Dark current imaging and Observation of local field emitters

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on behalf of many collaborators

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Outline

- Background and motivation
- High-resolution imaging principle in RF structures
- Experiment setup at Argonne Wakefield Accelerator Facility (AWA)
- Beam dynamics simulation
- Experiment results
- Summary and discussion
- Acknowledgement

Background and motivation

- **Field emission**
  - Critical role in high gradient devices, cold cathode electron sources
  - Strongly coupled to the RF breakdown phenomenon

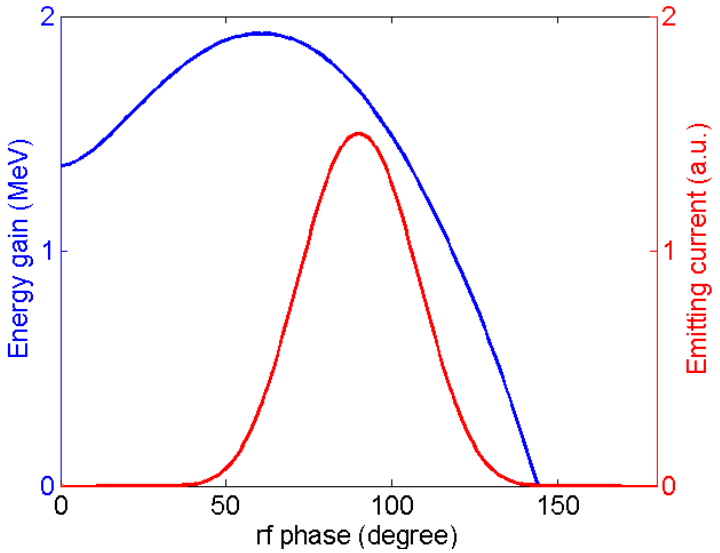
- **Puzzling questions still remain after a century study**
  - High field enhancement factor, low emission area
  - Origin and properties of emitters
  - Surface evolvements during conditioning
  - …

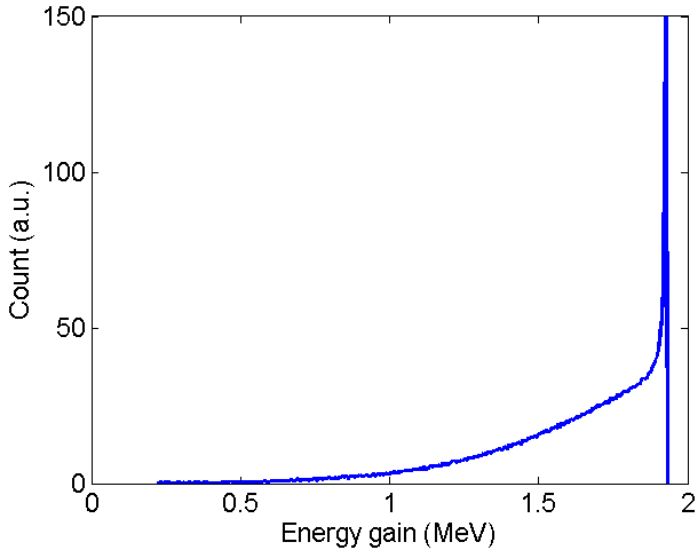
- **Real time high-resolution field emission observation**
  - Will significantly improve our understanding of field emission
  - Likely lead to breakthrough in high gradient devices

High-resolution imaging in RF structures

- **Difficulty**

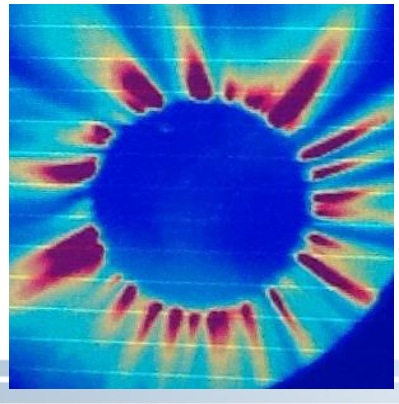
  - Wide energy spread leads to blurring

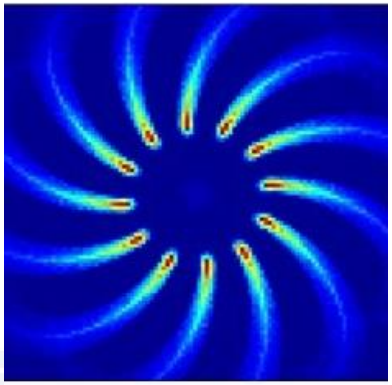




Energy spread of field emission current from an RF gun

Experiment results



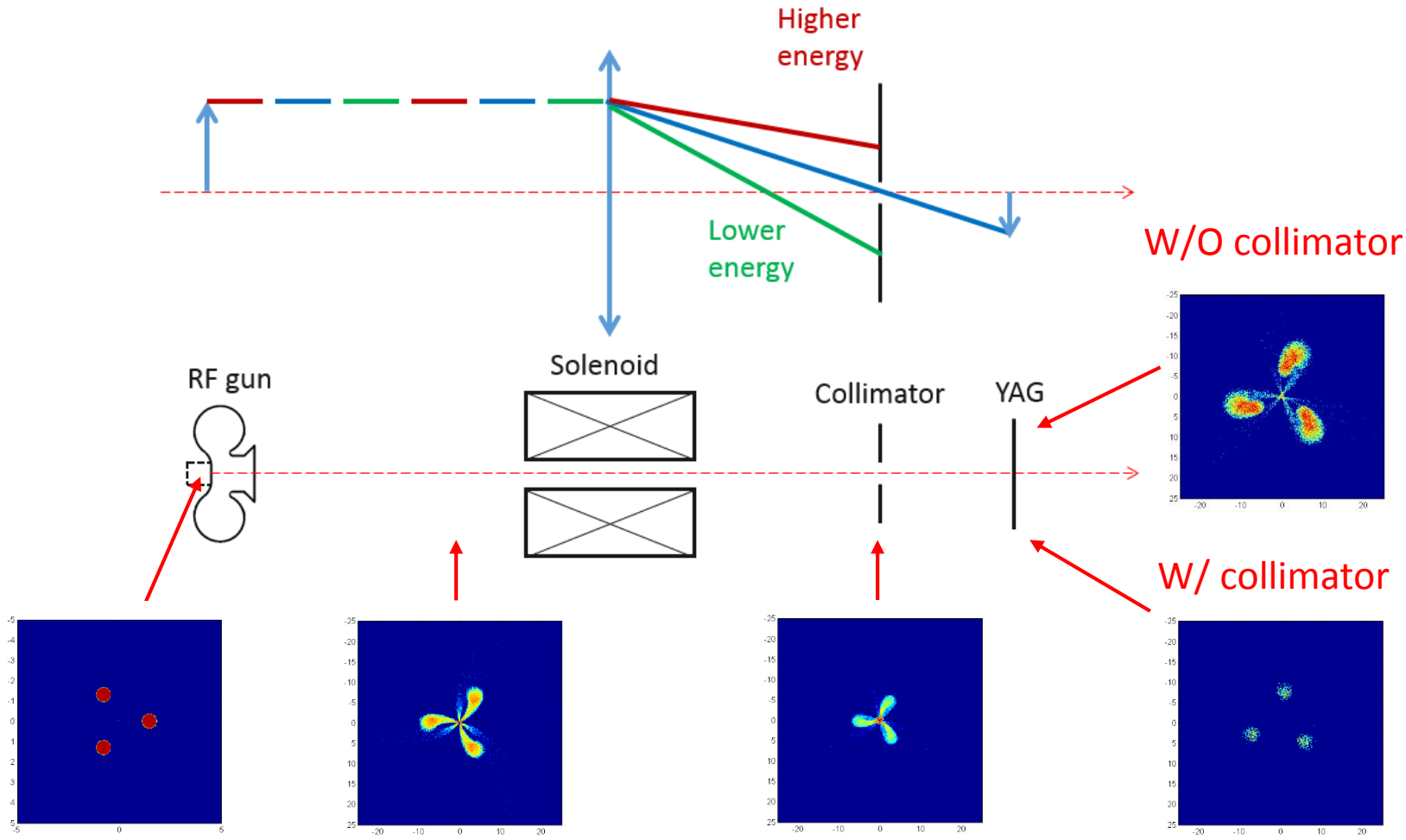


ASTRA simulation

High-resolution imaging in RF structures (continue)

