A SPECTROSCOPIC STUDY OF DISCHARGE SPECIES PRODUCED IN A PACKED BED DIELECTRIC BARRIER DISCHARGE

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THE IMPORTANCE OF MICROPLASMAS

- **<u>Spectroscopic Species and Packed Bed Reactors (PBRs)</u>**

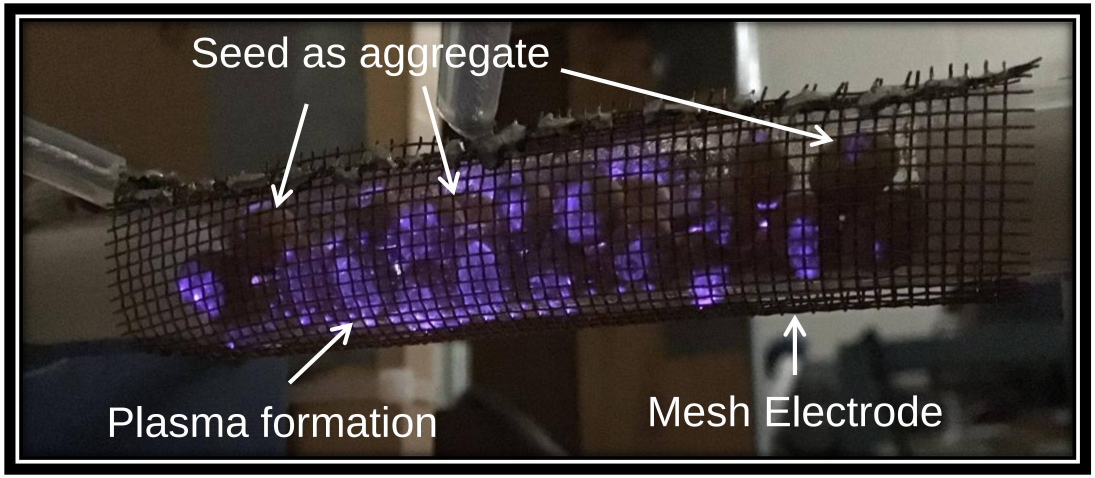
- **Non-thermal plasma production and propagation**
  - **What are the reaction kinetic mechanisms?**
  - **What surface properties enhance or limit plasma production in microporous media?**
  - **What variables are available to augment the plasma properties?**
  - **Will the atmospheric plasma non-thermally interact with aggregate media? Will they have non-destructive effects?**
  - **How does surface morphology effect behavior and propagation (e.g. catalysis, seeds)?**

- **Micro-plasmas have the potential to advance chemical processing.**

PACKED BED REACTOR DISCHARGES

- **Introduction to PBRs**
  - **Rod and mesh or film electrodes**
  - **Dielectric aggregate of varying size, shape, and material**
  - **Gas flow ports – feedstock gases, pollutants**
  - **Various power sources (DC, AC, RF, pulsed)**

- **Applications**
  - **Ozone generation**
  - **Pollutant mitigation**
  - **Dry-reforming of CH_4**
  - **Water reclamation**



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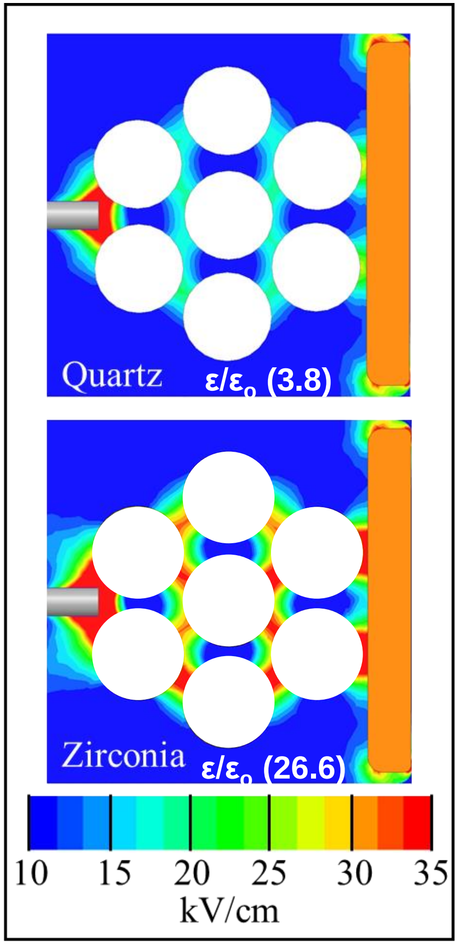
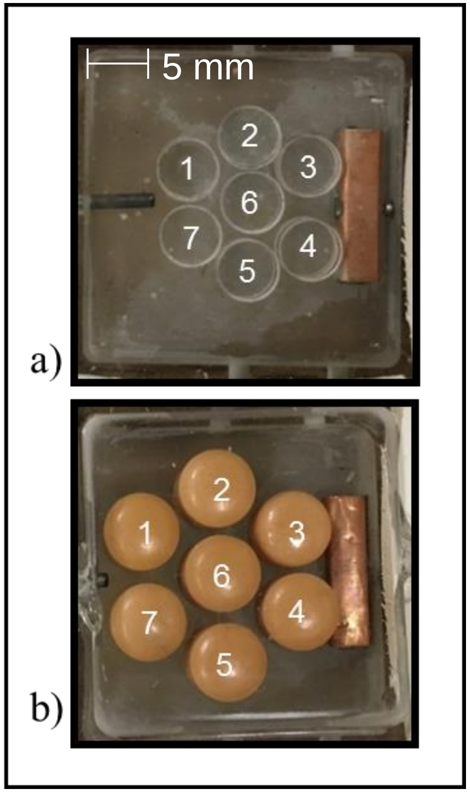
DETAILED APPROACH

- To visualize plasma propagation in PBRs, a 2D cell investigation was developed
- 2D minimizes overlapping plasmas components and optical analysis vs. 3D
- Time-resolved optical emission spectroscopy analysis with ICCD camera and spectrometer
    - Monitor electron energetics
    - Investigate modes for dielectric-to-dielectric plasma propagation
  - Structured and randomly placed aggregate
- Modeling
  - *nonPDPSIM, ANSYS:* Maxwell EM solver

EFFECT OF DIELECTRICS





- Dielectrics locally enhance the electric field
- Manipulation of media allows for varying discharge characteristics
- Highest enhancement at closest dielectric-dielectric contact points
- E/N scales with dielectric constant

