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Cavity Test Results for PIP-II

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TTC Meeting, Saclay

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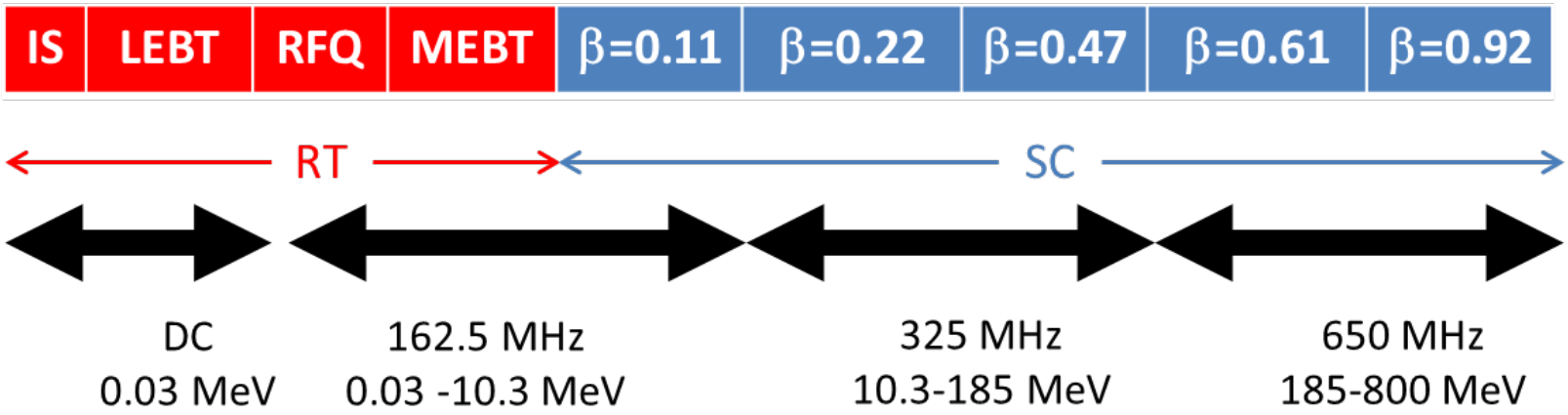
Outline

- PIP-II Technology Map
- Latest SRF Cavity Test Results
  - 162.5 MHz Half-wave Resonators (HWR)
  - 325 MHz Single Spoke Resonators (SSR1)
  - 650 MHz High Beta R&D
- Indian Institutes Fermilab Collaboration (IIFC)
  - SSR1
  - 650 MHz High Beta and Low Beta

PIP-II Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-10.3	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	10.3-35	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.47)	325	35-185	35/21/7	SSR, solenoid
LB 650 (β_g=0.61)	650	185-500	33/22/11	5-cell elliptical, doublet*
HB 650 (β_g=0.92)	650	500-800	24/8/4	5-cell elliptical, doublet*

*Warm doublets external to cryomodules

All components CW-capable

162.5 MHz Half-Wave Resonators*

- 8 HWR cavities
- 8 SC solenoids
- 1 CM

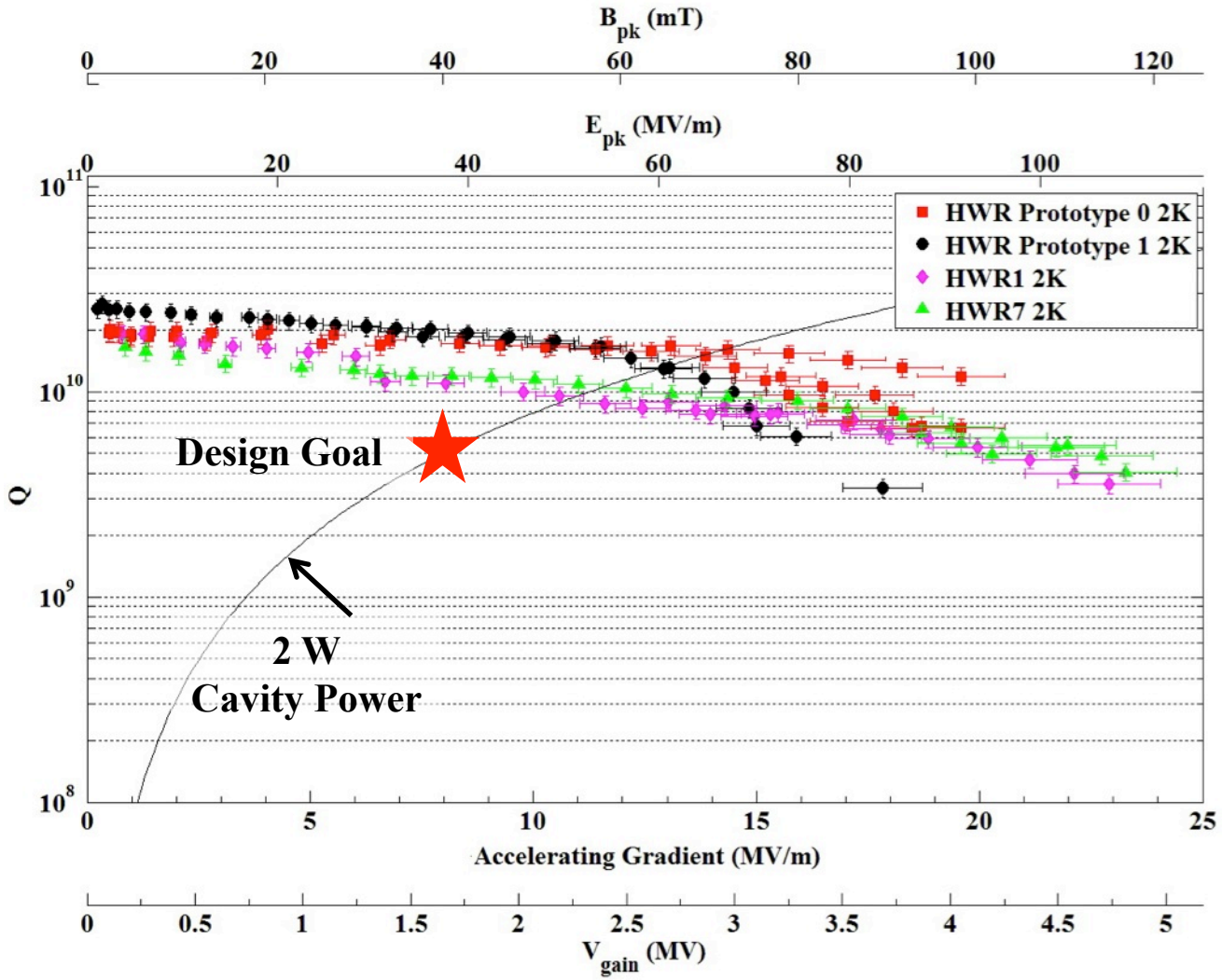
Cavity Type	HWR
Freq. (MHz)	162.5
β	0.112
l_{eff} (cm, $\beta\lambda$)	20.68
E_{pk}/E_{acc}	4.7
B_{pk}/E_{acc} (mT/(MV/m))	5.0
QR_s (Ω)	48.1
R_{sh}/Q (Ω)	272

