What is the timeline and milestone path to a machine with films technology with E_{acc} >16 MV/m, and Q>1.5e^{10}?

A perspective on Nb films on Cu cavities

- **Basic material processes exist**
  - proof-of-principle demonstrations for modest field applications

- **Principal present challenges**
  - Establish adequate process controls
  - Address technical challenges with scale-up

  - Though not fundamental, these require serious resource investment to establish “industrial” capability.
  - Half-hearted effort not worth doing, won’t reach the goal. Resources drive the timeline.

- **So, tool-up for the big cavities and refine process parameters in parallel on smaller scales.**

- Done right, also a reasonable stepping stone to truly “engineered surface”, with all the benefits of high Q, high field, low cost, and high reliability systems.

What is the timeline and milestone path to a machine with films technology with E_{acc} >16 MV/m, and Q>1.5e^{10}?

Scale of efforts required for aggressive timeline for production readiness

- Build a dedicated UHV cavity coating system based on Nb Energetic condensation technology
- Coat cavities (1- & multi-cells):
  - 1st cavity coated by end of 2018
  - Coating rate: 1.5 – 2 cavities/wk depending on frequency ➡ 100-150 coated cavity cycles
  - Tight coordination between substrate preparation, coating cycle and RF measurement (RF feedback needs to be timely, within 1 wk)
  - Specs [with E_{acc} >16 MV/m, and Q>1.5e^{10}] consistently achieved by end of 2020
- Develop Cu cavity electropolishing facility in parallel with deposition system
- Film material analyses in parallel for process parameter guidance

⚠ Assumes personnel has EC Nb film coating , cavity coating & UHV proficient skills on day 1

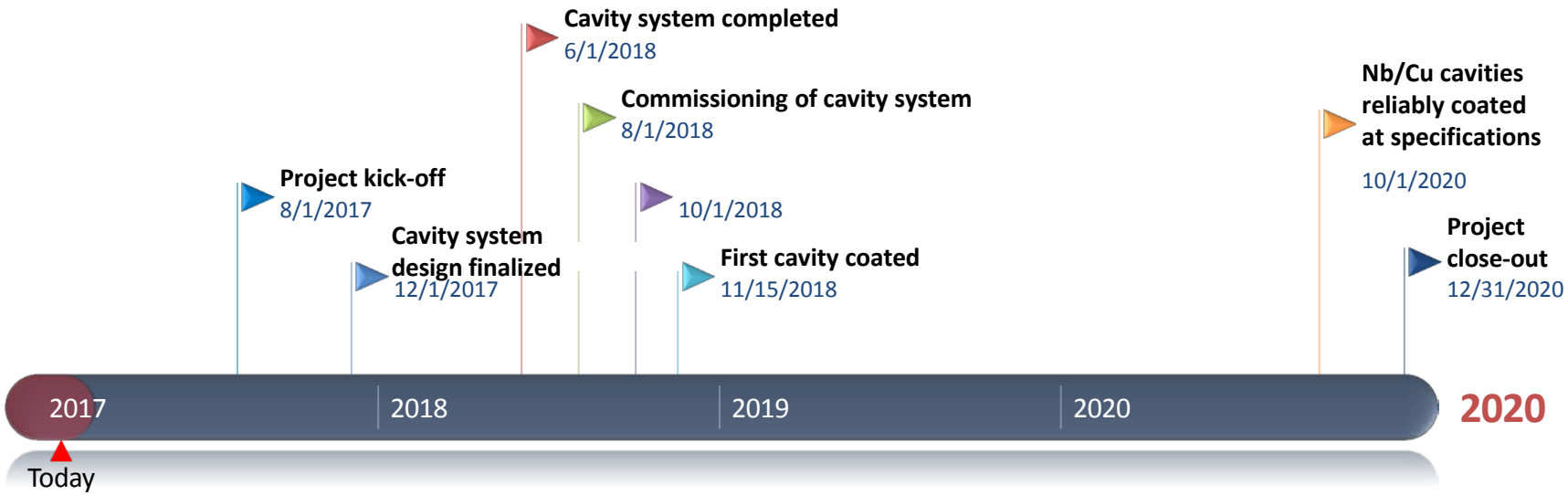
⚠ Assumes prior investments in utilities & infrastructures already in place:

