SRF-gun Development Overview

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Acknowledgment

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for the input they provided for this overview, and to BNL Colleagues

J. Smedley, J. Sinsheimer, M. Gaowei and V. Gofron

for the contribution to DESY SRF-gun program.

Outline

1. Introduction
2. Progress in the SRF-gun projects
   a. R&D at PKU
   b. R&D at KEK
   c. R&D at HZB
   d. R&D at HZDR
   e. R&D at DESY
3. Final remarks

The BNL SRF-gun R&D program will be discussed in the next presentation and is not included in this talk.

Motivation:

SRF photoinjectors have unique potential to generate high brightness electron beams at high duty factor

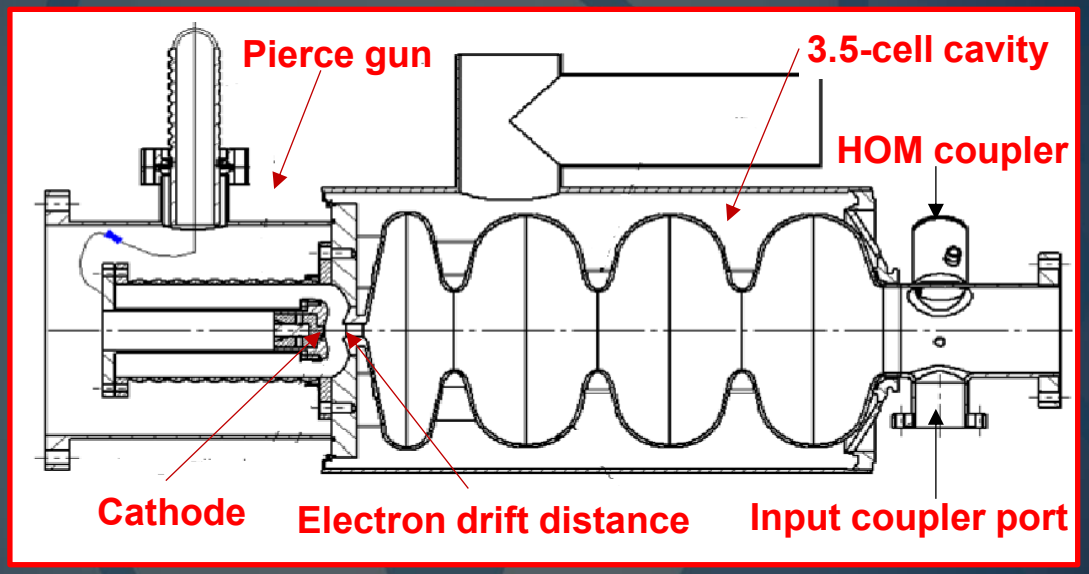
q/bunch		low ε_n		high DF
	+		+	
-> 1nC		≤ 1mm·mrad		-> 100%

They seem to be the best choice for this spec

1. Introduction

The most challenging, in all SRF-gun designs, is the integration of a cathode in a very clean sc cavity. There are 3 approaches to facilitate the integration.

1. DC Pierce gun attached to a sc cavity



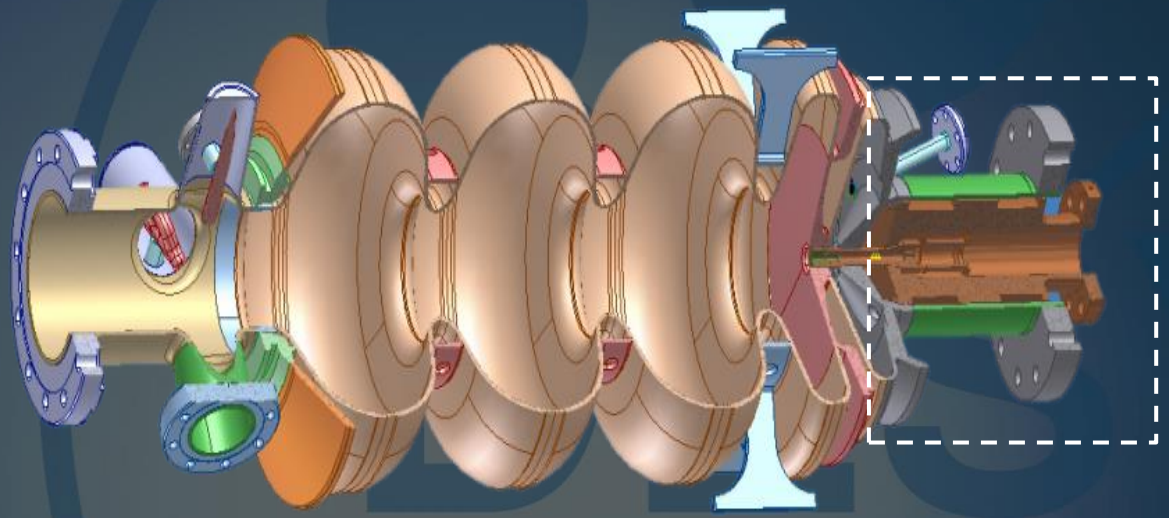
Courtesy J. Hao of PKU

(+) High QE cathode does not penetrate interior of the sc cavity.

(-) Low energy electrons in the Pierce gun drift before they enter high E_{acc} of the cavity; space charge force limits the charge/bunch.

Three approaches, cont.

