High brightness electron source using cryo-DC HV photogun

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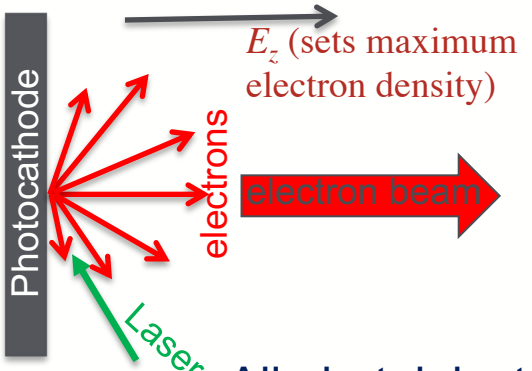
Outline

1. Drivers for high brightness
2. Experimental evidence in favor of cooling cathodes
3. Cryo-cooled HV DC gun concept
4. Simulated performance
5. Gun construction & first beam

Brightness, Emittance and Disordered Cathodes



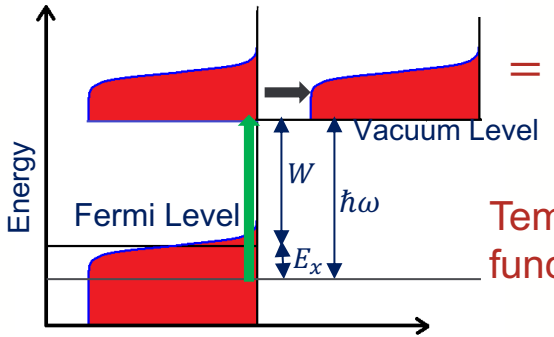
$$B = \frac{I}{\varepsilon_{nx}\varepsilon_{ny}} \propto \frac{E_z}{\mathrm{MTE}}$$

$$\mathrm{MTE} = \frac{1}{2}m\langle v_\perp^2\rangle = \frac{\langle p_\perp^2\rangle}{2m}$$

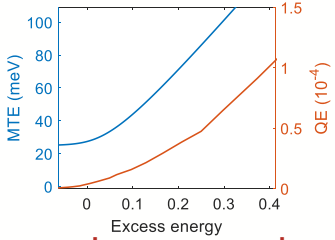
$$\varepsilon_{nx} = \sigma_x\sqrt{\frac{\mathrm{MTE}}{mc^2}}$$

All photoinjectors use cathodes with disordered surfaces (e.g. alkali-antimonides, polycrystalline metals, Cs:GaAs)

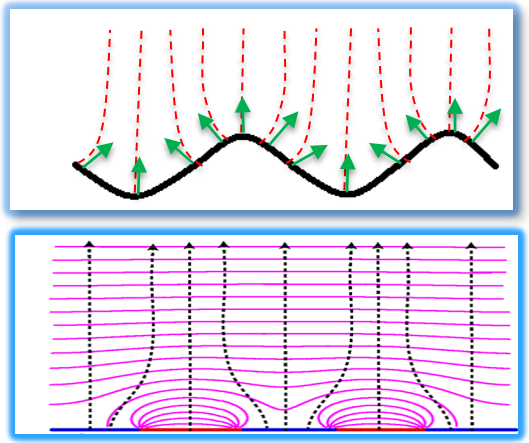
$$\mathrm{MTE} = \frac{E_x}{3} = kT\ (E_x \to 0)$$



Appl. Phys. Lett. 107, 134101 (2015)



Temperature, surface roughness, and work function variations eventually limit MTE



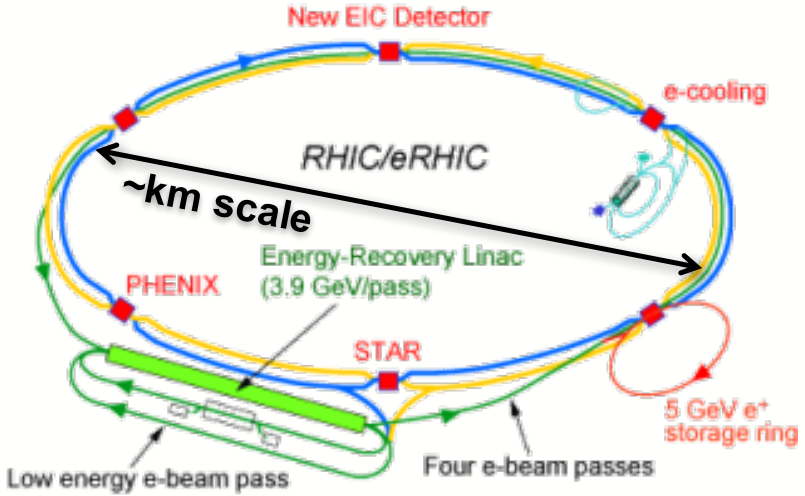
Phys. Rev. Applied 4, 024015 (2015)
J. Appl. Phys. 121, 044904 (2017)

Cornell's Center for Bright Beams

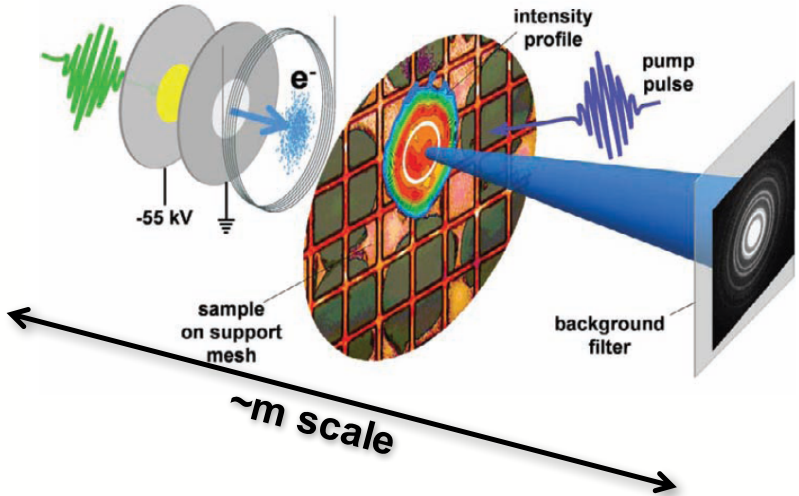
- **x100 brighter electron beams through better photocathodes, guns, beam dynamics, etc.**