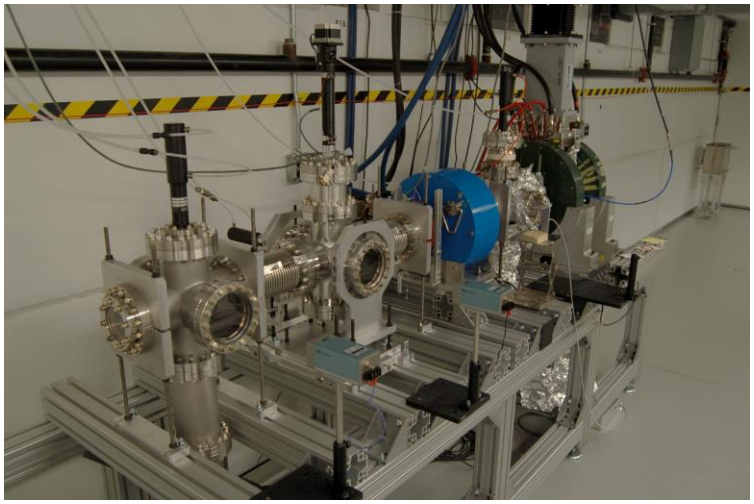
- **Solution**

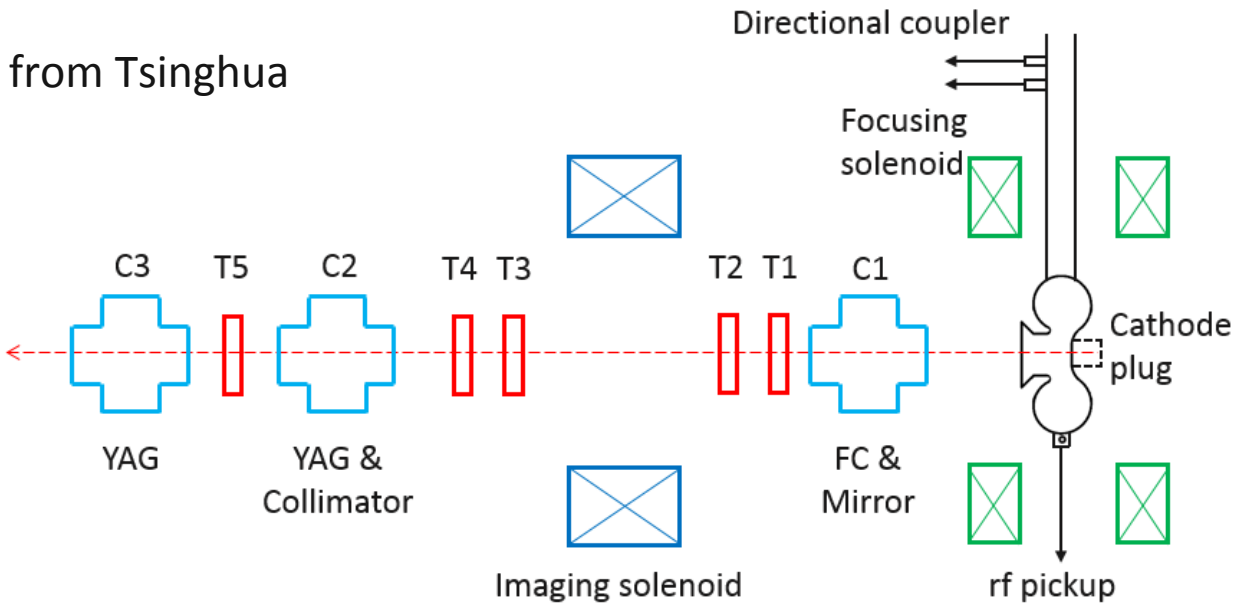
  - Use a collimator to select electrons with certain energies



Experiment setup at AWA

- **Photocathode gun**
  - Single cell, 1.3 GHz
  - Detachable cathode
- **Diagnostics**
  - Directional coupler, pickup
  - PI-MAX Intensified CCD
- **Apertures**
  - ϕ8 mm, ϕ1 mm, ϕ0.5 mm, ϕ0.2 mm
- **Cathode**
  - New shaped ones from Tsinghua



