HG2017, JUNE 13-17, 2017, VALENCIA, SPAIN

INTRODUCTION TO THE ARGONNE CATHODE TEST-STAND (ACT) AT AWA

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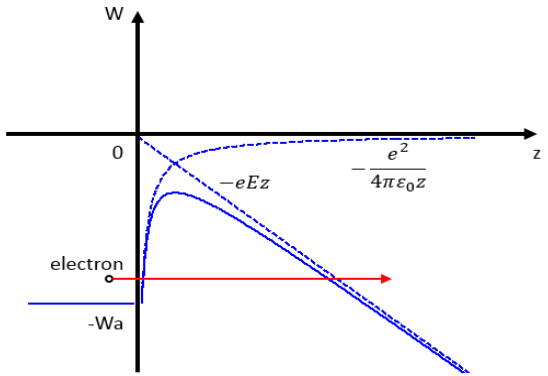
Postdoctoral Appointee

OUTLINE

- **Background and motivation**
- **Argonne Cathode Test-stand (ACT) at AWA**
  - current setup
  - undergoing upgrade
  - future upgrade
- **Experimental study at ACT**
  - dark current imaging
  - UNCD cathode test
- **Summary and future study**
- **Acknowledgement**

BACKGROUND AND MOTIVATION

- **rf breakdown**
  - One of the main limits of high gradient structures
  - Remarkable improvement during the last decades results from not only high precision fabrication and 'magic' surface processing, but also optimized design benefited from the study of fundamental physics
  - Field emission, an important procedure of rf breakdown, has many questions yet to be answered
- **Field emission (FE)**



Fowler-Nordheim equation:

$$\bar{I}_f = \frac{5.7\times10^{-12}\times10^{4.52\phi^{-0.5}} A_e(\beta E_0)^{2.5}}{\phi^{1.75}} \exp\left(-\frac{6.53\times10^9\times\phi^{1.5}}{\beta E_0}\right)$$

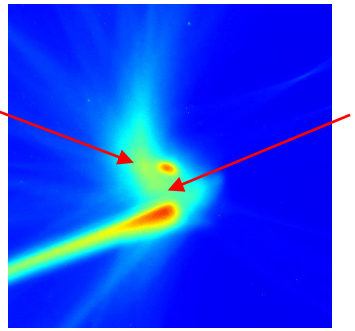
work function area enhancement factor

1. A. Grudiev, S. Calatroni, and W. Wuensch, PRST-AB 12, 102001 (2009).
2. J. W. Wang and G. A. Loew, SLAC PUB 7684 (1997).

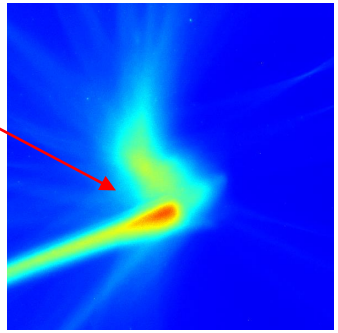
BACKGROUND AND MOTIVATION

- **Field emission as undesired dark current**
  - Trigger of rf breakdowns
  - Influence the beam quality in photocathode guns / accelerators

