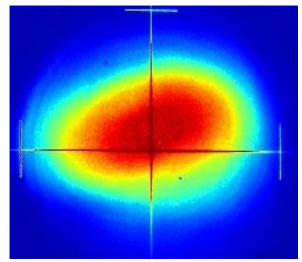
Photocathodes at FLASH

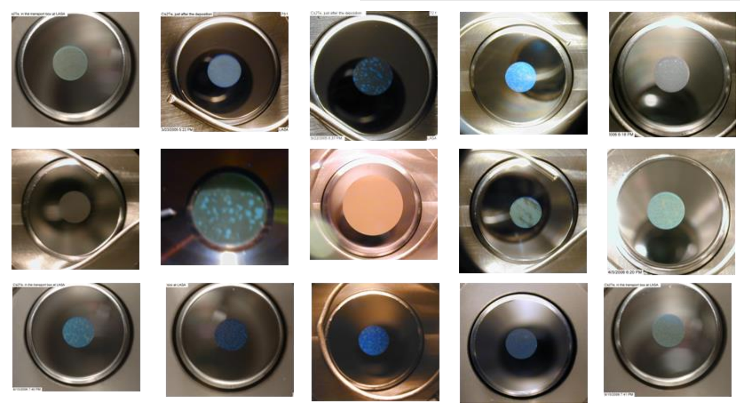
FLASH.
Free-Electron Laser in Hamburg

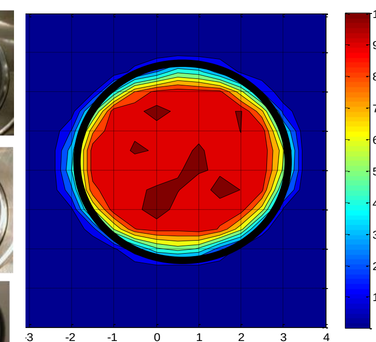
FLASH - free-electron laser user facility at DESY



Siegfried Schreiber
DESY

S. Lederer, I. Hansen, H.-H. Sahling (DESY, Germany)
L. Monaco, D. Sertore, P. Michelato, (INFN - Milano, Italy)





FEL 2012
August 26 - 31, 2012
Nara, Japan

Session:
FEL Technology 1
WEPD08

HELMHOLTZ | GEMEINSCHAFT

DESY

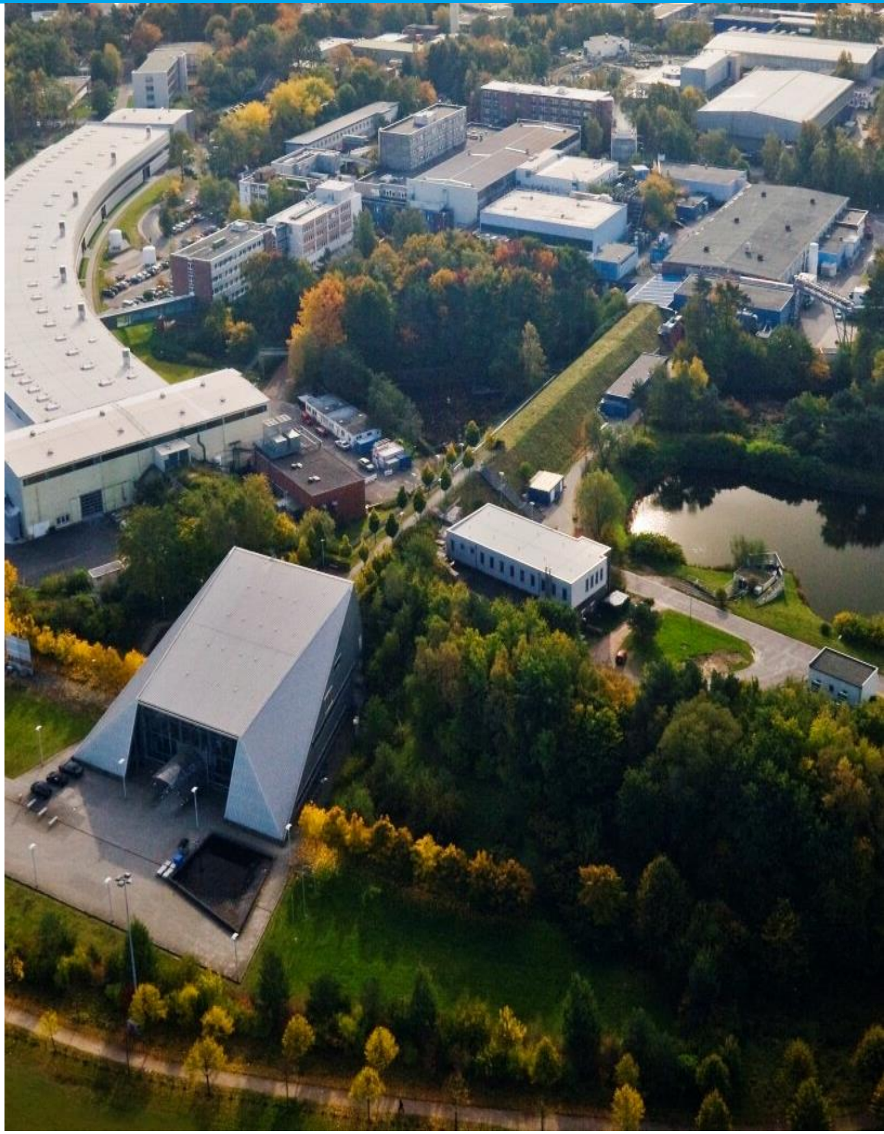
FLASH at DESY in Hamburg

FLASH.
Free-Electron Laser in Hamburg

FLASH at DESY in Hamburg

FLASH. Free-Electron Laser in Hamburg

- Single-pass high-gain SASE FEL
- Photon wavelength range from XUV to soft X-rays
- Free-electron laser user facility since summer 2005
  - 1st period: Jun 2005 – Mar 2007
  - 2nd period: Nov 2007 – Aug 2009
  - 3rd period: Sep 2010 – Sep 2011
  - 4th period: March 2012 – Feb 2013
- FLASH is also a test bench for the European XFEL and the International Linear Collider (ILC)
- FLASH2, a second undulator beam line is under construction



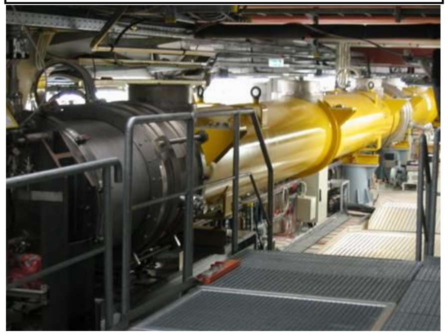
DESY

FLASH layout

FLASH. Free-Electron Laser in Hamburg

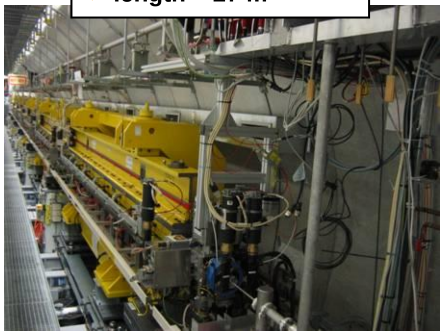
> 3rd harmonic cavity 3.9 GHz

> TESLA type superconducting accelerating modules 1.3 GHz

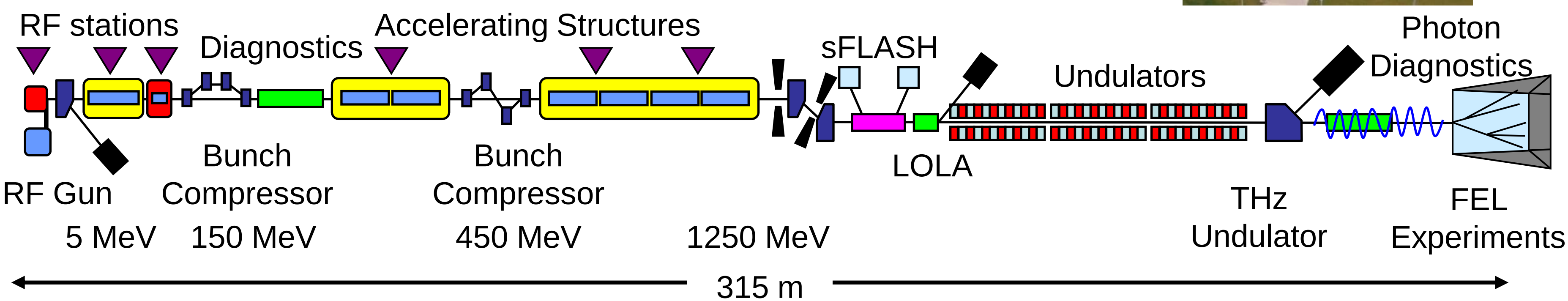


> Fixed gap undulator

> length ~ 27 m



> FEL Experimental Hall



> FEL Experimental Hall

- > Normal conducting 1.3 GHz RF gun
- > Ce_2Te cathode
- > Nd:YLF based ps photocathode laser

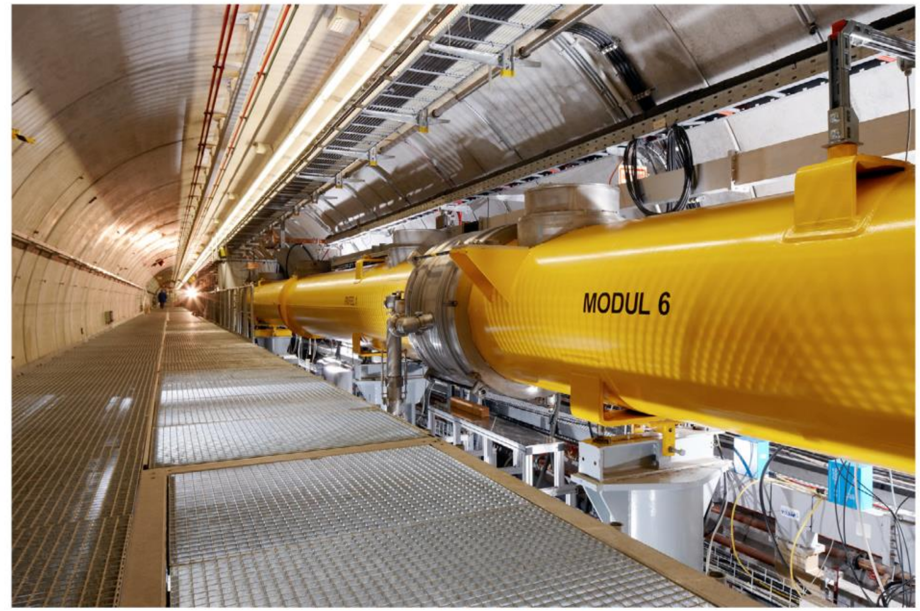
- > Diagnostics and matching
- >Deflecting cavity LOLA

- > sFLASH undulators (variable gap)
- >THz Undulator

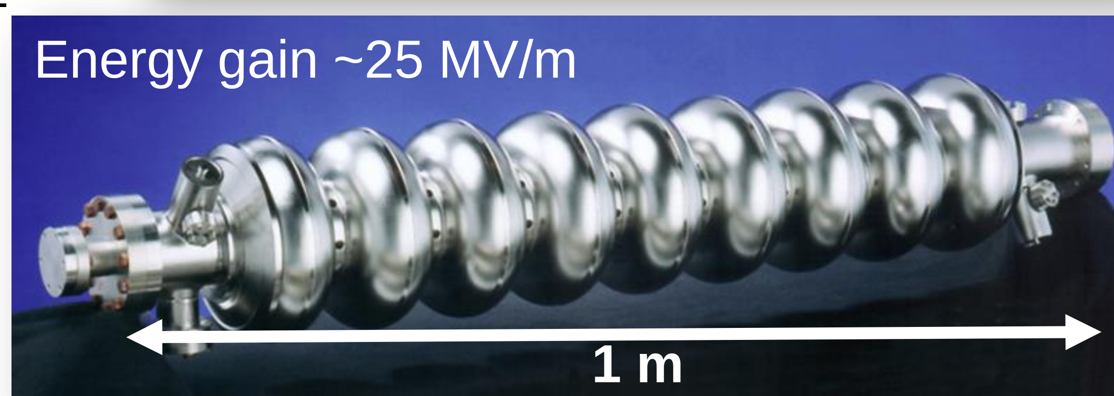
DESY

FLASH Accelerator

- FLASH uses TESLA technology
- 7 accelerating modules: each with 8 superconducting 9-cell cavities, 1.3 GHz
- Pure Nb, operated at 2 K
- Energy gain (nominal) 200 MeV per module
- Burst mode: 800 µs at 10 Hz
- Efficient acceleration: high Q ~ 10^{10} (loaded Q = 2 x 10^{6})
- Electron beam energy ~375 MeV - 1.25 GeV



