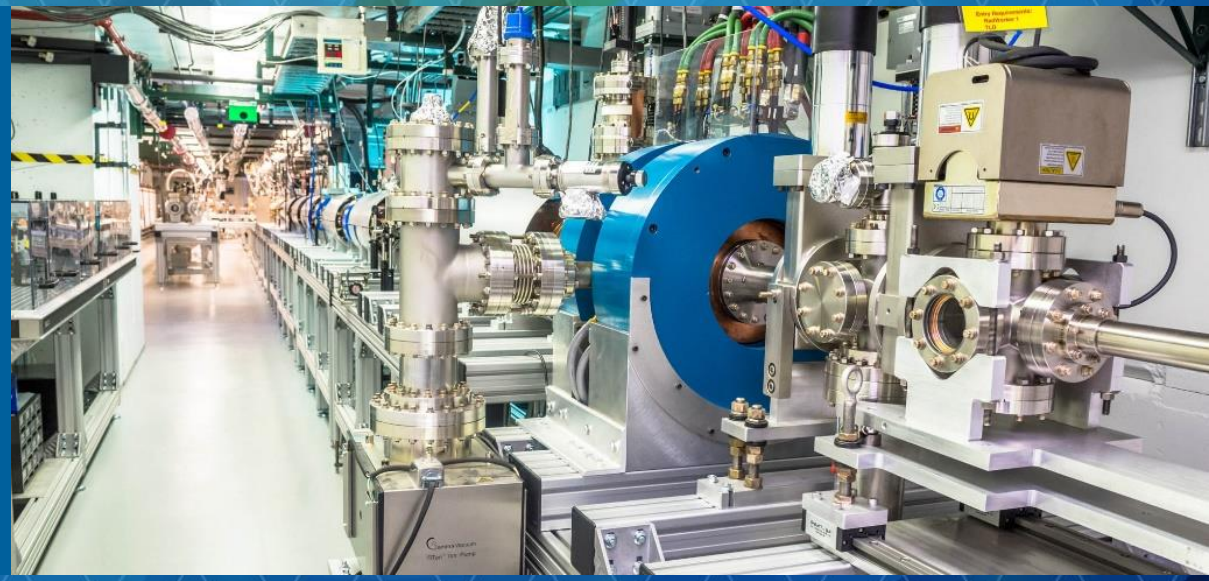
P3 2021 WORKSHOP NOV 10, 2021

ARGONNE WAKEFIELD ACCELERATOR FACILITY PHOTOCATHODE R&D PROGRAM UPDATE



ERIC WISNIEWSKI

AWA FACILITY MANAGER , ANL/ HEP

Session B

AWA RESEARCH THEMES

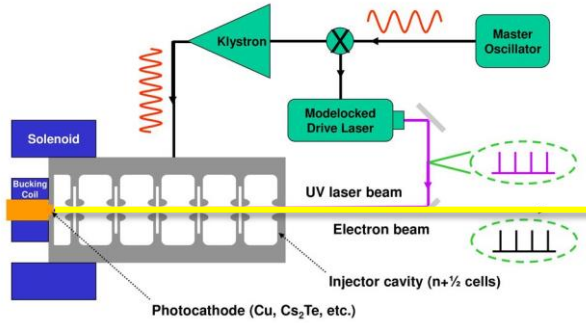
Long lasting, timeless research themes

APPLICATION

THEME 3 | THEME 2 | THEME 1

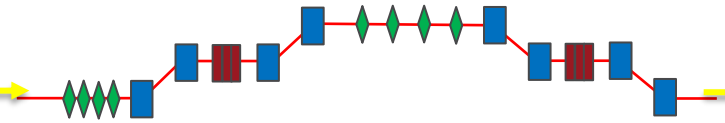
Beam Production → **Beam Manipulation** → **Advanced Accelerator** → ★

e.g. RF Photoinjector



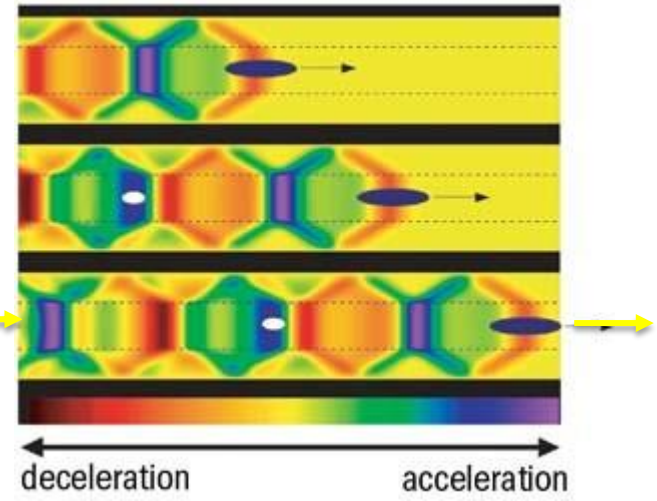
High-brightness and high-charge electron sources, novel cathodes

e.g. Double Emittance Exchange



Beam manipulation and control. Beam Diagnostics.

e.g. SWFA



High-gradient & high-efficiency SWFA & PWFA acceleration

AWA STAFF (2021)

NATIONAL LABORATORY

11 AWA STAFF

- **7 full-time, 4 part-time**

STRONG INDUSTRY CONNECTIONS

STRONG UNIVERSITY CONNECTIONS

Early Career Award

Group Leader

John Power

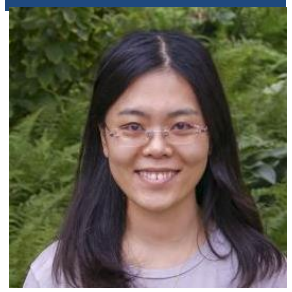
Advanced Accelerator Concepts

Chunguang Jing
Euclid/AWA

Beam Physics

Philippe Piot
NIU/APS/AWA

Advanced Accelerator Concepts



Xueying Lu
NIU/APS/AWA

Advanced Accelerator Concepts

Xiaowei Wu

Controls & RF Systems

Wanming Liu

Mech. & Civil Engineering

Scott Doran

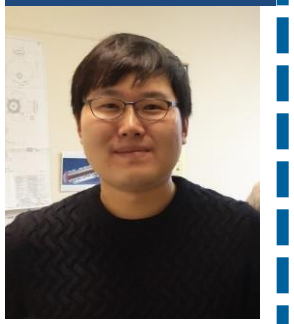
AWA Facility Manager

Eric Wisniewski

Making things work

Charles Whiteford

Beam Physics



Seong-Yeol Kim
(postdoc)

Beam Physics

Gwanghui Ha
(postdoc)