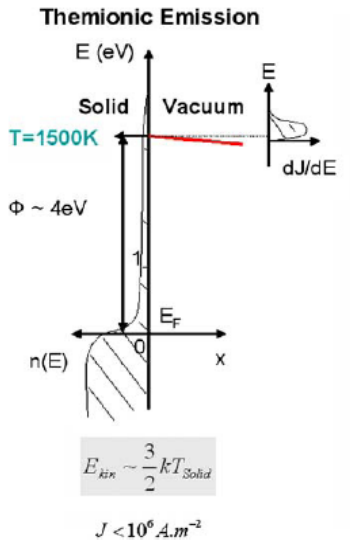
photoelectron current

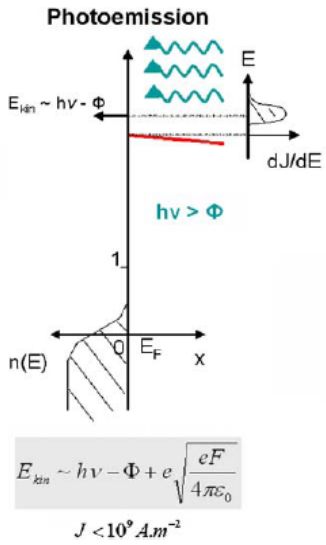


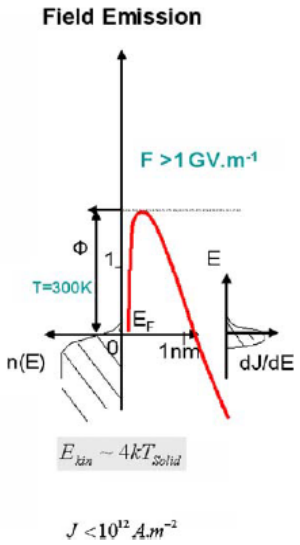
dark current



- **Field emission as desired electron source**







Advantage:
Simple configuration
Low transverse emittance
High current density

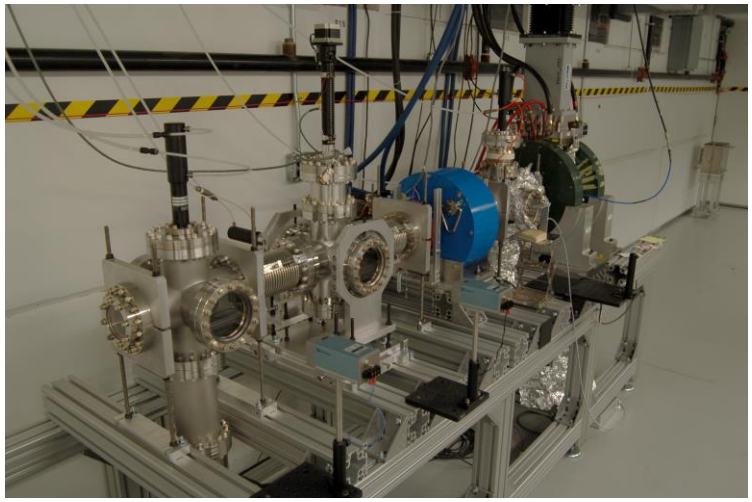
Disadvantage:
Long bunch
High longitudinal emittance
Lack of profile control

1. R. Ganter, R.J. Bakker, C. Gough, et al., NIMA 565, 423-429 (2006)

BACKGROUND AND MOTIVATION

- **Research at AWA**

  - ACT, a unique and dedicated beam line at AWA



  - Study rf breakdown and field emission by advanced experiments
  - Test advanced field emission / photoemission cathodes

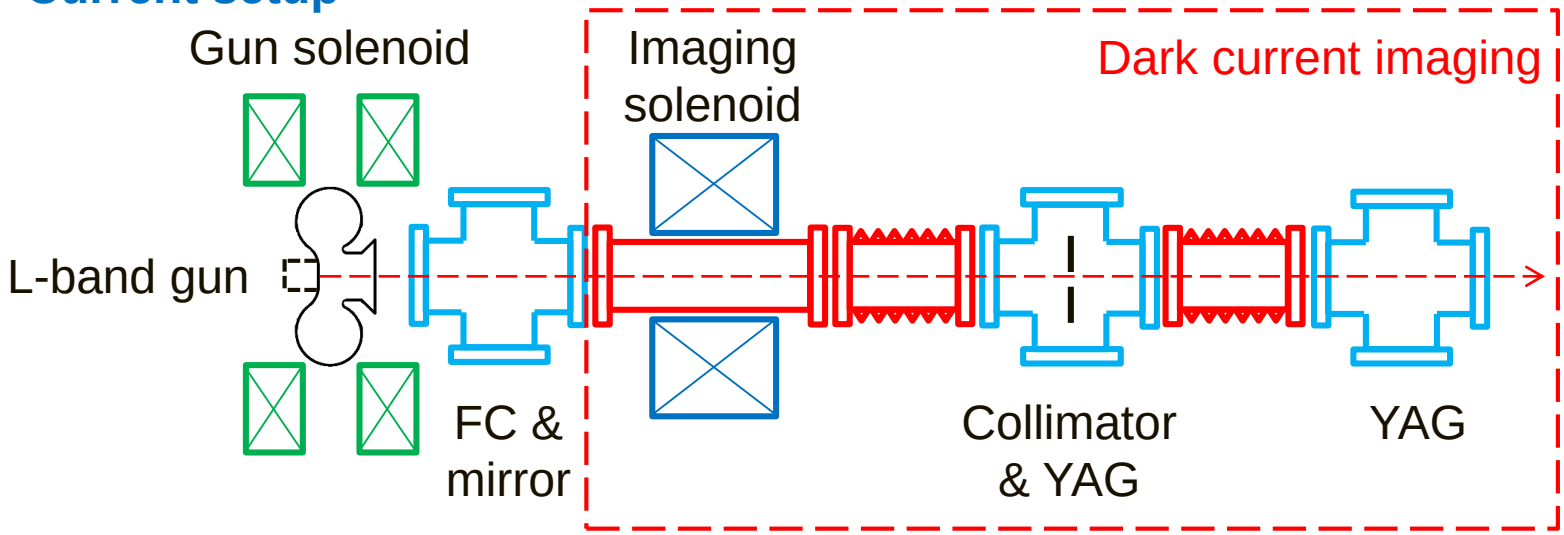
- **Our goal**

  - Thoroughly understand the nature of field emitters
  - Propose and demonstrate methods to improve/suppress field emission
  - Study the potential to use field emission in other applications

