Superconducting Photoinjectors

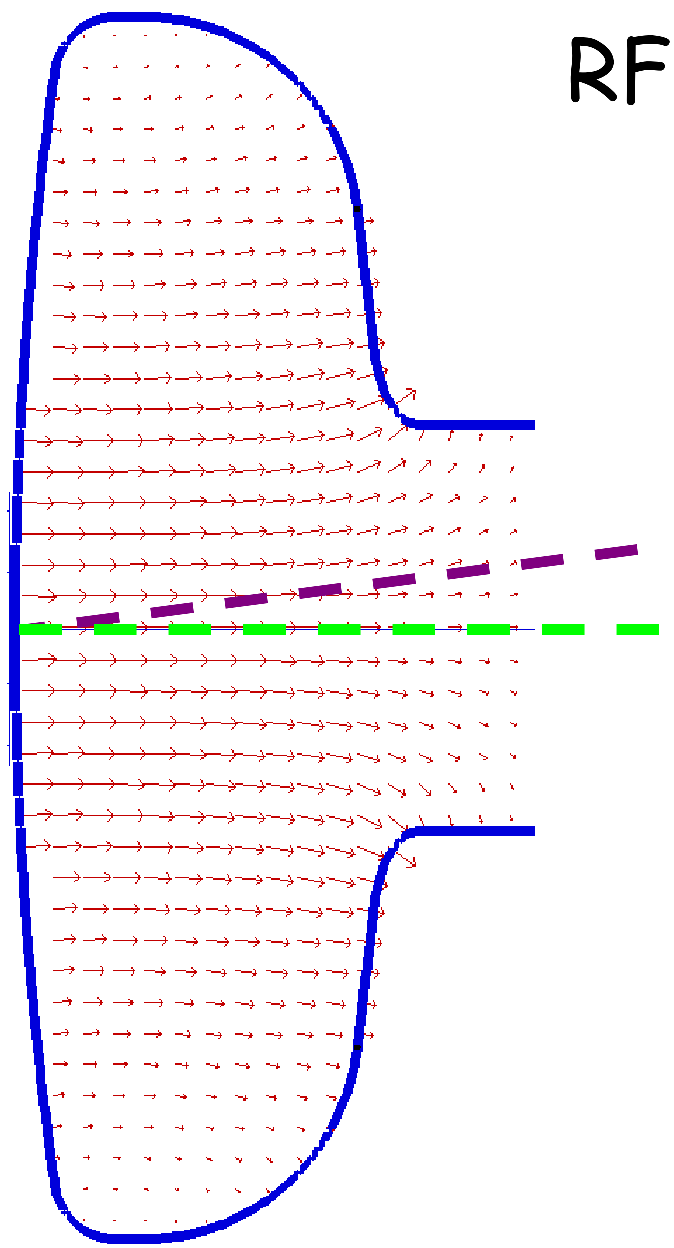
John Smedley

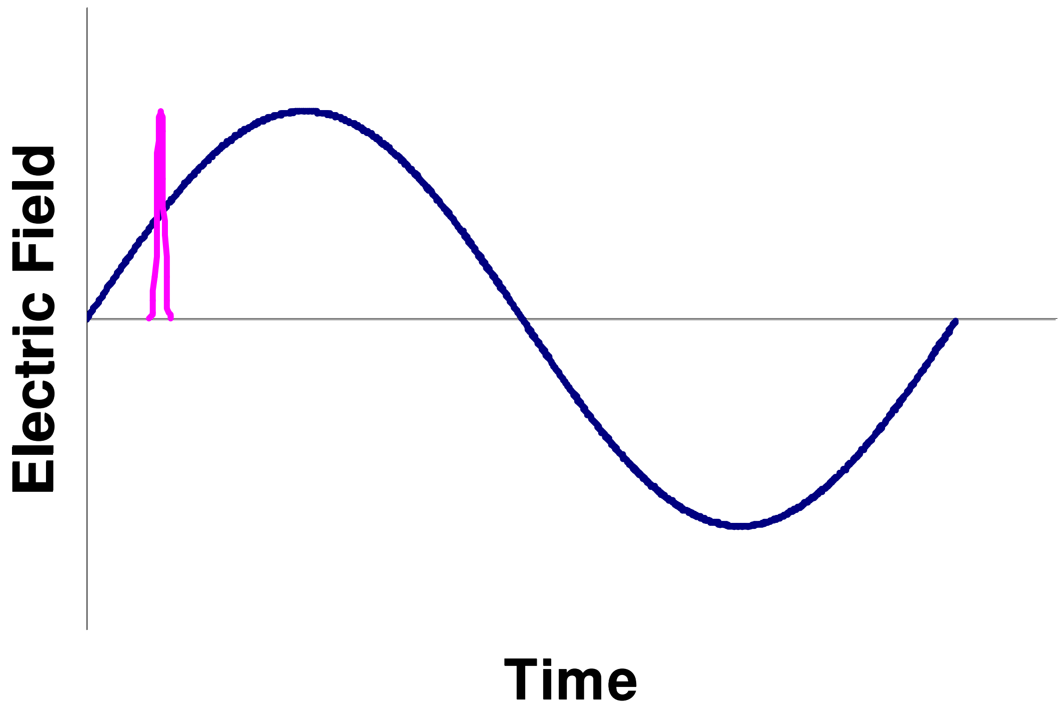
Superconducting RF photoinjectors
- What are they? How do they work?
- Why are they interesting?
- SRF cathode options
  - RF choke joint
  - Superconducting photocathodes

RF Cavity Tests
- Niobium cavity results
- Lead/niobium RF tests
- Photoemission Tests
- Quench Test

BROOKHAVEN
NATIONAL LABORATORY

RF Photoinjector





Why Superconducting?

- Allows true CW operation (RF duty factor 100%), while maintaining high (20+ MV/m) gradient
- High gradient needed to overcome space charge of bunches with high peak current density
- Thermal management much easier than "*Room Temperature*" Copper

J. Sekutowicz, et al.; Proposed continuous wave energy recovery operation of an x-ray free electron laser, Phys. Rev. ST Accel. Beams 8, 010701 (2005)

Cathode Options for SCRF Injector

Use the niobium wall as a cathode

Simple, but low Nb QE limits current

J. Smedley, T. Rao, and Q. Zhao, J. Applied Physics **98**, 043111 2005

Use an RF choke-joint to allow non-SC cathodes

Enables use of Cs_2Te, Cs_3Sb (and others)

D.Janssen et al., Nucl. Instr. And Meth. In Phys. Res. A445 (2000) 408-412.

A. Michalke et al., "First Operation of the High Quantum Efficiency Photocathodes Inside Super-conducting Cavities", EPAC92, 1014

Coat niobium in cathode region with another superconductor (lead), with better QE

