200MHz SCRF cavity development

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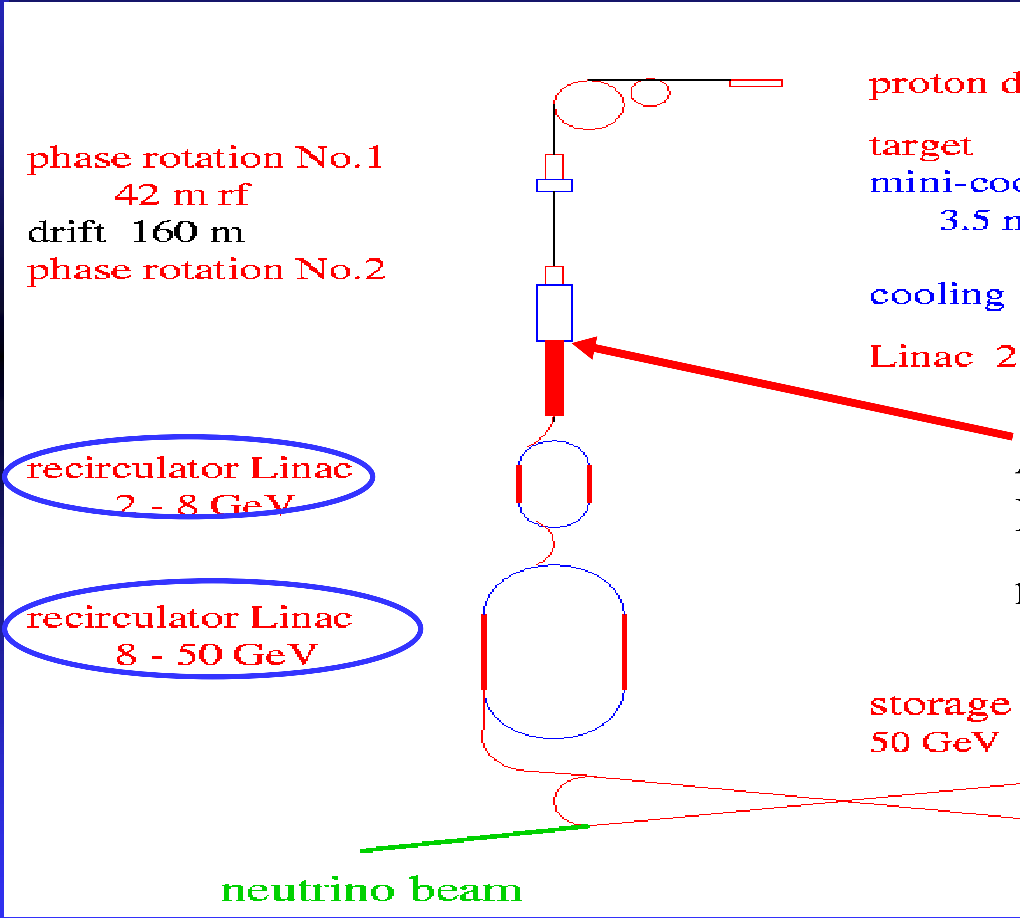
CERN

Contents

- Fabrication and RF tests
- Performance: Eacc and Q
- Q-slope
- Performance when $H_{ext} \neq 0$
- Future work plan and status
- Conclusion

Muon-based neutrino source



Acceleration starts after cooling
Fast acceleration required since muon has a short life time

Requirements to acceleration

- The highest possible Eacc to minimize muon decay
- Large transverse and longitudinal acceptances

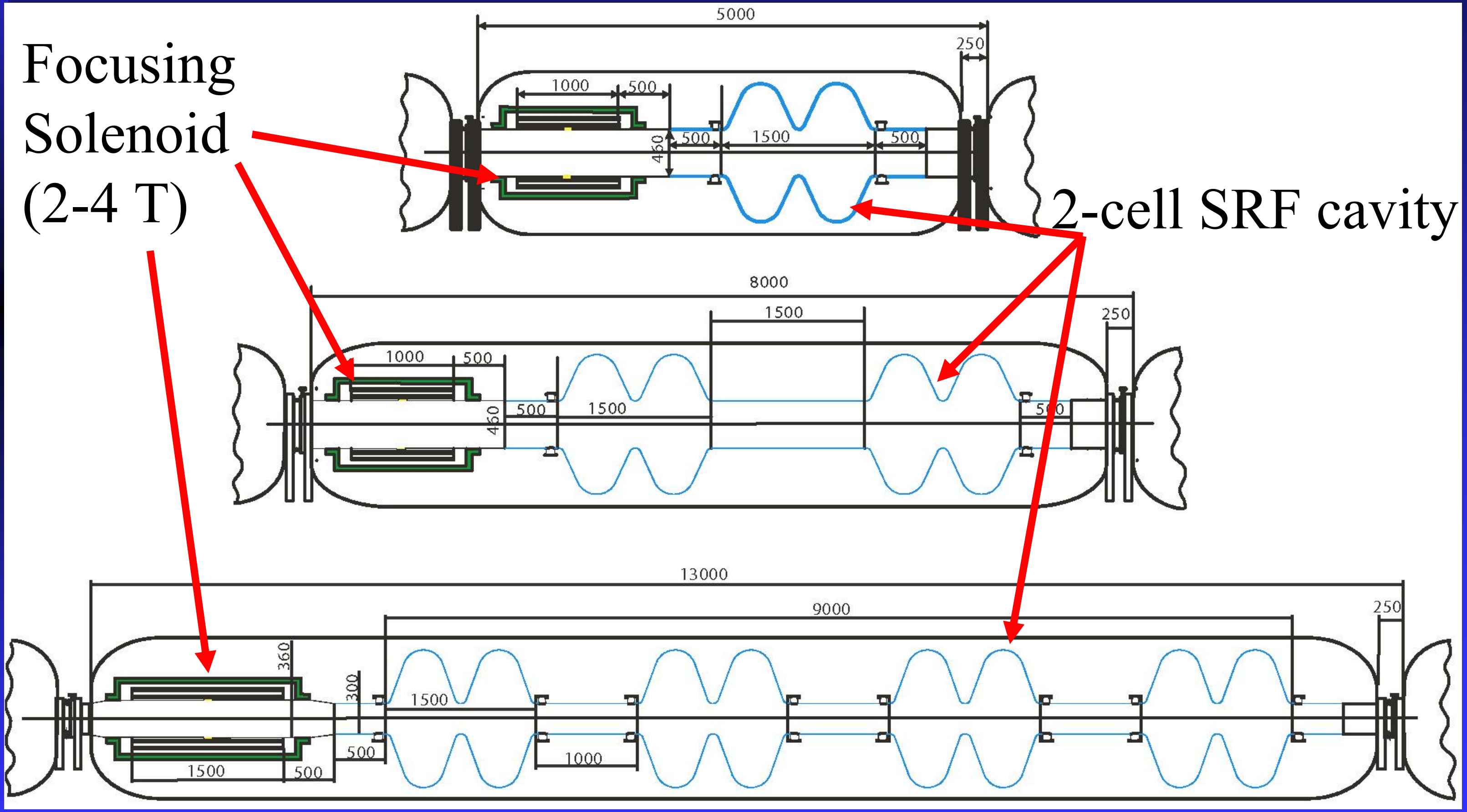
Both requirements favor the choice of SRF

- SRF cavities have a high Q_0

$$P_d = \frac{Eacc^2}{(R/Q)Q_0}$$

- SRF can achieve high gradients with modest RF power
- SRF cavities accommodate a larger aperture without a large penalty for the low R/Q

200MHz SRF layout for Linac



200MHz SRF parameter list

2-cell, 460 mm-aperture cavity parameters.

RF freq (MHz)	201.25
No. of cells per cavity	2
Active cavity length (m)	1.5
No. of cavities	43
aperture diameter (mm)	460
E_{acc} (MV/m)	15
Energy gain per cavity (MV)	22.5
Stored energy per cavity (J)	1932
R/Q (Ω/cavity)	208
E_p/E_{acc}	1.54
H_p/E_{acc} (Oe/MV/m)	44
E_{pk} at 10 MV/m (MV/m)	23.1
H_{pk} at 10 MV/m (Oe)	660
Q_0	6×10^9
Bandwidth (Hz)	200
Input power per cavity (kW)	980
RF on-time (ms)	3
RF duty factor (%)	4.5
Dynamic heat load per cavity (watt)	18.3
Operating temperature (K)	2.5
Q_L	10^6
Microphonics detuning tolerable (Hz)	40

2-cell, 300 mm-diameter cavity parameters.

RF freq (MHz)	201.25
No. of cells per cavity	2
Active cavity length (m)	1.5
No. of cavities	256
Linac	76
RLA	180
Aperture diameter (mm)	300
E_{acc} (MV/m)	17
Energy gain per cavity (MV)	25.5
Stored energy per cavity (J)	2008
R/Q (Ω/cavity)	258
E_p/E_{acc}	1.43
H_p/E_{acc} (Oe/MV/m)	38
E_{pk} at 15 MV/m (MV/m)	24.3
H_{pk} at 15 MV/m (Oe)	646
Q_0	6×10^9
Bandwidth (Hz)	200
Input power per cavity (kW)	1016
RF on-time (ms)	3
RF duty factor (%)	4.5
Dynamic heat load per cavity (W)	18.9
Operating temperature (K)	2.5
Q_L	10^6
Microphonics detuning tolerable (Hz)	40
Wall thickness (mm)	8
Lorentz force detuning at 15 MV/m (Hz)	128

