Review on superconducting RF Guns

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Superconducting RF Photogun

Main advantages

- Low RF power losses, CW operation
- High peak field near the cathode

Main concerns

- Photocathode inside a superconducting cavity
  (RF leakage, heat transfer, pollution of the cavity)
- Emittance compensation
  Magnetic DC field, Magnetic RF field, RF - focusing

All-Niobium SRF Gun

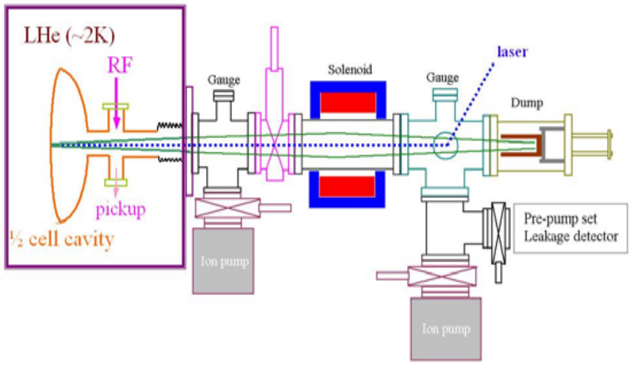
No contamination from cathode particles

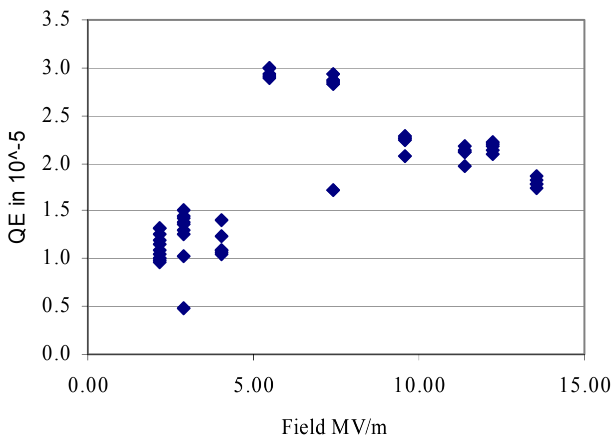
1/2 cell, 1.3 GHz
Maximum Field: 45 MV/m

Q.E. of Niobium @ 248 nm
with laser cleaning
before: 2×10^{-7}
after: 5×10^{-5}

H.Bluem et al. EPAC 2000, June 2000, p.1639

All-Niobium SRF Gun





T ~ 2K

λ = 248 nm, QE ~ $2x10^{-5}$
λ = 266 nm, QE ~ $2x10^{-6}$

T.Rao et al. PAC2005, Knoxville, May 2005.

SRF Gun with superconducting Cathode

Quantum efficiency of Pb at room temperature

λ= 248 nm QE = $1x10^{-4}$

λ= 213 nm QE = $1.7x10^{-3}$

3 W laser power @213 nm

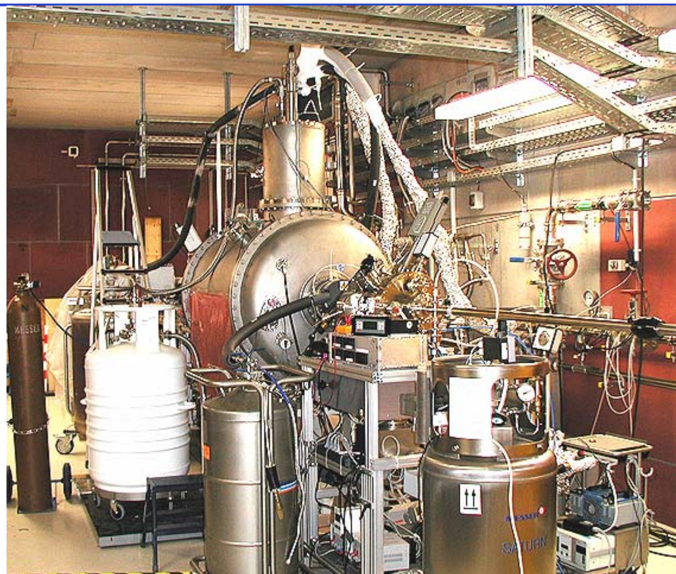
1nC @1MHz ⟹ 1mA

J.Smedley et al., PAC2005
Knoxville May 2005

SRF Gun with normal-conducting Cathode

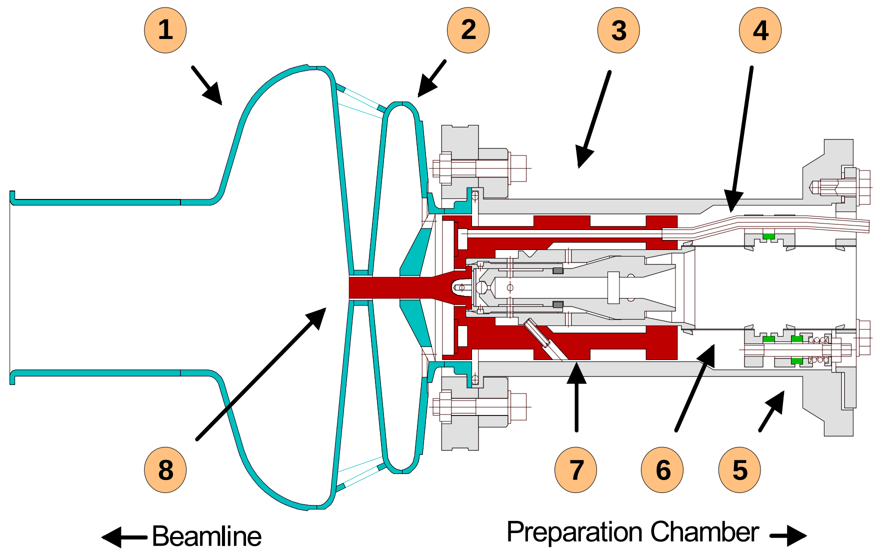
Cavity:	Niobium, gun cell + TESLA cells, E_{acc}=25MV/m
Frequency:	1.3 GHz
Cathode:	Cs_2Te , QE ~ $5x10^{-2}$
	thermally isolated, LN_2 cooled
RF:	choke filter
Laser:	λ = 262 nm, cw, f = 13MHz, P = 1-2W

First operation of a SRF Gun



D.Janssen et al., NIM-A, Vol. 507(2003)p314-317

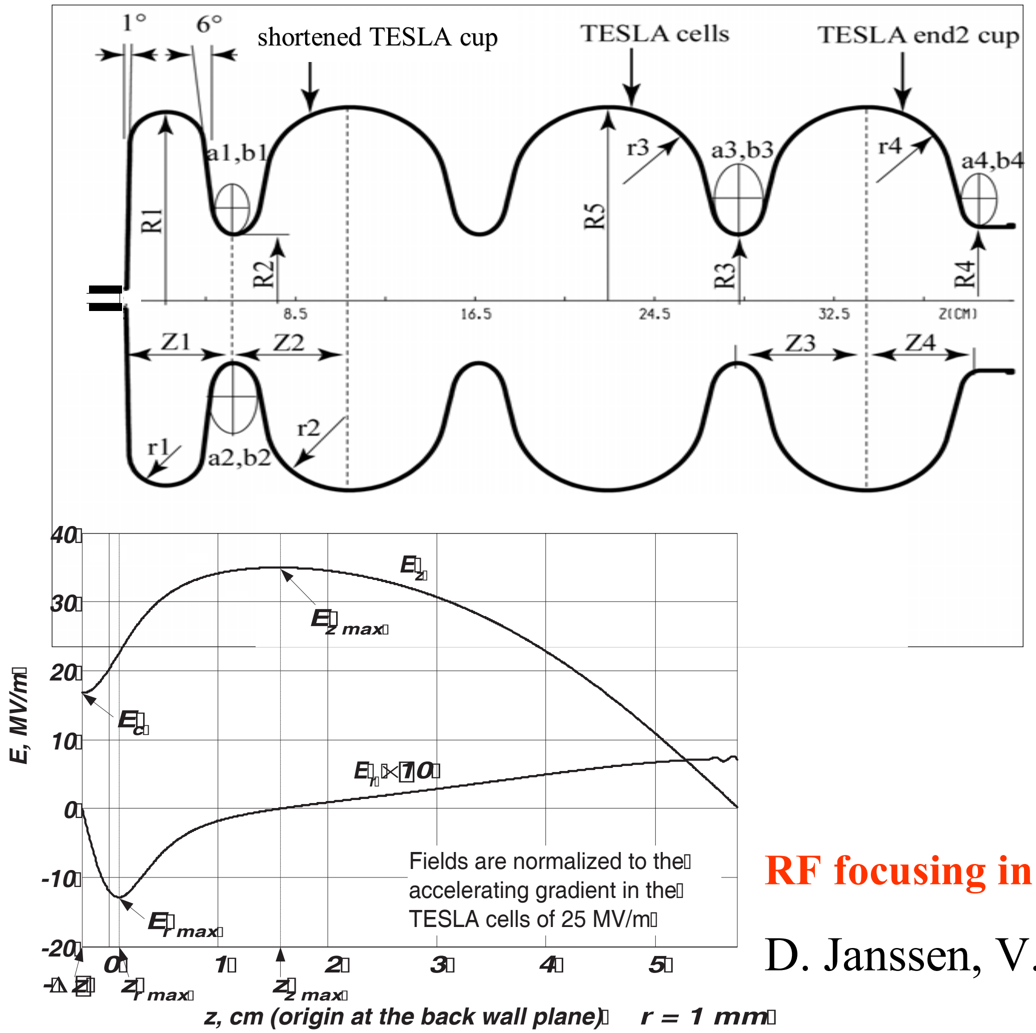
T = 4.2K, Q = $2.5*10^8$, Ez_{max}= 22MV/m
E = 900keV, I = 520µA