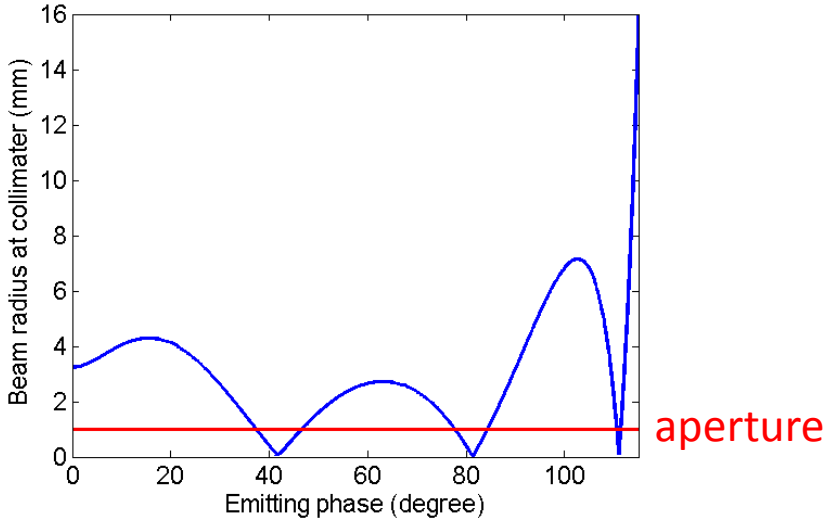


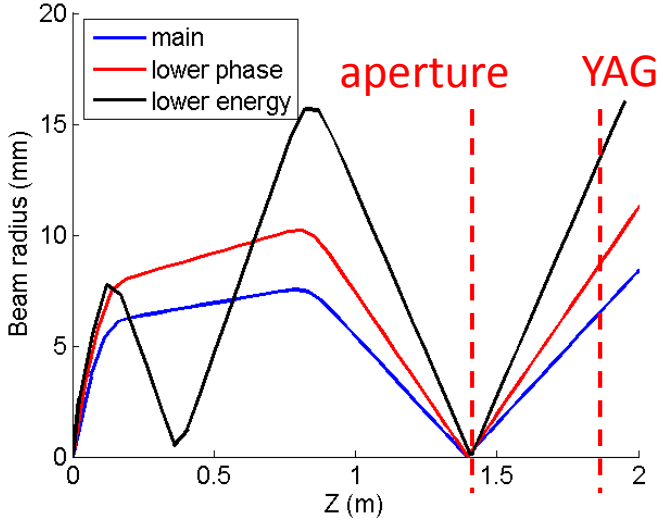
FC: Faraday cup C: cross T: trim magnet

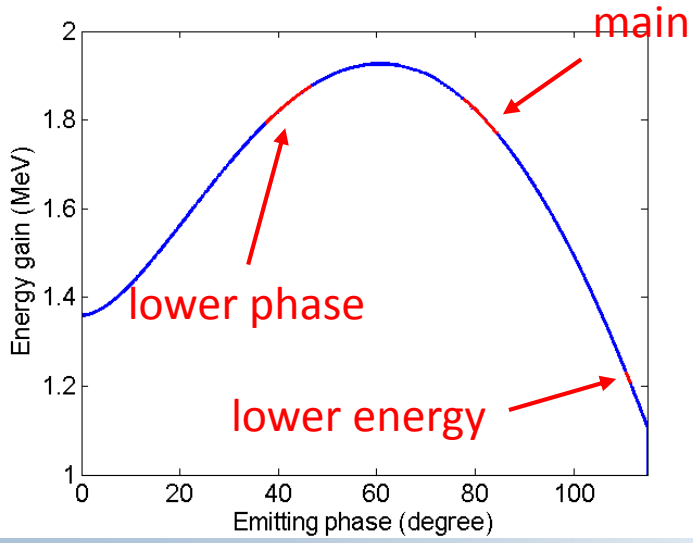
Beam dynamics simulation

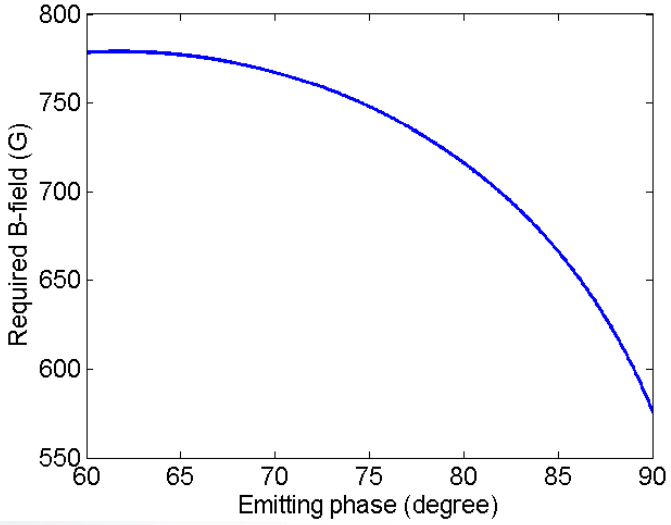
- **Phase/energy selection**

  - Electrons with up to three phases and two energies can pass through the aperture





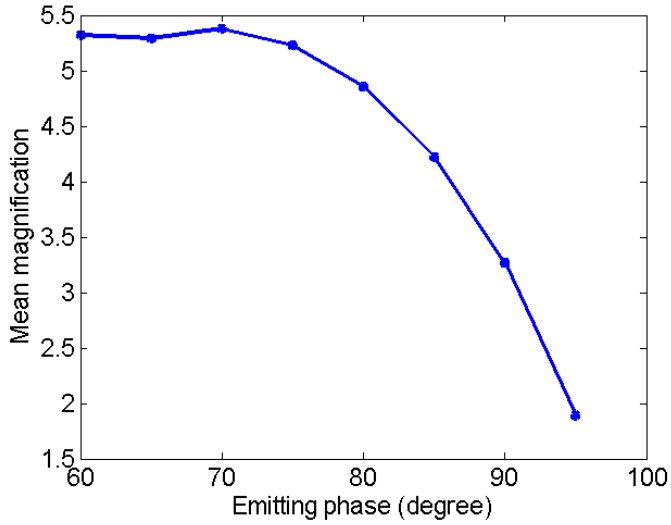


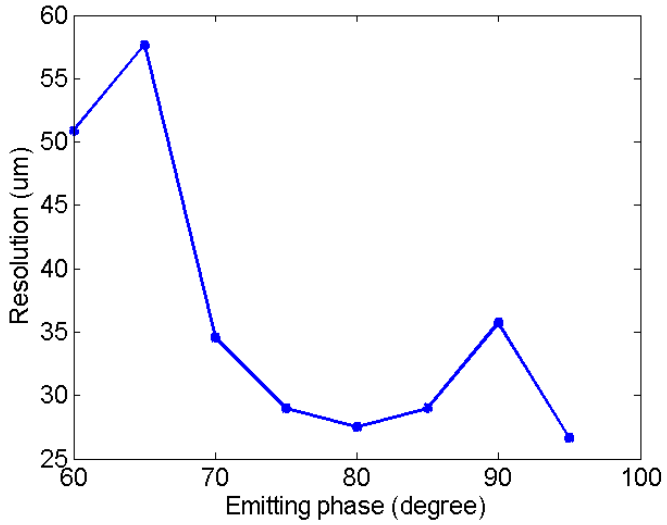


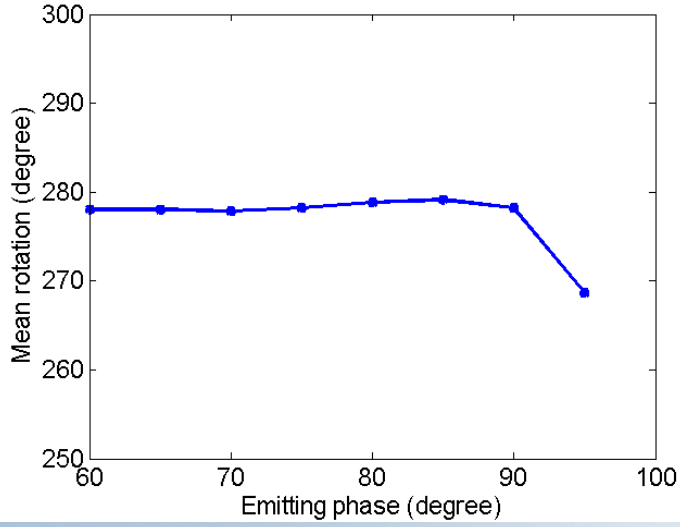
Beam dynamics simulation (continue)

