Isolating Internal Shorts with Metallized Polymer Current Collectors

8μm Aluminum Metalized Film Current Collector

China

Technical Features (Typical Properties)

PROPERTY	SPECIFICATION
Metal	Al
Substrate	PET
Substrate Thickness (μm)	6 μm
Total Thickness (μm)	8 μm
Metal Coating Thickness	1 μm/side
Surface Resistivity (mOhm/square)	22.86
Tensile (MPa)	27033

With beamtime at the European Synchrotron Radiation Facility

Eric Darcy

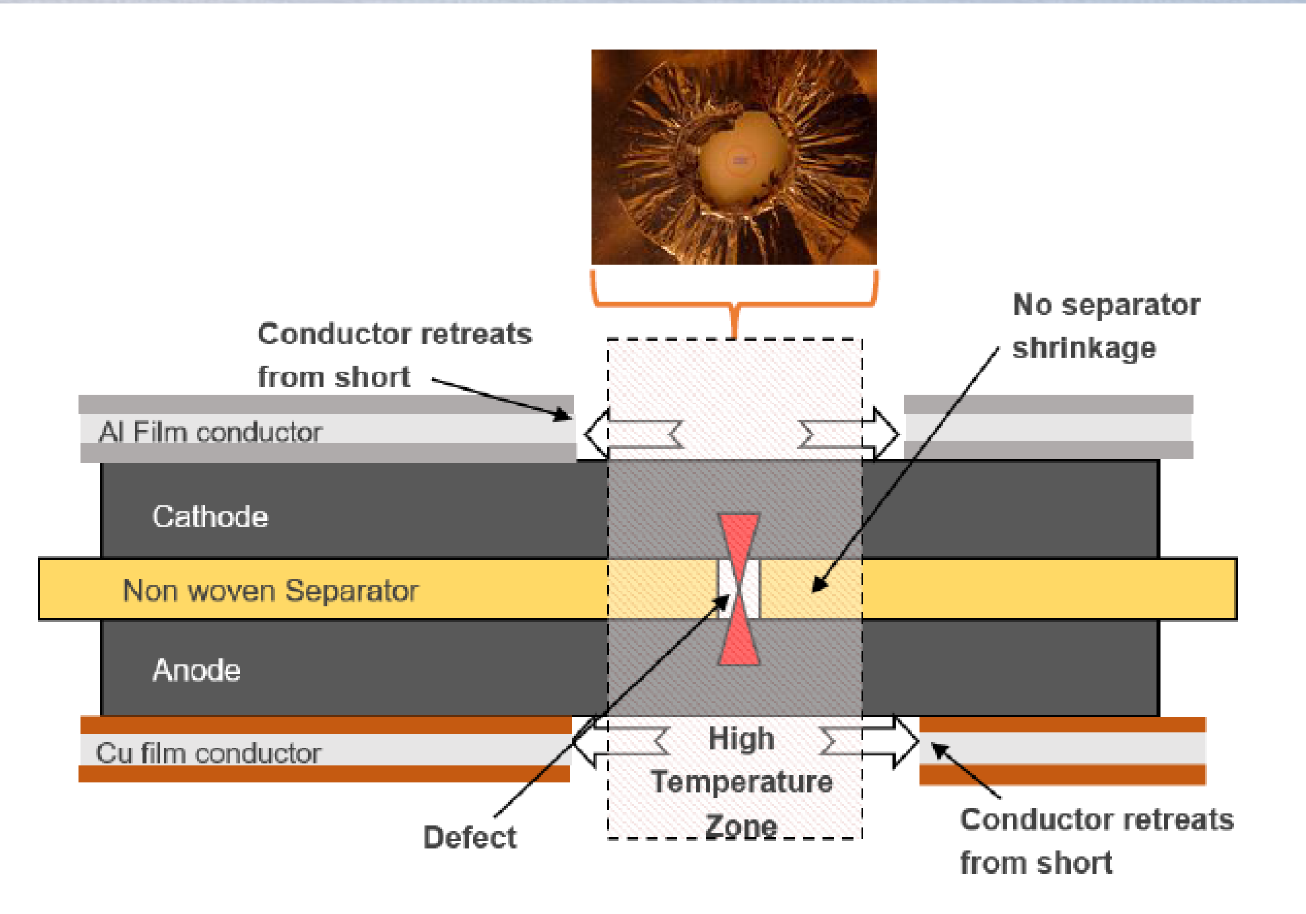
2025 NASA Aerospace Battery Workshop
Johnson Space Center, Houston, TX
21 Jan 2026

Contents

Cell Format: 21700
Capacity: ~5.0Ah
Anode: Graphite
Cathode: Polycrystalline NMC811
Specific Energy: >265 Wh/kg
Made by Coulometrics in Chattanooga, TN

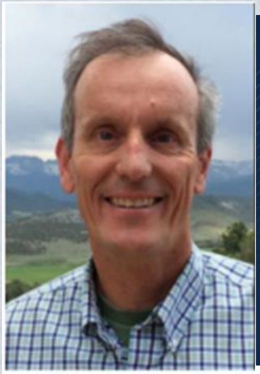
Motivation & Theory

- Motivation
  - What limits the effectiveness of Metallized Plastic Current Collectors (MPCCs) in isolating shorts?
  - Greatly reduce the design burden of achieving passive propagation resistance (PPR) batteries
- Theory
  - Plastic substrate of current collector thermally breaks down and isolates the electrochemically active materials from the defect within milliseconds



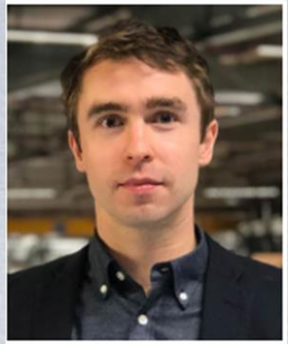
Graphics: B. Morin/Soteria

Team Effort




Dr. Eric Darcy   Jesus Trillo

NASA-JSC



Dr. Donal Finegan

NREL


Dr. Paul Shearing   Inez Kesuma

Oxford University

Alexander Rack

ESRF

- Sam Russell, Jesus Trillo, Brenda Esparza, Thuong Nguyen, Chris Blackwell, Aidan Byrne, Nathan Solomon, and Eric Darcy/NASA, Houston, TX, USA
- Donal Finegan/NREL, Golden, CO, USA
- Inez Kesuma and Paul Shearing, Oxford University, Oxford, UK
- Alexander Rack/ESRF, Grenoble, France
- **Brian Morin and Joe Turner/SoteriaBIG, Greenville, SC, USA**
- **Forrest Gaskin and Ed Buiel/Coulometrics, Chattanooga, TN, USA**

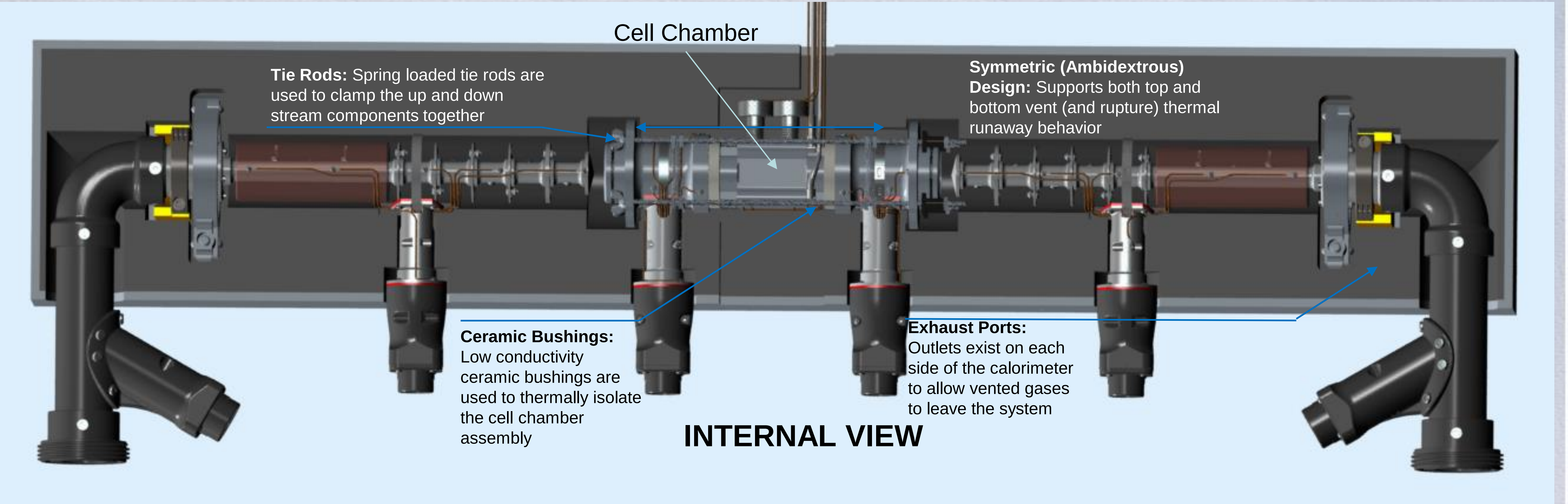
Acknowledgements

Thanks for the sponsors of our cell strategic reserve for funding this effort

- Orion, CCP, HLS, and NAVSEA

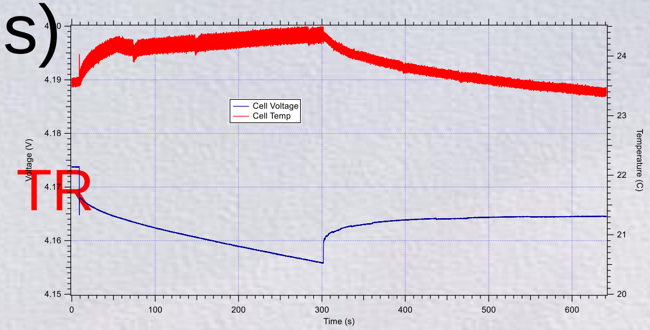
Fractional Thermal Runaway Calorimetry

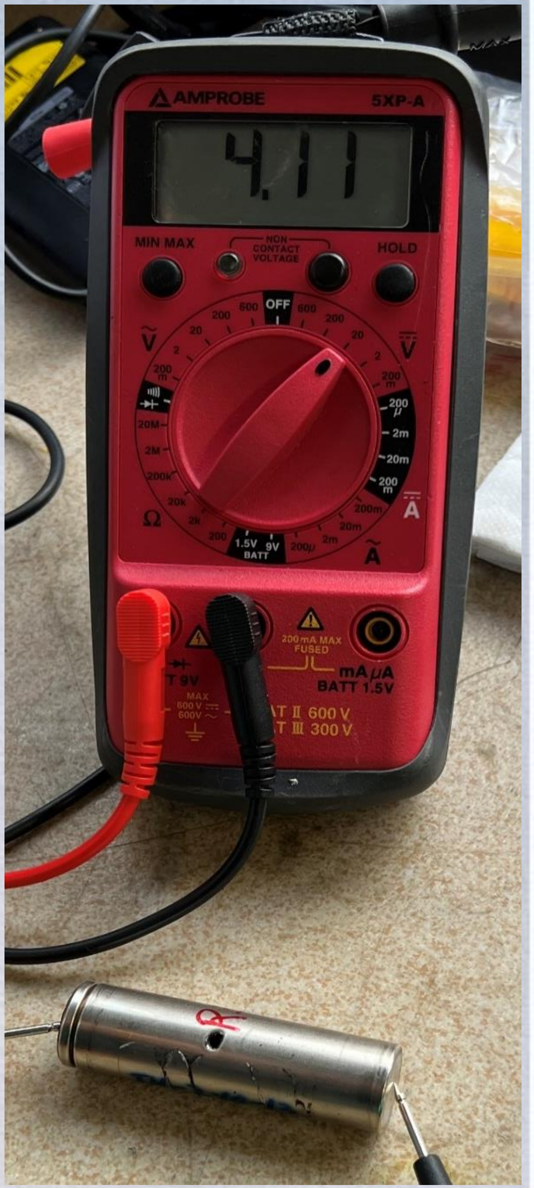
- **The FTRC is designed to help characterize directional/fractional thermal runaway heat output:**
  - X-ray transparent cell chamber assembly is isolated from the remainder of the up and downstream calorimeter components with low conductivity ceramic bushings.
  - Maintaining thermal isolation is critical to our team's ability to discern the fraction of energy released through the cell casing vs. through the ejected material.
  - The ejecta mating segment is designed to capture and stop complete jellyroll ejections.



