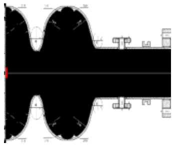
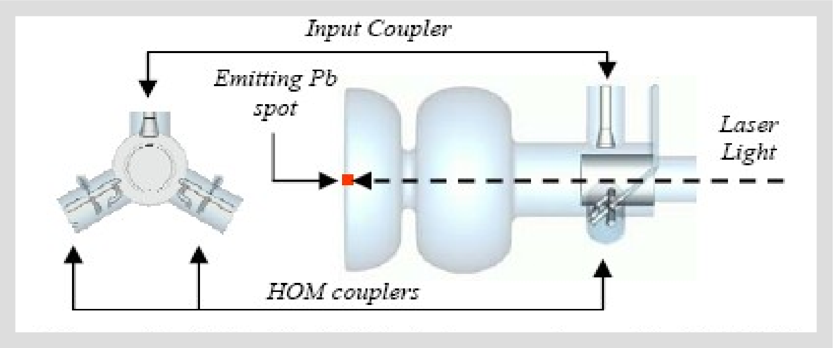
Status of Pb/Nb coatings for photocathodes

R. Nietubyć, J. Sekutowicz and P. Kneisel



Motivation

The goal is to build a Nb injector with the superconducting cathode made of lead for use in CW or near-CW operated high average current accelerators



CW electron accelerator

Acceleration

- No transient RF states
- Saves energy
- Necessary for ERL

High average power FEL

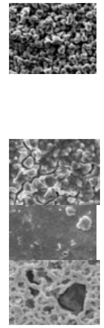
- Lowly probable phenomena
- Diluted samples
- Special applications
- Industrial applications

History I (first results)

Sample preparation

Various Pb samples were prepared:

- magnetron sputtered (a)
- electro-plated
- vacuum deposited (b)
- arc deposited (c)
- bulk lead (d)

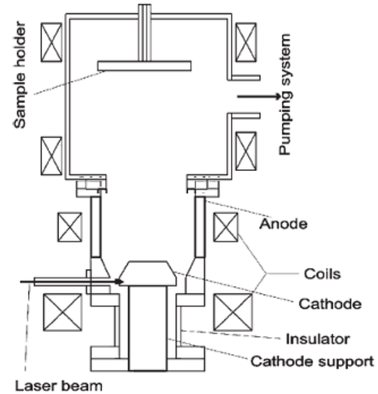


a

b

c

d



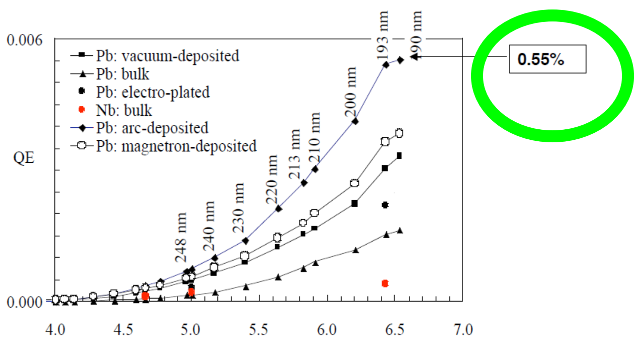
Cathodic arc - the simplest adaptation

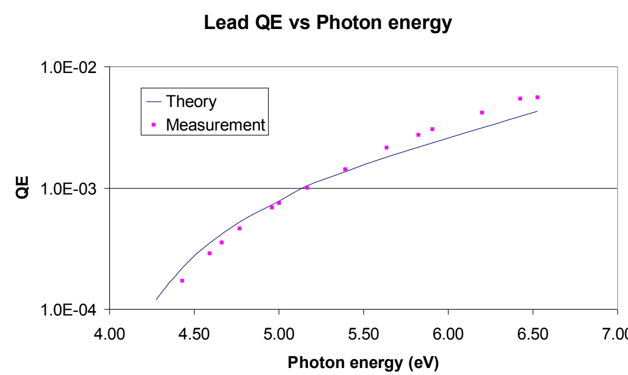
(based on Nb/Cu cavities coating):

- no microdroplets filtering,
- shortest possible distance in front of arcing cathode

QE Mesurements

Samples suraface was cleaned with KrF 10 ns 20 Hz pulses 248 nm 0.3 mJ/mm laser pulses, next QE was measured



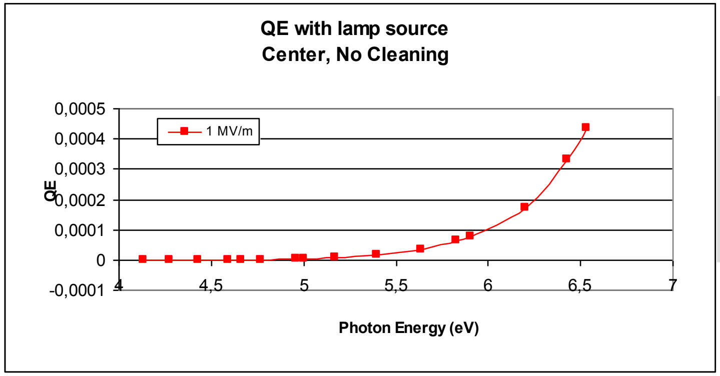


Arc deposited layer showed the highest QE

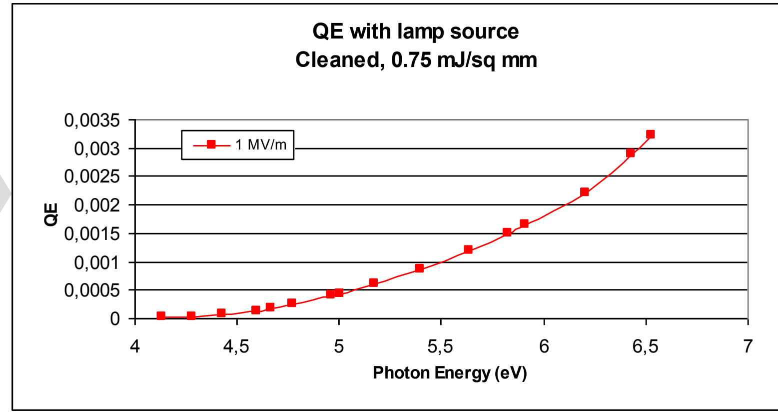
Experimental results confirm the calculations

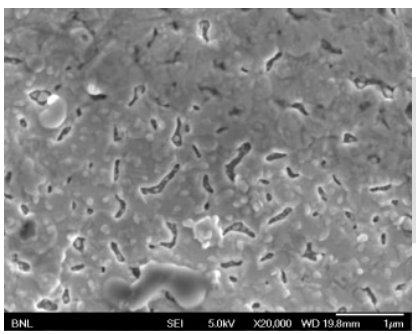
Conclusions : 1. QE evaluations for Pb were right 2. Arc deposited layer is the most efficient emmitter

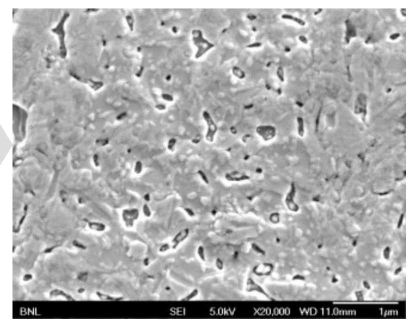
History II (recent results)



Gentle laser treatment : 190 nm, 30 min, 300 Hz 0.01 mJ/mm^2 per pulse







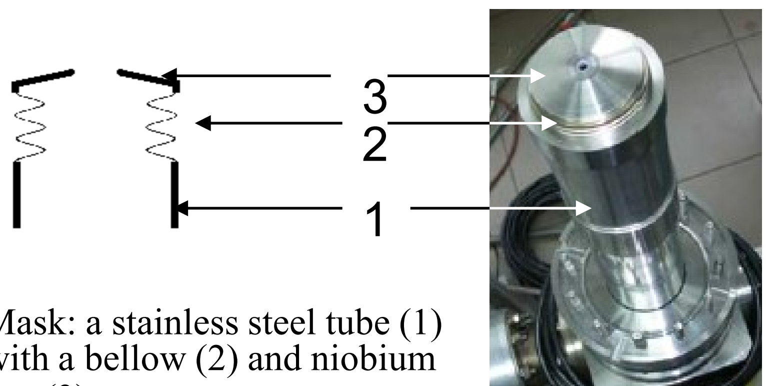
QE=3.3·10^{-3}

Conclusions : 1. microdroplets free layer is makeablble 2. optimal cleaning procedure was established 3. QE in the range of 10^{-3} has been achieved and there is still a room for improvement.

