Conduction cooled SRF photogun for UEM/UED applications

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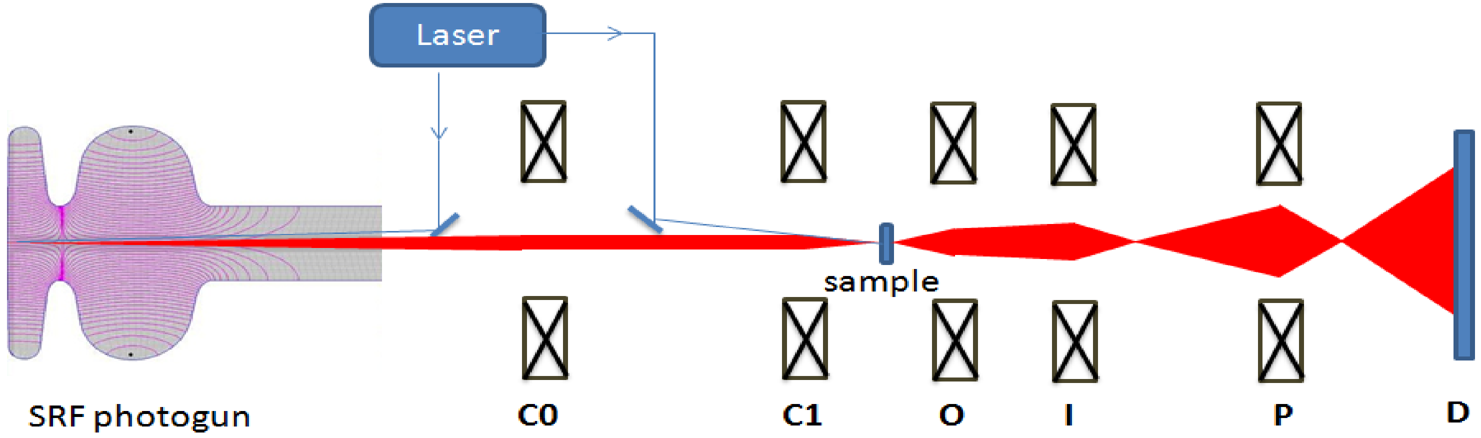
Proposal ID: UED-308081

Outline:

1. *Introduction to UEM/UED and requirements*
2. *SRF gun optimization studies*
3. *Cryomodule design*
4. *Current status*
5. *Conclusions*
6. *Future plans*



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Introduction:

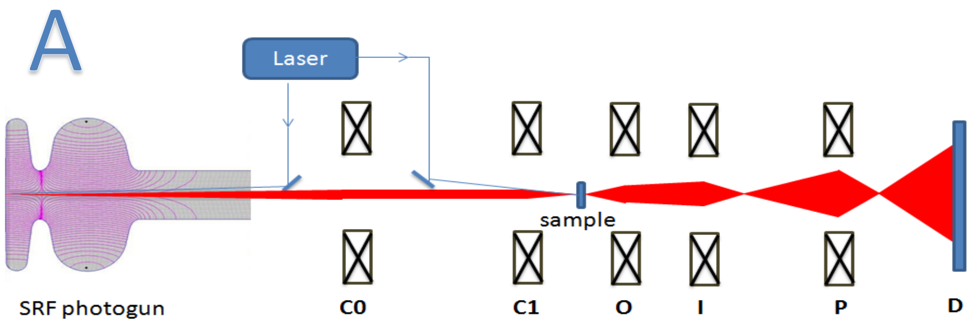
1. *Ultra-fast electron diffraction/microscopy stands for time resolved phenomena, where a bunched beam required*

2. *Standard approach is the use of laser generated photoemission beam (see A)*

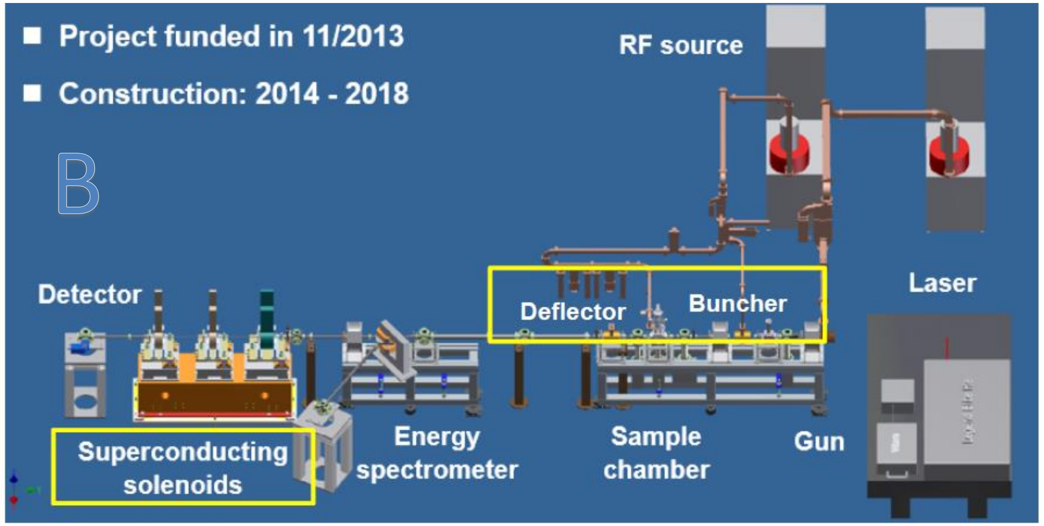
3. *MeV beam is required to reduce space charge effects*

4. *UED usually based on NC gun, which can operate with 100's Hz rep rate and requires MW's of RF power (see B)*

5. ***The proposed here L-band SRF photogun can work in CW mode powered by only 10W solid state amplifier (with consideration of excessive loss in the transmission line and a frequency detuning compensation), which can provide an order of magnitude higher stability. It can also reduce the footprint by 2/3***



Courtesy of Dao Xiang, talk at IPAC19



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RF Design

1. *Maximum energy gain and min energy spread of the beam corresponds to different RF phases*

2. *Cavity nose section was optimized to minimize the spread while keeping acceptable energy gain.*

