OAK RIDGE National Laboratory

Injection Molding of Large Plastic Scintillator Tiles at Optical Quality

Friederike Bock, Volker Buescher, Mike Febbraro, Amy Elliott, **Oskar Hartbrich**, Norbert Novitzky, Nicolas Schmidt

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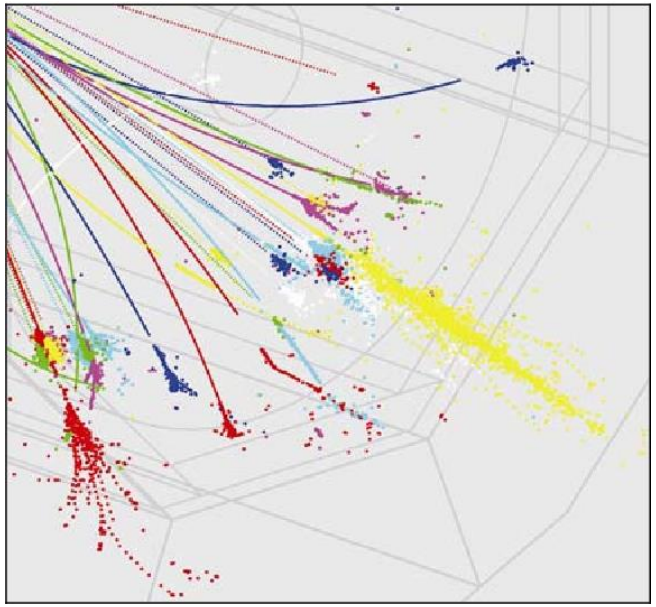
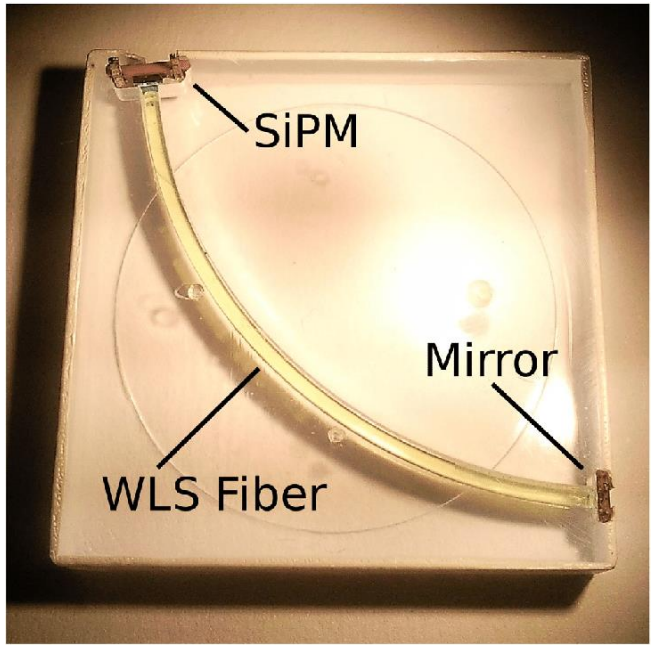
U.S. DEPARTMENT OF ENERGY

High Granularity Calorimeters

- Super high granularity calorimeters for Particle Flow Reconstruction
  - Originally envisioned for ILC detectors: CALICE
- HCAL: Metal absorber + plastic scintillator tiles
  - ~3x3cm^2 segmentation, 10M+ channels
  - Tiles individually read out with SiPM: small and "cheap"
  - CALICE AHCAL prototypes since 2004
- Nowadays baseline for many NP/HEP projects
  - CMS HGCAL, NA61, ALICE FOCAL, EPIC, DUNE…
- Common challenge: many discrete channels
  - Integration, assembly, electronics, mechanics…

