3D Printing and Neutron Scattering

DENIM 2015

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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outline

- Overview of 3D Printing state of industry
- Overview of available types of 3D printers
- SNS / HFIR 3D Printing capability
- Discussion of unique problems using 3d printed parts in neutron scattering
- Some SNS Case Studies

Current State of 3D Printing

- GE Aviation recently additively manufactured a miniature working jet engine that runs at 33,000 rpm
- Formula One Teams use 3D printing to make parts for wind tunnel testing
- A bridge in Amsterdam is being 3D printed
- Boeing 787 Dreamliner has 30 3D printed parts

Technology - SLA

- Stereolithography was invented in 1986 by Chuck Hull, who founded 3D Systems in the same year
- Uses a UV laser to selectively cure a photoactivated resin, one layer at a time
- Fast process, best surface finish

Chuck Hull, and a 3D Systems SLA Printer

3D Systems iPro 950 can print parts up to 1500 x 750 x 550 mm

Lotus F1 Windtunnel model in 3D Systems Lobby

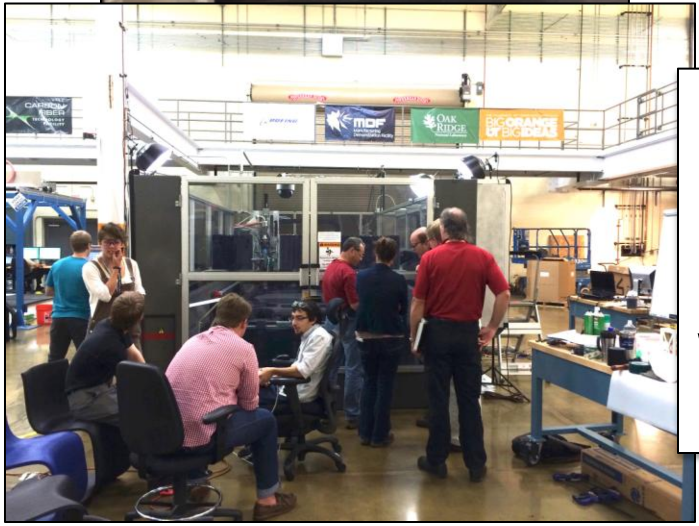
3D Systems SLA 250 in SNS Instrument Engineering Lab

Technology - FDM

Fused Deposition Modeling typically builds parts by feeding plastic filament to a hot extrude head, which is moved by X-Y linear stages and deposits melted plastic on a print bed, which moves, one layer at a time, on a Z stage

Stratasys Fortus 400, with lower door open, exposing its four filament cartridges

Stratasys Fortus 900 can print parts up to 914 x 610 x 914 mm



ORNL and Cincinnati Incorporated's custom built FDM printer, which was used to print a car

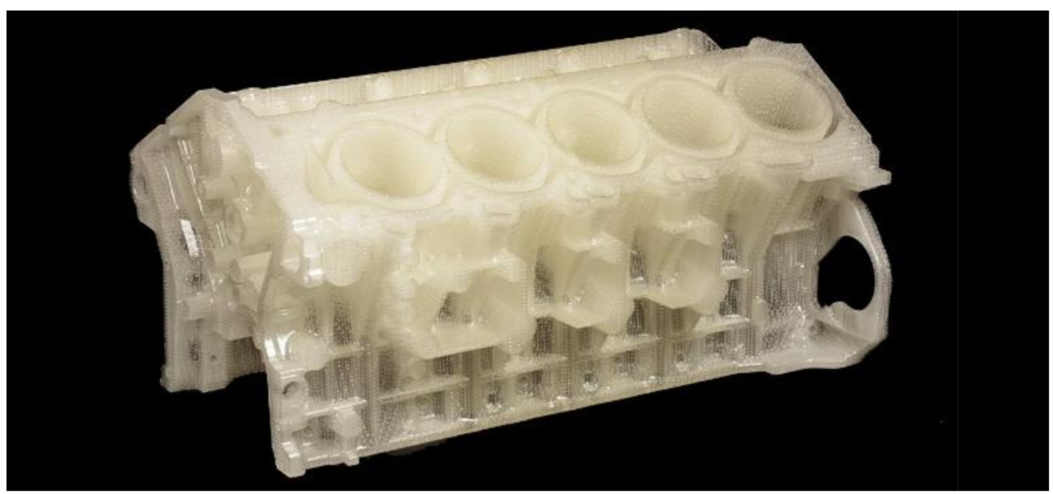
Technology - SLS

Selective Laser Sintering uses a laser to sinter powdered metal, plastic, glass or ceramic, one layer at a time, to build parts.

3D Systems sPro23o can print parts up to 750 x 550 x 750 mm

Technology - Metal Printing

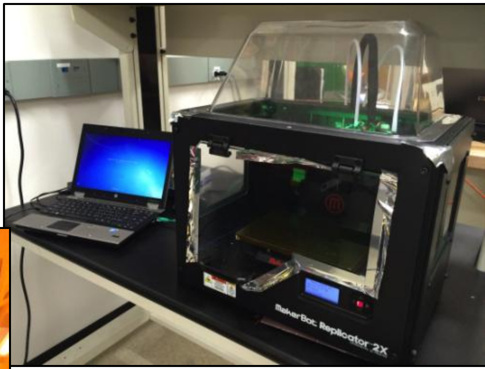
- ExOne
  - Uses a binder instead of adding heat, meaning less or no residual stress
  - Does not require supports
  - stainless steel, bronze, Inconel, iron, tungsten
  - Post print curing required
- 3D Systems and other manufacturers offer printable materials that burn away during casting process

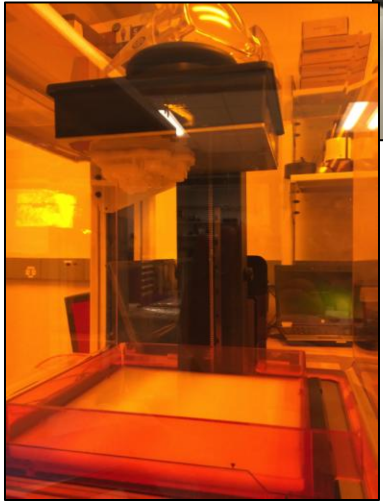


Technology – Desktop Printers

- Desktop Printers mostly use FDM
  - Mark Forged is selling a $5500, 320 x 132 x 160mm build size, printer that can print with long strands of carbon fiber, fiberglass or Kevlar
- some SLA printers on the market now, using either a laser or a DLP projector to UV cure the resin
- Aurora Labs is a kickstarter campaign not yet shipping, but taking pre-orders, for a $43,000, 200 x 200 x 500mm and a $33,000, 180 x 180 x 500mm sintered metal printer
  - Stainless, inconel, mild steel, bronze, etc