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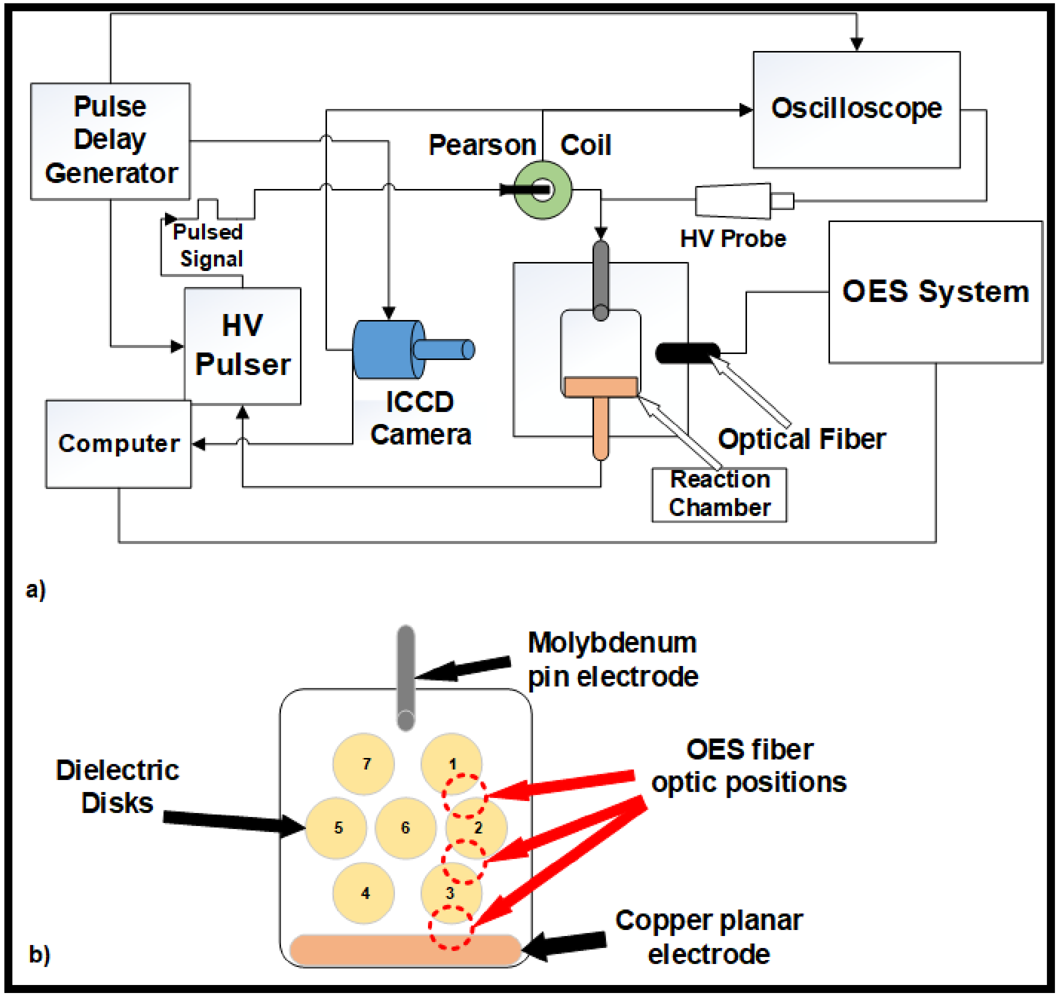
2D EXPERIMENTAL SETUP



- Nanosecond, pulsed discharge: 20 kV
- Gas Parameters
  - Room air composition
  - 760 Torr
- ICCD image capture
  - 10 Hz, 100 Hz
  - Pulse Delay Generator Timing

- Zirconia
- $\varepsilon/\varepsilon_o$ = (26.6)

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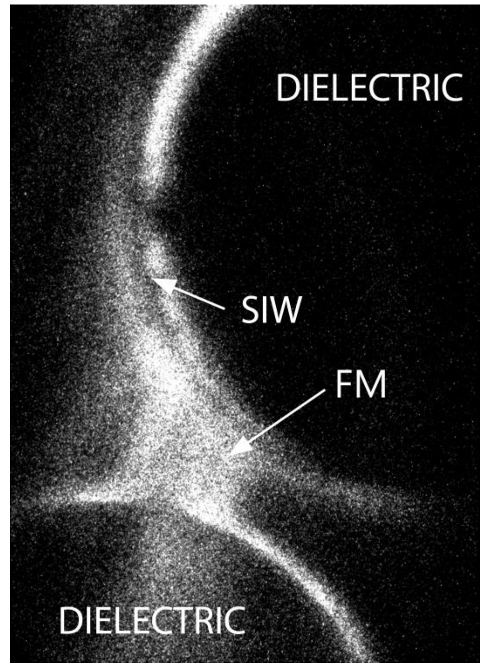
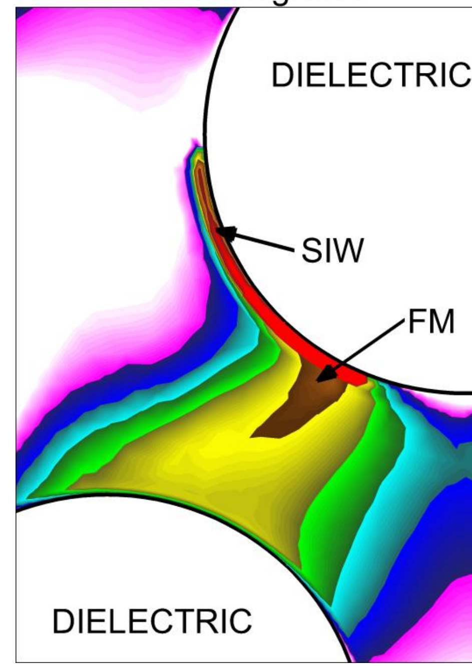
PREVIOUS EXPERIMENTAL FINDINGS

- **Filamentary Microstreamers (FM) to Surface Ionization Waves (SIWs) to FMs as plasma propagates in different modes through PBR**
- **Discharges influenced by strength of dielectric material**
  - **Quartz and zirconia materials studied**
- **Plasma localized at interstitial locations and surfaces of dielectric aggregate**



