



# ***Recent Developments in Vertical Electropolishing***

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# Outline

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- HEP vs VEP
- Advantages and problems in VEP
- Progress in VEP at Marui & KEK
  - VEP setups
  - Cathode shape
  - VEP parameter optimization to solve the problems
- Summary

# Horizontal vs Vertical EP Setups

## HEP Setup at KEK



## VEP Setup at Saclay



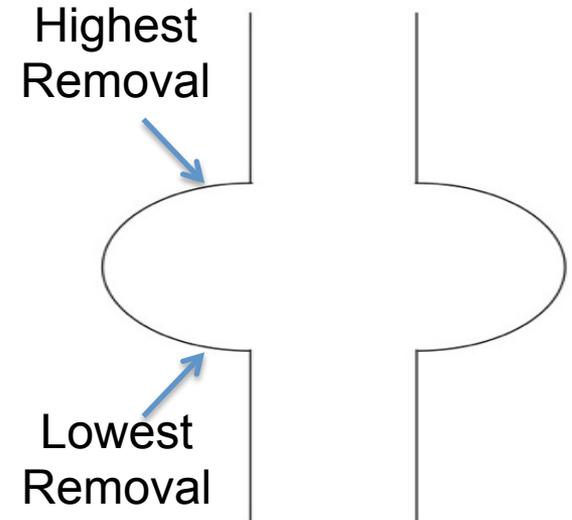
HEP	VEP
Complicated setup	Simple setup
Need rotation of a cavity	No cavity rotation
Sealing of rotating bodies	No sealing as no rotating body
Mechanism to make EP bed vertical for acid and water drainage	Already vertical
Large space	Comparatively small space
High Cost	Comparatively low cost

- Advantages of VEP setup attract us to use VEP for cavity surface treatment.

# Issues with VEP

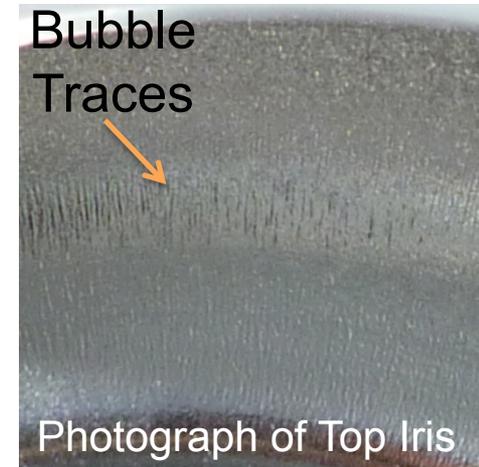
## ◆ Longitudinal Asymmetry in Polishing

- Top iris is always found with the highest removal of Nb. A removal thickness on the top iris remains ~3 times higher than that of the bottom iris.
- This might cause degradation of field flatness.



## ◆ Bubble Traces

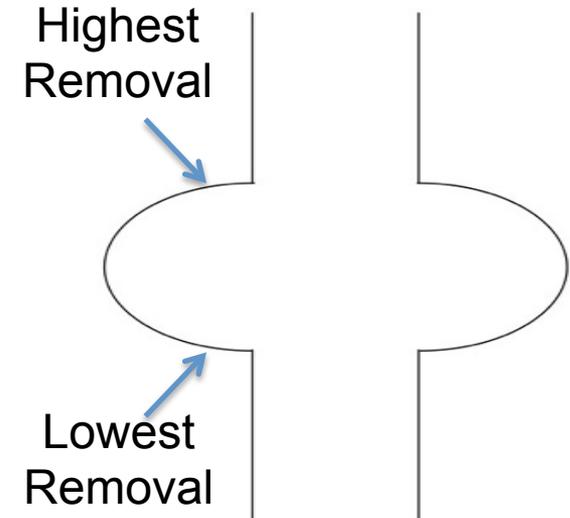
- Top iris surface is always found with bubble traces after VEP.
- This might limit cavity performance specially for multi-cell cavities.



# Efforts in other Labs to Solve the Issues

- **Flipping of Cavity**

- To minimize asymmetry of Nb removal, cavity can be flipped to repeat VEP.
- Requires long time and may not be suitable for mass production.



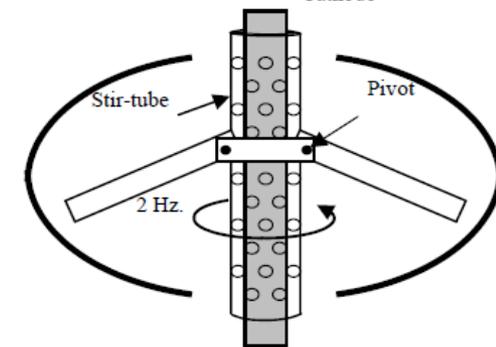
- **Cathode shape & Acid flow rate**

- As reported by Saclay and other labs, asymmetry might be due to high acid flow on the upper half cell. Cathode shape might improve acid flow in cavity cell.

- **Agitation**

- Cornell used paddles to stir EP acid. Some effect of the paddle was noticed on the top iris. However this could not solve the problem of inhomogeneous removal.

## Cornell's Stirrer



- **Bubble Bag**

- Bubble bag for cathode can help to guide bubbles to reduce bubble traces. Bubble bag is being used in VEP setup at Cornell.