E-field

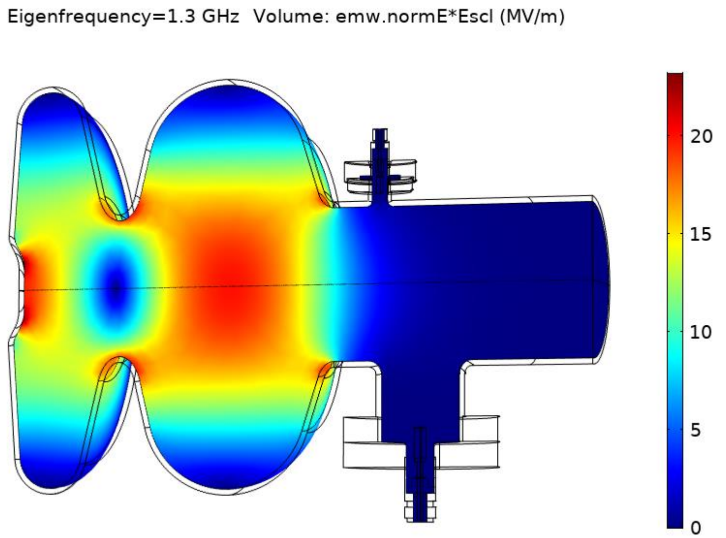
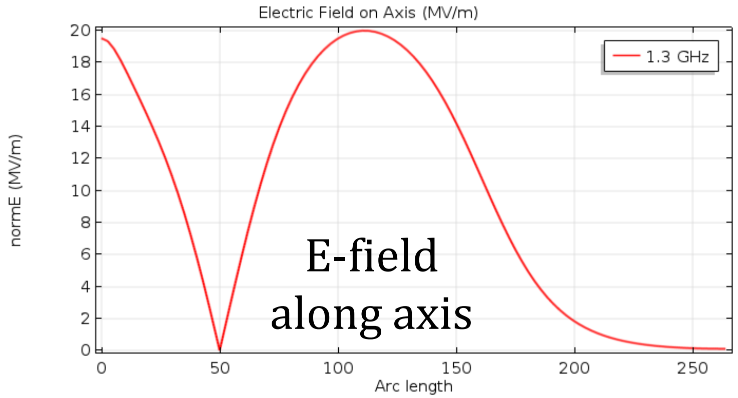
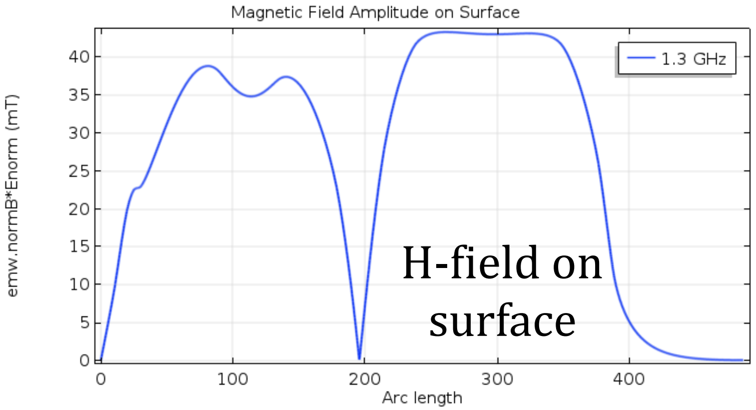


Table 1. RF parameters

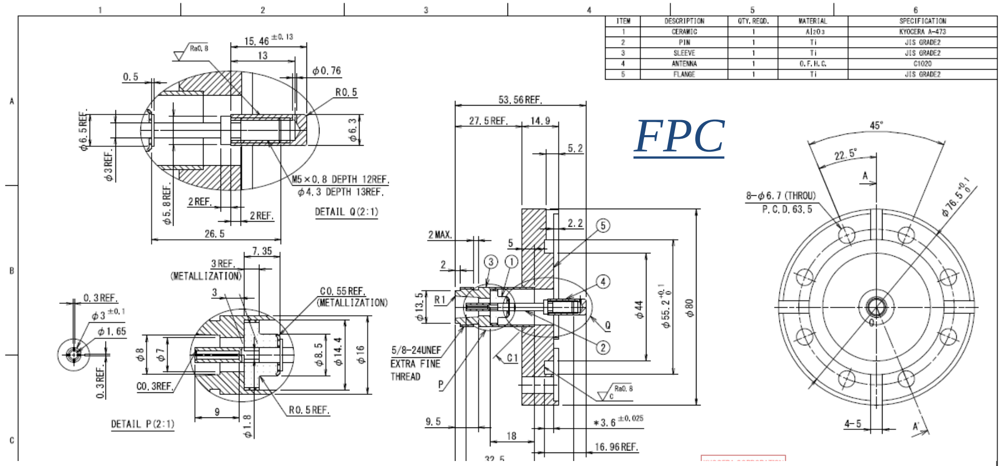
Parameter	Value
Frequency,	1.3 GHz
Length	1.45cell (160mm)
Q_0 at 4°K (Rs = 20 nΩ)	1.16×10^{10}
R/Q (critical coupling)	176.9 Ω
Geometry factor	232 Ω
Wall Power dissipation	1.3 W
$E_{on\ axis}$	20 MV/m
E_{max}	23.5 MV/m
B_{max}	43.3 mT
E_{acc}	10MV/m
Beam energy	1.65MeV