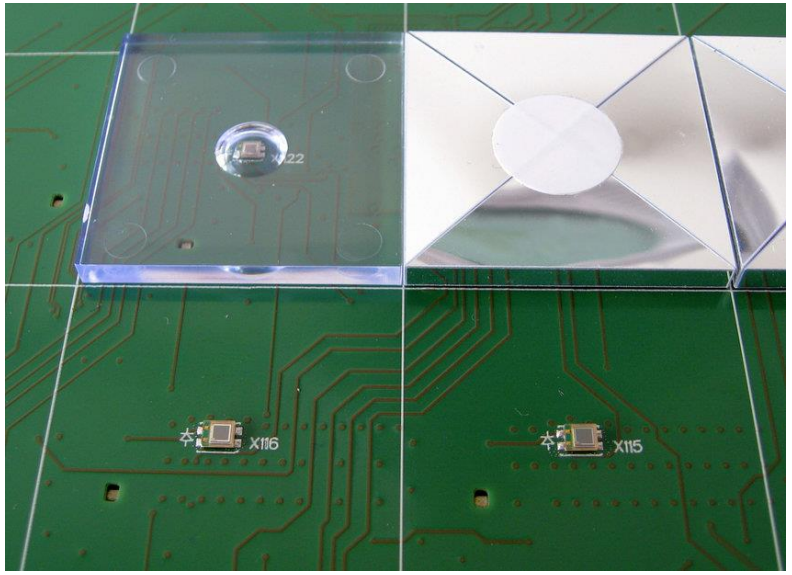


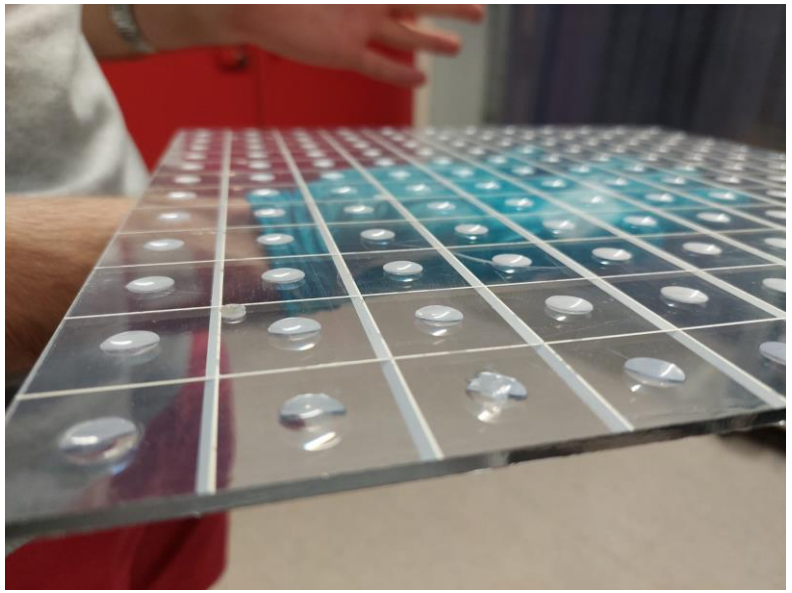


Injection Molding of Large Plastic Scintillator Tiles

Plastic Scintillator Tile Assemblies

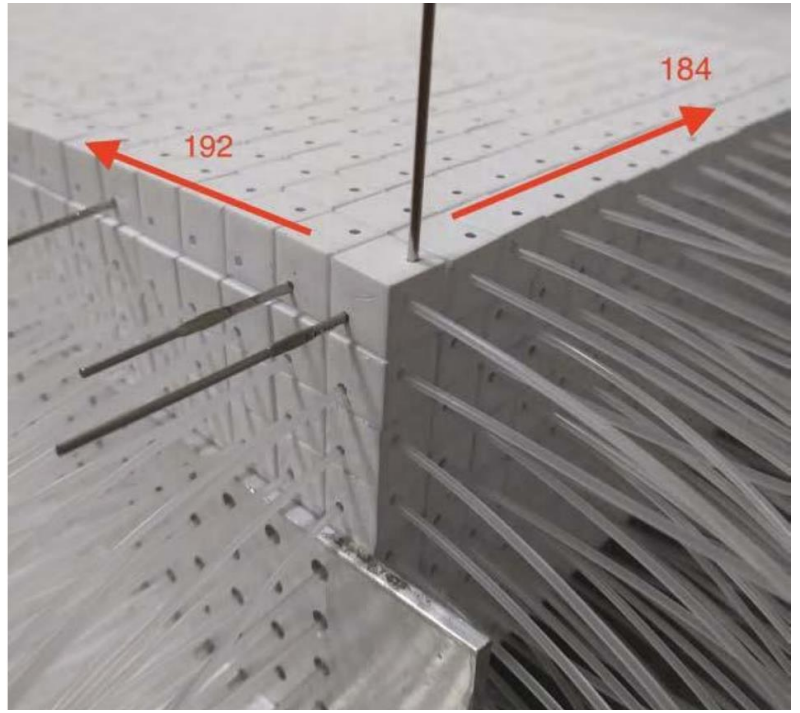
- Invididually wrapped tiles
  - Machined or injection molded small tiles
  - Individual wrapping, assembly
- "Megatiles"
  - Large scintillator plate scale of one "module"
  - Machined separation ridges, refilled with TiO_2+epoxy
  - Done for STAR FEMC, continuing R&D within CALICE (NIU, Mainz)
  - Time consuming, expensive production: equipment + machinists