# 1-cell Cavity Performance (Saclay VEP)

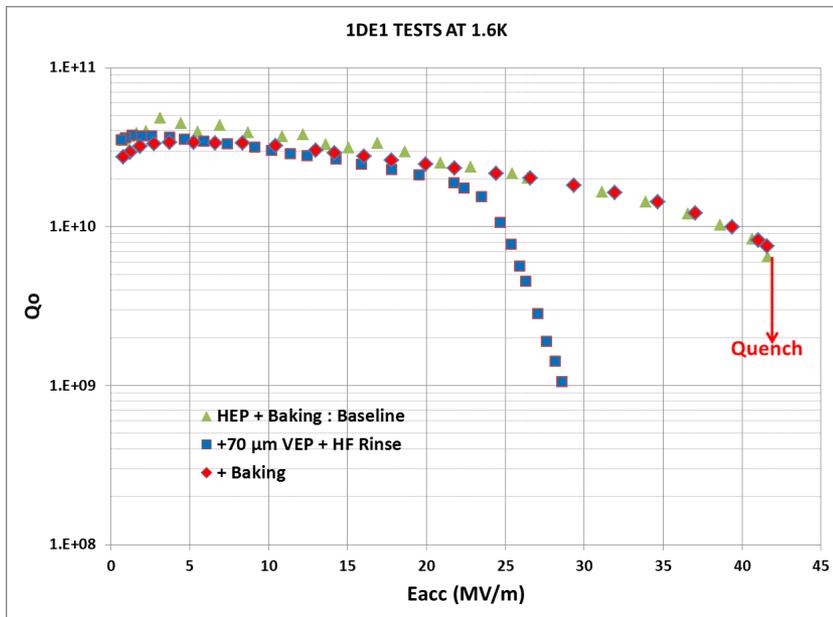


## 1DE1: Horizontal EP + 70 $\mu\text{m}$ VEP

- Parameters: 6V & >24L/min
- Bright and smooth surface
- Performance before/after baking similar to HEP
- High gradient maintained after VEP



1DE1 after HEP + 70  $\mu\text{m}$  VEP



### Aspects to improve:

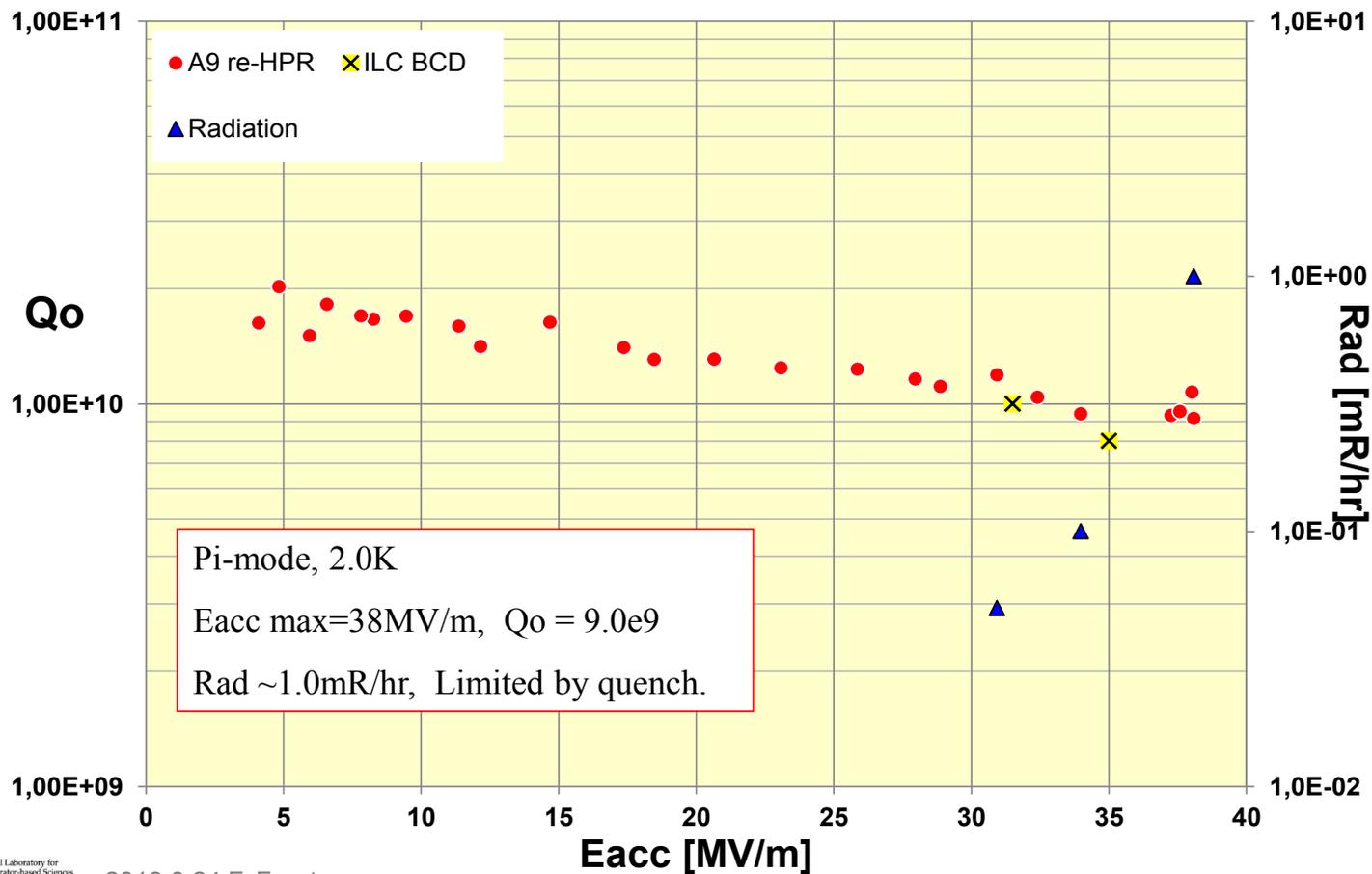
- Low removal rate at 19°C: 0.2 $\mu\text{m}/\text{min}$
- asymmetry: removal rate higher in the upper part of the cell (x 3)



Presented by Eozénou Fabien in 1st LCC/ILC Cavity Group Meeting (April 16th 2013)

# 9-cell Cavity Performance (Cornell VEP)

## 1<sup>st</sup> achievement of 40MV/m w/ VEP + TESLA 9-cell



# Progress at Marui

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We, in collaboration with KEK, are developing VEP facility and optimizing VEP parameters, cathode design to solve the existing problems in VEP.

## Our Joint Collaborations

- Marui-KEK-Saclay (Dr. F. Eozenou at Saclay)
  - Cavity performance is tested at Saclay.
- Marui-KEK-Cornell University (Dr. F. Furuta at Cornell University)
  - Our unique cathode (Ninja cathode) will be tested at Cornell University.

