High Energy & Nuclear Physics: Software

Computer Science and Physical Science Collide for the NuSteam Program

Gene Van Buren - Brookhaven National Laboratory - July 11, 2025

U.S. DEPARTMENT OF ENERGY
Office of Science

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

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?

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...

Data Flow

From experiment to publication

- Raw data (see Jeff Landgraf's presentation earlier this week)
- Reconstruction
  - Calibration
  - Production
- Analyses
- Presentations (talks, posters)
- Publication
- Archives

Data Formats

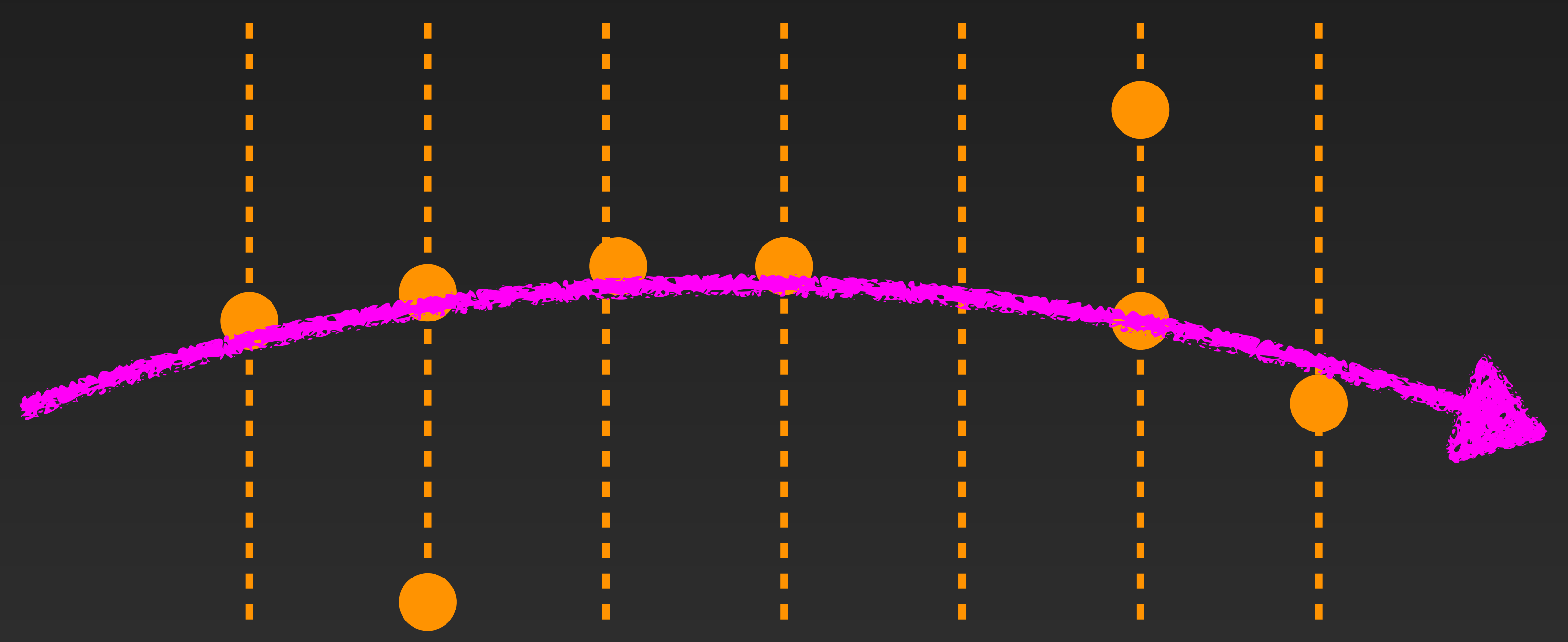
From experiment to publication

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

Reconstruction

Converting raw into physics

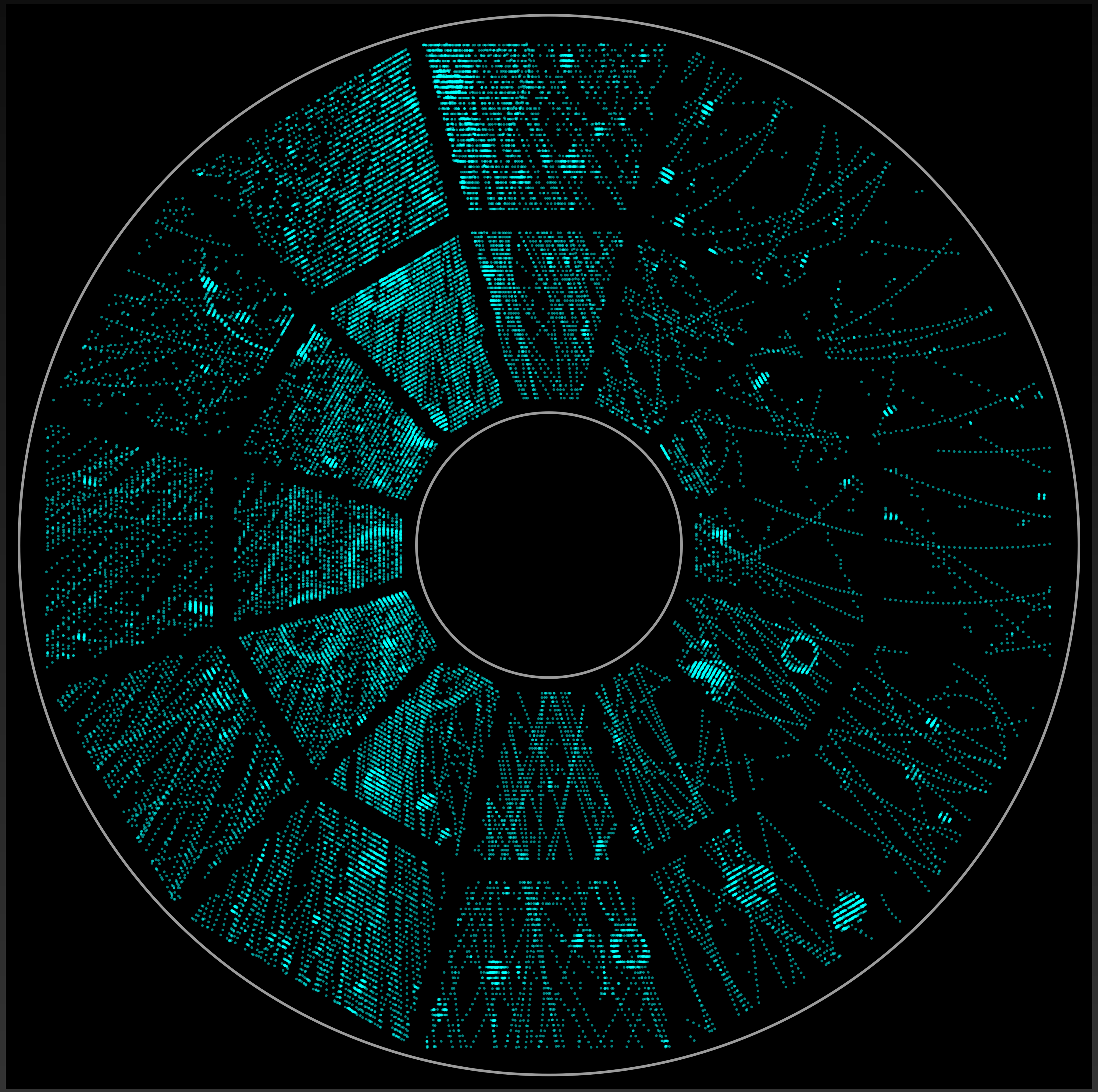
- Calibrations are applied to raw data to get physical measurements
- Physical measurements are quantitatively combined to get particle measurements