BAK 21700 4.6Ah Test Matrix and Results (Nail)

- Soteria metalized polyester (15 cells)
  - PCC only on cathode (cell achieves 251 Wh/kg)
  - Cu foil on anode like all other features in control version
  - 14 of 15 cells tolerated fast nail penetration at 100% SoC
    - No fire, sparks, venting, or TR in those 14
    - Muted TR in 1 cell, generating ~50% kJ of control average
- Control cells (8 cells)
  - Al and Cu foil CCs
  - All 8 cells went into TR





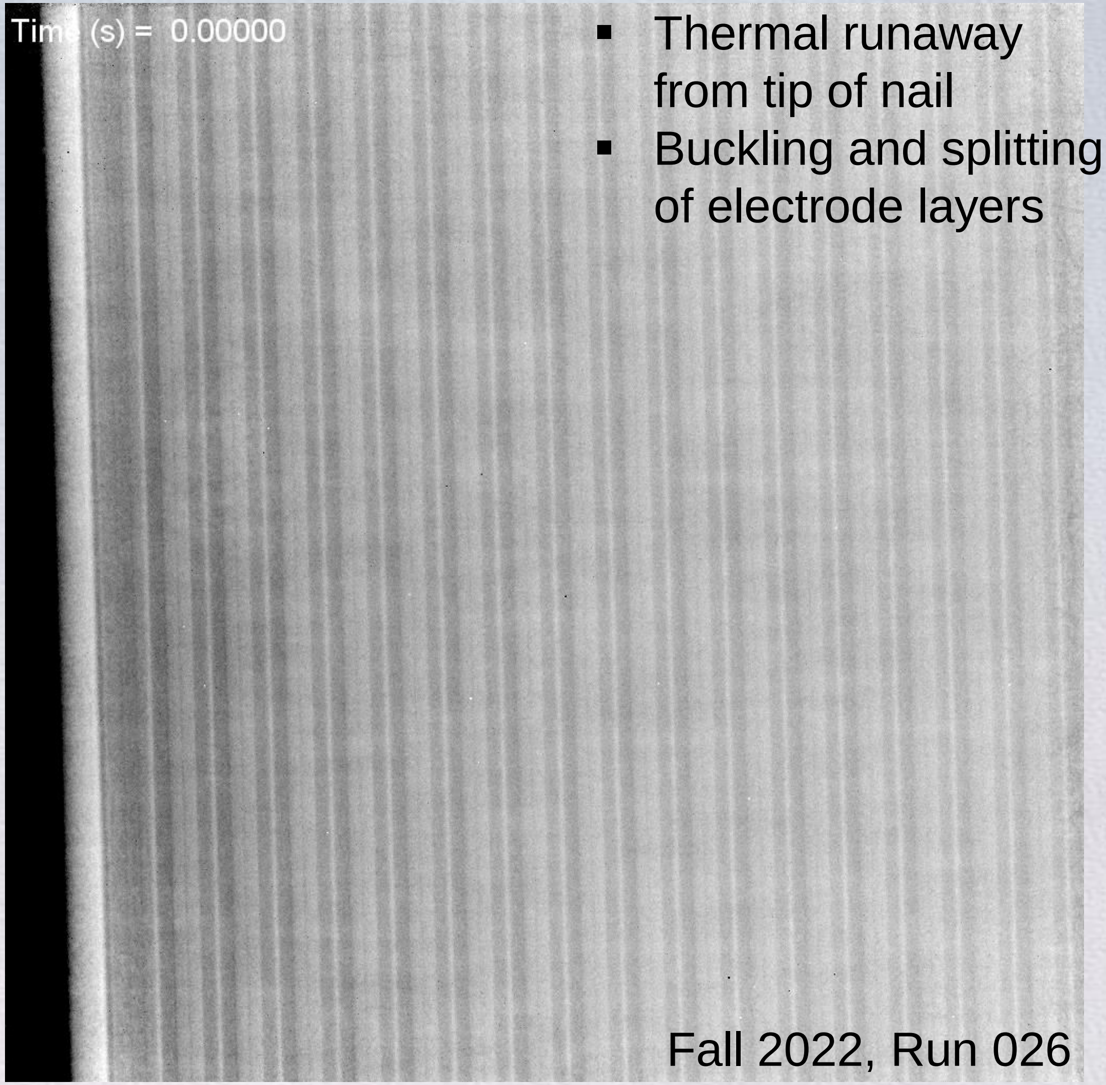
$\Delta t_{max} < 1°C$
$\Delta vmax < 19mV$

Tolerance demonstrated with near zero degradation of OCV!!!