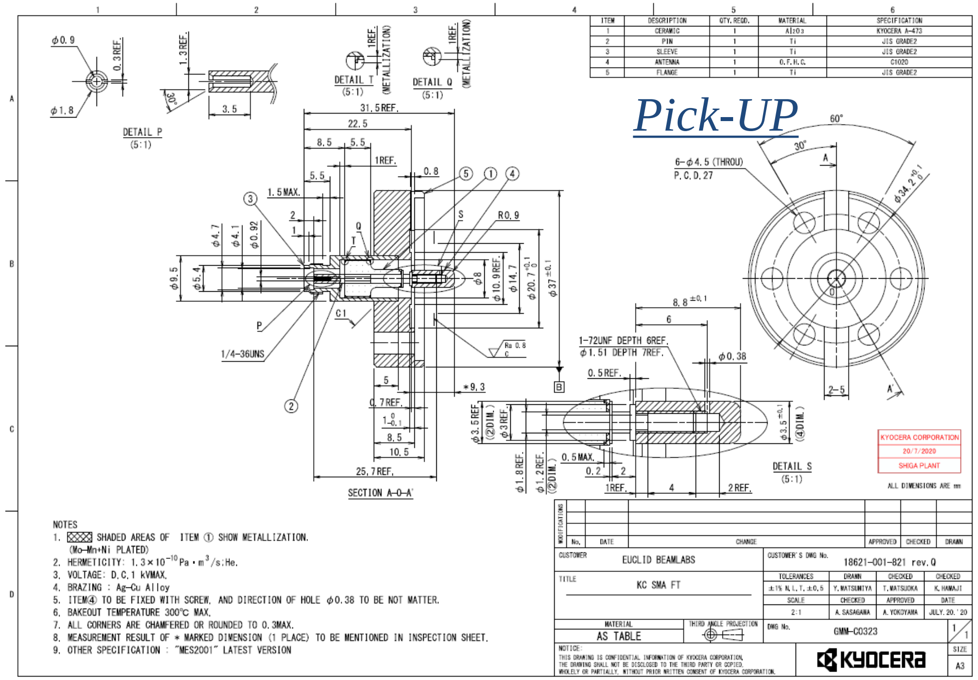




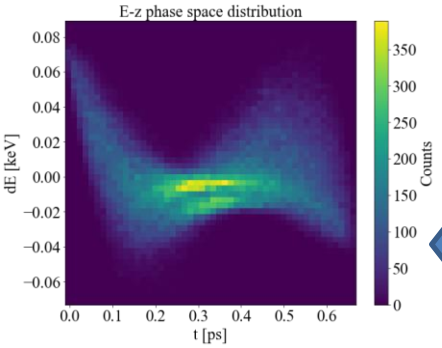
RF Design

1. *FPC and Pick-up couplers were optimized*
2. *FPC coupler is based on an N-type feedthrough.*
3. *Pick-up coupler is based on an SMA-type feedthrough.*
4. *Both couplers have a screw-on antenna which can be easily tuned if needed.*
5. *The couplers are ordered from Kyocera, blueprints were generated.*

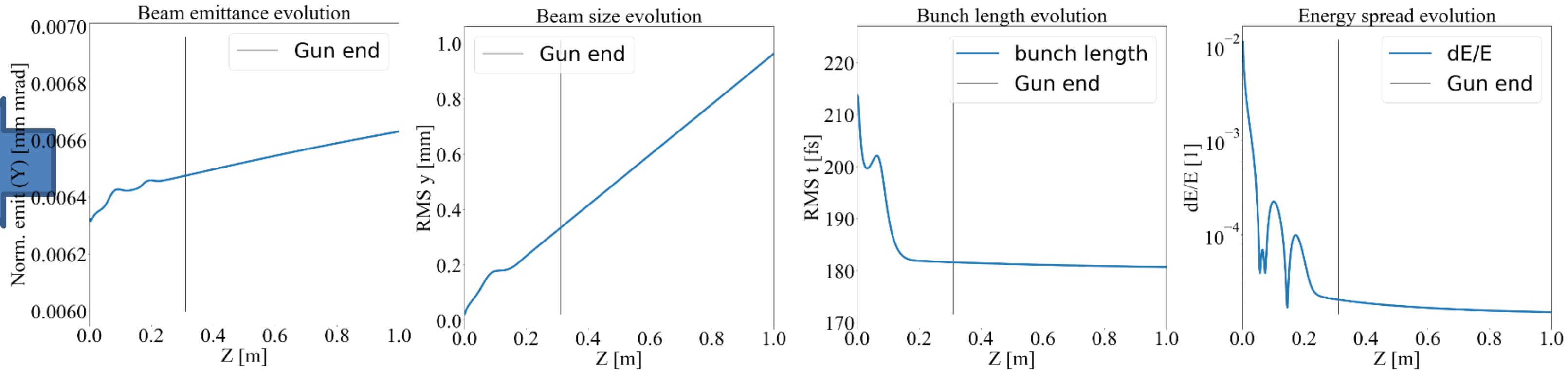


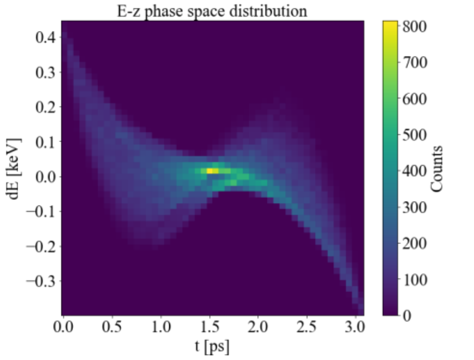


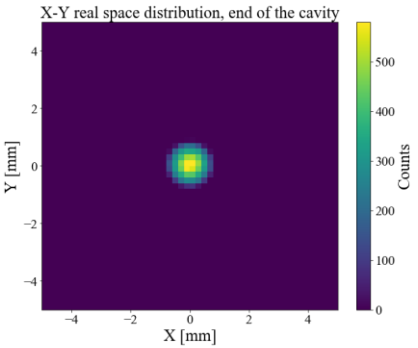
Beam dynamics



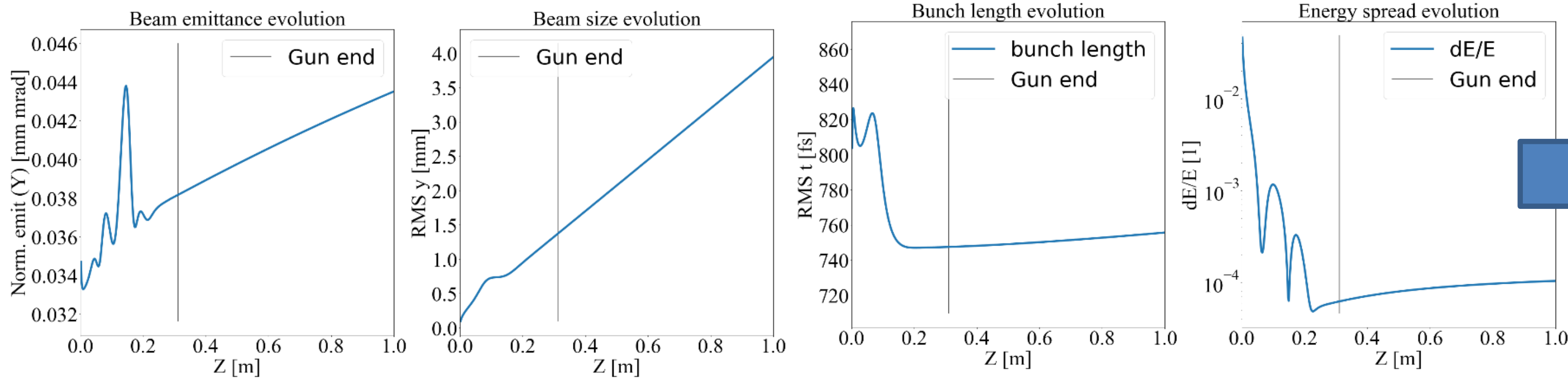
(a) Beam Simulation (UED Application, 5*fC*)