Transforms both large scale facilities and compact University-scale setups

E.g. future colliders

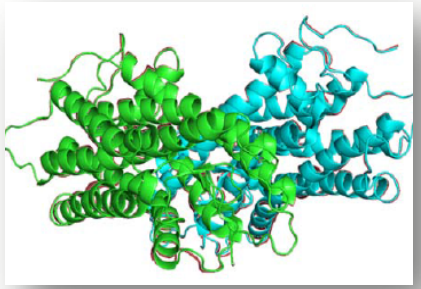


E.g. single shot imaging with electrons

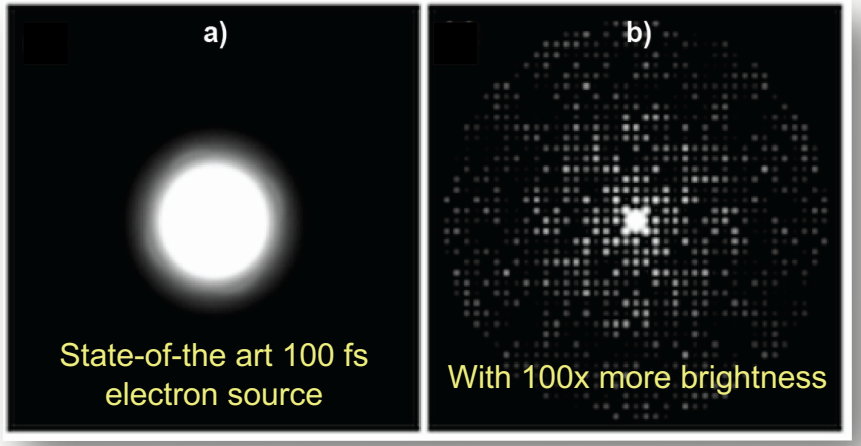


Ultrafast electron diffraction

Toward a molecular movie for biological processes with electrons…



light sensitive protein rhodopsin



1) Coherence length ≥ protein unit cell (~few nm)
2) Time resolution ~100fs (ultrafast scale)
3) Number of electrons (for signal) ≥ 10^5

Coherence length scaling

$$\frac{L_{c,x}}{\lambda\!\!\!^{-}_e} = \frac{1}{\sigma_{\gamma\beta_x}}$$

reduced Compton wavelength

cathode field

final spot size

$$\frac{L_{c,x}}{\lambda\!\!\!^{-}_e} \propto f_\epsilon \sigma_x \sqrt{\frac{m_e c^2}{\mathrm{MTE}}} \begin{cases} (E_0/q)^{1/2}, A \gg 1 & (\text{“pancake”}) \\ E_0(\sigma_{t,i}/q)^{2/3}, A \lesssim 1 & (\text{“cigar”}) \end{cases}$$

cathode emittance preservation ratio $\in (0, 1]$

Phys. Rev. Acc. Beams 19, 093402 (2016)

Points of impact

cathode field

emittance preservation

f_ϵ

E_0

breakdown (DC vs RF; field vs voltage)

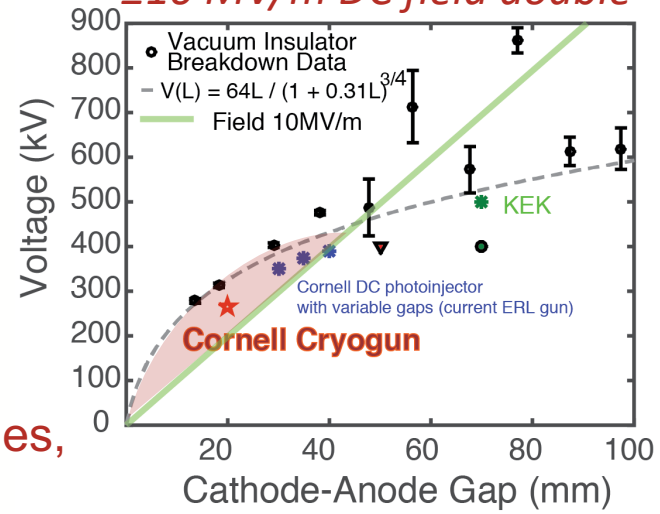
genetic algorithms &
beamline optimization

MTE

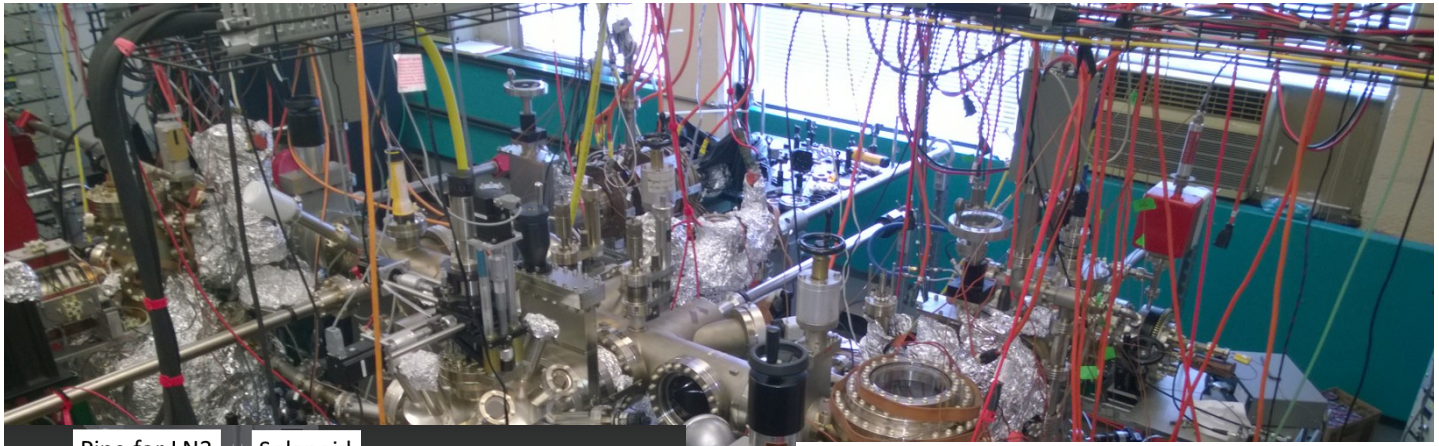
initial beam temperature

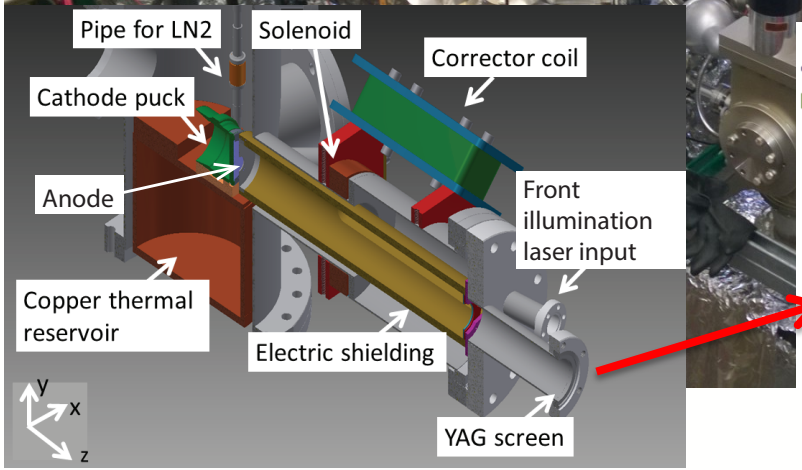
cold atoms, single-crystal cathodes,
cooling disordered cathodes