New Hires

Joint Appointment

Guest Scientist

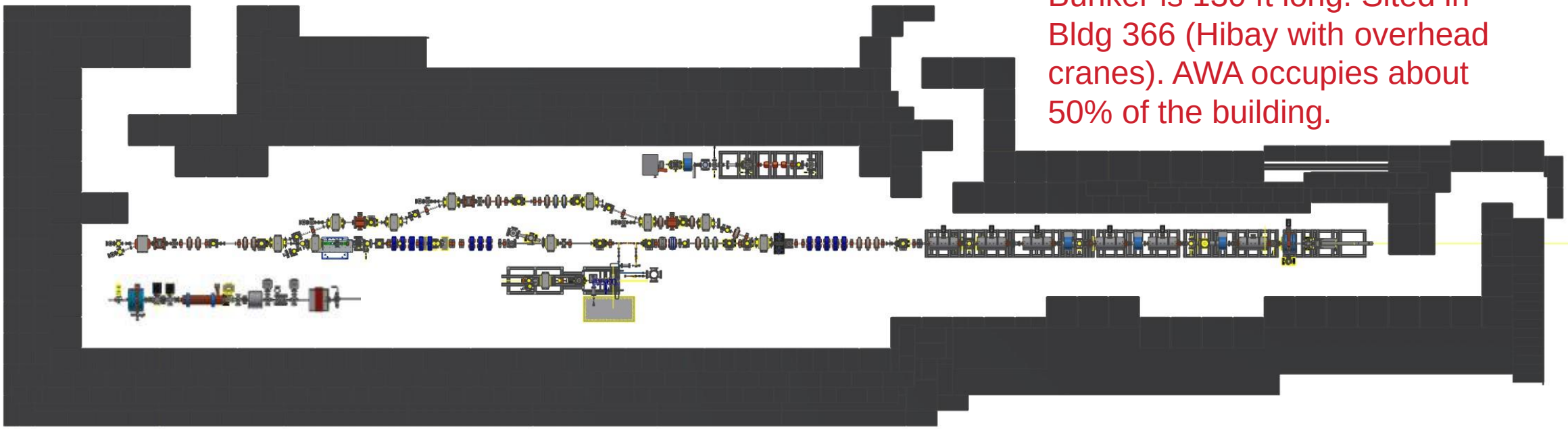
AWA BEAM PRODUCTION/ELECTRON SOURCES R&D CAPABILITIES - CURRENT

High Gradient Cathode Testing in NCRF gun

- **NCRF gun characterization of photocathodes and field emission cathodes**
  - High gradient RF testing (ACT)
  - Field emission testing and imaging (ACT)
  - Charge, QE measurement and emitter mapping capability
  - thermal emittance measurement and mapping
- **High-quality photocathode beam generation**
- **Cathode Development**
  - AWA developed and operates its own in-house high-charge large format Cs_2Te cathode deposition system
  - In-situ QE measurement vacuum chamber, second deposition chamber under construction
  - Kelvin probe work function (CPD) measurement vacuum chamber
  - SEM and other surface studies support available through other ANL divisions ie. CNM, MSD

AWA FACILITY OVERVIEW

3 L-band photoinjector beamlines (+ 1 X-band TW photoinjector), all beamlines dedicated to Accelerator Physics research: "the accelerator is the experiment"



Bunker is 130 ft long. Sited in Bldg 366 (Hibay with overhead cranes). AWA occupies about 50% of the building.

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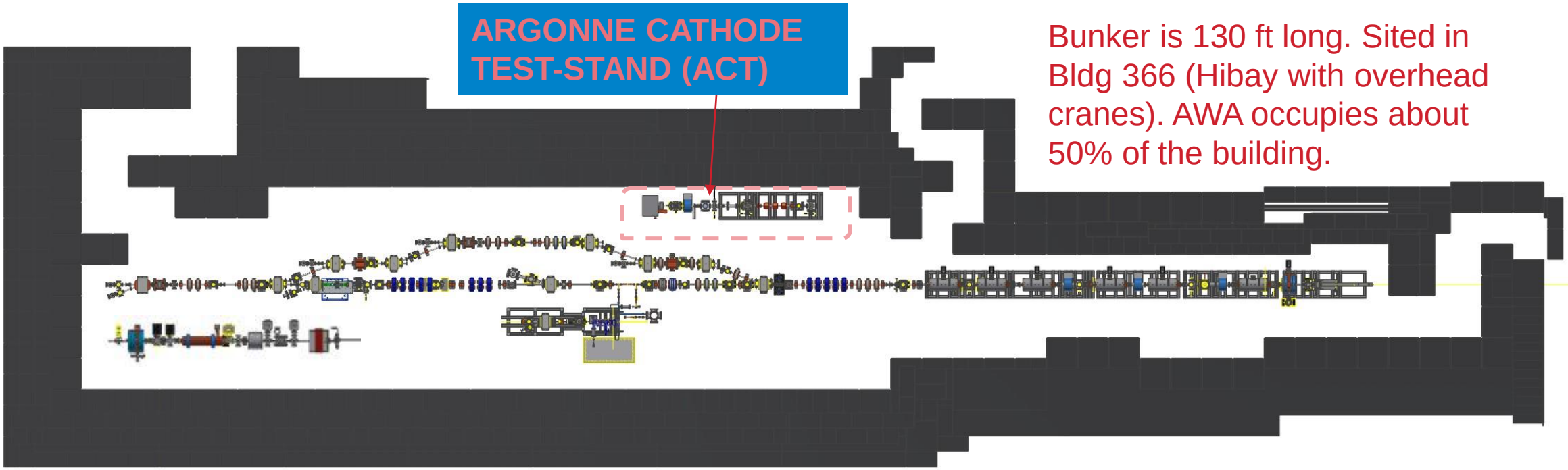

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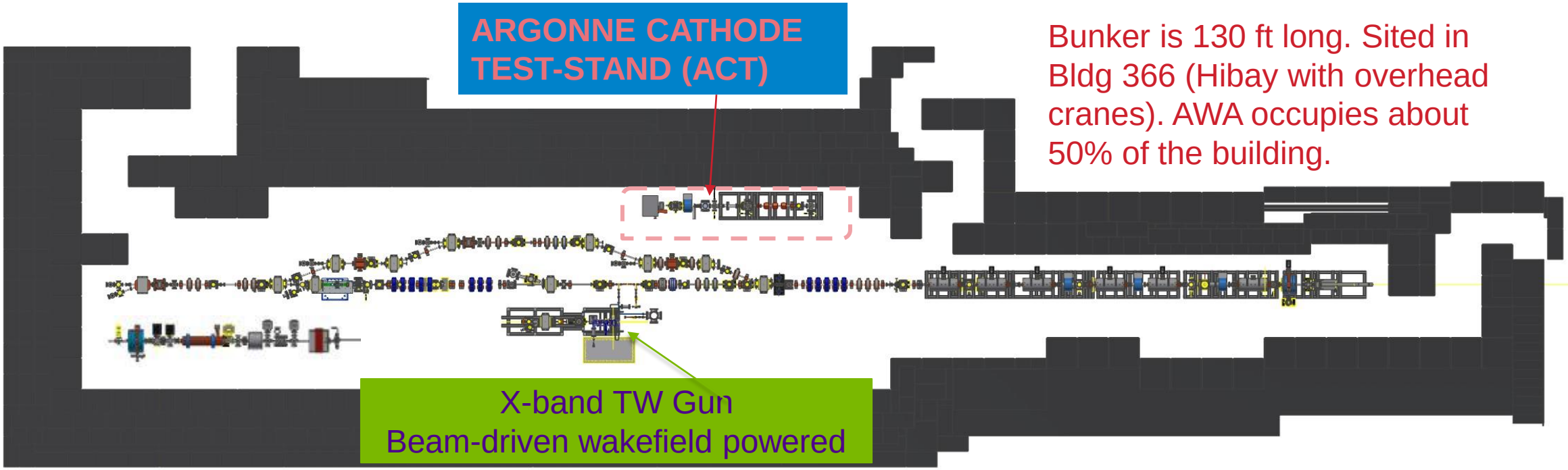