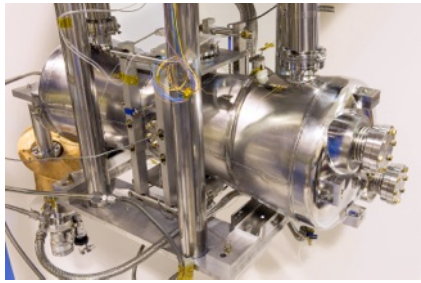
Bulk and light EP of jacketed HWR @ ANL

Bare HWR before jacketing

*HWR technology developed at ANL via ANL/FNAL PIP-II Collaboration.
Z. Conway, A. Barcikowski, S. Gerbik, C. Hopper, M.P. Kelly, M. Kedzie, S. Kim, P. Ostroumov, T. Reid.

Half-Wave Resonator Results*





2 Proto + 2 Production
Tested at 2K

HWR7 – June 10 2016:
Quench = 23 MV/m
dF/dP = 9.4 Hz/mbar
LFD = -1.25 Hz/(MV/m)^2

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Z. Conway, A. Barcikowski, S. Gerbik, C. Hopper, M.P. Kelly, M. Kedzie, S. Kim, P. Ostroumov, T. Reid.

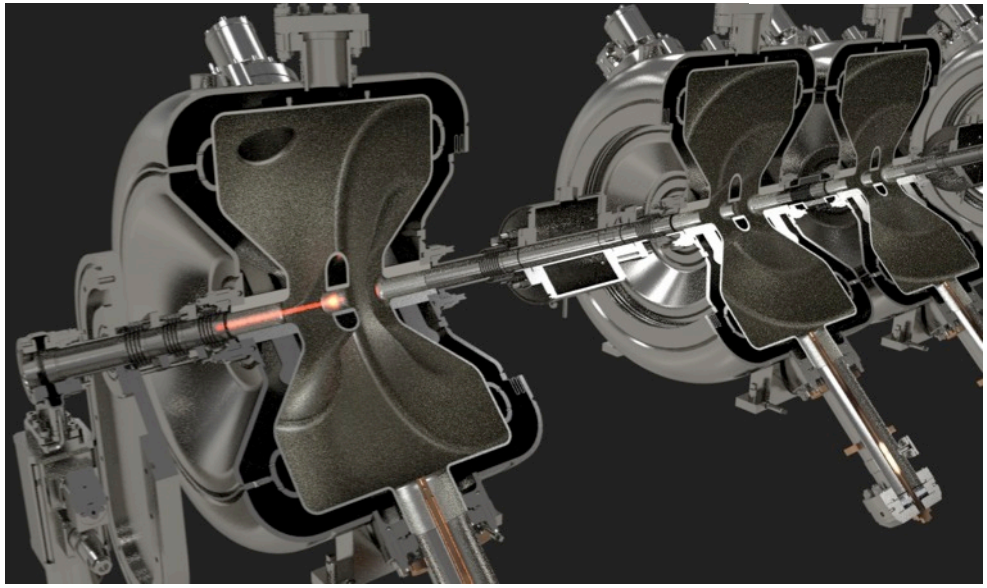
325 MHz SSR1 Resonators

- 2 Cryomodules
- 8 SSR1 Cavities/CM
- 4 SC Solenoids/CM
- 1st CM in construction

Table 1: Cavity operational and test requirements

Parameter	Value
RF resonant frequency	325 MHz
Bandwidth	±20 Hz
Operating accelerating gradient (E_{acc})	12 MV/m
Quality factor (Q_0) at E_{acc}	$> 5 \cdot 10^9$
Operating gain per cavity	2 MeV
Maximum power dissipation at 2 K	5 W
Sensitivity to He pressure fluctuations	< 25 Hz/Torr
Field flatness	±10%
Operating temperature	1.8 ÷ 2.1 K
Operating pressure	16 ÷ 41 mbar (differential)
Maximum allowable working pressure	2 bar at 293 K, 4 bar at 2 K
RF power input per cavity	6 kW (CW, operating)
Max Leak Rate (room temp)	$< 10^{-10}$ atm · cc/s

FNAL—Ristori, Orlov, Passarelli, et al.