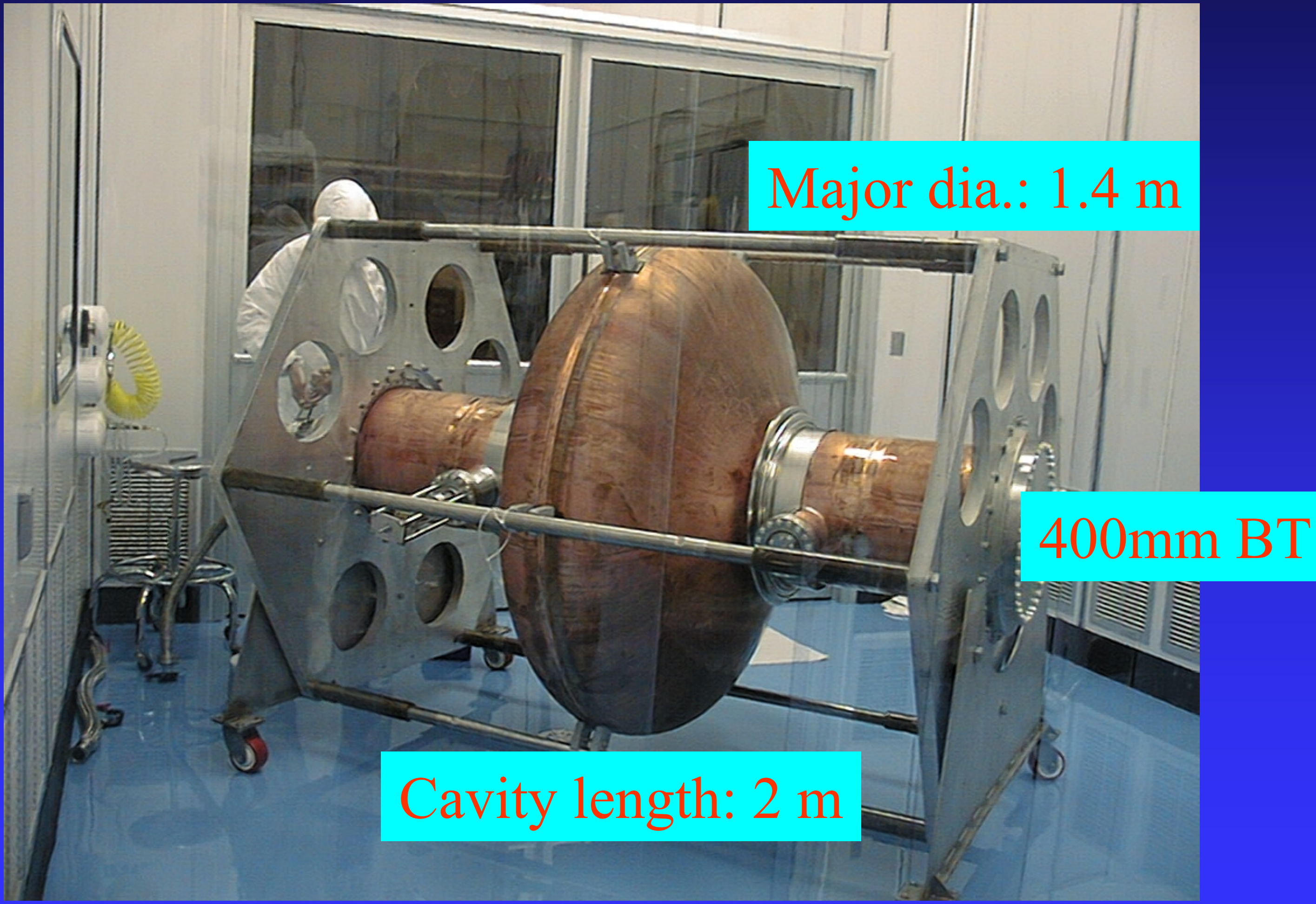
300 high gradient 200MHz cavities needed

Why Nb-Cu cavities?

- Save material cost
- Save cost on magnetic field shielding (Rs of Nb-Cu less sensitive to residual mag. field)
- Save cost on LHe inventory by pipe cooling (Brazing Cu pipe to Cu cavity)

1.5GHz bulk Nb cavity (3mm) material cost: ~ $ 2k/cell
200MHz: X $(1500/200)^2 = 56 \rightarrow$ $ 112k/cell
Thicker material (8mm) needed: X 2.7 $\rightarrow$ $300k/cell
Nb Material cost for 600 cells: 180M$
Cu (OF) is X 40 cheaper: 5M$

First 200MHz Nb-Cu cavity



Fabrication at CERN

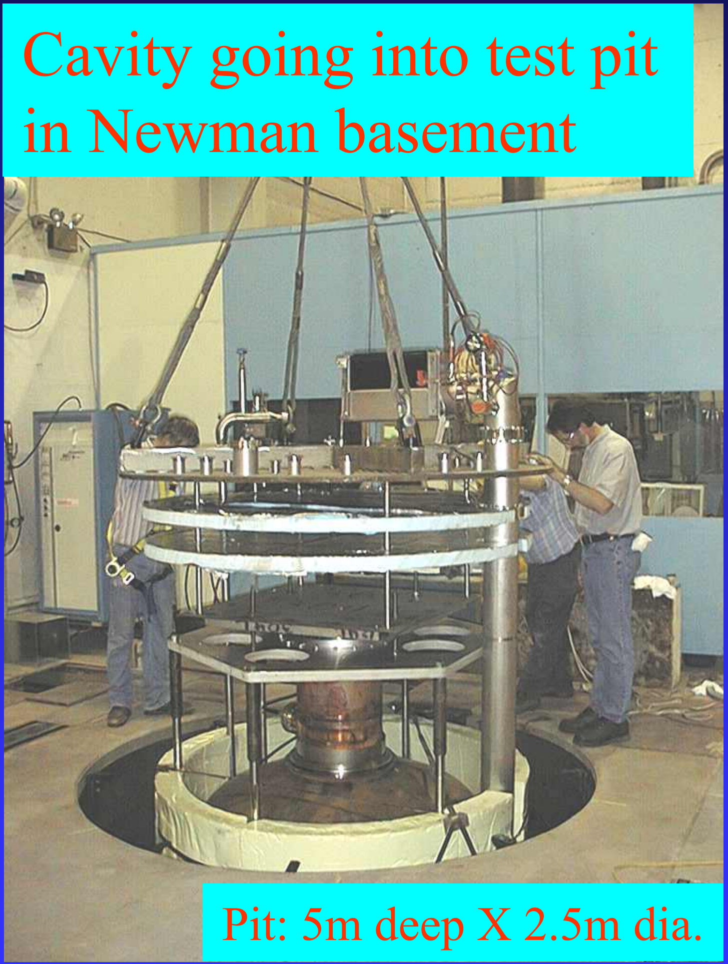
Electro-polished half cell

Magnetron Nb film (1-2 μm) sputtering

- DC voltage: 400-650 V
- Gas pressure: 2 mTorr
- Substrate T: 100 °C
- RRR = 11
- Tc = 9.5 K

RF test at Cornell

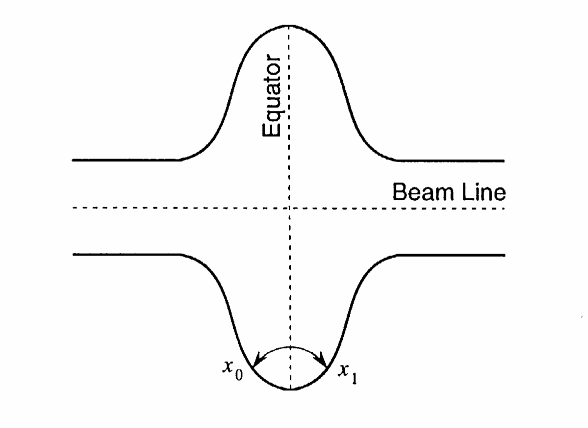
Cavity on test stand



Cavity going into test pit in Newman basement

Pit: 5m deep X 2.5m dia.

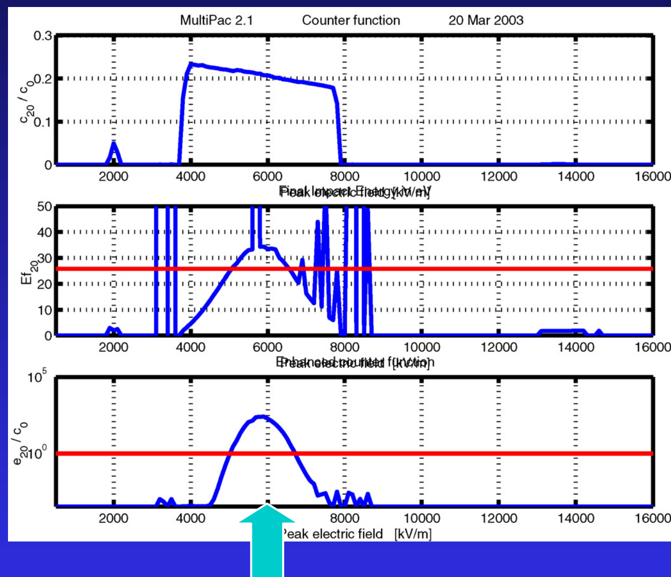
Two-point Multipacting



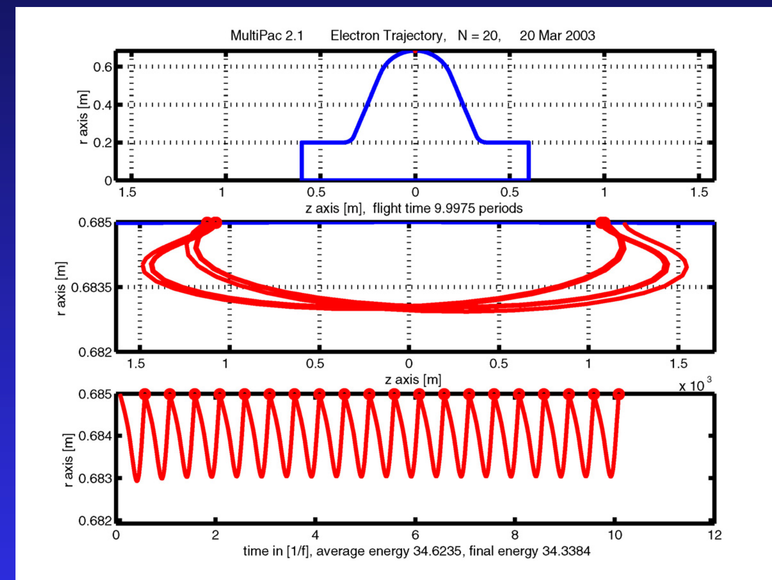
- Two points symmetric about equator are involved
- Spontaneously emitted electrons arrive at opposite point after T/2
- Accelerated electrons impact surface and release secondary electrons
- Secondary electrons are in turn accelerated by RF field and impact again
- The process will go on until the number of electrons are saturated

MP electrons drain RF power → A sharp Q drop

Two-point MP at 3 MV/m



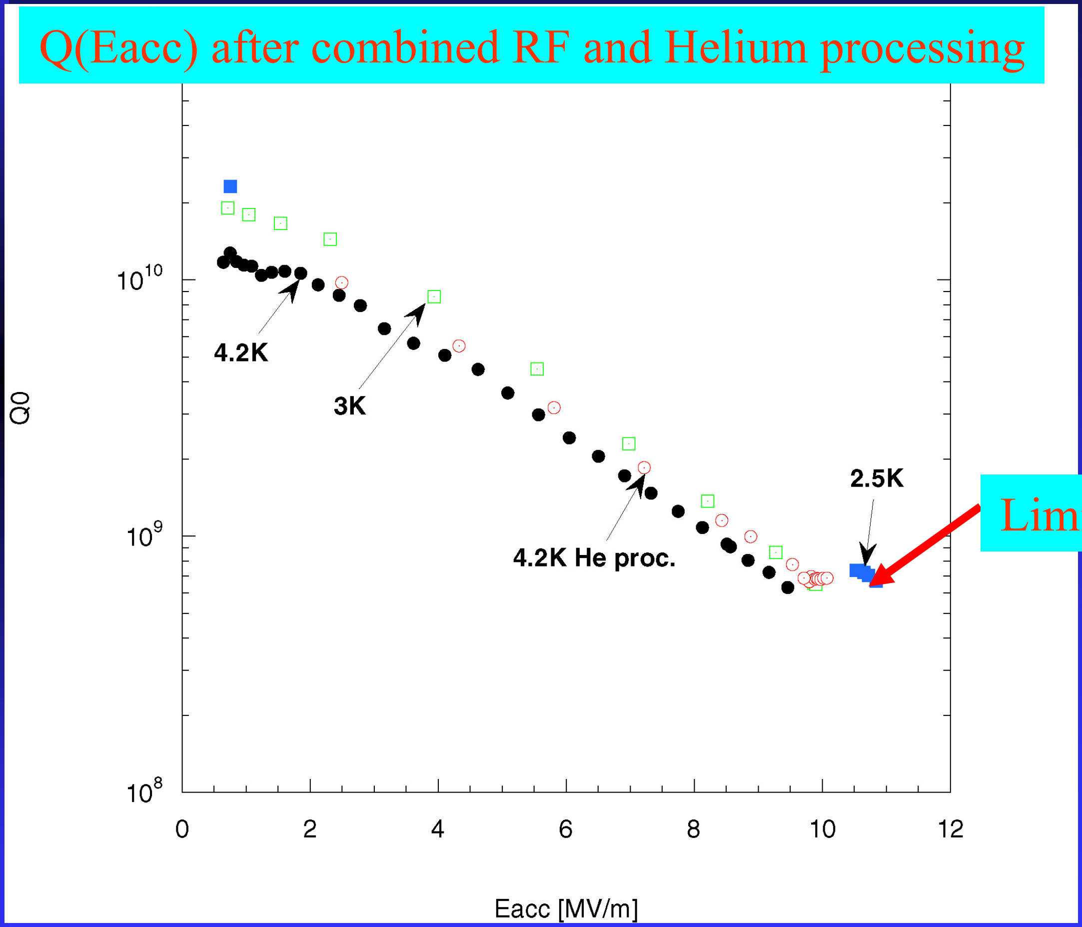
MULTIPAC simulation confirmed exp. observation



