High Energy & Nuclear Physics: Software

Computer Science and Physical Science Collide for the NuSteam Program

Gene Van Buren - Brookhaven National Laboratory - July 12, 2024

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About me
Dr. Gene Van Buren

- PhD in nuclear physics

- Participated in a variety of physics experiments, but most of my career has been on the STAR Experiment at RHIC

- Calibrations & Productions Leader for STAR

- Co-Leader of STAR's Software & Computing Team for 10 years

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Programming
Languages, Scripting

- Programming : Fortran [almost dead], C, C++, Java, Python

- Scripting : csh (or other shells), Python, Perl (and PHP), xml, HTML, Javascript, Jupyter Notebook

- Frameworks [not a complete list] :

  - Community-wide: PAW [Fortran: dead], Root

  - Smaller: Clara, Fun4All, Root-spinoffs (e.g. AliRoot, root4star, FAIRRoot)

- Parsing/interpreting/compiling

  - On-the-fly?

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Root
Framework example

- Write one, or a few lines of code directly at the prompt and see the results immediately

- Write a macro with up to a modest number of code lines that may be worth executing repeatedly, and test immediately

- Load compiled shared object libraries and execute C functions and use shared objects and their member functions

  - Use at the Root prompt requires a dictionary and a few standard rules

- Let's go to the command line and try it out...

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Data Flow
From experiment to publication

- Raw data (see Jeff Landgraf's presentation next week)

- Reconstruction

  - Calibration

  - Production

- Analyses

- Presentations (talks, posters)

- Publication

- Archives

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Data Formats
From experiment to publication

- Raw data (see Jeff Landgraf's presentation tomorrow)
    - raw data files
- Reconstruction

    - Calibration
        - databases or constants files
    - Production
        - binary data summaries ("DSTs")
- Analyses
    - user data summaries or text files
- Presentations (talks, posters)
    - tables & plots
- Publication
    - selected tables & plots
- Archives
    - all of the above go to long term storage == tape