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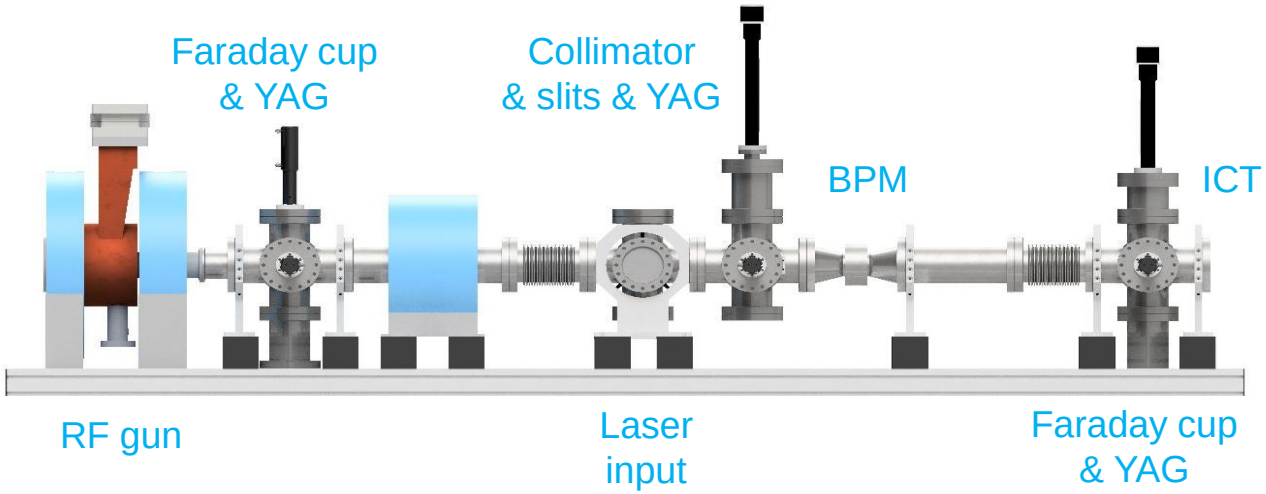
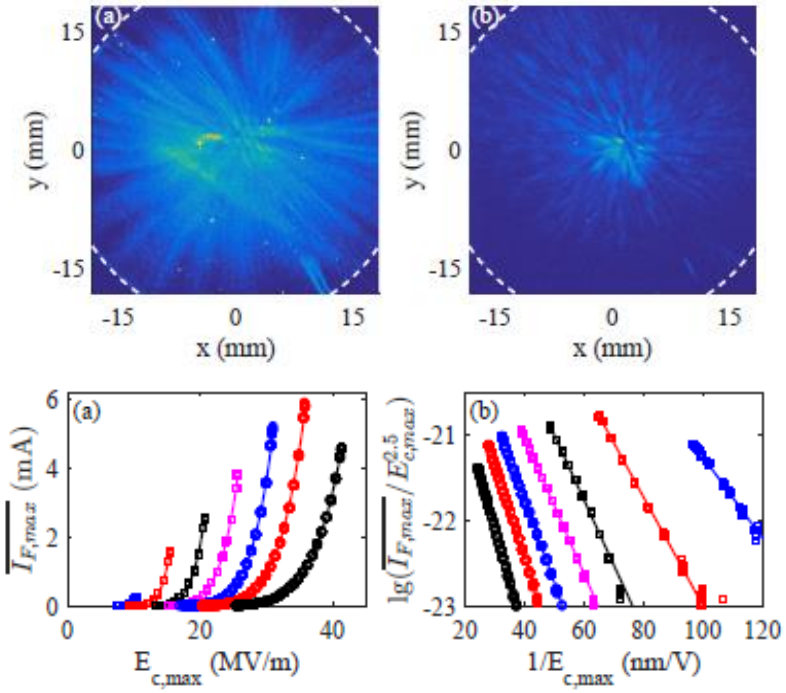
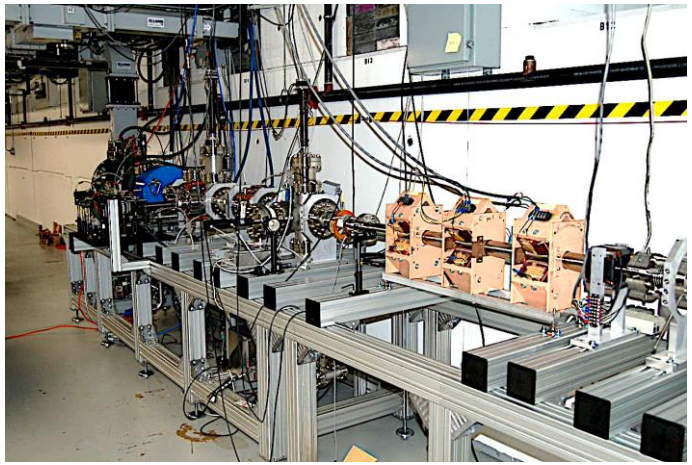
ARGONNE CATHODE TEST-STAND (ACT)

Standalone beamline dedicated to fundamental R&D on Field Emission and RF breakdown, novel cathodes, and low energy beam applications





- **Capability**
  - FE/BD study: BD location, FE imaging
  - Cathode study: QE, charge, transverse profile
  - Application: low energy beam (field emission/photoemission) delivered with quad triplet focusing to the ample space at the end of the beamline