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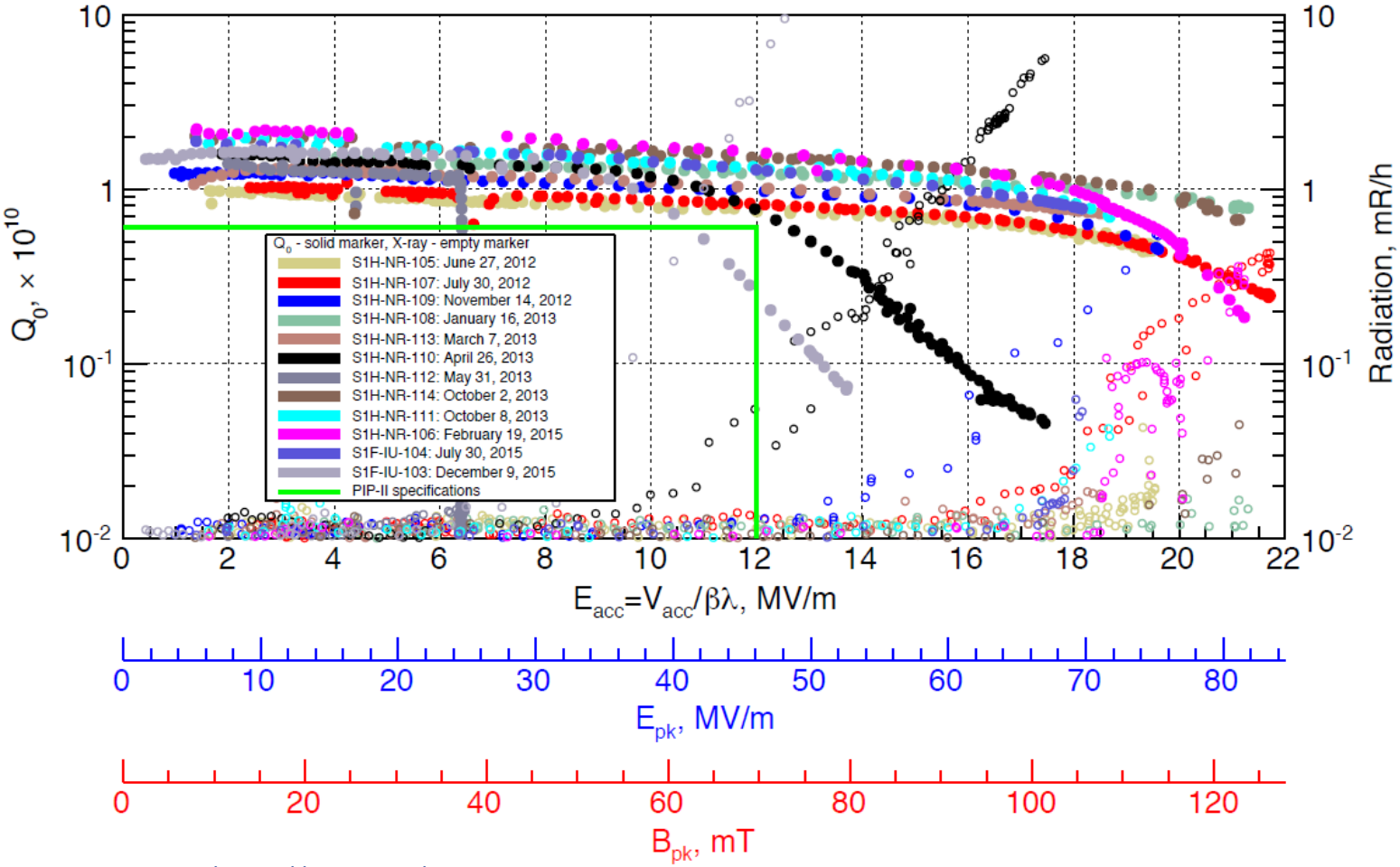
325 MHz SSR1 Results

- 10 qualified bare cavities through VTS + 1 through STC
- 2 IIFC (IUAC) collaboration cavity tested in VTS (1 qualified)



FNAL—Ristori, Sergatskov, Sukhanov, et al.