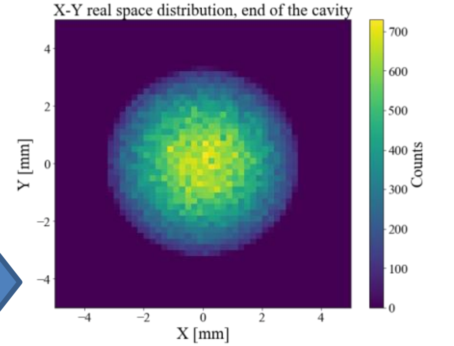


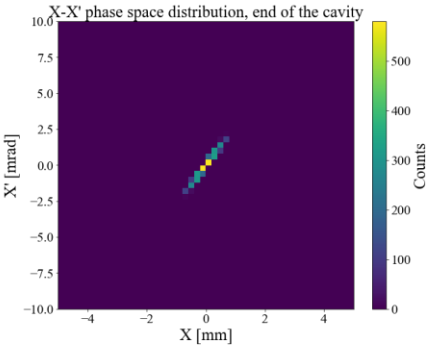


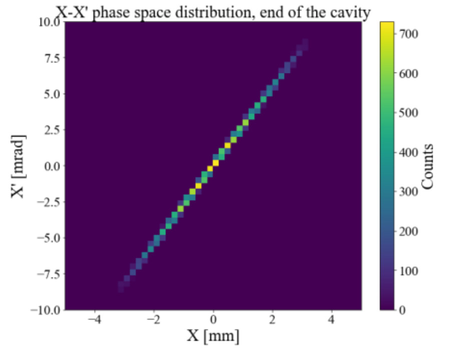


(b) Beam Simulation (UEM Application, 0.5*pC*)









Parameter	*Value*	
Application	*UED*	*UEM*
Beam energy	*1.655MeV*	*1.655MeV*
Charge	*5fC*	*0.5pC*
Laser pulse length, rms	*6.4fs*	*6.4fs*
Laser spot size	*36um*	*180um*
Beam bunch length, rms	*182fs*	*751fs*
Beam emittance	*6.5nm*	*38nm*
Energy spread (relative)	*1.3e-5*	*6.4e-5*

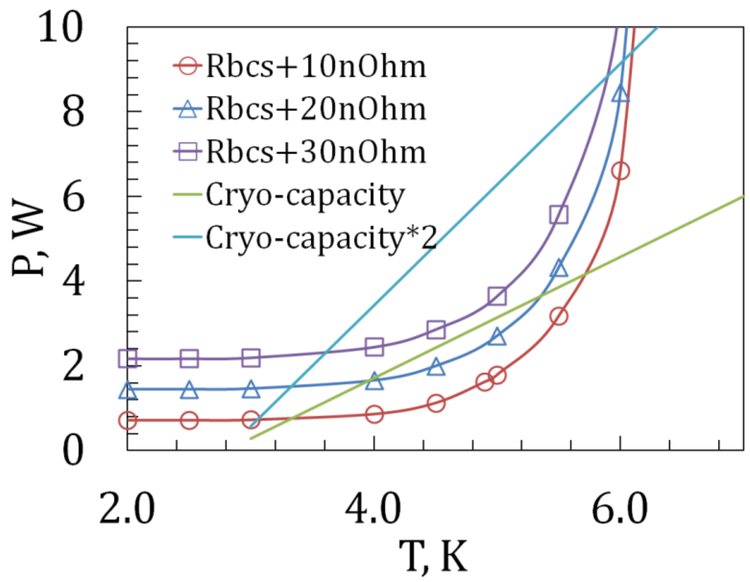
Thermal Analisys and Conduction Cooling

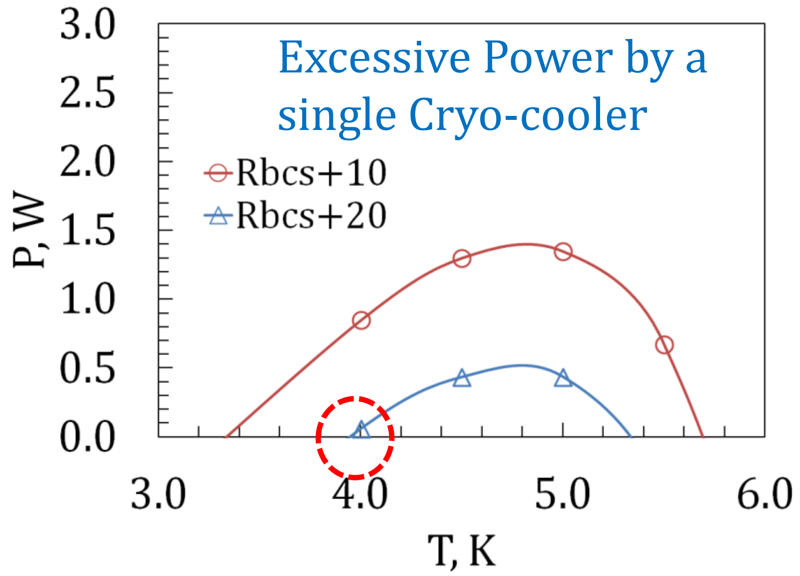
1. *Thermal modeling was done for different cryocooler temperatures to find stable operation regimes for the case of Eacc=10MV/m (1.6MeV beam)*

2. *Dissipated power in the gun along with the capacity of the cryocooler are presented below.*

3. *In the ideal case (Rbcs+10nOhm) with no additional heat from radiation or conduction the gun will stabilize at 3.5K. 1.5W of cryocooler capacity is still available to accommodate the other sources of heat*

4. *In the case of Rbcs+20nOhm, the gun will stabilize at 4K with additional cryocooler capacity of 0.5W.*





