Photocathodes at FLASH and European XFEL

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Photocathodes Physics for Photoinjectors Workshop
10th - 12th November, 2021
SLAC

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

INFN LASA Istituto Nazionale di Fisica Nucleare Laboratorio Acceleratori e Superconduttività Applicata

FLASH Free-Electron Laser in Hamburg

European XFEL

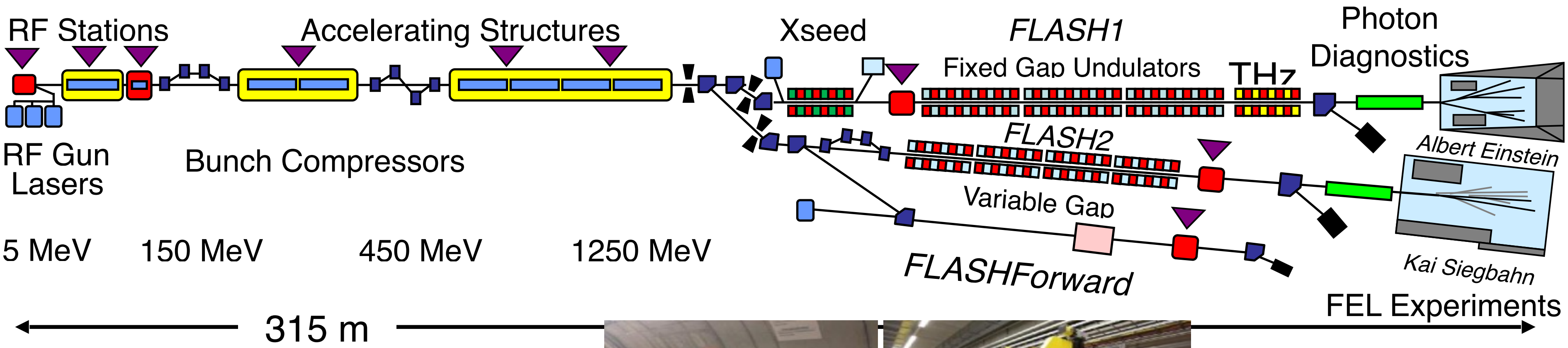
DESY.

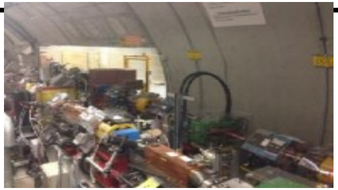
FLASH – The Free-Electron Laser in Hamburg (Germany)

FLASH Layout 2021

FLASH: the first soft X-ray FEL user facility operating two undulator beamlines simultaneously

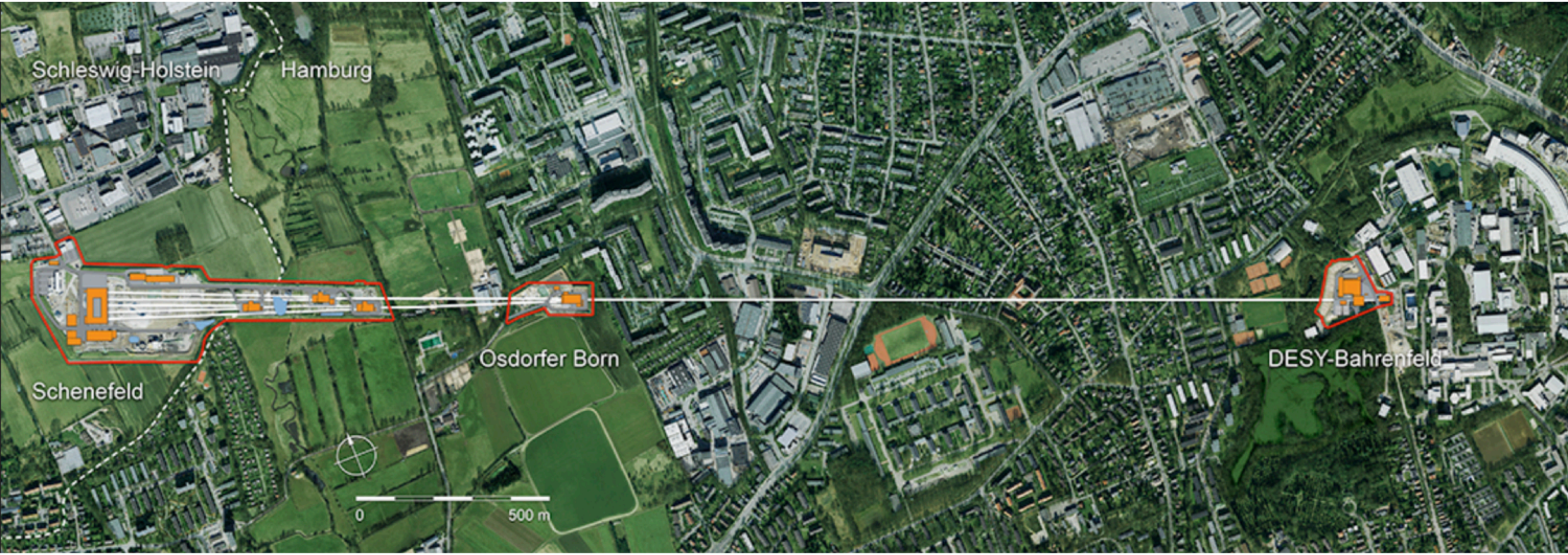






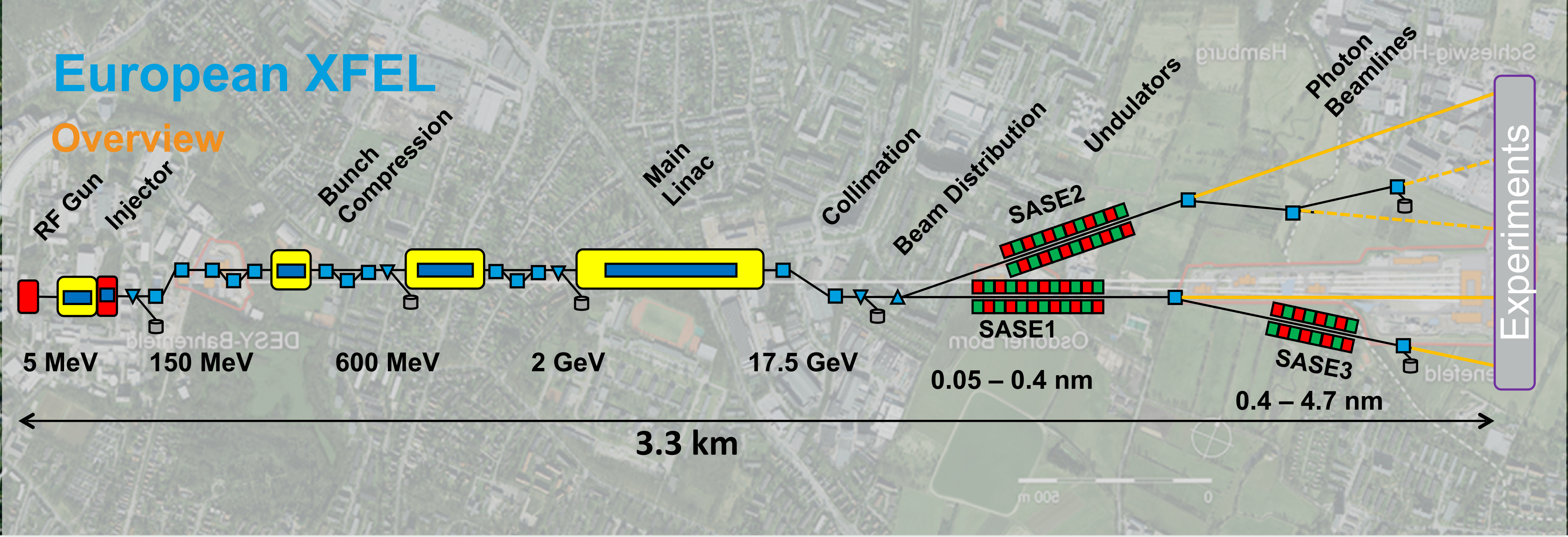
European XFEL

Overview



European XFEL

Overview



- Laser driven RF-gun
- 3 bunch compressors
- 97 1.3 GHz superconducting accelerator modules
  - Maximum beam energy 17.5 GeV
- Up to 600 kW beam power