ARGONNE CATHODE TEST-STAND (ACT) AT AWA

ARGONNE CATHODE TEST-STAND (ACT) AT AWA

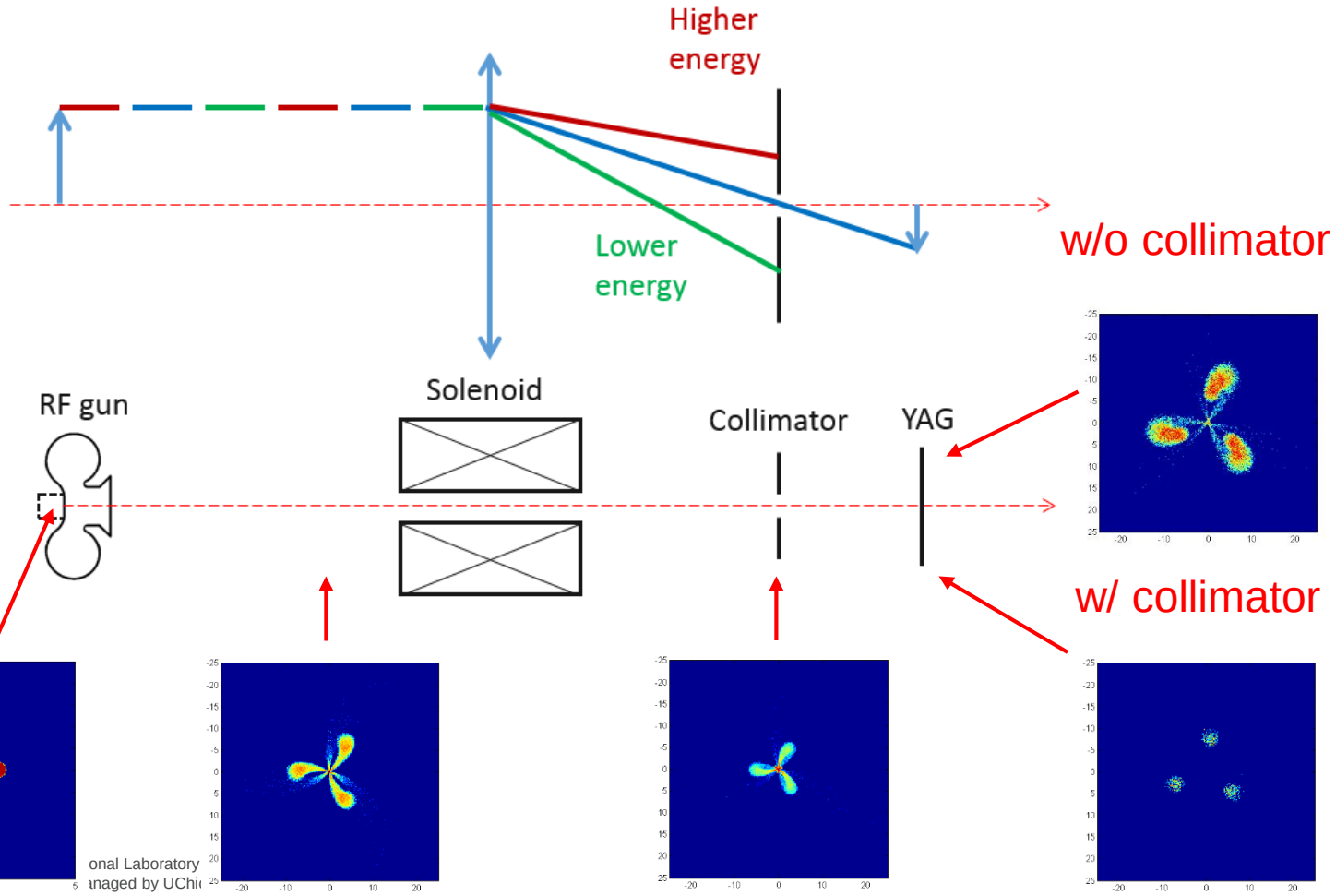
- **Current setup**



- **Measureable parameters**
  - Input and reflected power (direction coupler)
  - Field profile inside the gun (rf pickup)
  - Field emission current and field enhancement factor (Faraday cup)
  - rf breakdown location (mirror & dark current imaging system)
  - Field emitter location (dark current imaging system)
  - Beam energy (trim magnets)

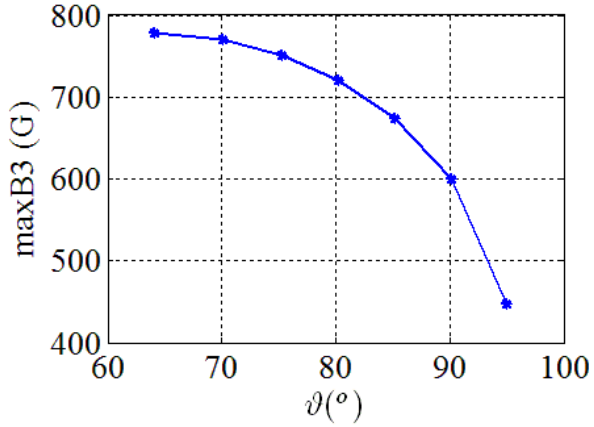
ARGONNE CATHODE TEST-STAND (ACT) AT AWA

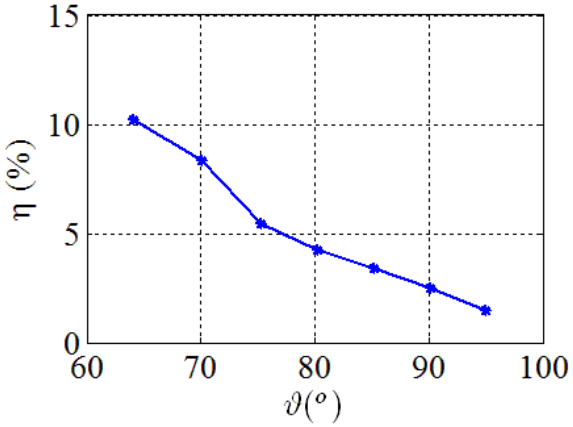
- **Dark current imaging system**
  - Key component to study the origin and properties of field emitters
  - Use collimator to select electrons for high resolution