Mark One Composite 3D Printer





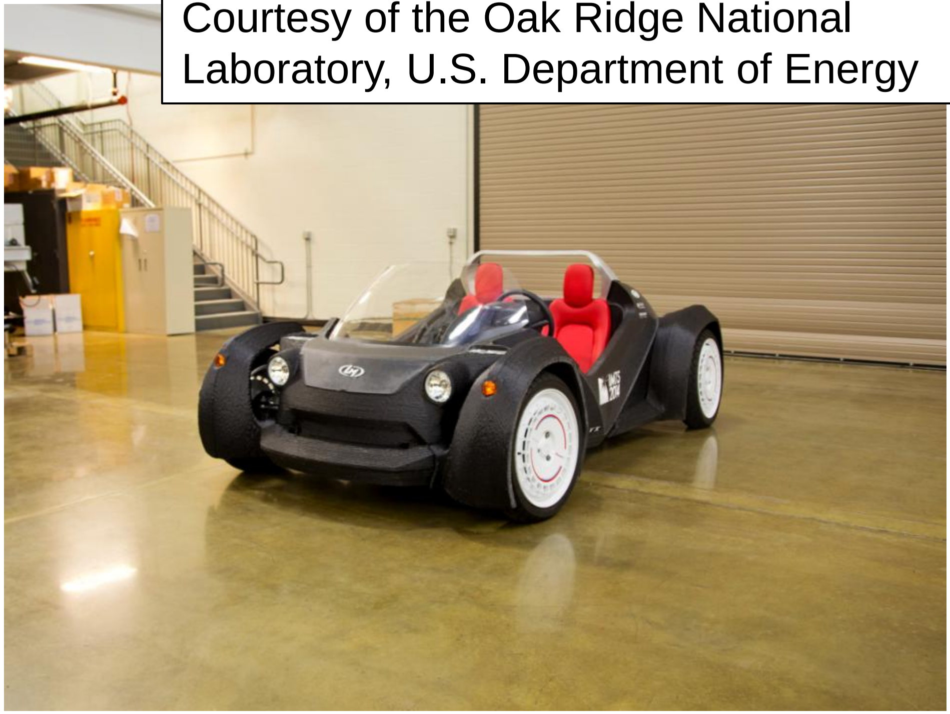
Makerbot 2x (above) and Formlabs Form 1+ (left) in the SNS Instrument Engineering Lab

Getting Someone Else To Print Your Parts

- quickparts.com
  - Owned by 3D Systems
  - Upload your parts and get quotes immediately
  - Plastic, metal, SLA and SLS
  - Have locations in North America, Europe and Asia
- protolabs.com
  - Similar to quickparts
- stratasysdirect.com
  - Owned by Stratasys
  - FDM parts available
  - Other processes as well
- www.additivemanufacturingllc.com
  - SLA, FDM, PolyJet, SLS, DMLS,

BAAM

- Big Area Additive Manufacturing
- 20 feet long, 8 feet wide and 6 feet tall
- co-developed between ORNL MDF and Cincinnati Incorporated
- Manufactured at least 2 cars

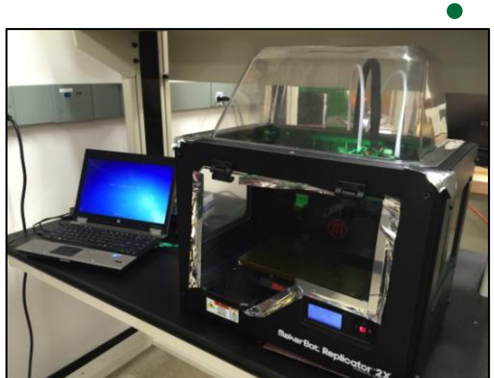


Courtesy of the Oak Ridge National Laboratory, U.S. Department of Energy

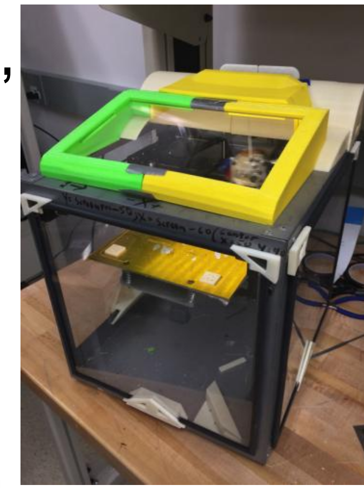
SNS / HFIR Capability

- 3D Systems SLA 250
  - 250 x 250 x 250 mm build size
  - Running almost continuously since it arrived last Fall
  - Almost 20 years old

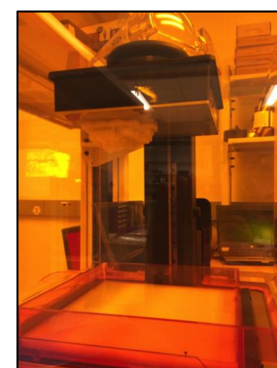
- Makerbot 2x
  - 245 x 150 x 150 mm build size
  - Dual extrude heads
  - Can print with dissolvable filament



- Solidoodle Gen 3
  - 1 slightly modified
  - 2nd heavily modified, but uncomissioned
  - 200 x 200 x 200 mm build size
  - Runs on open source software
  - Requires significant effort to get good parts

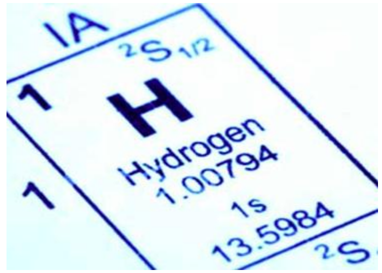


- Formlabs Form 1+
  - 125 x 125 x 165 mm build size
  - SLA
  - Produces nice parts