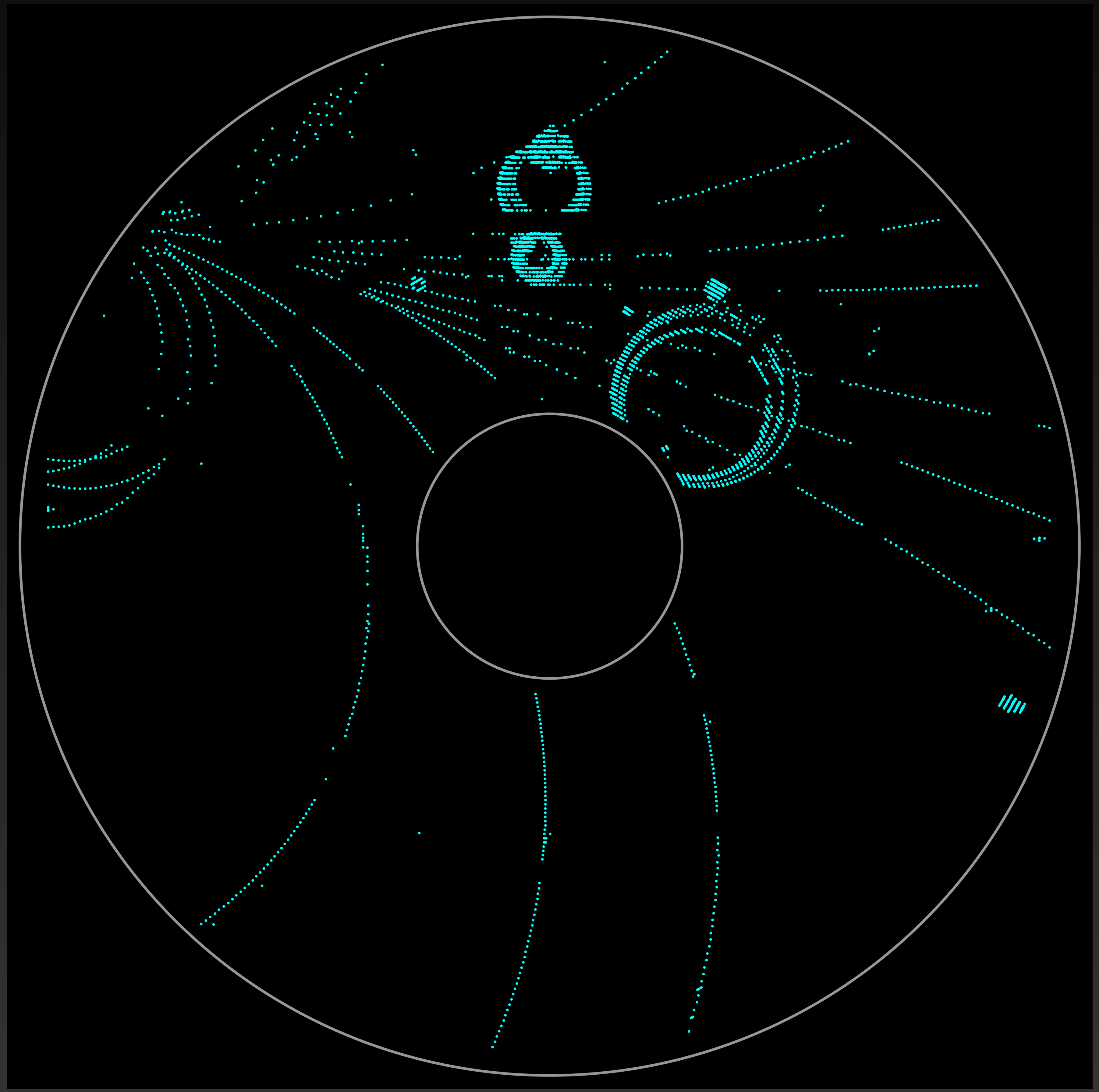


- Analysis: particle measurements are combined to get statistical measures of actual physics