2. Sc cavity + choke filter



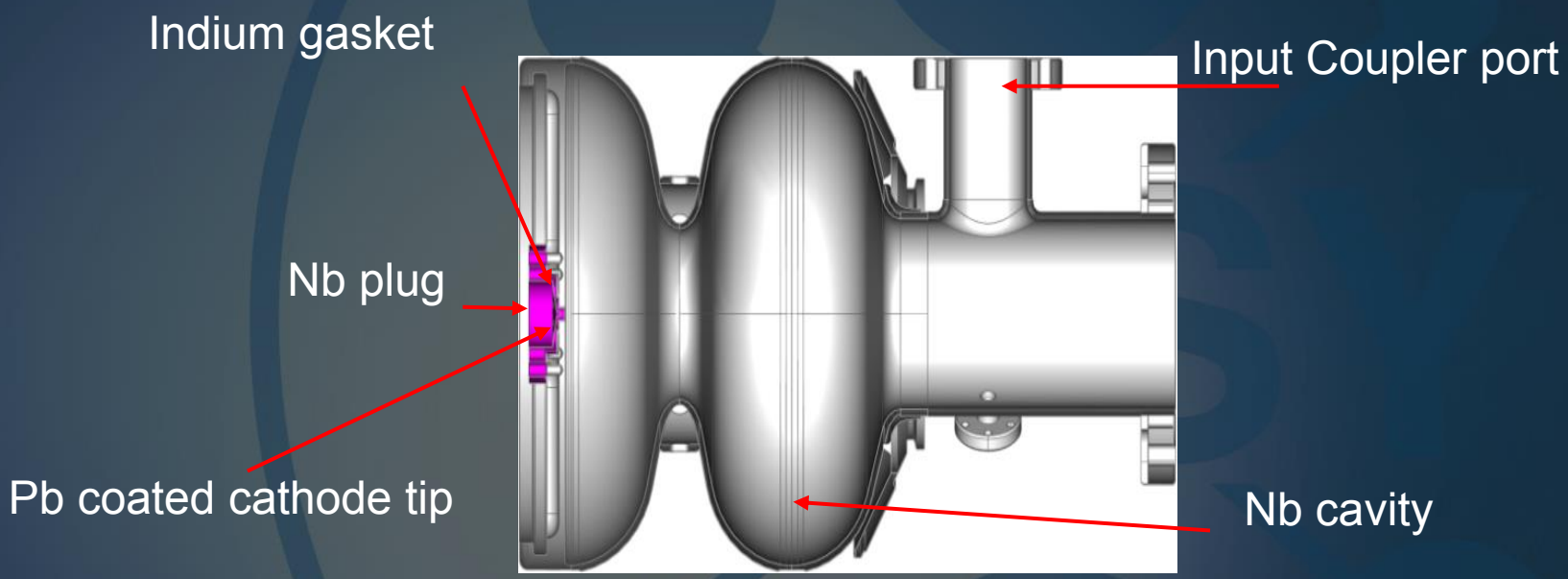
Courtesy A. Arnold and J. Teichert of HZDR

(+) High QE alkali cathodes allow for high beam currents.

(-) Cathode penetrates cavity interior and to avoid an RF-leak a choke filter must be implemented. Unfortunately this often causes multipacting leading to degradation in the cavity performance.

Three approaches, cont.

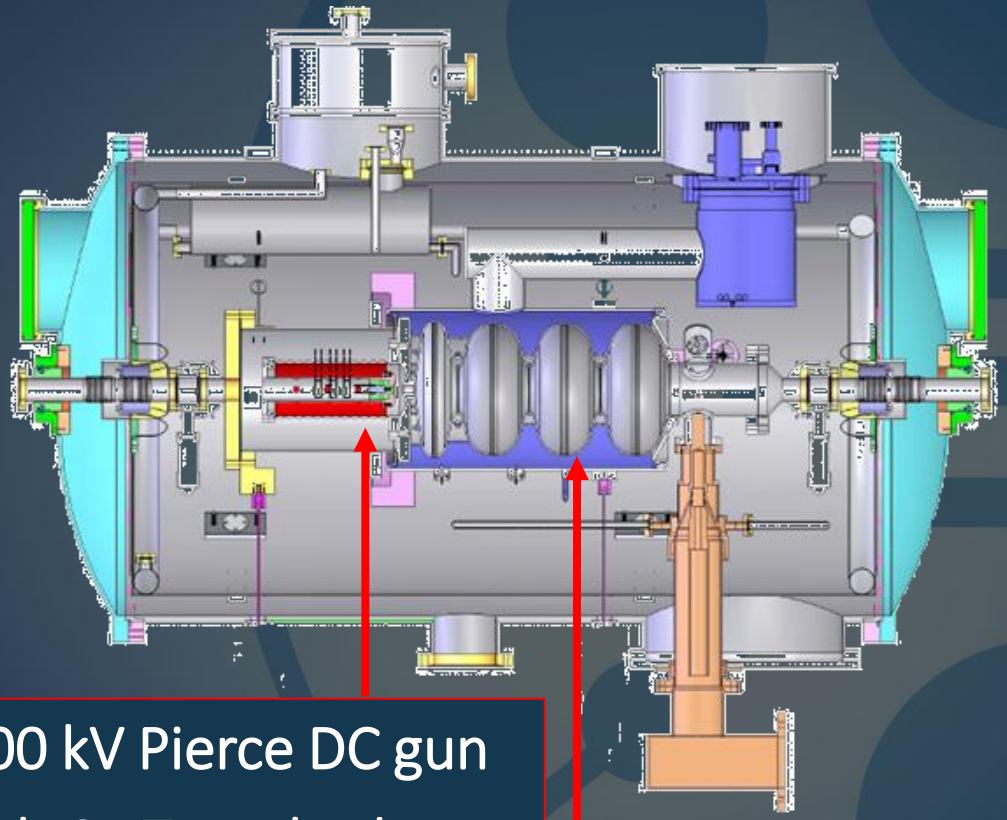
3. Sc cathode integrated in sc cavity (all sc injector)

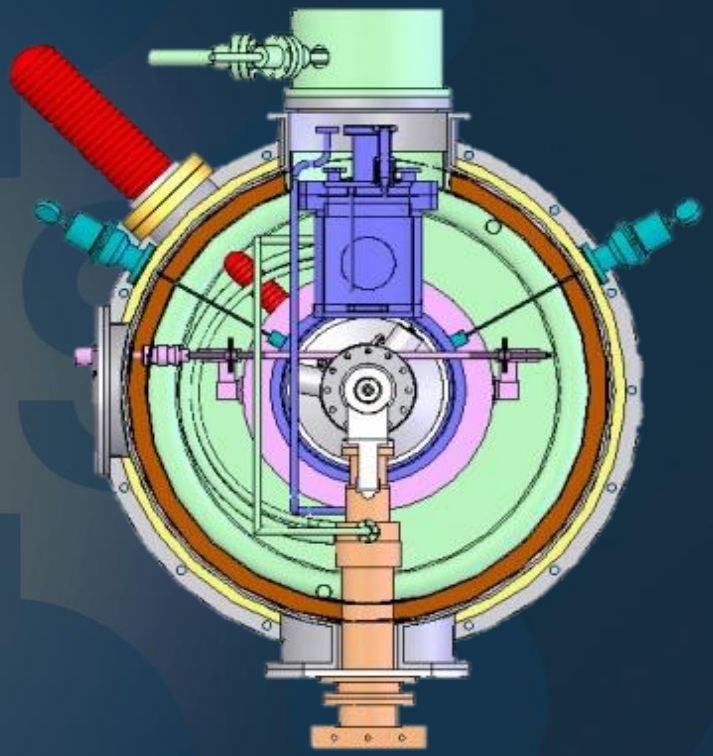


Courtesy D. Kostin, DESY

(+) A sc cathode simplifies the design, and can be exposed to high E
(-) Moderate QE limits beam current to a fraction of 1mA

