Processing of spoke cavities at ANL/FNAL and rotational BCP

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PIP-II Technical Workshop

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A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

Outline:

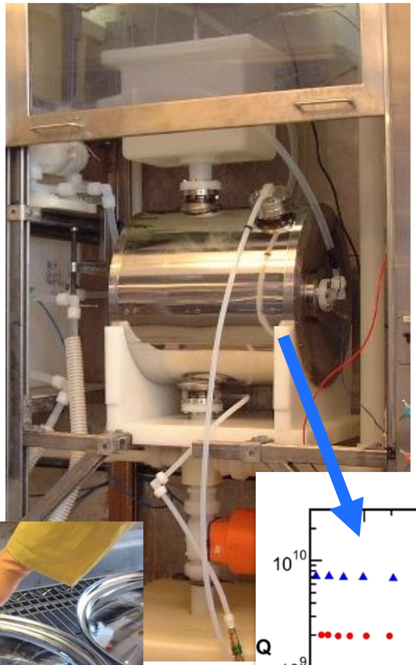
I. Introduction
II. Experience with SSR1 BCP
III. Plans for SSR2 BCP

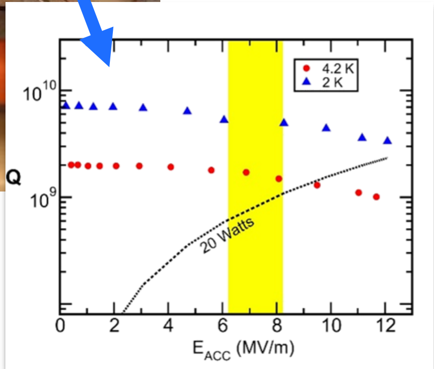
I. Introduction

Spoke Cathode

End Plate Cathode

Flash BCP





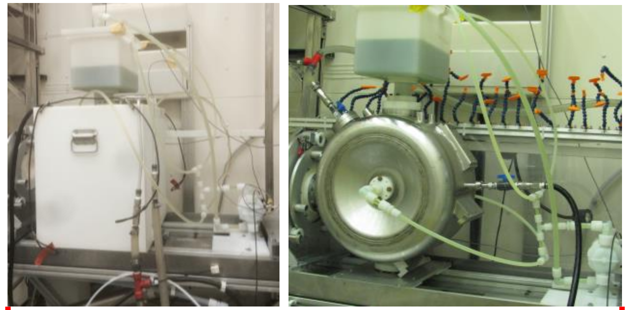
- Double (2002) & Triple (2004) Spoke Cavities for RIA
- Spoke and end plate assemblies electropolished (~150 μm)
- Flash BCP (<20 μm total) after final welding of complete cavities
  - Acid flow through beam ports
  - Flipped halfway due to trapped air bubble (no etching)
  - Helium jacket used for cavity cooling
- Test performance good for time; not great by today’s standards

- SSR1 (2009) for HINS proton driver at FNAL
- Same facility and similar procedures as used on RIA spokes
  - Bare cavity: Bulk (120 μm) and light (20 μm) BCP
    - Water bath used for cavity cooling
    - Non-uniform etching
  - Jacketed cavity: Flash (<20 μm) BCP
    - Helium jacket used for cavity cooling