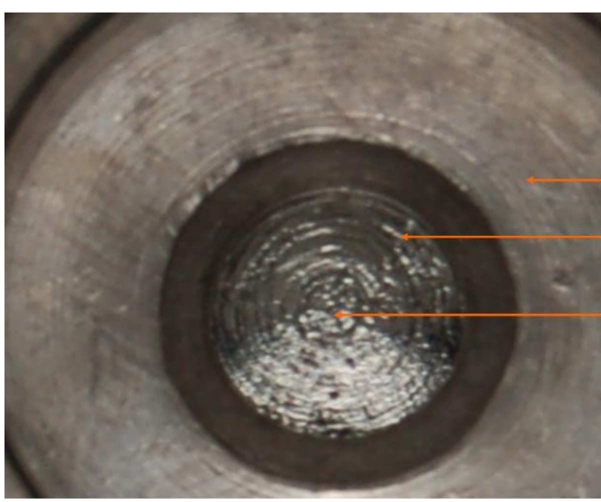
Cavity coating preparations

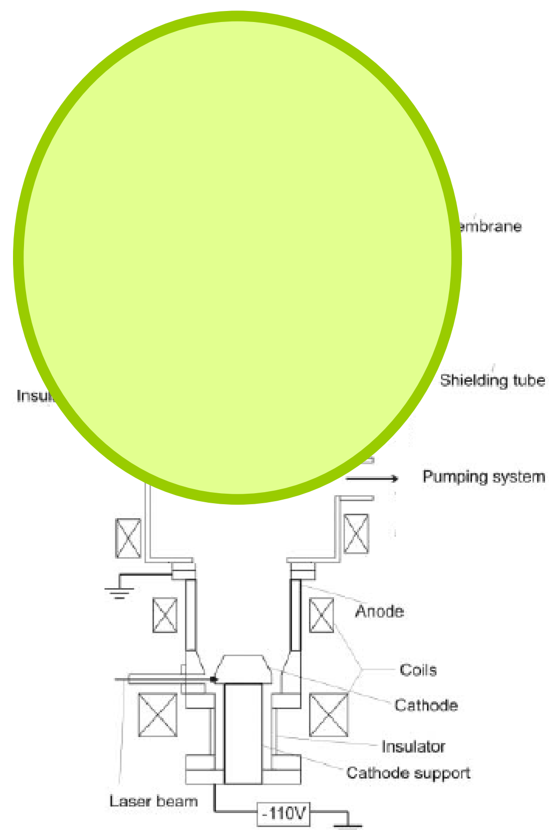
Coating the cavity back wall imposes large source-substrate distance.

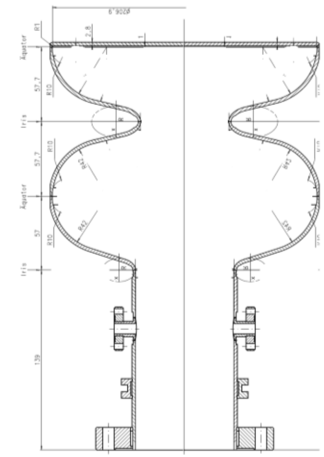
The inner surface must be covered againts lead



Mask: a stainless steel tube (1) with a bellow (2) and niobium cap (3)







Cavity coating - the simplest way

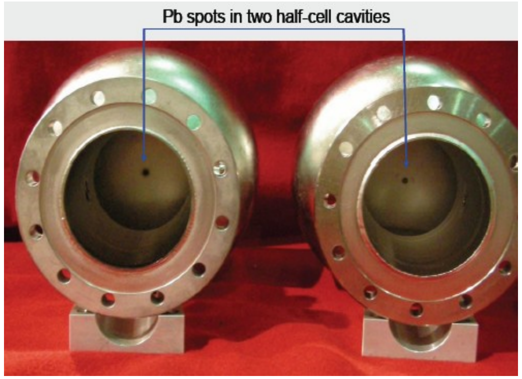
Deposition at IPJ

polarisation = -110 V
base pressure $<10^{-7}$ mbar
arc current = 25 A
coil current = 120 A
arc voltage = 17-18 V
ion current = 25 mA
deposition time < 80 min
Pb spot diameter = 3 mm
thickness < 1μm

After the deposition, the mask was dismounted, Pb spot spent a few minuts in air, next the cavity was filled with Ar and sent to TJNAL for BCP, HPWR same as in typical Nb cavities treatment. They were followed by cold rf tests.

deposition stage

½ and 1.6-cell cavities



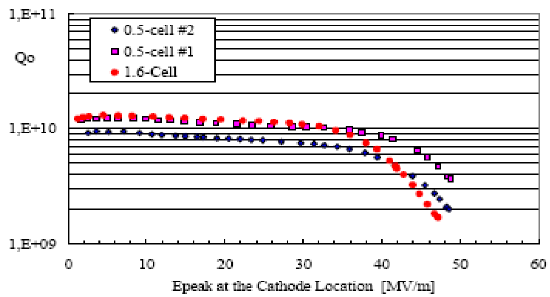
photocathodes

mask for BCP

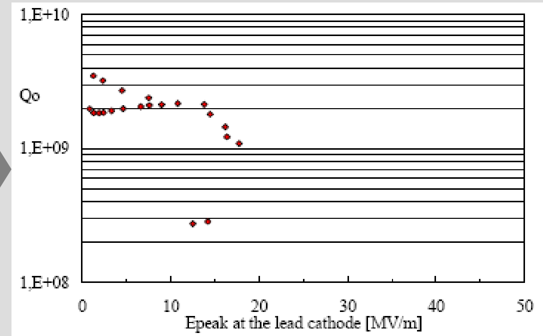
teatment

RF tests

Cavities without lead spot



1,6 cell cavity with lead spot



Q decesese caused by hydrogen, which got into teh walls during the deposition

Multipacting caused by insuficient BCP+HPWR

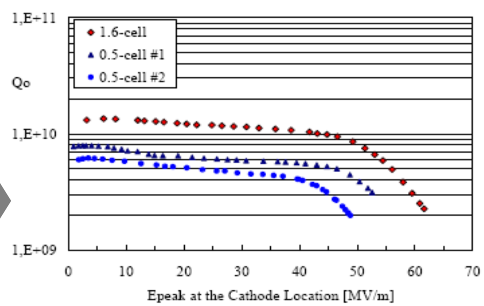
Pb removal:

BCP +HPWR,

H_2 removal

vacuum annealling in 600 °C

RF test of cleaned cavity



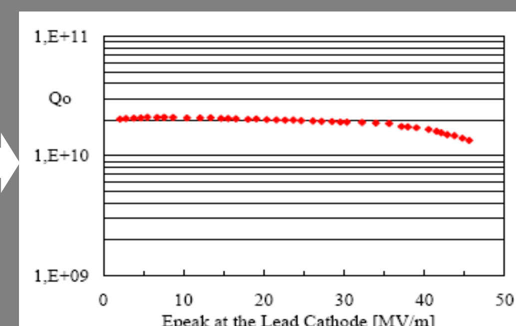
50 MV/m reached, but in cases of ½ cell cavity with Q slightly lower than in first baseline test