Injection Molding of Plastic Scintillators

- Expensive startup cost (mold), cheap and fast production
- FNAL is producing injection molded plastic scintillators already
  - Base material "Polystyrene 665“ ~$10/kg
  - Achieved reasonable light yield
  - FNAL molder limited to ~100g/shot
- Our goal: Large injection molded Megatiles
  - High aspect ratio: large and thin
- The Challenge: intricate patterns
  - Relative scale of structures, not absolute size of structures.

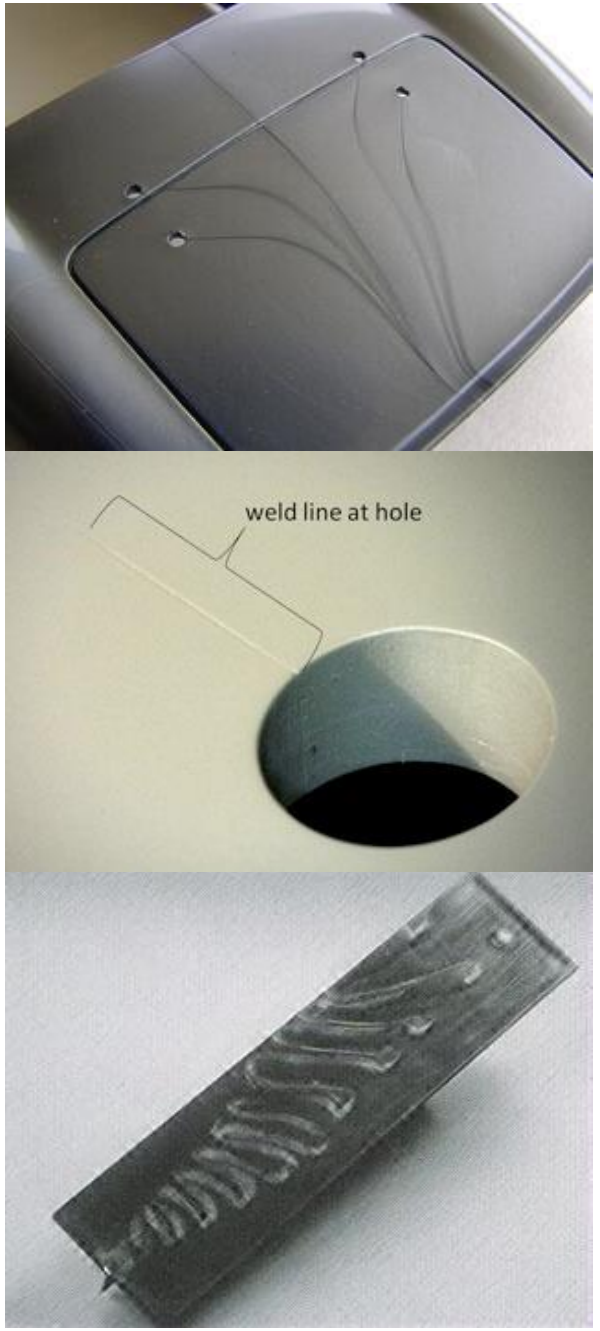


Sample Name	Total Light Yield (pe)
Cast Eljen EJ200	33.9+-1.0
Cast Eljen EJ208	34.8+-1.0
Cast Eljen EJ262	33.0+-1.0
injection molded sample 1	23.4+-0.7
injection molded sample 2	23.7+-0.7

[Jim Freeman, FNAL, CPAD'21]

