The Center for
BRIGHTBEAMS
A National Science Foundation Science & Technology Center

Cryogenic Cathode Emission for High Brightness RF Photoinjectors

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Outline of presentation

1. Cryogenic photoemission introduction & motivations
2. RF test cavity
3. Beamline & implementation status
4. Future directions/conclusions

1. Metallic photoemission

- Emission properties of photocathodes change @ cryogenic temperatures (<93K)
- Where hν ≫ ϕeff scaling as below

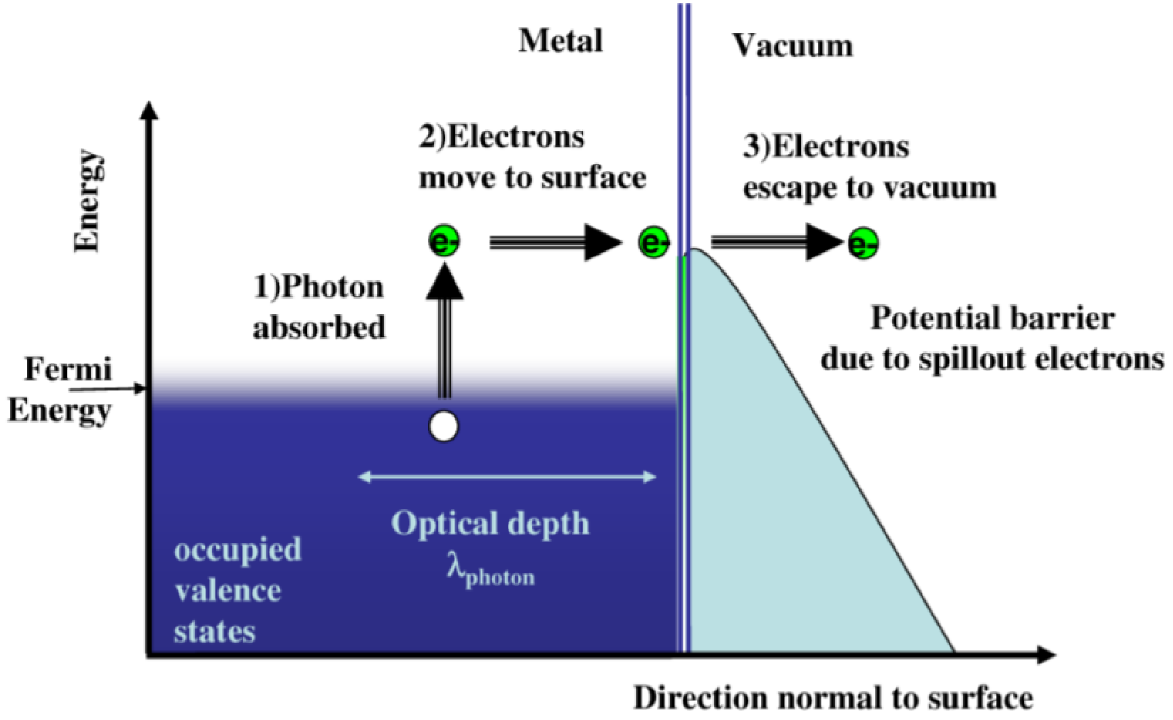
$$k_b T_c = (h\nu - \phi_{\text{eff}})/3$$

$$QE = N_{e-}/N_\gamma \propto (h\nu - \phi_{\text{eff}})^2$$

- Cu photocathodes emission temp ranges from ~100 meV to 1 eV depending on wavelength
- Brightness scaling (below)
- From UXFEL NJP, note 6D brightness importance

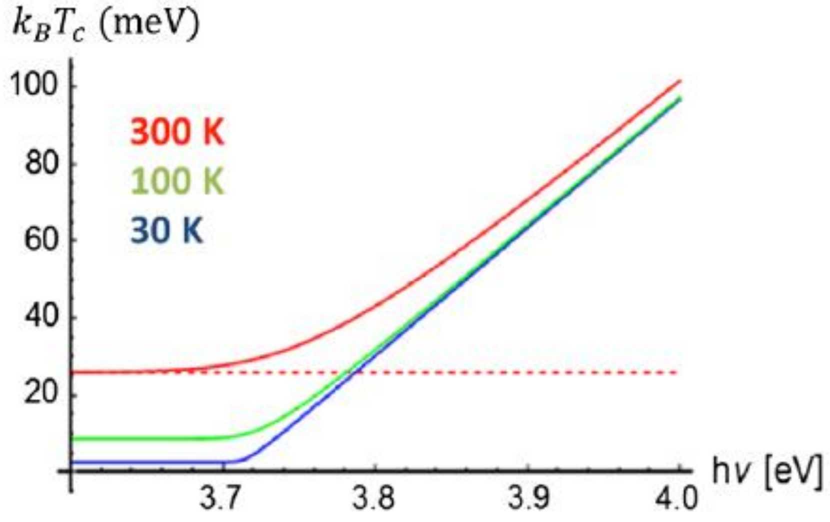
$$B_{e,b} \approx \frac{2ec\varepsilon_0}{k_B T_c}(E_0 \sin\phi_0)^2$$

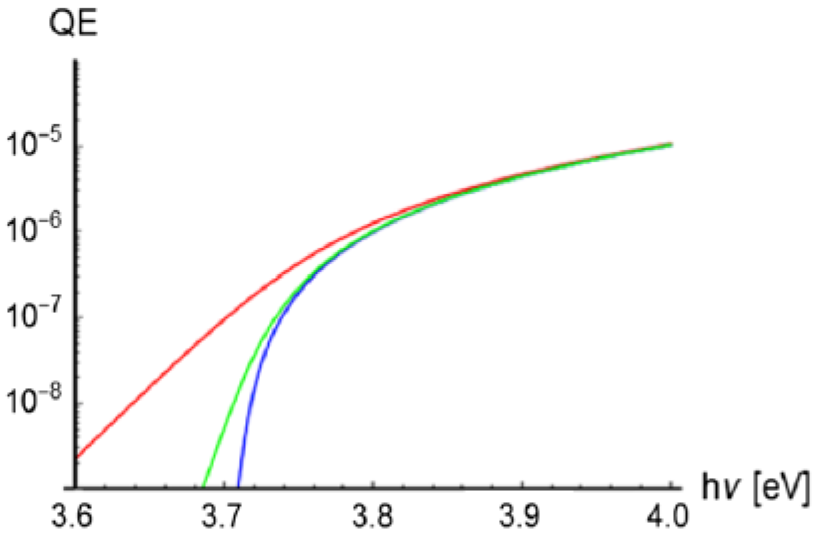
D. Dowell and J. Schmerge, Phys. Rev. ST Accel. Beams 12, 074201 (2009).