# VEP Setups at Marui

## 1-cell Cavity



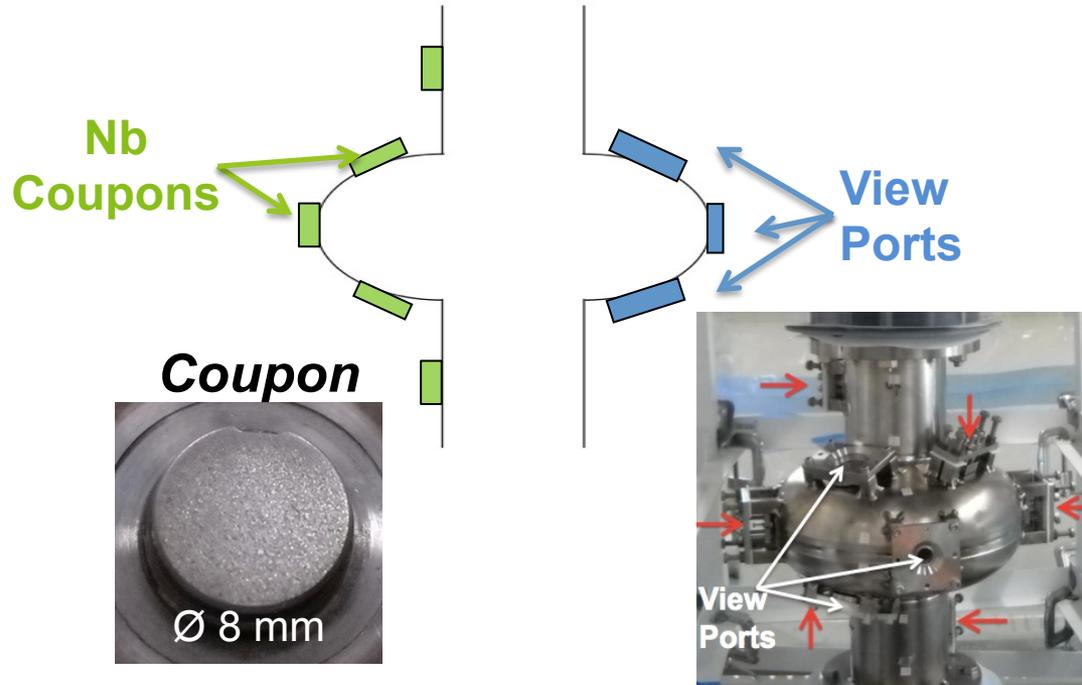
## 9-cell Cavity



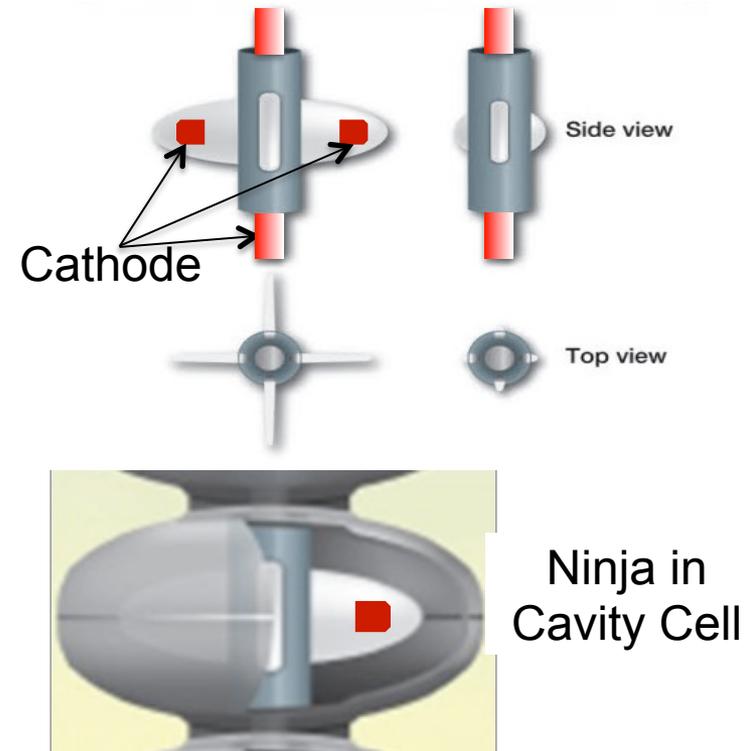
✧ Both setups were prepared with PVC materials in order to reduce cost of surface treatment of cavities in mass production.

# Coupon Cavity & Ninja Cathode

## Coupon Cavity



## Ninja Cathode



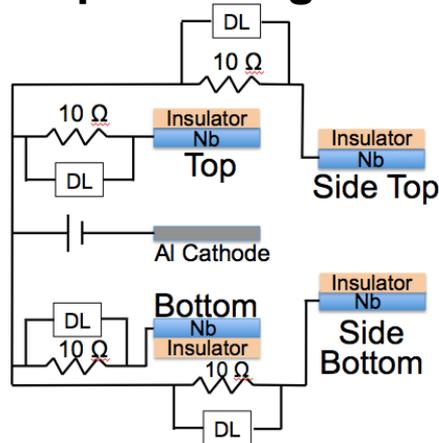
- Cavity contains 6 coupons at beam pipes, irises and equator.
- EP current can be measured for individual coupon.
- Coupon surfaces are analyzed with several surface analytical tools.
- The cavity is having 4 view ports on the top iris, bottom iris and equator for light introduction and in-situ observation of cathode wings and H<sub>2</sub> bubbles.

- ❖ Ninja cathode was developed in order to agitate EP acid and to use its wings as cathode.

# Cause of Asymmetry (Lab EP)

- Lab EP experiments were carried out in order to understand cause of asymmetry.