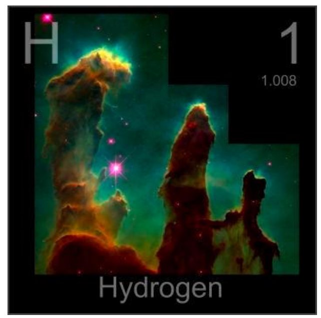


Neutron Scattering Issues

- Hydrogen, Hydrogen, Hydrogen



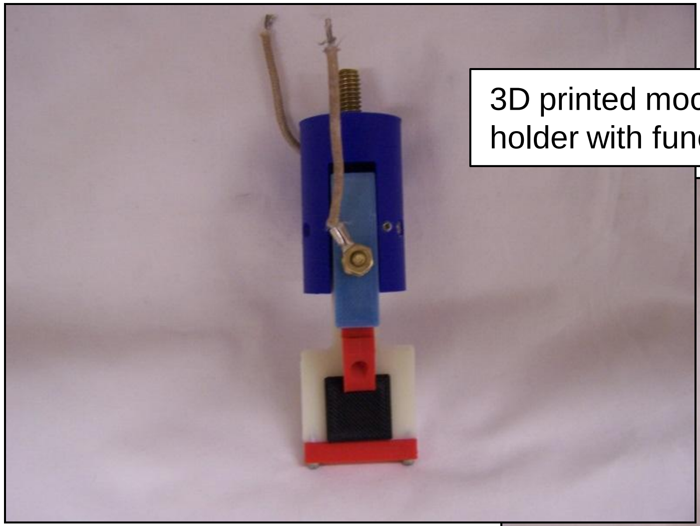
  - Can be avoided by using metal printers, but the cost for these is MUCH higher

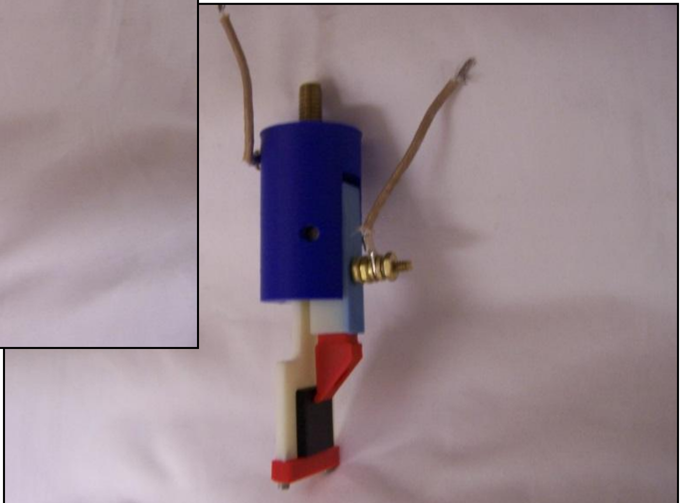


- What is the effect of radiation on printed materials?
- Configuration control of part files is different than what you may be used to
- Material pedigree can be an issue
  - FDM printers have materials that meet ASTM specification
  - Other technologies use “equivalent” materials that are often proprietary
- A 3d Printer is a manufacturing device, and may not be a good fit in a design organization

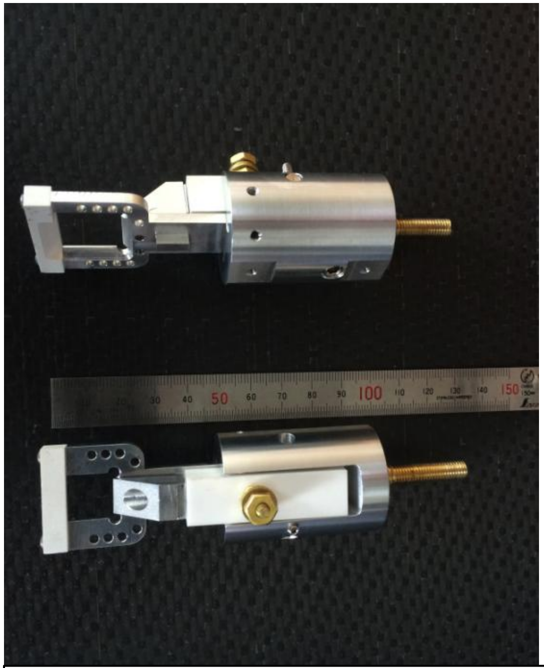
HYSPEC High Voltage Sample Holder Mockup

- Requested to support an experiment for a user who wanted to apply high voltage to a crystalline sample
- Designed parts in CAD, made plastic mockups on Solidoodle
- Met with beamline scientist and user for feedback
- Incorporated comments into final design