- ✓ RF testing facility (dewar, RF power…) able to accommodate up to 4-cell 400 MHz cavities
- ✓ Cooling water and power in coating facility
- ✓ HPWR and cleanroom infrastructures

Personnel:	5FTEs /yr. involving 7-8 scientists & professionals
Graduate students:	2 FTEs/yr
Dedicated cavity deposition system & ancillaries (portable cleanroom/substrate inspection):	470-570 K$
Cu cavity substrates (cost dependent on frequency) :	120 to 240 K$
Other direct expenses (supplies, machine shop, material analyses):	285 k$
Project duration 40 Mos.	Direct costs

Focused Timeline

Assumes Nb film, cavity coating and UHV proficient skills available on day 1
Assumes adequate funding on day 1 for personnel and procurements



Project Kick-off meeting
8/1/2017 8/1/2017

Cavity deposition system design
8/2/2017 12/1/2017

Dedicated cavity deposition system procurement & assembly
12/1/2017 6/1/2018

cavity deposition system commissioning
6/1/2018 8/1/2018

Map cavity deposition parameter space
8/1/2018 10/1/2018

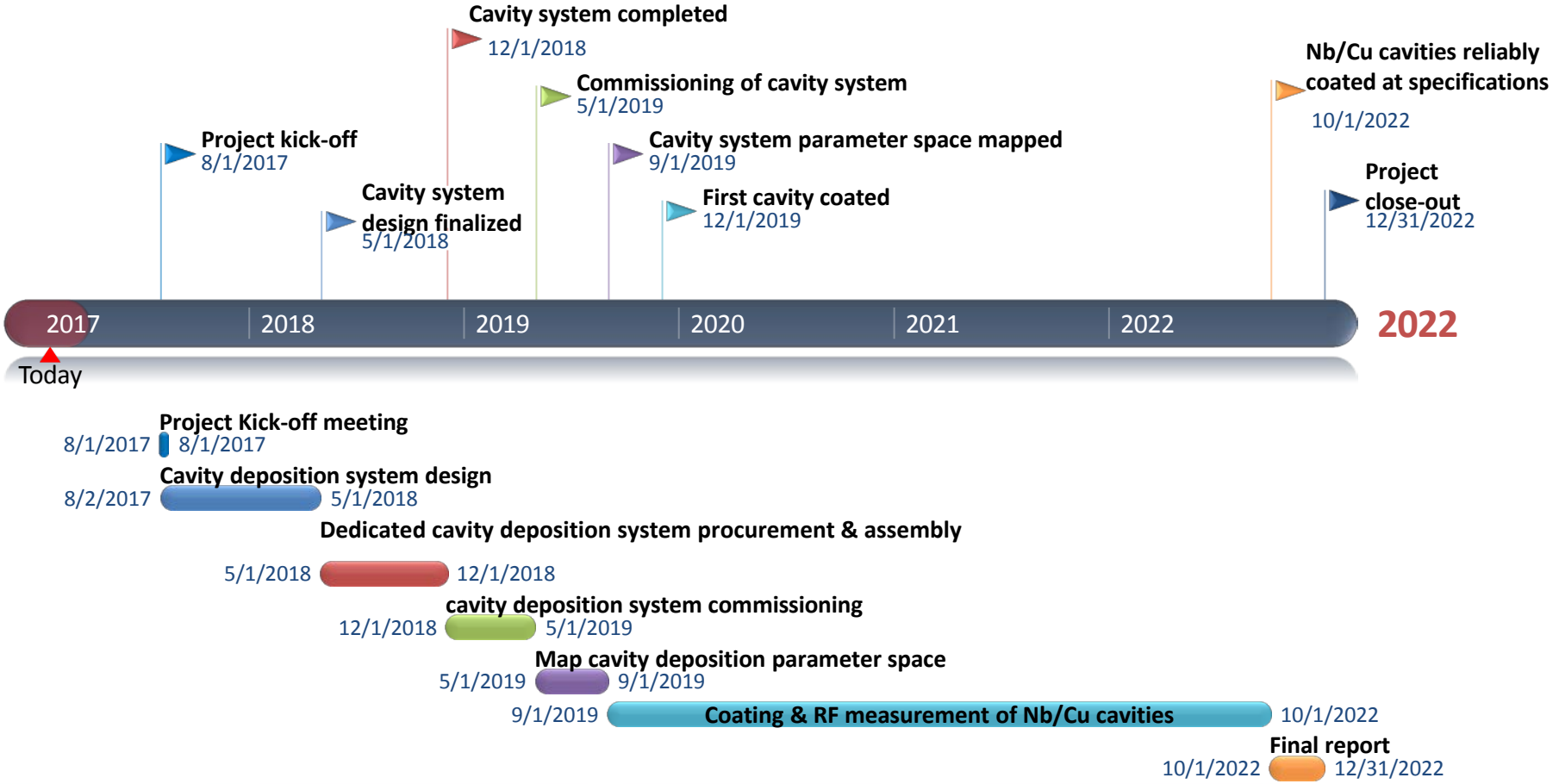
10/1/2018 Coating & RF measurement of Nb/Cu cavities 10/1/2020

