Supporting Simulated Diagnostics with VisIt's X Ray Image Query

DOECGF

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Lawrence Livermore National Laboratory

Acknowledgements

We have worked closely with Steve Langer, who has decades of experience as an ICF designer.

- *Comparisons of simulated x-ray data to NIF experiments*, by Steve Langer, Richard Town, George Kyrala, Marilyn Schneider, Jose Milovich, Nathan Meezan, Oggie Jones, and Scott Sepke. Presented at the Anomalous Absorption Conference, 13-18 June 2010

Information on NIF Diagnostics:

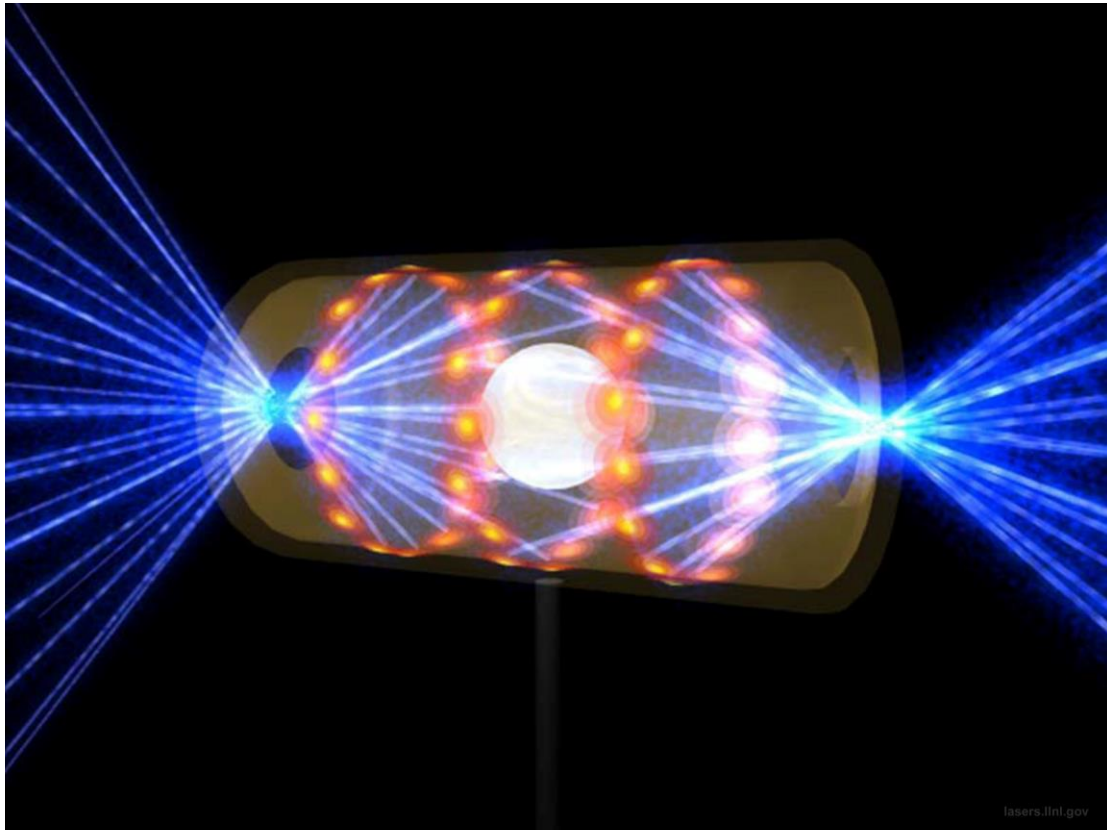
- https://www.llnl.gov/news/dante-measuring-nif%E2%80%99s-inferno
- https://www.llnl.gov/news/diagnostics-were-crucial-nifs-historic-ignition-shot

For more information on NIF and the historic fusion achievement:

- https://wci.llnl.gov/facilities/nif
- https://www.llnl.gov/news/national-ignition-facility-achieves-fusion-ignition
- https://www.llnl.gov/news/three-peer-reviewed-papers-highlight-scientific-results-national-ignition-facility-record
- https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.129.075001
- https://www.llnl.gov/news/star-power-blazing-path-fusion-ignition
- https://www.flickr.com/photos/llnl/albums/72157607099824019

Our simulation capabilities support experimental discovery

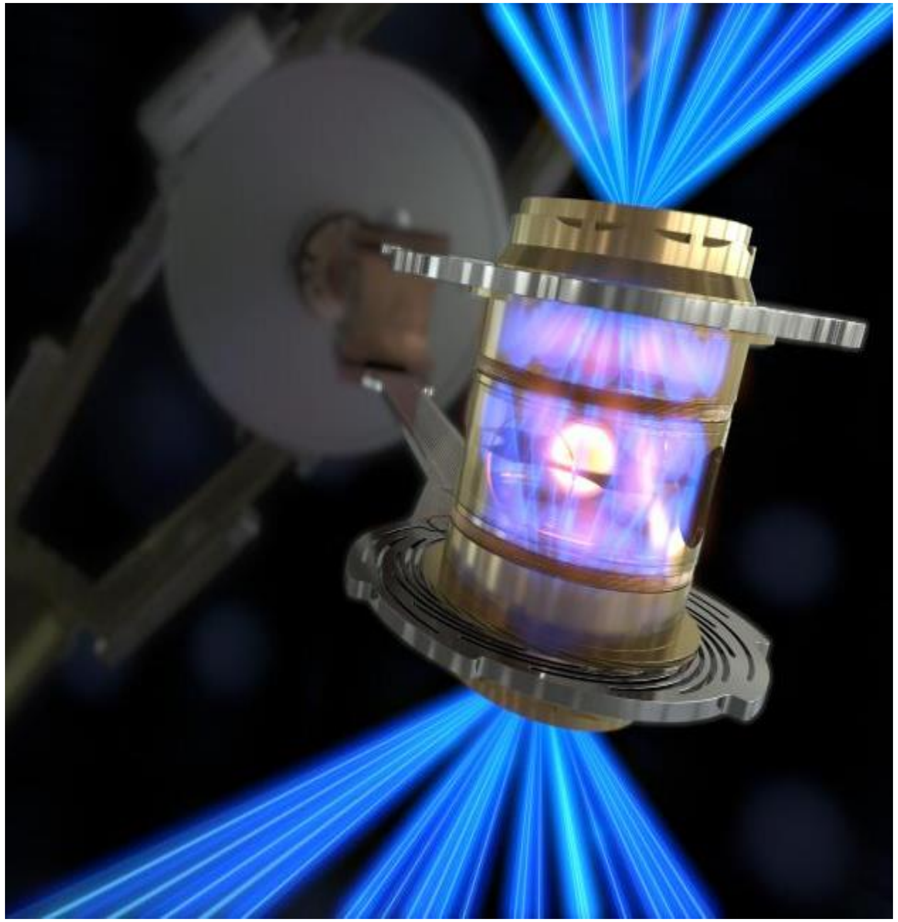
The National Ignition Facility (NIF)
https://www.flickr.com/photos/llnl/2842663693/in/album-72157607099824019/