(1) Niobium Cavity
(2) Choke Flange Filter
(3) Cooling Insert
(4) Liquid Nitrogen Tube

(5) Ceramic Insulation
(6) Thermal Insulation
(7) 3 Stage Coaxial Filter
(8) Cathode Stem

Design Parameter of the 3½ cell SRF Gun

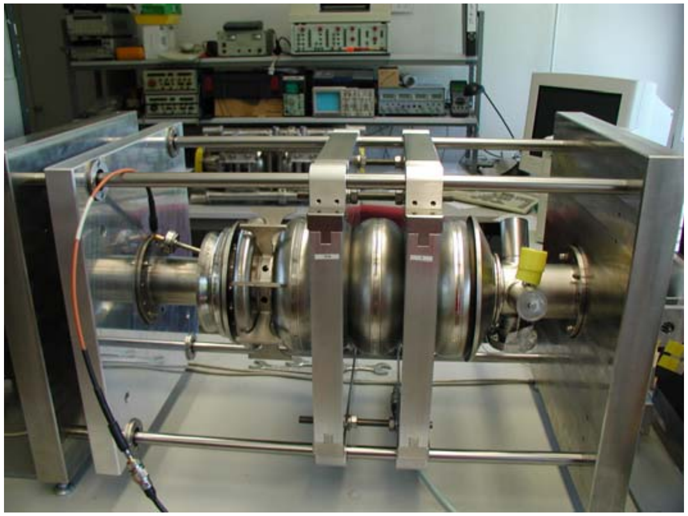


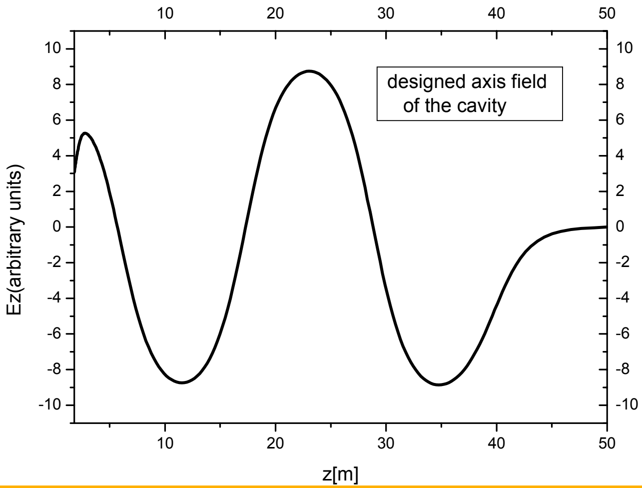
1. 3 GHz, 10 kW optimized half cell & 3 TESLA cells $E_{z,max}$= 50 MV/m (T cells) = 33 MV/m (1/2 cell)	
77 pC	1 nC
I_{av}= 1 mA	
E = 9.5 MeV	
ε_{trans}=0.5 mm mrad	ε_{trans}=2.5 mm mrad

