3D Printing Gaseous Radiation Detectors

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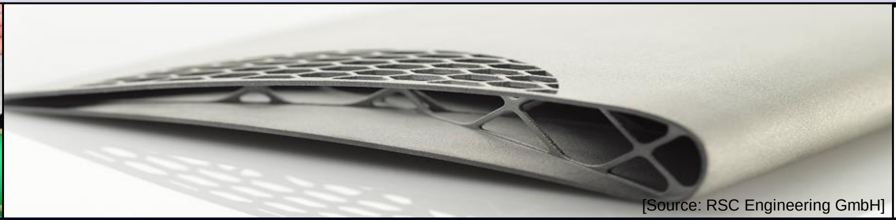
Motivation

- The Technology
- The ‘Grand Challenge’
- The Possibilities

The Technology

- **Rapidly growing** technology, with increases in print speed, print size and feature resolution.
- **Decreasing cost** of printers and **inexpensive** build materials, with costs likely to continue decreasing.
- Build materials are **durable**, strong, relatively **heat**, **chemical and moisture resistant.**
- Constantly **growing market** (predicted 300% growth in next decade).


[Image: Darren England/AAP]


[Source: RSC Engineering GmbH]


[Source: GE Aviation]

The 'Grand Challenge'

	Current capability	Performance goal
Printing resolution in x-y	~ 75 μm	~ 1 μm
Layer thickness in z	~ 50 μm	~ 1 μm
Print speed	10 cm/s	> 100 cm/s
Materials	Either polymers or metals	Polymer-metal composites
Object size	50 cm × 50 cm × 25 cm	200 cm × 100 cm × 10 cm

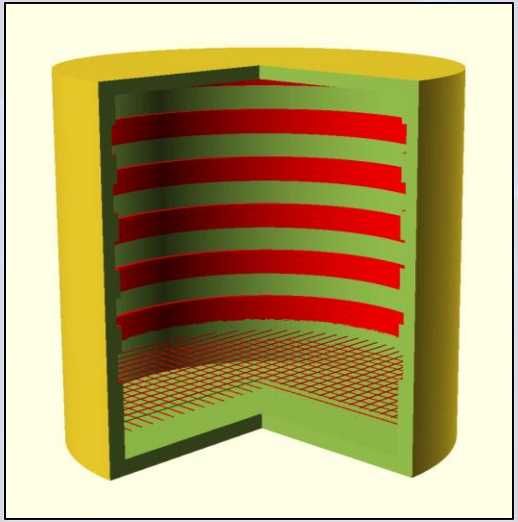
Table comparing commercial Additive Manufacturing (AM) capabilities to the performance needed to 3D print complete MPGCs, containing GEMs, for high spatial resolution detectors required in HEP experiments [Hohlmann, 2013].

Current capabilities ≠ Performance Goals

But we can still use it!

The Possibilities

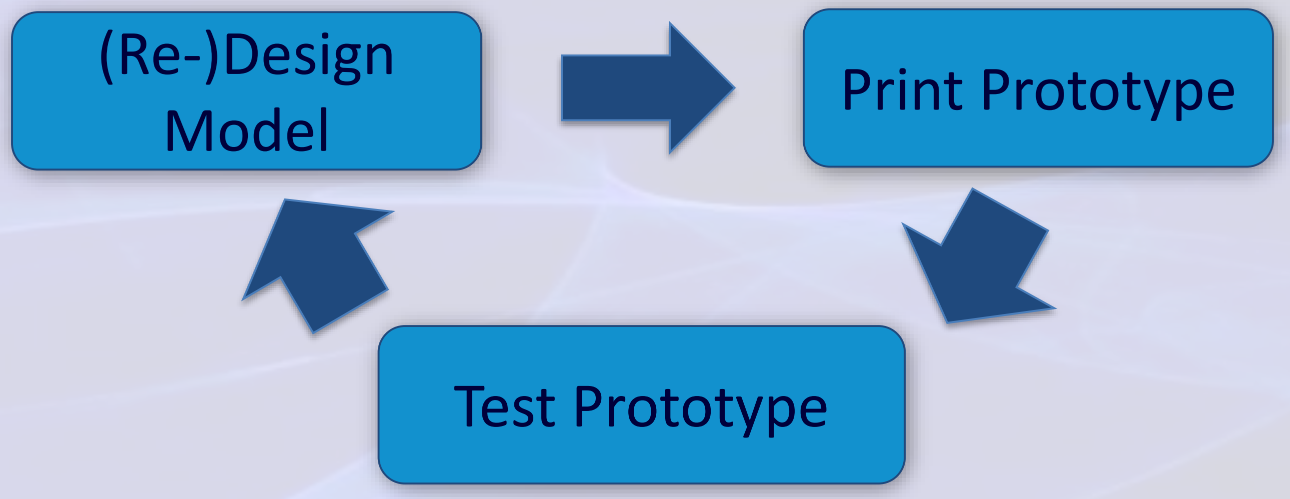
- Produce **modular detector** arrays that can have broken modules easily **replaced.**
- Possibility of **biodegradable** materials; giving the detectors significant longevity without compromising the environment.
- Ease of design alteration allows **customizability** and **scalability**.
- Produce prototype detectors to **test electronics.**
- Print detectors in **remote locations**.
- Investigate **new geometries** of detectors.
- Easily print detectors for **Outreach.**
- **Low radioactivity** of build materials minimizes background.