A Visualization of a NIF Experiment
https://www.flickr.com/photos/llnl/2843501990/in/album-72157607099824019/

What is The National Ignition Facility (NIF)?

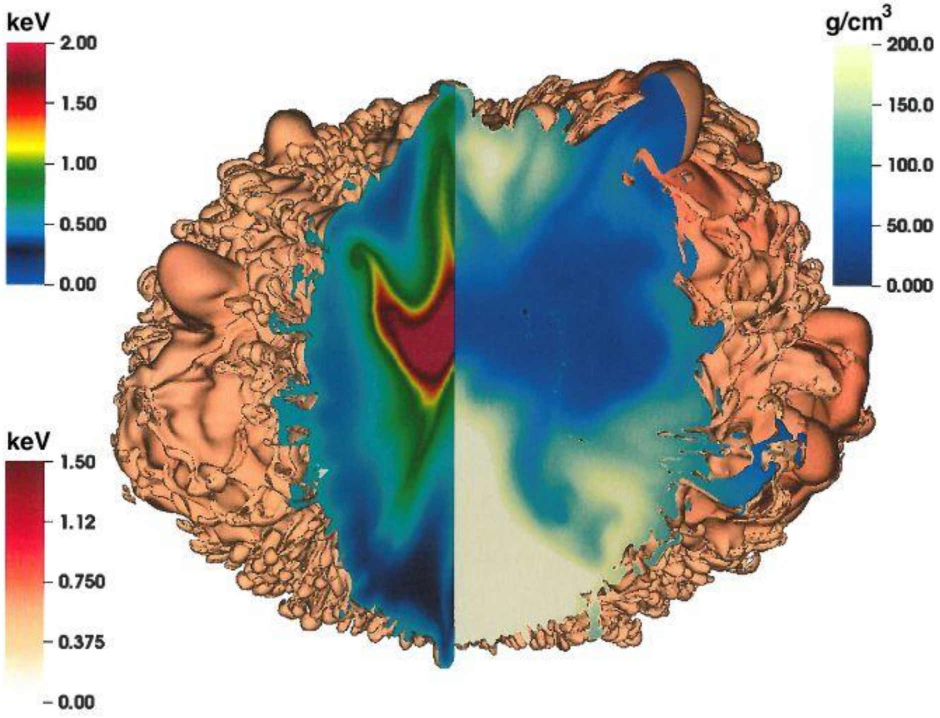
- The NIF is the world's largest and highest-energy laser, and a High Energy Density Physics (HEDP) experimental platform.
- NIF is capable of creating temperatures (in excess of 3 million degrees kelvin) and pressures (hundreds of billions of earth atmospheres) similar to those that exist only in the cores of stars and giant planets and inside nuclear weapons.
- For Inertial Confinement Fusion (ICF) experiments, it focuses 192 giant laser beams on what is called a *hohlraum*, which is a small gold cylinder that holds a BB-sized target capsule filled with hydrogen fuel.
- After decades of work, we were finally able to achieve fusion at NIF: an ICF experiment generated more energy (3.15 megajoules) from the fusion reaction than the laser energy (2.05 MJ) delivered to the hohlraum.



https://www.llnl.gov/news/national-ignition-facility-achieves-fusion-ignition

Simulations and Experiments work hand in hand to enable High Energy Density Physics Research

- Achieving fusion required a great deal of precision for every piece of the puzzle.
- We use simulation codes and visualization tools to help us design and iterate on our experiments.
- **We would not have achieved ignition without interplay between computer simulations and experiments; neither one can do the job on its own.**



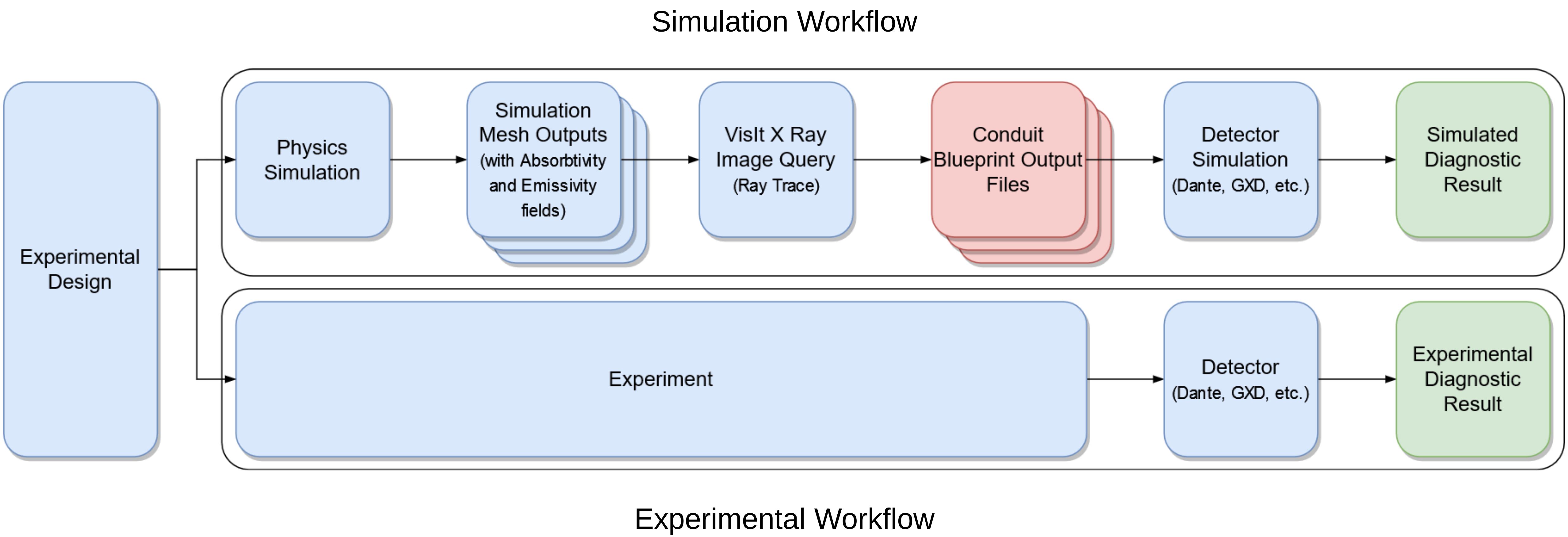
Hydra is one of the simulation codes that LLNL uses to simulate ICF experiments.
https://wci.llnl.gov/stockpile-science/high-performance-computing/proprietary-software