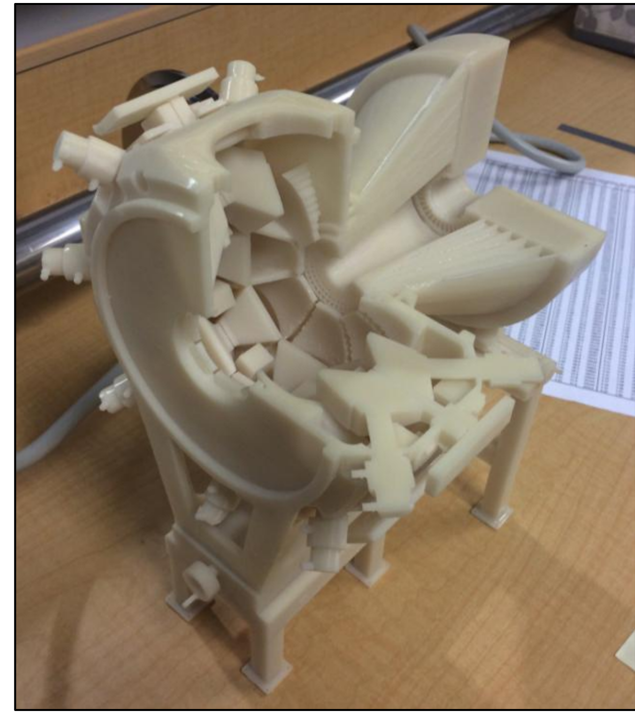
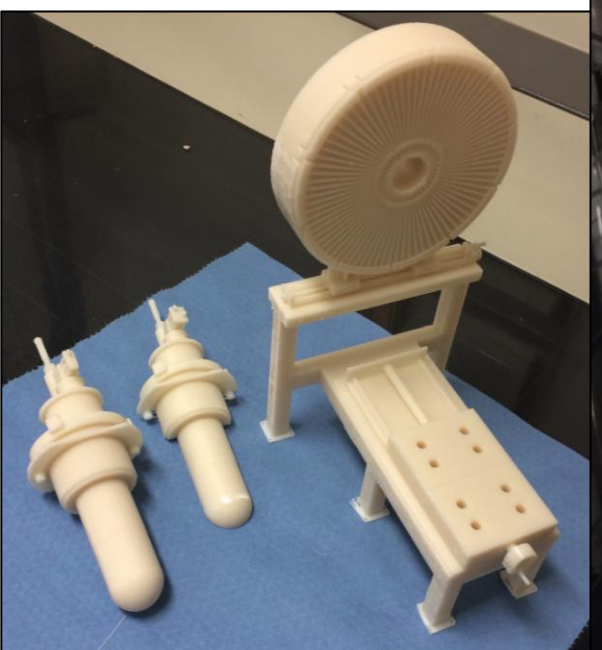
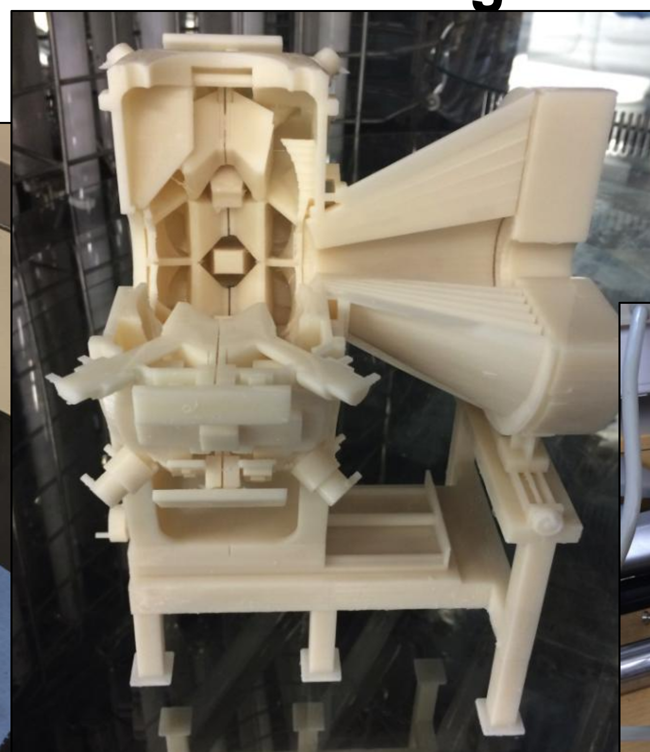
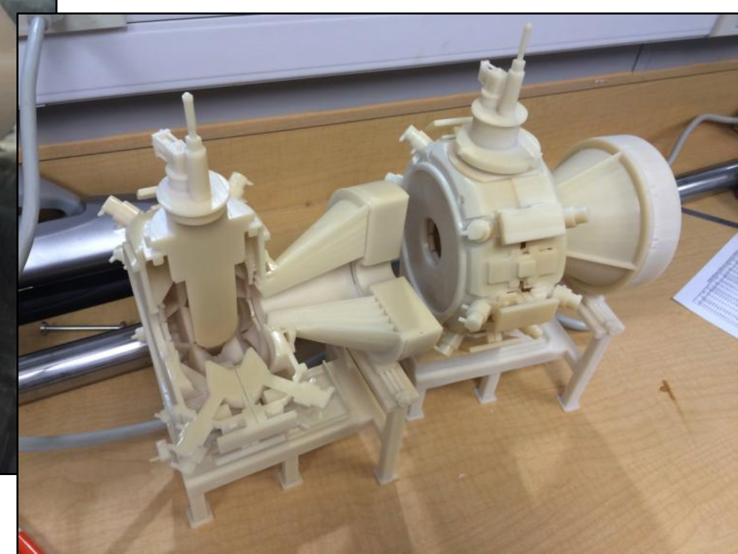
3D printed mockup of sample holder with functional clamping



Actual parts used for experiment

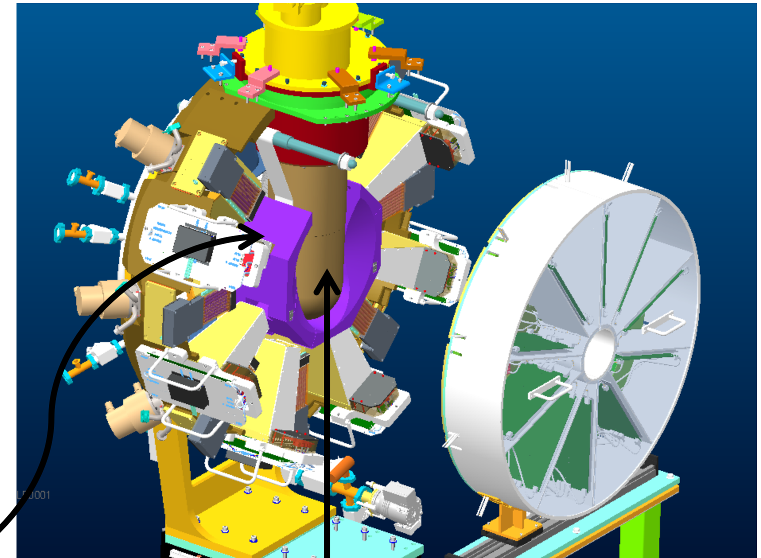
3D Printed Model of VISION Beamline

- Separate-able and cutaway versions of VISION beamline modeled and 3D Printed
- Models aid visualization of spectrometer internals / increase understanding of the instrument

VISION Background Reduction

- A new sample environment vacuum shroud was installed to reduce background and maximize sample space.
- A background shielding assembly was created from 3-D printed shells filled with borated polyurethane beads



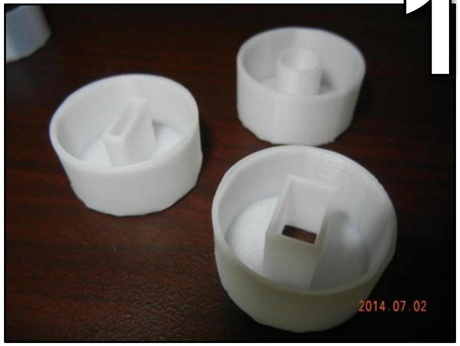
Background Shielding

Vacuum shroud

NOMAD Re-entrant Sample Well Beam Apertures created using 3-D Printing Technology

- **Molds for the epoxy mix were created and printed with dissolveable PLA plastic**
- **The molds were filled with a mixture of epoxy and enriched boron carbide powder and cured**
- **The molds were then dissolved with limonene solution.**

1



Molds Manufactured On 3D Printer From Dissolvable PLPA

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Molds With Enriched Boron Epoxy Mix

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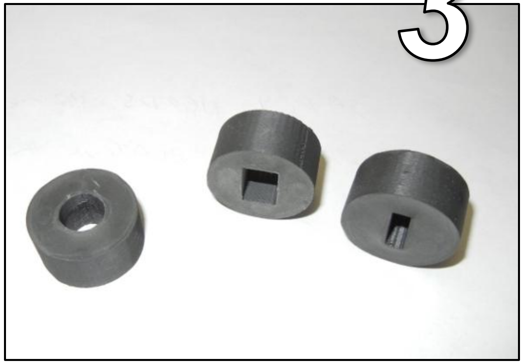