RF focusing in SC gun cavities

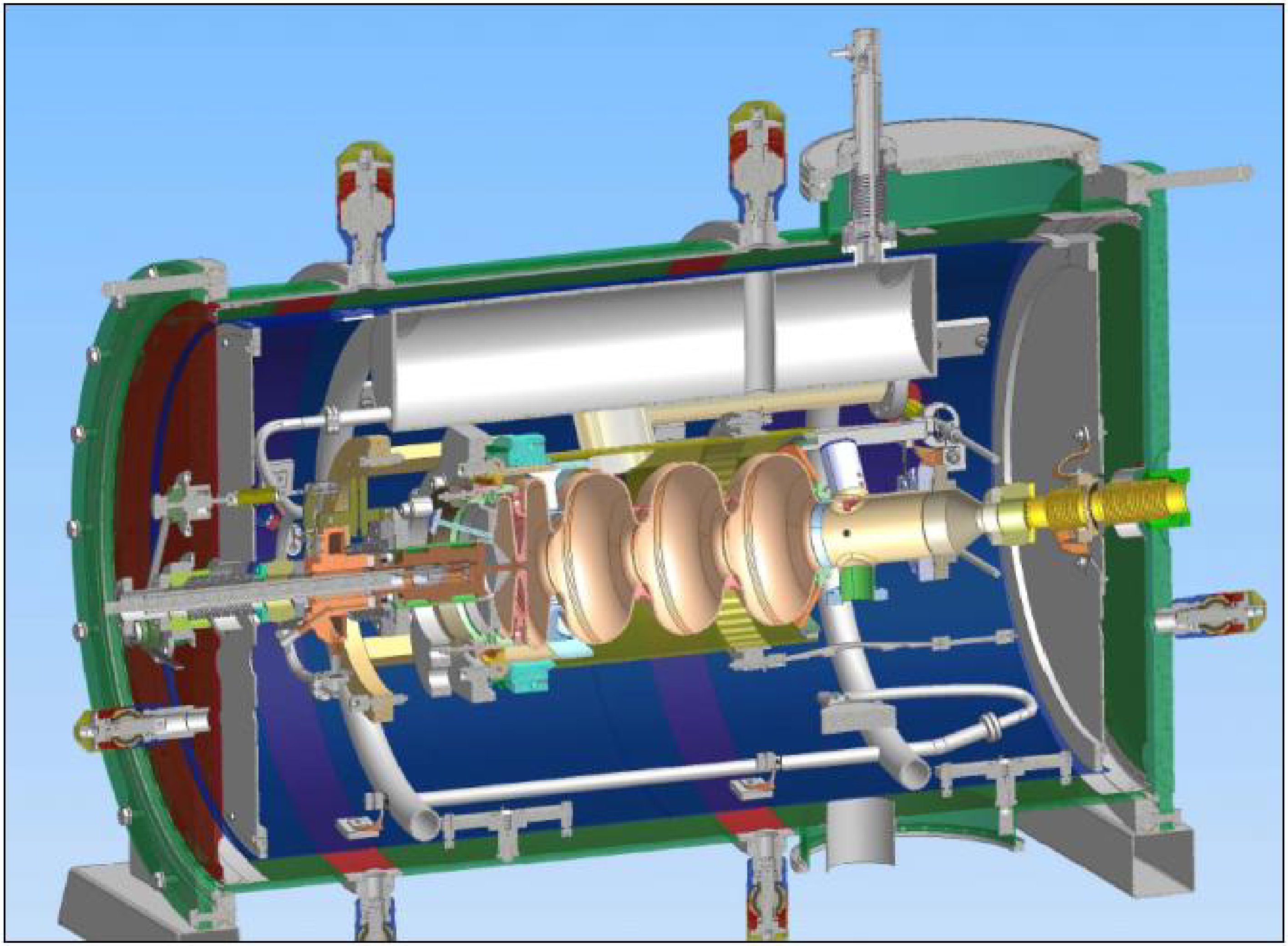
D. Janssen, V.Volkov, NIM A452(2000)34

Shape verification and warm tuning of the cavity

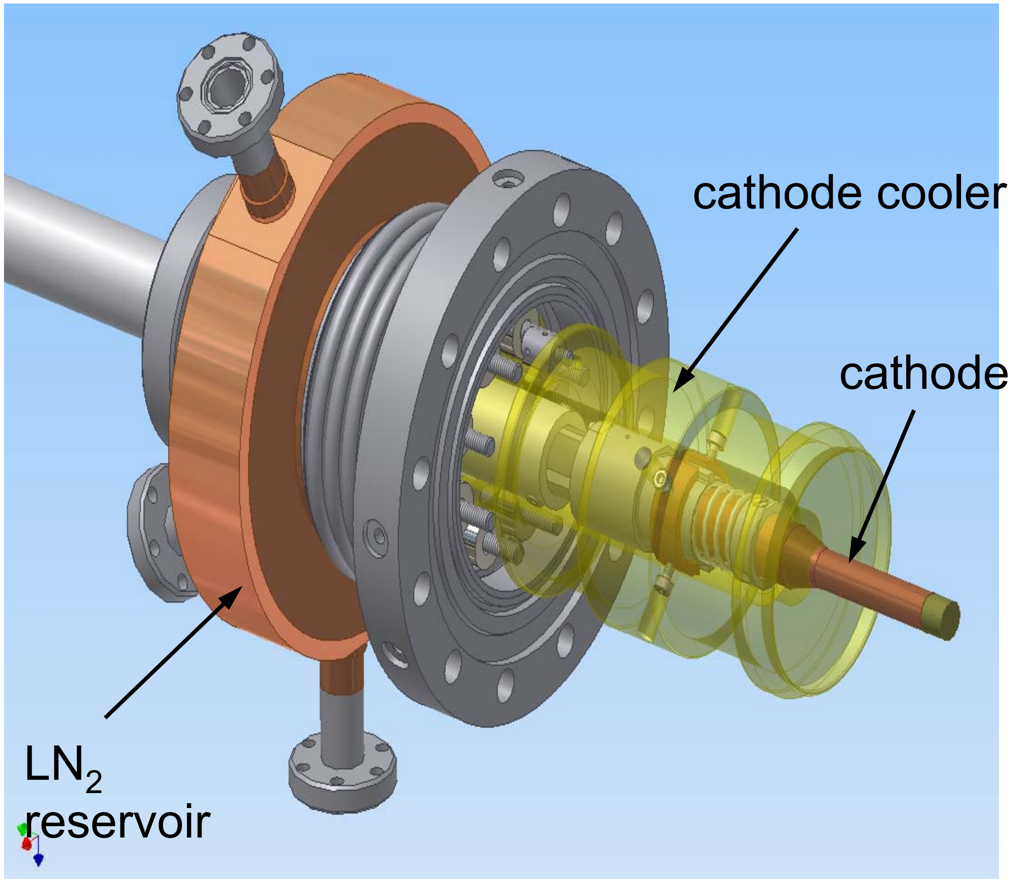


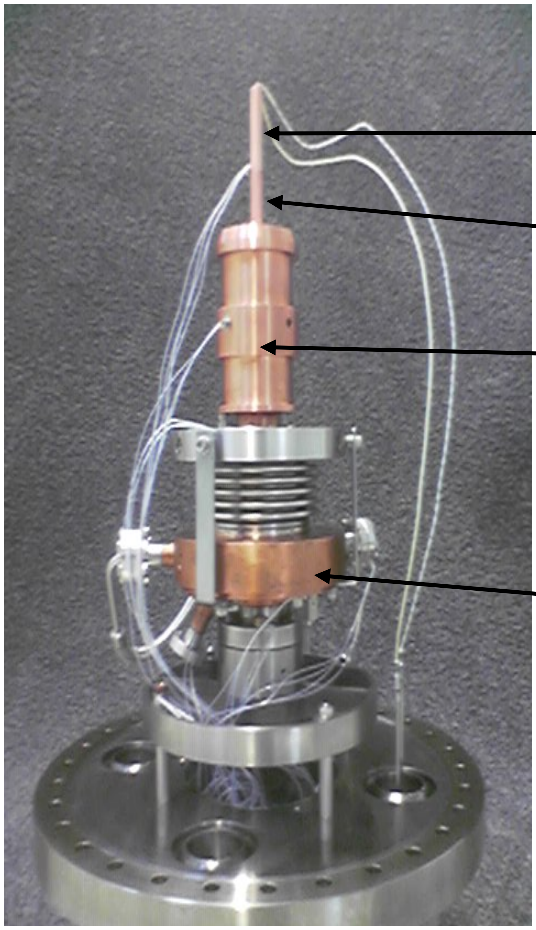


Cryomodule design of the SRF gun



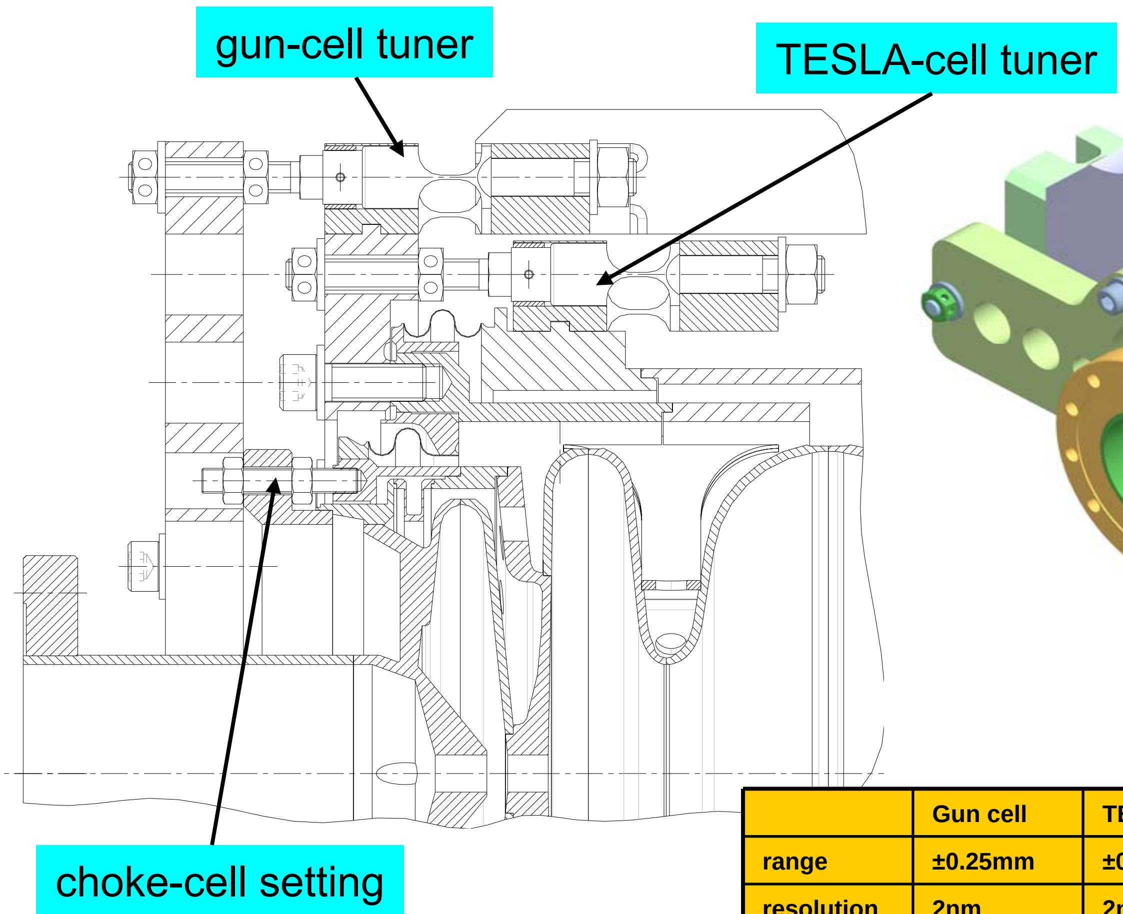
Liquid N_2 Cathode Cooling

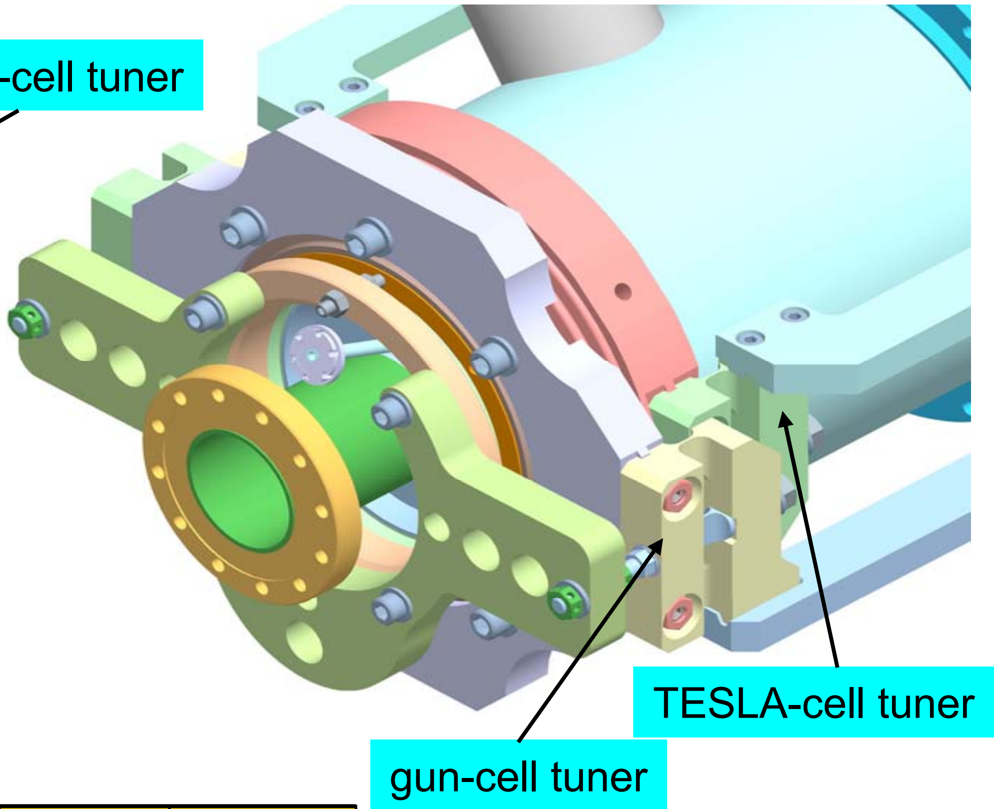




Q_{cath}= 20 W
ΔT = 30 K

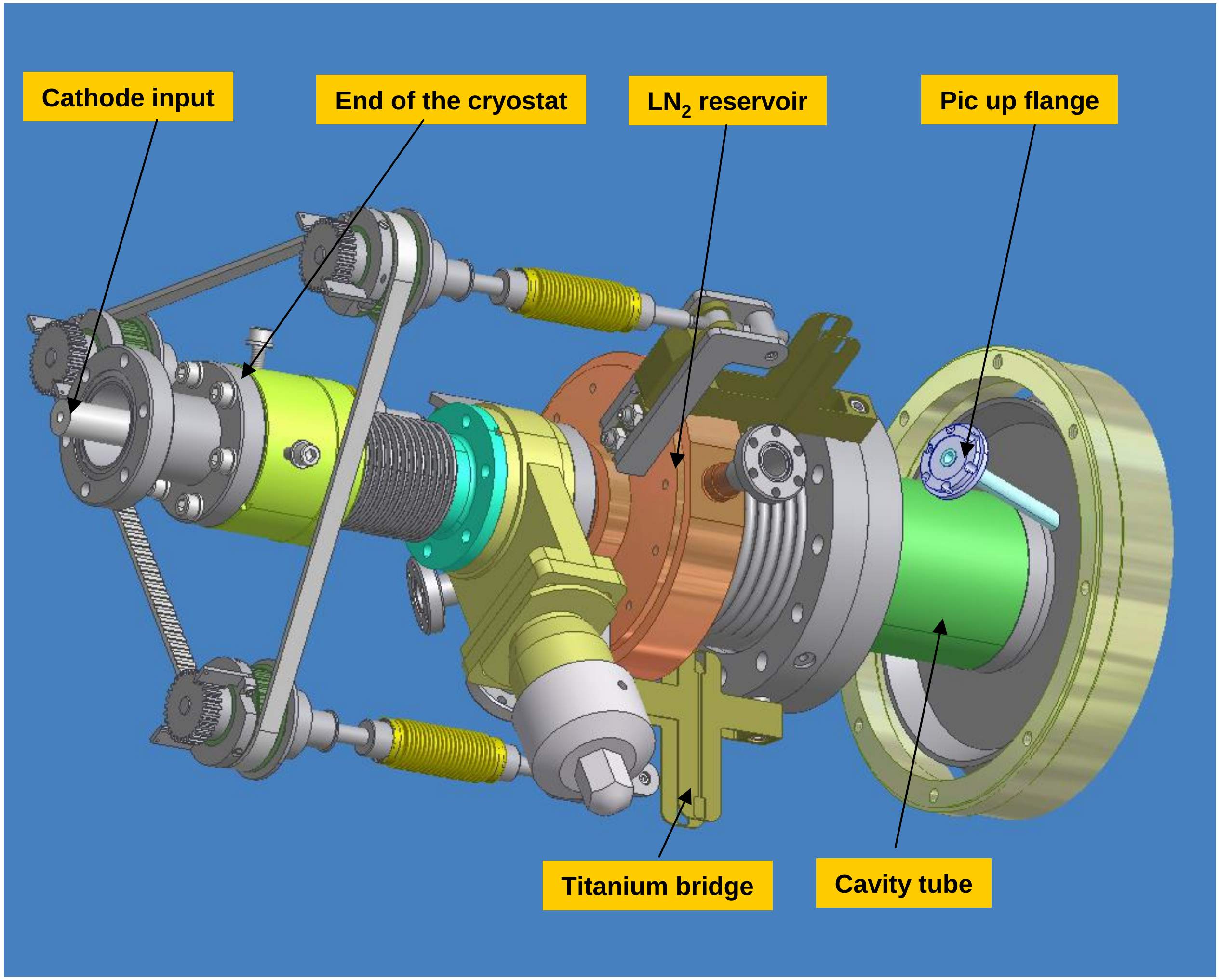
Dual tuning system





	Gun cell	TESLA cells
range	±0.25mm	±0.3mm
resolution	2nm	2nm
load	±2250N	±2700N
frequency	±30kHz	±300kHz

Cavity with cathode tuning system



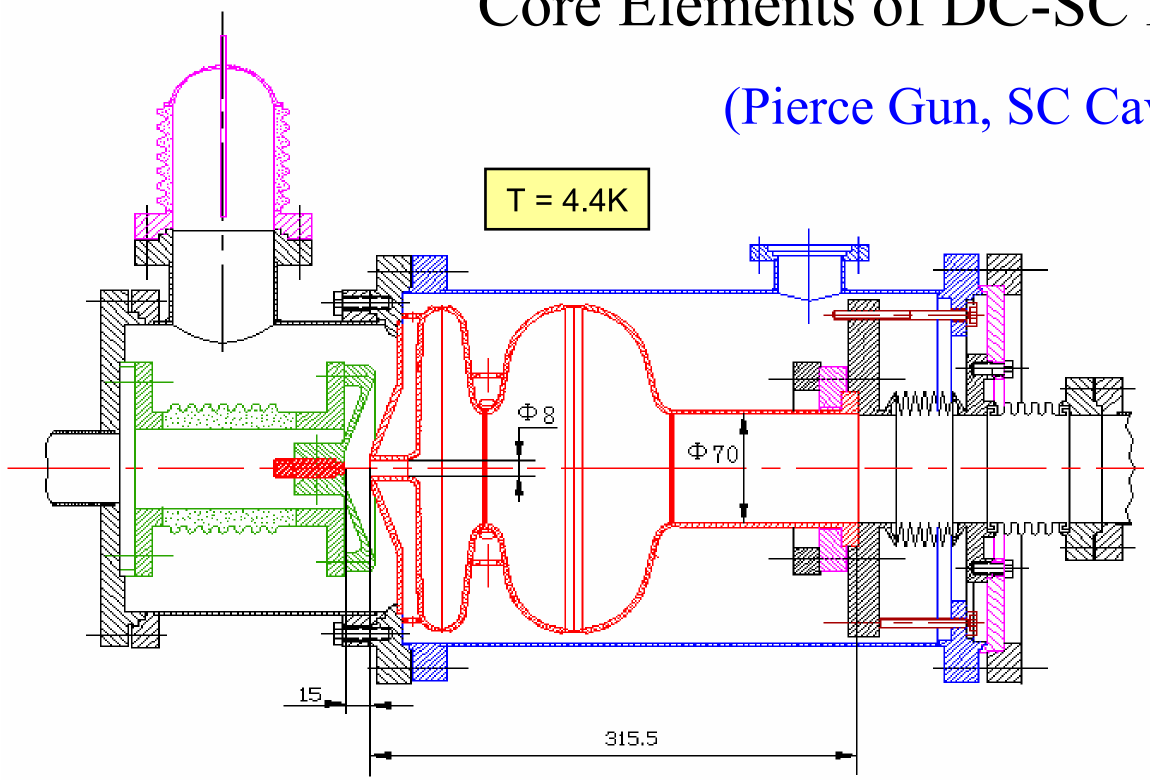
Present Status and next steps

Cavity:	Fabrication of 2 (RRR 40 & 300) cavities at ACCEL finished
	warm tuning in Rossendorf is running
	next step: BCP, HPR, tests at 2K at DESY
Cavity tuners:	Fabrication finished
	test bench: design finished, in the workshop
Cathode cooling system:	
	Fabrication and tests finished
	Cathode transfer system: Design finished, in the workshop
Cathode preparation chamber:	
	Design and fabrication finished, assembling and tests running
Cryomodule:	Design and fabrication finished
	next step: assembling
He-Transfer Line:	ordered
First beam:	**2006**

DC-SC Gun of the IHIP, Peking University

Core Elements of DC-SC Photoinjector

(Pierce Gun, SC Cavity)