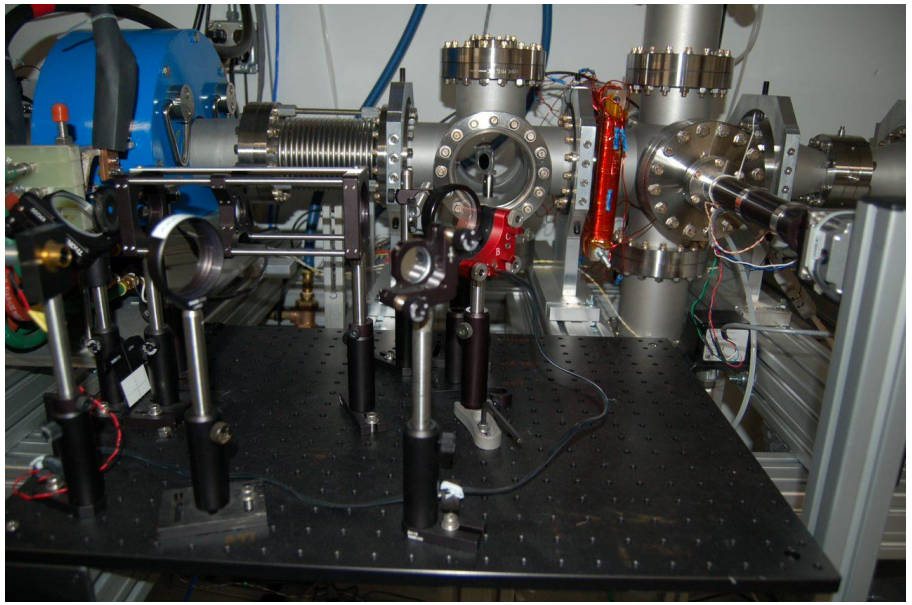
ARGONNE CATHODE TEST-STAND (ACT)

Details

- L-band 2.5 MW
- Vacuum: 5x10^{-9} Torr
- Rep rate : 2 Hz
- Duration: 5 μs flat top
- Field for DFEA experiments: 10-35 MV/m
- Field for breakdown studies of flat cathode: 0-100 MV/m
- Protruding tip cathode: max field up to 700 MV/m

ACT UTILITY AND CAPABILITIES

- RF testing at high gradient
  - RF testing high gradient 0-100 MV/m with flush-mounted flat cathode
  - RF testing high gradient up to 700 MV/m with a protruding cathode
- Dark current imaging capability: features include
  - solenoid focusing
  - selectable collimator beamline
  - imaging optics setup with 2” YAG screens
- Laser input system
  - 262 nm laser
  - 1 mJ per pulse
  - 0.4-6 ps variable pulse length
  - 2 Hz rep rate
- Planned upgrades:
  - Load-lock system
  - MLA based laser homogenizer



ACT CATHODE SAMPLE HOLDER ALTERNATIVES

Currently three formats for cathode sample testing at the ACT exist

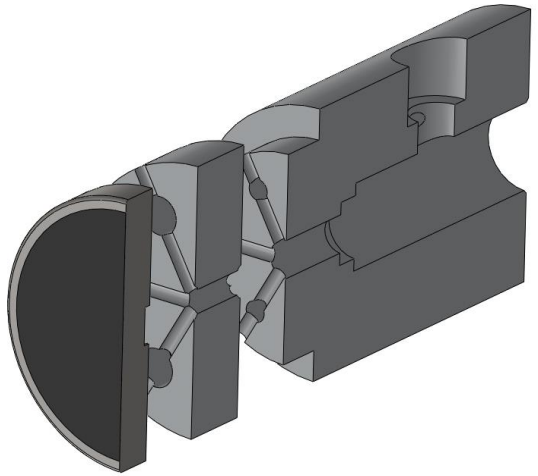
- A one-piece machined and polished cathode (original - example)

- Three-piece cartridge cathode with removable puck
  - Solid metal puck choice of substrate material
  - Thin-film deposited on metal puck in air
  - Re-usable holder
- Three-piece cartridge cathode with captured thin disk
  - Eliminates the need to machine pucks
  - Re-usable holder
- All holders use the same contact spring and actuator

3-PIECE SAMPLE HOLDER - PUCK STYLE

Custom re-usable cathode sample holder

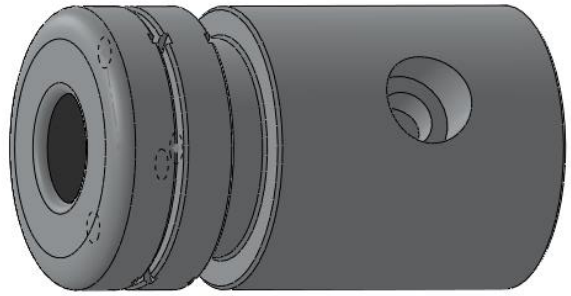
- Some details
  - aluminum or stainless, other material possible
  - surface study friendly design
  - Provides good electrical contact
  - Proven robust design
- Features:
  - Cost-effective: no expense machining pucks; replace only the thin film, re-use the cathode cartridge.
  - Efficient: AWA can pre-load additional cartridges and reduce the turn-around time
- Practical Info
  - Load time is about 30 min. Or less
  - Gun is always purged with dry Nitrogen from a Dewar.
  - Pump time is 3-5 days depending on vacuum requirements.
  - A planned load-lock system installation will improve pumping time



3-PIECE SAMPLE HOLDER -CAPTURED THIN DISK

Custom re-usable cathode sample holder

- Some details
  - developed in conjunction with G. Chen's UNCD studies
  - THIN DISK IS PLACED IN ELECTRICAL CONTACT WITH BODY OF CATHODE AND RETAING RING CAPTURES IT
  - Provides good electrical contact
  - Proven design



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  - Load time is about 30 min. Or less
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AWA CATHODE RESEARCH PROGRAM

– Overview (2019-21)
– Selected highlights

CATHODE RESEARCH

In-house: The AWA group **& Collaborators:** IIT + LANL + *SLAC/LCLS* + *SLAC/THz*

PHOTOCATHODES

RECENT

- **(in-house) Halavanau,** et al., Tailoring of an electron-bunch current distribution via space-to-time mapping of a transversely shaped, photoemission-laser pulse, Phys. Rev. Accel. Beams. 22, 114401 (2019).
- **(in-house) L. Zheng**, et al., Rapid thermal emittance and quantum efficiency mapping of a cesium telluride cathode in rf photoinjector using multiple laser beamlets, Phys. Rev. Accel. Beams 23, 052801 (2020).
- **(IIT) Gongxiaohui Chen,et al**., "Demonstration of nitrogen-incorporated ultrananocrystalline diamond photocathodes in a RF gun environment", Appl. Phys. Lett. 117, 171903 (2020)

FUTURE

- (SLAC/LCLS) John Llewellyn for LCLSII-HE cathode
  - Multiakali photocathode study as a function of preparation methods
  - Primary Goal: Measure field emission and MTE as a function of gradient
  - Stretch goal:MTE at mutliple laser wavelengths

CATHODE RESEARCH

In-house: The AWA group **& Collaborators:** IIT + LANL + *SLAC/LCLS* + *SLAC/THz*

FIELD EMISSION CATHODES

RECENT

- **(in-house) J. Shao**, et al., High power conditioning and benchmarking of planar nitrogen-incorporated ultrananocrystalline diamond field emission electron source, Phys. Rev. Accel. Beams 22, 123402 (2019).
- **(LANL) K. E. Nichols,** et al.,"Demonstration of transport of a patterned electron beam produced by diamond pyramid cathode in an rf gun", Appl. Phys. Lett. 116, 023502 (2020)
- **(LANL) Andrews,** et al., "Shaped Beams from Diamond Field-Emitter Array Cathodes," in IEEE Transactions on Plasma Science, vol. 48, no. 7, pp. 2671-2675, July 2020
- **(LANL) M. Schneider**, et al., FEbeam: Cavity and electron emission data conversion, processing, and analysis. A freeware toolkit for rf injectors, Review of Scientific Instruments 92, 053305 (2021).