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Cryomodule design

1. *Cryomodule was developed to host the photogun*

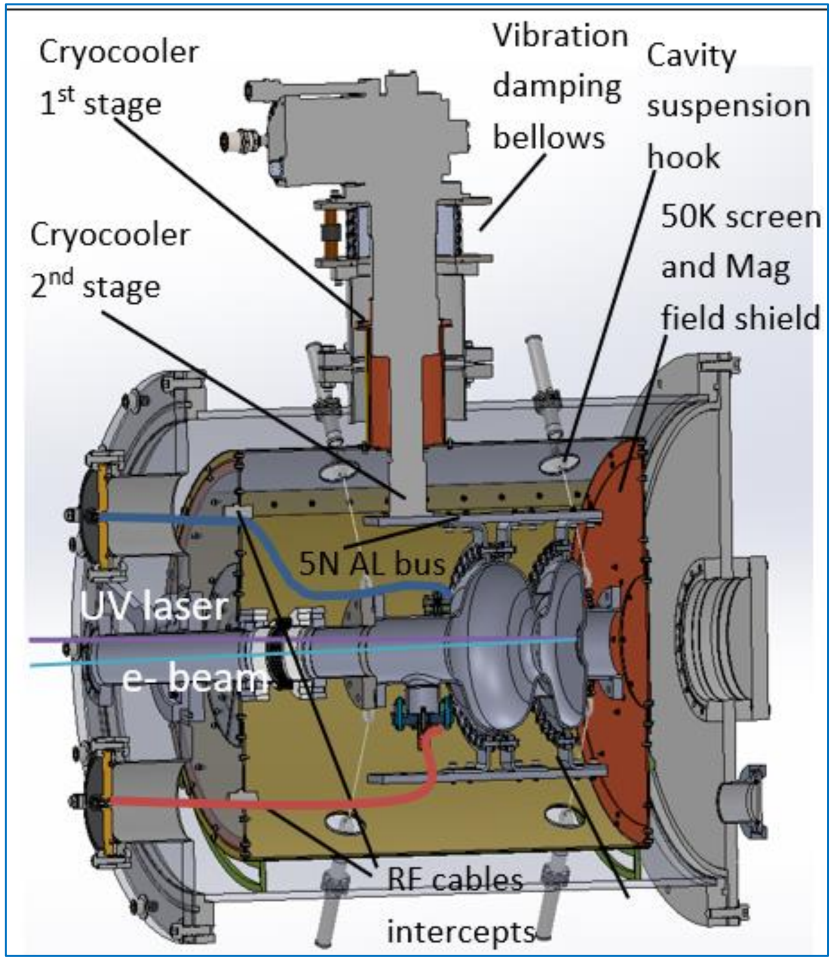
2. *It is based on conduction cooling approach and is cooled by one Sumitomo cryocooler (CC)*

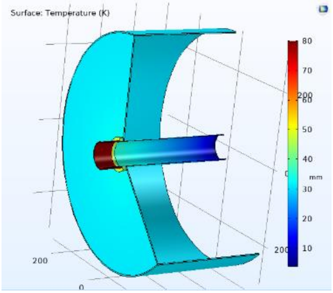
3. *1st stage of the CC is used as a thermal intercept and cools down a copper thermal radiation screen.*

4. *There is a 1mm thick magnetic screen (A4K) on top of the radiation screen*

5. *The cavity is supported by 8 Kevlar strips (k=0.05W/m/K)*

6. *The total power to the cavity is less than 0.2W, while the intercept has a heat flow of 20W*





Temperature distribution in the copper thermal shield connected to the beam pipe.

Table 1. Static heat load to 30K and 4K zones in UEM cryomodule.

	Radiation	Beam pipe	Suspension	RF cables	Total
30K zone	2 W	17 W	NA	0.8 W	20 W
4K zone	0.01 W	0.03 W	0.05 W	0.05 W	0.14 W

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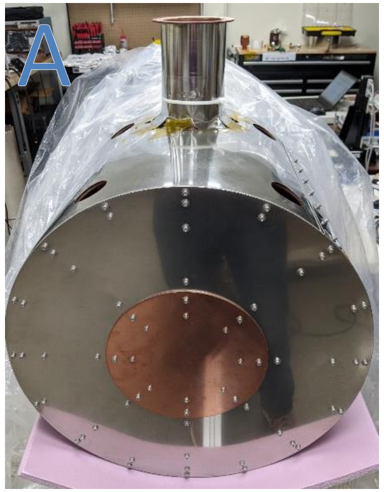
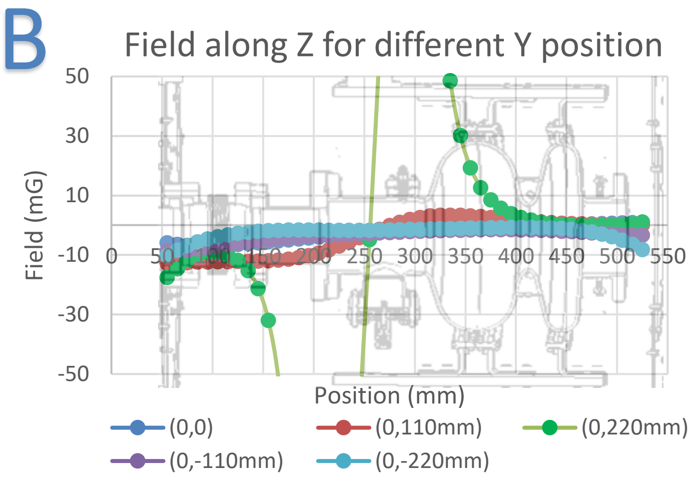
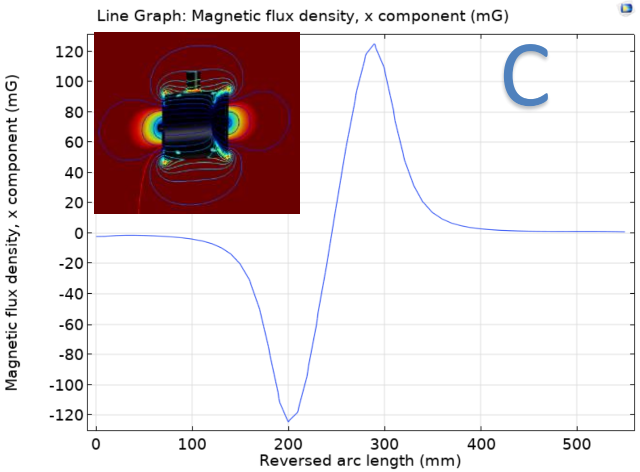
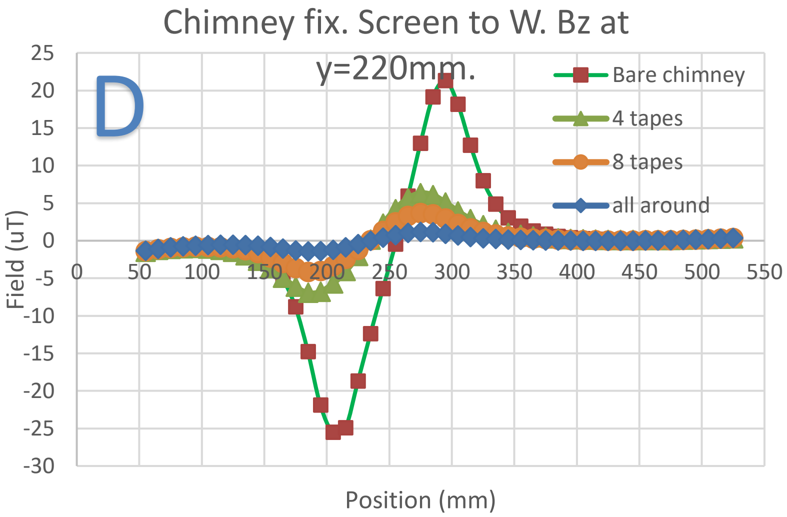
Magnetic shield in the cryomodule