Resonant trajectory of MP electrons

It was possible to process through MP barrier

Performance of the cavity

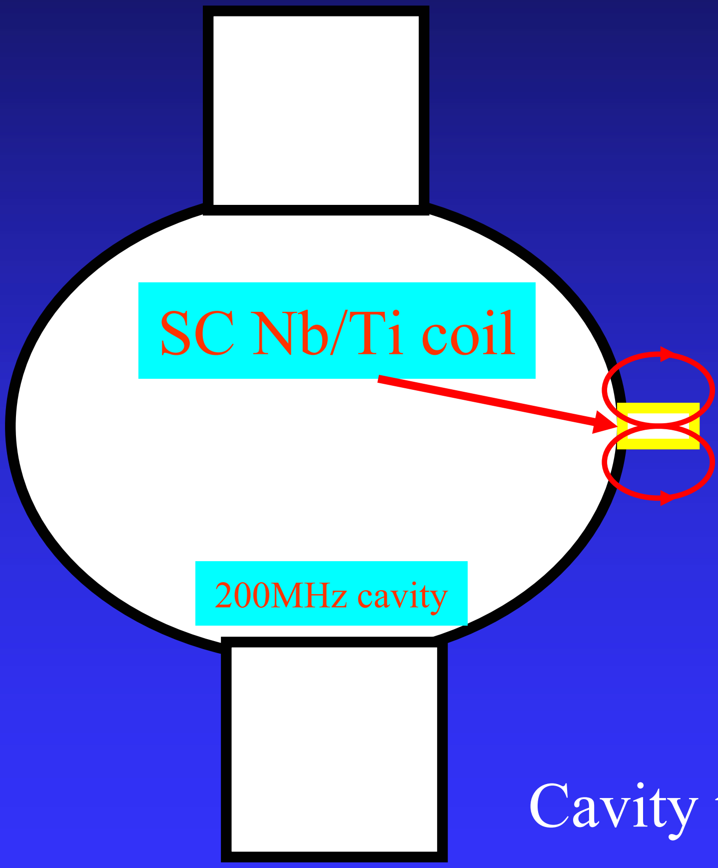


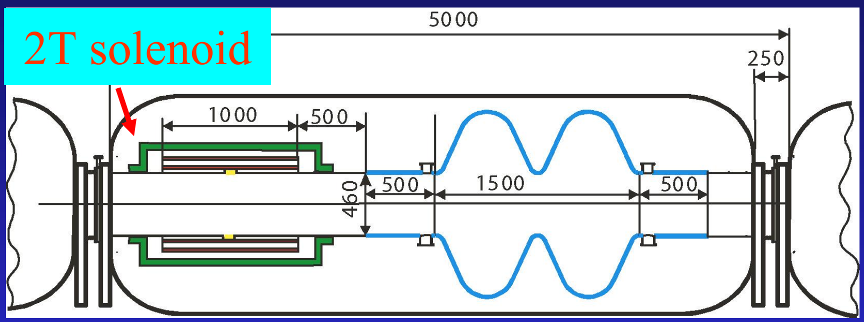
- Eacc = 11MV/m
- Low field Q = 2E10

- 75% goal E_{acc} achieved
- Q-slope larger than expected

Q improves with lower T
→ FE not dominant

H_{ext} effect on cavity



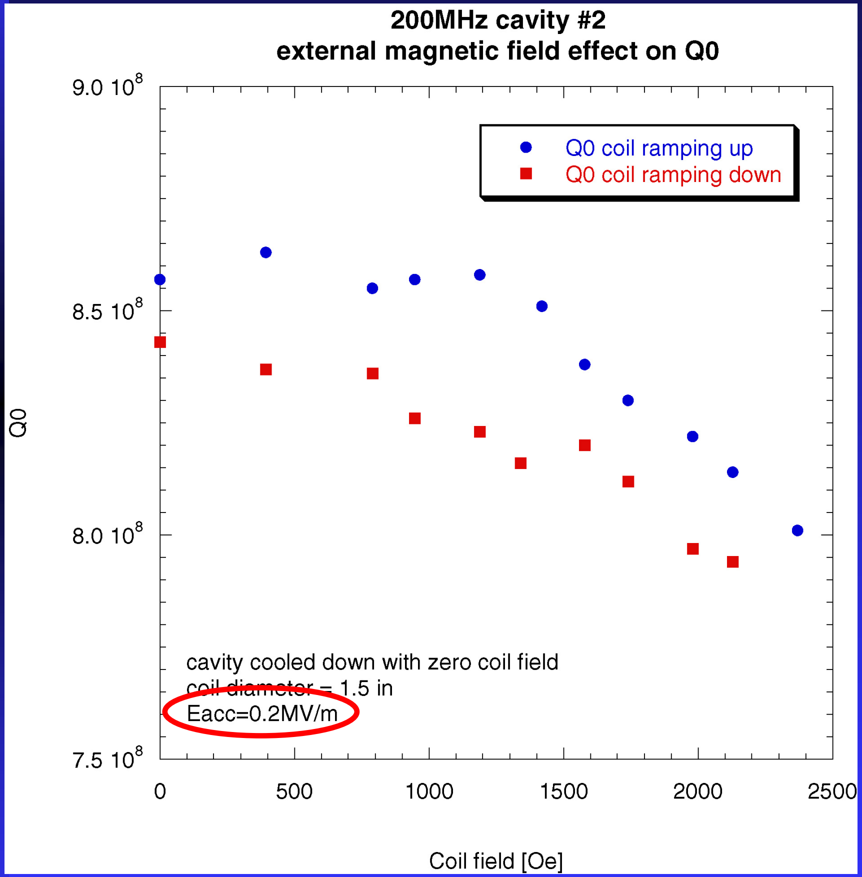


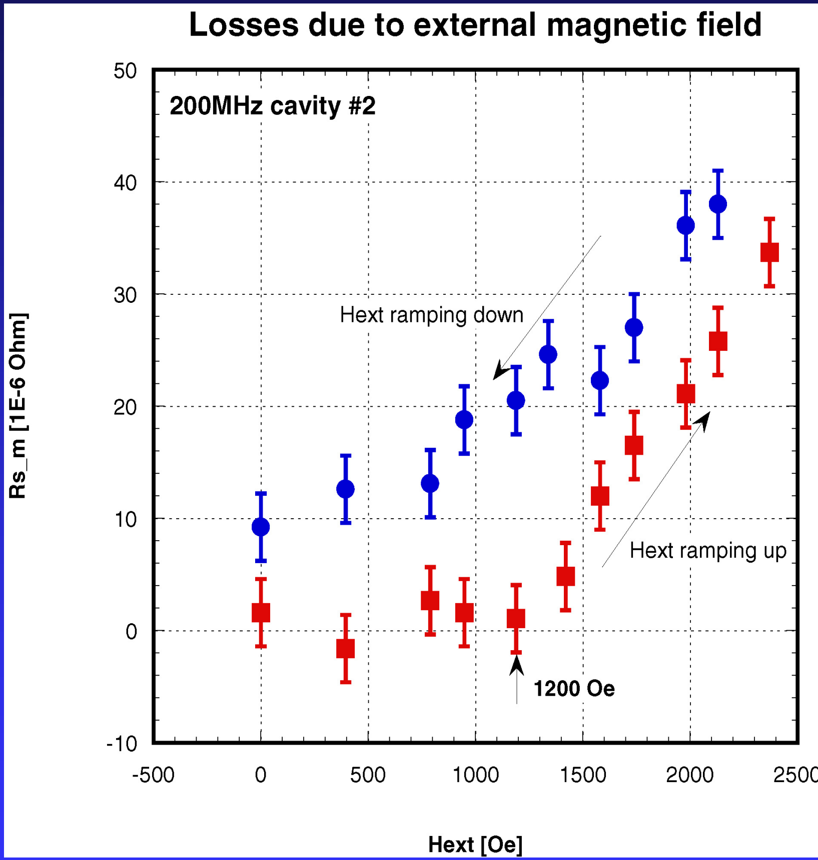
Layout of Linear Accelerator for ν source

- 2T solenoid needed for tight focusing
- Solenoid and cavity fitted in one cryostat
- Large aperture (460 mm)
- Q: Will cavity still work $H_{ext} > 0$?