1. Cryogenic metallic photoemission

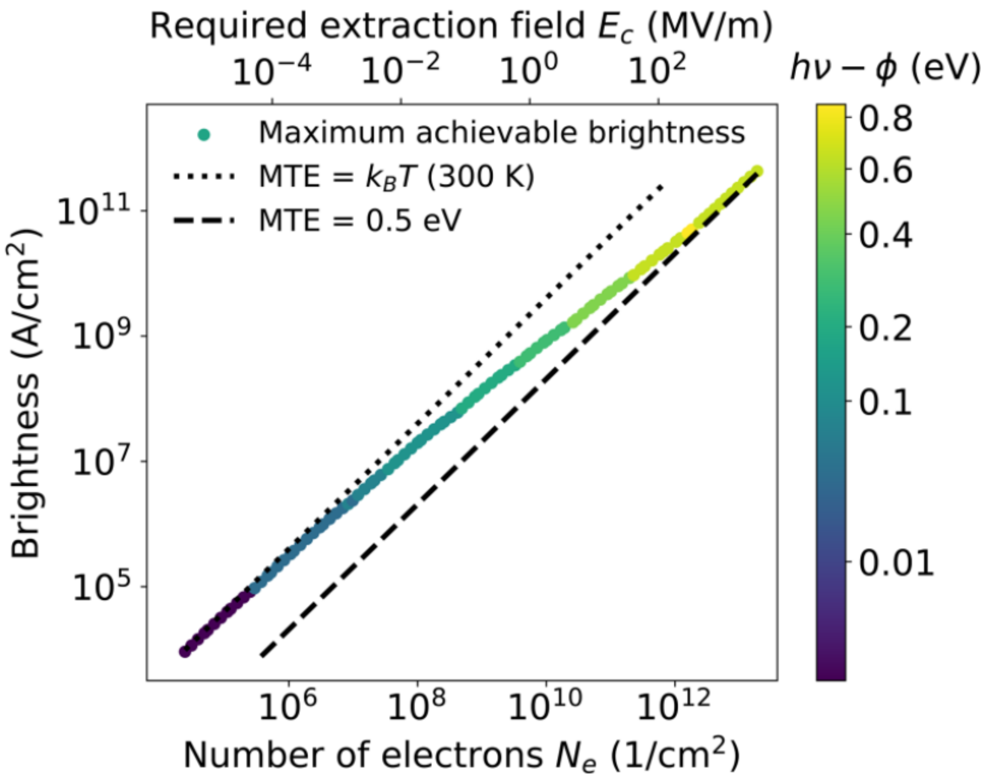
- Near threshold emission from tail of Fermi-Dirac distribution
- Now including full FD distribution with temperature dependence (right)
- hv → ϕeff, photoemission temperature approaches physical cathode temperature, k_BT_c → 26 meV at 300 K
- Very low QE, so higher laser fluence needed





1. Cryogenic metallic cathode issues

- Easiest if Cu satisfies all cathode requirements
- Extremely challenging due to non-linear emission
- 100 pC from 75 um rms spot size at 250 MV/m accelerating field, 38 nm-rad intrinsic emittance ➔ 130 meV MTE, ~10^{12} e^{-}/cm^2
- 50 fs pulse – could be better for 5 ps pulse
- Need to characterize cathodes in these extreme condition

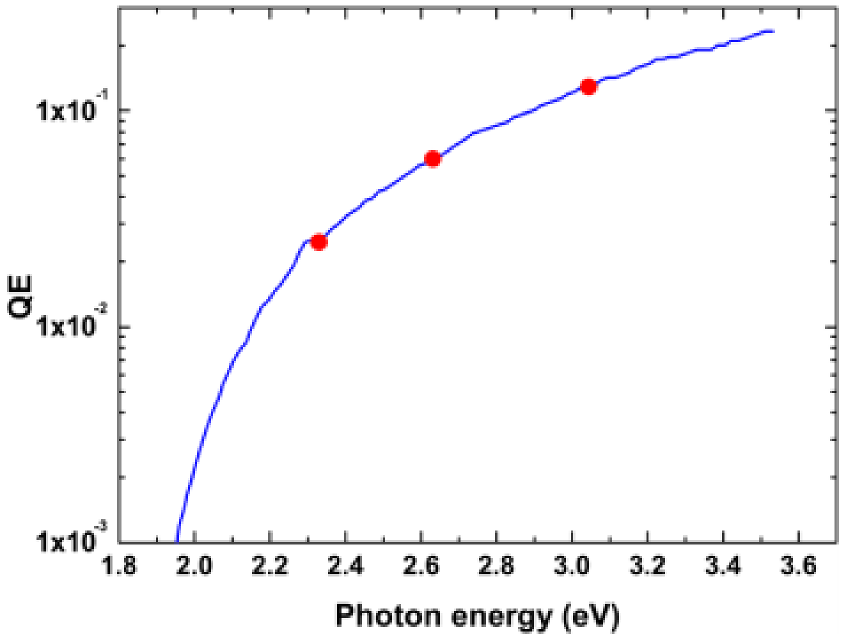


J. K. Bae, I. Bazarov, P. Musumeci, S. Karkare, H. Padmore, and J. Maxson, J. Appl. Phys. 124, 244903 (2018).

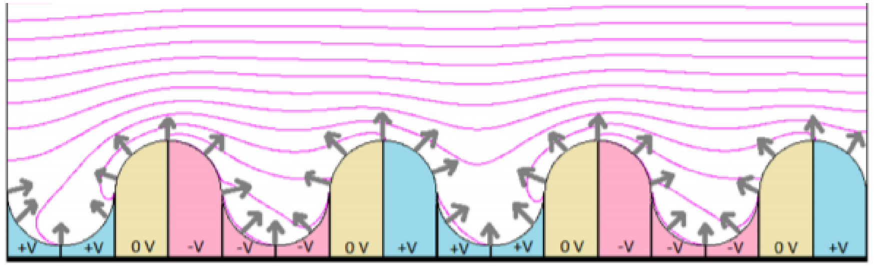
1. Cryogenic semiconductor cathodes

- High QE photocathode, many orders of magnitude higher than Cu, promising
- Alkali antimonides, Cs2Te
  - Field emission could be an issue due to lower work functions/roughness.
- Cs/GaN or n-doped polar GaN
  - High QE in UV, high work function
  - Could result in very low MTE
  - never been tested in photoinjectors
  - Potential vacuum concerns
- Reduction of MTE at cryogenic temps observed