21700 BAK cells with Radiography at 3000 fps

Bright is most dense material, nail, cell can, NMC

With standard Al foil CC in the cathode

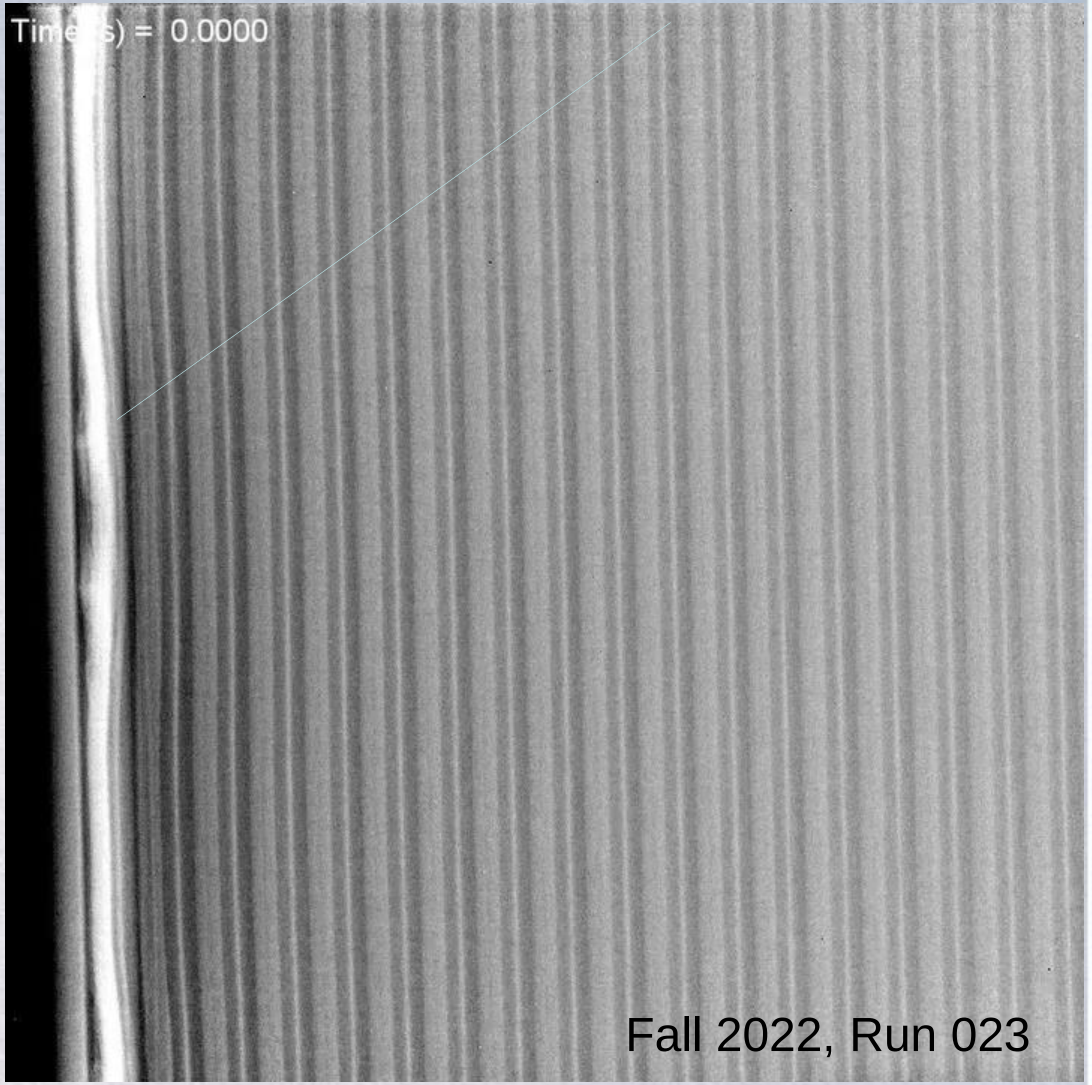


- Thermal runaway from tip of nail
- Buckling and splitting of electrode layers

Fall 2022, Run 026

Notice that TR starts at the surface of the nail

With Al PCC in the cathode



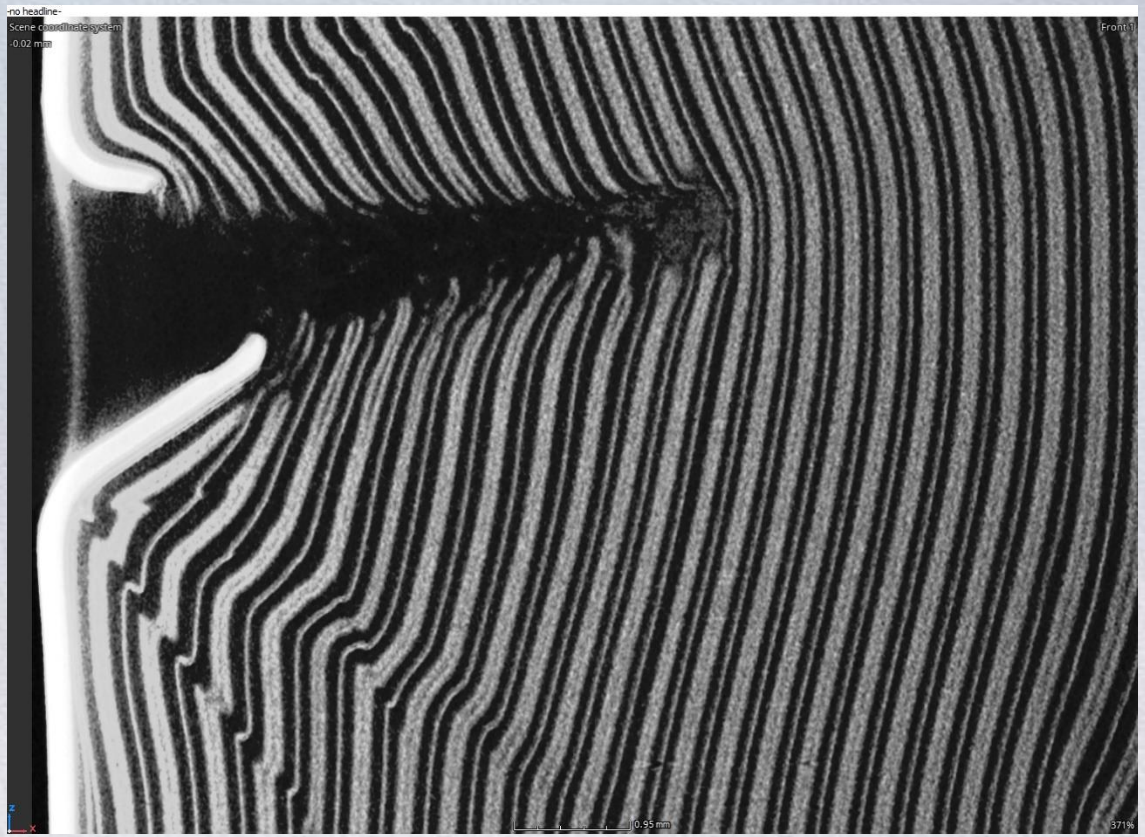
Fall 2022, Run 023

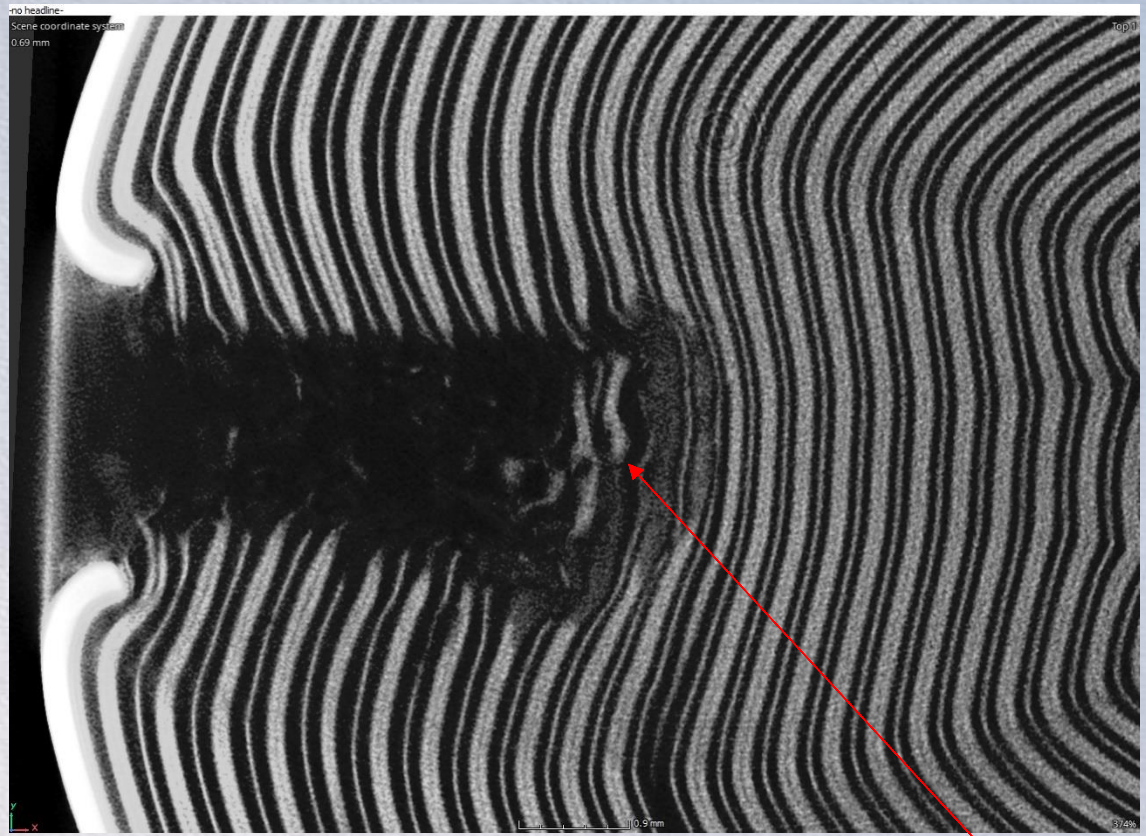
Notice deformation cone

CT Images of BAK 21700 with Cathode PCC

Axial view of nail penetration zone

Radial view of nail penetration zone





Al coated PCC for cathode is thin gray layer between NMC active material coatings.
Axial view shows cathode PCC is clearly missing at nail interface (split ends).

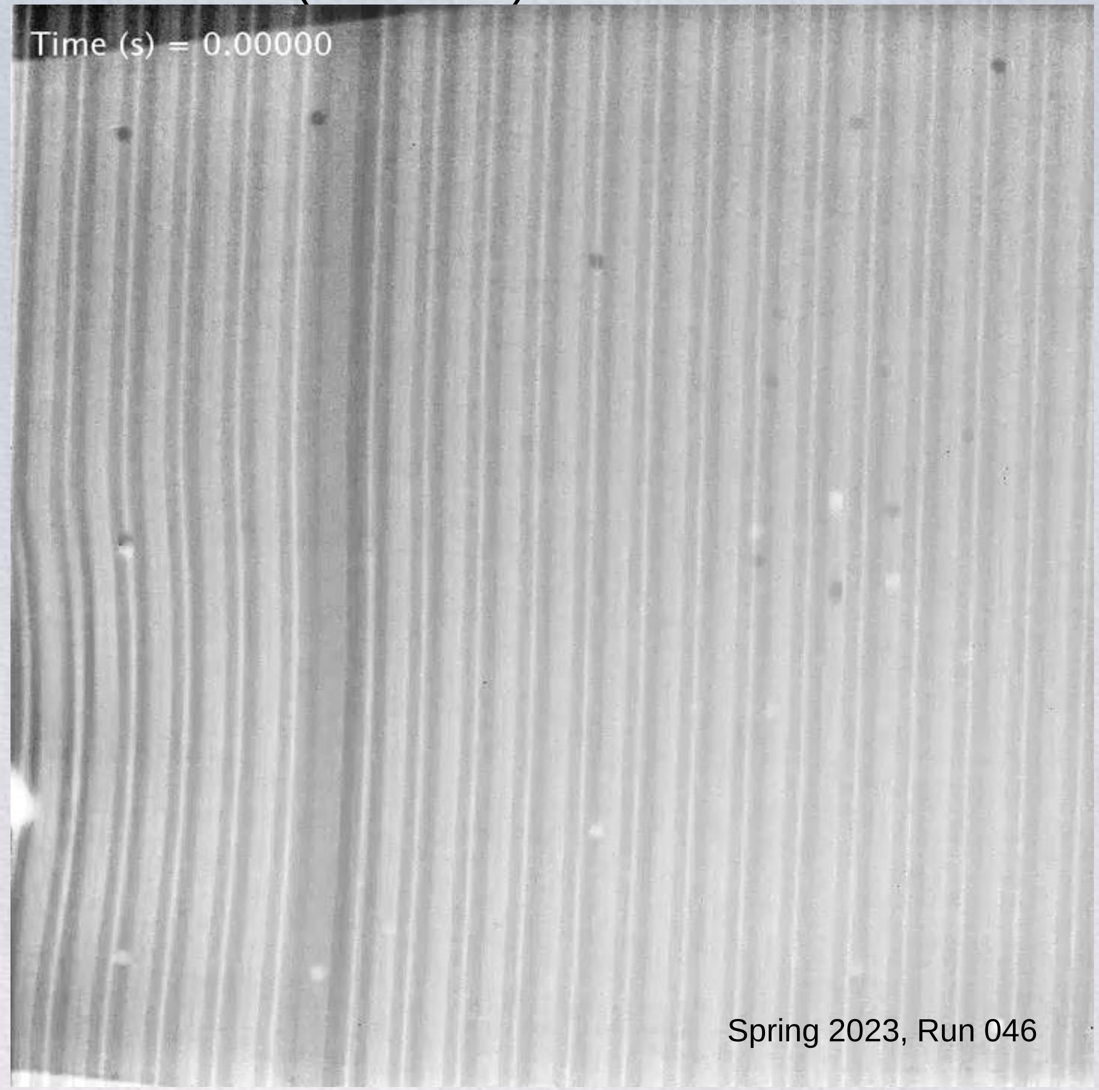
Stranded NMC

Pham et al., Cell Reports Physical Science, Volume 2, Issue 3, 100360, March 24, 2021

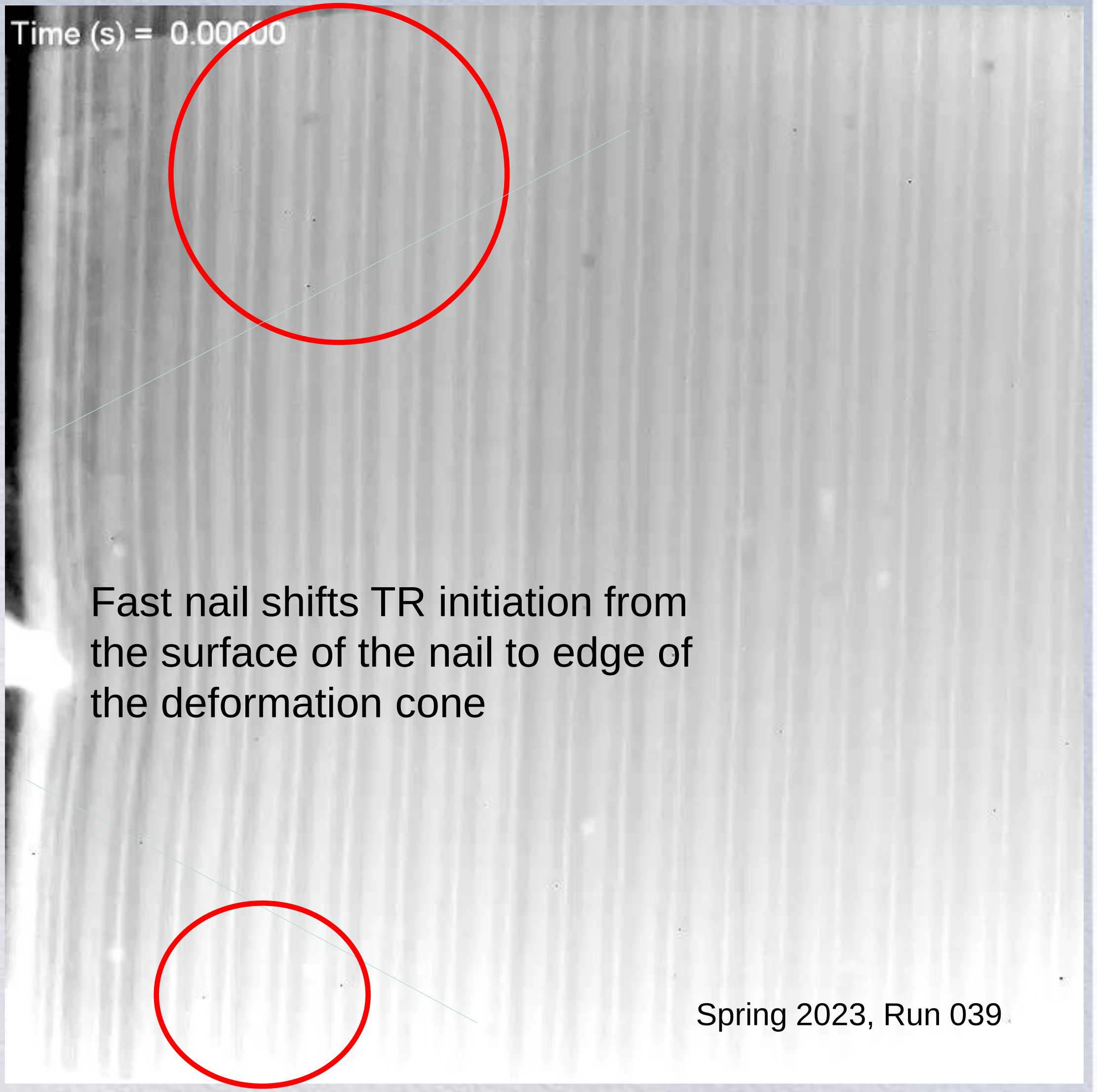
21700 Coulometrics cells achieving >265 Wh/kg

- with anisotropic strength ceramic coated polymer separator

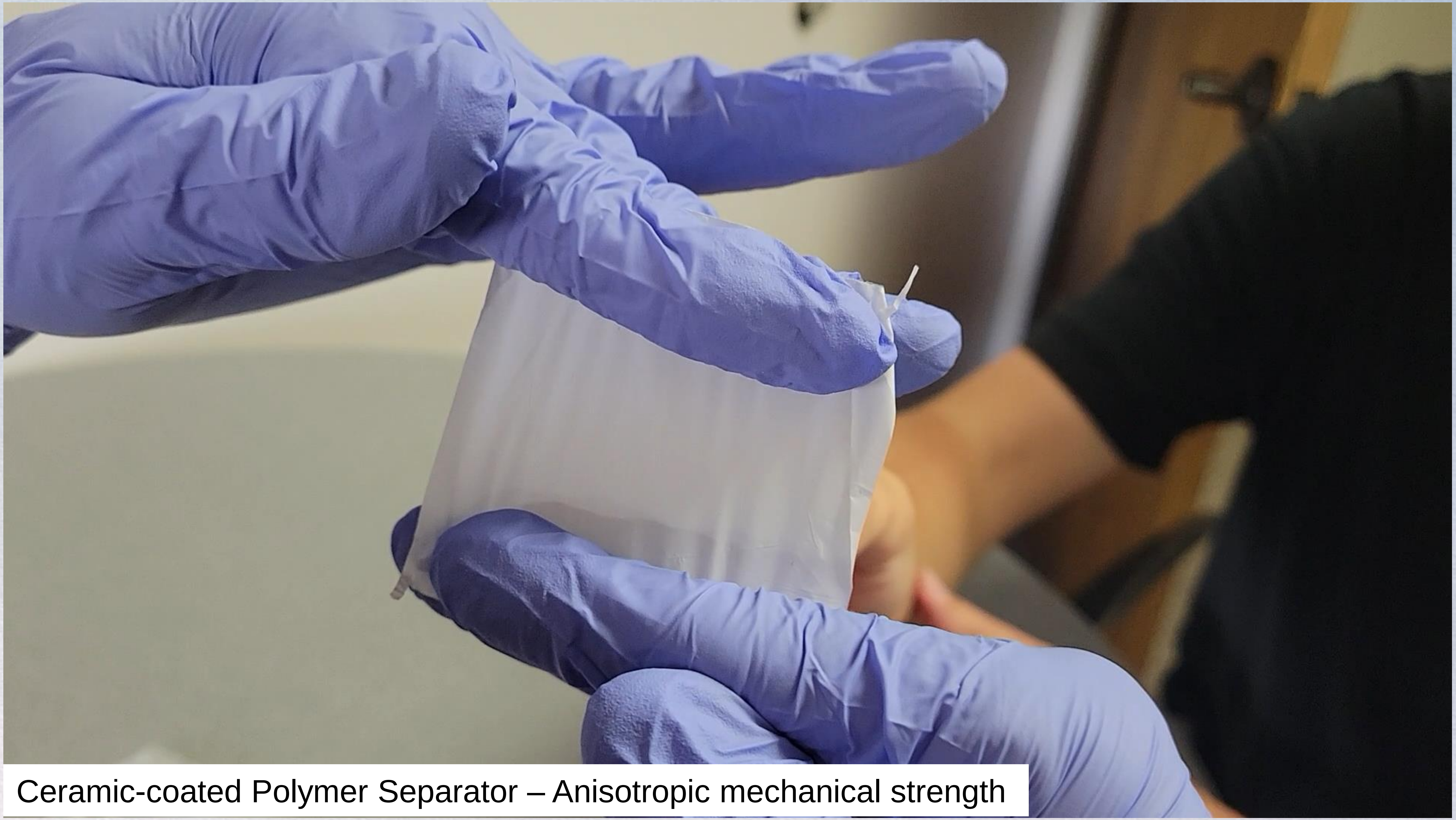
Without PCC (Al foil CC)



