Improving Flux Expulsion & Proposals

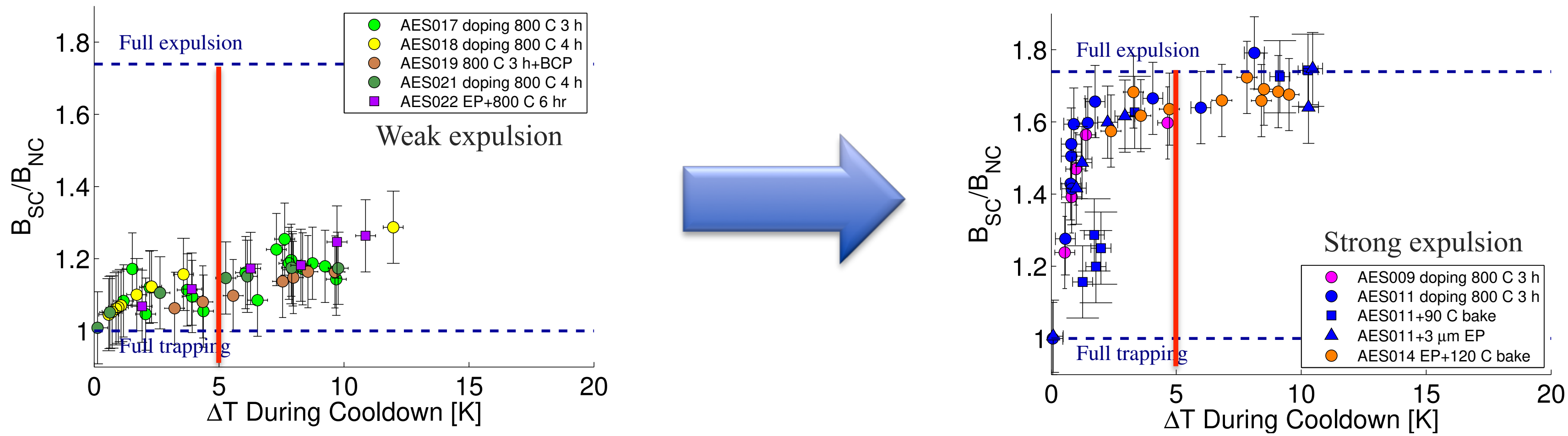
Sam Posen

Flux Expulsion Meeting

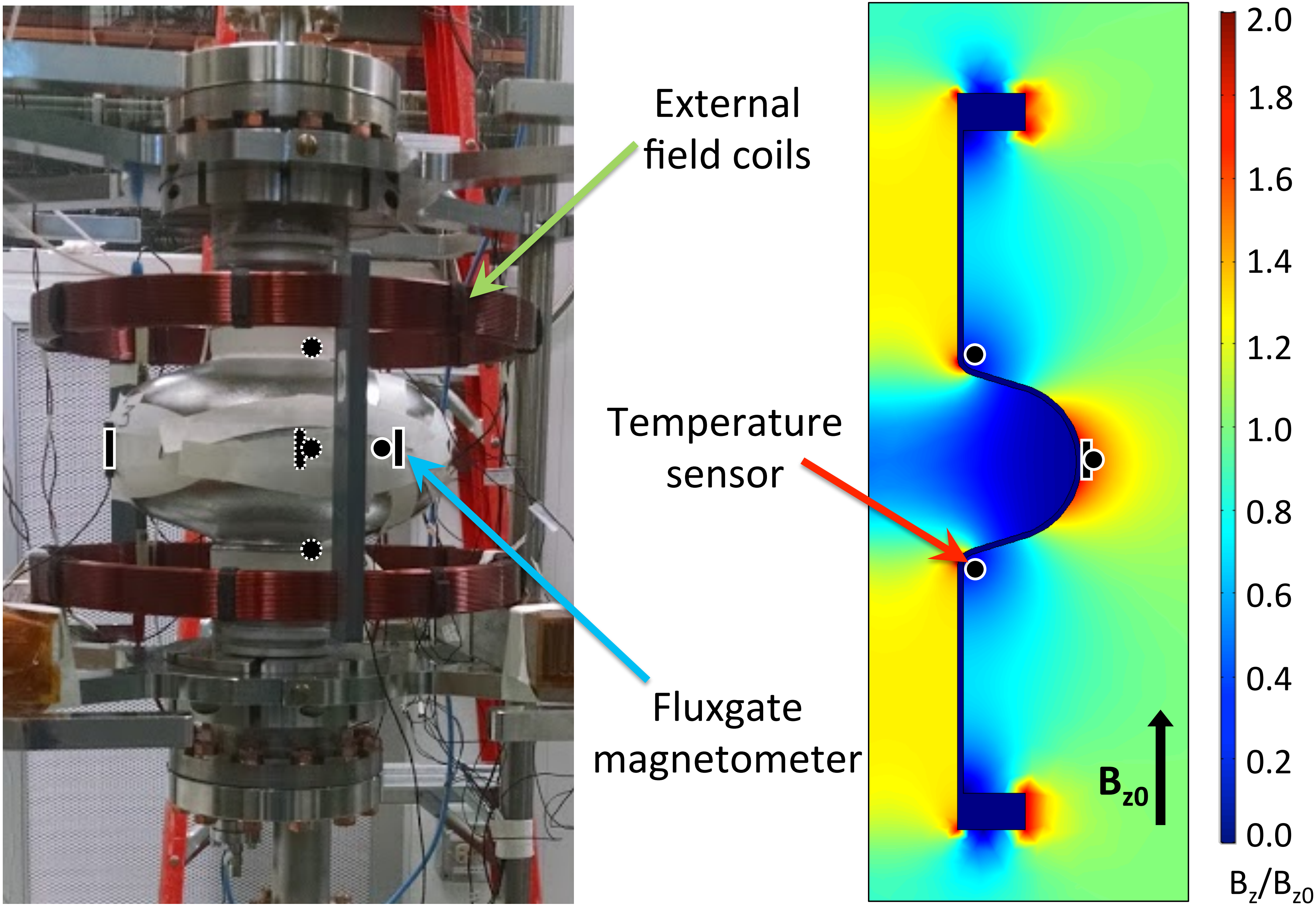
30 June 2016

Improving Expulsion

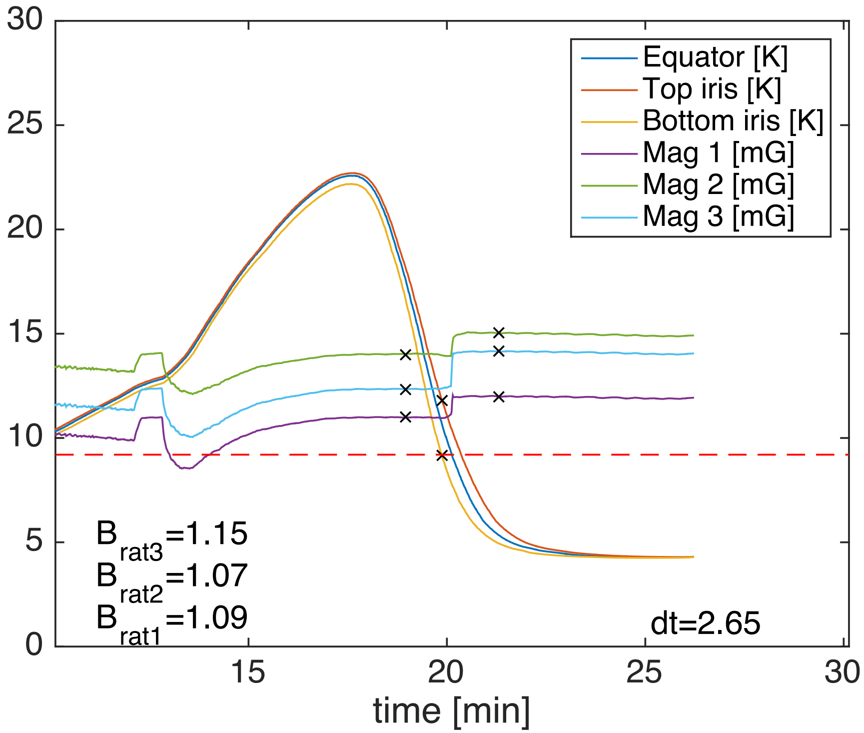
- First data shows poor flux expulsion in the LCLS-II material
- How do we convert material that shows poor expulsion? We want a “cure” that brings about stronger expulsion

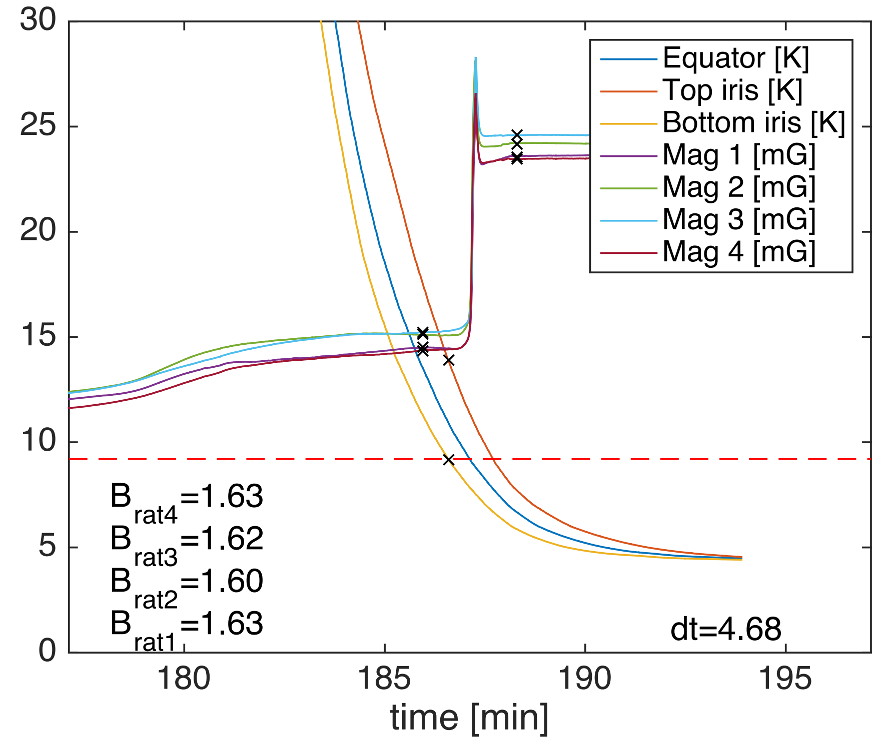


- Our experiments show that a 900°C furnace treatment can dramatically improve expulsion behavior
- I will review this data, then discuss proposed next steps


External field coils
Temperature sensor
Fluxgate magnetometer
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
B_z/B_{z0}
B_{z0}

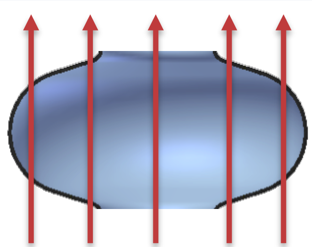
Measuring Expulsion

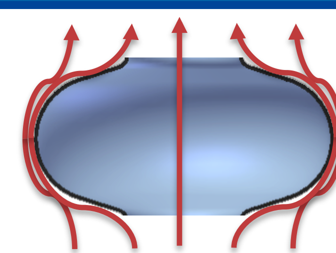




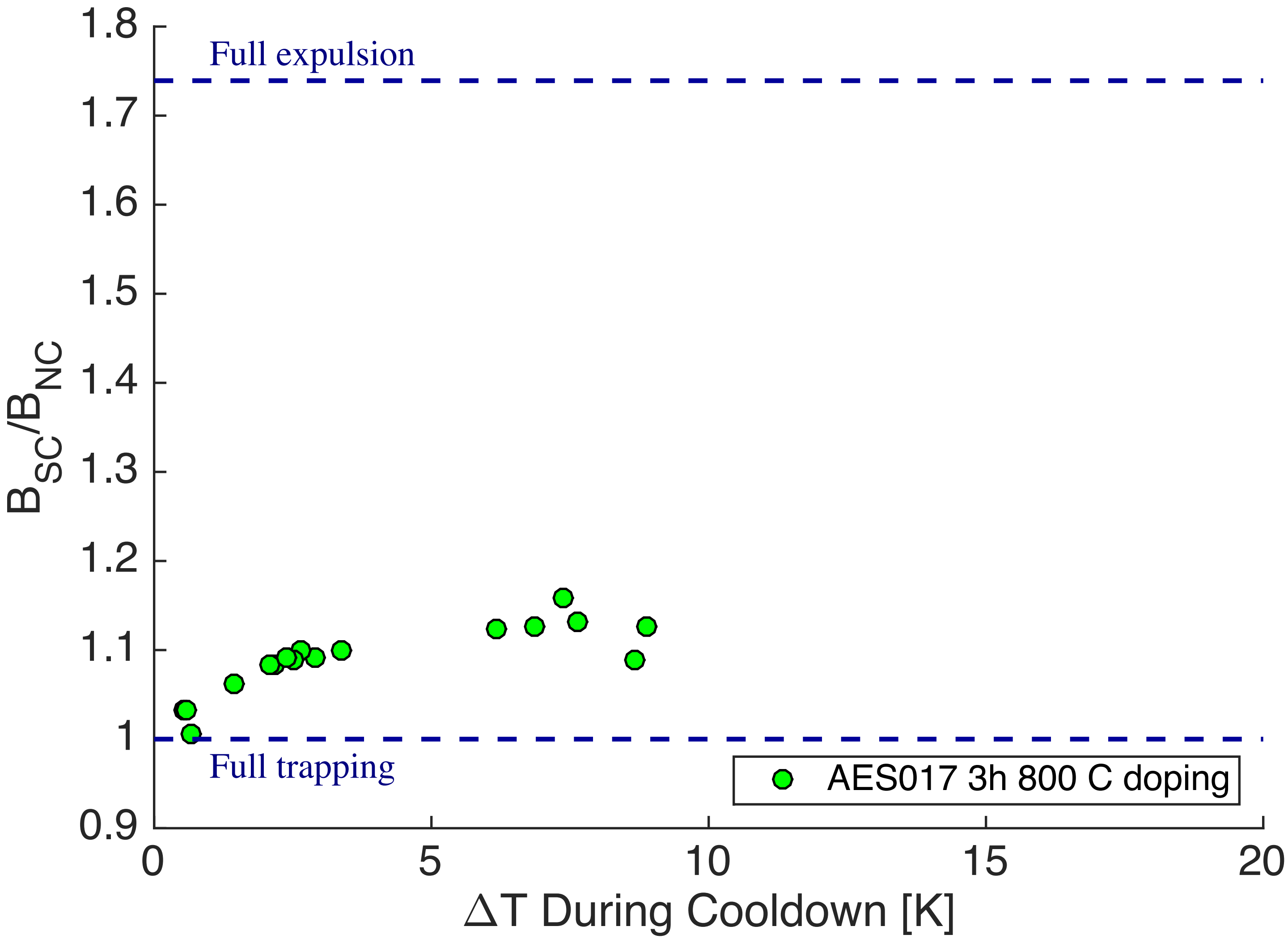
Poor expulsion: $B_{SC}/B_{NC} \sim 1.1$

