

# Lessons Learned From Nitrogen Doping at JLab

Exploration of Surface Resistance with Varied Interstitial Atom Diffusion on Niobium Cavity Surfaces

Ari D. Palczewski, SRF Scientist  
Jefferson Lab, USA

9/14/2015

MOBA07



# What to remember/what I learned

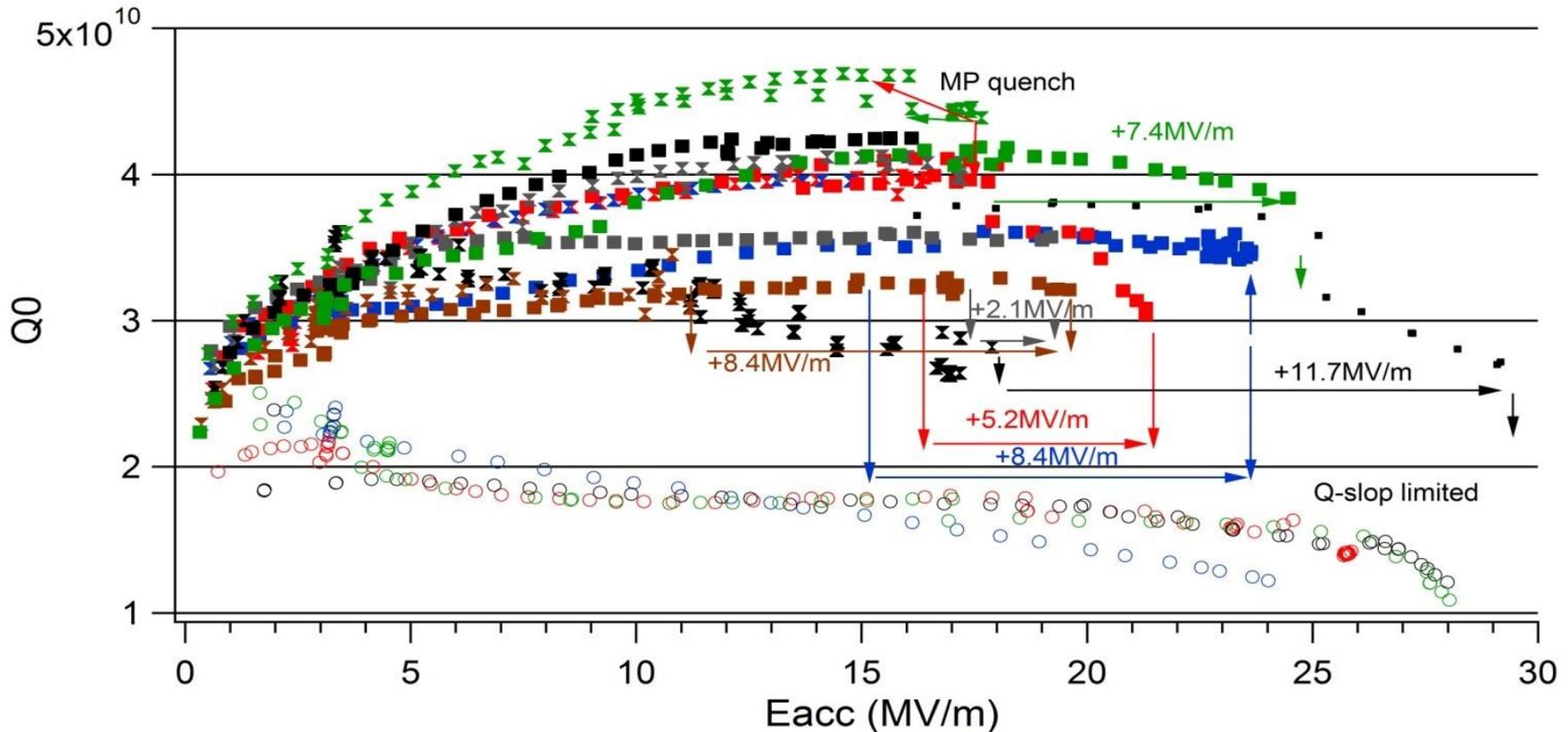
- 1) It now seem clear, Nitrogen doping i.e. getting nitrogen into cavity at 800C is the easy part.
- 2) Controlling the test environments: magnetic field, cooling rate, and test hardware is the hard part. *Environmental monitoring instrumentation is your friend.*



- 3) Q vs Eacc is not enough, Q vs Eacc vs T in a controlled environment with “surface resistance decomposition” is a must (all data that follows is 1.3GHz @ 2.0K unless noted).
- 4) What is the nitrogen doing? Where is it going?

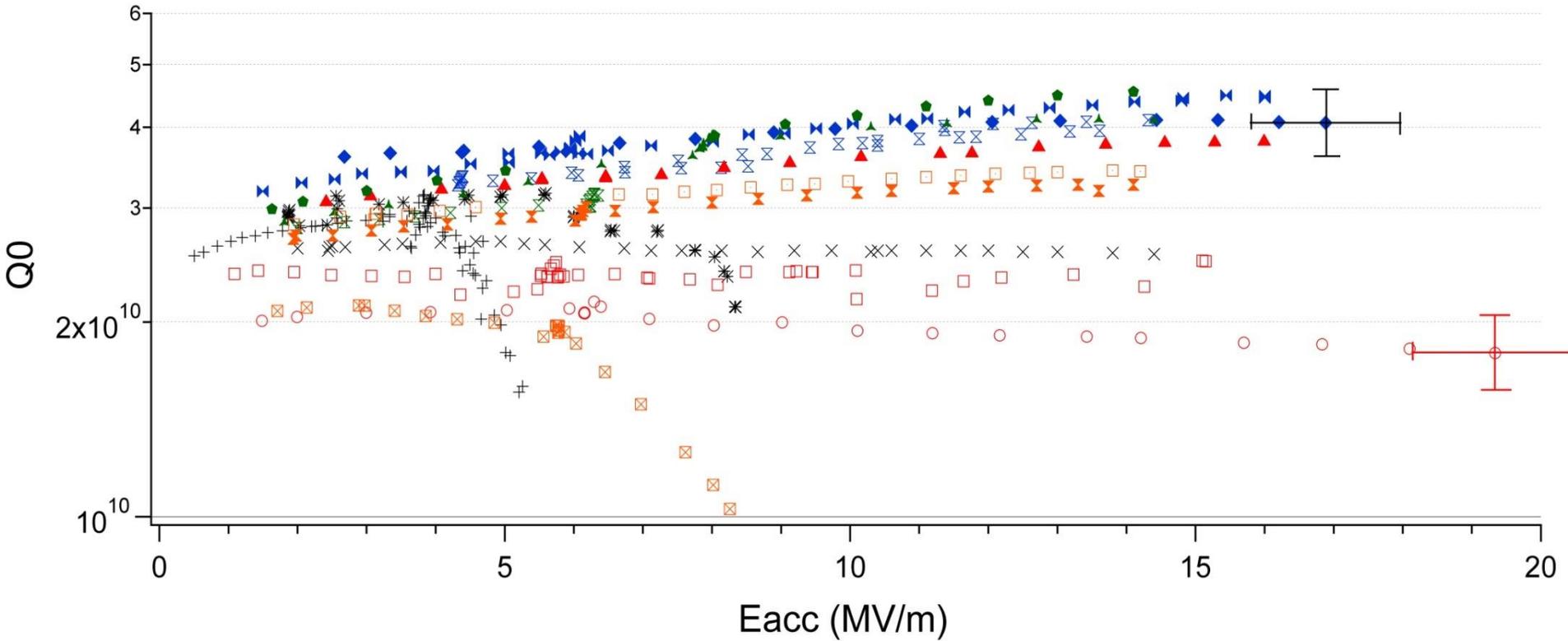
# Cavity tests to date – 2.0K

## LCLS-II 9 cell RF data @ 2.0K



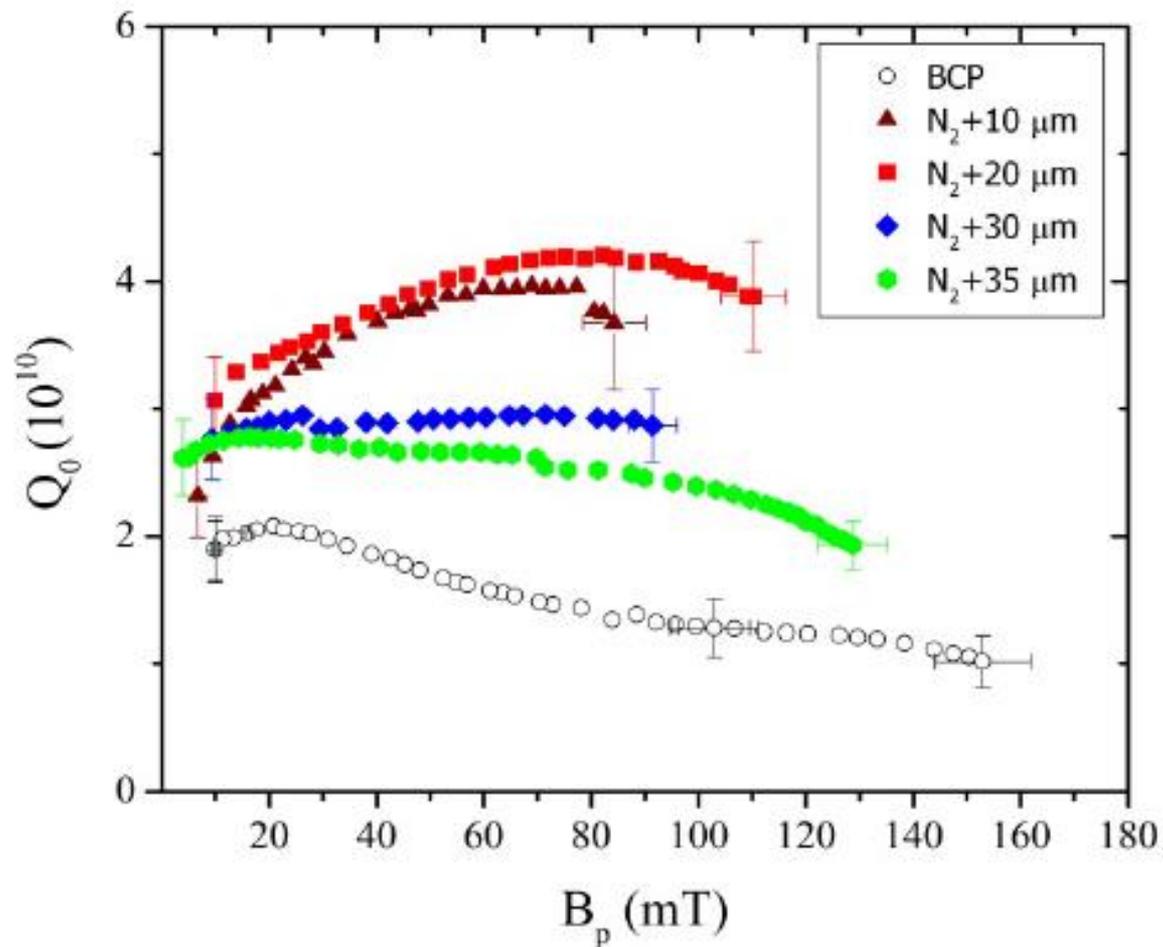
9 cell mini production and re-doping second run

