Materials issues from recent cavity experience and in view of a 650 MHz option for Project X

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Overview

- Questions and drivers from ILC, XFEL, and other 1.3 GHz cavity R&D
- Project X option at 650 MHz
- Issues being debated for the baseline cavity process
  - Includes repair, alternatives

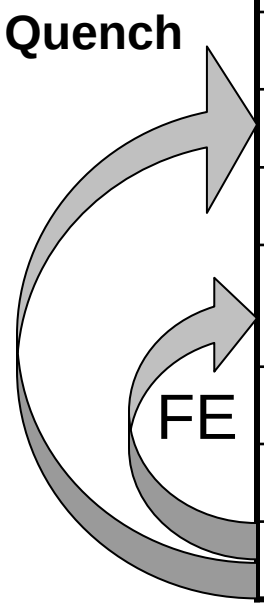
Acknowledgments

- S. Holmes, J. Kerby, M. Champion, R. Kephart, C. Ginsburg, A. Rowe, G. Wu
- JLab, Cornell, MSU programs
- Cavity vendors

SRF cavity fabrication sequence

	Step	Why?	Tool / facility
At niobium vendor	Melt Nb	Clean, high K_{Th} $E_{Acc} \propto RRR^{1/2}$	E-beam melt
	Forging	10 cm grains	Forge Proprietary
	Roll	Make sheets	Mill, Oven Proprietary
	Rx and level	Ductility, flatness	High-vac Oven, Proprietary
	Deliver		
At cavity vendor	Form ½ cells	Cavity shape	Die + press
	Iris weld (from inside)	Clean weld	Electron Beam Weld + tooling
	Dumbell weld (from outside)	Geometry difficult	EBW + tooling
	End pcs weld		EBW + tooling

Chemical processing sequence



Step	Why?	Tool / Facility
Degrease		Ultrasonic tank (US) + ultra-pure water (UPW)
Outer etch	Better heat xfer	BCP tool + Acid
Bulk EP	150 µm damage	EP tool + Acid
Wash	Chem. Residue	US + UPW
800 °C bake	Hydrogen	High-Vac Oven
Re-tune	Shape changes	Tuning machine
Fine EP	Smooth inner surface	EP tool + Acid
Wash	Chem. Residue	US + UPW + alcohol?
Rinse	Dust	High Pressure Rinse with UPW in class 10
Assemble		Vac, Class 10
120 °C bake	(It works)	Low-T oven
Vert. test		VTS

1.3 GHz at a glance

- Handful of 9-cell cavities now being processed to >40 MV/m at JLab! FNAL/ANL now getting into 30s...
- 1-cell cavities can be processed to >40 MV/m routinely!
- Dressed (i.e. with couplers, cryostats) cavities are entering into the processing stream.
- Multiple vendors in cavity stream
  - ACC or RI, AES, PAVac, NR Niowave-Roark, ZANon...
- Localized quenches still provide limitations.
  - Pits near equator welds (HAZ)
  - Stains, oxidation, and other processing breakdowns
- Field emission has not gone away
  - Processing breakdowns, often fixed by re-rinse and re-assembly