Good expulsion: $B_{SC}/B_{NC} \sim 1.6$



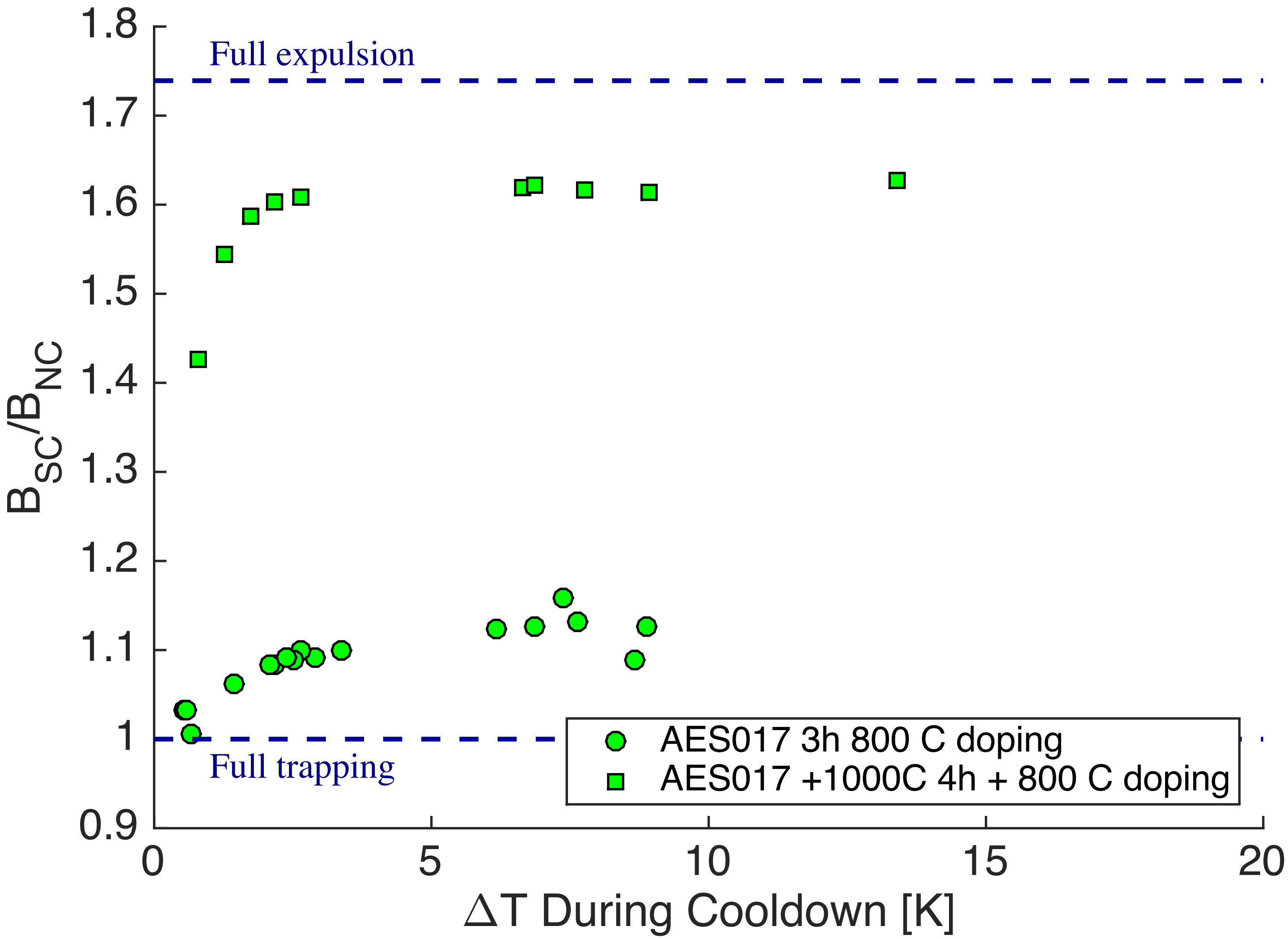


TE1AES017 – Baseline



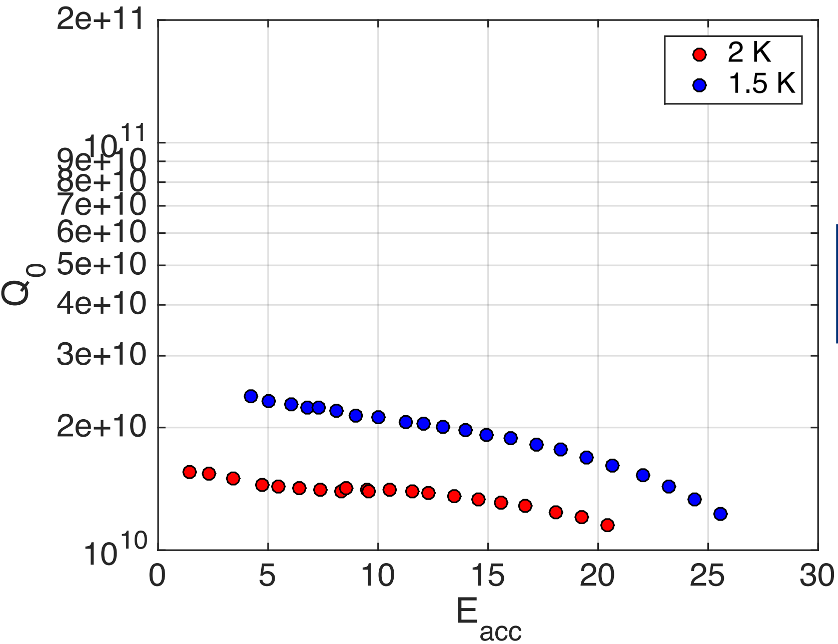
TE1AES017 – 1000°C 4 h

TE1AES017 – 1000°C 4 h

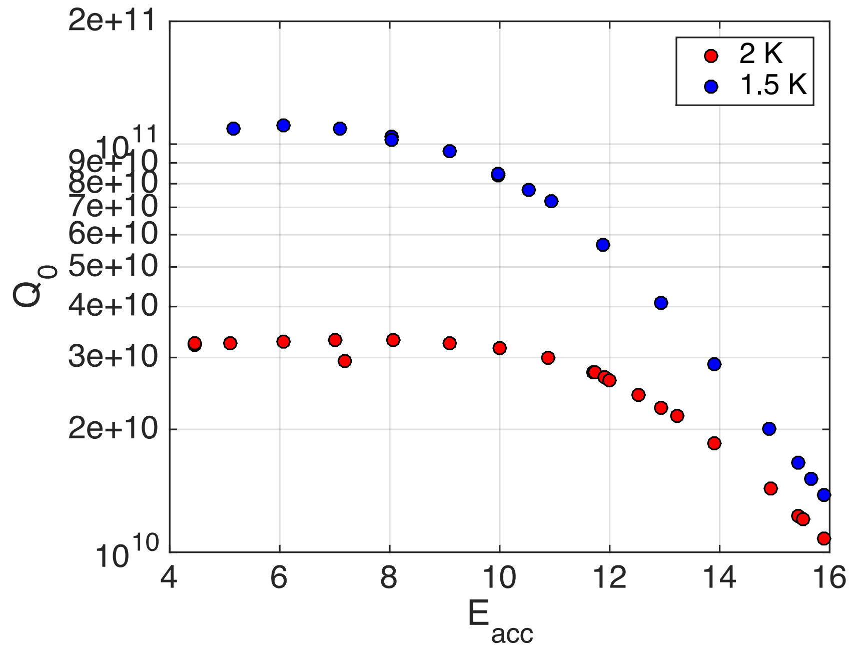


TE1AES017 – RF Data

AES017 cooled in 10 mG



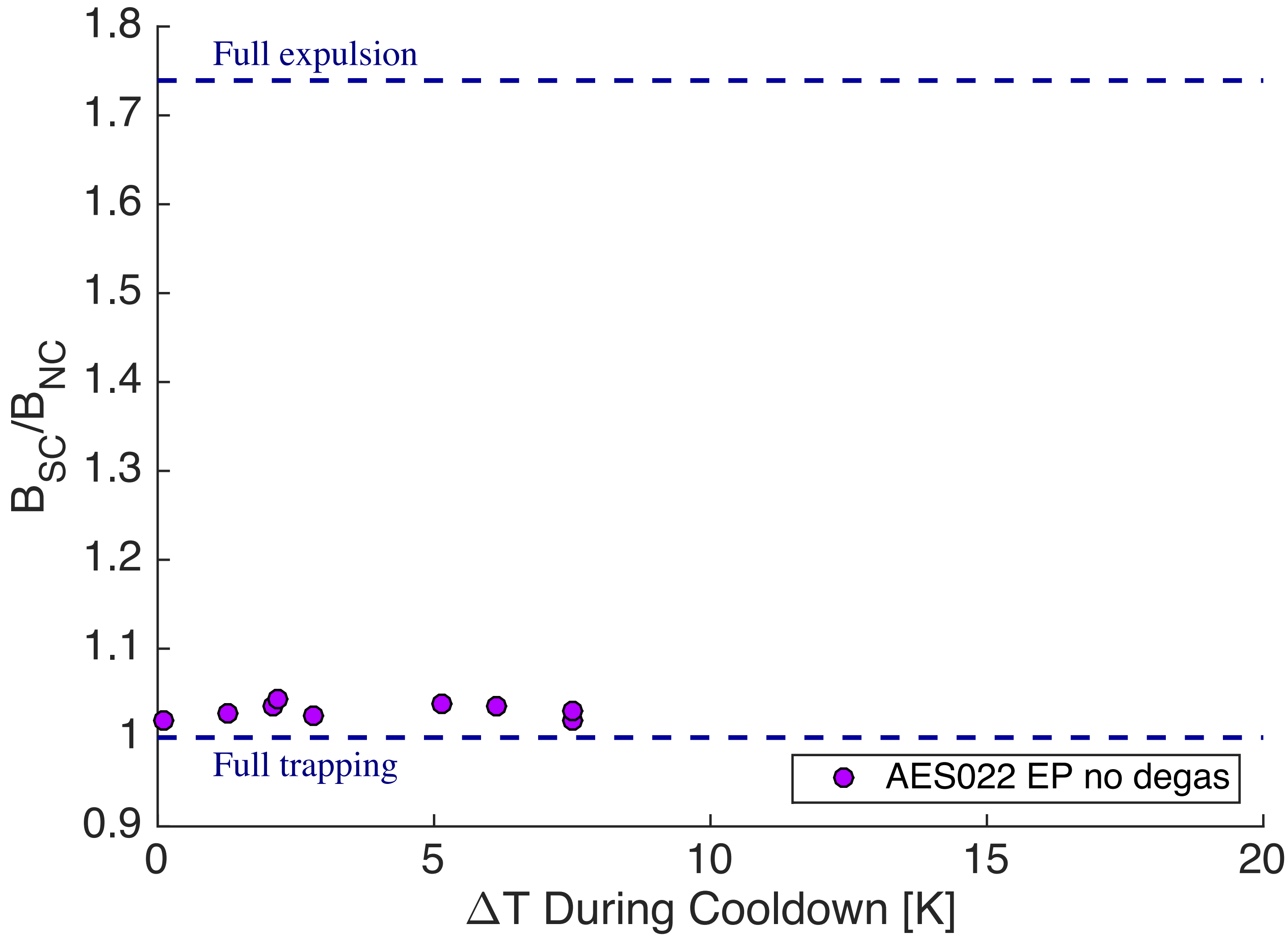
1000 C Bake



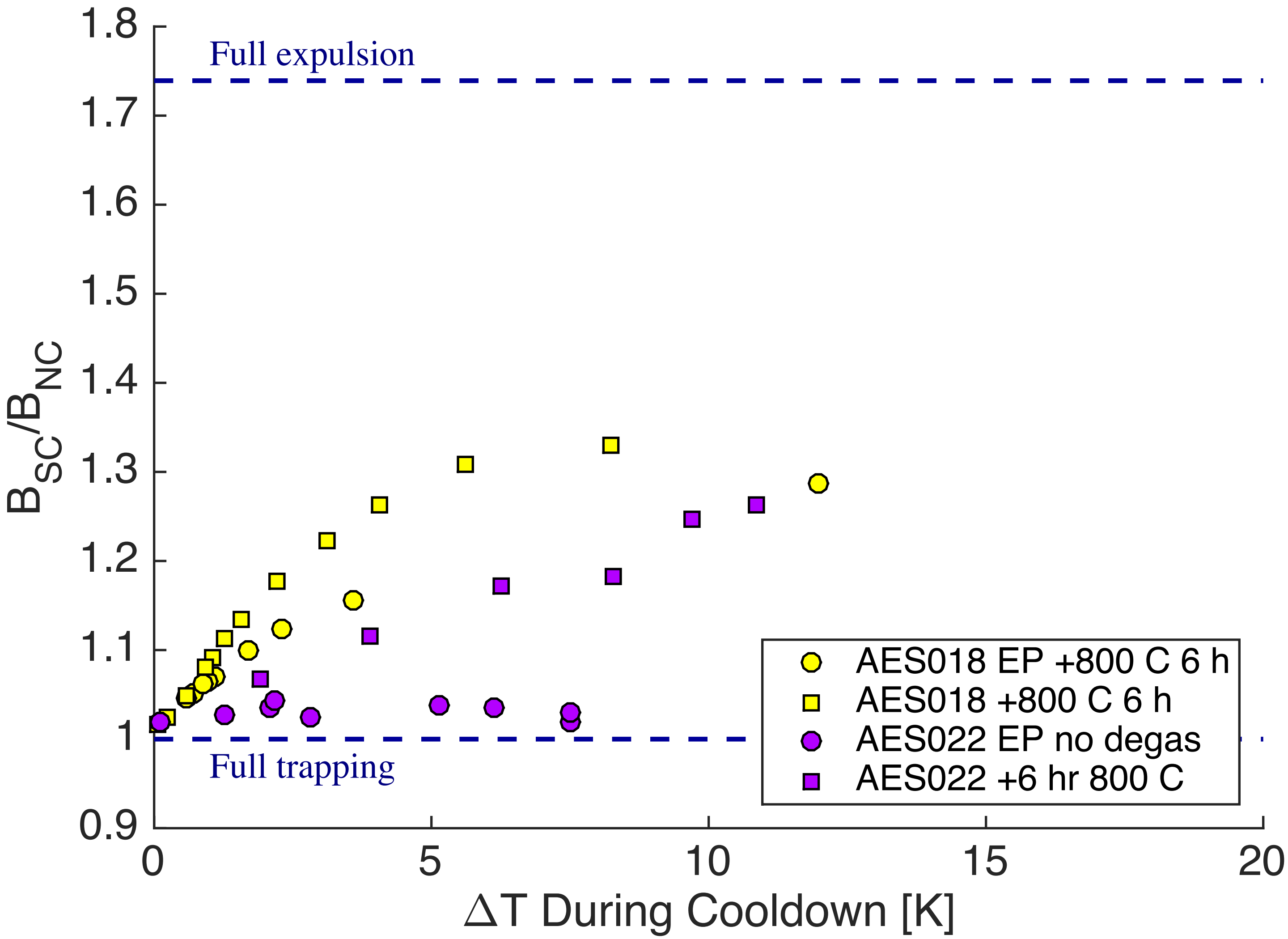
Poor expulsion: B_{SC}/B_{NC} ~ 1.1