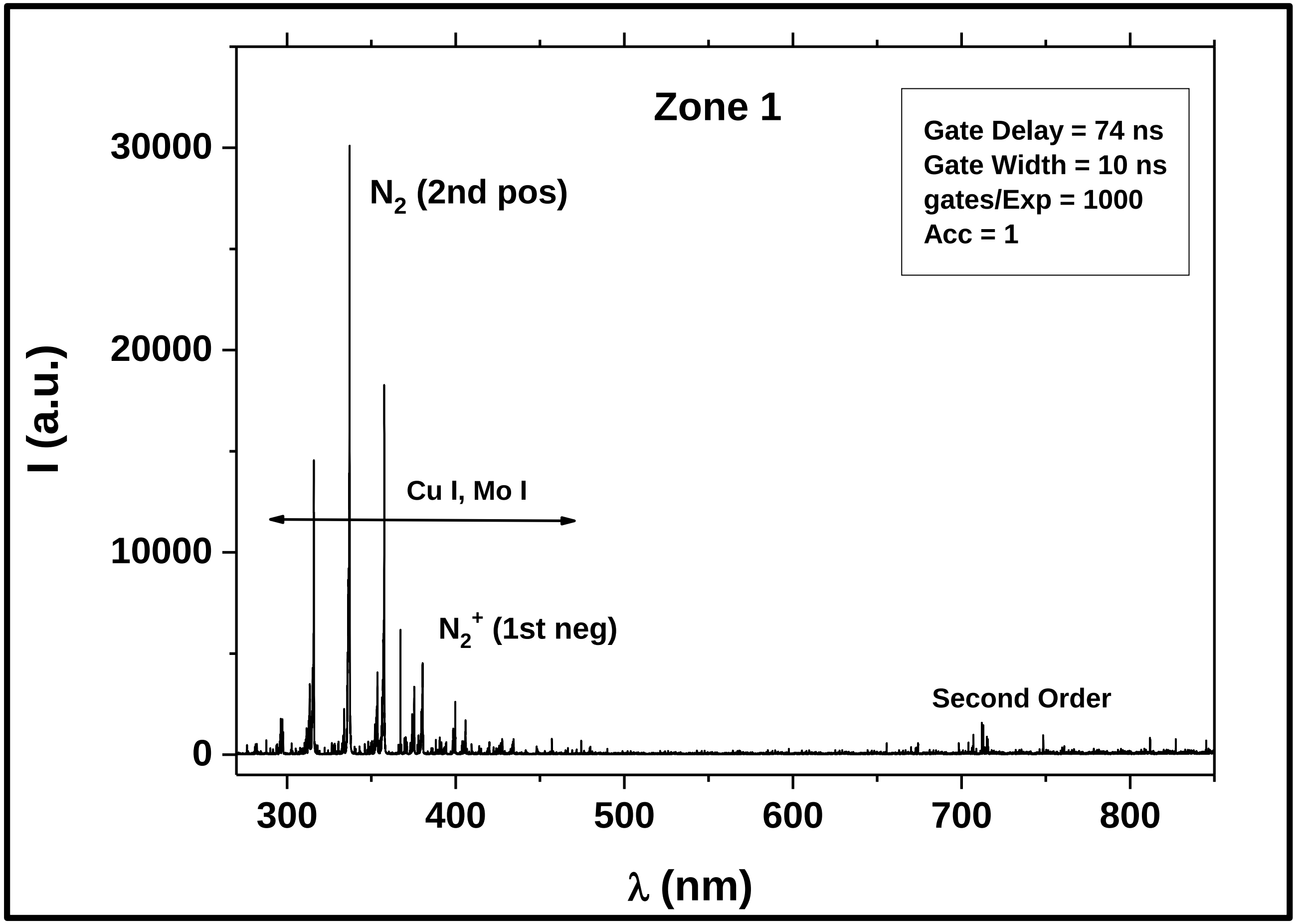
• Experiment
1 ms, integrated

$[N^*+N^{**}]$ (10^{14} cm^{-3}, 4 dec)
time integrated



• Model,
nonPDPSIM

OPTICAL EMISSION SPECTROSCOPY

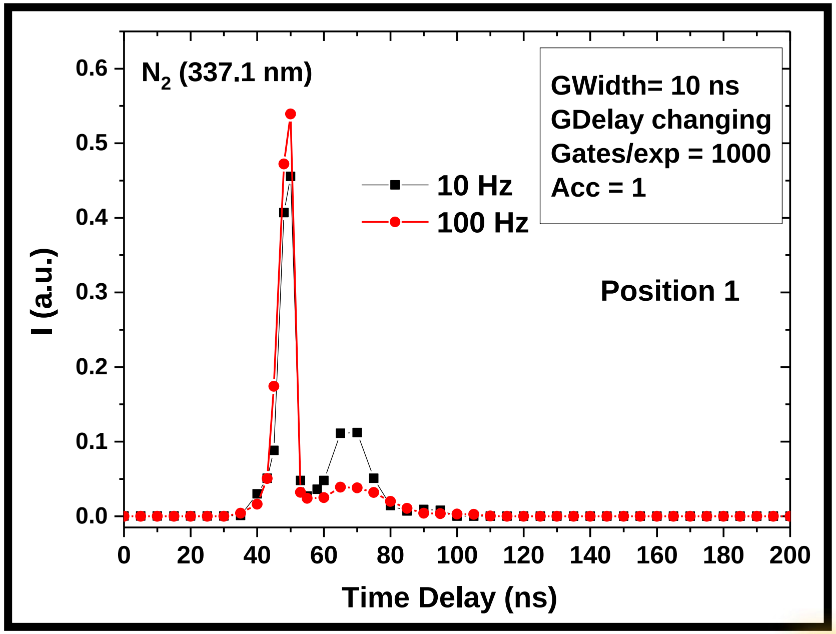


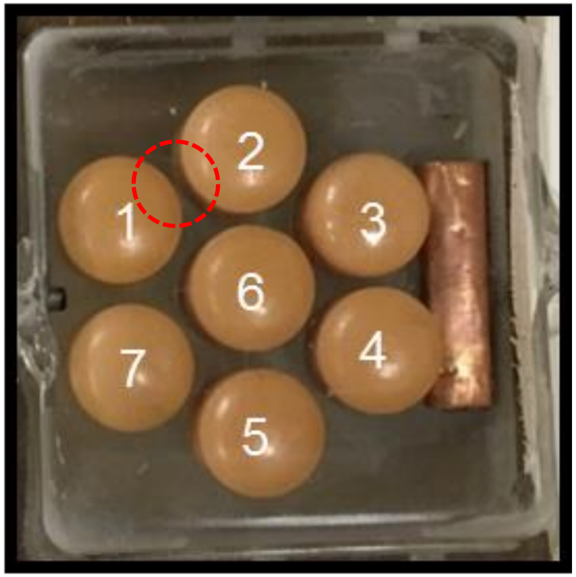
- **Provides insight into the plasma**
  - **Species produced**
  - **Plasma properties**

- **Investigations focused on N_2 (337 nm) emission**
- **Pi-Max3 Acton Spectrometer**

OPTICAL EMISSION SPECTROSCOPY

- **<u>Position (1)</u>**
  - **Placement between disks 1 and 2**
  - **Data taken at 10 Hz, 100 Hz**
  - **4x Magnification of time-resolved imaging**
  - **$T_{gas} \approx 345$ K**





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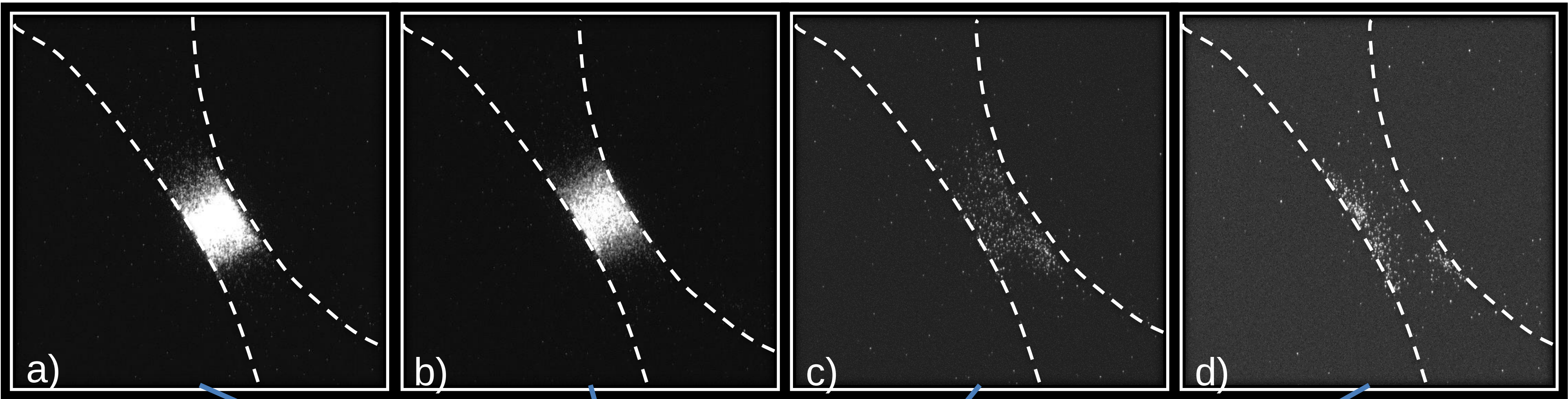
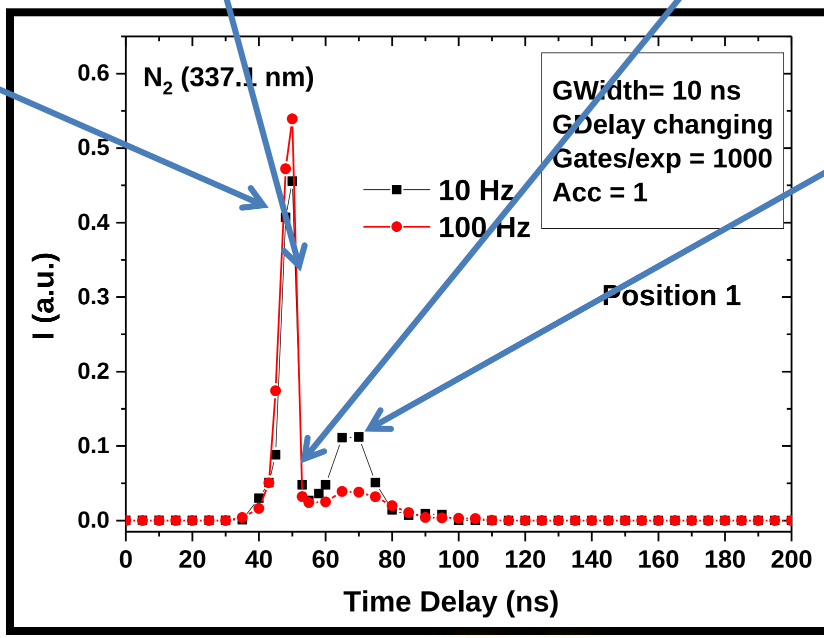
TIME-RESOLVED IMAGES: POSITION 1, 10 Hz