Cavity test in the presence of an H_{ext}

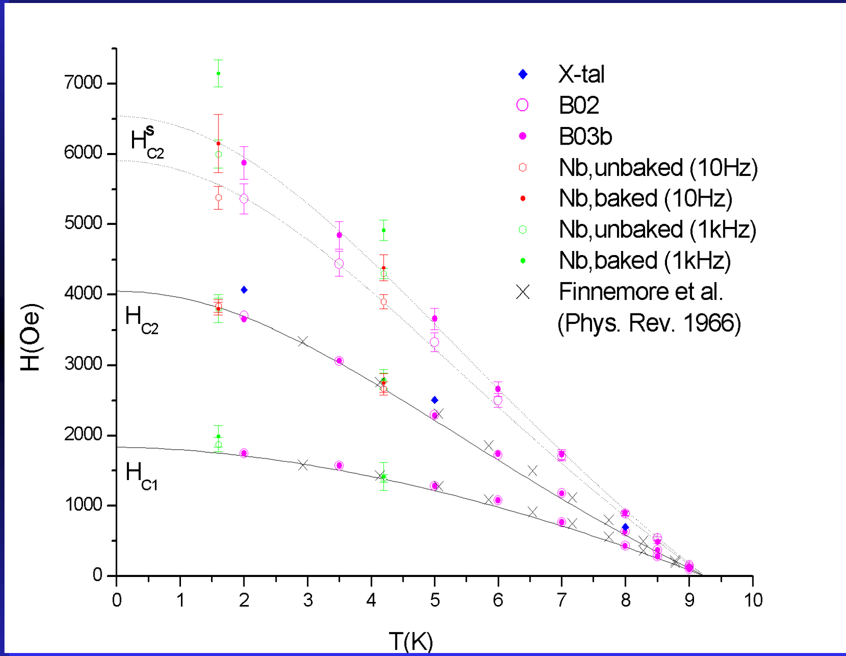
H_{ext} effect on cavity





Cavity stays intact up to Hext = 1200 Oe

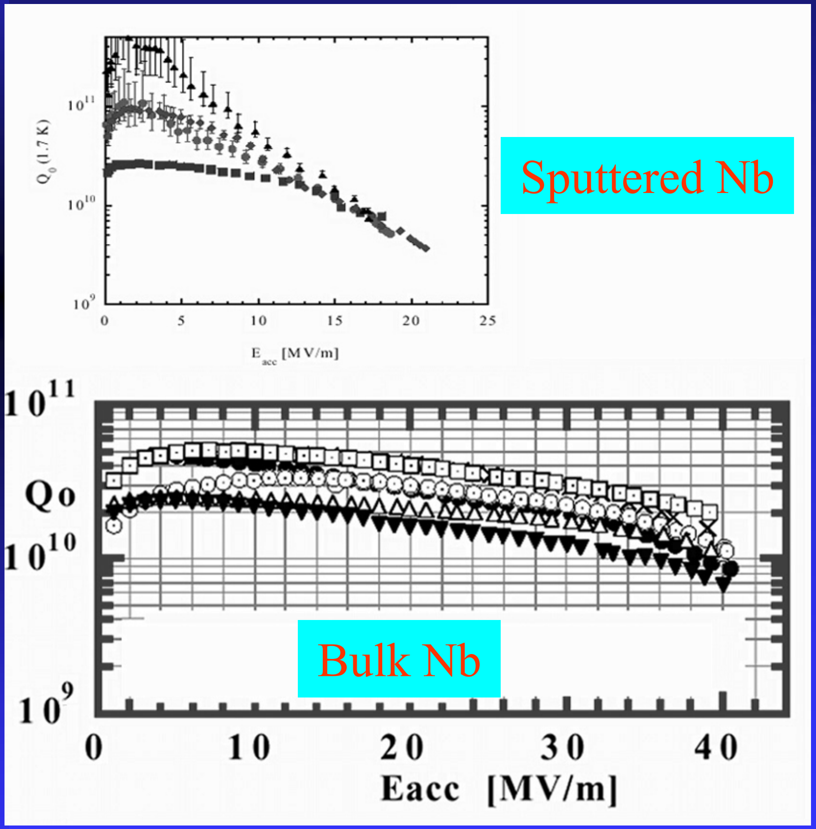
Hext effect on cavity



- Nb is a type-II SC
- Mixed state above Hc1
- Magnetic flux penetration
- Normal cores cause Rs ↑

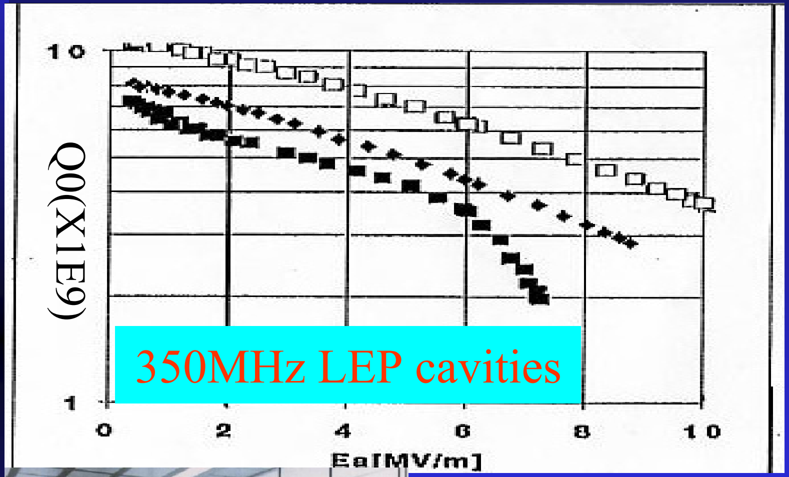
- Onset H_{ext} for loss increase consistent with Hc1 of Nb
- Msmts at higher Eacc needed: $H_{ext} + H_{RF}$; resistive flux flow

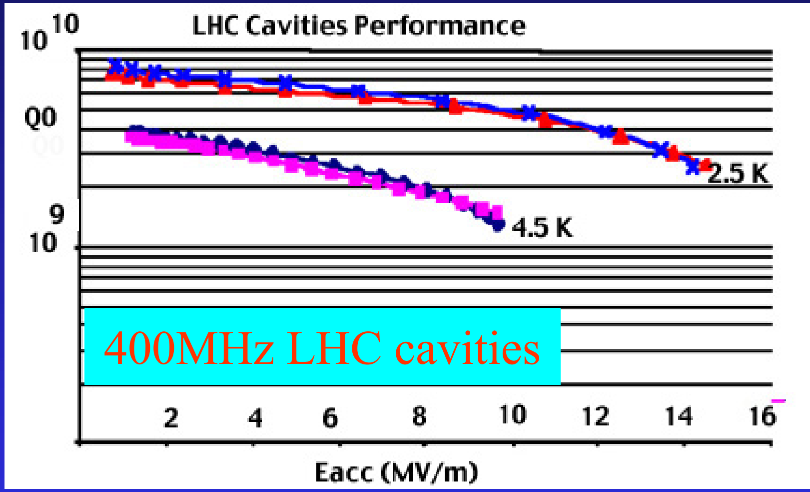
Q-slope of sputtered film Nb cavities

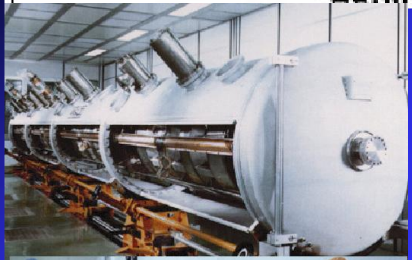


- Q-slope is a result of material properties of film Nb
- The Cu substrate (surface) has some influence
- The exact Q-slope mechanism is not fully understood

Nb-Cu cavities



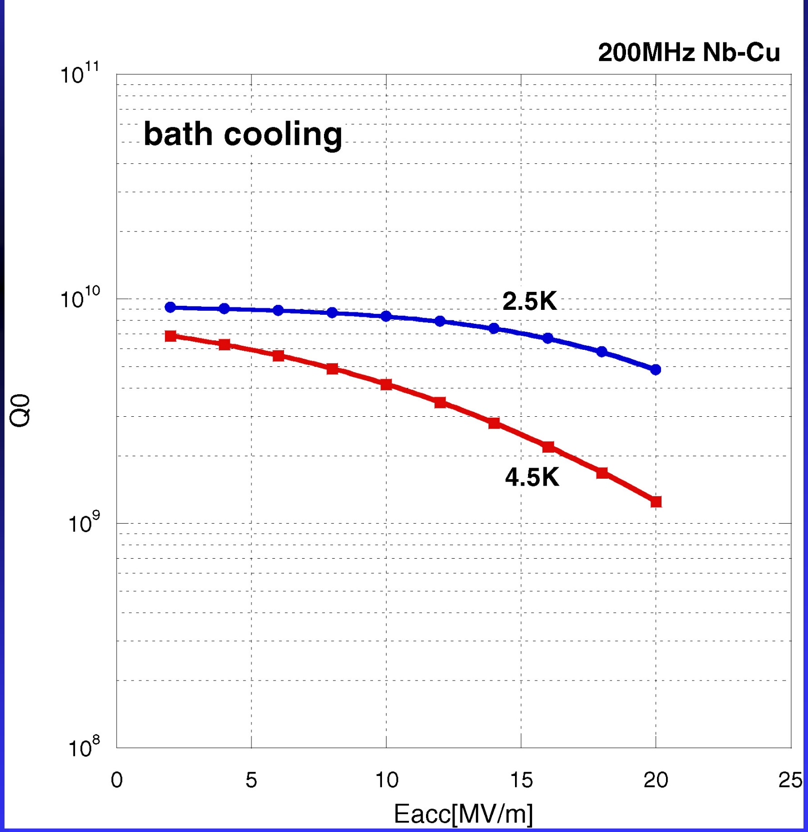


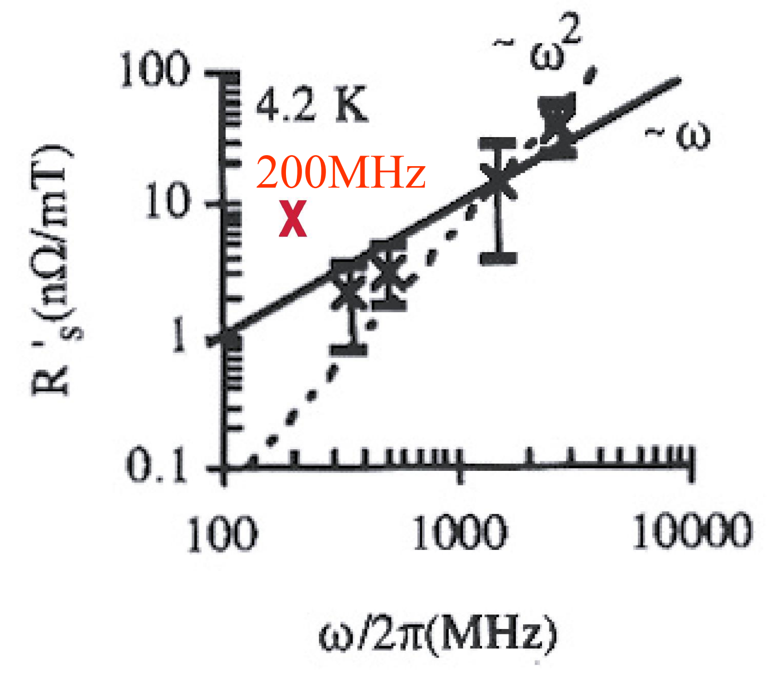


Despite Q-slope, sputtered Nb-Cu cavities have achieved a 15MV/m Eacc at 400MHz

Expected performance

Projecting LHC 400MHz to 200MHz

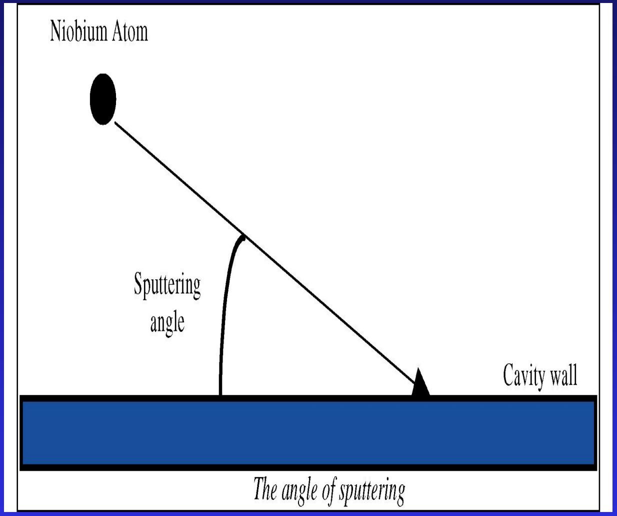




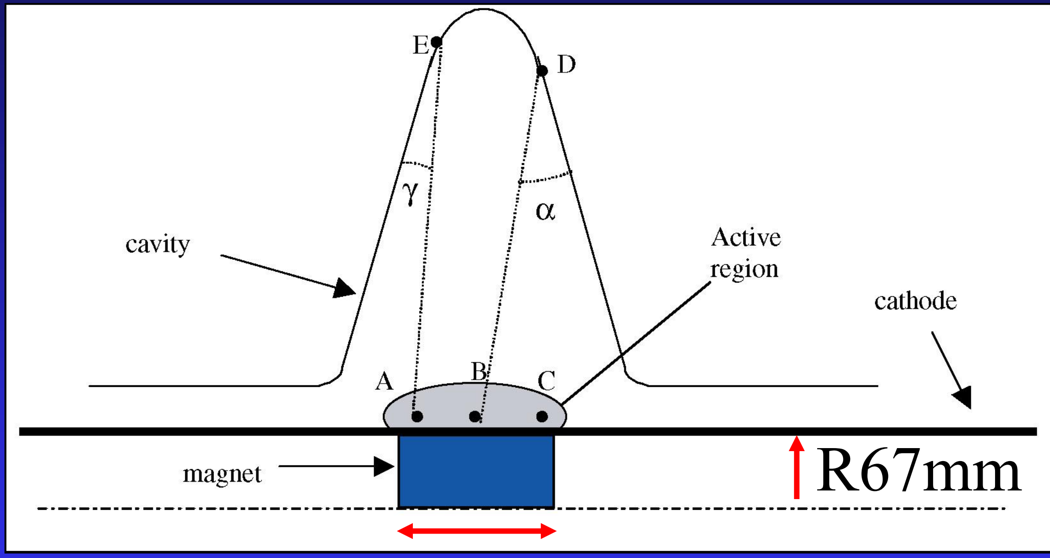
Empirical frequency dependence of Q-slope