With Al PCC on the cathode



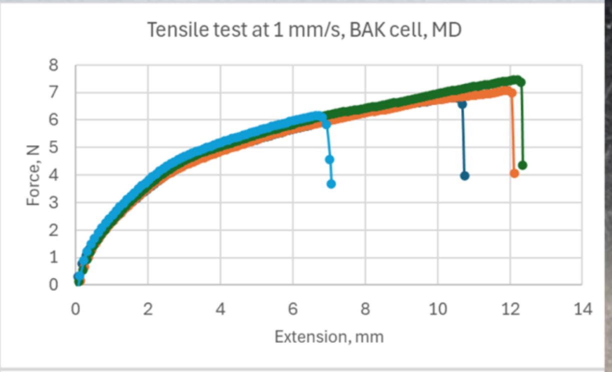
Separator properties

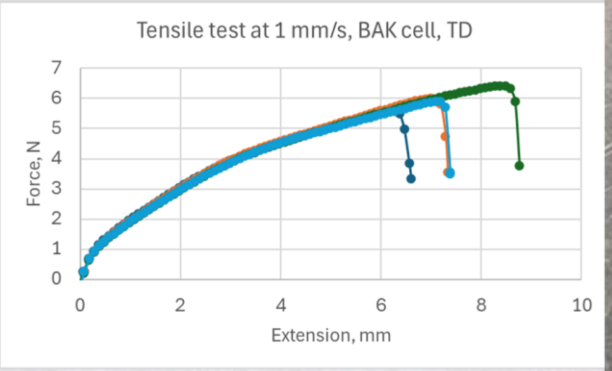


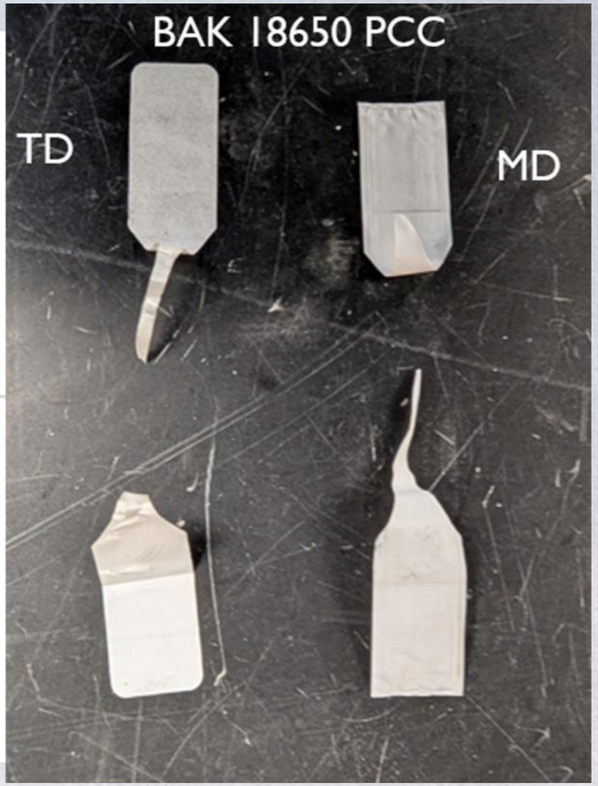
Ceramic-coated Polymer Separator – Anisotropic mechanical strength

Separator properties

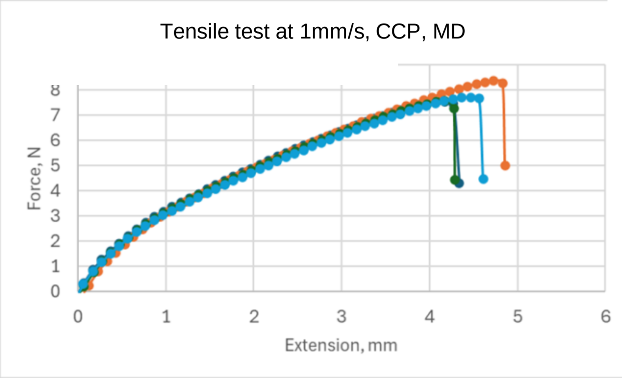
Isotropic extension property for BAK separator in both directions, machine (MD) and tensile (TD)

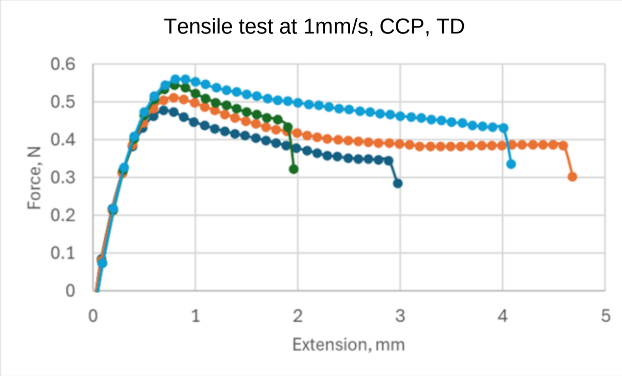






Ceramic coated polymer (CCP) separator is much weaker in tensile direction (TD)





Ceramic coated polymer (CCP) separator

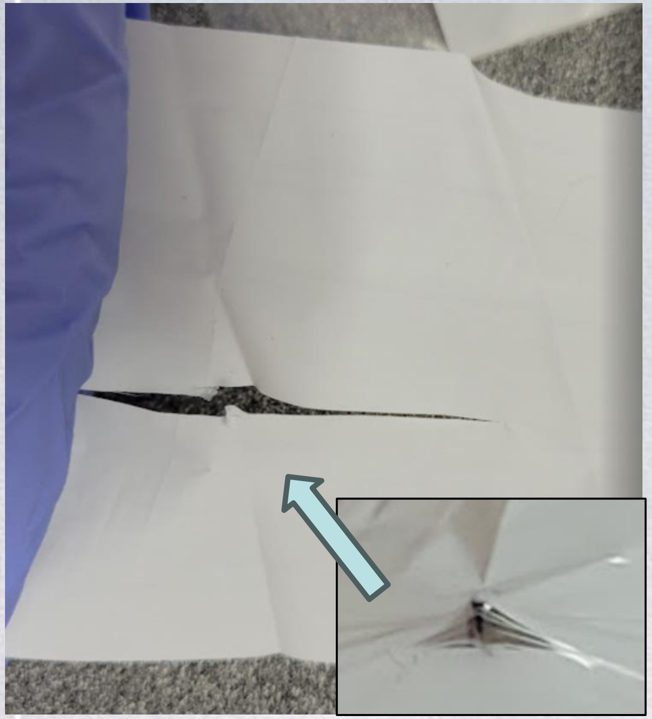
Could the superior isotropic extension ability of BAKs cell avoid separator tearing at the edge of the deformation cone?

Images and plots from NREL, D. Finegan

Separator properties

Anisotropic

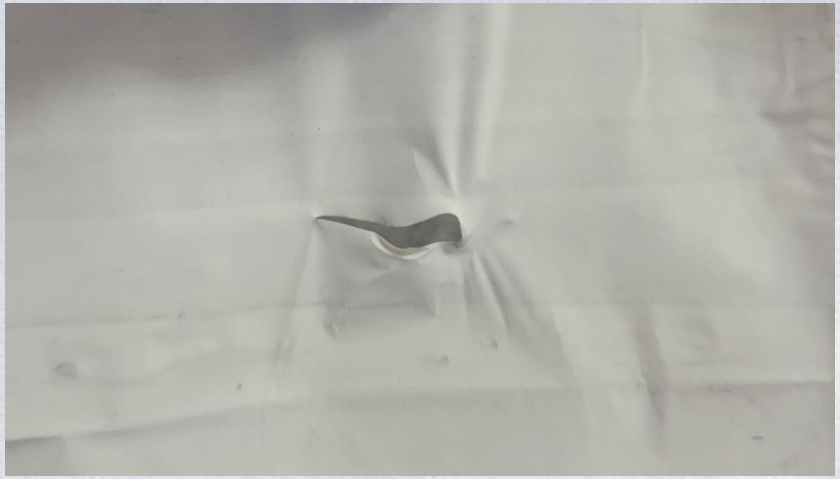
Ceramic-coated polymer separator



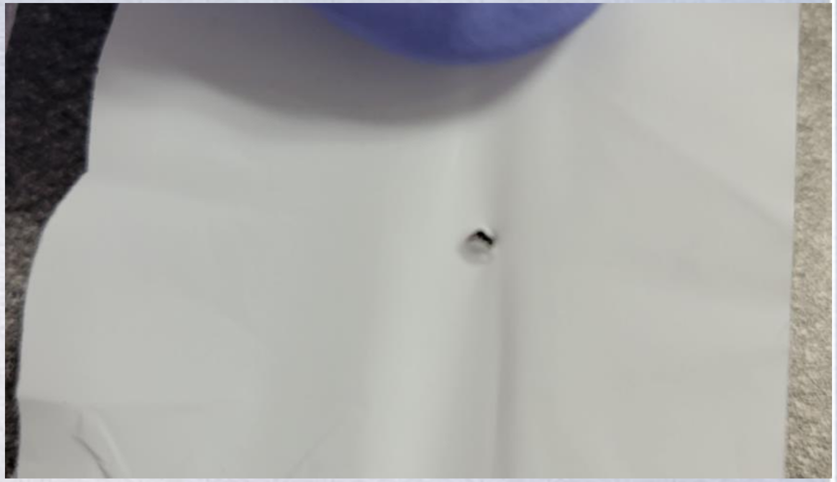
Anisotropic tensile strength incurs a large-area tear when deformed

Isotropic

BAK separator



All ceramic separator



Isotropic separators incur a symmetric small-area tear

Images from D. Finegan, NREL

Our hypotheses

- The PCC prevents TR initiation from the surface of the nail
  - It can isolate very localized high currents from small-area shorts
- The PCC cannot isolate wide-area shorts that arise from the separator splitting
- Preventing wide-area splitting requires changing the separator mechanical properties to be more ductile, higher stretchiness, and less prone to ripping
- A combination of a PCC and a ductile, thermally-stable separator, may be the key combination to enhanced mechanical and thermal abuse tolerance

The challenges

- How to test localized small-area shorting if internal deformation leads to wide-area shorting?
- How to test the efficacy of separators in resisting splitting and wide-area shorting?