Choke Joint Cavities

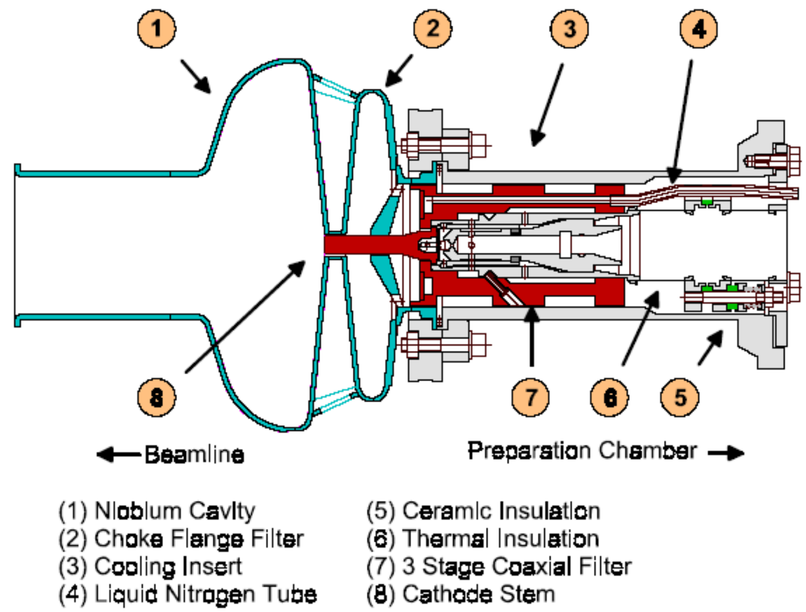
Cathode deposited onto a stem

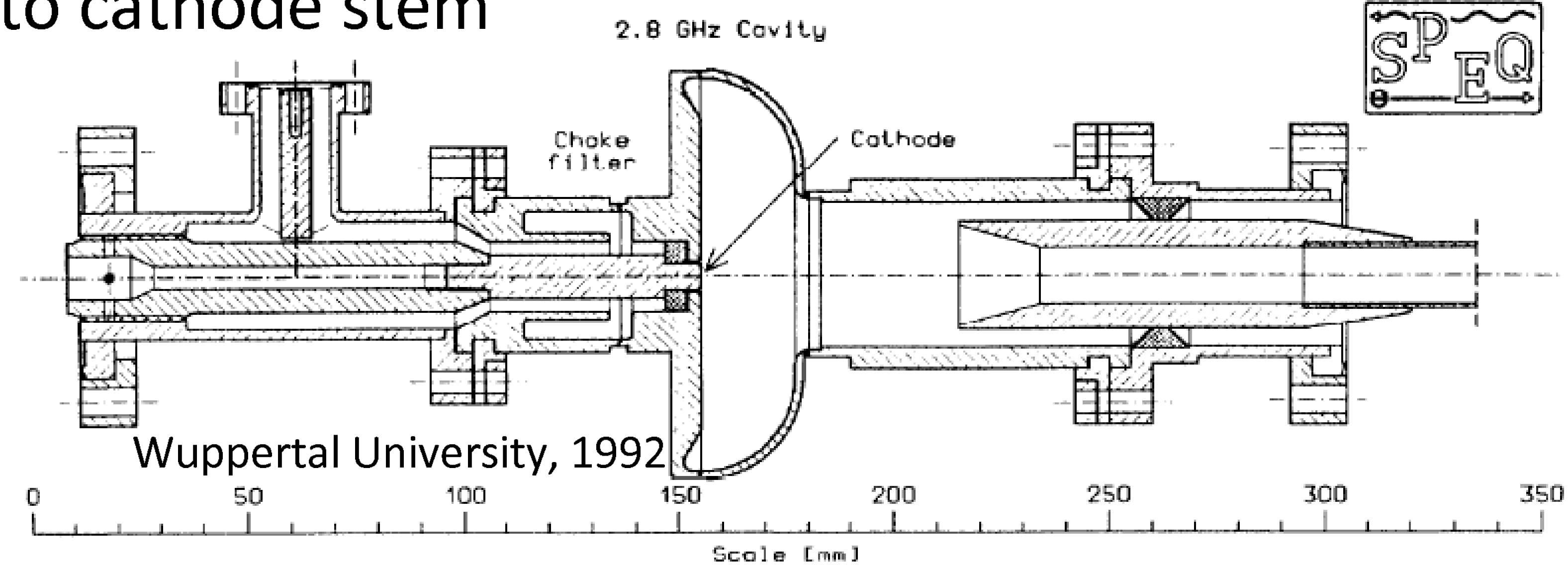
Stem cooled (LN_2 or He)

Requires load-lock

Stem thermally isolated

Use filter to block RF coupling to cathode stem

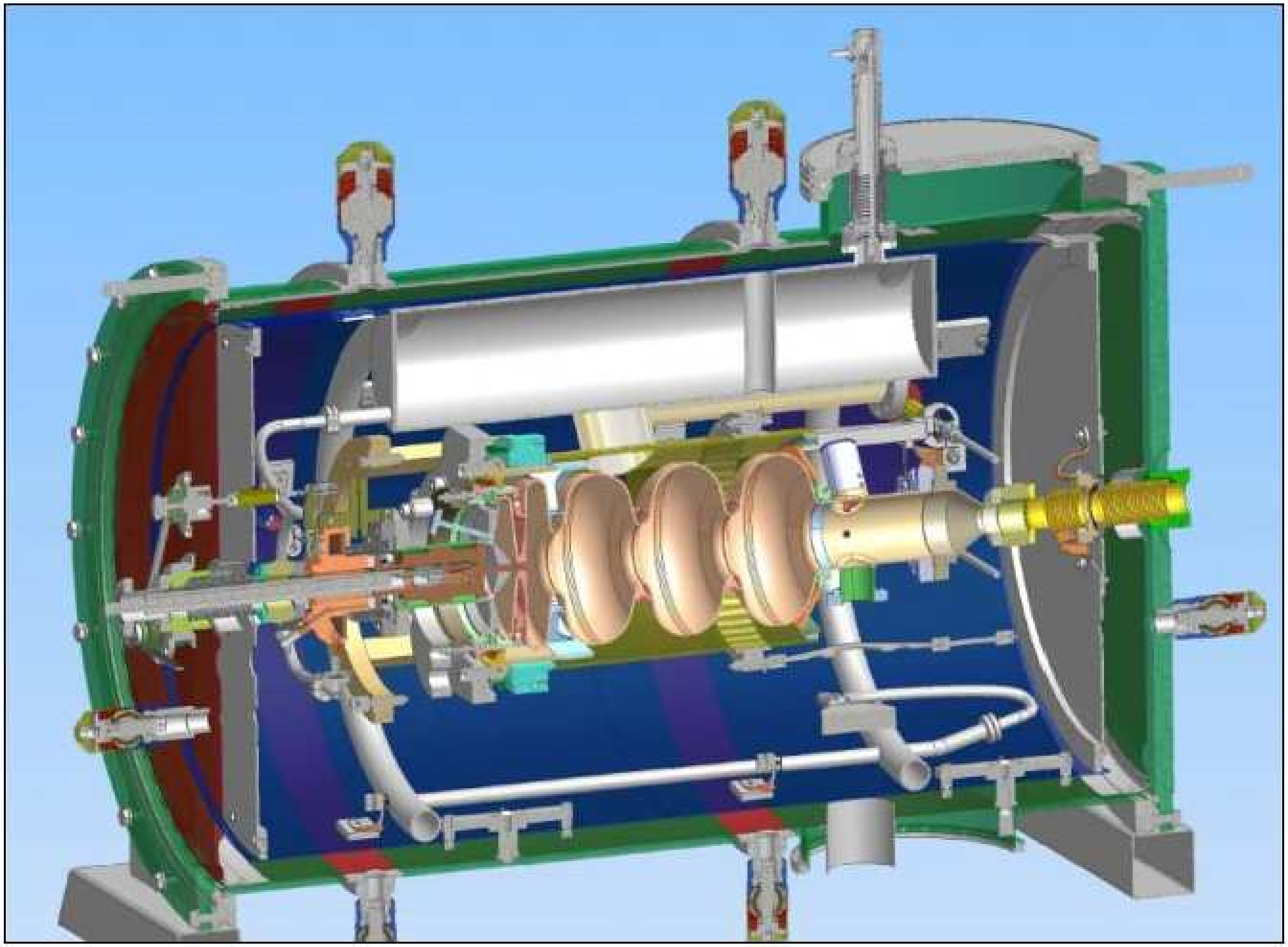




Wuppertal University, 1992

Planned Choke Injectors

Rossendorf 1.3GHz 3.5 cell

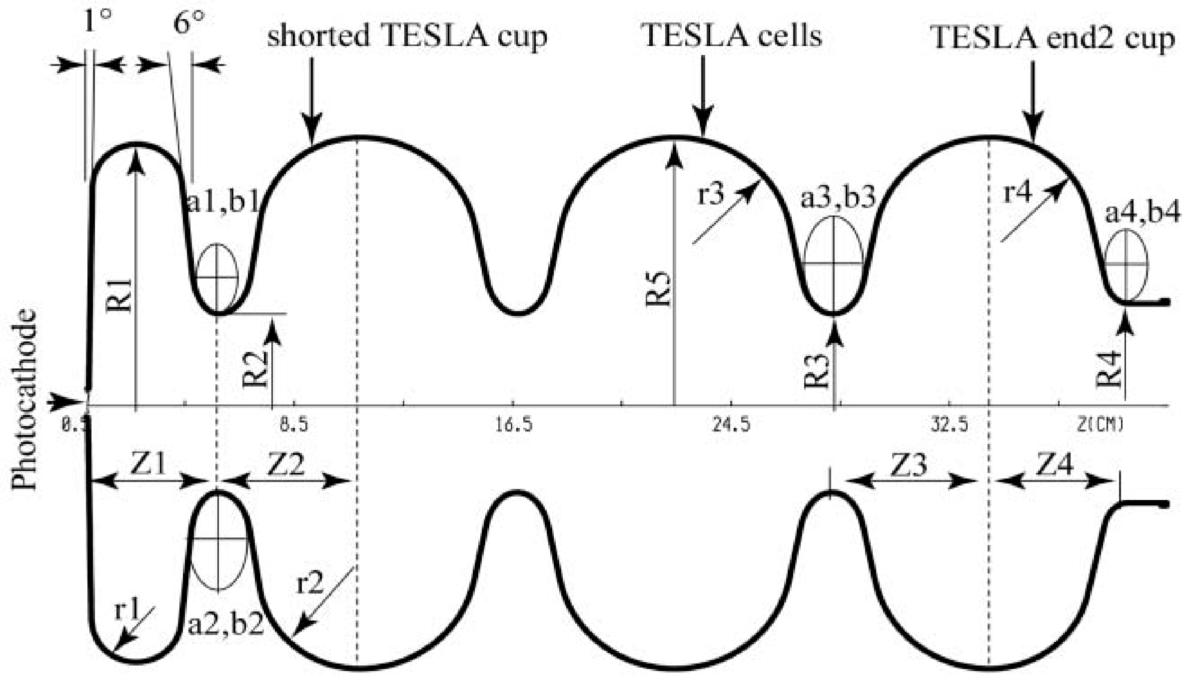


Planned Choke Injectors
Rossendorf 1.3GHz 3.5 cell

	ELBE mode	High charge mode	BESSY-FEL
SRF frequency [GHz]	1.3		
E [MeV]	9.5		
Operation mode	CW		
Driving laser λ [nm]	262		
Photocathode	Cs_2Te		
QE [%]	> 1		> 2.5
I_b [mA]	1	0.5	2.5
Pulse duration [ps]	5	15	40
f repetition [kHz]	13 000	500	1
q/bunch [nC]	0.077	1	2.5
ε [μmrad]	1	2.5	3

Planned Choke Injectors
Rossendorf 1.3GHz 3.5 cell

cell	shape parameter	name	value
gun half-cell	back wall angle		1°
	cathode hole diameter	d_0	12
	length	Z_1	37.7
	equator radius	R_1	102.5
	iris radius	R_2	35
	circular arc radius	r_1	11.44
	ellipse horizontal half axis	a_1	9
	ellipse vertical half axis	b_1	16
shortened TESLA midcup	length	Z_2	52
	equator radius	R_5	103.3
	iris radius	R_2	35
	circular arc radius	r_2	37.12
	ellipse horizontal half axis	a_2	12
	ellipse vertical half axis	b_2	19
TESLA midcup	length	Z_3	57.7
	equator radius	R_5	103.3
	iris radius	R_3	35
	circular arc radius	r_3	42
	ellipse horizontal half axis	a_3	12
	ellipse vertical half axis	b_3	19
TESLA endcup	length	Z_4	56
	equator radius	R_5	103.3
	iris radius	R_4	39
	circular arc radius	r_4	40.3
	ellipse horizontal half axis	a_4	10
	ellipse vertical half axis	b_4	13.5