Final report
10/1/2020 12/31/2020

Alternate Timeline

Assumes Nb film, cavity coating and UHV proficient skills available on day 1
Half manpower & same procurements

Personnel:	2.5FTEs /yr. involving 4 scientists & professionals
Graduate students:	2 FTEs/yr
Dedicated cavity deposition system & ancillaries :	470-570 K$
Cu cavity substrates (cost dependent on frequency) :	120 to 240 K$
Other direct expenses :	285 k$
Project duration 64 Mos.	Direct costs

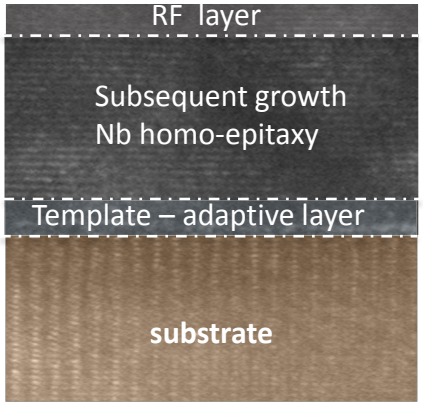


Why energetic condensation?

Enable excellent crystal structure for optimum RF performance

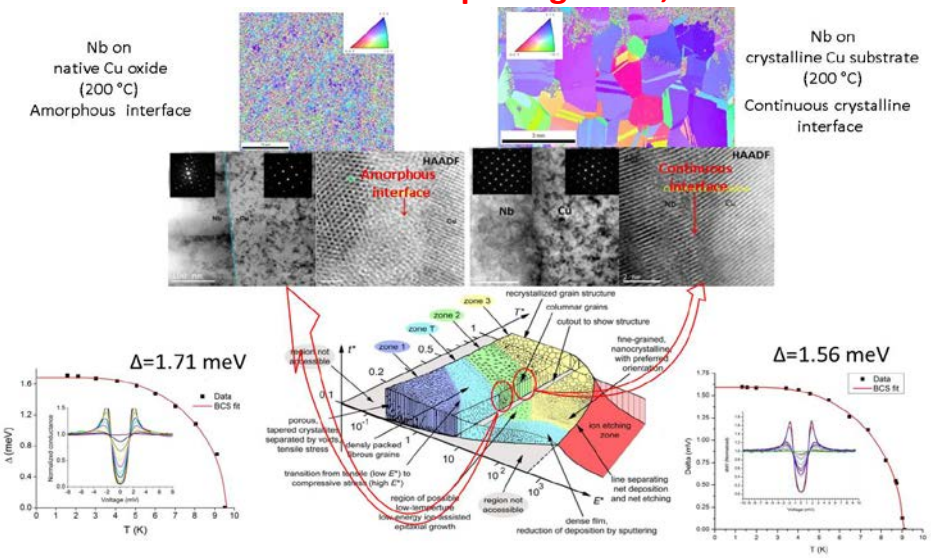
- Interface
- Film nucleation
- Growth of appropriate template for subsequent deposition
- Deposition of final surface optimized for minimum defect density.