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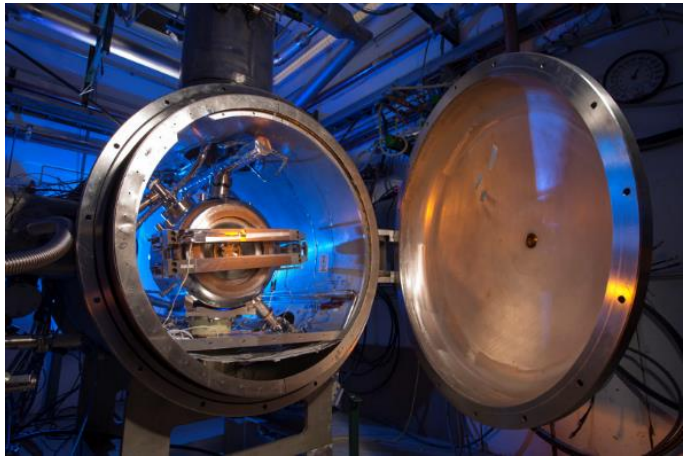
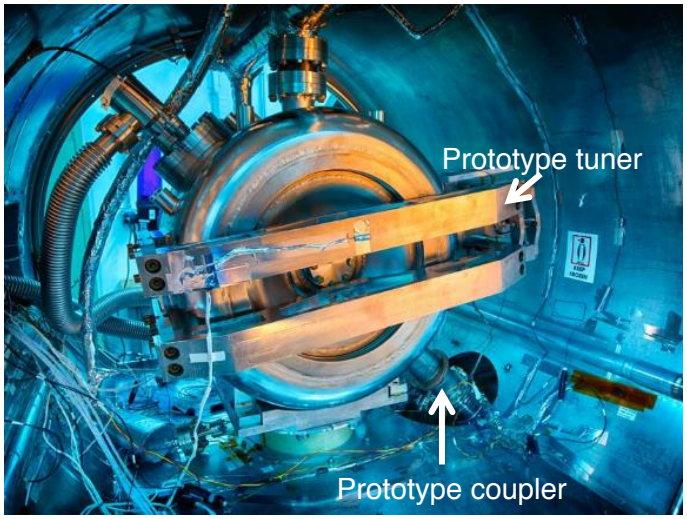
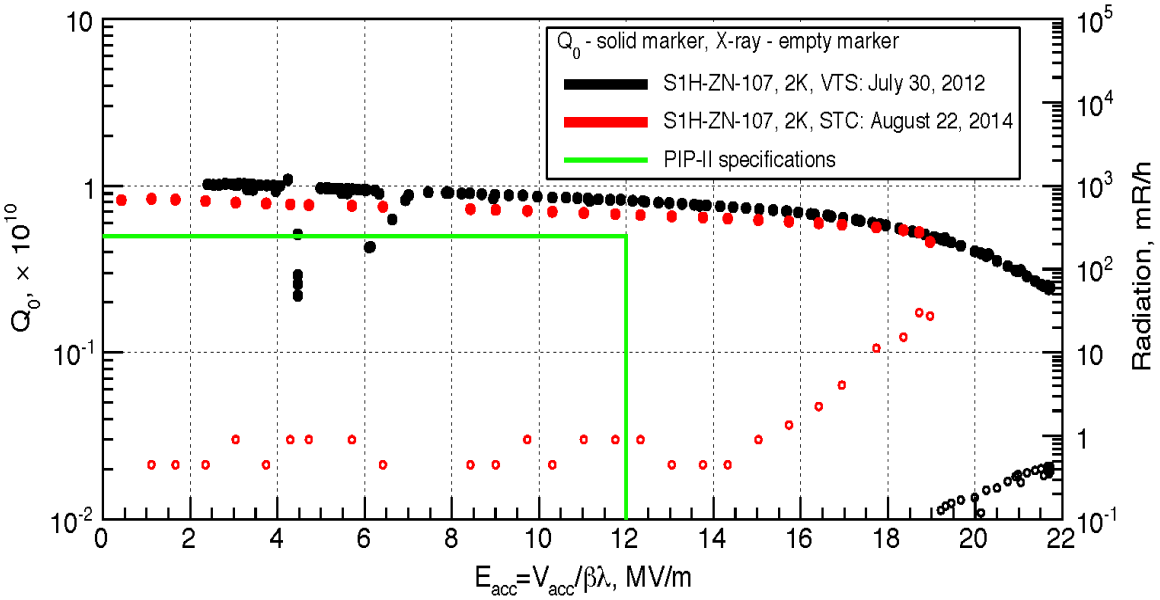
S107 “Ice Breaker” Fully-Integrated Tests in STC





- First jacketed cavity was tested in the STC cryostat
- Prototype coupler and prototype tuner installed
- Performance of cavity, coupler and tuner were confirmed with a total of 4 tests
- No degradation found VTS→STC (see below)



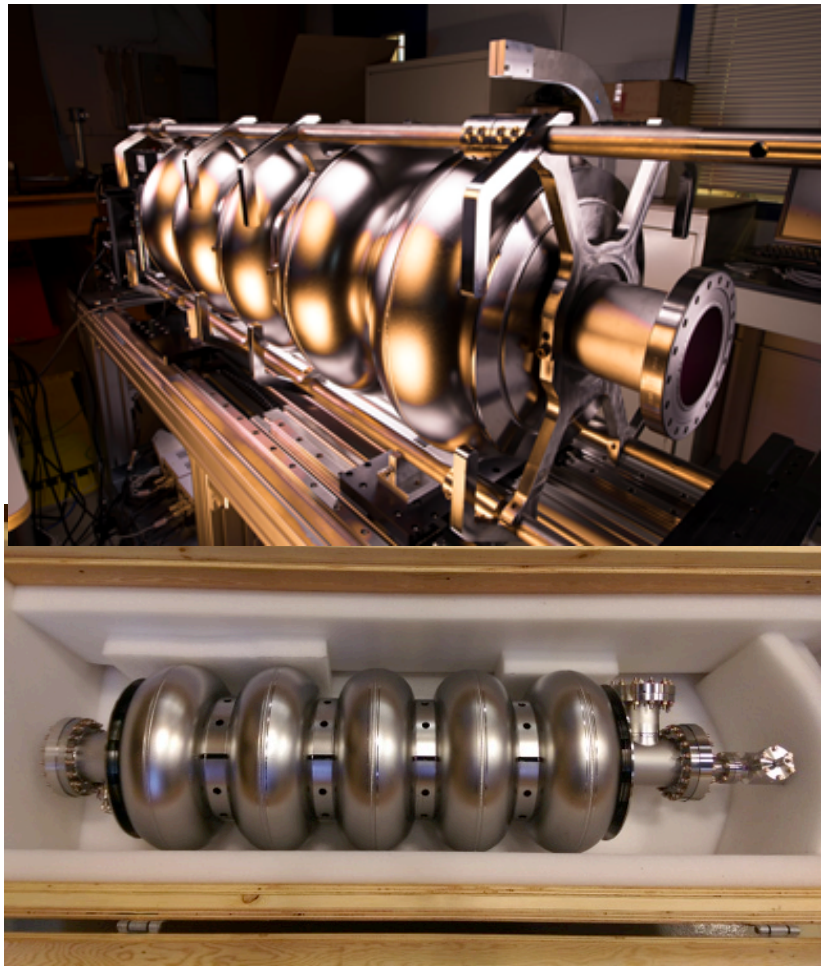
No Q0 degradation found in comparison of performance of cavity S107 in VTS (black) and STC (red). Mild FE present in STC consistently through each test.