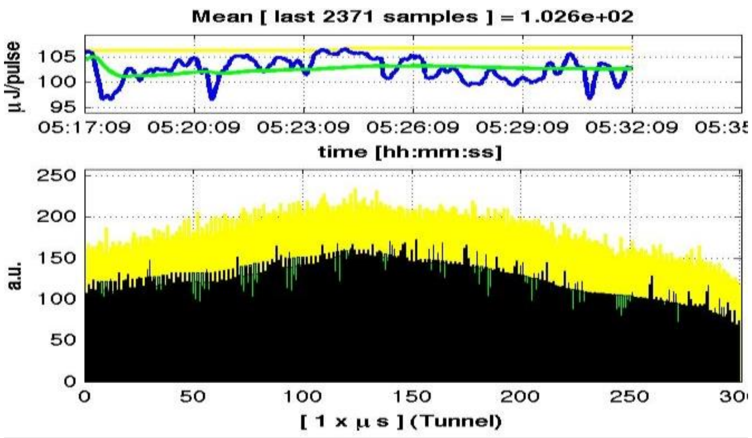
Fotoshooting bei DESY, FLASH-Tunnel, Februar 2012
Fotos: Heiner Müller-Elsner

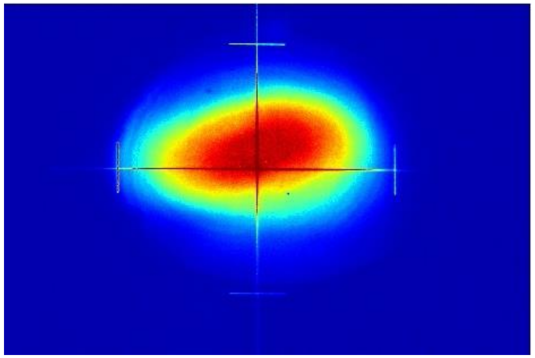


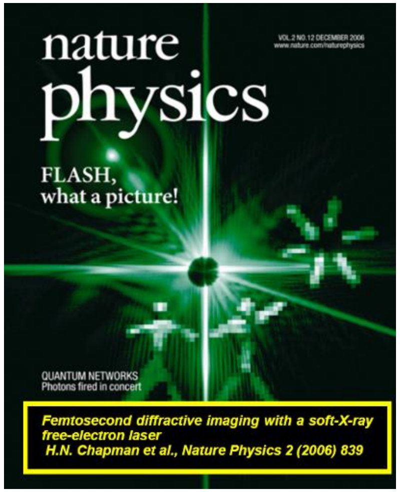
FLASH Parameters

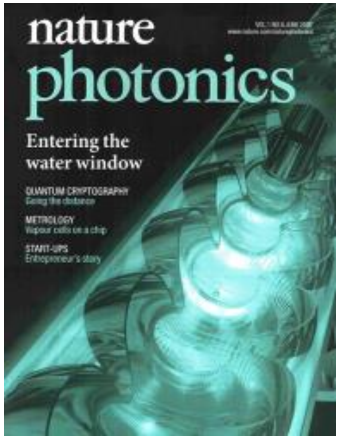
FEL Radiation Parameters	
Wavelength range (fundamental)	4.2 – 45 nm
Average single pulse energy	10 – 500 µJ
Pulse duration (FWHM)	<50 – 200 fs
Peak power (from av.)	1 – 3 GW
Spectral width (FWHM)	~ 0.7 - 2 %
Photons per pulse	$10^{11} – 10^{13}$
Average Brilliance	$10^{17} – 10^{21}$ B*
Peak Brilliance	$10^{29} – 10^{31}$ B*

* photons/s/mrad^2/mm^2/0.1%bw









> 168 publications on photon science at FLASH, many in high impact journals

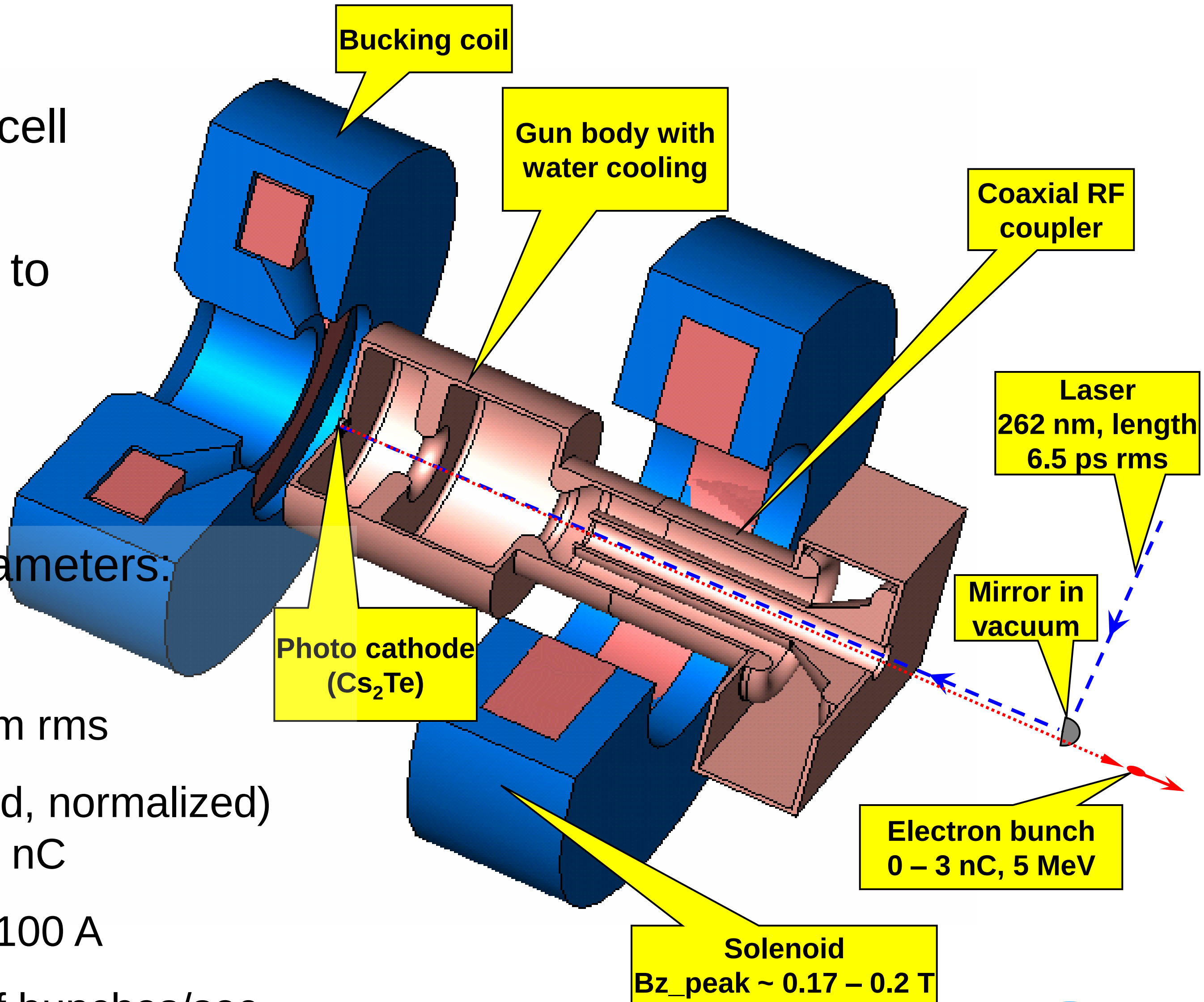
- http://hasylab.desy.de/facilities/flash/publications/selected_publications

DESY

Photoinjector

RF-Gun

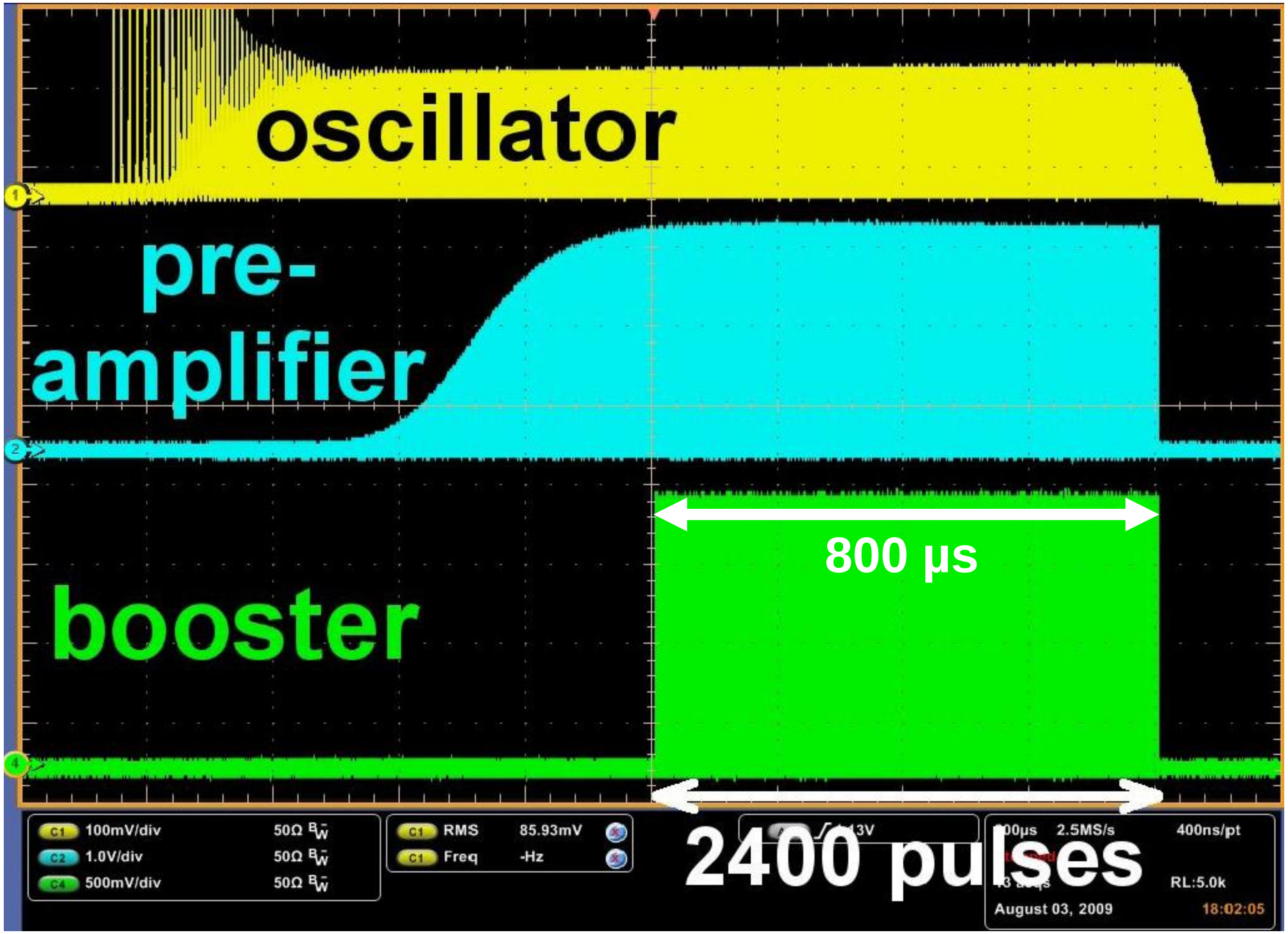
- RF gun: 1.3 GHz
  copper cavity, 1 ½ cell
- RF power 4 MW,
  RF pulse length up to
  850 µs, 10 Hz
  (av. Power 34 kW)
- Cs_2Te cathodes
- Electron beam parameters:
  - Charge 0…3 nC
  - Bunch length ~2 mm rms
  - Emittance (projected, normalized)
    <1.5 mm mrad @ 1 nC
  - Peak current 40 to 100 A
  - Trains thousands of bunches/sec