Good expulsion: B_{SC}/B_{NC} ~ 1.6

TE1AES018 & TE1AES022 – Baseline (no furnace)

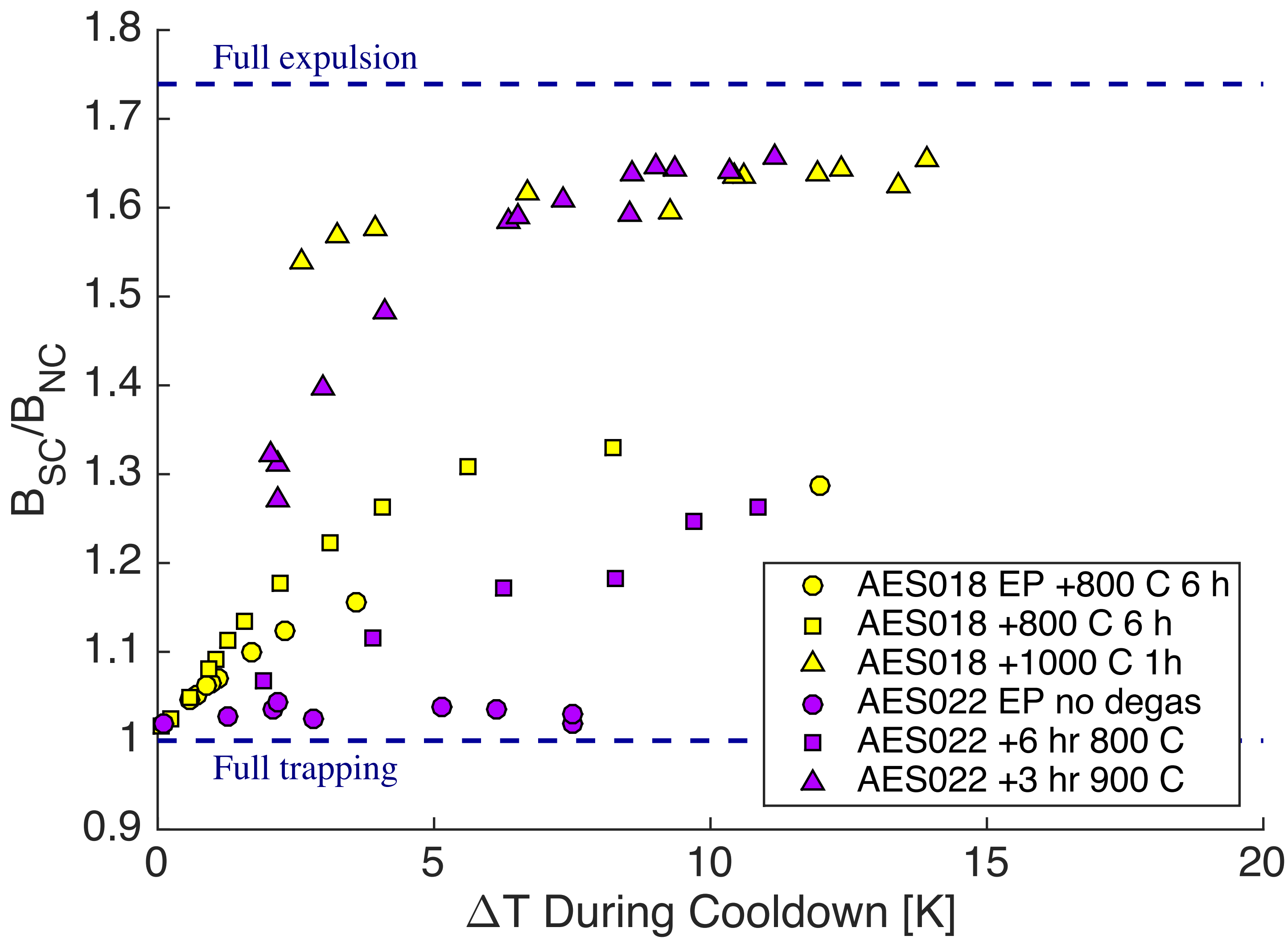


TE1AES018 & TE1AES022 – 800°C 6 h

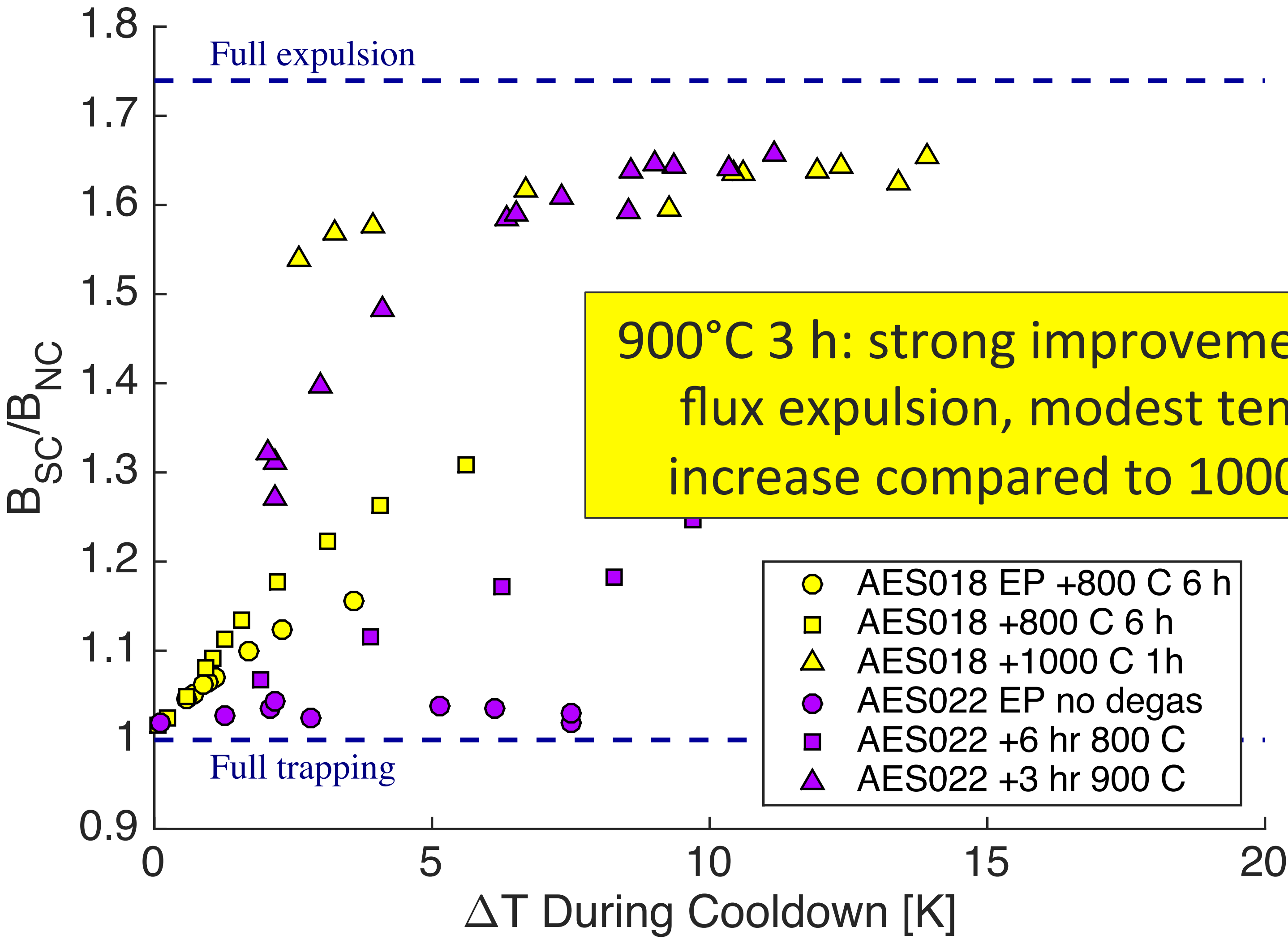


Fermilab

TE1AES018 & TE1AES022 – 1000°C 1 h & 900 C 3 h

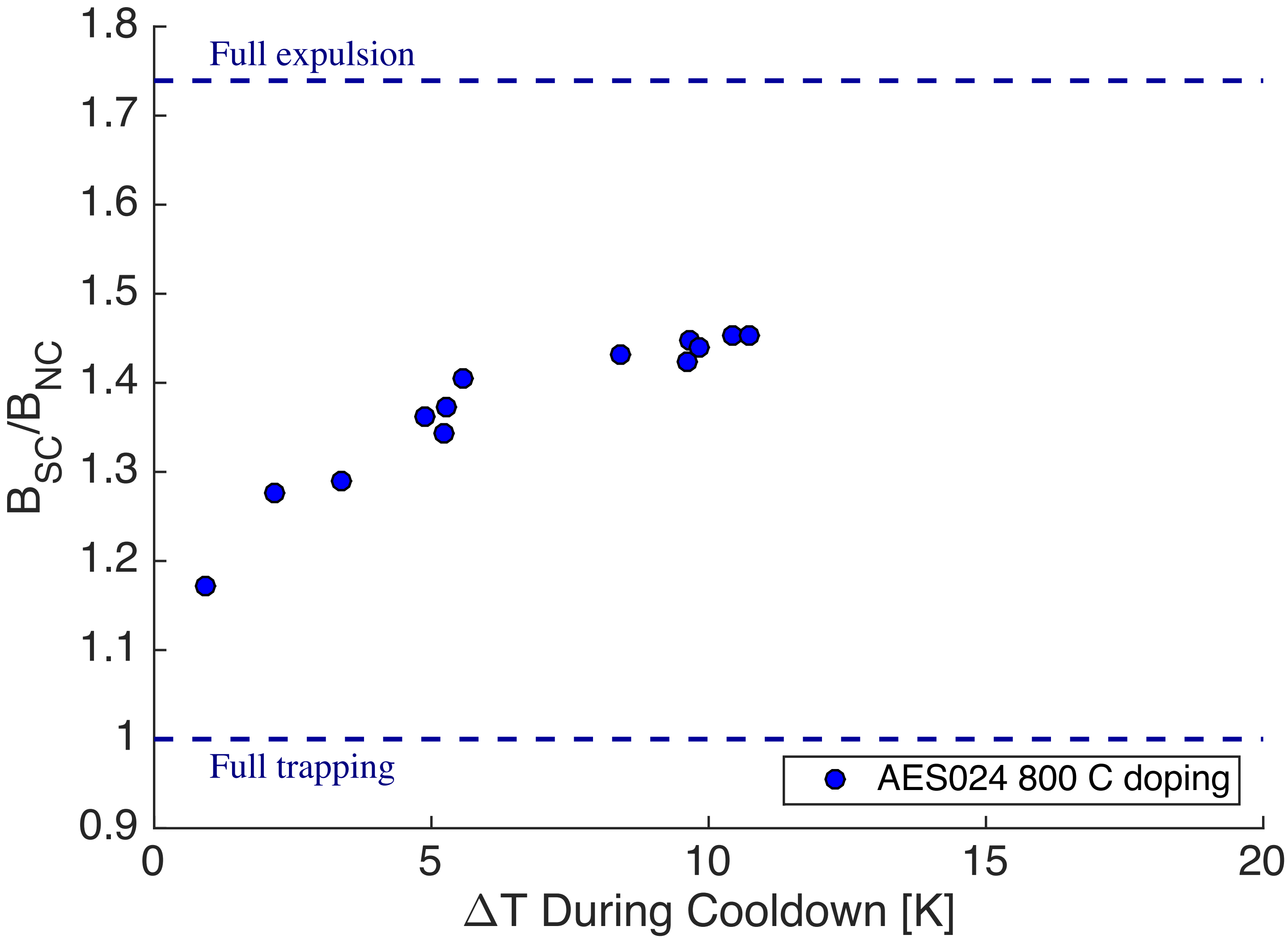


TE1AES018 & TE1AES022 – 1000°C 1 h & 900 C 3 h



900°C 3 h: strong improvement in flux expulsion, modest temp increase compared to 1000°C