The type 1 SRF-gun at PKU will be an electron source for the ERL 50MeV@1mA





Courtesy J. Hao of PKU

100 kV Pierce DC gun with Cs_2Te cathode

SRF Cavity : 3.5-cell

Core part of the PKU injector is a large grain 3.5-cell cavity:

Courtesy J. Hao of PKU

Test at TJNAF in a vertical cryostat:

- 800C/2h, BCP, HPR
- 23.5 MV/m with Qo >1E10 @ 2K

PKU team continues beam experiments since 2013

Courtesy J. Hao of PKU

Spec and demonstrated (in green) parameters of the PKU injector

	Unit	Spec	Test
Bunch charge	pC	20	6-50
Bunch length	ps	1-3	1-3
Bunch rep. rate	MHz	81.25	0.1625 ; 81.25
RF-pulse	ms	5-10	7
Trans. emittance	μrad	1.7	2.0
Energy	MeV	5	3.4
Beam current	mA	1.6	0.55
QE at 266nm	%	>1	>2
Cath. life time	h	-	>150
E on cathode	MV/m	5	2.6
Eγ on cathode	nJ	12	12
Laser pulse	ps	5	5
Spot size (rms)	mm	1	1

Next steps

Following parameters have not been fully demonstrated up to now:

	Unit	Spec	Measured
Trans. emittance	µrad	1.7	2.0
Beam energy	MeV	5	3.4

To reach the specification:

- the Pierce gun has to operate at the nominal DC-voltage of 100kV
- the cavity has to operate at the nominal E_{acc} of 13MV/m.

Both have not been reached yet, due to the break downs of the DC voltage higher than 50kV and issues with the FPC.

2. b R&D at KEK

SRF-gun program at KEK is new. The goal is an injector of type 2 for the ERL facility which will operate with beams up to 100mA at 3GeV.

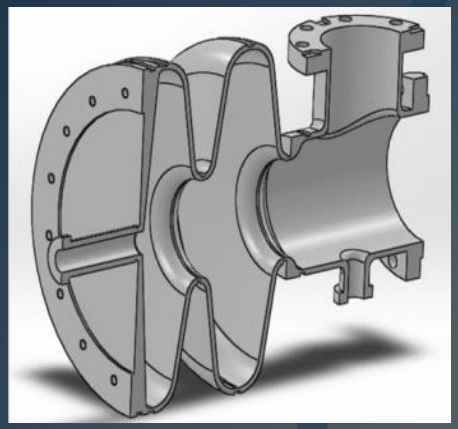
Parameters of the SRF-injector at KEK

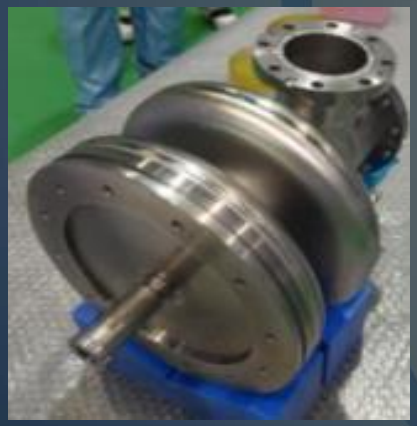
	Unit	Mode 1	Mode 2
Bunch charge	pC	77	7.7
Bunch length	ps	3.2	3.2
Bunch rep. rate	MHz	1300	1300
Trans. emittance	μrad	1.0	0.3
Beam current	mA	100	10
Energy	MeV	2	
QE at 520nm (K_2CsSb)	%	3	
E on cathode	MV/m	25	
Input power	kW	200	

Challenging parameters are marked in yellow

2. b R&D at KEK, cont.

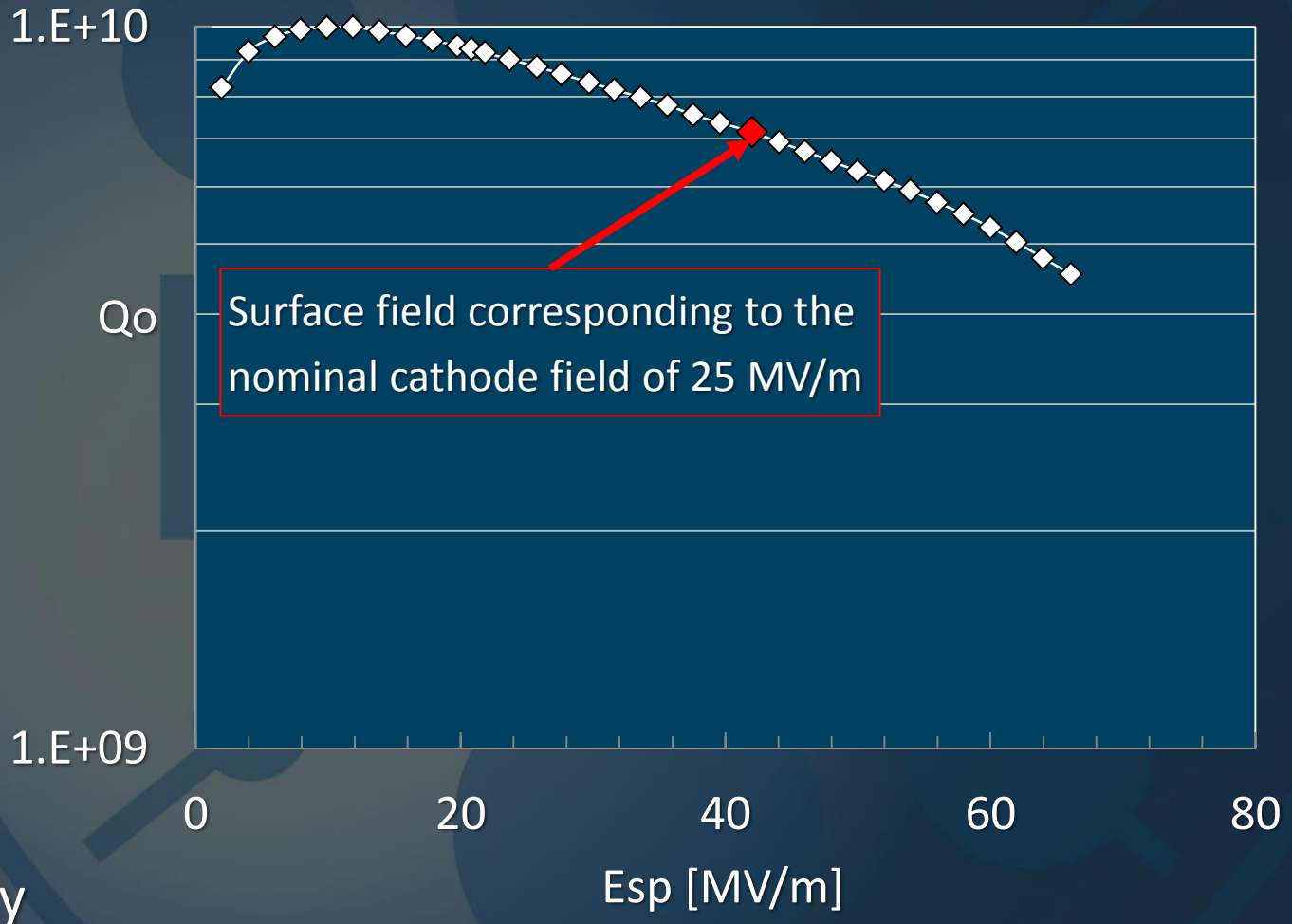
A simplified prototype (only one FPC port, no choke filter, no cathode) of the 1.5-cell gun cavity was built and tested recently.