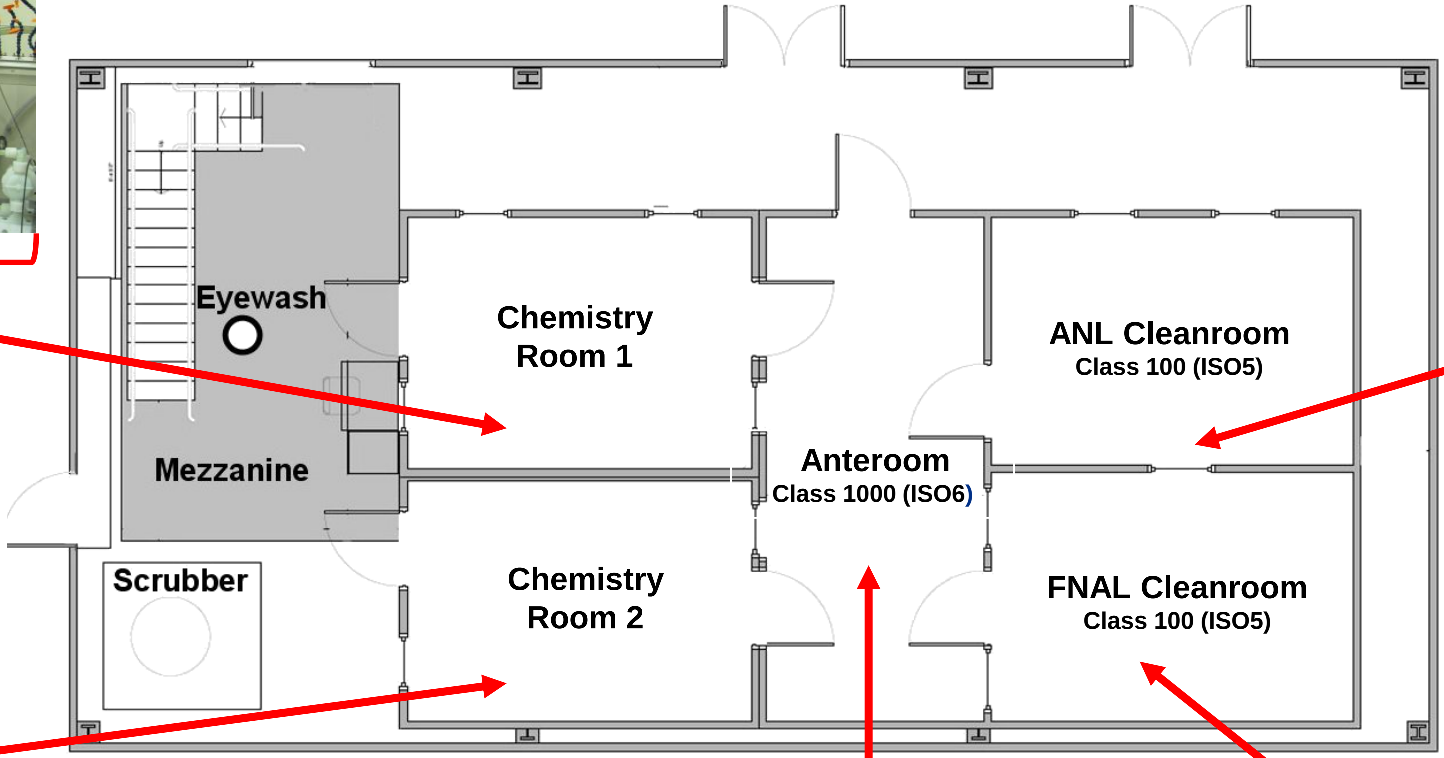
I. Introduction

ANL/FNAL joint cavity processing facility

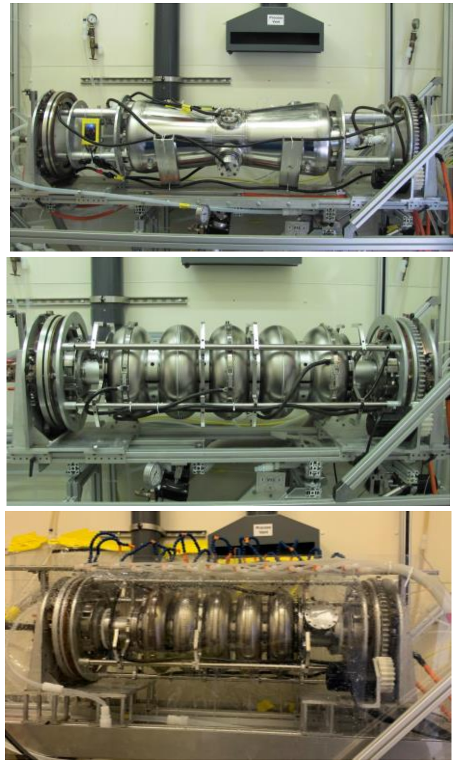
- 2000 ft^2 hi-bay (located at ANL)
- Fully operational since 2009 (1.3 GHz cavities)



SSR1 BCP



HWR + SSR1 HPR



HWR + 650 MHz Cavity EP
SSR2 BCP (planned)

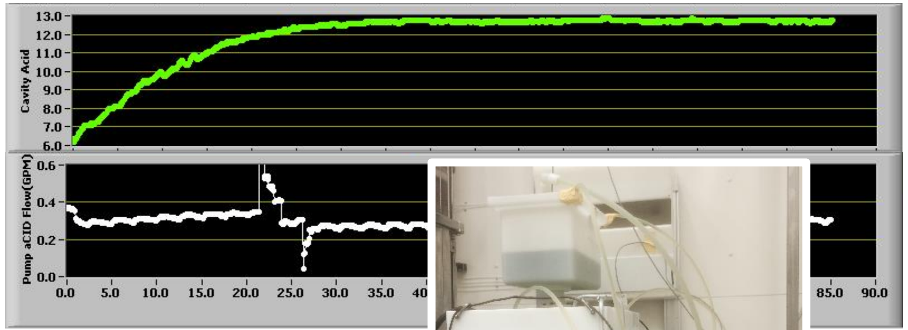
Cavity Ultrasonic Cleaning

650 MHz Cavity HPR

II. Experience with SSR1 BCP

- New facility, same procedure as HINS cavity BCP
  - Additional mixing to prevent stagnant areas
- Standard 1:1:2 BCP mix
  - Pre-chill overnight (2-7° C)

	Bulk BCP (bare)	Light BCP (bare)	Light BCP (jacketed)
Target Removal (µm)	120-150	20-30	20
Acid Temperature (°C)	<15		
Cavity Cooling	External Water Bath		Helium Jacket
Flow Rate (gpm)	~0.5		