TE1AES024 and TE1AES025 – Baseline



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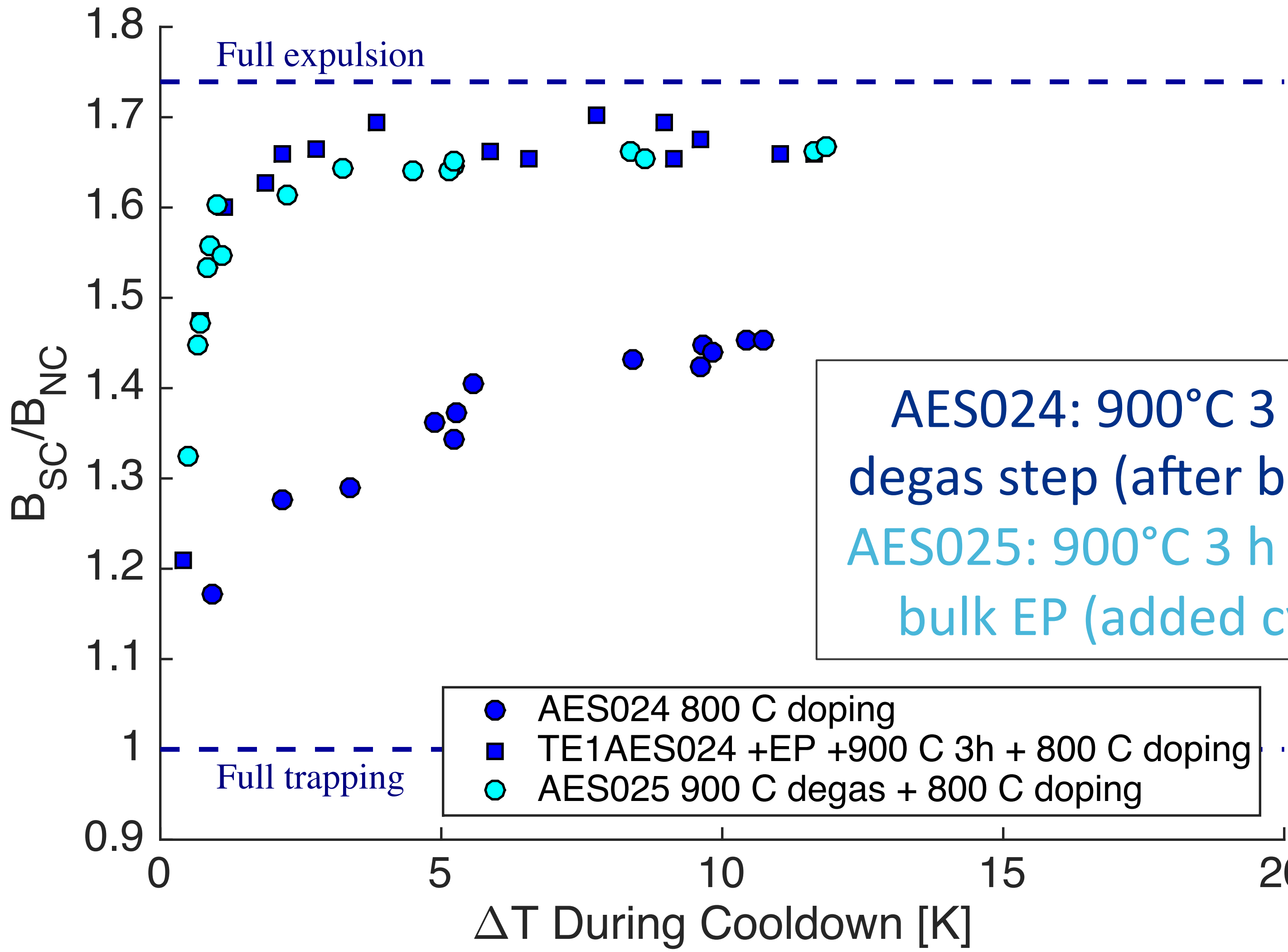
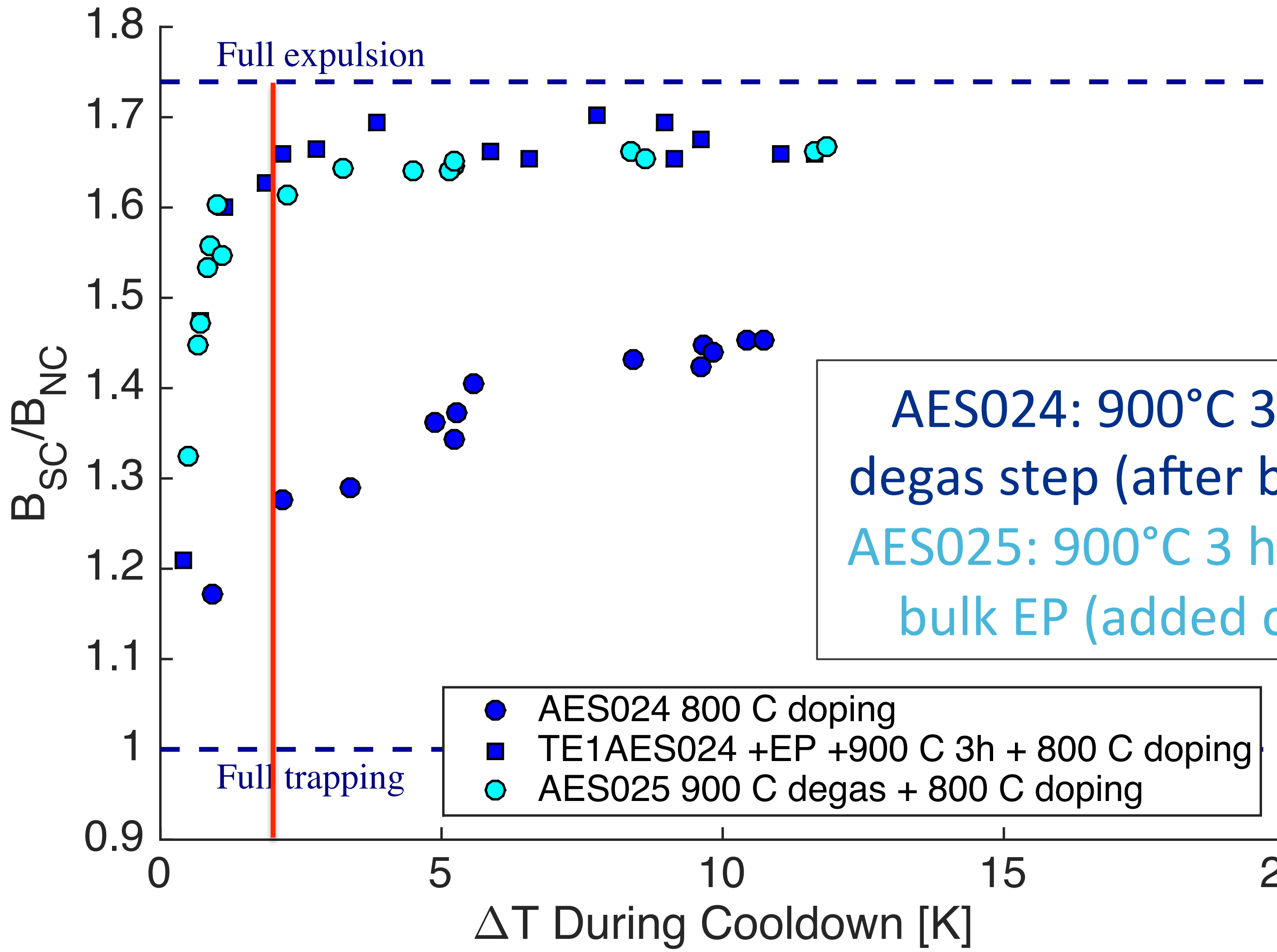
TE1AES024 and TE1AES025 – 900°C 3 h



AES024: 900°C 3 h for degas step (after bulk EP)

AES025: 900°C 3 h before bulk EP (added cycle)

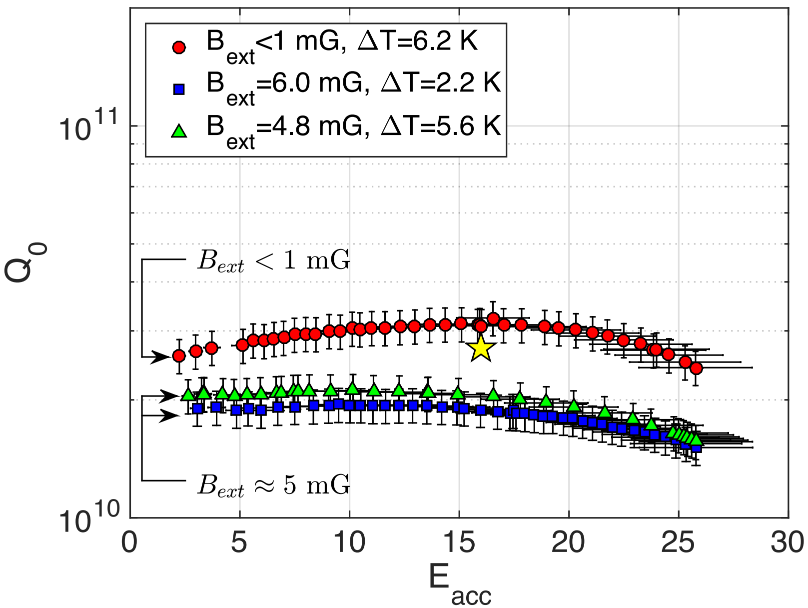
TE1AES024 and TE1AES025 – 900°C 3 h



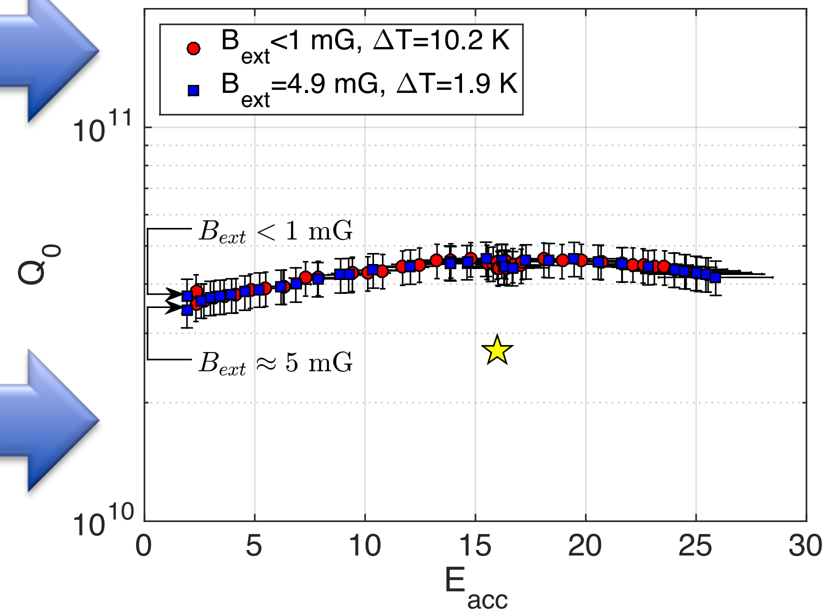
AES024: 900°C 3 h for degas step (after bulk EP)
AES025: 900°C 3 h before bulk EP (added cycle)

