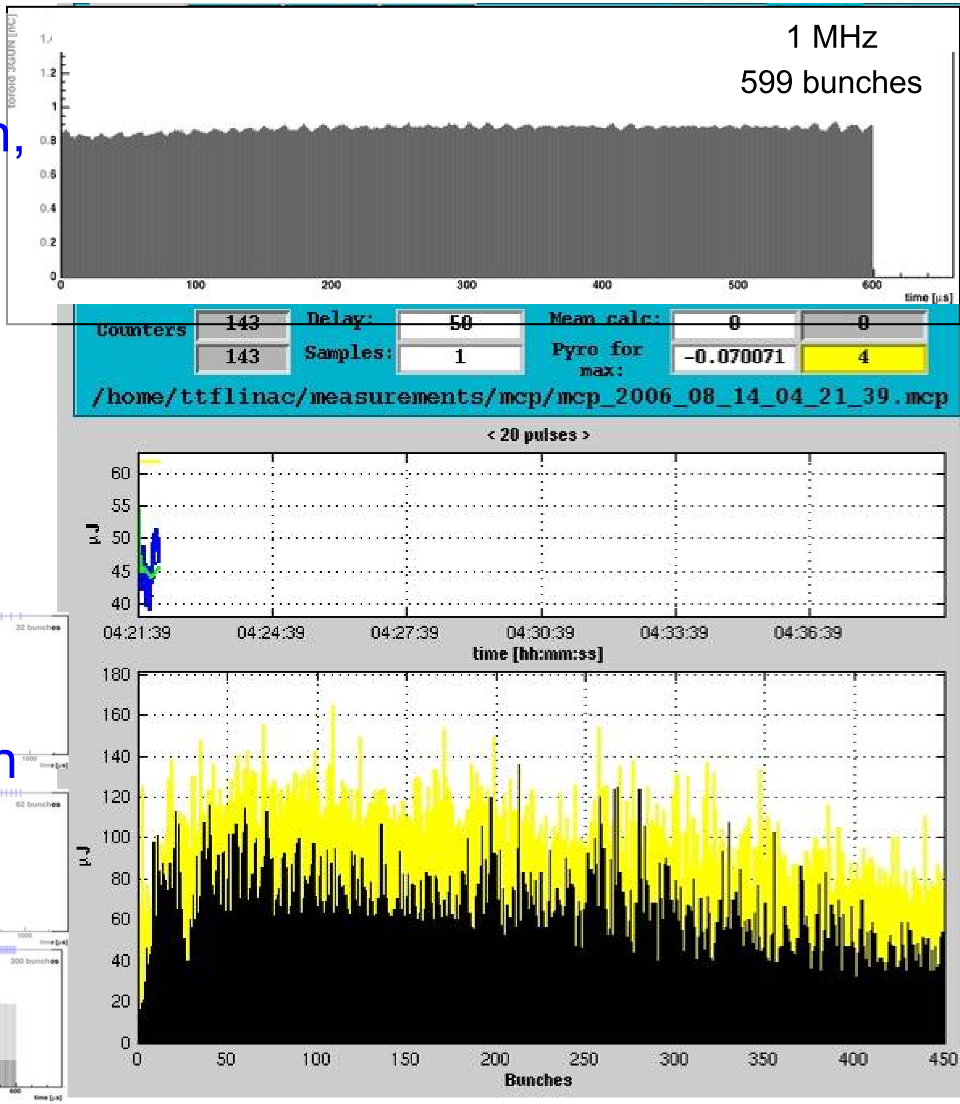
- FLASH design: up to 72000 electron bunches per sec
- Laser system average power in the Watt range
- Requires high QE cathodes

Example for long bunch trains

Cathode must deliver

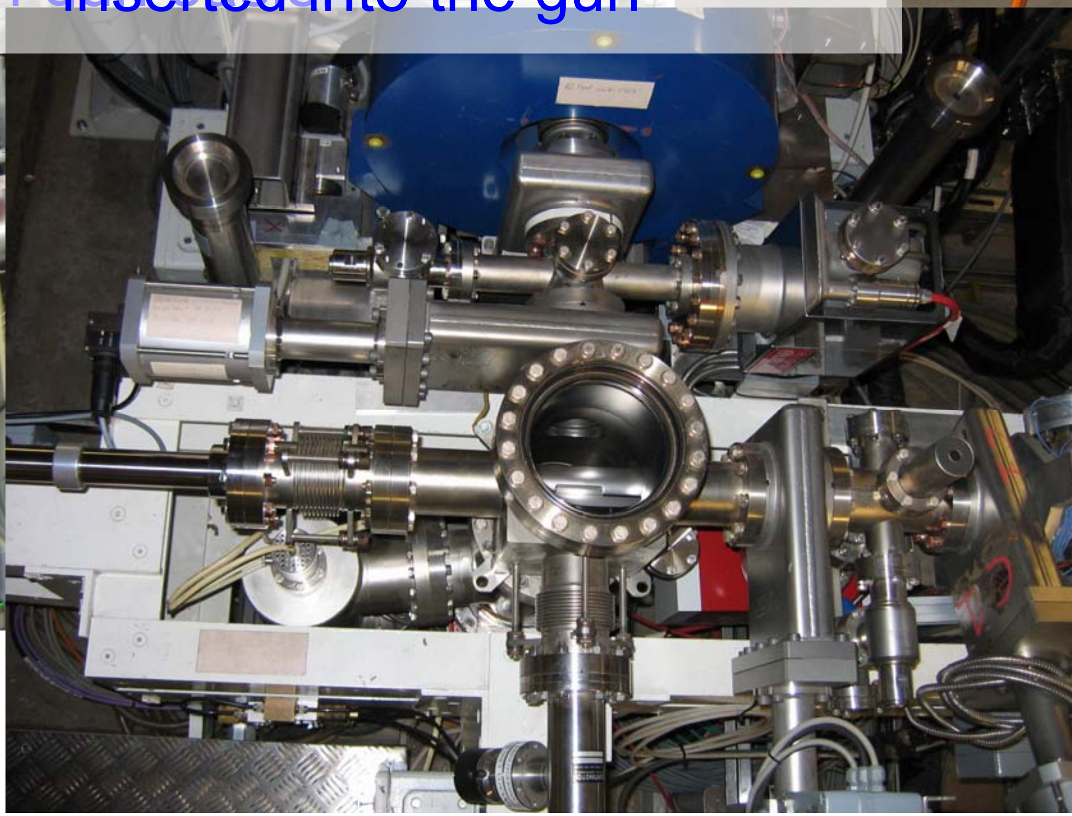
- Up to 800 bunches (1 MHz) per train, 1 nC/bunch (1 mA)
- Design goal:
  Up to 7200 bunches (9 MHz), 9 mA
- Peak current/bunch 100 A
- Rep.rate 5 or 10 Hz
  → up to 72 µC/sec
  → should deliver about 1000 C in 6 months
- Currently, most experiments run with an average of 50 bunches/sec
  → delivers normally 1 C per 6 months





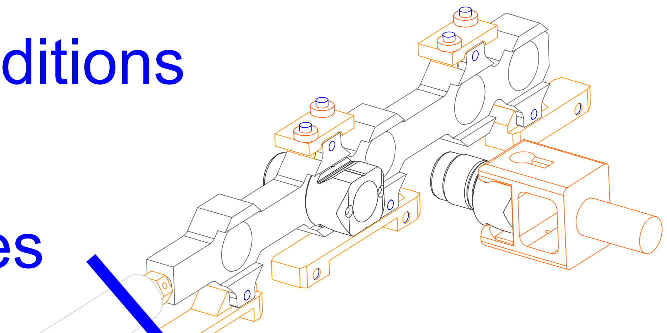
Cathode System

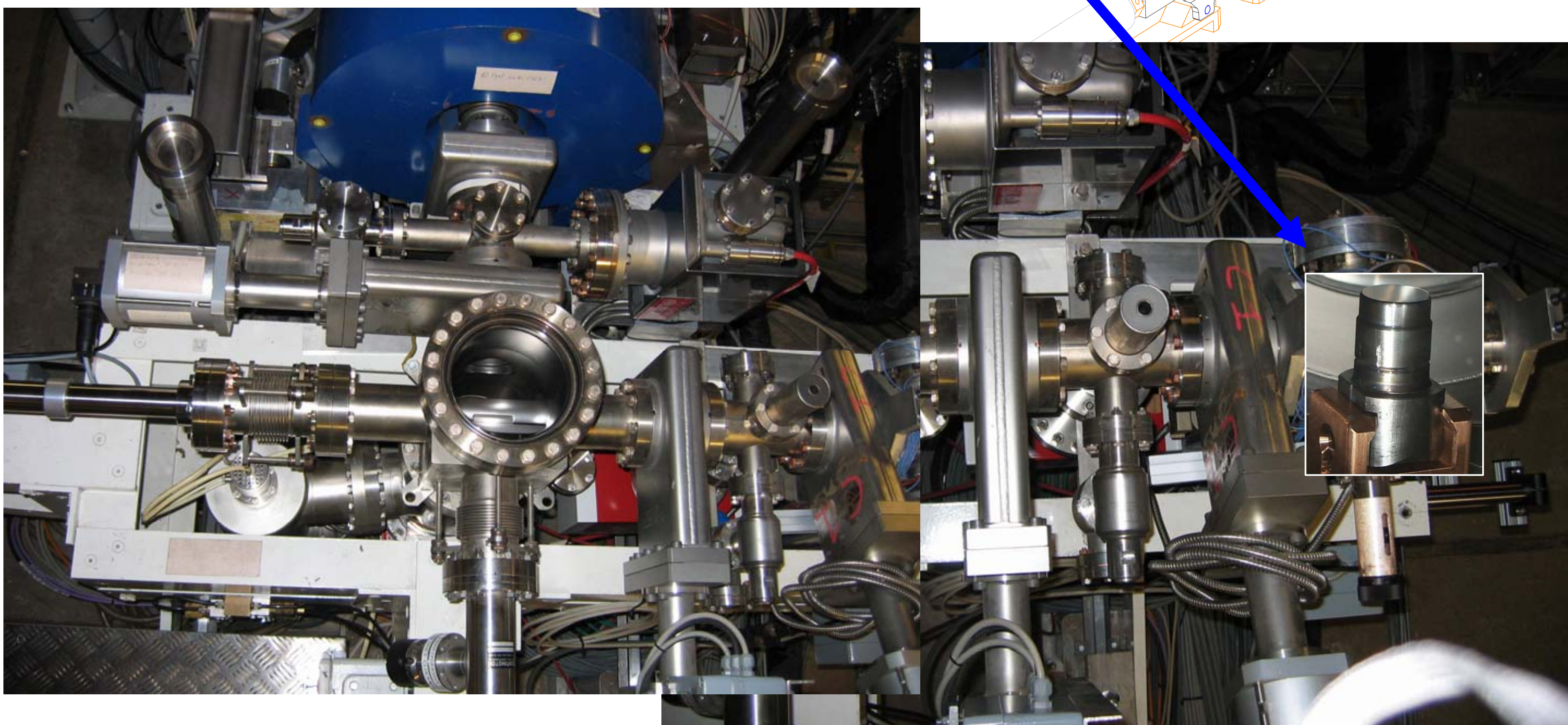
- Cathode system from the top: main chamber, where the plugs are picked and inserted into the gun