Sequential phases for film growth



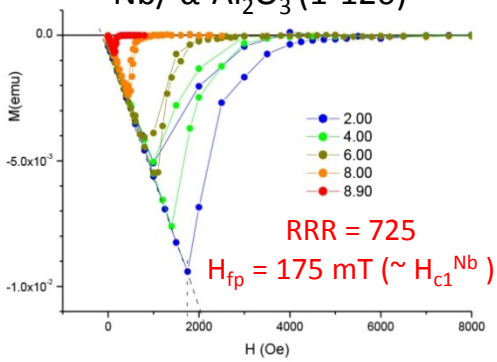
Full control over final SRF performance with strict process protocols

Control over nucleation & subsequent growth, thus structure

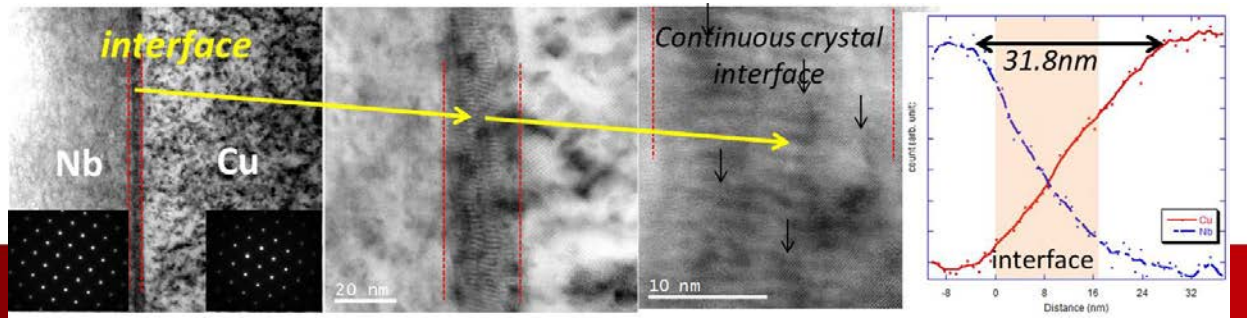


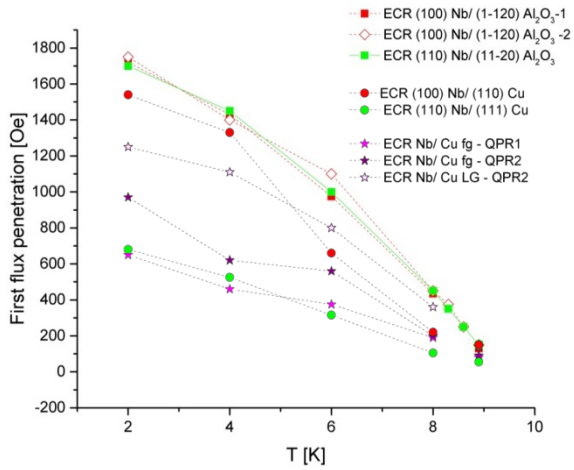
Flux Penetration comparable to H_{c1} for bulk Nb

Nb/ α-Al_2O_3 (1-120)