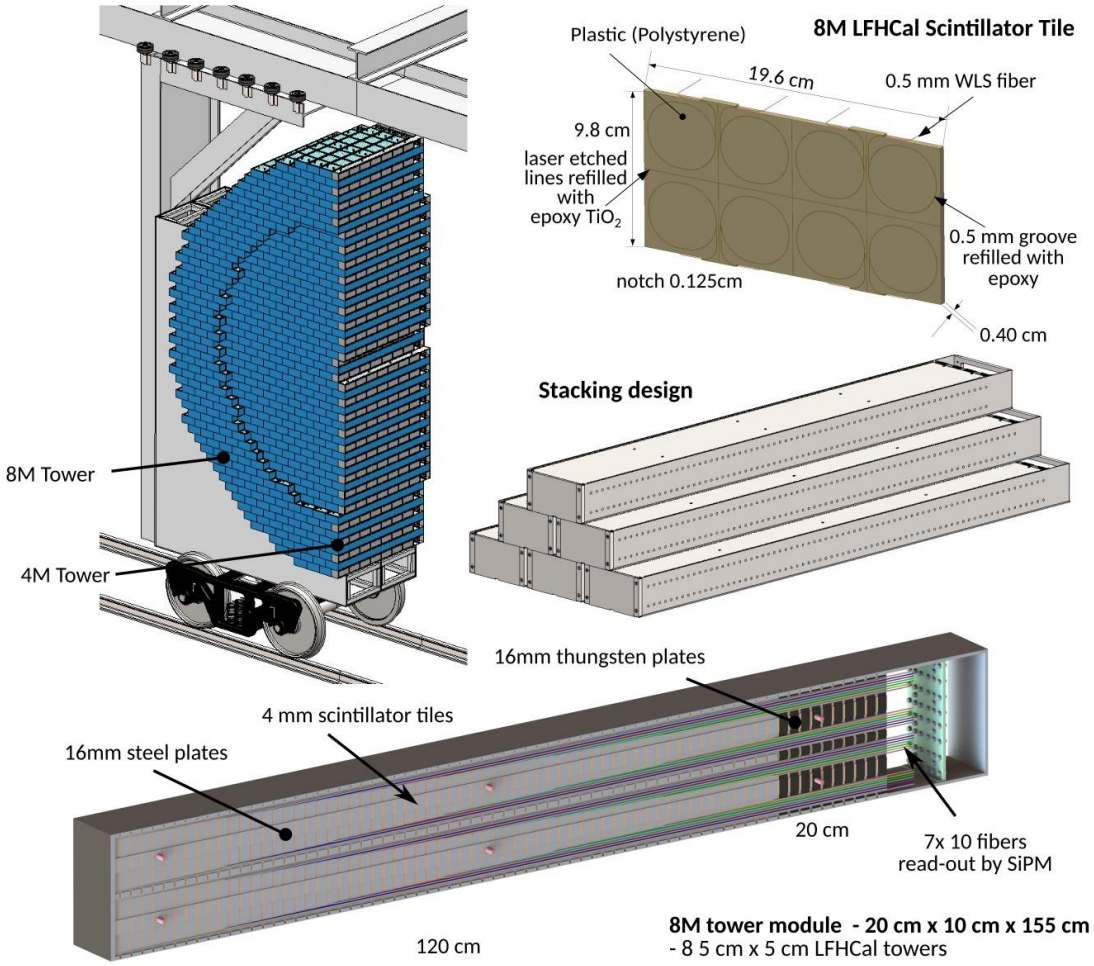
Injection Molding Challenges

- How to make our tile designs moldable?
  - Not everything that is machinable can be injection molded
  - Draft angles, feature widths, minimum material thickness…
- How to produce flawless tiles?
  - Mold design is an art
  - Thin, large area injection molding is extra difficult
- Need engineering consulting and test runs
  - Machine parameters, mold design details…



The Benefit

- Based on latest EPIC LFHCAL budgeting
  - 80,000pcs 20x10cm^2 tiles
- **90%** cost reduction
  - Machined tiles: $5,000k
    - $65/tile (material, machining)
  - Molded tiles: <$500k
    - 3 molds: $100k
    - Effort: $120k (80 days)
    - Material: $120k
- **90%** less production time
  - Machined tiles: 2-4 years for raw material
  - Molded tiles: 4 months, 8h/day