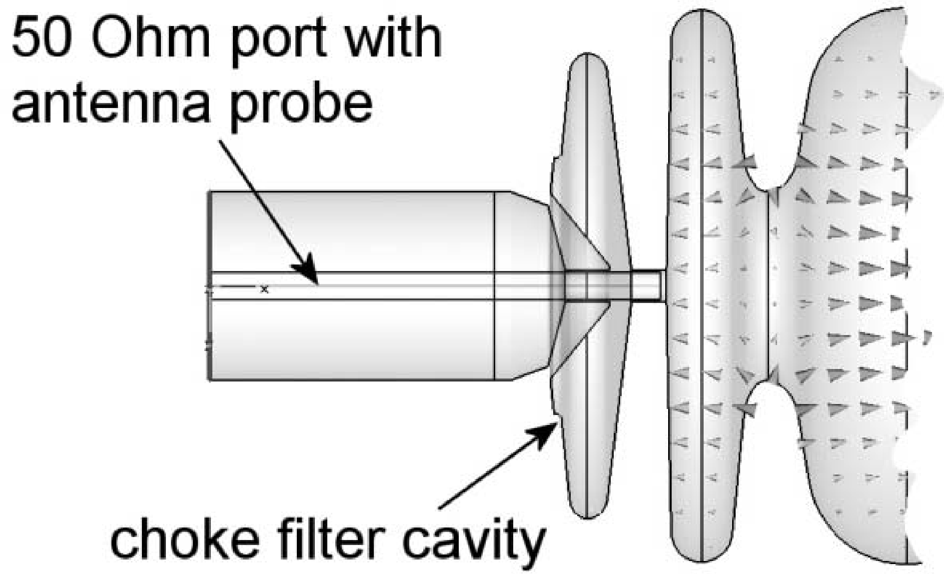
Thermal expansion from 293K to 2K = 0.17%

Operated frequence at 2K = 1300.00 MHz

R2 at 293K = 3.5(TESLA like); 3.56; 3.58; 3.6 cm

J. Teichert, et al, EPAC04

Planned Choke Injectors
Rossendorf 1.3GHz 3.5 cell

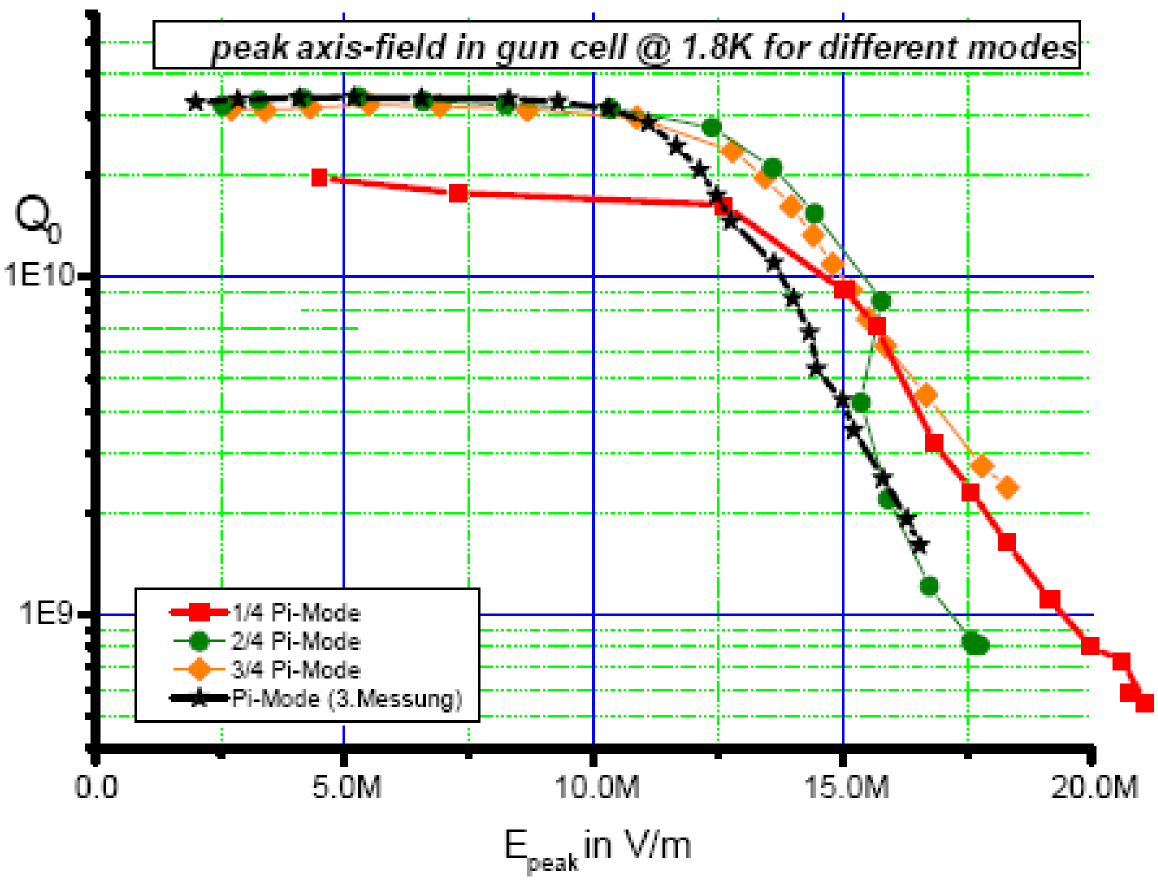


Coaxial trap filter

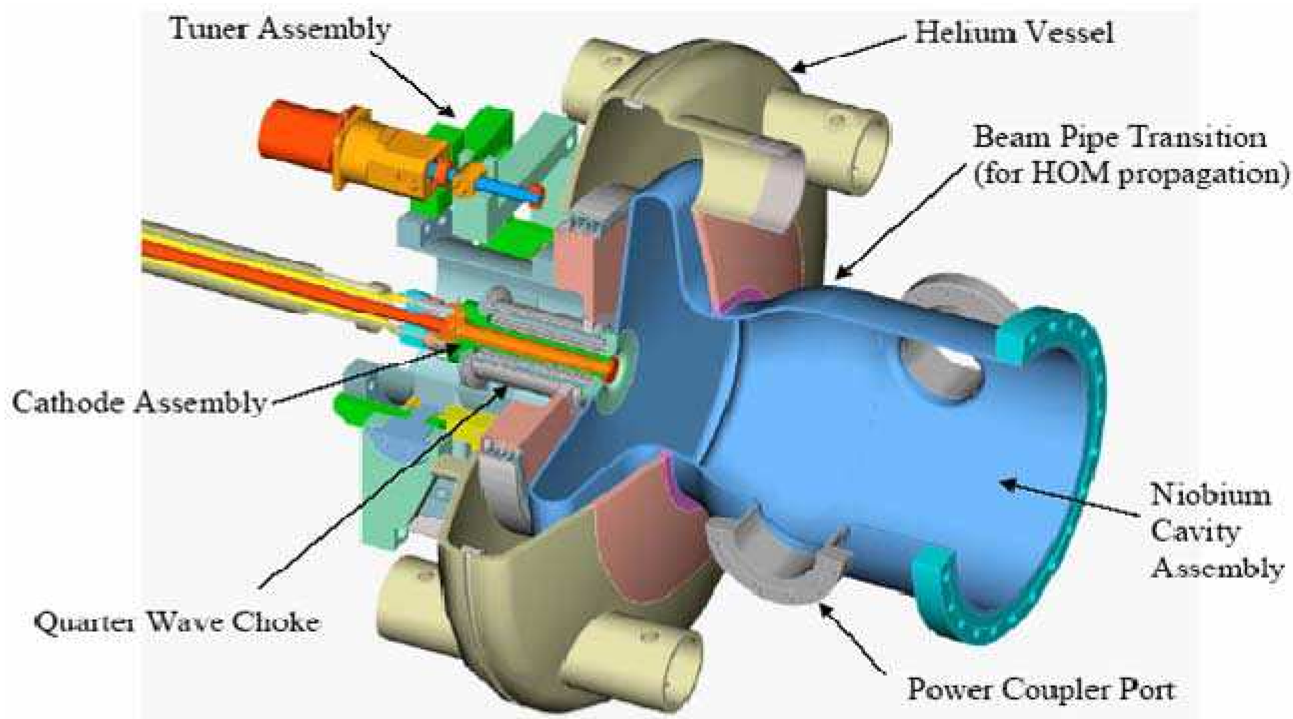
Design calls for P_{tr}<1% of P_{diss}, $Q_{ext}=10^{12}$

A. Arnold, et al. EPAC06

Planned Choke Injectors
Rossendorf 1.3GHz 3.5 cell



Planned Choke Injectors
BNL/AES 703 MHz ½ cell



Iris dia	9.5 cm
r/Q	95.0 Ω
Ep/Ea	1.43
Bp/Ea	2.96 (mT/(MV/m))