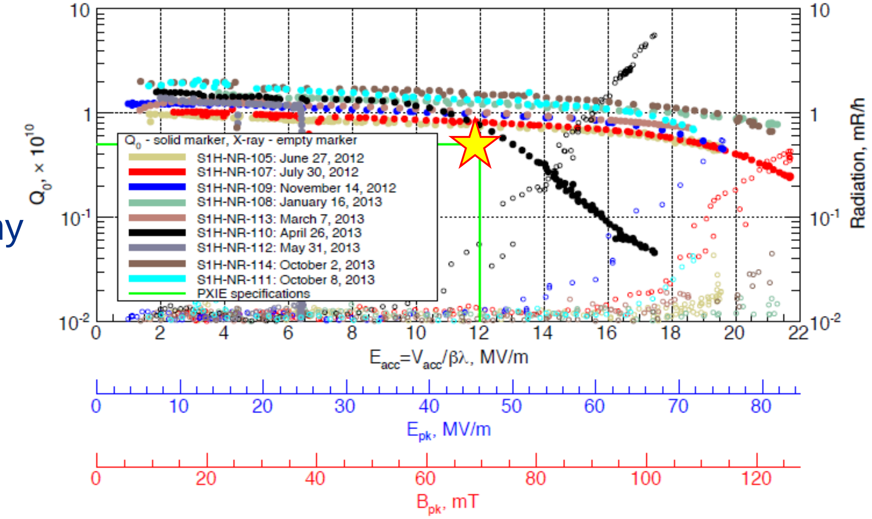


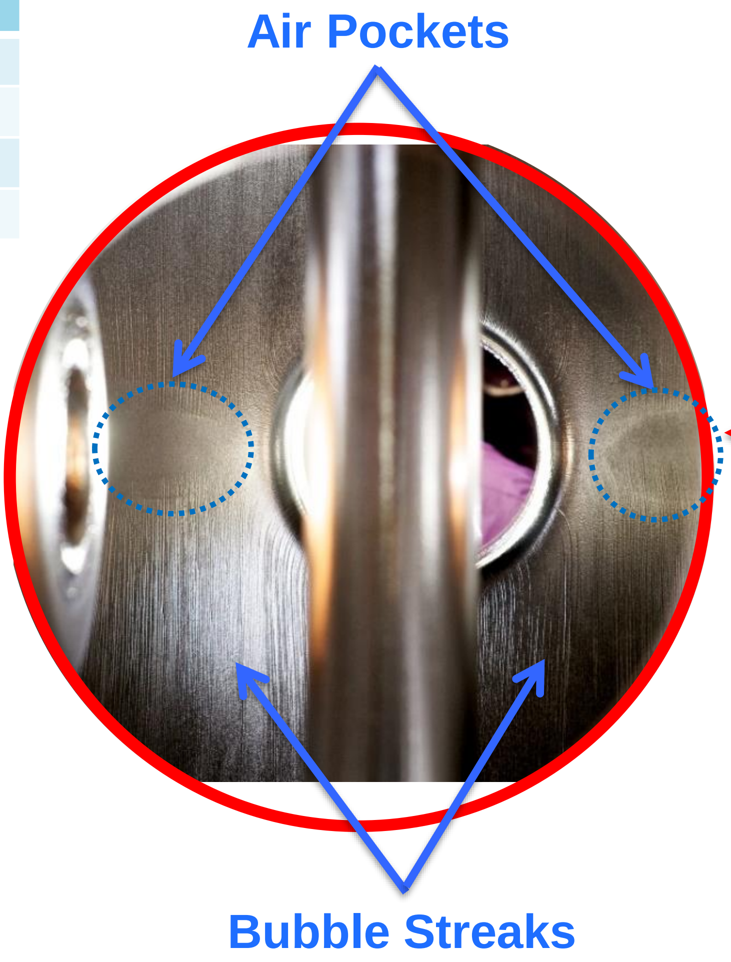
Max acid temp: 13°C
Run Time: 90 min

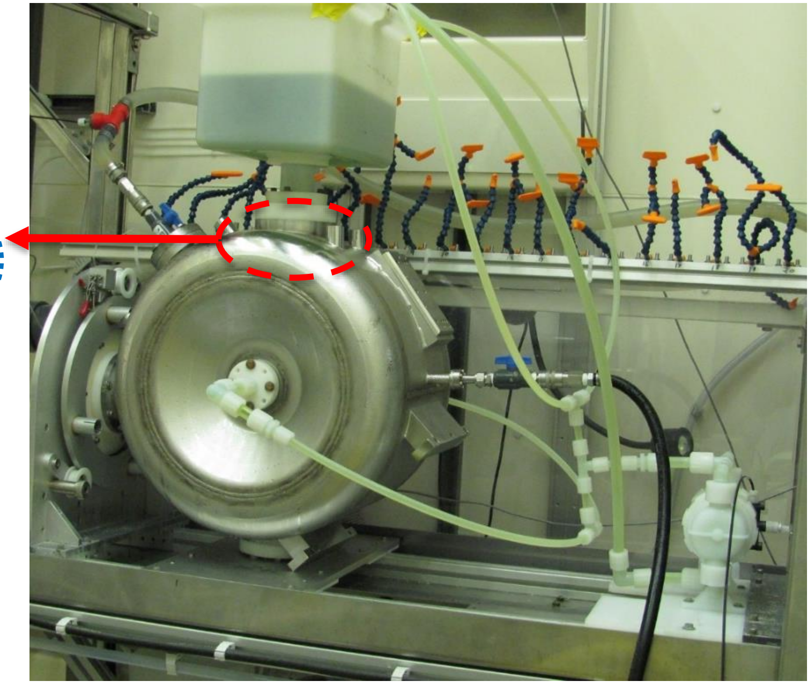
Bulk BCP of bare cavity

- Fixed cavity BCP results in unwanted surface features
- Cavity performance pretty good (lots of multipacting, not sure if any relation to chemistry)
- But room for improvement

A. Sukhanov (FNAL), Linac2014, THPP057







Light BCP of jacketed cavity

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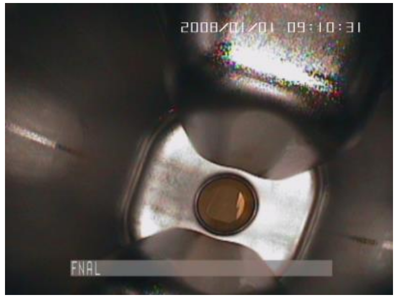
III. Motivation for SSR2 BCP