- **10 Hz**
- **20 kV, 120 ns pulse width**
- **5 ns exposure**
- **4x mag.**



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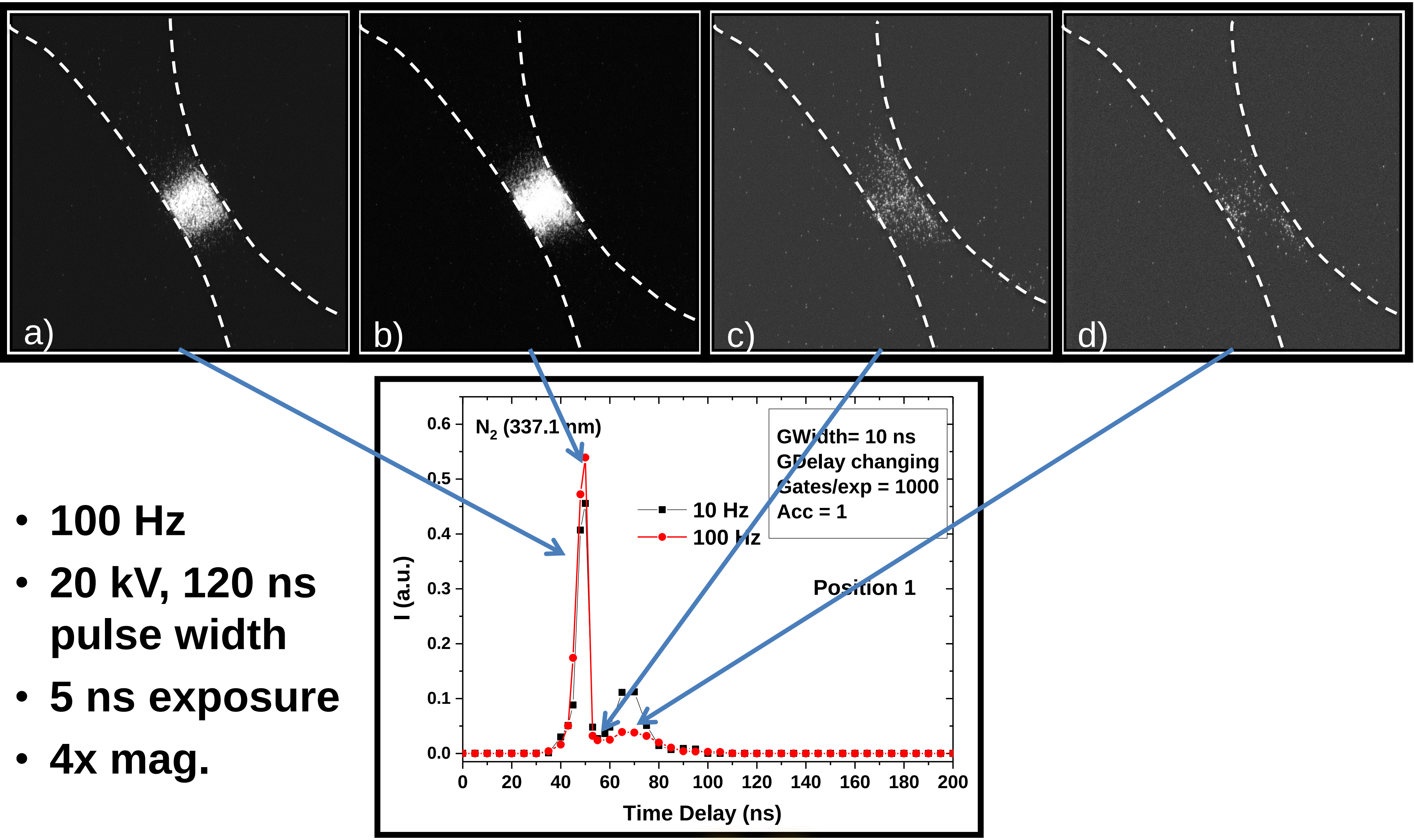
TIME-RESOLVED IMAGES: POSITION 1, 100 Hz