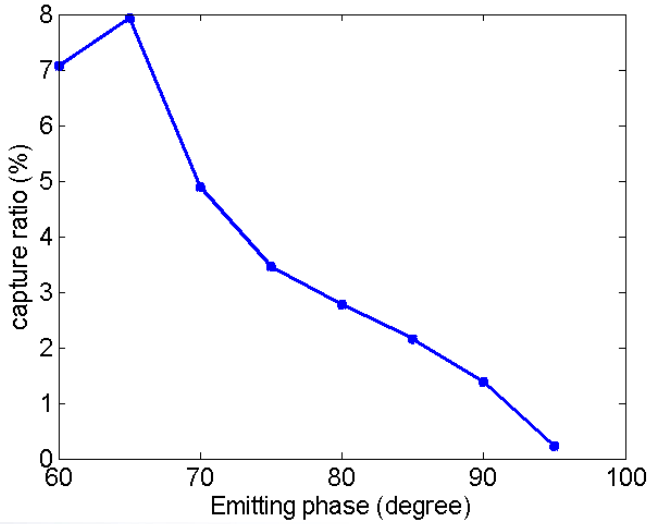
- **Phase/energy selection**

  - ϕ 0.2 mm collimator, 0 initial emittance





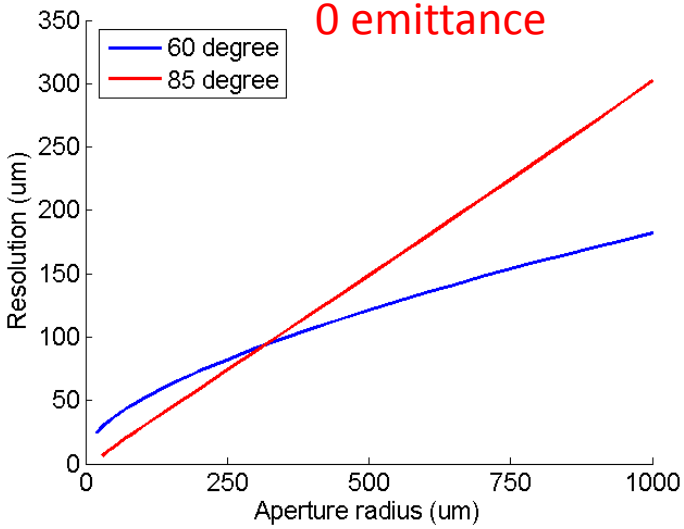


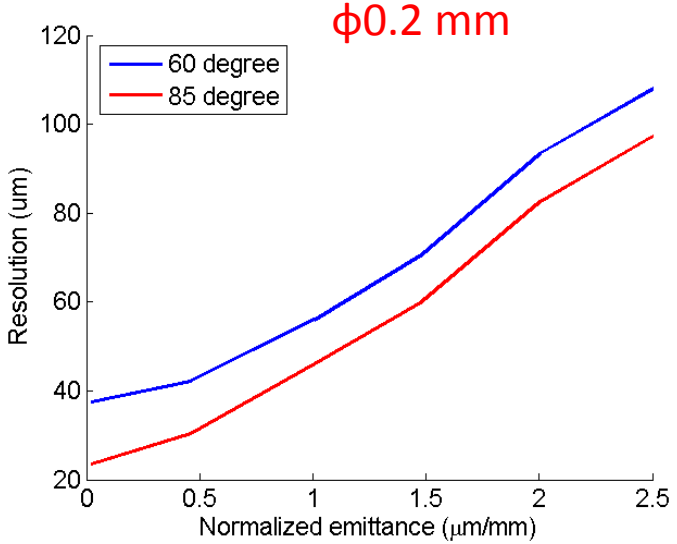


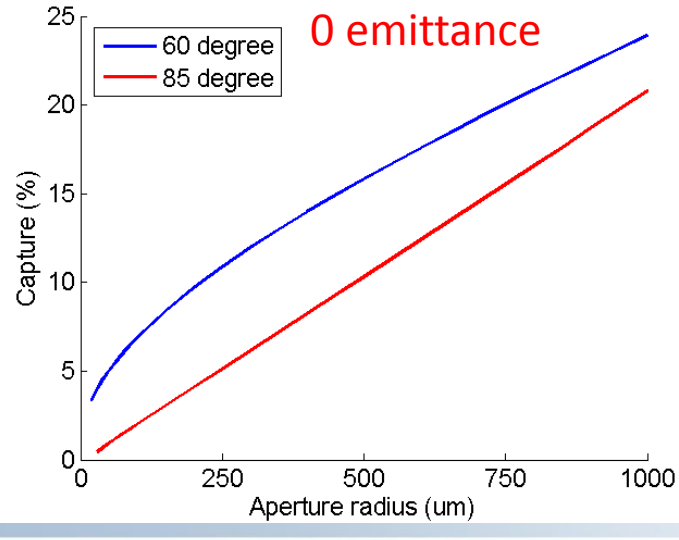
Beam dynamics simulation (continue)

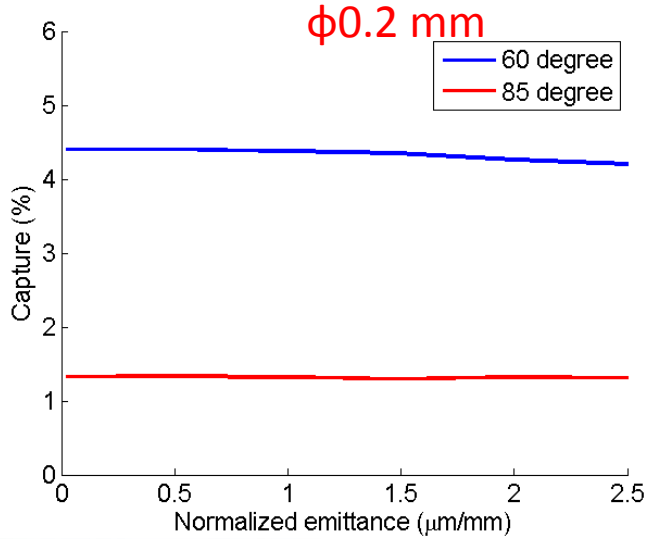
- **Influence of aperture size and initial emittance**

  - Resolution better than 100 μm is expected in the experiment



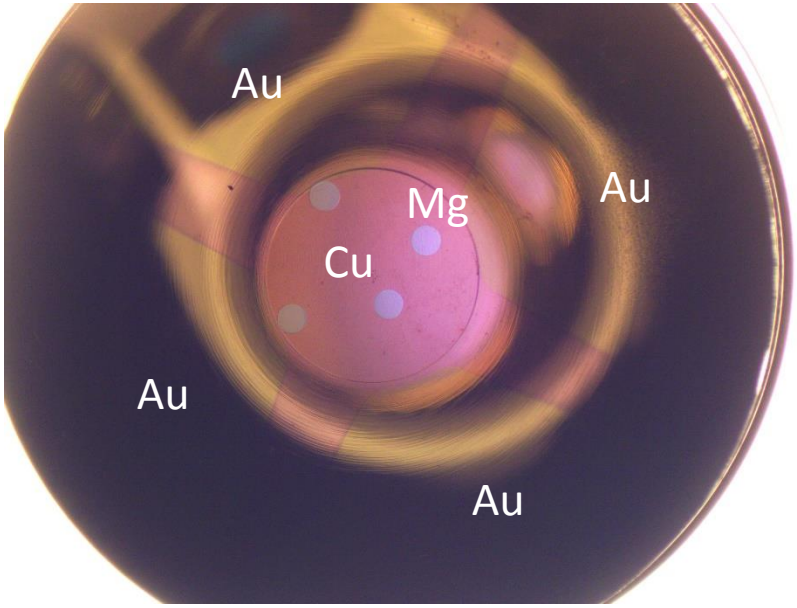


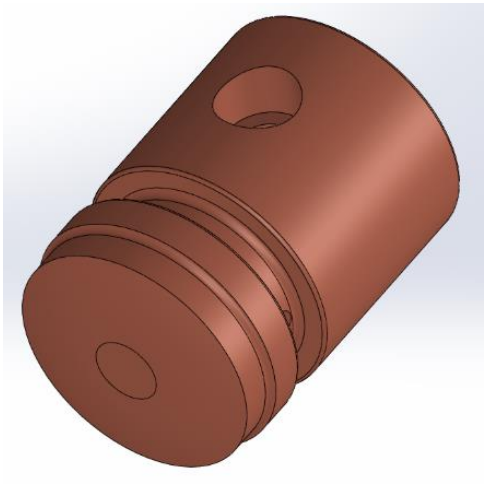


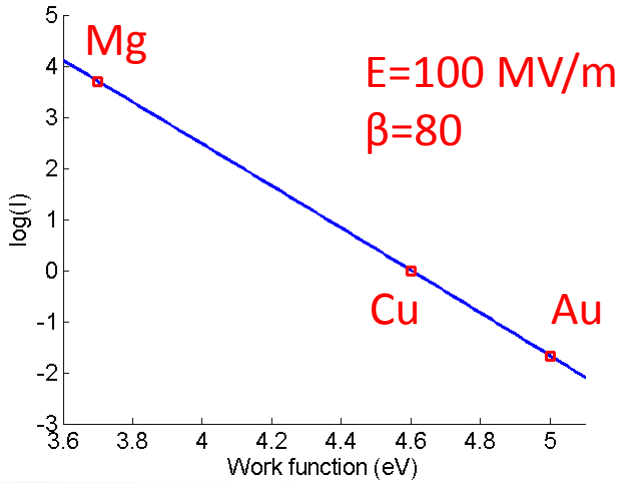


Experiment results

- **Cathode preparation**
  - Very fine finishing Cu cathode from Tsinghua
  - Sputter 100 μm thick Au on the rounded surface to suppress field emission
  - Sputter 100 μm thick Mg spots on the flat surface to increase field emission
  - Strong emission from Mg is expected