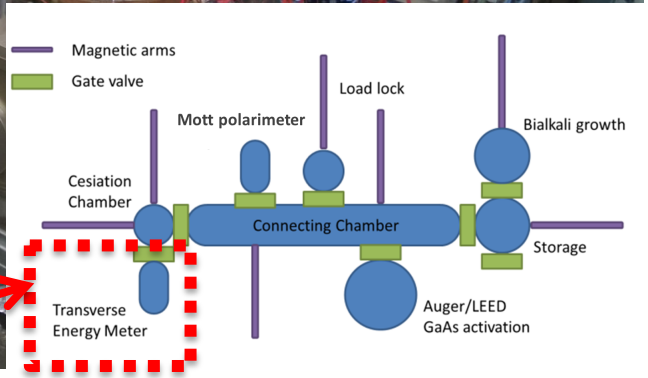
≥10 MV/m DC field doable



Cooling alkali antimonides to 90K



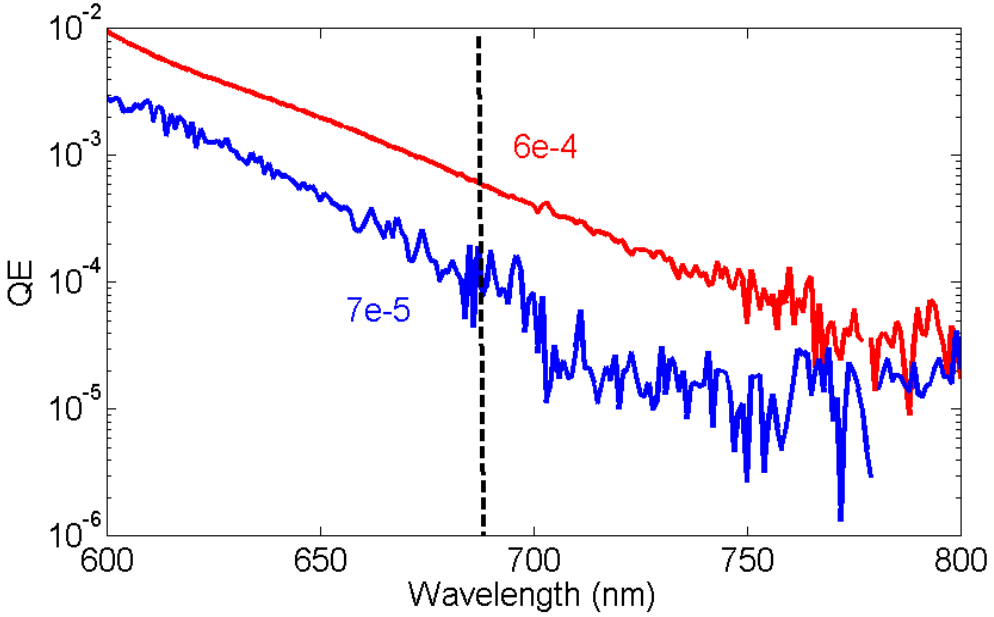


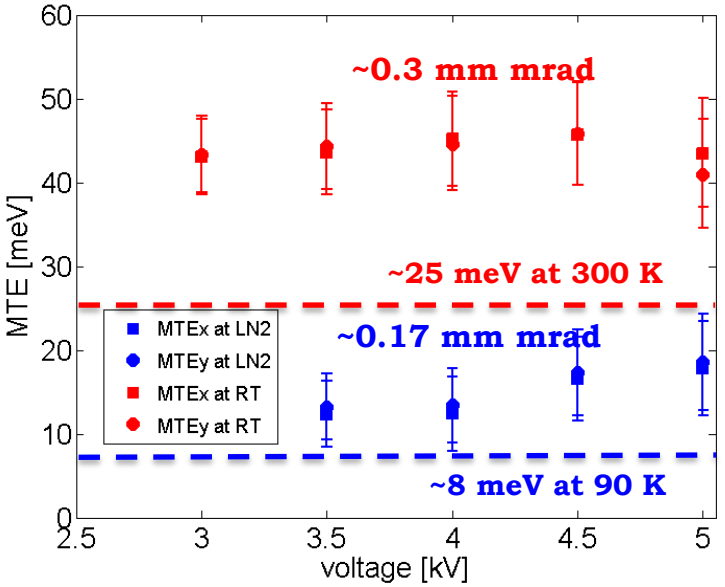


Cooling alkali antimonides to 90K

What happens if we cool the cathode to cryogenic temperature?

As ***T* lowers from 300 K to 90 K**, MTE should lower from **25** to **8** meV



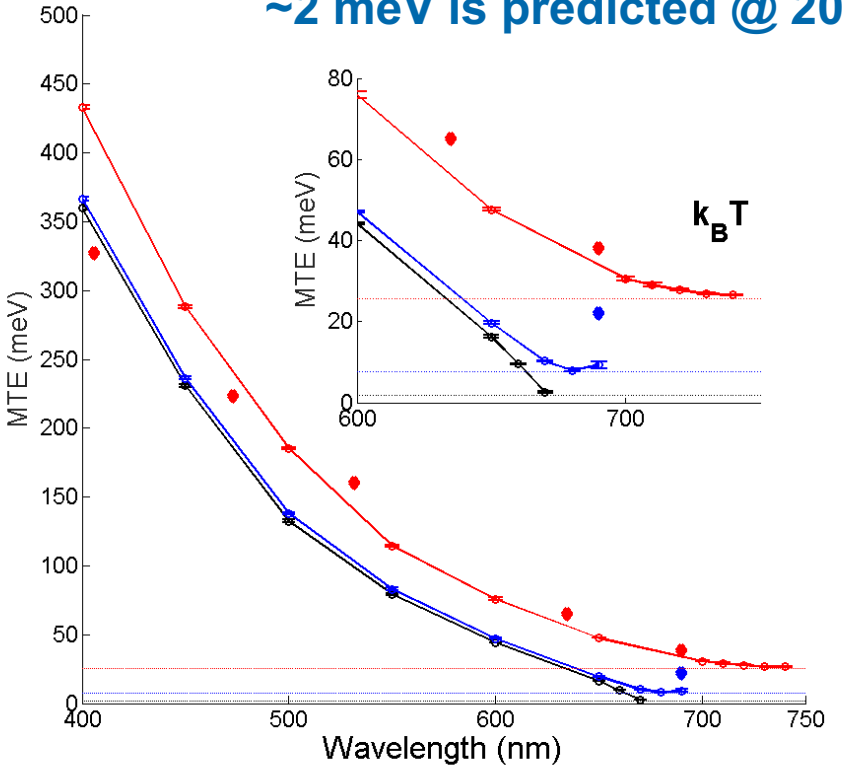


actual MTE ~14 meV or **160 K equiv. temp.**

Cooling even further?