- Horizontal rotating BCP
  - 400 MHz RF-Dipole crab cavity for LHC-HiLumi (2018)
- Based on horizontal EP
  - Plastic tube replaces Al cathode
  - Cavity 60% full of acid
  - Bubbles rise to surface of acid bath
  - Don't have to flip cavity for uniformity
- Two 10 kW chillers for process temperature control
  - External water-cooling spray
  - Active acid-cooling



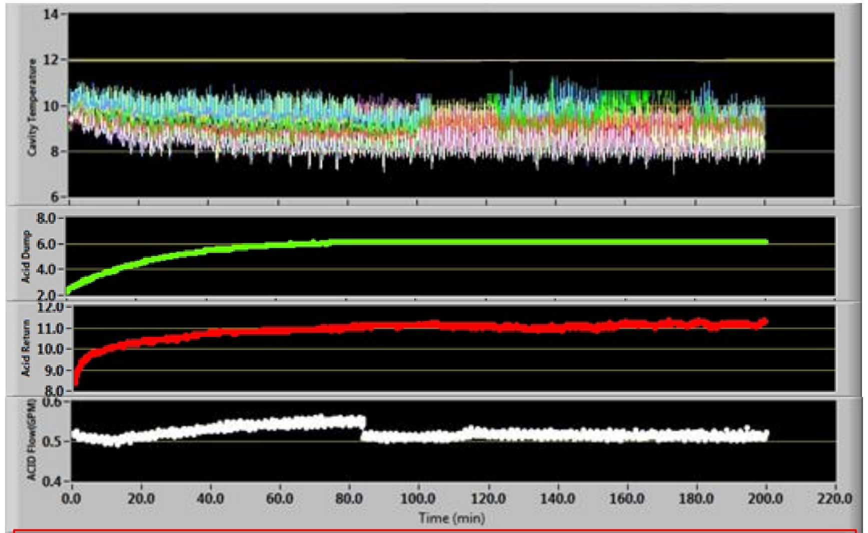
After rotational BCP – no bubble streaks!

(8-11°C) External Cavity Surface Temps (°C)

(~6°C) Acid In (°C)

(~11°C) Acid Out (°C)

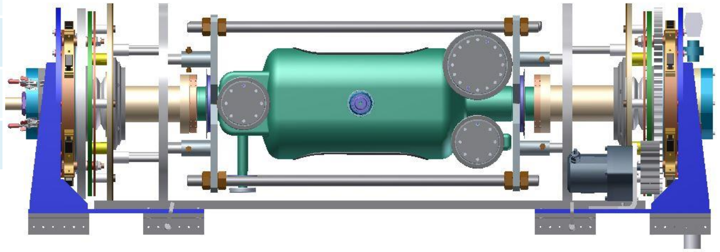
(0.5 gpm) Flow Rate (gpm)



Etch Rate: 0.58 μm/min

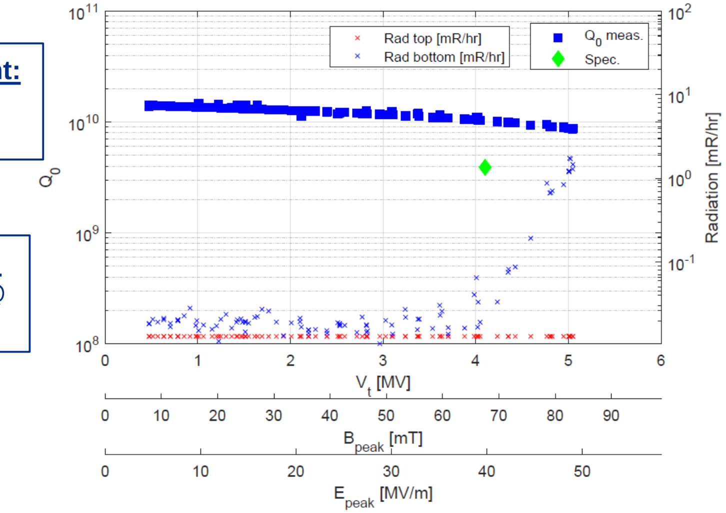
Run Time: 200 min (3.3 hrs) Removal: 117 μm

	Bulk BCP (bare)	Light BCP (bare)
Target Removal (μm)	140 (40+100)	10
Cavity Temperature (°C)	<15	
Flow Rate (gpm)	~0.5	
Rotation Speed (rpm)	1	
Cavity Cooling	External Water Spray	