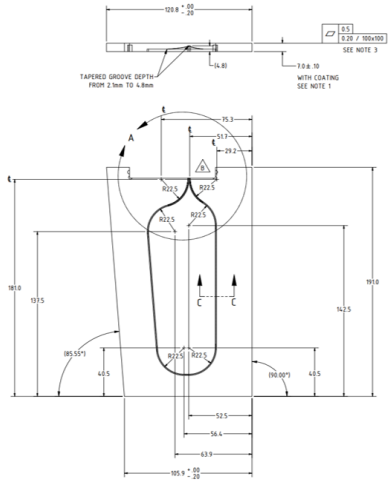
The Team

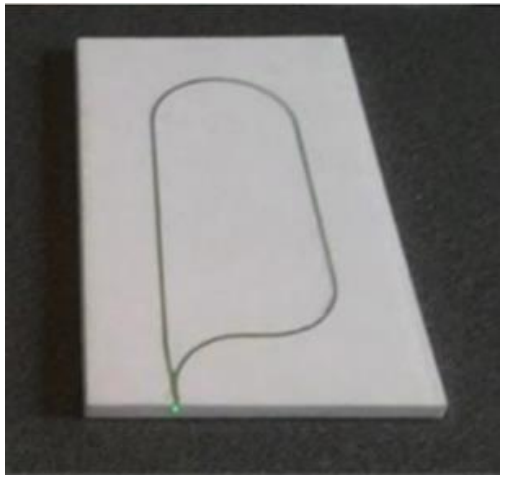
- ORNL MDF: **The** place for manufacturing techniques
  - In-house expertise in materials, tooling and fabrication
  - Available injection molder, >>100g/shot
  - Contacts to local mold manufacturers for consulting/mold production
  - Full-scale metrology equipment available
- ORNL RNP: Main proponents of the EPIC LFHCAL
  - Existing design for machined Megatiles integrated into LFHCAL mechanics
  - Access to testbeam time for EPIC LFHCAL prototypes
- Uni Mainz: CALICE Megatile R&D
  - Experience with machined SiPM-on-tile Megatile production including post processing, handling etc.
  - Established test stands for CALICE geometry, available reference tiles, experience...

The Plan

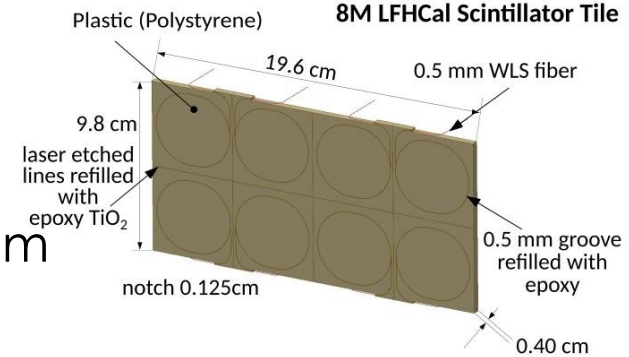
complexity

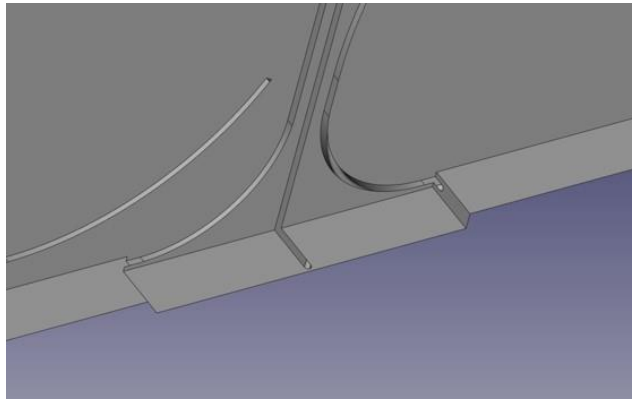
- Phase 1: sPhenix iHCAL tile
  - Few features, single fiber channel
  - Test in existing sPhenix test stands



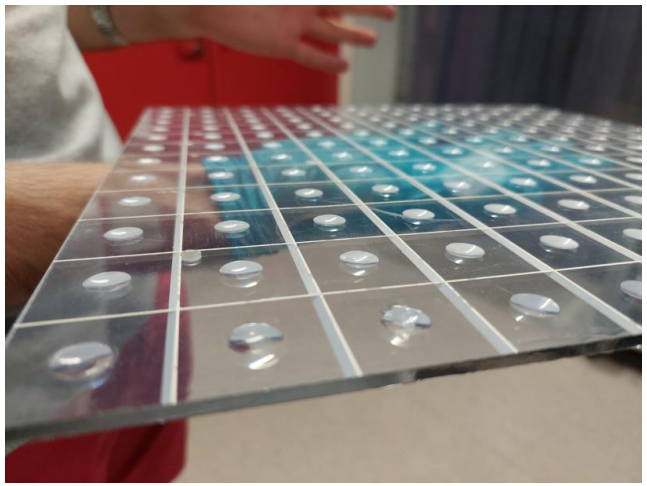


- Phase 2: LFHCAL "8M" tile
  - 20x10cm^2, eight fiber channels
  - Added deep separation ridges
  - Integration into LFHCAL testbeam prototypes





- Phase 3: CALICE AHCAL Megatile
  - Large: 36x36cm^2, SiPM coupling "dimples"
  - Many deep separation ridges
  - Existing CALICE AHCAL test stand



Reviewer Question #1

"The performance criteria for optical quality and crosstalk were not quantified. This should come from experience or simulation. What are the allowable specifications? How does this relate to the main physics cases for the detector systems at EIC?"