- We suspect that the cathode roughness manifests itself here
- Active research ongoing that promises much smoother surface
- Our Monte-Carlo modeling of the bulk scattering suggests cryo-cooling can bring MTE further down

~2 meV is predicted @ 20K



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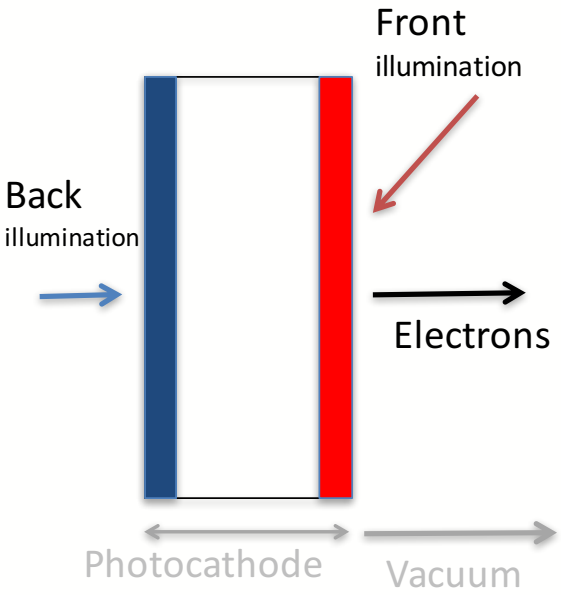
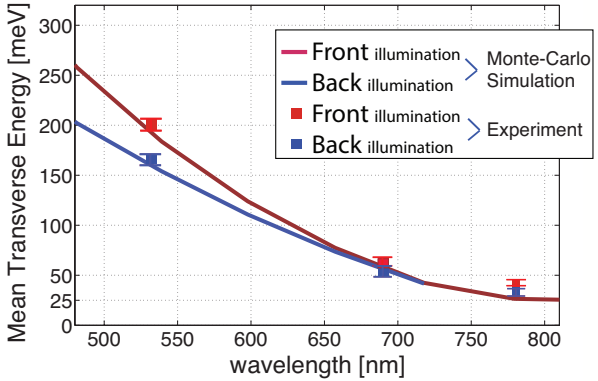
Transmission cathodes



When you shine the laser from back, electrons travel longer through the cathode

Monte-Carlo simulation & experiments showed
The kinetic E reduction

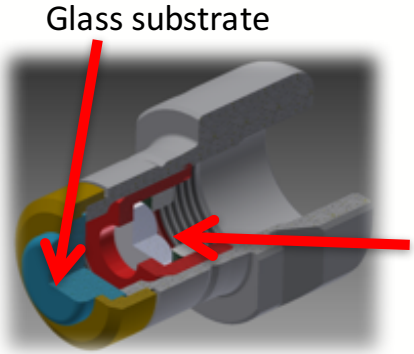


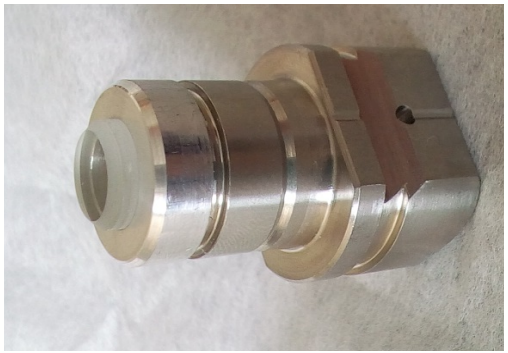
Back illumination makes brighter electron beams!

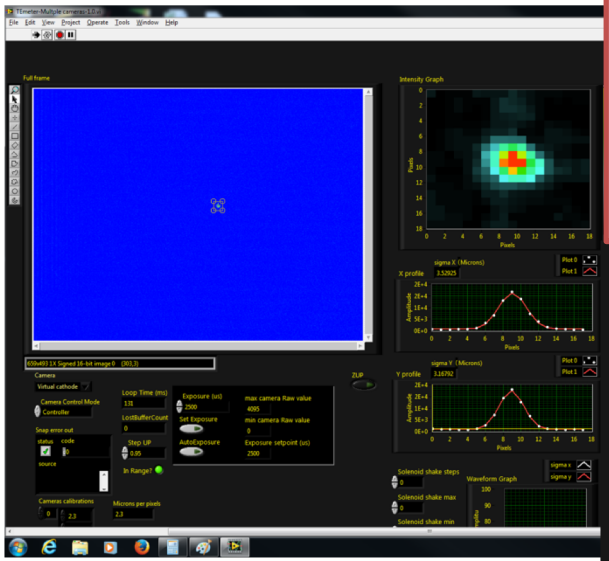
Appl. Phys. Lett. 108, 124105 (2016)

Best configuration for tight laser focusing

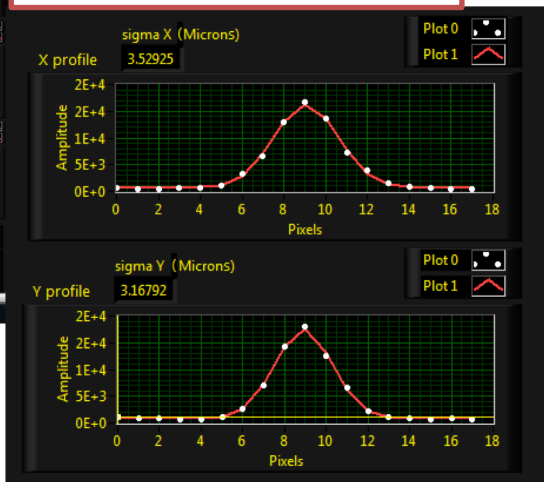
~µm size laser spot can be obtained using transmission cathode → place a ~mm focusing lens in-vacuum behind the glass substrate