Experimental Diagnostics

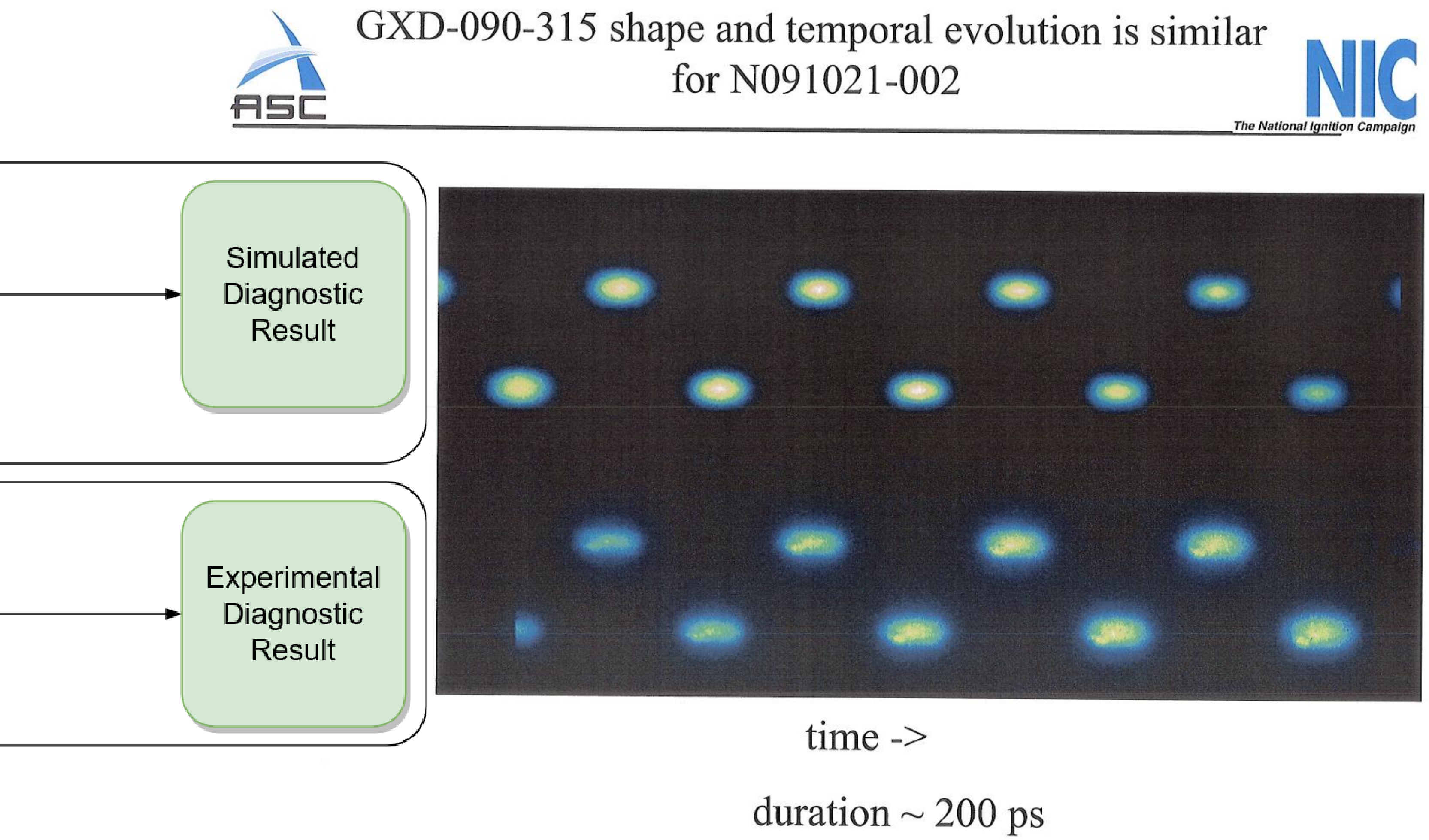
- The NIF lasers heat the hohlraum to millions of degrees Fahrenheit, causing the gold wall to emit x rays.
- We use diagnostics during experiments to detect these x rays.
- The data they capture is used to calculate the radiation spectrum and infer the temperature of the radiation field within the hohlraum. This information is directly compared to hohlraum simulations to determine if the hohlraum and laser pulse are performing as expected.
- DANTE and GXD are two of many types of diagnostics used.
- We want to simulate these diagnostics so we can have an analog to real world experimental diagnostics.