Photoinjector Laser

FLASH.
Free-Electron Laser in Hamburg

- Burst mode: pulse trains, 1 MHz, 800 µs length, 10 Hz; 3 MHz @ 5 Hz



DESY

Cathode Quantum Efficiency (QE)

FLASH. Free-Electron Laser in Hamburg

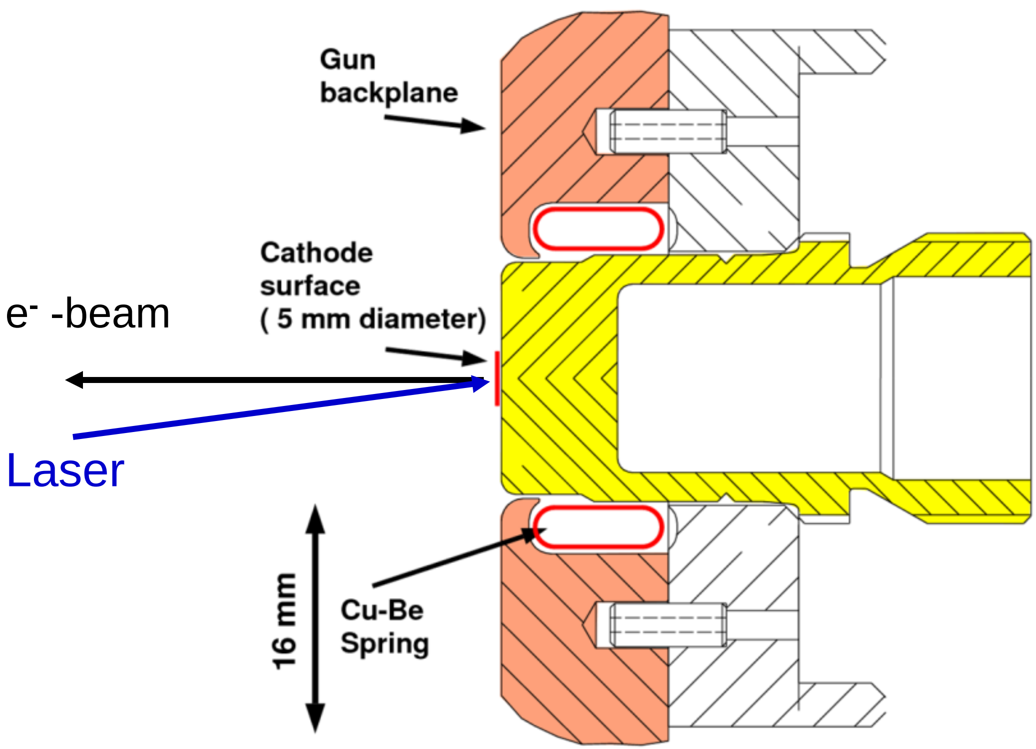
- Burst mode accelerators like FLASH or European XFEL require to produce thousands to ten-thousands of bunches per second
- The is only possible with high QE cathodes
- With this laser average power can be kept within a reasonable limit
  - QE >> 1 %
  - Robust, long lifetime
- Cs_2Te cathodes found to be the best choice for FLASH and E-XFEL
  - Work function 3 … 4 eV: needs UV Laser (~260-270 nm)
  - Average laser power in the 1 to 10 W range (depending on overhead)

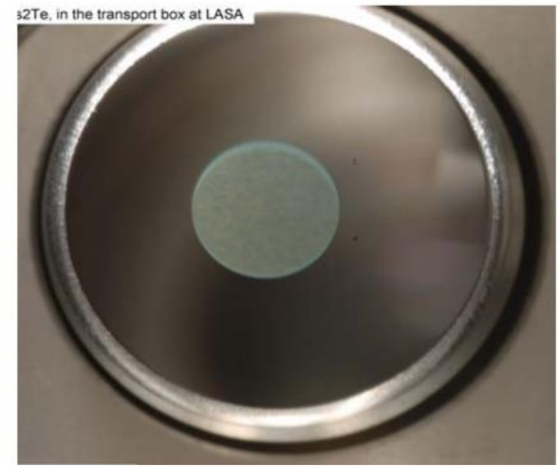
Example:

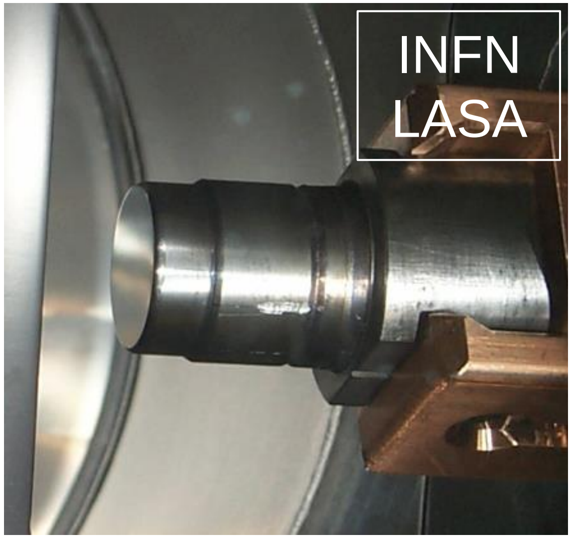
QE(%) ≈ 0.5*Q(nC)/E(μJ) @ λ = 262 nm
→ 0.1 μJ for 1 nC with QE=5%

Cs_2Te Cathodes

- Cs_2Te: high quantum efficiency at high beam currents
- Thin film on Mo, quantum efficiency ~ 10 %
- Lifetime depends on vacuum condition
  - FLASH gun: ~10^{-10} mbar → lifetime > 150 days



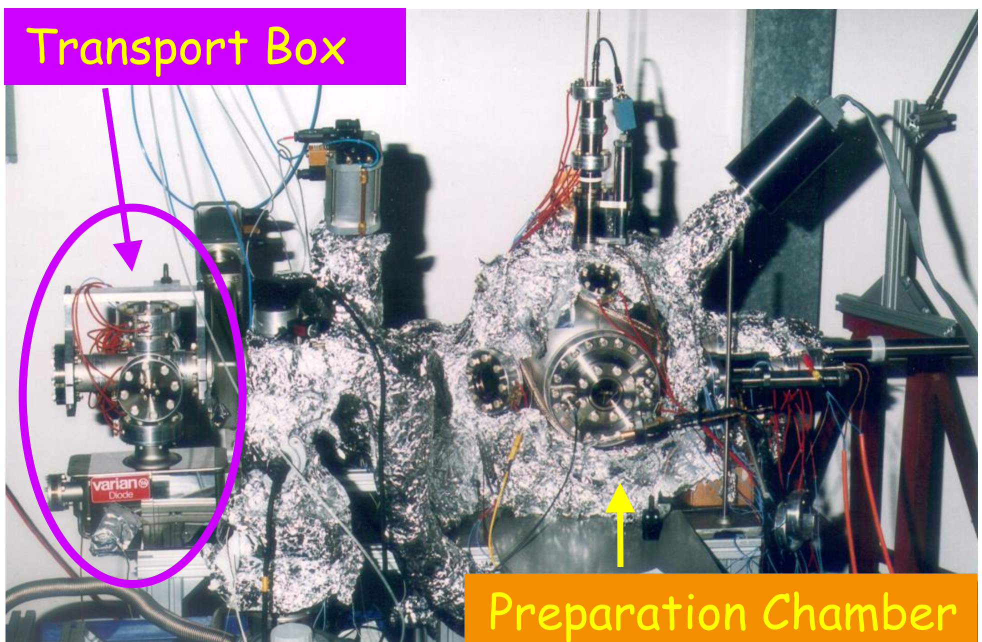


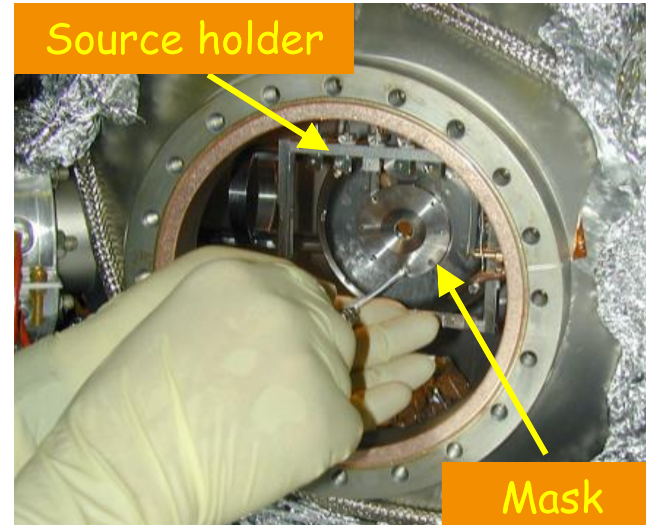


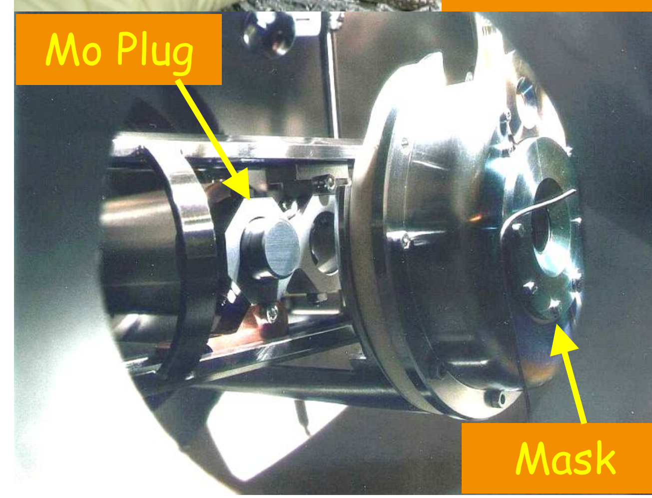
Cathode Preparation

Cathode Preparation at INFN-LASA

- First two RF-Guns (both from Fermilab) in operation at DESY 1998 to 2002
- Since then, cathode preparation at INFN-LASA, Milano, Italy
- Transport under UHV per truck from Milano to Hamburg – many, many times