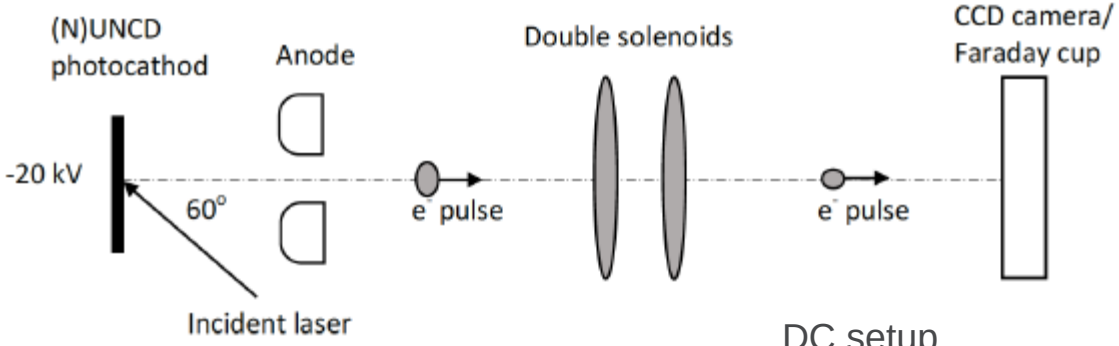
FUTURE

- (SLAC/THz gun) Emilio Nanni – M. Schneider
  - UNCD FE cathodes studies towards a THz e- gun.

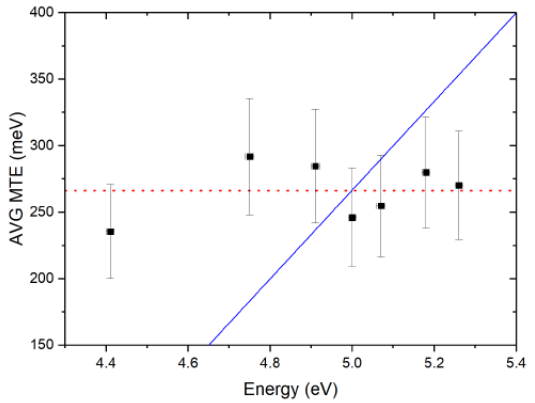
Highlight 1 (photocathode)

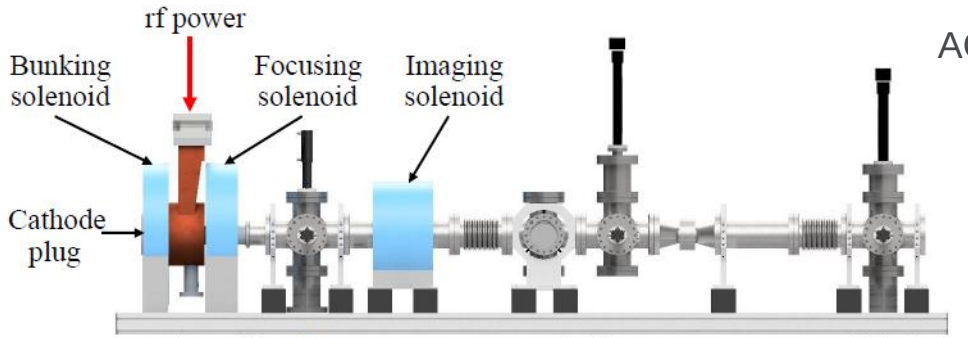
NCRF GUN CHARACTERIZATION OF PHOTOCATHODES

1. (N)UNCD photocathode characterization on ACT compared with the results obtained in DC guns; **G. Chen/L. Spentzouris/et al.,** result: Ph.D. thesis and two APL papers*



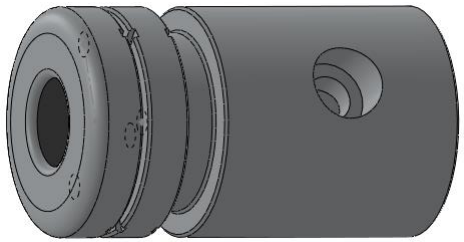
DC setup





ACT

Flexible cathode design



*G. Chen, et al., APL **114**, 093103 (2019), G. Chen, et al., APL **117**, 171903 (2020)

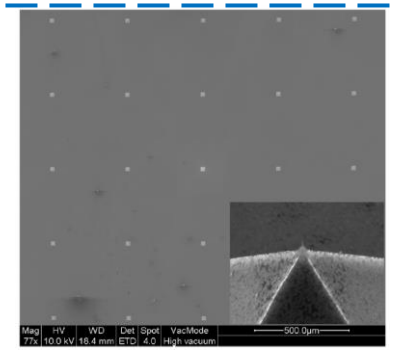
Highlight 2 (field emission)