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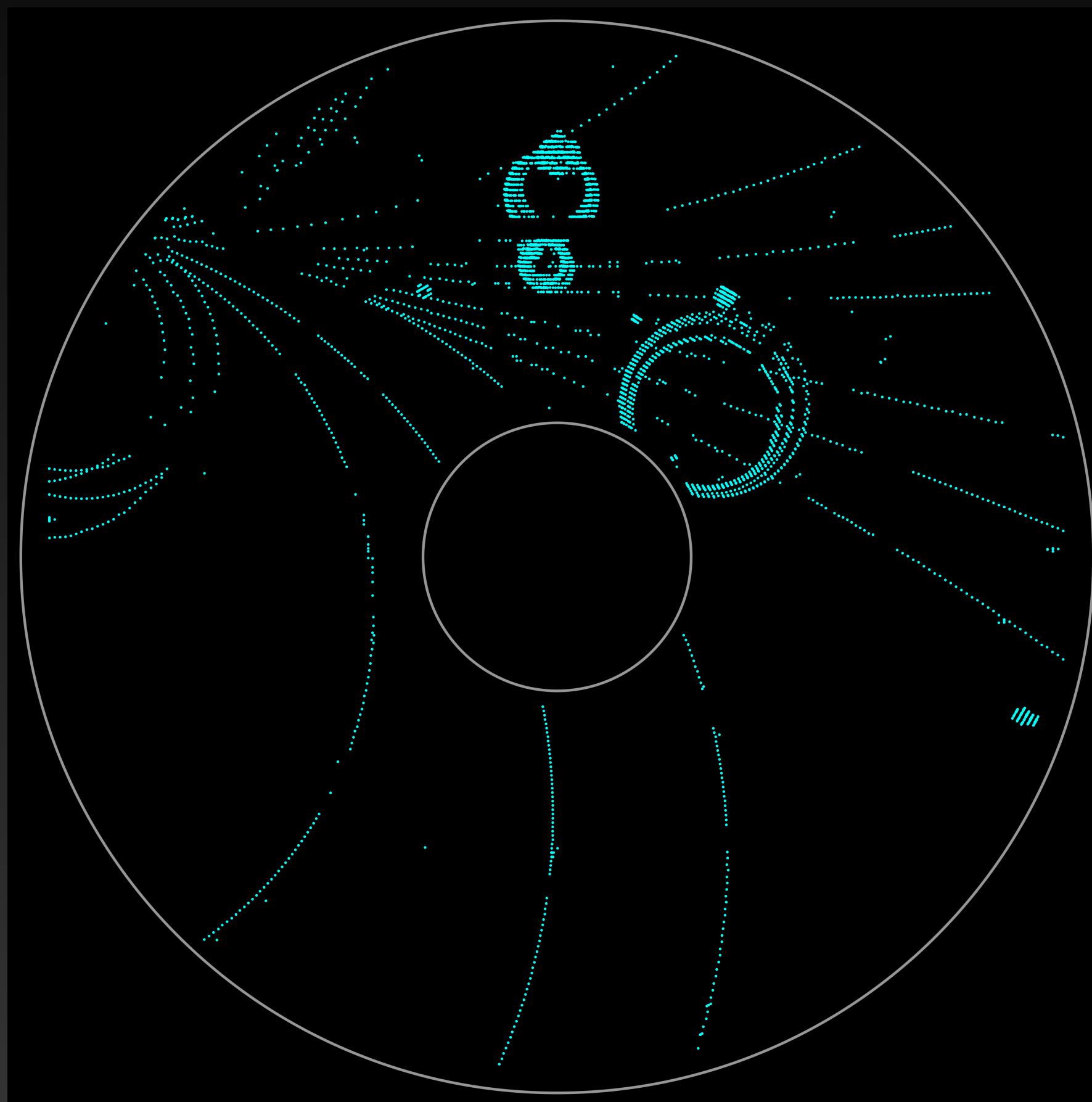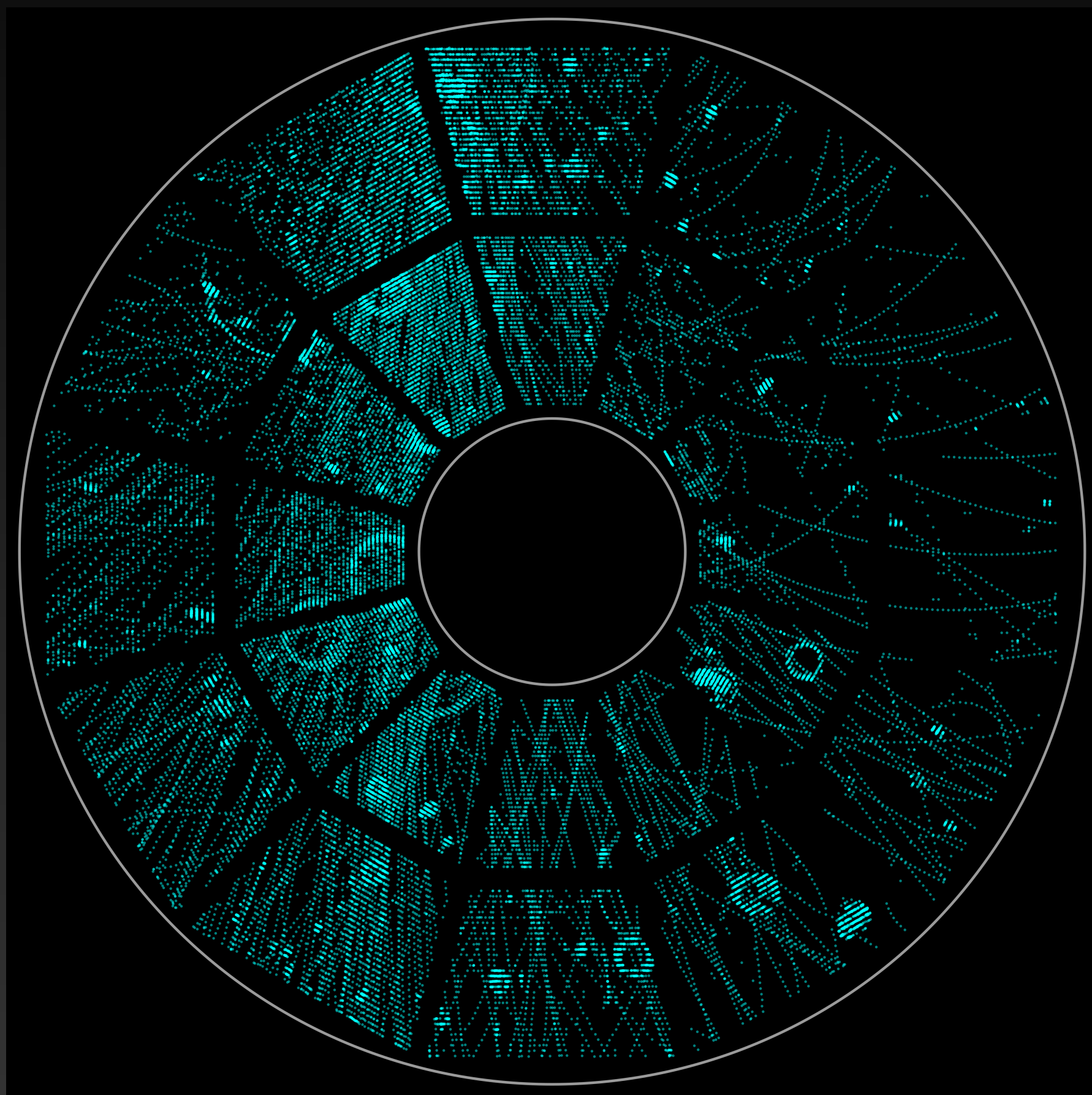# Reconstruction
Converting raw into physics