- Three variable gap undulators
  - SASE1 and SASE2
    - 175 m magnetic length
    - 0.05 – 0.4 nm wavelength (25 keV – 3 keV)
  - SASE3
    - 105 m magnetic length
    - 0.4 – 4.7 nm wavelength (3 keV – 0.26 keV)

4th Generation light sources

High brightness electron injectors

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Review

On the Importance of Electron Beam Brightness in High Gain Free Electron Lasers

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Abstract: Linear accelerators delivering high brightness electron beams are essential for driving short wavelength, high gain free-electron lasers (FELs). The FEL radiation output efficiency is often parametrized through the power gain length that relates FEL performance to electron beam quality at the undulator. In this review article we illustrate some approaches to the preliminary design of FEL linac-drivers, and analyze the relationship between the output FEL wavelength, exponential gain length and electron beam brightness. We extend the discussion to include FEL three-dimensional effects and electron beam projected emittances. Although mostly concentrating on FELs based upon self-amplified spontaneous emission (SASE), our findings are in some cases highly relevant to externally seeded FELs.

Keywords: free electron laser; gain length; electron beam brightness

High Brightness Electron Injectors for 4^{th} Generation Light Sources

LECTURE 1:
INTRODUCTION AND MOTIVATION

DAVID H. DOWELL
STANFORD LINEAR ACCELERATOR CENTER

Abstract. The objective of this lecture is to justify the importance of injectors for the new generation of light sources based on Free Electron Lasers. This is done from both technical and economic points of view. The evolution of injector technology and the improvement in beam quality over the years is presented.

1. Introduction

The advancement of FEL-based light sources has been made possible in large part by the development of brighter electron sources due to an ever improved understanding of charged particle optics. The importance of low-emittance can be demonstrated by evaluating the ratio of normalized emittance to beam energy required for a FEL to operate at a given wavelength, FEL, as given by the following relation,

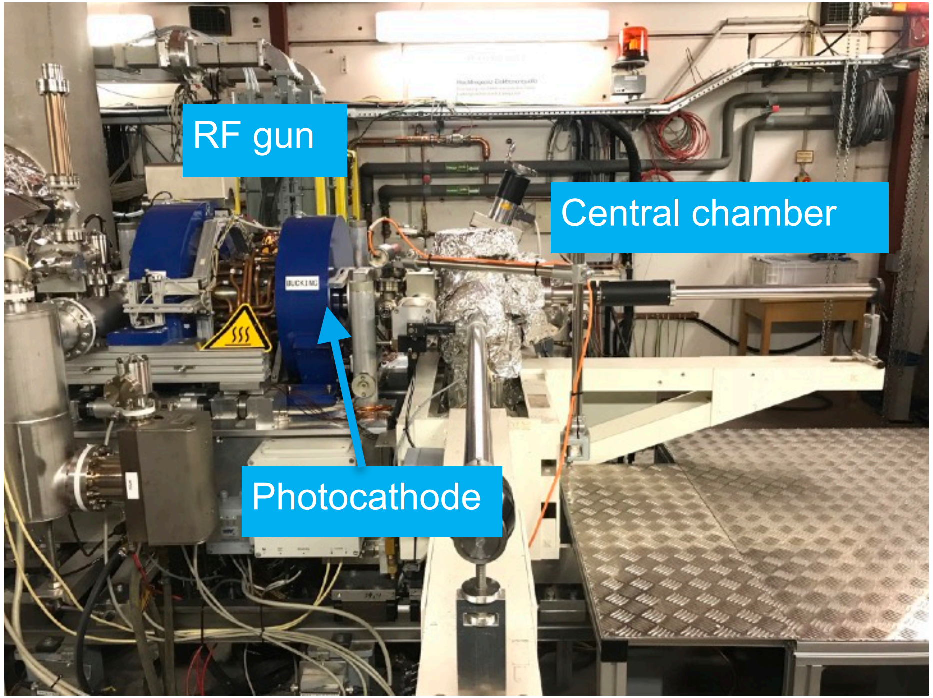
$$\frac{\epsilon_N}{\gamma} < \frac{\lambda_{FEL}}{4\pi} \qquad (1)$$

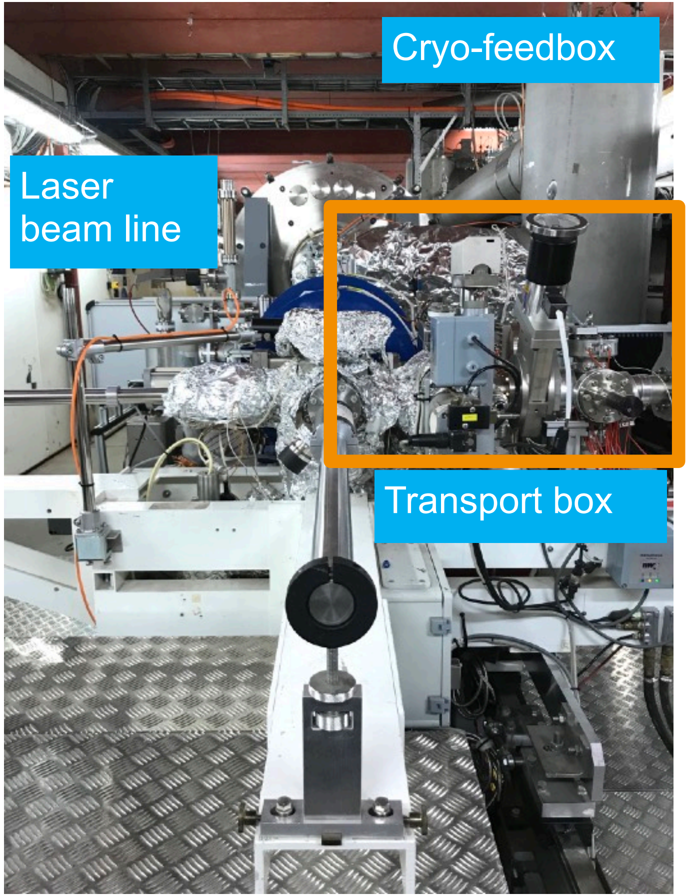
Where ϵ_N is the normalized emittance and γ is the reduced beam energy. Thus, it is possible for an FEL to operate at any beam emittance provided the energy is high enough to satisfy this condition. However this is done at great expense, especially for the new x-ray devices being constructed and proposed.