# Cavity tests to date – 2.0K



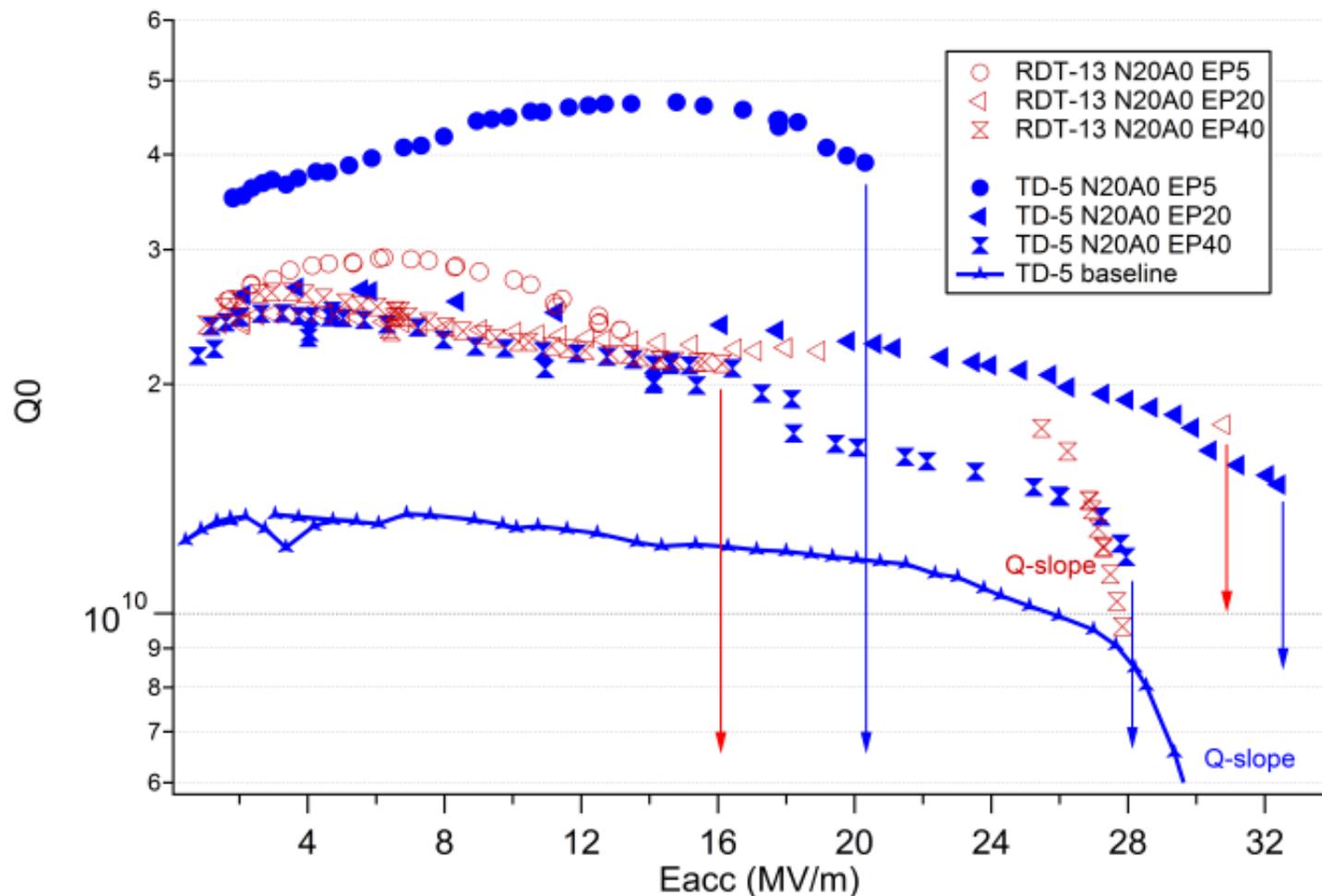
Single cell systematic doping

# Cavity tests to date – 2.0K



Single cell large grain incremental EP –  
Dhakal et al, IPAC 2015 WEPWI009

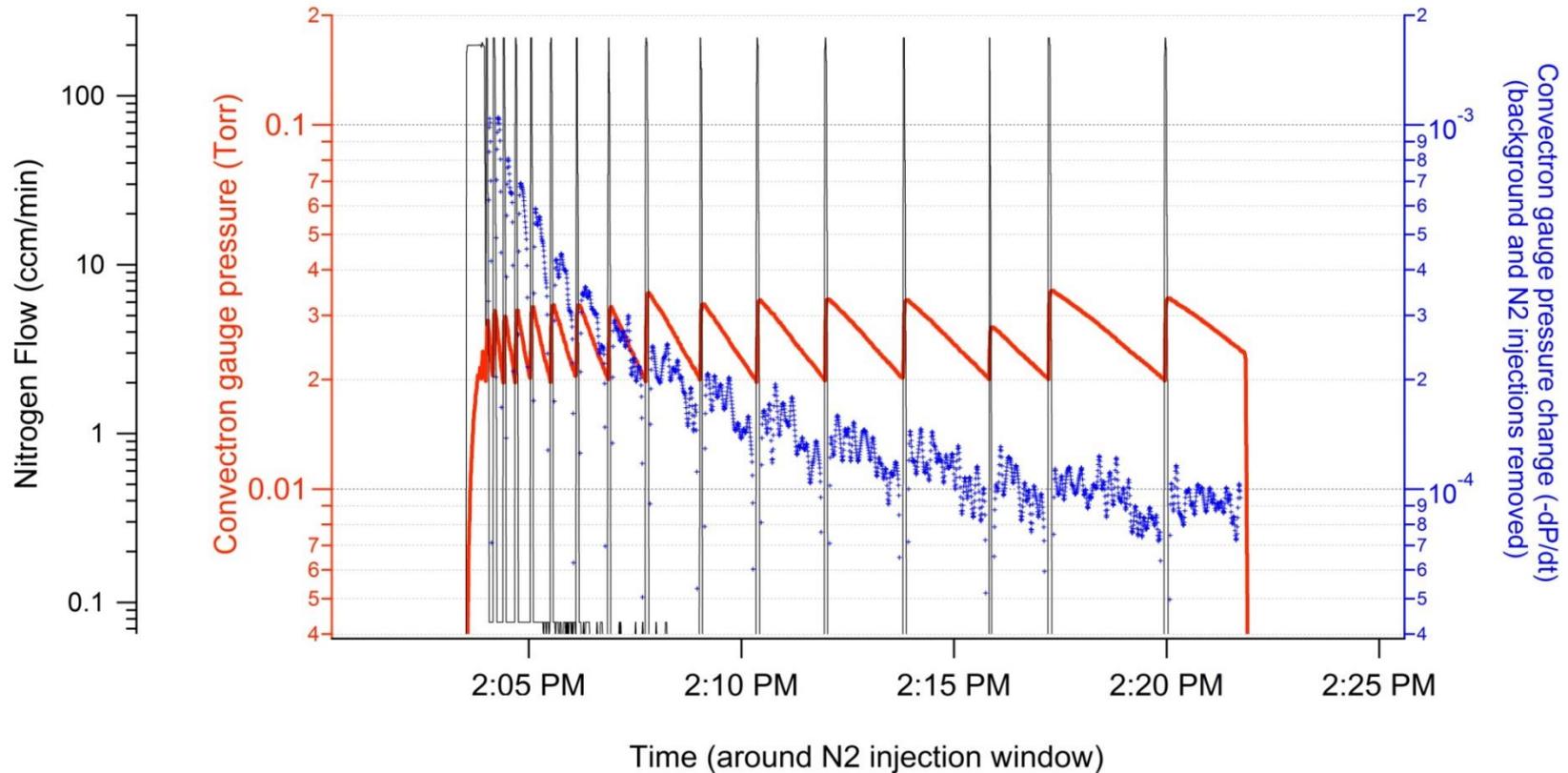
# Cavity tests to date – 2.0K



Large grain vs fine grain – systematic removal

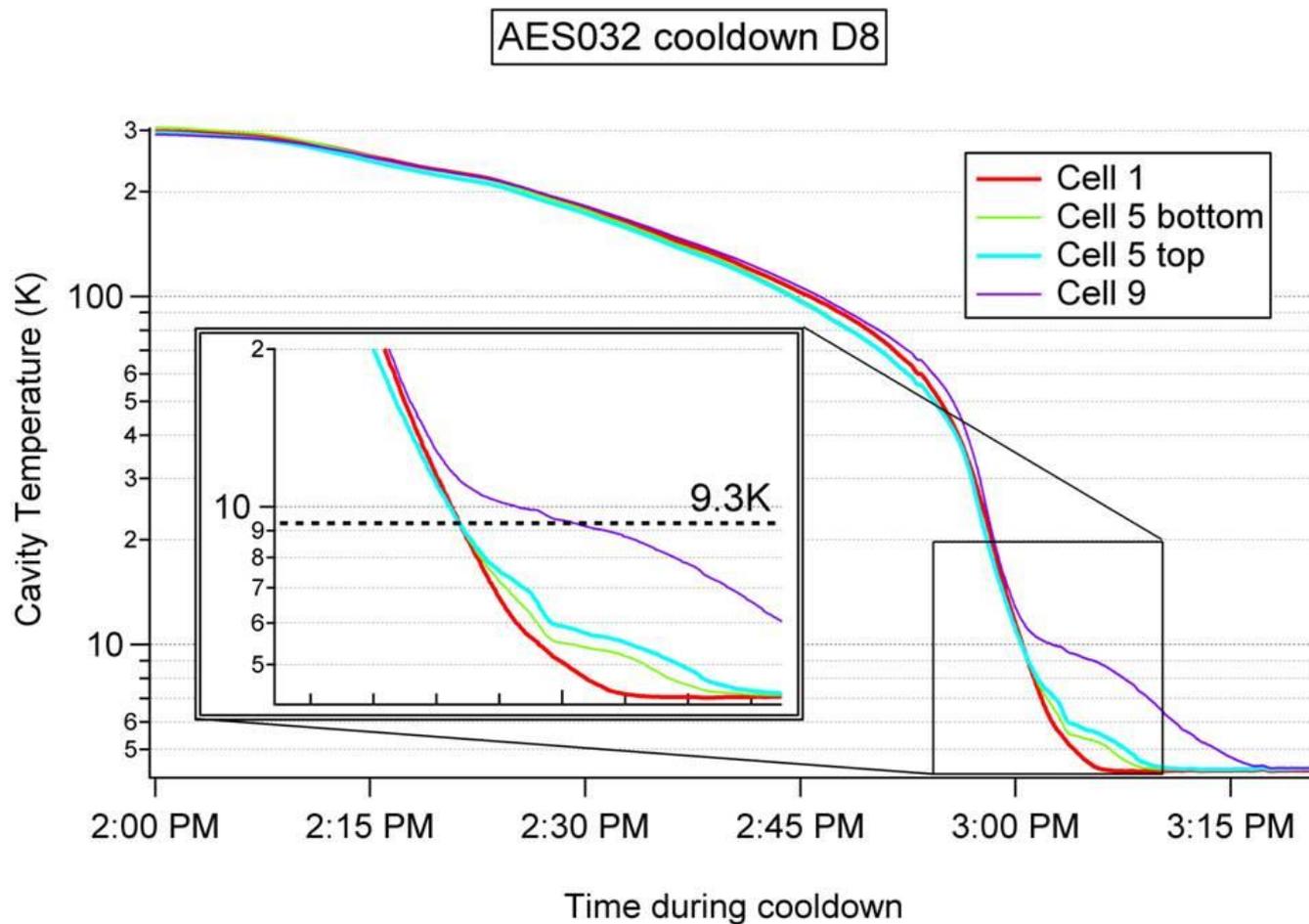
# Furnace doping - absorption rate

AES031 Nitrogen doping  
@800C with 20mTorr set point  
total pressure drop ~ 150 standard Torr-Liters @ 25C