Creation

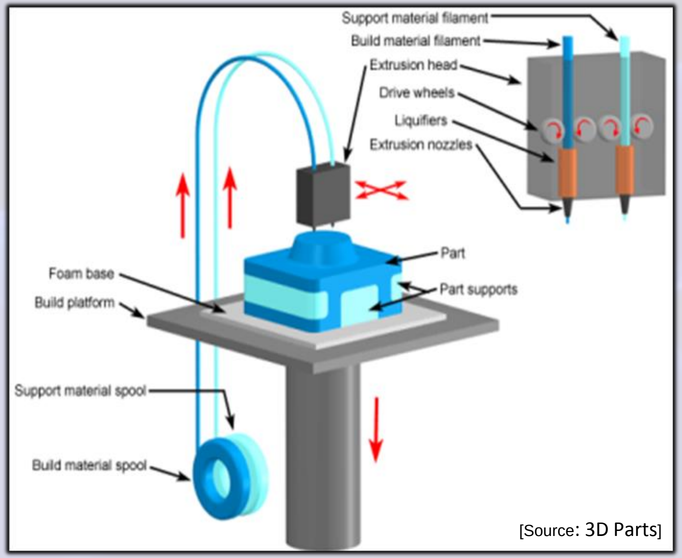
- Quick Introduction to Rapid Prototyping
- Introduction to Fused Deposition Modelling (FDM)
- The Prototype
- The Process
- The Tracker

Quick Introduction to Rapid Prototyping



Introduction to Fused Deposition Modelling (FDM)

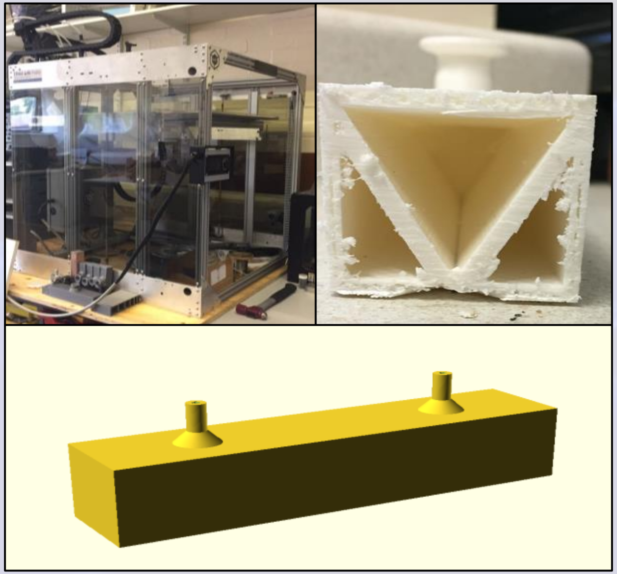
- 3D models are constructed **layer by layer** from CAD file.
- Each layer is created by **extruding molten thermoplastic** in the x-y plane.
- The base plate moves in the z-axis to build up layers.
- The layers are **thermally fused** on contact to create a solid structure.



[Source: 3D Parts]

The Prototype

- **Iarocci tubes** are of the simplest in design and function:
  - **Consists of a central tube, anode wire (high tension) and highly resistive cathode coating.**
- **OpenSCAD** to create CAD model.
  - **Triangular prism shaped volume**
  - **142 mm × 24 mm × 28 mm (x × y × z)**
- **Gigabot** to print:
  - **Large scale FDM printer.**
  - **Build size 600 mm x 600 mm x 600 mm.**
- **PLA** as print material
  - **Polylactic Acid, $(C_3H_4O_2)_n$**
  - **Low warping**
  - **Low Outgassing (TML: 0.56%, CVCM: 0.01%, WVR: 0.03%)**