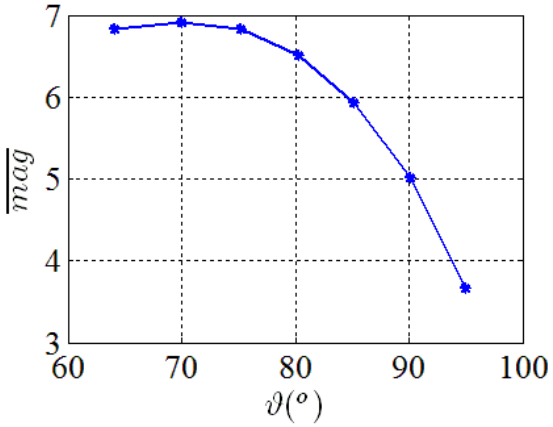


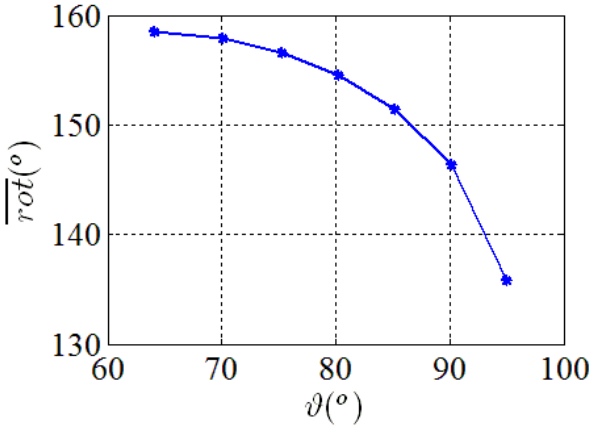
ARGONNE CATHODE TEST-STAND (ACT) AT AWA

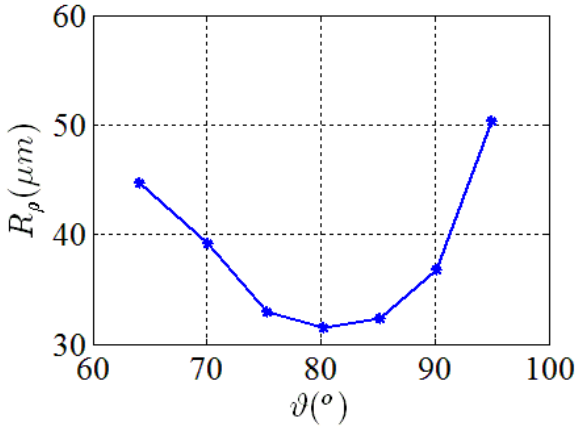
- **Properties of the dark current imaging system**
  - In simulation: E-field on cathode 111 MV/m, initial emitter off-axis 0.5 mm, aperture size 200 μm in diameter

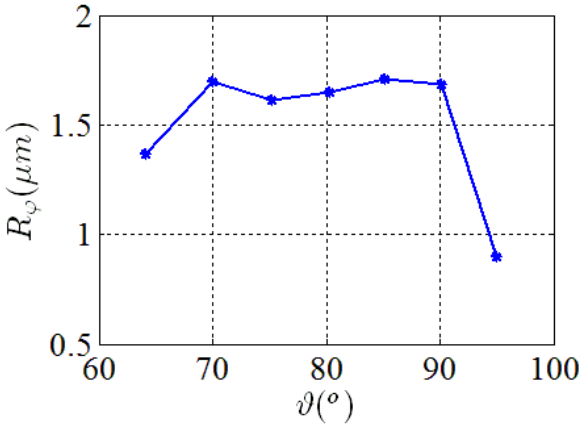






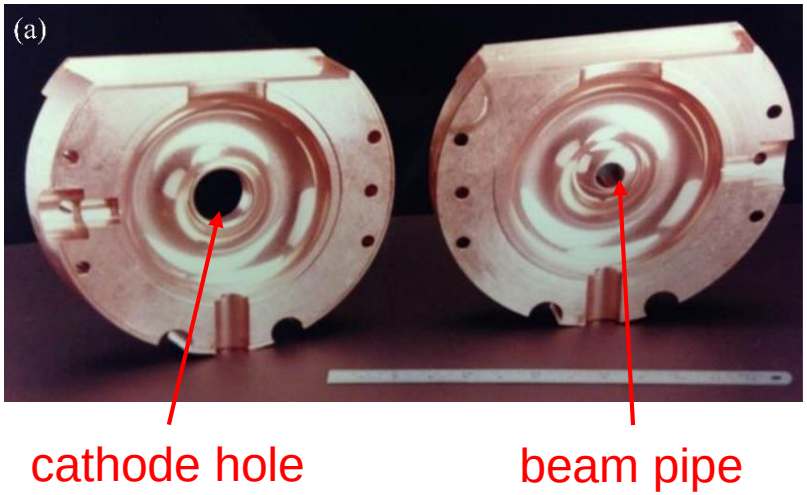


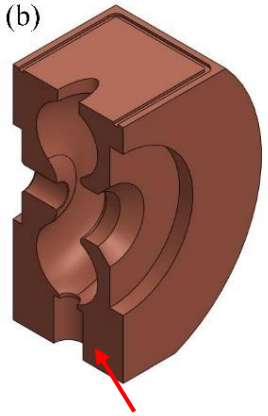


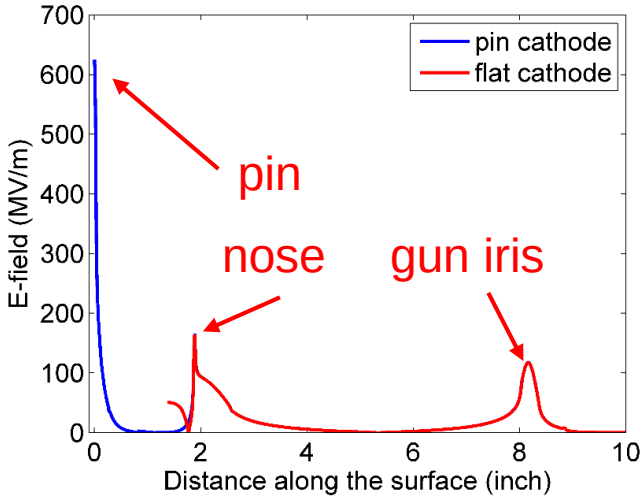


ARGONNE CATHODE TEST-STAND (ACT) AT AWA

- **The L-band single cell gun**
  - Nose design to lower the power requirement (2 MW for 100 MV/m surface field on conventional flat cathode)
  - Ultra-high surface field ~ 700 MV/m achieved with a pin cathode