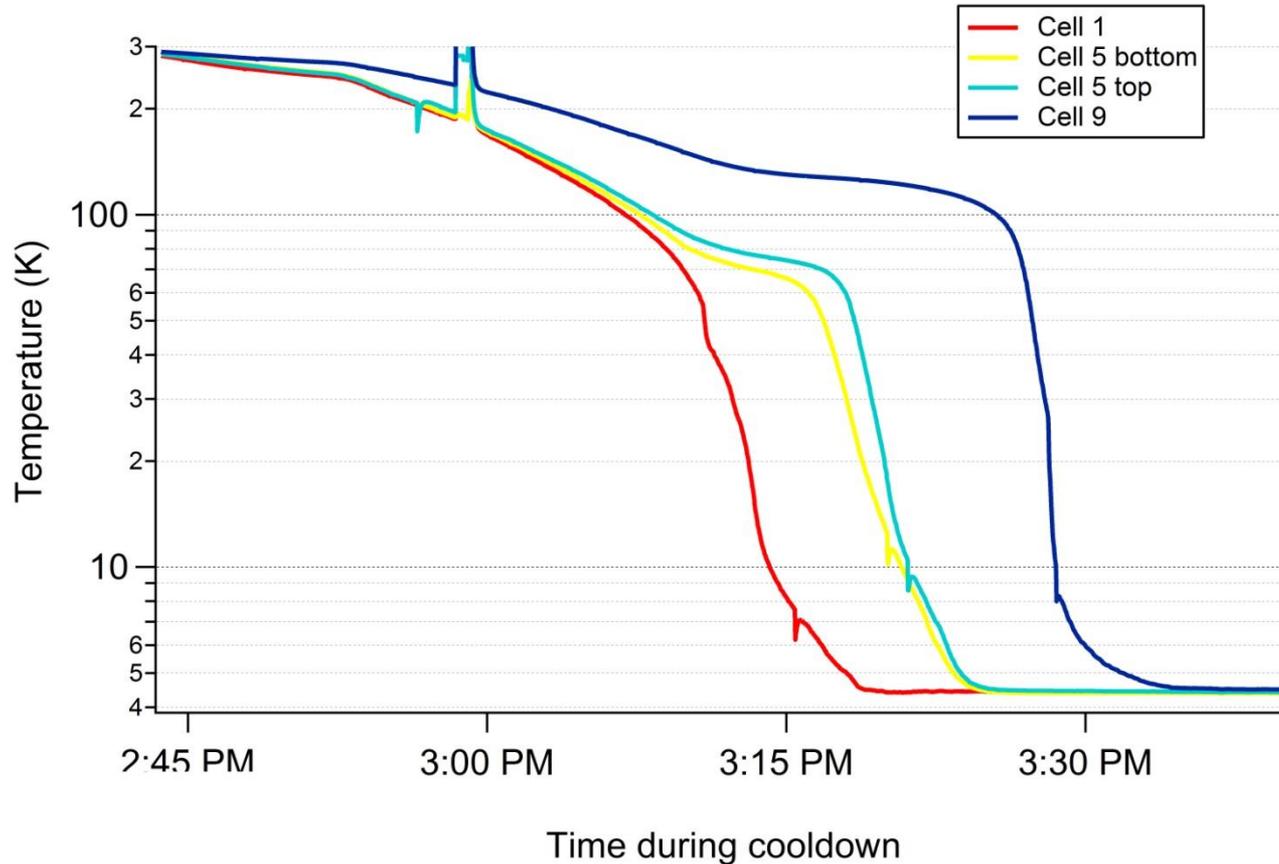
See Report for JLab High Q0 R&D for LCLS-II - FY14, JLab tech note JLAB-TN-15-008

# Test environment – accidental uniform cooling D8



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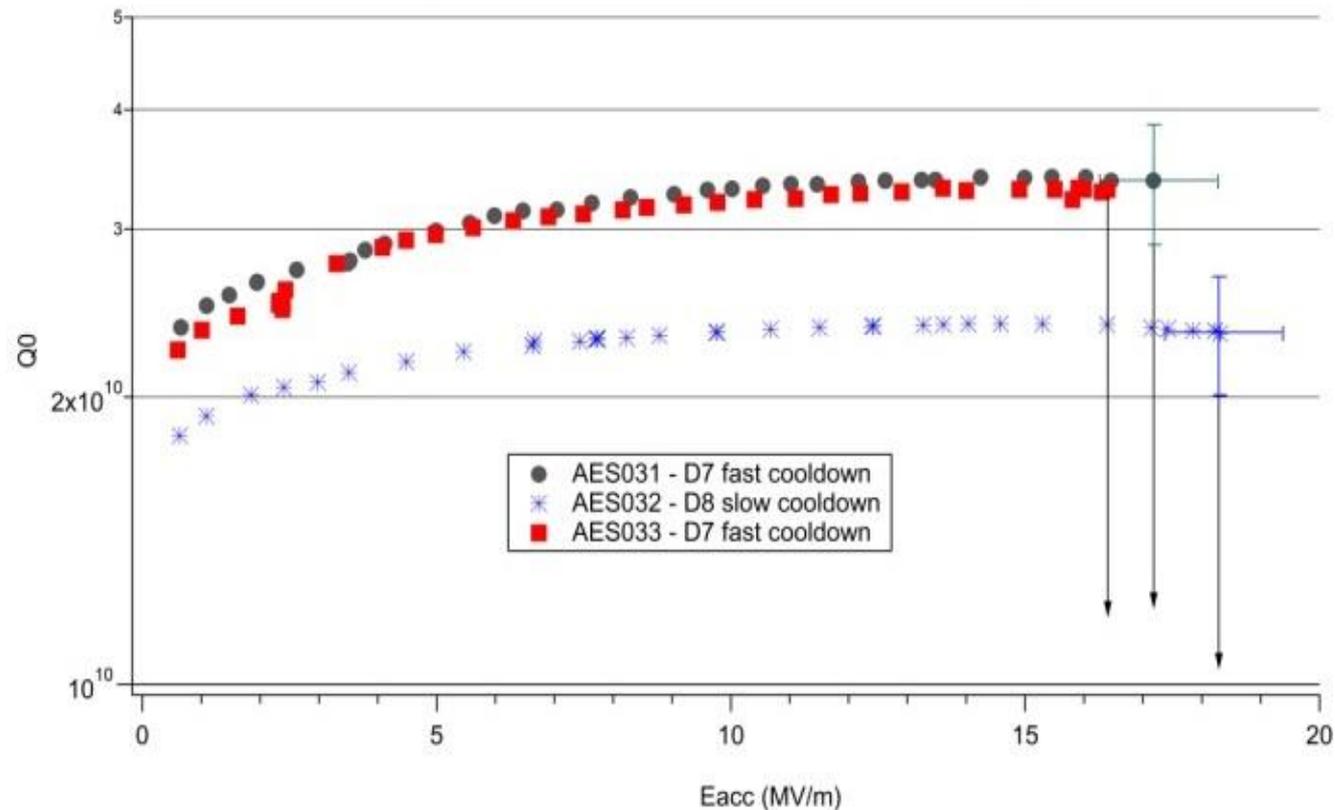
AES032 - D7