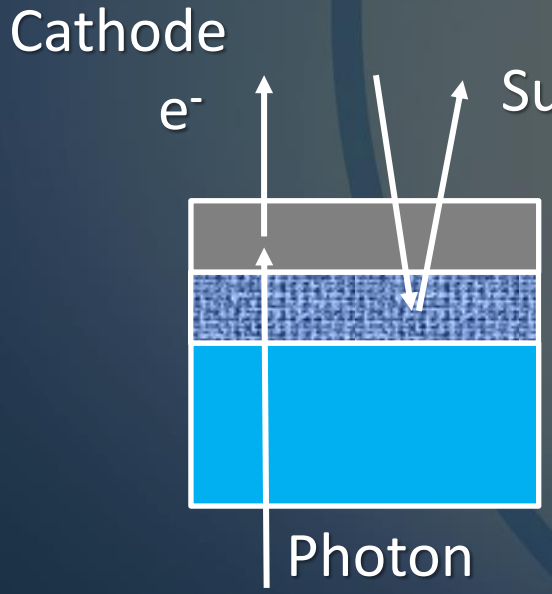
1.3GHz gun cavity

Courtesy E. Kako, T. Konomi



In the next coming vertical tests, the cavity will be stepwise equipped with additional components. This will allow for study of the design complexity:

- Test#2: Cavity + cathode rod
- Test#3: Cavity + choke cell (w/o inner conductor)
- Test#4: Cavity + choke filter + cathode rod
- Test#5: Cavity + choke filter + cathode rod + transparent cathode irradiated from the back.



Photocathode: K_2CsSb , thickness (t) ~100nm

Transparent superconductor: $LiTi_2O_4$, t ~100nm

Substrate: $MgAl_2O_4$, t=0.5mm

2. c R&D at HZB

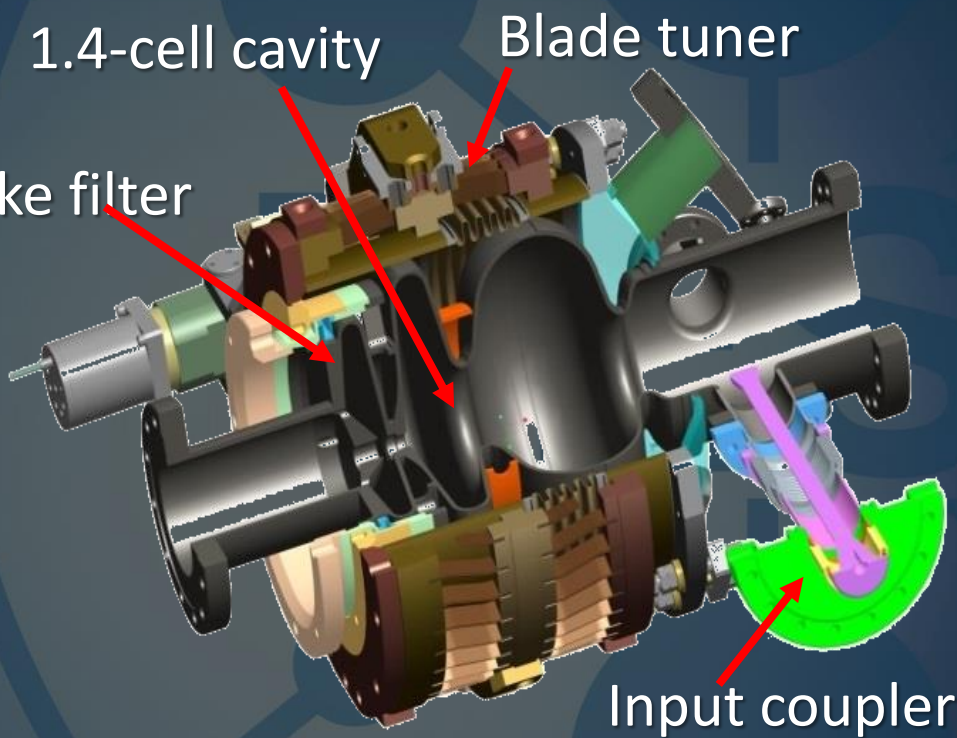
The ongoing R&D SRF-gun (type 2) program is a part of the bERLinPro project, which will be a 50 MeV ERL, operating with I_{beam} -> 100mA.

	Unit	GunLab (new test stand)	Final version
Bunch charge	pC	0-100	77
Bunch length	ps	2-10	4.6
Bunch rep. rate	Hz	10-10^4	$1.3 \cdot 10^9$
Transvers emittance	µrad	0.4-10	0.5-1.0
Energy	MeV	1.2-3.5	2.3
Beam current	mA	<0.04	100
Input power	kW	20	230
E on cathode	MV/m	14-34	24
Emitting material	-	CsK_2Sb	
QE at 515nm	%	1 (demonstrated 5%)	
Cathode life time	day	>7	
Eγ on cathode	nJ	400@258nm 200@515nm	20@515nm

Challenging parameters are marked in yellow

2. c R&D at HZB, cont.

The HZB injector employs 1.4-cell cavity, which will be equipped with 2 FPCs, a choke filter and load lock unit to exchange cathodes.