Original Result of Cold Tests of the Fermilab SSR1 Cavities, A. Sukhanov et al., Proceedings of LINAC2014, Geneva, Switzerland

Status of High Q_0 R&D:

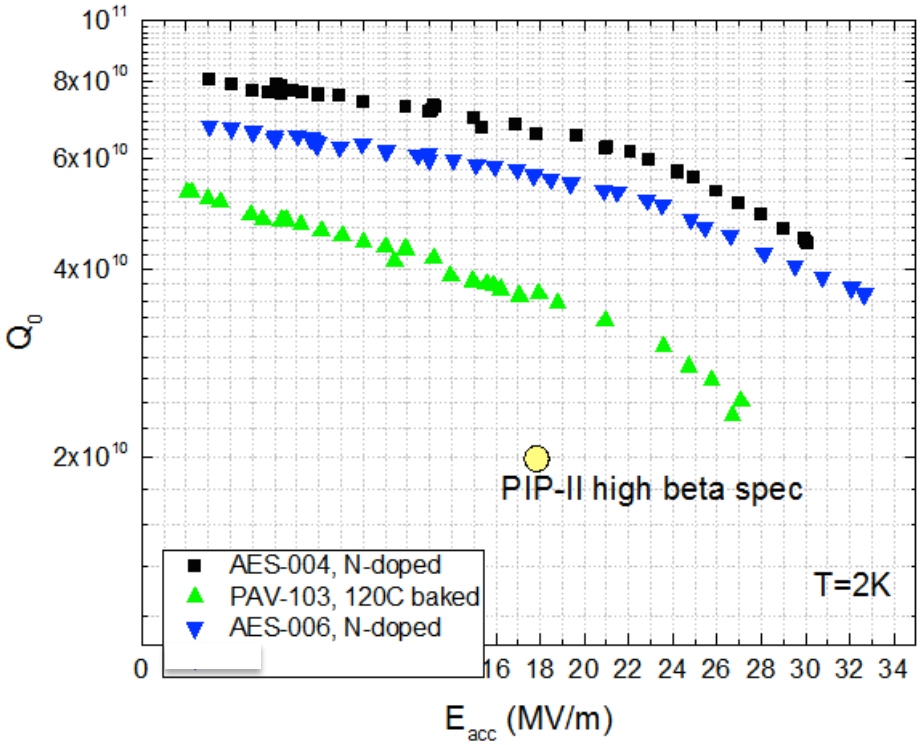
- N-doping evolved from discovery to proven technology
- It is a basic technology for LCLS II, operating at 1.3 GHz
- PIP-II operation in CW dominated by dynamic heat loads in 650MHz section.
  - Foreseen cryoplant size determines requirement of $Q_0 > 4e10$
  - R&D on High-Q is of fundamental importance now for PIP-II
- Same sequence of investigations under way for PIP-II low-beta ellipticals
  - Single cell cavity (DONE!)
  - Five cell cavity (In Process)
  - Dressed five cell cavity (Later)

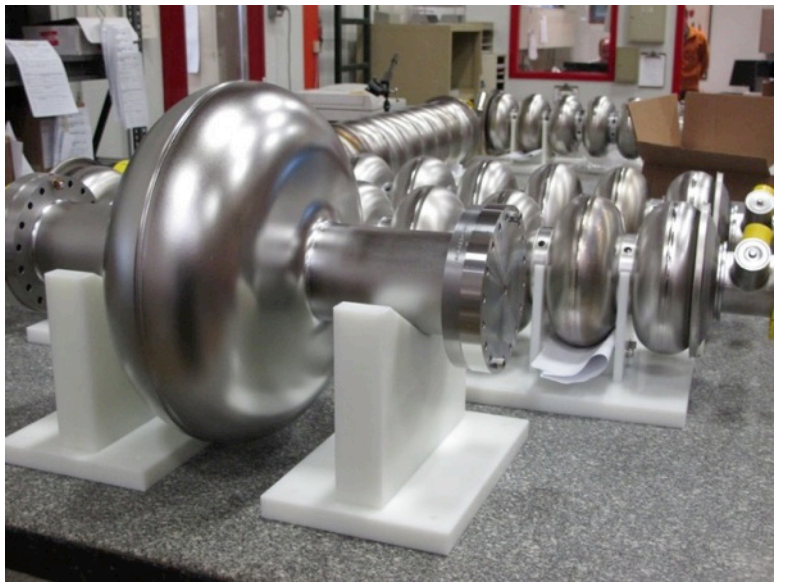
Technology does not exist for 650 MHz yet



650 MHz High Beta Single-Cell Q_0 R&D

- Results – highlights – 120C bake versus N doping
  Q_0~ 7e10 at 2K, 17 MV/m – world record at this frequency!
- Applying N doping to 650 MHz (beta=0.9) leads to double Q compared to 120C bake (standard surface treatment ILC/XFEL)





FNAL—Grassellino, Melnychuk, Merio, Rowe, Sergatskov, et al.