NaKSb



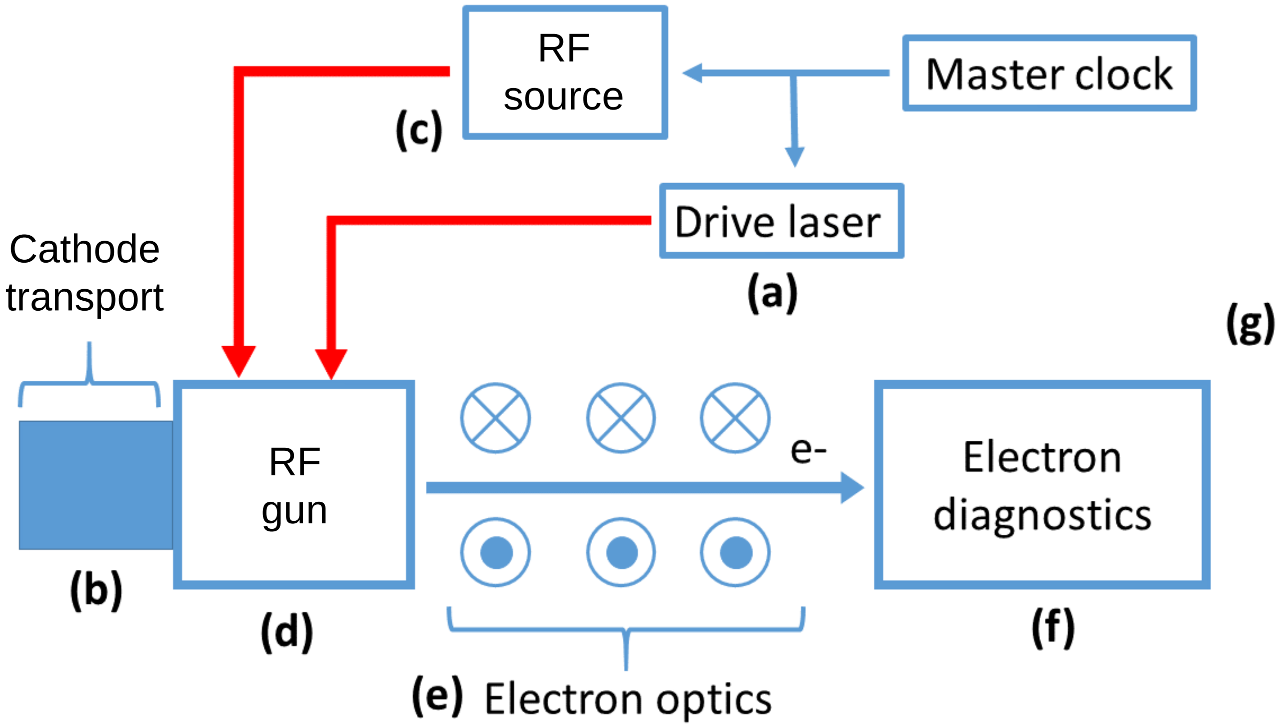
L. Cultrera et al., Appl. Phys. Lett. 103, 103504 (2013).



G. S. Gevorkyan et al., Phys. Rev. Accel. Beams, vol. 21,p. 093 401, 9 Sep. 2018.

1. Testbed schematic

- Generalized cathode testbed schematic to right
- Cryogenic operation of gun advantage from RF perspective as well
- Cryogenic DC guns tests have been successful
- Development of cryogenic RF test bed becomes critical UCXFEL
- Full multi-cell photoinjector gun (below) too complex for cathode measurements
- ½ cell gun sufficient



RF source

Master clock

(c)

Drive laser

(a)

Cathode transport

(g)

RF gun

e-

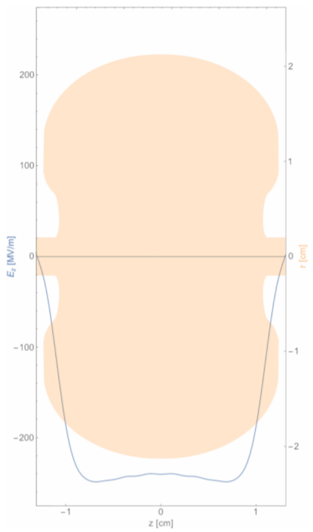
Electron diagnostics

(b)

(d)

(f)

(e) Electron optics



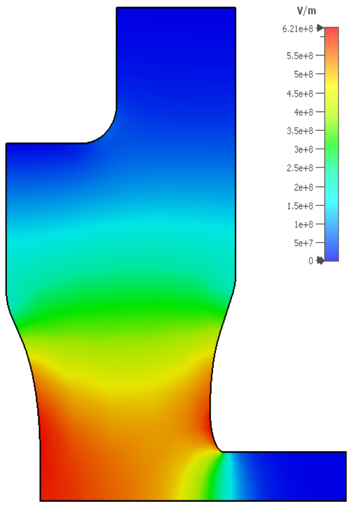
RR Robles et al. *Physical Review Accelerators and Beams* 24 (6), 063401

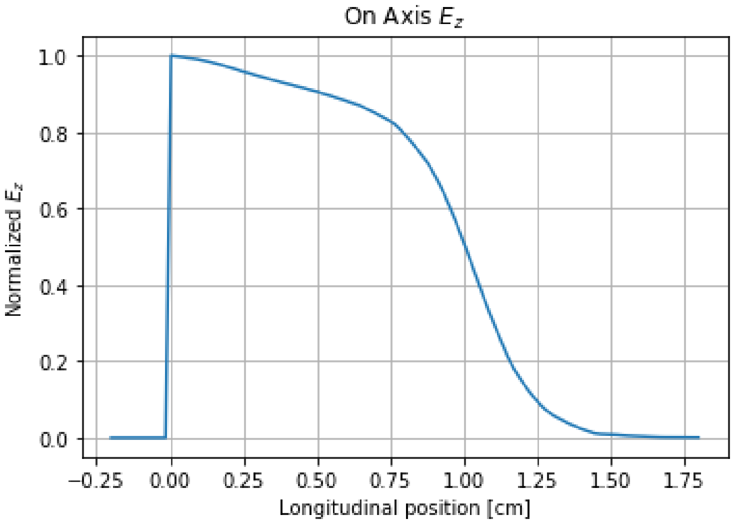
2. ½ Cell gun specs

- Reentrant cavity with high shunt impedance Tantawi-style
- Cryogenic temperature provided RF stability and cathode studies
- 2.9 factor improvement of Q_0 from 300K to 77K
- Cryogenic load lock and replaceable cathode plug coupling

Parameters	Value
Launch field	120-250 MV/m
Operating temp	45K-77K
# of cells	½
Cavity frequency	5.712 GHz
Beta	4 @ 77K
Q_ext	6056
Q_0	24750