- Calibrations are applied to raw data to get physical measurements

- Physical measurements are quantitatively combined to get particle measurements
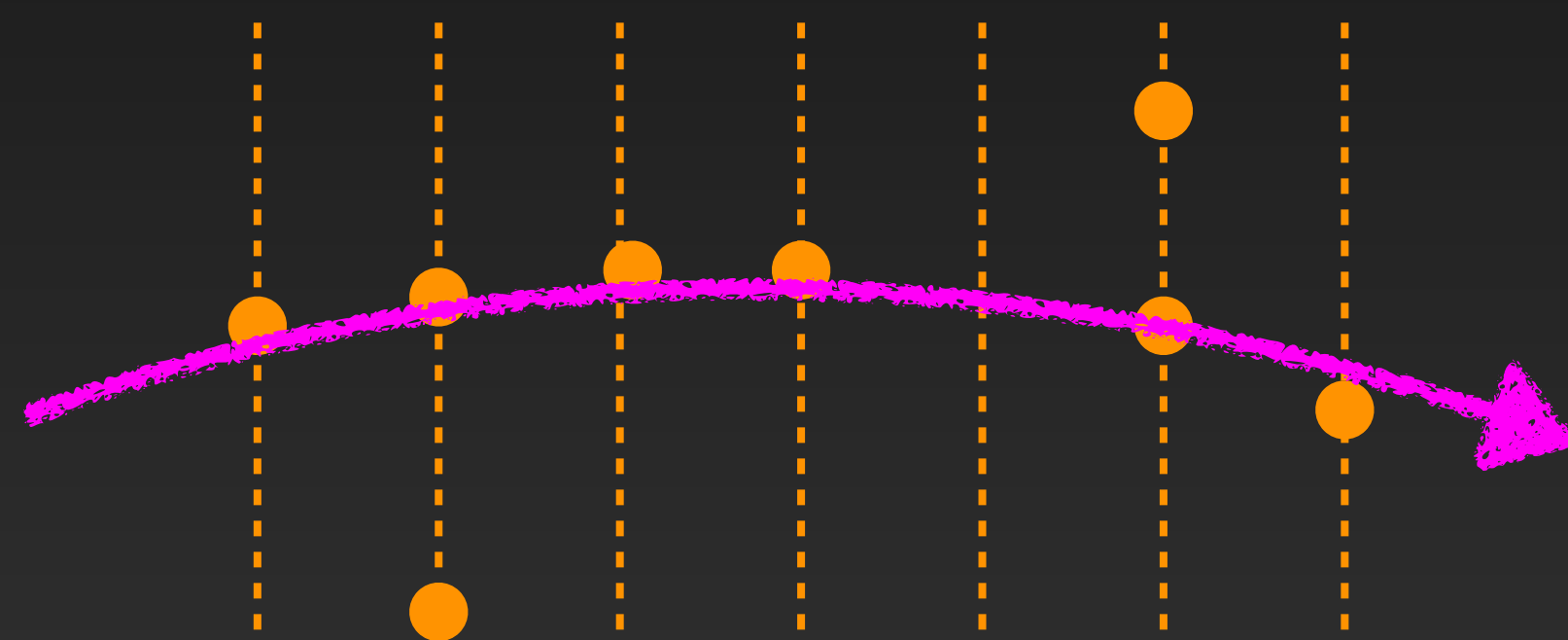
- Analysis: particle measurements are combined to get statistical measures of actual physics