Our Approach

- Slow and (3mm) shallow nail (more representative of localized defect internal short)
- Slow and (9mm) deep nail
- Static internal short circuit device (most representative of a localized defect internal short)

Improving Separator & Anode Coatings

- All ceramic (boehmite) separator is too fragile to wind with acceptable yields
  - Could it (boehmite) be slot-die coated on the anode?
  - Then, wind coated anode with a cathode? No
    - Need a separator to pass JR isolation resistance
- BAK polymer separator has large isotropic strength
  - Water-based polymer separator with isotropic tensile strength
  - Combined isotropic separator with boehmite coated anodes

21700 Cell Design Details

- 2508-NA03: Al MPCC + All Ceramic Sep.,
  - 4.68Ah, 48.8mΩ DCIR
- 2508-NA04: MPCC + Isotropic strength polymer separator
  - 4.80Ah, 41.2mΩ DCIR
- 2508-NA06: MPCC +Isotropic strength polymer separator and ceramic coated anode
  - 4.48Ah, 56.3m Ω DCIR
- All designed and made by Coulometrics, Chattanooga, TN

Shallow Nail Results for 2025

		At ESRF					At Coulometrics				Total		
CC	Separator Design	Nail	TRs	Runs	%		TRs	Runs	%		TRs	Runs	%
Al MPCC	Free Standing All Ceramic	Shallow	0	15	0%		0	2	0%		0	17	0.0%
Al MPCC	Ceramic Coated Polymer	Shallow	0	6	0%						0	6	0.0%
Al MPCC	Isotropic Strength Polymer	Shallow	0	12	0%		2	8	25%		2	20	10.0%
Al MPCC	Isotropic & Ceramic Coated Anode	Shallow	0	12	0%		0	5	0%		0	17	0.0%
									Total		2	60	3.3%

- All 4 cell designs > 253 Wh/kg
- All designs show good promise to tolerate shallow nail penetrations
- Combining the thermal stability of the ceramic anode coating with the isotropic strength polymer separator appears **best** to enable the safety of the metallized plastic current collectors

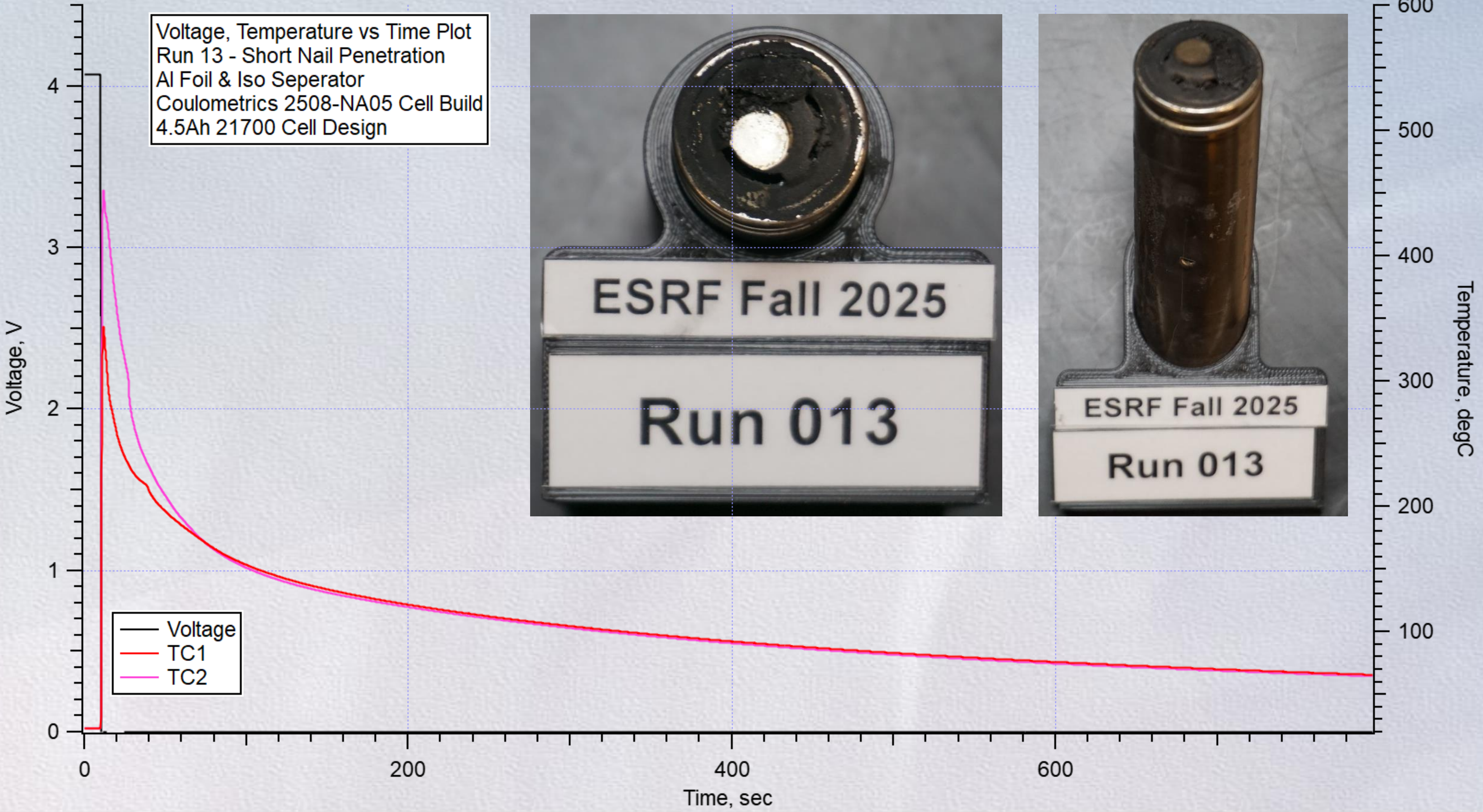
Summary of Nail Results for 2025

			At ESRF			At Coulometrics			Total		
CC	**Separator Design**	**Nail**	**TRs**	**Runs**	**%**	**TRs**	**Runs**	**%**	**TRs**	**Runs**	**%**
Al MPCC	Free Standing All Ceramic	Shallow	0	15	0%	0	2	0%	0	17	0%
Al MPCC	Free Standing All Ceramic	Deep	4	13	31%	0	5	0%	4	18	22%
Al MPCC	Ceramic Coated Polymer	Shallow	0	6	0%				0	6	0%
Al MPCC	Ceramic Coated Polymer	Deep	2	7	29%				2	7	29%
Al MPCC	Isotropic Strength Polymer	Shallow	0	12	0%	2	8	25%	2	20	10%
Al MPCC	Isotropic Strength Polymer	Deep	0	6	0%	2	8	25%	2	14	14%
Al MPCC	Isotropic & Ceramic Coated Anode	Shallow	0	12	0%	0	5	0%	0	17	0%
Al MPCC	Isotropic & Ceramic Coated Anode	Deep	0	5	0%	0	5	0%	0	10	0%
Al foil	Free Standing All Ceramic	Shallow	1	3	33%				1	3	33%
Al foil	Free Standing All Ceramic	Deep	2	2	100%				2	2	100%
Al foil	Ceramic Coated Polymer	Shallow	3	3	100%				3	3	100%
Al foil	Ceramic Coated Polymer	Deep									
Al foil	Isotropic Strength Polymer	Shallow	3	3	100%	3	3	100%	6	6	100%
Al foil	Isotropic Strength Polymer	Deep									
Al foil	Isotropic & Ceramic Coated Anode	Shallow	0	4	0%	3	3	100%	3	7	43%
Al foil	Isotropic & Ceramic Coated Anode	Deep	4	4	100%				4	4	100%

Combining the ceramic anode coating with the isotropic strength separator shows most consistent nail tolerance!