~3 µm rms laser spot on the cathode

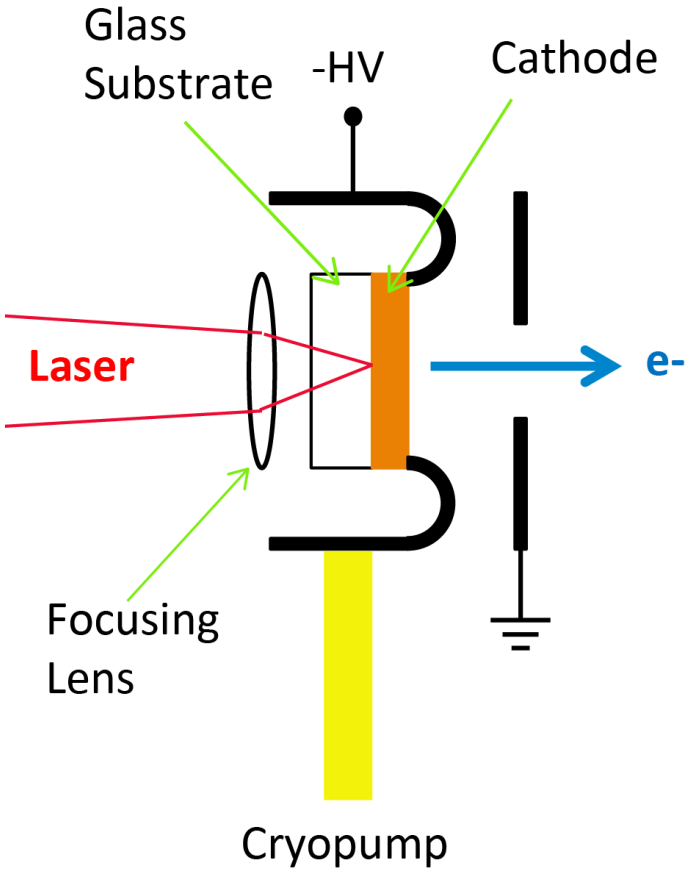


Cryo-cooled photogun concept

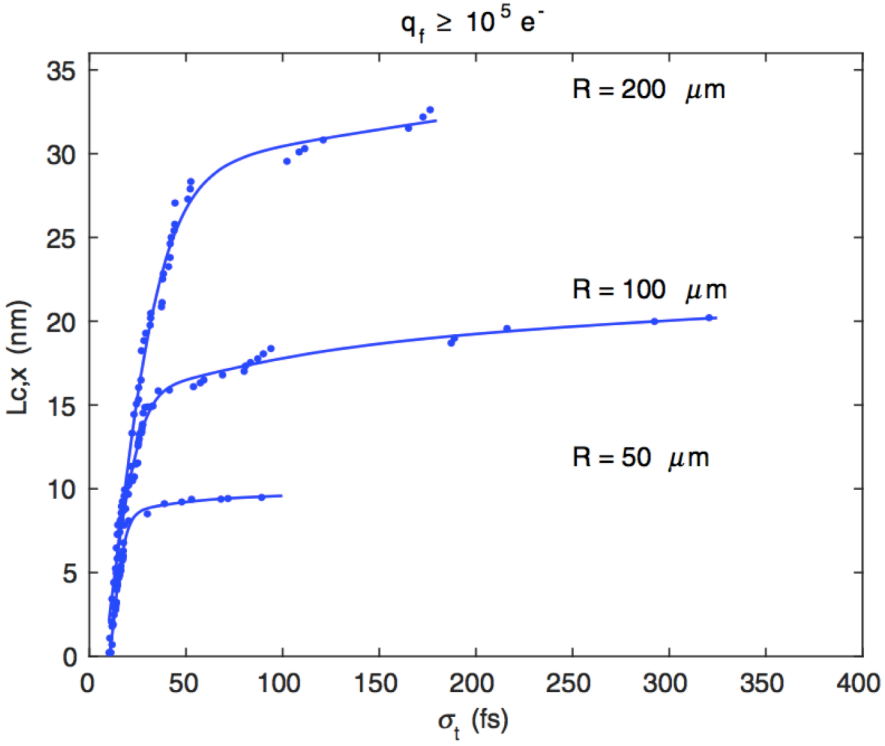
1) HV DC photoemission gun
   - Voltage: >200kV
   - Cathode E-field: >10MV/m

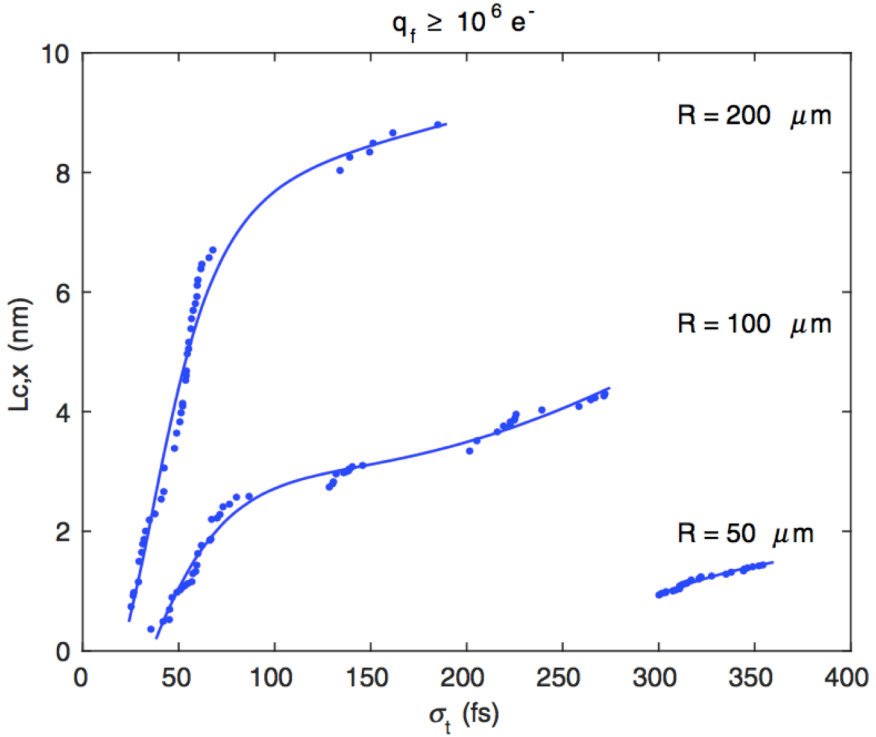
2) Cathode cryo-T (20K)

