Superconducting electron gun for CW operation of superconducting linacs

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In behalf of an international collaboration

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National Centre for Nuclear Studies

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History

From the plasma physics laboratory to the the first e-gun with lead photocathode

Last year progress

E-gun tests at Hobicat

New cavity

New deposition system

Emittance studies

The beginning was in CARE

Plasma Physics and Technology Department at SINS Swierk

plasma confinement for nuclear fusion
plasma diagnostics methods dedicated for tokamaks and stellarators
plasma focus and Z-pinch systems

cathode erosion
possibility of material transportation and deposition
thin films

CARE: Nb thin film cavities

UHV arc vacuum systems ,
system optimisation: geometry , droplets filtering
3-cell coating achieved but problems with adhesion encountered

Lead thin film spot for photocathodes

Pb as a superconducting emitter

Fully sc injectors for cw linacs

CW electron accelerator

Acceleration

- saves energy
- no transient states

High average power FEL

- lowly probable phenomena
- diluted samples
- special applications
- industrial applications

Fully sc injector

- avoid normal conducting materials in the cavity
- keep simplicity similar to Nb back-wall gun
- get a reasonable QE

Thin lead film

superconductor of the 1 st type

critical H 80 mT

critical T 7.2 K

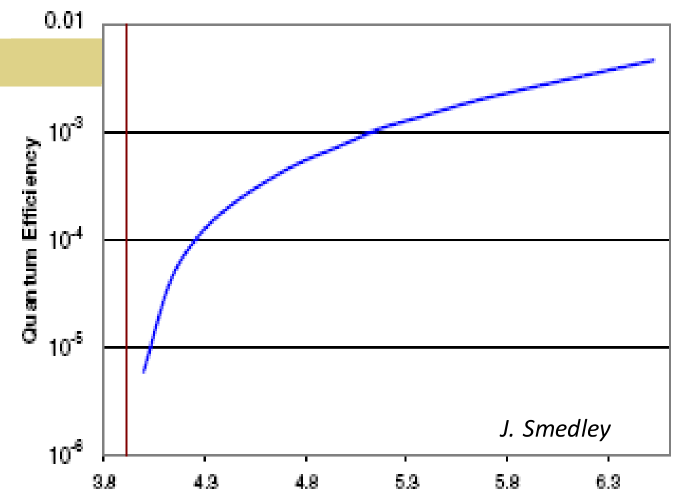
work function 3.95 eV

s.c. metals

	Tc	Pb	La	V	Hg
T_c[K]	7.8	7.2	5.9	5.3	4.2

Tc: does not exist on Earth

La: too reactive



Pb/Nb film

Calculations show reasonable QE

J. Smedley

First proof - samples

UHV Cathodic Arc Deposition

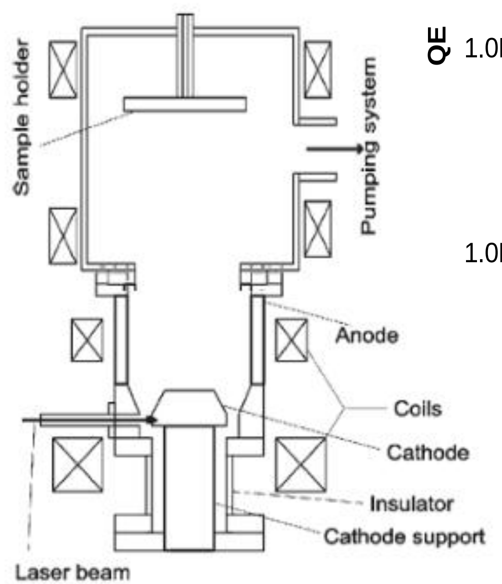
energetic multiply ionised ions from the cathode

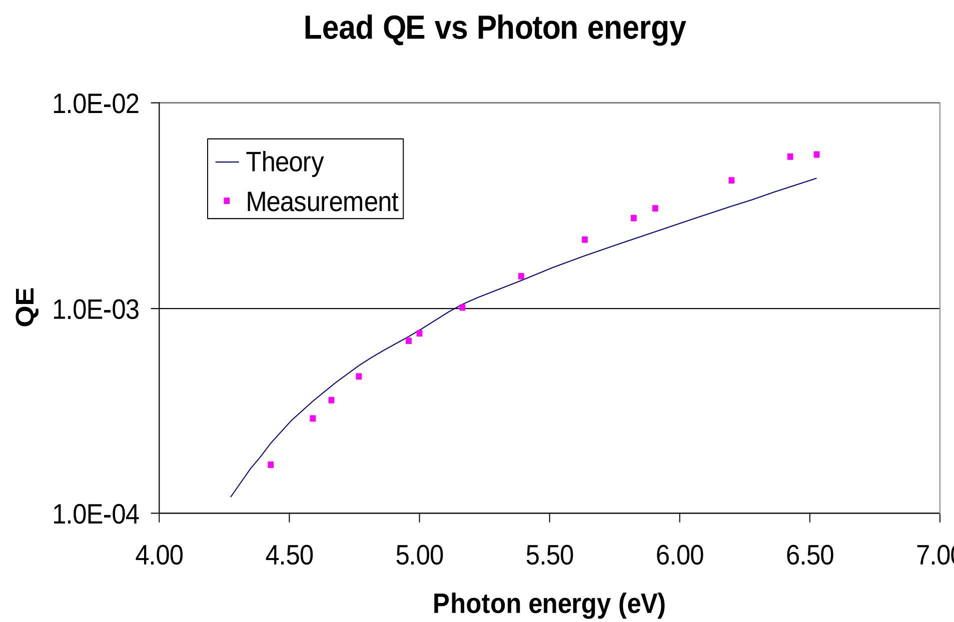
Source: ions emission from a small explosive spot. That spot is a local explosion decompression and ejection of neutrals and ions.

High ions fraction enables a coupling to electrons and driving with the H field

The simplest adaptation:

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



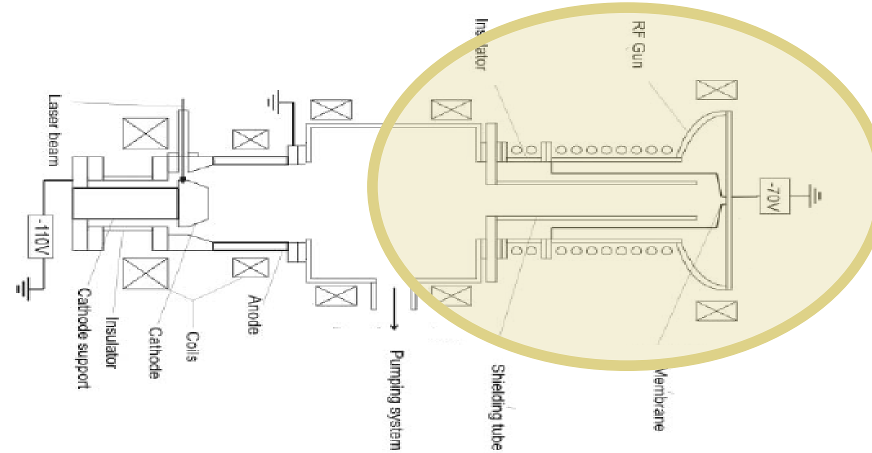


- Experiment supported the calculation results
- Vacuum arc deposited film showed the best performance

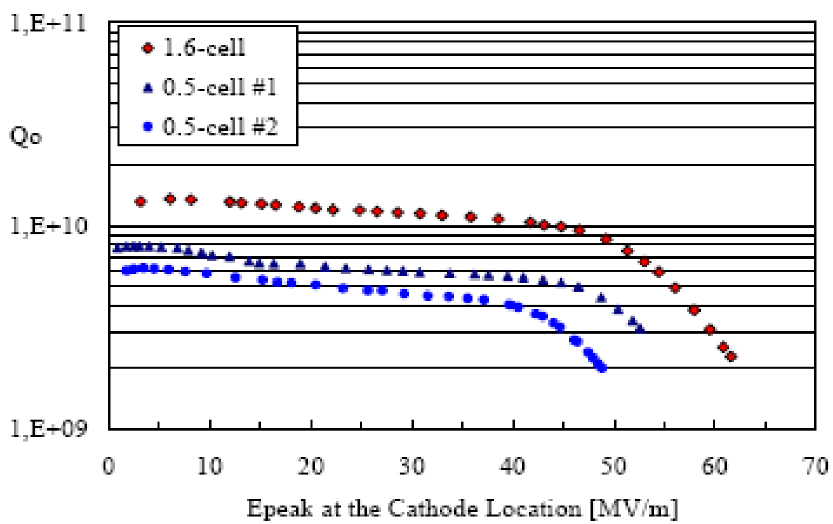
Second proof - cavities

Coating the cavity

- masking
- long distance between Pb cathode and the back wall

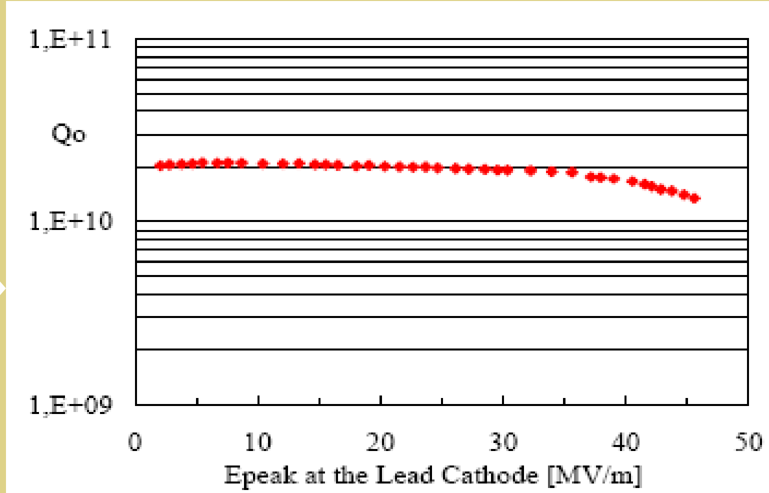


baseline test



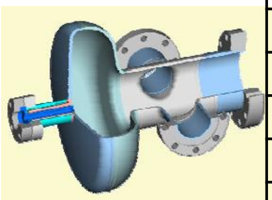
50 MV/m reached, but in cases of ½ cell cavity with Q slightly lower than in first baseline test