Cathode System

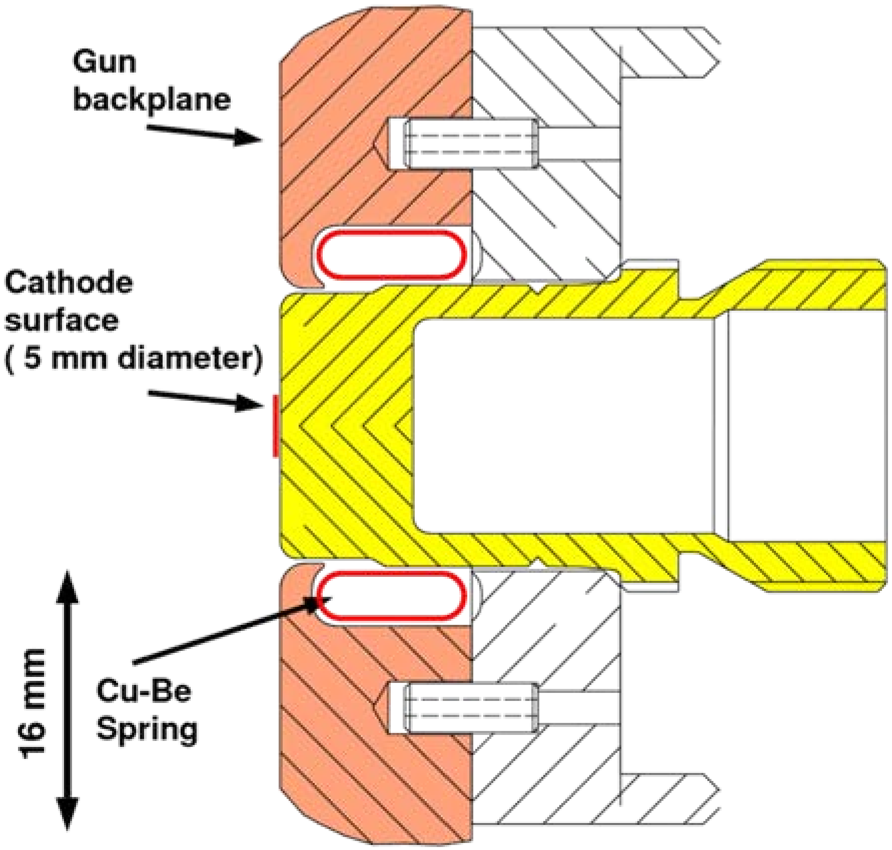
- Cs_2Te cathodes stay under UHV conditions
- Cathode preparation not in situ
- Transport of cathode in vacuum boxes

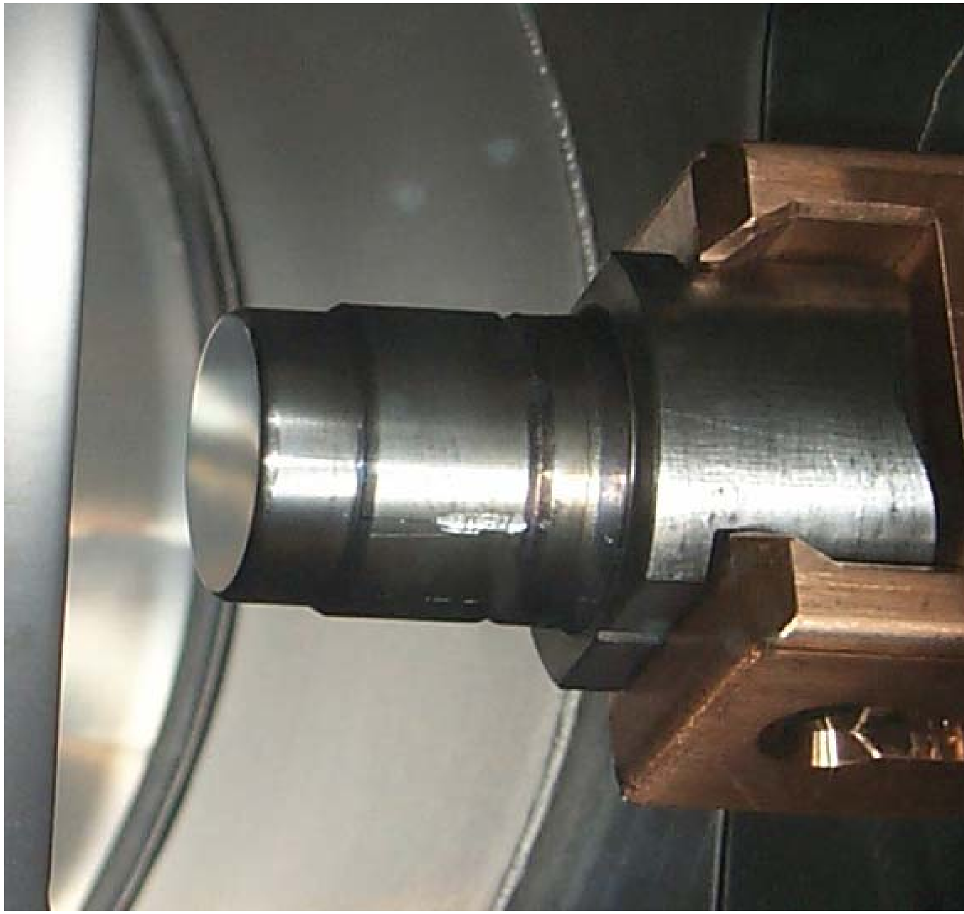




Cathode

- Cathode: Cs_2Te film on a molybdenum plug
- RF contact with silver coated Cu-Be spring