3) Compact design



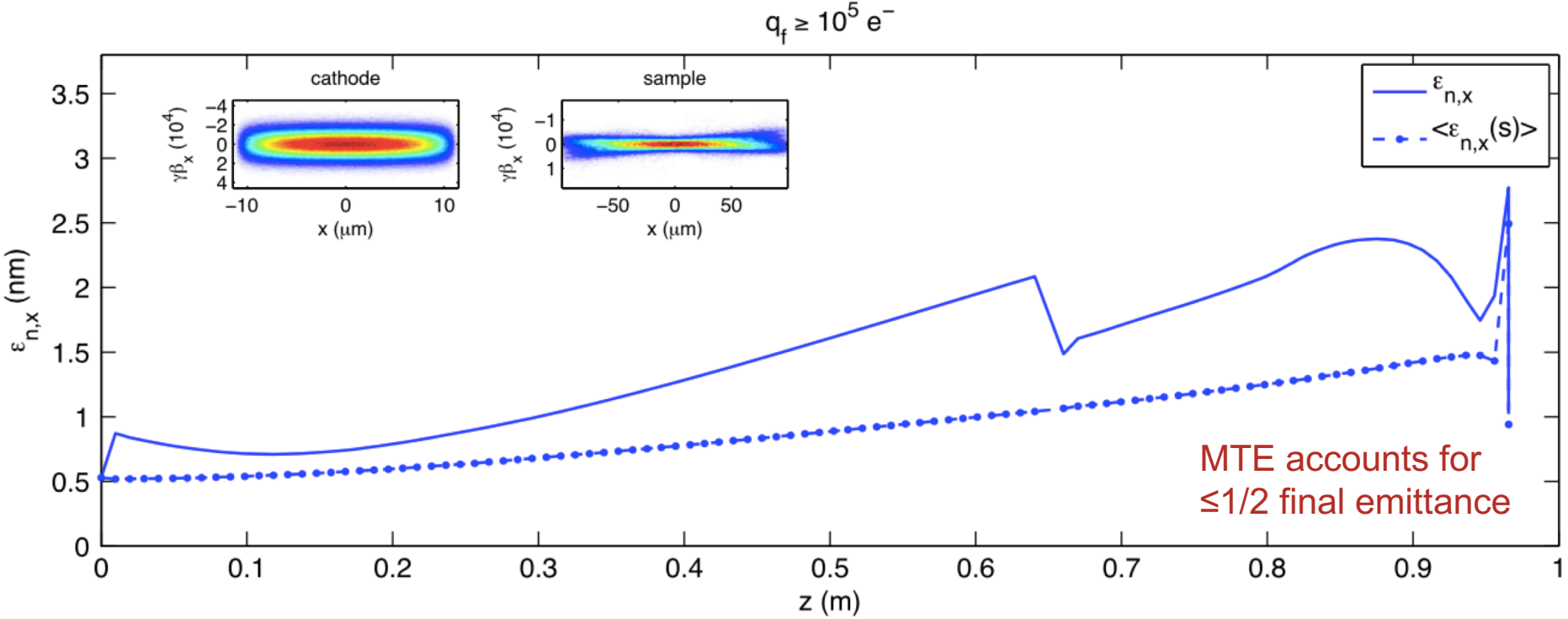
Simulated performance





Phys. Rev. Acc. Beams 19, 093402 (2016)

10^5 electrons (MTE = 5 meV)



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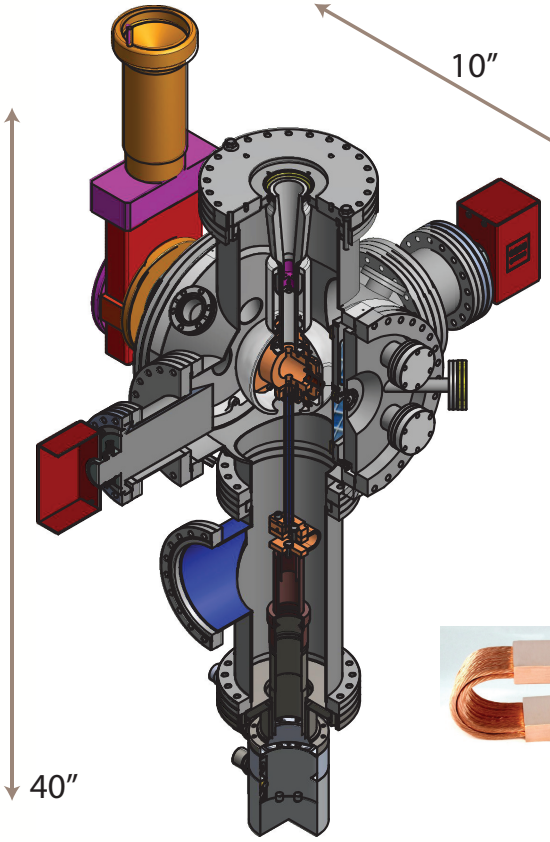
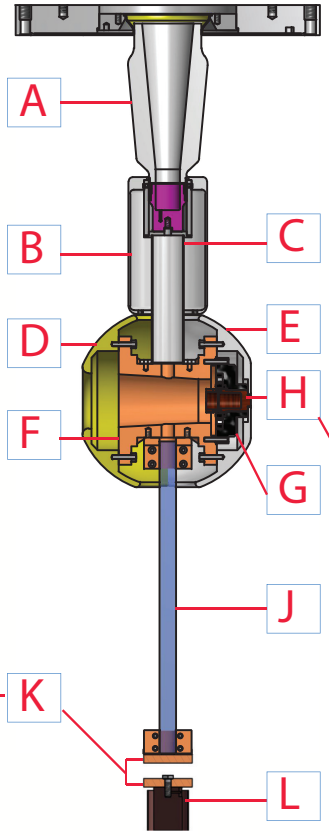
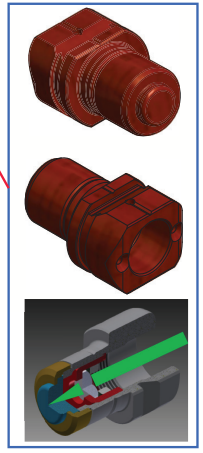
Gun construction



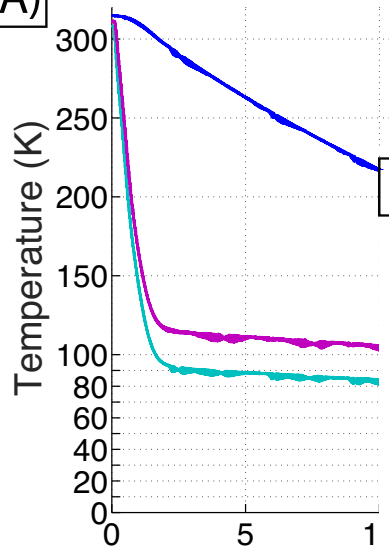


(A) Insulator
(B) Screening electrode
(C) HV stalk
(D) Back electrode
(E) Front electrode
(F) Copper core
(G) Puck holder
(H) Minipuck
(J) Sapphire rod
(K) Copper strap
(L) Cryopump