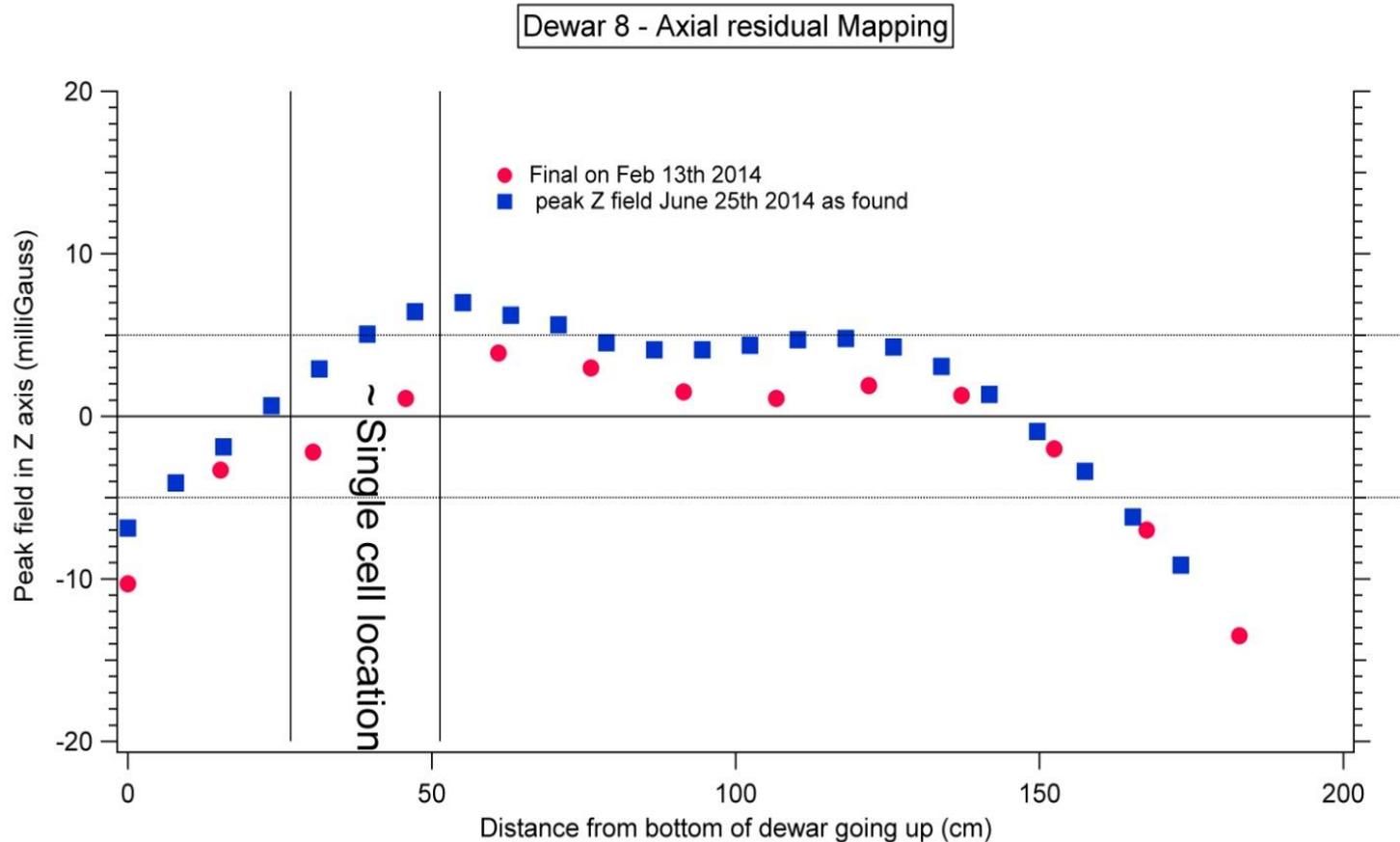
Temperature sensors

# Test environment – accidental uniform cooling D8

LCLS-II baseline 9 cell RF data 2.0K - JLab

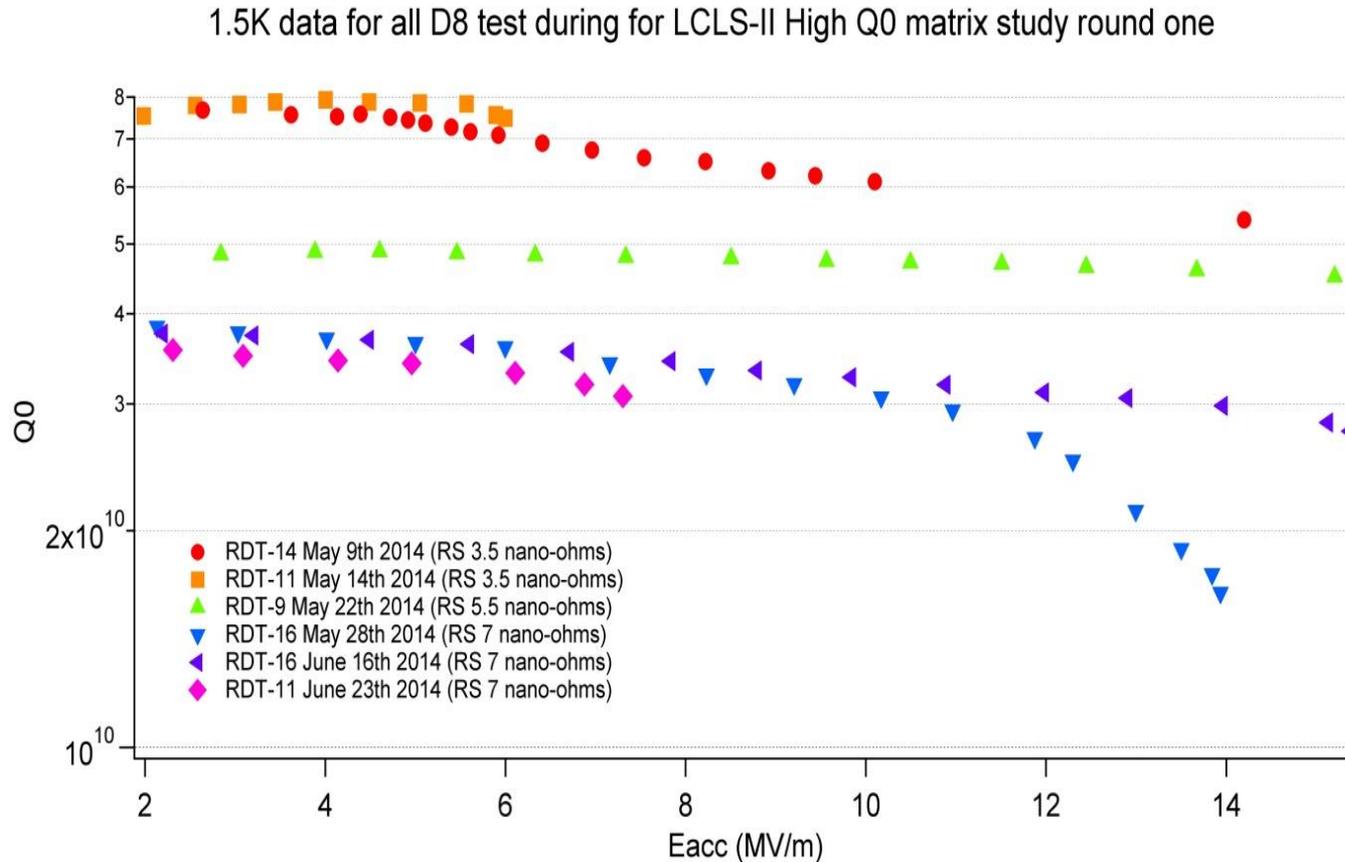


# Test environment - magnetic field drift



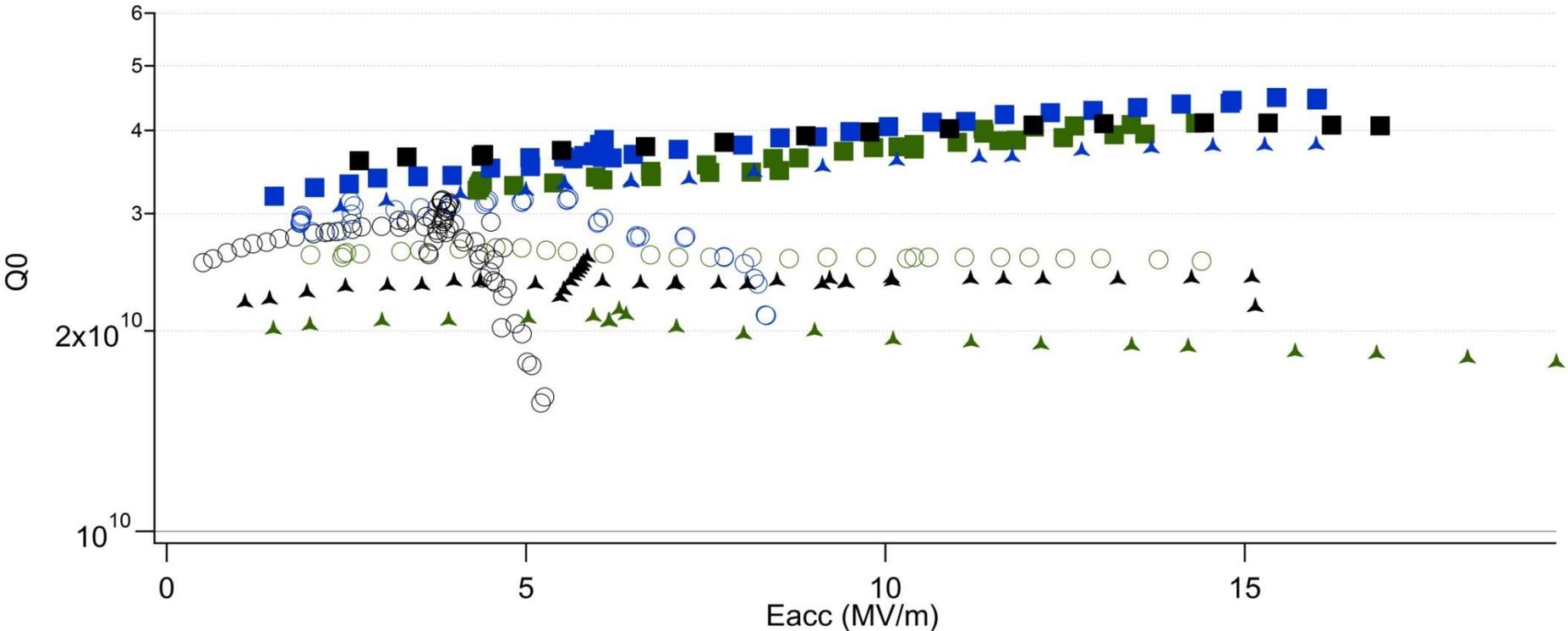
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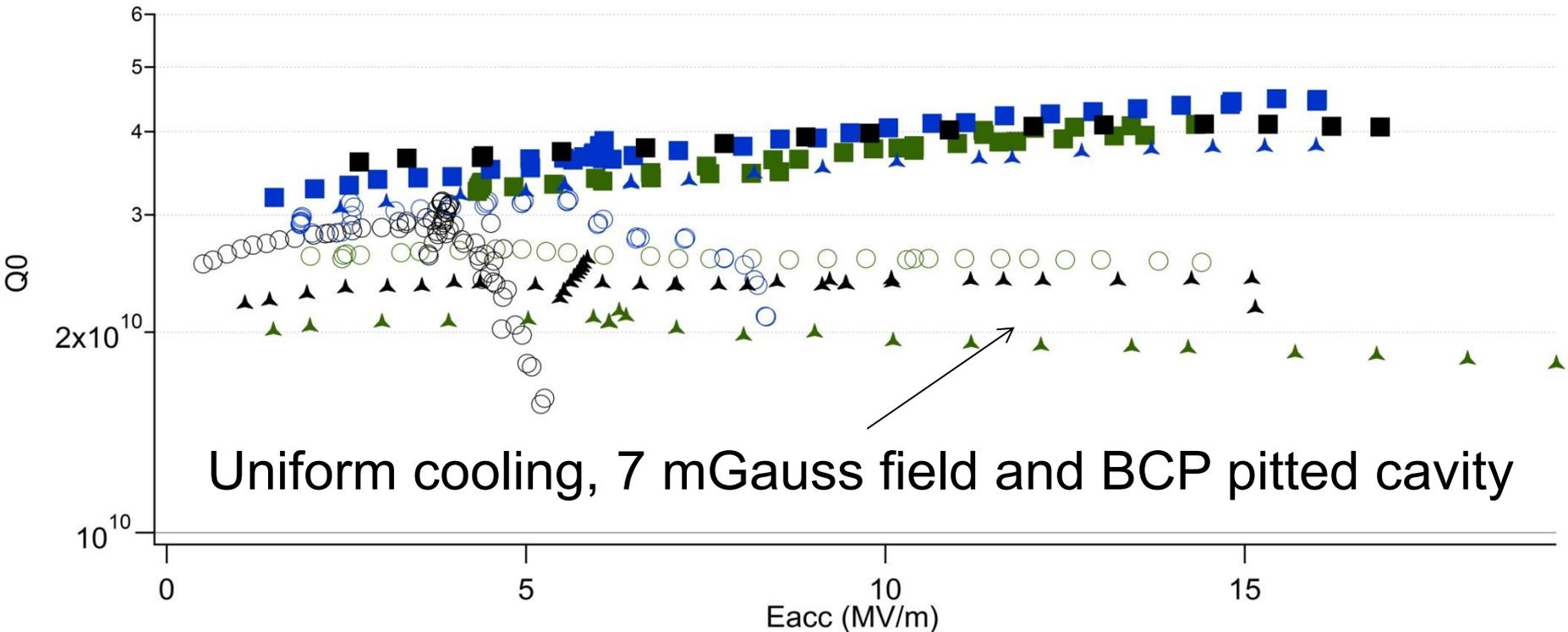
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# Surface decomposition is essential - $Q_0$ vs. $E_{acc}$ vs. T



All single cell cavities, all with now know good doping, all should easily have  $Q_0 > 3.5e10$  @ 16MV/m

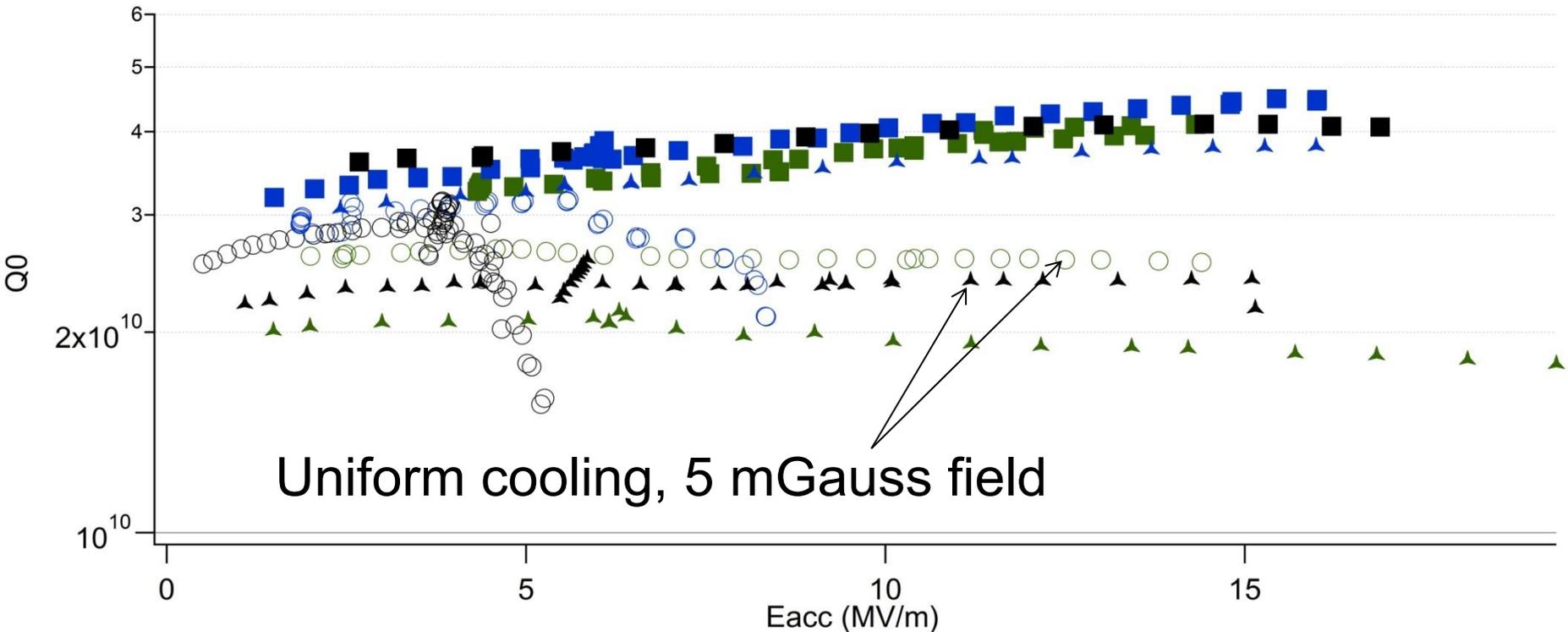
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Uniform cooling, 7 mGauss field and BCP pitted cavity