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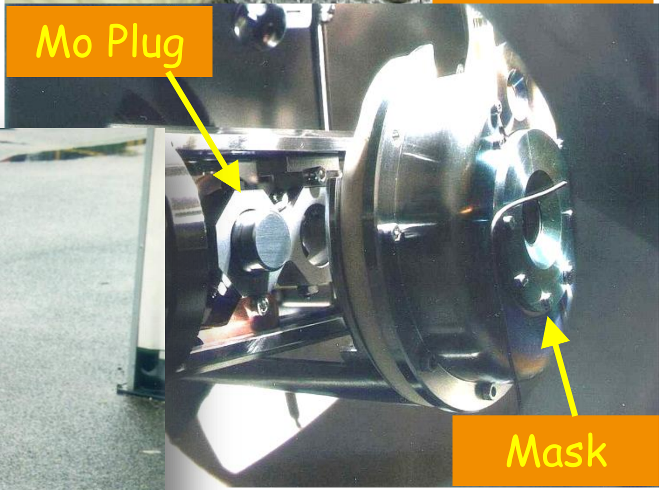
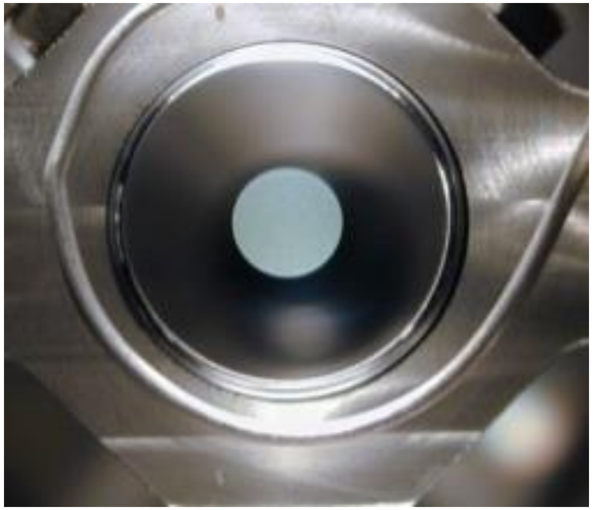
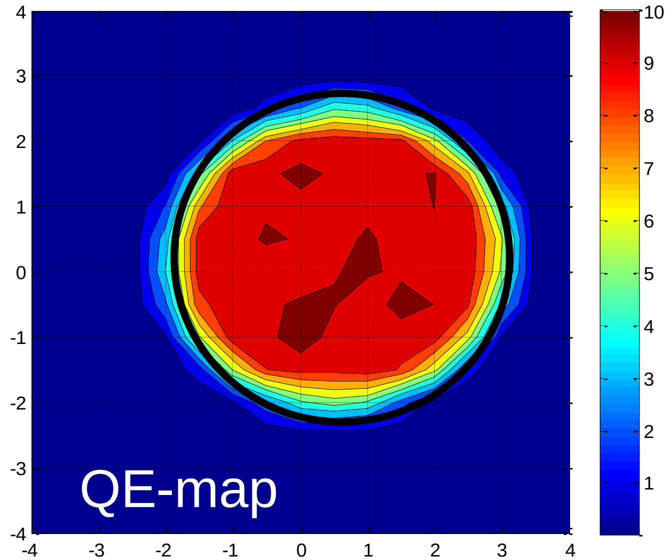
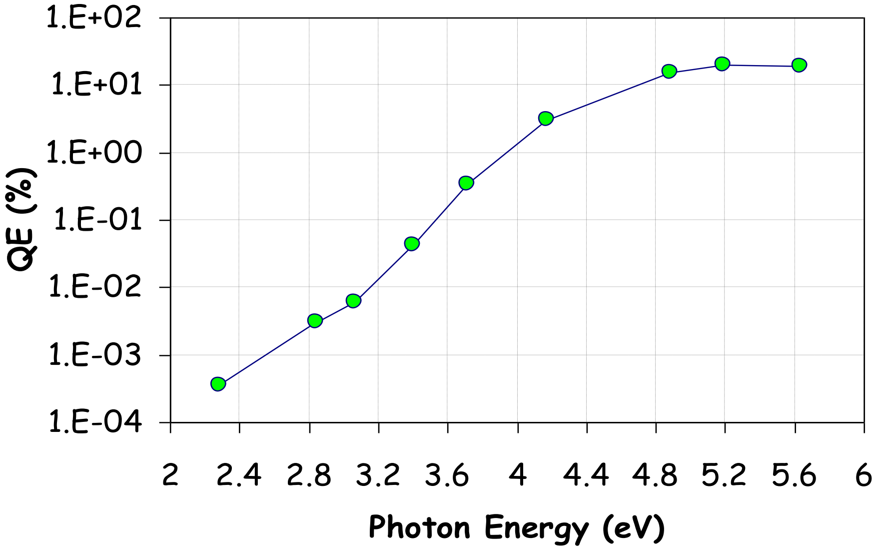


Cathode Preparation

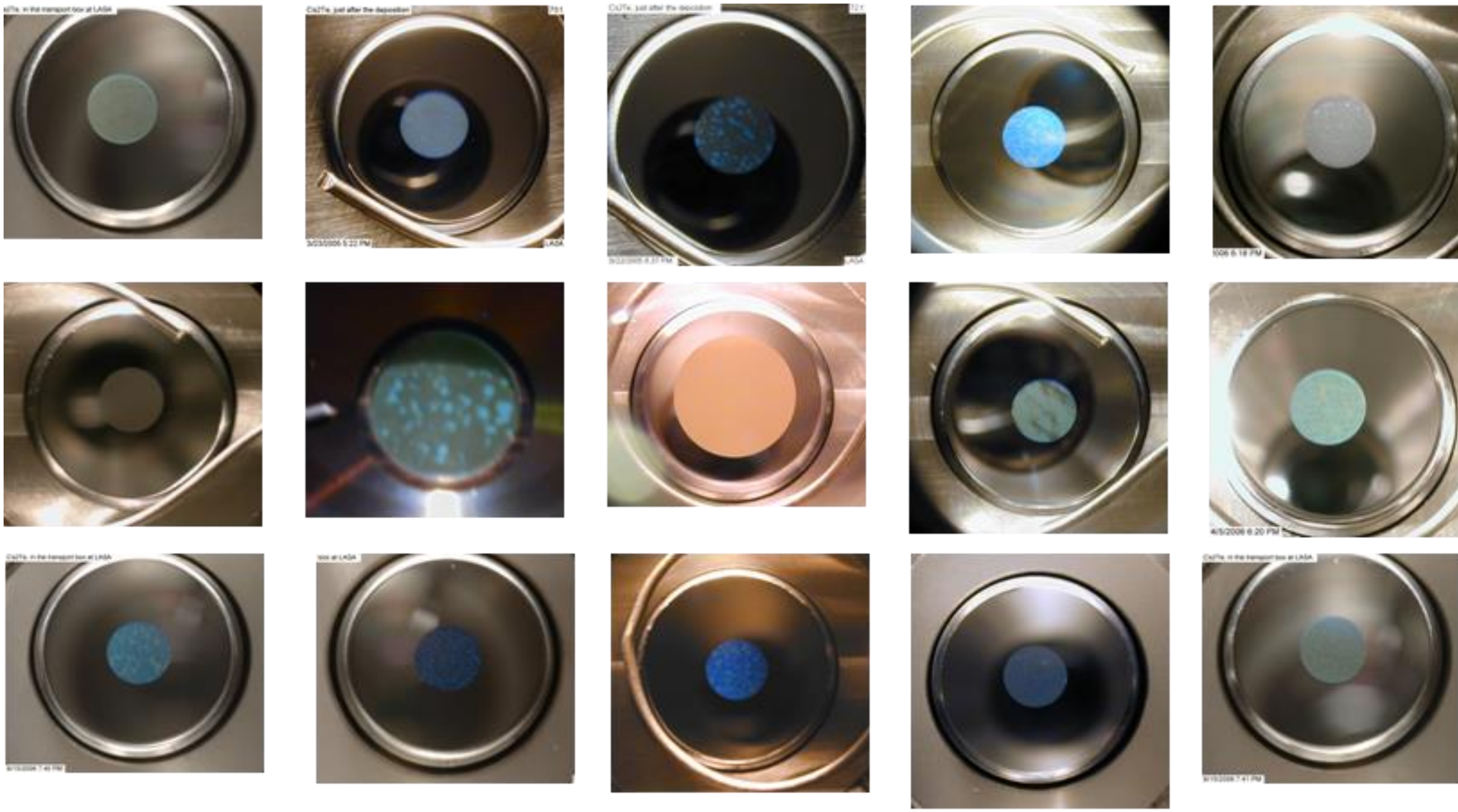
- Substrate: mirror polished Mo-plug
- Plug 16 mm, cathode film 5 mm Ø
- Preparation at 120 dgC
  - Deposition of 10 nm Te
  - Starting Cs evaporation
  - During Cs deposition: QE monitoring
  - QE max. reached → stop Cs evaporation







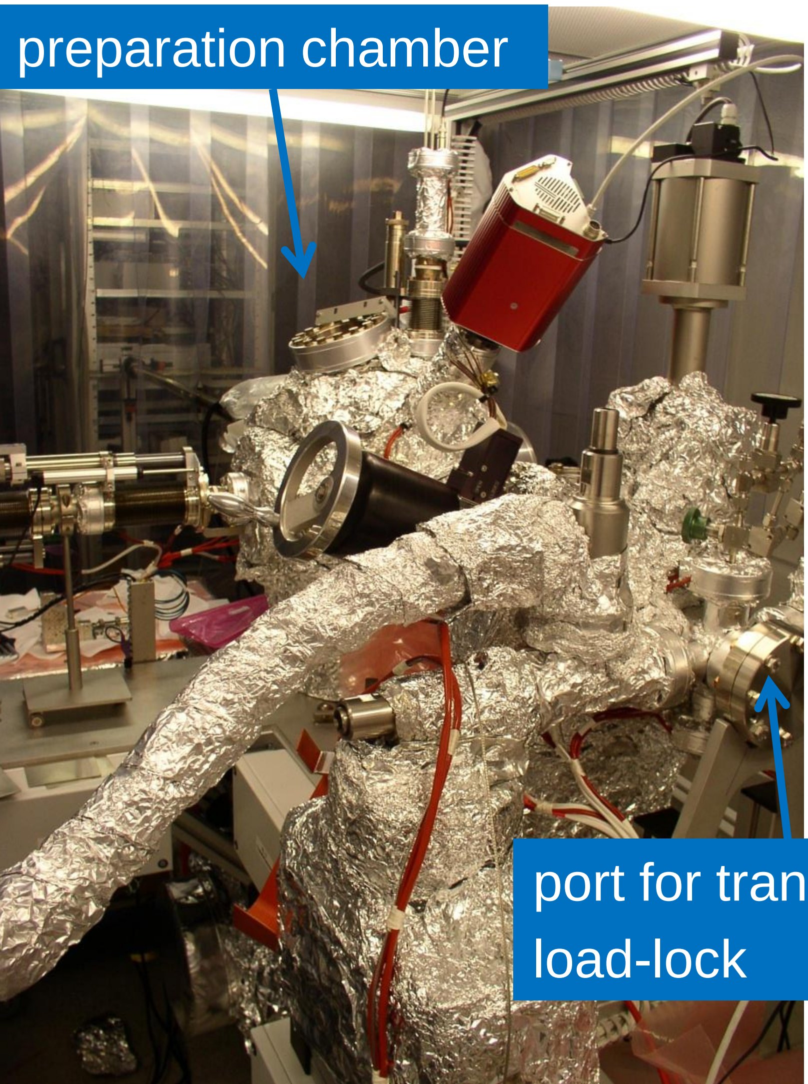
Kaleidoscope of Colors

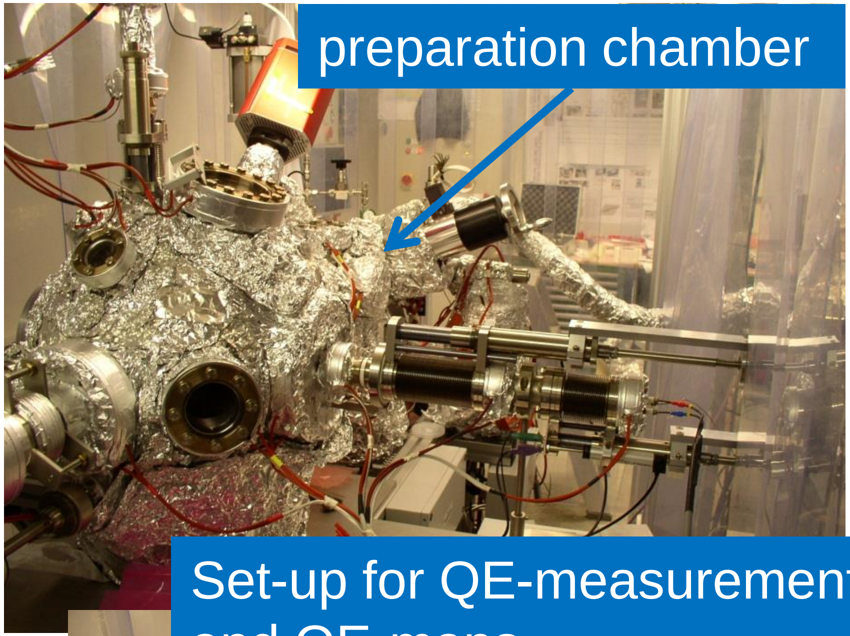


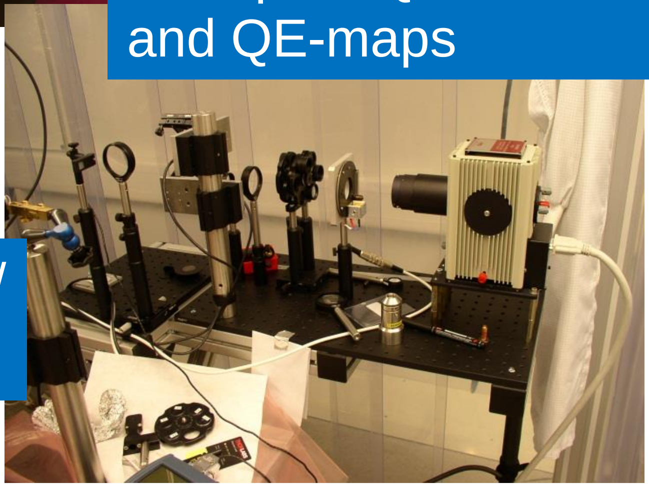
New Preparation System set-up at DESY

FLASH.
Free-Electron Laser in Hamburg

- Built by INFN-LASA in cooperation with DESY
- Two systems LASA&DESY for FLASH, PITZ, REGAE, European XFEL