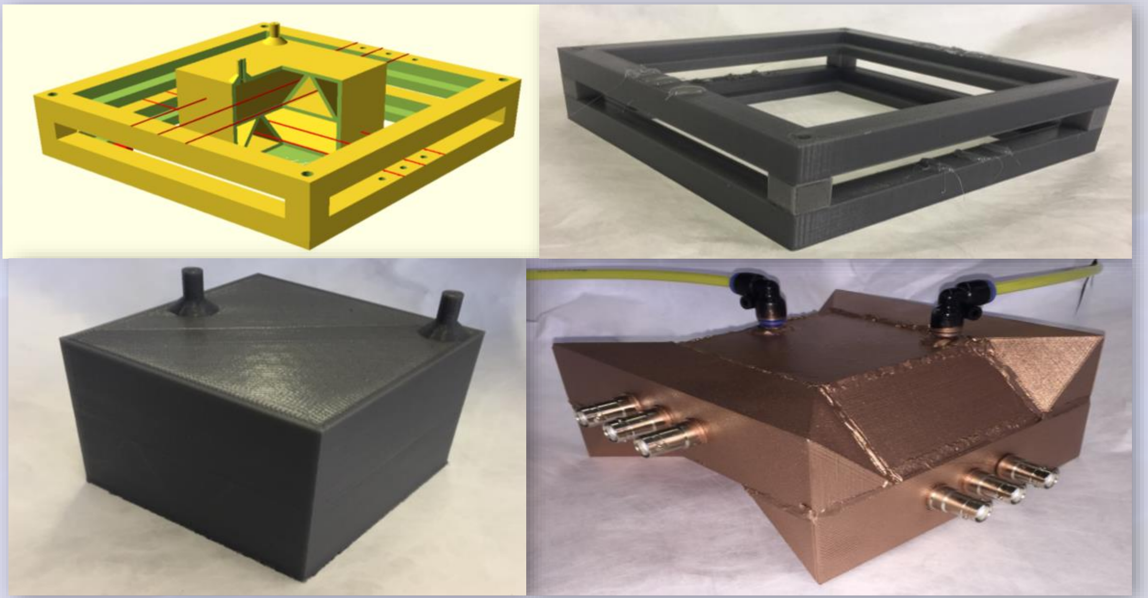


The Process

- Wire frame 3D printed to hold **anode wire** at **high tension**.
  - **Percentage infill investigated to provide sufficient friction.**
  - **Stainless Steel Wire (r_a~50 μm)**
- Hollow tube designed and the **GCODE edited**:
  - **Pause print at midway point to allow the introduction of the anode wire.**
  - **Deposit more molten plastic in layers closest to wire, to ensure sufficient grip.**
- Tube coated in **copper shielding** spray (to act as grounded cathode).
- End caps 3D printed to protect anode wire.

[Source: re:3D]