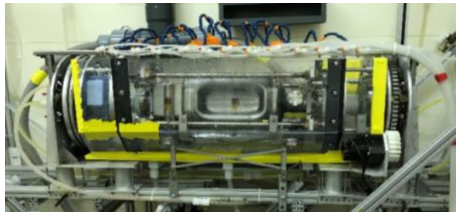


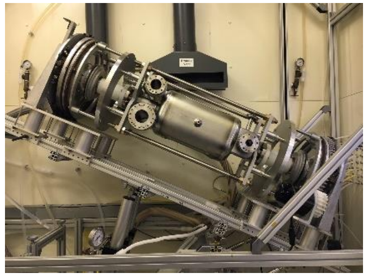
Requirement:
Q_0=3.9E9
V_t=4.1 MV

Measured:
Q_0=1E10 @
V_t=4.1 MV



P. Berutti (FNAL), US HL-LHC AUP, 2020





External water-cooling

Horizontal HPR

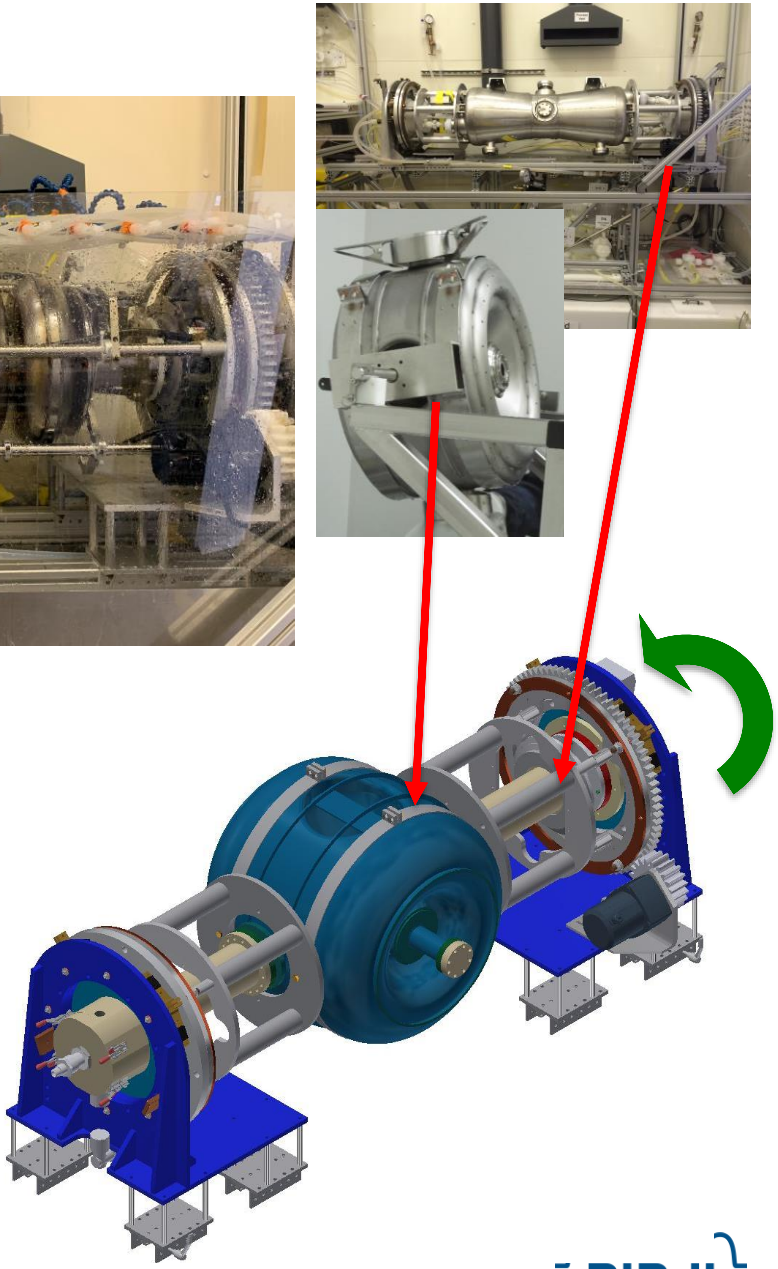
Vertical HPR

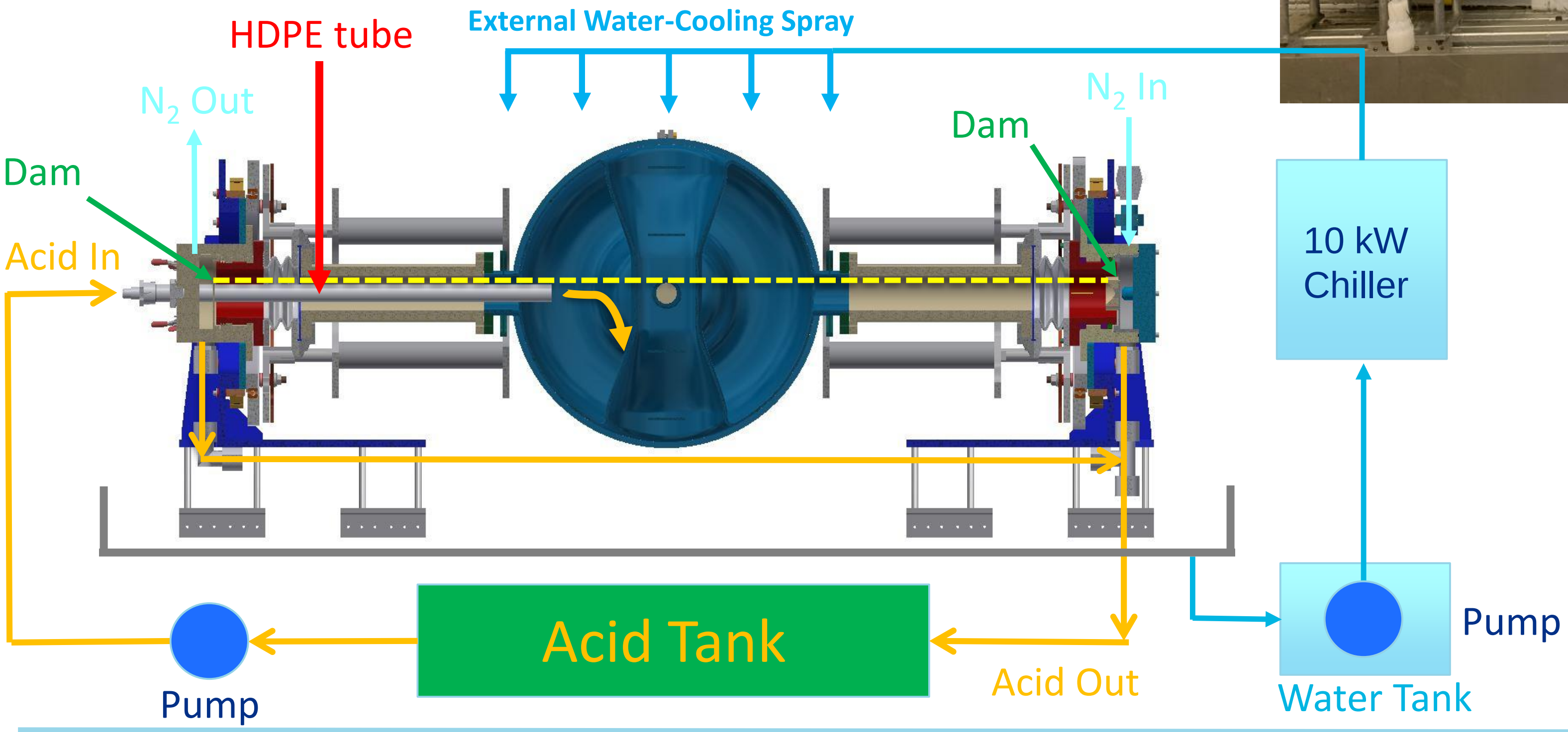
Quench increased from 3.47 to 5.1 MV after rotating bulk BCP + subsequent processing