- **Vacuum level**
  - Low 10^{-9} Torr
  - Suitable for metallic cathodes (not Mg) and semi-conducting cathodes with less strict vacuum requirement

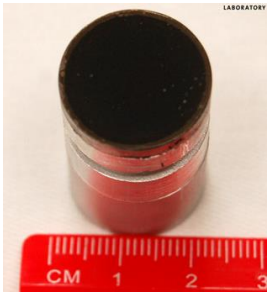
ARGONNE CATHODE TEST-STAND (ACT) AT AWA

- **The detachable cathode (20 mm in diameter)**
  - Convenient to test cathodes with different shape/finishing/material
  - Has attracted many collaborators and users

flat

- FE evolution (AWA)
- FE in static magnetic field (LBNL)

UNCD



- FE from UNCD (Euclid Techlabs)

Nb/Mg

- FE from superconducting material (IIT)

pin

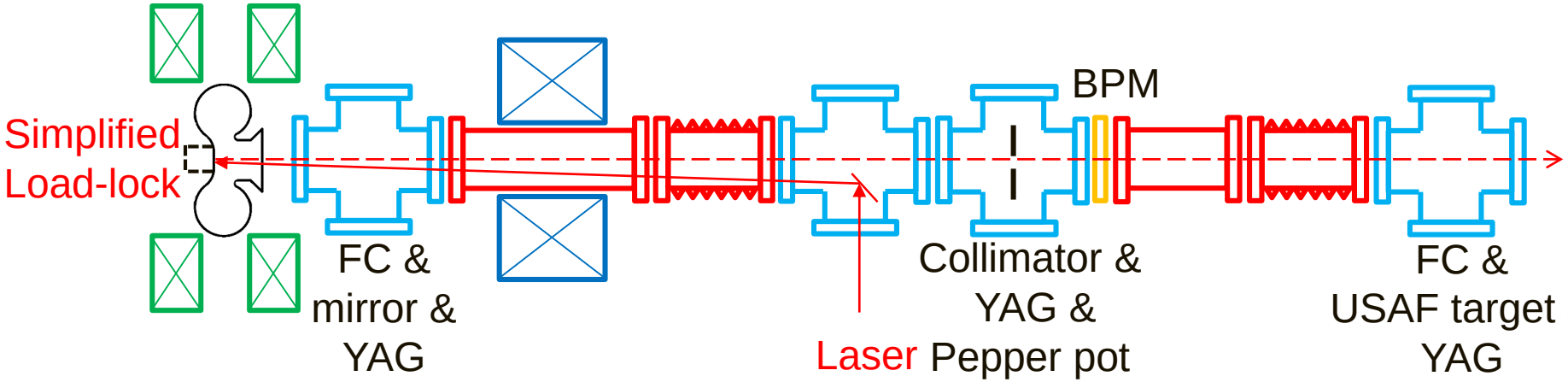
- Ultrahigh surface field (AWA&SLAC)
- FE dependence on stored energy (AWA&SLAC)

new shape

- Dark current imaging (AWA&Tsinghua)

ARGONNE CATHODE TEST-STAND (ACT) AT AWA

- **Ongoing upgrade (will be completed in 2017.8)**



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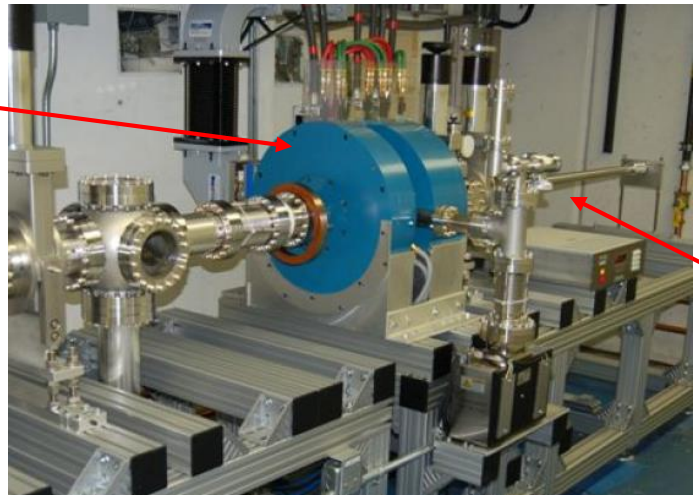
  - Field profile inside the gun (rf pickup)
  - Field emission current and field enhancement factor (Faraday cup)
  - rf breakdown location (mirror & dark current imaging system)
  - Field emitter location (dark current imaging system)
  - Beam energy and spread (trim magnets and dark current imaging system)
  - Photocurrent and quantum efficiency (BPM)
  - Emittance (Pepper pot and solenoid scanning)

ARGONNE CATHODE TEST-STAND (ACT) AT AWA

- **Future upgrade**
  - A new 1.6 cell L-band rf gun is scheduled for the AWA drive beam line. The current drive gun will replace the single cell gun on ACT in 1-2 years.