DANTE Diagnostic
https://www.flickr.com/photos/llnl/3775084967

A Tale of Two Workflows



Gated Xray Detector (GXD) Example



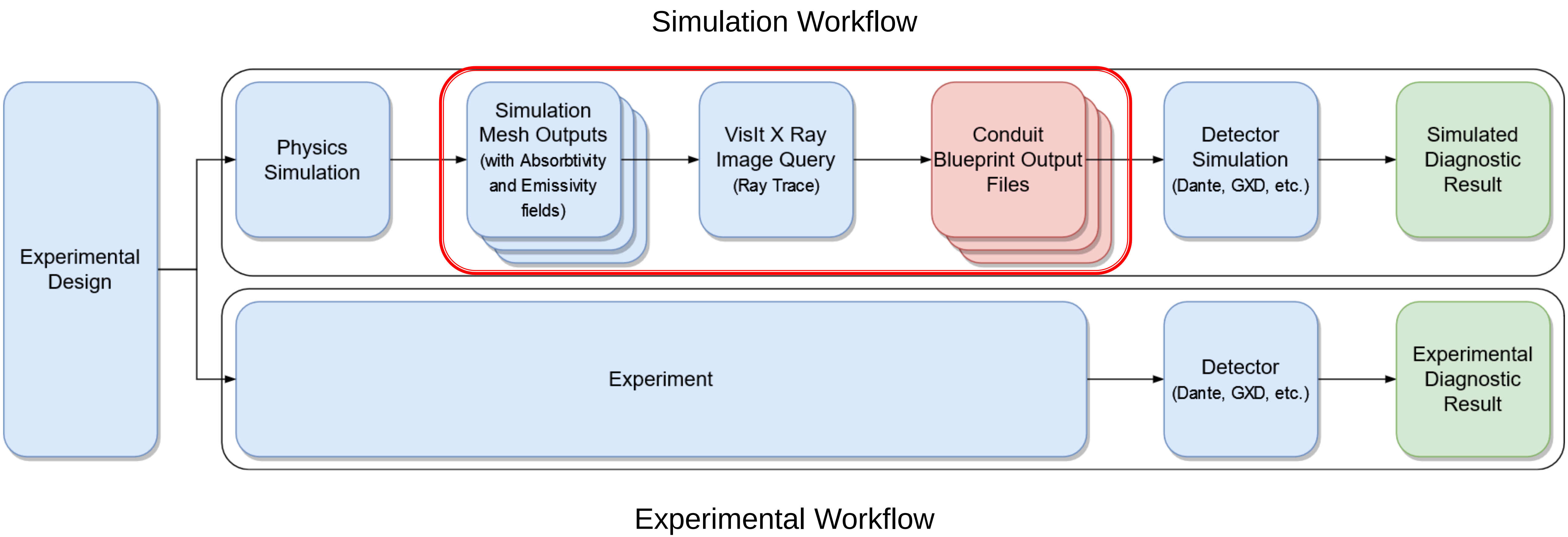
Comparisons of simulated x-ray data to NIF experiments

Authors: Steve Langer, Richard Town, George Kyrala, Marilyn Schneider, Jose Milovich, Nathan Meezan, Oggie Jones, and Scott Sepke

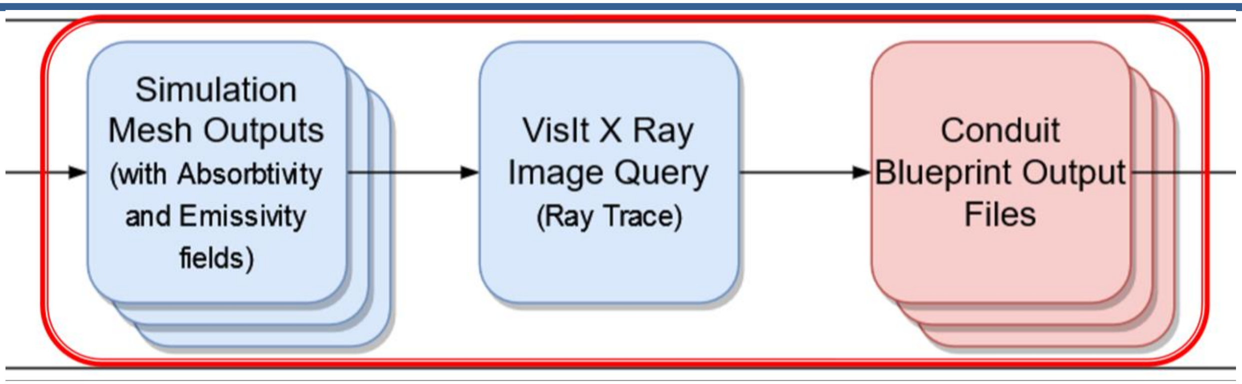
Presented at the Anomalous Absorption Conference

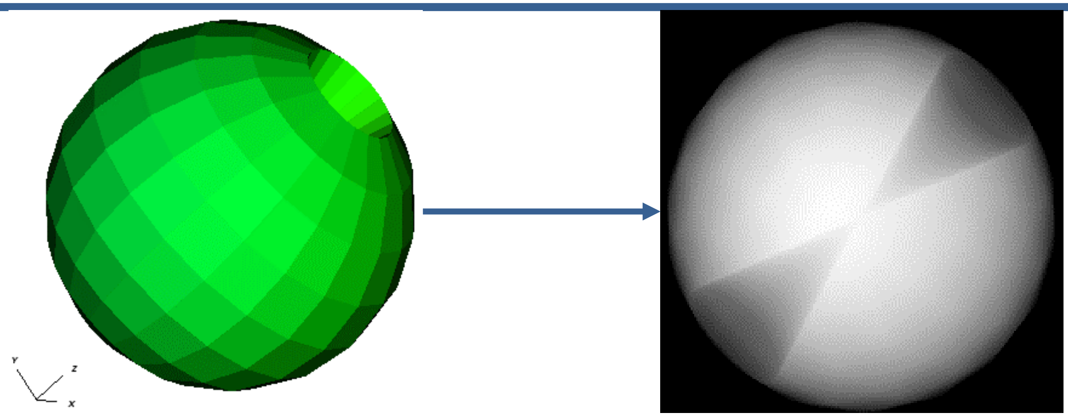
13-18 June 2010

A Tale of Two Workflows: Our Focus for This Talk



What is the VisIt X Ray Image Query?





- The X Ray Image Query is part of a larger workflow that helps us to simulate x ray detectors.
- The query computes the attenuation and self-emission for radiation passing through an object.
- The input is a mesh with zone-centered opacities (absorbtivities) and emissivities. (These can be arrays to support multiple energy groups.)
- The output is a set of images representing the result of a ray trace for each energy group.

Problems with the X Ray Image Query Workflow

- Steve Langer (who has decades of experience as an ICF designer) has helped us identify problems and feature ideas for the X Ray Image Query Workflow.

