Quench in SRF cavities

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Joint HiLumi-LARP Meeting & 24th LARP Collaboration Meeting

Fermilab

11-13 May 2015

Introduction.

Why?

- Locating quench in SRF cavities by 2nd sound detection.
  - "circle of confusion" issue
- Cavity performance degradation after quenching in external magnetic field

Contributors

- Sergey A. Antipov (Fermilab/U of Chicago)
- Iouri Terechkine (Fermilab)
- Timergali Khabiboulline (Fermilab)
- Slava Yakovlev (Fermilab)
- Early work:
  - Evgeny Toropov (Fermilab -> CMU)
  - Yulia Maximenko (Fermilab -> UIUC)

Model and simulation results.

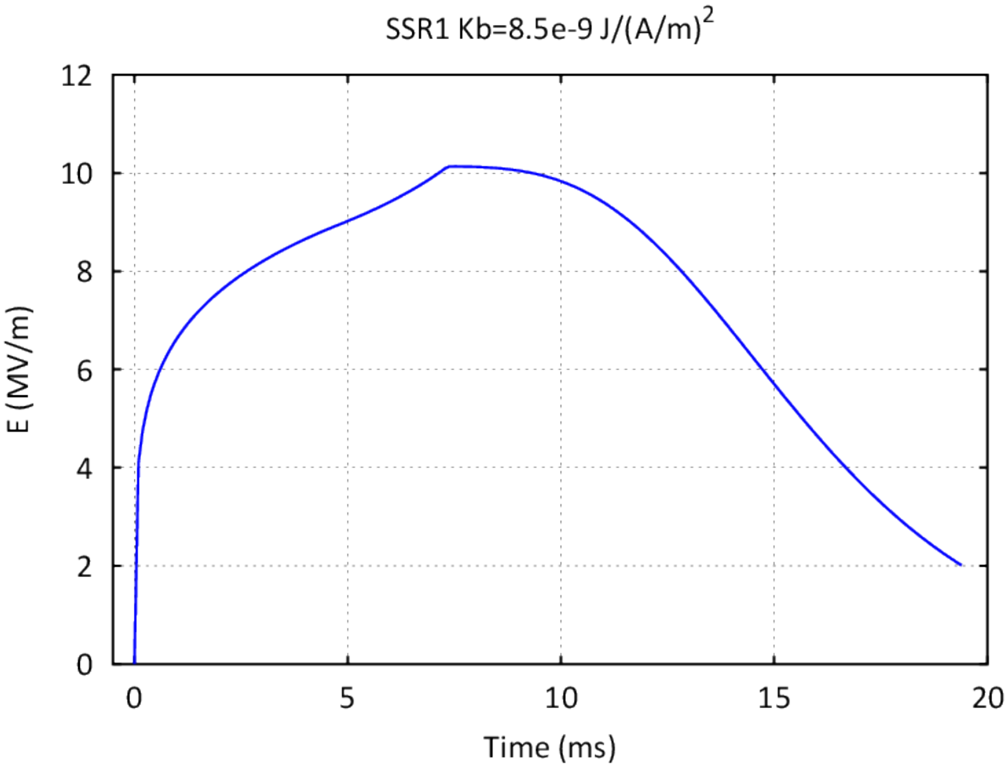
Framework Definitions and Assumptions

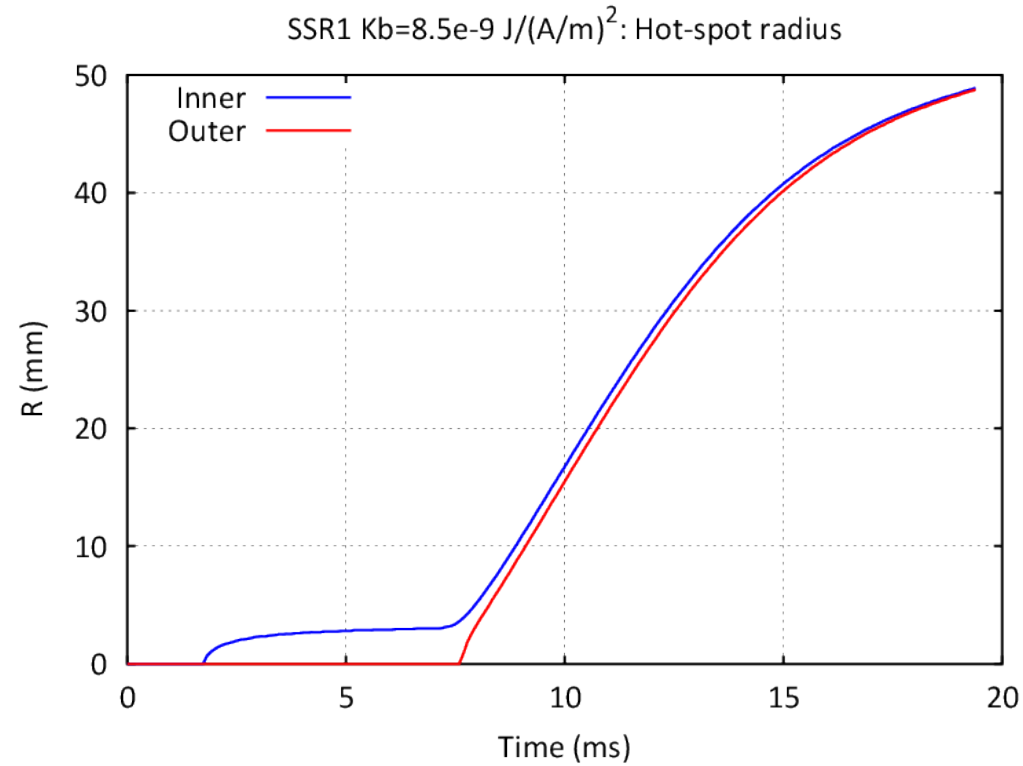
- Quench is a thermal runaway process that causes a rapid loss of the stored RF energy
  - Plasma discharge is another, different loss mechanism
- Vertical test of TESLA (9-cell, 1.3 GHz)
  - 2nd sound quench detection is the primary "customer" for his work
  - A week coupling to the external RF system (~100 W of *cw* RF pumping)
  - Cavity is in infinitely large bath of superfluid helium
  - Later work expanded to different cavity types (spoke – SSR1, 650 MHz elliptical, crab cavity)

Further simplifications

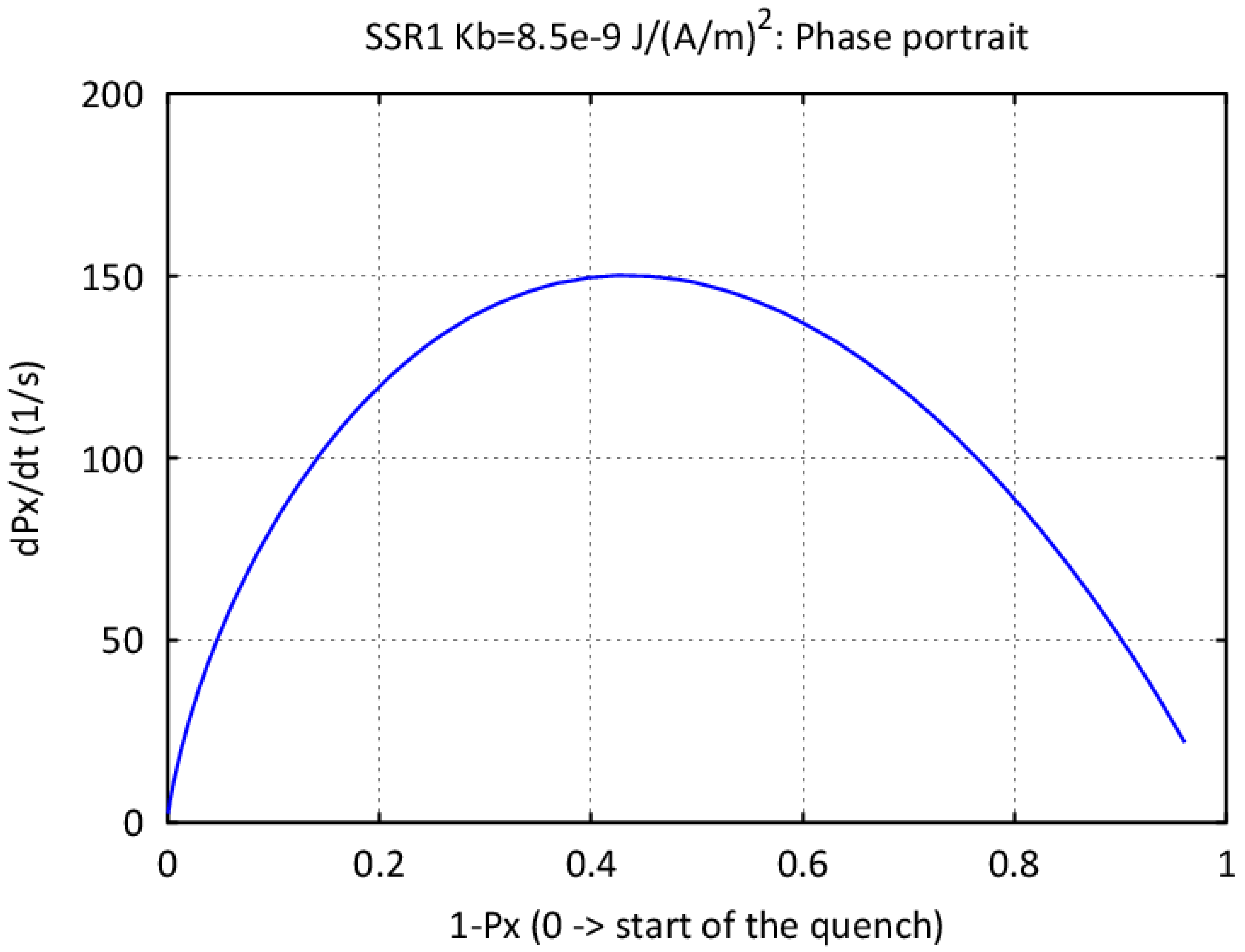
- Ignore cavity shape – 2D problem
- Quench nucleation – circle of Nb in normal state
- Quench is *slow* ($\tau \approx 1$ msec) relative to RF processes (RF modes are preserved since $\Delta\omega/2\pi > 1$ MHz, hence $\tau \cdot \Delta\omega >> 1$)
- Ignore helium cooling (for the first few msecs)
- Ignore SRF losses