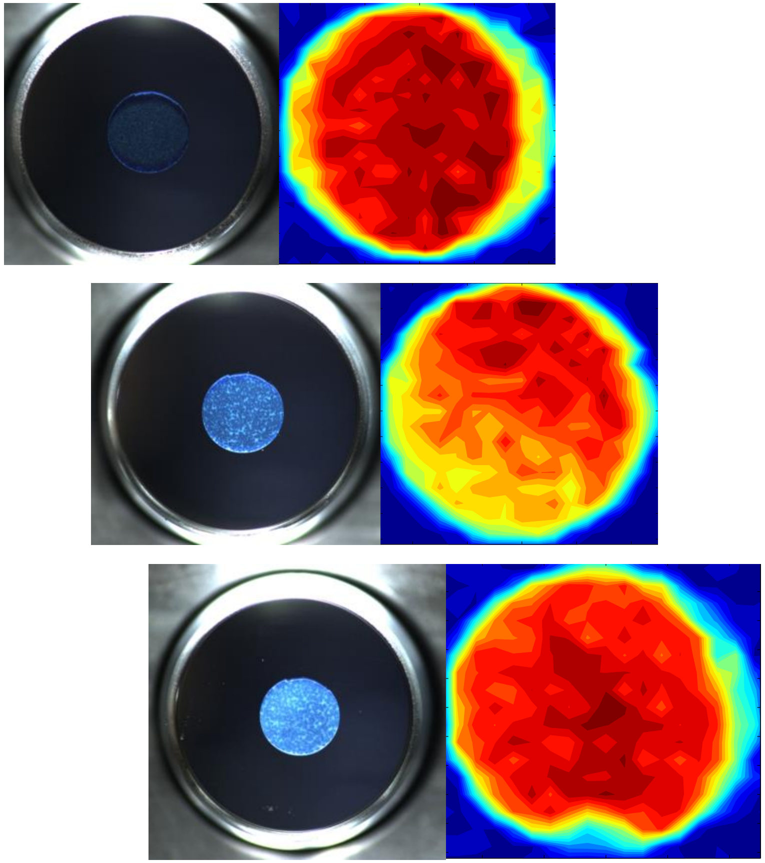




DESY

First Cathodes Produced at DESY

- #22.6
  - Plug produced and polished at LASA
- #613.1
  - Plug produced and polished at DESY
  - estimated roughness factor 2 higher than #22.6
- #625.1
  - Plug produced and polished at DESY
  - estimated roughness factor 2 higher than #22.6
- New carrier design from LASA: it works really nice!
- The lab includes an EDX facility and a raster electron microscope



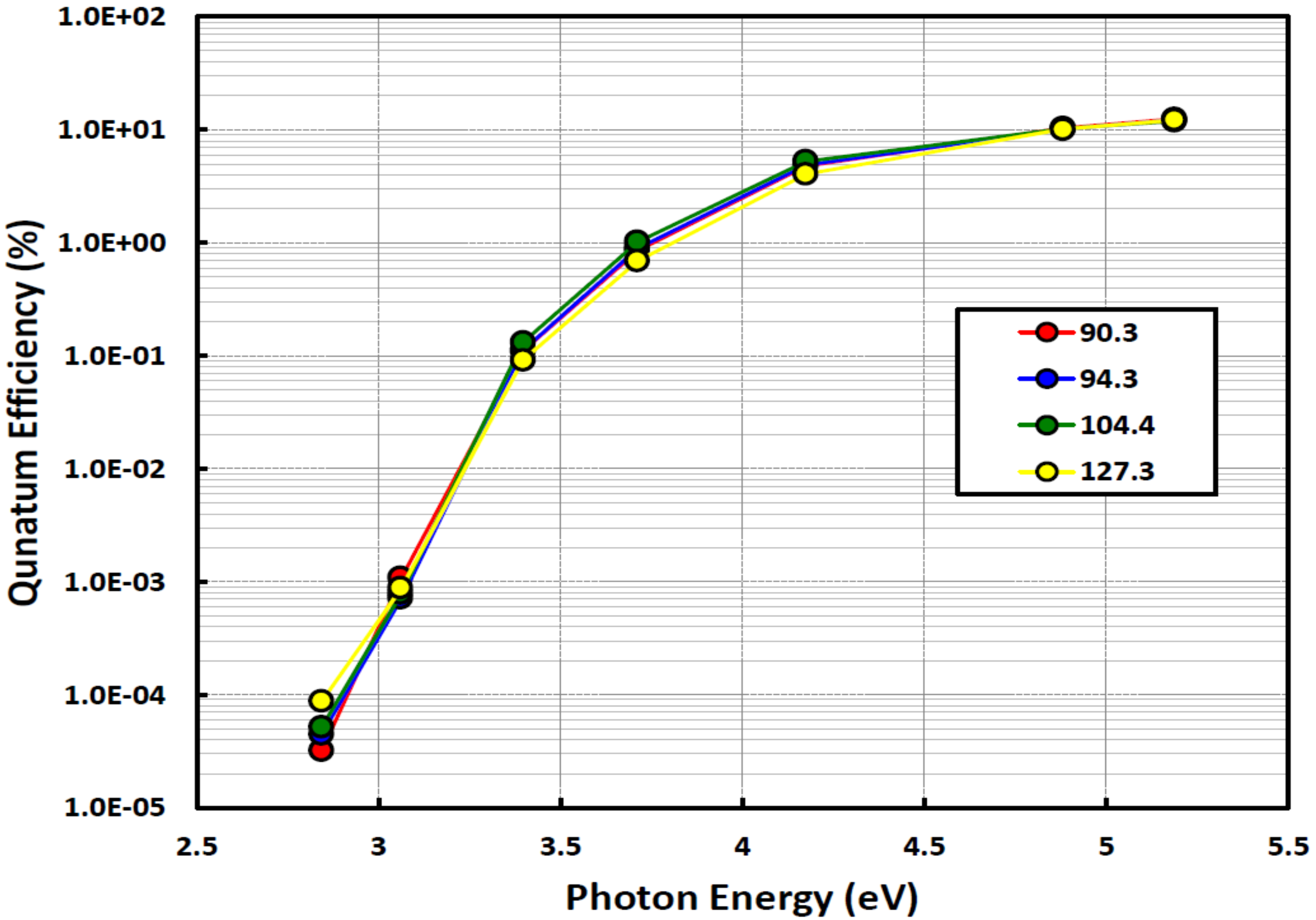
Cathode image after production

QE map

Quantum Efficiency and Spectral Response

Spectral response

> Measured with Hg-lamp after preparation



Spectral Response Analysis at 254 nm

FLASH. Free-Electron Laser in Hamburg

cathode	90.3	94.3	104.4	127.3
$(E_G + E_A)_1$ (eV)	2.77	2.73	2.82	2.70
m_1	2.50	2.50	1.12	2.50
A_1	0.02	0.01	0.04	0.01
$(E_G + E_A)_2$ (eV)	3.26	3.27	3.28	3.23
m_2	1.83	1.75	1.63	2.02
A_2	4.09	4.26	4.58	3.42
QE(%)	10.4	10.1	10.2	10.1

$$QE = A_1 \left(E_{\mathrm{ph}} - (E_G + E_A)_1\right)^{m_1} + A_2 \left(E_{\mathrm{ph}} - (E_G + E_A)_2\right)^{m_2}$$

- Two step model
- The work function $(E_G + E_A)_2$ is in fair agreement with the theoretical value
- Powel et al.(*) estimate: E_G = 3.3 eV, E_A = 0.2 eV for Cs_2Te

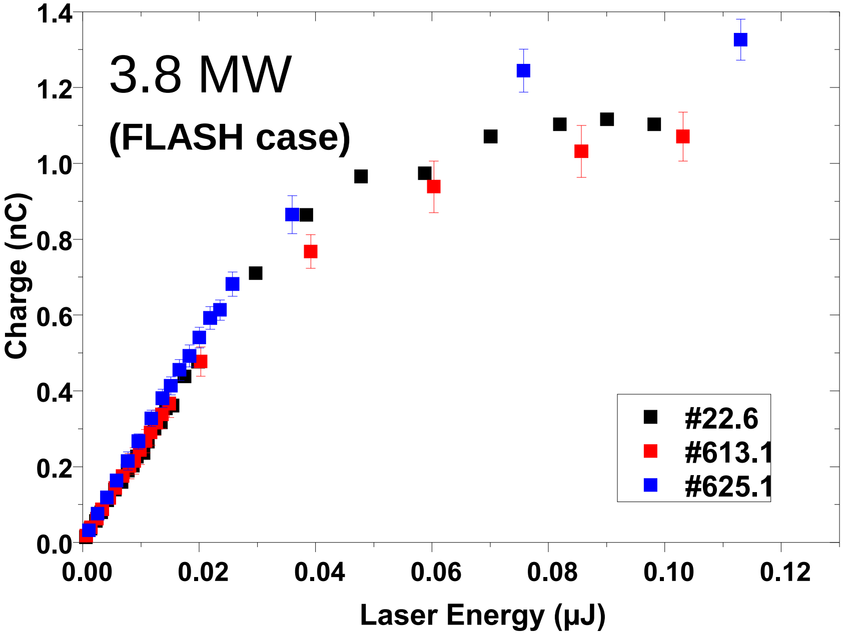
**R. Powel et al., Phys. Rev. B 8 (1973), 3987*

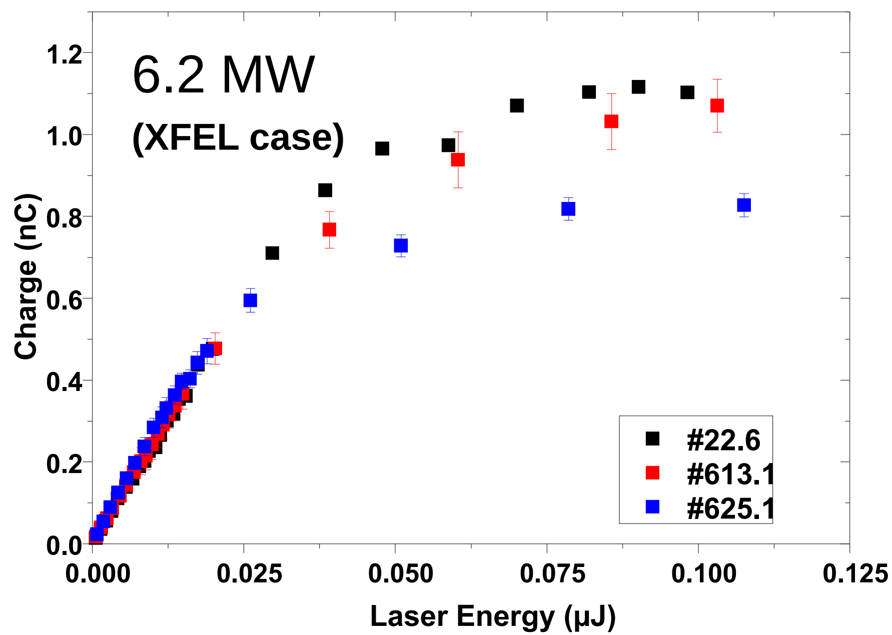
DESY

QE measurements – in situ

- QE = charge extracted from RF-gun / laser energy on cathode
- Measured at nominal launch phase (38 dg off zero crossing), ***not at maximum charge yield***