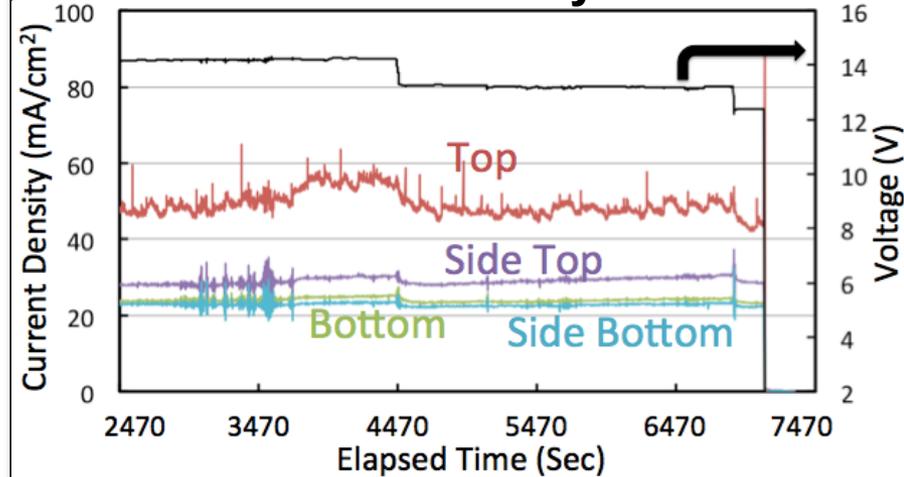
## Sample Arrangement



Sample Size: 20x14 mm<sup>2</sup>

The samples were set to simulate with top and bottom irises of a cavity in VEP.

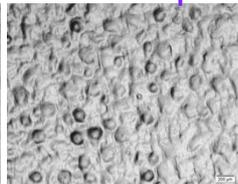
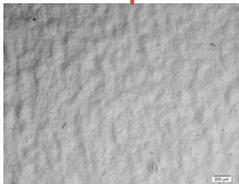
## EP Current Density Profiles



Top

Side Top

RT = 77.8  $\mu$ m  
Ra/Rz  
=0.25/1.3  $\mu$ m

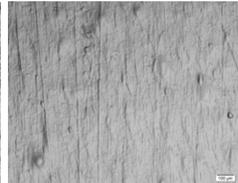
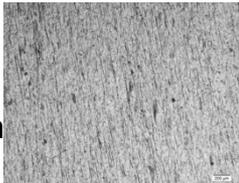


RT = 47.5  $\mu$ m  
Ra/Rz  
=0.80/4.6  $\mu$ m

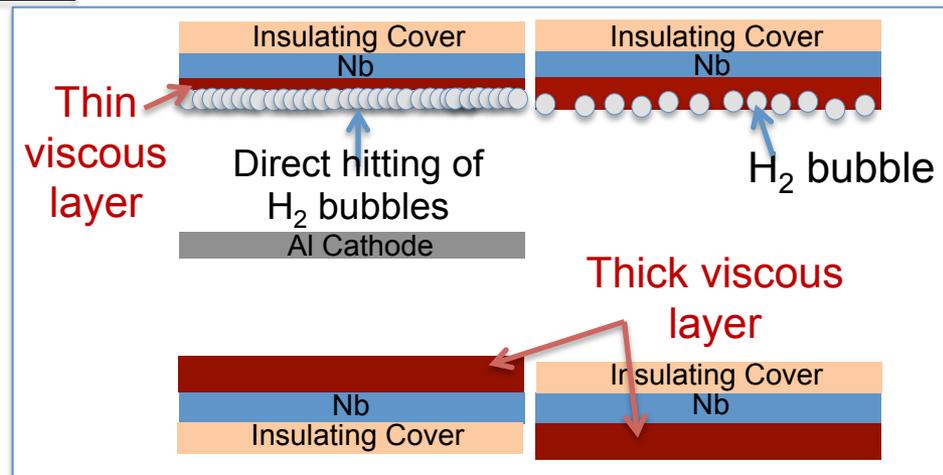
Bottom

Side Bottom

RT = 40.7  $\mu$ m  
Ra/Rz  
=0.36/2.5  $\mu$ m



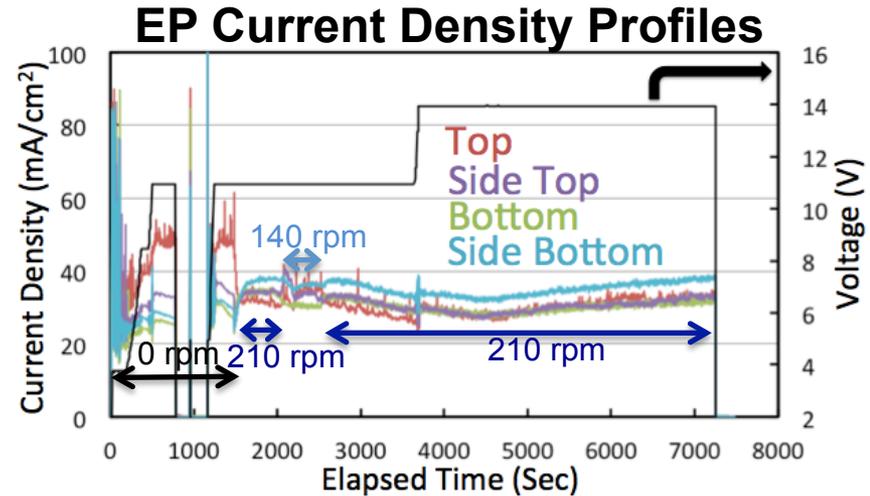
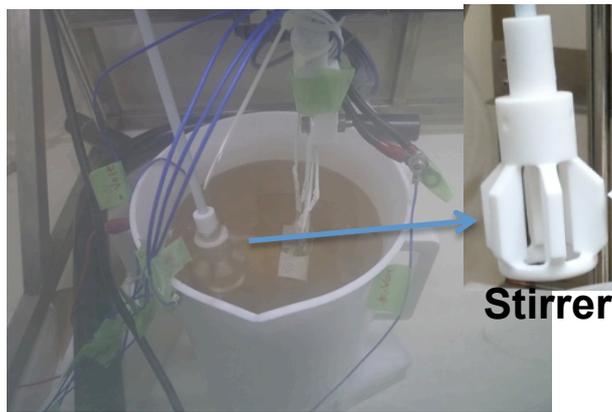
RT = 39.0  $\mu$ m  
Ra/Rz  
=0.29/2.2  $\mu$ m



- H<sub>2</sub> bubbles enhance EP rate for higher removal thickness.
- Similar EP currents for both the bottom samples shows that gravity effect is not strong to cause asymmetry.
- Long residence time of bubbles on Nb surface results in a rough surface.