TE1AES024 and TE1AES025 – RF Data, 2.0 K

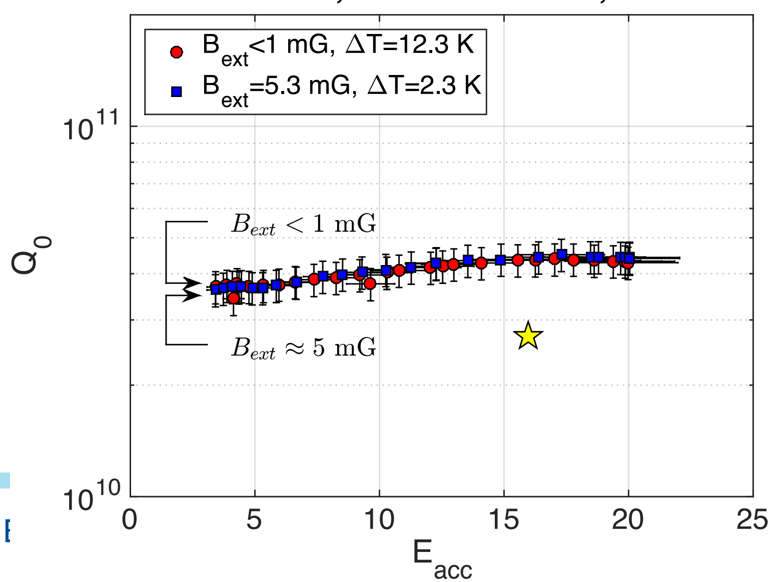
AES024, LCLS-II baseline recipe, 2 K



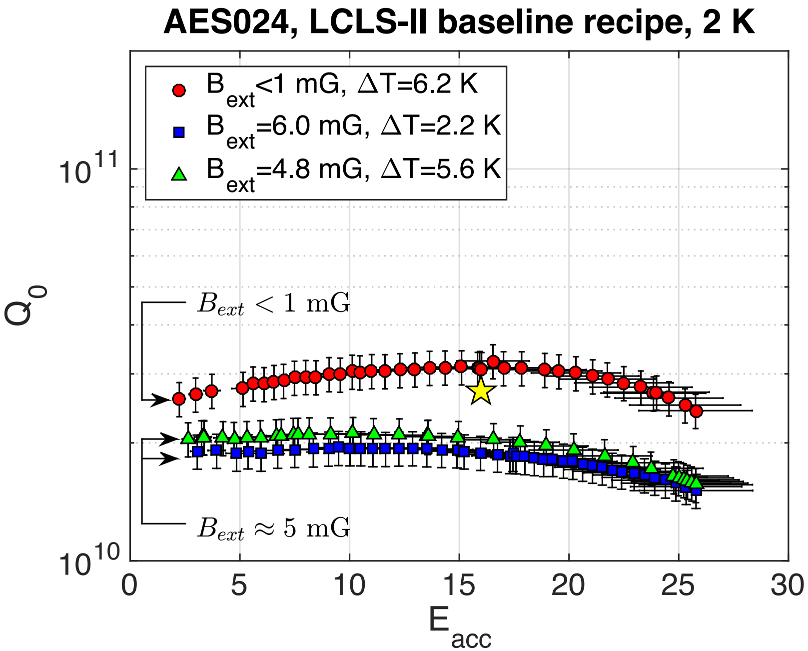
AES024, 900 C degas before doping, 2 K

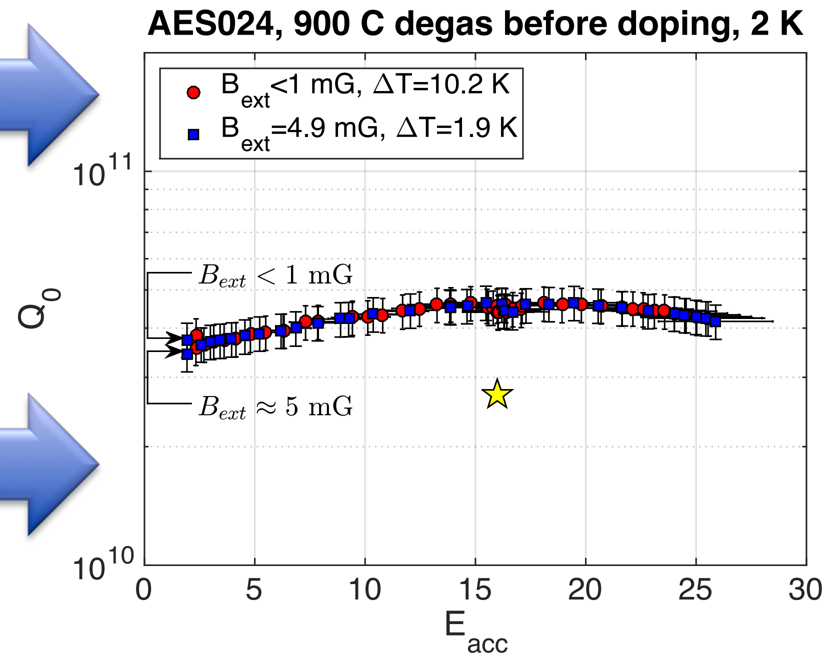


AES025, 900 C before EP, 2 K

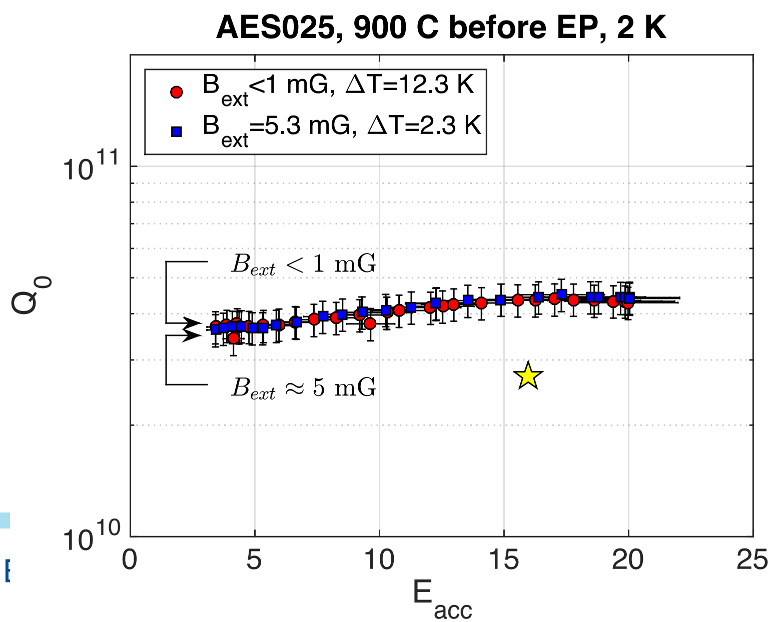


TE1AES024 and TE1AES025 – RF Data, 2.0 K



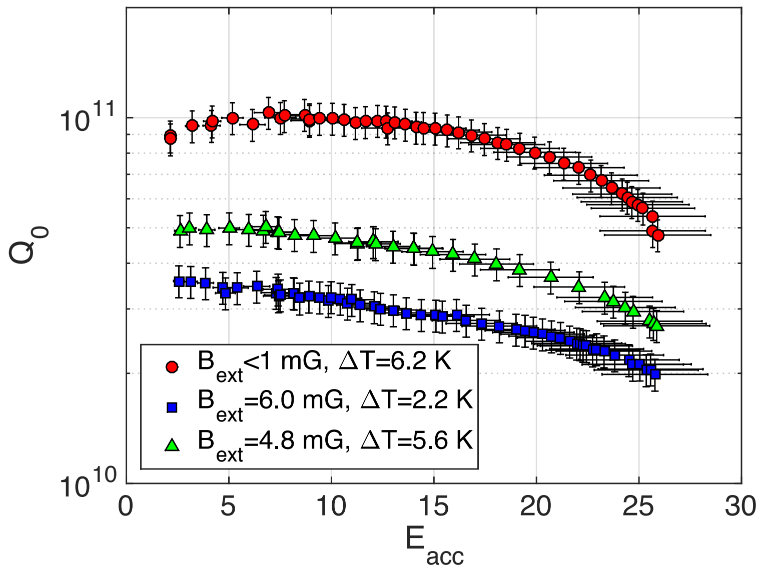


900°C 3 h substantially reduces Q_0 degradation in 5 mG field

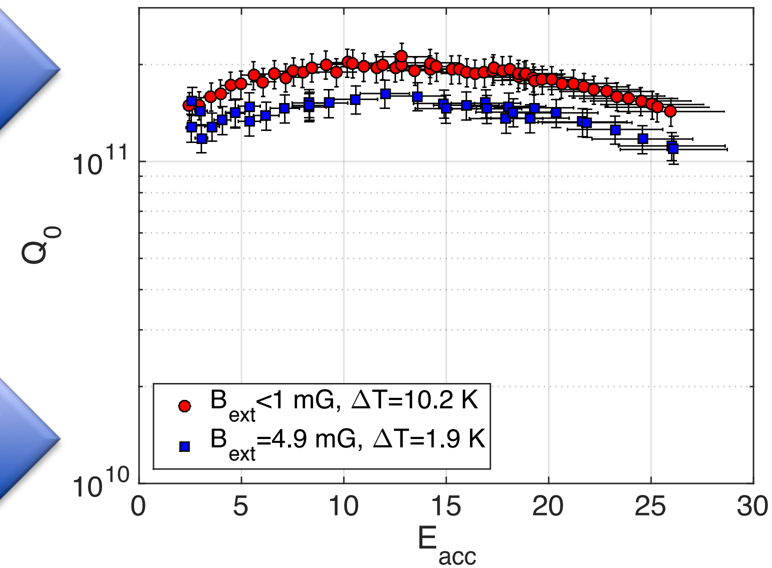


TE1AES024 and TE1AES025 – RF Data, 1.5 K

AES024, LCLS-II baseline recipe, low T

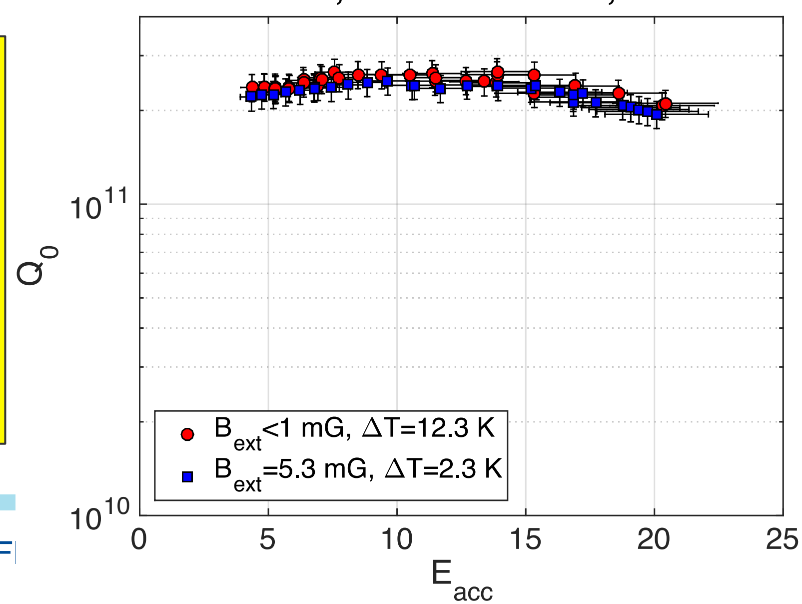


AES024, 900 C degas before doping, low T



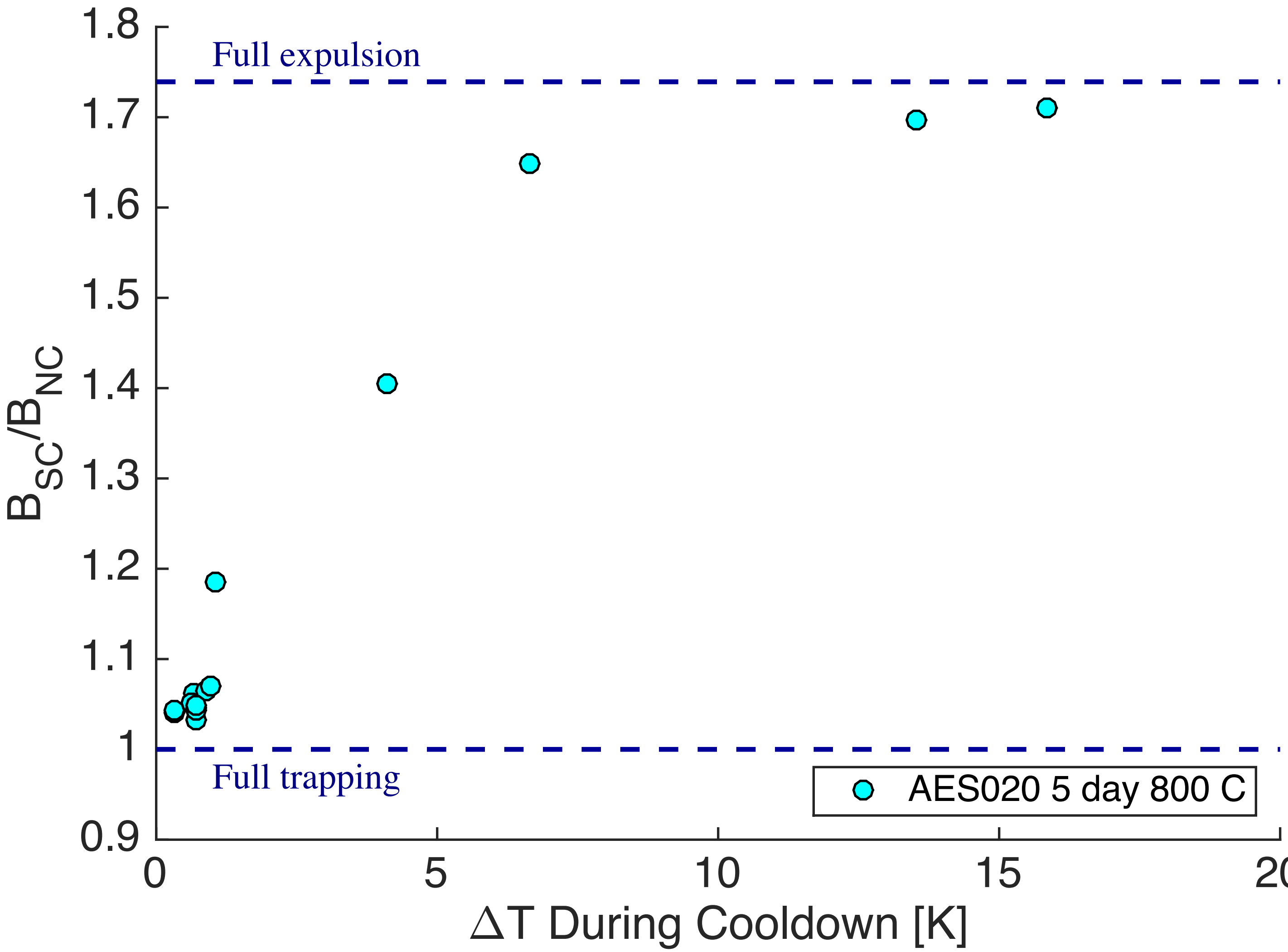
900°C 3 h substantially reduces Q_0 degradation in 5 mG field