Enriched Boron Apertures Removed From Molds

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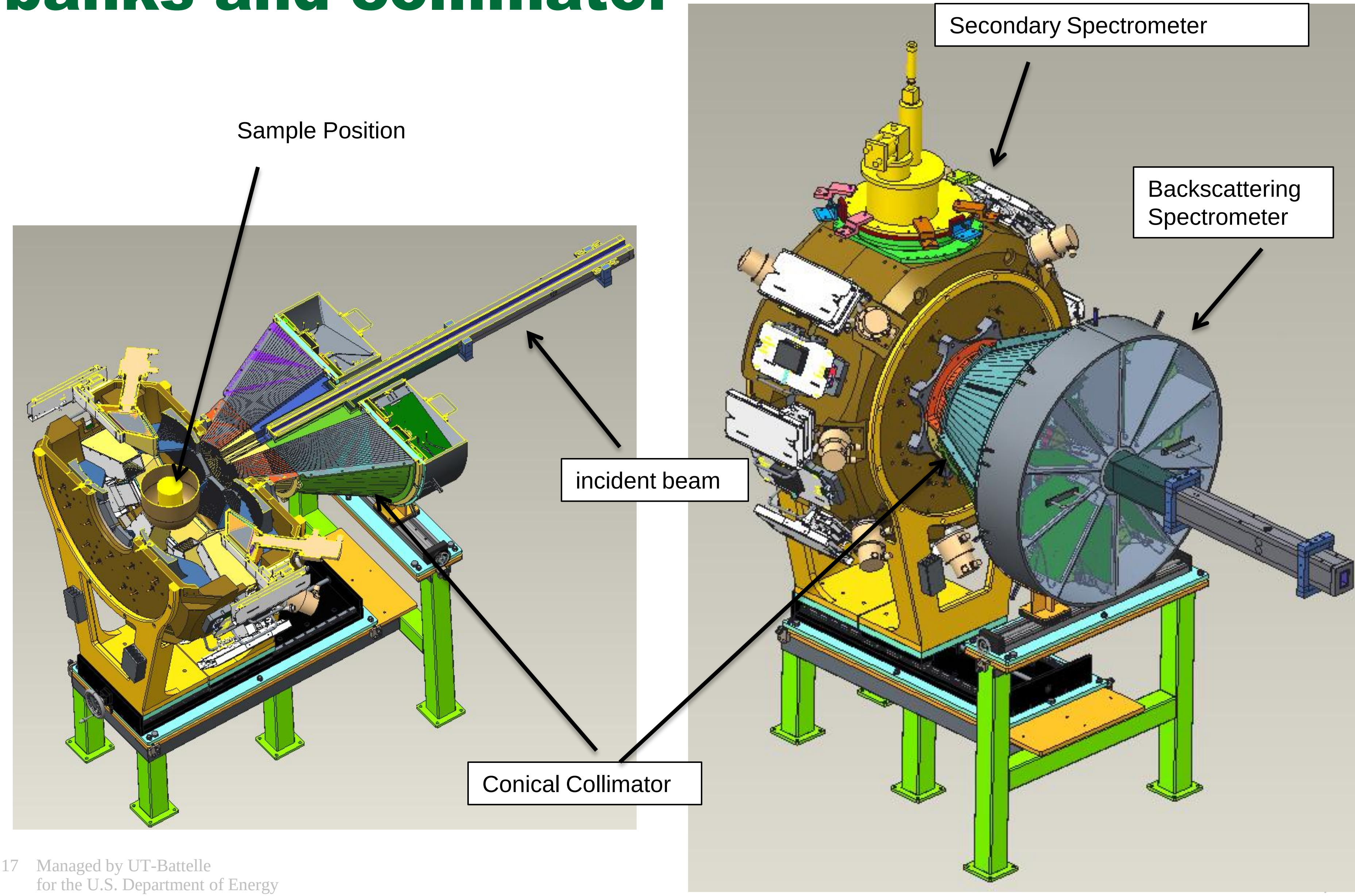
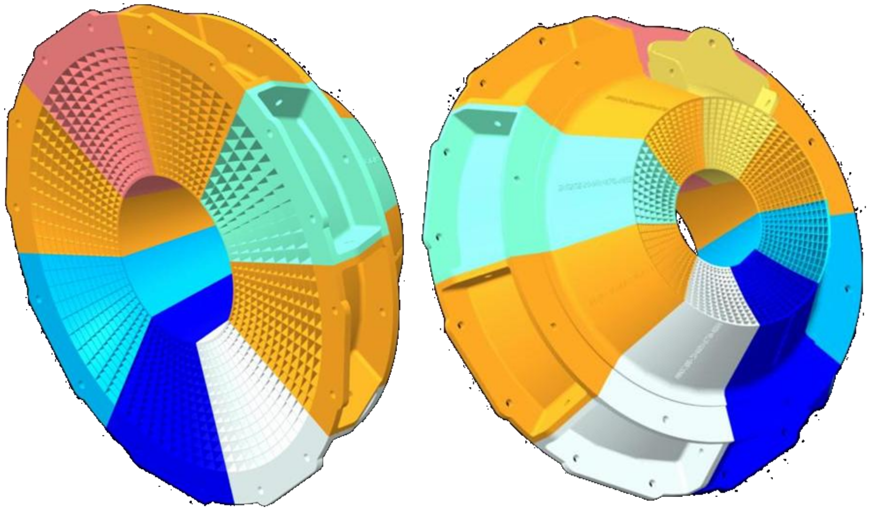
The enriched boron apertures were combined with boron nitride cylindrical parts to create the finished product