Quench simulation on "face" of spoke (SSR1) cavity

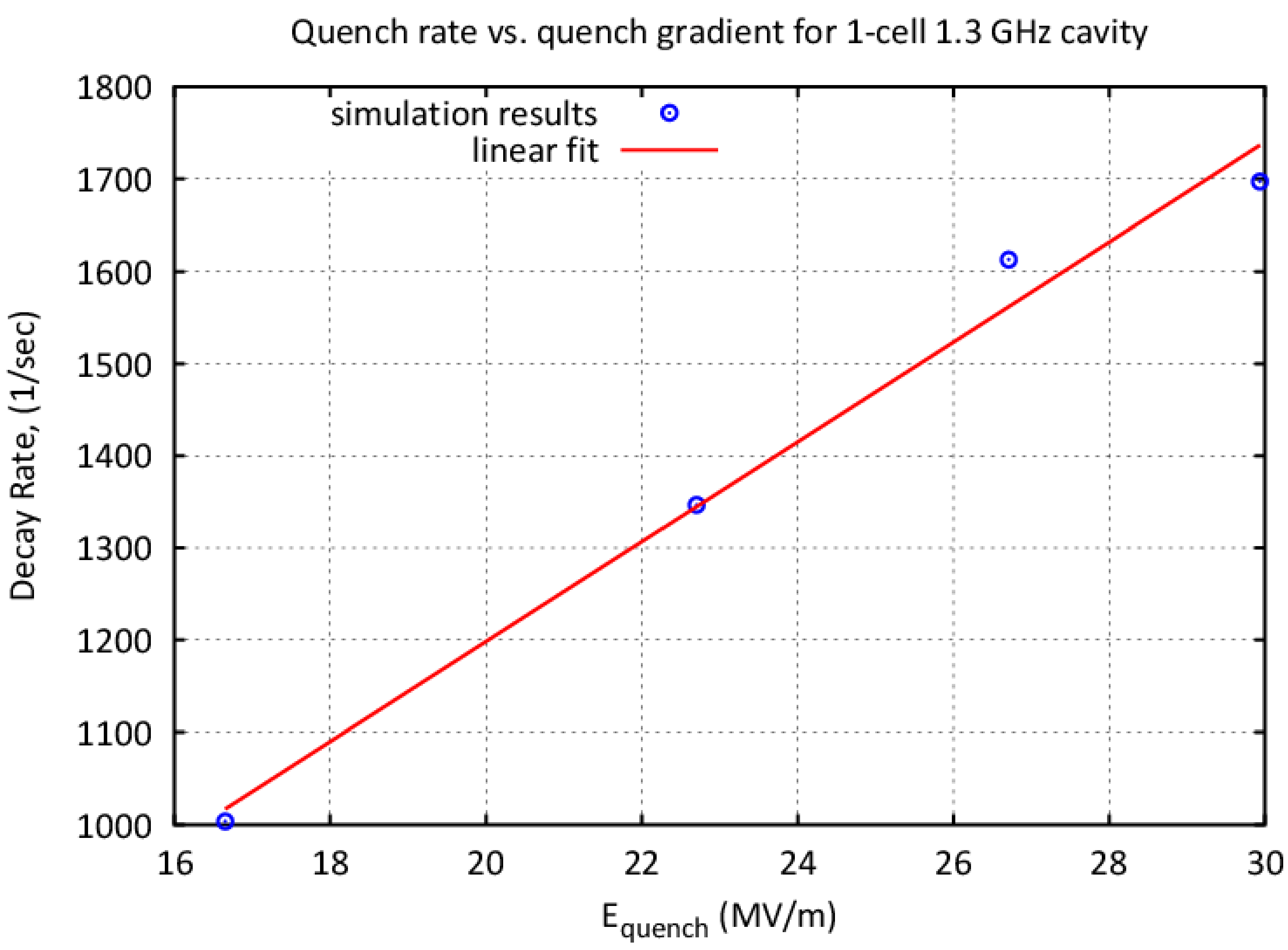




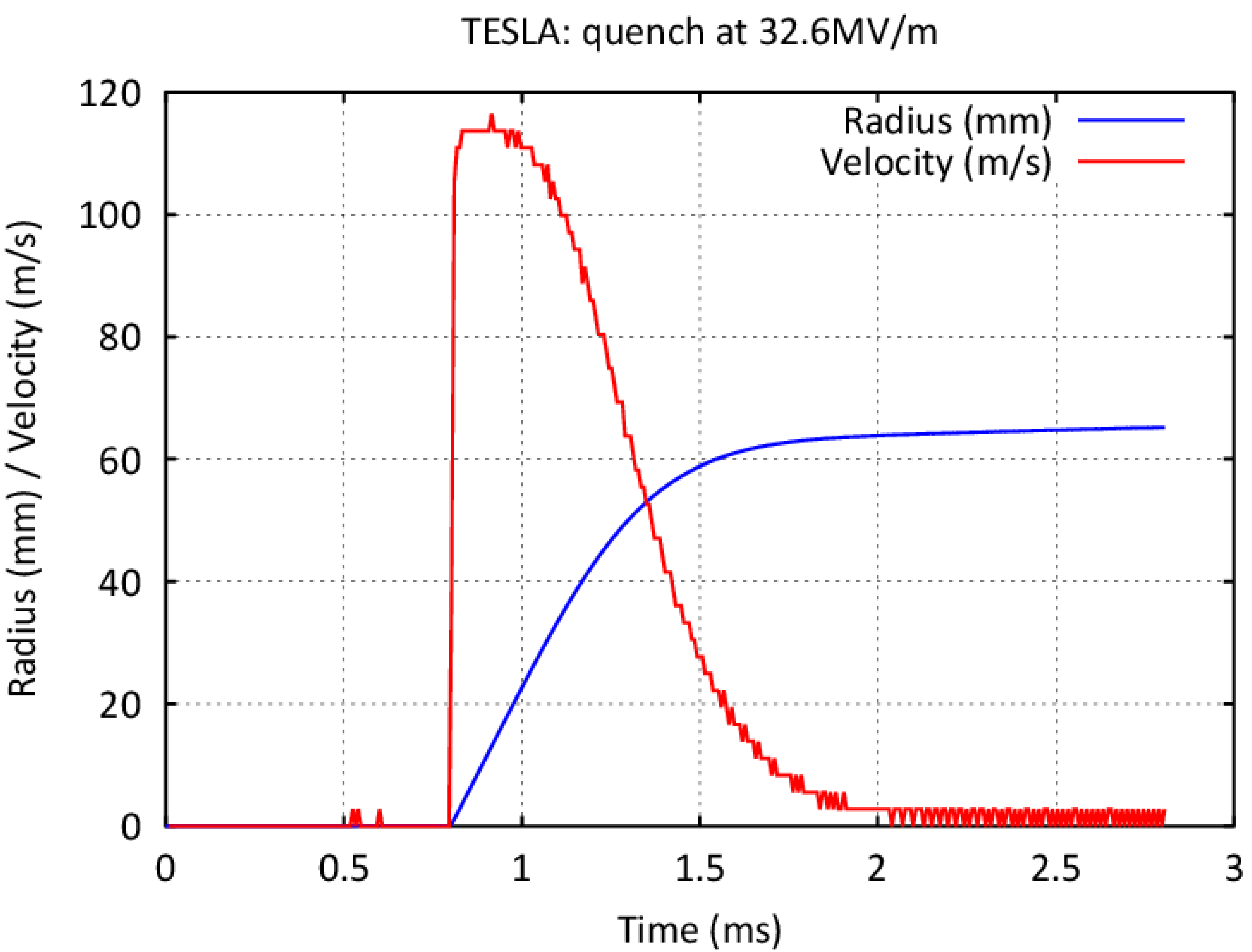
Phase portrait of quench