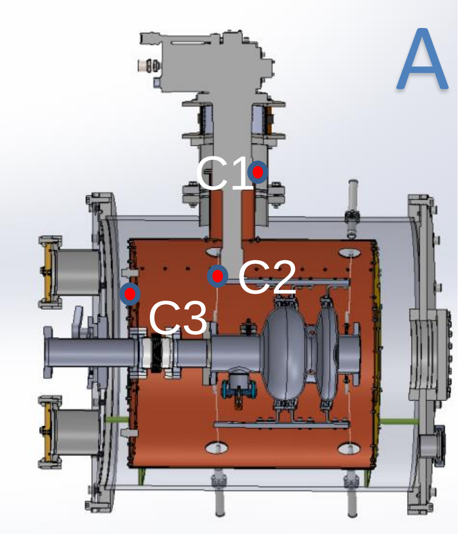


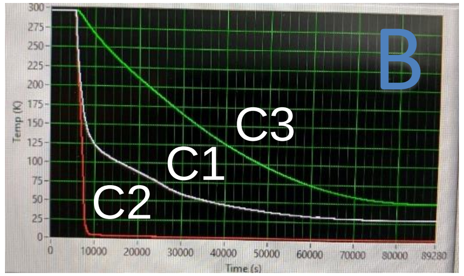
1. *Initial magnetic field measurements identified a gap in the magnetic shielding (see B) between the chimney and the cylindrical body (see A and B).*
2. *The results correlates with Comsol model (see C).*
3. *Nevertheless, the field in the cavity region (R=110mm, Z=(250;500)) is below 10mG at room temperature for A4K screen (See B).*
4. *A patch from Mu-metal foil (see C) reduced the field penetration at R=220mm down to 10mG (D).*
5. *Cryogenic performance measurement is ongoing.*
6. *Thanks to Y.Tereshkin for helpful discussions*

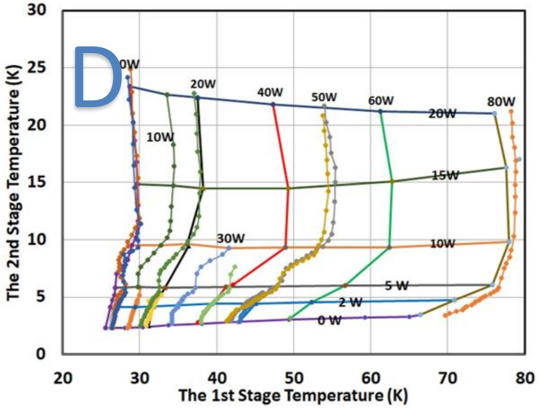


Cryomodule cool down (no cavity)

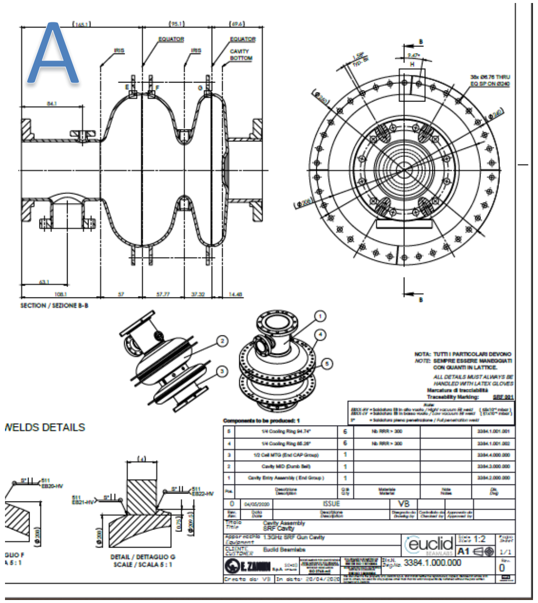
1. *The cryomodule was assembled and successfully cooled down.*
2. *Aluminum foil was taped to the vacuum chamber walls to reduce heat radiation for the initial cool down studies. MLI is waiting to be installed.*
3. *The vacuum level was low E-5Torr went down to high E-8 Torr once cooled down.*
4. *Apiezon-N was applied on Cernox thermal sensors for better thermal contact.*
5. *Temperature of the 1st stage reached 28K in 24hrs while the 2nd stage cooled down to 2.5K and are within the expected values.*
6. *C1 and C2 temperatures corresponds to ~10W and ~0W to the 1st and the 2nd stages according to the provided by Sumitomo capacity map.*
7. *20K difference is observed between the 1st stage and the thermal screen, which demonstrates a poor thermal contact*







SRF GUN Status



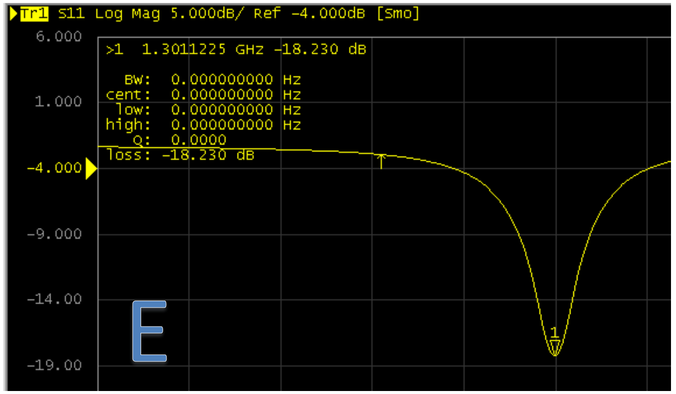
1. *Conduction cooled SRF photogun drawings were produced (see A)*