Recent changes in the 1.3 GHz process

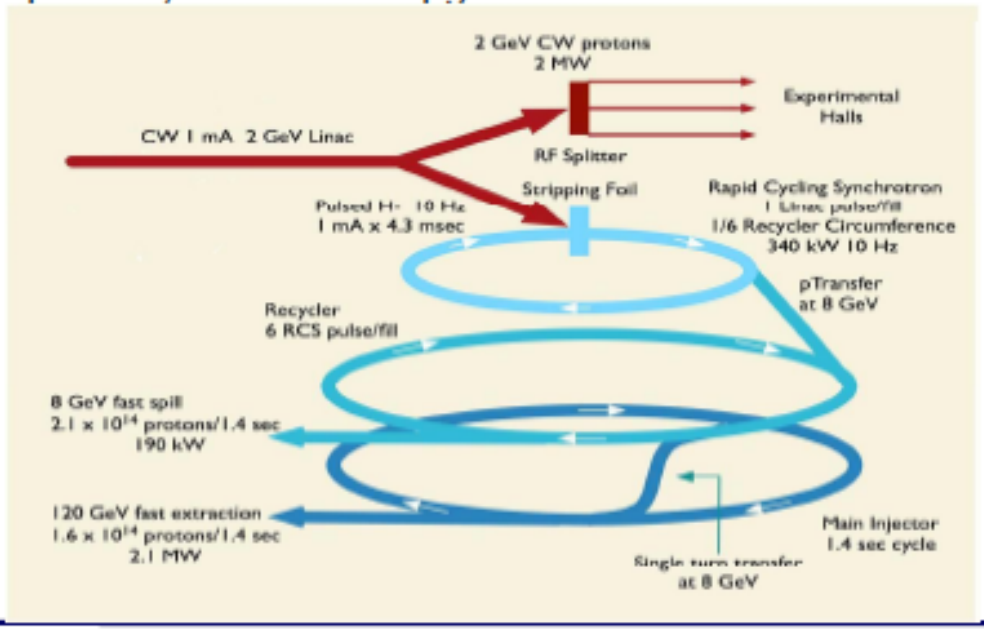
- Short (10 min?) BCP is given prior to the bulk EP
  - Thought to remove weld spit and vapor
- Hydrogen de-gas baking at 800 °C for 2 hrs instead of 600 or 650 °C for 10 hrs.
  - Gain: recrystallization or recovery? Better thermal conductivity
  - Loss: mechanical strength
- Final EP at lower temperature (~25 °C) than the bulk EP (~35 °C)
  - Gain: Smoother surfaces, better control of viscous layer