$$\varepsilon \leq \frac{\lambda}{4\pi}$$

FLASH photoinjector

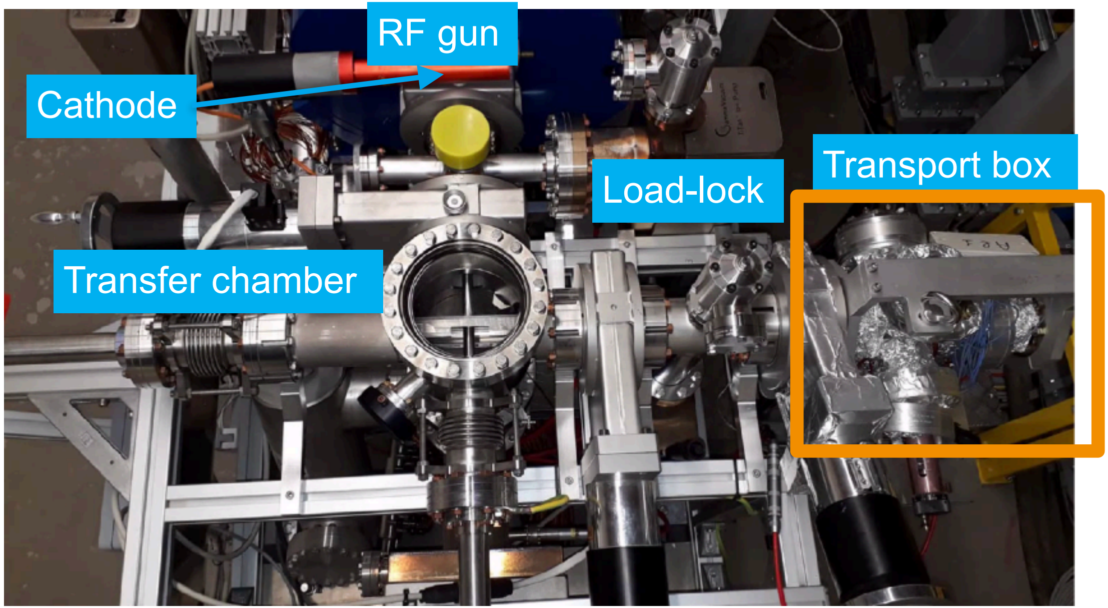
FLASH – transfer system





European XFEL photoinjector
European XFEL – transfer system

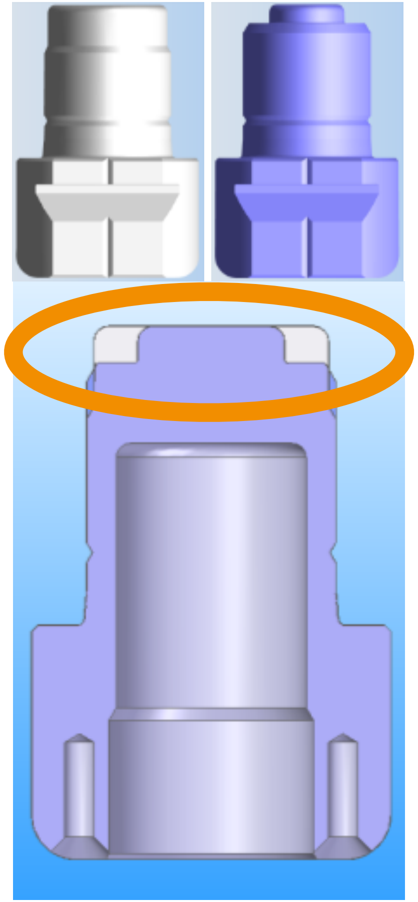
- System 100 % compatible to FLASH
- Improvements
  - Easier alignment between chambers (rails)
  - Improved visibility in the central chamber by means of a side view port
    - Positioning of the pincer much easier
  - Rails exchangeable



Cathodes for
FLASH & EuXFEL

Cathode Plug
Comparison

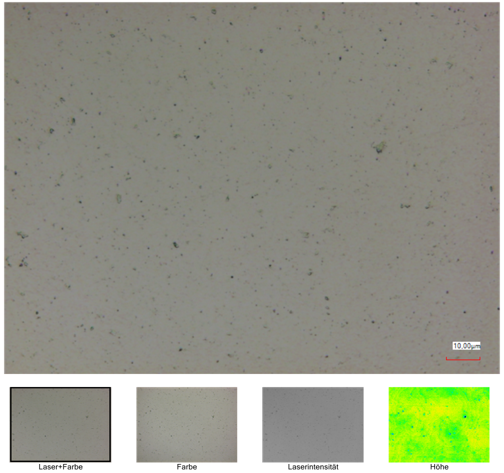
- Original INFN cathode plug design, used at European XFEL and FLASH
- For comparison, new INFN/Fermilab cathode plug design
  - used e.g. at APEX-gun @ LBL, CLARA @ STFC Daresbury, LCLS II @ SLAC, REGAE and SINBAD @ DESY
- Differences only in the front region, therefore
  - 100 % compatibility in preparation and transfer systems

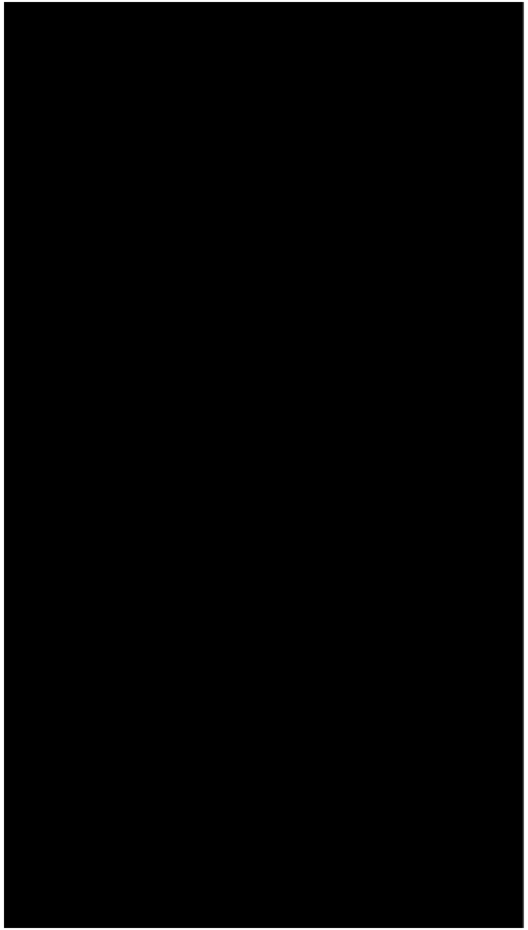


Plugs fabrication and polishing

Done at DESY in Hamburg

- Mo-Plugs are produced at DESY Hamburg
- Polishing recipes for different materials and designs
- Reflectivity at 532 nm around 60 %
- Surface-roughness Ra ~ 20 to 30 nm

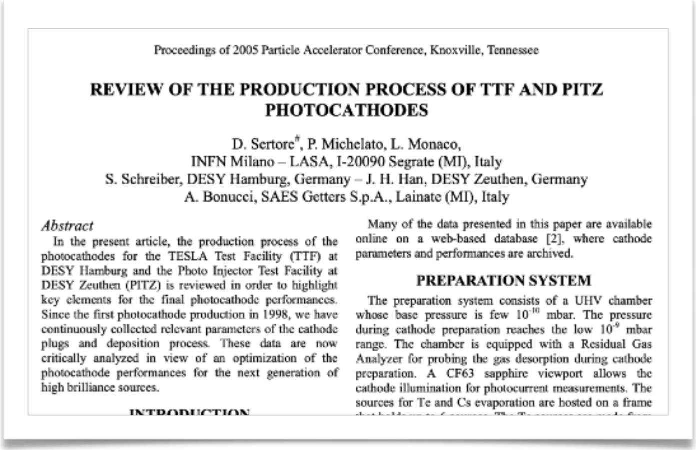




Cs_2Te Photocathodes

DESY deposition system // LASA's recipe

- INFN-Milano and LASA deposition system design
- Assembled by LASA in close collaboration with DESY
- All components are 100 % compatible to the Milano system



Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

REVIEW OF THE PRODUCTION PROCESS OF TTF AND PITZ PHOTOCATHODES

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A. Bonucci, SAES Getters S.p.A., Lainate (MI), Italy

Abstract

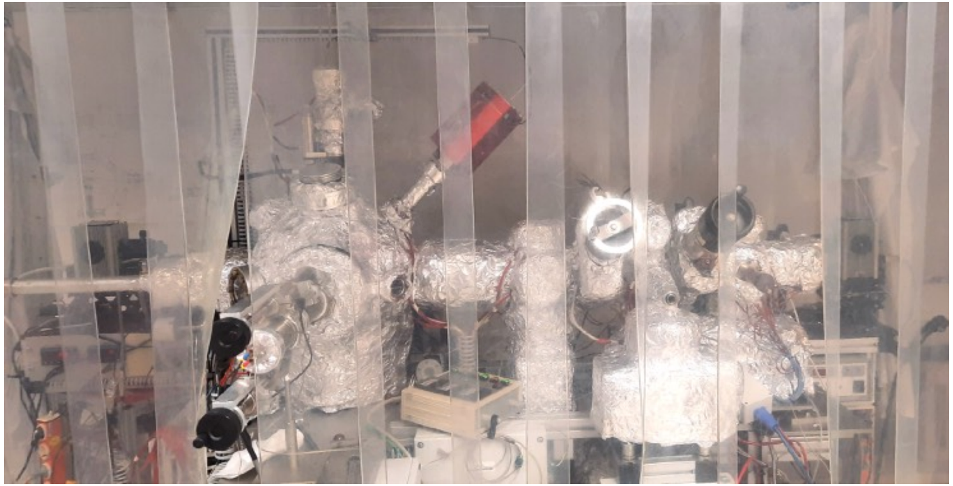
In the present article, the production process of the photocathodes for the TESLA Test Facility (TTF) at DESY Hamburg and the Photo Injector Test Facility at DESY Zeuthen (PITZ) is reviewed in order to highlight key elements for the final photocathode performances. Since the first photocathode production in 1998, we have continuously collected relevant parameters of the cathode plugs and deposition process. These data are now critically analyzed in view of an optimization of the photocathode performances for the next generation of high brilliance sources.

INTRODUCTION

Many of the data presented in this paper are available online on a web-based database [2], where cathode parameters and performances are archived.

PREPARATION SYSTEM

The preparation system consists of a UHV chamber whose base pressure is few 10^{-10} mbar. The pressure during cathode preparation reaches the low 10^{-9} mbar range. The chamber is equipped with a Residual Gas Analyzer for probing the gas desorption during cathode preparation. A CF63 sapphire viewport allows the cathode illumination for photocurrent measurements. The sources for Te and Cs evaporation are hosted on a frame

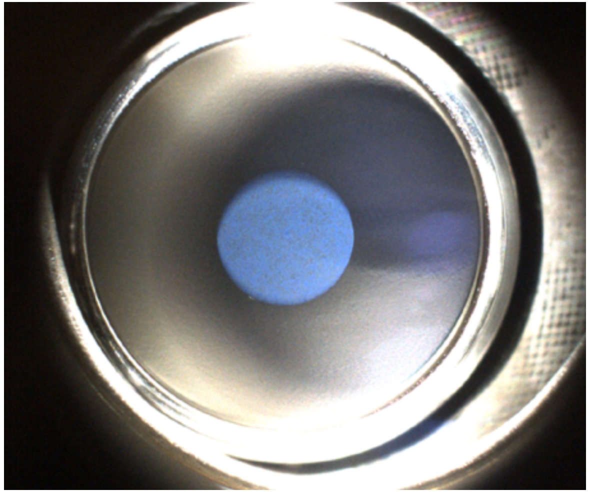


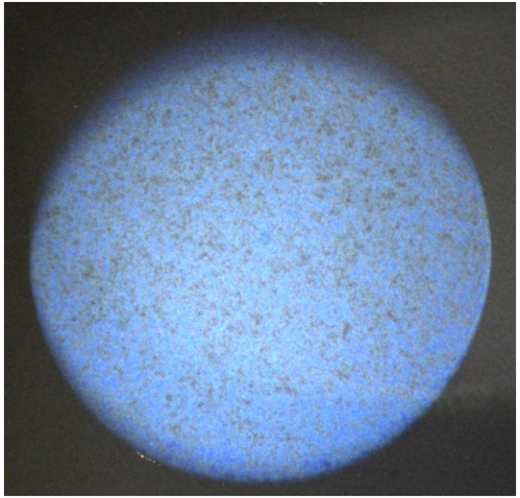
- Plug is heat to 450 °C then kept to 120 °C
- Tellurium source starts
    - Rate of 1 nm/min ~ 10 nm thickness
- Followed by Caesium source
    - Rate of 0.5-1.0 nm/min
    - Until the QE maximum is reached
- Photocurrent monitored during the process
- The cathode is cooled down to room temperature after deposition
- QE measured at 254 nm in its transport box

Cs_2Te Photocathodes

DESY deposition system // LASA's recipe

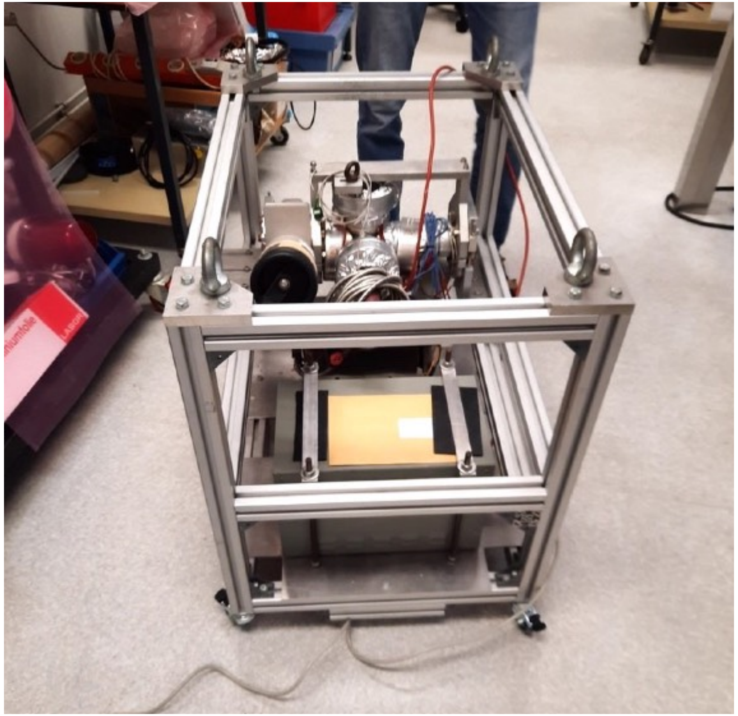
- Mo Cathode 722.1 polished and inserted in the system
- Cs_2Te deposition