AES025, 900 C before EP, low T

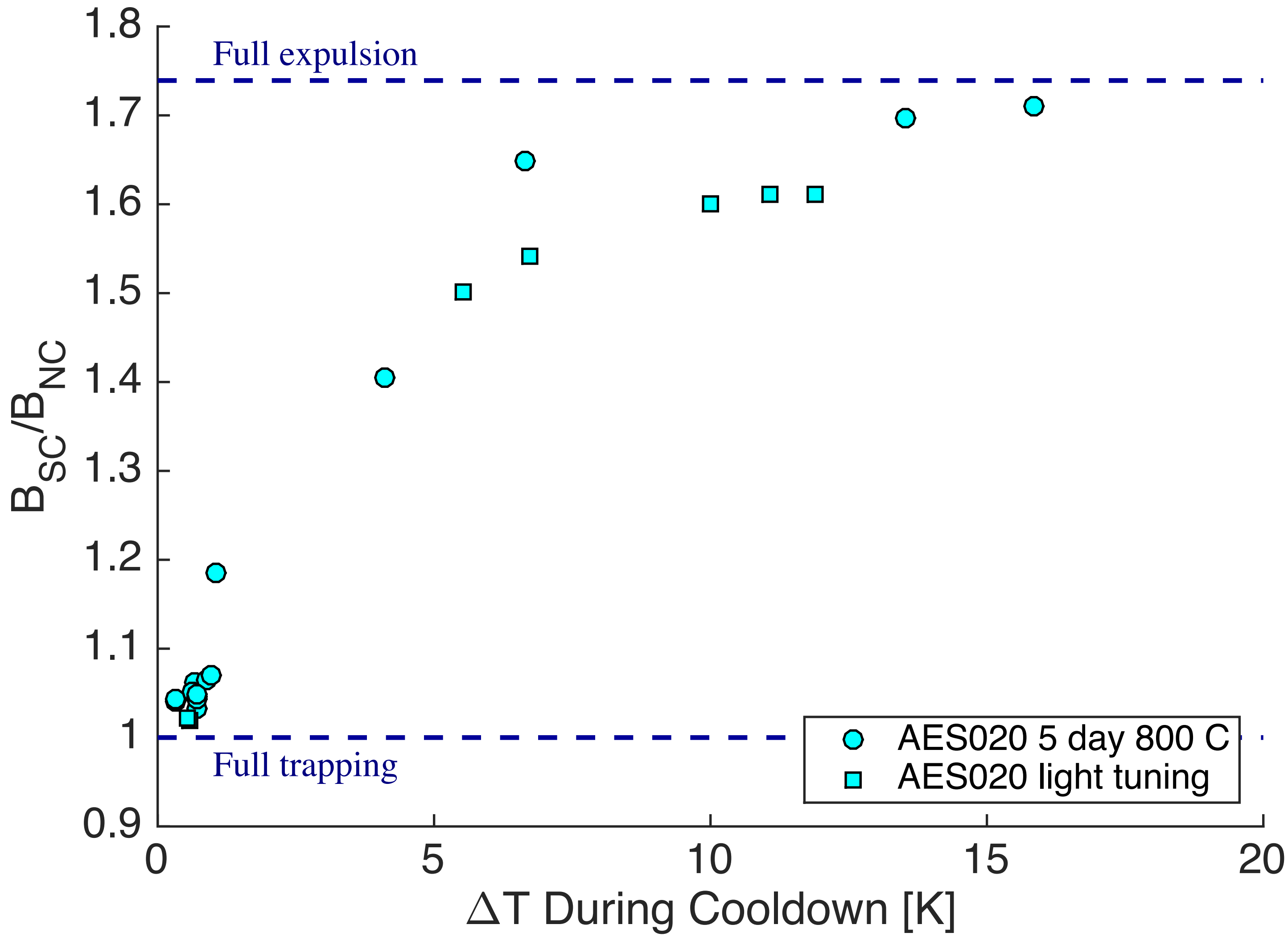


Fermilab

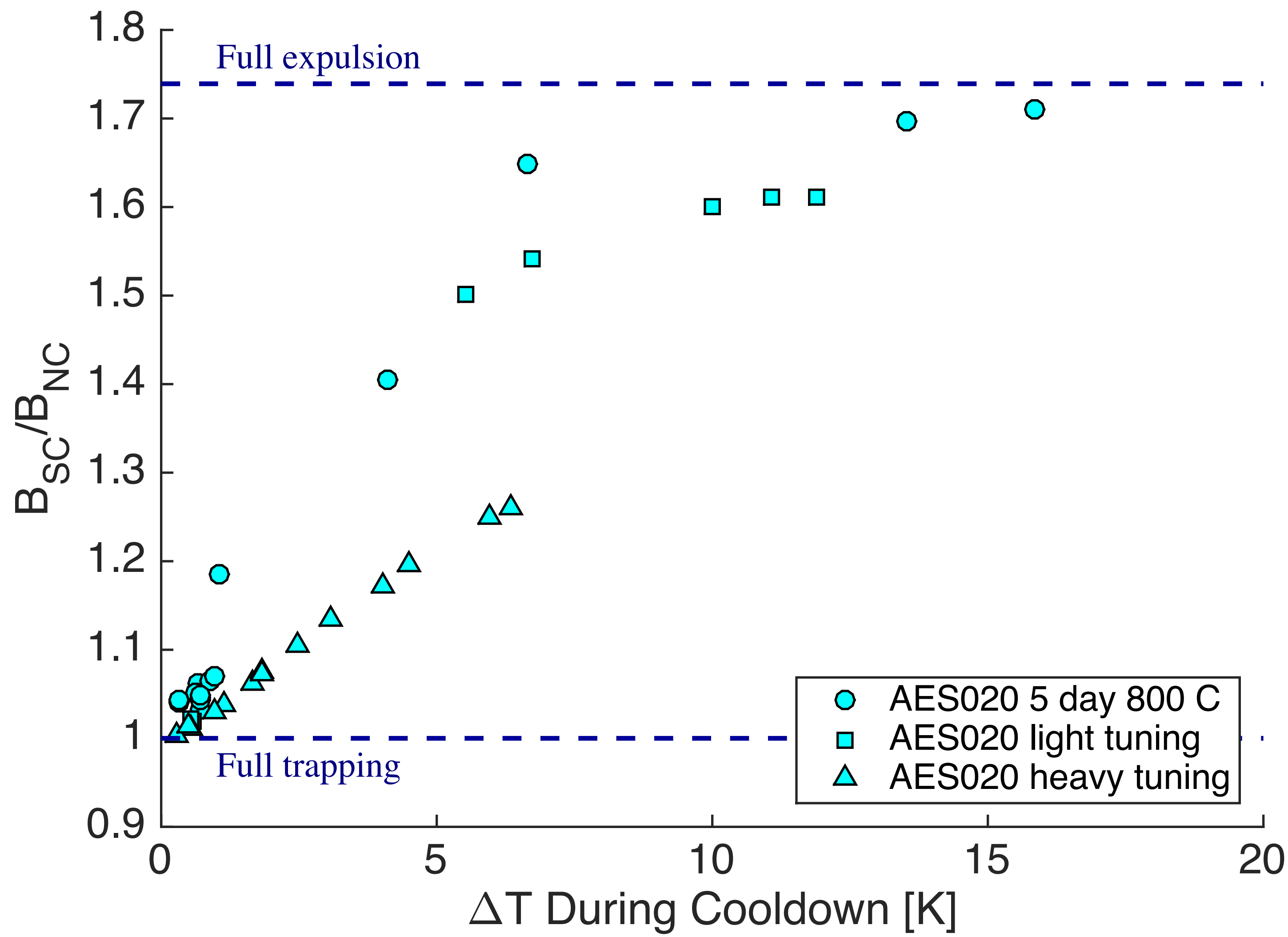
AES020 – Baseline



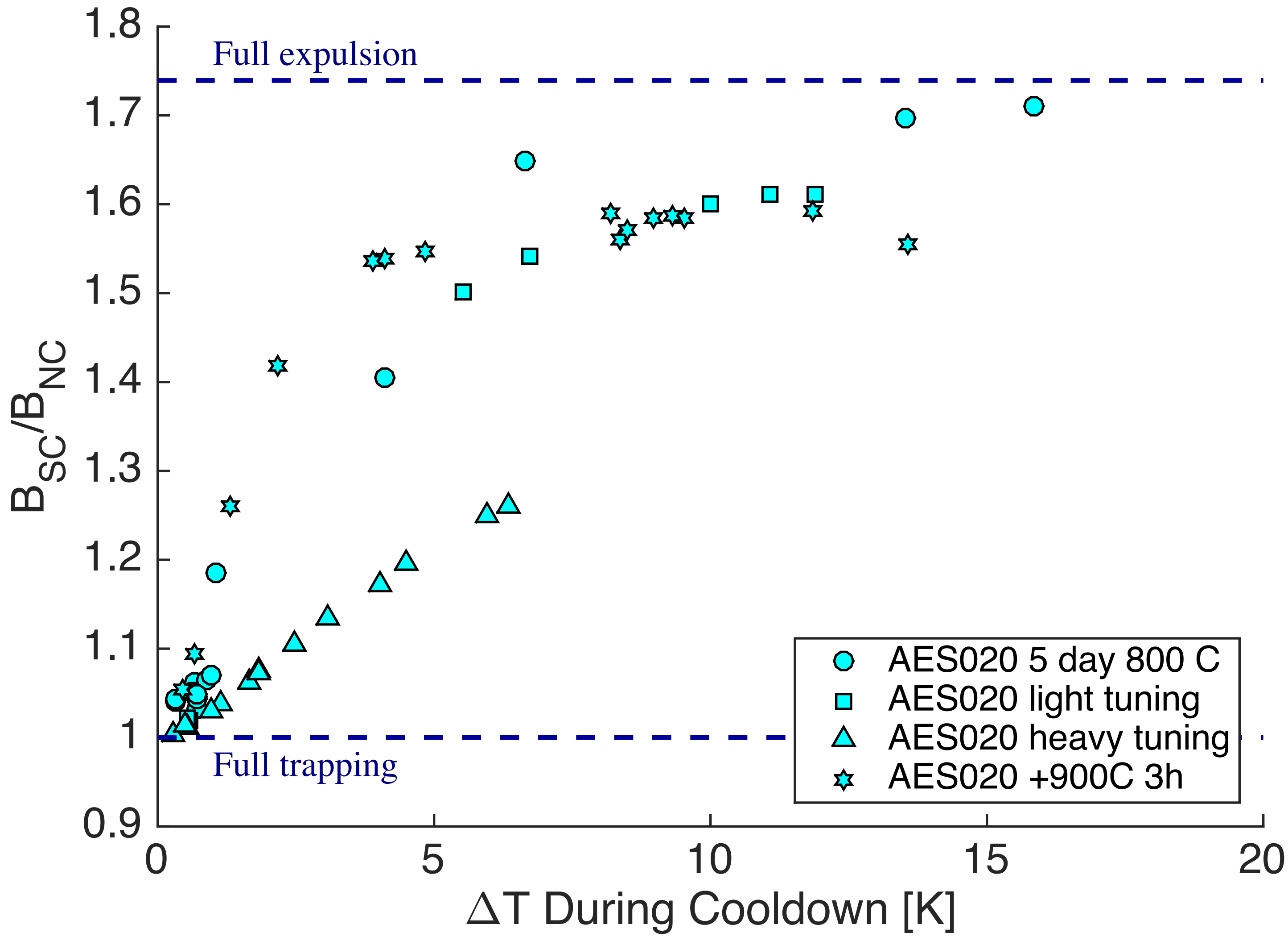
AES020 – Light Tuning



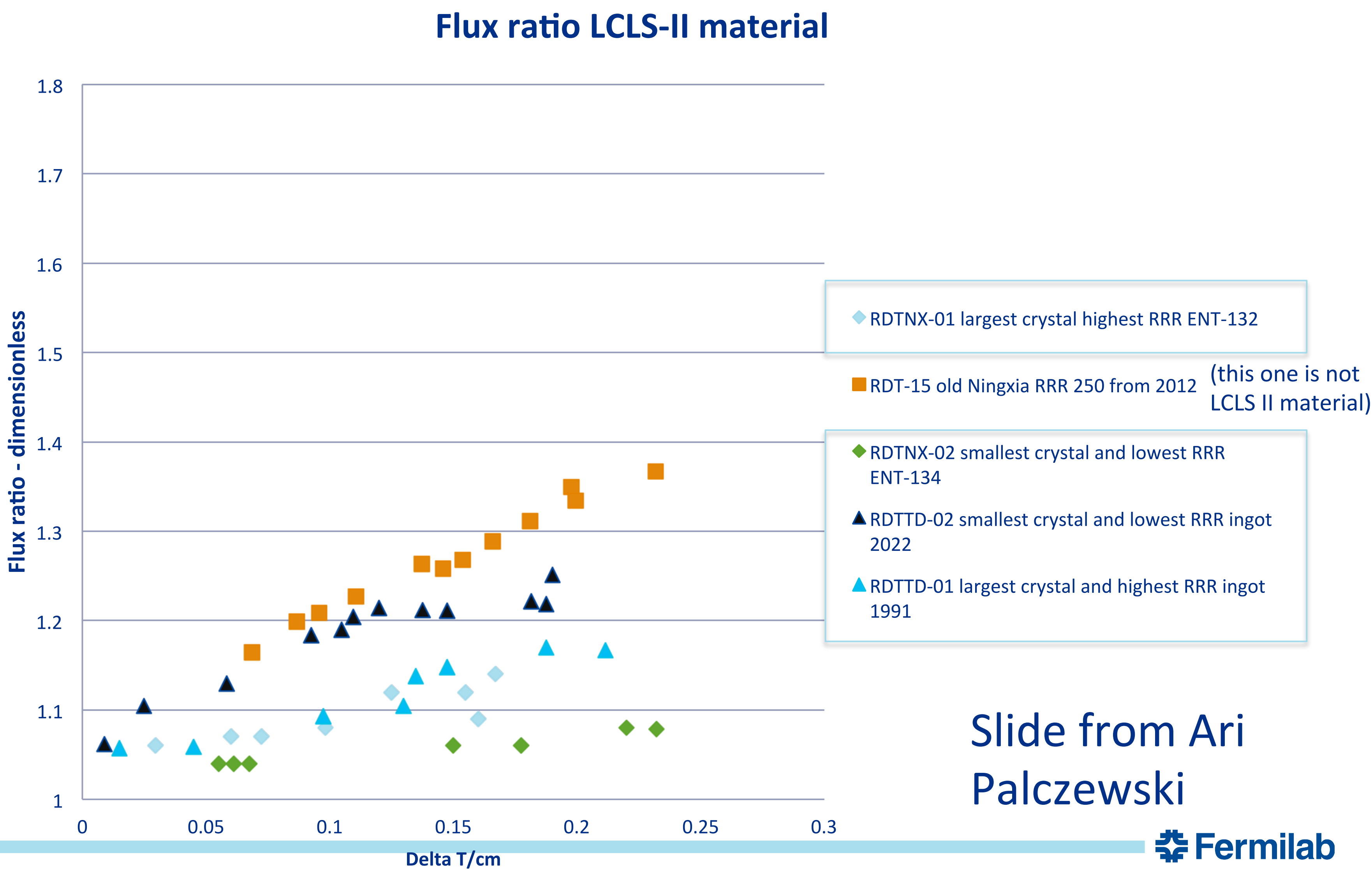
AES020 – Heavy Tuning



AES020 – 900°C 3h

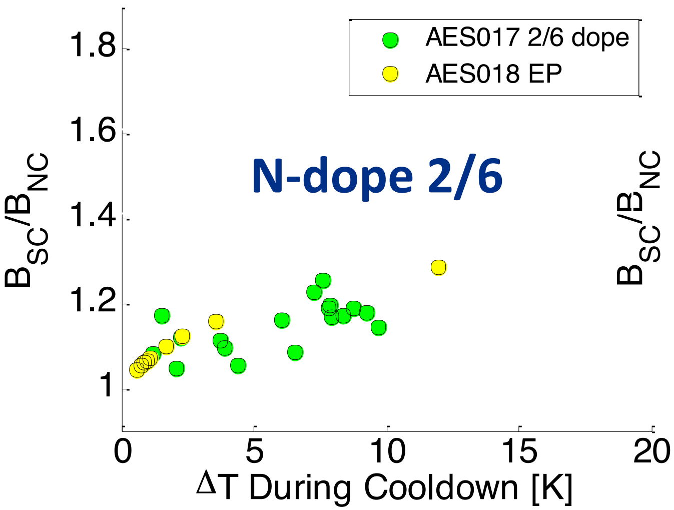


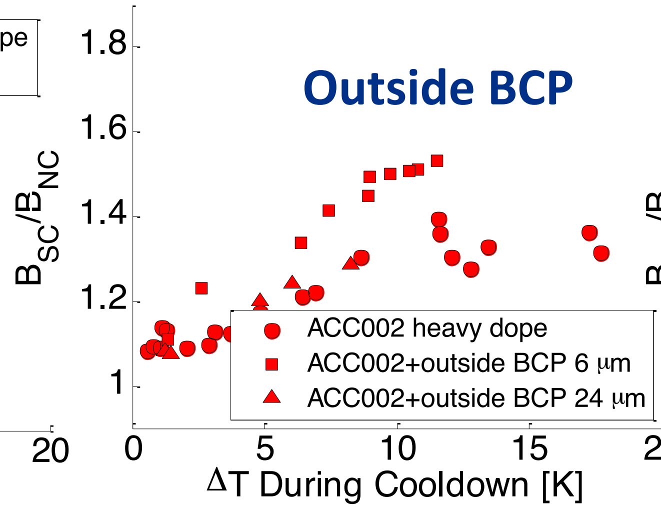
This is flux ratio as a function of temperature difference per cm about equator, there are 2 sensors on the equator, each 20mm away from equator at flux gate location – I also have the data for RDT-15 which I used to baseline cooldown cycles as well.

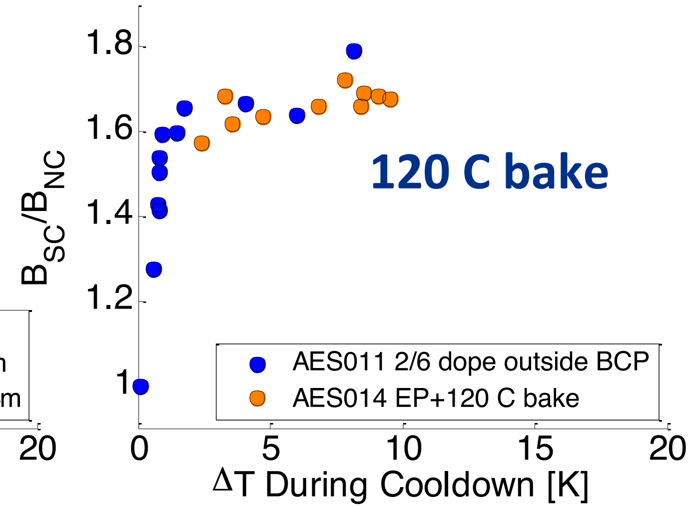


Slide from Ari Palczewski

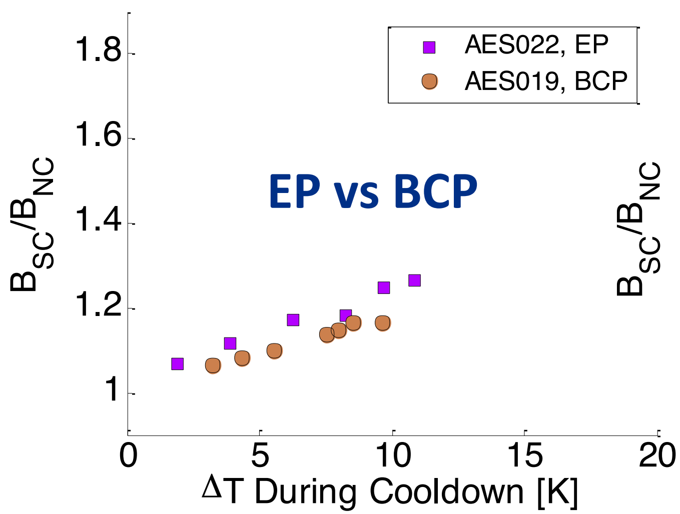
Surface Alteration With No Significant Effect on Expulsion

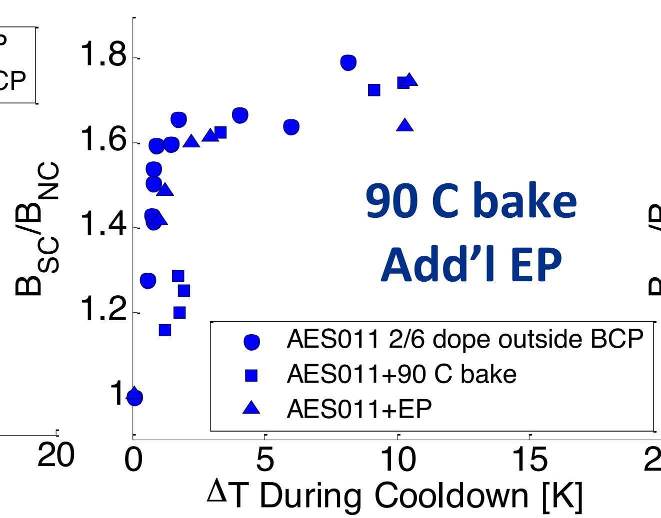


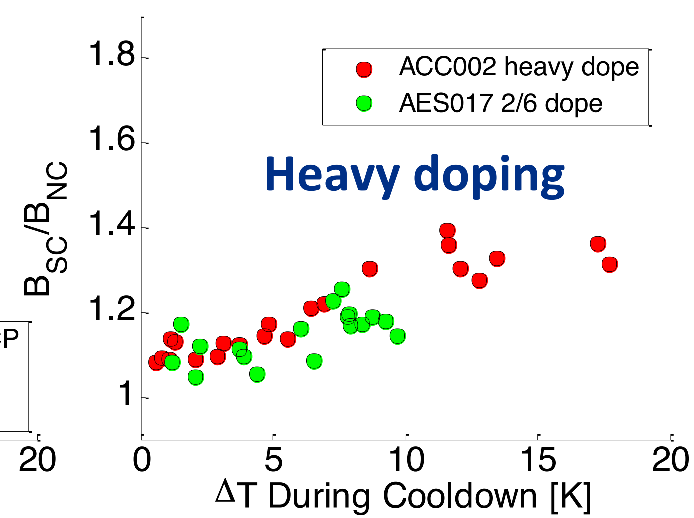