VISION back scattering (diffraction) banks and collimator

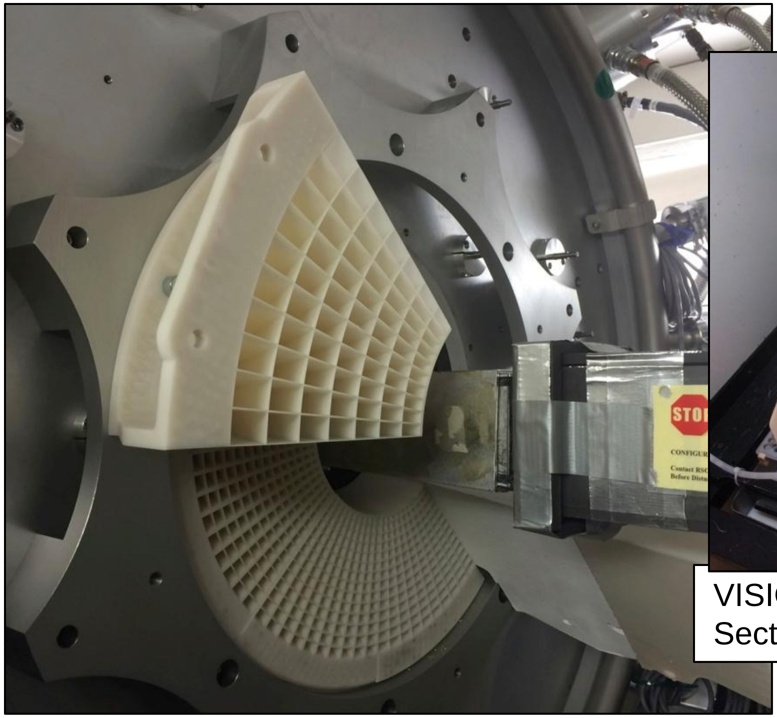


3D Printed VISION Conical Collimator

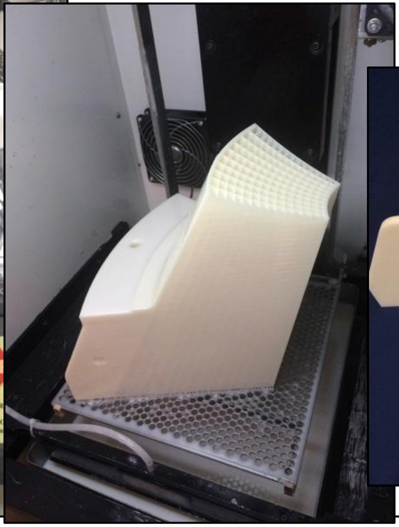
- **On-Site 3D Printing has enabled us to iteratively optimize VISION Conical Collimator**
- **Able to see the effect of different angular resolutions, blade thicknesses and part coatings**



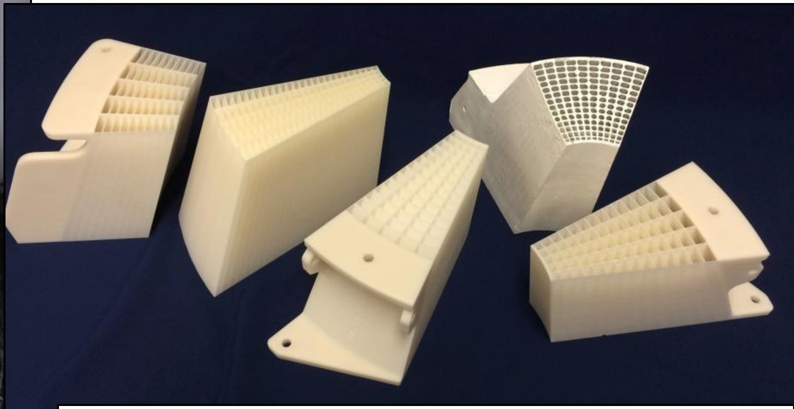
Two CAD model views showing the assembled collimator