- **Current drive gun**
  - Cs_2Te cathode with high quantum efficiency (~5%)
  - Full load-lock system (both gun and cathode are always under vacuum)
  - Ideal for cathode test which requires ultra-high vacuum (low 10^{-10} Torr)

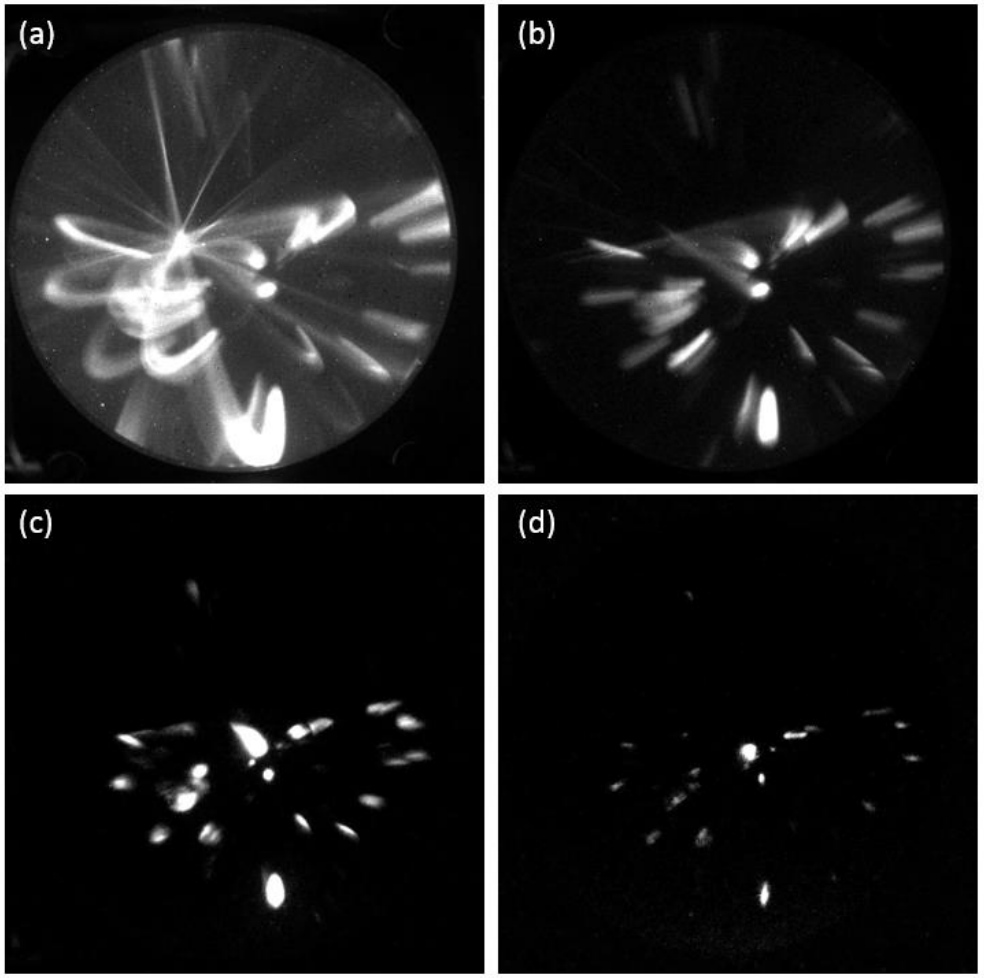
1. M.E. Conde, D.S. Doran, W. Gai, et al., Proc. IPAC2011, WEPZ014 (2011)

EXPERIMENTS AT ACT

EXPERIMENTS AT ACT – DARK CURRENT IMAGING

- **In-situ observation**
  - ~100 μm resolution, non-uniform distribution of field emitters