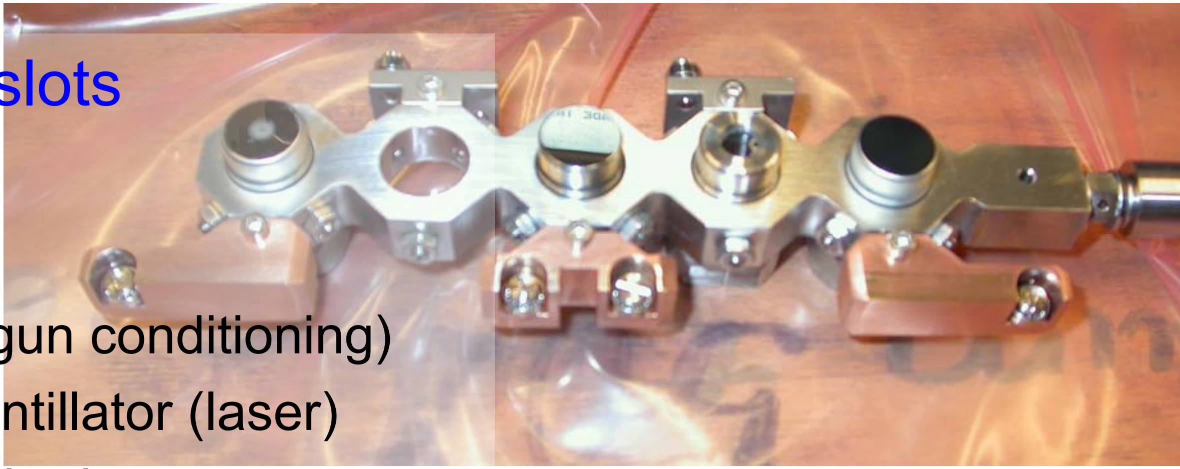


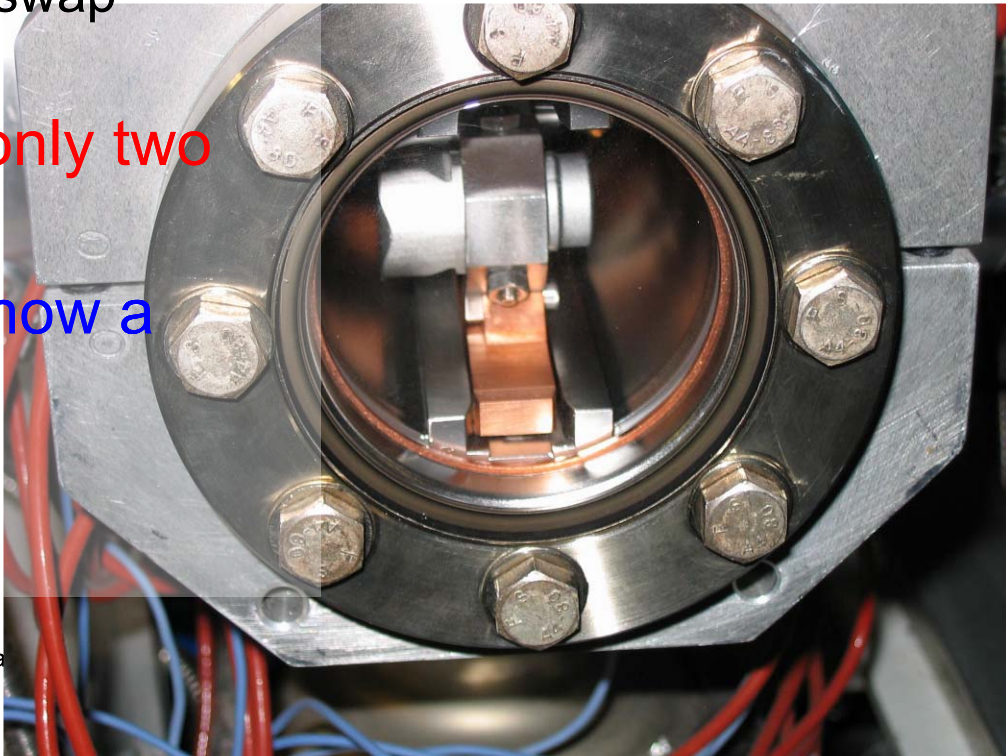
Carrier

- The carriers have 5 slots
- Usually, we use
  - 2 Cs_2Te cathodes
  - 1 blank Mo plug (gun conditioning)
  - 1 Mo plug with scintillator (laser)
  - 1 empty slot (required to swap cathodes)

→ conservative choice, but only two fresh cathodes available

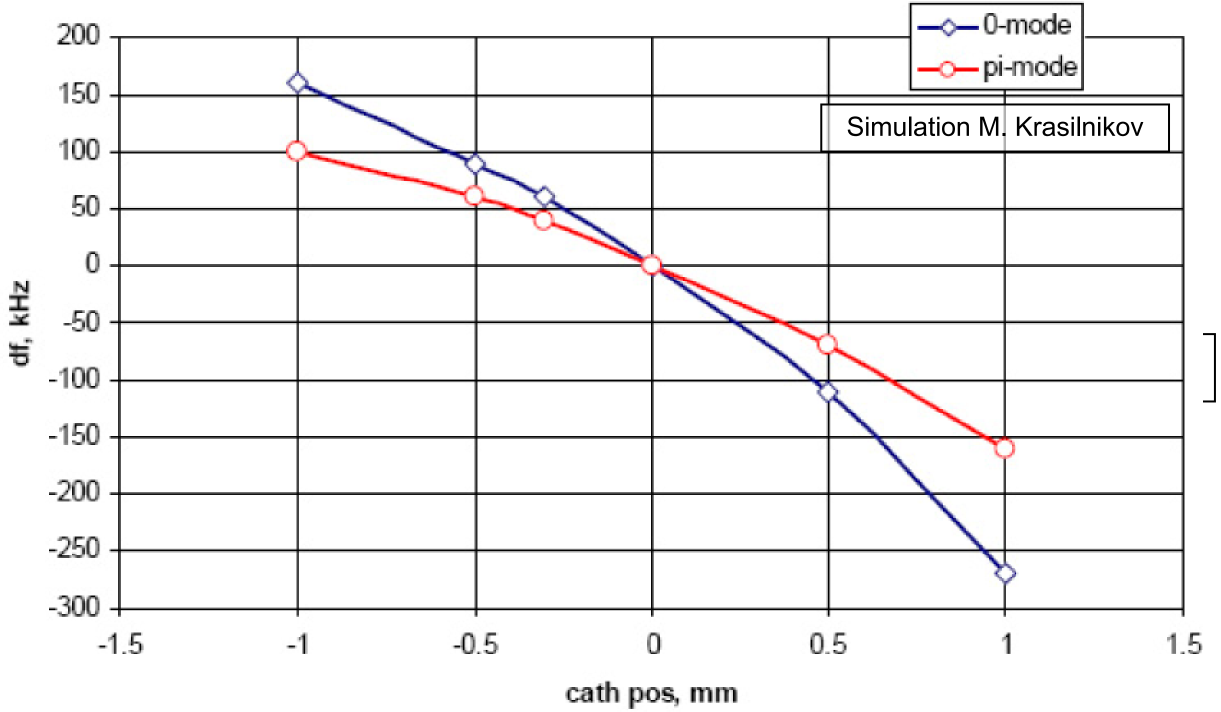
- For the first time we have now a carrier with
  - 4 Cs_2Te cathodes
  - 1 empty slot





Cathode Insertion precision

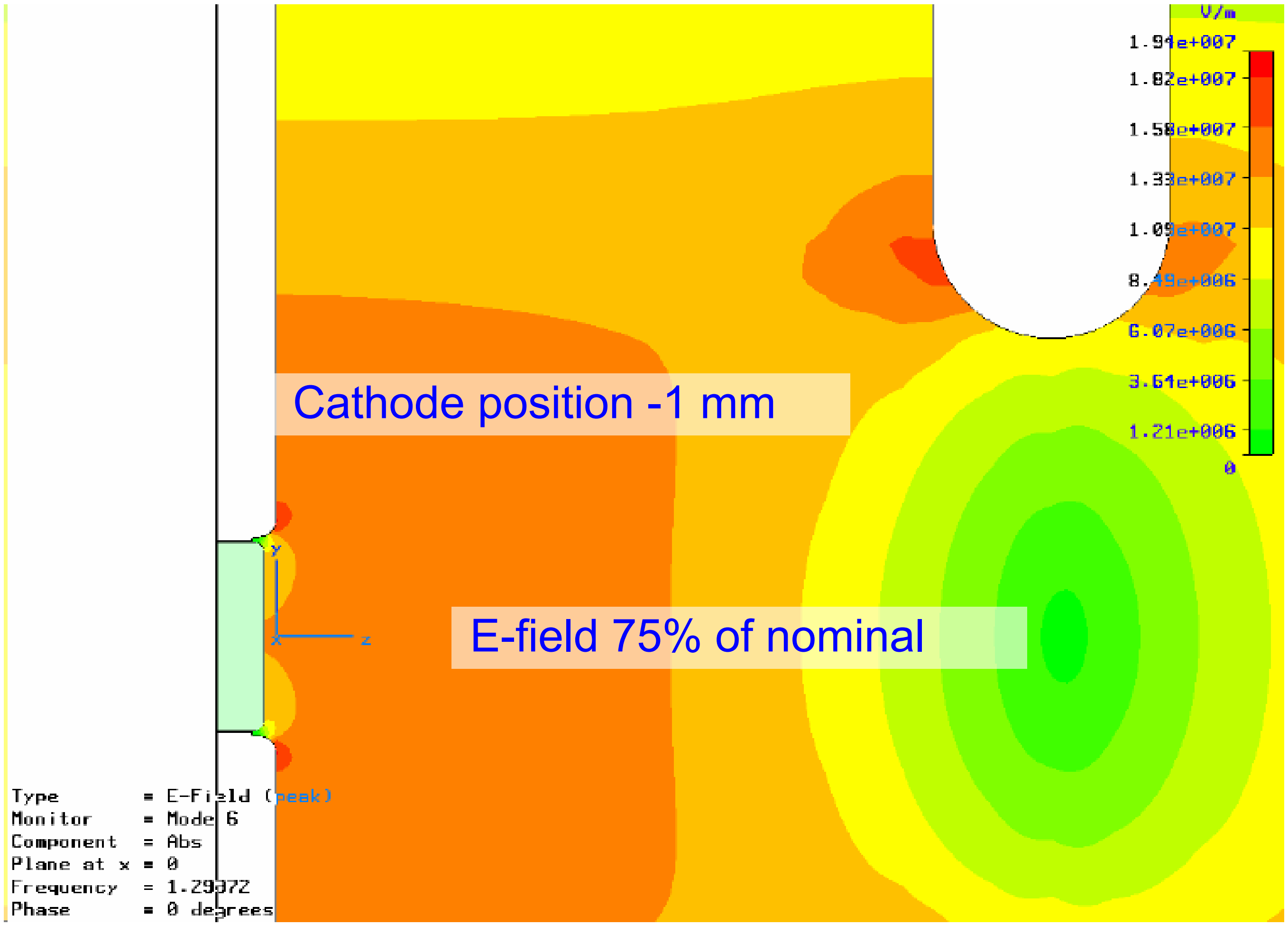
- Cathode insertion: there is an uncertainty, where it ends up



- Slight retuning of rf gun water temperature required after each cathode change, sometimes 2 dgC, sometimes 0.2 dgC
  $\rightarrow$ df = 4 to 40 kHz or dz = 35 to 350 µm
- Measured df (cathode in/out) = 330 kHz, -21.7 kHz/dgC