E field magnitude

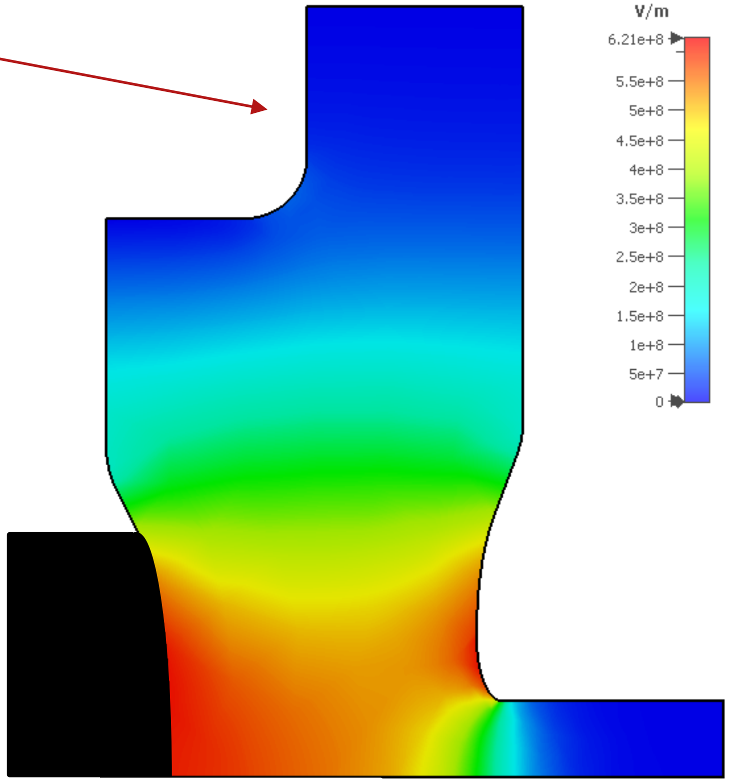




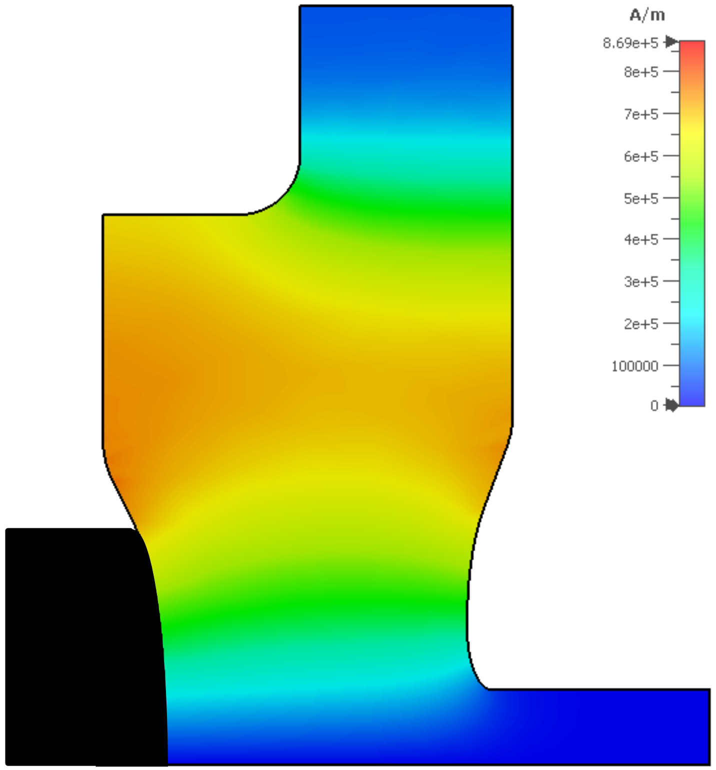
2. ½ Geometry with fields

RF feed

E field magnitude



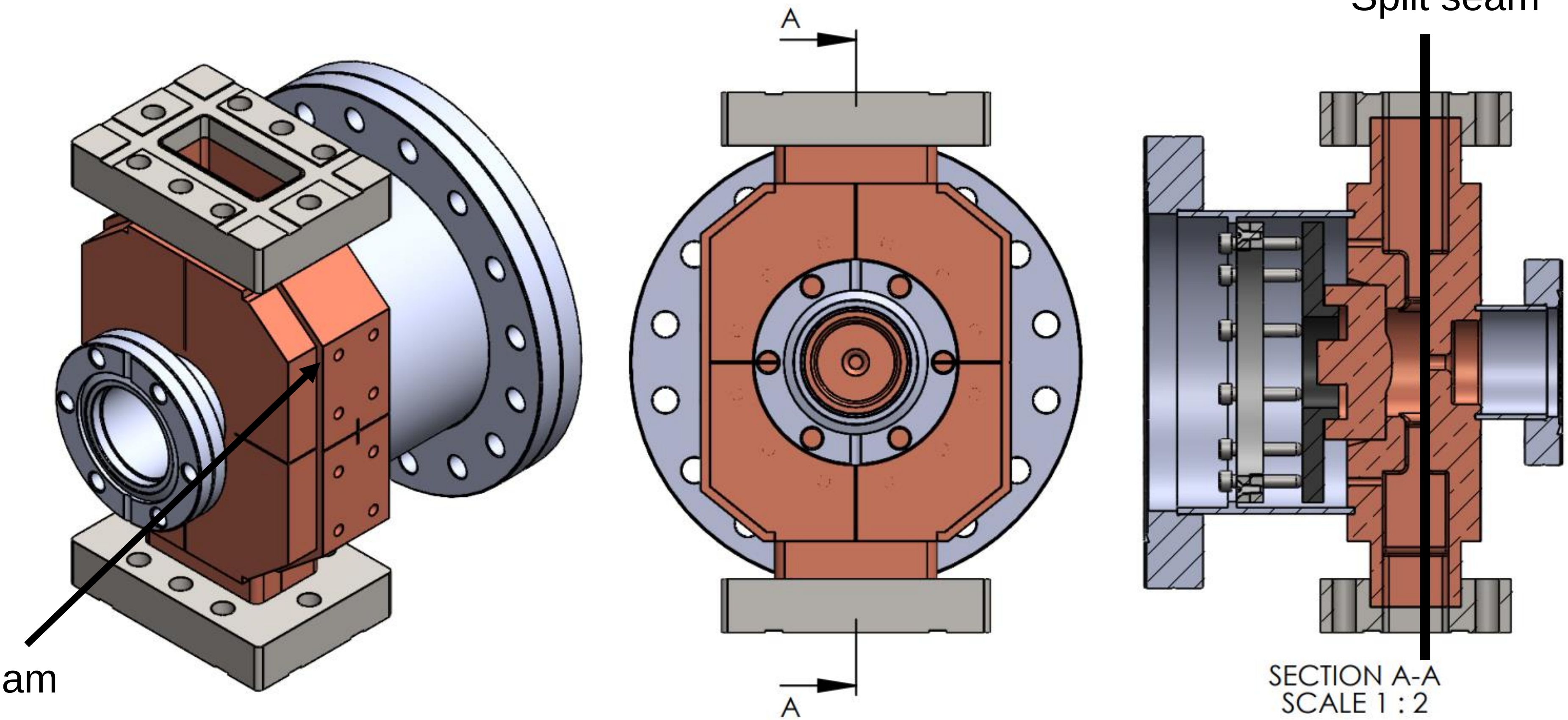
H field magnitude



Cathode

2. ½ Cell Gun Drawings

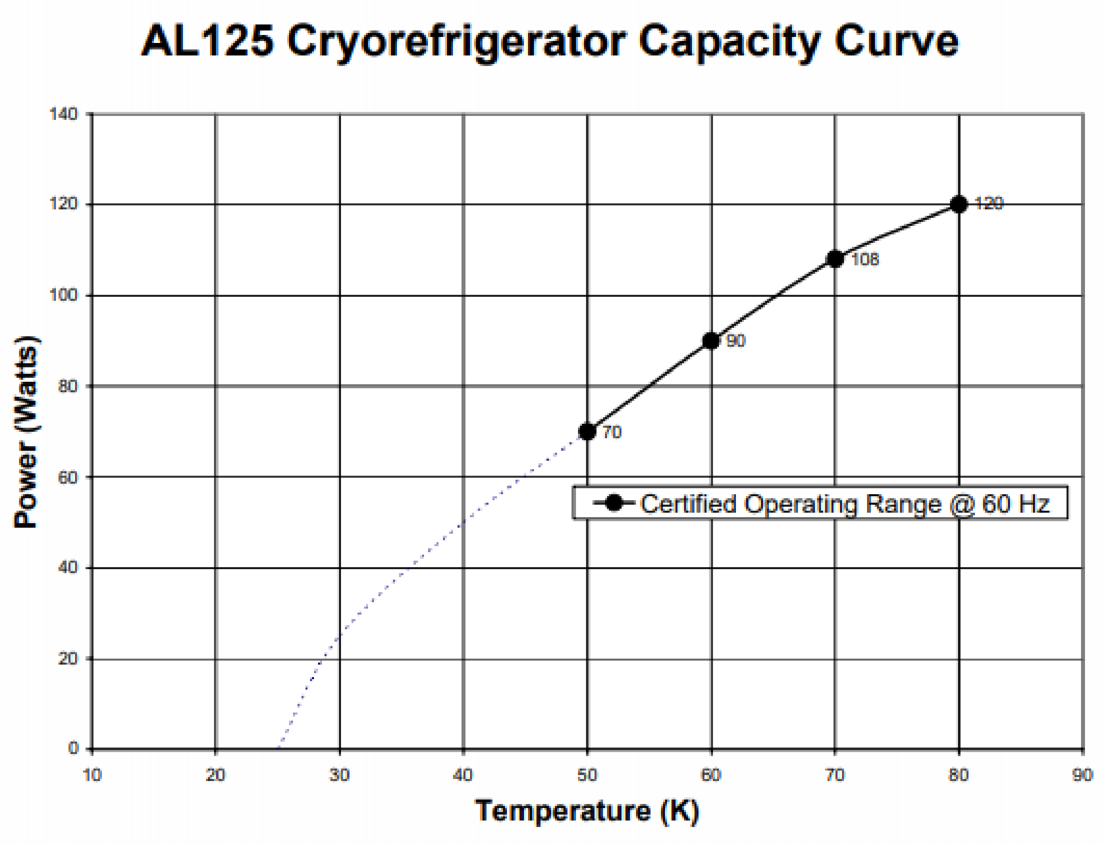
- Drawings with fully removable backplane based on FERMI gun design