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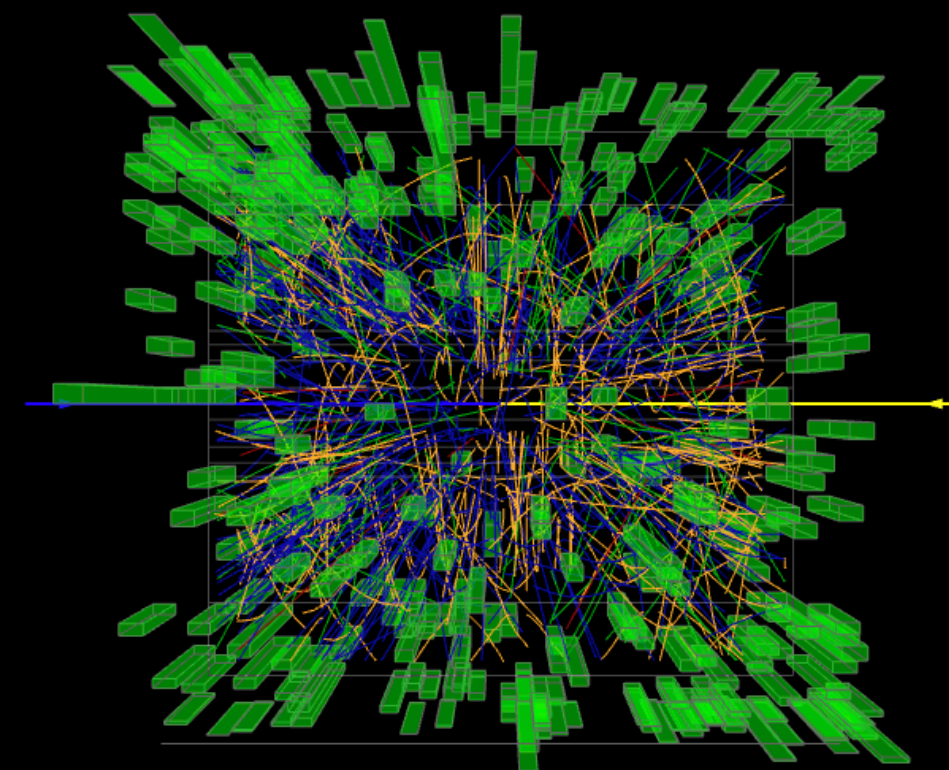
Reconstruction
Example images from STAR

Fun 3D display: https://www.star.bnl.gov/~iraklic/EventDisplay/gide/?file=gdml/star-complete-2018.gdml&event=/~iraklic/EventDisplay/Run2019/FXT/Track_20160026_86.json&WorldRef=TPCE&VisLevel=1&trans=1