- Visual inspection for defects to guide machine parameters
- Compare lightyield and crosstalk to machined tiles
  - Using existing test setups
  - Expect 25% lightyield reduction due to material (from FNAL studies)
  - 5% crosstalk acceptable (Mainz Megatile 1-2%)

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Reviewer Question #2

"What optical quality has been reached so far at ORNL?"

- MDF has not injection molded transparent materials before
  - Also no direct experience with Polystyrene 665
  - Injection molding PET with 3D printed molds was optically perfect
- Consulting with mold producer and FNAL will help to with reasonable starting parameters.
  - Expect some parameter optimization during the first molding runs

Reviewer Question #3

"Is there a reasonable limit on the size of these devices, and how does that match the production and development? Explain the interplay of the size of tile, size of SiPM, optics, cross talk, and physics requirements."

- Practical maximum is the size of an assembly/readout module
  - CALICE AHCAL 36x36cm^2 (400g), EPIC LFHCAL 20x10cm^2 (80g)
  - Handling will become difficult at these scales due to separation ridges.
- Size of SiPM is independent of size of Megatile and not part of this proposal.
- Crosstalk depends on quality of filling
  - shown to be feasible by STAR and CALICE. Filling is optically opaque
  - Ultimately depends on achievable depth of separation ridge and wrapping

Reviewer Question #4

"Different examples are presented, how will the decision on which type to take forward be made?"

- This R&D proposal is generic, not focused on any specific project
- Goal is to figure out what is possible at which level of compromise
  - We propose the given phases of test for increasing complexity and for availability of existing test stands and machined reference tiles.
- The results of this R&D will inform future detector proposals on what can be achieved and what needs more work

Reviewer Question #5

"The work plan looks very aggressive/ambitious to fit within one year. What steps for evaluation and process improvement are planned? What is the expected feedback mechanism?"

- We plan three types of tiles with increasing difficulty
  - Baseline funding assumes one additional mold production (4 mold productions for 3 tile types)
  - Incorporate lessons learned from one type into next type
  - Partially parallelizable: go/no-go next mold design/production based on visual quality of previous phase
- Gained knowledge might alter the plans
  - R&D is also about learning which questions to ask

Summary

- Investigate large area injection molding of plastic scintillator materials
- Inter-disciplinary proposal:
  - ORNL MDF: Engineering, Manufacturing
  - ORNL RNP: Nuclear Physics
  - Uni Mainz: High Energy Physics
  - Industry partner: Mold manufacturing, consulting
- Generic in application
  - EIC Detector 2, EPIC nHCAL, EPIC HG insert, greater NP and HEP…
- High risk, high reward
  - 90% cost and production time reduction compared to machined tiles

Institute	Item	Cost per item in $	Number of items	Total cost in $
ORNL RNP	tile prototype quality assessment		0.2 FTE	(in-kind) 0
ORNL	mechanical engineering tile/mold	180/h	100h	18K
ORNL	raw materials, shipping			5K
ORNL MDF	mold printing	5000	4	20K
ORNL MDF	mold machining	5000	4	20K
ORNL MDF	injection molding run	6000	5	30K
ORNL RNP	travel	5000	1	5K
JGU	postdoc support		0.2 FTE	14K
JGU	graduate student support		0.2 FTE	7K
JGU	tile post processing	90/h	100h	9K
Total				**128K**

Backup

Funding Allocation

Table 1: Funding allocation for FY23.

Institute	Item	Cost per item in $	Number of items	Total cost in $
ORNL RNP	tile prototype quality assessment		0.2 FTE	(in-kind) 0
ORNL	mechanical engineering tile/mold	180/h	100h	18K
ORNL	raw materials, shipping			5K
ORNL MDF	mold printing	5000	4	20K
ORNL MDF	mold machining	5000	4	20K
ORNL MDF	injection molding run	6000	5	30K
ORNL RNP	travel	5000	1	5K
JGU	postdoc support		0.2 FTE	14K
JGU	graduate student support		0.2 FTE	7K
JGU	tile post processing	90/h	100h	9K
Total				**128K**

Table 2: Funding matrix FY23.

Institute	Production	Characterization	Engineering	Total cost
ORNL	$75K	$5	$18K	$98k
JGU	$9K	$21K	$0K	$30K
Total	$84K	$26K	$18K	