- Fabrication at Comeb

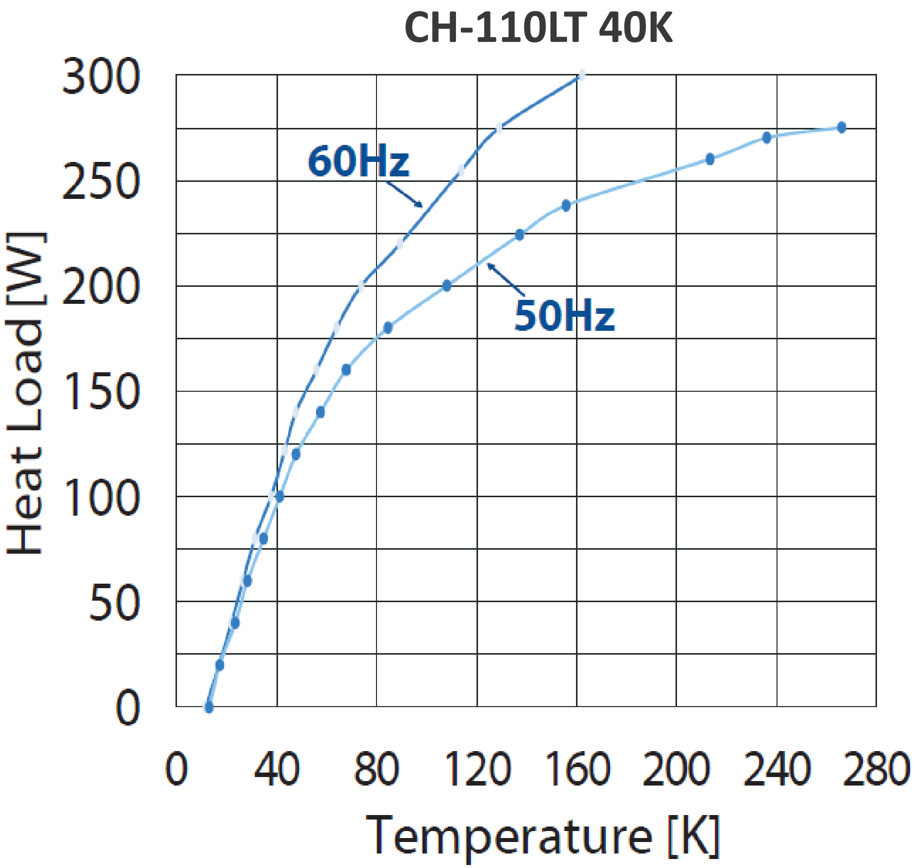


Split seam

Split seam

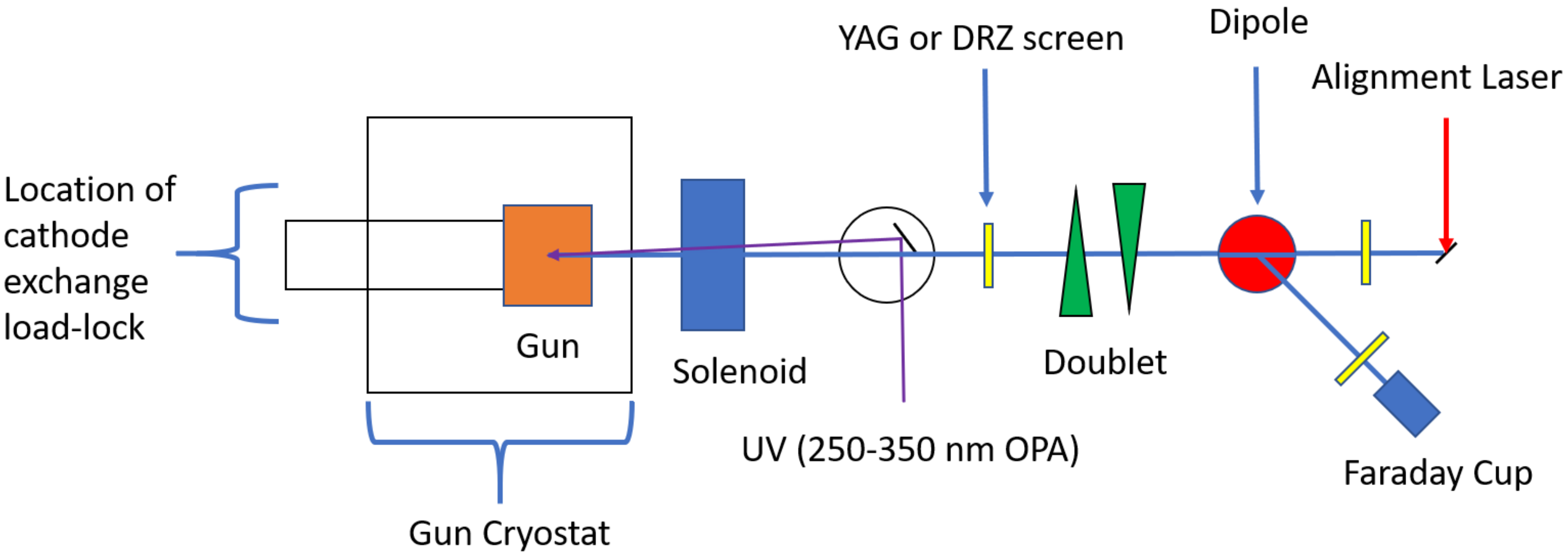
Bonus Slide


AL125 Cryorefrigerator Capacity Curve
Power (Watts)
140
120
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
Temperature (K)
70
90
108
120
Certified Operating Range @ 60 Hz