R. Calaga, PhD Thesis

Planned Choke Injectors
BNL/AES 703 MHz ½ cell

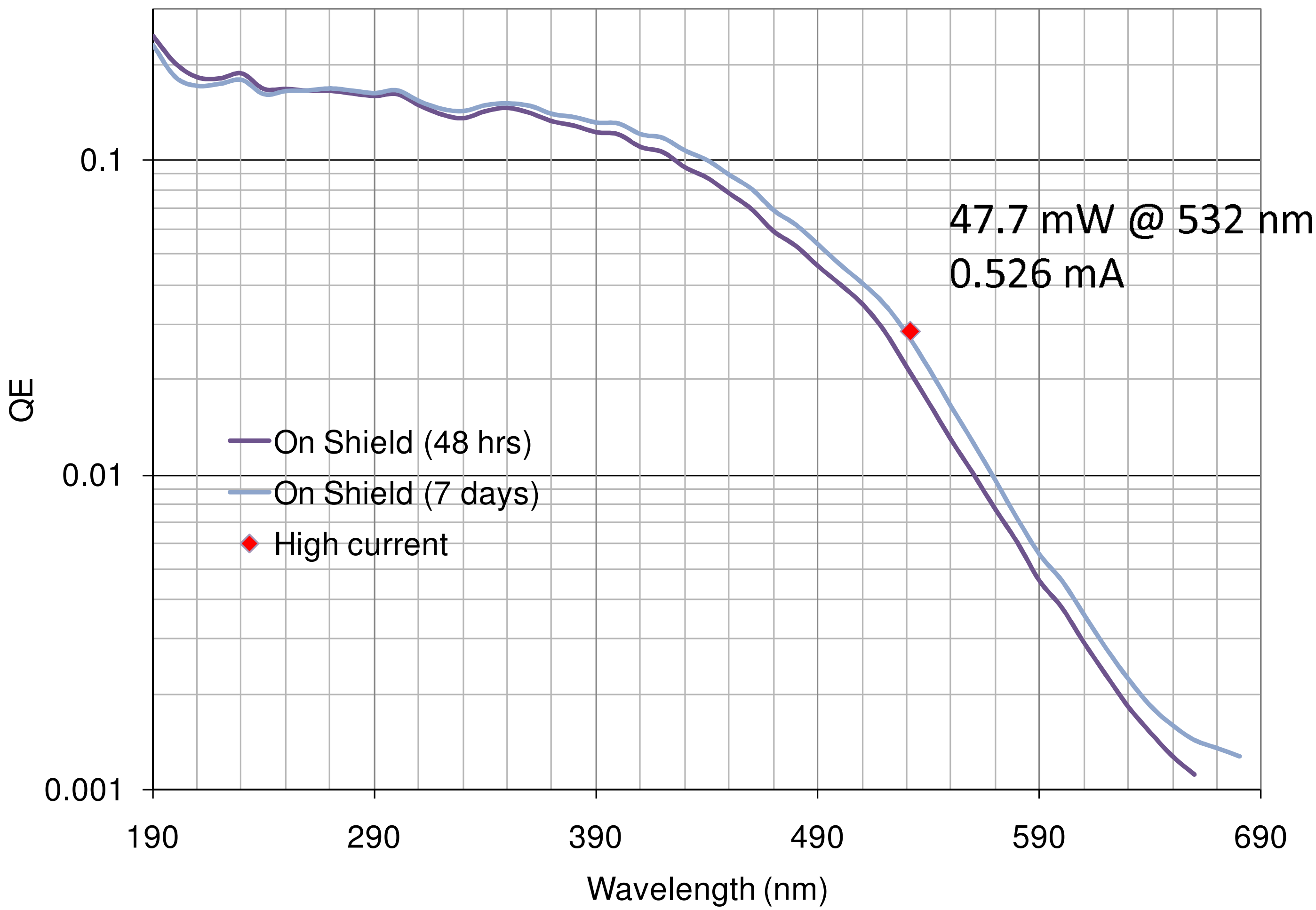
	High Charge	High Current
f [MHz]	703.75	703.75
q/bunch [nC]	5	0.7
ε_n [μm rad]	<10	2
E [MeV]	2.5	2.5
P_b [MW]	0.1	1
I_b [A]	0.05	0.5
f_{rep} [MHz]	9.4	352
Cathode	CsK_2Sb	w/ Diamond Amplifier
QE [%]	1 (532nm), 5 (355 nm)	x100

Vladimir N. Litvinenko, et al, PAC07

Planned Choke Injectors

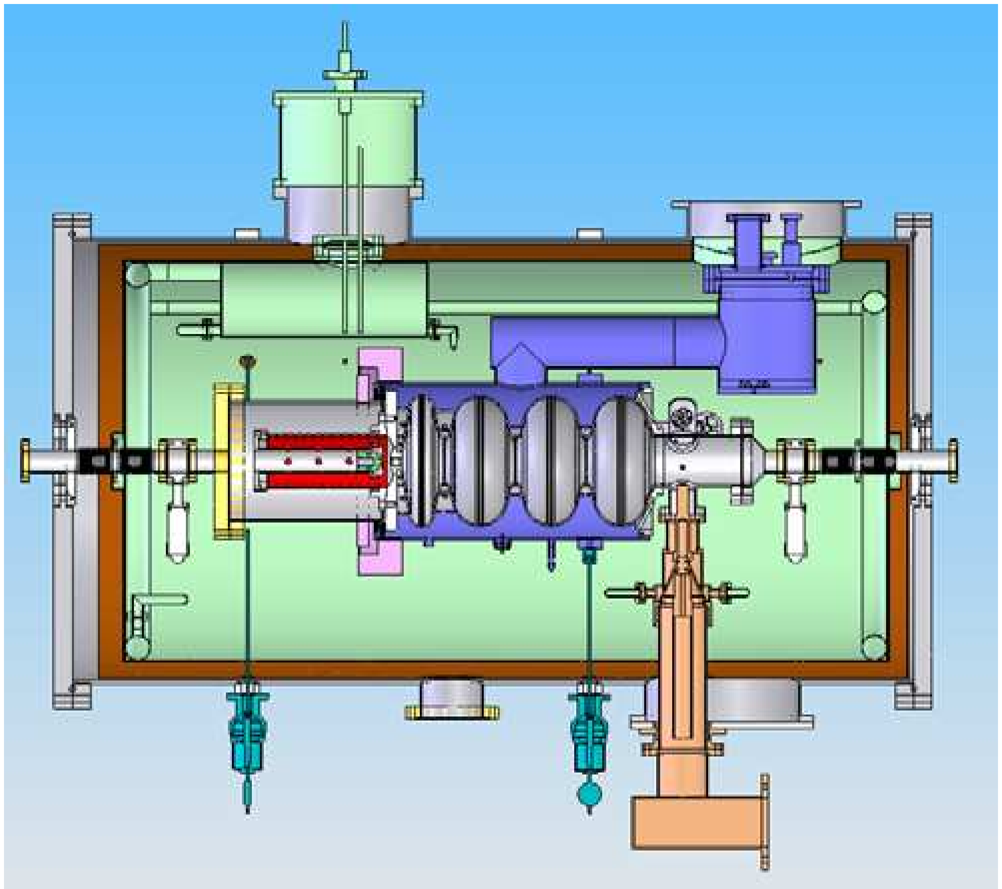
BNL/AES 703 MHz ½ cell

K_2CsSb performance in deposition chamber



Planned Choke Injectors

IHIP (Peking University) 1.3 GHz DC/SRF



f [GHz]	1.3
E_{cath} [MV/m]	6
q [pC]	100
E [MeV]	5
ε [μm rad]	3.6
I_{peak} [A]	20
I_b [mA]	1~5
f repetition [MHz]	26
Photocathode	Cs_2Te
QE [%]	1~5
Driving laser λ [nm]	266

J. Hao, et al., NIMA **557** (2006) 138

First 40keV gained in DC accelerator

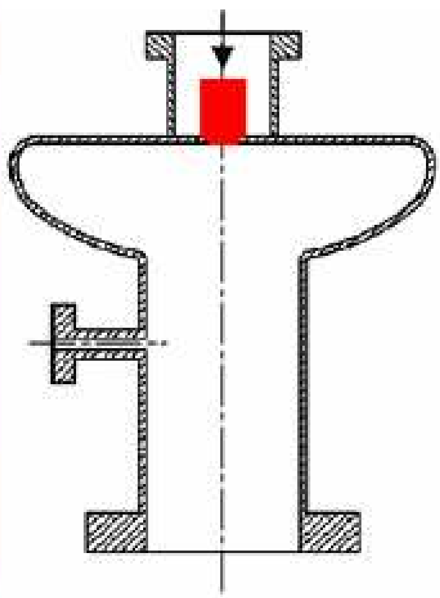
8mm diameter drift tube serves as RF isolation

Hybrid Cavity Options

Plug Gun (Jlab)