- **100 Hz**
- **20 kV, 120 ns pulse width**
- **5 ns exposure**
- **4x mag.**

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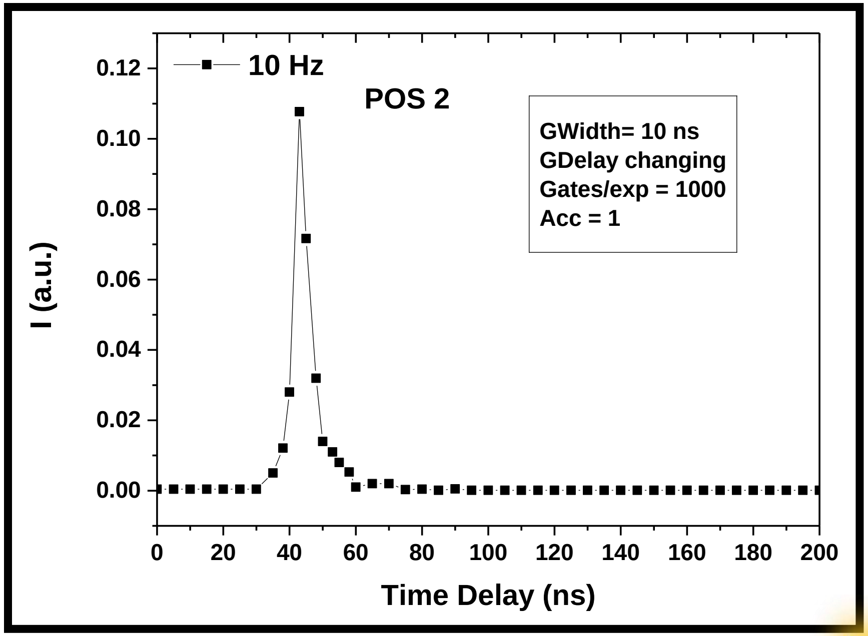
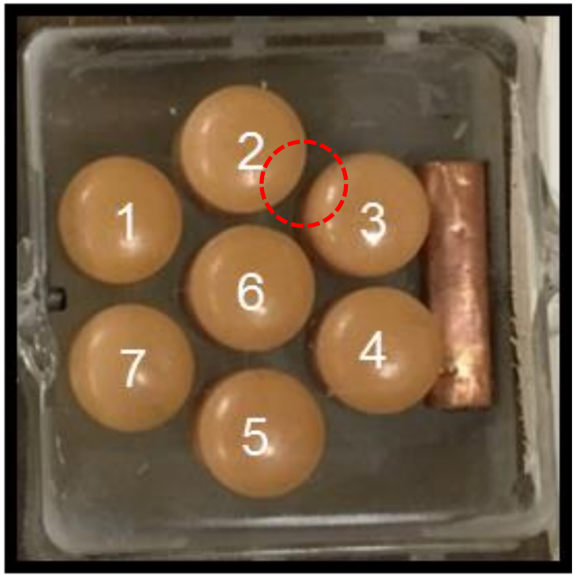
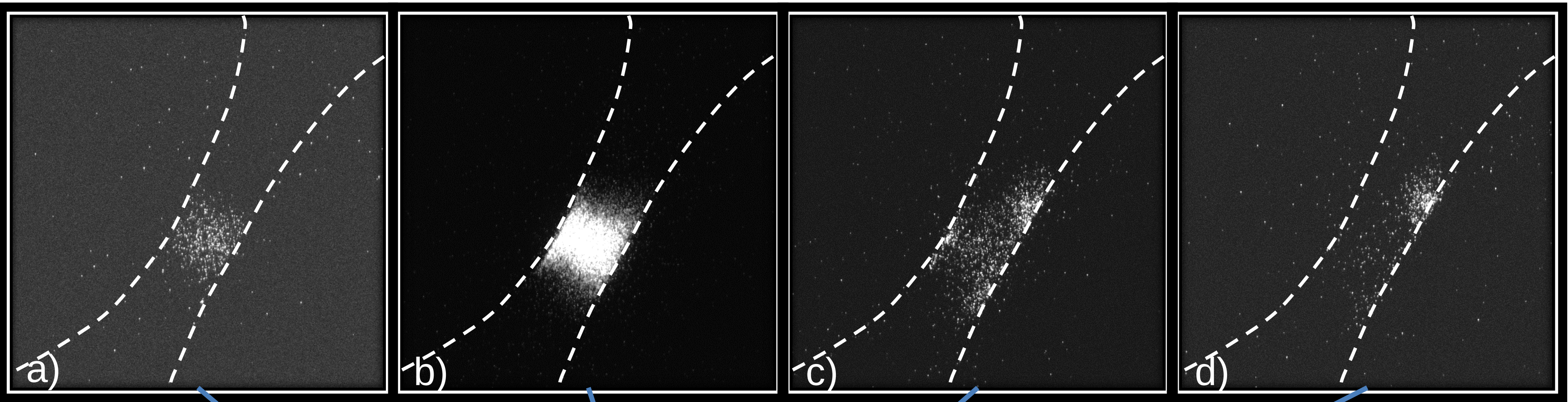
OPTICAL EMISSION SPECTROSCOPY

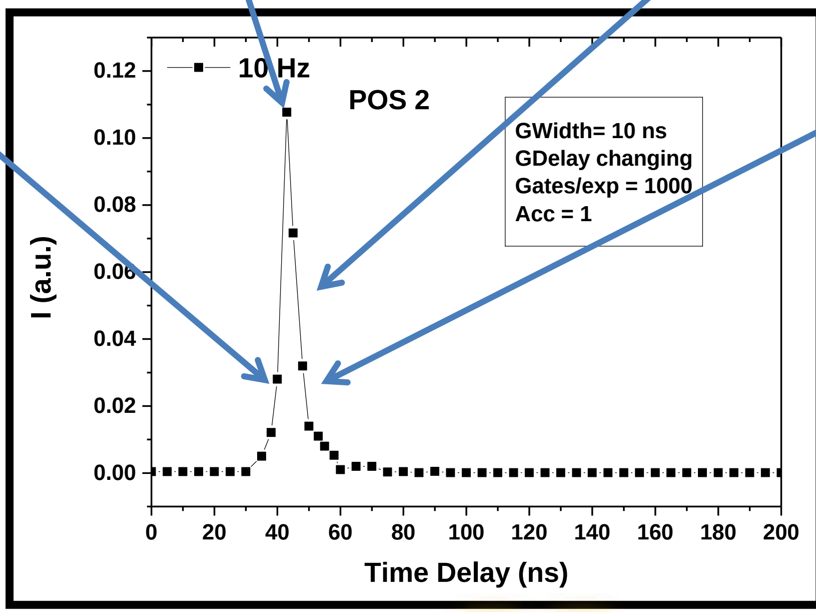
- **<u>Position (2)</u>**
  - **Placement between disks 2 and 3**
  - **Data taken at 10 Hz**
  - **4x Magnification of time-resolved imaging**
  - **$T_{gas} \approx 345$ K**





TIME-RESOLVED IMAGES: POSITION 2, 10 Hz





- **10 Hz**
- **20 kV, 120 ns pulse width**
- **5 ns exposure**
- **4x mag.**

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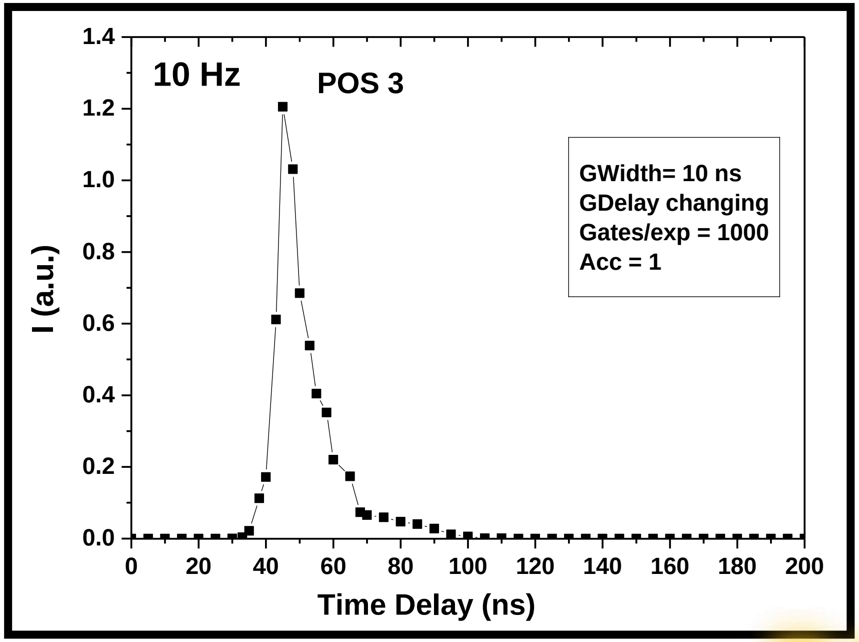
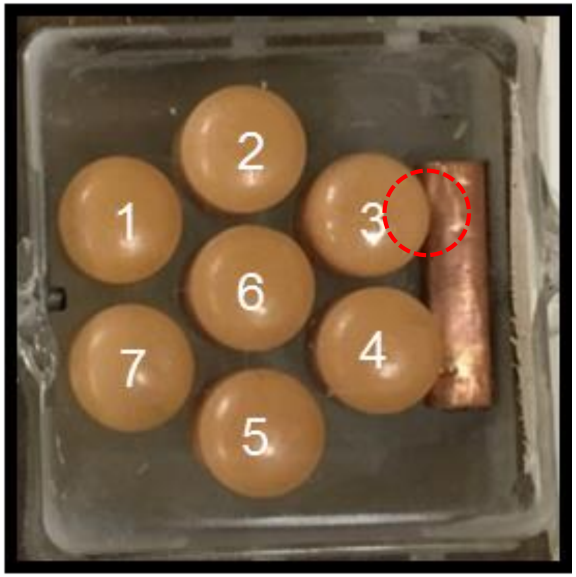
OPTICAL EMISSION SPECTROSCOPY

