

PROBLEM DEFINITION

# Defining the Problem

Josh Bub

As passionate students of the sciences, we felt as though there was a lack of teaching tools available for professors. The issue is that as science topics become more complex, they often focus on the smallest, fastest things. It can be difficult for a student to visualize these subatomic interactions without ever seeing them firsthand. But how could that be possible? Well, what about a cloud chamber?

**Educators need a way to introduce students to complex topics and get them interested in the natural sciences.**

We translated those problems into five measurable success criteria so we could objectively assess whether a given iteration actually solved the problem — not just looked like it did. Every design decision was judged against this rubric. Our north star: bridge the gap between textbook particle physics and Brandeis students. The cloud chamber should not only be a fun project but also a useful educational tool.

SUCCESS CRITERIA

- Compact & portable form factor
- Consistent, repeatable results
- Educational value for students
- Low-cost & replicable design
- Minimal user involvement required

USER RESEARCH

# User Profile

Josh Bub

After some discussion, we concluded that our cloud chamber should cater specifically to educators. The design should make it easy for someone to demonstrate the cloud chamber and for the student to enjoy it. With this ideal user dynamic in mind, we wrote design statements to guide our iteration for the rest of the project.

DESIGN STATEMENTS

## Guiding Our Iteration

- › The cloud chamber must be easy to use for people with no experience in the sciences.
- › The system should incorporate educational aids to translate observed particle behavior into physics concepts.
- › The cloud chamber must be designed such that high-contrast, easily visible particle paths appear so users with varying levels of visual ability can clearly observe and distinguish particle trajectories.

These statements ensure we don't forget that this cloud chamber is not actually for us. It's not about how exciting we find it, but how easy it is to find exciting in general. The statements are meant to remind us about that.

Designed for educators - every iteration choice follows from this -



BACKGROUND RESEARCH

# User Research

Roy Kongwalei



ONLINE SOURCES

### Community Resources

There are several online resources that gave us some direction for this project, but only a few of them have actually created designs that were feasible given our time and budget constraints.

- › Dry-ice flat-pan builds (most common)
- › Peltier-cooled continuous-operation designs
- › 3D-printed enclosure tutorials (Instructables)
- › What do larger-scale cloud chambers look like?
- › What materials are used in the most common designs?

YouTube Tutorials

Personal Builds

Blog Posts

EXPERT CONSULTATIONS

### Primary Sources

- › **Physics Advising Head (Prof. Emily Tiberi):** Reiterated the importance of the lack of visual teaching tools for introducing students to particle physics.
- › **Lab technicians (physics):** Warned against unstable power supplies based on past experience and helped clarify the supersaturated state we needed. Both individuals displayed interest in the project, but were skeptical that the project would be able to function in the form factor we intended.
- › **Prior DIY builder (online community):** Shared failure modes — most failures come from enclosure leaks and alcohol evaporation rate mismatches.

Consultants chosen to cover three failure domains: pedagogy, electronics, build quality.



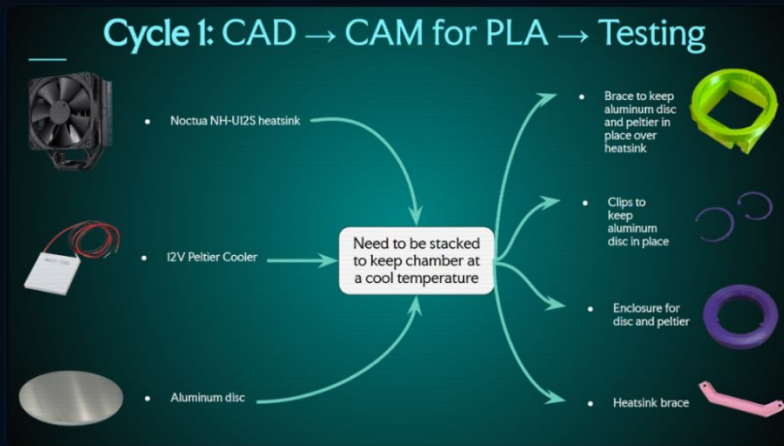


ITERATION CYCLE 01

# Cycle 1 — Baseline

Logan Gruss

05



DESIGN GOALS MET:

- 3D prints fit their associated hardware without needing modification.
- Parts are all compatible; Peltier stack can be built without force.
- Parts survive temperatures -30°C or colder for 10+ minutes without deforming.
- Stack can be fully disassembled without tools or reprinting parts.
- All parts fit on one PRUSA Mini+ build plate.

WHAT WE CHANGED & WHY

Our model uses a single Peltier module (TEC1-12709) between an aluminum cold plate and a heatsink with a CPU fan. Therefore, for our next iteration we focused on ensuring the stack is not just secure but allowing sufficient contact between the plate, peltier, and heatsink.