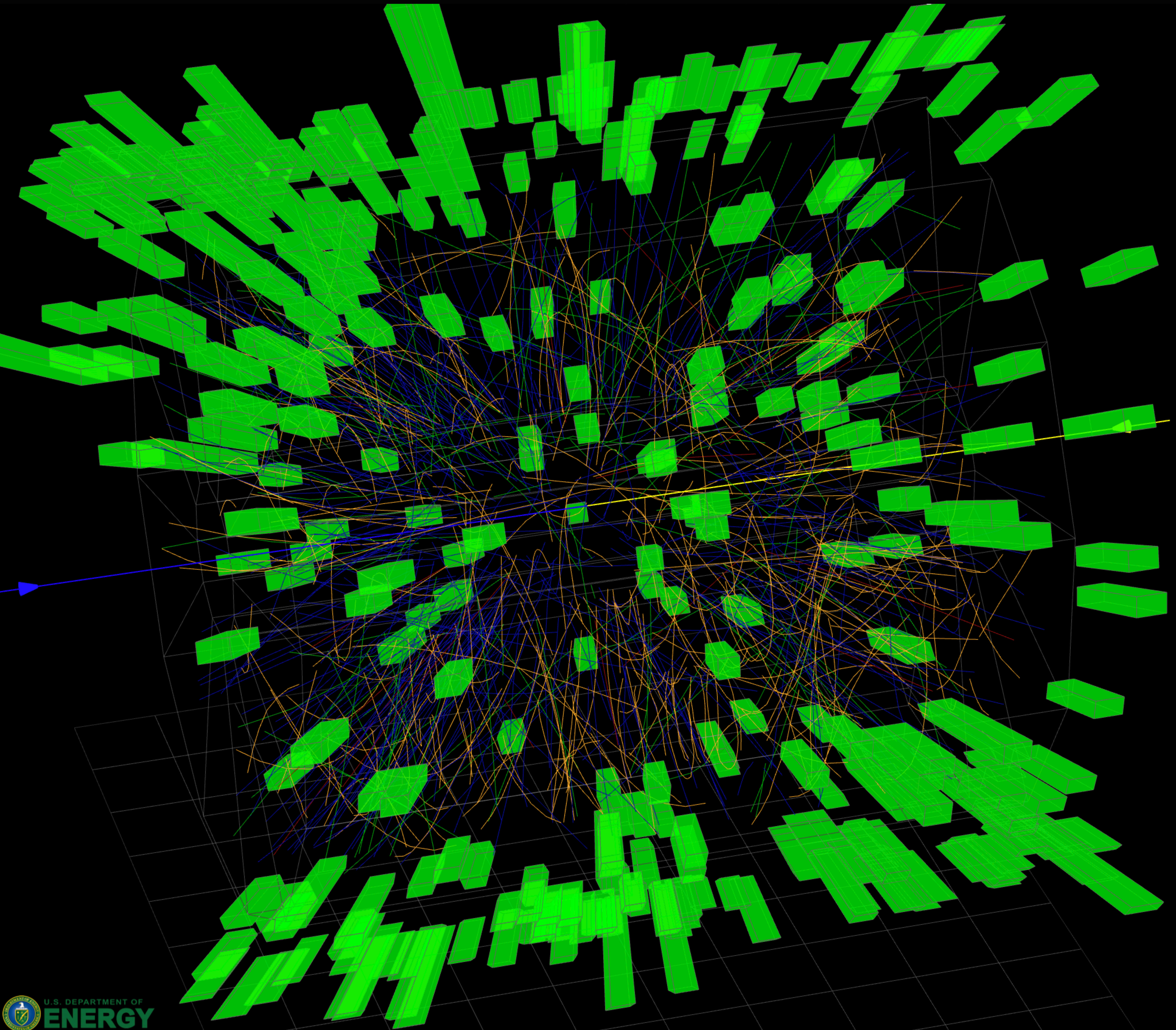
Reconstruction

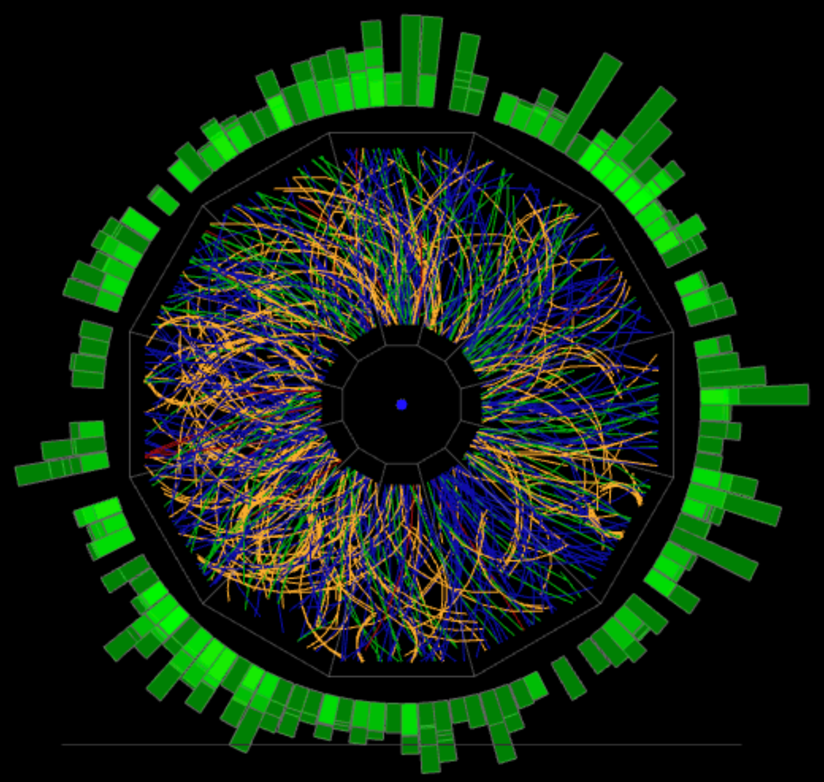
Example images from STAR





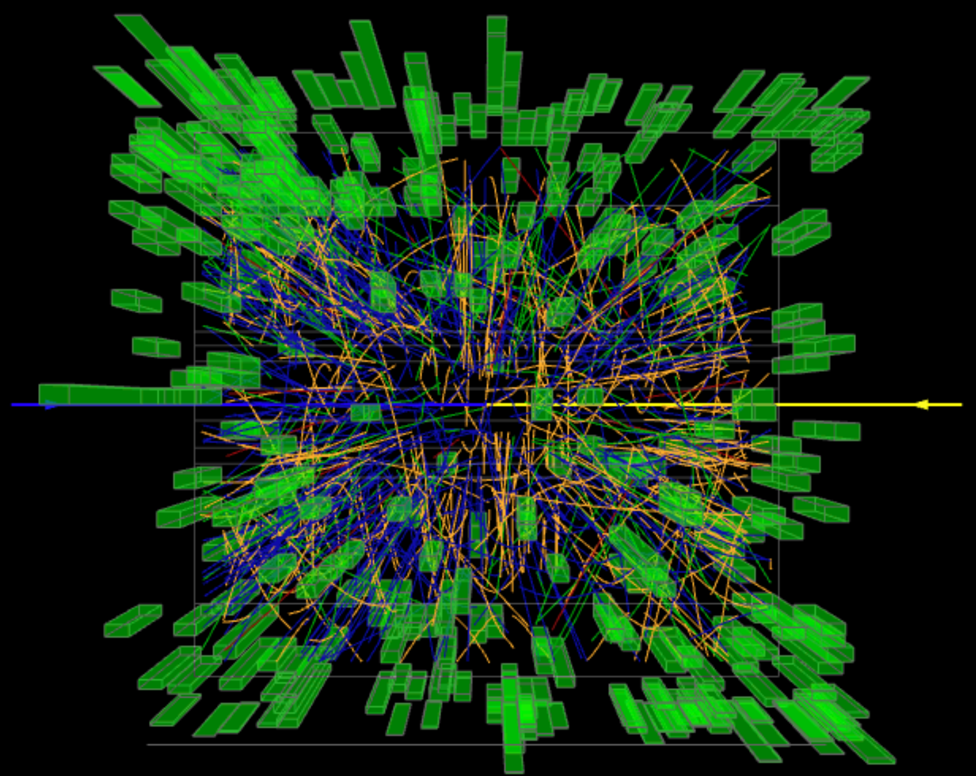
Fun 3D display: https://www.star.bnl.gov/~iraklic/EventDisplay/gide/?file=gdml/star-complete-2018.gdml&event=/~iraklic/EventDisplay/Run2019/FXT/Track_20160026_86.json&WorldRef=TPCE&VisLevel=1&trans=1