CH-110LT 40K
Heat Load [W]
300
250
200
150
100
50
0
0
40
80
120
160
200
240
280
Temperature [K]
60Hz
50Hz

3. ½ Cell w/ diagnostics

- Simplified phase 1 of cryogenic test bed design
- Measurements of QE for cryogenic copper



3. ½ Cell w/ diagnostics

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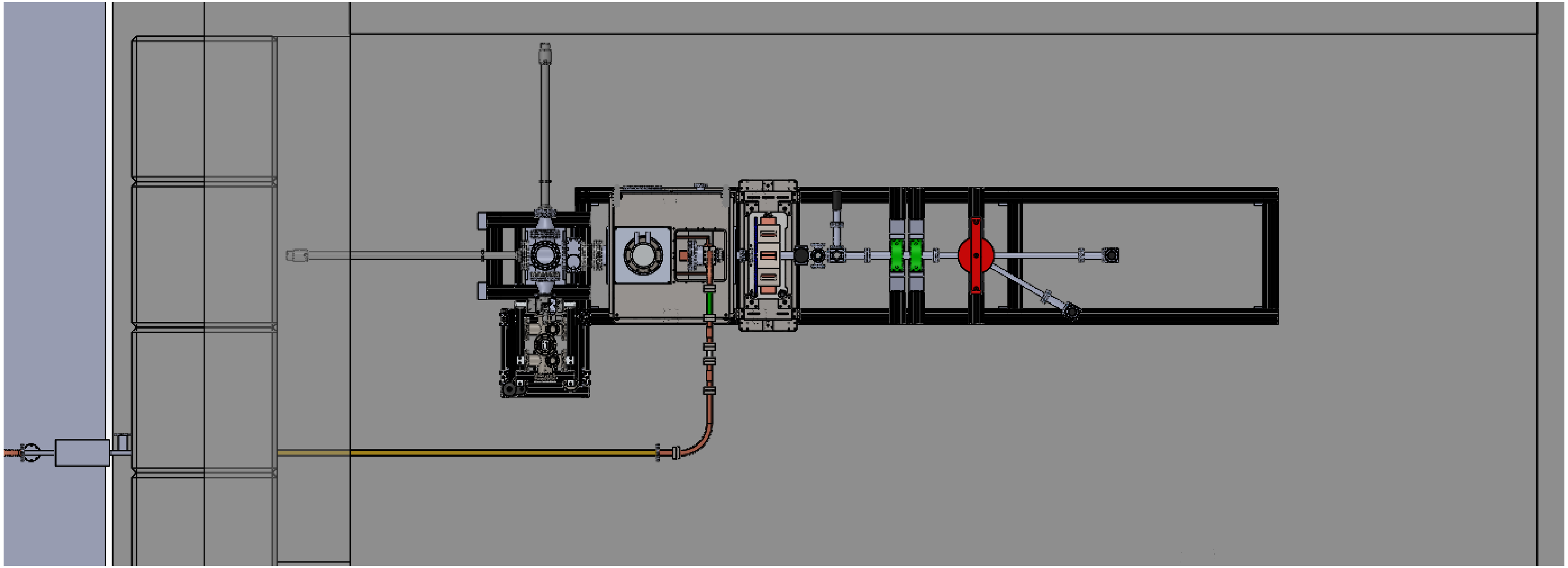
- Measurements of QE for cryogenic copper

5.2 m

1.37m



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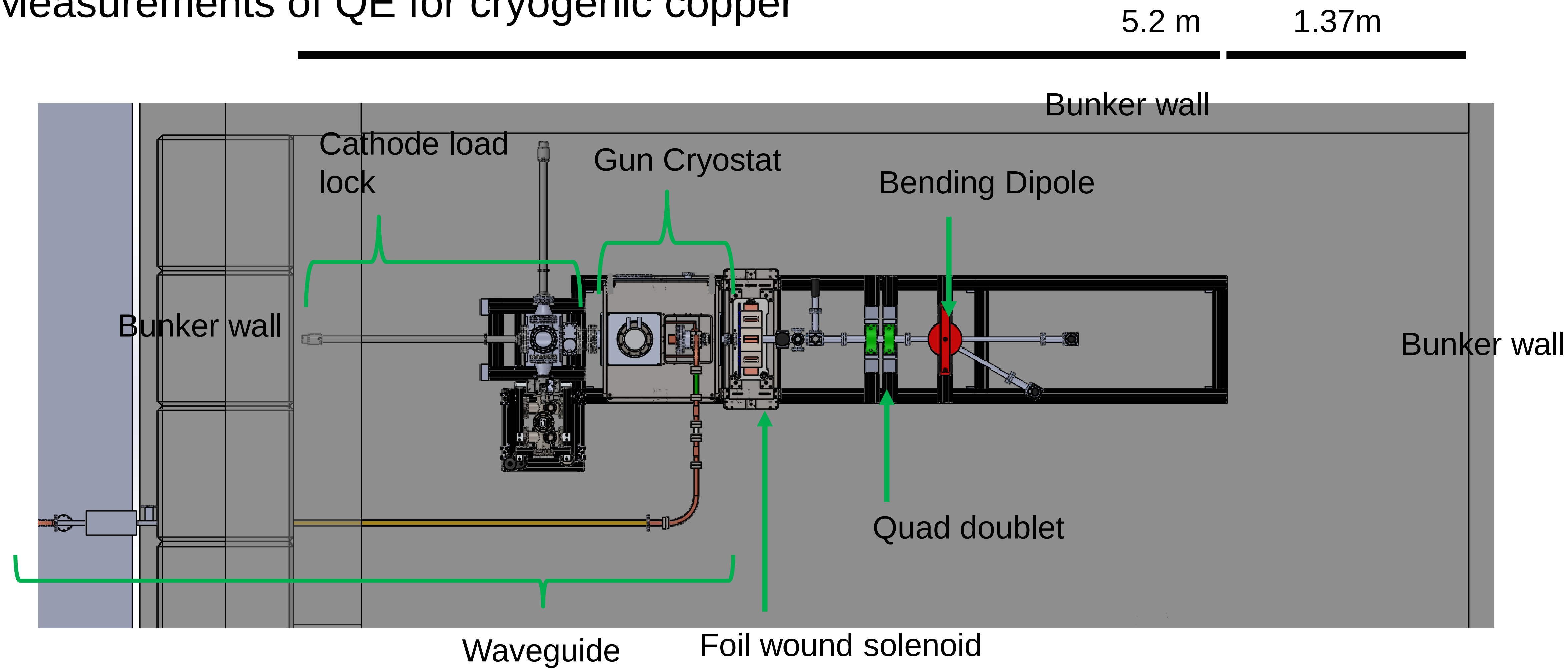