test with Pb photocathode



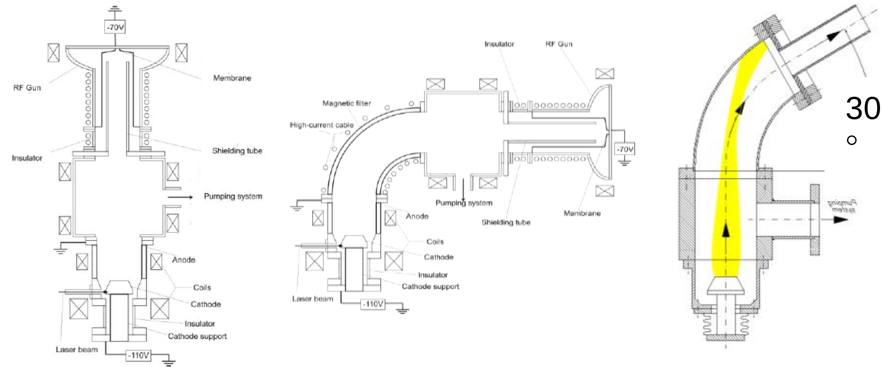
46 MV/m

Coating improvement

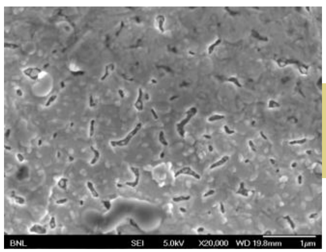


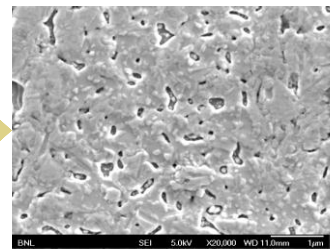
No	Time [s]	Nb type	Distance	Setup	Pump
1	1800	poly	1.6 cell	Straight	oil
2	1800	poly	1.6 cell	Straight	oil
3	1800	mono	1.6 cell	Straight	oil
4	2700	poly	1.6 cell	Bent	dry
5	2700	poly	1.6 cell	Bent	dry
6	2700	mono	0.5 cell	Bent	dry
7	2700	mono	0.5 cell	Bent	dry
8	6000	poly	1.6 cell	Bent	dry

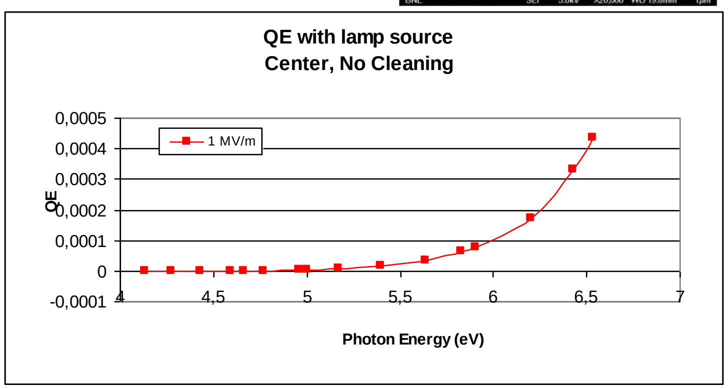
Geometry



Laser treatment

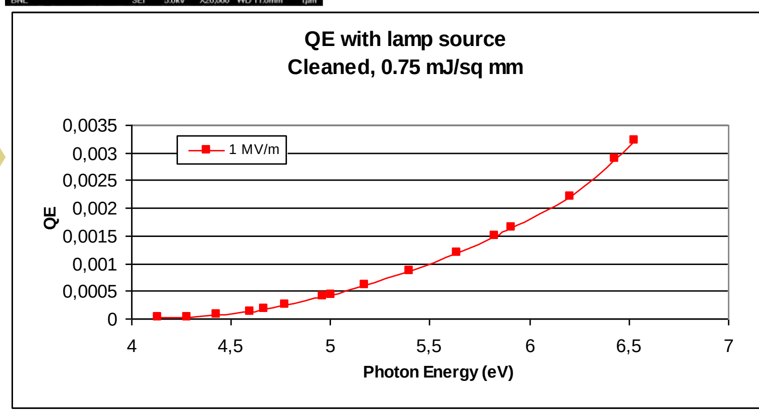






Gentle laser treatment : 190 nm, 30 min, 300 Hz 0.01 mJ/mm^2 per pulse

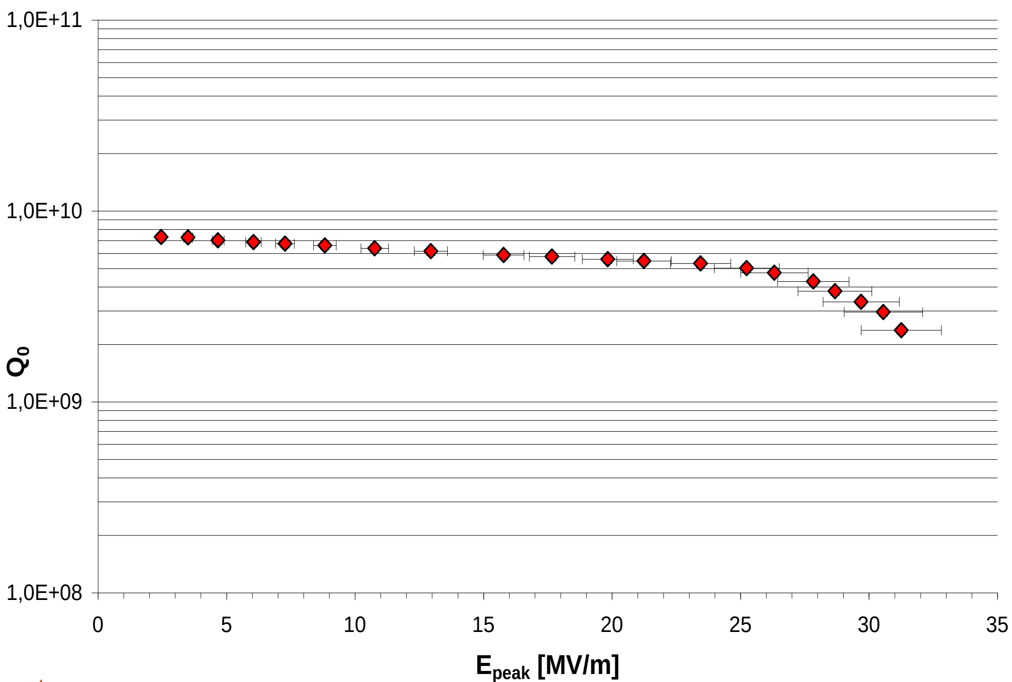
as compared to:213 nm, 1 min, 25 Hz, 0.2 mJ/mm^2 per pulse



We have established an optimal laser treatment and reached **QE=3.3·10^{-3}**

Coating cavities back-wall

JLab	46 MVm^{-1} 2008	
DESY 1.1	39 MVm^{-1}	He leak, spot damged
HZB 1.1	29 MVm^{-1}	yellow spot, spot disappeared, ring
HZB 1.2	31 MVm^{-1}	sent to Hobicat
DESY 2.1	20 MVm^{-1}	chemical treatment failed



sent to Hobicat

4 cavities were succesfully coated in 2010 - 2012.