2nd Coating

cycles: 15 × (3 min and 40 min interval)
⇒T< 33° C

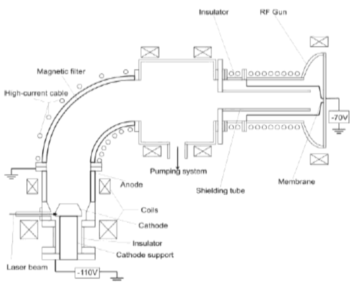
manipulations in N_2 flow chamber

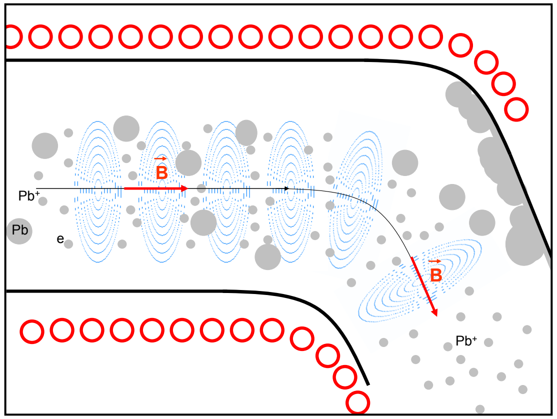
2 nd Test of 1,6 cell cavity

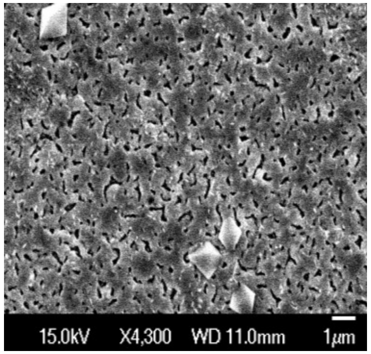


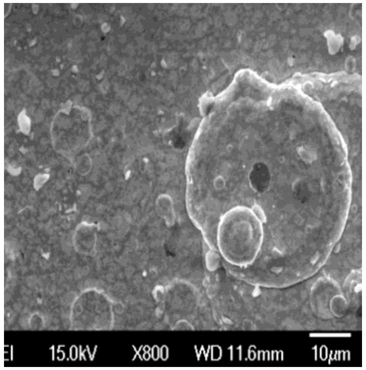
46 MV/m

Cavity coating - filtered arc







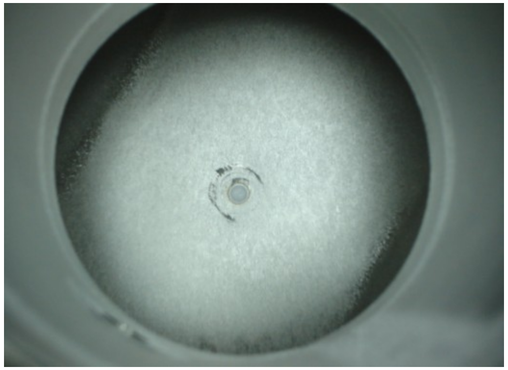


The arc carries not only ions but also droplets of few micrometers size. The cause a surface roughness which may results in angular divergence of emitted electrons

Micro-droplets can be filtered by bending the arc channel with magnetic field but in cost of transmission

DESY cavity 1.

A final test before coating the cavity to be used in Hobicat

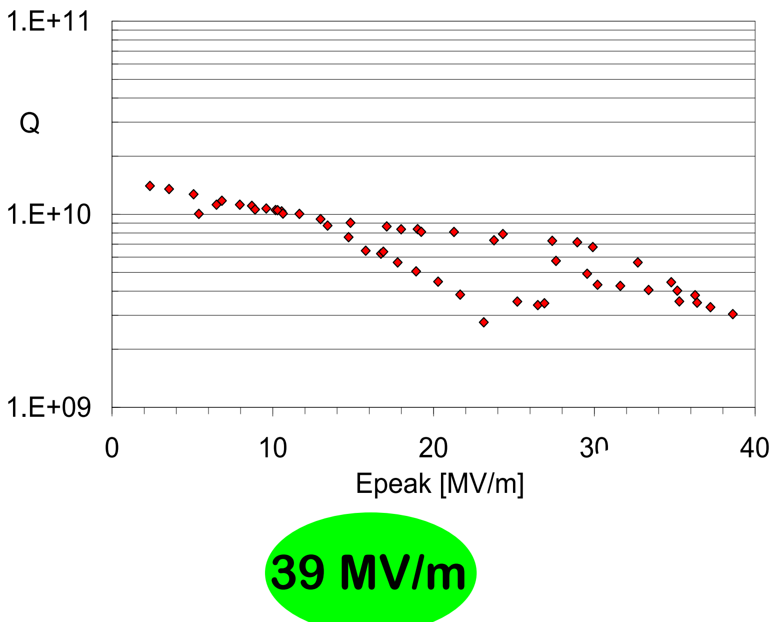


Pb deposition at IPJ (March 2010)

effective deposition time = 80 min (16×5 min arc + 30 min cooling)
base pressure < $2\cdot10^{-7}$ mbar
coil current = 75 A
ion current = 10 mA
deposition time = 80 min
wall temperature < 34 °C
thickness < 200 nm (roughly from EDS measurements for samples)

Post- deposition treatment and cold RF tests at TJNAL (May 2010)

Ø 8 mm spot → 5μm BCP → HPWR → Ø 3 mm spot ⟶ drying in cleanroom class 10



He leakage, $p=3\cdot10^{-6}$ mbar

Pb spot: shiny metallic

Quality factors: at low E_{acc} $Q = 1.4\cdot10^{10}$

Two measurements at high E_{acc} $Q = 3\cdot10^{9}$ at 39 $MeVm^{-1}$ and Q = 29 $MeVm^{-1}$, respectively

However: discharges and radiation 92 mrem

That promising test has could not been continued after the leak it was removed.

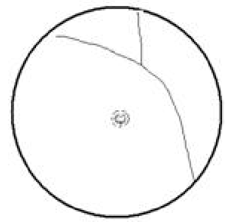
The film was eathed with a typical BCP acids mixture.

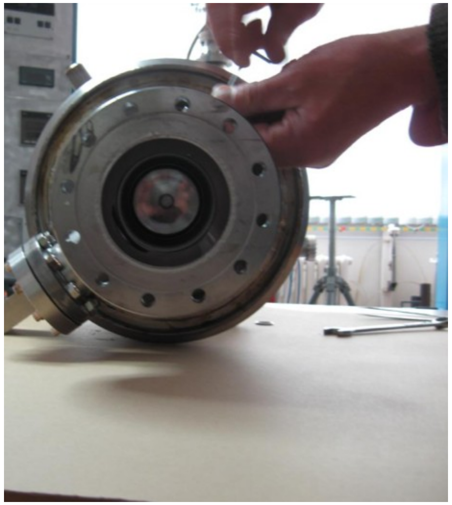
The cavity was sent for re-coating.

H Z B c a v i t y 1.

Back wall consist of three single crystalline domains.

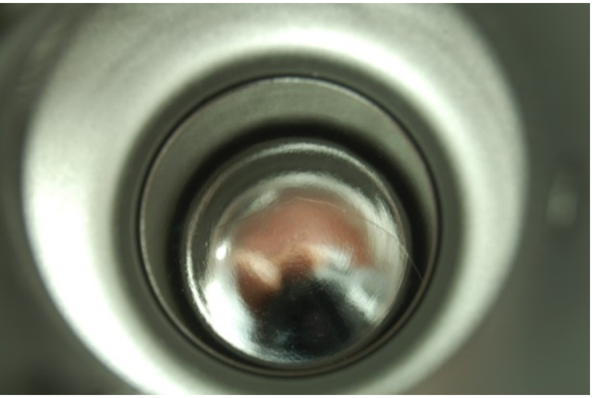
A heluim tank is assembled.





Coating at IPJ (May 2010)

coil current = 75 A, enhanced
ion current = 11 - 14 mA
deposition time = 80 min
T < 28 °C



Exactly the same deposition procedure was repeated for this cavity

A uniform spot of 1 cm in diameter was obtained. Next to a deposition the cavity was filled with N_2 and sent to JLab

20 days later, when it was opened

Film got orange

After HPWR it got black

HZB cavity 1.