2D E-field of pi-mode

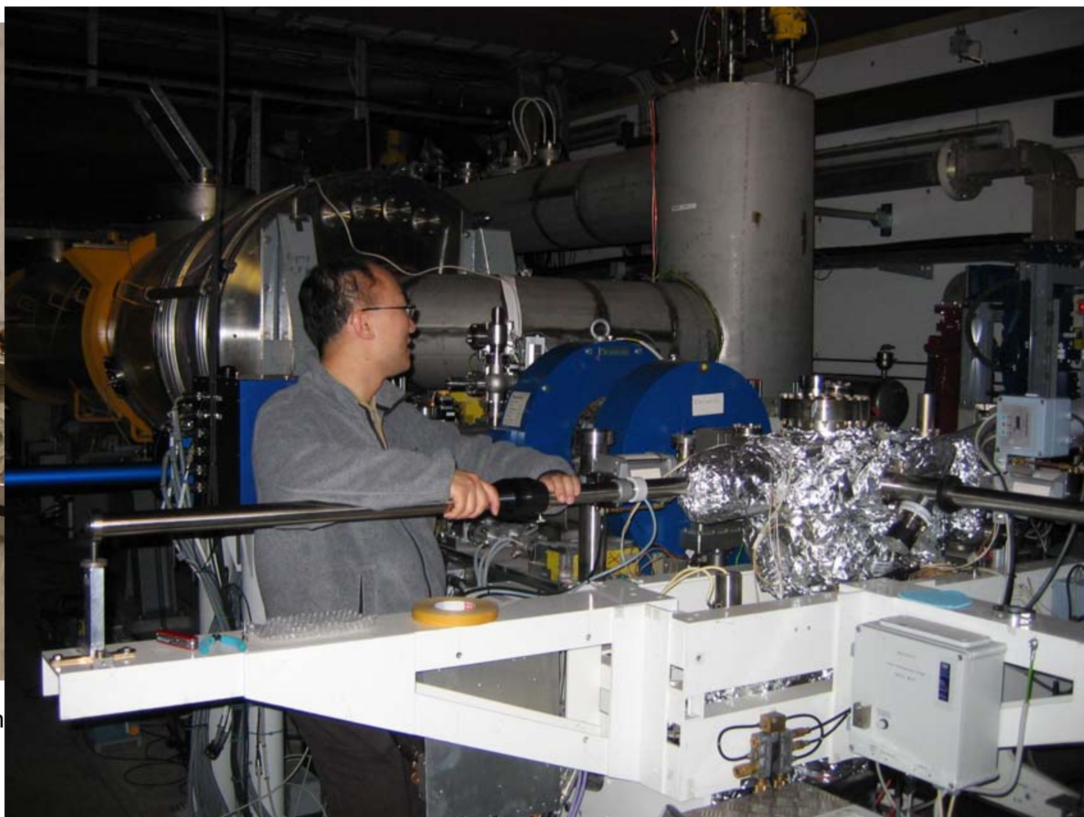
- Not correctly positioned cathode led to a reduction of accelerating field on the cathode surface



Simulation M. Krasilnikov

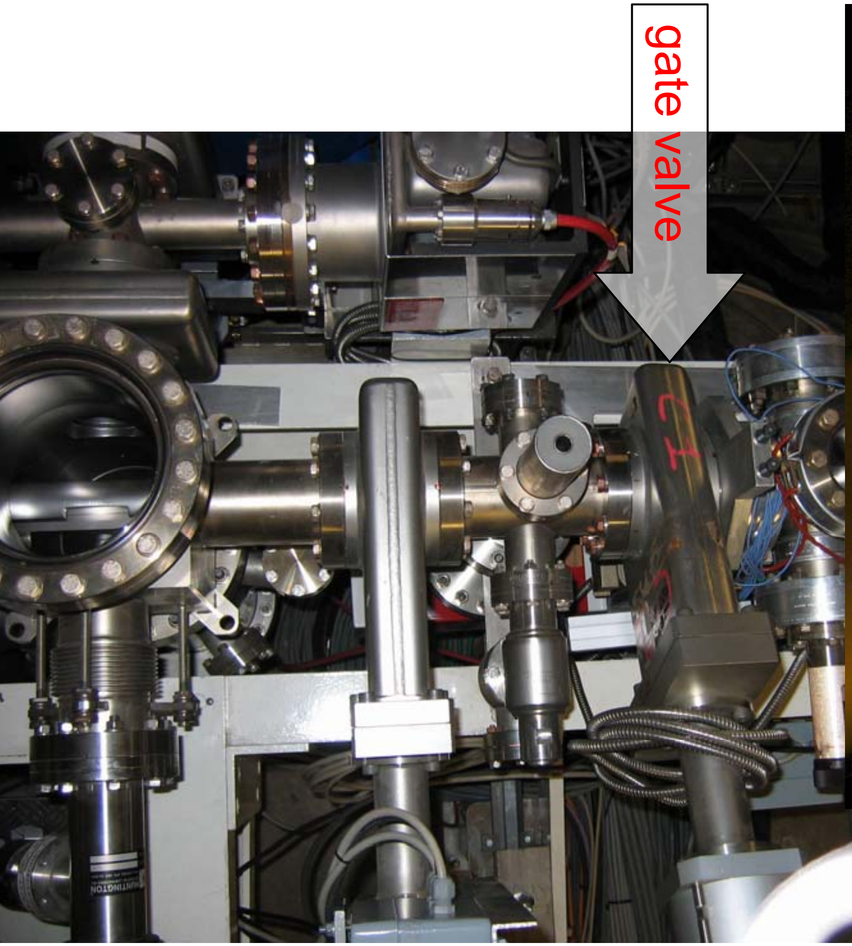
Handling of cathodes difficult

- Replacing cathodes with manipulators difficult, especially catching the carrier
    - “soft feel” of the magnetic coupled actuator
    - Lack of visibility
- Seams only be possible by hand

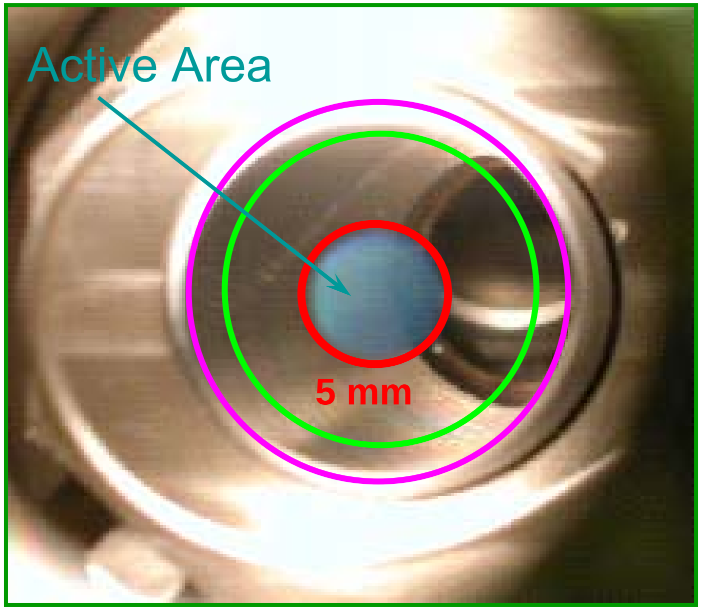


Accidents during cathode handling

- Accidental closing of vacuum valves into components possible – and happened twice at PITZ and once at FLASH
- Need to develop an interlock scheme



Cathode Size

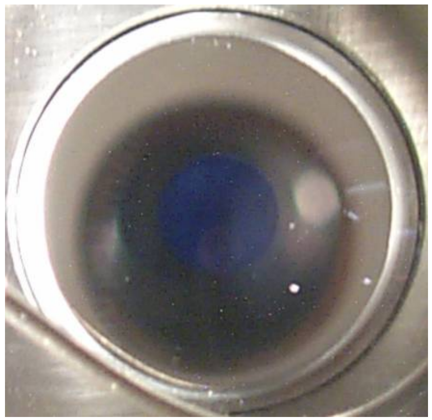


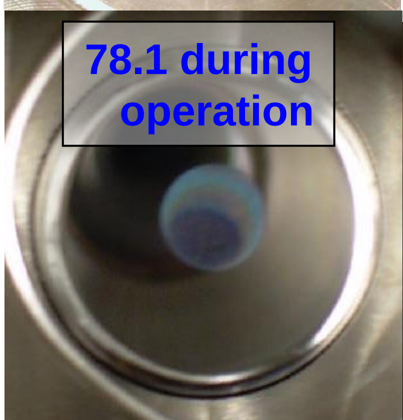
- A circular masking system shapes the emissive layer
- centered on the plug
- Since there is only one mask in the preparation system, we need to chose one
- Present choice: diameter = 5 mm

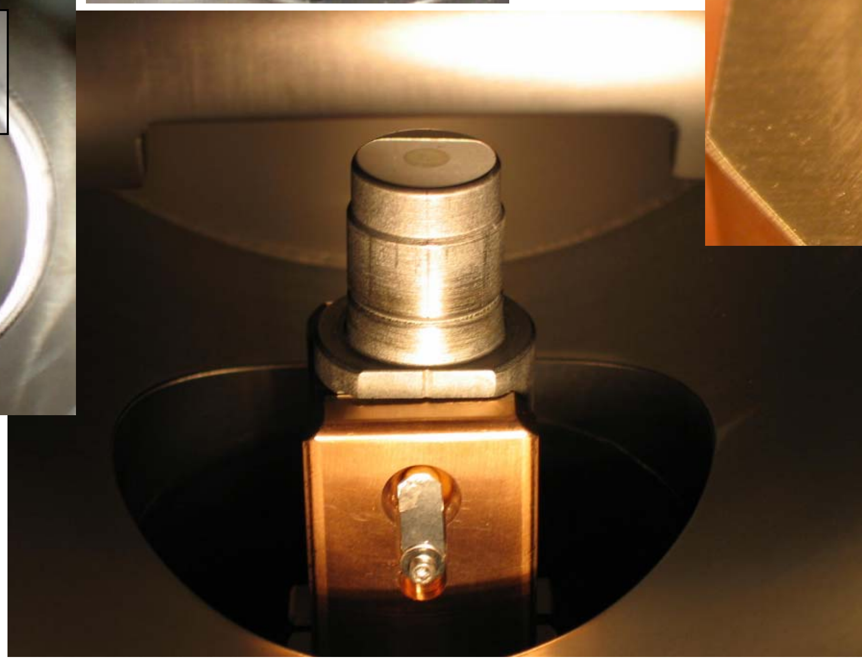
- From the laser point of view:
  - Best would be to chose the optimum size in terms of emittance: 3 mm in our case
  - Overfill the cathode with the laser (gain in pointing stability and homogeneity)
  - Needs a precisely centered and homogeneous layer
- Prep chamber with variable cathode size option required