Quench decay rate *vs* quench gradient

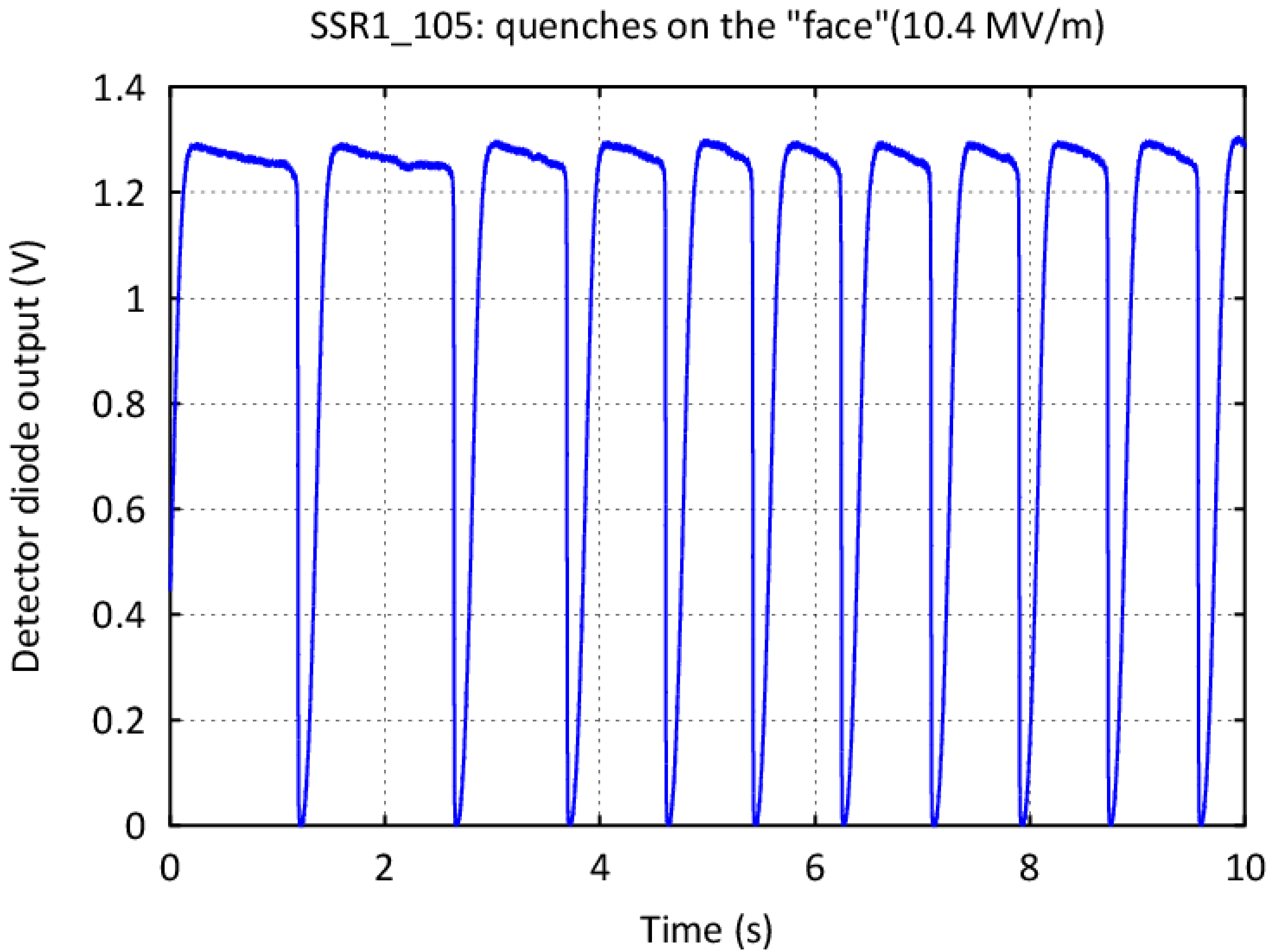


Hot-spot evolution.

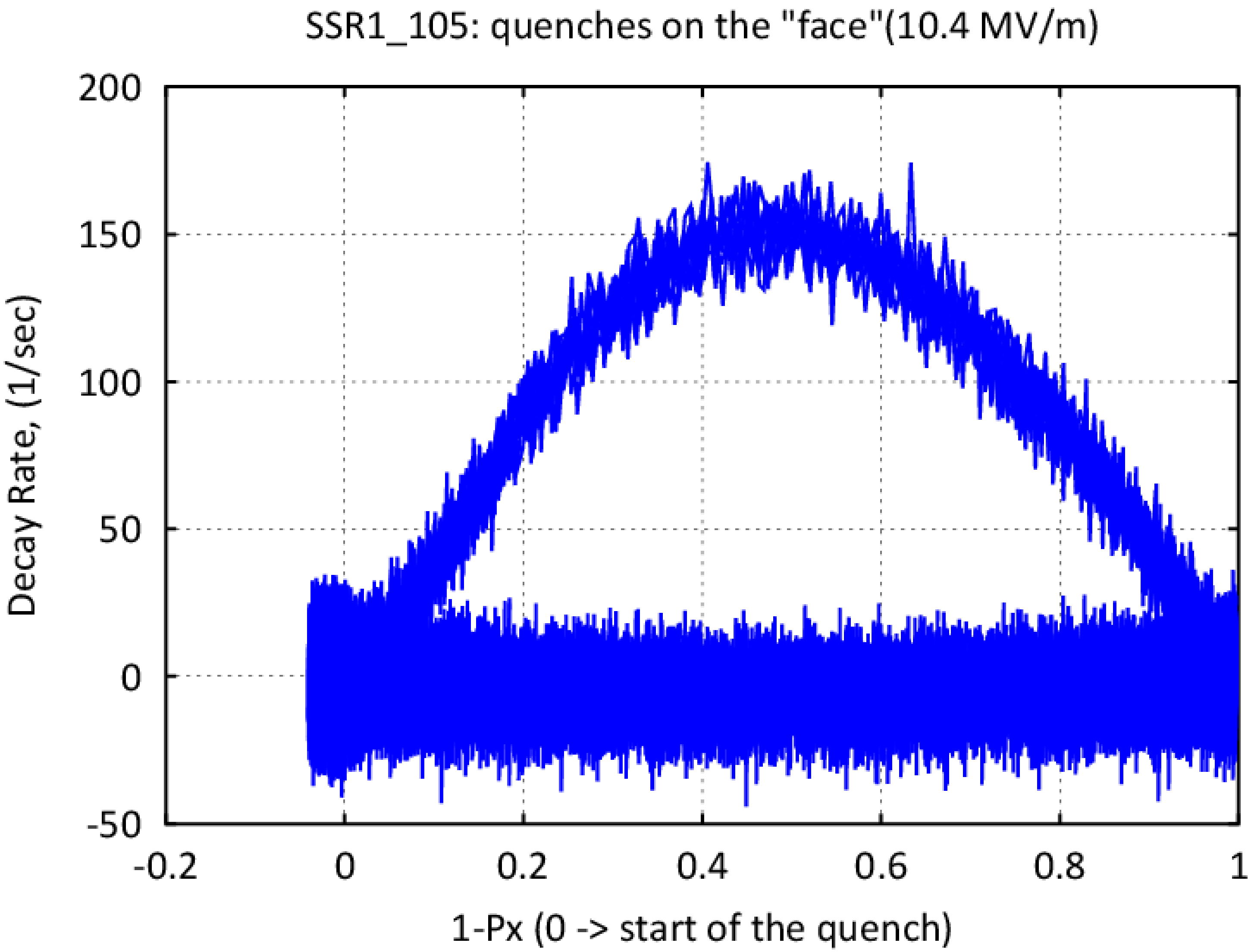


Experiment.