Cold RF tests at TJNAL

He leakage, $p=3\cdot10^{-7}$ mbar at 2.5 K and $p=2\cdot10^{-7}$ mbar at 2.5 K

warming → tighting → cooling

f = 1299.923 MHz

Quality factors: at low E_{acc} $Q = 9\cdot10^{9}$ at low E

$Q = 2{,}34\cdot10^{9}$ at 29.4 $MeVm^{-1}$

Again discharges and radiation 72 mrem

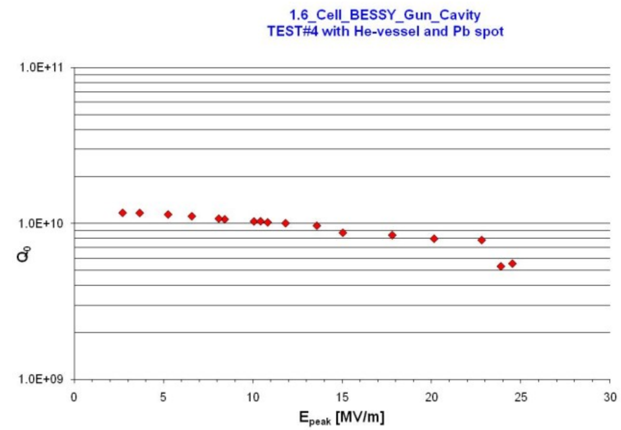
Reassembling and stain removal from the flange → vacuum fell down to $5\cdot10^{-9}$ mbar

Measurement: $Q = 1\cdot10^{10}$ at low E_{acc}

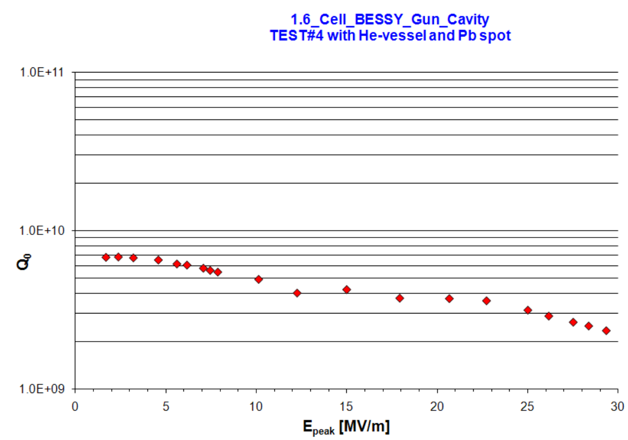
But the cavity was warming and did not surpass 10 MVm^{-1}

HPWR →

The spot disappeared



Q vs E_{acc} measuremts at T=2.2 K



Q vs E_{acc} measuremts at T=2.0 K

As the layer was successfully deposited and spoilt only due to unknown reason. We considered that the experiment is worth of severe work and schedule rearrangement in order to try again.

HZB cavity 1.

Ring

A ring of 10 mm diameter after 10 mm BCP and next 8 min BCP at bacv wall only → another 20 mm

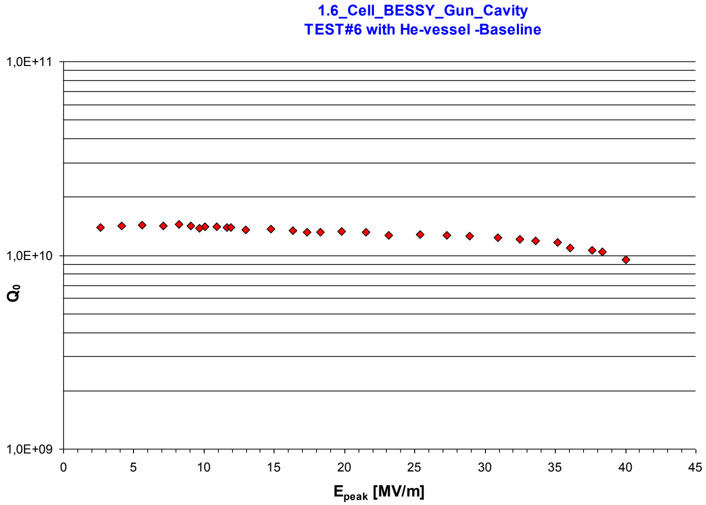
At that point a BCP treatment was stopped because of possible cavity detuning

Polishing + degreasing + BCP of back wall 20 μm + 20 μm BCP of all inner surface of the cavity + drying

Verification:

Q vs E_{acc} measurement

$9.3 \cdot 10^9$ at 40 MVm^{-1}



Sent to Swierk

HZB cavity 2.

Coating at IPJ (August 2011)

The same process parametres

Filled with Ar and closed for transportation

Post-deposition treatment and tests at TJNAL (Sept., October 2010)

10 days later at TJNAL the spot was again very slightly yellowish. Much less than before

Degrasing + BCP + HPWR. After tha the spot was still at its place

Drying, pumped down to $p = 2\cdot 10^{-8}$ mbar, baked out in 120 °C, then $p = 1\cdot 10^{-8}$ mbar

Cooled to T = 2 K, pressure fell down to $5\cdot 10^{-9}$

RF tests failed at $E_{acc} < 10\ MVm^{-1}$

Warming → cooling cycle does not help

BCP 1:1:2, 2 min + HPWR 20 min +drying

Pumped down to $p < 1\cdot 10^{-5}$ mbar and baked at T=114 °C, then $p=1.5\cdot 10^{-8}$ mbar

RF tests stopped at the same problem as before

That behaviour was not undertand, It might be

- field emission
- multipacting
- bad Pb/Nb thermal contact
- local normal conducting

} rather not

however luckily that was not lead what was responsible for the strong power absorption

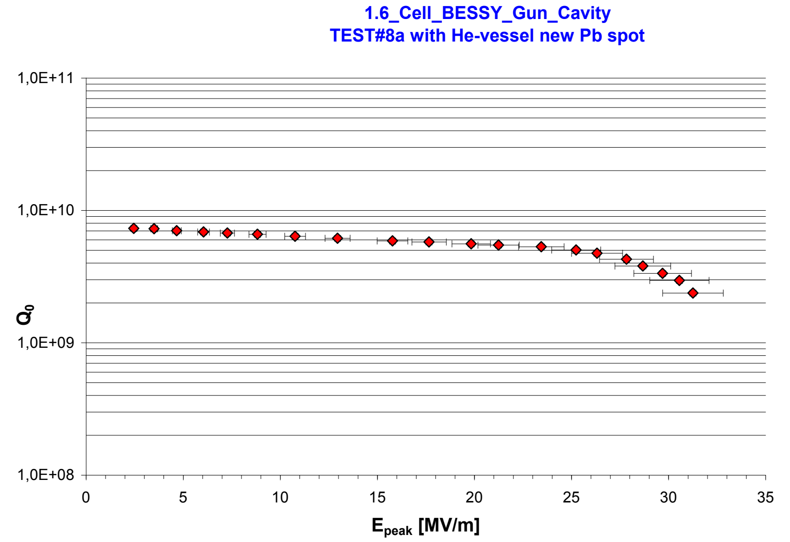
HZB cavity 2.

Further tests at TJNAL (October 2010)

The cavity was leak checked and baked at 95°C for 18 hrs;

When cooled down to room temperature, the vacuum was $p = 7 \cdot 10^{-9}$ mbar,

After the further cooling down to 2 K the pressure was , $p < 5 \cdot 10^{-9}$ mbar



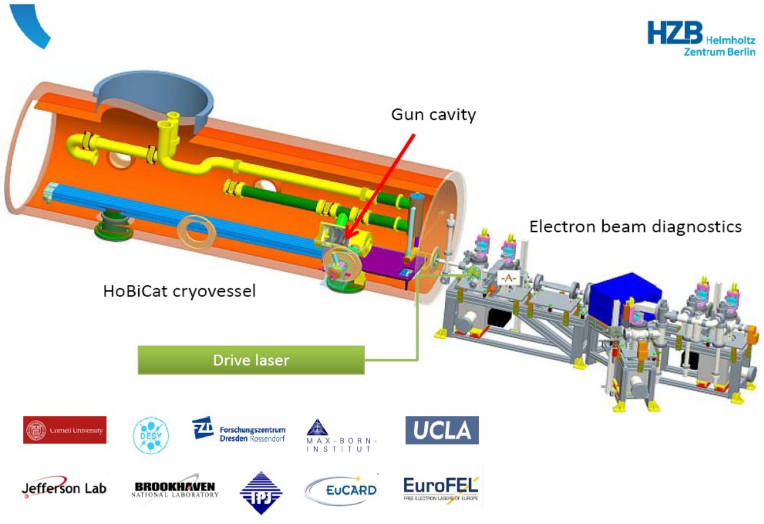
Q measurement gave:

$Q = 7.3 \cdot 10^9$ at low E_{acc}

$Q = 2.4 \cdot 10^9$ for $E_{acc} = 31.25\ MVm^{-1}$

sent to Hobicat

Thorsten Kamps and his group at HZB



Measurements:

Q

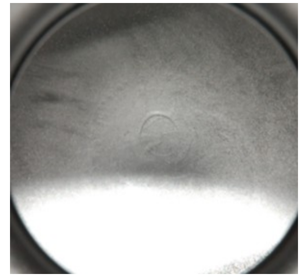
dark current

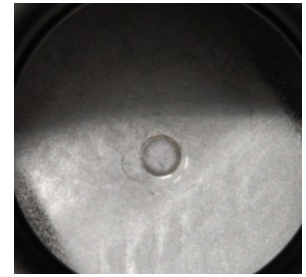
Bunch

- charge
- length
- profile

Coating (September 2010)

The same procedure with the only difference: an additional coil was wrapped around the back wall to enhance B field



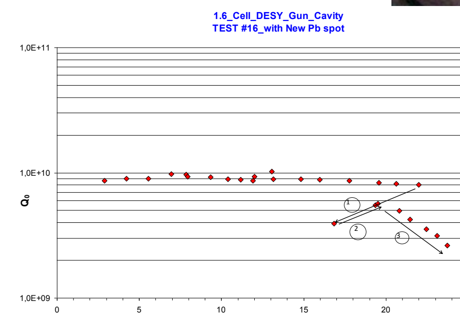


Post-deposition treatment and tests at TJNAL (December 2010)

Reached 20 MVm^{-1} with $Q = 7 \cdot 10^9$

Pb spot was damaged in chemistry

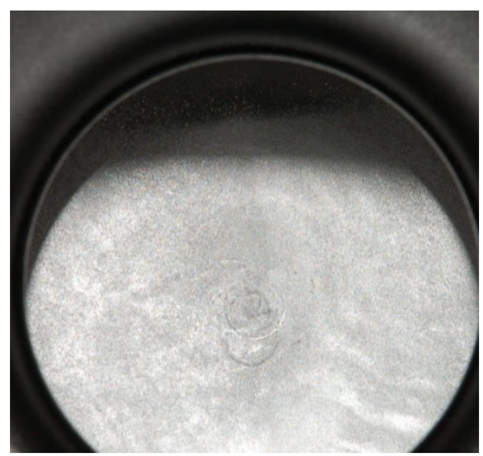
Cavity sent for re-coating

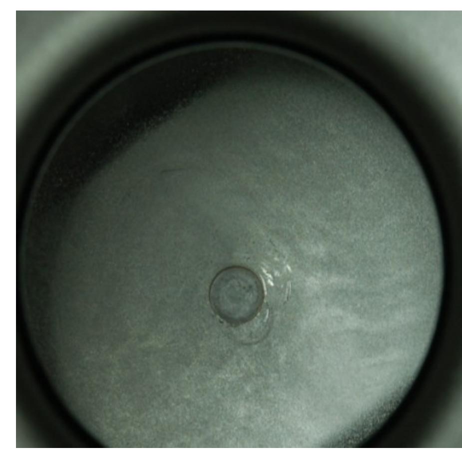


D E S Y   c a v i t y   3.

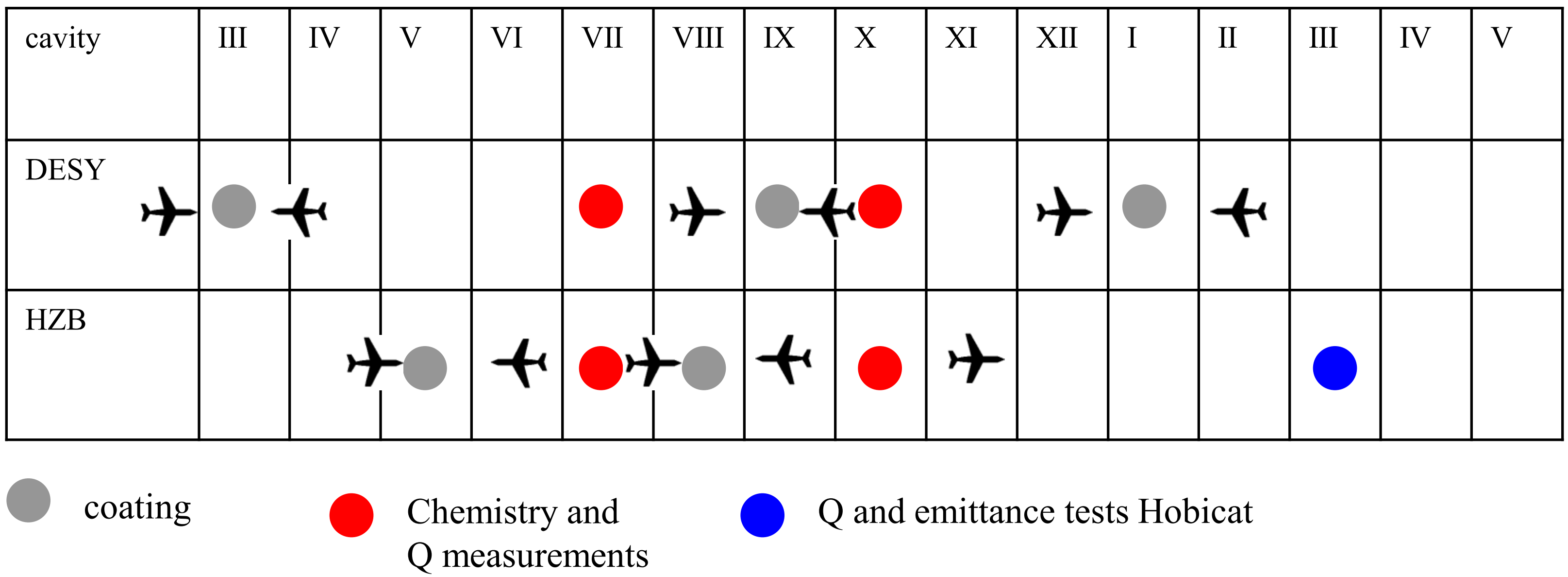
Coating (January 2011)