Cathode after usage

- Cs_2Te thin film layer may be damaged after usage in the rf gun

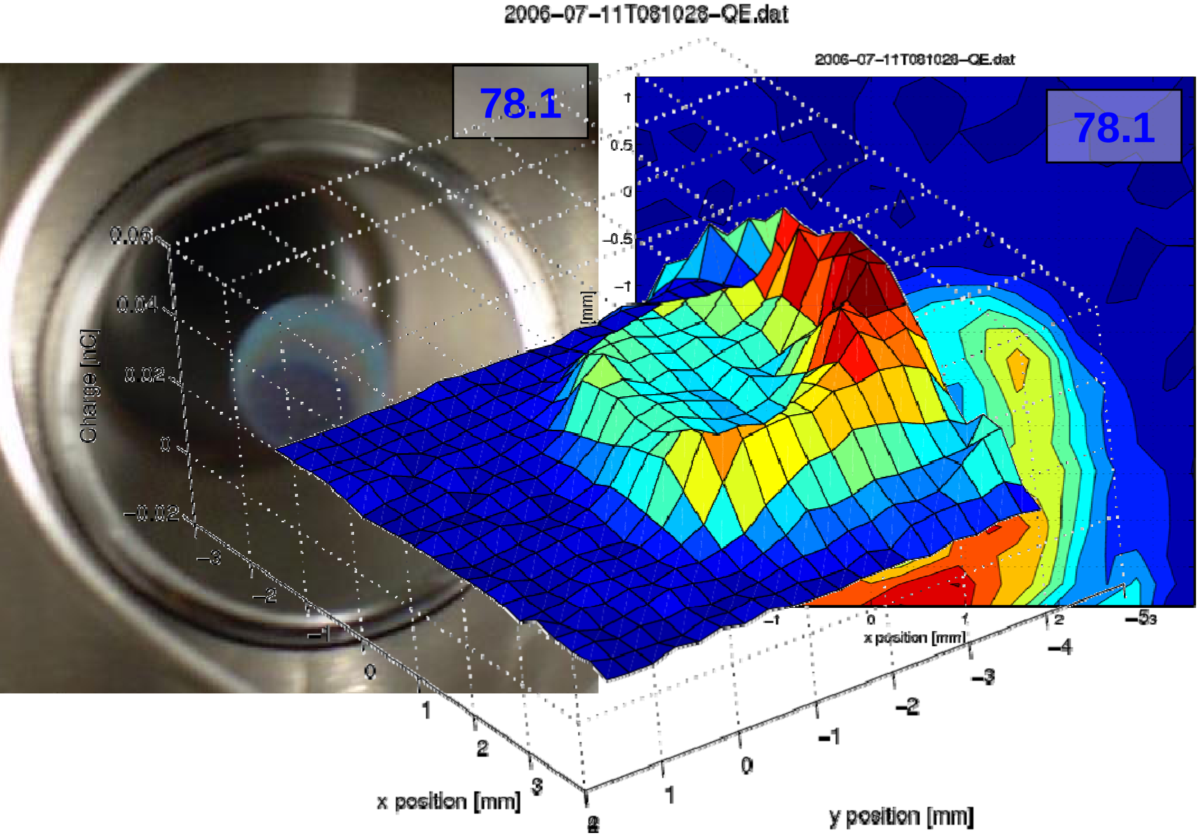


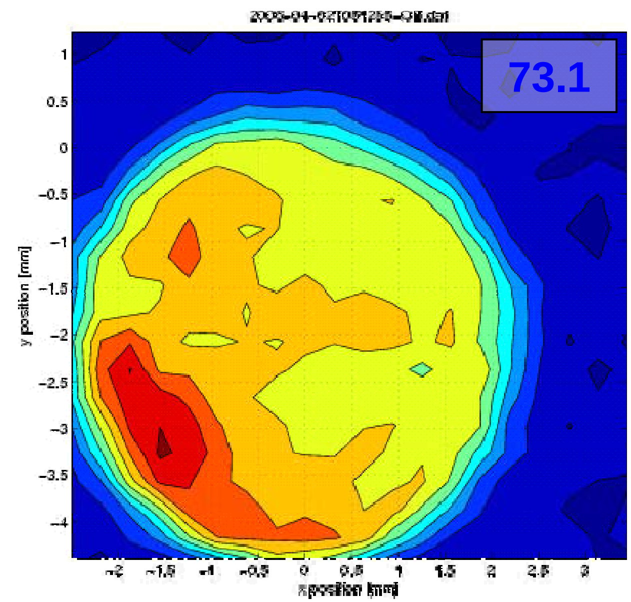




QE maps

- QE map: scan with small laser spot (200 µm) over the cathode (step size 300 µm)
- useful to diagnose status of cathode uniformity

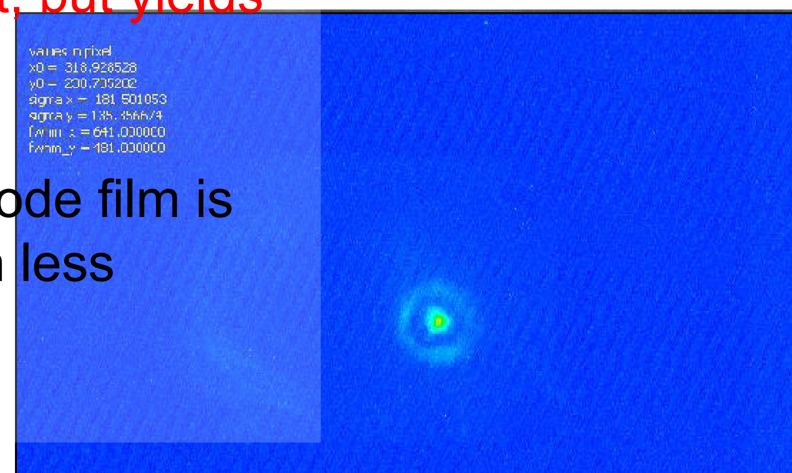




Alignment of Laser

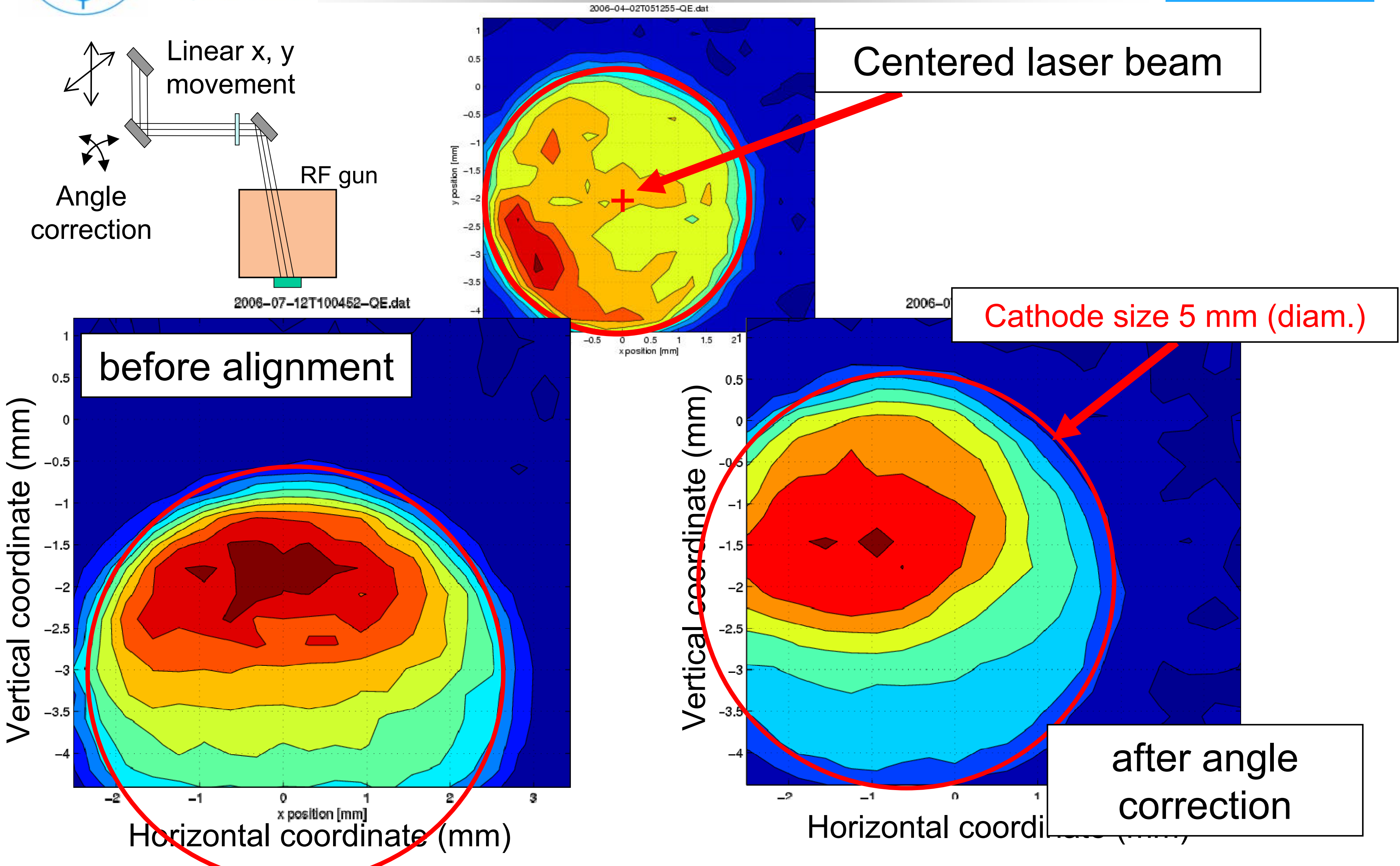
- Initial alignment of laser beam onto the cathode using a scintillator mounted into the plug