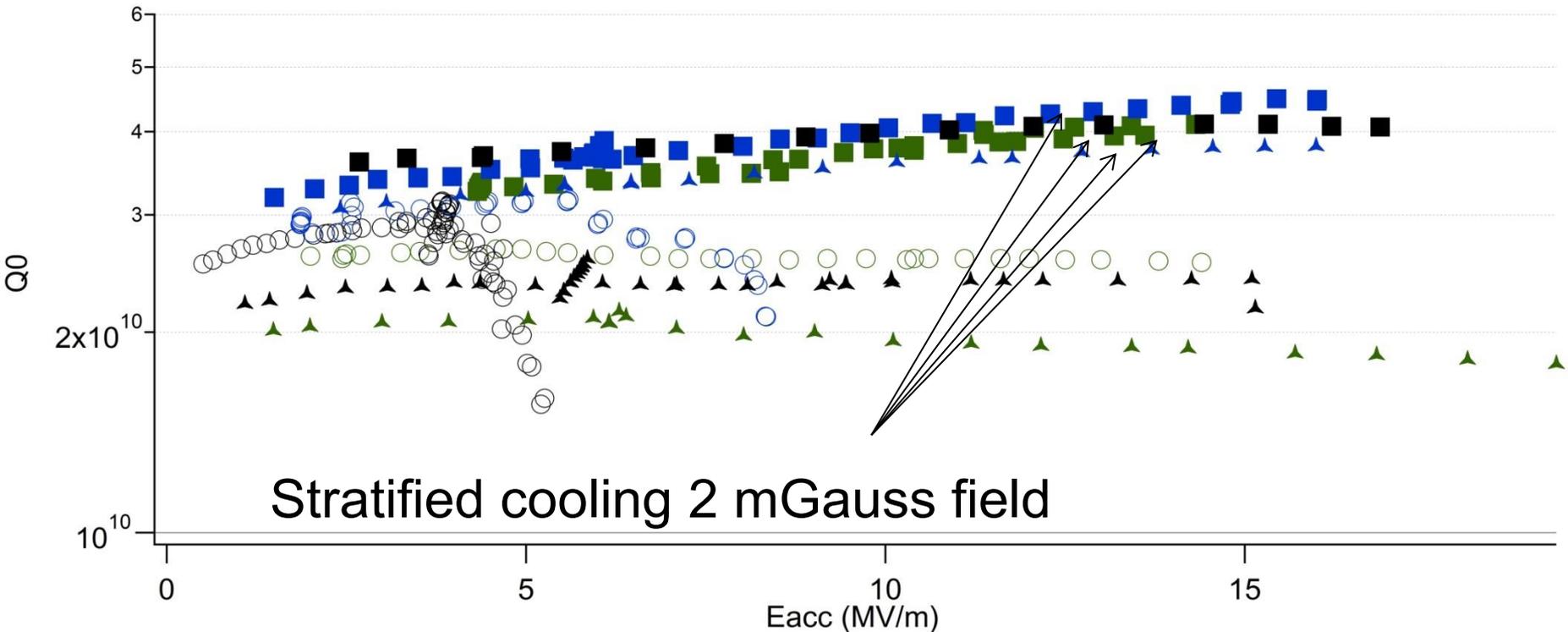
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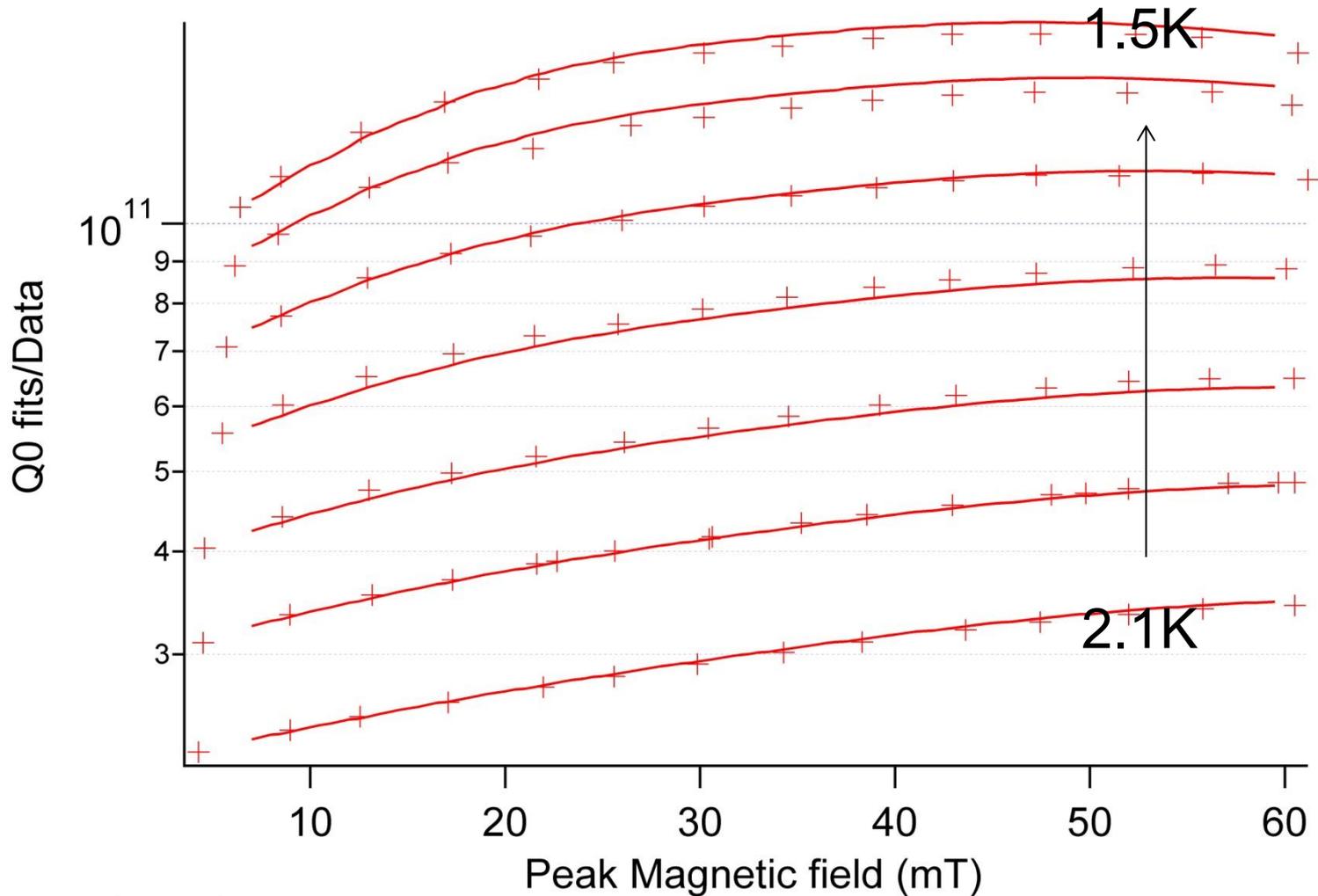
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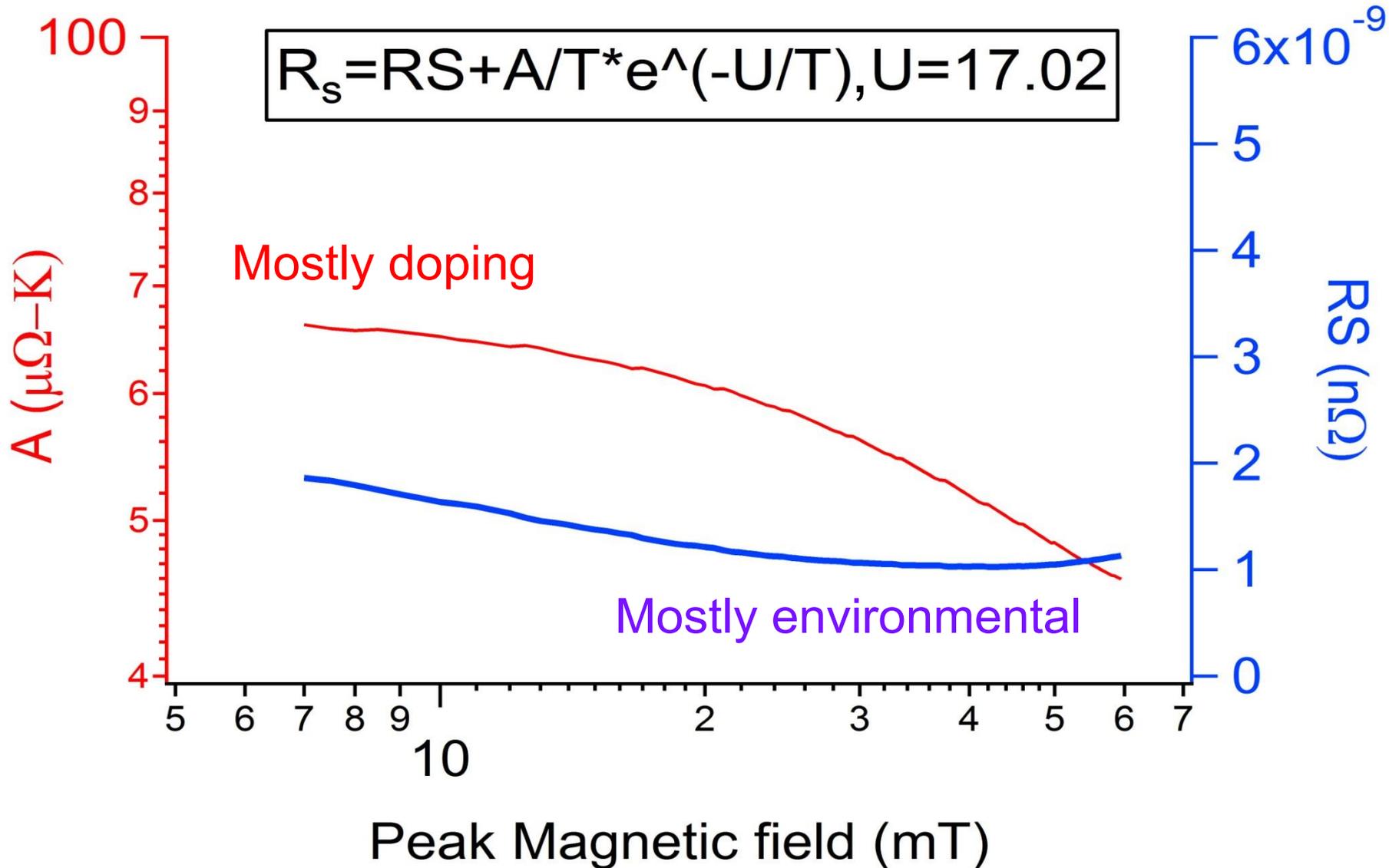