- Big Pain Point: X Ray Image Query creates too many files that were very difficult to manage. *For Example:*
  - Ray Tracing 60 energy groups would generate 120 BOV files.
  - These files lack important context/metadata about the details of the raytrace setup.
  - The name scheme of these files is esoteric.
  - These file sets led to a lot of external data management that was easy to get wrong.

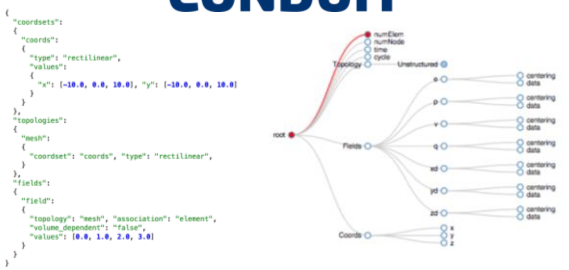
- Additionally, users had to choose between raw data or image files; it was not easy to have both.

- To simplify things, we reorganized the X Ray Image Query to output Conduit Blueprint data.

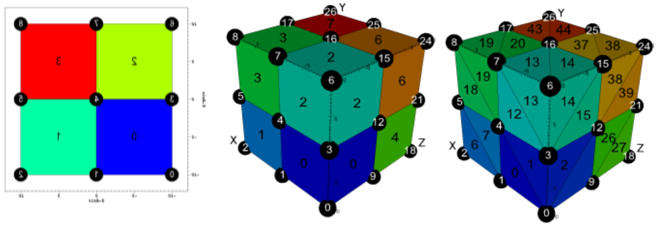
Conduit provides intuitive APIs for in-memory data description and exchange

- **Provides an intuitive API for in-memory data description**
  - Enables *human-friendly* hierarchical data organization
  - Can describe in-memory arrays without copying
  - Provides C++, C, Python, and Fortran APIs
- **Provides common conventions for exchanging complex data**
  - Shared conventions for passing complex data (e.g. *Simulation Meshes*) enable modular interfaces across software libraries and simulation applications
- **Provides easy to use I/O interfaces for moving and storing data**
  - Enables use cases like binary checkpoint restart
  - Supports moving complex data with MPI (serialization)

CONDUIT



Hierarchical in-memory data description



Conventions for sharing in-memory mesh data

http://software.llnl.gov/conduit
http://github.com/llnl/conduit

Website and GitHub Repo

Why was Conduit Blueprint output a good choice for this data?

- Each X Ray Image Query call now generates one file.
- The single output file presents the query output in multiple ways using well-described meshes.
- There are three supported Conduit output types: HDF5, YAML, and JSON.
- Instead of having to choose between only getting out data or only getting out an image, we get the best of both worlds, because all the meshes provided in the output can be plotted in VisIt and everything in the output can be digested in Python using Conduit's Python API.
- The output also includes metadata such as…
  - View parameters (view normal, focus, imaging planes, etc.)
  - Query parameters (variable names, pixel extents, units, etc.)
  - Other metadata (spatial extents, variable maxes and mins, etc.)

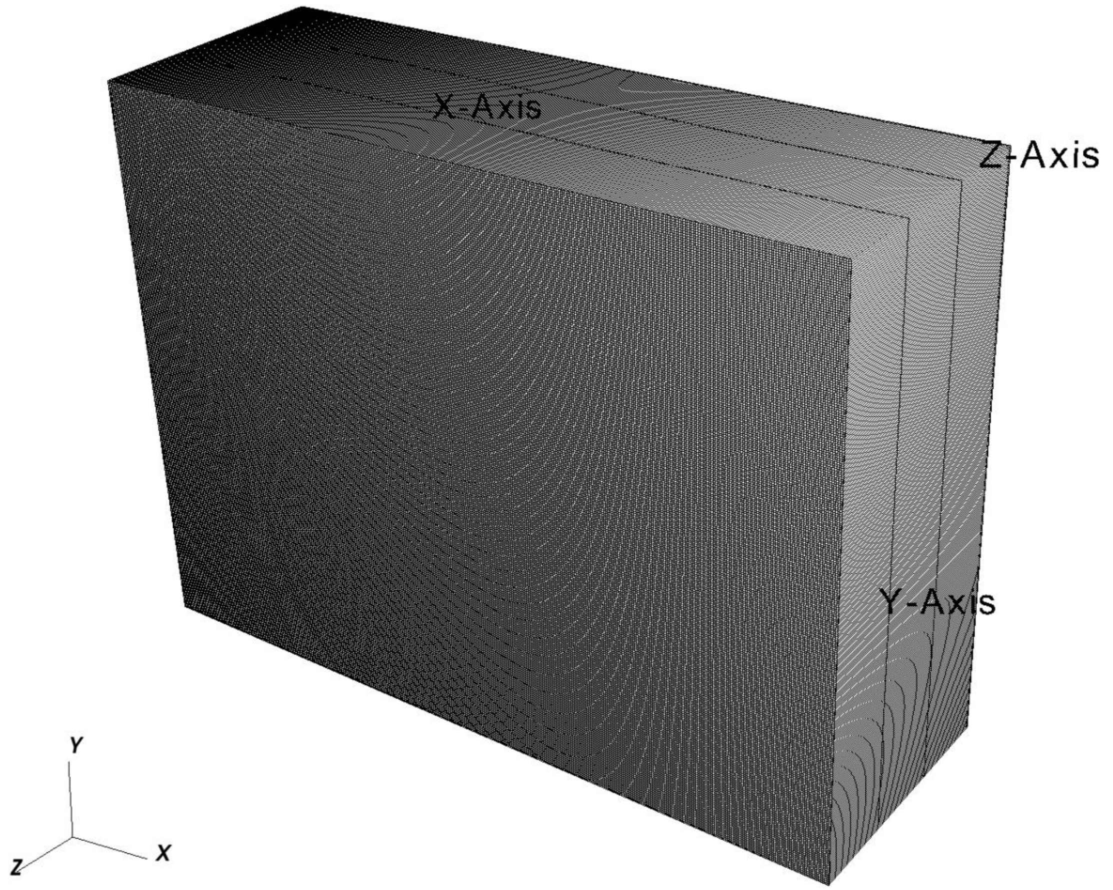
What does the Blueprint Output look like?


```yaml
state:
  time: 4.8
  cycle: 48
  xray_view:
    ...
  xray_query:
    ...
  xray_data:
    ...
  domain_id: 0
```

```yaml
coordsets:
  image_coords:
    type: "rectilinear"
    values:
      x: [0, 1, 2, ..., 399, 400]
      y: [0, 1, 2, ..., 299, 300]
      z: [0, 1]
    labels:
      x: "width"
      y: "height"
      z: "energy_group"
    units:
      x: "pixels"
      y: "pixels"
      z: "bins"
```

```yaml
topologies:
  image_topo:
    coordset: "image_coords"
    type: "rectilinear"
```