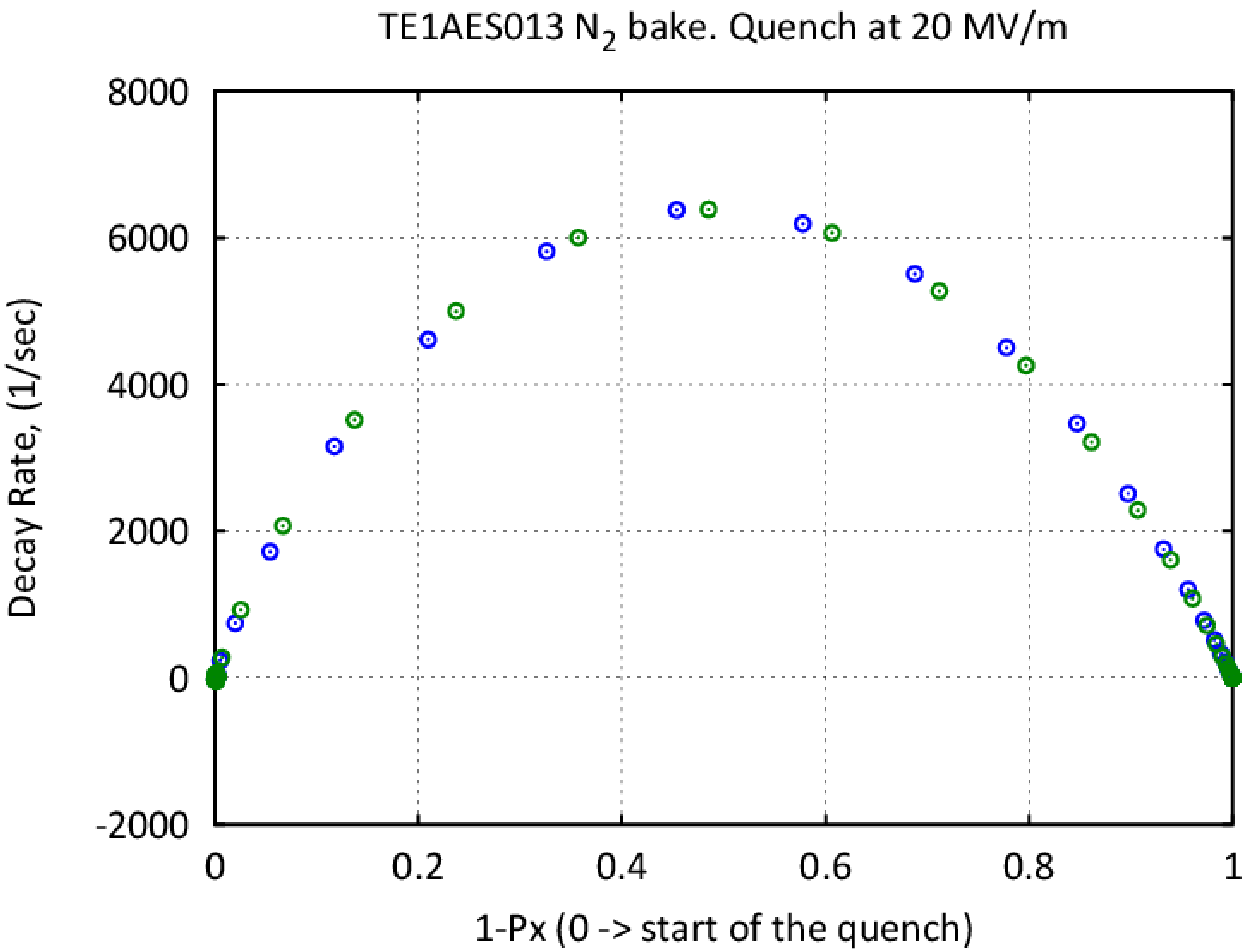
Quench “train” during m/p processing in SSR1



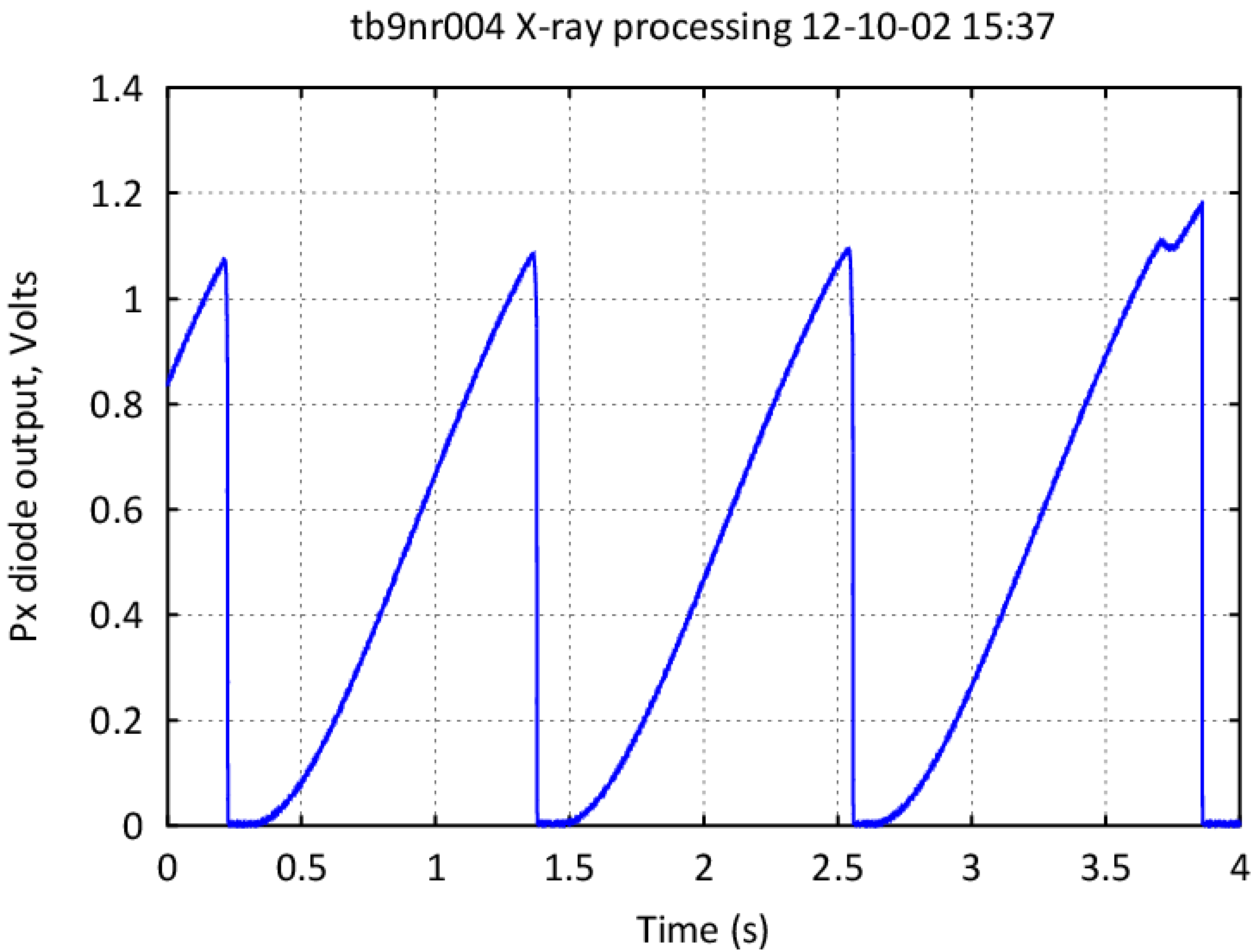
Phase portrait of quench "train"