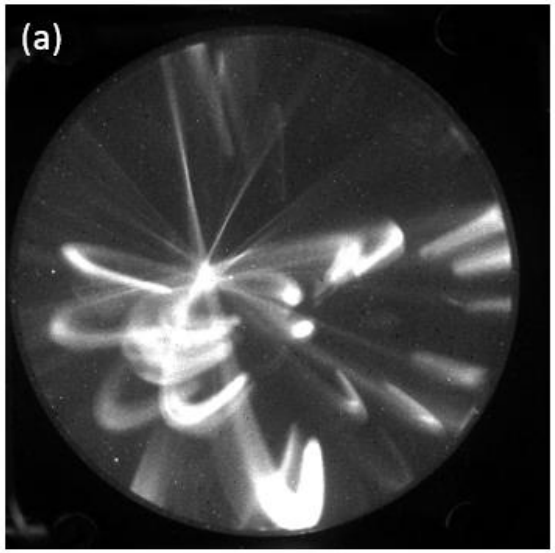


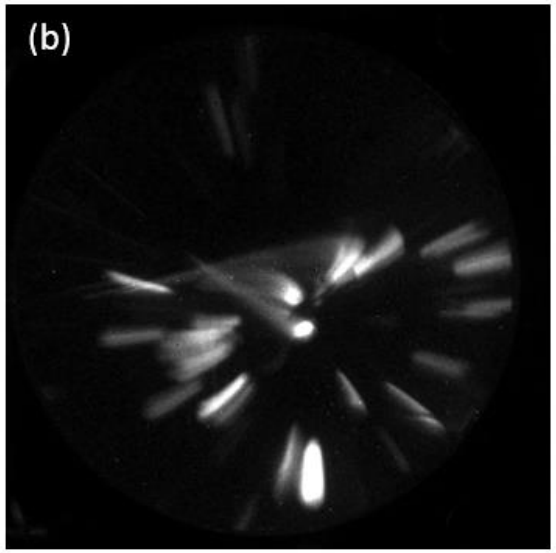
Experiment results (continue)

- **High-resolution imaging**

  - PI-MAX ICCD, 10 μs exposure, 50 μm/pixel, using external trigger

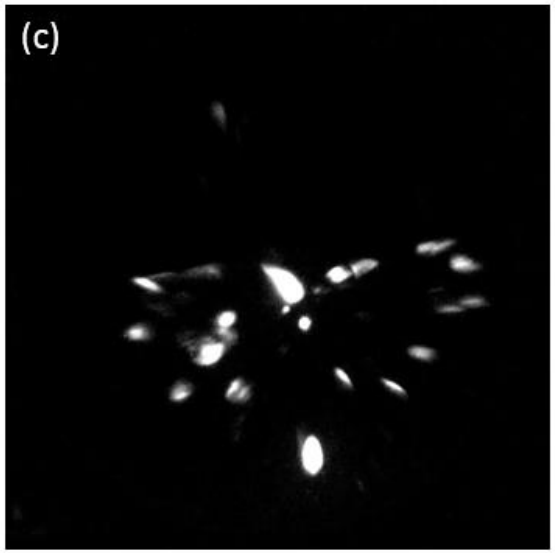
No aperture
20 shots

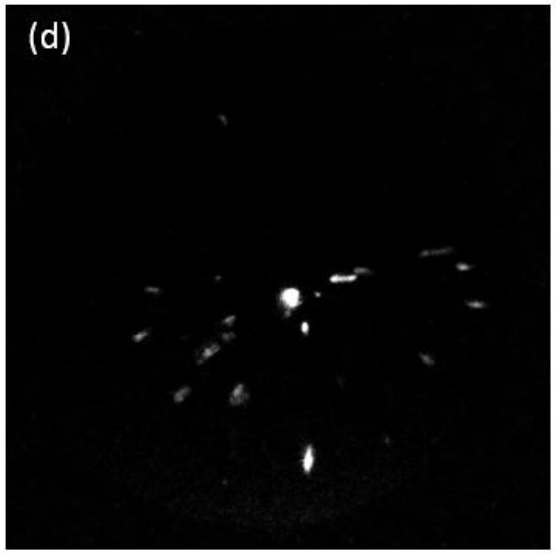




ϕ8 mm
20 shots

ϕ1 mm
100 shots

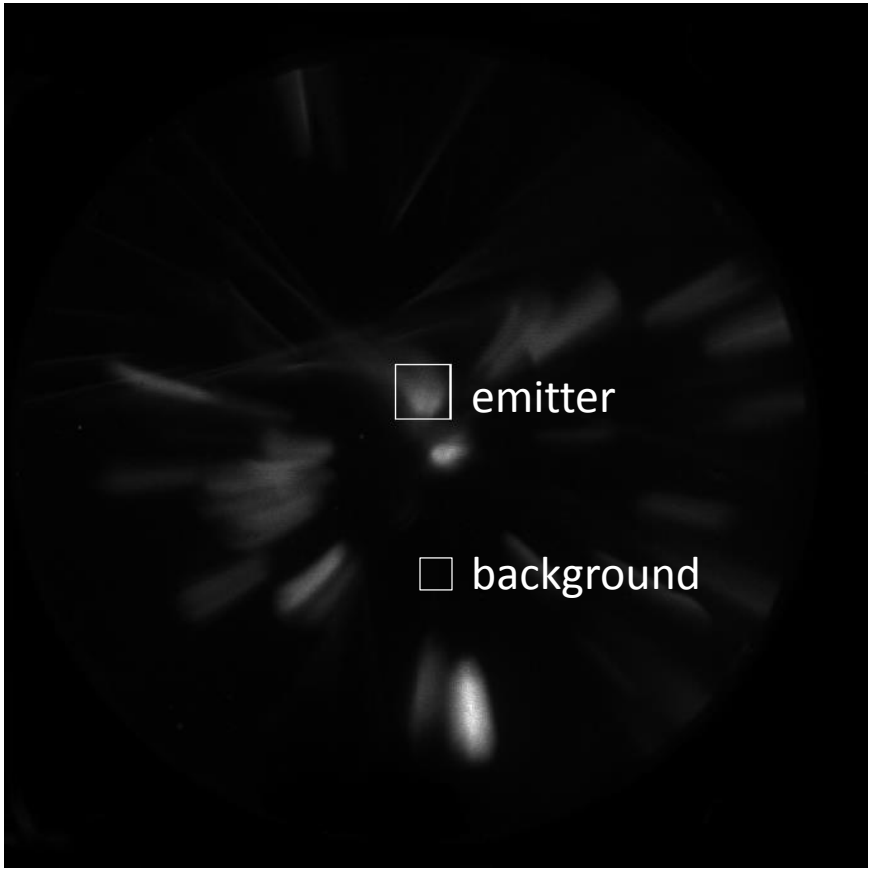




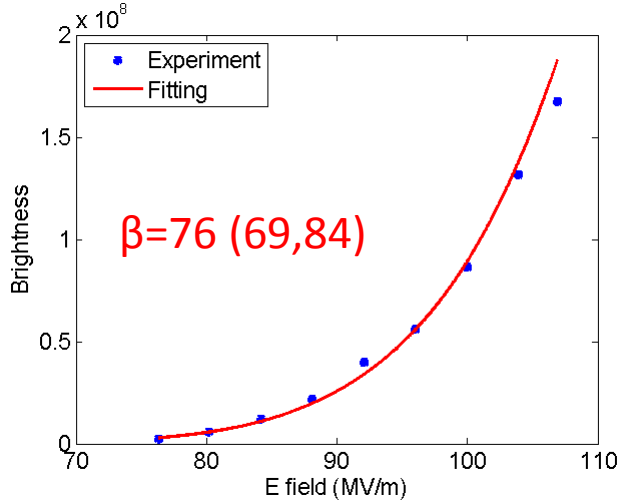
ϕ0.2 mm
100 shots

Experiment results (continue)