# Solution of Inhomogeneous Removal in Lab EP

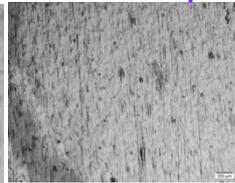
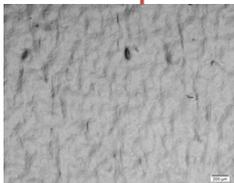
Stirrer was set in front of samples and effect of different speeds was observed.



Top

Side Top

RT = 47.6  $\mu$ m  
Ra/Rz  
=0.44/2.2  $\mu$ m

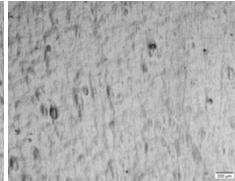
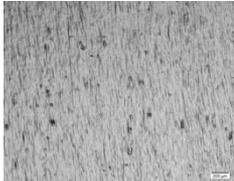


RT = 44.3  $\mu$ m  
Ra/Rz  
=0.39/2.4  $\mu$ m

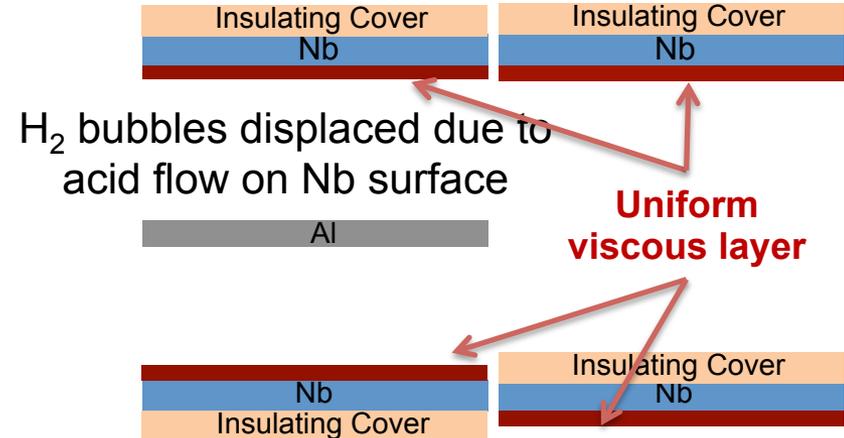
Bottom

Side Bottom

RT = 45.0  $\mu$ m  
Ra/Rz  
=0.32/2.0  $\mu$ m

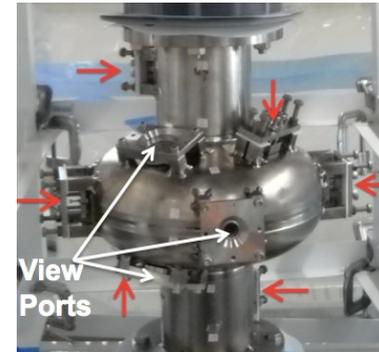
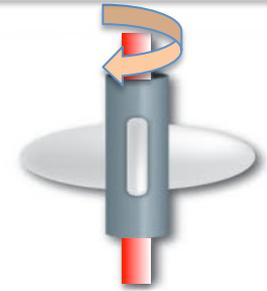


RT = 46.7  $\mu$ m  
Ra/Rz  
=0.31/1.8  $\mu$ m

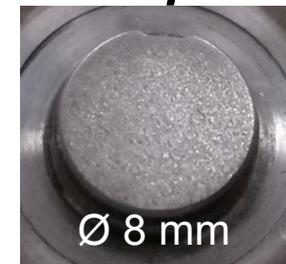


- Similar removal thicknesses and surfaces of samples were obtained.
- At the high rotational speed:
  - bubbles cannot stay on surface
  - uniform acid flow might make uniform thickness of viscous layer on Nb samples