Preparation (= mounting + pumping) takes 1 week

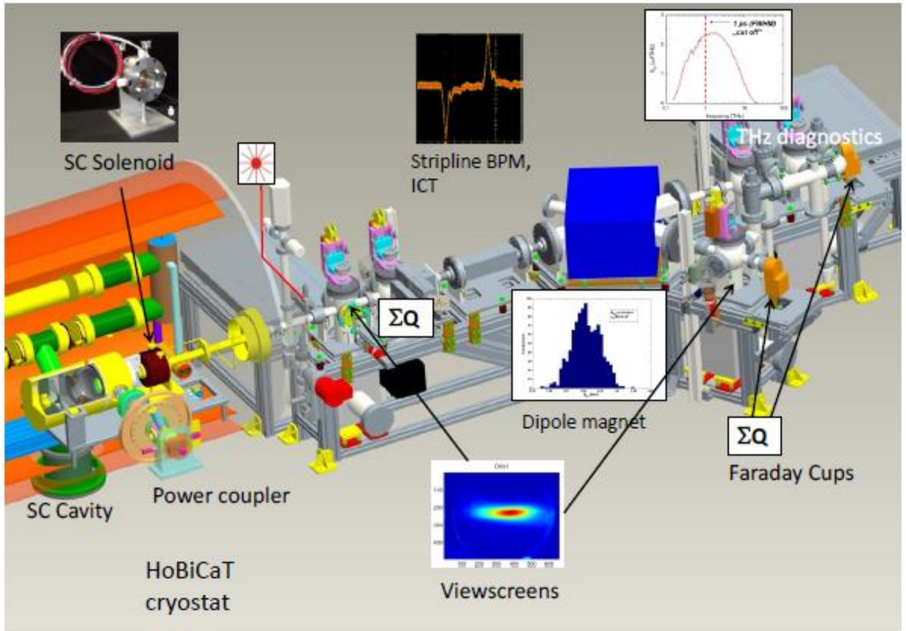
Deposition takes 3 days

Dismounting, packing, shipping take 1 day

System conservation takes few days before each run

HZB cavity at Hobicat

e-gum tests



The Horizontal Bi-Cavity Test facility (HoBiCaT)

Cryogenic photoinjector test stand

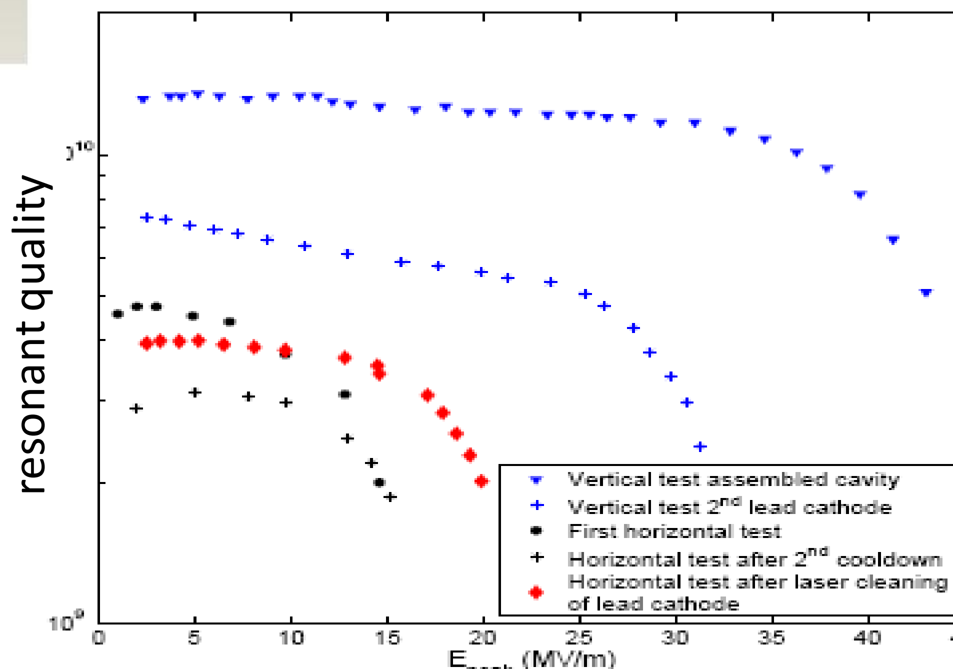
UV: 258 nm, 8 kHz, RF: 17 kW IOT

Diagnostics:

- YAG screens and Faraday cups
- ICT
- BPM
- Dipole spectrometer
- THz beamlime

Examination programme

JLab vertical test reproduction
Test with cathode
Horisontal test
Second cooldown horisontal
Laser cleaning

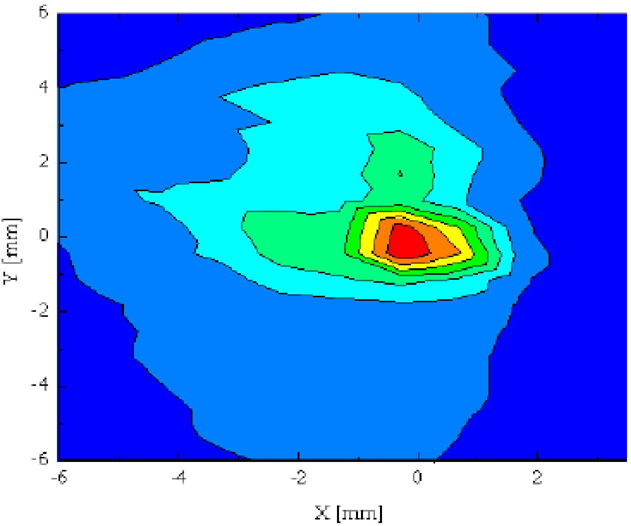


A. Neuman et al

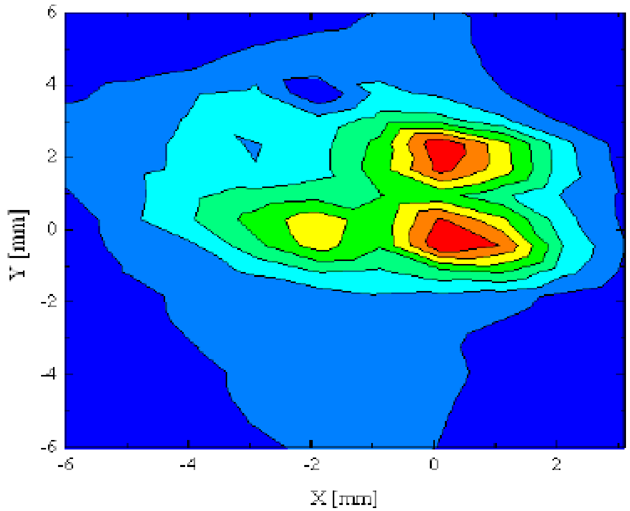
Photocathode irradiation inside the e-gun