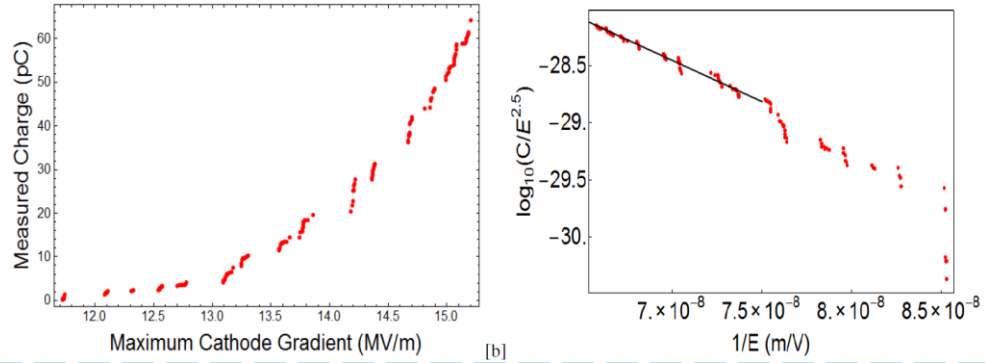
NCRF GUN CHARACTERIZATION OF FIELD EMISSION CATHODE

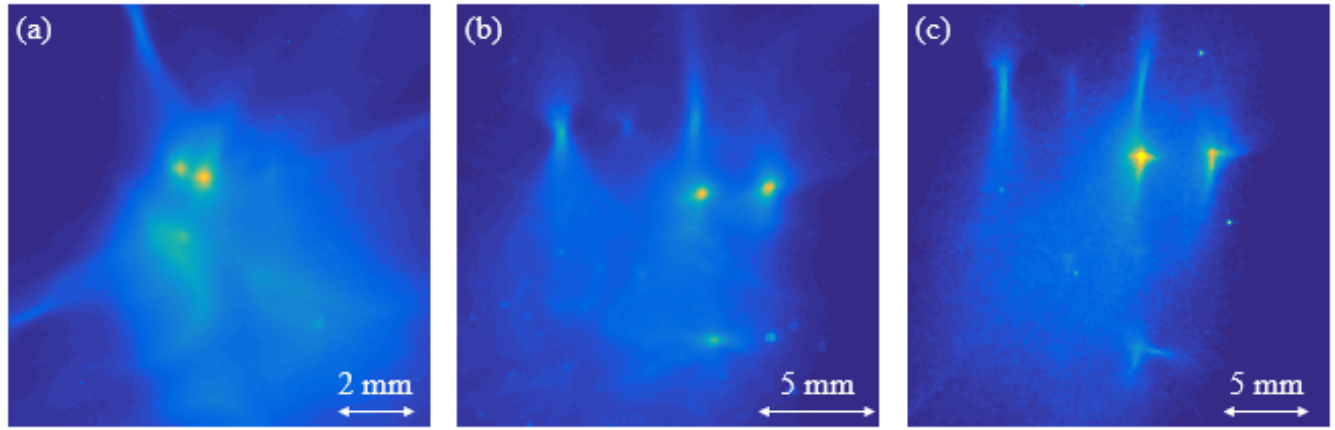
2. Pattern beam generation from field emission array cathode

(K. Nichols/H. Andrews/E. Simakov, LANL,APL paper*)

- Aims for bunch train generation together with emittance exchange
- Observed pattern beam at 15 MV/m on ACT







*K. E. Nichols, et al., Appl. Phys. Lett. 116, 023502 (2020)

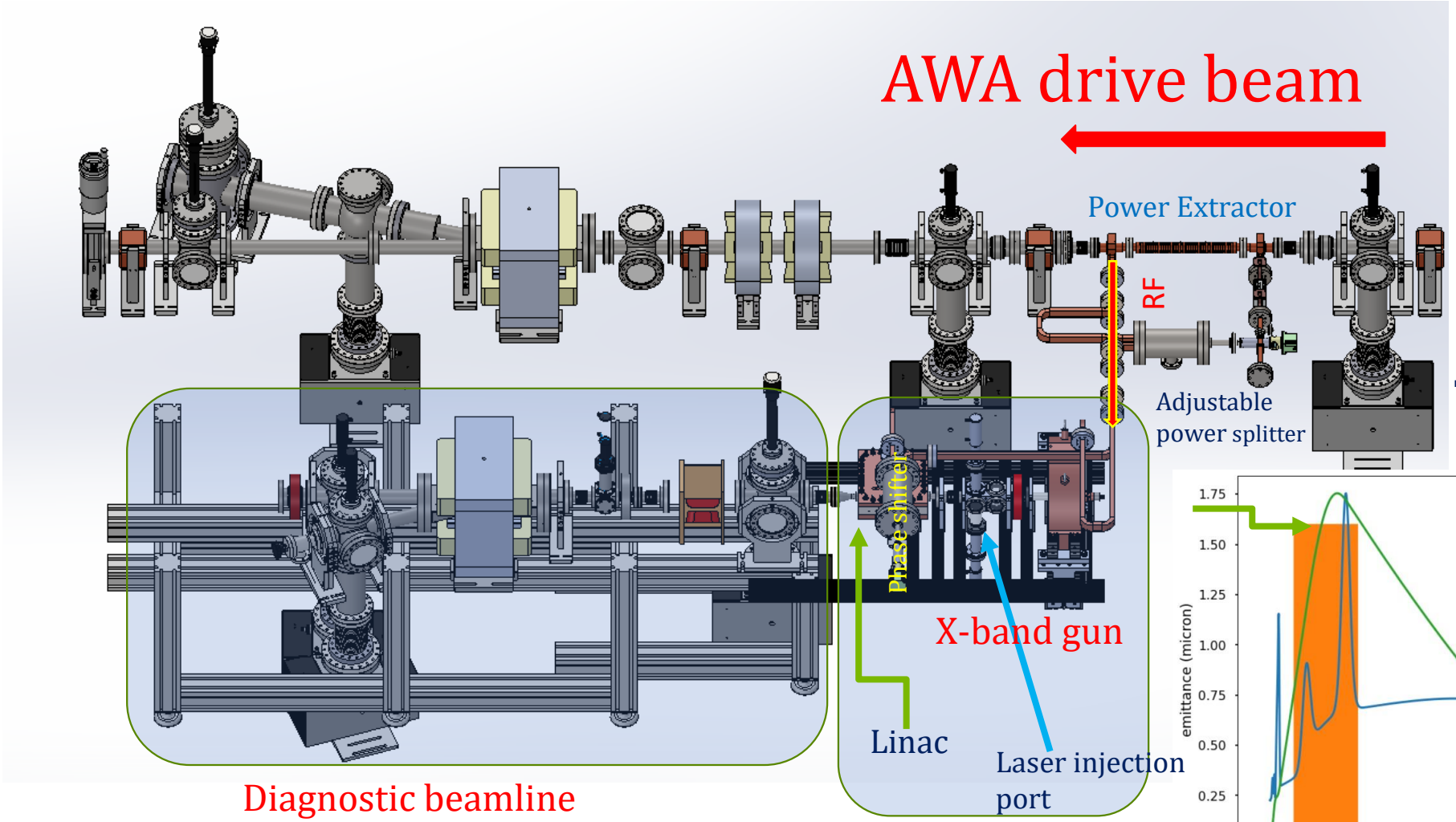
SURPRISE ANNOUNCEMENT

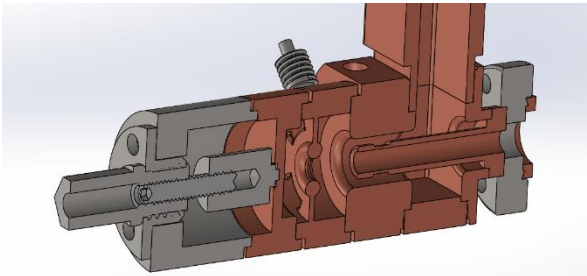
BREAKTHROUGH IN HIGH GRADIENT PHOTOCATHODE X-BAND GUN

AN APPLICATION OF SHORT PULSE ACCELERATION

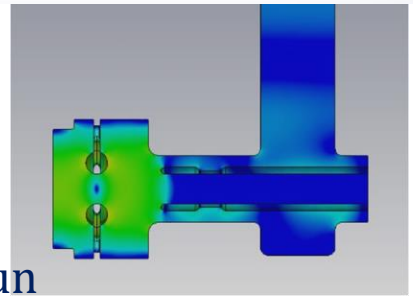
- Ultrashort RF pulse, < 10 ns
- Targeting >300 MV/m, 200nm, 100pC at room temperature
- → low dark current due to duty cycle