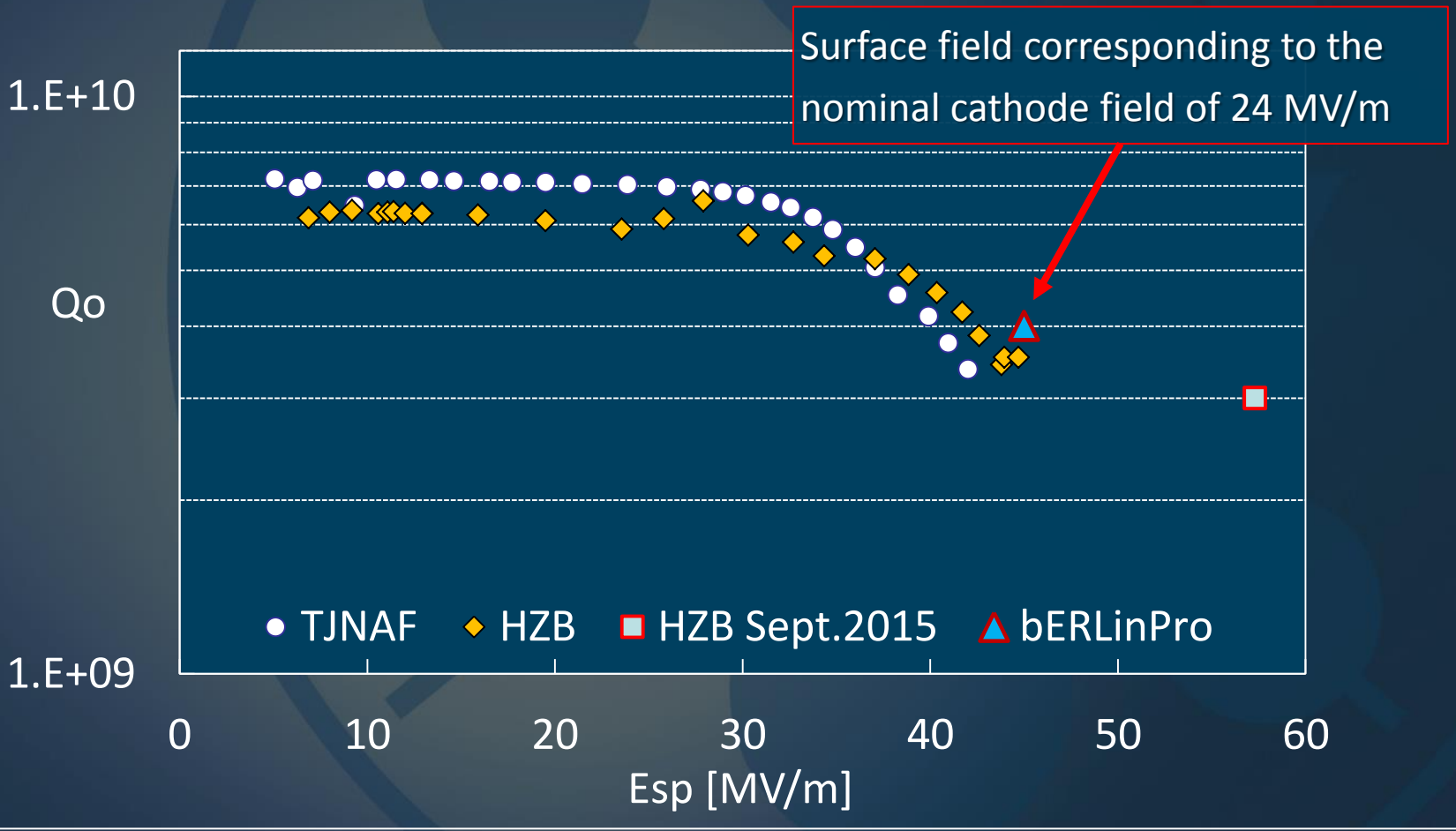


Courtesy A. Neumann

bERLinPro
Helmholtz-Zentrum Berlin

2. c R&D at HZB, cont.

The 1st cavity prototype was built and vertically tested at TJNAF and later tests continued at HZB in the horizontal cryostat HoBiCaT. The tests were performed at 1.8K, w/o cathode (cathode stalk).

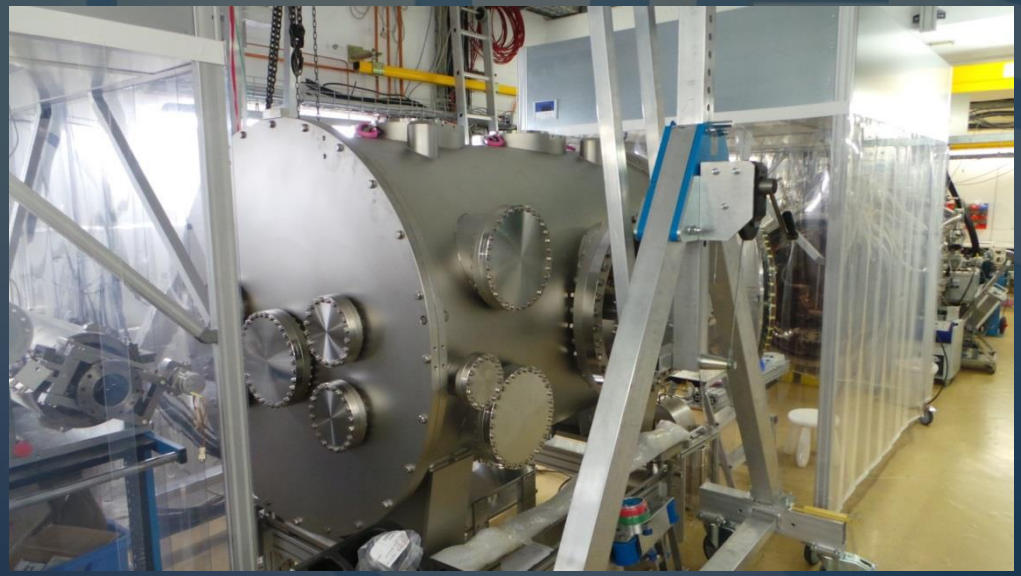


What is next:

- Testing of the 1st prototype in the HoBiCaT cryostat, equipped with 2 TTF-3 FPCs, cold tuner and solenoid, will continue this fall.

- Assembly of the 2nd prototype in a **new horizontal cryostat** will begin also in fall. The cavity will be fully equipped including a unit for the cathode exchange. The experiments at the new test stand, GunLab, will begin in summer next year.