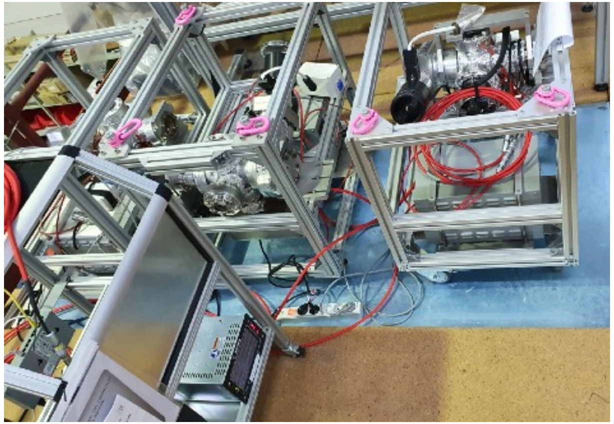


Cathode’s transport box

From Hamburg to PITZ and Milano to Hamburg



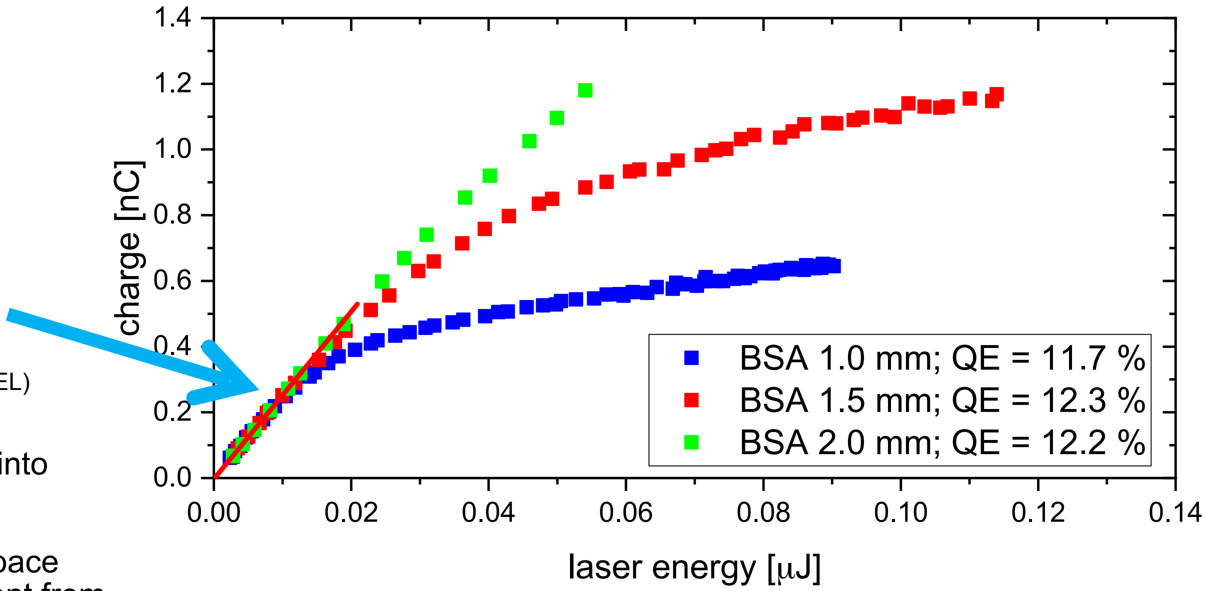
- Portable transport box
- 3 different designs boxes that are available to serve several facilities
- Powered through a DC/DC converter by a car battery
- The vacuum is in the low 10^{-10} mbar range
- The vacuum level is monitored continuously
- The 4 cathodes stored can stay alive for a long time



QE measurement procedure

At FLASH photoinjector

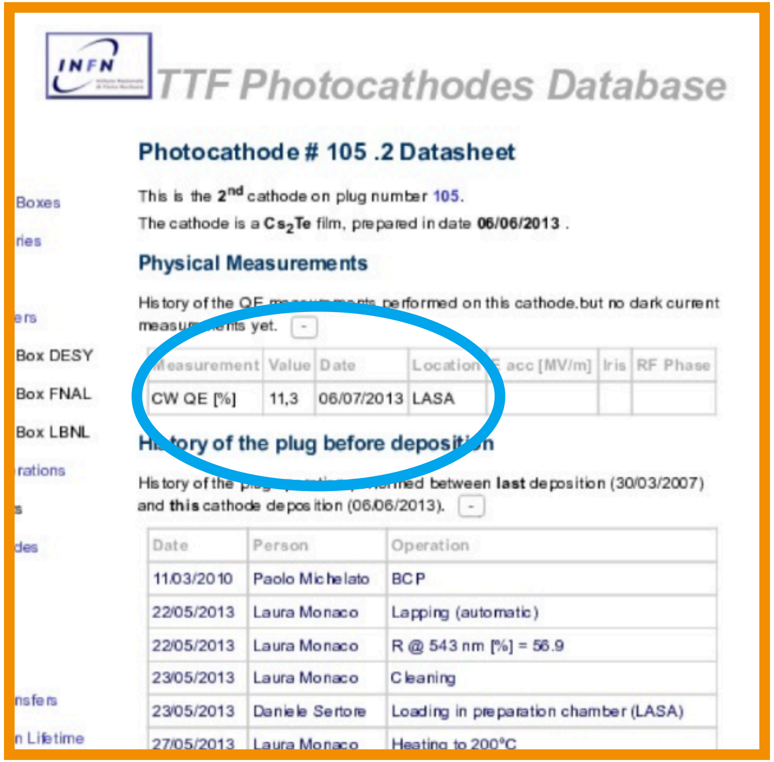
- Laser No. 2, 1 MHz, 30 Bunches, flat train with apertures 1.0, 1.2 and 2.0 mm
- Gun phase scan with max 200 pC
- Gun phase to 38 deg off zero
- Different laser apertures
- Laser energy measured by
  - Calibrated joulemeter (FLASH)
  - Cross-calibrated photo diode (European XFEL)
- Transmission of vacuum window and reflectivity of in-vacuum mirror taken into account
- QE is obtained from linear fit in not space charge dominated regime (independent from laser spot size for homogeneous cathodes)



QE map measurement procedure

At FLASH photoinjector

Cathode 105.2



INFN

TTF Photocathodes Database

Boxes

ries

ers

Box DESY

Box FNAL

Box LBNL

rations

s

des

nsfers

n Lifetime

Photocathode # 105 .2 Datasheet

This is the 2nd cathode on plug number 105.

The cathode is a Cs_2Te film, prepared in date **06/06/2013** .