Different surface conditions in cavities with similar bulk history: similar expulsion







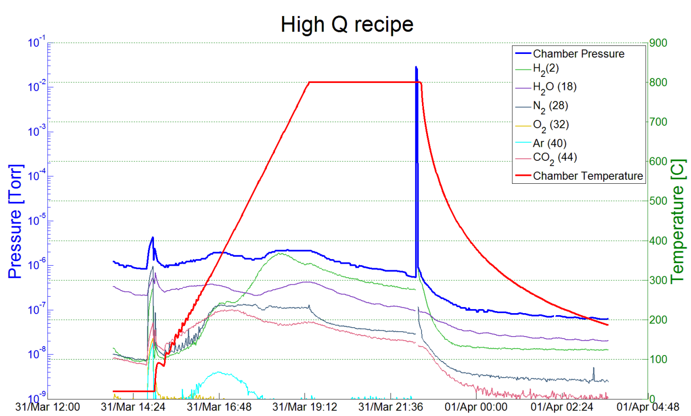
Summary of Measurements

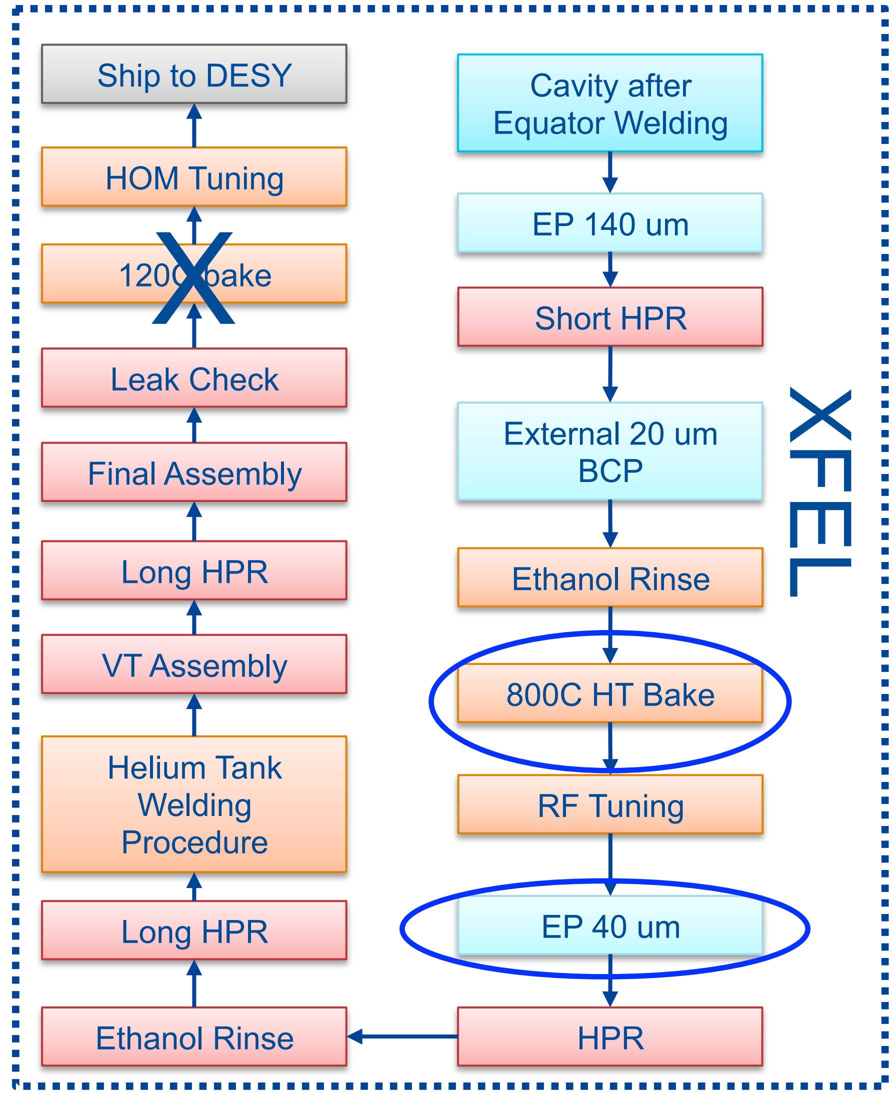
- We have shown evidence that high temperature furnace treatment substantially improves expulsion behavior (i.e. expulsion as a function of thermal gradient)
- For cavities that have shown little improvement after 3 h at 800°C, treatment at 900°C for 3 h has had a strong impact
- 1000°C also has a strong impact even with short duration, but it may have a stronger influence on mechanical properties
- Supporting data from both magnetic measurements and RF measurements
- No significant changes from surface treatment – seems to be a bulk material effect

Flux Expulsion Improvement

Cavity Treatment:

- Bulk EP
- 800 C anneal for 3 hours in vacuum
- 2 minutes @ 800C nitrogen diffusion
- 800 C for 6 minutes in vacuum
- Vacuum cooling
- 5 microns EP