KrF, 248 nm, 5 ns (FWHM), 500 Hz
10 min, 0.09 J mm^{-2}, cooled, no RF

before cleaning

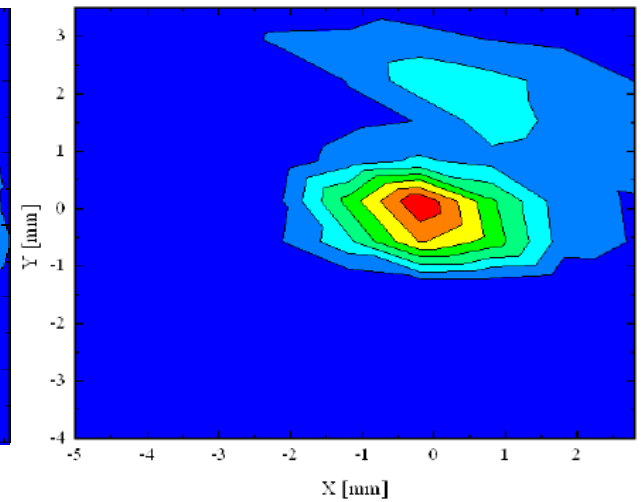


$3.6 \cdot 10^{-5}$



$4.8 \cdot 10^{-5}$

3 weeks later

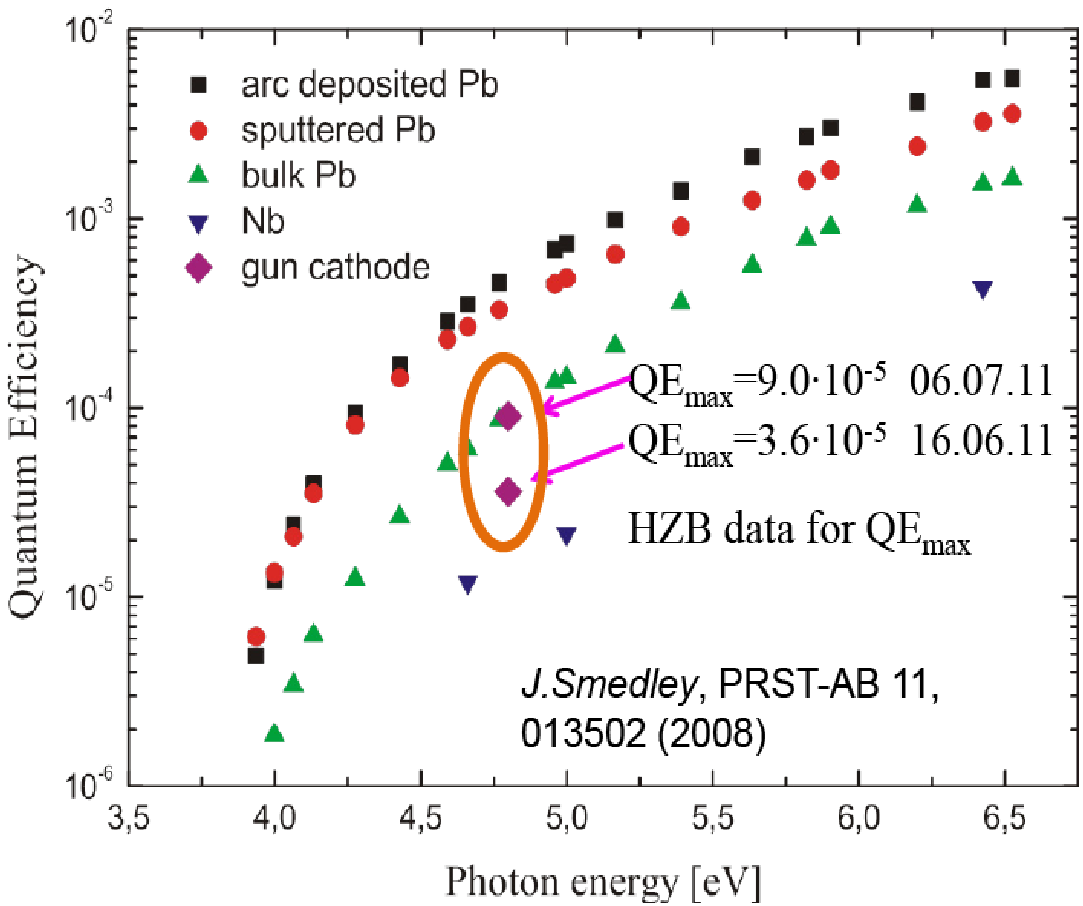


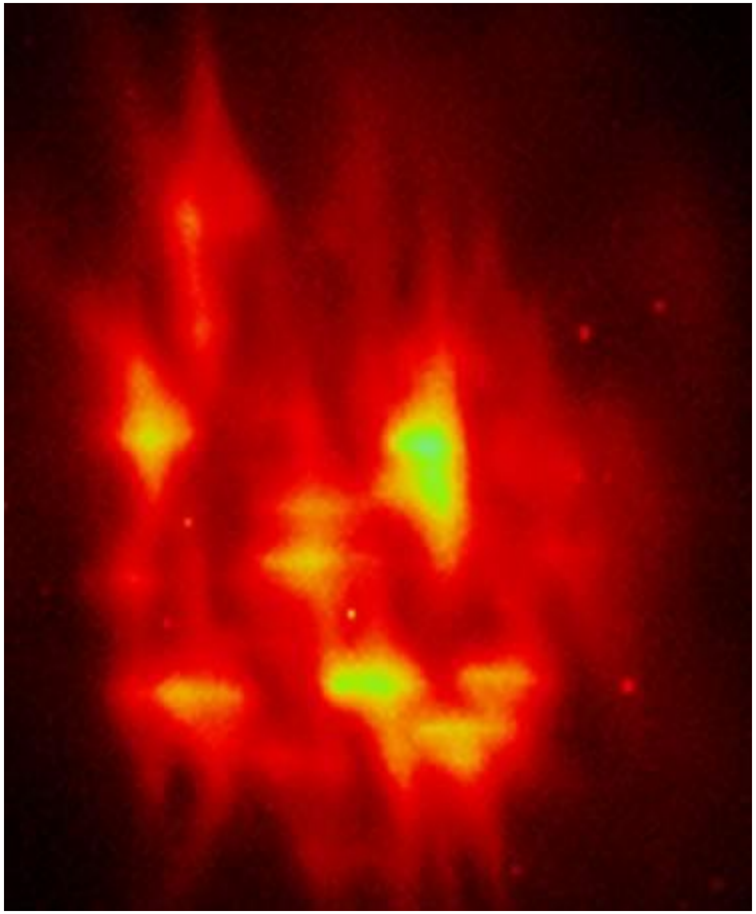
$8.6 \cdot 10^{-5}$

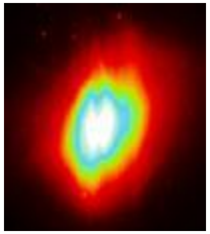
QE maps

T. Kamps, R. Barday

Successful cavity HZB







T. Kamps, R. Barday

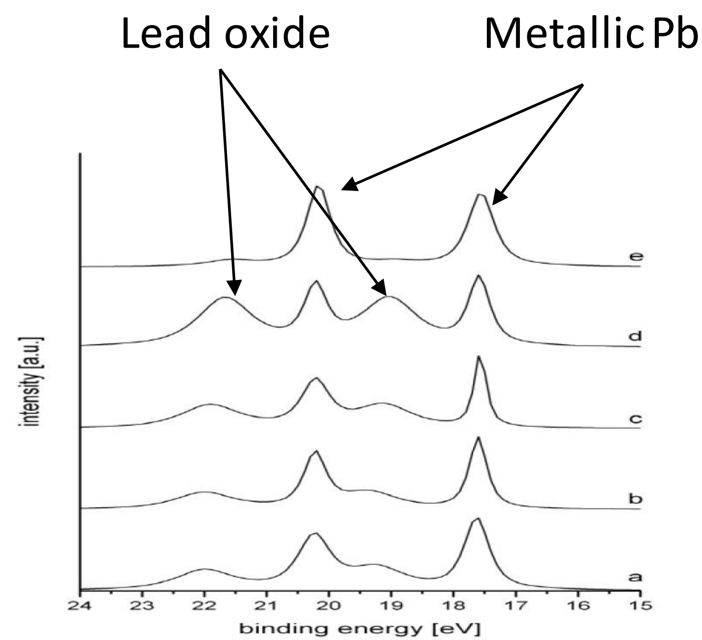
Metal cathodes installed in the rf guns typically have lower QE than the one of the test probe.
QE of the cathode is 10 times higher than for cleaned Nb
I_{max}=50 nA demonstrated

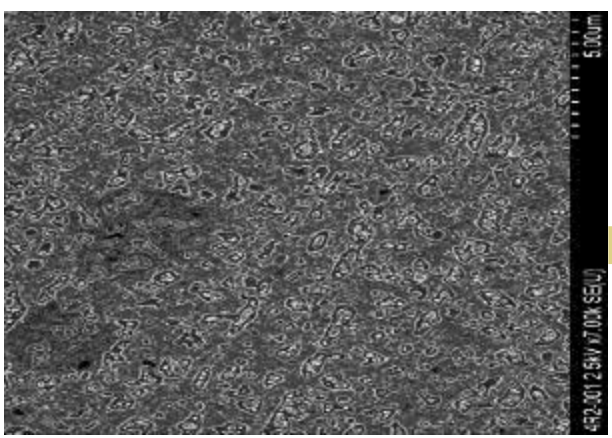
UV photoemission

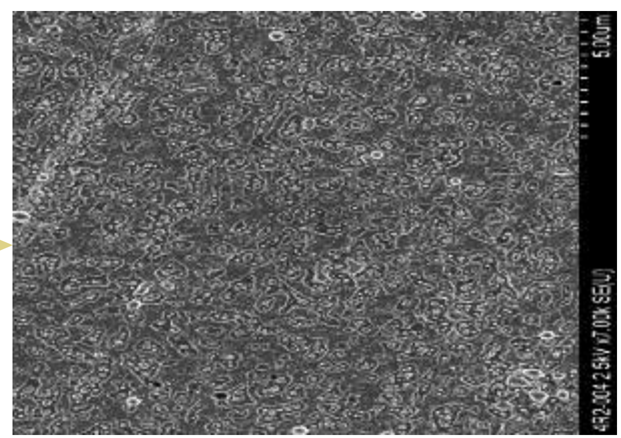
Irradiation and UPS Pb 5d hν = 140 eV at Bessy II UE112 PGM

KrF, 248 nm, 5 ns (FWHM), 500 Hz
10 min, 19 mm^2

a) initial stage (no illumination)
b) 0.024 mJ/mm2;
c) 0.09 mJ/mm2;
d) 0.19 mJ/mm2;
e) 0.32 mJ/mm2

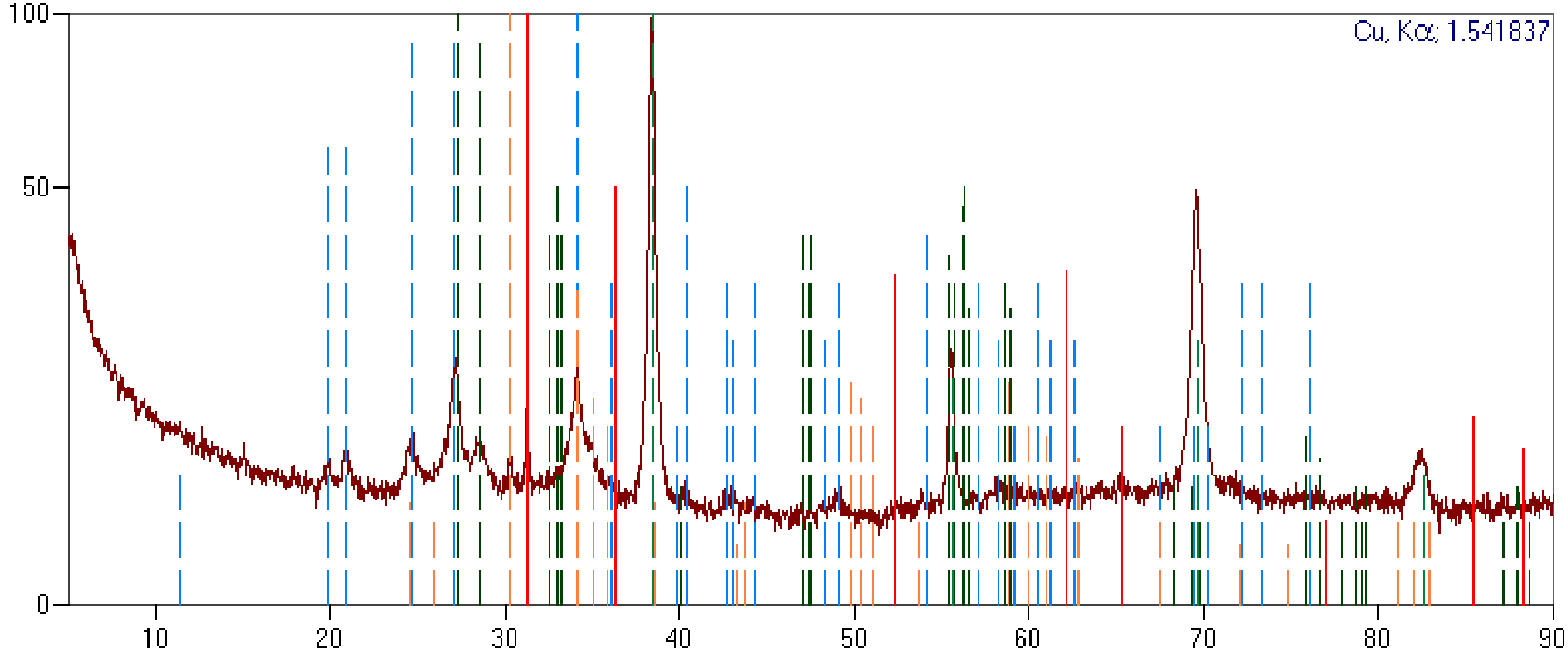






T. Kamps, R. Barday, S Schubert

X-ray diffraction characterisation



Matched Phases:

— — — — (green)	35-0789	Nb	Niobium
— — — — (blue)	13-0131	Pb3 (C O3)2 (O H)2	Lead Carbonate Hydroxide / Hydrocerussite, syn
— — — — (orange)	52-0752	Pb O2	Lead Oxide
— — — — (dark green)	19-0697	Pb12 O19	Lead Oxide
——— (red)	04-0686	Pb	Lead / Lead, syn

Motivation for the second HoBiCaT test with new 1.6-cell cavity

1

Performance of the 1.6-cell HZB injector was reasonable but still rather far from what we need for the cw and long pulse operations of XFEL. Particularly the coating was still not satisfactory:

- uniformity
- thickness
- droplets

2

Quantum Efficiency of the coating is far from the best we have measured

$2.7 \cdot 10^{-3}$ at 213 nm
$4.8 \cdot 10^{-3}$ at 258 nm

3

HZB was interested to study operation of the injector with the cold tuner

4

High QE was reached for a films deposited in a short arc geometry

The old concept revisited

To increase a throughput in cost of surface smoothness

↓

To abandon filtering for short and straight plasma path to the substrate

↓

To let the cathode into the cavity

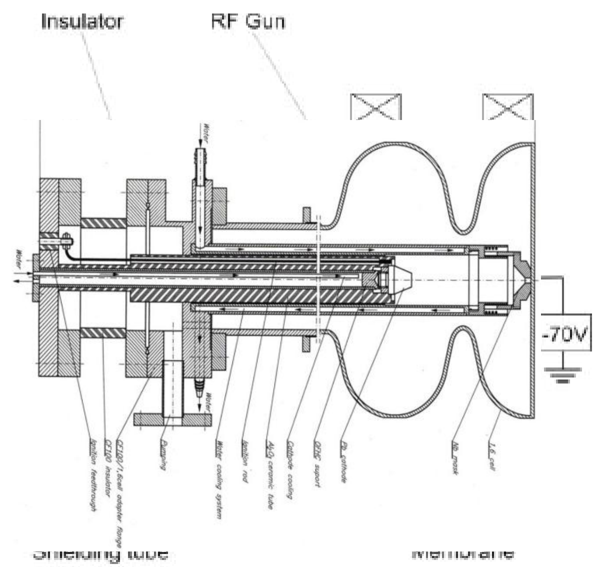
↓

For that we took an effort to solve a problems

- distant ignition
- limited cooling
- limited space

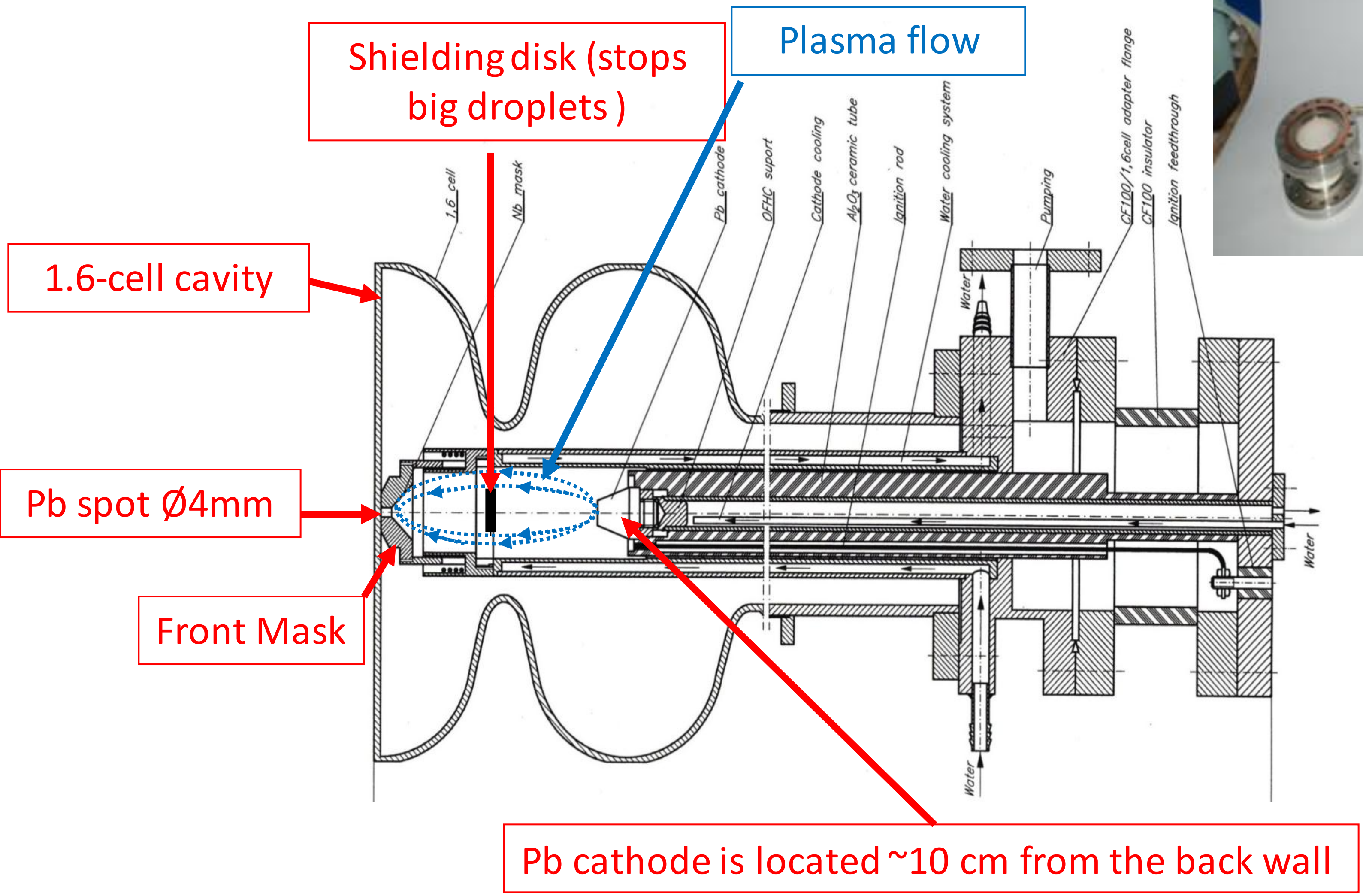
The old concept revisited

The best Pb samples (in 2005-2006), demonstrating the highest uniformity and QE, were coated with short arc. The distance between the Pb cathode and target was ca. 10 cm.
We decided in 2011 to have similar conditions for the back wall coating.