Measured Q-slope of 200MHz cavity is 10 times too steep than projected

Q-slope: impact angle effect



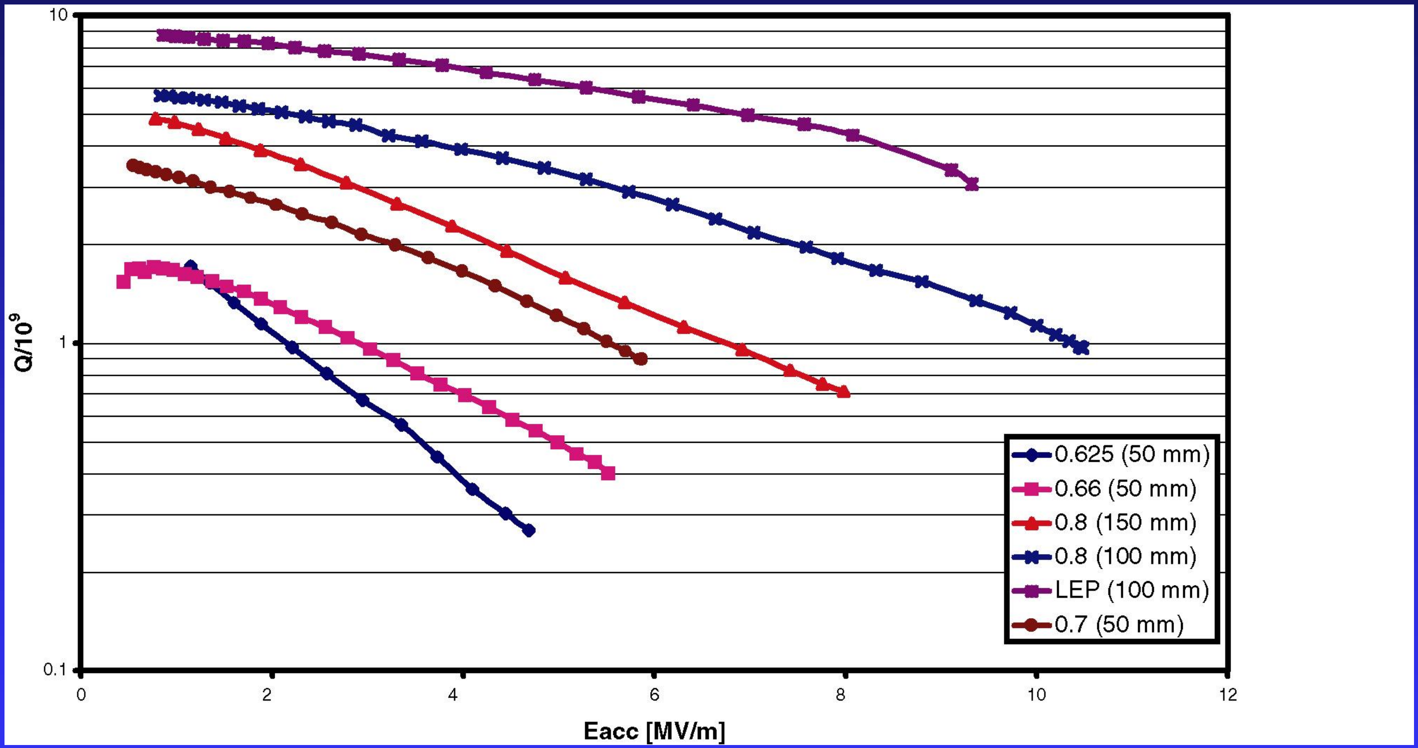
Impact angle of Nb atom: γ



100mm

- CERN explored low β 350MHz cavities
- With the same cathode geometry, lower β → low γ

Q-slope: impact angle effect



Correlation: lower β → lower γ → steeper Q-slope

Q-slope: impact angle effect

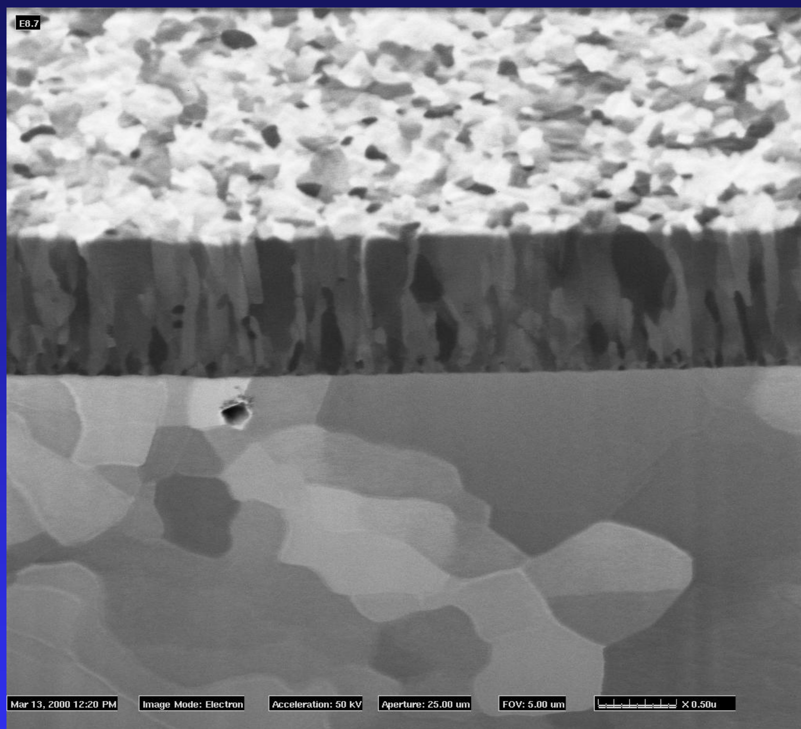
- A smaller impact angle results in pronounced shadowing effect and poor film quality (open boundaries, voids, dislocations)
- The cathode used to sputter 200MHz cavity was recycled from sputtering system for LEP2 cavities
- Due to an increase in equator radius, a smaller impact angle is evident for 200MHz cavity
- Cavity returned to CERN for recoating with improved geometry - expect completion in March - retest 7/04

Other techniques for Nb film deposition

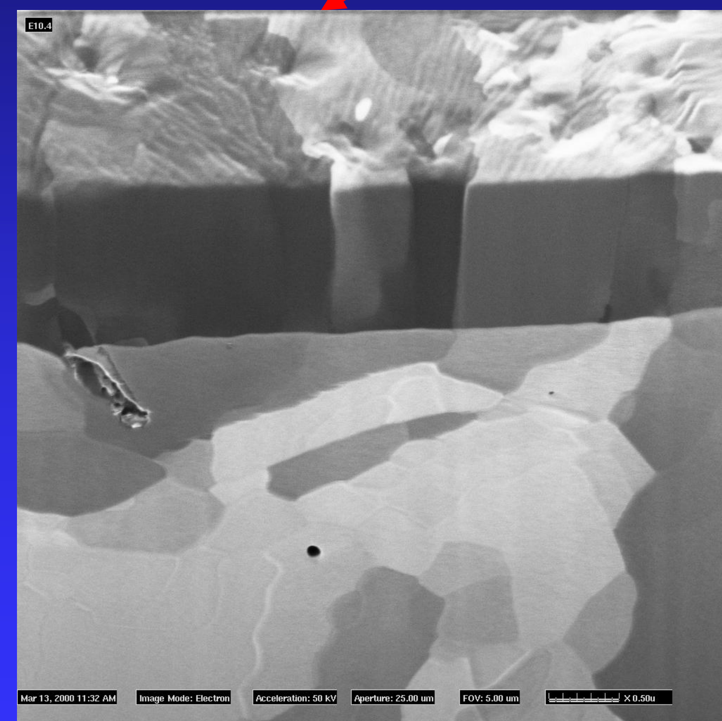
- Bias sputtering
- Energetic deposition in vacuum
- Vacuum arc deposition
- Electron cyclotron resonance sputtering

Nb Sputtering Variation

Standard Films



Oxide-free



- Standard films have rod like form
- Avoid oxide formation
- More uniform and larger grains

Reducing Q-Slope

- Study Nb film with 500MHz cavities (less LHe) with existing LEPP infrastructure developed for CESR SRF
- Seamless Cu cavities to simplify fabrication (Italy)