QE(%) ≈ 0.5*Q(nC)/E(μJ)





Cathode	QE (45 MV/m)	QE (60 MV/m)
#22.6	11.0 %	11.4 %
#613.1	9.6 %	12.2 %
#625.1	13.5 %	13.7 %

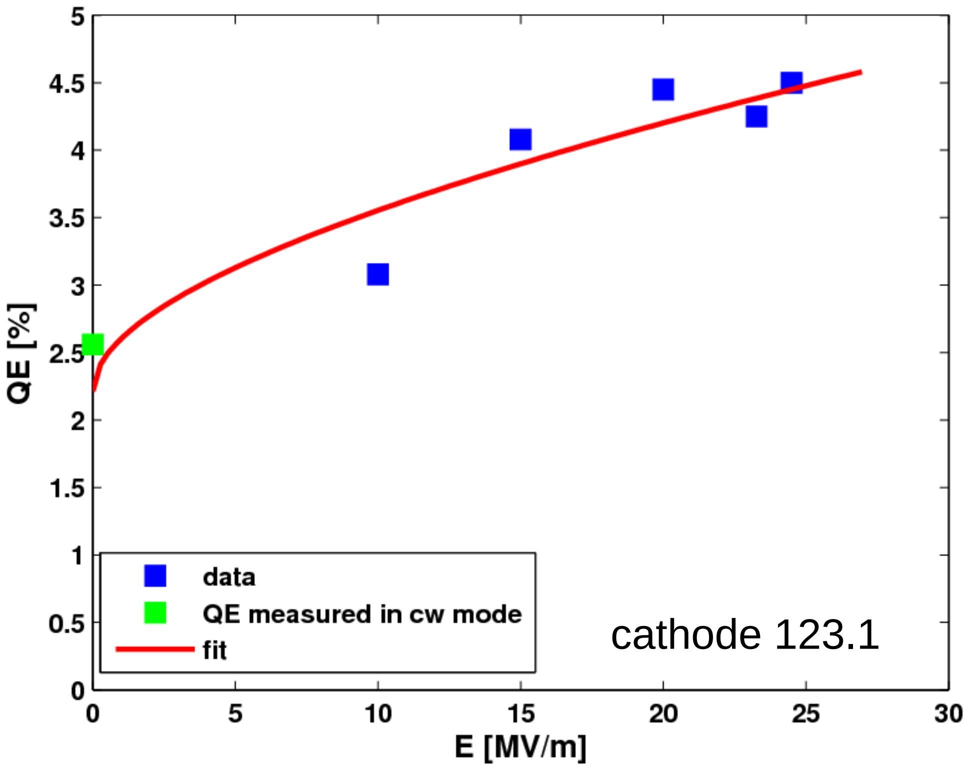
All data measured at PITZ

Field Enhancement

- Measure QE as a function of electric field on cathode
- Gives information on the work function W and the geometric enhancement factor β

$$QE = A\left(E_{ph} - W + q_e\sqrt{\frac{q_e \cdot \beta \cdot E}{4 \cdot \pi \cdot \varepsilon_0}}\right)^m$$

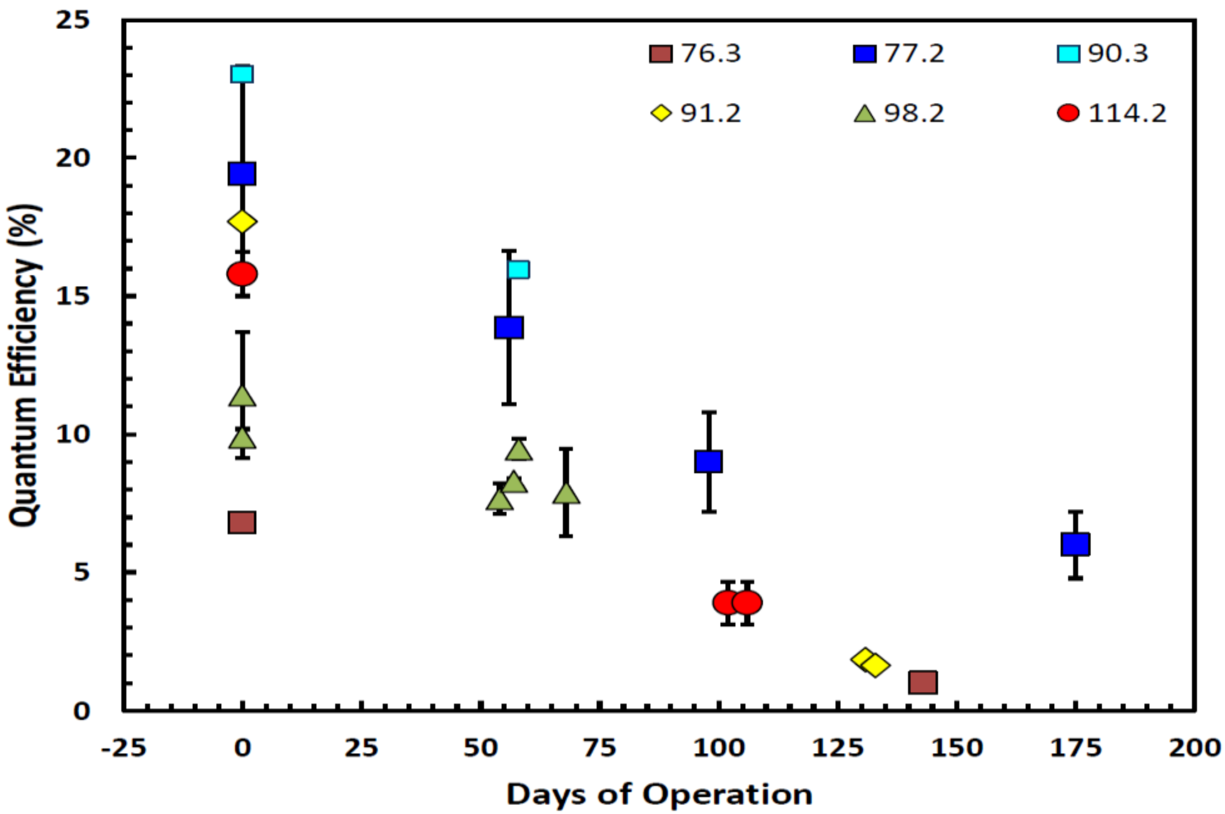
- In this example:
  - Work function W = 3.6 eV
  - Field enhancement β=7
  - QE @ zero field = 1.6 %



Lifetime

Cs_2Te lifetime at FLASH

- Cathode lifetime > 150 days established
- Key issue: keep vacuum pressure in the gun below 10^{-9} mbar all time
- Total charge produced during a lifetime ~4 C