- Fine adjustment with
  - Beam based alignment (electron beam position as a function of rf phase for low charge, solenoids off) → time consuming (2 shifts) an difficult, but yields center in respect to rf, precise
  - Scan laser over cathode → scan is fast, but assumes that cathode film is centered in respect to the rf, correction less accurate



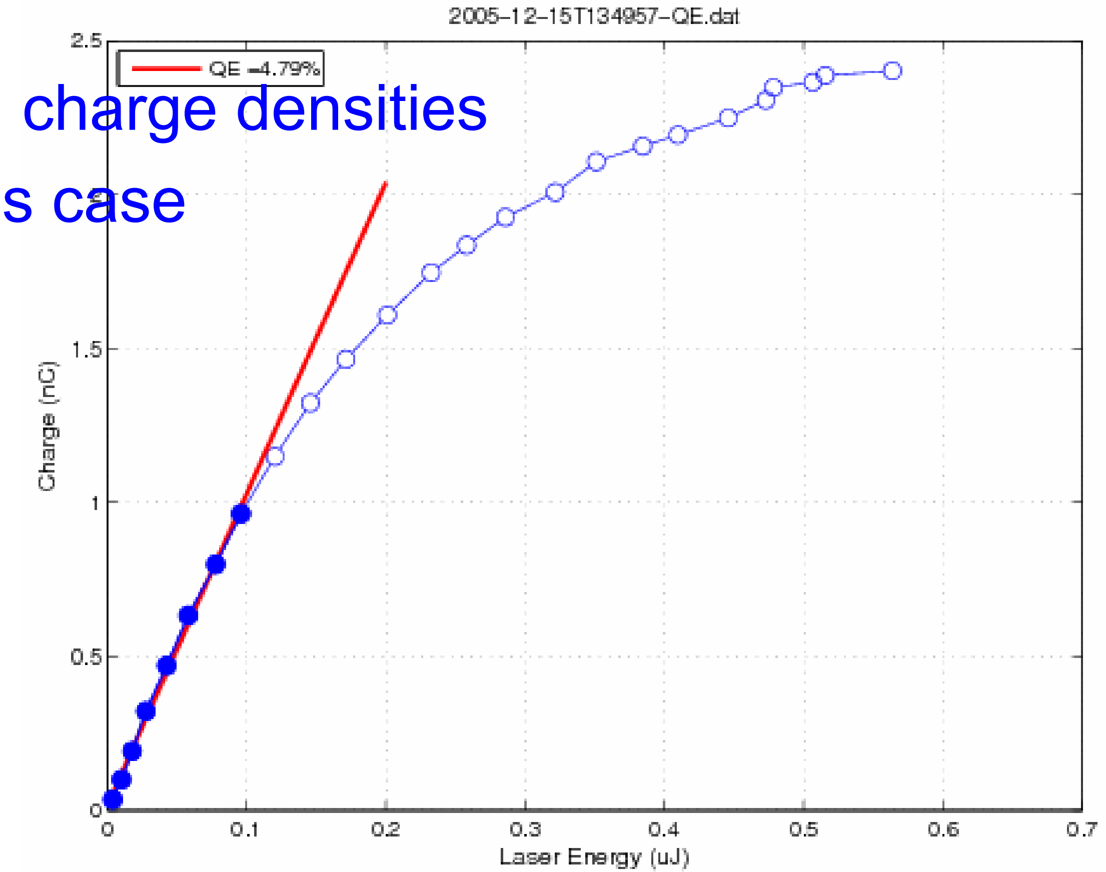
darkcurrent ring may also be used for rough alignment

Alignment using QE scans



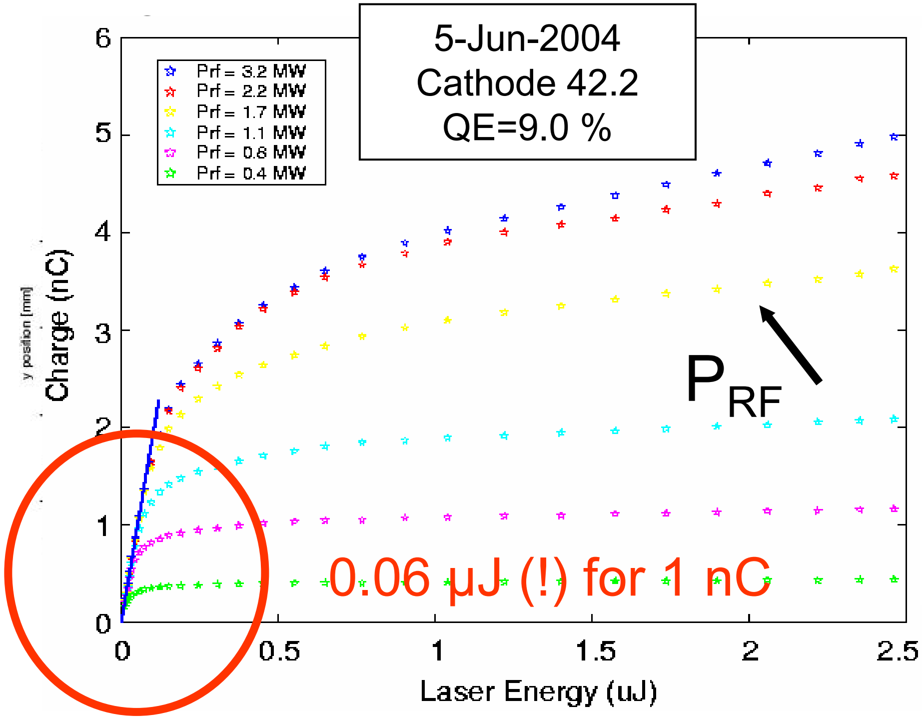
Quantum Efficiency

- Example of a QE measurement:
  charge at rf gun exit as a function of laser pulse energy
- Linear fit at small charge densities
- QE = 4.8 % in this case

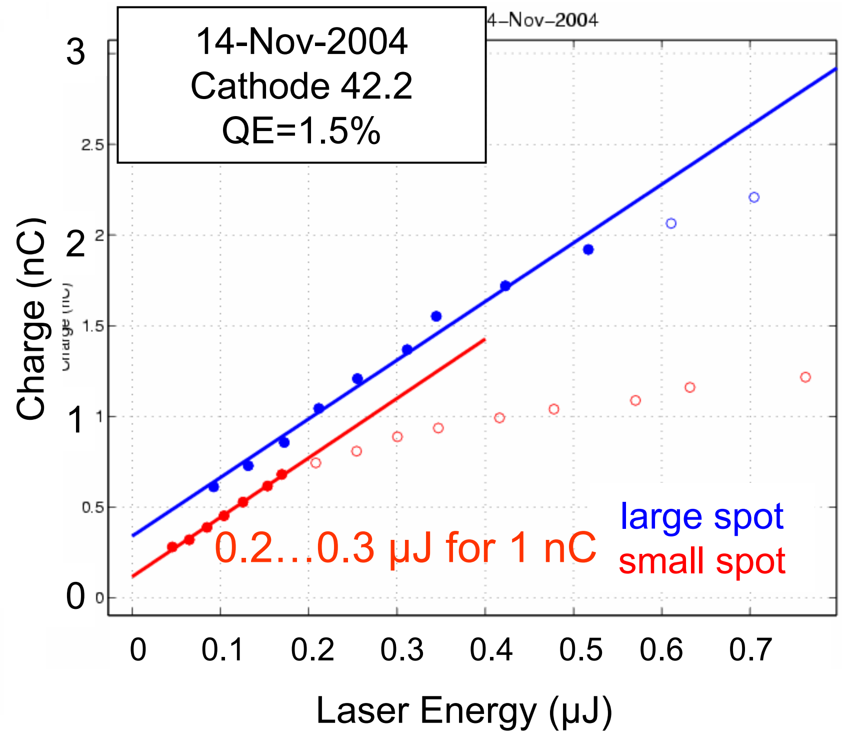


QE development with time

- In 2004/2005, the cathode lifetime was > 6 months
- Lifetime ends, if QE < 0.5 %
- Example for cathode 42.2: drop with 5 months from 9 to 1.5 %