- **Position (3)**
  - **Placement between disk 3 and planar electrode**
  - **Data taken at 10 Hz**
  - **4x Magnification of time-resolved imaging**
  - **$T_{gas} \approx 345$ K**





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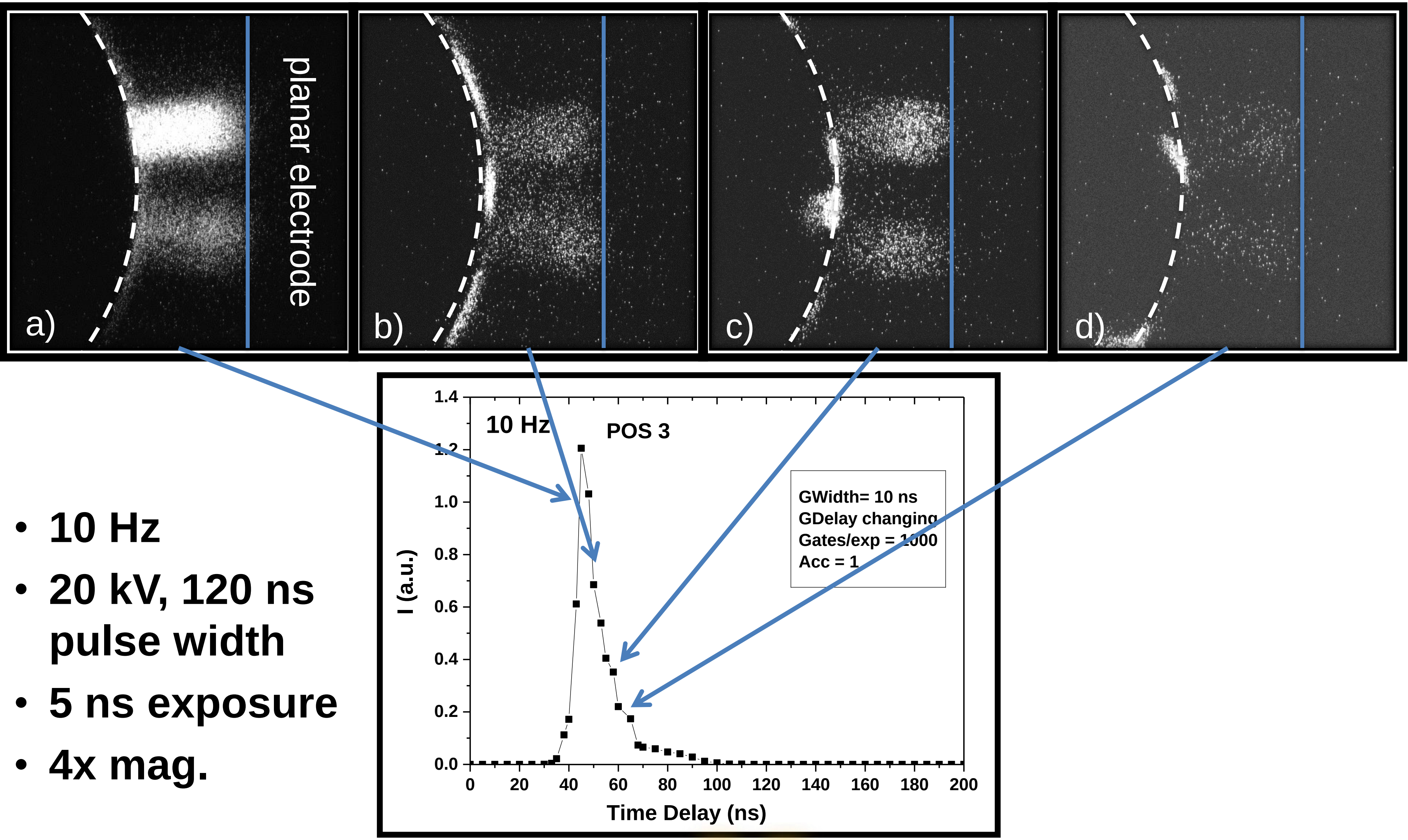
TIME-RESOLVED IMAGES: POSITION 3, 10 Hz



- **10 Hz**
- **20 kV, 120 ns pulse width**
- **5 ns exposure**
- **4x mag.**

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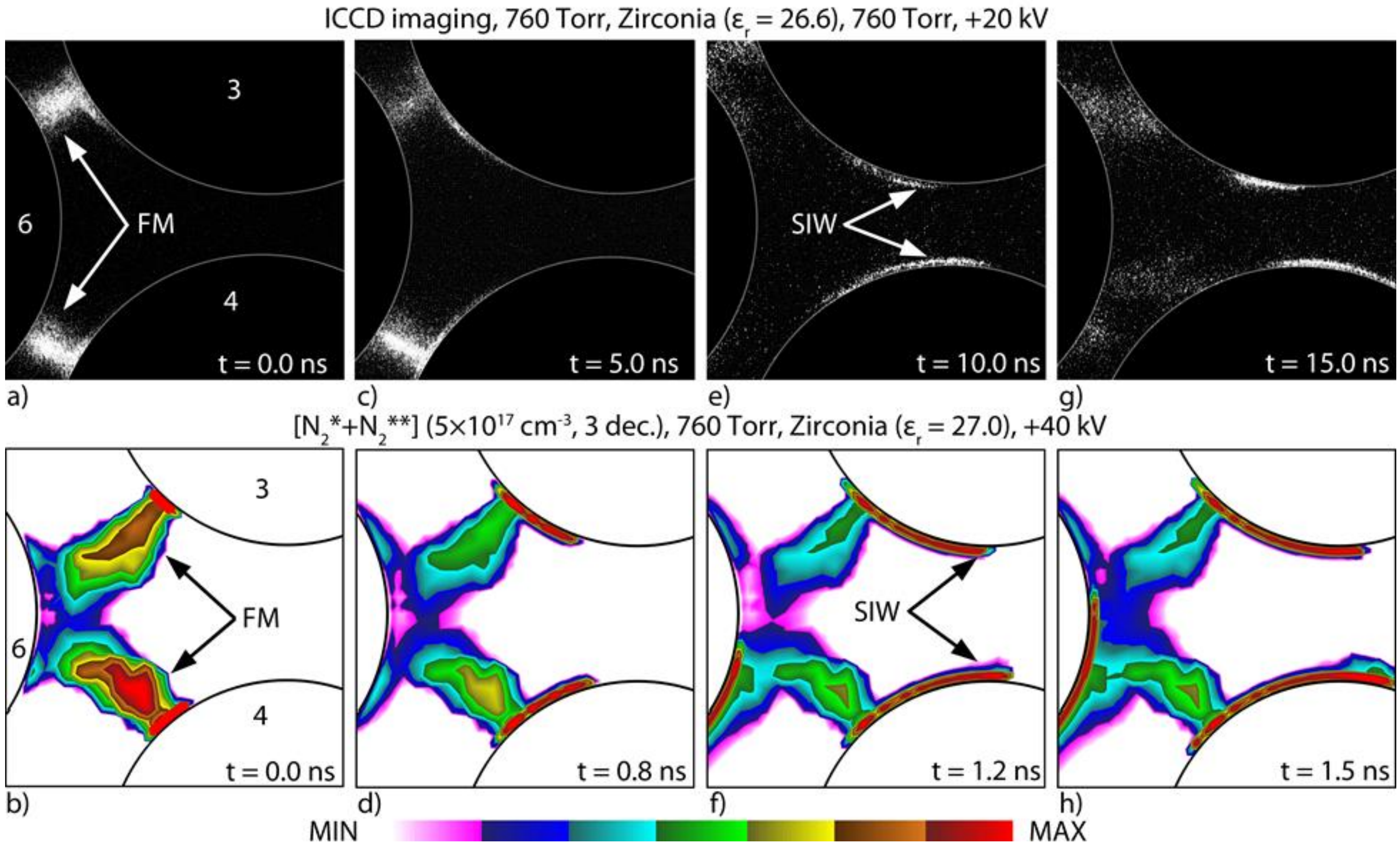
COMPARISON WITH MODEL