The device at this point was functional, but not built for a favorable environment. We faced a temperature differential too small for supersaturation, which we attributed to a poor seal and limited thermal paste. These issues were addressed by further design iterations.

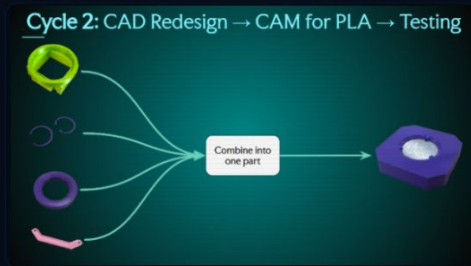


ITERATION CYCLE 02

# Cycle 2 — Sealing

Josh Bub

07



DESIGN GOALS STATUS

- 3D prints fit their associated hardware without needing modification.
- Parts are all compatible; Peltier brace can be built without force.
- Parts survive temperatures  $-20^{\circ}\text{C}$  or colder for 10+ minutes without deforming.
- Brace can be fully disassembled without tools or reprinting parts.
- All parts fit on one PRUSA Mini+ build plate.

WHAT WE CHANGED & WHY

We checked off two new goals with the second iteration but lost two in the process. The first iteration was entirely modular, so taking apart the brace was much easier and could be done without any tools.

In the second iteration, taking the aluminum disc out of the brace required either having small enough fingers to remove the part or using needle-nosed pliers to get the bottom of the brace open. Thankfully, from here on out, we don't backtrack during an iteration cycle. It's all up from here!

THERMAL PASTE AMOUNT & CHANGE IN MINIMUM TEMPERATURE

Amount	None	Minimal	Moderate	Lots	Lots + Glass Chamber
Temperature	$3^{\circ}\text{C}$	$2^{\circ}\text{C}$	$-15^{\circ}\text{C}$	$-25^{\circ}\text{C}$	$-40^{\circ}\text{C}$
Change	—	$-1^{\circ}\text{C}$	$-17^{\circ}\text{C}$	$-10^{\circ}\text{C}$	$-15^{\circ}\text{C}$

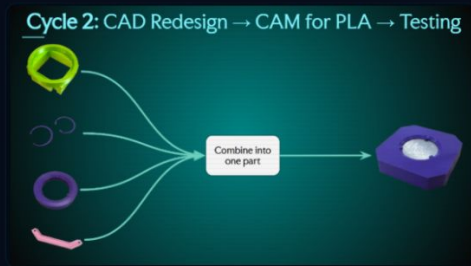


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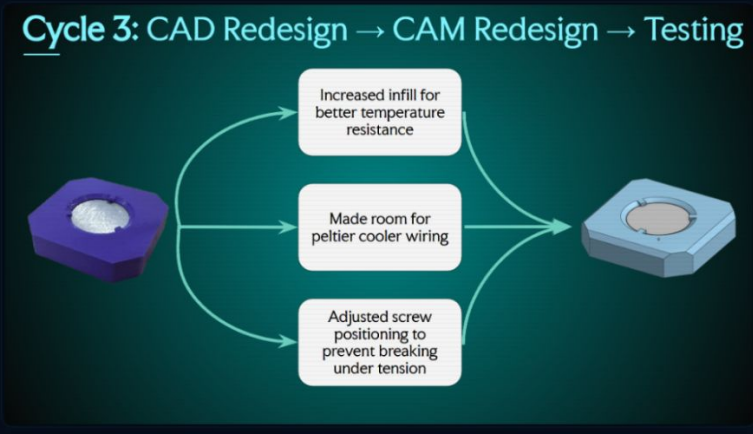
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ITERATION CYCLE 03

# Cycle 3 — Miniaturizing

Ian Dyer



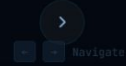
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WHAT WE CHANGED & WHY

We changed from using several 3D printed pieces to just 2. This made the 3D printing process simpler as well as making the geometry of the parts more friendly to printers and older computers.