  - Loss: much lower material removal rate

Project X option at 650 MHz – S. Holmes

Project X

DOE Briefing
IC-2 Overview

- Project X Design Criteria
  - 2 MW of beam power over the range 60 – 120 GeV;
  - Simultaneous with 2 MW beam power at 2 GeV;
  - Compatibility with future upgrades to 2-4 MW at 8 GeV



Collaboration Council, January 13, 2010

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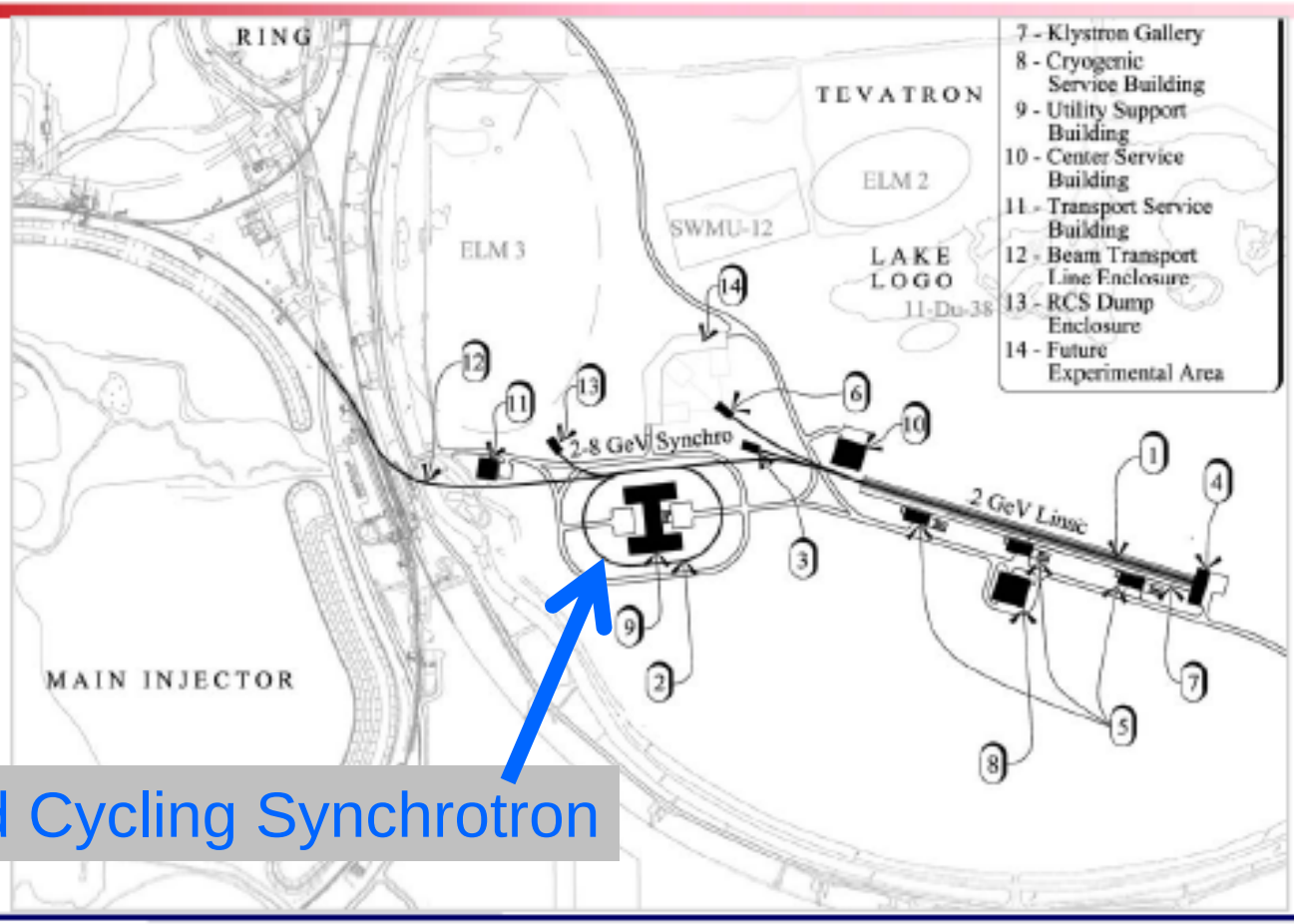
Project X