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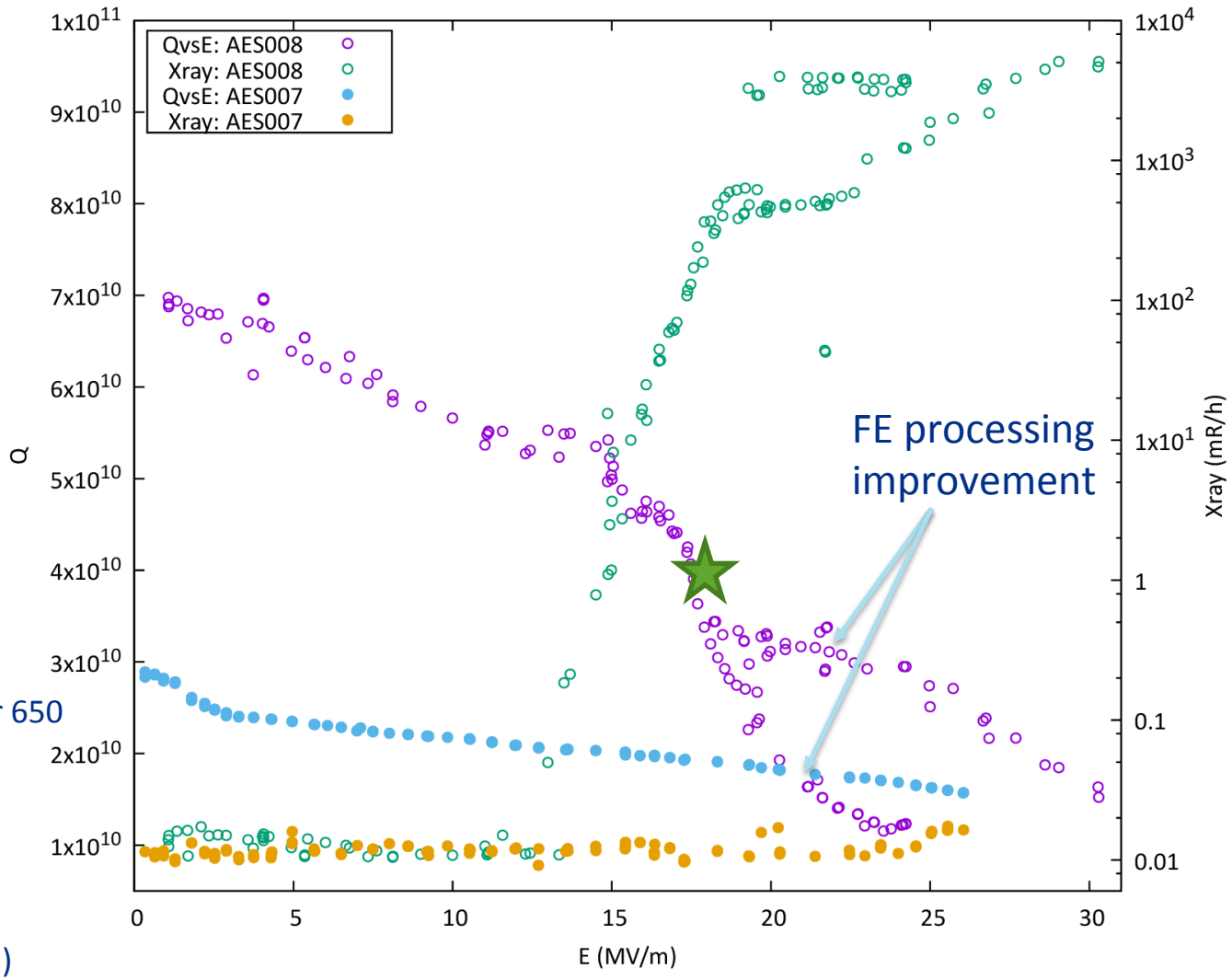
650 MHz High Beta Multi-cell Results

Processing Regime
- 120 um EP
- 800C Degas + 2/6 N2
- RF tuning
- 20 um EP (AES008)
- 5 um EP (AES007)

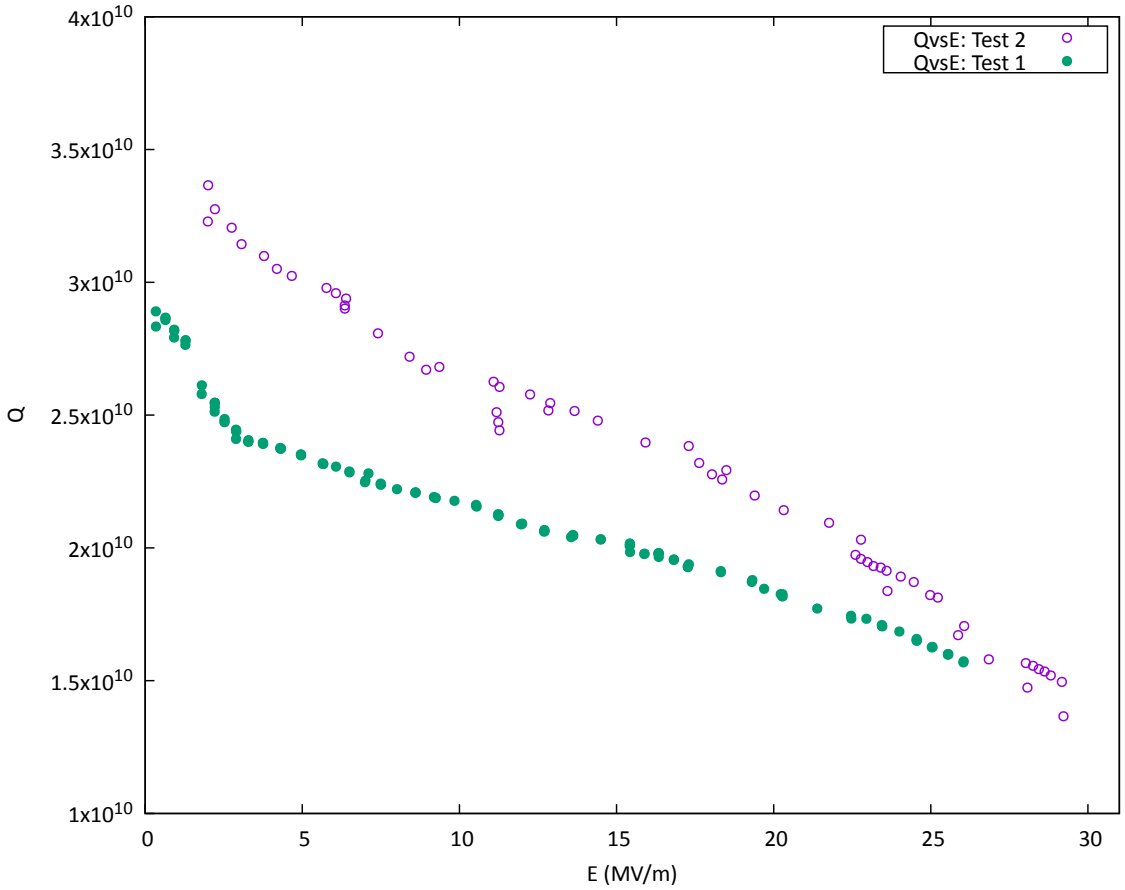
AES008
- **Excellent gradient**
- **Record Q~5e10 mid field**
- Multi-pacting & High FE
- No Quench (power limit)
- Aggressive re-cleaning
- Re-rinsed
- 2nd Test FE persisted