1.42 GHz niobium cavity w/ removable plug

$Q_0=3x10^9$ w/ Nb Plug

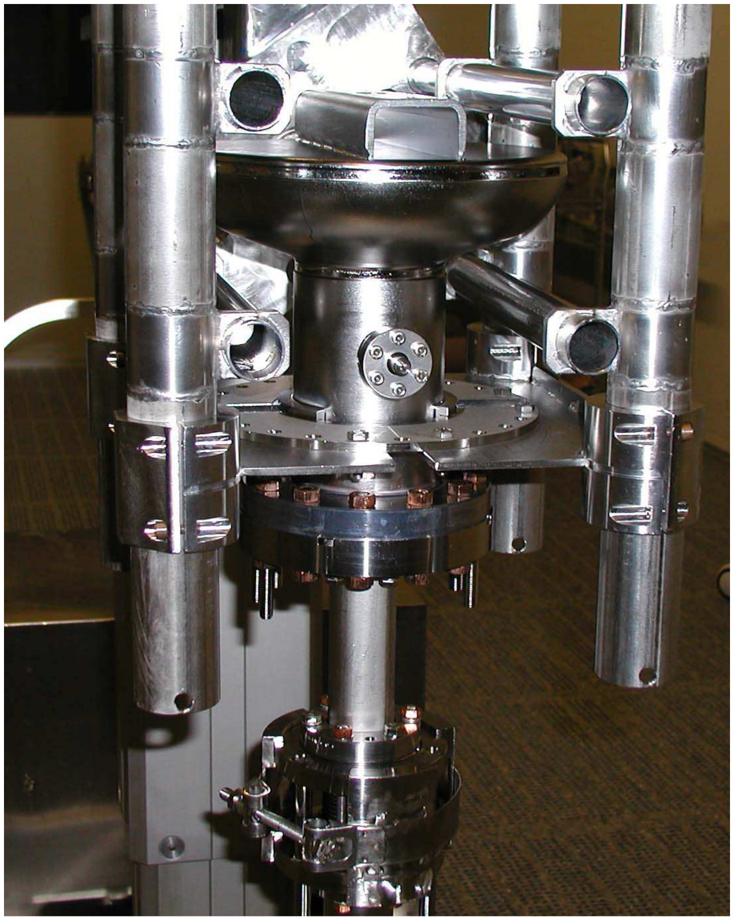


P. Kneisel, et al., PAC 05

DESY Gun

1.3 GHz niobium cavity

$Q_0=1x10^{10}$ w/o Lead Plating



Hybrid Cavity Options

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DESY Gun

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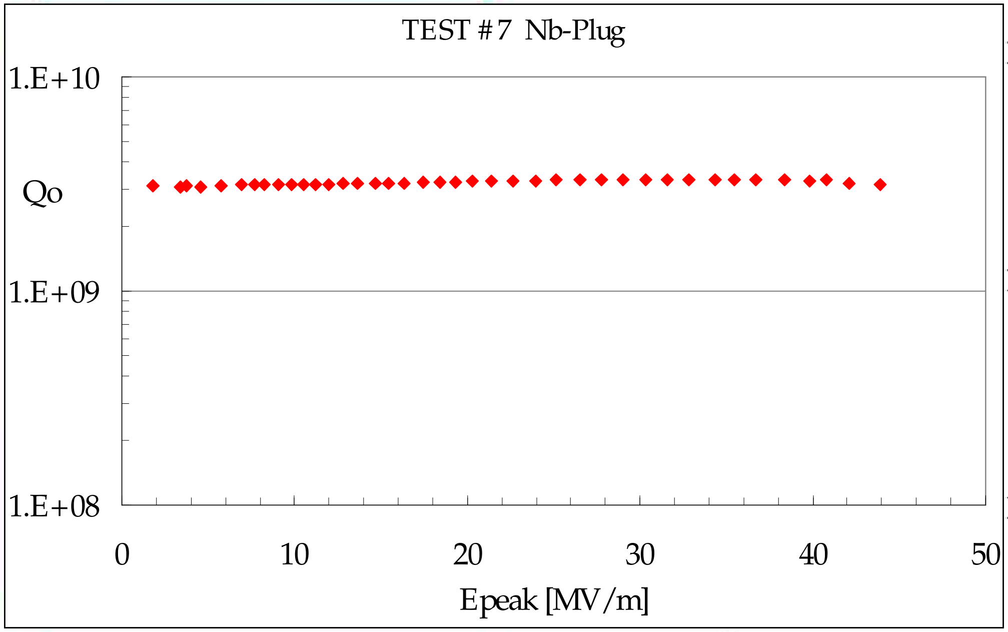
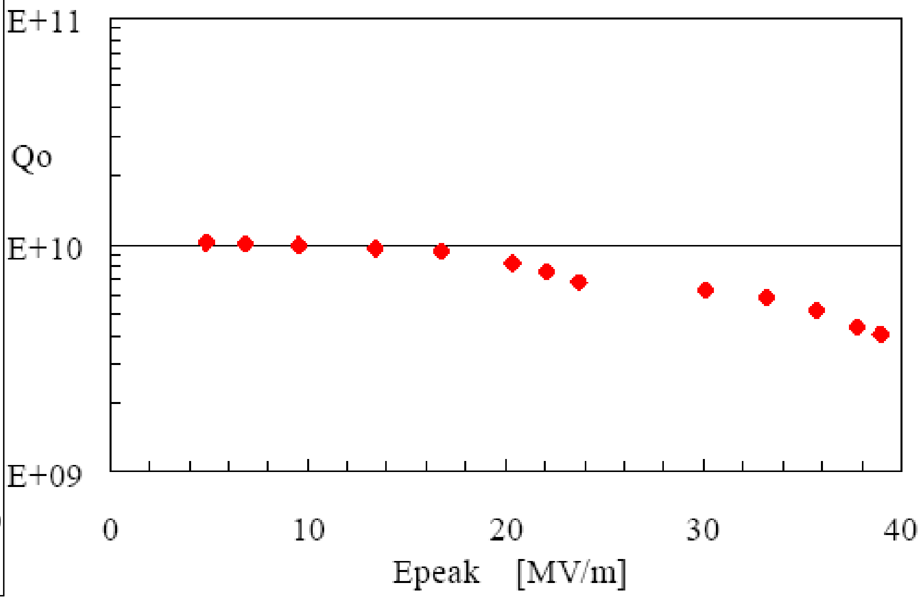
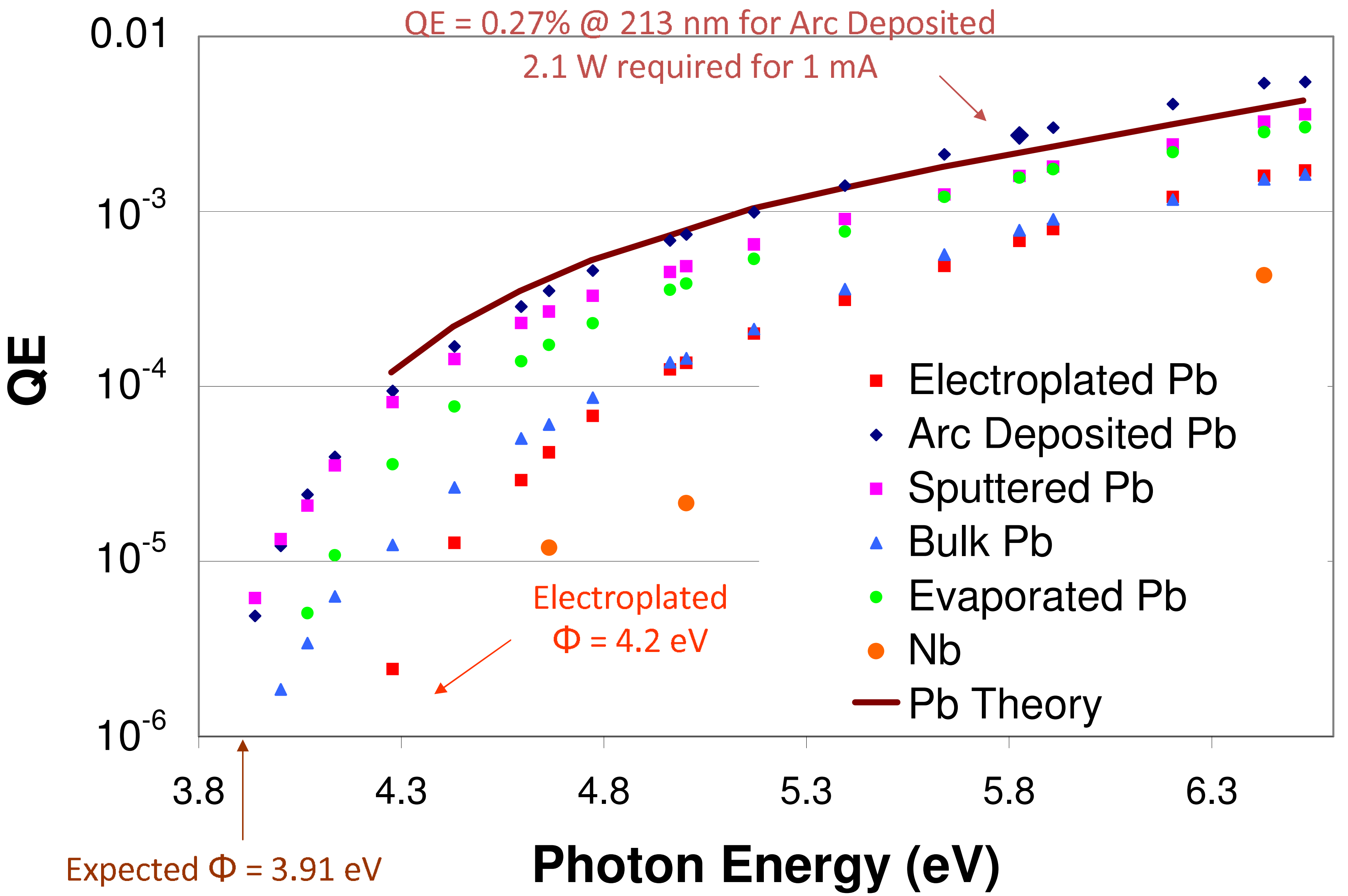