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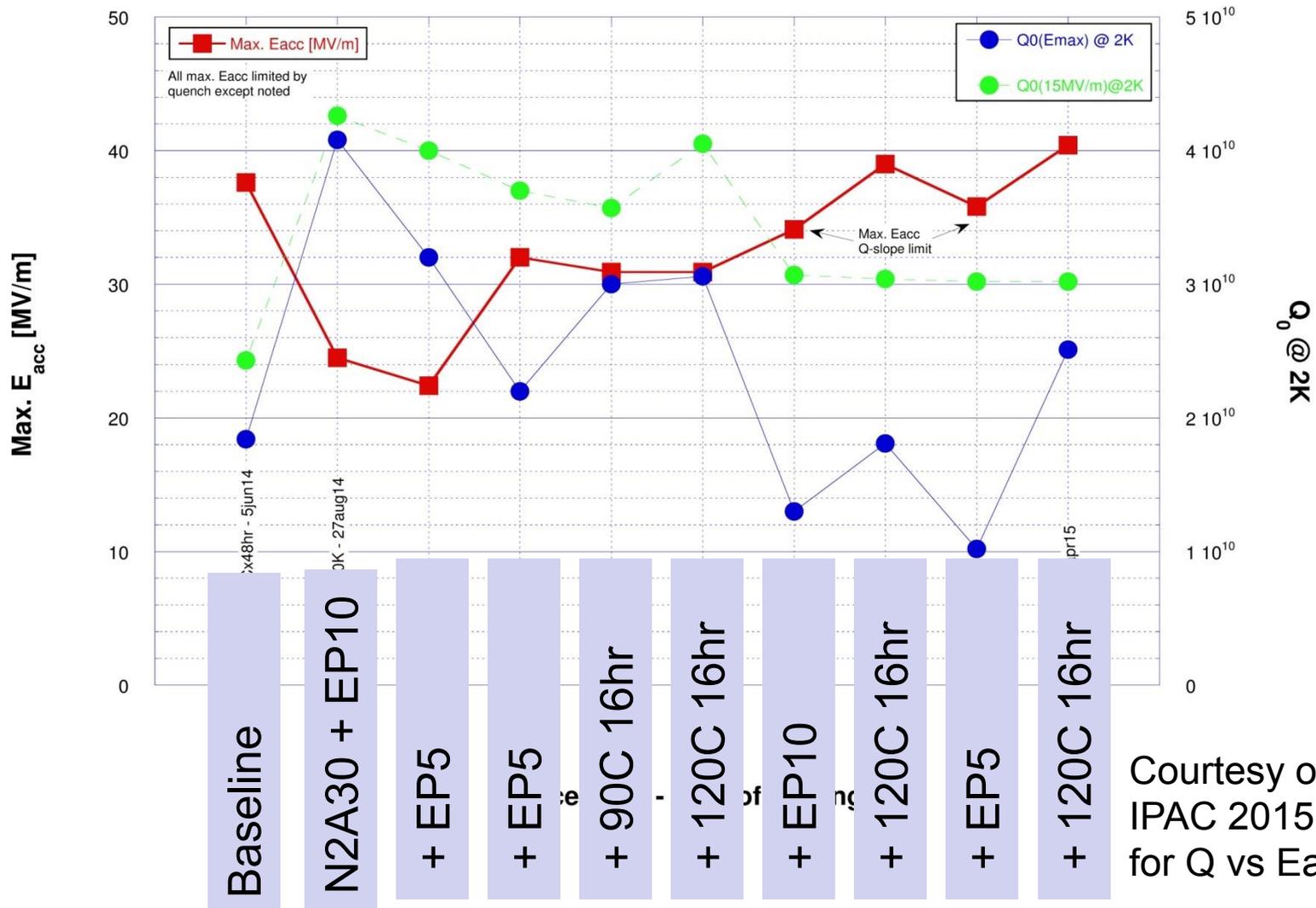


# Surface decomposition is essential - $Q_0$ vs. $E_{acc}$ vs. $T$



# G2 – Large grain incremental EP

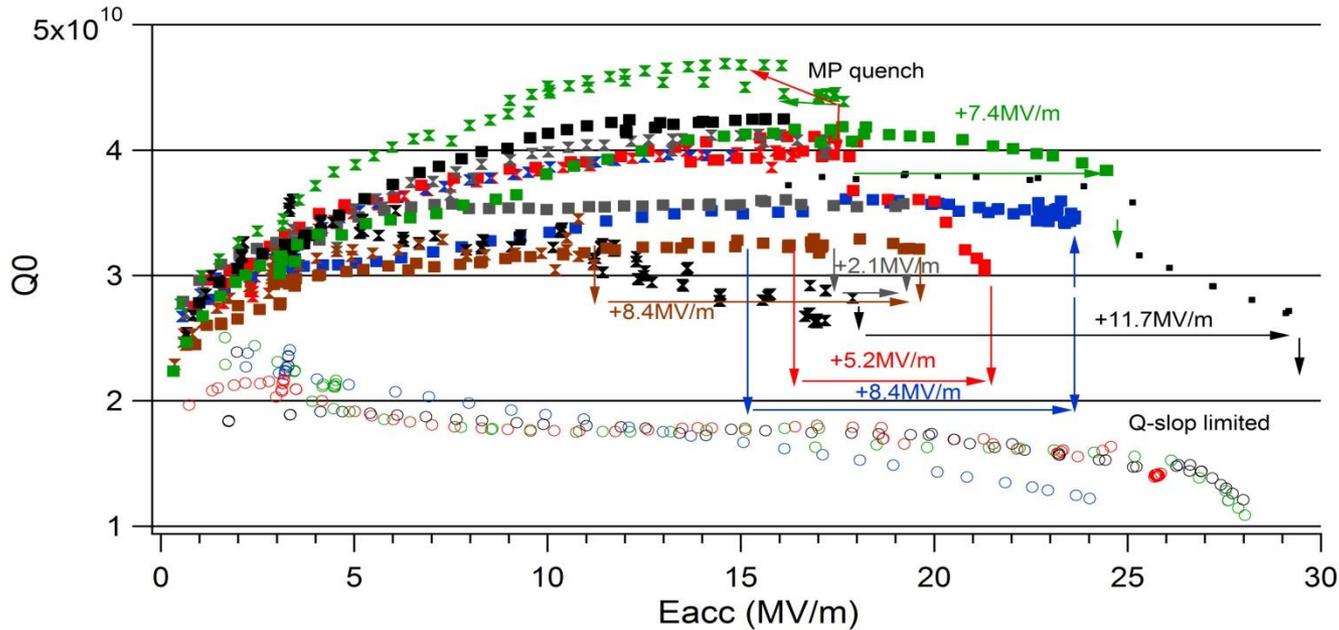
JLAB SRF 1-Cell 1.3 GHz Large-Grain Niobium Cavity G2 Performance Evolution



Courtesy of R.L. Geng  
IPAC 2015 WEPWI013  
for Q vs Eacc

# Quench analysis on 9 cell cavities

**LCLS-II 9 cell RF data @ 2.0K**



N20A30 + EP  
16 $\mu$ m  
Average quench  
field – 16.8MV/m

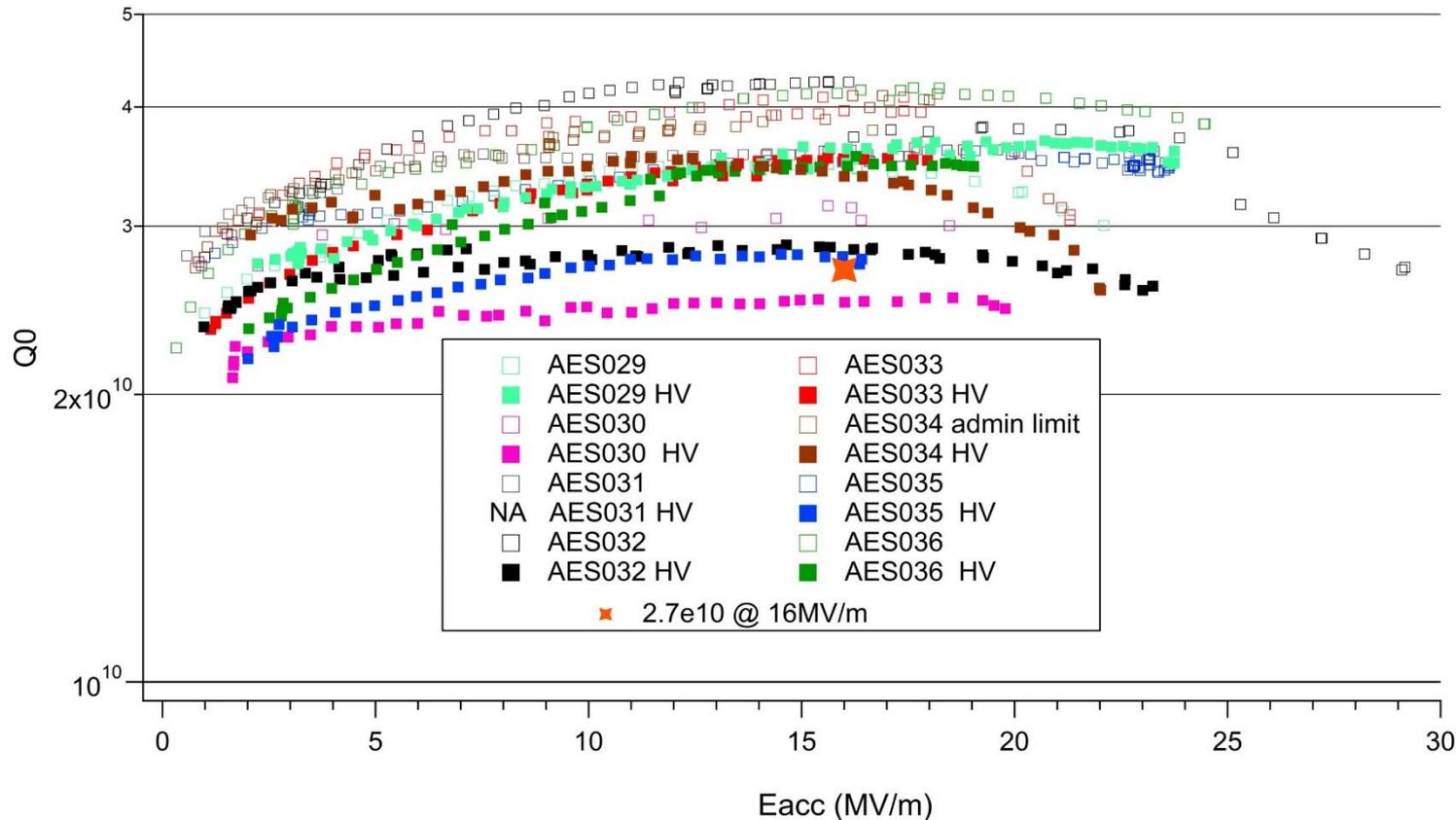
N2A6 + EP 5  $\mu$ m  
Average quench  
field – 23MV/m

lower Q0 @  
16MV/m With  
lower N2?