# Effect of Stirring in VEP

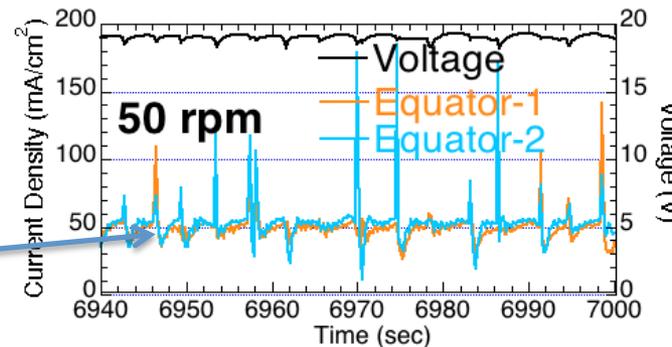
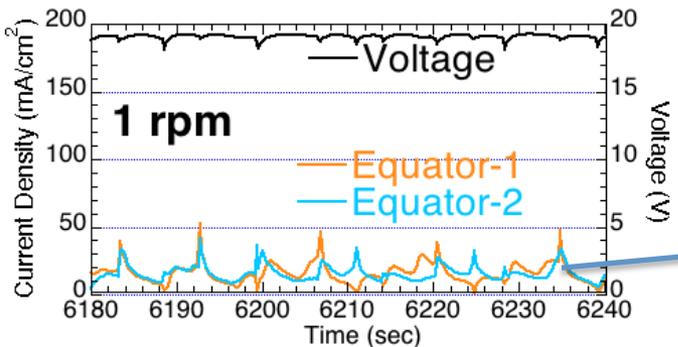
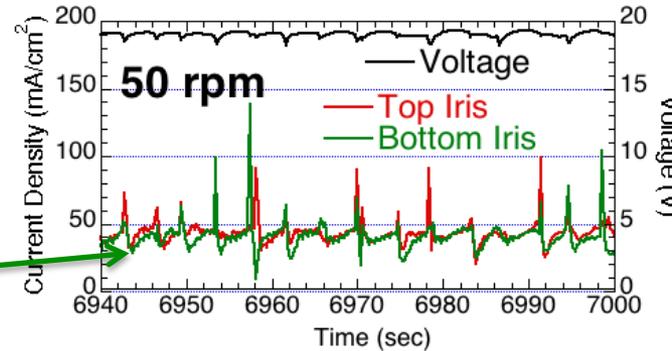
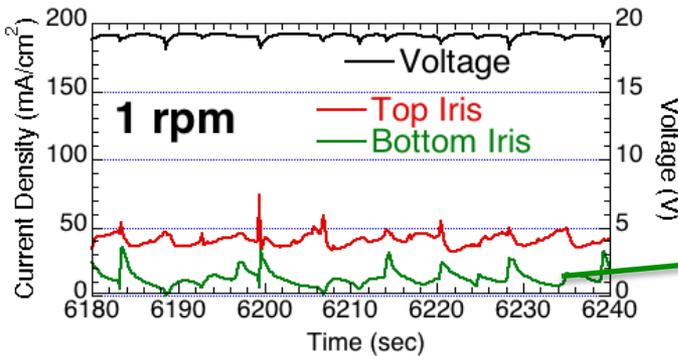
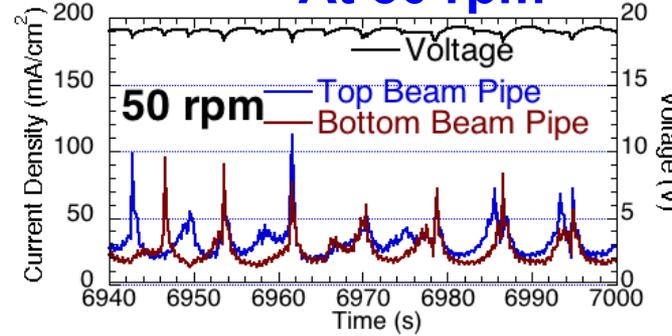
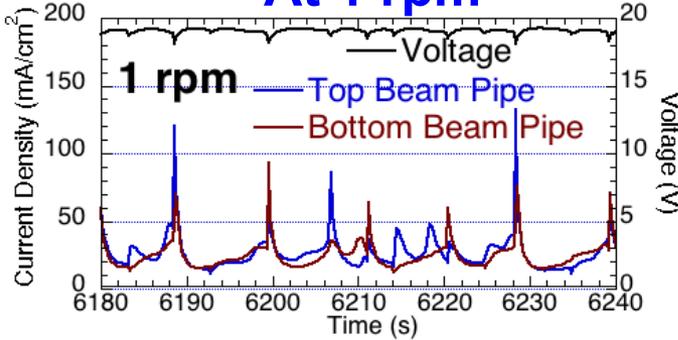


**Coupon**



**At 1 rpm**

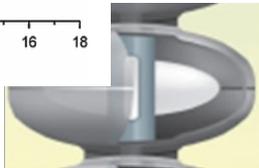
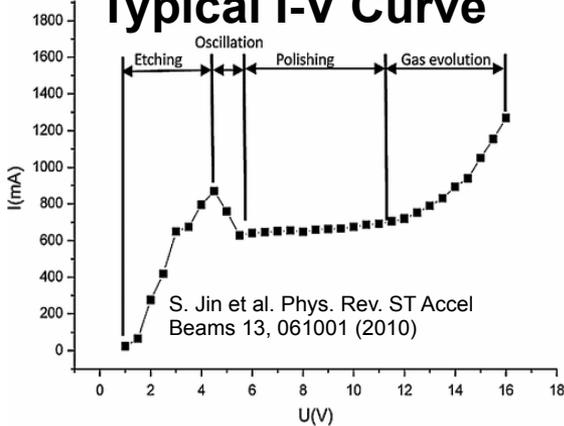
**At 50 rpm**



- The top iris coupon current was the highest at 1 rpm because of accumulation of  $H_2$  bubbles on the top iris.
- Ninja cathode rotating at 50 rpm displaced the bubbles from the top iris to make similar polishing rate in the cavity cell.

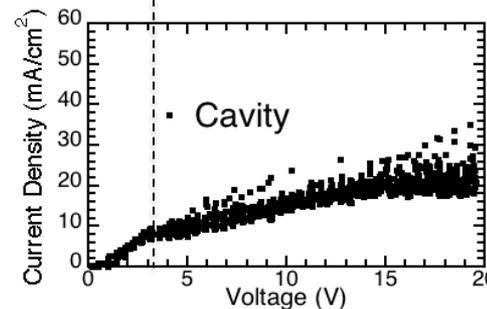
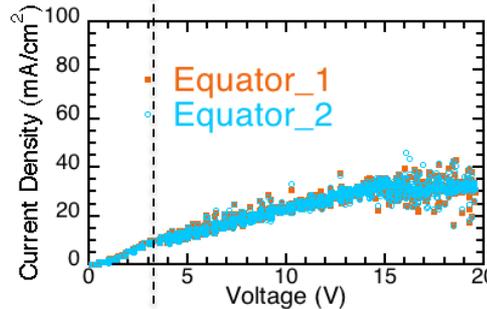
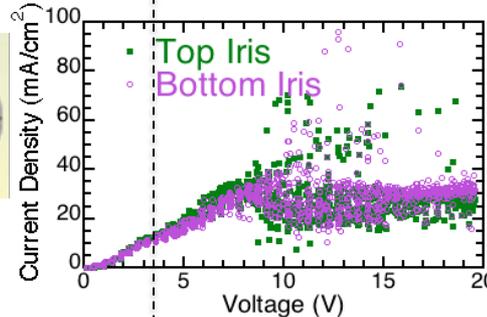
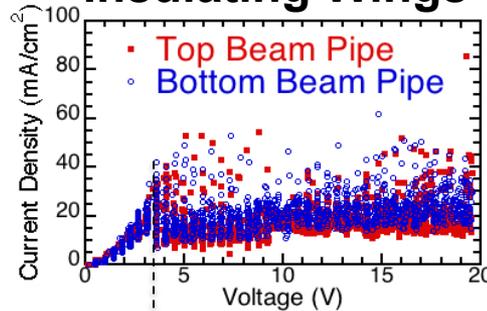
# Effect of Partial Cathode Wings