DC Room Temperature Photoemission Results

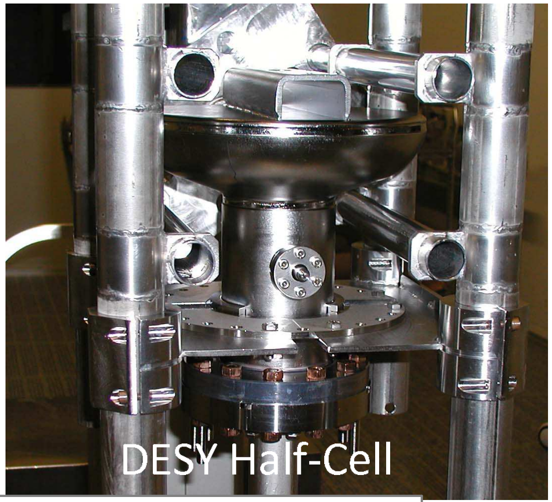


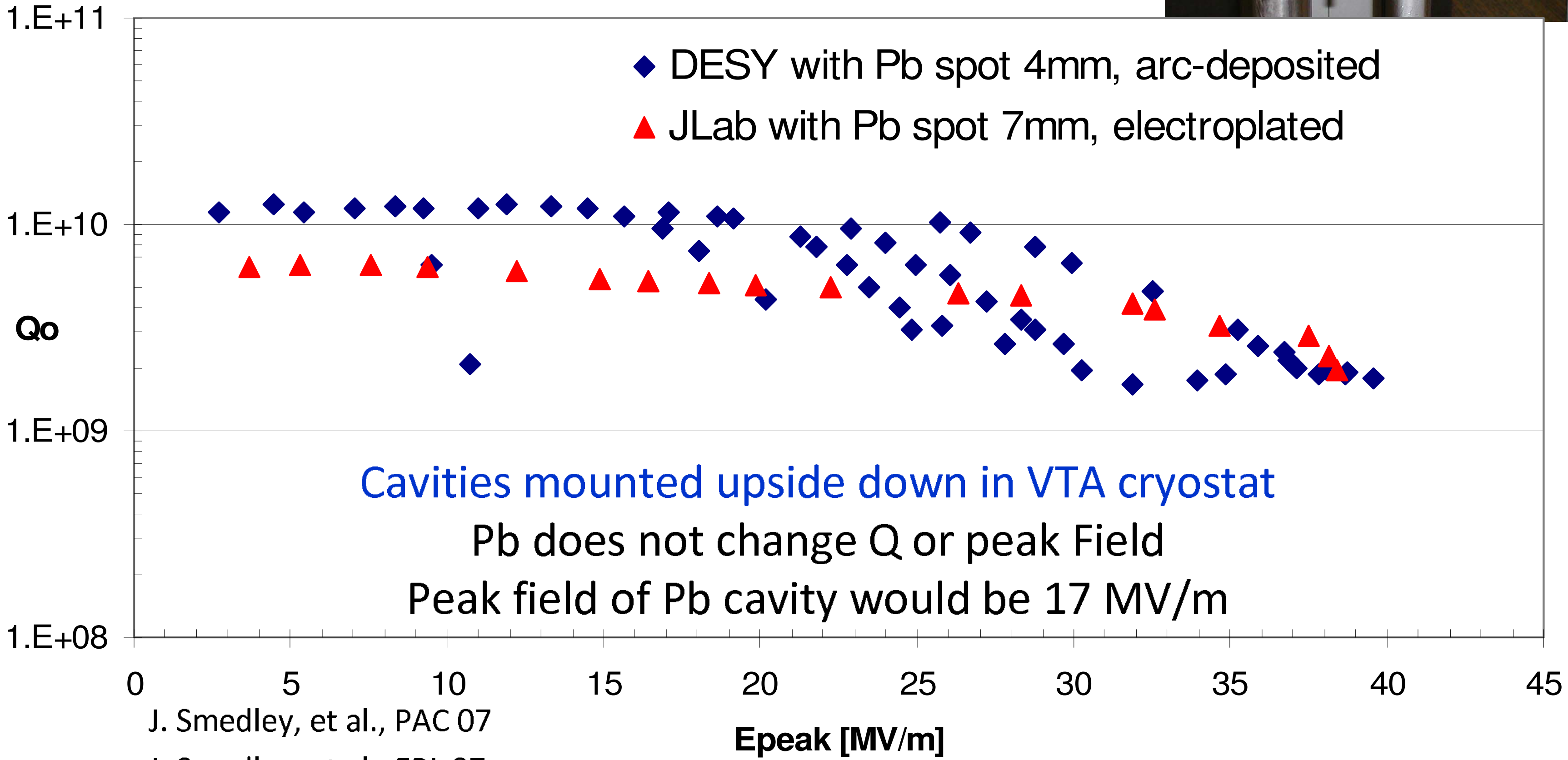
J. Smedley, T. Rao , J. Sekutowicz Phys. Rev. ST Accel. Beams **11**, 013502 (2008)

Cavity Tests

Nb-Pb Half-cells

Status March 07



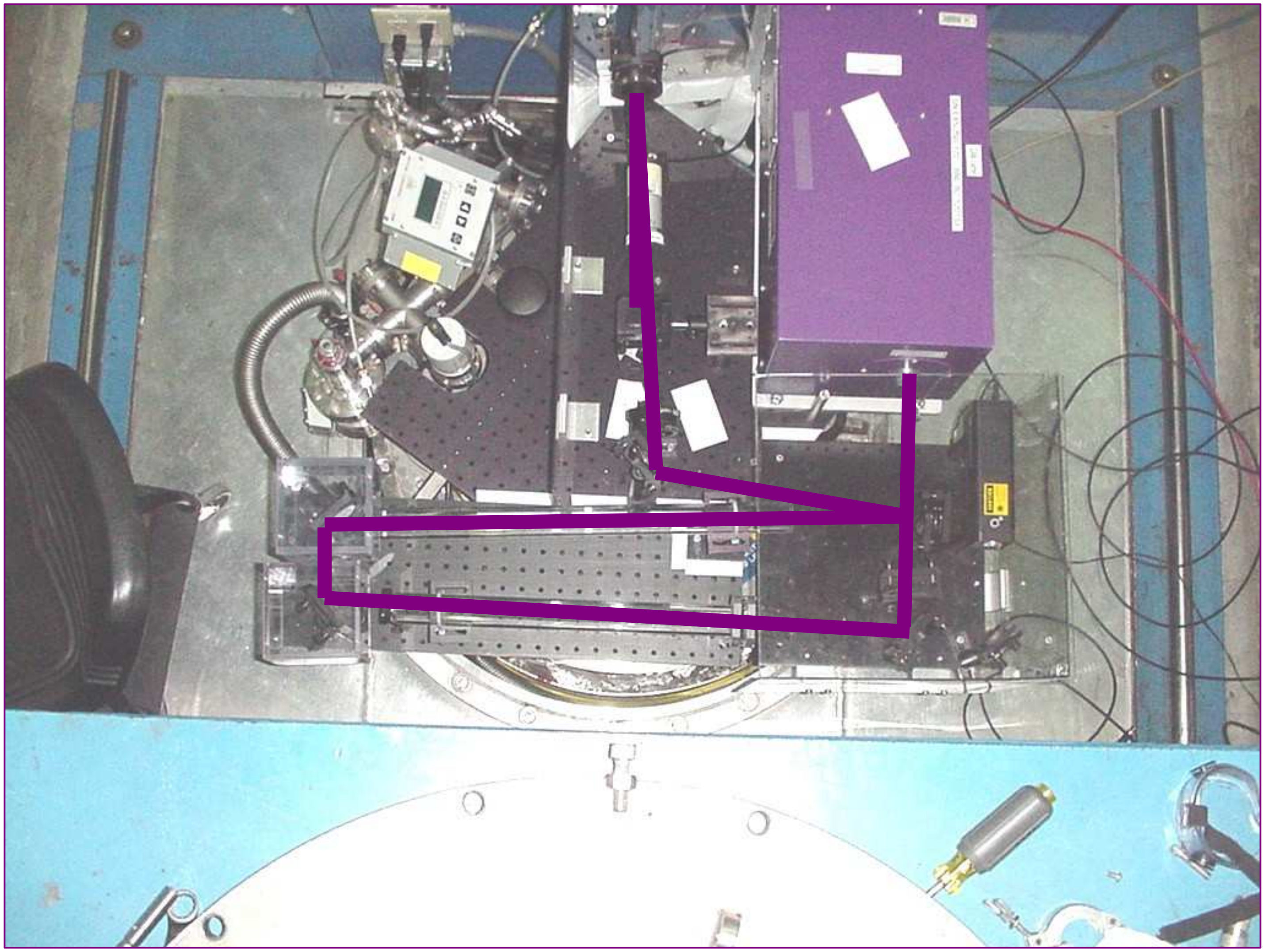


J. Smedley, et al., PAC 07

J. Smedley, et al., ERL 07

J. Sekutowicz, et al., PAC 07

Optical Layout in Shield



Laser Parameters

248 nm (5 eV)