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

Simulations: detectors

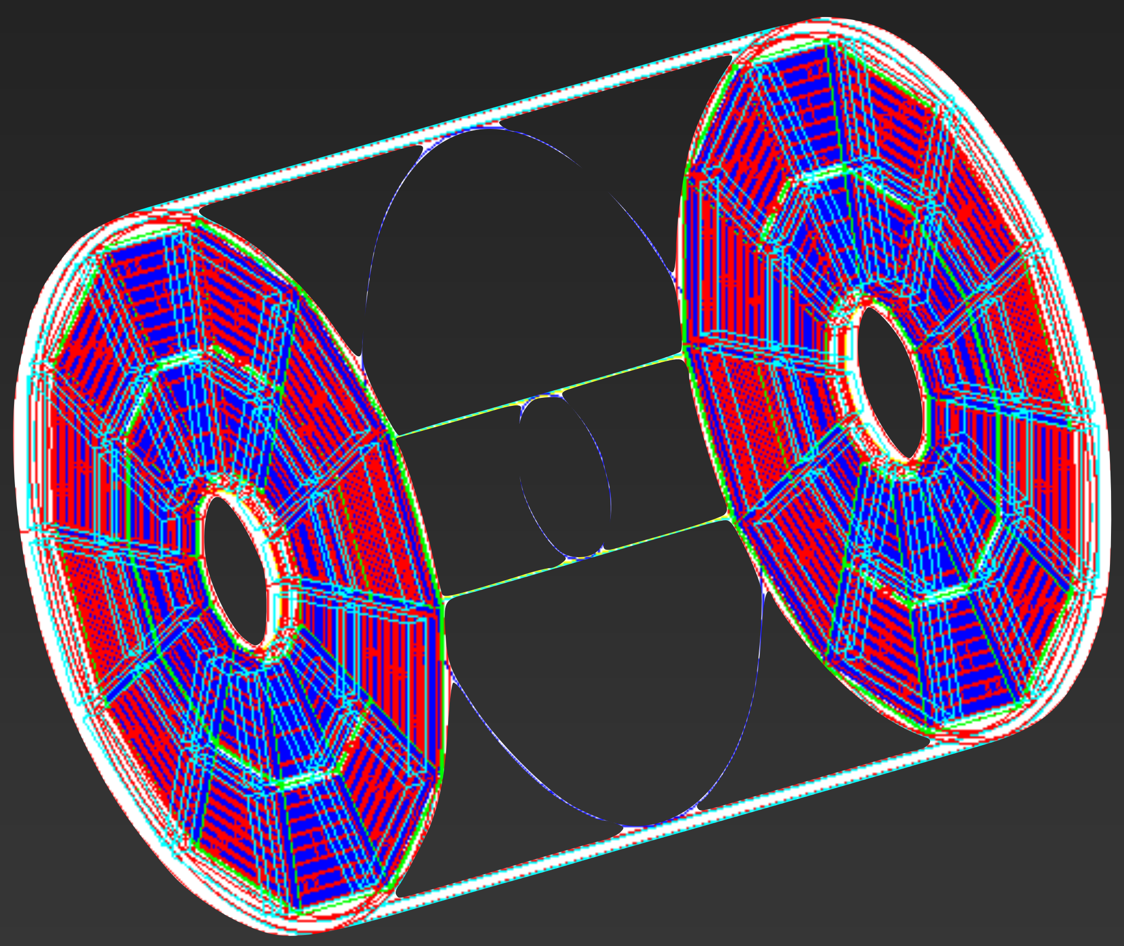
Understanding the experiment

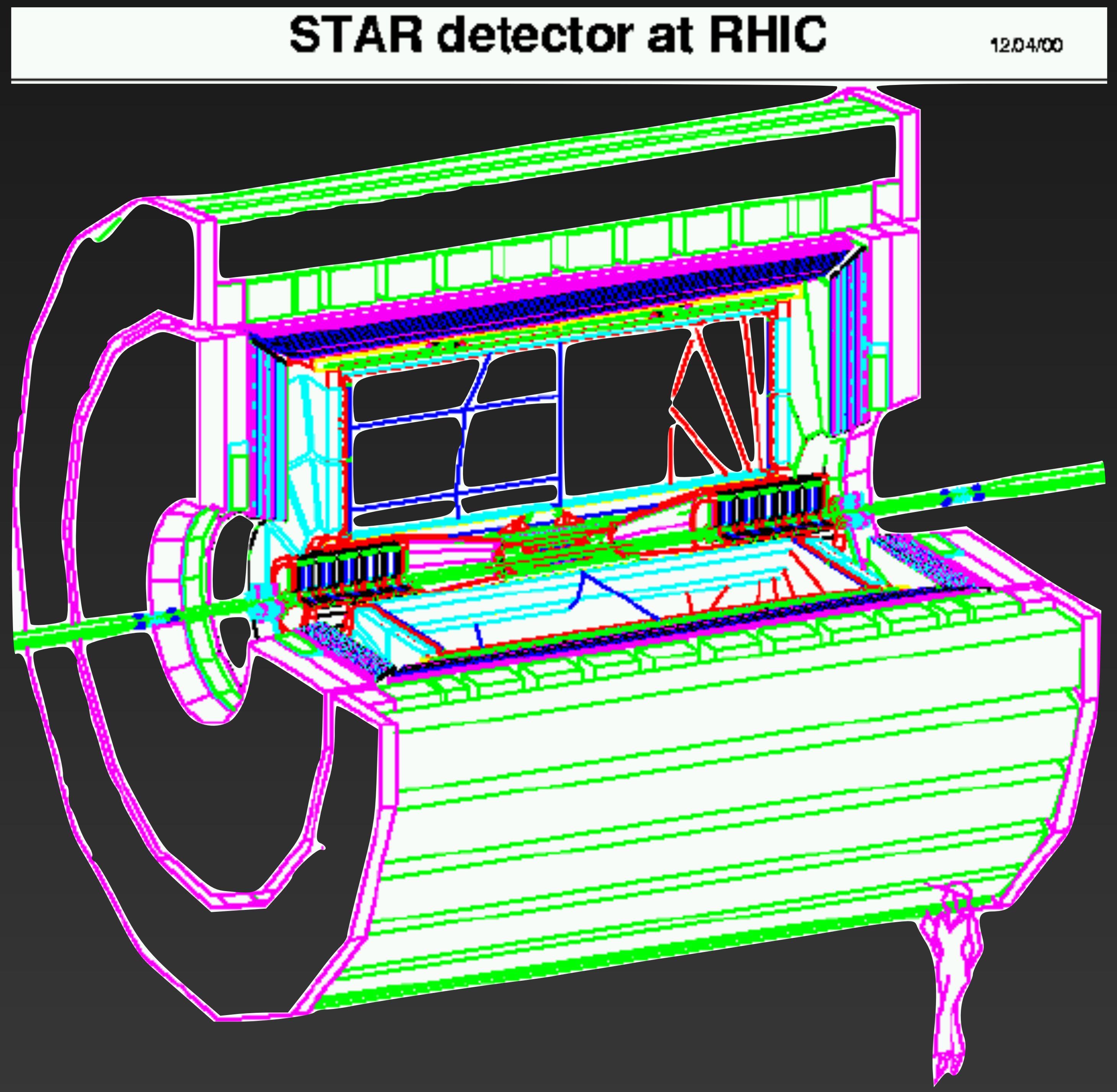
- Frameworks for describing the detectors, and for executing the physical process that occur when particles traverse those detectors (GEANT)
- Design stage:
  - Are detectors capable of achieving performance needs? (e.g. how spatial resolution of multiple measurements becomes a single momentum resolution)?
  - Are detectors susceptible to impeding factors (e.g. background particles, occupancies, blocking materials or fields)?
  - How does reconstruction software perform?