The old concept revisited

New deposition system



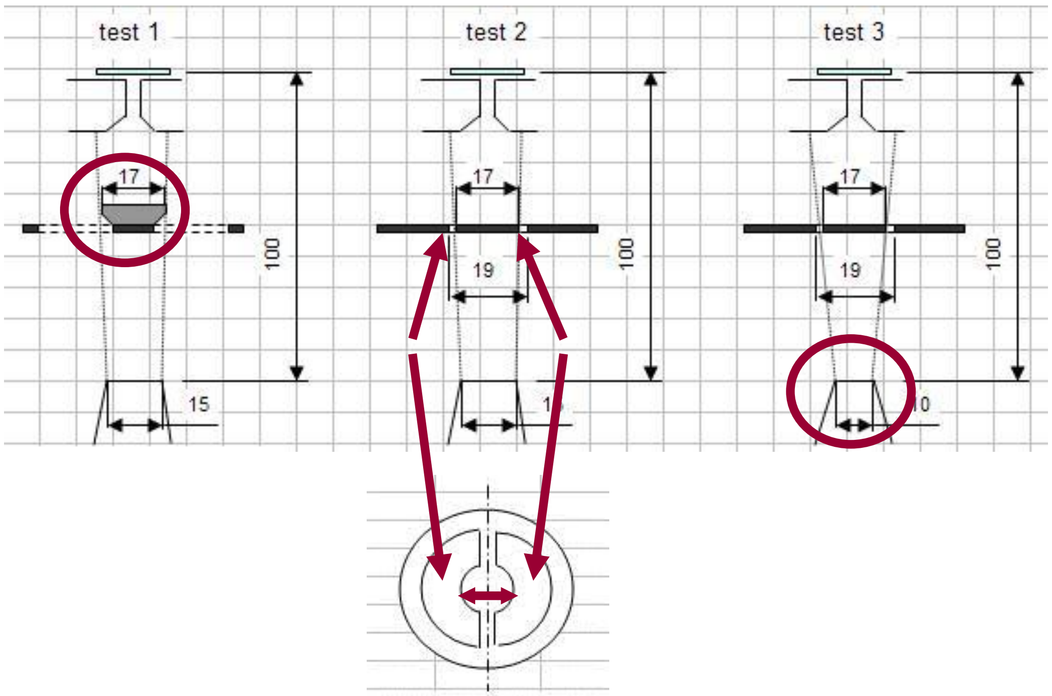
Micro-droplets removal

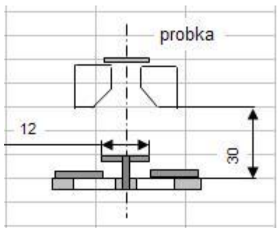
Arc current reduction from 15 A to 5 A

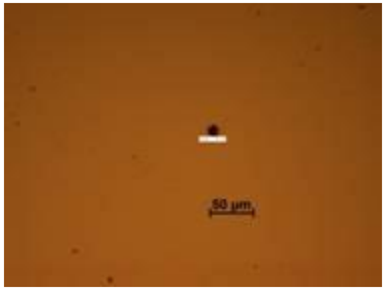
A shield with round slit combined with cathode size aperture was applied to remove the micro-droplets

profile | clearence **2 mm** | cathode width **15 mm** | chicane

width **12 mm**





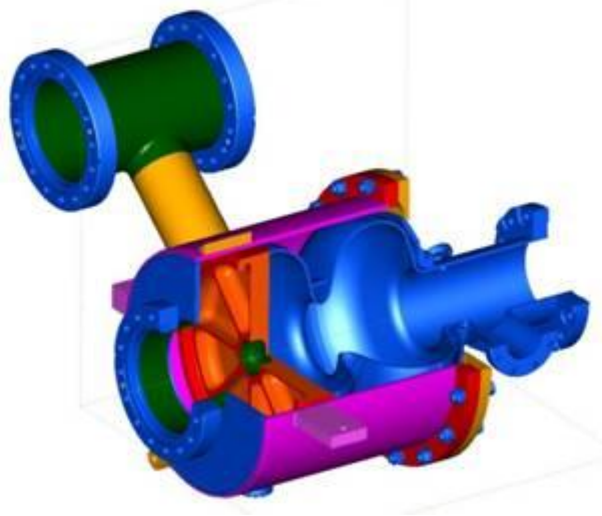


Low droplets population, but peeling appears.

Next cavity

DESY II 1.6-cell cavity follows in designed HZB 2 gun, with two exceptions:

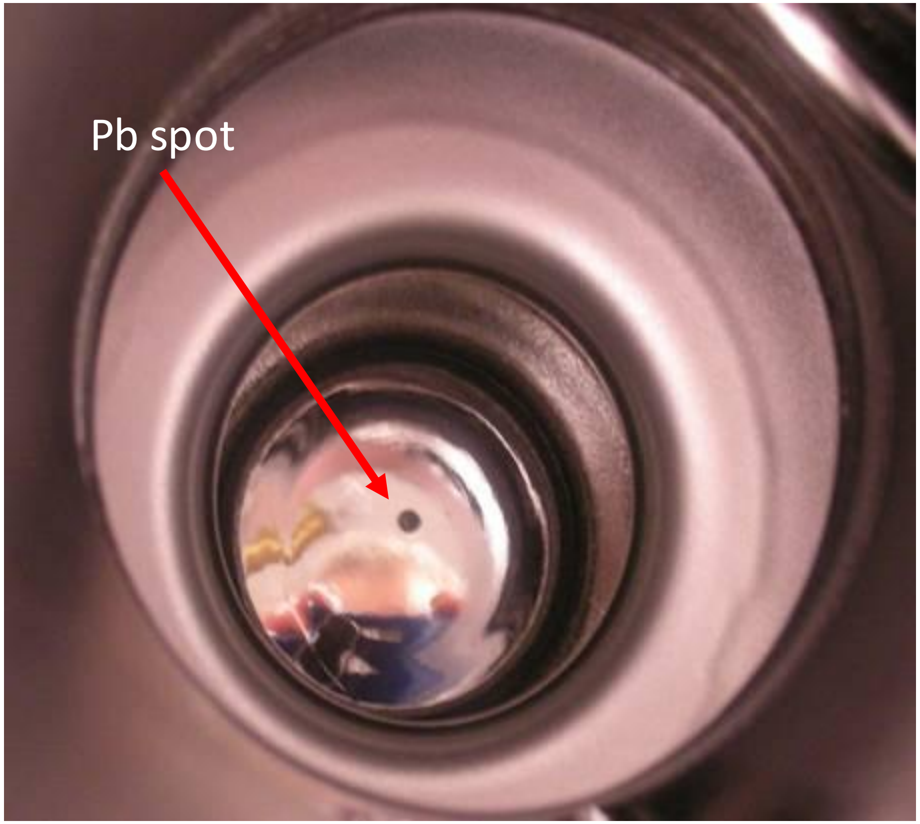
- Back wall is made of 30 mm thick Nb plate (it is very stiff) and it has features to attached the cold tuner.
- Helium vessel is demountable.



Cavity fabrication, preparation and tests were done by P. Kneisel and G. Ciovati at TJNAF

Coating and preparations

Pb spot on the back wall.

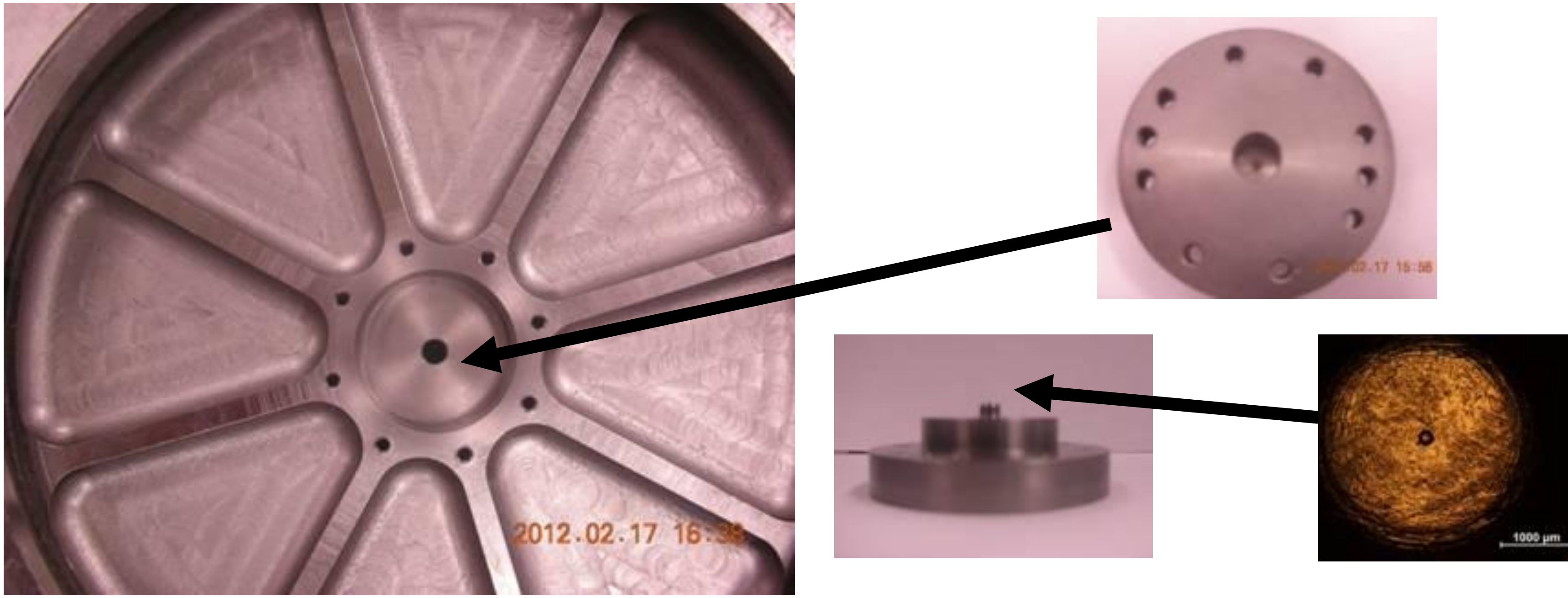


The spot was pretty round, without black ring , not uniformly thick due to two additional approaches to coat fully surface of the circle.

It has looked the same after the BCP but it **disappeared** completely after the HPR.

Plug version

Few weeks were left to the date test facilities at TJNAF should be shut down.
The only way out was to proceed with a plug option of the injector to avoid loss of time for cavity shipment, which takes usually weeks.