- **Model (nonPDPSIM) predicts FM to SIW transition.**

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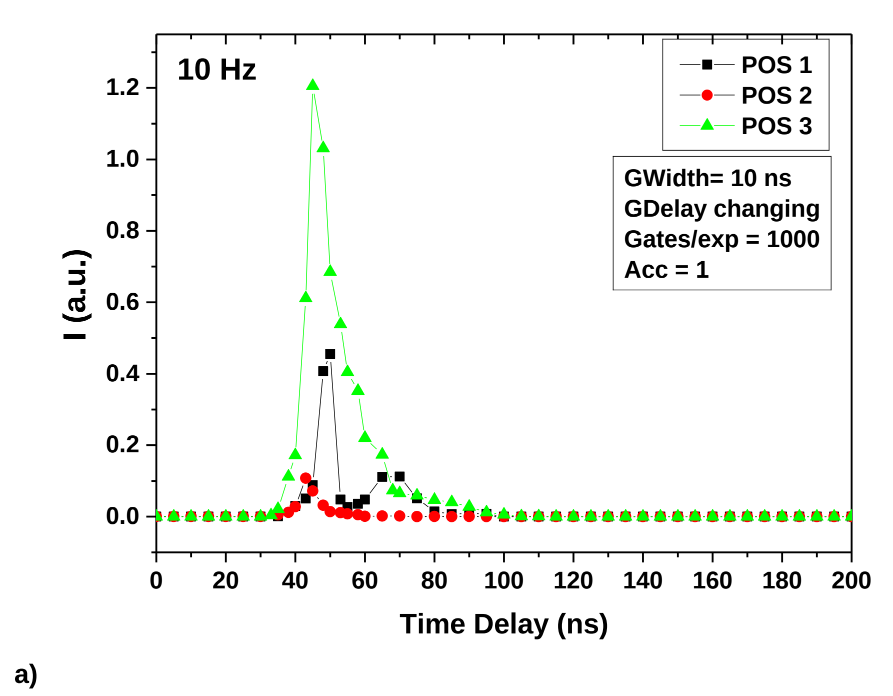
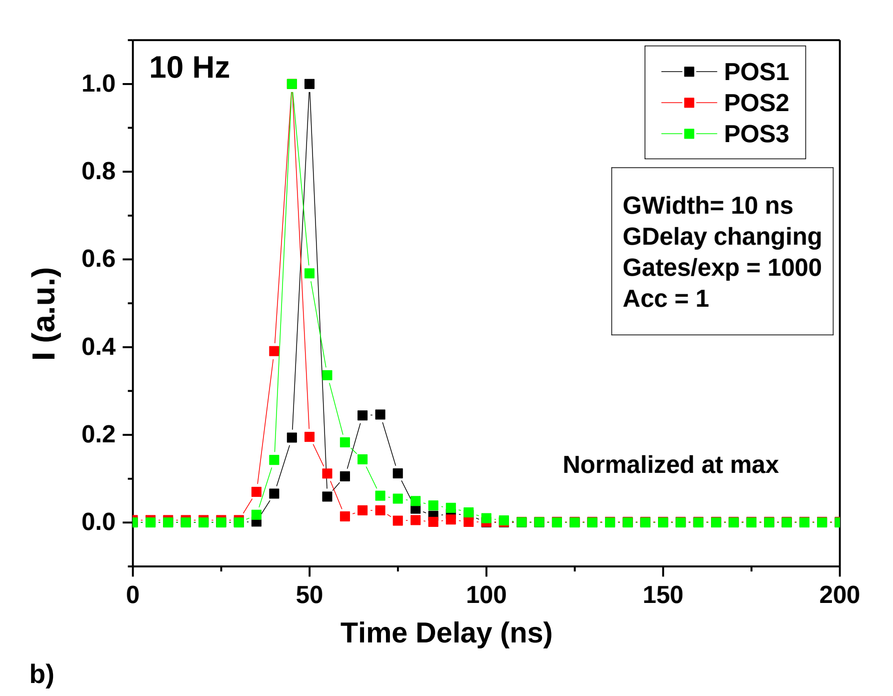
SUMMARY OF EMISSION vs POSITIONS





- **Intensity increases as discharge propagates through PBR**
- **Evidence of restrike (double maximum)**