✕ AES031 - N20A30 + EP16	✕ AES033 - N20A30 + EP16	✕ AES035 - N20A30 + EP16
■ AES031 - N20A30 + EP26	○ AES033 - baseline	○ AES035 - baseline
✕ AES032 - N20A30 + EP16	■ AES033 N2A6 + EP5	■ AES035 - N2A6 + EP5
○ AES032 - Baseline	✕ AES034 N20A30 + EP16	✕ AES036 N20A30 + EP16
■ AES032 - N2A6 + EP5	■ AES034 N2A30***	○ AES036 Baseline
■ AES032 - N2A6 + EP5 - retest	■ AES036 N2A6 + EP5	
* to FE onset ** retest no FE from FR onset of first test - bad input cable Q0 not real *** R&D doping, expected lower Q0		

Palczewski et al. – IPAC2015 WEPWI019 QUENCH STUDIES OF SIX HIGH TEMPERATURE NITROGEN DOPED 9 CELL CAVITIES FOR USE IN THE LCLS-II BASELINE PROTOTYPE CRYOMODULE AT JEFFERSON LABORATORY

# LCLS-II prototype results before and after HV welding

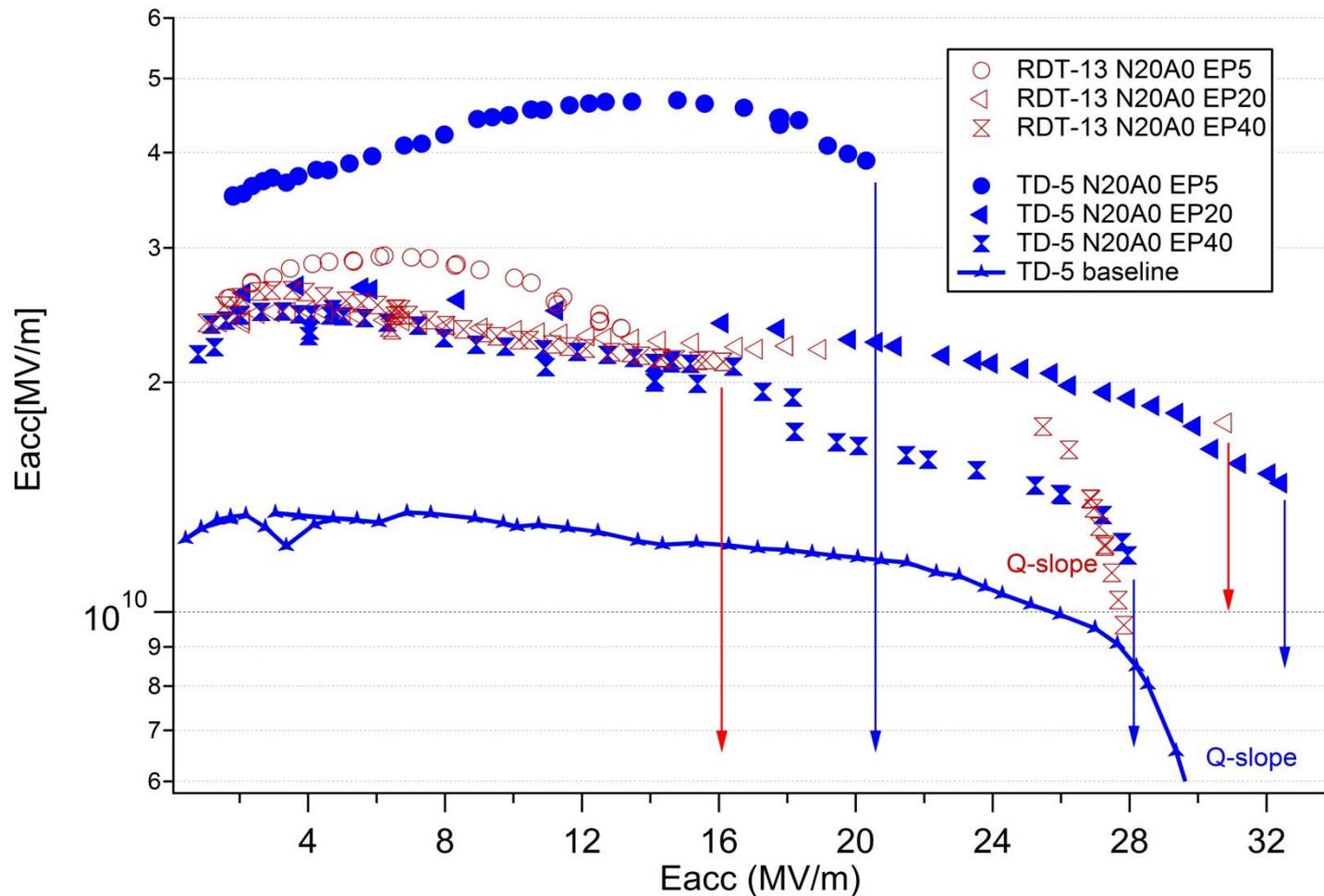


Average  $Q_0$  is lower after HV welding by  $\sim 10\%$  or  $1.25n\Omega$

Current data suggest environmental effects are the major cause of  $Q_0$  degradation after HV welding.

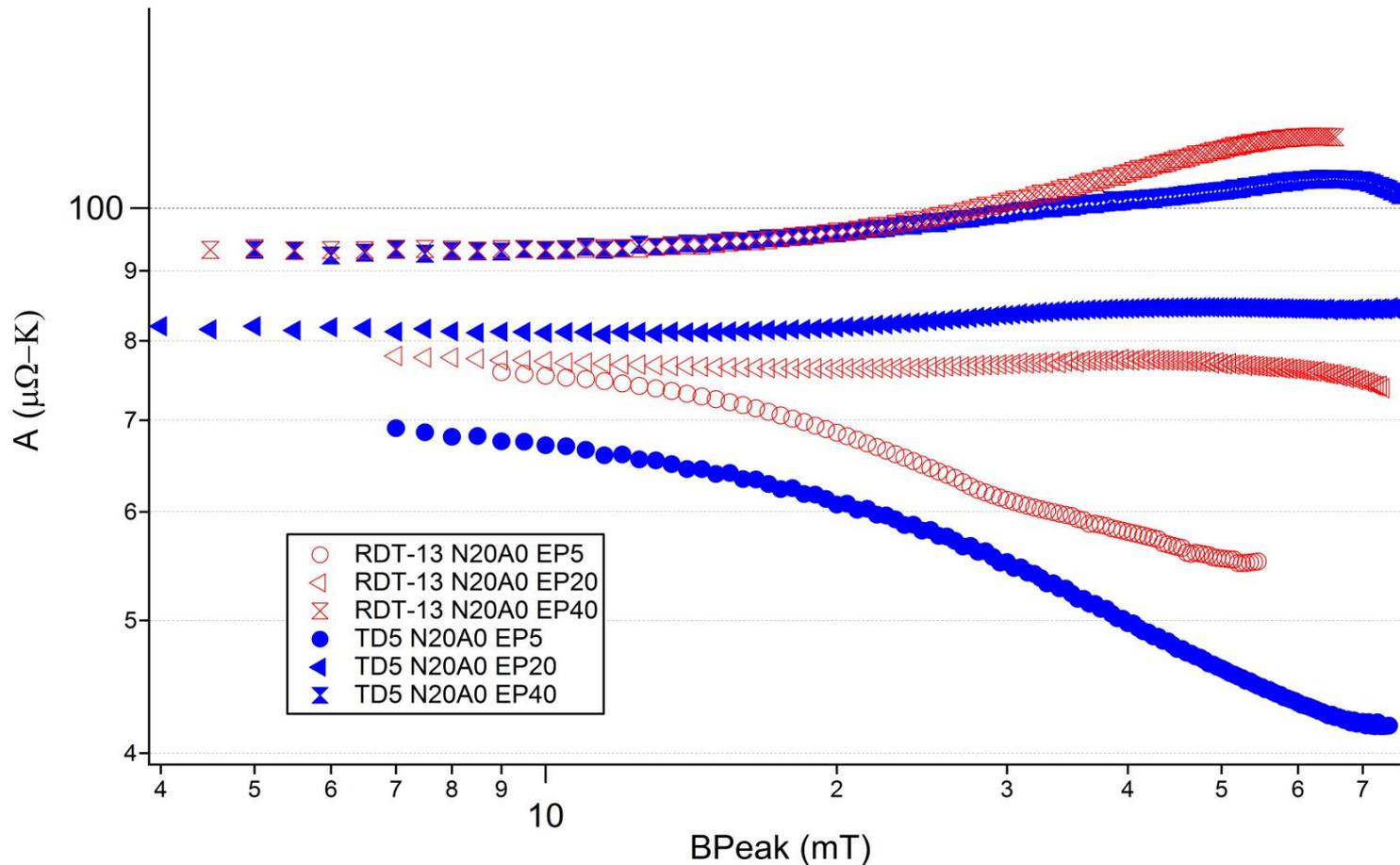
Palczewski et al. – this conference MOPB040 today

# Systematic doping vs. EP (FG and LG)



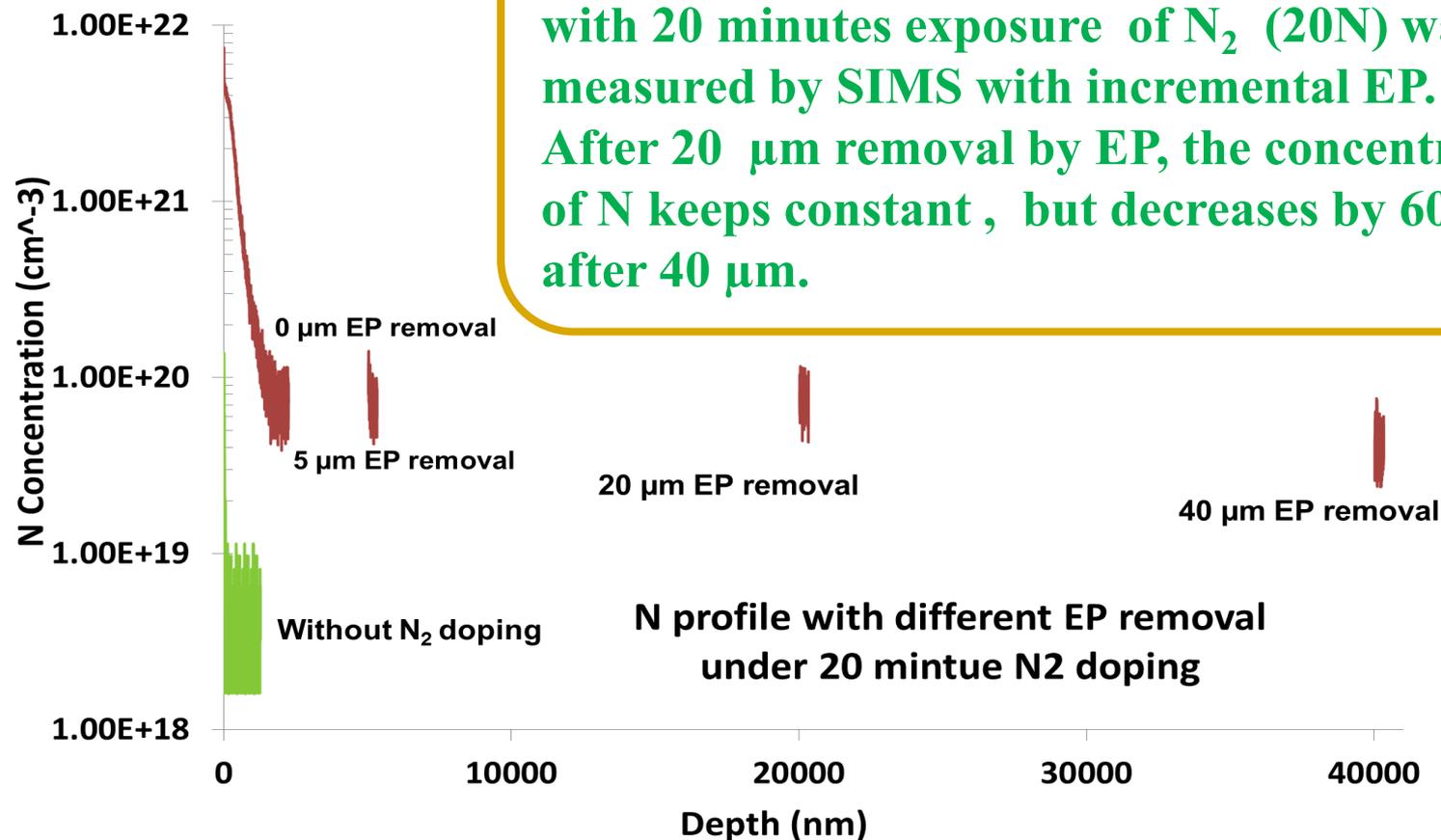
# Systematic doping vs. EP (FG and LG)