I_{ave}=200μA , E=0.5MeV,

Q = 50pC, $L_{laserpuls}$=6ps,

ε_{rms}=5.4 mm.mrad,

I_{ave}=70μA , E=0.59MeV,

Q = 18pC, $L_{laserpuls}$=6ps,

ε_{rms}=2.8 mm.mrad,

U_{DC}=40 kV, E_{cath}=2.7MV/m

Courtesy of Hao Jiankui

High Current SRF Gun

SRF Gun Performance Goals

Courtesy of Alan Todd

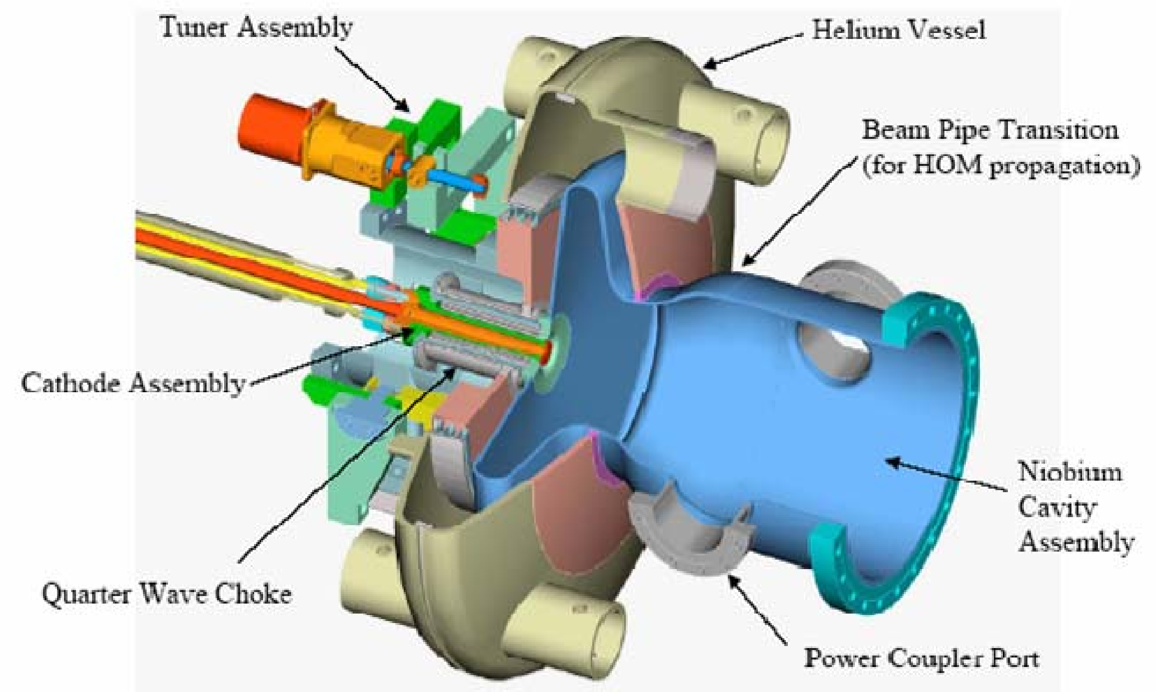
- 703.75 MHz
- 1.42 nC @ 703.75 MHz => 1 A
- For 1 A => ~ 2 MeV delivered
- 2 MW into ½ cell
- 2 opposed 1 MW couplers
- ½ cell => ~ 0.1 m
- 2 MeV / 0.1 m => ~ 20 MV/m