DOE Briefing

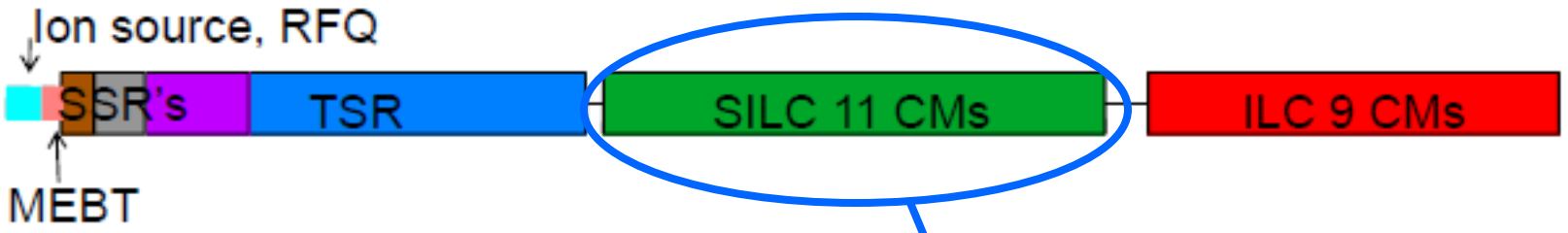
IC-2 Provisional Siting

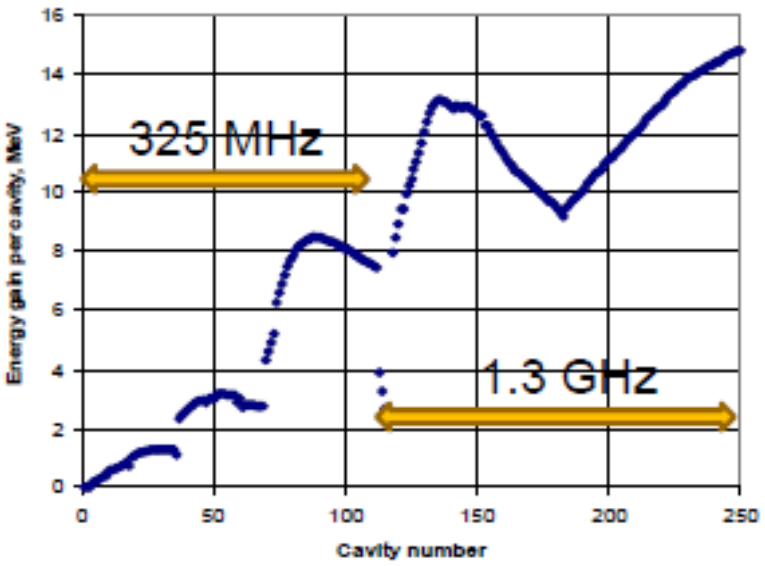


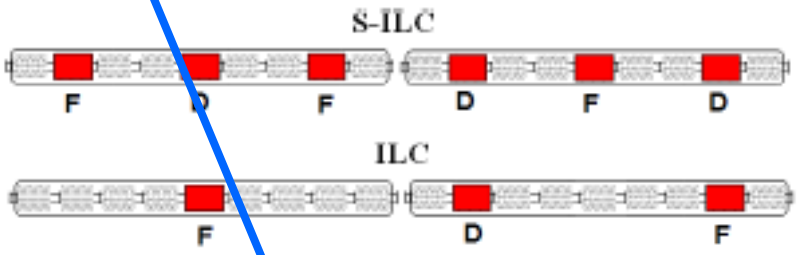
Rapid Cycling Synchrotron

Project X

Initial Configuration-2
Technology Map







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Project X

IC-2v2.0
"Option 4"

- Option 4 = 3 GeV CW linac with a 650 MHz intermediate system, based on 5-cell cavities.

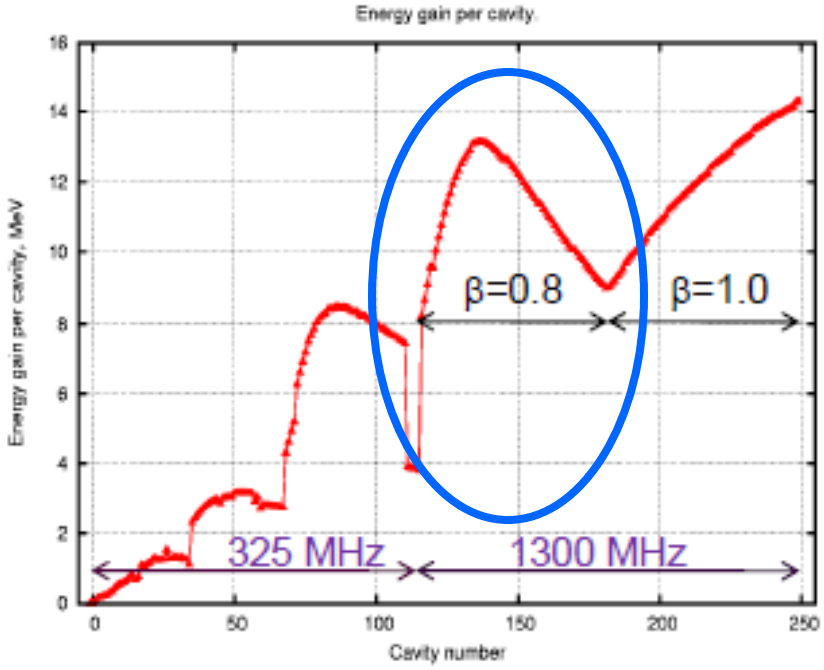
Note: 650 MHz, β=0.9, 5-cell cavities are same physical length as 1300 MHz, β=1.0, 9cell cavities

Project X

IC-2v2.0
"Option 4"

- What's problem are we trying to solve?