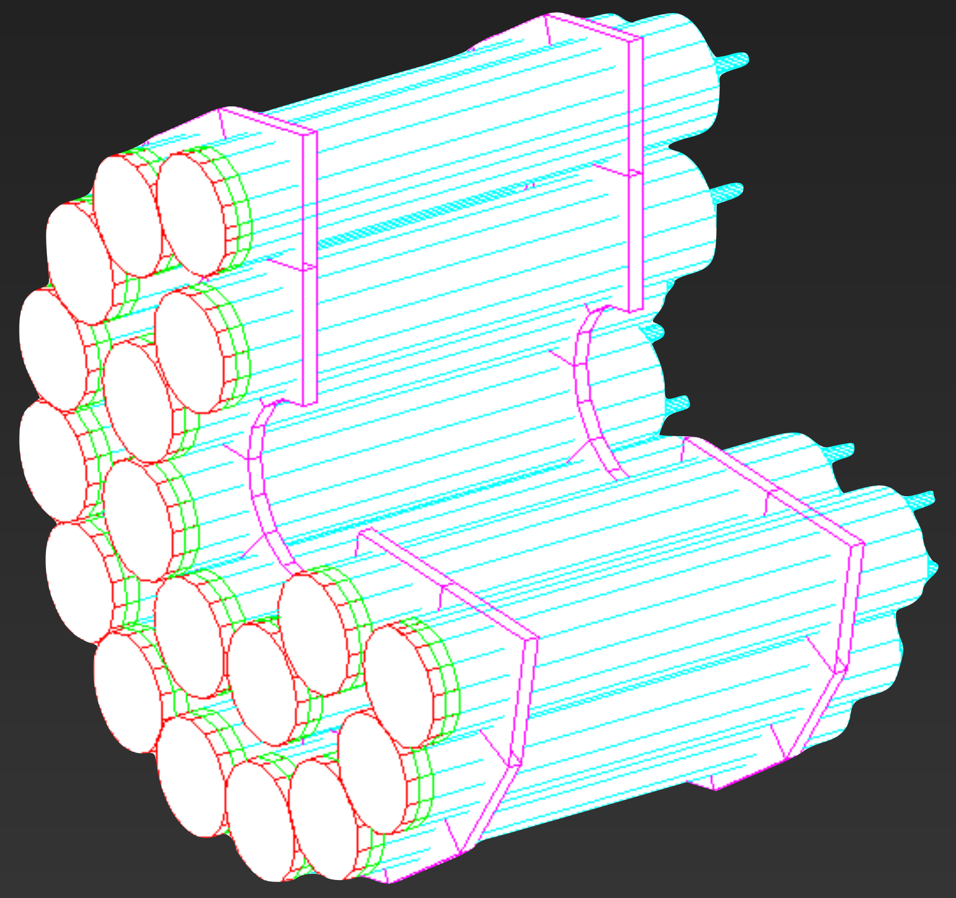
Simulations: detectors

Understanding the experiment

Various GEANT versions of STAR detector components





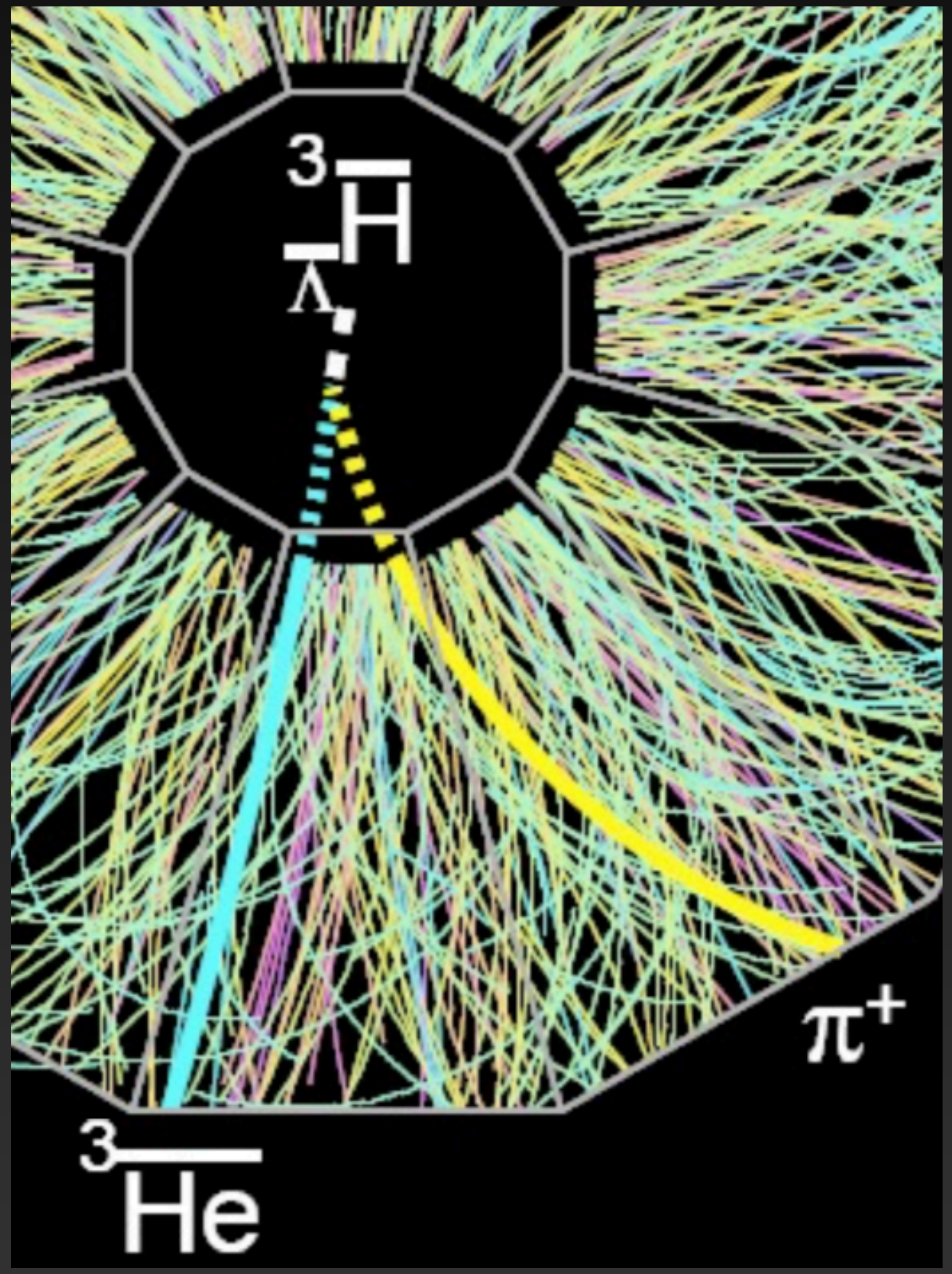


Simulations: embedding

Understanding the experiment

- 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)

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



Simulations: Monte Carlos

Understanding complex math

- 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

"It can all be done in software."

Thanks for your time and attention! Good luck!