AES007
- Q0 good but below std for 650
- Suspect Q-disease
- Quench @ 27 MV/m
- **VERY GOOD! No FE**
- Minimal multipacting
- Suspected Over-doping
- Tried more EP (next slide..)



FNAL—Sergatskov, Grassellino, Melnychuk, Merio, Rowe, et al.

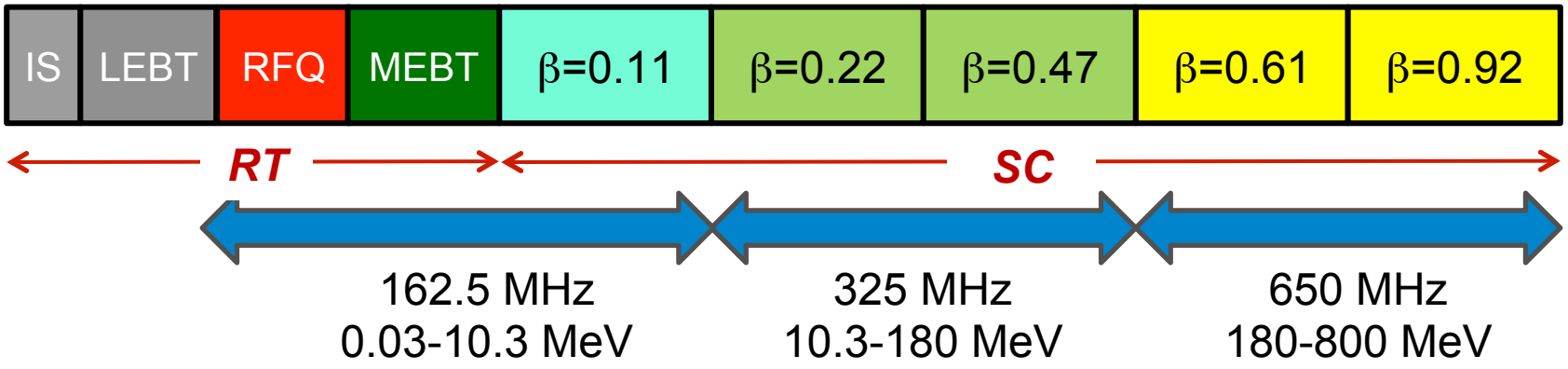
AES007 before/after add. 5 micron EP



- Additional 5 microns EP performed, improved a bit Q_0 (2→2.5e10) and Gradient (27→29 MV/m)
- Q-disease still suspect for lower than average Q_0 (expecting 2x)
- No clear reason for Q-disease from light EP data, 100K soak and test this week to confirm
- Field Emission GOOD with onset > 25 MV/m

FNAL—Sergatskov, Grassellino, Melnychuk, Merio, Rowe, et al.

Indian Institutes Fermilab Collaboration Org.