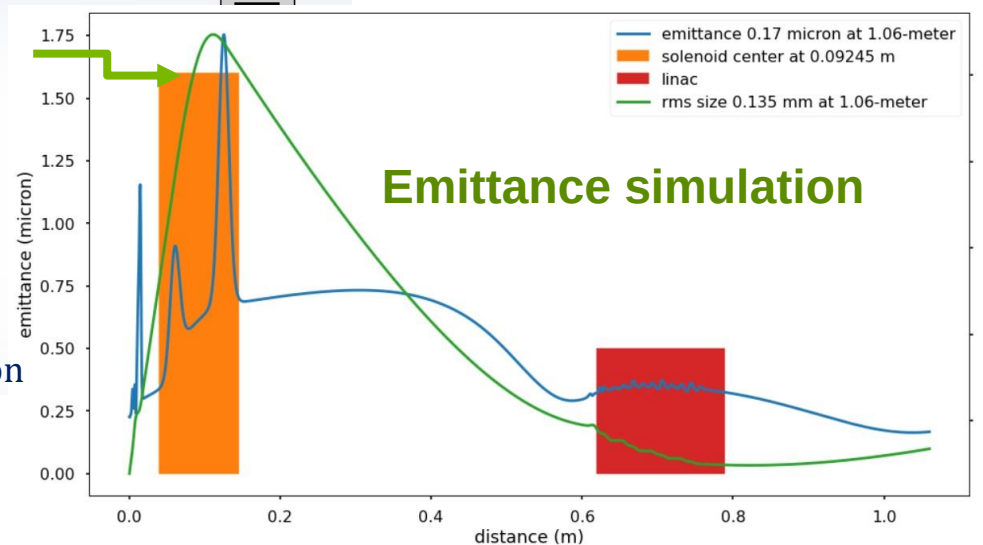
DESIGN





TW-photogun





BREAKDOWN TEST AT AWA (2020) AND THE FIRST BEAM (2021)

To be published

SUMMARY

AWA maintains an active cathode research program on **field emission** and **photoemission** cathodes.

- The Facilty operates and maintains 3 NCRF photoinjectors
- Capabites for testing field emission and photocathodes.
- The Argonne Cathode Test-stand (ACT) beamline is dedicated to high-quality electron source R&D in a rich, collaborative environment.
  - High quality photocathode beam generation
  - NCRF gun characterization of photocathodes
  - NCRF gun characterization of field emission cathodes
- Expanded capabilities for growing photocathodes under development.
  - The secondary photocathode prep chamber and load-lock system (under construction) will soon provide additional resources for photocathode studies.
- X-band RF photocathode gun breakthrough.
  - To be published.

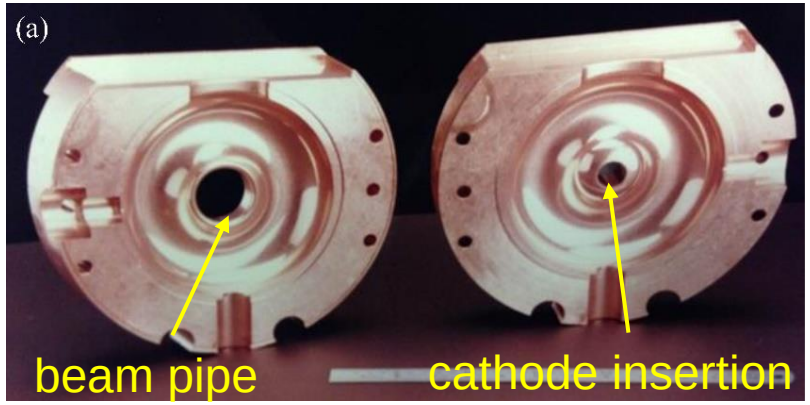
THANK YOU FOR YOUR ATTENTION

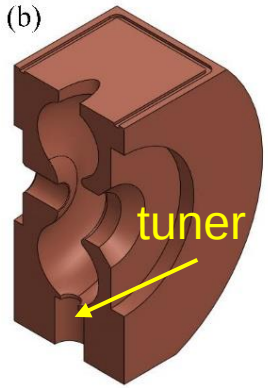
BACKUP SLIDES

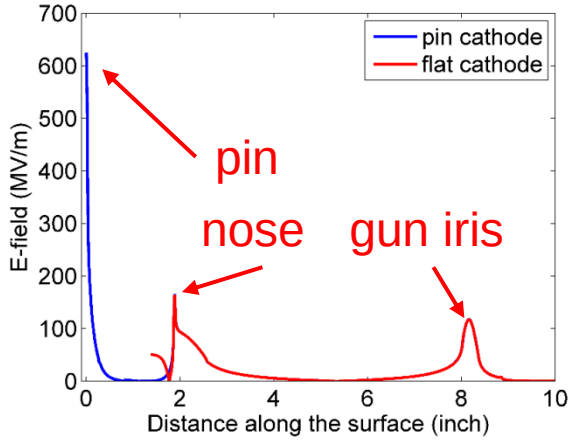
ARGONNE CATHODE TEST-STAND (ACT)

- **L-band single-cell rf gun**

  - High gradient (100 MV/m) with modest rf power (2.5 MW)



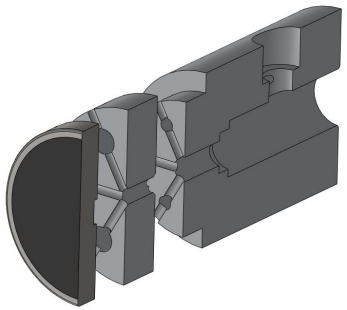




- **Detachable cathode**

Regular flat cathode
~Φ20 mm, metallic

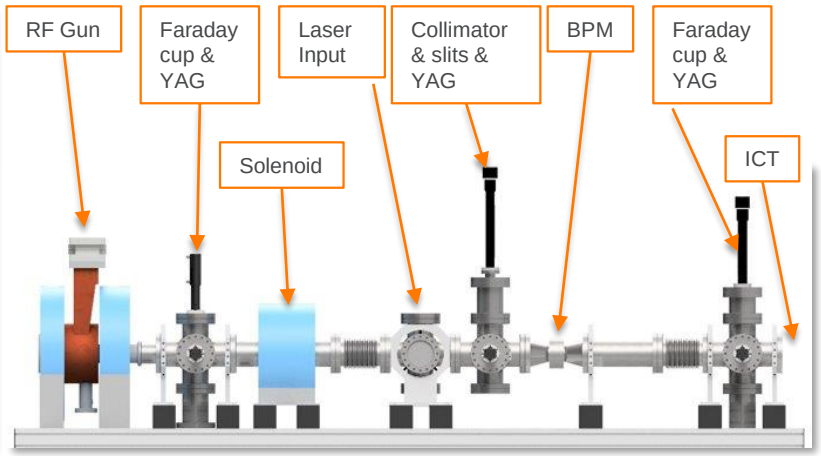
Pin-shape cathode
~Φ1 mm, metallic



3-part cathode
metallic/advanced

P³ 2021

Summary: AWA Argonne Cathode Test-stand (ACT)



ACT at AWA

- The ACT operates as an independent beamline in the same bunker but not connected to other AWA beamlines.
- The high-field L-band gun is powered with one of the AWA drive beam klystrons. An RF waveguide switch gives AWA the ability to easily transfer the RF power from the drive linac accelerating cavity to the ACT gun with adjustable This, along with careful scheduling, provides flexibility for collaborators to operate the ACT even while the other beamlines may be unavailable due to experiment installation or other circumstances .
- The ACT started out as an RF breakdown studies beamline where we can quickly install cathodes and performed quick turnaround RF only experiments. With the addition of laser input, and low power beam diagnostics we have been able to expand these capabilities to include photoemission cathode studies.