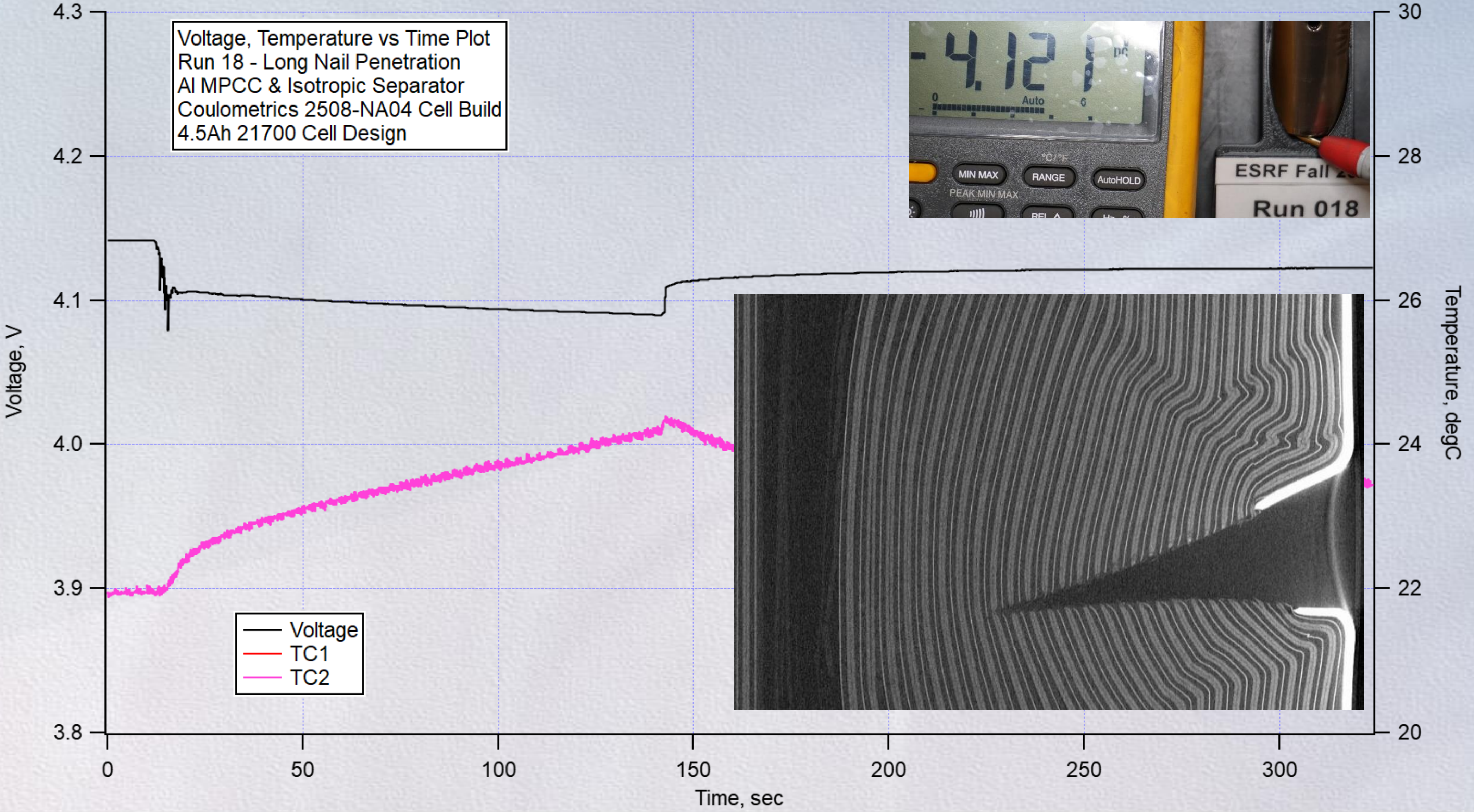
Isotropic Strength Separator

Maximum ΔV: 4.07 V
Maximum ΔT: 429 °C



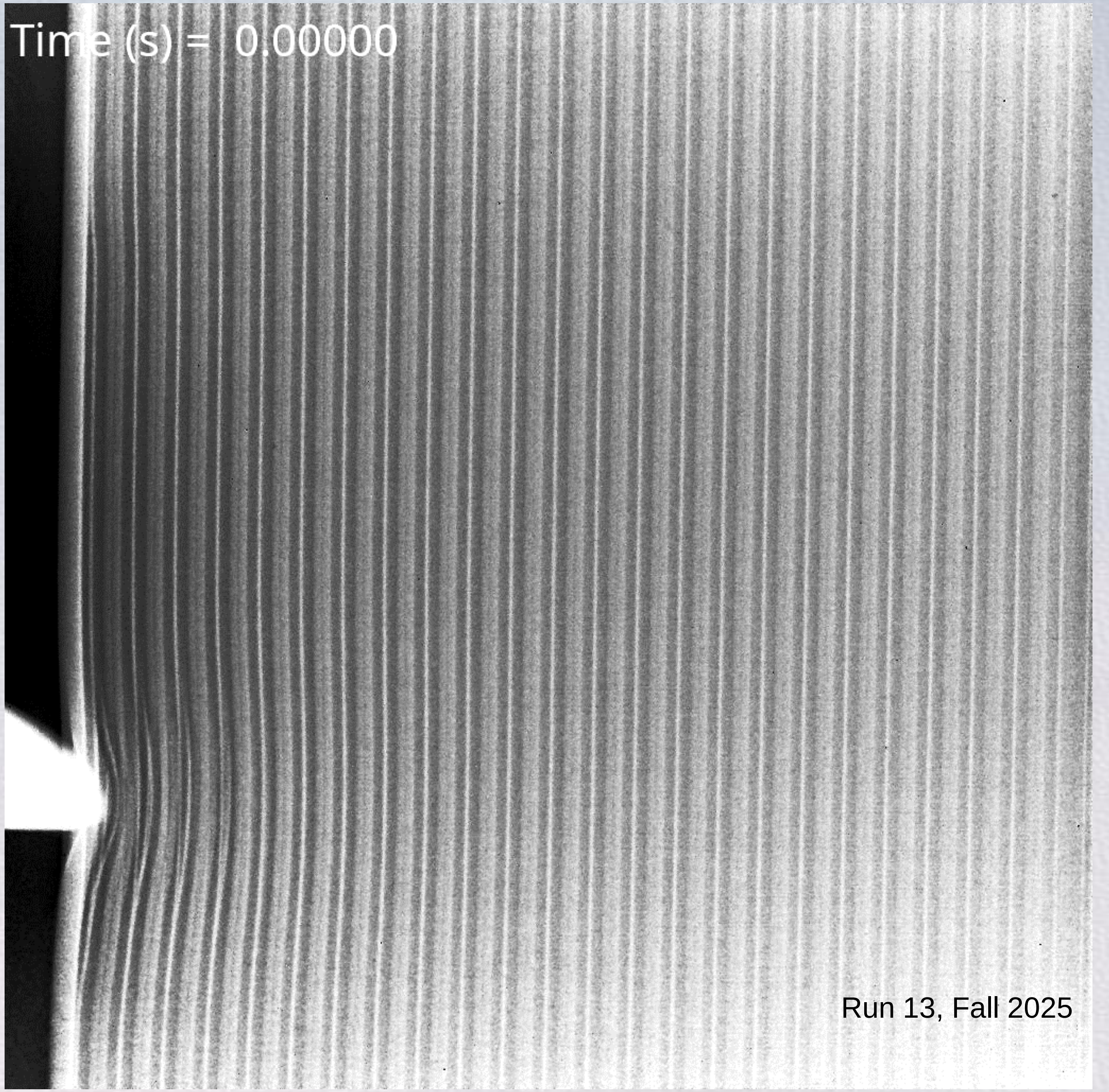
MPCC =Isotropic Sep - Long Nail

Maximum ΔV: 63.0 mV
Maximum ΔT: 2.4 °C

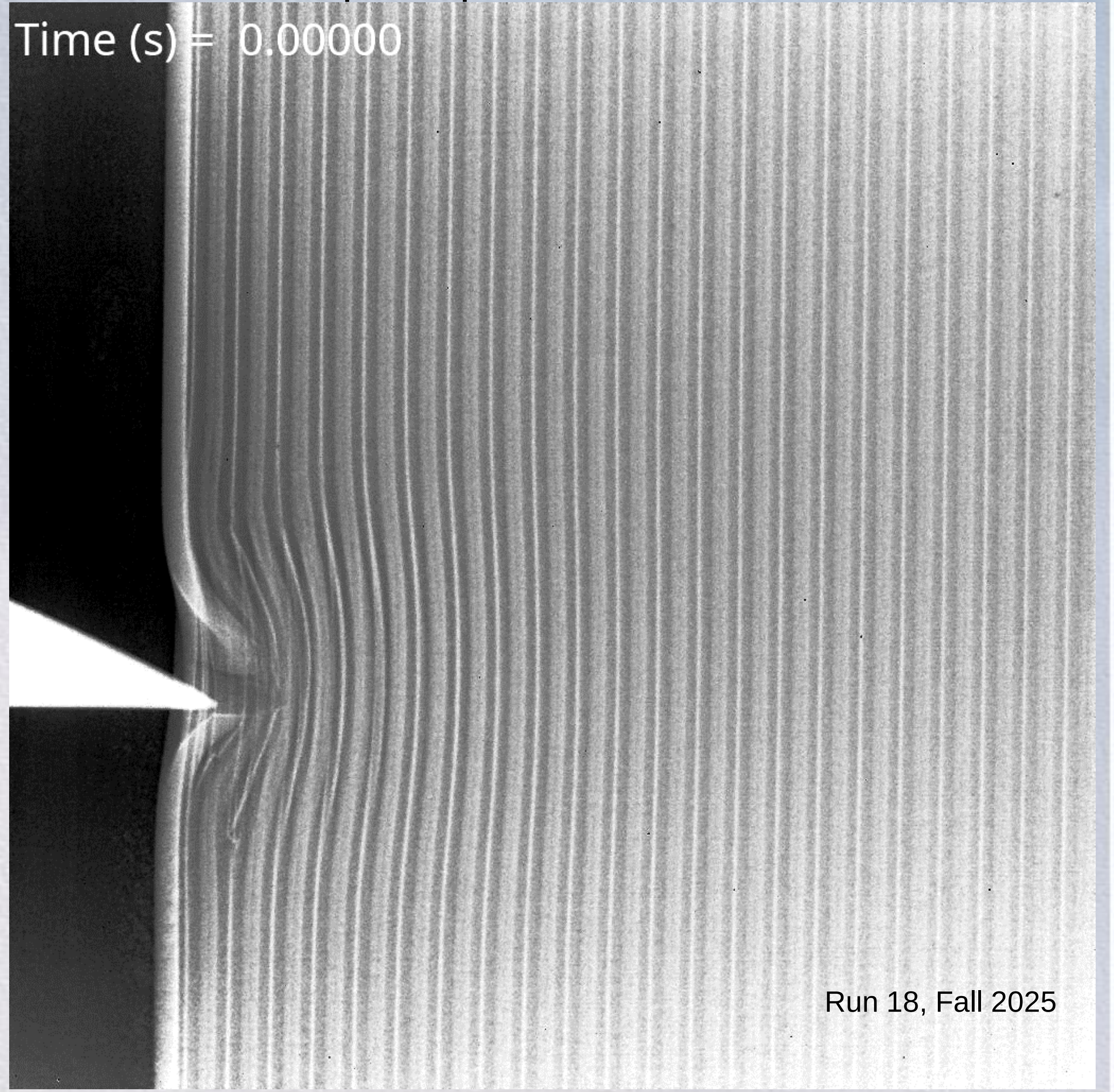


Isotropic Strength Polymer Separator

With Al CC, immediate TR with shallow nail

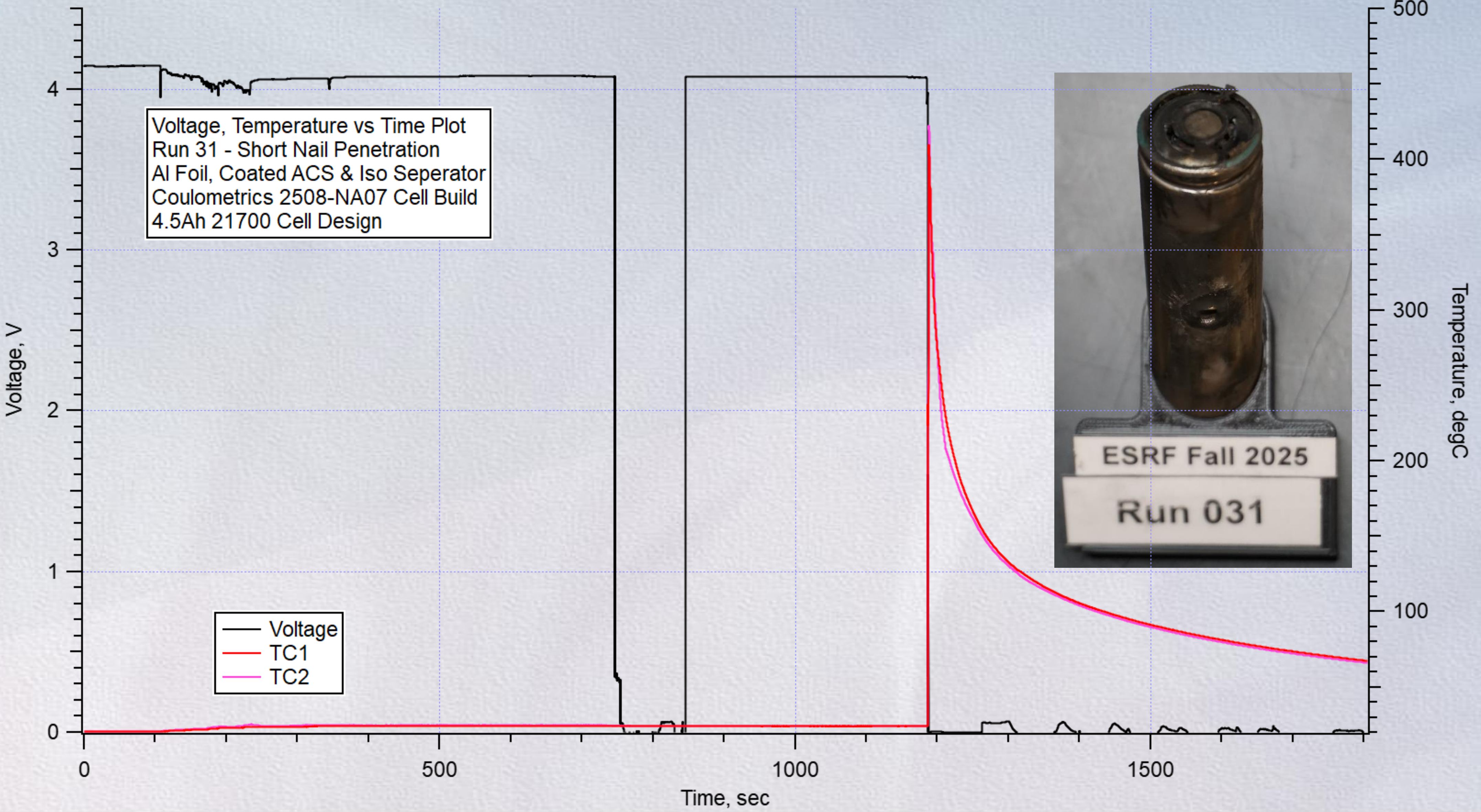


With Al PCC, deep nail penetration in shallow hole



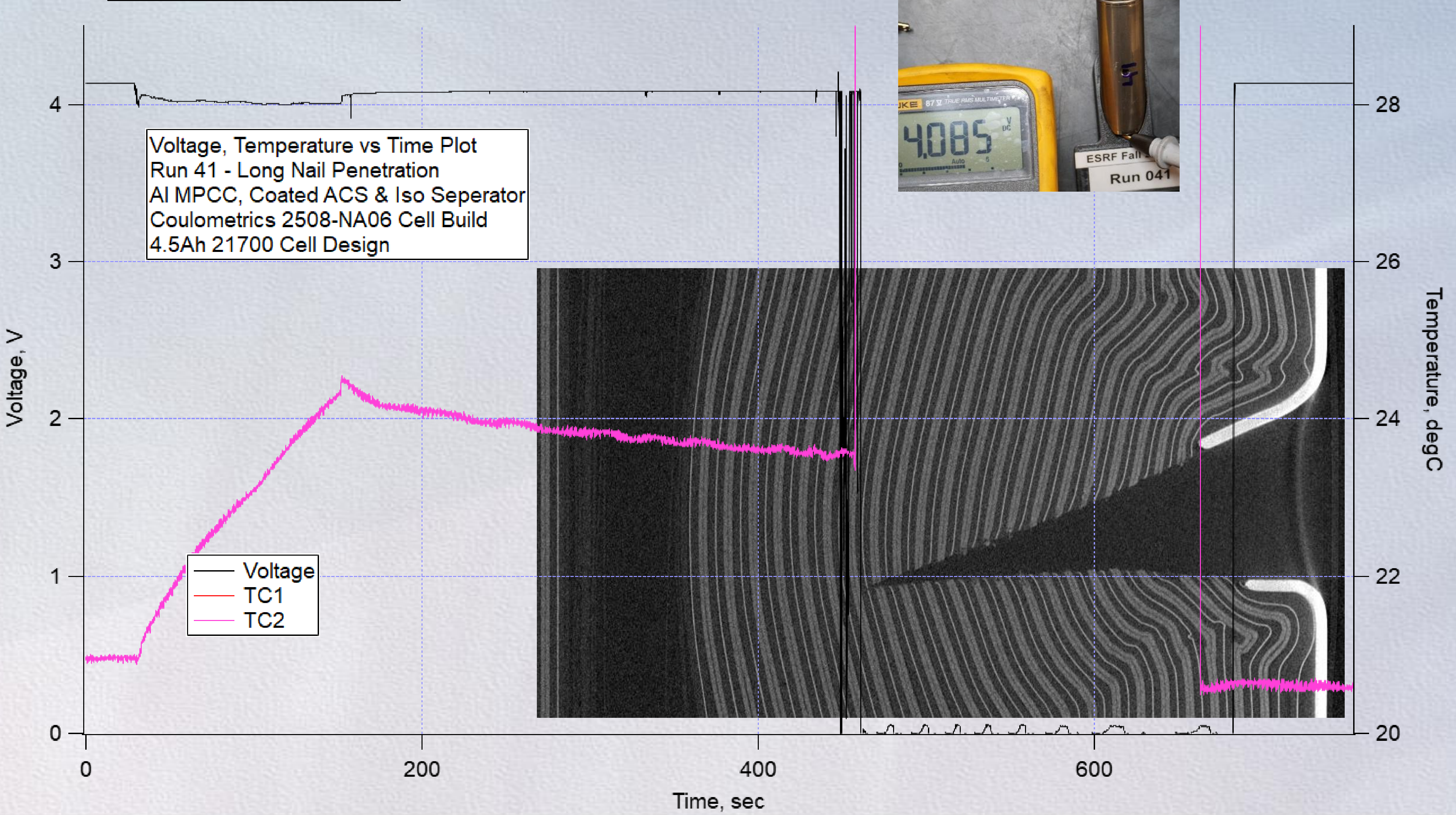
Ceramic Coated Anode & Isotropic Separator