Fitting results remove environmental effects



Palczewski et al. – this conference MOPB039 today

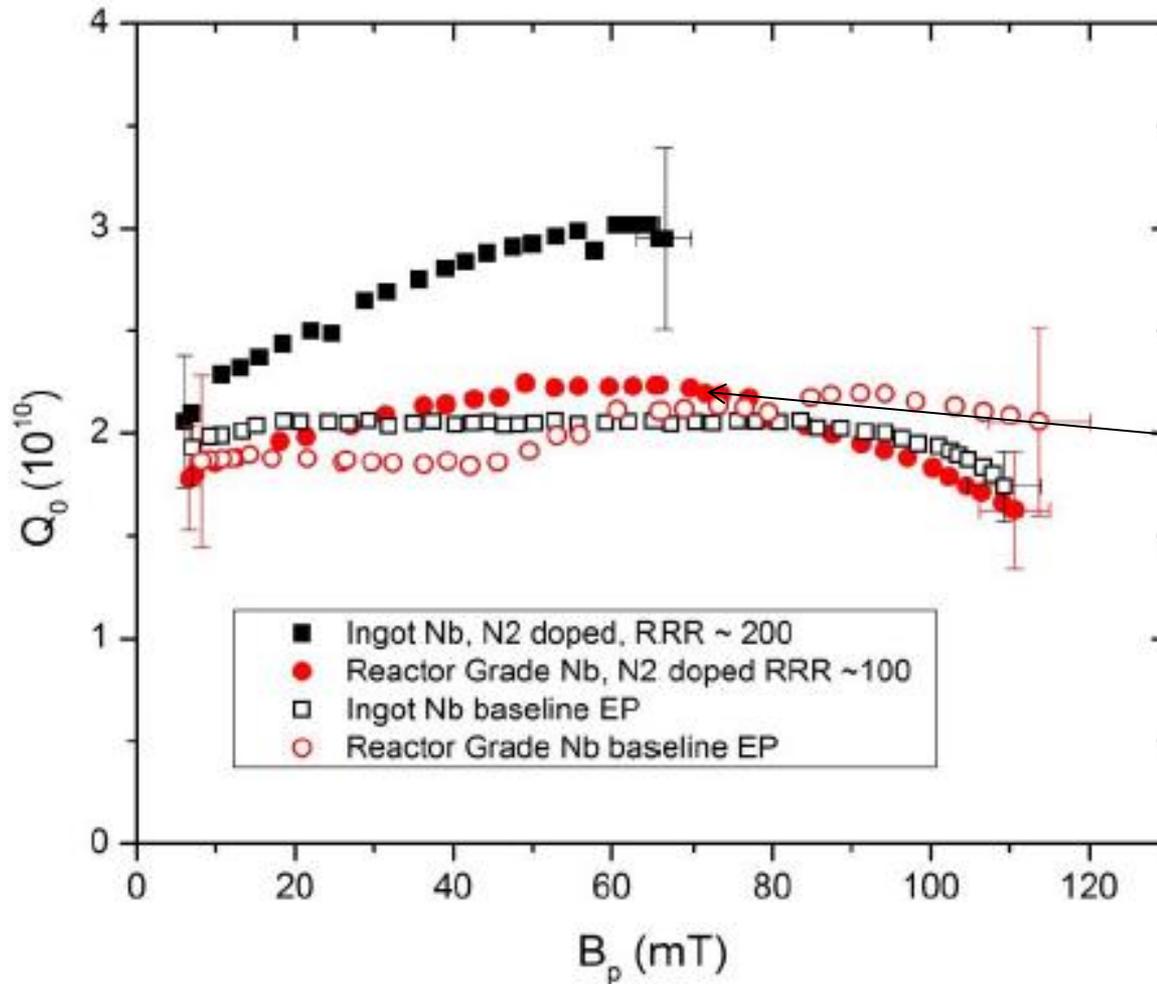
# Sample analysis High resolution – from previous slide



The near surface N concentration of Nb sample with 20 minutes exposure of N<sub>2</sub> (20N) was measured by SIMS with incremental EP. After 20 μm removal by EP, the concentration of N keeps constant, but decreases by 60% after 40 μm.

H. Tian et al. – this conference MOPB107 today

# Effectiveness of doping vs niobium RRR



No significant signature of doping @ 2.0K on low RRR FG cavities

These are 1.5Ghz @ 2.0K

Pashupati Dhakal et. al ASC'14 1L0r1B-05

# Questions?

## Contributing Data

C. E. Reece

Pashupati Dhakal

Grigory Ereemeev

Hui Tian

R.-L. Geng



Making nitrogen doping work is not that easy but can be done – off to the cryomodules.

## Funding

Special thanks to LCLS-II, especially for taking chance on Nitrogen doping

-Initial single cell studies and all 9 cell work

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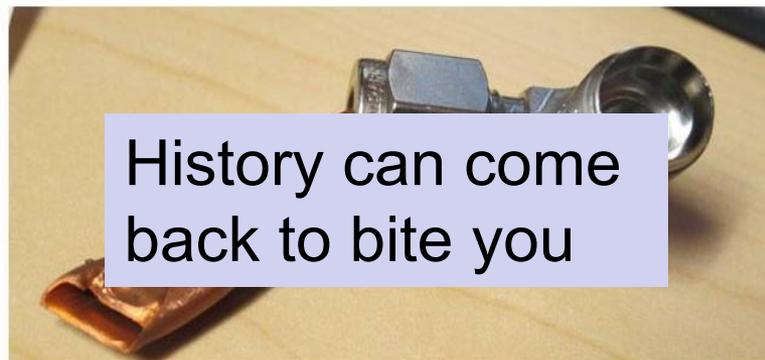
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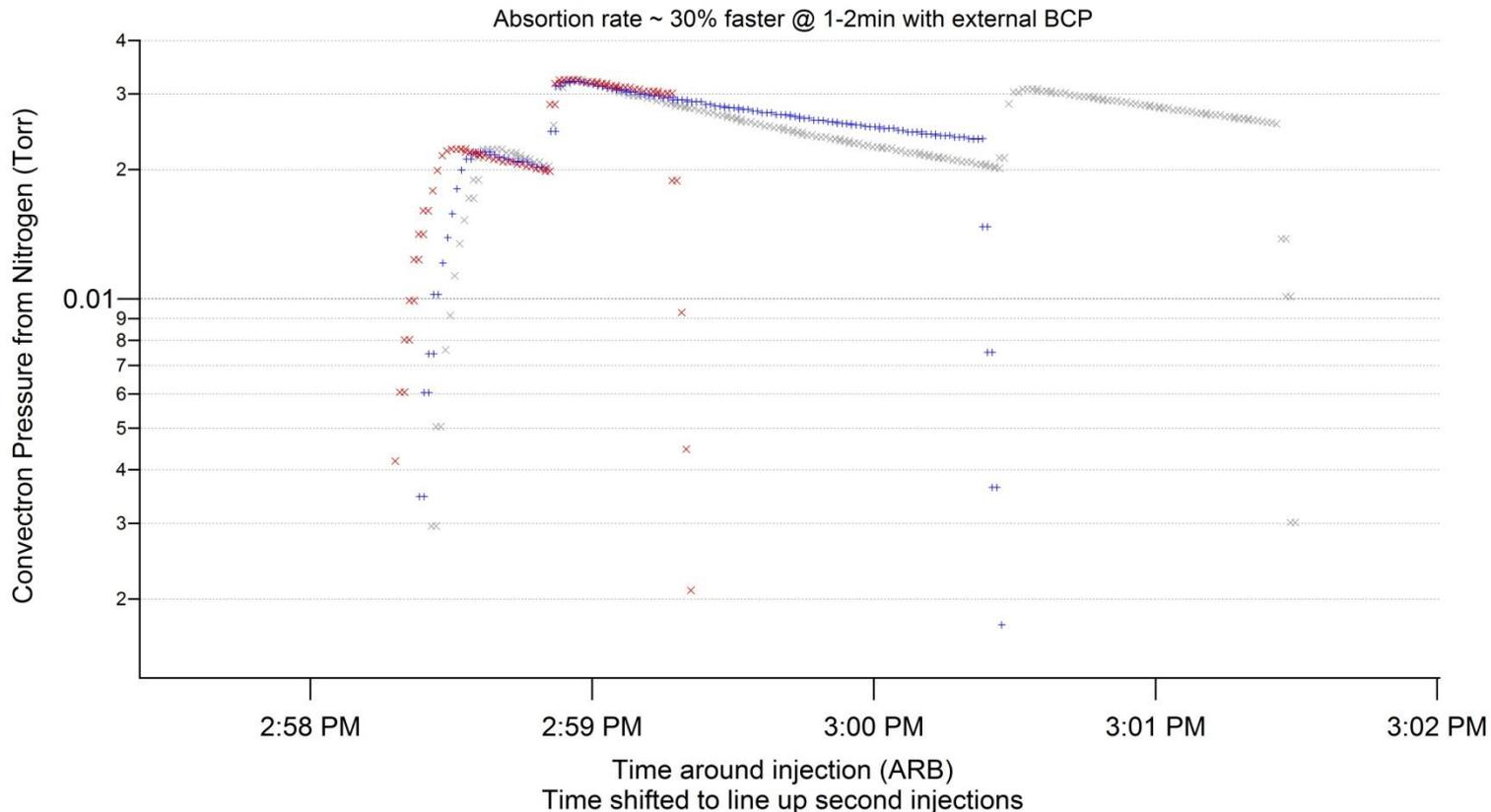
Making nitrogen doping work is not that easy but can be done – off to the cryomodules.

# Backup

# Furnace doping - redoping

## Short injection - Long anneal single cell absorption compare

- × RDT-13 800C\_A180\_N1@27mtorr\_A60 - 4.85 to 6.25 Torr liters @ standard atm (25C)
- + RDT-14 800C\_A180\_N2@26.5mtorr\_A60 - 6.9 to 8.3 Torr liters @ standard atm (25C)
- × RDT-15 800C\_A180\_N3@26mtorr\_A60 (external BCP) - 13.2 to 14.5 Torr liters @ standard atm (25C)



Re-doping with external chemistry changes total absorption rate