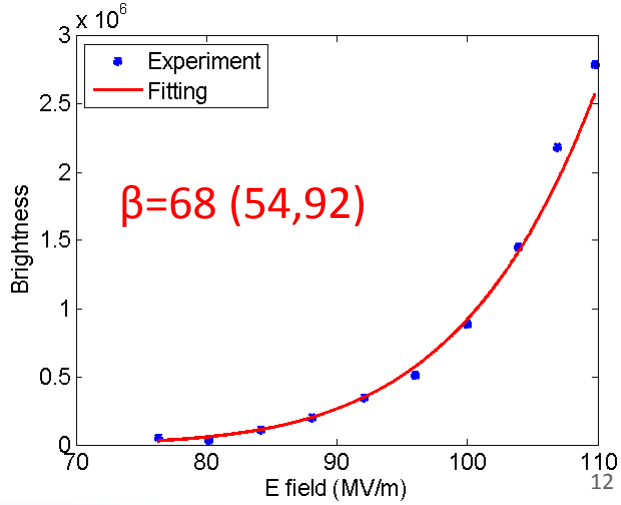
- **Measure field enhancement factor (β) of each emitter**
  - Use ϕ8 mm aperture to ensure nearly constant capture at various field level
  - Subtract background due to X-ray, secondary emission, reflection,…
  - Similar β~70 of the background and the emitters



emitter



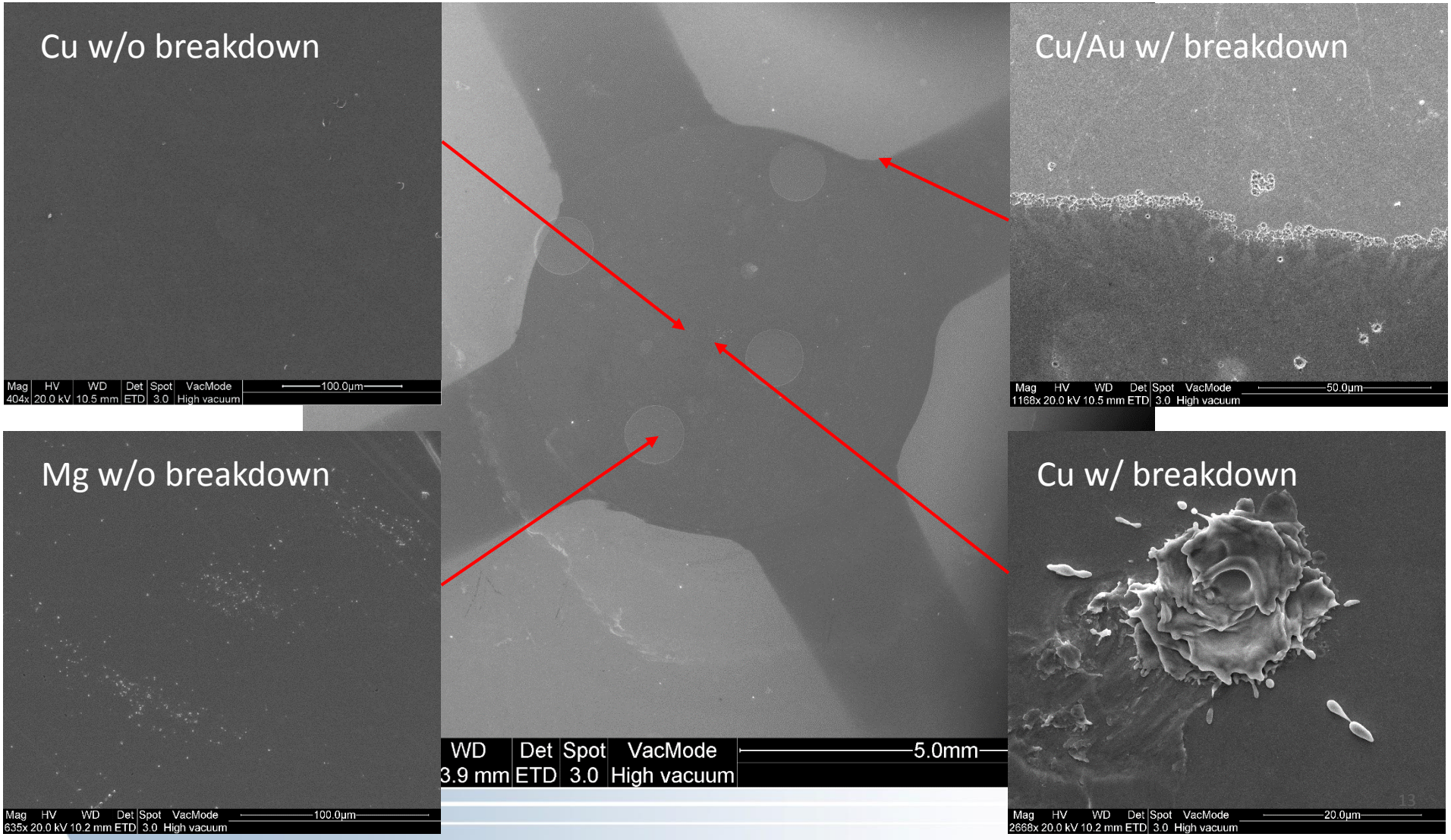
background



Experiment results (continue)