Recent Papers

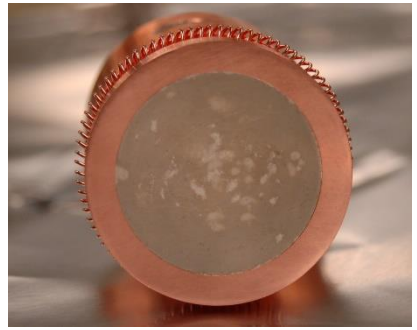
- Gongxiaohui Chen, et al. - *"Demonstration of nitrogen-incorporated ultrananocrystalline diamond photocathodes in a RF gun environment"* - https://doi.org/10.1063/5.0029512
- Heather Andrews, et al. - *"Shaped Beams from DiamondField-Emitter Array Cathodes"* - https://doi.org/10.1109/TPS.2020.2984156
- K. E. Nichols, et al. - *"Demonstration of transport of a patterned electron beam produced by diamond pyramid cathode in an rf gun"* - https://doi.org/10.1063/1.5128109

Future/Nascent Research

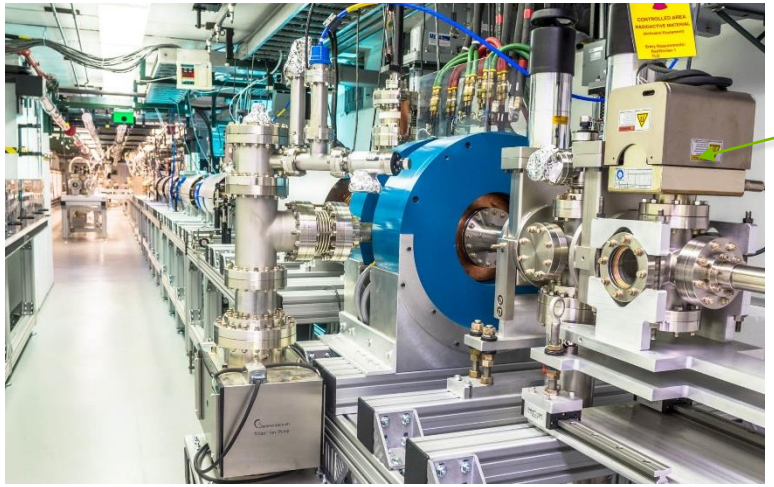
- John Llewellyn – SLAC LCLSII-HE cathode studies
- Emilio Nanni – M. Schneider UNCD cathodes studies

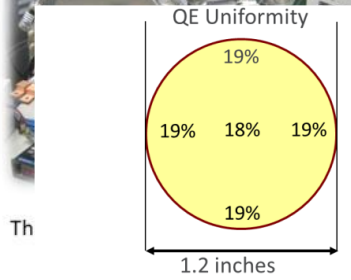
BRIEF HISTORY OF AWA'S PHOTOCATHODE R&D

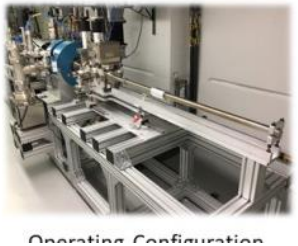
- **Witness gun (~2001-present)**
  - Mg photocathode, conical slug set in a copper plug, designed for low to moderately high charge



- **Drive gun (~2013-present)**
  - Cs_2Te on Mo plug, 30 mm diameter, 60-75 MV/m
  - World's highest charge photocathode: up to 600 nC with bunch train



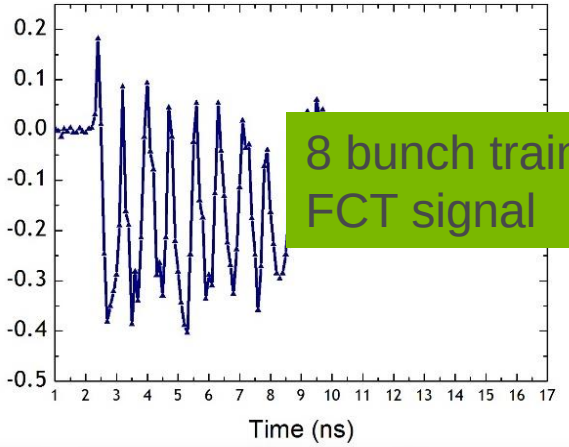




WORLD'S HIGHEST CHARGE Cs_2Te CATHODE IN A HIGH GRADIENT L-BAND GUN

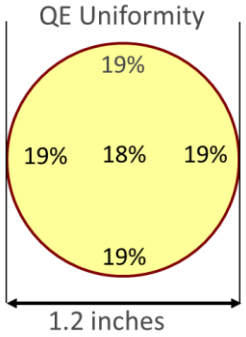
- High Gradient L-band gun (80 MV/m)
- large area cathodes for high charge short bunches
- Single Bunch
  - 100 *nC* single bunch beams
- Bunch trains
  - 8x60 *nC*
  - I_{pk} of 17 kiloAmps
  - I_{avg} 100 Amperes

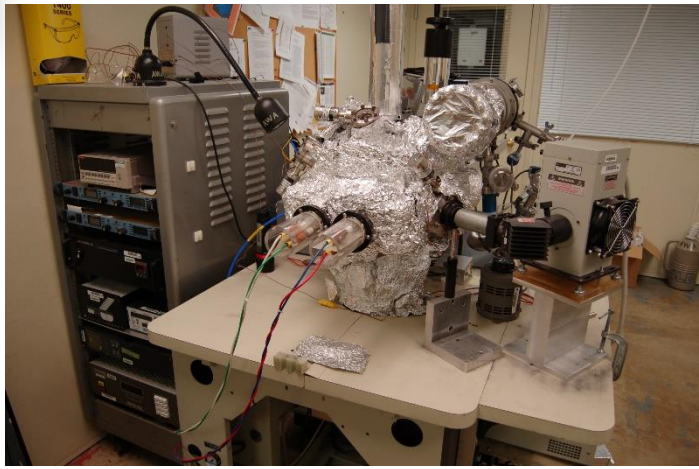
Current project (to be completed soon): adding a second deposition chamber for cathode studies to be used in conjunction with the ACT.



8 bunch train FCT signal

2.5% Operating QE at 75 MV/m for 2 years





AWA photocathode deposition chamber (original)