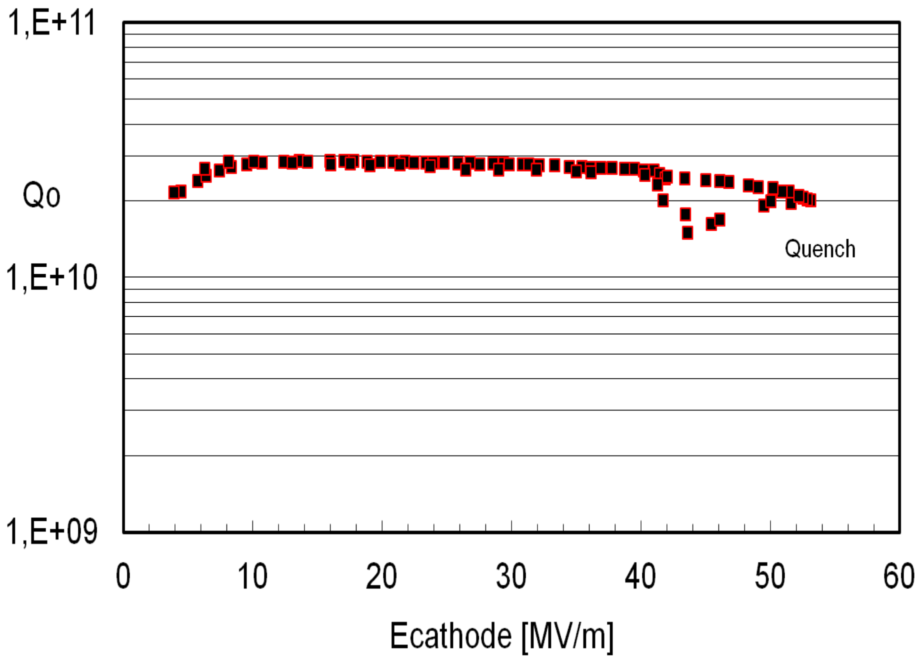
Within 2 days 5 mm hole was drilled in the back wall and 2 plugs were fabricated, one for test at JLab the second was shipped for coating.

Front surface of the plugs was not polished after manufacturing Plug was coated at NCNR .. Estimated thickness of the coating is 400 nm.

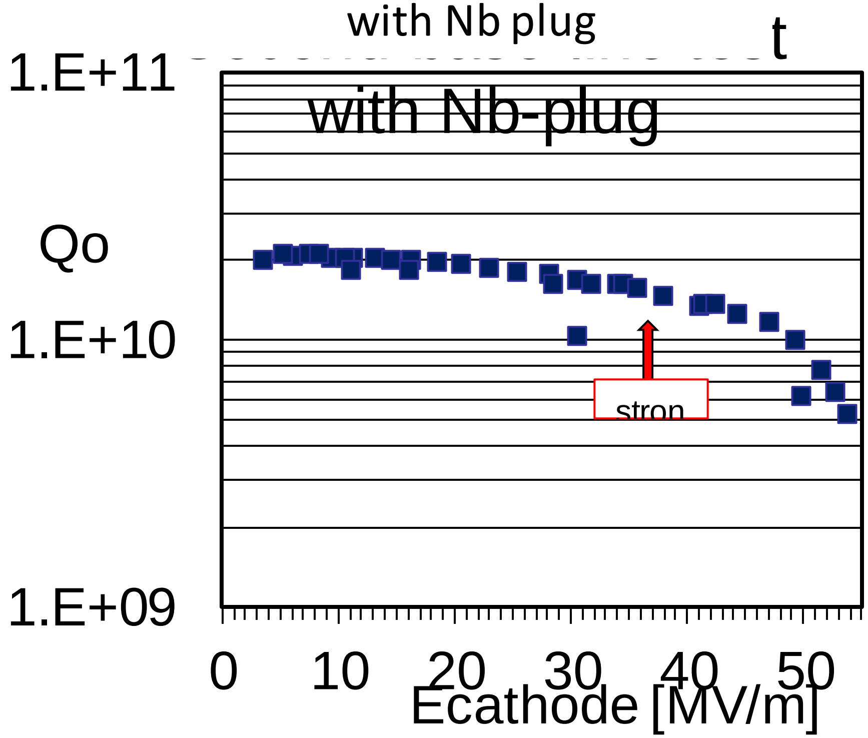
Cavity fabrication, preparation and tests were done by P. Kneisel, J. Sekutowicz and G. Ciovati at TJNAF