Courtesy A. Neumann



bERLinPro
Helmholtz-Zentrum Berlin

2. d R&D at HZDR

The SRF-gun program for the ELBE facility is the most advanced from all discussed here programs. The gun (type 2) will operate in 2 modes:

	Unit	Mode 1 High charge	Mode 2 FEL
Cathode	-	Cs_2Te	Cs_2Te
Bunch charge	pC	1000	77
Bunch length	ps	10	2
Bunch rep. rate	MHz	0.5	13
Trans. emittance	µrad	2.5	1.0
Electron Energy	MeV	9.5	9.5
Beam current	µA	500	1000
QE at 258nm	%	1	
Max. E on cathode	MV/m	30	

Challenging parameters are marked in yellow

Because the electron energy is high (9.5MeV), the ELBE gun cavity is 3.5-cell long.

2. d R&D at HZDR, cont.

Two cavities were built up to now.

Gun1 (shown on the picture) was in operation from 2010-2013.

Gun2 is in operation since June 2014. It continues operation with the Cu cathode, after it was contaminated by Cs_2Te cathode in Jan. 2015.

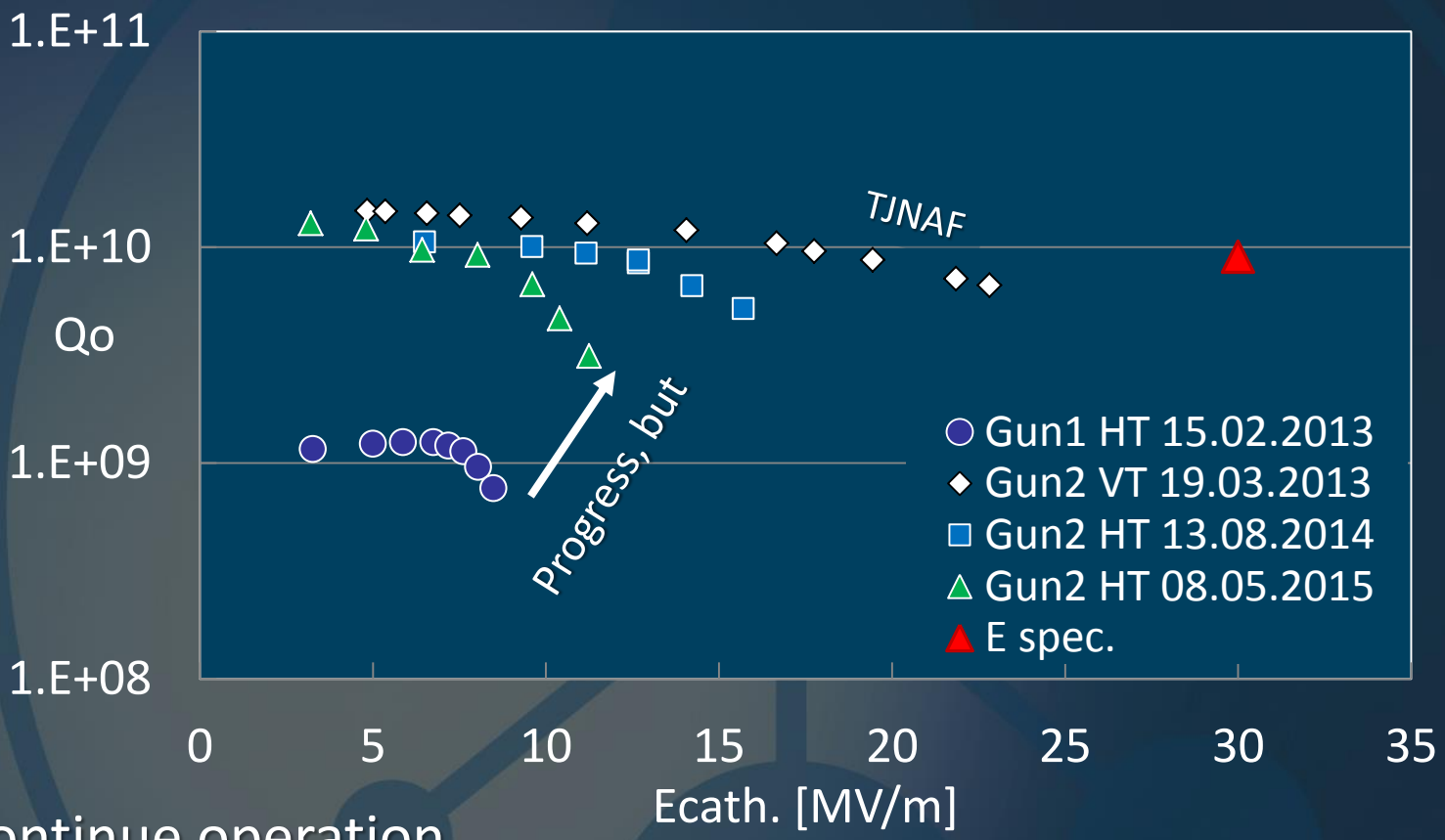
Courtesy A. Arnold and J. Teichert

	Unit	Operation	
Gun#	-	Gun1	Gun2
Cathode	-	Cs_2Te	Cu
Bunch charge	pC	up to 400	3
Bunch rep. rate	MHz	up to 13	0.1
Trans. emittance	µrad	3@80pC	0.3
Energy	MeV	3.5	4.5
Beam current	µA	400	0.3
QE at 258nm	%	1	0.002
Max. E on cathode	MV/m	9.6	16

Not demonstrated yet spec parameters are marked in yellow

Please visit posters THPB055, THPB057

Summary of the Gun1 and Gun2 performance



Next

- Gun2 will continue operation
- Refurbishing and test of the Gun1 cavity
- Refurbishing of the Gun2 cavity (2017)
- Gun3 and 4 will be ordered (2017)

} DESY will help with EP/BCP, clean room assembly and VT tests.