No aperture
20 shots



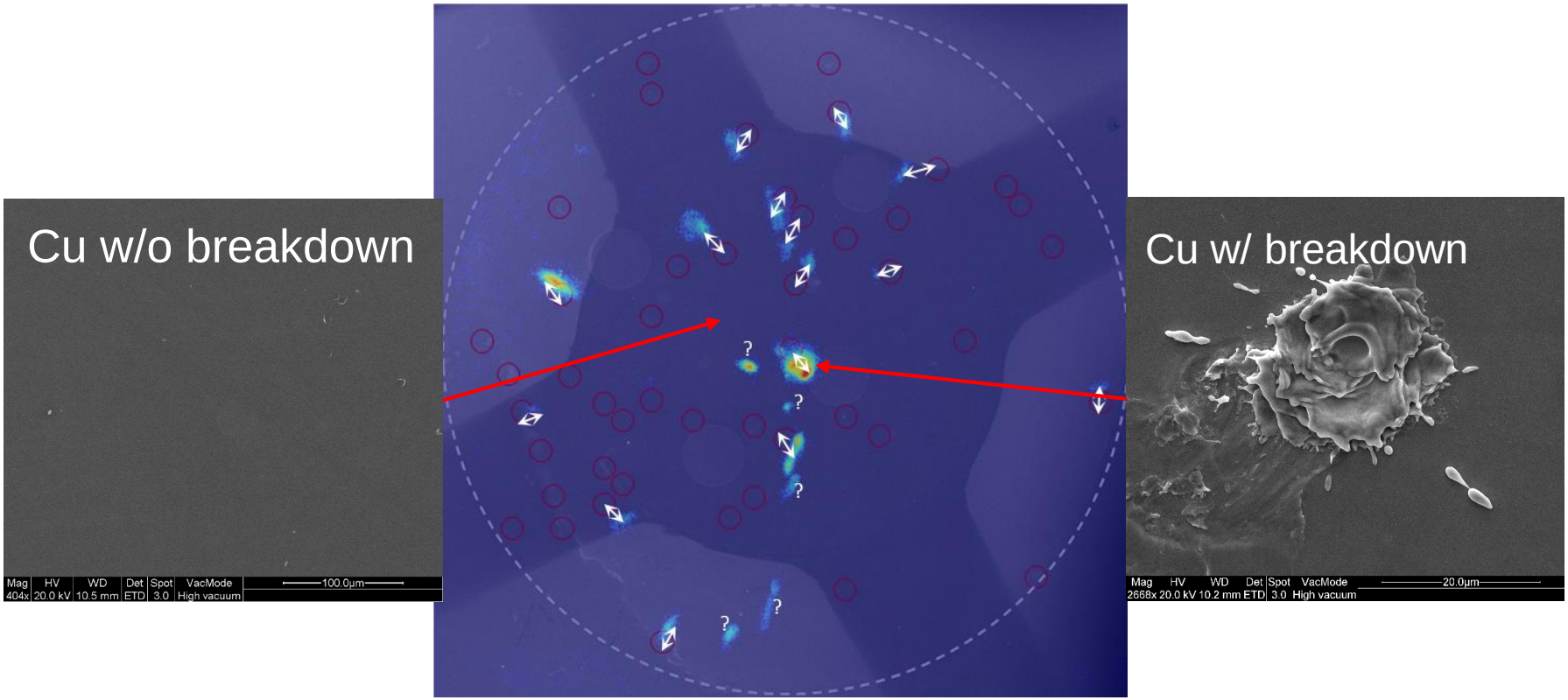
Φ 8 mm
20 shots

Φ1 mm
100 shots

Φ 0.2 mm
100 shots

EXPERIMENTS AT ACT – DARK CURRENT IMAGING

- **Ex-situ observation**
  - Most strong field emitters overlap with breakdown spots
  - Half of breakdown spots don't emit strong current

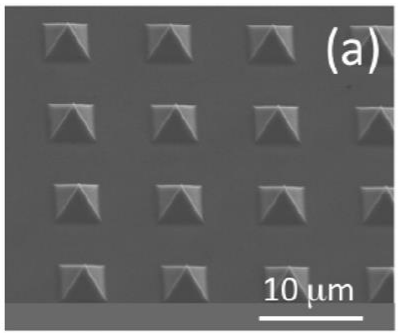


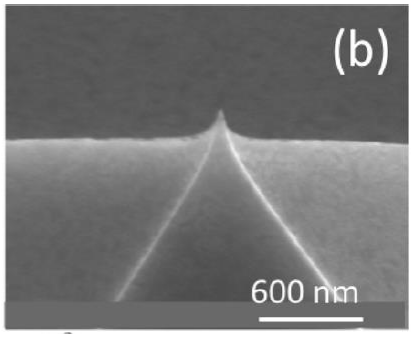
J. Shao, S. Antipov, S. Baryshev, et al., PRL 117, 084801 (2016)

EXPERIMENTS AT ACT – UNCD CATHODE

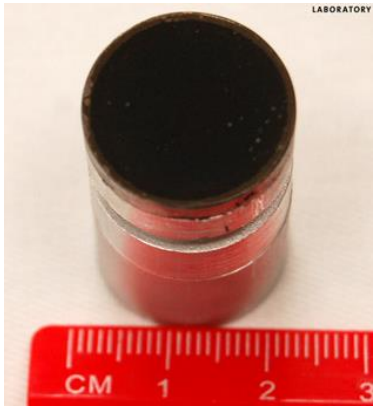
- **Motivation**
  - Develop advanced field emission cathode
- **Planar ultrananno crystalline diamond (UNCD) cathode**
  - Much simpler than the field emitter array (FEA) cathode
  - Highest emission area among synthetic polycrystalline diamonds due to the highest grain boundary density
  - Low current load