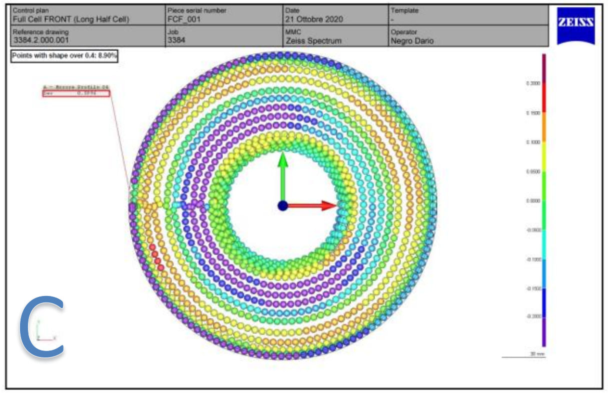
2. *Half cells were die-pressed from copper first, then from pure RRR300 Niobium (see B)*

3. *The Half cells were inspected by CMM and are within the tolerances (see C)*

4. *The cavity manufacturing is complete (see D). The sizes are within the tolerances. Target frequency is 1301.1MHz (see E). It will be tuned upon arrival.*

5. *The target delivery date of the gun is end of December 2020 (X-mas gift).*





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Conclusions

1. *The cryomodule was assembled and successfully cooled down.*

2. *Magnetic field insulation inside the shielding was measured at room temperature and is below 10mG*

3. *SRF gun manufacturing is complete.*

4. *All of the components are acquired.*

5. *LLRF control similar to one delivered to Fnal-IARC (see C) is developed.*

6. *The cryomodule is in the commissioning stage and will be ready soon to host the cavity*

7. *Capacity map of the cryocooler and cryogenic magnetic shielding performance is ongoing.*

Work to finish in phase II prior to ATF

1. *Zanon will deliver the cavity to Euclid Dec 2020*
2. *Nb3Sn deposition will be carried out by Fnal. The agreement is signed.*
3. *The preparation work has been already initiated.*
4. *Test of the bare Nb gun in vertical test stand (VTS) to benchmark the performance*
5. *Nb3Sn deposition followed by the test in VTS*
6. *Test of the Nb3Sn gun at Euclid using conduction cooling cryomodule*
7. *Demonstration of 10MV/m of accelerating gradient as required to get 1.6MeV beam*

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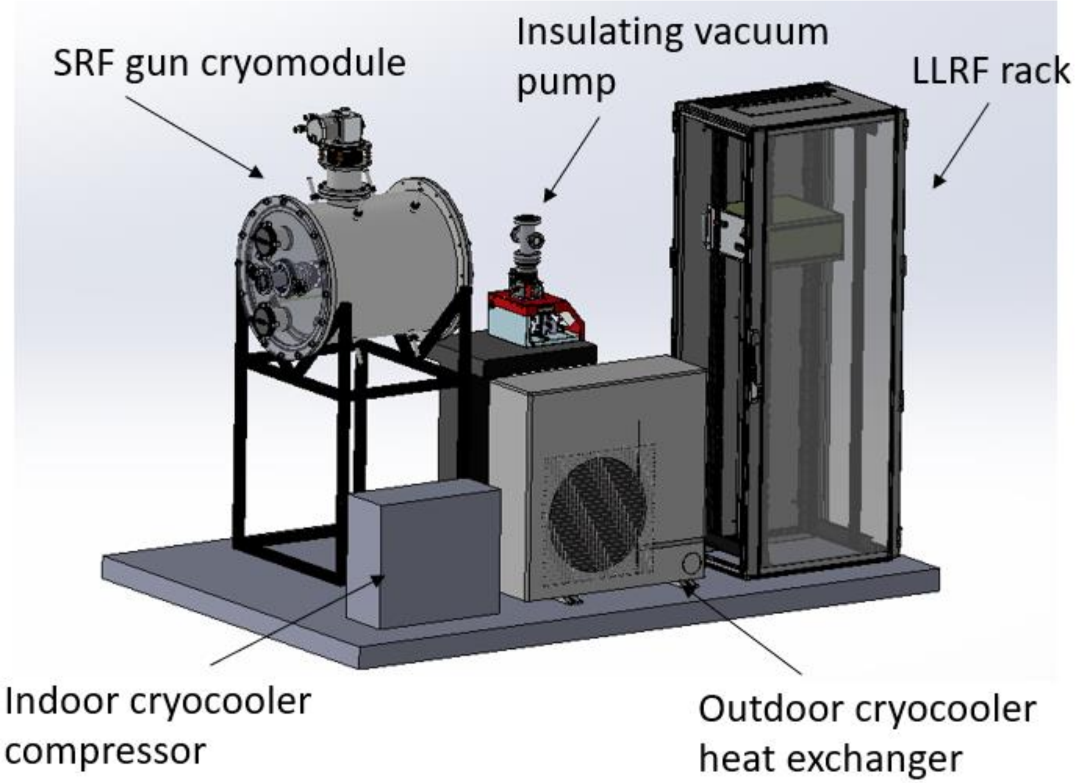
Timeline at ATF

1. Assemble electron beamline with the required components for beam characterization (see task 5)
2. Integrate the conduction cooled cryomodule with the beamline
3. Introduce UV laser into the gun
4. Beam generation by the UV laser in the SRF gun
5. Beam characterization:
    a. Energy spread
    b. Charge per bunch
    c. Emittance of the beam
    d. Bunch length



Task	Months 1	Months 2	Months 3
Cryomodule assembly			
Beamline assembly			
UV laser introduced to the beamline			
Beam generation by the laser			
Beam characterization			