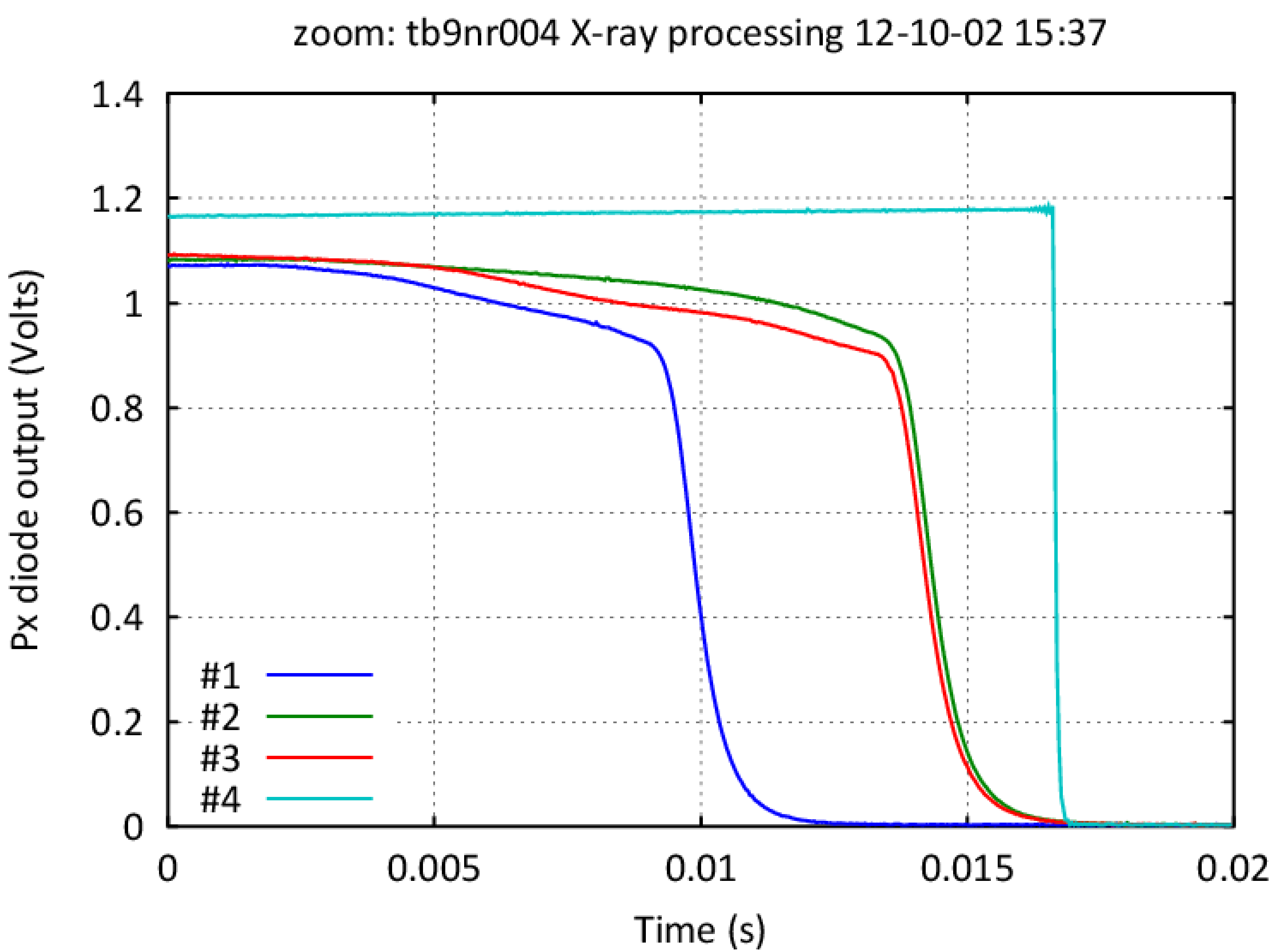
Quench is fast in N_2-treated cavities



When quench is not a quench

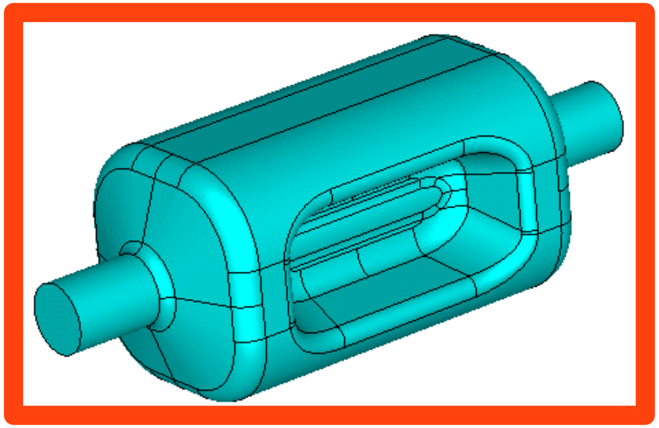


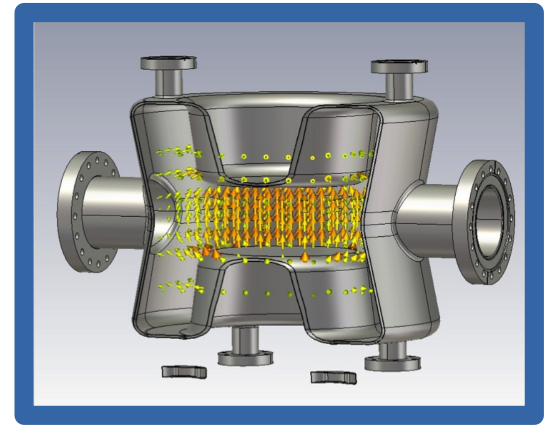
When quench is not a quench (zoom)



Crab Cavities.