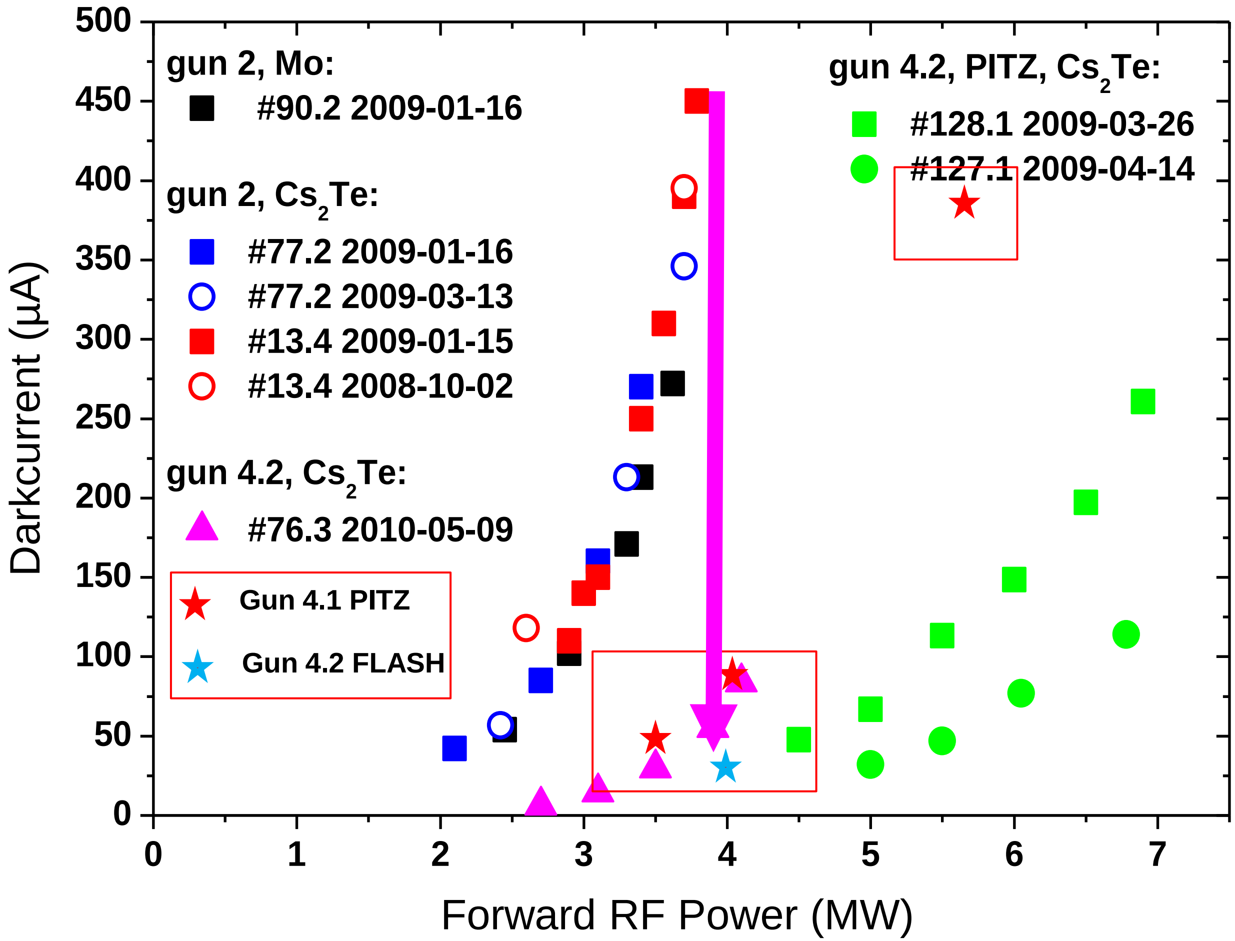


Darkcurrent

Darkcurrent Guns 2, 4.1, and 4.2

FLASH.
Free-Electron Laser in Hamburg

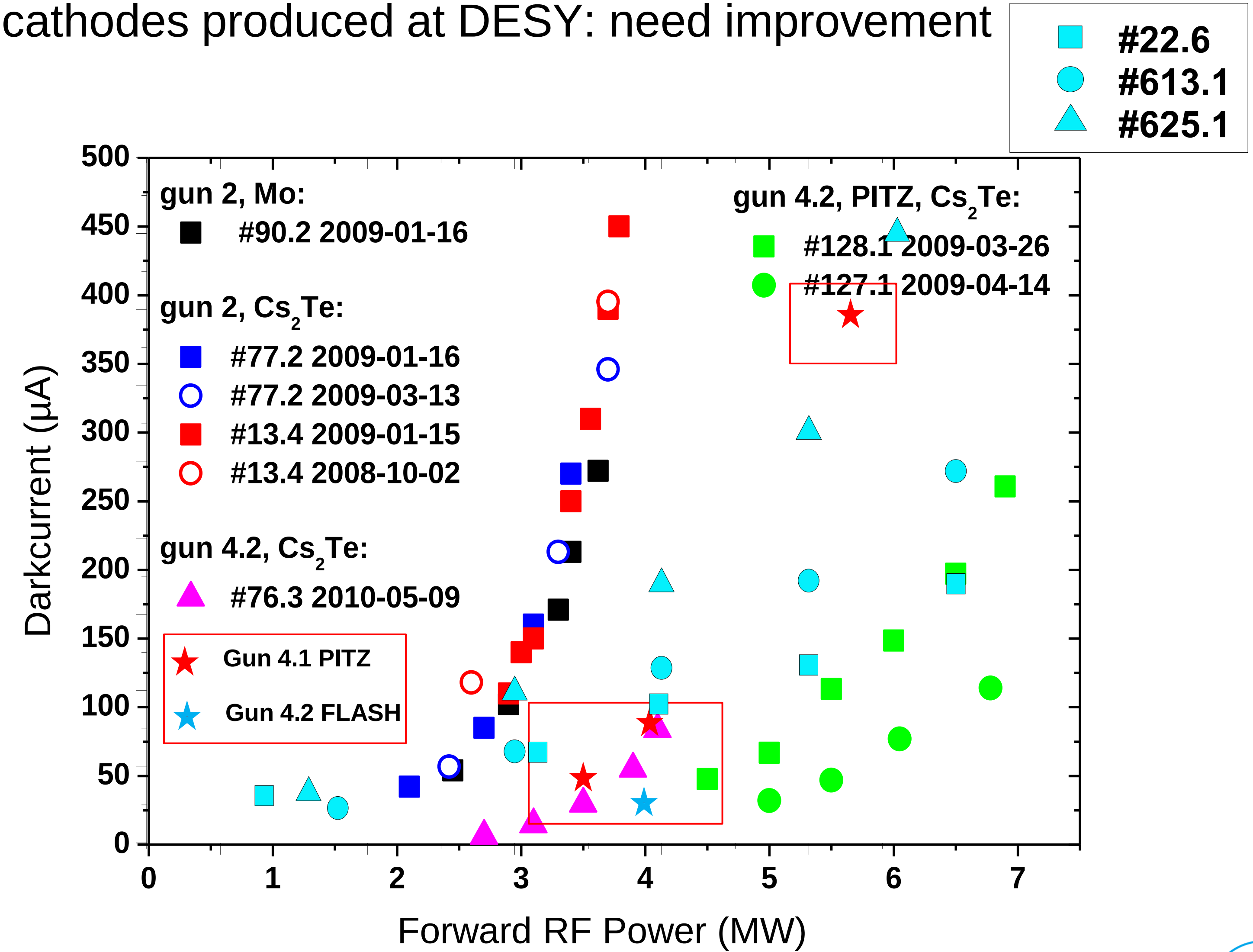
- Reduction of darkcurrent of RF gun after dry ice cleaning by a factor of 10 (@ 4 MW, nominal FLASH RF power)



DESY

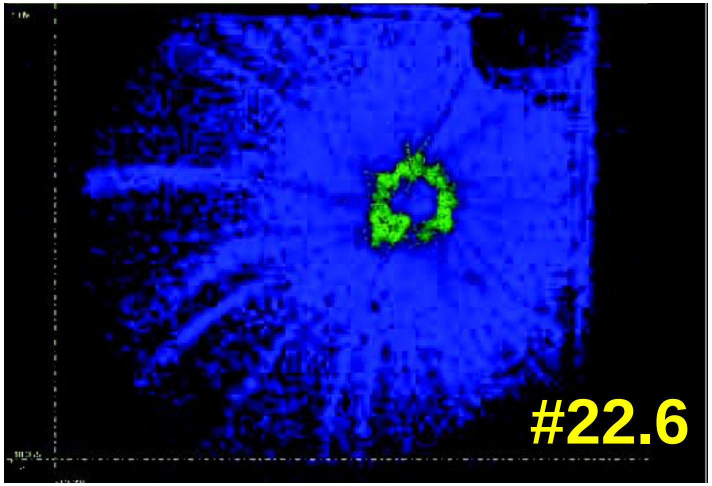
Darkcurrent Guns 2, 4.1, and 4.2

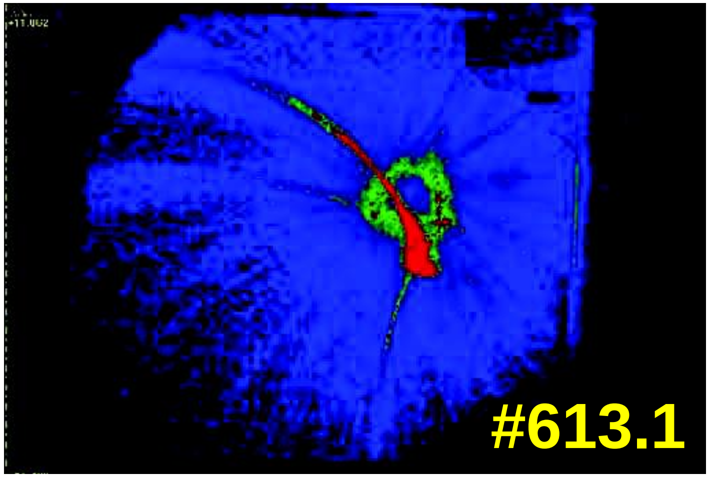
- New cathodes produced at DESY: need improvement



Darkcurrent Images

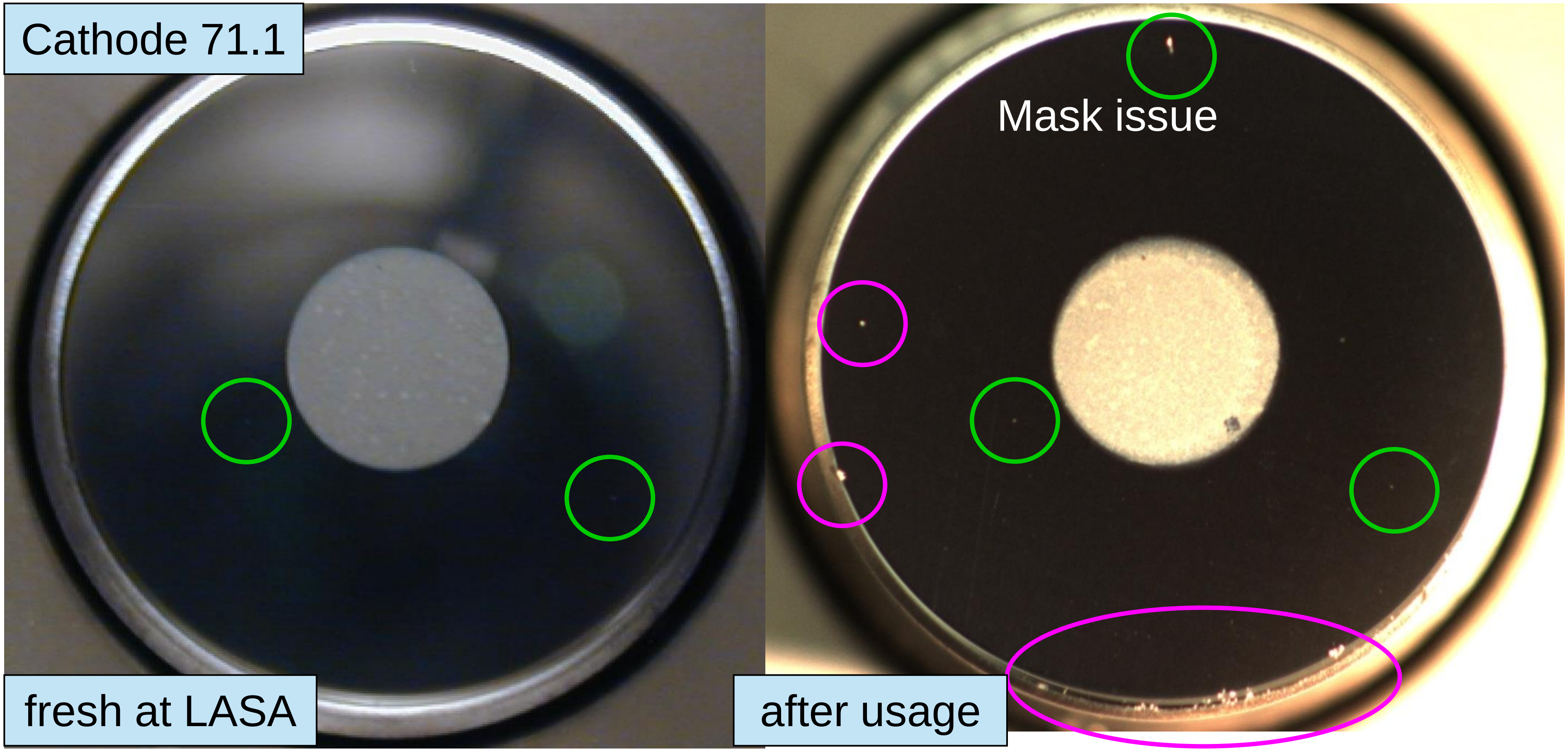
- Darkcurrent images taken downstream the RF-gun (Ce:YAG screen)
- Single particle emitters on cathode surface
  - Particle free assembly a must – we learn from SC cavity assembly procedures
  - Cathode exchange requires movements of components in vacuum
  - Friction produces particles
- New design with less friction and “particle friendly” materials





P_{for} = 6 MW, solenoid current 390 A.

Example of particles on cathodes

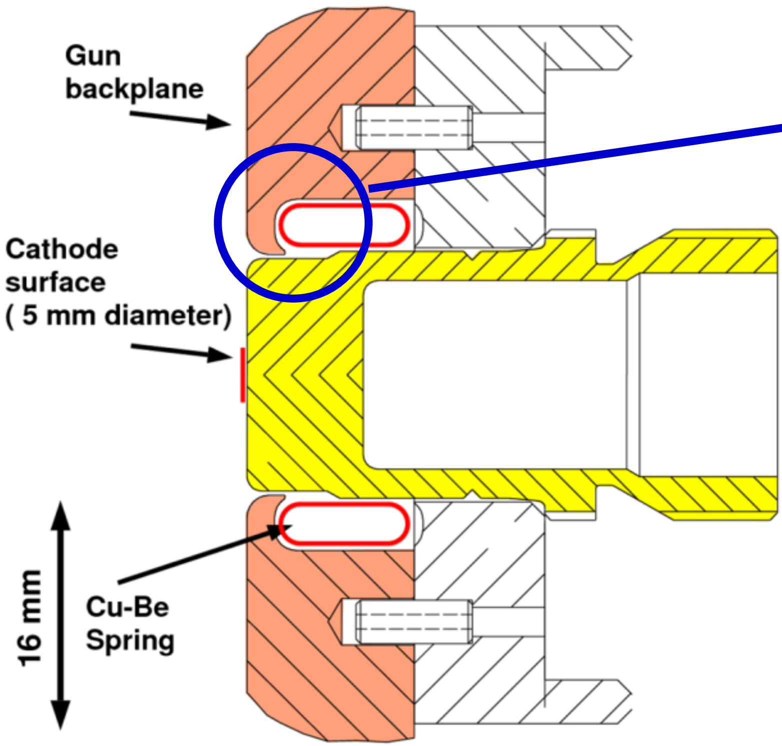


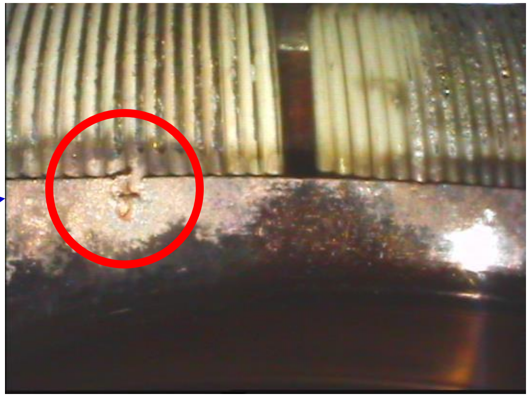
- Particles already present at LASA - N_2 flushing not applied (green)
- New particles after usage at FLASH – due to transfer (magenta)