The same coating procedure as in September



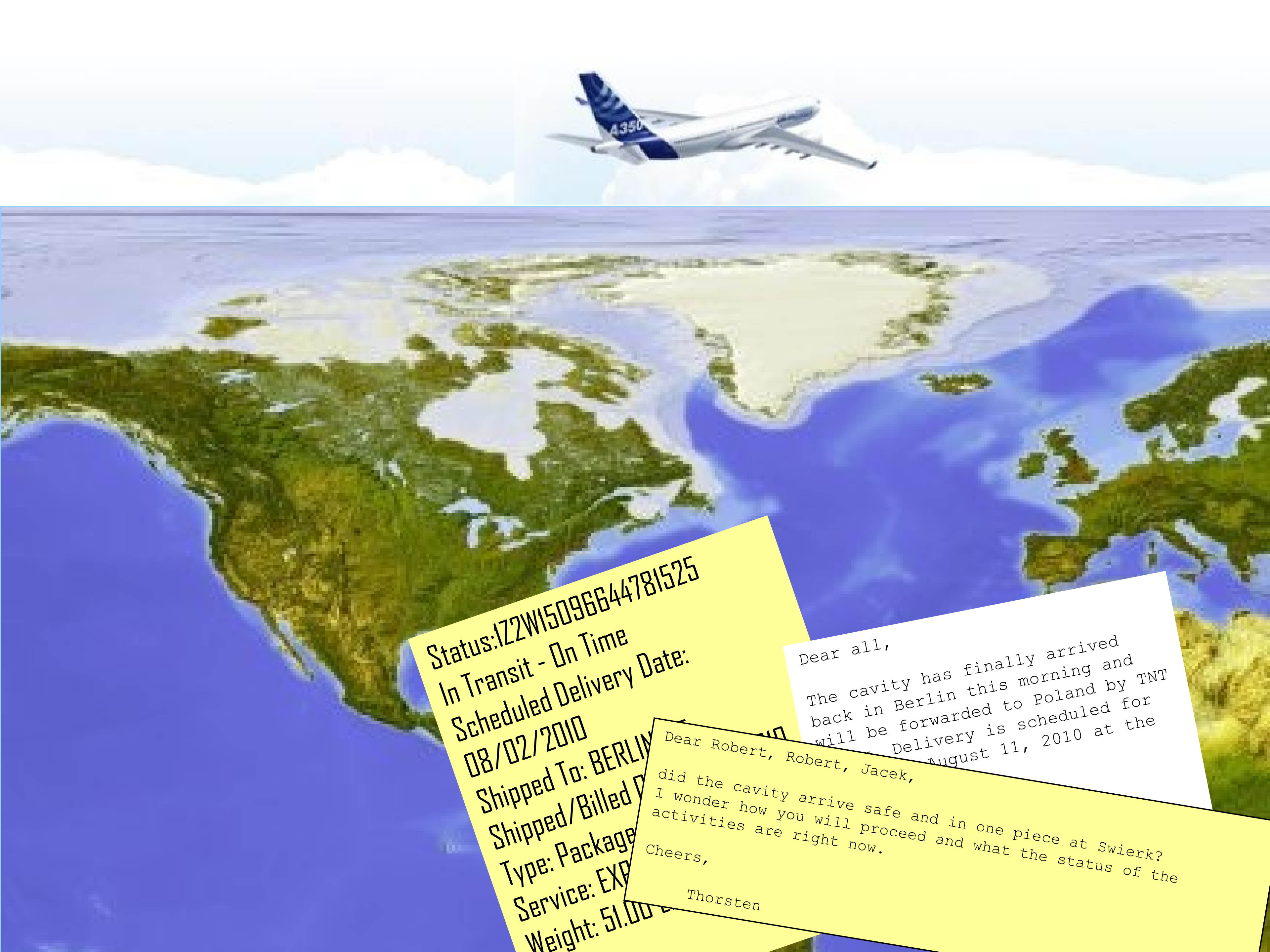


Chemical treatment and RF tests soon…



1. DESY cavity 1. — 39 MVm^{-1} , He leak, spot damged
2. HZB cavity 1. — 29 MVm^{-1} , yellow spot, spot disappeared, ring
3. HZB cavity 2. — 31 MVm^{-1} , sent to Hobicat
4. DESY cavity 2, — 20 MVm^{-1} chemical treatment failed
5. DESY cavity 3 — RF tests in May 2011

5 cavities were succesfully coated in 2010 and 2011.
Preparation (= mounting+pumping) take 1 week
Deposition takes 3 days
Dismounting, packing, shipping take 1 day
System conservation takes few days before each run

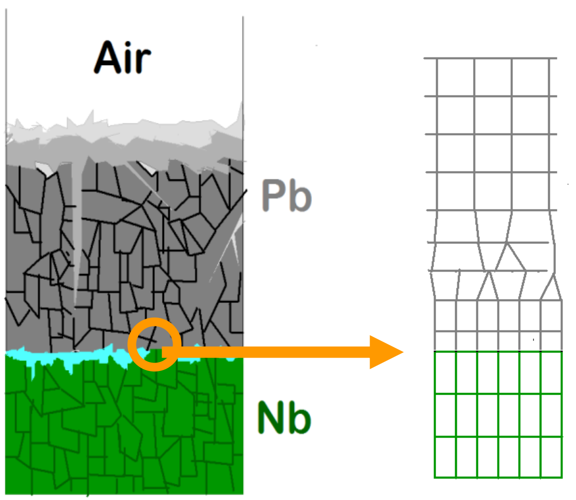


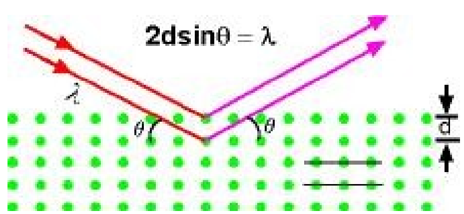
Status:1Z2W15096644781525
In Transit - On Time
Scheduled Delivery Date:
08/02/2010
Shipped To: BERLIN
Shipped/Billed
Type: Package
Service: EX
Weight: 51.00
Dear all,
The cavity has finally arrived back in Berlin this morning and will be forwarded to Poland by TNT. Delivery is scheduled for August 11, 2010 at the
Dear Robert, Robert, Jacek,
did the cavity arrive safe and in one piece at Swierk?
I wonder how you will proceed and what the status of the activities are right now.
Cheers,
Thorsten

X – ray difraction studies

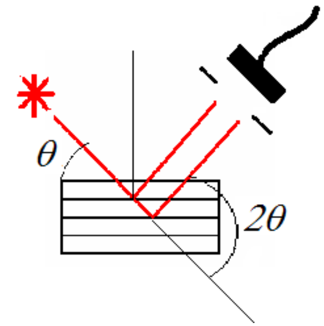
1. Morphology – sublayers, crystallites size and orientation
2. Impurites – oxides, (orange colour)
3. Crystalline structure - strain

object

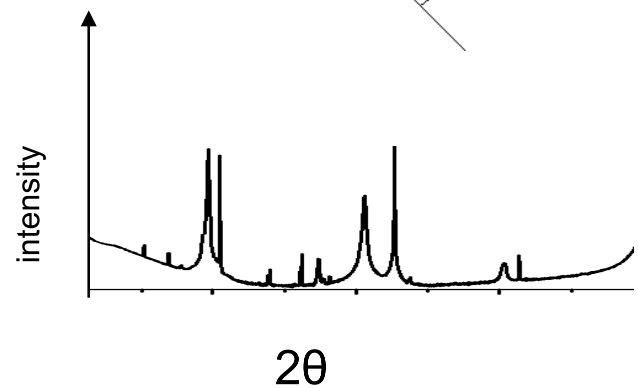




measurement



result

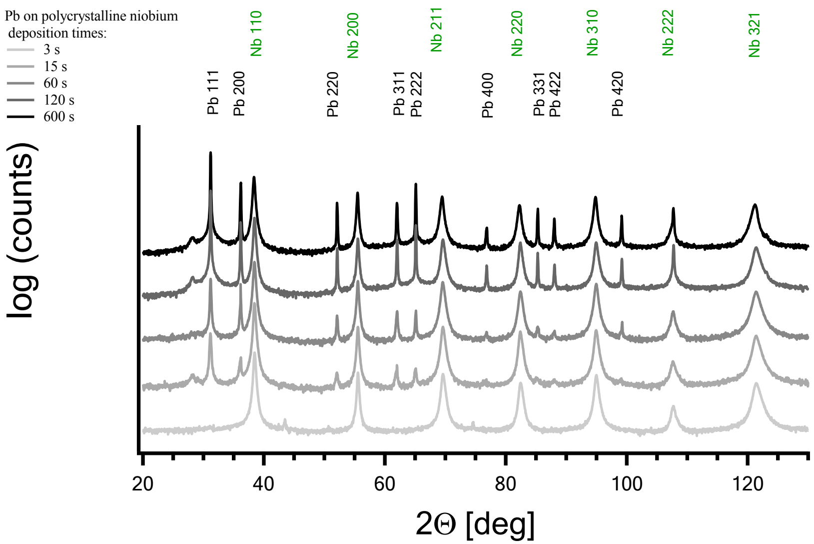


interpretation

Grain size	–	width of maxima
Orientation	–	relative intensities
Phases	–	pattern
Strains	–	positions and shapes of maxima
Density	–	reflectometry