Physical Measurements

History of the QE measurements performed on this cathode.but no dark current measurements yet. [-]

Measurement	Value	Date	Location	E acc [MV/m]	Iris	RF Phase
CW QE [%]	11,3	06/07/2013	LASA			

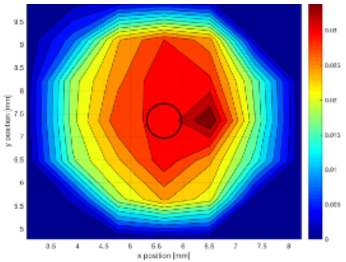
History of the plug before deposition

History of the plug operations performed between **last** deposition (30/03/2007) and **this** cathode deposition (06/06/2013). [-]

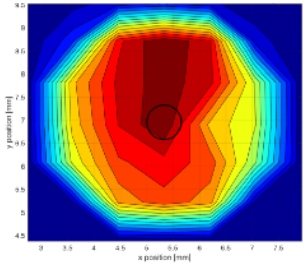
Date	Person	Operation
11/03/2010	Paolo Michelato	BCP
22/05/2013	Laura Monaco	Lapping (automatic)
22/05/2013	Laura Monaco	R @ 543 nm [%] = 56.9
23/05/2013	Laura Monaco	Cleaning
23/05/2013	Daniele Sertore	Loading in preparation chamber (LASA)
27/05/2013	Laura Monaco	Heating to 200°C

- Laser No. 2, 1 MHz, 30 Bunches, flat train with 100 um aperture -> 80 um sigma size
- Gun phase scan with max 200 pC
- Gun phase to 38 deg off zero

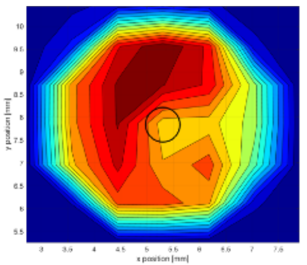
23-Mar-2021, QE=8.90 %



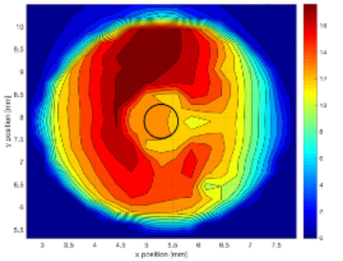
23-Mar-2021, QE=8.90 %



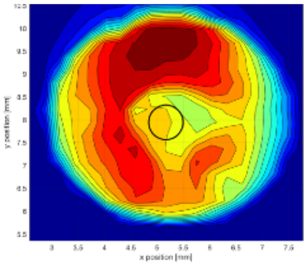
11-May-2021, QE=6.54 %



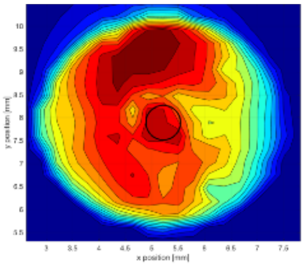
24-May-2021, QE=6.44 %



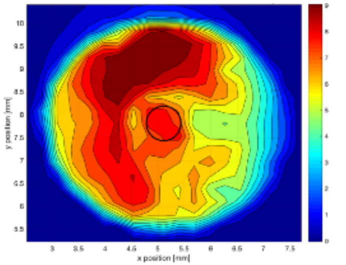
28-Jul-2021, QE=5.89 %



07-Sep-2021,



06-Oct-2021

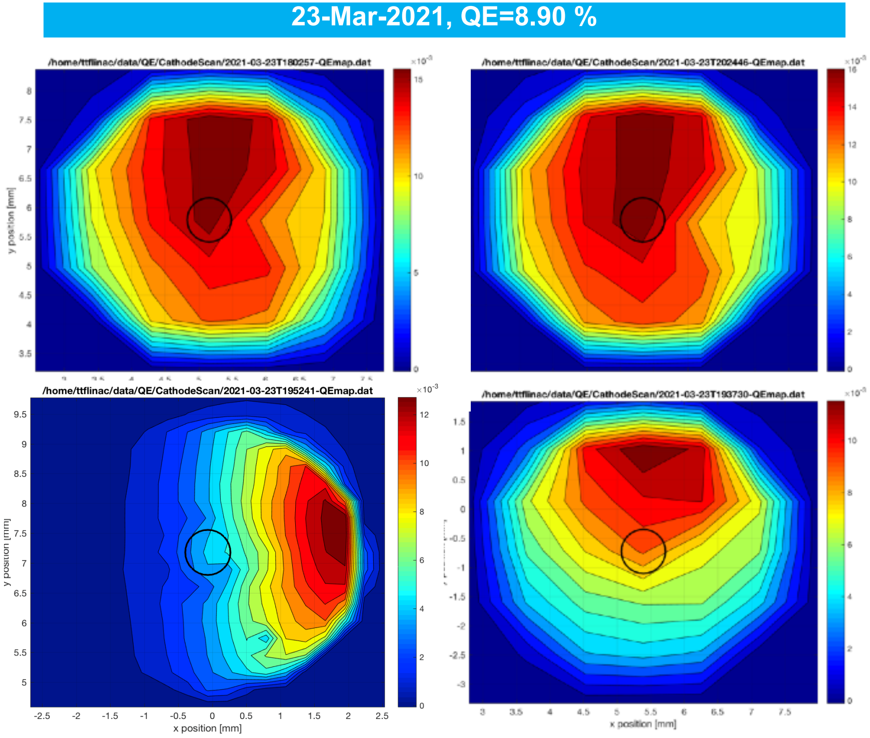


QE map measurement

At FLASH photoinjector

Cathode 105.2

The idea is to have the laser on the centre of the vacuum mirror while being at the edge of the cathode, this to compare if QE at the edges is actually low



extreme movement horizontally

extreme movement vertically

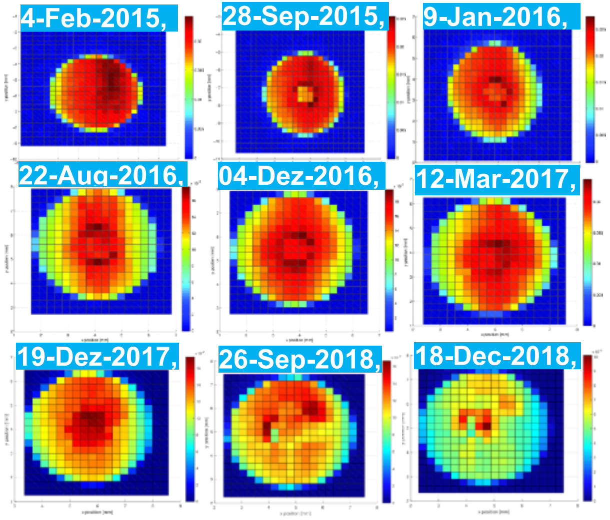
Current photocathode lifetime

FLASH cathodes comparison

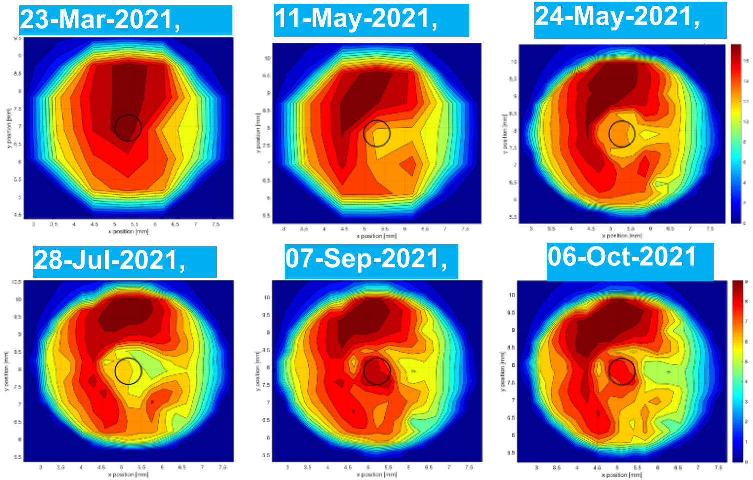
- Cathode # 73.3
  Operated from
  Feb-2015 to Dec-2018
  for **1413 days**