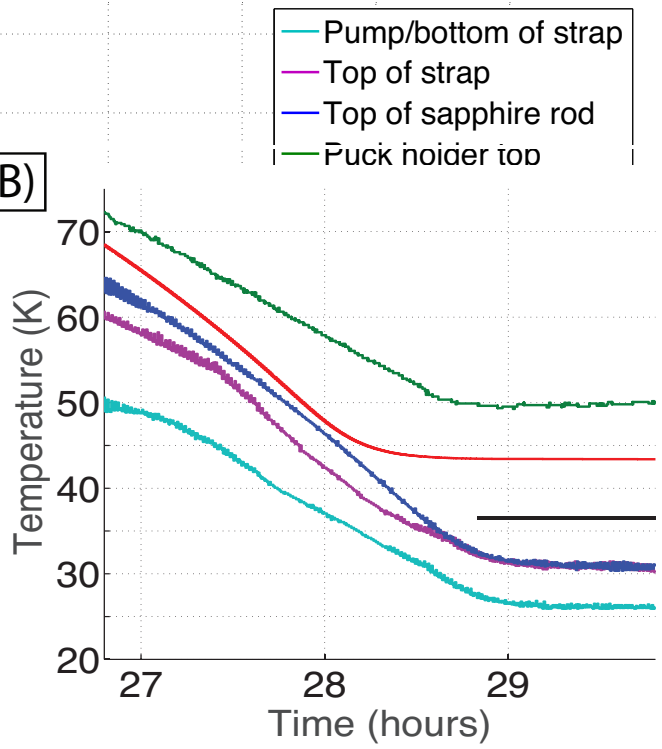


Cryo-tests

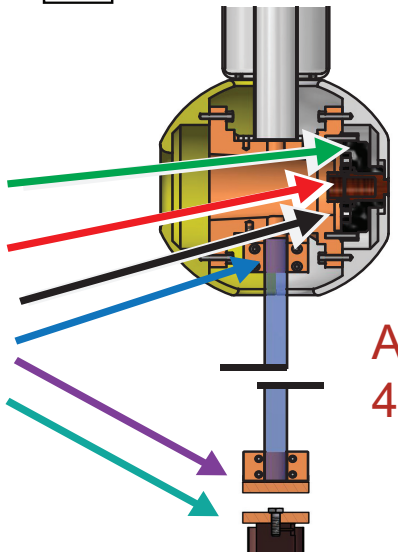
(A)



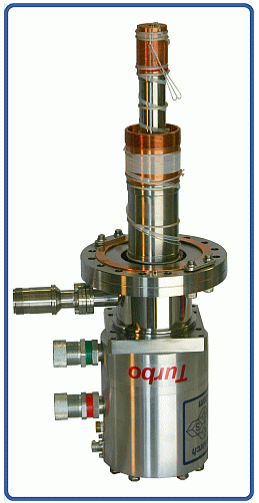
(B)



(C)

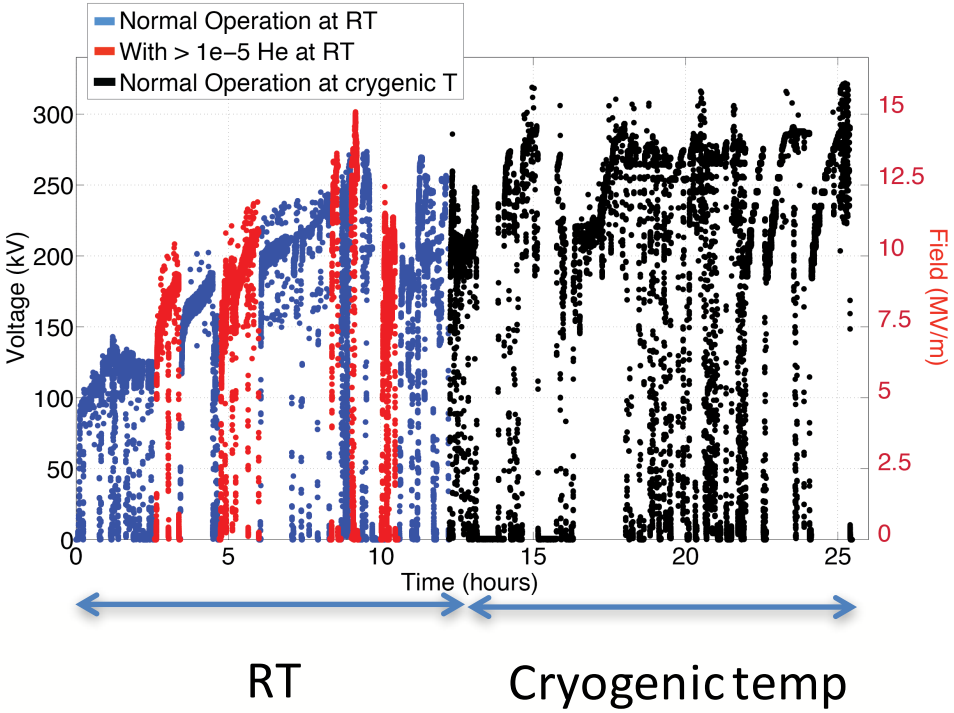


Cryopump
(~6W at 15K)