Energy gain/cavity in IC-2v1.0

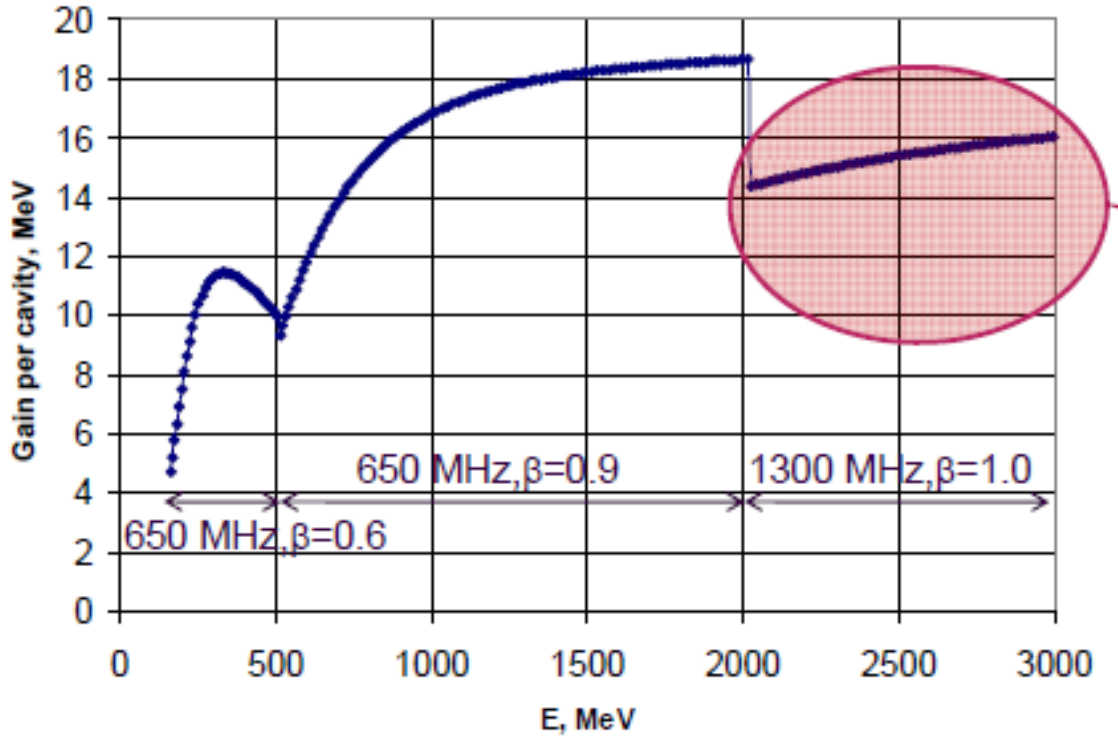


- 1300 MHz section is not an efficient accelerator
- Primary culprit is transit factor,
  - but also H_{max}=72 mT
- Maximal gain at zero synchronous phase is 17 MeV (β=1 section).

Project X

IC-2v2.0
"Option 4"