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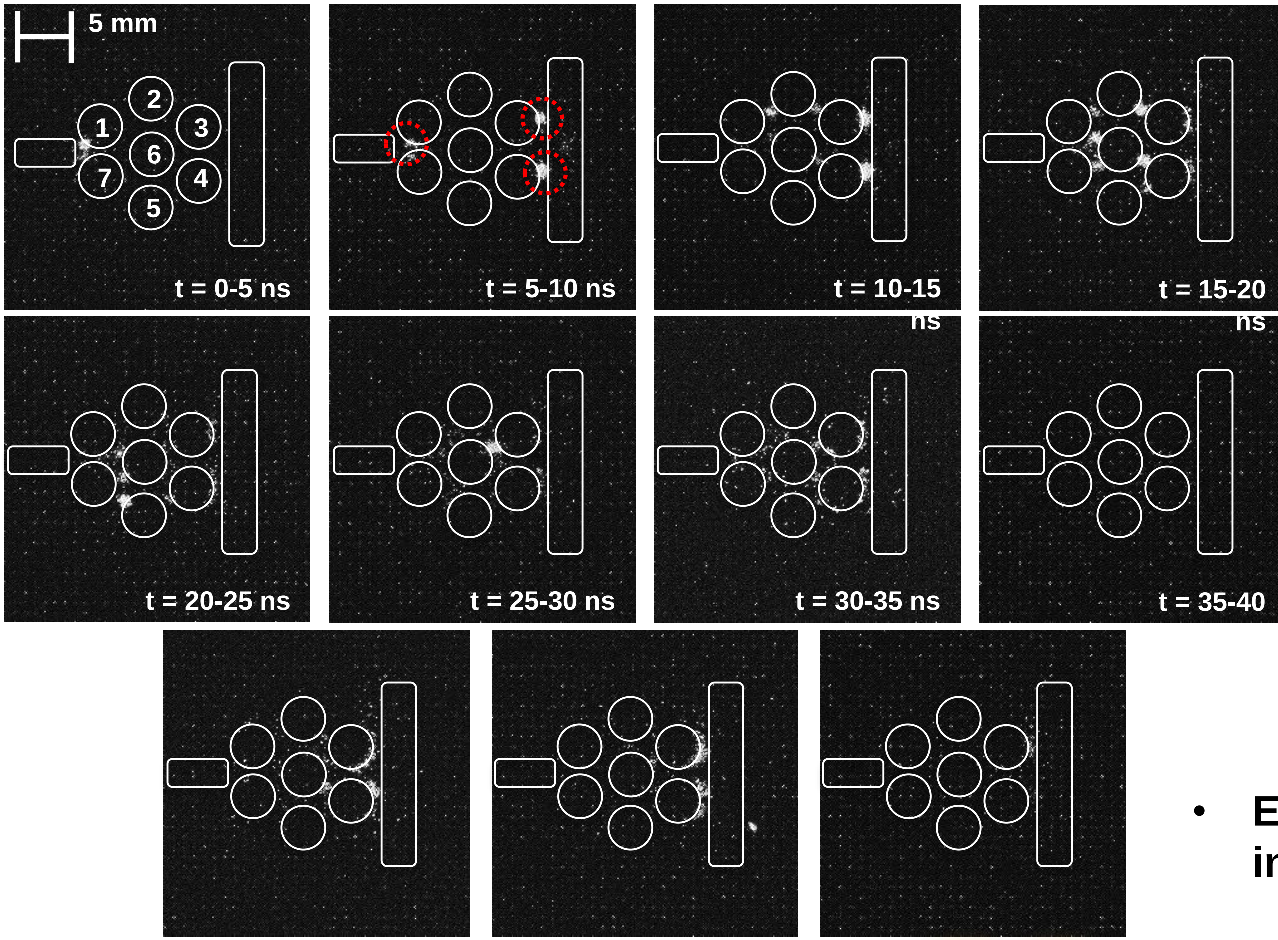
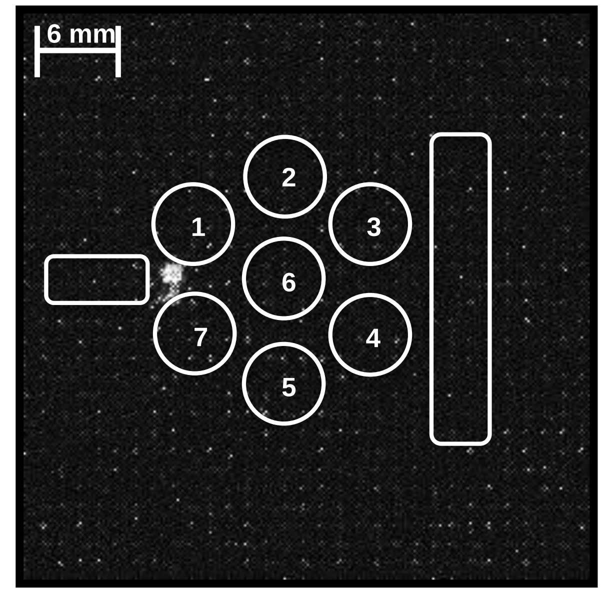
ZIRCONIA: DISCHARGE PROPAGATION THROUGH PBR





E —— Overall E-field Direction ——→

- Explains time differences in emission spectrum

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CONCLUDING REMARKS

- **Evidence of restrikes seen with N_2**
  - **Double maximum in emission spectra**

- **N_2 (337.1 nm) peak emission intensity was dependent upon location for this geometry**

- **Emission peaks at each location at some point in time showing the plasma propagation through the cell**
  - **Likely tracking the density of electrons with energy above the excitation threshold**

- **Future Investigations:**
  - **Active interrogation to find atomic N populations**
  - **Expand the N_2 emission study**
  - **Compare emission spectrum with that using materials of various dielectric strengths**

QUESTIONS

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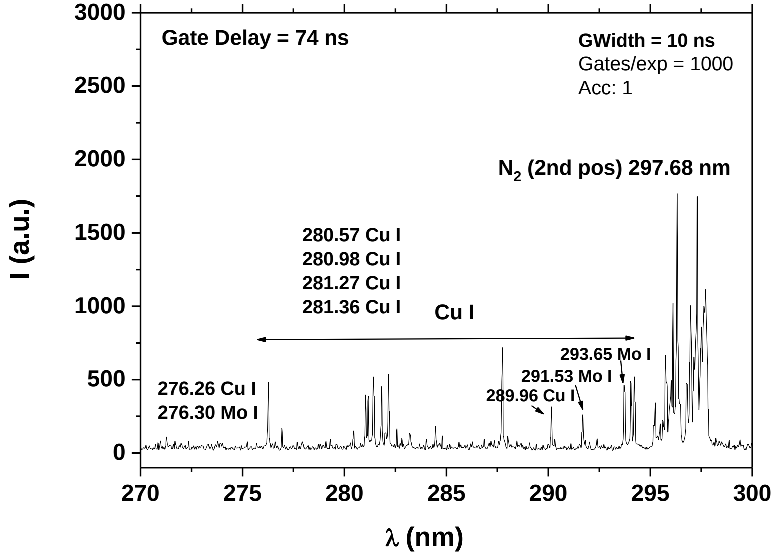
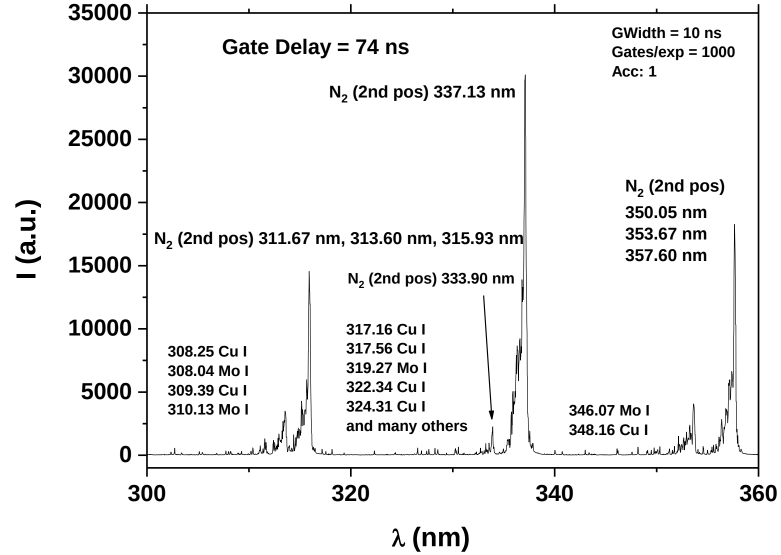
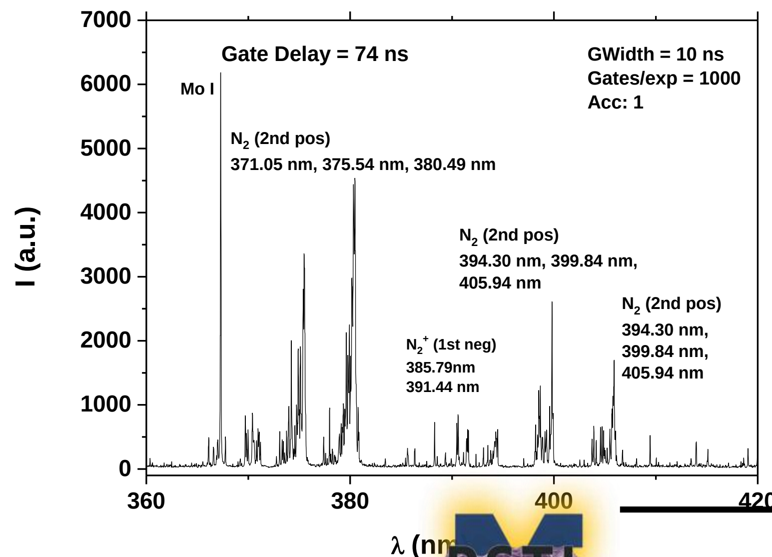
ADDITIONAL SLIDES







ADDITIONAL SLIDES