6 mJ/pulse

5.3 ns FWHM

150 Hz (20-250)

Not synchronized

Layout

6 m transport

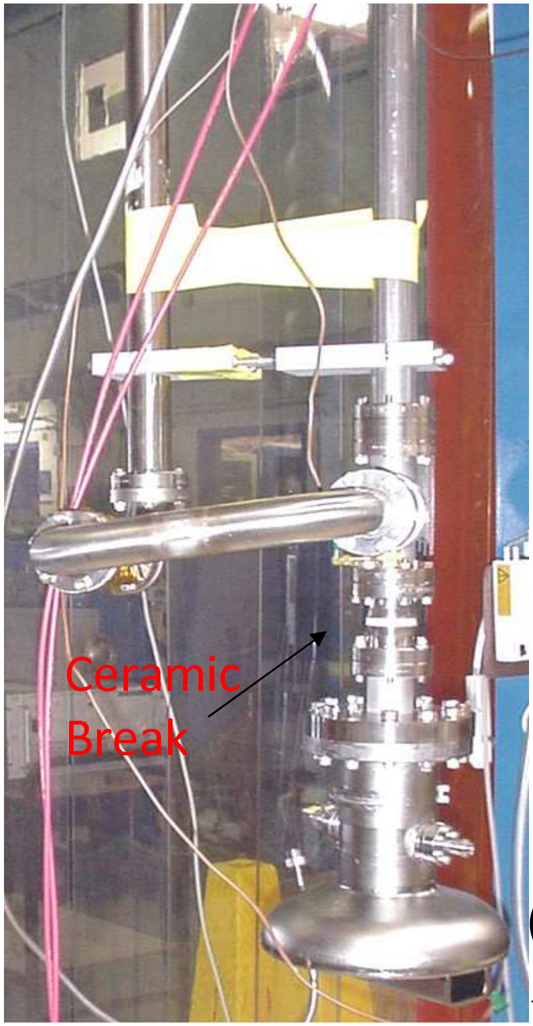
2.7 m in cryostat

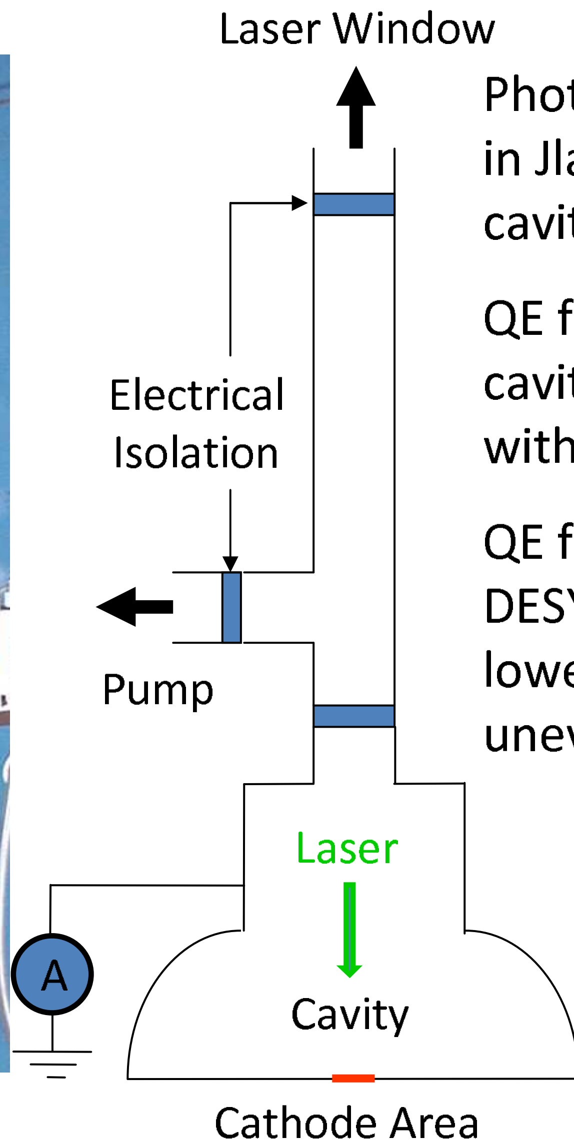
1.5 m lens

1:1 imaging of iris

3 mJ/pulse on cathode w/iris open

Charge Measurement



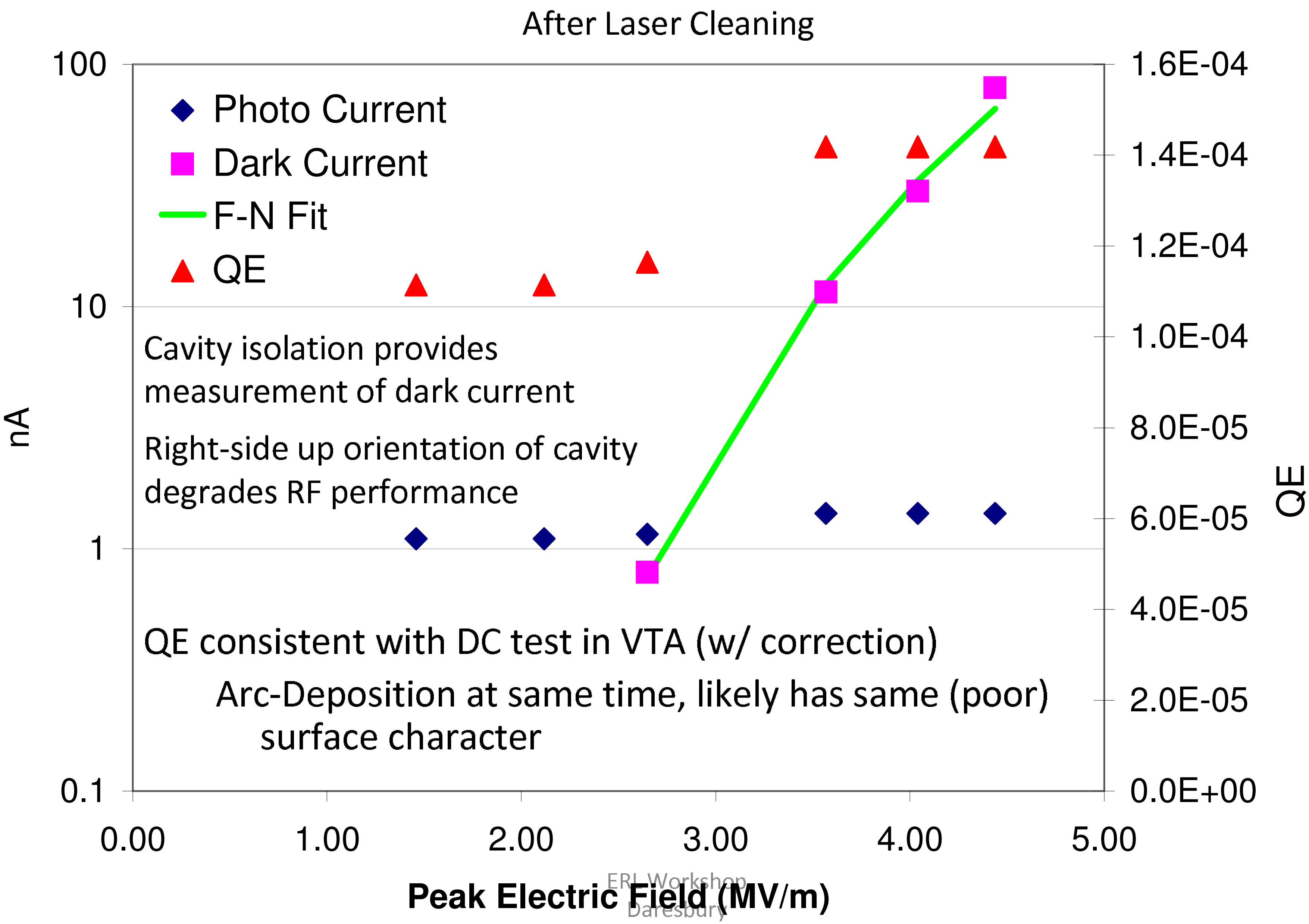


Photocurrent for both cavities measured in Jlab Vertical Test Area, by isolating the cavity and monitoring the current leaving

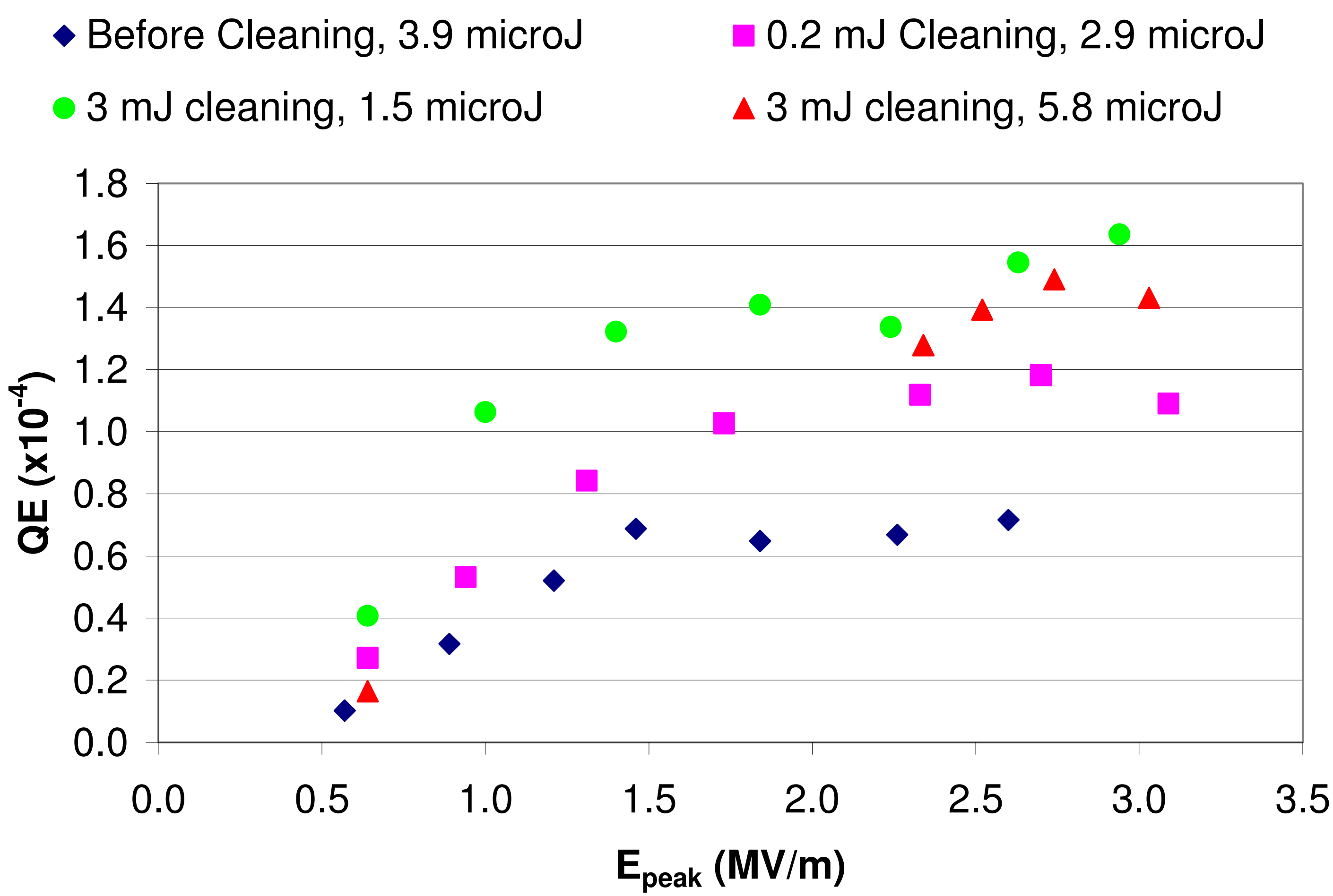
QE for electroplated lead plug in Jlab cavity was 1.6×10^{-4} (@248nm), in line with expected performance