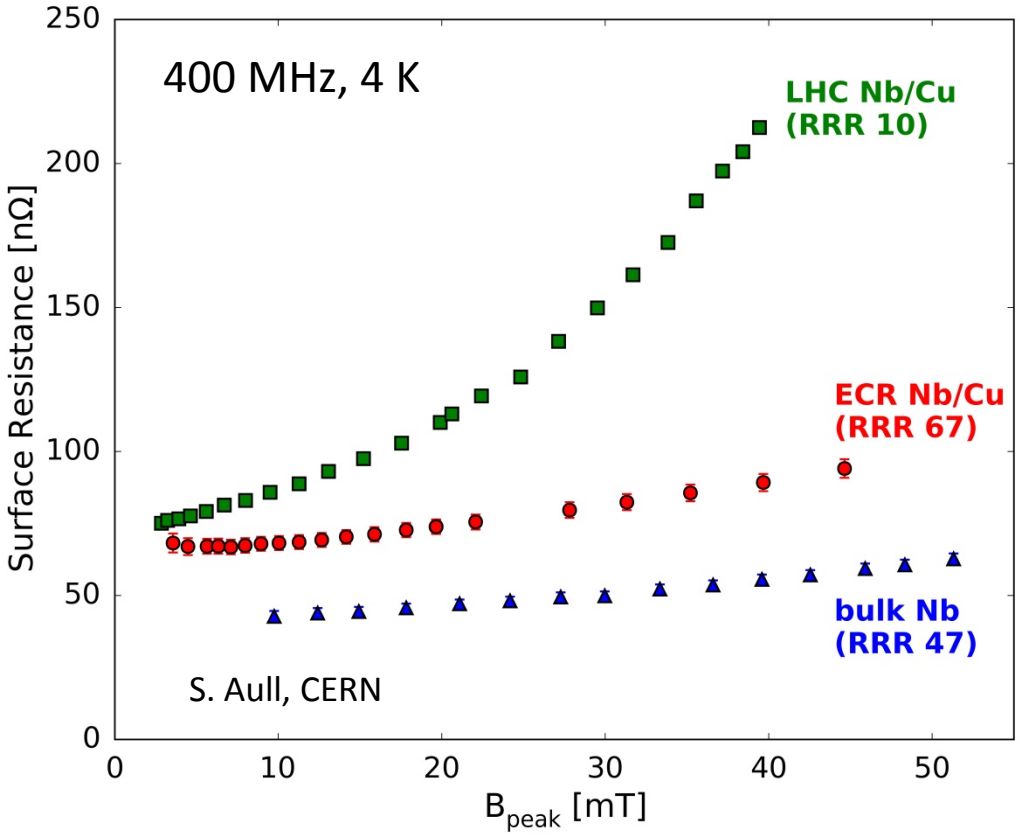
Full control of interface for enhanced adhesion



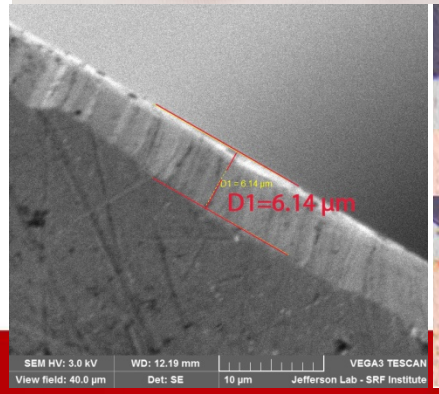


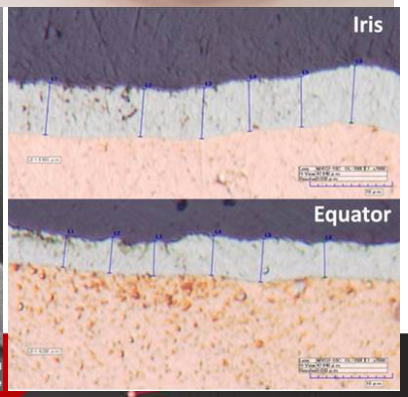
Why energetic condensation?

ECR Nb/Cu film shows a much reduced slope compared to sputtered Nb/Cu cavities.