(Condensed Example of YAML-style output)

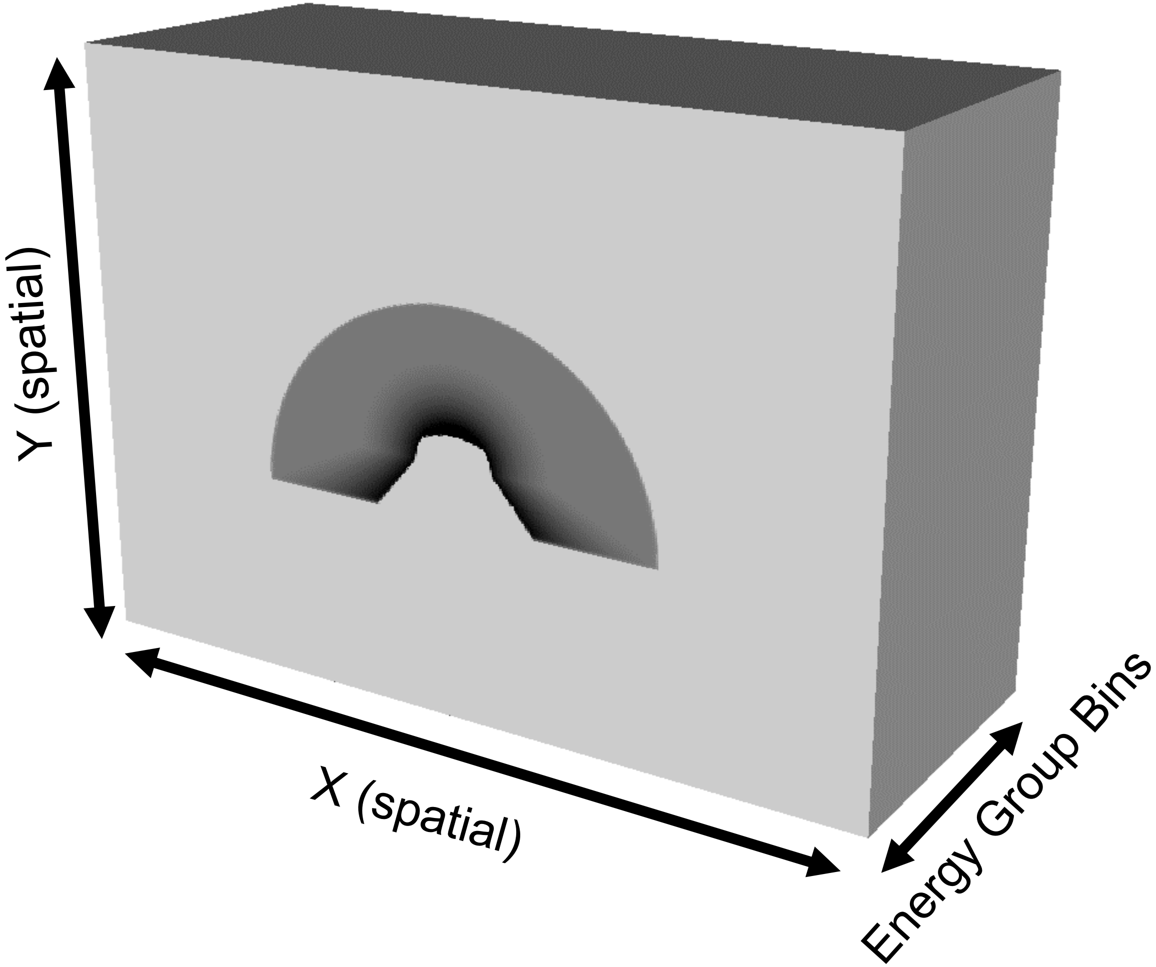


A render of the output topology

Output provides per-energy group 2D intensities and path lengths stacked into a 3D grid

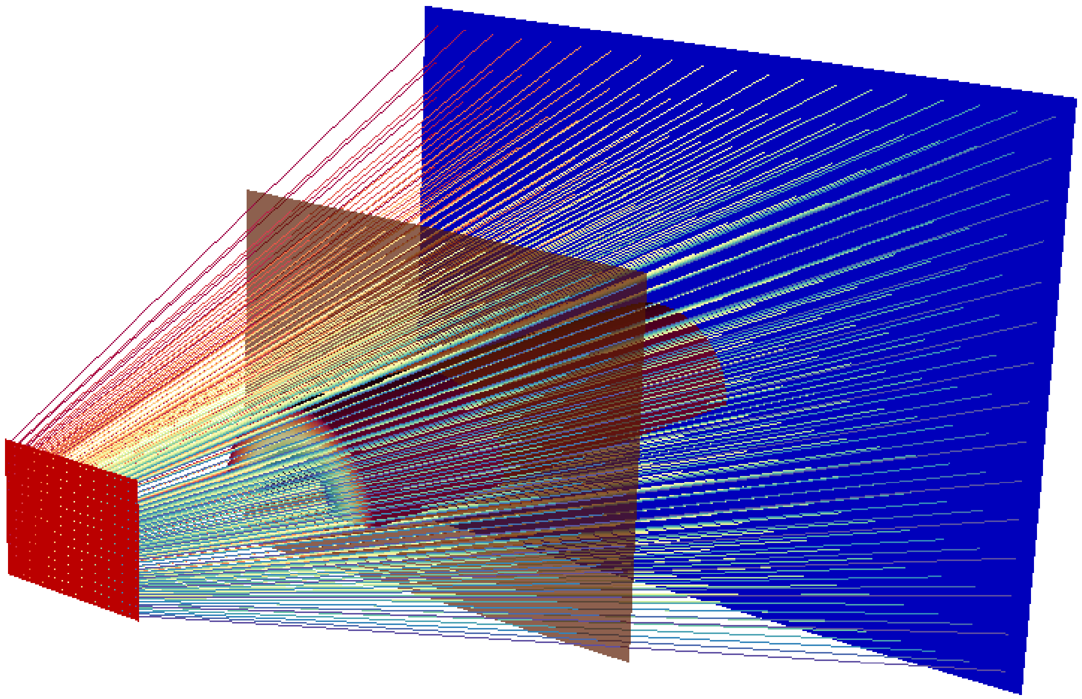

```yaml
fields:
  intensities:
    topology: "image_topo"
    association: "element"
    units: "intensity units"
    values: [0.281004697084427, 0.281836241483688, 0.282898783683777, ..., 0.0, 0.0]
    strides: [1, 400, 120000]
  path_length:
    topology: "image_topo"
    association: "element"
    units: "path length metadata"
    values: [2.46405696868896, 2.45119333267212, 2.43822622299194, ..., 0.0, 0.0]
    strides: [1, 400, 120000]
```