Energy gain/cavity in IC-2v2.0

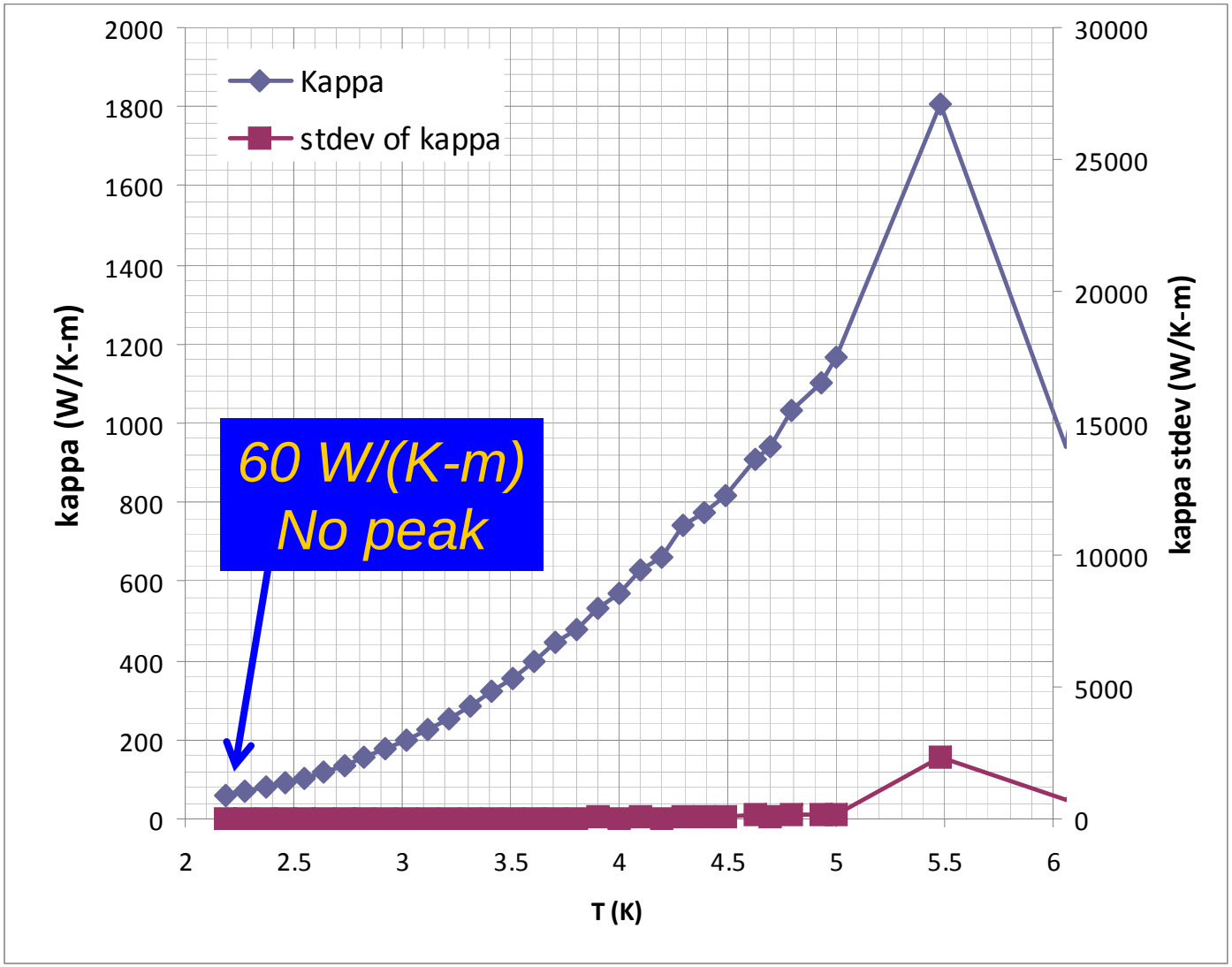


Discontinuity can be effectively eliminated with a β=0.95, low loss cavity design

Impact of 650 MHz PX on materials R&D

- Gradient for 650 MHz is not demanding, surface fields are not encroaching on Nb superconducting surface.
- But 3x more Nb mass, 2x more area, 2x more reaction heat during chemistry for 650 vs 1300 MHz
  - 4 mm thick for mechanical support
- Will BCP be good enough?
- How to predict performance? Dmitri's talk...
  - 3.9 GHz performance showed fantastic performance, as if Rs fell below the BCS prediction ?!??
    - **Anomalously high thermal conductivity? No phonon peak has been seen.**
  - 650 MHz performance not easy to predict based on present 1.3 GHz Rs data at different temperatures

Niobium used in 3.9 GHz cavity – RRR > 400
Data courtesy of Jun Liu, NHMFL - FSU



Processing issues

- Different facilities use different EP parameters & protocols
  - Flow, Temperature, masking, preparation, rinsing, ...
  - What should we change globally? (This workshop)
- Is EP necessary for 325 and 650 MHz?
  - Answer not clear, headroom helps engineering, but complex?
  - What about spoke resonators? EP prior to welding?
- What process monitors are needed?
  - In-line Raman? IR detection?
- What is the future of alternate processing?
  - Tumbling works for bulk removal (Cooper talk), what about final polish? Will it become main-line bulk removal?
- Baking – what happens at 800 C vs 600 C?
- Everybody uses 120 C final bake – anything to learn?

QA and QC issues

- Inspection – everybody can do it now!
  - LEDs are must-have upgrade, excellent clarity
  - Can we get topography directly from images?
- Repair / remediation
  - Laser melting doesn't kill a cavity (Mingqi Ge talk)
  - Can we raise 20 MV/m to 35 MV/m by repair?
- Thermal mapping still is essential
  - 2nd sound works, could be good processing diagnostic
  - Carbon resistors necessary for detection of pre-heating
  - Cavity mapping systems not making rapid impact

Niobium specification

- Delivered sheet batches seem to be different every time
- Several sheet batches produce cavities that meet or exceed 35 MV/m
- Use ASTM B393-05? FNAL is tighter, but always forces vendors to take exception
  - Flatness – needed for ECS. Use x-ray instead?
  - Grain size – is ASTM 5 or 4 good enough?

- Is the niobium product over-specified?
  - Where do we back off, and why? (this workshop)

Conclusion:

Have a great workshop!

Your discussions matter!
Your recommendations will have broad impact!