## Typical I-V Curve

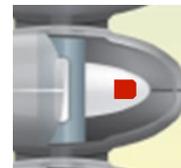
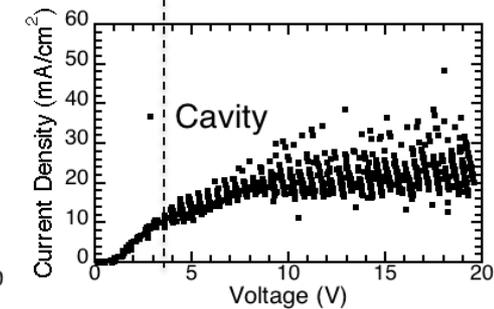
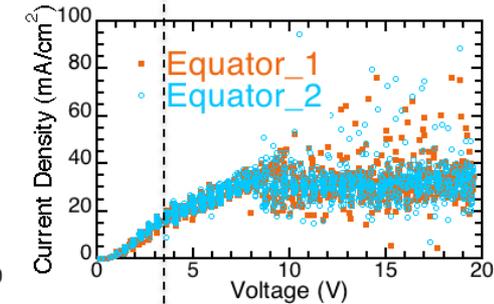
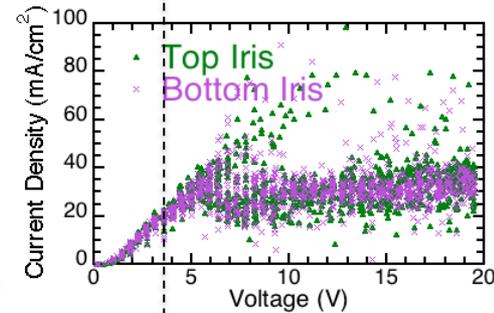
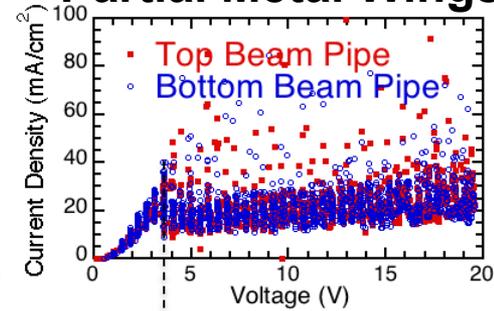


- $H_2$  bubbles can screen the cathode and reduce ion migration to the cathode.
- A distance between anode and cathode might be important for small area of cathode.
- Electric field on equator might be low due to large distance from cathode.
- Wing cathode might enhance ion transportation and electric field on equator surface.