- **SEM images after the experiment**

  - Several breakdown spots observed on the surface

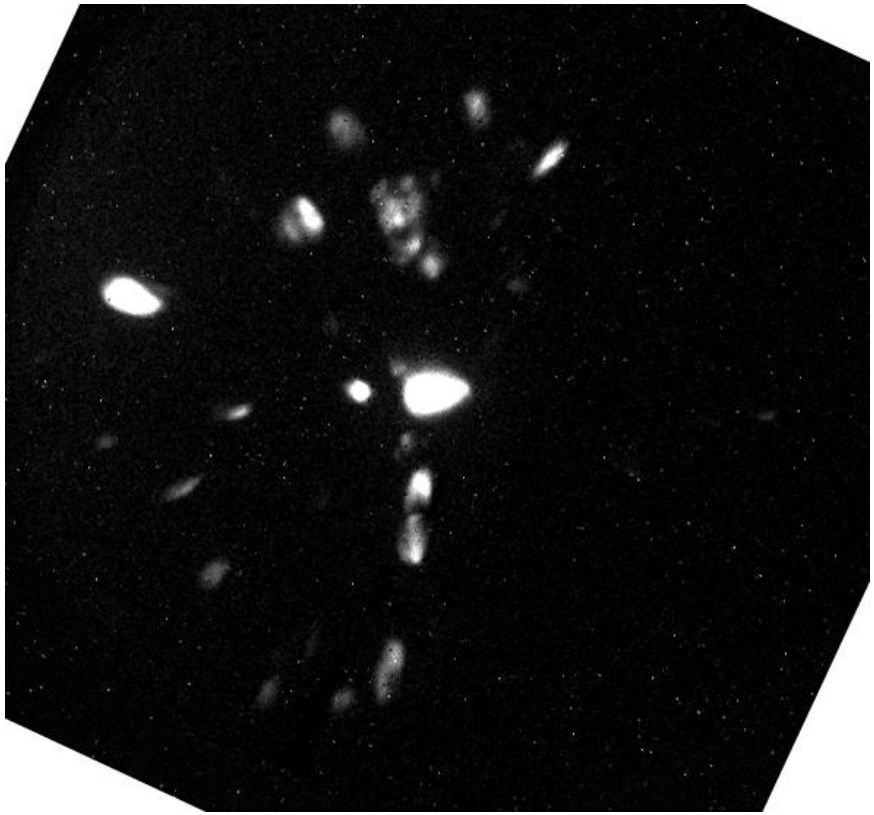


Experiment results (continue)

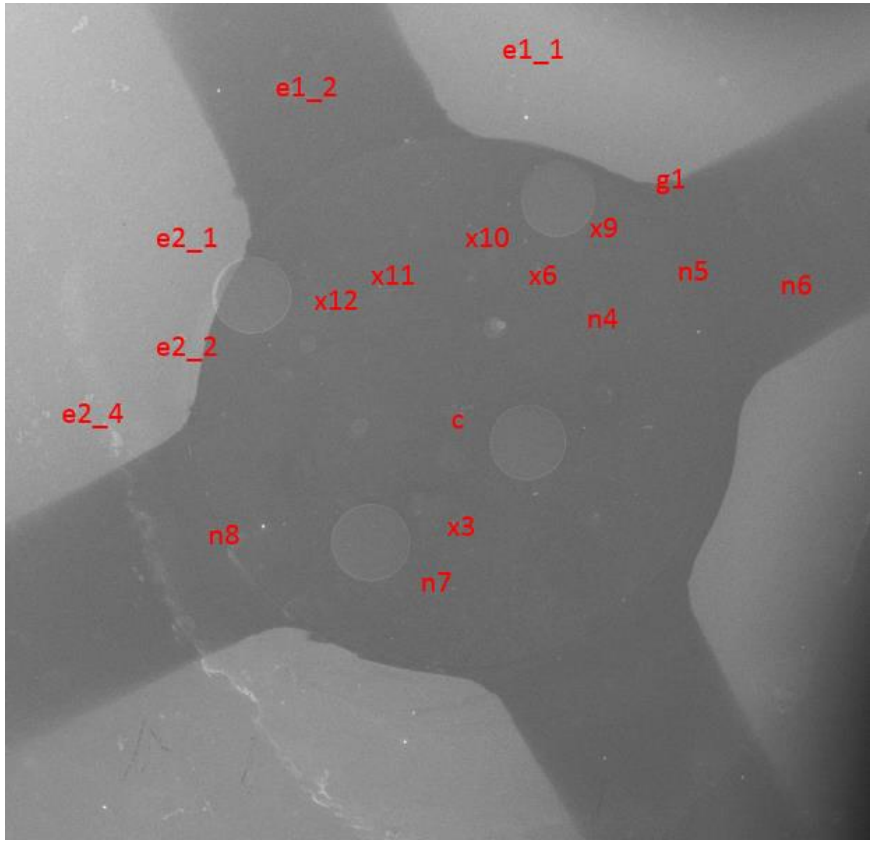
- **Overlap of emitters to breakdown spots**

  - Dark current image transformation based on magnification and rotation angle from ASTRA simulation

Dark current imaging

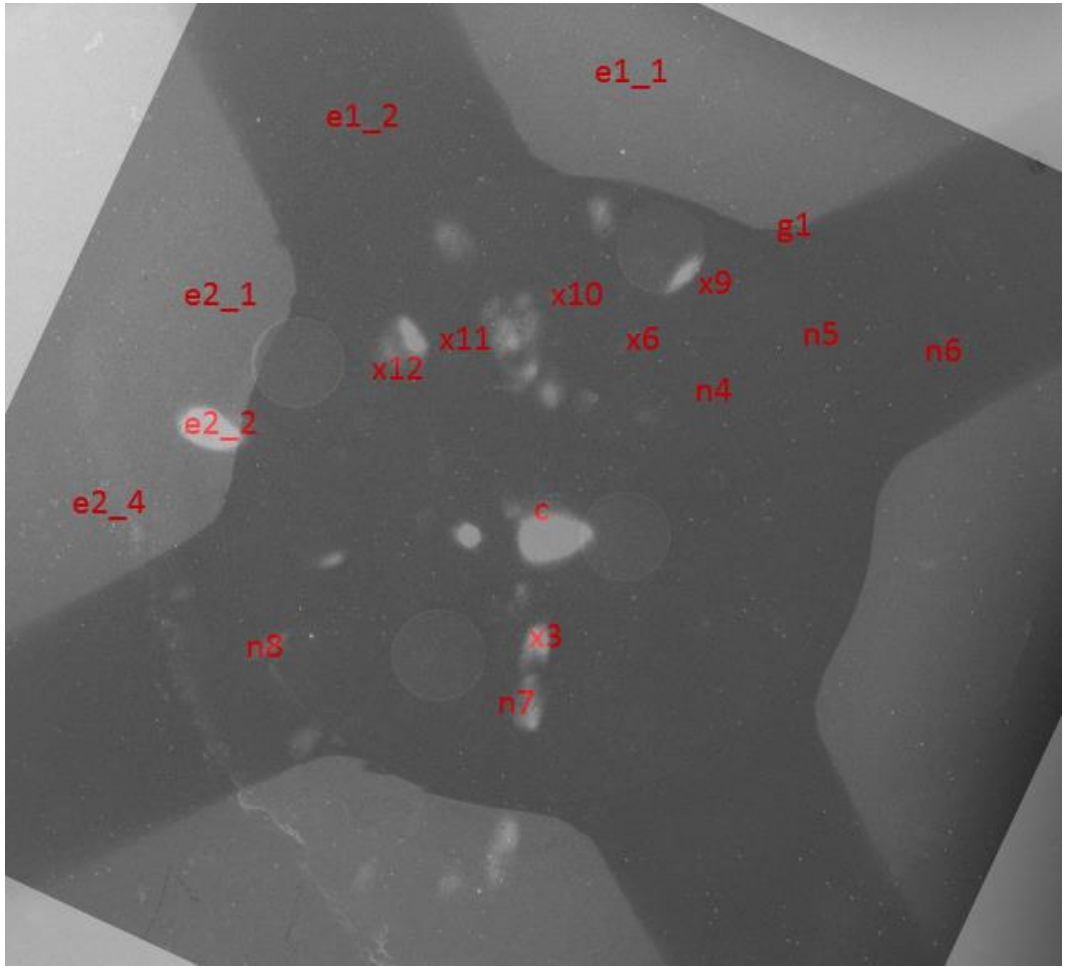


Breakdown spots distribution



Experiment results (continue)

- **Overlap of emitters to breakdown spots**
  - Most emitters overlaps with breakdown spots
  - Needs more SEM to reveal other emitters



Summary and discussion

- **Conclusion**
  - High-resolution dark current imaging has been achieved
  - Field enhancement factor has been measured for each single emitter
  - Most emitters overlap with breakdown spots