The Tracker

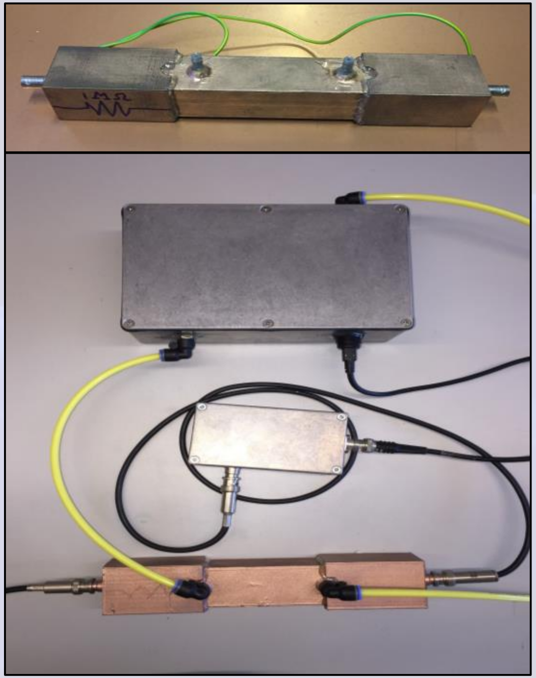


Operation

- The Setup
- Tube 1 Results
- Tube 2 Results
- 3D Tracker

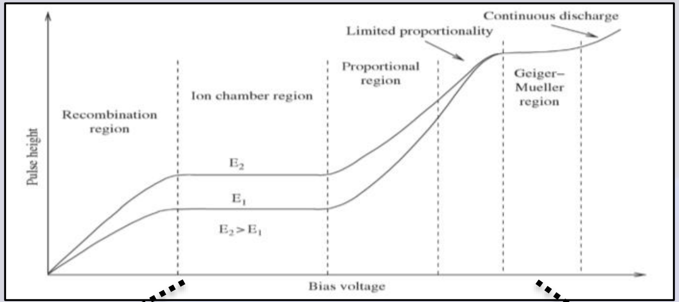
The Setup

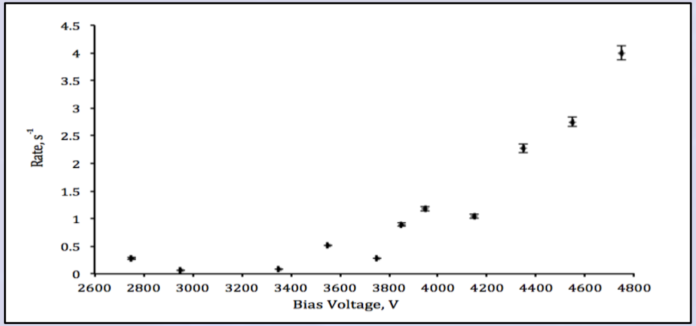
- Two tubes produced by similar methods.
- **Argon-Methane** (95:5) gas mixture flowed through tube at constant flow rate:
    - **< 0.09 liters/min**
    - **Oxygen level monitored and maintained below 250ppm.**
- Temperature kept constant at **299 ± 1 K**.
- **Cosmic Ray Muons** main source of signal.
- Pulse height and rate measured.

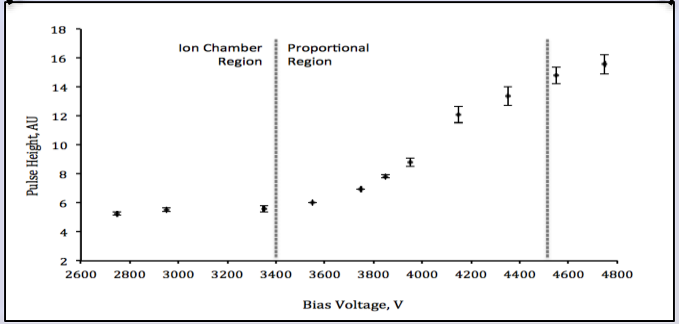


Tube 1 Results

- Pulse height plotted against bias voltage.
  - Graph appears to take characteristic form over range of bias voltages applied.
- Rate of pulses plotted against bias voltage.
  - Correlation between rate and bias voltage.

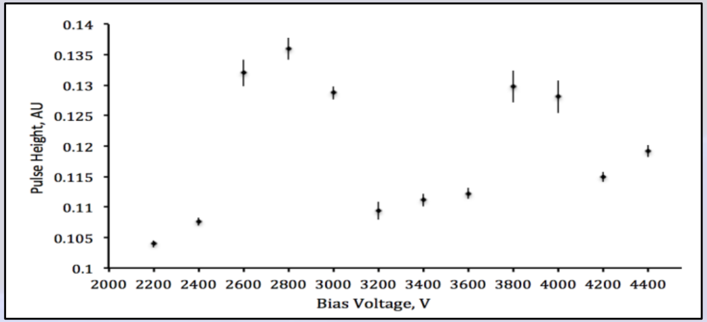


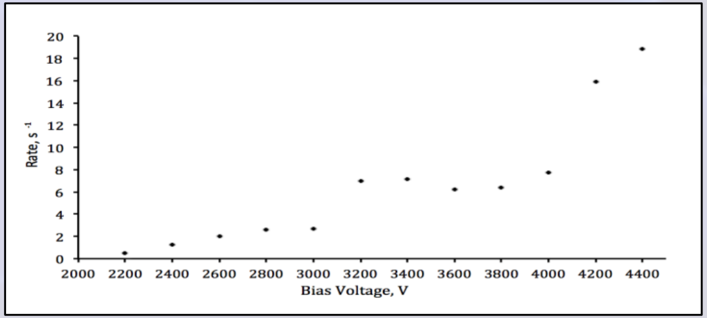




Tube 2 Results

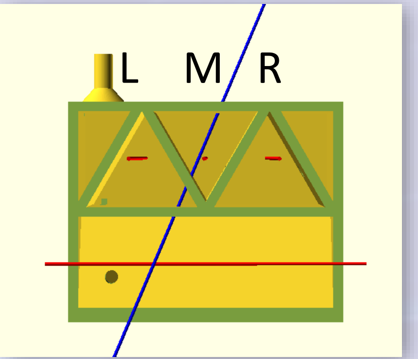
- Pulse height plotted against bias voltage.
  - **Not as expected.**
- Rate of pulses plotted against bias voltage.
  - **Some correlation between rate and bias voltage.**
- Difference in operation between tubes possibly due to moisture in tube or charge buildup due to lack of cathode.
  - **Check data with oxygen monitor data**
  - **Currently retaking data in humidity controlled environment.**
  - **Next stage to print tube with cathode.**