(Condensed Example of YAML-style output)

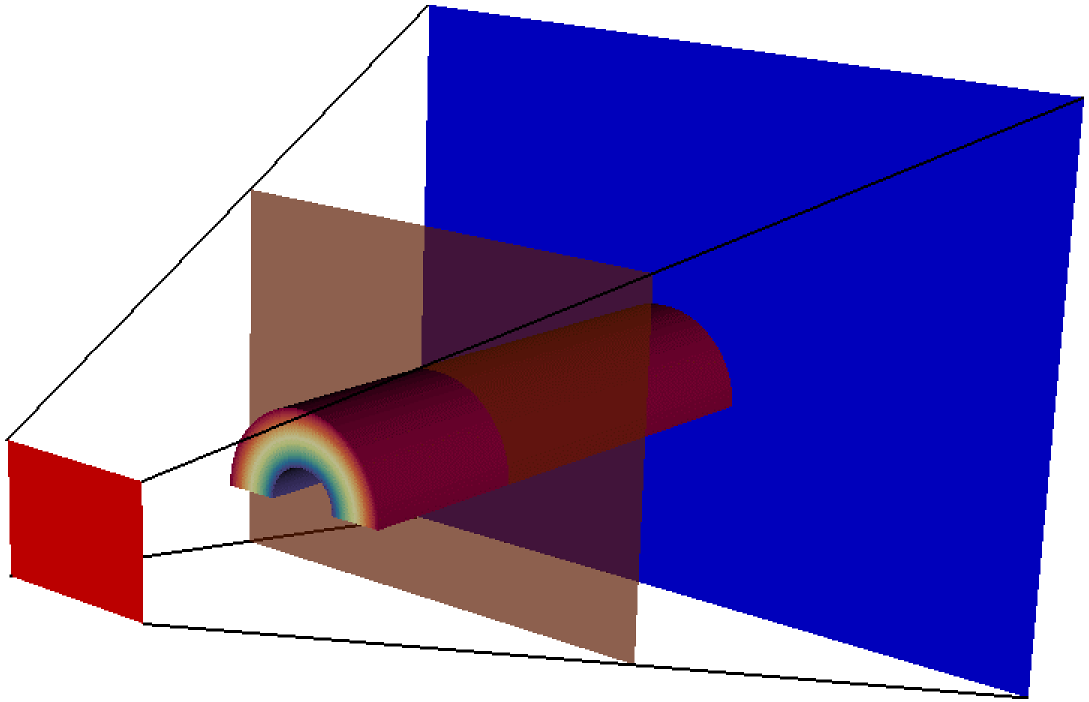


A render of the output intensities field

Output provides imaging planes and rays meshes so users can easily visualize the simulated x ray detector setup alongside their input data