2. e R&D at DESY

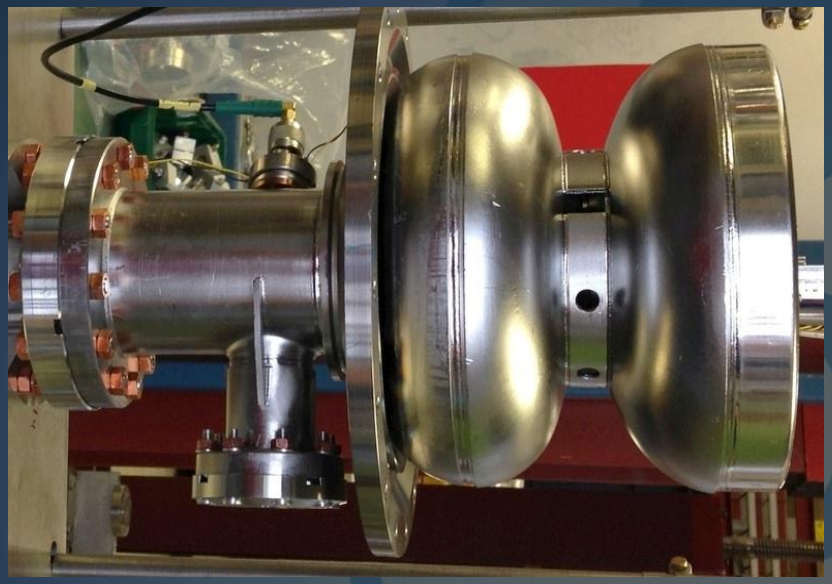
The SRF-injector (type 3) program at DESY is motivated by perspective of an increased flexibility in the time structure of the FLASH/EXFEL photon beams by enabling cw/lp operation.

Present parameters of the DESY injector

	Unit	Spec 2014
Cathode	-	Pb
Bunch charge	pC	100-300
Bunch length	ps	3
Bunch rep. rate	kHz	100-33
Trans. slice emittance	µrad	< 0.7@100pC
Energy	MeV	3.7
Beam current	µA	10
QE	%	0.015@260nm
Max. E on cathode	MV/m	40
Eγ on cathode	µJ	2.4-7.2
Laser P at cathode	W	0.24
Laser P at 1032	W	24

Challenging parameter is marked in yellow

The 1.5-cell gun cavity prototype was built at TJNAF. The present plug version has very effective cooling of the cathode.