QE for Arc deposited lead cathode in DESY cavity was 1.4×10^{-4} (@248nm), lower than expected, possibly due to uneven lead coating

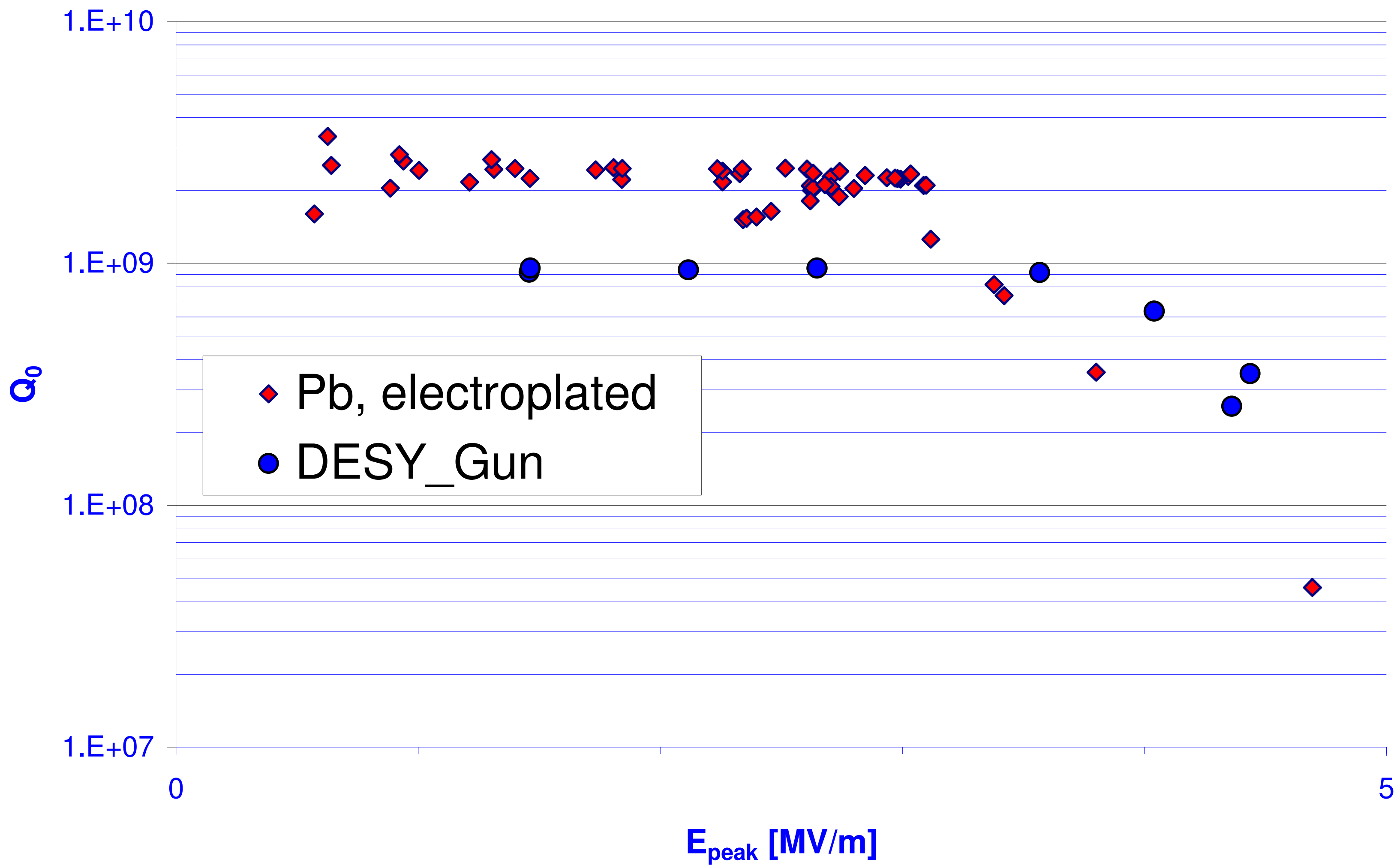
DESY Cavity, Arc-Dep Cathode



Jlab Plug Cavity QE



Exit-up cavity orientation



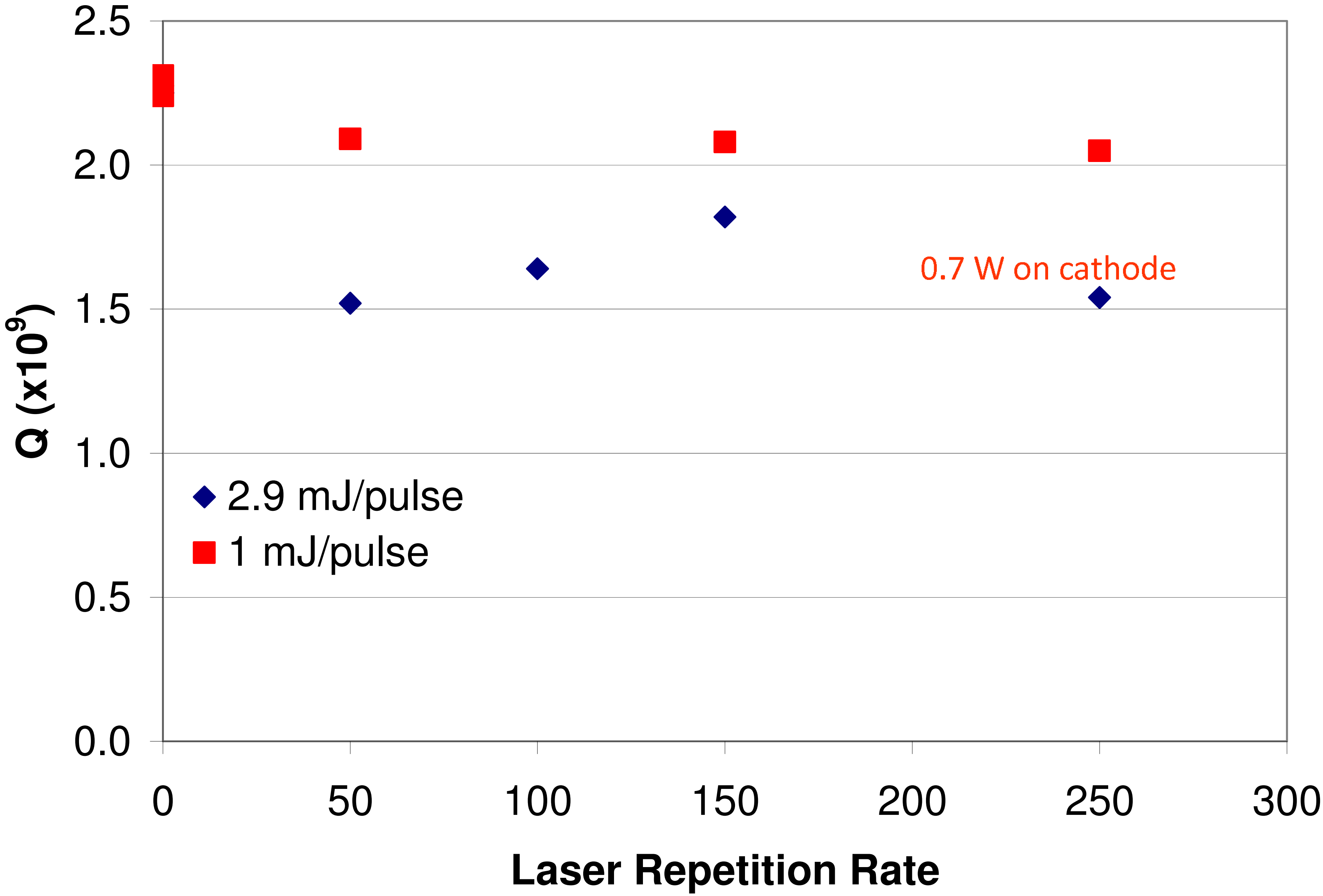
Electroplated Plug Quench Test

- Irradiate Nb wall with full laser energy
  - Nb, because this energy might evaporate Pb w/ field on
- 1 mJ (2.9x3 mm^2) & 2.9 mJ (4x5 mm^2) per pulse

0.7 W on cathode

- Vary repetition rate, observe Q change
- Q drops ~20-30%, no evidence of quench
- No strong dependence on repetition rate
- Cooper pairs recovering between shots
- From theory, we expect this recovery time to be ~1 μs
- Good news for 1 MHz operation at ~3μJ/pulse

Electroplated Plug Quench Test



Summary

- Niobium, although a great superconductor, is a relatively poor photocathode
- For moderate average currents (~1 mA), lead plating the cathode may be an attractive alternative to more complicated options (e.g. choke joint, cathode load-lock)
- For high average currents, choke designs permit the use of high-QE semiconductor cathodes (lifetime?)
- Lead does not greatly affect RF performance
- 2.9 mJ/pulse @ 250 Hz is insufficient to cause quench
- Performance of cathodes in RF cavity is consistent with DC measurements
- Jlab Plug gun opens possibility of testing other materials (YBCO, MgB_2, Pb-Sn…)