Contact Spring Problems

RF Gun (4.2) breakdown event May 2012

> RF breakdown event caused severe damage of RF-gun backplane



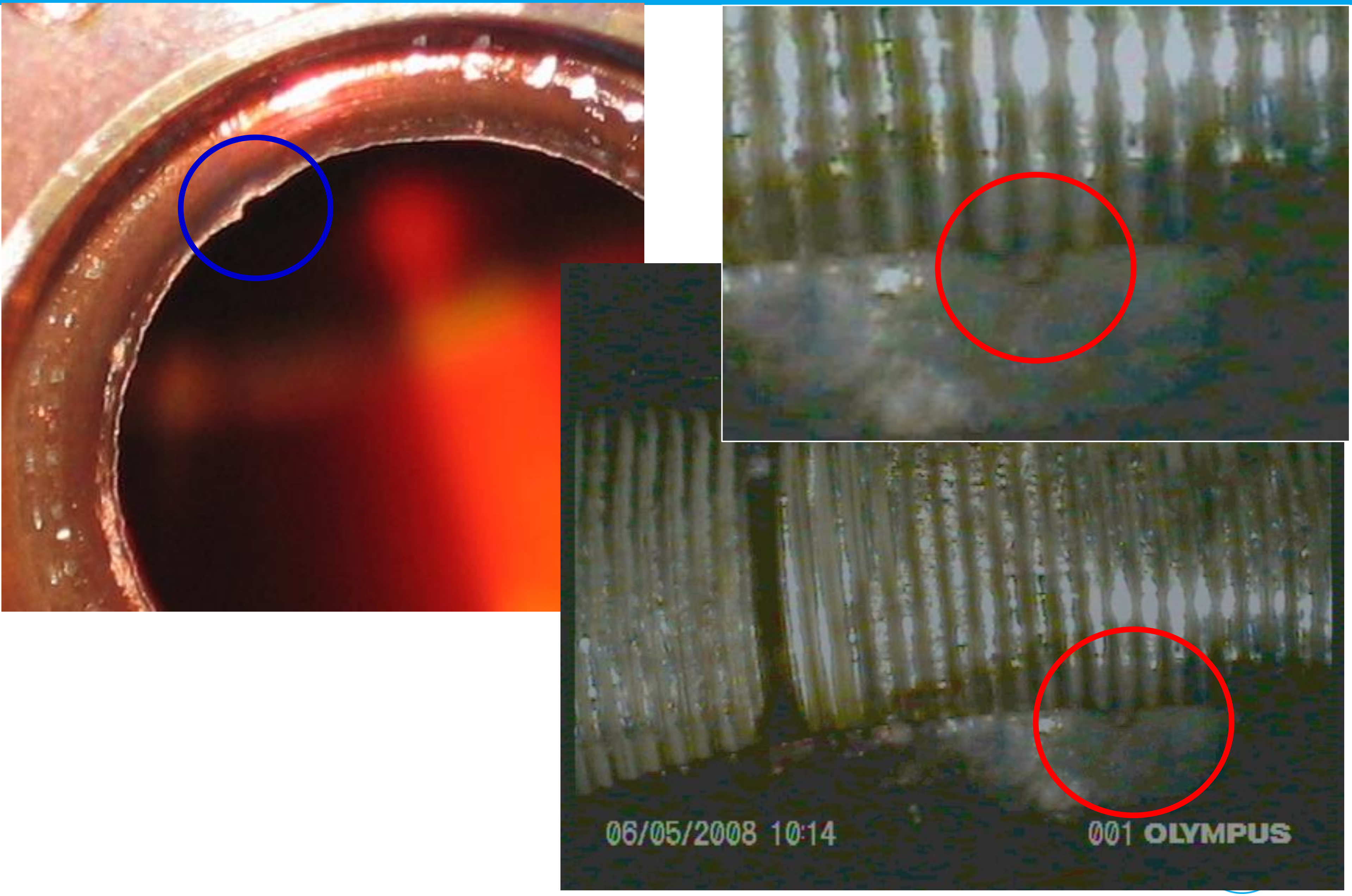


RF contact spring

Spring removed

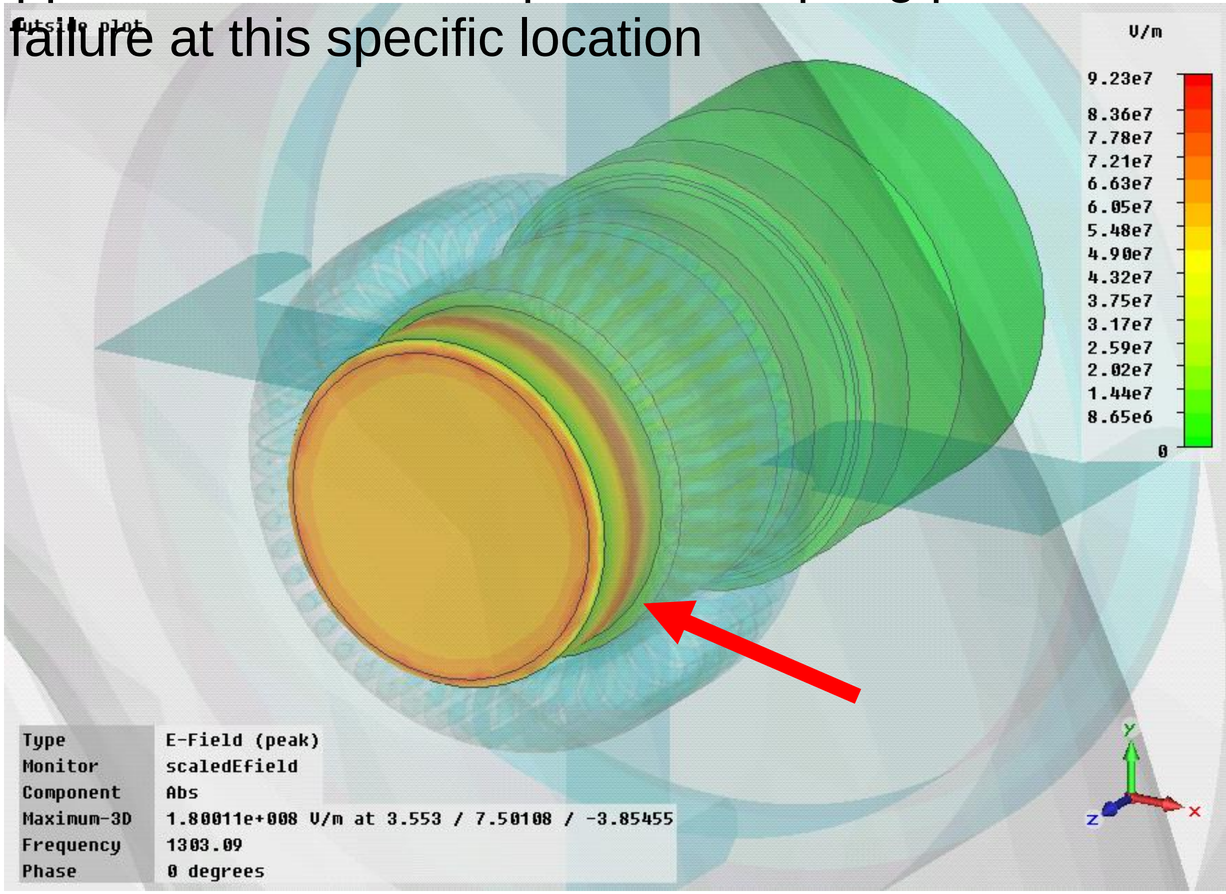
Spark marks observed frequently

Similar damage Gun 2 (April 2008)



Simulation

- Recent simulation with more realistic geometry of the RF-spring
- As expected: field on cathode rim considerably larger
- Unexpected: due to finite conductivity of the materials involved, a ring with high field strength appears between backplane and spring position, which might explain the failure at this specific location

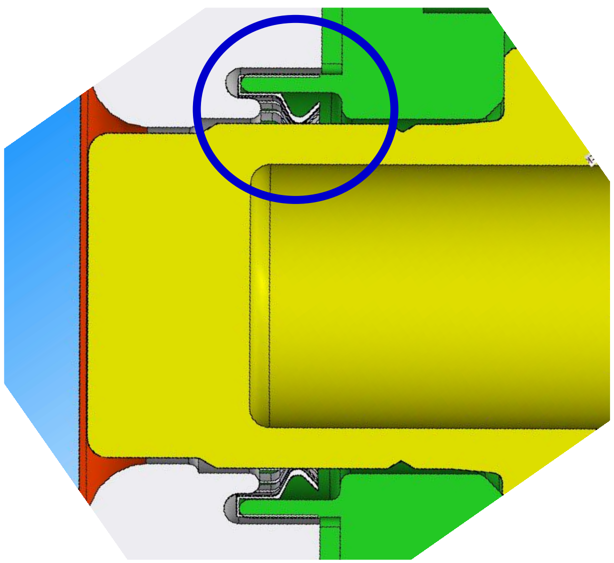


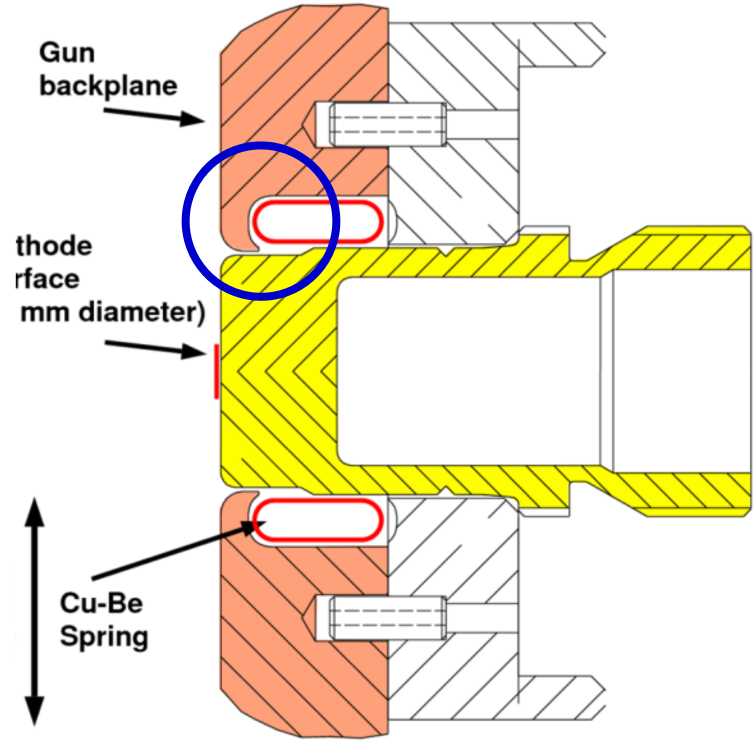
More refined simulation in progress

(D. Lipka, DESY)

New Spring Designs

- We considered the Fermilab design applied at some facilities and REGAE at DESY
- We also investigate a new design with RF fingers (compatible with our present cathode design)





- Design considerations:
  - Avoid “direct view” to RF cavity
  - Robust, good contact, avoid fragile copper parts (like the thin rim)

Summary

FLASH. Free-Electron Laser in Hamburg

- High duty cycle photoinjectors require high QE cathodes
- FLASH uses Cs_2Te cathodes since 1998
  - High QE ~10 % and long lifetime > 150 days
  - Typical charge extracted during lifetime ~4 C
- Darkcurrent due to particle contamination
  - Particle free assembly, dry ice cleaning of RF gun
  - New carrier design to reduce friction and thus particles
- RF contact spring issue
  - Considerable damage due to sparking spring-cathode (2008 and 2012)
  - New RF contact spring design under way
- The new DESY preparation system produced first cathodes
  - Not yet as perfect as LASA, but already very promising performance