Maximum ΔV: 4.07 V
Maximum ΔT: 398 °C



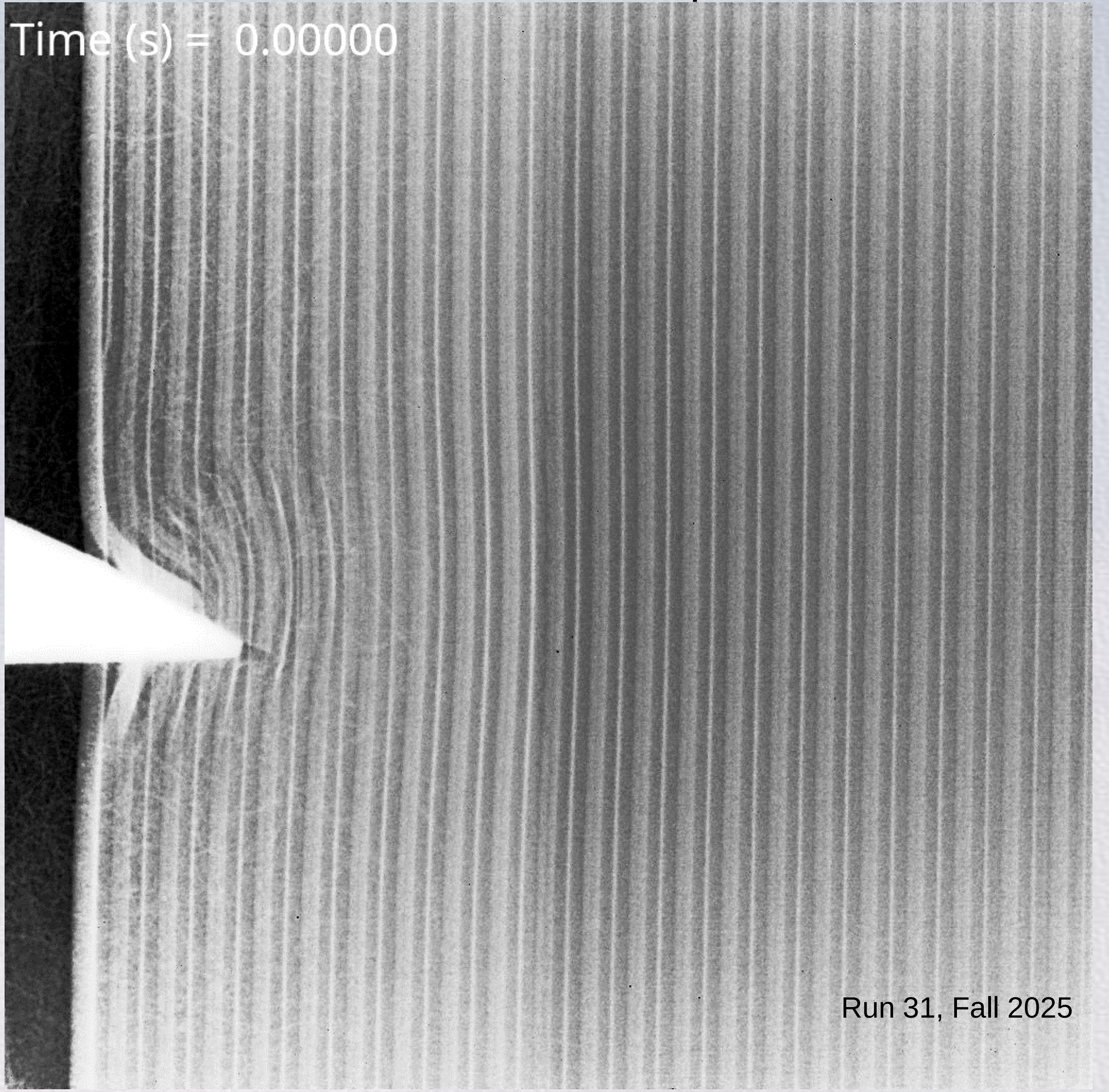
MPCC – Coated Anode – Isotropic Sep – Long Nail

Maximum ΔV: 133 mV
Maximum ΔT: 3.6 °C

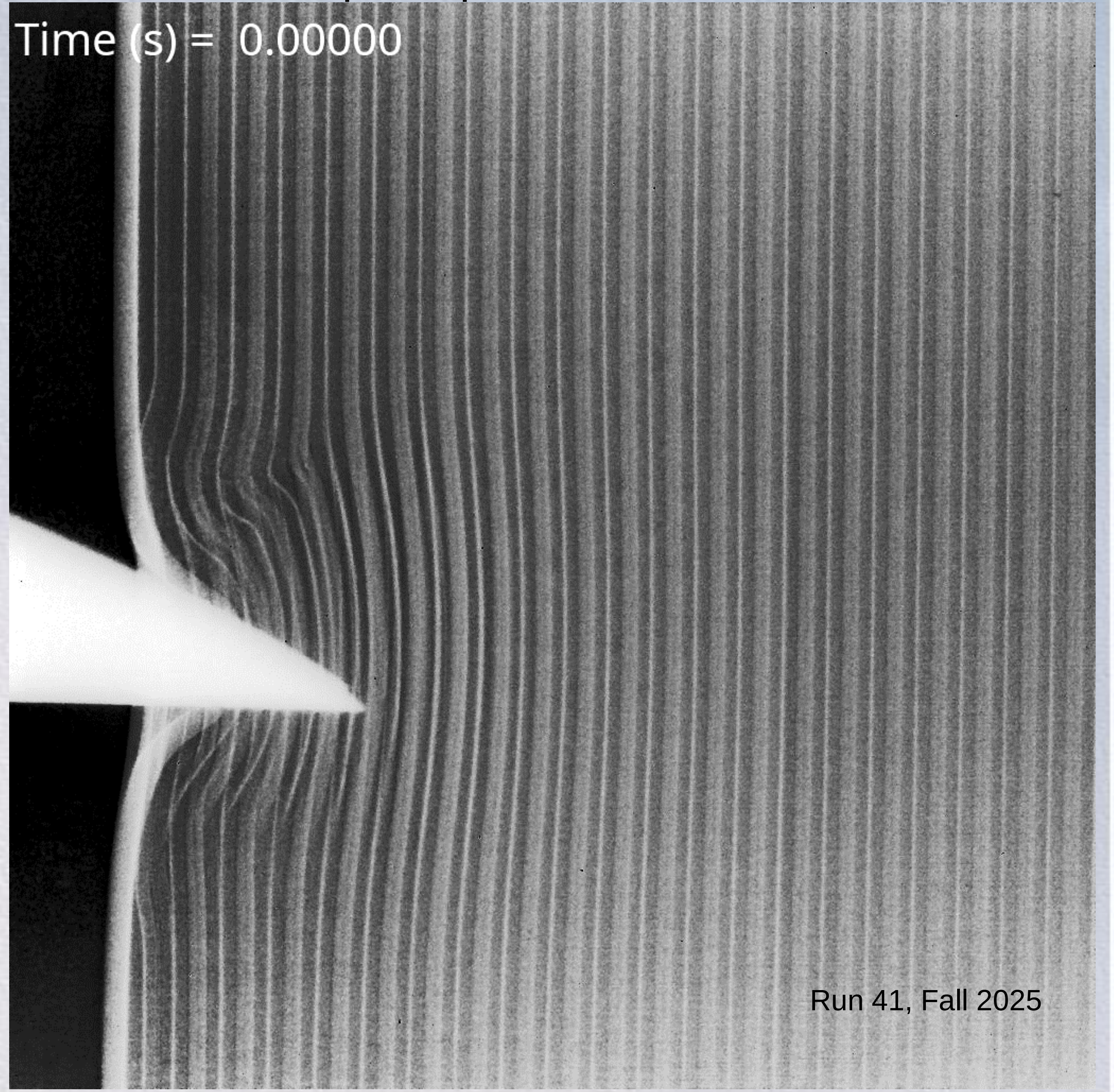


Ceramic Anode Coating & Isotropic Separator

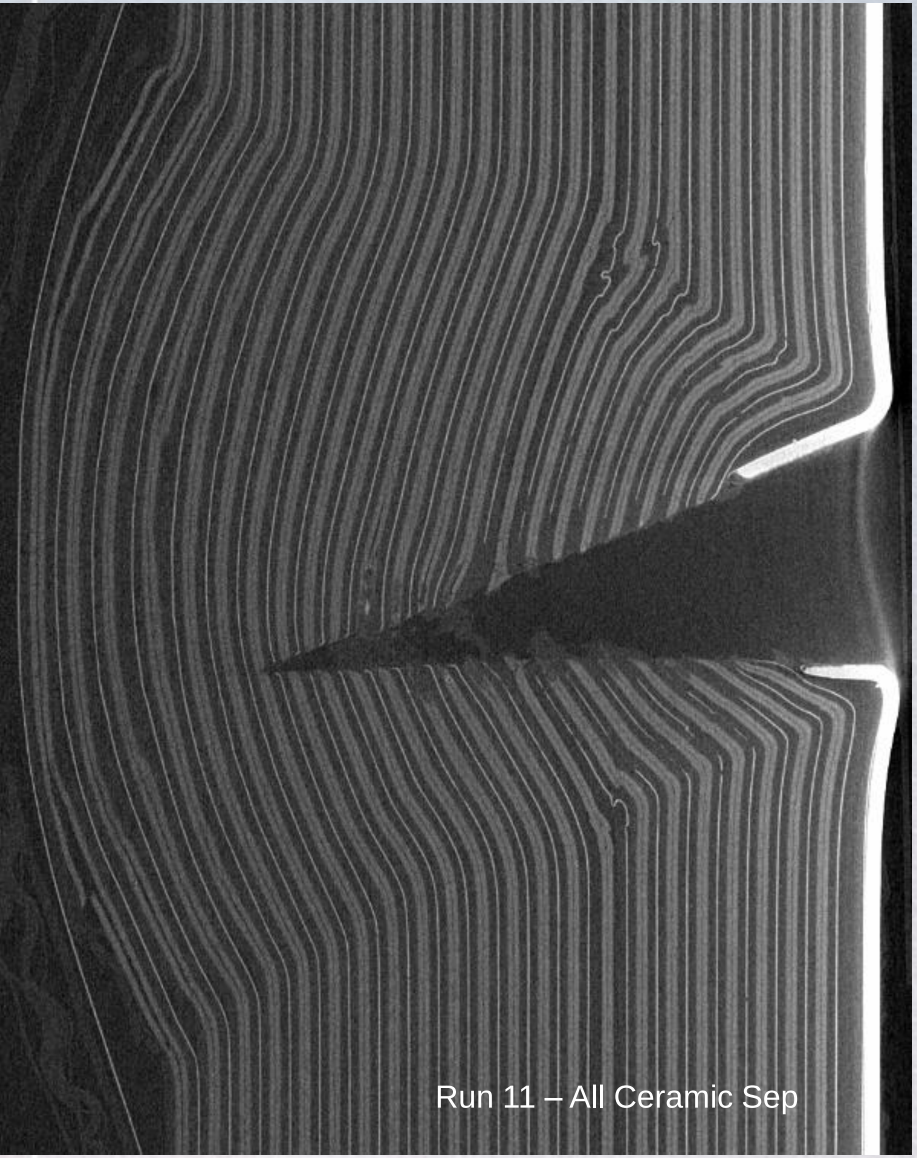
With Al CC, immediate TR with deep nail in shallow hole