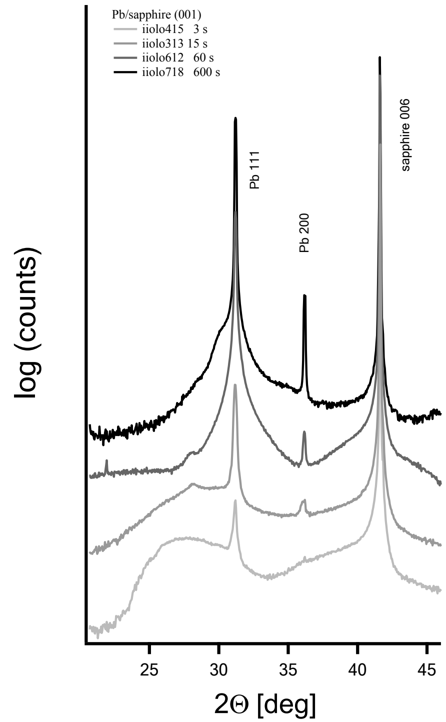
X – r a y d i f r a c t i o n

Measurements vs thickness

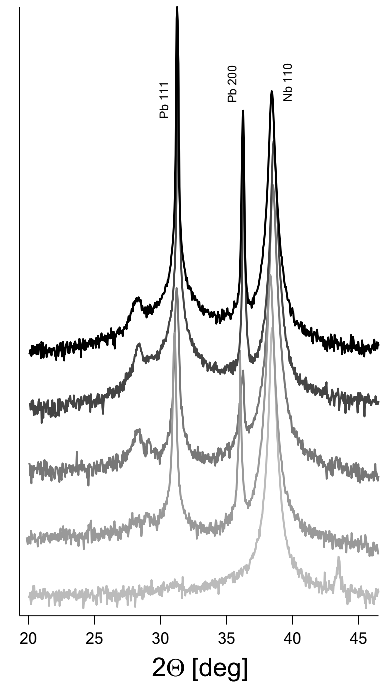


Dep. Time [s]	lattice constant [Å]
3	4.95899
15	4,96449
60	4,96423
120	4,96714
5×120	4,96144
10×60	4,95896

Lattice constant and size of grain do not change with the layer growth on rough Nb



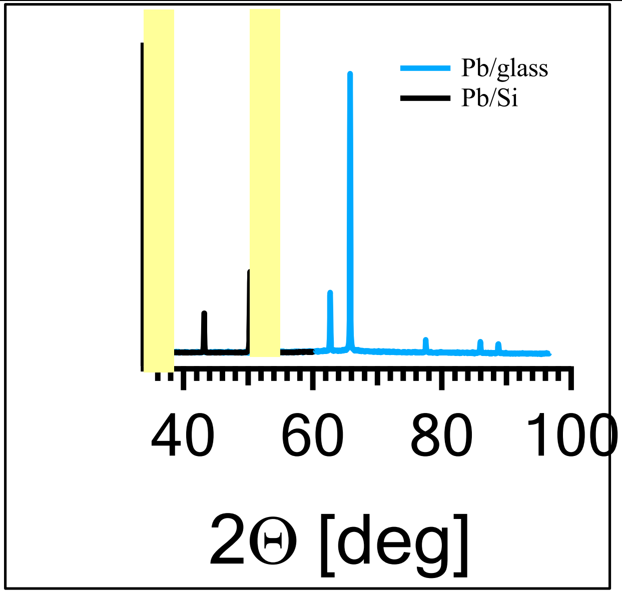
Pb/Al_2O_3 (001)

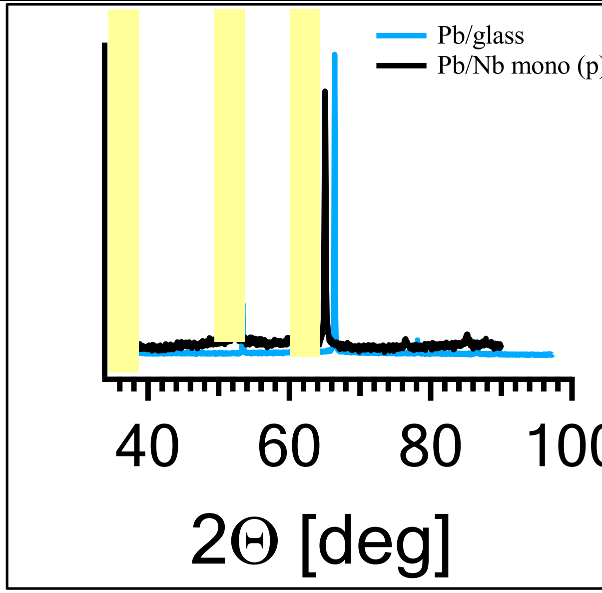


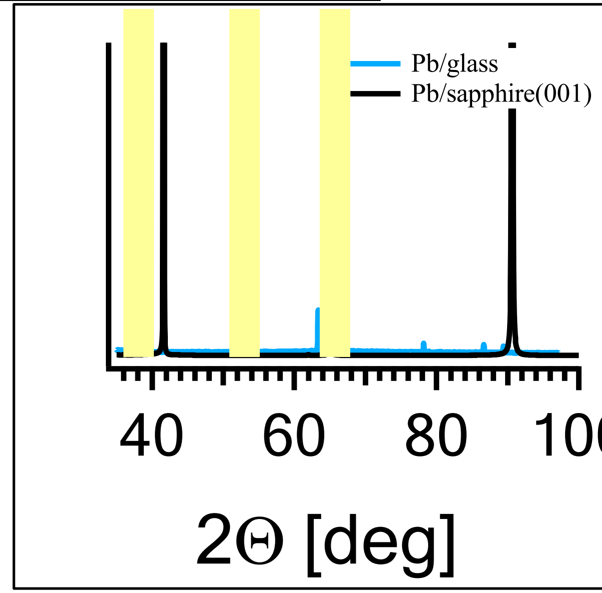
Pb/Nb (poly)

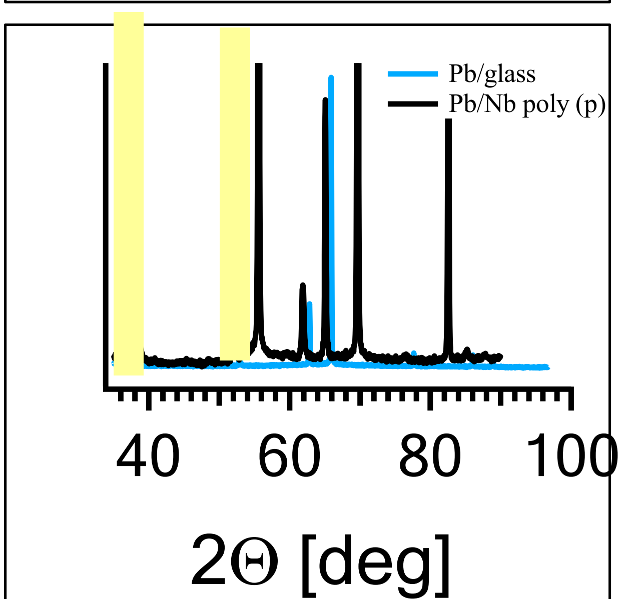
Nano-crystalline Pb phase occurs in the interface with single crystal Al_2O_3 but not in Pb/Nb (pokly)