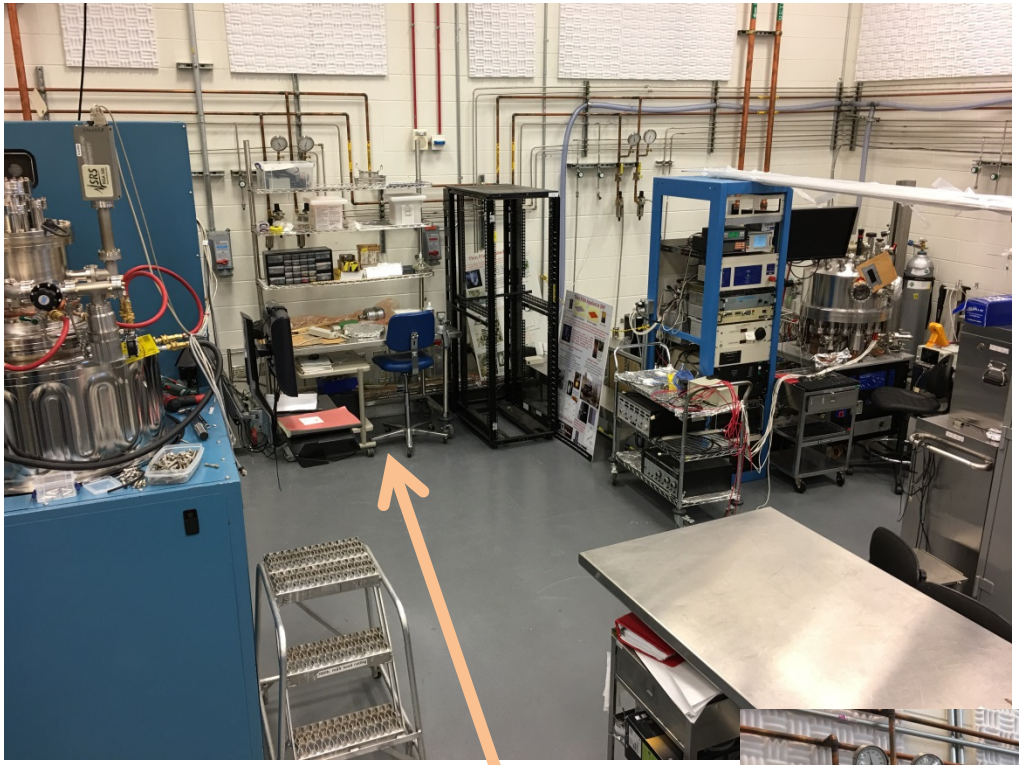


Conformal process

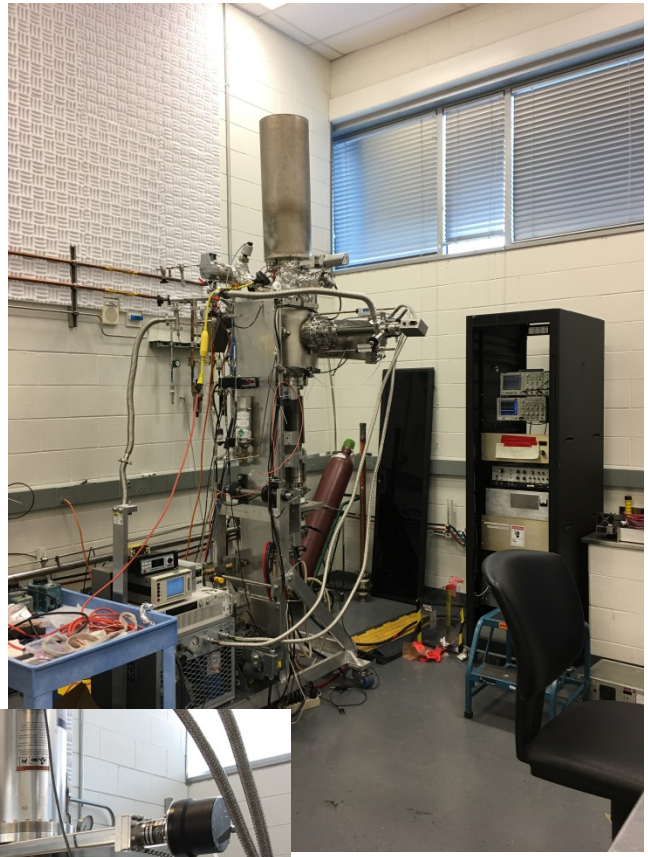


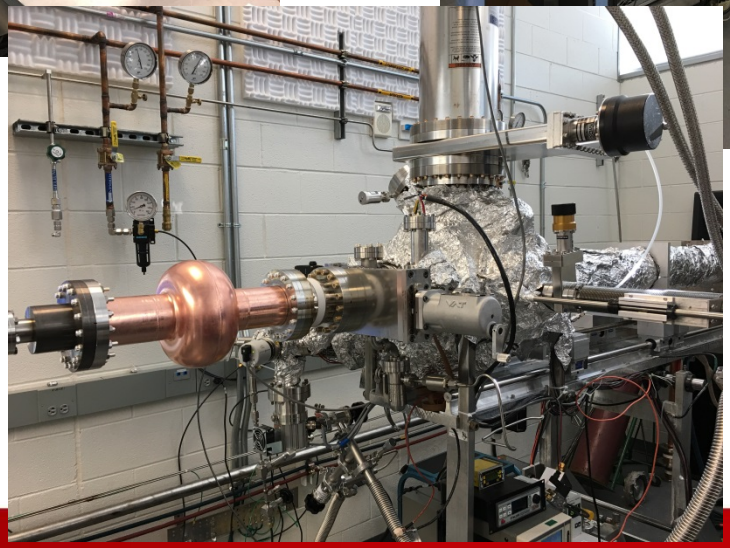