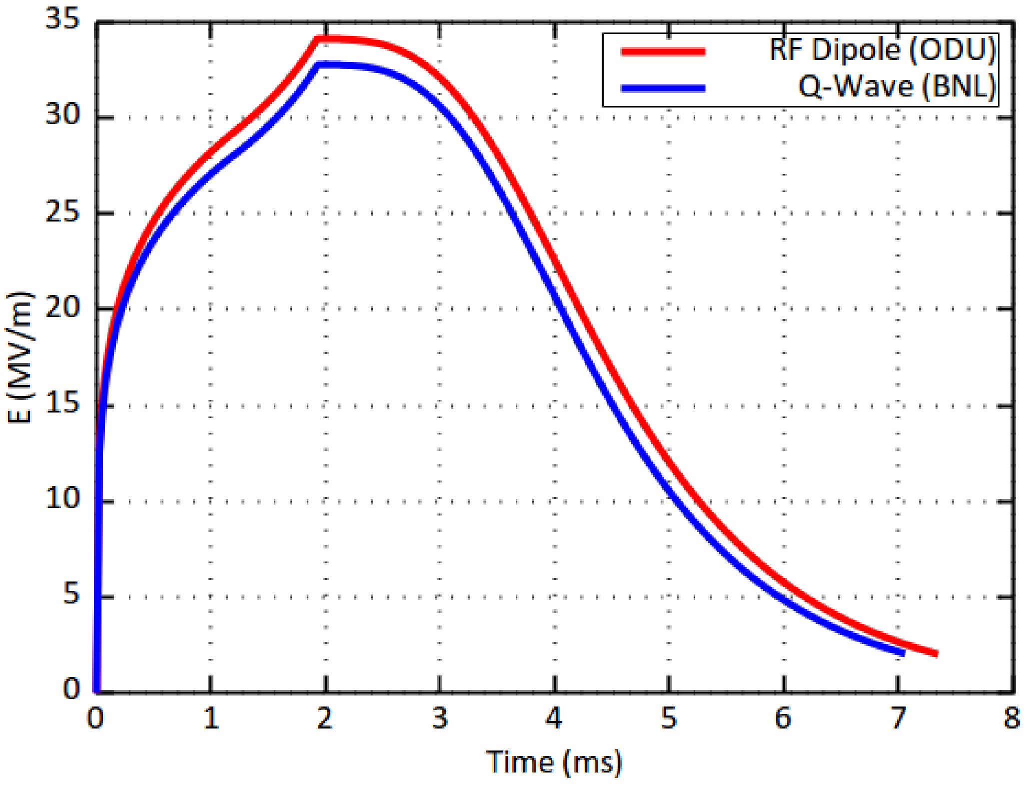
Two crab cavities

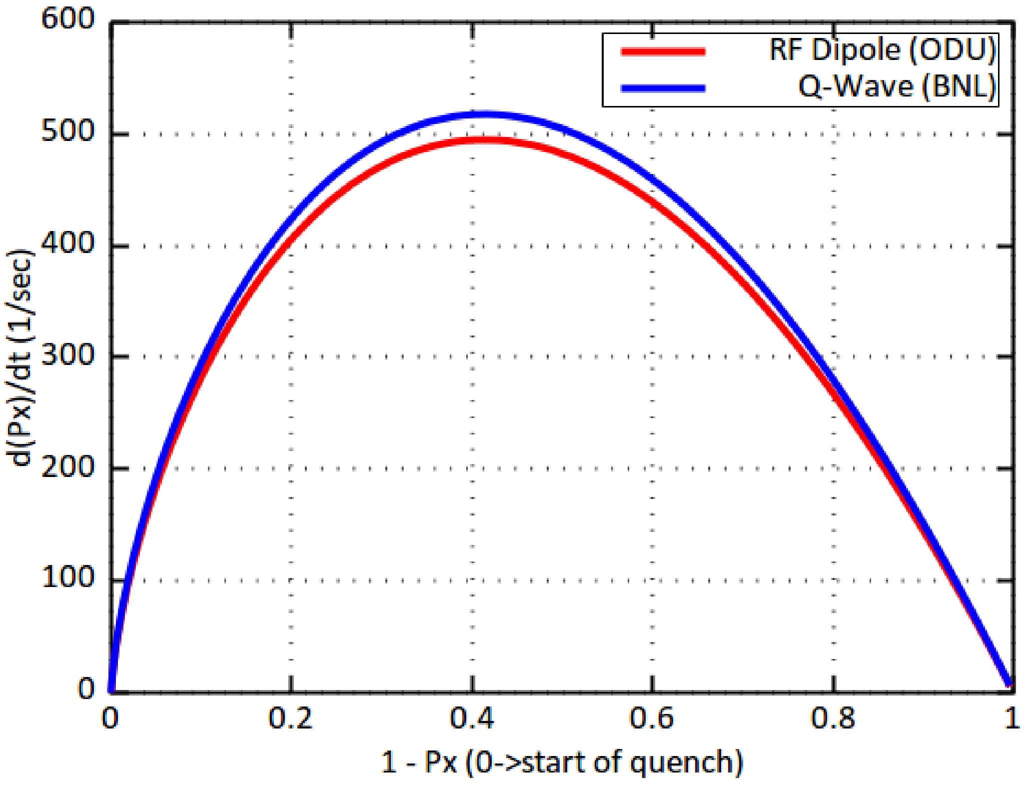




	RF Dipole (ODU)	¼ Wave (BNL)
Cavity Radius, mm	147.5	142.5
Cavity Length, mm	~ 600	~ 400
Beam Pipe, mm	84	84
Frequency, MHz	400	400
Peak E-field, MV/m	33	32.3
Peak B-field, mT	56	57.3
R_T/Q, Ω	574	636
Stored Energy, J	12	10.8

Crab cavity quench simulation





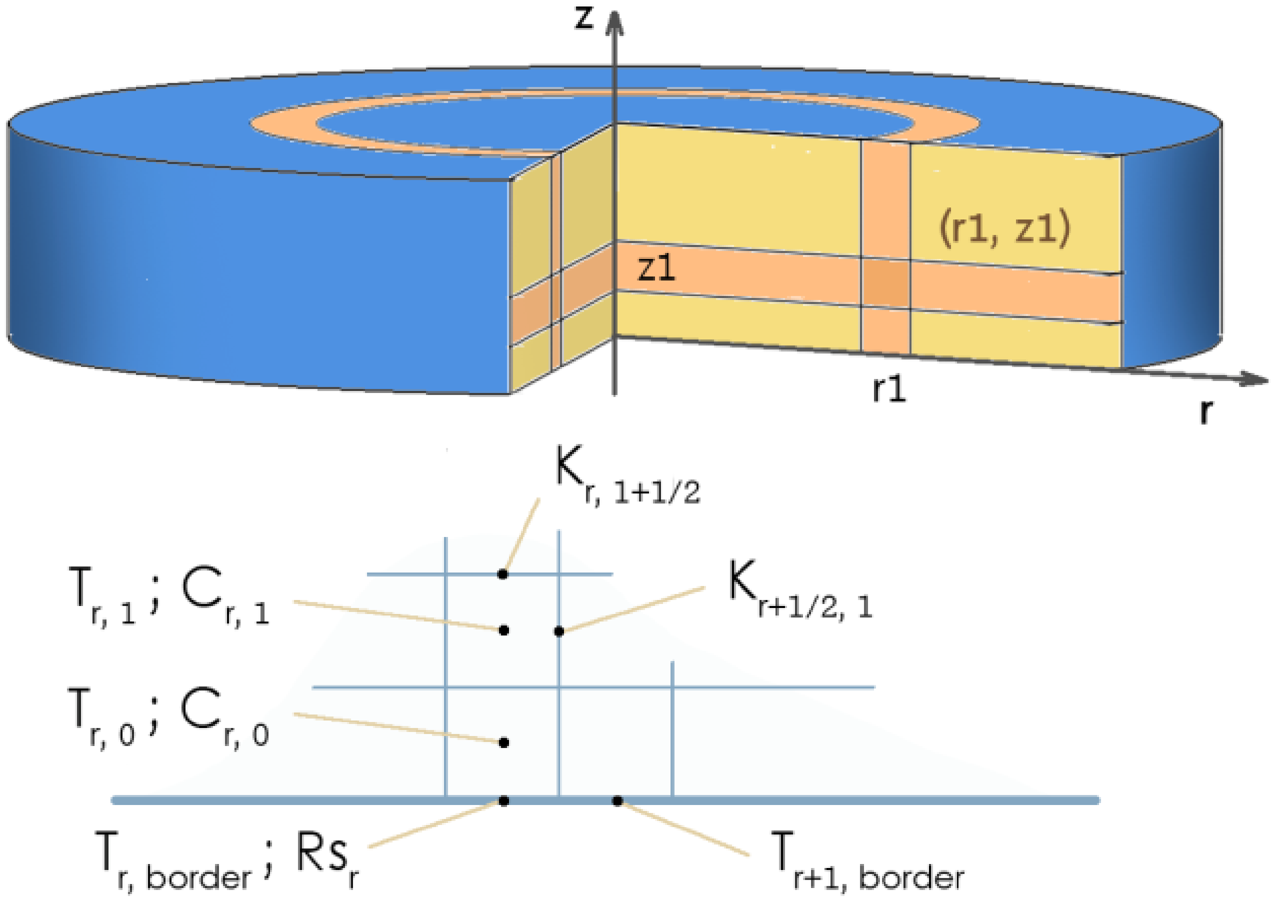
Crab cavity simulation summary

Parameter	RF Dipole (ODU)	¼ Wave (BNL)
Material	Nb, RRR = 300	Nb, RRR = 300
Helium temperature	2 K	2 K
Cavity wall thickness	4 mm	4 mm
Initial peak E-field	34 MV/m	32.7 MV/m
Radius of thermal defect	0.4 mm	0.37 mm
Time constant of energy consumption	2 ms	2 ms
Max growth rate	20 m/s	20 m/s
Max radius of normal conducting zone	5 cm	4.5 cm

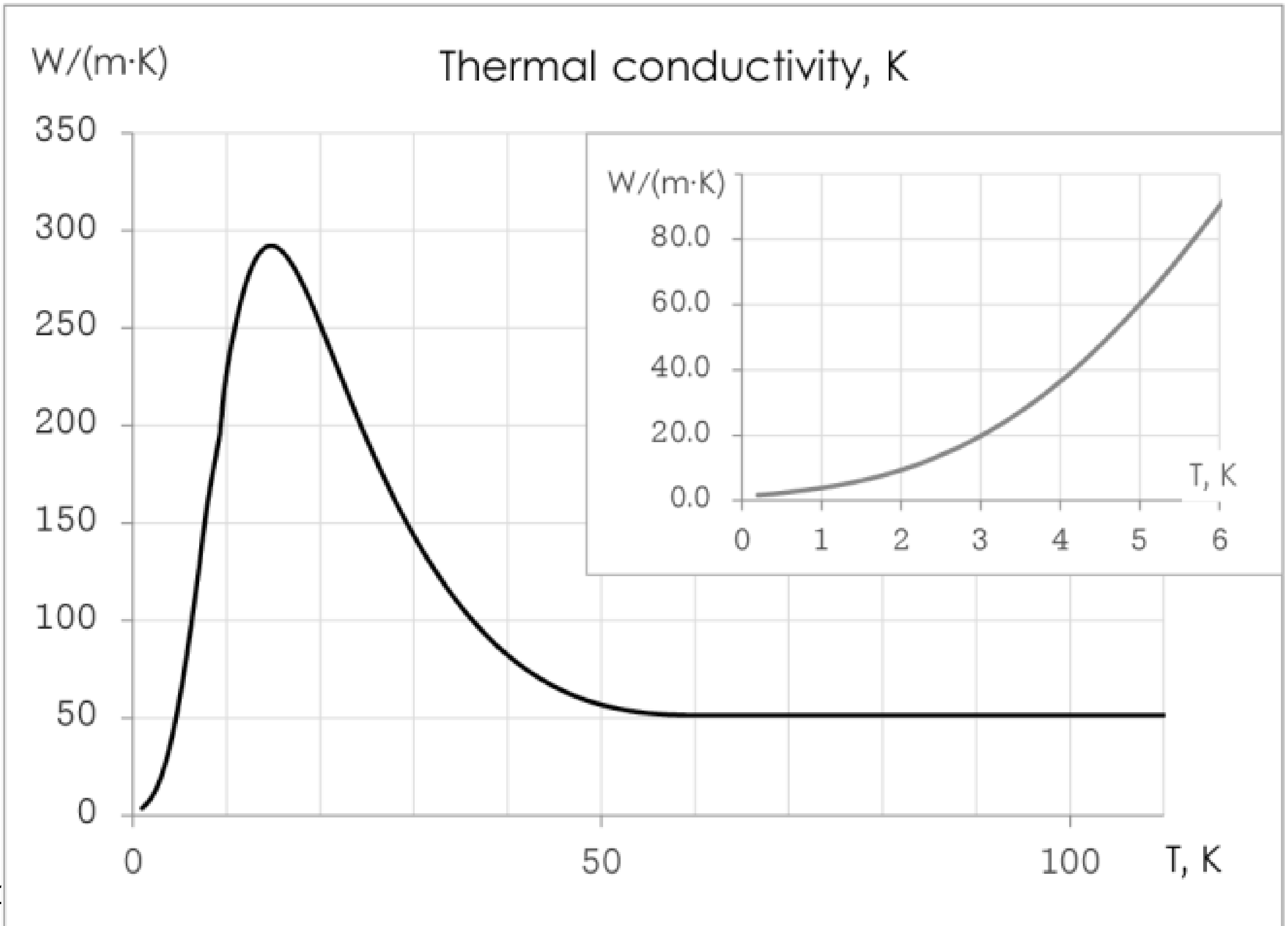
The End.