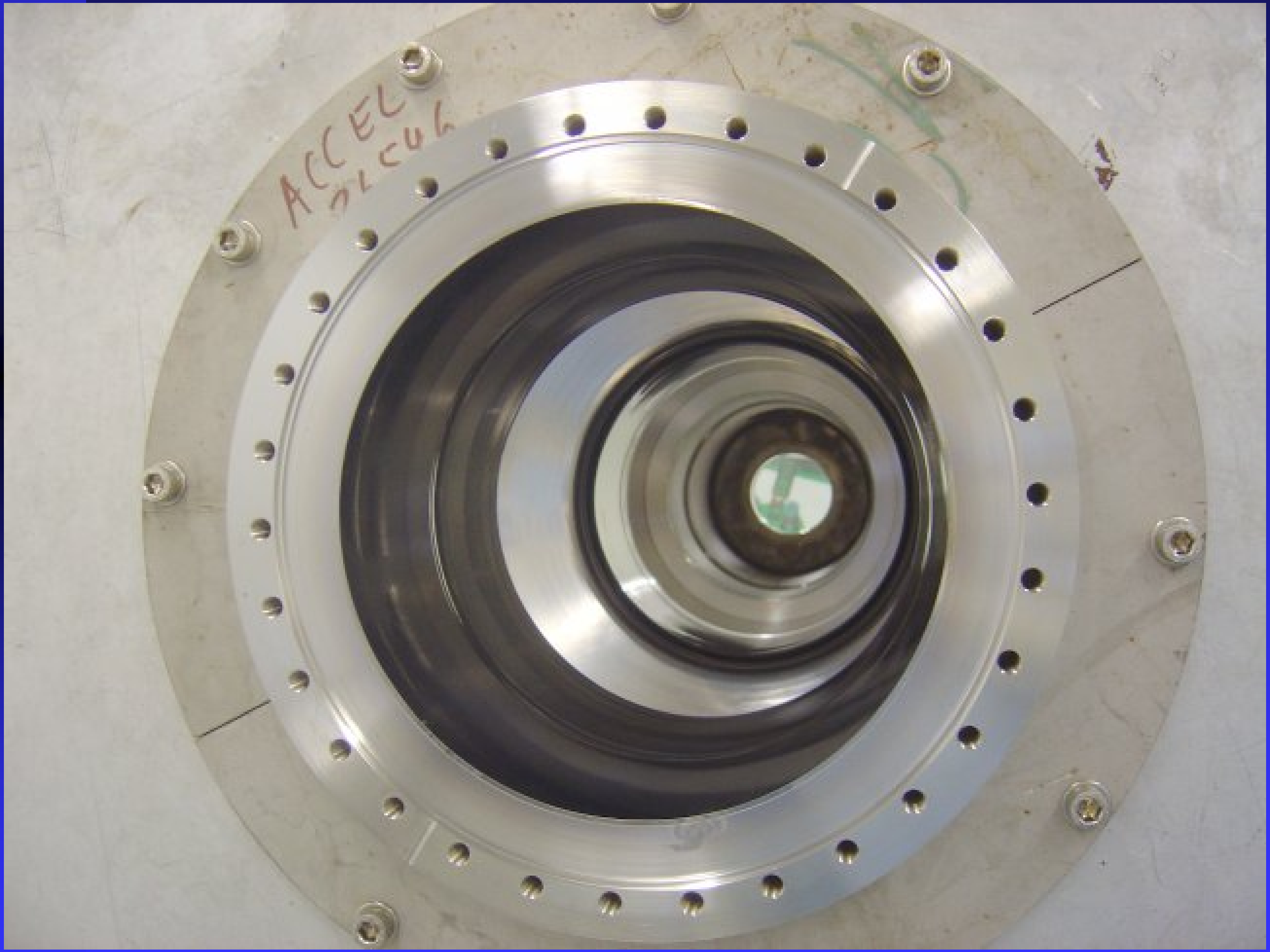
500 MHz Progress

ACCEL Etching Facility

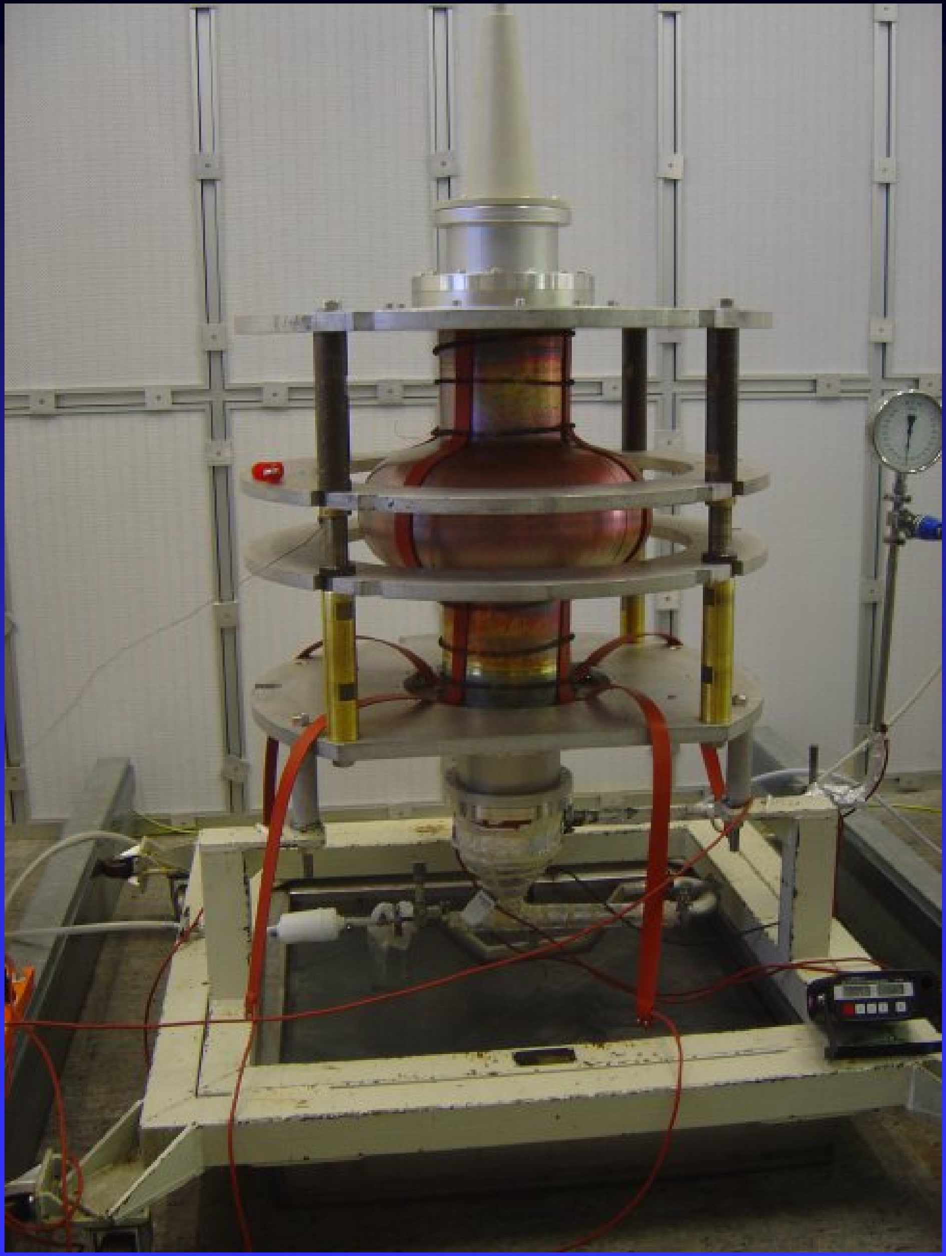
500 MHz

ACCEL Sputtering Setup

500 MHz Progress



ACCEL Nb Coated Cavity before Final Water Rinse



500 MHz

Final Water Rinse after Nb Sputter Coating at ACCEL

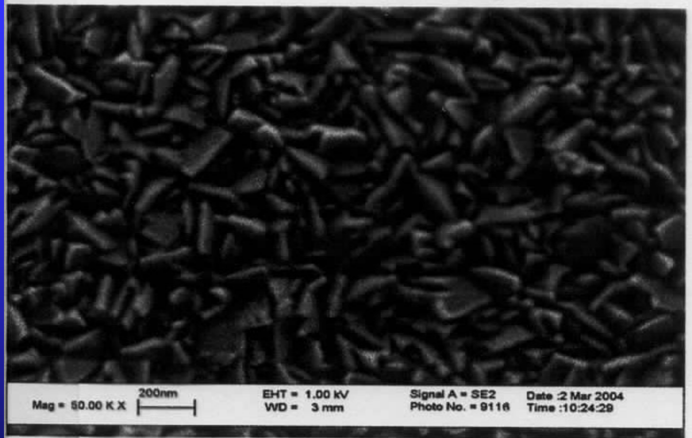
Near term Program

- 500 MHz cavity from ACCEL, assembled and tested to 4MV/m with heavy field emission - back to ACCEL for recoating.
- Recoat 200 MHz cavity #1 at CERN in 3/04 - peeling observed - recoating with new parameters - expect to test again this summer.
- Use Auger surface analysis system and SIMS to further characterize Nb sputtered surfaces.
- Explore effectiveness of Atomic Force Microscopy in characterizing good Nb RF surfaces.

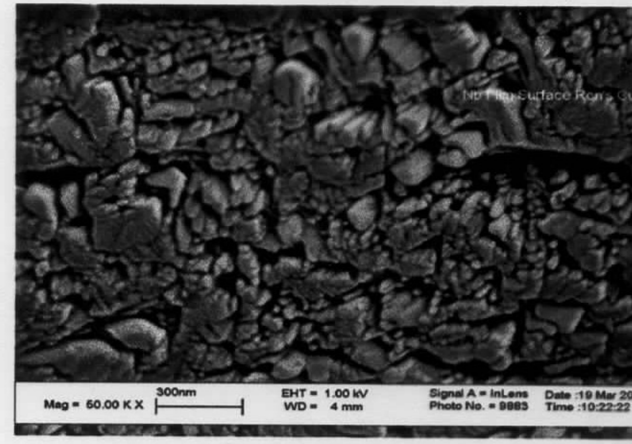
Near term Program

- Continue support of Electron Cyclotron Resonance Coating R&D work at JLAB.
- Incorporate the results from these studies into the 500 MHz cavity program.
- Spin a 500 MHz cavity from explosion bonded Nb-Cu sheet. Single cell 1300 MHz cavity spun from this material has achieved 40 MV/m accelerating gradient.
- Bias Sputter coat a spun Cu single cell 1500 MHz cavity.
- Hope to have good understanding of Q-slope problem by end of the year.

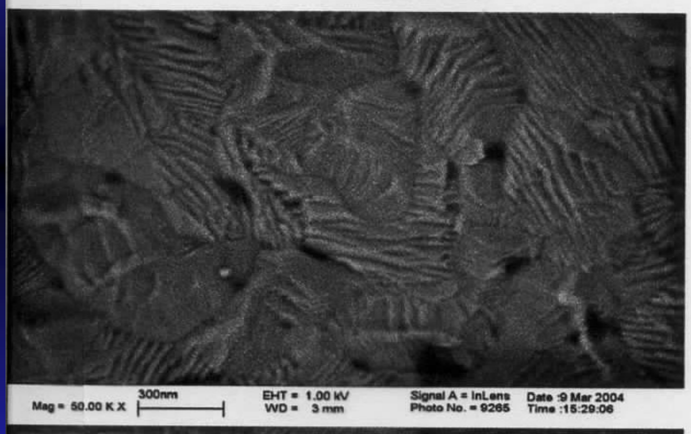
PKU Bias Sputtered



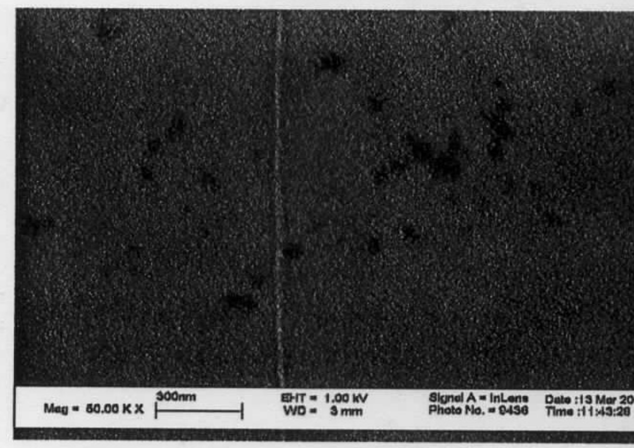
Accel Magnetron Sputter (Jlab)