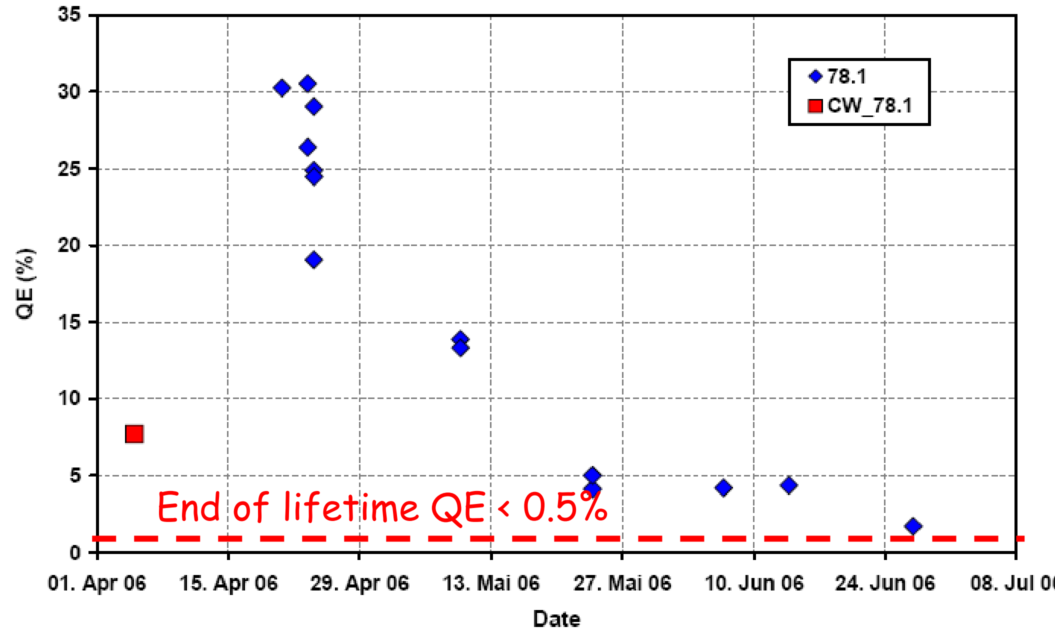


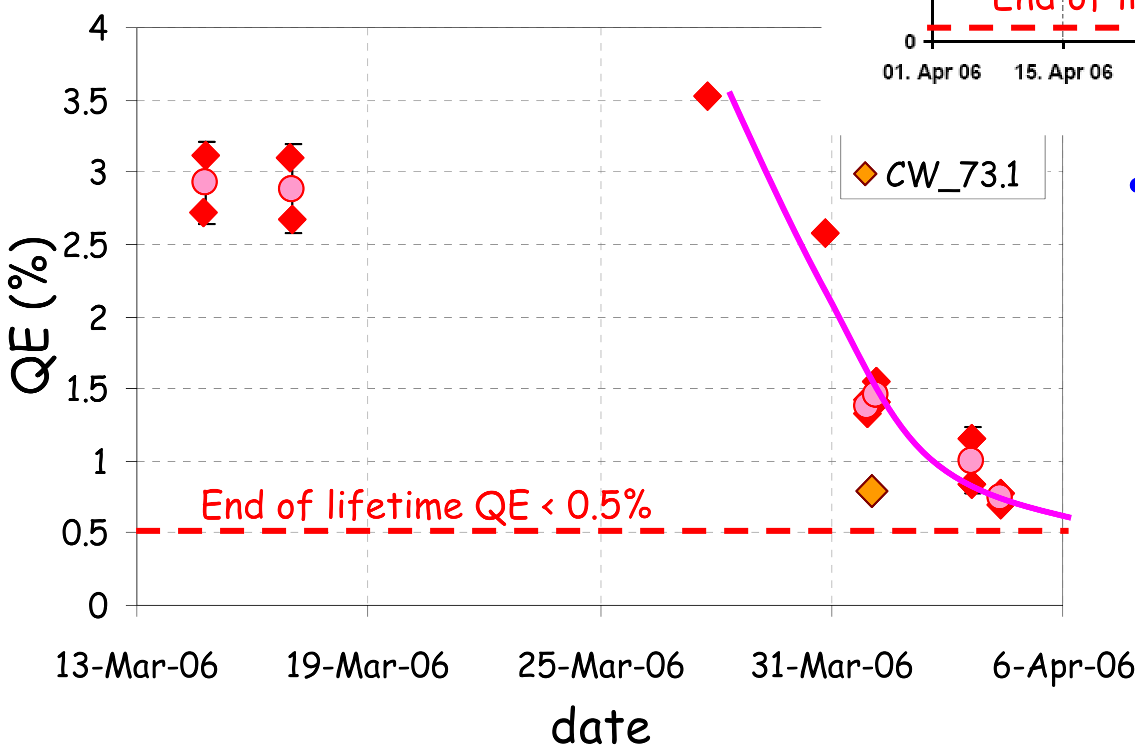
QE(%) = 0.5*Q(nC)/E(µJ)



Cathode lifetime

- Early 2006 we observe a more rapid decrease of QE:
  to a level of 0.5 to 1 %
  within 2 months (78.1)

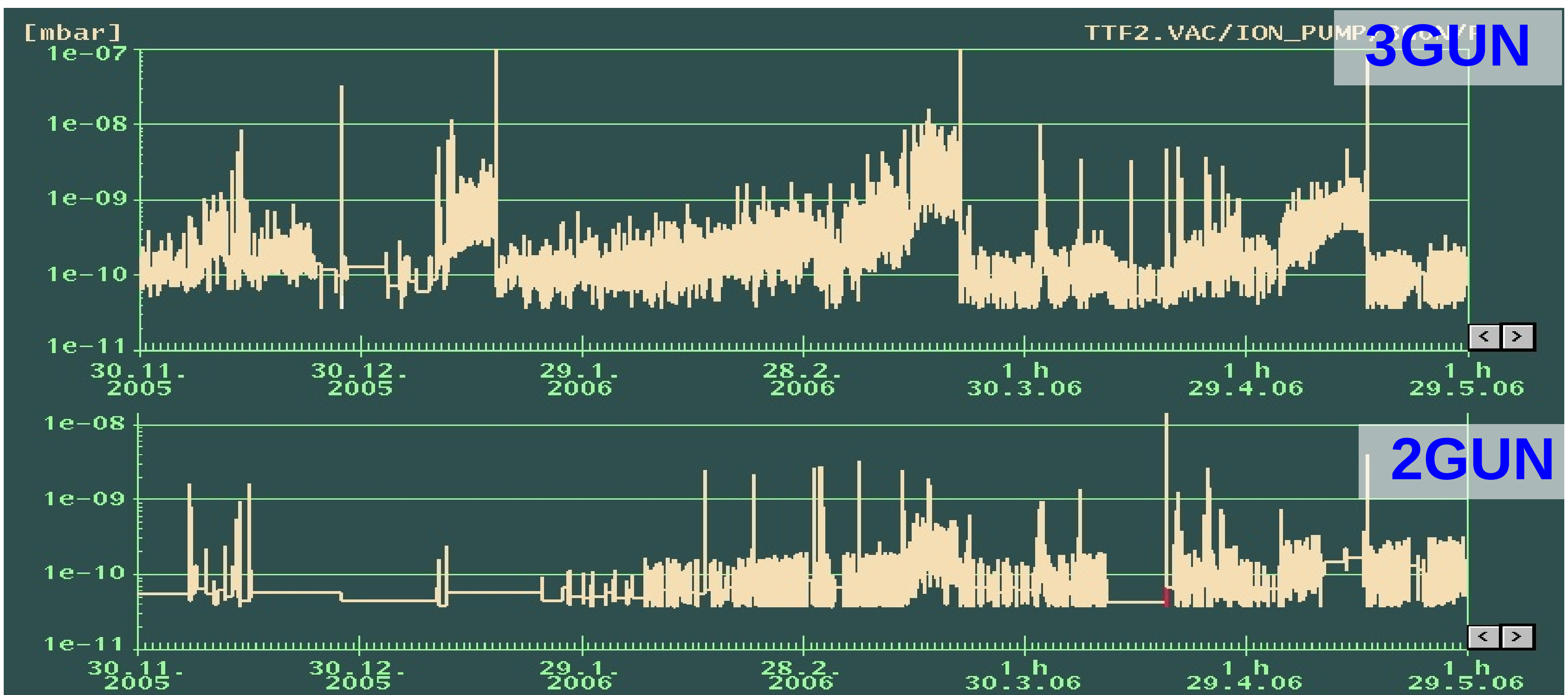




- Most probable related to long rf pulse operation when initially the vacuum degraded by an order of magnitude

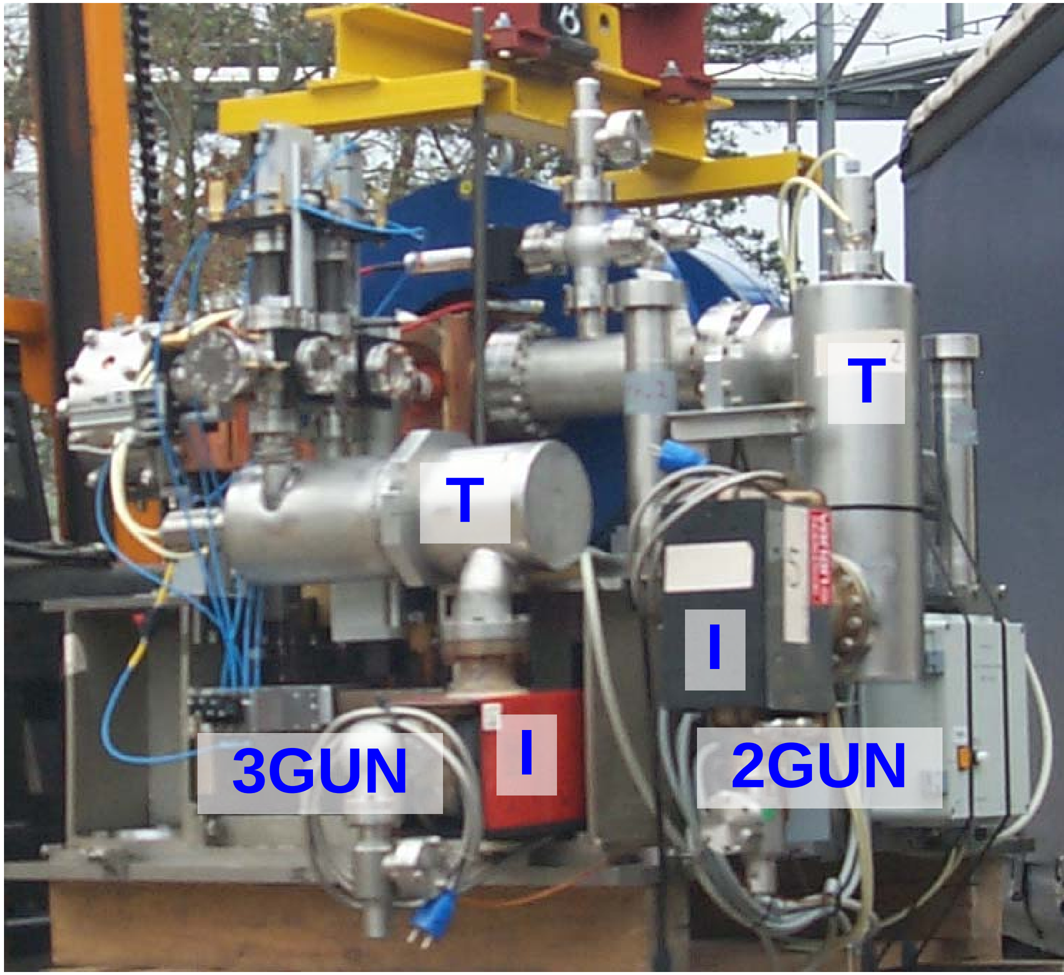
Vacuum in the gun

- Vacuum pressure measured with ion getter pumps buffered by large TiSub-pumps at gun exit (2GUN at coupler, 3GUN at laser cross)
  - No direct pressure measurement close to cathode
- Frequent increase of vacuum due to
  - Long rf pulses (900 µs) after long runs with short (100 µs)
  - Outgasing of Ce:YAG screens/FCup when operated
- Activating TSPs brings back initial pressure < 1E-10 mbar