Backups.

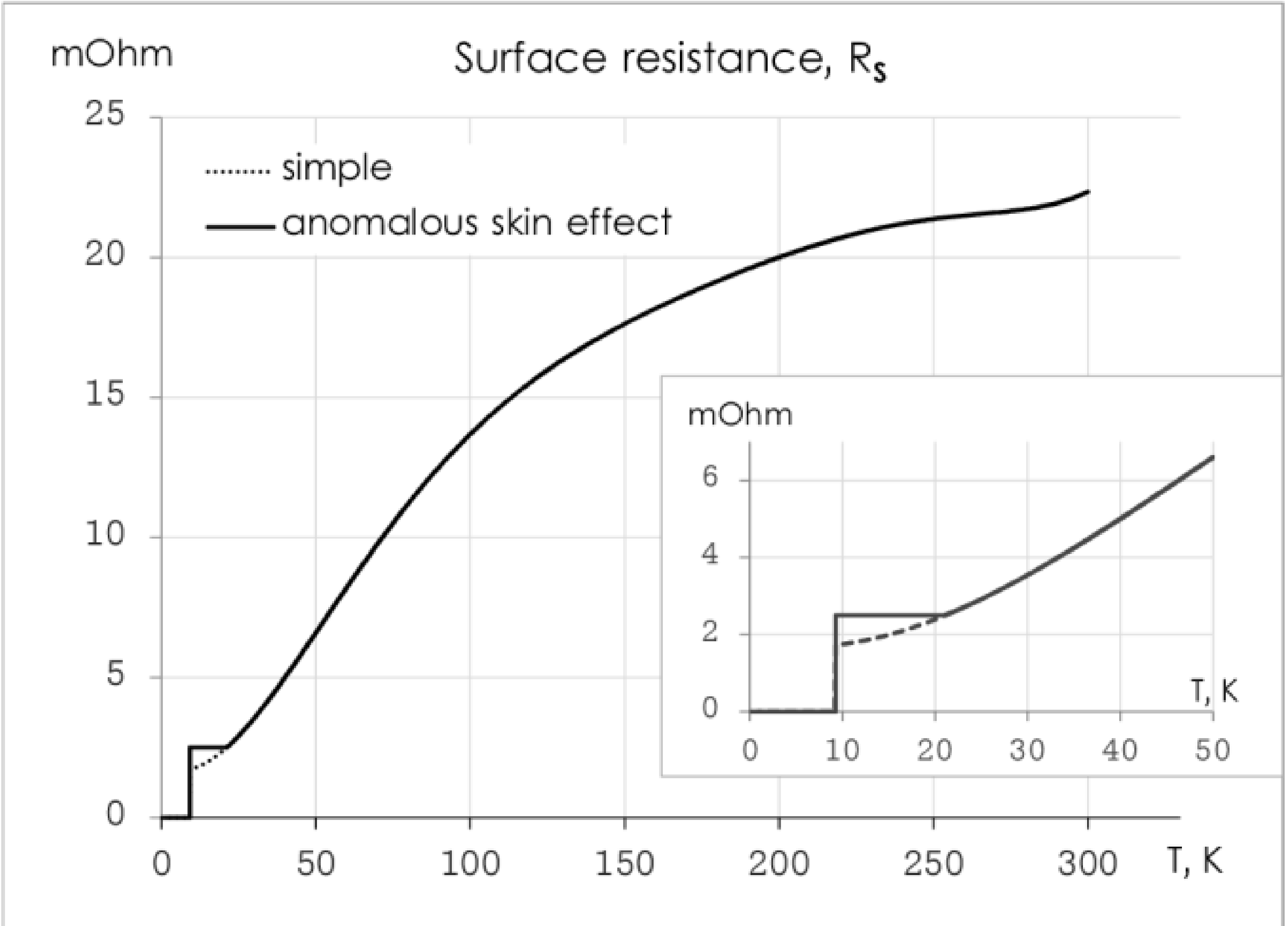
Numeric grid



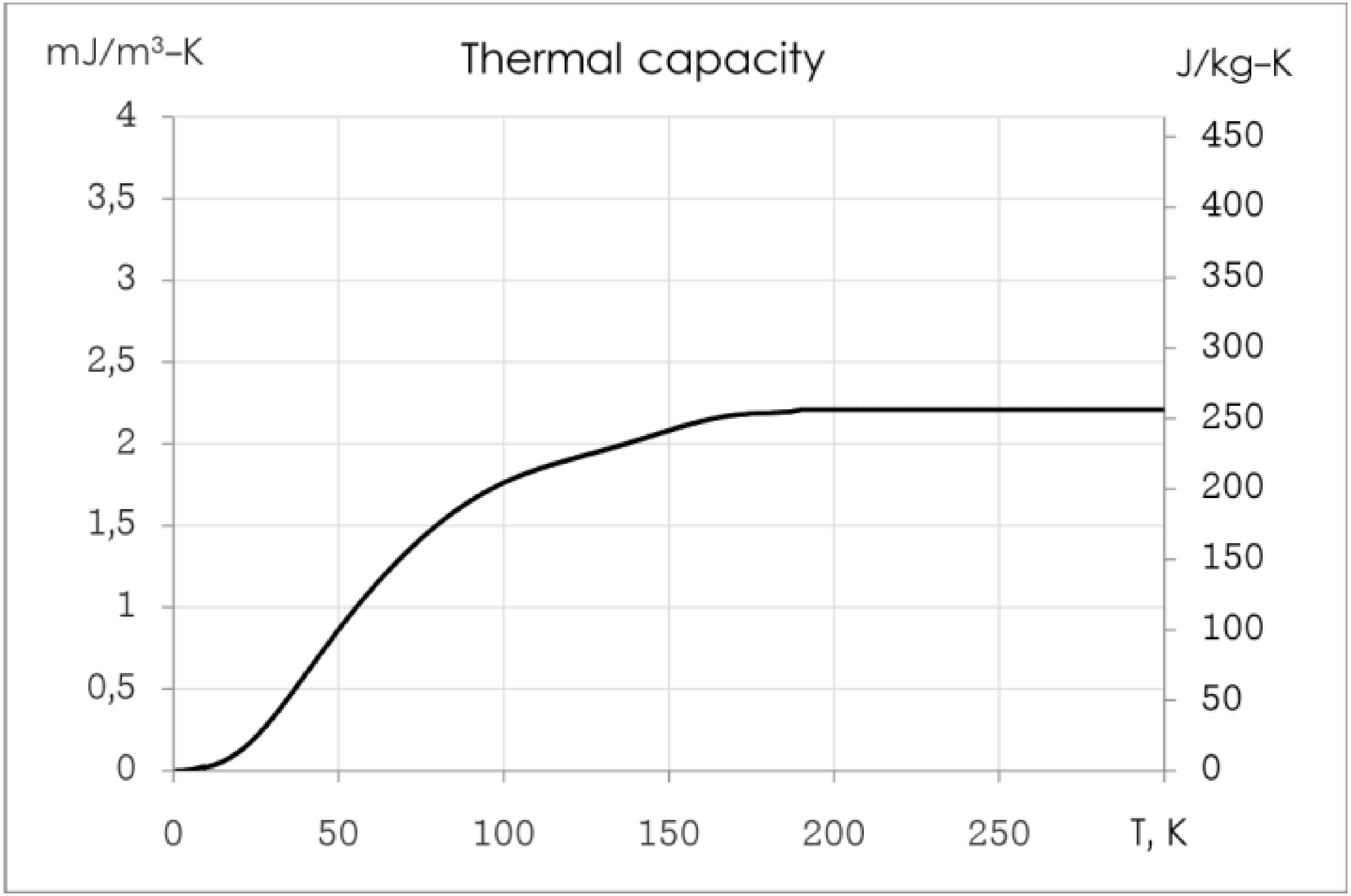
Nb thermal conductivity



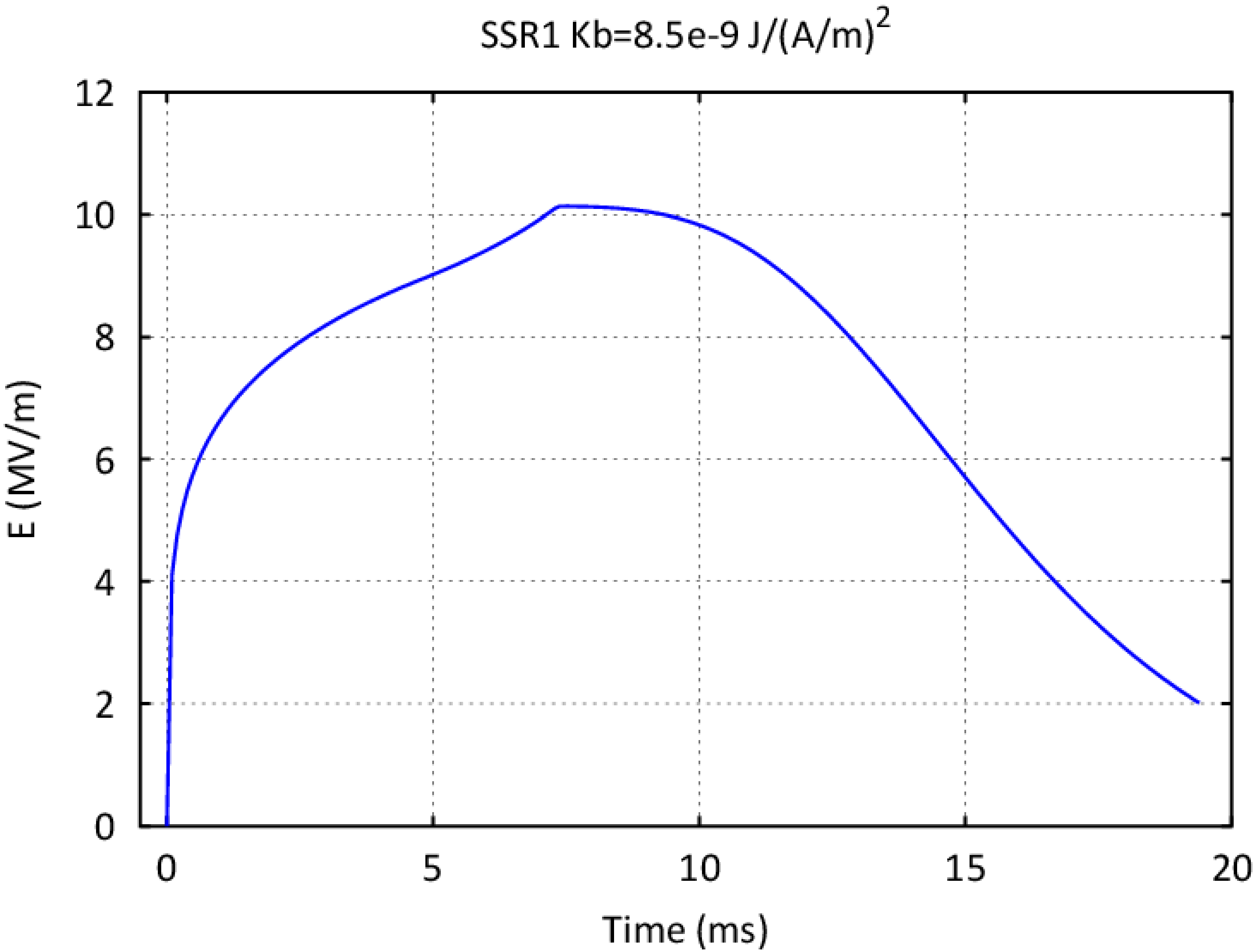
Nb surface resistance