Collaborators and Acknowledgements

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Fermilab

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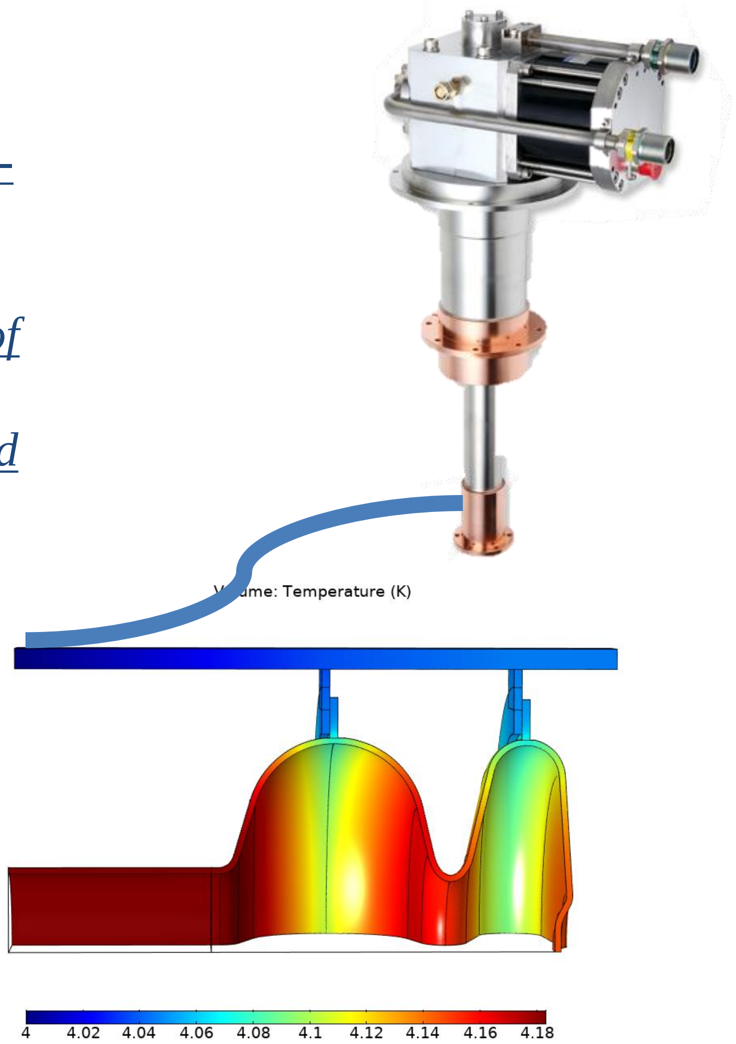
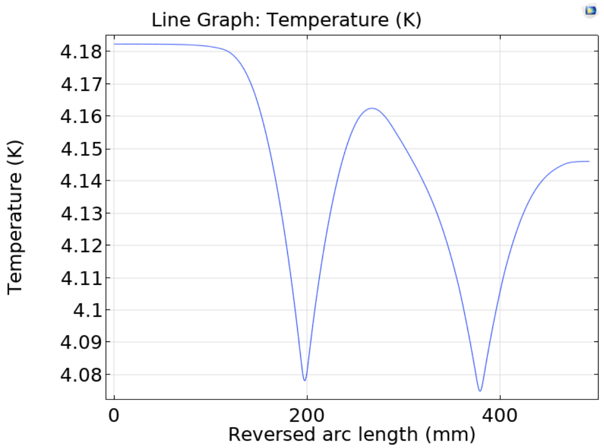
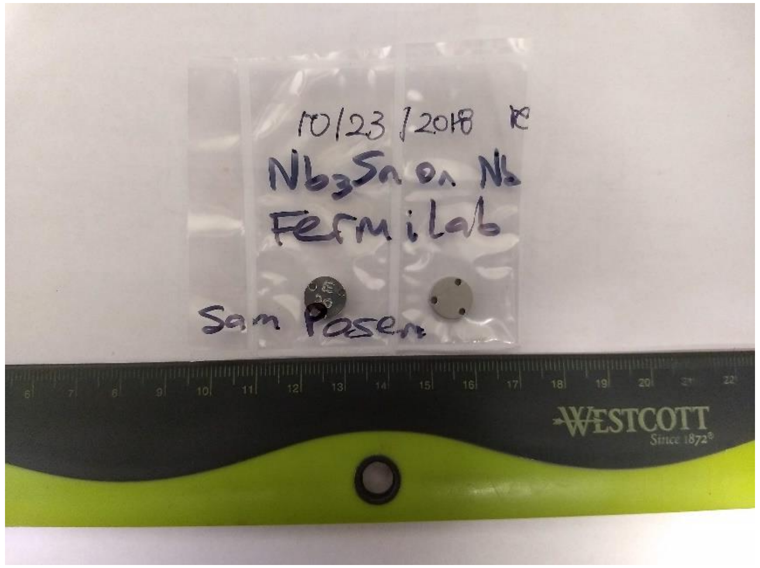
Thermal Analsys and Conduction Cooling

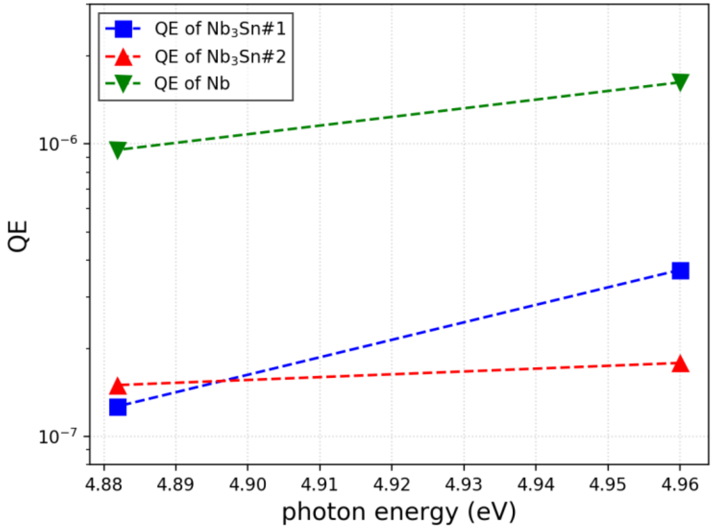
Cryo-cooler

1. *5N pure AL buses are used for conduction cooling*
2. *Cryocooler is connected to the end of the of the AL bus*
3. *Thermal contact resistance is included in the model between AL-AL, AL-Nb and Nb-Nb.*
4. *Temperature dependent surface resistance Rbcs was used*
5. *Temperature difference in the cavity is 0.1K at 4K temperature of the cryocooler*
6. *Stable operation regions for Eacc=10MV/m found and presented on the next slide*









UED		UEM
UV Wavelength, nm	254	254
UV Nue, Hz	1.181E+15	1.1811E+15
Planck, const	6.62E-34	6.62E-34
Photon energy, J	7.82E-19	7.82E-19
Photon energy, eV	4.89	4.89
QE	1.00E-07	1.00E-07
Charge per bunch, C	5.00E-15	5.00E-13
Number of e- in bunch	3.13E+04	3.13E+06
Number of photons req-d	3.13E+11	3.13E+13
PhotonEnergy per bunch, J	2.44E-07	2.44E-05
Pulse length rms (sigma), s	6.40E-15	6.40E-15
Peak Power, W	1.62E+07	1.62E+09
Rep rate, Hz	1.00E+06	1.00E+02
Duty factor	6.40E-09	6.40E-13
Power avg, W	1.04E-01	1.04E-03
Current, A	7.81E-01	7.81E+01
Avg current, A	5.00E-09	5.00E-11
Spot size D, m	3.60E-05	1.80E-04
Laser fluence, J/cm2	1.48E-02	5.92E-02

1J/cm2 is a metal in Vacuum threshold for fluence