Partially assembled collimator installed at the beamline



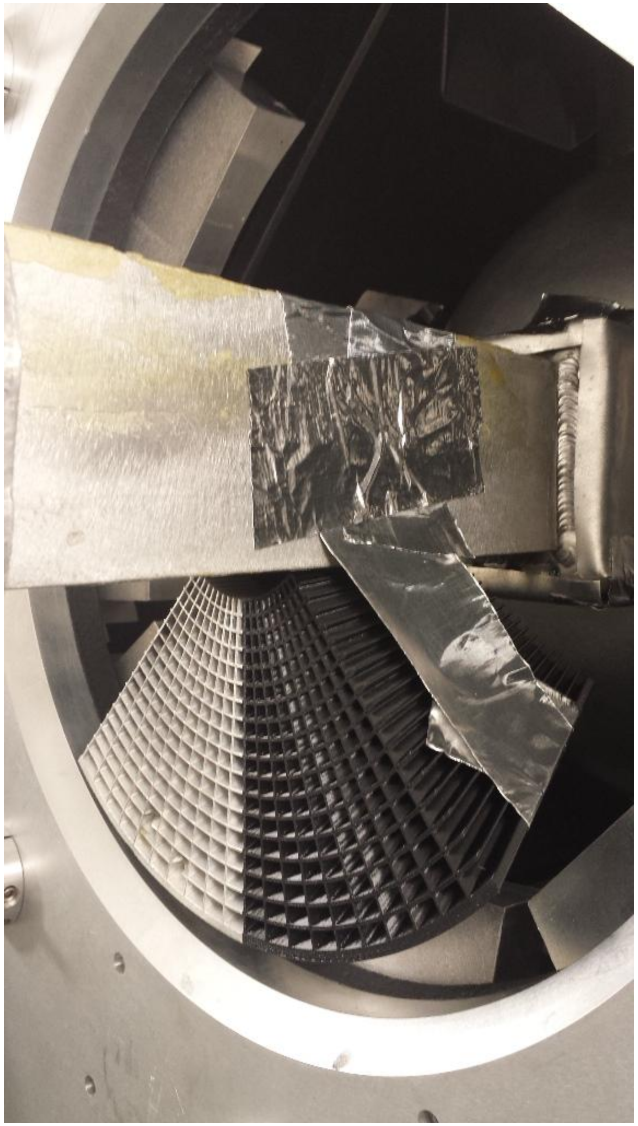
VISION Conical Collimator Section

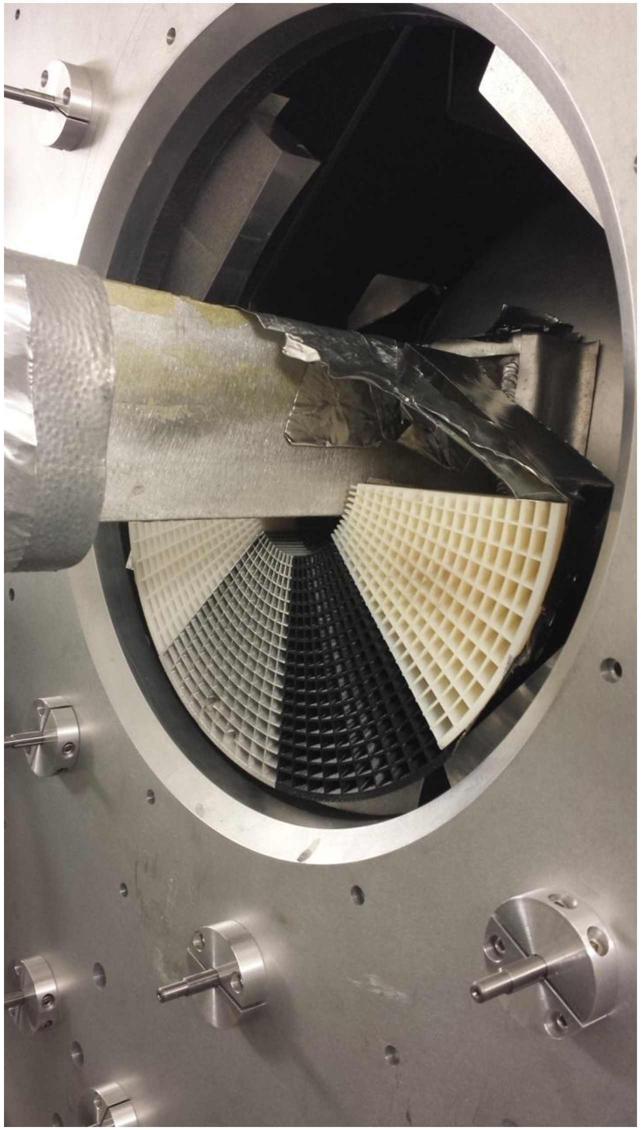


Collimator Section Assortment

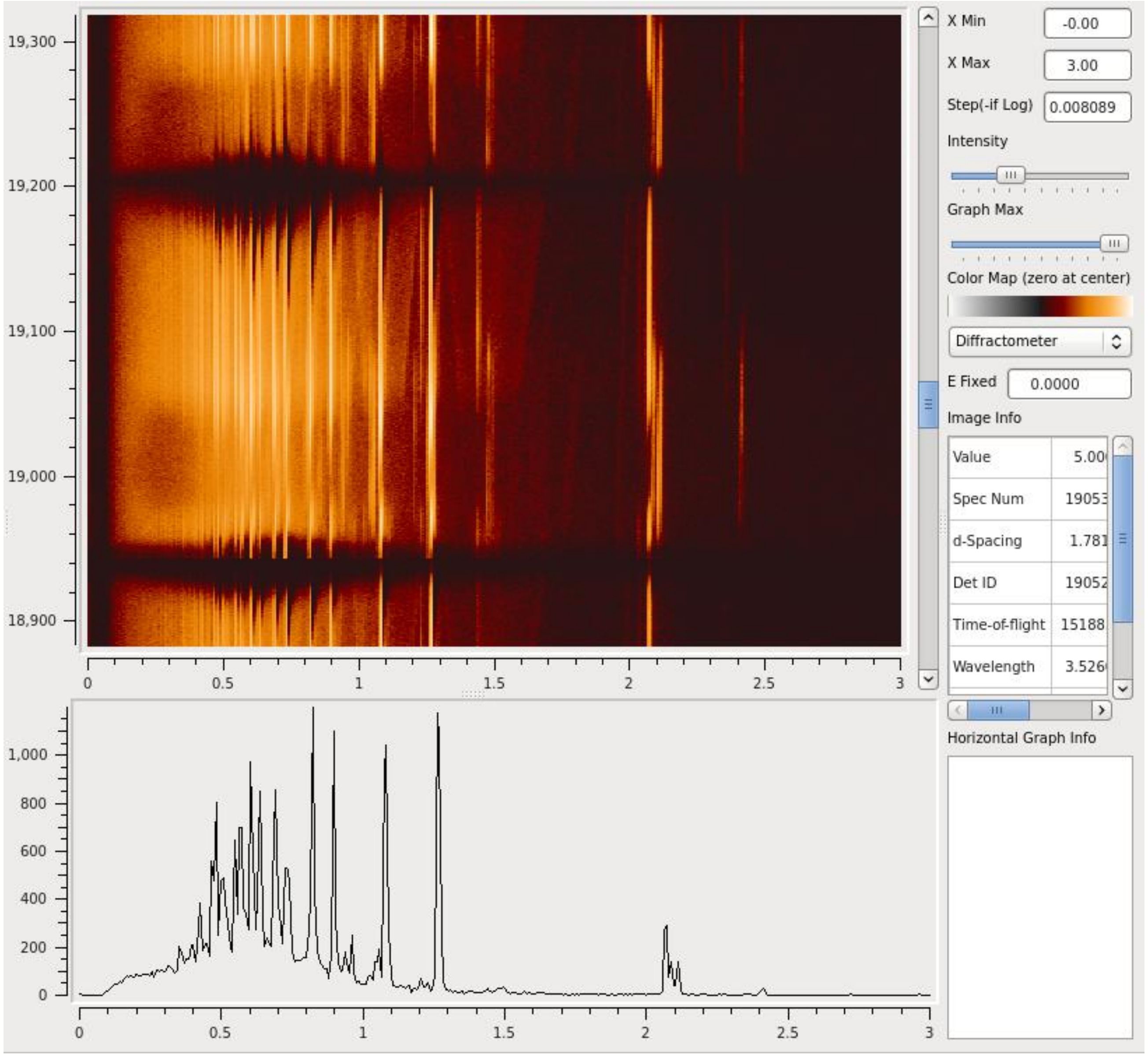
Initial Tests Of Collimators

- Geometry is not yet optimized