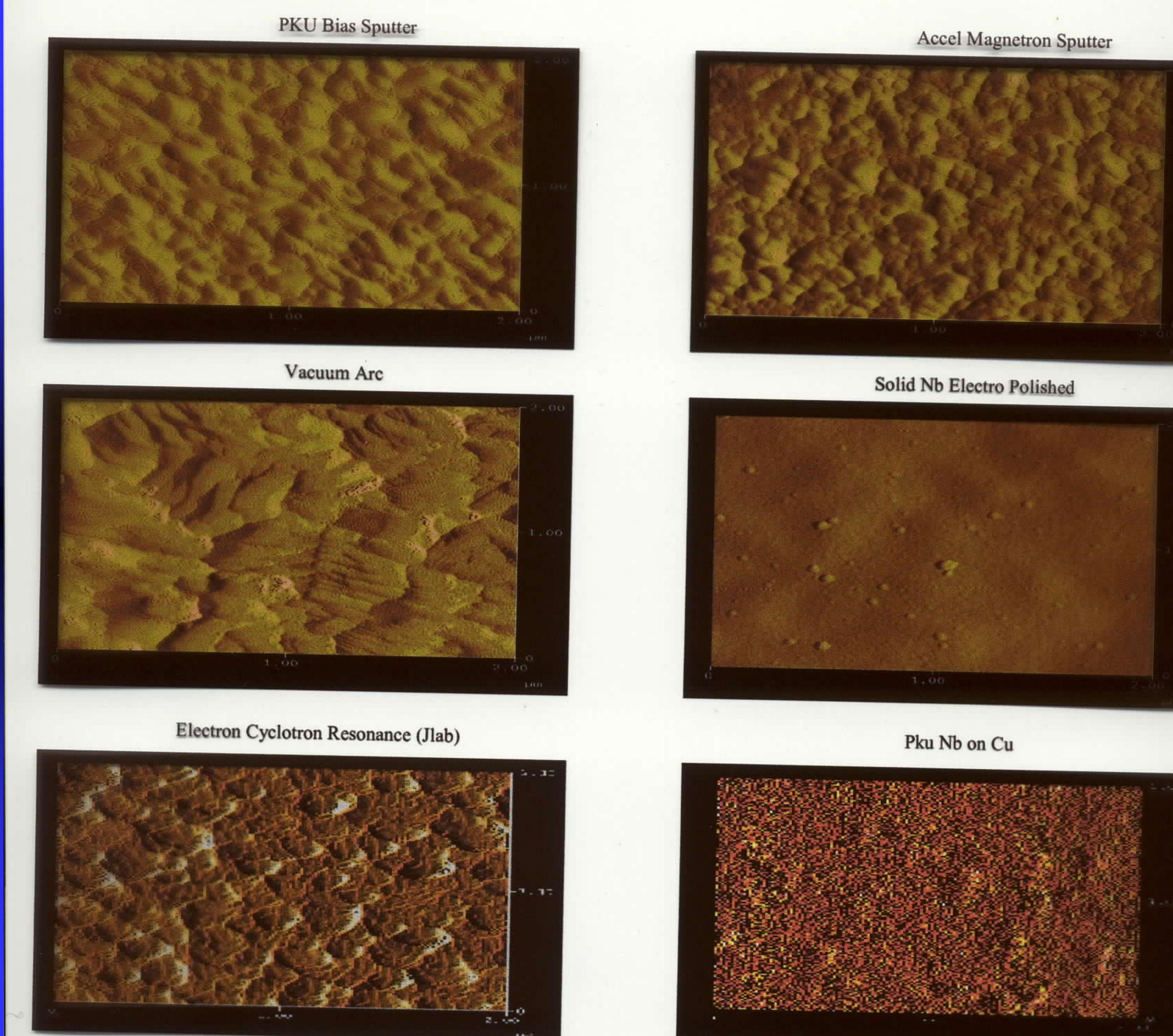
Vacuum Arc



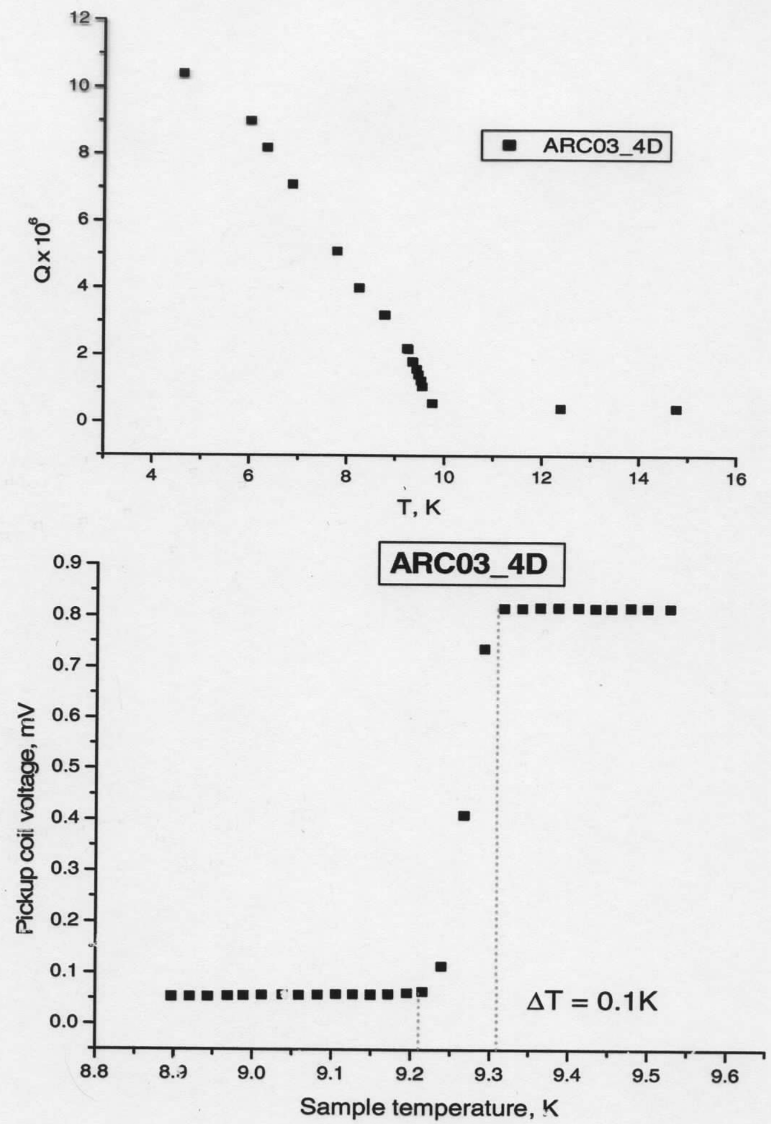
Solid Nb Electro Polished



Jlab Electron Cyclotron Resonance

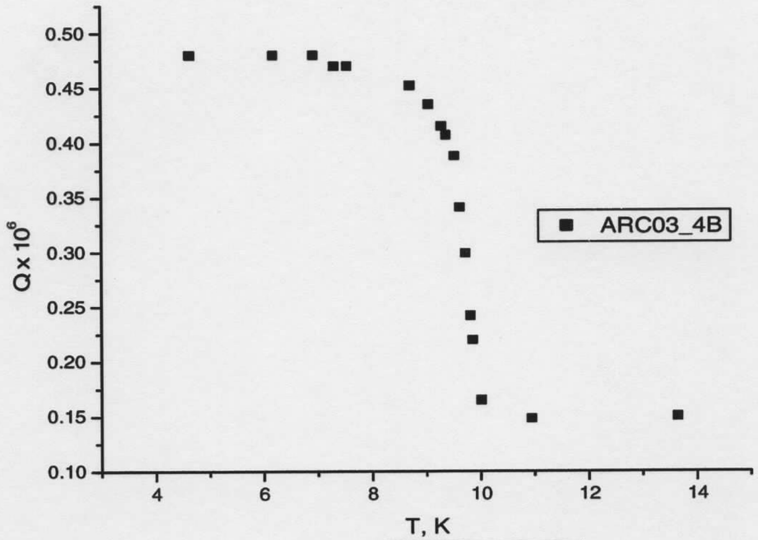

PKU Bias Sputter
Accel Magnetron Sputter
Vacuum Arc
Solid Nb Electro Polished
Electron Cyclotron Resonance (Jlab)
Pku Nb on Cu

ARC03_4D

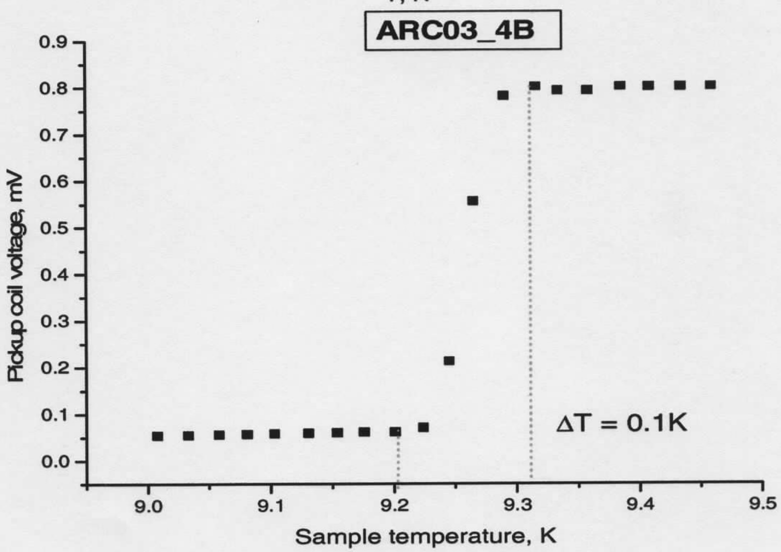


ARC03_4D
Q x 10^6
T, K
ARC03_4D
Pickup coil voltage, mV
Sample temperature, K
ΔT = 0.1K