ε_{trans} = 5 mm mrad

Putting Accelerator Technology to Work

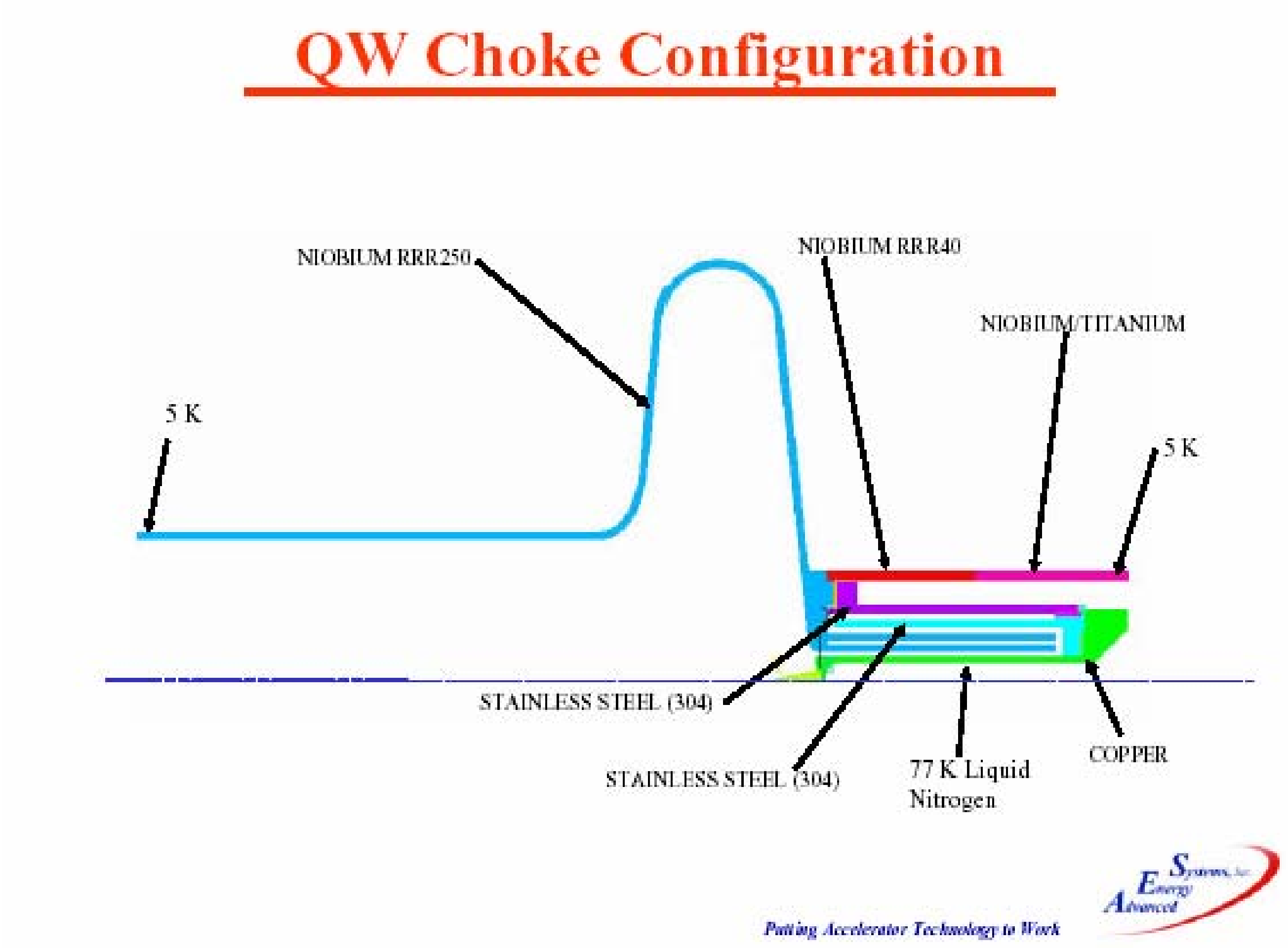
High Current SRF Gun

Courtesy of Alan Todd

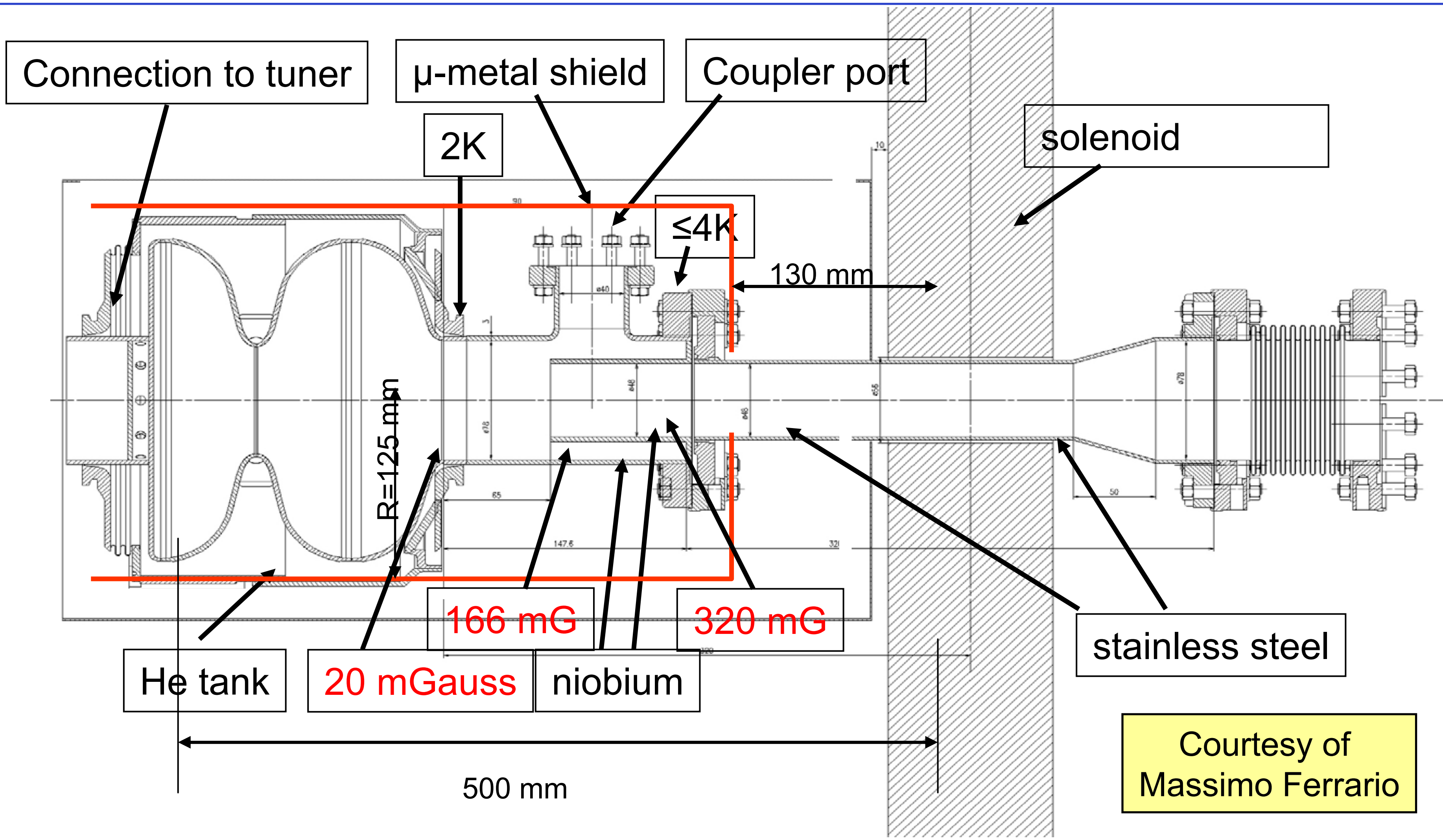


High Current SRF Gun

Courtesy of Alan Todd

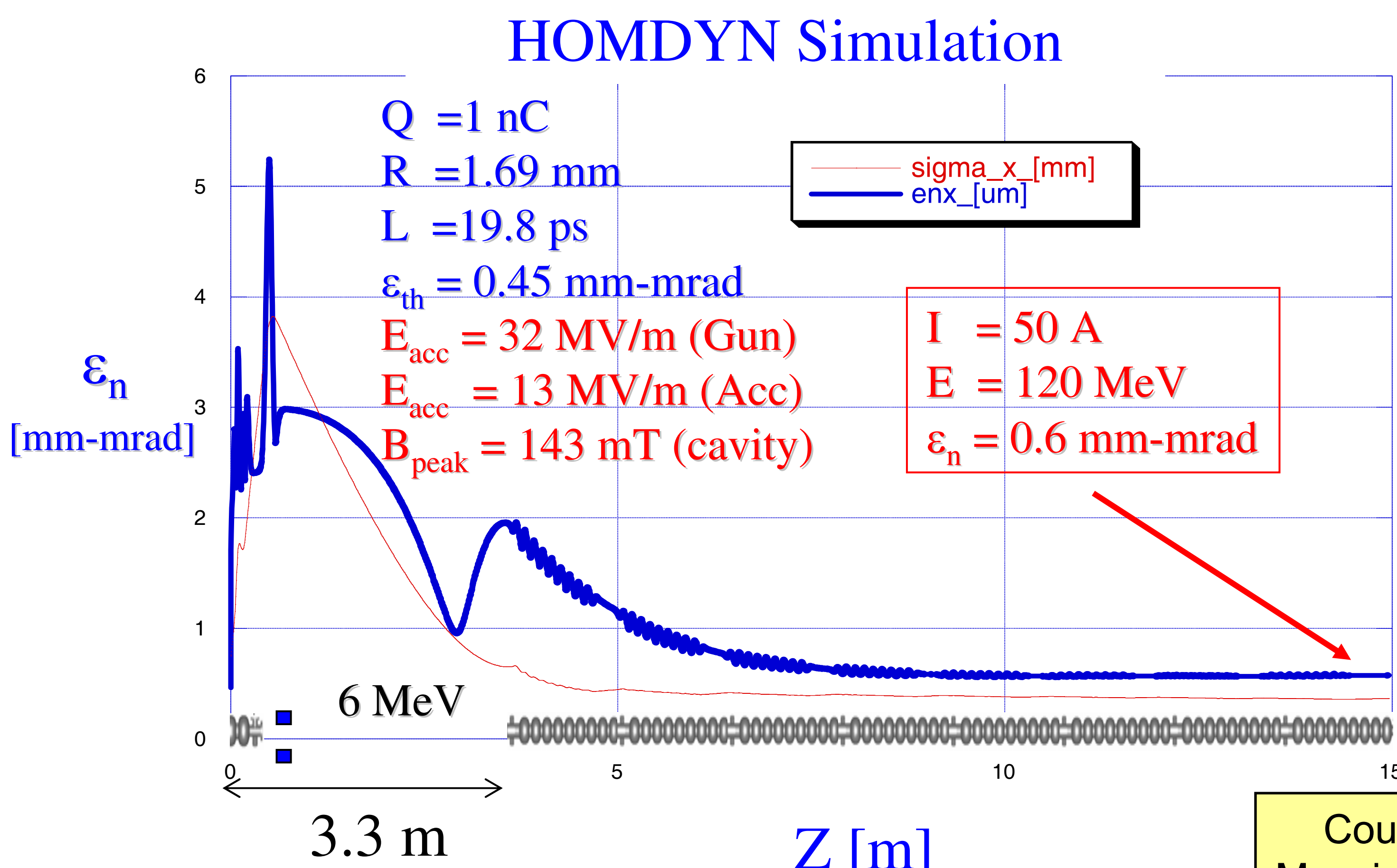


Emittance compensation by a static B field



Courtesy of
Massimo Ferrario

Emittance compensation by a static B field

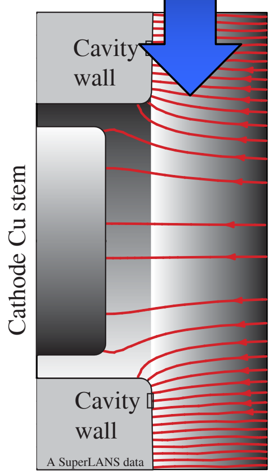


Courtesy of Massimo Ferrario

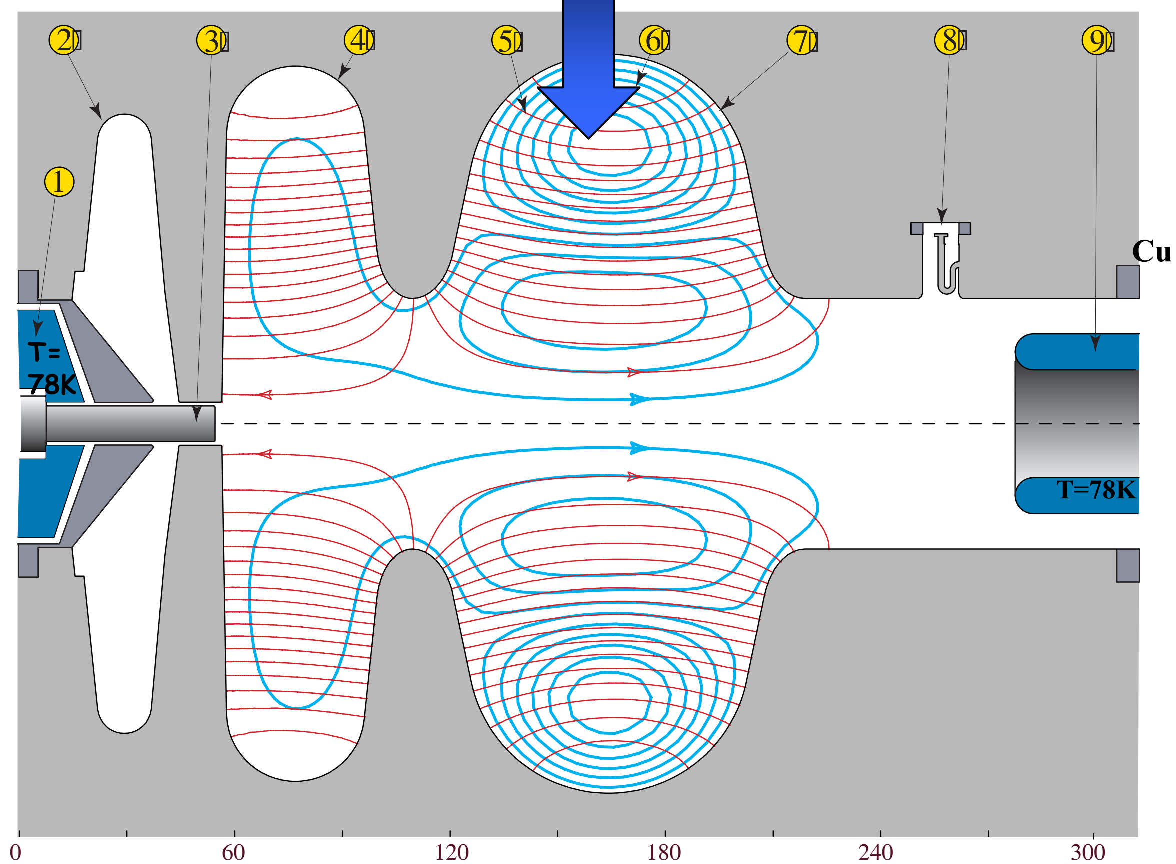
Emittance compensation by a magnetic RF field