III. Plan for SSR2 BCP

- Apply horizontal rotational BCP to eliminate unwanted surface features inherent to fixed cavity BCP as seen in SSR1s
- Only needed hardware is a cavity support structure and flange adapters
  - Based on SSR1 HPR cage and 162 MHz HWR processing cage

	Bulk BCP (bare)	Light BCP (bare)
Target Removal (µm)	120-180	20-30
Acid Temperature (°C)	<15	
Flow Rate (gpm)	~0.5	
Rotation Speed (rpm)	1	
Cavity Cooling	External Water Spray	





Summary

- More than two decades of spoke cavity chemistry at ANL
- Fixed cavity BCP (fill and dump) works OK for moderate performance requirements
  - Simple to design and implement
  - Unwanted RF surface geometrical features due to bubbles are practically unavoidable
- Rotational BCP solves issue of features produced by bubbles
  - Likely improves overall uniformity in almost all geometries relative to fixed BCP
  - Proof of principle with recent 400 MHz crab cavity for HL-LHC

QUESTIONS?

III. SSR Electropolishing

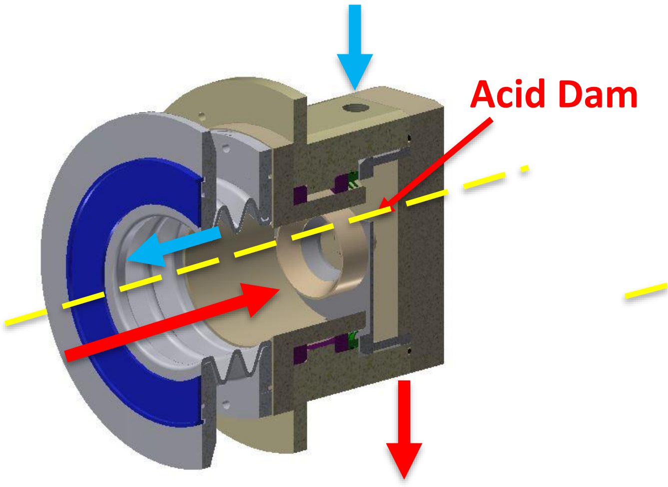
Electropolishing Considerations:

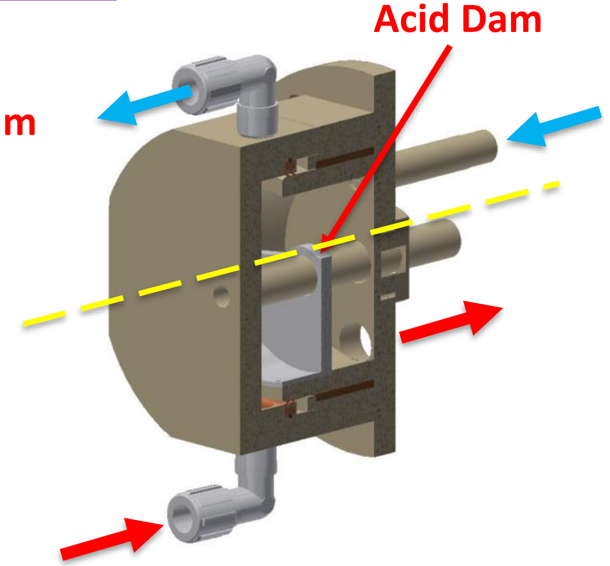
H. Tian (JLAB), SRF2011, WEIOA01

- Need at least 10:1 cavity to cathode surface area ratio
- Can use more than one cathode
- Multiple cathodes require a second sliding electrical contact
- Cathodes don't have to be used to transfer acid
- Different end groups for different acid flow scheme