Existing Infrastructure



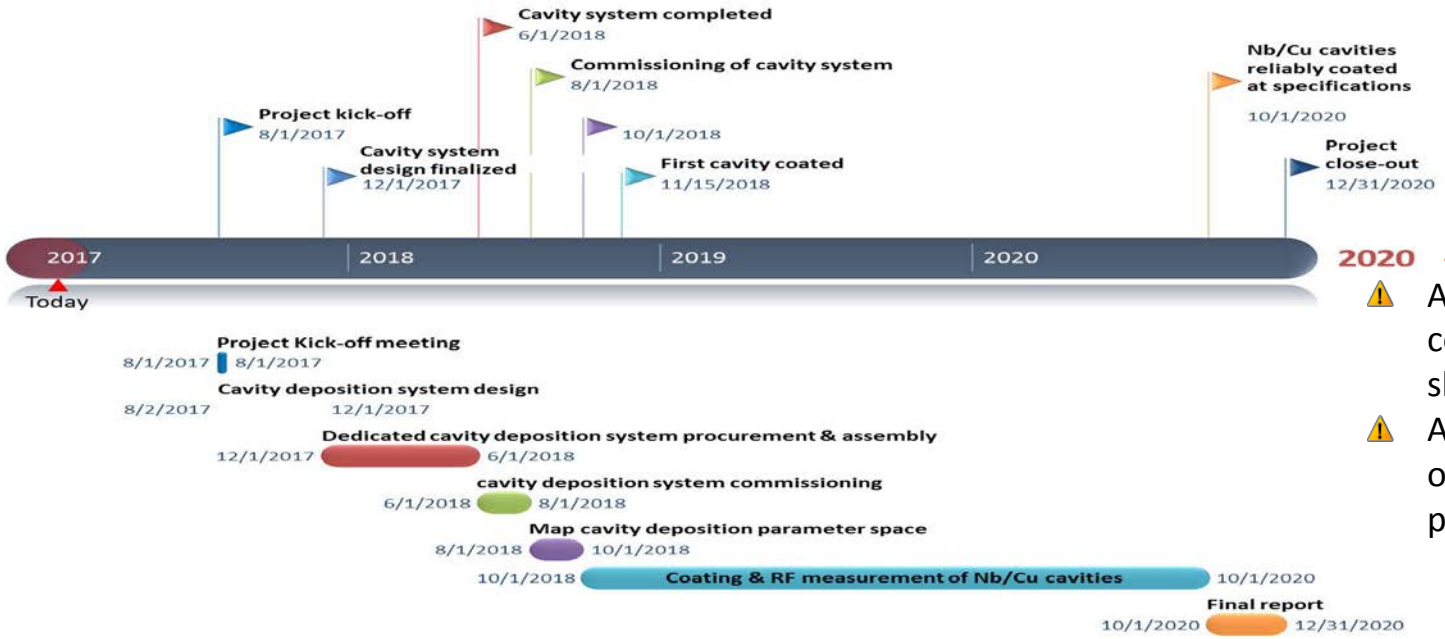
Location reserved for scale-up cavity deposition system