Electric RF focusing region

Magnetic RF focusing region

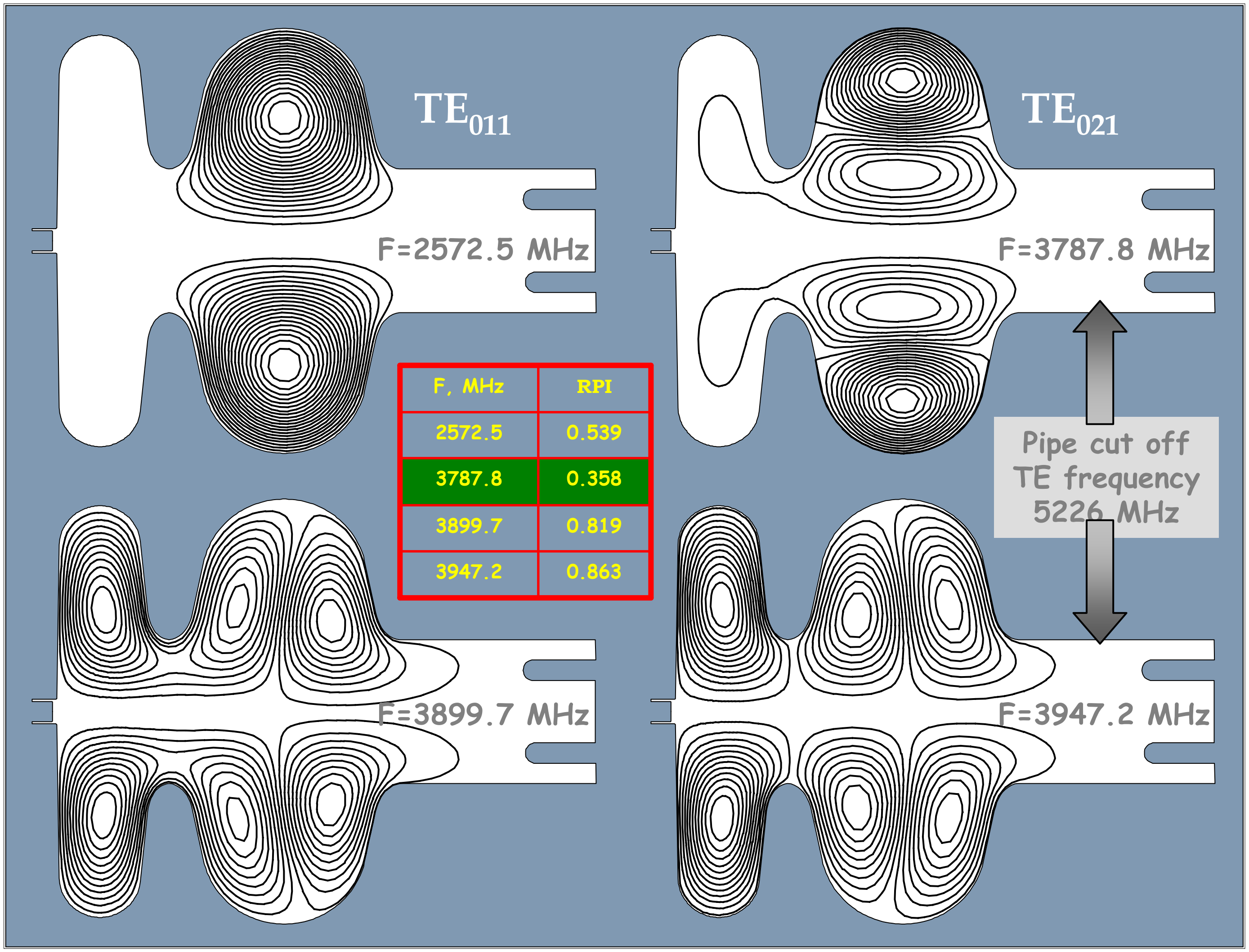


Scaled cathode region



1 – Heat sink
2 – Choke cell
3 – Photocathode Cu stalk
4 – Cathode cell
5 – Electric TM field pattern
6 – Magnetic TE field pattern
7 – Cavity full cell
8 – TE mode coupler (90º routed)
9 – TM mode coupler pipe

Magnetic RF fields in the 1 ½ cell cavity

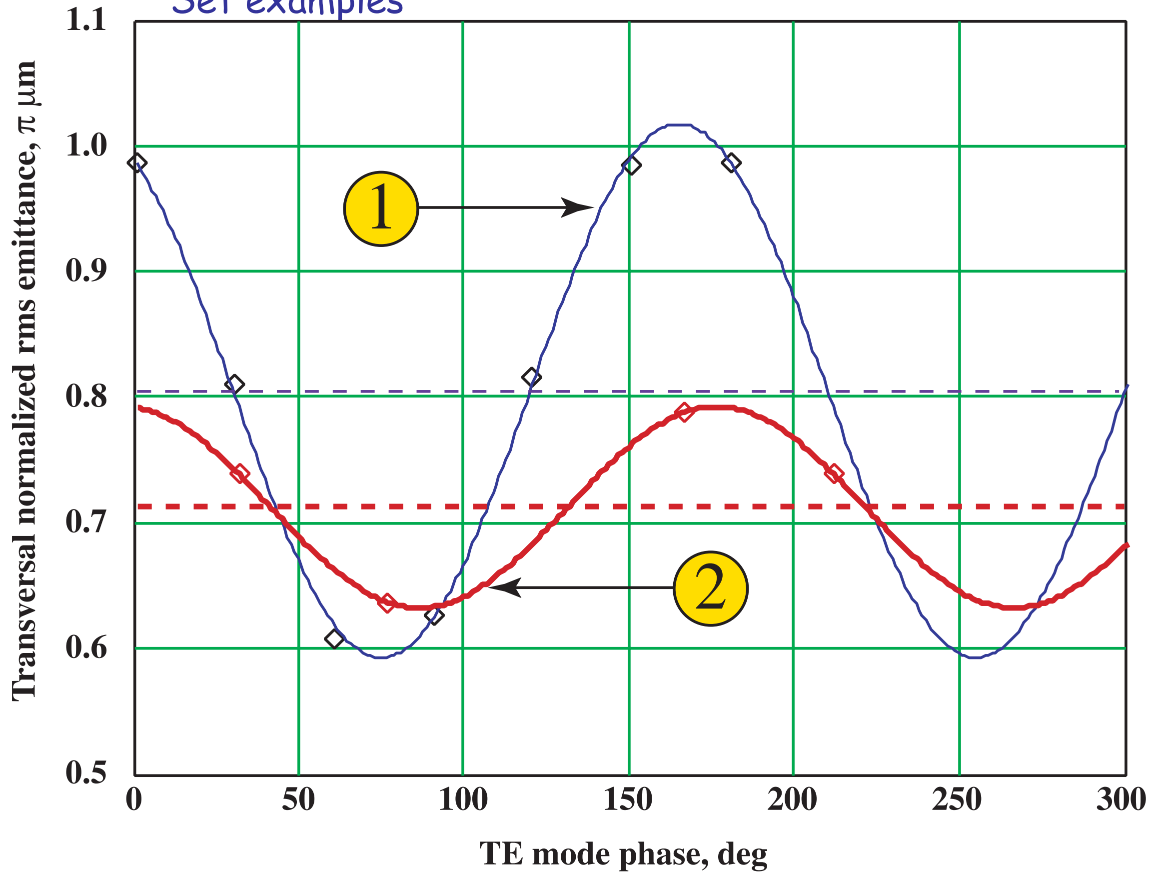


F, MHz	RPI
2572.5	0.539
3787.8	0.358
3899.7	0.819
3947.2	0.863

Emittance dependence on TE field phase

$$\varepsilon_n = \varepsilon_{av} + A_\varepsilon \cdot \sin(2 \cdot \varphi_{TE} + \varphi_o)$$

Set examples



ε_n – transverse normalized rms emittance
ε_{av}- average emittance
A_ε – emittance amplitude
φ_{TE} – TE mode phase
φ_o - constant phase
B_{TE} – TE mode peak induction at the axis, T
R – laser spot radius at the photocathode, mm
φ_{TM} – launch phase (here φ_{TM}=50º at maximum bunch energy)