SSR2 Example	Units (m^2)
Cavity Surface Area	1.472
Cathode Surface Area	0.1472

N_2 Purge In
Acid Out





Elliptical cavity end group

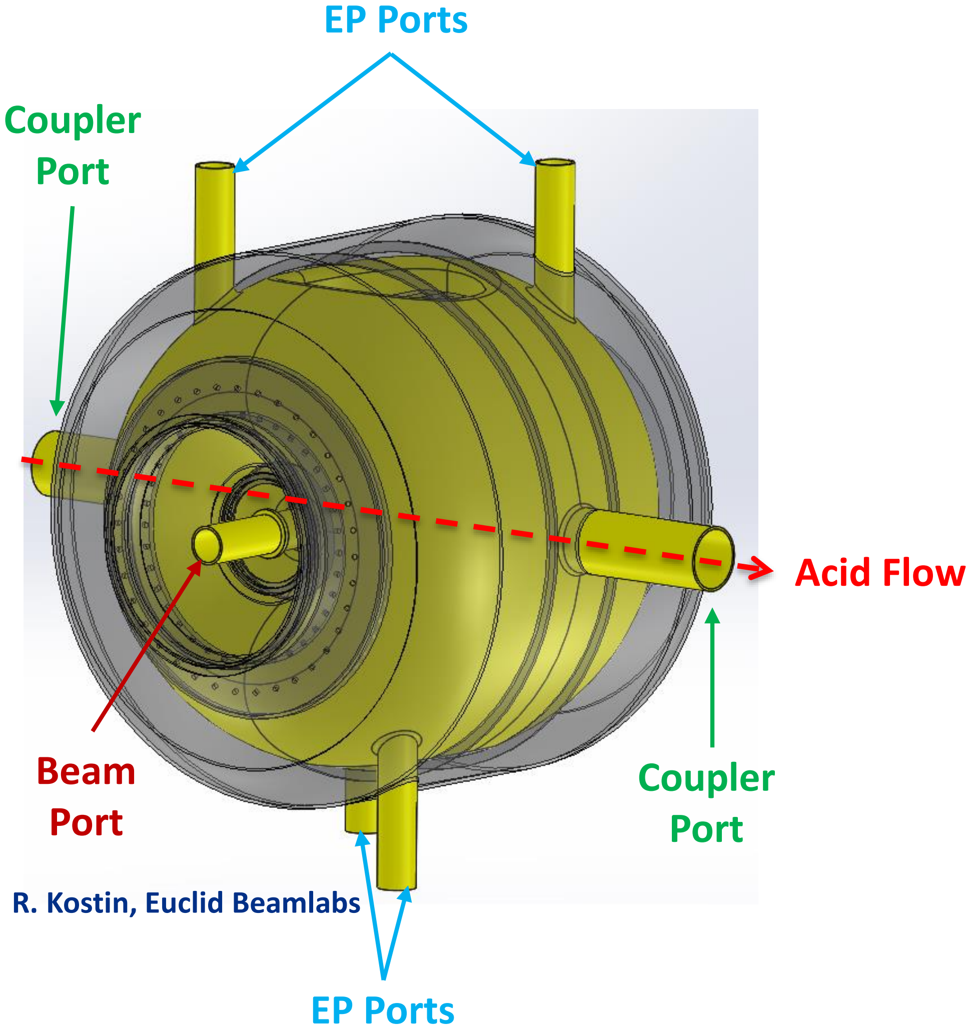
- Designed for 650 MHz 1-cell and 5-cell cavities
  - Upsized version of 1.3 GHz setup
  - One fixed cathode
- Can also be used for BCP with no cathode

Low-β end group

- Designed for Low-β QWR and HWR
  - Four rotating cathodes
- Can also be used for BCP with no cathode