Present cavity HiPIMS system with LSF Cu cavity – Matt Burton's PhD thesis work

Timeline & Budget for Nb/Cu cavity development (based on 400 MHz)

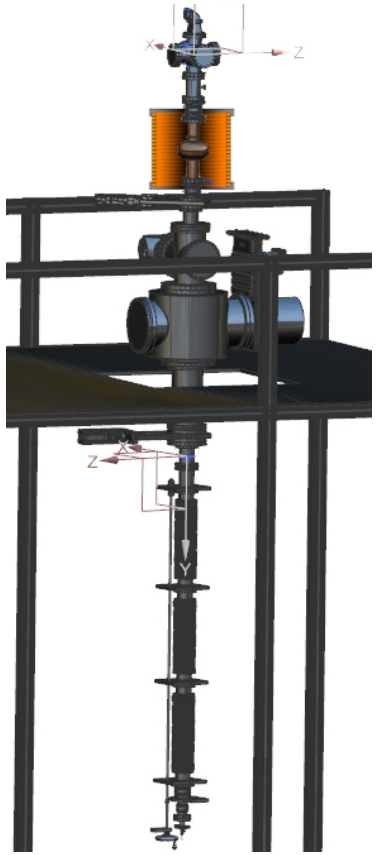


Aggressive Timeline

- ⚠ Assumes Nb film, cavity coating and UHV proficient skills available on day 1
- ⚠ Assumes adequate funding on day 1 for personnel and procurements

400 MHZ cavity coating development : 40 Mos.	TOTAL		YEAR 1		YEAR 2		YEAR 3		YEAR 4	
SENIOR PERSONNEL	CAL		CAL		CAL		CAL		CAL	
Scientists	90.0	$691,080	24.0	$177,962	24.0	$182,411	24.0	$186,972	18.0	$143,735
Senior Scientists	31.0	$389,618	10.0	$122,394	10.0	$125,454	10.0	$128,590	1.0	$13,180
(3) TOTAL SENIOR PERSONNEL	121.0	$1,080,698	34.0	$300,356	34.0	$307,865	34.0	$315,562	19.0	$156,915
OTHER PERSONNEL										
2 OTHER PROFESSIONAL (TECHNICIAN, DESIGNER, ETC.)	90.0	$449,203	28.0	$134,028	24.0	$132,169	26.0	$118,669	12.0	$64,337
2 GRADUATE STUDENTS	96.00	$216,000		$54,000		$54,000		$54,000		$54,000
TOTAL SALARIES AND WAGES (A+B)		$1,745,901		$488,385		$494,034		$488,230		$275,252
FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)		$914,881		$259,762		$263,141		$259,670		$132,309
TOTAL SALARIES, WAGES AND FRINGE BENEFITS	307.0	$2,660,782		$748,147		$757,175		$747,900		$407,560
Cavity coating system		$450,000		$450,000						
Portable cleanroom		$50,000		$50,000						
Substrate Inspection		$70,000		$70,000						
400 MHz cav		$240,000				$240,000				
TOTAL PERMANENT EQUIPMENT		$850,000		$570,000		$240,000		$40,000		
TRAVEL		$50,000		$5,000		$8,000		$12,000		$15,000
OTHER DIRECT COSTS										
MATERIALS AND SUPPLIES		$100,000		$50,000		$20,000		$20,000		$10,000
CONSULTANT SERVICES		$95,000		$30,000		$30,000		$20,000		$15,000
MACHINESHOP		$90,000		$50,000		$10,000		$15,000		$15,000
TOTAL OTHER DIRECT COSTS		$285,000		$130,000		$60,000		$55,000		$40,000
TOTAL DIRECT COSTS		$3,845,782		$1,453,147		$1,065,175		$854,900		$462,560
TOTAL INDIRECT COSTS (~60%)		$2,150,683		$779,166		$588,371		$492,152		$285,481
TOTAL COST OF PROJECT		$5,996,465		$2,232,312		$1,653,546		$1,347,052		$748,041

Existing Infrastructure



ECR cavity deposition system
Under design