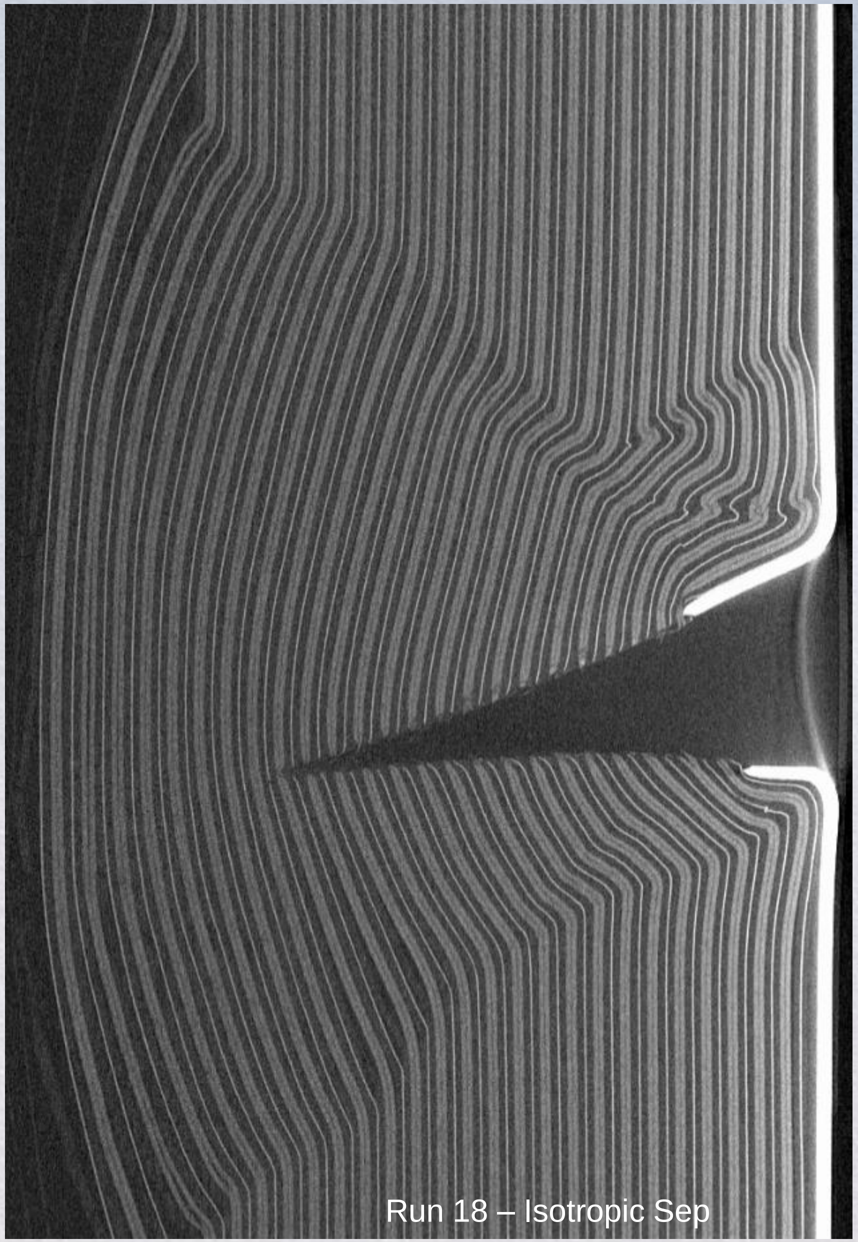
With Al PCC, deep nail penetration in shallow hole



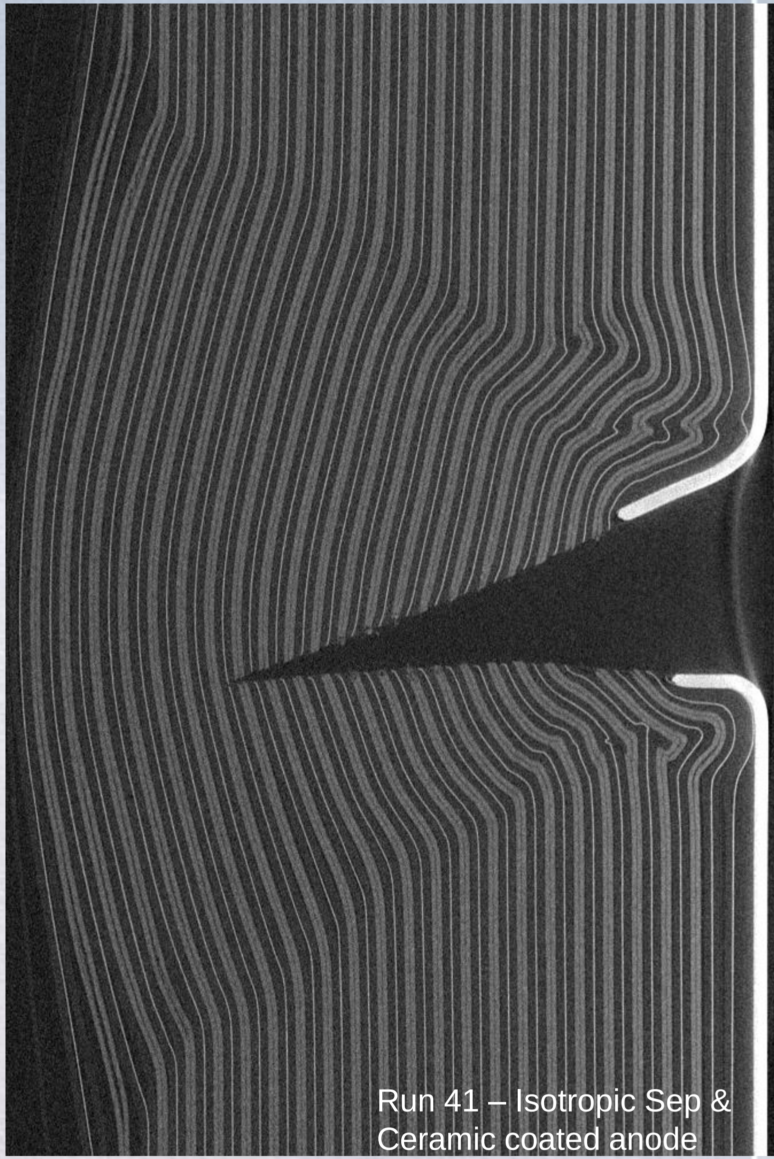
Nail Holes for MPCC Cells



Run 11 – All Ceramic Sep

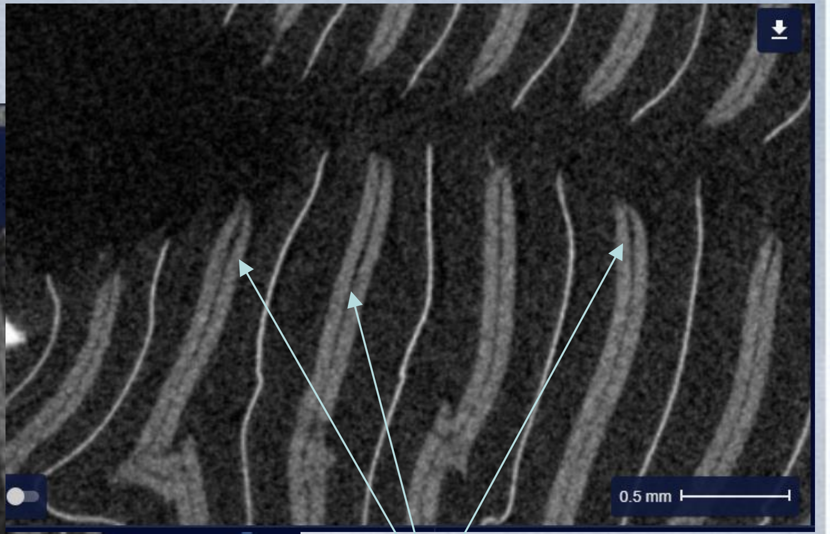


Run 18 – Isotropic Sep



Run 41 – Isotropic Sep & Ceramic coated anode

Close-up Images

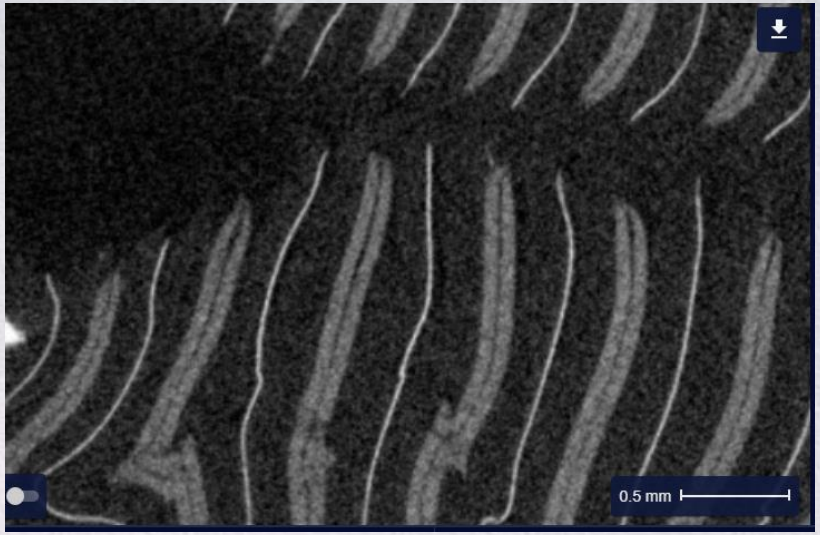


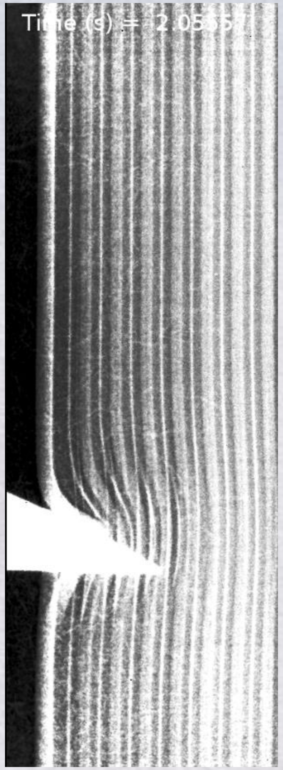
Absence of MPCC at the nail interface leaving delaminated active graphite coatng

Conclusions & Forward Work

Conclusions

- High specific energy cells (> 253 Wh/kg cell designs) need
  - thermally stable anode coating
  - and isotropic strength separator
  - for most robust & consistent nail tolerance
  - 0 TRs out of 27 nail penetrations





Forward Work

- Prove MPCCs can protect against static Internal Short Circuit Device
- Get high volume cell manufacturers to try cells MPCC with
  - Isotropic strength separator
  - Anode ceramic coating & Isotropic strength separator
- Determine if tab-less JR 21700 cells will tolerate nail with MPCC
  - Will it need isotropic strength sep?
  - Will it need ceramic coated anode?
  - Will the impedance penalty be reduced?

Backup Slides

Findings

Row Labels	Average of max dT	Average of dV (mV)
Al Foil, Coated ACS & Iso Seperator	367.43	3990.2
Al MPCC & Free Standing ACS	22.81	248.0
Al MPCC & Isotropic Seperator	30.68	782.0
Al MPCC, Coated ACS & Iso Seperator	13.32	370.1

- 34 of 35 MPCC cells tolerated nail penetration without TR
  - Shallow (3mm) and deep (9mm) nail
  - Only TR (Run 42) was due to nail penetrating (+) positive
    - But delayed by 30s
    - Only instance of (+) tab nail contact
- Free standing all ceramic has largest ΔV and ΔT of the 3 types of MPCC cell designs
- Coated anode & isotropic sep yield the lowest ΔV of the 3 types of MPCC cell designs with deep nail