- Cathode # 105.2
  Operational since
  Dec-2018 until today.
  With 1058 days

FLASH – cathode 73.3



FLASH – cathode 105.2

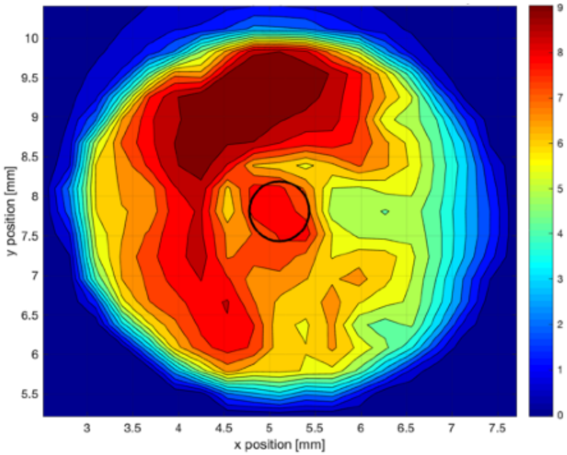


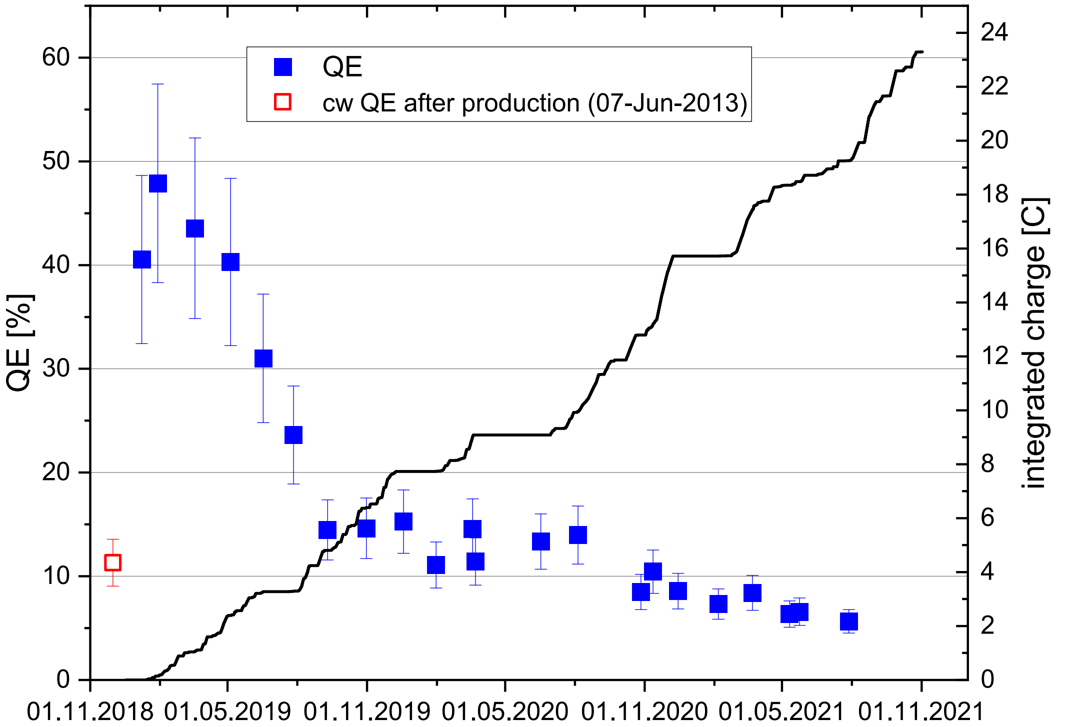
Both cathodes were produced at LASA

Cathode life time at FLASH

Cathode 105.2

- Cathode prepared 03-Jul-2013 at INFN-LASA
- In operation since 18-Dec-2018
- Operation time of 1058 days
- Total charge extracted 23.3 nC

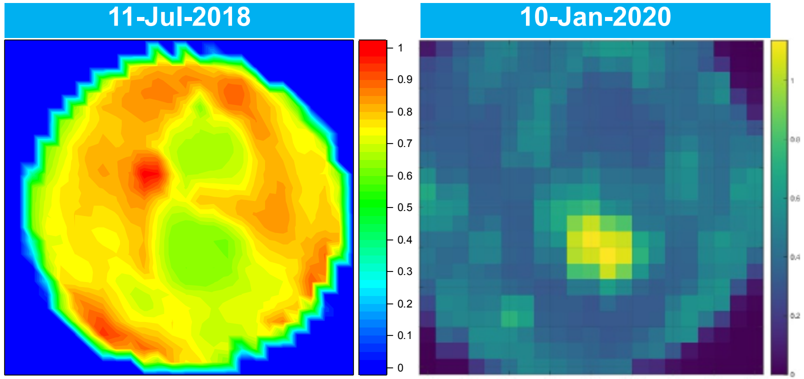


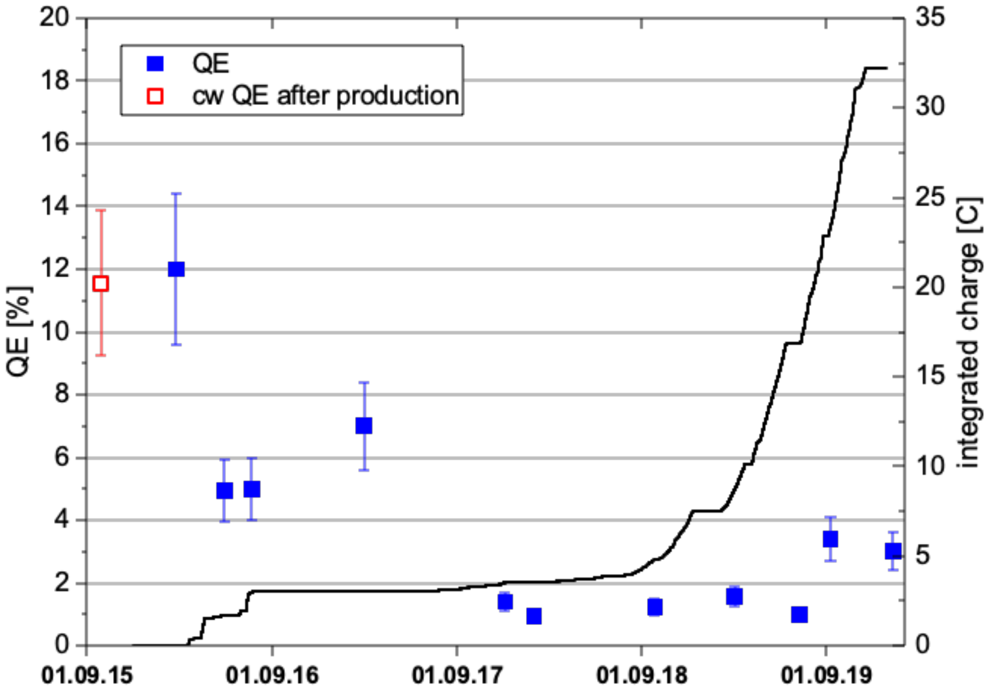


Cathode life time at European XFEL

Cathode 680.1 - Previous one

- Cathode prepared 01-Sep-2015 at DESY
- **Operation record time of 1452 days (previous one)**
- Total charge extracted 32.2 nC