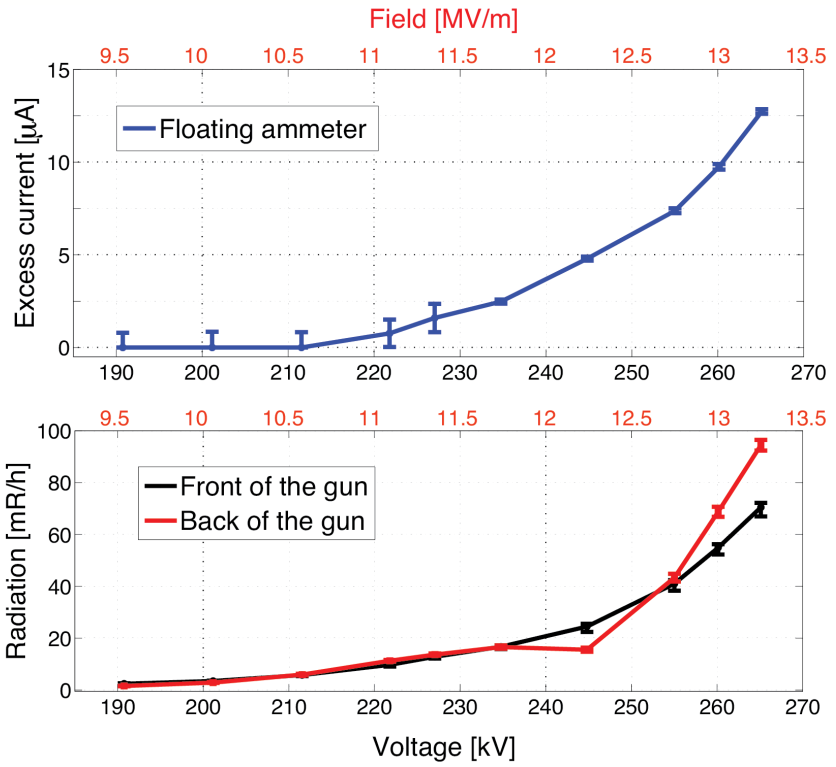


At the cathode
43±1K

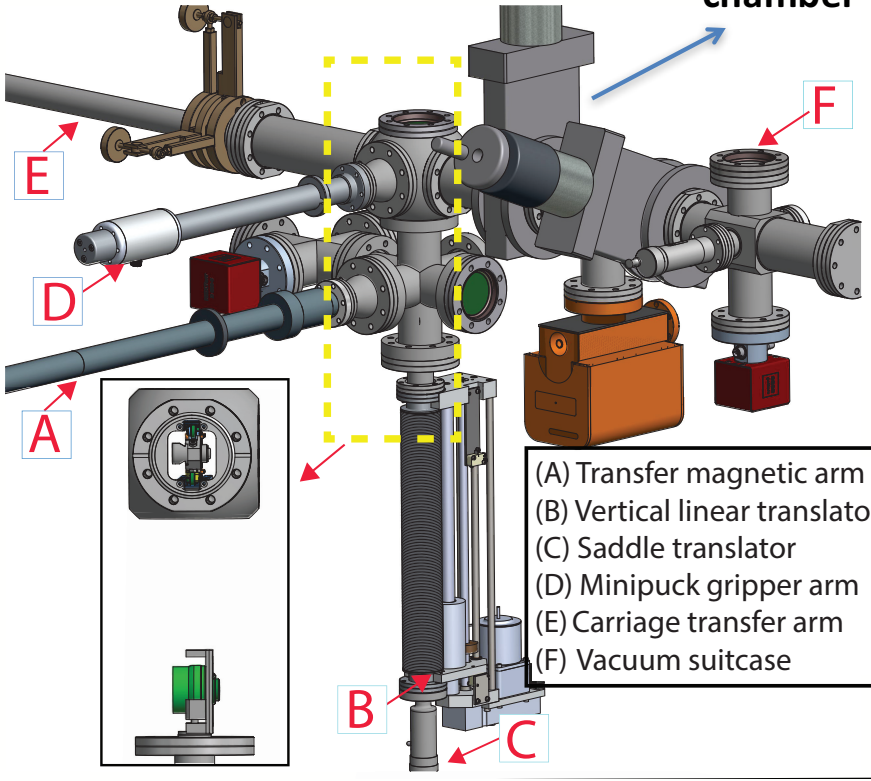
HV processing

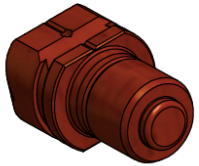


Performance at cryogenic temp



Puck transfer

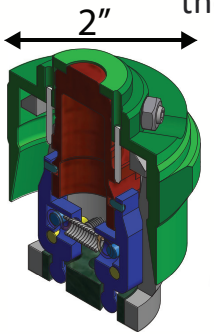




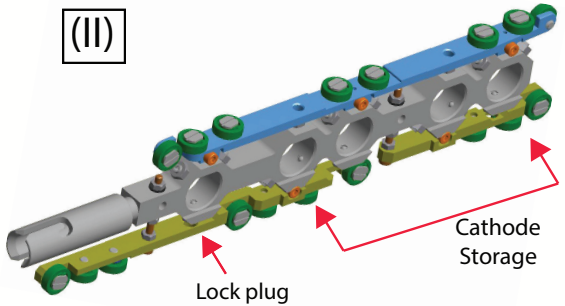
Photocathode puck
(INFN/DESY/LBNL miniplug)

Interface jacket to the old Cornell puck

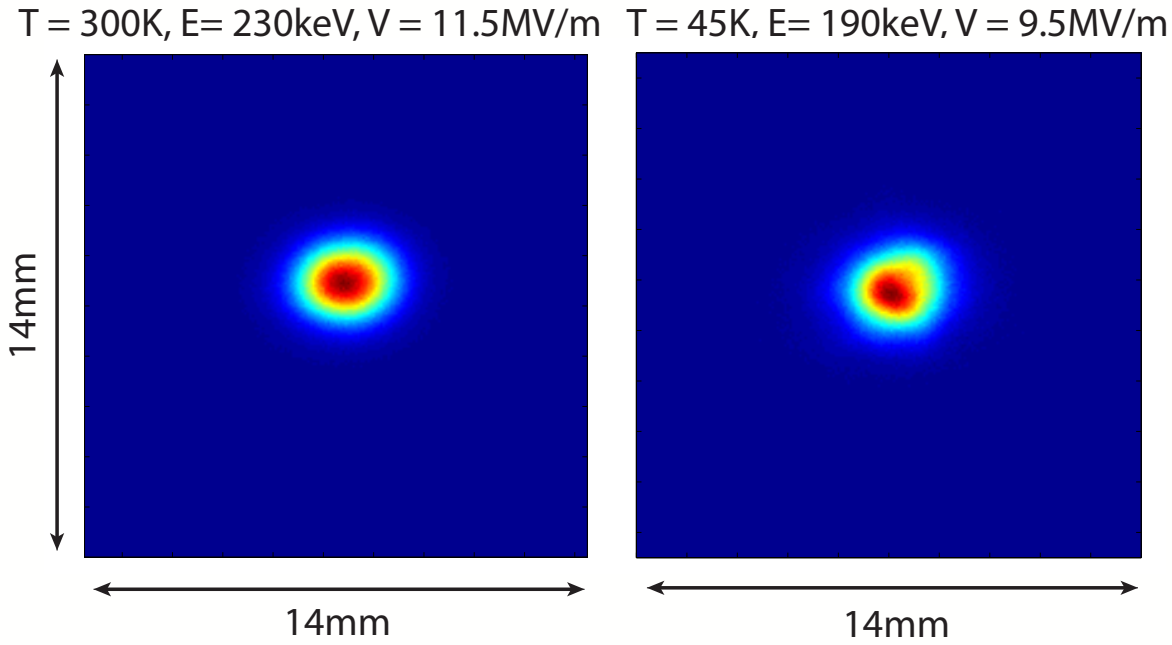
(I)



(II)



First beam!



- Made first beam at ~200 kV (10MV/m) at both RT and cryo-T (40K)
- The gun is now being relocated to its permanent home, more results soon!