## Insulating Wings

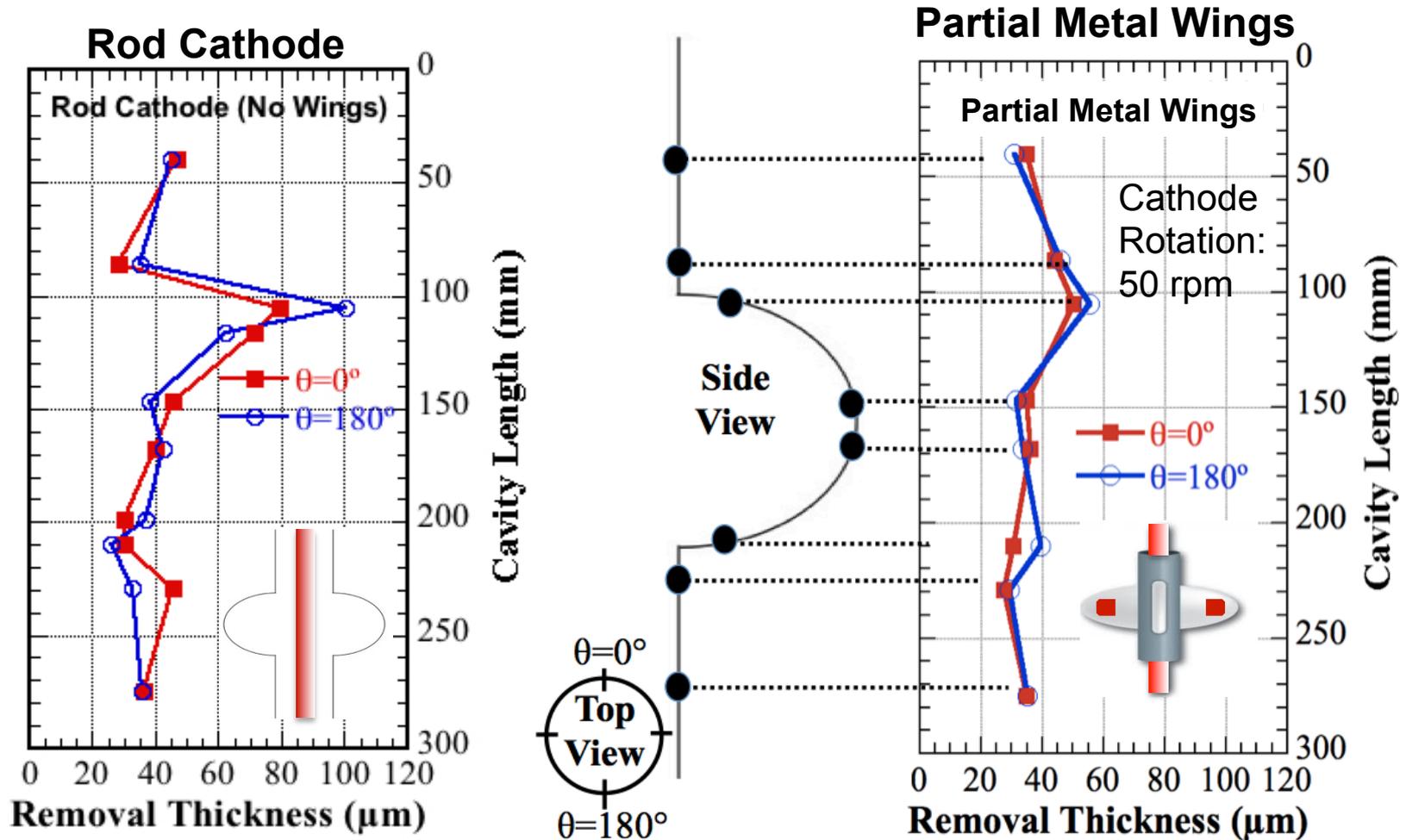


## Partial Metal Wings



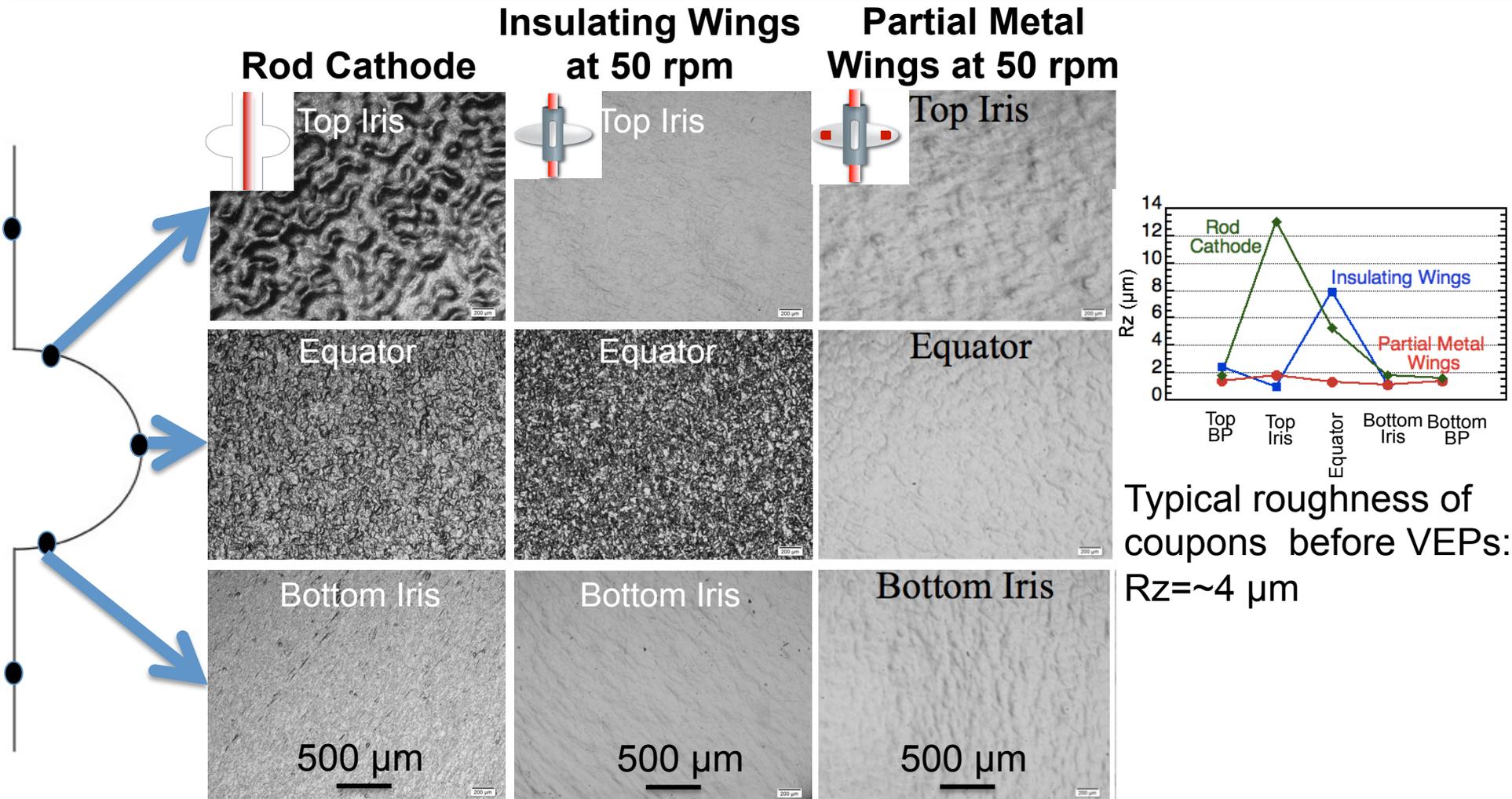
# Removal Thickness W/O and W/ Wings

✧ Removal thickness was measured with ultrasonic thickness gauge.



✧ Ninja wings were found to be effective as a stirrer in order to minimize longitudinal asymmetry of Nb removal.

# Surfaces of Coupons



Typical roughness of coupons before VEPs:  
Rz = ~4 µm

- Rough equator surface of coupon with rod cathode and insulating wings might be due to polishing in etching region. (Since equator remains in etching region at applied voltages.)
- Ninja with partial metal wings resulted in smooth surface of the equator.

# Summary

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- VEP setup has several advantages over HEP setup and can reduce cost of cavity surface treatment.
- Encouraging results of VT for 9-cell and 1-cell cavities were shown by Cornell and Saclay.
- However inhomogeneous removal (higher removal of upper half cell) of a cavity was still unresolved and flipping is done to minimize asymmetry.
- Ninja cathode improved homogeneity of Nb removal and resulted smooth surface of the cavity cell.

# Future Work

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- Further improvement is possible in VEP parameters and Ninja cathode to achieve perfect homogeneous removal with smooth surface of single/multi cell cavities.
- VT for 1-Cell Cavity will be performed at Saclay.
- Ninja cathode will be tested at Cornell University.

# Thank You