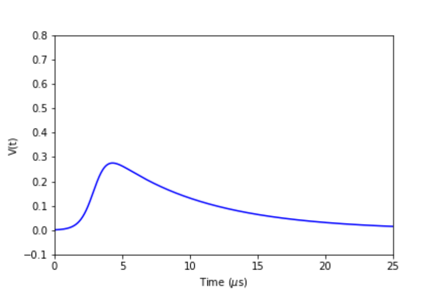


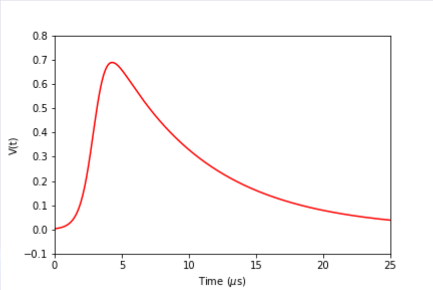


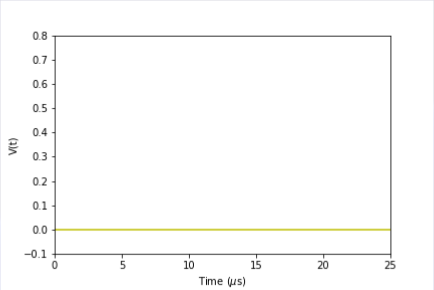
Operation

3D Tracker









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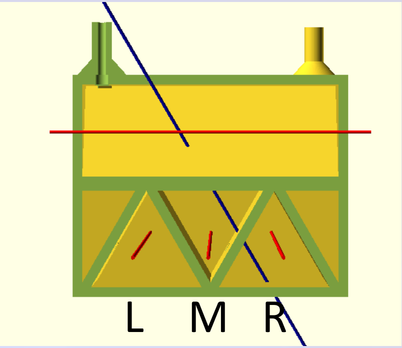
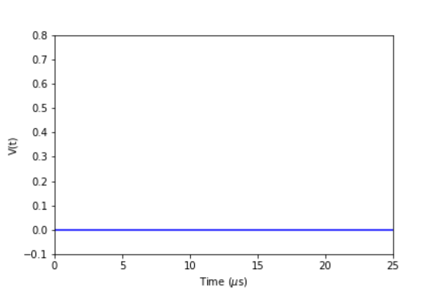
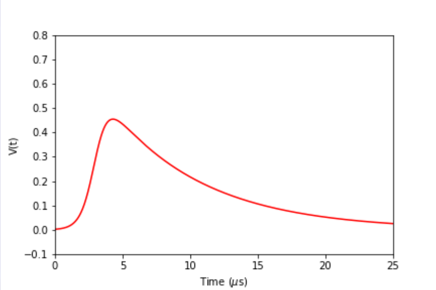
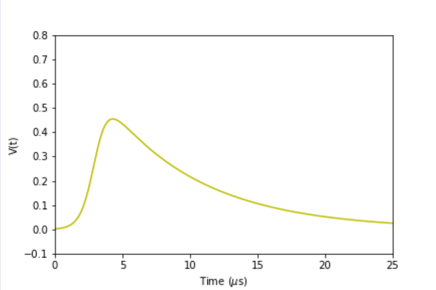


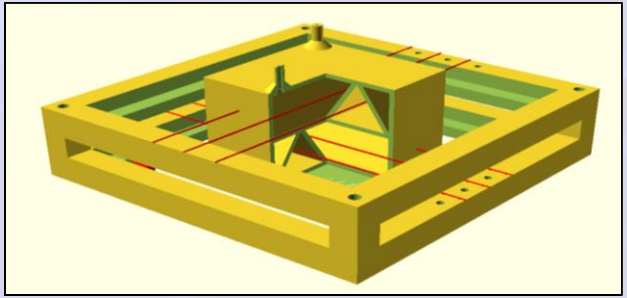






Future Plans

- Print more tubes to optimise print process **reliability** and to investigate **repeatability**.
- Print tubes containing **cathode structure** using either **conductive filament** or **conductive pastes**.
  - **New printer just arrived with these capabilities**
- Advance onto **TPCs** and **MPGCs** using **Conductive Inkjet Printing** for electrode structures.
  - **Silver nanoparticles suspended in ink in standard Inkjet Printer**
- Develop method of printing **plastic scintillator.**



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1. Hohlmann M. *Printing out Particle Detectors with 3D-Printers – a Potentially Transformational Advance for HEP Instrumentation*. 2013

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