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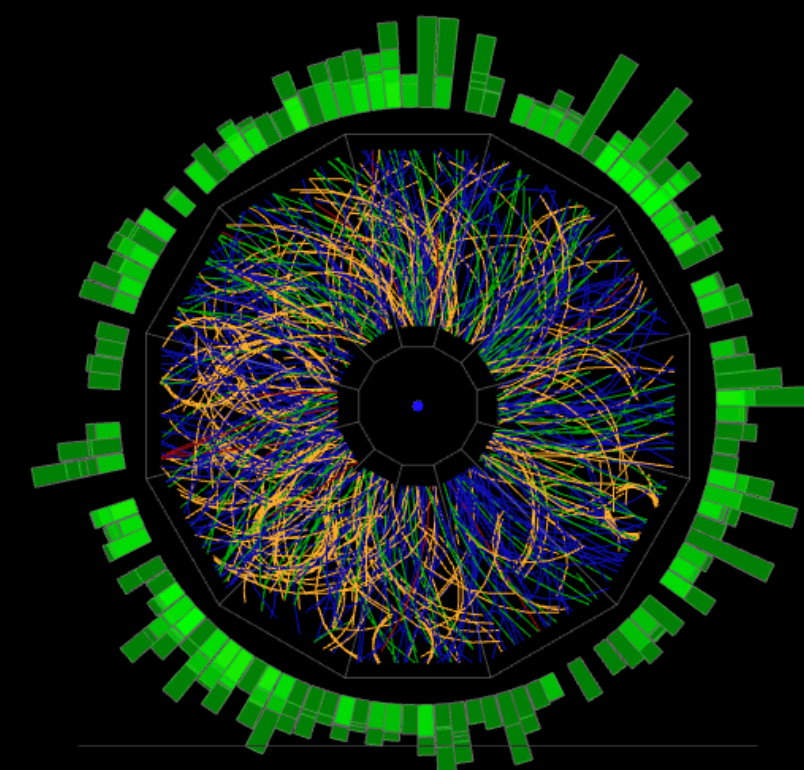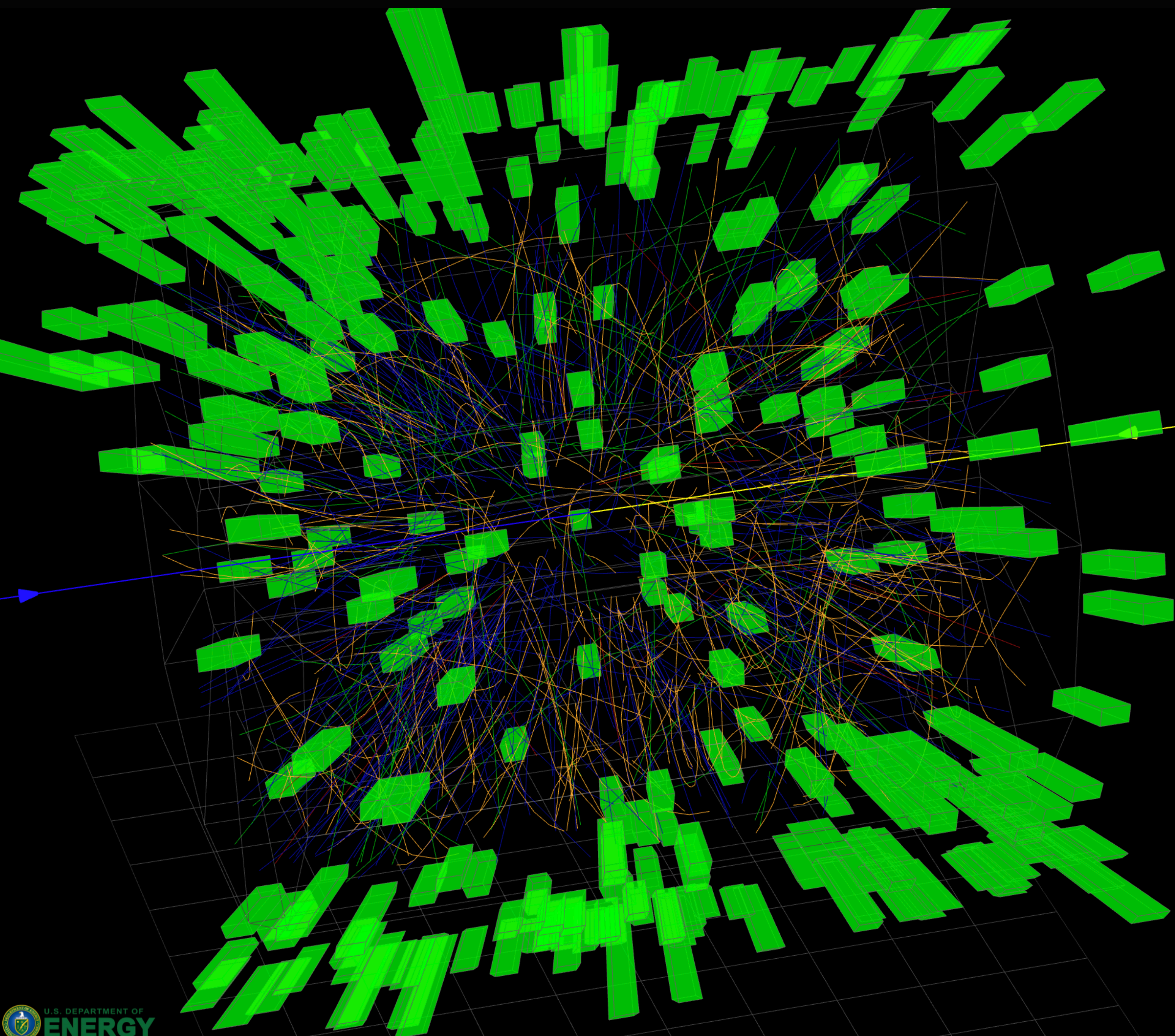
Reconstruction