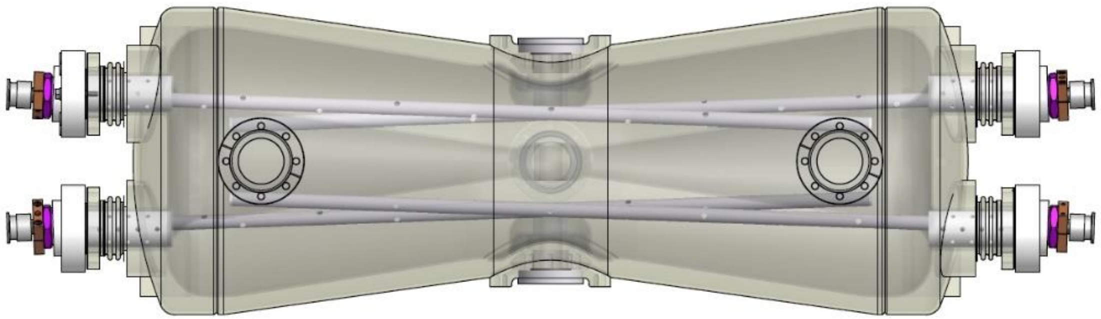
S. Gerbick (ANL), SRF11, WEIOA03

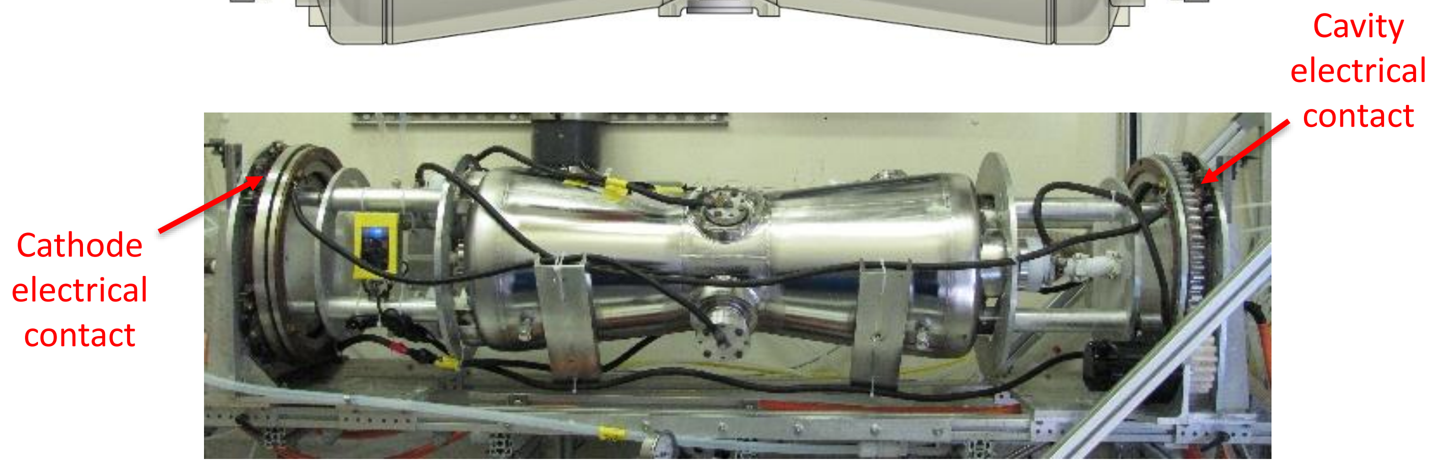
III. 'Balloon' Spoke Cavity



Euclid Beamlabs
325 MHz 'Balloon' SSR1

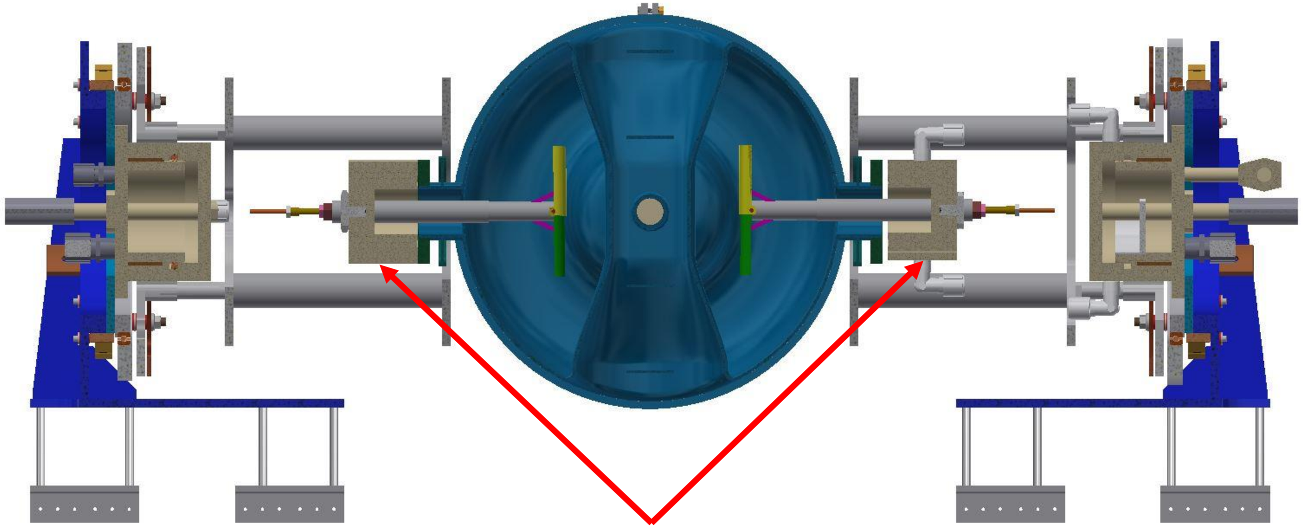
- Most practical way to apply EP to spoke cavity geometry is to add ports for cathodes to cavity design
- Can easily achieve necessary amount of cathode surface area
- Similar concept used for 162 MHz HWRs
- Same end groups used for SSR2 BCP (650 MHz end group)
- Four cathodes
  - Requires second sliding electrical contact



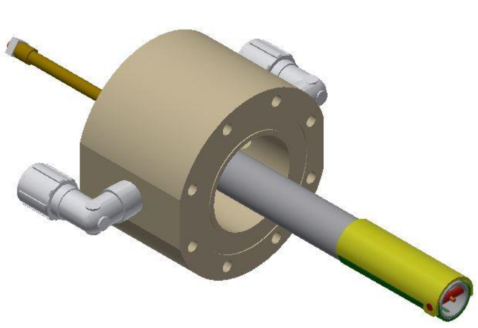


T. Reid (ANL), IPAC15, WEPTY010

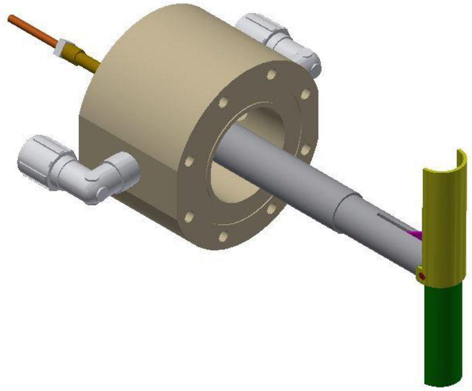
III. SSR Electropolishing



Cathode Closed Position



Cathode Open Position



- EP of existing SSR1 and SSR2 geometries is also possible
- Low-β end groups + adapter end groups used for acid flow
- Expanding cathode increases cathode surface area
- Minimal moving parts, all made from high-purity aluminum
- Cathodes loaded in the closed position, and opened inside cavity

SSR2 Example	Units (m^2)
Needed Cathode SA	0.147
Cathode SA (x2)	0.136

Increase cathode diameter to further increase surface area