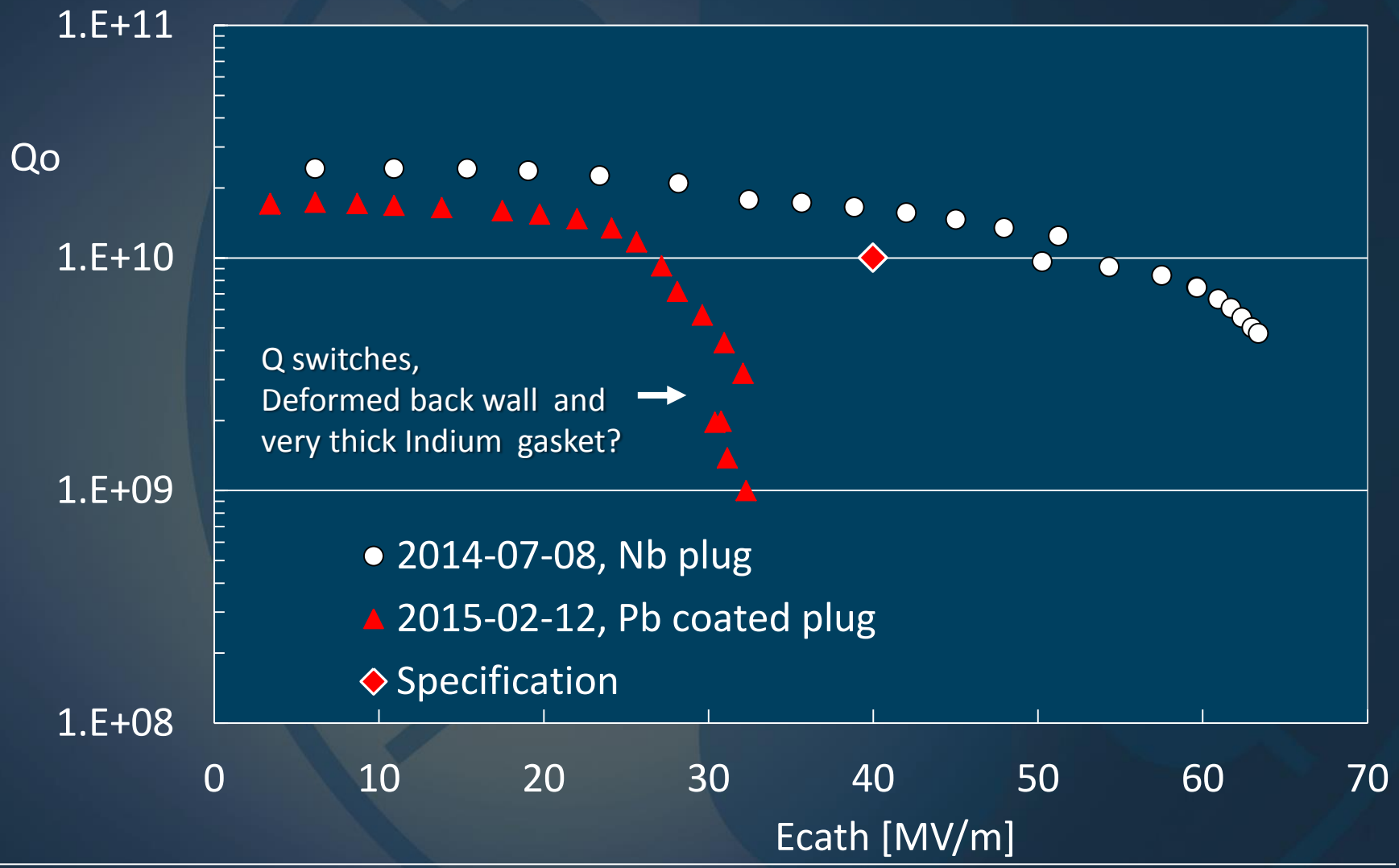
1.5-cell , 1.3 GHz gun cavity

New plug with
LHe channels

Nb/Pb
cathode

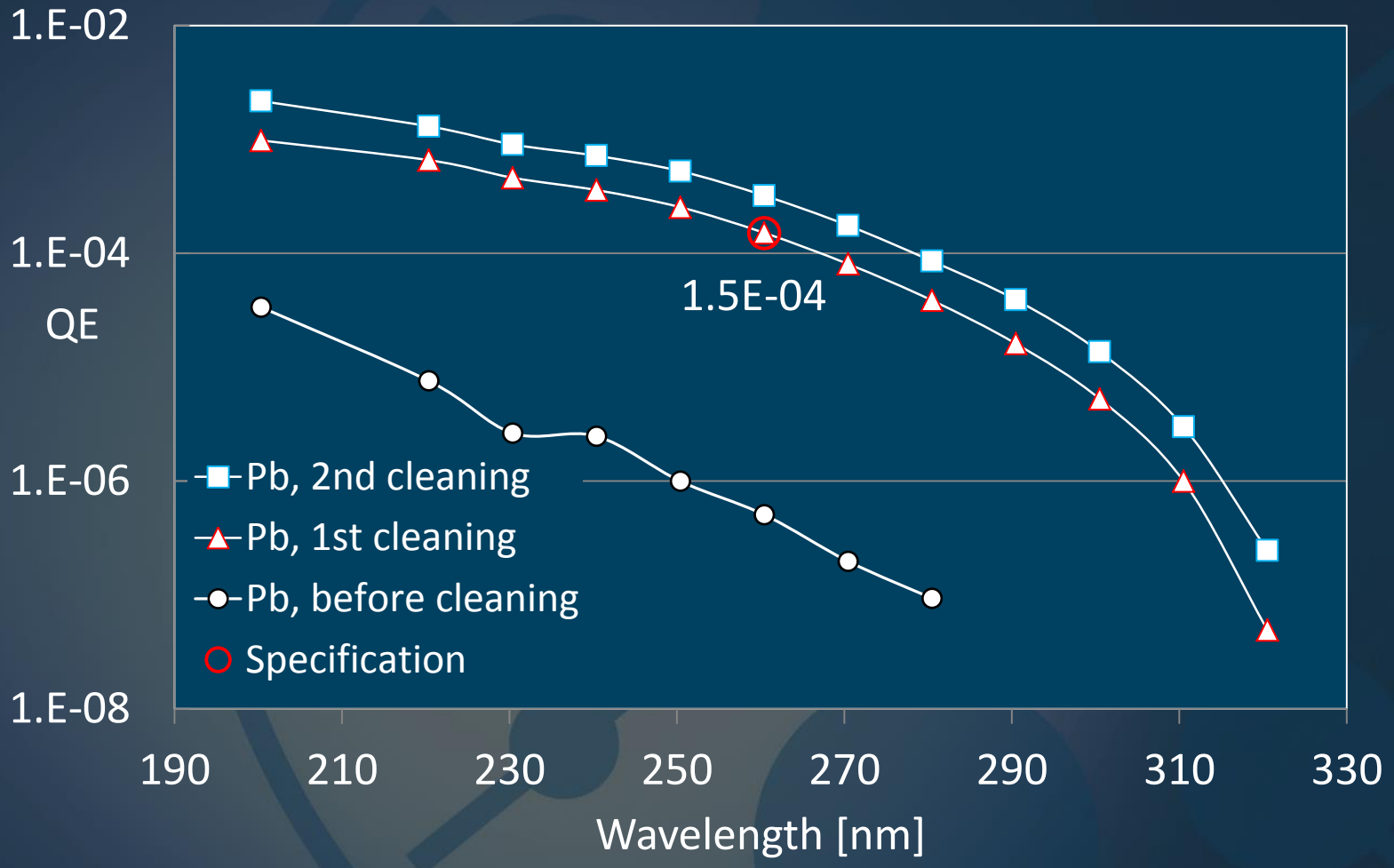
2. e R&D at DESY, cont.

The test results of 1.5-cell gun cavity with Nb and Pb-coated cathode.



2. e R&D at DESY, cont.

Recent QE test at BNL of the Pb coating on new plug

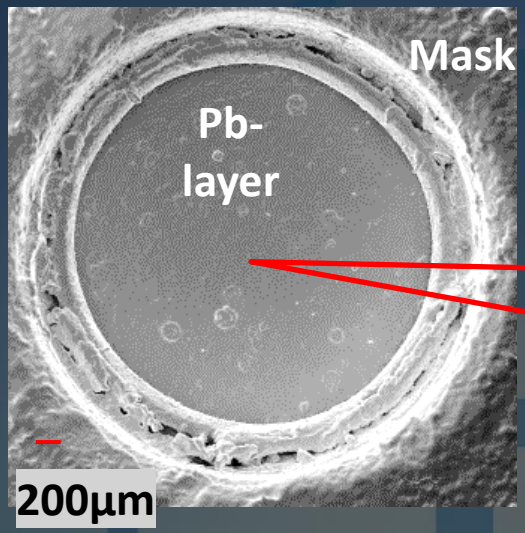


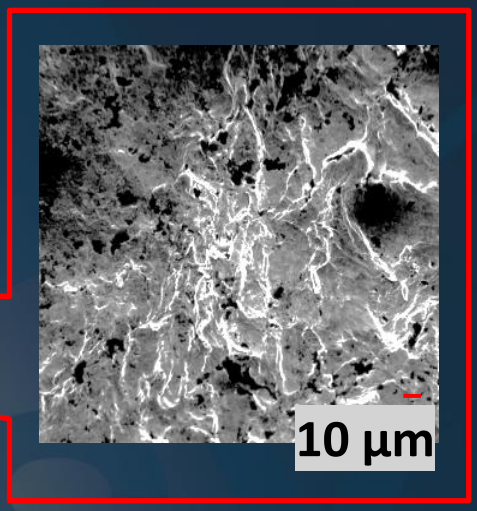
Courtesy J. Smedley, J. Sinsheimer, M. Gaowei and V. Gofron

Laser cleaning: 1st 1000 shots with 0.6 mJ/mm^2,
2nd 10000 shots with 0.6 mJ/mm^2, all at 248nm

Roughness of the Pb coating (arc-deposition) on new plug

Courtesy NCBJ





Courtesy BNL

Pb-layer after the plasma treatment
Droplets ϕ ca. 100µm, elevation few µm

Pb-layer after the 2nd laser cleaning

Next

- Surface is too rough. Pb-layer is 15µm thick. It will be molt by laser irradiation and then QE test will be repeated.
- The Pb-coated plug will be then installed in 1.5-cell at DESY for the SRF-test.

3. Final remarks

- There is a remarkable progress in the SRF-gun R&D programs over last two years, especially at PKU and HZDR where the electron injectors are correspondingly almost read to or already in operation.

- The new project at KEK and the project at HZB are in progress too, which is demonstrated in the computer modelling, prototyping, testing and cathode production.

- The R&D program at DESY for a low current injector showed recently the highest gradients on cathodes and the goal QE for the superconducting metallic cathode. In this program in near future, more attention will be paid to improve the quality and smoothness of the coatings.