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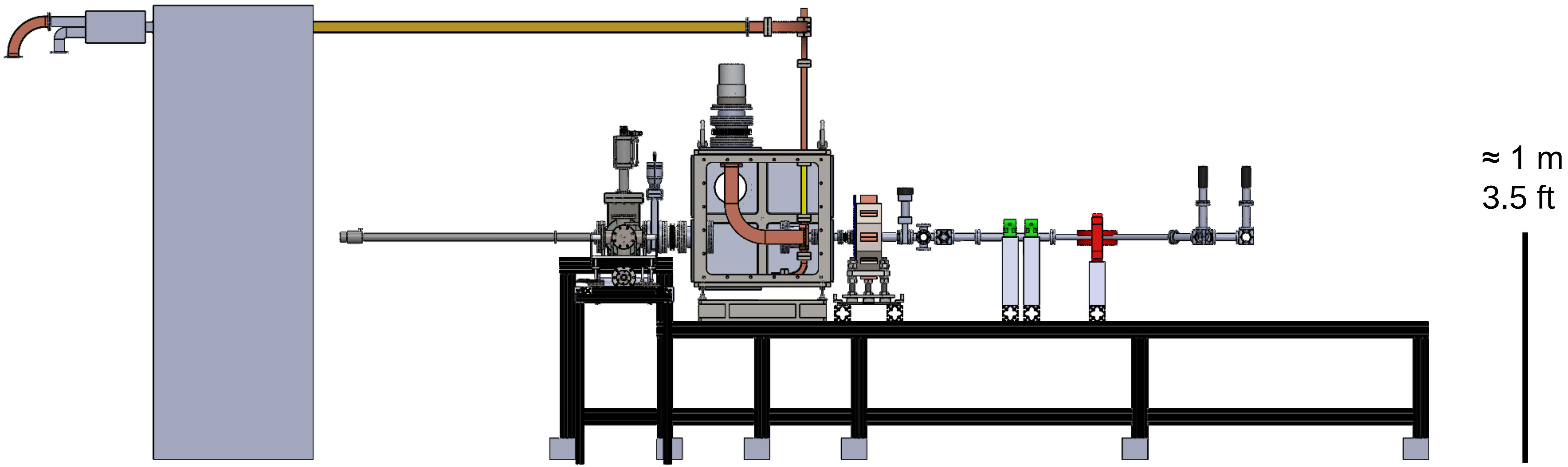

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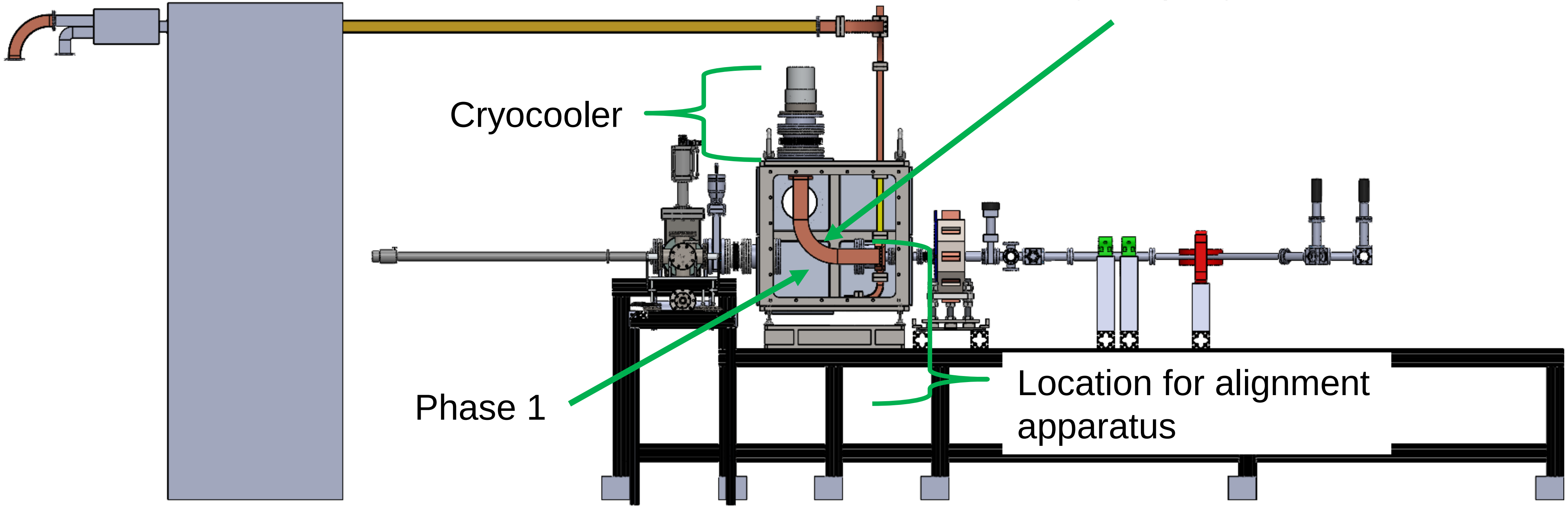