Dressed SRF Cavities

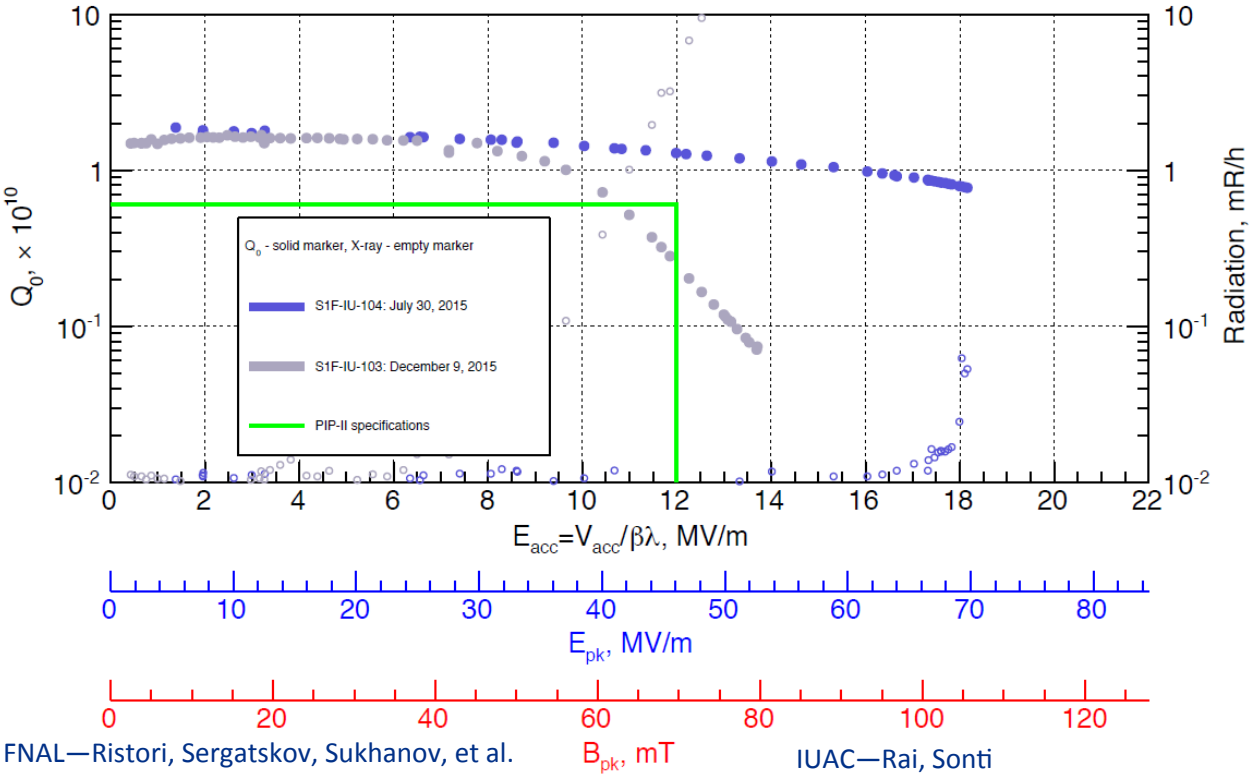
- β = 0.22: IUAC & VECC
- β = 0.47: BARC & IUAC
- β = 0.61: VECC/(Europe?)
- β = 0.92: RRCAT
- 325 MHz RF Power: BARC
- 650 MHz RF Power: RRCAT

Non SRF components (BARC)

- Cryogenic Plant and Distribution
- RF
  - LLRF
  - Protection System
- Instrumentation: BPM, BLM
- Controls
- MEBT Magnets

Indian Institutes Fermilab Collaboration (IIFC)

- IUAC delivered two SSR1 cavities
- Chemically processed at ANL and cold-tested at Fermilab
  - IUAC fabricated cavity meets the PIP-II specifications
- Cavities will be dressed at IUAC/BARC, then prepared and tested at FNAL/STC



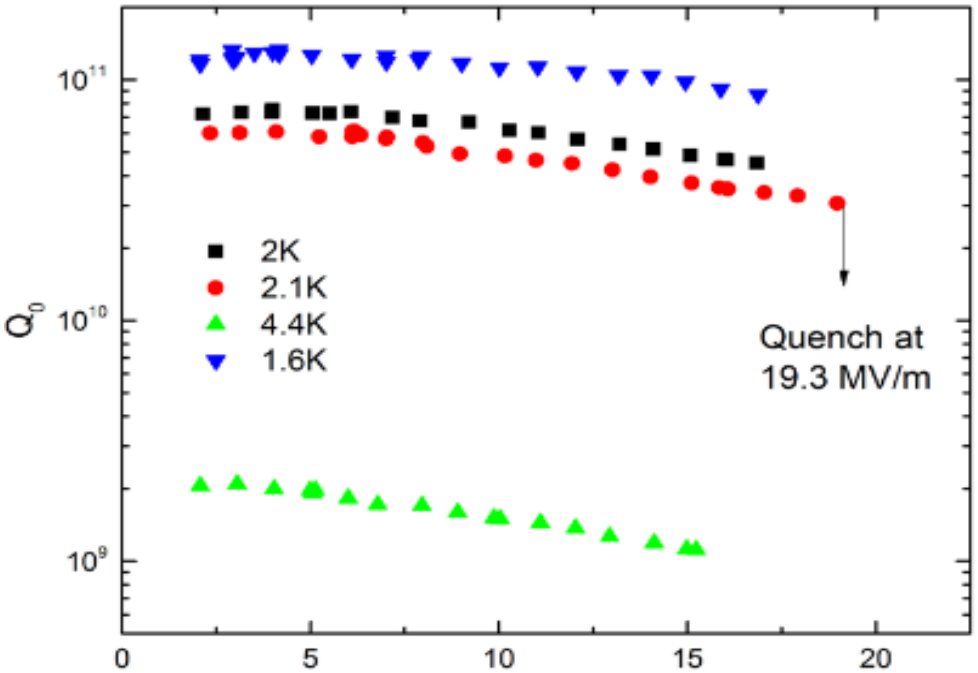
FNAL—Ristori, Sergatskov, Sukhanov, et al.

IUAC—Rai, Sonti

Indian Institutes Fermilab Collaboration (IIFC)

- RRCAT/IUAC Fabricated one Nb HB650 650 MHz single-cell cavity (July 2013).
  - Processed & tested at FNAL/ANL
  - The cavity achieved E_{acc} 19.3 MV/m with Q > 4E10 at 2K.
  - VECC B6AS-VECC-001 processing now at FNAL/ANL, expected test June 2016

B9AS-RRCAT-301 @ VTS



FNAL—Grassellino, Menlnychuk, Sergatskov, et al.

RRCAT—Khare, Puntambekar, et al.

B9AS-RRCAT-301 VTS results

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Acknowledgements

- ANL HWR CM Development - Zack Conway, Lead
- FNAL SSR1 CM Development – Leonardo Ristori, Lead
- FNAL/IIFC HB 650 MHz CM Development
  - Tom Nicol, FNAL Lead
  - Prashant Khare, IIFC (RRCAT) Lead
- FNAL/IIFC LB 650 MHz CM Development
  - Tom Nicol, FNAL Lead
  - Sumit Som, IIFC (VECC) Lead
- FNAL Cavity Performance – Grassellino, Lead
- ANL Cavity Chemistry – Reid, Lead