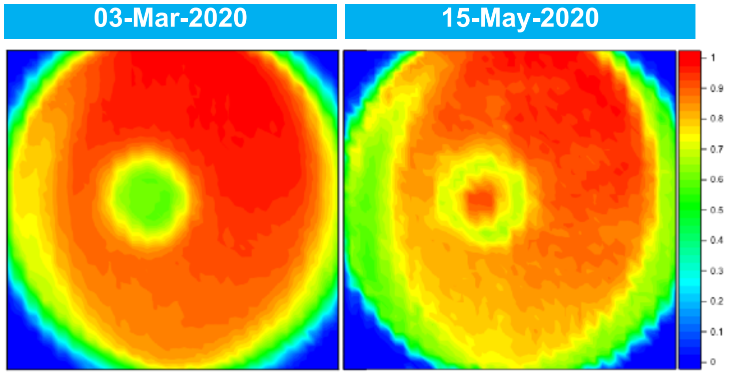


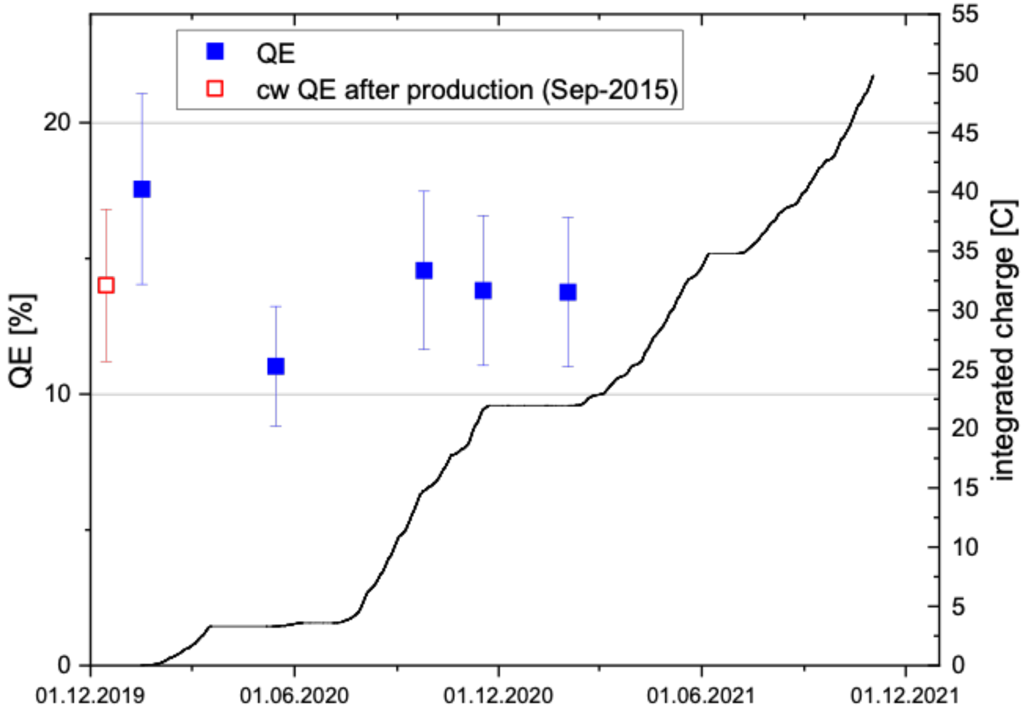


Cathode life time at European XFEL

Cathode 681.1 - Current photocathode

- Cathode prepared 08-Sep-2015 at DESY
- In operation since 14-Jan-2020
- **Operation time of 670 days**
- Total charge extracted 49.8 nC





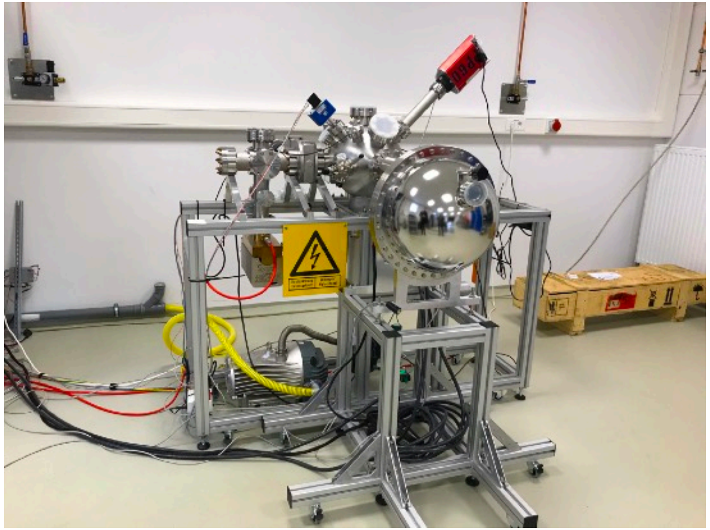
New deposition system

at DESY - LINAC III was

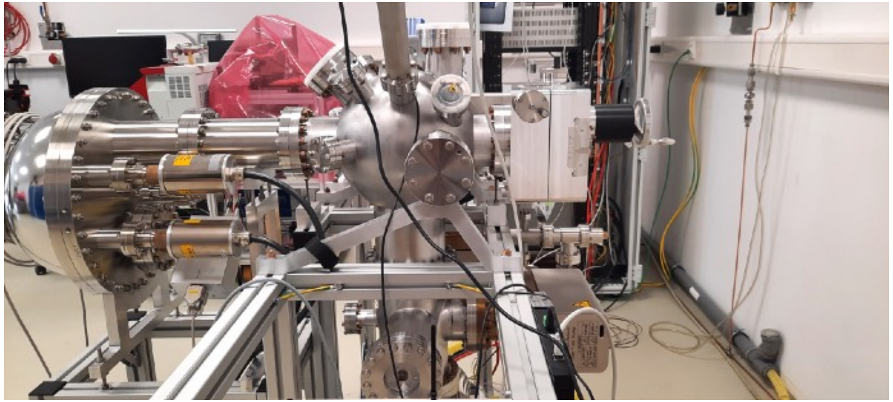
New characterisation system

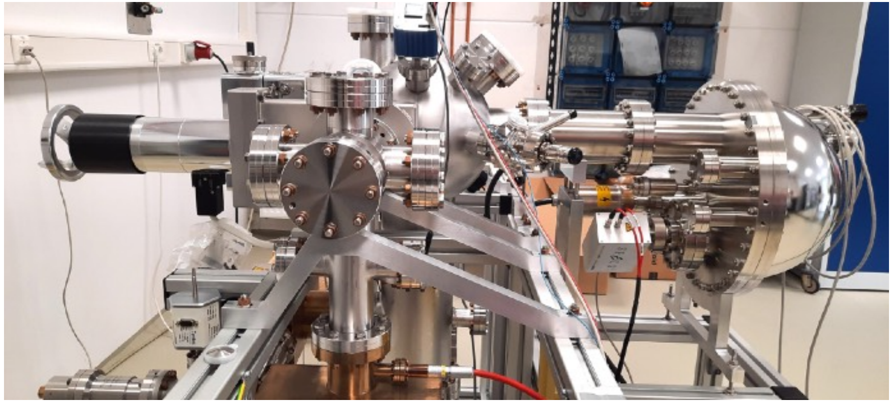
Blue Lab at DESY

- Building a characterisation system (XPS and AES).
- Build an electron transverse momentum spectrometer. (Grant in progress)
- Investigate green cathodes in collaboration with LASA - PITZ



Current system





Summary

Summary

- Cathode handling and transfer at FLASH and European XFEL works reliable but is continuously improving.
- At FLASH and European XFEL currently no cathode’s life-time issues of Cs_2Te photocathodes
- Cs_2Te fits well for FLASH and European XFEL as a user facility with its high QE and long lifetime
- Collaboration with PITZ and INFN-LASA in order to investigate green cathodes

Thanks

Questions?