Thermal braids for cavity coupling

Cryocooler

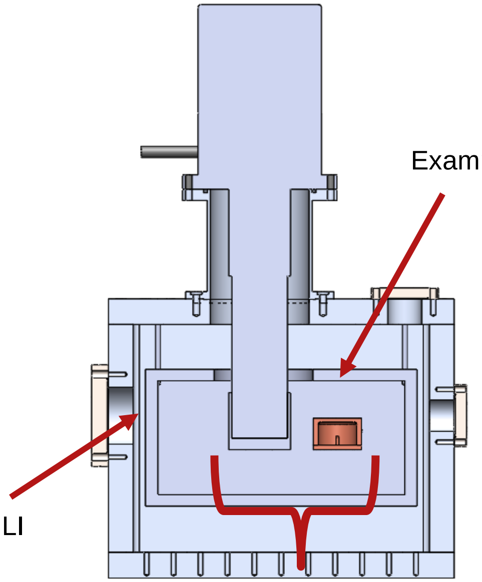
Phase 1

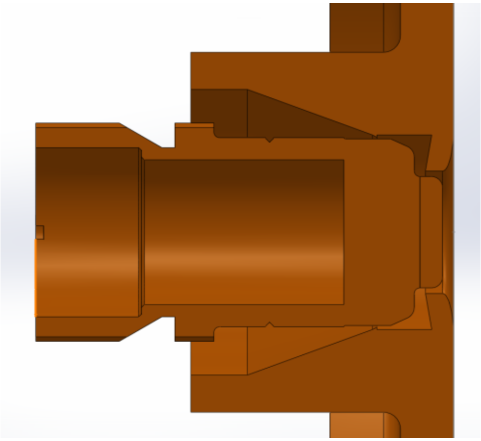
Location for alignment apparatus

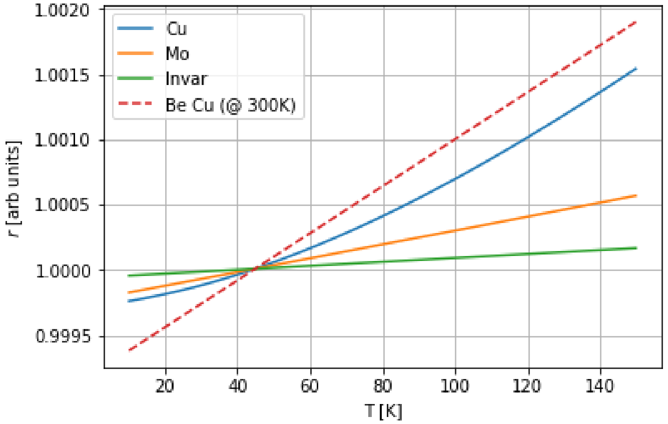
≈ 1 m
3.5 ft

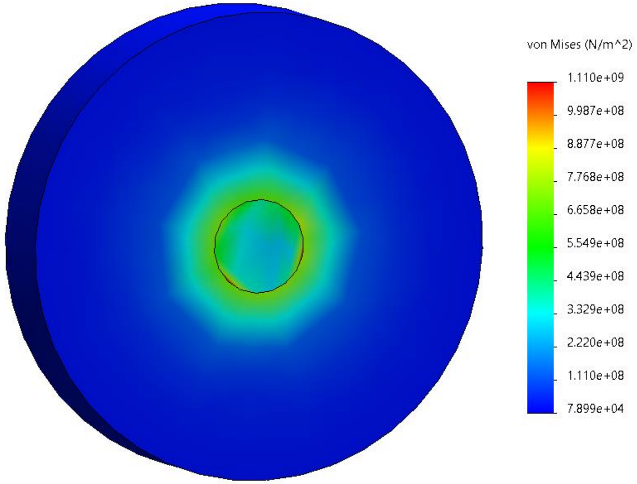
3. Cathode integration cont.

- For 1st phase of test bed, CF flange sealed off w/ blank from back of cavity and test copper cathode
- Later test involving UHV transfer of cathodes from transfer chamber into gun cell
- Molybdenum substrate puck difficult to achieve knife edge seal UCLA Pegaus experience
- Calculation of radii of hole and plug below and stress from contraction on plug to right and stress calculations below
- Cornell-style leaf spring plug holder complex
- Simplest setup for properties tests at cryogenic temperature (right)





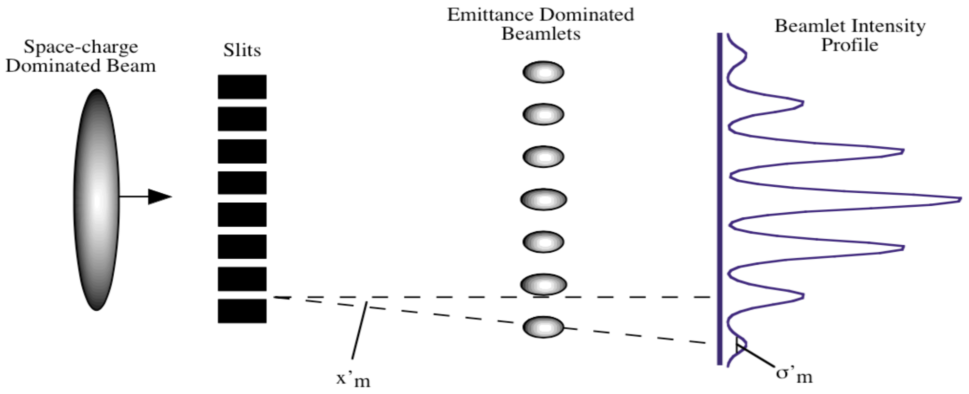


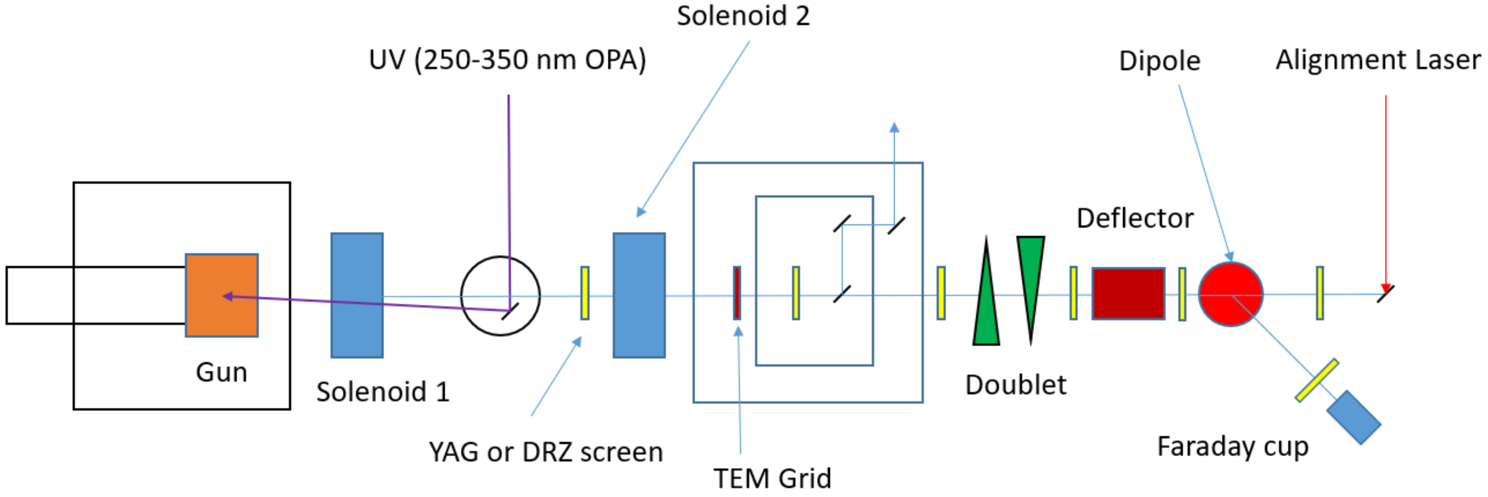


4. Measurement beamline directions

- Phase 1 initial tests of QE will lead to phase 2 MTE measurement of cryogenic copper cathode backplane
- Parallel development of load lock infrastructure
- Phase 2 measurements of QE and MTE of cryogenic semi conductor cathodes

D. Marx et al. Phys. Rev. Accel. Beams 21, 102802 (2018).





4. Conclusions

1. Studies of cathodes in extreme conditions necessary for UCXFEL application
2. Cryogenic temperatures are important regime of study
3. UCLA test beds for these studies progressing nominally

Thank You

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