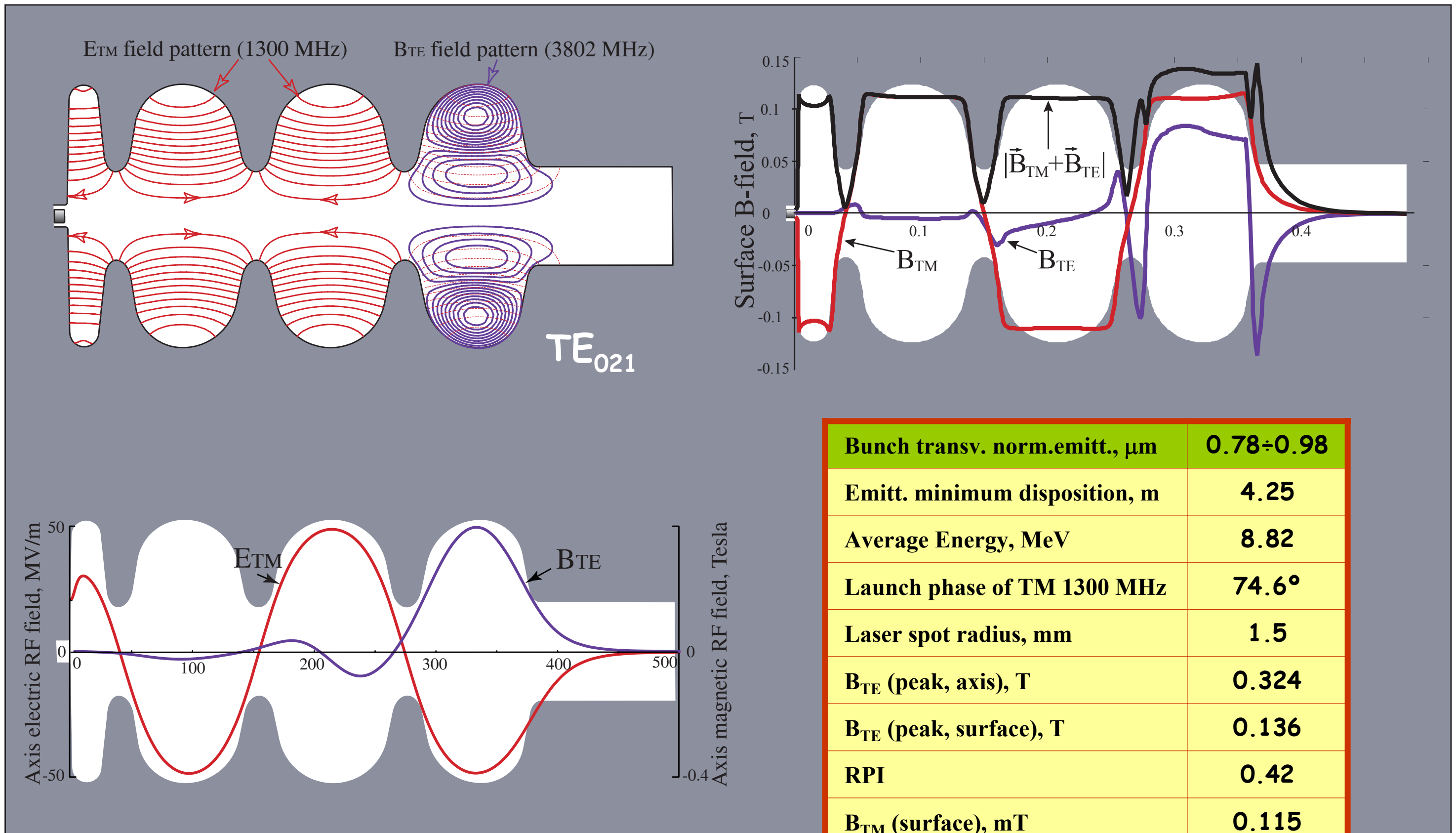
Set examples

	1	**2**
ε_{av}, µm	0.805	0.712
A_ε, µm	0.212	0.08
B_{TE}, T	0.28	0.3
R, mm	1.0	1.5

Results for a 1 ½ cell cavity

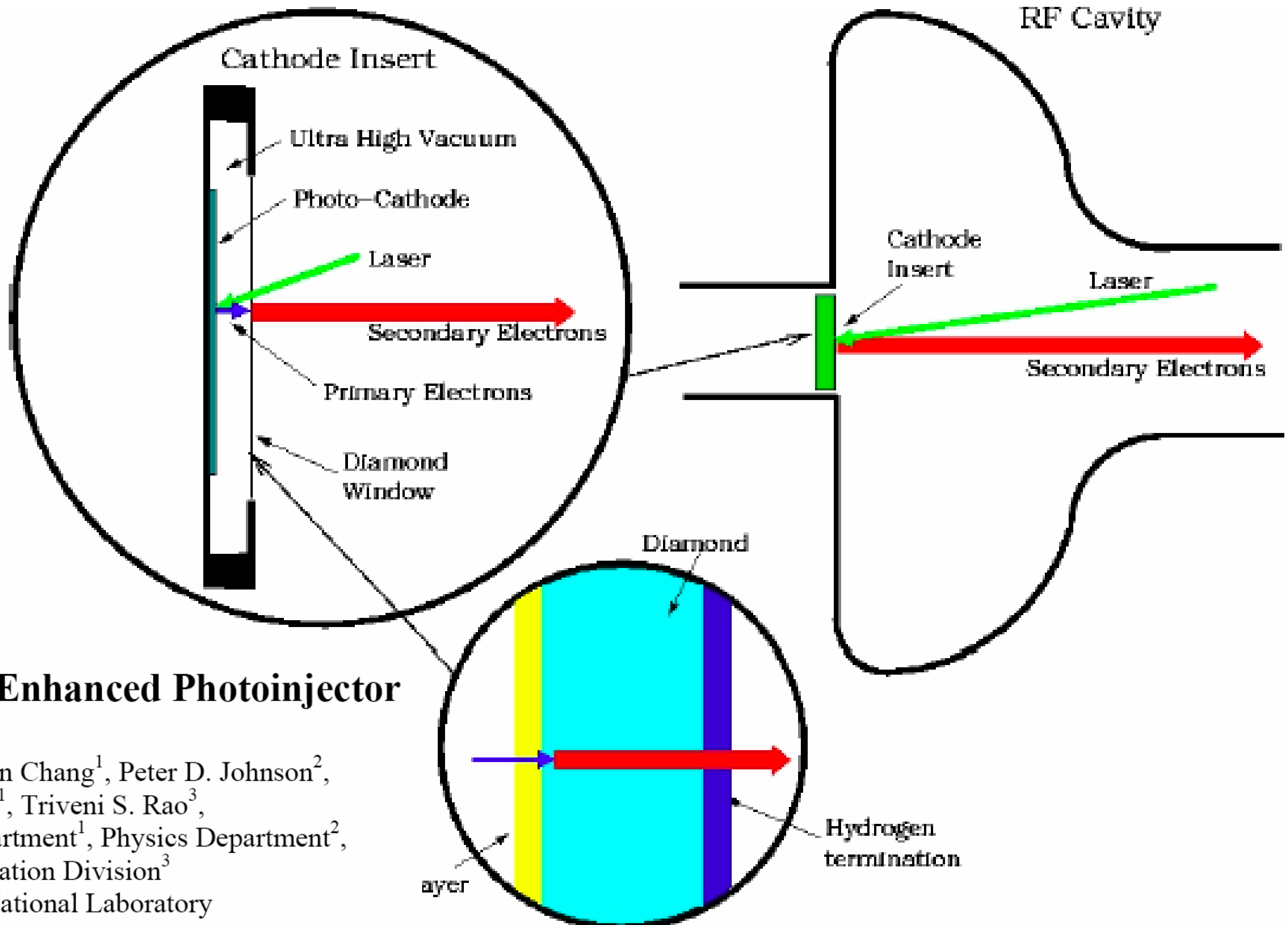
Optimized settings & performances	Without any RF focusing	Electric RF focusing only	Magnetic RF focusing only	Electric and magnetic RF focusing
ε_n, π mm mrad	**3.66**	**1.49**	**1.28**	**0.62**
$(\varepsilon_n^2 + \varepsilon_{th}^2)^{1/2}$	3.76	1.72	1.44	0.89
R (laser), mm	2	2	1.5	1.5
φ_{TM}, deg	49.4°	46.3°	49.4°	55°
Cathode depth, mm	0	2	0	2
B_{TE} (axis, peak), T	0	0	0.3	0.3
B (surf., peak), T	0.128	0.128	0.132	0.132

Results for the 3 ½ cell cavity



Bunch transv. norm.emitt., μm	0.78÷0.98
Emitt. minimum disposition, m	4.25
Average Energy, MeV	8.82
Launch phase of TM 1300 MHz	74.6°
Laser spot radius, mm	1.5
B_{TE} (peak, axis), T	0.324
B_{TE} (peak, surface), T	0.136
RPI	0.42
B_{TM} (surface), mT	0.115
$\mid B_{TM}+ B_{TE}\mid$, mT	0.144

Diamond amplifier



Secondary Emission Enhanced Photoinjector

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Conclusion

•Superconducting RF guns are the ideal injectors for high current- low emittance application.

•For average currents I > 1mA on has to put a normal conducting cathode into a supercondicting cavity. The proposed design works for T = 4.2K and Q = $2.5*10^{8}$. For T = 2K and Q ~ 10^{10} one has to check it.

•For SRF guns with I < 1mA a superconducting cathode is an interesting alternative, which one has to prove.

•New ideas and developments as the diamond amplifier and the magnetic RF modes can enlarge the performance of superconducting RF guns.

•I dare the prediction, that within the next three years the first SRF photoelectron gun will work as injector for a linac in routine run.