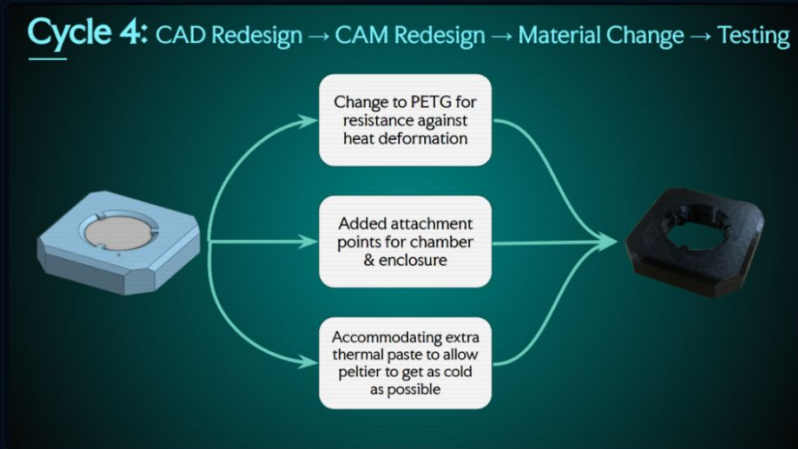
Enclosure changed from acrylic to glass. Initially, the plan was to cut pieces of acrylic to the desired size and place it over the aluminum plate, but we switched to using an empty, upside-down Yankee Candle to remove another step from the production process.



ITERATION CYCLE 04 - FINAL

# Cycle 4 — Final Product

Ben Khayat



DESIGN GOALS STATUS — ALL MET

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- ✔ All parts fit on one PRUSA Mini+ build plate.

WHAT WE CHANGED & WHY

Final iteration focused on cost reduction and minimizing user involvement. Printed a stand for the isopropanol rag to sit on.

Switched from PLA to **PETG** — dramatically improved performance against extreme freezing without structural deformation. Added finger clearance at the bottom of the brace for complete tool-less disassembly.



LIVE DEMONSTRATION

# Live Demo & How It Works

Logan Gruss

THE PHYSICS

### Why tracks appear

- › **Cooling:** A Peltier module cools the metal plate to about -25 to -30 degrees Celsius.
- › **Vapor Source:** Isopropyl alcohol evaporates from warm felt near the top of the chamber and diffuses downward.
- › **Supersaturation:** When that vapor reaches the cold plate, it becomes supersaturated, meaning the air holds more alcohol vapor than it normally can at that temperature.
- › **Ionization Path:** Charged particles passing through this thin layer knock electrons off nearby molecules and leave an ionized path (free electrons).
- › **Droplet Formation:** Alcohol vapor condenses around those ions, forming tiny droplets.
- › **Visible Tracks:** A bright light makes these droplet trails very visible, letting us see particle paths that are normally invisible, proving the existence of ionizing radiation with the naked eye.

● DEVICE IS LIVE!

WHAT TO LOOK FOR

### Track identification guide

#### Alpha Particle

Thick, short, straight- from Uranium glass, Am-241 smoke detector source, etc.

#### Beta Particle

Thin, curly, erratic- from Potassium-40, Tritium, etc.

#### Cosmic Muon

Long, razor-straight- from cosmic rays penetrating from above

#### Gamma Ray

Dense, branching- Medical imaging, radiotherapy sources, etc.




OPEN SOURCE

# GitHub Repository

Roy Kongwalei

Everything we built — CAD files, wiring schematics, build instructions, BOM, and code for microcontroller components — is publicly available. We documented as we went so this can be **reproduced by any school or lab.**

 [github.com/benkhayat/ECC-Files](https://github.com/benkhayat/ECC-Files)

Note: This repository may be a work-in-progress at time of presentation. We'll walk through what exists at the moment of presenting.

CAD / STL files

Wiring diagrams

Bill of materials

Build guide (PDF)

WHY GITHUB?

## Open Source Particle Physics

The prints required for this project are more involved than we would like, and having the files & instructions all in one place makes finding the desired resources easier for everyone. For this project, a Dozuki guide wouldn't have provided as much utility as a GitHub repository could.

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TARGET BOM




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LOOKING FORWARD

# Future Improvements

Ian Dyer

ENCLOSURE DESIGN

## Precision Housing

Make the enclosure more 'portable'; make the form factor large enough to keep large enough to keep the temperatures stable enough to see collisions, but small enough that it can be carried around and used anywhere with a power source.

POWER SUPPLY

## Dedicated Power Supply

Because of a mailing issue, the power supply we ordered never arrived. Instead of using the temporary variable DC power supplies that require constant rewiring, having a dedicated power supply would make starting up quicker, easier, safer, and more reliable.

AUTOMATION & GUIDES

## Improved Documentation

Improve the build guide with illustrated step-by-step instructions. At the moment, the guide requires more engineering and physics knowledge than our target demographic would be expected to have, and improving the documentation to provide simpler explanations for each instruction and troubleshooting guidance would improve our product's usability and breadth.

COST REDUCTION

## Sub-\$35 Target BOM

The amount of time and money we spent getting our version of the chamber working is not replicable for smaller physics departments or personal builders. While it would require a lot more testing, finding ways to cut the cost through using a cheaper heatsink and avoiding external heating tools would mean many more members of our target demographic would have access to making their own chambers.