- Mounting is not exact (duct tape

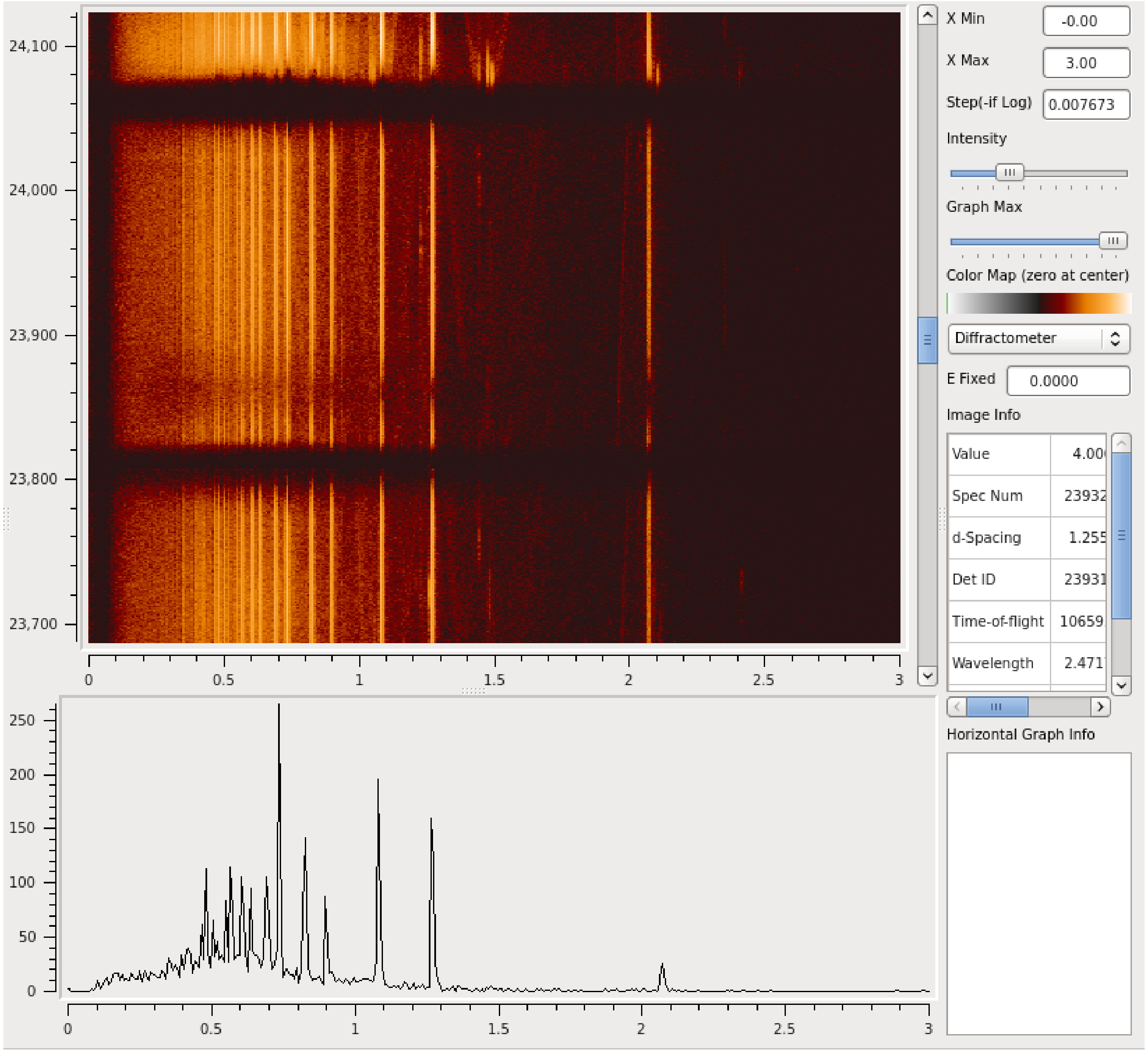




Un-Collimated Diffraction Pattern

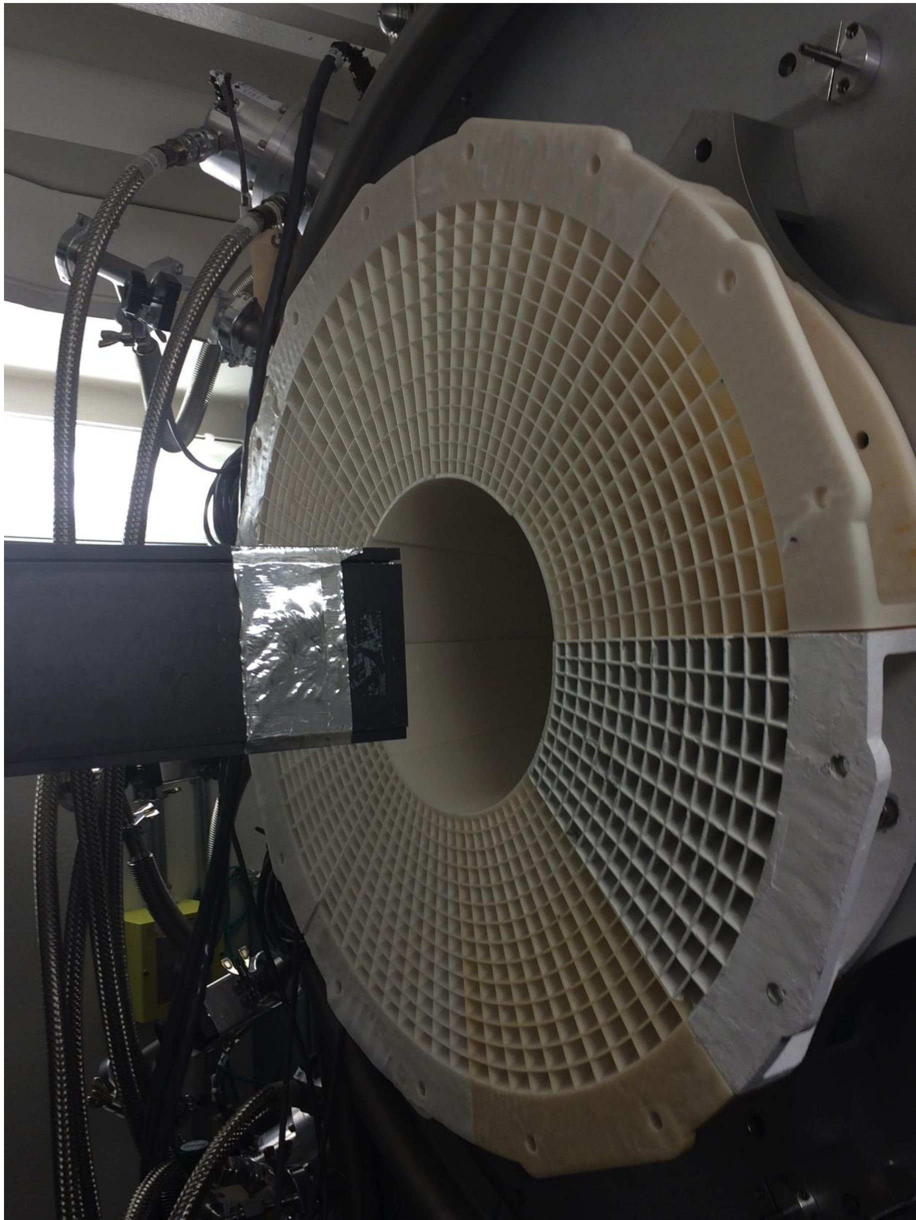


Plastic Conical Collimator



VISION Conical Collimator

- Once Geometry was decided, 8 x 45 degree segments were manufactured
- Each part took ~ 7 days to print



Questions?