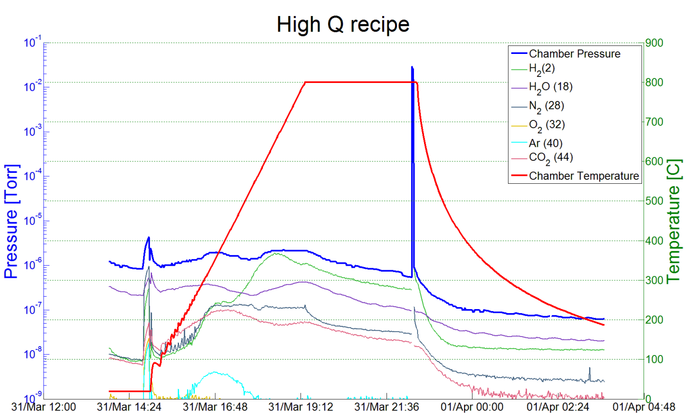


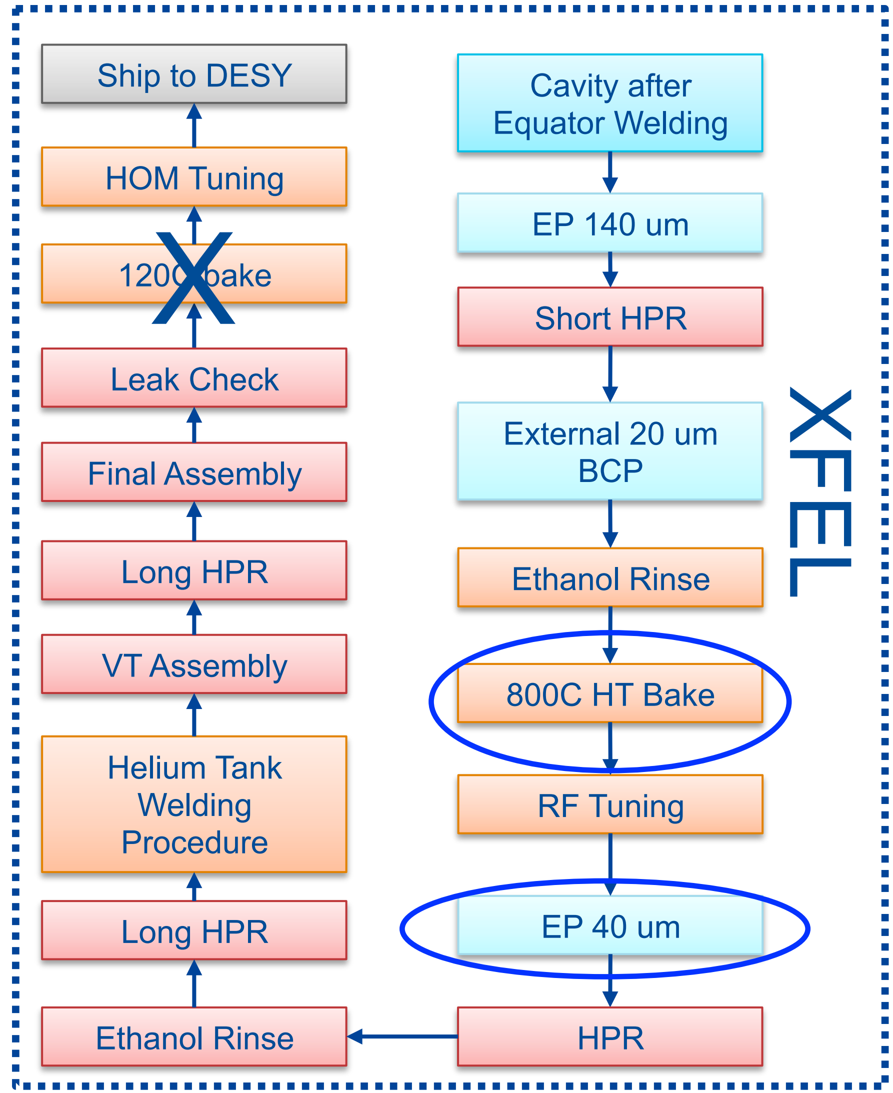
Flux Expulsion Improvement

Cavity Treatment:

Option 1: 900 C treatment before bulk EP

- Bulk EP
- 800 C anneal for 3 hours in vacuum
- 2 minutes @ 800C nitrogen diffusion
- 800 C for 6 minutes in vacuum
- Vacuum cooling
- 5 microns EP





Fermilab

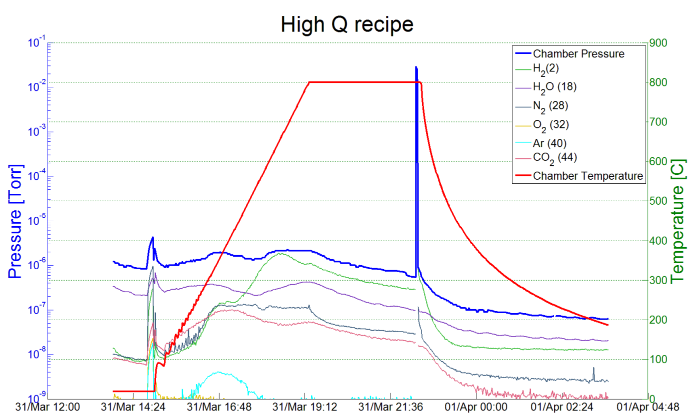
Flux Expulsion Improvement

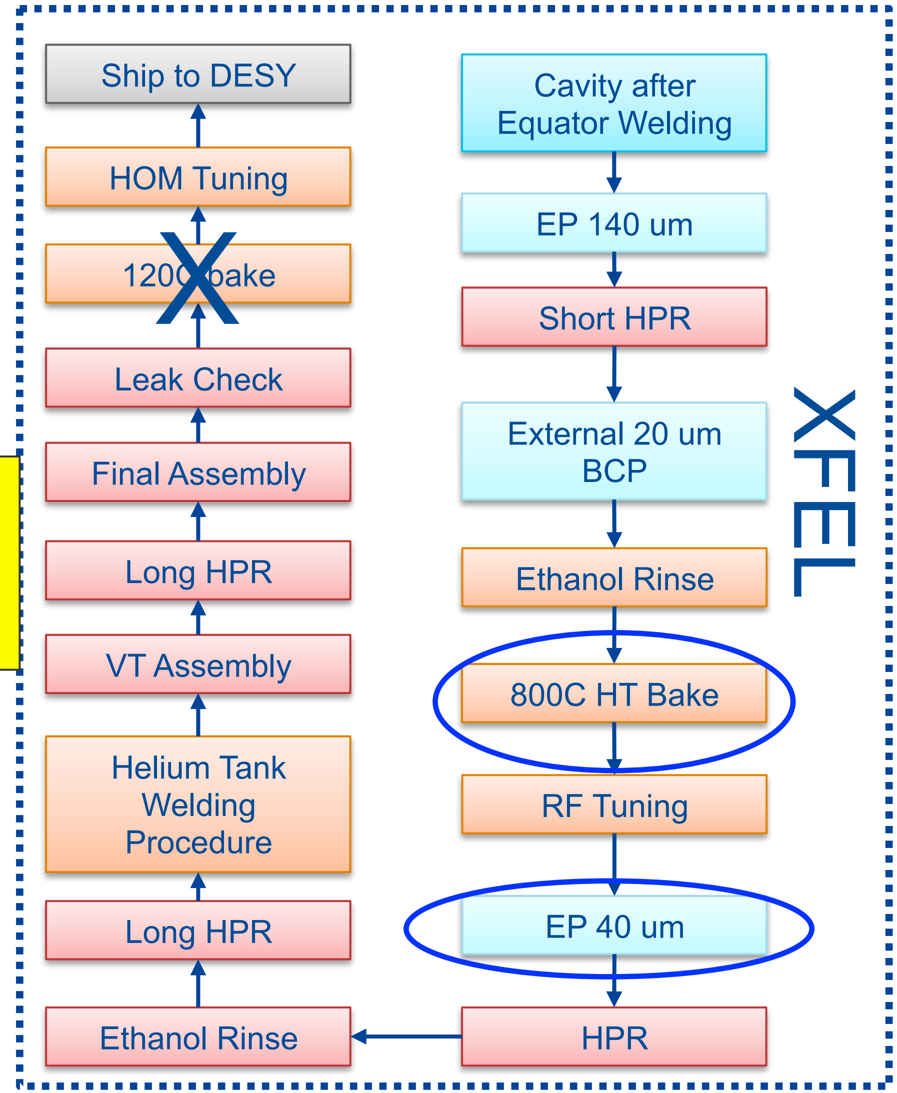
Cavity Treatment:

- Bulk EP
- 800 C anneal for 3 hours in vacuum
- 2 minutes @ 800C nitrogen diffusion
- 800 C for 6 minutes in vacuum
- Vacuum cooling
- 5 microns EP

Option 1: 900 C treatment before bulk EP

Option 2: Change degas temp to 900 C (800 C for doping)





Requirements from Project

- Any mitigation methods for flux expulsion:

1. should cause no production schedule delay
   –

2. should be applicable during the production cycle, so that the overall linac cryogenic heat-load is reduced
   –

3. should be inherently low-risk
   –

Requirements from Project

- Any mitigation methods for flux expulsion:

1. should cause no production schedule delay
   - Changing degas temperature should have minimal impact on schedule
2. should be applicable during the production cycle, so that the overall linac cryogenic heat-load is reduced
   - Need to continue evaluation of effectiveness of 900 C treatment on LCLS-II material single cells
3. should be inherently low-risk
   - Need to evaluate mechanical concerns

Mechanical Studies

- Need to evaluate change in sensitivity to plastic deformation in transit for 900°C vs 800°C (field flatness, tuning, trapped modes, etc.)
- Some positive notes:
  - There is precedent – 1000 C baked cavity in LCLS-II prototype cryomodule
  - We expect both flux expulsion AND mechanical properties to be related to dislocation content and grain structure—if cavity that shows substantial grain growth after 800°C has acceptable mechanical properties, cavity that shows modest grain growth after 900°C may be as well

Proposal to be reviewed (1/2):

1. Complete an *assessment of the data* taken up to present, including single-cell, nine-cell (a few), and ambient magnetic-field suppression studies.
   - Collect heat-treatment records of the 16 prototype cryomodule cavities. (at least one has been heat-treated above the nominal 800C.)
   - Collect mechanical tuning-stability records for these cavities.
   - Develop VT technique (to be used during production) to measure the effects of magnetic field in 9-cell bare and dressed cavities.
   - Complete metallurgical crystallization testing and analysis of LCLS-II Nb sheet samples.

Proposal (2/2):

2. Prepare to modify the cavity de-gas/doping *heat-treatment recipe* so that the cavity weldment is pre-annealed, i.e. the oven temperature is raised above the baseline temperature.
   - Fix recipe-modification details using single-cell test results
   - Evaluate associated risks, (most of which are mechanical), and develop counter-measures and test them with single cells and nine cells.
3. ***Assuming the associated risks are properly addressed***, identify which cavity in the planned production cycle should be the first to receive the modified recipe.
4. *Trigger* the modified recipe to be applied following a review of 1) to 3).

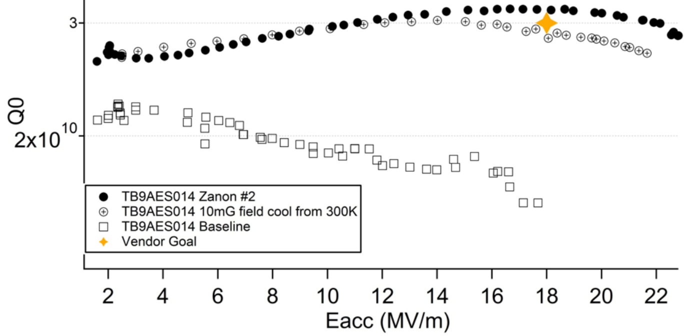
Next Steps

- In parallel:
  - 1-cell cavities – study impact of 900°C 3 h treatment on 1-cell cavities made from LCLS-II material
  - Mechanical studies – treat 9-cell cavity in inventory with 900°C 3 h
  - Sample studies – study yield, modulus, hardness on LCLS-II material before/after 800°C and 900°C
- 9-cell cavities: Ideal step after this is to have 9-cell cavities with LCLS-II material fabricated and dressed treated at vendor to evaluate in full-scale test, including shipping from Europe
  - 2 cavities for evaluation enough?

9-cell Expulsion

RF results – TB9AES014

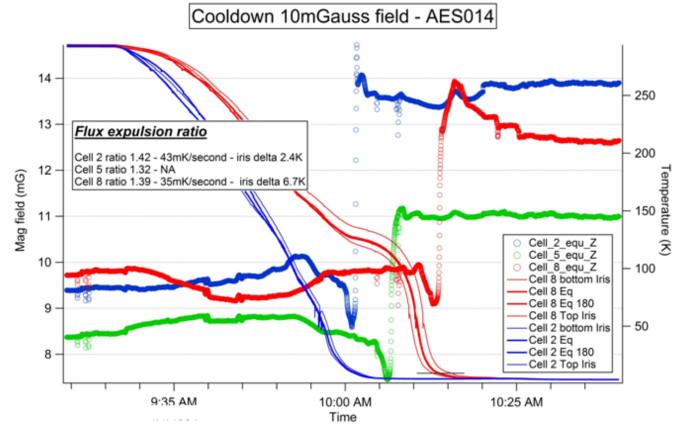
Slide from Ari Palczewski

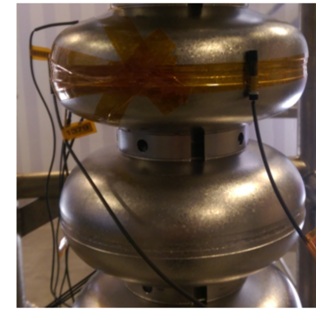


Almost zero flux trapping

Jefferson Lab

Example Flux expulsion ratio AES014





Single cell data from Cornell/FNAL (Sam Posen) 1.6-1.8 all flux expelled, it is unclear if this is the same for 9 cells

Slide from Ari Palczewski

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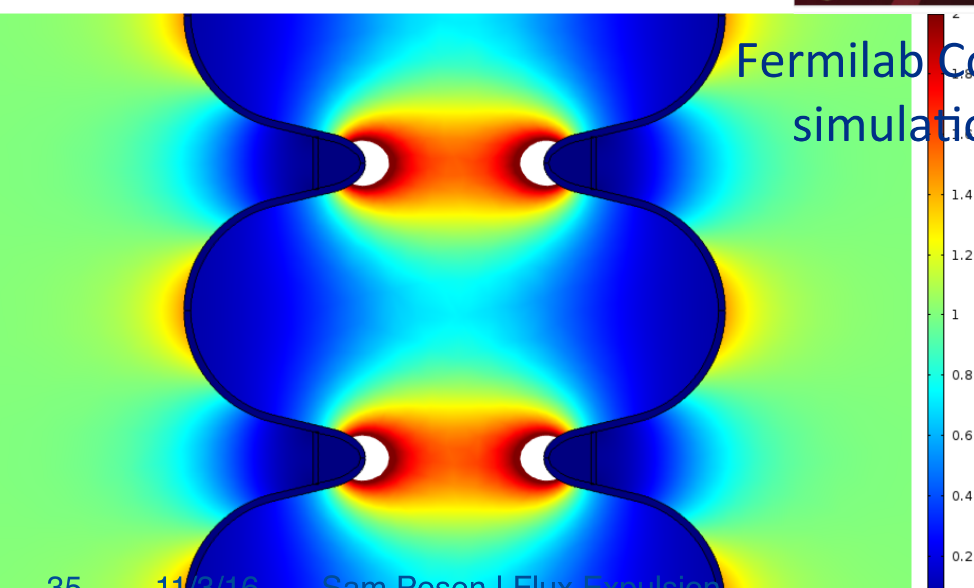

Fermilab Comsol simulations