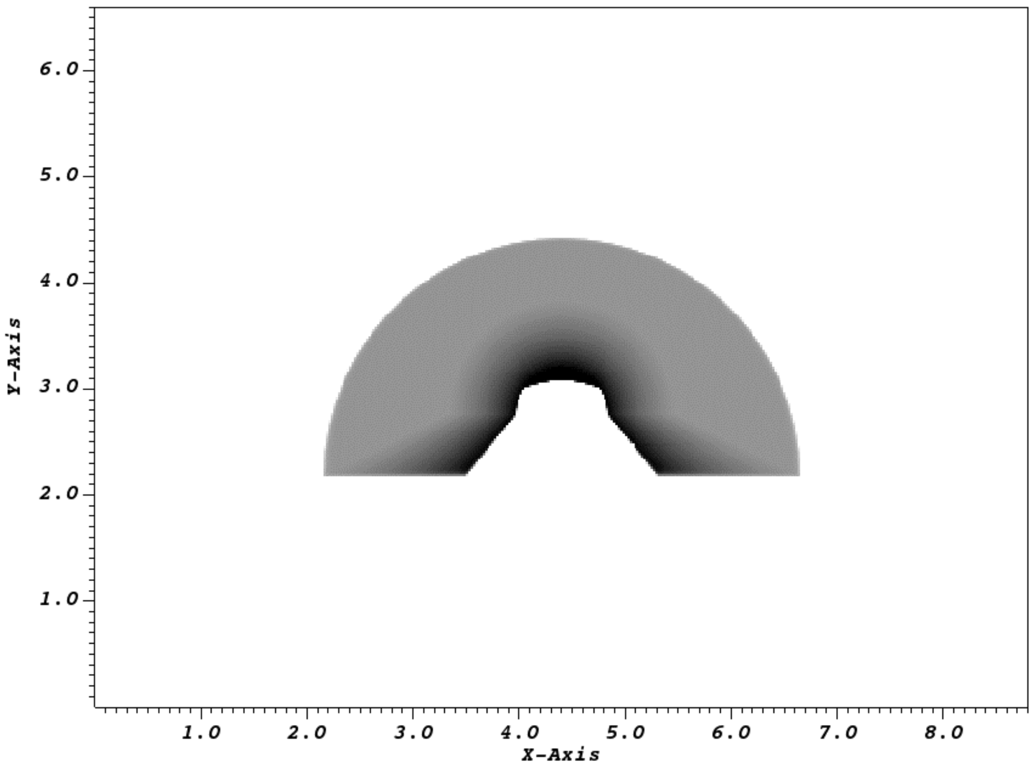


Rays



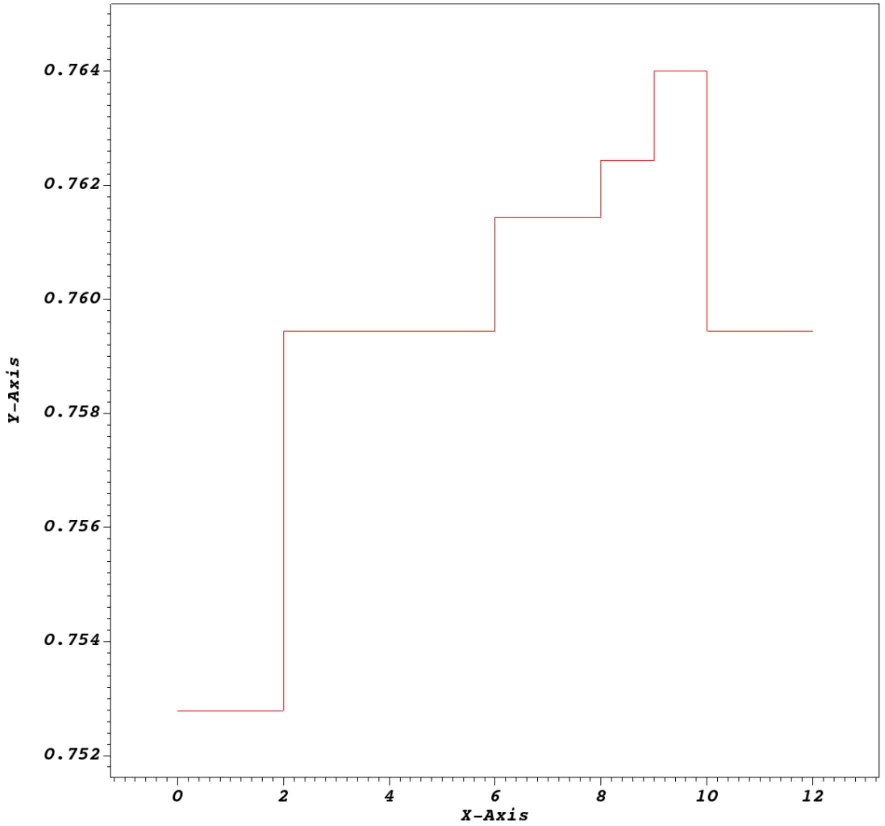
Ray corners -> view frustum

Output provides collapsed 2D Spatial Energy Images and Spectra Curves



Spatial energy reduced mesh

(All energy groups collapsed to 2D image)



1D Spectra curve

(Each energy group collapsed to create a 1D curve)

Documentation

- Everything discussed today concerning the X Ray Image Query and the Conduit Blueprint output from it is extensively documented in the VisIt Manual: https://visit-sphinx-github-user-manual.readthedocs.io/en/develop/using_visit/Quantitative/XRayImageQuery.html

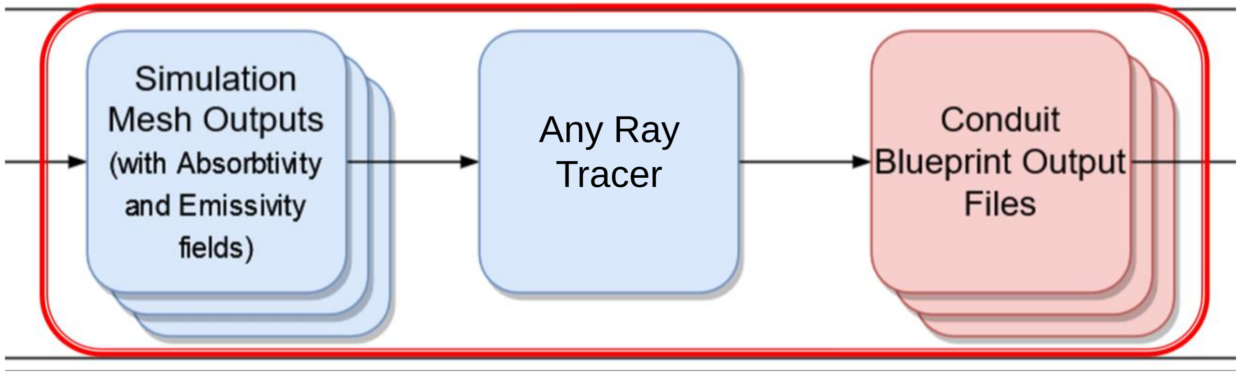
- These docs include descriptions of every part of the output, how to visualize each part with VisIt, how to digest the output with Python, troubleshooting, potential pitfalls, and more.

VisIt User Manual
develop

Search docs

8.3. X Ray Image Query

We are working towards ray tracer agnostic workflows to support a wider set of tools



- We want to make a clear split between ray tracing and simulating a specific detector.

- There are lots of tools; we want them to standardize on Blueprint input and output to enable a modular capability.

- Part of this plan will be supporting this same feature set to Ascent for in situ use.
  - It will mirror VisIt's support and provide Blueprint output with the same meshes and metadata.
  - The ray trace in Ascent will be GPU accelerated.
  - There are low-order and high-order ray tracing paths, both need development work to support multiple energy groups.

Summary

- Simulations and Experiments work hand in hand to enable High Energy Density Physics Research, like the recent fusion breakthrough at the NIF.
- The VisIt X Ray Image Query is a part of a larger workflow for simulating diagnostics used in NIF experiments.
- We have worked to enhance the output of the query by providing the option to output Conduit Blueprint files.
- Conduit Blueprint provides far richer output that is easy to visualize in VisIt, easy to digest with Python, and also makes it much easier to understand what the query is doing.
- This work is part of a larger effort to standardize Conduit Blueprint output from ray tracers used in this kind of workflow.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.
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