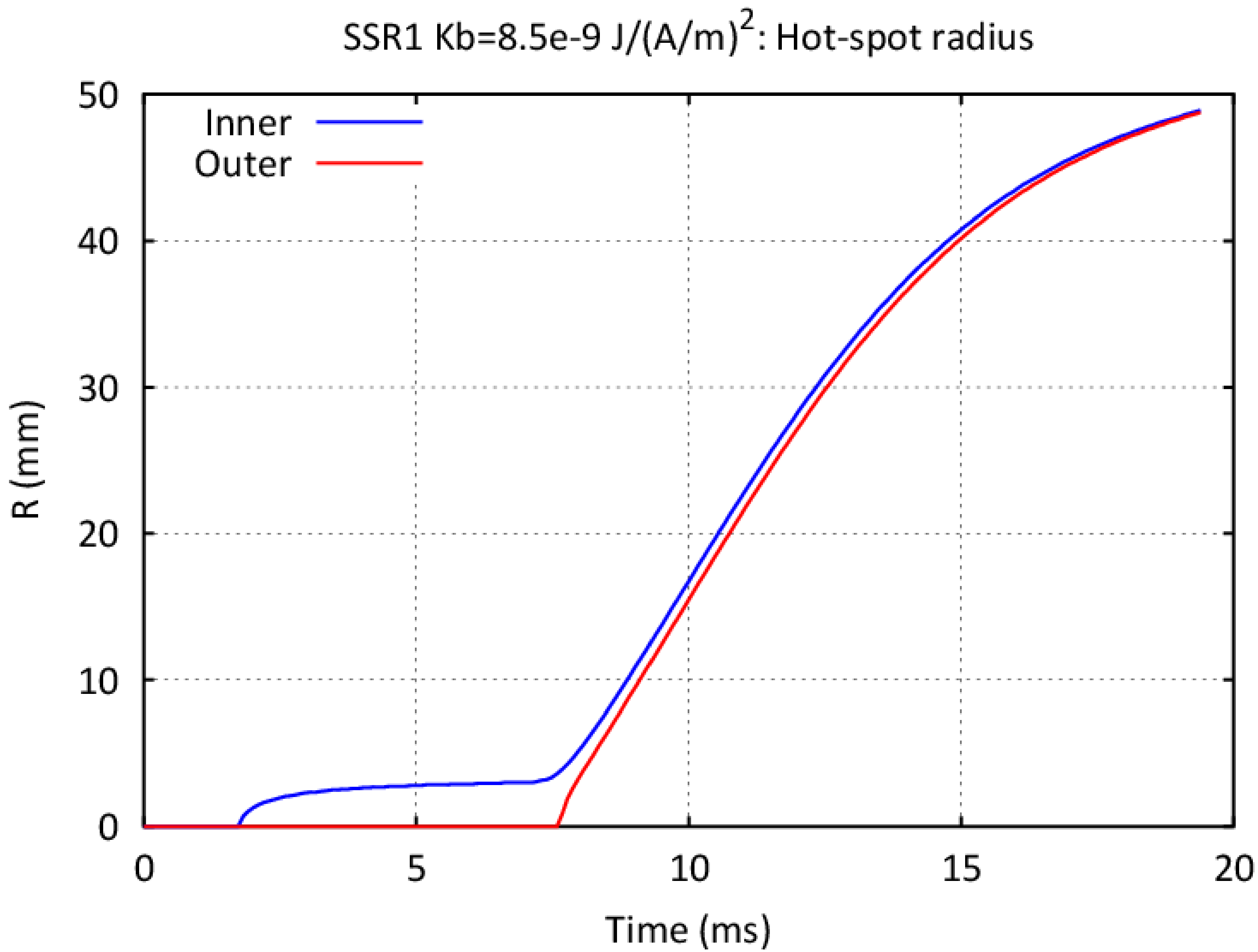
Nb heat capacity



Accel gradient evolution during quench



Hot-spot evolution during quench



Quench time vs gradient (earlier results).