Example images

Simulations: event generators
Understanding the science

- Execute the physics of a particle or nuclear collision (e.g. Pythia, Hijing, URQMD)

  - No description of detectors

- Pre-experiment:

  - What are signatures we can look for experimentally?

- Post-experiment:

  - What can explain what we see experimentally?

Animation example: https://www.sdcc.bnl.gov/phobos/Animations/zx_jan122008.mpg

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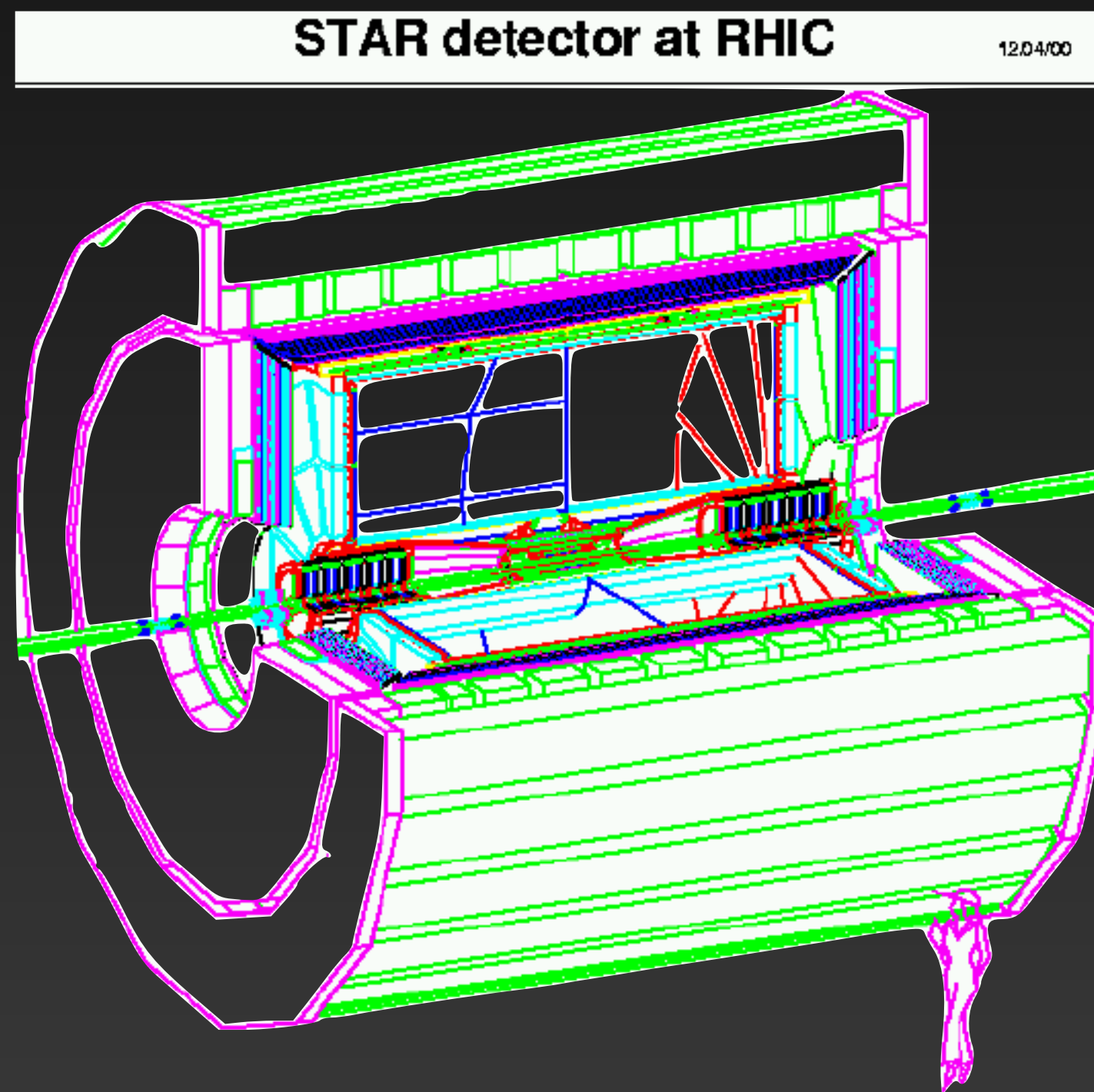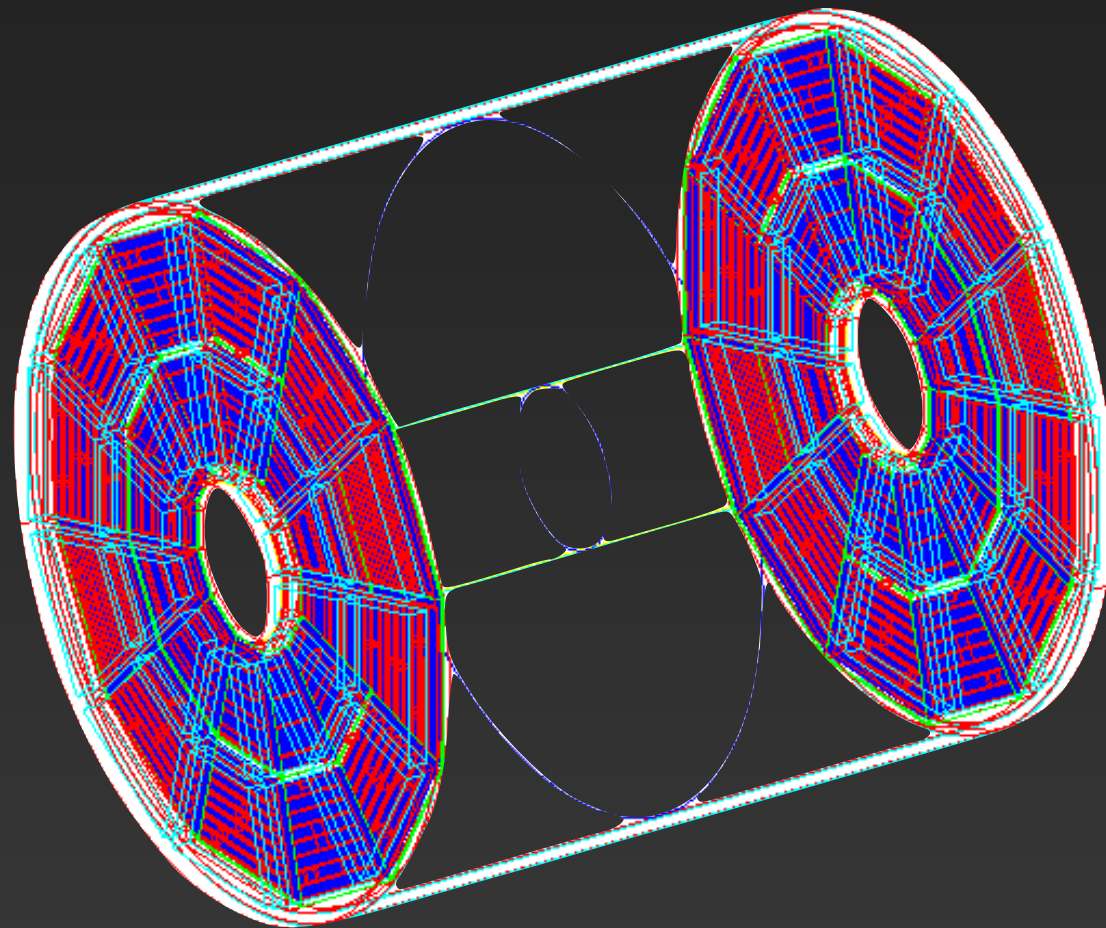
Simulations: detectors
Understanding the experiment

- Frameworks for describing the detectors, and for executing the physical process that occur when particles traverse those detectors (GEANT)

- Design stage:

  - Are detectors capable of achieving performance needs? (e.g. how spatial resolution of multiple measurements becomes a single momentum resolution)?