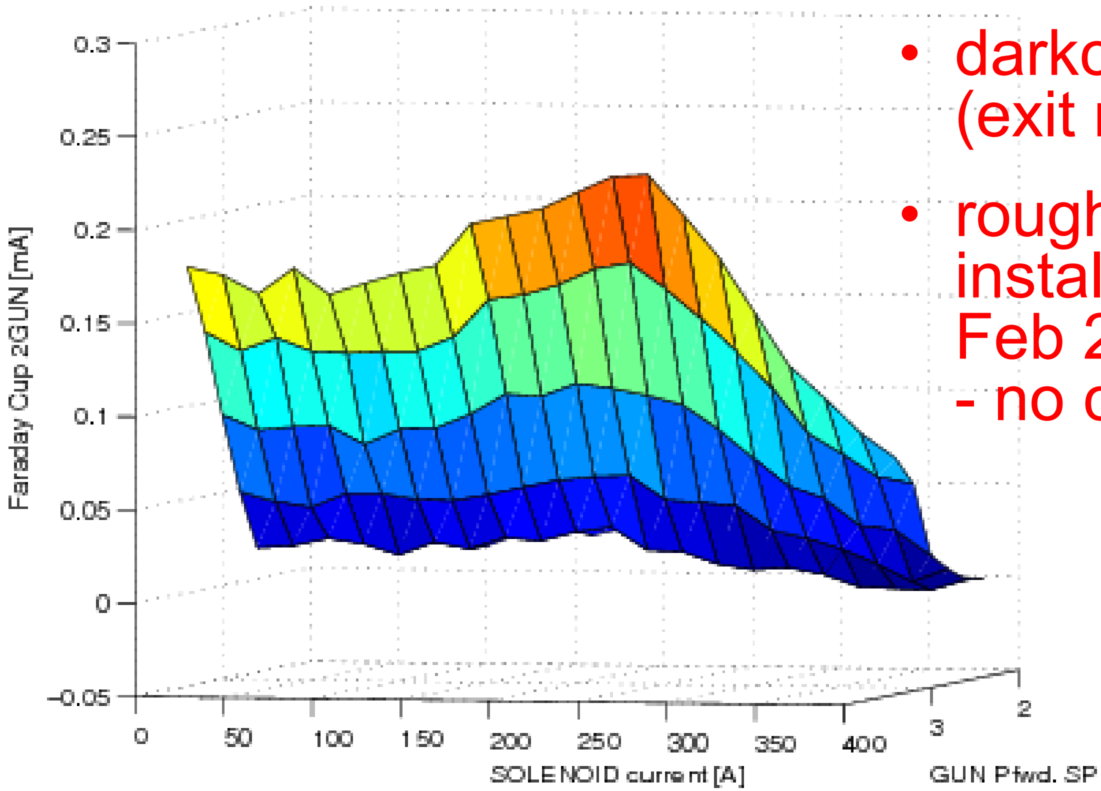
Vacuum pumps

- Pumps at the gun:
  - Ti-Sublimation pumps **T**
  - Ion getter pumps **I**
  - Pressure measure through current of ion getter pumps
- Ion getter pumps are "shielded" by the TSPs
- Vacuum close to cathode cannot be measured

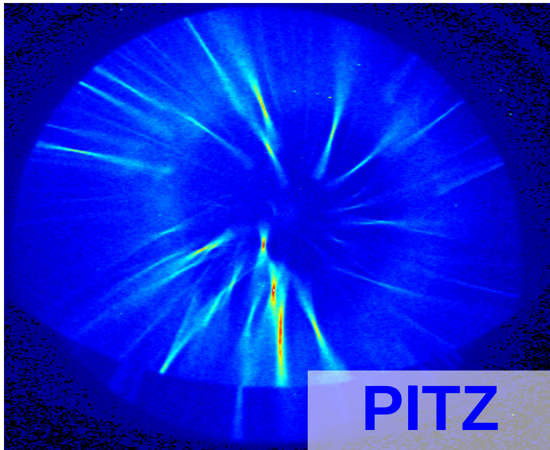


Darkcurrent

- Darkcurrent is a serious issue for sc accelerators (cryogenic load) and permanent magnet undulators (change of B field on high irradiation)



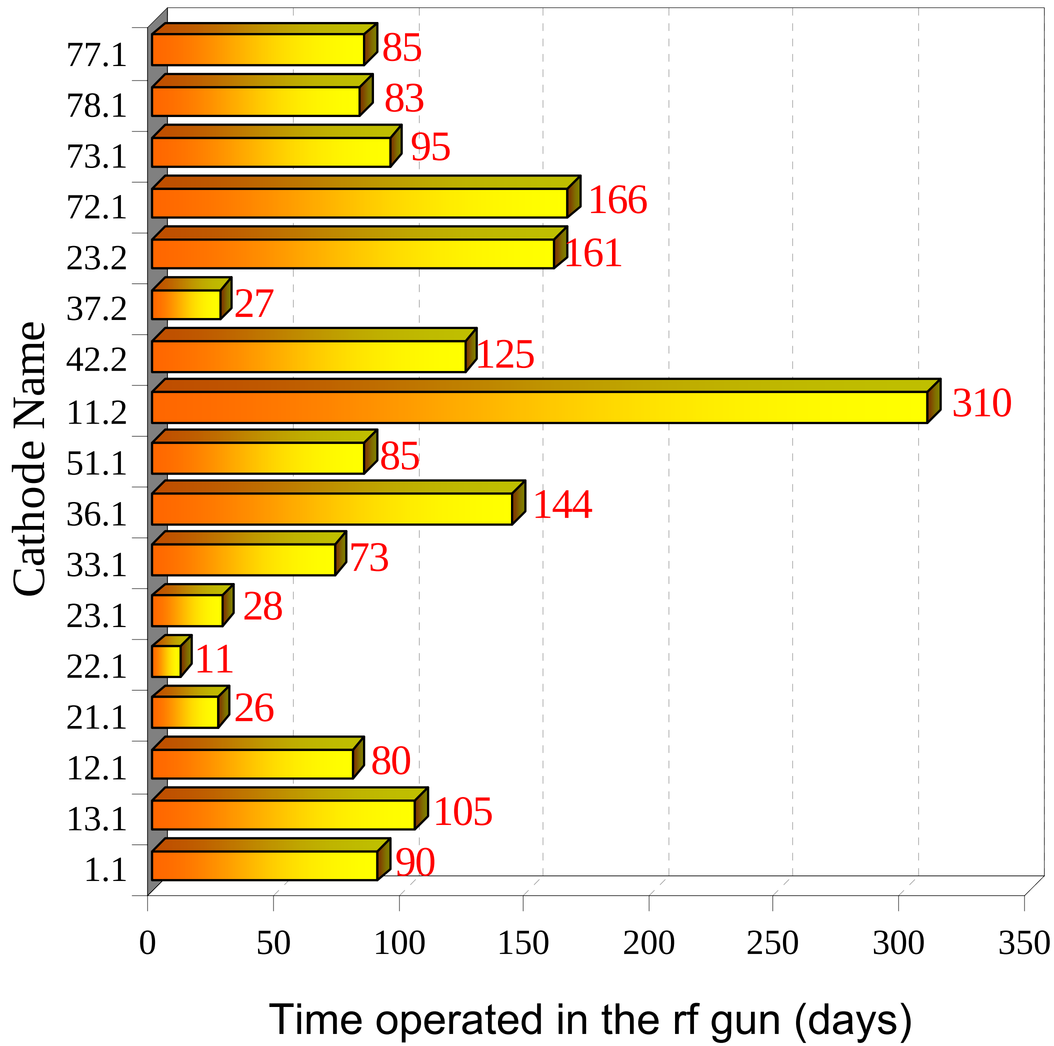
- darkcurrent 200 to 250 µA (exit rf gun)
- roughly constant since the installation of the gun in Feb 2004
  - no conditioning effect?



Operation statistics

FLASH Free-Electron Laser in Hamburg

- Cathodes have been changed for various reasons:
  - Darkcurrent
  - Testing of new cathodes
  - Low QE
    - only for the last few cases: 23.2, 72, 73, 78
- Cathodes in operation ~ 3 to 6 months



Summary

- FLASH uses Cs_2Te cathodes
- Quantum efficiency of fresh cathodes >> 0.5 %
- For us, lifetime ends when QE reaches 0.5 %
- Lifetime between 3 and 6 months, depending on the vacuum conditions, in few cases longer
- Cathode handling manually with risk of accidents: 1 accident at FLASH and 2 at PITZ so far
- Charge extracted per cathode in the order of 1 C
- We need more data on extraction of long bunch trains
- We need to work on cathode surface roughness/QE homogeneity before/after operation
- We need to understand better the darkcurrent emission