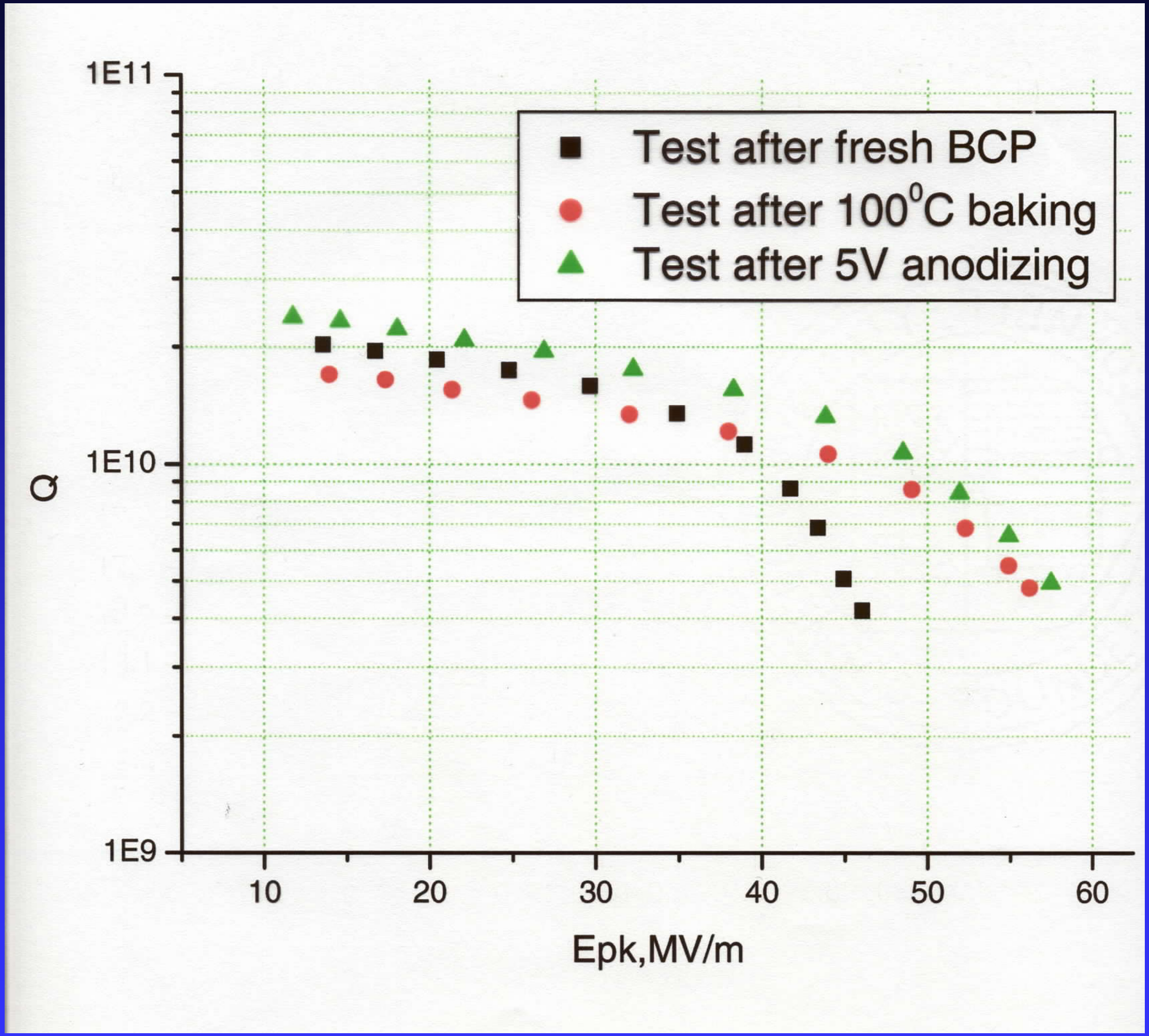
ARC03_4B



0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
Q x 10^6
ARC03_4B
4
6
8
10
12
14
T, K

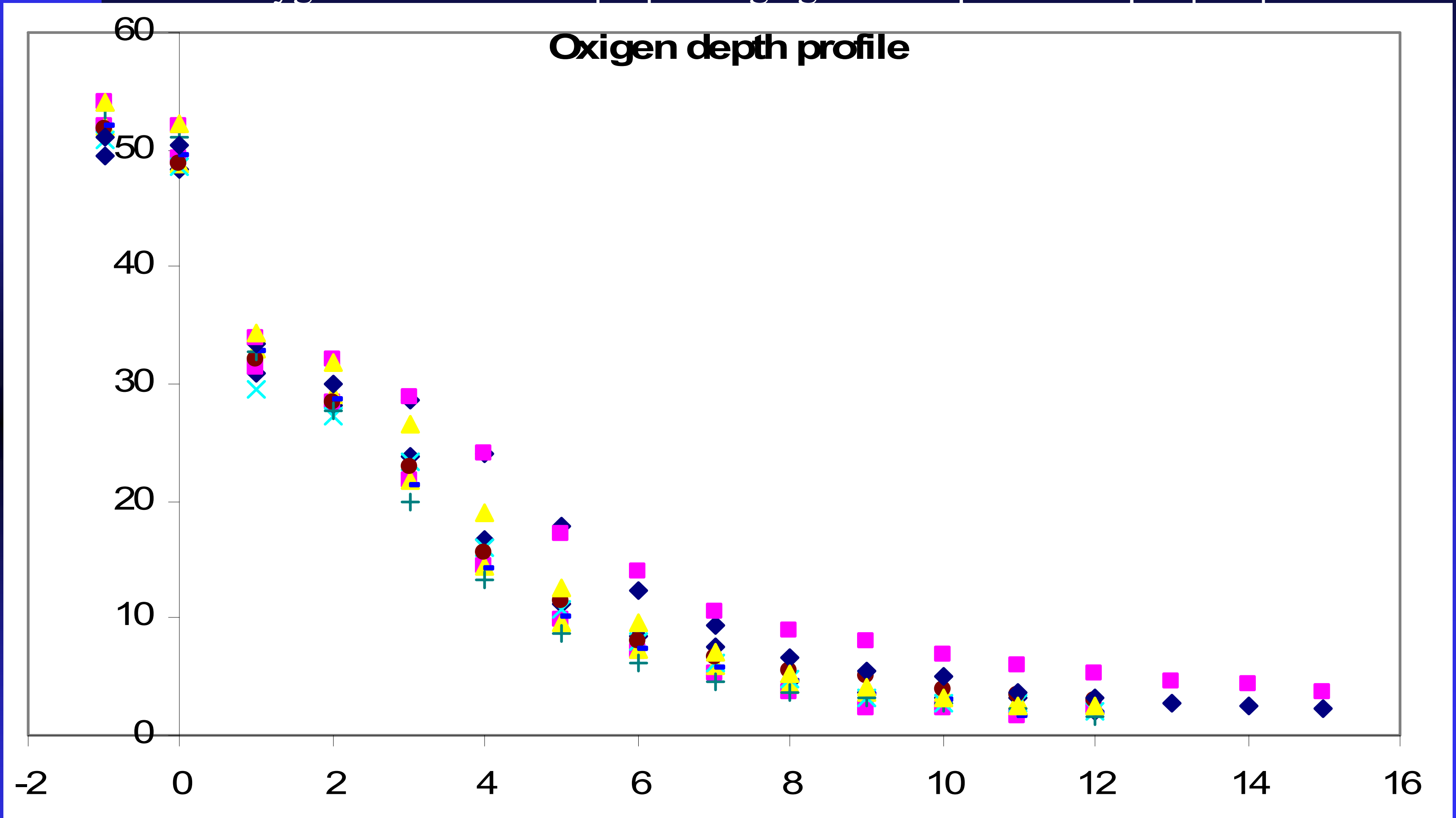


ARC03_4B
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Pickup coil voltage, mV
ΔT = 0.1K
9.0
9.1
9.2
9.3
9.4
9.5
Sample temperature, K

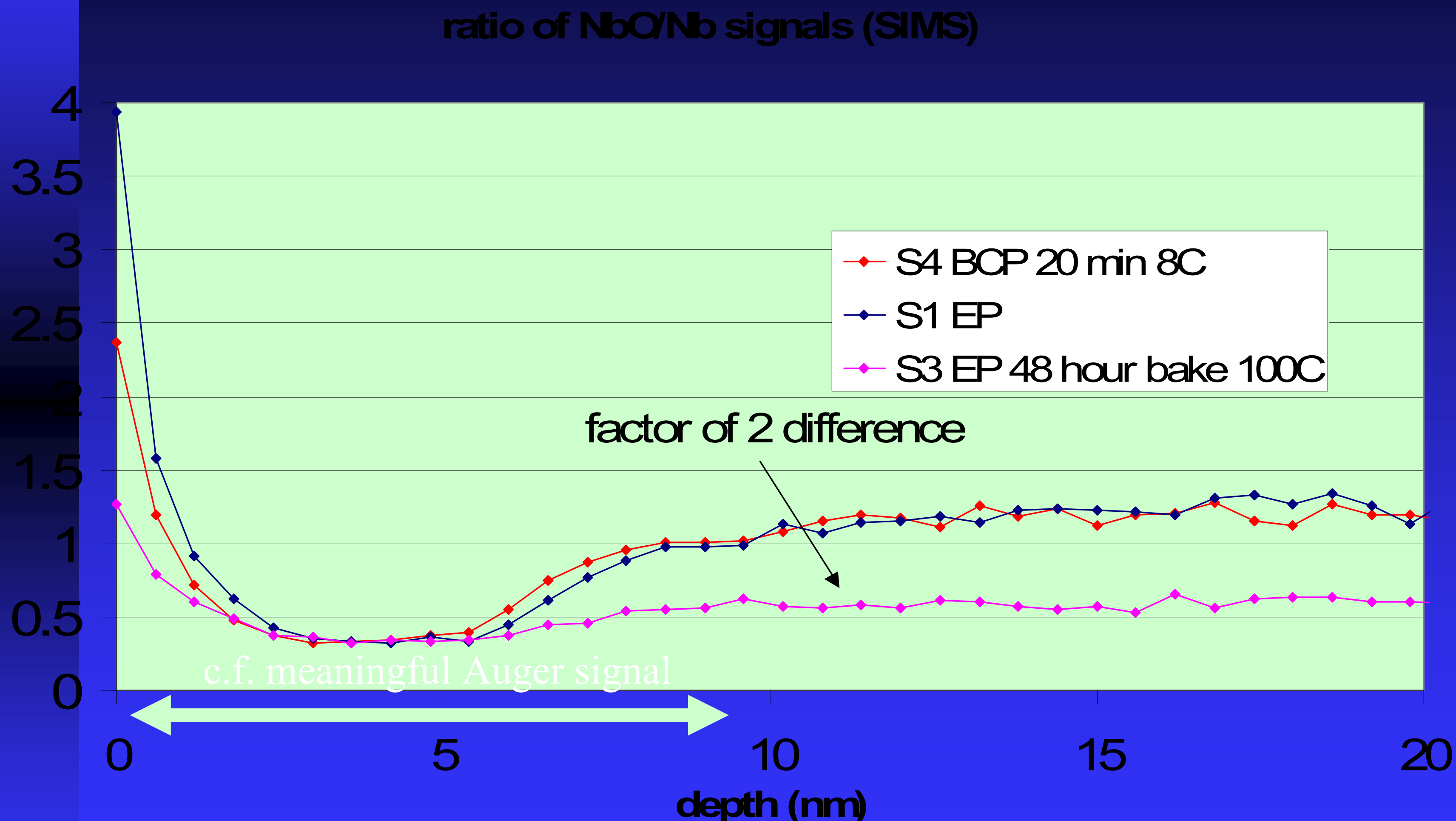

1E11
1E10
1E9
Q
10
20
30
40
50
60
Epk,MV/m
Test after fresh BCP
Test after 100°C baking
Test after 5V anodizing

Auger O-depth profile: no distinguishable difference for baked vs. unbaked Nb

Oxygen concentration [%] in large grain samples vs. depth [nm]



SIMS NbO-depth profile: clear difference between baked vs. unbaked Nb



Conclusion

- First 200MHz SC cavities have been constructed
- Test results for first cavity -> Eacc = 11 MV/m with Q_0 = 2E10 at low field
- MP barriers are present and can be processed through
- Cavity performance not affected by Hext < 1200 Oe
- Near term program focused on reducing Q-slope
- Next 200 MHz test will include measurements on Hext effect at higher Eacc
- Plan continued effort in developing sputter coated cavities after the end of the current NSF muon contract