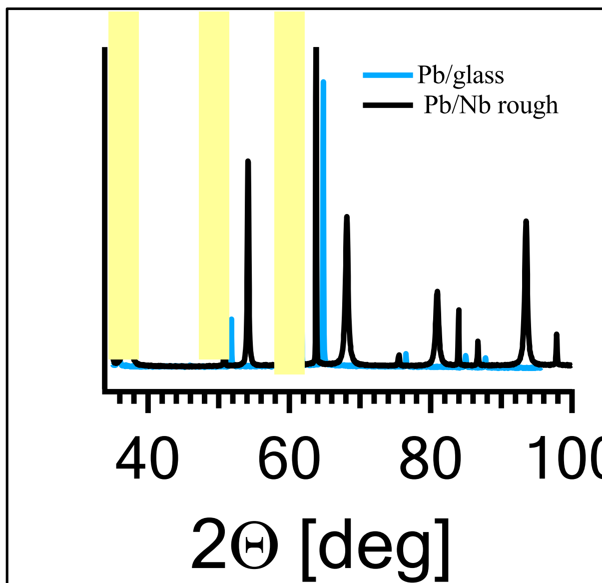
Pb grains orientation









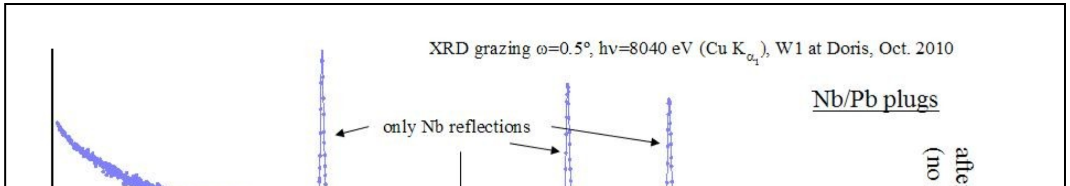


Orientation of Pb grains depends on the substrate

Polycrystalline or monocrystalline

Rough or plain

Impurities identification



PbO

$Pb(CO_3)_2 \cdot H_2O$

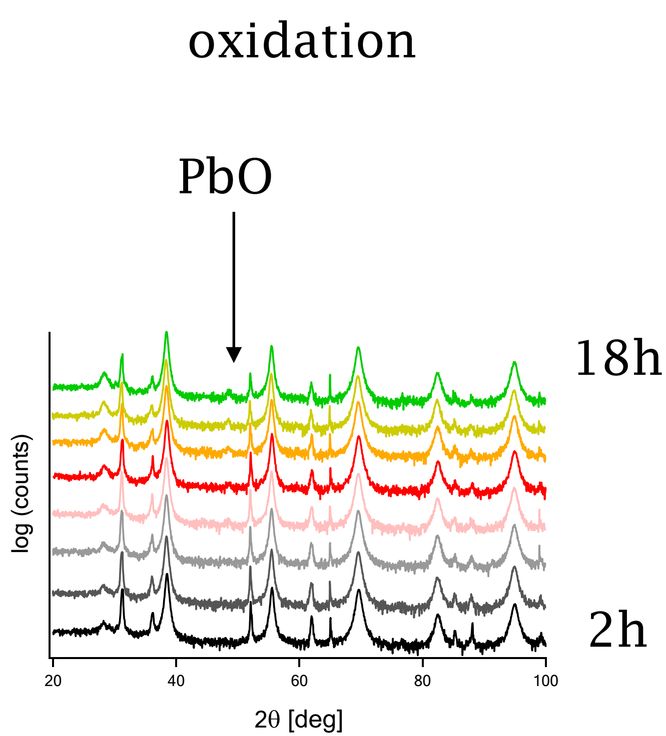
Two Pb/Nb samples were investigated. One of them was put into Ar environment immediately after a deposition and kept 14 days, the other was treated in similar way but in N_2. The measurements were done immediately after the storage and showed a presence of a compound, which occurs in the sample stored in N_2 only.

The measurement done for both samples 10 h later showed different phases formed as a result of interaction with air.

Also the products of interaction with water were different. The layer kept in Ar dissolved completely, while another unidentyfied compound remained on the sample kept in N_2. Phase identification will be done soon

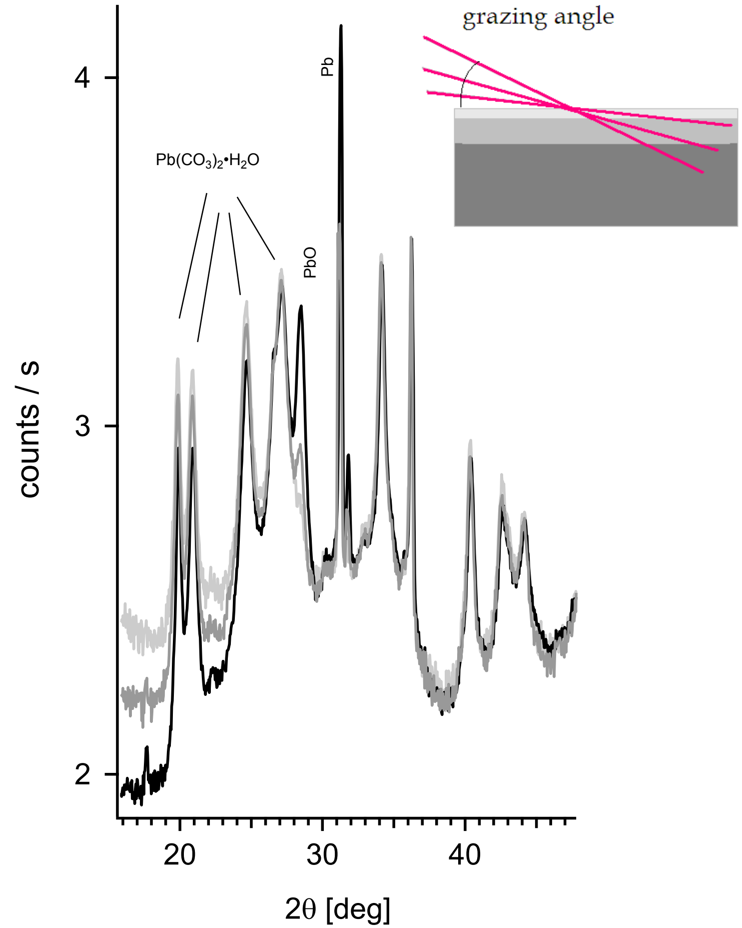
Impurities

Measurements vs time



Impurities appear after hours of Pb film exposition to air

Measurements vs depth



Their composition depends on depth

Communications

TEST RESULTS OF COMPONENTS FOR CW AND NEAR-CW OPERATION OF A SUPERCONDUCTING LINAC*

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R Nietubyc, A. Soltan INS, 05400 Swierk/Otwock, Poland

FABRICATION, TREATMENT AND TESTING OF A 1.5 CELL PHOTO-INJECTOR CAVITY FOR BESSY*

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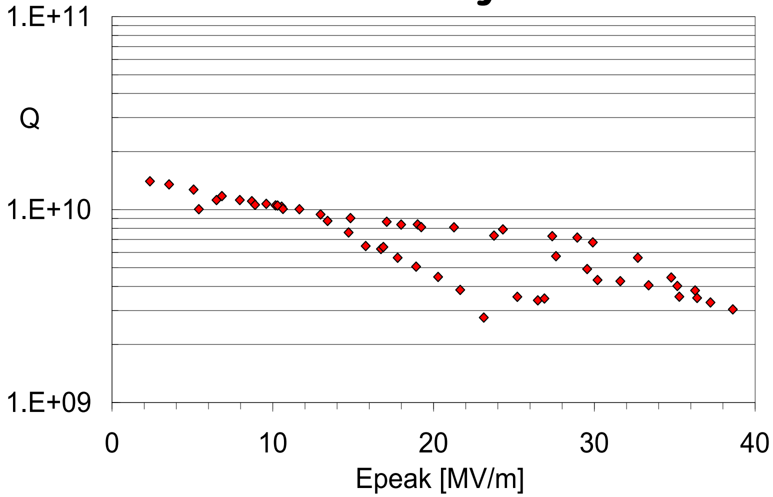
R. Nietubyc, Soltan Institute, Swierk,, Poland
and
O. Kugeler, A. Neumann, Helmholtz Zentrum Berlin, Germany

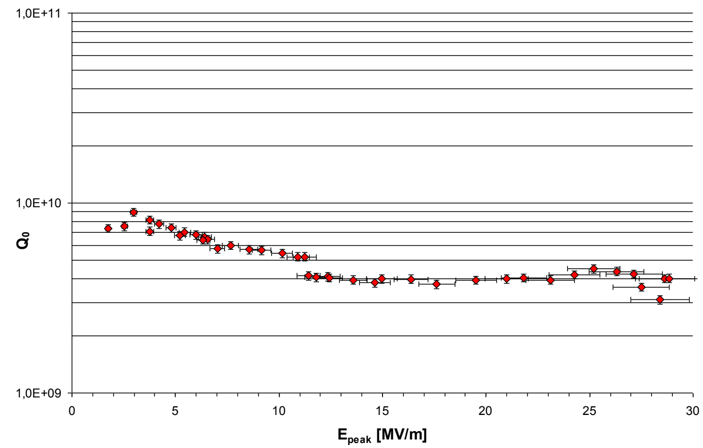
Summary

➡ Routine operation of deposition stage – 5 coatings in 2010

DESY cavity



HZB cavity



M.10.4.1	**Lead deposition on samples for photocathode development**
D.10.4.1	**QE data for Pb/Nb deposited photo cathode samples**
M. 10.4.2	**Lead deposition on the half-cell and 1.6-cell cavities**
D.10.4.3	**Cold test results for the test cavities with and without the deposited lead photo cathode**

➡ X-ray Pb film diagnostics

Orientation and morphology depend on substrate roughness (?)