RF performance of DESY II

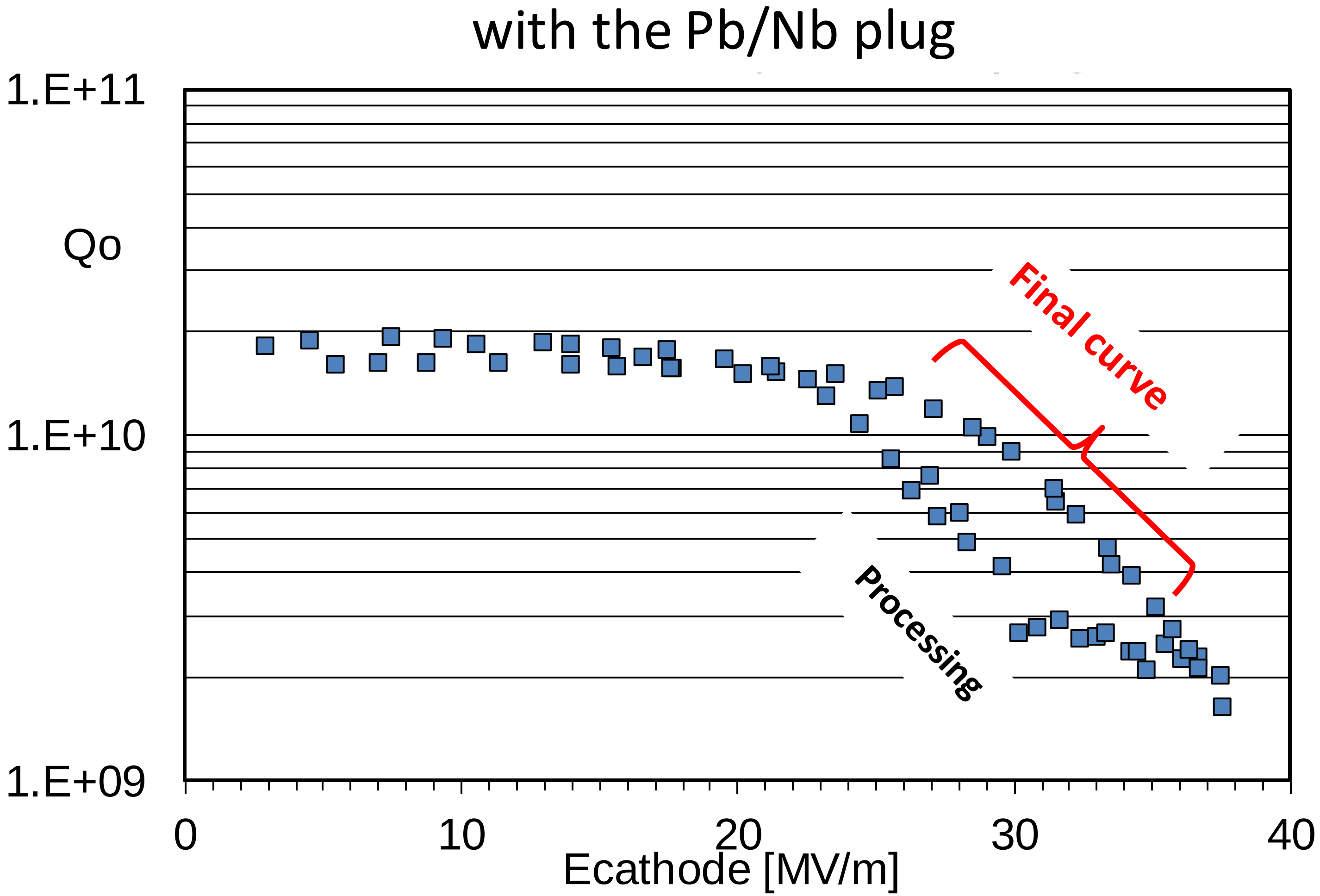
without plug



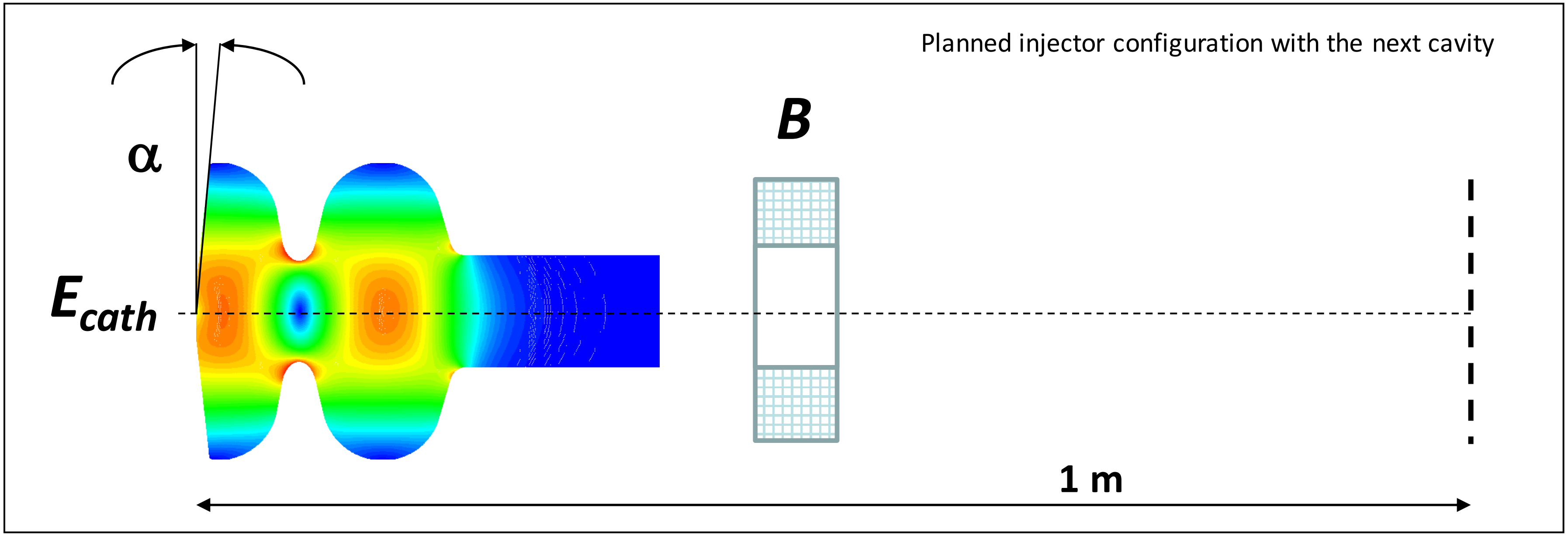
with Nb plug



RF performance of DESY II



Emmitance studies



Optimised variables: inclination angle *α,* electric field at cathode E_{cath} and solenoid induction *B*

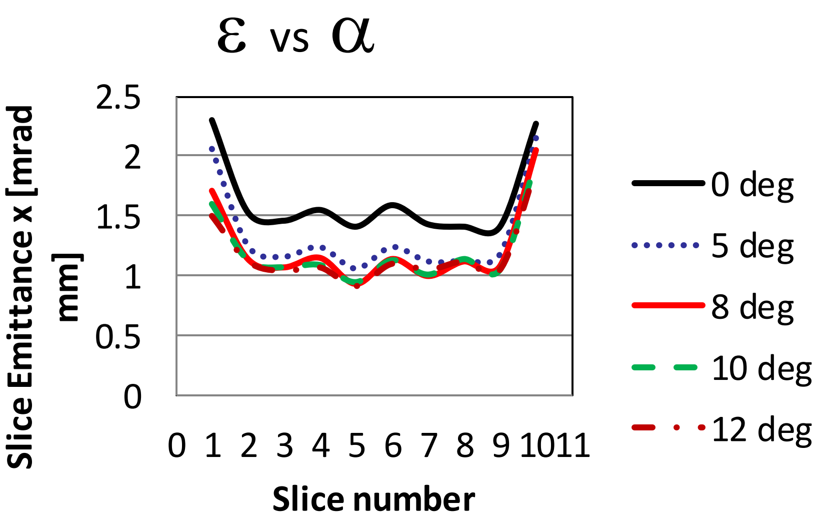
Fixed assumptions: τ= 10 ps, l=41 cm, q=1 nC

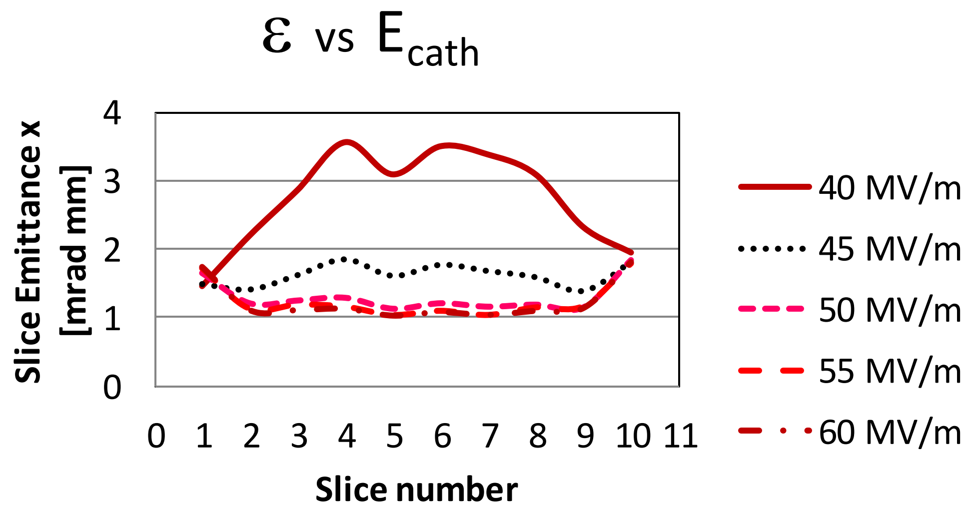
Criterion was emittance of slices in middle part of a bunch, 1 m apart from the Pb cathode

Codes used up to now: FEM (field calculation) and ASTRA (beam quality)

Optimization is still in progress: next steps will be recessed plug and 3D modeling

Inclination and E_{cath}





We chose α = 8°(▬) for the further studies

q = 1 nC

τ = 20 ps

B = 0.25 T

l = 0.41 m

$E_{cath} \geq$ 55 MVm^{-1} (▪ ▪ ▪) is good enough

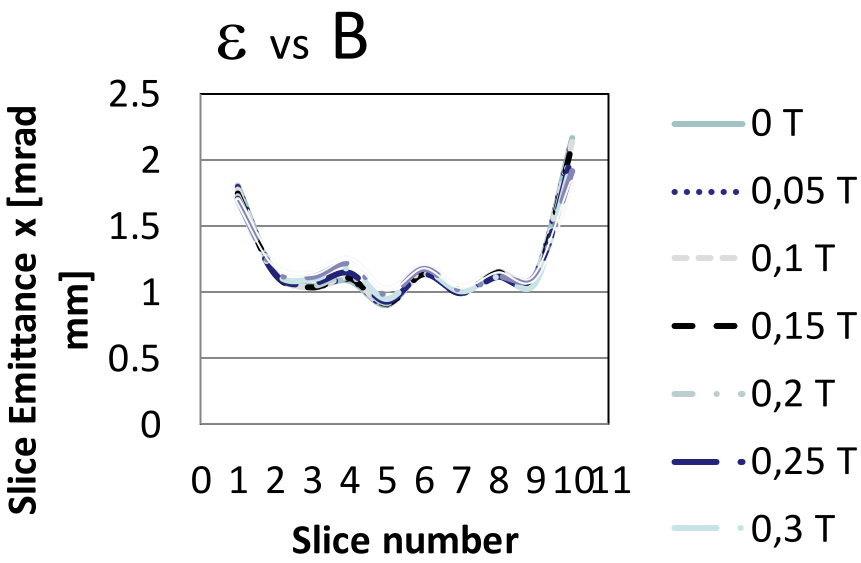
q = 1 nC
α = 8°
τ = 20 ps

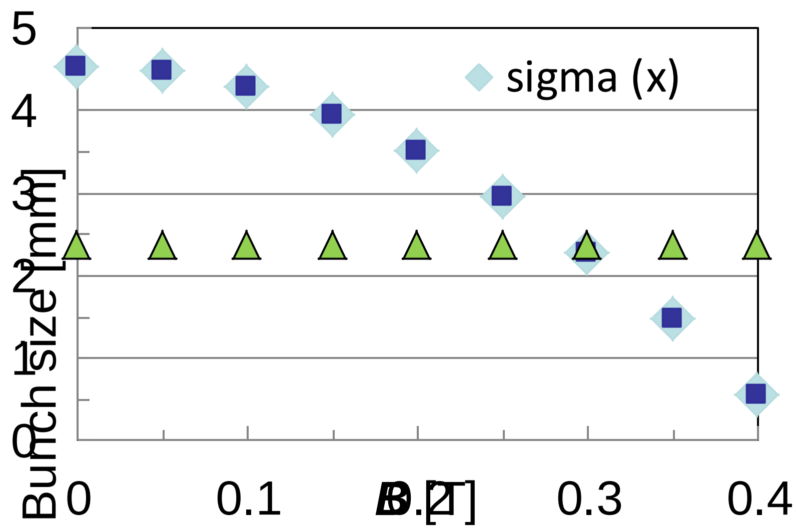
B = 0.25 T

l = 0.41 m

Calculations by T. Wasiewicz

Solenoid B





Conclusion ***B*** has weak influence on emittance.

Usually ***B*** rather increases emittance but helps to reduce transvers size of the bunch.

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Calculations by T. Wasiewicz

Conclusions (2011-2012)

1. Plug cavity was the only choice we had to keep the schedule
2. Baseline tests for cavity with and without plug gave the same results ~53-54 MV/m
3. With Pb coated plug DESY II demonstrated reasonable Qo > $4 \cdot 10^{-9}$ up to 33 MV/m
4. With the test at BESSY we will gain experience not only with the cathode but also with the LLRF and cold tuner.
5. 8° angle gives improvement in slice emittance
6. .
   τ = 10 ps,
   l = 41 cm,
   Q =1 nC ensures the emittance of 1· 10 -6 m · rad
   α = 8°
   B = 0.25 T
   E_{cath} = 55 MVm^{-1}

Long term goals

- 1nC & 1 μm·rad @ 50 kHz
- QE > $2 \cdot 10^{-3}$ @ 213 nm and QE > $2 \cdot 10^{-5}$ @ 258 nm
- E_{peak} > 60 MVm^{-1} @ $Q_o > 10^{10}$ with Pb spot