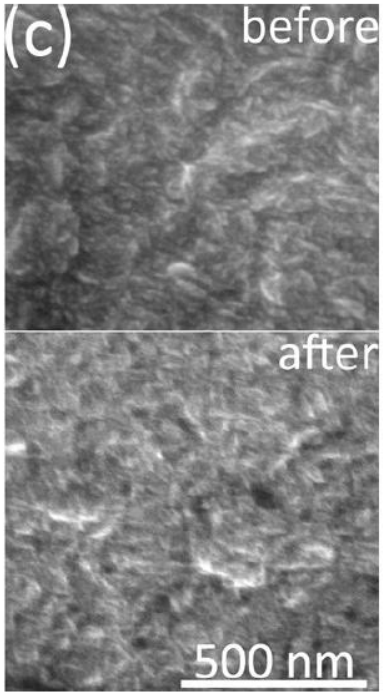
FEA





UNCD



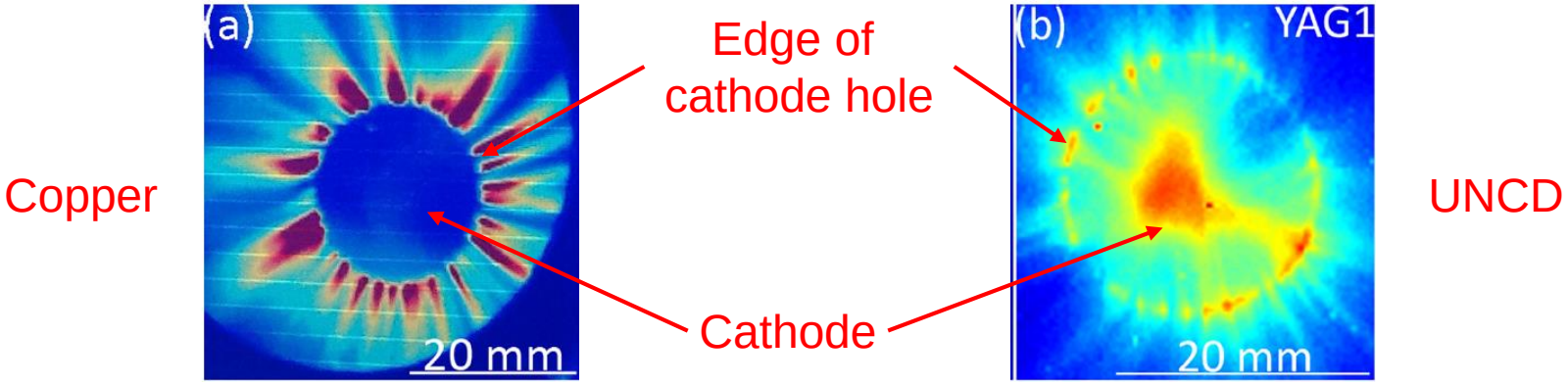


1. P. Piot, C. A. Brau, B. K. Choi, et al., APL 105, 203505 (2014).
2. V. Chatterjee, R. Harniman, P. W. May, et al., APL 104, 171907 (2014)

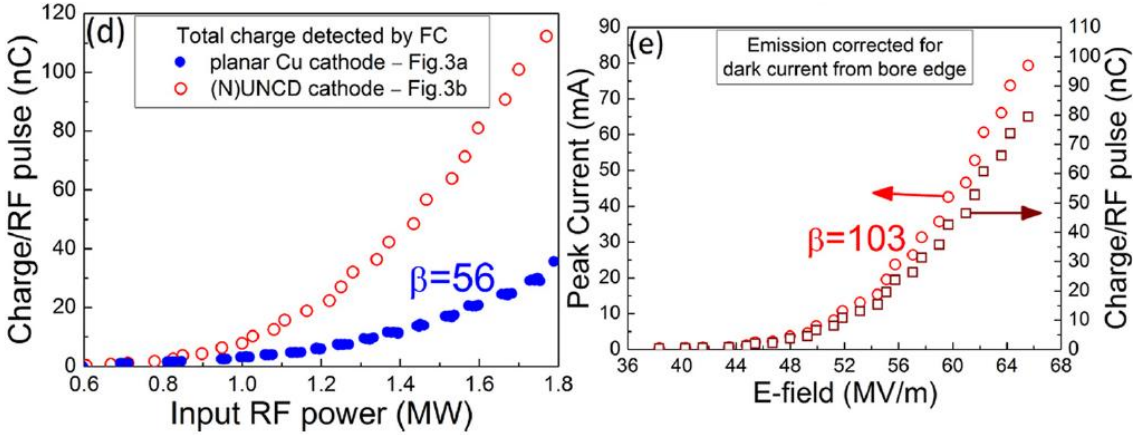
EXPERIMENTS AT ACT – UNCD CATHODE

- **Results**

  - Successful demonstration of UNCD as field emission cathode in rf gun



  - 65 MV/m surface field, 80 mA peak current, 80 nC per pulse



S. Baryshev, S. Antipov, J. Shao, et al., APL 105, 203505 (2014)

SUMMARY AND FUTURE

- **Field emission**
  - Unwanted source of background electrons / trigger of breakdowns in high gradient structures
  - Promising electron source
  - Remaining questions yet to be answered

- **Study at AWA**
  - Unique and dedicated test stand - ACT
  - Advanced experiments to understand the field emission phenomena
  - Test bed for various field emission cathodes

SUMMARY AND FUTURE

- **Future study**

  - The undergoing upgrade will remarkably improve the capability of ACT
  - Some new experiments have already been planned:
    1. dark current imaging with improved resolution (2017.9)
    2. evaluation of field emitter during rf conditioning (2017.10)
    3. electron irradiation on superconducting material (2017.12, MSD of ANL)
    4. thermal emittance measurement (2018.1-2, Tsinghua)
    5. laser-assisted field emission (2018.3-4)
    6. photoemission from UNCD cathode (2018, Euclid Techlabs)
  - The future upgrade to replace the single cell gun will allow more cathodes to be tested

New collaborators and users are very welcome!

ACKNOWLEDGEMENT

- The work at AWA is funded through the U.S. Department of Energy Office of Science under Contract No. DE-AC02-06CH11357. The work at Tsinghua University is supported by National Natural Science Foundation of China under Grant No. 11135004. The work at SLAC is funded by the U.S. Department of Energy Early Career Research Program under project code LAB 11-572.

- This work is in collaboration with Wei Gai, Chunguang Jing, Faya Wang, Huaibi Chen, Jiaru Shi, Sergey Baryshev, and Sergey Antipov

- All staffs in AWA group for their great help and support for experiments

- SLAC and Tsinghua machining shop for preparing cathodes

- Dr. Klaus Floettmann from DESY for discussing about the ASTRA simulation

THANKS!

WELCOME TO TEST YOUR IDEAS AND SAMPLES AT ACT!