- **Future study**
  - More SEM to reveal other emitters
  - Develop a new gun for higher resolution and shorter cathode switching time
  - Use more cathodes with pre-defined pattern (exotic material, sand-blasting,…)

- **Discussion**
  - What is field enhancement factor?
  - Why strong emission from Mg has not been observed?
  - What's the origin for the rest emitters?
  - Why some breakdown spots don't emit?
  - …

Acknowledgement

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

- Tsinghua machining shop for preparing new-shaped cathode

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

Welcome to High Gradient Workshop at Argonne National Laboratory on June 6-8, 2016 (the most beautiful season of Chicago)

International Workshop on Breakdown Science and High Gradient Accelerator Technology (HG2016)

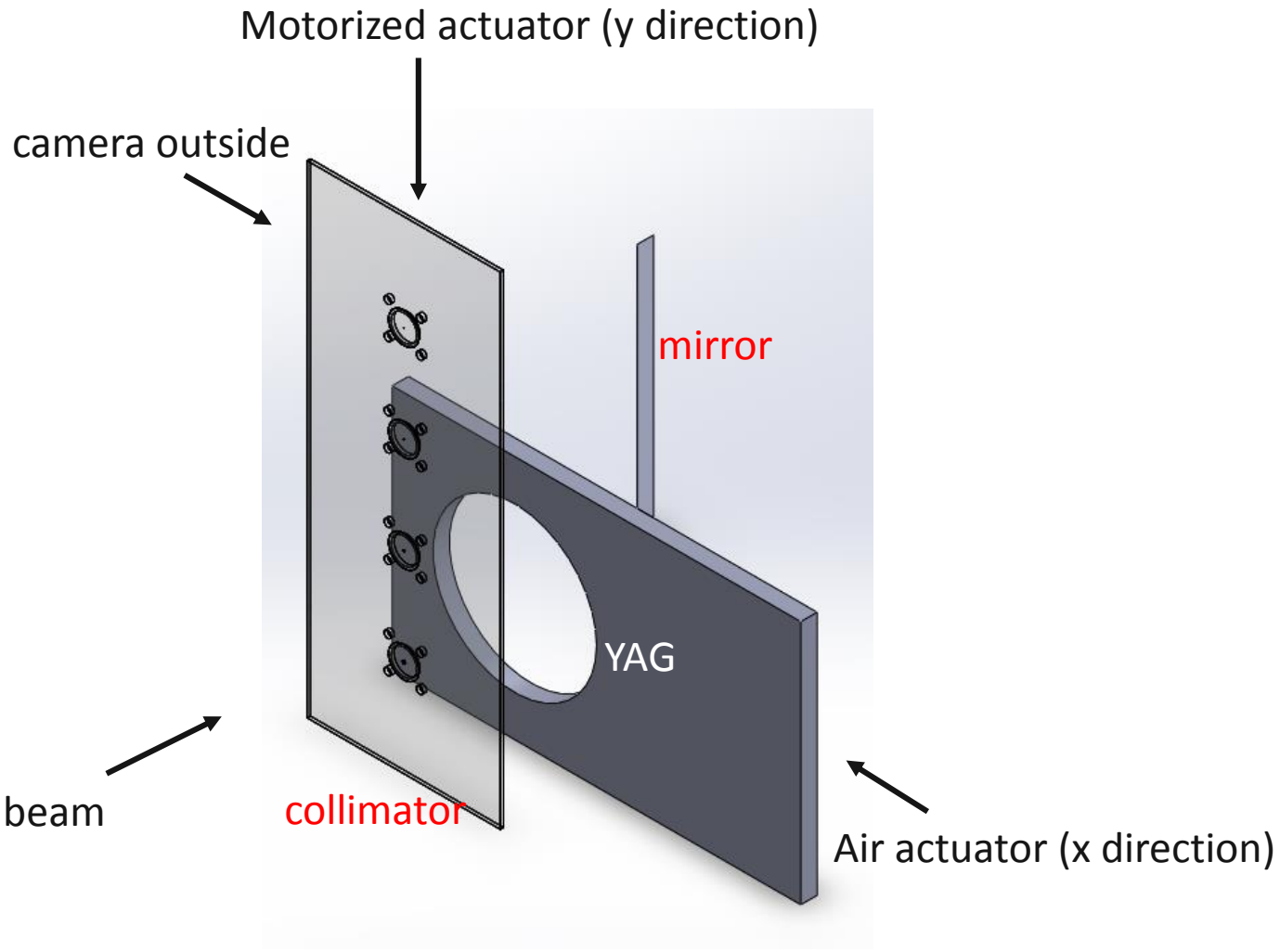
6-8 June 2016
Argonne National Laboratory
US/Central timezone

Details: https://indico.hep.anl.gov/indico/conferenceDisplay.py?confId=963

Organizing Committee Members: Gerardo D'auria (Elettra Sincrotrone Trieste) Wei Gai (ANL) Toshiyasu Higo (KEK) Chunguang Jing (Euclid) Jiaru Shi (Tsinghua University) Sami Tantawi (SLAC) Walter Wuensch (CERN)

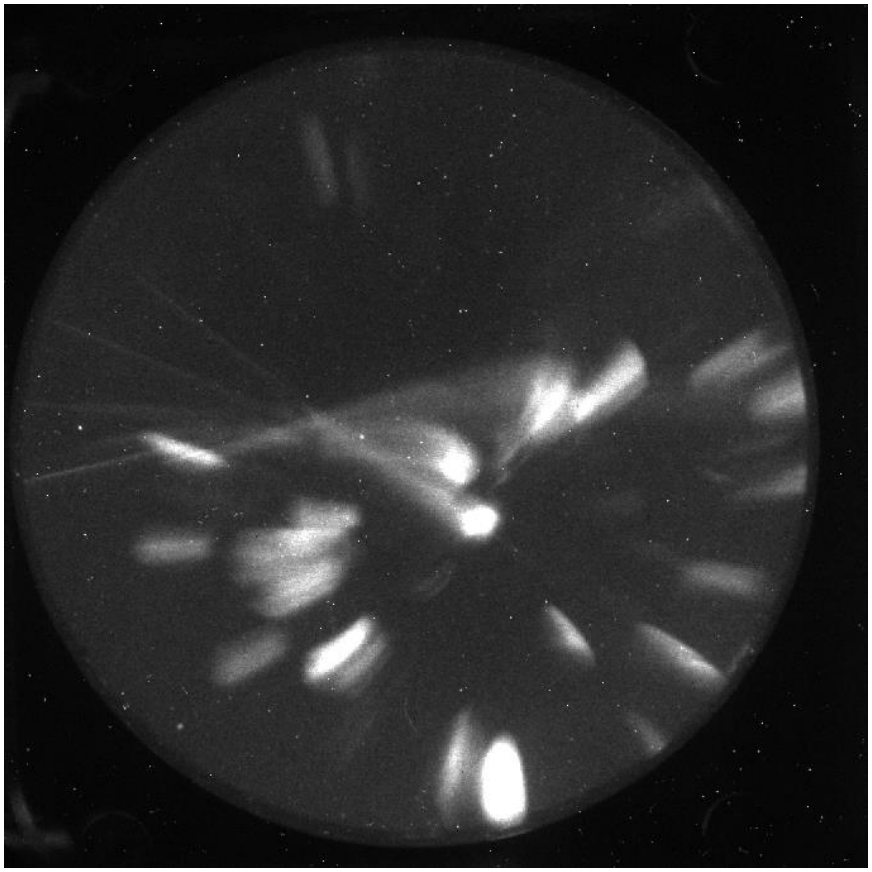
Backup

Elements in C2



Background subtract

ϕ8 mm aperture



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