  - Are detectors susceptible to impeding factors (e.g. background particles, occupancies, blocking materials or fields)?

  - How does reconstruction software perform?

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Simulations: detectors
Understanding the experiment

Various GEANT versions of STAR detector components

STAR detector at RHIC   12.04/00
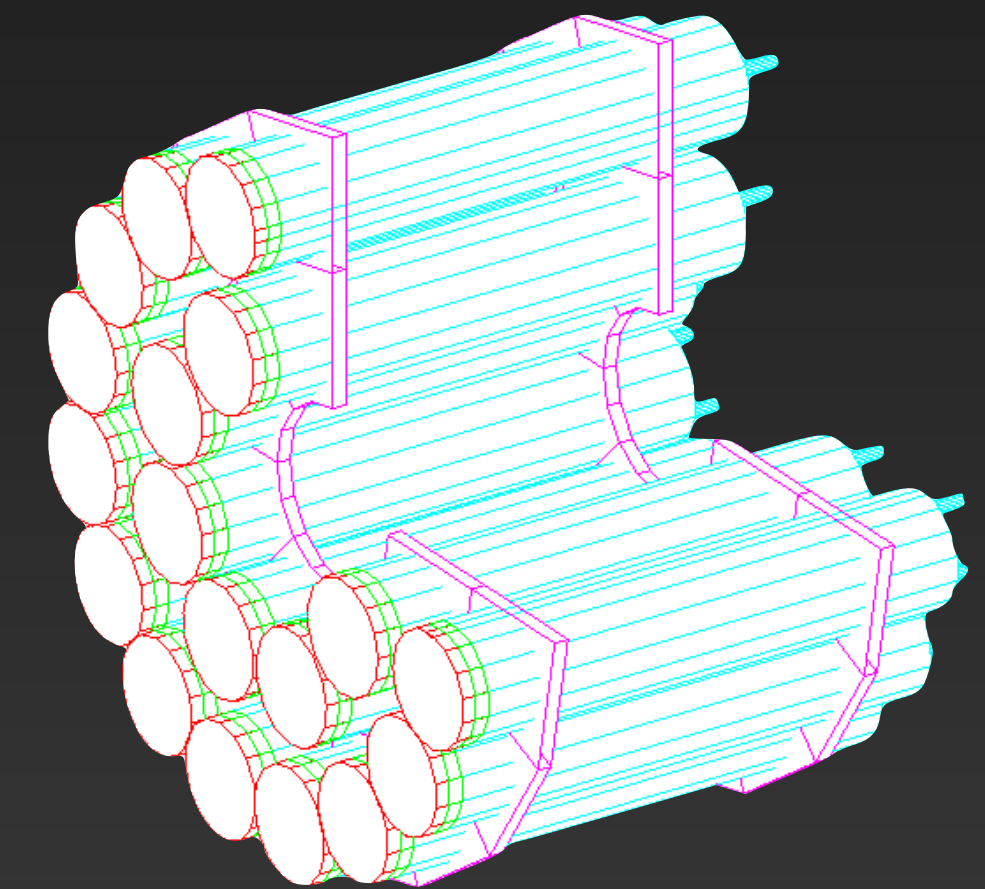
Simulations: embedding
Understanding the experiment

Embedded (overlaid) simulated particles on a real event in STAR

- Extensions to detector simulators allowing for overlay of simulated data (particles or whole events) into real data (real backgrounds, occupancies, statuses)

- Analysis stage:

  - How well did the reconstruction software perform in a real (non-ideal) data environment?

  - What can be learned about systematic uncertainties? (quantify to some degree what it is we don't know)

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Simulations: Monte Carlos
Understanding complex math

Random Thing 1

Random Thing 2

Random Thing 3

Random Thing 4

Random Thing 5

- Simulations often involve a complex system of materials and possibilities

- The possibilities are often factorizable as random probabilities

- Even so, determining expectation values for averages or ranges of any sort can involve daunting ... usually impossible ... integrals of these various probabilities

- In a Monte Carlo simulation, a statistical approximation is found by repeatedly running the experiment and throwing the dice for each random probability

  - Repetition (often in the millions) builds up statistically strong answers

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"It can all be done in software."

Thanks for your time and attention! Good luck!